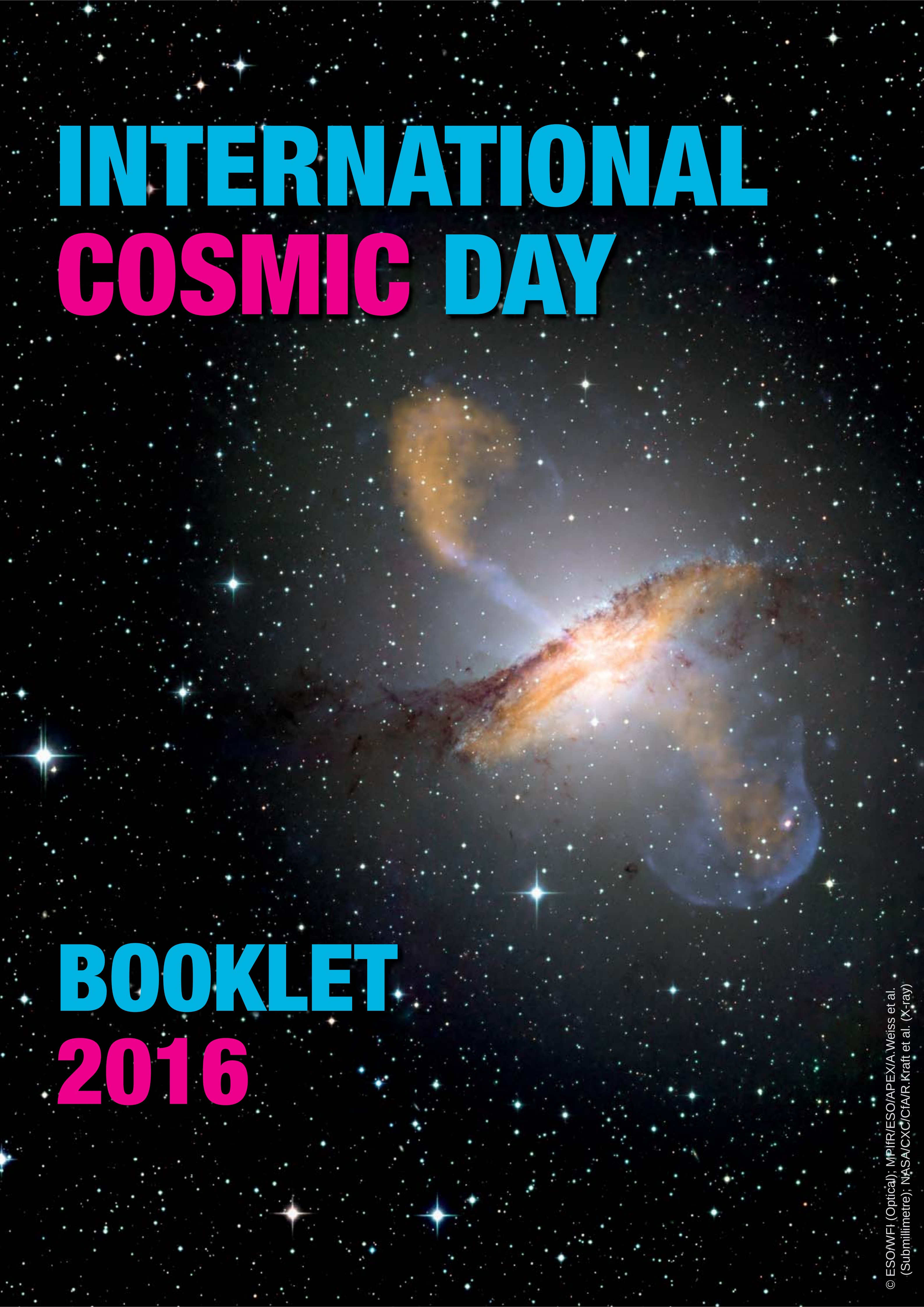
INTERNATIONAL COSMIC DAY



BOOKLET 2016

INTERNATIONAL COSMIC DAY

Dear Young ICD-Researchers,

Thank you for your participation and contribution to the 5th International Cosmic Day!

Over 900 students, teachers and scientists in 45 groups from 16 countries have made this day possible.

Various cosmic particles constantly reach the Earth – particles that can provide insights into events happening in the depths of the universe. You – the ICD young researchers – studied cosmic rays for one day. For 24 hours around the globe, cosmic particles were at the center of interest. All over the world, we discussed questions like:

What are cosmic particles?
Where do they come from?
How can they be measured?

You all have done your measurements very well. It is really great to see all the results, which show only small differences but many agreements.

We hope the International Cosmic Day gave you an insight into astroparticle physics – a young research field located at the interface between astrophysics, particle physics, astronomy and cosmology.

Maybe you have become interested and it opens a new window for you to explore the universe.

In this booklet you can find information about all participating groups, the results of their measurements and web links to more information about astroparticle physics.

USA
INDIA
ITALY
CHINA
JAPAN
TAIWAN
MEXICO
FRANCE
UKRAINE
GEORGIA
GERMANY
DENMARK
COLOMBIA
SWITZERLAND
NETHERLANDS
UNITED KINGDOM

Discover Cosmic Rays

INTERNATIONAL COSMIC DAY

November 02 | 2016

Scientists worldwide are committed to school projects in order to give students insights into their research and answer questions like:

What are cosmic particles?
Where do they come from?
How can they be measured?

© ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)

Become a Scientist for a Day

Discover the world of cosmic rays like an astroparticle physicist.

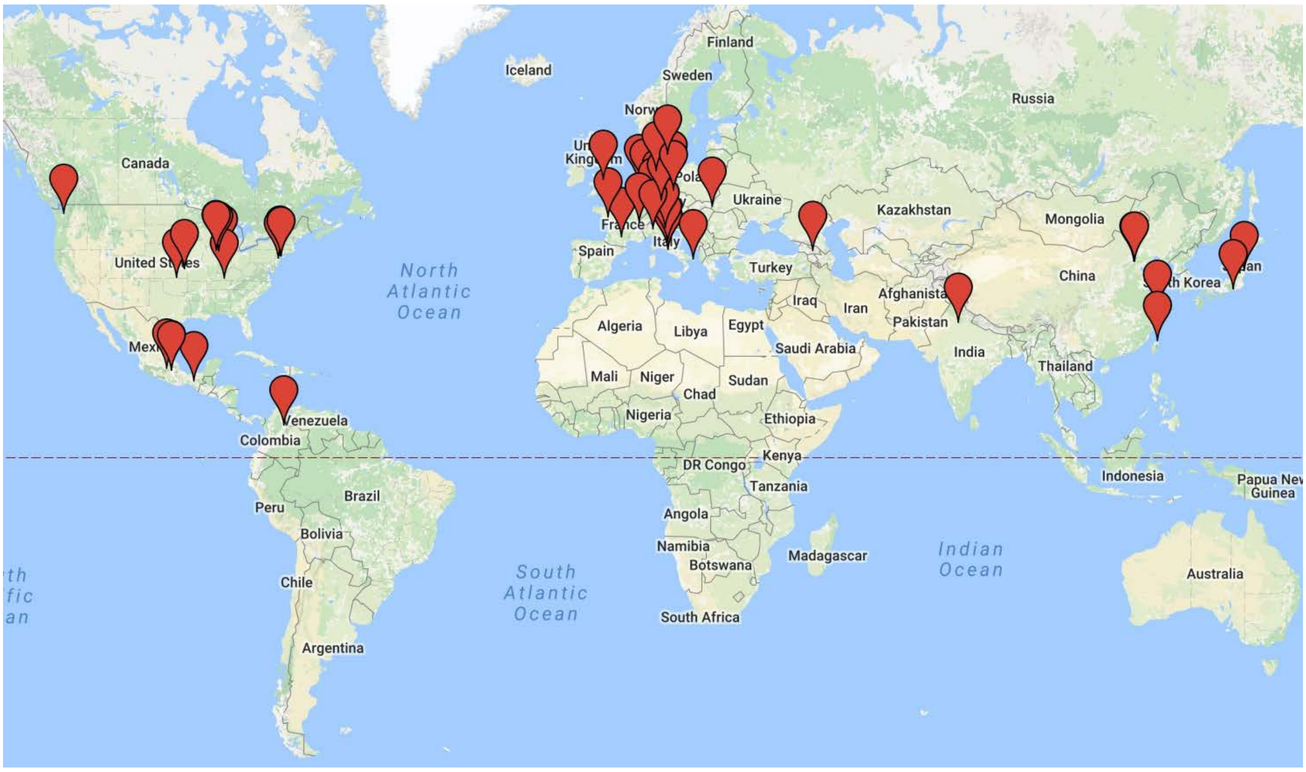
More Information:

http://icd.desy.de

IPPOG International Particle Physics Outreach Group · Netzwerk Teilchenwelt · DESY · Fermilab · QuarkNet

ALL PARTICIPATING GROUPS

INTERNATIONAL
COSMIC DAY



The google map shows the location of the registered participants.

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How many muons per s per m²?

Louis Rascol high school (Albi / France)

Abstract:

we will talk about how many muon per second depending on the area of the platform.

Method:

1. Put the detector on a horizontal plane
2. Start the detector for 3 minutes
3. observe the results obtained

Result:

-platform area= 16*30 = 576 cm2
-calculation average =(11+9+17+15+10+18)/6
=13,33 muons
during 30 seconds for 576 cm2

= 13,33/30
=0,44 muon/576 cm2
during 1 second for 576 cm2

=0,44*10000/576
=7,64 muons/m2 (during 1 second for 1 m2)

-

Conclusion:

We just obtained averages...
We could have made more measures.

Different results are possible depending on :

- position (in the school building)
- altitude

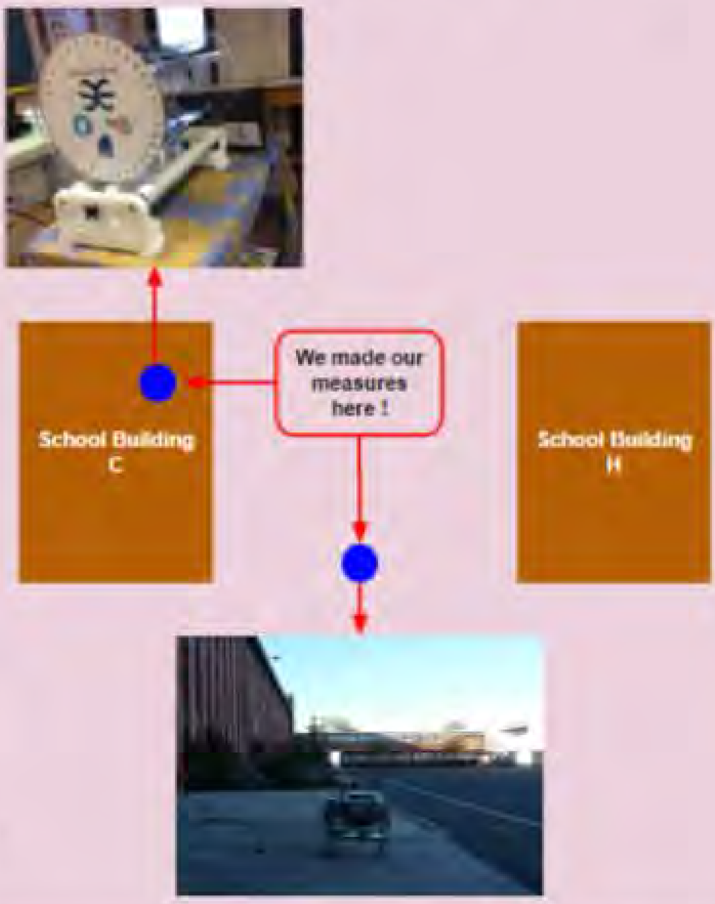
Team members :

Mouton Marine (15 years old)
Clau Mailys (15 years old)
Bergon Caroline (15 years old)

DO WE RECEIVE MORE MUONS WHEN WE ARE INSIDE OR OUTSIDE ?

Rascol High School, (Albi / France) - FERNANDEZ, CAYRAC & DUBOURG

Hypothesis : we think that the flow of muons is more important outside than inside.



Equipment :
- cosmic wheel ;
- computer ;
- extension cords.

Protocol :
- Place the cosmic wheel in building C on the second floor at 0° (rotation);
- Make several measurements every 10 seconds for 2 minutes ;
- Place the cosmic wheel outside at 0° (rotation) ;
- Make several measurements every 10 seconds forg 2 minutes.

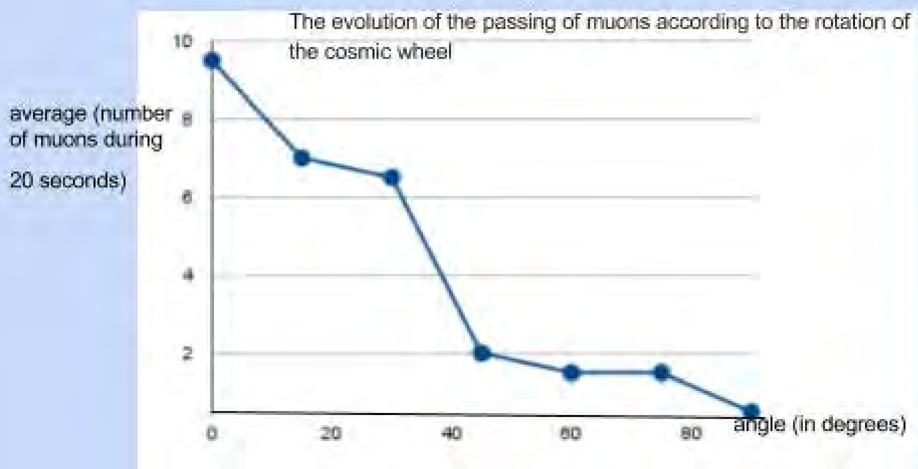
Time (in s)	Number of muons inside	Number of muons outside
10	0	3
20	2	3
30	2	4
40	5	8
50	2	0
60	4	2
70	2	4
80	2	8
90	6	4
100	3	0
110	3	1
120	2	5

Conclusion : we calculated the average. we found out that the flow of muons is more important outside than inside.

Rotating of the cosmic wheel

Protocol:

- Determine the total time on 5 minutes and the duration of intervals every 20 seconds ;
- Place the cosmic wheel on 0,15, 30, 45, 60, 75 and 90 degrees ;
- Measure the quantity of muons who pass through the two sensors for each inclinations.



Graphic of the evolution of the passing of muons

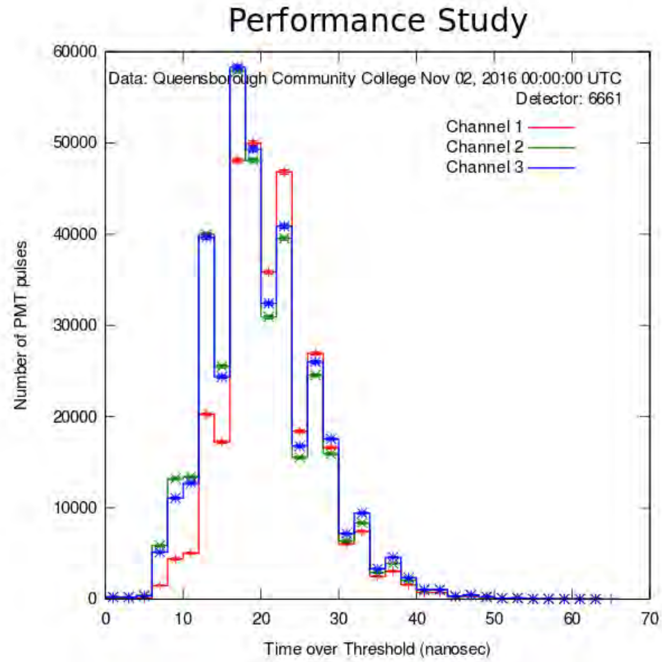
Warning: Make all the measurements in the same place (weather…)

Angle of the wheel	0	15	30	45	60	75	90
Average of muons	9.5	7	6.5	2	1.5	1.5	0.5

Compare the results: More muons from the zenith direction
0 degrees> 15 degrees> 30 degrees> 45 degrees> 60 degrees > 75 degrees> 90 degrees.

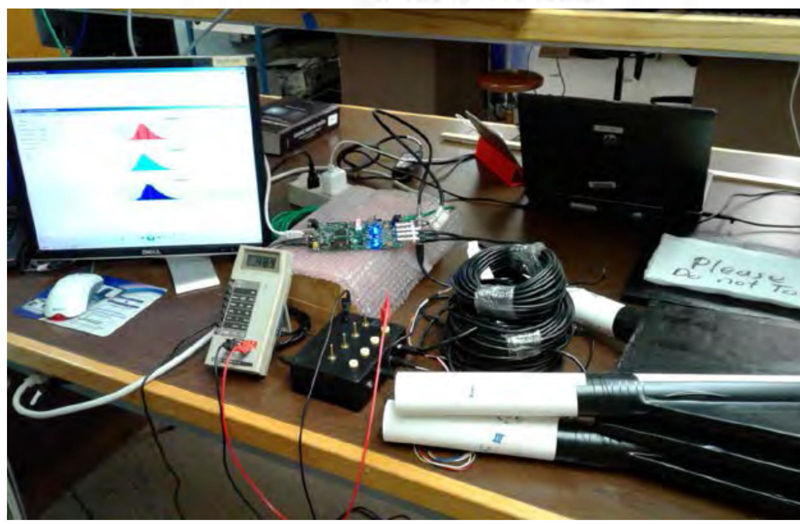
High school Louis RASCOL

QUEENSBOROUGH COMMUNITY COLLEGE CUNY



Detected 1.5 million cosmic ray muon pulses in 3 scintillator detectors at the Queensborough Community College Physics Department, a QuarkNet Center in Bayside, New York on November 1st, 2016

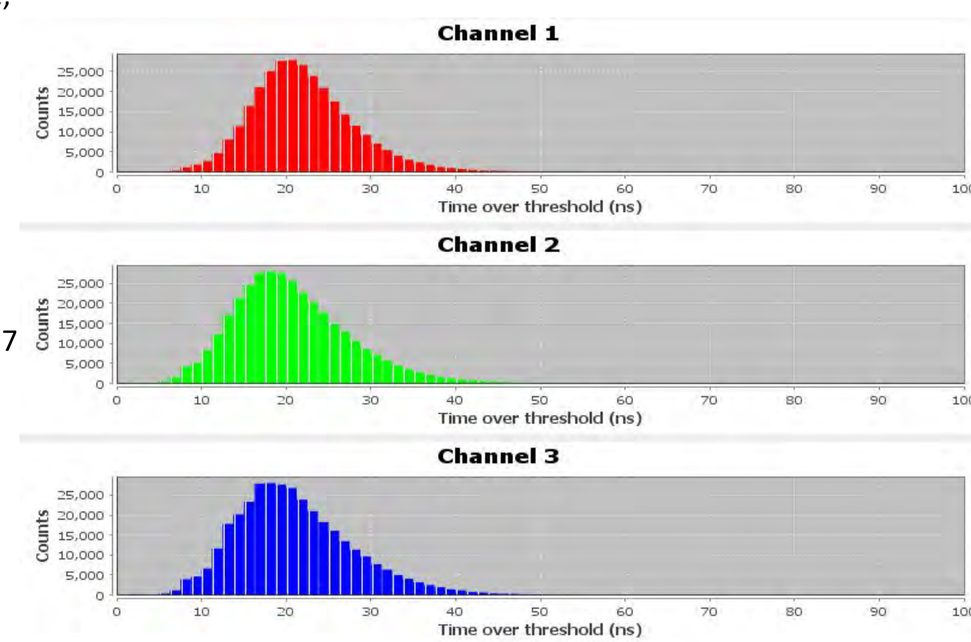
Xin Josh Zhao, David Buitrago, and Aye Paing (students), and Raul Armendariz PhD



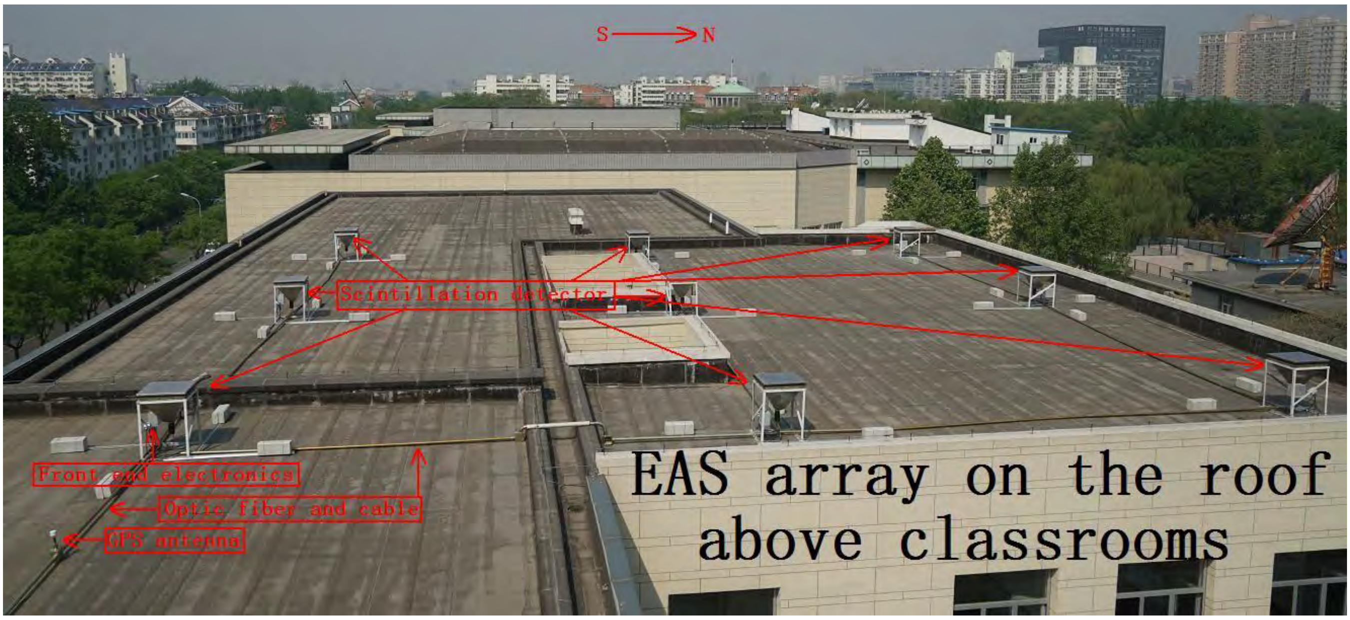
QuarkNet Detector
Scintillator:
Eljen-200,
PVT with organic fluors,
Light output 64% Anthracene,
λ max emission 425 nm,
rise time 0.9ns,
decay time 2.1 ns,
pulse width 2.5nm FWHM.

Photomultiplier tubes:
Sens-Tech P30CW5,
λ max response 350 nm
output pulse rise time 4.5ns, 7 FWHM

DAQ Board series 6000



The EAS array in Beijing Donzhimen High School, Beijing, CHINA

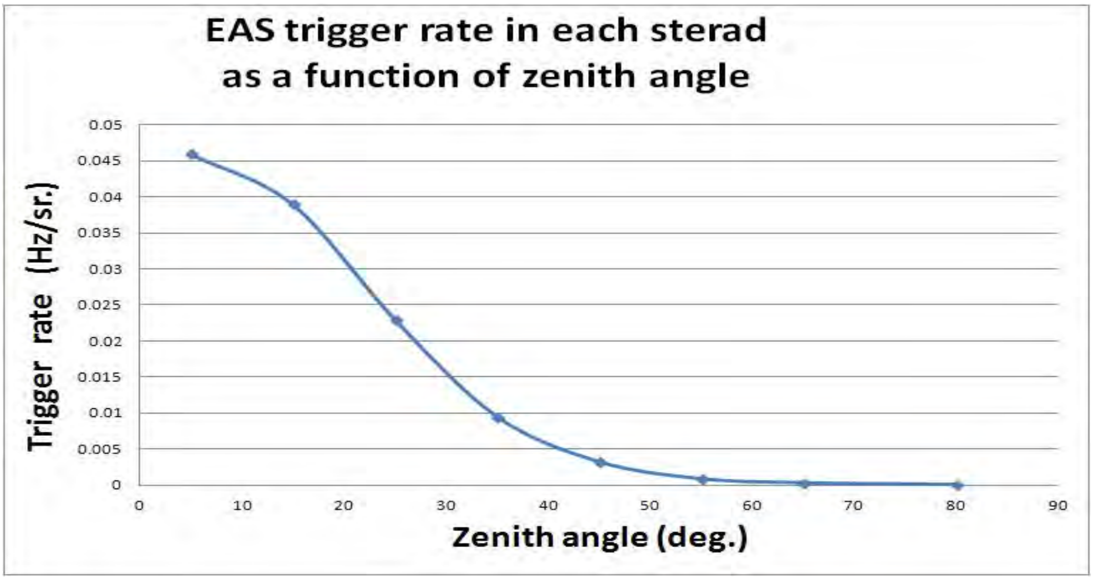


We have built an EAS array on the roof of our shcool. It consists 9 Scintillation detectors with sensitive area 0.5 squere meter each, spaced 9 meters as a 3×3 matrix. Its location is: latitude N.39° 56', longitude E. 116° 25', altitude 46.4m. The electronics digitize signal of detectors, and an computer continuously acquires data and control all equipments on line. When any charged cosmic ray passes our detector, the GPS time, amplitude of signal and the number of the detectors are recorded.

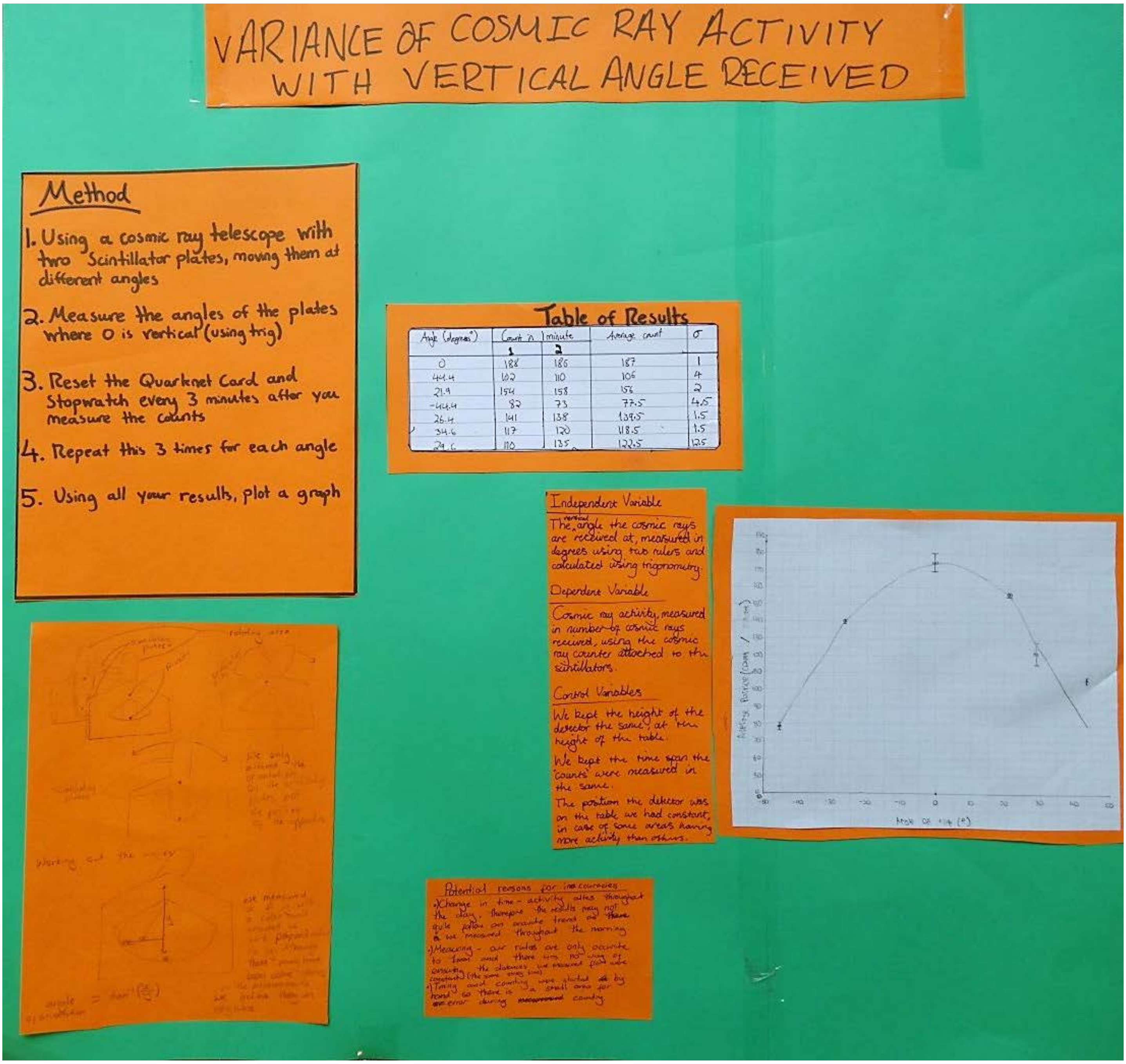
Physicist made a program to reconstruct measured tracks of shower if the fired detector number (coincident fold)≥4, get its direction. We analysed direction of each triggerd shower in measurement time t=728 minutes, get trigger number N_i in each range among 8 renge of zanith angle. Then calculate trigger rate $n_i=N_i \div t$.

