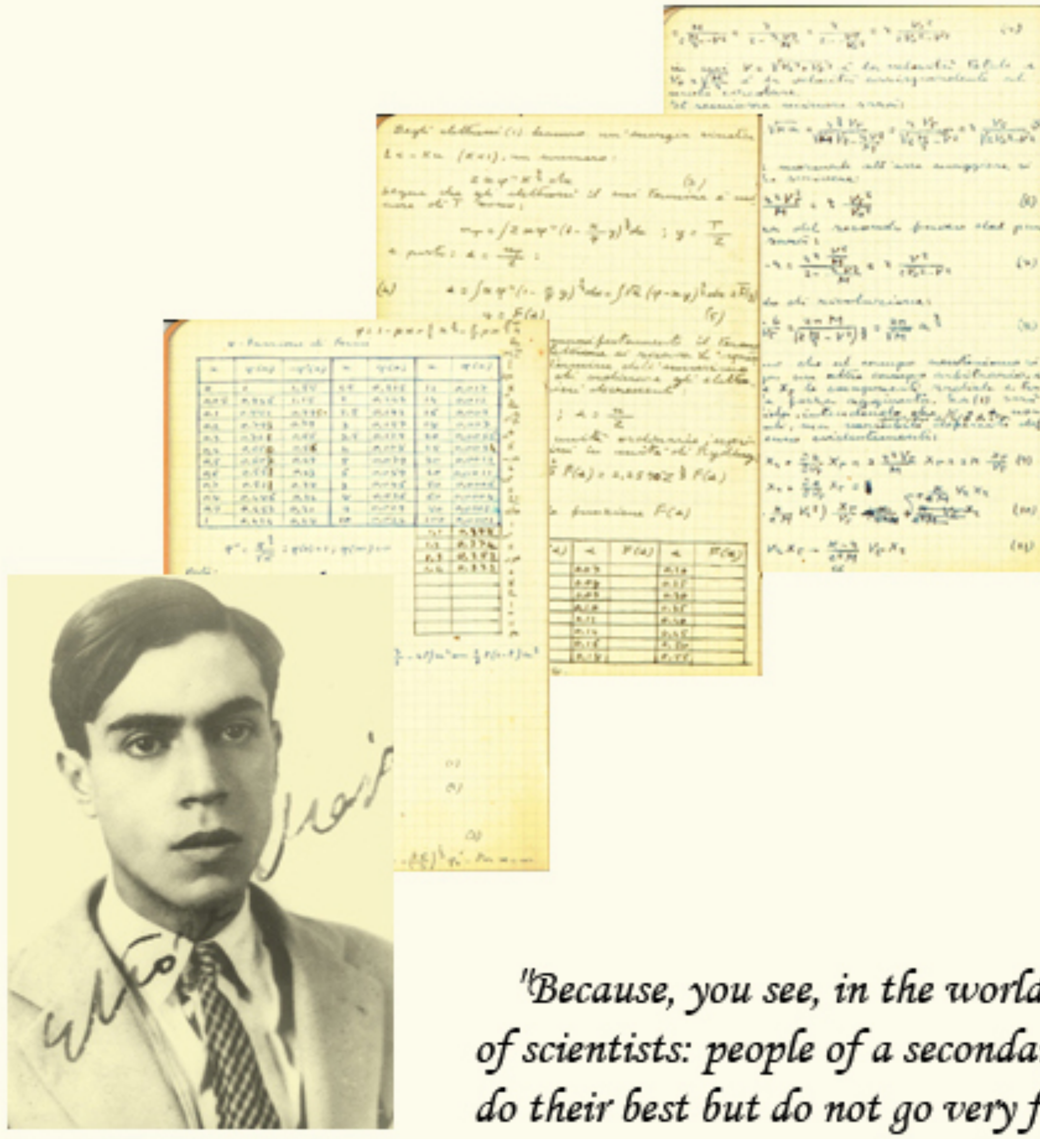
Ettore Majorana meets his shadow (IV)

J.J. Gómez Cadenas
IFIC-CSIC-U.Valencia
CERN Summer Student Lectures
2008

Meet the genius

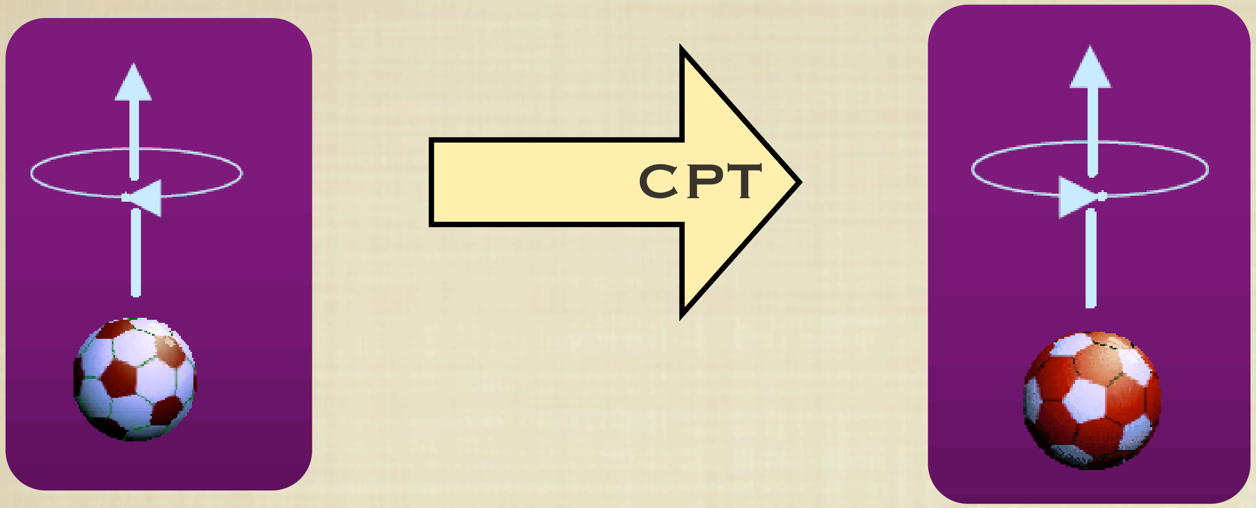


"Because, you see, in the world there are various categories of scientists: people of a secondary or tertiary standing, who do their best but do not go very far. There are also those of high standing, who come to discoveries of great importance, fundamental for the development of science.

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

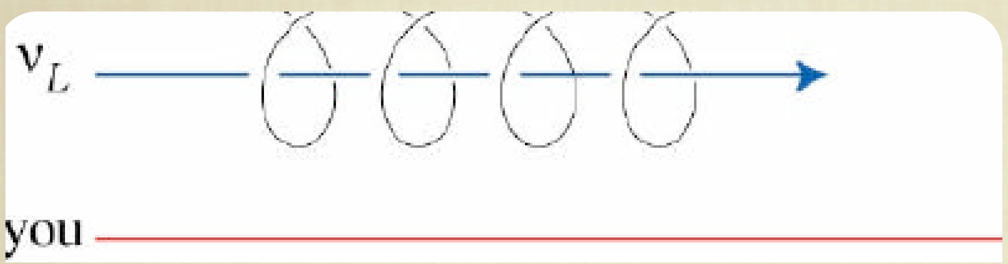
Particles & antiparticles

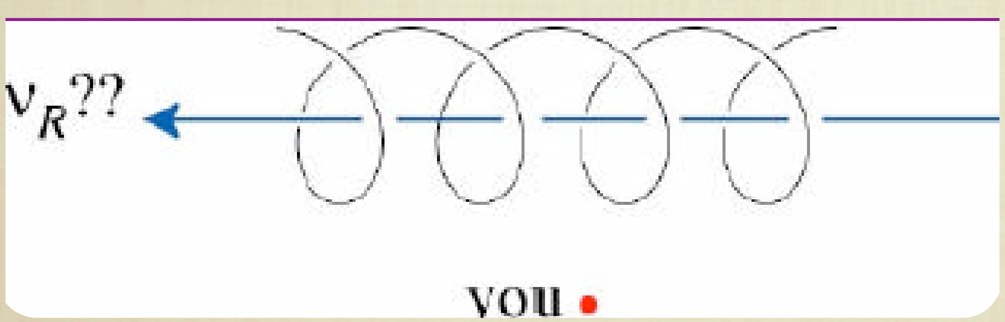


Same mass

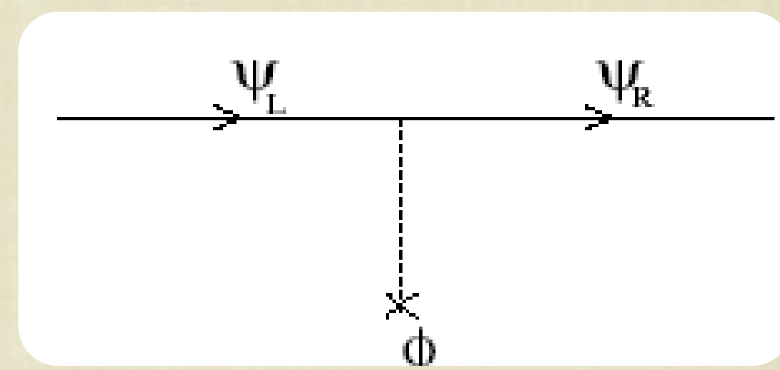
Opposite electric charge

Opposite helicity





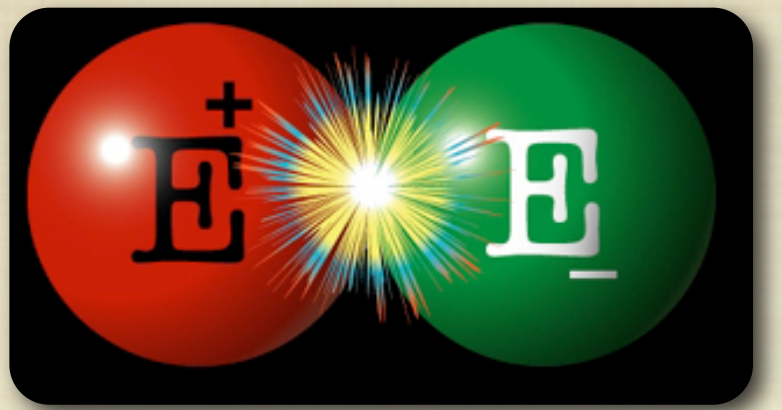
If a particle is massive left and right states must exist



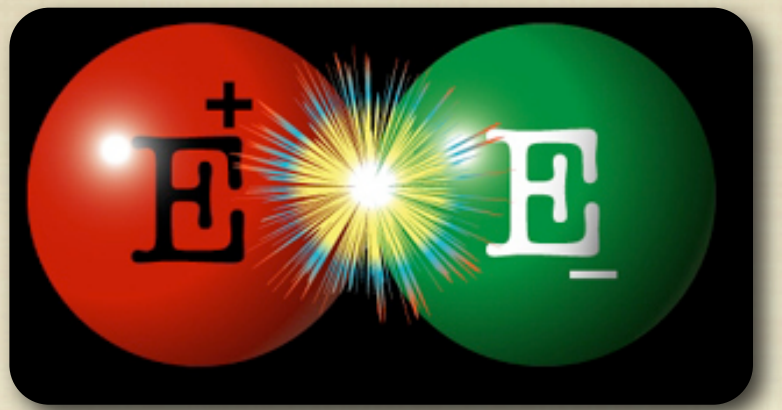
A (electrically) charged fermion such as the electron as left and right states for particle and antiparticle (which are distinct by electric charge)

Charged fermions couple left-right states to a scalar (the Higgs) to generate masses

Majorana's Inside



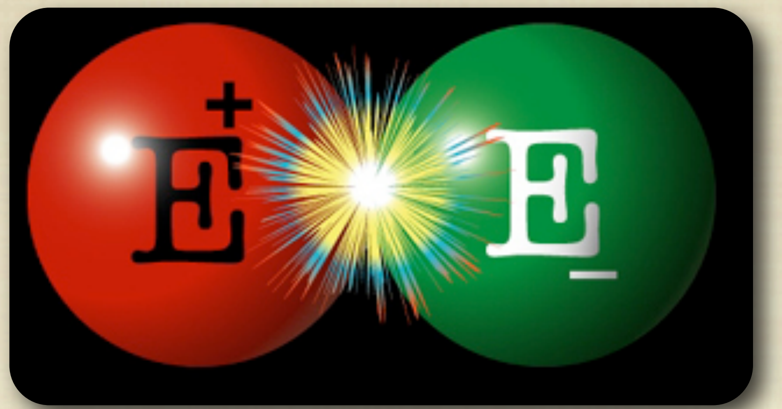
Majorana's Inside



The neutrino does no have electric charge.

It could be the only known (elementary) particle that is its own antiparticle

Majorana's Inside



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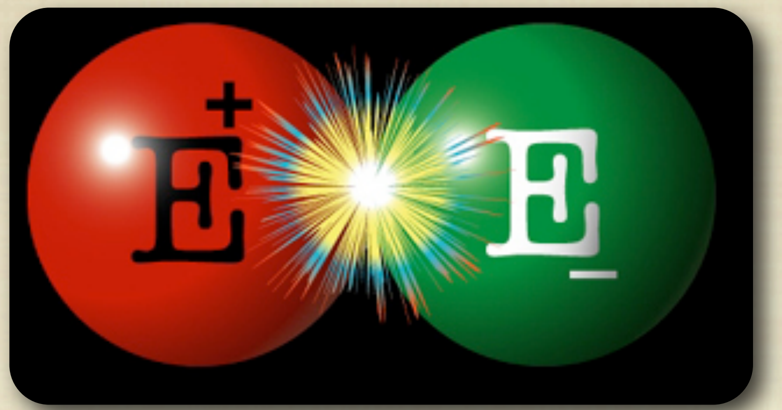

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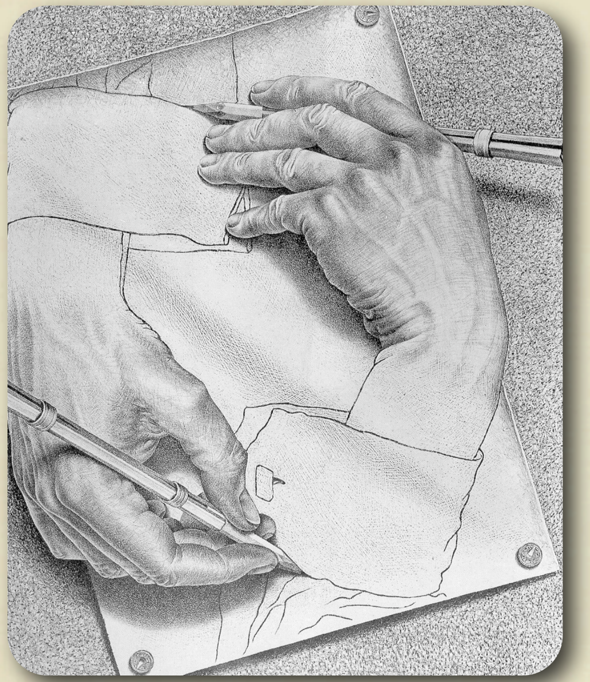
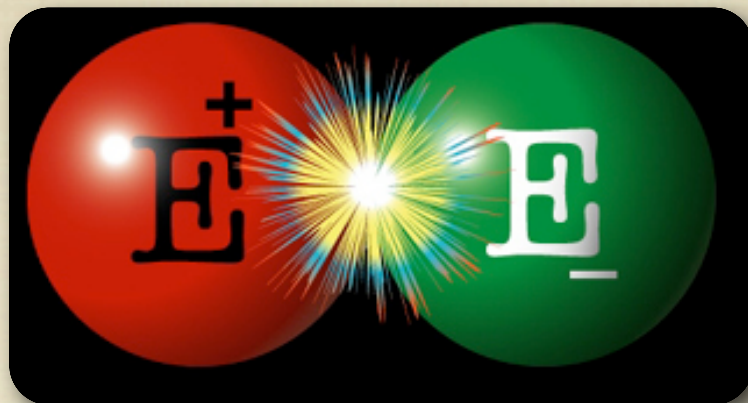


