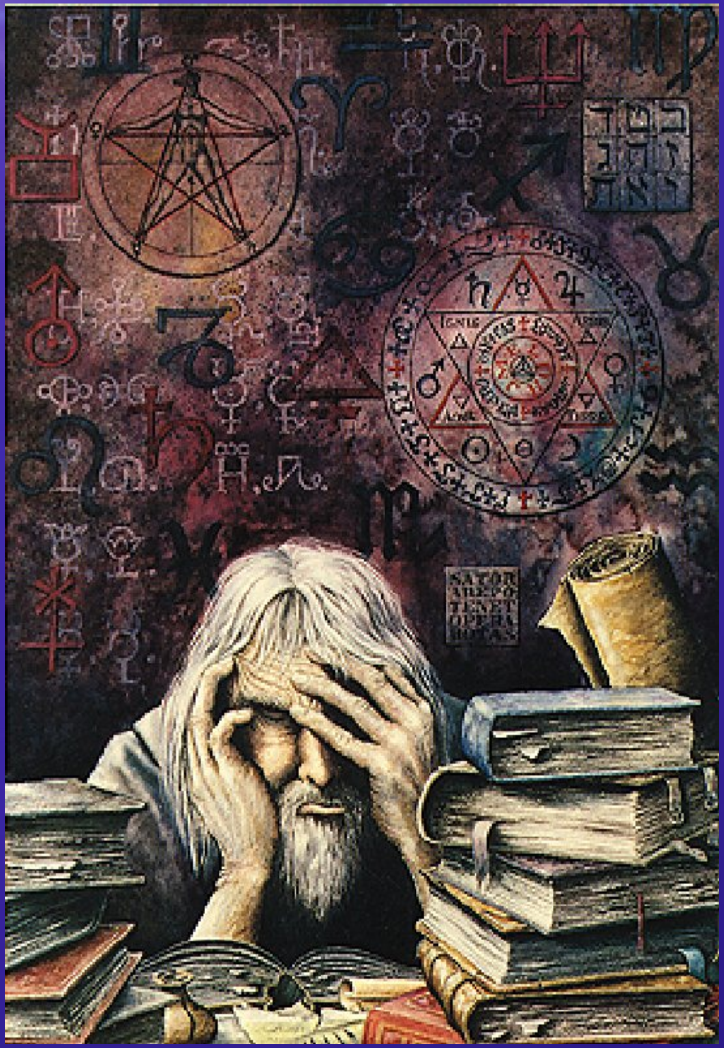
Kai Zuber, University of Sussex

Other double beta experiments

Workshop Astroteilchenphysik, DESY Zeuthen 4.-.5.10.2005

How to explain all other double beta proposals in 20 mins

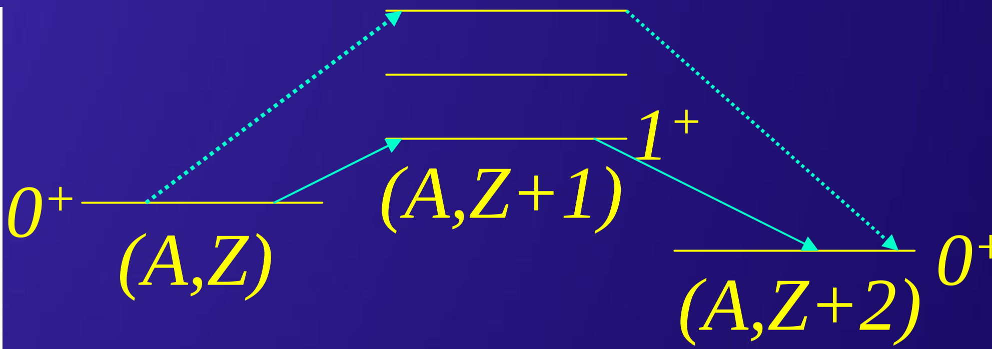
Contents



- Introduction
  NME
- Current experiments
- Other German activities (Cryo-detectors, Nd-loaded scintillator, COBRA)
- Summary and conclusions

Double beta decay

- $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ $2\nu\beta\beta$
- $(A,Z) \rightarrow (A,Z+2) + 2e^-$ $0\nu\beta\beta$



In nature there are 35 isotopes

$2\nu\beta\beta$: Seen in 9 isotopes, important for nuclear physics input

$0\nu\beta\beta$: Only possible if neutrinos are Majorana particles

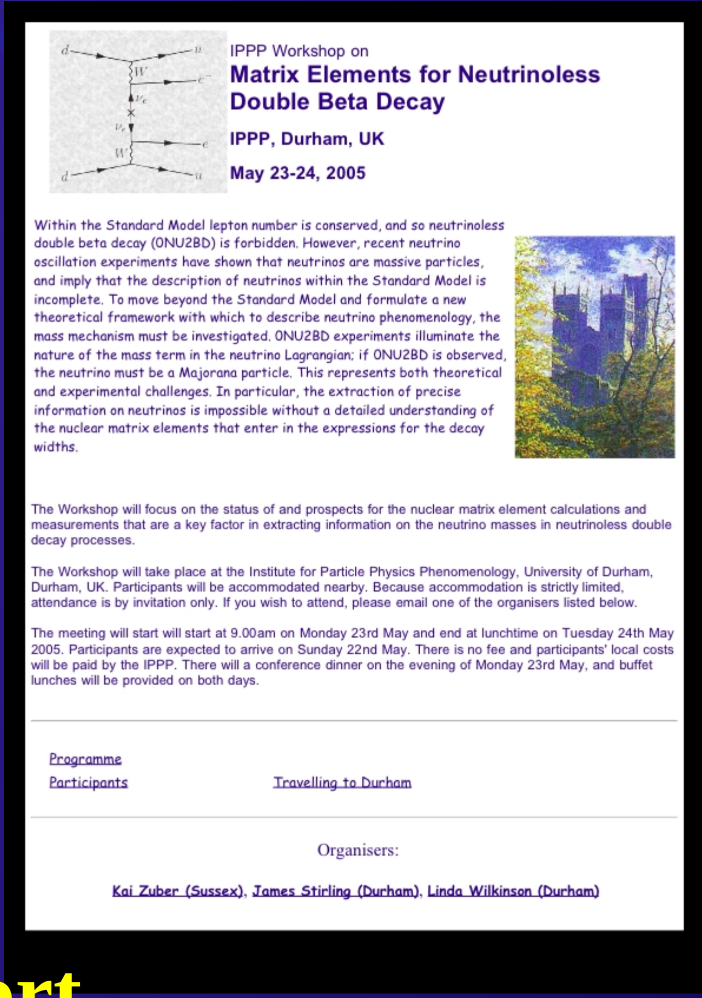
Nuclear matrix elements

measured quantity — quantity of interest

$$1 / T_{1/2} = PS * NME^2 * (m_\nu / m_e)^2$$

The big unknown

Started worldwide effort for a coherent program to reduce NME uncertainty down to 30%, summary report available soon (next two weeks)


IPPP Workshop on

Matrix Elements for Neutrinoless Double Beta Decay

IPPP, Durham, UK

May 23-24, 2005

Within the Standard Model lepton number is conserved, and so neutrinoless double beta decay (0NU2BD) is forbidden. However, recent neutrino oscillation experiments have shown that neutrinos are massive particles, and imply that the description of neutrinos within the Standard Model is incomplete. To move beyond the Standard Model and formulate a new theoretical framework with which to describe neutrino phenomenology, the mass mechanism must be investigated. 0NU2BD experiments illuminate the nature of the mass term in the neutrino Lagrangian; if 0NU2BD is observed, the neutrino must be a Majorana particle. This represents both theoretical and experimental challenges. In particular, the extraction of precise information on neutrinos is impossible without a detailed understanding of the nuclear matrix elements that enter in the expressions for the decay widths.

