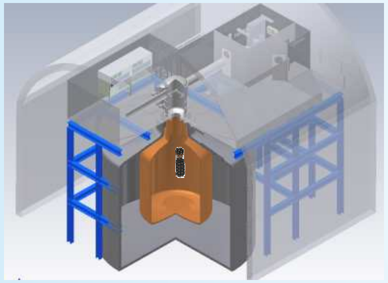
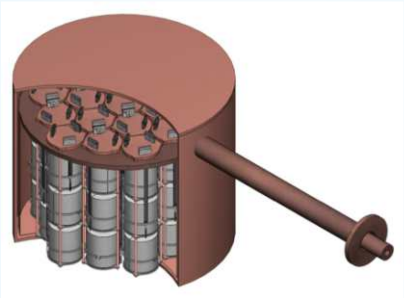
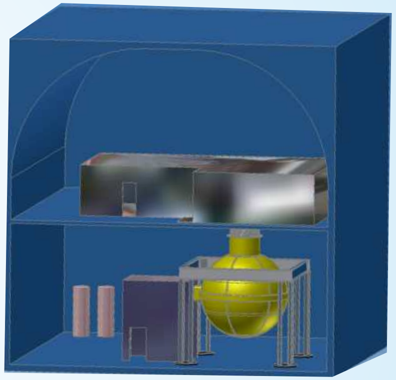
The Path to a 1 ton Germanium Experiment



GERDA



MAJORANA



SPHERE

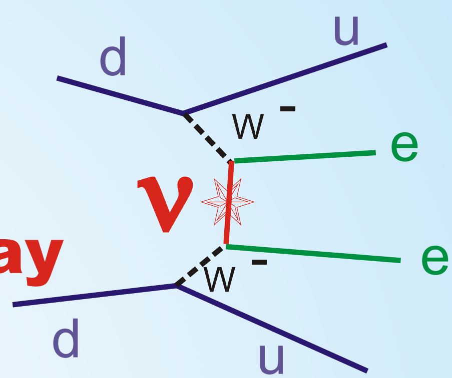
Beijing, 24.3.2011

I.Abt, MPI München

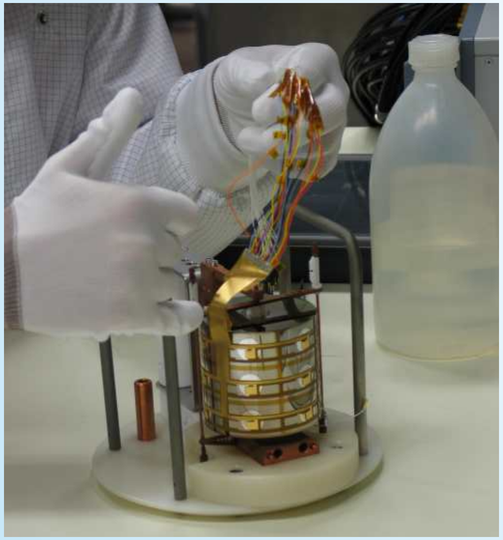
Content

Why do we want this?

- **dark matter**
- **neutrinoless double beta decay**



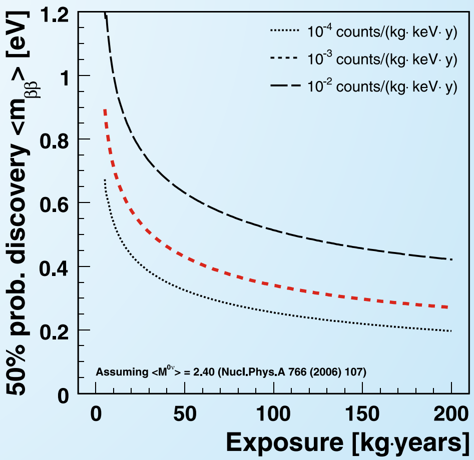
Experimental Options



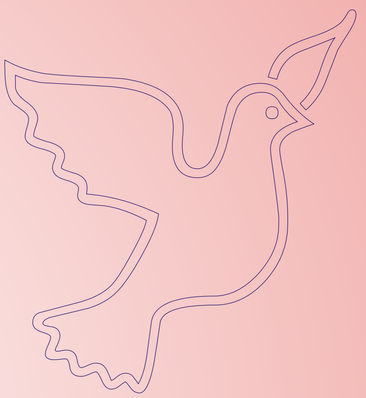
Experimental Reach

Background

Germanium



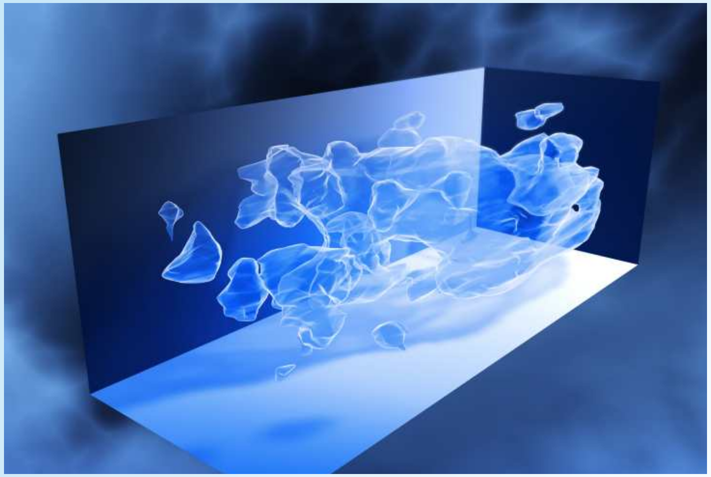
DISCLAIMER



I am not a member of either GERDA or MAJORANA.

Any opinion expressed is mine and does not represent the official view of GERDA or MAJORANA or the MPI für Physik.

Dark Matter And Neutrinos

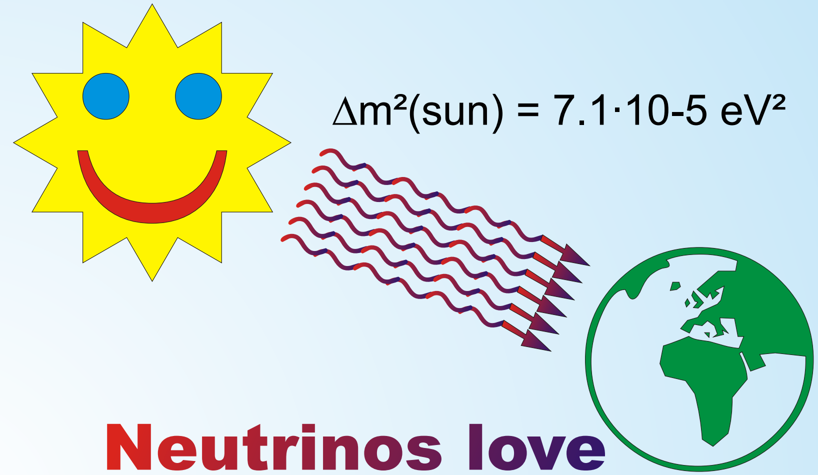


The universe is full of things we cannot see! → Zhou, Yufeng

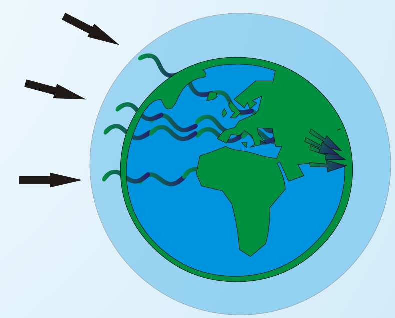
Dark Matter Searches

→ Yue, Qian
→ Ni, Kaixuan
→ Yang, Changgen

What is that stuff?



Neutrinos love to oscillate



Δm^2(atm) = 2.0·10-3 eV^2

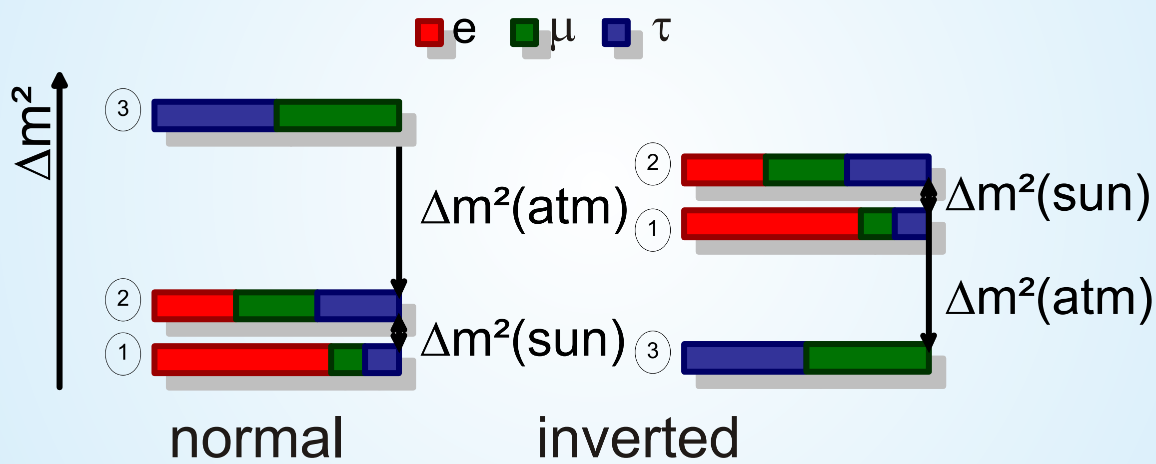
What is the scale?

Neutrinos Today

They are massive, massively mixed

might have an inverted hierarchy

inverted hierarchy

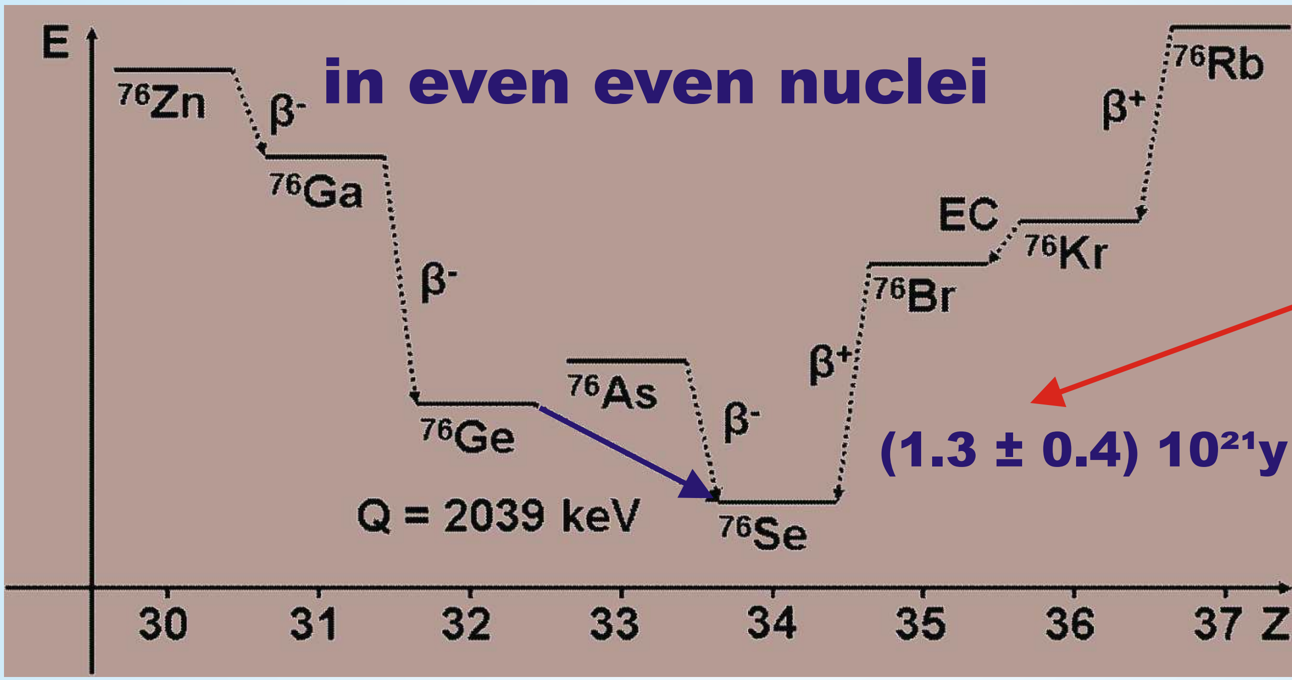


and might be Majorana particles.