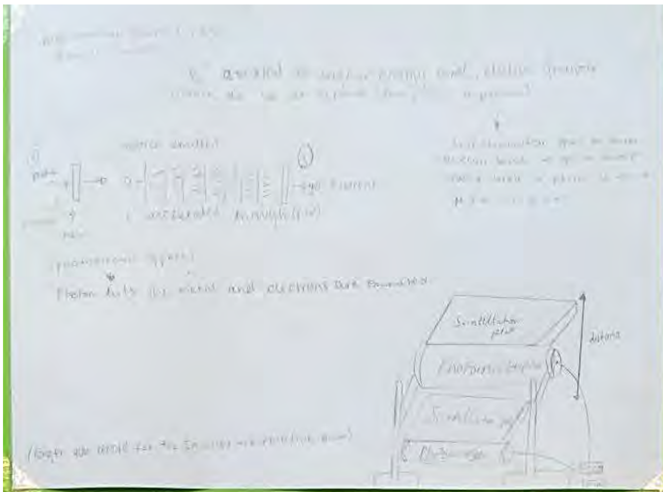
For zenith angle range A to B, its sterad Ω is calculated by formula $\Omega=2\pi(\cos A - \cos B)$. We got the trigger rate in unit sterad $Y_i=n_i \div \Omega_i$ as following table, and the curve Y_i as function of zenith angle.

Serial number of ranges i	1	2	3	4	5	6	7	8
Range of zenith angle (deg.)	0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70°	70-90°
Average zenith angle (deg.) Zi	5°	15°	25°	35°	45°	55°	65°	80
Trigger numbers in the range Ni	191	480	462	260	107	32	11	1
Trigger rate in each range ni (Min.$^{-1}$)	0.262	0.659	0.635	0.357	0.147	0.044	0.015	0.0014
Trigger rate in each sterad Yi (Hz/sr.)	0.046	0.039	0.023	0.0095	0.0032	0.00082	0.00025	0.00001



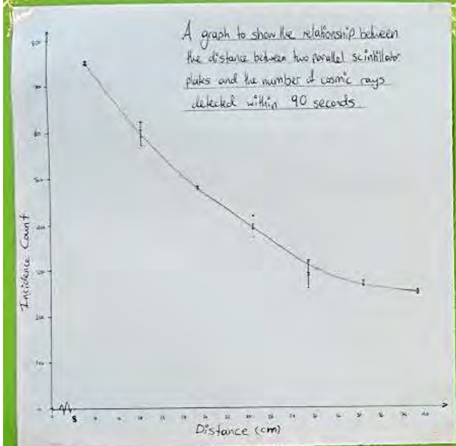
University of Birmingham

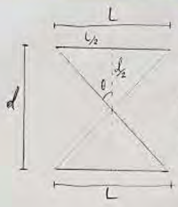




Distance (cm)	Time (mins)	Count #1	Count #2	Count #3	Average	Standard deviation
14.5 (±0.1)	1	392	384	400	392	8
14.5 (±0.1)	0.5	227	202	208	212.$\dot{3}$	13.1
14.5 (±0.1)	1.5	602	598	592	597.$\dot{3}$	5.03
9.5 (±0.1)	1.5	700	756	796	750.$\dot{6}$	48.2
19.5 (±0.1)	1.5	479	487	474	480	6.56
24.5 (±0.1)	1.5	383	406	400	396.$\dot{3}$	11.9
29.5 (±0.1)	1.5	220	332	325	292.$\dot{3}$	62.7
34.5 (±0.15)	1.5	268	284	257	269.$\dot{6}$	13.6
39.5 (±0.15)	1.5	262	252	235	249.$\dot{6}$	13.7

A graph to show the relationship between the distance between two parallel scintillator plates and the number of cosmic rays detected within 90 seconds.





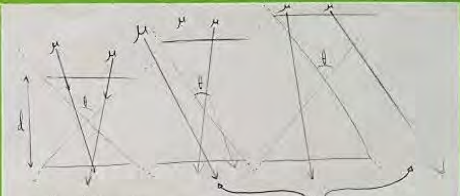
$\tan\theta = \frac{L}{d}$

As the length (L) of the scintillator plates did not change, i.e. is a constant, we can simplify the equation to:

$\tan\theta = \frac{1}{d}$

$\therefore \tan\theta \propto \frac{1}{d}$

The graph shows this inverse relationship



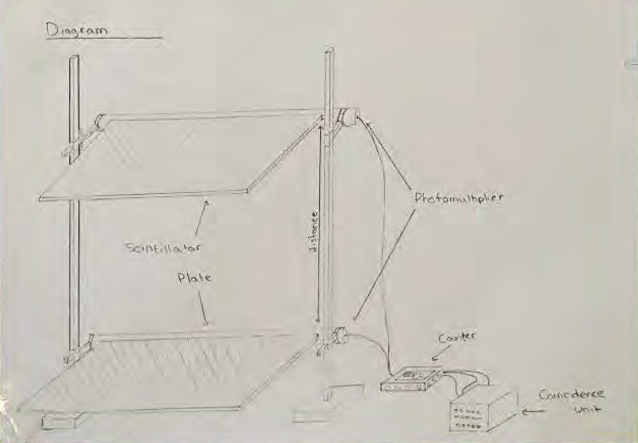
As distance (d) increases, the angle of acceptance (θ) decreases and so less cosmic rays have the potential for detection.
Therefore as the distance between the two scintillator plates increases, the detected number of incidences in a time period decreases.

Cosmic rays only detected once are not discounted by the coincidence unit.

Method

1. Set up the apparatus. Using two clamp stands, suspend two photomultipliers that are each attached to a scintillator plate. The scintillator plates should be arranged so that they are parallel one above the other.
2. Connect each photomultiplier to a circuit board that records each detection of a cosmic ray.
3. Measure the distance between the scintillating plates, which should be as close as possible together.
4. Start a timer and simultaneously reset the counter. Record the number of detections in 90 seconds. Repeat the experiment another 2 times.
5. Change the distance between scintillator plates in equal increments. Repeats should occur at each different distance.
6. Record results in a table and calculate standard deviation and mean.
7. Draw a graph where distance between scintillating plates (cm) and average number of detections can be compared.

Diagram



Cosmic Rays

by

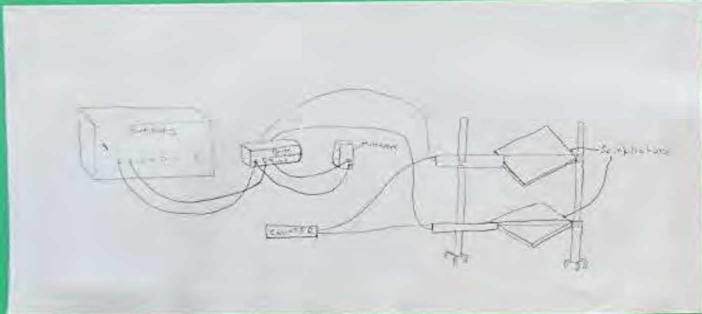
Errors

- Distance between two scintillator had a uncertainty of (±0.1cm) from zero and measurement errors. Also the measurement of >70 cm had ± 0.15 cm. The parallax error brings this up to ± 1cm
- Stopwatch has human error, an uncertainty of ±1s
- The counter fast nature of the counter, means it has an uncertainty of ± 5 occurrences

COSMIC RAY INVESTIGATION

Hypothesis: As the distance between the two scintillator plates decreases the number of muons detected increases.

Hello we represent Marling school as well as Archbishop Ilsley catholic school. Today we spent our time recording data from two scintillator plates and we changed the distance between them to see how that would affect the number of muons we detected.

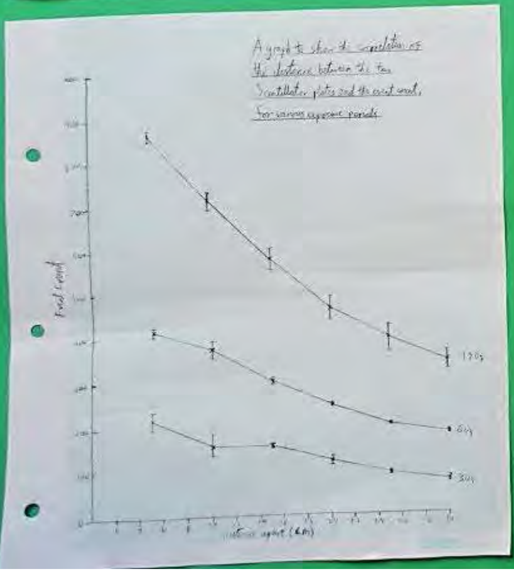


The diagram shows how increasing the separation decreases the solid angle.
A smaller solid angle reduces the number of cosmic rays through the detector, because they have to enter the plates at a more perpendicular angle so they are correctly detected.

Collecting Results

Time:
- → 3 different time periods
- → The larger the time period the larger the values recorded
- → Therefore the percentage error is smaller, as when calculating the fraction the $\sqrt{n}$ becomes smaller in comparison to the muon number

Repitition:
- → Each stage of the experiment was repeated 3 times
- → This allowed for the elimination of anomilies, leading to more accurate averages and standard deviations



A table to show the correlation of the distance between the two scintillator plates and the event count, for various exposure periods.

Time (s)	Distance (cm)	Event count 1	2	3	Average	Standard Deviation
30.00	30.00	72	85	72	76.3	±7.51
30.00	25.00	100	89	90	93	±6.08
30.00	20.00	115	109	130	118	±10.82
30.00	15.00	155	161	156	157.3	±3.49
30.00	10.00	164	192	183	168	±23.51
30.00	5.00	198	237	217	217.3	±19.50
60.00	30.00	167	179	179	175.3	±6.35
60.00	25.00	201	205	202	202.7	±2.08
60.00	20.00	255	245	243	247	±6.43
60.00	15.00	305	300	290	298.3	±7.64
60.00	10.00	377	386	360	376.3	±21.09
60.00	5.00	425	404	412	413.7	±10.60
120.00	30.00	346	326	372	347	±23.64
120.00	25.00	396	364	429	396.3	±32.50
120.00	20.00	489	460	506	485	±23.51
120.00	15.00	745	768	804	772.3	±26.65
120.00	10.00	718	698	741	719.7	±25.03
120.00	5.00	862	878	852	864	±13.11

From our data we observed that the greater the distance between the scintillator plates, the greater the number of muons detected. This is because when the distance increases the solid angle becomes smaller so therefore, you detect less particles. We also found that the longer the time we recorded for, the smaller the relative errors. For example, the times 30 seconds, 60 seconds and 120 seconds the relative error as a percentage gradually decreased as follows; 6.8%, 4.9% and 3.4%. Final errors were calculated using standard deviation.

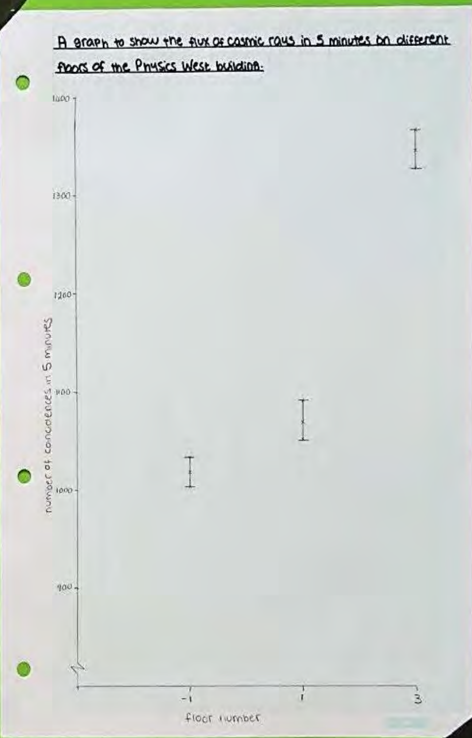
Measuring cosmic ray fluxes on different floors of a building

by...
eve talkowski
lissie hogg
molly davies
emma berry
cormac healy
jodie grice
nathan coxson

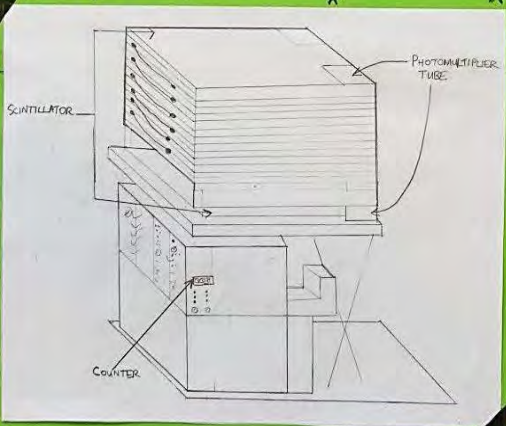
method - what we did

In the beginning, we recorded the number of cosmic rays detected by the scintillators over a period of 60 seconds. This was then decided to be too short of a time period as the differences between results were too great. After trying 3 minutes, we then decided that 5 minutes would be our chosen time period as it left us with a smaller uncertainty than 1 or 3 minutes. For each floor of the building, we took 3 - 4 readings of the number of cosmic rays per 5 minutes. We took 4 readings on some of the floors as one or more of the readings on the floor 1 didn't seem to fit the pattern.

our data...



spark chamber



more data

	no. of coincidences in 5 minutes			
floor	1	2	3	4
-1	909	1076	928	117
1	1081	1071	1058	
3	1602	1291	1229	1265

making our results precise

How would we know that the results for the experiment are accurate.

If we take the average mean of our experiment to be 1058, we square root this value. This gives us an answer of 32.5 approximately. So, taking this value we would look at our other results and if all of the results are within this range, ±32.5 we know that our results are accurate enough.

N	$\sqrt{N}$	$\sqrt{N} \div N$	%
10	3.2	0.320	32
100	10	0.1	10
1000	32	0.032	3.2

As you increase N, the percentage decreases. this means that the value that we get will be more accurate.

Our results support the fact that cosmic rays come from the sky as our results show a lower count of cosmic rays as we were on lower floors. Cosmic rays were absorbed by the concrete floor boards of the building.

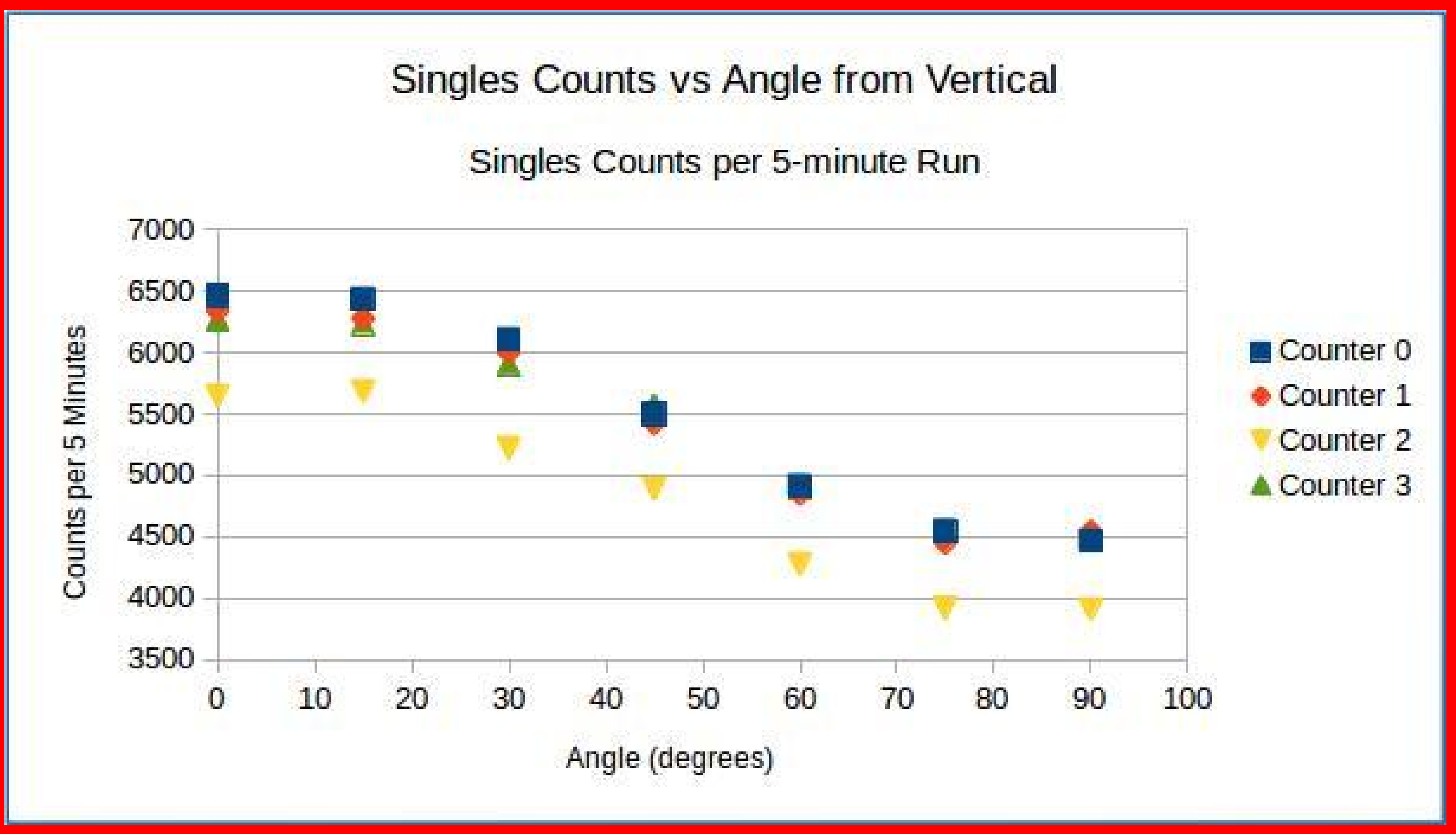
in conclusion...

In conclusion, our results show a positive correlation between the number of coincidences and the floor level. At the highest floor level, the scintillator detected the highest number of coincidences. This is because at the lowest level, the concrete of the floors above absorbs the cosmic rays, therefore less are detected in the atmosphere. The results showed a significant difference on different floors as the uncertainties do not overlap with one another.

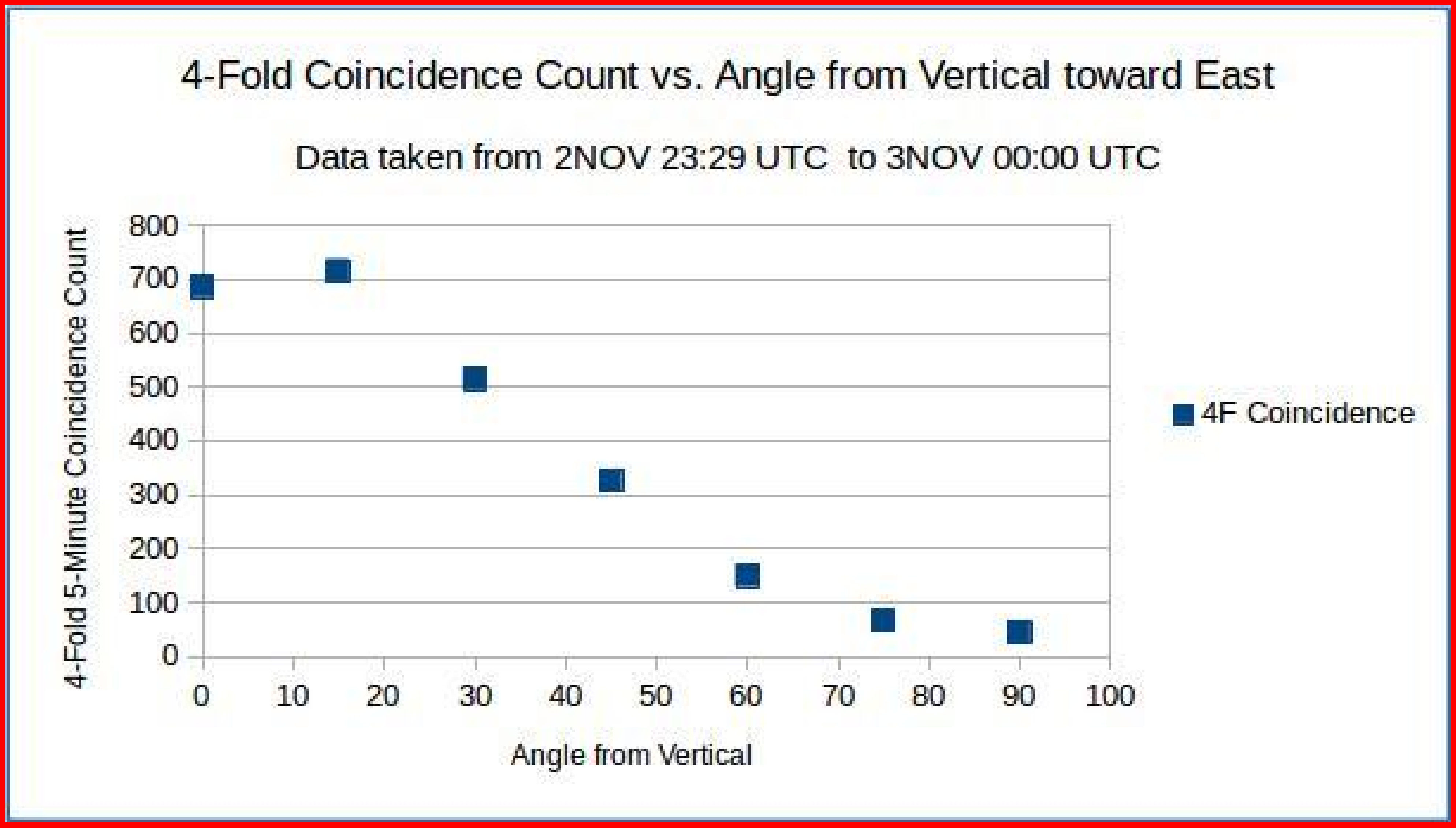
Ottawa High School
Ottawa, Kansas, United States
38.600522N -95.279578W Elevation 280 m

Teacher: Mr. Jim Deane
Student Researcher: Ms. Brittany Crossen

We constructed a new enclosure for our standard QuarkNet CRMD counters (scintillator paddles). The spacing from top to bottom is 46cm, giving us a one steradian “view”.



We plateaued our counters in a vertical position. The plateauing for counters 0, 1, and 2 was as expected, but counter 3 (bottom) had significant noise in the plateauing data. We chose a value that seemed to be reasonable for the PMT voltage and proceeded with data collection. Our singles rate also shows counter 2 may need slightly higher voltage to the PMT.

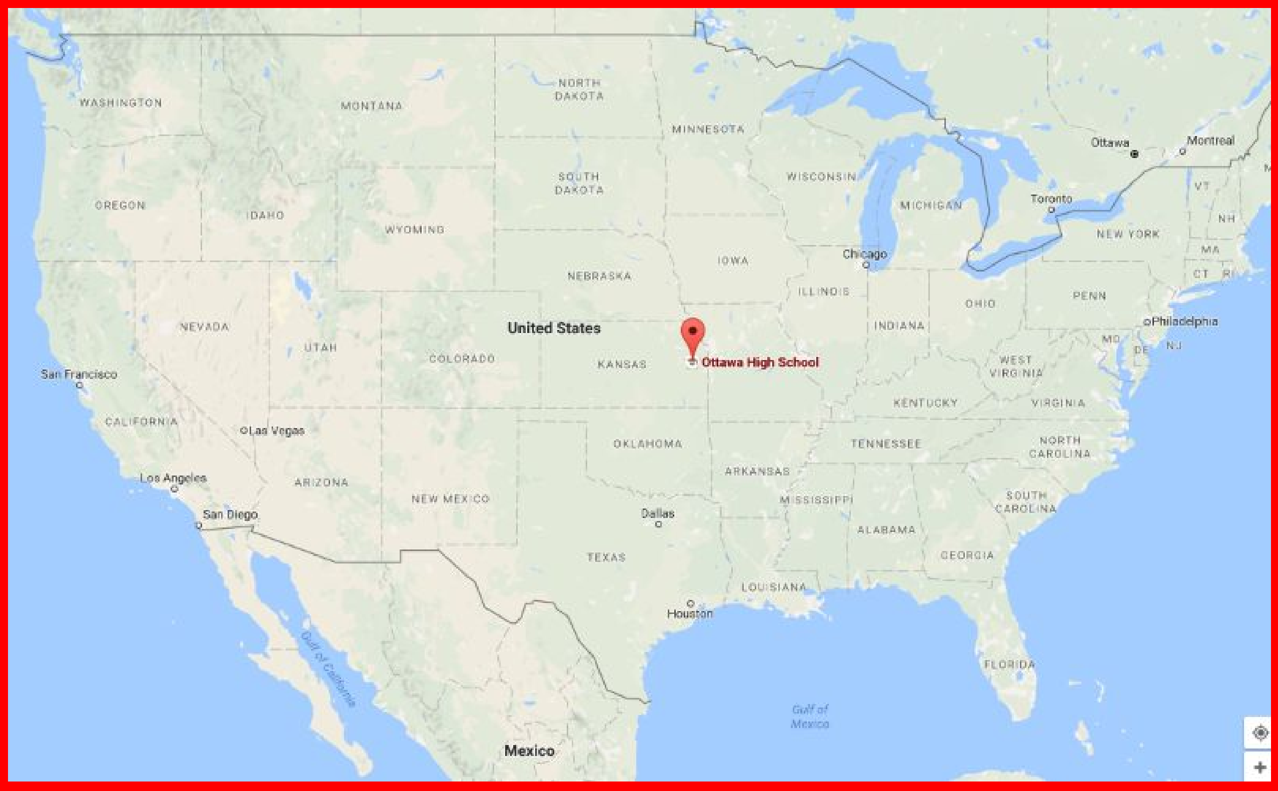


We began taking data in five-minute runs, changing the counter stack angle from horizontal to vertical in fifteen degree increments. In the graph, a value of 0 on the horizontal axis represents 0 degrees from vertical.

Data was taken with four-fold coincidence, using the counts from five-minute status updates for our analysis.

We see that the muon count is much lower as the angle approaches horizontal, but we did not successfully fit an equation to this data.

The unusual feature of the vertical data showing fewer coincidences when fully vertical than at fifteen degrees is unexpected. We did not have time to repeat our data collection, but repeating this data collection process to see if the unusual feature is still there is in our plan for the year.



U.S. DEPARTMENT OF ENERGY | Office of Science

QuarkNet

Cowley College

INTERNATIONAL COSMIC DAY 2016

ZENITH ANGLE DISTRUBUTION OF SHOWER PARTICLES

OCTOBER 31ST – NOVEMBER 3RD

Figure 1: The Quarknet cosmic ray detector at a zenith angle of 75 degrees.

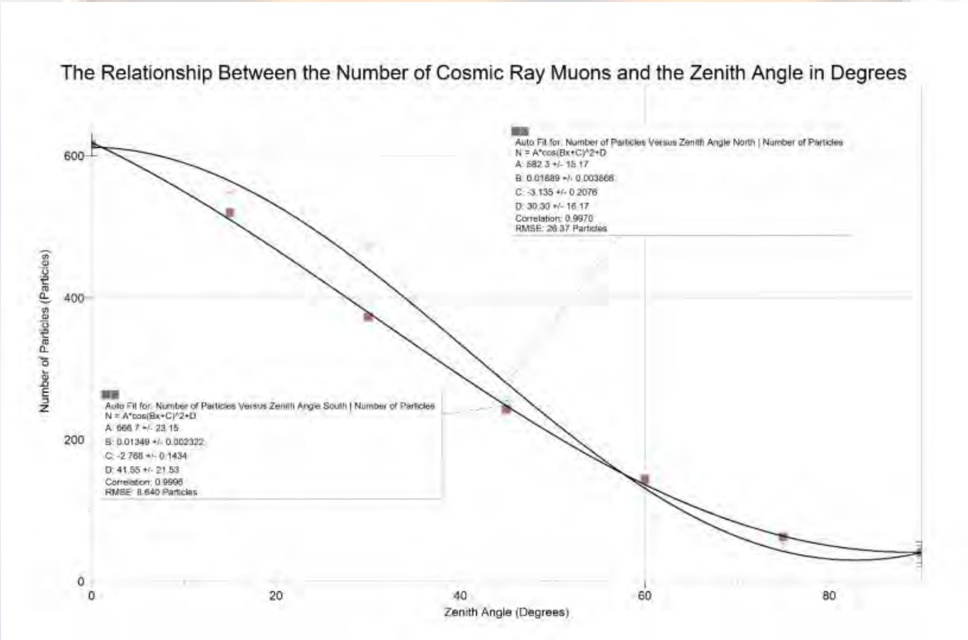


Figure 2: Number of cosmic ray muons for north and south zenith angles

Conclusion: The greater the zenith angle, the less muons that passed through the counters. The southern zenith data run shows a decrease in muons at the lower zenith angles between 15 and 45 degrees. This could possibly be due to the greater amount of atmosphere the muons coming from the south have to travel through in order to reach the detector. Both graphs indicate a $\cos(\theta)^2$ fit. The correlation of the north graph was 0.997 while the south graph was 0.999 with the x-axis being the zenith angle and the y-axis being the number of muons.

Procedure:

The experiment was setup using a rack to hold all four counters that were approximately 15 cm apart so that the distance between the top and bottom counter was 46 cm. In order for the muons to be recorded they had to pass through all four counters. The starting data run was at a 0 degree zenith angle which is a 90 degree horizontal angle. After each data run the experiment was rotated 15 degrees to the north until it was flat then started again at zero and rotated 15 degrees south. Each data run lasted for five minutes. After the five minutes, the number of muons was recorded in Logger Pro to create a graph.

STUDENTS RESEARCHERS:
HARVEY BAKER
TANNER BALSTERS
HANNAH CORYEA
ZACHARY MAVIS
GARRETT MISORA
SHAINA SCHOENECKER

SPONSORED BY:
MARTIN SHAFFER

INTERNATIONAL COSMIC DAY 2016

Fun Facts About Us:

- Approximate number of students enrolled per semester: 2,900
- Size of Arkansas City, Kansas campus: 15 acres
- Most notable majors: Nursing and Business
- Unique major available: NDT (nondestructive testing)
- Ranked 21st best JUCO in the state of Kansas.
- Tuition & Fees (per 3 credit hours)
    - Kansas Residents: $297
    - Out-of-state Residents: $438
    - International Students: $579

COWLEY COLLEGE

Est. 1922

Figure 3

Now named Ireland Hall, this building was the original Cowley College. When the high school shut down, the basement was once used as classrooms for the college. As the number of students grew, new buildings were built around the area. Ireland Hall is now used as the criminal justice and cosmetology building.

