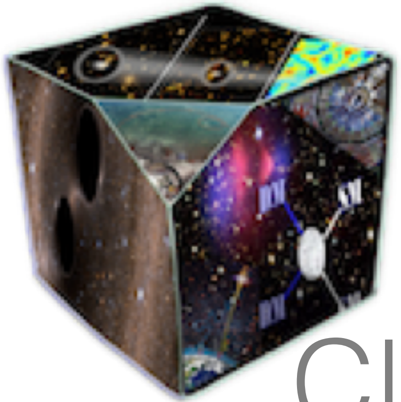
Non-accelerator-based neutrino experiments

Stefan Schönert, TU München

UK HEP Forum 2019 - What do the next 10 years have in store?

24-25 Sep. 2019, The Cosener's House, Abingdon, UK



SFB 1258 Neutrinos Dark Matter Messengers

Non-accelerator-based neutrino experiments:

Closing down on neutrino masses and properties with laboratory experiments and cosmology

Stefan Schönert, TU München

UK HEP Forum 2019 - What do the next 10 years have in store?

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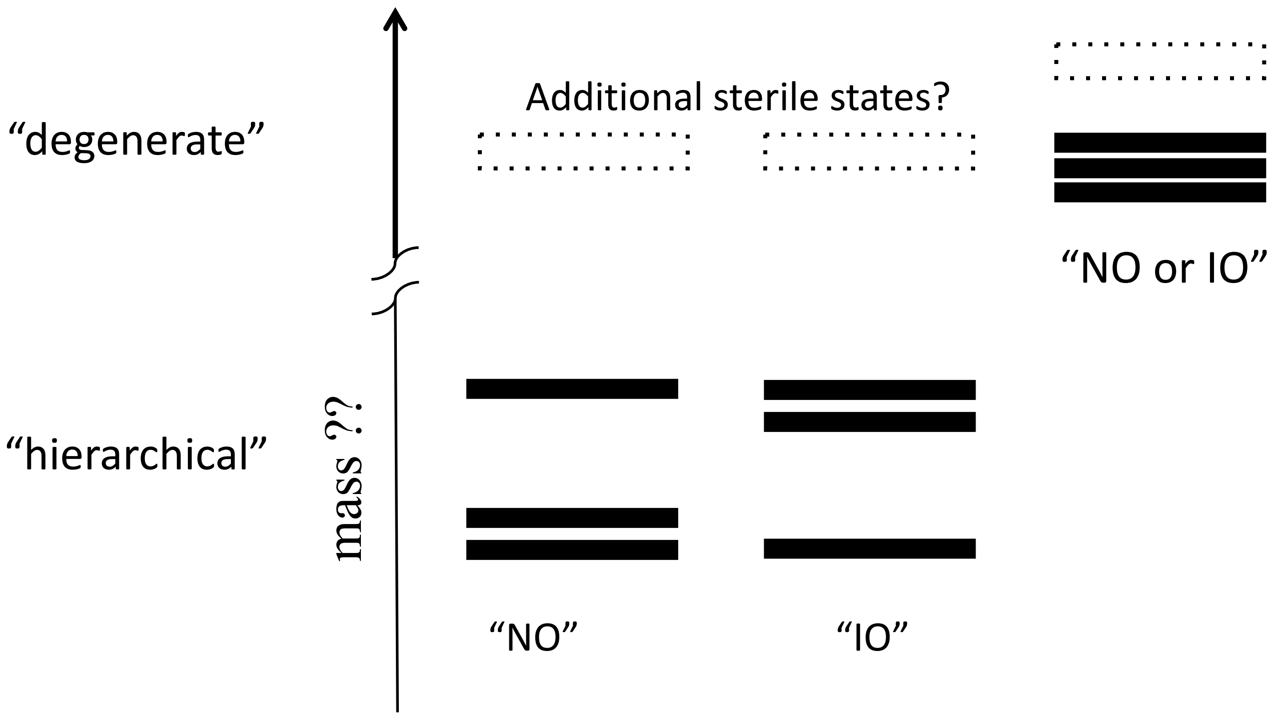
LMU TUM ORIGINS Excellence Cluster

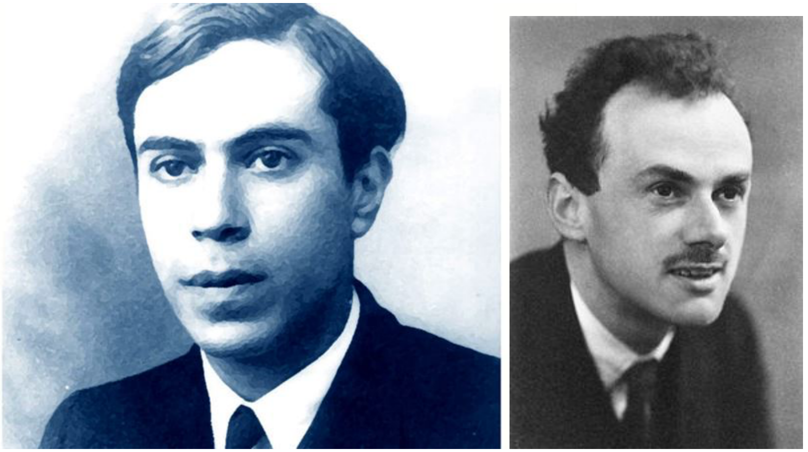
TUM

The Quests

What is the neutrino mass scale?



Are neutrinos their own anti-particles?



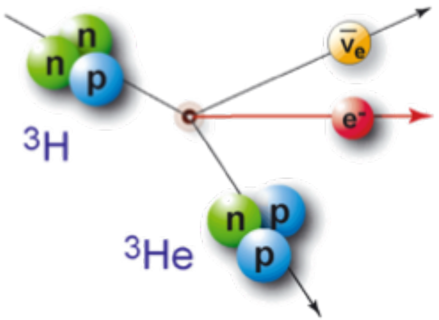
Is lepton number violated?

No reason for global symmetries to be exact!
[e.g Edward Witten, arXiv:1710.01791]

- Why are neutrinos so much lighter than charged leptons ?
- What is the origin of the matter anti-matter asymmetry ?

ν-mass observables

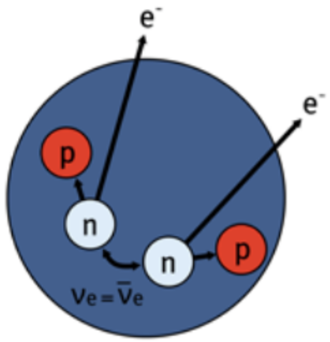
β-decay



$$m_\beta = \sqrt{\sum_i |U_{ei}|^2 \cdot m_i^2}$$

(Dirac or Majorana)

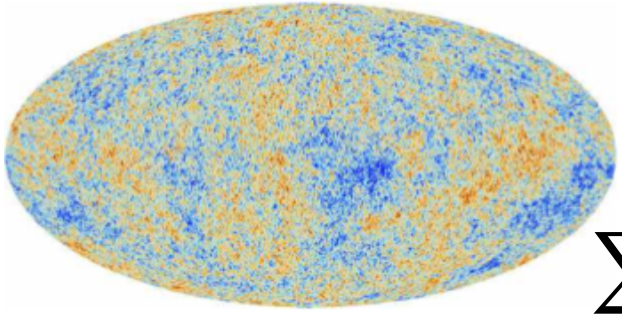
0νββ-decay



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

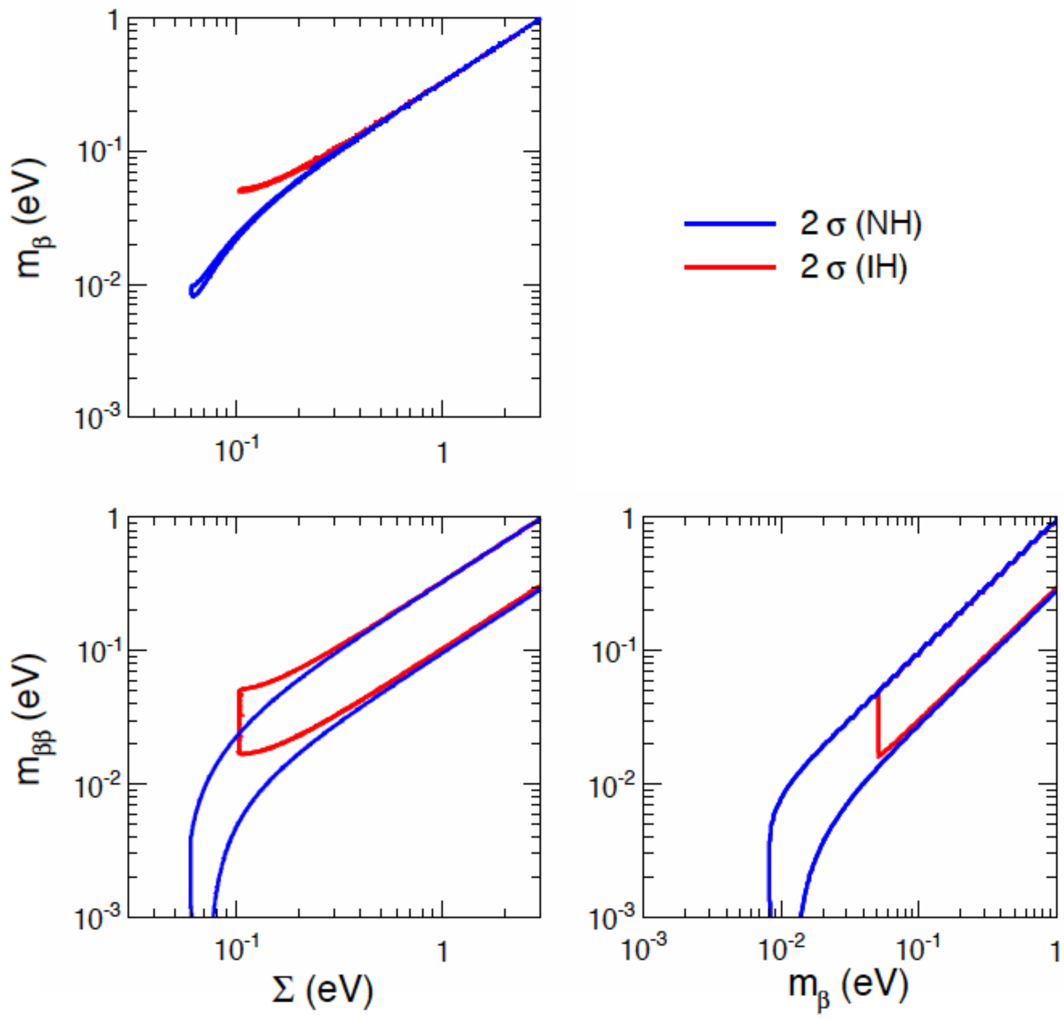
(Majorana)