Charged fermions: 4 states
2(particle/antiparticle)x 2
(left right)

Majorana's Inside



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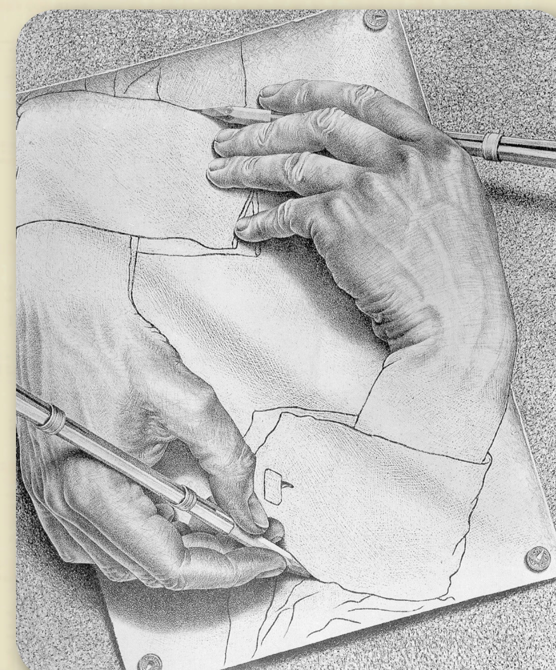

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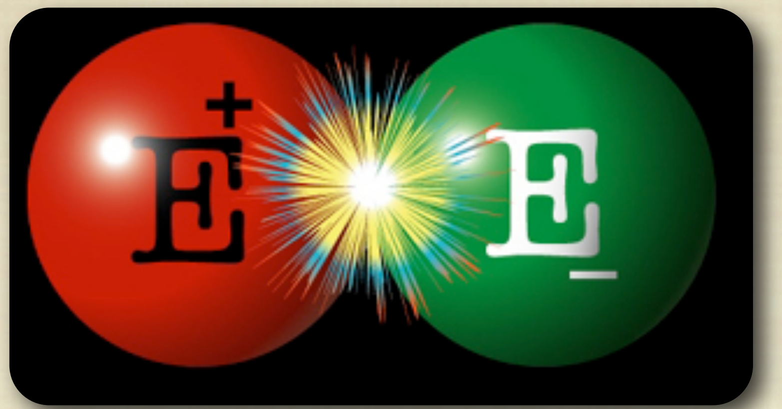
Majorana's Inside



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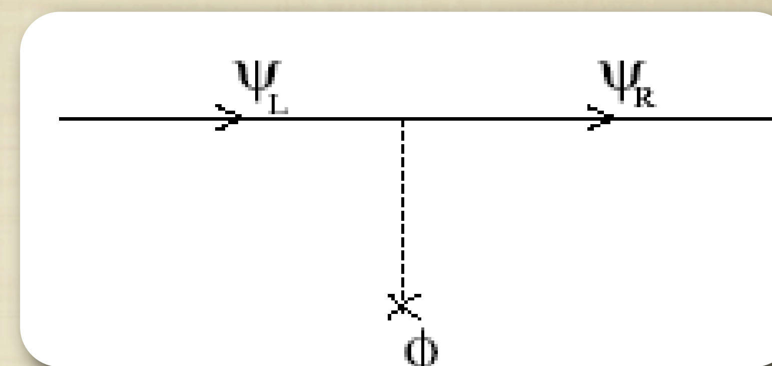
electric charge.

It could be the only known (elementary) particle that is its own antiparticle

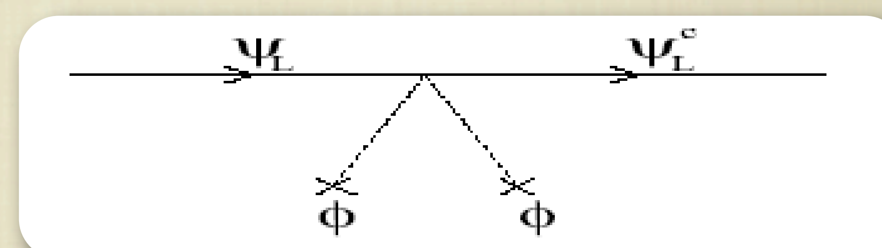
Charged fermions: 4 states 2(particle/antiparticle)x 2 (left right)

Neutrinos: can use the right handed state (that must be there if massive) to describe the antiparticle

Majorana's neutrino

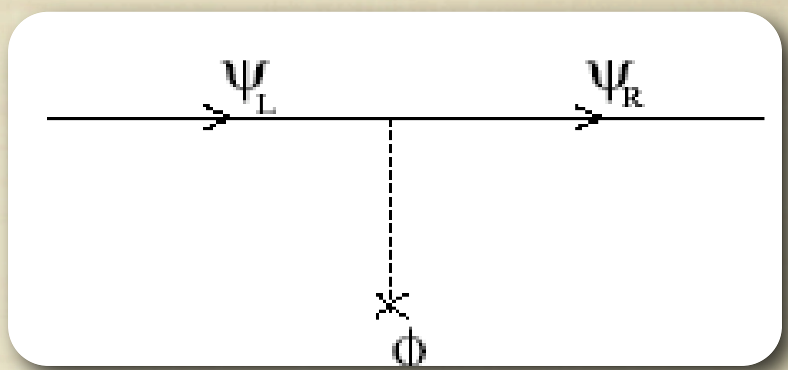


$$m_\nu = \lambda v$$



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

Majorana's neutrino



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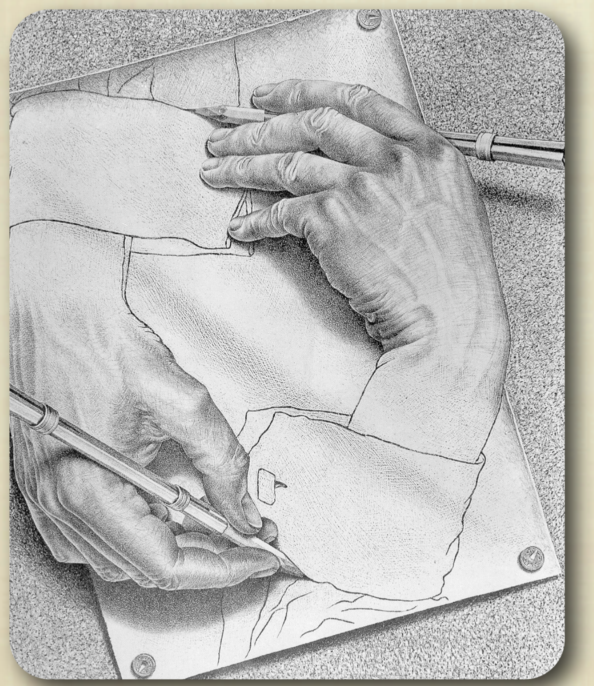

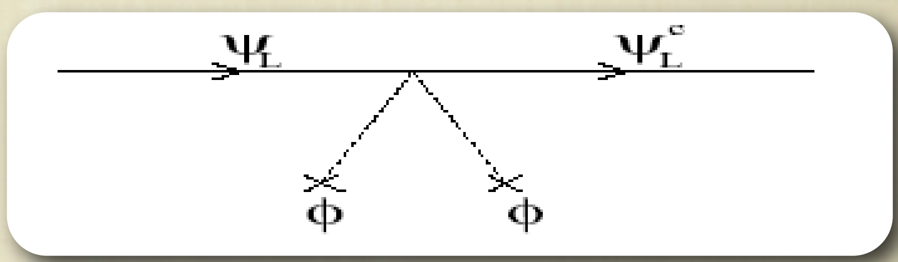

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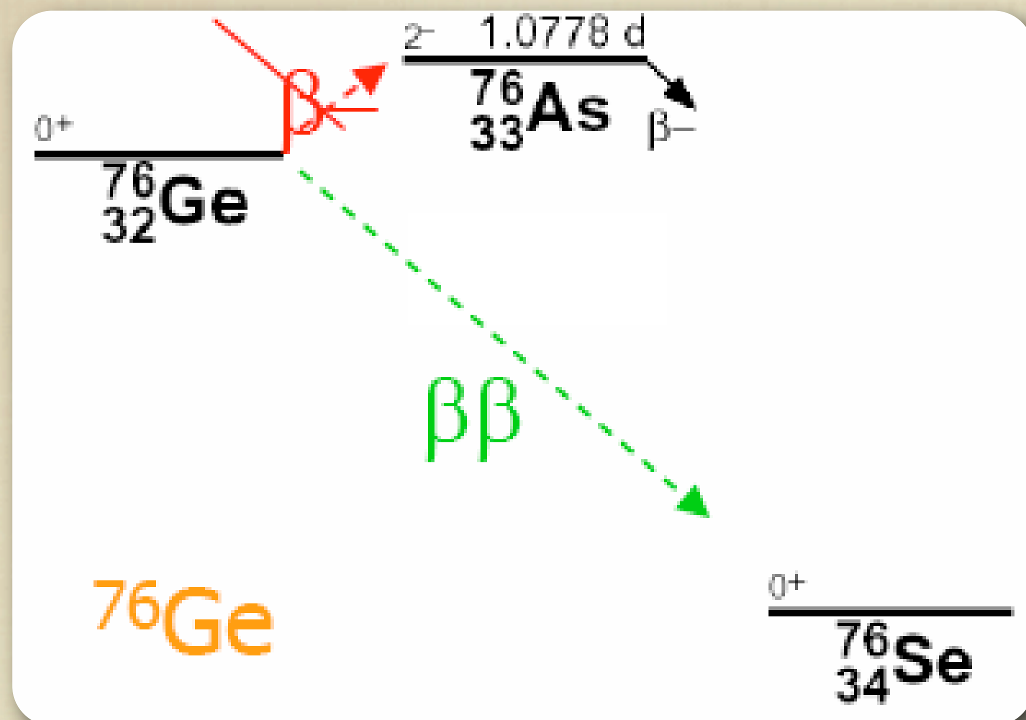
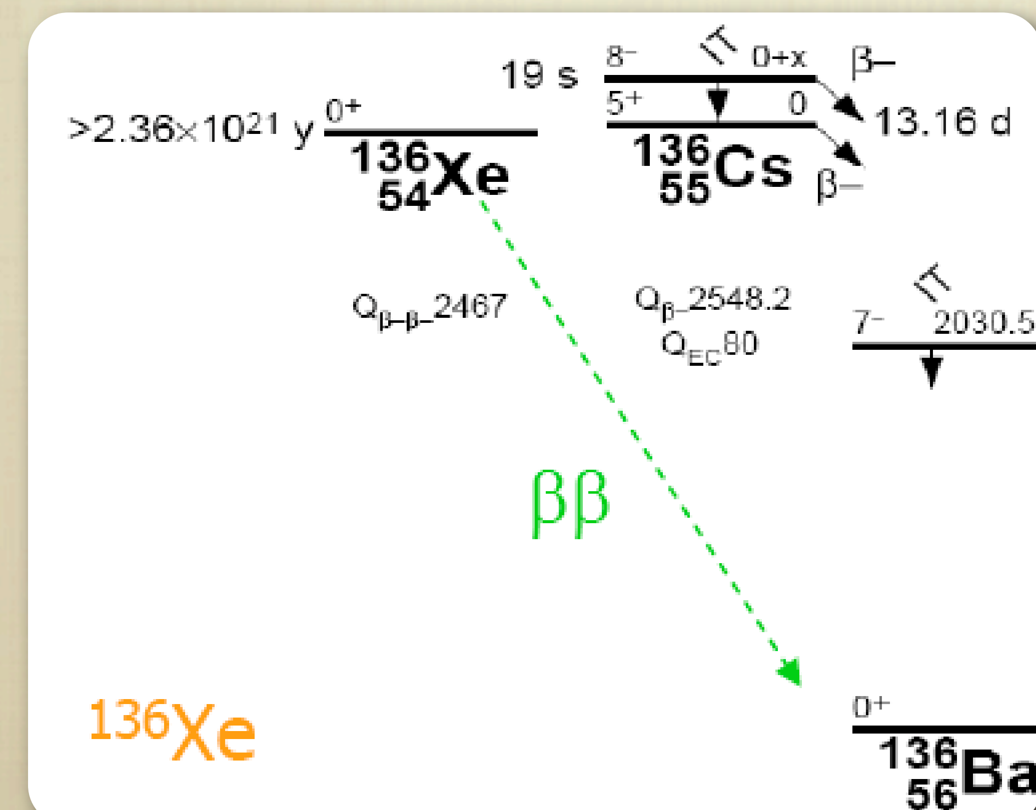
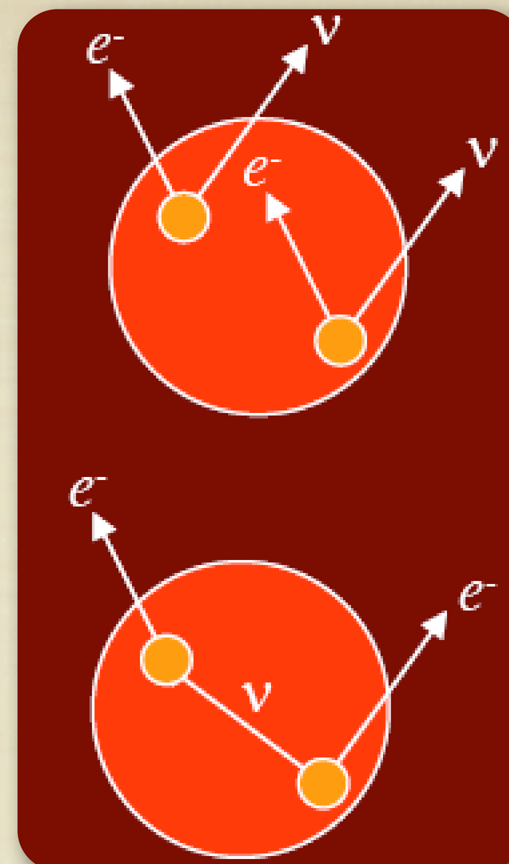
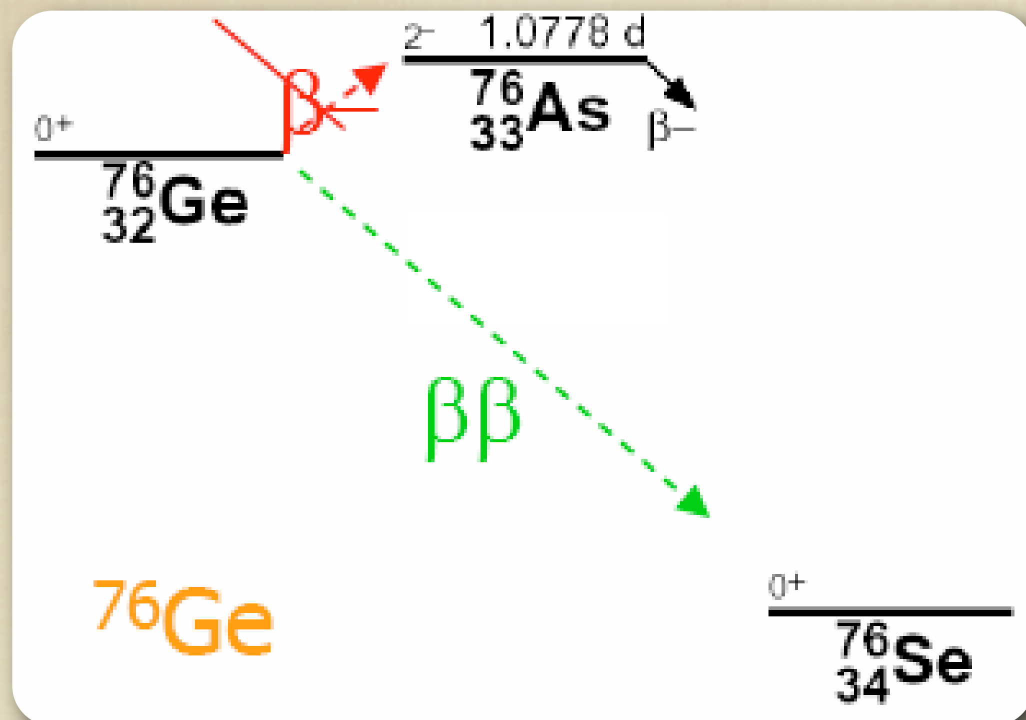
Neutrino double-beta decay

