Ettore Majorana through the Looking-glass

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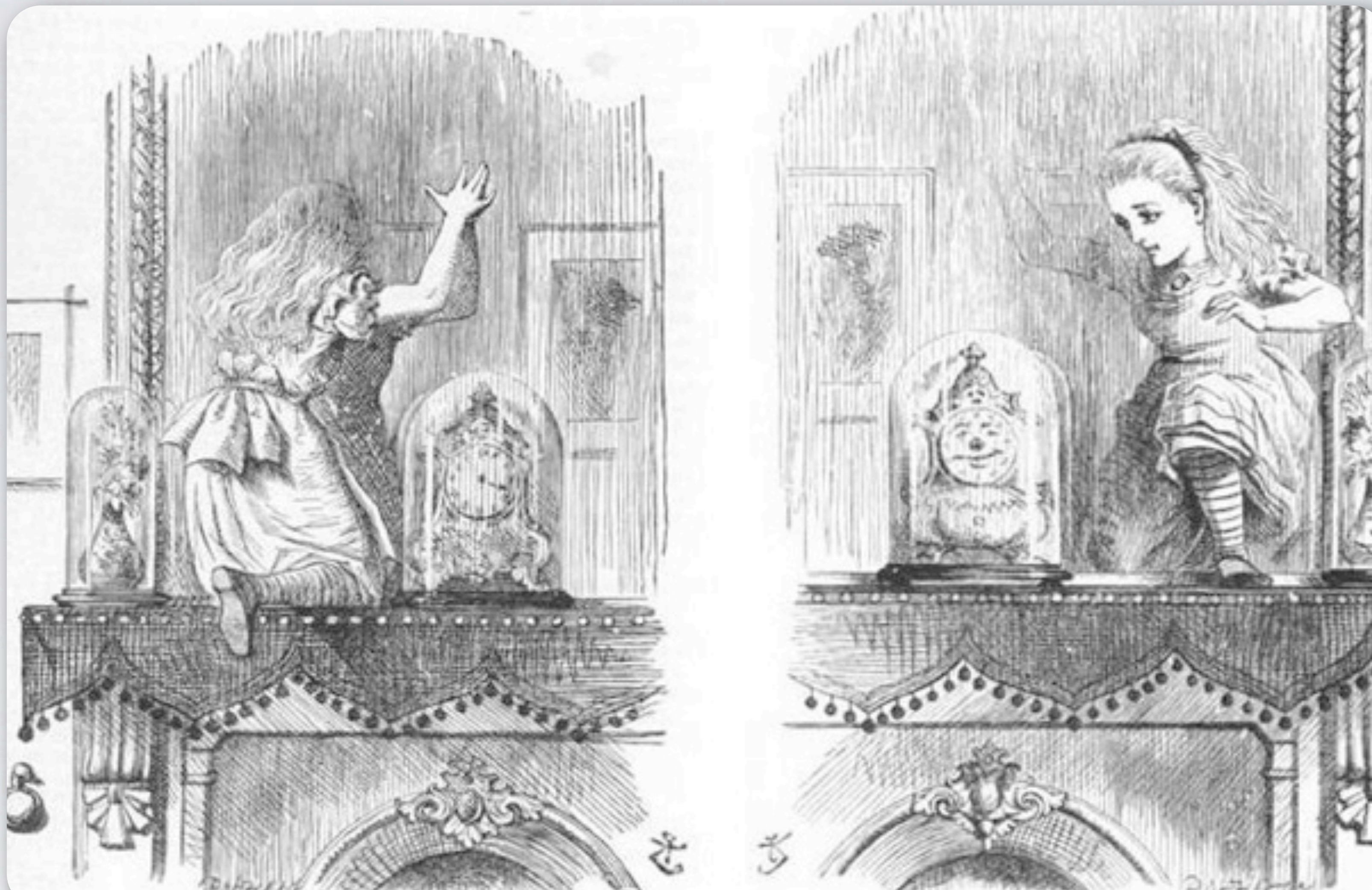
Instituto de Física Corpuscular (CSIC & UVEG)

CERN, January, 2013

Alice through the looking glass

Alice through the looking glass



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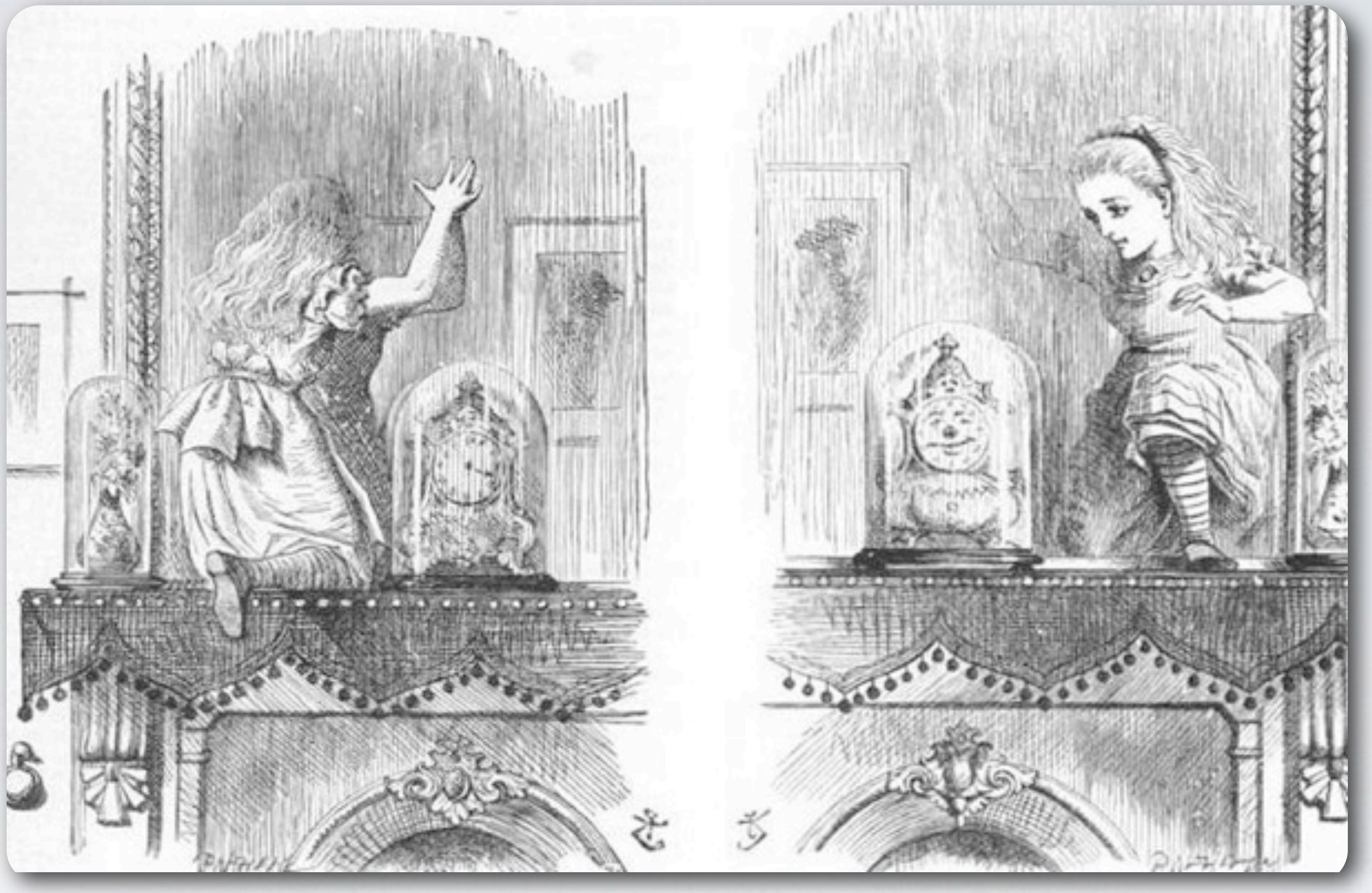
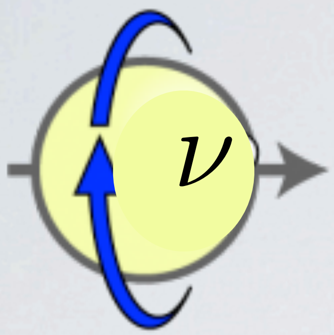
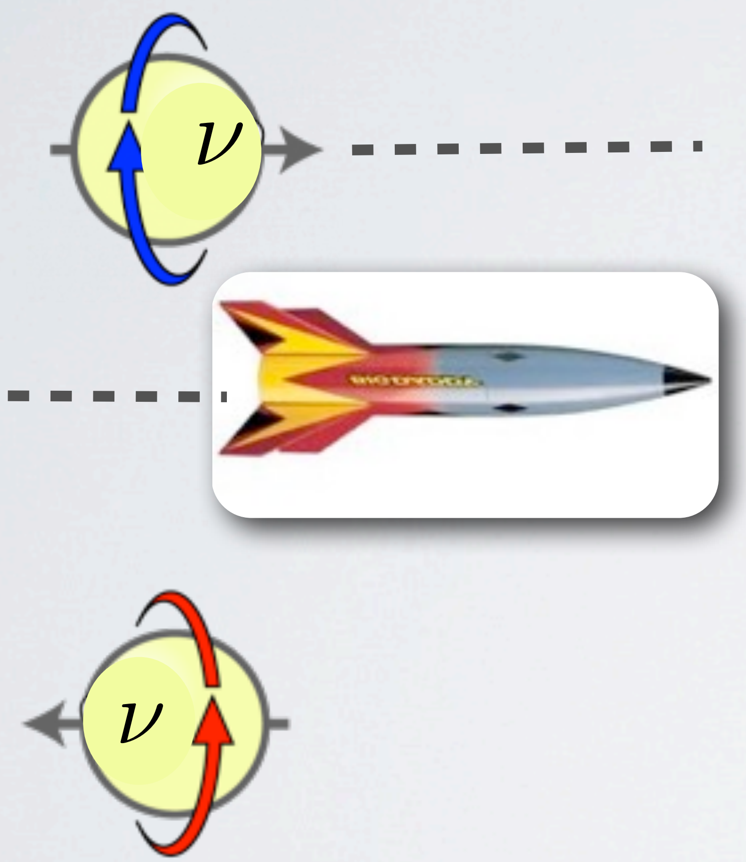


Lewis Carroll: The world at the other side of the mirror is not just a dead reflection of ours but has rules of its own.

Neutrino through the looking glass



- In the Standard Model neutrinos are massless and left handed (antineutrinos are right handed)



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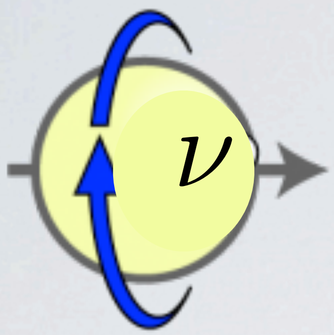

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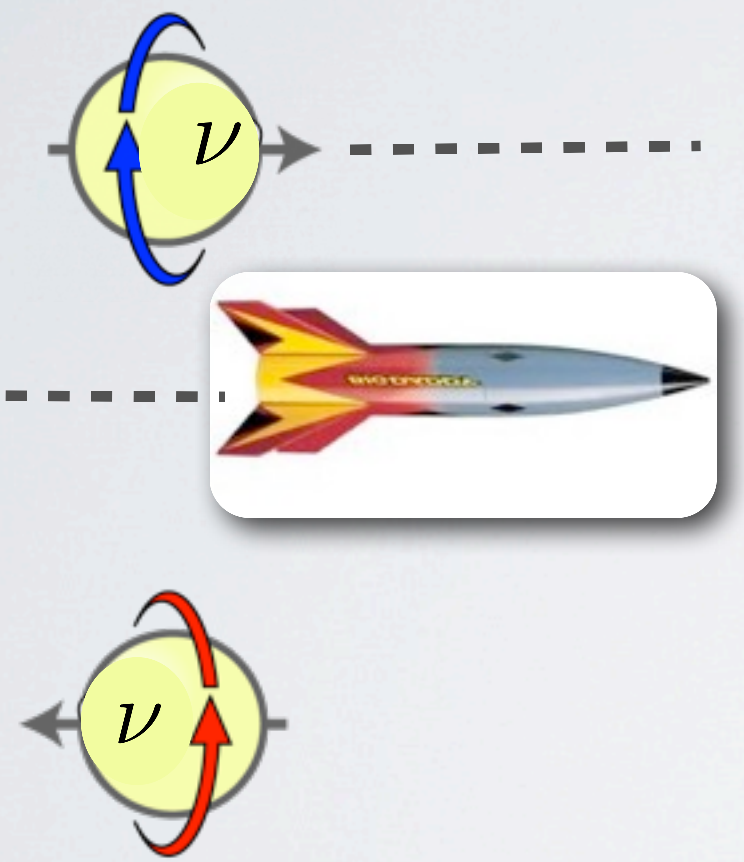

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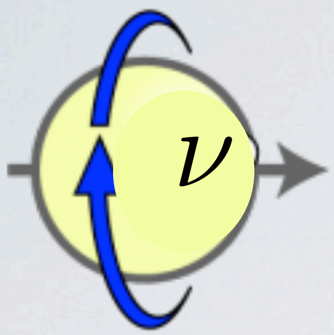

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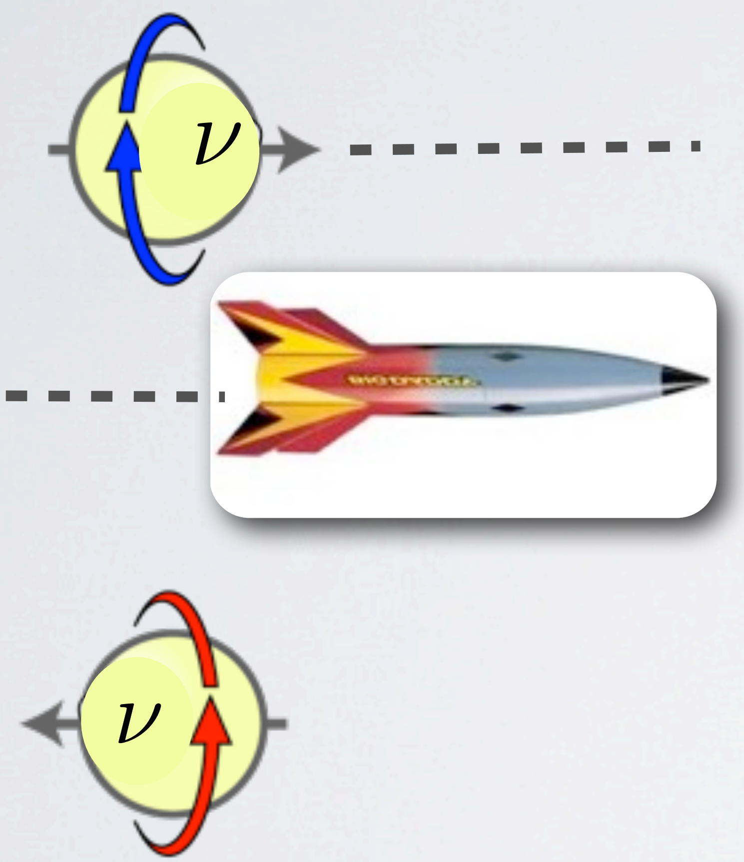

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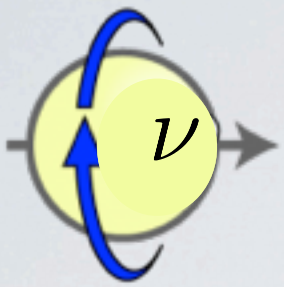

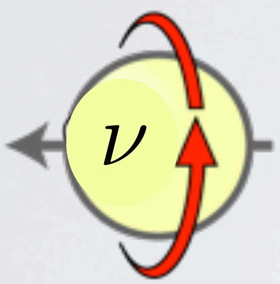

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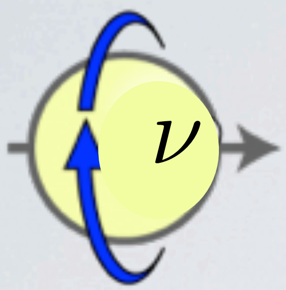
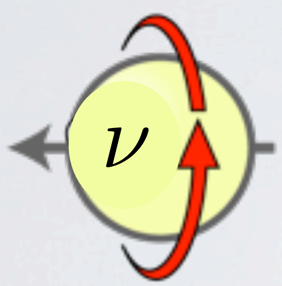


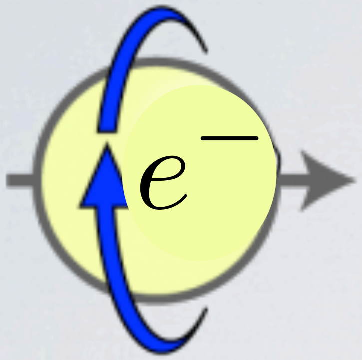


- Reversing the argument, left-handed and right-handed neutrinos are guaranteed to exist. How does a massive neutrino reflects in the mirror?

- Who is the right-handed neutrino state ? How do we give neutrinos a mass ?

Electrons through the looking glass

Electrons through the looking glass



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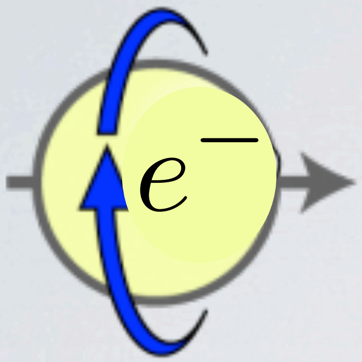

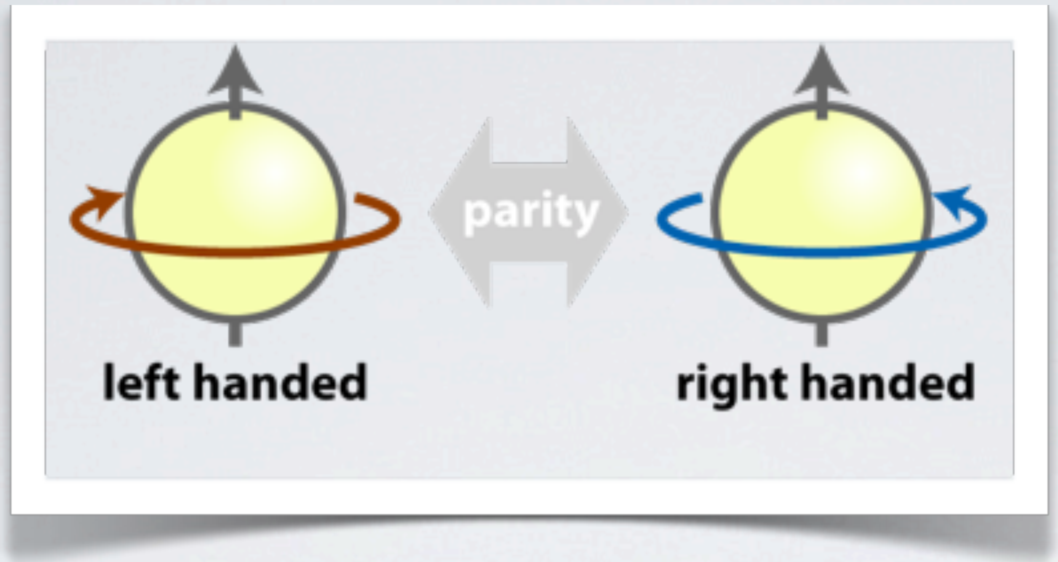

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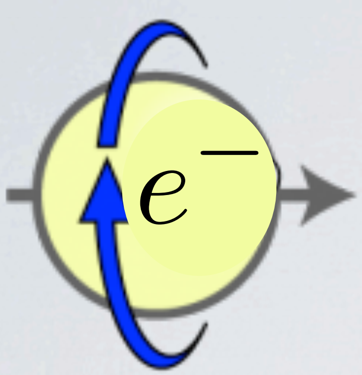

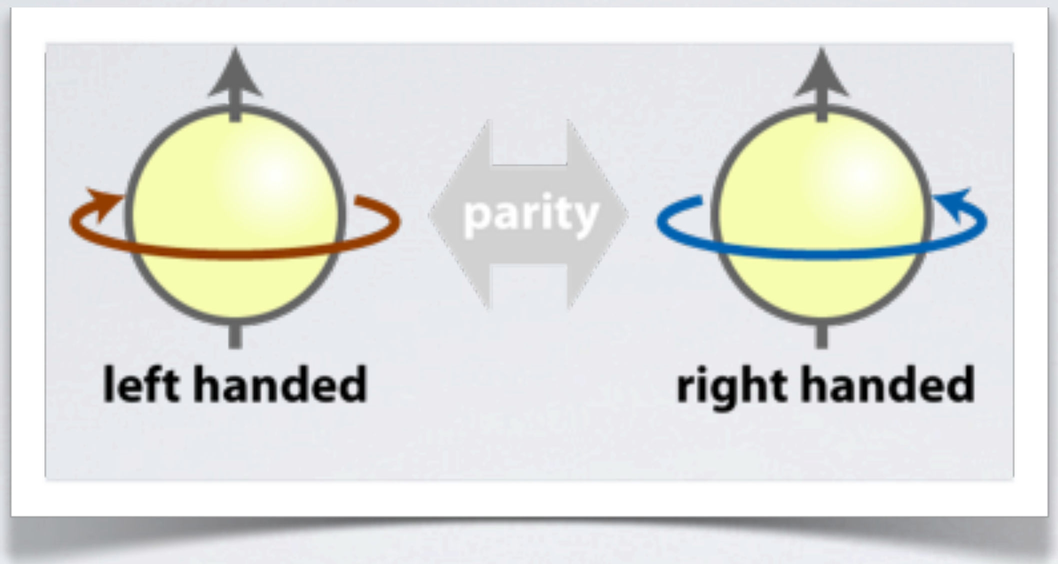

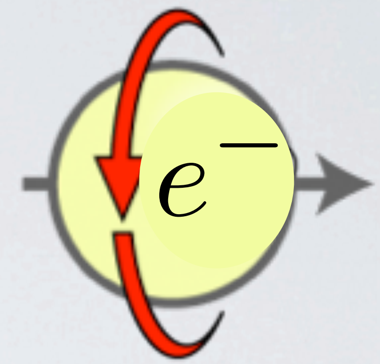

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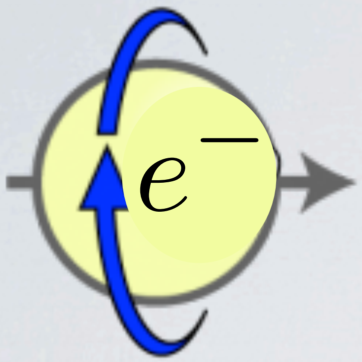

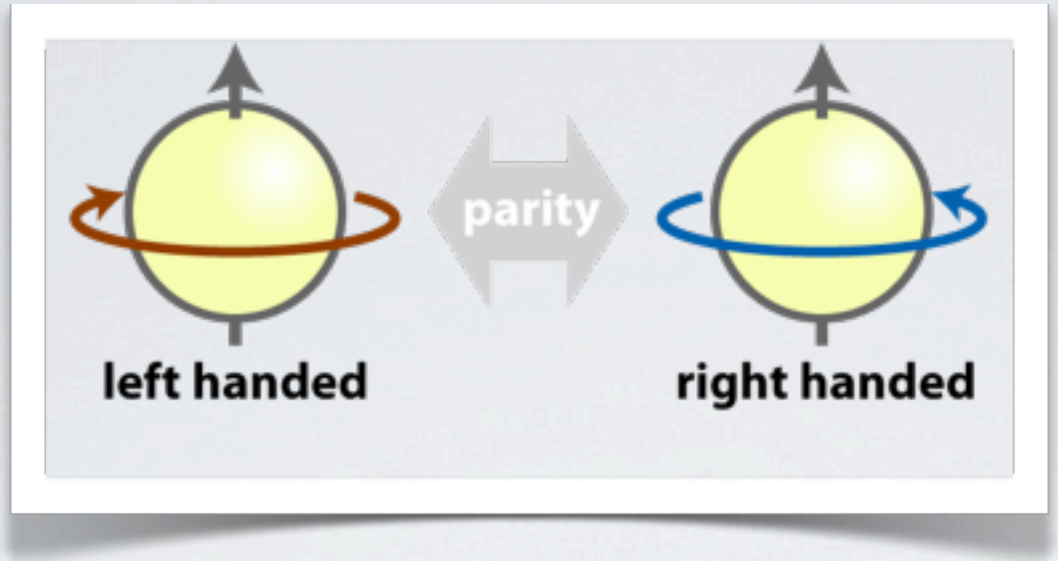

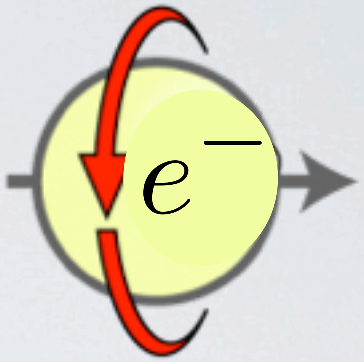

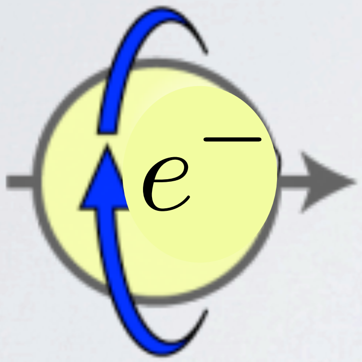

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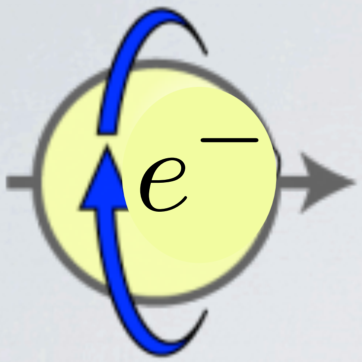

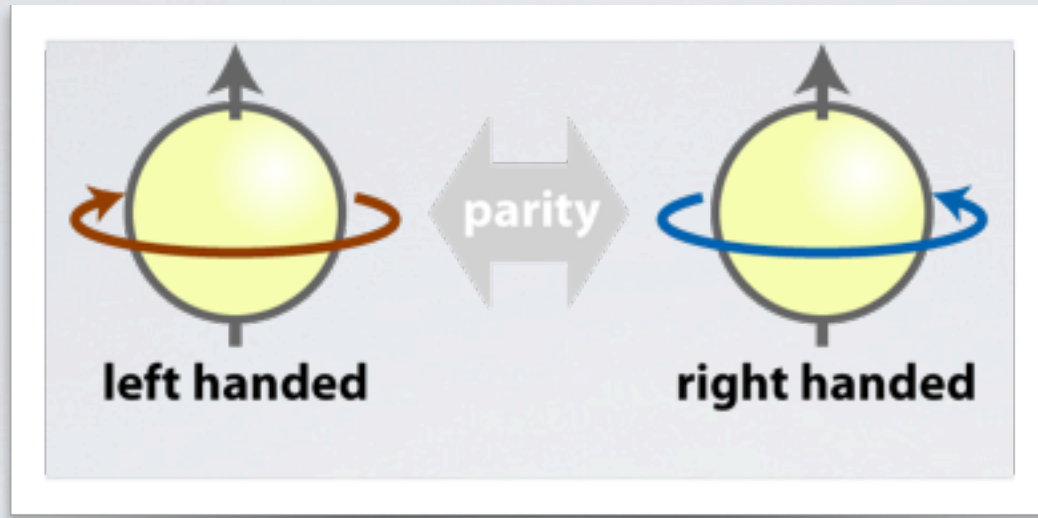

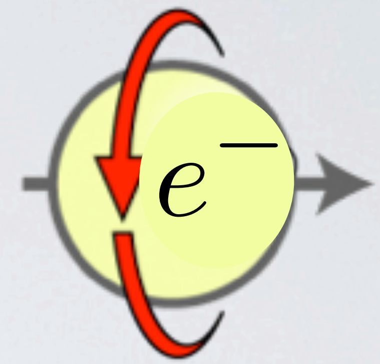

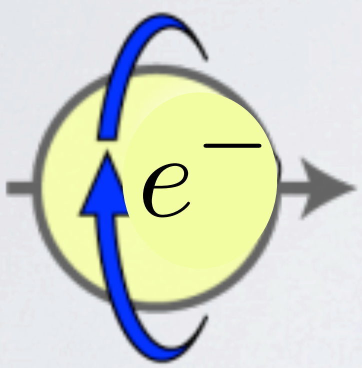

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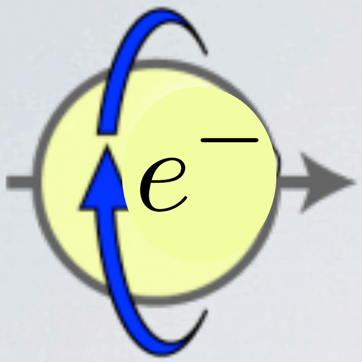

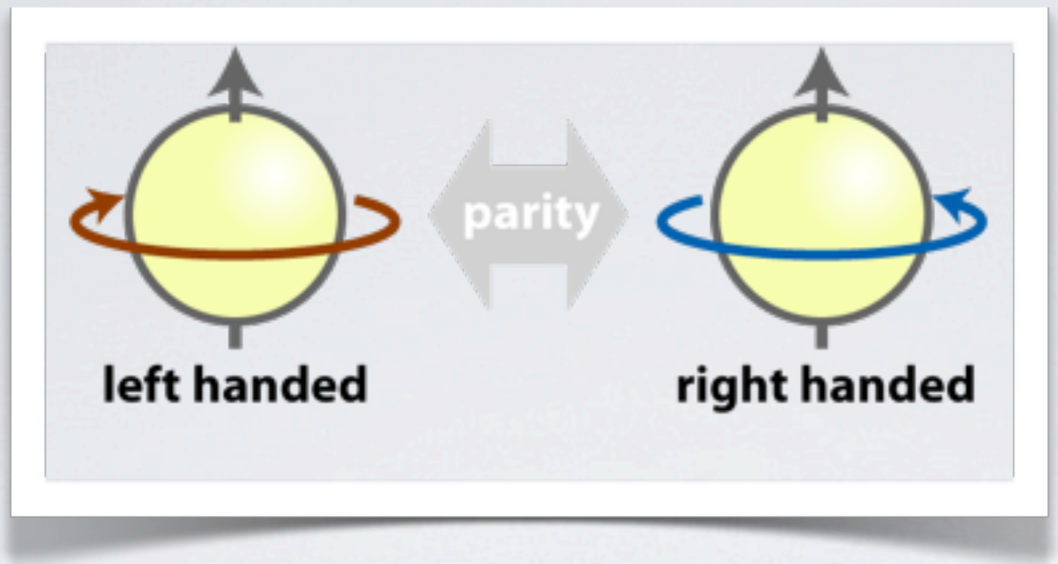

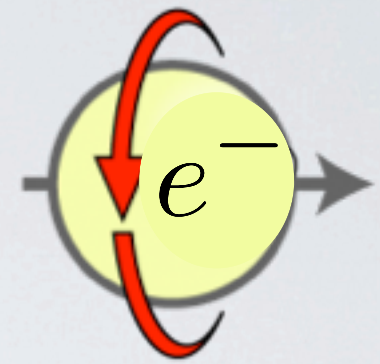

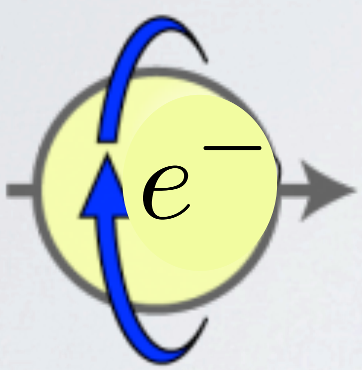

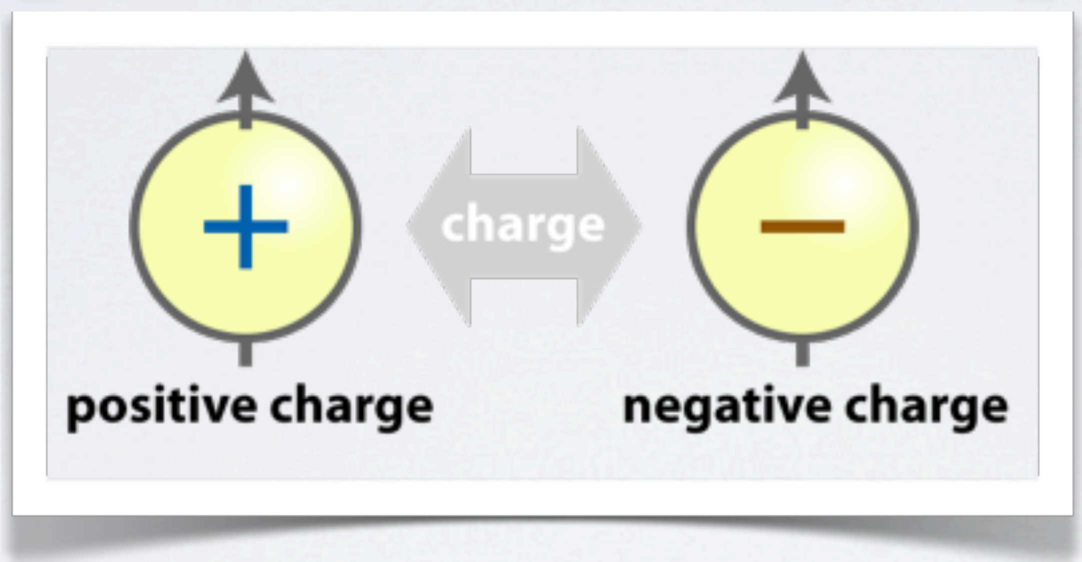

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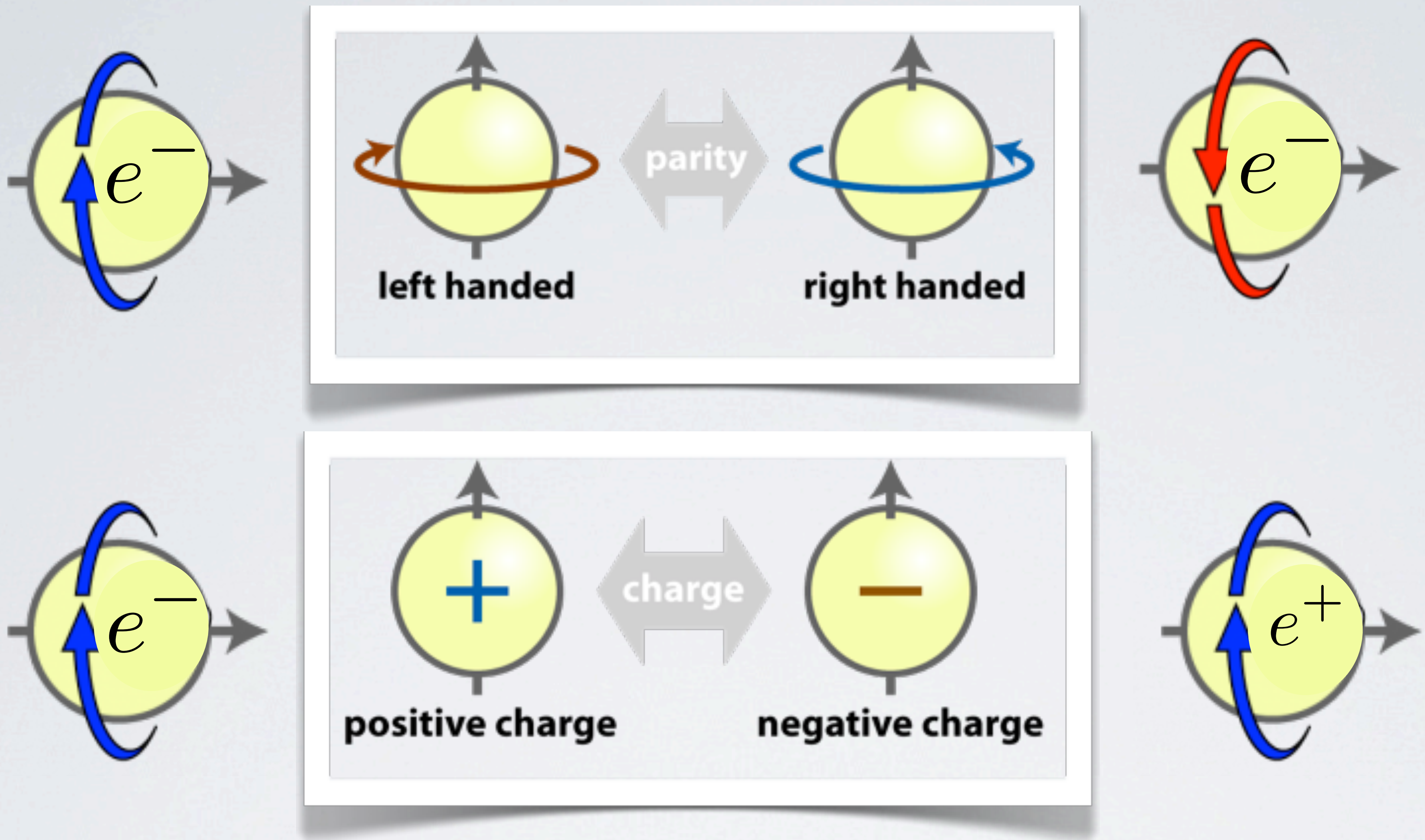

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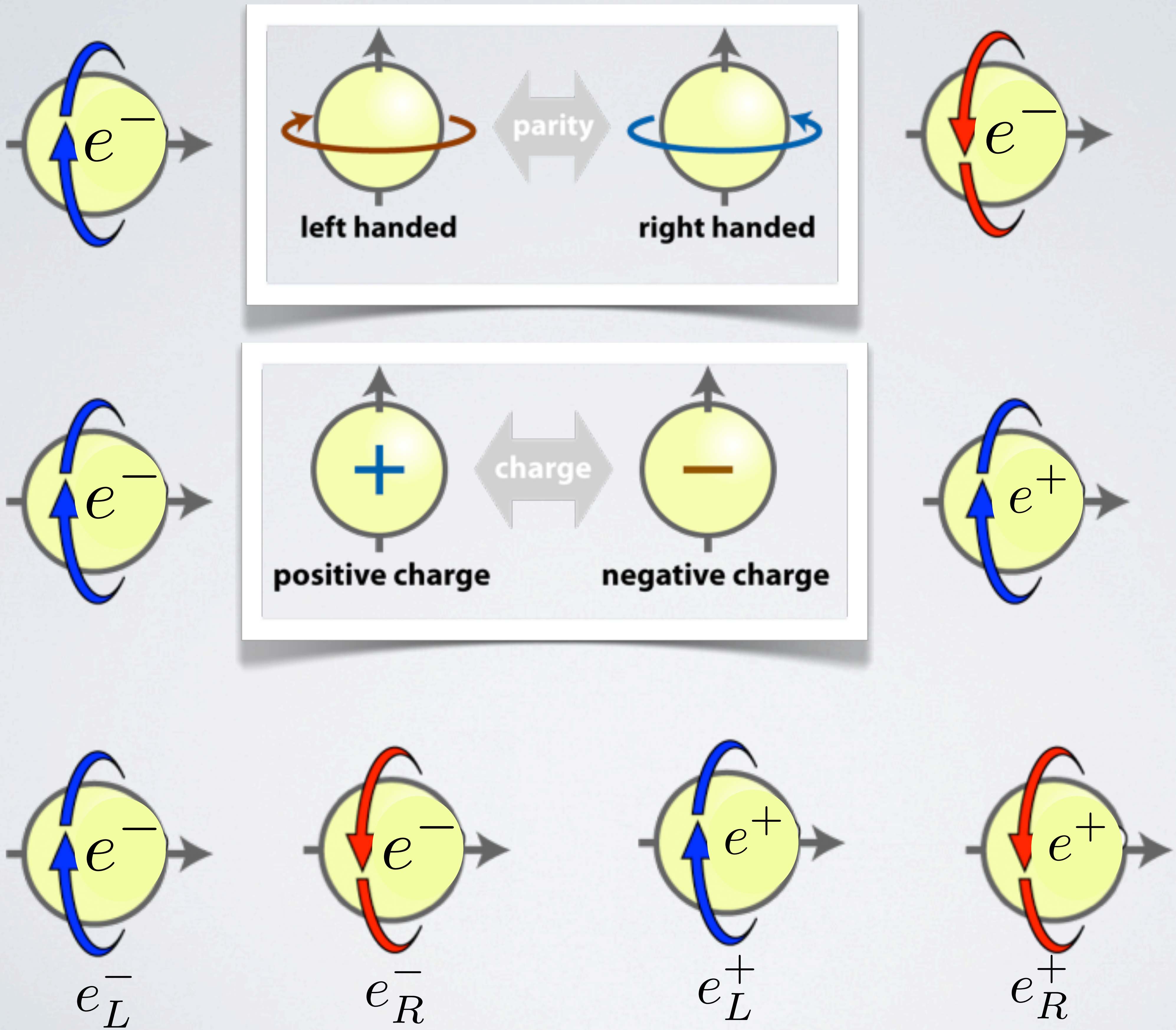

Electron mass

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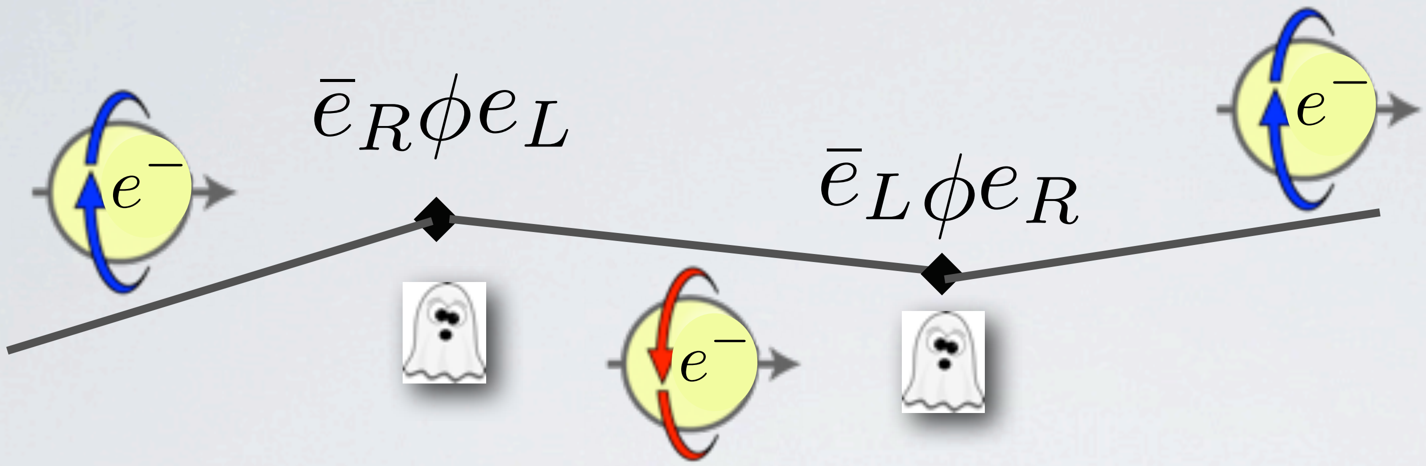

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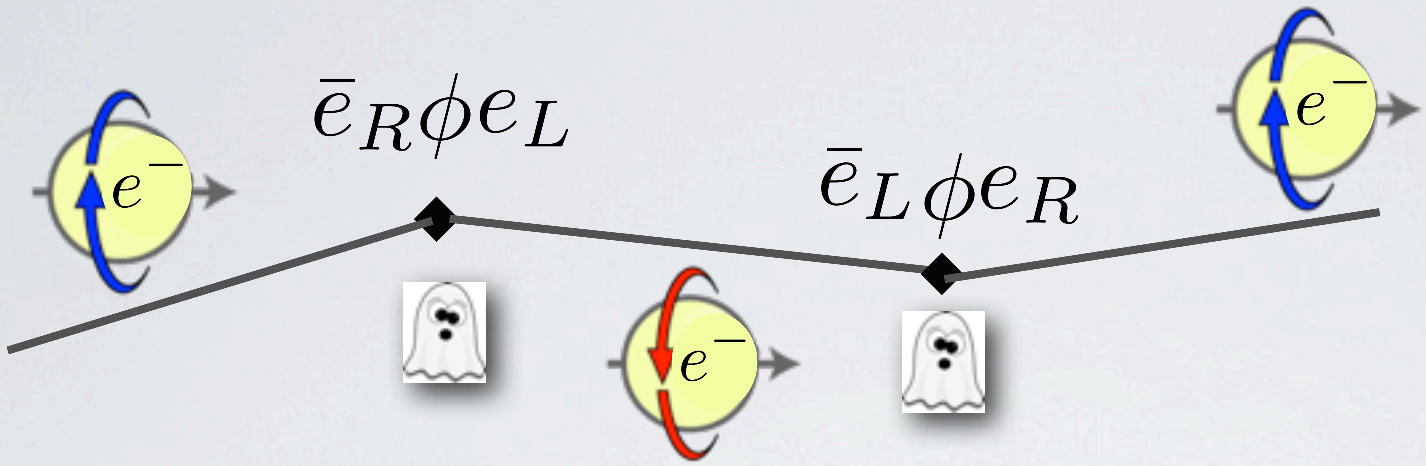

left and right handed states bump against the Higgs field

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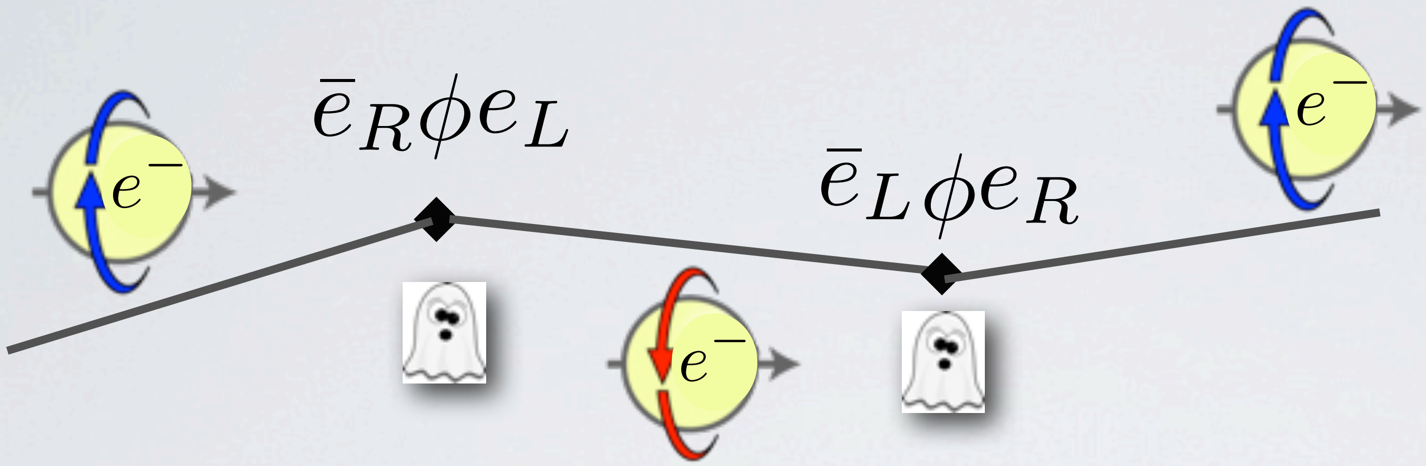

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$$\mathcal{L}_D = \bar{e}_L m_e e_R + h.c.$$

$$\lambda \bar{e}_R \phi e_L \to \lambda v \bar{e}_R e_L$$

$$m_e = \lambda_e v$$

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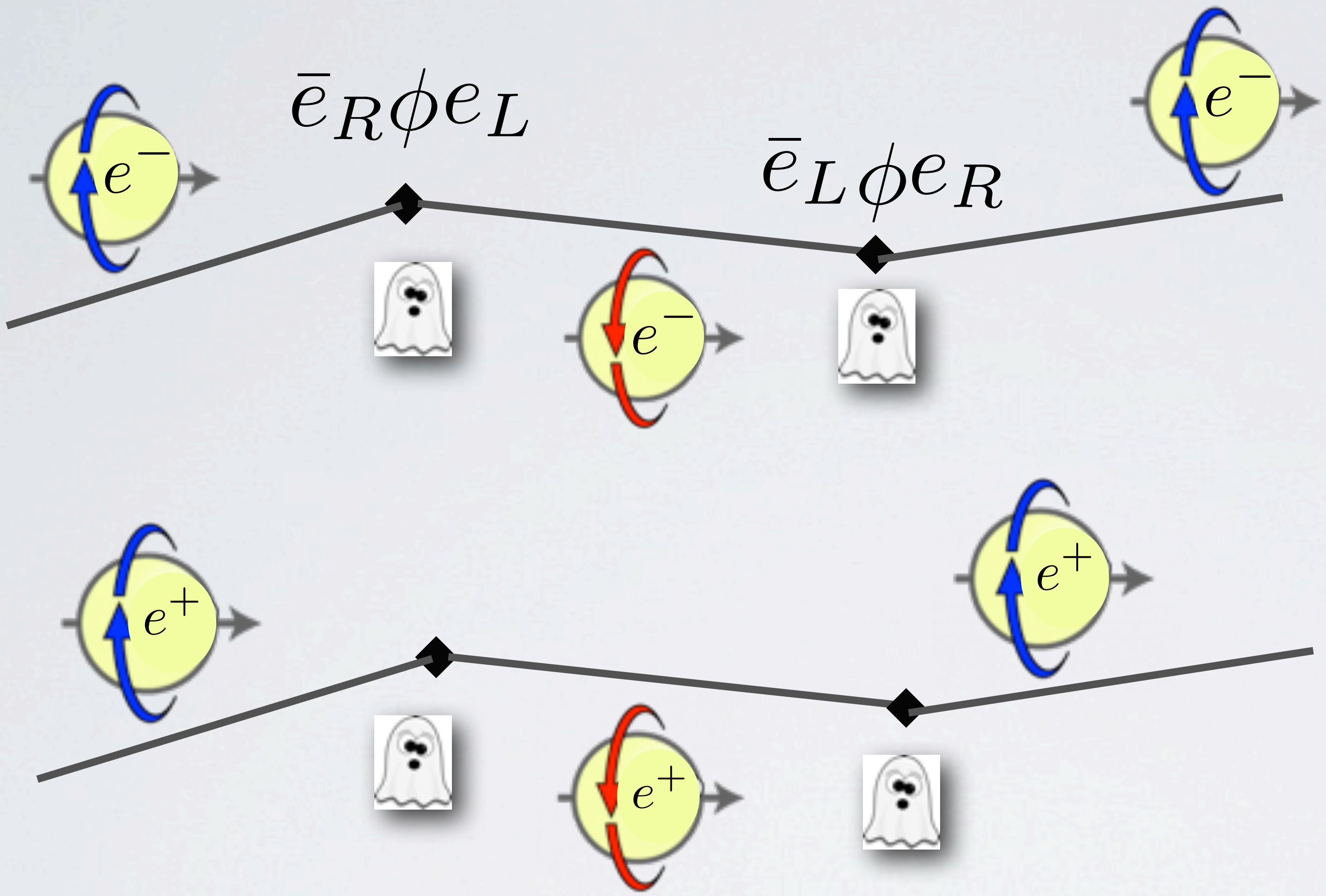

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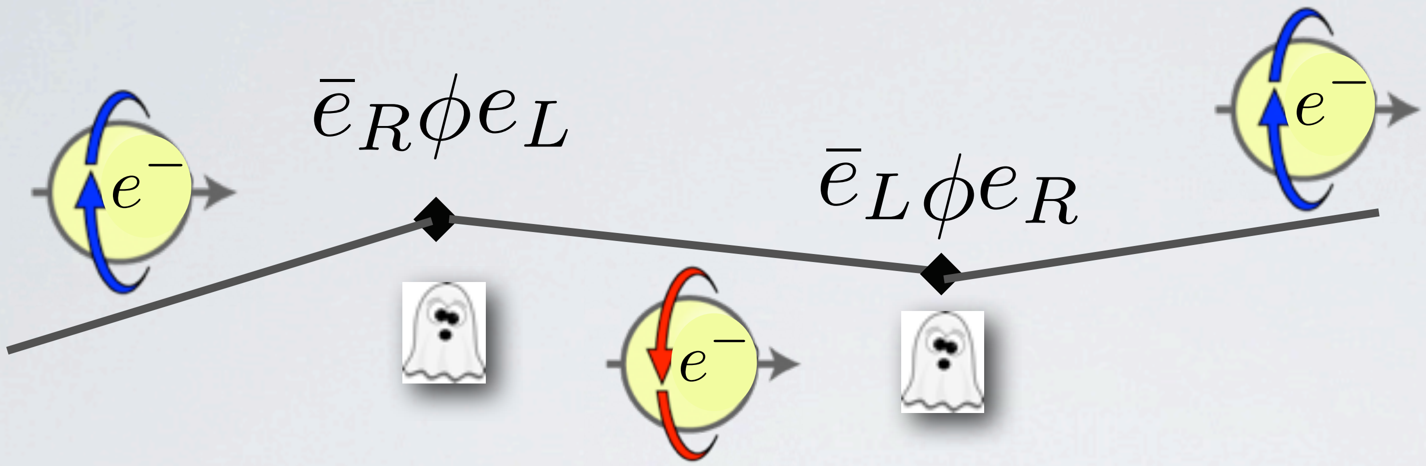

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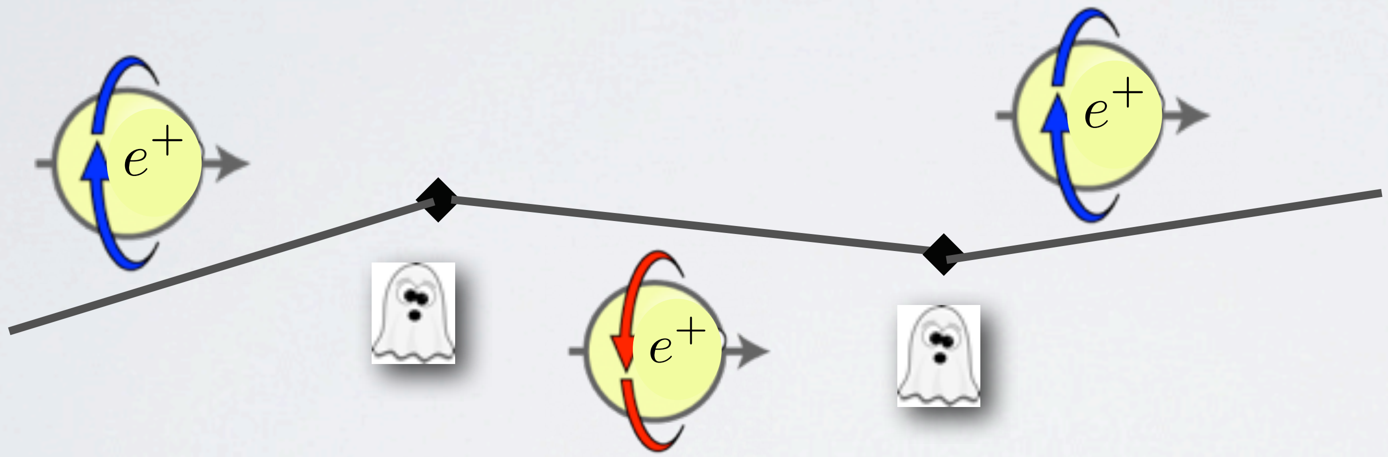

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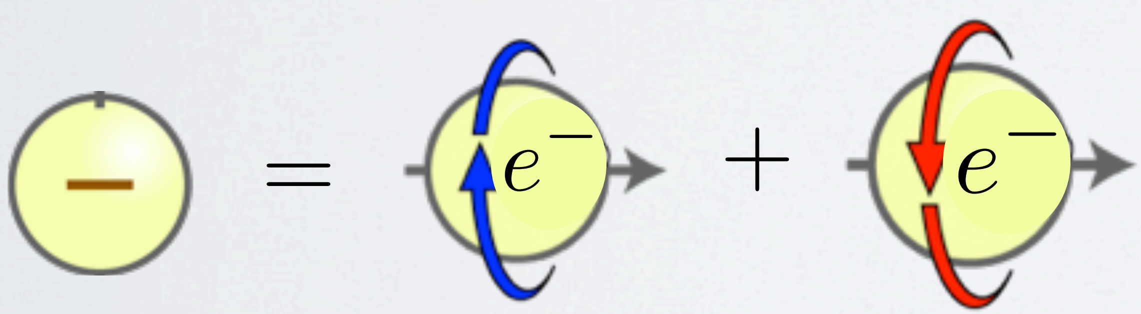
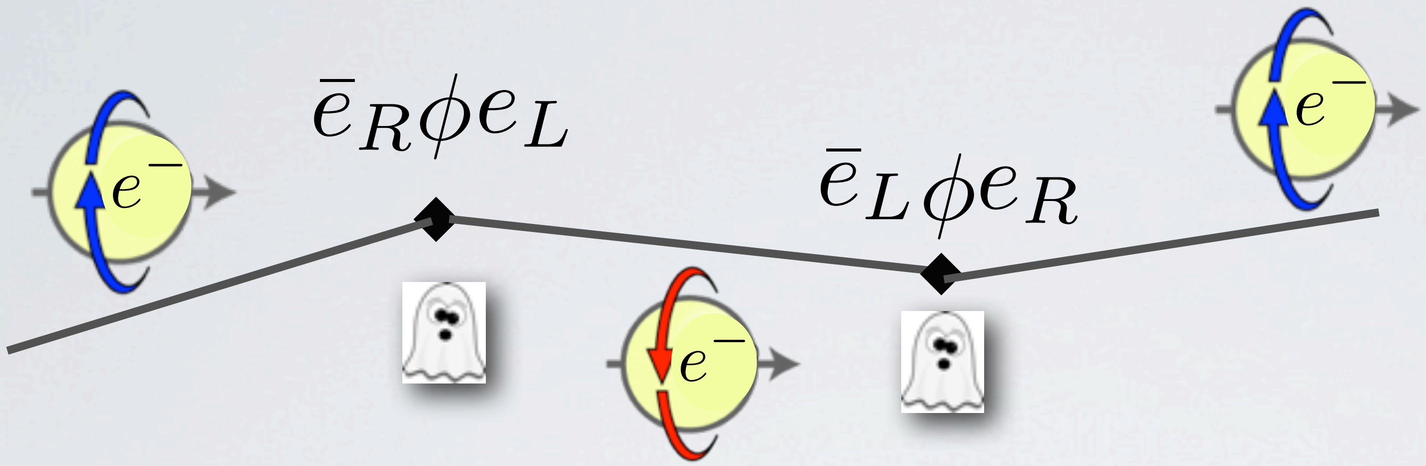


$$e^- = e_L^- + e_R^-$$

Electron mass



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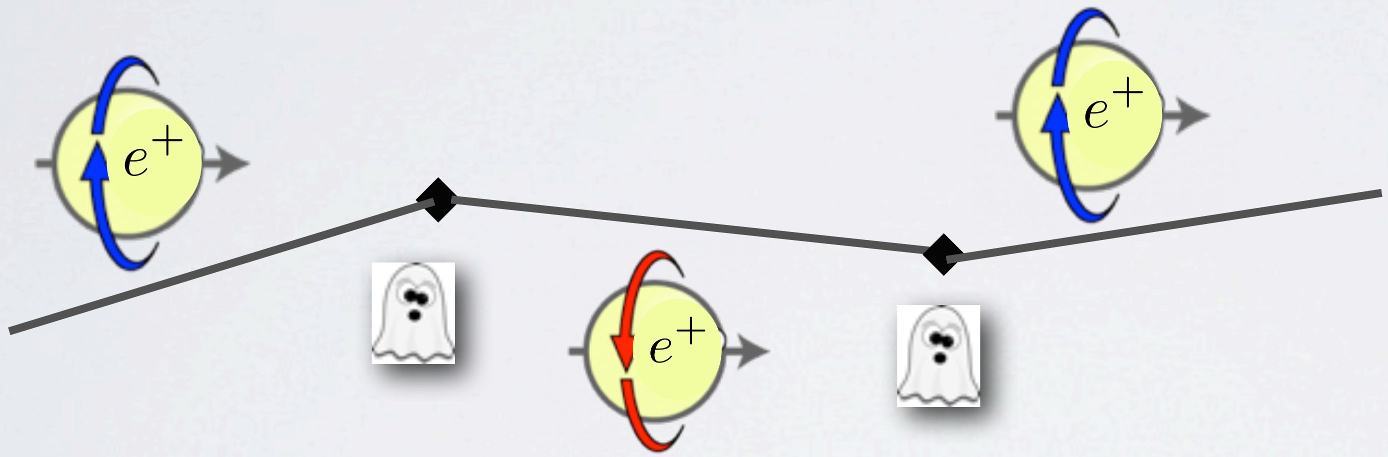

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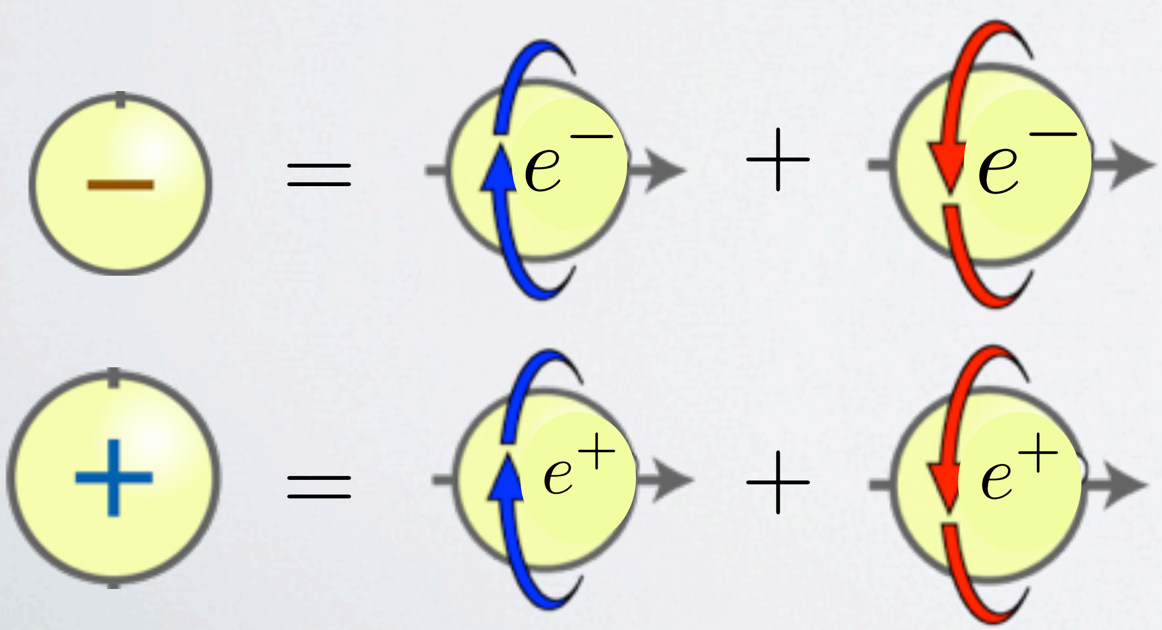

$$e^- = e_L^- + e_R^-$$

$$e^+ = e_L^+ + e_R^+$$

Neutrino mass (Dirac recipe)

