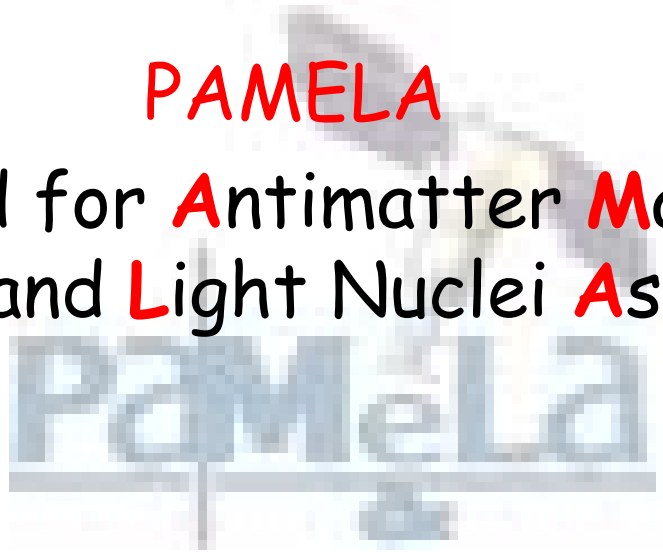
The PAMELA Space Mission

Ralf Wischnewski

DESY

PAMELA

Payload for Antimatter Matter
Exploration and Light Nuclei Astrophysics



DESY Zeuthen, Seminar, April 28th, 2004

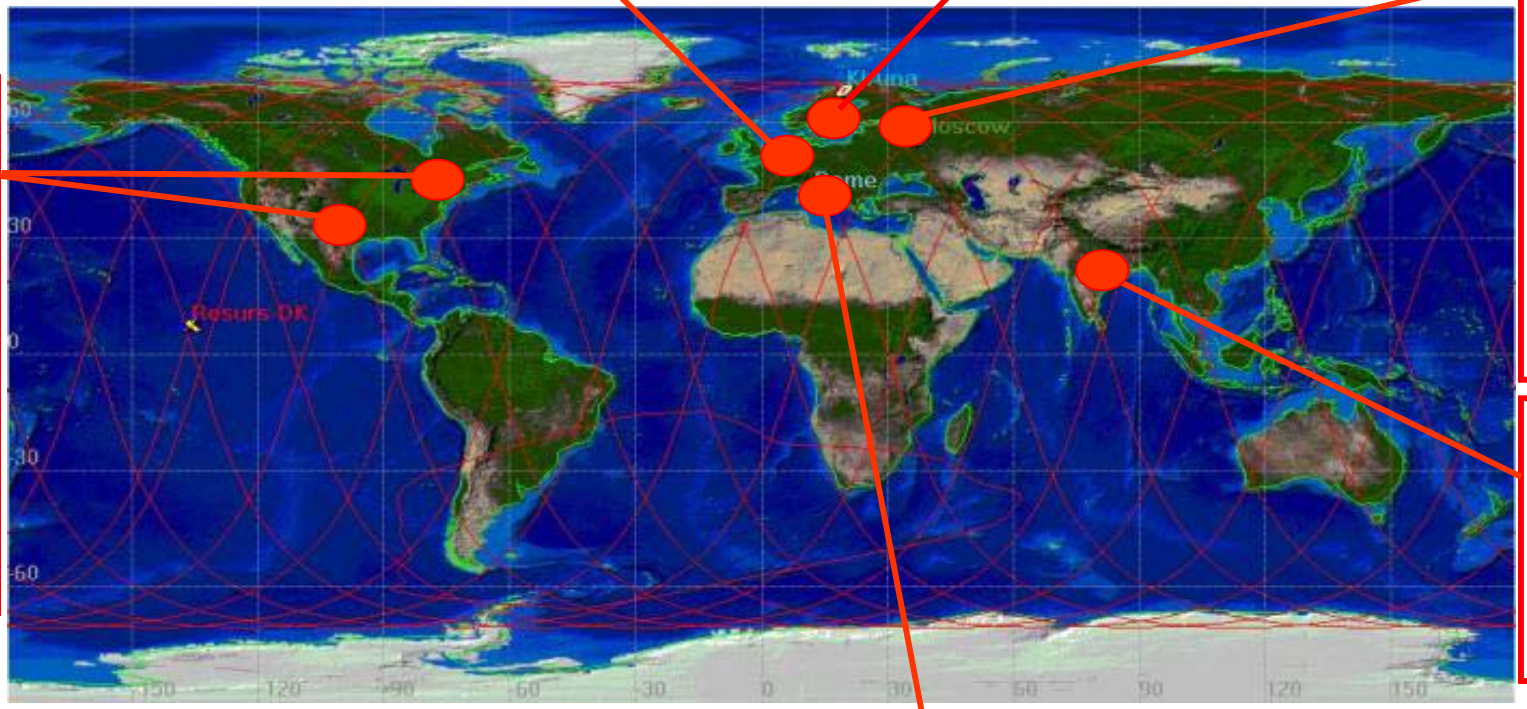
The PAMELA Collaboration

Germany:
Universität Gesamthochschule Siegen
Siegen

Sweden:
Kungl Tekniska Högskolan
KTH, Stockholm

Russia:
Физический Институт
Ioffe Physico-Technical Institute
МИФИ
Moscow
St. Petersburg

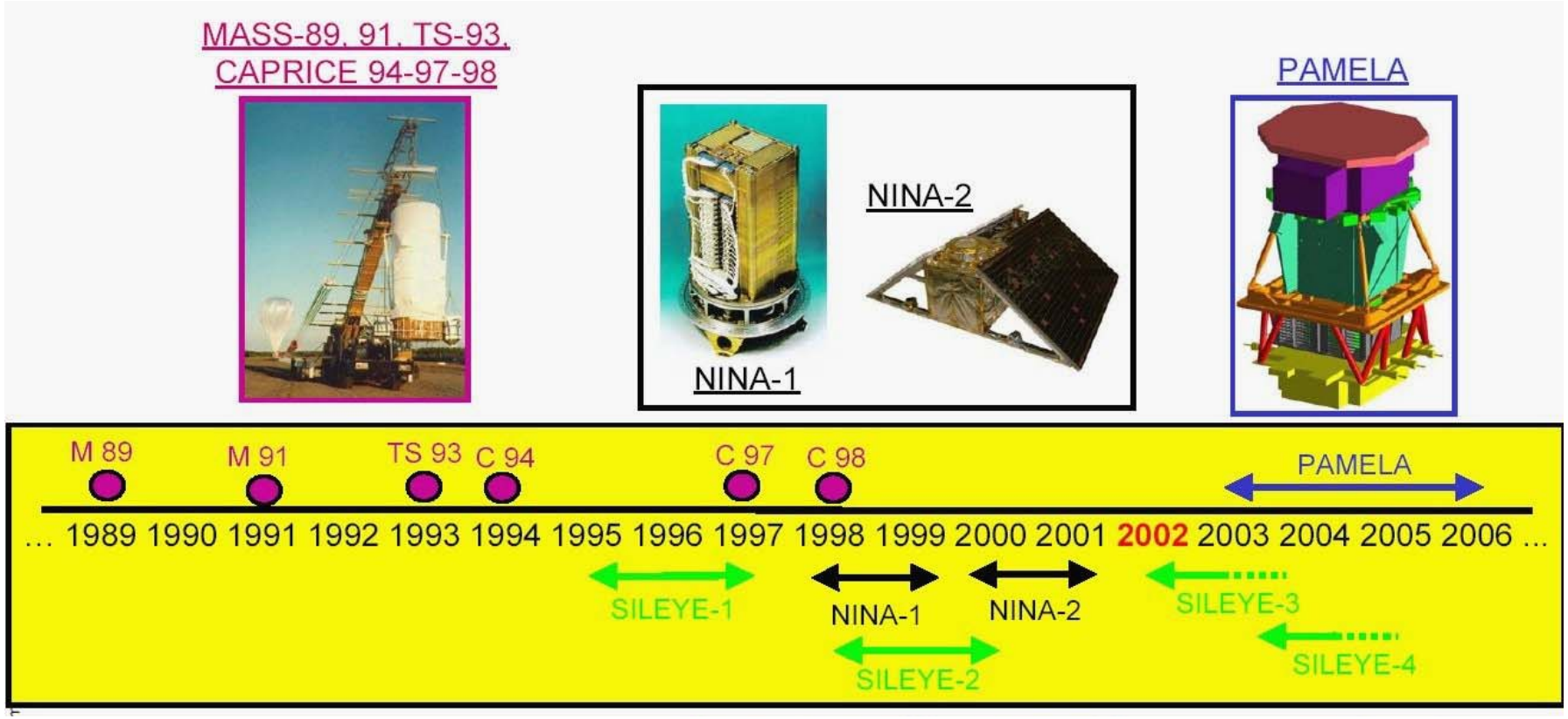
USA:
GSFC
NMSU



India:
TIFR
Bombay

Italy:
Bari
Florence
Frascati
Naples
Rome
Trieste
CNR, Florence

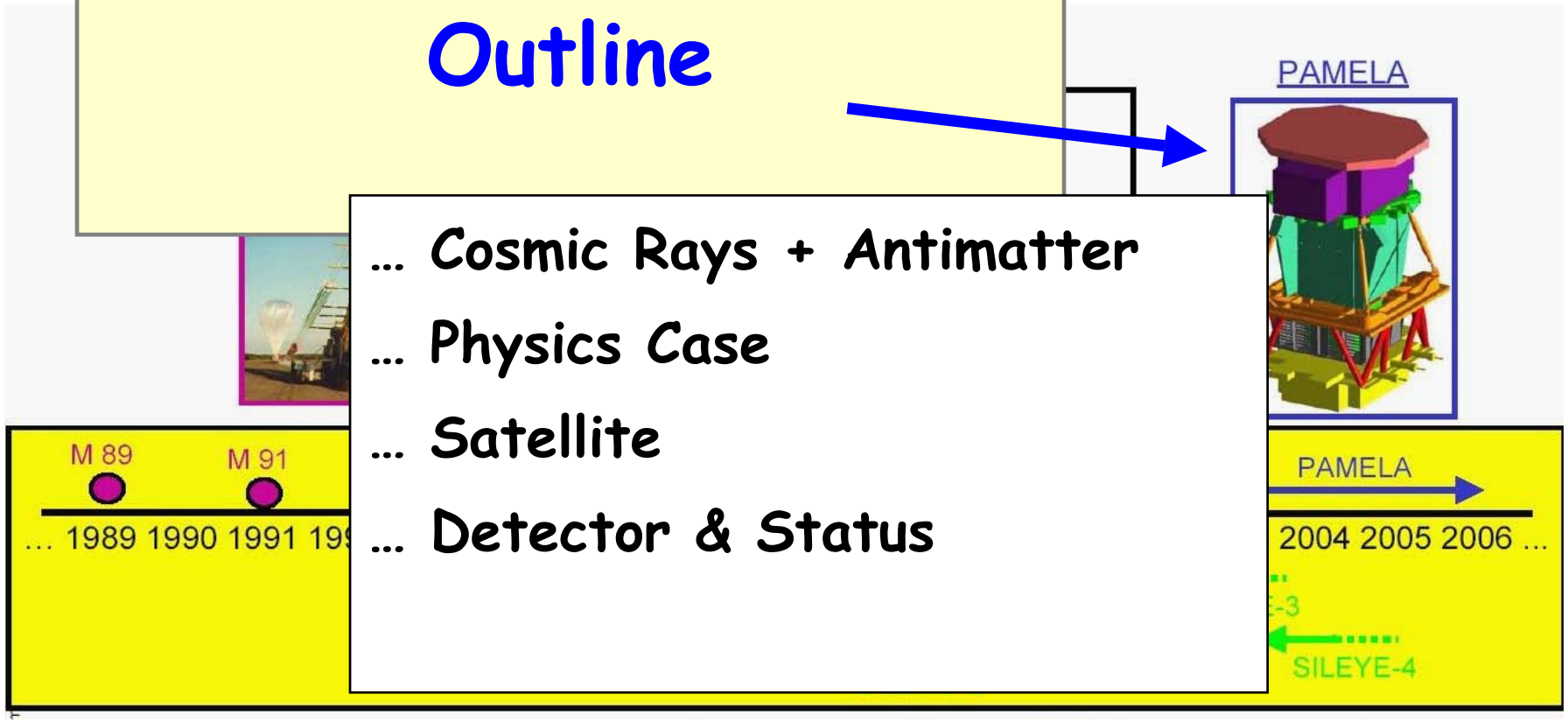
CR Experiments by WiZard Collaboration



CR Experiments by WiZard Collaboration

Outline

- … Cosmic Rays + Antimatter
- … Physics Case
- … Satellite
- … Detector & Status



Cosmic Rays at Earth

→ dN/dE ~ $E^{-2.7\ldots3.0}$ …

→ proton + *A* ~ 98%

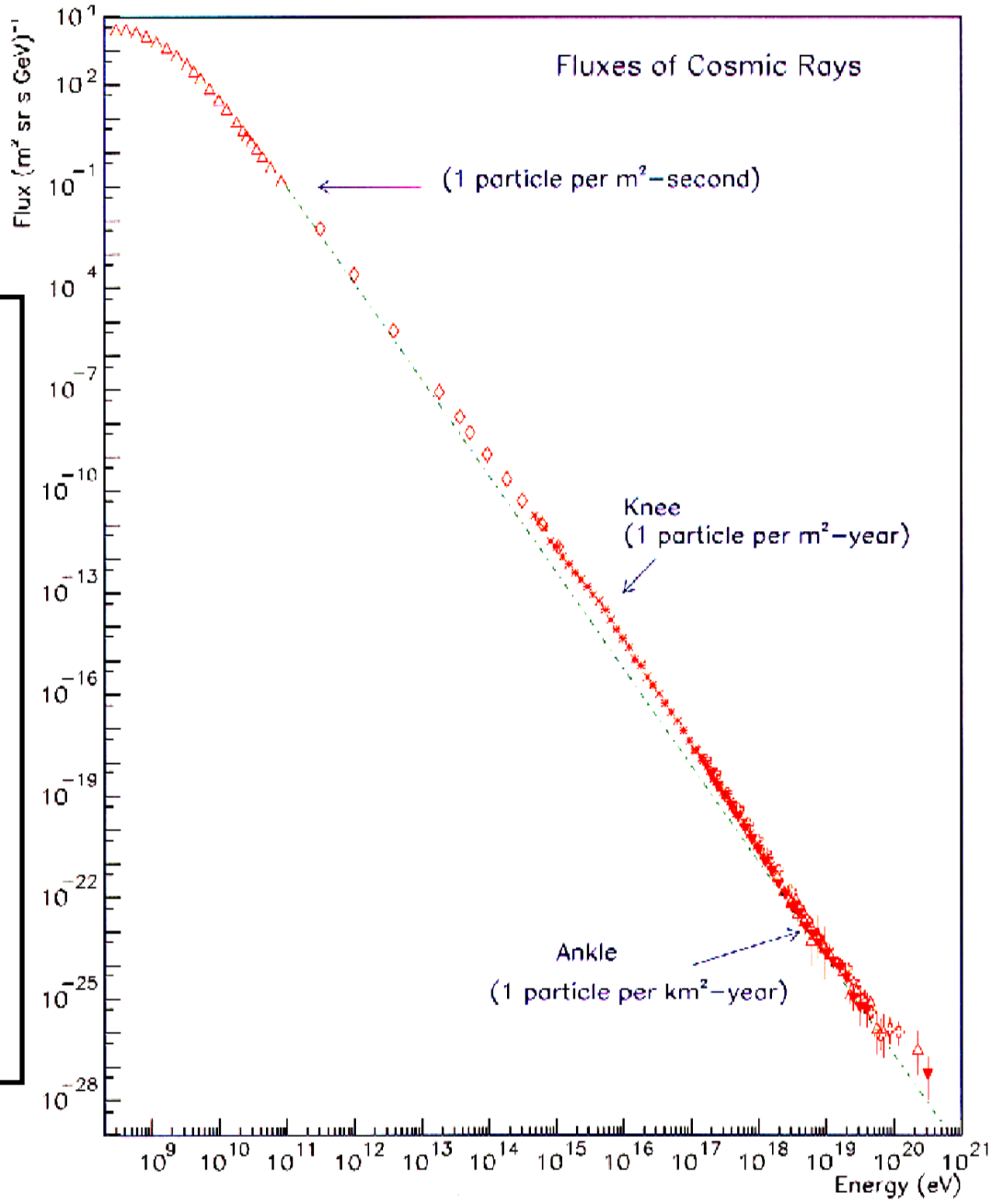
electron ~ 2%

[p: 87% He: 12% Z>2 1%]

→ positron ~ 10^{-3} (1965)

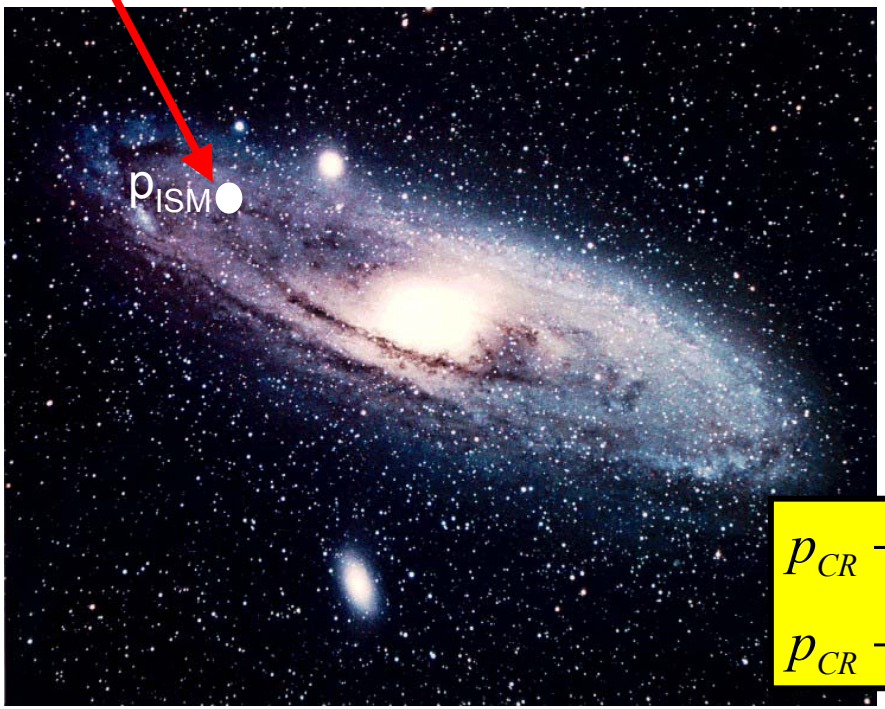
→ Anti-proton ~ 10^{-4} (1979)

→ No Anti-Nuclei, Z>1



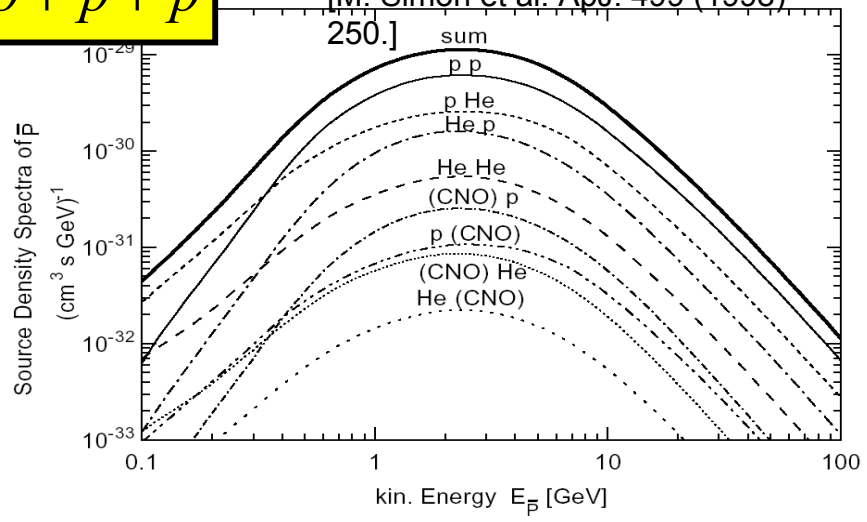
Antiparticles in Cosmic Rays: $\bar{p}$ and e^+

CR-proton



$$p_{CR} + p_{ISM} \rightarrow \bar{p} + p + p + p$$

[M. Simon et al. ApJ. 499 (1998) 250.]



$$p_{CR} + p_{ISM} \rightarrow \pi^+ + X; \pi^+ \rightarrow \mu^+ + \nu_\mu; \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

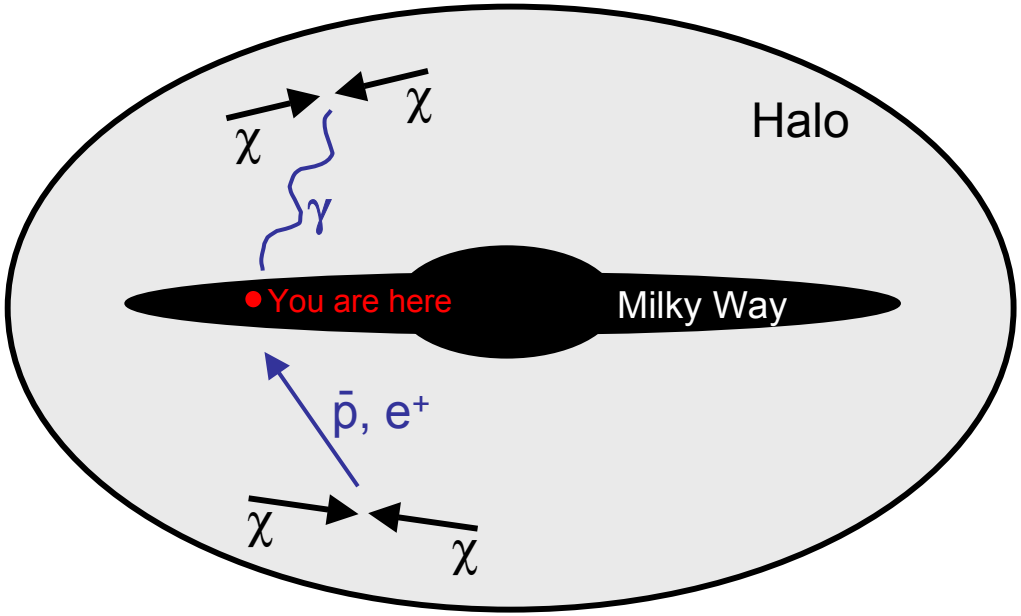
$$p_{CR} + p_{ISM} \rightarrow \pi^0 + X; \pi^0 \rightarrow \gamma + \gamma; \gamma \rightarrow e^+ + e^-$$

Anti-p and positrons are compatible with secondary production

Neutralino Annihilation

Neutralino as
CDM-Candidate →
Indirect DM-Search

WIMP
annihilation →



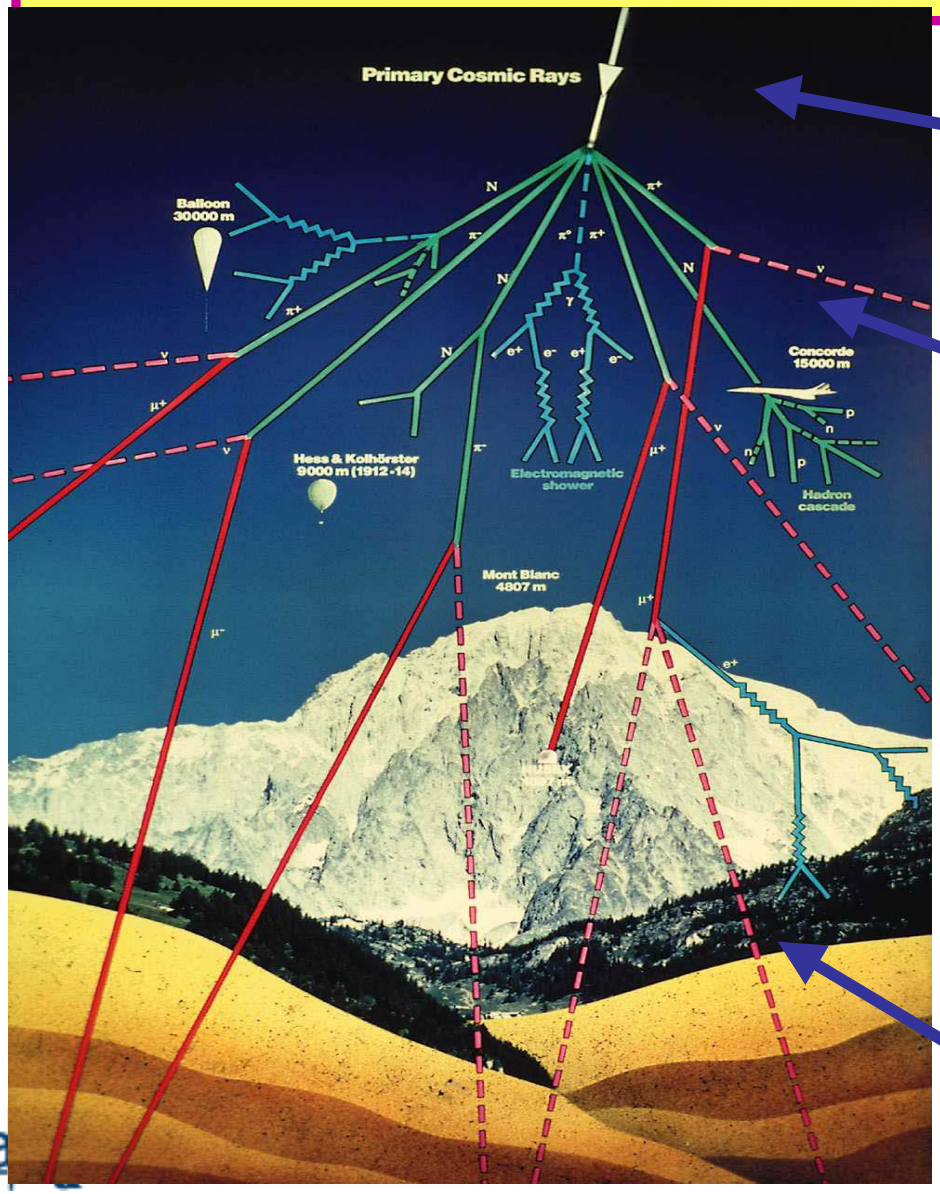
$$\chi + \bar{\chi} \rightarrow X + \gamma$$
$$+ \nu$$
$$+ \bar{p}$$
$$+ e^{+}$$

EGRET, Agile, GLAST

Baikal, AMANDA, ...

PAMELA
(and Bess,
HEAT, AMS etc.)