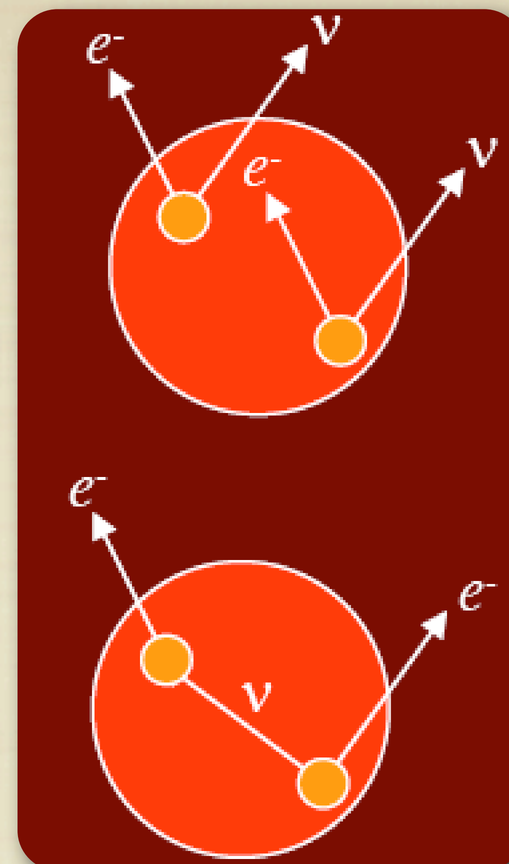


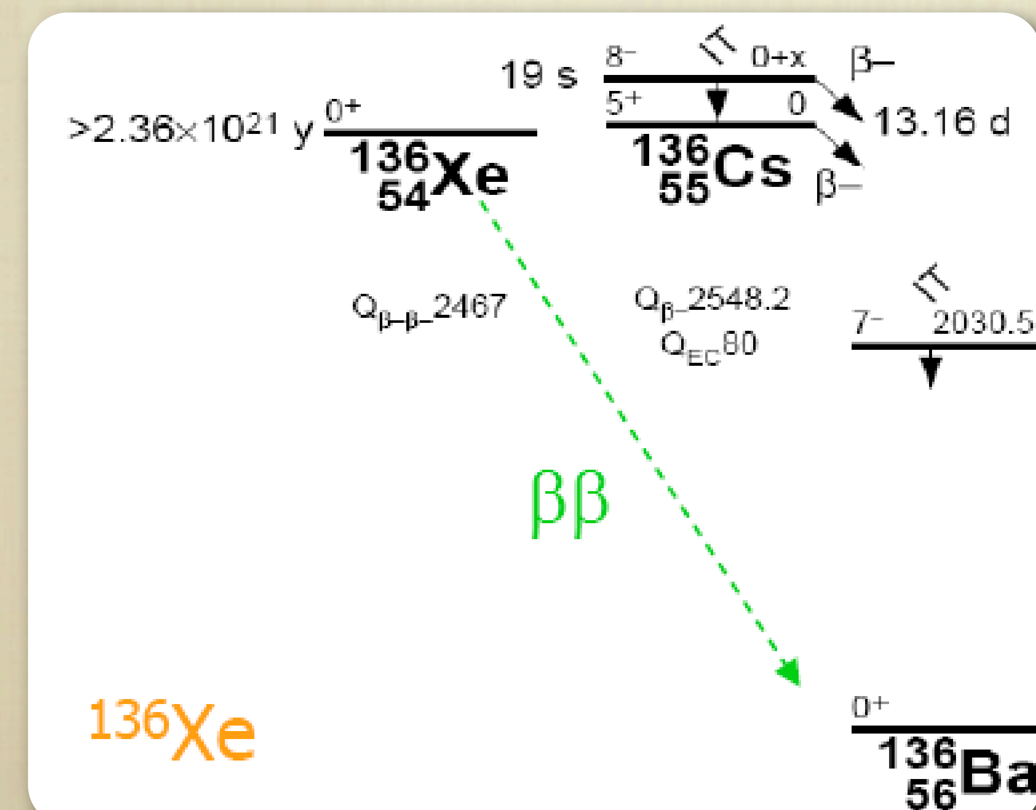


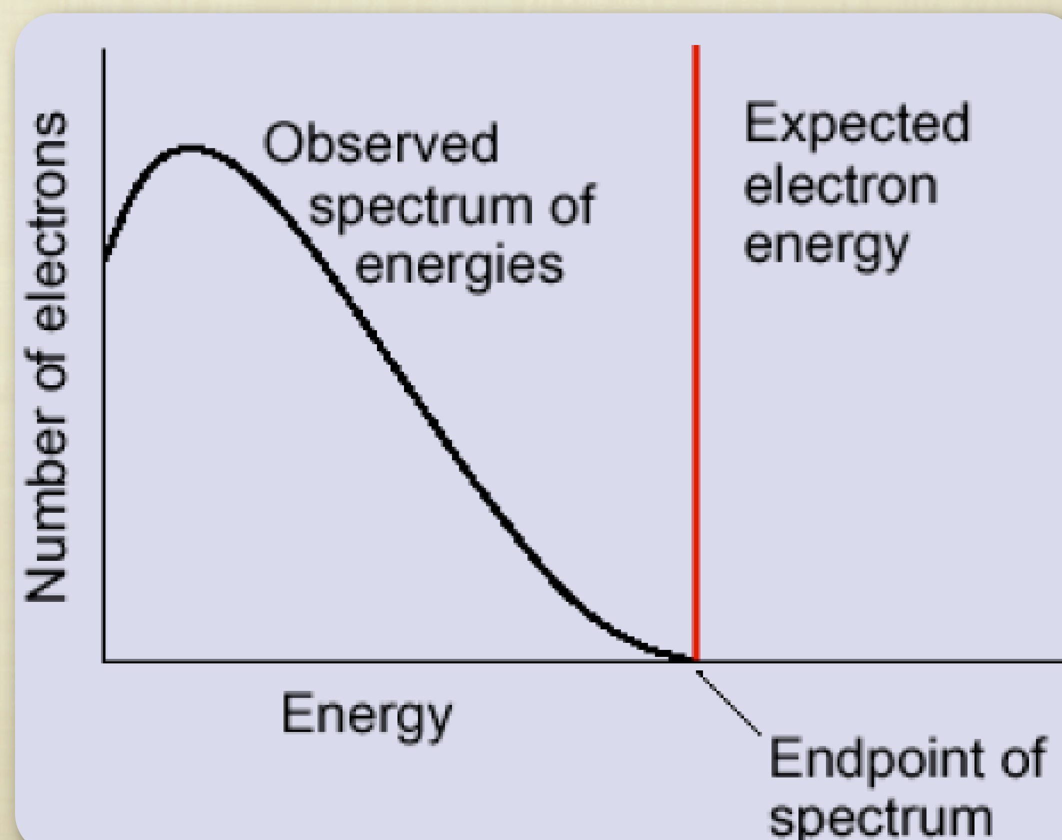


Neutrino double-beta decay









Neutrino double-beta decay

ββ2ν: two simultaneous β decays

$$(Z, A) \to (Z+2, A) + e_1^- + e_2^- + \overline{\nu}_{e_1} + \overline{\nu}_{e_2}$$

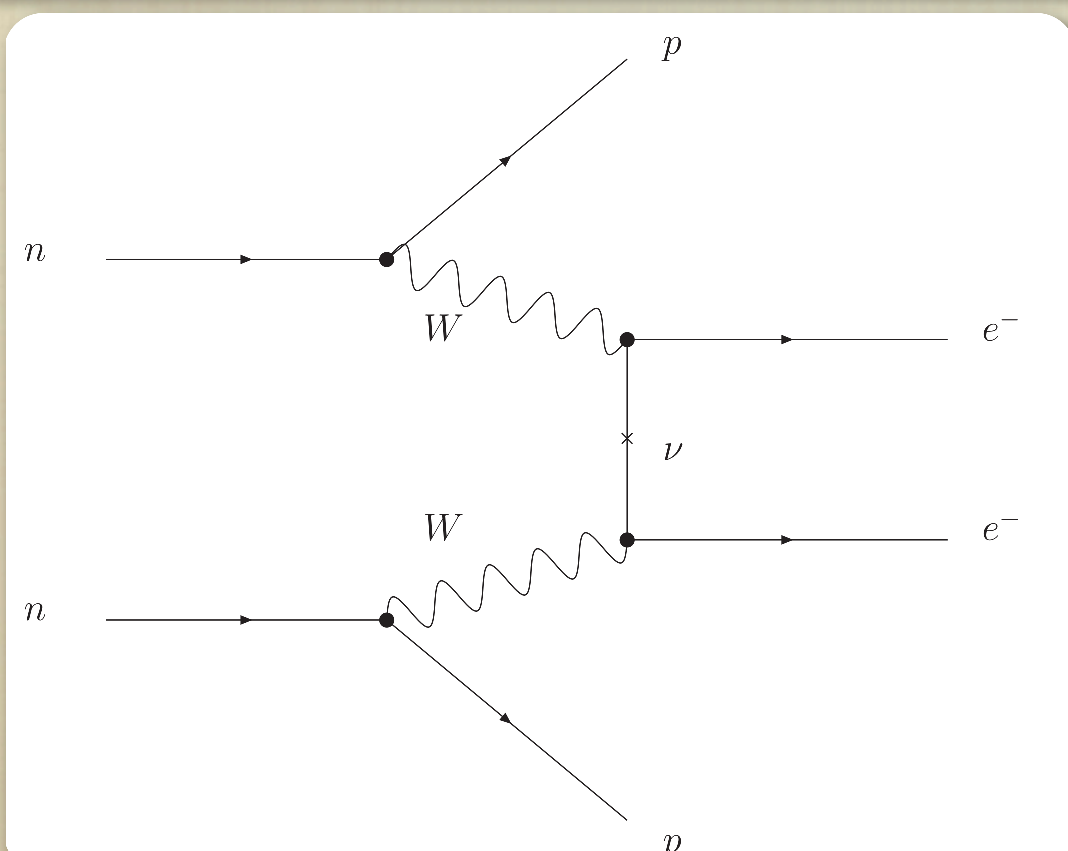
$$\frac{1}{T_{1/2}^{2\nu}} = G^{2\nu}(Q, Z)|M^{2\nu}|^2$$

ββ0ν: requires massive Majorana neutrinos. Non-SM process.

$$(Z, A) \to (Z+2, A) + e_1^- + e_2^- + \xcancel{\overline{\nu}_{e_1} + \overline{\nu}_{e_2}}$$

$$(\Delta L = 2)$$

$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q, Z)|M^{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$