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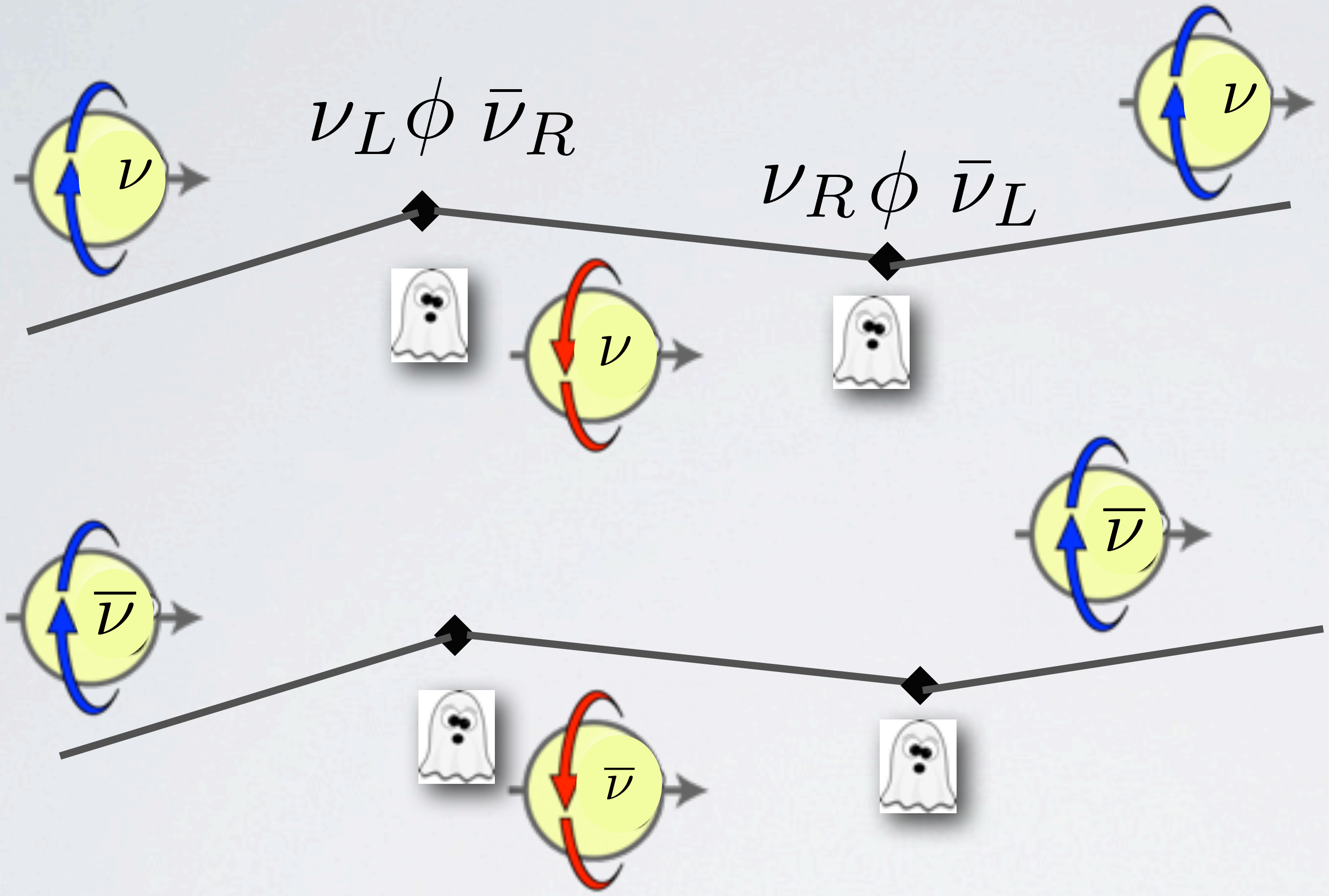

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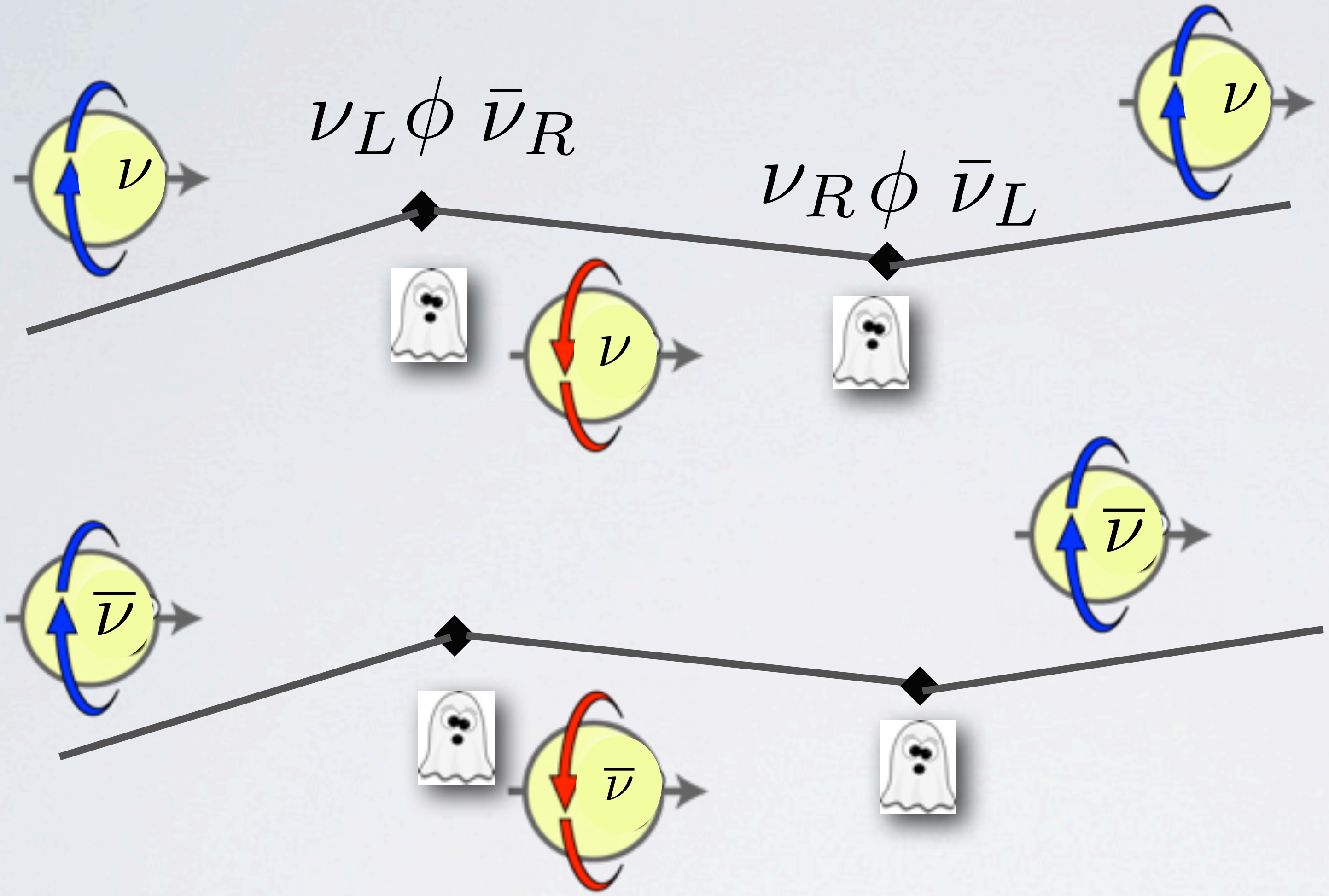

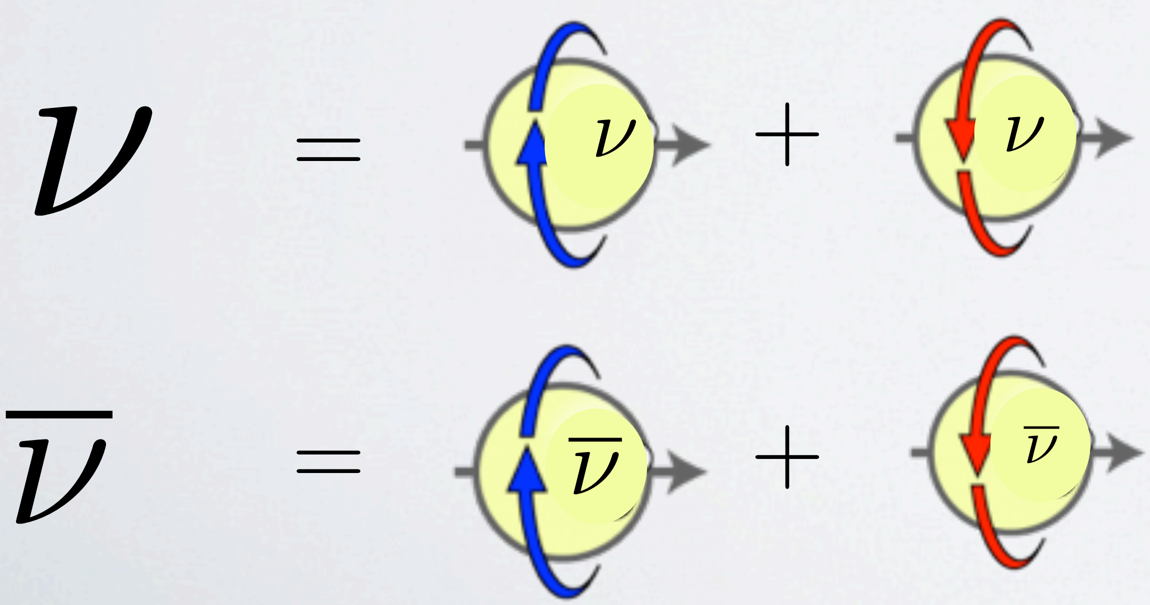

$\nu = \nu_L + \nu_R$

$\nu^C = (\nu_L)^C + (\nu_R)^C$

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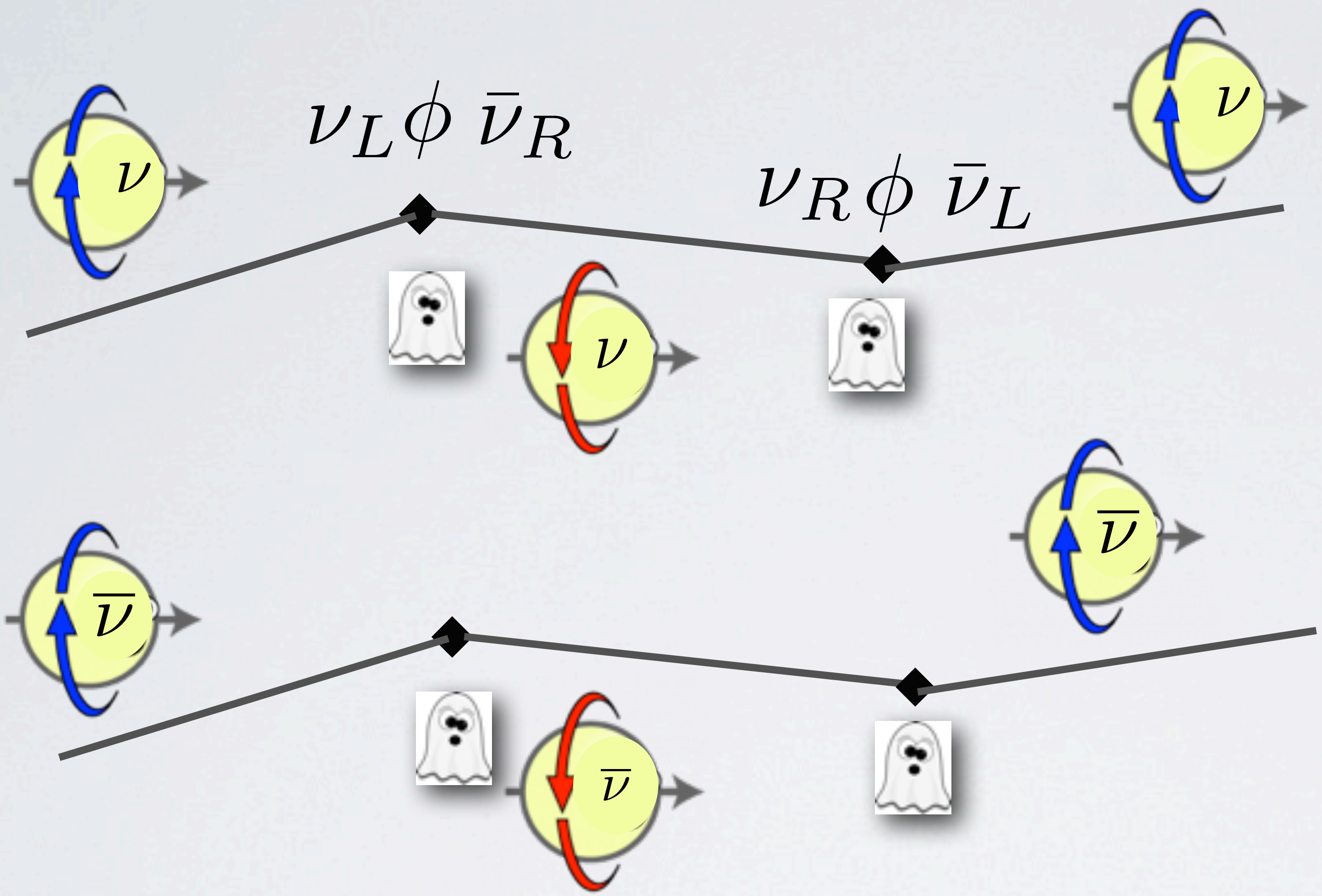
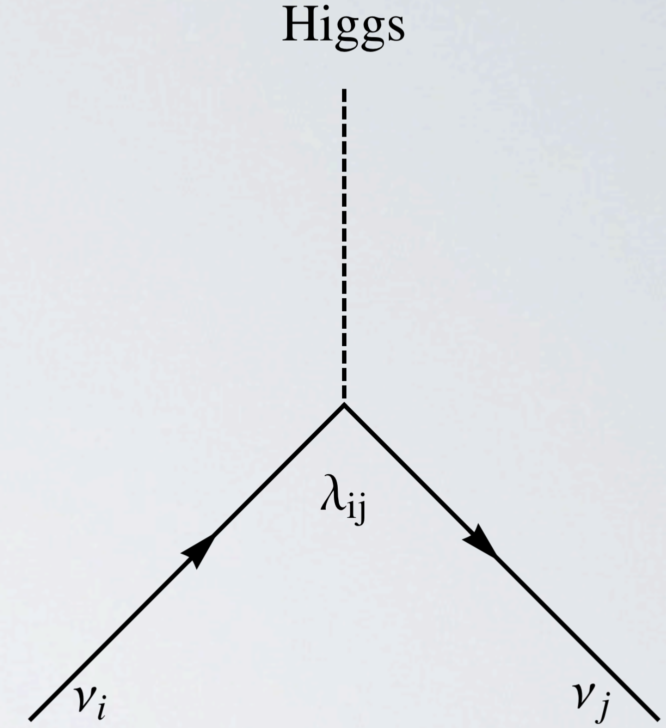
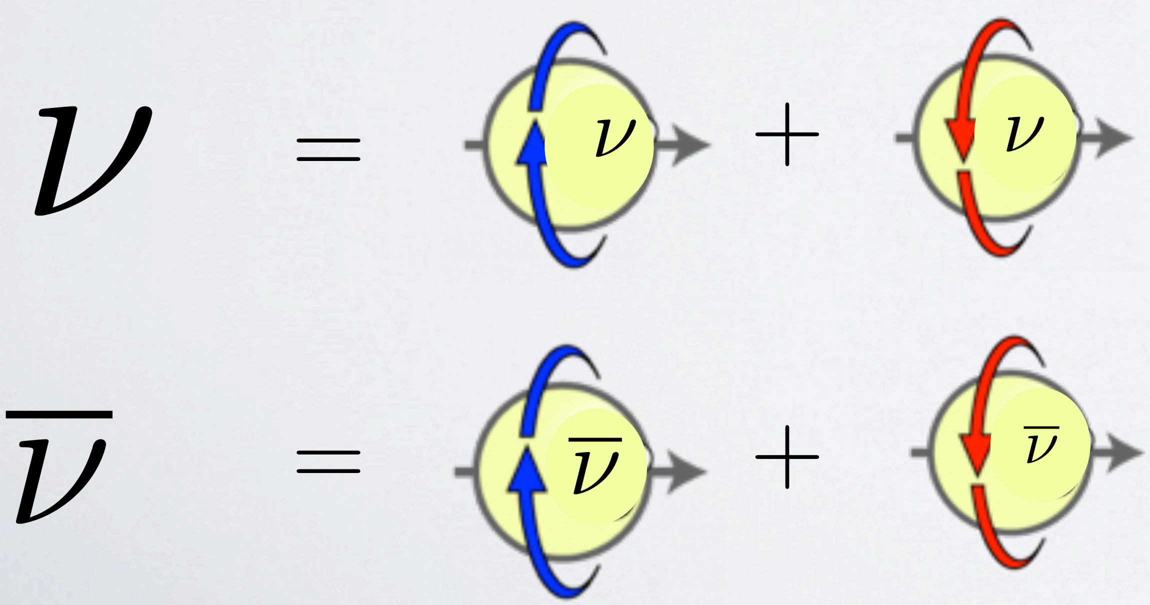




$$-\mathcal{L}_{\text{Dirac}} = \bar{\nu}_L m_\nu \nu_R + h.c.$$

$$m_\nu = \lambda_\nu v$$



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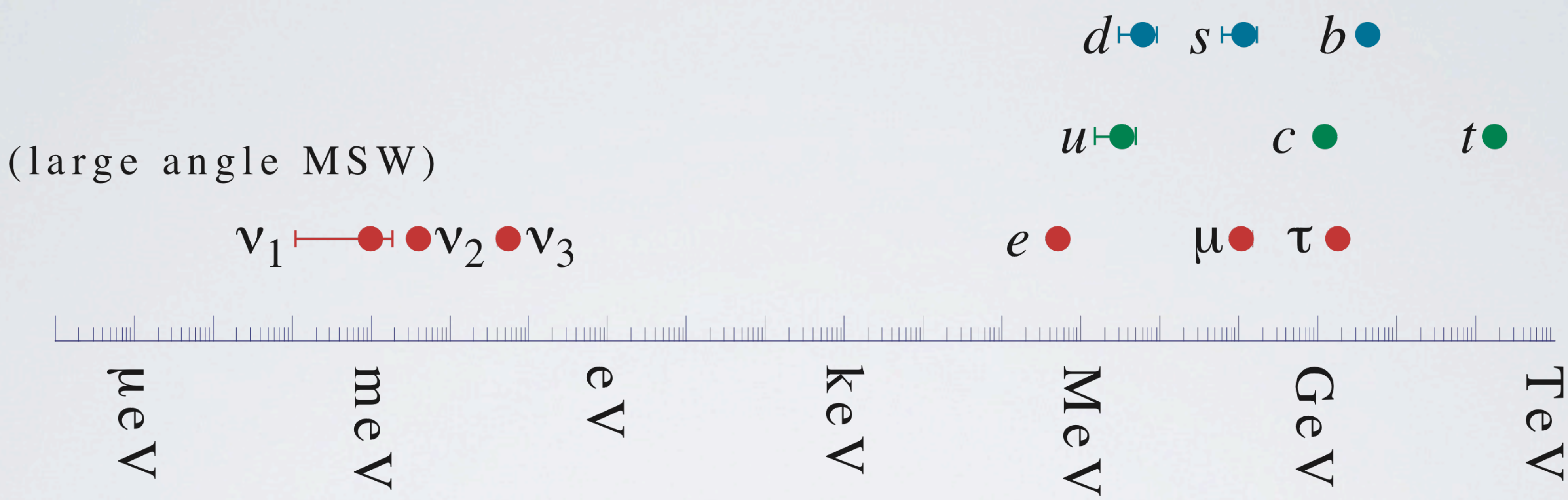
$$\nu^C = (\nu_L)^C + (\nu_R)^C$$

Deus ex machina

The phrase comes from Horace's where he instructs poets that they must never resort to a god from the machine (mekhane) to solve their plots.

A deus ex machina Latin: "god from the machine" is a plot device whereby a seemingly unsolvable problem is suddenly and abruptly solved with the contrived and unexpected intervention of some new event, character, ability, or object. Depending on usage, it can be used to move the story forward when the writer has "painted themselves into a corner" and sees no other way out, to surprise the audience, or to bring a happy ending into the tale.

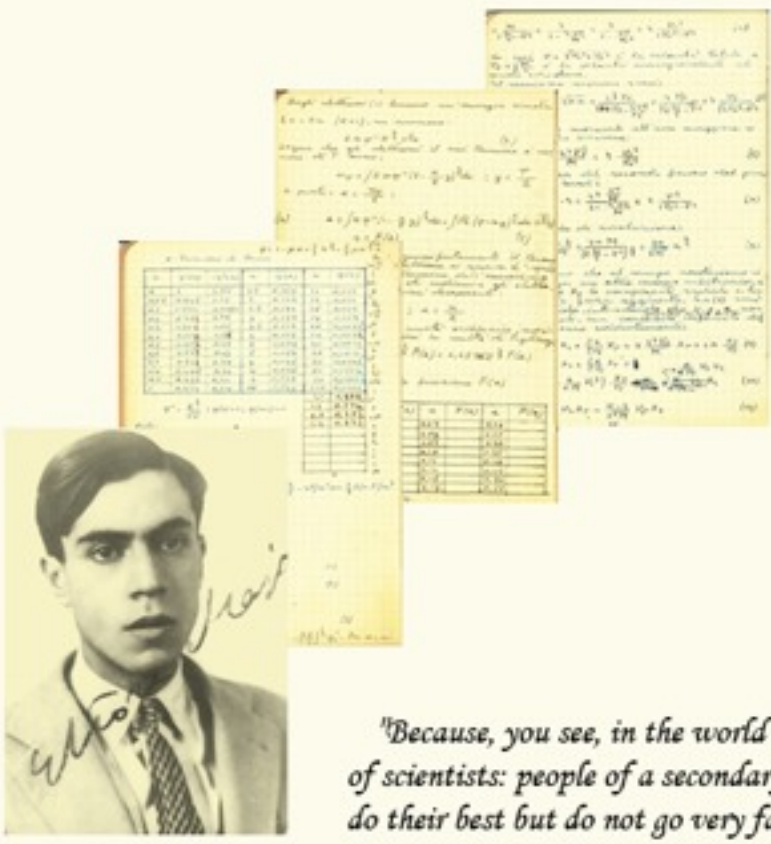
Dirac neutrinos: Deus ex machina



Nature has painted herself into a corner and sees no other way out to explain small neutrino masses than to resort to arbitrarily small coupling constant, that she lowers from the machine...

$$\lambda_\nu << \lambda_e?$$

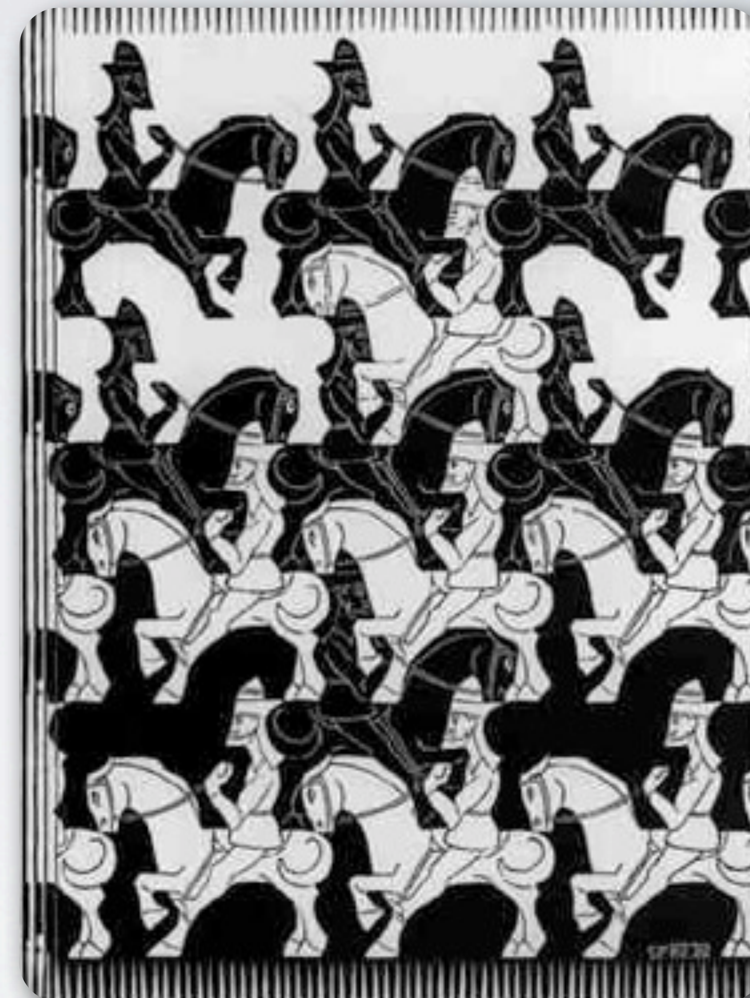
Ettore's plot



"Because, you see, in the world there are various categories of scientists: people of a secondary or tertiary standing, who do their best but do not go very far. There are also those of high standing, who come to discoveries of great importance, fundamental for the development of science.

But then there are geniuses like Galileo and Newton. Well, Ettore was one of them. Majorana had what no one else in the world had".

E. Fermi



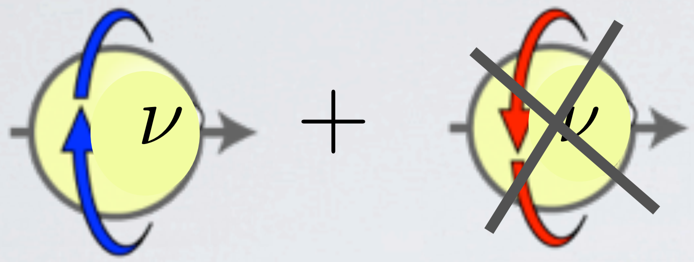
Neutrino's charge conjugation

Charge conjugation reverses the electric charge of the electron.

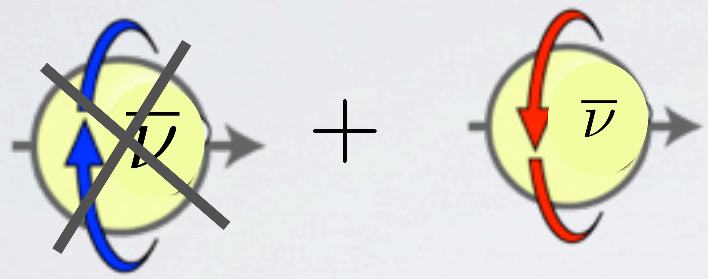
But the neutrino has no electric charge that needs to be conserved.

Majorana neutrinos

ν =



$\nu = \nu_L + \nu_R$ (with ν_R crossed out)

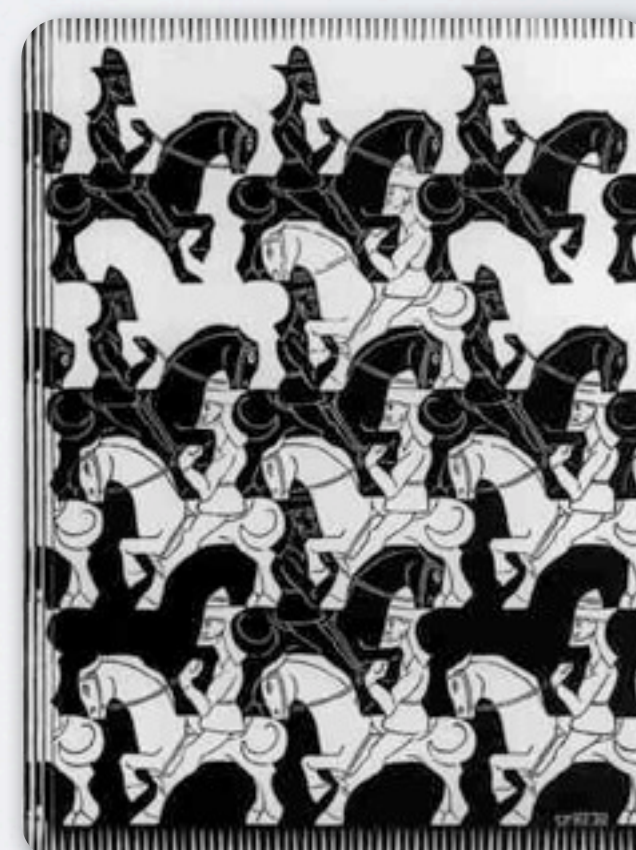


$\nu^C = (\nu_L)^C + (\nu_R)^C$ (with ν_R crossed out)

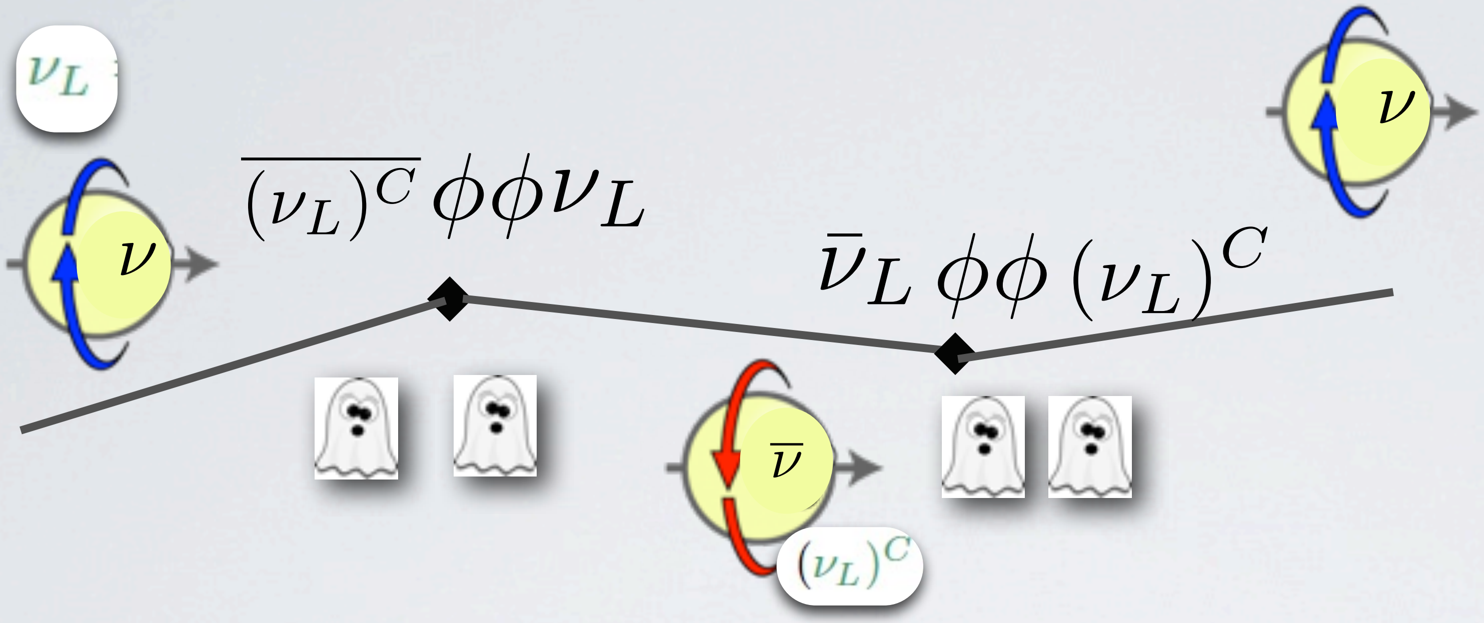
$$\nu = \bar{\nu}$$

$$\nu = \nu_L + \nu_L^C \qquad \nu^c = \nu$$

The neutrino is made, like in the Escher's tableau of black and white chevaliers.



Neutrino mass (Majorana recipe)



$\nu_L = (\nu_R)^C \qquad (\nu_L)^C = \nu_R$

$$-\mathcal{L}_{\text{Majorana}} = \bar{\nu}_L m_\nu \nu_L^c + h.c.$$

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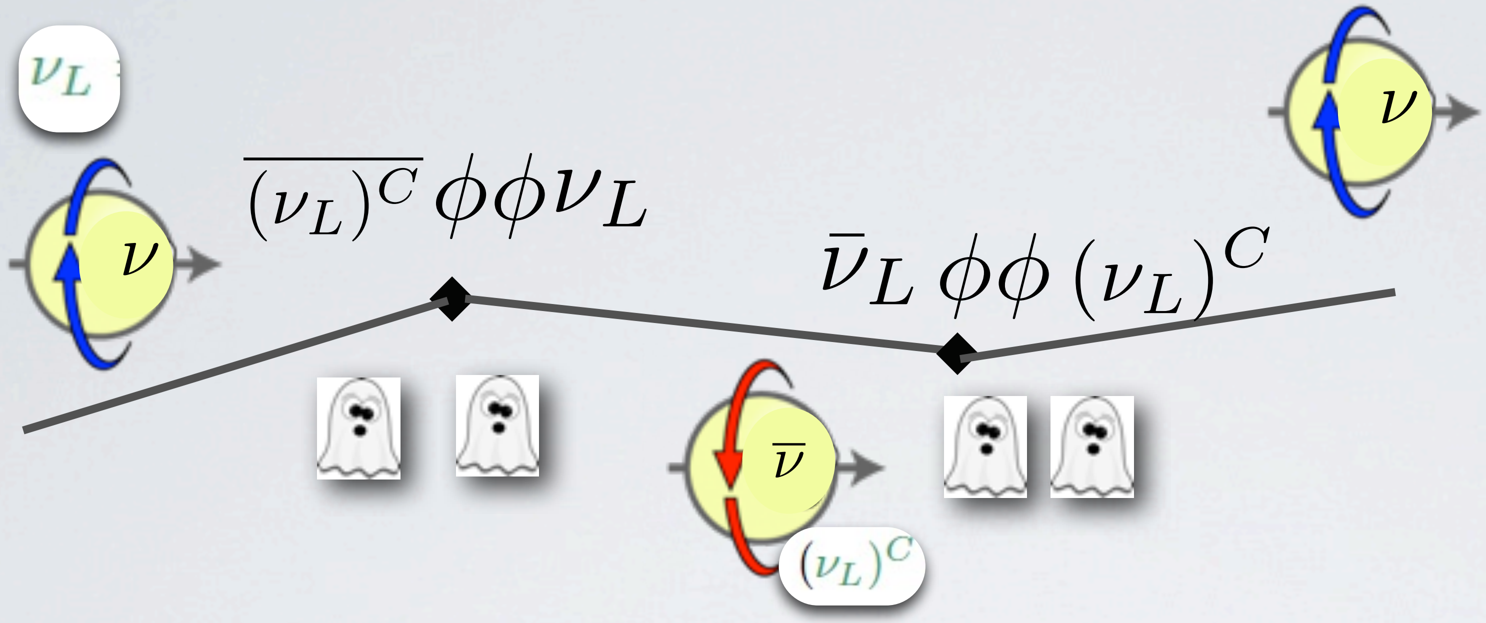
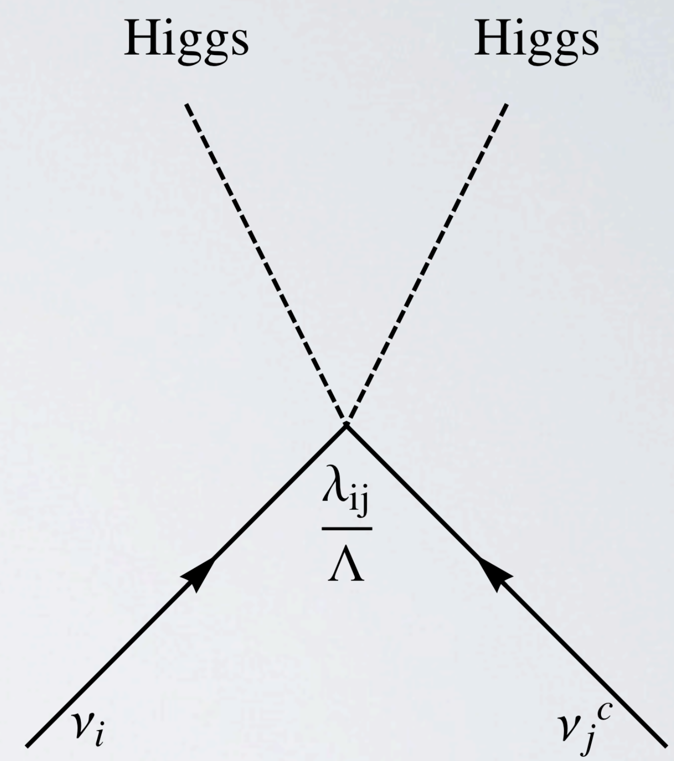




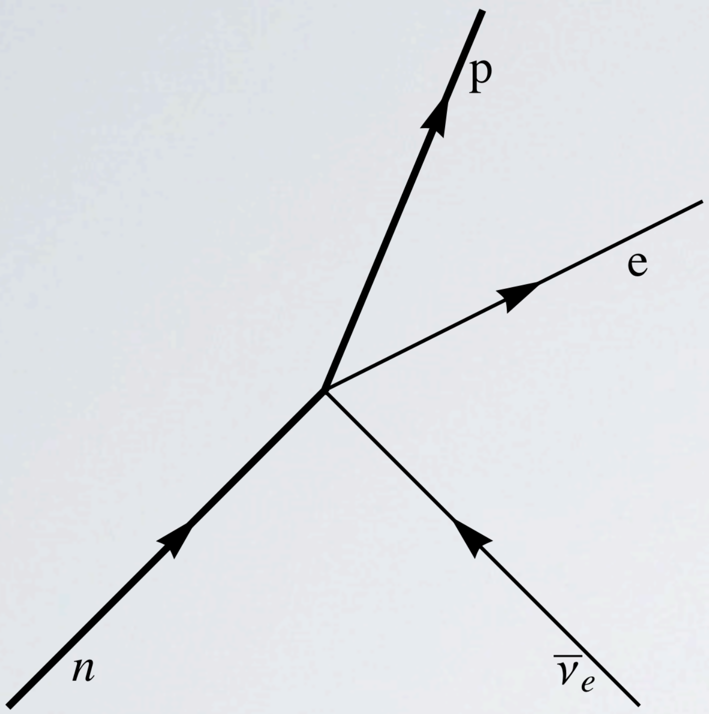
$$\nu_L = (\nu_R)^C \qquad (\nu_L)^C = \nu_R$$

$$-\mathcal{L}_{\mathrm{Majorana}} = \bar{\nu}_L m_\nu \nu_L^c + h.c.$$

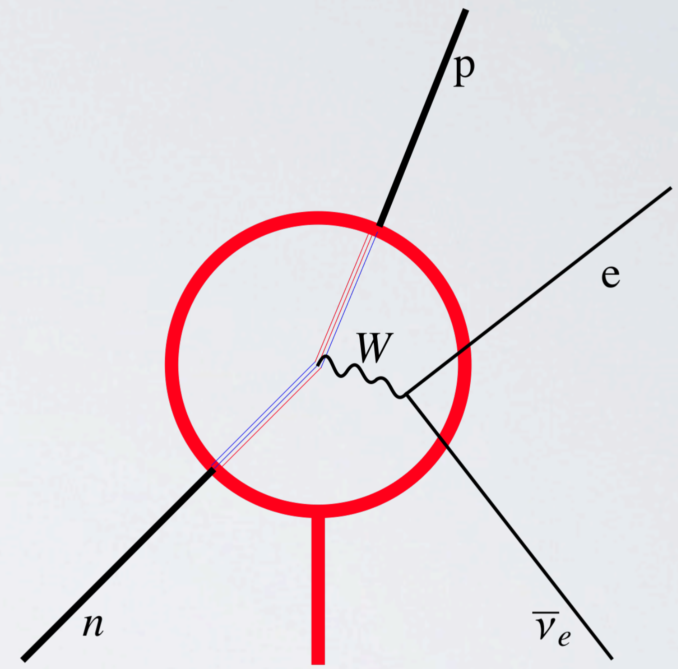
$$m_\nu \sim \lambda \frac{v^2}{\Lambda}$$

Effective theory (Fermi constant)

Standard Model

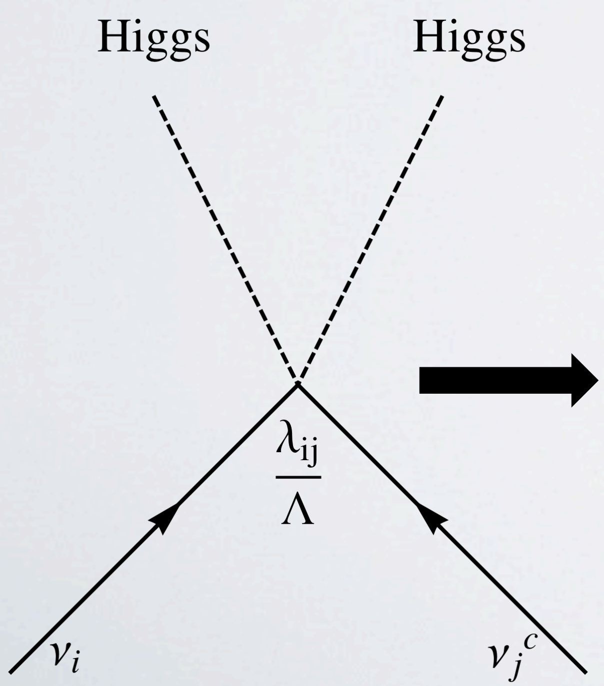


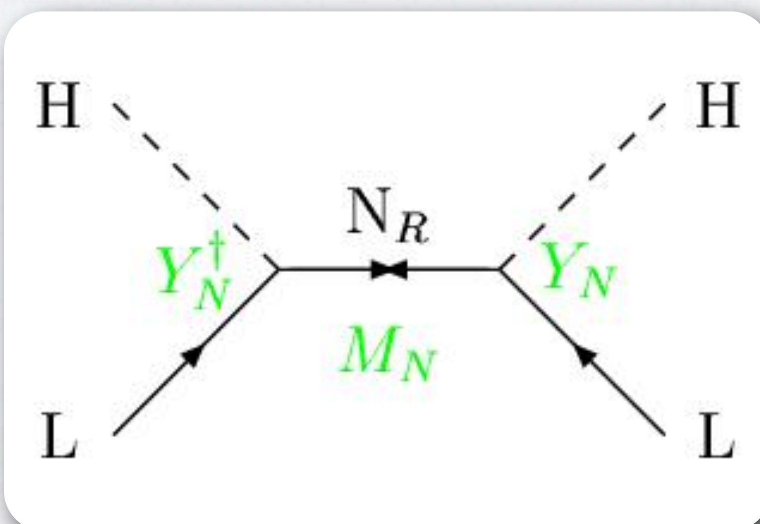
$$G_F \sim \frac{1}{M_W^2}$$



Effective theory (Λ)

Extension of Standard Model

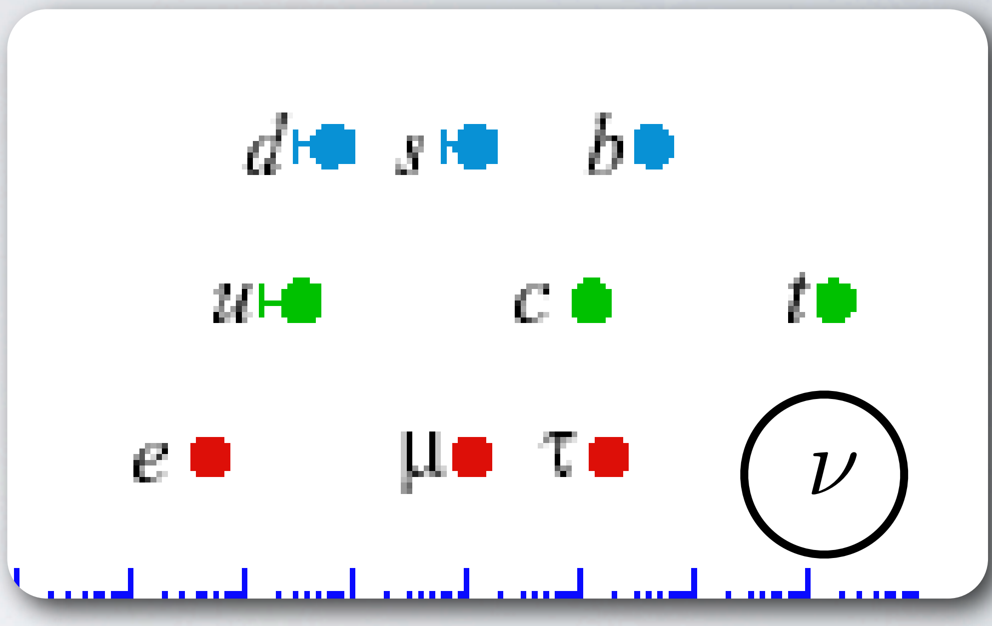




$$m_\nu = \frac{\alpha v^2}{\Lambda} \equiv Y_N^T \frac{v^2}{M_N} Y_N$$

See-saw models

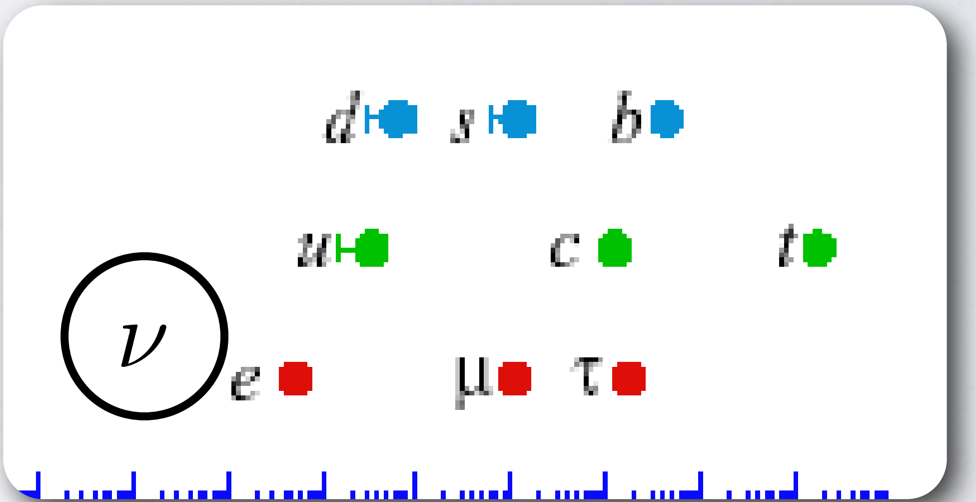
M_N = GUT



Yukawa

$$m_\nu = \frac{\alpha v^2}{\Lambda} \equiv Y_N^T \frac{v^2}{M_N} Y_N$$

M_N = TeV



Yukawa

The mystery of the missing antimatter

- The Big-Bang theory of the origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning
- What generated the asymmetry between matter and antimater?

CP violation and Majorana neutrinos

$$N \rightarrow e^- + H^+ \quad \text{and} \quad N \rightarrow e^+ + H^-$$

Standard-Model Higgs

- If there is CP violation in the lepton sector, the heavy Majorana neutrino N can violate CP too and decay with different rates to electrons and positrons. This results in an unequal number of leptons and antileptons in the early universe

- Leptonic asymmetry is later transferred to baryons, resulting in...

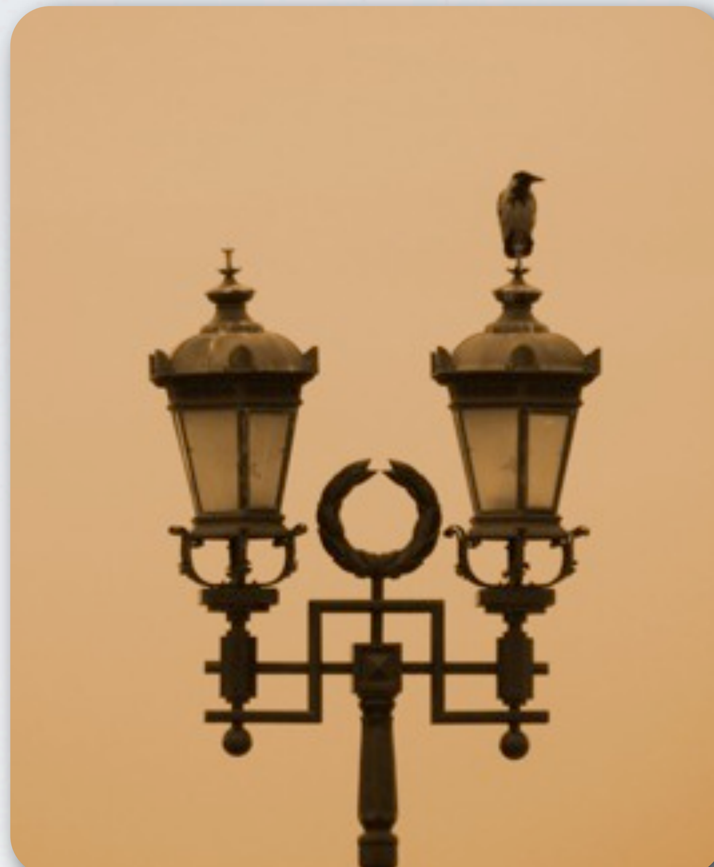
The Universe

The Universe

+

The Universe

+



The Universe

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=

The Universe

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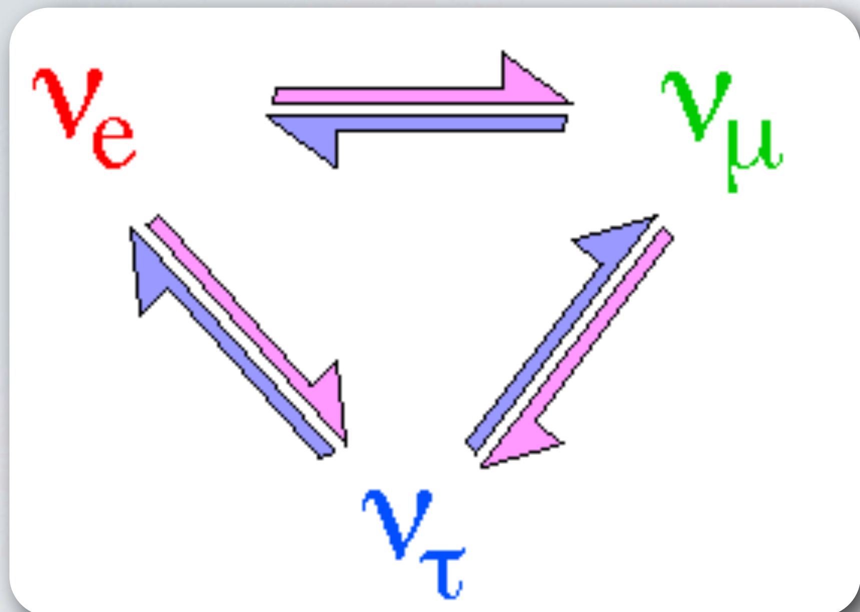
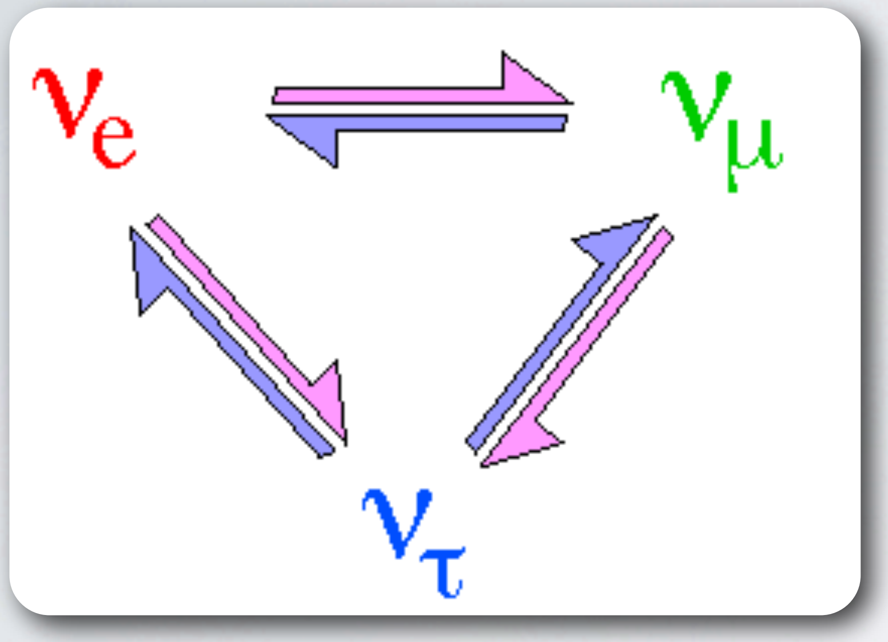
=

What do we know about neutrino masses?

Neutrino oscillations

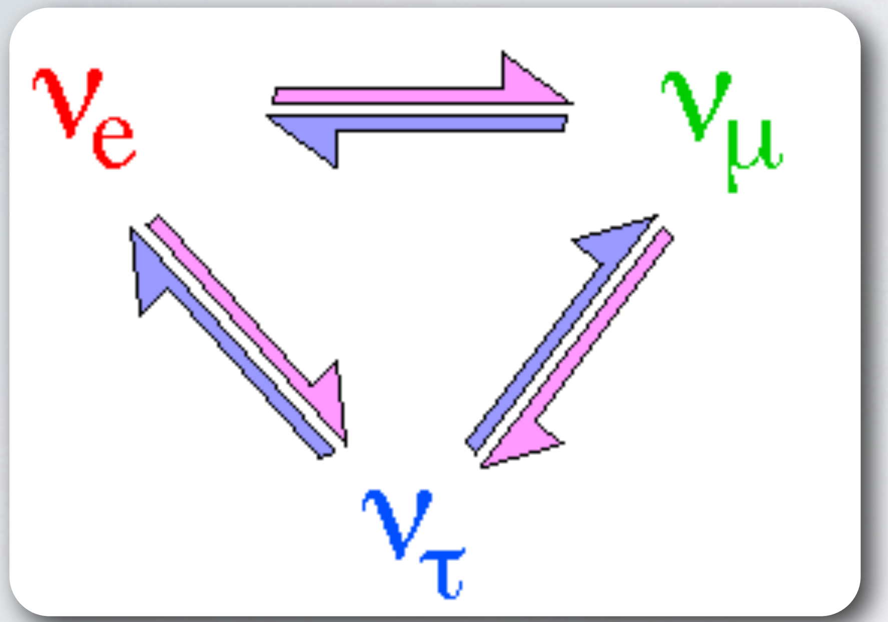


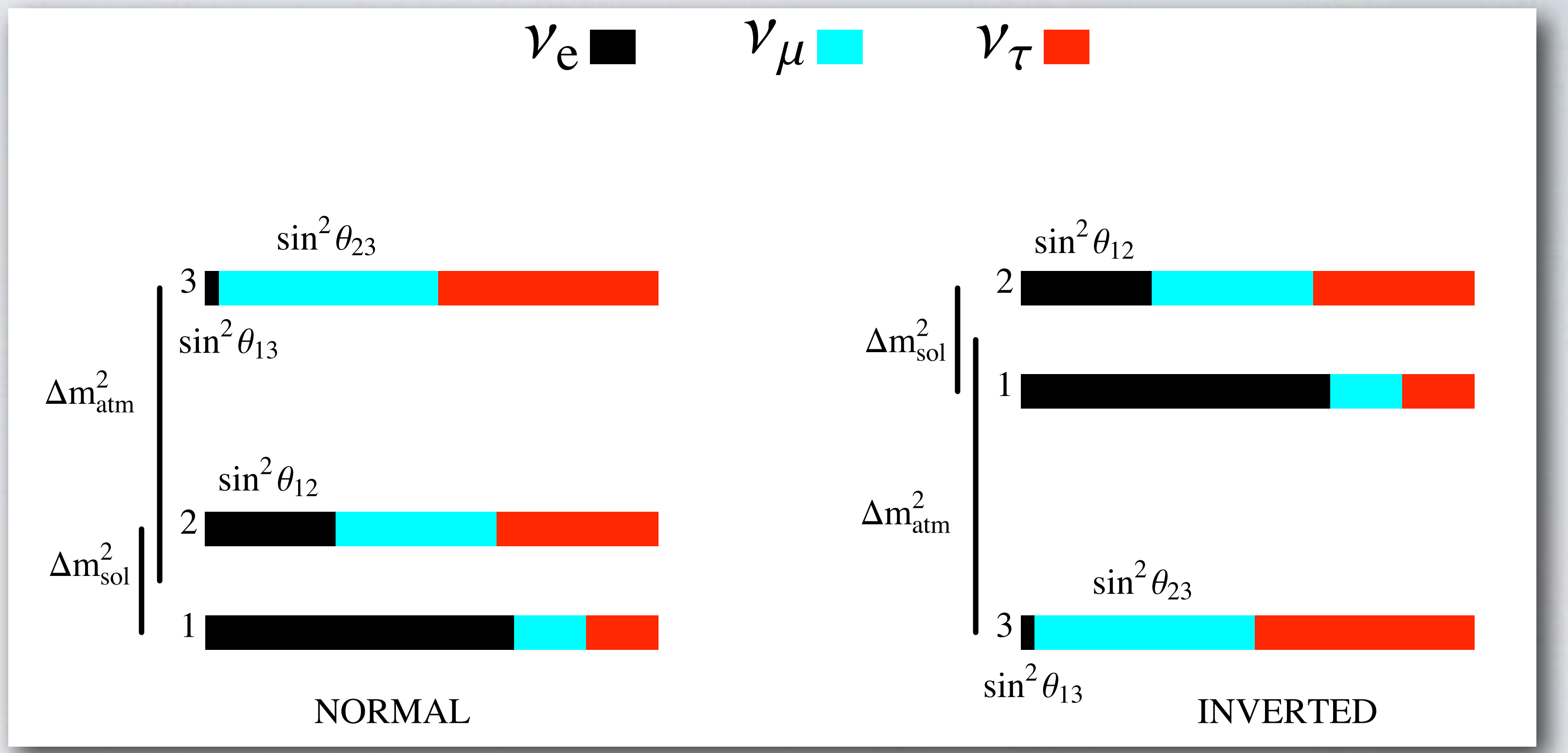
Neutrino oscillations



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS}(\theta_{12}, \theta_{23}, \theta_{13}, \delta, ...) \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Neutrino oscillations





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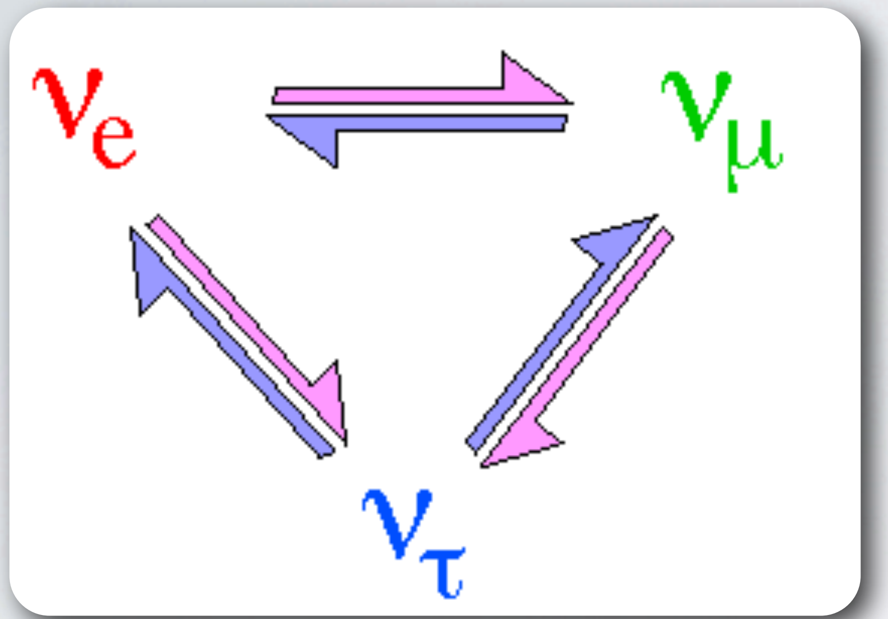
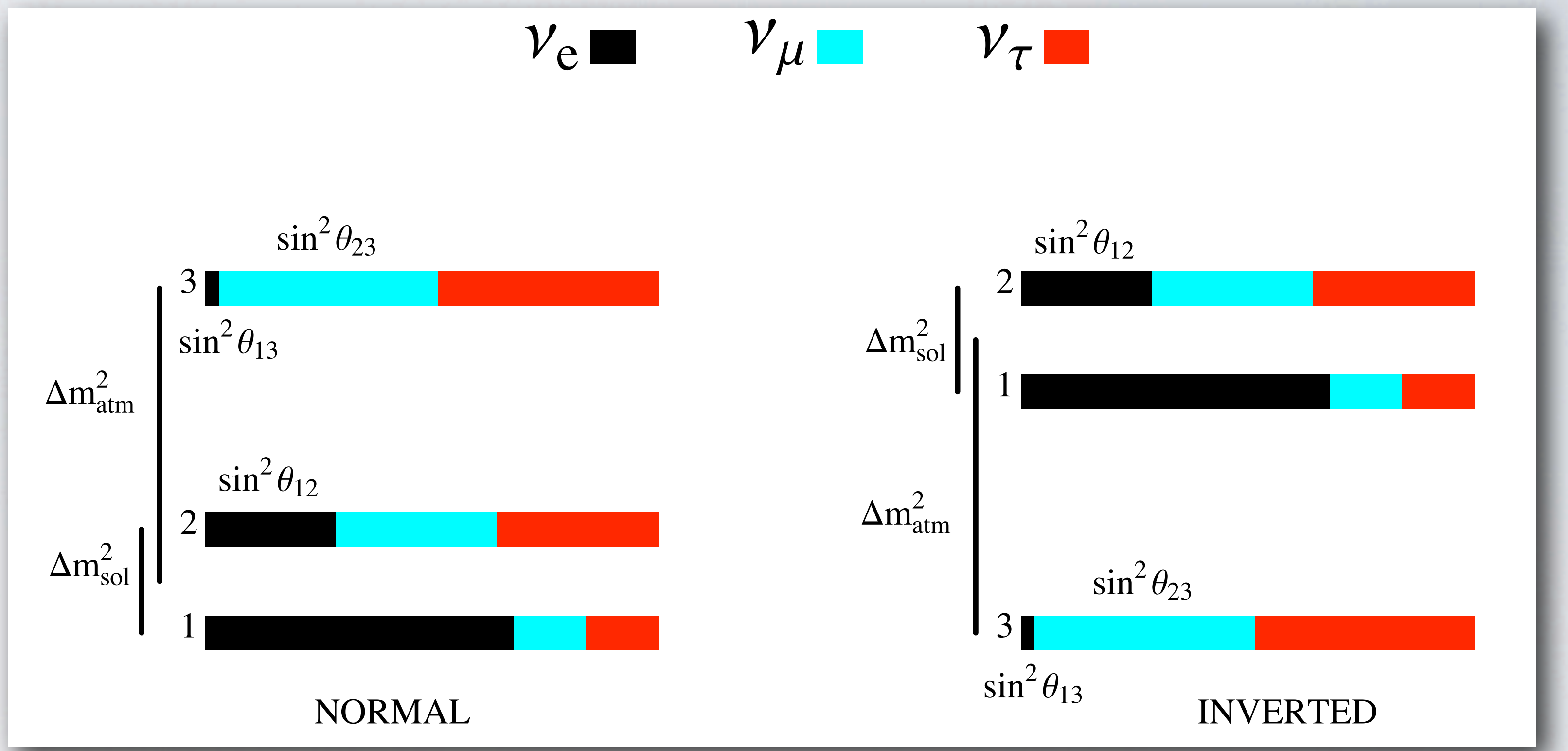
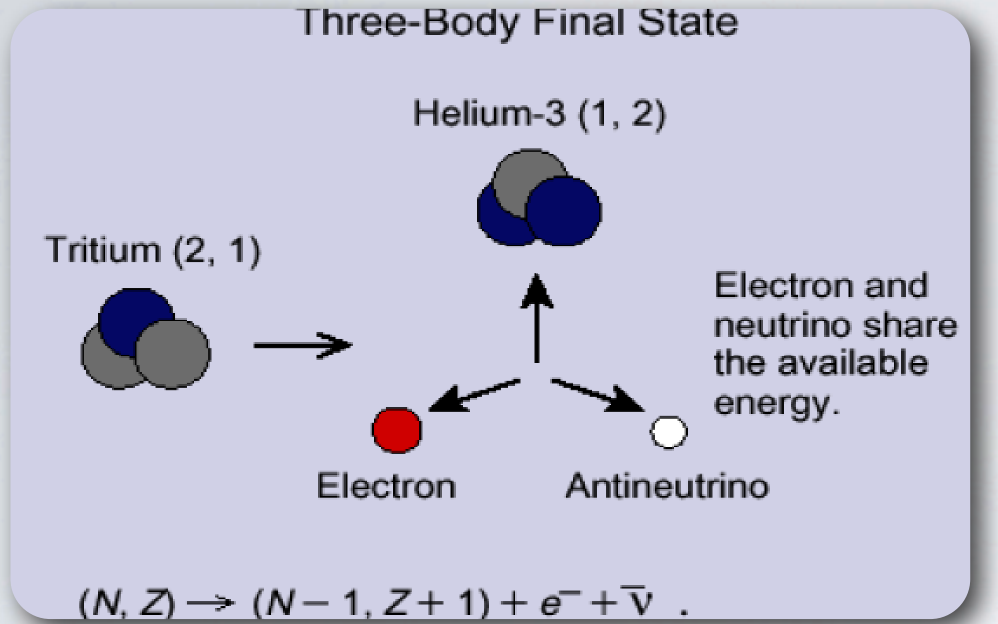




