Exploring Majorana landscape

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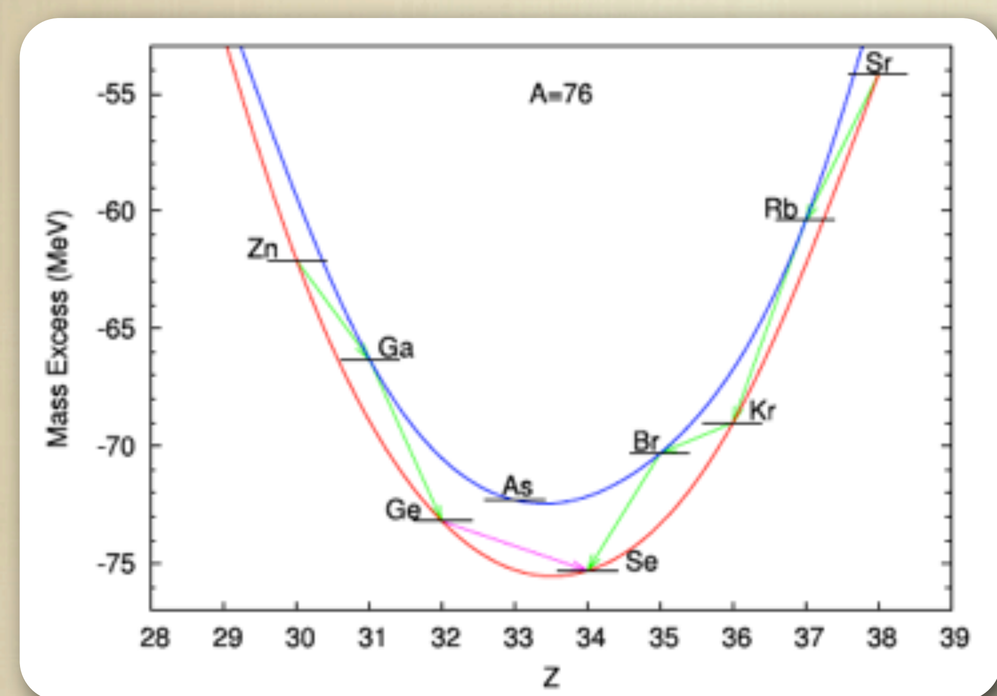
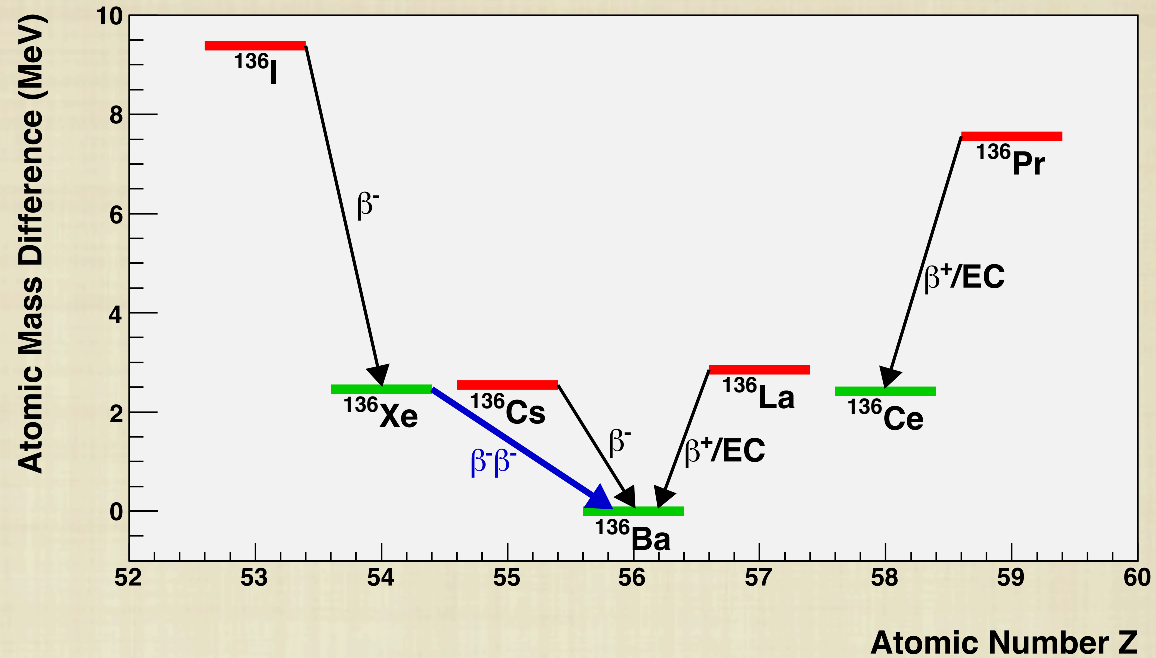
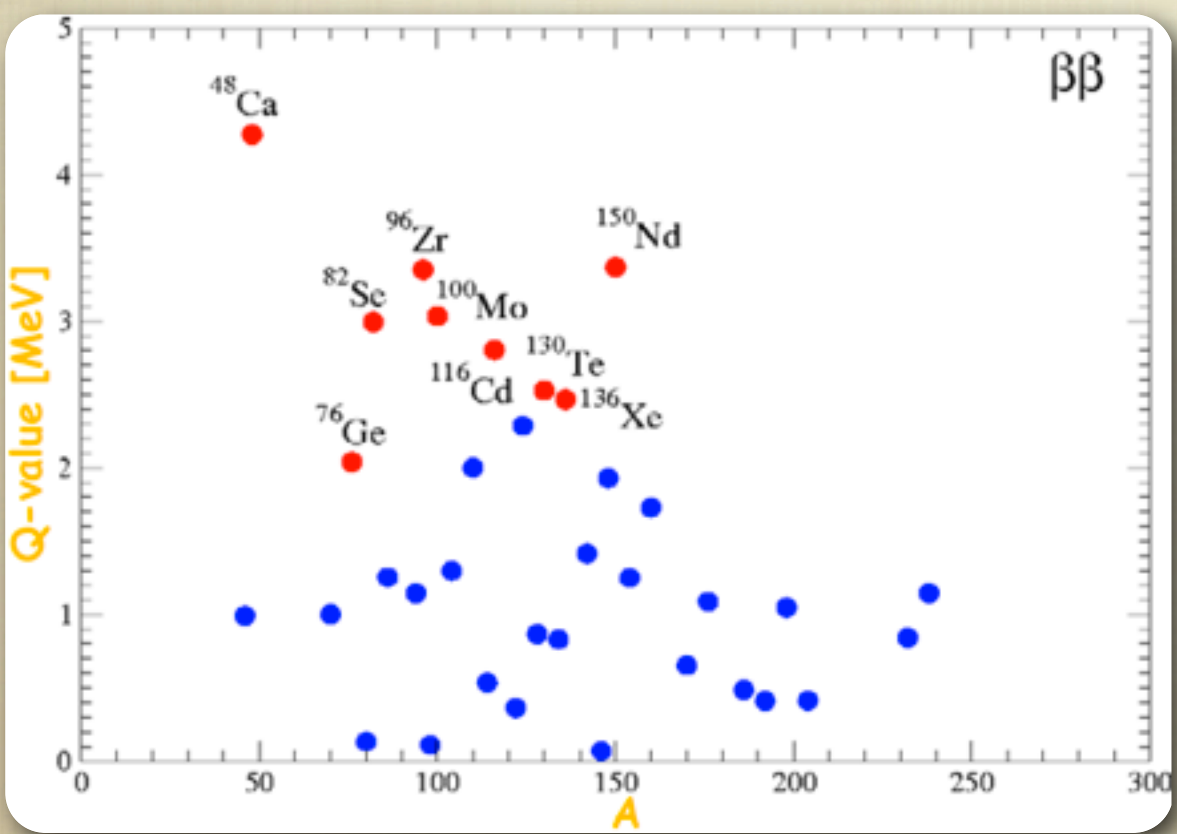
Florence, July, 2012

Double beta decay

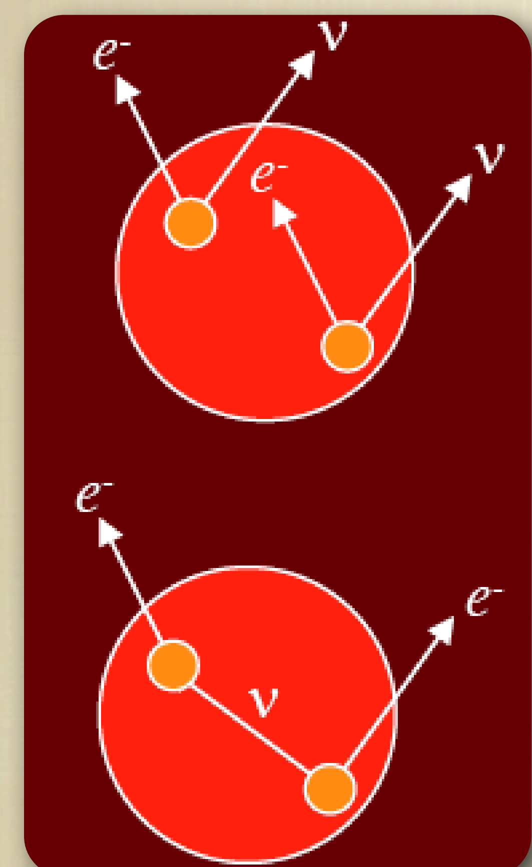




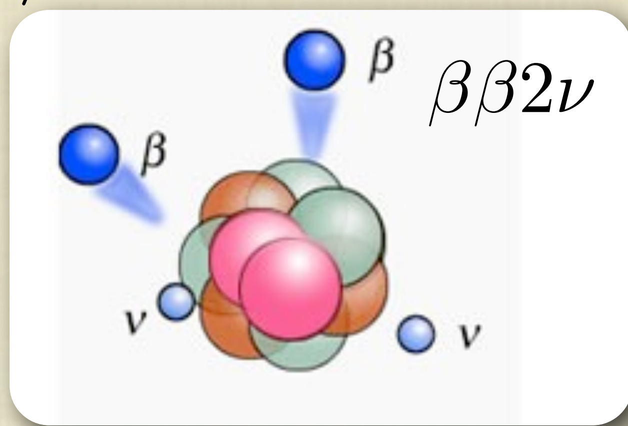


- About 10 isotopes, A ~70-150
- Q_{bb} ~2-3.5 MeV
- $T_{1/2}$ ~10^{18}-10^{20} yr.

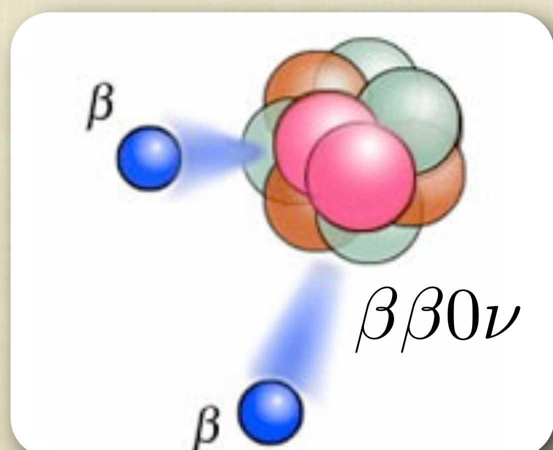
Neutrinoless Double Beta Decay



$$T_{1/2} \sim 10^{18} - 10^{20} \text{ y}$$



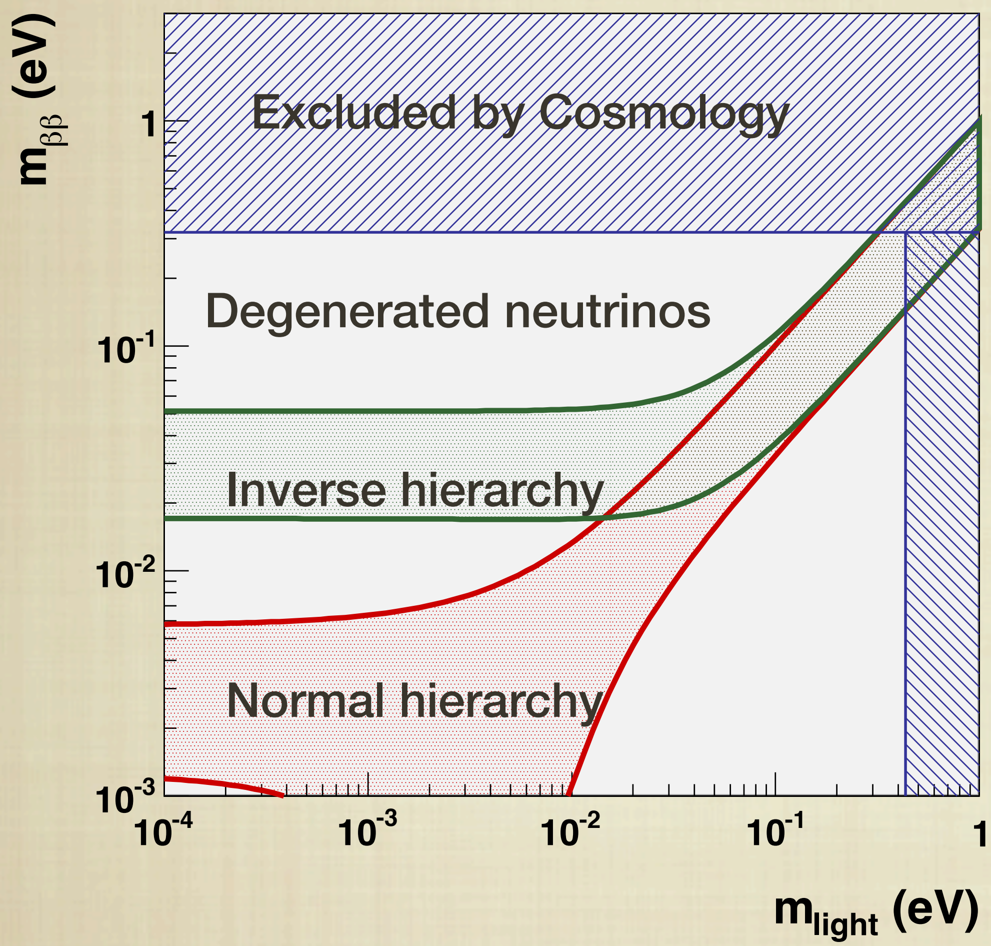
$$T_{1/2} > 10^{25} \text{ y}$$

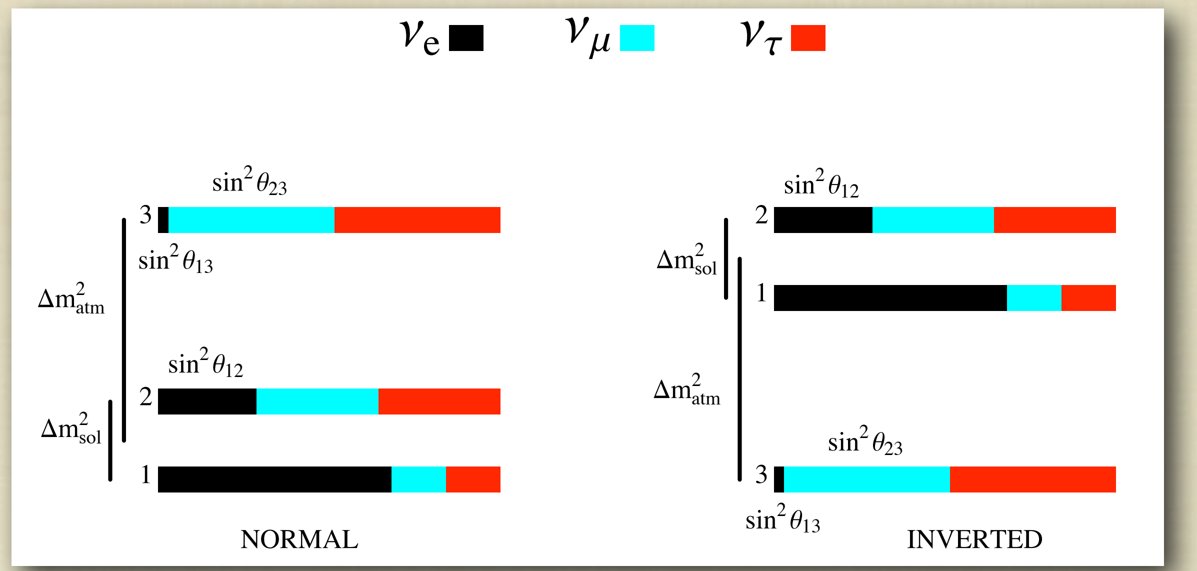


- If the neutrino is a Majorana particle the process called Neutrinoless Double Beta Decay may exist
- In bb0n, no neutrinos are emitted. The sum of the energies of the two electrons equals the mass difference between mother and daughter nuclei (Qbb).
- The process requires an helicity flip, and therefore it becomes more likely as the neutrino mass increases.