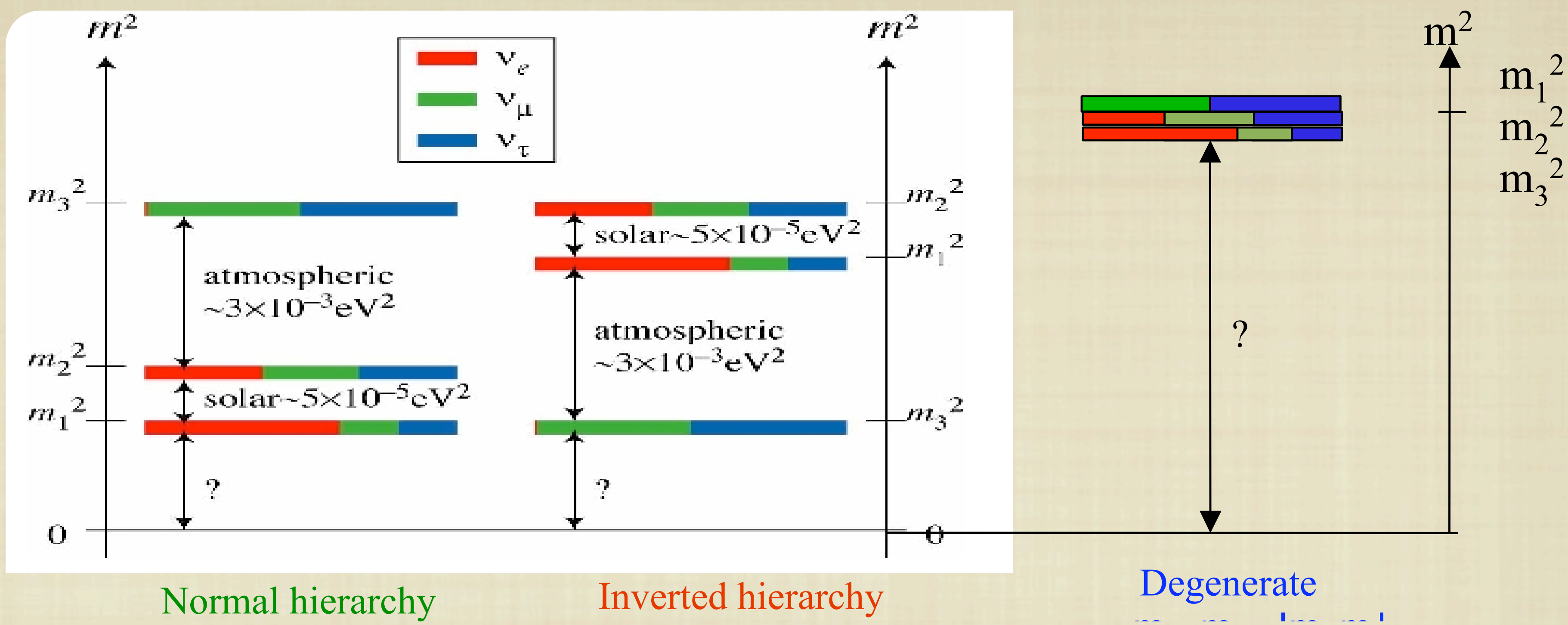


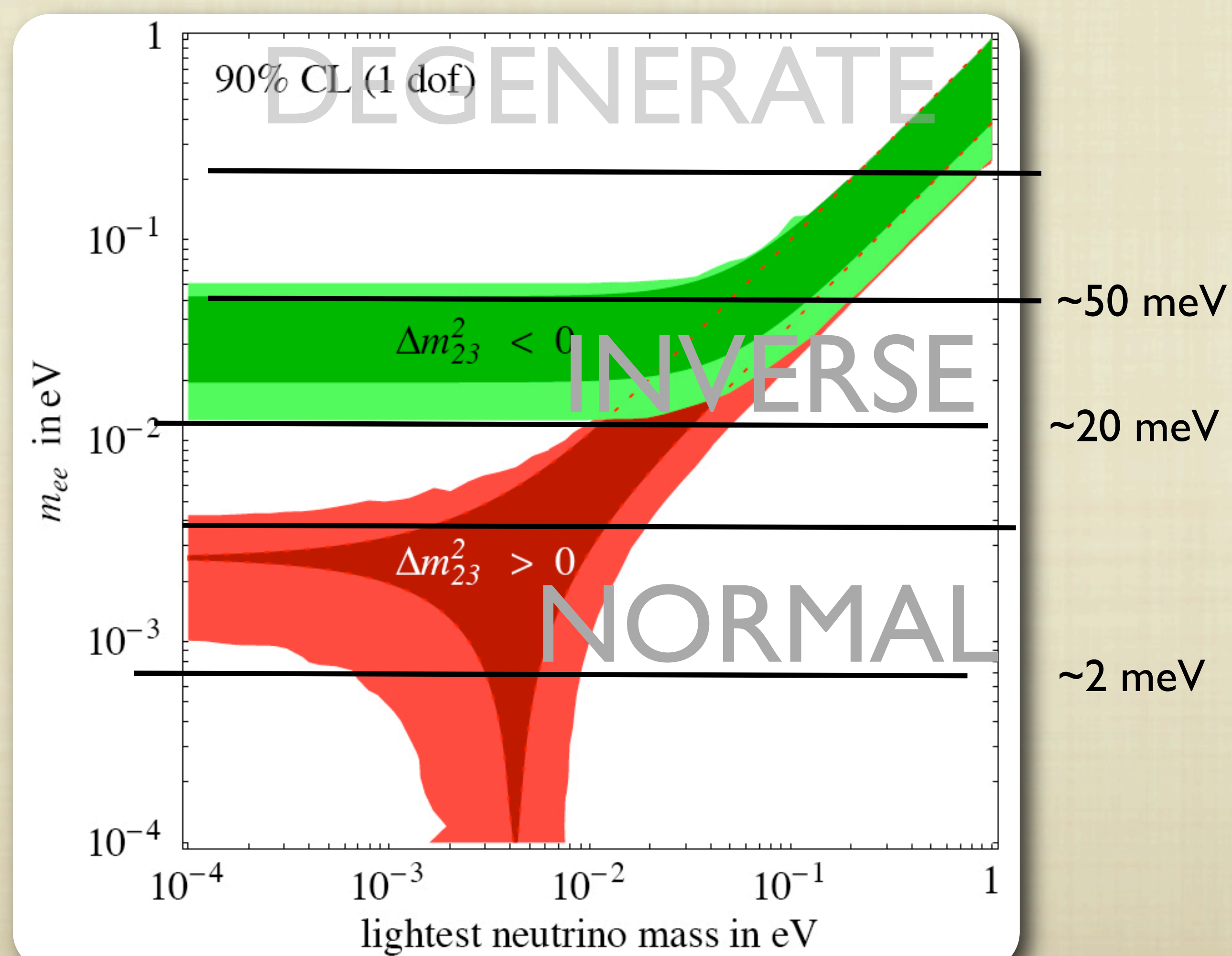
Neutrino double beta decay (standard but rare decay. Lifetime of the order of 10^{18} y for most nuclei

Neutrinoless double beta decay can only happen if neutrino is a Majorana particle

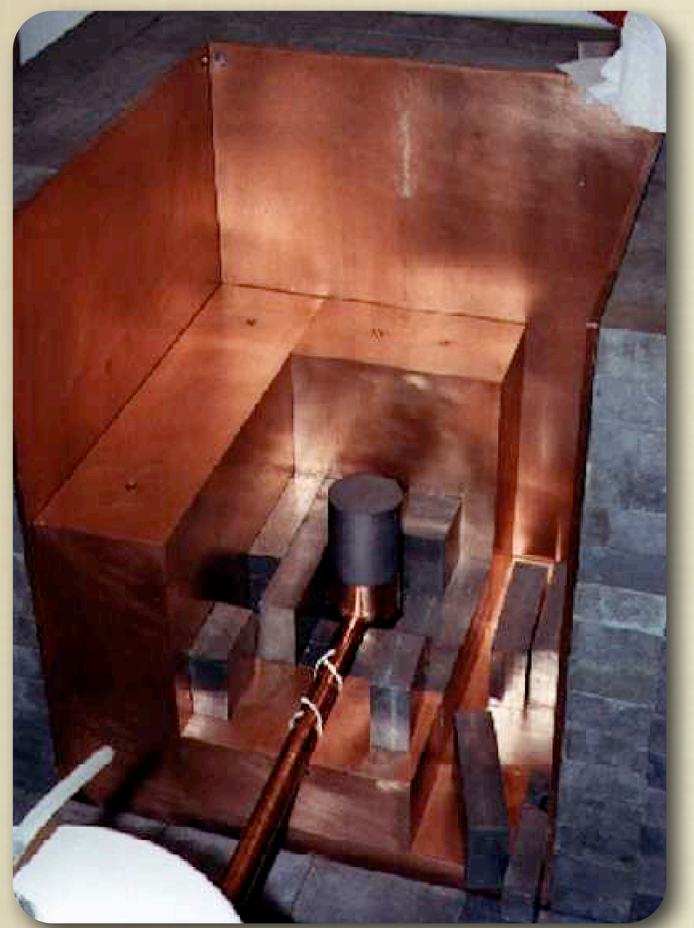
If neutrino mass too small difference vanishes

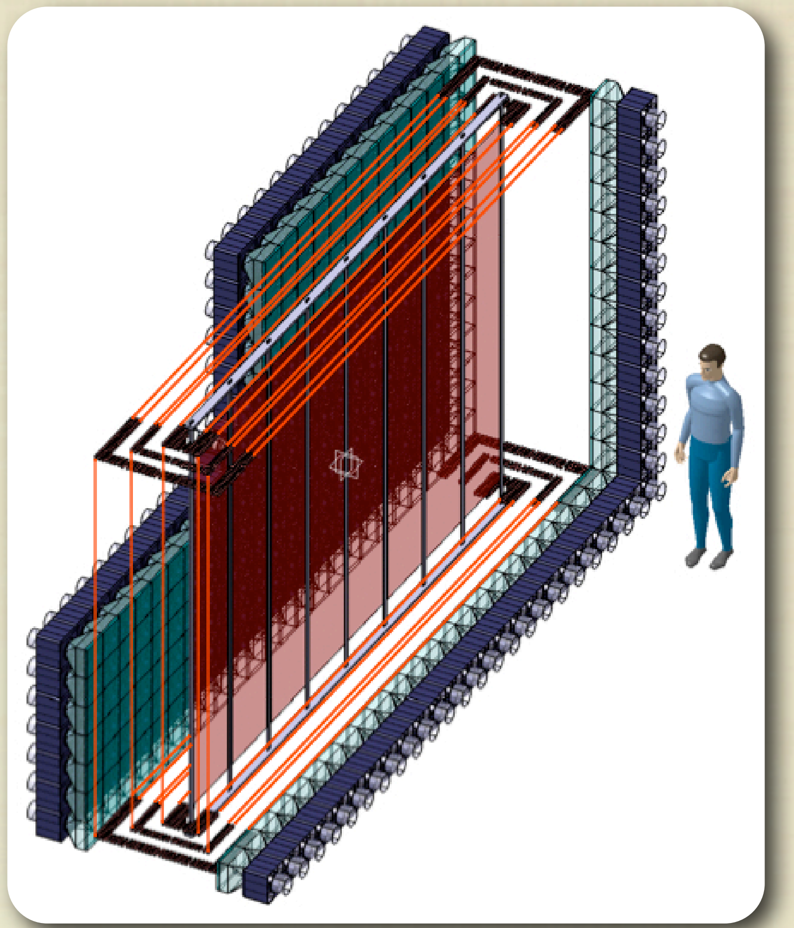
BBOnu & mass hierarchies

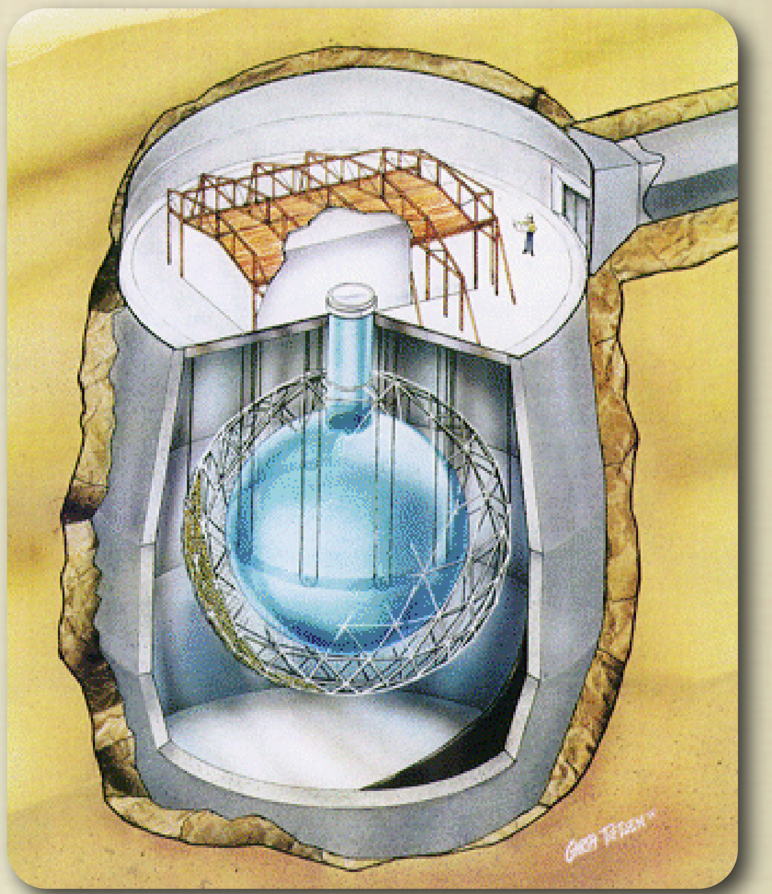




Experimental techniques







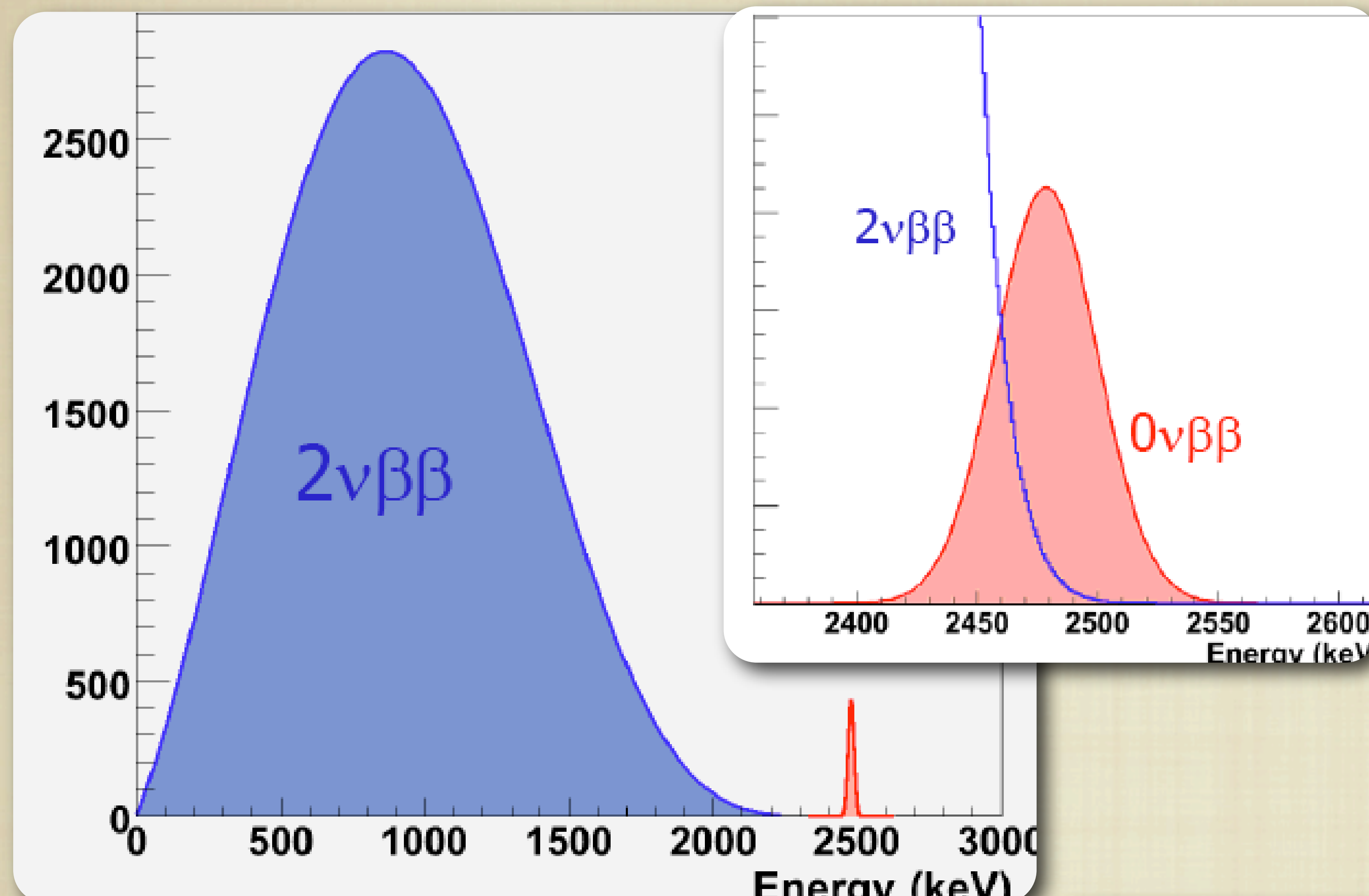
Diodes & Bolometers
GERDA
Majorana
Cuore
COBRA