Investigating Cosmic Rays



In **space** (>50km) ⇒ protons, nuclei, electrons and neutrinos

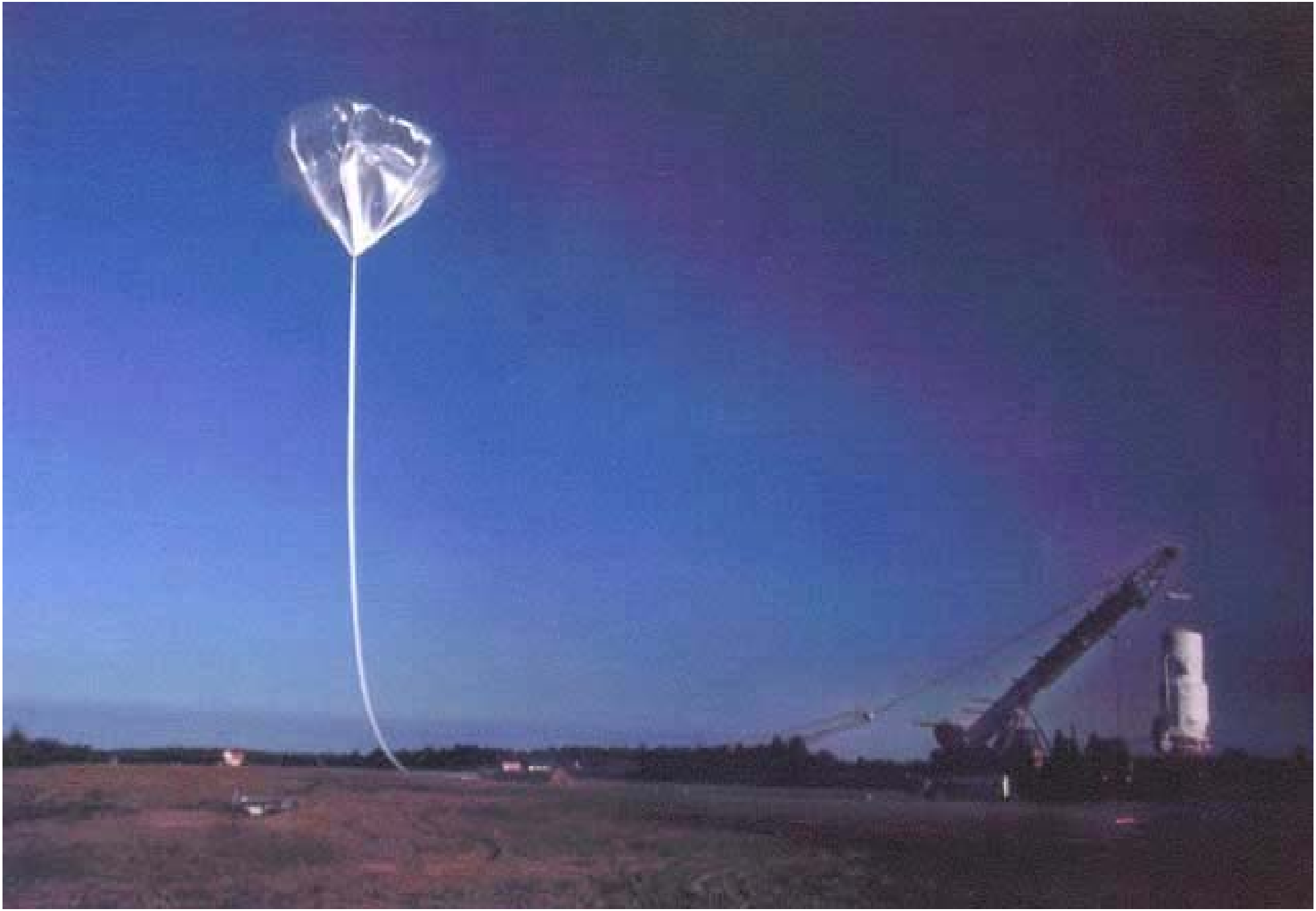
Small detectors but long duration

In **balloons** (~30km) ⇒ protons, nuclei, pions, electrons, muons and neutrinos

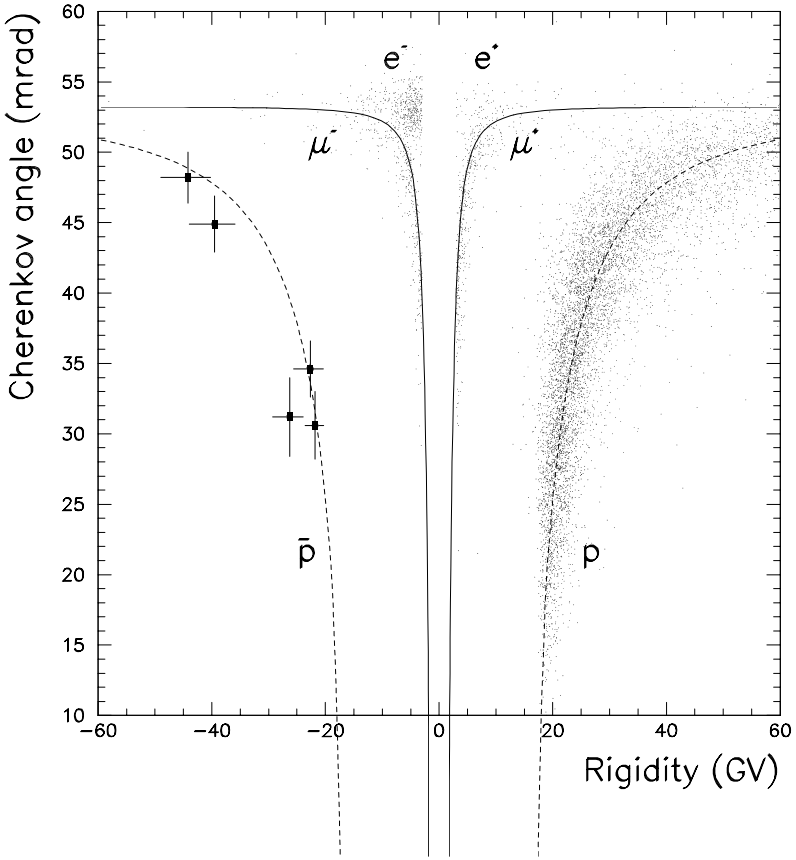
Larger detectors but short duration.
Atmospheric overburden ~5 g/cm^2.

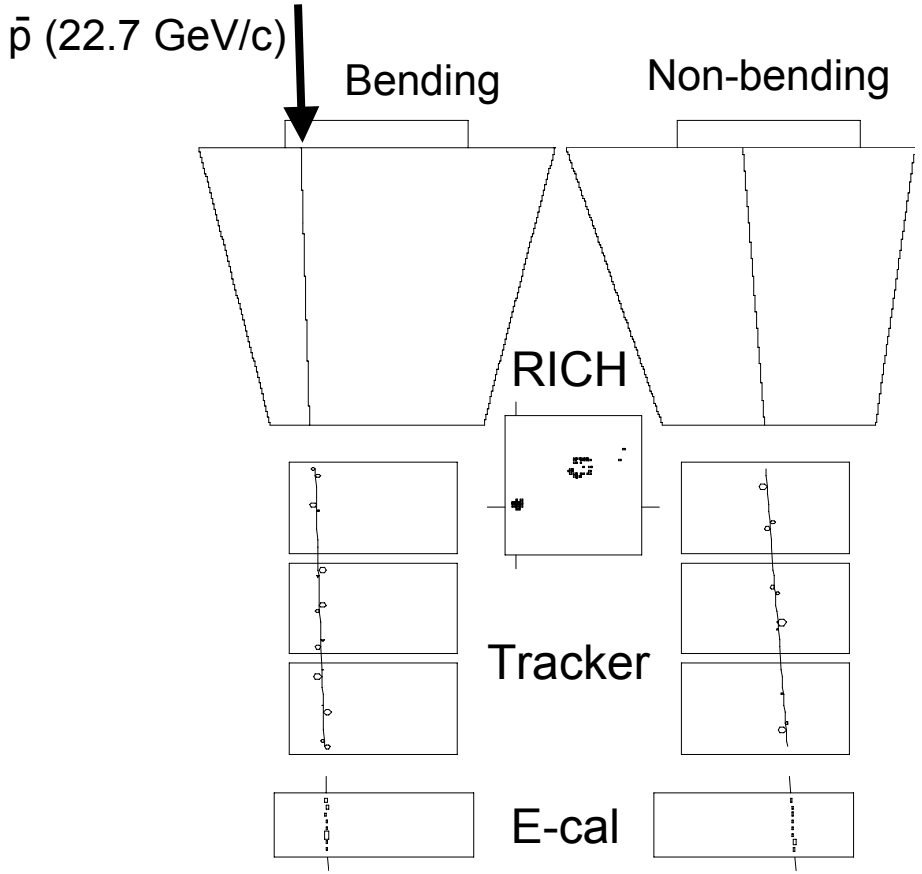
On ground ⇒ E.A.S., HE muons + neutrinos

'Infinite' size and duration but atmospheric overburden ~1000 g/cm^2 !



Antiprotons with CAPRICE





- First high energy (>5 GeV) *mass-resolved* antiprotons were observed by CAPRICE 98

PAMELA – Main Physics Goals

- Antiproton / proton flux
- Positron / electron flux
- Light nuclei (N<6)
- Anti-He / He flux

Also:

- Energetic particles from the sun (E<10 GeV)
- Solar CR-modulation (precision study)
- High energy particles in Earth magnetic field

PAMELA – Main Physics Goals

- Measure Antiproton and Positron Spectra up to few hundred GeV, to study
  - Sources and Transport Mechanism of Cosmic Rays inside our Galaxy
  - Formation and Evolution of our Galaxy and the Universe.

- To search for hints for Exotic Sources of Antiprotons/ Positrons, e.g.from SUSY - WIMPs (e.g.Neutralinos), that could be gravitationally trapped in the Halo of the Galaxy (DarkMatter).

- Direct Antimatter Search for e.g. AntiHelium
  (from sources outside our local cluster (R>20Mpc))
  (AntiHe C.R. production rate ~10^{-14})

PAMELA – Sensitivity

		particles / 3 years
• Antiproton flux	80 MeV - 190 GeV	>3 10^4
• Positron flux	50 MeV – 270 GeV	>3 10^5
• Electron flux	up to 400 GeV	6 10^6
• Proton flux	up to 700 GeV	3 10^8
• Electron/positron flux	up to 2 TeV	
• Light Nuclei (up to Z=6)	up to 200 GeV/n	He/Be/C: 4 $10^{7/4/5}$
• AntiNuclei search	(sensitivity of < 10^{-7} in $\overline{\text{He}}$/He)	

→ Unprecedented Statistics and new Energy Range in CosmicRays

→ Energetic Particles from the Sun, Nuclei abundance, ...

→ High energy particles in Earth Magnetosphere, ...

PAMELA ANTIPROTON expectation

Secondary production:

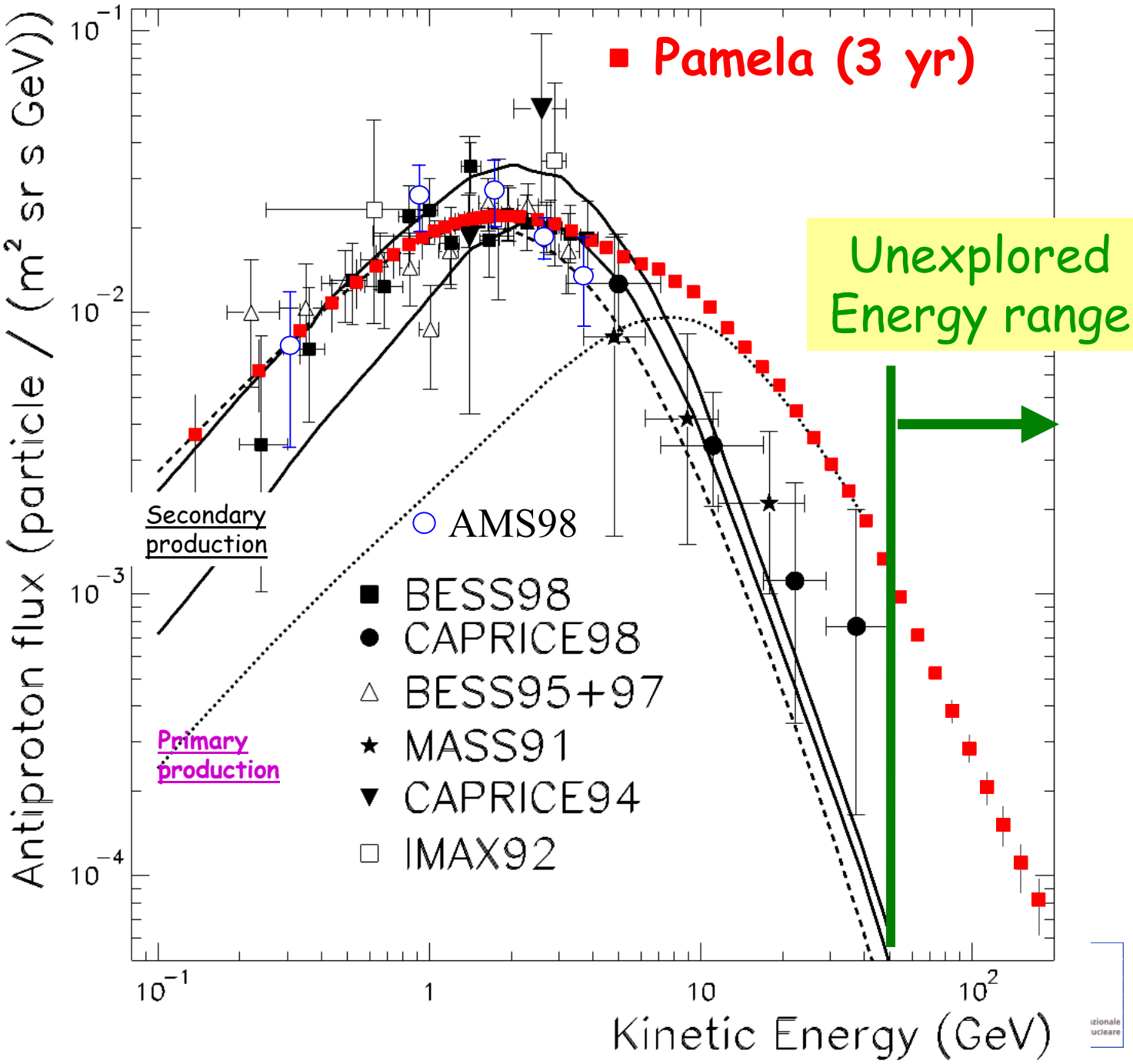
Cosmic Rays + ISM

(upper and lower limits, Simon et al.)

Primary production:

from $\chi\ \chi$ annihilation

($m(\chi)$ = 964 GeV)



PAMELA POSITRONS **expectation**

Secondary production

'Leaky box model'

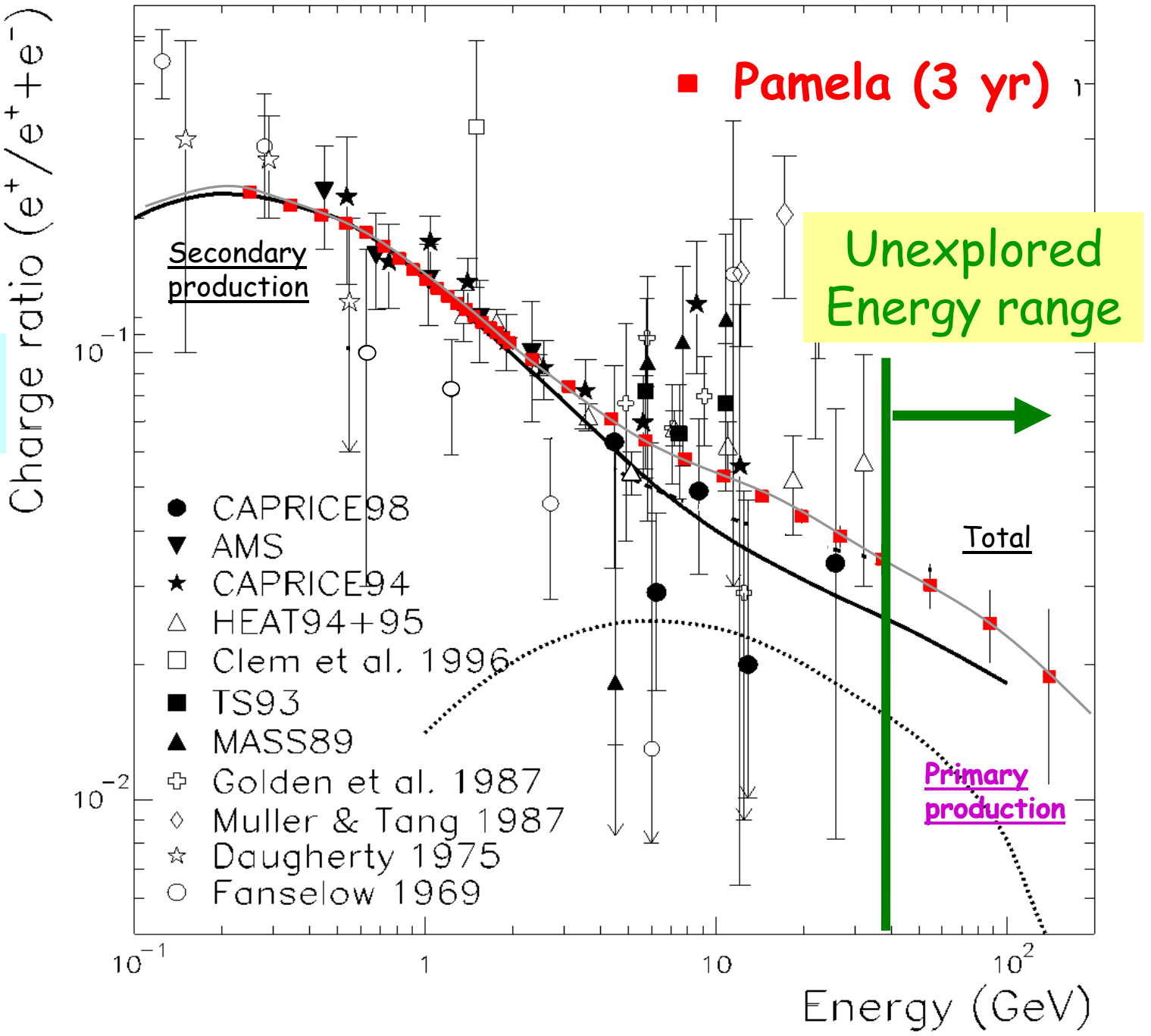
Secondary production

'Moskalenko + Strong model' without reacceleration

Primary production

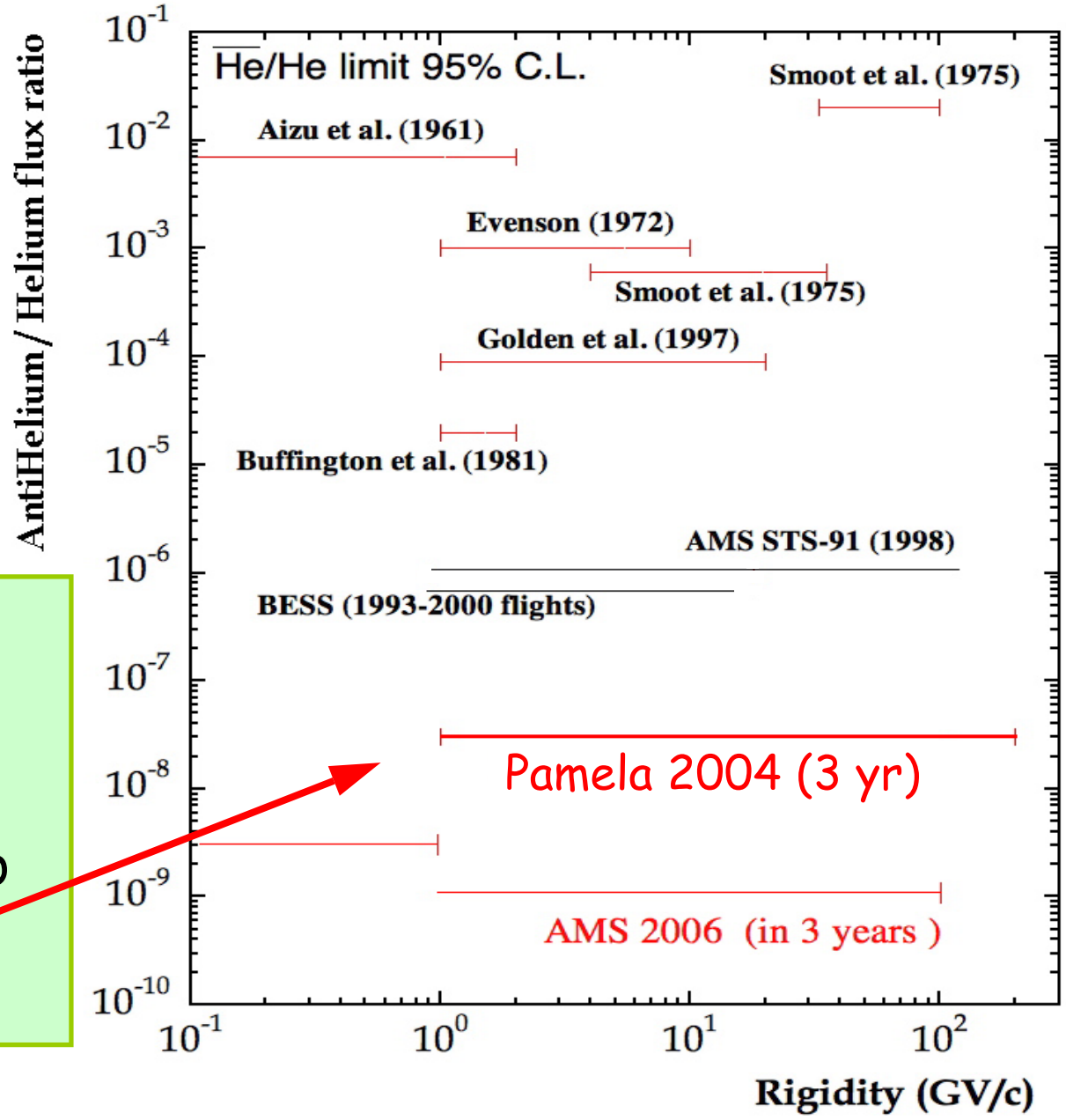
from $\chi\,\chi$ annihilation

(m(χ) = 336 GeV)

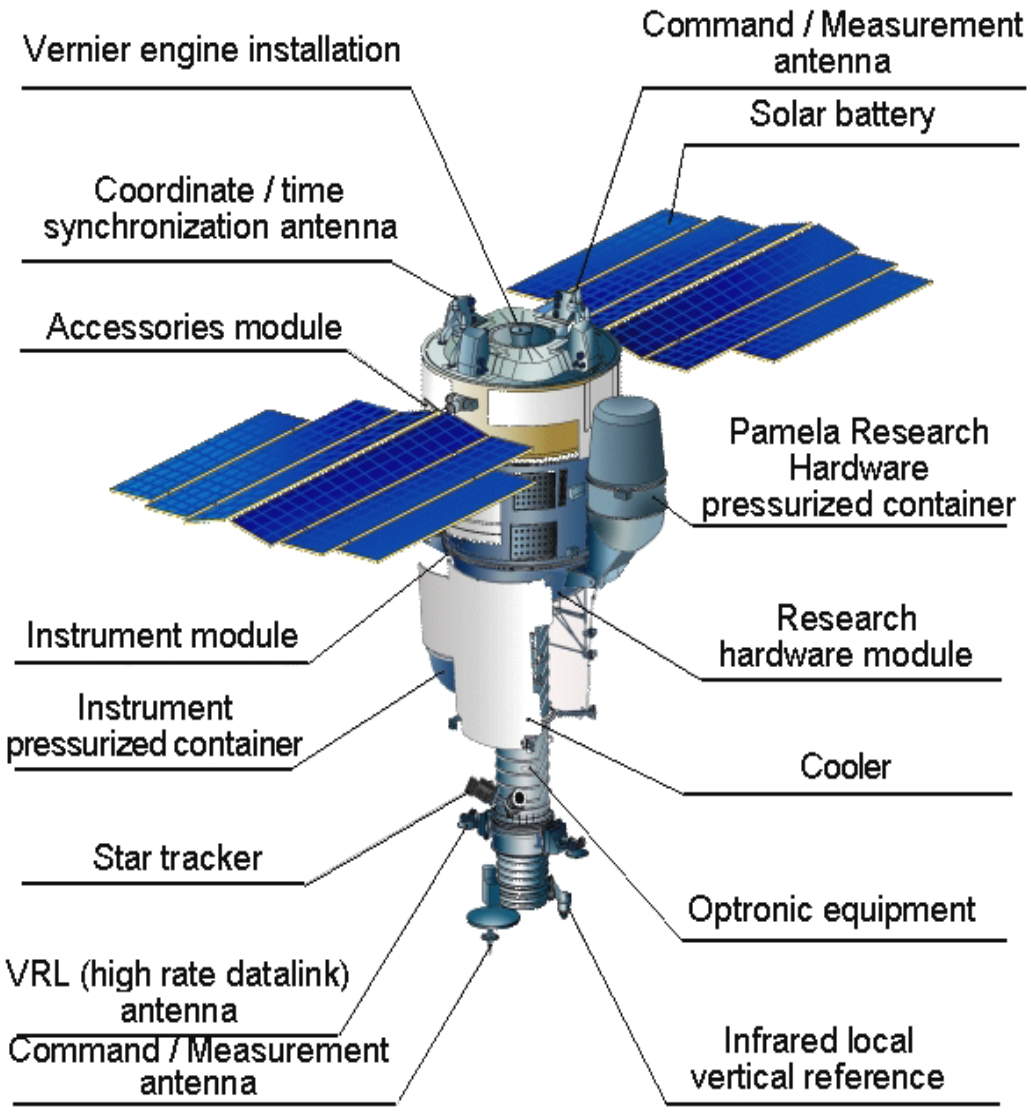


AntiMatter Limits

- Search for Anti-Helium
- Sensitivity of better 10^{-7} in ratio $\overline{He}$ / He