Cosmology



$$\sum_i m_i$$

Predictions from oscillation experiments for mass observables



$$m_\beta = \left[c_{13}^2 c_{12}^2 m_1^2 + c_{13}^2 s_{12}^2 m_2^2 + s_{13}^2 m_3^2\right]^{\frac{1}{2}}$$

β–decay, "effective electron neutrino mass"

$$m_{\beta\beta} = \left| c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3} \right|$$

0νββ–decay, "effective Majorana neutrino mass"

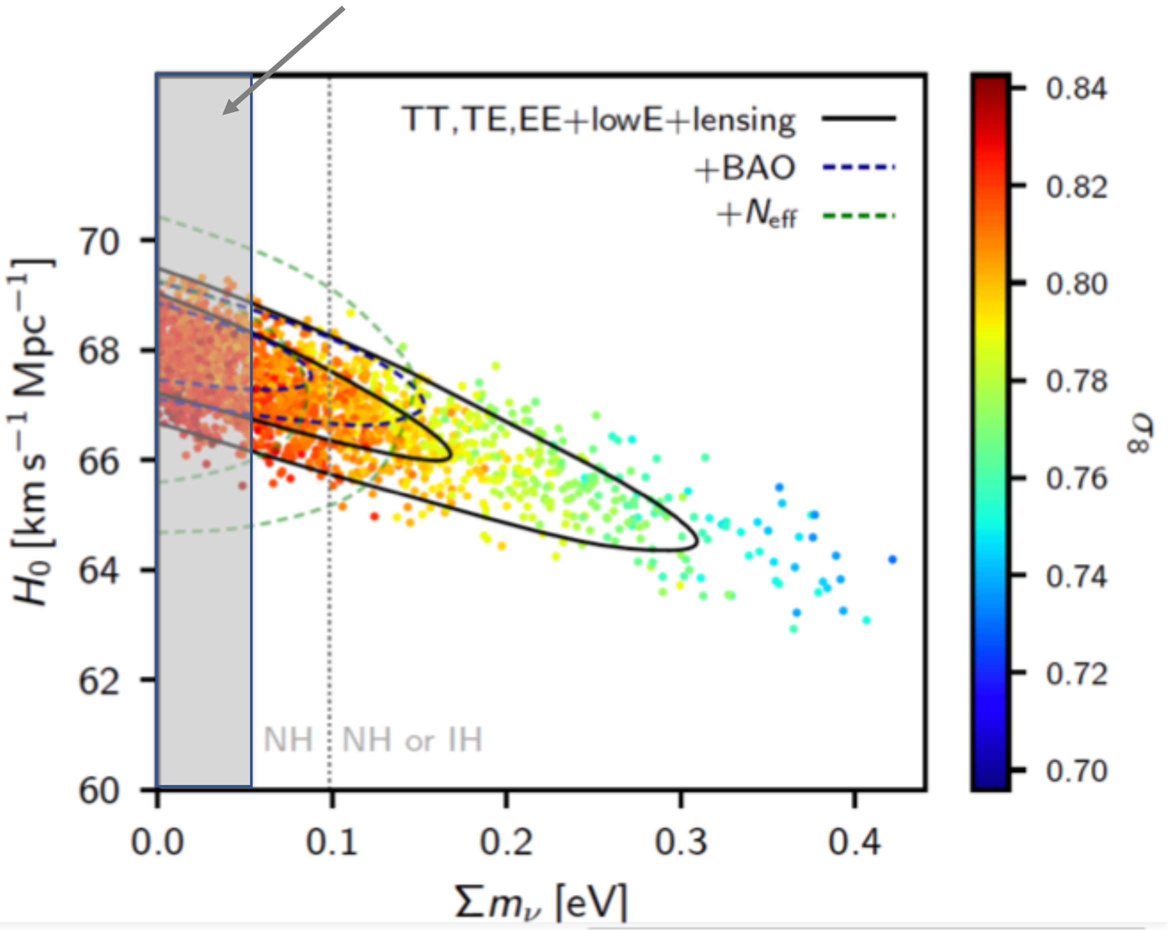
$$\Sigma = m_1 + m_2 + m_3$$

Cosmology, sum of neutrino mass

From E. Lisi et al.

Neutrino mass constraints from cosmology

Excluded by ν–oscillation experiments



"Increasing the neutrino mass leads to lower values of H_0 , and hence aggravates the tension with the distance-ladder determination of Riess et al."

Distance ladder:
H0 = (73.48 +-1.66) km s^{-1}Mpc^{-1}

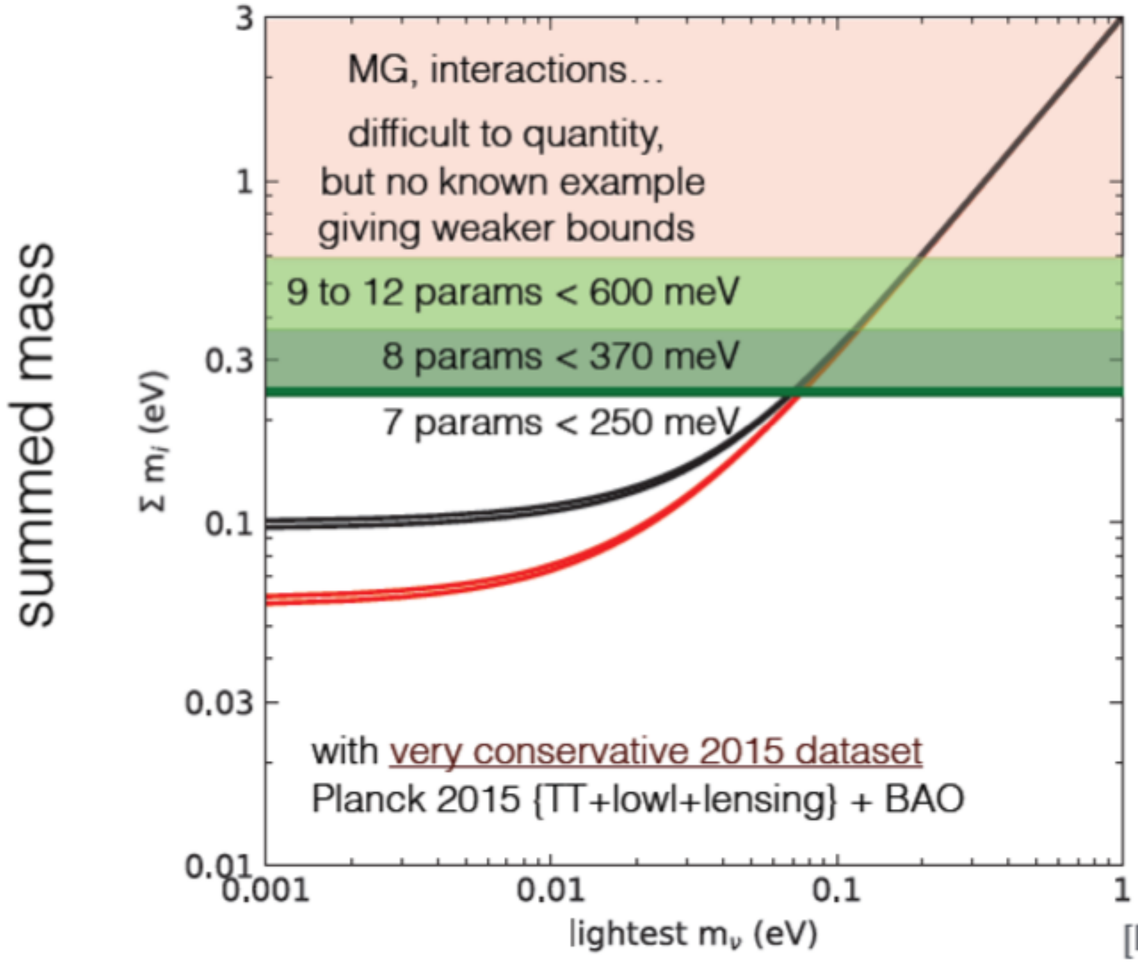
Planck:
H0 = (67.27 +-0.60) km s^{-1}Mpc^{-1}

⇒ 3.5 σ discrepancy

Planck 2018

Neutrino mass constraints from cosmology

95%CL upper bounds on $\Sigma_i m_i$ beyond 7 parameters



Usual suspects:

- extra massless relics
- extra light relics
- spatial curvature
- simplest dynamical DE
- primordial GWs
- primordial tilt running