DBD and neutrino mass

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ m^2_{\beta\beta}$$





- EXO sets a limit of

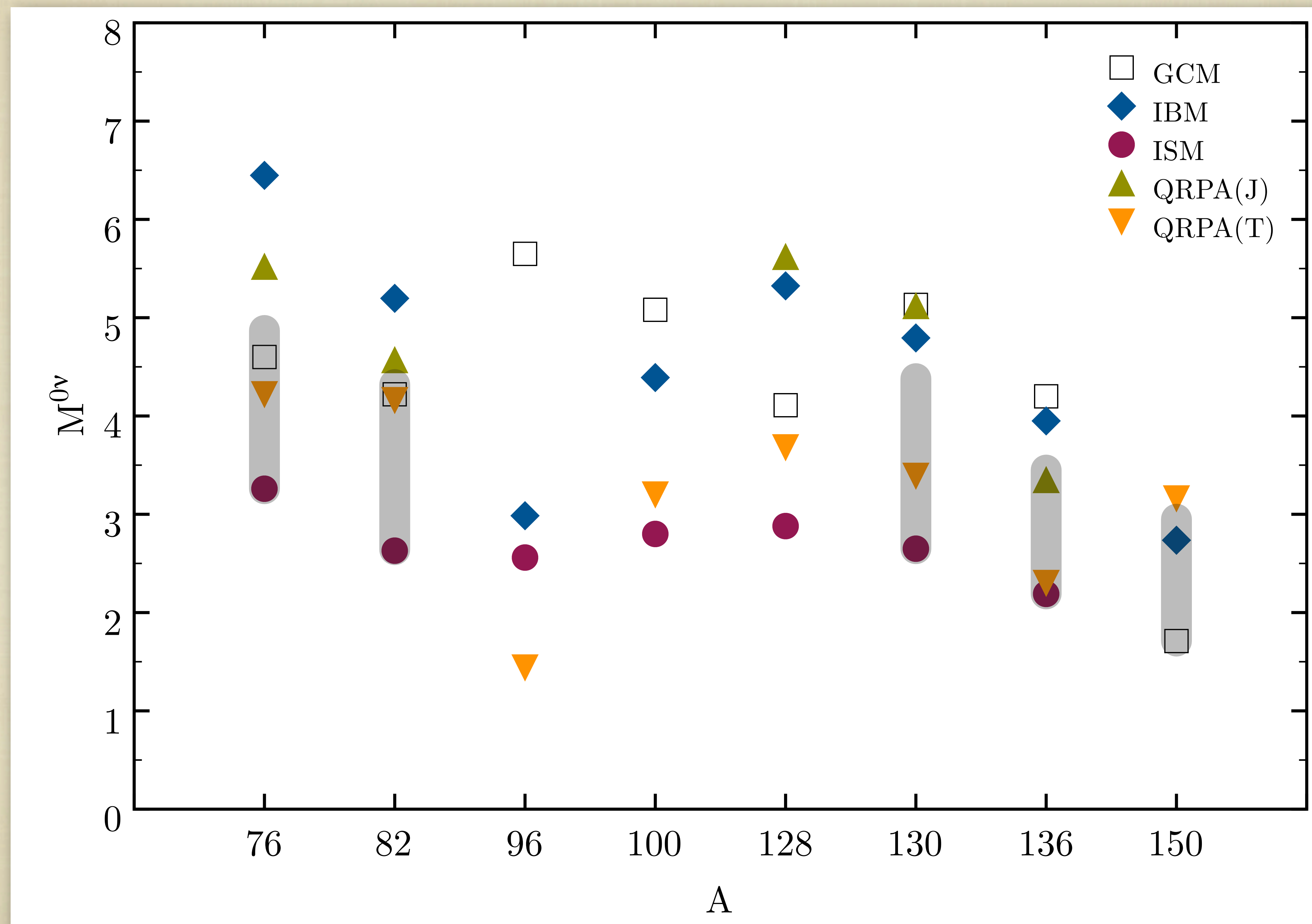
$$T_{1/2}(Xe^{136}) = 1.6 \times 10^{25}\ \mathrm{yr}\ (90\%\ \mathrm{CL})$$

- Corresponding to

$$m_{\beta\beta} \sim 140 - 380\ \mathrm{meV}$$

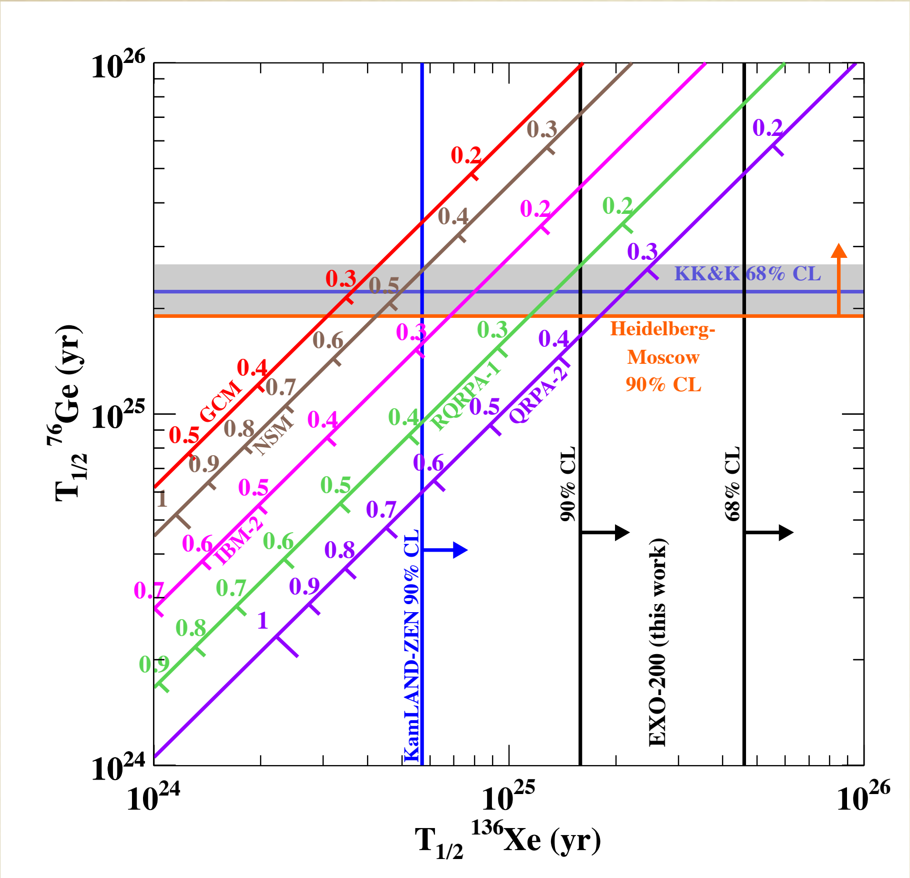
$$m_{\beta\beta} = \left| \sum_i m_i U^2_{ei} \right|$$

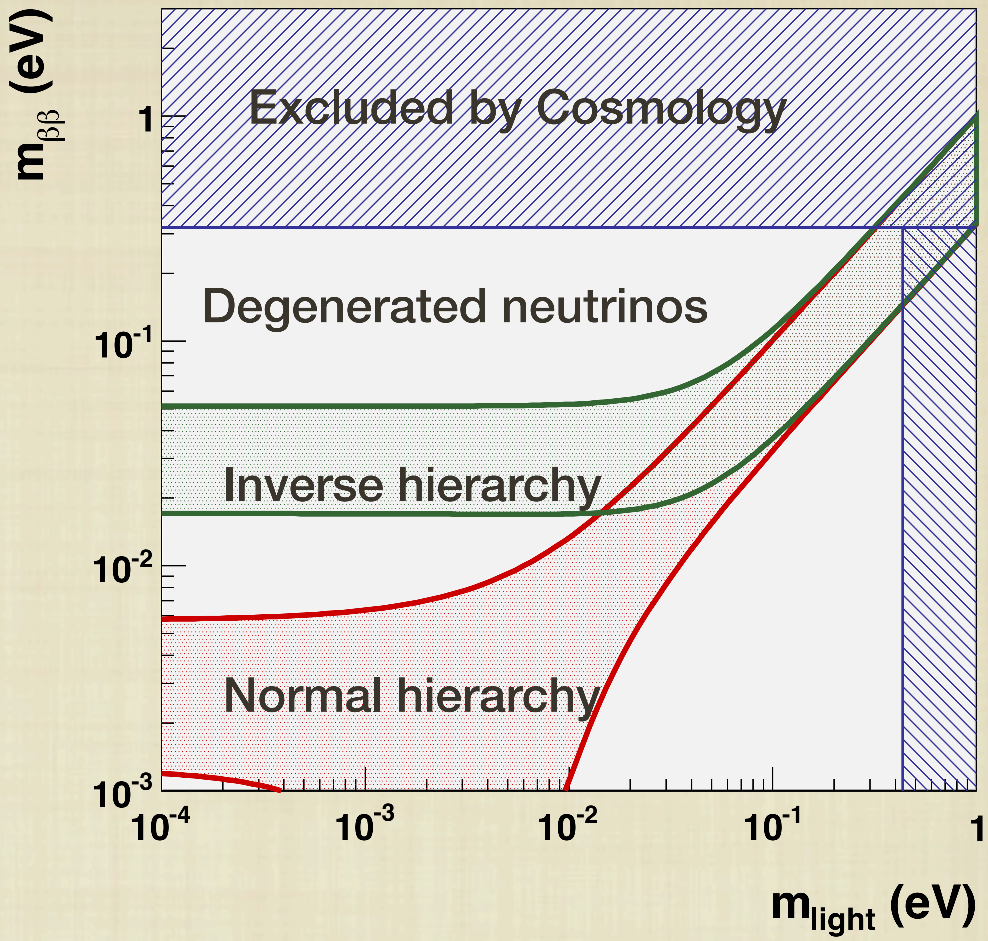
NME Industry



Gomez-Cadenas *et al.*, *JCAP* **1106** (2011) 007

Current experimental situation

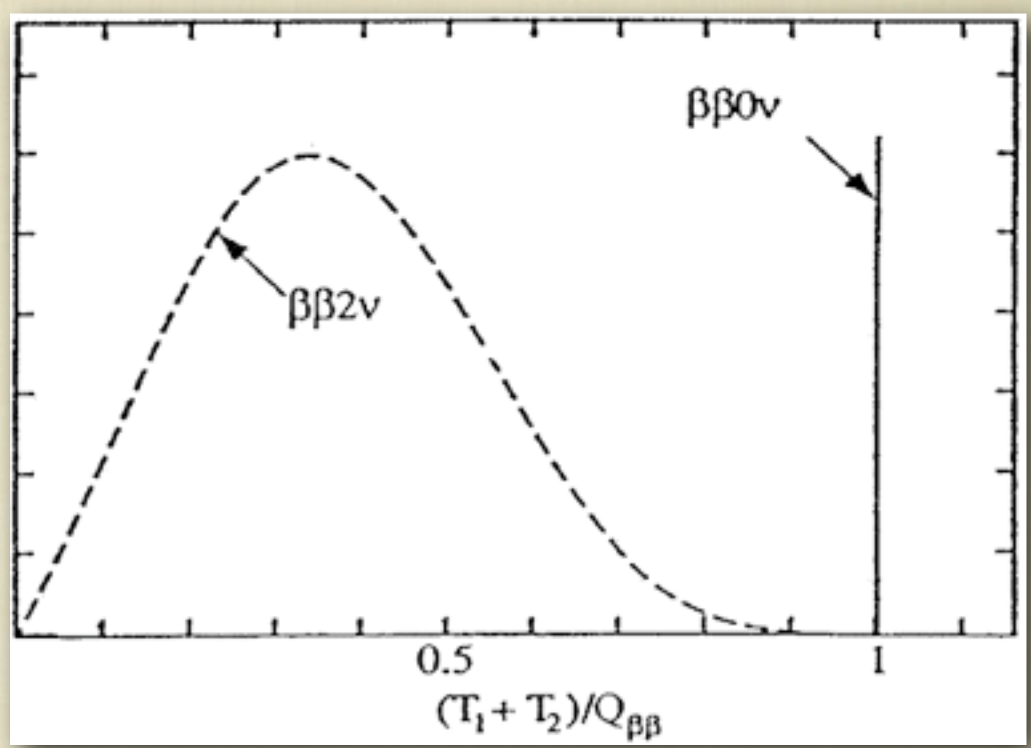




- EXO result has excluded the claim of KK for all but one of the NME's sets. It appears that KK claim will not hold water. GERDA should settle the matter soon.
- The region of m_{bb} between 50-300 meV corresponds to the so-called degenerated hierarchy.
- EXO: $T_{1/2}$ ~10^{25} y (m_{bb} ~150 meV). To reach m_{bb}~50 meV needs T_{12}~10^{26}y

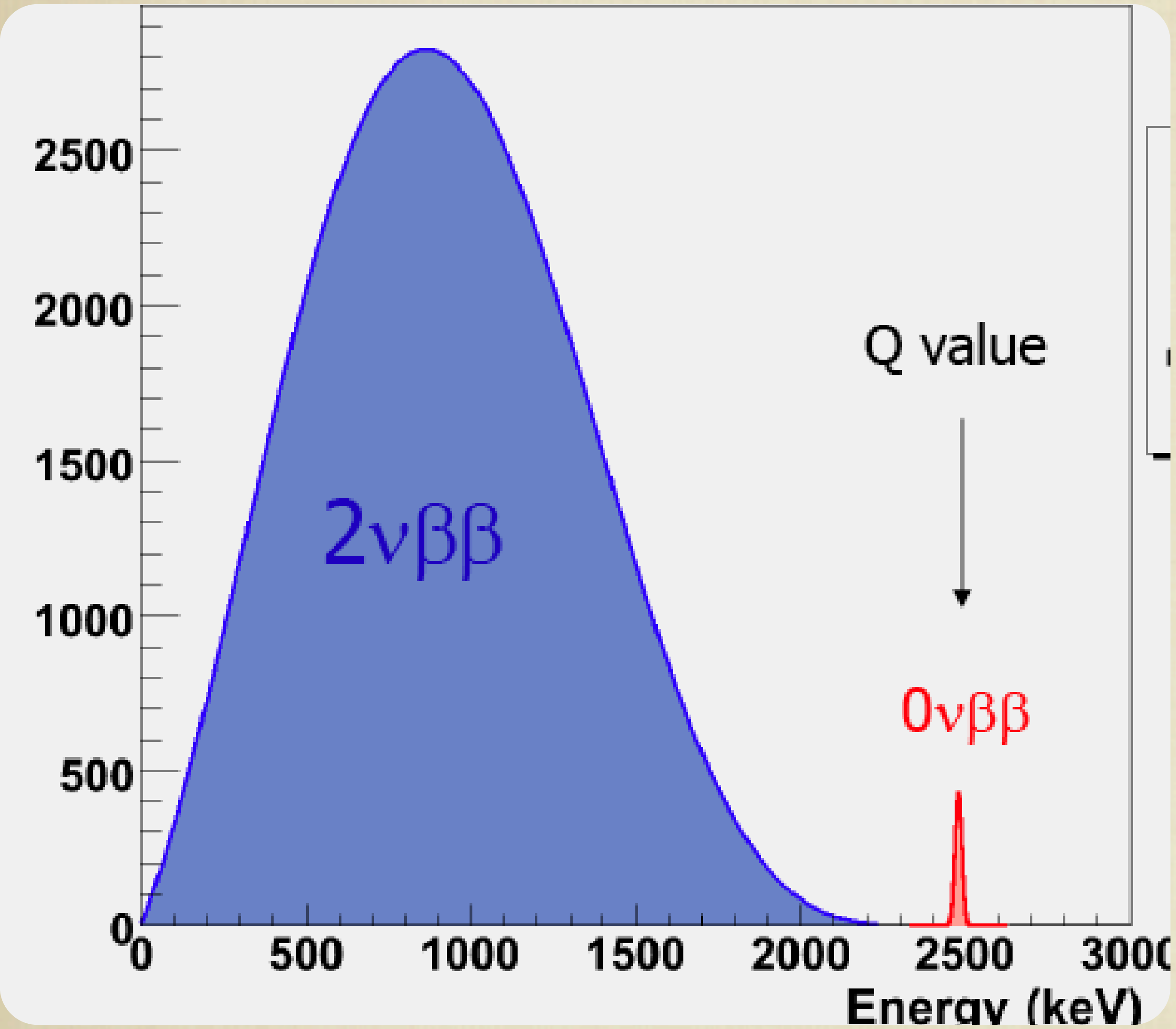
Ideal bb0nu experiment

- Get a large mass of double beta decay source ($N = MtN_A/A$).
- Measure the energy of the emitted electrons.
- Select those with (T1+T2)/Qbb = 1
- Count the number of events and calculate the corresponding half-life.



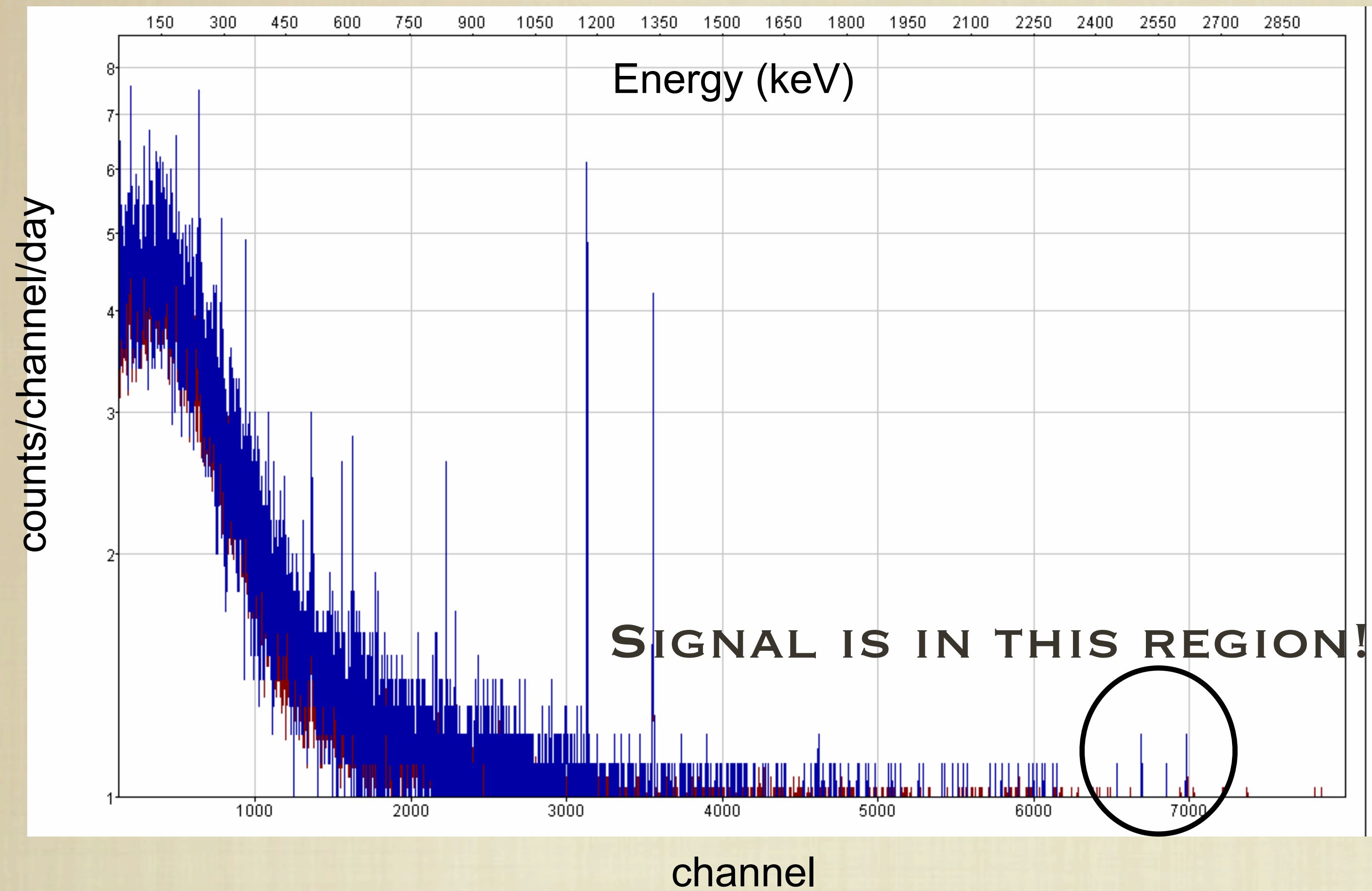
$$T_{1/2} = \log 2 \; \frac{N_A \; Mt}{A \; N_{\beta\beta}}$$