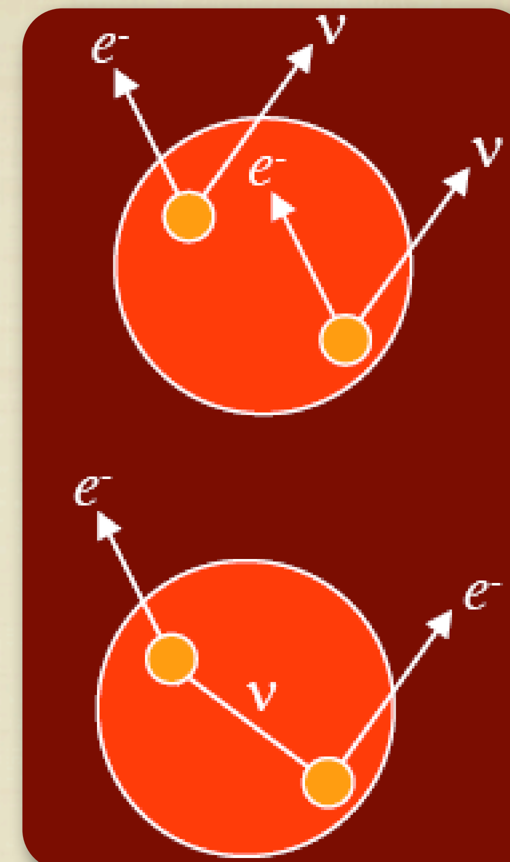
Calo+Tracko
SuperNEMO

Xenon TPCs
EXO
NEXT

Liquid Scintillator
CANDLES, CAMEO, SNO+

The energy signature

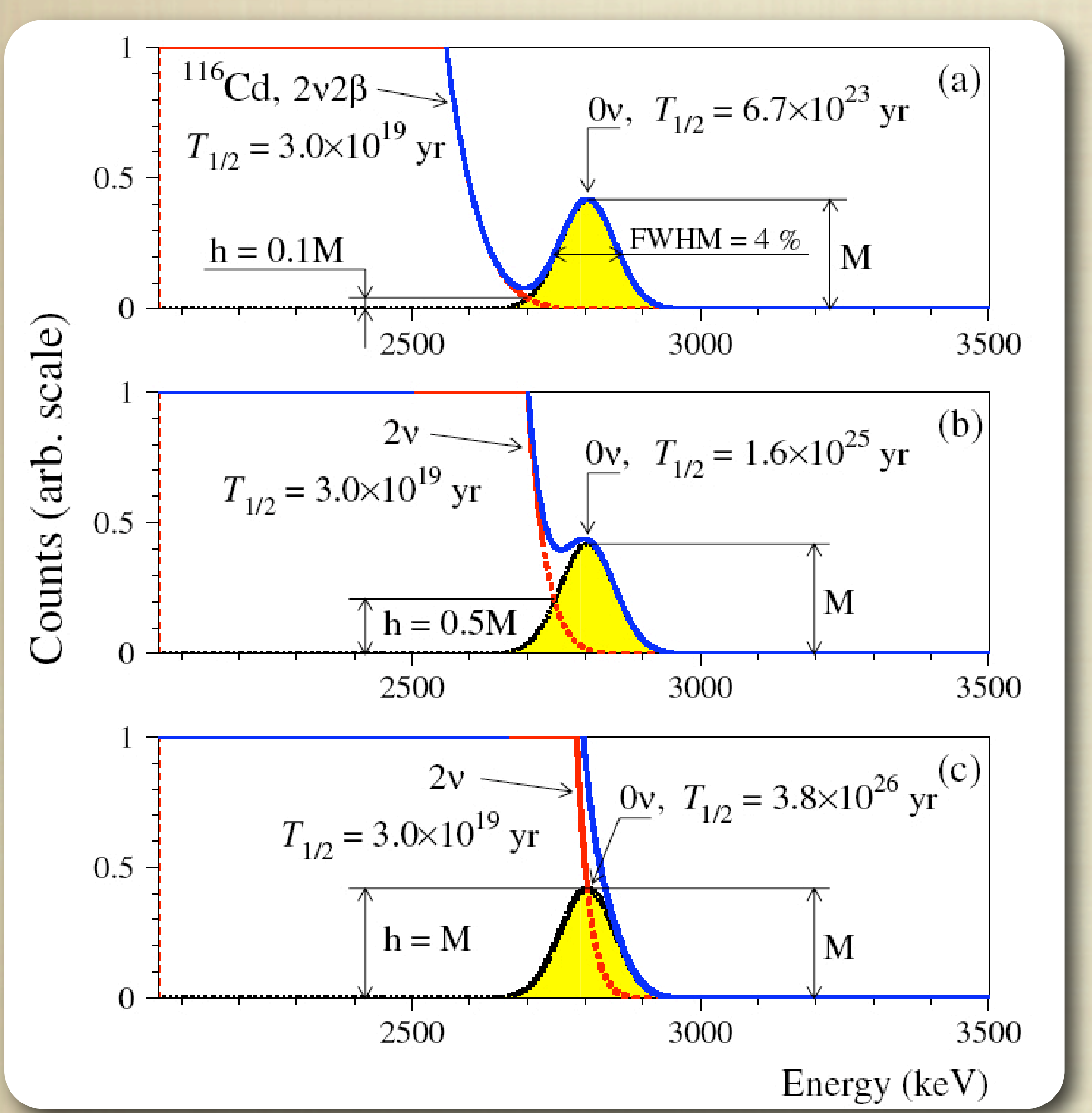




Energy resolution is a MUST
One is tipically aiming to separate 5-7 orders of magnitude

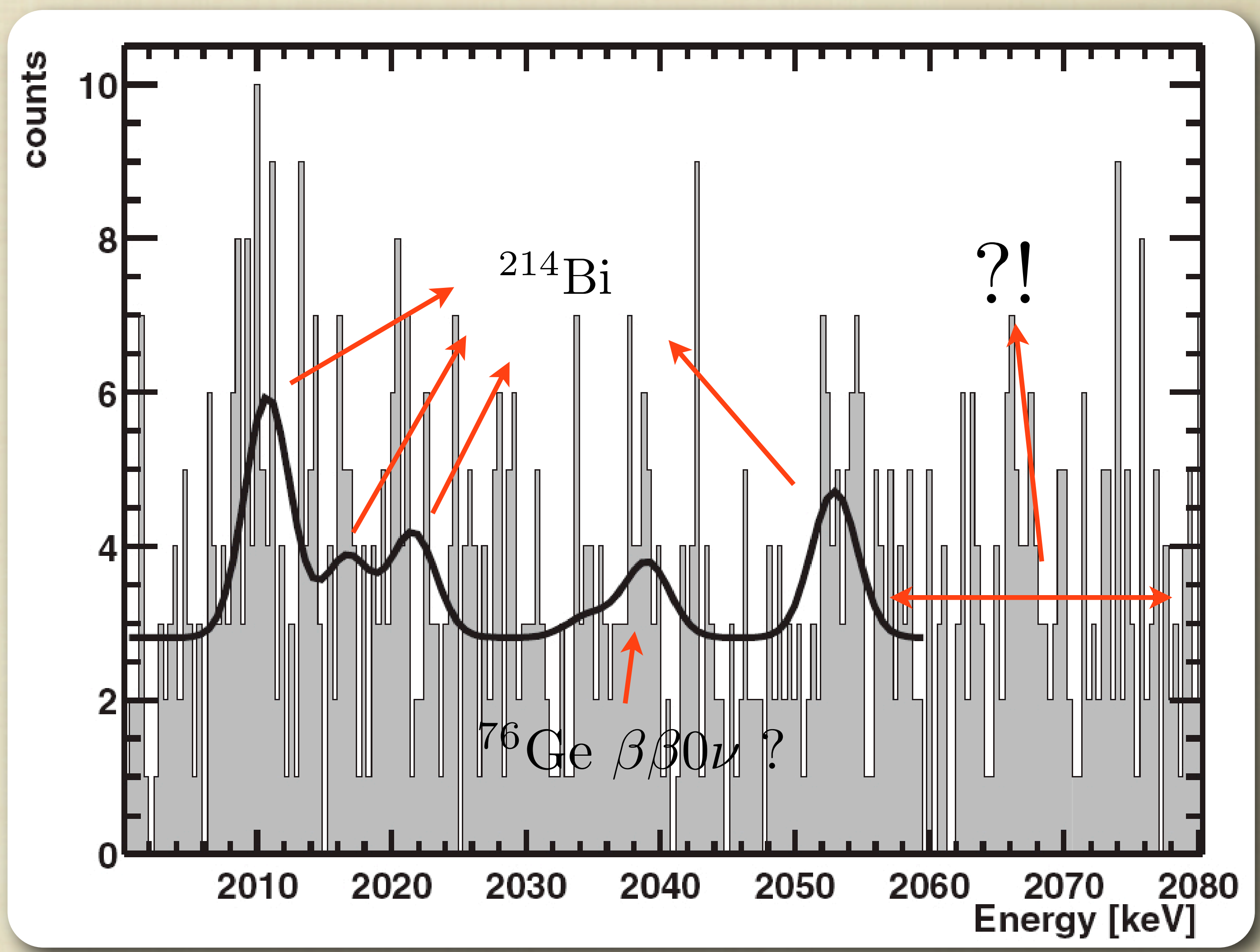
Resolution only may not be enough

Y. G. Zdesenko *et al.*, J. Phys. G **30** (2004) 971-981



ββ2ν background can only be separated from ββ0ν signal using energy resolution.

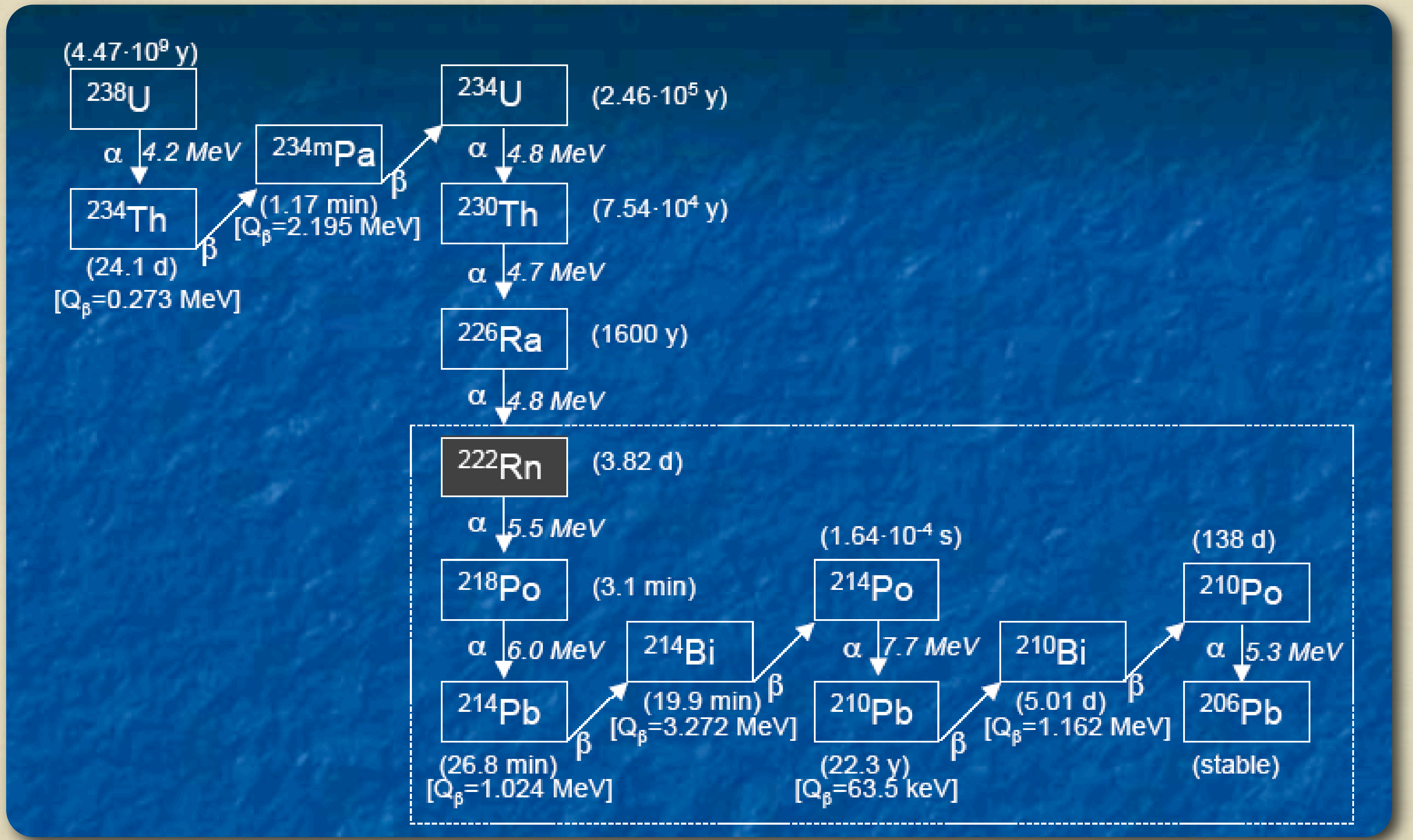
Klapdor-Kleingrothaus *et al.*, [arXiv: hep-ph/0302248].



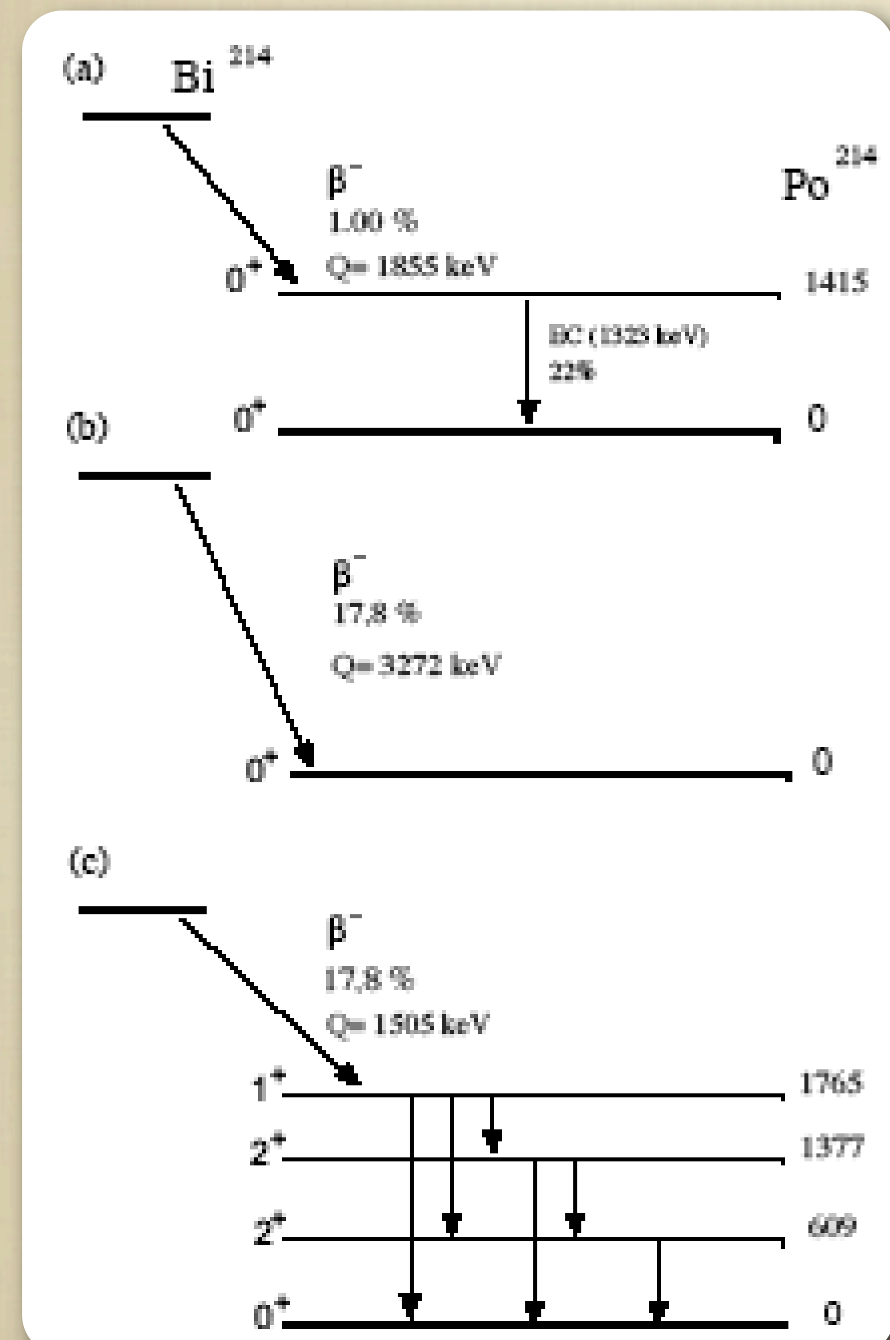
Example: KK's claim in Heidelberg-Moscow experiment.