Figure 4

Pictured from left to right: Tanner Balsters, Garrett Misora, Harvey Baker, Zachary Mavis, Hannah Coryea, and Shaina Schoenecker. Photographed by Martin Shaffer

The cosmic ray collaboration

This project was a collaboration between Roskilde Gymnasium and Borupgaard Gymnasium. The purpose was to measure cosmic rays in search of muons. We spend the whole day working in mixed groups with people from both schools measuring cosmic rays, making posters and solving tasks.

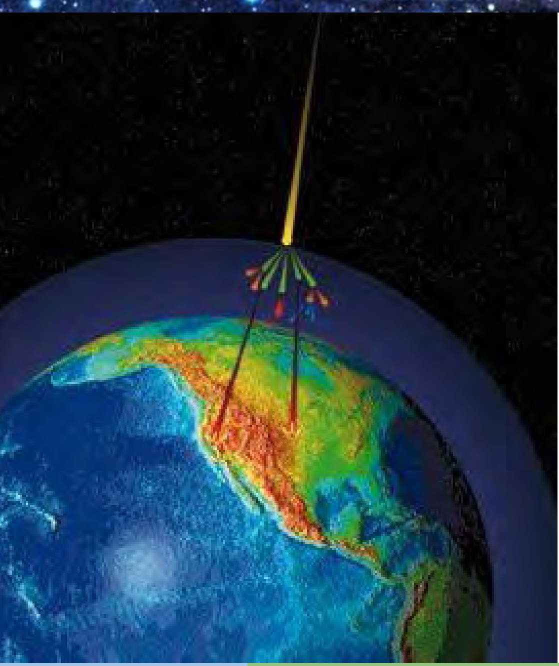
IMG_1032.JPG

Borupgaard Gymnasium

Roskilde Gymnasium

We have measured cosmic rays , and this is the result.

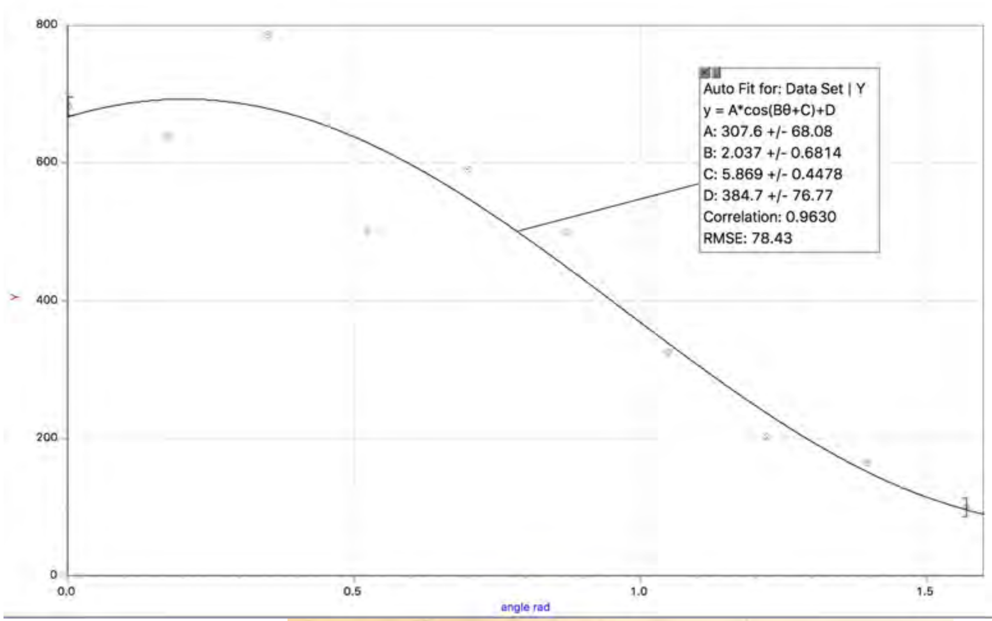
Cosmic rays

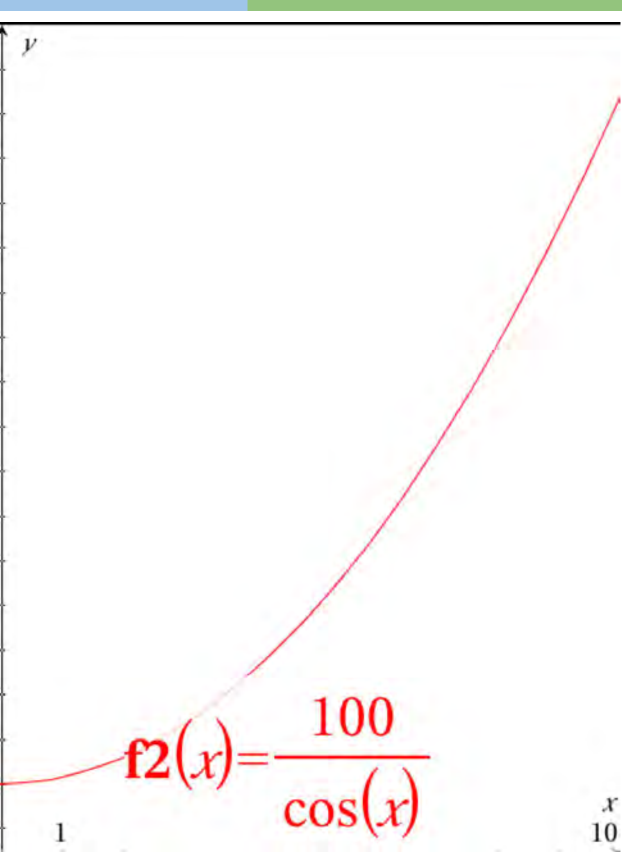


The Earth's magnetic field deflects most of the cosmic rays. Except muons. The atmosphere protects us, from most of the damage that the rays would have caused.
At the North and South pole the magnetic field, lets some of the rays in, and that's what we can see, when we look at the northern lights (Aurora).

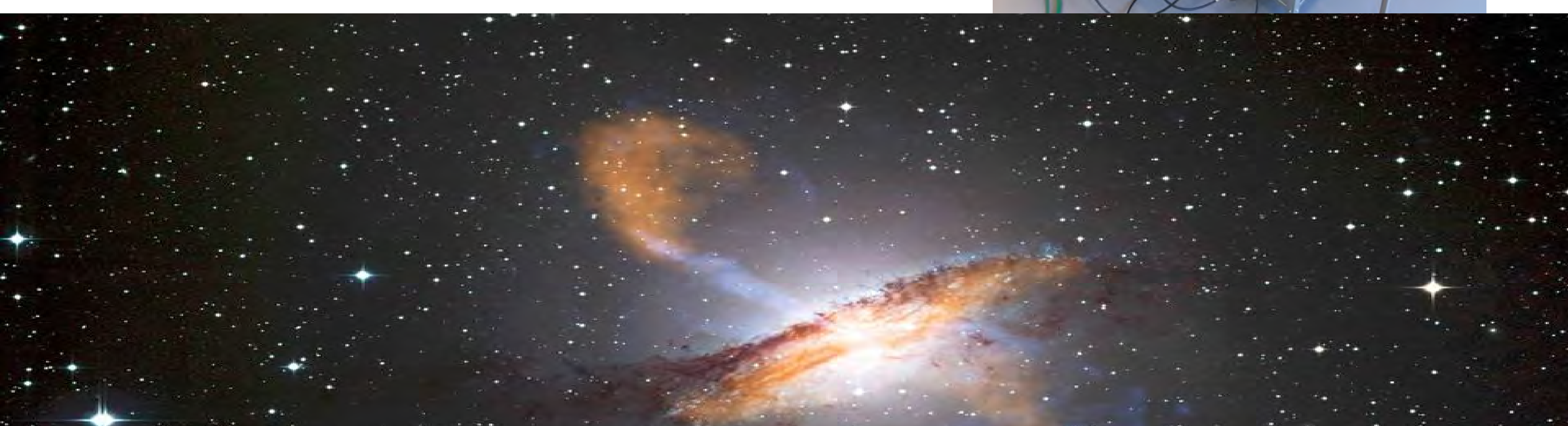
Angle from zenith in degrees	Counts	Counts	Signal rate in Hz
90	0	0	0,00
80	155	174	0,55
70	194	209	0,67
60	335	315	1,08
50	523	474	1,66
40	632	549	1,97
30	520	482	1,67
20	793	779	2,62
10	627	649	2,13
0	728	636	2,27

A graphic illustration of our collected data points, it shows us that the further we move away from zenith, the smaller the amount of muons.





This adds up with our second graph, which shows us that when we measure closer to 90 degrees the muons will have to pass through a bigger amount of atmosphere, which in turn increases the chances of the muons being stopped by other particles.



INTERNATIONAL COSMIC DAY

IN DRESDEN

International Cosmic Day

We are 16 students of different schools throughout Saxony, Germany, who met at the Institute for Nuclear and Particle Physics at the Technical University Dresden. After having listened to an introductory presentation, we divided into four groups to conduct

various experiments. It was our main goal to measure cosmic particles (particularly muons) and even to make them visible with a cloud chamber, which we built ourselves. We learned a lot and enjoyed ourselves too.

International Particle Physics Outreach Group

NETZWERK TEILCHENWELT

DESY

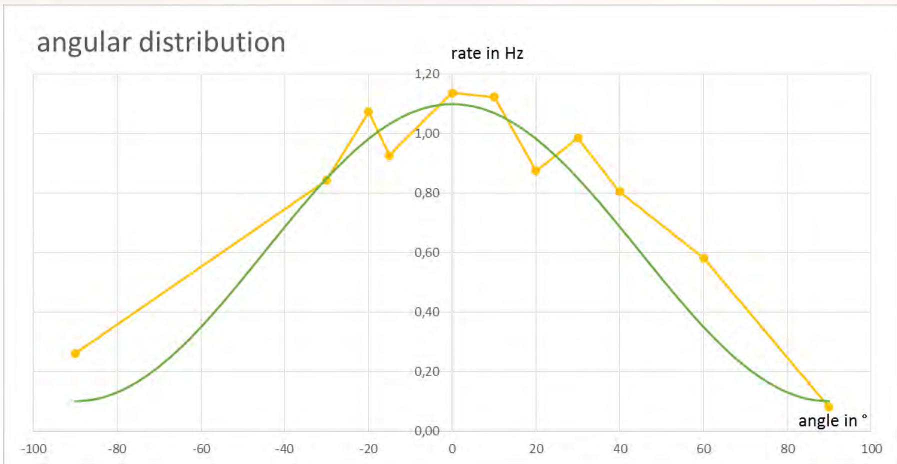
Fermilab

QuarkNet

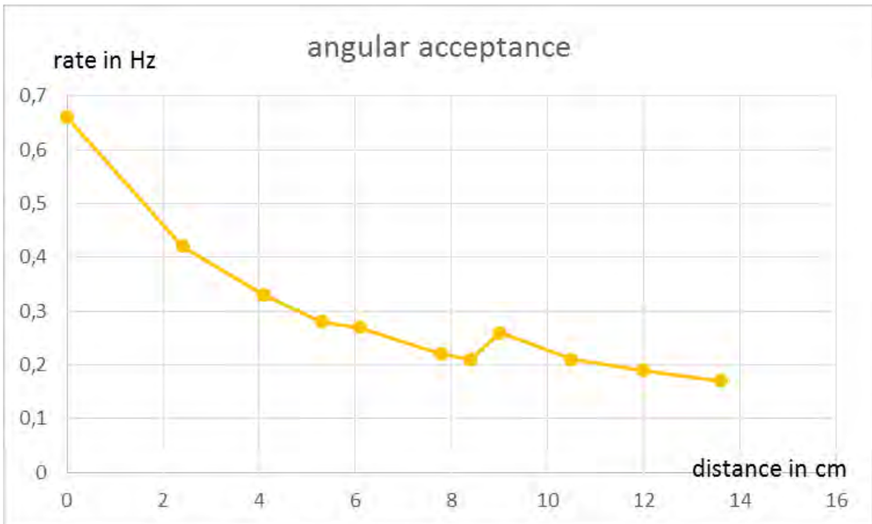
INTERNATIONAL COSMIC DAY

Measurements:

In one experiment, we investigated the relation between the angle of the detectors and the rate of muons detected. After having plotted the results on the graph below, we found that the function that shows this relation is proportional to the cosine squared. ($r = k \cos^2 \alpha$). Our measurements are shown in orange and the cosine squared curve was added in green for comparison.



In our second experiment, we measured how many muons were detected by two detectors at the same time at different distances. The shape of the graph should roughly represent a hyberbola.



International Particle Physics Outreach Group

NETZWERK TEILCHENWELT

DESY

Fermilab

QuarkNet

ıttp://privatschulen-ve.de/gymnasium-villa-elisabeth.html

Gymnasium Villa Elisabet

Gymnasium Villa Elisabeth is a private secondary school located in Wildau in the south of Berlin, Germany. It has an international orientation and a developing focus on natural sciences. Cooperations exist with the TH Wildau, the DESY in Zeuthen and the Netzwerk Teilchenwelt, a German outreach group for particle physics. 2016 marks Villa Elisabeth´s 4th participation in the International Cosmic Day. As in 2015 we had a day BC (Before Cosmicday) to give our students a crash course into particle physics and cosmic particles. The days AC were used to perform longer experiments, such as muon decay and muon speed. Participating students attend two physics courses of grade 11.

From our side this year´s participants were our students Leonard Biedermann, Oliver Buck, Maximilian Fender, Pauline Gehrke, Pieter Hartwig, Marc Heinemeyer, Helene Hielscher, Niklas Hütten, Leoni Itzigel, Miriam Karschunke, Max Kuhn, Tina Latz, Tim Lauterbach, Maximilian Lebek, Nele Lehmann, Franz Martin, Sören Mittag, Erik Mittelstaedt, Luca Pirschel, Lena Rusdorf, Leon Seide, Sung Woo Yi, Leonard Wasserkampf, Franz Weiß as well as the physics teachers Marco Muth and Stefan Bläß, PhD. We are particularly grateful to Carolin Schwerdt from the DESY, Zeuthen, for providing the hardware (muon detectors – CosMO and Kamiokannen) and organizing the ICD. We are also grateful to Hans-Peter Bretz and Moritz Hütten for their theoretical input, experimental coaching, data mining and last not least an enthusiastic presentation of their scientific work at DESY at the end of the day. Last not least we are grateful to Roman Kobosil, this year´s participant at the LHC workshop for students at CERN, for being a guest speaker.

n cooperation with

NETZWERK TEILCHENWELT

DESY IN ZEUTHEN.

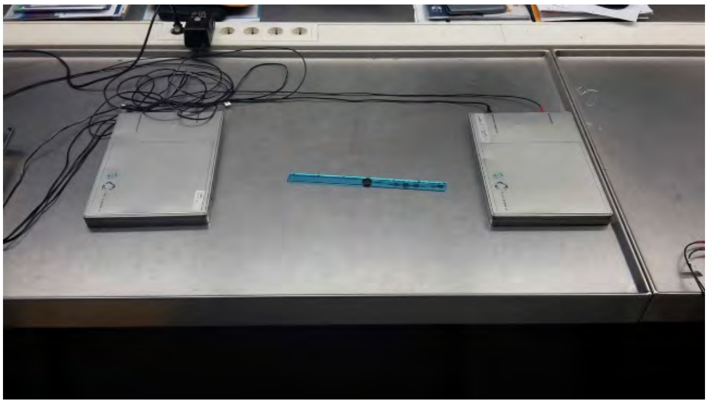
DESY

CosMO – Detection of Cosmic Muons

Leonard Biedermann*, Pieter Hartwig*, Marc Heinemeyer*, Niklas Hütten*, Max Kuhn*, Tina Latz*, Nele Lehmann*, Lena Rusdorf*, Leon Seide*, Sung Woo Yi*, Leonard Wasserkampf*, Hans-Peter Bretz[#], Moritz Hütten[#], Stefan Bläß. * Gymnasium Villa Elisabeth, Wildau; [#] DESY Zeuthen, Germany

Materials and Methods

PC + Muonic software, 1 DAQ card, 2 muon detectors (scintillator plates), power supply (5 V), cable connections.



1. Laptop with Muonic software, 2. DAQ box, 3. scintillator plate (channel 0), 4. scintillator plate (channel 1), 5. 5 VDC power adapter, 6. Lemo BNC cable, 7. USB cable, 8. 5 VDC splitter

The two detectors were arranged in different positions in relation to each other, calibrated, varying thresholds were set and frequencies of coinciding events were measured (fig. 1). At optimum thresholds for each detector, varying distances (fig. 2) and varying angles against a horizontal support of the detectors aligned in parallel and a distance of 0,4 m (fig. 3) coincidence measurements were performed.

Results and Discussion

We observed that muon detection decreased with higher thresholds (set in mV) (fig. 1). Further, the frequency of coinciding muon detection events was highest with both detector plates arranged in parallel to the horizontal support (table surface) and lowest with both detector plates arranged perpendicularly to the table surface. Also muon detection was highest the closer the distance of the detector plates and lower the farther they were arranged apart (fig. 2).

With lower thresholds particles able to trigger an event require less energy than at higher thresholds. Thus, high thresholds bias for high-energy particles. – The majority of muons originate from particle collisions in the higher atmosphere – predicted to shower in a $\cos^2(\Theta)$ dependency – which we could nicely demonstrate (fig. 3).

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

NATURWISSENSCHAFTLICHE
FAKULTÄT

International Cosmic Day 2016

at Friedrich-Alexander-Universität Erlangen-Nürnberg

Dr. Angela Fösel, Paul Fadler, Jonas Neuser
Department of Physics
angela.foesel@fau.de

Motivation

On 2nd November 2016, students aged 14 to 18 years and interested in particle physics met at the Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg to learn more about cosmic radiation. The organizing team, Dr. Angela Fösel, Paul Fadler and Jonas Neuser, presented the basic ideas of cosmic radiation, the methods of detecting cosmic radiation and the reason for doing this research.

Cosmic rays are high-energy radiation, mainly originating outside the solar system. Composed primarily of high-energy protons and atomic nuclei, they have two origins: supernovae remnants and black holes. Most of those arriving on earth are a secondary product of swarms originating in the atmosphere by primary cosmic rays, with interactions that typically produce a cascade of secondary particles starting from a single energetic particle. These particles, e.g. muons, can be observed using special equipment.

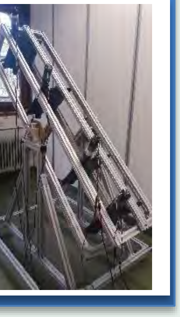
Experimental Setup

On International Cosmic Day, we at the department of physics at FAU took measurements of the cosmic ray muon flux as a function of the zenith angle, using a special cosmic ray detector:

Four scintillator plates are used to detect the muons.

For each plate, the photons produced in the scintillator plate are detected by a photomultiplier.

The plates are mounted on a traversable frame, so that the zenith angle could be varied while measuring the cosmic ray muon flux.



Procedure

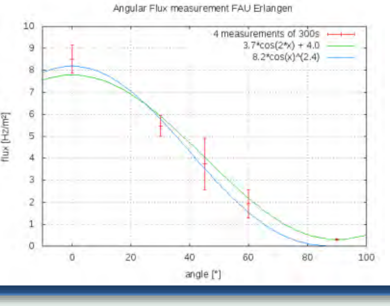
The signal of the photomultipliers is converted by a DAC-card.

A python package called ‘Muonic’ then checks the data for events that took place in all four plates at approximately the same time to filter out noise.

The resulting data – cosmic ray muon flux versus zenith angle - are plotted.

We fitted curves to our data, one of them (green curve) ‘best fit’ and one (blue curve) following the theory, see results.

Results



Discussion

We carried out measurements of muons of secondary radiation using scintillators, photomultipliers, DAQ-cards and the computer program ‘Muonic’, varying the zenith angle.

We expected that increasing the angle should lower the trigger rate due to the longer way of the muons through the atmosphere.

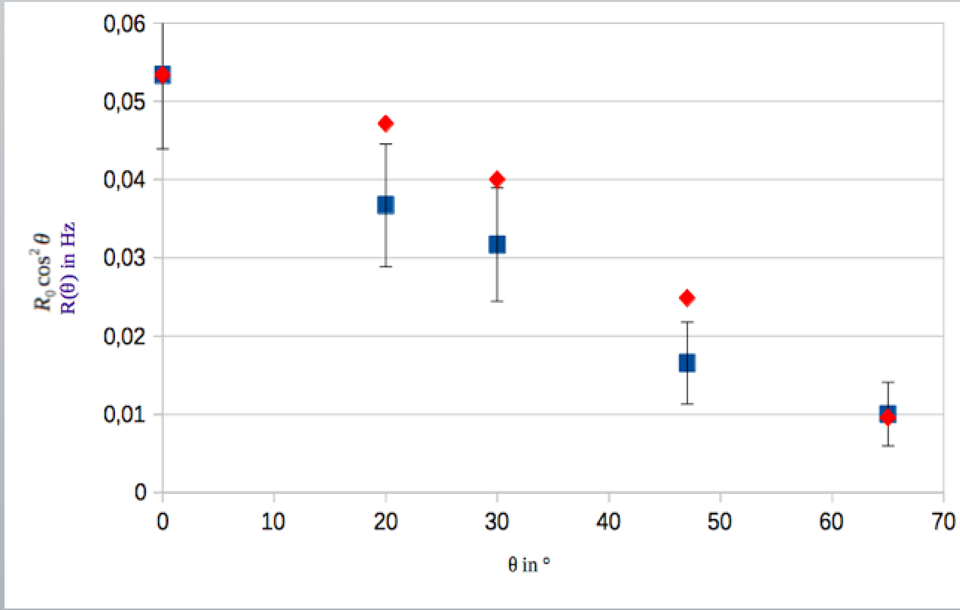
The data confirmed our expectation and they are consistent with the theory, which predicts a cos²-dependency.

Student team

Janina Bauer, Felix Maximilian Dietz, Julia Haas, Vanessa Kasper, Julian König, Thomas Kornalik, Anke Mosbrugger, Jasmin Schlicker

Cosmic Day 2016
Myon rates in dependence of various angles
Bergische Universität Wuppertal, Germany

On Wednesday the third November we, students from St-Anna Wuppertal, met each other in the University of Wuppertal for measuring Myons in dependence of different zenith angles.
We divided into two groups of three students and built a tower of three Scintillator detector plates from DESY. With the help of the program “mounic” we could measure Myon rates ten minutes long for each angle settings and created a table in which we calculated measurement errors, experimental and theoretical Myon rates. This values were transferred in a graphic which shows the angle Θ on the X axis, the theoretical and experimental rate R(Θ) was assigned to the Y axis.
As expected, the values ran in a form of a cosine curve. We noticed that our experimental values were in acceptable proximity to the theoretical $R_0\cos^2\Theta$ curve. The second value at 20° was a little bit to high, more precise, the second value theoretical curve was not even included in the fault tolerance. Furthermore, the third measured value (30°) was within the theoretical curve in contrast to the next angle 47°. In this case the Myon rate was slightly to low. Fortunately, the last measured angle which was 65° fits perfectly to the theoretical assumption.



Concluding, all students could get valuable experiences regarding scientistic work and learned many important properties and facts about Myons.

BERGISCHE
UNIVERSITÄT
WUPPERTAL

International Cosmic Day 2016
DESY, Hamburg Site

Our Results

At DESY in Hamburg we had six groups investigating the different muon properties.

One group measured the muon velocity, using four different scintillator plate distances and counting over 800 events at each distance. With the linear fitting function they found a muon velocity of $2.84 \cdot 10^8$ m/s (see Fig. 1).

The other five groups investigated the angular distribution: They varied the detector orientation between -90° and +90° in 15° steps and counted the incoming muons for ten minutes at each position. Their results could be described with a cos² fitting function independent of the orientation (see Fig. 2 and 3).

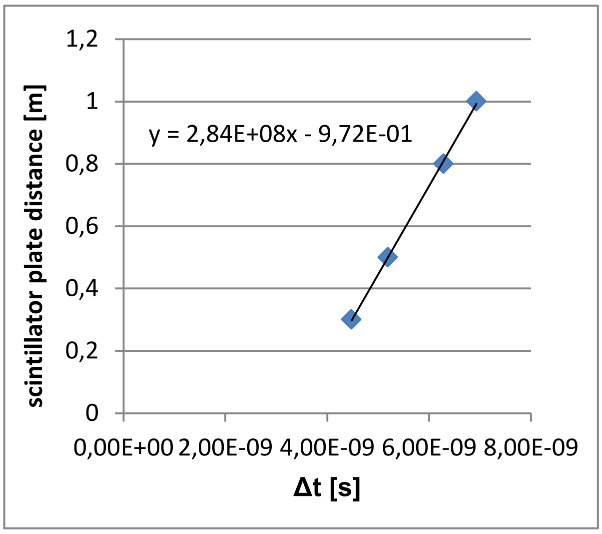


Fig. 1: Determination of the muon velocity

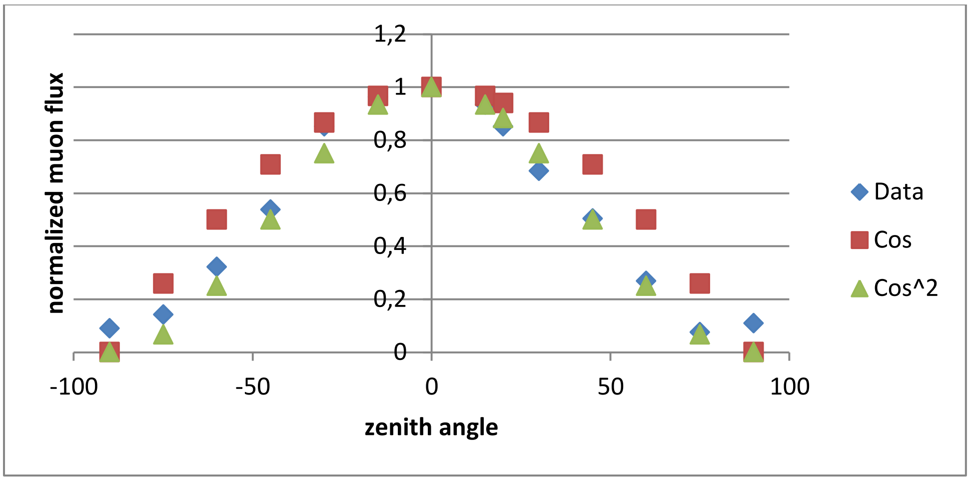


Fig. 2: Muon flux versus zenith angle in north-south-direction (blue data points) with the fitting functions cos (red) and cos² (green).

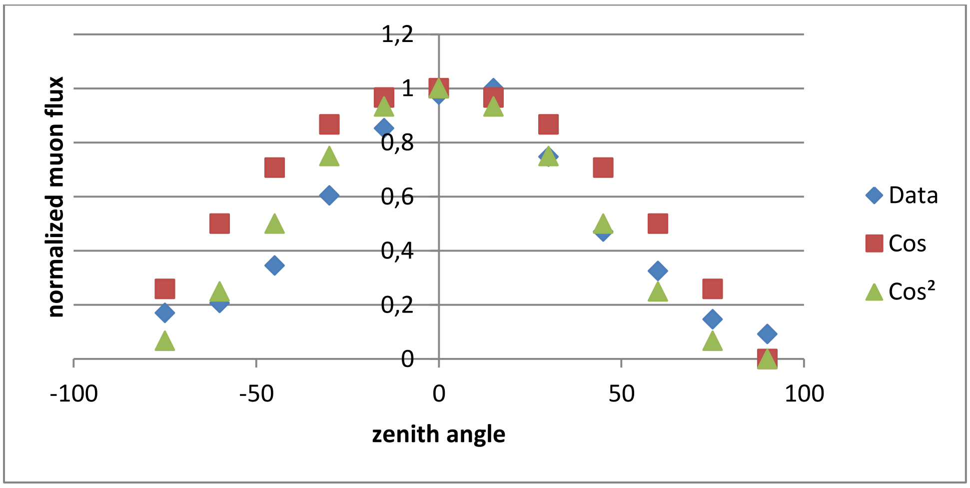
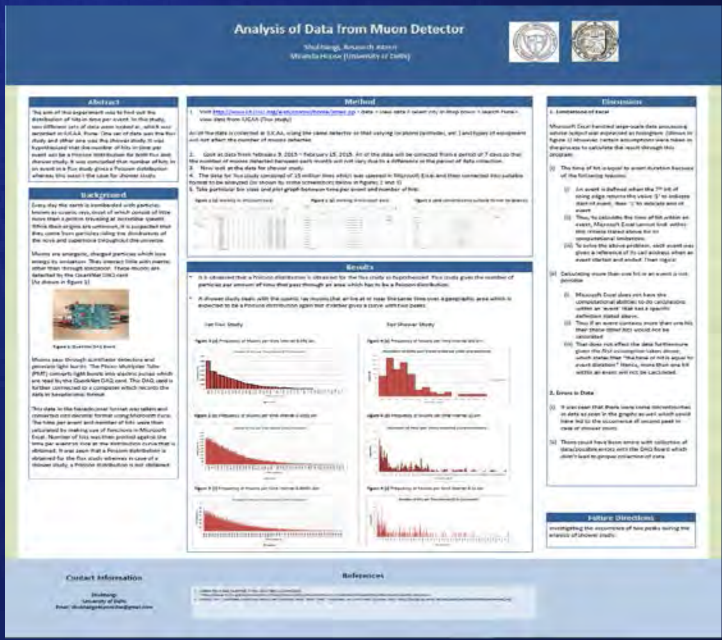


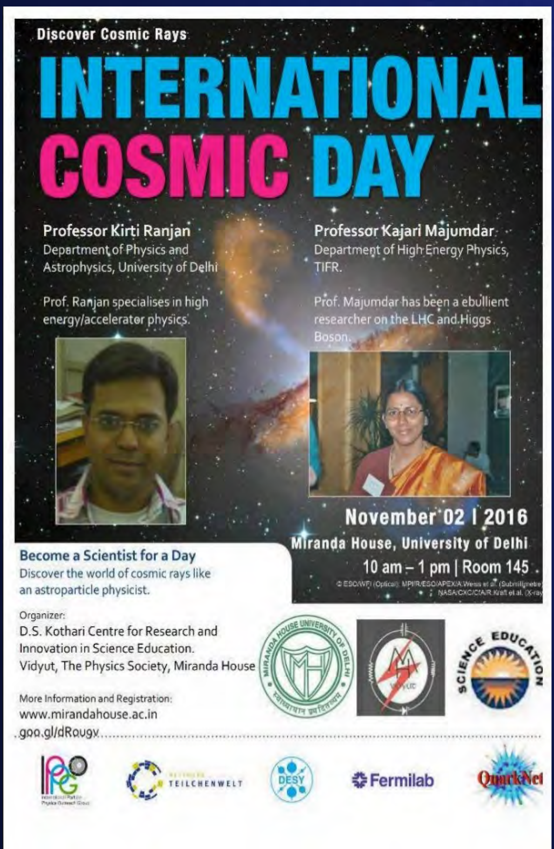
Fig. 3: Muon flux versus zenith angle in east-west-direction (blue data points) with the fitting functions cos (red) and cos² (green).