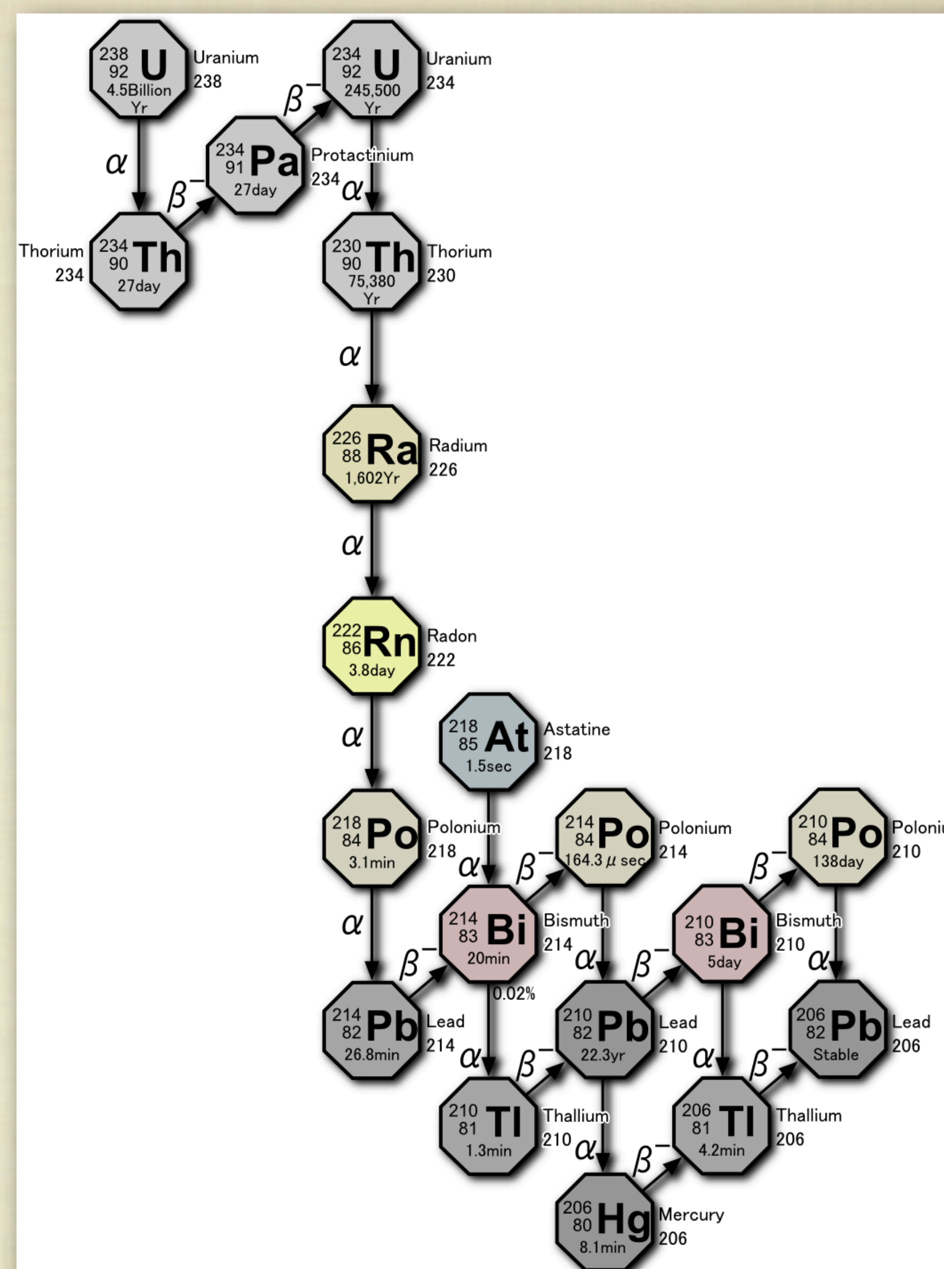
Energy resolution



- If detector resolution is not perfect, energy spike around Q becomes a Gaussian.
- Background events, both from bb2n process and from U & Th radioactive chains will leak into the Gaussian region (the ROI)
- Everything else (radiopurity, extra handles) being the same, experiments with superb energy resolution are preferred, to minimize the impact of background events.

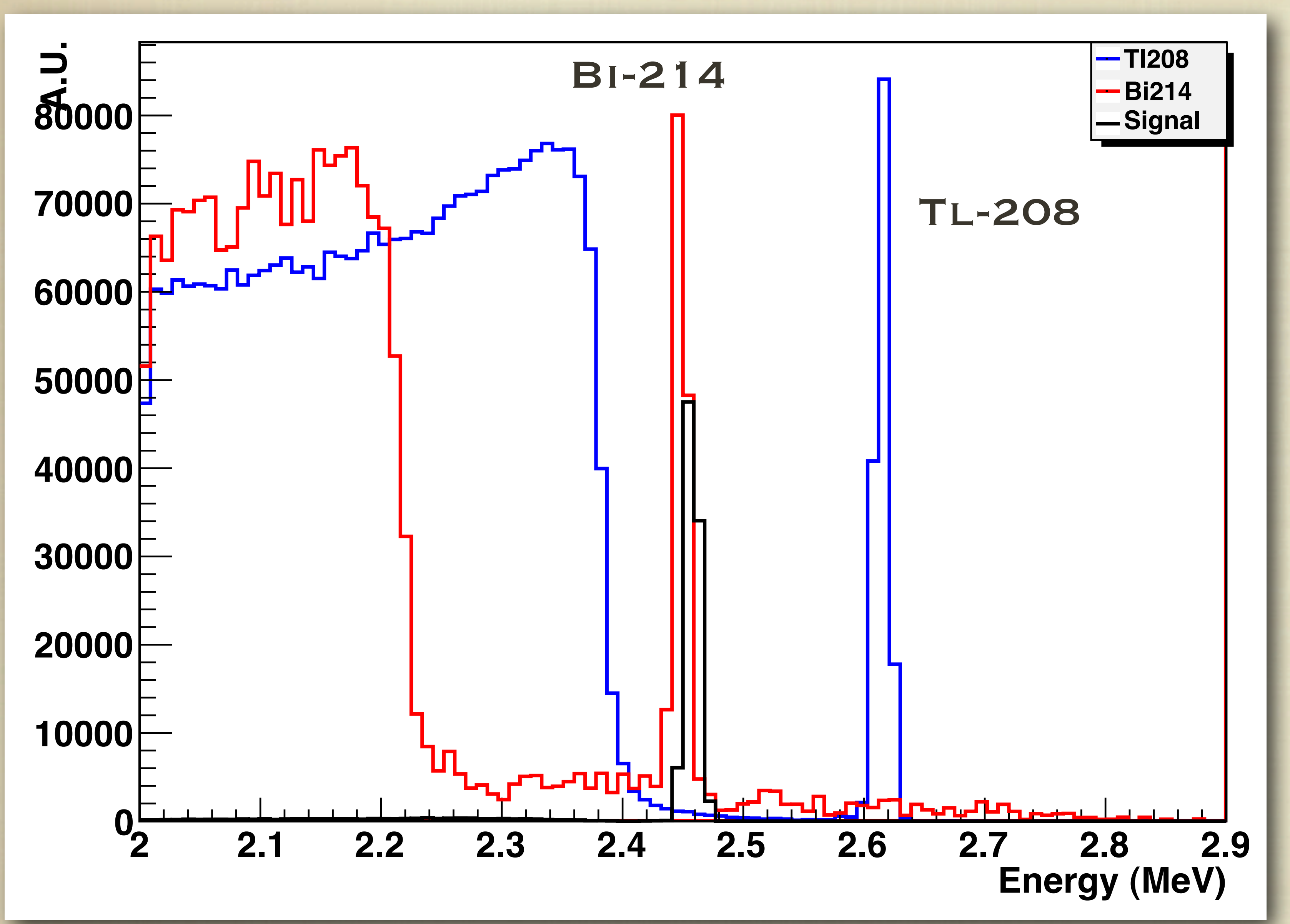
Radioactive background





- Due to the radioactive chains of U and Th.
- Earth is a very radioactive planet. About 1 gr of U and 3 gr of Th per ton of rock.
- Lifetime of U-238 is 4.5×10^9 yr to be compared with a signal lifetime of $\sim 10^{26}$ (10^{27}) yr

Radioactive background in Xenon

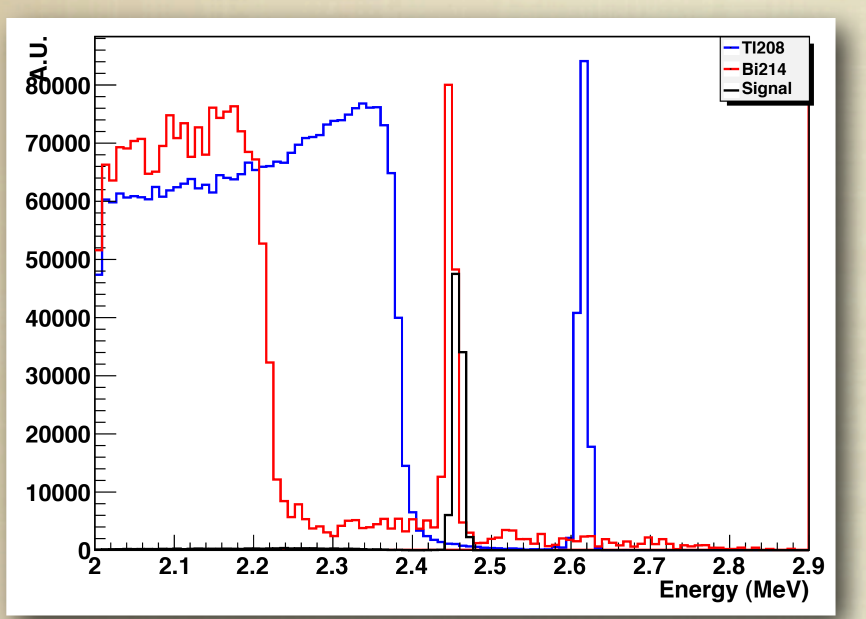


Arbitrary normalization

Assumed resolution: 1% Qbb

Main backgrounds: high-energy gammas from Tl-208 and Bi-214 (natural radioactivity in detector materials).

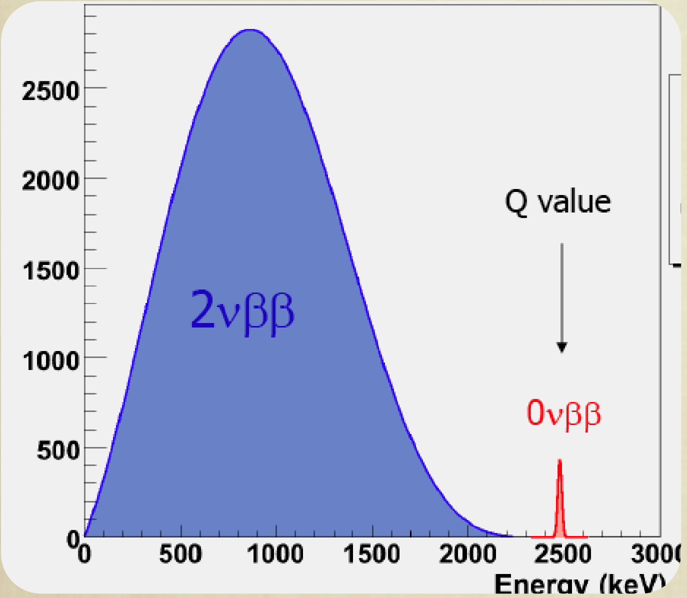
Signal & Background



Imagine that signal is at a level of T1/2 ~10^{25} y. How many events per year and kg?

$$T_{1/2} = \log 2 \; \frac{N_A \; Mt}{A \; N_{\beta\beta}}$$

$$N_{\beta\beta}(Xe^{136}) = \log 2 \frac{6 \cdot 10^{23} \cdot 10^3(g) \cdot 1(y)}{10^{25} \cdot 136} \sim 0.1$$



Need a large mass to see the signal (100 kg yr for $T_{1/2}=10^{25}$ y)

Imagine that natural background for Bi-214 line is of the order of 1muBq. This is one count of background every 10^6 seconds. One year has 3 10^7 seconds. Thus 30 counts of Bi-214 go into the Bi-214 peak which overlaps at 50 % with signal peak. B/S ~1!!!

Improving T is difficult

$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

K ➡ isotope yield

ε ➡ detection efficiency

M ➡ isotope mass

t ➡ running time

b ➡ background rate

Δ*E* ➡ energy resolution

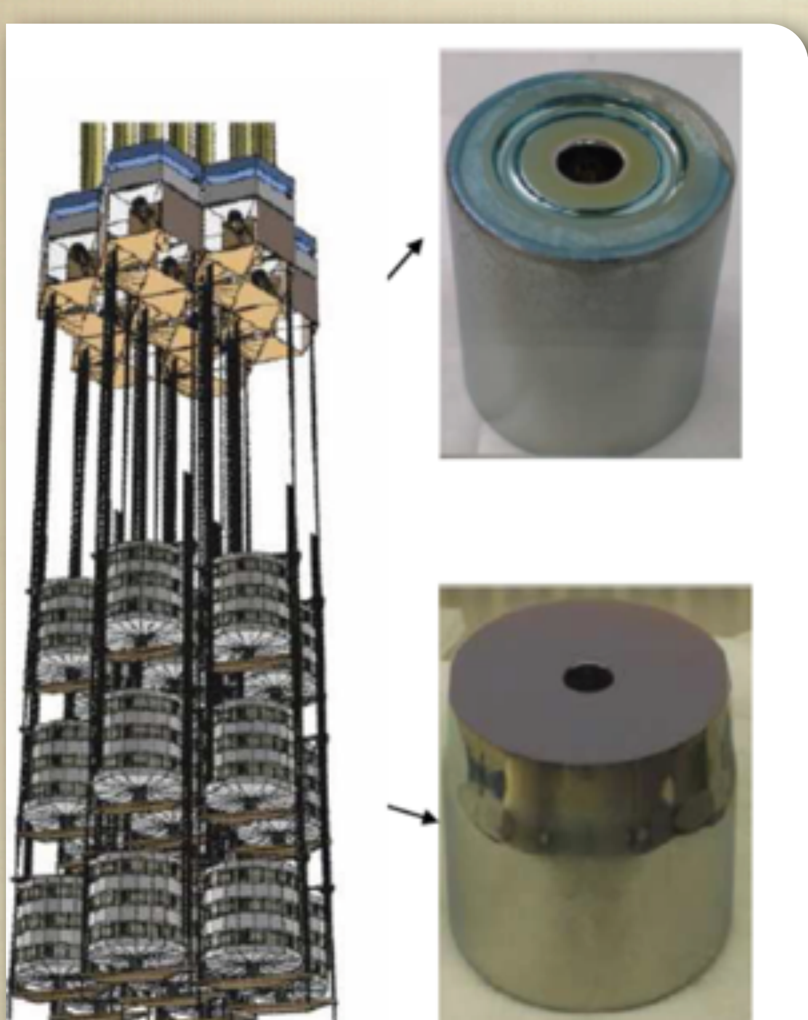
- Assume a, ε and Δ*E* constant.
- To improve T1/2 by 10 one needs to: a) Increase Mt by 10^2 or decrease B by 10^2 or increase Mt by 10 and decrease B by 10.
- CHALLENGE: Build a detector with 10 times the mass and 10 times less background.

Improving m is VERY difficult

$$m_{\beta\beta} = K \sqrt{1/\varepsilon} \left(\frac{b \, \Delta E}{Mt}\right)^{1/4}$$

- Today: 150 meV. Degenerated: 50 meV. Inverse: 20 meV
- First jump: Improve ( ) by 3^4 ~100 Second jump: Improve by 6^4 ~1000
- EXO: ~100 kg yr: Fist jump: 10,000 kg yr, second jump: 100,000 kg yr
- No go, unless one reduces B at the same time by a factor 10 (100).