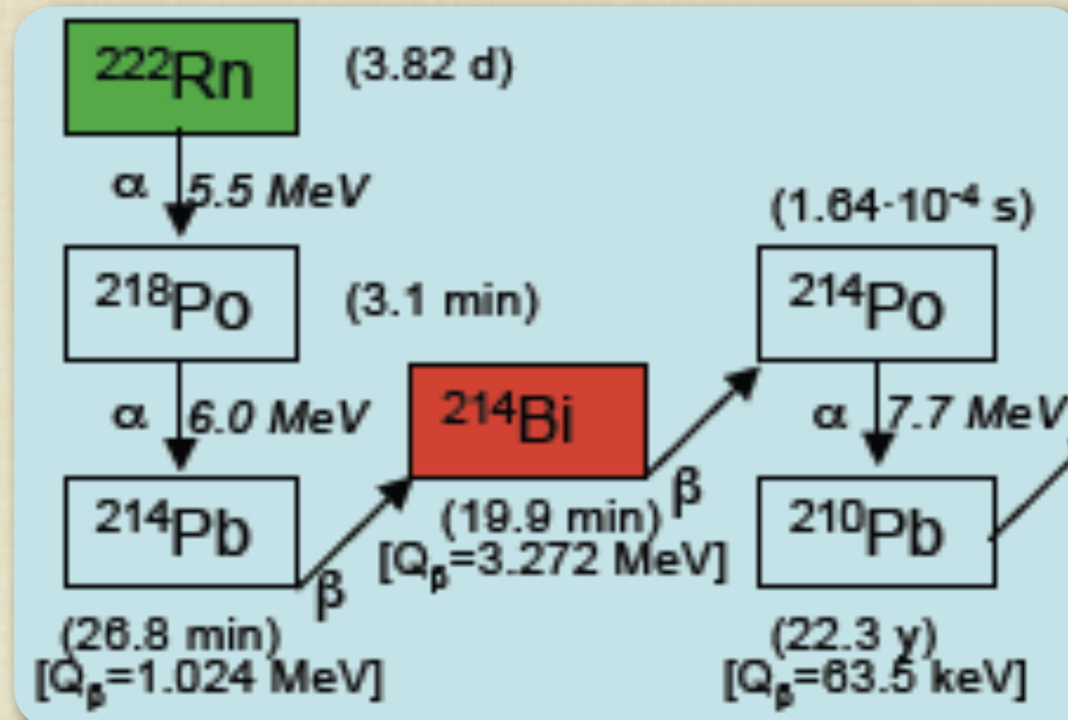
Backgrounds other ββ2ν than become dominant if only total energy available: any energy deposition under signal peak fakes the signal. Need extra handles!!

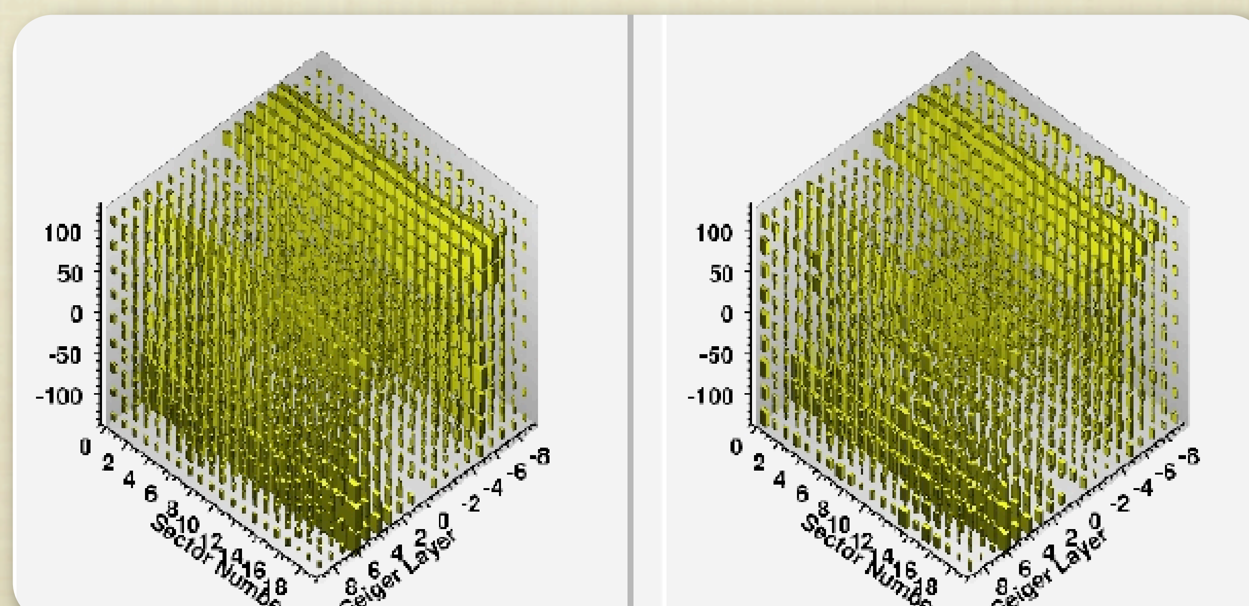
The natural radioactivity chains (or, the experimentalist nightmare)



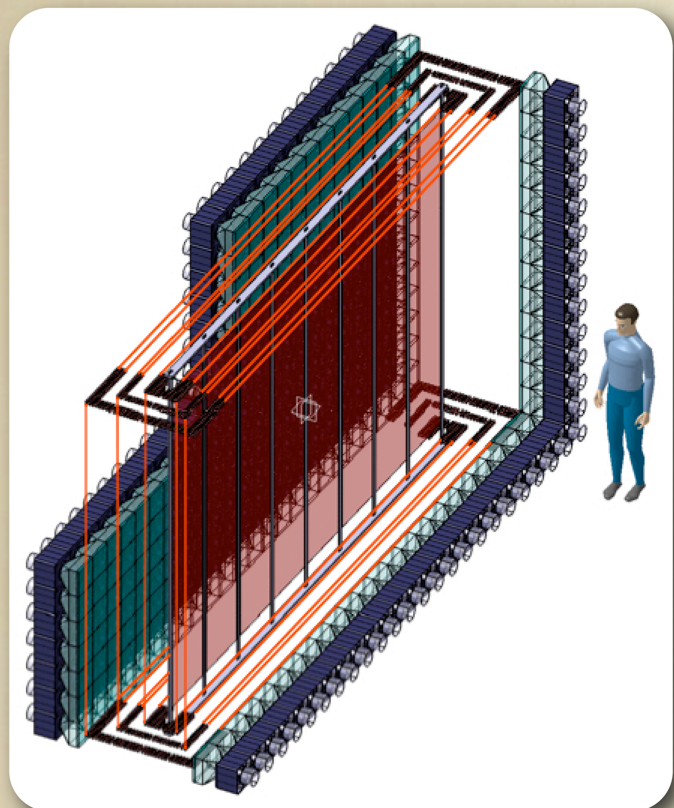
THE ^{222}RN NIGHTMARE

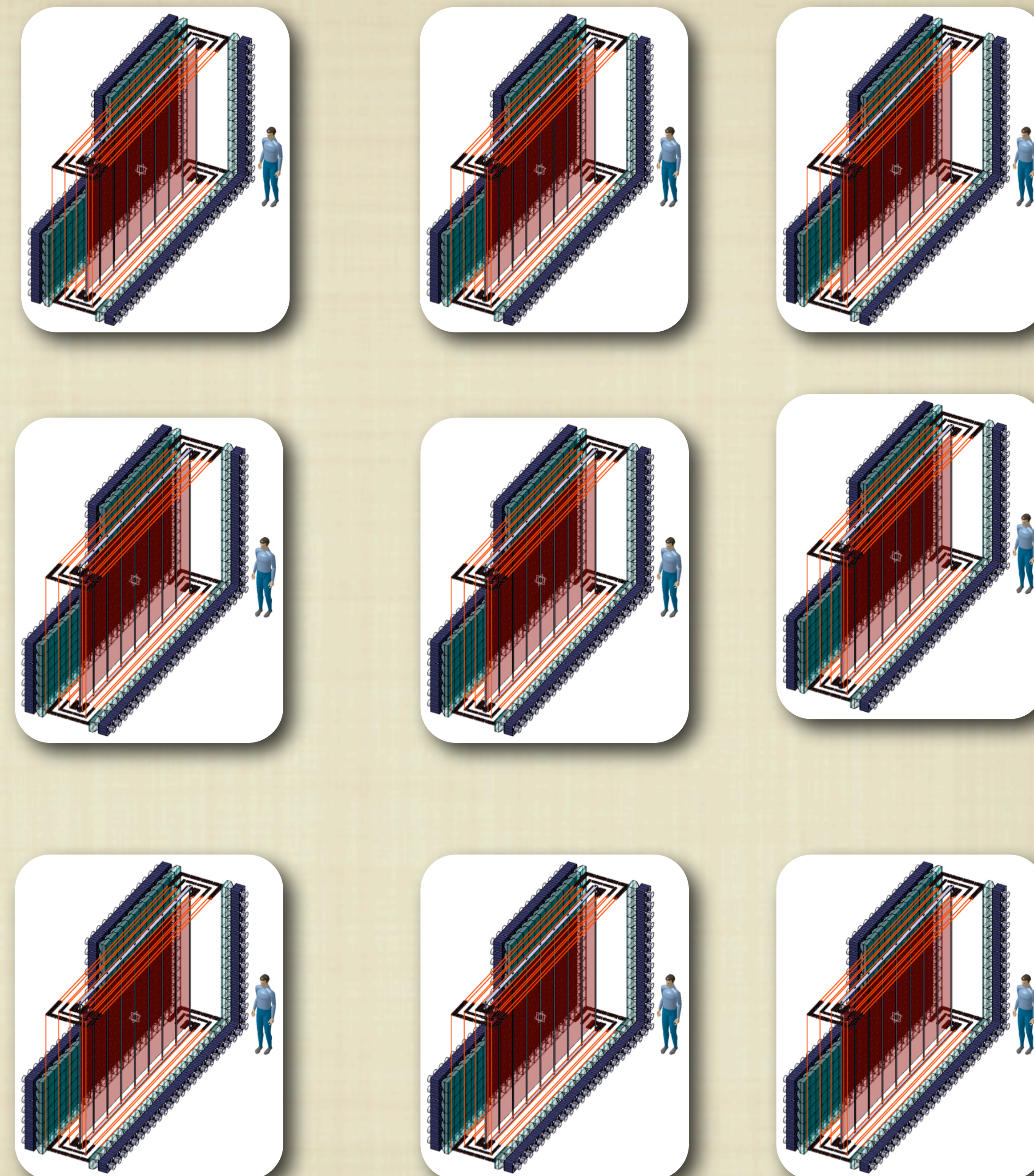






The problem of scaling





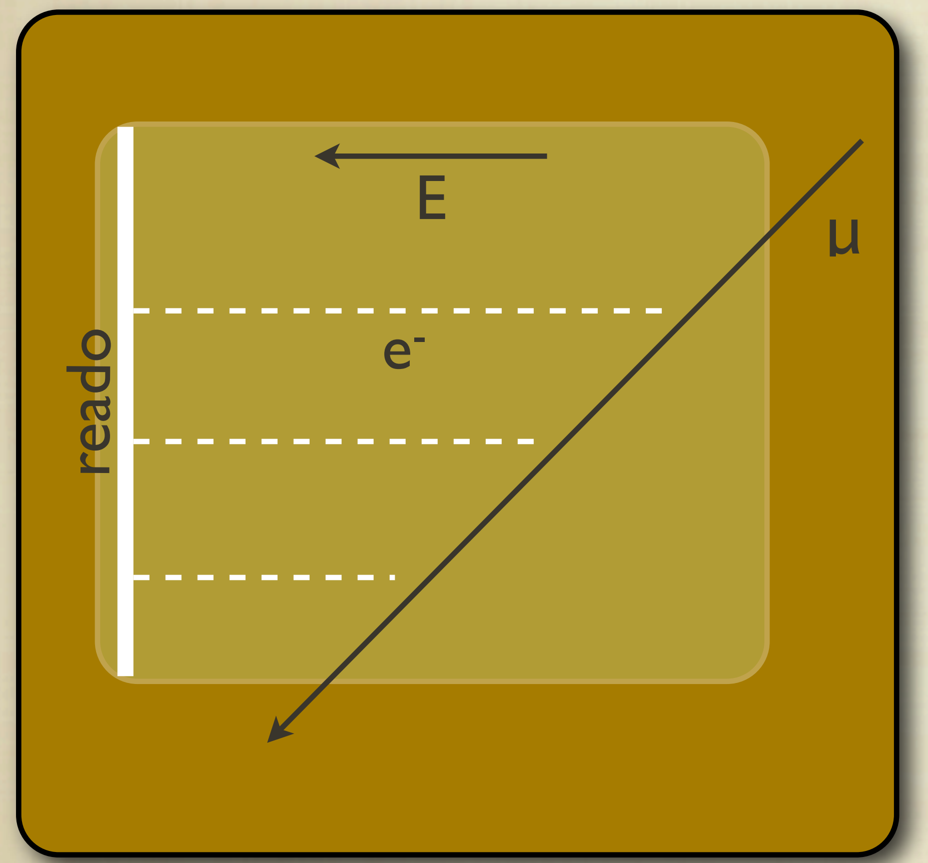
Modular detectors must be duplicated

Price & effort scales linearly

Backgrounds (proportional to surfaces) scale linearly

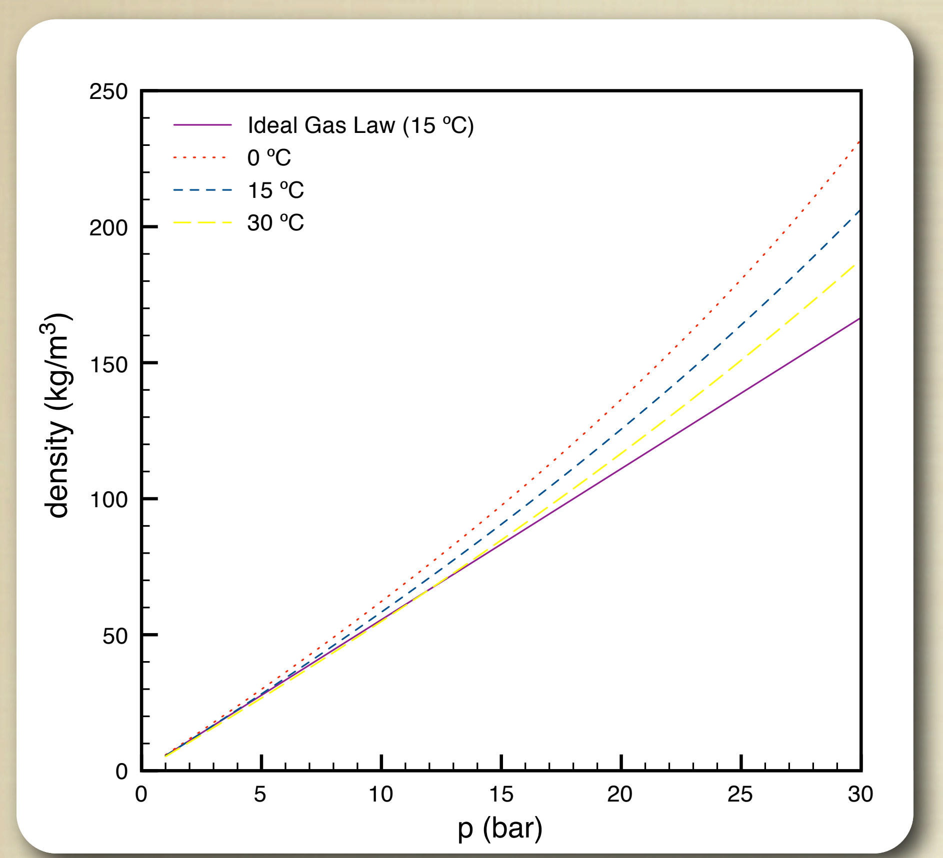
The TPC detector

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

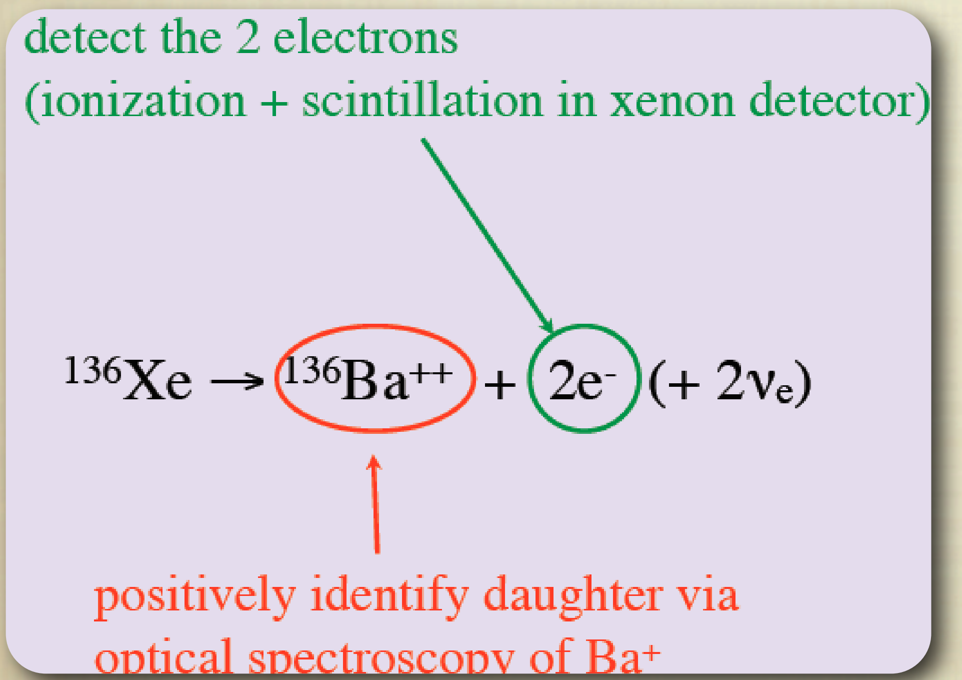


- Requires a noble gas to operate
- Charged particles traversing TPC ionize gas leaving a track
- If track stops inside TPC then its energy is calorimetrically measured (with good resolution)
- Large volume possible (thus large mass)
- No surfaces in fiducial volume for background ions to attach to