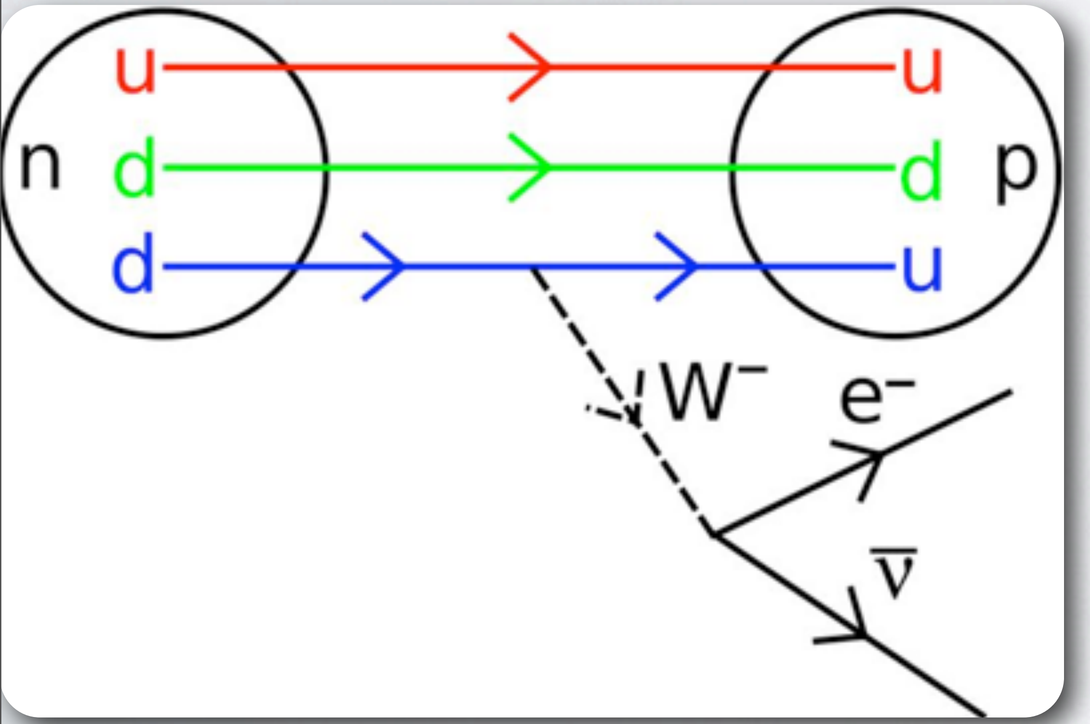
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS}(\theta_{12}, \theta_{23}, \theta_{13}, \delta, \ldots) \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

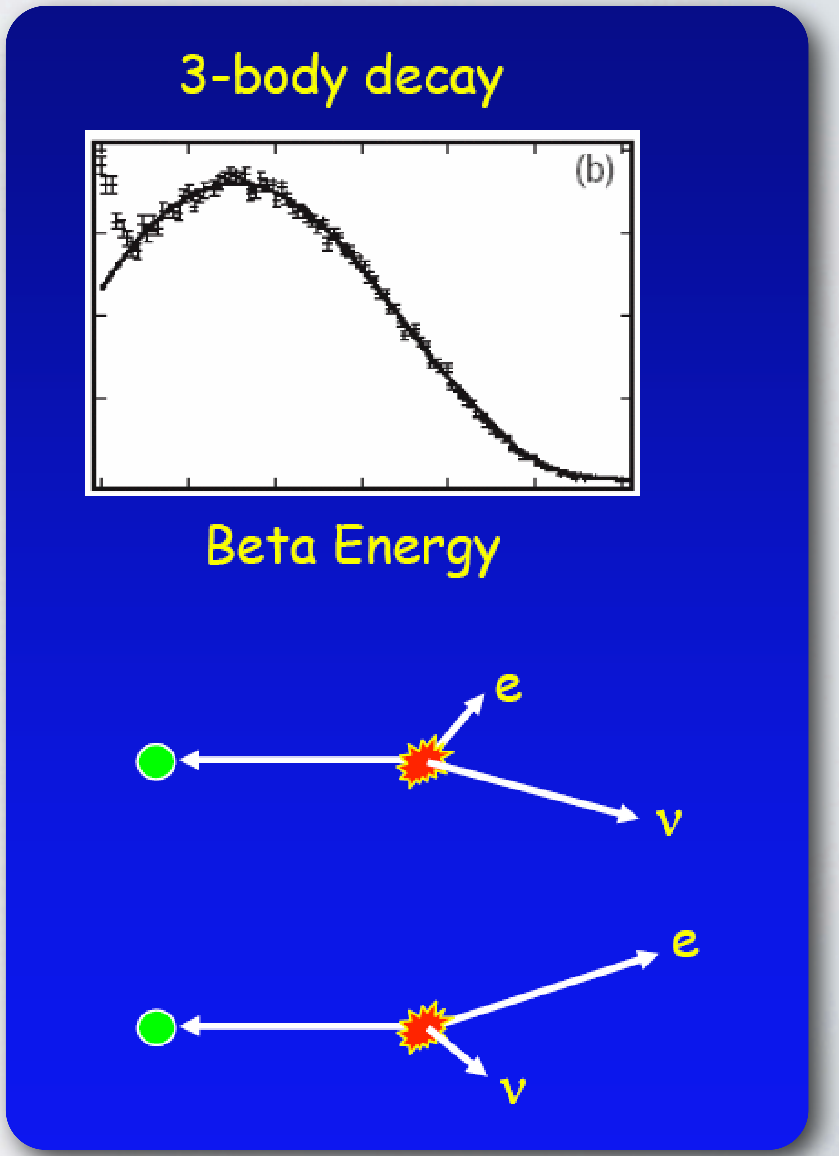
Neutrino oscillation experiments measure two mass difference squared

Beta-decay of tritium

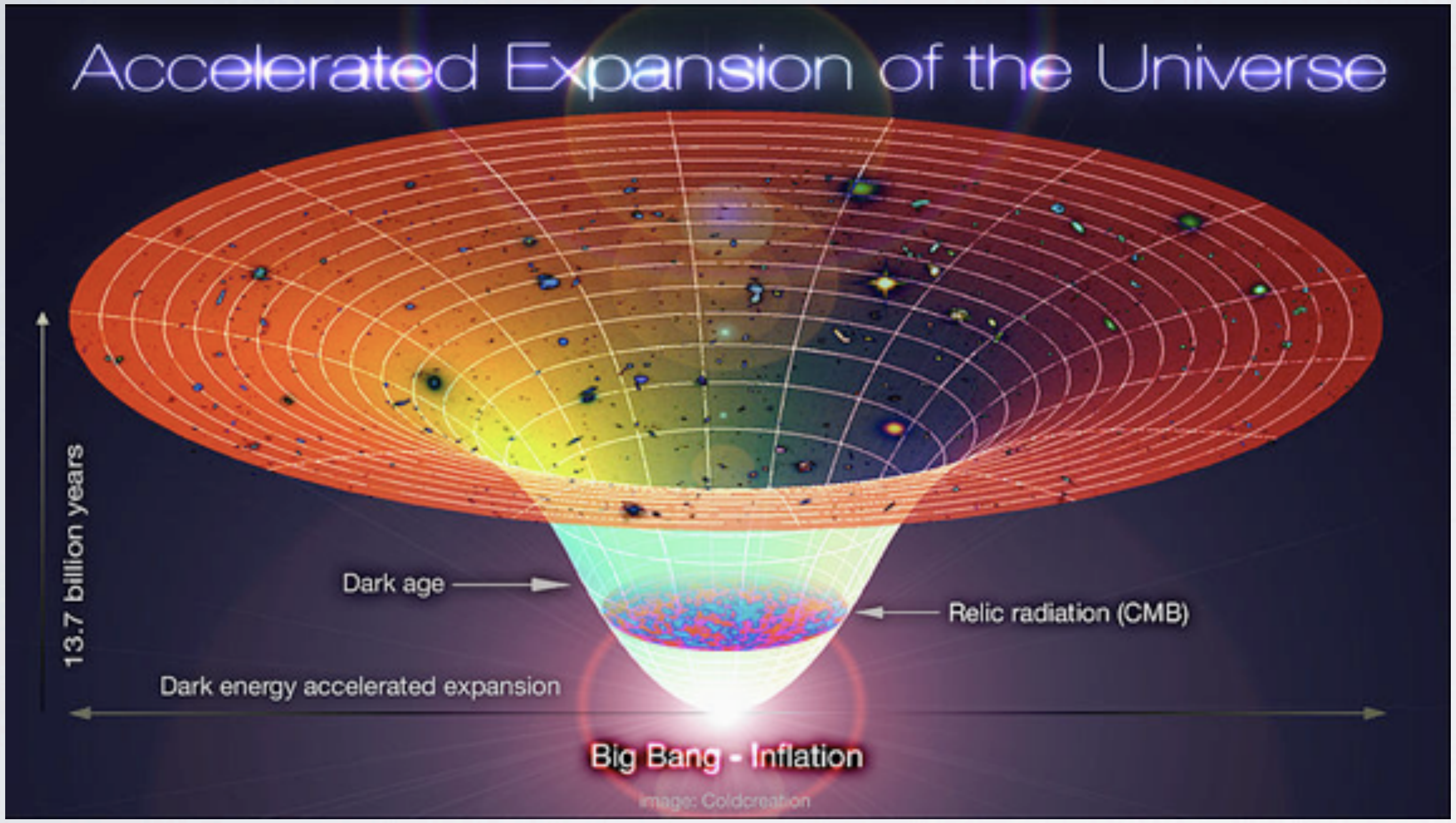


$$m_\beta^2 = \sum_{i=1}^{3} |U_{ei}|^2 m_i^2$$



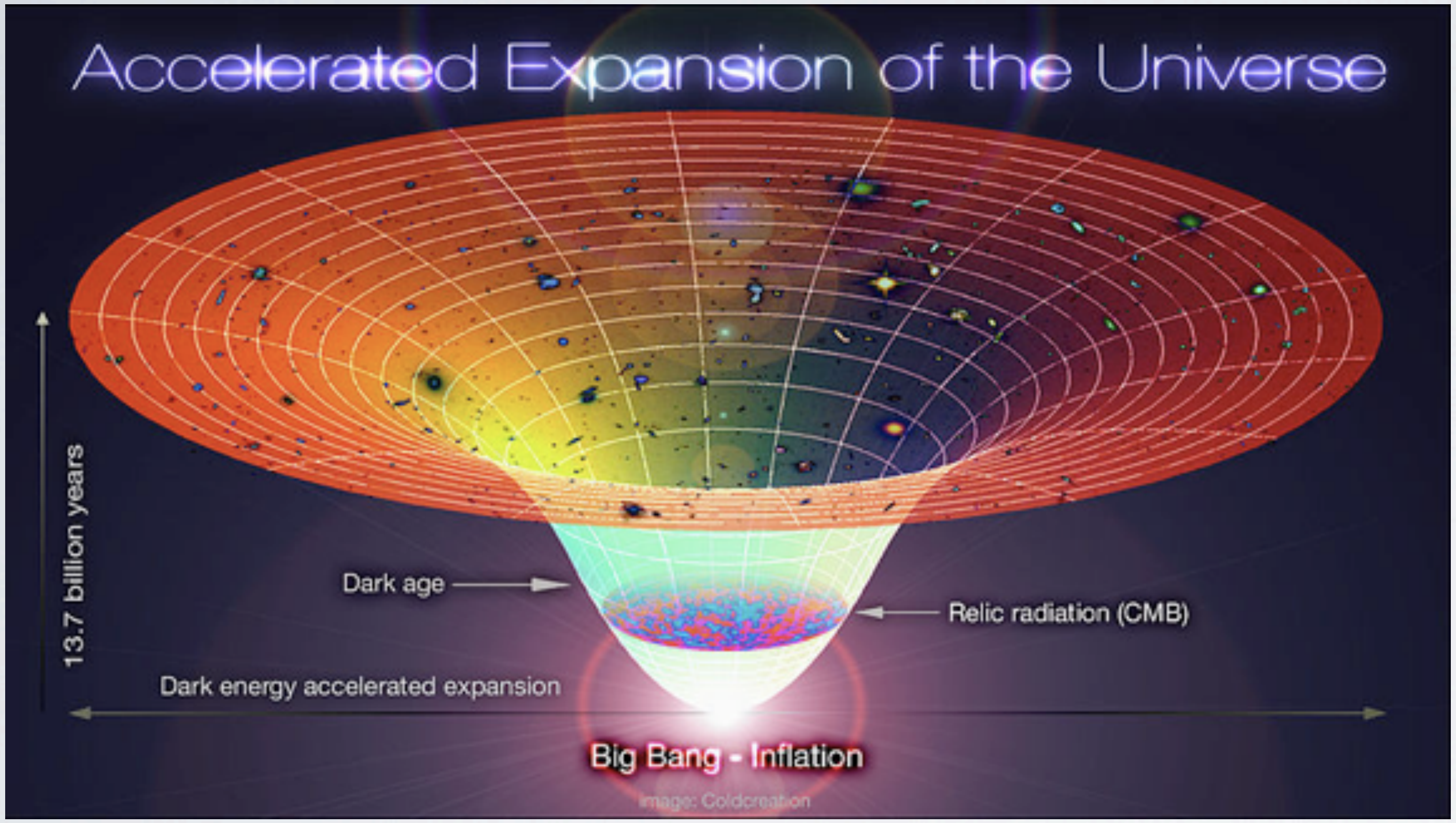


Cosmological measurements



$$m_{cosmo} = \sum_{i=1}^{3} m_i$$

Cosmological measurements



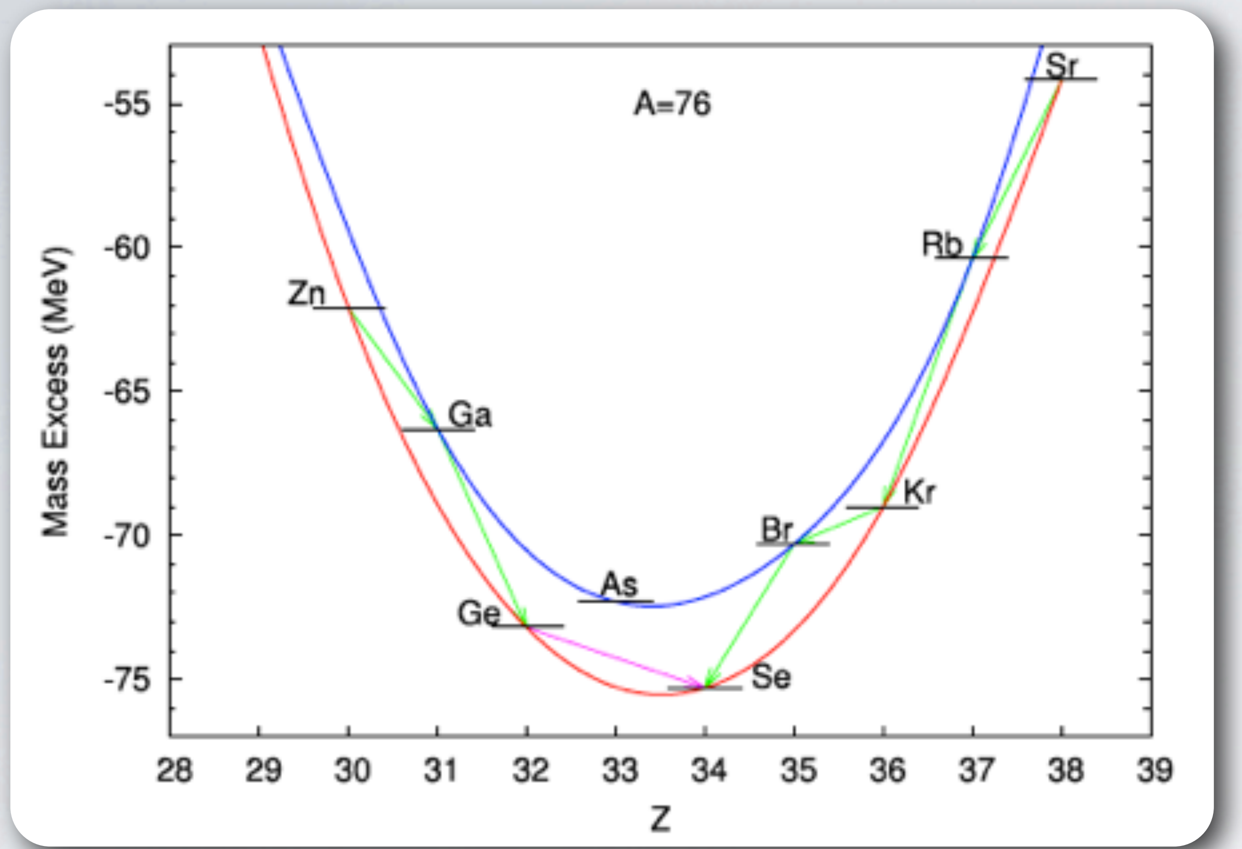
ΛCDM: Big-bang + Inflation (CMB)
Dark energy (73% of energy density), cold dark matter (23%) ordinary matter (4.5%)
Light neutrinos can enter extensions of the ΛCDM model as "hot dark matter"

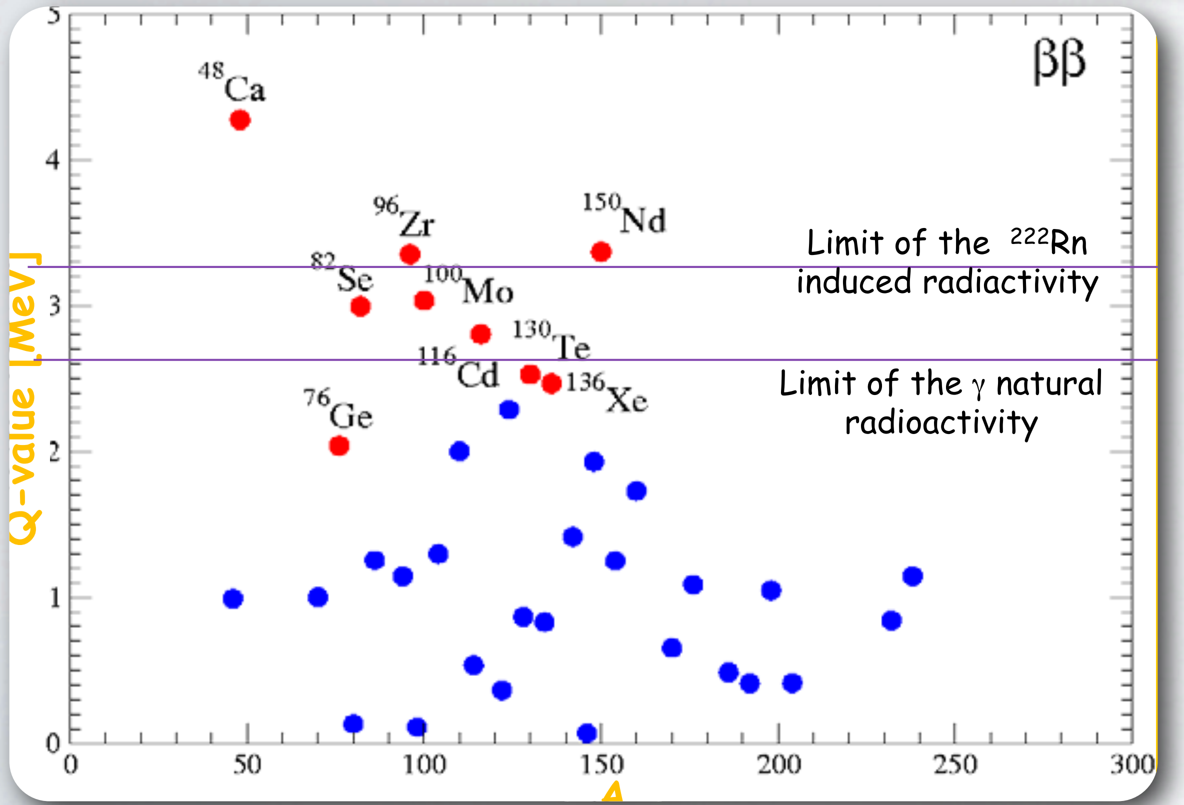
$$m_{cosmo} = \sum_{i=1}^{3} m_i$$

Are neutrino Majorana particles? To find out play...


Reiner Knizia
Double
or
Nothing
OUT
Funagain.com
überplay

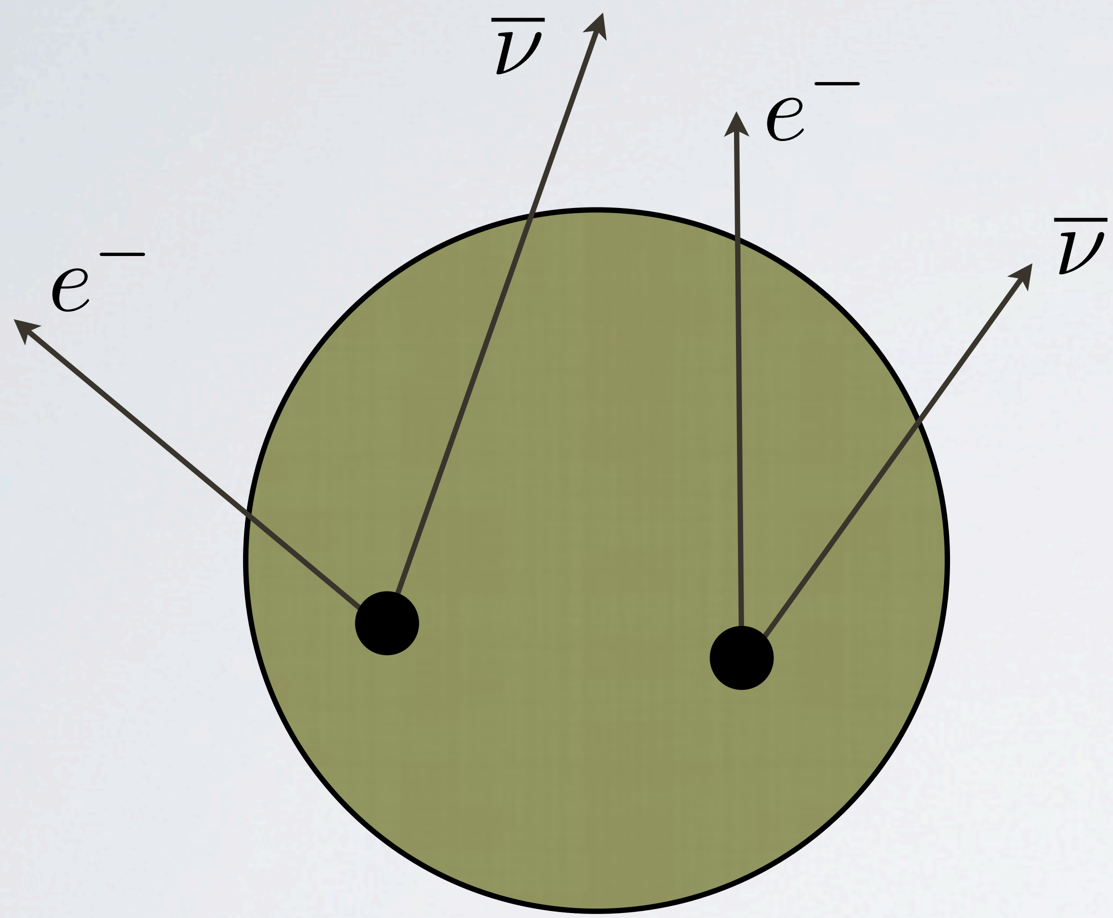
Double beta decay





- Some nuclei, otherwise quasi stable can decay by emitting two electrons and two neutrinos by a second order process mediated by the weak interaction.
- This process exists due to nuclear pairing interaction that favors energetically the even-even isobars over the odd-odd ones.

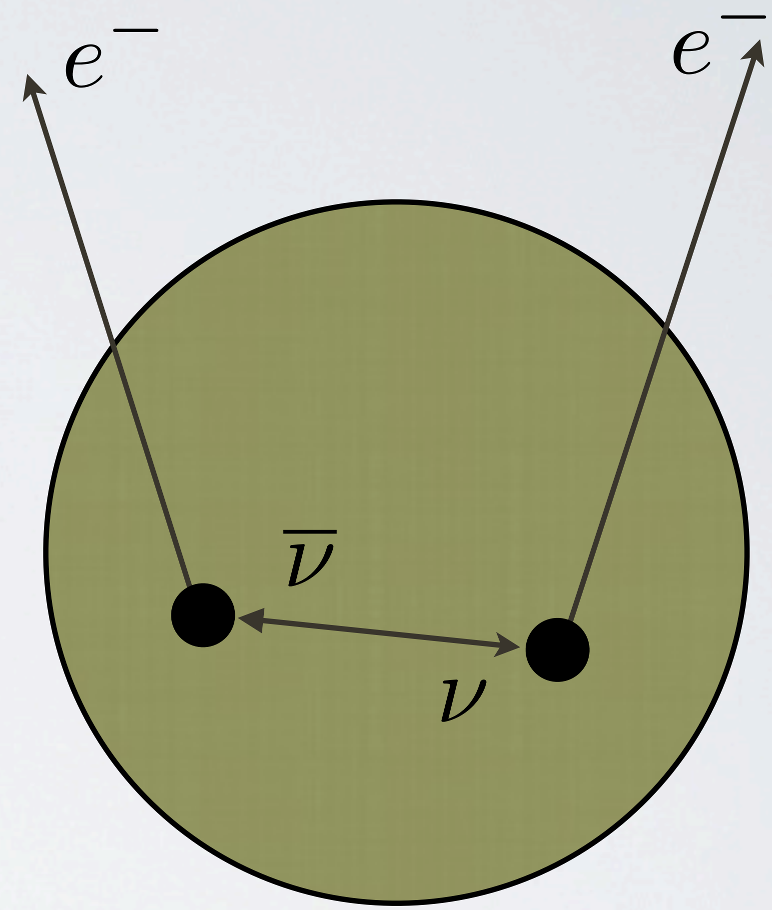
Double beta decay



$\beta\beta2\nu$

SM-allowed process.
Measured in several nuclei.

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



$\beta\beta0\nu$

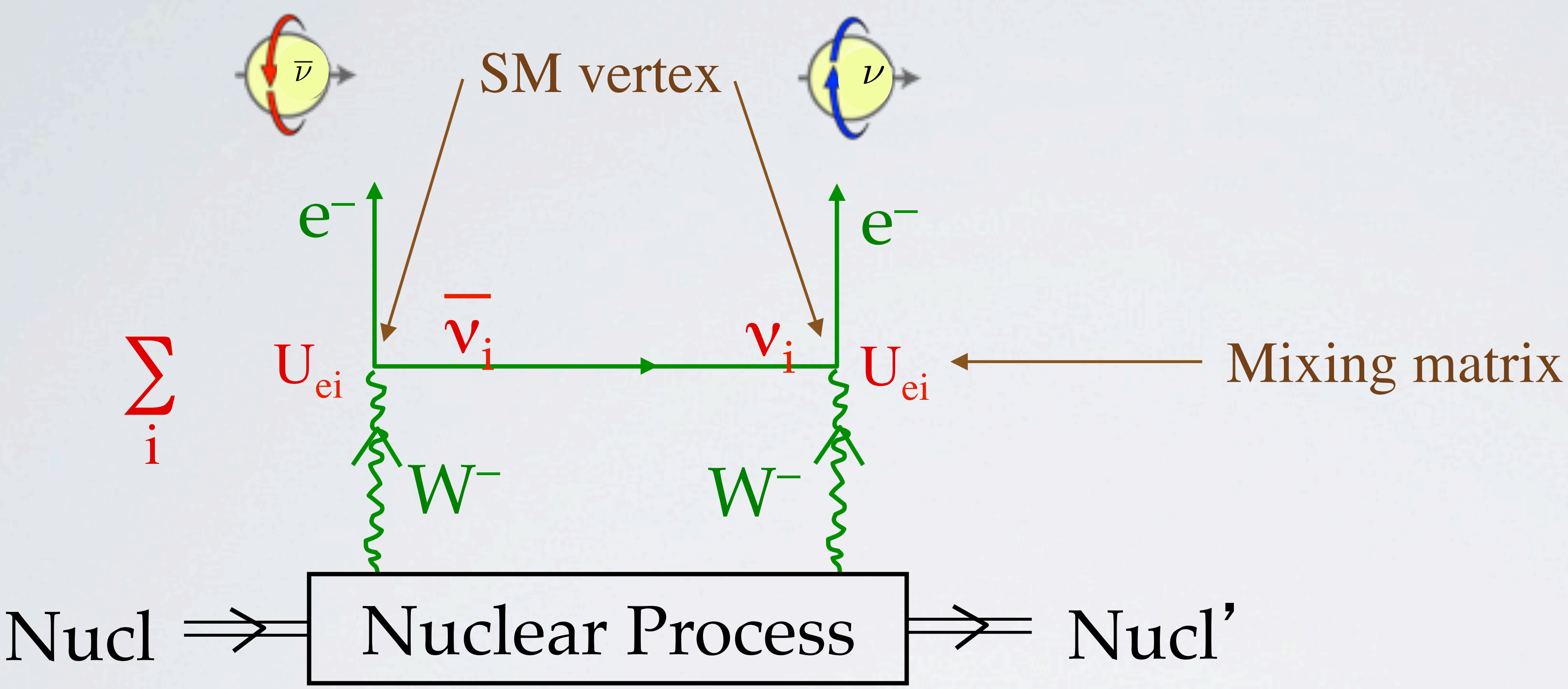
Lepton number violating process.
Requires massive, Majorana neutrinos.

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

Majorana mass

$$m_{\beta\beta} = ||U_{e1}|^2 m_1 + e^{i\alpha_1}|U_{e2}|^2 m_2 + e^{i\alpha_2}|U_{e3}|^2 m_3|$$

Majorana mass



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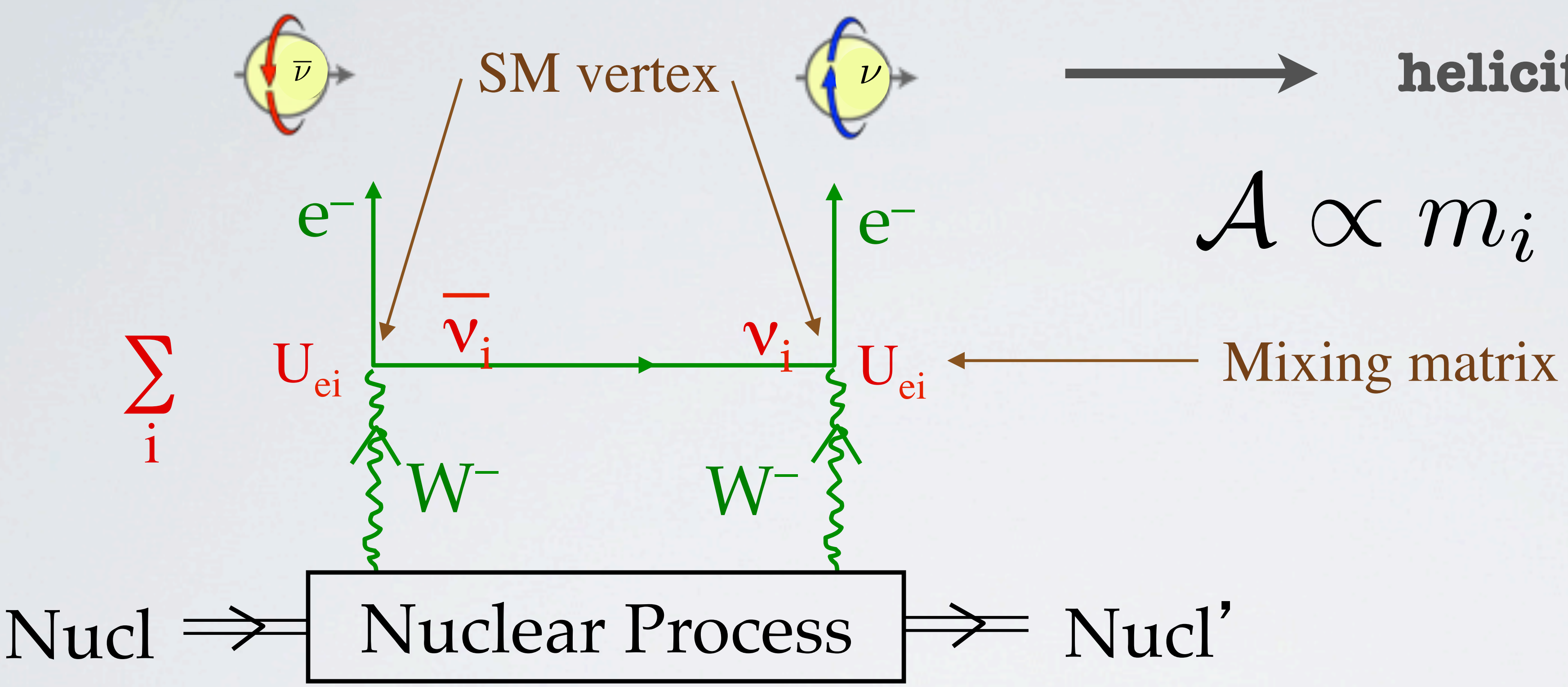
Majorana mass

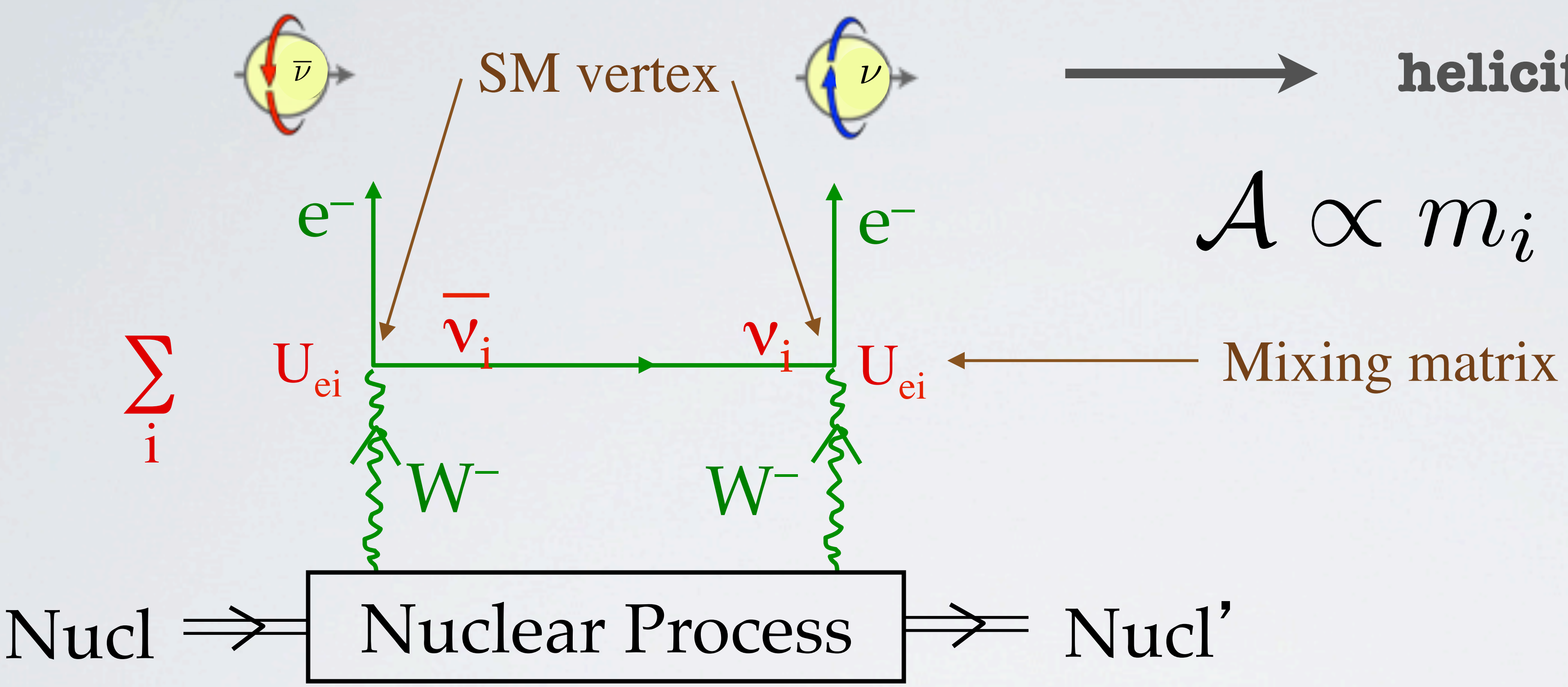


helicity flip $\propto \frac{m_i}{E}$

$\mathcal{A} \propto m_i$ **for each** ν_i

$$m_{\beta\beta} = ||U_{e1}|^2 m_1 + e^{i\alpha_1}|U_{e2}|^2 m_2 + e^{i\alpha_2}|U_{e3}|^2 m_3|$$

Majorana mass



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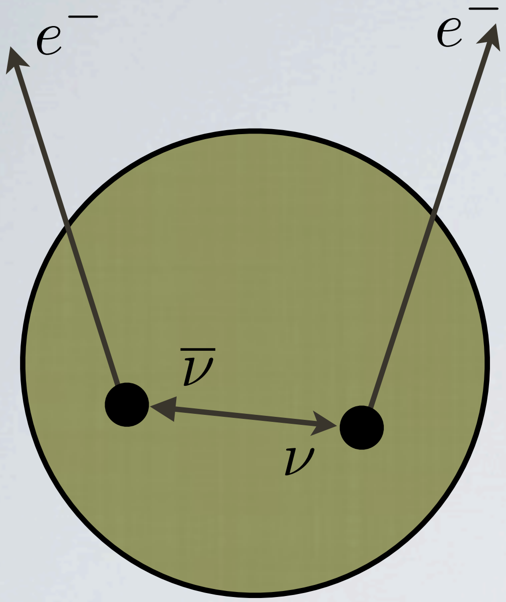
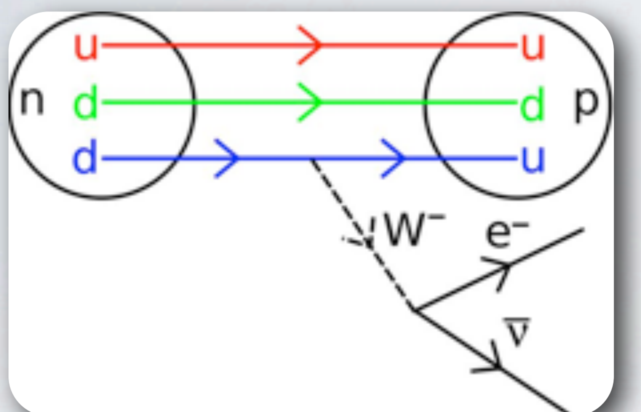
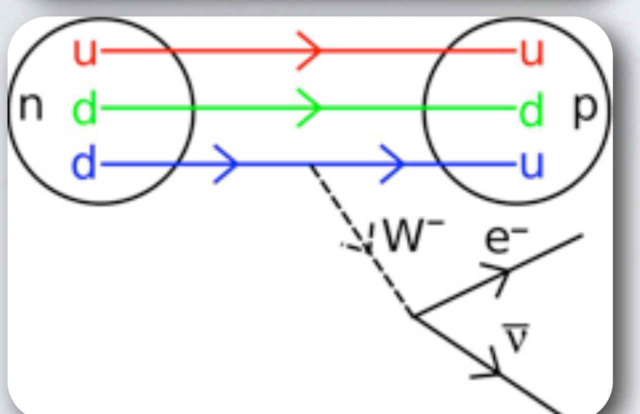
The Uei terms are measured by neutrino oscillation experiments. Nothing is known about the two Majorana phases.

Nuclear physics



$\beta\beta0\nu$





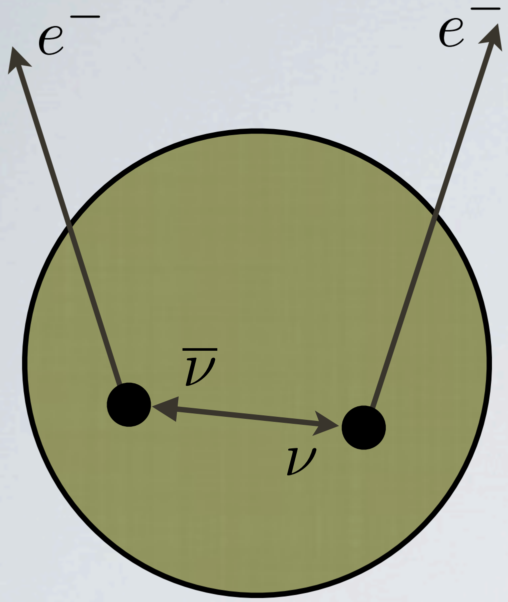
$$(T^{0\nu}_{1/2})^{-1} = \boxed{G^{0\nu}(Q,Z)}\,\boxed{|M^{0\nu}|^2}\, m^2_{\beta\beta}$$

phase-space

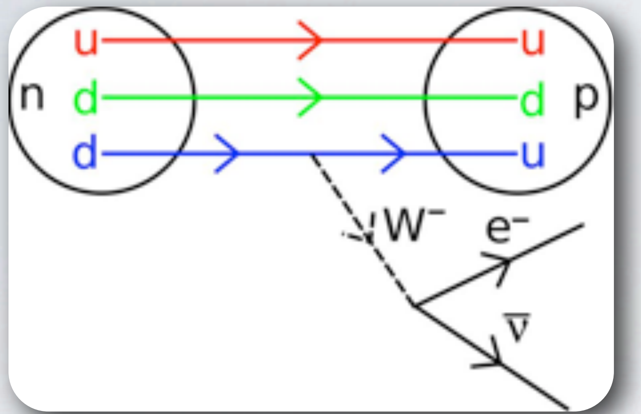
nuclear matrix

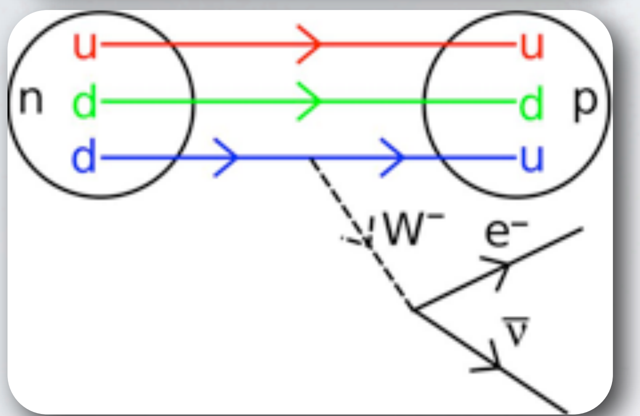
Majorana neutrino

Nuclear physics



$\beta\beta0\nu$





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

phase-space

nuclear matrix

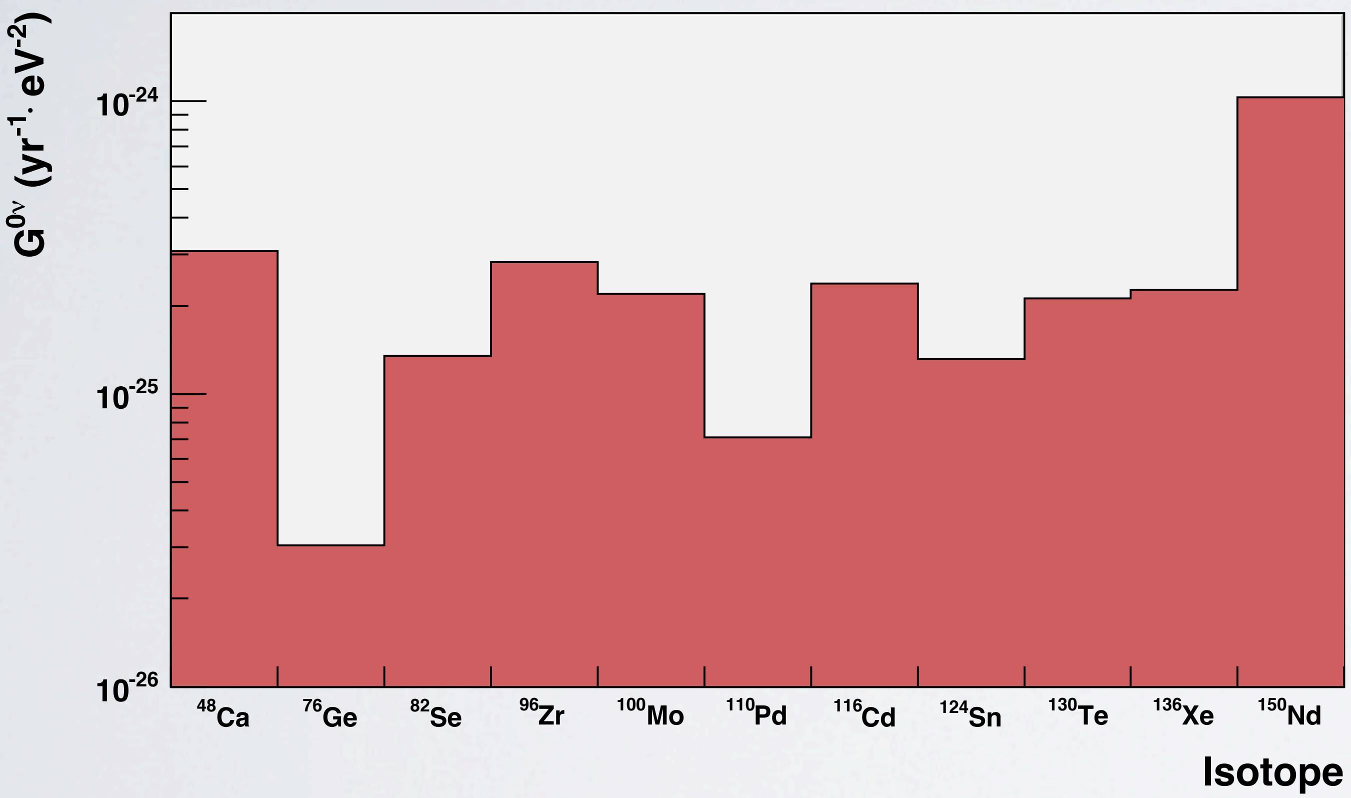
Majorana neutrino

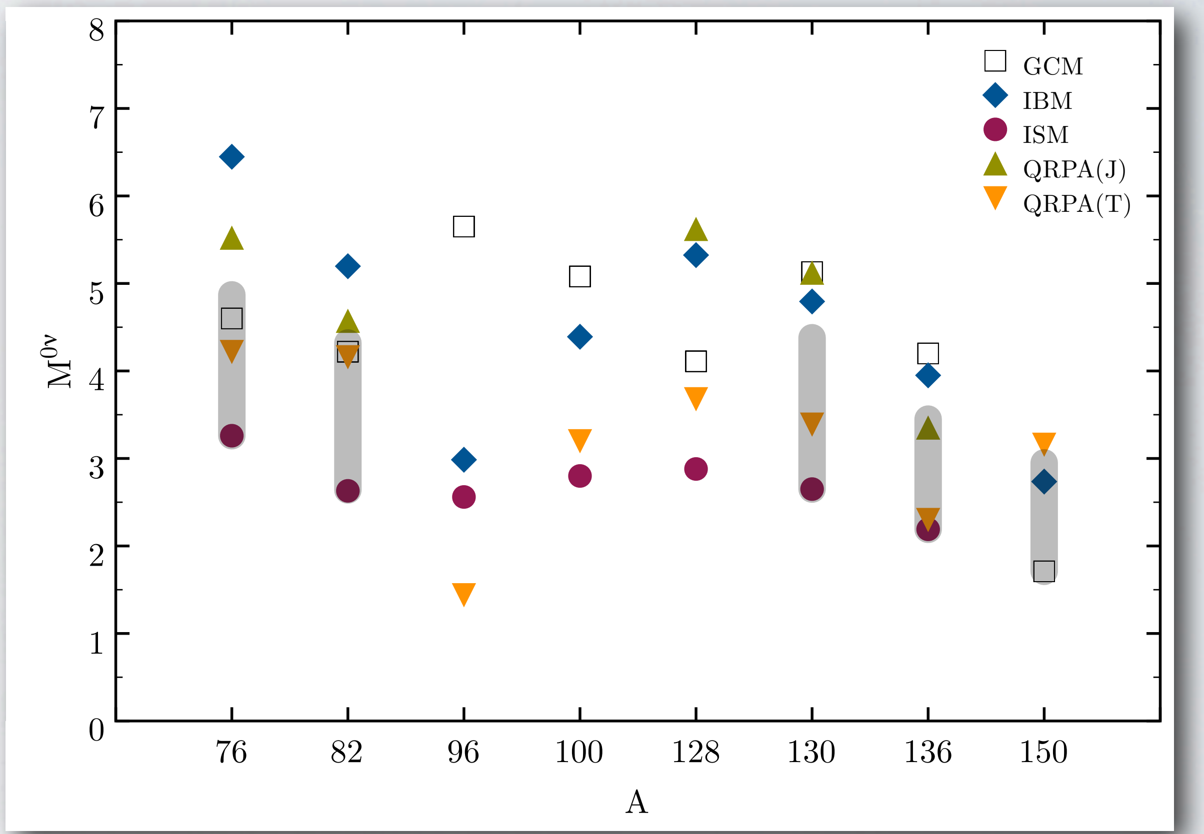
Two protons decay simultaneously in a heavy isotope
Nuclear physics results in proportionality constants between period and the inverse of the Majorana mass squared

The NME industry

http://arxiv.org/abs/1109.5515

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





The NME industry

http://arxiv.org/abs/1109.5515

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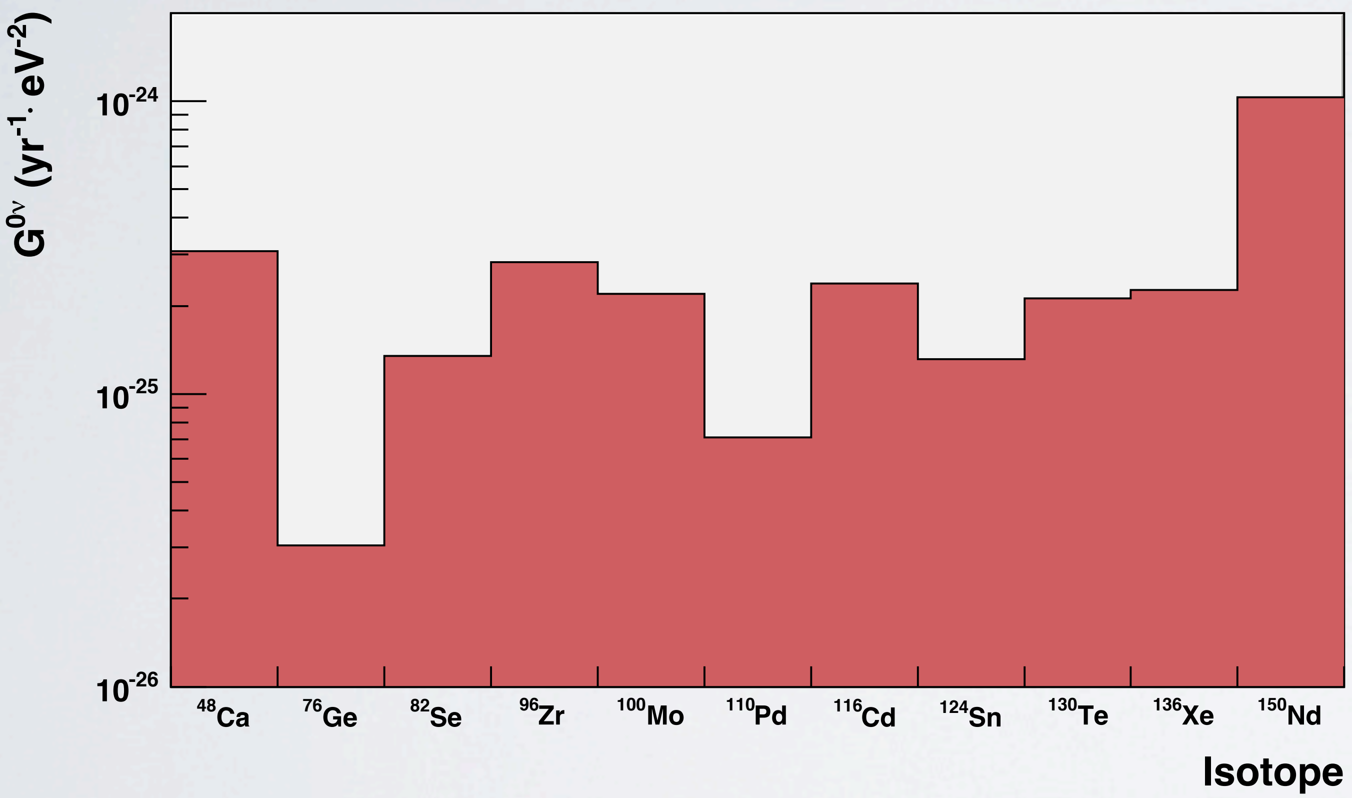
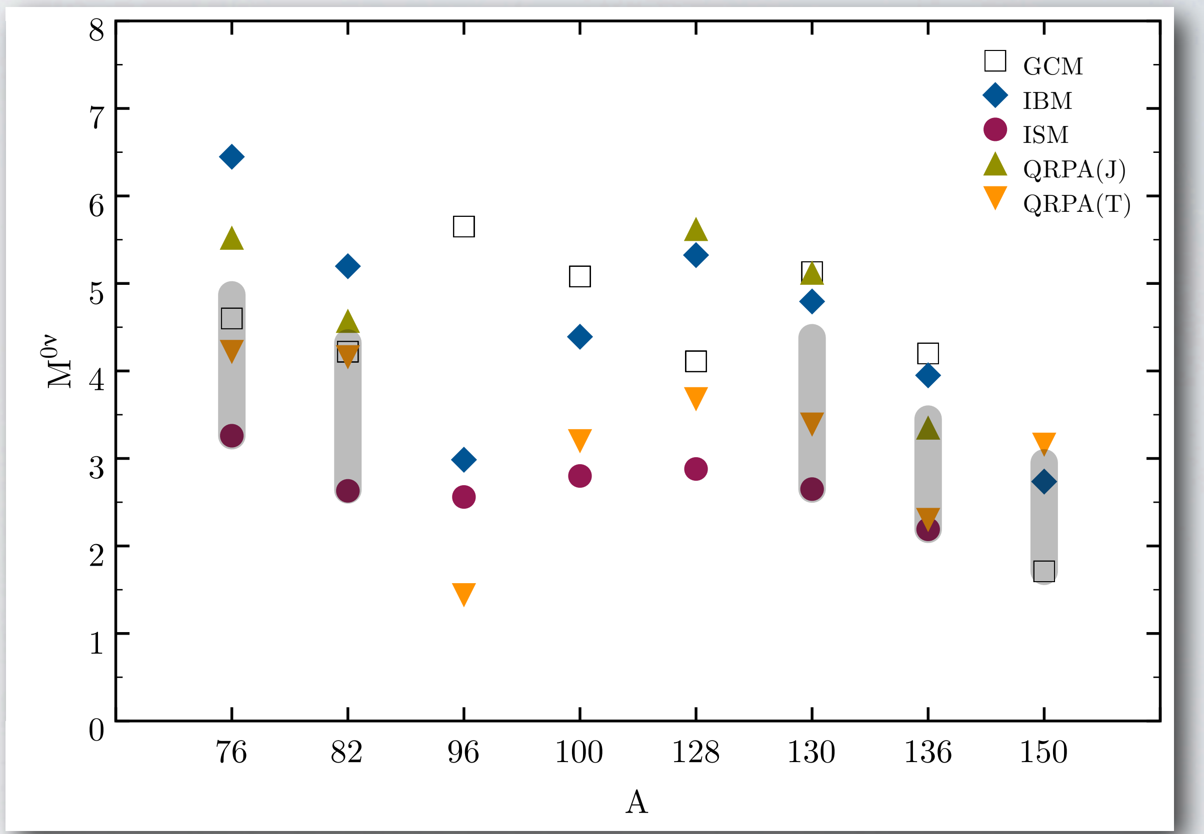
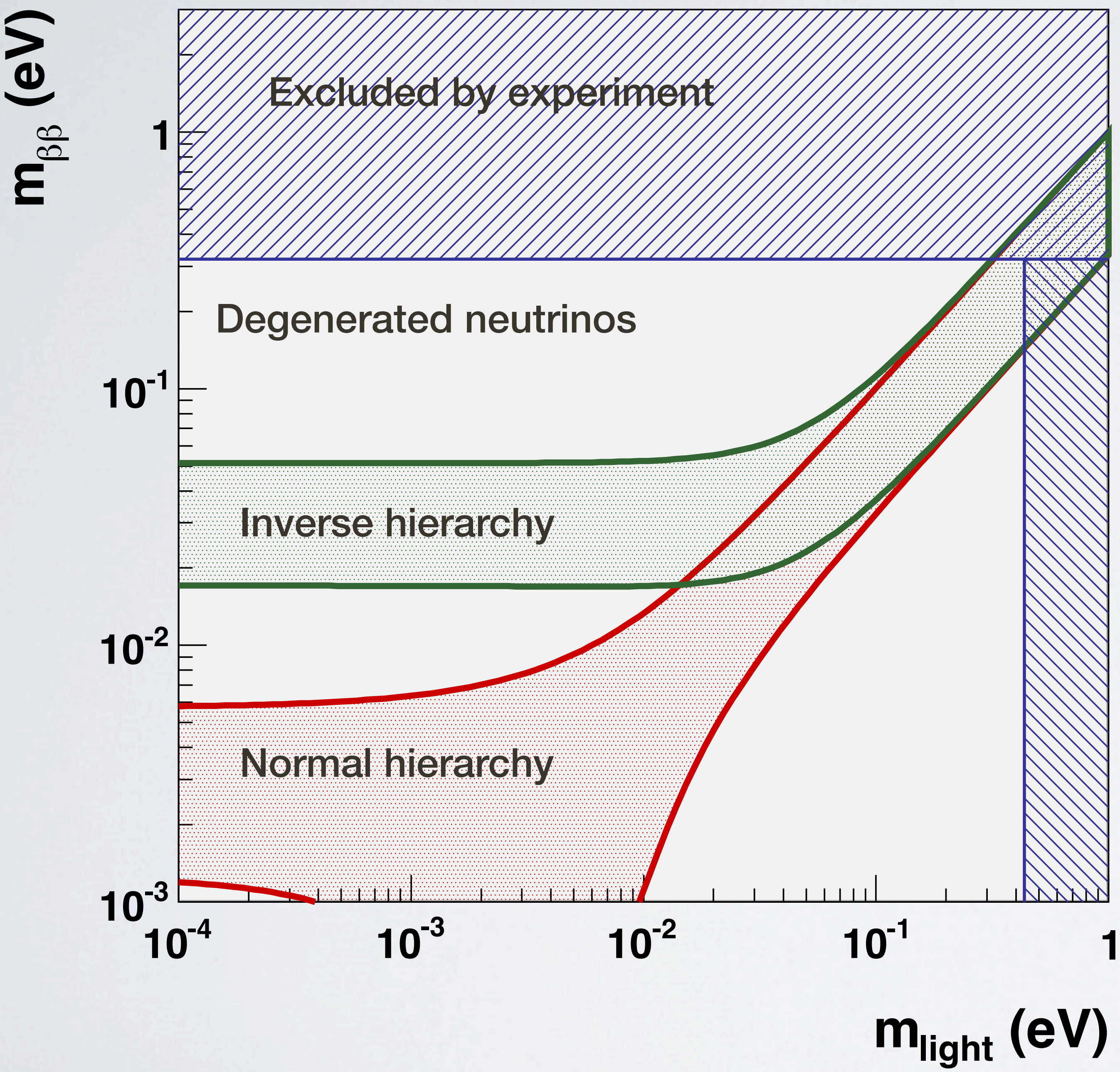


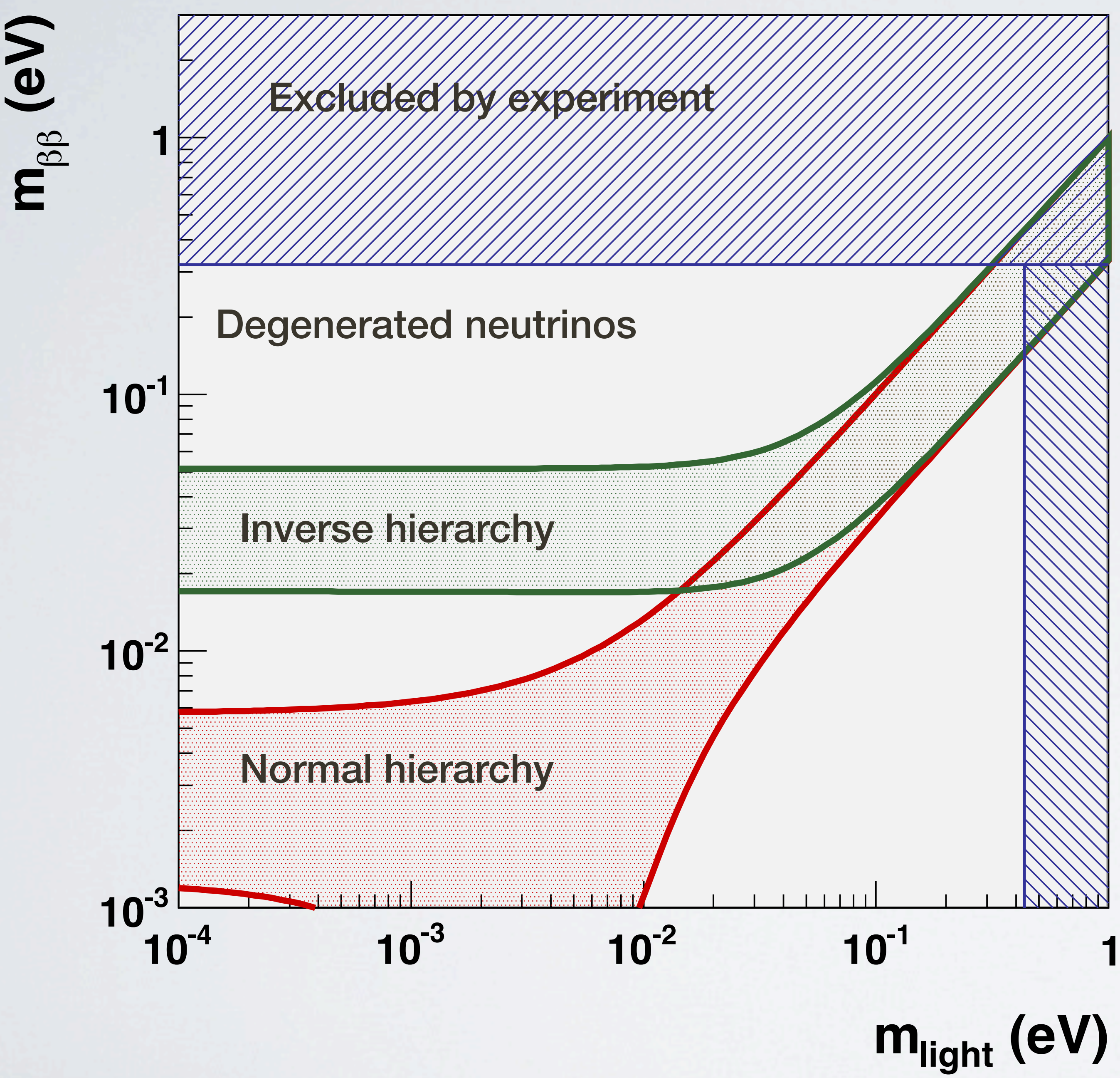


Phase space pretty democratic expect for a few isotopes
Considerable spread between NME elements
In this talk: Use of PMR range.