Calorimeters/Bolometers



$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

ΔE ➡ 0 initial reach OK

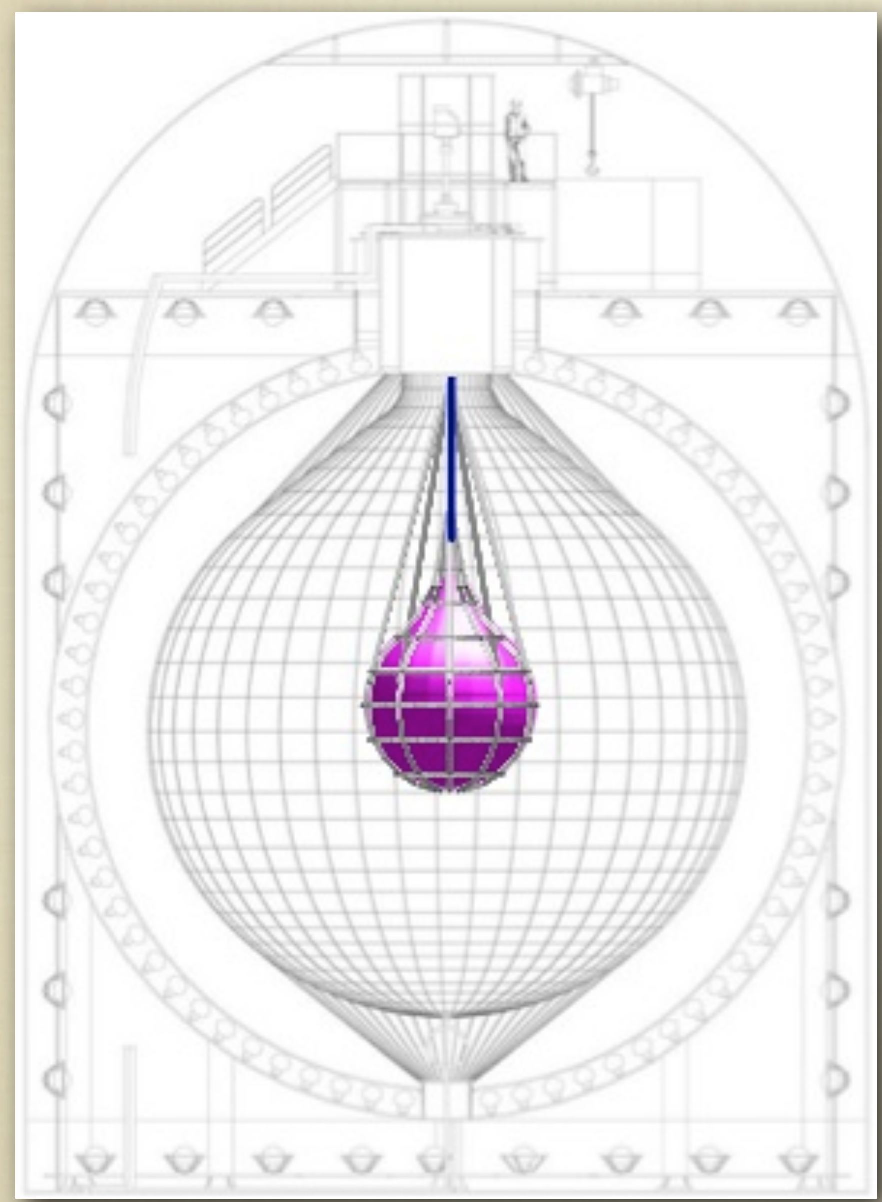
b ➡ S/V large, alpha particles.

M ➡ expensive an modular (no scale)

b ➡ Can improve by a factor 10 with advanced techniques.

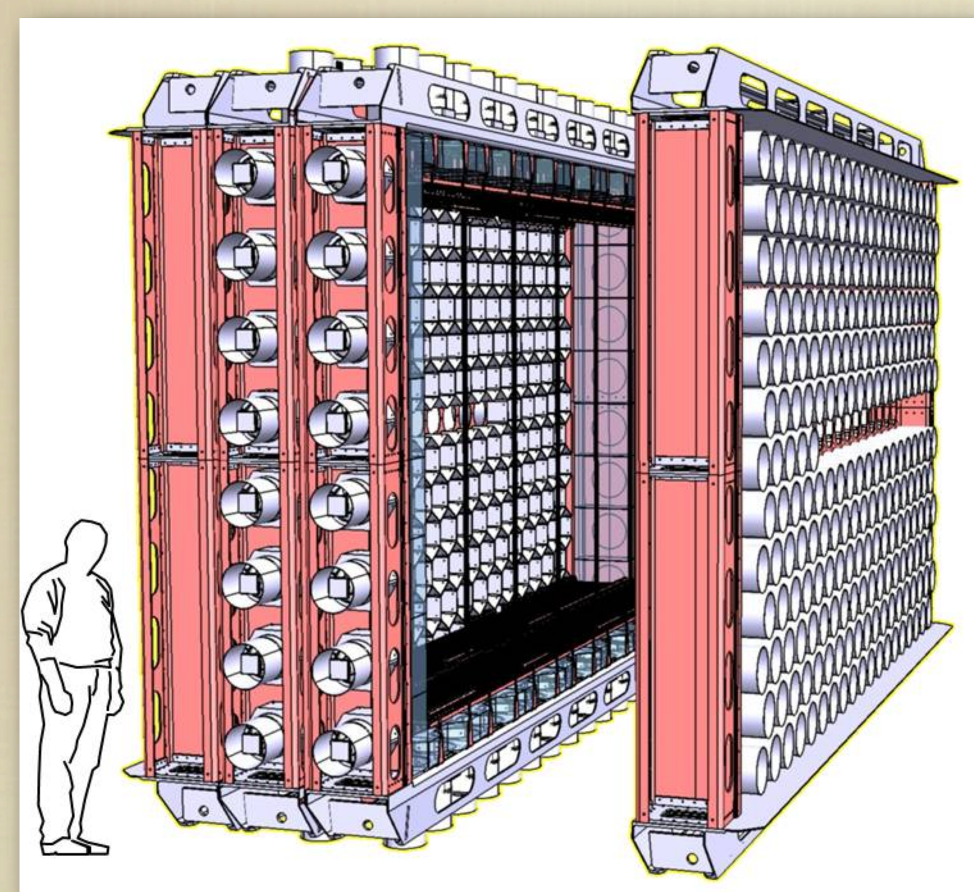
Main limitation: S/V and Mass.

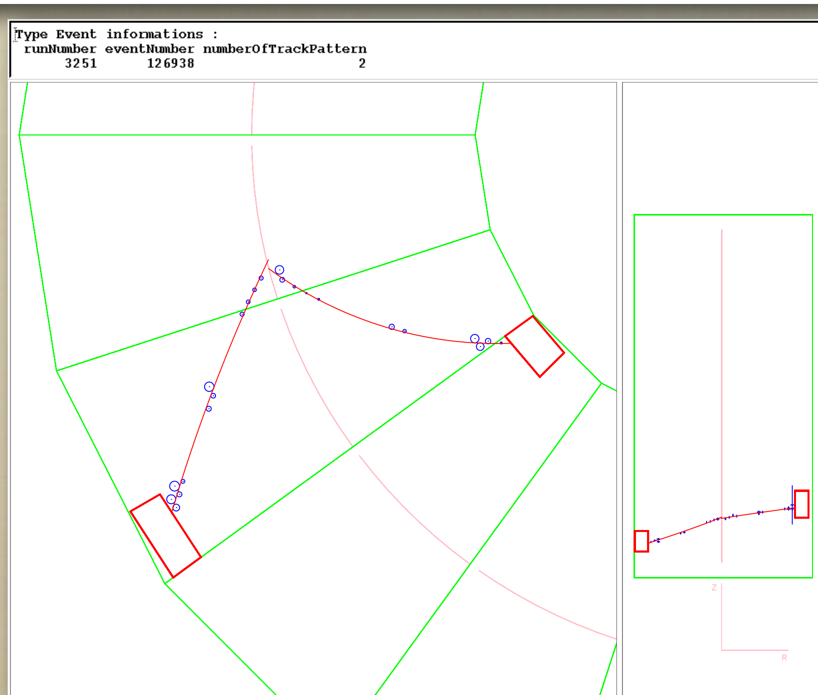
Low resolution calorimeters



- Enriched xenon dissolved in liquid scintillator.
- Poor resolution, 10% FWHM at the Q-value.
- Easy to pile up large mass
- Difficult to control backgrounds (K-ZEN initial run 10^2 larger than expected)

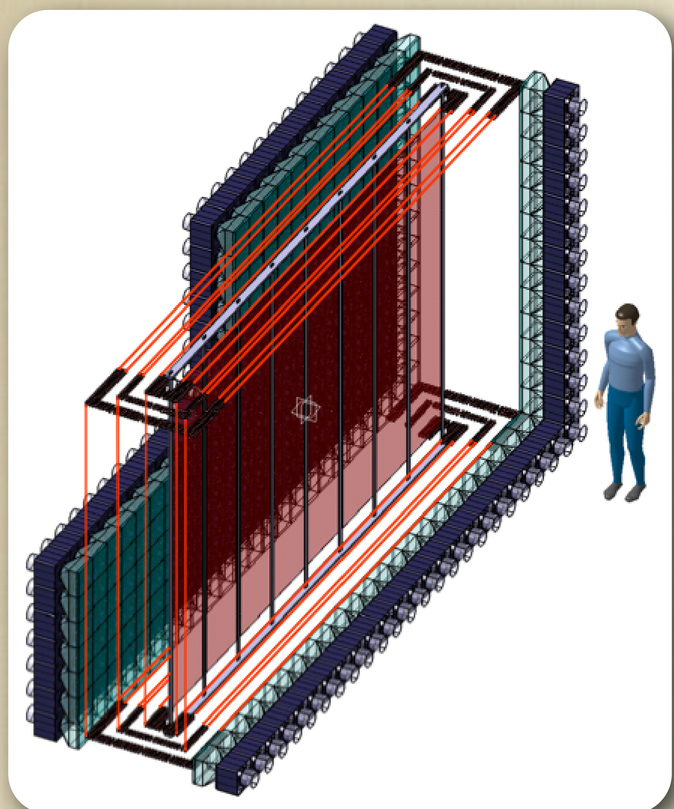
Modular/non-homogenous

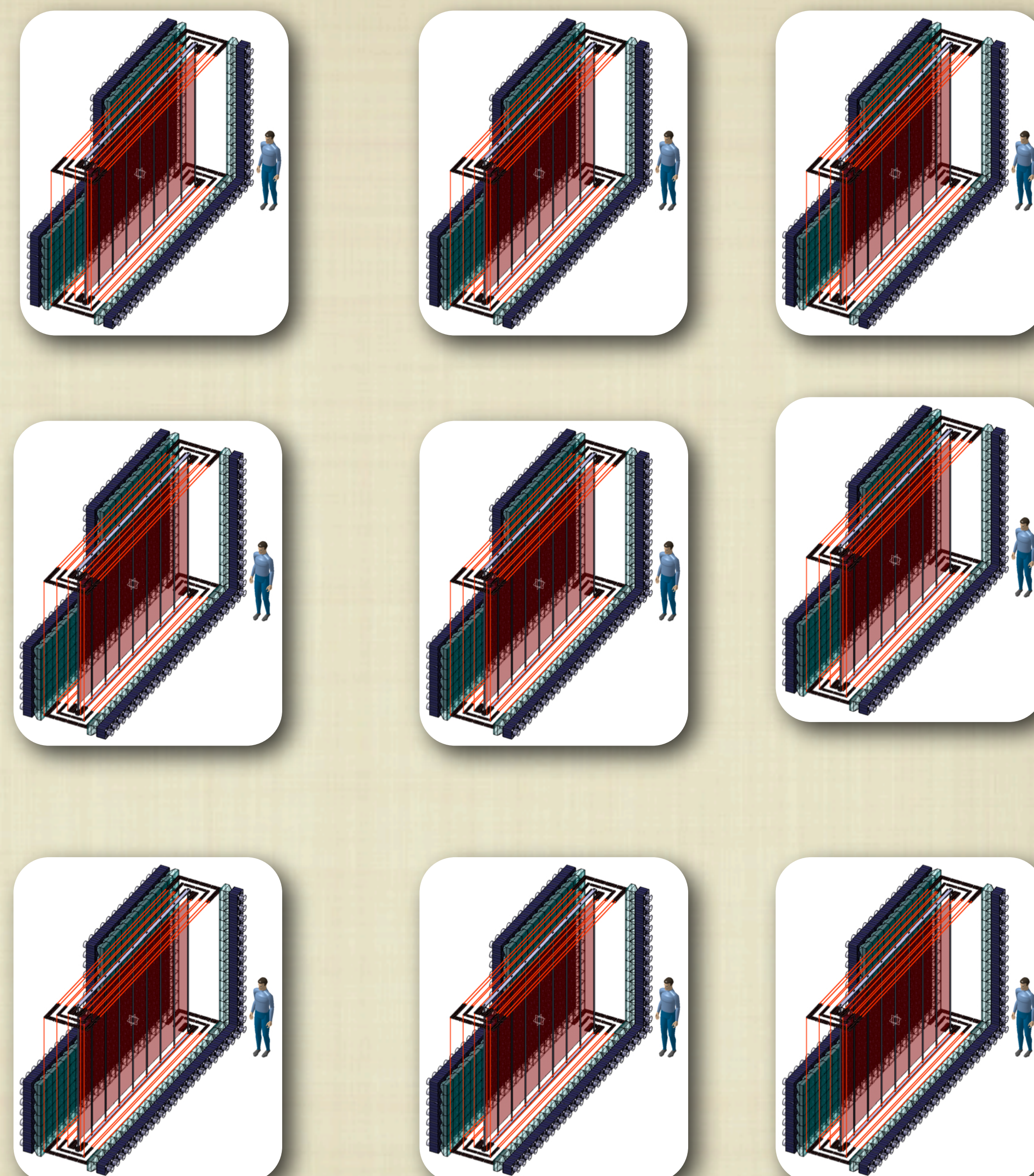




- Thin source foil (Se-82) within a tracking chamber surrounded by a calorimeter.
- Mediocre resolution, 4% FWHM at Q-value.
- Low efficiency (~30%).
- Extra handles (tracks)

No-go technique





Price & effort scales linearly

Backgrounds (proportional to surfaces) scale linearly

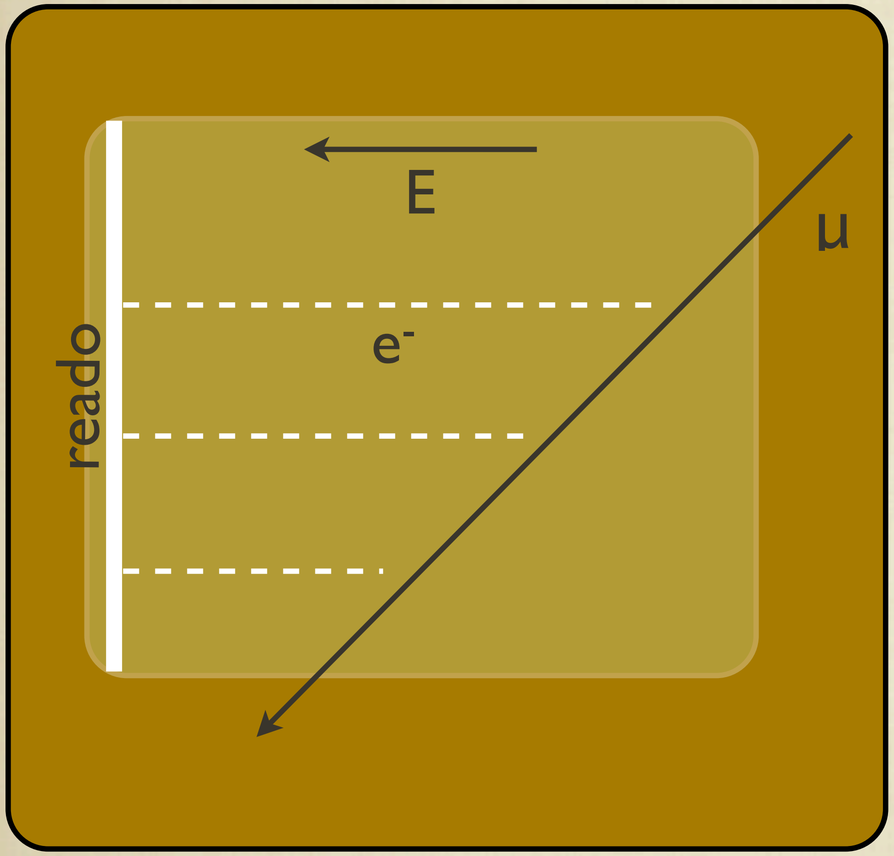
Not homogenous detector

Not suited even for current modest scale

Best feature of detector: Propaganda.

The TPC detector

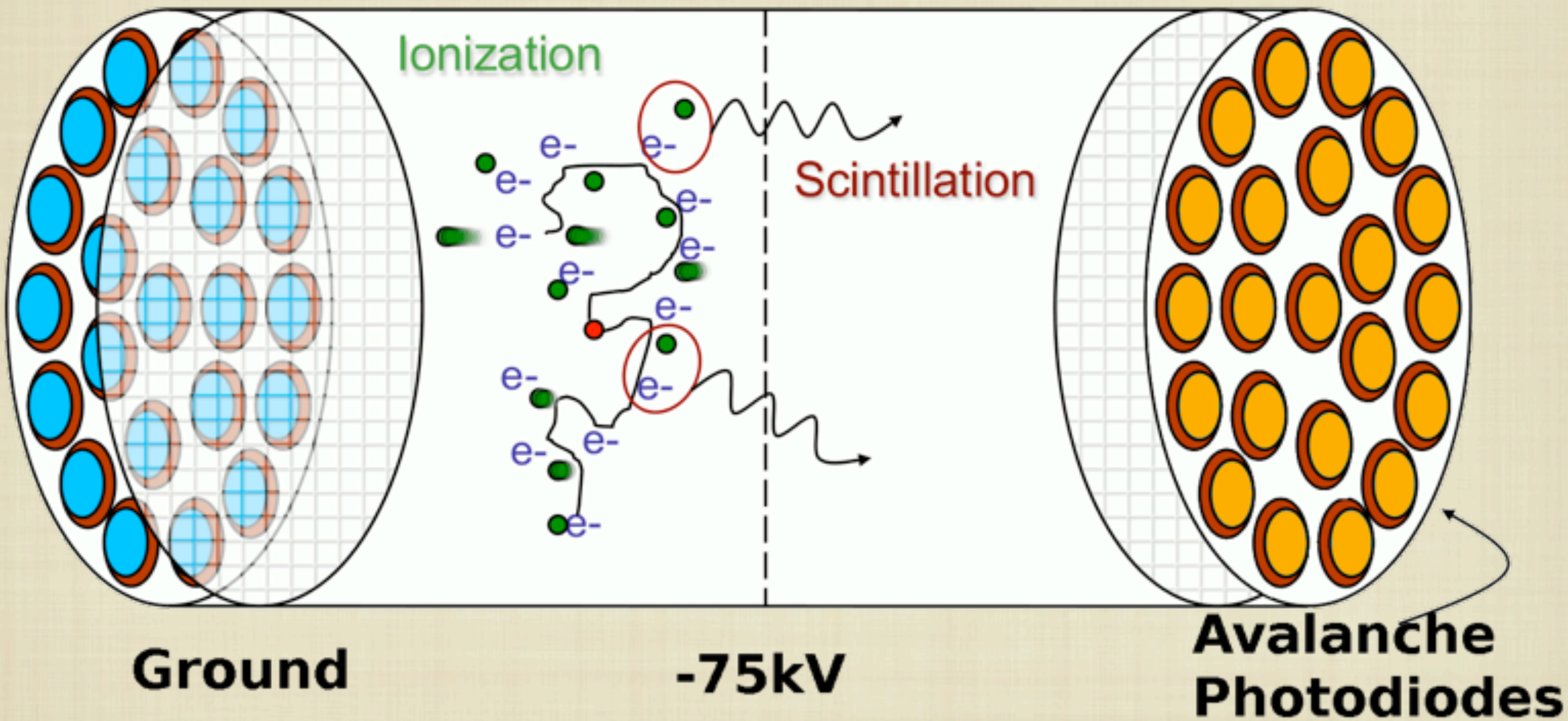
Time Projection Chamber: invented by D. Nygren in the 1970's.
Can be seen as an electronic bubble chamber.