The Workshop will focus on the status of and prospects for the nuclear matrix element calculations and measurements that are a key factor in extracting information on the neutrino masses in neutrinoless double decay processes.

The Workshop will take place at the Institute for Particle Physics Phenomenology, University of Durham, Durham, UK. Participants will be accommodated nearby. Because accommodation is strictly limited, attendance is by invitation only. If you wish to attend, please email one of the organisers listed below.

The meeting will start will start at 9.00am on Monday 23rd May and end at lunchtime on Tuesday 24th May 2005. Participants are expected to arrive on Sunday 22nd May. There is no fee and participants' local costs will be paid by the IPPP. There will a conference dinner on the evening of Monday 23rd May, and buffet lunches will be provided on both days.

Programme
Participants — Travelling to Durham

Organisers:

Kai Zuber (Sussex), James Stirling (Durham), Linda Wilkinson (Durham)

Needs international coherent effort

http://www.ippp.dur.ac.uk/0NU2B/2005.html

Back of the envelope

$T_{1/2} = \ln 2 \bullet a \bullet N_A \bullet M \bullet t \,/\, N_{\beta\beta}$ ($\tau >> T$) (Background free)

50 meV implies half-life measurements of $10^{26\text{-}27}$ yrs

1 event/yr you need $10^{26\text{-}27}$ source atoms

This is about 1000 moles of isotope, implying 100 kg

Now you only can loose: nat. abundance, efficiency, background, ...

Phase space

$0\nu\beta\beta$ decay rate scales with Q^5

$2\nu\beta\beta$ decay rate scales with Q^{11}

Isotope	*Q-value (keV)*	*Nat. abund. (%)*	*$(PS\ 0\nu)^{-1}$ (yrs)*	*$(PS\ 2\nu)^{-1}$ (yrs)*
Ca 48	**4271**	**0.187**	**4.10E24**	**2.52E16**
Ge 76	**2039**	**7.8**	**4.09E25**	**7.66E18**
Se 82	**2995**	**9.2**	**9.27E24**	**2.30E17**
Zr 96	**3350**	**2.8**	**4.46E24**	**5.19E16**
Mo 100	**3034**	**9.6**	**5.70E24**	**1.06E17**
Pd 110	**2013**	**11.8**	**1.86E25**	**2.51E18**
Cd 116	**2809**	**7.5**	**5.28E24**	**1.25E17**
Sn 124	**2288**	**5.64**	**9.48E24**	**5.93E17**
Te 130	**2529**	**34.5**	**5.89E24**	**2.08E17**
Xe 136	**2479**	**8.9**	**5.52E24**	**2.07E17**
Nd 150	**3367**	**5.6**	**1.25E24**	**8.41E15**

Future considered projects

J. Engel, S.Elliott, JPG 2004

CARVEL	Ca-48	100 kg $^{48}CaWO_4$ crystal scintillators
COBRA	Te-130	10 kg CdTe semiconductors
DCBA	Nd-150	20 kg Nd layers between tracking chambers
NEMO	Mo-100, Various	10 kg of ββ isotopes (7 kg of Mo), expand to superNEMO
CAMEO	Cd-114	1 t $CdWO_4$ crystals
CANDLES	Ca-48	Several tons CaF_2 crystals in liquid scint.
CUORE	Te-130	750 kg TeO_2 bolometers
EXO	Xe-136	1 ton Xe TPC (gas or liquid)
GEM	Ge-76	1 ton Ge diodes in liquid nitrogen
GENIUS	Ge-76	1 ton Ge diodes in liquid nitrogen
GERDA	Ge-76	~30-40 kg Ge diodes in LN, expand to larger masses
GSO	Gd-160	2 t Gd_2SiO_5:Ce crystal scint. in liquid scint.
Majorana	Ge-76	~180 kg Ge diodes, expand to larger masses
MOON	Mo-100	Mo sheets between plastic scint., or liq. scint.
Xe	Xe-136	1.56 t of Xe in liq. Scint.
XMASS	Xe-136	10 t of liquid Xe

small scale ones will expand, very likely not a complete list...

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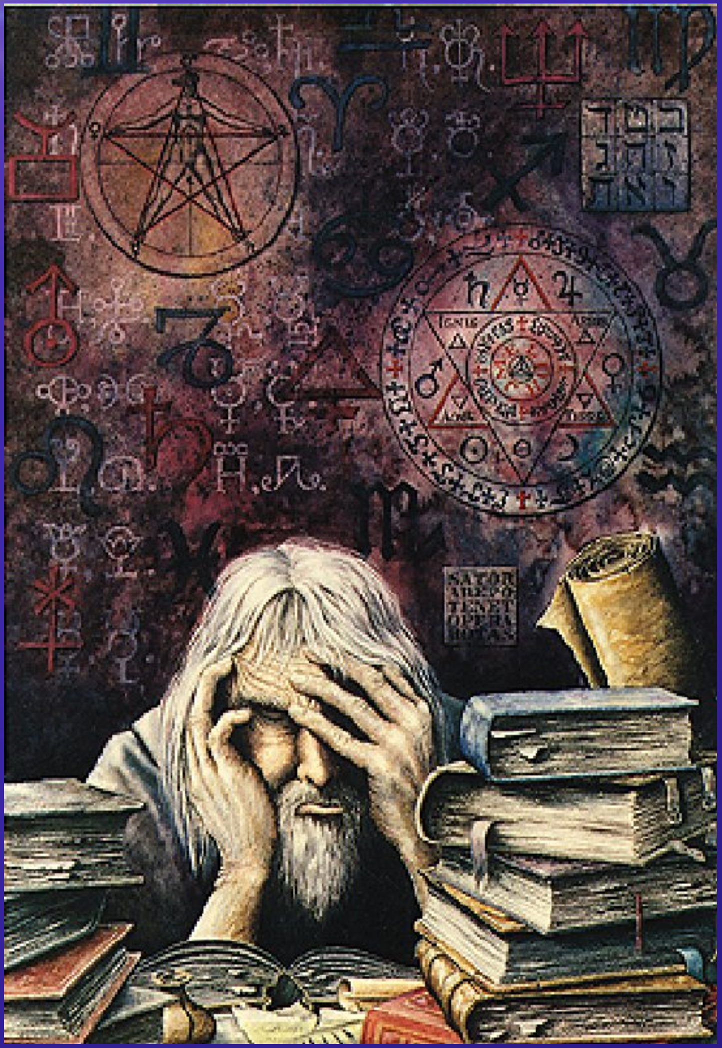