WHY A XE TPC



- GOOD IONIZATION DETECTING MEDIUM. PROVIDES ALSO SCINTILLATION LIGHT. CAN BE LARGE (SCALABILITY).
- XENON IS A NOBLE GAS: EASY TO ENRICH, PURIFY AND MANIPULATE.
- NO LONG-LIVED ISOTOPES THAT CAN BE ACTIVATED.
- XE-136 HAS A SLOW $\beta\beta2\nu$ MODE.
- NO SURFACES/WIRES FOR ^{214}BI TO ATTACH TO.
- KINEMATICAL SIGNATURE (OBSERVE TWO ELECTRONS)
- BA^{++} TAGGING USING OPTICAL SPECTROSCOPY.

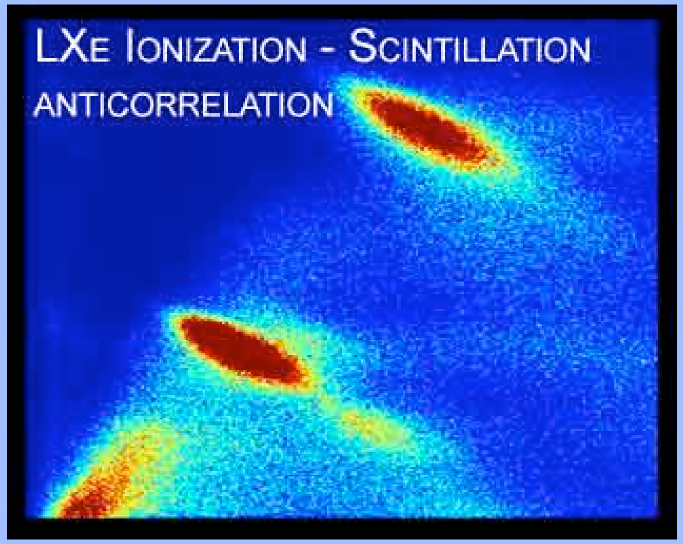


Xe TPC

Liquid Xenon: EXO

- Mass scalability (compact detector).
- Ba+ tagging.

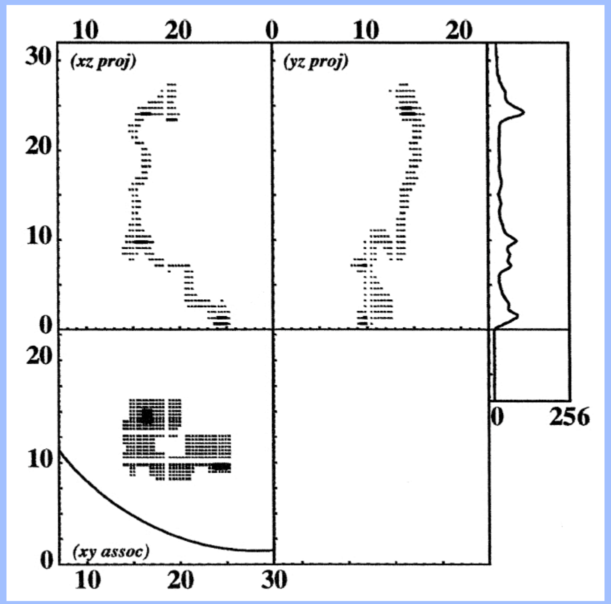
- Energy resolution.
- Lost of tracking capabilities.

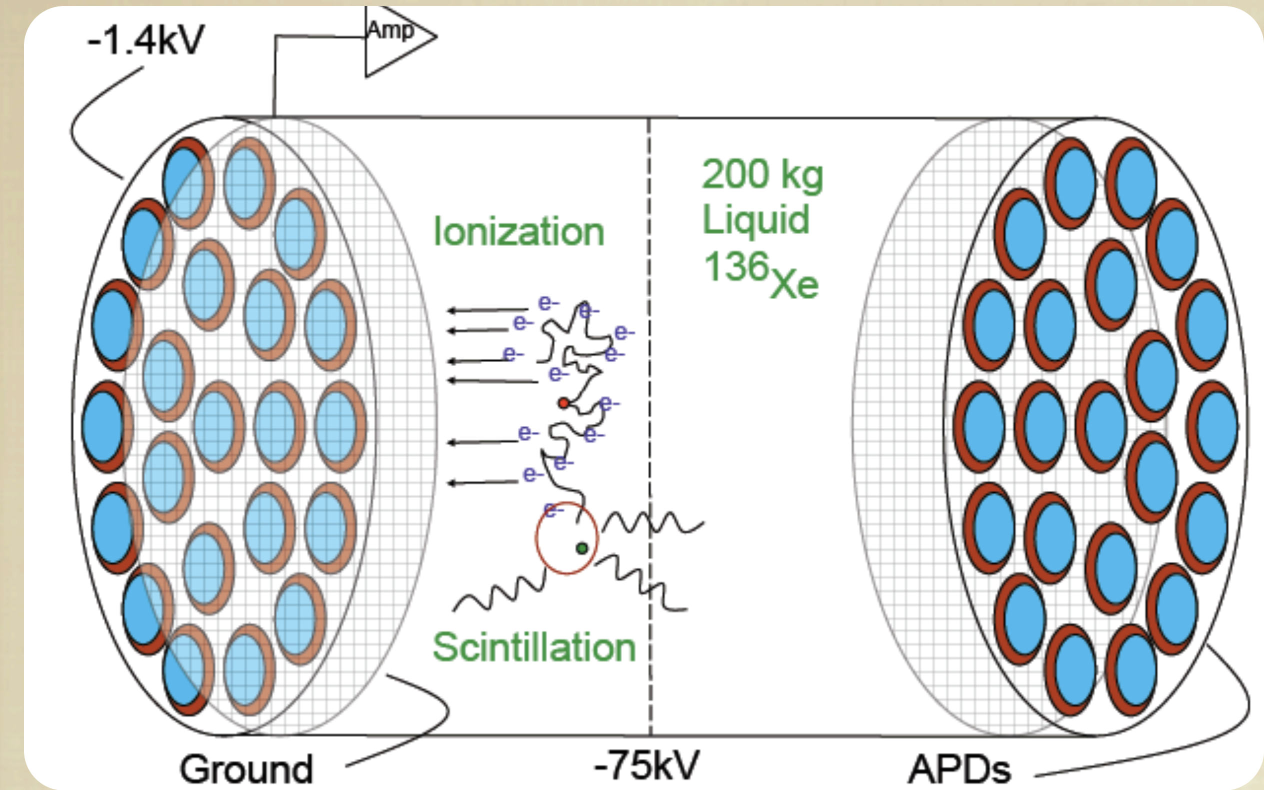


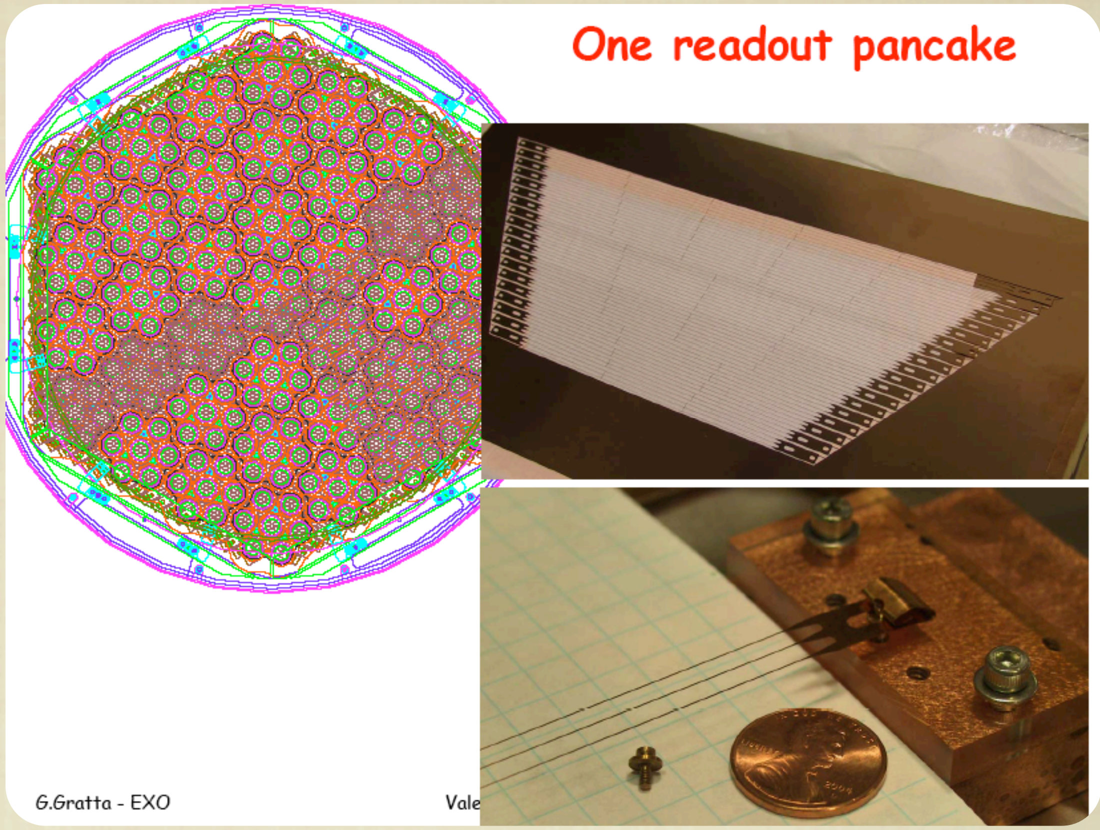
Gas Xenon: Gotthard

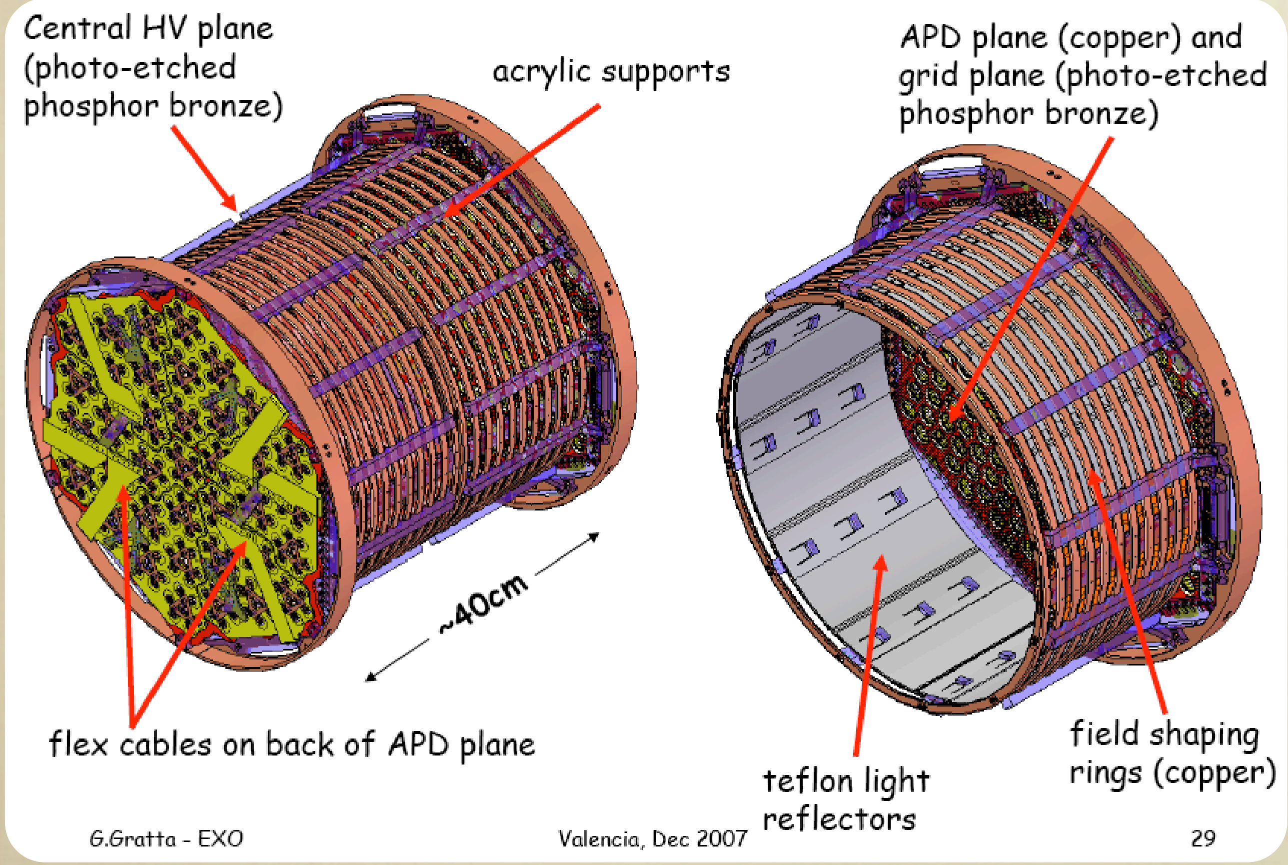
- Good energy resolution.
- Mass scalability.
- Ba+ tagging and event kinematics.