The Majorana landscape

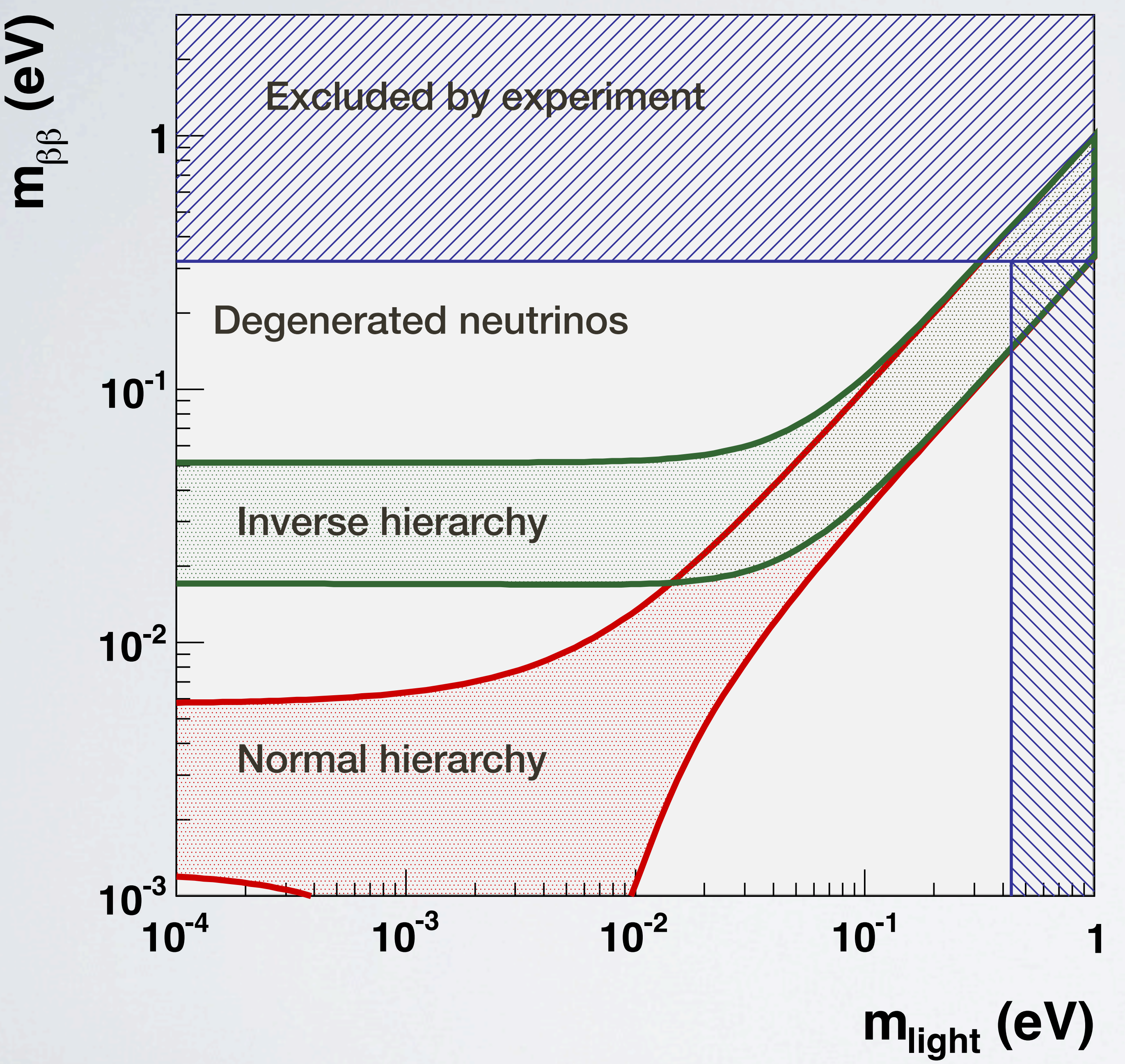


The Majorana landscape



Cosmological limits and limits from previous bb0nu experiments included in this plot.

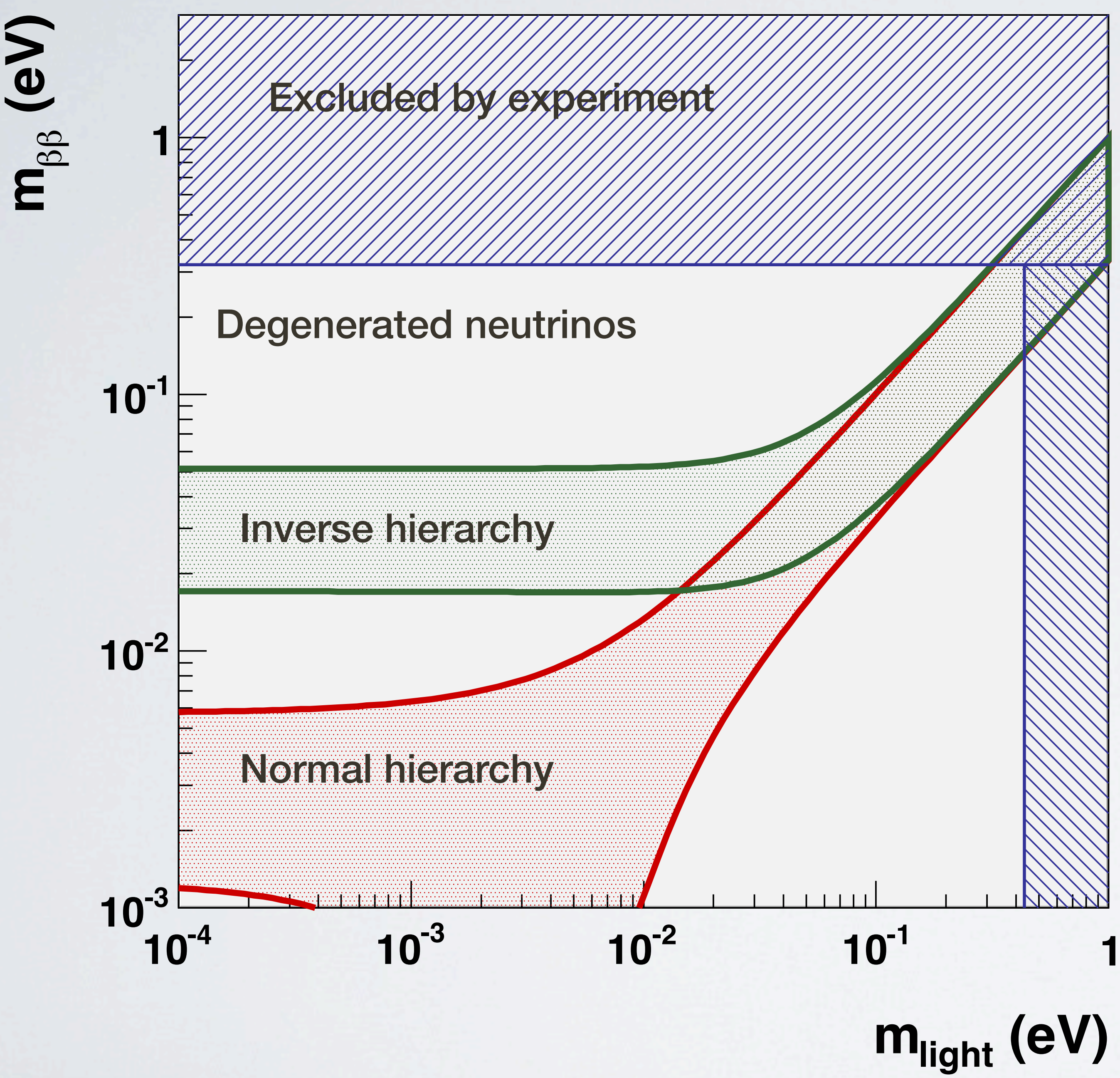
The Majorana landscape



Cosmological limits and limits from previous bb0nu experiments included in this plot.

Exploring the inverse hierarchy requires sensitivity to mbb < 20 meV

The Majorana landscape

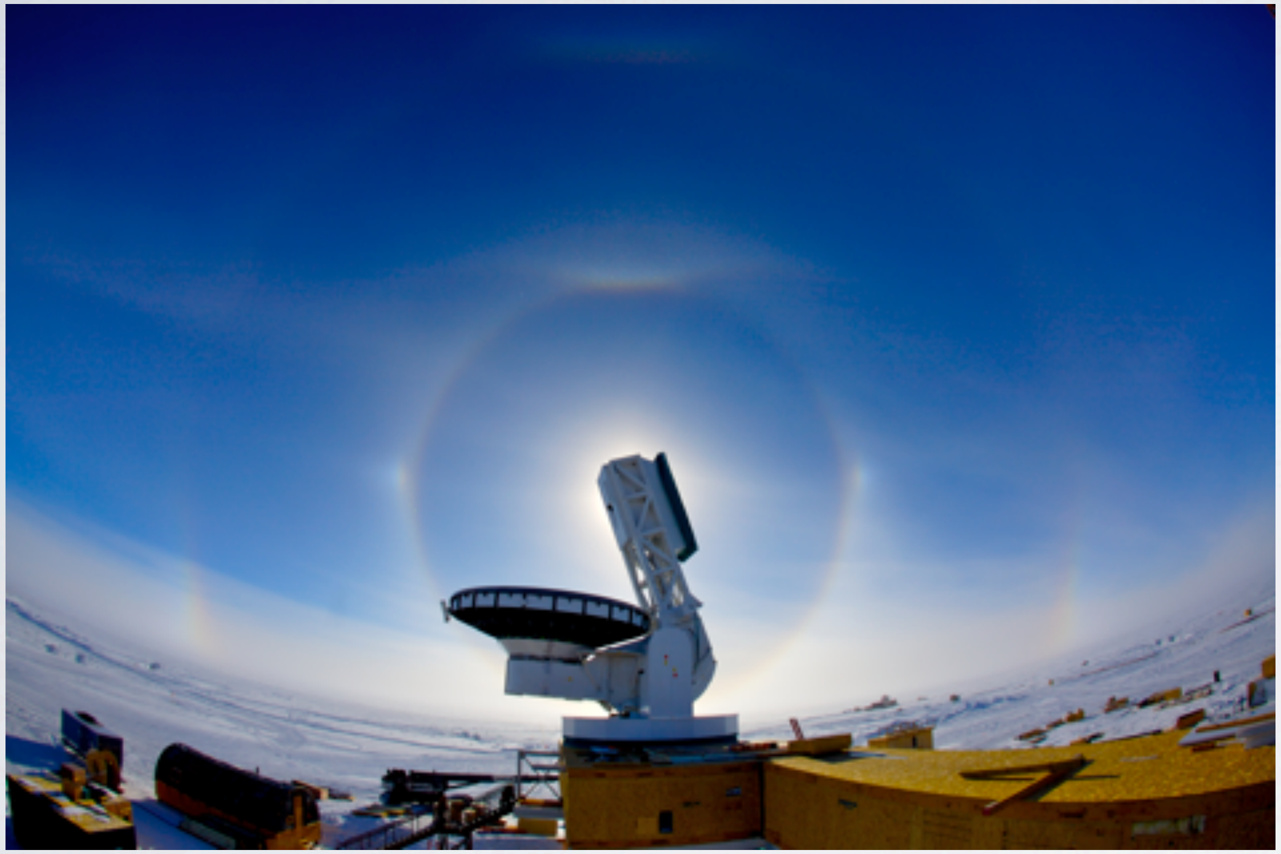


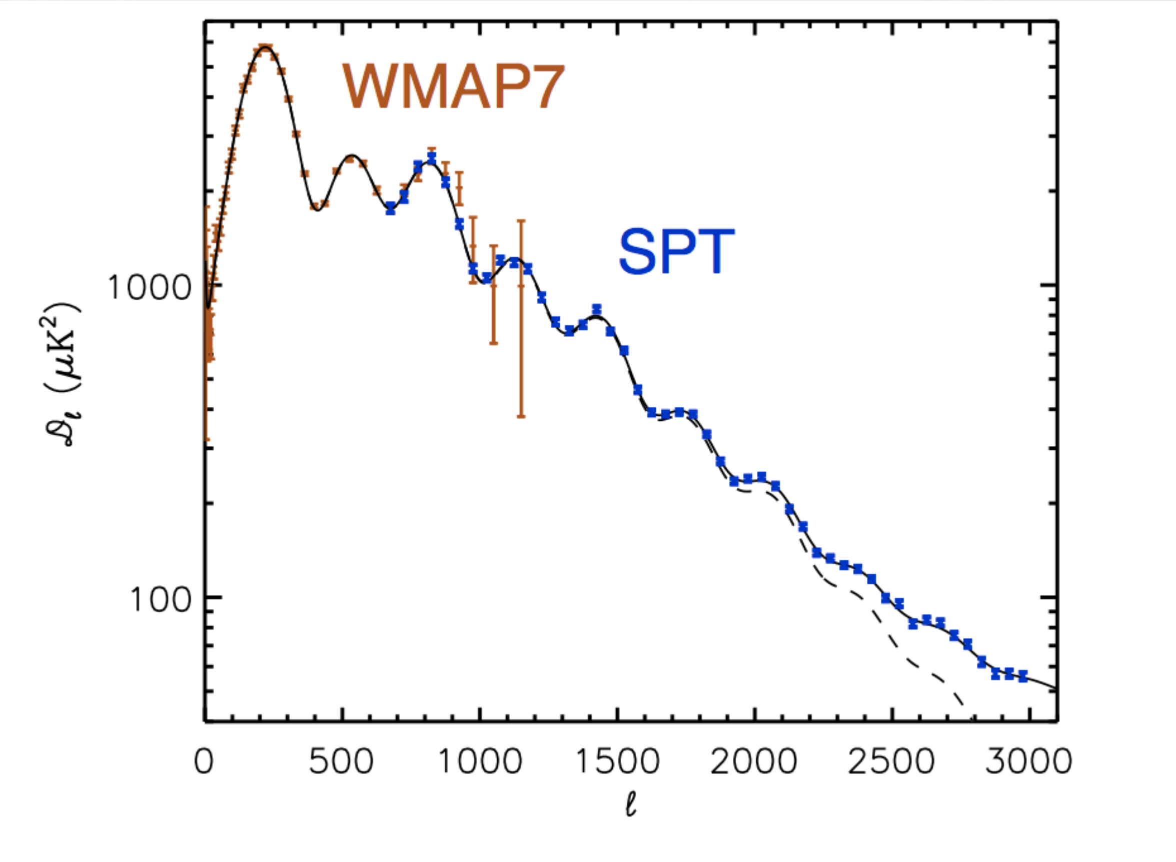
Cosmological limits and limits from previous bb0nu experiments included in this plot.

Exploring the inverse hierarchy requires sensitivity to mbb < 20 meV

Normal hierarchy experimentally inaccessible (today)

News from Antarctica

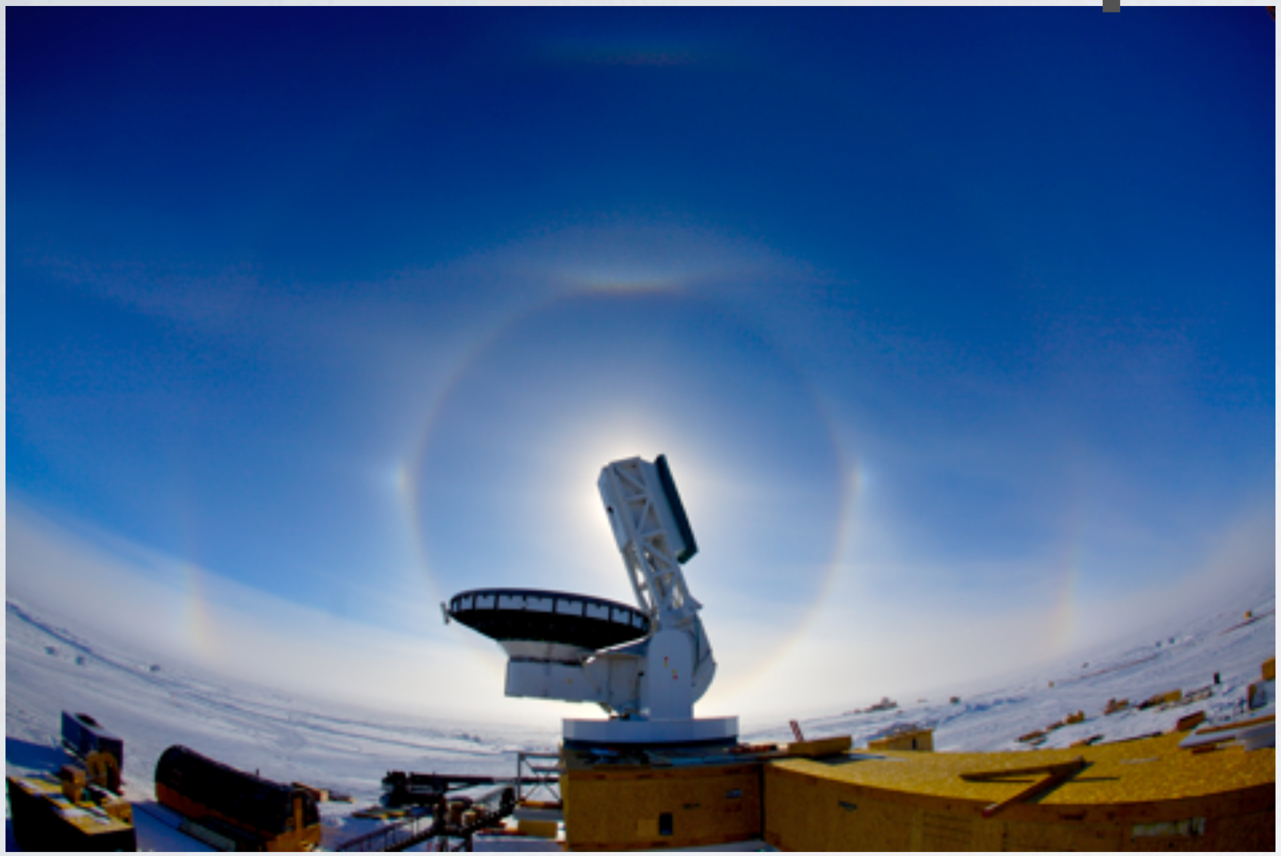


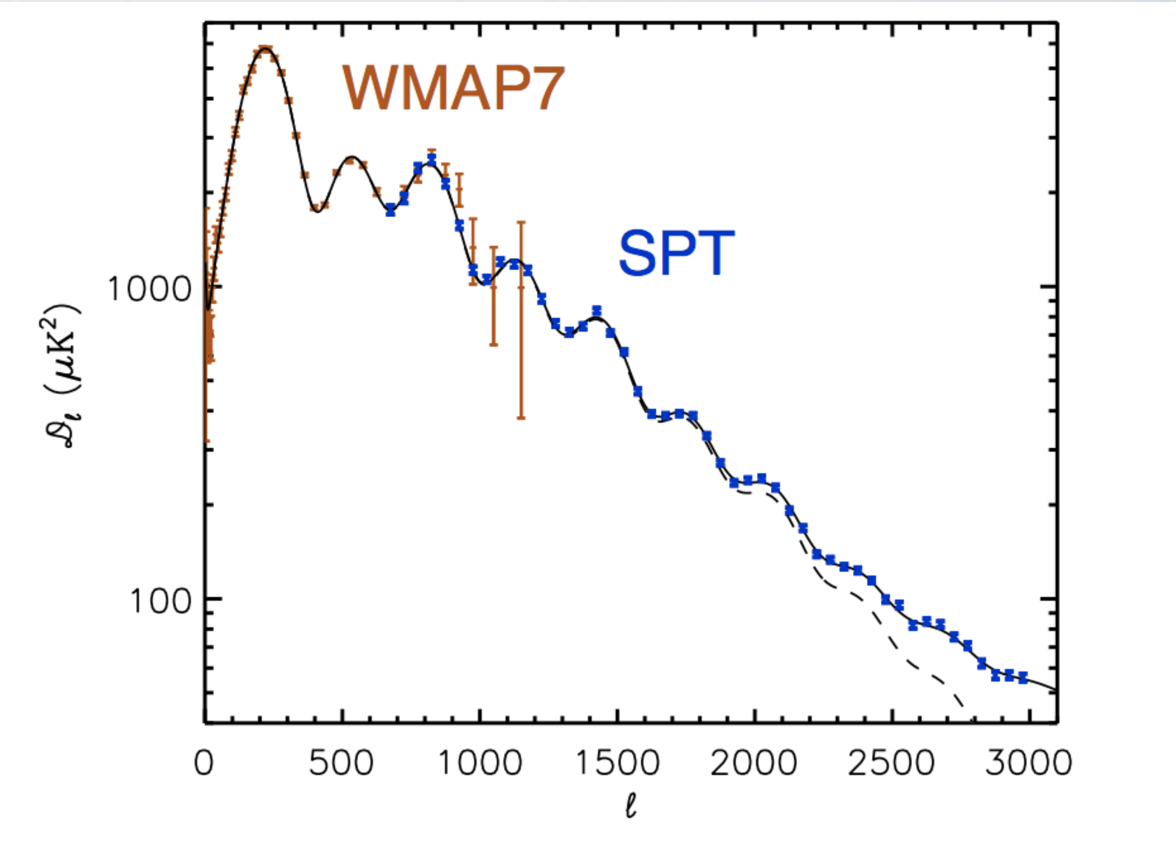


arXiv:1210: 7231

News from Antarctica

South Pole Telescope





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News from Antarctica

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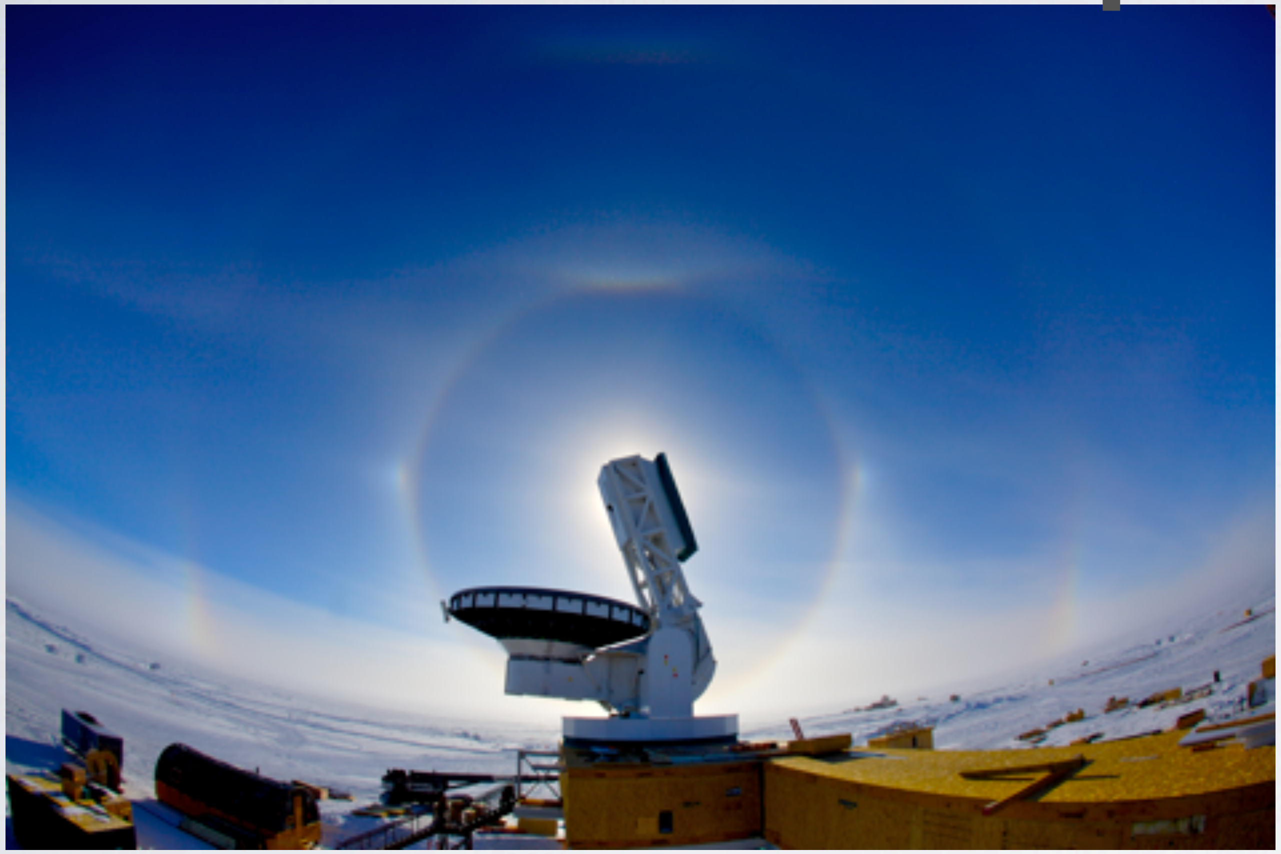
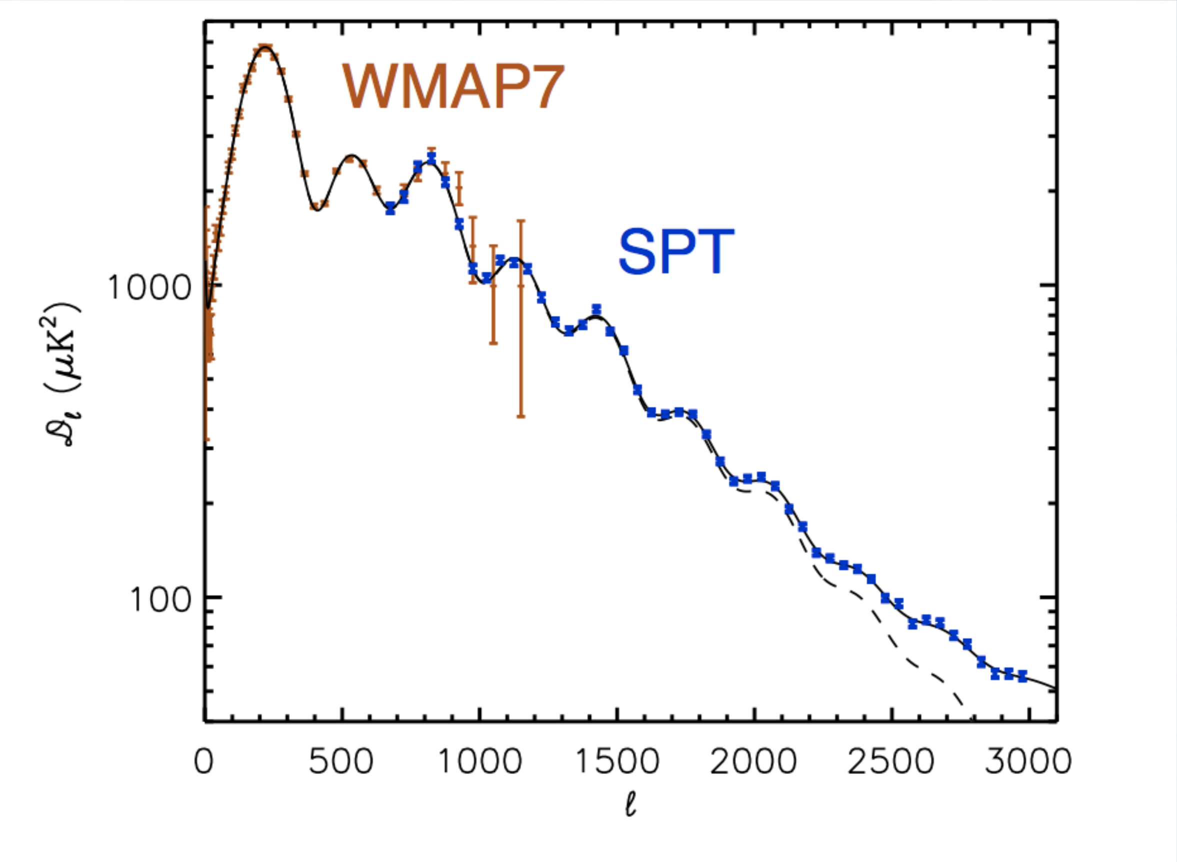
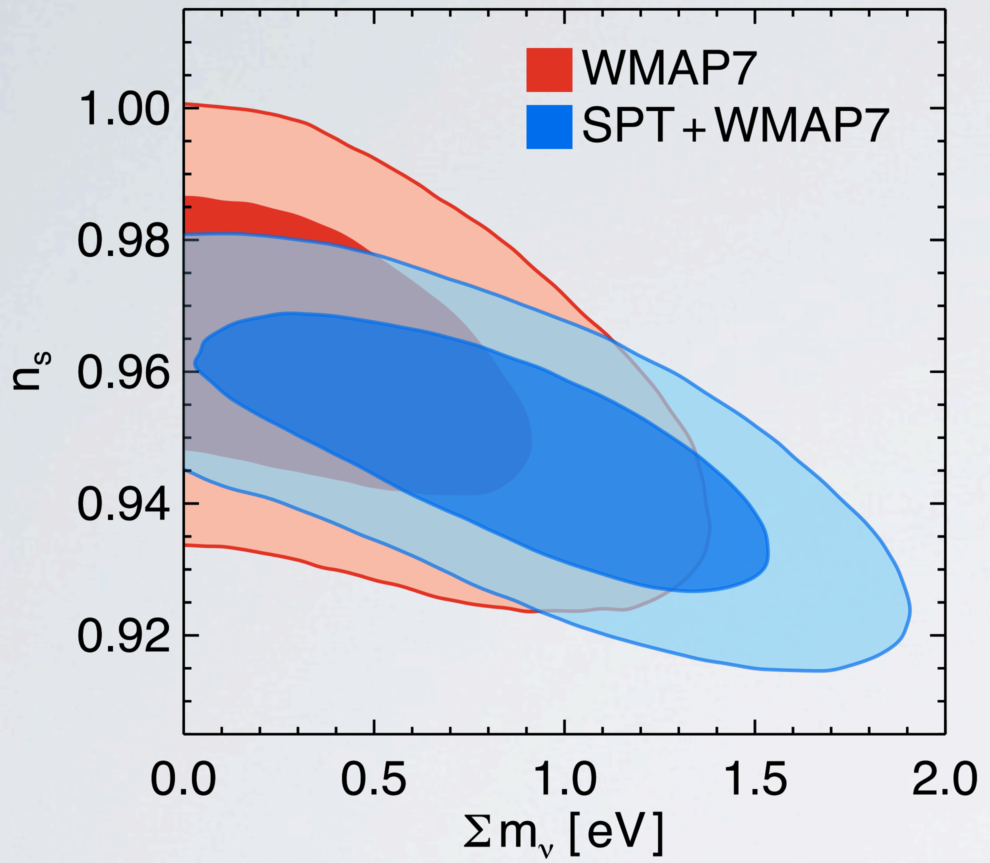


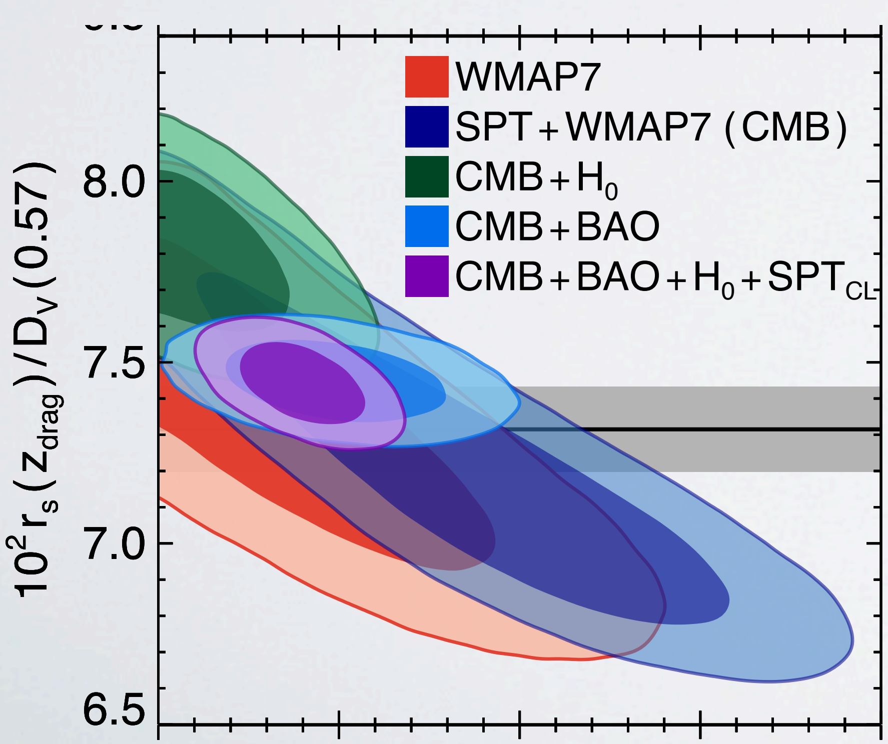


SPT measures CMB in the region or large l.

arXiv:1210: 7231

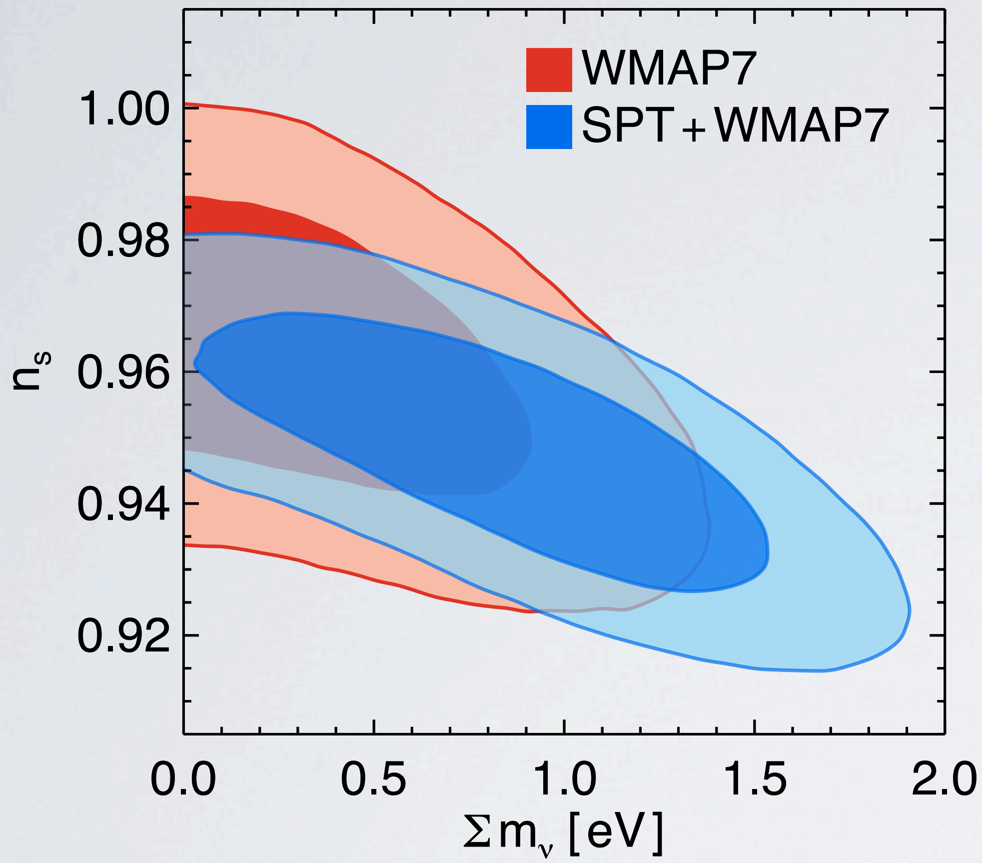
Adding SPT data

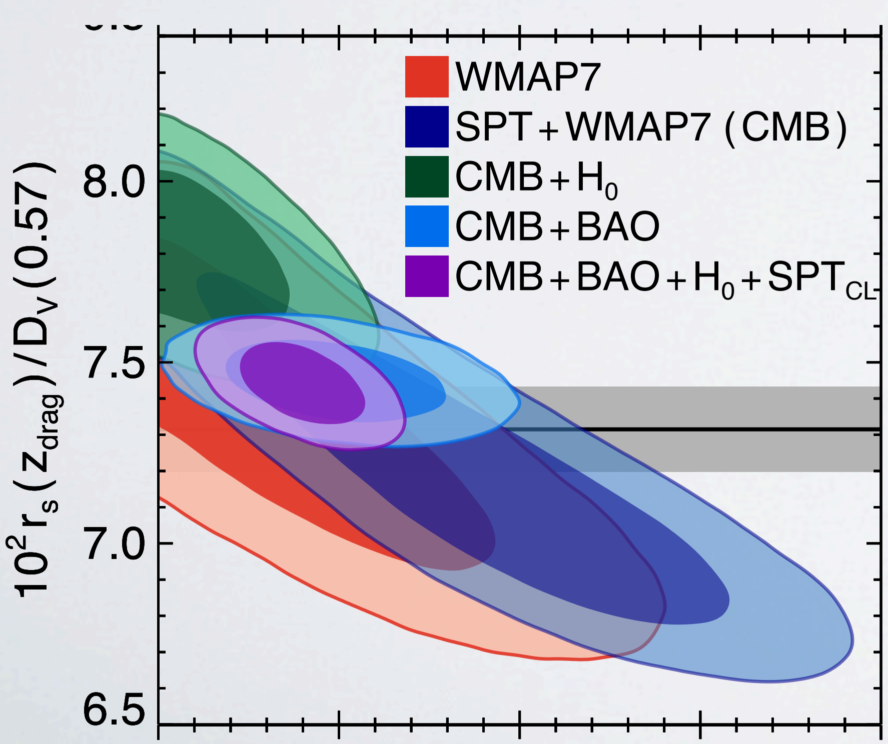




arXiv: 1212: 6267

Adding SPT data

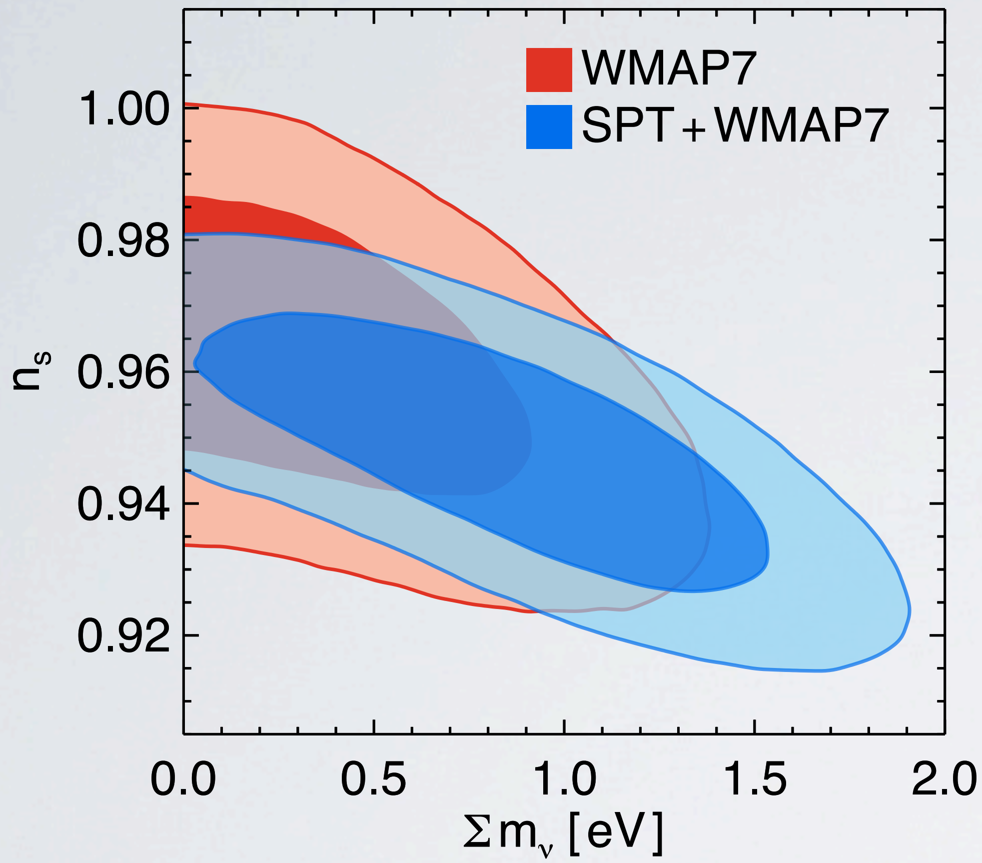




SPT alone prefers a lower value of ns relative to WMAP7, which causes the preferred value of ∑mν to increase when SPT data are combined with WMAP 7.

arXiv: 1212: 6267

Adding SPT data



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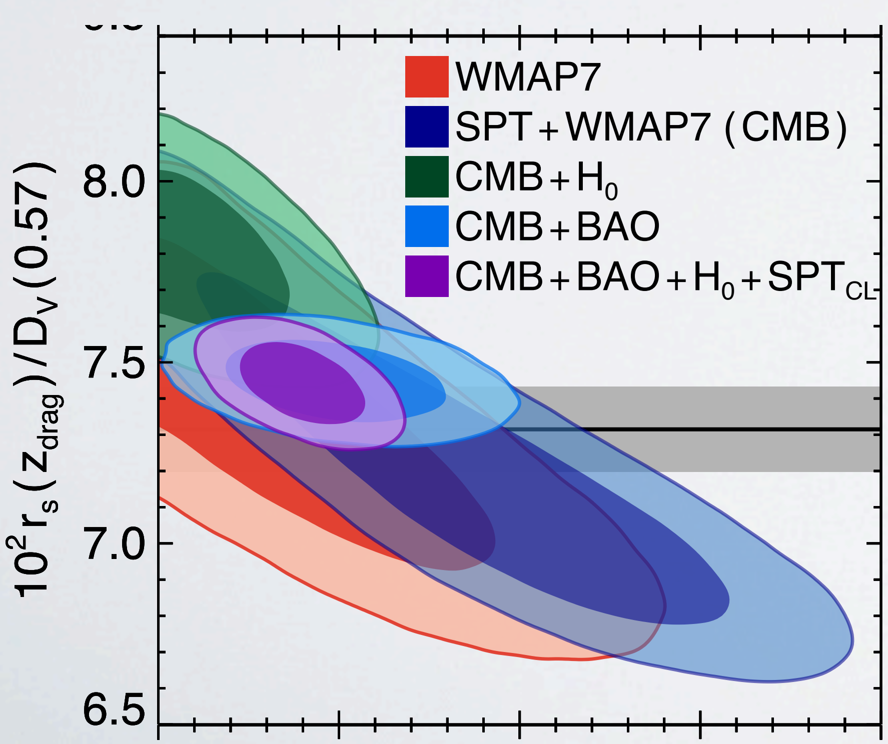
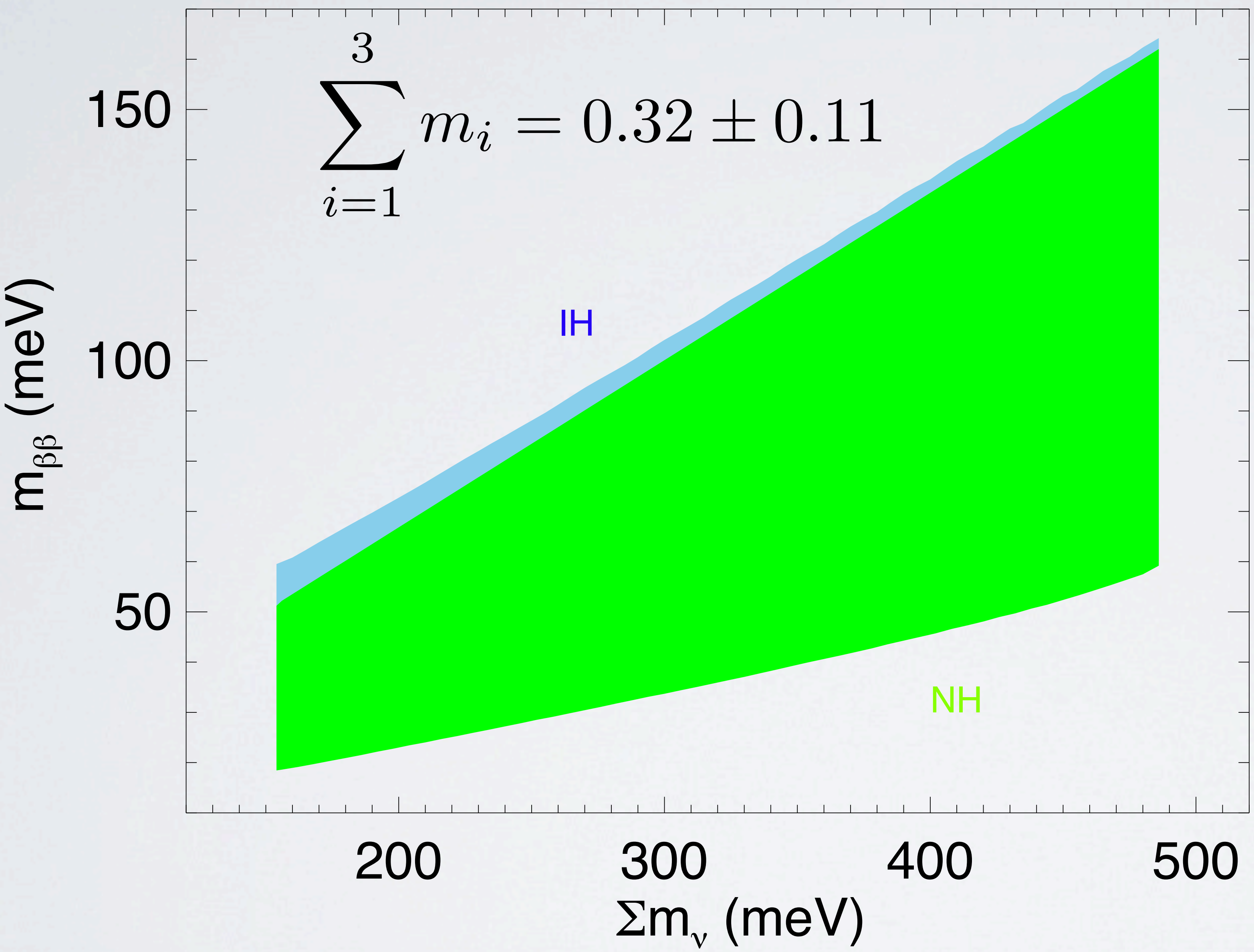


Low redshift data contribute to the constrains in ∑mν.

arXiv: 1212: 6267

Majorana landscape revisited



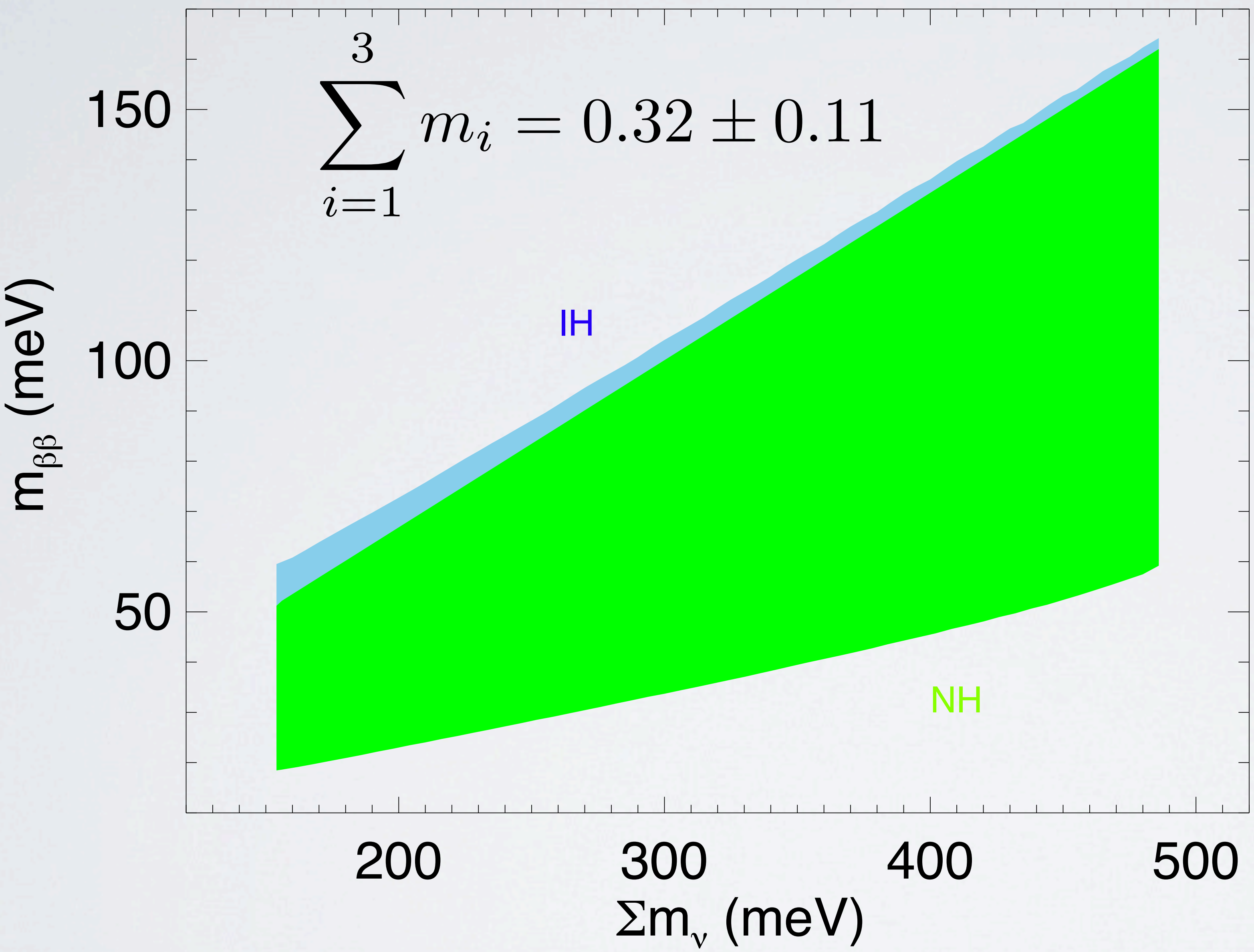
Normal hierarchy

$$26 \leq m_{\beta\beta} \leq 143$$

Inverted hierarchy

$$28 \leq m_{\beta\beta} \leq 145$$

Majorana landscape revisited



Normal hierarchy

$$26 \leq m_{\beta\beta} \leq 143$$

Inverted hierarchy

$$28 \leq m_{\beta\beta} \leq 145$$

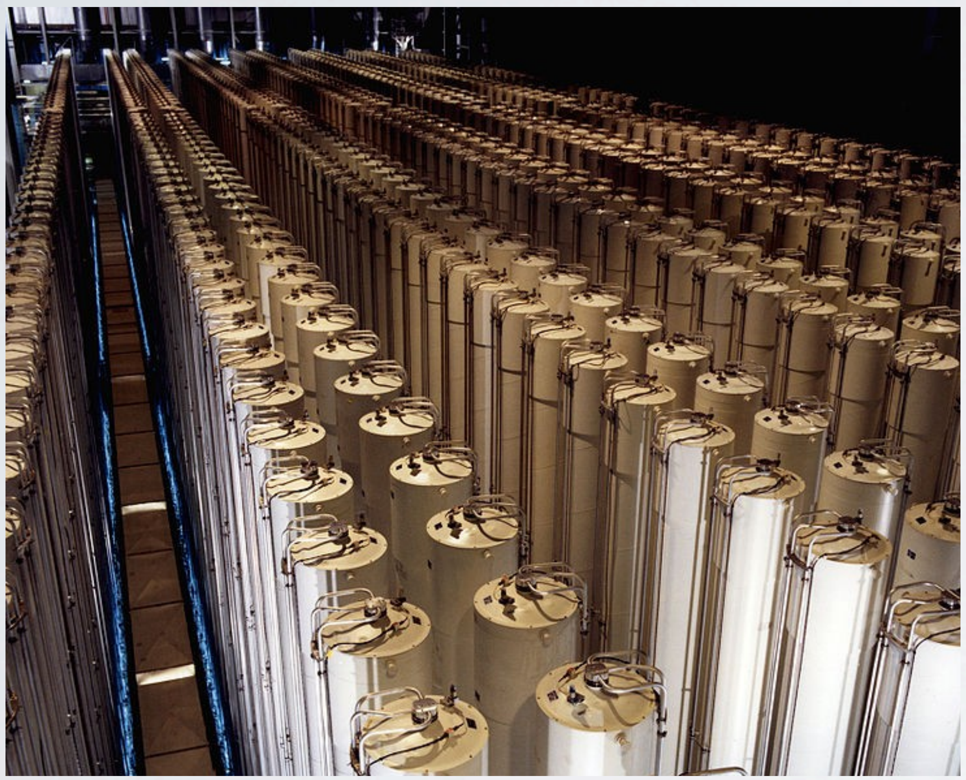
Cosmological measurement: very recent, to take cum grano salis. But it true, clear goal for ββ0ν experiments

Experimental challenges

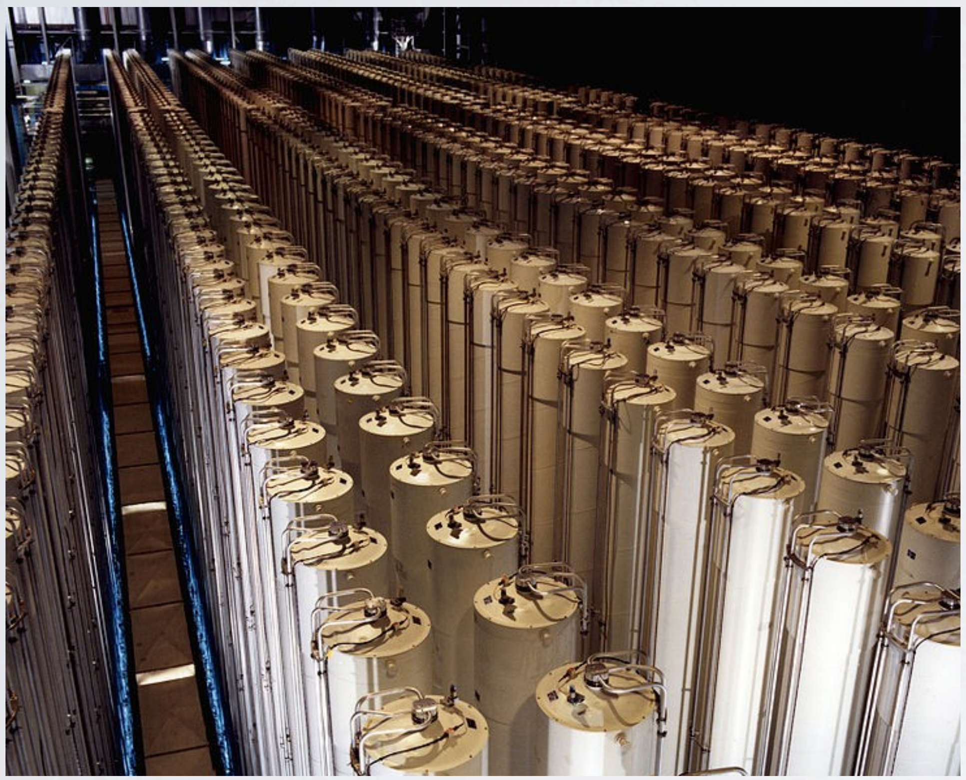
Building an ideal experiment

Photo by Nym Park

How to build your ββ0ν experiment

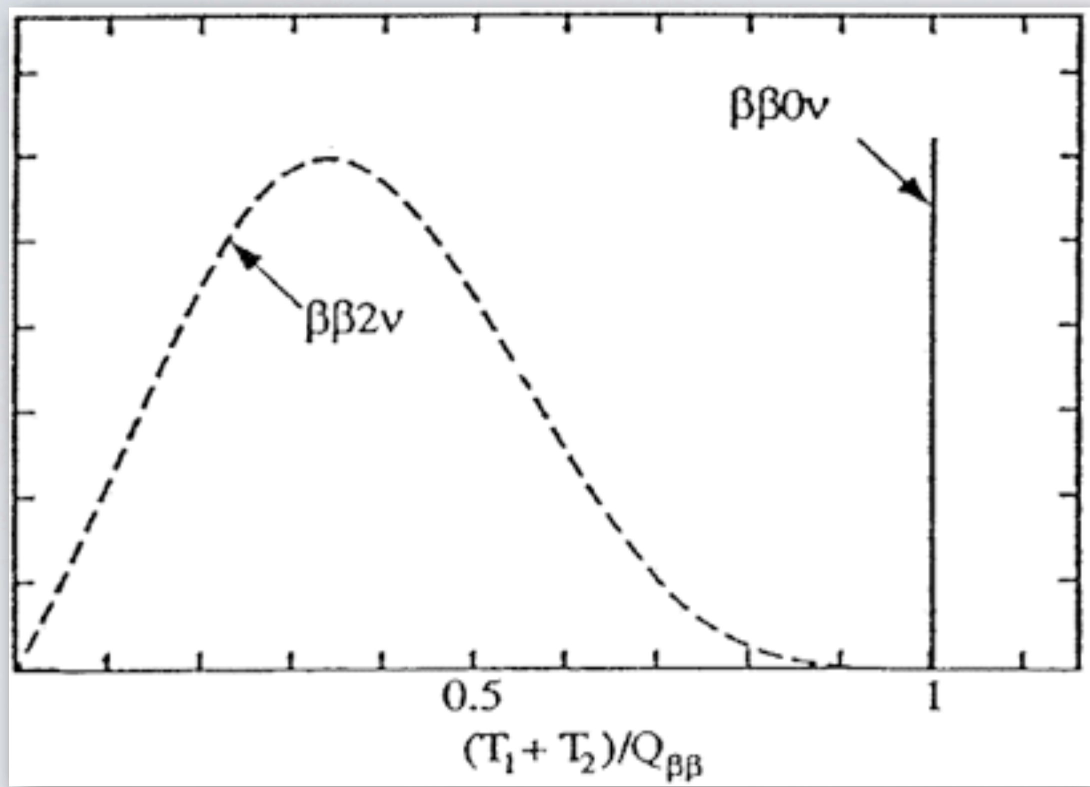


How to build your ββ0ν experiment



- Get a large mass of double beta decay source.
- Almost all isotopes must be enriched.
- Easiest and cheapest: Xe-136 from Xenon

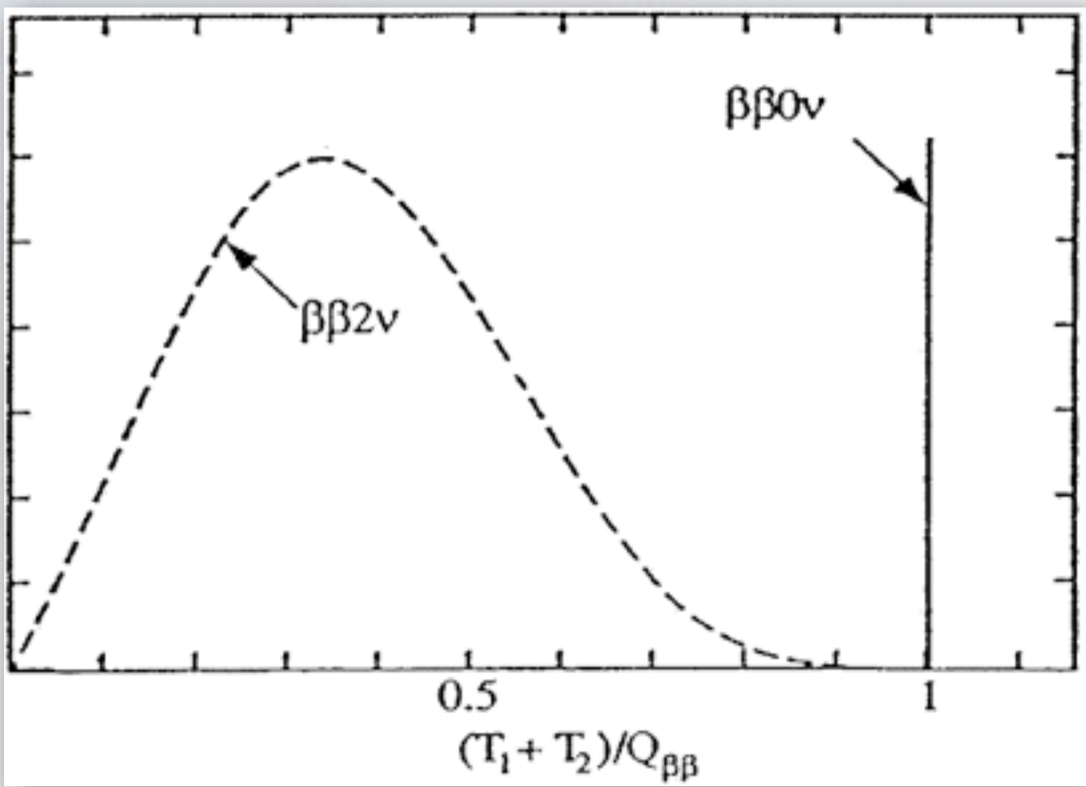
How to build your ββ0ν experiment



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

$$M = 100 \ kg, \ A = 136, \ T_{1/2} = 10^{26} y \ N_{\beta\beta} \sim 3$$

How to build your ββ0ν experiment

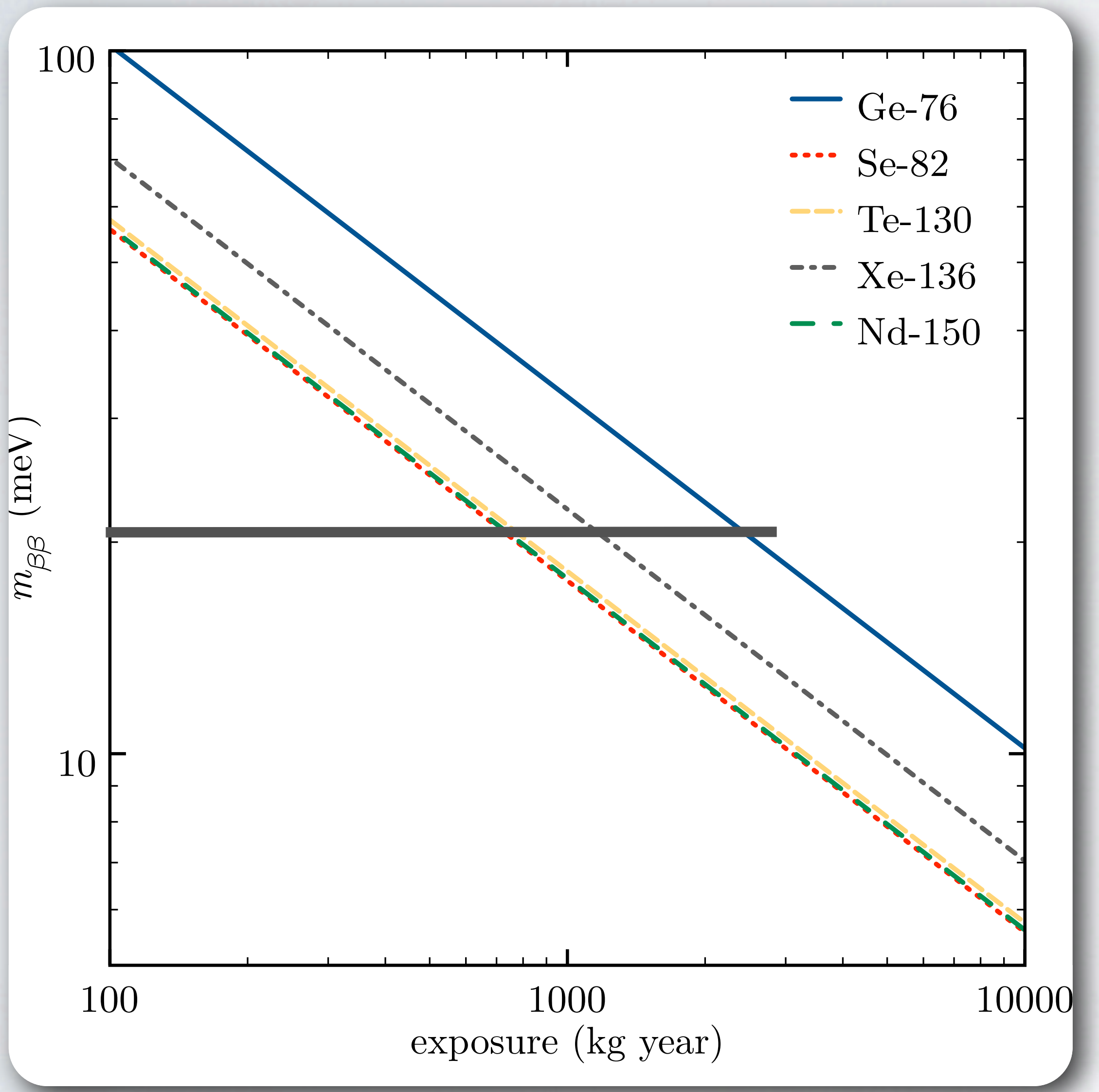


- Get yourself a detector with perfect energy resolution
- Measure the energy of the emitted electrons and select those with (T1+T2)/Qbb = 1
- Count the number of events and calculate the corresponding half-life.
- In Xe-136, a perfect detector of 100 kg observes 3 events for a lifetime of 10^{26} y.