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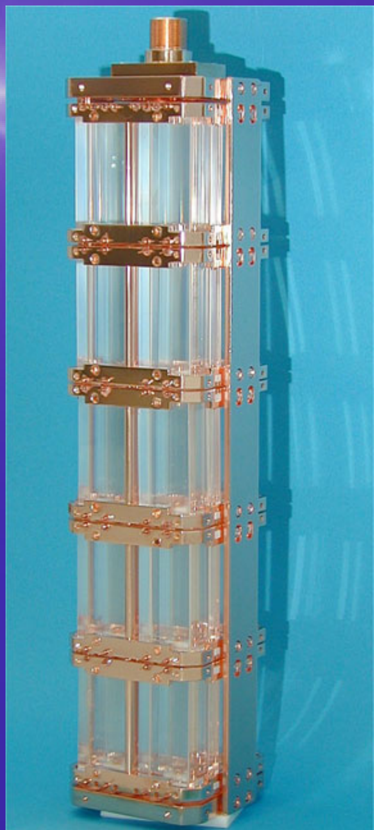
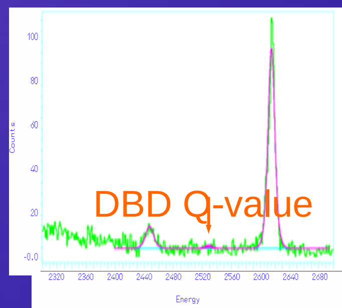
Running experiments



CUORICINO: cryogenic bolometers

40.7 kg TeO_2



$T_{1/2}$ > 1.8 x 10^{24} yr (90% CL)

m_ν <0.2 -1.1 eV

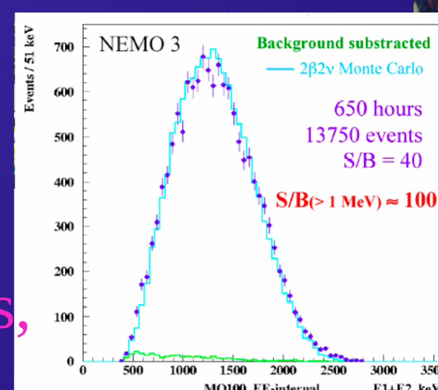
C. Arnaboldi et al, hep-ex/0501034

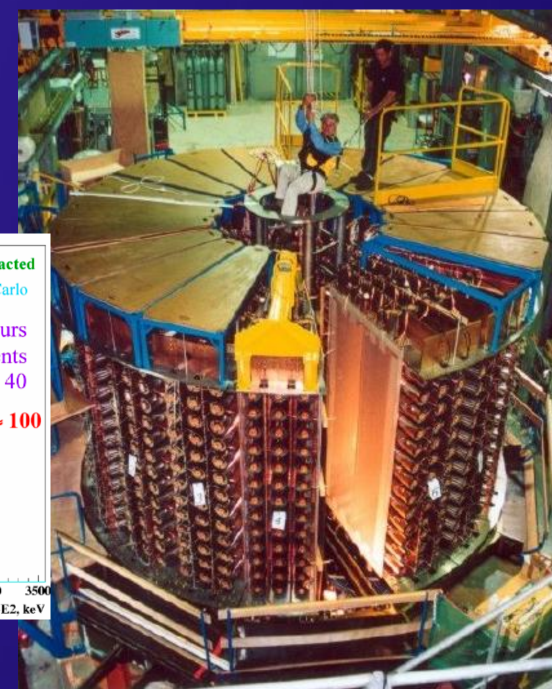
Future: CUORE

760 kg TeO_2

approved

NEMO-3: TPC





10 kg enriched foils,

6 kg ^{100}Mo

$T_{1/2}$ > 4.6 x 10^{23} yr (90% CL)

m_ν < 0.7 - 2.8 eV

R. Arnold et al, hep-ex/0507083

Idea: Super-NEMO (100 kg)

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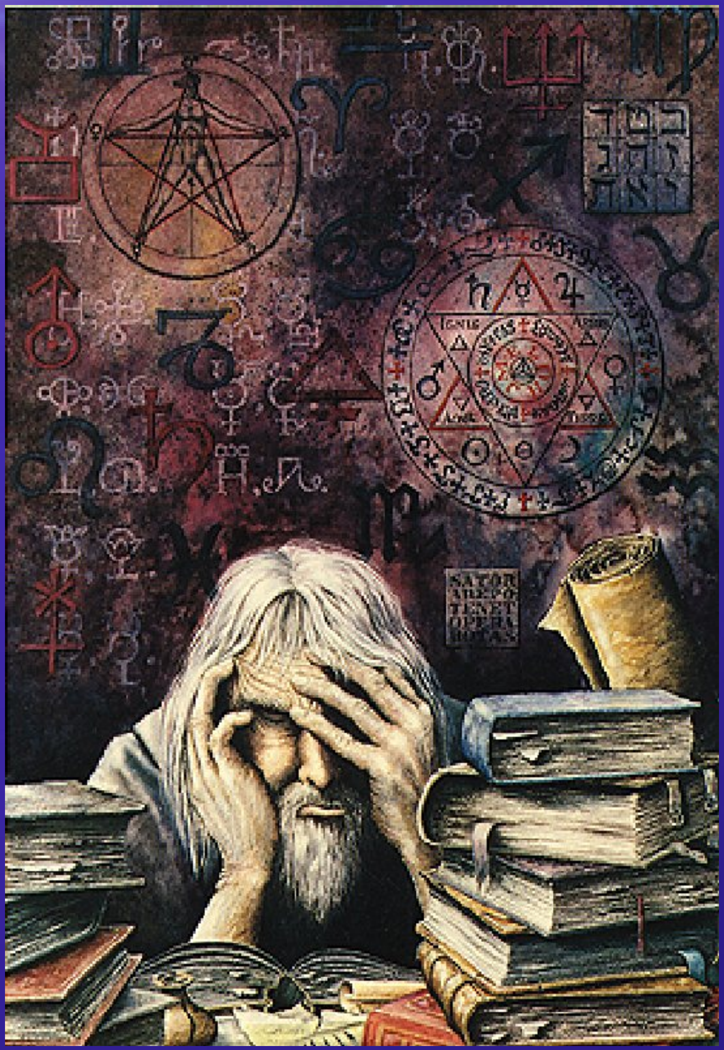