→ Kai Zuber   Wong,Henry   Cao,Jun

A Chance to see Majorana Features

Double Beta Decay provides the stage.



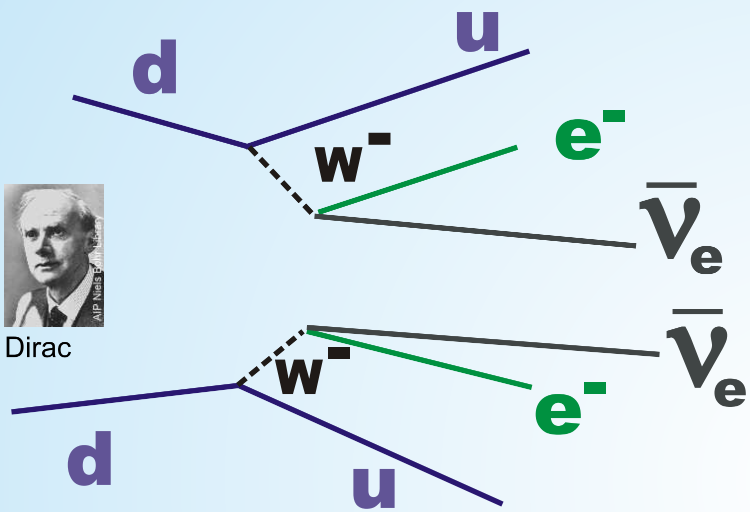
compare to age of universe $1.3\ 10^{10}$y

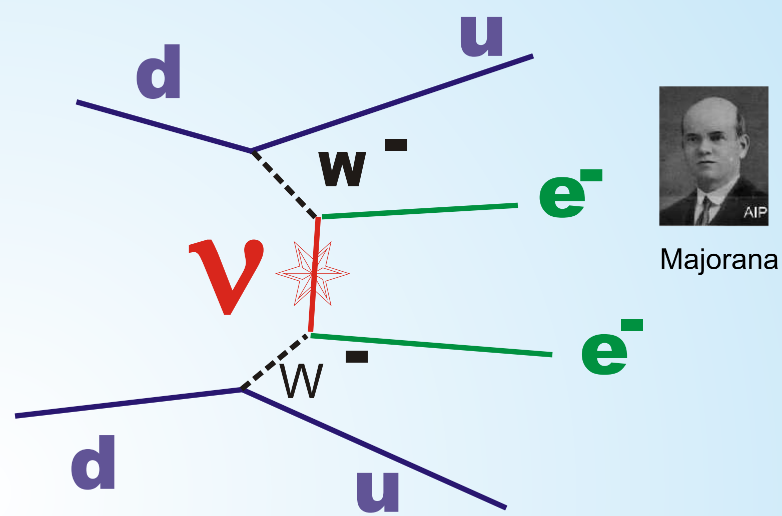
$^{76}Ge \rightarrow ^{76}Se$ Q = 2.039 MeV

Allready Dirac neutrinos can do that.

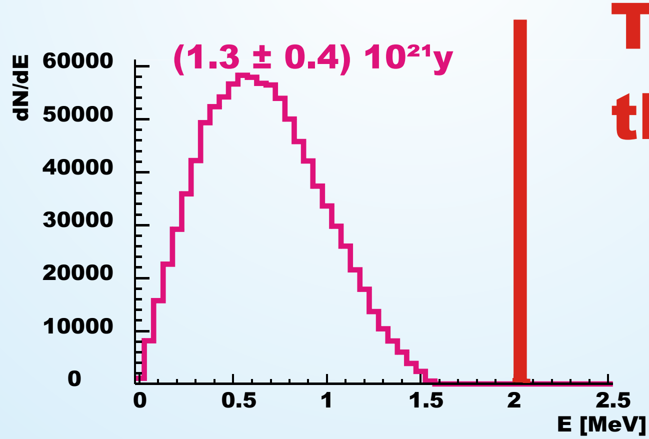
Many options: ^{48}Ca ^{76}Ge ^{82}Se ^{96}Zr ^{100}Mo ^{116}Cd

Neutrinoless Double Beta Decay





$$\nu = \bar{\nu}$$



The return of the line.

Unfortunately, it is not that big and there is background, not only

Halflife and Mass

$$\left[T_{1/2}\right]^{-1} = \sum_{spins} \int \left|M\right|^2 \delta\left(E_1 + E_2 - Q\right) \frac{d^3 p_1}{2\pi^3} \frac{d^3 p_2}{2\pi^3}$$

$$\left[T_{1/2}\right]^{-1} = G(Q,Z) \times \left| M^{GT} - \frac{g_V^2}{g_A^2} M^F \right| \times \left\langle m_{\beta\beta} \right\rangle^2$$

observable

Phase space

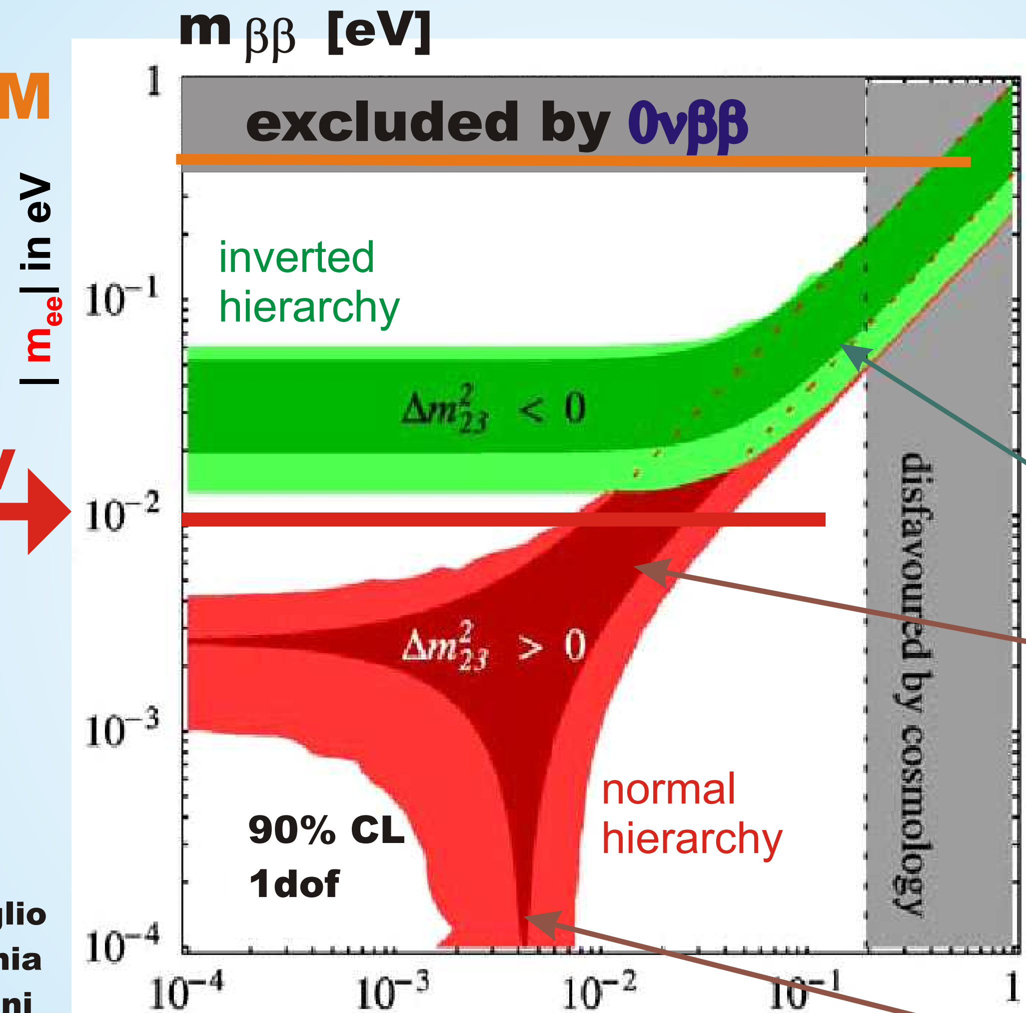
Nucl. Matrix elements

Coherent mass

$$\left\langle m_{\beta\beta} \right\rangle = \left| \sum_j m_j U_{ej}^2 \right| = \left| m_1 \cdot \left|U_{e1}\right|^2 + m_2 \cdot \left|U_{e2}\right|^2 e^{i(\alpha_2 - \alpha_1)} + m_3 \cdot \left|U_{e3}\right|^2 e^{i(-\alpha_1 - 2\delta)} \right|$$

Expectations and Goals

CLAIM



Lightest neutrino (m_1) in eV

10 meV

good goal

Feruglio
Strumia
Vissani
NPB 637

"Evidence for 0νββ"
$1.2 \cdot 10^{25}$
(0.69-4.18 3σ)
H.V.Klapdor - Kleingrothaus et al
Phys. Lett. B 586 (2004)

uncertainty from Majorana CP phases

This assumes that the neutrino is purely Majorana.

Conspiracy of Majorana phases

Experimental Situation

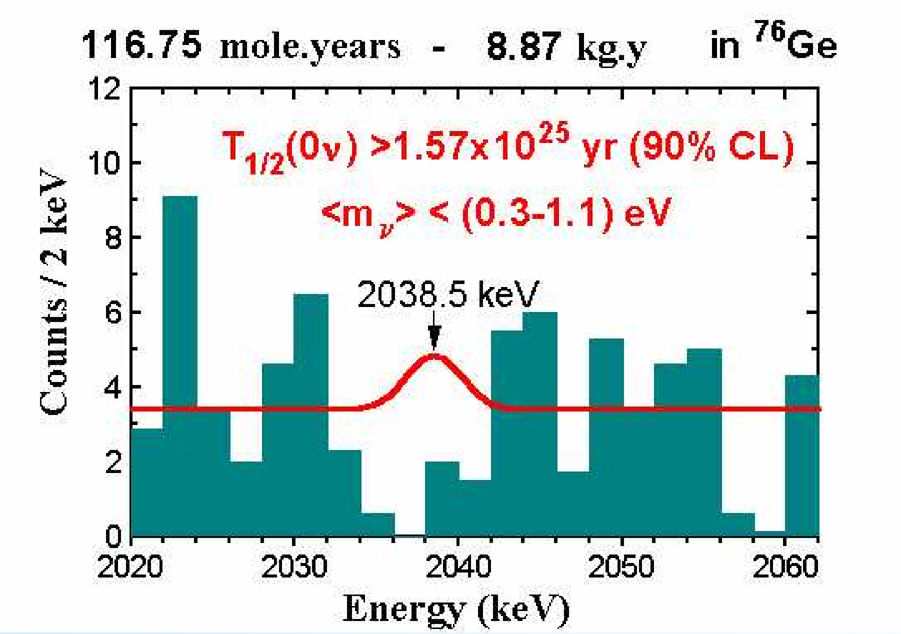
Experiment	Isotope	$\langle m_{\beta\beta} \rangle$ [meV]	$T_{1/2}$ [y]
Heidelberg-Moscow	^{76}Ge	440 [240 - 580]	$1.2 \cdot 10^{25}$
Heidelberg-Moscow	^{76}Ge	< 460	$> 1.9 \cdot 10^{25}$
IGEX	^{76}Ge	< 360 – 1070	$> 1.6 \cdot 10^{25}$
CUORICINO	^{130}Te	< 190 – 680	$> 3.0 \cdot 10^{24}$
NEMO-3	^{100}Mo	< 450 – 930	$> 1.1 \cdot 10^{24}$
NEMO-3	^{82}Se	< 1300 – 3200	$> 1.9 \cdot 10^{23}$