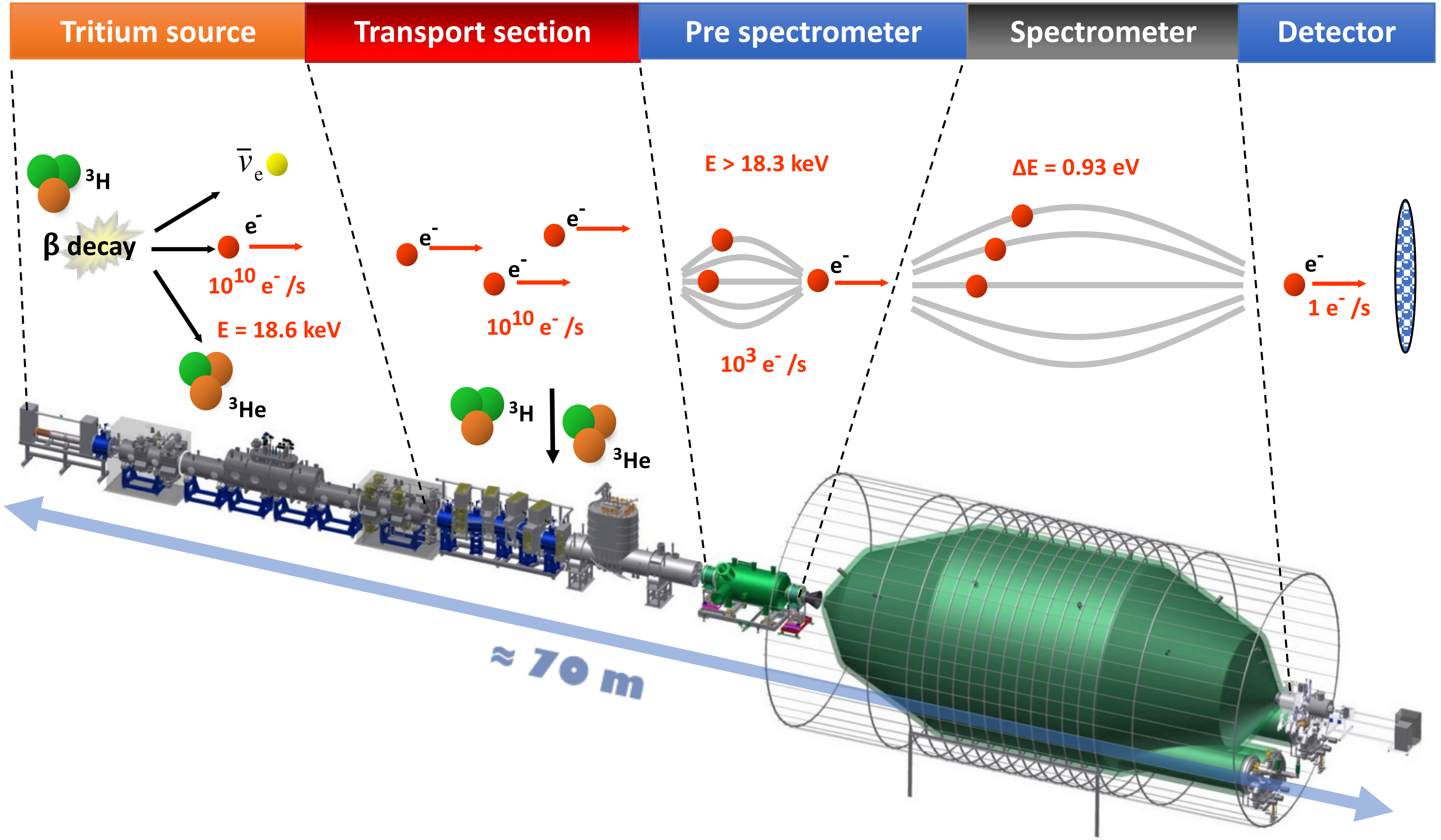
Even more freedom in:

- modified Einstein Gravity
- interactions in DM sector
- ~~primordial perturbations~~

[Planck col.] 1502.01589; Di Valentino et al. 1507.06646

J. Lesgourgues, Neutrino 2018; T. Brinkmann, PPC 2018

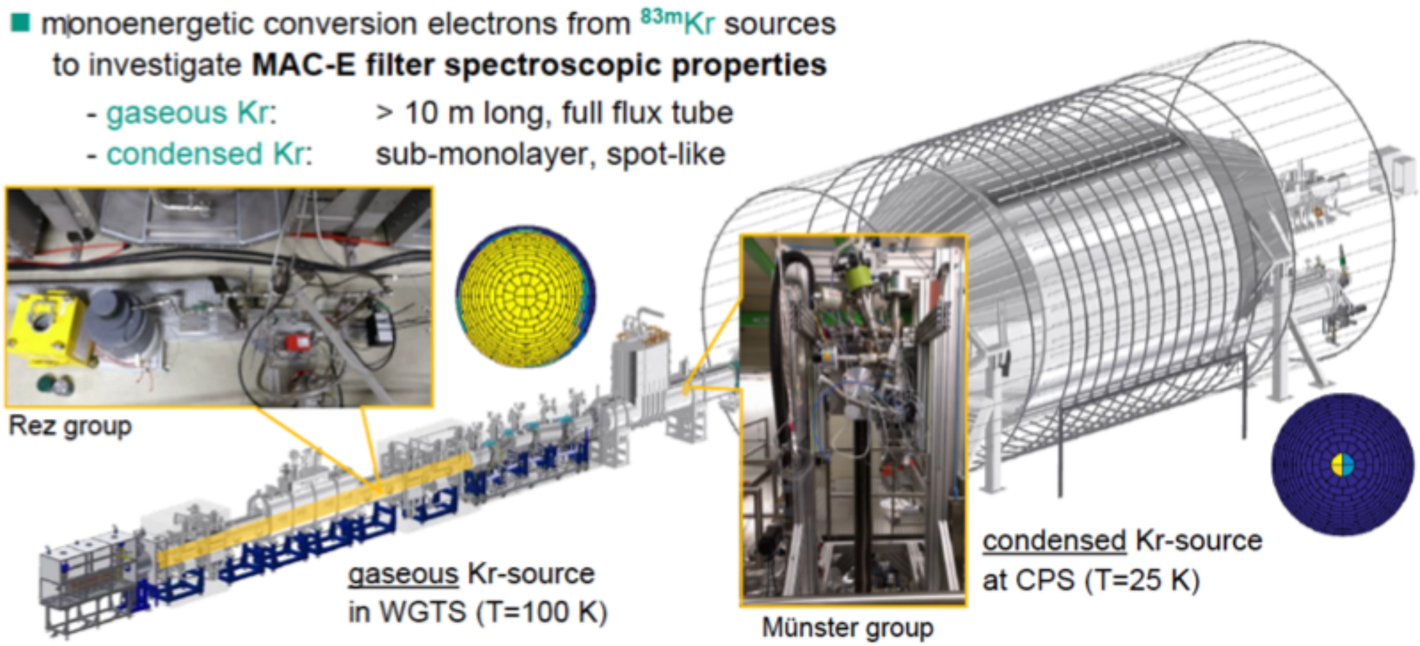
ν-mass from ^{3}H decay: KATRIN

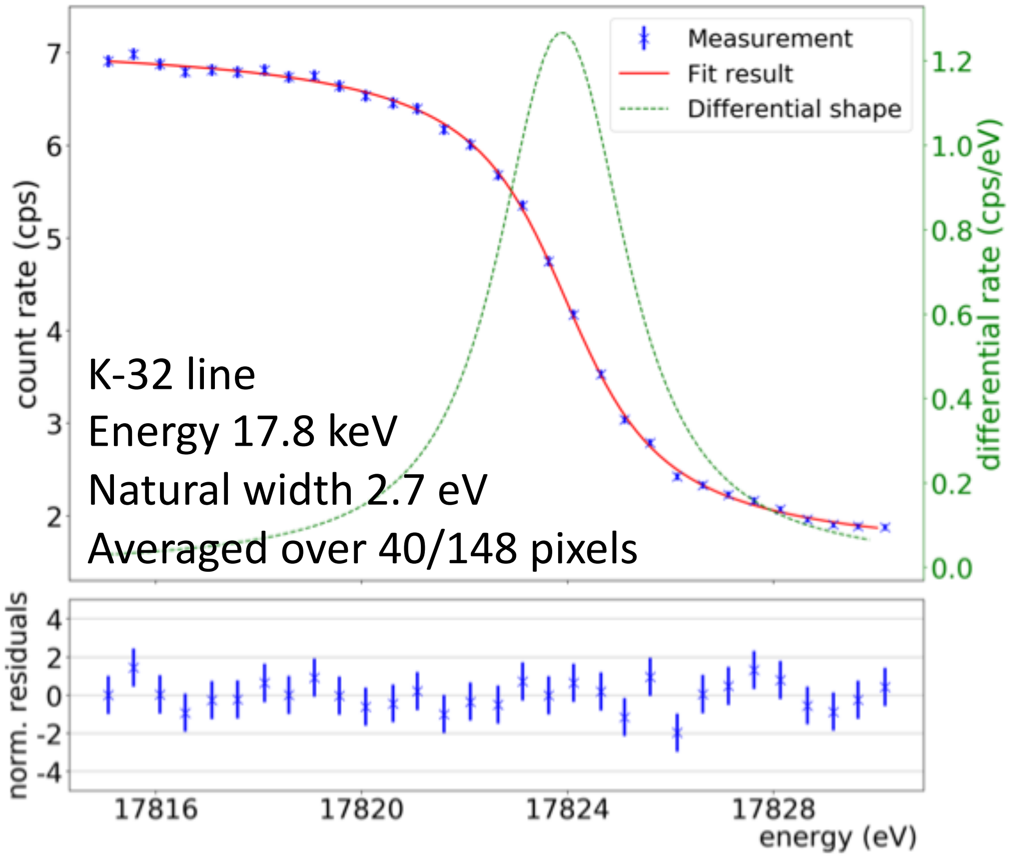


Courtesy T. Thümmler (Katrin)