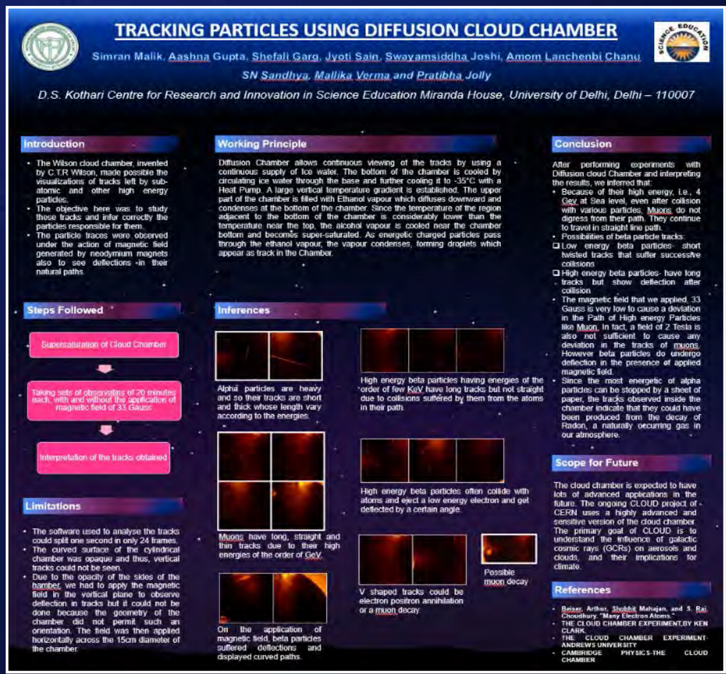
MIRANDA HOUSE
UNIVERSITY OF DELHI
NEW DELHI, INDIA

International Cosmic Day at Miranda House

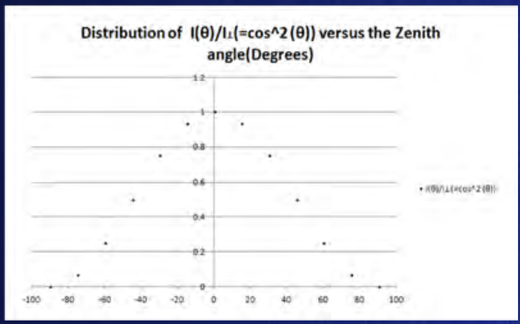
COSMIC RAYS

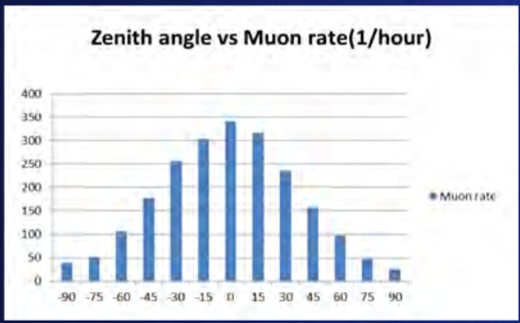


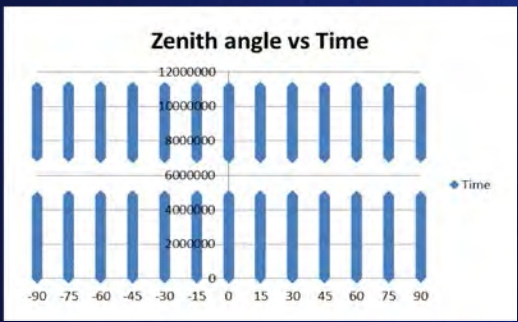


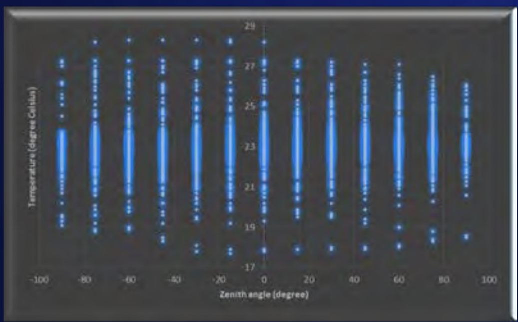


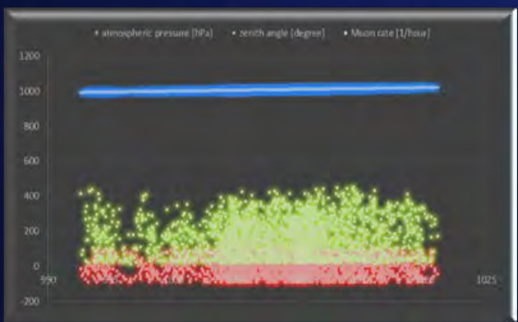
DATA ANALYSIS

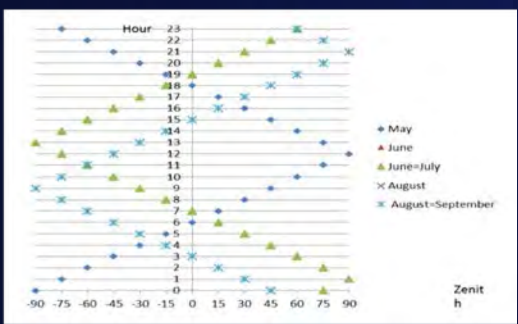












INFERENCES:

- It is found that the muons at a zenith angle of 90° and -90° were the least in numbers.

- A normal distribution is obtained when the graph between zenith angle and muon rate is plotted. The reason for this can be that at higher zenith angles, muons have greater energy and hence the muon flux is lower at higher angles and increases as the angle decreases. This further tells us that most of the muons hit vertically at a zenith angle of 0°. Therefore, the muon flux is highest at 0° zenith angle.

- It can be concluded that temperature and atmospheric pressure don't have a significant effect on zenith angles whereas the variation of zenith angle with muon flux is quite evident.

- It is also found that the ratio between the muon intensity at a zenith angle θ and the muon intensity at a zenith angle 0° is approximately $\cos^2\theta$ by taking into account various approximations. It is seen that the graph between the zenith angle θ and $\cos^2\theta$ gives a normal distribution.

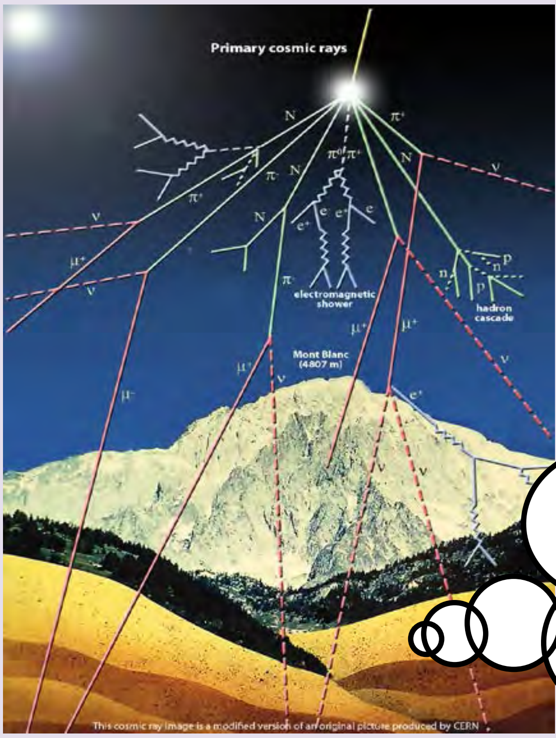
- It is also seen that month has an effect on zenith angle. This is due to the fact that position of earth changes with respect to the sun so

INTERNATIONAL COSMIC DAY

2/11/2016

Liceo Scientifico Leonardo da Vinci - Casalecchio di Reno (BO), ITALY

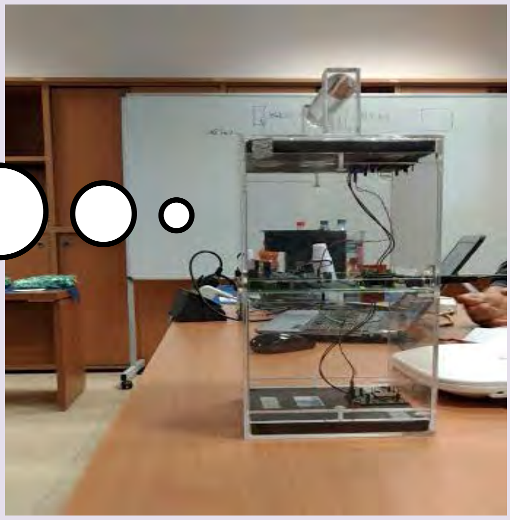
INFN – National Institute of Nuclear Physics (University of Bologna)



COSMIC RAYS are immensely high-energy radiation, mainly originating outside the Solar System (Supernovae and black holes). When rays crash against the atmosphere, they swarm in other particles (like protons, muons or electrons), in a sort of cosmic shower, and get grounded.

On the 2nd of November we took part at the International Cosmic Day at INFN in Bologna. This experiment was about measuring – with the help of a Cosmic Box – how many secondary particles produced by cosmic rays reaching the Earth surface. We took measurements every 15 minutes, altering the angle between the Cosmic Box and the Zenith (0°C, 15°C, 30°C, 60°C, 90°C). Finally, we put data in a spreadsheet to obtain a plot.

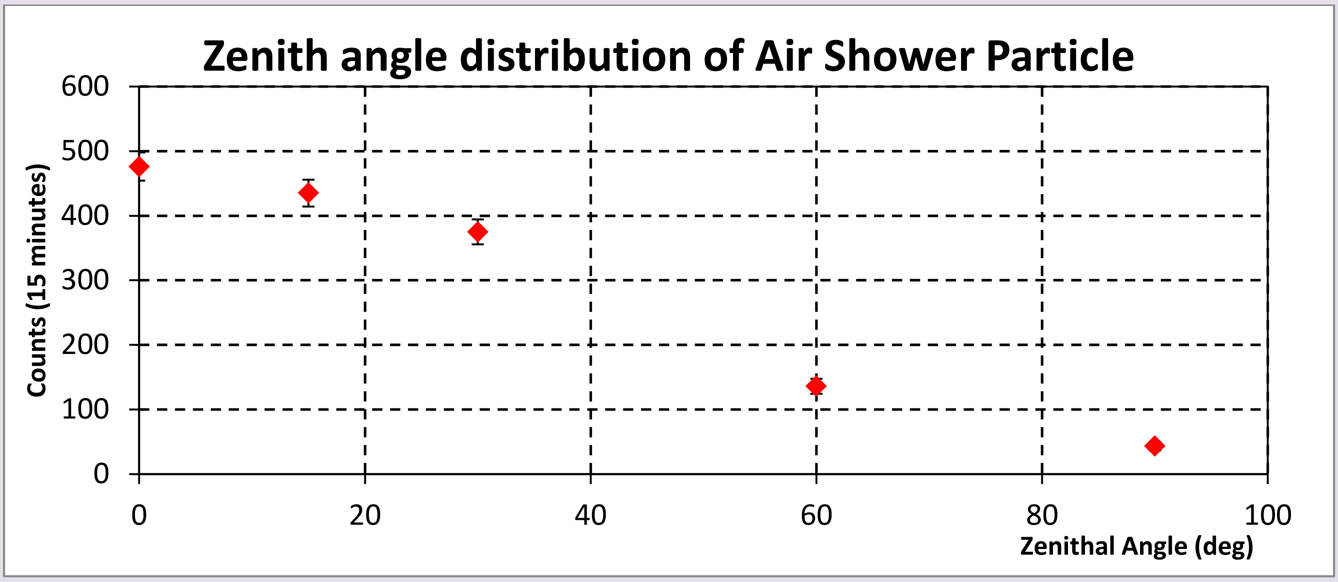
The COSMIC BOX is a detector consisting of a photomultiplier, which converts a light signal into a digital signal, and two scintillators, which are used to determinate the trajectory of the particle.

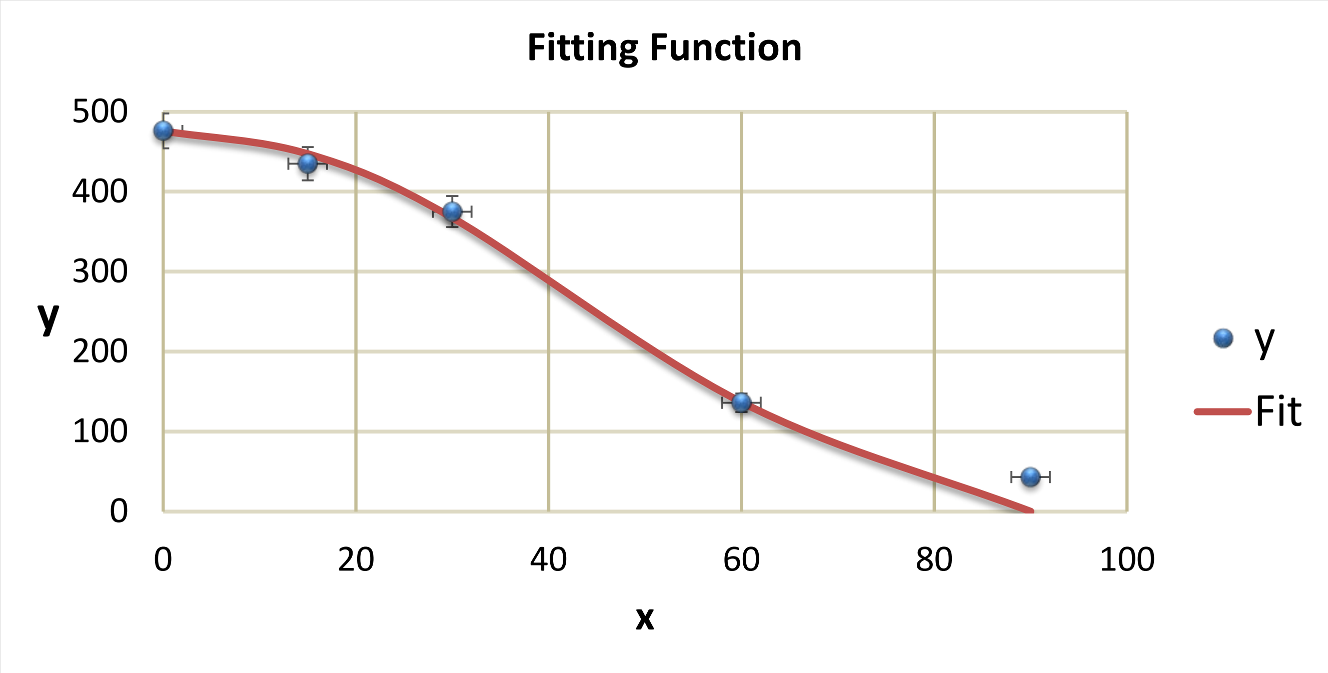


Our results

Frequency (Hz)	Zenith angle (Deg)	Measurement S of μ	error	Y normalized	$\cos\theta$	$\cos^2\theta$	$\cos^3\theta$
0,5289	0	476	21,82	1	1,00	1,00	1,00
0,4833	15	435	20,86	0,92	0,97	0,93	0,90
0,4167	30	375	19,36	0,79	0,87	0,75	0,65
0,1511	60	136	11,66	0,29	0,50	0,25	0,12
0,0478	90	43	6,56	0,09	0,00	0,00	0,00
$Y/15\cdot 60$	X	Y	Square root (Y)		$\cos(X\cdot\pi/180)$	$\cos^2(X\cdot\pi/180)$	$\cos^3(X\cdot\pi/180)$

If we compare normalized data with the value of the various powers of the cosine and use Excel to fit data we can deduce that the best fit occurs with the function $y = N(0)\cdot(\cos(x))^{1,8}$, where $N(0) = 476$ counts.





How we can deduce from the plot, the last measure (zenith angle equal 90°) isn't in accordance with the fitting function . Due to the earth curvature, in fact, the rays always impact on the earth with an angle greater than zero, and then in the plot the experimental point is above the point provided for by the fit function.

Baroncini Vittorio - Lenzi Jacopo - Martignani Lorenzo Eugenio - Prantoni Giulia – Righetti Giovanni – Taglioli Riccardo - Venturi Claudia

Angular distribution of cosmic muons in Pavia (Italy)

F. Ballerini[1], M. Bersani[1], A. Buttini[1], L. Capaldo[1], S. Ferraiuolo[1], G. Gjuzi[1], C. Lazzeri[1], L. Mantuano[1], G. Mascheroni[1], A. Menegolli[1,2], C. Mercalli[1], C. Quispe[1], G. Papini[1], M. Repossi[1], L. Sfolcini[1], A. Sorano[1], D.M. Tirro[1], A. Tragni[1], and A. Varesi[1]

[1]INFN, Sezione di Pavia, via Bassi 6, 27100 Pavia (Italy)
[2]University of Pavia, via Bassi 6, 27100 Pavia (Italy)

Introduction

In this report results on the angular distribution of the cosmic muons at sea level from the measurements carried out by the students of the INFN Pavia group are shown. A cosmic ray telescope already available in a dedicated laboratory of INFN Pavia (Italy) was used. This telescope consists of three parallel slabs of NE102 plastic scintillator read by both ends by Photo-Multiplier Tubes (PMTs), XP2020 model by Philips, see Fig. 1. A control knob, see Fig. 2 (left), allows for the rotation of the telescope of a selected angle as read on an angle meter, see Fig. 2 (right).

Figure 1: The cosmic ray telescope inside the dedicated laboratory of INFN Pavia (Italy).

1 Measurements and results

After having turned on all the six PMTs, setting them at the proper High Voltage, the rate of the cosmic muons crossing the three slabs of scintillators put in coincidence was measured as a

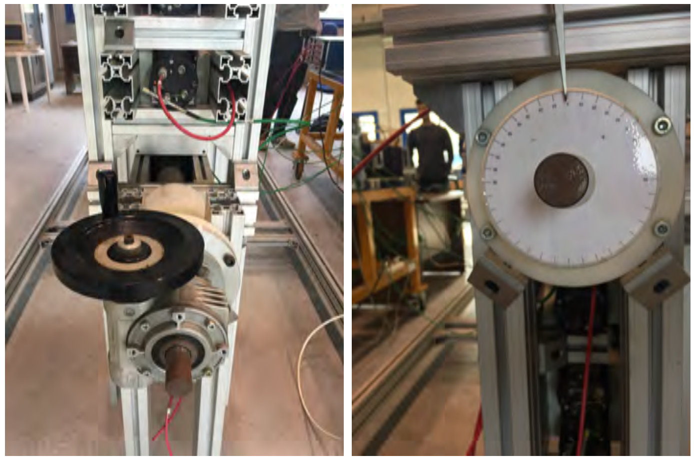


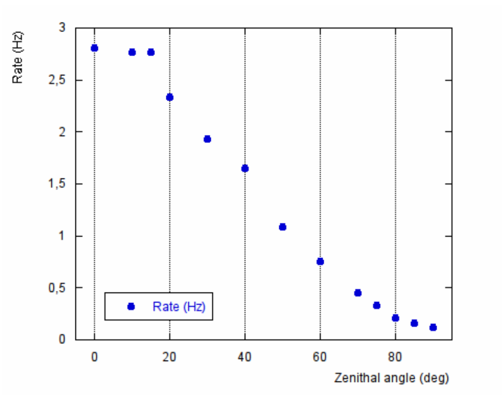
Figure 2: Left: the control knob of the telescope. Right: the angle meter.

function of the zenith angle. PMT signals were sent through dedicated electronic modules for the signal discrimination and to generate a coincidence signal to be put on a scaler to count the muons, see Fig. 3. Muon number was measured for thirteen selected angles, ranging from zero to ninety degrees, each one for few minutes.
Cosmic muon rate as a function of the zenith angle is shown in Fig. 4 (left): the decrease of the rate due to the inclination of the telescope is evident. The rate has to be then converted to a flux by introducing some correction factors: the scintillator area (0.144 m^2), the solid angle subtended by the scintillators (0.38 srad) and the six PMT system overall efficiency (0.5). By doing this, the plot of Fig. 4 (right) is obtained: a best fit curve with a function of the type:

$$\phi(\theta) = Acos(\theta)^b \tag{1}$$

is superimposed to the experimental points. The best fit values for the amplitude A and the cosine exponent b are $A = 101.5 \pm 2.4$ m^{-2} s^{-1} srad^{-1} and $b = 1.9 \pm 0.1$, consistent with the expectation of a maximum flux A of about 100 m^{-2} s^{-1} srad^{-1} and an exponent$b$ roughly 2 [1].

Figure 3: Electronics for PMT signal discrimination, coincidence and counting.



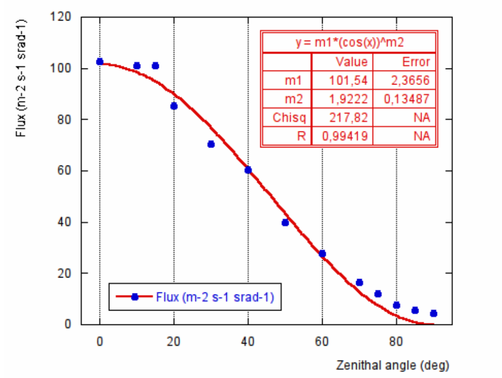


Figure 4: Left: Cosmic muon rate. Right: cosmic muon flux with the best fit curve superimposed to the experimental points.

2 Conclusions

INFN Pavia group of students measured cosmic ray flux at sea level as a function of the zenith angle with a telescope made of plastic scintillator slabs read by PMTs at both ends. Results were consistent with expectations, confirming the values found in literature.

References

[1] P. K. F. Grieder, *"Cosmic Rays at Earth"*, Elsevier, 1^{st} Edition (2001).

DIPARTIMENTO DI FISICA E GEOLOGIA
Università degli Studi di Perugia
Italia

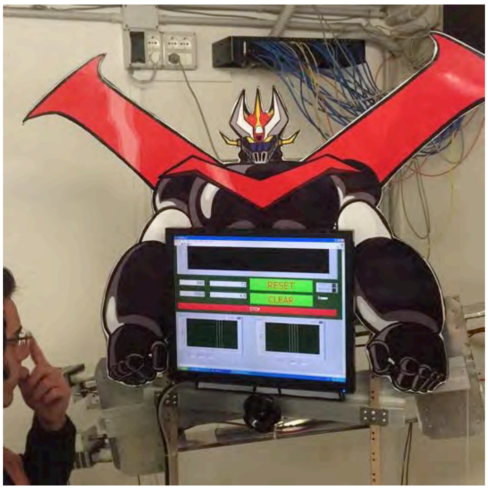
In Perugia the event was organized in the Physics and Geology Department of the Università degli Studi. The Department hosts, also, a local division of the INFN, the Italian Institute for Nuclear and Particle Physics.
Researcher from both the INFN and the University are involved in several large collaborations (such as CMS at CERN LHC, NA62 at CERN SPS, …) and, among them, in some of the most important experiments in the field of the astroparticle and cosmic ray physics, either on ground or in space:

Sezione di Perugia
INFN
Istituto Nazionale di Fisica Nucleare

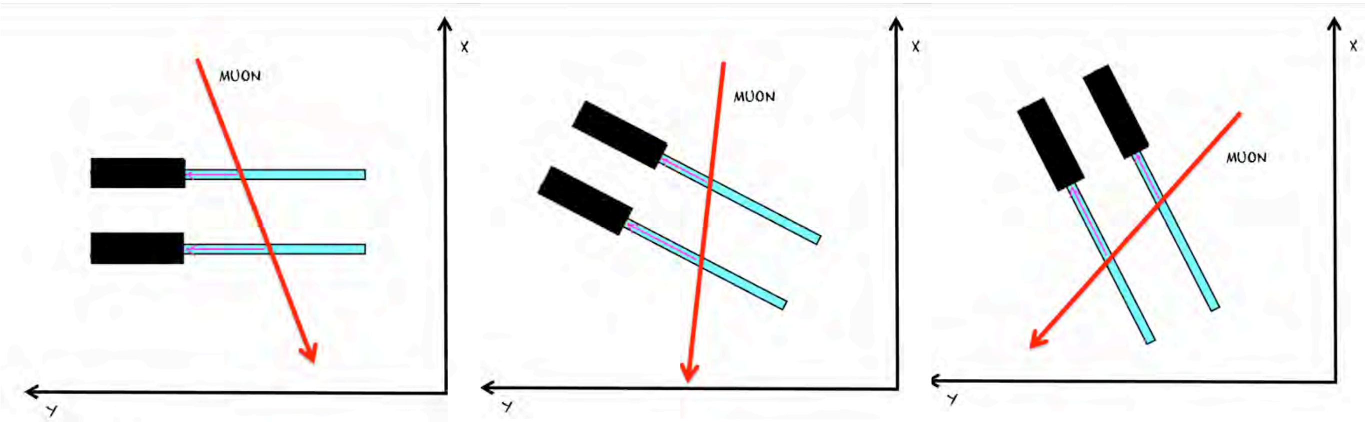
- the Alpha Magnetic Spectrometer, AMS, on the International Space Station (ISS);
- the DArk Matter exPlorEr, DAMPE, on board a China National Space Administration (CNSA) satellite;
- the Cherenkov Telescope Array, CTA;
- the Fermi-LAT, on board a National Aeronautics and Space Administration (NASA) satellite.

The people involved in the astroparticle field built the detector and invited some high school students to conduct the measurements and analyze the collected data. We had a total of 26 students from two high schools:

- Liceo Classico “Annibale Mariotti”
- Istituto Tecnico Tecnologico Statale “Alessandro Volta”

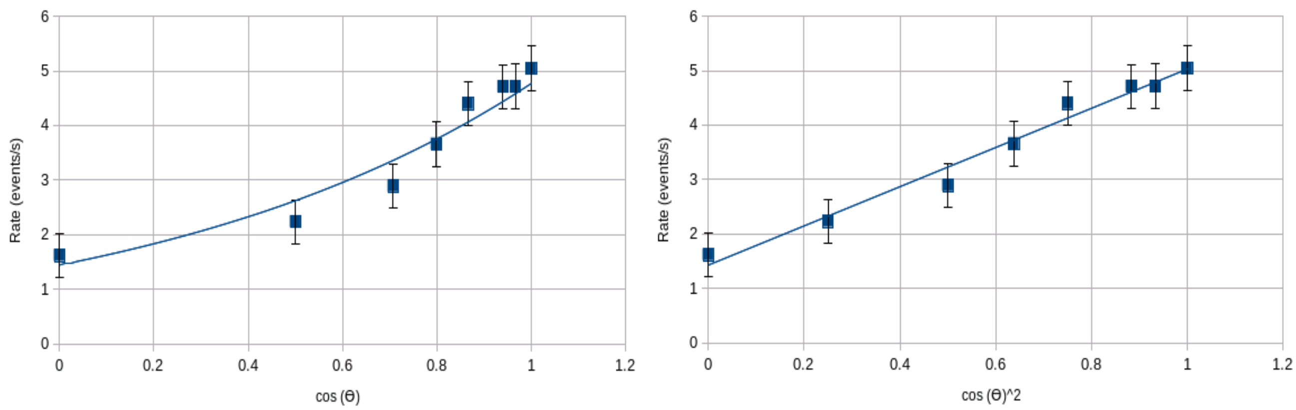


Our detector - see the picture on the left - has a nice “cover” inspired by Mazinga! (Mazinga was defending the Earth from the Vegans and among its weapons there were the “cosmic rays”!).
It hides two 10X100 cm^2 scintillating planes, mounted at a distance of $\sim$ 10 cm one from each other. This telescope can be rotated (see the picture below) at any angle to change the average zenithal field of view. The two scintillators flew to space on board the NASA Space Shuttle STS-91, for the AMS-01 experiment.
The DAQ is realized with a NIM board controlled by LabView: the users can define a time interval and the data taking will flow continuously giving the number of counts in a single plane (read on both the ends) and by the coincidence of the two planes.



The students were divided in groups of 3-4, conducting the measurement (measuring the angles and then the counts) for few angles. Then the data of the various groups were exchanged and merged to increase the number of different angles and to increase the statistics for a single angle.

And finally our results:



The coincidence rate as a function of cosθ and $\cos^2\theta$: clearly the rate is proportional to $\cos^2\theta$!

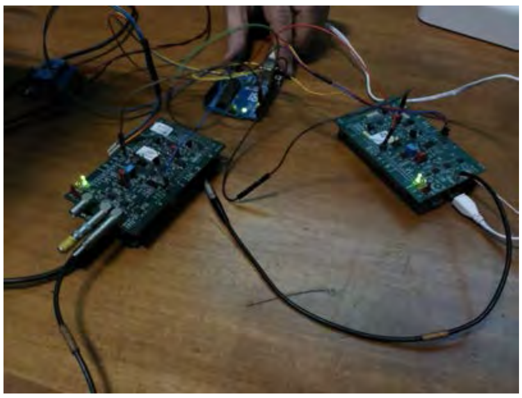
Dipartimento di Fisica
Sapienza Università di Roma

INFN Istituto Nazionale di Fisica Nucleare

INTERNATIONAL COSMIC DAY ROMA

About 250 students participated to the International Cosmic Day in Roma. They observed cosmic rays tracks with a spark chamber and were introduced to the physics of cosmic rays.