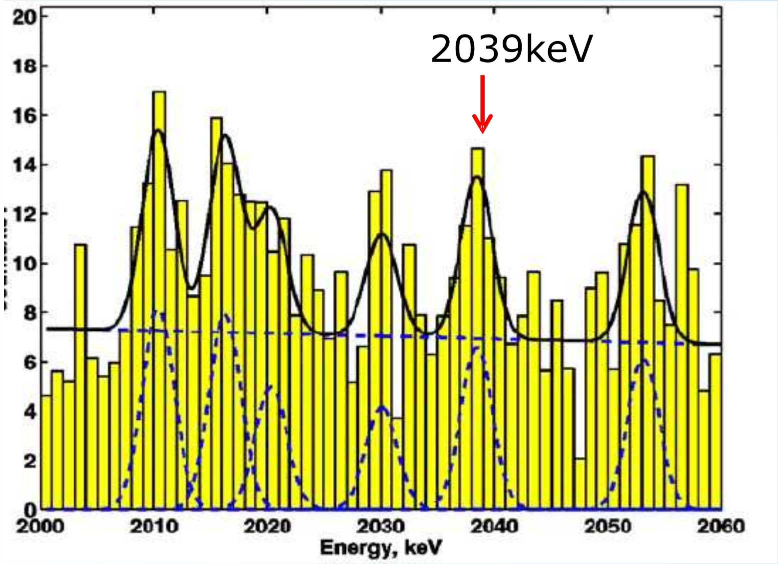
The same collaboration, Heidelberg-Moscow, published a limit and a claim.

The interpretation of all experimental data suffers from badly known matrix elements.

Quite a number of experiments planned.

Germanium Results





IGEX **Heidelberg-Moscow**

I cannot show you more revealing spectra....

Experimental Options

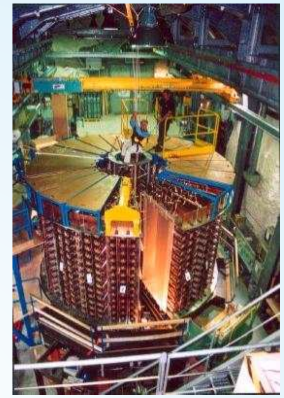
source = detector
germanium
tellurium

good efficiency
good energy resolution

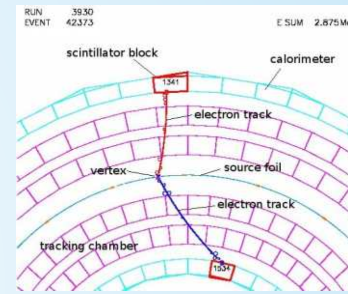
GERDA, MAJORANA

→ 1 ton

CUORE, EXO



source ≠ detector

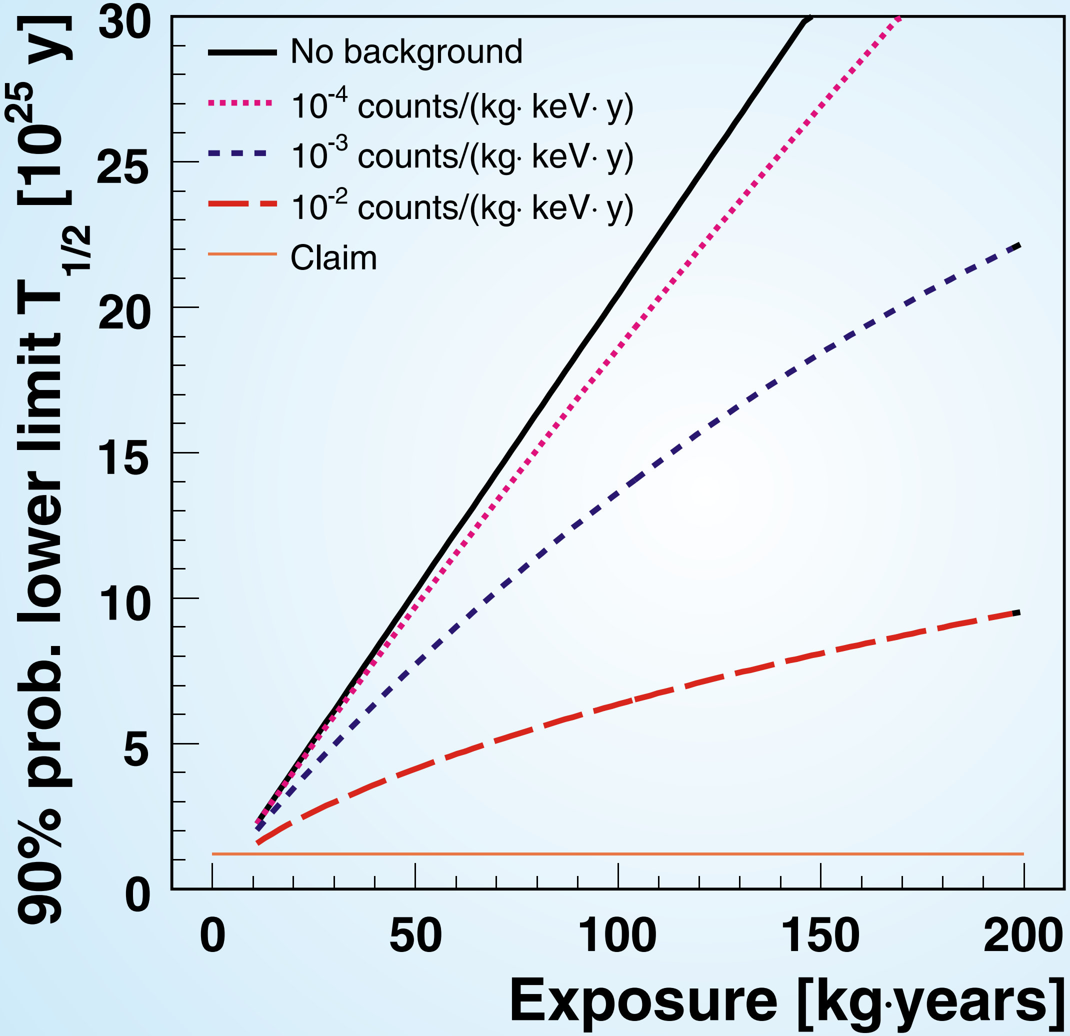


many
isotopes in parallel

NEMO

$2\nu\beta\beta$ is irreducible background

Importance of Background

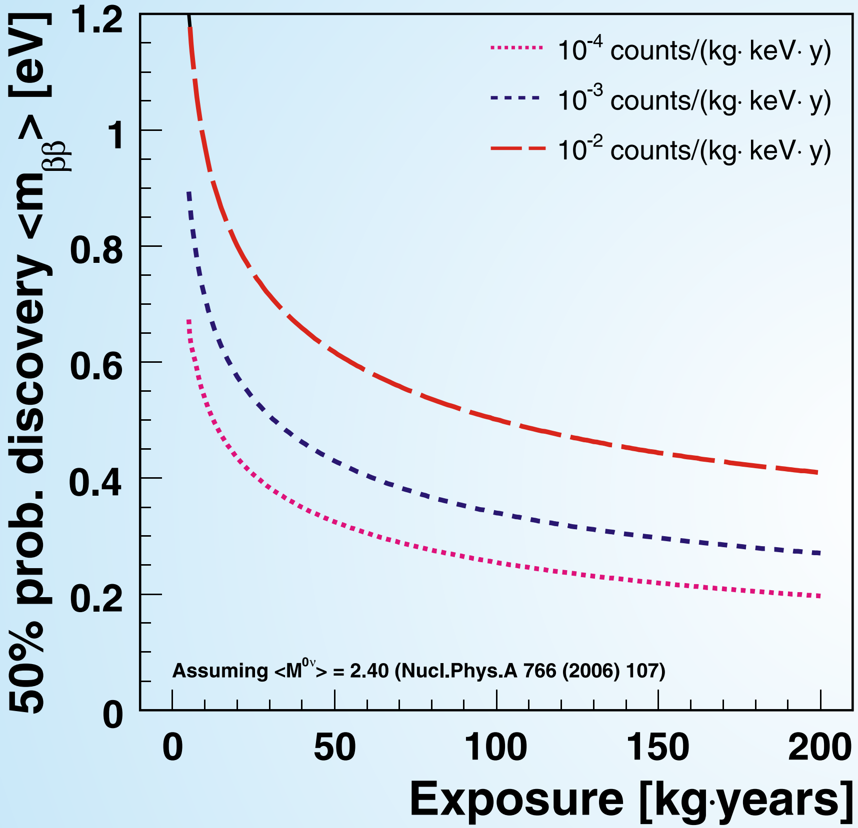


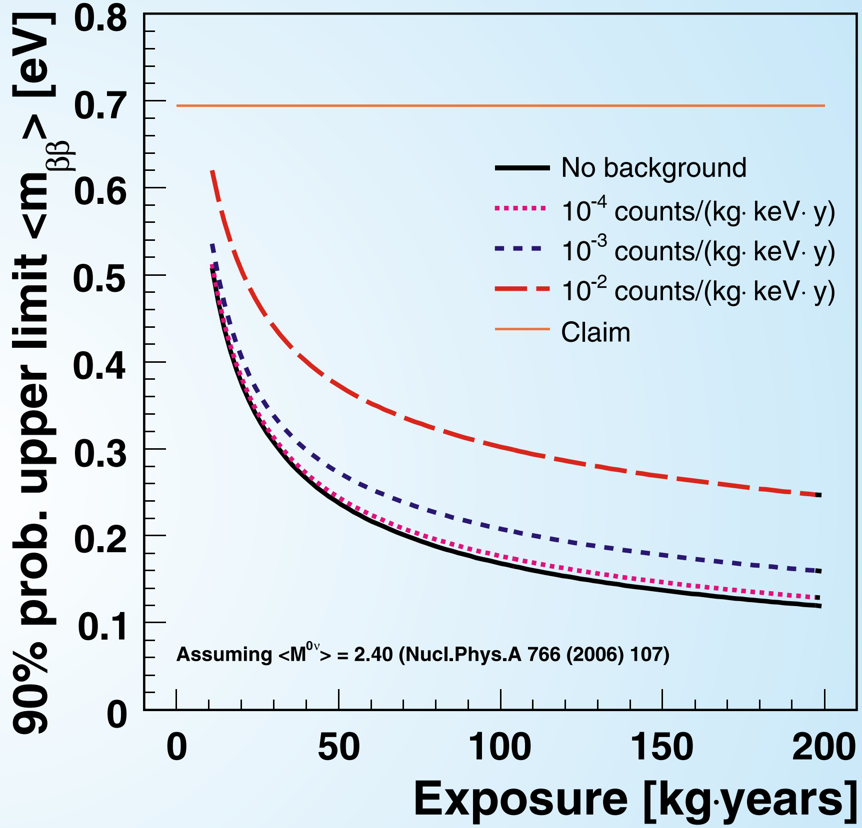
Reach is proprtional to exposure, but for background.