- Requires a noble gas to operate
- Charged particles traversing TPC ionize gas leaving a track
- If track stops inside TPC then its energy is calorimetrically measured (with good resolution)
- Large volume possible (thus large mass)
- No surfaces in fiducial volume for background ions to attach to

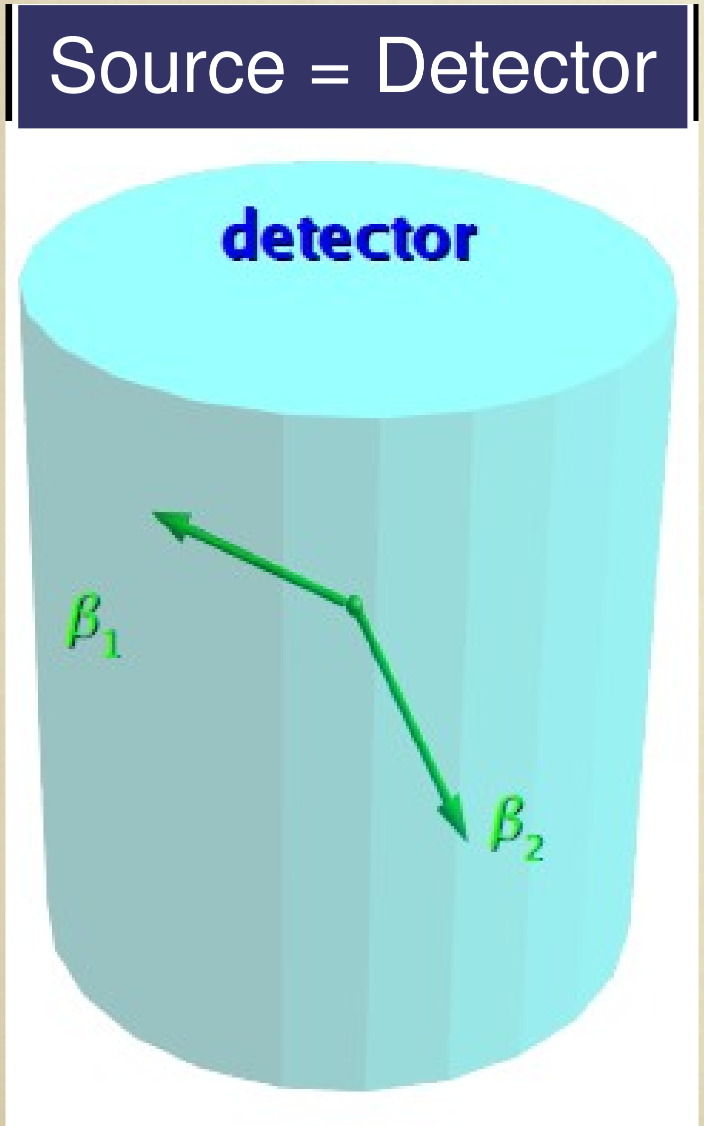
Imaging Xe chambers

high-pressure gaseous Xenon (HPGXe) or LXe



Ionization and Scintillation in Xenon can be recorded in Xe chambers

Xe chambers are an homogenous detector



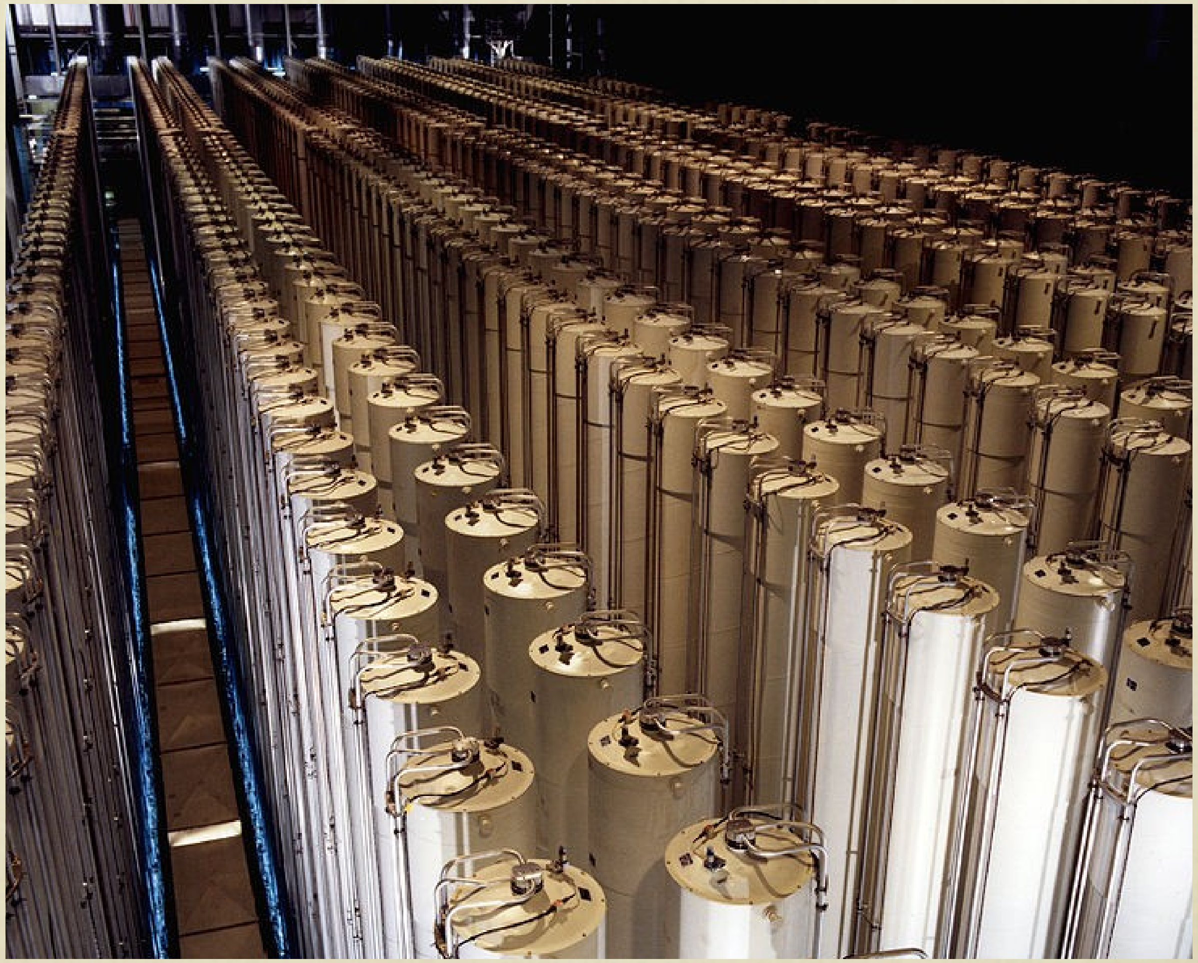
$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

Large TPC
Mass goes with L^3
Large mass and good fiduciality
Backgrounds scale with L^2.
Improve (doing nothing) as you make it larger.

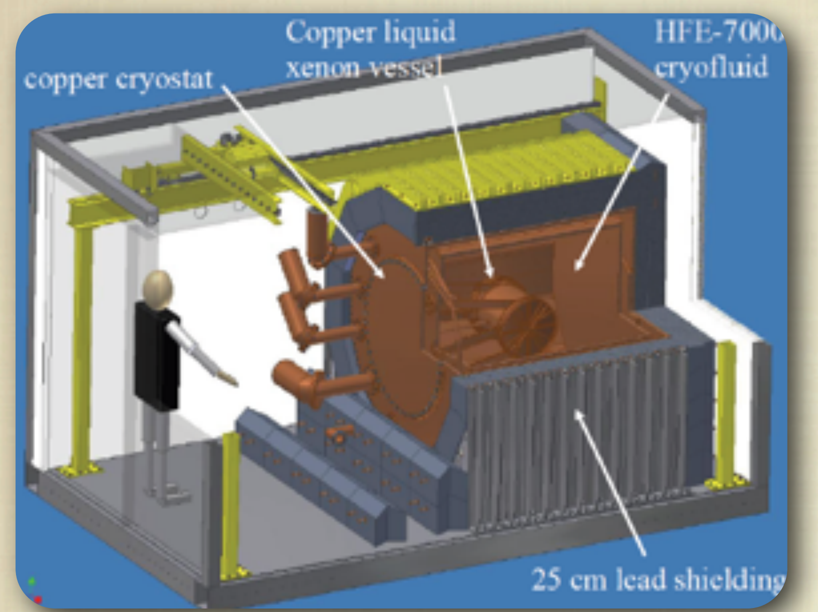
$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

Easy to enrich to >90% and “cheap”.

Isotope	Natural Abundance (%)
^{48}Ca	0.2
^{76}Ge	7.8
^{82}Se	9.2
^{96}Zr	2.8
^{100}Mo	9.6
^{110}Pd	11.8
^{116}Cd	7.5
^{124}Sn	5.6
^{130}Te	34.5
^{136}Xe	8.9
^{150}Nd	5.6



EXO-200

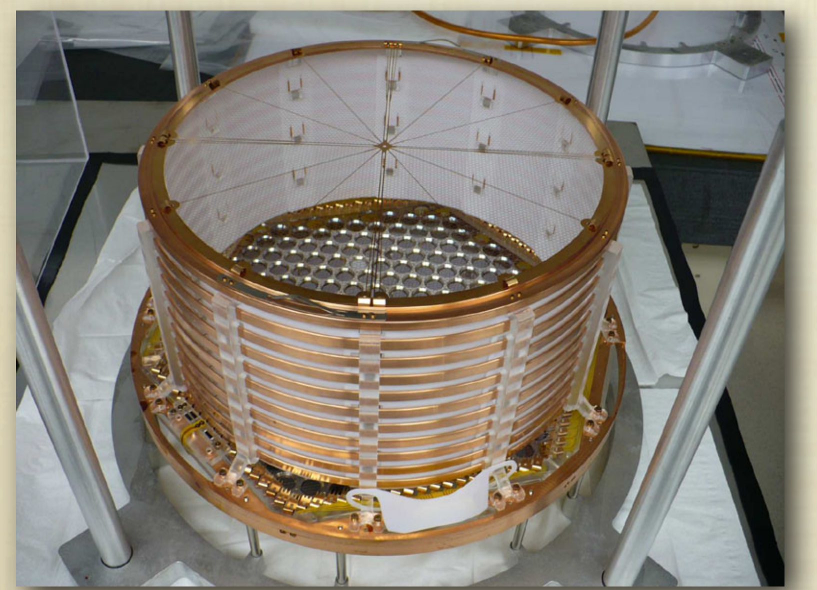


200 kg of liquid Xenon TPC
~4 % FWHM at Qbb
70% efficiency (hard fiducial cut needed for self-shielding)
Bkgnd --> ~ 10^{-3} c/(kg kev y)

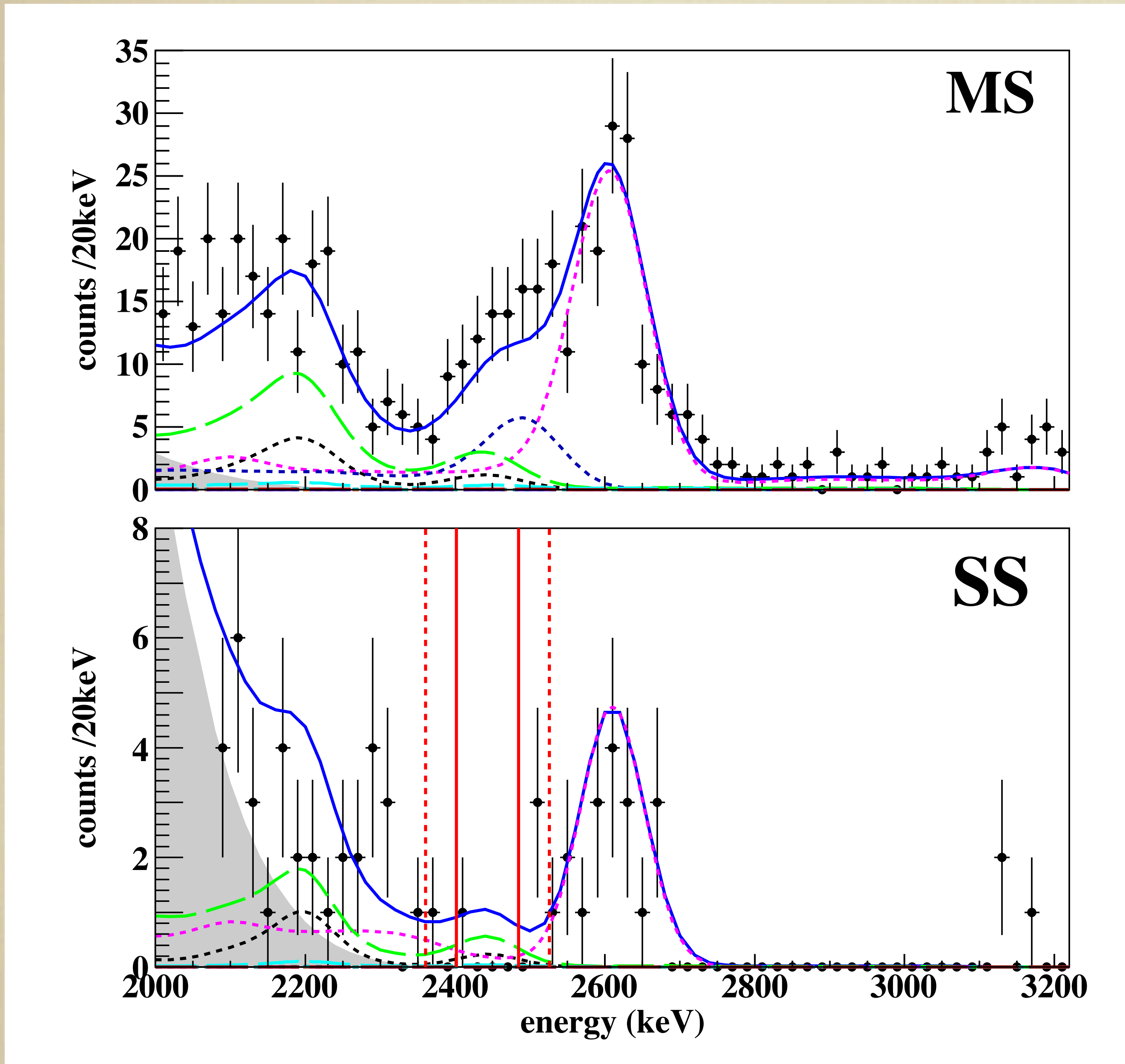
Large mass easy to achieve (liquid Xenon is very dense).

Strong points: compact, self-shielding, mass, scalability.

Weak points: mediocre resolution, low efficiency for effective shielding.

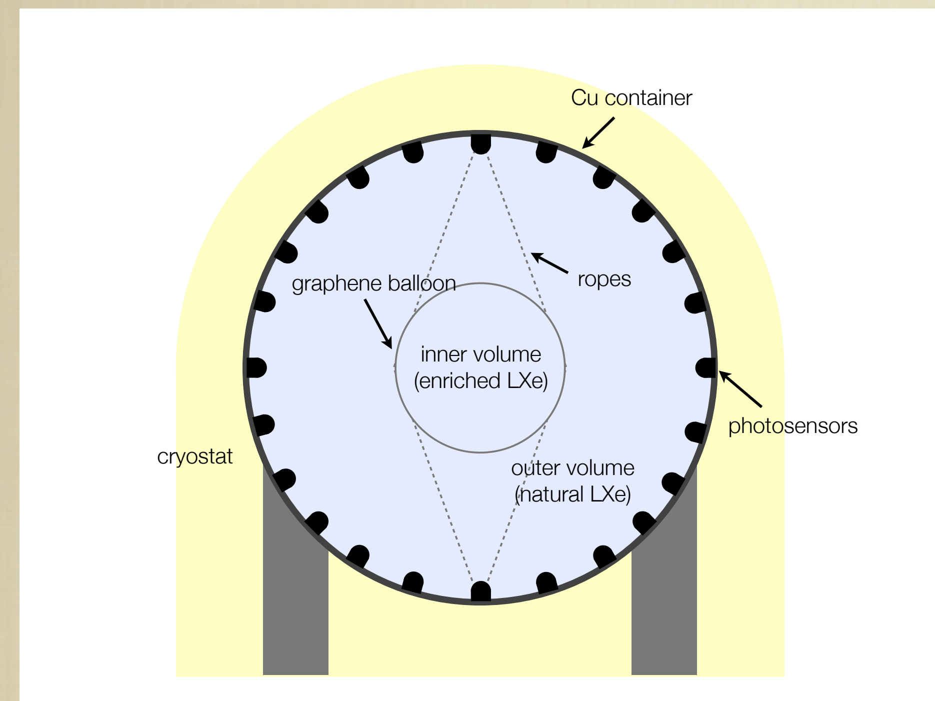


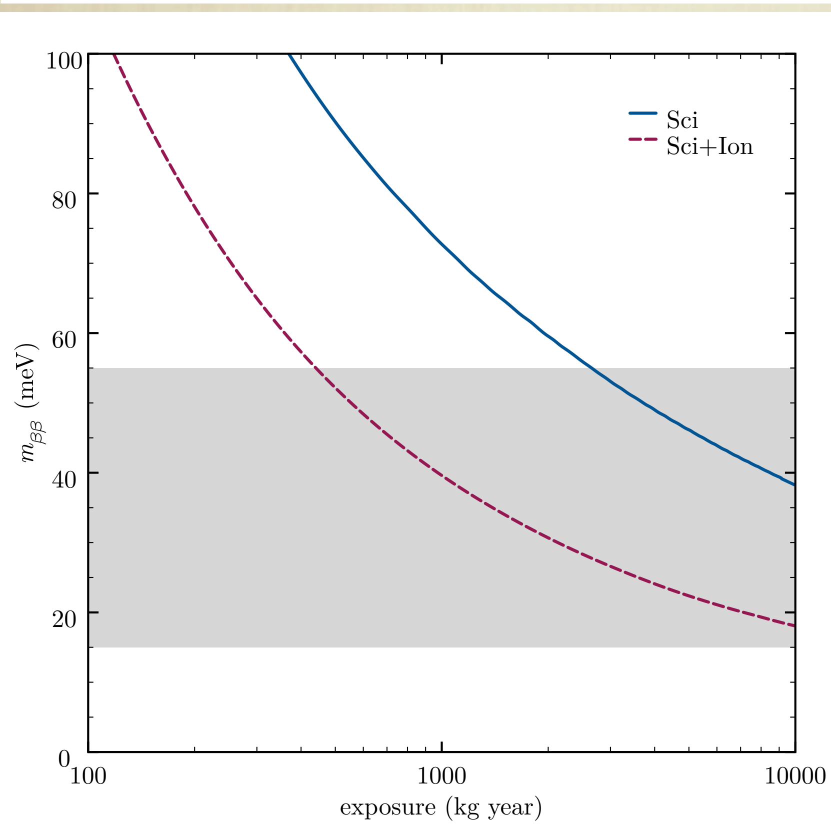
EXO-Limitations



- Expects 4 events in 1 sigma.
- Observes 4.
- Got lucky.
- Hard to improve with exposure (could get worse).
- Limitations: energy resolution lack of extra handles, expensive self-shielding.