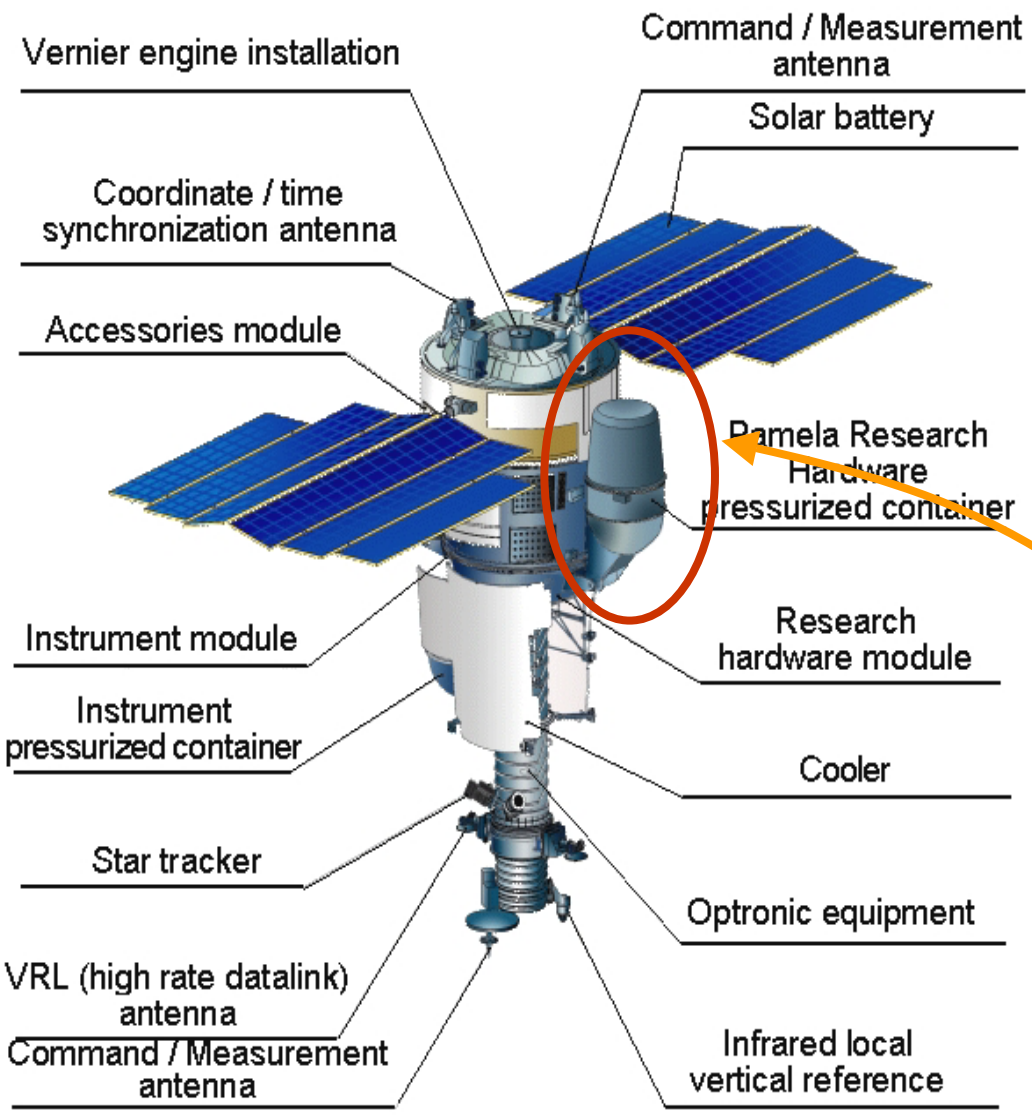


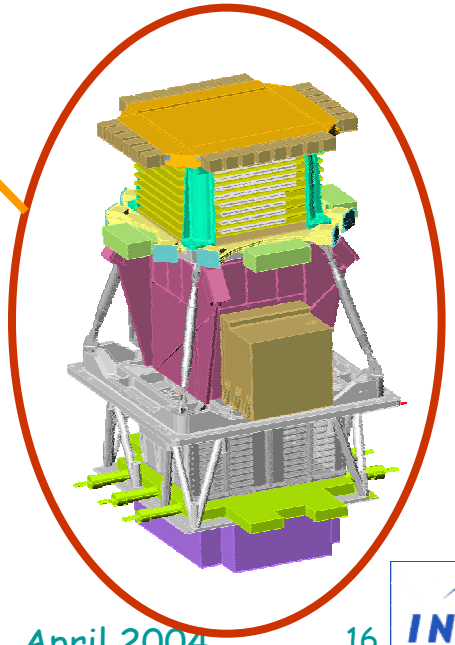
The Satellite: RESURS-DK1



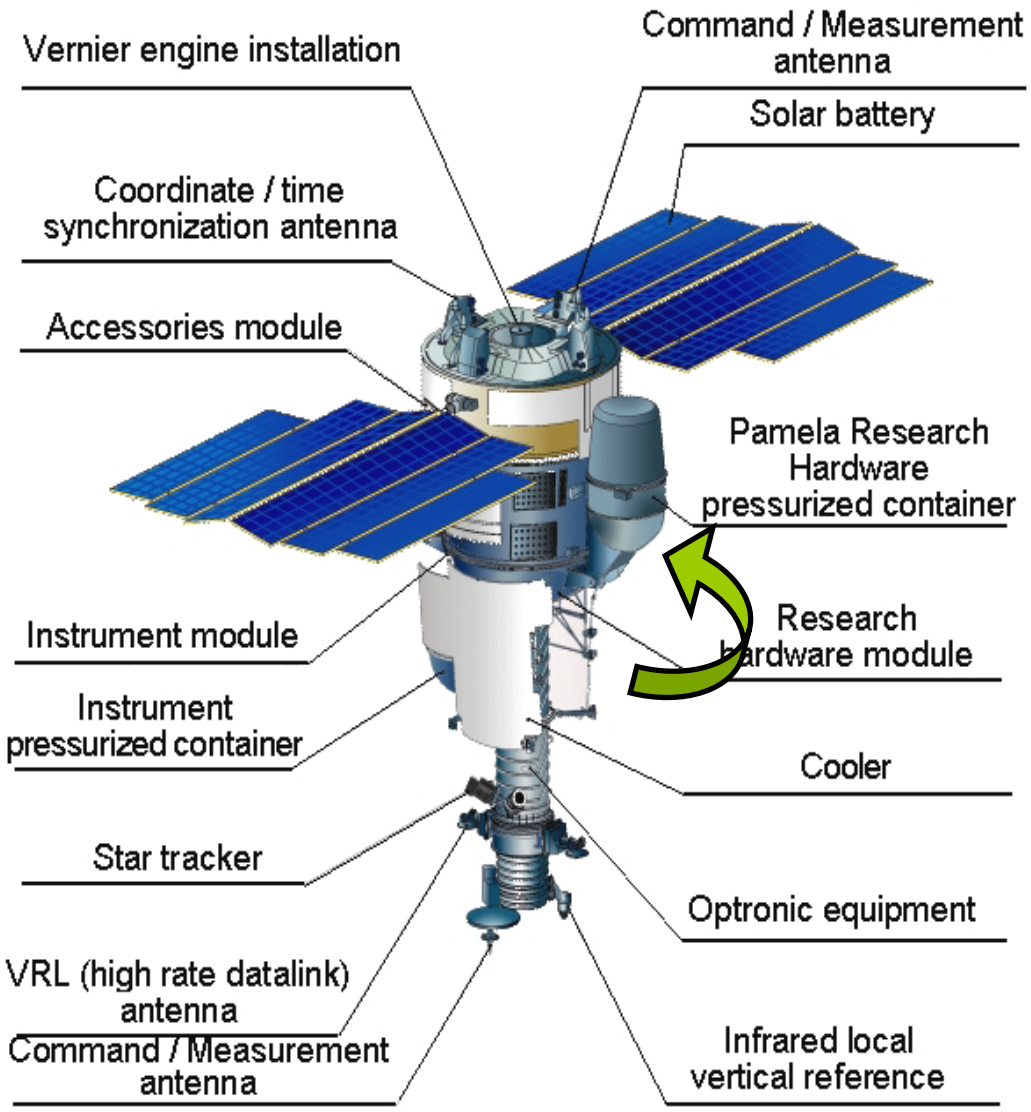
- Earth-Observation-Satellite
- Soyuz-TM Launcher from Baikonur
- Launch in 2004
- Lifetime >3 years
- PAMELA mounted inside a Pressurized Container, attached to Satellite

The Satellite: RESURS-DK1





The Satellite:
RESURS-DK1

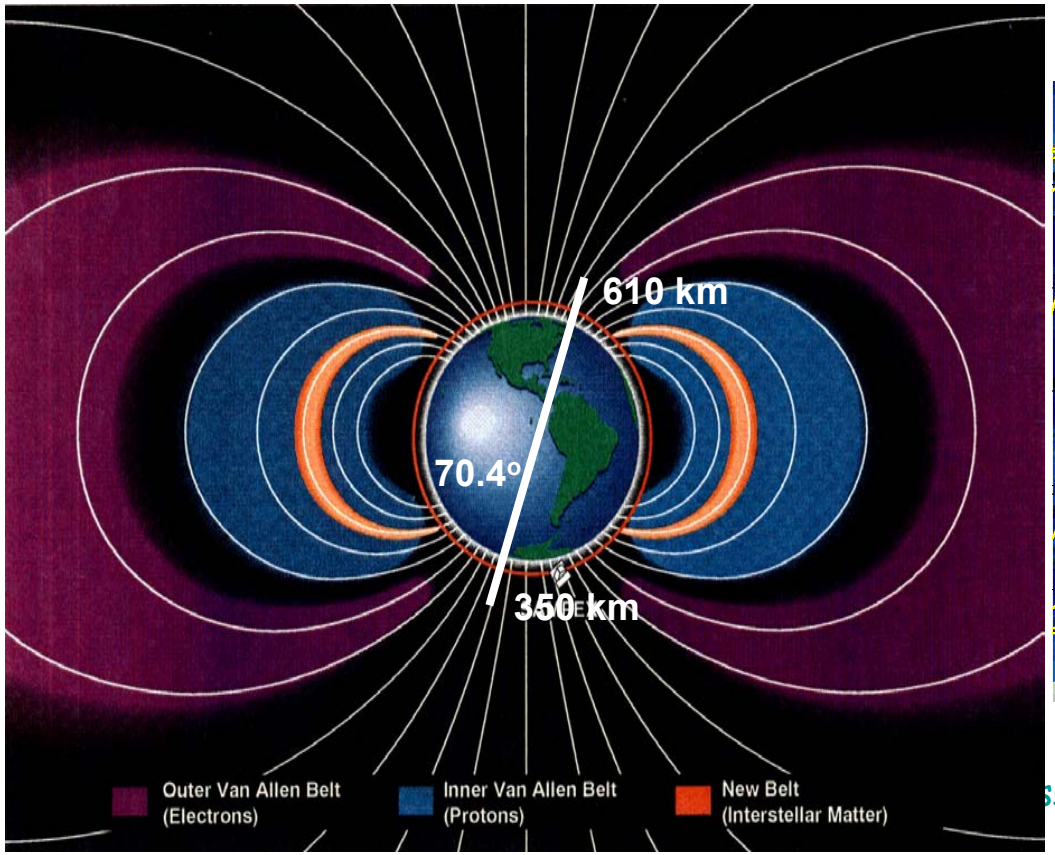


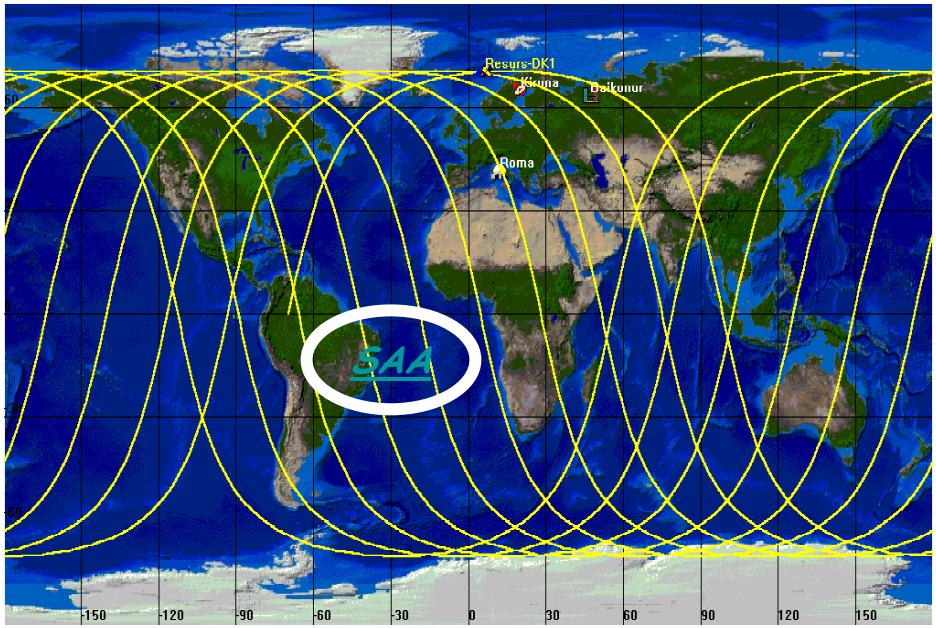
RESURS-DK1: Orbital Characteristics

Low-Earth-Orbit: Elliptical (*300-600 km*) & Quasi-Polar (70.4°)

→Sensitivity to low energy CR spectrum (polar region)

Orbit duration ~90 min.

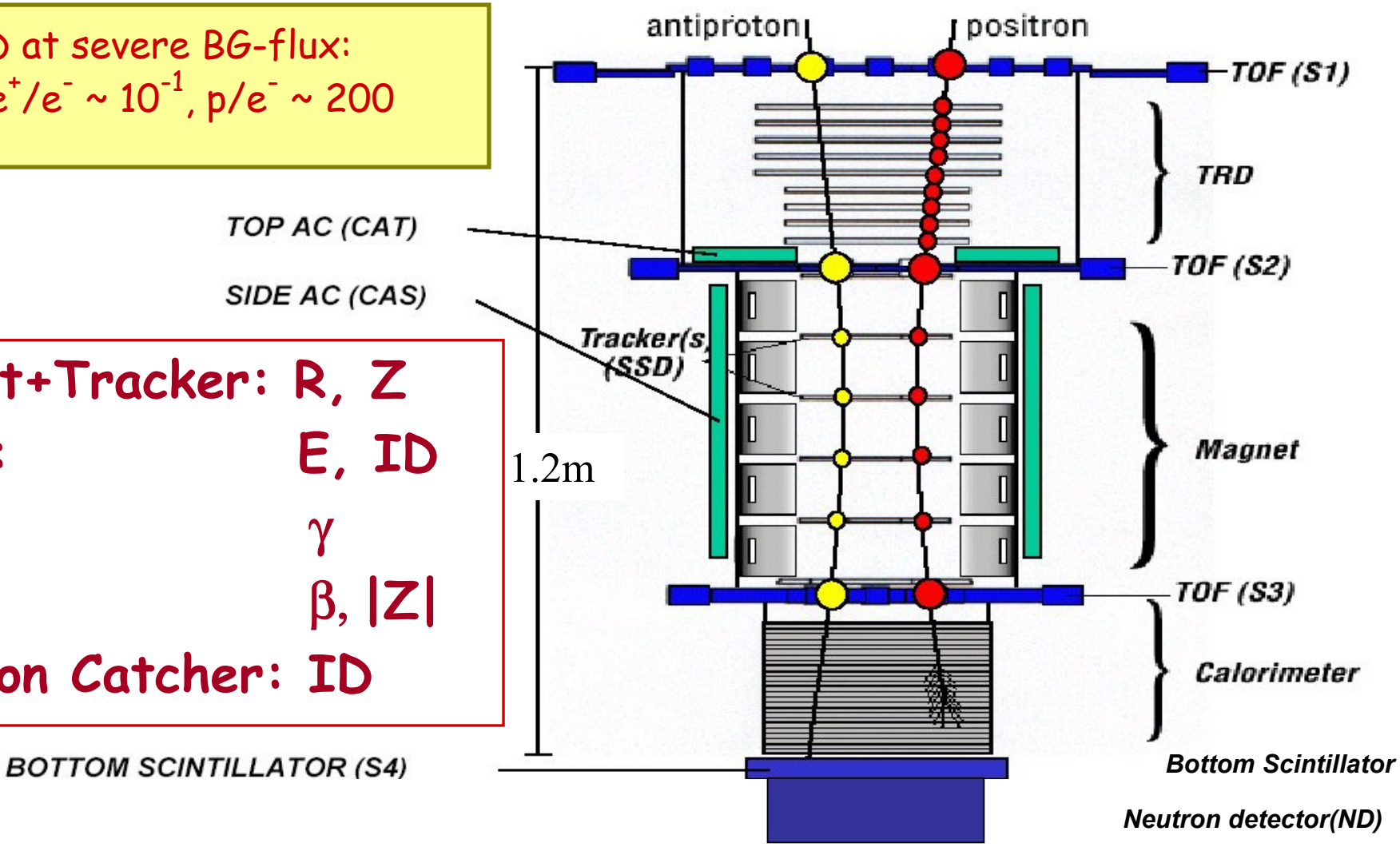




PAMELA: e^+ and $\bar{p}$ detection

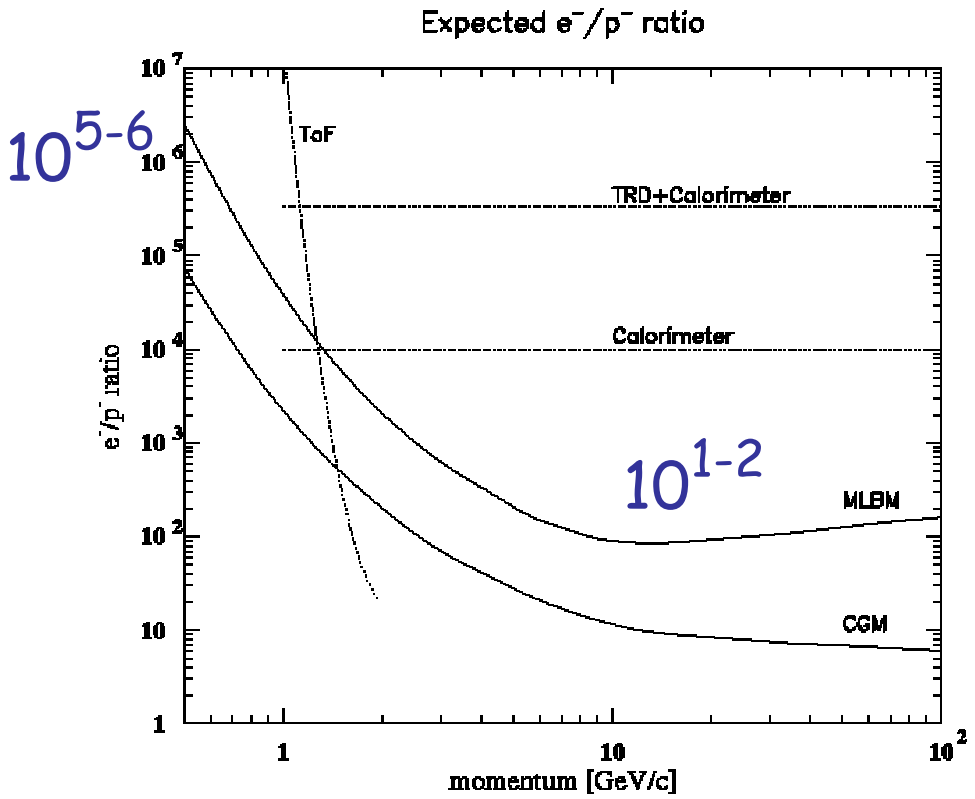
Particle ID at severe BG-flux:
$\bar{p}/p \sim 10^{-4}$, $e^+/e^- \sim 10^{-1}$, $p/e^- \sim 200$

- Magnet+Tracker: R, Z
- CALO: E, ID
- TRD: γ
- TOF: β, $|Z|$
- Neutron Catcher: ID



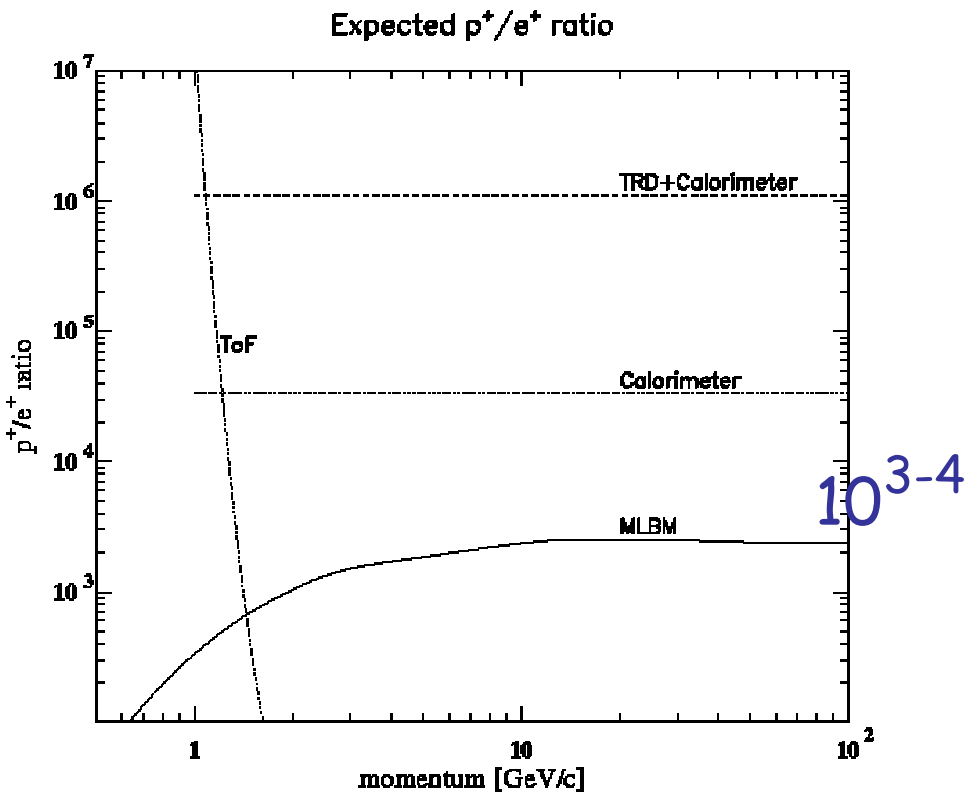
e^-/p^- and p/e^+ - Ratios

Pamela Proposal, 1997



10^{5-6}

10^{1-2}

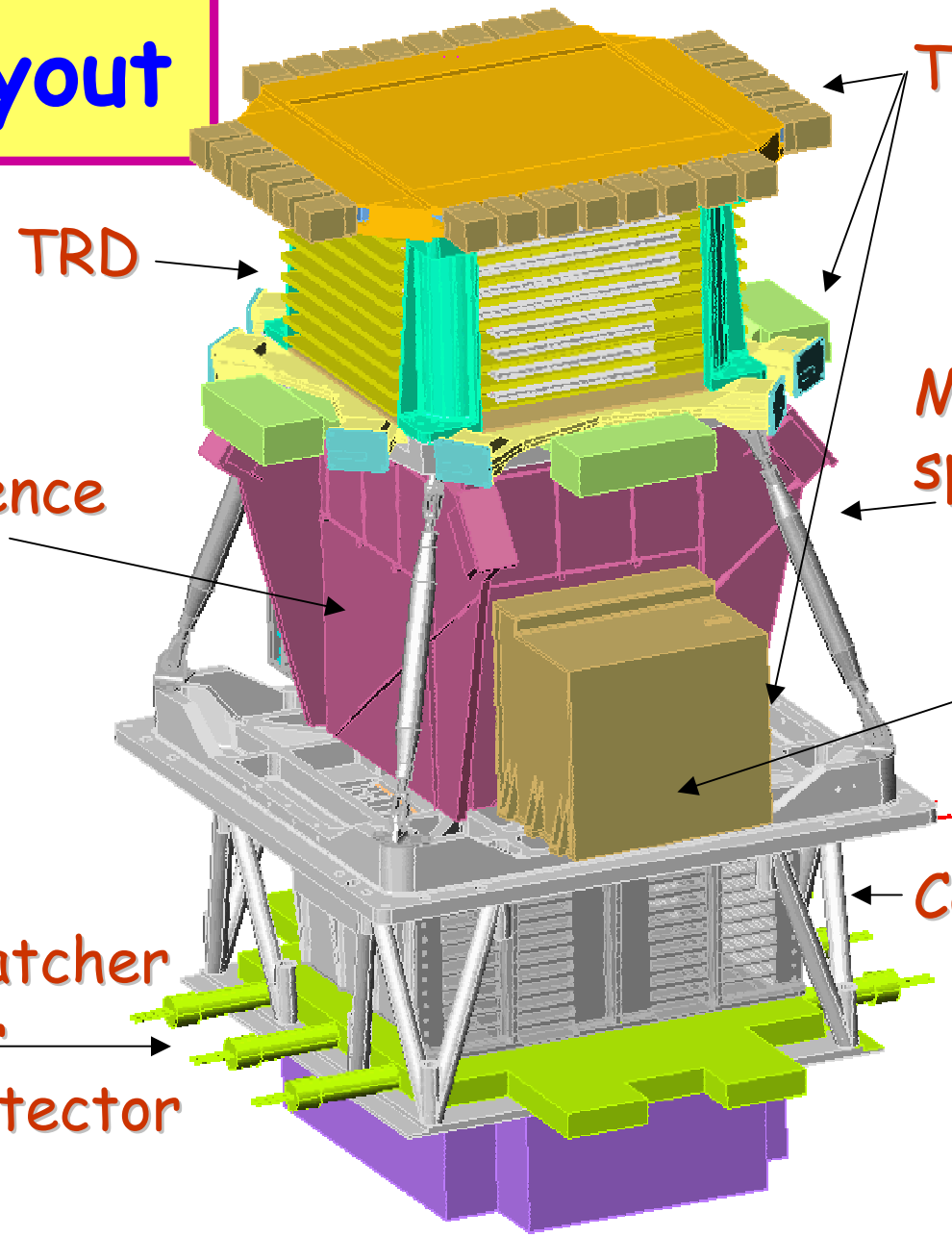


10^{3-4}

LeakyBoxModel

PAMELA - Layout

- Power 350 W
- 450 kg total
- 1.3 m Height



... not shown: GasSystem, SlowControl, R/O-Boards, PowerSupply, ...

ITALY

- Sezione INFN and Physics Department of Bari University
- Sezione INFN and Physics Department of Florence Universitiy
- Sezione INFN Roma II and Physics Department of Roma "Tor Vergata" University
- Sezione INFN and Physics Department of Trieste University
- Sezione INFN and Physics Department of Naples University
- INFN National Laboratories of Frascati
- IFAC - CNR Florence

USA

- NASA Goddard Space Flight Center
- Particle Astrophysics Laboratory, New Mexico State University, Las Cruces

RUSSIA

- Cosmic Rays Laboratory, Moscow Engineering and Physics Institute, Moscow
- Laboratory of Solar and Cosmic Ray Physics, P.N. Lebedev Physical Institute Academy of Sciences of Russia
- Ioffe Institute, St. Petersburg

GERMANY

- Physics Department of Siegen University

SWEDEN

- Royal Institute of Technology, Stockholm

INDIA

- Tata Institute of Fundamental Research, Bombay

Institutions

see: http://wizard.roma2.infn.it/pamela

RESPONSIBILITIES

Principal Investigator: Piergiorgio Picozza

Co-Principal Investigator: Arkady Galper

Scientific Coordinator: Piero Spillantini

Technical Coordinator: Guido Castellini

Program Committee: Per Carlson (Sweden), Arkady Galper (Russia), Joh Mitchell (USA), Manfred Simon (Germany), Piergiorgio Picozza (Italy)

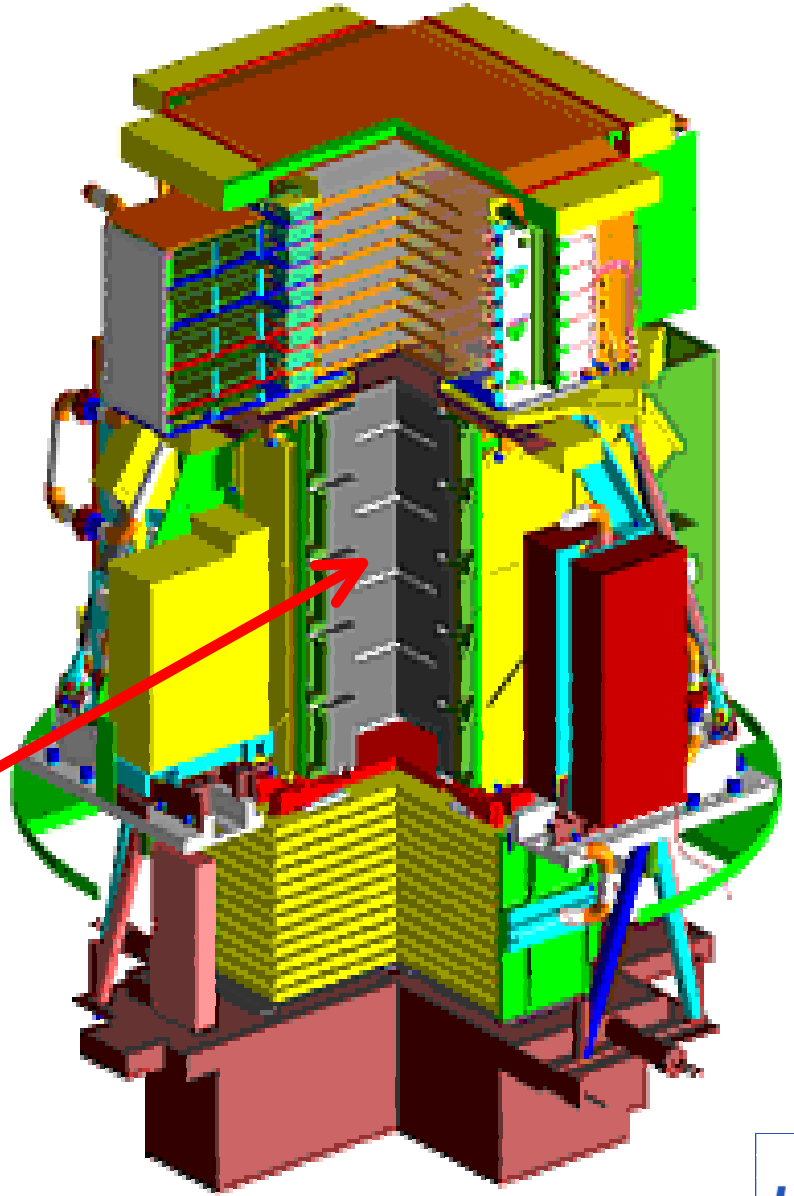
Scientific Committee: Arkady Galper (Chairman, Russia); Giancarlo Barb (Italy), Eduard Bogomolov (Russia), Per Carlson (Sweden), Carlo De Mar Maria Pia De Pascale (Italy), Marco Ricci (Italy), Manfred Simon (Germa Piergiorgio Picozza (Italy), Piero Spillantini (Italy), Alfred Stephens (Indi Stochaj (USA), Yuri Stozhkov (Russia), Robert Streitmatter (USA), Andre (Italy)

RESPONSIBLES FOR SUBSYSTEMS

Responsibilities

- TOF: G.Barbarino (Naples)
- TRIGGER: Manfred Simon (Germany)
- TRD: Francesco Cafagna (Bari)
- MAGNET: Paolo Papini (Florence)
- TRACKER: Oscar Adriani (Florence)
- CALORIMETER: Valter Bonvicini (Trieste)
- BOTTOM SCINTILLATOR: Sergej Voronov (Mephi)
- NEUTRON COUNTER: Yuri Stozhkov (Lebedev)
- ANTICOINCIDENCE: Mark Pearce (Sweden)
- ON BOARD SCU: Ralf Wischnewski (Rome)
- EGSE: Sergej Voronov (Mephi)
- MGSE: Marco Ricci (Frascati)
- SYSTEM: Guido Castellini (Florence)
- SIMULATIONS: Francesco Cafagna (Bari)
- RESURS SATELLITE : Boris Abramov (Samara)

