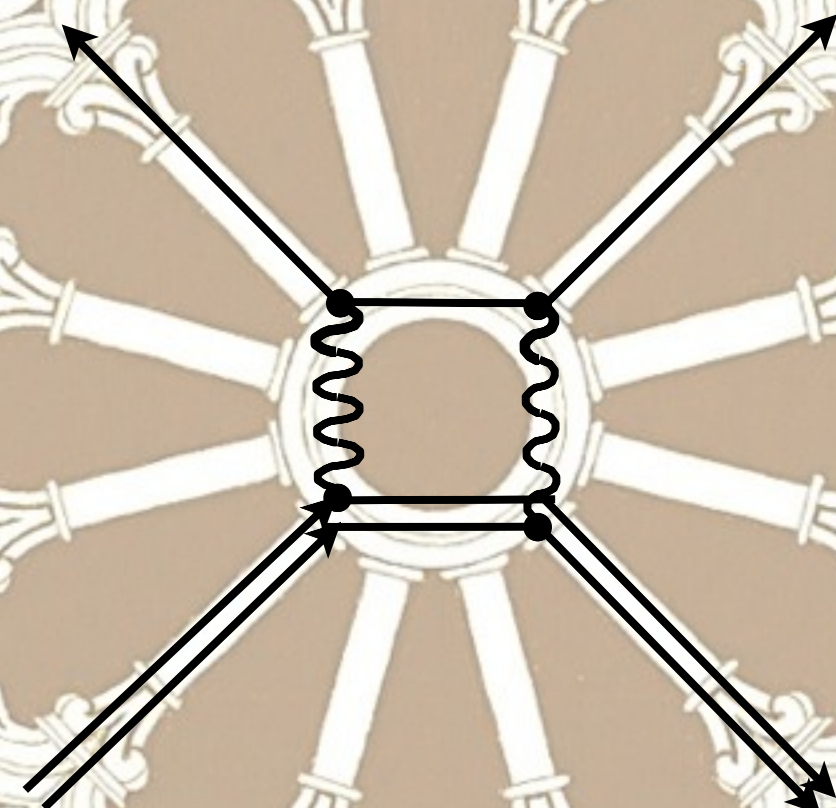
Experimental searches of neutrinoless double beta decay



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NOW2012 - September 10, Otranto, Italy

Outline

Neutrinoless Double Beta Decay

Experimental approaches and technologies

Present status: few relevant examples

Future perspectives: a critical comparison

Conclusions

Neutrinoless Double Beta Decay

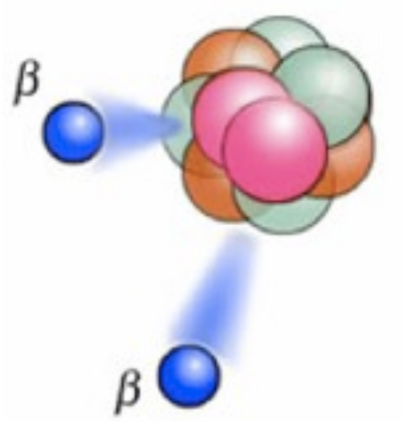
Neutrinoless double beta decay (0νββ)

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

is a very rare nuclear decay, particularly intriguing for its implications in particle Physics. First of all

- **Lepton Number** non conservation

that would be a cogent manifestation of incompleteness of the standard model.



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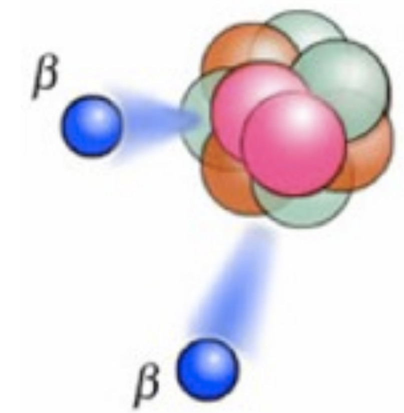
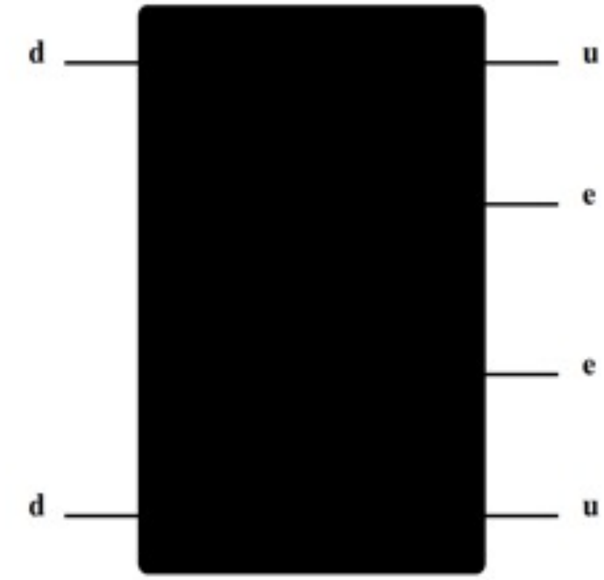
In principle any theory satisfying the constraints must be taken into account to fill the box.





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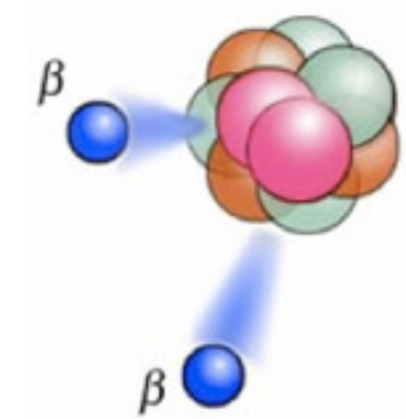
It was originally proposed in the framework of the weak interactions (Furry 1939) as a possible mode of the nuclear double beta decay proceeding through the exchange of a virtual neutrino.
Since then it is considered as a unique tool to check

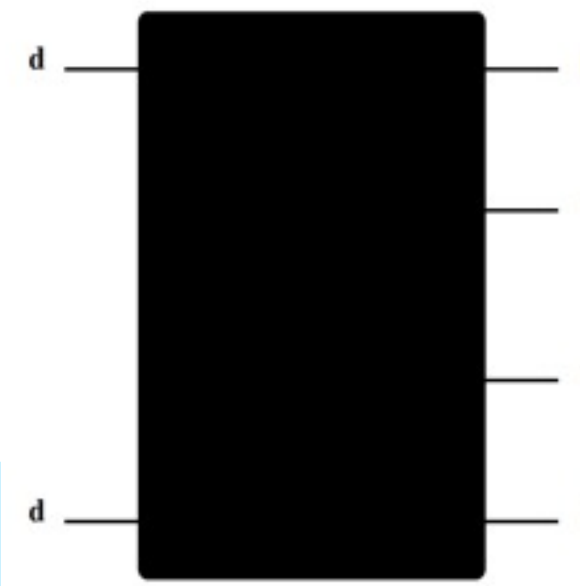
- **Majorana nature of the neutrino**

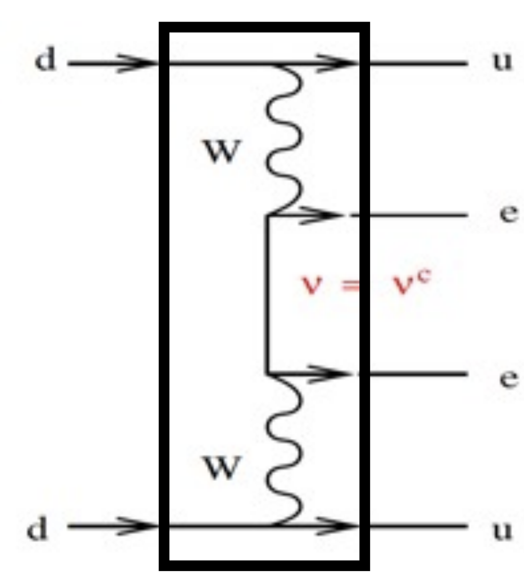
and provide relevant information on

- Absolute ν **mass scale**
- Neutrino **mass hierarchy**
- **CP** violation in the leptonic sector

Such a mission has become particularly compelling after the evidence of neutrino oscillations.

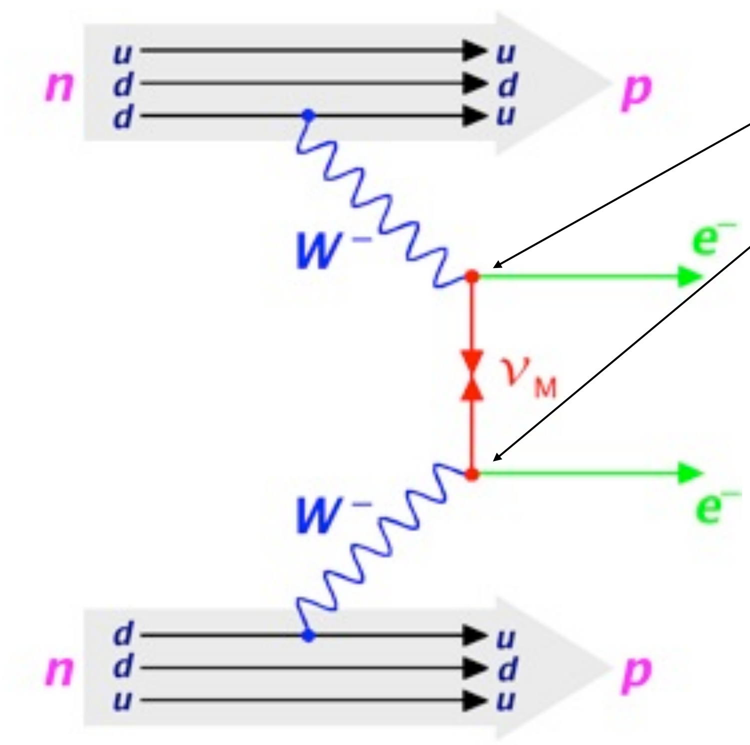






0νββ: mass mechanism

Exchange of a light Majorana neutrino



RH antineutrino (L=1) is emitted at one vertex
LH neutrino (L=-1) is absorbed at the other vertex

- **Majorana particle**
- **Helicity flip**

In the limit of small neutrino masses, the half lifetime can be expressed as

$$\tau_{0\nu}^{-1} = G_{0\nu}(Q,Z)|M^{0\nu}|^2 < m_{ee} >$$

PHASE SPACE FACTOR — NME — EFFECTIVE MAJORANA MASS

$$< m_{ee} > = \sum_k U_{ek}^2 m_k$$

NEUTRINO MIXING MATRIX — NEUTRINO MASS EIGENVALUES

$$= c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i\alpha} m_2 + s_{13}^2 e^{i\beta} m_3$$

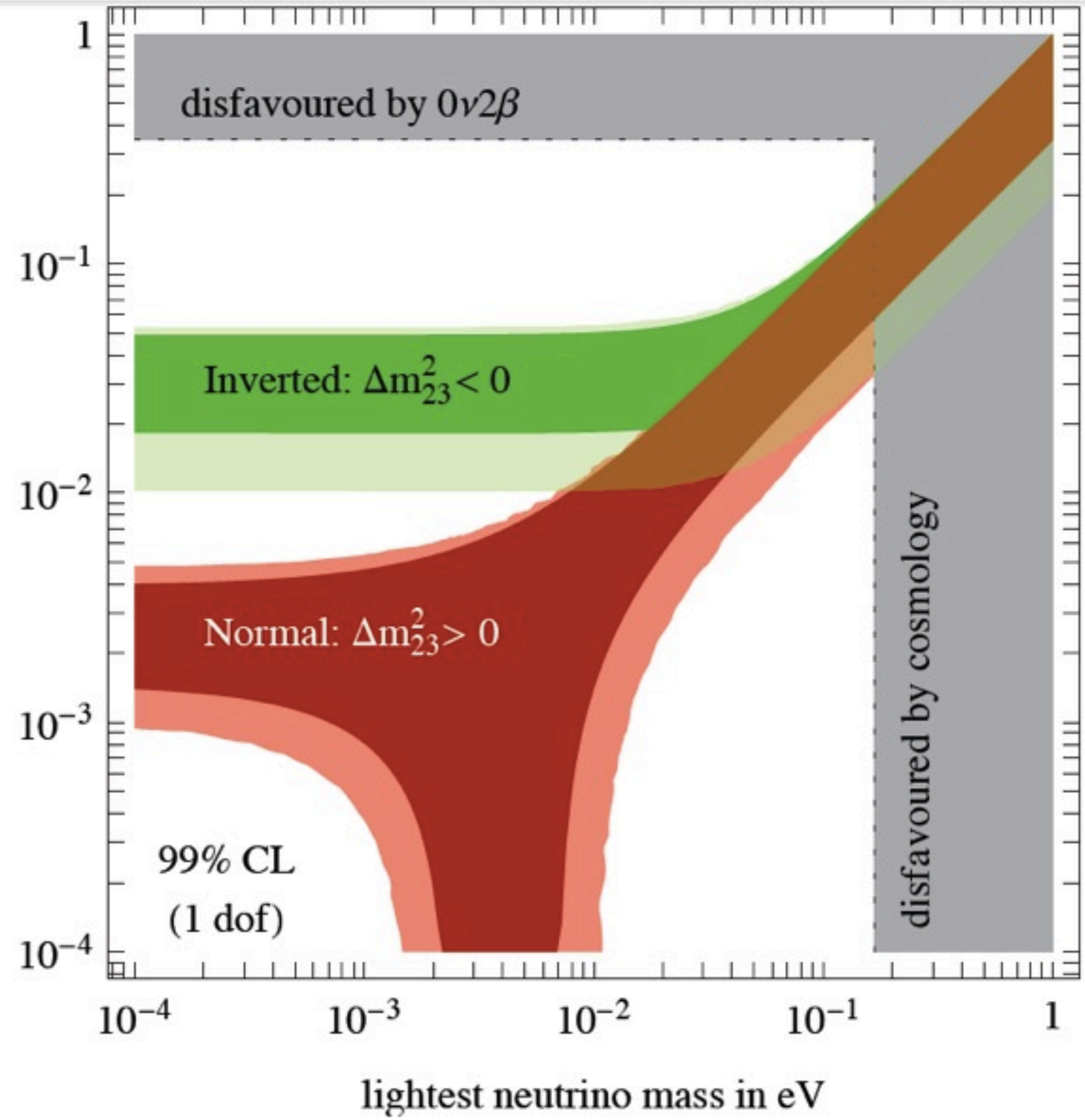
Seven unknown quantities:

- 3 masses: m_k
- 2 angles: θ_{12} and θ_{13}
- 2 CP violating phases: α and β

N.B.: Majorana phases make m_{ee} cancellation possible (**m_{ee}** could be smaller than any of the **m_i**).

Only one experimental constraint
More complementary measuremets needed!

ββ0ν and ν oscillations

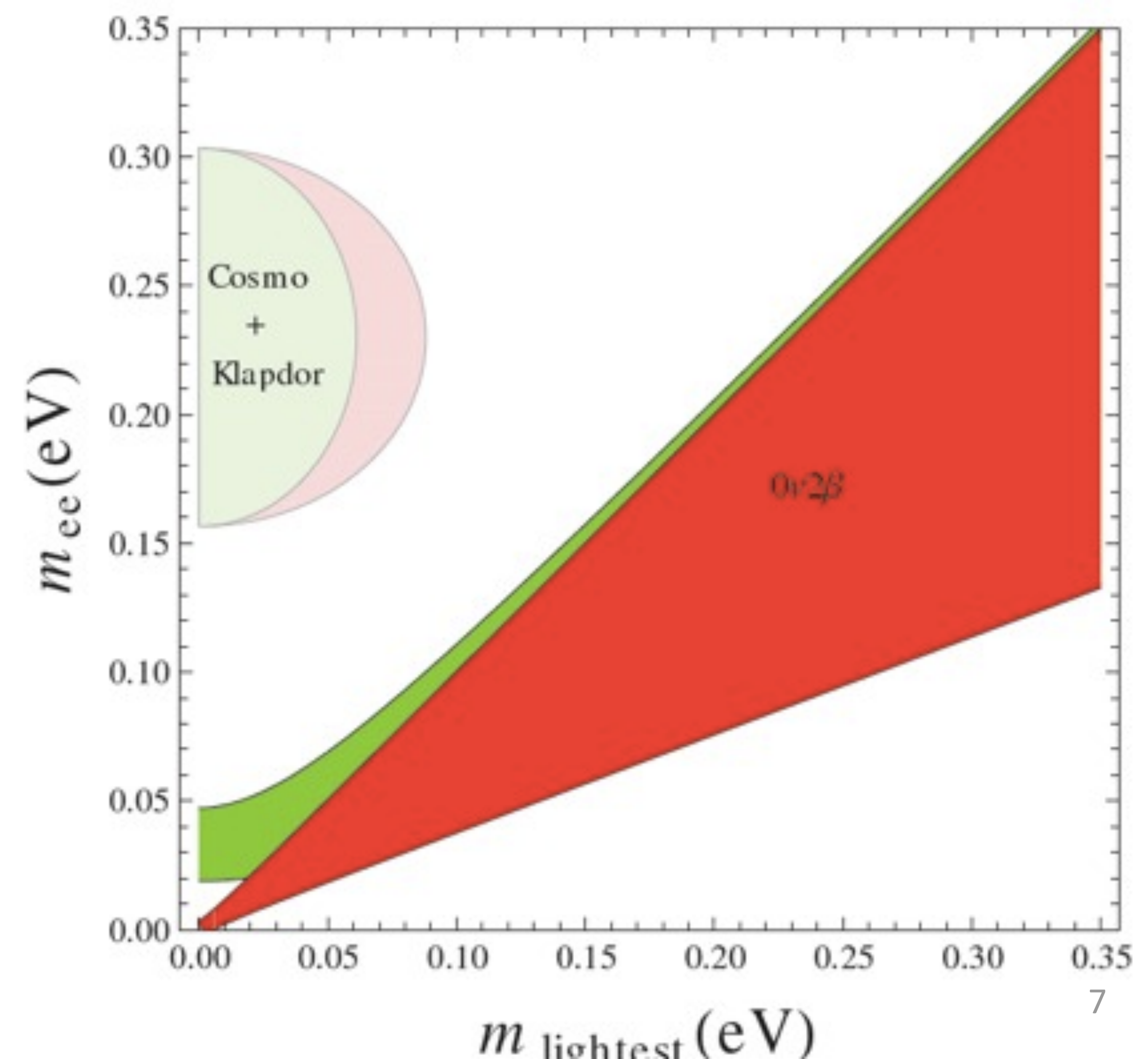


Thanks to the information from oscillations m_{ee} can be expressed in terms of three unknown quantities:

- the mass scale, represented by the mass of the lightest neutrino $\mathbf{m_{min}}$
- the two Majorana phases.