We then show them how to build their own detectors and perform their own measurements using ArduSiPM: a commercially available Arduino shield to detect radiation with a scintillator and a silicon photomultiplier.



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ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INTERNATIONAL COSMIC DAY

November 02 | 2016

INFN Istituto Nazionale di Fisica Nucleare Sezione di Bologna

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

LICEO SCIENTIFICO
AUGUSTO RIGHI
BOLOGNA, ITALY

BOLOGNA, ITALY

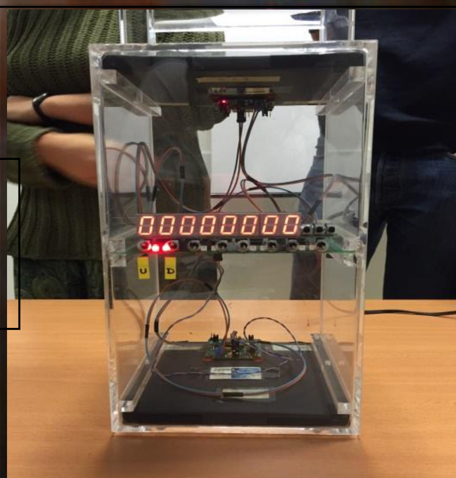
What are cosmic rays?

Cosmic rays are high energy radiations that originate in outer space. High energy collisions in the atmosphere produce cadscades of lighter particles: pions and kaons, which decay in muons. Muons make up more than half of the cosmic radiations (at sea level) with electrons, positrons and photons from cascades events.

We are a group of 16 high school students reporting from INAF in Bologna, Italy (44°30'03''N 11°21'25''E). Our topic is to observe the cosmic ray flux as a function of the Zenith angle.

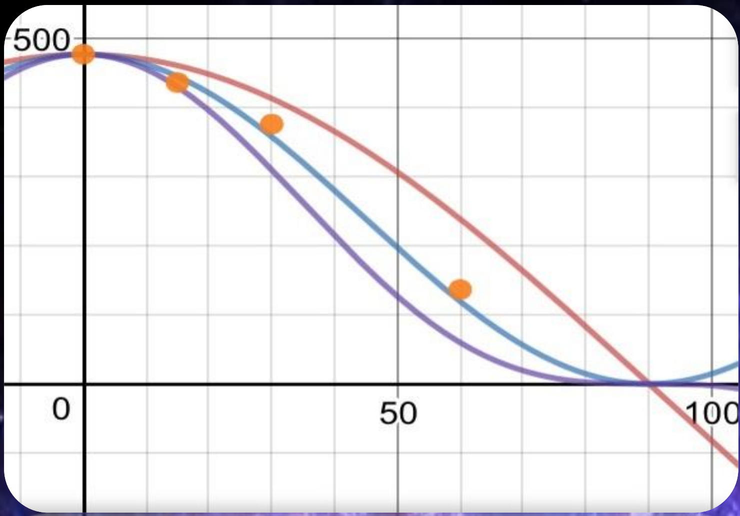
We first assembled cosmic boxes with scintillators and silicon receivers, which elaborates and counts the signals from cosmic rays.

Then we measured the fluox of muons throught a cosmic box set in different angolations related to the Zenith angle(0°, 15°, 30°, 60°, 90°).



These are the results we collected during the experience we did on the International Cosmic Day:

x	y
0	476
15	435
30	375
60	136



1. $y = 476 \cos(x)$
2. $y = 476 \cos^2 x$
3. $y = 476(\cos(x))^3$

x	y
0	100
15	93
30	75
60	25
90	0

1. $y = 100 \cdot \cos(x)$
2. $y = 100 \cdot (\cos(x))^2$
3. $y = 100 \cdot (\cos(x))^3$

We elaborated the number of cosmic rays that the cosmic box received and, as it can be seen from the graphics, the function that better approximates the trend of the curve is y=(cosx)^2.

International Cosmic Day

INTERNATIONAL COSMIC DAY @ INFN PADOVA

The National Institute for Nuclear Physics (INFN) conducts theoretical and experimental research in the fields of subnuclear, nuclear and astroparticle physics. Its Padova unit is located in the Department of Physics and Astronomy of the University of Padova.

For the International Cosmic Day 2016, the researchers were joined by 180 students and nine teachers from six upper secondary schools: Licei Scientifici “Curiel”, “Fermi” and “Galilei”, Liceo “Nievo”, Liceo Classico “Tito Livio and l’IIS “Alberti”.

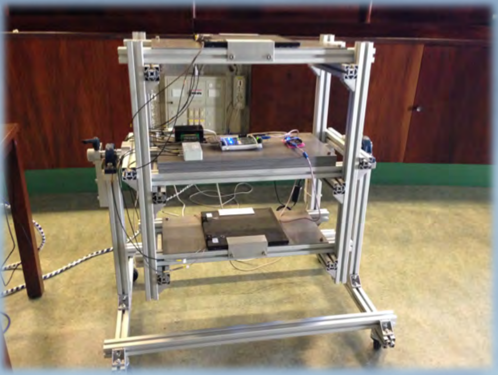
Dipartimento di Fisica e Astronomia Galileo Galilei

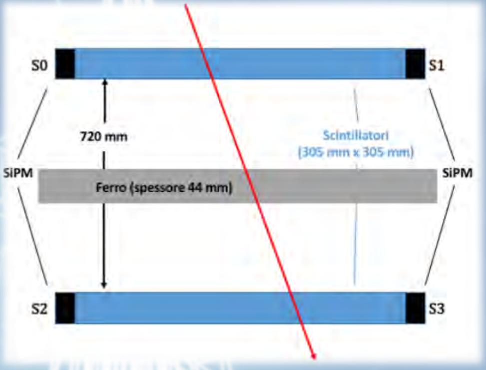
INFN Istituto Nazionale di Fisica Nucleare
Sezione di Padova

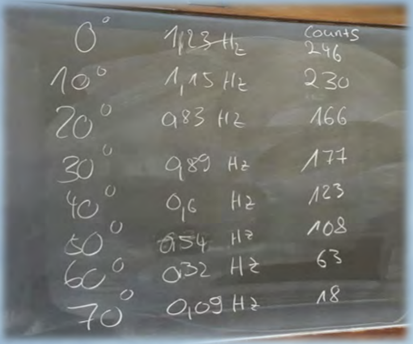
International Cosmic Day

INTERNATIONAL COSMIC DAY @ INFN PADOVA

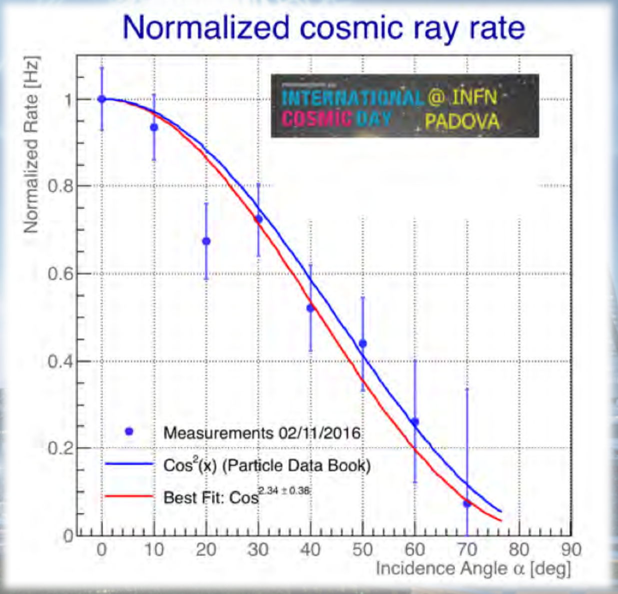
The cosmic muon detector is made of two scintillator counters readout by two SiPM each, mounted on a rotating structure. The SiPM signals are processed by an electronic card hooked up to a mini-computer that exports the data on a publicly available webpage.







We measured the muon rate for several zenith angles and normalized it to the rate at 0°. The data agree well with the cosine-square expected dependence.



Dipartimento di Fisica e Astronomia Galileo Galilei

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Padova

Liceo Classico Statale Francesca Capece

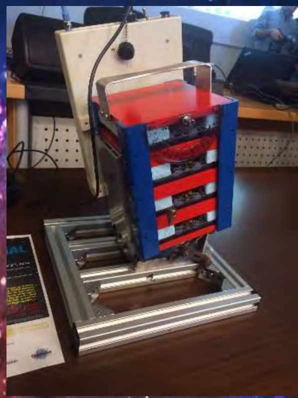
Università del Salento

V Edizione

UNIVERSITÀ DEL SALENTO

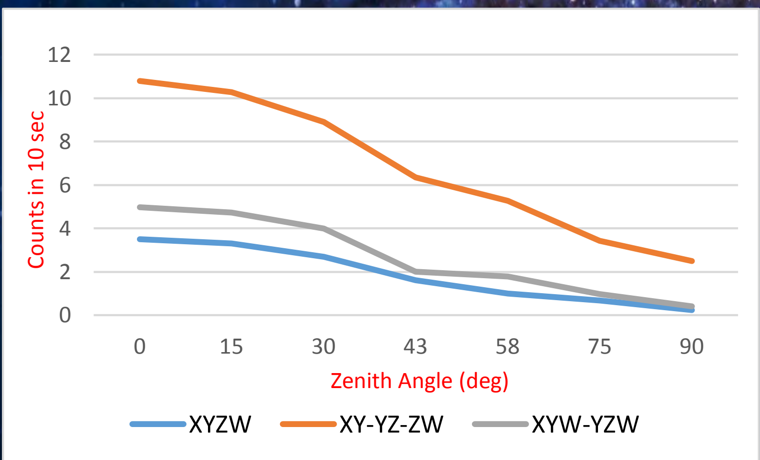
Giornata Internazionale dei raggi cosmici

On 2nd November 2016, the 5th edition of the international Cosmic Day took place in Univeristy of Salento. Students of different local schools joined this event including us, six students from Liceo Francesca Capece in Maglie (LE).



The aim of this project was to inform student about cosmic rays. At first, the organizers explained the history of the cosmic rays' discovery. We found out that cosmic rays are particles that hit the Earth from anywhere beyond its atmosphere. Afterwards we were asked to analyze some data that we have collected during the day performing an experiment using a detector made by four planes of plastic scintillator (named X, Y, Z, W). We measured the counts rate as a function of zenith angle. Here there is a table with the measurements.

°	X	Y	Z	W	XY	YZ	ZW	XYZ	YZW	XYZW	Twofold coinc. average	Threefold coinc. average
0	38.61	32.82	30.41	36.16	10.92	10.67	11.37	5.90	4.06	3.5	10.795	4.98
15	38.76	32.68	29.66	34	10.7	9.86	9.78	5.61	3.85	3.3	10.28	4.73
30	38.98	32.60	30.57	35.32	9.2	8.6	8.5	4.75	3.26	2.7	8.9	4.0005
43	33.88	29.40	27.30	32.90	6.5	6.20	6.4	3.01	1.88	1.6	6.35	2
58	33.28	28.43	26.14	31.33	5.73	4.94	5.15	2.33	1.22	1	5.27	1.77
75	32.51	26.75	26.06	31.46	3.53	3.2	3.55	1.3	0.63	0.68	3.42	0.96
90	31.12	25.65	24.27	30.63	2.67	2.44	2.35	0.56	0.26	0.22	2.48	0.41



Partecipans:

Stefano Giannuzzi, Maria Grazia Biasco, Alessandra de Fabrizio, Francesca Negro, Daniele Vergaro, Matteo Fracasso.

Teacher:

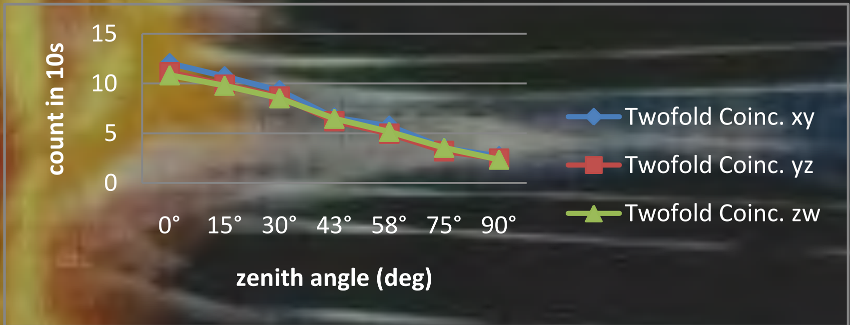
Prof. ssa Giusy Negro

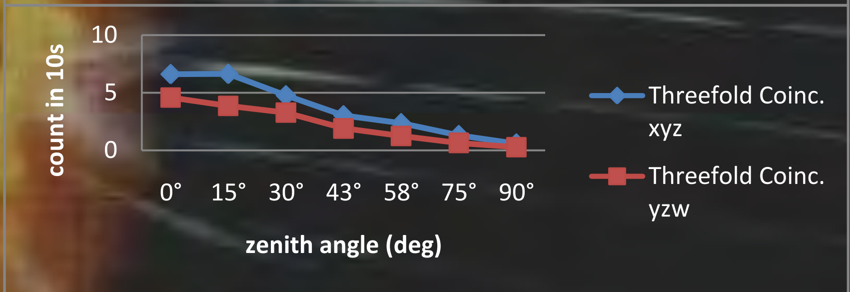
Liceo Scientifico Statale
Cosimo De Giorgi
Viale De Pietro, 14 - 73100 - Lecce

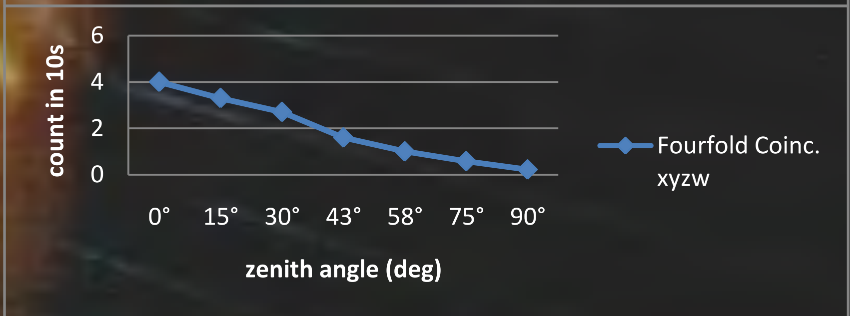
INTERNATIONAL COSMIC DAY

2nd November 2016

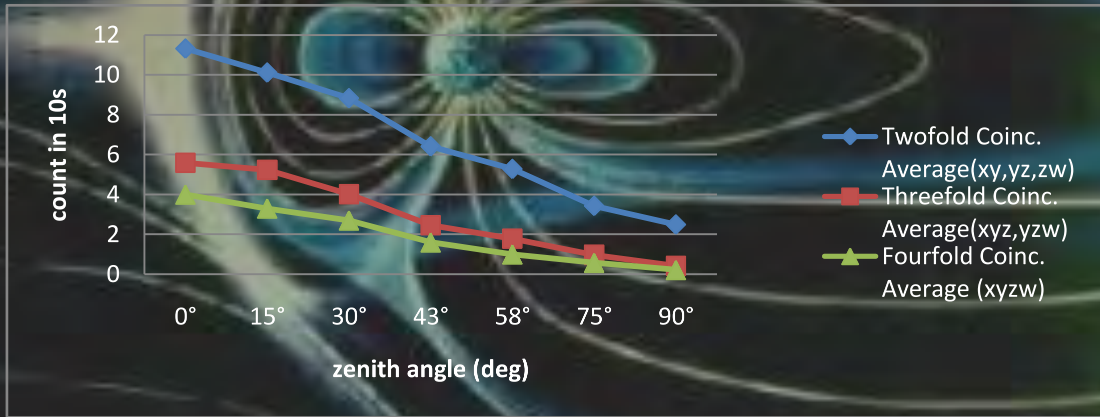
The ICD was organized to bring students, teachers and scientists together, to talk and discuss about cosmic rays. After a brief introduction about the nature of these rays, the students were divided into groups to measure the amount of radiations as a function of Zenith angle using CORAM: a device composed by four planes of scintillating materials(X, Y, Z, W). Below we show the plots of the measurements performed.







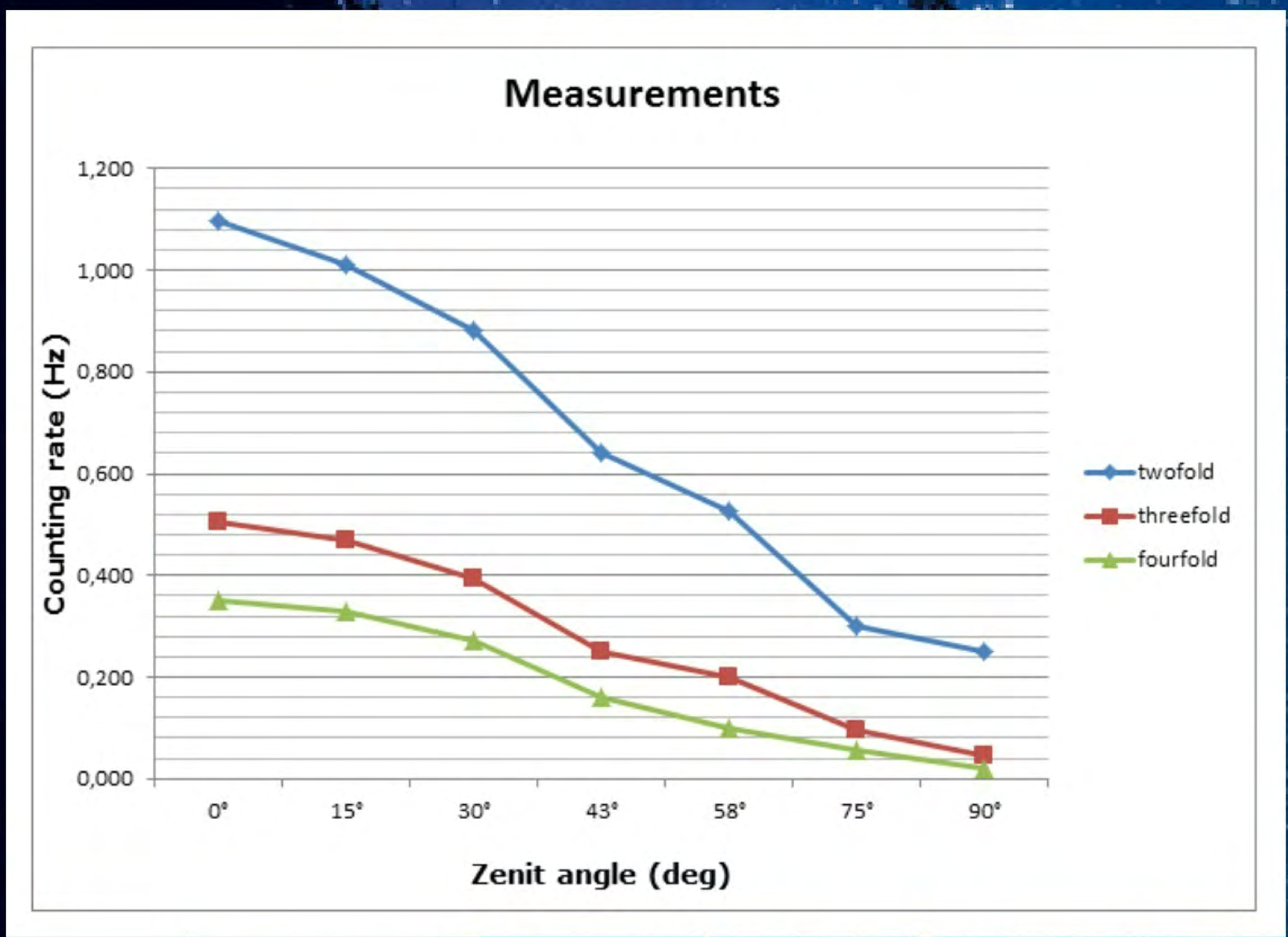
We can observe from the plots that the amount of cosmic rays detected decreases getting close to the horizontal position as expected.



Alessandrelli Andrea V L
Cairo Mariagrazia V B
D'Oria Matteo V D
Falli Emanuele V N
PascaliAllison V I
Ricchiuto Marta V C
Trigilio Marco V F
Teacher:
Prof. Giordano Luigi

I.I.S.S. Epifanio Ferdinando

COSMIC DAY



Cosmic rays are elementary particles including protons, electrons, nuclei, positrons and photons. The primary cosmic rays interact with the Earth atmosphere producing secondary particle showers. The flux of these particles (a few hundred particles per m^2sec) increases with the increase of altitude, and then decrease again. Most of them are charged particles, because they are influenced by Earth magnetic field. The device we used during the ICD allows to detect the cosmic rays. We measured the counts rate of cosmic rays as a function of the Zenith angle. In the plot below we show the two-three-four-fold coincidence rate that decreases increasing the Zenith angle as expected.

Prof Federico Guarini
Arianna Denitto
Aldo Agrimi
Andrea Mandurino
Virginia Tamburrano
Francesco Brunetti
Marco Falcone

COSMIC RAY DAY

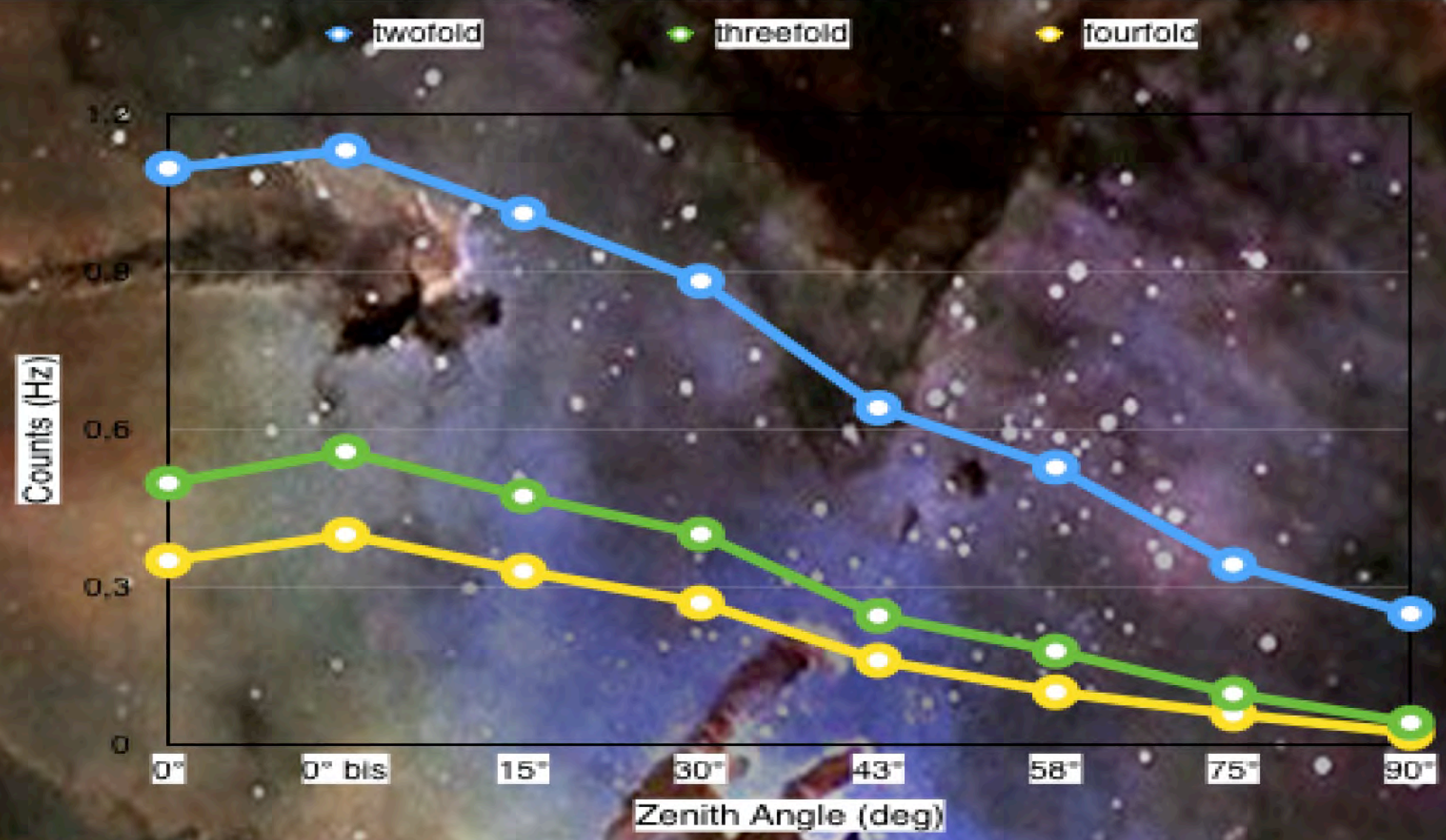
WHAT ARE COSMIC RAYS?

What are cosmic rays?

Cosmic rays are energetic particles coming from the outer space interacting with the Earth atmosphere and producing secondary particle showers.

Their nature is still unknown, as their origin: The Sun, novaes, supernovaes, nebulas (like the Crab).

Not all the cosmic rays can reach the Earth surface been absorbed by the atmosphere, except the most energetic mainly muons.



THE EXPERIMENT

During the ICD we used a detector made by 4 scintillator planes (X, Y, Z, W) interposed with iron absorbers.

We measured the dependence of the counts rate of the cosmic rays respect to the Zenith angle.

In the plot above we show the coincidence rate of two (blue line), three (green line) and four (yellow line) planes. The results are in agreement with the expectation.

Buttazzo Filippo; Cesari Fabiana; de Nitto Personè Matteo; Mastrobisi Andrea; Pellegrino Danilo; Rizzo Maria Sofia

INTERNATIONAL COSMIC DAY

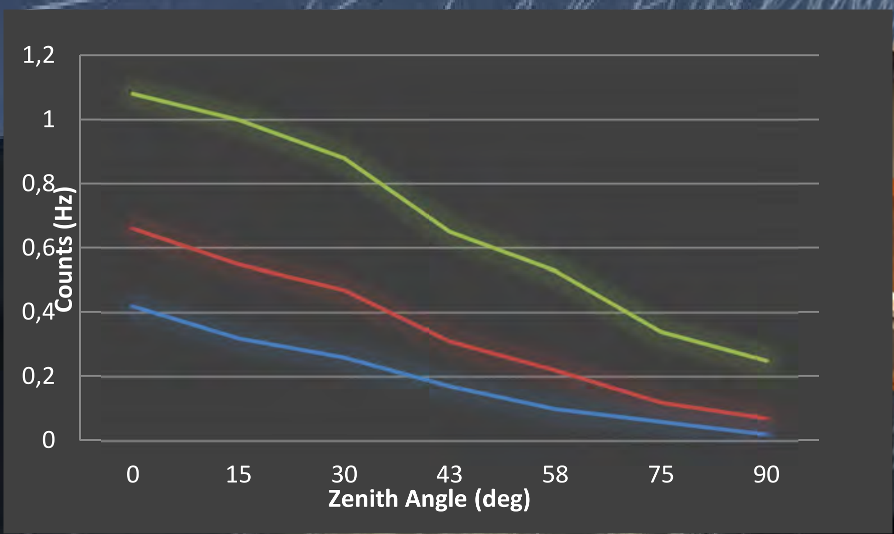
QUINTO ENNIO

GALLIPOLI

Cosmic rays are high-energy particles coming from space, mainly composed by protons and atomic nuclei. They arrive on Earth's surface as showers of particles originated by their interaction with the atmosphere.

This *particle detector* is composed by four planes (X,Y,Z,W), each one formed by a layer of plastic scintillator. Iron layers are interposed in order to absorb and stop low-energy particles while the plastic scintillators can detect high-energy particles.The device allows to detect the number of particles passing through one, two, three and four layers.

Increasing the detector angle respect to the vertical position, we can see that the counts rate decreases as expected. This is shown in the plot below where the counting rate of the two-three-four-fold coincidences is given as a function of the Zenith angle.



ABATE FRANCESCA – BRUNO ALESSANDRO – DEL TUFO ANDREA – DEL TUFO FABIO – LEONE ROBERTO – MANCO GAIA – MAGGIO LUCA – MARGARI DIEGO

TEACHER RESTA SABRINA

INTERNATIONAL COSMIC DAY

University of Salento,
Dipartimento di Matematica e Fisica,
and INFN, Lecce, Italy, 2nd November 2016

Zenith Angle Distribution of Extended Air Shower Particles generated by Cosmic Rays

Benedetta Ferrari, Andrea Panico, Federico Coppola, Stefano Toma

Liceo Scientifico Statale "G. C. Vanini". Via Reno. 73042 Casarano (LE). Italy

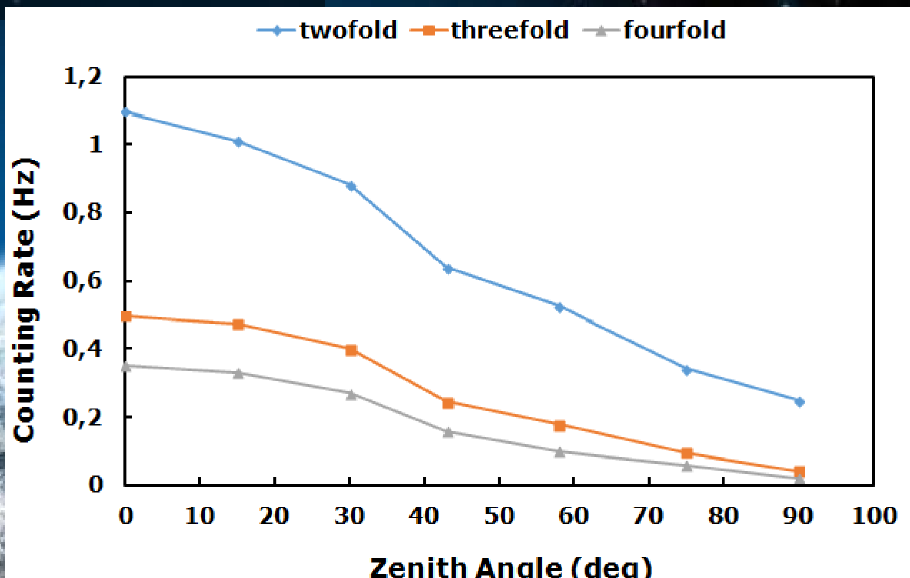
Astroparticle physics is a multidisciplinary field of research connecting particle physics, astrophysics and cosmology. Extending the investigation of fundamental interactions up to the largest structures in the Universe is a key factor to shed light on the history of the Universe itself.