Exposure larger than 100 kg year is wasted for background of 10^{-2} /(kg keV y)

Courtesy of Kevin Kroeninger

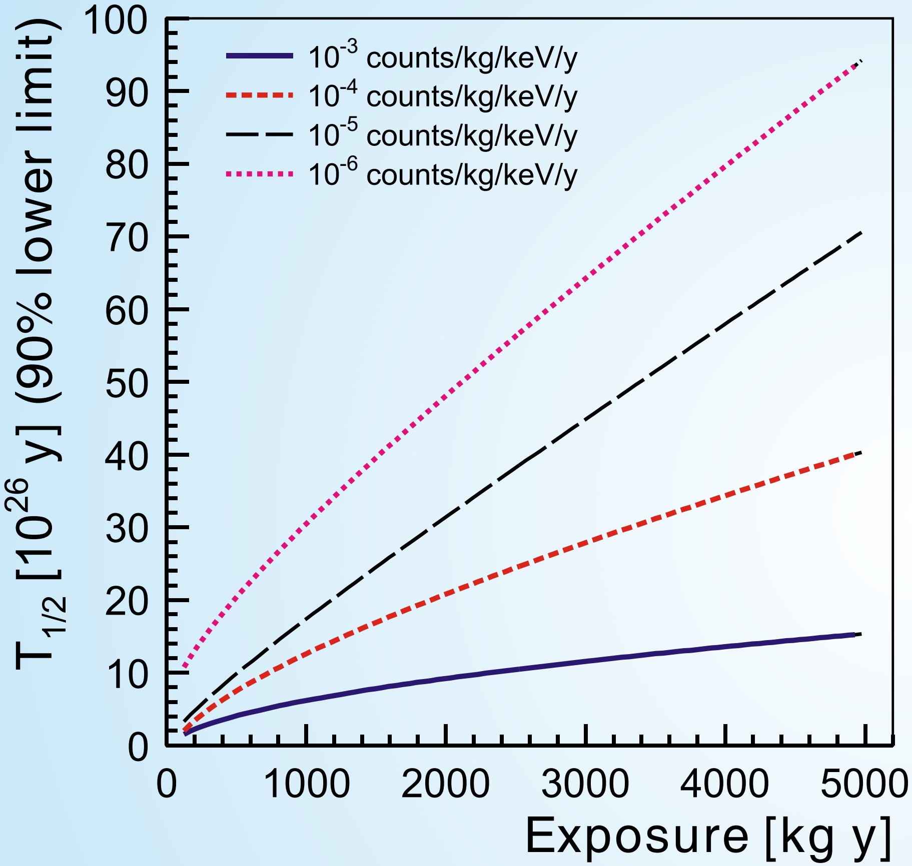
Importance of Background

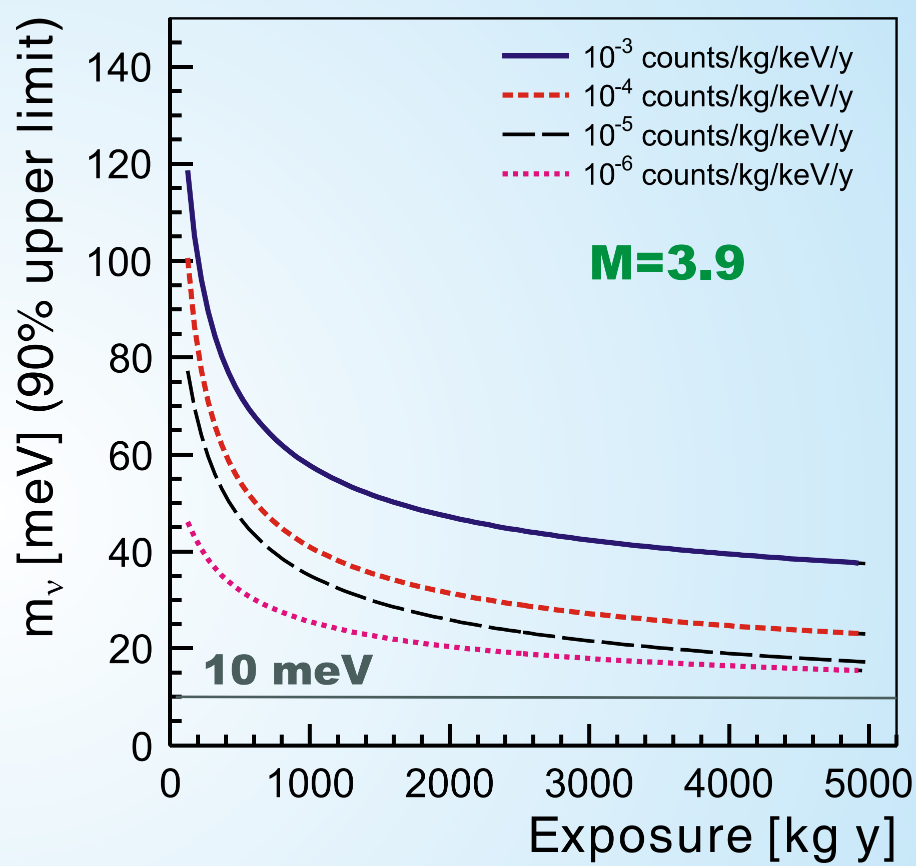




GERDA and MAJORANA are on the 100 kg years scale and far away from the 10 meV needed to exclude inverted hierarchy.

Importance of Background

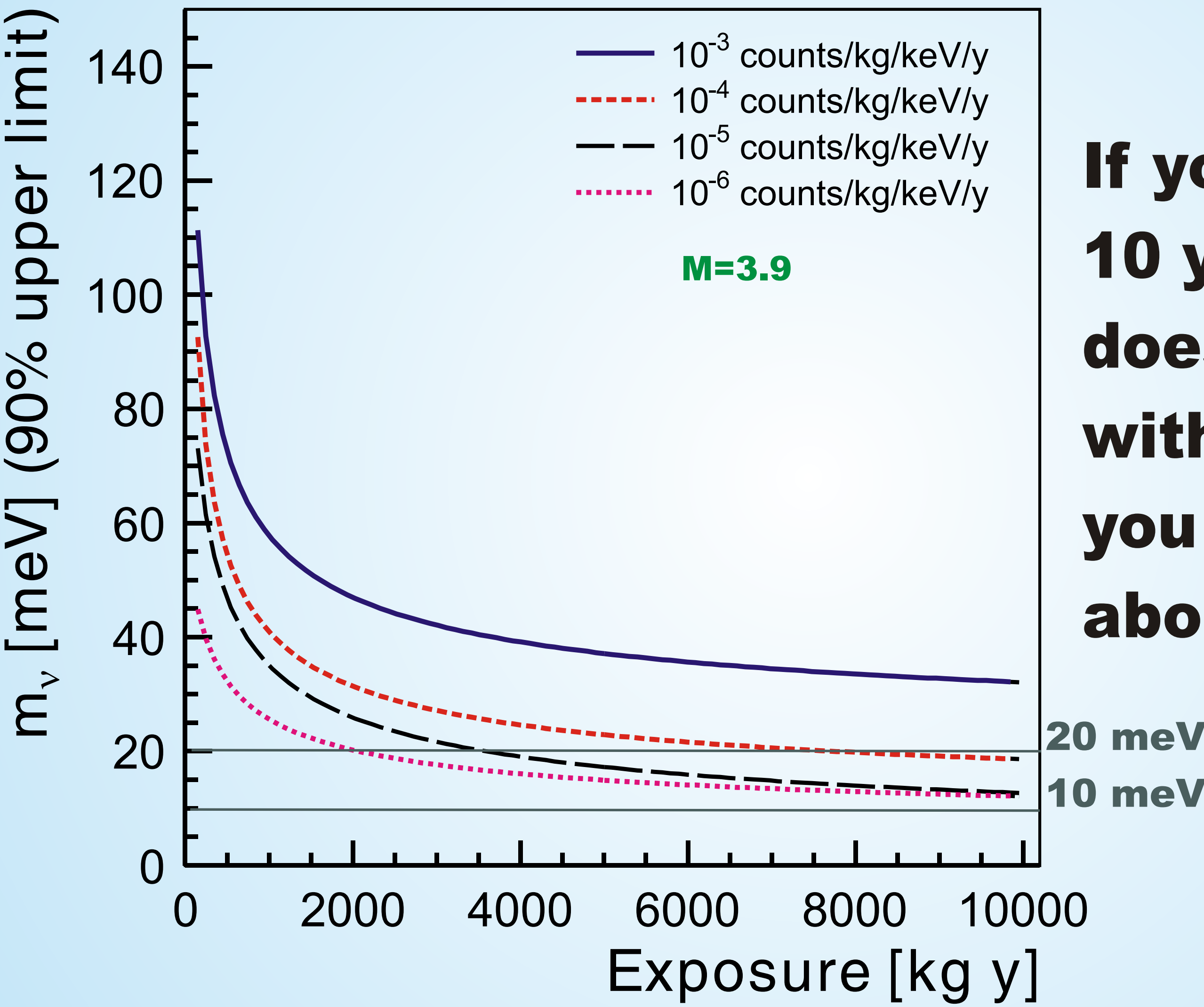




Even 10^{-6} is not good enough to reach 10 meV with 5000 kg y .

Courtesy of Kevin Kroeninger

Reaching the Limits



If you measure 10 years, 10^{-6} does not help; with $10^{-5/-4}$ you can reach about 13/20 meV.

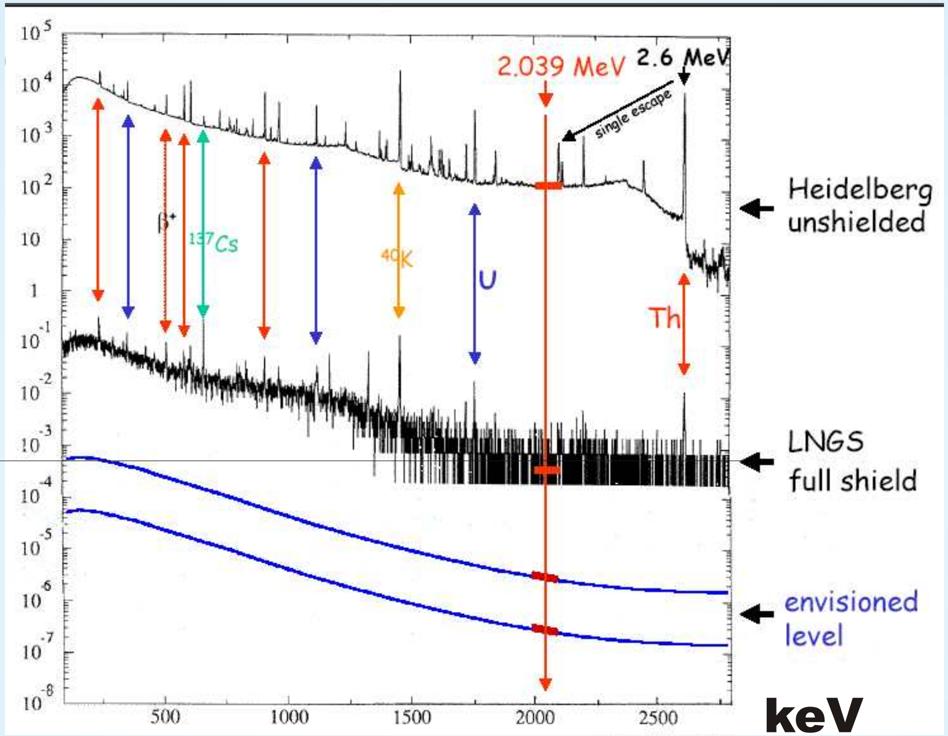
Courtesy of Kevin Kroeninger

Background as Seen

Experience from Heidelberg-Moscow

cnts/
(keV kg d)

0.15 cnts/
(kev kg year)



Primordial decay chains dominate the spectrum.