KATRIN milestone 2017

krypton campaign demonstrating sub-eV energy resolution

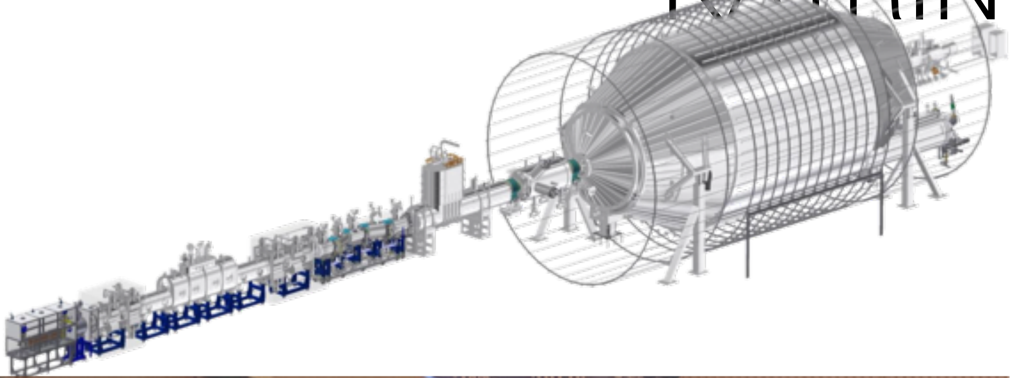


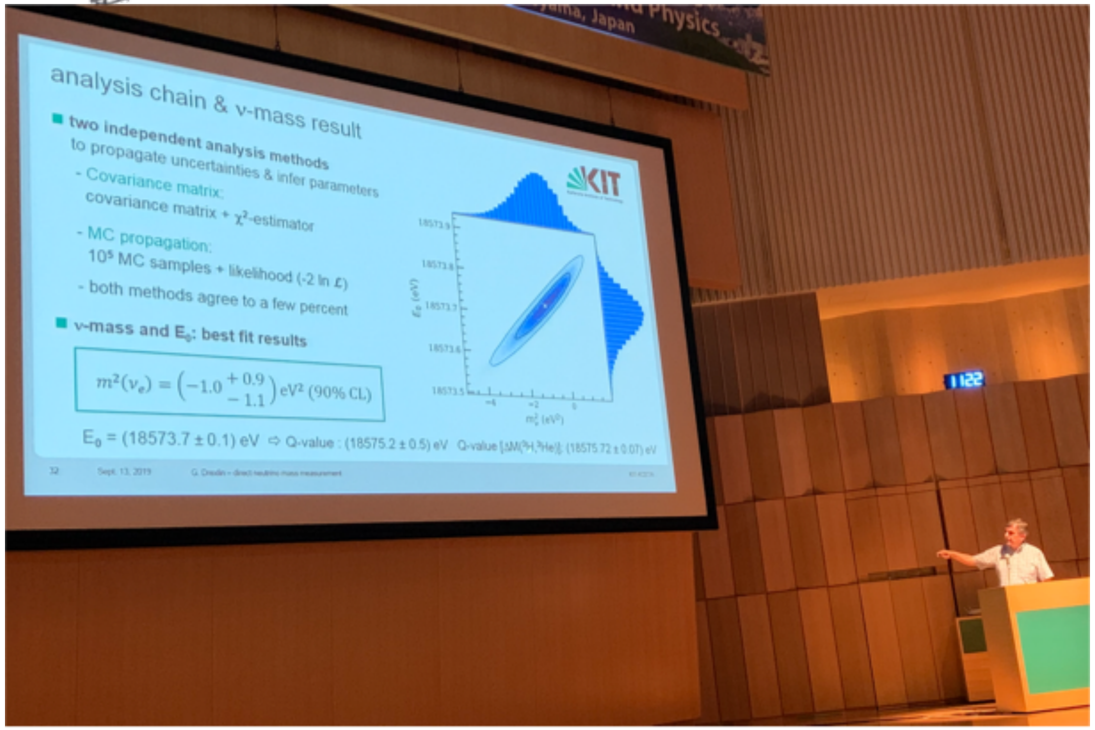


KATRIN collab., EPJ C 78 368 (2018)