GRAXE: A concept to improve LXe reach

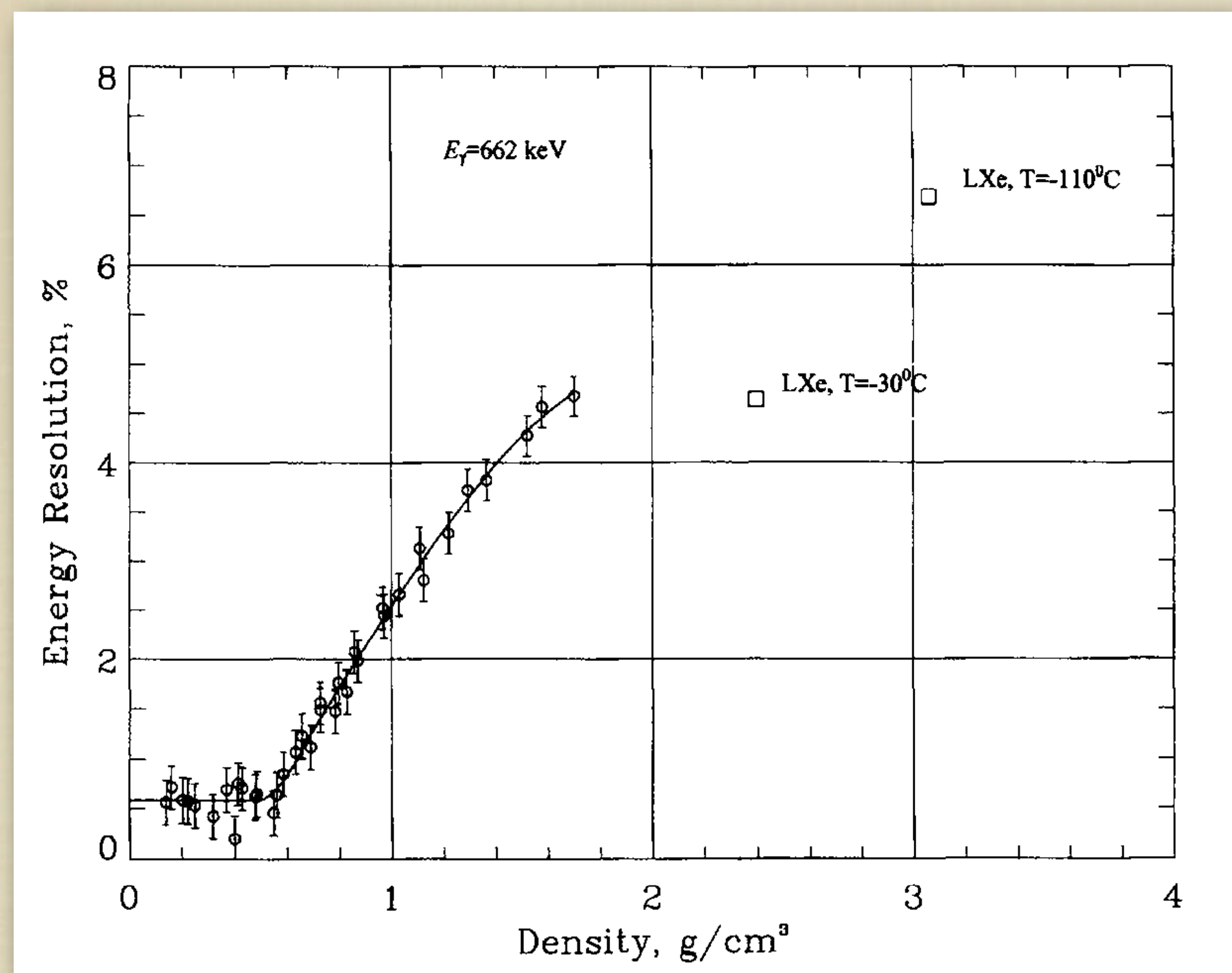




- GraXe is an spherical TPC. Conceptually identical to EXO.
- But EXE isolated from background by a buffer of pure NXE (no radioactive background)
- EXE enclosed in a graphene baloon that lets UV light through (also perfect metallic conductor, for spherical TPC).
- 20 tons of NXE will kill PMT radioactive background (and make up for a nice DM experiment)
- 1 ton extremely isolated EXE.
- Sci only (mediocre due to poor resolution: KZEN is a no-go in the long run)

Energy resolution in HPXe

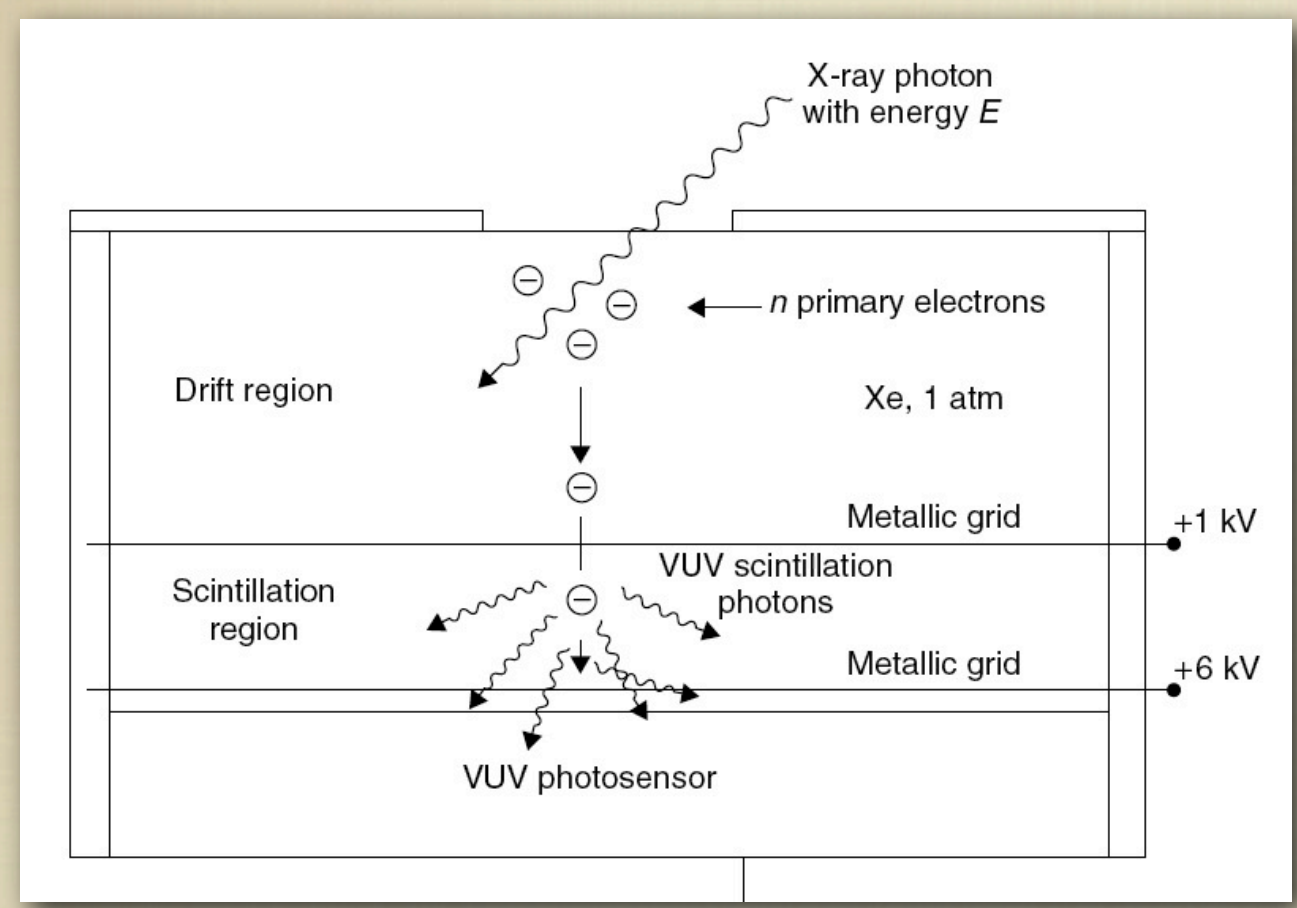
Bolotnikov and Ramsey, NIM A 396 (1997)

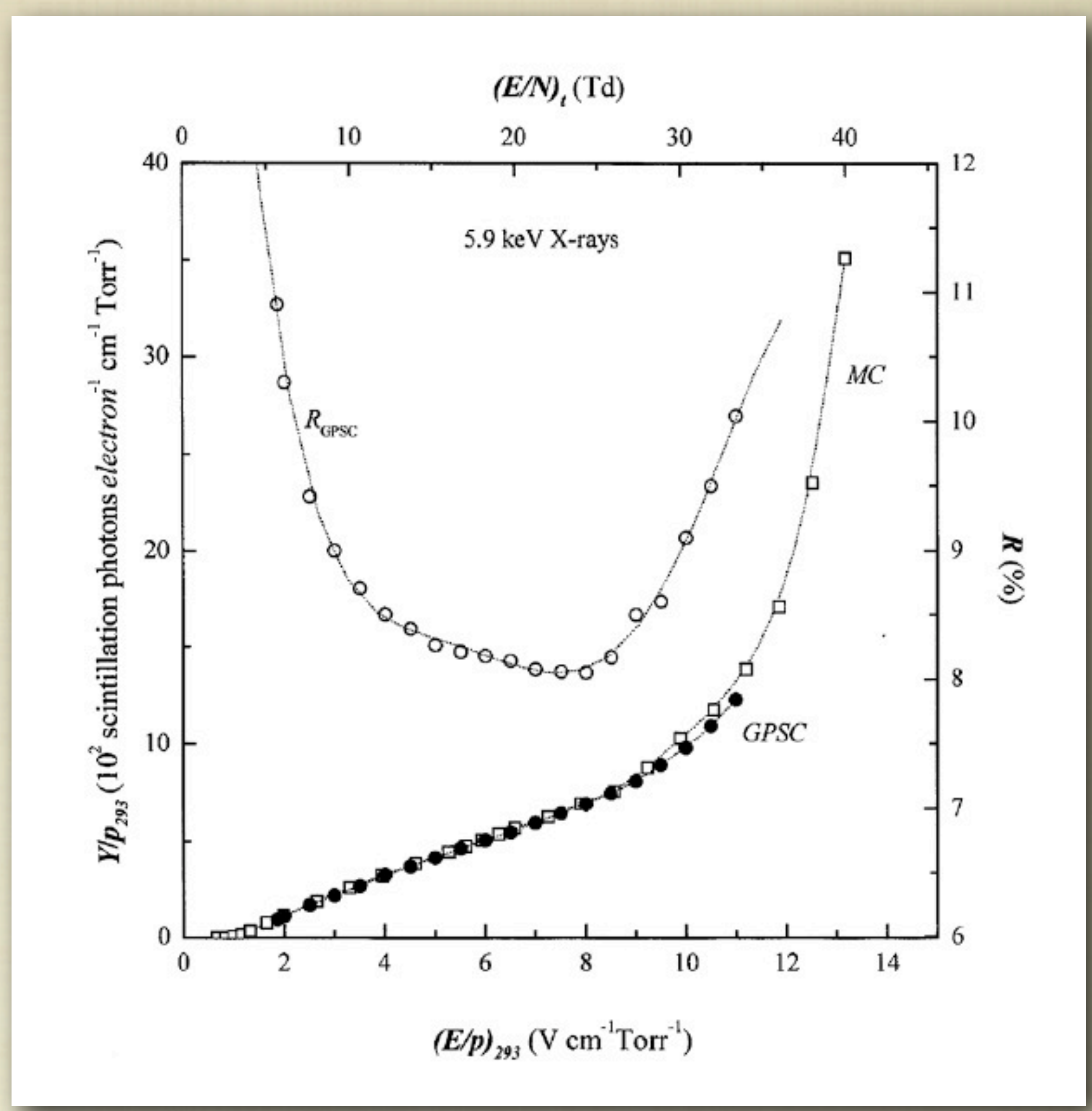


$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

- Intrinsic resolution (Fano factor) at $Q_{\beta\beta}$ (2458 keV): 3×10^{-3} FWHM.
- Best experimental result: 5×10^{-3} FWHM.

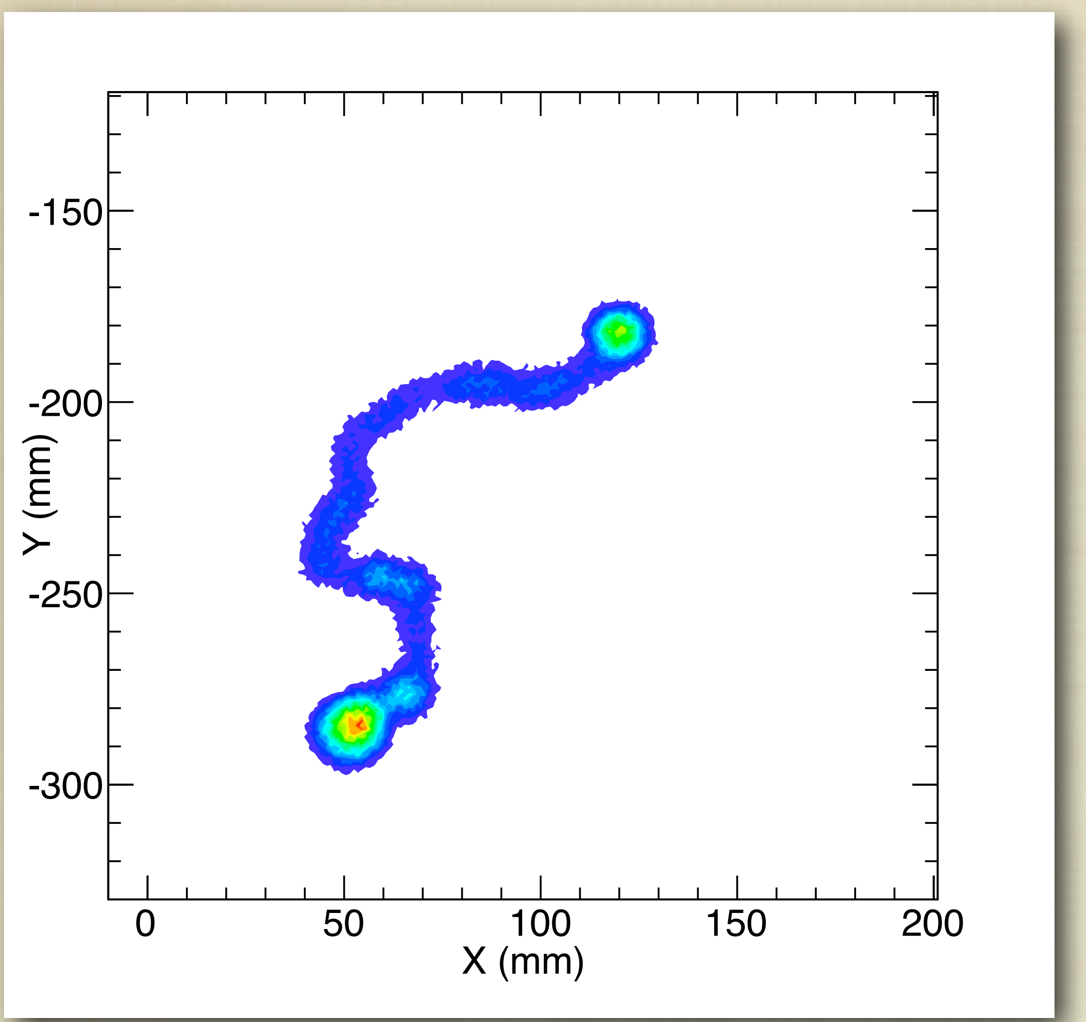
Electroluminescence





Emission of scintillation light by atoms excited by a charge accelerated by a moderate electric field.
Linear process, sub-poissonian fluctuations, huge gain at $3 < E/p < 6$ kV/cm/bar.