It is then common to distinguish three mass patterns:

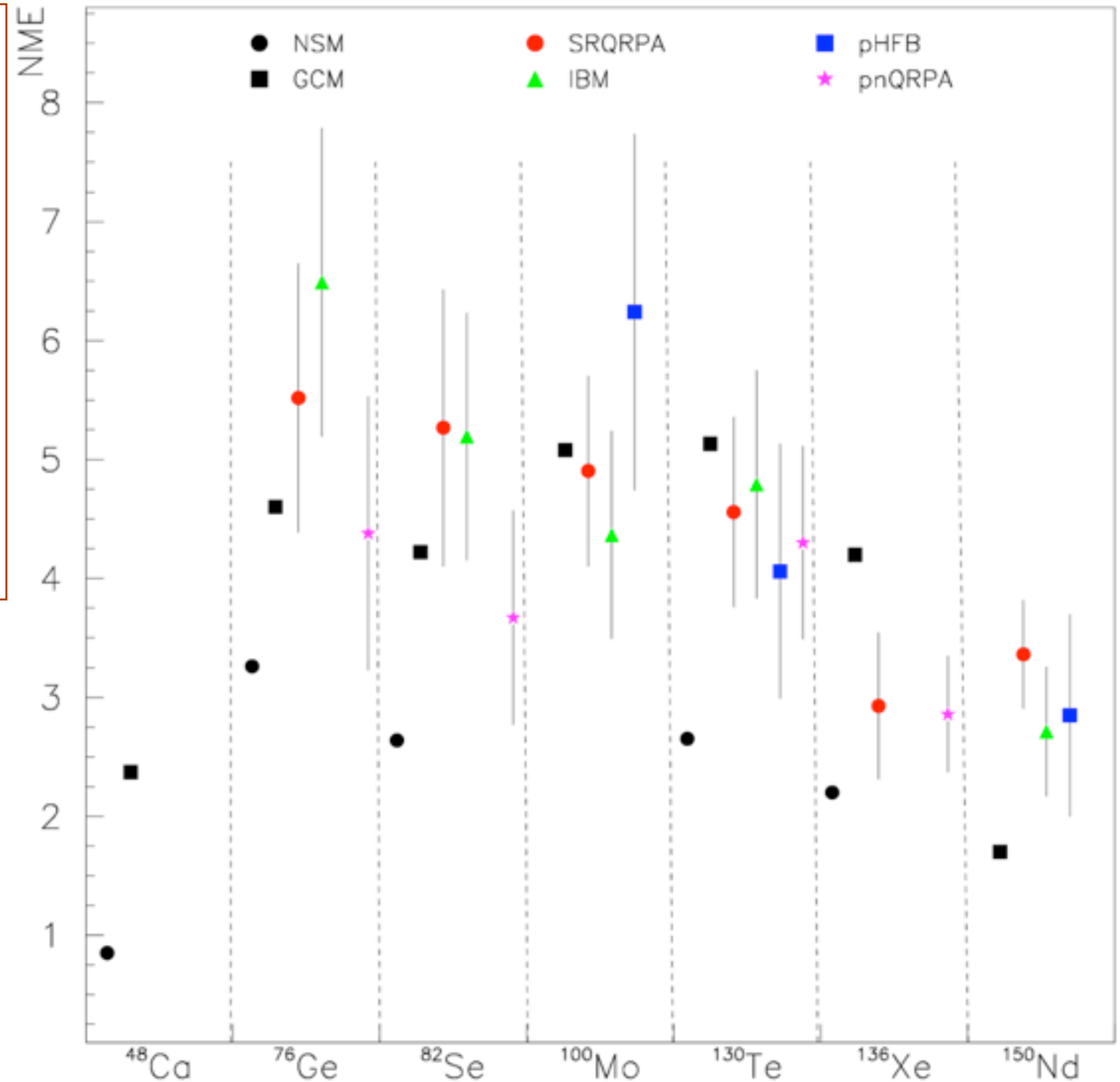
- **normal hierarchy (NH)**, where $\mathbf{m_1 < m_2 < m_3}$
- **inverted hierarchy (IH)** where $\mathbf{m_3 < m_1 < m_2}$
- **quasi-degenerate pattern (QD)**, where the differences between the masses are small with respect to their absolute values



Nuclear Matrix Elements

Nuclear matrix elements (NME) are calculated according to various models:
QRPA (RQRPA, SQRPA, …….), Shell model, IBM2 ...
Calculation discrepancies are one of the largest sources of uncertainties

NSM nuclear shell model, Nucl. Phys. A 818 (2009) 139.Phys. Rev. C80 (2009) 048501(1)
SRQRPA self-consistent renormalized quasiparticle random phase approx.(2), Phys Rev D83 (2011) 113015, Phys Rev C79 (2009) 055501(1), Phys Rev C83 (2011) 034320
pnQRPA proton-neutron QRPA, Nucl Phys A847 (2010) 207
GCM generating coordinate method Phys. Rev. Lett. 105 (2010) 252503.
IBM interacting boson model(3), Phys Rev C79 (2009) 044301
pHFB projected Hartree-Fock-Bogoliubov Phys Rev C82 (2010) 064310



- more groups calculate NME with different methods
- NSM lower than other calculations
- NME vary by factor 2-3 for a given nucleus
- ”errors” on NME calculations largely correlated for different A
- difference between QRPA calculations small

- **no** ”super” element from NME point-of-view

Experimental signature

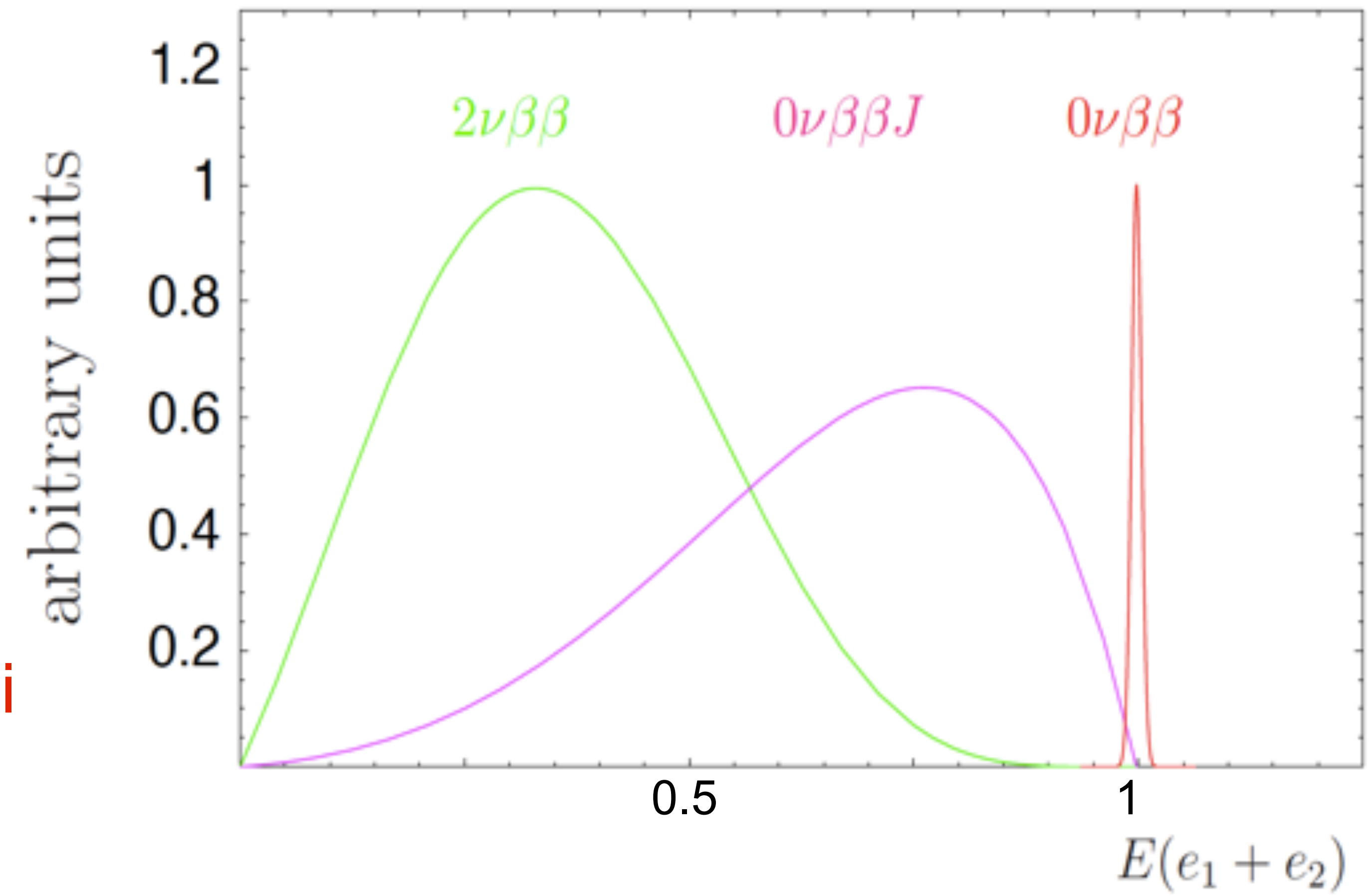
$(A,Z) \rightarrow (A,Z+2)^{++} + 2\ e^-$

- A new (ionised) isotope
- Two electrons

Minimal information:

- two e^- energy sum spectrum

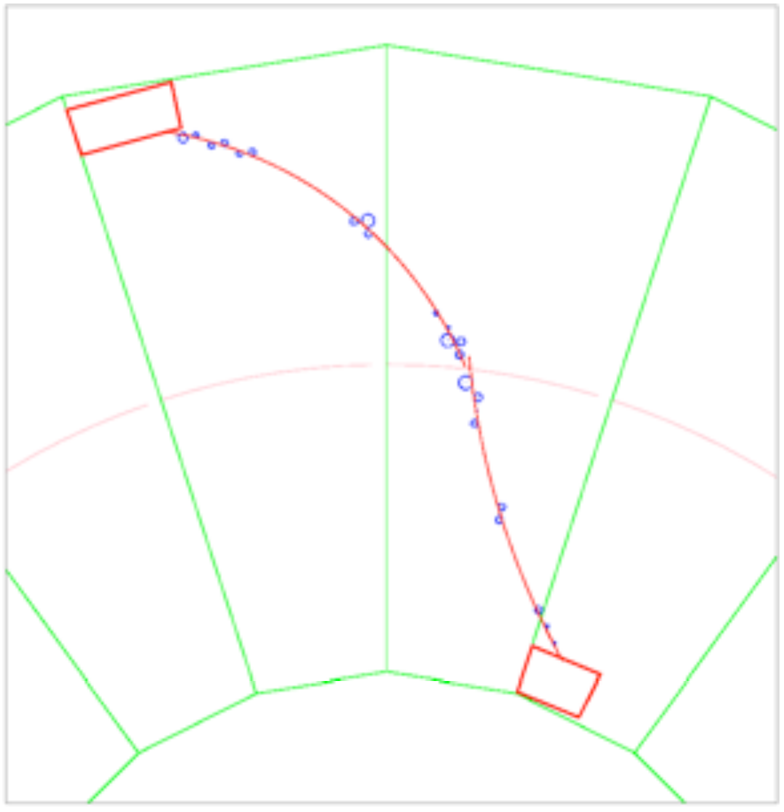
0νββ exhibits a **peak at Q** over 2νββ tai
(and background contributions)



Additional signatures:

- Single electron energy spectrum
- Angular correlation between the two electrons
- Daughter nuclear species

Track and event topology
Time Of Flight



Experimental sensitivity

$$\tau^{0\nu}_{1/2} = ln2\frac{\epsilon N_{nuclei} t_{meas}}{N_{\beta\beta}}$$

Lifetime corresponding to the minimum detectable number of events over background at a given confidence level

$$N_{\beta\beta} \leq \sqrt{bkg \cdot \Delta E \cdot M \cdot t_{meas}}$$

N_{nuclei}	number of active nuclei in the experiment
t_{meas}	measuring time [y]
M	detector mass [kg]
ε	detector efficiency
i.a.	isotopic abundance
A	atomic number
ΔE	energy resolution [keV]
bkg	background [c/keV/y/kg]

N_B = bkg ΔE T M

number of background events expected along the experiment lifetime

N_B >> 1

$$S^{0\nu}_{1/2} \propto \epsilon\frac{i.a.}{A}\sqrt{\frac{M \cdot t_{meas}}{bkg \cdot \Delta E}}$$

N_B ≤ O(1) → "zero background"

$$S^{0\nu}_{1/2} \propto \epsilon\frac{i.a.}{A} M \cdot t_{meas}$$

<m_{ee}> →

$$S^{0\nu}_{1/2}(m_{ee}) \propto \epsilon\frac{i.a.}{A}\frac{1}{\sqrt{G^{0\nu}}|M^{0\nu}|}\sqrt[4]{\frac{bkg \cdot \Delta E}{M \cdot t_{meas}}}$$

- **Isotope choice**

- **Isotopical abundance**
- **Mass**
- **Energy resolution**
- **Background level**

Experimental strategy

The sensitivity formula drives the experimental strategy. In all cases develop of a proper nuclear detector to reveal the two emitted electrons in real time:

- Minimal information
  - measure their sum energy spectrum
- (If possible) add more information
  - single electron energy and initial momentum
  - species of the daughter nucleus
- Nucleus choice
  - favourable nuclear factor of merit ($F=G*M^2$)
  - high istopic abundance
  - large Q value (^{130}Te (Q=2527 keV), ^{116}Cd (Q=2802 keV), ^{76}Ge (Q=2039 keV), ^{136}Xe (Q=2479 keV), ^{82}Se (Q=2995 keV), ^{100}Mo (Q=3034 keV), ^{150}Nd (Q=3367 keV) and ^{48}Ca (Q=4270 keV))

Desirable features of the nuclear detector:

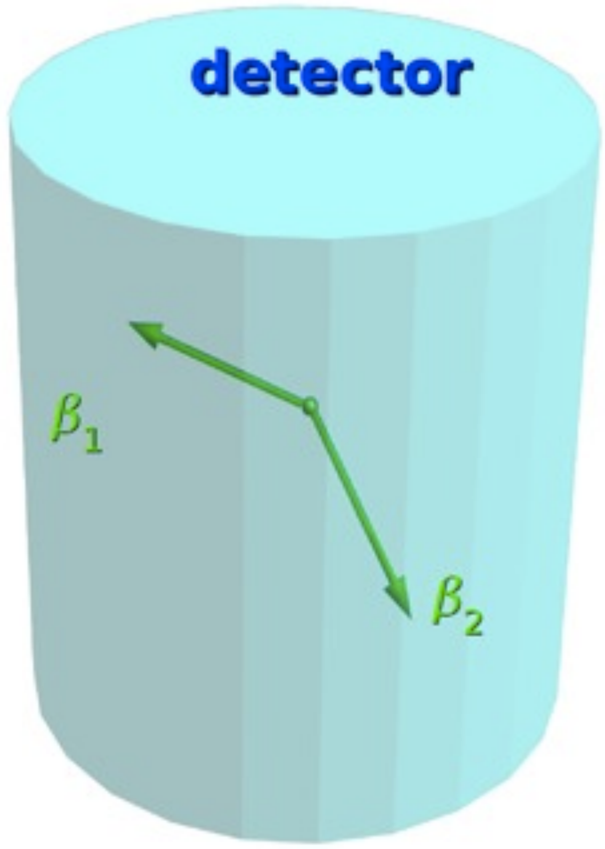
- High energy resolution
- Low background
  - Underground detector operation (to shield cosmic rays)
  - Very radiopure material
  - Well designed passive and/or active shielding against local environmental radioactivity.
- Large targets (now 10-100 kg → 1-10 tons)
- Track events or add any piece of information that can help distinguishing from background

Normally, these features cannot be met simultaneously in a single set-up

Experimental approaches

Two main approaches:

- homogeneous (calorimetric or source ⊆ detector)
- inhomogeneous (external-source)



Calorimeters

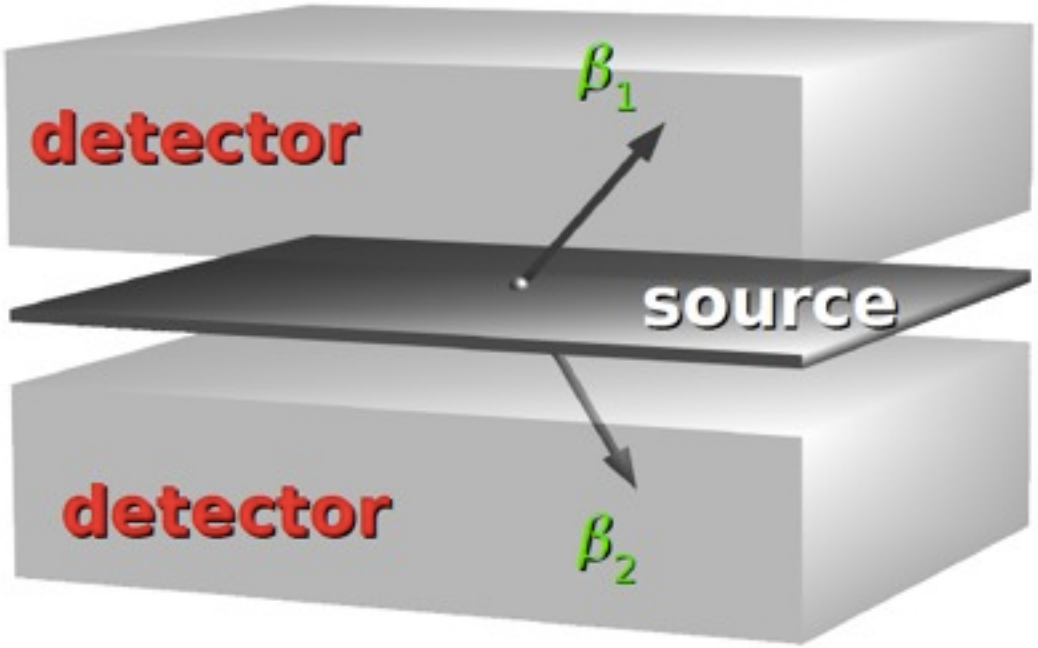
Solid-state devices, bolometers, scintillators, gas detectors

+ Very large M possible (demonstrated ~50kg, proposed ~1t)
+ High efficiency (ε~1)
+ Very high energy resolution (ΔE~0.015% with Ge-diodes, bolometers)
+ Event topology (in gas/liquid Xe detectors or pixellization)
+ Good background levels
- Constraints on detector choice (except for bolometers)
- No or partial particle id

External-source detectors

Scintillators, gas TPC, gas DC, magnetic field and TOF

+ Event topology allowing ¨clean bkg¨ (except 2νββ)
+ Several ββ candidates can be studied with same detector
- Difficult to get large source M
- Difficult to get high efficiency
- Difficult to get good resolution



Status: (Near) Past

Heidelberg –Moscow (HM) (stopped in May 2003)

dominated DBD scenario over a decade. claim of evidence!!