- Equalization & calibration
- Mechanics




-1.4kV
Amp
Ionization
200 kg
Liquid
136Xe
e-
Scintillation
Ground
-75kV
APDs


One readout pancake
G.Gratta - EXO
Vale


Central HV plane
(photo-etched
phosphor bronze)
acrylic supports
APD plane (copper) and
grid plane (photo-etched
phosphor bronze)
~40cm
flex cables on back of APD plane
teflon light
reflectors
field shaping
rings (copper)
G.Gratta - EXO
Valencia, Dec 2007
29

Backgrounds for EXO

- γ (2449 keV) from ^{214}Bi decay (from ^{238}U and ^{222}Rn decay chains)
- γ (2615 keV) from ^{208}Tl decay (from ^{232}Th decay chain)
- γ (1.4 MeV) from ^{40}K (a concern for the $2\nu\beta\beta$)
- ^{60}Co: 1173 + 1333 keV simultaneous γ's (from $^{63}Cu(\alpha,n)^{60}Co$)
- other γ's in ^{238}U and ^{232}Th chains
- other cosmogenics of Cu (a concern for the $2\nu\beta\beta$)
- ^{222}Rn anywhere (Xe, HFE, air gaps inside lead shield)
- in situ cosmogenics in Xe, neutron capture de-excitations, ...

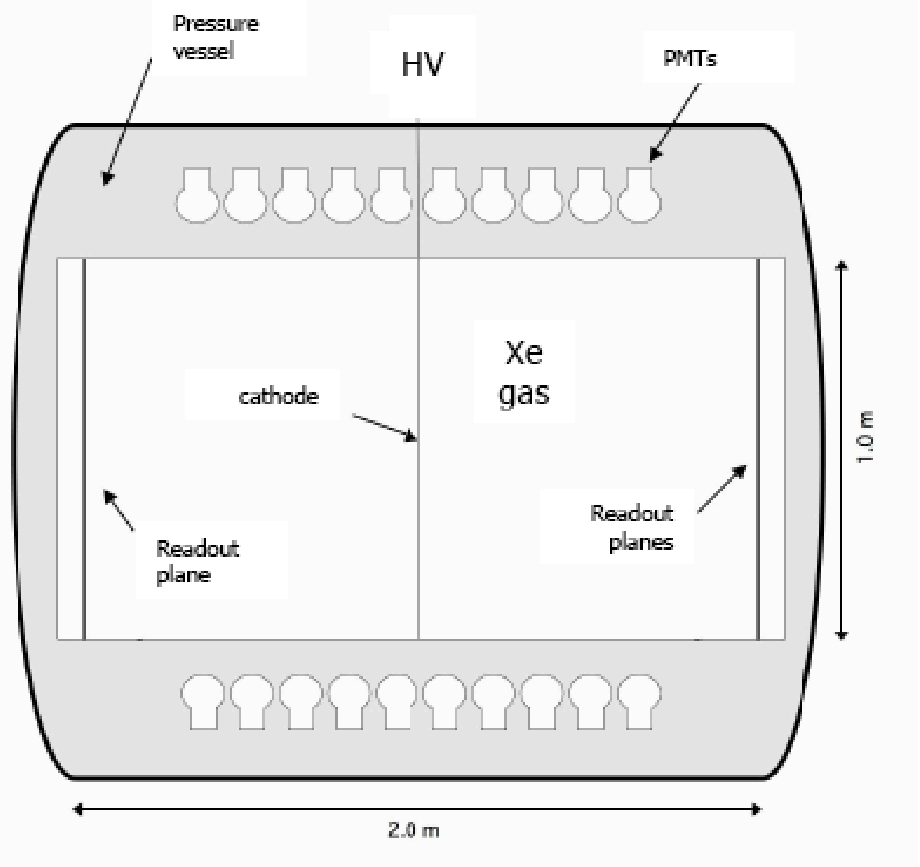
EXO does not discriminate gammas from two electrons!

A Xe detector for the NEXT generation

NEXT

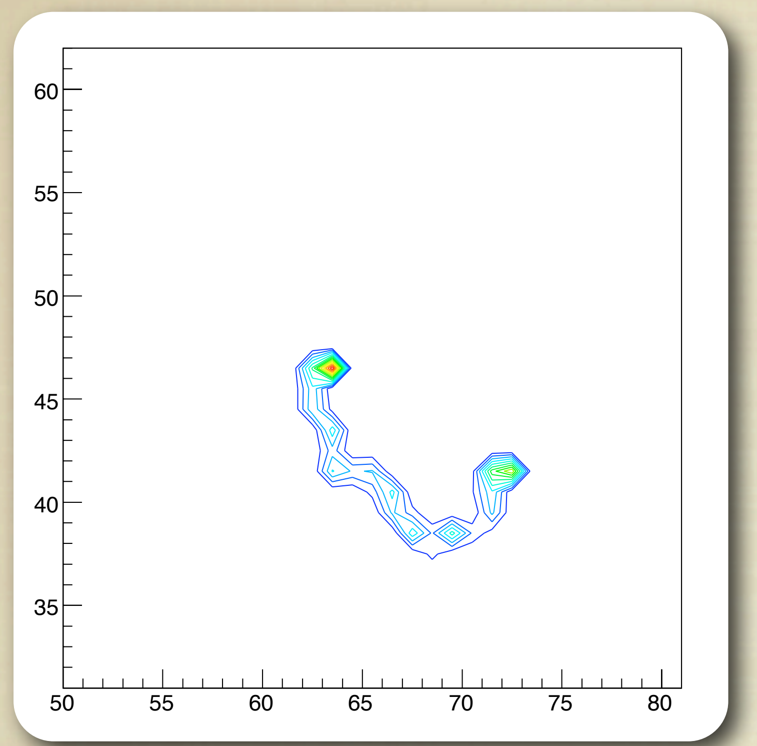
- A **N**eutrino **E**xperiment with a gas **X**e **T**PC may:

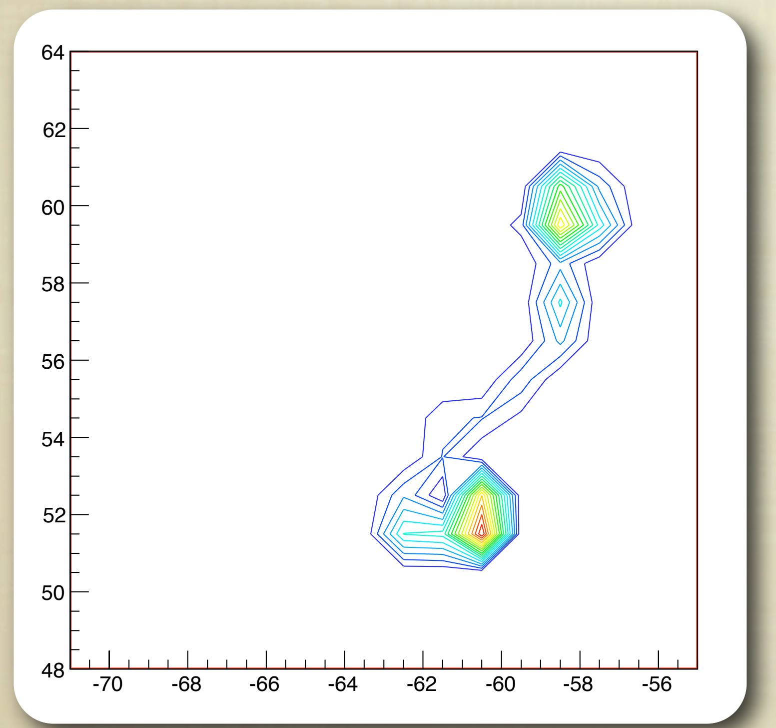
1. Have all advantages of a Xe monolithic detector (like EXO)
2. Outdo Liquid Xe by getting topological info
3. Override tradicional limitation of gas TPCs (Gothard) by applying the latest developments on TPC readouts
4. Be a competitive option for the next (ton scale) generation of experiments



PID

An spaguetti with two meat balls





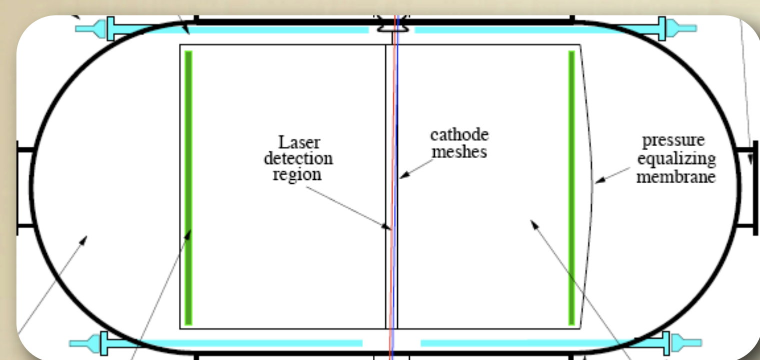
Kinematical signature allows to reject non BB backgrounds

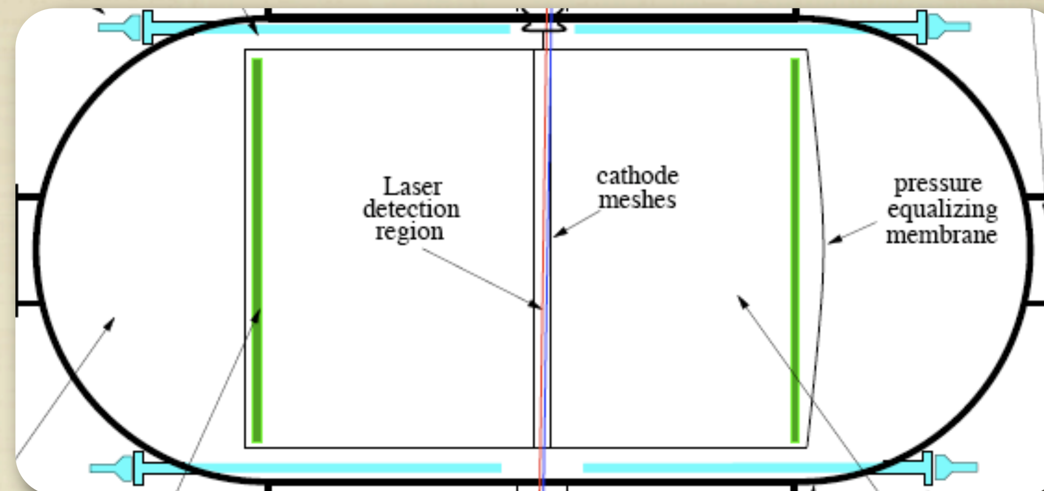
EXO: gammas will fake the signal

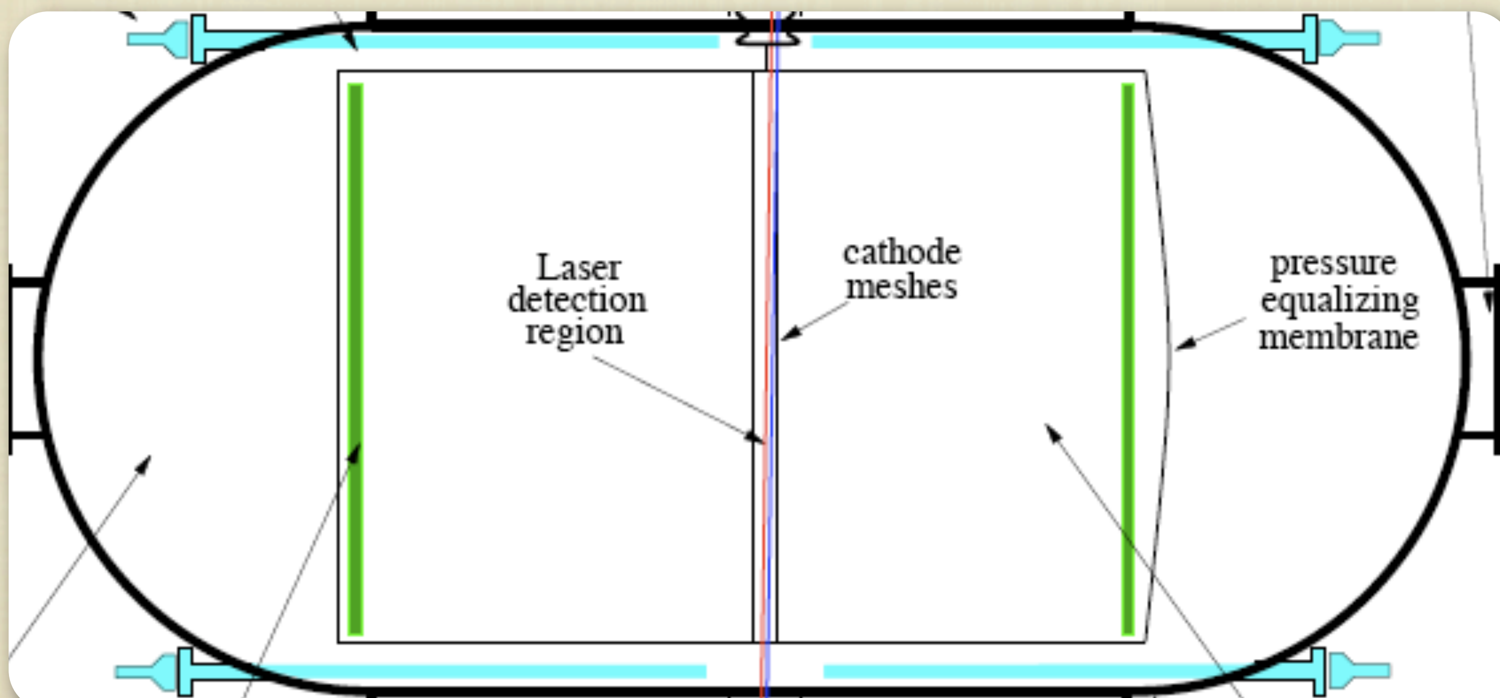
GXE: Tracks are seen, gamma need to convert in fiducial volume to be a background

Plus, signature of two electron different from single electron. Extra rejection

Scaling a TPC

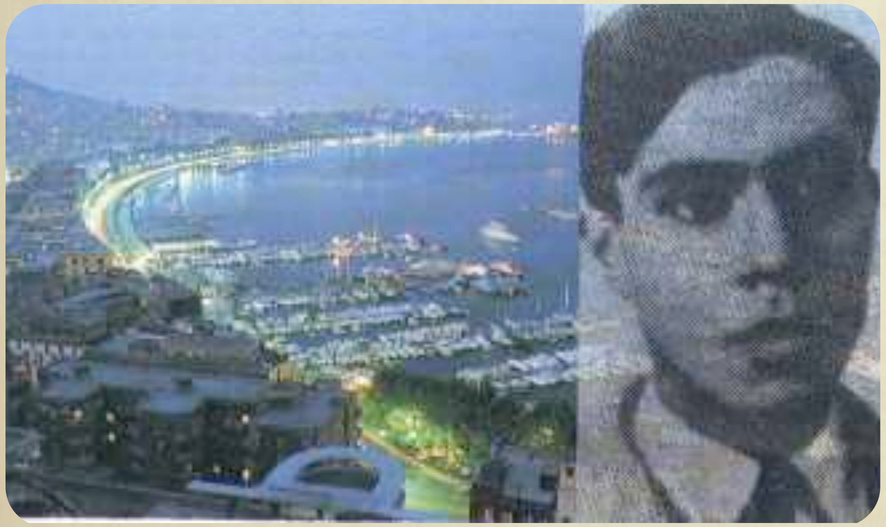






No modules! Win with L^3. Pay with L^2 (for electronics) No internal surfaces! Target=detector!

Ettore Majorana meets his shadow



The neutrino, as Ettore Majorana himself is a misterious particle.

Why Did Majorana dissapear? Did he commit suicide? Did he choose to vanish, to retire from the world, to become a shadow?

If so, he could be still alive, 100+ years old and still wandering if the neutrino is its own antiparticle its own shadow

Maybe the answer can come soon. The NEXT generation of bb0nu experiment may answer the question...

Perhaps Ettore Majorana will meet his shadow at Canfranc