Tracking in HPXe

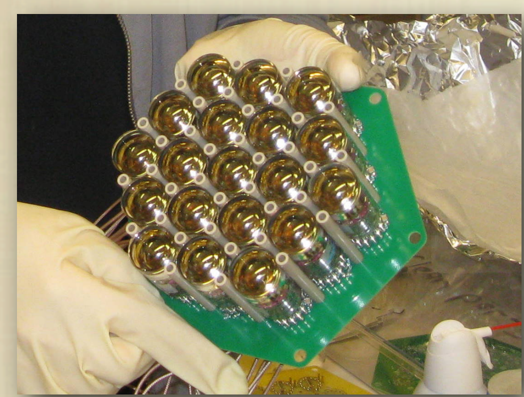


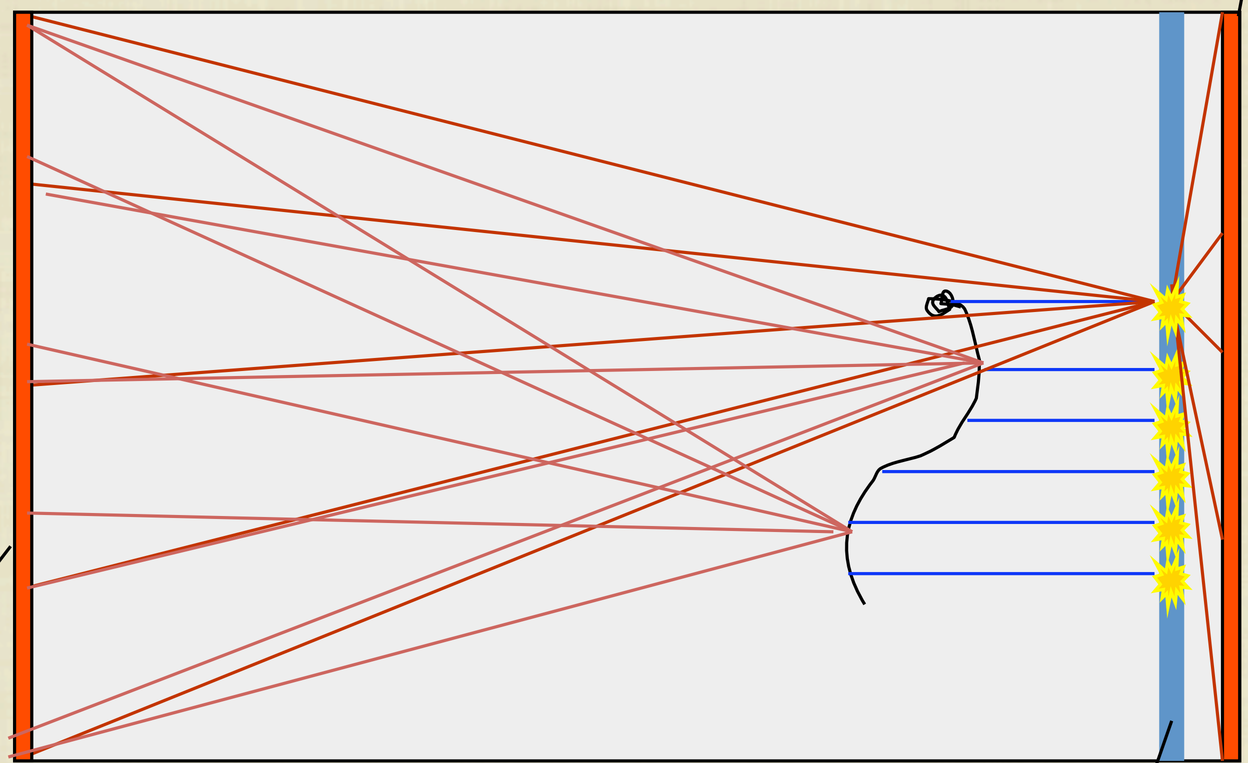
$$T_{1/2}^{-1} \propto a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot B}}$$

Electrons travel on average ~15 cm each. Trajectories highly affected by multiple scattering. Electrons behave as MIPs except near the endpoints (*blobs*).