NEMO3

intermediate generation experiment capable to study different isotopes

CUORICINO (stopped in june 2008)

intermediate generation experiment based on the bolometric technique

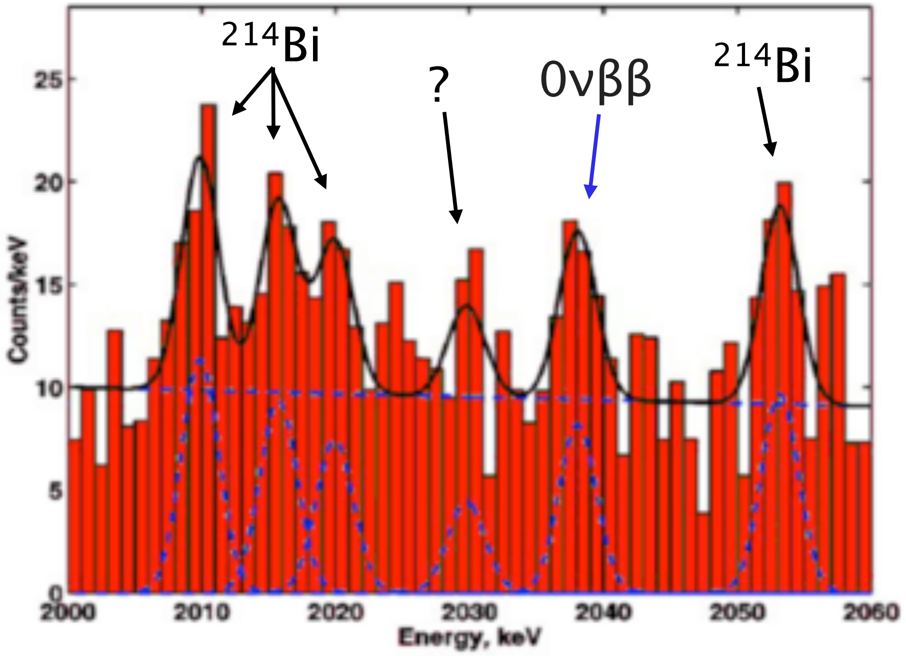
Nucleus	Detector	EXP	Material	kg y	$\tau_{1/2}$ Limit (y) (90% CL)
^{76}Ge	Ge diode	IGEX/HDM*	Ge	~ 47.7	> 1.6-1.9 x 10^{25}
^{82}Se	Tracking	NEMO3	Se	4.5	> 3.2 x 10^{23}
^{100}Mo	Tracking	NEMO3	Mo	31.5	> 1.0 x 10^{24}
^{96}Zr	Tracking	NEMO3	Zr	0.03	> 9.2 x 10^{21}
^{150}Nd	Tracking	NEMO3	Nd	0.1	> 1.8 x 10^{21}
^{128}Te	Bolometer	Cuoricino	TeO_2		> 1.1 x 10^{23}
^{130}Te	Bolometer	Cuoricino	TeO_2	19.75	> 2.8 x 10^{24}
^{136}Xe	Xe scint	DAMA	L Xe	~ 4.5	> 1.2 x 10^{24}
^{116}Cd		Solotvina			> 1.7 x 10^{23}
^{48}Ca					> 1.4 x 10^{22}
^{160}Gd					> 1.3 x 10^{21}

* Existing claim for a positive result by part of the same group

H.V.Klapdor et al.: ^{76}Ge 0νββ evidence

First claim in January 2002 (**Klapdor-Kleingrothaus HV et al. hep-ph/0201231**) with a statistics of 55 kg y and a 2.2-3.1 statistical significance → strong criticism

Claim confirmed in 2004 with the addition of a significant (~1/4) new statistics and improved in the following years



1990 - 2003 data, all 5 detectors
exposure = 71.7 kg×y

$\tau_{1/2}$ = 1.2×10^{25} years

⟨m⟩ = 0.44 eV

H.V.Klapdor-Kleingrothaus et al., Phys. Lett. B 586 (2004) 198

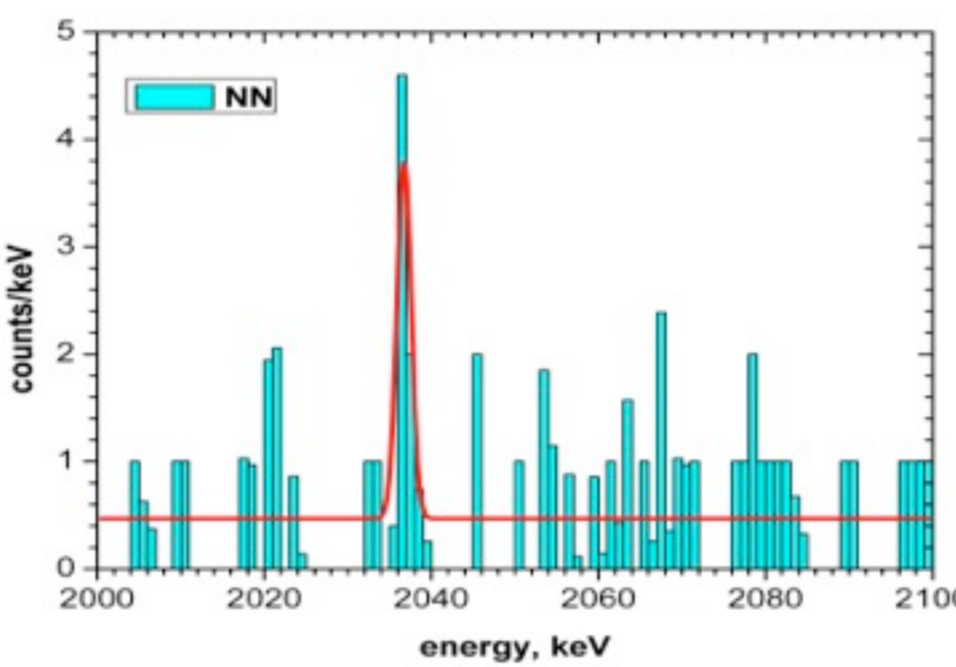
1995-2003 data new re-analysis:
SSE selection by MC & ANN

6.4σ signal

7.05 ± 1.11 events

$2.23^{+0.44}_{-0.31}$ 10^{25} years / 0.32±0.03 eV

H.V.Klapdor-Kleingrothaus et al., Phys. Scr. T127 (2006) 40-42

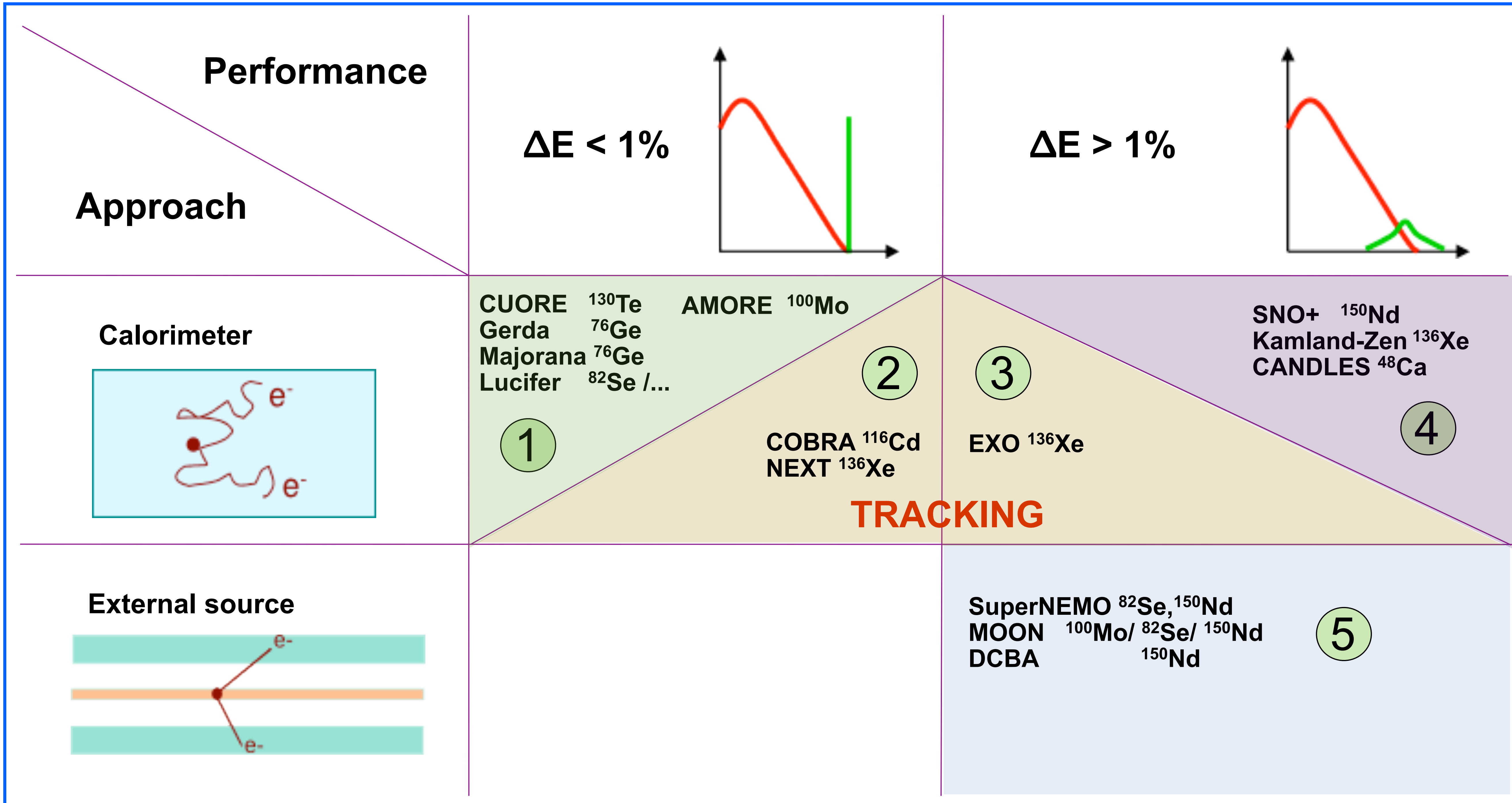


all future experiment will certainly have to cope with this result

arXiv:1006.2025v1 [hep-ph]: Kirpichnikov alternate interpretation of 2039 keV line

Present/Future experiments

4 complementary approaches + some



Many project have been proposed. Many of them are R&D or still only proposals.
Only a representative list is given here.

Experiments: group 1

Homogeneous with high energy resolution

CUORE ^{130}Te
- Array of low temperature natural TeO_2 calorimeters operated at 10 mK
- First step: 200 Kg (2014) – LNGS – takes advantage of Cuoricino experience
- Proved energy resolution: 0.2 % FWHM

GERDA - ^{76}Ge
- Array of enriched Ge diodes operated in liquid argon
- First phase: 18 Kg; second phase: 40 Kg - LNGS
- Proved energy resolution: 0.2 % FWHM

MAJORANA – ^{76}Ge
- Array of enriched Ge diodes operated in conventional ultra-pure Cu cryostats
- Modular; first step (demonstrator): 2x20 Kg modules
- Proved energy resolution: 0.16 % FWHM

LUCIFER - ^{82}Se – ^{116}Cd – ^{100}Mo
- Array of scintillating ZnSe bolometers operated at 10 mK
- First step: ~ 10 Kg (2014) – LNGS – R&D project to fully test the principle
- Proved energy resolution: 0.3 – 0.7 % FWHM

Experiments: group 2

Homogeneous with high energy resolution and tracking

NEXT - ^{136}Xe
- High pressure Xe (gas) TPC
- Total mass: 100 kg
- Energy resolution (goal) down or below 1% FWHM (electroluminesce in high field region)
- Detection concept and performance proved with 2 small rototypes

COBRA - ^{116}Cd competing candidate – 9 ββ isotopes
- Array of ^{116}Cd enriched CdZnTe (semiconductor detectors) at room temperatures
- Small scale prototype at LNGS
- Energy resolution: 1.9% FWHM
- Tracking capability: pixellization

Experiments: group 3

Homogeneous with low energy resolution + tracking

EXO-200 ^{136}Xe

- TPC of enriched liquid (first phase) and gaseous (second phase) Xenon
- Event position and topology; in prospect, tagging of Ba single ion (DBD daughter) through optical spectroscopy ⇒ only 2ν DBD background
- EXO-200: funded, taking data: 200 kg – WIPP facility
- Further steps: 1-10 ton
- In parallel with the EXO-200 development, R&D for Ba ion grabbing and tagging

Experiments: group 4

Homegeneous with low energy resolution

KamLAND-ZEN ^{136}Xe
- Enriched Xe gas dissolved in KAMLAND liquid scintillator (3% wt)
- Dedicated balloon immersed in the main vessel.
- Larger number of PMT and different scintillator – up to 400 kg of enriched Xe in the first phase

SNO+ – ^{150}Nd
- SNO detector filled with Nd-loaded liquid scintillator
- 0.1% loading with natural Nd → 1000 Kg Nd in 1000 tons scintillator → 56 Kg of isotope
- Nd enrichment and purity are an issue.

XMASS – ^{136}Xe
- Multipurpose (Dark Matter, Double Beta Decay, solar neutrinos) scintillating liquid Xe detector
- Three development stages: 3 Kg (prototype) ⇒ 1 ton ⇒ 10 tons natural or 1 ton enriched
- DBD option: low background in the MeV region (water tank)
- Good light yield and collection efficiency ⇒ energy resolution down to 1.4%

CANDLES – ^{48}Ca
- Array of natural (no Eu doping) CaF_2 scintillators
- Proved energy resolution: 3.4 % FWHM
- Very high Q-value of ^{48}Ca: 4.27 MeV
- PSD and space-time correlation for Bi-Po and Bi-Tl

Experiments: group 5

Inhomogeneous with low energy resolution

SUPERNEMO - ^{82}Se or ^{150}Nd

- Modular (source foils). Tracking (drift chamber in Geiger mode) and calorimetric (low Z scintillator) sections - Magnetic field for charge sign.
- 20 modules with 5 kg source for each module ⇒ 100 Kg in Modane extension.
- Energy resolution: 4 % FWHM. Takes advantage of NEMO3 experience
- First step:single module (demonstrator) @ Modane

MOON - ^{100}Mo or ^{82}Se or ^{150}Nd

- Multilayer plastic scintillators interleaved with source foils + tracking section (PL fibers or MWPC)
- MOON-1 prototype without tracking section (2006)
- MOON-2 prototype with tracking section
- Proved energy resolution: 6.8 % FWHM
- Final target: collect 5 y x ton

DCBA - ^{150}Nd

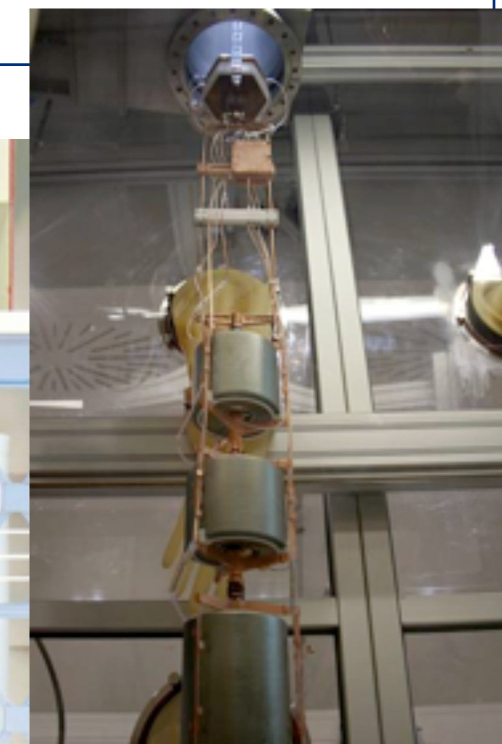
- Momentum analyzer for beta particles consisting of source foils inserted in a drift chamber with magnetic field
- Test prototype DCBA-T2 completed: space resolution ~ 0.5 mm; energy resolution 6 % FWHM at 3 MeV
- Test prototype DCBA-T3 under construction: improved energy resolution (higher magnetic field 2kG) and better space resolution
- Final target: 10 modules with 84 m^2 source foil for module (126 through 330 Kg total mass)

Experimental Status

Experiment	Nucleus	Mass	Technique	Location	Date
Current experiments (funded, construction, running)					
GERDA I/II	^{76}Ge	15/35	ionization	LNGS	2011/13
Majorana	^{76}Ge	30	ionization	SUSEL	2014
EXO200	^{136}Xe	200	liquid TPC	WIPP	2011
CUORE0/CUORE	^{130}Te	10/200	bolometer	LNGS	2012/14
Kamland-Zen	^{136}Xe	400	liquid scintillator	Kamioka	2011
SNO+	^{150}Nd	44	liquid scintillator	Sudbury	2014
R&D (funding, prototyping)					
NEXT	^{136}Xe	100	gas TPC	Canfranc	2013+
Candles III	^{48}Ca	0.35	scintillating crystals	Oto Cosmo	2011
MOON	^{82}Se/^{150}Nd				
DCBA	^{150}Nd	32	tracking		
Cobra	^{116}Cd		solid TPC	LNGS	
SuperNEMO	^{82}Se	7/100-200	track/calorimeter	Modane	2014/?
XMASS	^{136}Xe		liquid scintillator	Kamioka	
Lucifer	^{82}Se	17.6	scintillating bolometer	LNGS	2014

GERDA

Ge diodes (86% enriched ^{76}Ge) **in Lar cryostat** (active in phase II) **in water tank** (active)
BEGe technology in phase-II**:** better E resolution, Multi/Single interaction discrimination
@LNGS Phase-I ~ end 2011 Phase-II ~ 2013



ββ candidate: ^{76}Ge **– Q** 2039 keV

Source Mass:
Phase-I: 18 kg ^{76}Ge – $\mathbf{N_{\beta\beta}}$ 1.4 x10^{26}
Phase-II: 40 kg ^{76}Ge – $\mathbf{N_{\beta\beta}}$ 3.2 x10^{26}

Projected Bkg:
Phase-I: 0.01 c/keV/kg/y
Phase-II: 0.001 c/keV/kg/y

Sensitivity $T_{1/2}^{0\nu}$:
Phase-I: 2.5x10^{25} y in 1 y
Phase-II: 1.9x10^{26} y in 5 y

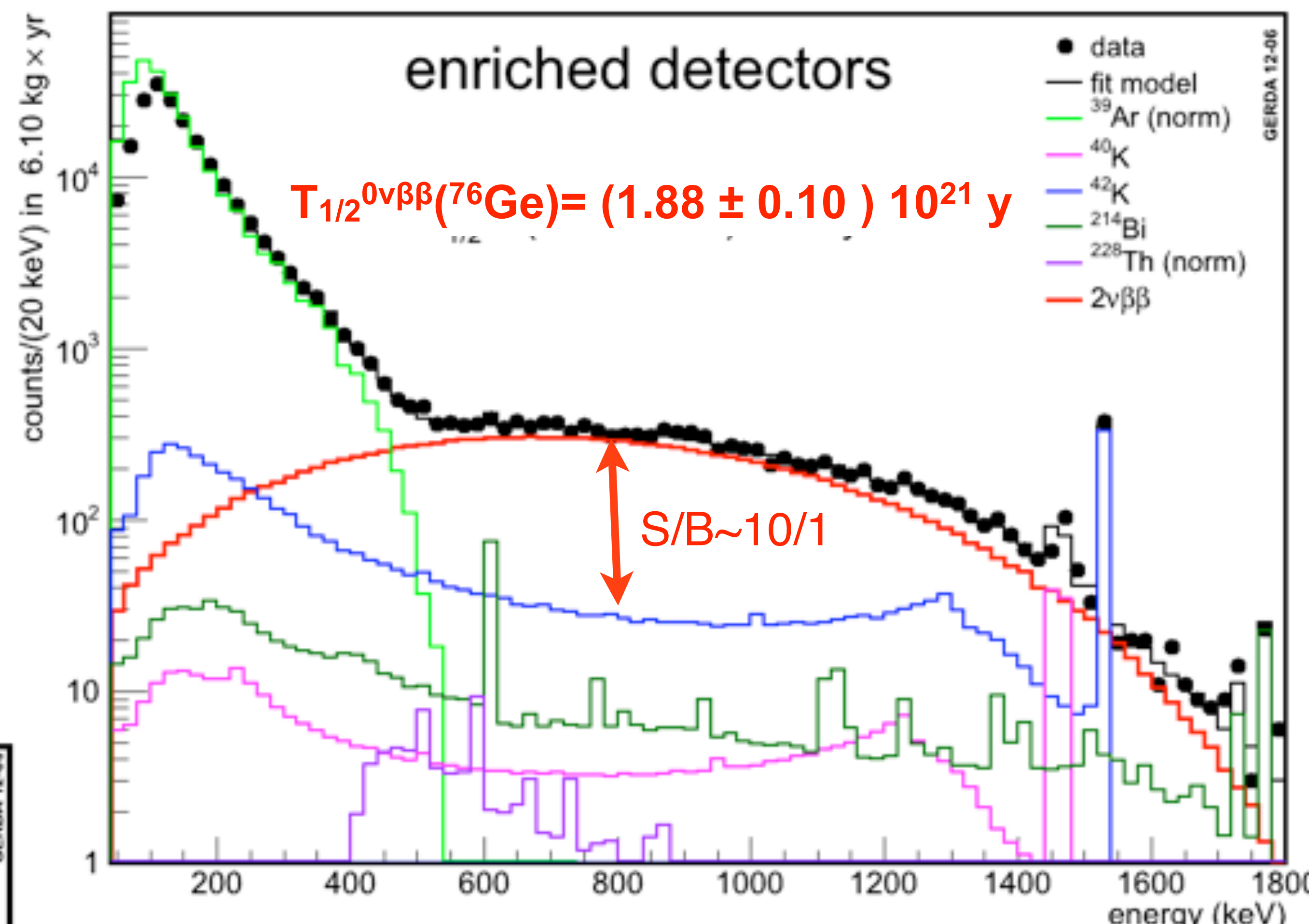
Sensitivity <m_{ee}>:
I: Scrutinize KK claim (if true 7 bb cts over 0.5 cts of bkg) in < 2 y
II: <m_{ee}> < 73 ÷ 203 meV in 5 y **> IH**