PAMELA – by Subsystems …



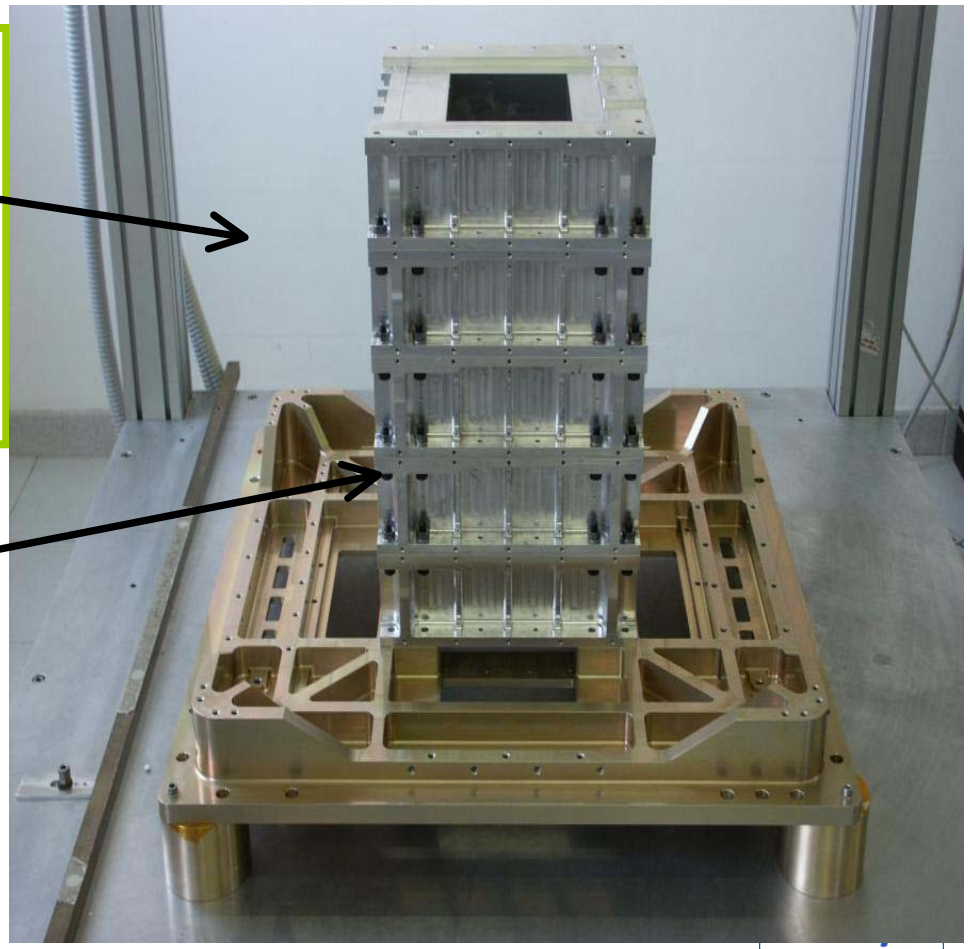
Magnetic Spectrometer

Spectrometer: Magnet

Permanent magnet:

- 5 Blocks of Nd-B-Fe Alloy
- 0.48 T at cavity center
- MagnetTower:
  13x16cm^2 x 44.5cm height

→ Geometric factor: 20.5 cm^2 sr



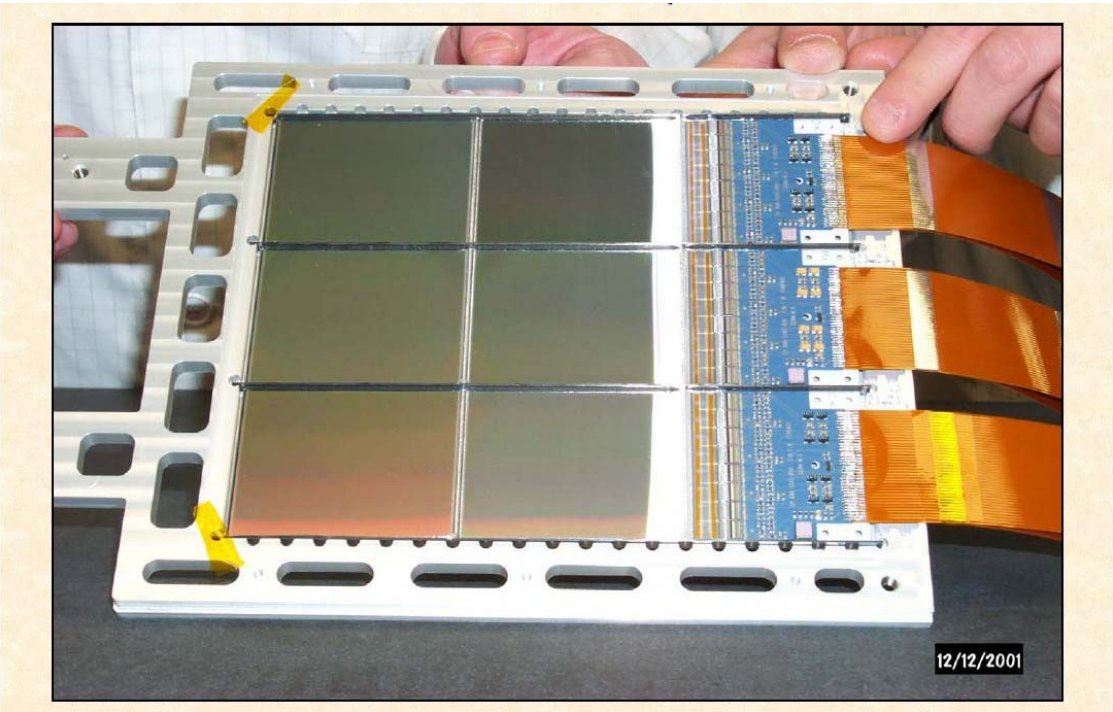
Tracking System:

- 6 layers Dubole sided Si-microstrips

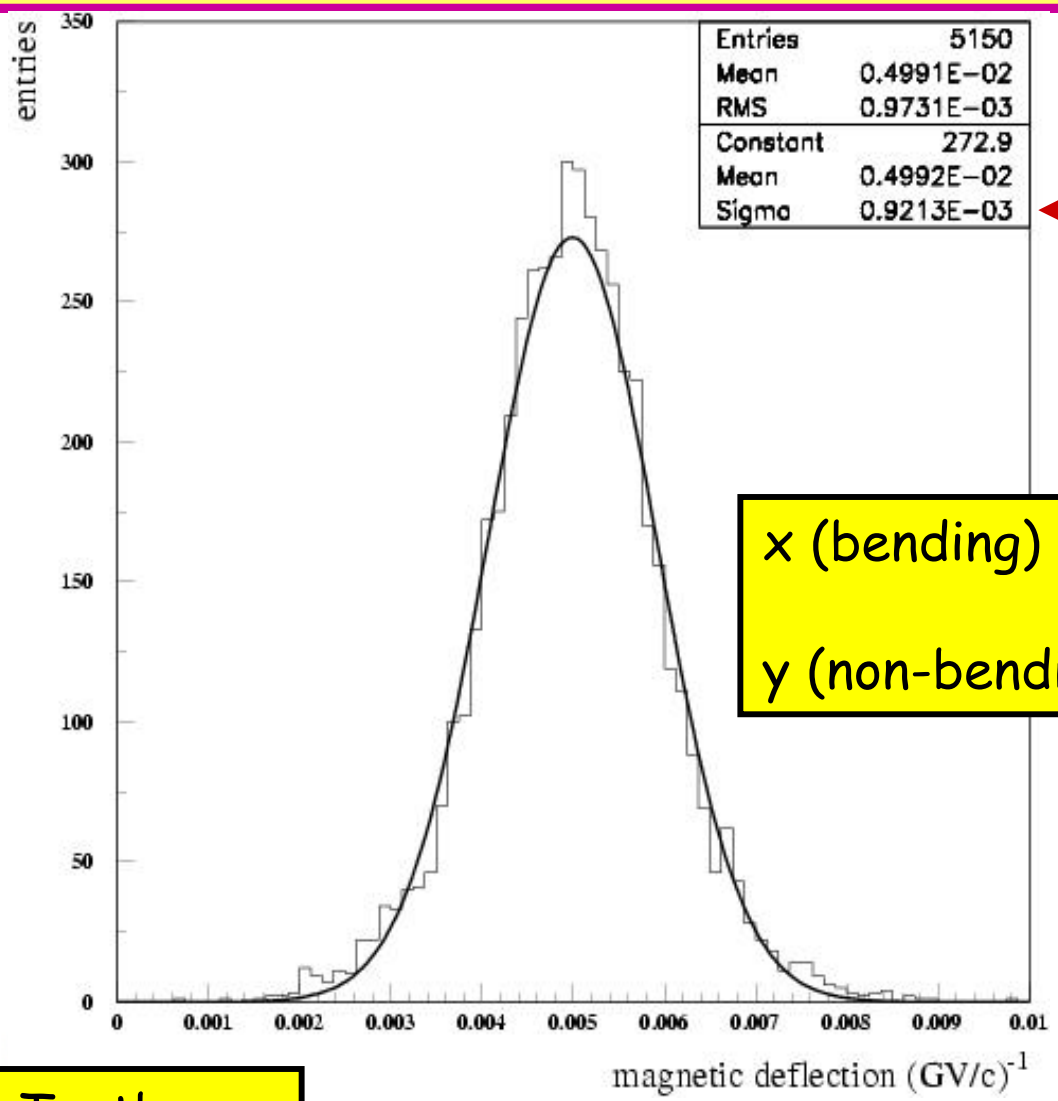
Spectrometer: Silicon Tracker

- 6 Floors of Double Sided Si-MicroStrip Det.
- X-Strip: 25 μm implantation pitch / junction
- Y-Strip: 67 μm pitch / ohmic side
- Readout Pitch: 50 μm in X/Y, d=300 μm.

- 36864 Channels
- VLSI-VA1 Chip
- 55 W total



Spectrometer: Resolution



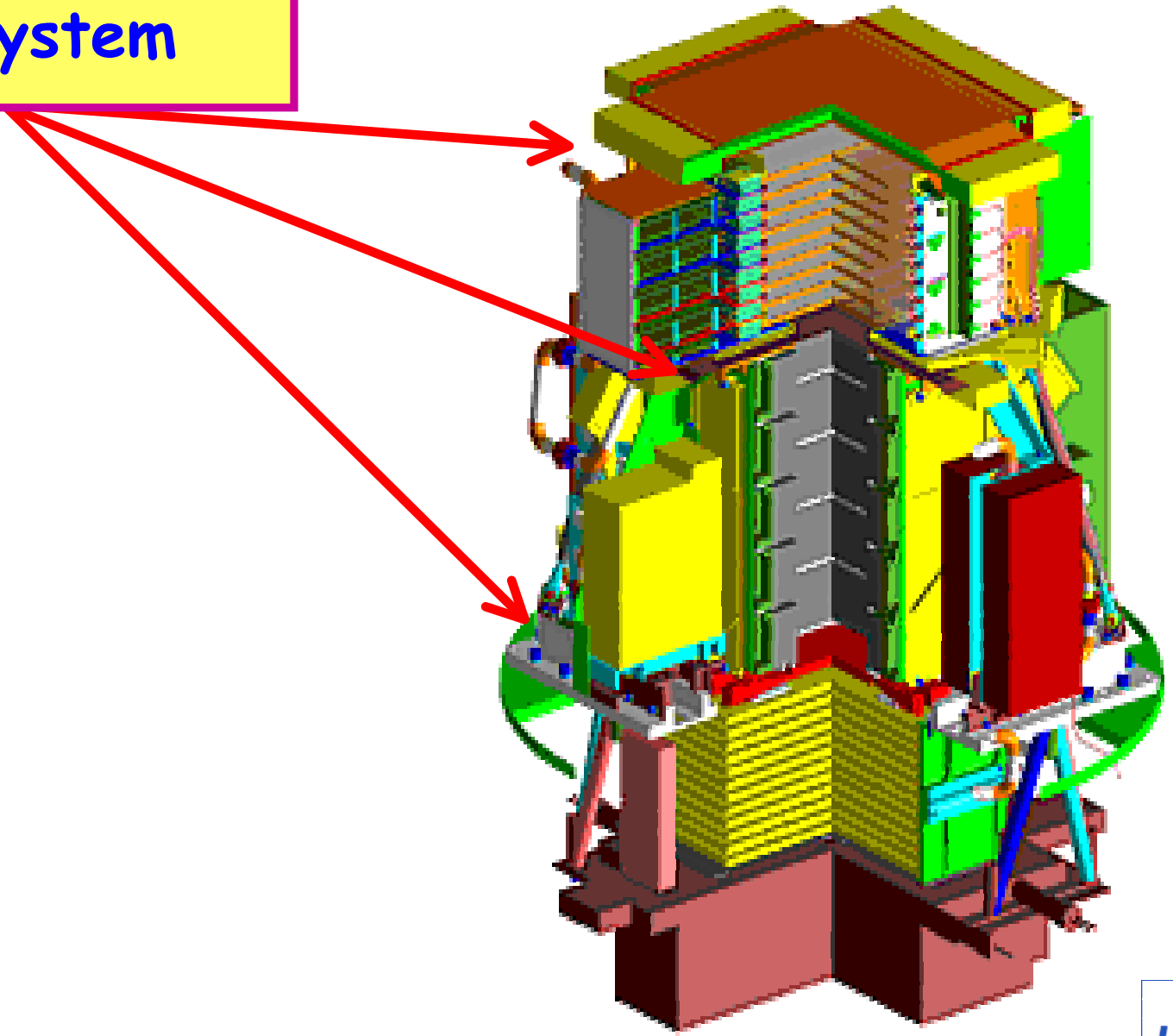
MaxRigidity
≅1080 GV (Δp/p = 1)
→ $\overline{p}$ separation up to >190 GeV
(proton-spillover)

x (bending) resolution = 2.7μm

y (non-bending) resolution = 12μm

SPS Testbeam
p 200 GeV/c

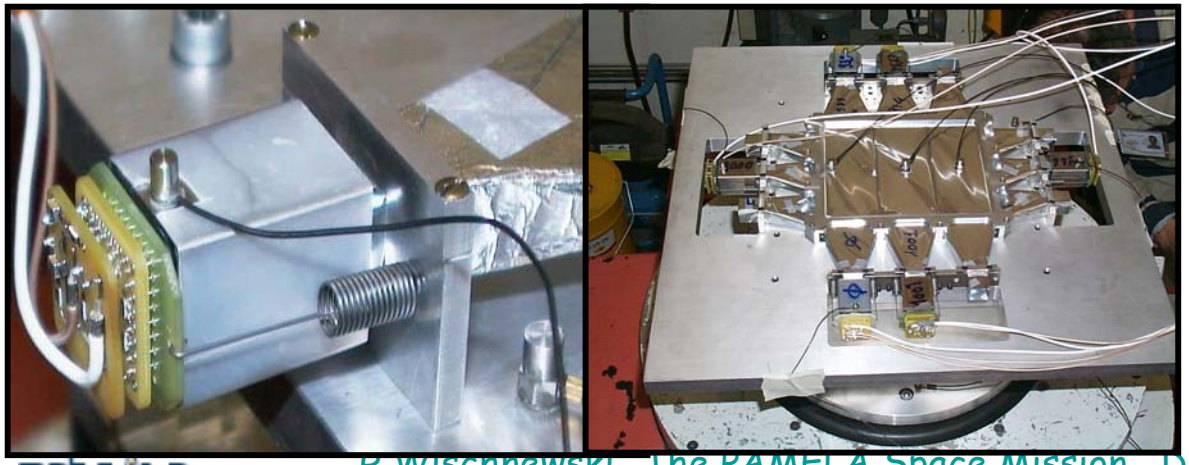
TOF - System

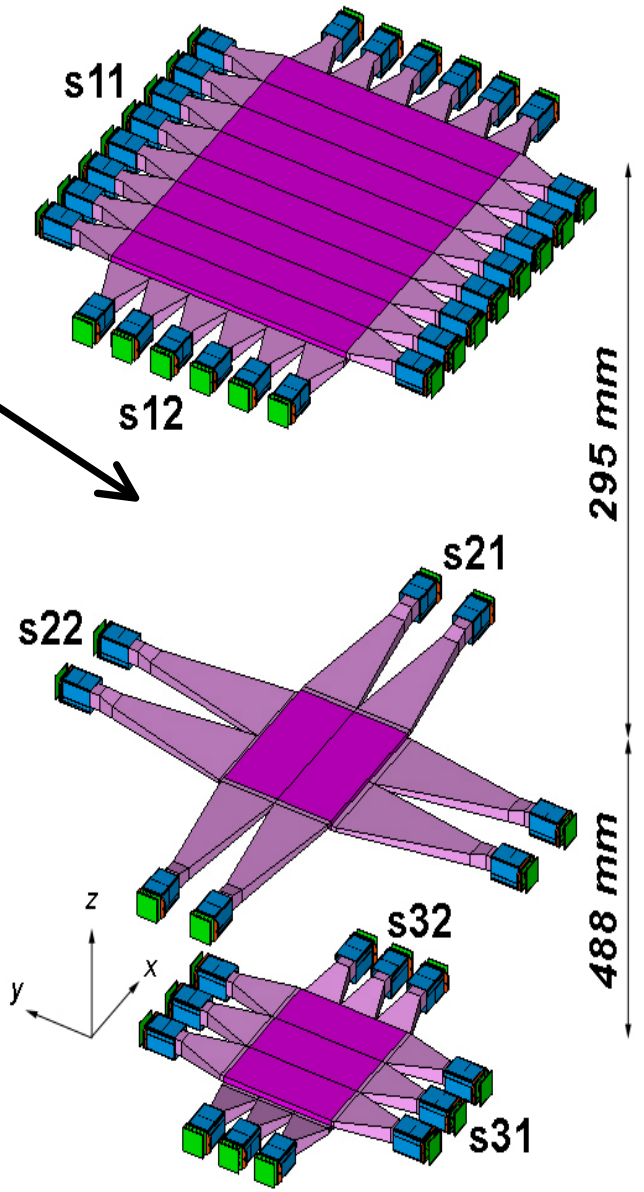


TOF System

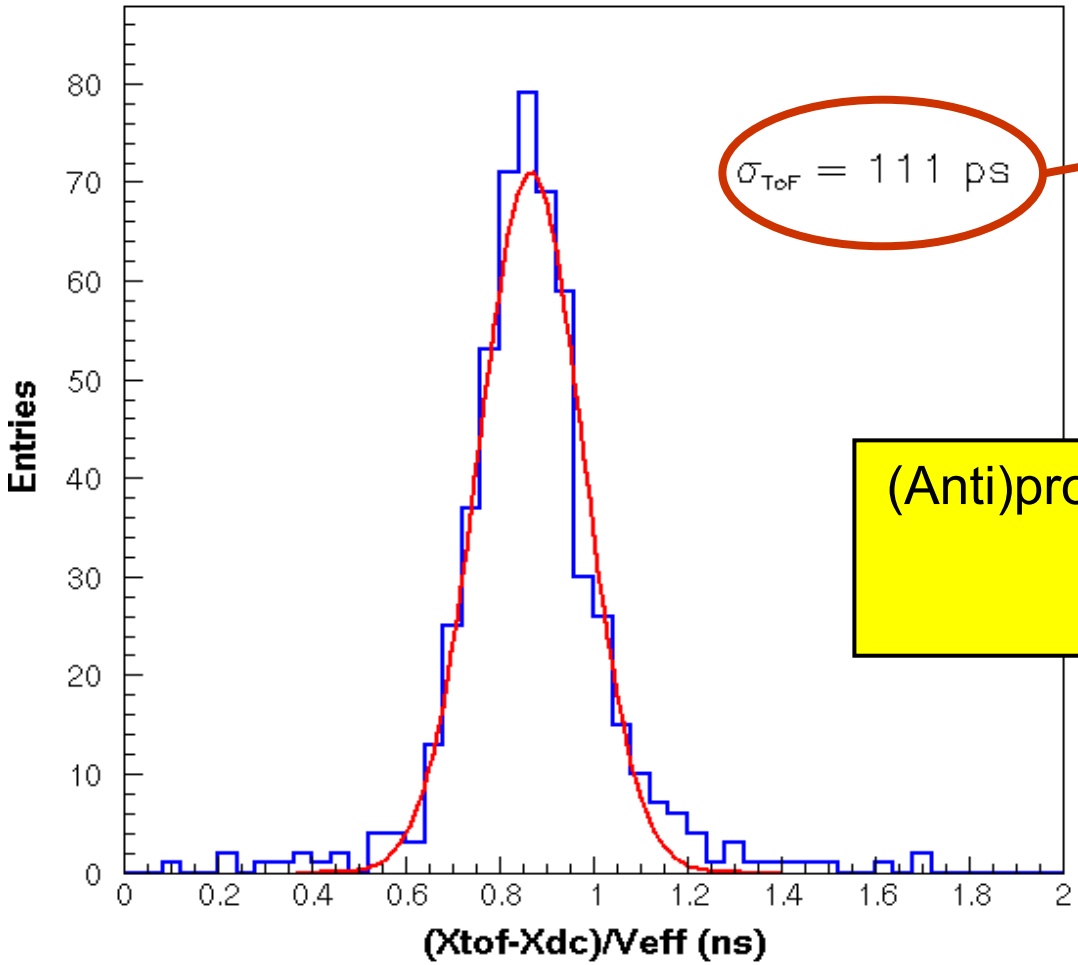
- 3 Planes of Scintillators S1, S2, S3
- Each plane: two segmented X- Y-layers
- Hamamatsu PMT R5900, 48 Channels

- **TRIGGER**: S1 x S2 x S3
- **TOF**: ParticleID / albedo rejection
- **dE/dx** measurements (charge)



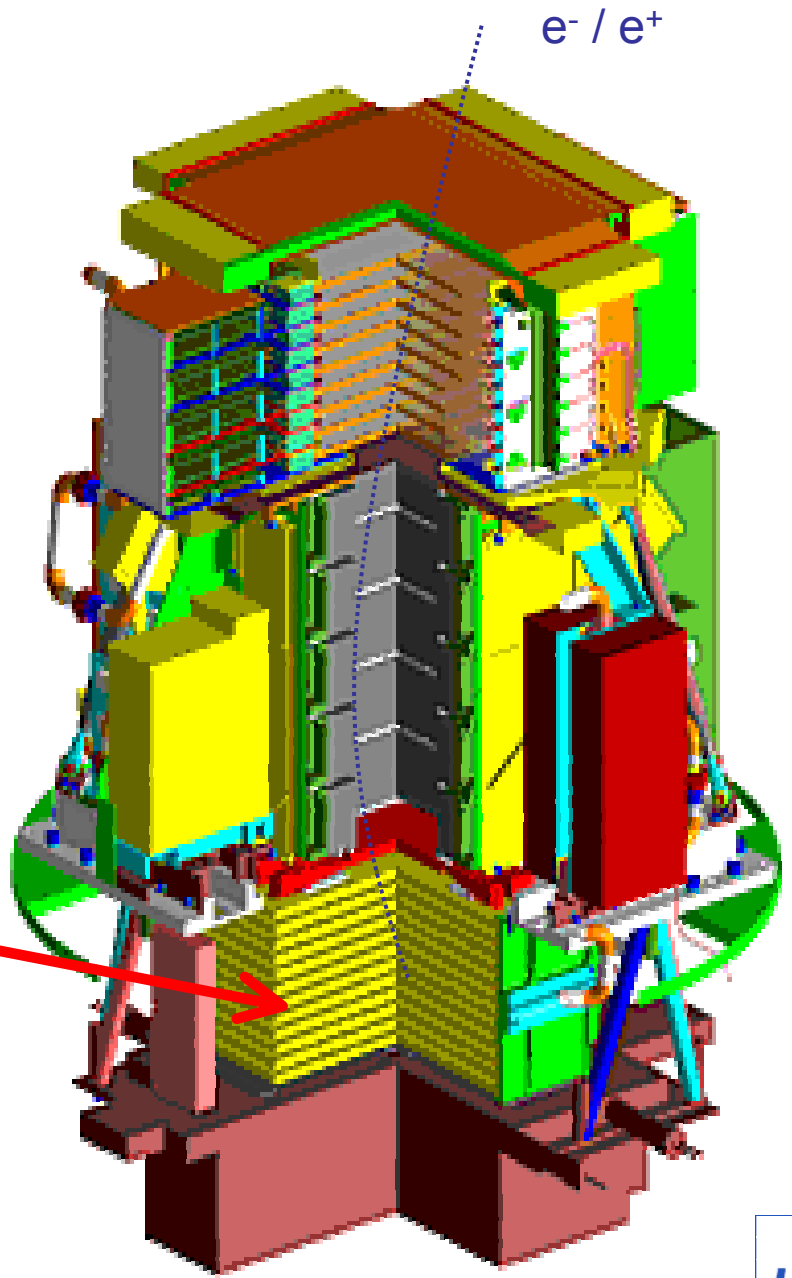


ToF : Time Resolution



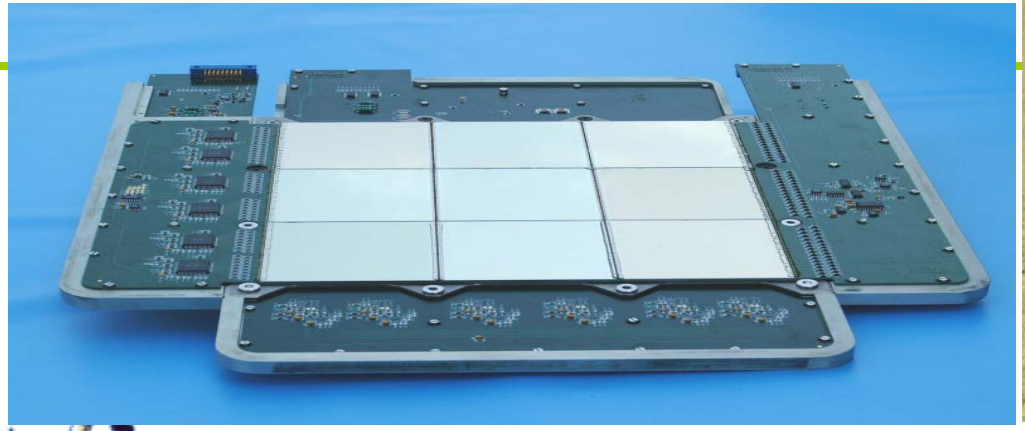
(Anti)proton/electron discrimination possible up to ~ 1.5 GeV/*c*

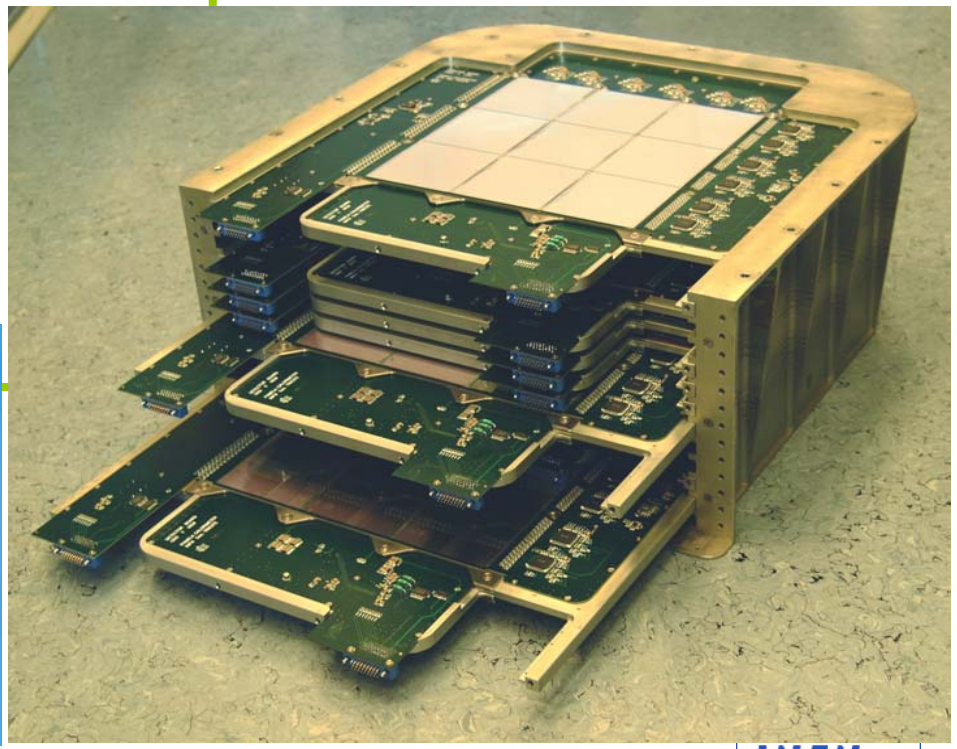
Imaging Calorimeter



Si-W Imaging Calorimeter

- **22 planes of Si (380μm) / Tungsten (2.6mm)**
  96 strips per plane (2.4mm pitch)
- **16.3 Rad.Length, 0.6 IntLength**
- 4224 channels
- Dyn.range 1400mip, Self-trigger option
  Pamela-ASIC CR1.4P