Diana Parno, Neutrino 2018

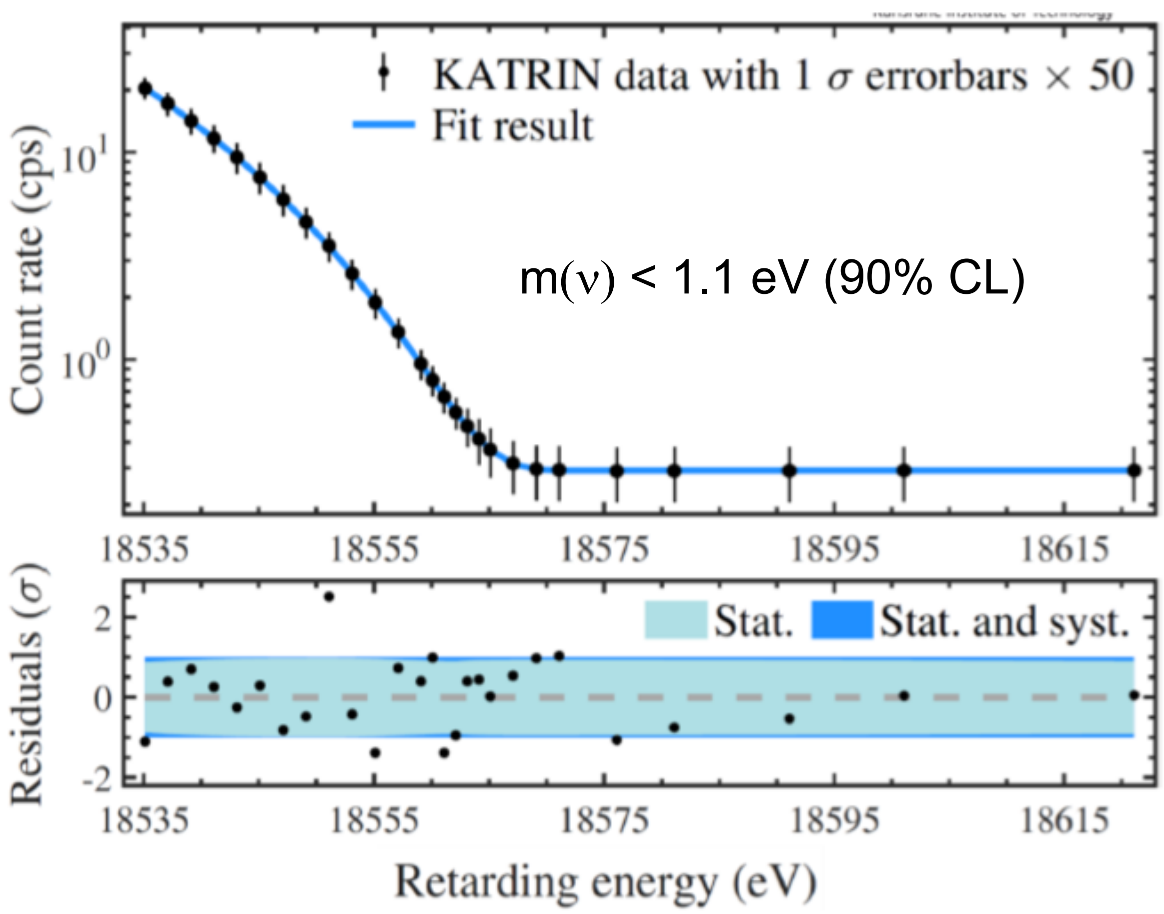
KATRIN neutrinomass campaign #1





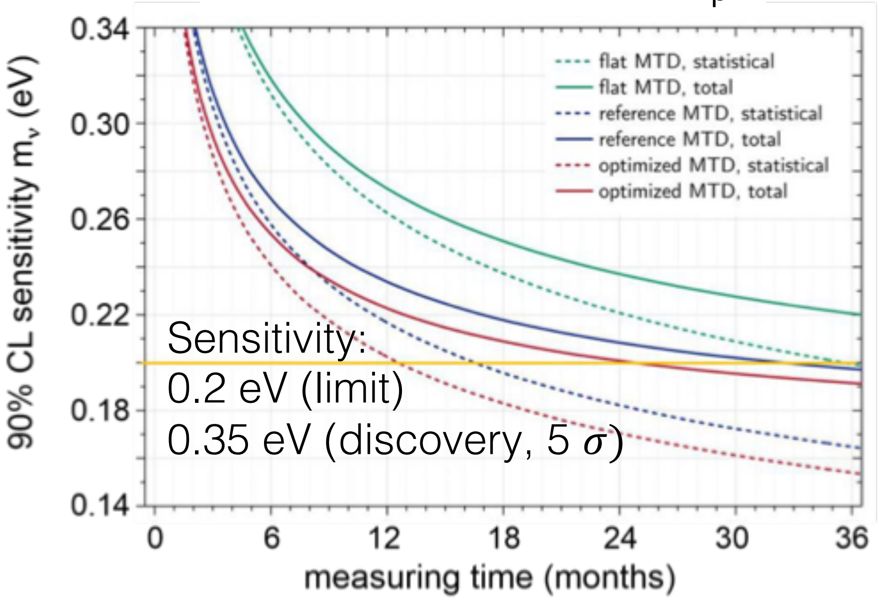
Guido Drexlin, TAUP 2019

April 10 – May 13, 2019
22% of nominal source activity

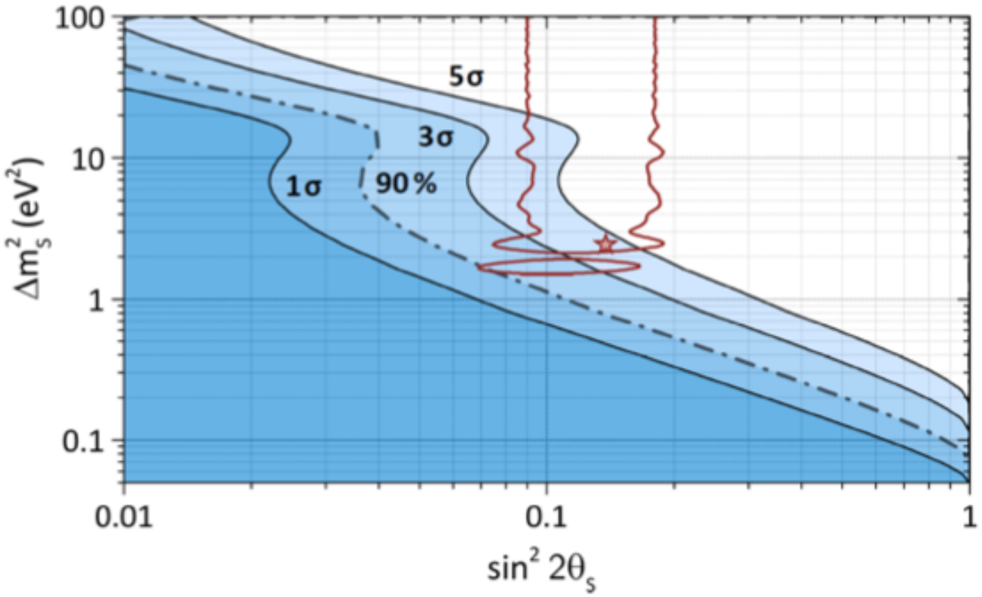


KATRIN: 2019-2024 regular tritium data taking

measure / constrain m_β



eV-scale sterile neutrinos



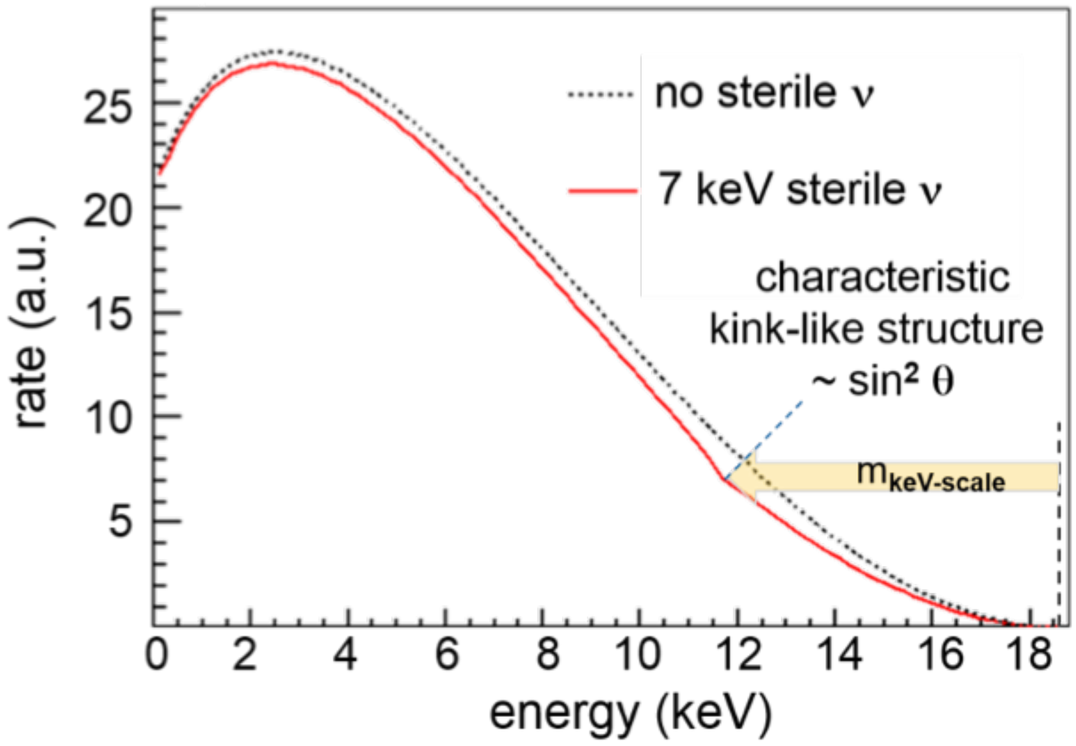
R&D to reach ~0.1 eV:

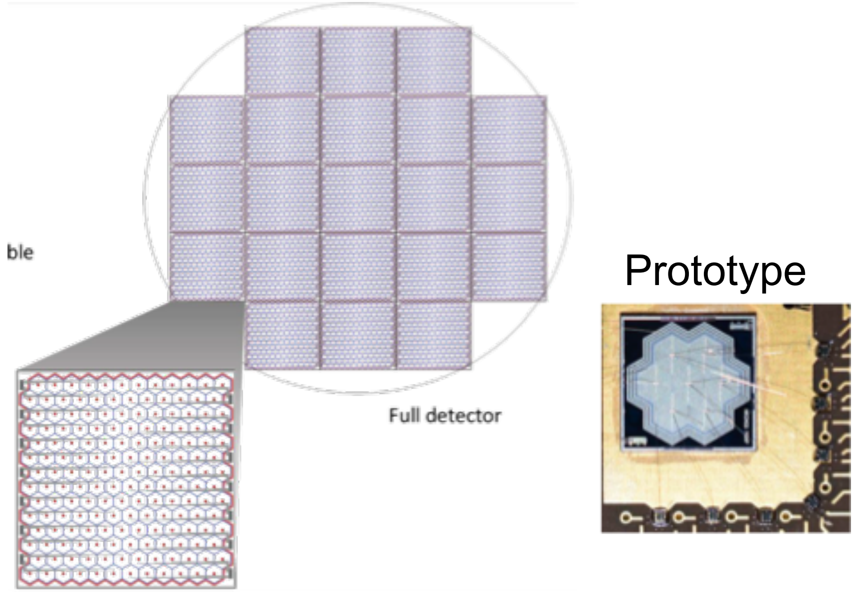
- differential read-out via ToF-technique or cryo-bolometer
- novel source concepts: atomic tritium

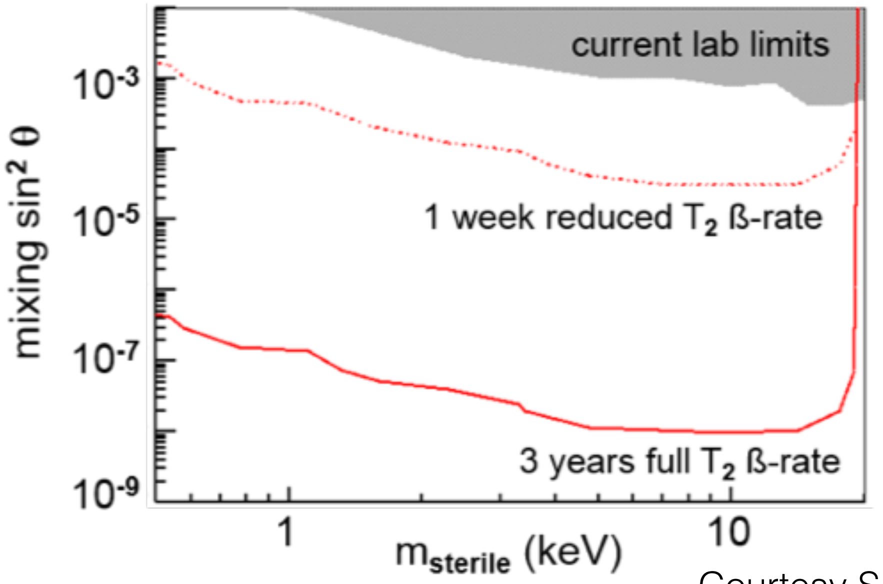
Courtesy G. Drexlin

KATRIN future: TRISTAN – search for keV scale ν´s

New Si-array (TRISTAN) to search for kink in ß-spectrum over entire tritium spectrum (0-18.6 keV)





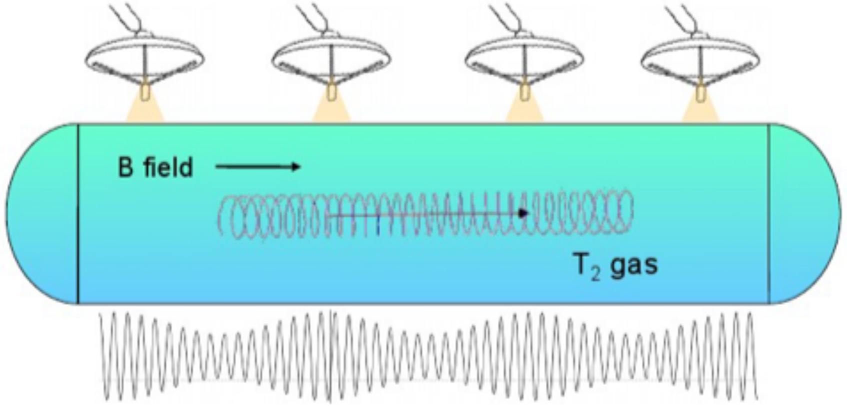


Courtesy S. Mertens

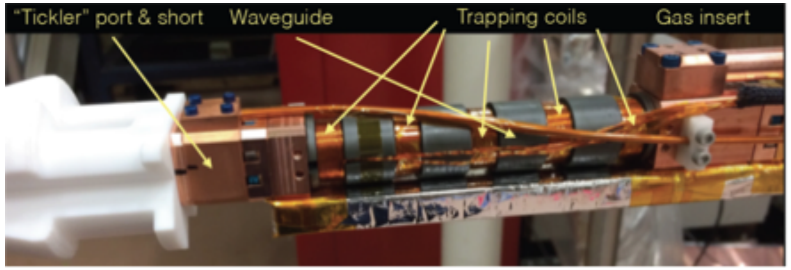
Project 8

Measurement of cyclotron radiation of tritium electrons

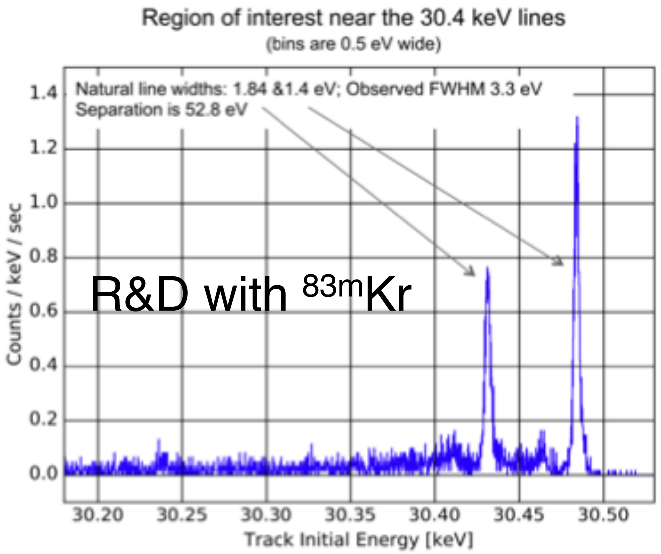
- B-field: 1 Tesla
- ω(18 keV) ~ 26 GHz
- P(18 keV) = 1.2 fW