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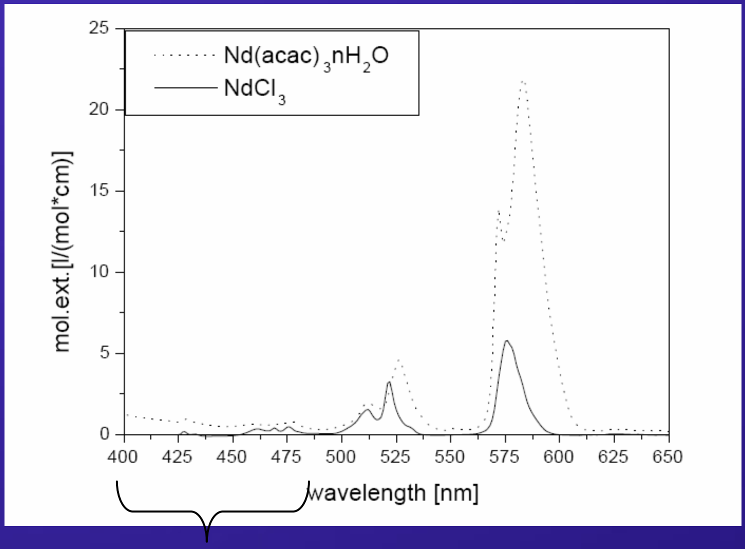
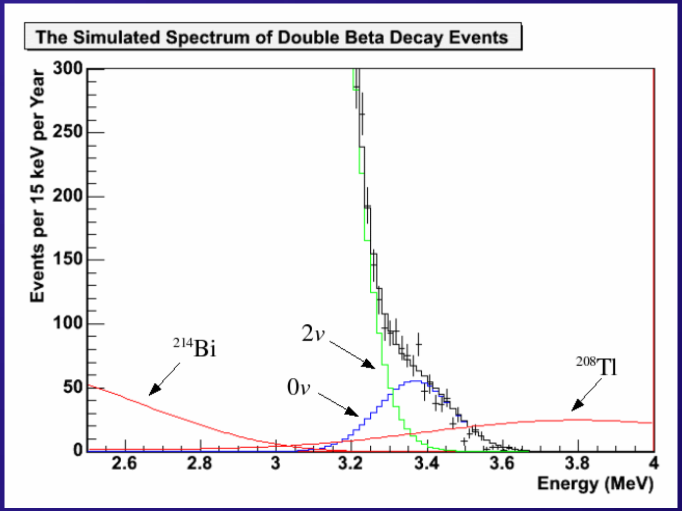
Other German activities

- R&D request for development of a cryogenic double beta in preparation (TU München)
- Metal loaded organic scintillator development (MPIK Heidelberg), Nd-loaded for double beta



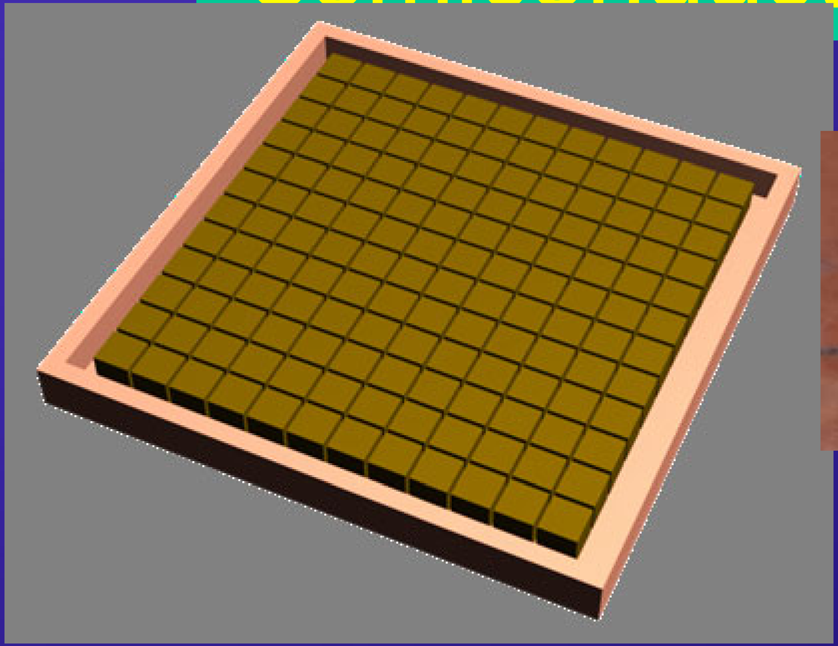
Window for scintillation light

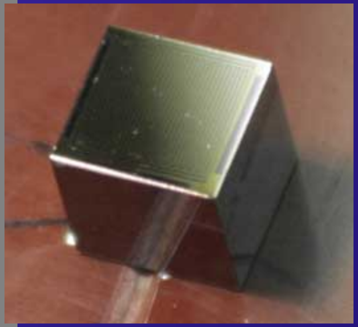


SNO++, Nd-loaded scintillator from BNL

COBRA

Use large amount of CdZnTe Semiconductor Detectors





Array of $1cm^3$ CdZnTe detectors

K. Zuber, Phys. Lett. B 519,1 (2001)

+ further interested institutes

Cobra - The people

C. Gößling, H. Kiel, D. Münstermann, S. Oehl, T. Villett
University of Dortmund
J. Dawson, C. Montag, D. Polzaird,
C. Reeve, J. Wilson, K. Zuber
University of Sussex
P.F. Harrison, B. Morgan, Y. Ramachers, D. Stewart
University of Warwick
A. Boston, P. Nolan
University of Liverpool
B. Fulton, A. Smith, R. Wadsworth
University of York
T. Bloxham, M. Freer
University of Birmingham
A. Fauler, M. Fiederle
Material Research Centre Freiburg
P. Seller
Rutherford Appleton Laboratory
M. Junker
Laboratori Nazionali del Gran Sasso

Isotopes

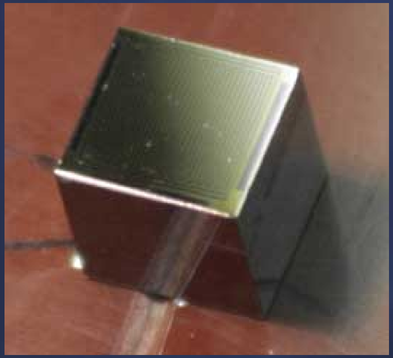
	nat. ab. (%)	Q (keV)	Decay mode
Zn70	0.62	1001	ß-ß-
Cd114	28.7	534	ß-ß-
Cd116	7.5	2805	ß-ß-
Te128	31.7	868	ß-ß-
Te130	33.8	2529	ß-ß-
Zn64	48.6	1096	ß+/EC
Cd106	1.21	2771	ß+ß+
Cd108	0.9	231	EC/EC
Te120	0.1	1722	ß+/EC

Advantages

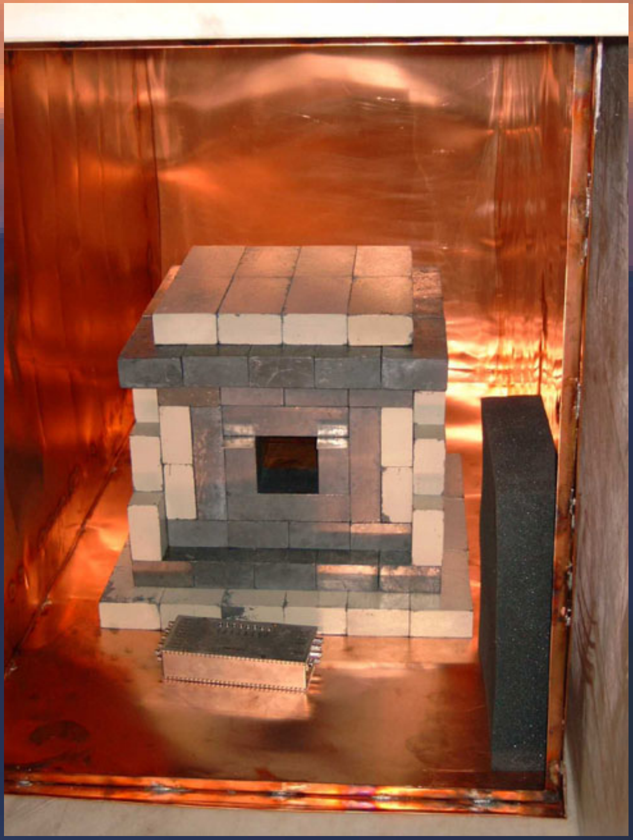
- Source = detector
- Semiconductor (Good energy resolution, clean)
- Room temperature
- Modular design (Coincidences)
- Two isotopes at once
- Industrial development of CdTe detectors
- ^{116}Cd above 2.614 MeV
- Tracking („Solid state TPC“)