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

$$M = 100 \; kg, \; A = 136, \; T_{1/2} = 10^{26} y \; N_{\beta\beta} \sim 3$$

How to build your ββ0ν experiment



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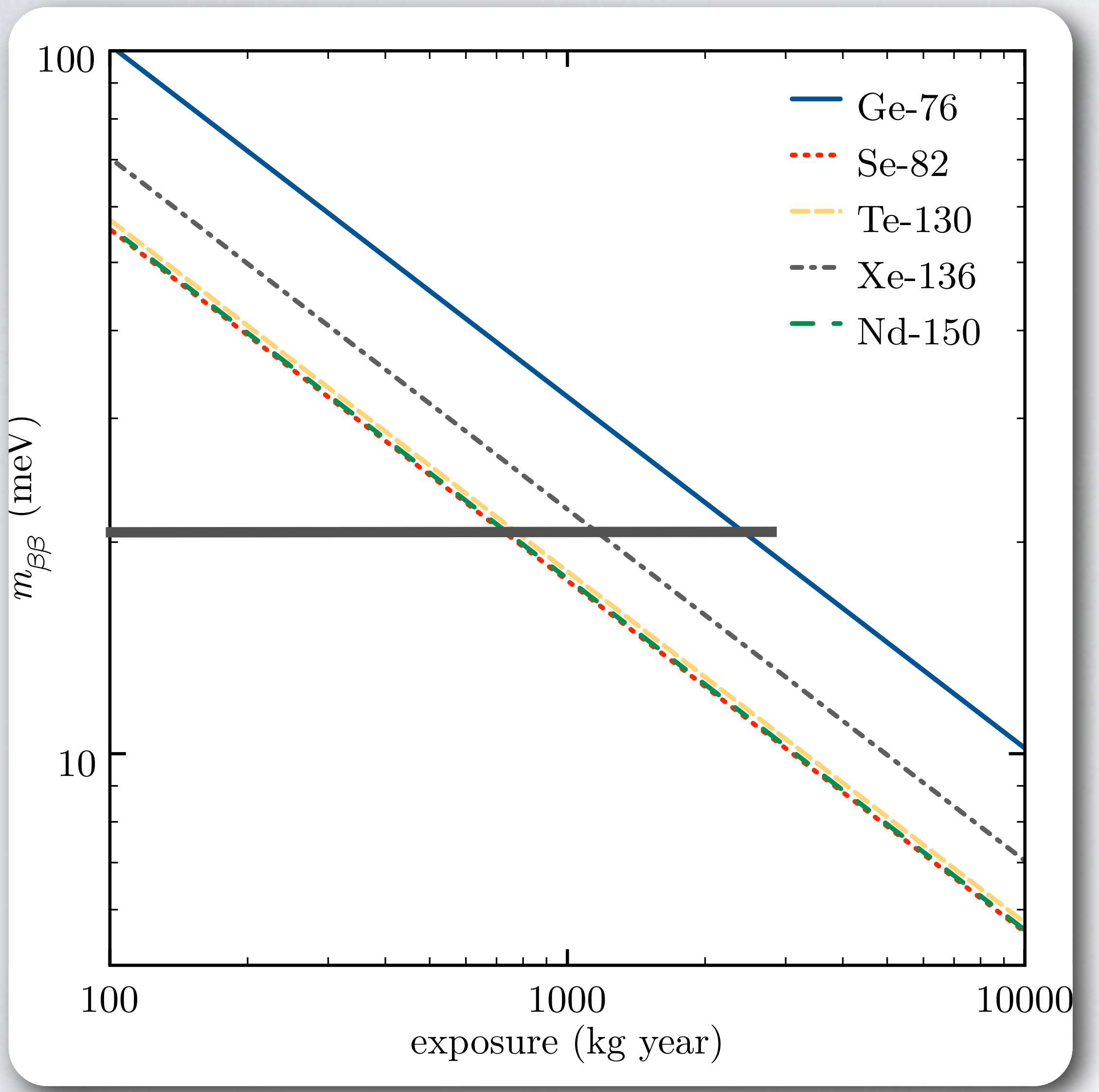

- Compute mββ from $T^{0\nu}$
- In the absence of background improvement in period is proportional to the exposure (Mt) but improvement in mββ goes with the square root of exposure.

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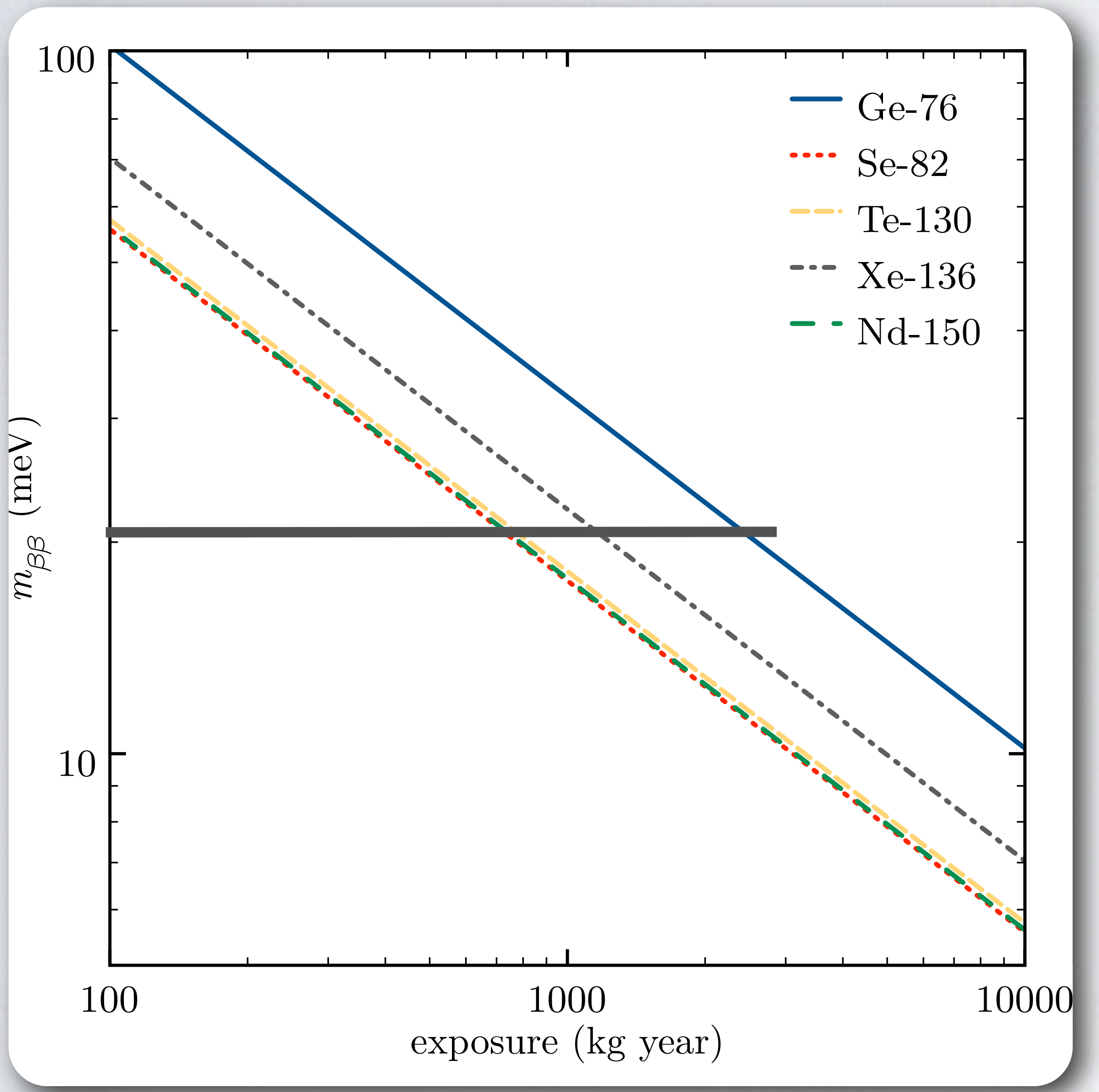

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ m^2_{\beta\beta}$$

- Compute mββ from $T^{0\nu}$
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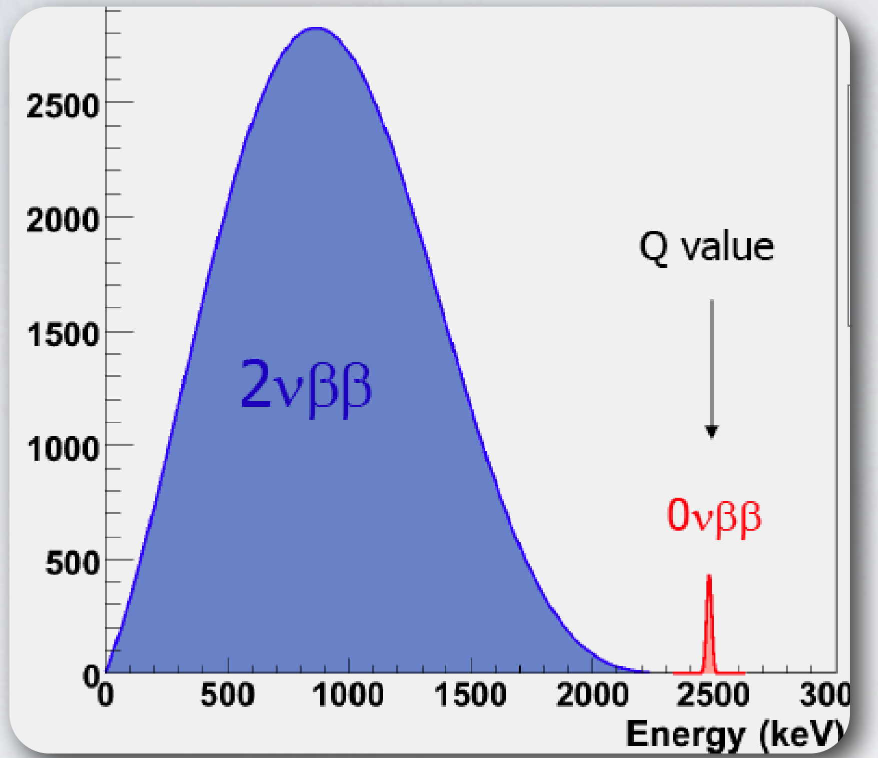
Recipes for real bb0nu experiments

Energy resolution

Why Energy resolution?



- Even in the absence of other backgrounds, must separate ββ2ν from ββ0ν

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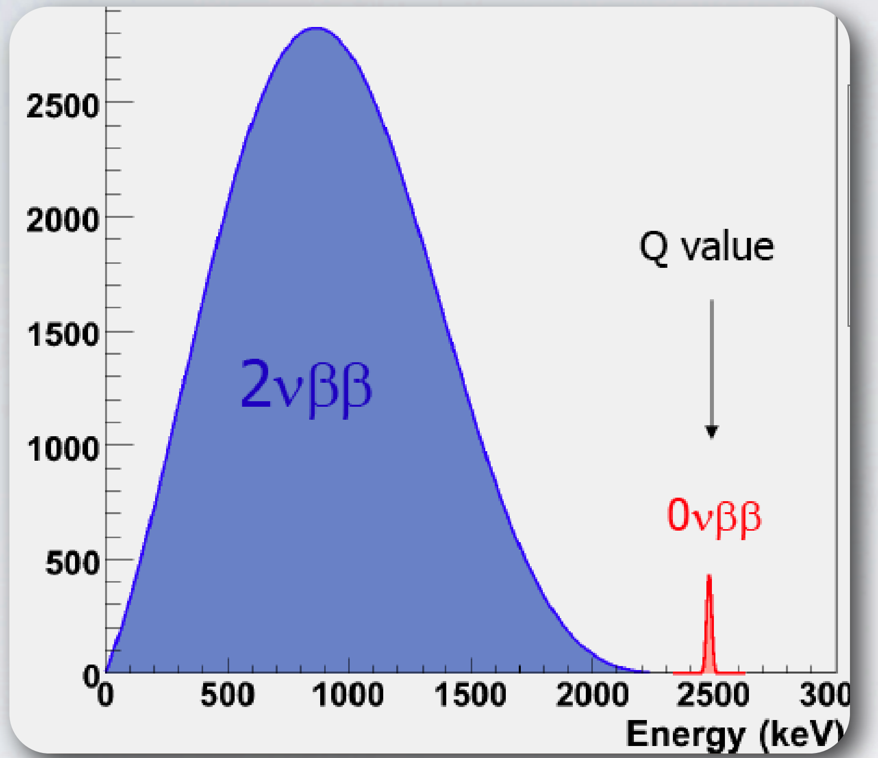

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- As the energy resolution worsens this becomes more difficult and limits, eventually the sensitivity.

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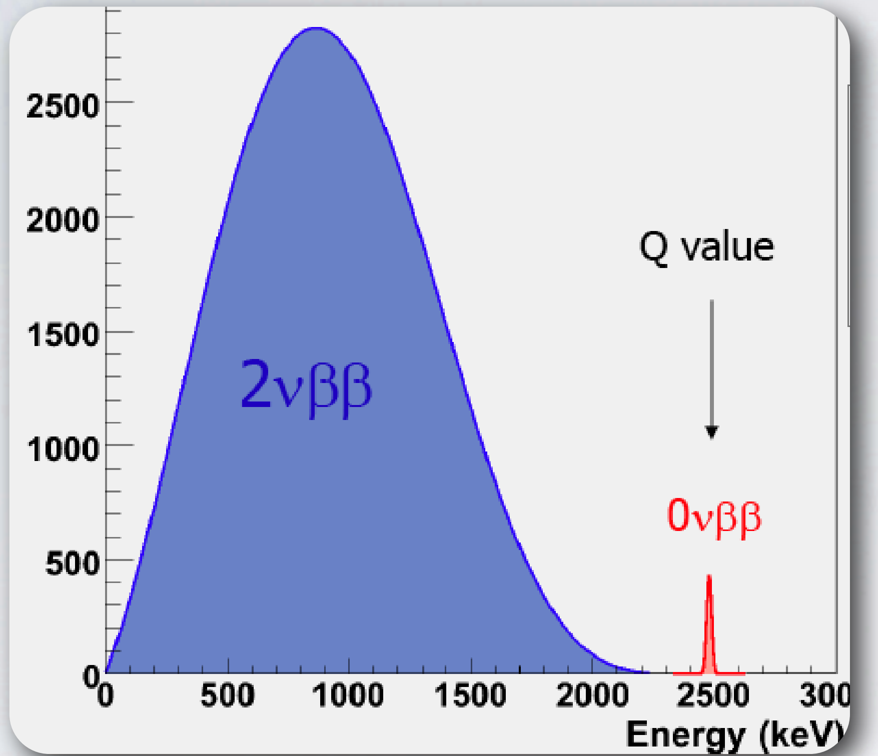

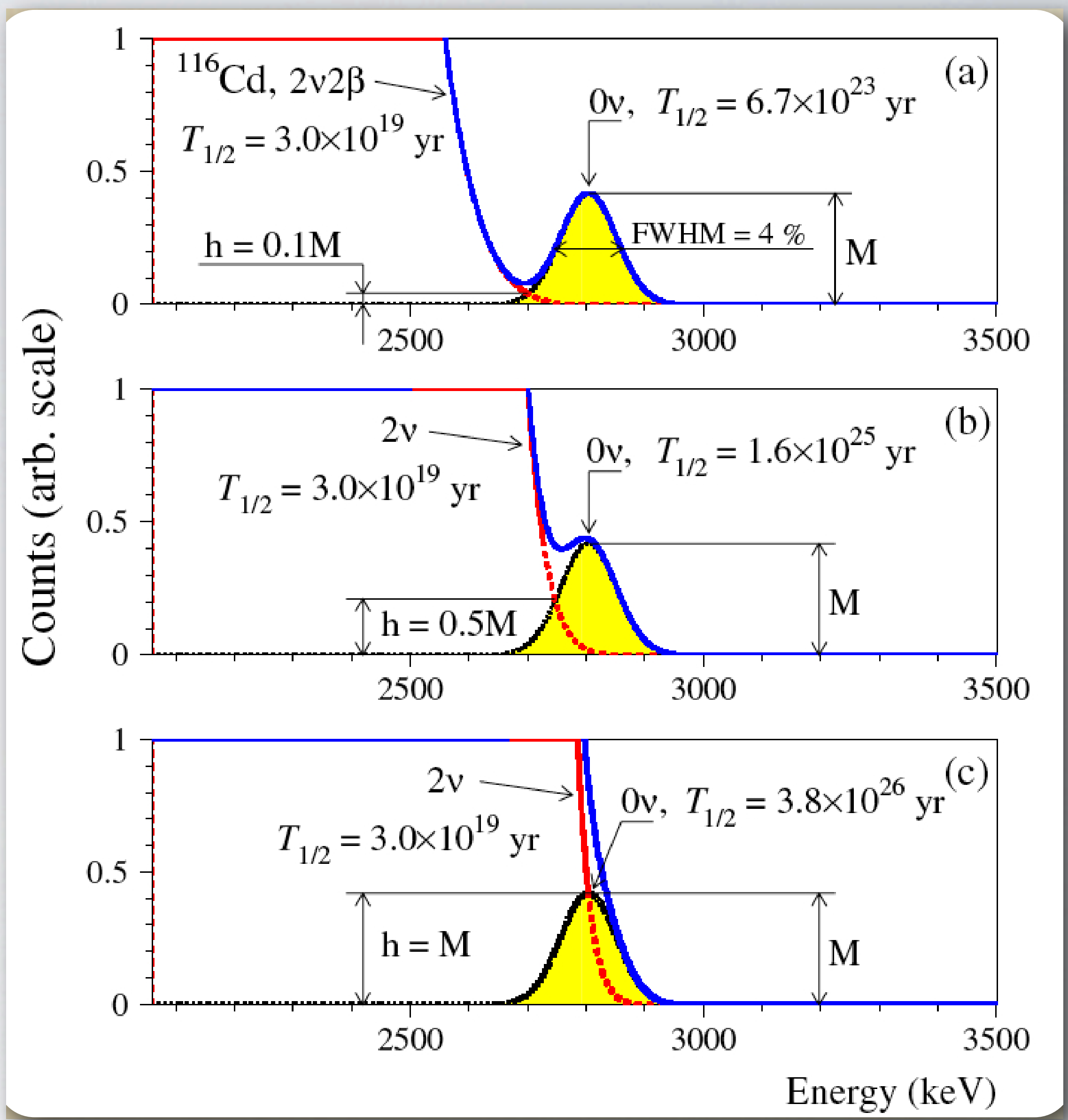

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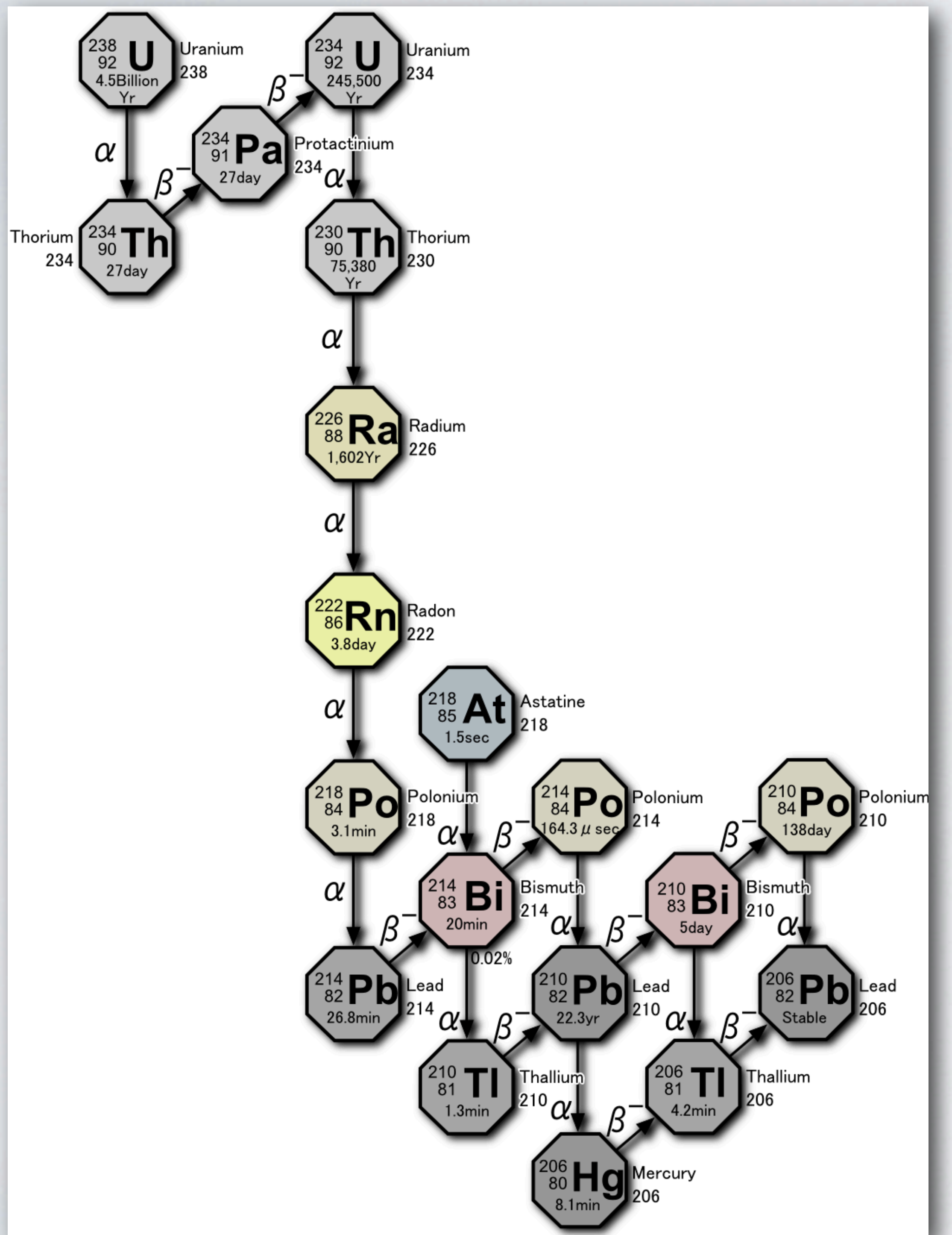

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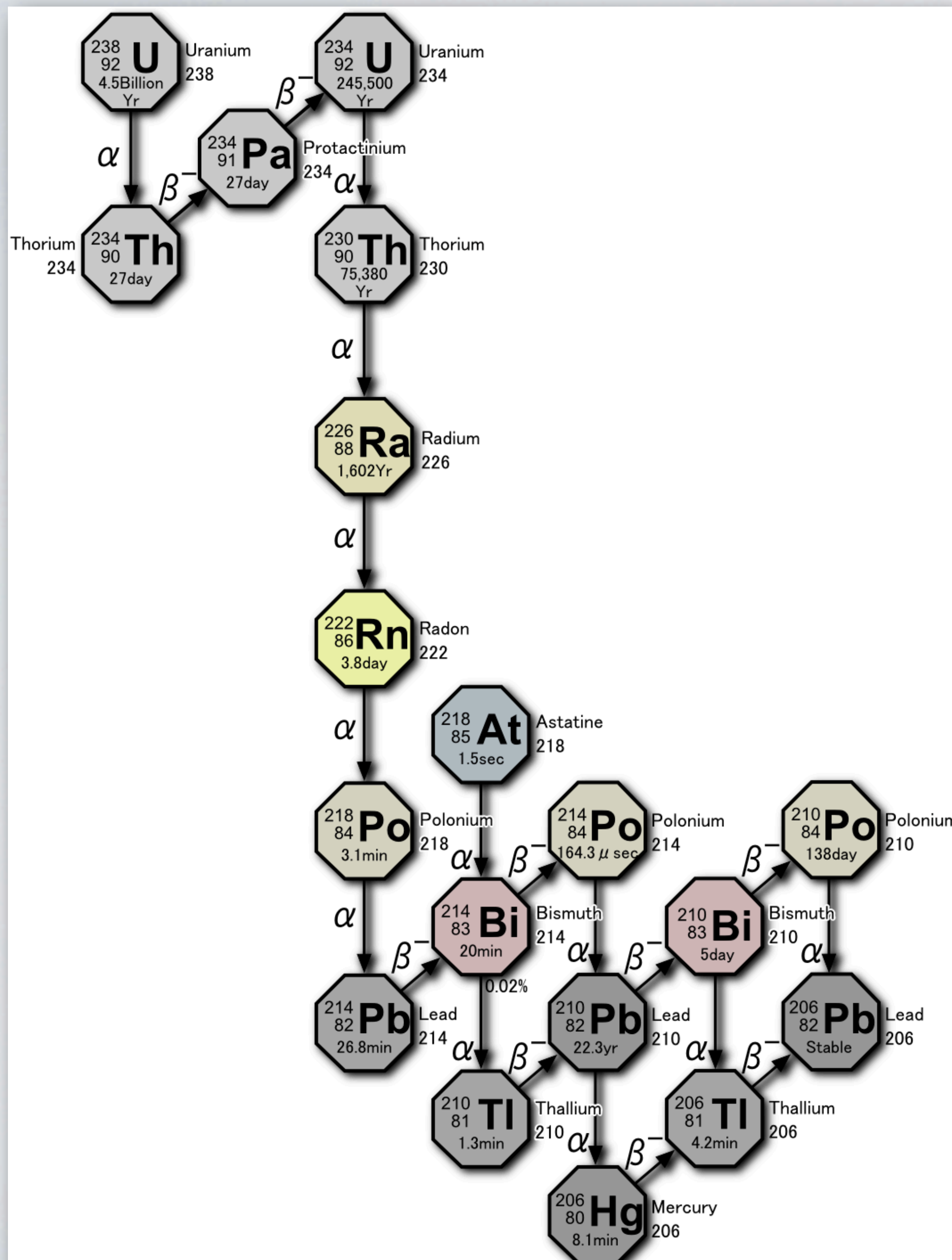
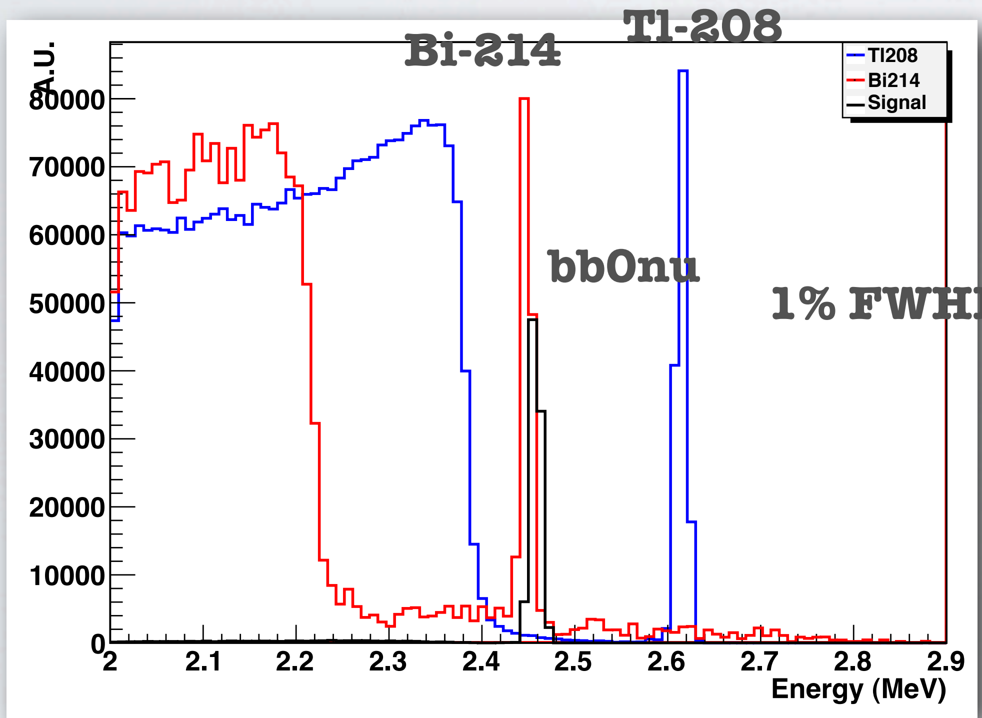
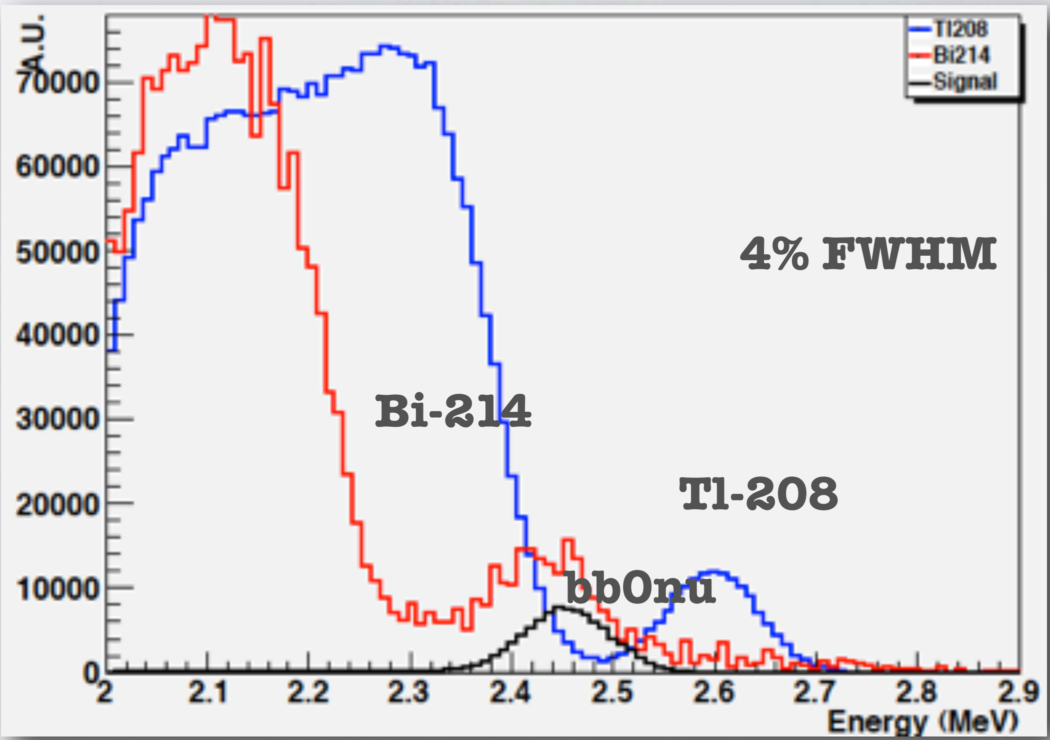


- But ββ2ν is the least of our problems!
- Earth is a very radioactive planet. There are about 3 grams o U-238 and 9 grams of Th-232 per ton of rock around us.
- This is an intrinsic activity of the order of 60 Bq/kg of U-238 and 90 Bq/kg of Th-232.
- The lifetime of U-238 is of the order of 10^9 y and that of Th-232 10^{10} y. We want to explore lifetimes of bb0nu of the order of 10^{26} y.

Why Energy resolution?

- 10^{16}: number of sand grains (1mm diameter) in a beach 1 km long, 1km wide, 10 m deep.





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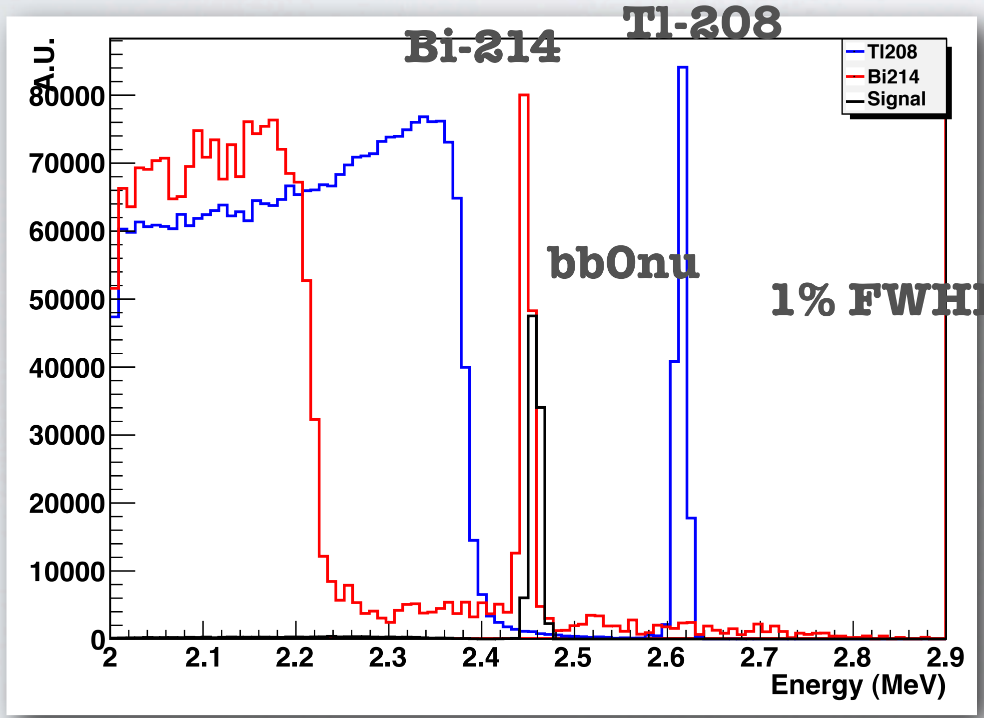

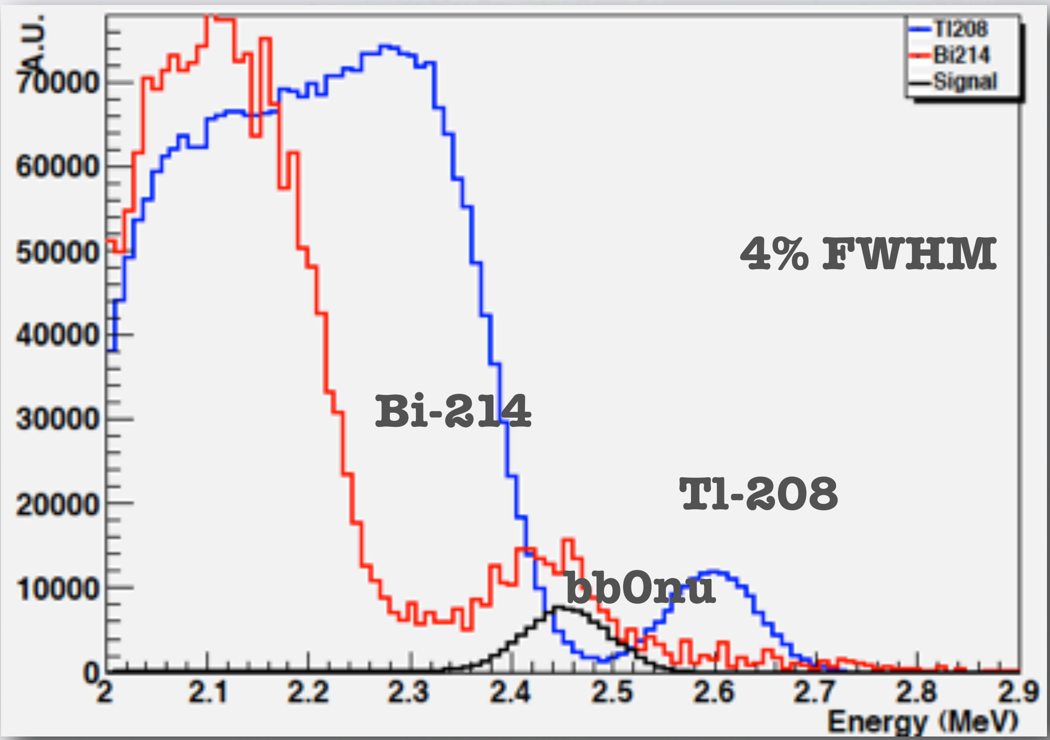

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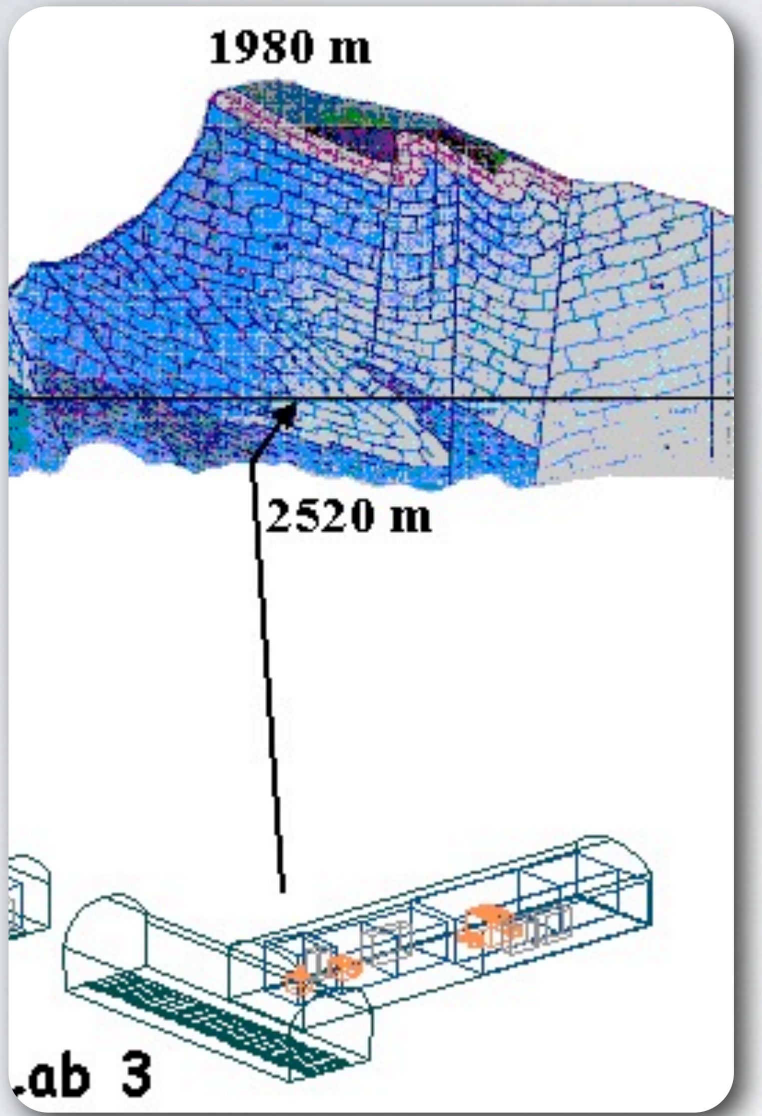
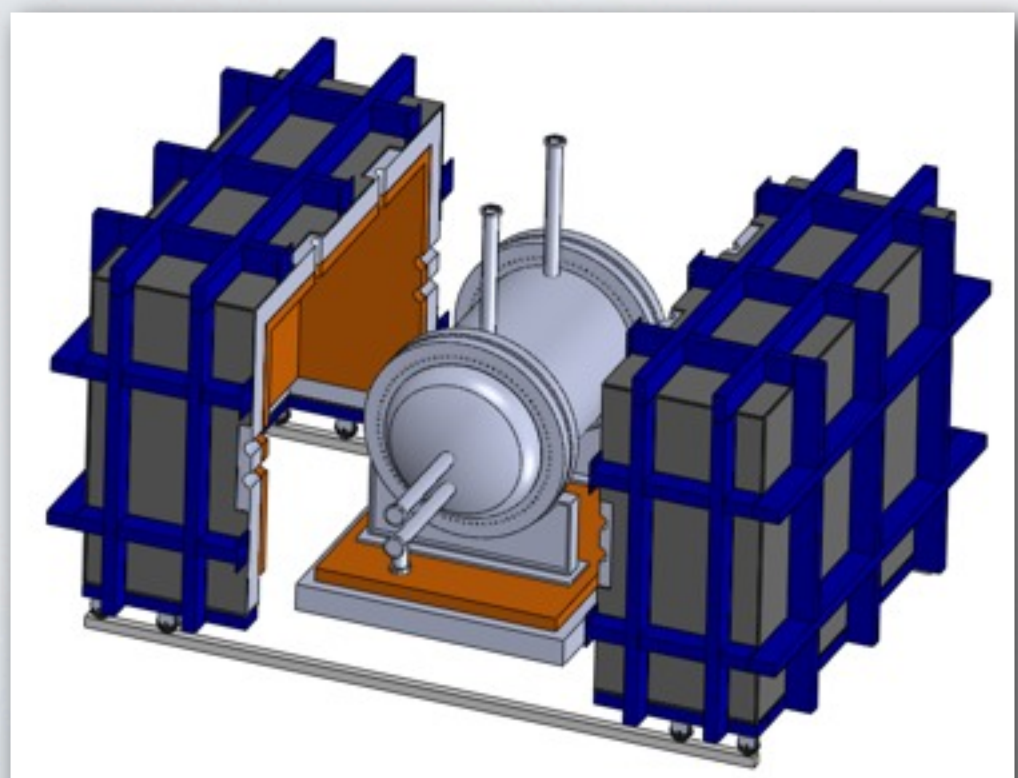
Other recipes

Shielding



- Underground laboratory to reduce cosmic background (muons, cosmogenic activation, etc.)

Matrioska structure



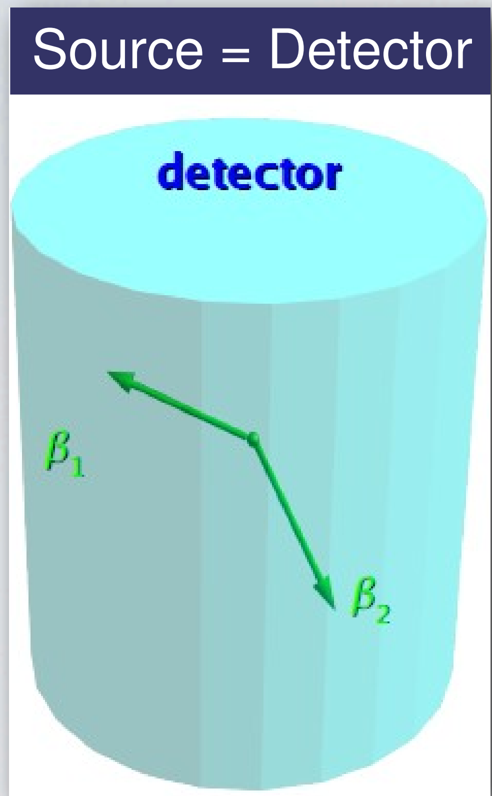
- Lab walls shoot us 10^3 gammas of high energy (direct background) per square meter or about 5,000 gammas into the detector.
- Stop them with a wall of 30 cm of radiopure lead (300 muBq/kg)
- Stop the gammas from the lead with ultra-radiopure copper inside the vessel (10 mqBq/kg)

Radio purity

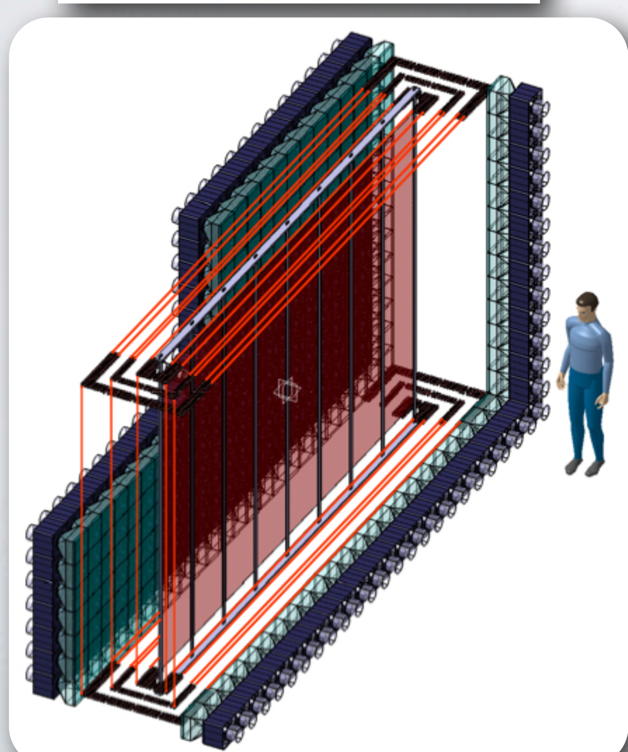
- Build everything out of extremely radiopure materials.
- Typical activities in detector material in the range of muBq/kg.
- We are way more radioactive than that (K-40 in our bones)

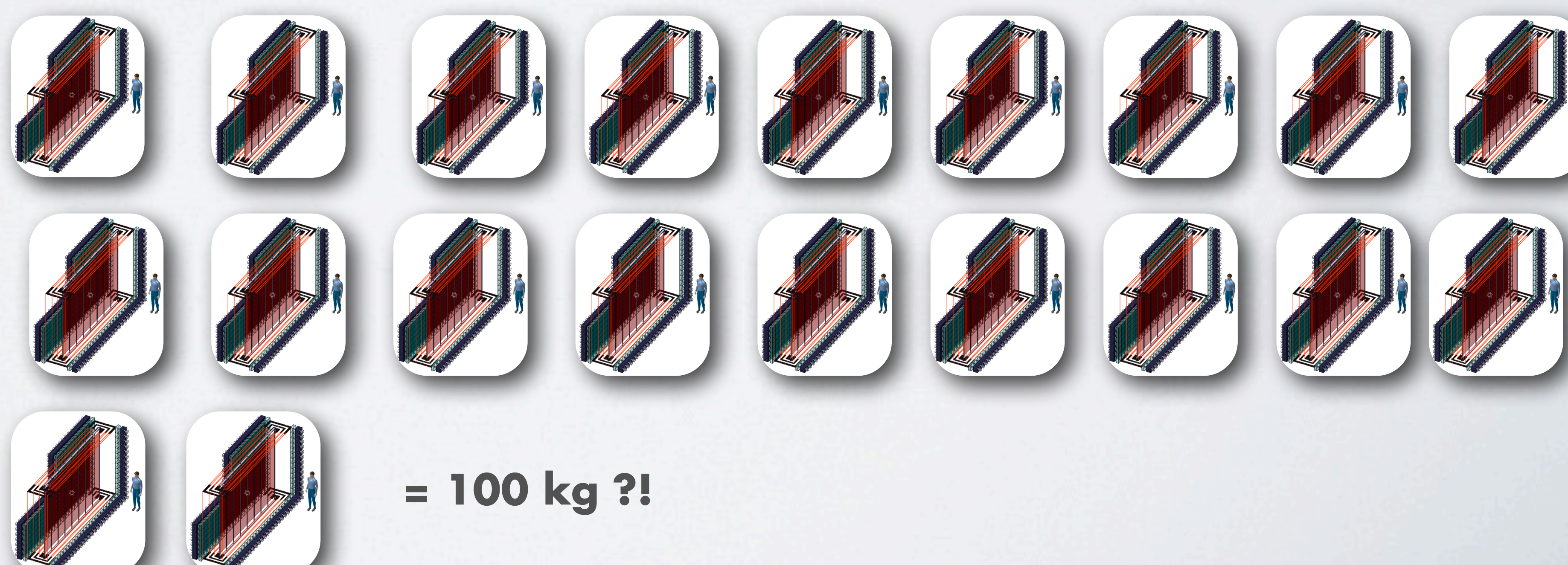
Everything is radioactive unless proven otherwise by screening.

Scalability

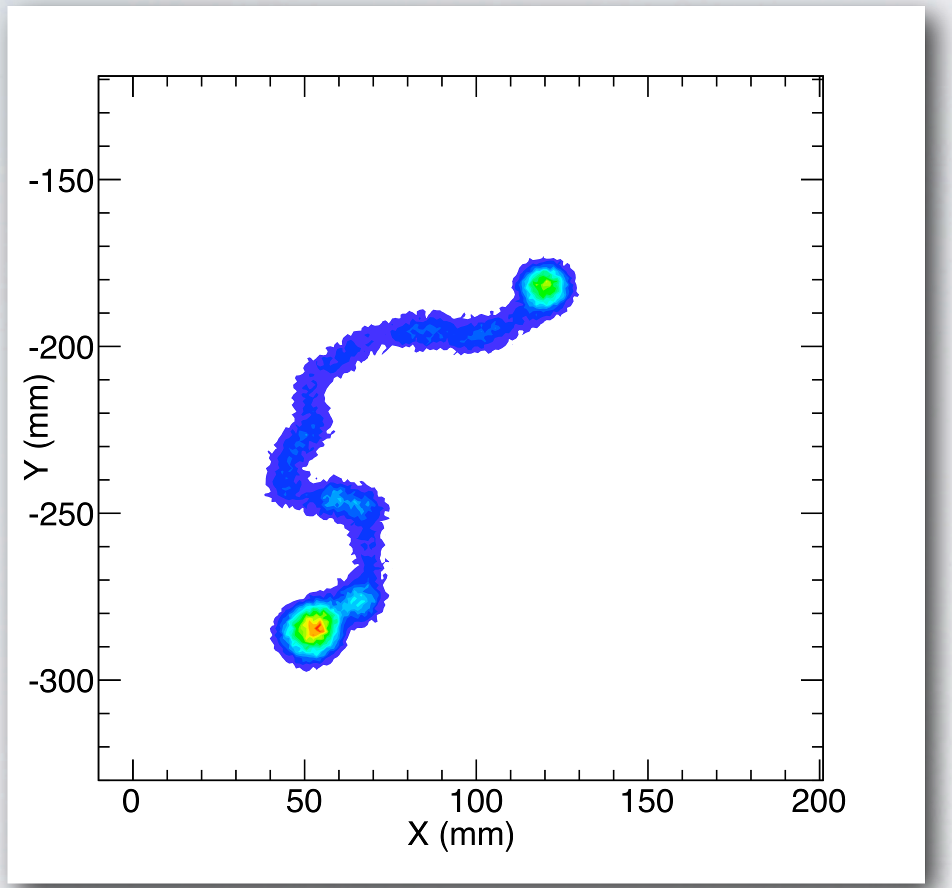


- Source must be equal to detector (dead fiducial law)
- Scale going to larger volume rather than replicating modules





Extra handles



TOPOLOGICAL signature of two electrons in a HPGXe (NEXT)

The experiment Rubik's cube

The experiment Rubik's cube

The experiment Rubik's cube

radio-purity

scalability (mass, cost)

control of background

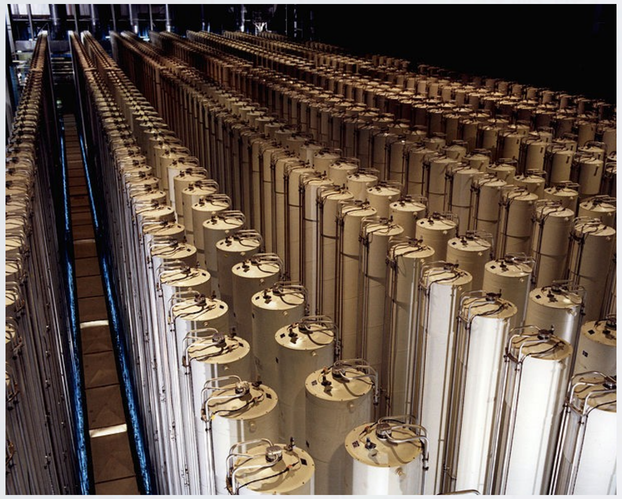
Resolution

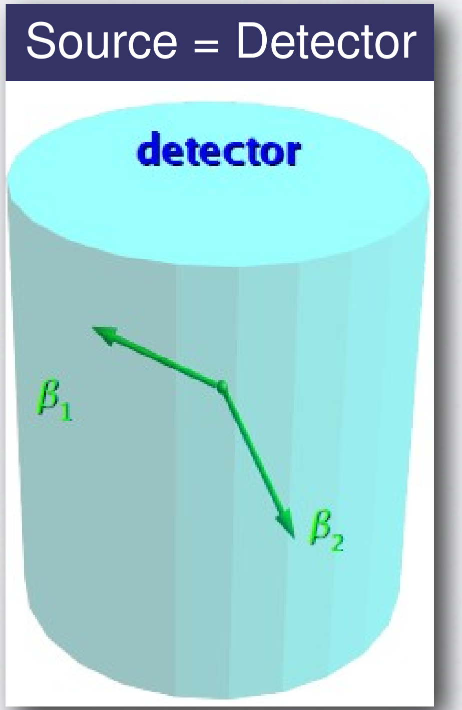
Volume/Surface

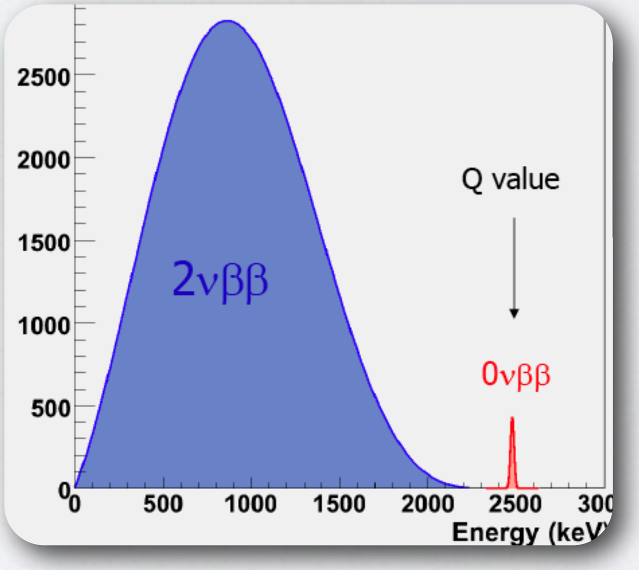
extra handles

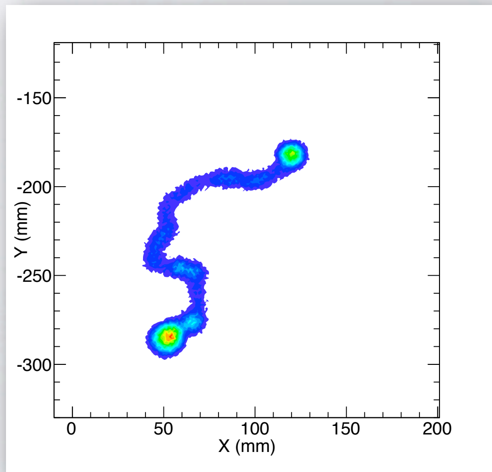
Figure of merit

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$









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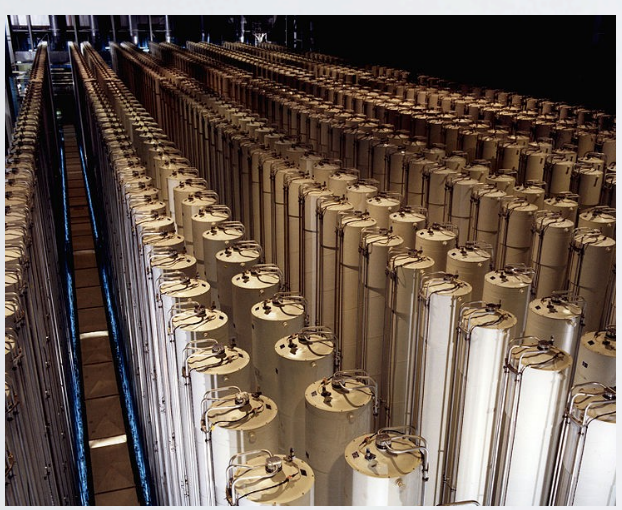

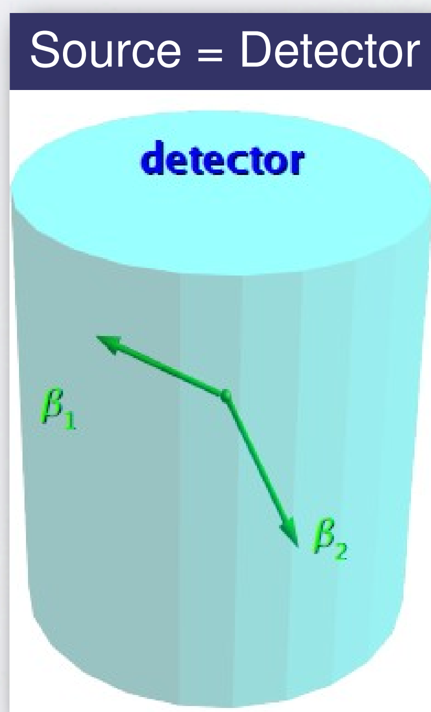

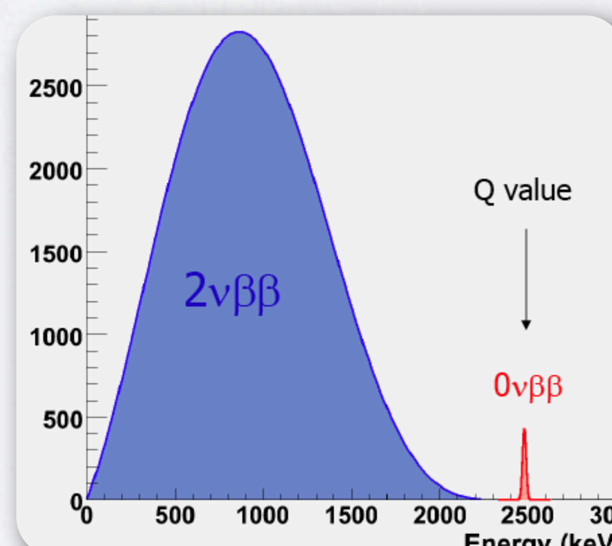

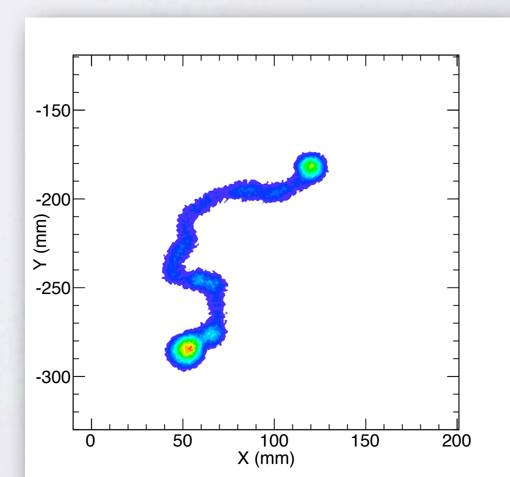

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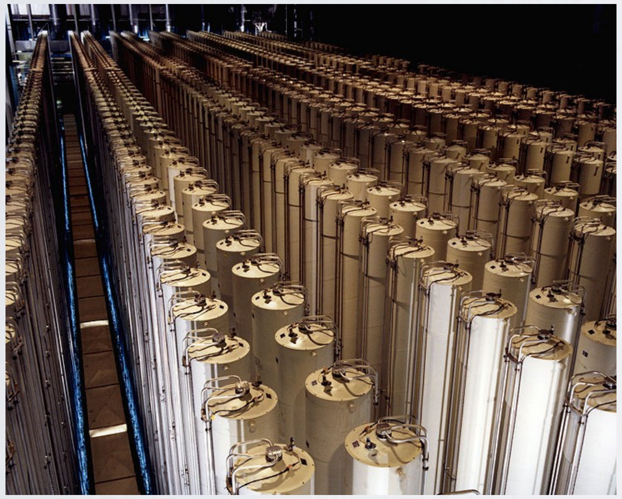