R&D with tritium



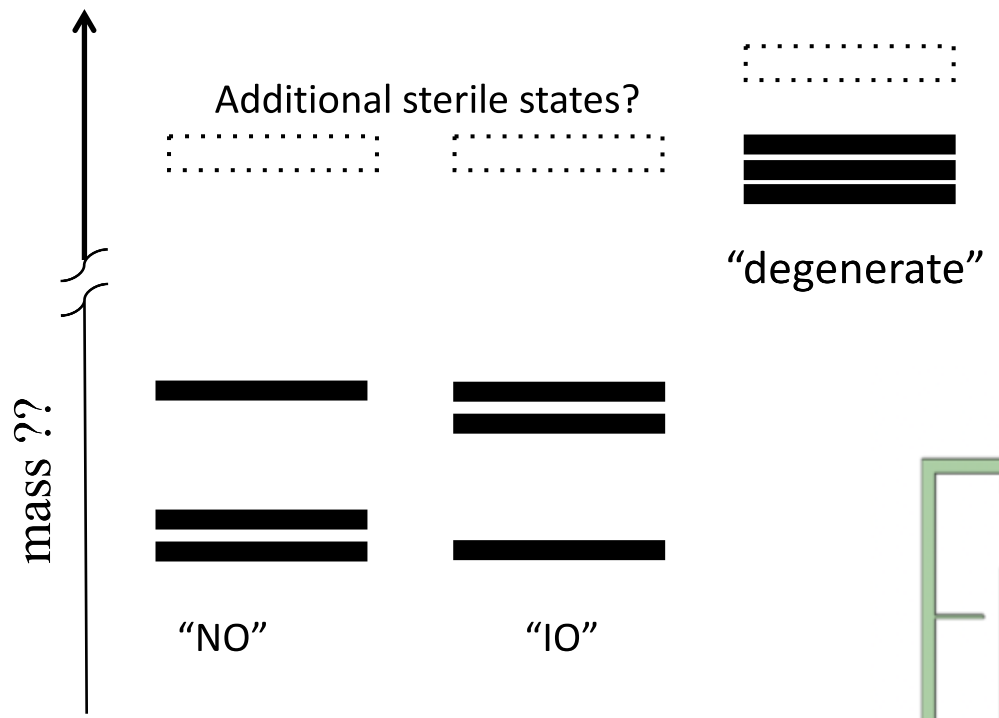
- 10^{11} molecules/cm^3, 10 m^3 ,1 year: optimistically 100 meV
- If 100 m^3 atomic tritium source possible: 40 meV

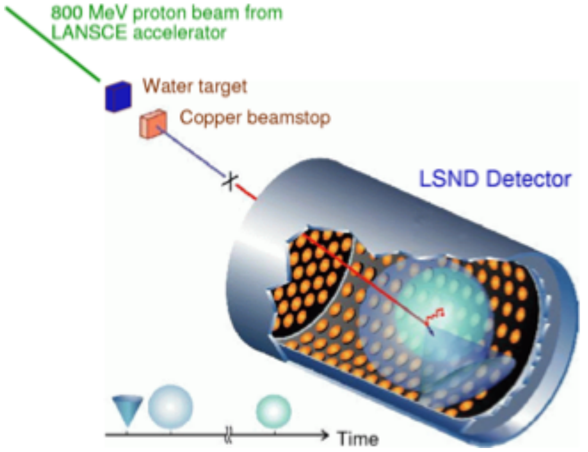


R&D with ^{83m}Kr

eV-sterile ν's

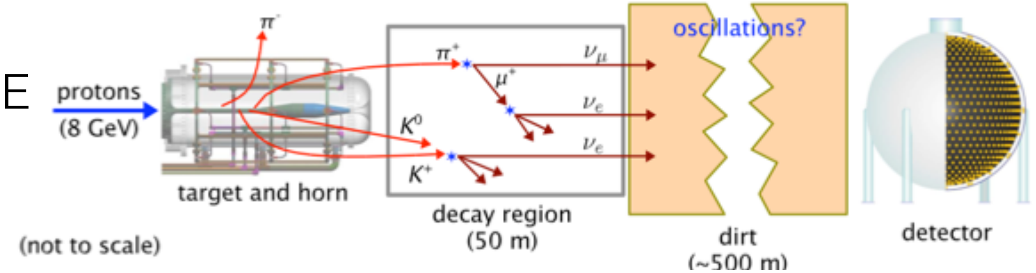
various experiments hint for eV-scale ν–oscillations



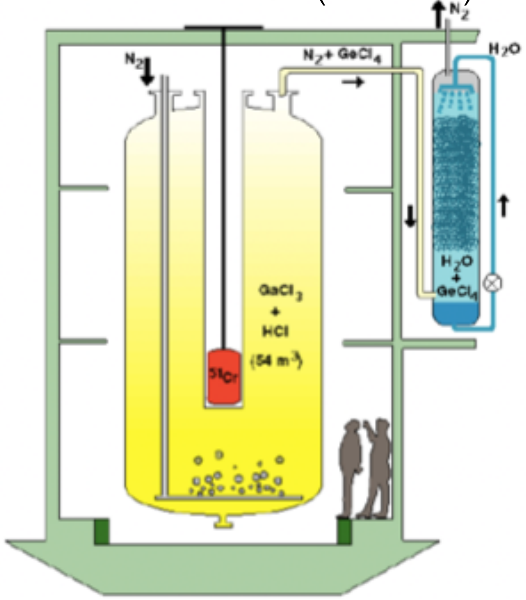


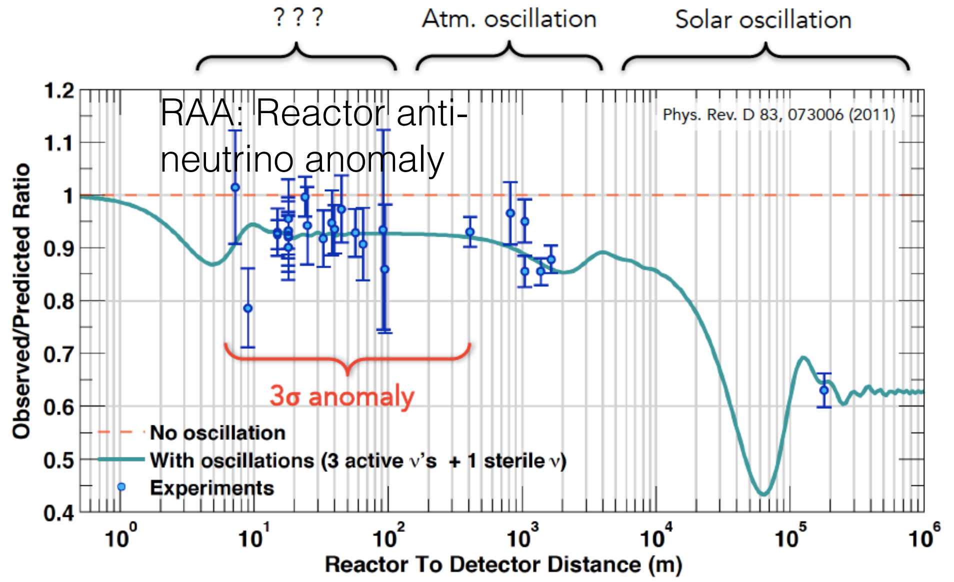
LSND
(3.8 σ)

MiniBooNE
(4.8 σ)