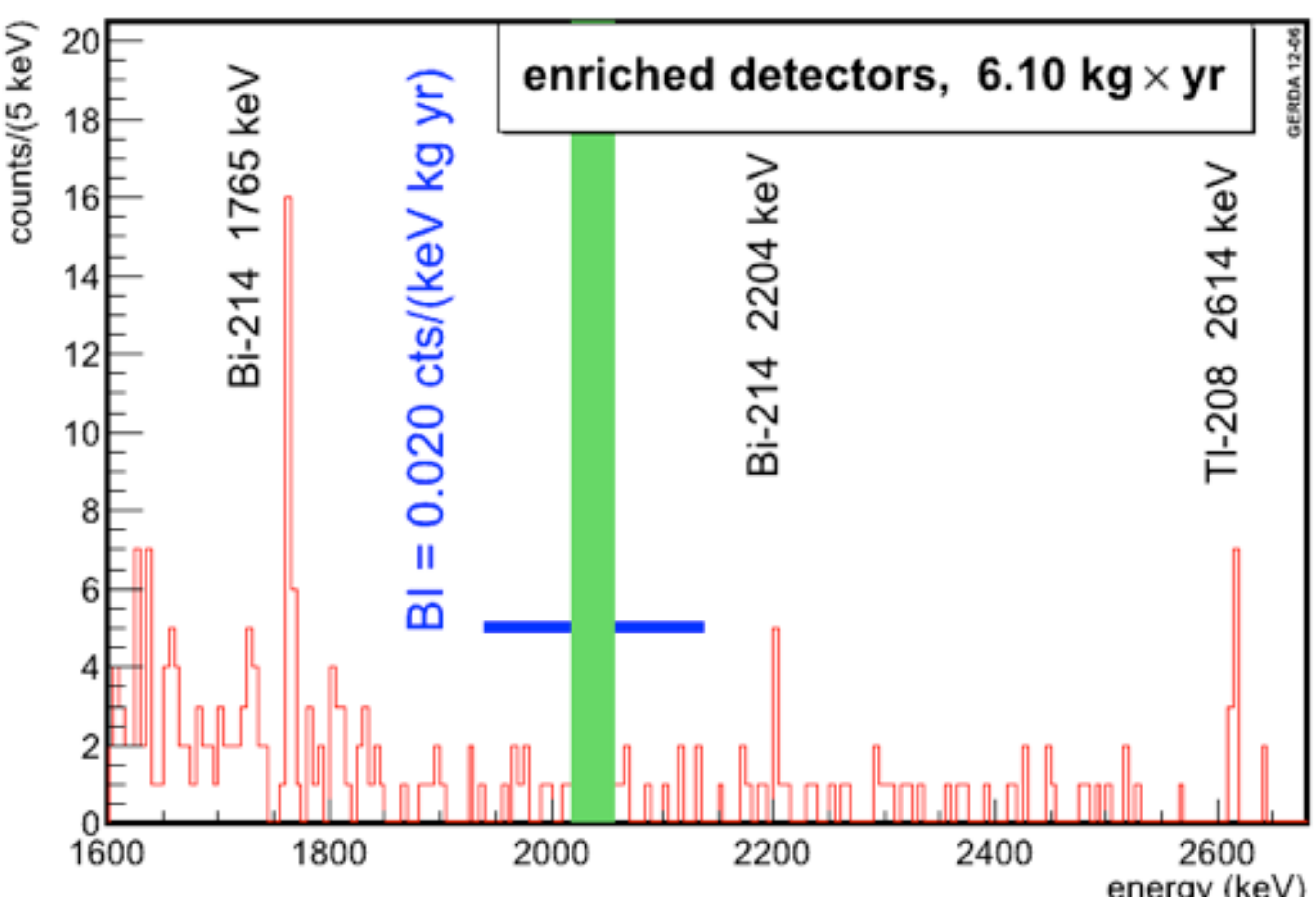
GERDA status

2vββ

GERDA is running and taking data

- **statistics:** 1.11.2011 – 21.5.2012 (enrGe exposure 6.10 kg yr)
- **systematics**: blinding 2019 – 2059 keV
- **background index** (BI) : 0.020 +0.006 -0.004 cts/(keV kg yr) [68% coverage]
- **LAr**: ^{42}Ar (^{42}K) activity determined: (93.0 Å}





0vββ

CUORE

988 TeO_2 (33.8% ai ^{130}Te) **bolometers at ~ 10 mK in a granular structure** (741 kg mass)
@LNGS Phase-I (CUORE0): starts ~ mid 2012 Phase-II: ~ 2014 Future: enr., scintillating bolom.?

ββ candidate: ^{130}Te **– Q** 2527.5 keV

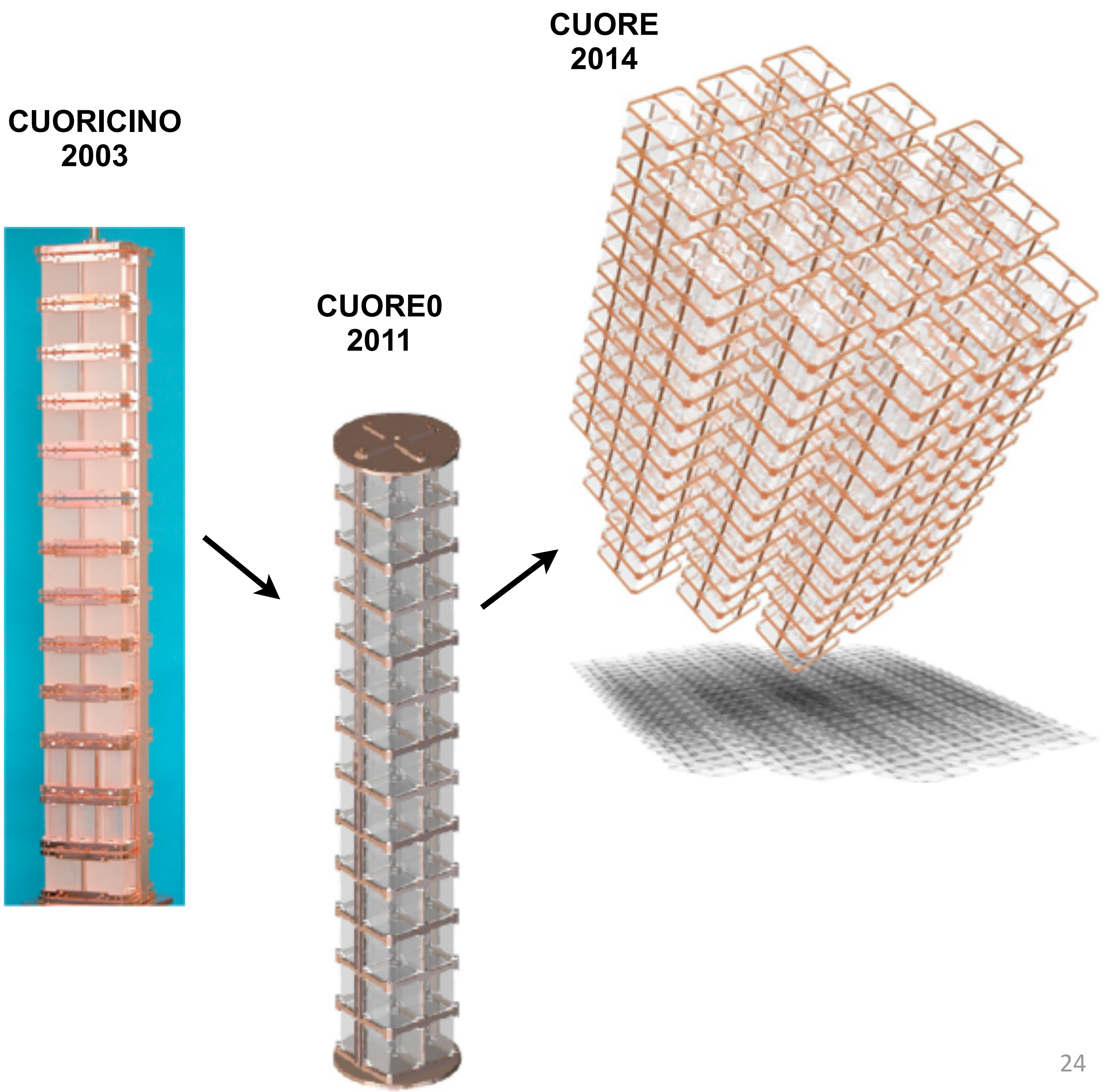
Source Mass:
Phase-I: 10.8 kg ^{130}Te – $\mathbf{N_{\beta\beta}}$ 5.0 x10^{25}
Phase-II: 206 kg ^{130}Te – $\mathbf{N_{\beta\beta}}$ 9.6 x10^{26}

Projected Bkg:
Phase-I : 0.05 c/keV/kg/y
Phase-II: 0.01 c/keV/kg/y

Resolution: ~ 5 keV @ROI

Sensitivity $T_{1/2}^{0\nu}$:
Phase-I: 4.2x10^{24} y in 1 y
Phase-II: 1.6x10^{26} y in 5 y

Sensitivity Phase-II <m_{ee}>:
<m_{ee}> < 40 ÷ 94 meV in 5y (IH)

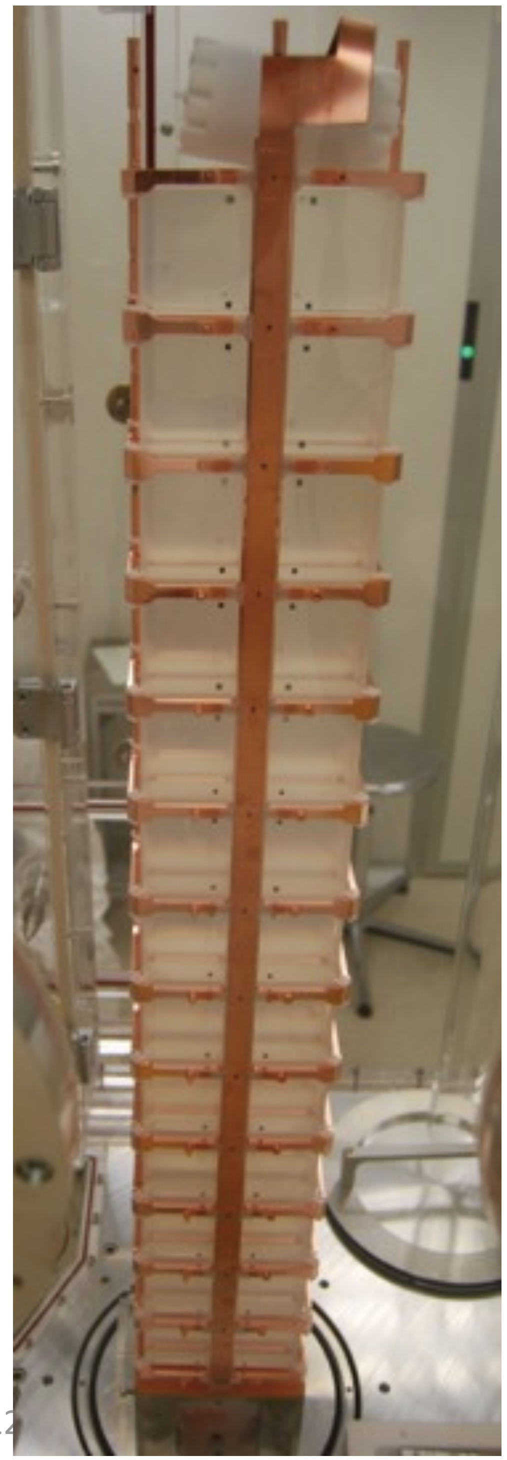


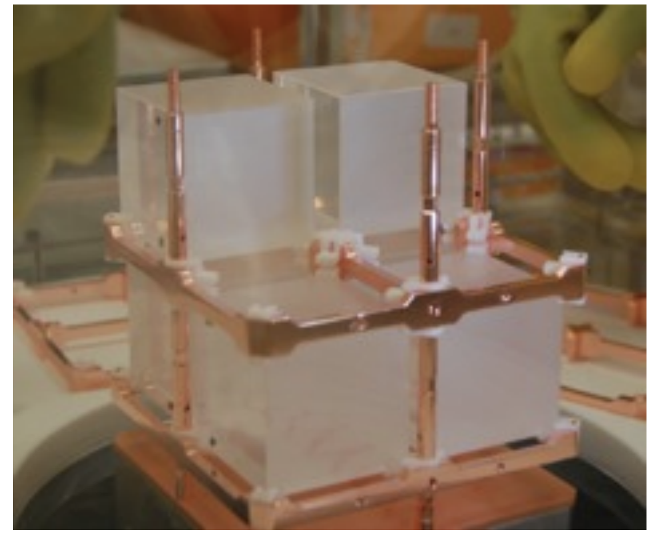
F. Bellini et al., Astrop. Phys. 33 (2010) 169
F. Alessandria et al., nucl-ex:1109.0494v1
C. Arnaboldi et al., Phys. Rev. C 78 (2008) 035502

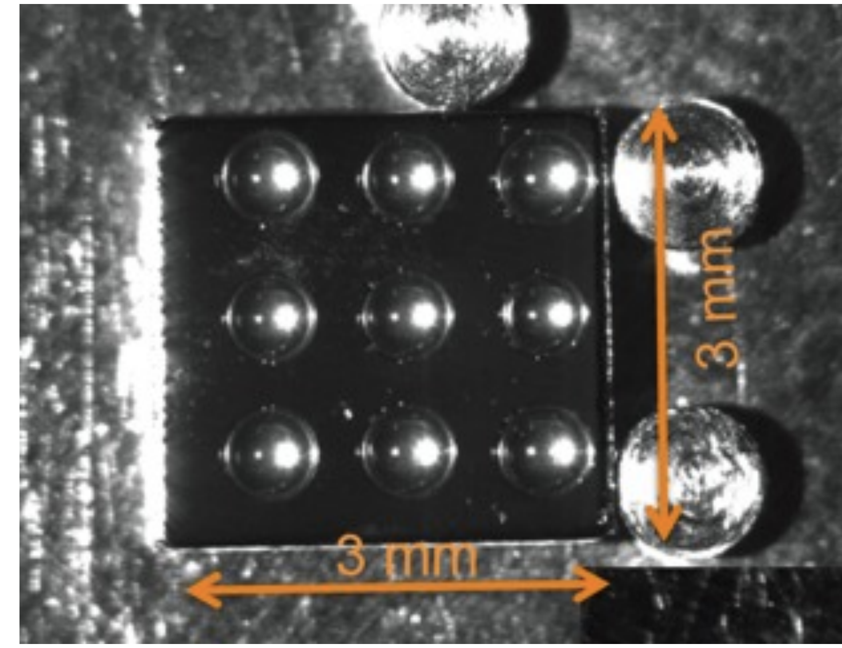
CUORE-0

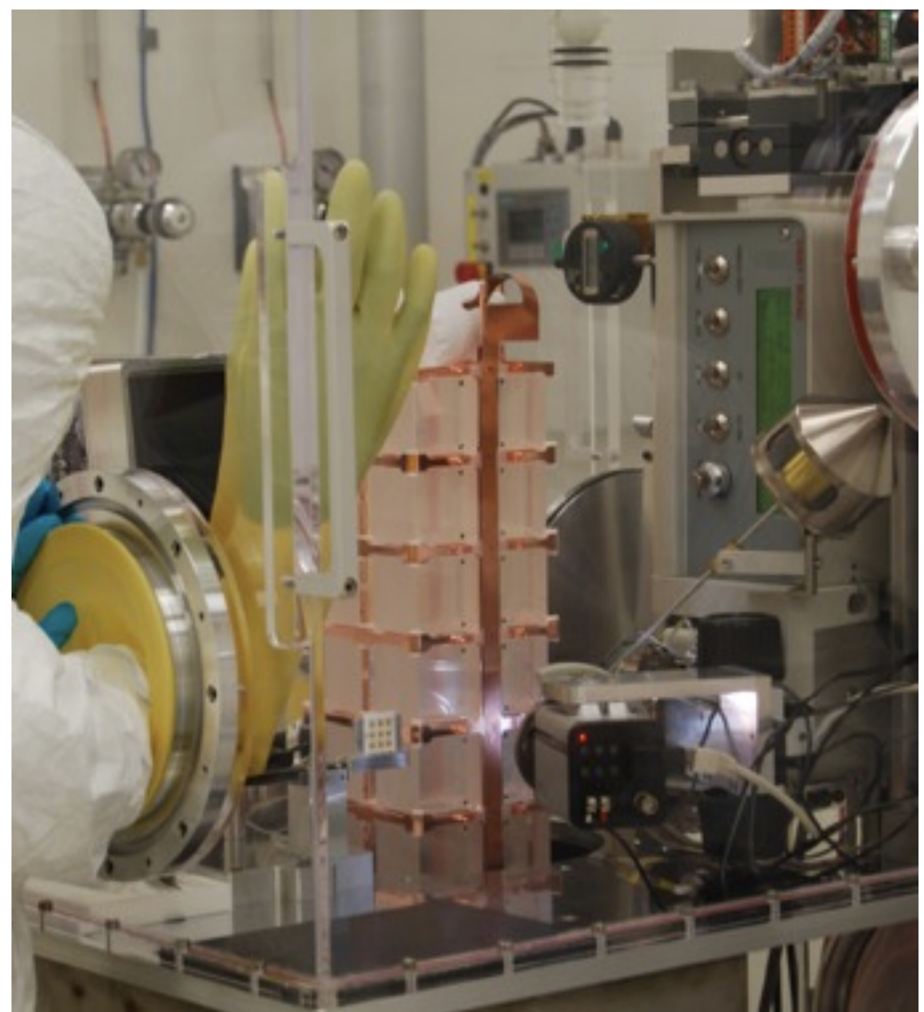
Goals:
- full test and debug of the new CUORE assembly line
- high statistics check of the improved uniformity of bolometric response