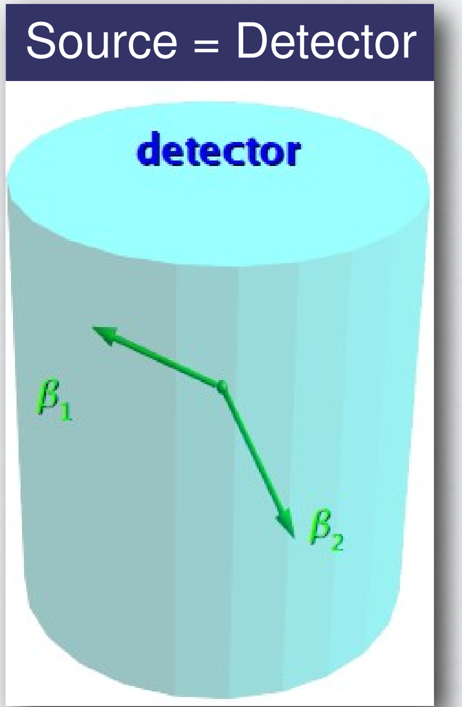

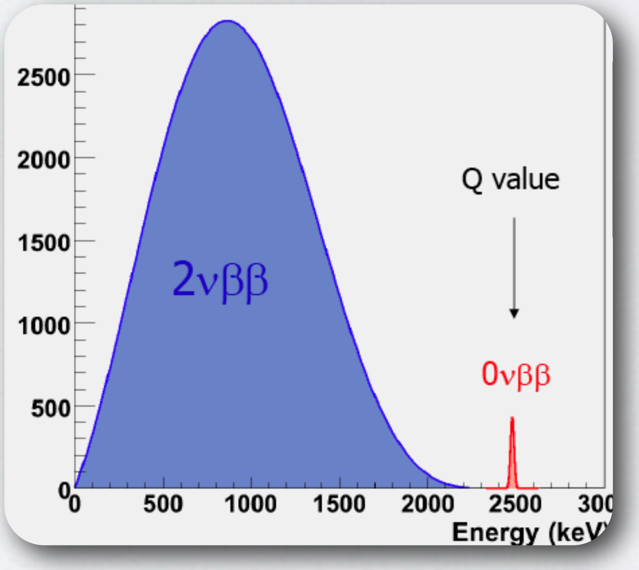

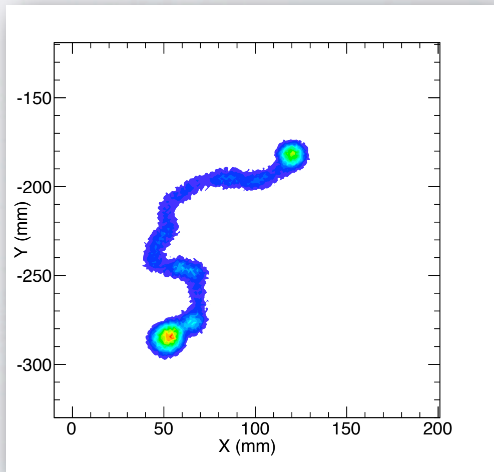

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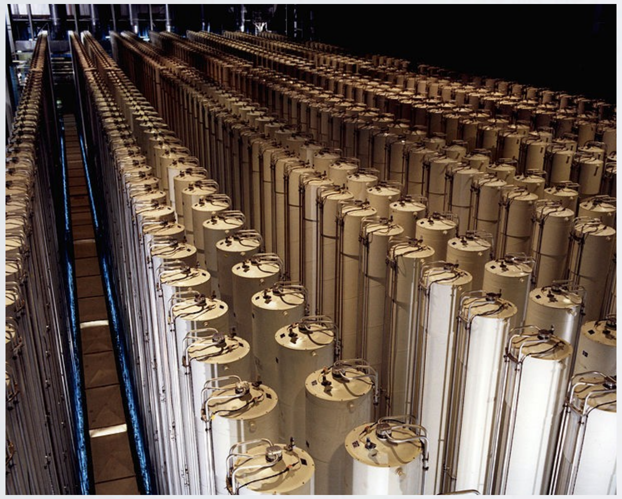

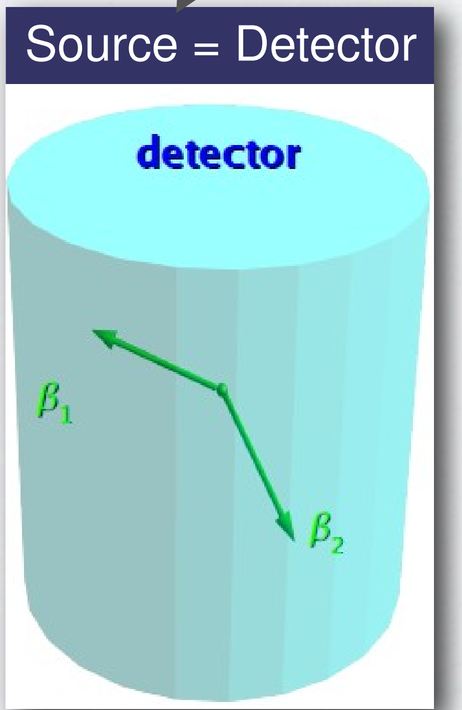

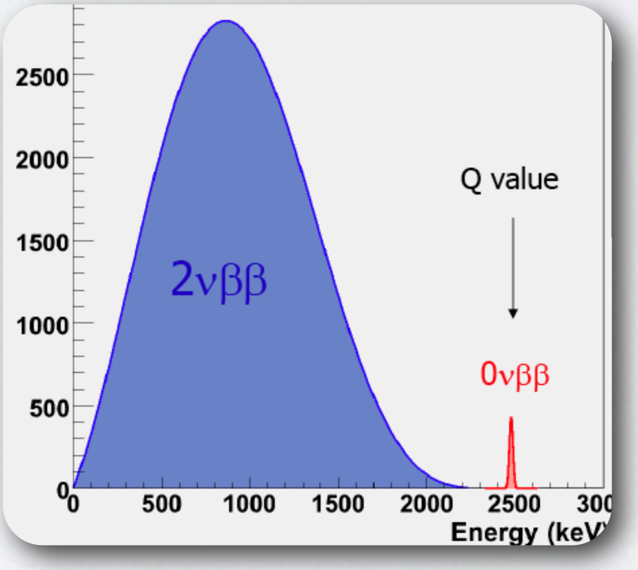

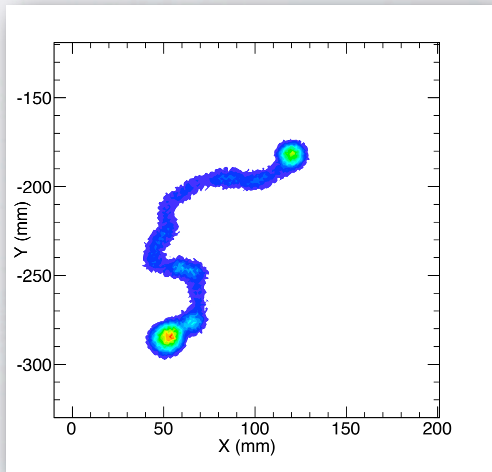

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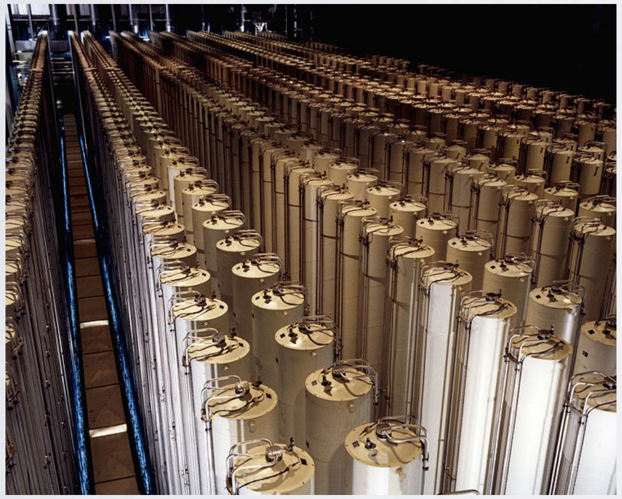

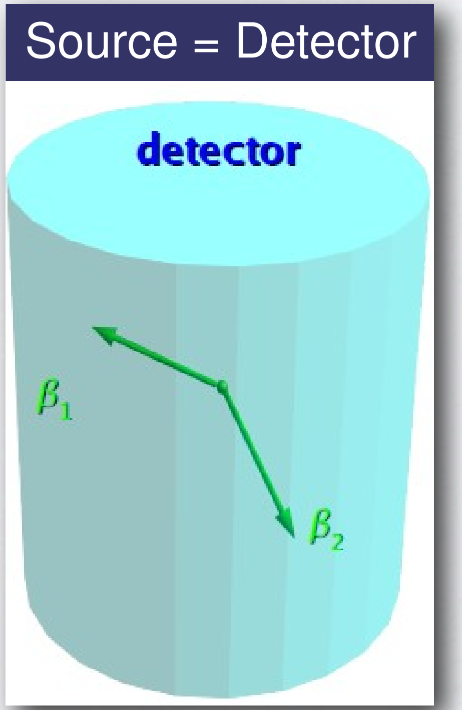

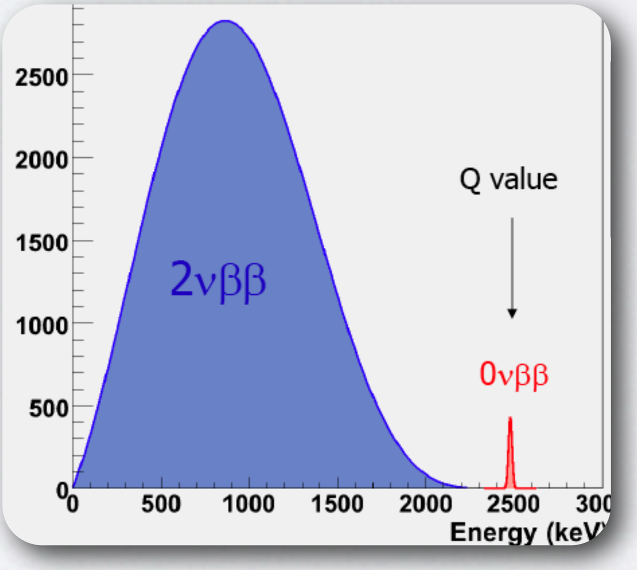

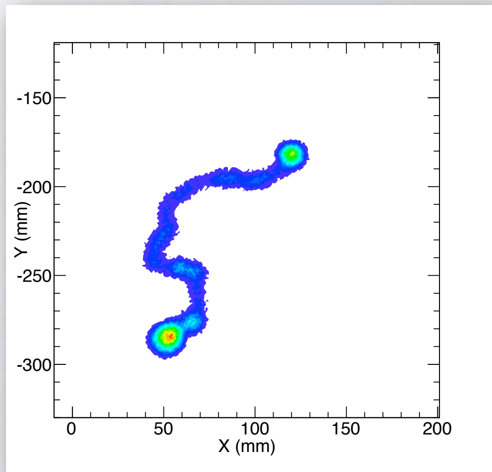

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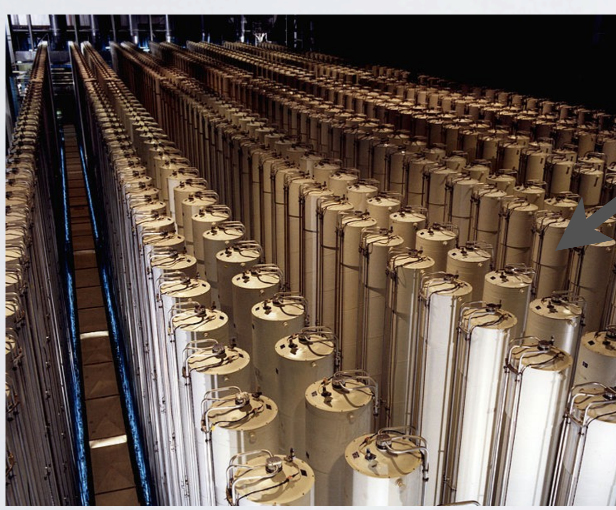

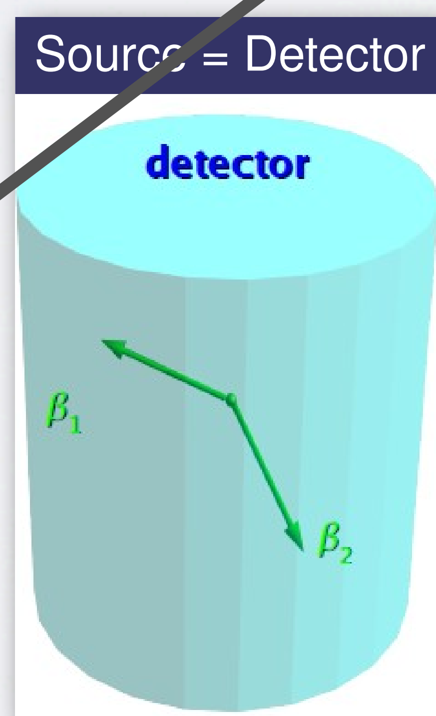

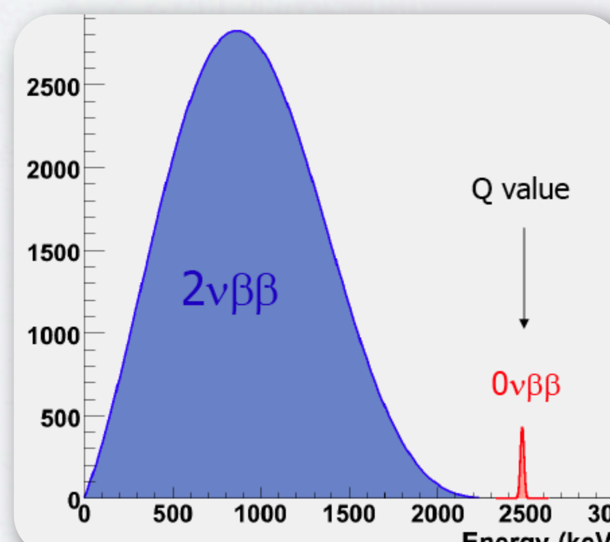

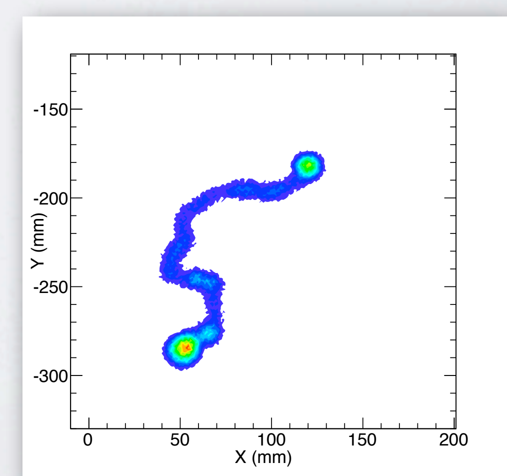

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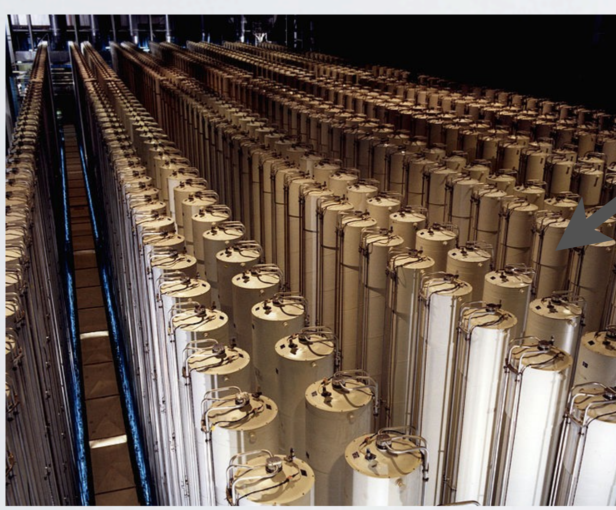

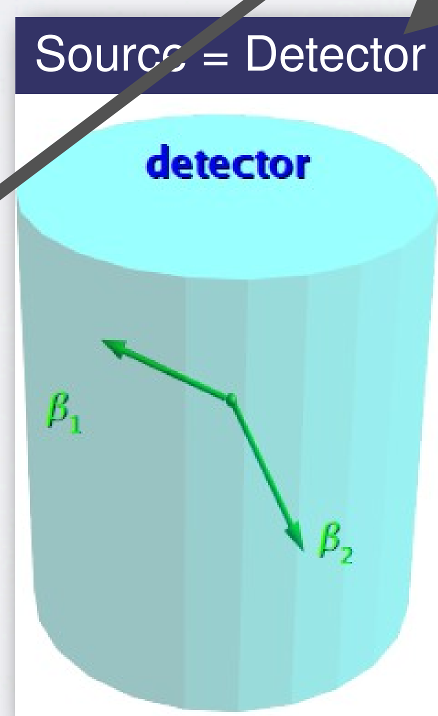

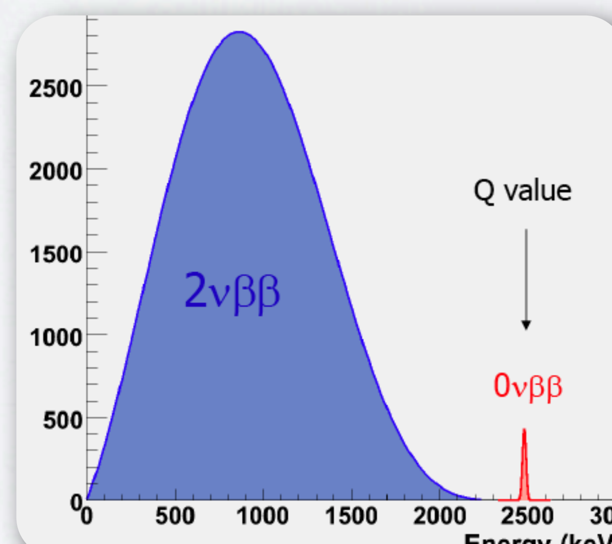

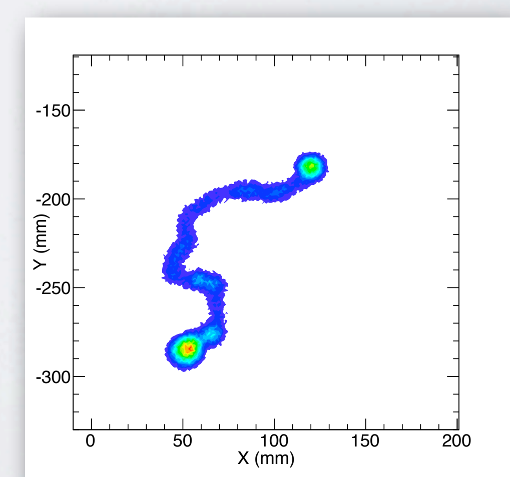

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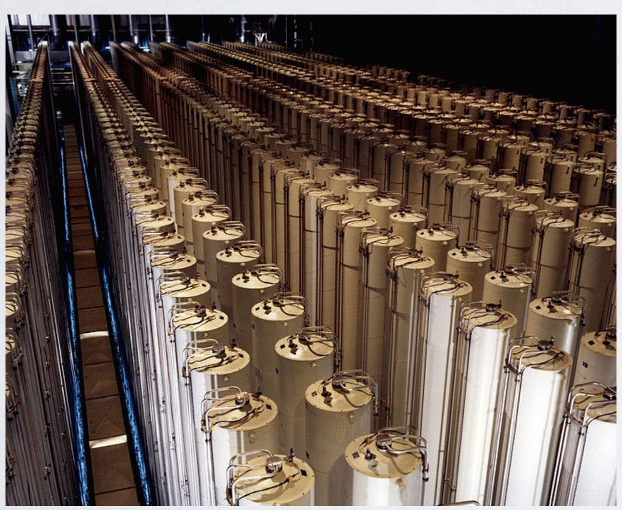

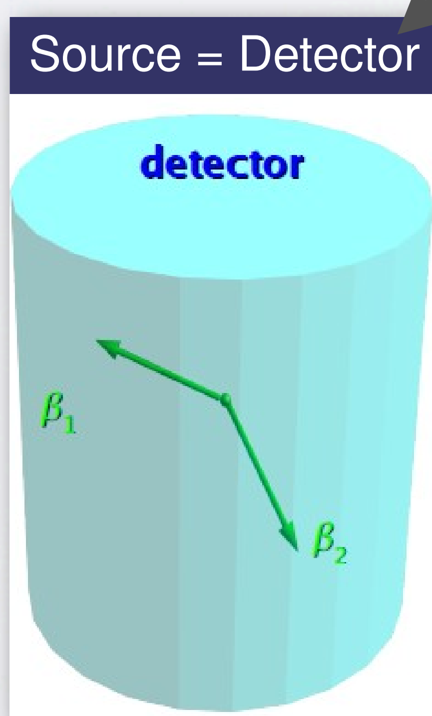

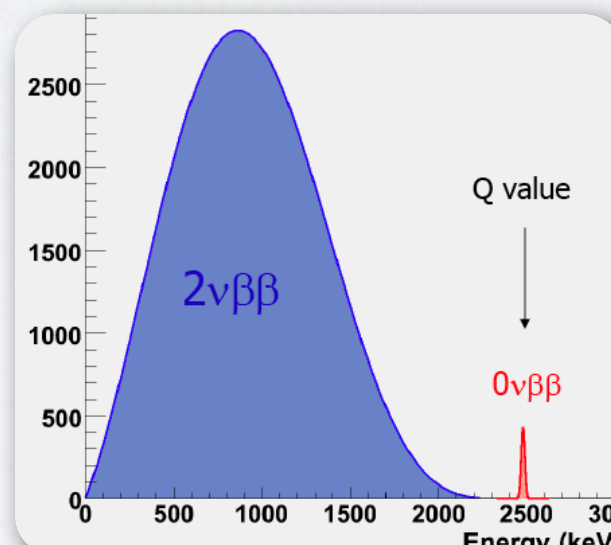

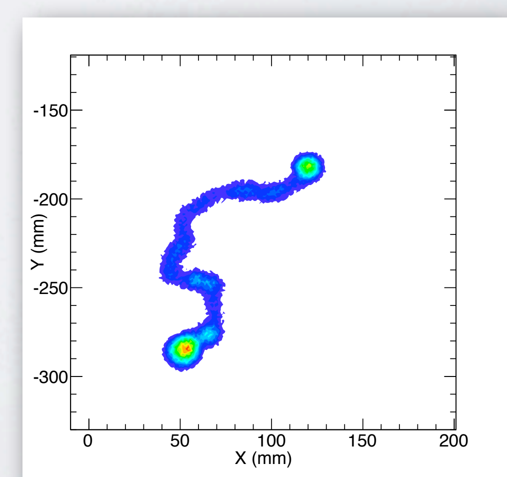

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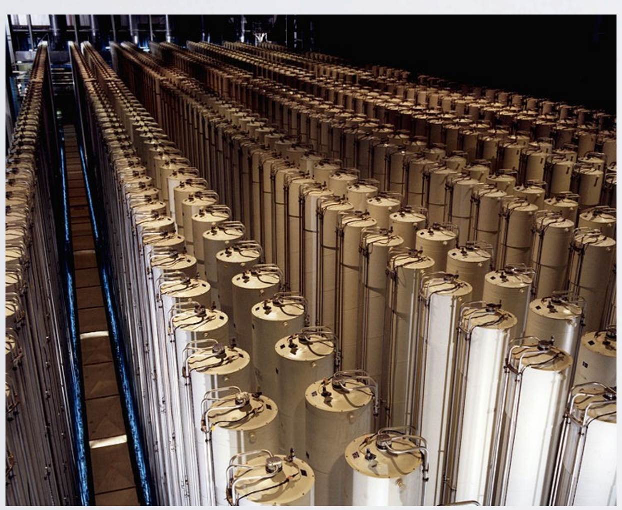

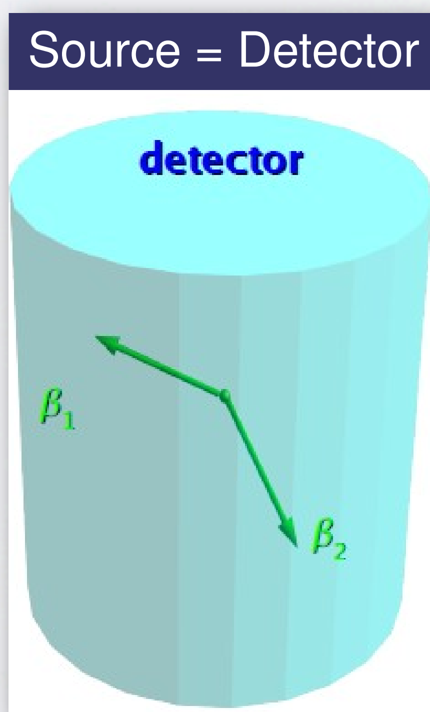

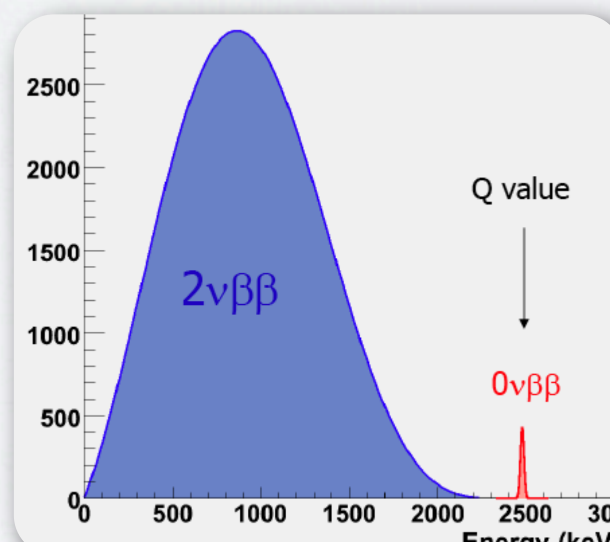

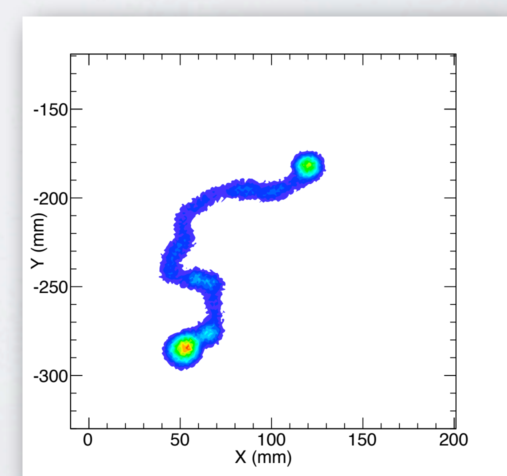

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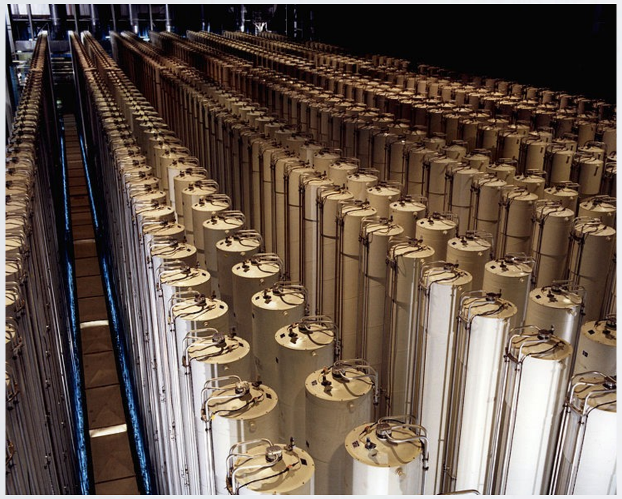

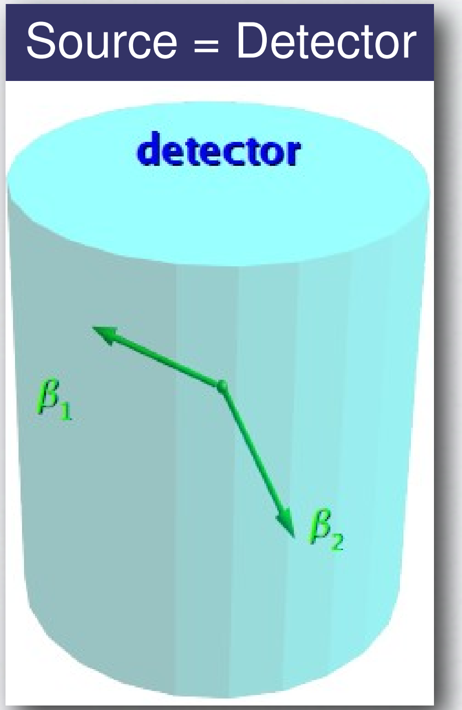

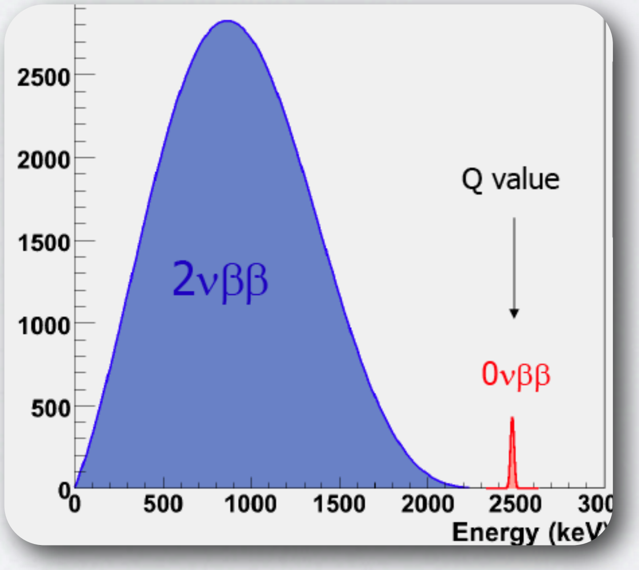

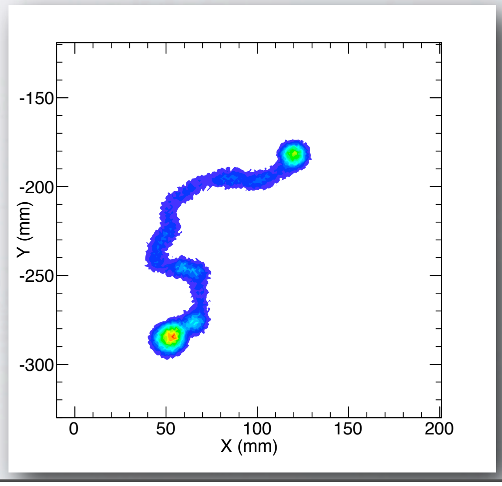

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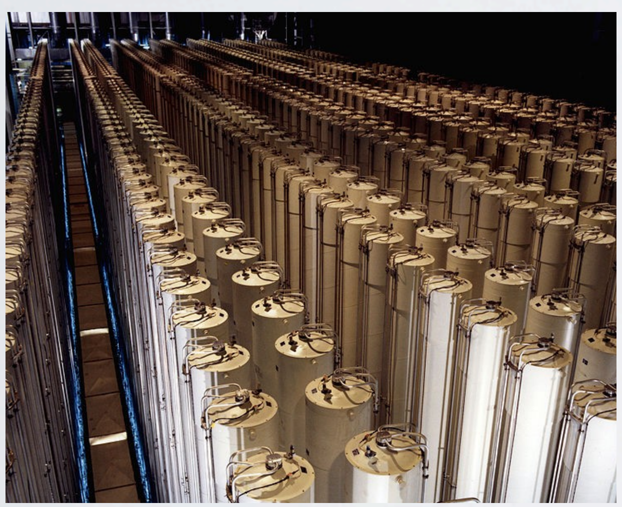

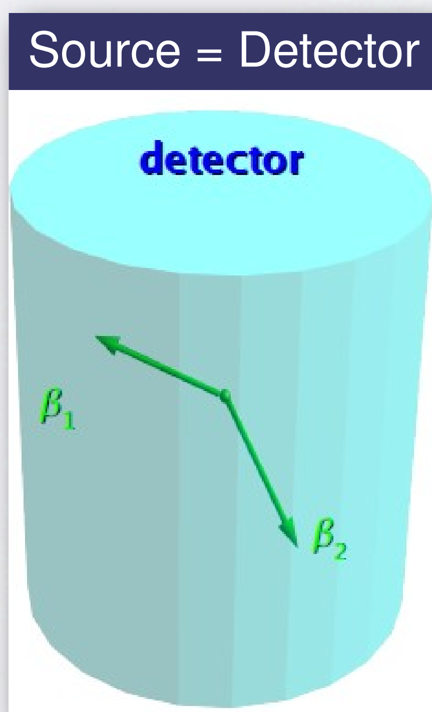

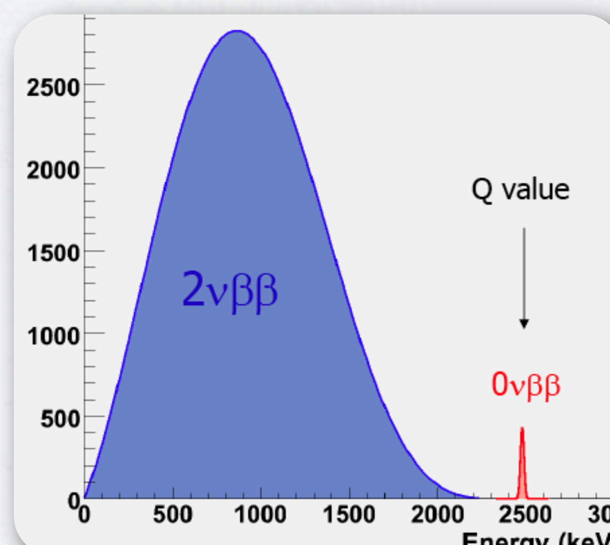

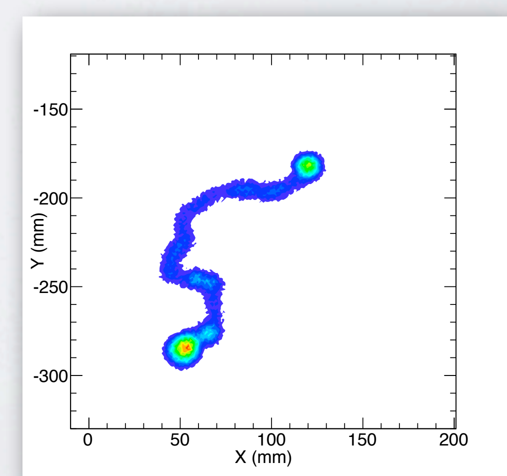

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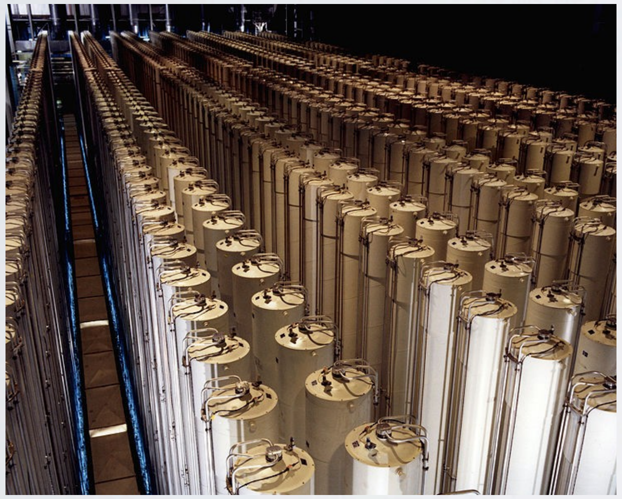
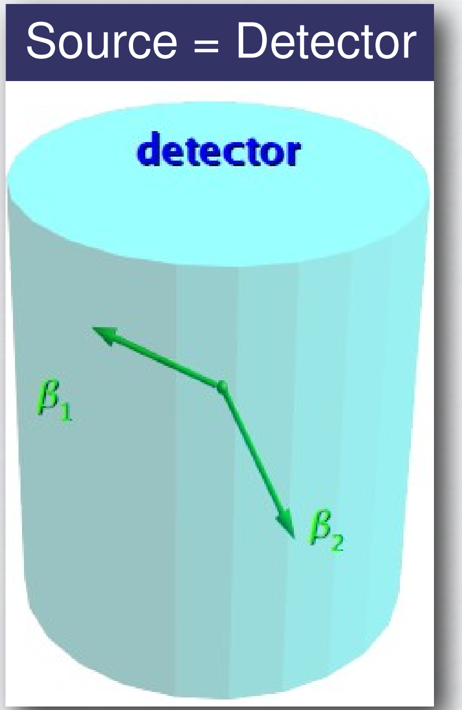
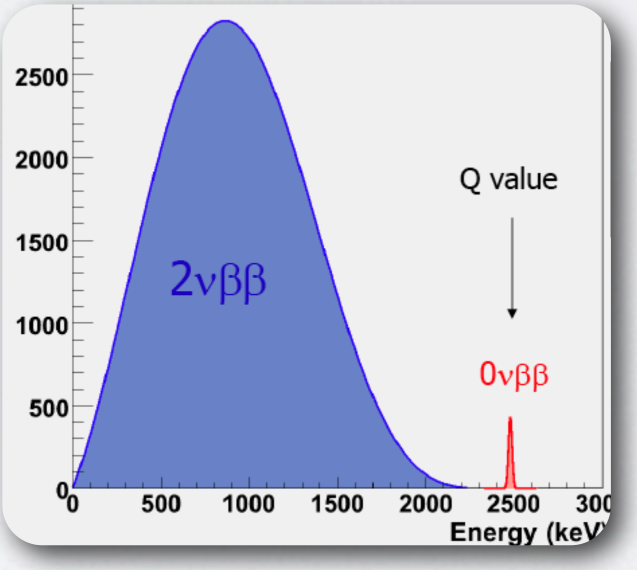






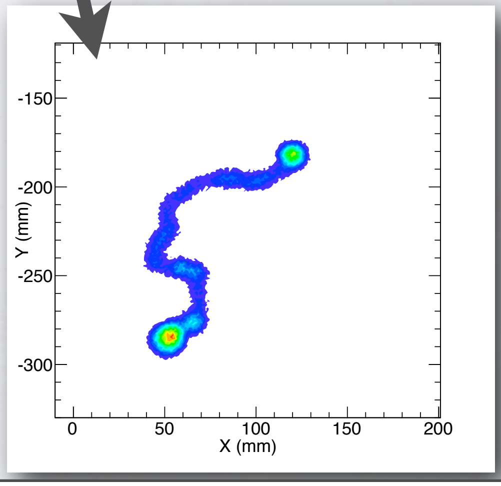
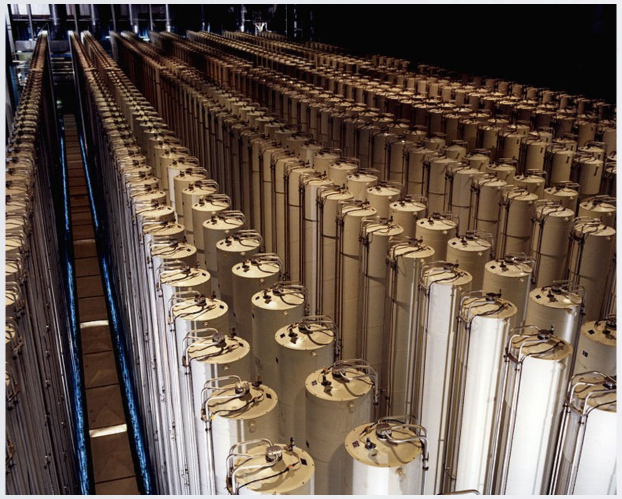
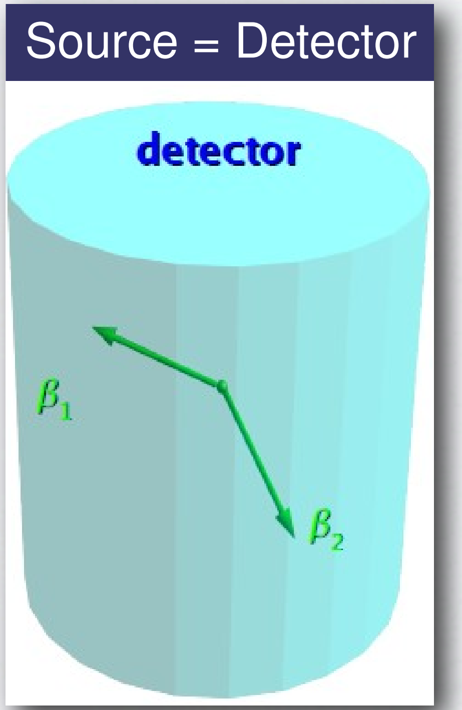
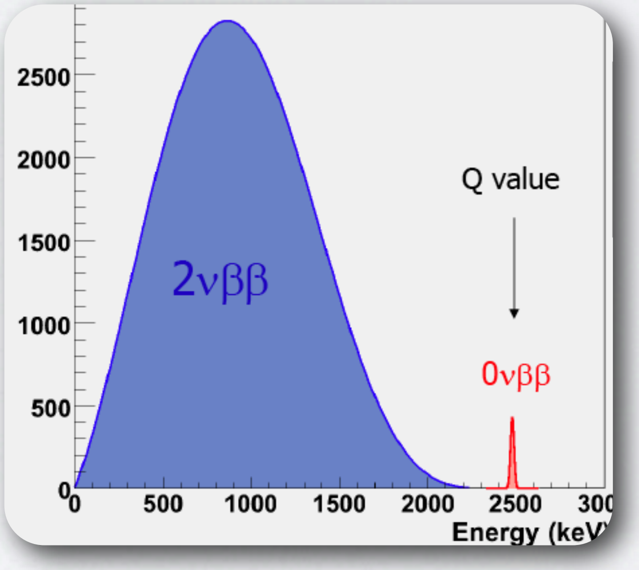


Figure of merit

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$







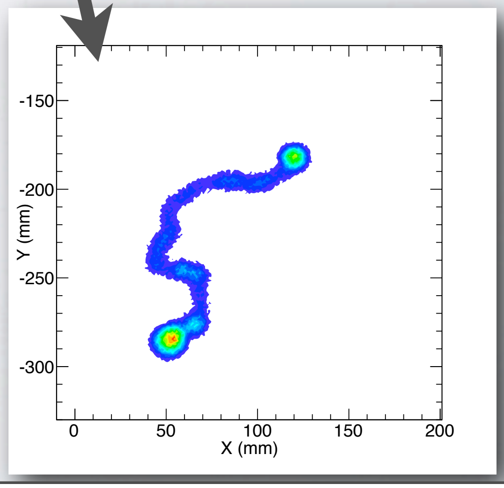
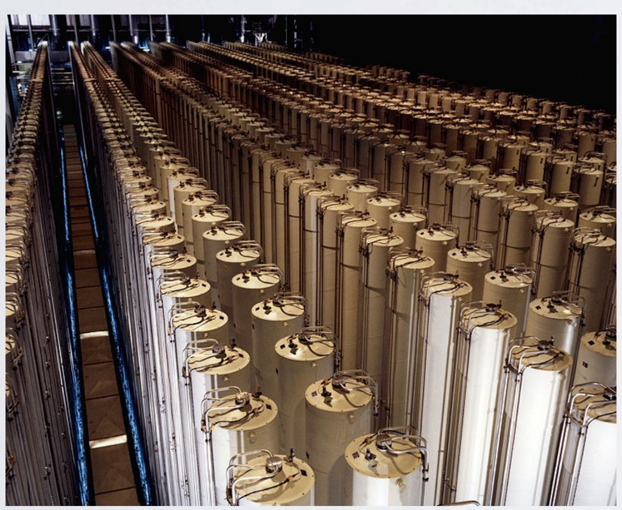
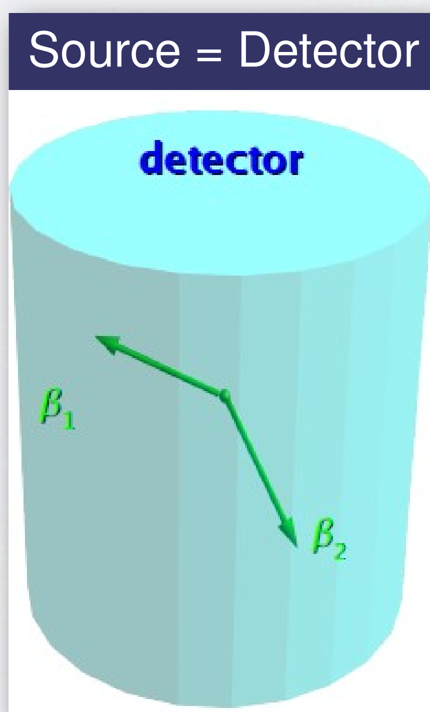
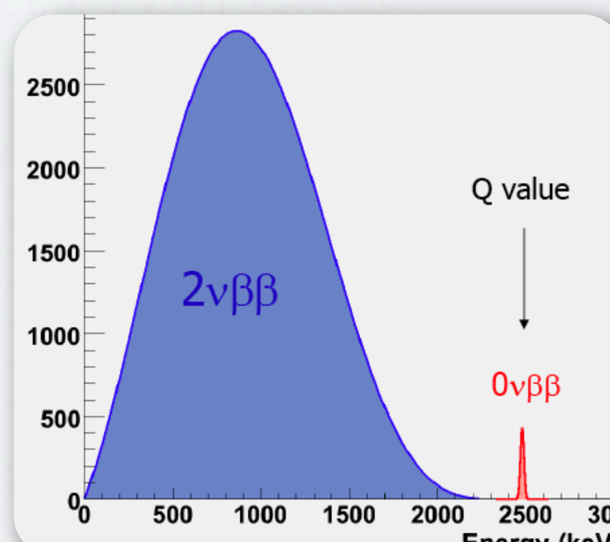


Figure of merit

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$







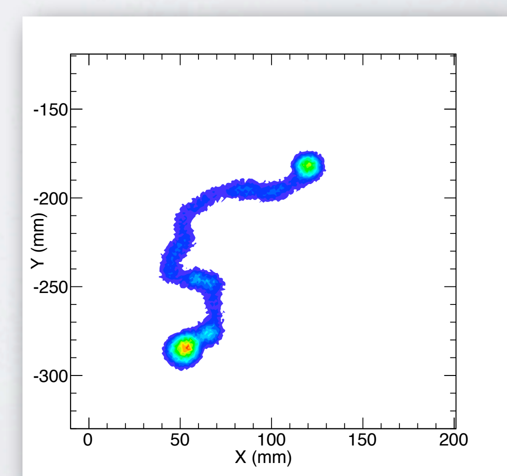
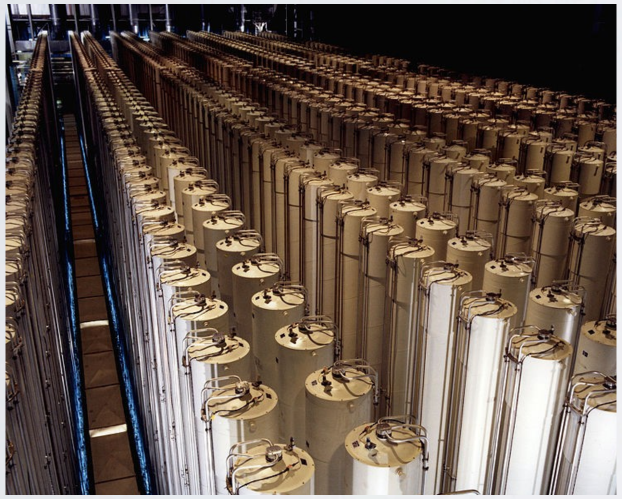
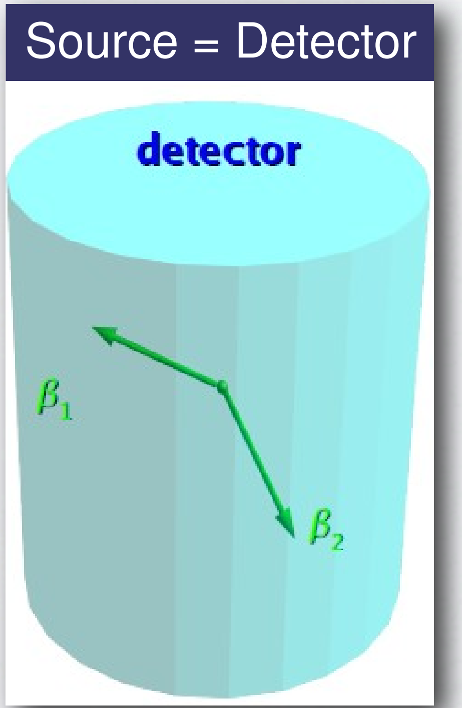
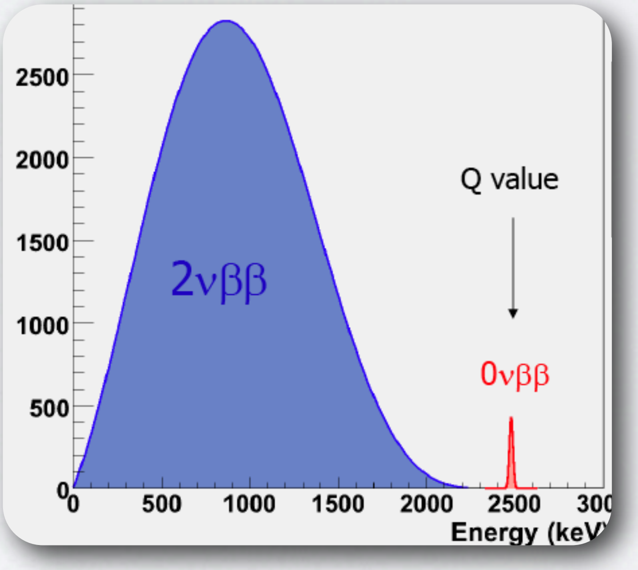


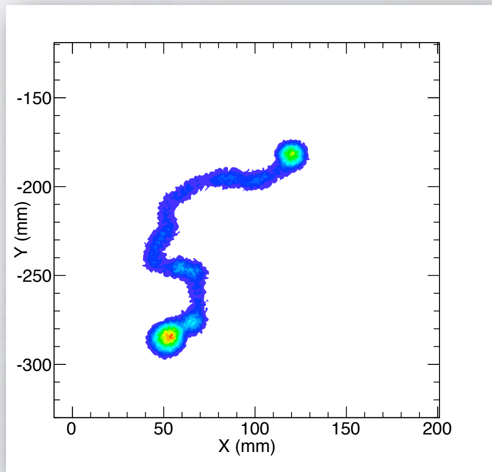
Figure of merit

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

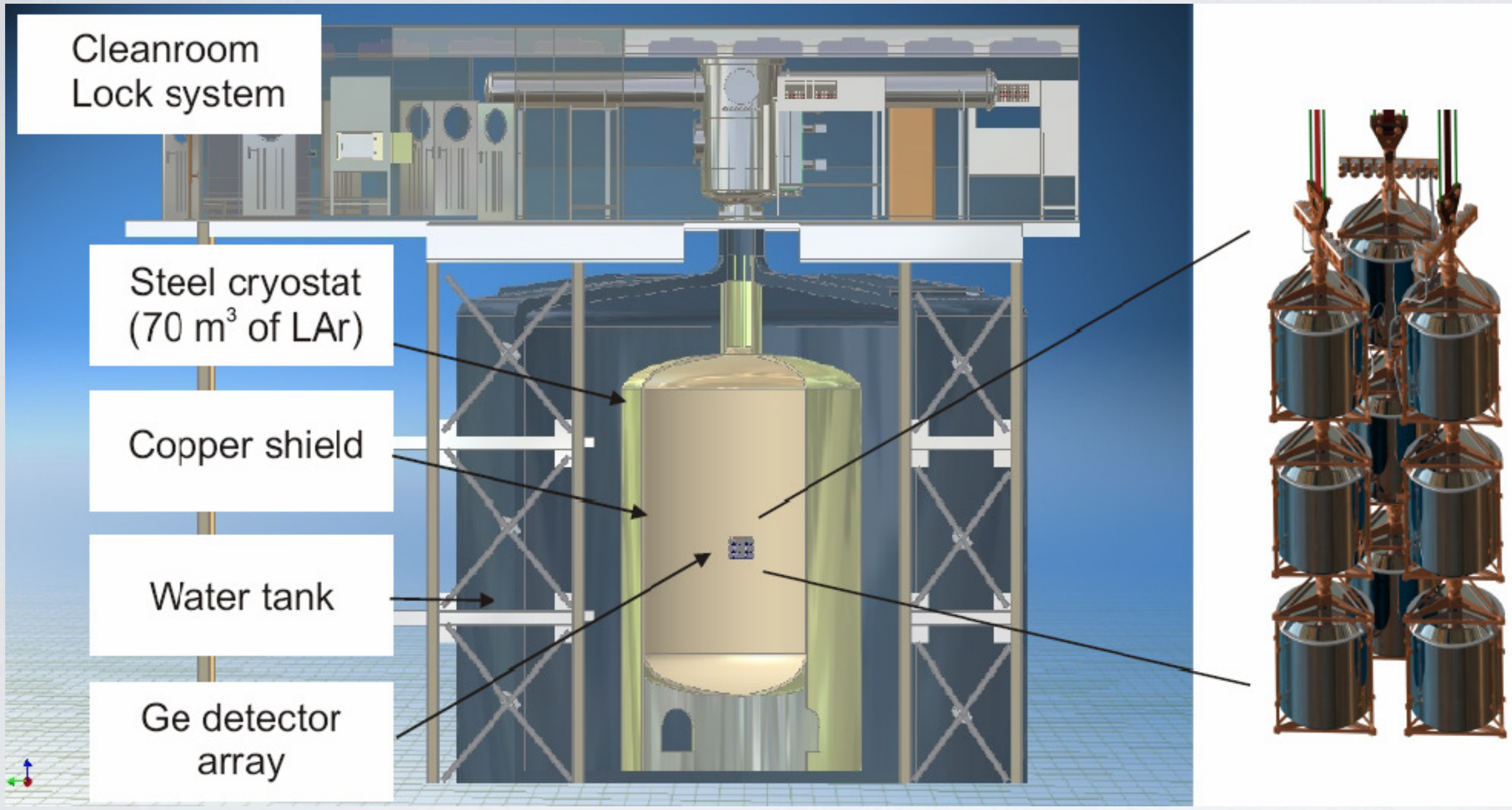








Classical approach: Ge detectors

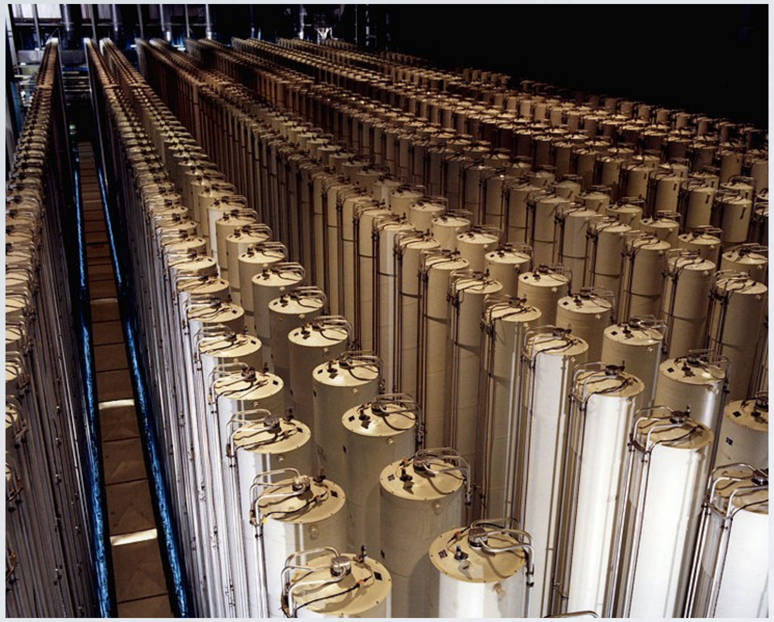


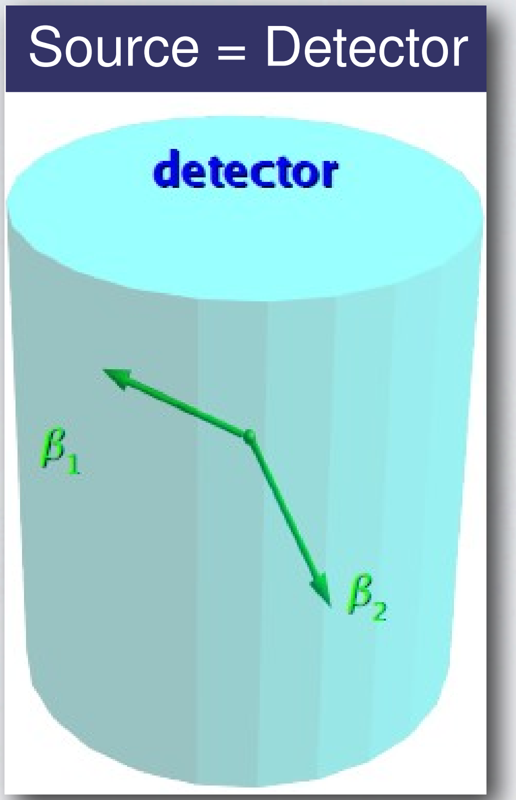
- **a**: expensive
- ε: > 80 %
- **Mt:** Limited (≈100 kg)
- ΔE Excellent (0.2 % FWHM)
- **b** good to very good (10^{-2} to 10^{-3} ckky)

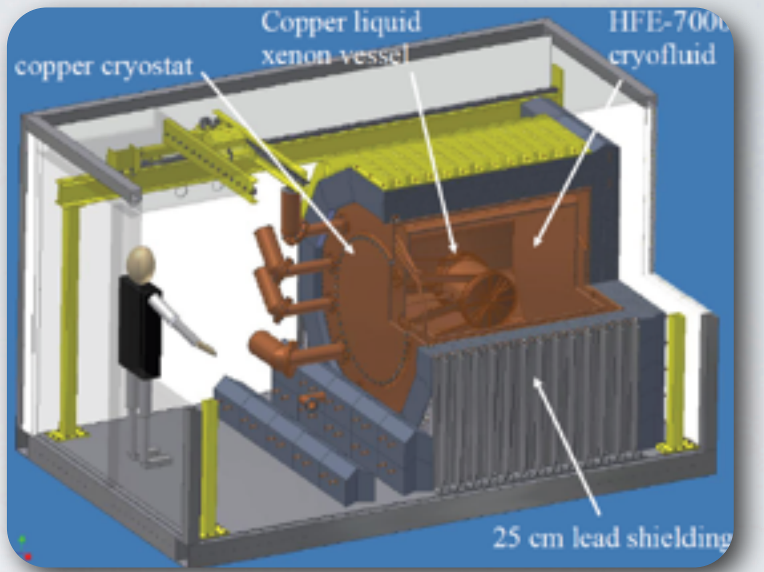
- Excellent
- Very good
- Good
- Moderate
- Poor

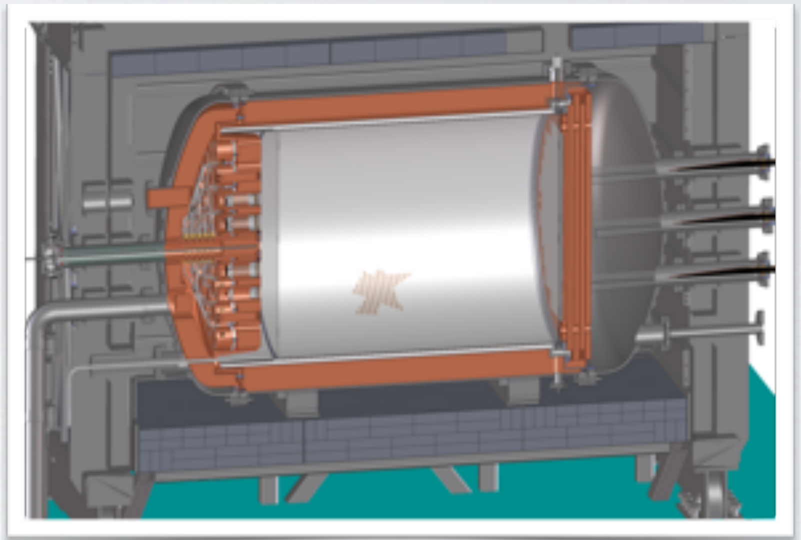
$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