Since their discovery, dating back over a century ago, many doubts still remain about the origin of the most energetic cosmic rays.

Any place in the Universe acting like a natural accelerator (galaxies) is a potential source of cosmic rays, with energies remarkably higher than the ones achieved on Earth by artificial means.

The interaction of high energy cosmic rays with atoms and molecules, in the Earth's upper atmosphere, results in Extensive Air Showers (EAS) of particles.

These secondary particles simultaneously reach a small fraction of Earth's surface.



We measured the Zenith Angle Distribution of EAS particles at local latitude and altitude, by means of a custom detector purposely developed at the National Institute for Nuclear Physics (INFN) and at the University of Salento in Lecce. This device was assembled using four planes of plastic scintillator (BC-412), aligned and spaced with iron absorbers (side picture) which easily detected muons.

As predicted by theory and verified through previous experiments, we confirmed that the Zenith angular dependence of the counts rate approximately follows a $(\cos\theta)^2$ law.

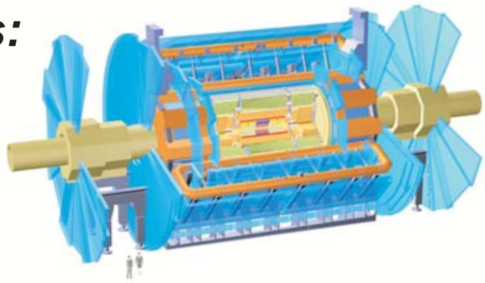
Liceo Scientifico Giulio Cesare Vanini

Teachers: Pasquale Paiano, Giuseppe Isernia, Carlo Macrì

Scientific coordinator: Stefania Acquaviva

Dipartimento di Matematica e Fisica "Ennio De Giorgi" - INFN Lecce

Main research topics in high energy physics:

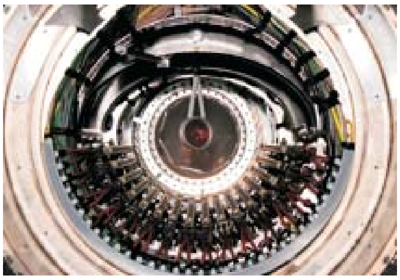


Particle and Astroparticles Physics

Physics at the accelerators

Detectors development

Nuclear Electronics



The Department is engaged in many international experiments:

ATLAS at CERN

MEG at PSI

AUGER at Malargue

ARGO at Yangbajing

Dipartimento di Fisica

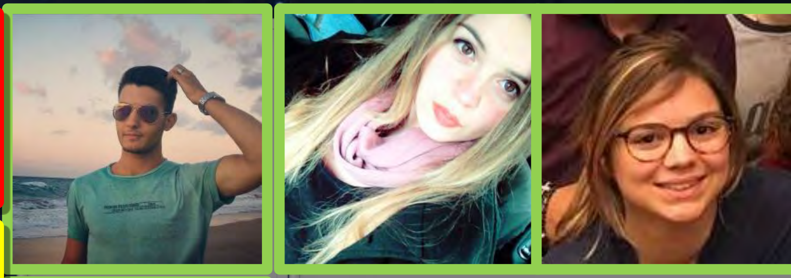
to learn more about the Department visit
www.matfis.unisalento.it/

INFN
Istituto Nazionale di Fisica Nucleare

INTERNATIONAL COSMIC DAY 2016

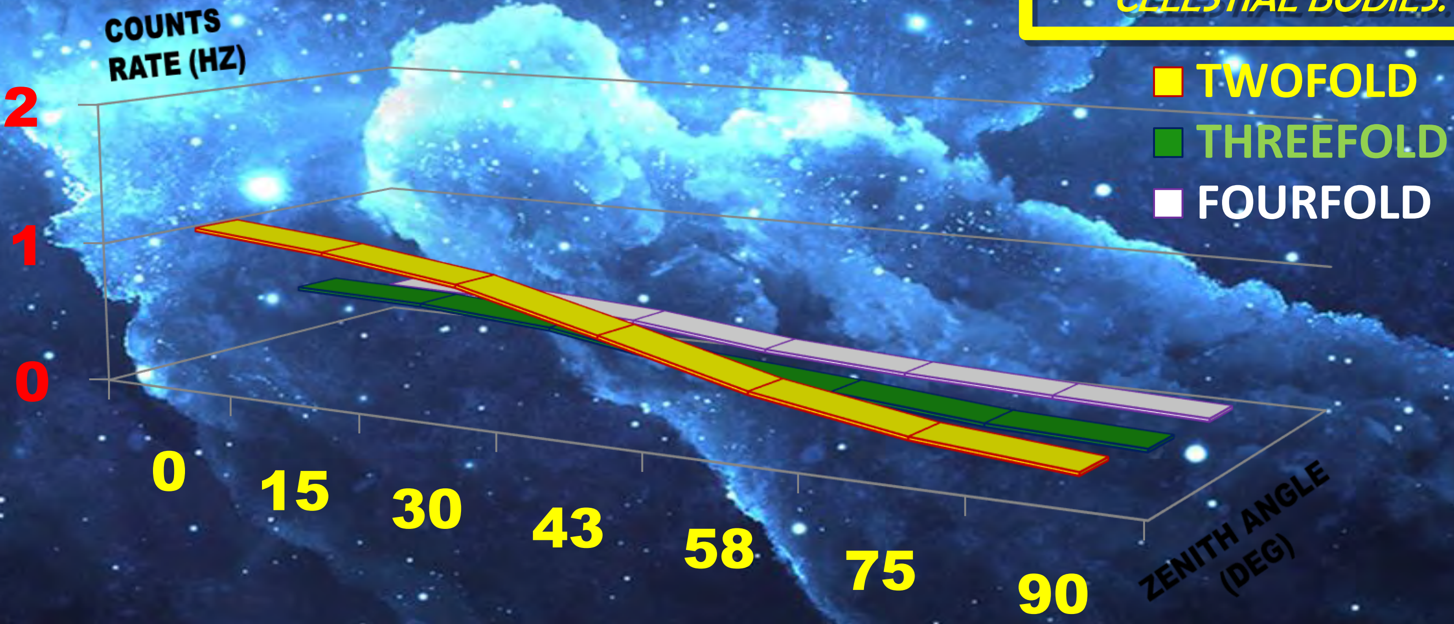
WHAT IS THE "INTERNATIONAL COSMIC DAY"?

IT IS AN ANNUAL EVENT, WHICH INVOLVES VARIOUS UNIVERSITIES AND STUDENTS FROM MANY COUNTRIES. DURING ICD, THE STUDENTS PERFORM MEASURMENTS ON COSMIC RAYS.



WHAT ARE COSMIC RAYS?

COSMIC RAYS ARE PARTICLES, COMING FROM SPACE, WHICH GIVE US INFORMATIONS ABOUT THE UNIVERSE ALLOWING THEREFORE TO STUDY COMPLEX PHENOMENA AND DIFFERENT TYPES OF CELESTIAL BODIES.



WHAT'S ABOUT THIS EXPERIENCE?

STUDENTS FROM EACH INDIVIDUAL INSTITUTE HAD THE TASK TO ELABORATE DATA TAKEN BY USING A DETECTOR MADE BY FOUR LAYERS OF PLASTIC SCINTILLATOR. THE DEPENDENCE OF COUNTS RATE ON THE ZENITH ANGLE HAS BEEN STUDIED (SEE PLOT). RESULTS WERE COMPARED WITH OTHER STUDENTS FROM OTHER COUNTRIES BY VIDEOCONFERENCE.

I.I.S.S. ETTORE MAJORANA - BRINDISI

IISS Enrico Mattei - Maglie

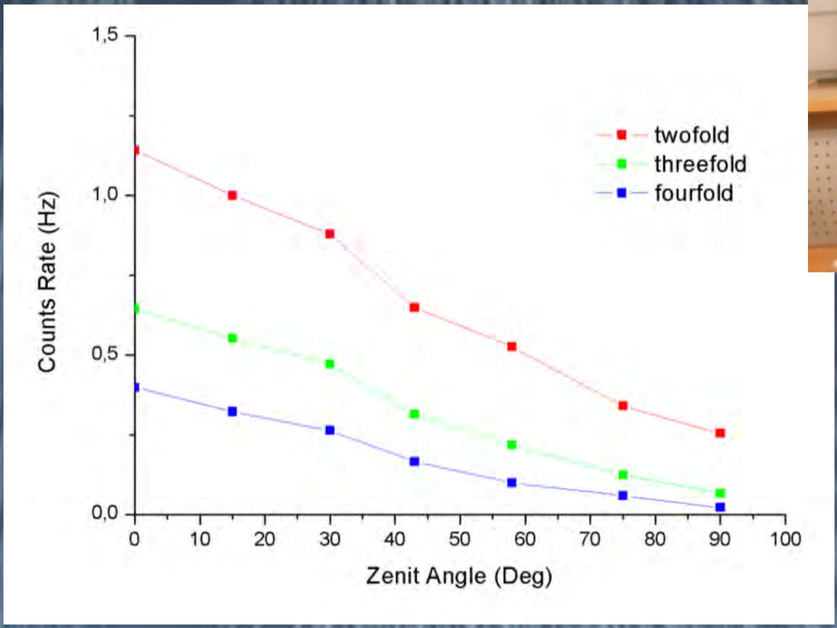
INFN

INTERNATIONAL COSMIC DAY

2016 - V EDIZIONE

Cosmic rays are

high energyradiation, mainly originating outside the Solar System. Impacting with the Earth's atmosphere, cosmic rays produce a showers of secondary particles whose study could give important information about the place they come from. The cosmic rays, originated outside of Earth's atmosphere, are mainly composed by nuclei, and photons. During our experience, we measured the number of particles impacting the detector area per second (rate at which cosmic rays reach the ground).
To do this we used CORAM, a device composed of four scintillator planes interposed with iron absorbers. We measured the single and the two-three-four-fold coincidence rate. Measurements have been taken over ten minutes long and by varying the angle of CORAM.
In the plot below, we represent the counting rate as function of the Zenith angle.



Luca Carrisi
Andrea Castrì
Chiara Sticchi
Antonio Bavia
Giovanni Treglia
Elena Longo
Teacher: D.Diso
Istituto E.Mattei Maglie

LICEO “G. GALILEI” – NARDO’

ISTITUTO D’ISTRUZIONE SECONDARIA SUPERIORE

con sezioni associate di

LICEO CLASSICO – LICEO SCIENTIFICO – LICEO delle SCIENZE APPLICATE

LICEO delle SCIENZE UMANE- LICEO ECONOMICO SOCIALE

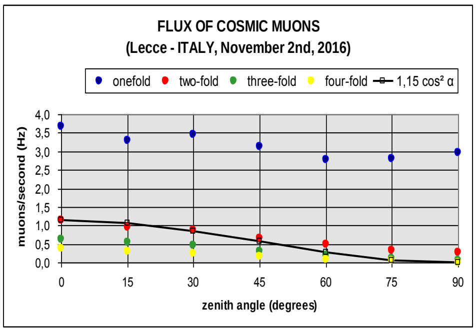
Cosmic rays are subatomic particles coming from different sources of the Universe (supernovae, black hole). They are composed primarily of high-energy protons and atomic nuclei up to10^20 eV. They arrive on Earth, interacting with air in high atmosphere and generate so-called secondary particles most of them arrive on the soil, typically muons. These particles can be observed using special devices. Thanks to INFN team of Physics Department University at Lecce (Southern Italy), using a cosmic ray detector, we took measurements of the cosmic rays flux as a function of the zenith angle every ten minutes. The detector is composed by four layers of scintillating material interposed with iron absorbers plates in which is inserted an optical fiber. When a particle goes through the plate, it produces a light flash which is captured by the fiber and readout by two photodiodes, triggered and converted into electrical signal .

The detector can be inclined at different angles using a mechanism at the bottom of the apparatus.

We performed several measurements using coincidence of single, two, three and four layers. As the detector can be inclined , the cosmic rays flux was measured changing Zenith angle from 0 to 90 degrees with respect to the normal at each multiple of 15 degrees every 10 minutes. Finally we put data in a table to obtain a plot.

The averages flux-values of muons for each zenith angle considering single, twofold, threefold and fourfold coincidence for adjacent detectors are shown in table and graph, with the square cosine dependence . We can note that, while as expected the two-, three- and four-fold coincidences decrease according normalized $\cos^2\alpha$ law, the single layer measurements are almost independent from the angle.

zenith angle (α)	average rate for one-fold	average rate for two-fold	average rate for three-fold	average rate for four-fold	$1{,}15 \cos^2\alpha$
(degrees)	(Hz)	(Hz)	(Hz)	(Hz)	(Hz)
0	3,7	1,1	0,6	0,4	1,1
15	3,3	1,0	0,5	0,3	1,0
30	3,5	0,9	0,5	0,3	0,9
45	3,1	0,7	0,3	0,2	0,6
60	2,8	0,5	0,2	0,1	0,3
75	2,8	0,3	0,1	0,1	0,1
0	3,0	0,3	0,1	0,0	0,0



Our Team: (from the left)

Students: *Giovanni Maceri, Greta Papadia, Cosimo Lorenzo Persano, Vincenzo Filograna, Pierpaolo Trifoglio, Ludovica Livieri*,

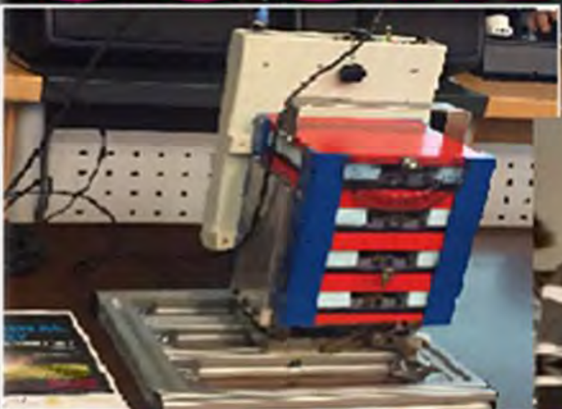
Teacher: *Lucio Vernich*

I.I.S.S. SALVEMINI
ALESSANO (LE-ITALY)

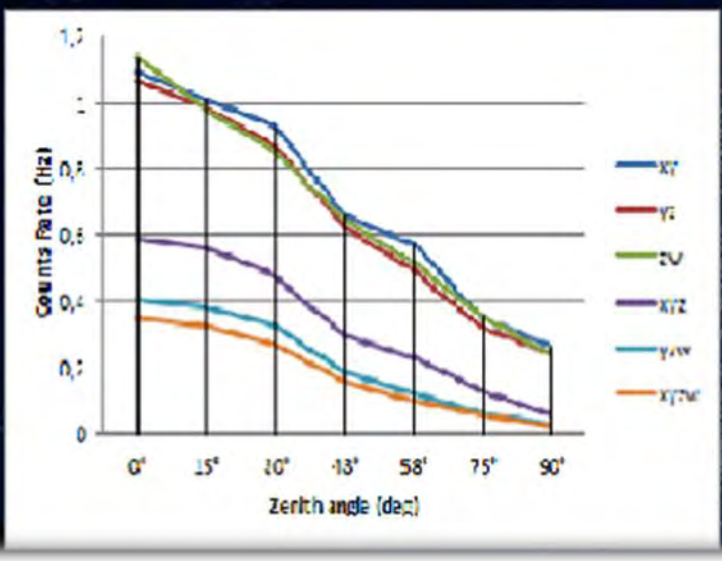
Discover Cosmic Rays

INTERNATIONAL COSMIC DAY

November 02 | 2016



The fifth edition of the "International Cosmic Day" took place on November 2nd 2016 at the Mathematics and Physics Department of the Salento University. As students at Salvemini High School in Alessano, we perform the measurements of cosmic rays flux as a function of the Zenith angle. The detector, made up of four planes of plastic scintillator (X, Y, Z, W) was tilted at different angles respect to the vertical position.
In the plot and table below we show the two-three-four-fold coincidences rate among adjacent planes. As result we can see that the rate decreases going from 0deg to 90deg as expected.
During the day we were in contact with other Universities and we compared the results with other students.



Students:
Buffelli Claudio, Caccioppola Raffaella, Donnicola Maria, Pedone Ilenia, Sergi Sofia.
Teacher:
Buffelli Francesco.

	0°	15°	30°	43°	58°	75°	90°
XY	1,092	1,007	0,93	0,656	0,574	0,353	0,268
YZ	1,067	0,987	0,867	0,621	0,495	0,32	0,245
ZW	1,137	0,978	0,852	0,647	0,516	0,355	0,235
XYZ	0,59	0,562	0,475	0,302	0,233	0,13	0,057
YZW	0,406	0,385	0,326	0,189	0,123	0,063	0,026
XYZW	0,35	0,33	0,27	0,16	0,1	0,058	0,022

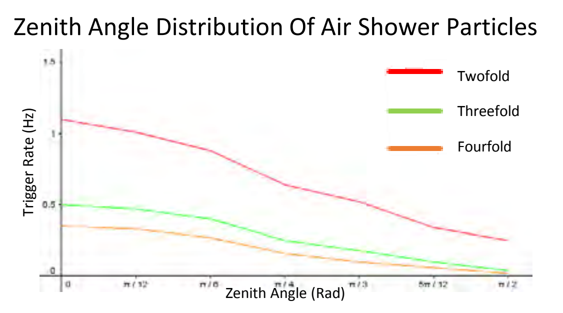
INTERNATIONAL COSMIC DAY

SCIENTIFIC HIGH SCHOOL «G. STAMPACCHIA» TRICASE (LE)

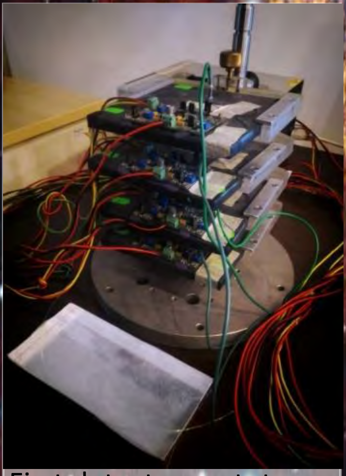
The detector build at the INFN that will be sent in Argentina for the AUGER project

CORAM, the cosmic rays detector we used during the event

Cosmic rays are high-energy particles originated mainly from black holes and supernovae. Their interaction with our atmosphere, produces several secondary particles that we can observe. On November 2nd, 2016 the Mathematics and Physics Department of "Università del Salento" allowed us to measure the Zenith angle dependence of air shower particles (mainly muons). During the day we could share the results with students from all over the world participating to the ICR and we could visit the INFN's labs.



The plot of the data acquired during the ICD. The results are in agreement with the expectations.

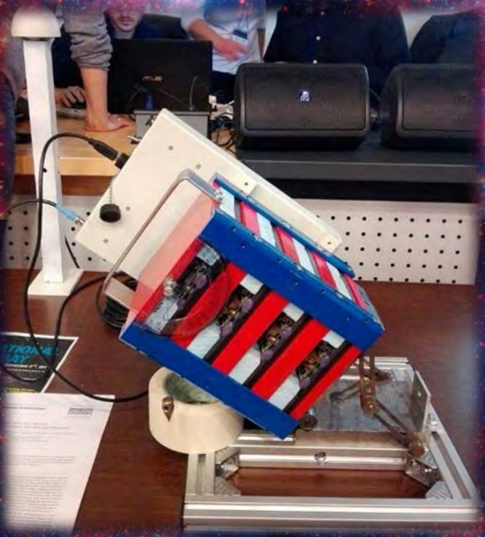


First detector prototype.

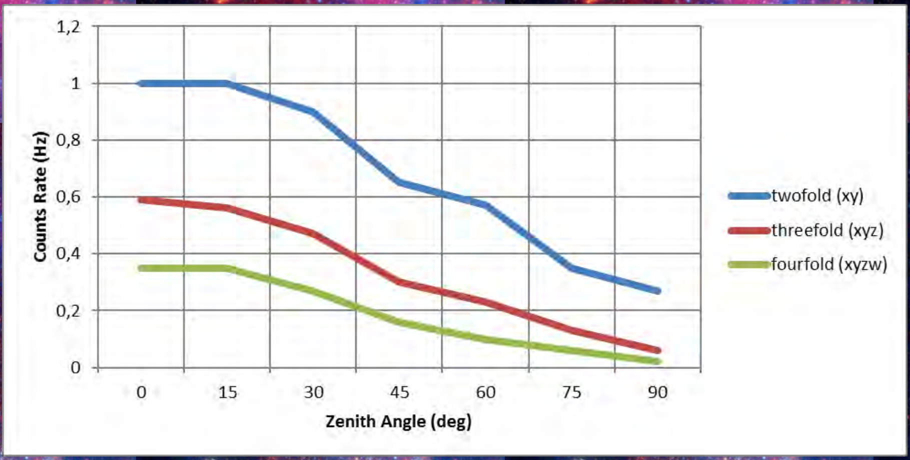
From the left to the right: MAGGIORE Giorgio, MAURO Walter, PAGANO Raffaele, PROTOPAPA Matteo, GALILEI Giuseppe, SCIURTI Elisabetta, Prof. PISCOPIELLO

Istituto di Istruzione Secondaria Superiore
"SALVATORE TRINCHESE"
MARTANO

INTERNATIONAL COSMIC DAY



This plot shows the relationship between cosmic rays' event rate and the zenith angle. By increasing the angle, the cosmic rays' event rate decreases as expected.



Cosmic rays continuously arrive on Earth, after being originated outside the Solar System, mainlyby supernovae remnants and black holes.
Cosmic rays are composed of high-energy particles, such as protons and atomic nuclei.
Interacting with the terrestrial atmosphere, the cosmic rays generate showerof secondary particles.
Among these particles the ones detected by our device are mainly high-energy muons.
On 2nd November 2016, at the Mathematics and Physics department of the "Università del Salento", we measured the dependence of the cosmic ray flux on the zenith angle, by using a detector made by four scintillator planes interleaved by iron absorbers. We measured the coincidence rate between two, three and four planes.

Giacomo Chiriatti, Carlotta De Franciscis, Fabio Della Tommasa, Annapaola Licci, Mauro Antonio Murrone, Erika Nocco, Elena Pirla, Benedetta Russetti, Alessia Saracino, Chiara Sicuro, Nenci Zacheo, Sara Zaminga

Zenith Angle Dependence of Cosmic Ray Muons

Miyagi-ken Sendai Daiichi High School Physics Club
Sendai JAPAN

Introduction

Muons are produced by the interaction between cosmic rays and the atmosphere. The amount of muons on the ground depends on the zenith angle. We observed this dependence and compared it with the well-known empirical relationship.

Hypothesis

We can define the intensity of muons as the number of muons per square meter, per minute and per steradian. The intensity, on the other hand, can be defined from the zenith angle θ as $J(\theta)$. The well-known empirical relationship is

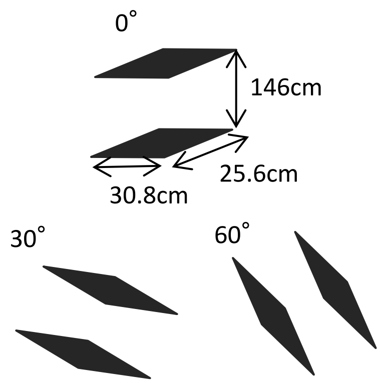
$$J(\theta)=J(0)\cos^2\theta$$

We hypothesize that the observed flux $J'(\theta)$ has the same relationship:

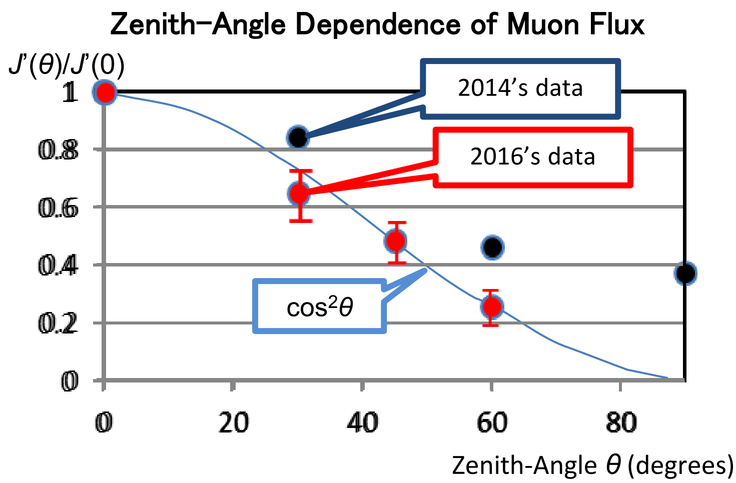
$$J'(\theta)=J'(0)\cos^2\theta \text{ ,or}$$
$$J'(\theta)/J'(0)=\cos^2\theta$$

Method

- We set three scintillator plates 146 cm apart from each other using a shelf.
- We observed flux using three fold coincidence at zenith angles of 0, 30, 45, 60 degrees in the north direction.



Results



- The y axis indicates the relative flux $J'(\theta)/J'(0)$, and the x axis indicates the zenith angle θ in degrees.
- Red dots represent the data observed in 2016.
- Black dots represent the data observed in 2014.
- Light blue line indicates $\cos^2\theta$ or empirical relationship curve.
- Observation time is from 11/9/2016 0:00 to 11/11/2016 0:00 UTC (not on ICD).

Discussion

- We got a similar data with all the scintillators in piles with only little gap in 2014.
- This year's data are closer to the empirical relationship curve compared to that of 2014's.
- We think this year's flux data have sharper directivity and are closer to the intensity than the old one.

Future Plans

We have some plans to observe the same phenomenon as follows:

- on the rooftop to prevent the obstruction by the building structures.
- more data at more zenith-angles.
- in other directions aside from the north.
- using the scintillators with the optimized gap.

Lycée Europe Robert Schuman, Cholet – FRANCE
International Cosmic Day   November 2, 2016

Our group

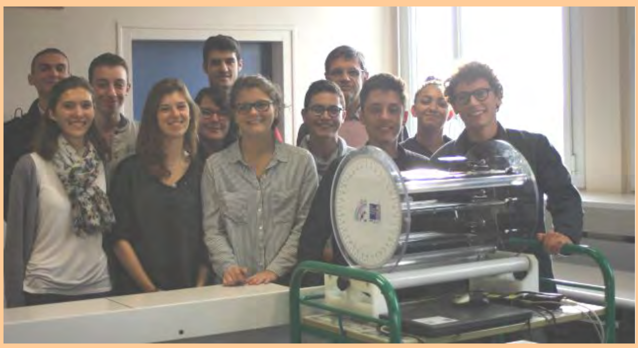
We are 11 students of the French high school “Lycée Europe Robert Schuman” in Cholet, Maine et Loire, FRANCE.
We study sciences and we chose to attend a physics and chemistry course in English once a week.
We worked with the collaboration of our teacher and a lab assistant.

In the morning, we had a presentation (via Skype) on the cosmic rays by Corinne Béra, a physicist from the Laboratory of Subatomic Physics & Cosmology (LPSC, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France). Thanks to her !

Then we made the measurements and we participated in the 14 UTC Skype video call. Unfortunately, we couldn't present our results because of a microphone problem...We'll do better next year !

Device

We made our measurements thanks to a comodetector. This detector is part of the “Sciences at school” program, in partnerships with the CERN, CPPM and IN2P3. It is lent to our high school since 2012.



Students: Achille Berthou, Marion Frouin, Elodie Gibouin, Clément Jacquet, Zoé Lacolle, Eléa Loupy, Maxence Marot, Rémy Mimbré, Axel Séchet, Océane Serisier, Thomas Zimbardo.

Lab assistant: Séverine Frouin.

Teacher: Thierry Mineau.

Lycée Europe Robert Schuman, Cholet – FRANCE
International Cosmic Day   November 2, 2016

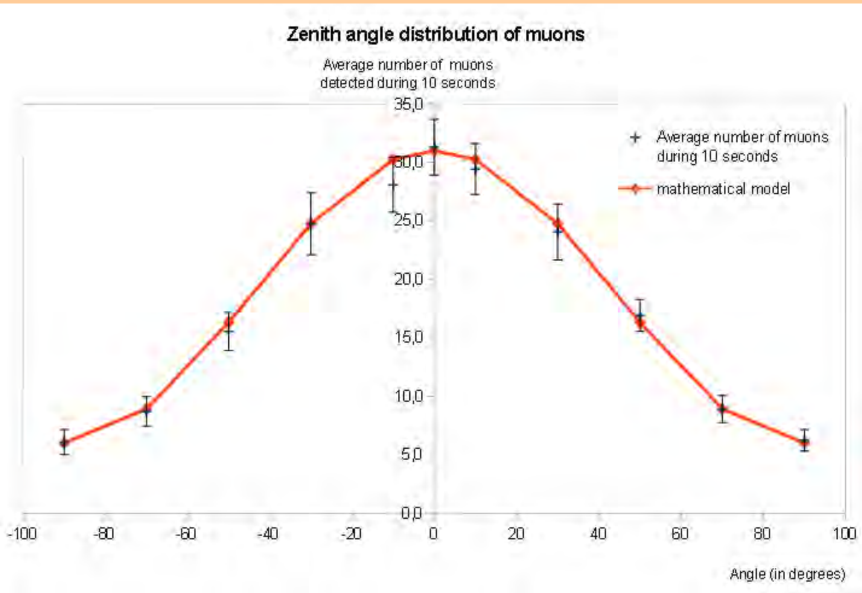
Measurements

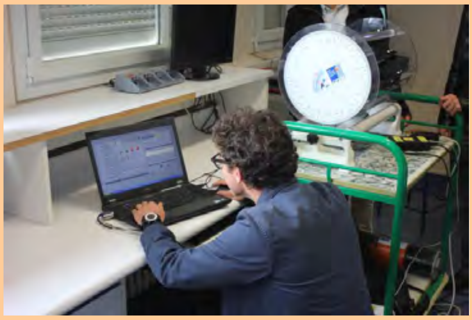
We used 2 of the 3 scintillator paddles of our cosmodetector. Each of them was connected to a photomultiplier. We counted the muon coincidences between the two paddles, during 10 seconds. We repeated 24 times the counting for each angle. A software piloted the detector and recorded the data. In a spreadsheet, we calculated the average number of muons and the expanded uncertainty. This experiment did not take into account a correction for the angle-dependent detector effective surface.