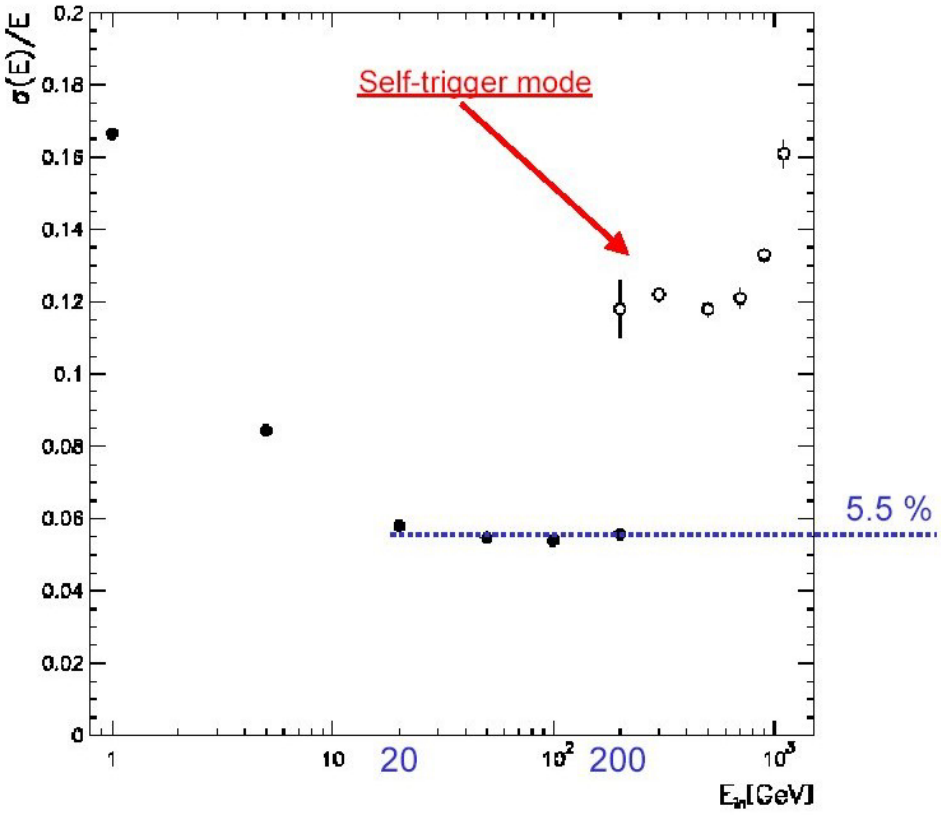


Imaging Calorimeter: Performance

- **Energy resolution** **~5 %** at 200GeV

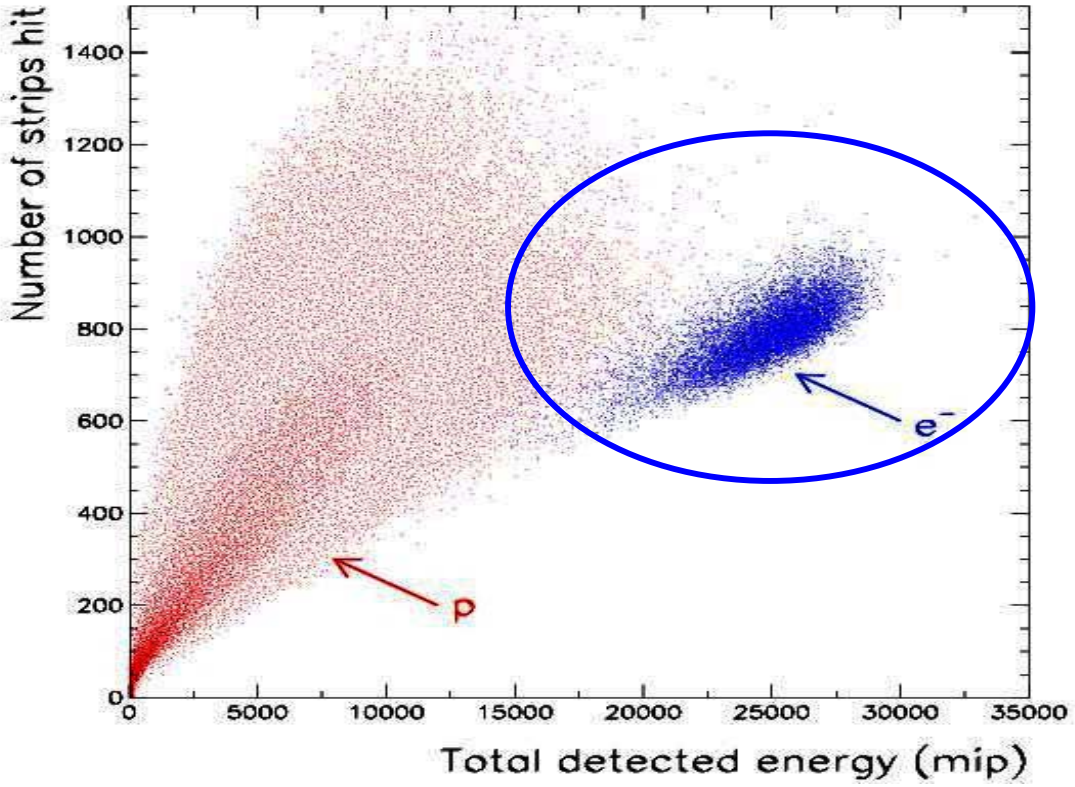
- **SelfTrigger mode**:

  >300 GeV at G.F. ~ 600cm^{2}sr (x 30)
  e^--identification up to 1-2TeV.