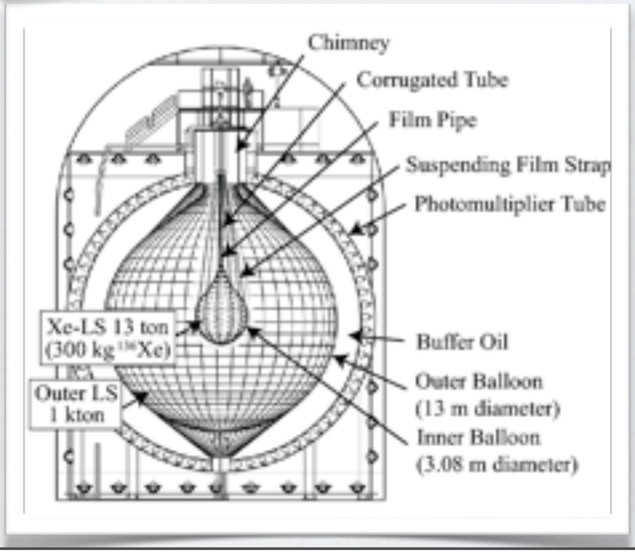
Xenon: the new kid in the block



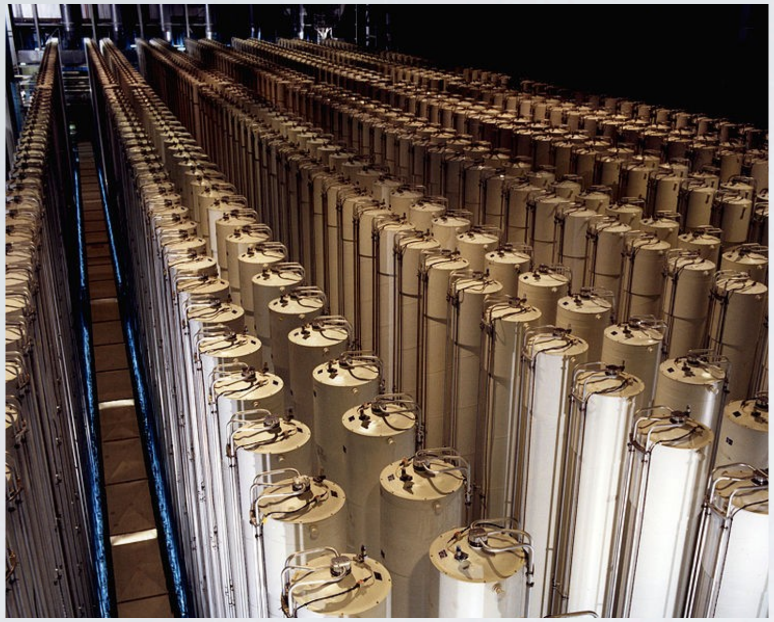


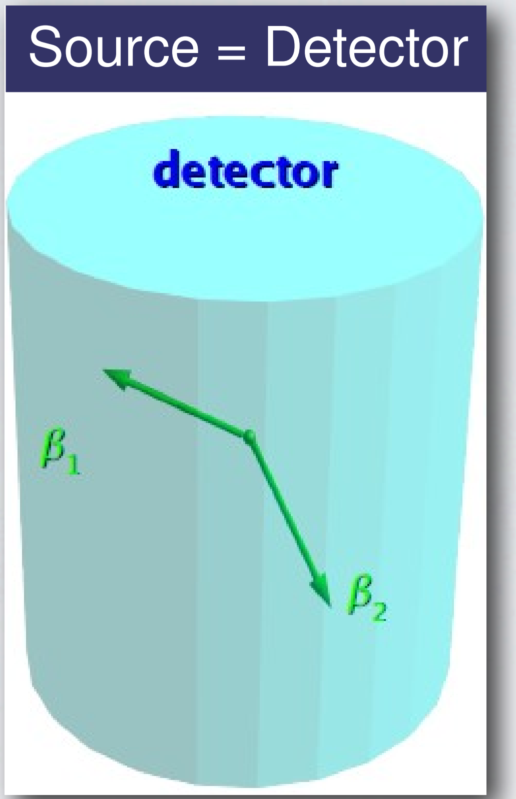


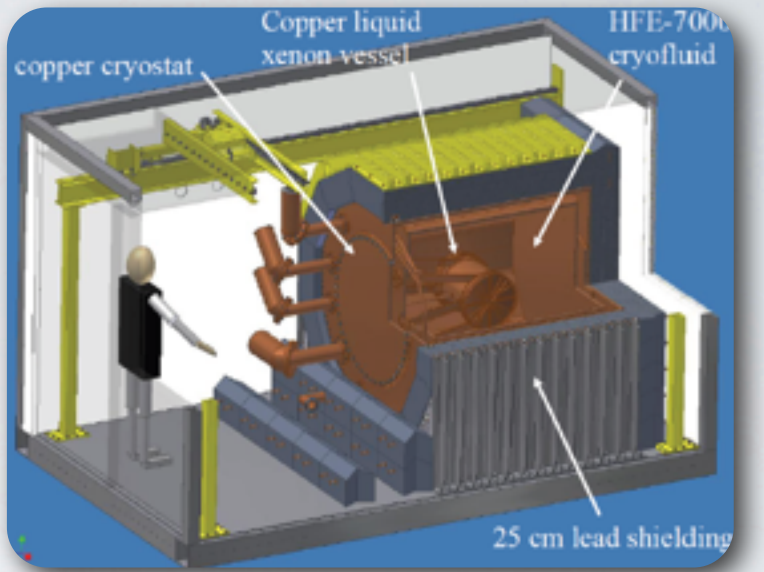


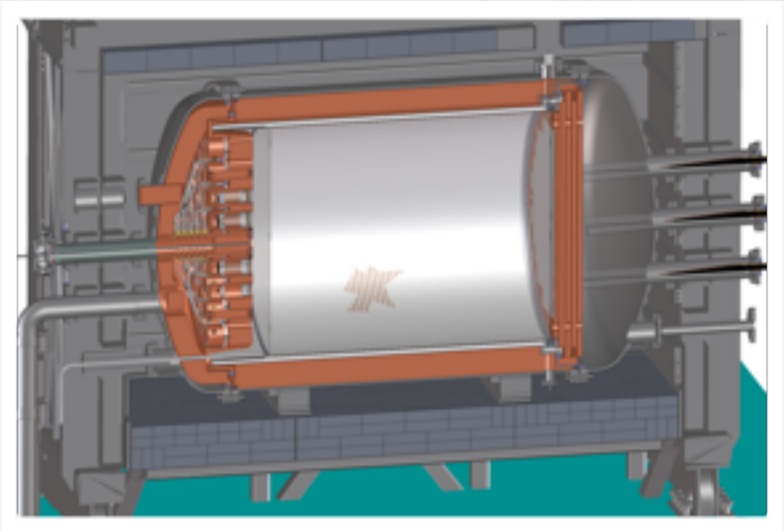


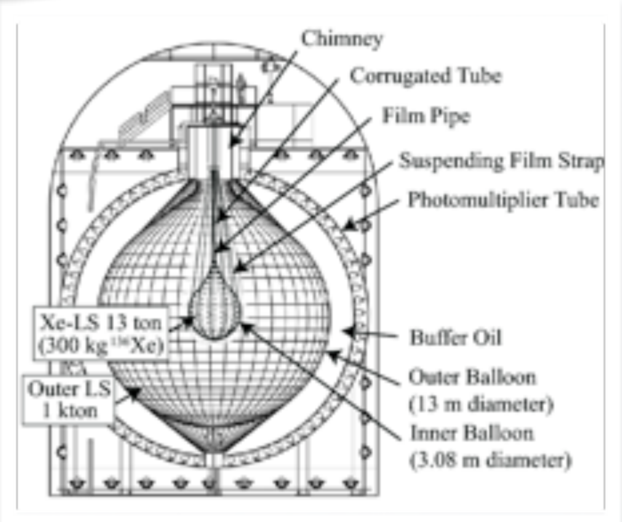
Xenon: the new kid in the block





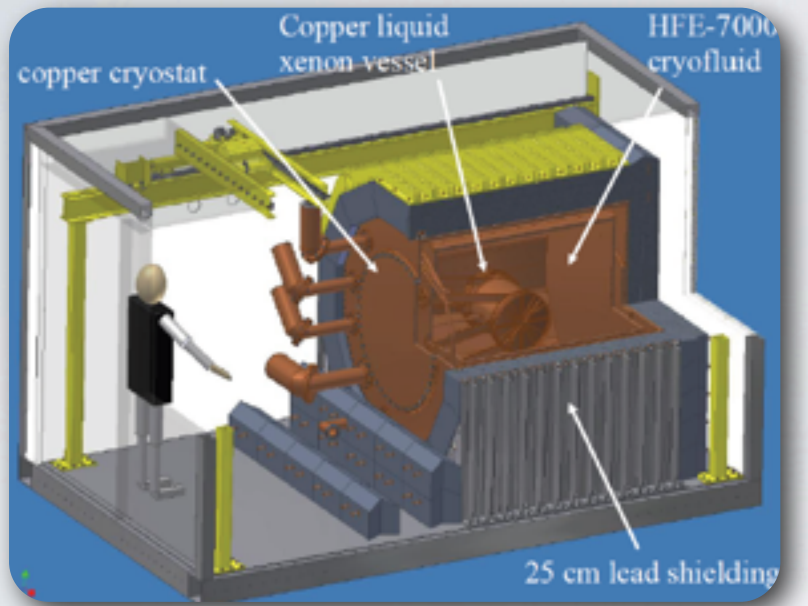


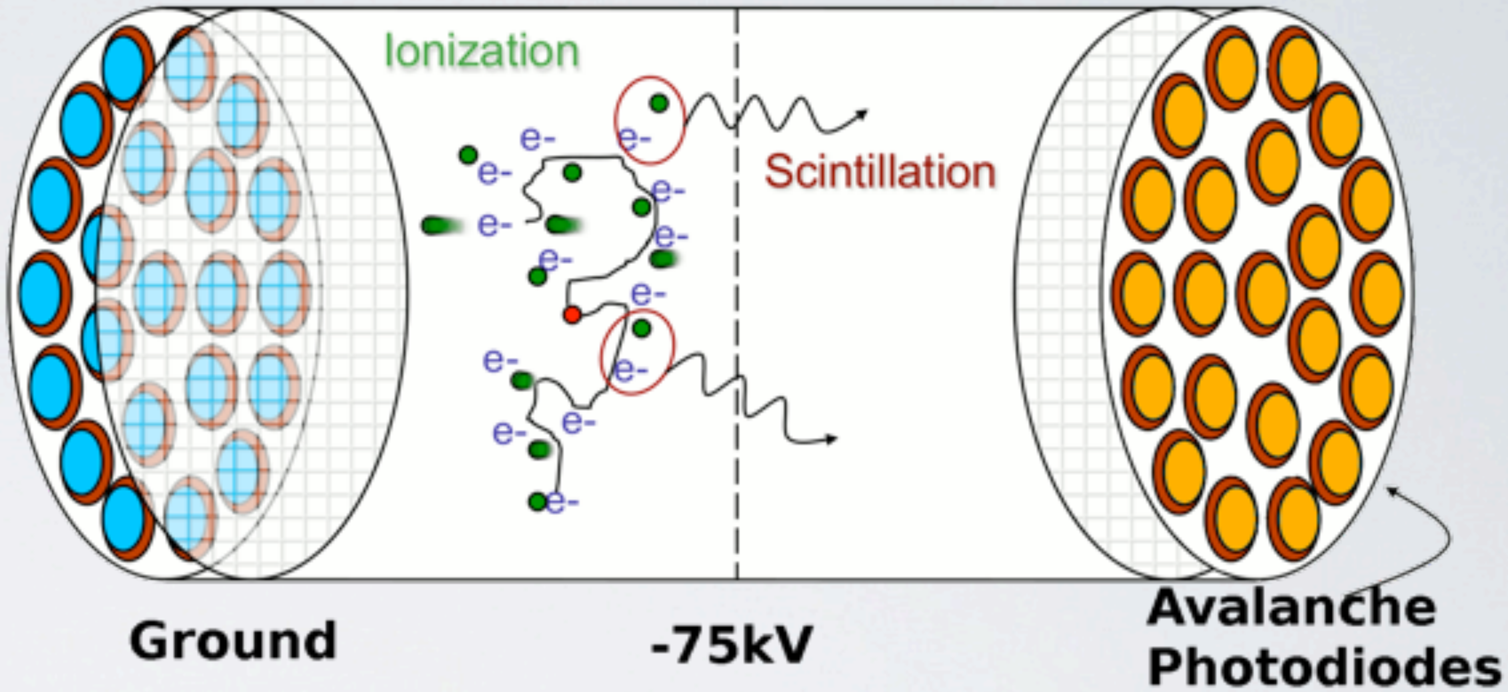


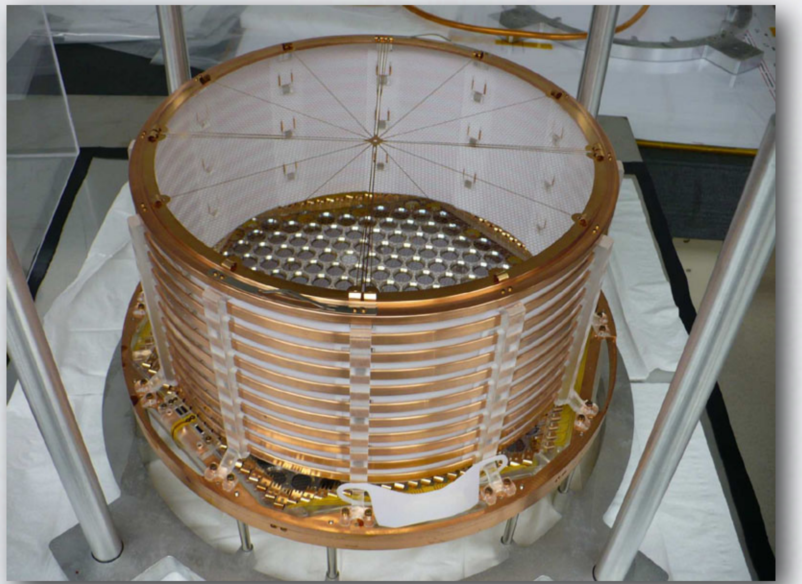


- Xenon: cheap and easy to enrich (1/10 other isotopes).
- Good Qbb. No other radioactive isotopes.
- Noble gas: can be used to build HPXe or LXe. Can be dissolved in LScint.
- Fully active, scalable detectors.

LXe: EXO

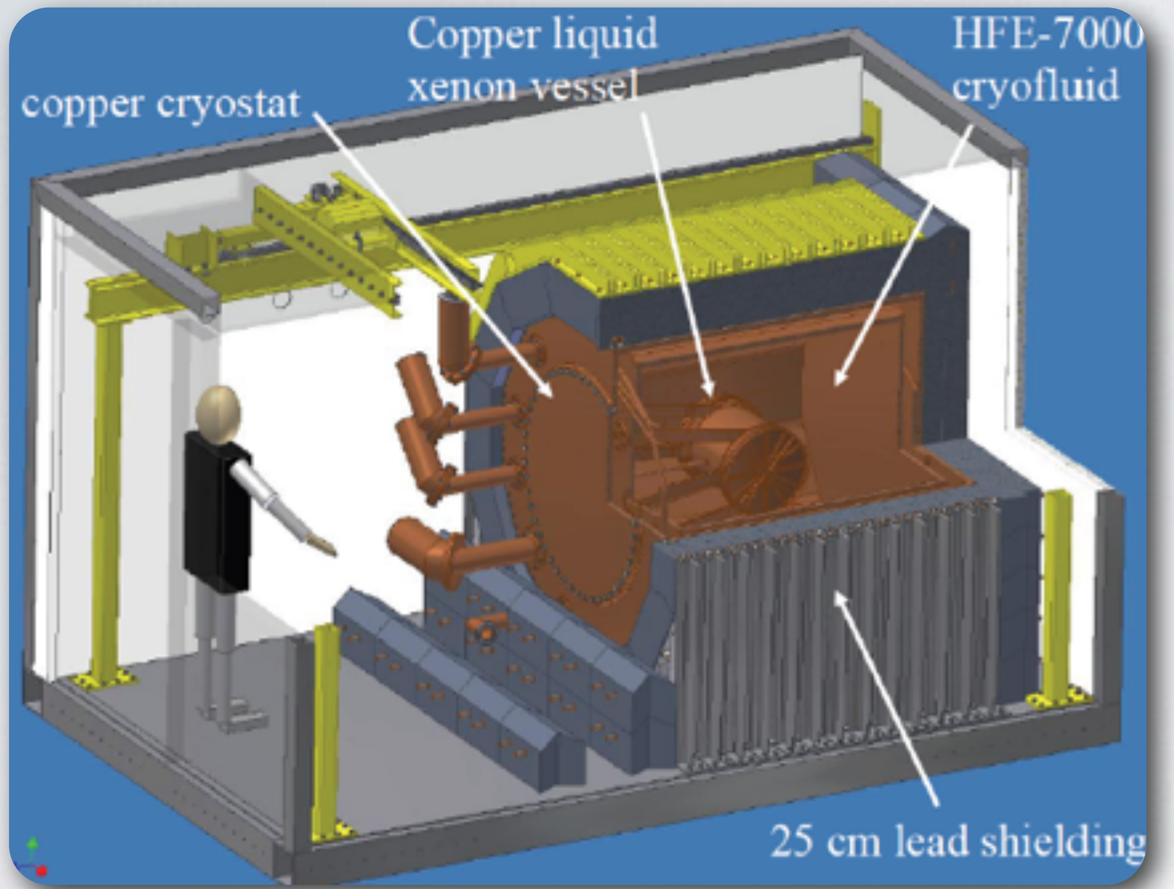






Detail of the LAAPD read-out plane

EXO

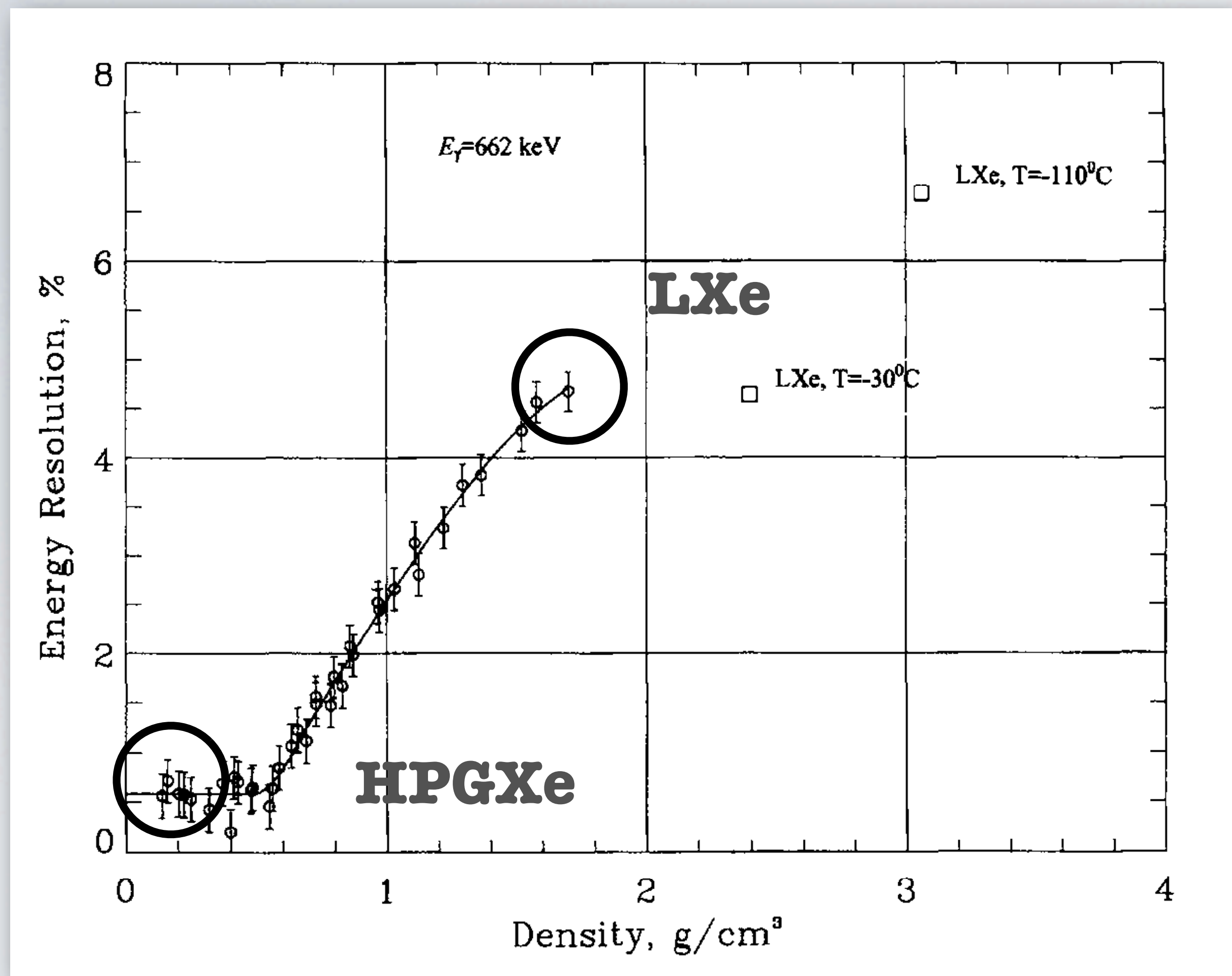


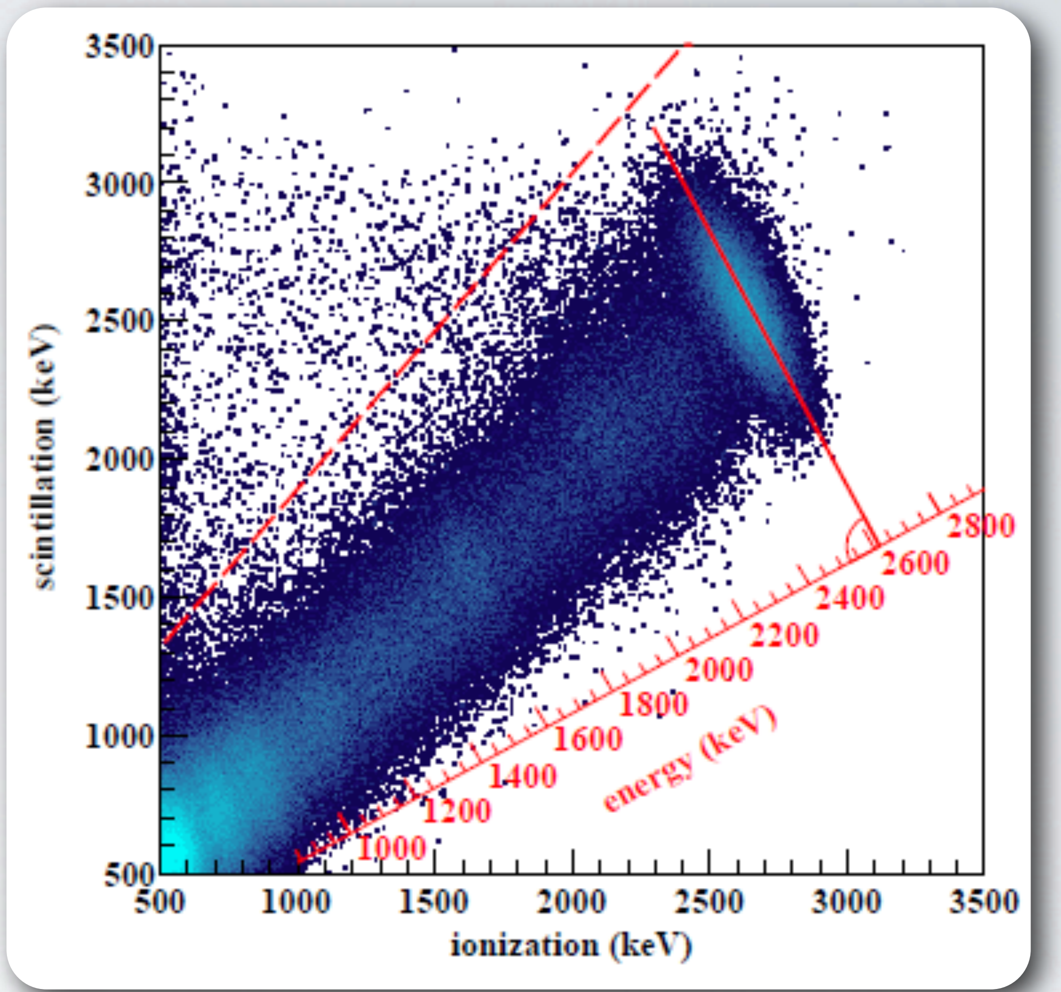
- Excellent
- Very good
- Good
- Moderate
- Poor

- **a**: Feasible (cheap)
- ε: 30-40% (self shielding)
- **Mt:** Scalable (≈multiton)
- ΔE moderate to poor (4 % FWHM)
- **b** good to very good (10^{-3} -10^{-4} ckky)

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

LXe: Energy resolution

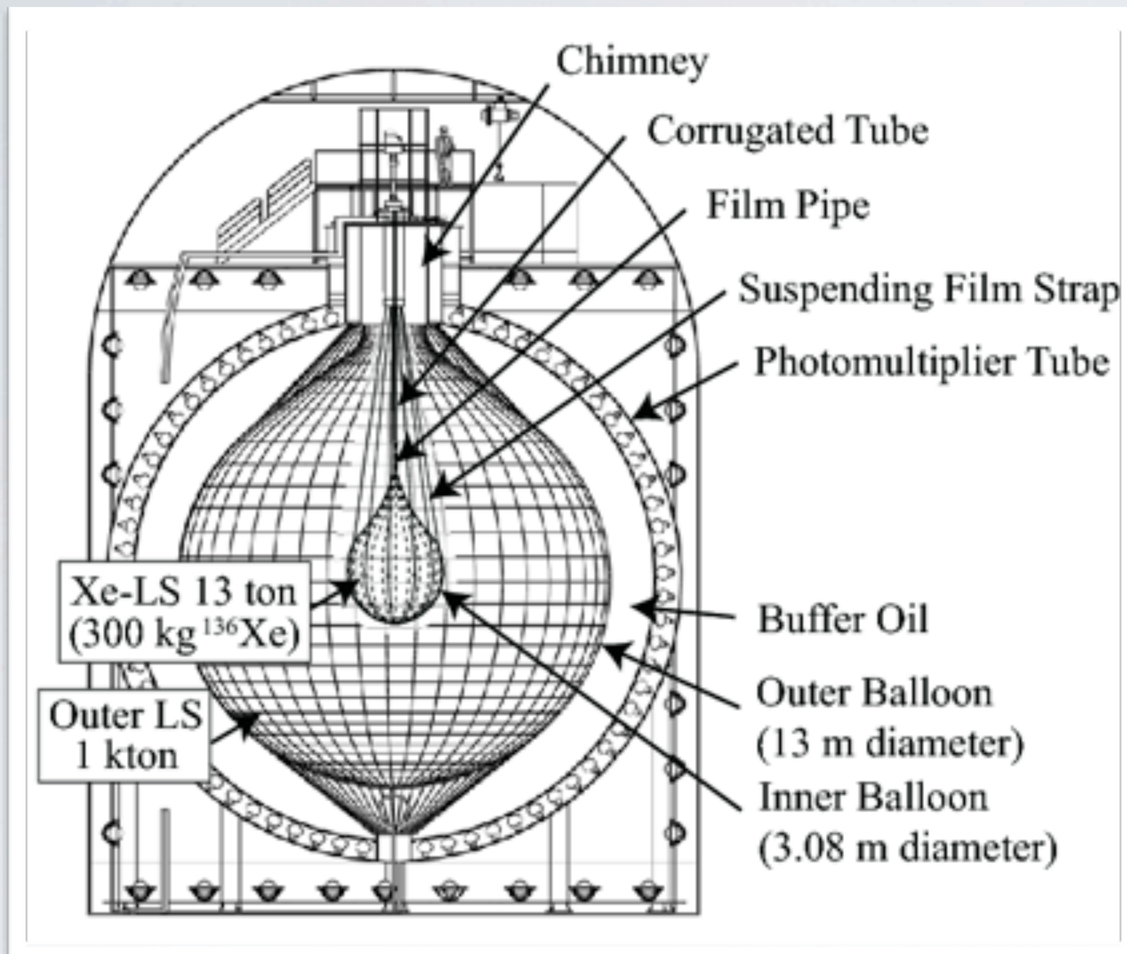




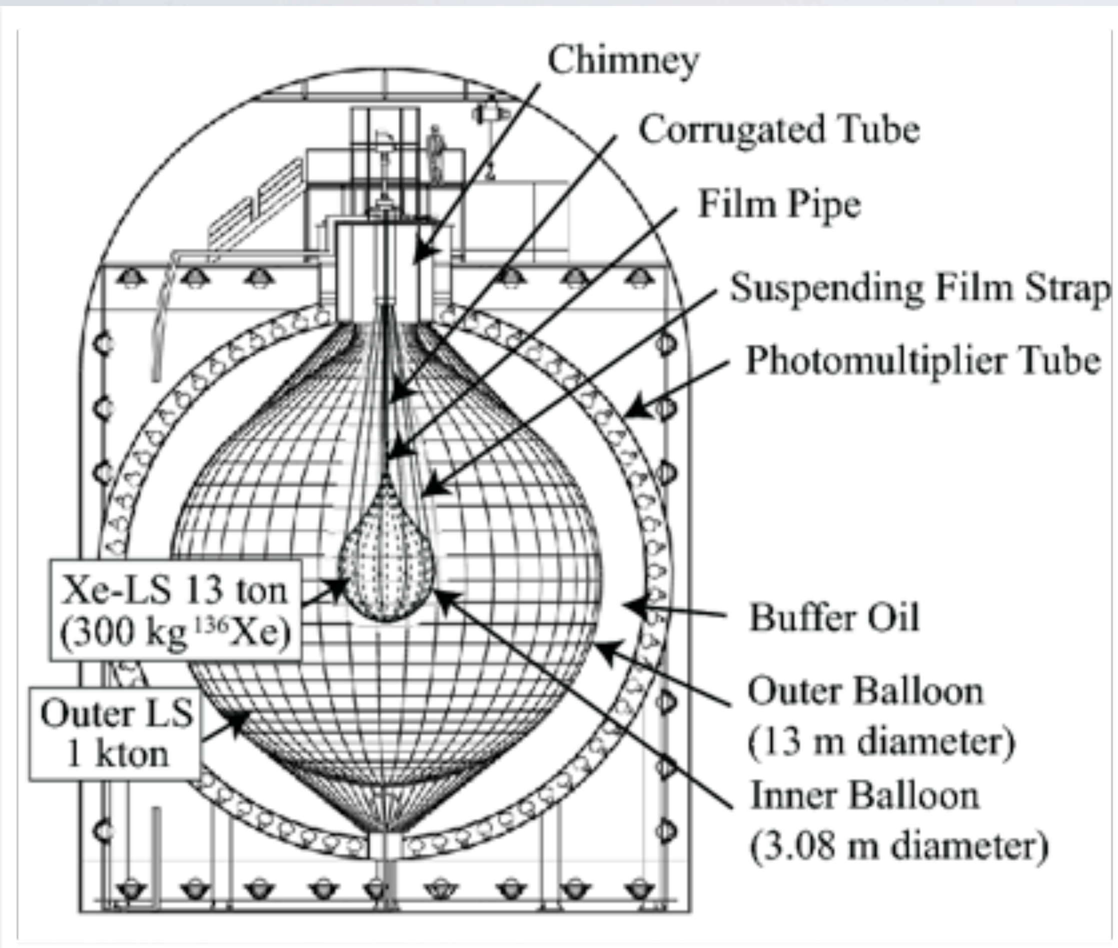
Energy resolution: Anomalous in LXe. Much worse than in HPXe.

Energy resolution: 4% FWHM at Q, using anti-correlation between scintillation and ionization

SciXe: KamLAND-Zen

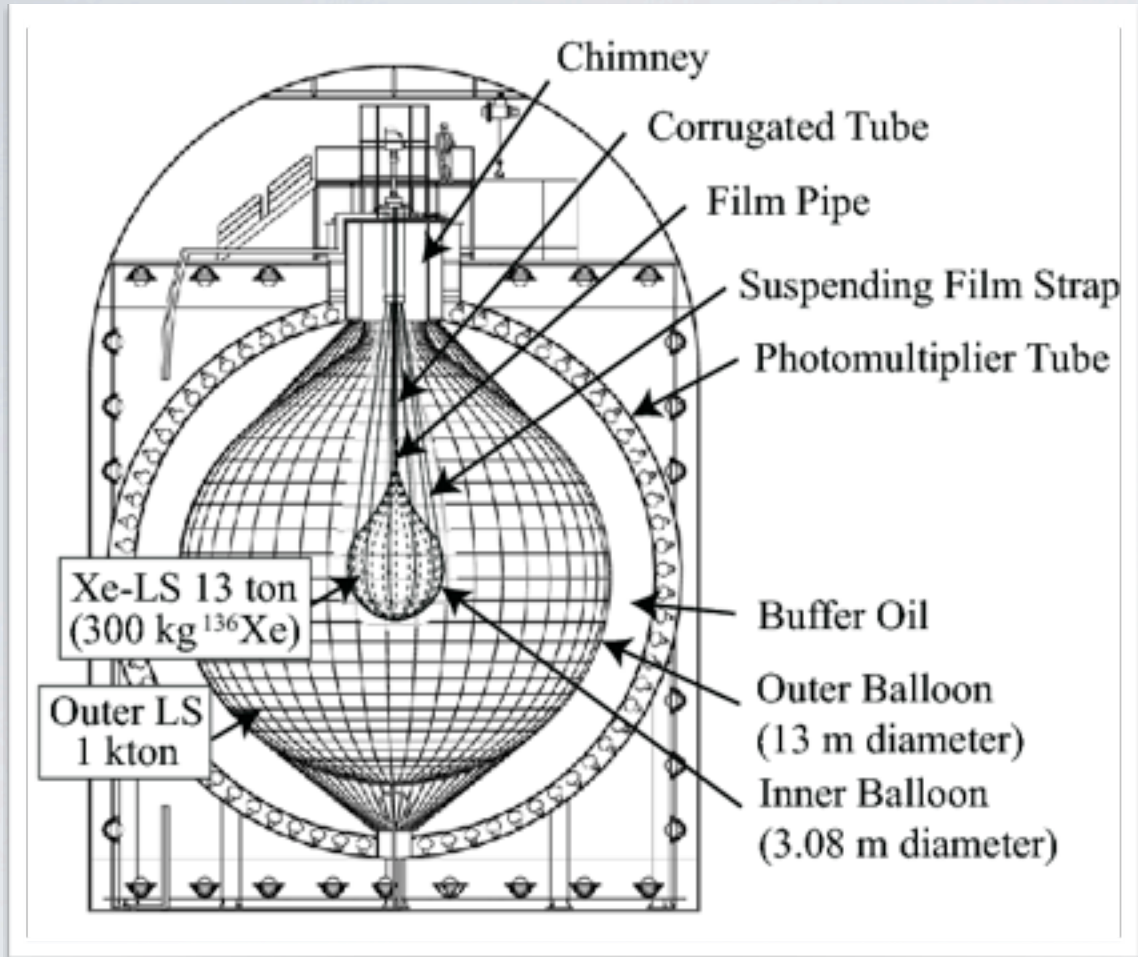


SciXe: KamLAND-Zen



- 320 kg of Xe-136 dissolved in 13 tons of liquid scintillator, held in an acrylic balloon (R~3 meter).
- Energy resolution is 10 % FWHM at Q
- Spacial resolution ~10 cm (1 sigma).
- Activity from external world including PMTs shielded by liquid scintillator.
- Activity from balloon shielded by fiducial volume cut (leaves about 100 kg of Xe-136 in fiducial volume)
- Currently dominated by "unexpected " isotopes Ag-110m

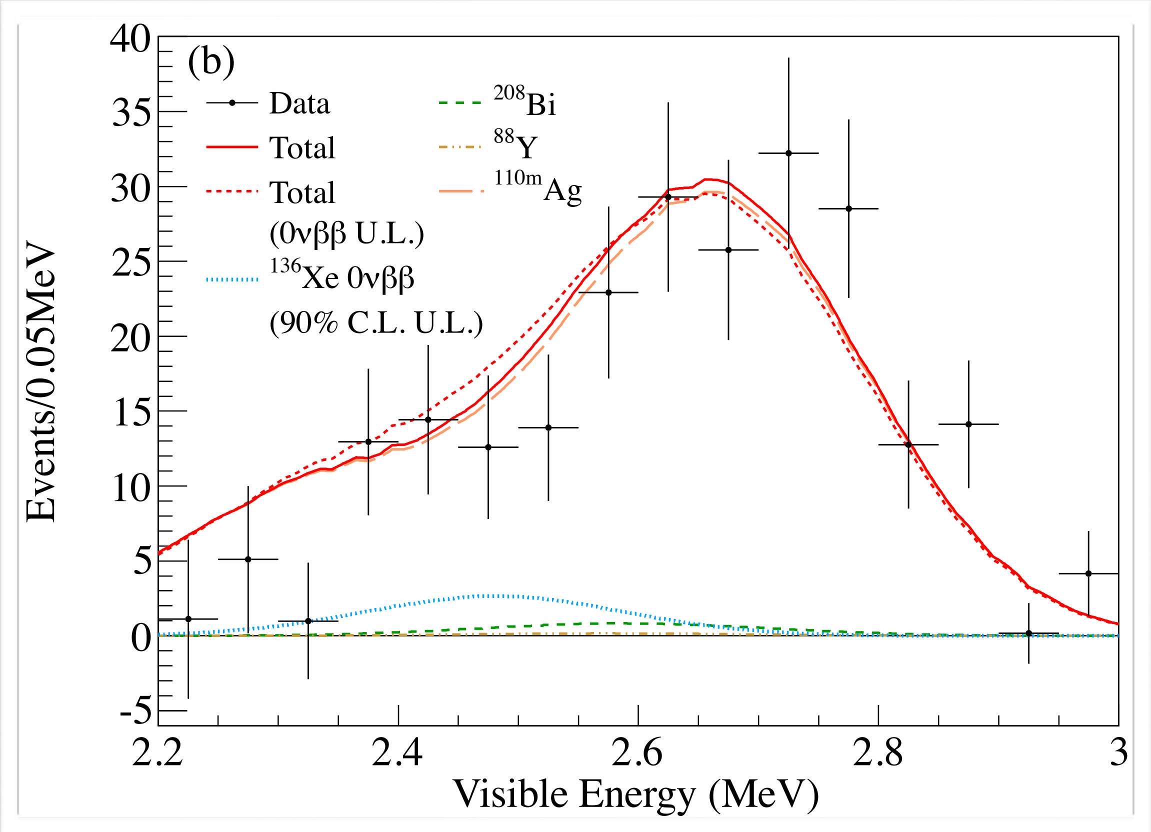
KamLAND-Zen

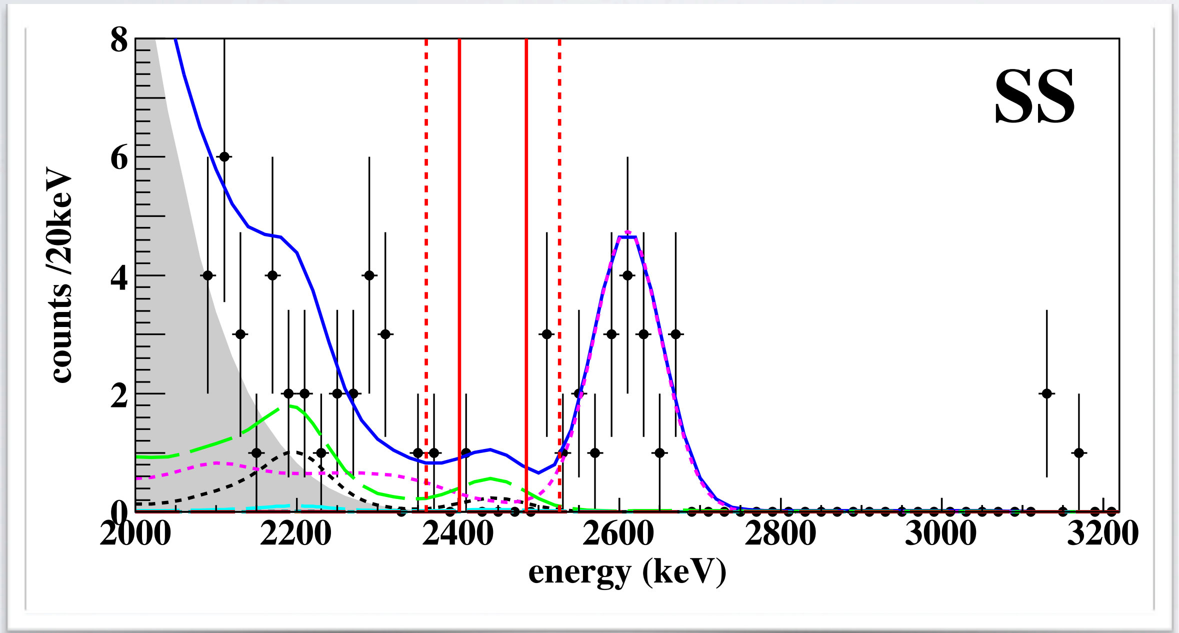


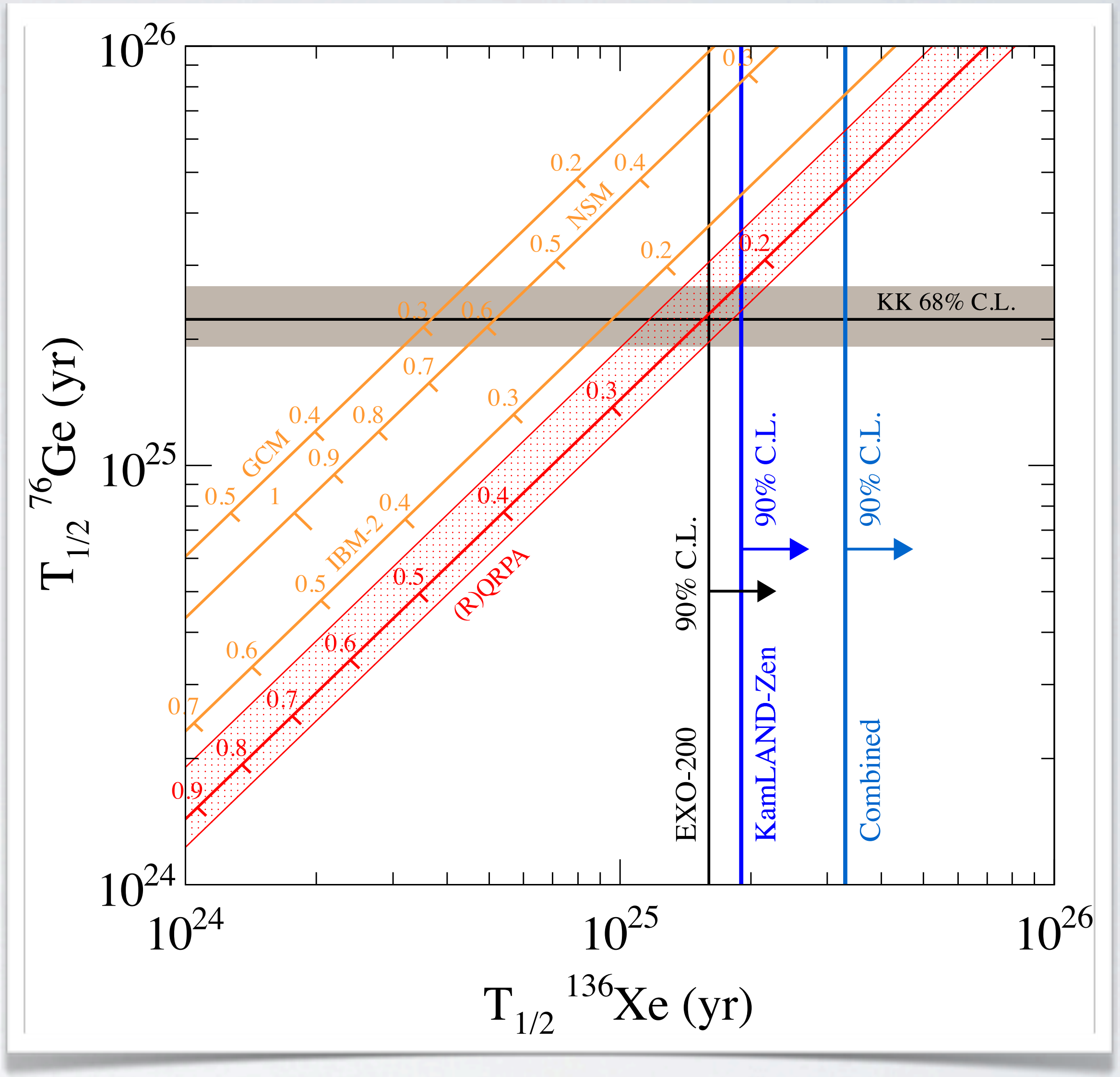
- **a**: Feasible (cheap)
- ε: 40% (fiducial cut)
- **Mt:** Scalable (≈multiton)
- ΔE poor (10 % FWHM)
- **b** good to very good (10^{-3} - 10^{-4} ckky)

- Excellent
- Very good
- Good
- Moderate
- Poor

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$







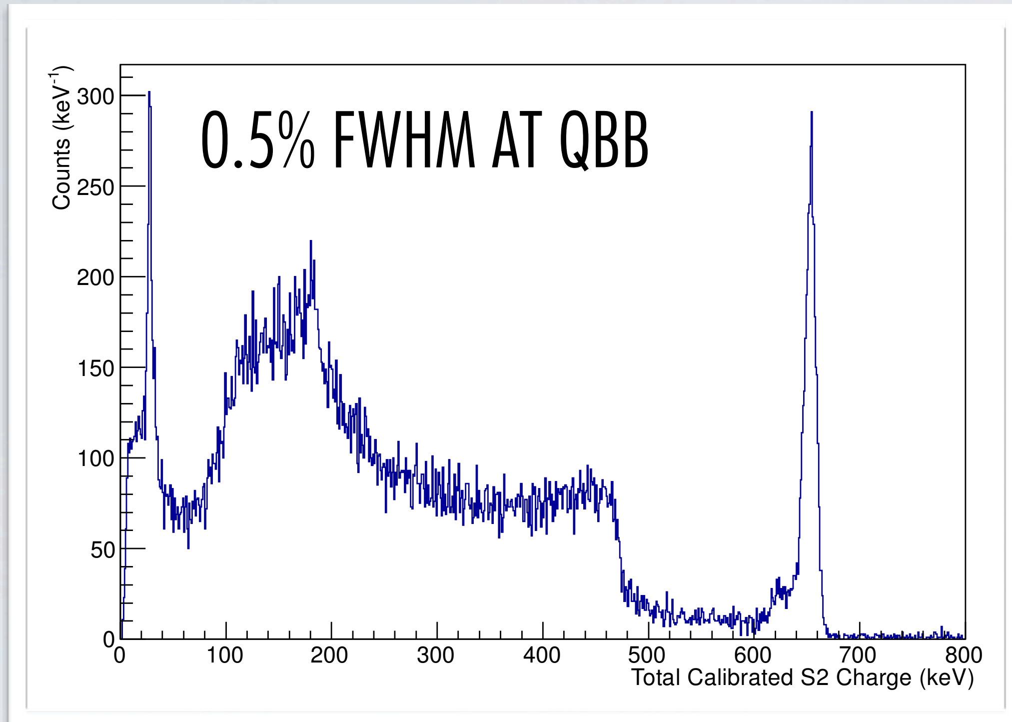
^{136}Xe-based experiments currently dominating the field (But KK will only be fully killed by Gerda...)

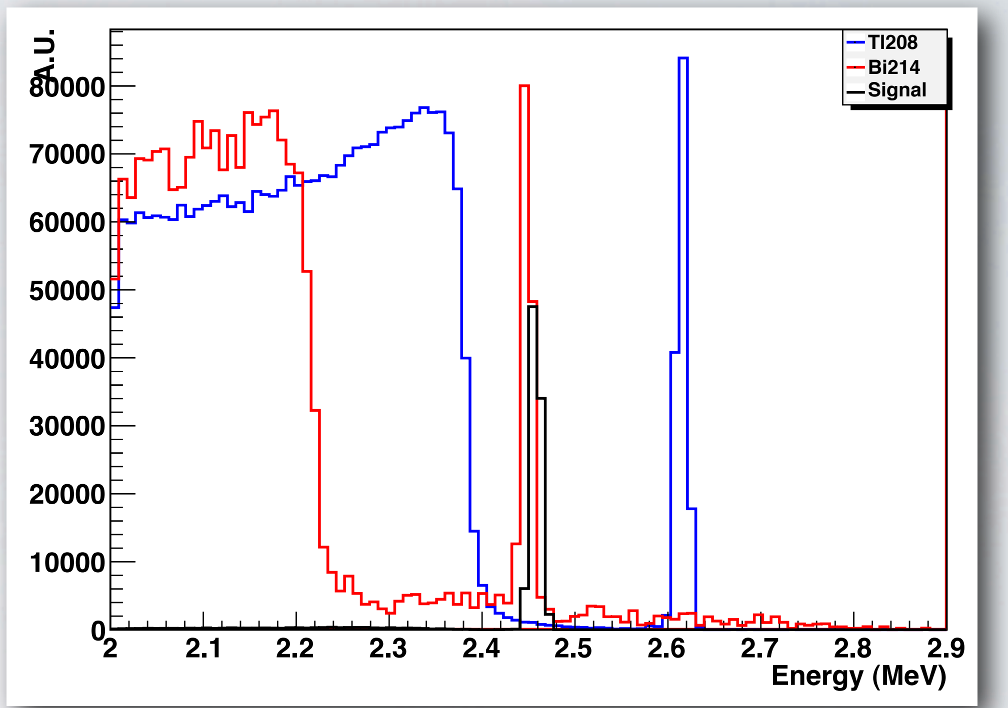
THE THIRD WAY: NEXT

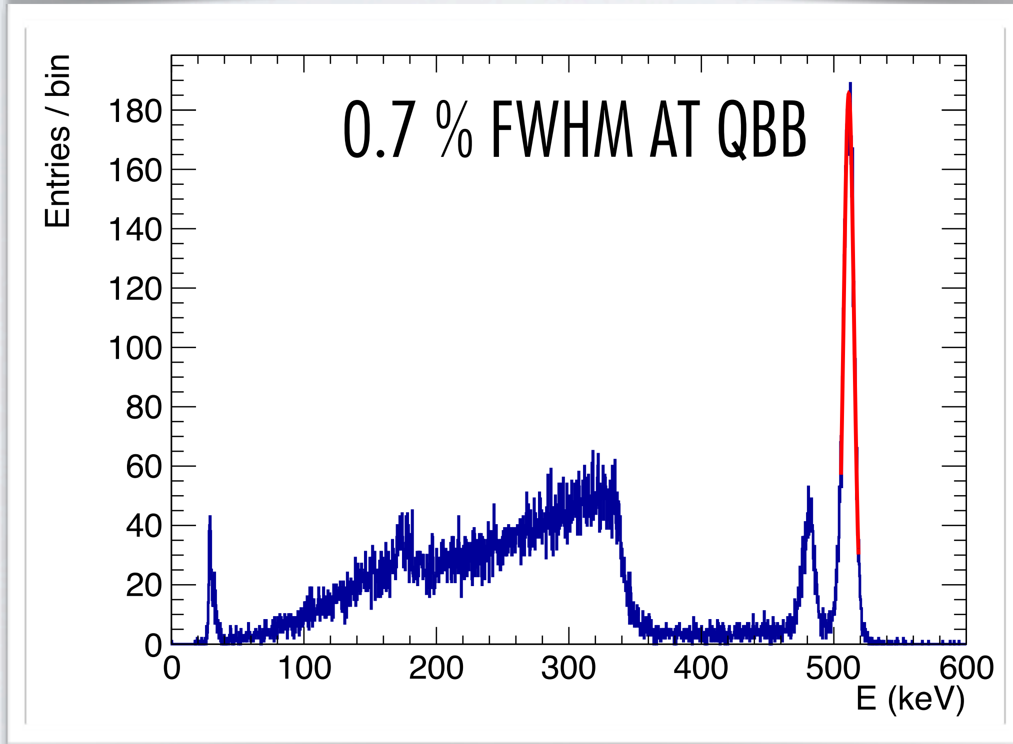
- Neutrino Experiment with a Xenon high pressure (HPXe) gas TPC
- Very good energy resolution: ~0.5-0.7% FWHM @ Q
- Powerful background rejection using the event topological signature (10^{-4} ckky)
- Being built at the Laboratorio Subterráneo de Canfranc (LSC), under the Spanish Pyrenees.

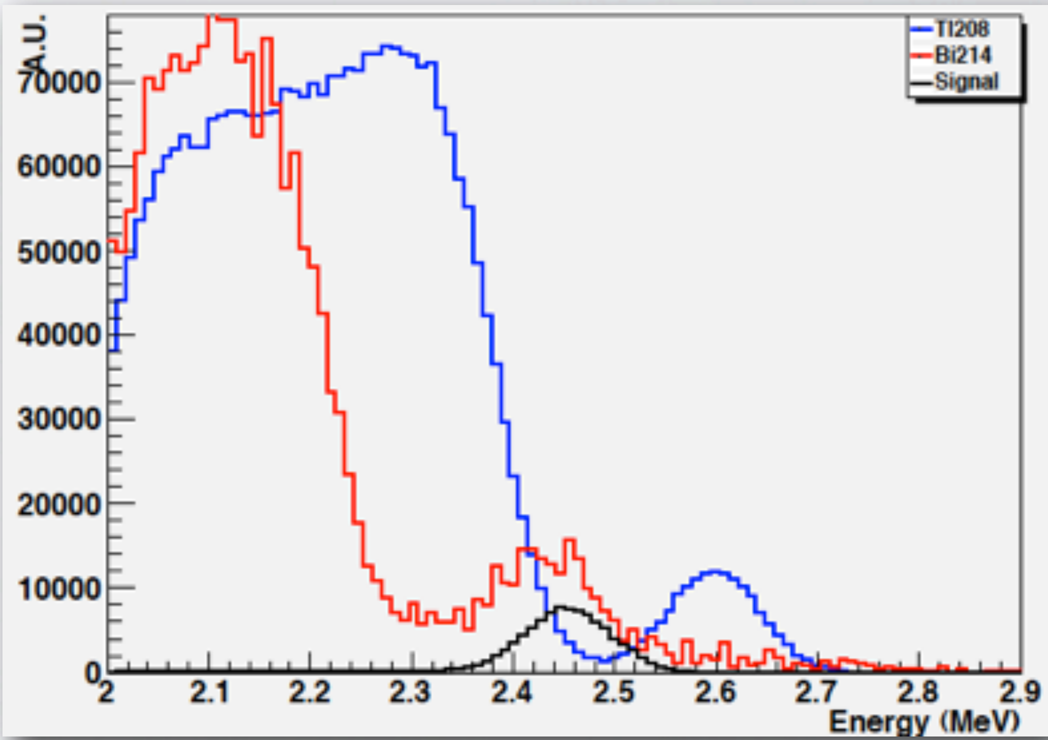
- **http://next.ific.uv.es/next/**

HPGXe vs LXe



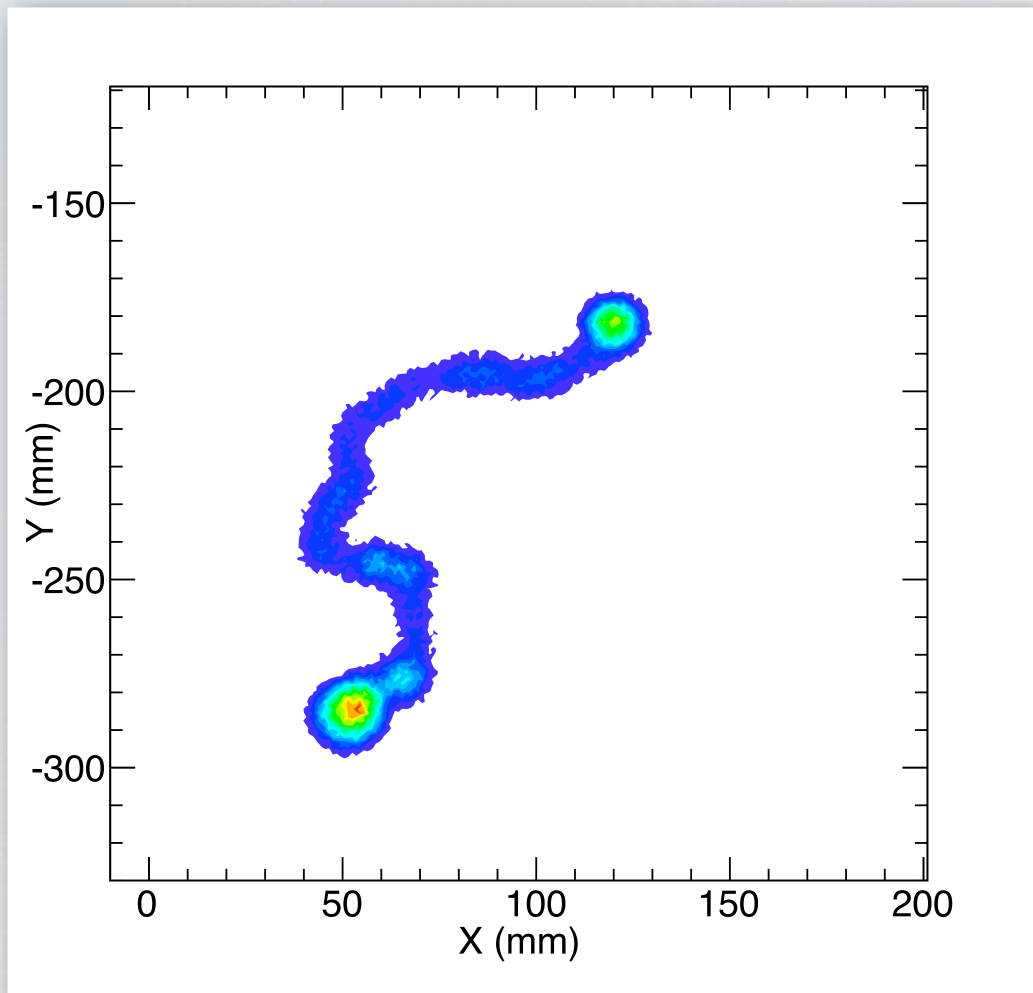


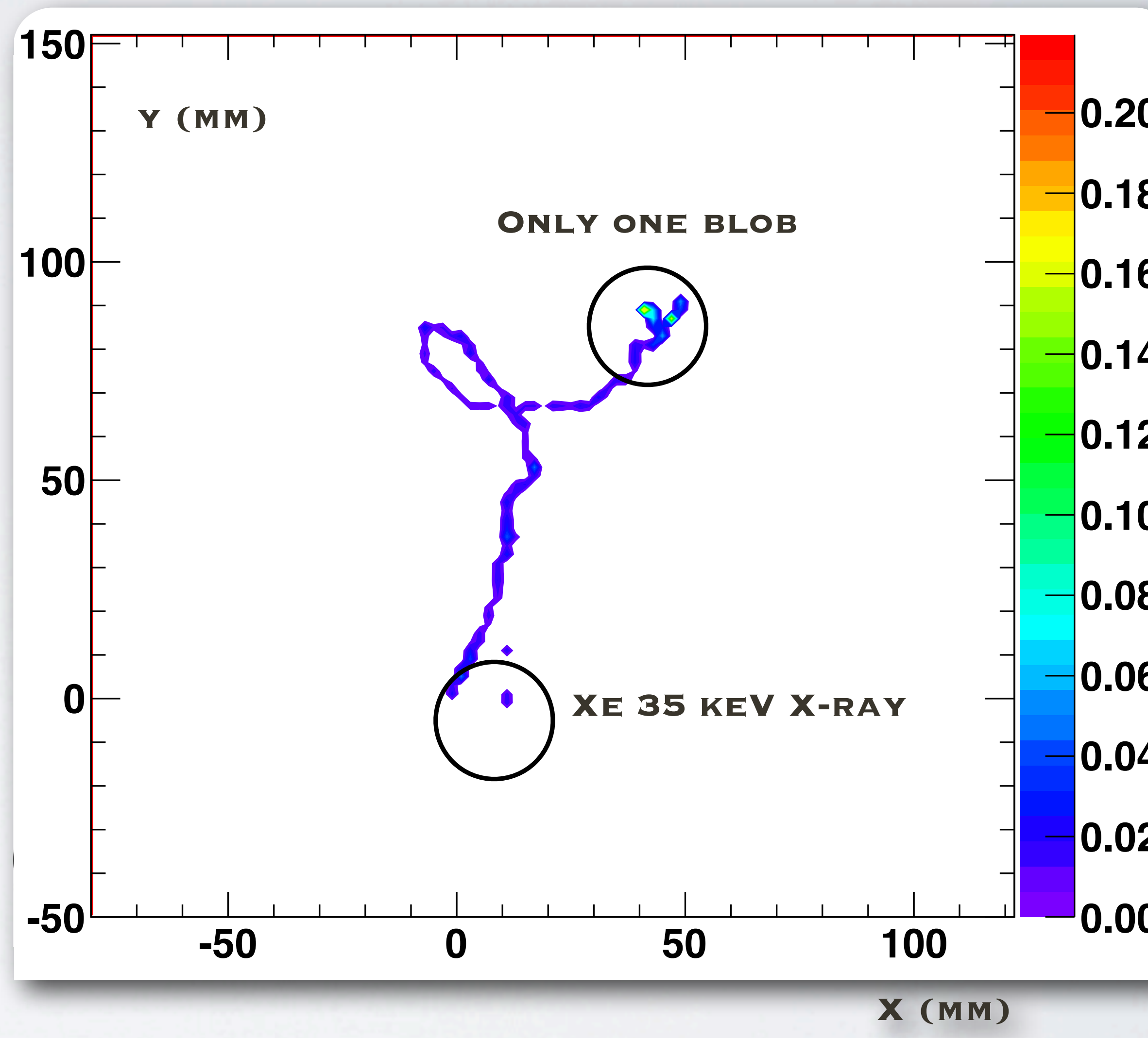




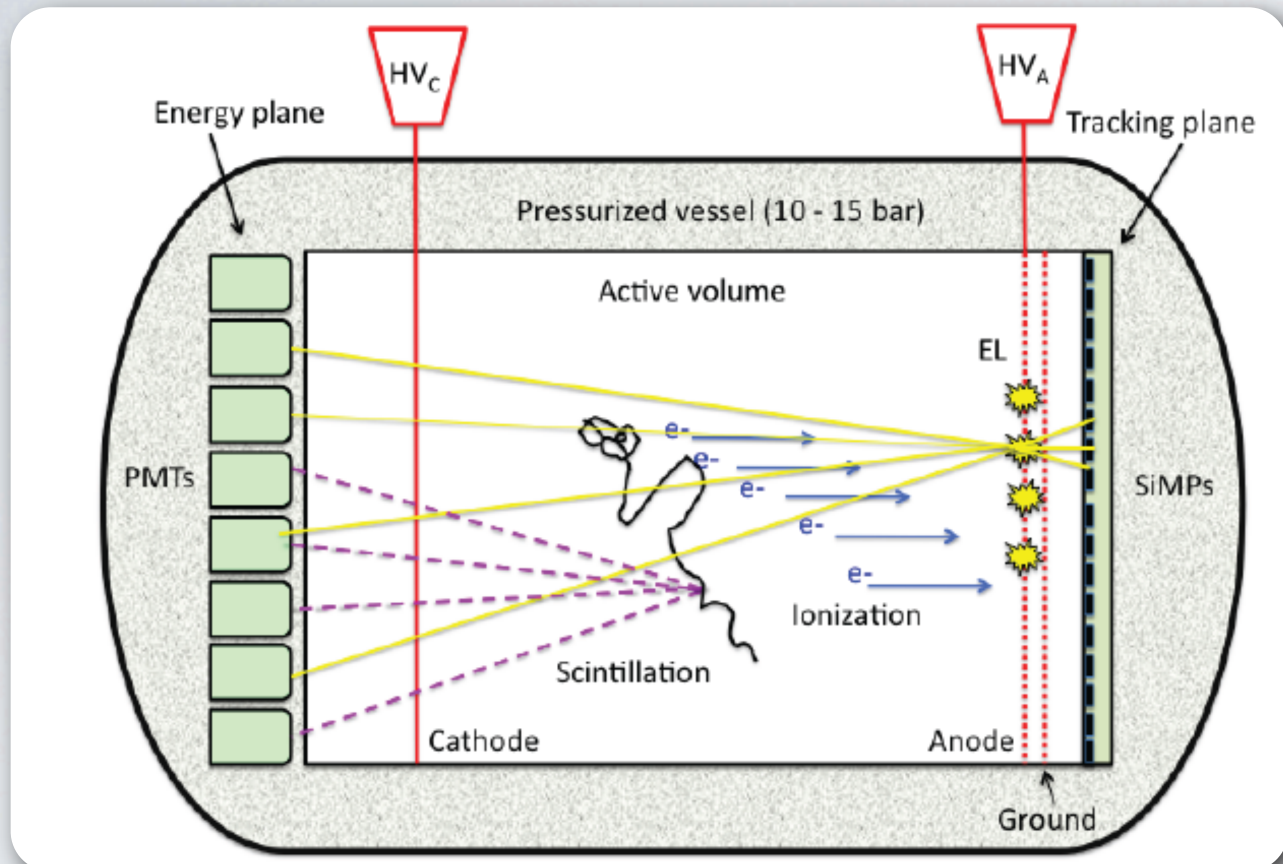
- **V.~Alvarez *et al.* [NEXT Collaboration],** **``Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment," arXiv:1211.4838 [physics.ins-det].**