The SOFT concept

Readout
Plane A
- **position**



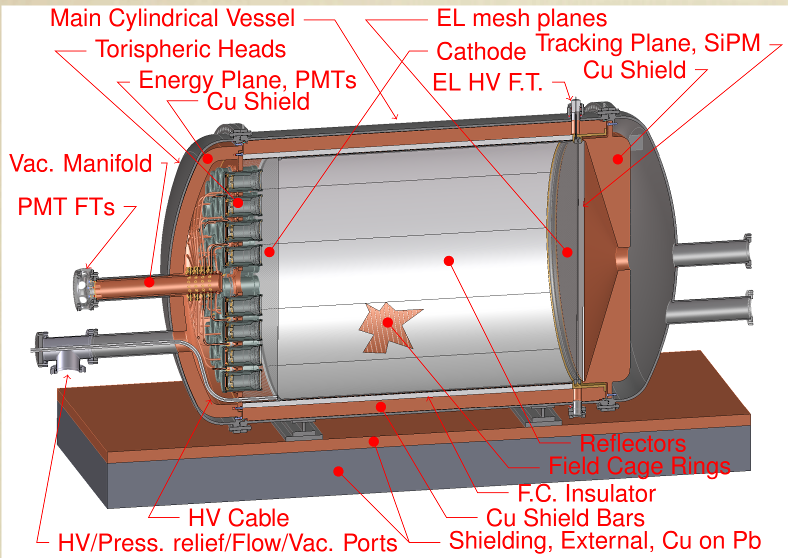


Readout
Plane B
- **energy**

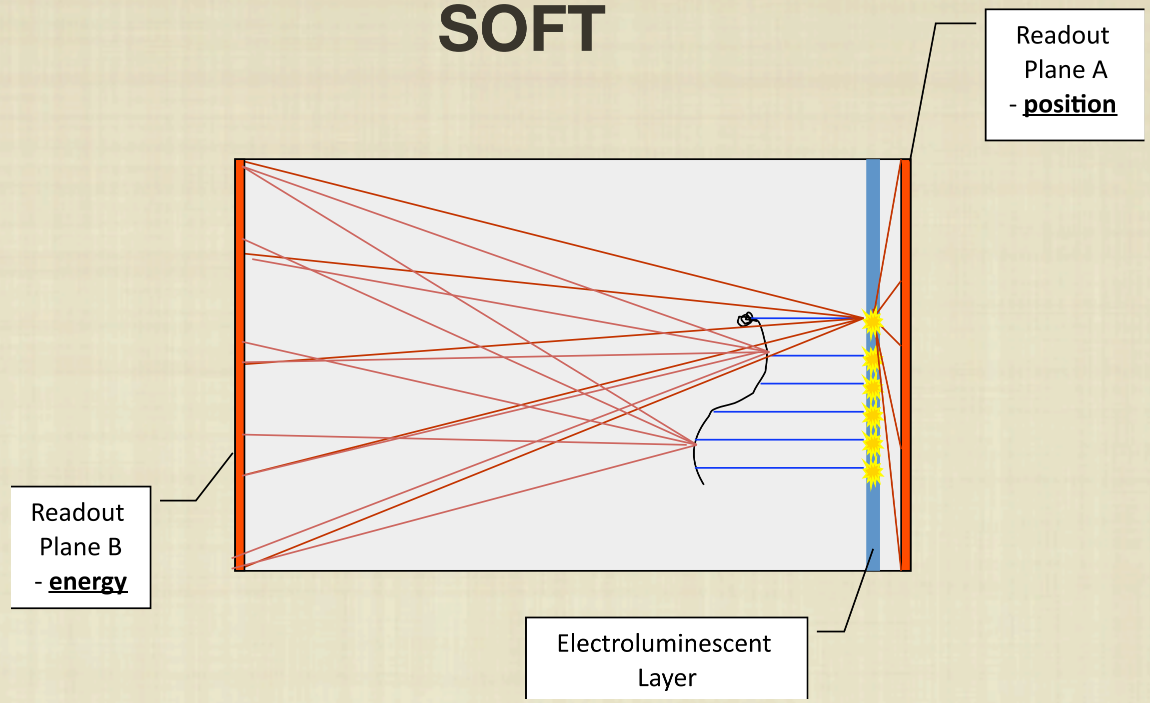
Electroluminescent
Layer

NEXT concept

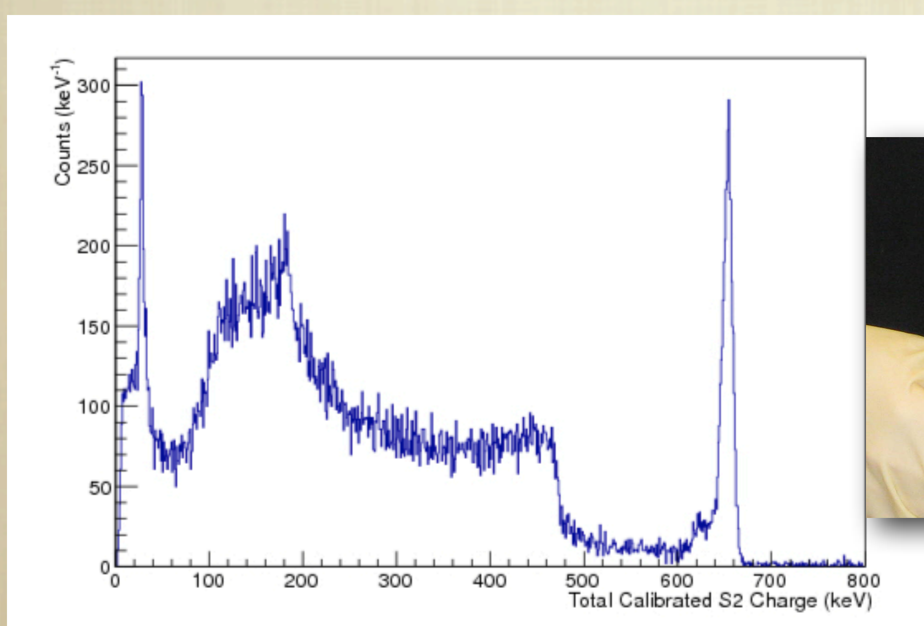
HPGXe



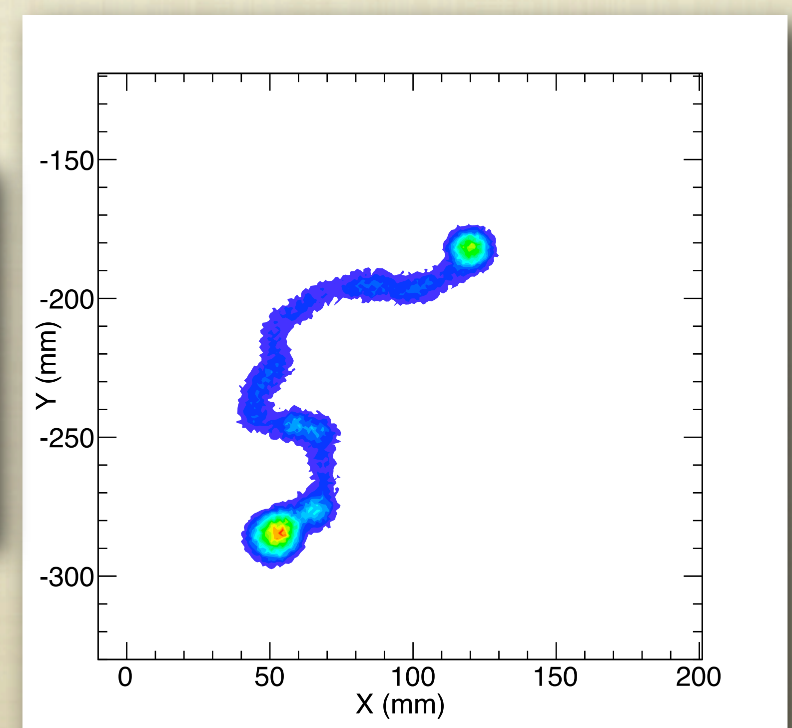
SOFT



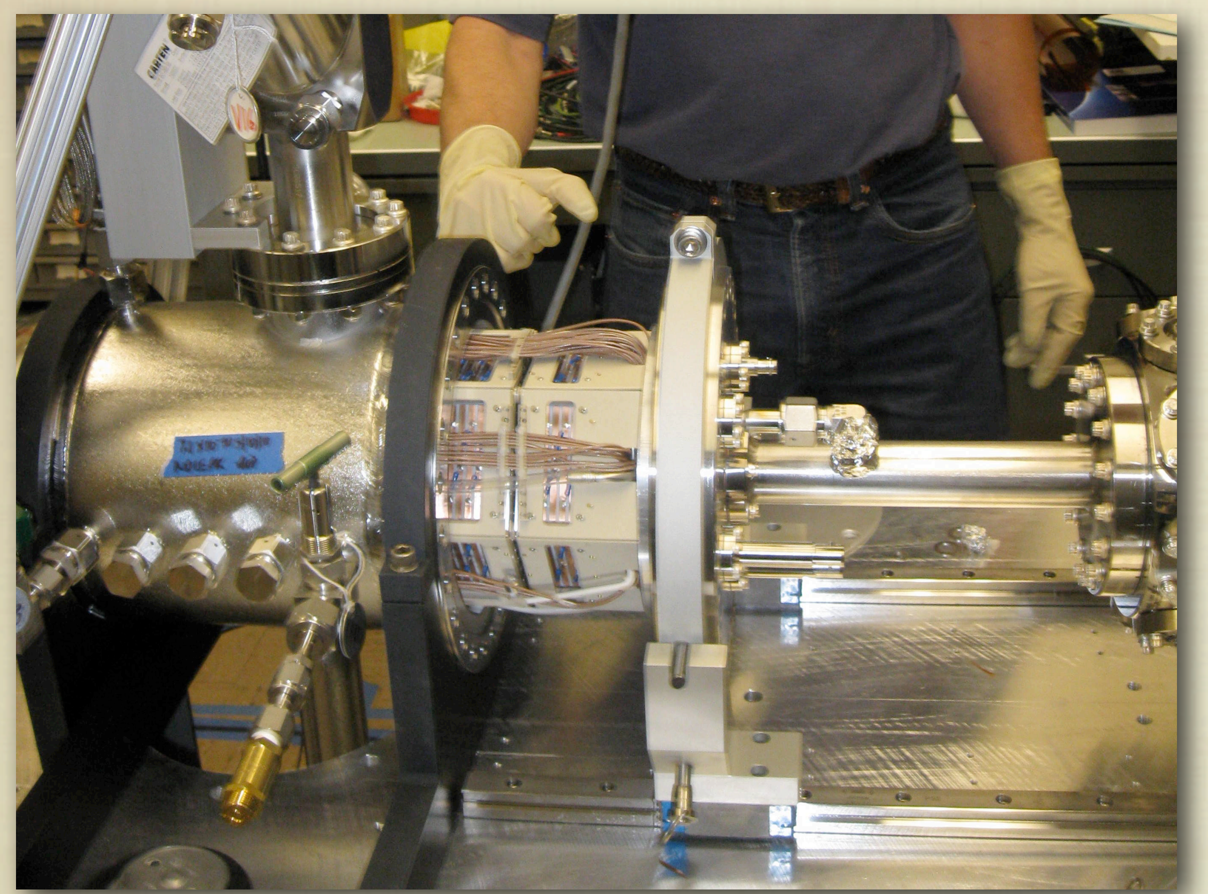
Energy resolution



Topological signature



NEXT-1 prototypes



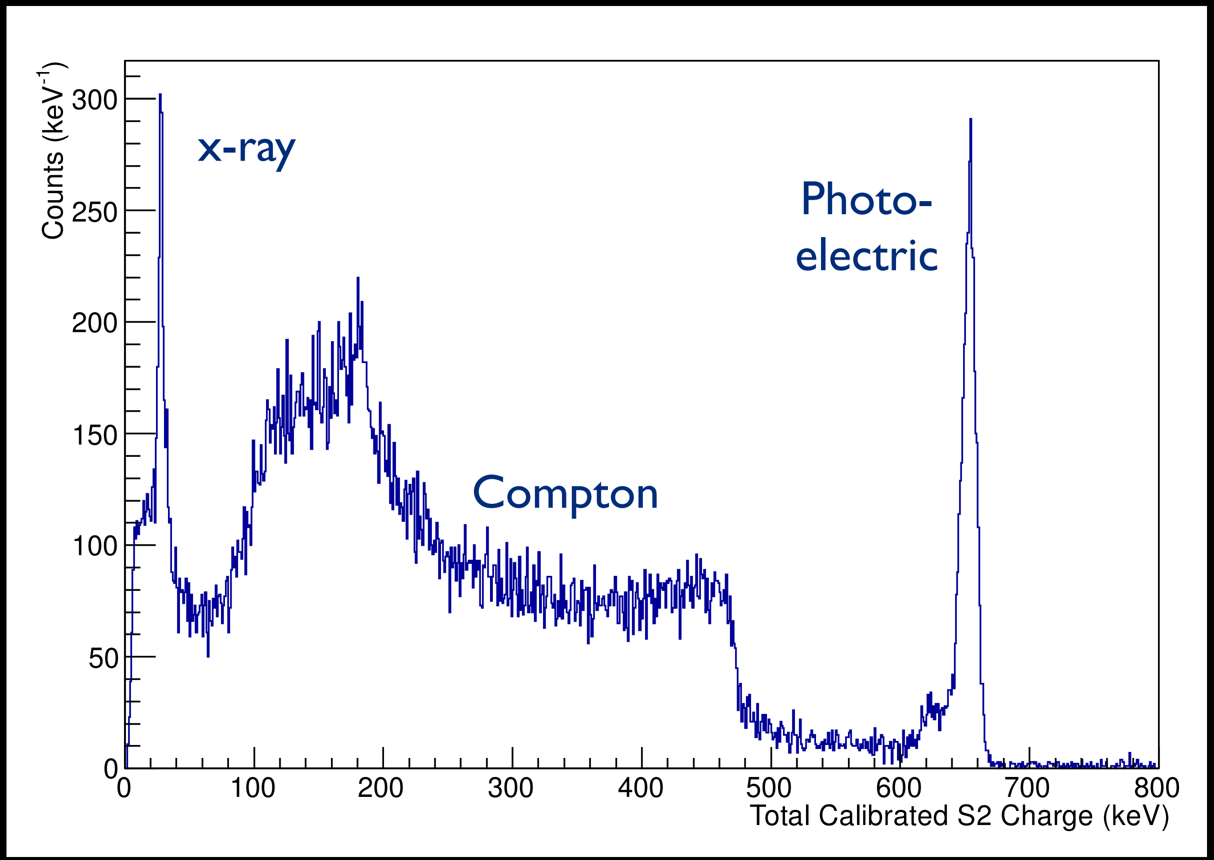
NEXT-DBDM
Energy resolution in HPXe

NEXT-DEMO
NEXT detector concept

Energy resolution demonstrated

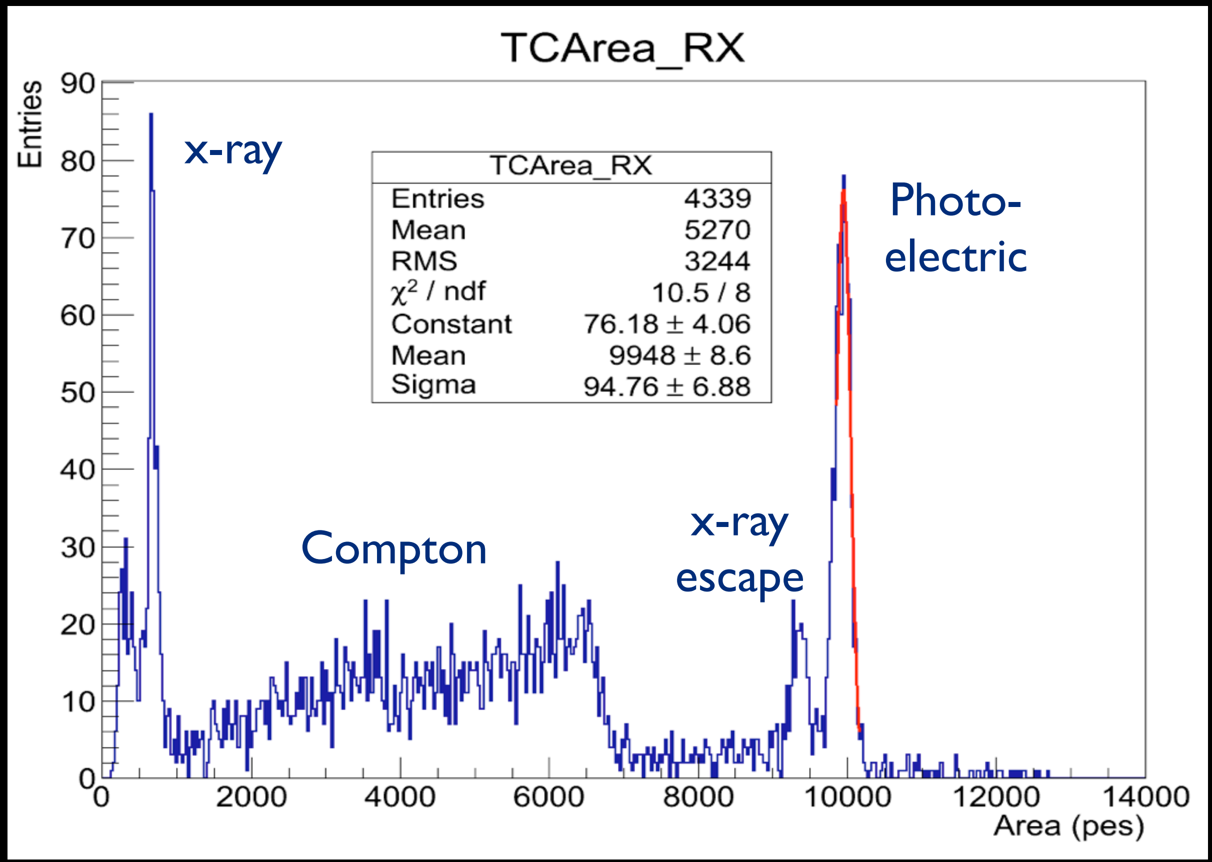
- **Experience and results from prototypes**
  - Testing ground for all foreseeable technical hurdles in NEXT-100
  - 0.5-1% FWHM energy resolution at $Q_{\beta\beta}$ demonstrated

Energy, 662 keV gammas from ^{137}Cs in NEXT-DBDM prototype



0.5% FWHM at Qbb in central region

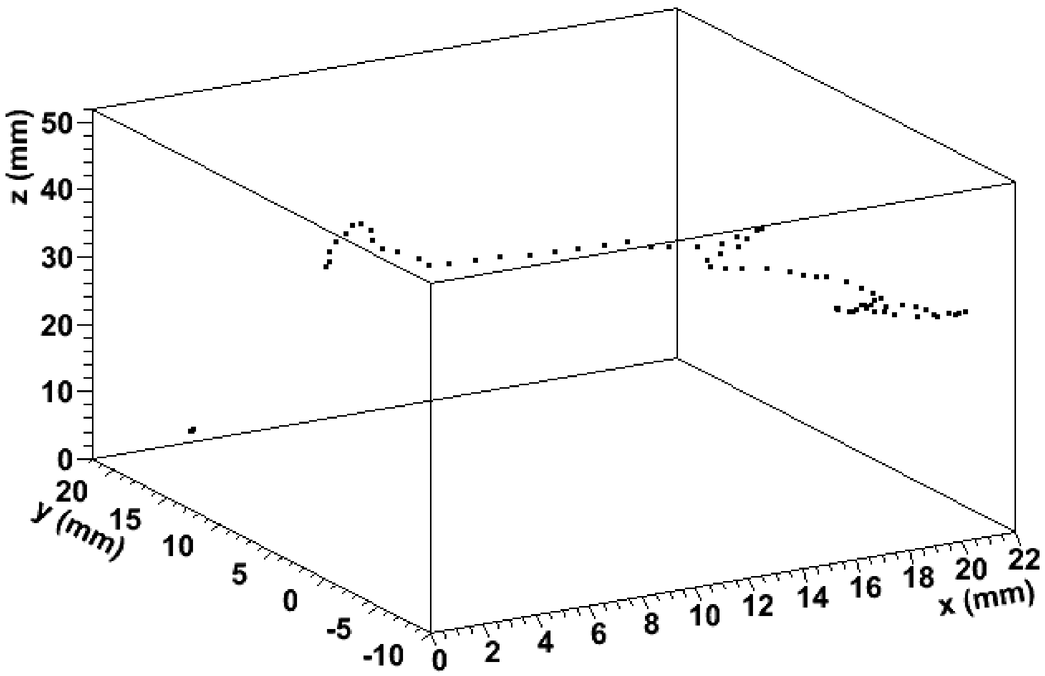
Energy, 511 keV gammas from ^{22}Na in NEXT-DEMO prototype



1% FWHM at Qbb in full fiducial

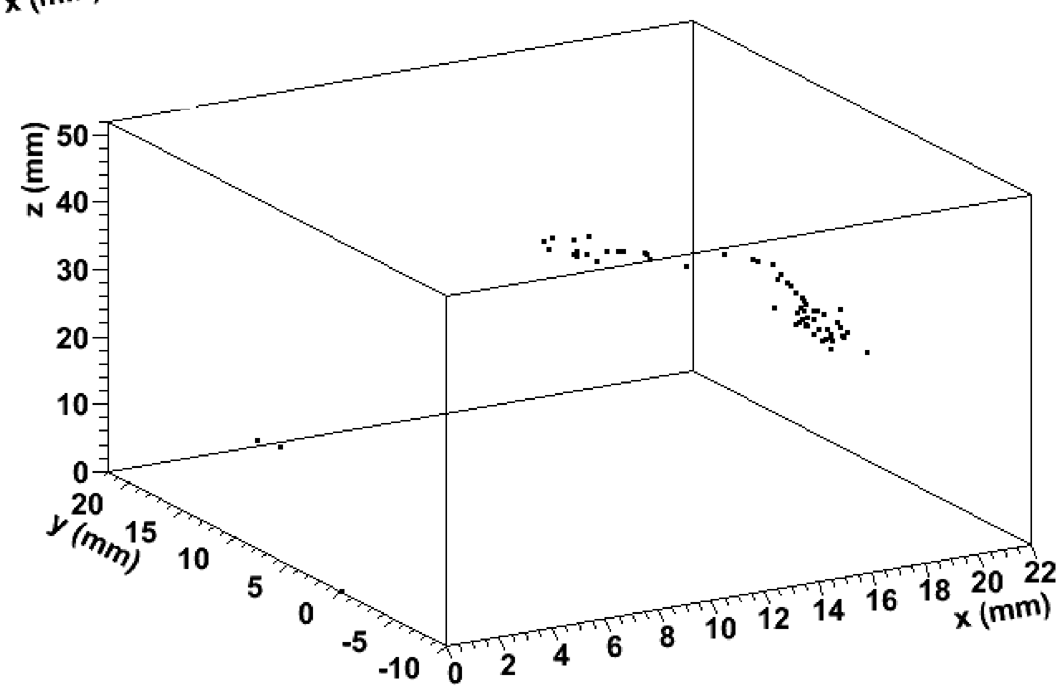
TRACK RECONSTRUCTION

Track reconstruction with SiPMs:



← MC Truth

Reconstructed →

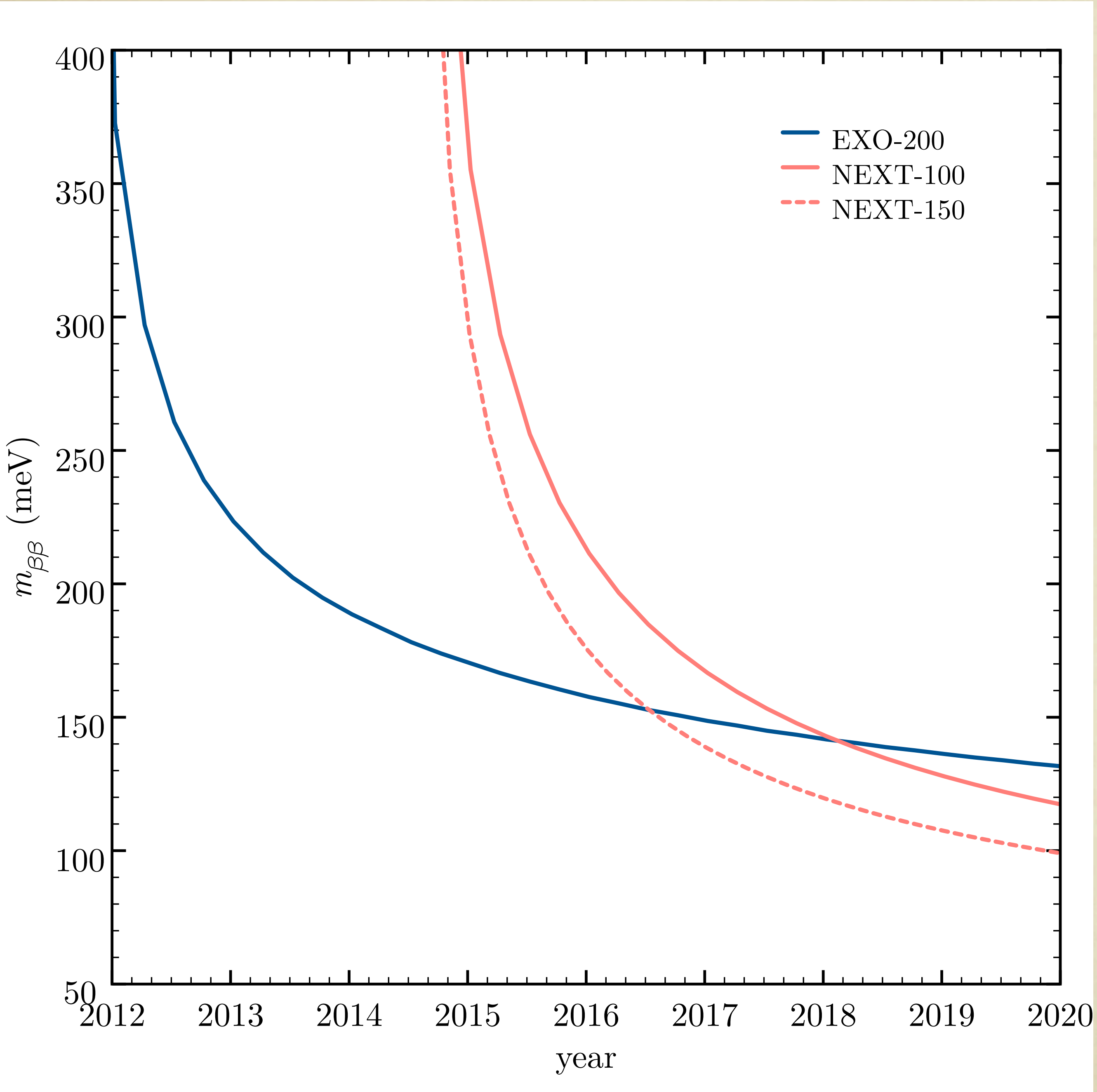


NEXT-100 performance

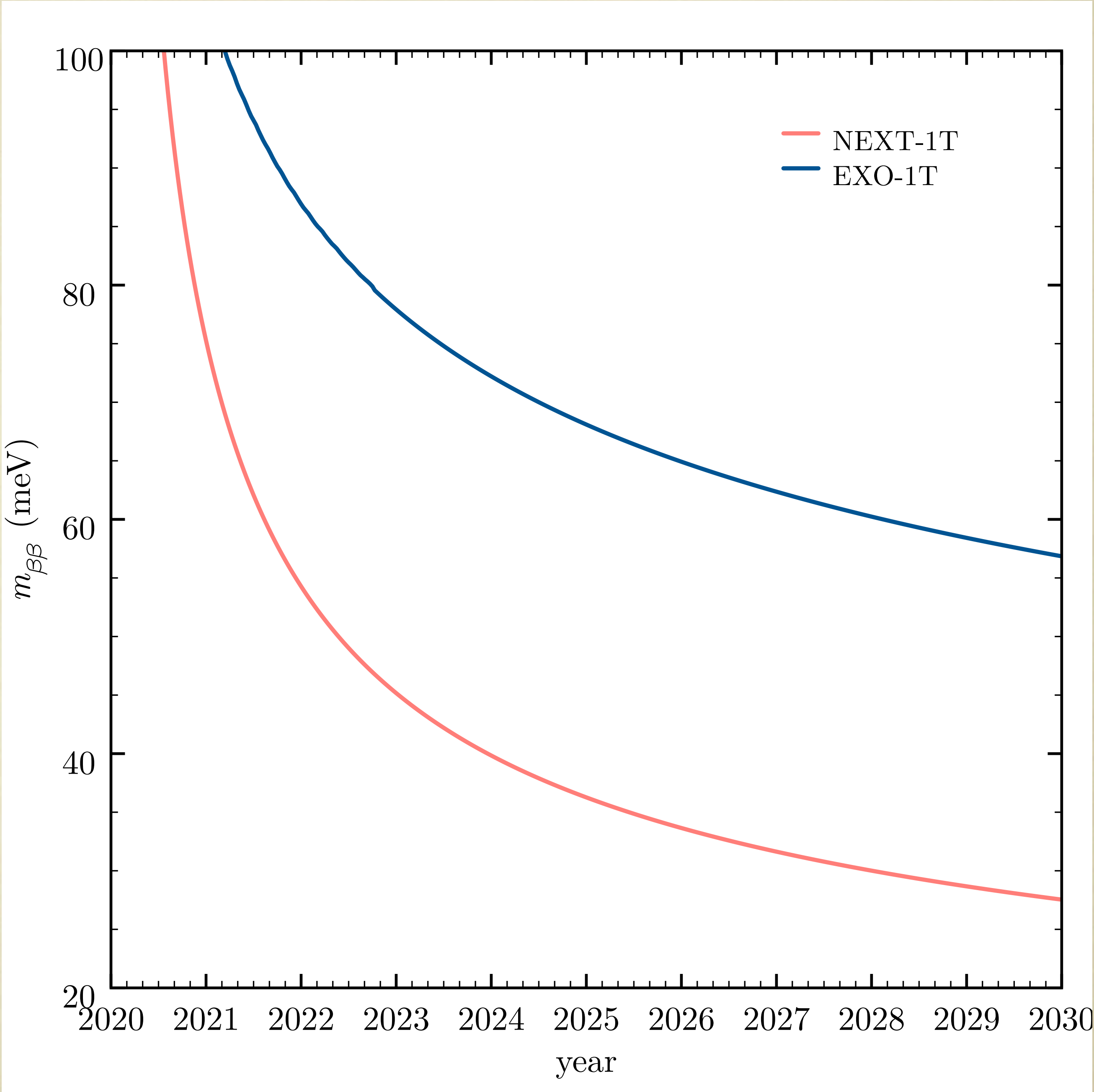
	Signal	^{214}Bi	^{208}Tl
1 track cut	0.48	6.0×10^{-5}	2.4×10^{-3}
ROI	0.33	2.2×10^{-6}	1.9×10^{-6}
Topological cut	0.25	1.9×10^{-7}	1.8×10^{-7}

Rejection Potential	$\sim 10^{-7}$
Background	2.0×10^{-4} counts/keV/kg/yr

NEXT vs EXO



400
350
300
250
200
150
100
50
2012
2013
2014
2015
2016
2017
2018
2019
2020
year
$m_{\beta\beta}$ (meV)
EXO-200
NEXT-100
NEXT-150



100
80
60
40
20
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
year
$m_{\beta\beta}$ (meV)
NEXT-1T
EXO-1T

Outlook

- A large detector (1 ton) capable of exploring periods > 10^{25} y (inverse hierarchy ~10^{26} - 10^{27} y) requires a homogenous cheap isotope. Xenon is a noble gas and the cheapest in the market, it has no radioactive isotopes, is a great calorimeter and in the gas phase has excellent resolution.

- There are two ways to reach the 1 ton mass, T1/2 ~10^{26} - 10^{27} y, with manageable background (1 event per ton per year)

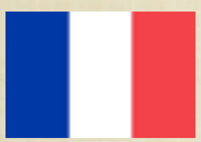
- LXe, if a way to kill all radioactive background is implemented (Ba++ tagging, Graxe concept).

- HPGXe, taking advantage of excellent resolution and extra handle.

NEXT Collaboration

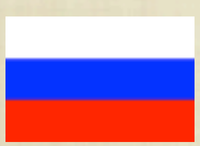
U. Girona • IFIC (Valencia) • U. Santiago de Compostela • U. Politécnica Valencia • U. Zaragoza

LBNL • Texas A&M



CEA (Saclay)

U. Coimbra • U. Aveiro



JINR (Dubna)

UAN (Bogotá)

Spain provides:

- Most collaborators
- Most of secured funding
- Host laboratory (LSC)

Key contributions from international groups:

- TPC detector design
- Gaseous detectors
- Xe supply and enrichment

Spain: Beyond soccer?

http://next.ific.uv.es/

Euro 2012

The next big thing

Jul 2nd 2012, 13:27 by P.L.

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