The 2x2 prototype

Setup installed at Gran Sasso Underground Laboratory



4 naked 1cm^3 CdZnTe



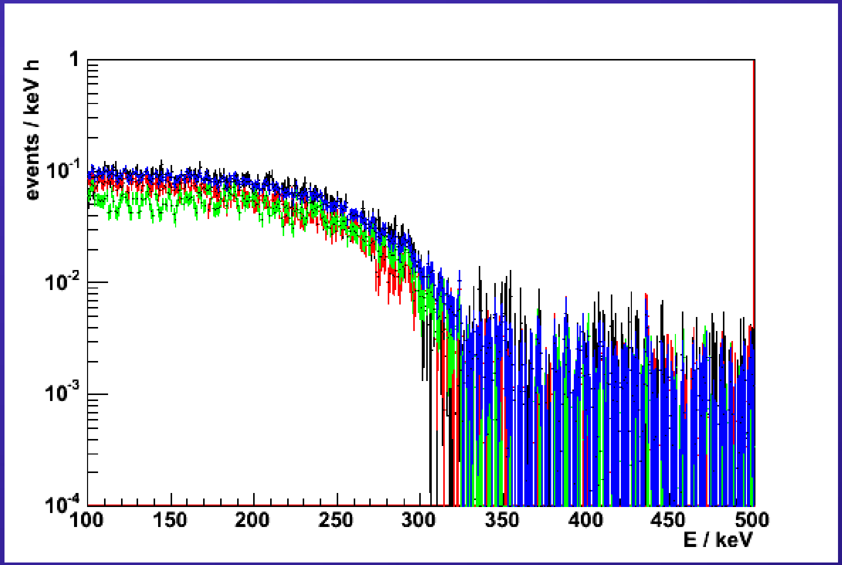
Half-life limits improved by a factor 5-10

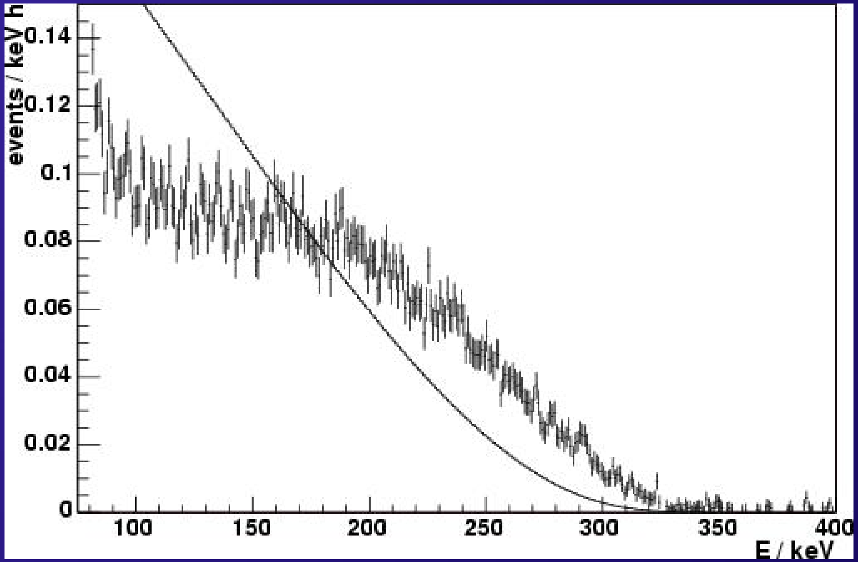
2.5 kg x days of data

Physics - ^{113}Cd

^{113}Cd one of only three 4-fold forbidden β-emitters known in nature

$$T_{1/2} = (8.2 \pm 0.2\ (\text{stat.})\ ^{+0.2}_{-1.0}\ (\text{sys}))\ 10^{15}\ \text{yrs}$$

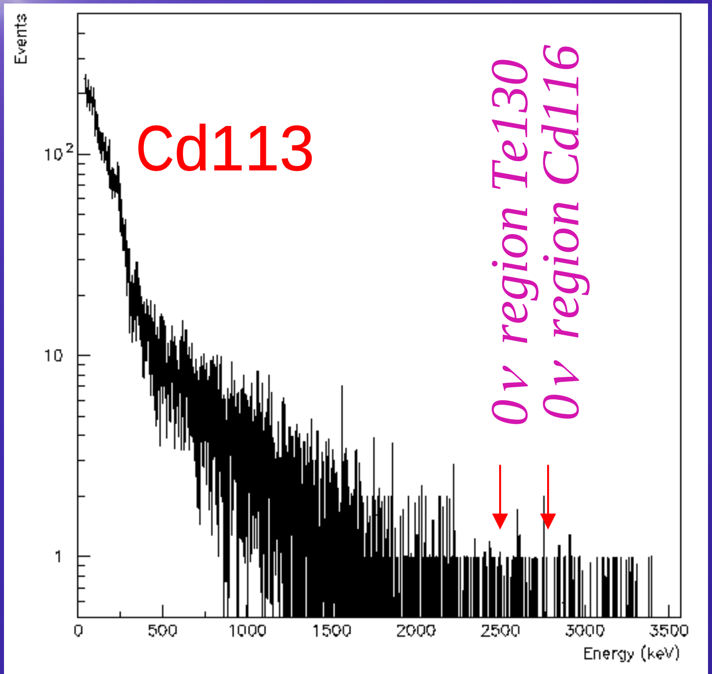




C. Goessling et al., nucl-ex/0508016

COBRA results

H.Kiel, D. Münstermann, K. Zuber, Nucl. Phys. A 723,499 (2003)



$0\nu\beta\beta$	NPA723	Current
^{70}Zn	1.3×10^{16}	2.9×10^{17}
^{116}Cd	8.0×10^{18}	1.1×10^{19}
^{130}Te	3.3×10^{19}	8.2×10^{19}

EC-modes		NAP723	Current
^{106}Cd	0■β^+ EC	3.8×10^{17}	1.6×10^{18}
^{64}Zn	0■β^+ EC	2.8×10^{16}	2.6×10^{17}
^{120}Te	0■β^+EC	2.2×10^{16}	9.3×10^{16}
Current results are preliminary			