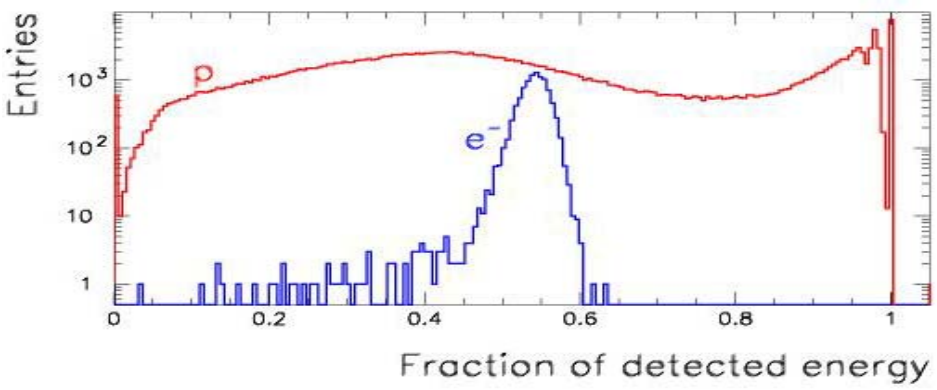
Calorimeter: Electron-Proton Separation

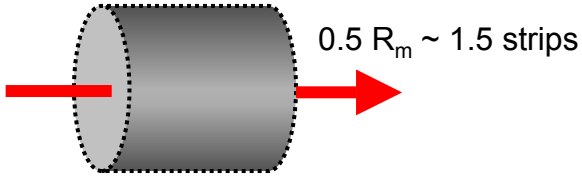
SPS Test Beam:
p & e^-
200 GeV/c



Calorimeter: Electron-Proton Separation

SPS Test Beam:
p & e^-
200 GeV

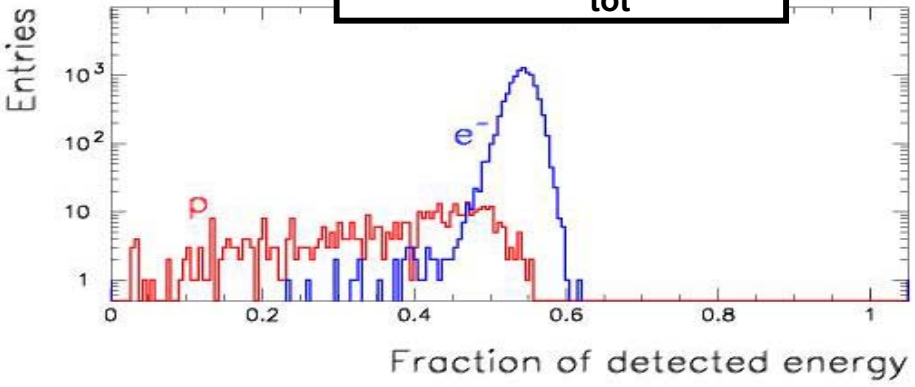




Energy fraction in cylinder around particle track

→ **Transversal shower profile**

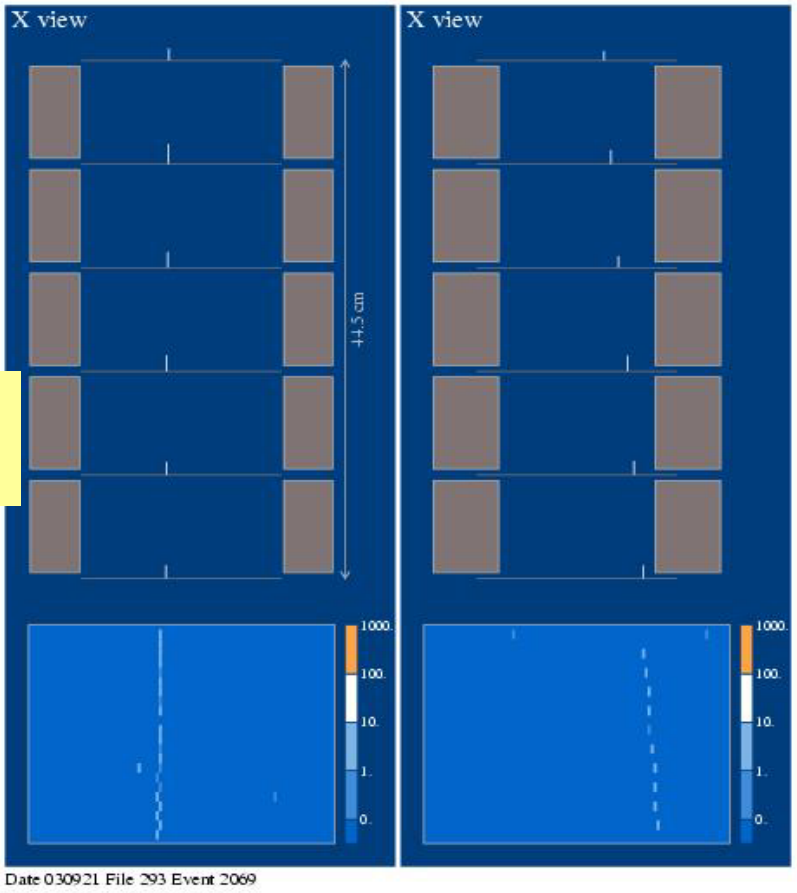
+ cut on E_{tot} ⇒

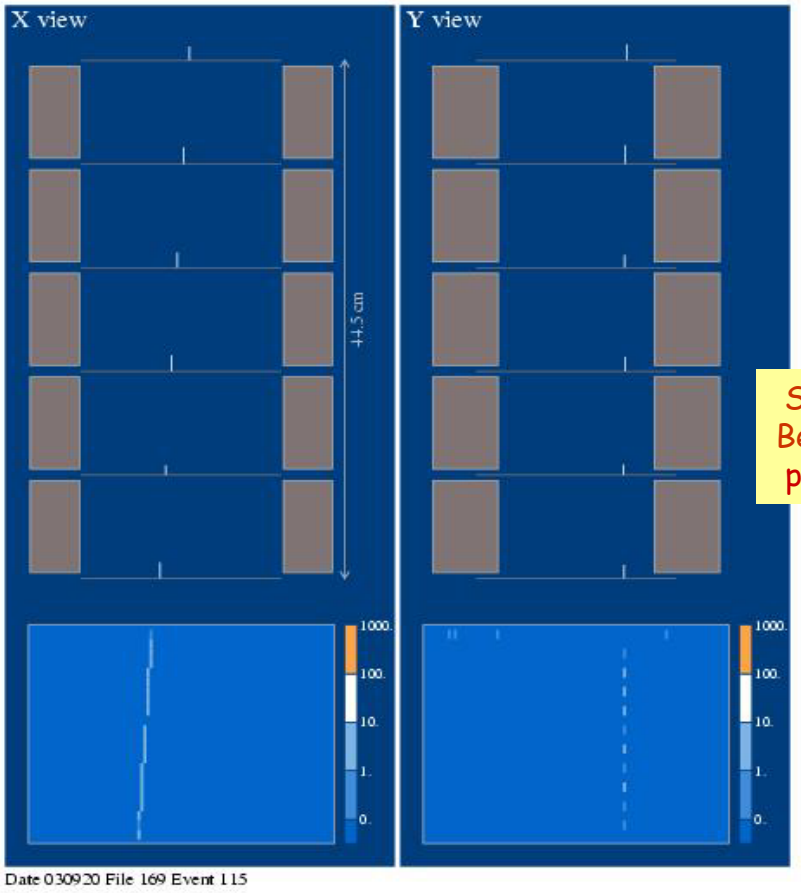


- **Proton rejection factor ~ $3x10^4$**
- **Electron selection efficieny 95%**

Tracker+Calorimeter Performances

SPS Test Beam : P 50 GeV/c

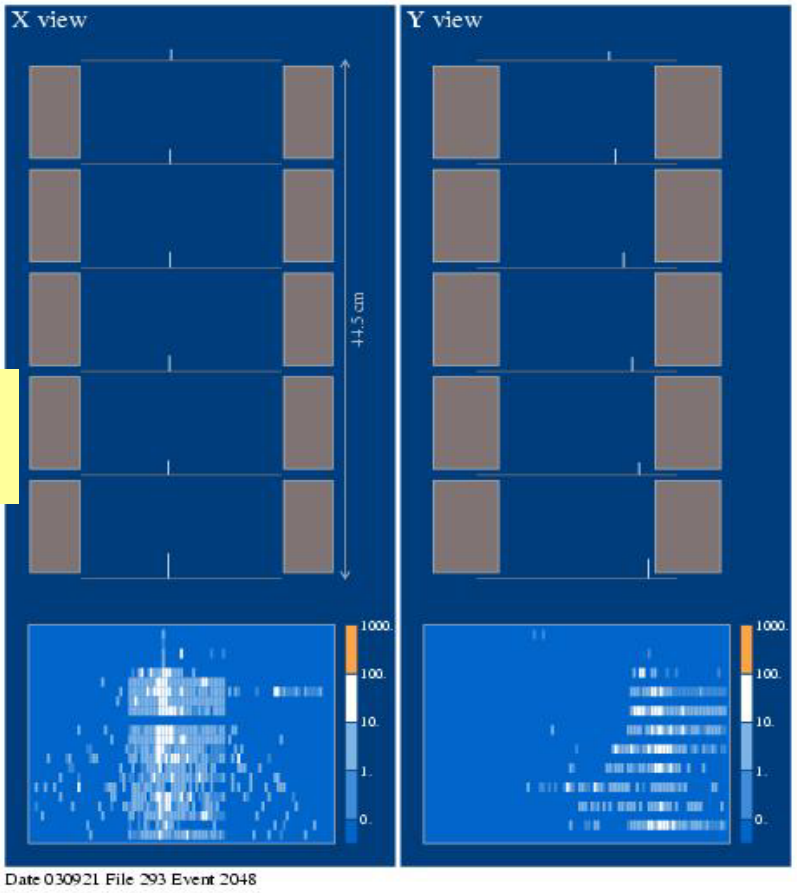


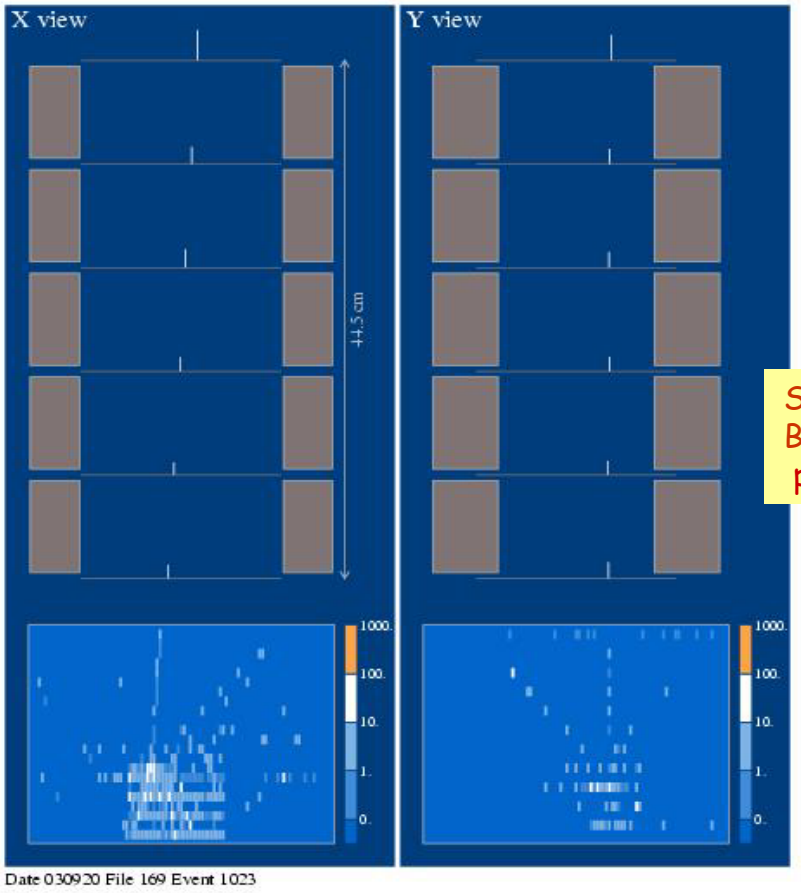


SPS Test Beam : p 100 GeV/c

Tracker+Calorimeter Performances

SPS Test Beam : P 50 GeV/c

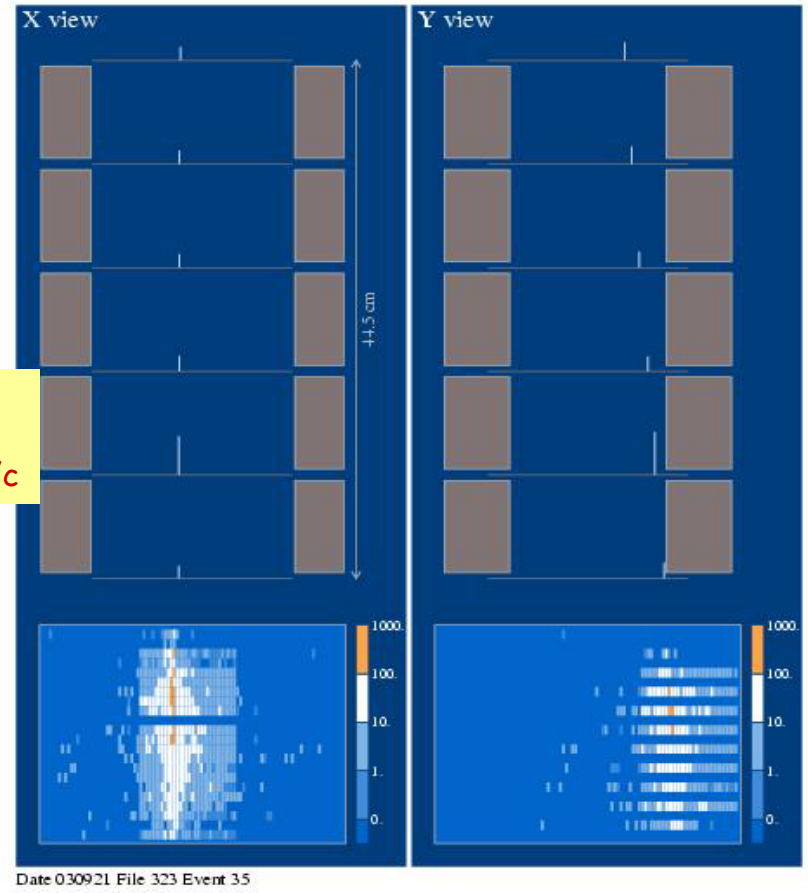


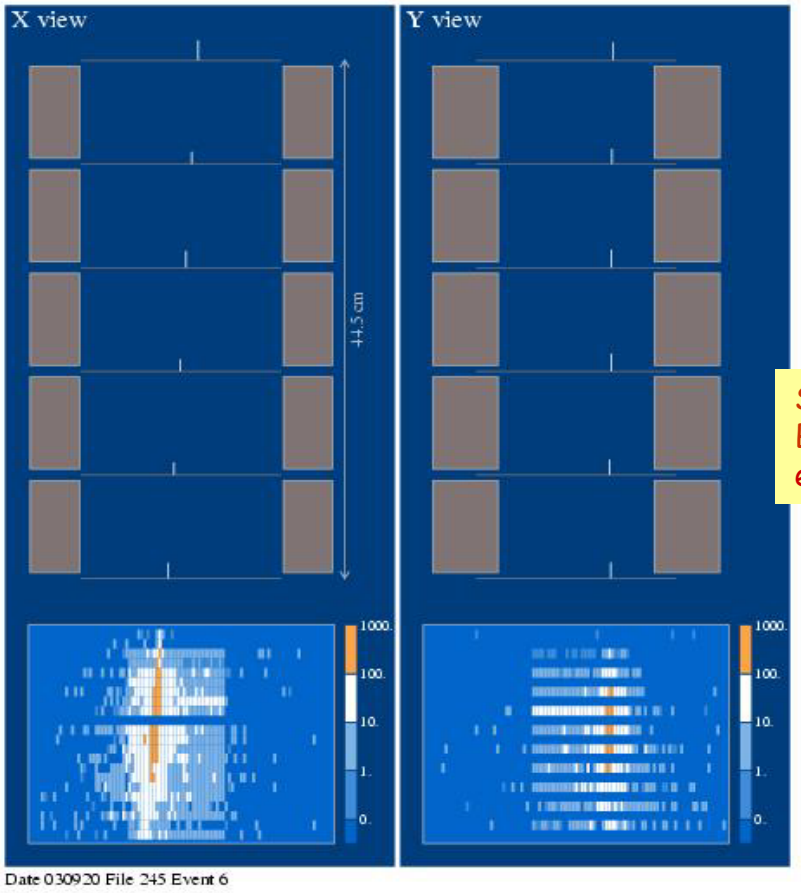


SPS Test Beam : p 100 GeV/c

Tracker+Calorimeter Performances

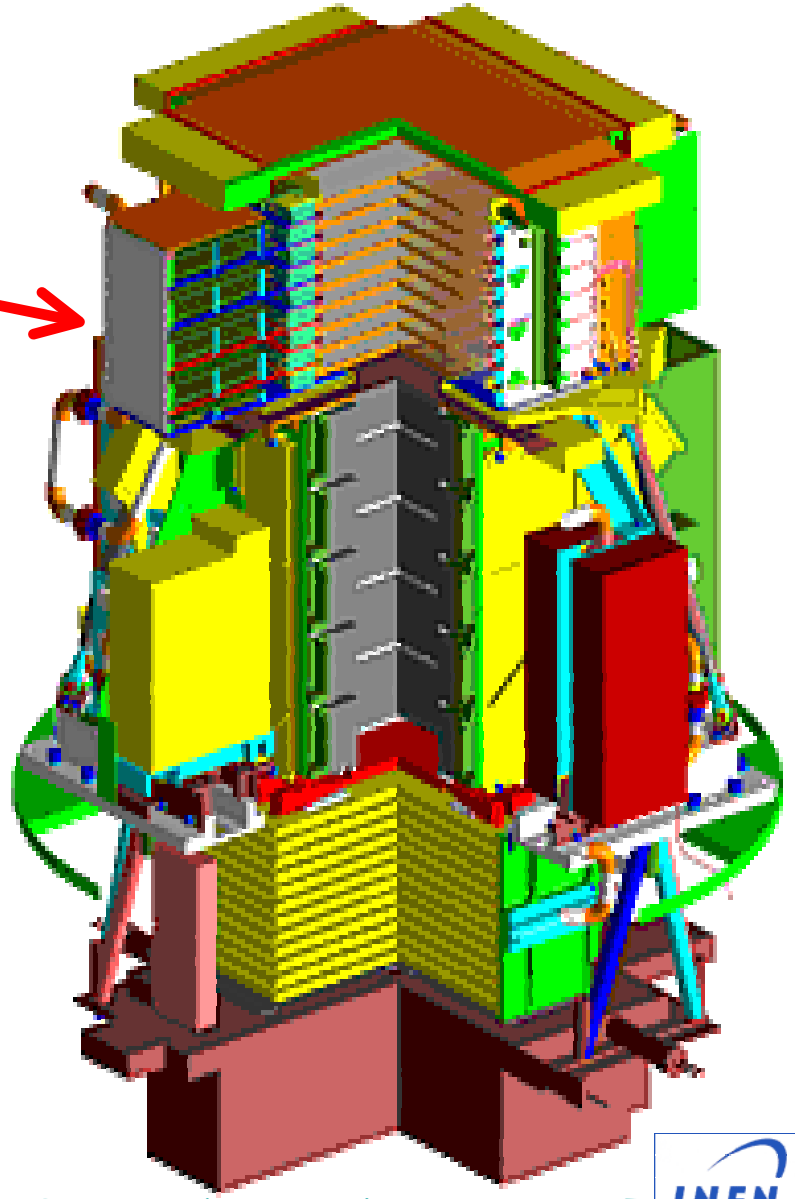
SPS Test Beam : e^- 50 GeV/c





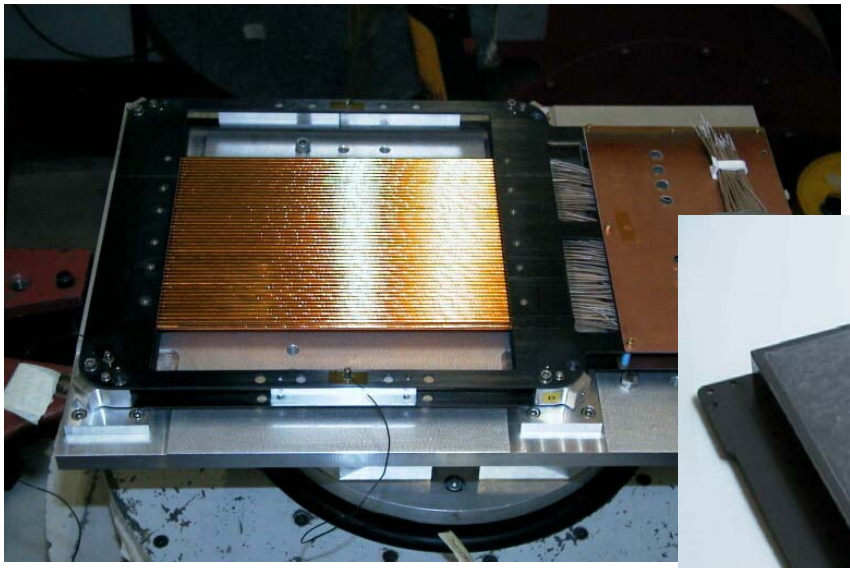
SPS Test Beam : e^- 100 GeV/c

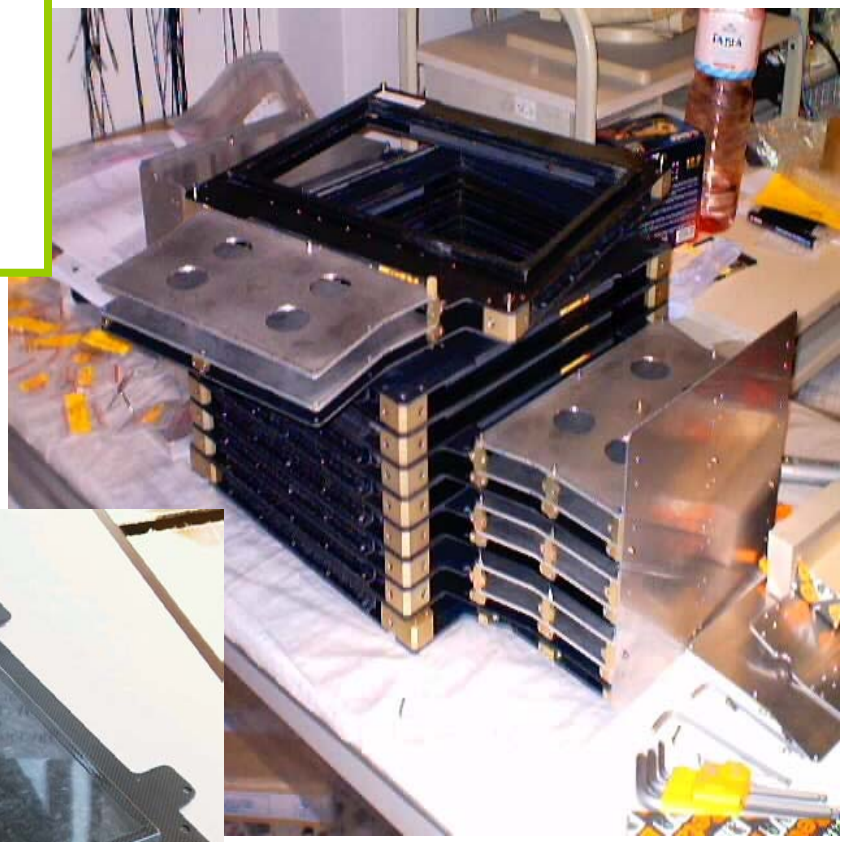
Transition Radiation Detector



Transition Radiation Detector

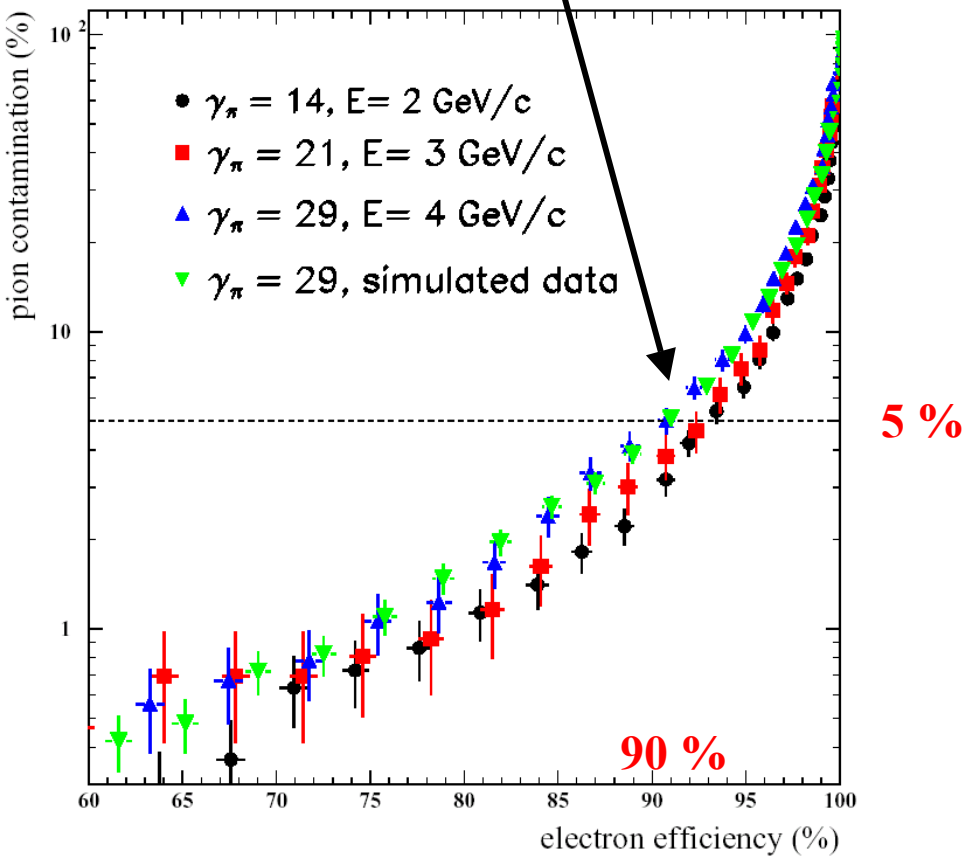
- 9 planes of 1024 straw tubes (28cmx4mm)
  → crude tracking
- HV 1400 V; Gas Xe/CO_2 ~ 80/20%
- Radiator: Carbon fibre (60g/l)



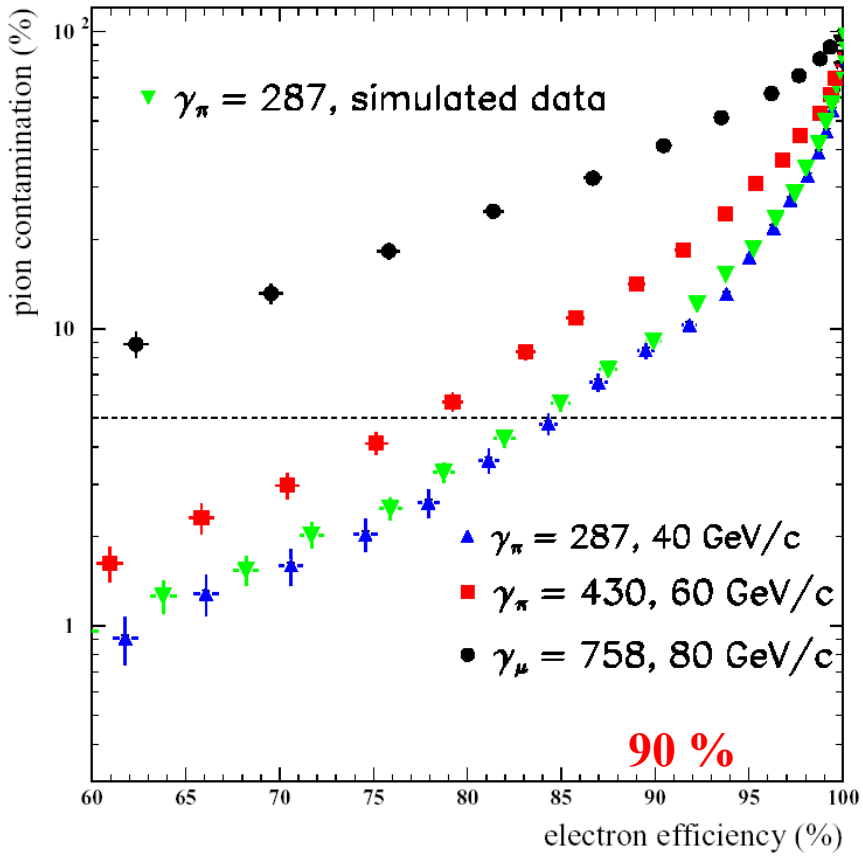


TRD Performance

Design goal: 5% hadron contamination @ 90% electron-efficiency



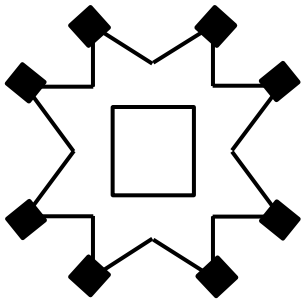
[CERN PS]



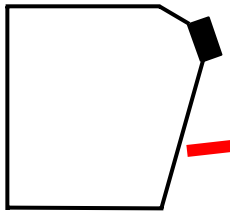
[CERN SPS]

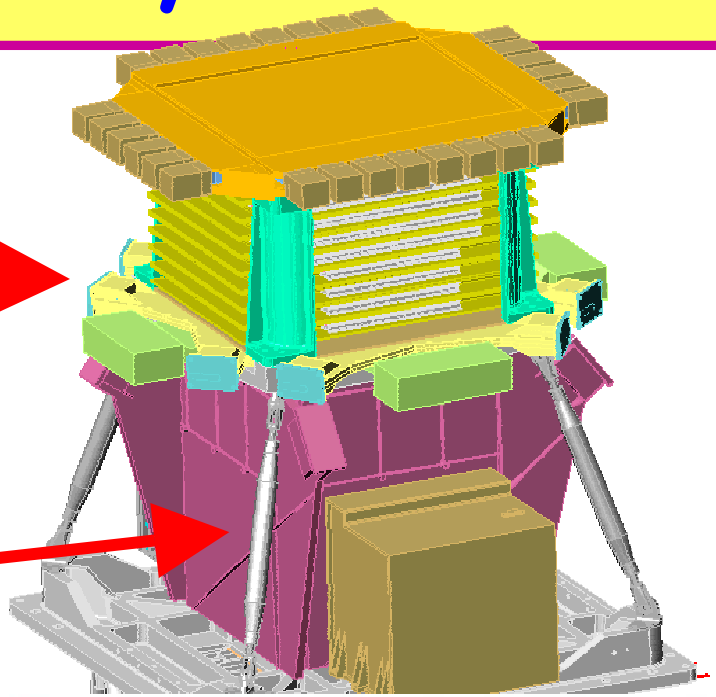
AntiCoincidence System

CAT:
1 Plane with
8 PMT

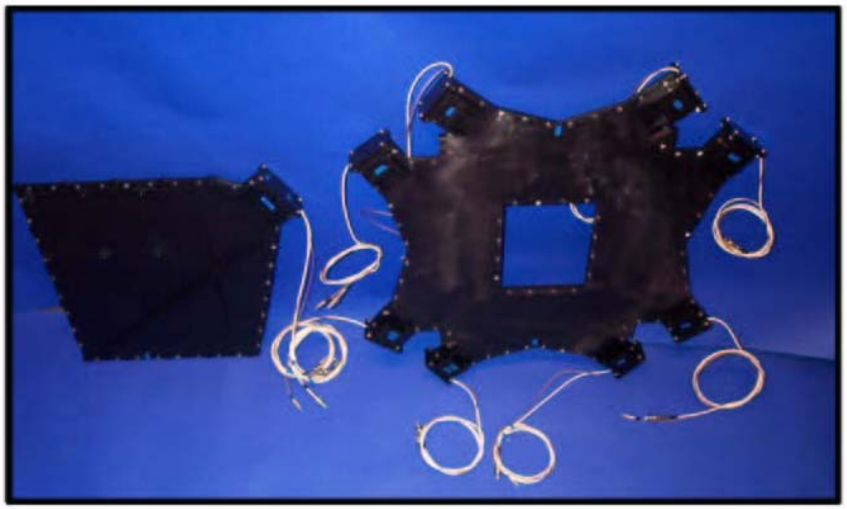


CAS:
4 Planes around Magnet,
with 2 PMTs each





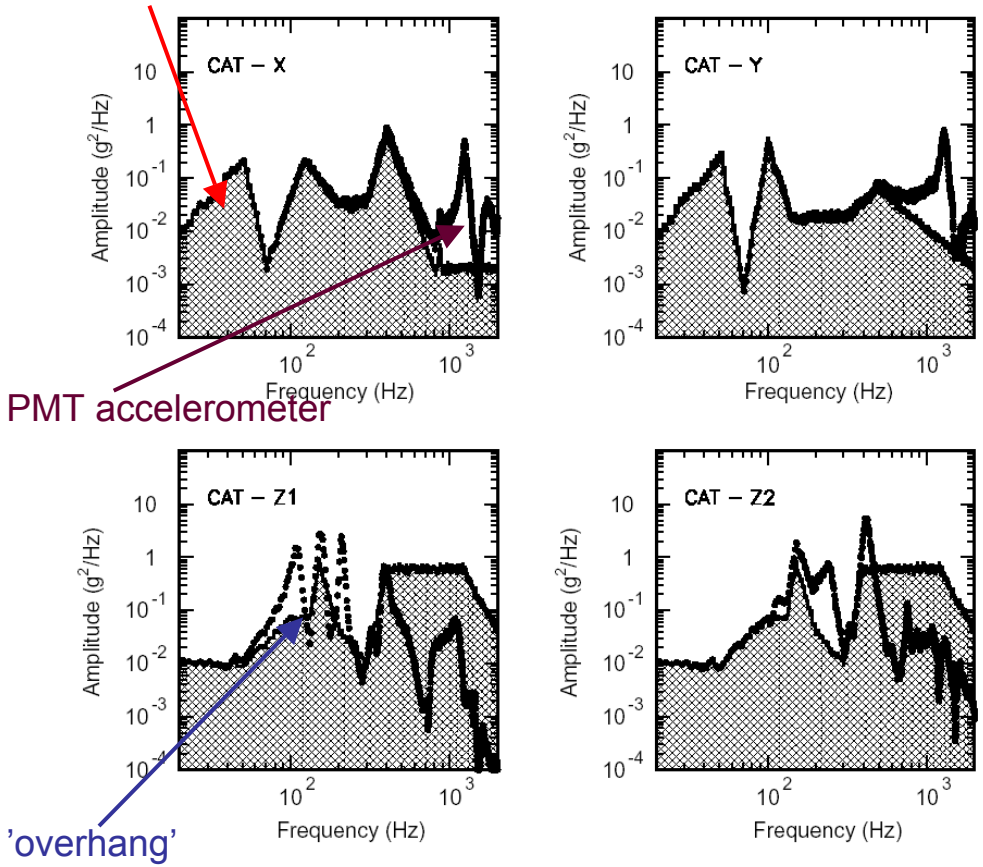
- Detector-efficiency high: >99.9%
- Purpose:
  reject spurios trigger from particles in "blind" areas



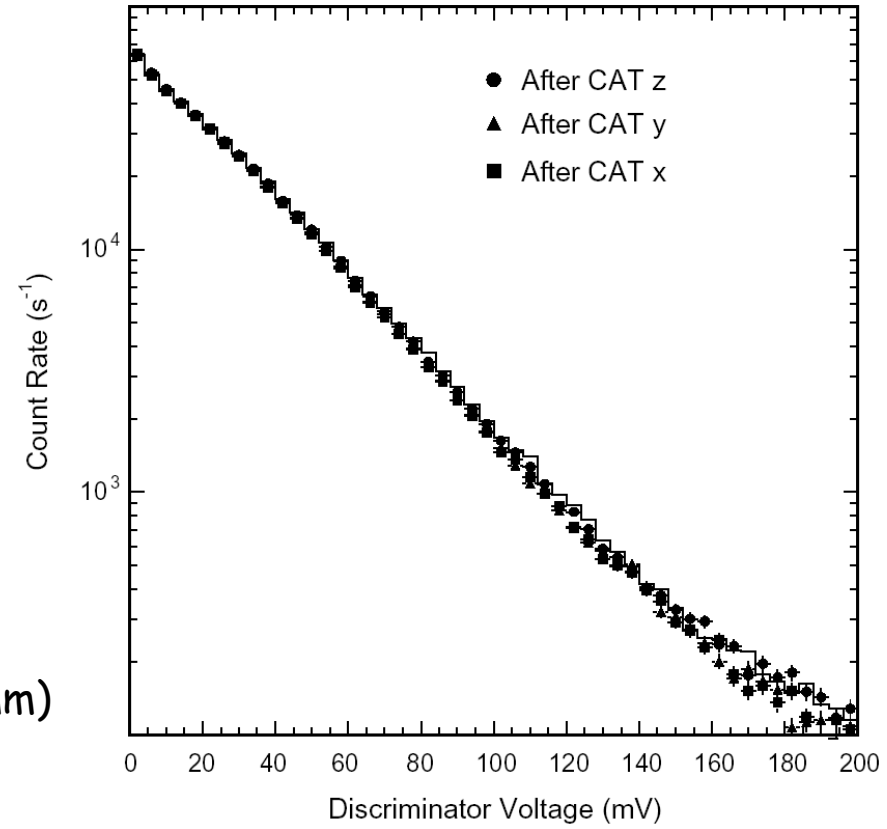
R.Wischnewski The PAMELA Space Mission,

AntiCoincidence - Random Vibration Tests

Stimulus
[20 Hz → 2 kHz / 120 s]



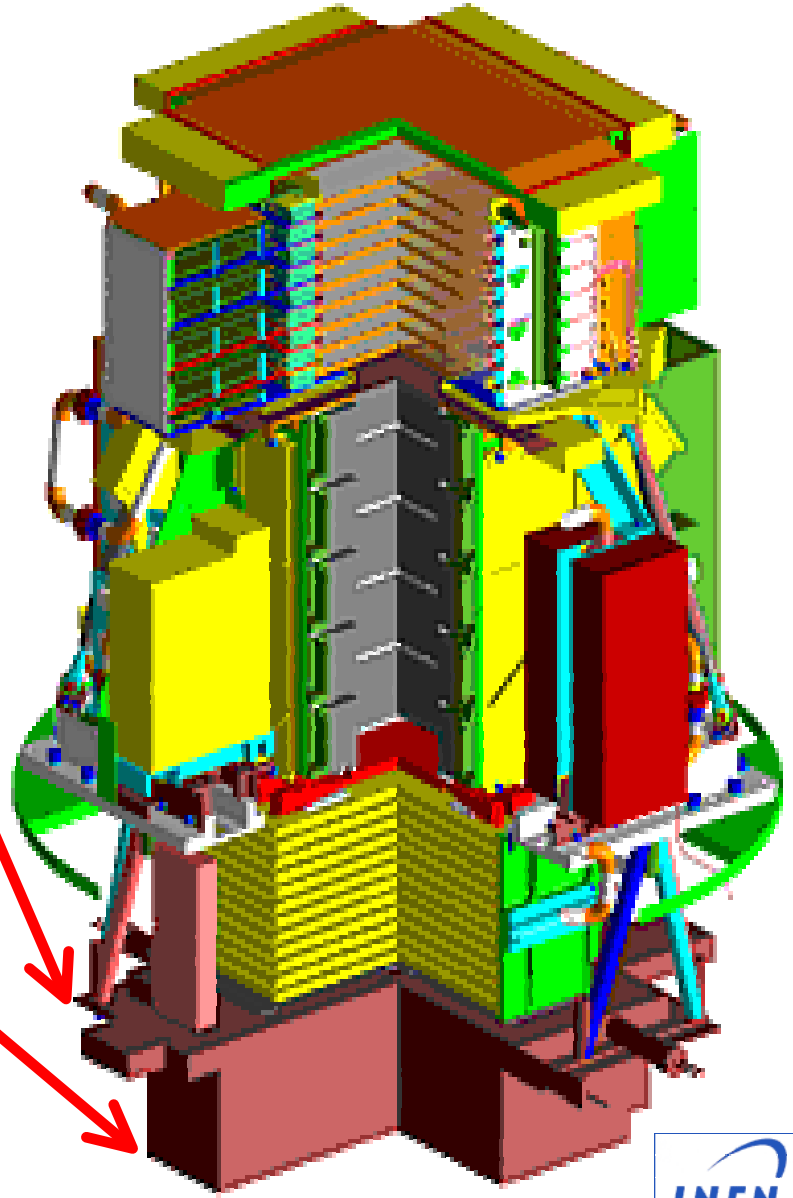
- O(20) gRMS integrated amplitude per PMT
- Resonance run (5 Hz → 2 kHz / 120 s / 0.5 gRMS) used to check for structural damage
- PMTs assessed with threshold scans



- PMTs have thin (0.8 mm) windows !
- Coupled to scintillator with silicone cookies (3 mm)

[NIM A488 (2002) 536]

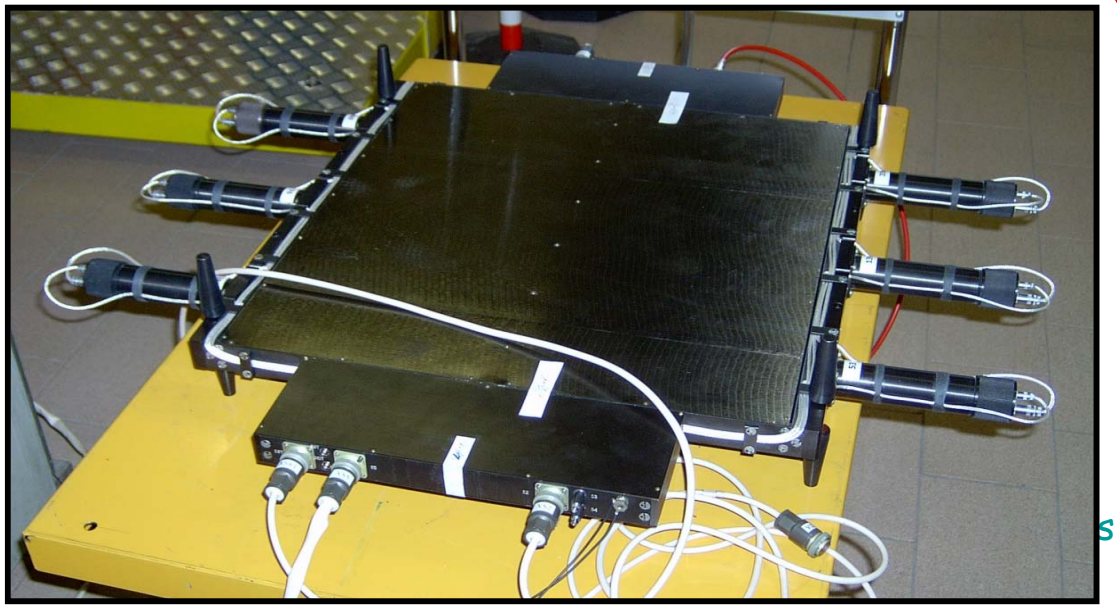
Bottom Scintillator & Neutron Detector



Shower Scintillator

10^{11} eV – 10^{13} eV e^- ⇒ local probe

- Plastic scintillator: 482 mm x 482 mm x 10 mm
- 6 PMT read-out
- Dynamic range: 1 - 1000 MIP



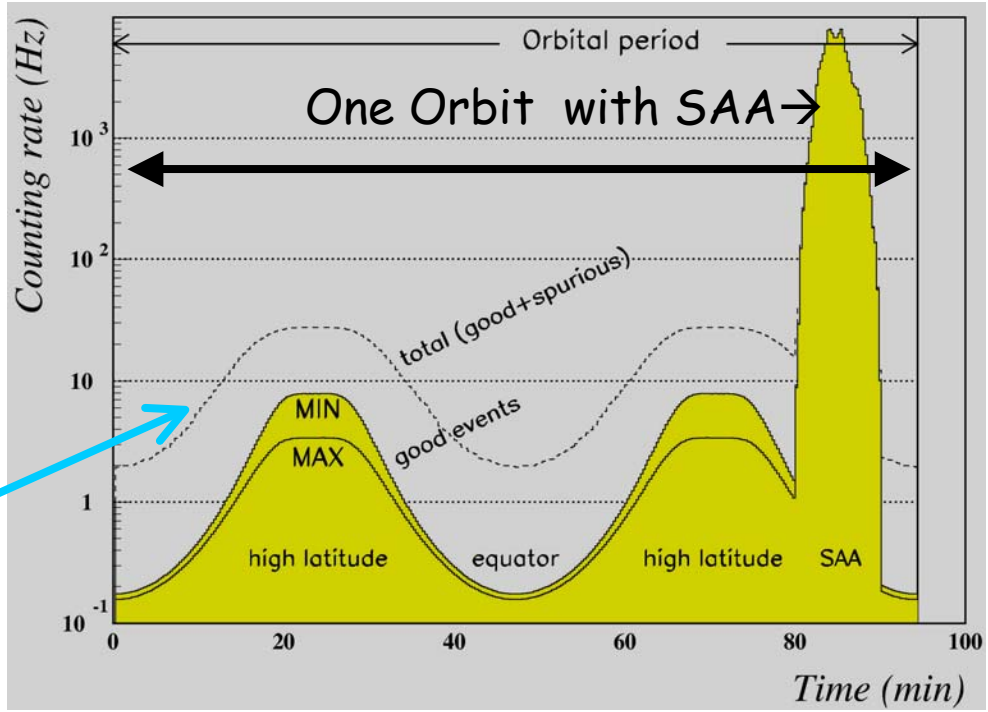
sion

Neutron Counter

Trigger

- 2 x 18 ^{3}He proportional counters (polyethylene moderator / Cd envelope)
- 600 × 550 × 150 mm^3
- n + ^{3}He → p + ^{3}H + 765 keV
- O(10) more n's in hadronic cascades than in EM

Trigger + DataRate



Level_1:

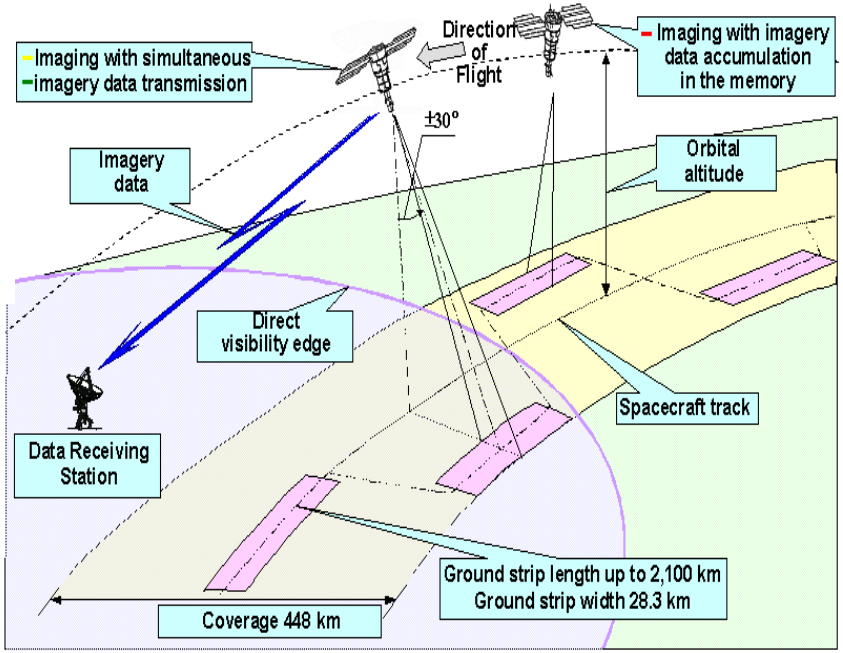
- TOF Scintillator Coincidence
  - S1 x S2 x S3 or
  - S2 x S3