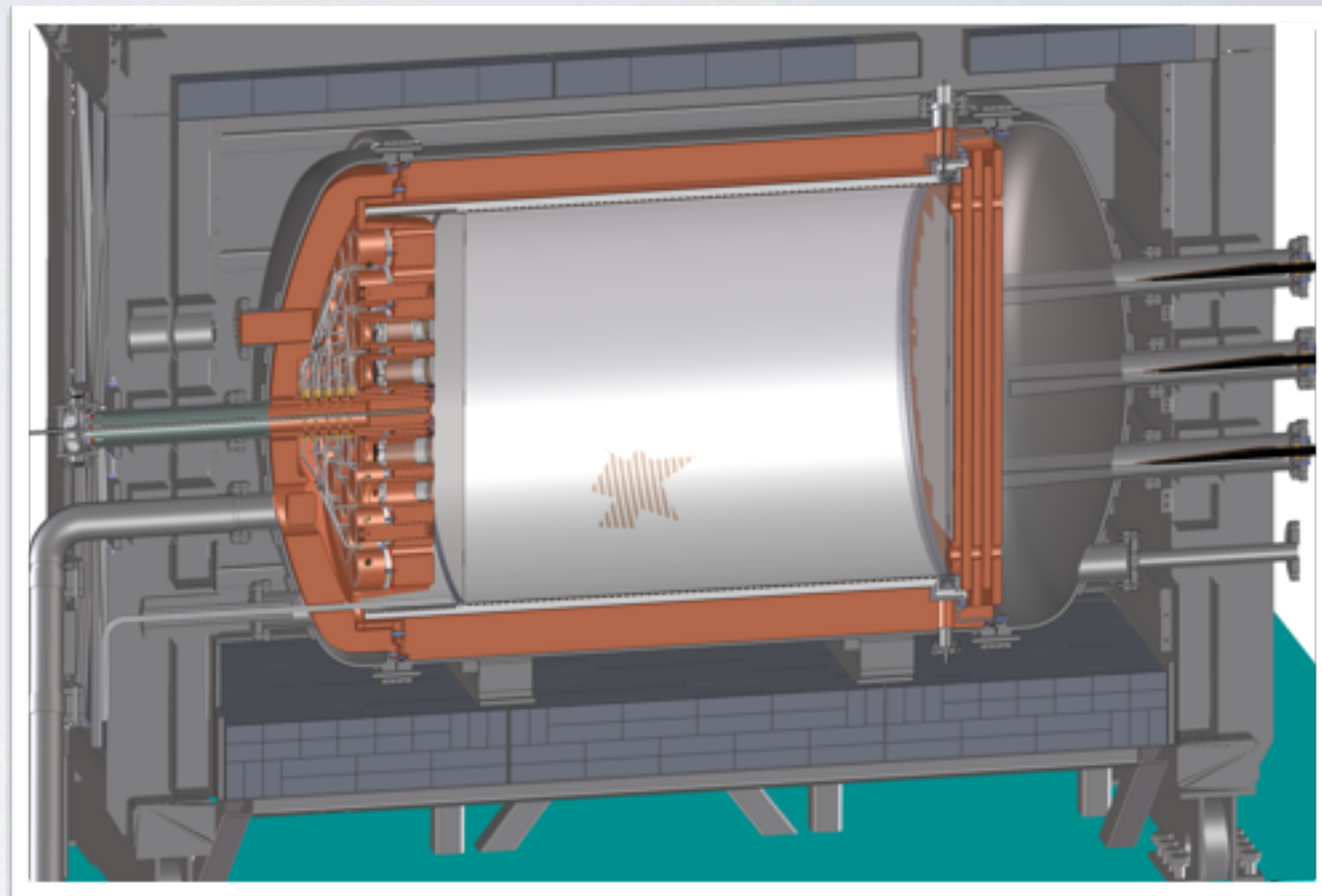
HPGXe has a topological signature (extra handle)





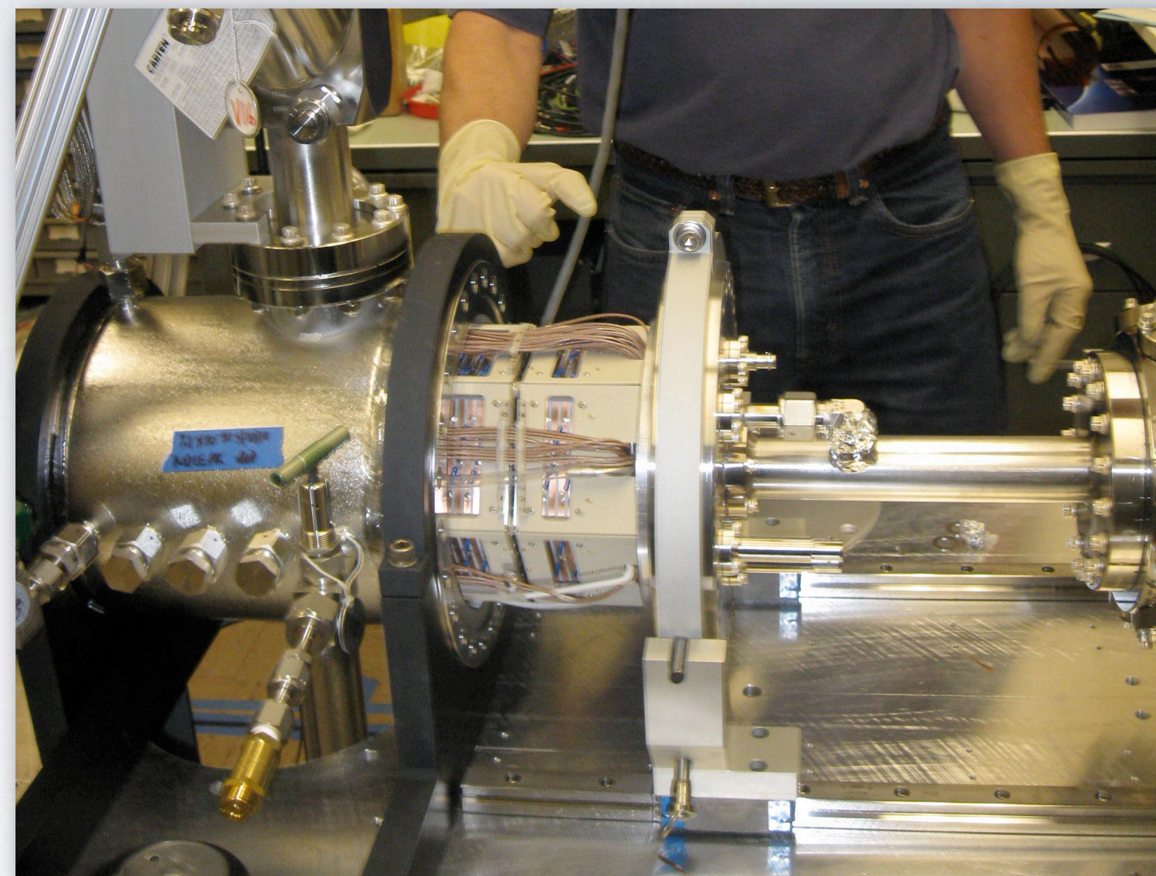
NEXT: An EL TPC



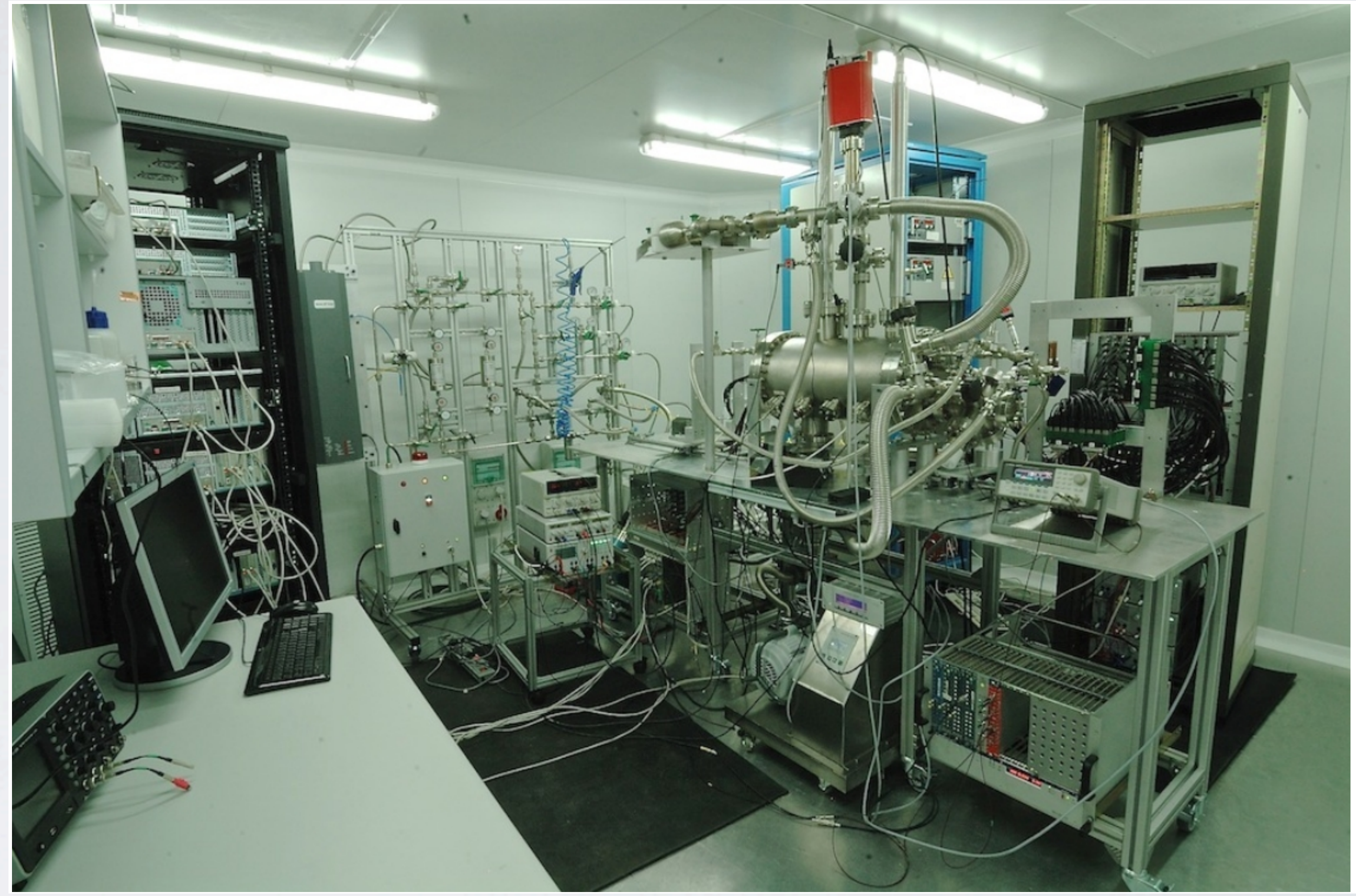


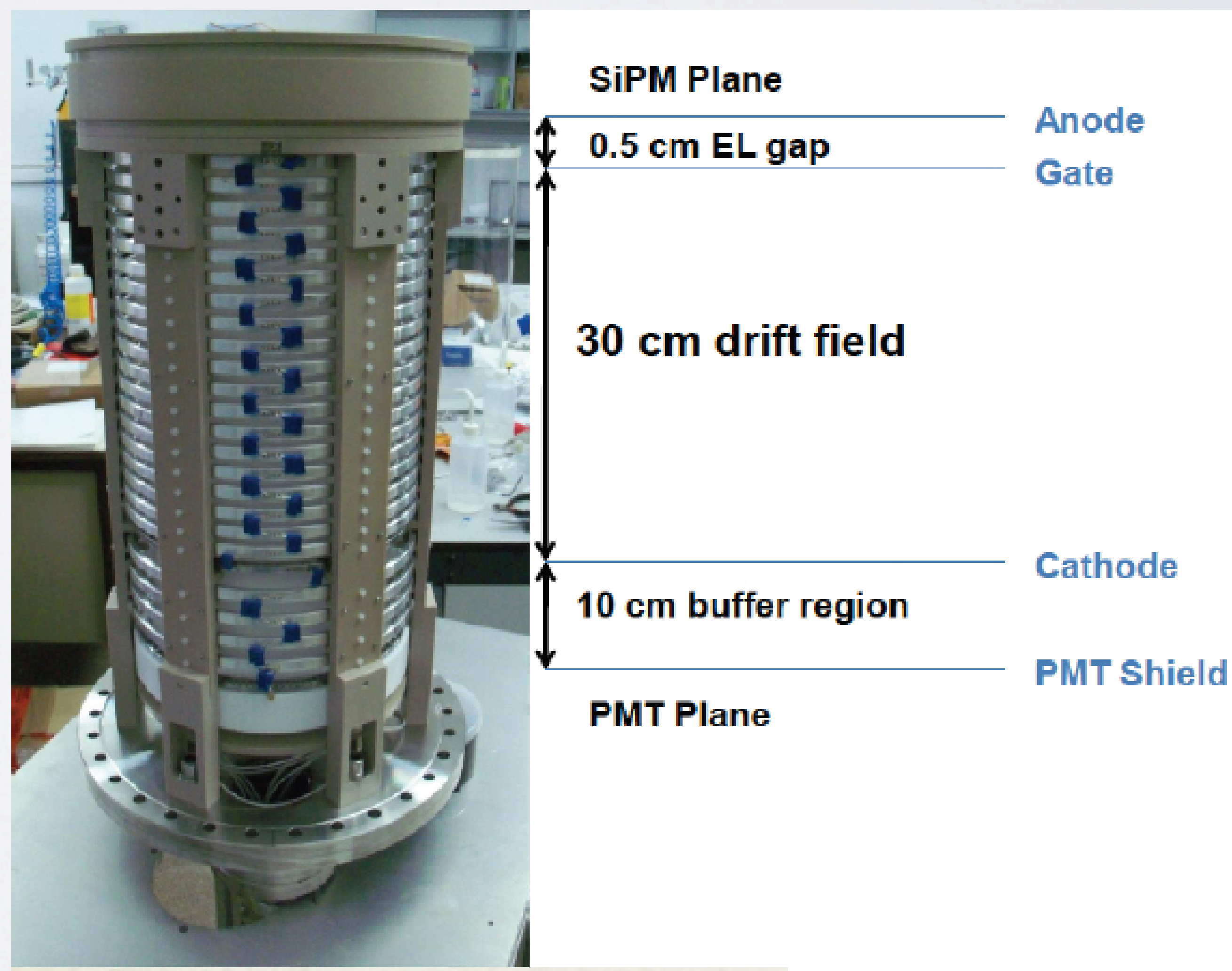
NEXT Collaboration, NEXT-100 Technical Design Report, arXiv:1202.0721

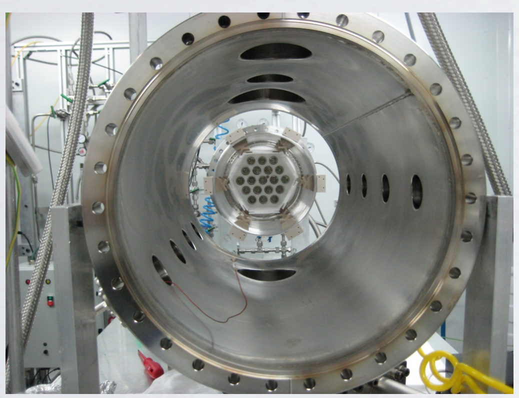
NEXT DEMO/DBDM

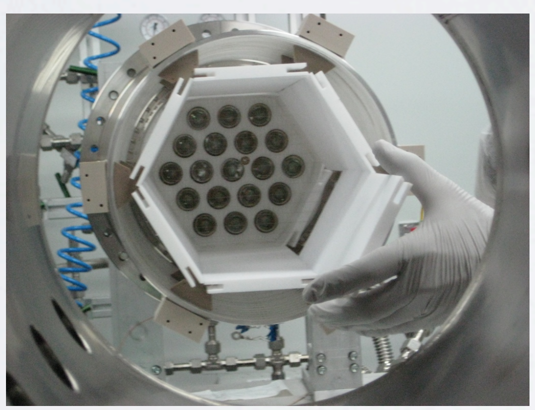


NEXT-DBDM at LBNL O(1 kg of gas). NEXT-DEMO at IFIC, O(5 kg of gas) St. Gottard!

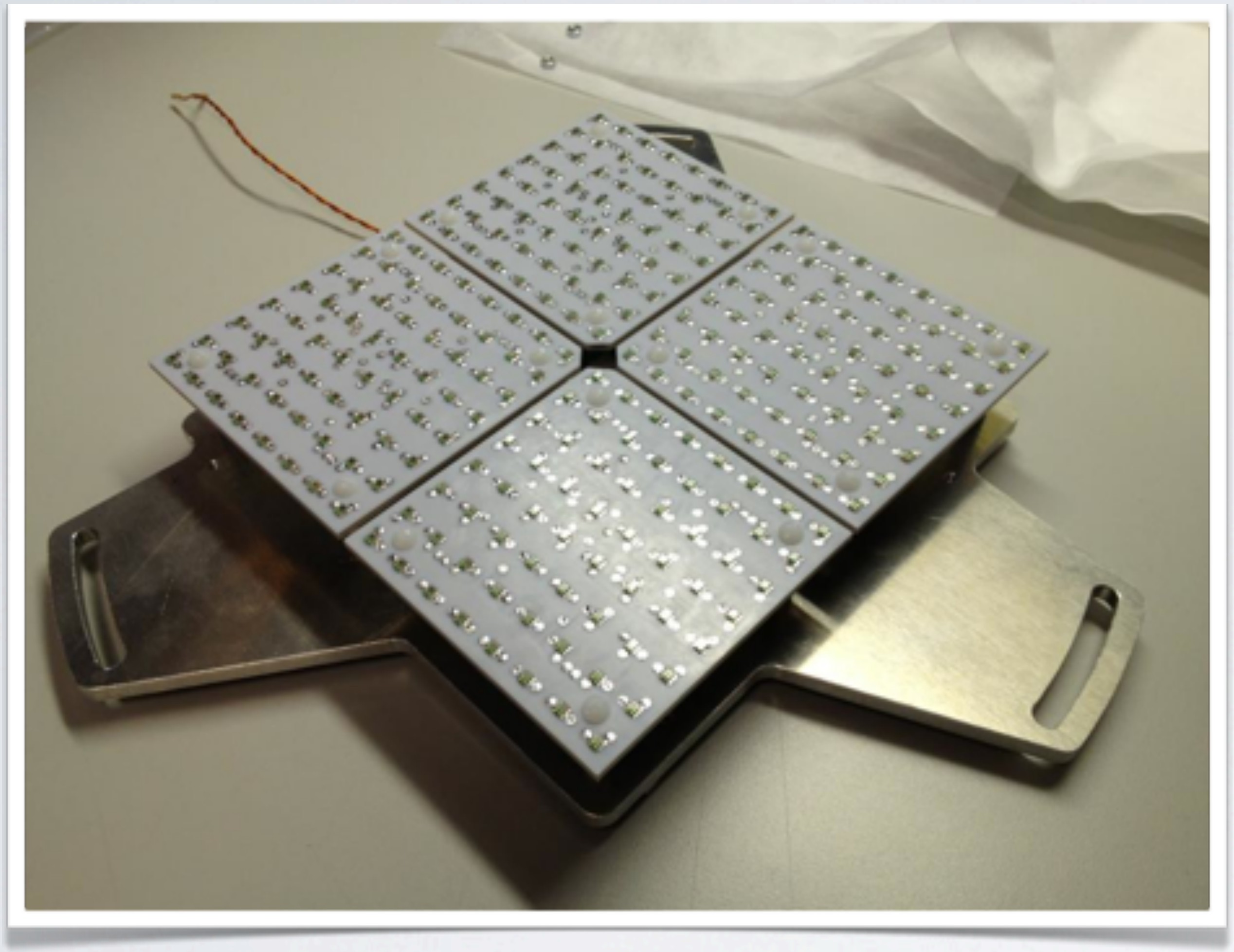


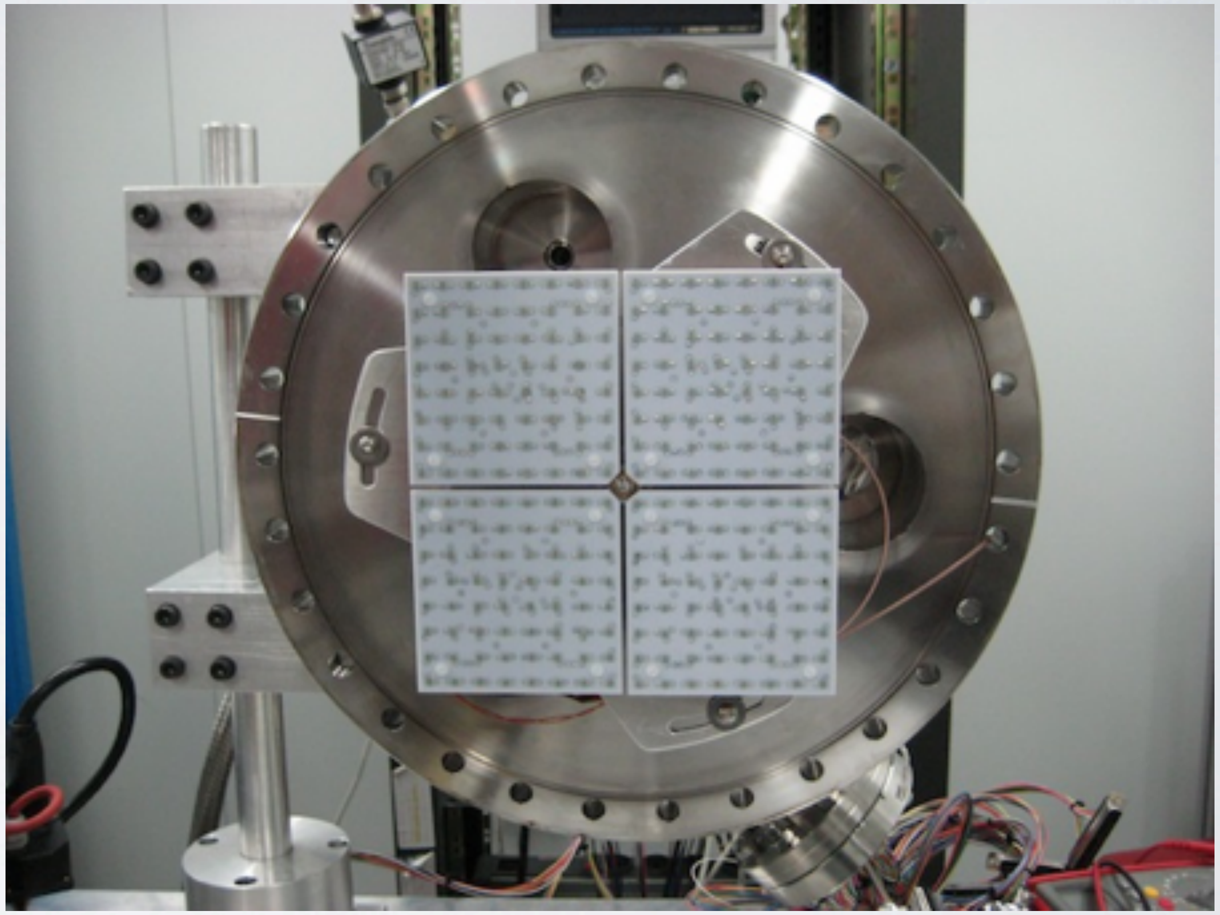

SiPM Plane
Anode
0.5 cm EL gap
Gate
30 cm drift field
Cathode
10 cm buffer region
PMT Shield
PMT Plane





THE TRACKING PLANE

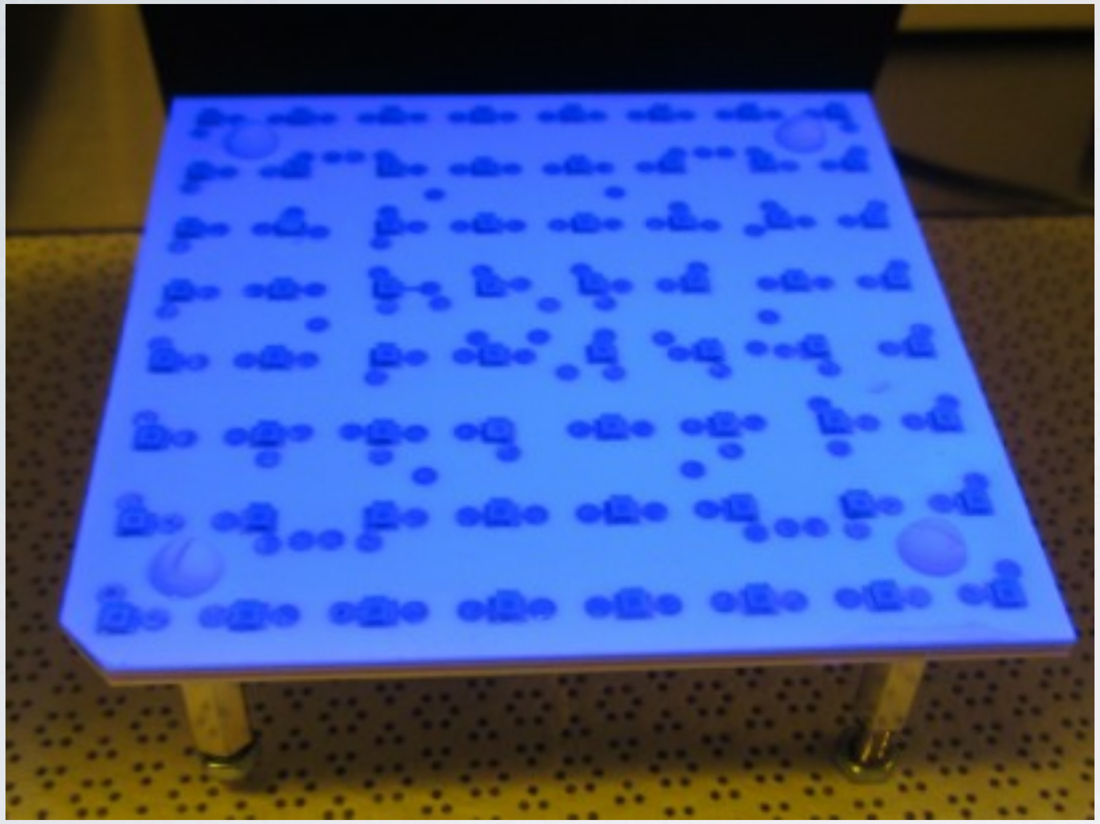


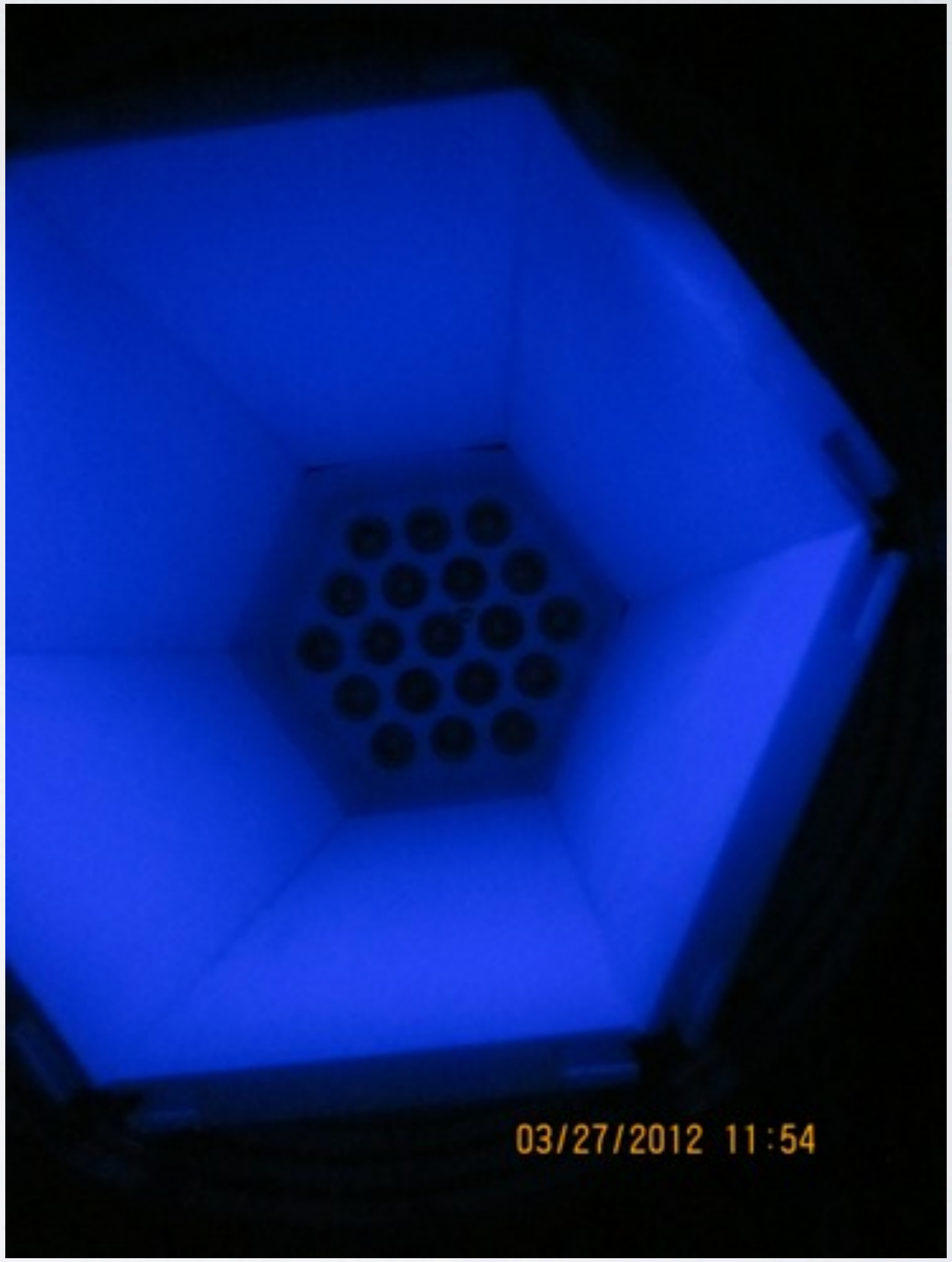


DBs made of Cuflon, hosting 64 PMTs per DB. In NEXT-100 there is about 110 DBs and 7000 channels.
First Light pixel plane operating in a detector

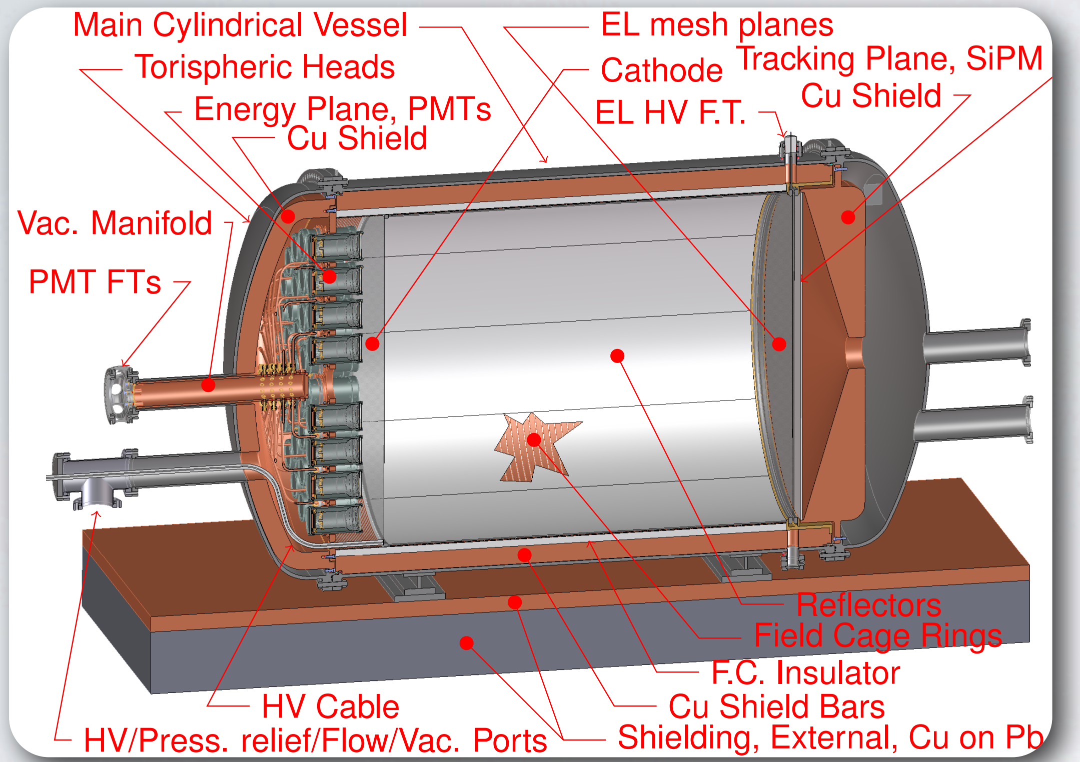
White through the looking glass

NEXT in blue





NEXT



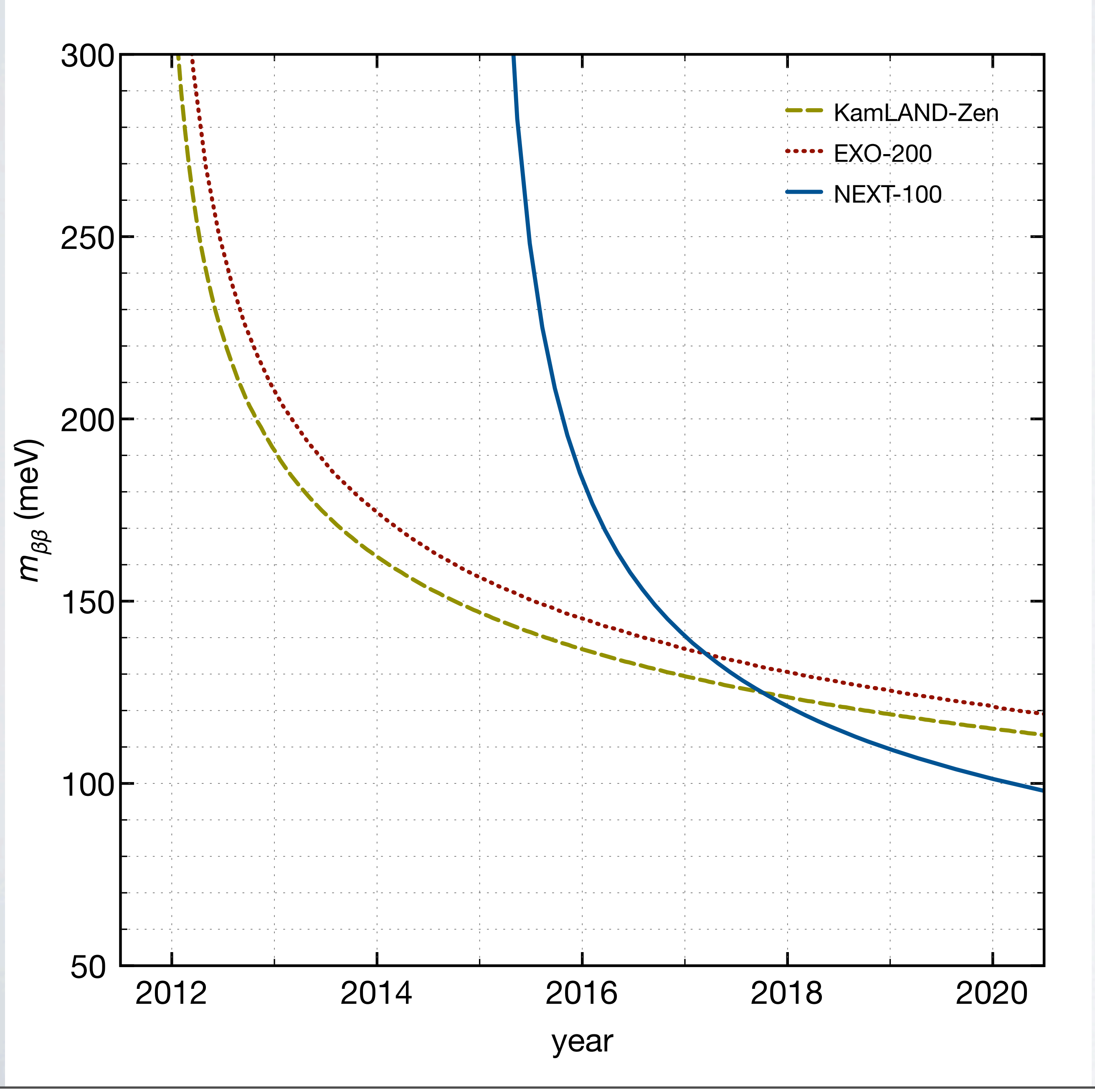
- **a**: Feasible (cheap)
- ε: moderate (30%)
- **Mt:** Scalable (≈multiton)
- ΔE good to very good (0.7% to 0.5% FWHM)
- **b** very good to excellent (10^{-4} ckky)

- Excellent
- Very good
- Good
- Moderate
- Poor

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

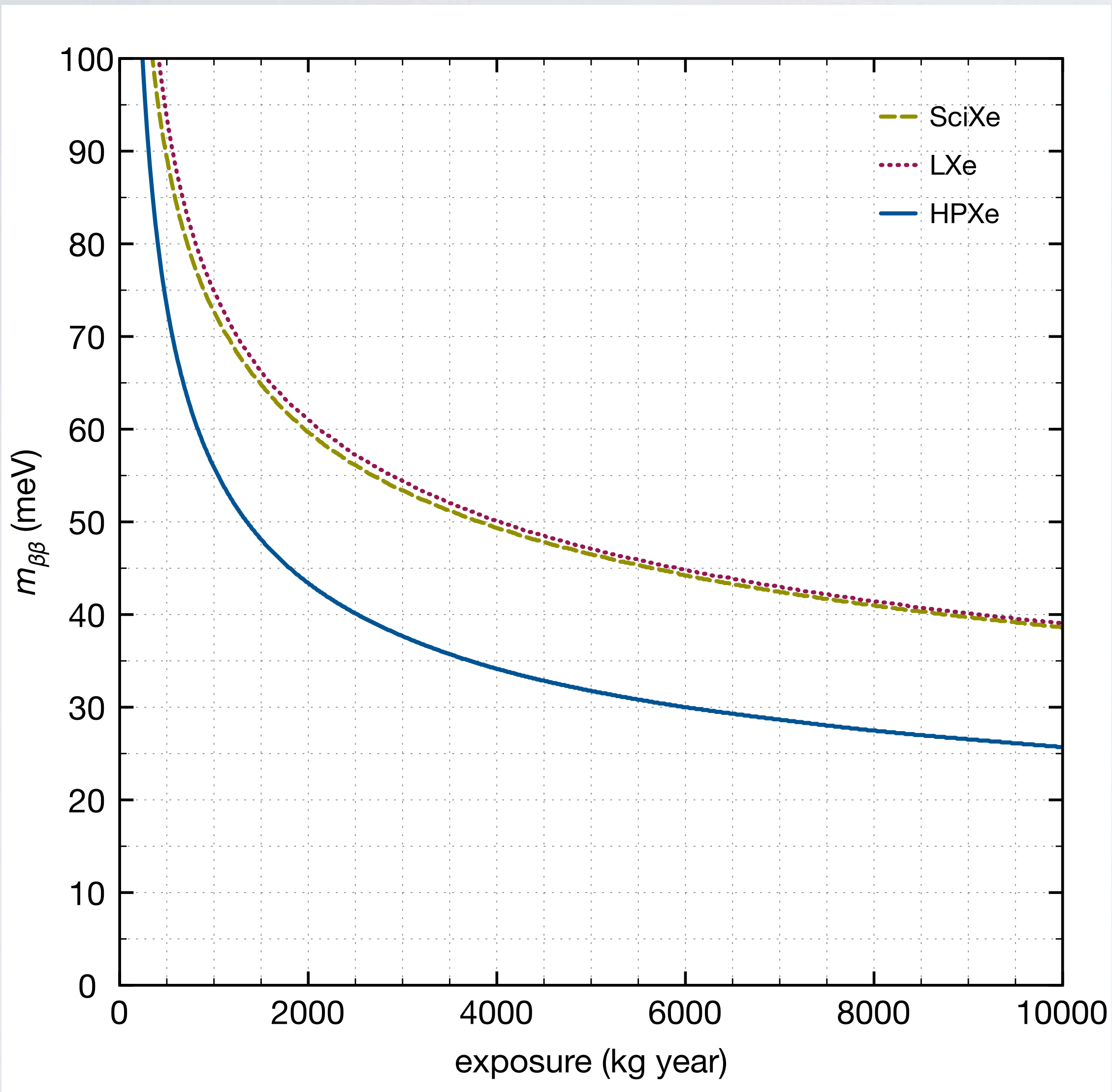
Sensitivity

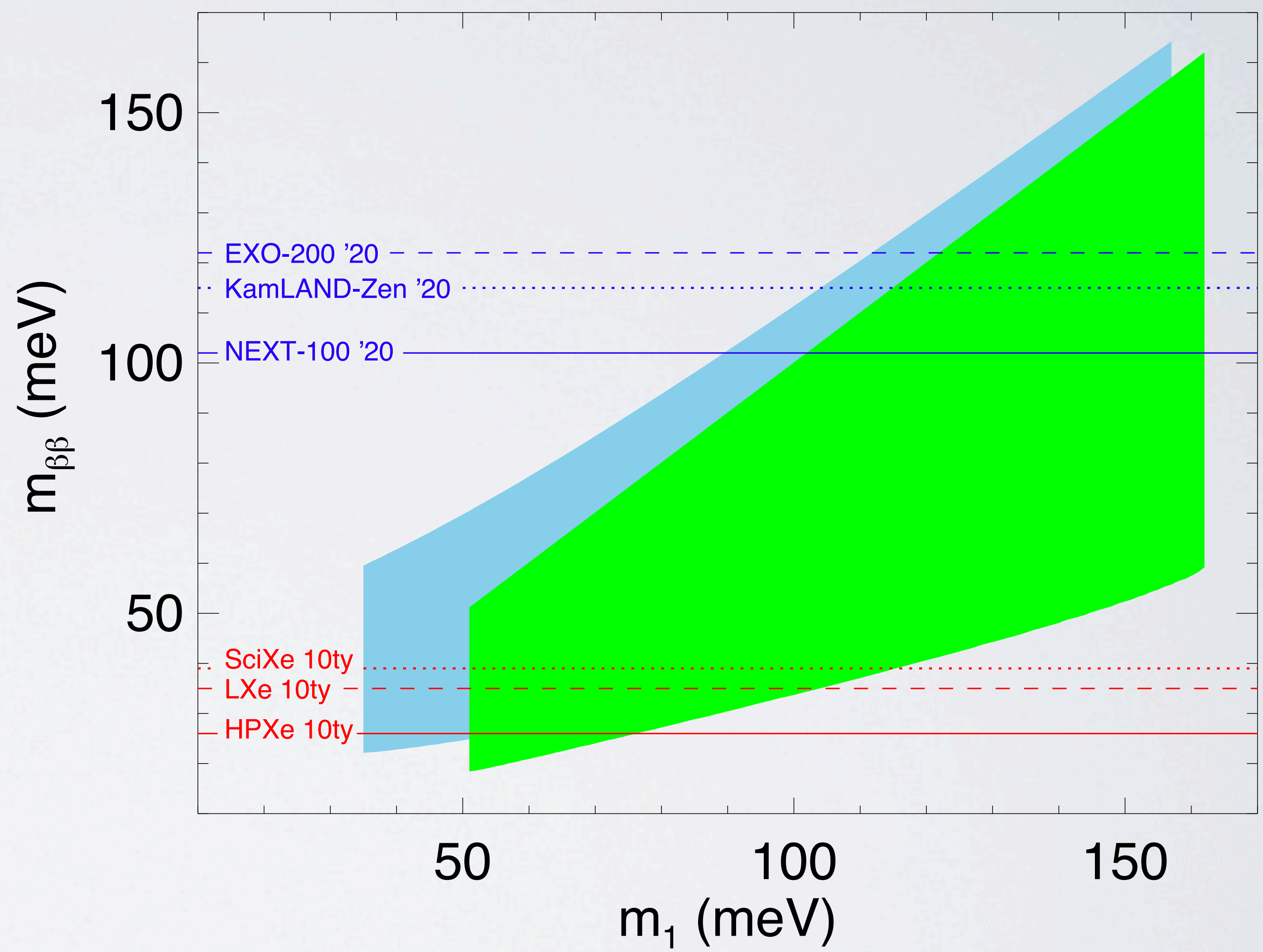
Experiment	M (kg)	f (%)	ε (%)	δE (% FWHM)	b (10^{-3} ckky)
EXO-200	110	0.81	0.56	4.0	1.5
KamLAND-Zen	330	0.91	0.42	9.9	1.0
NEXT-100	100	0.91	0.30	0.7	0.5



Discovery potential of xenon-based neutrinoless double beta decay experiments in light of small angular scale CMB observations.
J.J. Gomez-Cadenas, J. Martin-Albo, J.Munoz Vidal, C. Pena-Garay. Jan 2013. 17 pp.
e-Print: arXiv:1301.2901 [hep-ph] |

Experiment	ε (%)	δE (% FWHM)	b (10^{-3} ckky)
LXe	0.38	3.2	0.1
XeSci	0.42	6.5	0.1
HPXe	0.30	0.5	0.1





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LXe	0.38	3.2	0.1
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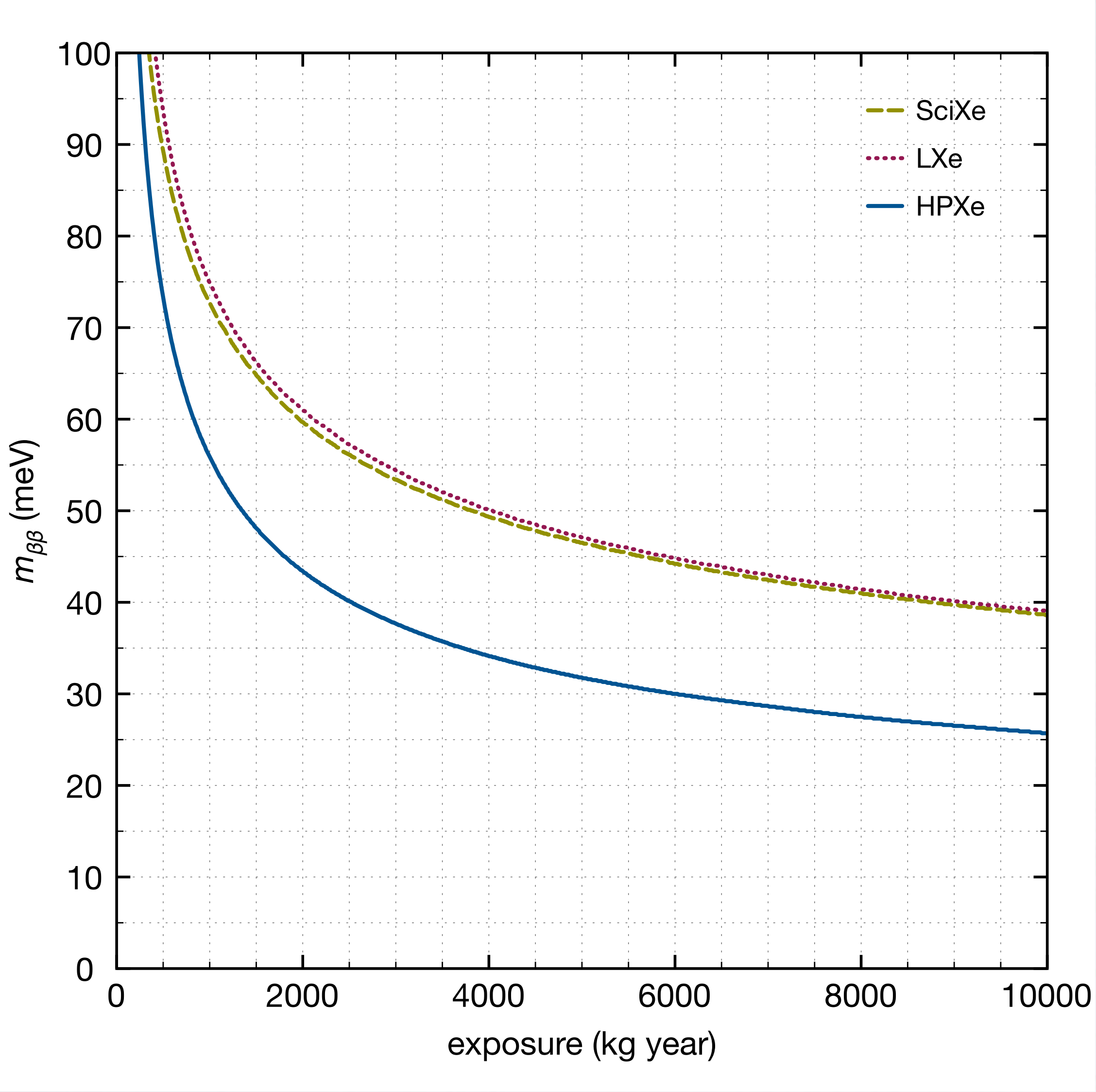

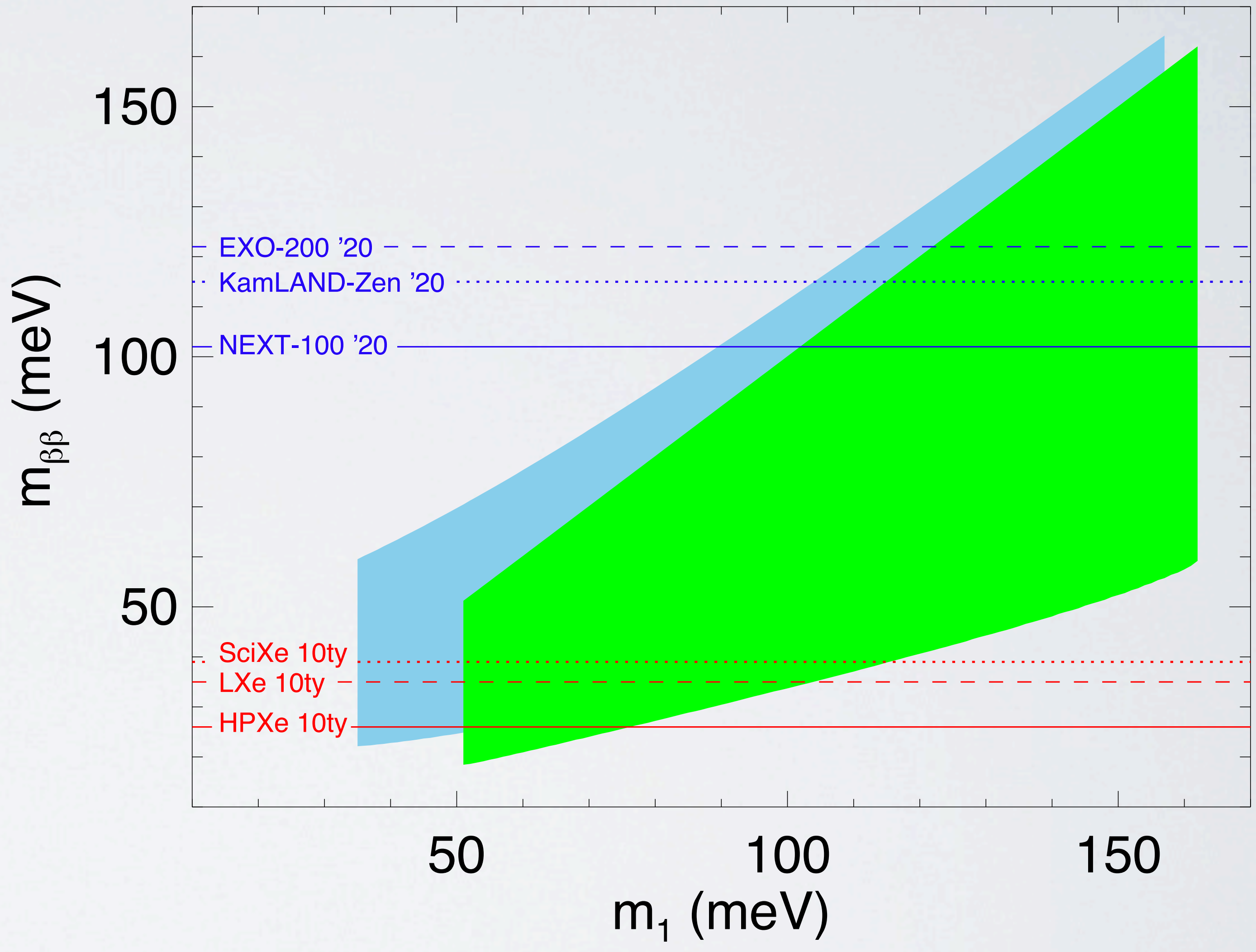

If recent cosmological measurements are correct, xenon experiments (in particular NEXT) can make a major discovery.

Summary and outlook

- Neutrino are being cornered. Cosmological measurements, direct measurements and neutrino oscillation experiments will reveal their mass spectrum in the next few years.
- Neutrinoless double beta decay experiments are coming to age. Exploring whether the neutrino is its own antiparticle may require detectors in the range of the (multi)ton isotope mass, with good efficiency and extremely good background rejection. Xenon experiments can provide all the above.
- In addition, HPXe can provide superb energy resolution. If the recent claim on the cosmological mass of the sum of the three neutrinos holds, the potential for discovery is very high.

Neutrino through the looking-glass

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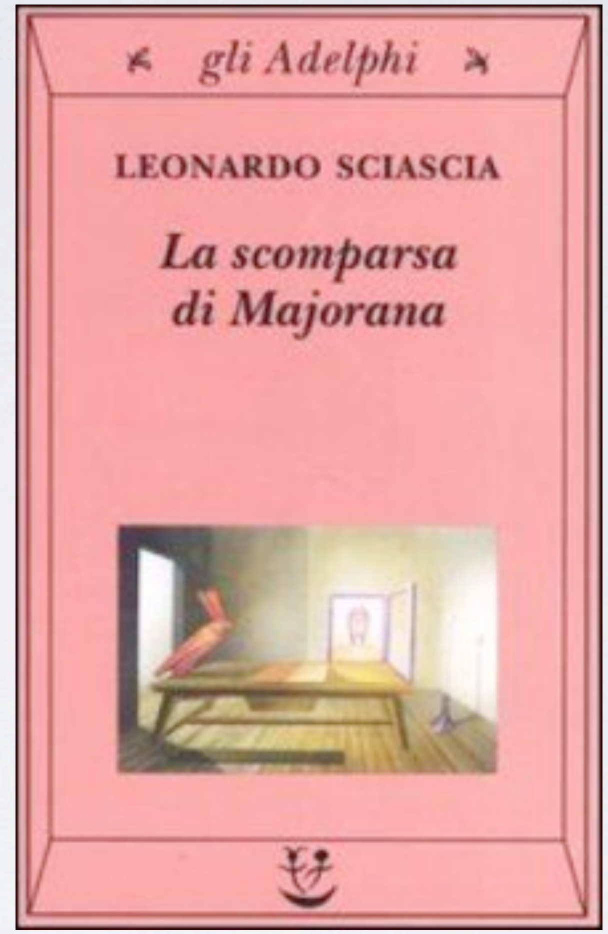
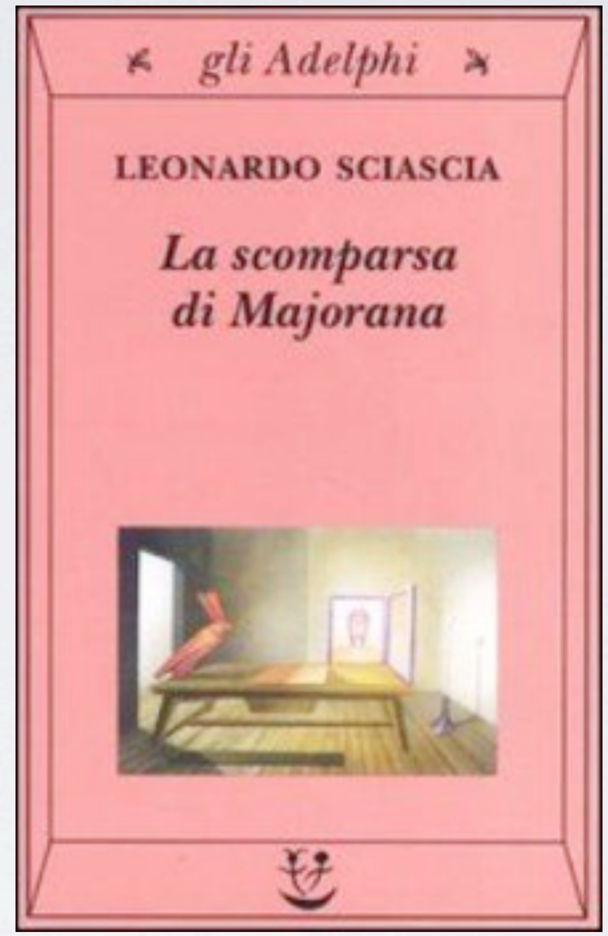


- Majorana disappeared in the sea, in March 1938, aged 32. His body was never found. The reasons for his alleged suicide remain obscure.

Ettore Majorana through the looking-glass



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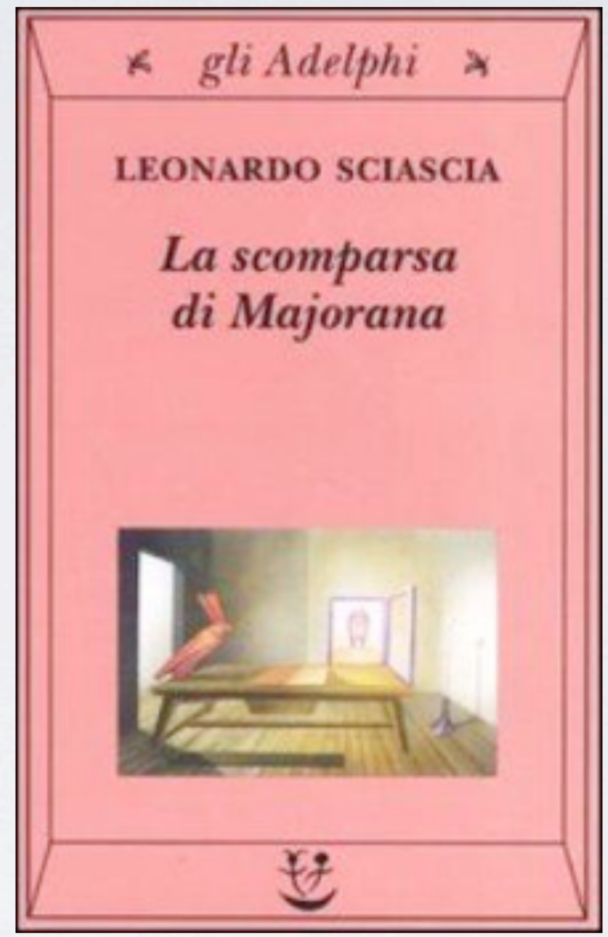
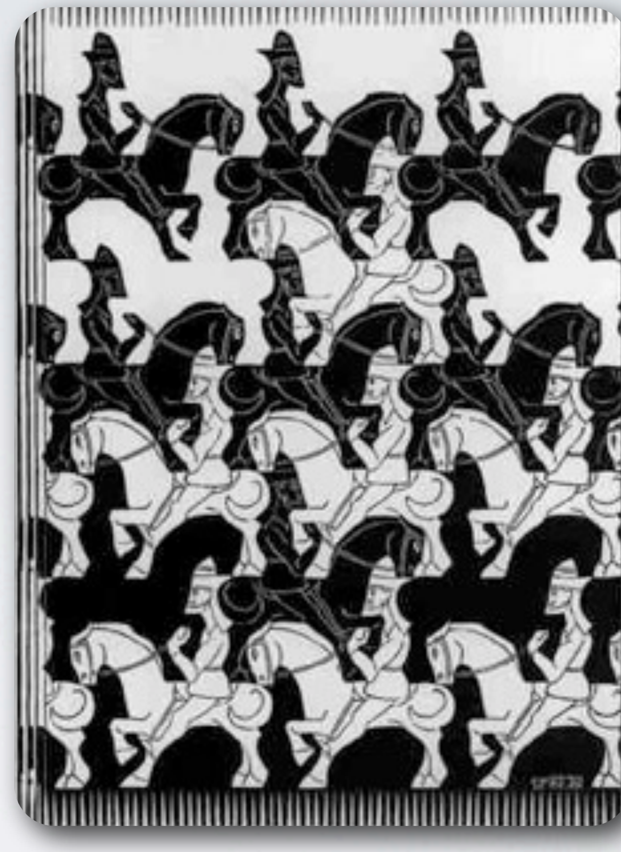
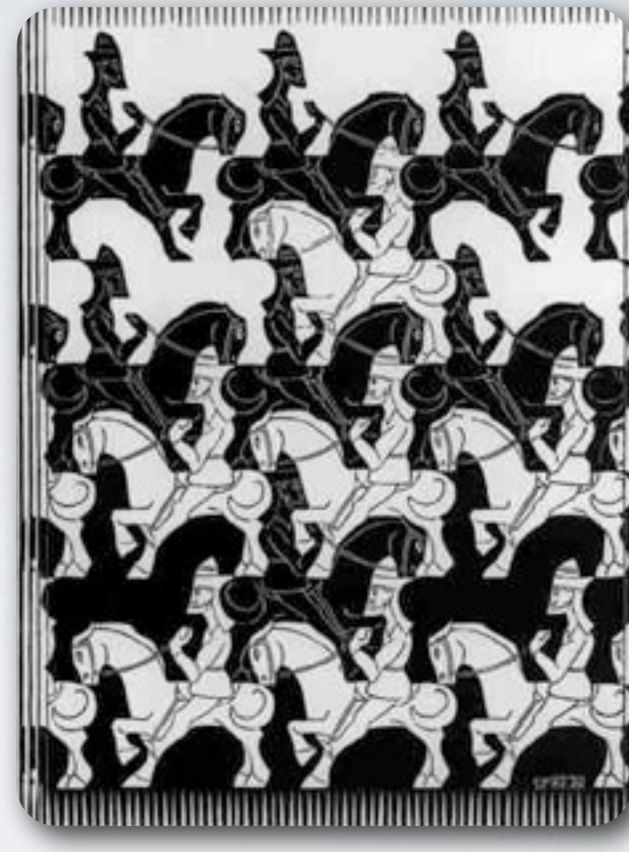
Ettore Majorana through the looking-glass



- Majorana disappeared in the sea, in March 1938, aged 32. His body was never found. The reasons for his alleged suicide remain obscure.
- Perhaps, like Alice, he managed to escape, through the looking-glass, to a better World.





Thanks for your attention