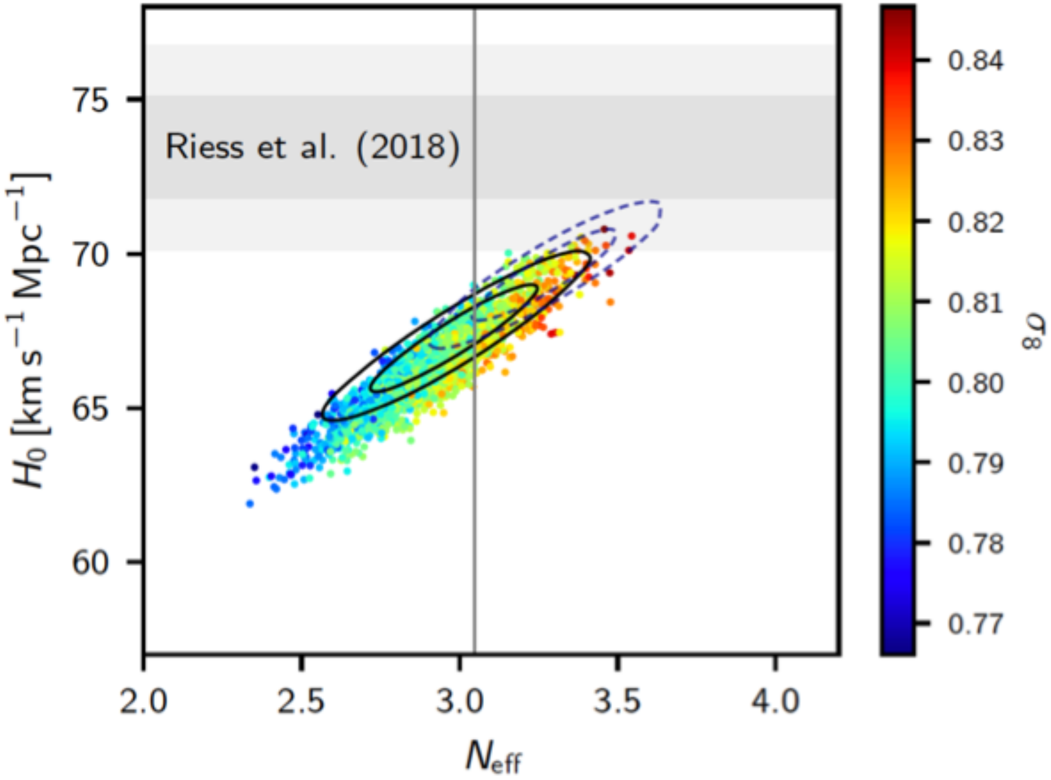


Gallex (& SAGE)





Light (thermalized) sterile ν's in conflict with cosmological data



$$\left.\begin{aligned} N_{\mathrm{eff}} &< 3.29, \\ m^{\mathrm{eff}}_{\nu,\,\mathrm{sterile}} &< 0.65\ \mathrm{eV}, \end{aligned}\right\} \begin{aligned} &95\,\%,\ \mathit{Planck}\ \mathrm{TT,TE,EE{+}lowE} \\ &\mathrm{+lensing{+}BAO}, \end{aligned}$$

Planck 2018

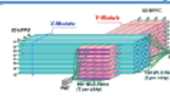
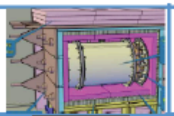
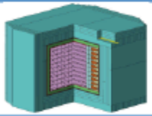
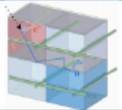
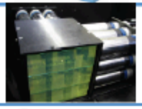
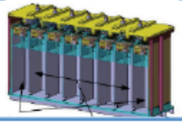
Sterile ν's correlate with high values for H_0

SB anomalies require mixing of sterile-ν('s) with active ν's
⇒ Sterile-ν's acquire thermal distribution in early Universe
⇒ ΔN_{eff} ~1
⇒ Excluded at ~6 σ (Planck 2018)

Production of sterile neutrinos would need to be suppressed by

- non-standard interactions
- low-temperature reheating
- or other special mechanisms

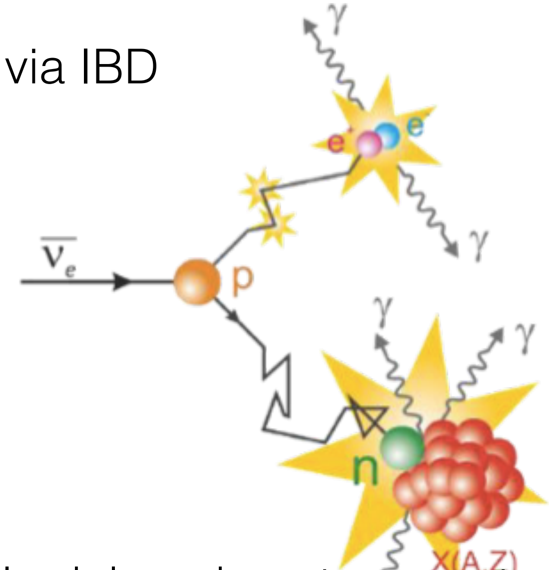
Short baseline experiments at nuclear reactors

Experiment		Reactor Power/Fuel	Overburden (mwe)	Detection Material	Segmentation	Optical Readout	Particle ID Capability
DANSS (Russia)		3000 MW LEU fuel	~50	Inhomogeneous PS & Gd sheets	2D, ~5mm	WLS fibers.	Topology only
NEOS (South Korea)		2800 MW LEU fuel	~20	Homogeneous Gd-doped LS	none	Direct double ended PMT	recoil PSD only
nuLat (USA)		40 MW ^{235}U fuel	few	Homogeneous ^{6}Li doped PS	Quasi-3D, 5cm, 3-axis Opt. Latt	Direct PMT	Topology, recoil & capture PSD
Neutrino4 (Russia)		100 MW ^{235}U fuel	~10	Homogeneous Gd-doped LS	2D, ~10cm	Direct single ended PMT	Topology only
PROSPECT (USA)		85 MW ^{235}U fuel	few	Homogeneous ^{6}Li-doped LS	2D, 15cm	Direct double ended PMT	Topology, recoil & capture PSD
SoLid (UK Fr Bel US)		72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm multiplex	WLS fibers	topology, capture PSD
Chandler (USA)		72 MW ^{235}U fuel	~10	Inhomogeneous ^{6}LiZnS & PS	Quasi-3D, 5cm, 2-axis Opt. Latt	Direct PMT/ WLS Scint.	topology, capture PSD
Stereo (France)		57 MW ^{235}U fuel	~15	Homogeneous Gd-doped LS	1D, 25cm	Direct single ended PMT	recoil PSD

N. Bowden AAP 2016

IBD experiments at nuclear reactors: different reactor types and detector concepts

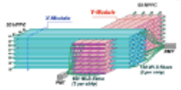
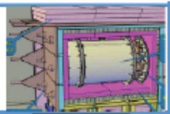
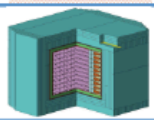
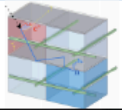
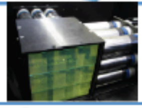
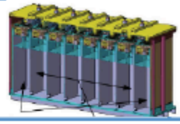
- Power reactors: large core, LEU
- Research reactors: compact core, ^{235}U
- Detection via IBD



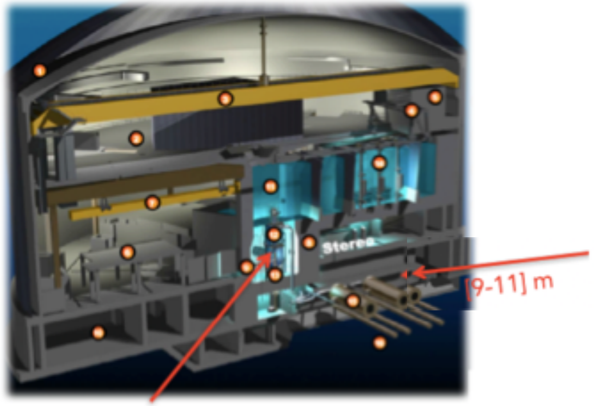
- Tagging via delayed neutron capture on Gd or Li

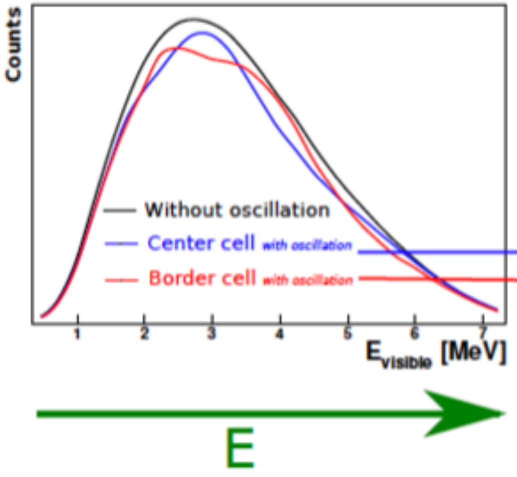
$$n + {}^6\text{Li} \rightarrow {}^3\text{H} + \alpha + 4.78\ \text{MeV}$$

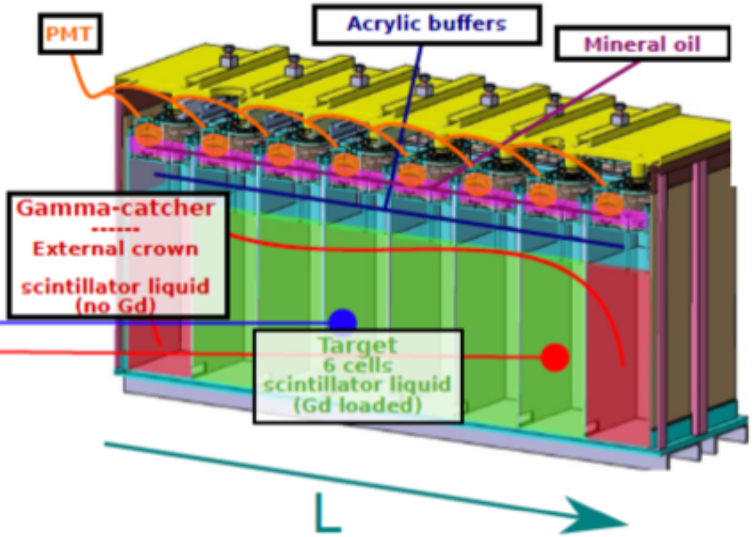
$$\text{n} + \text{Gd} \rightarrow \text{Gd} + \Upsilon + 8\ \text{MeV}$$