$T_{1/2}$ close to 10^{20} years obtained

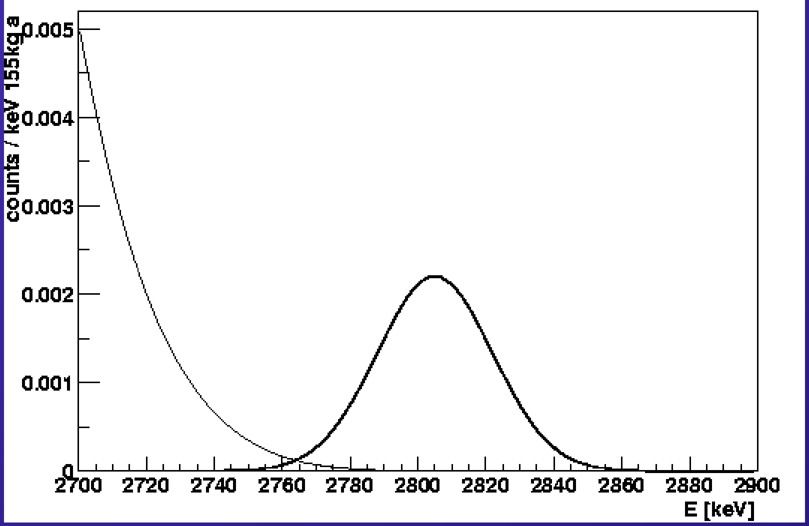
2νββ - decay

2νββ is ultimate, irreducible background

Energy resolution important → semiconductor

Fraction of 2νββ in 0 νββ peak: $$F = \frac{8Q(\Delta E/Q)^6}{m_e} = 3.7*10^{-10}$$

S. Elliott, P. Vogel, Ann. Rev. Nucl. Part. Sci. 2002



Signal/Background:

$$\frac{S}{B} = \frac{1}{F}\frac{T_{1/2}^{2\nu}}{T_{1/2}^{0\nu}} = 433$$

$$T_{1/2}^{2\nu} = 3.2\times10^{19}\,yrs$$

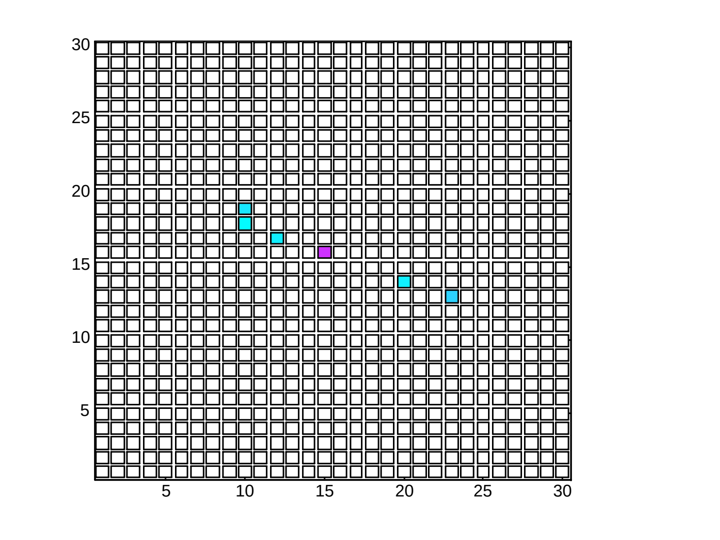
$$T_{1/2}^{0\nu} = 2\times10^{26}\,yrs$$

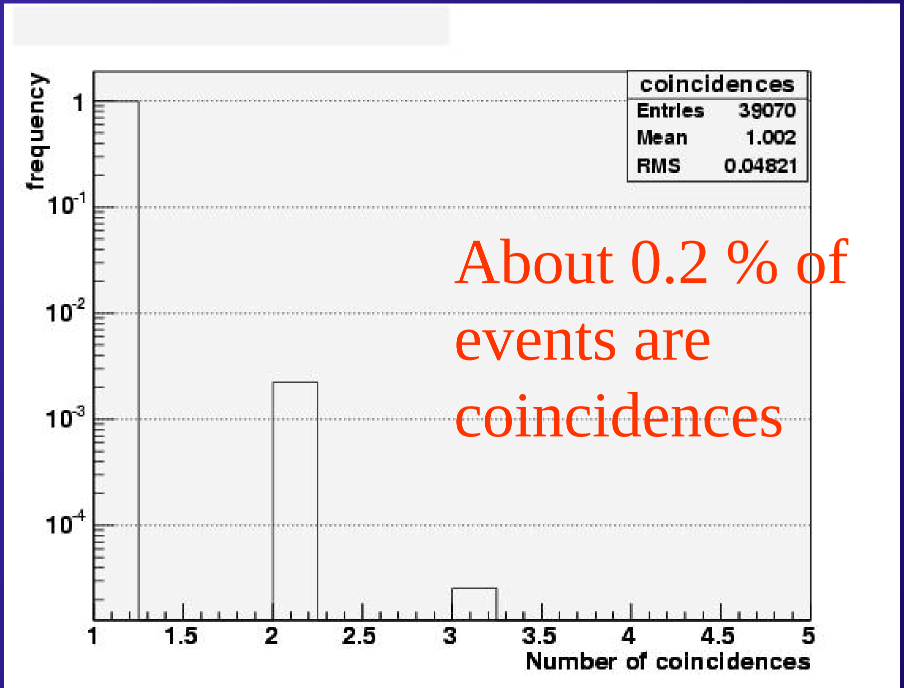
+ Tracking option

Coincidences

Aim: Coincidences among crystals should significantly reduce gamma background

2614 keV gamma (MC)