  12 Hz / G.F. = 20.5 $cm^2 sr$ + b.g.
- Calorimeter SelfTrigger (E_e>0.3TeV)

  10 mHz / G.F. = 600 $cm^2 sr$

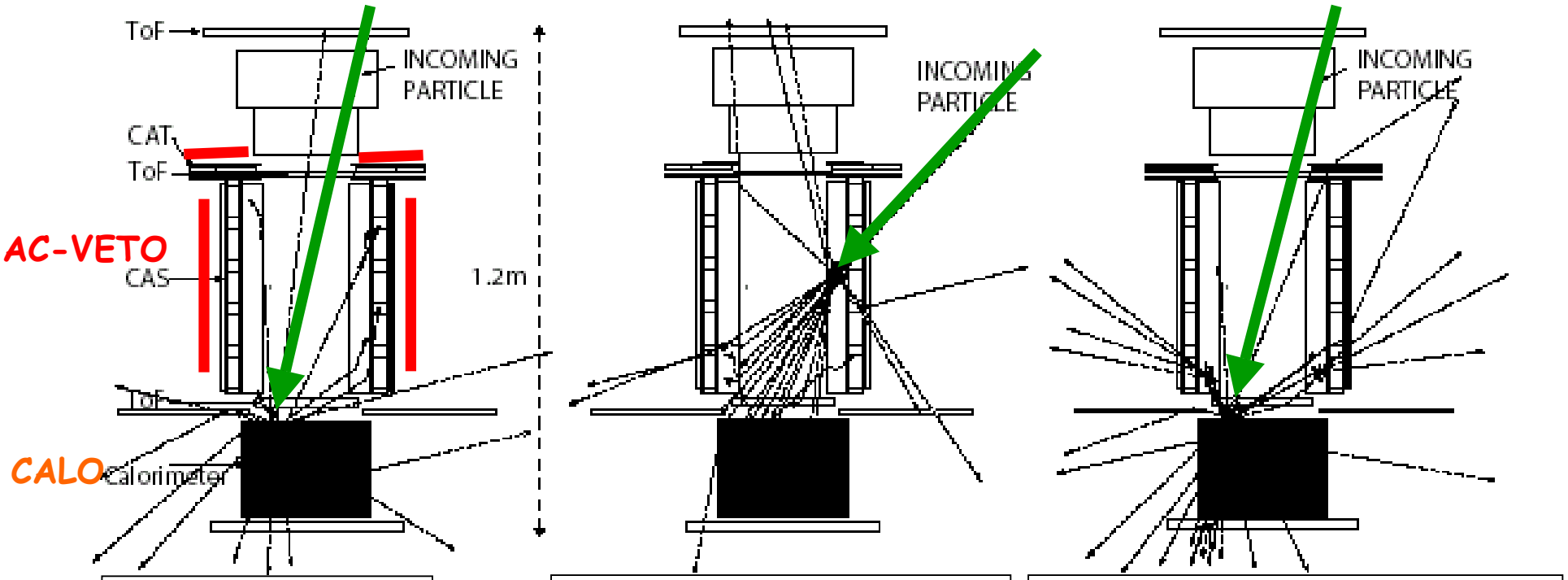
Data Rate / Storage / DownLink

- 12 Hz x 5kB/evt ~ **5 GB/day**
- **Up to 20 GB daily** accumulation + downlink in a few ground-connections



R.Wischnewski The PAMELA Space Mission, D

Trigger_VETO with AntiCoincidence



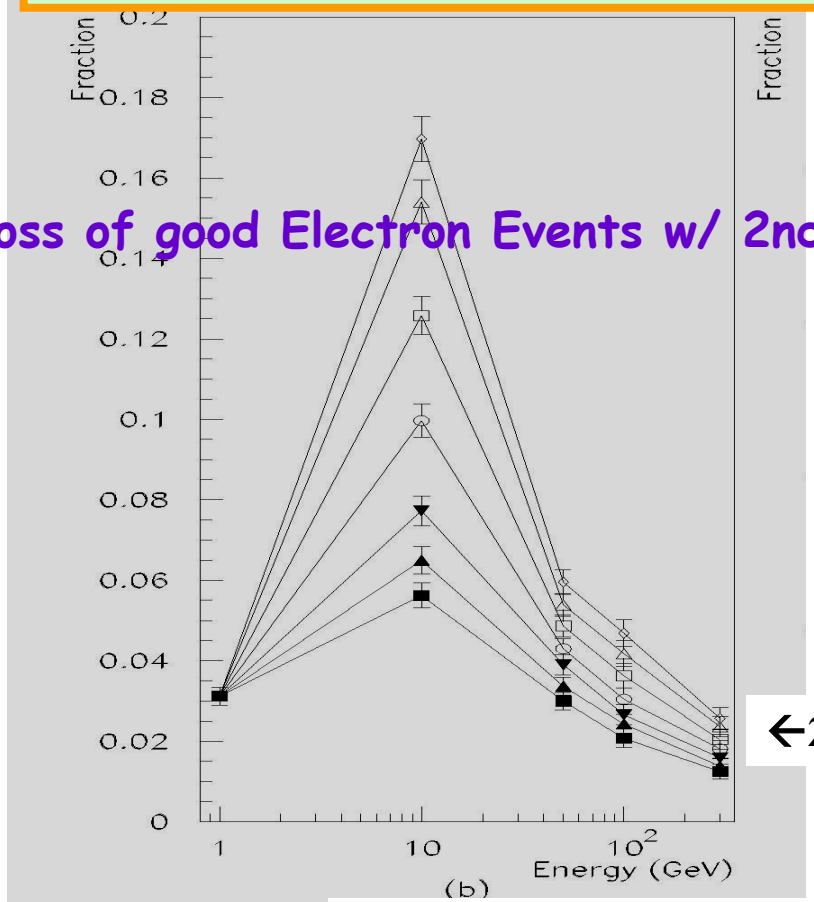
With a simple AntiCoincidence -VETO in 1st or 2ndLevel Trigger →
high Veto-Rate by BackScattering from CALO for good & rare events

- No AC-VETO
  .OR.
- (AC-VETO .AND. (low CALO activity))

→ Efficiency above 100 GeV reaches >95%

PAMELA – 2nd Level Trigger

Loss of good Electron Events w/ 2ndTrigger

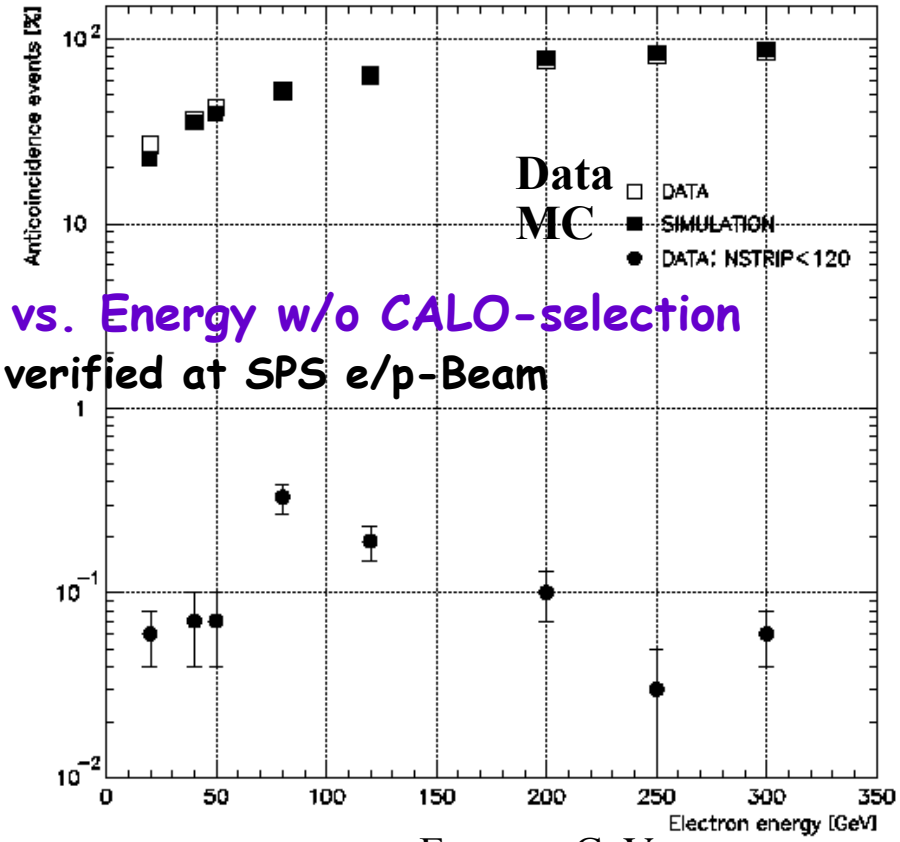


←2 %

Energy , GeV

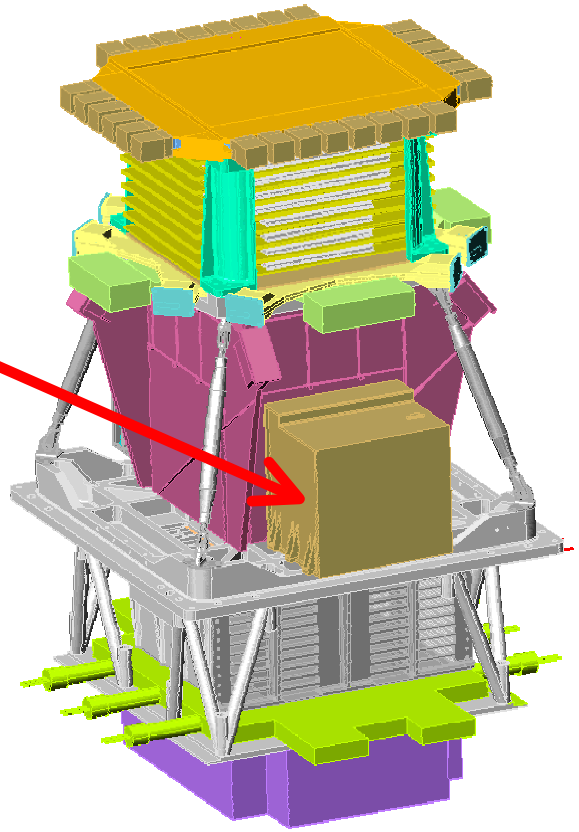
Loss vs. Energy w/o CALO-selection

verified at SPS e/p-Beam



Energy , GeV

OnBoard - DataAcquisition ("PAMELA CPU")

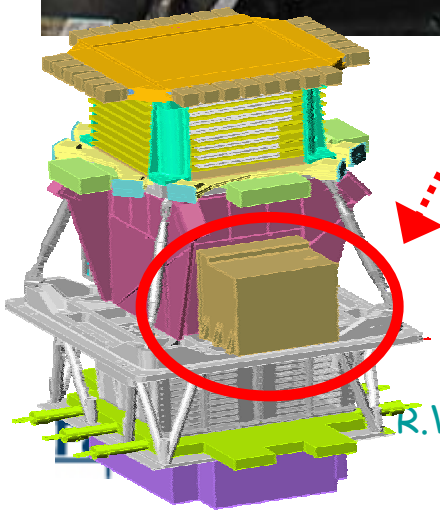


- DAQ for the Experiment
- Satellite ←→ PAMELA communication
- Emergency handling 'autonomous'

  (few times / day only ground control)

- Design with high reliability & redundancy
- Careful system debugging on ground

The "Pamela Storage and Control Unit"



RAM (2x2 GB)

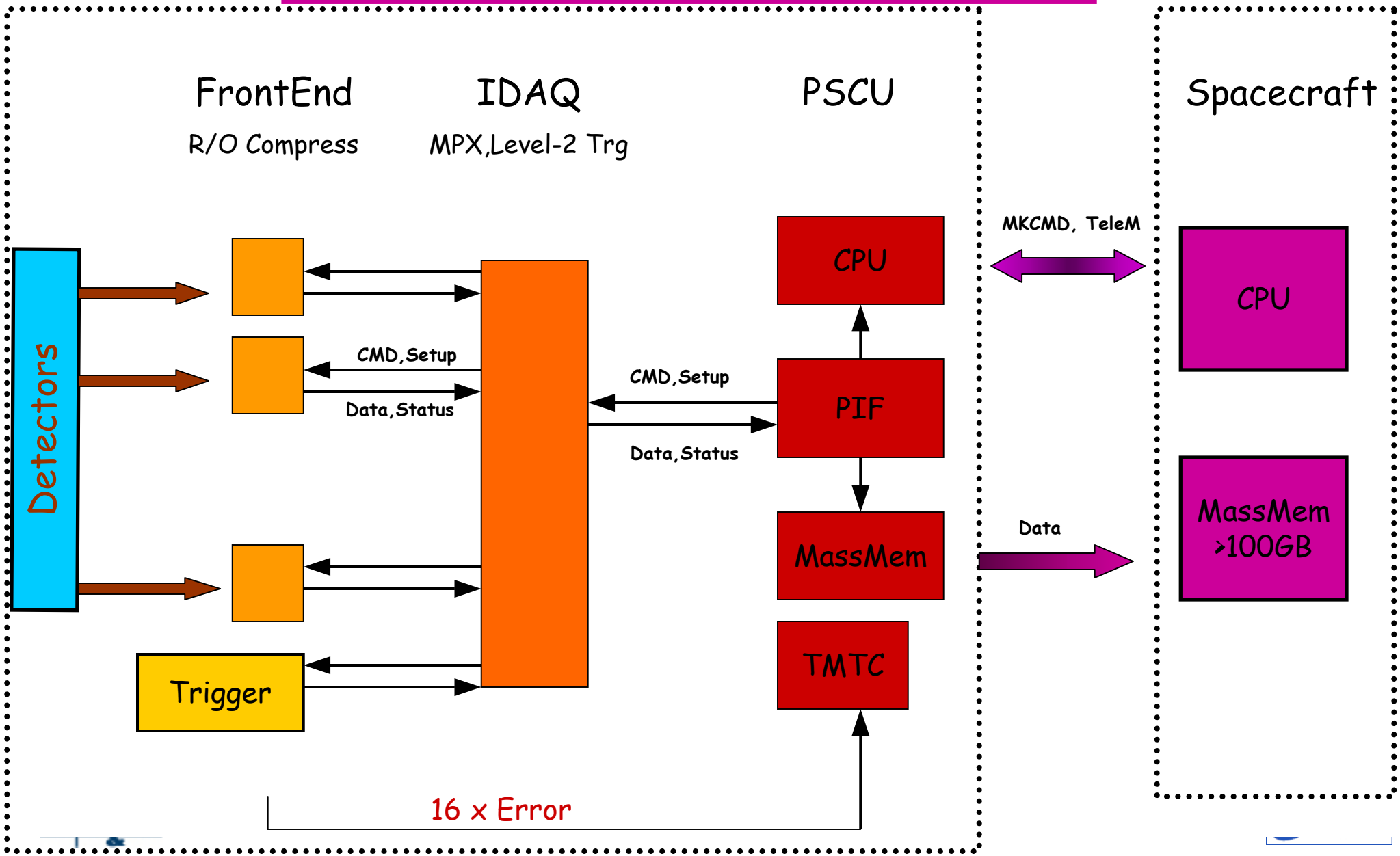
CPU, Interfaces

- CPU 17 Mips/24MHz ERC32/LABEN-SpA

  → a recently space-qualified SPARC V7
- 4 Mbyte SRAM
- 2+2 GB Mass Memory
- Mil-1553 RemoteTerminal to Satellite
- Telemetry & Housekeeping & Pamela-IF
- RealTimeOS: RTEMS (ESA/ESTEC Develop.System)

- Software: careful system design – "standalone operation"
- Power/Weight 30W / 7 kg; Total Cost: O(10^5 Eur)

PAMELA DAQ – Schematics



PAMELA Status: The " 3 Models "

- Satellite manufacturing follows a main "dogma" :

Production goes in 3 steps with 3 "Models" for satellite projects.

(1) MASS
THERMAL MODEL → mechanical, thermal, dimensional test. Correct.
DYNAMICAL

(2) TECHNOLOGICAL MODEL → verify functions & Satellite Interfaces. Correct.
Full "1:1 copy" of final Satellite
with all active components (~ a "backup of the original").

(3) FLIGHT MODEL → verify & ready to fly.

All "lessons" from Technological Model included;
use space-qualified components.

PAMELA - Status

(0) Detectors and Systems are designed & ready.

(1) MASS and THERMAL MODEL → done.

→ All tests passed.

(2) TECHNOLOGICAL MODEL → ~ done.

→ Assembly finished @ Rome (~1 yr).

→ Now Integration with Satellite at Samara in 5/2004.

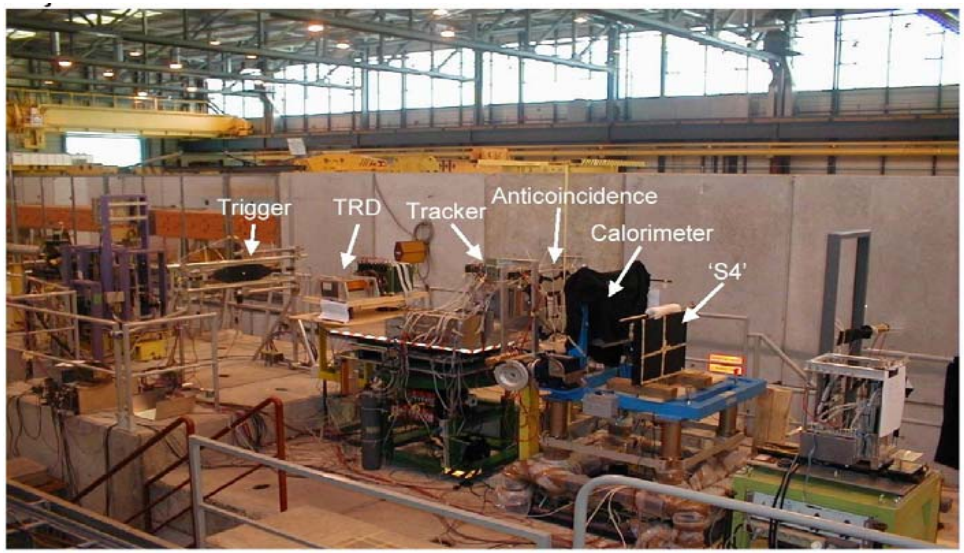
(3) FLIGHT MODEL

→ System Integration is under way @ Rome.

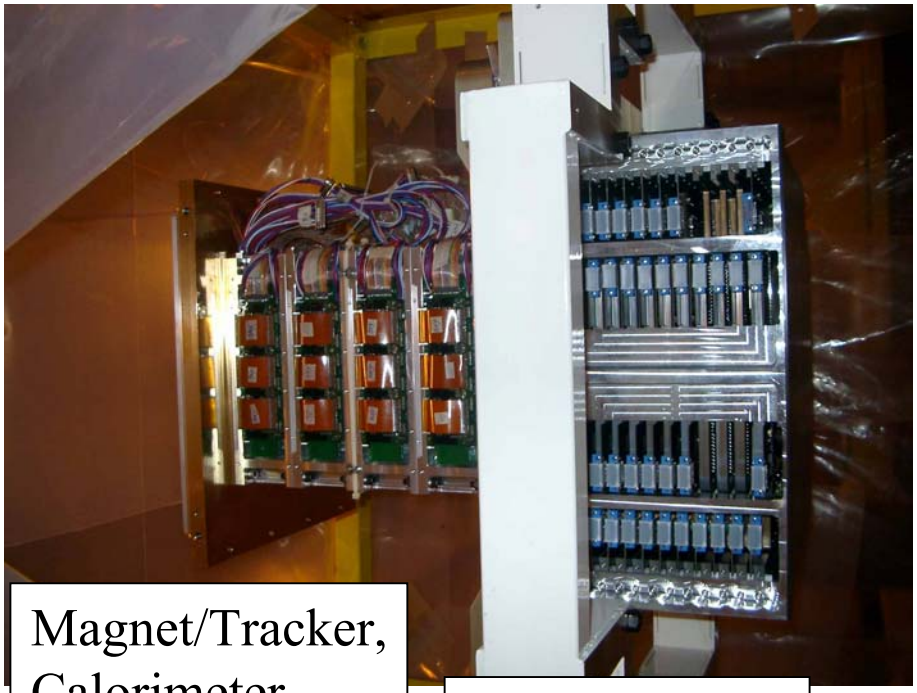
→ SPS BeamTest of almost complete setup done in Sept/2003 for final calibration & alignment.

PAMELA - Detector tests

Detectors operated at CERN PS/SPS TestBeams as Prototypes and in FM configuration.