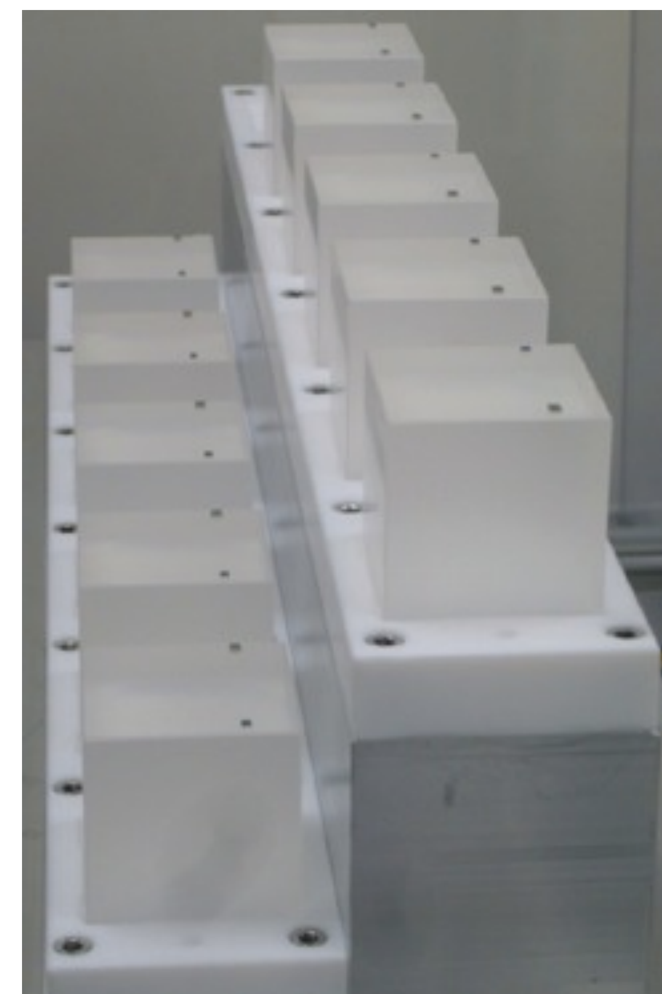
→ P.Gorla talk





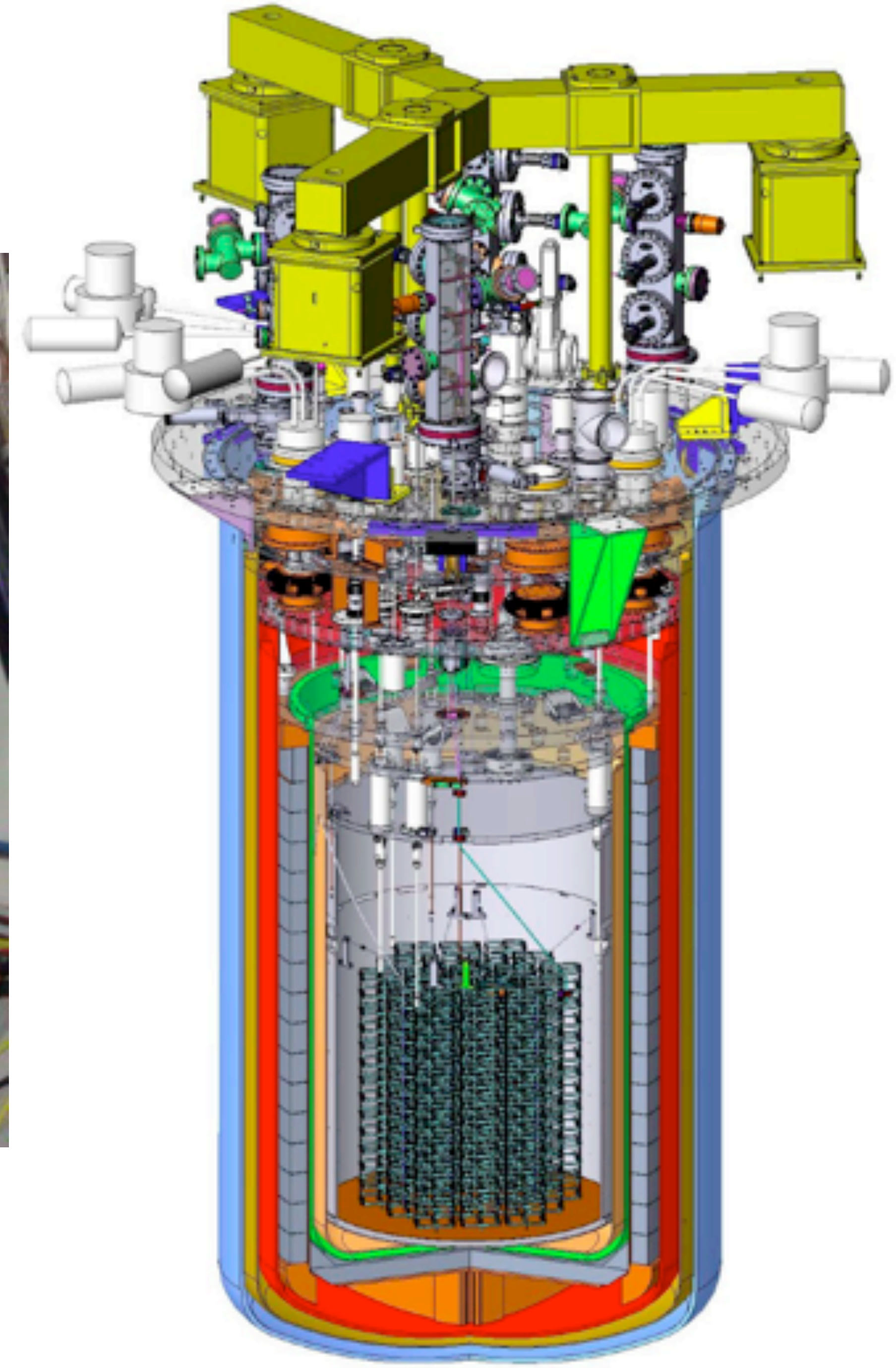






CUORE status

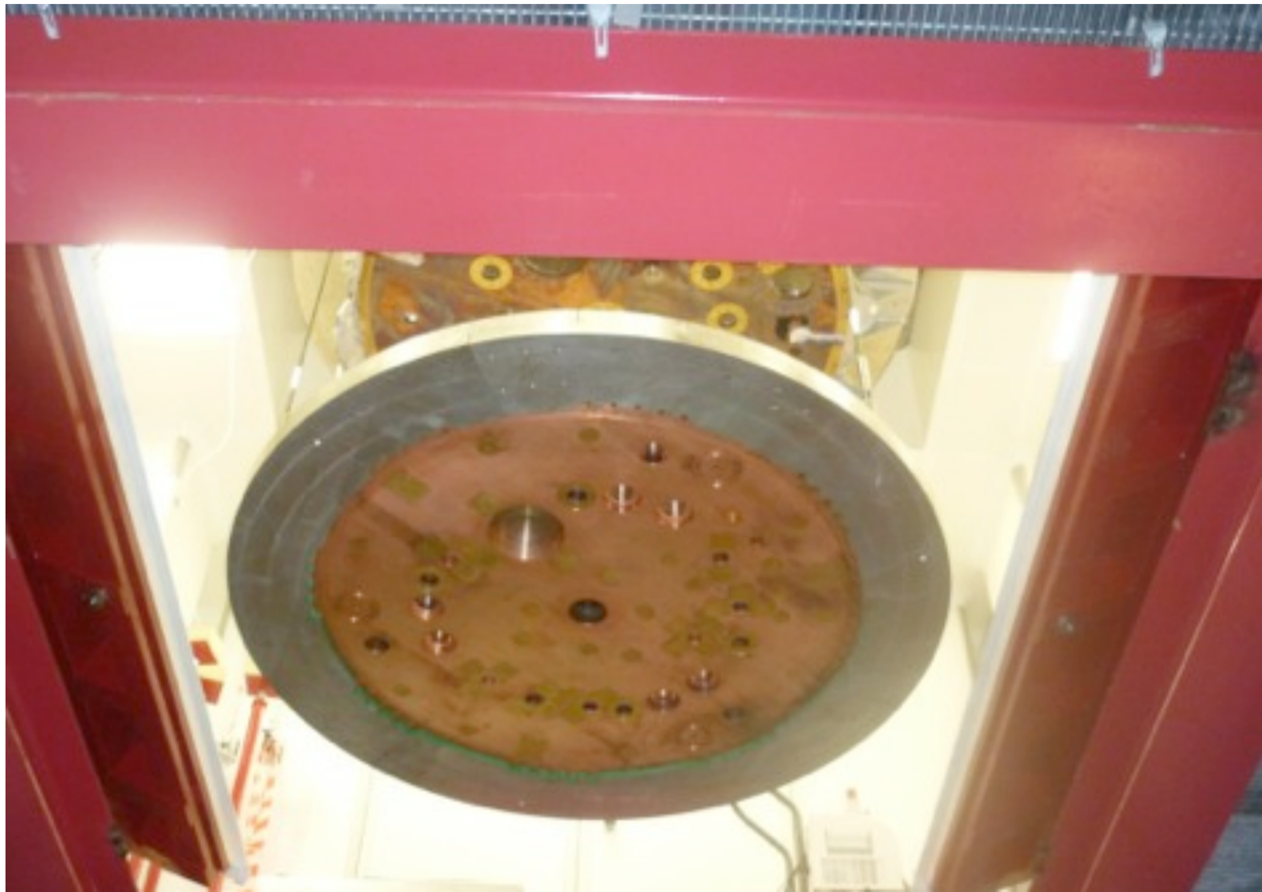
- Crystals, almost completely arrived (all at LNGS by the end of 2012
- Copper parts are being machined and cleaned
- Dilution unit performance better than expected and delivered to LNGS
- CUORE Hut, and most of all the infrastructures, ready
- Detector assembly line, ready and tested (CUORE0)
- Radon abatement system installed
- 3 (of 6) cryostat vessels tested and delivered at LNGS
- Commissioning of the cryostat started on July 2012



Crystals	12/12
Thermistors	13/03
Cleaned Cu parts	13/12
Cryogenic	13/12
Tower Assembly	14/04
Detector insertion	14/07
Cool Down	14/11

CUORE

Crystat commissioning
in the CUORE underground lab @ LNGS



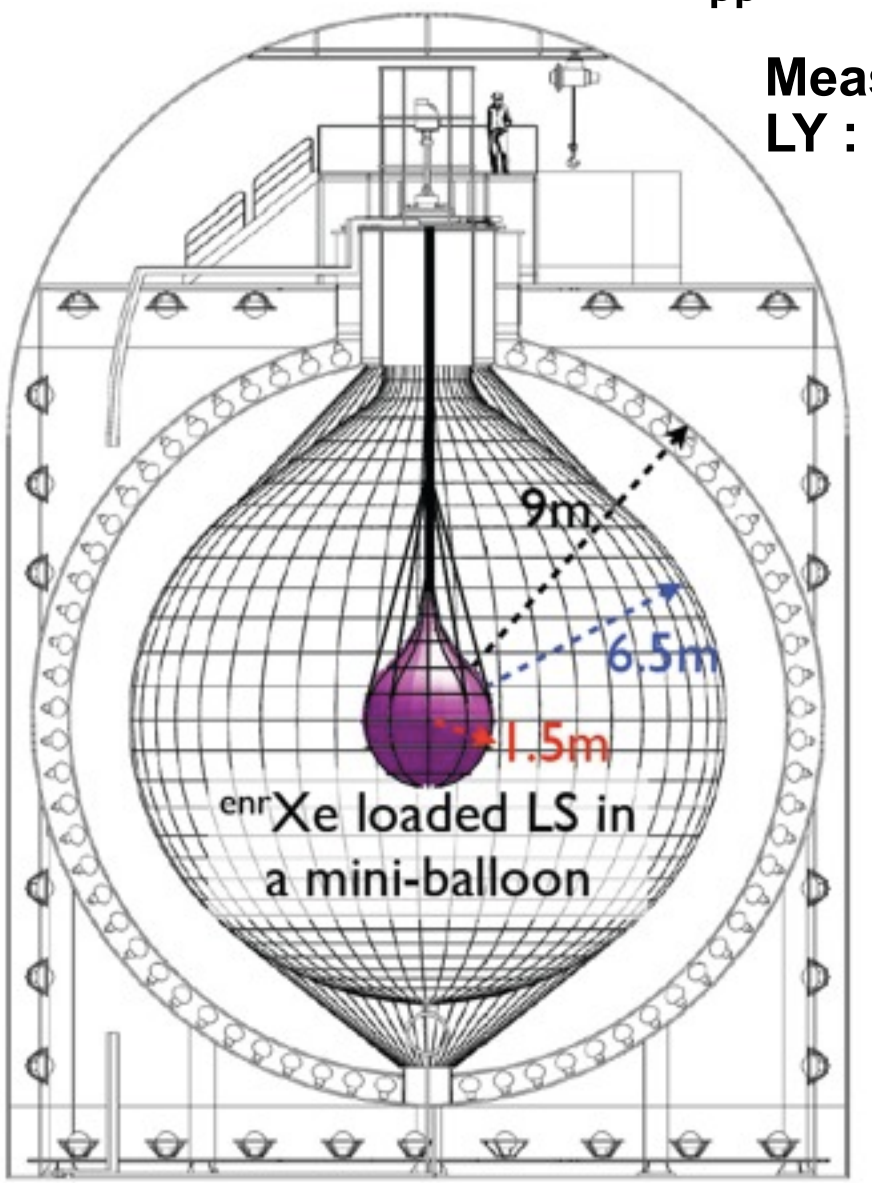
Kamland-Zen

~16 t (40 t in 2nd phase) **Liquid Scintillator 2.5wt% ^{enr}Xe loaded** (91% enrichment of ^{136}Xe) in a Ø3.4m Mini Baloon in Kamland detector (1000t LS+Buffer Oil+Water Cherenkov Outer Detector)
@Kamioka mine 1st Phase~ end 2011 2nd Phase >2013

ββ candidate: ^{136}Xe **– Q** 2476 keV

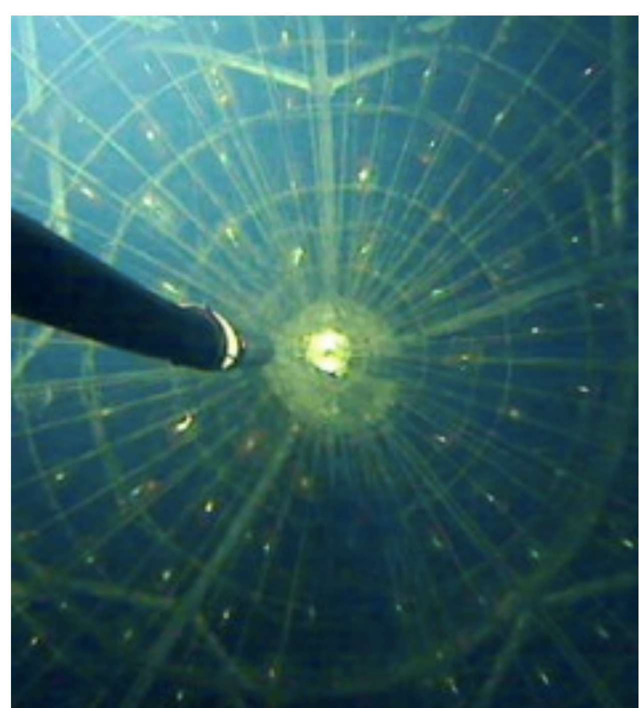
Source Mass:
1st Phase: 364 kg ^{136}Xe – $N_{\beta\beta}$ 1.6 x10^{27}
2nd Phase: 700 kg ^{136}Xe – $N_{\beta\beta}$ 4.0 x10^{27}

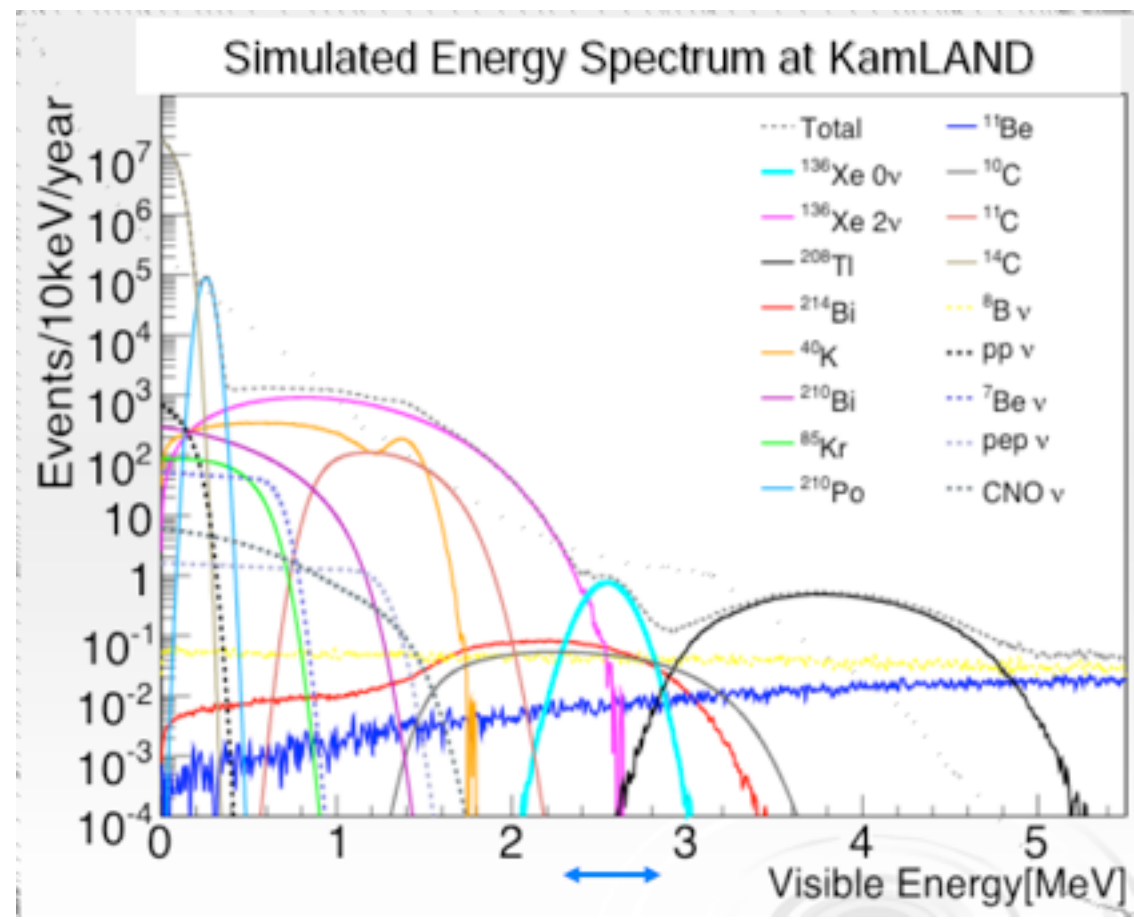
Main Bkg:
- 2νββ ^{136}Xe (slow: $T_{1/2}$~10^{22} y)
- ^{10}C, ^{11}Be (1/10 with tag)
- ^{8}B solar ν
- ^{214}Bi, ^{208}Tl from MB (vertex cut)