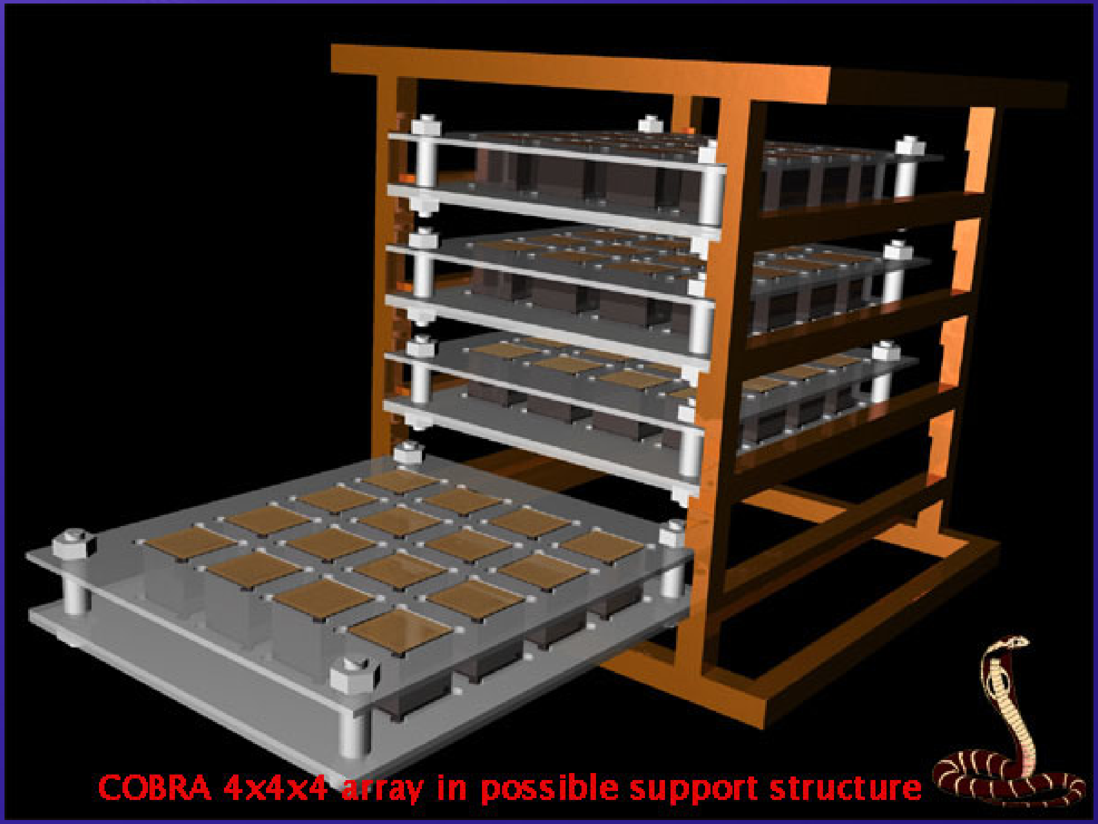




Array too small to prove power of coincidences → Larger Array

The 64 detector array

Aim for next 2 years: The next step towards a large scale experiment,
Scalable modular design, explore coincidences



Mass factor 16 higher, about 0.4 kg CdZnTe

Include:
Cooling
Nitrogen flushing

Physics:
- Can access 2νECEC in theoretically predicted region
- Precision measurement of 113Cd
- New limits

All detectors at Dortmund, LNGS end 2005

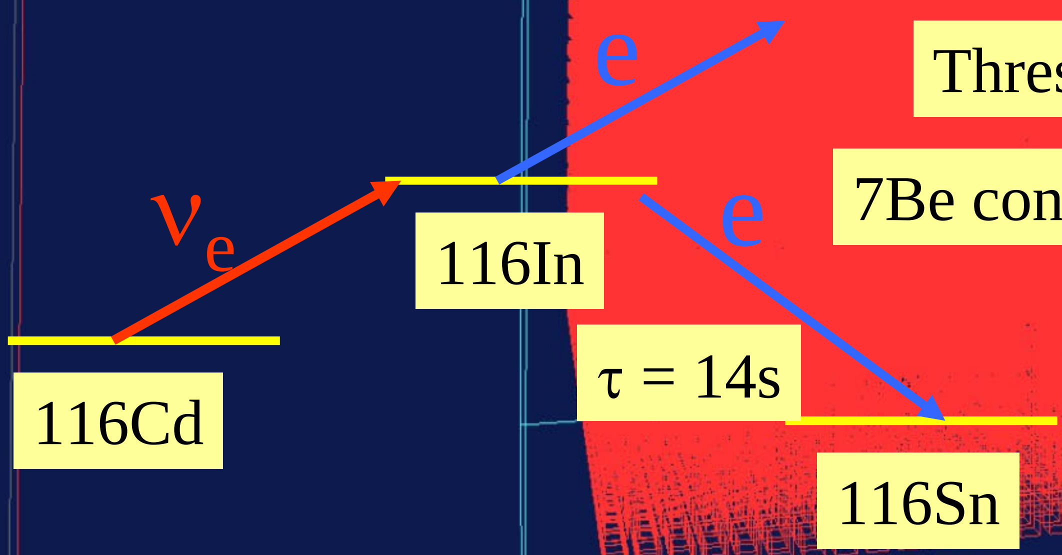
Dimension it right!

Current idea: 40x40x40 CdZnTe detectors = 420 kg, enriched in 116Cd

A real time low-energy solar neutrino experiment?

Threshold energy: 464 keV

7Be contribution g.s. alone: 227 SNU

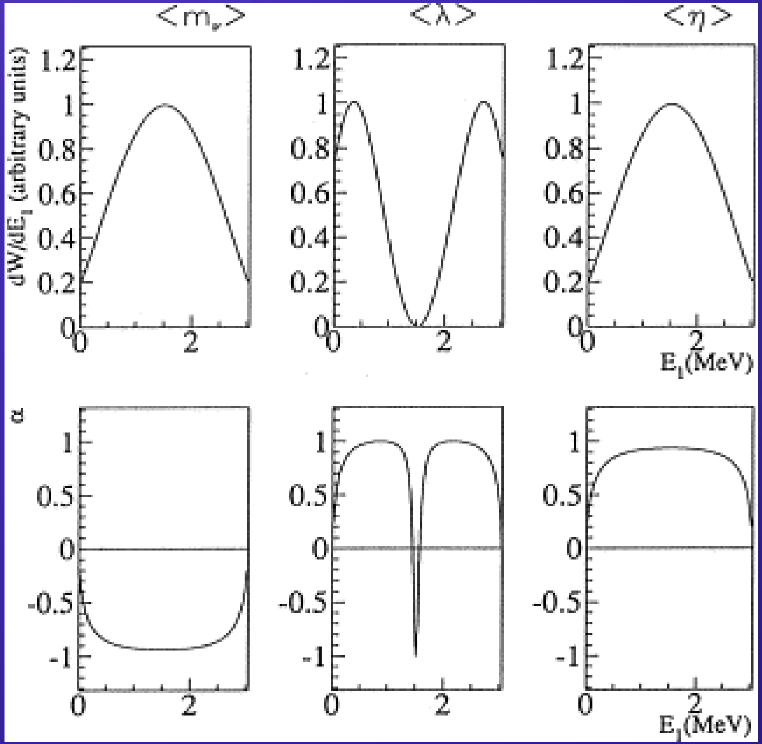


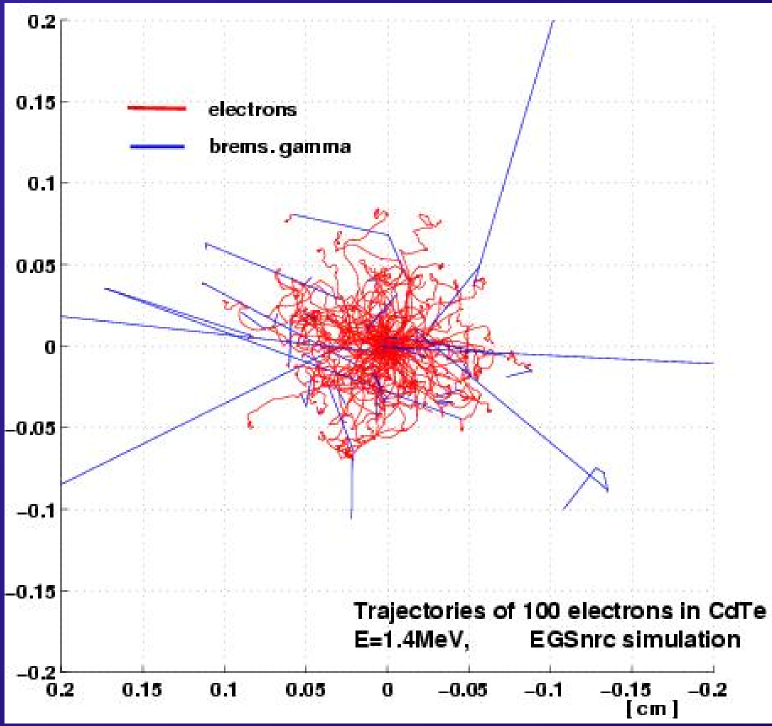
K. Zuber, Phys. Lett. B 571,148 (2003)