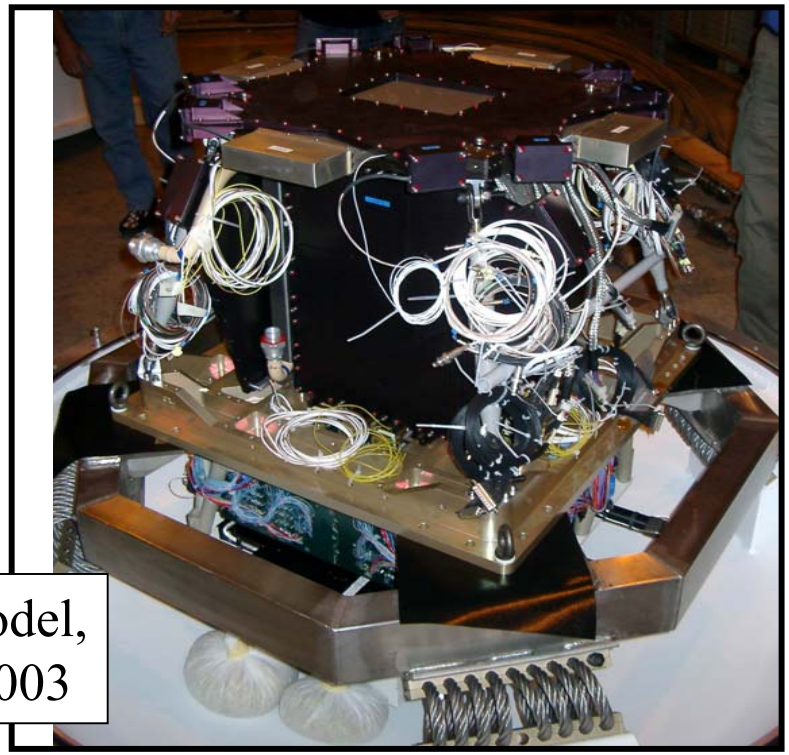


SPS, July 2000



Magnet/Tracker, Calorimeter

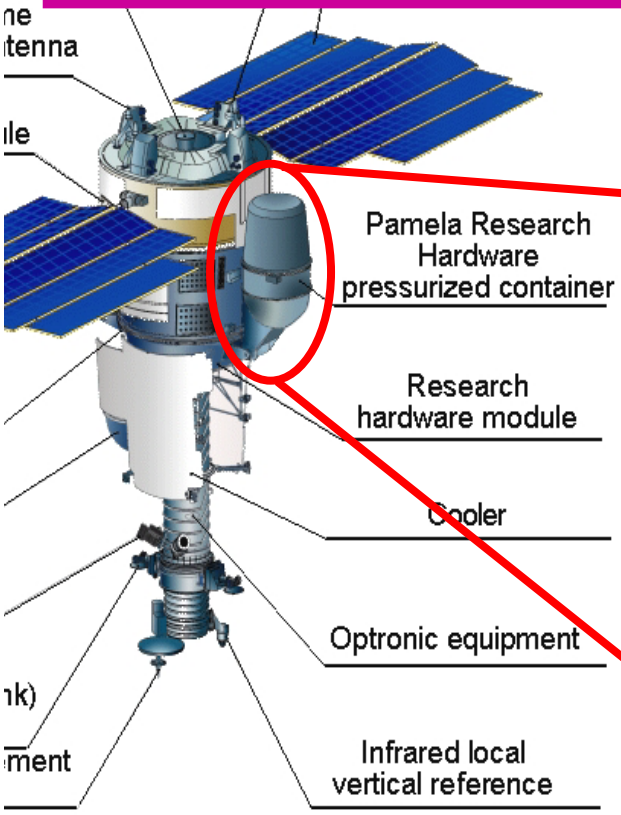
SPS, July 2002

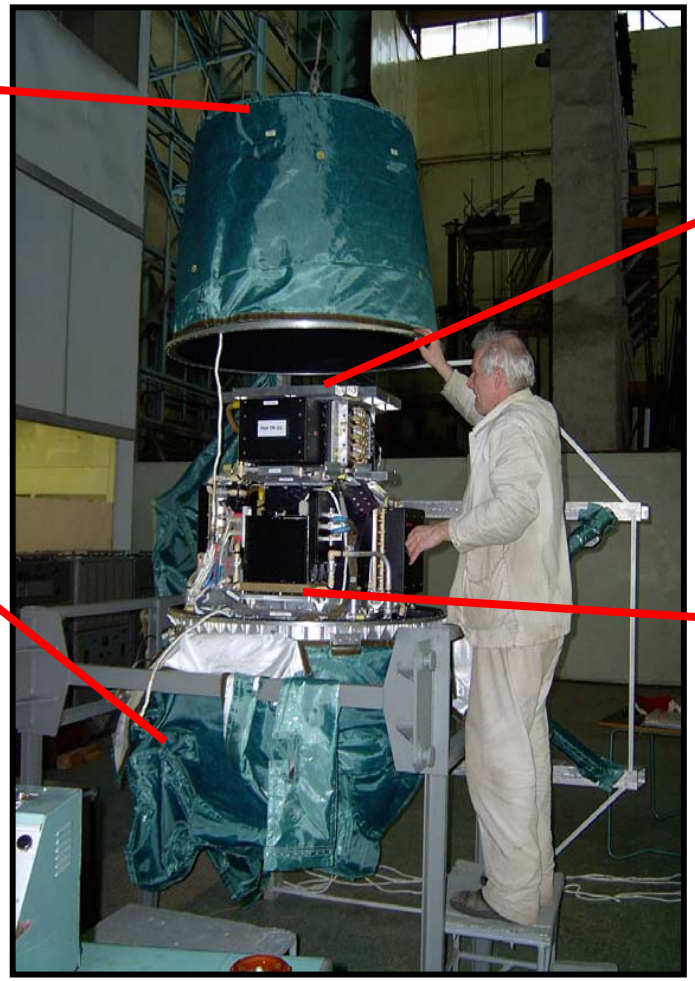


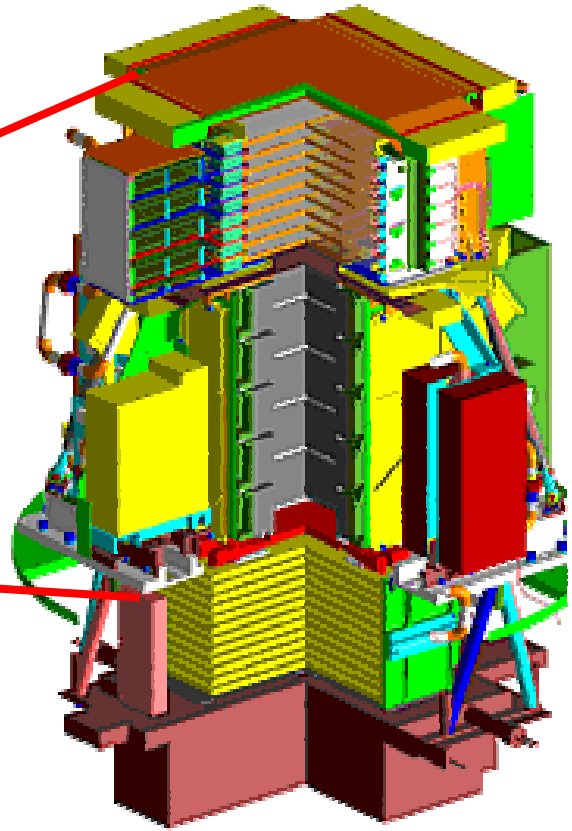
FlightModel, SPS, 9/2003

PAMELA - Integration

MassThermalModel +
Pamela Container at
TsSKB Samara/Russia

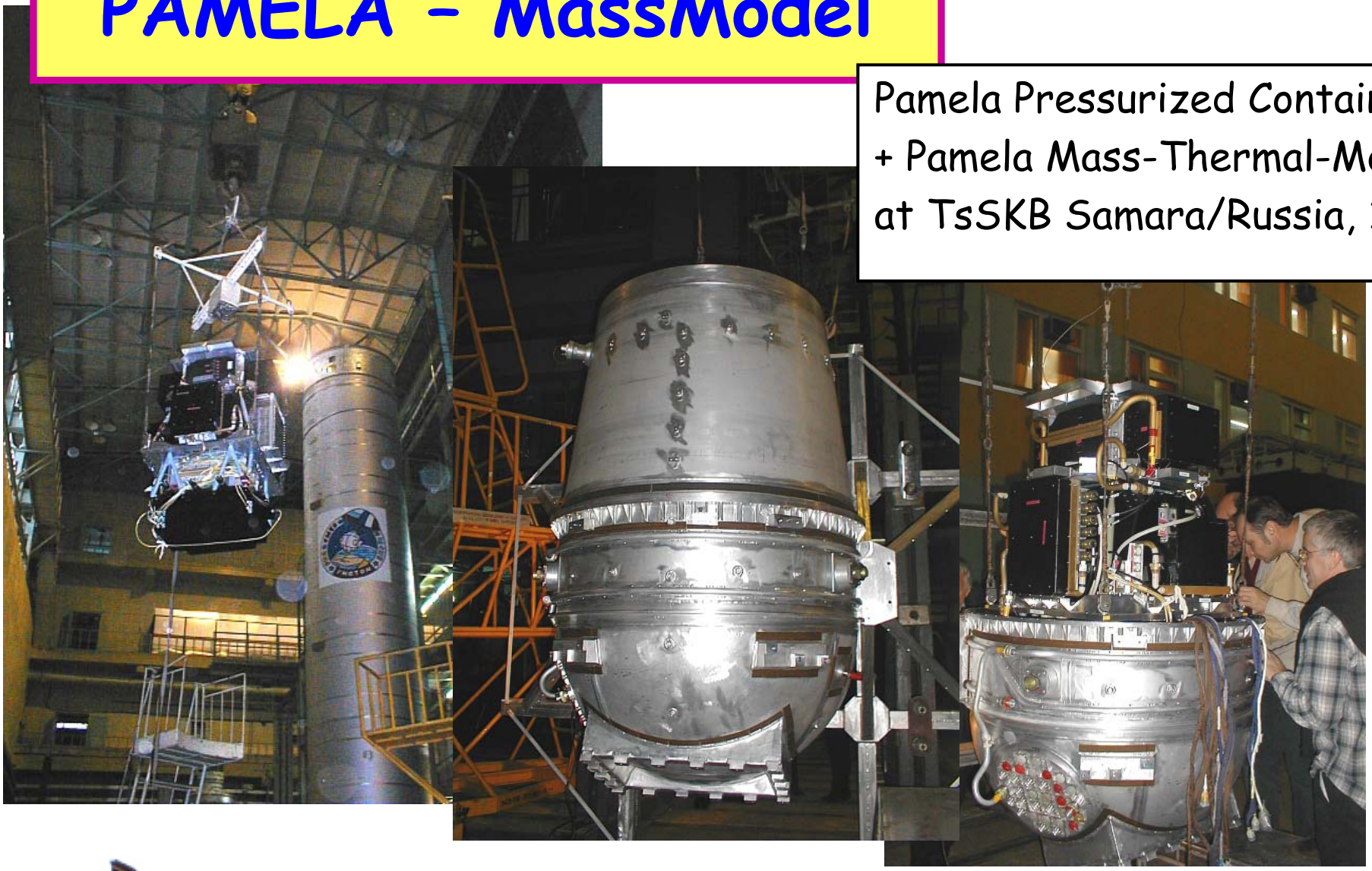






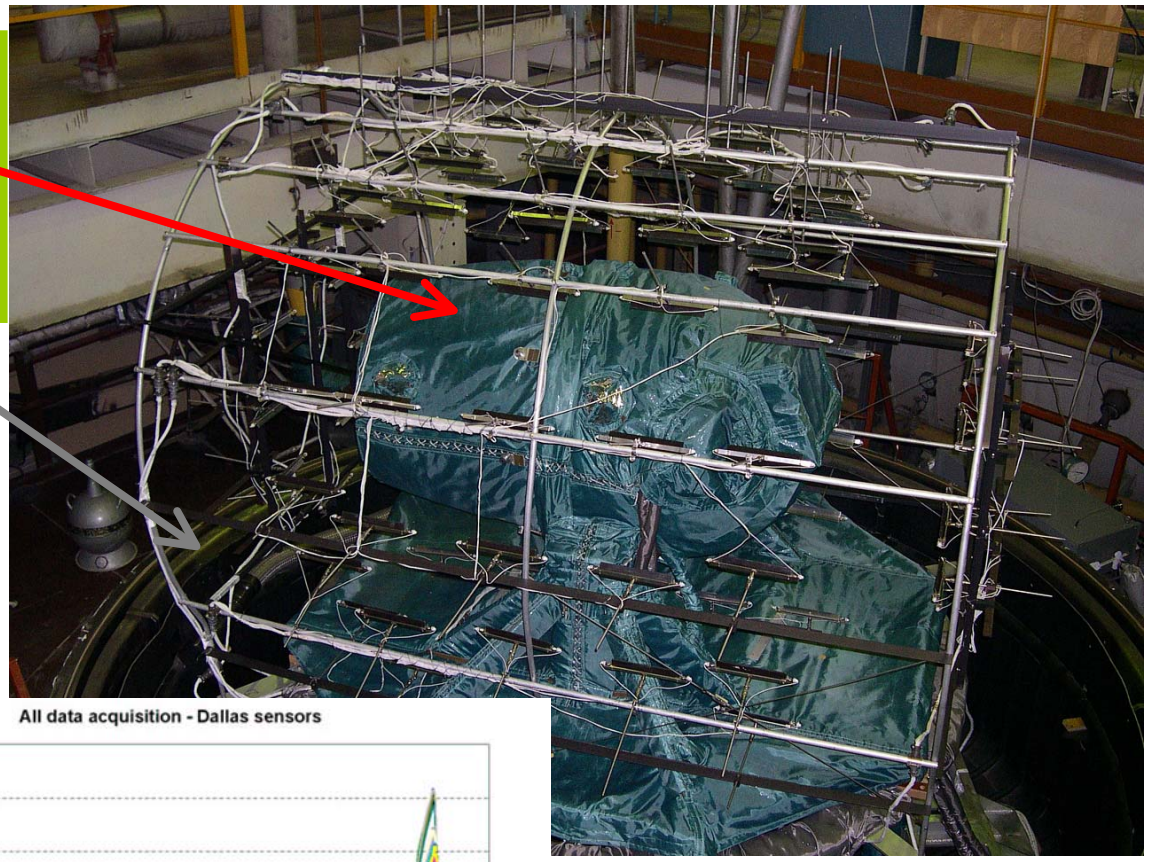
PAMELA – MassModel

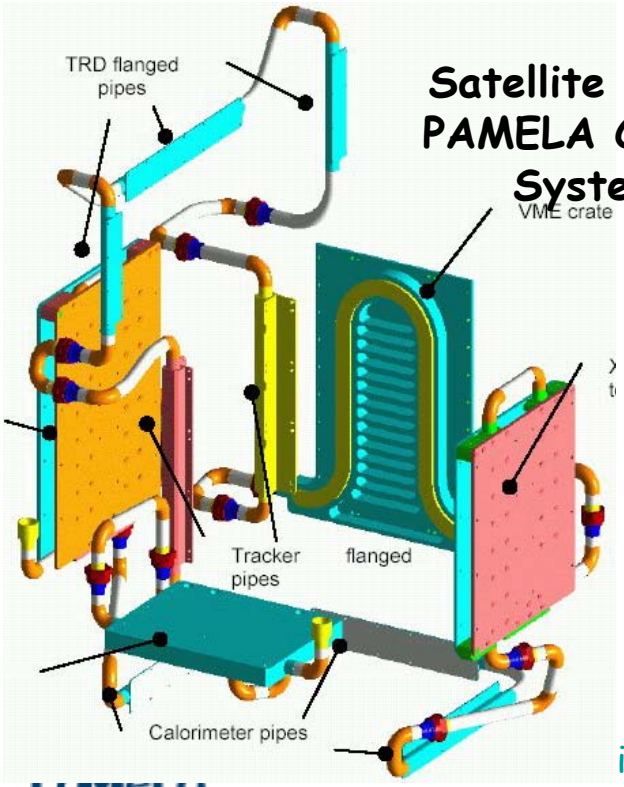
Pamela Pressurized Container
+ Pamela Mass-Thermal-Model
at TsSKB Samara/Russia, 11/2002



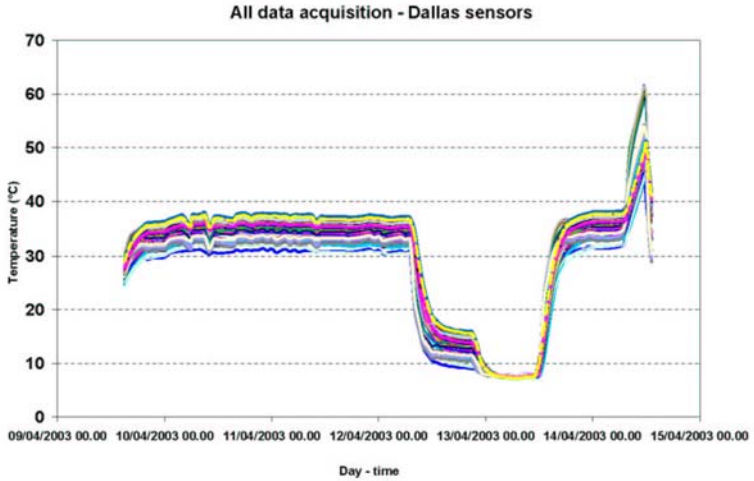
PAMELA – Thermal Model

Complete PAMELA ThermalModel passed Thermal in TsSKB Thermal/Vacuum Chamber





Satellite driven PAMELA Cooling System



PAMELA - Vibration Model

Full Cycle of Vibration / Shock passed

at IBAG/ Munich and TsSKB

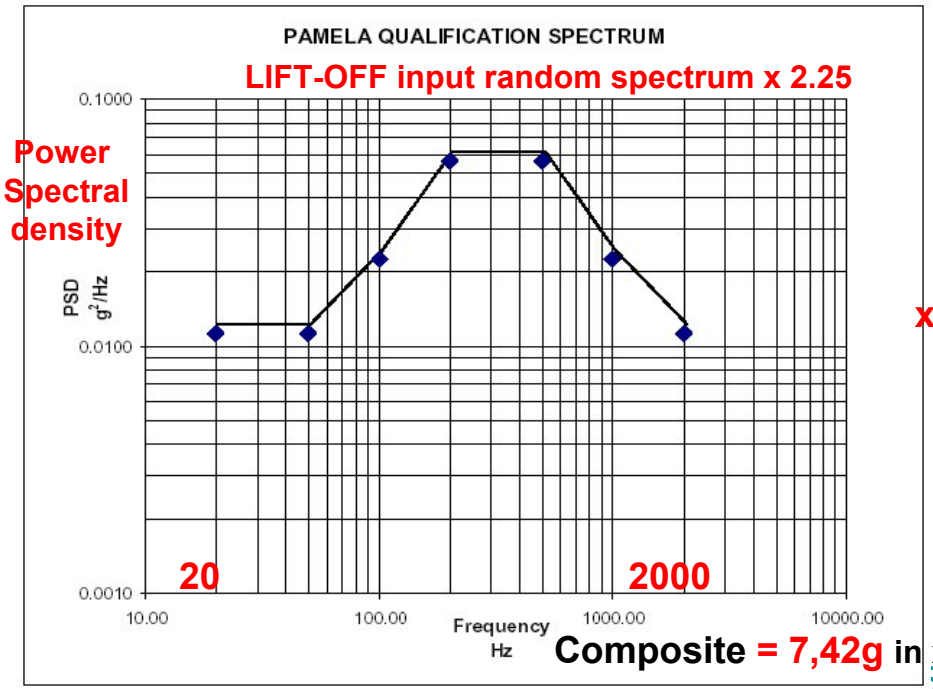
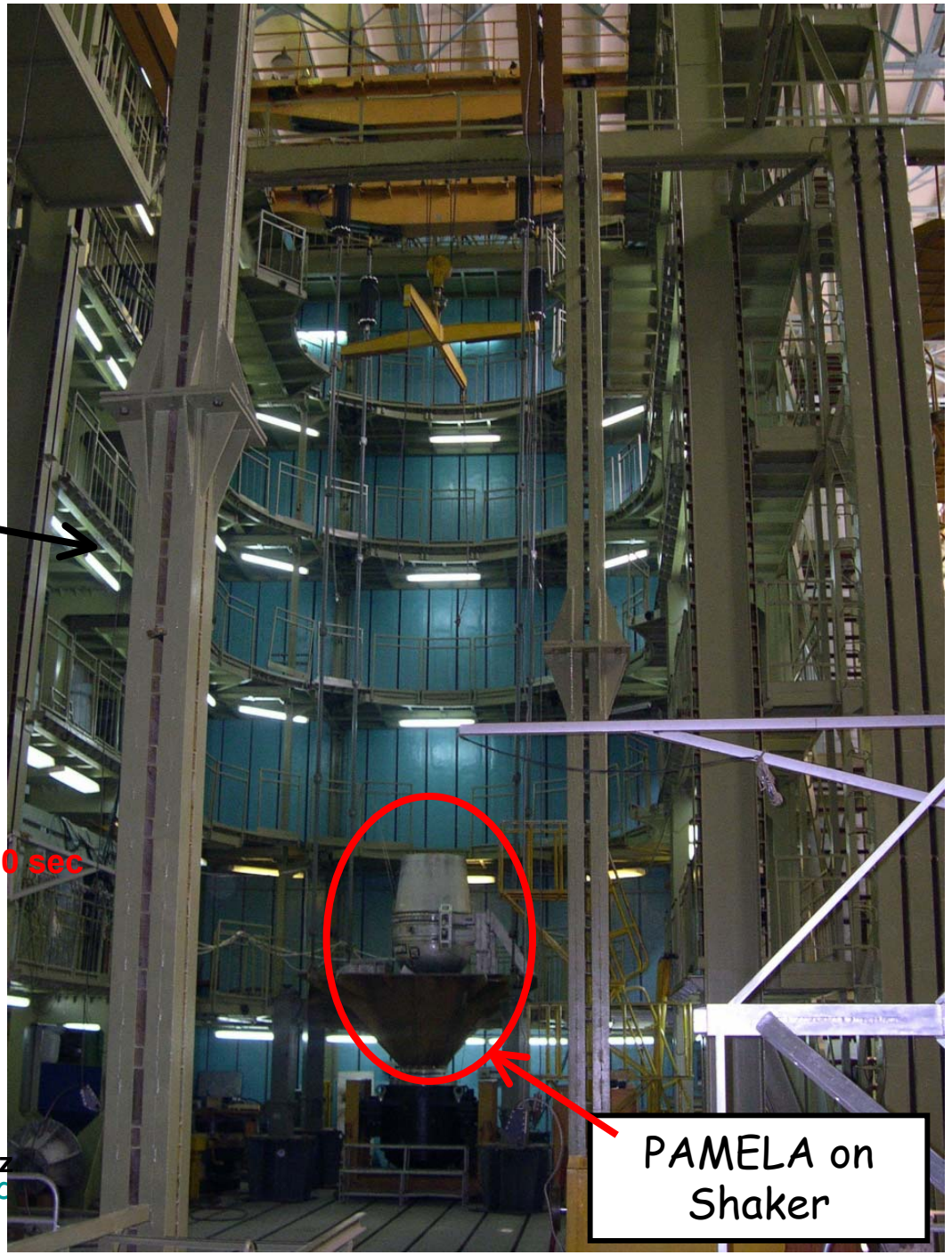
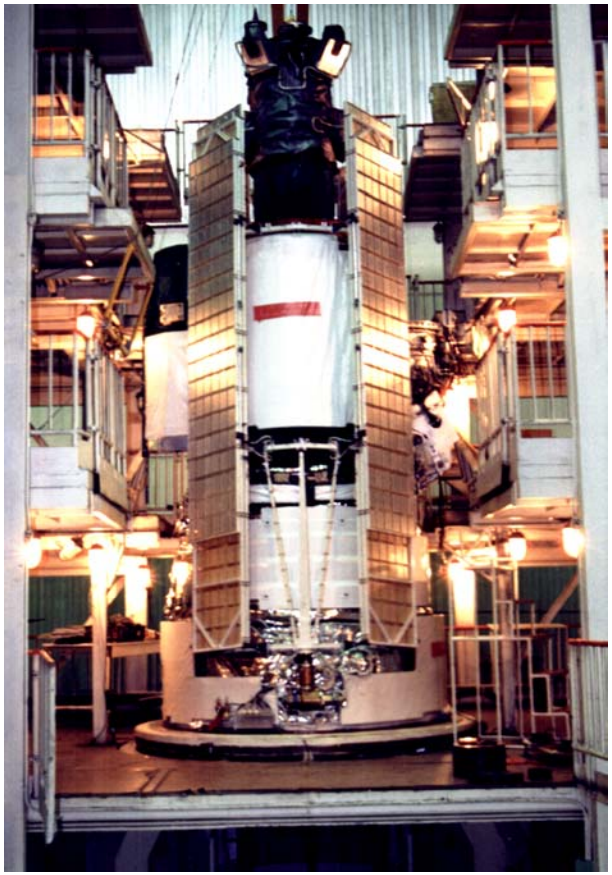


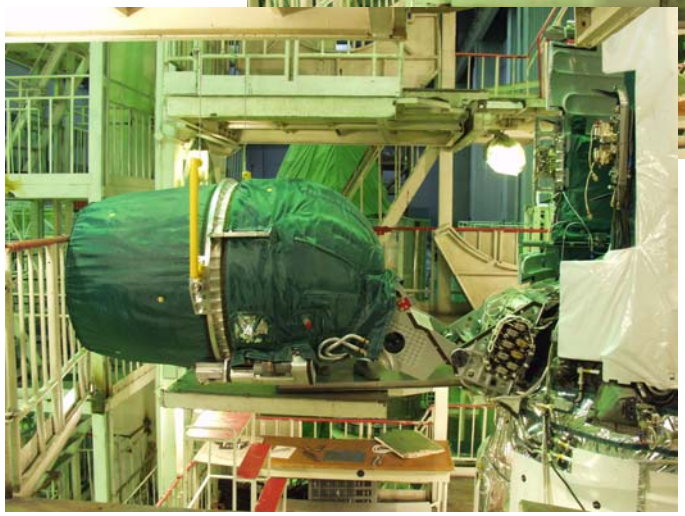
figure 7-10 PAMELA qualification spectrum

x 120 sec



Satellite & PAMELA Tests





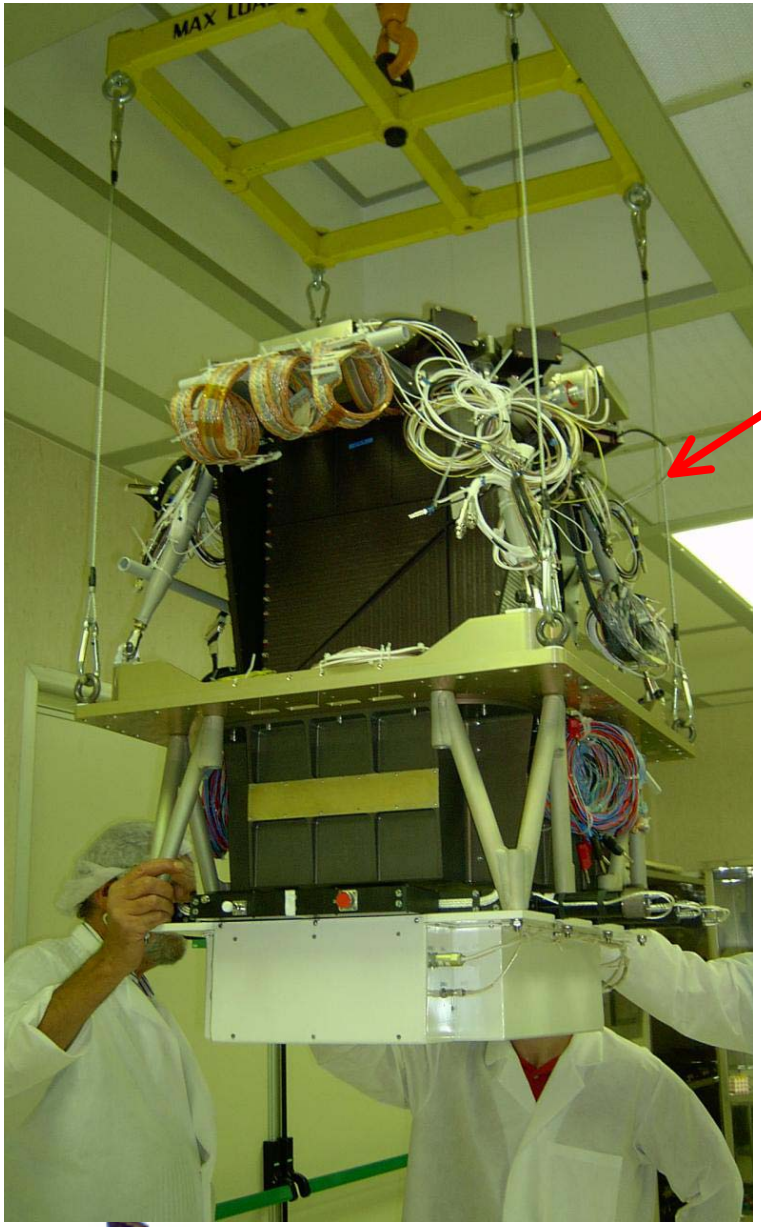
Satellite RESURS-DK1:

Dynamic verification

Verifying PAMELA Orbital Operations:

Parking ←→ Working Position

Flight Model Integration @ INFN -Rome2



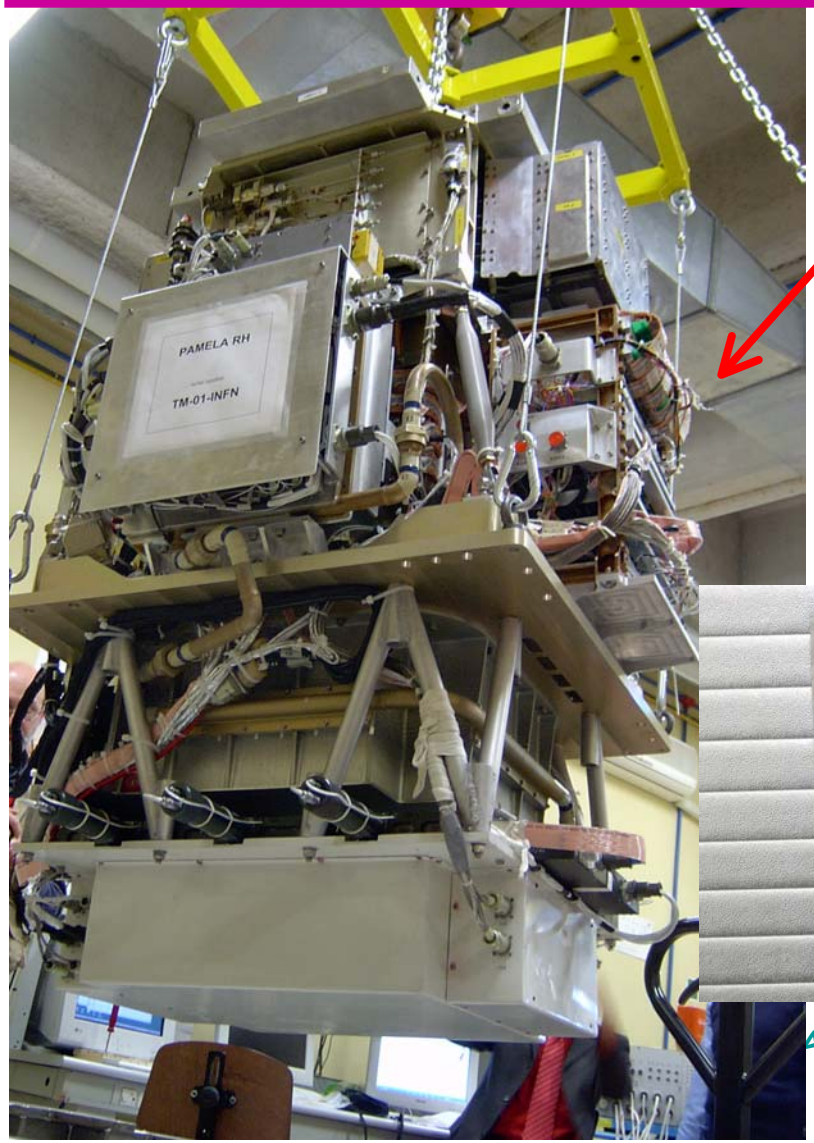
FlightModel leaving to CERN/SPS, Sept.2003 (w/o TRD,TOF, ext.Elect.)

PAMELA-FM inside TransportContainer

Design: >5000km flight & 1000km rail, +40/-50C outside

Technological Model @ INFN-Rome2

TModel is completed and shipped to Samara, April 9th, 2004



PAMELA-TM inside TransportContainer

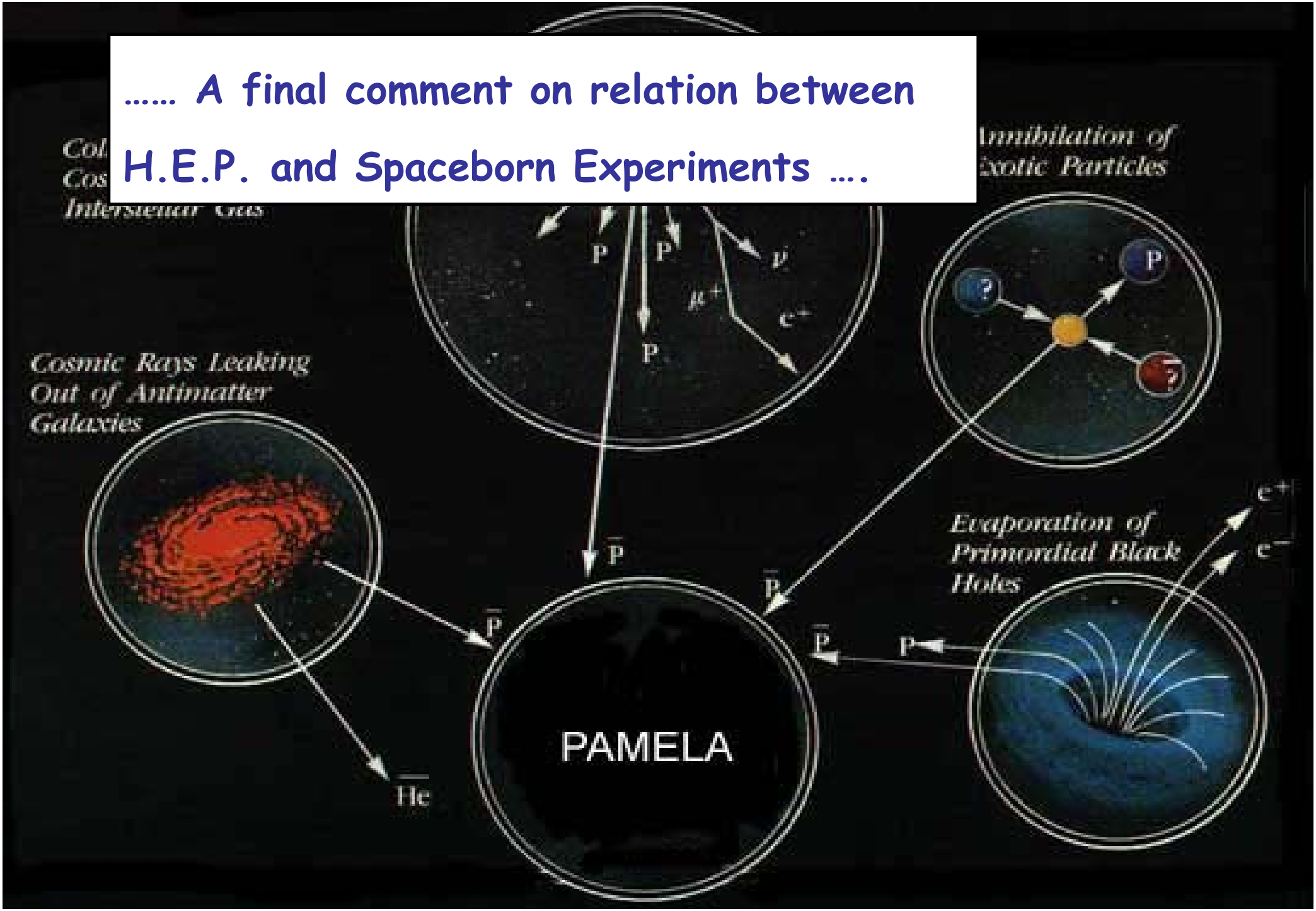
Summary

- PAMELA has an exciting Astrophysics and Particle Physics program:

  DarkMatter & AntiMatter

- **The PAMELA Launch is late 2004 from Baikonur –**

  Launcher, Satellite and PAMELA will be ready.


…… A final comment on relation between
H.E.P. and Spaceborn Experiments ….
Annihilation of Exotic Particles
Cosmic Rays Leaking Out of Antimatter Galaxies
Evaporation of Primordial Black Holes
PAMELA
P
$\bar{P}$
$\bar{He}$
e^+
e^-
ν
μ^+
?

- PAMELA's finalization is now at top-priority @ INFN.

- Upcoming spaceborn projects with major INFN contributions:
  - AGILE (2005) Gamma-Rays
  - GLAST (2006) Gamma-Rays
  - AMS-02 (2007) AntiMatter + Gammas
  - EUSO (>2010) EHE-CRs
  - LISA (>2010) Grav.Waves
  - …

Excellence in (AP-) Physics and DetectorTechnology, usage of HEP-tools, Timescale, … - suggests that these projects are viable options for the future of any HEP-laboratory…