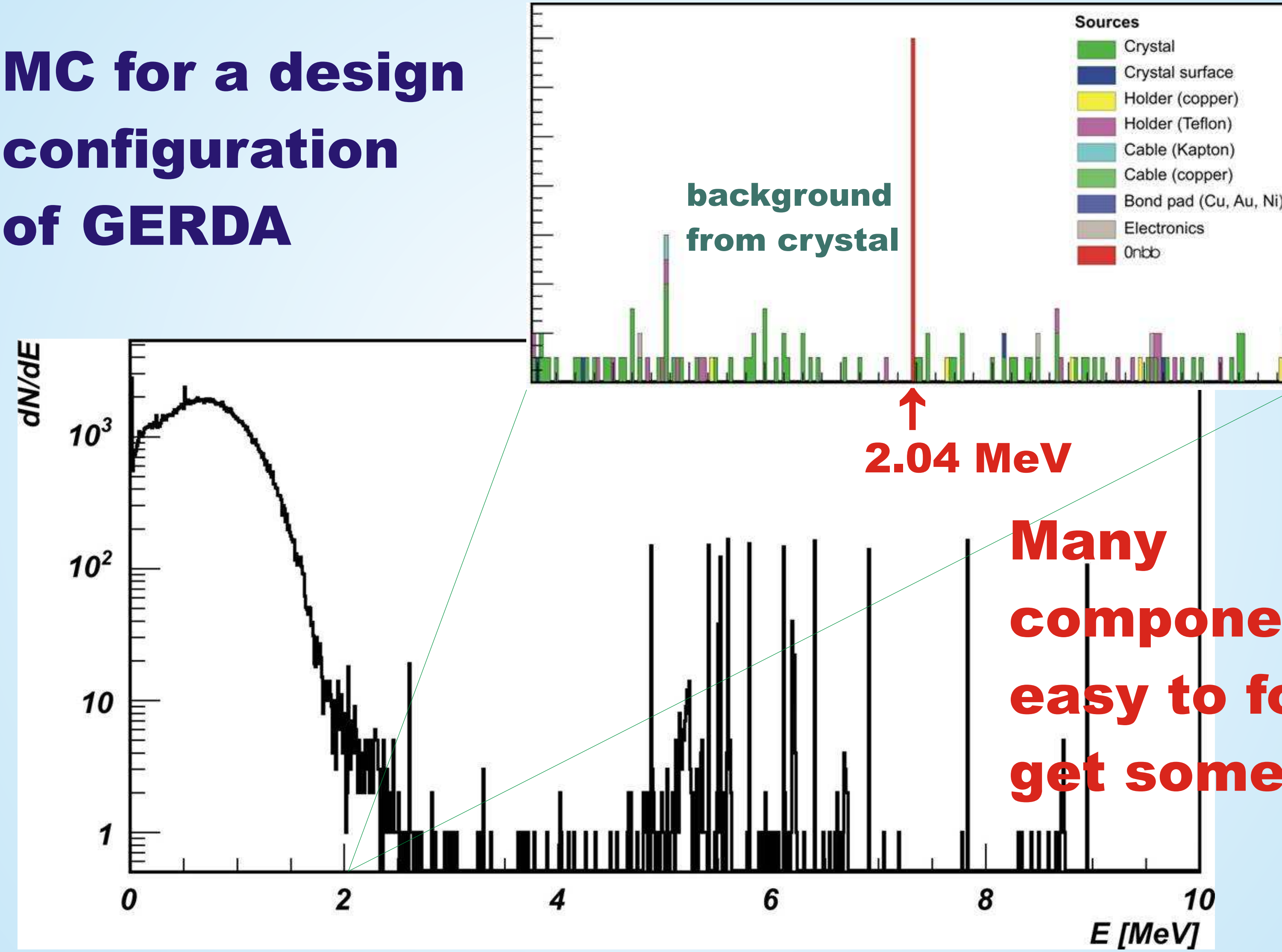
Cosmogenic activation will become important.

Avoid radiation close to/in the detectors
→ Bela Majorovits

and shield against exterior.
→ Karl-Tasso Knöpfle, Xiang Liu

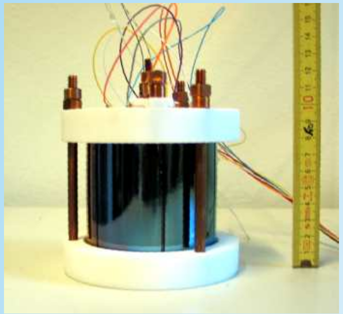
Background as envisioned

MC for a design configuration of GERDA



Many components, easy to for-get something.

Cosmogenic Activation



after crystal growing

^{60}Co

(T½=5.27 years)

10 days → 40 ^{60}Co atoms/kg

1/6000 within 1keV

β^-: 300 + γ : 1173 + γ :1332 keV

after enrichment

^{68}Ga

from ^{68} Ge (T½=270 d)

180 days → 400 ^{68}Ge atoms/kg

1/5000 within 1keV

β^+: 1900keV 2 γ of 511 keV [annihilation]

Background Strategies

Avoid background:

Store enriched material underground

Grow crystals and make detectors underground

Avoid cosmic muons by going deep underground

Shield against rock with water or plastic

Shield against the water and the plastic with

→ copper → MAJORANA

→ cryoliquid → GERDA

→ Karl-Tasso Knöpfle

Minimize material close to detectors

to avoid muons→neutrons→metastable

→ Peter Grabmayr

Recognize background:

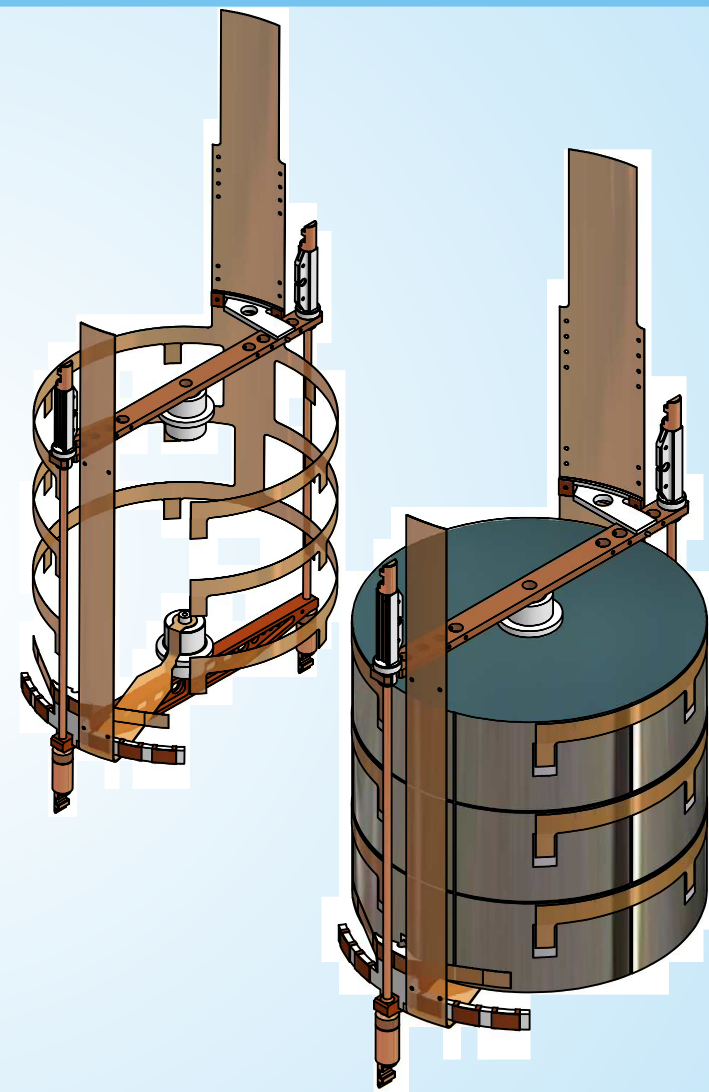
Build intelligent detectors

→ Jürgen Eberth

Example for Intelligent Design

18-fold segmented detectors

with reduced metallization



r = 75mm h = 70mm

1.6 kg Ge in 34 g of Cu

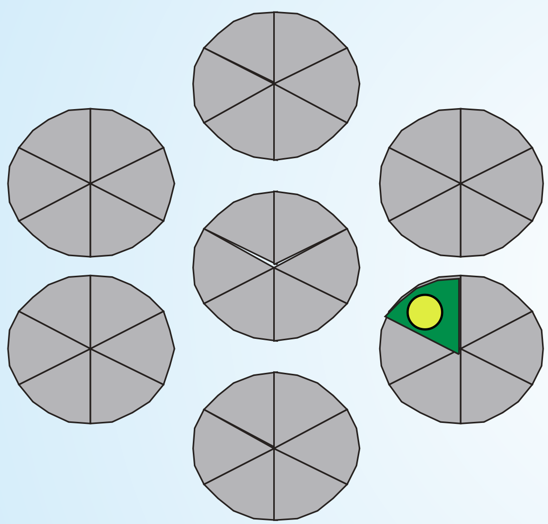
7 g of Teflon

Kapton cables → PEN

with Cu snap contacts

Signal and Background

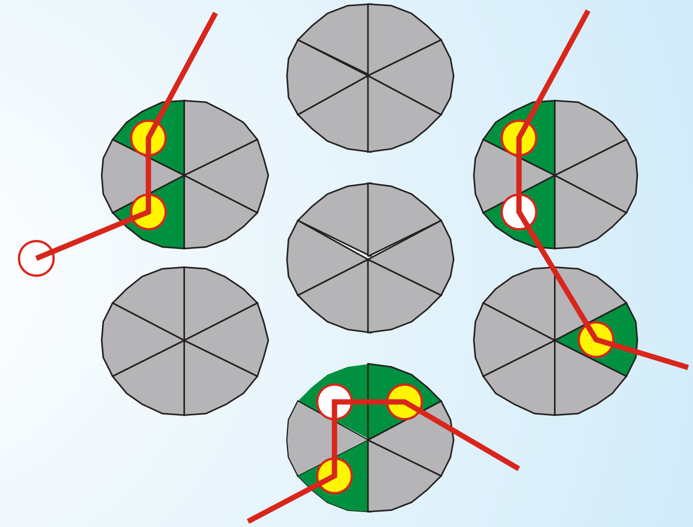
$0\nu\beta\beta$



localized deposit

single site event

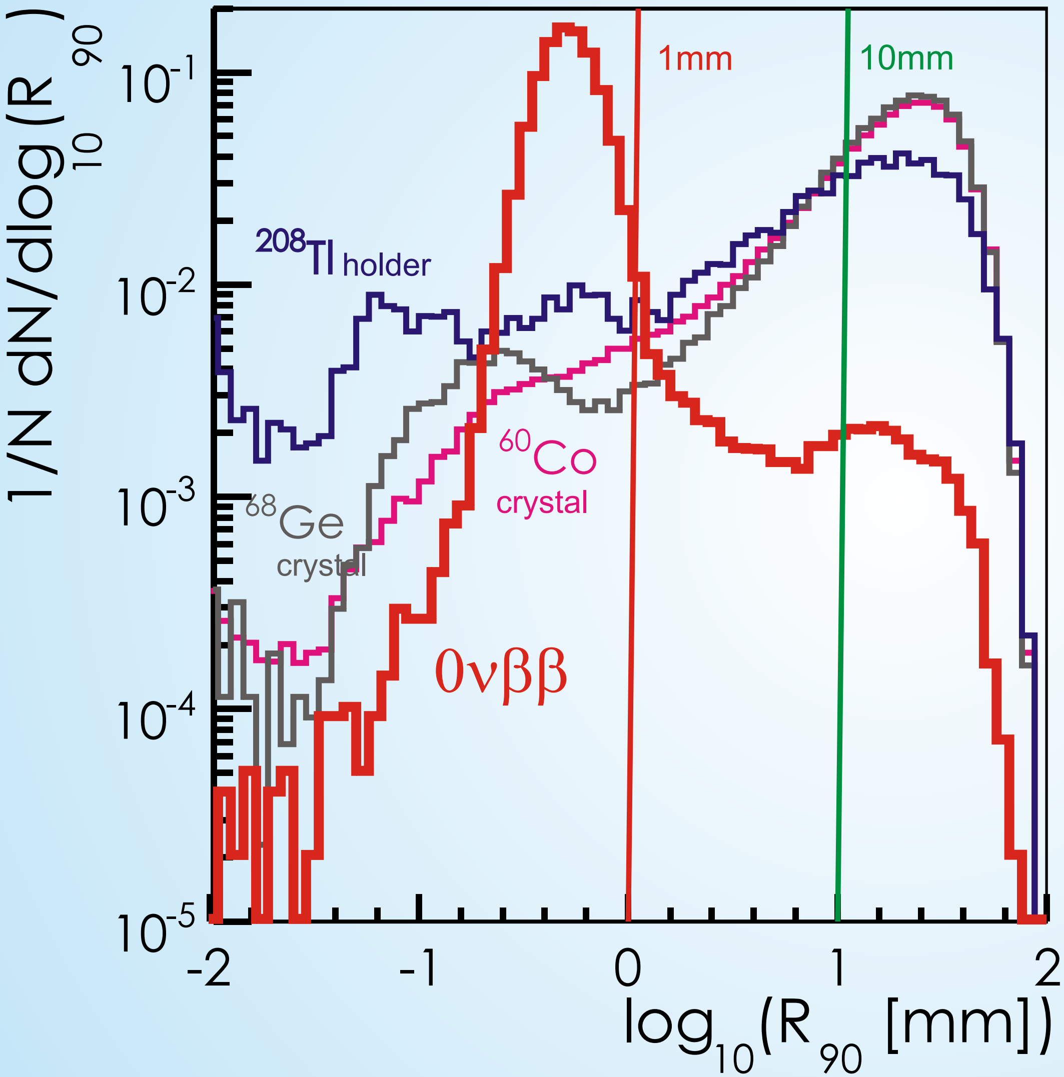
γ or 2γ

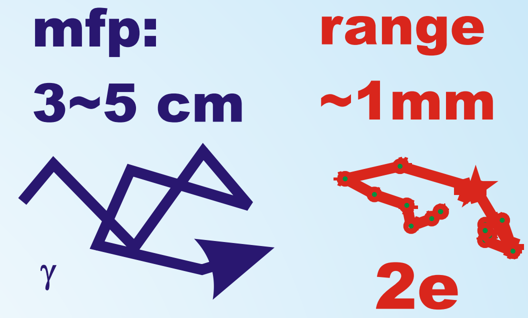


several deposits

multi site event

Size of Events





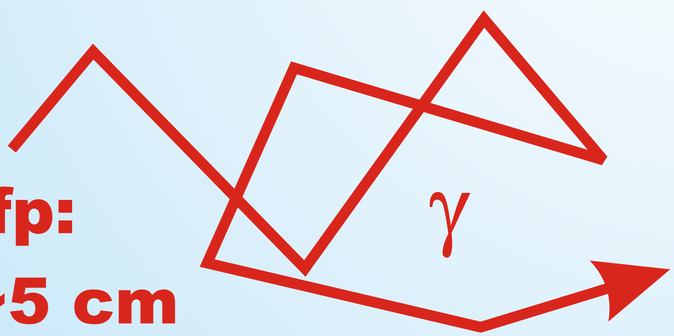
Source	Reduction	
^{208}Tl (in Ge)	13	2.6
^{60}Co (in Ge)	38	3.2
^{68}Ge (in Ge)	18	2.4
^{210}Pb (α on Ge surface)	1	
^{208}Tl (in holder)	5	2
^{60}Co (in holder)	157	6.7
^{208}Tl (in cable)	5	3

single segment cut **eff: 85%**

Background Reduction

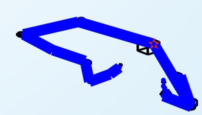
Source	Reduction	
^{208}Tl (in Ge)	13	2.6
^{60}Co (in Ge)	38	3.2
^{68}Ge (in Ge)	18	2.4
^{210}Pb (α on Ge surface)	1	
^{208}Tl (in holder)	5	2
^{60}Co (in holder)	157	6.7
^{208}Tl (in cable)	5	3

Reduction factors for 7 x 3 GERDA array using segment or crystal anticoincidences determined from a GEANT4 Monte Carlo simulation