Result

With the cosmodetector we studied the zenith angle distribution of muons.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Angle (in degrees)**	**-90**	**-70**	**-50**	**-30**	**-10**	**0**	**10**	**30**	**50**	**70**	**90**
2	**Average number of muons during 10 seconds**	**6,1**	**8,7**	**15,5**	**24,8**	**28,1**	**31,3**	**29,4**	**24,0**	**16,9**	**8,9**	**6,3**
3	Expanded uncertainty at 95% confidence level	1,1	1,3	1,6	2,6	2,4	2,4	2,2	2,4	1,4	1,2	0,9





We detected more muons when the zenith angle is close to zero.

When we turned the cosmodetector to the zenith, we detected an average number of 31,3 muons (during 10 seconds). So the most important part of the muons arrived perpendicularly to the ground.

For a ± 90° zenith angle, the number of muons was not zero, so they arrived from all overhead directions, but this number was lower than that of a zero zenith angle. Indeed, they travelled much more through the atmosphere.

Finally, we compared our measurements to a theoretical model $N(\theta) = a.\cos^2(\theta) + b$. We chose the values of the constants "a" and "b" by trial and error.

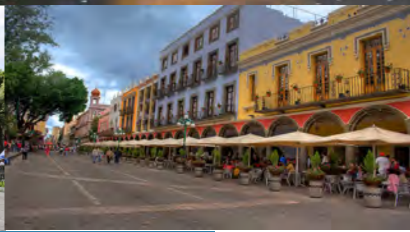
BENEMÉRITA UNIVERSIDAD AUTÓNOMA DE PUEBLA

PREPARATORIA EMILIANO ZAPATA

Discover Cosmic Rays

INTERNATIONAL COSMIC DAY

November 02 I 2016



ABSTRAC:

The measurement of cosmic rays will be made in order to quantify the amount of external particles that reach the earth.

Puebla and the advantages:
Puebla is located in the central east of the Mexican territory; the state has an average altitude of 2160 meters above sea level, this data benefits the measurement of cosmic rays.

What are cosmic particles?

They are particles principally nucleus of the atoms most common in the universe: Hydrogen and Helium.

Where do they come from?

They come from four sources:

*Solar
*Anomalous (close stars)

*Galactic

How can they be measured?

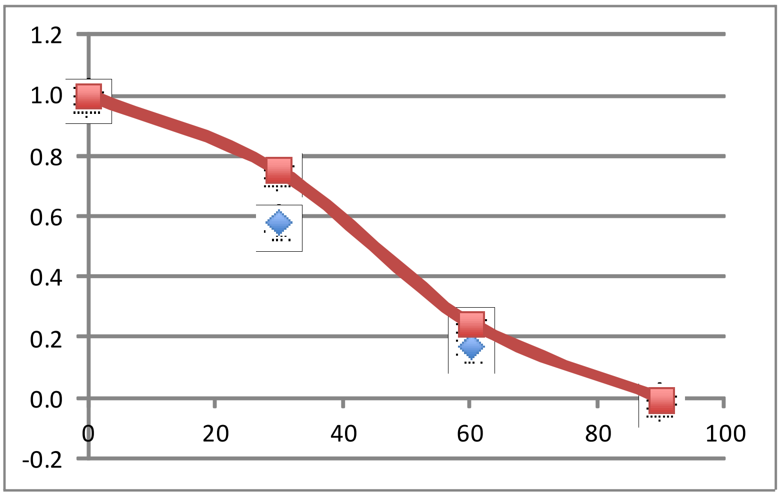
By means of photomultiplier and flashers crystals.

DESY NETZWERK TEILCHENWELT International Particle Physics Outreach Group QuarkNet Fermilab INFN Istituto Nazionale di Fisica Nucleare

BENEMÉRITA UNIVERSIDAD AUTÓNOMA DE PUEBLA

PREPARATORIA EMILIANO ZAPATA

Angle	Radians	Data	Data value by subtracting 90 °	Normalized data	Error	Normalized Error	Theory Cos^2
0°	0.000	360	331	1.0	37.9	0.115	1.00
30°	0.524	222	193	0.6	14.9	0.045	0.75
60°	1.047	87	58	0.2	9.3	0.028	0.25
90°	1.571	29	0	0.0	5.4	0.016	0.00



Conclusion:

The principal conclusion of this work is that the cosmic particles pass through us all the time, and the amount of particles it decreases with the inclination give. At an angle 90° the particles are received directly and with the inclination involved in the passage of particles other factors so the amount of particles is less.

THE TEAM

Reference:

Connolly B., Westerhoff S., Finley C., O´Neill A. *The Search for the Origin of Cosmic Rays*. [November 02nd] https://www.i2u2.org/elab/cosmic/content/CosmicExtremes.pdf

INTERNATIONAL COSMIC DAY

The students from "ITAES" and "CECYTECH" made an interesting project to discover how the "Cosmic Rays" are part of our life and how it works inside the earth.

The objective of this activity was to detect the flux of cosmic rays with the detector "Escaramujo".

The measurement was done with three zenith angles:

0°, 45°, 90°.

Results:

UNIVERSIDAD AUTONOMA DE CHIAPAS

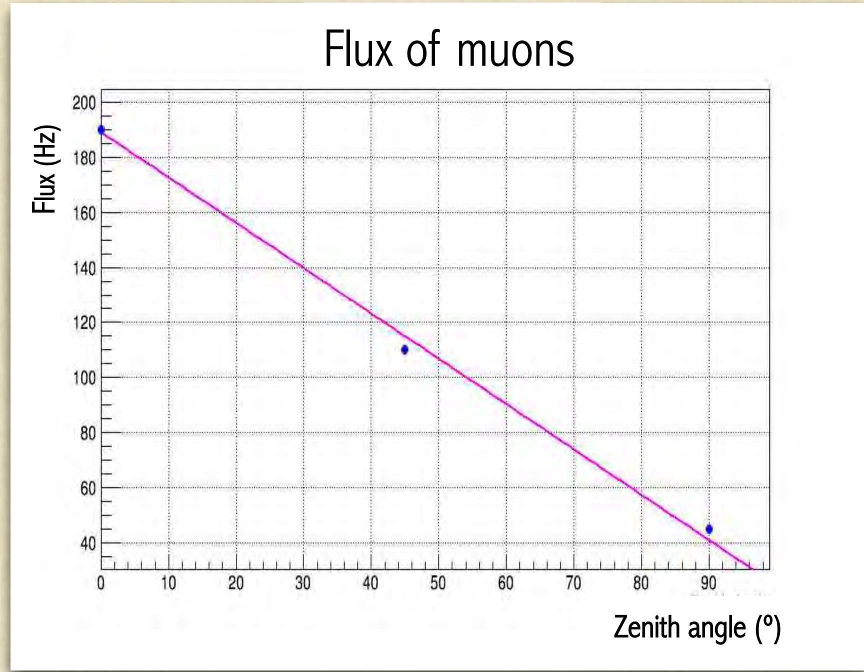
UNACH

POR LA CONCIENCIA DE LA NECESIDAD DE SERVIR

EXPERIMENTAL DATA

- THRESHOLD USED 20 mV
- 3 SCINTILLATOR EJ-200
- DOUBLE COINCIDENCE METHOD
- FOR 5 MINUTES EACH ANGLE
- THE ALTITUDE OF OUR LOCATION,

TUXTLA GUTIÉRREZ, CHIAPAS, MÉXICO
IS 522 m OVER THE SEA LEVEL



International Particle Physics Outreach Group

NETZWERK TEILCHENWELT

DESY

Fermilab

QuarkNet

MCTP
Mesoamerican Centre for Theoretical Physics

International Cosmic Day 2016

Introduction

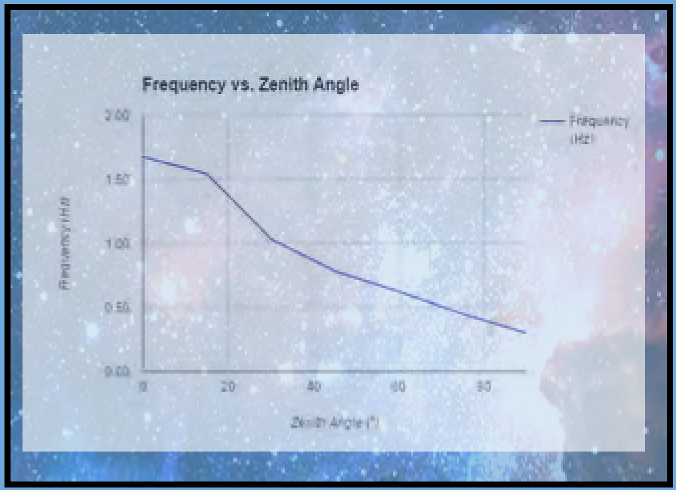
We are an independent research class that meets weekly to study cosmic rays as part of Quarknet. We attend Naperville Central High School which is located just west of Chicago, Illinois. We are happy to be joining many other institutions to celebrate International Cosmic Day and work together to investigate the rate of muons tracked by our sensors based on the set zenith angle.

Experiment

The cosmos must have truly aligned for the chicago area- not only was is ICD but it is also the Day the Chicago Cubs won the World Series! Go Cubs! In order to determine the relationship between zenith angle and rate of muon detection, we set up three detectors and compared the number of hits received in a two-minute interval at various angles. At the time threshold of 18 nanoseconds, the angles were increased in 15° increments, from 0° to 90°. As the detectors in the experiment were separated, the purpose was not to measure coincidences, but to independently focus on the activity of individual detectors.

Findings

Detection rates decreased as zenith angle neared 90°. We hypothesize more of the cosmic rays detected came from directly above, so decreasing the surface area resulted in a smaller frequency of muons. Of the three detectors used, only one reported cohesive data, which is reported below. Our data follows loosely a $\sin^2 \theta$ function.



Students: Colin Jensen, Bethany Simos, Phoebe Harmon, Shirley Wu, Yangyang Li, Sarah Kee, & Sanjana Ramrajvel

Not pictured: Annie Zhou & Jee Kim | Instructor: Katherine Seguino | Special Thanks to Dr. Mark Adams of Fermilab

NAPERVILLE CENTRAL HIGH SCHOOL

NAPERVILLE, IL, USA

QuarkNet

Fermilab

2016 International Cosmic Day
Zenith Angle Distribution of Cosmic Muon Flux

S.S. Hsiao[1],Alan Yang[2], K.L. Chang[2],
[1] QuarkNet-TW, Taipei, Taiwan
[2] Taipei Astronomical Museum, Taipei, Taiwan (http://www.tam.gov.taipei)

Using metal frames purchased from B&Q, a cosmic ray telescope is constructed(Fig.1) with quarknet detector. The DAQ card and a gravity sensor are connected to a credit card size computer raspberry pi 2(Rpi2). The gravity sensor is used to determine the zenith angle to which the telescope is pointed. Our computer programs are written in python. Access to Rpi2 is done remotely via wi-fi connection using VNCviewer. The frame is not balanced such that a attached string can be used to adjust the zenith angle easily.

Fig. 1, Our cosmic ray telescope is setup at the visitor center of Xiaoyoukeng where the altitude is 800m and is a scenic spot of Yangmingshan (http://www.ymsnp.gov.tw).

Our telescope consists of one counter at one end separated from two counters at another end by 140cm. Local flux from all direction can be measured by the bottom counters(Fig.2) for the purpose of calibration.

Fig. 2, Local flux calibration.

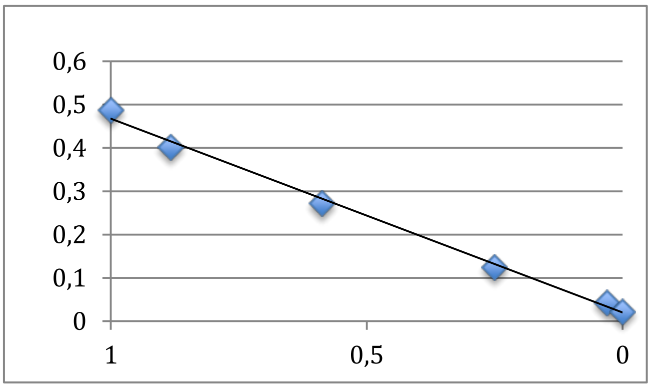
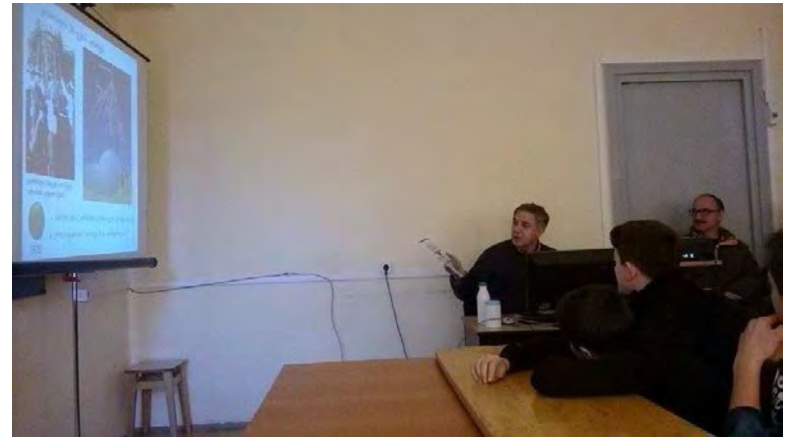


Fig. 3, Cosmic muon flux vs. $\cos(\theta)^2$ where θ is the westward azimuthal angle. The unit of flux is counts/sec.

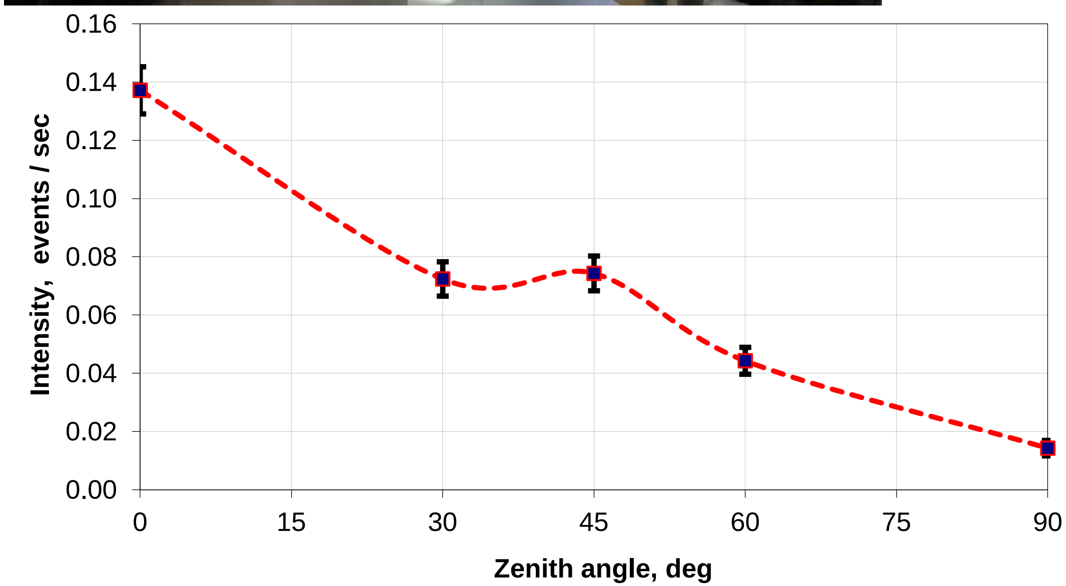
Our final angular distribution is shown by Fig.3. The linear variation of flux as $\cos(\theta)^2$ is verified.

2 November 2016

E.Andronikashvili Institute of Physics (TSU)

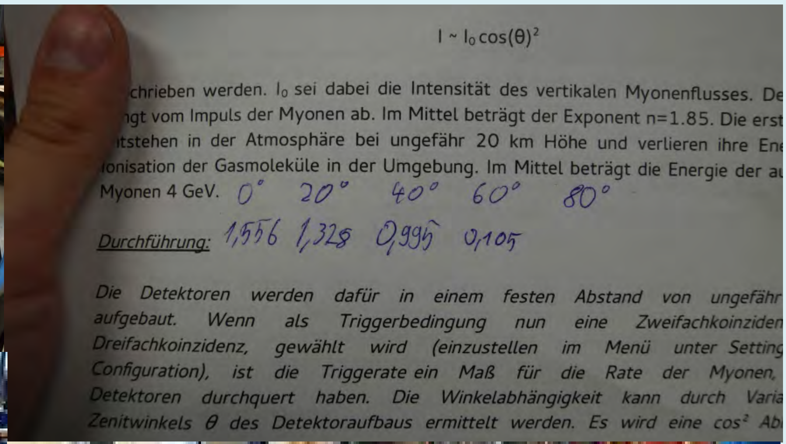


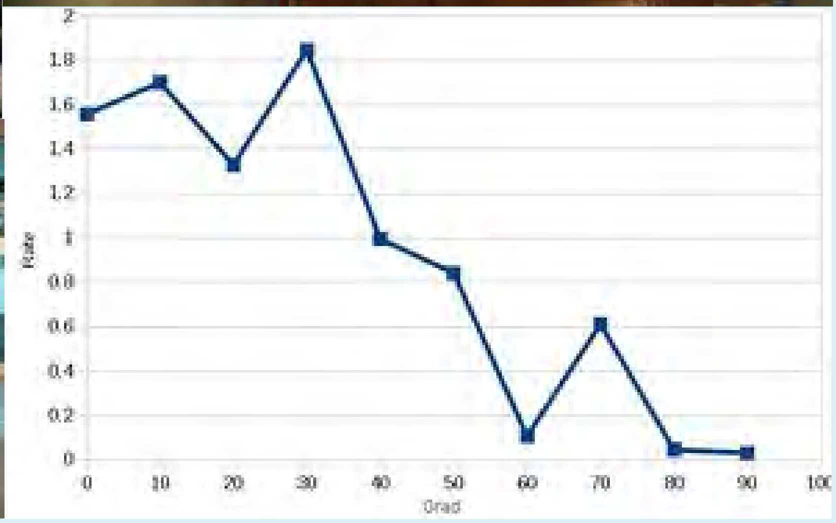
“IceCube – Neutrino Telescope on a South pole” - Revaz Shanidze



Cosmic Ray muons' intensity dependence on the arrival Zenith angle

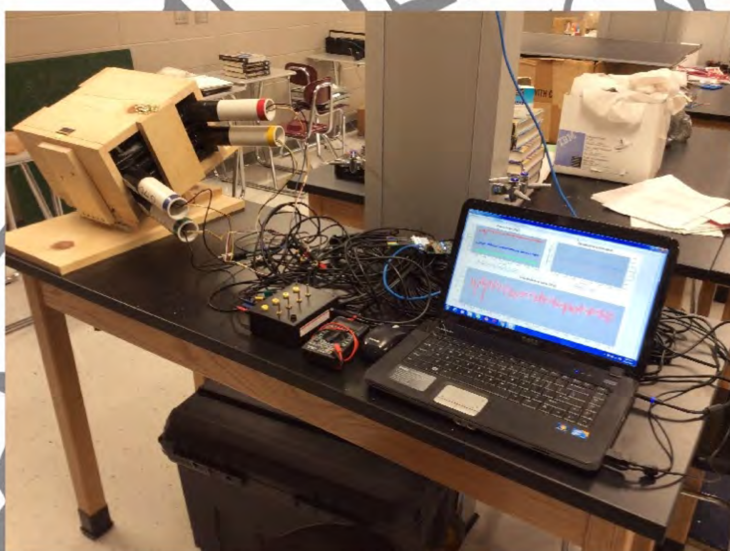
Universität Tübingen





WINAMAC COMMUNITY HIGH SCHOOL

Winamac, Indiana, USA



International Cosmic Day

November 2, 2016

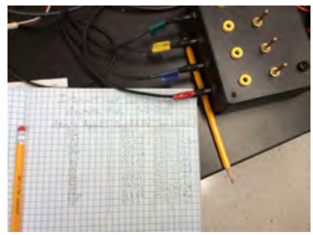
International Cosmic Day 2016 - Data and Results
Winamac Community High School in Winamac, Indiana, USA

Setup

We used a four paddle scintillator based detector that could be tilted at various angles throughout the day.

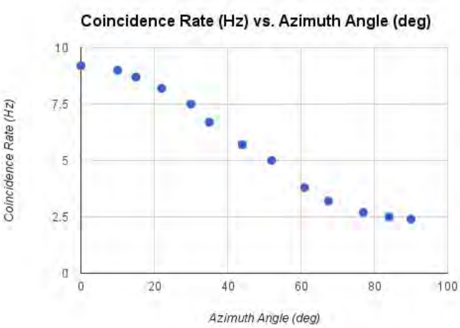
Data

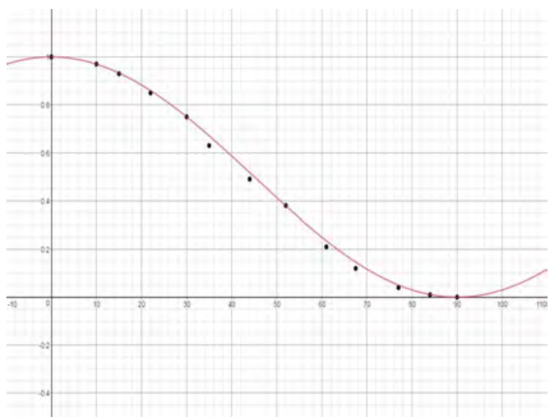
Each student set the detector at a different angle and recorded the coincidence rate after about an hour.



Results

Our raw data appears sinusoidal and the normalized data closely matches a (cos)^2 curve.





International Cosmic Day 2016 in Würzburg

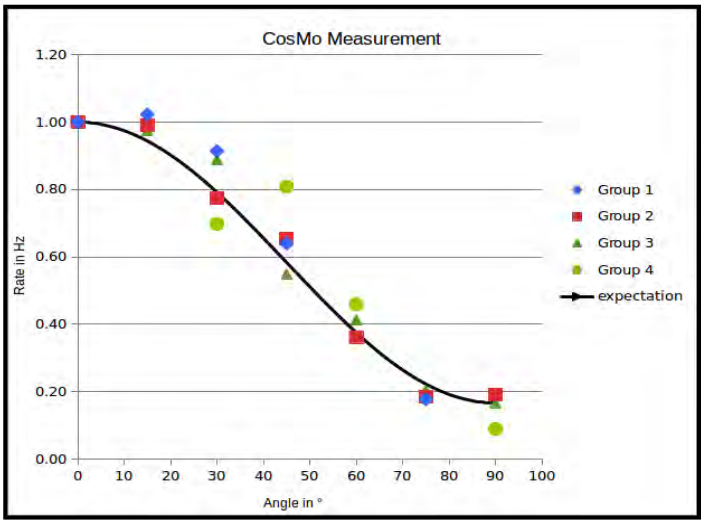
Today is the International Cosmic Day and it's the 2nd of November 2016 at the University of Würzburg. We are 8 pupils from the 9th to the 12th grade who are interested in studying the physics of cosmic rays.
The first part was the introduction of the different ways of measuring the cosmic rays, for example the gamma ray telescope (FERMI), the neutrino telescopes (ANTARES and IceCube), the cherenkov telescope (MAGIC), and the ATLAS experiment at CERN in Geneva (Switzerland).
After the presentation we did two experiments to detect muons: The detection of muons with scintillators and with a cloud chamber.
Then we created the paper for the presentation.

Experiments

First we divided the eight students into groups of two and distributed the different components of the cloud chamber to start the first experiment. Inside the chamber we saw different particles flying through, leaving white stripes in the fog. Most of them were muons, electrons and alpha particles, but some were muons decaying into electrons and invisible neutrinos. Afterwards we had a short look at the Kamiokanne experiment, which is able to detect muons.
The most detailed experiment, however, was the examination of muons with scintillators. The three scintillators were placed on a frame with a distance to measure the rates for different angles. Connected to the scintillators, the computer counted the trigger rates (the appearance of a muon) and calculated the mean.

Results

Muons arise 10 kilometres above the ground because of collisions of cosmic ray particles with atmospheric nuclei. Due to their short lifetime (2.2 microseconds) and their velocity of 99.8% of the speed of light the muons would only be able to pass a distance of about 600 m. In spite of that, we can detect them 10 km from their location of creation, which is caused by the effects of the theory of relativity. Because of this, the probability of a muon being detected on the scintillator plate at an angle of 0° is the highest as the distance is a lot shorter. Furthermore, particles tend to reach the earth surface in showers which leads to incorrect measurements when taken in short time spans. This problem can only be avoided in long-term measurements. There are also multiple other reasons for different registrated data. Background noise is the detection of electrical signals not caused by muons. Another reason for differences in results was the use of wooden frames and boxes for installing the required angles. In order to compensate for the differences caused by the different environments of the measuring stations all rates for 0° were set to the value of 1 Hz.



Particle Physics

Standard model measurements and search for new physics with the ATLAS detector
(http://www.atlas.ch)

Developement of new muon detectors

Electroweak precision calculations and LHC phenomenology

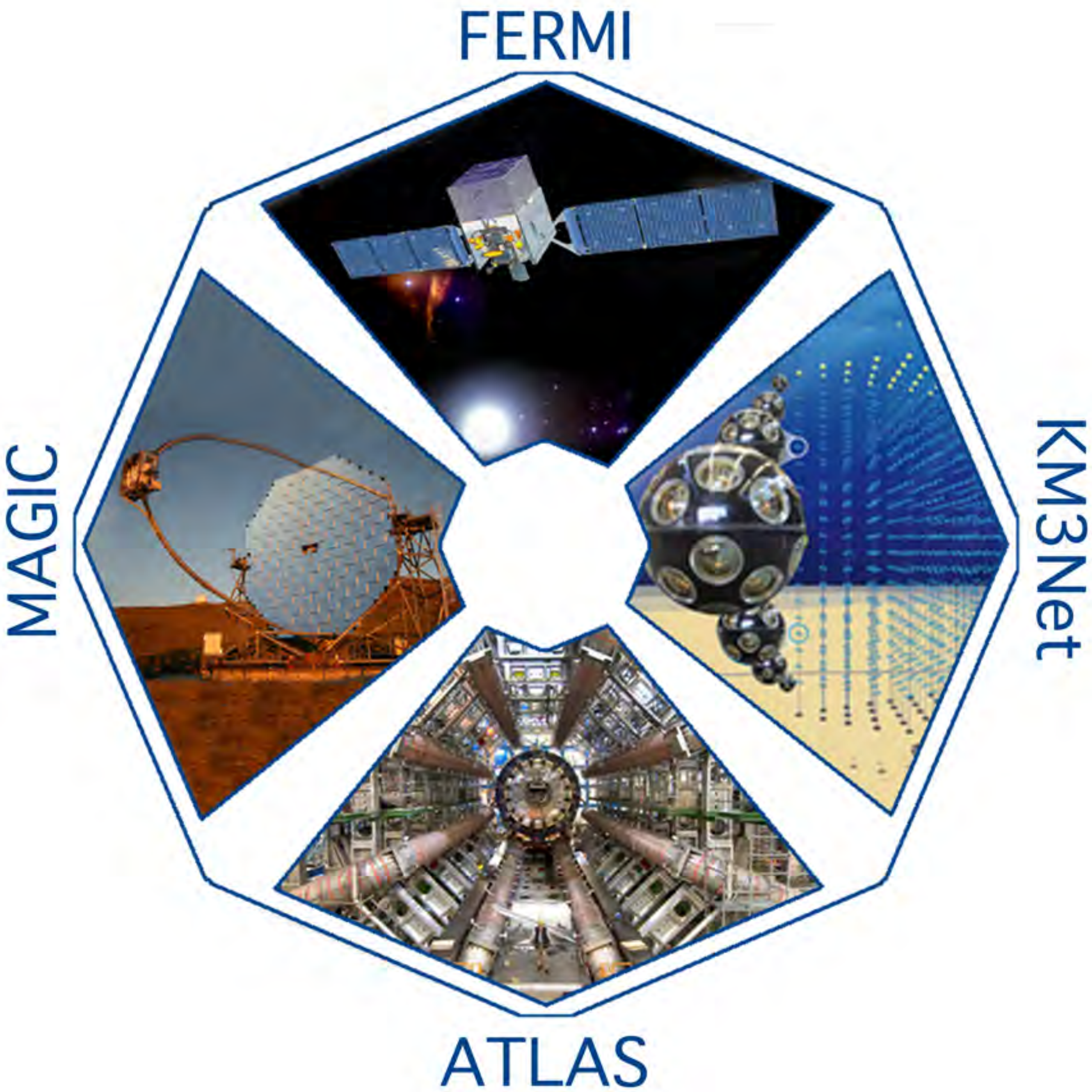
Astrophysics

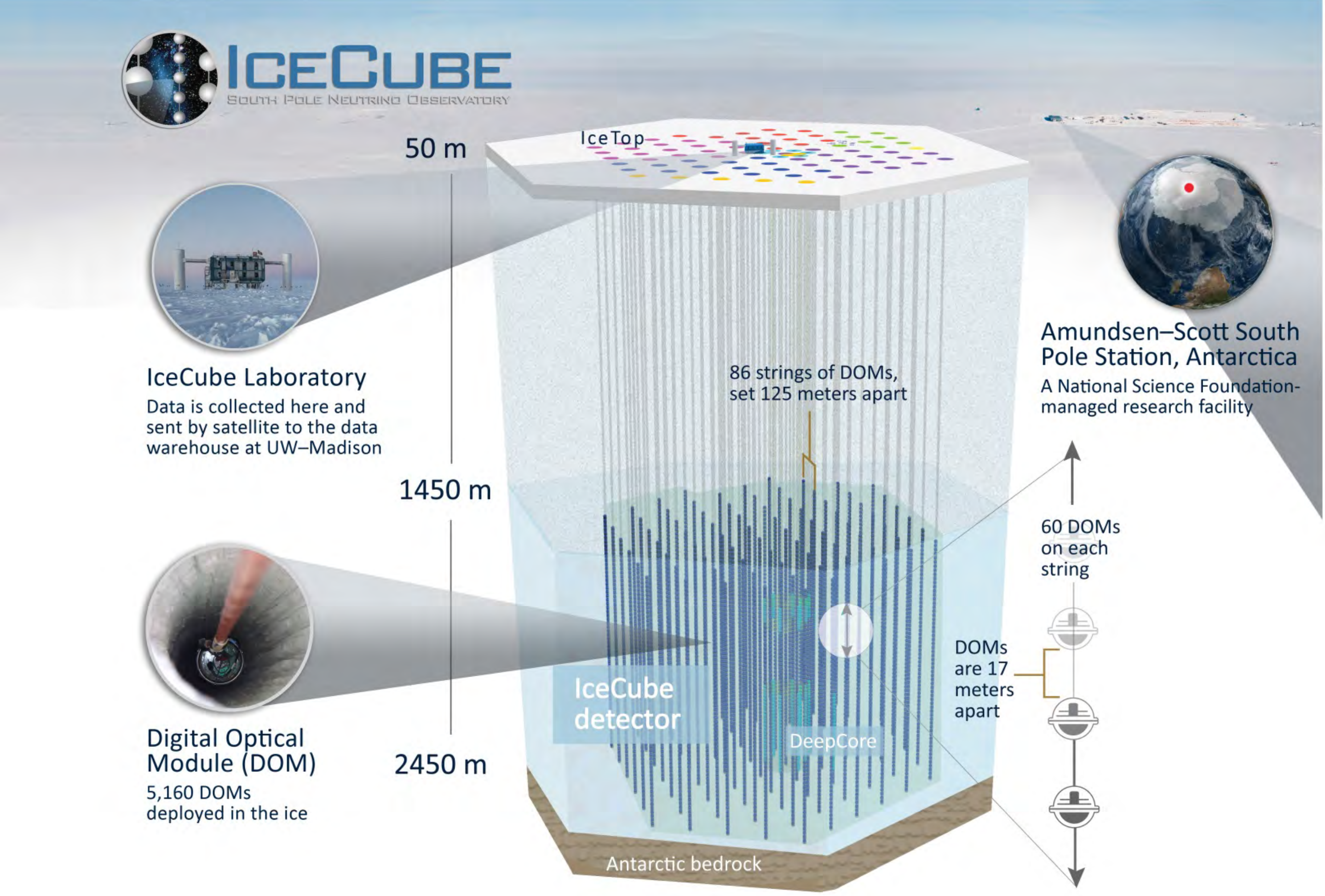
MAGIC (FACT): Gamma-ray astronomy at low energies with high sensitivity with two Imaging Cherenkov Telescopes
(https://magic.mpp.mpg.de/)