Measured FWHM: ~ 10% @ROI
LY : 8000 photons/MeV

=> expected S/Bkg ~ 2

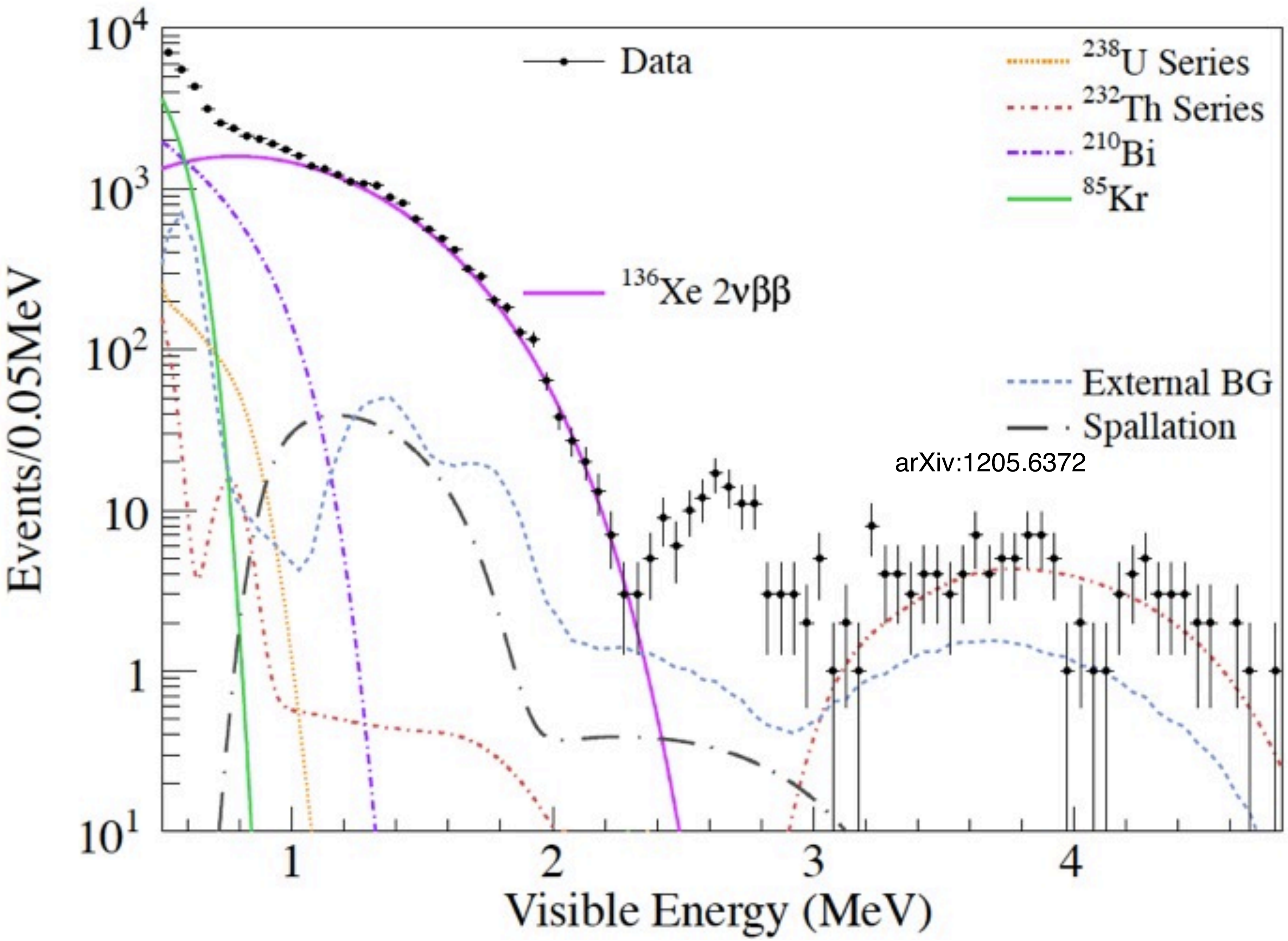


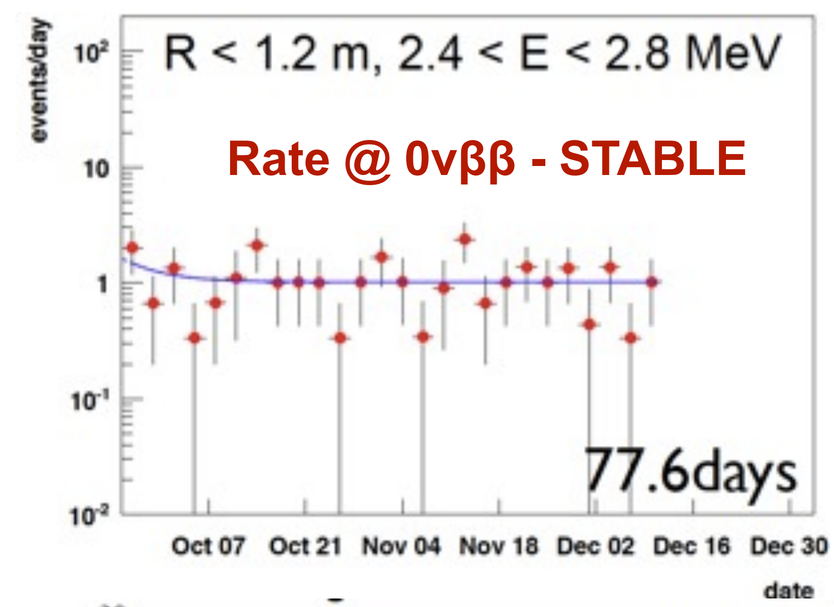


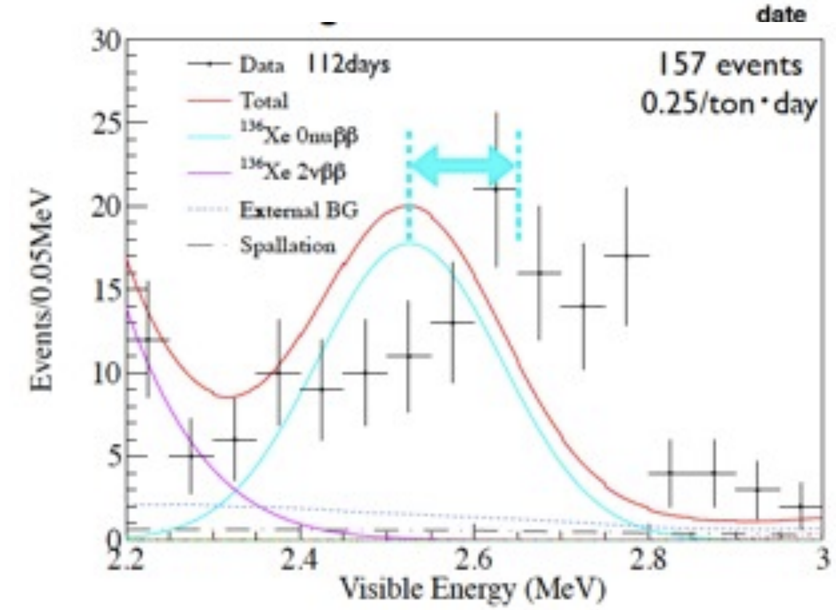
Target Sensitivity:
1st phase: $<m_{ee}>$ ~ 60 meV @1 y
2nd phase: $<m_{ee}>$ ~ 25 meV @5 y (IH)

Kamland-Zen 2νββ

arXiv:1205.6372





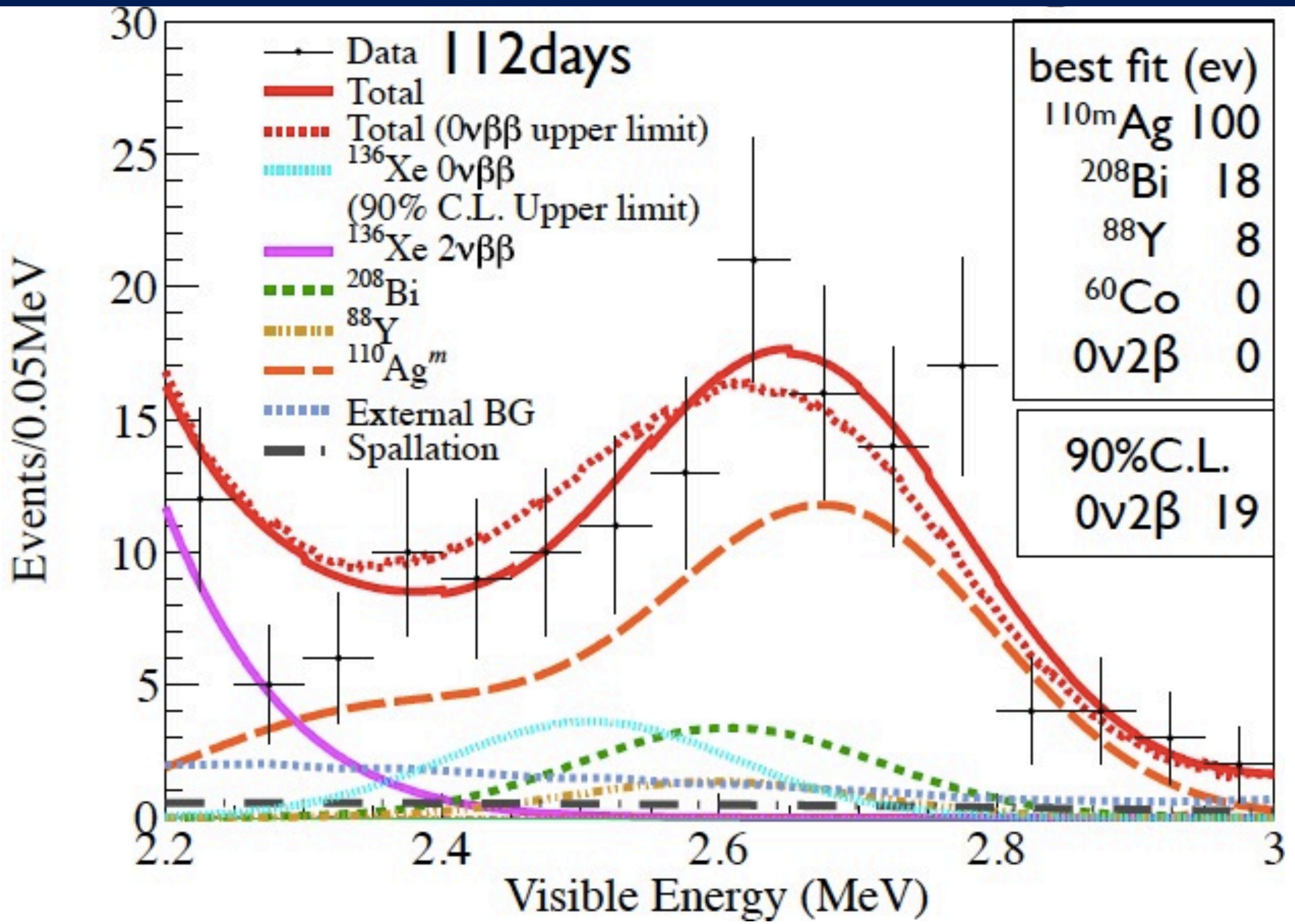


precise measurement of the 2νββ half-life:

$\tau_{1/2}^{2\nu\beta\beta}$ (^{136}Xe) = (2.30 ± 0.02 stat ± 0.12 sys)·10^{21} yr

Kamland-Zen 0νββ

arXiv:1205.6372



- KL-Zen: 112 days
- ^{110}Ag + ^{208}Bi fit

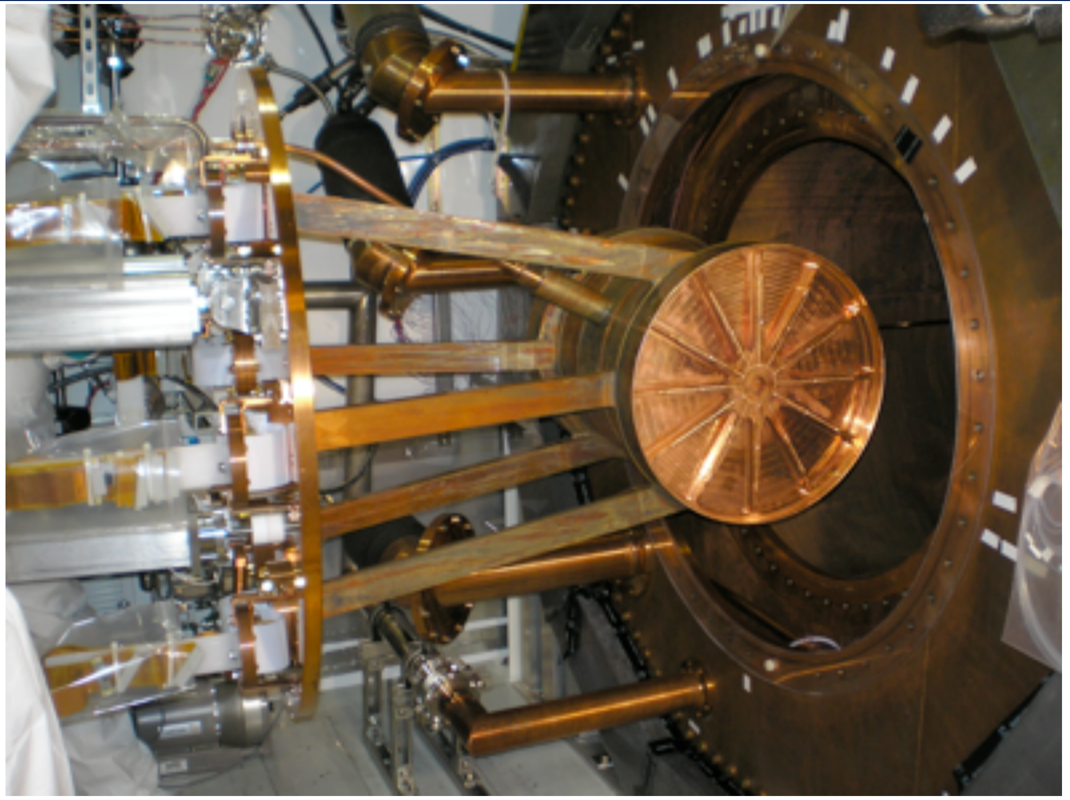
$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > $6.2\cdot10^{24}$ y

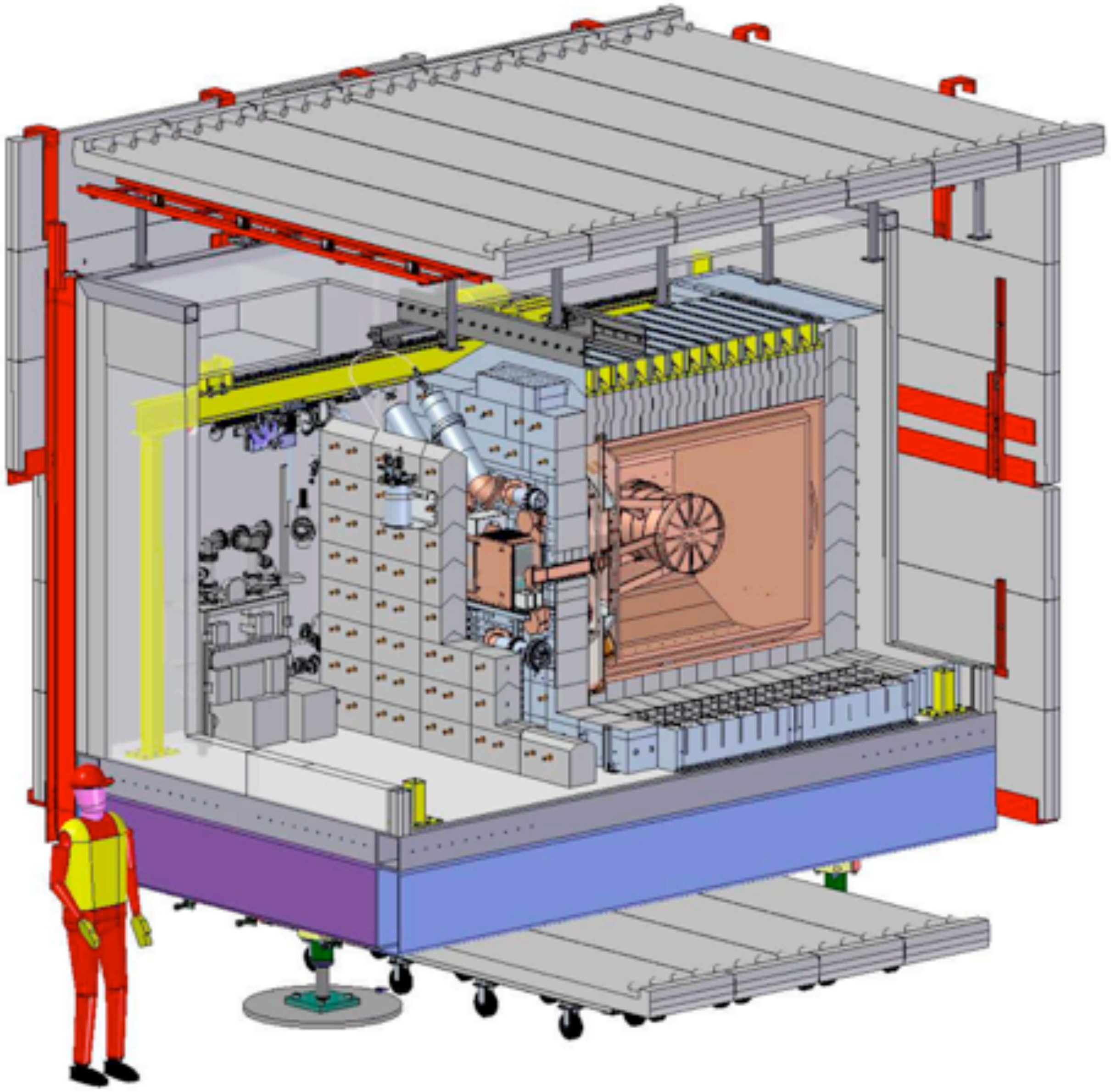
Results and perspectives:

- validity of using the low radioacivity environment of neutrino detector for a rare phenomena study
- better understanding of background → effective purification is about to start (reduction factor 100)
- R&D for larger Xe concentration and better light yield

EXO-200

~ 1 ton TPC of liquid ^{enr}Xe (80.6% of ^{136}Xe) at 167 K with double read-out **(ion+scint)** allowing event **3D tracking** and **α/β discrimination + Ba^+ daughter tag** for **free bkg exp**.
GOAL of EXO-200: 1st step with 175 kg LXe without Ba^+ tag for QD region @WIPP
Exo-200: Started 2011 – 2νββ result: $T_{1/2}$ ~ 2.1×10^{21} y
Start Exo-full ?





ββ candidate: ^{136}Xe – **Q** 2458 keV

Source Mass:
- Exo-200: ~ 80 kg FMass ^{136}Xe – $N_{\beta\beta}$ 3.5 x10^{26}

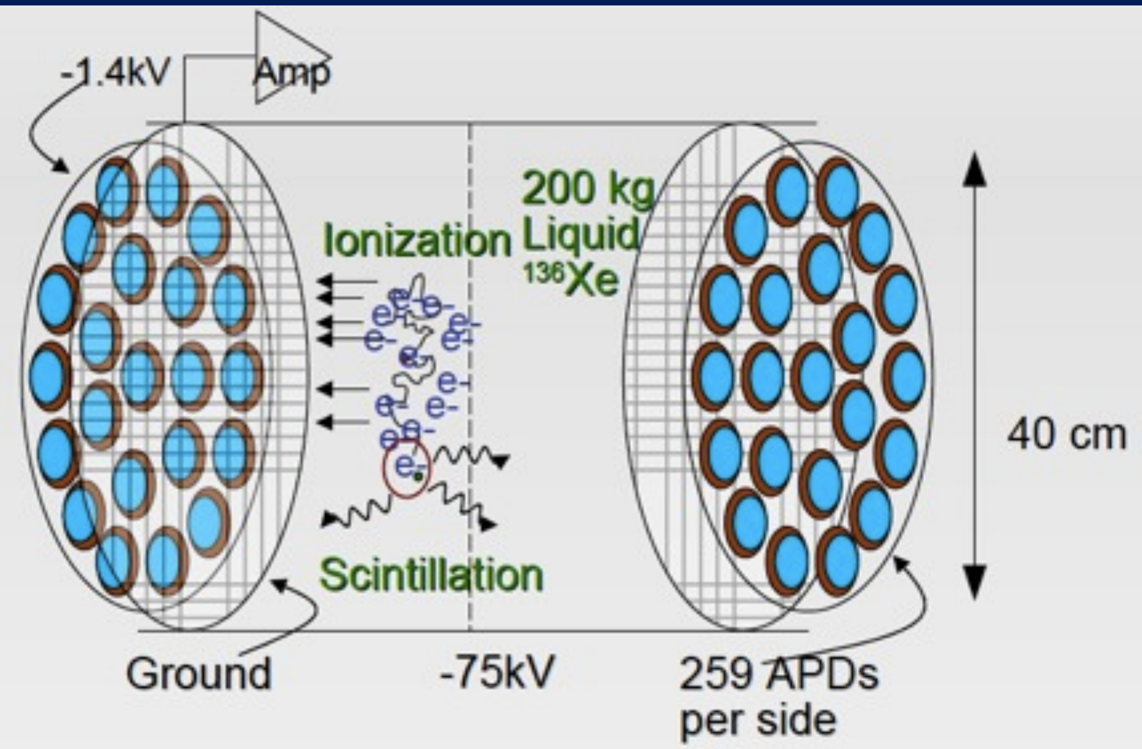
Bkg Strategy:
- low activity materials / LXe purity check
- conventional screening techniques+ FV cut
- 3D track (double grid (xy) + Avalanche Photo Diodes (t_0->z))
- α/**β** discrimination through ion. vs. light
- Ba^+ tag with Resonant Ionization Spectrosc.