mfp: 3~5 cm

2e



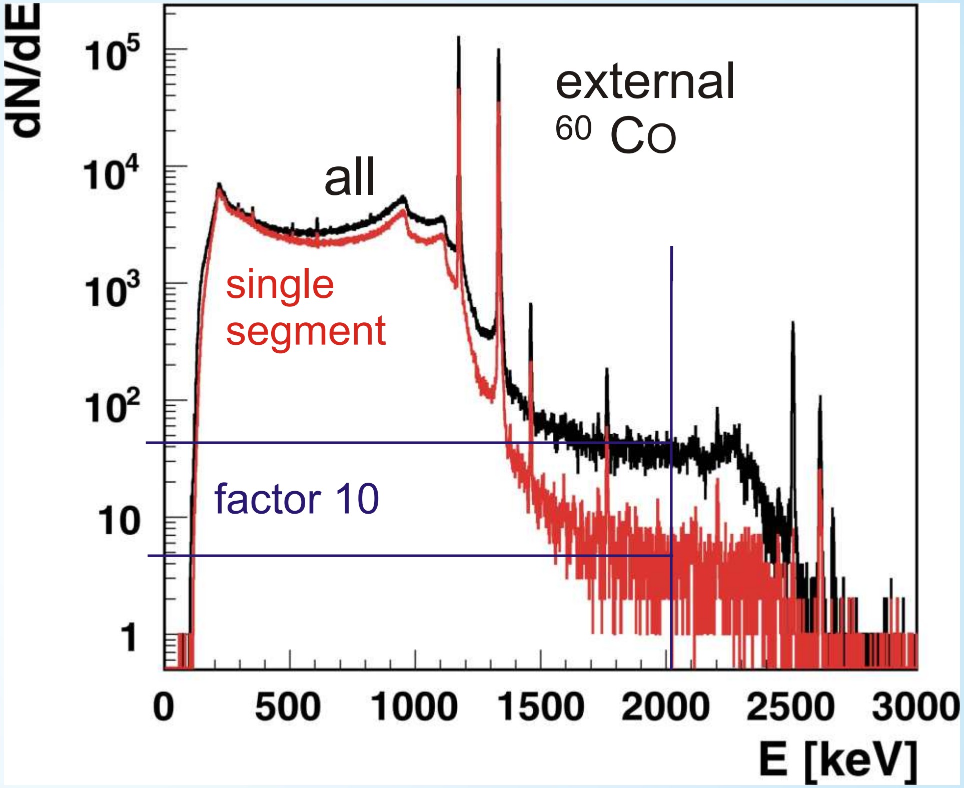
range ~1mm

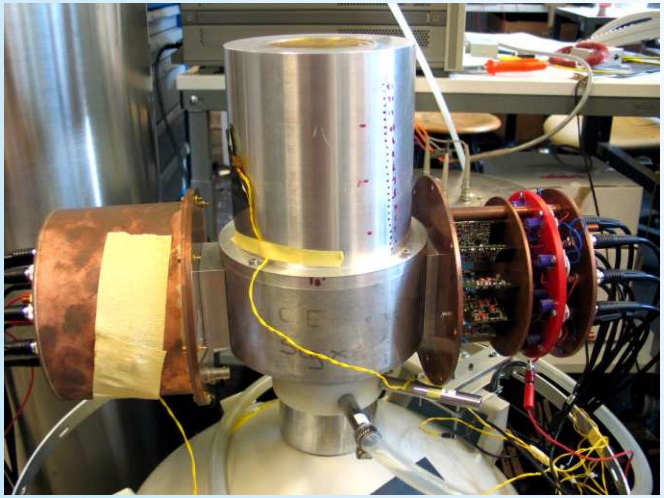
eff: 85%

Germanium Detector Test

n-type
z=70 mm
d=75 mm

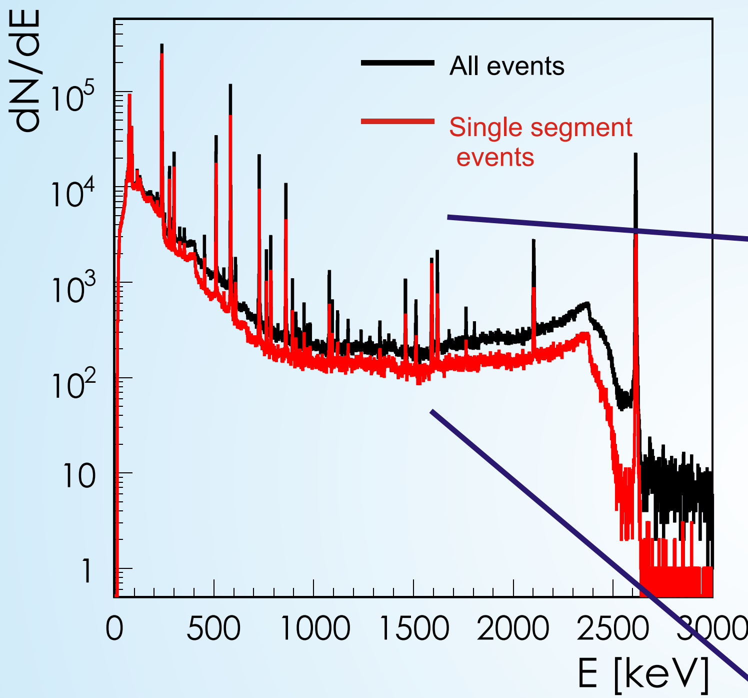
segmented
3 in z
6 in φ



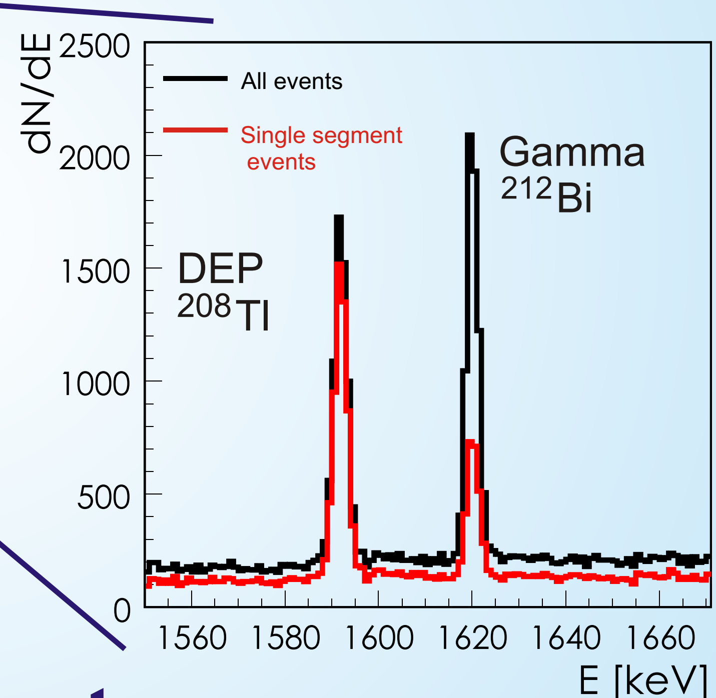


Operation in vacuum
test cryostat

Rejecting Photons



228 Thorium

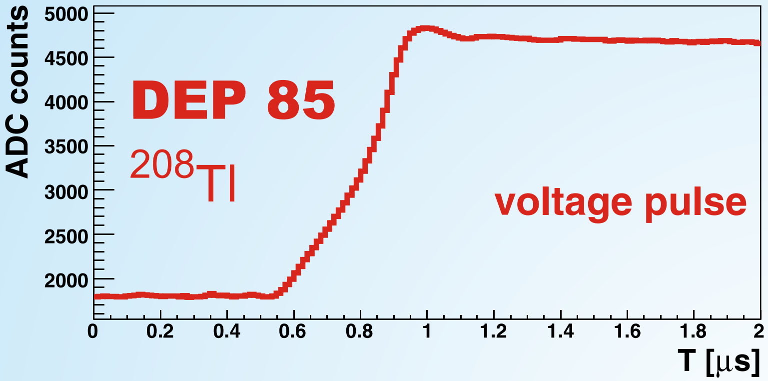


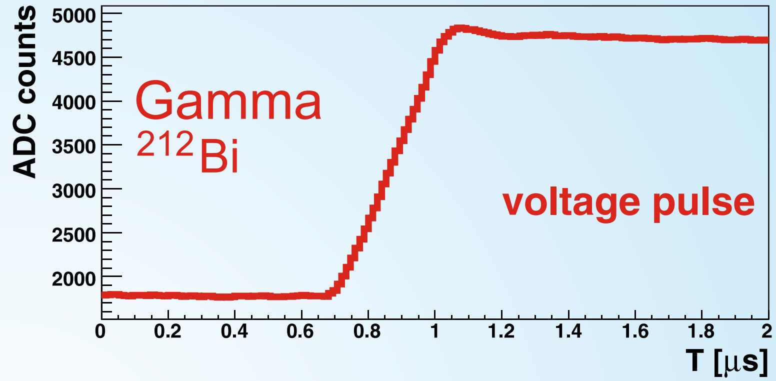
We get rid of what
we try to get rid of...

Test facilities are important

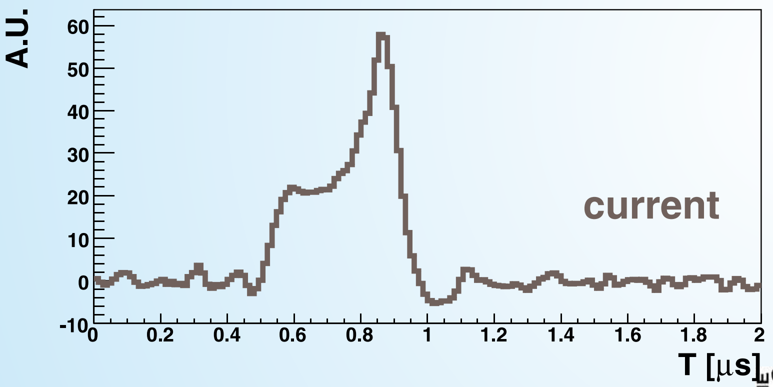
→ Ruan,Xichao Sabine Dinter

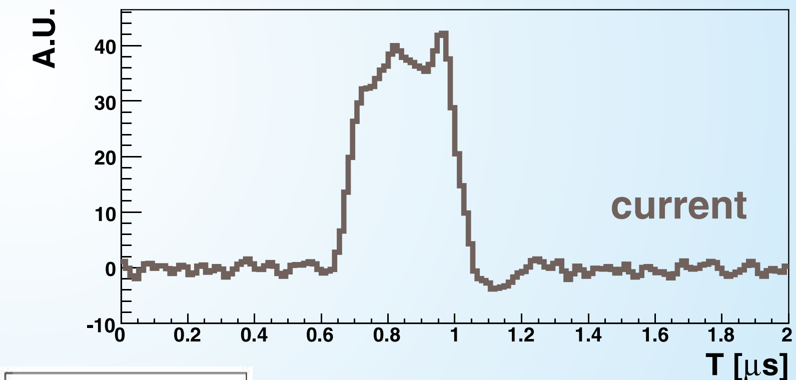
Pulse Shape Analysis



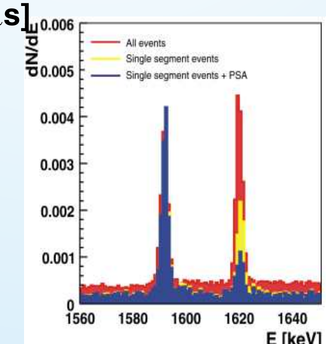


Test stand data





You get an extra 1.4 for single segment events.



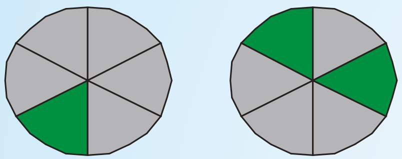
→ Fabiana Cossavella

→ PSS talks

→ Oleksandr Volynets

Pros and Cons

Segmented detectors can identify background events by counting.

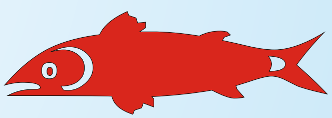


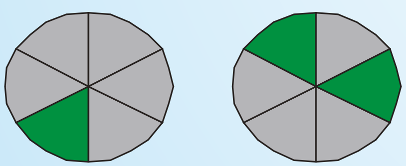
factor ≈ 10

This is robust, can be simulated and does not require extremely good energy resolution, i.e. a lot of fiddeling with electronics.

It requires extra cables… .

Pulse Shape Analysis is often seen as a cableless saviour.

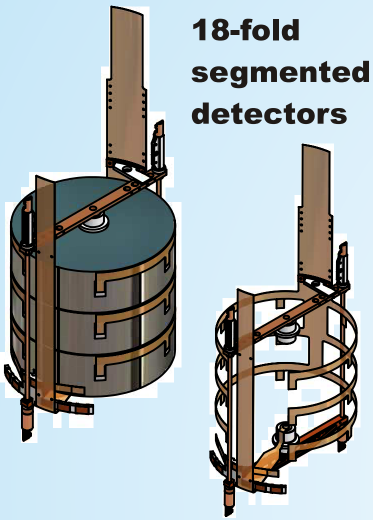




≈ 1.4   4~5

This is tricky, needs a lot of input to be simulated and requires good bandwidth, i.e. a lot of fiddeling with cables & electronics.

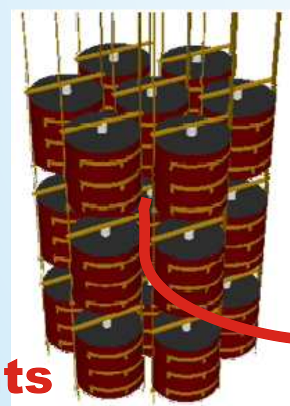
Array



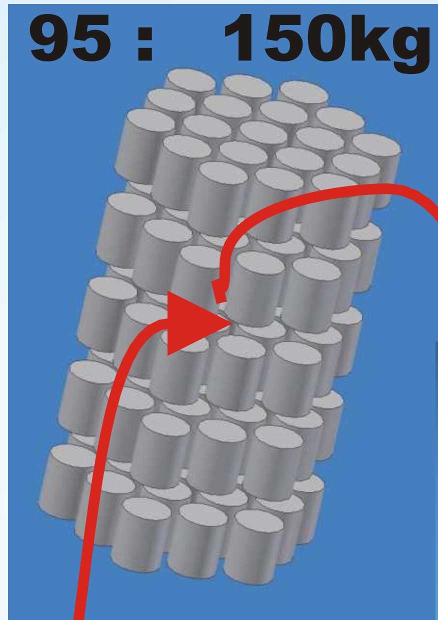
18-fold segmented detectors

1.6 kg Ge
31 g Cu
8 g Teflon

21: 34kg



$3{\cdot}10^{-5}$ $\frac{\text{counts}}{\text{kg kev y}}$

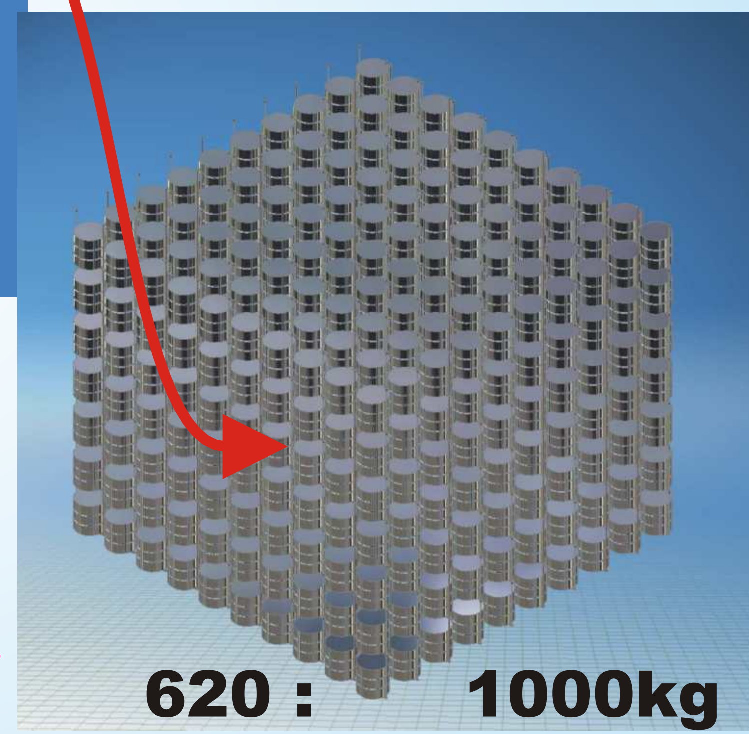


This is technically possible.

This is not

Screen every piece used.
But, HOW?

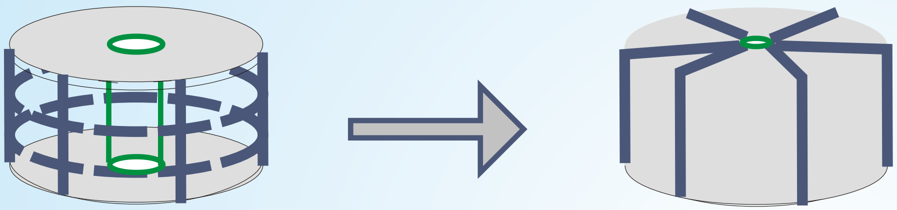
→ Zeng, Zhi



Array of the Future

Path to 1 ton is not clear at all. **Need 10^{-4} bgr.**

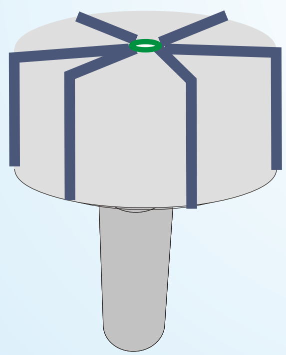
Some ideas



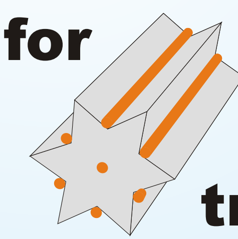
6 x 3 true coax **6**

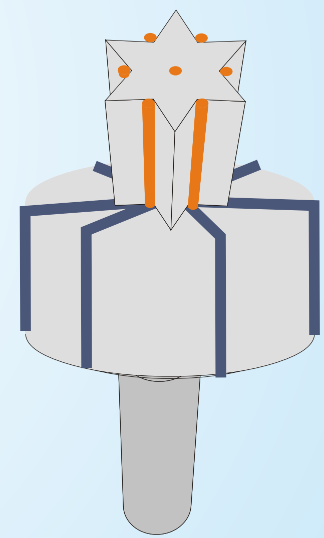
Point contact segmented detectors

Support out of "Optical" germanium crystals



Laminate copper for signal transfer





We need new technology!

→ Marie O. Lampert

→ Crystal Pulling

1 ton Detector Array

Some guidelines:

- Detectors need to be simple and robust.
- Segmentation is desirable.
- Support Structure needs to be low mass and low activity.
- Cables need to be low mass and low activity.
- Electronics should be "far away" and low mass.