The solid state TPC

Introduce tracking properties by using segmented, pixellated electrodes and pulse shape analysis

Single electron spectra

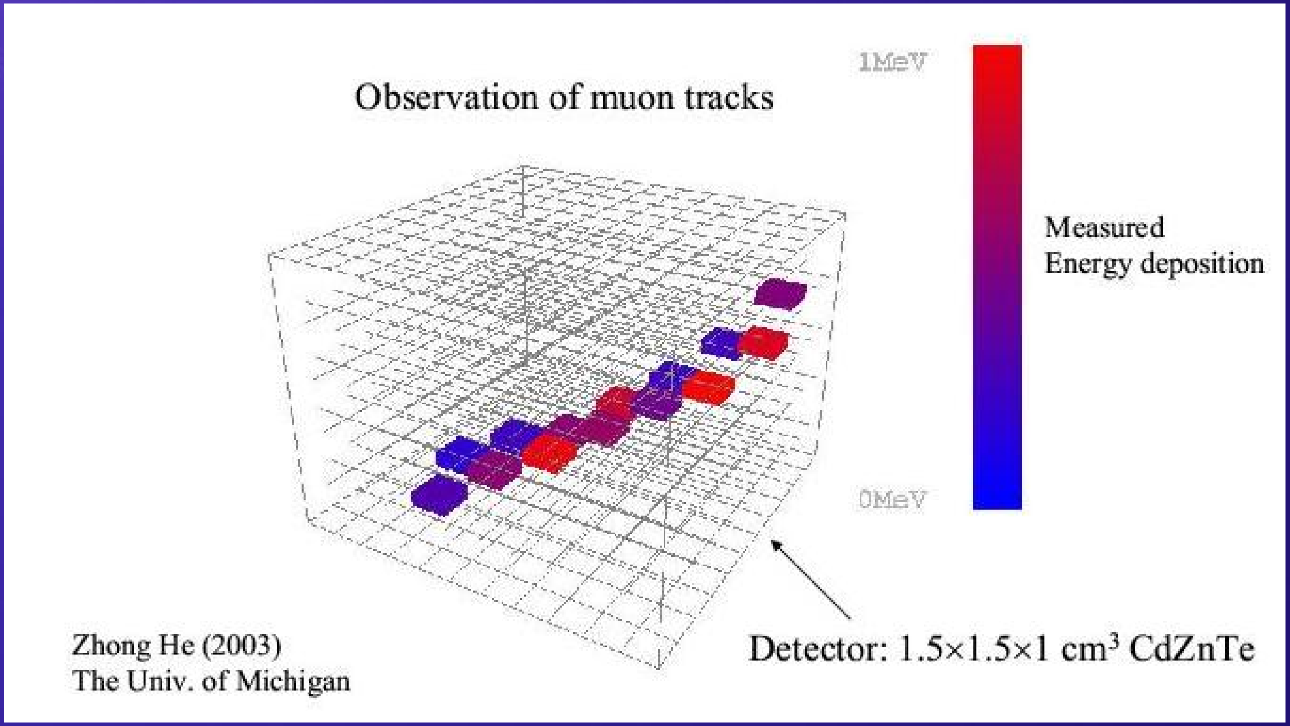


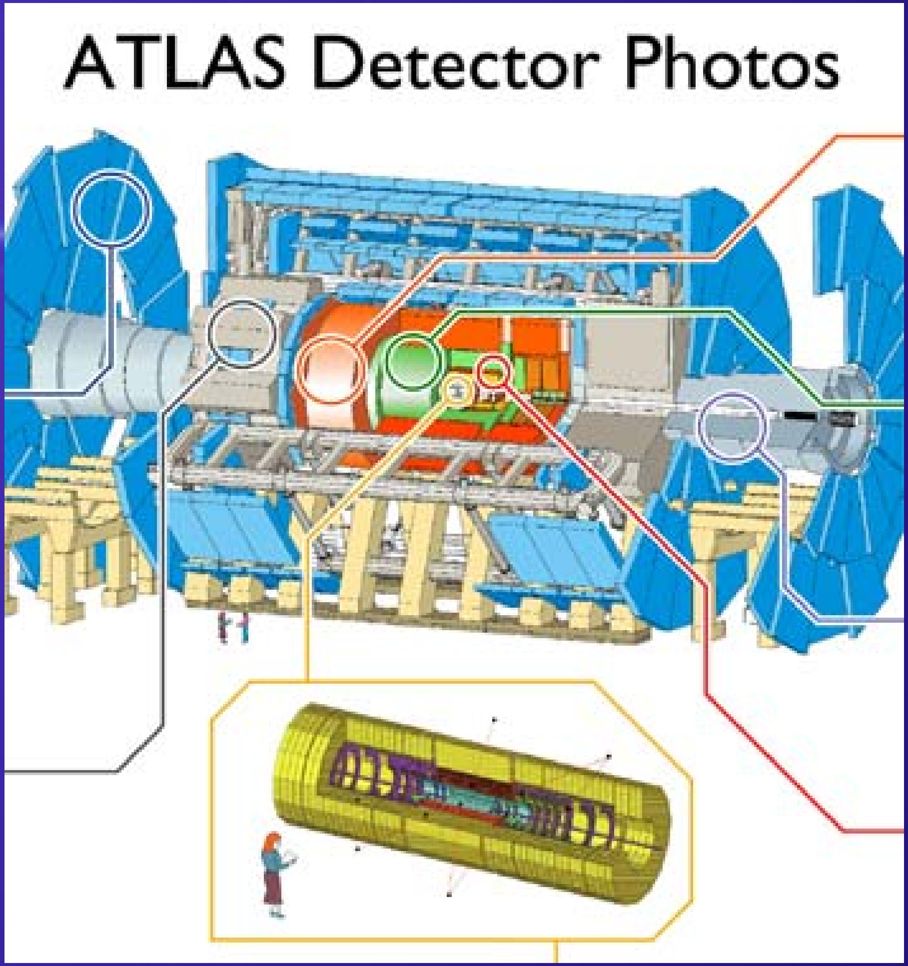


Angular correlation coefficient α

Pixellated detectors

3D - Pixelisation:





Nobody said it was going to be easy, and nobody was right

George W. Bush

Summary

- Neutrino physics made major steps forward in the last decade by establishing a non-vanishing rest mass
- Double beta decay is the gold plated channel to probe the fundamental character of neutrinos, considered to be the most important thing to do
- Coherent effort has started to provide nuclear matrix element calculations with better experimental input
- A lot of ongoing activities and experimental approaches
- COBRA rather new idea, but now a real existing experiment
- At least two different isotopes have to be measured