Projected Bkg: ~ 10^{-4} c/keV/kg/y

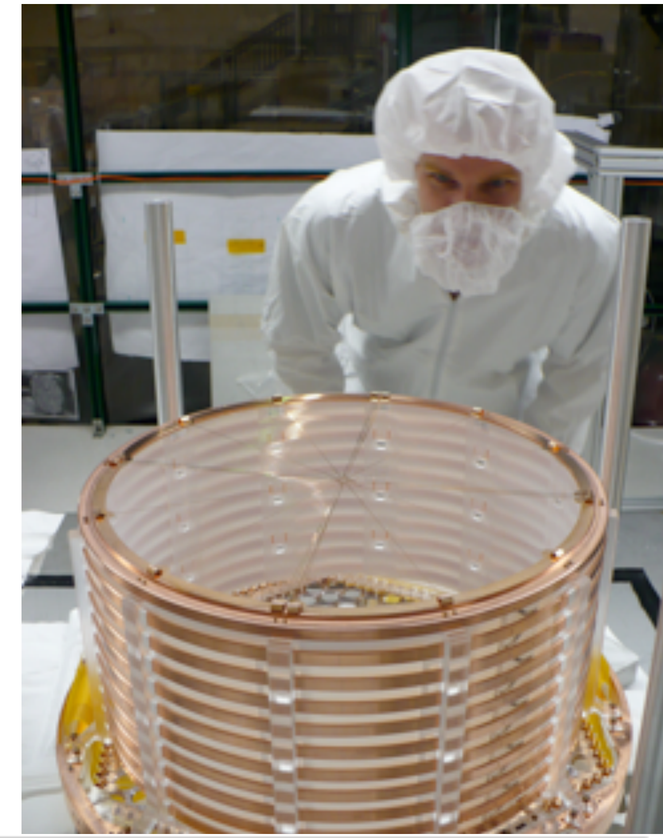
Projected FWHM: ~ 3.7% @ROI (maybe better if gas Xe)

Target Sensitivity:
- Exo-200: $T_{1/2}$ ~ 6.4×10^{25} y @2y <m_{ee}> < 87 ÷ 224 meV in 2y
- Exo-full: $T_{1/2}$ ~ 2.0×10^{27} y @ 5y <m_{ee}> < 16 ÷ 40 meV in 5y

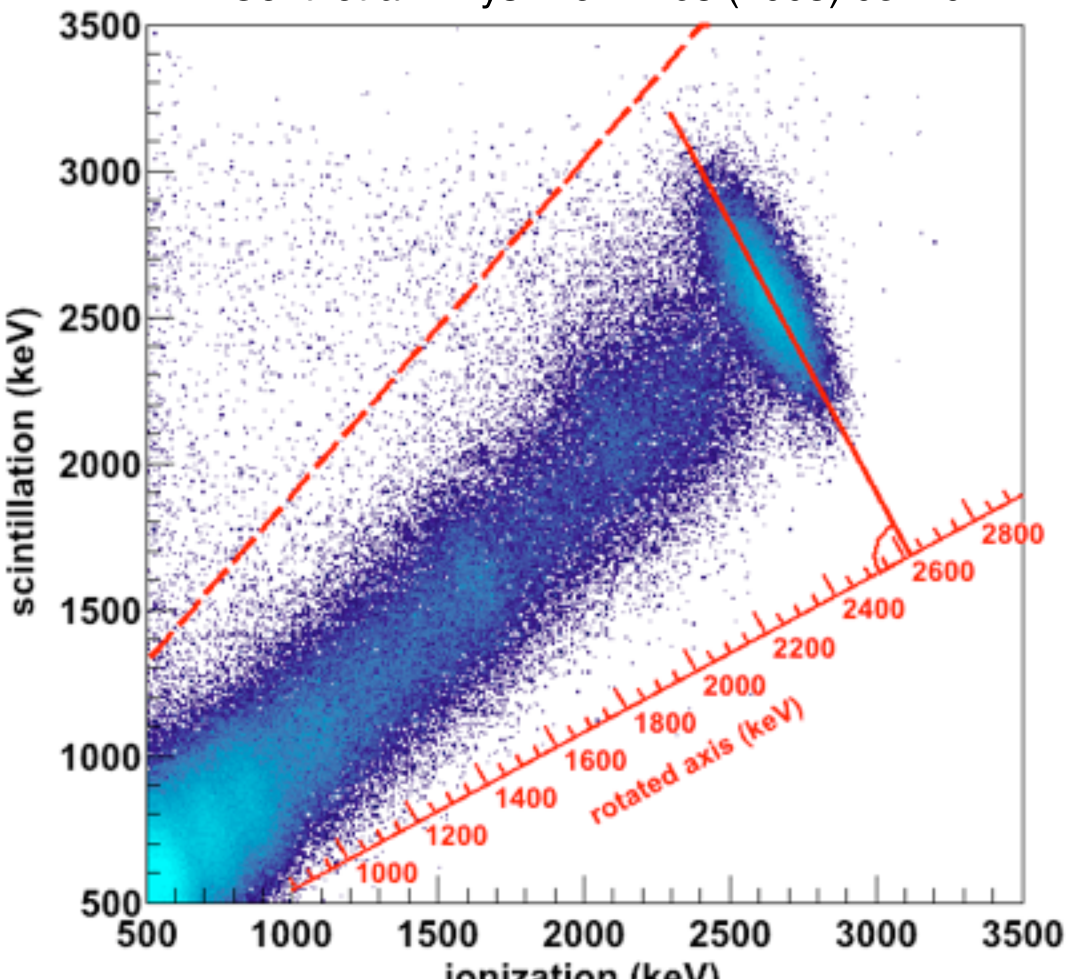
Resolution: scintillation vs charge

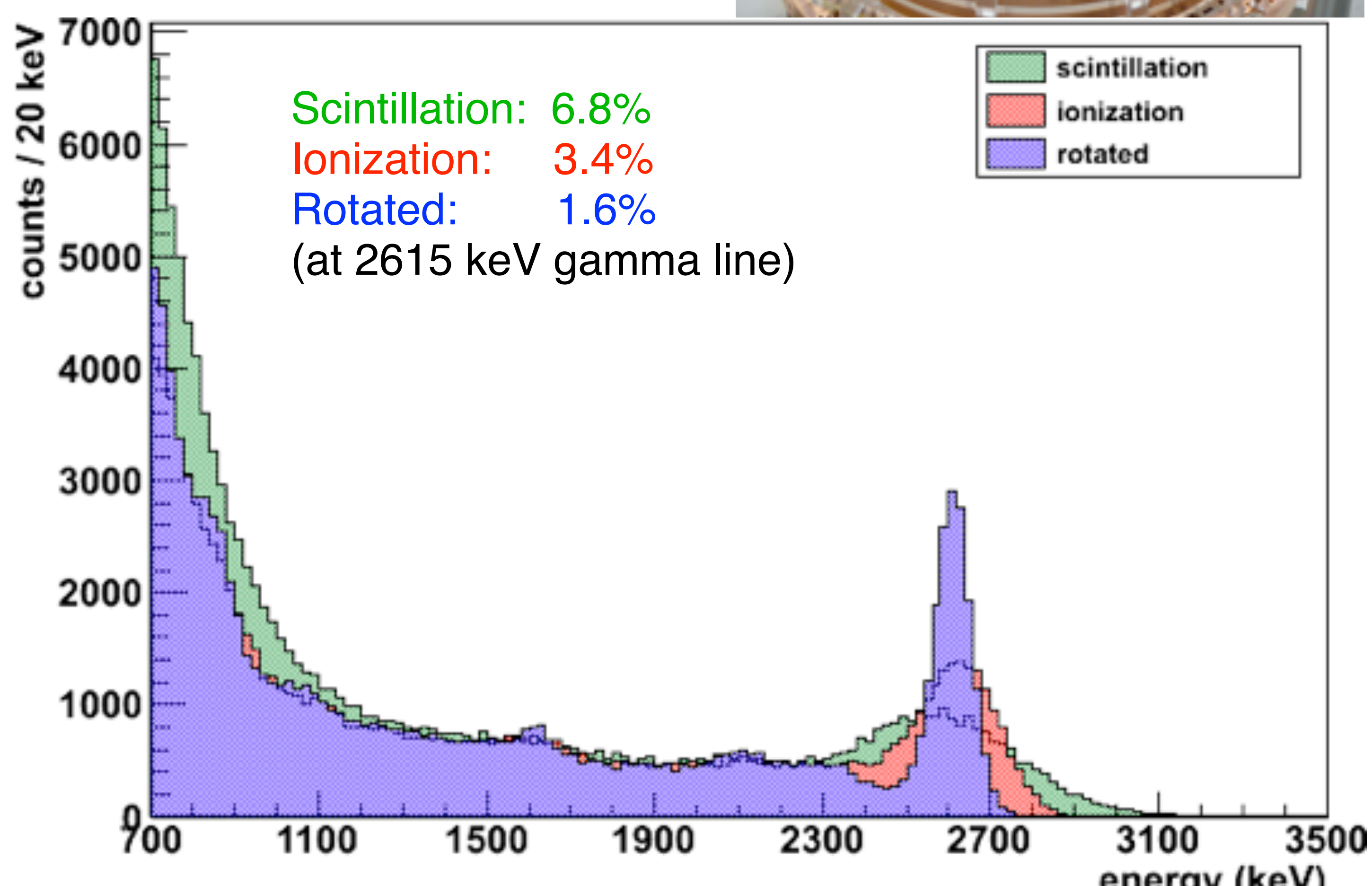


- Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa).
- Use projection onto a rotated axis to determine event energy



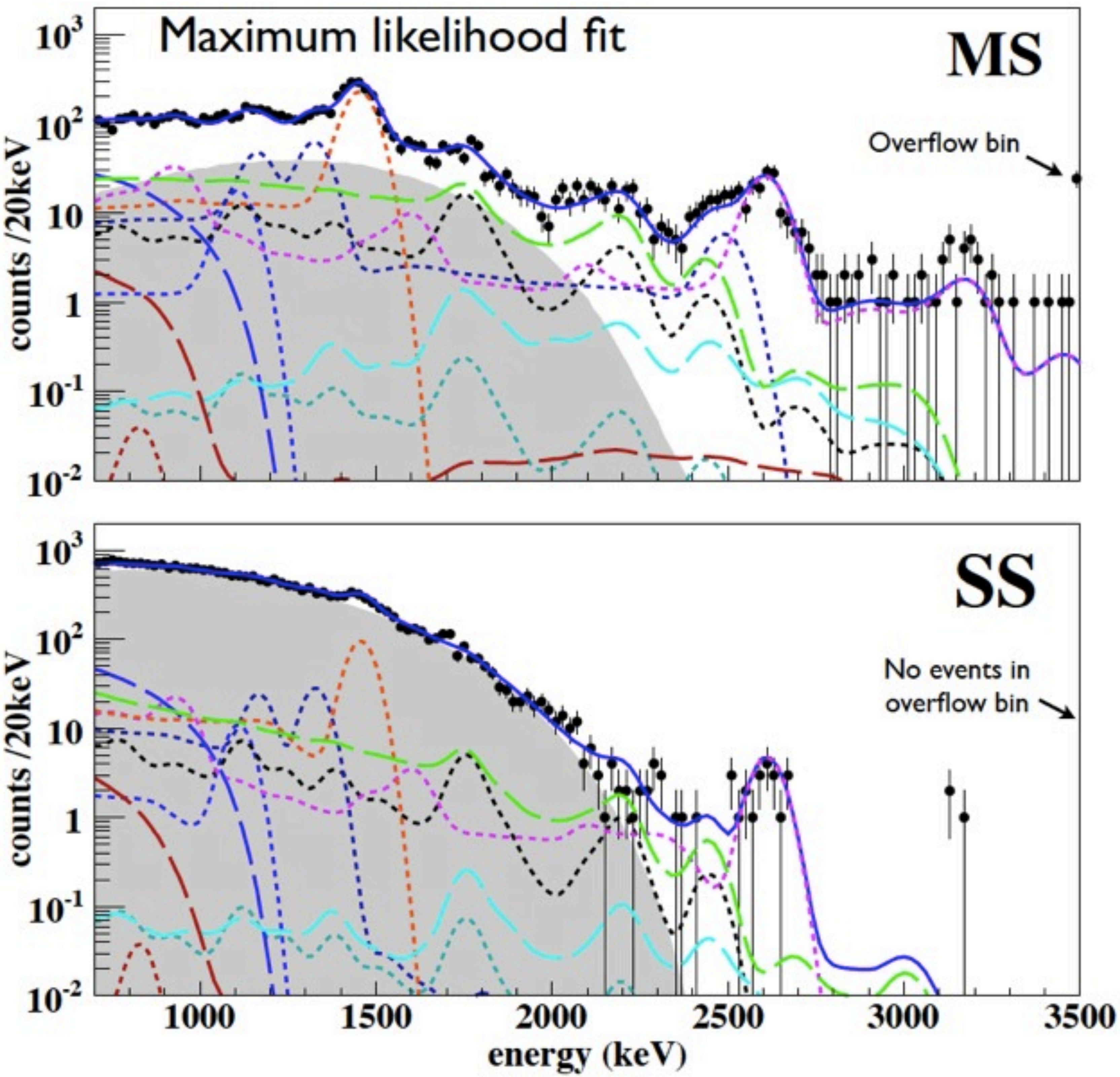
E. Conti et al. Phys. Rev. B 68 (2003) 054201





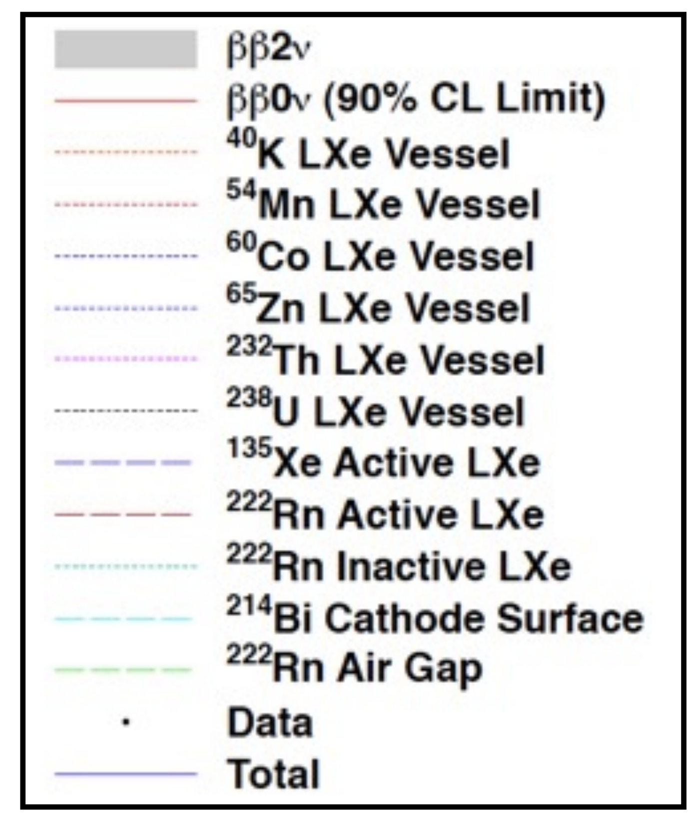
EXO: 2νββ

hep-ex: 1205.5608



- Trigger fully efficient above 700 keV
- Low background run livetime: 120.7 days
- Active mass: 98.5 kg LXe (79.4 kg 136LXe)
- Exposure: 32.5 kg.yr
- Total dead time from vetos: 8.6%

- ~22,000 2νββ events !
- Also populate MS spectrum, partly due to bremsstrahlung
- MC predicts that 82.5% of 2νββ are SS



$\tau_{1/2}^{2\nu\beta\beta}$ (^{136}Xe) = (2.23 ± 0.017 stat ± 0.22 sys)·10^{21} yr

5 times faster than previous limit

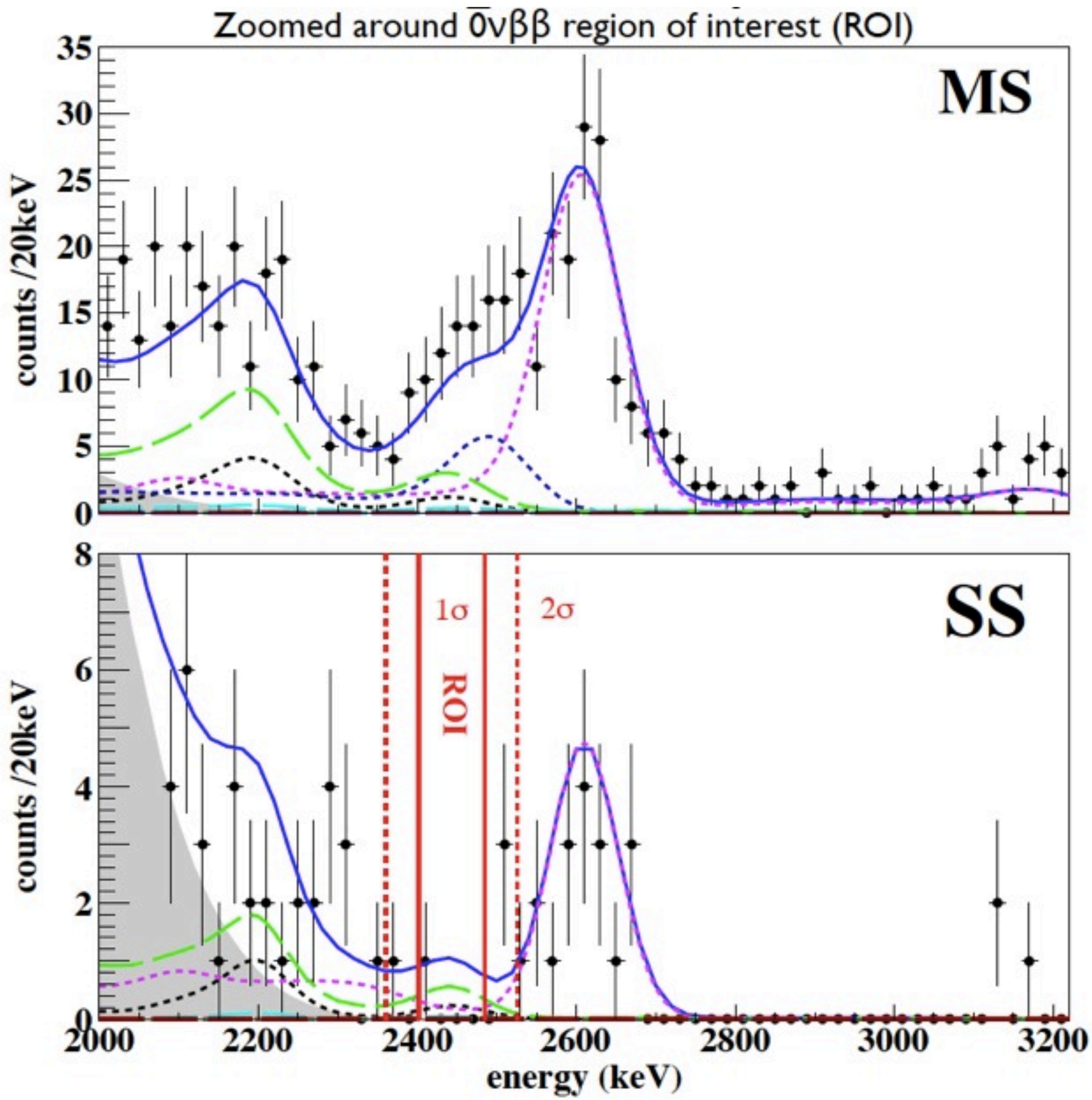
EXO-200 0νββ

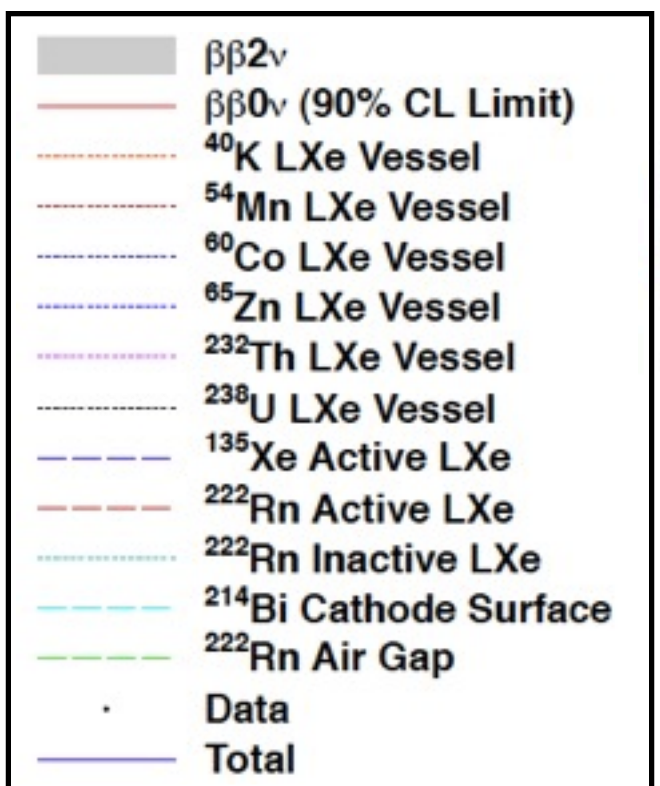
hep-ex: 1205.5608

EXO-200 is taking low background data. Detector works well:

- Energy resolution: 1.67% at $Q_{\beta\beta}$
- Background: 1.5×10^{-3} (kg keV yr)$^{-1}$
- 1 (5) counts in 1σ (2σ) 0νββ ROI
- Background within expectation

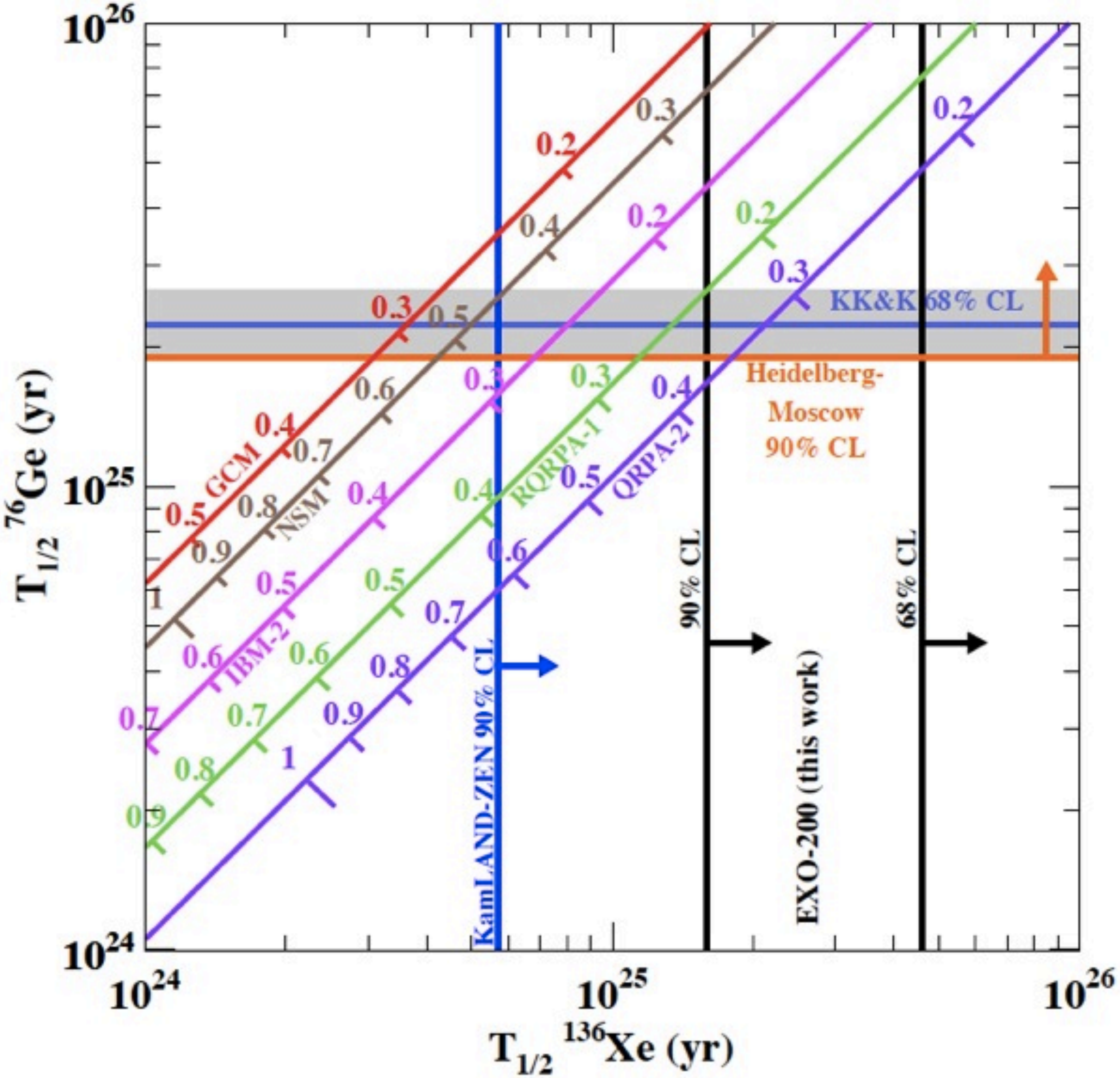
- Improvements on resolution and b in progress
- EXO-200 approved to run for 4 more years





$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > 1.6 ·10^{25} yr (<m_{ee}>140-380 meV) arXiv:1205.5608

EXO-200 and ββ0ν evidence



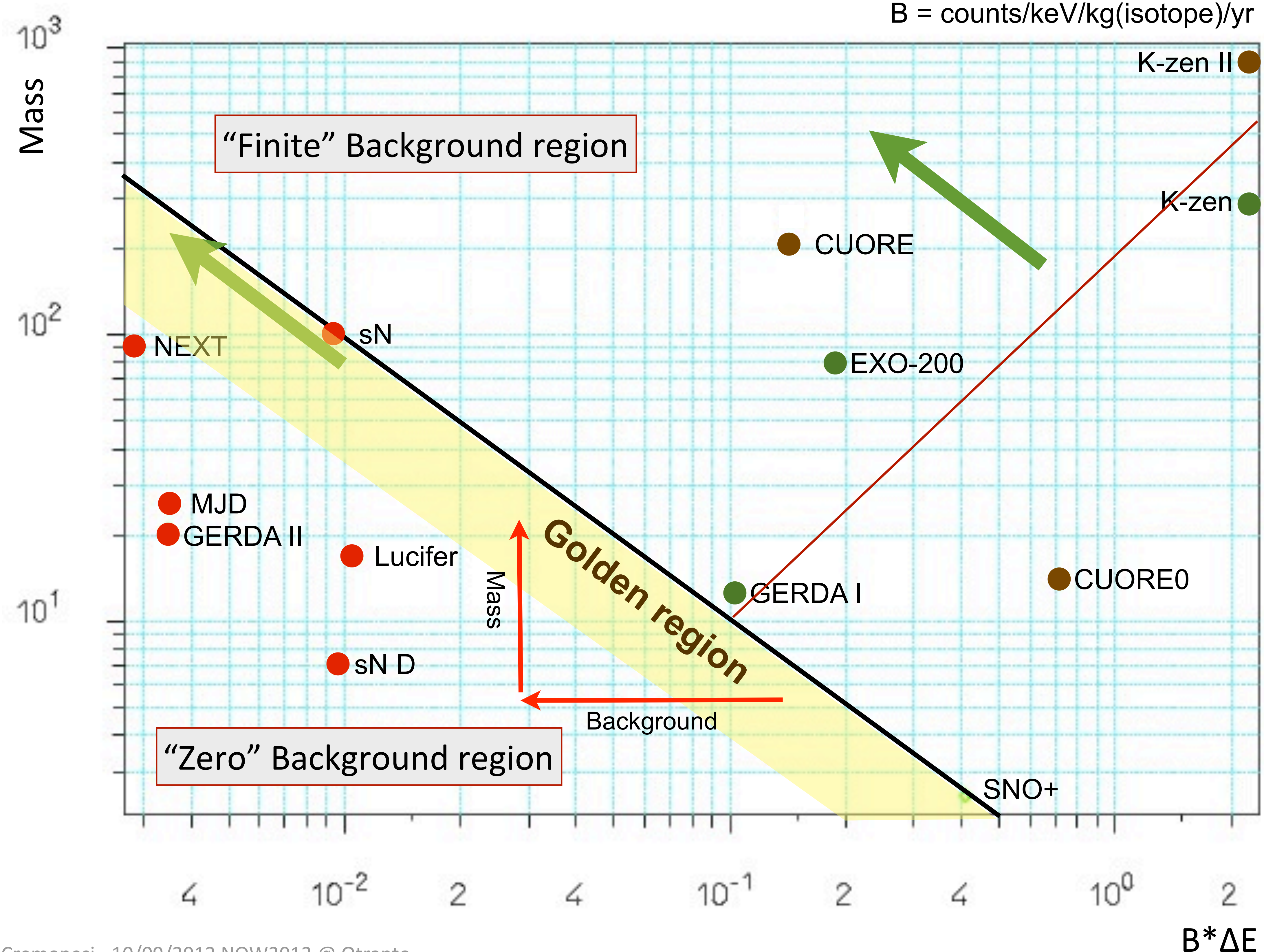
Comparison between ββ0ν half lifetimes in ^{76}Ge and ^{136}Xe for different matrix element calculations

The claim is excluded by the EXO-200 result according to most NME calculations.

QRPA-2: A. Staudt, K. Muto and H. V. Klapdor-Kleingrothaus, Europhys. Lett. 13 (1990) 31
GCM: T.R. Rodriguez and G. Martinez-Pinedo, Phys. Rev. Lett. 105 (2010) 252503.
NSM: J. Menendez et al., Nucl. Phys. A 818 (2009) 139.
IBM-2: J. Barea and F. Iachello, Phys. Rev. C79 (2009) 044301
RQRPA-1: F. Simkovic et al., Phys. Rev. C 79 (2009) 055501.

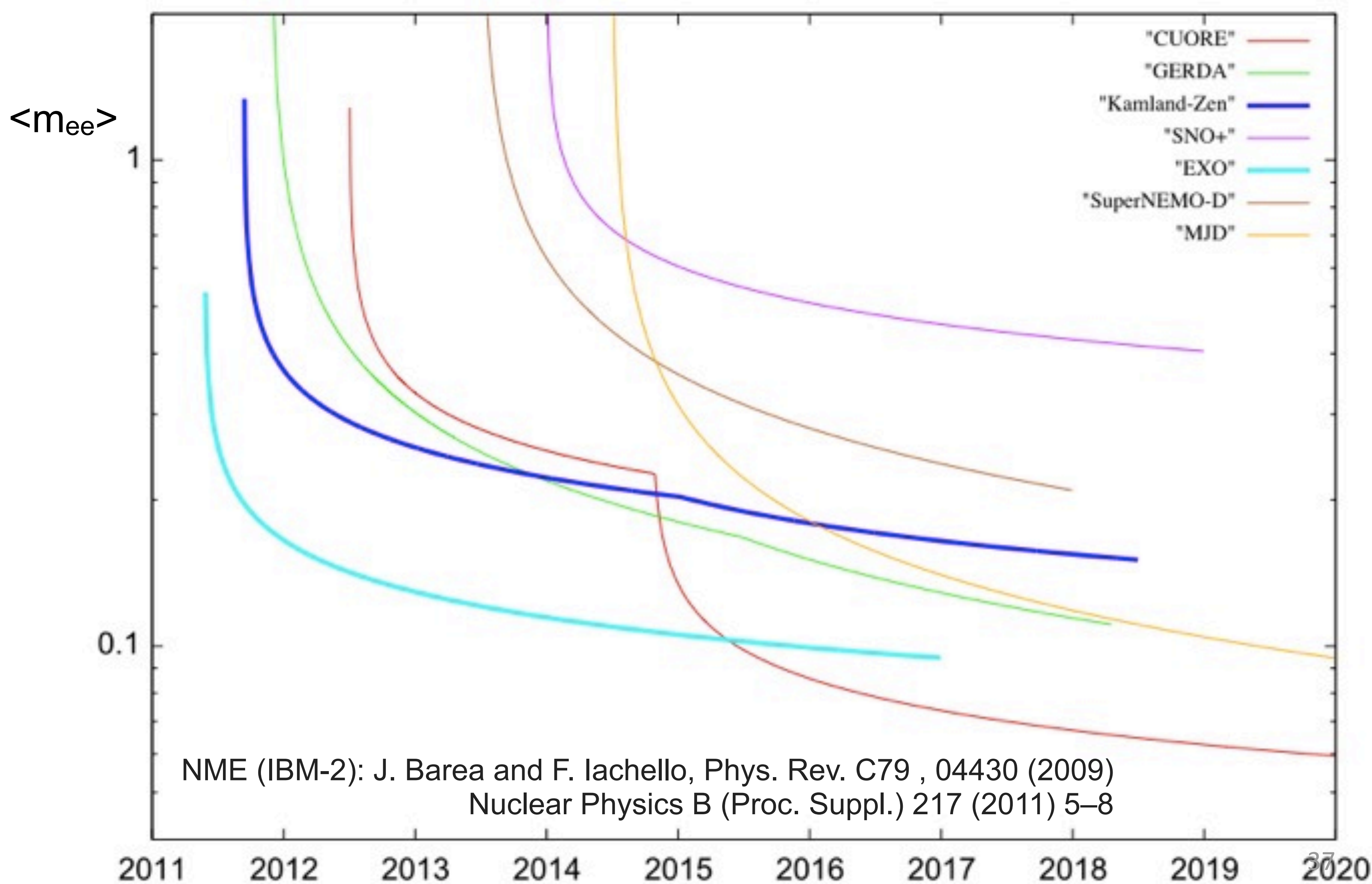
Experimental perspectives

Mass = kg of isotope
B = counts/keV/kg(isotope)/yr



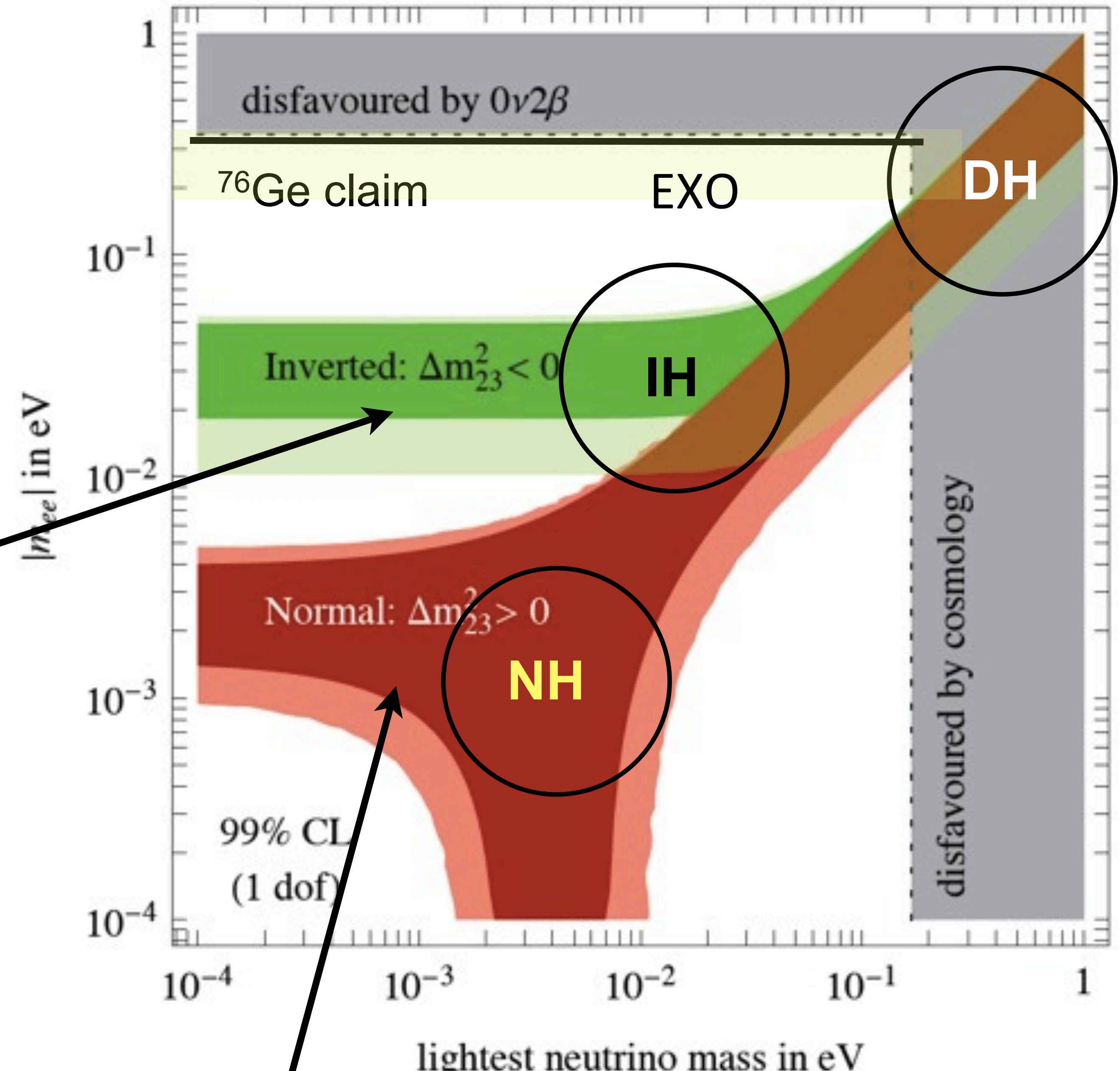
Present/Next Future

	Isotope	Q	FWHM	bkg	mass	i.a.	counts per year	S(5y)
CUORE	^{130}Te	2527	5	1×10^{-2}	750	0.35	32.3	2.14×10^{26}
GERDA-I	^{76}Ge	2039	5	2×10^{-2}	14.6	0.86	1.1	7.35×10^{25}
GERDA-I/II	^{76}Ge	2039	3	1×10^{-3}	3.5	0.86	0.0	8.24×10^{25}
GERDA-II	^{76}Ge	2039	3	1×10^{-3}	24	0.86	0.1	3.85×10^{26}
K-Zen	^{136}Xe	2458	243	8.1×10^{-3}	320	0.90	266.4	3.33×10^{25}
K-Zen II	^{136}Xe	2458	243	8.1×10^{-3}	700	0.90	582.9	4.93×10^{25}
EXO	^{136}Xe	2458	96	1.5×10^{-3}	98.5	0.81	11.8	1.19×10^{26}
MJD	^{76}Ge	2039	3	1×10^{-3}	30	0.86	0.1	3.78×10^{26}
SuperNEMO D	^{82}Se	2997	120		7	1.00	0.0	3.35×10^{25}



Conclusions

- $0\nu\beta\beta$ searches have still a very strong scientific motivation: lepton number violation, Majorana nature and properties (mass) of ν
- NME calculations: better understanding but still discrepancies ~2 in calculations
- Present generation experiments look for large masses (~100 kg) good energy resolutions and low background to sound the IH region in a variety of DBD nuclei
- Three of them (GERDA, EXO-200 and Kamland-Zen) have already started data taking and have just provided exciting results while CUORE is in an advanced phase of construction.



- Claim for evidence in ^{76}Ge with $\langle m_{ee} \rangle \sim 0.3$ eV (DH) (6σ) will be soon scrutinized.
- A number of 10-50 kg projects aim at understanding backgrounds origin and demonstrating the feasibility of high sensitivity "zero background" next generation experiment to sound the NH region in the next 5-10 years.
- Their results will determine the best isotope and technique for future experiments