KM3Net (successor of ANTARES): km3Scale Mediterranean Neutrino Telescope and DeepSea Research Infrastructure
(http://www.km3net.org/)

FERMI: Gamma-ray all-sky space telescope to explore the high-energy Universe
(http://fermi.gsfc.nasa.gov/)

For more information visit:
www.pid.physik.uni-wuerzburg.de
www.astro.uni-wuerzburg.de



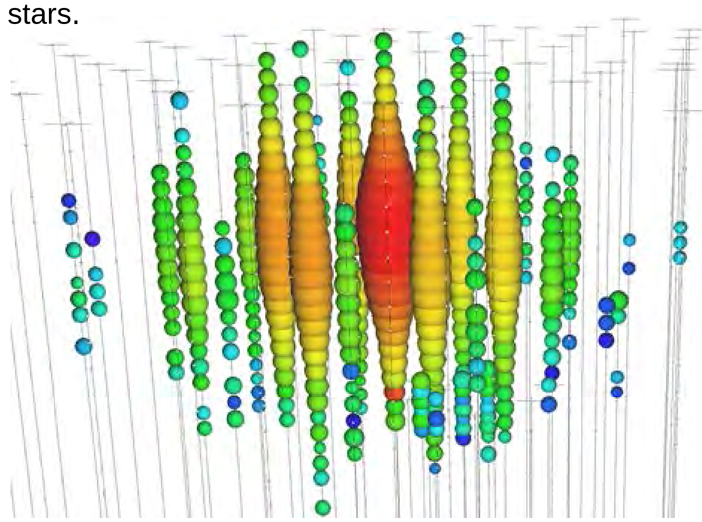


IceCube is the world's largest neutrino detector. Encompassing a cubic kilometer of ice, it comprises of 86 vertical cables, called strings, each holding 60 digital optical modules (DOMs). Every one of those 5160 modules is installed between 1450 and 2450 meters beneath the surface and contains one 10-inch photomultiplier tube, an extremely sensitive light detector. Additionally installed minicomputers ditize the signals and relay the data to the IceCube Laboratory on the surface.

The focus of investigation are the nearly massless subatomic particles called neutrinos that can travel the whole universe nearly unperturbed. IceCube searches for neutrinos reaching us from the most violent astrophysical sources: exploding stars, gamma-ray bursts, and cataclysmic phenomena involving black holes and neutron stars.

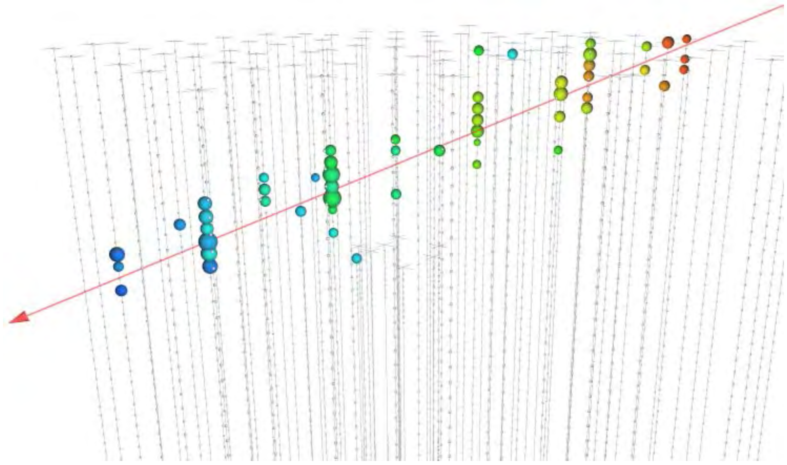
The IceCube telescope could reveal the physical processes associated with the enigmatic origin of the highest energy particles in nature.

After it has been completed in 2010, the IceCube Observatory detected several extremely high-energy neutrinos. One event, observed in 2012, was nicknamed "Big Bird" and can be seen in the picture on the right.

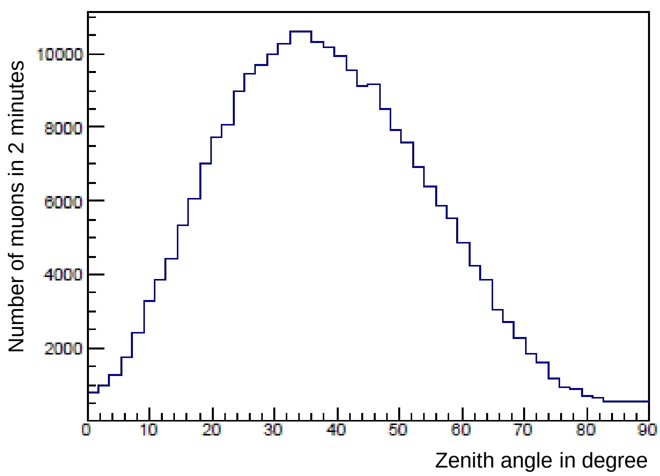


Not only neutrinos, also a large number of atmospheric muons pass through IceCube. Every second, IceCube detects about 2500 atmospheric muons.

A high-energy atmospheric muon going through the IceCube detector after having travelled through several kilometers of ice looks like this:



The histogram below shows the number of muons arriving from different zenith angles:



The x-axis shows the zenith angle in degrees. The y-axis shows the number of muons measured in a 2-minute interval.

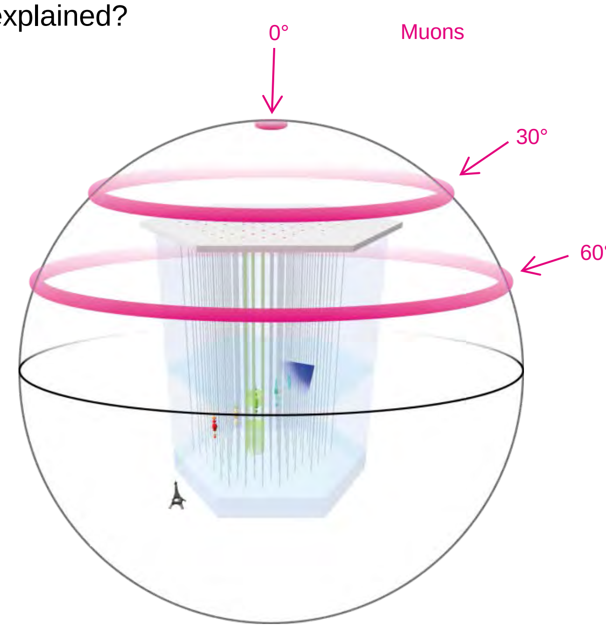
What do we learn from the histogram? At 0°, corresponding to vertically down-going particles, IceCube measures only few muons. The muon number peaks between 30° and 40° and decreases again towards horizontal muons at 90°.

So IceCube also observes a drop in the muon rate from 30° to 90°.

But how can the distribution between 0° and 30° be explained?

Let's look a bit closer at IceCube's measurement. IceCube detects muons coming from all directions. With increasing zenith angle, also the solid angle grows from which muons can reach the detector. There is just less space available for vertical muons than for more inclined muons.

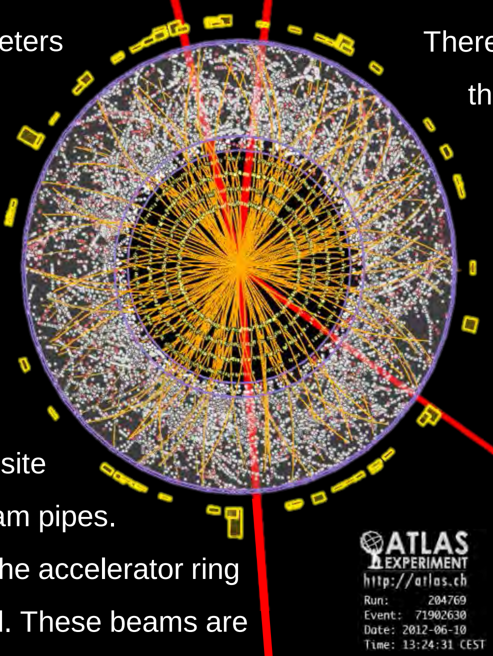
At 30° things change. The muon rate starts to decrease despite the still growing solid angle. It is not only the larger depth of the atmosphere that is responsible for this decrease, but also the overburden of ice which the muons have to cross increases strongly for larger zenith angles.



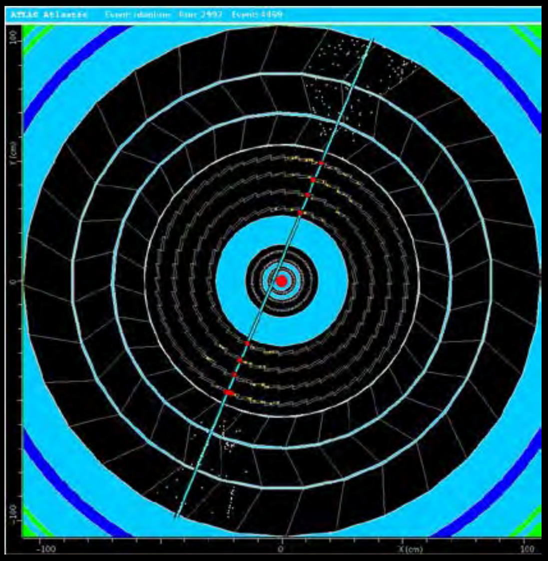
ATLAS

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. It was built by the European Organization for Nuclear Research (CERN) between 1998 and 2008, and first started up on 10 September 2008. LHC is located in a tunnel 175 meters beneath the ground and 27 km in circumference. Inside the accelerator, two high-energy proton beams travel at close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam pipes. They are guided around the accelerator ring by a strong magnetic field. These beams are made to collide at four locations around the accelerator ring, corresponding to the positions of four particle detectors: ATLAS, CMS, ALICE and LHCb.

ATLAS is one of two general-purpose detectors at LHC. It investigates a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter. With a length of 46 m, a height of 25 m and a width of 25 m the 7000 tonnes ATLAS-detector is the biggest particle detector ever constructed.



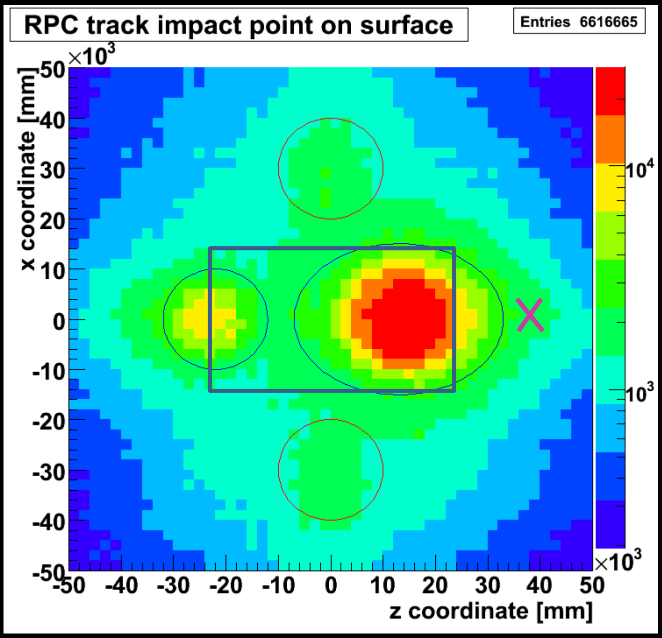
There are numerous researches going on at the ATLAS experiment. The discovery of Higgs boson in July 2012 was a major Breakthrough in the field of particle physics. A typical Higgs event can be seen on the left. It contains uncountable tracks formed by those particles that are produced when a proton collides with another proton. The red lines represent muons from the Higgs decay.



Cosmic rays are energetic, subatomic particles, such as muons, that arrive from outside the Earth's atmosphere. The ATLAS detector is located in a cavern 100 m below ground. Thus, most of the cosmic muons are filtered by this thick layer of concrete. The figure on the left shows that cosmic particles which are detected by the ATLAS leave a track passing all sub-systems from the top to the bottom of the detector but don't cross the detector's middle.

Knowing that the tracks left by muons is twice as long at those created by particles that came into being after a proton-proton-collision, the detector can be calibrated. When a muon passes by, the scientists compare the upper and the lower half of the track in the detector, which should have the same momentum if the measurement systems work properly.

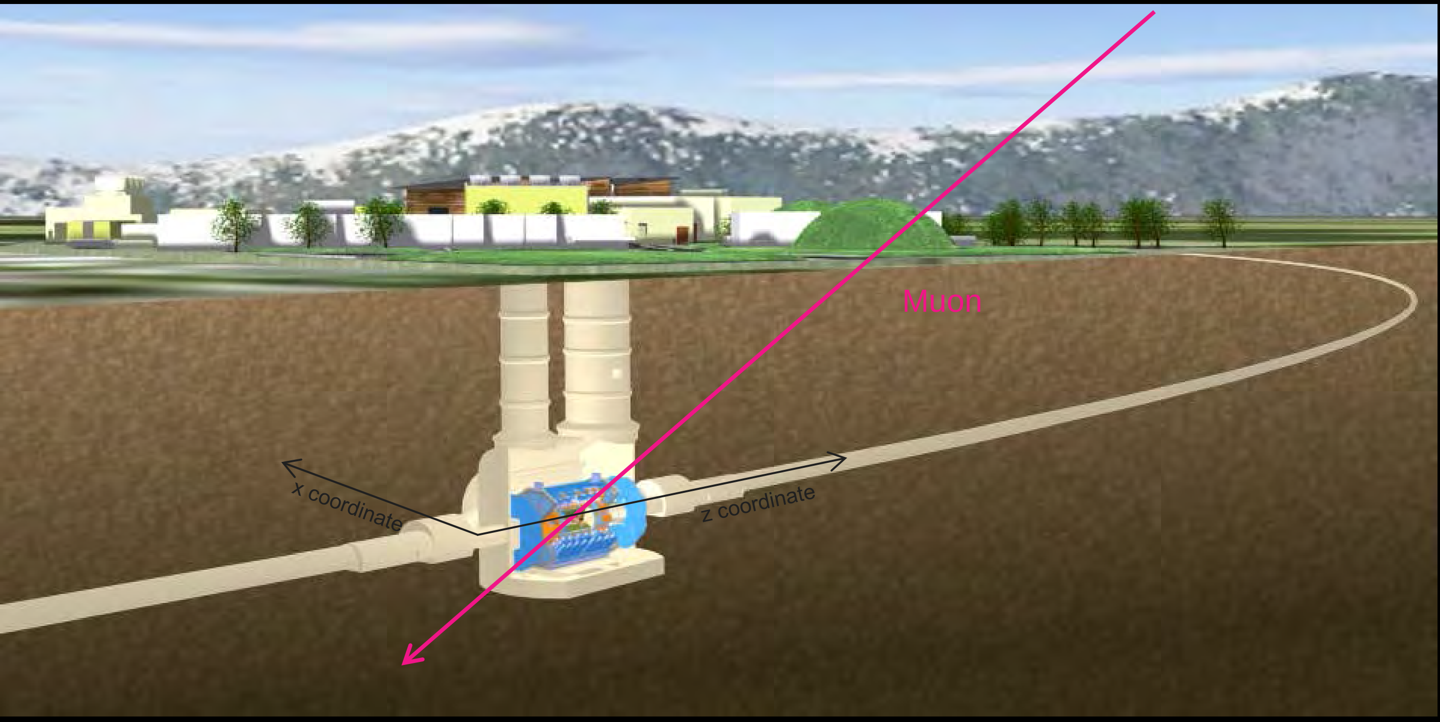
ATLAS analyses the incoming atmospheric muons:



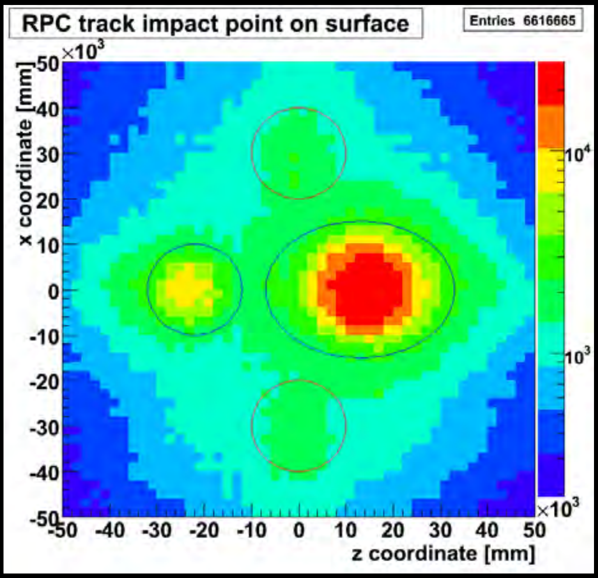
The chart above displays the spatial coordinates from the bird's eye view. The unit of the axis is given in 103mm which equals 1m. A colour range illustrates the amount of muons that crossed the earth's surface and reached the detector. In the top right hand corner, you can see the total number of muon entries. There were 6616665 muons detected.

The grey rectangle in the middle of the coordinate system symbolises the ATLAS detector itself. Please be aware that ATLAS is located 100m beneath the ground.

The pink x stands for a striking point and corresponds to the exemplary muon that you can see in the under figure.



How does the measurement come about?
The muon measuring chambers in the ATLAS detector are capable of a clear muon investigation. Thus, it is possible to reconstruct the muon traces and to identify the exact point on the surface where the muons entered the ground.



What is conspicuous in this histogram?

1. There are two areas with a very high amount of muon counts (> 10 000 entries).

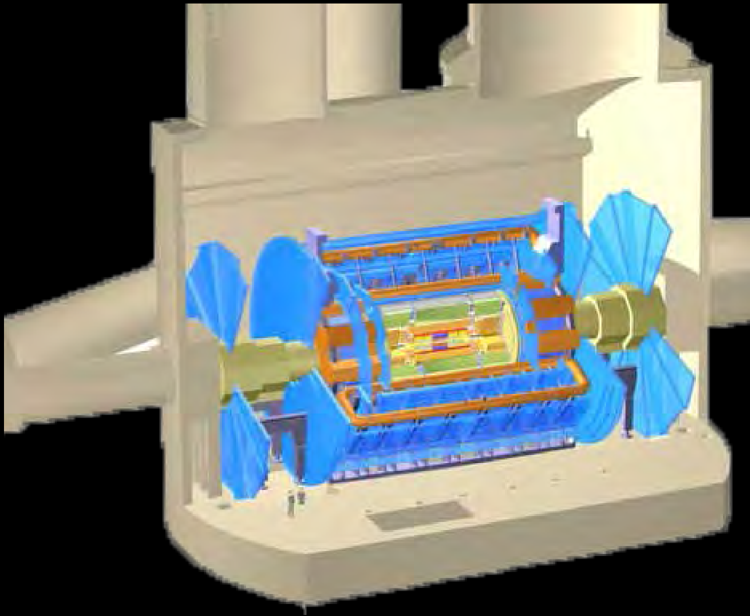
2. Two other areas show a high amount of muon counts (> 1 000 entries).

3. The whole histogram is characterized by a rhomboid structured distribution of frequencies.

How can we understand and interpret these observations?

1. It is easier for the muons to pass air than to pass water or concrete.
   There are two shafts above the ATLAS detector. Muons can travel within the shafts without being absorbed by the thick layer of concrete so that their chances of reaching the detector are really good.

2. On the left and on the right of the detector are two more shafts. Horizontally incoming muons are able to enter the ATLAS through those shafts and are not stopped by the concrete.

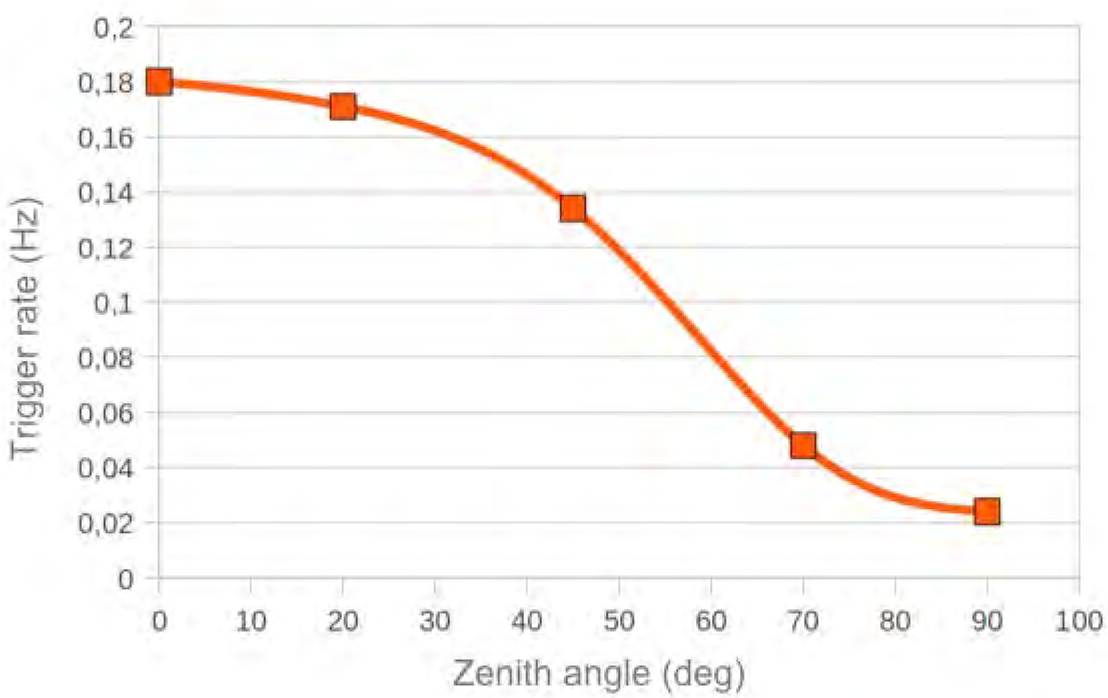


3. At first, the histogram displays what you already measured as well: the greater the zenith angle is, the smaller the amount of measured muons (1000 muons in the green area vs. 100 muons in the blue area).
   The rhomboid structure can be explained when having a closer look at the setup of ATLAS. The detector contains two vertical muon measuring chambers at the ends of the detector. Along the beam line the muon chambers are cylindrically arranged. That’s why it is possible for the detector to record the angular measurement with a higher resolution regarding the x-coordinate. Apart from that, the detector’s “edges” aren’t able to reconstruct the muon tracks properly. Owing to this, the rhomboid structure of the histogram isn't caused by the muons themselves. It is a result of the structural features of the detector.

SUMMARY

INTERNATIONAL COSMIC DAY

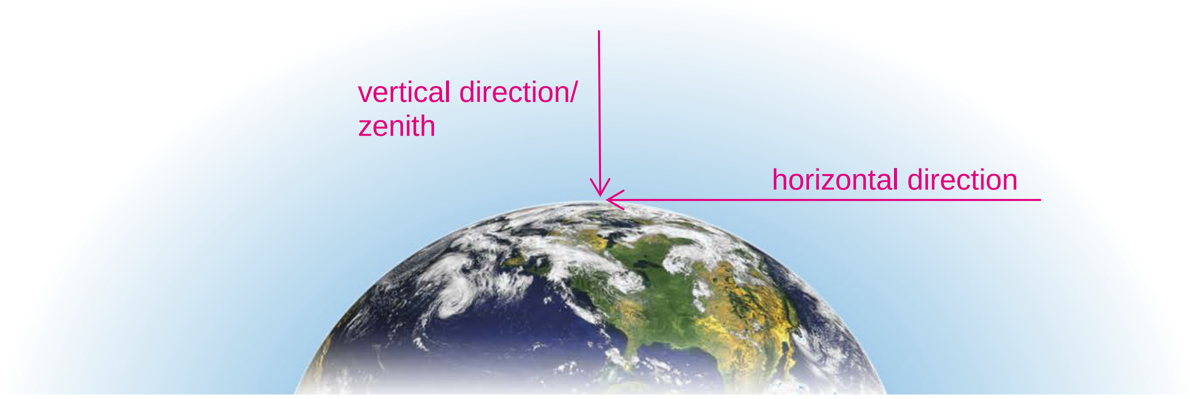
Zenith Angle Distribution of Air Shower Particles



The goal was to measure the rate of muons, produced in extended air showers, as a function of the zenith angle.

Those of you who have done this measurement have seen that the rate has its maximum when pointing the detectors upwards, towards the zenith. When increasing the zenith angle, i.e. inclining the detectors more and more towards the horizon, the muon rate decreases. From this we concluded that most of the cosmic particles reach us from straight up ahead.

This result can be easily understood when remembering where the muons come from. The muons are produced in the upper atmosphere of the earth, in the height between 10 and 15 kilometers above the sea level. This is the distance they have to travel when they hit us from straight above. Muons that reach us from a horizontal direction, i.e. at a large zenith angle, have to travel a much larger distance, more than 400 kilometers. Then remember that muons have a very short lifetime: In average, after only two millionth of a second, they decay. Thus muons travel as fast as possible - with over 99% of the speed of light – the farther the distance, the higher is the probability that they decay before reach us. Consequently, the larger the zenith angle at which we point our detectors, the lower is the measured muon rate.



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More about Muons

Intriguing anomaly found inside the Great Pyramid at Giza using muography:
http://arstechnica.com/science/2016/10/intriguing-anomaly-found-inside-great-pyramid-at-giza/

More about Nobel Prize in Physics 2015 and Neutrinos

Nobel Prize in Physics 2015 “for the discovery of neutrino oscillations”:
http://www.nobelprize.org/nobel_prizes/physics/laureates/2015/press.html

‘Tiny Ghosts’ – A music video about neutrinos:
http://www.worldsciencefestival.com/2015/10/tiny-ghosts-neutrinos-music-video

More outreach programs for students

International Particle Physics Masterclasses – Analyze particle physics data:
http://www.physicsmasterclasses.org

IceCube Masterclass – Analyze IceCube data:
http://icecube.wisc.edu/outreach/masterclass

QuarkNet – Overview over physics outreach programs in the USA:
https://quarknet.i2u2.org

Netzwerk Teilchenwelt – Overview over astroparticle and particle physics outreach programs in Germany:
http://www.teilchenwelt.de

LEARN MORE

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More outreach programs for students

The Pierre Auger Observatory outreach website:
http://www.auger.org/education
http://auger.colostate.edu/ED

If you want to know more about cosmic particles and astroparticle physics, we have collected here a few links. Have fun on the tracks of science!

Comic about Cosmic Ray from NASA:
http://www.nasa.gov/pdf/752017main_CRaTER_minicomic.pdf

IceCube – Life at the South Pole:
http://icecube.wisc.edu/pole/life

Video “The fantastic voyage of Nino the neutrino” from INFN:
http://www.youtube.com/watch?v=dhkCMO1lG7g

ScienceNews for Students – “Where cosmic rays are born”:
https://www.sciencenewsforstudents.org/article/where-cosmic-rays-are-born

Fermilab:
http://ed.fnal.gov/home/students.shtml

Outreach website astroparticle group at DESY:
https://astro.desy.de/outreach

IPPOG – The International Particle Physics Outreach Group:
http://ippog.web.cern.ch/