→ Electronics talks

What we have now will NOT do

- Detectors are simplistic and easy to destroy.
- Electroformed copper, PEN cables, Teflon
- Copper is perhaps fine, but it needs ↑.

↳ **Infrastructure needs to be "perfect".**

The Price for a 1ton Ge Array

Germanium Enrichment ~40 M€ — Easy, but for cos-mogenic activation

Crystal Growing ~?0 M€ — Alchemie
Many problems
plus cosm. activ.

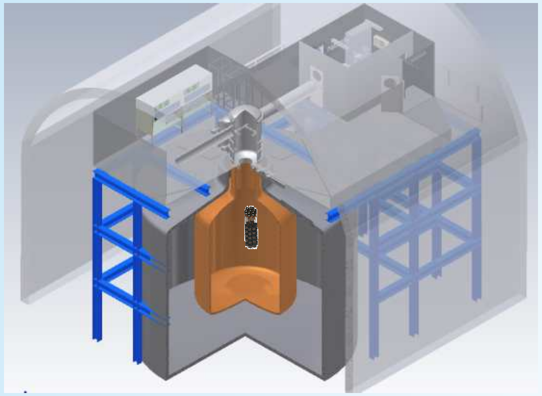
Detector Manu-facturing ~80 M€ — Very few sources!

All this can perhaps be solved by spending money.

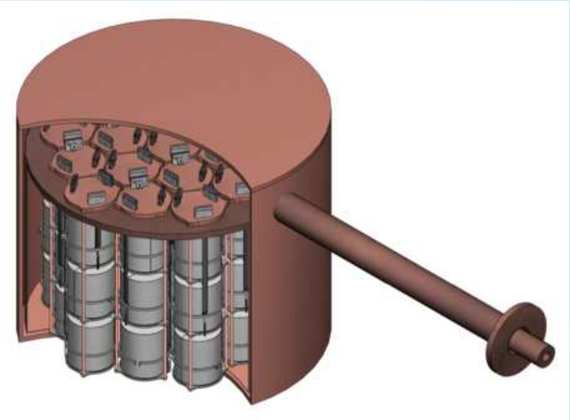
System Integration will require thinking!

And we need infrastructure

Infrastructure of the Future

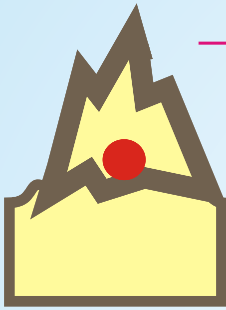


Gerda
or
Majorana
or .....



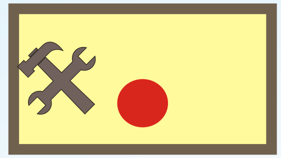
Cryogenic Shield		**Copper Shield**
integrated cooling		compact
homogenous		cracks
lower more strings	scaling	build more enclosure
cost is almost fixed		increases $\propto$ mass
longer signal path		
LAr is also high Z $\rightarrow$ LN		high Z $\Rightarrow \mu \rightarrow$ neutrons
LAr $\rightarrow$ calorimeters		detectors prefer vacuum

Infrastructure of the Future



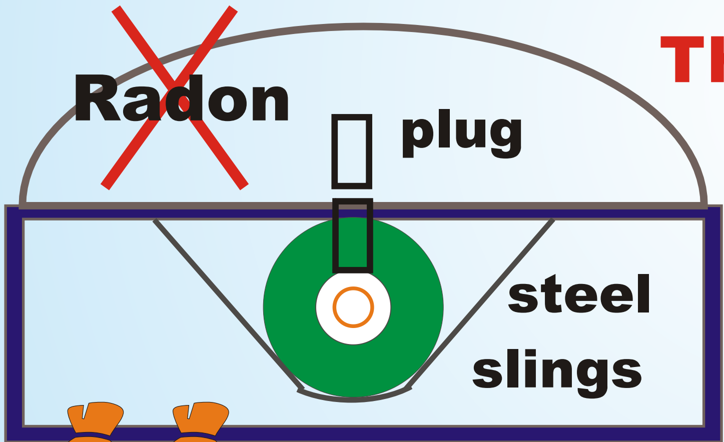
→ B. Schwingenheuer

or



→ CPJL talks

Need to go deep, with homogenious overburden to get rid of (neutrons from) μ



The hall has to be large!

water shielding

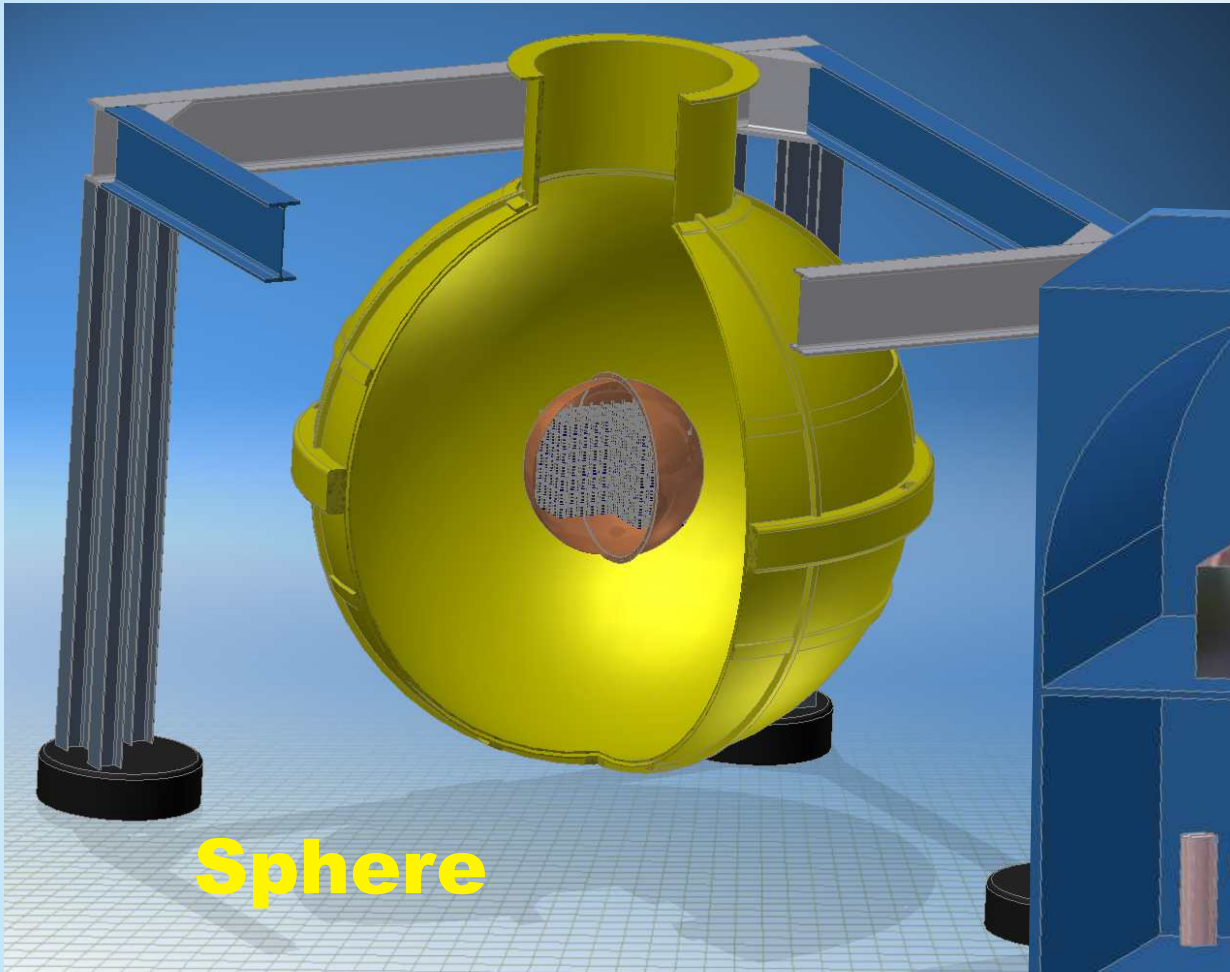
LN shielding

Copper vessel with vacuum holds array

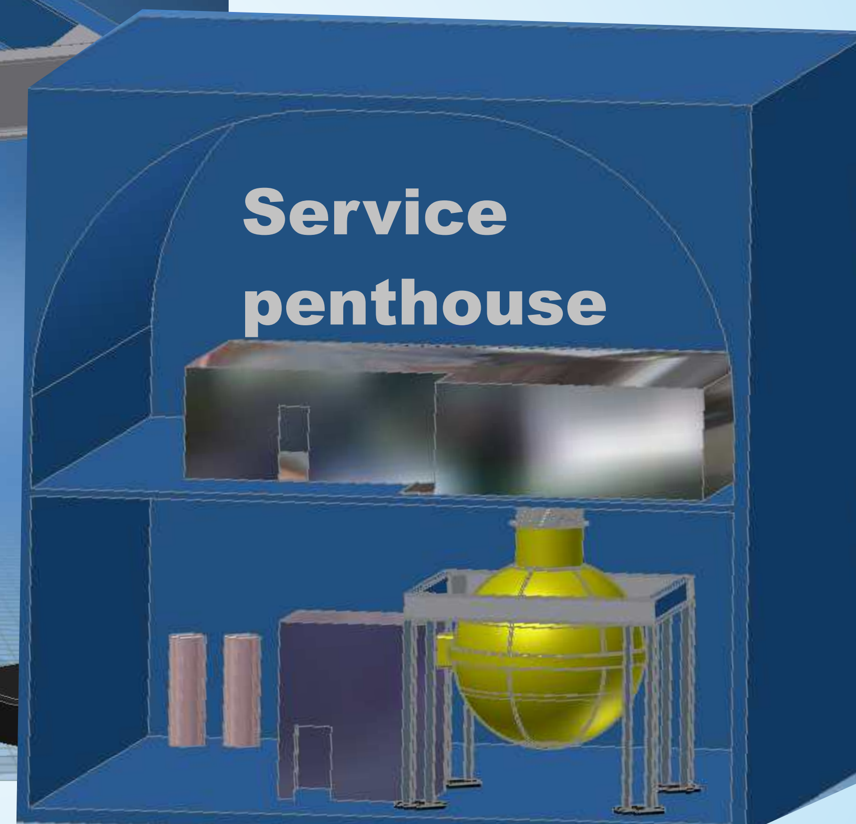
There ain't no such thing as free lunch.

NO compromises!

Infrastructure of the Future



Some
bad dreams.



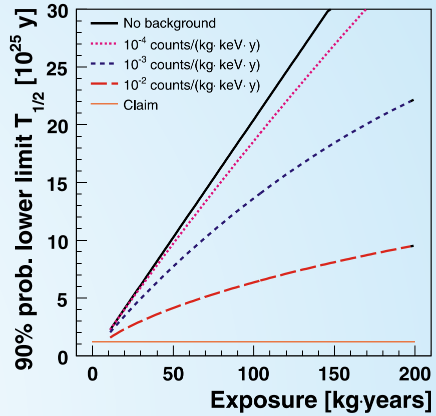
MC to be done soon.

multiply the lower hall

[In]Famous Last Words

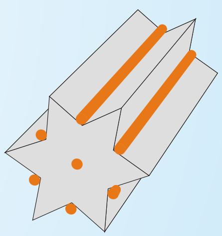
A 1t experiment will be all about background.

I am absolutely not convinced that 1 ton Ge experiment makes sense.



New technology will be needed together with a gigantic amount of simulation and screening.

We need benchmarks to verify our simulations and we need another expe-riment to screen.



A 1t experiment will need a lot of good engineering, also electronics engineering.