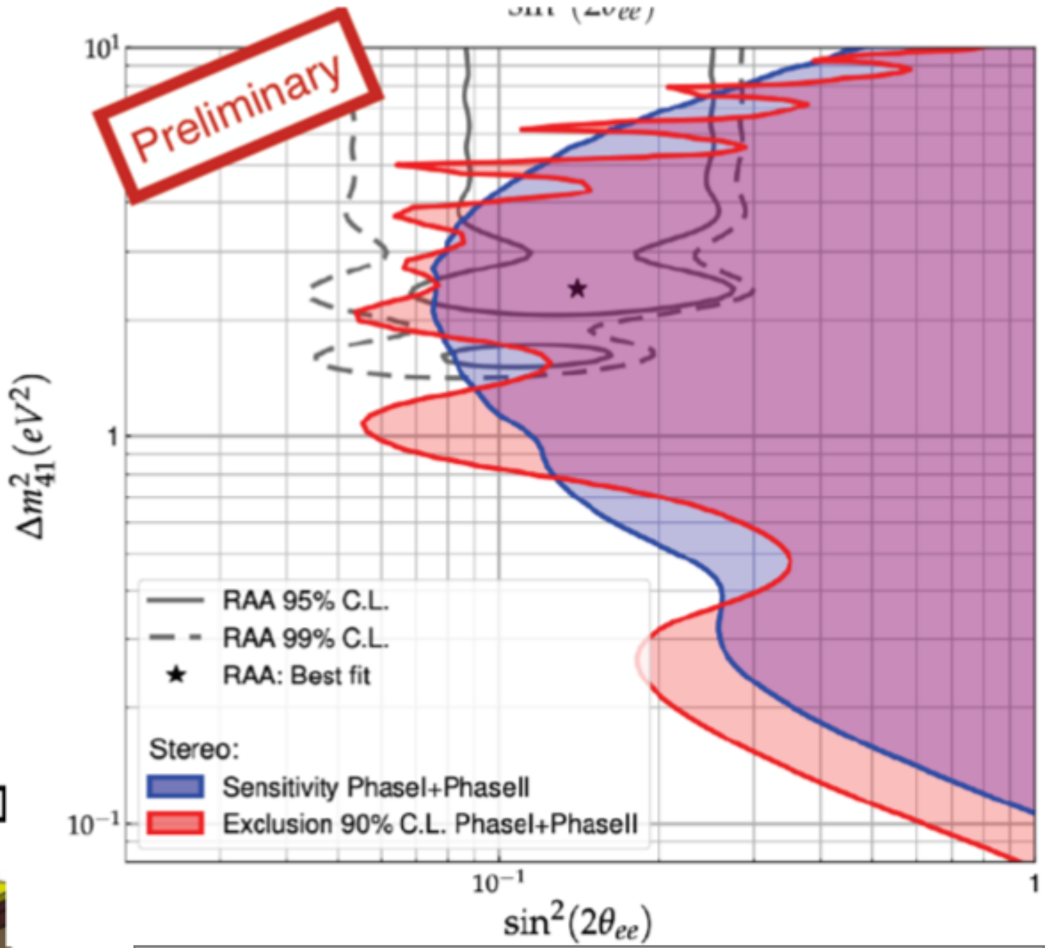
	Experiment	Reactor Power/Fuel	Overburden (mwe)	Dete Mat
Gd	DANSS (Russia) 	3000 MW LEU fuel	~50	Inhomog PS & Gd
Gd	NEOS (South Korea) 	2800 MW LEU fuel	~20	Homoge Gd-dope
Li	nuLat (USA) 	40 MW ^{235}U fuel	few	Homoge ^{6}Li dope
Gd	Neutrino4 (Russia) 	100 MW ^{235}U fuel	~10	Homoge Gd-dope
Li	PROSPECT (USA) 	85 MW ^{235}U fuel	few	Homoge ^{6}Li-dope
Li	SoLid (UK Fr Bel US) 	72 MW ^{235}U fuel	~10	Inhomog ^{6}LiZnS &
Li	Chandler (USA) 	72 MW ^{235}U fuel	~10	Inhomog ^{6}LiZnS &
Gd	Stereo (France) 	57 MW ^{235}U fuel	~15	Homoge Gd-dope

STEREO @ILL









Best-fit value of the RAA* rejected at 99.8% C.L.

* RAA(2011) parameters:

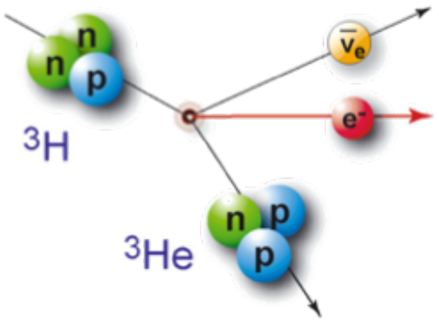
$$\begin{cases} \Delta m^2_{RAA} = 2.3\,eV^2 \\ \sin^2(2\theta_{RAA}) = 0.14 \end{cases}$$

Stefan Schönert, UK HEP Forum 2019

Adrien Blanchet, TAUP 2019

ν-mass observables

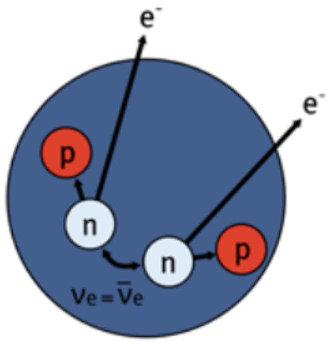
β-decay



$$m_\beta = \sqrt{\sum_i |U_{ei}|^2 \cdot m_i^2}$$

(Dirac or Majorana)

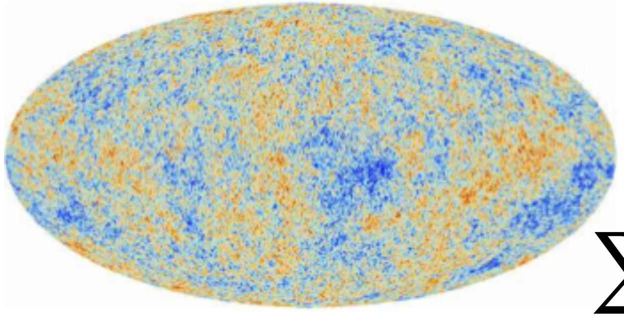
0νββ-decay



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

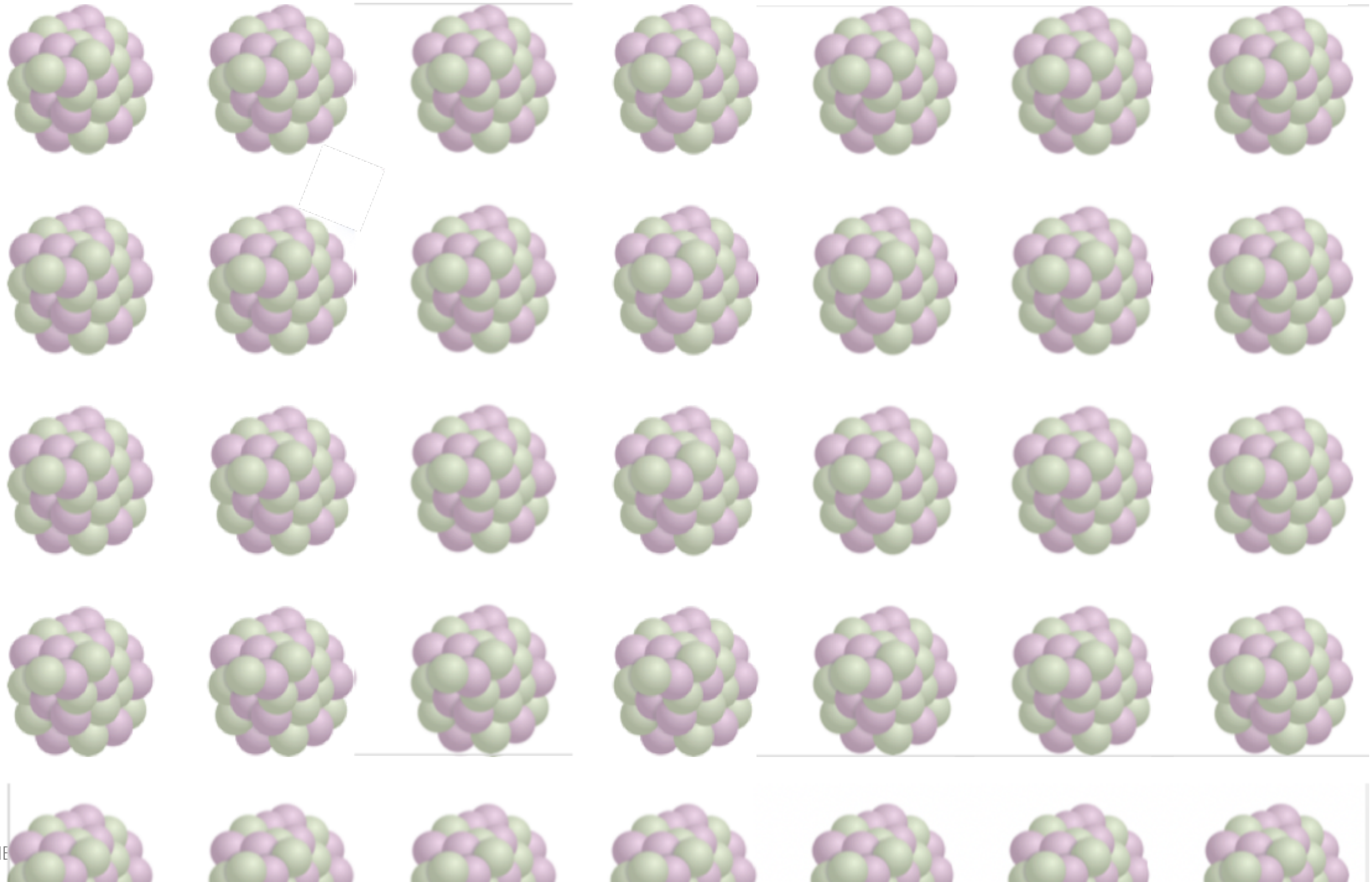
(Majorana)

Cosmology

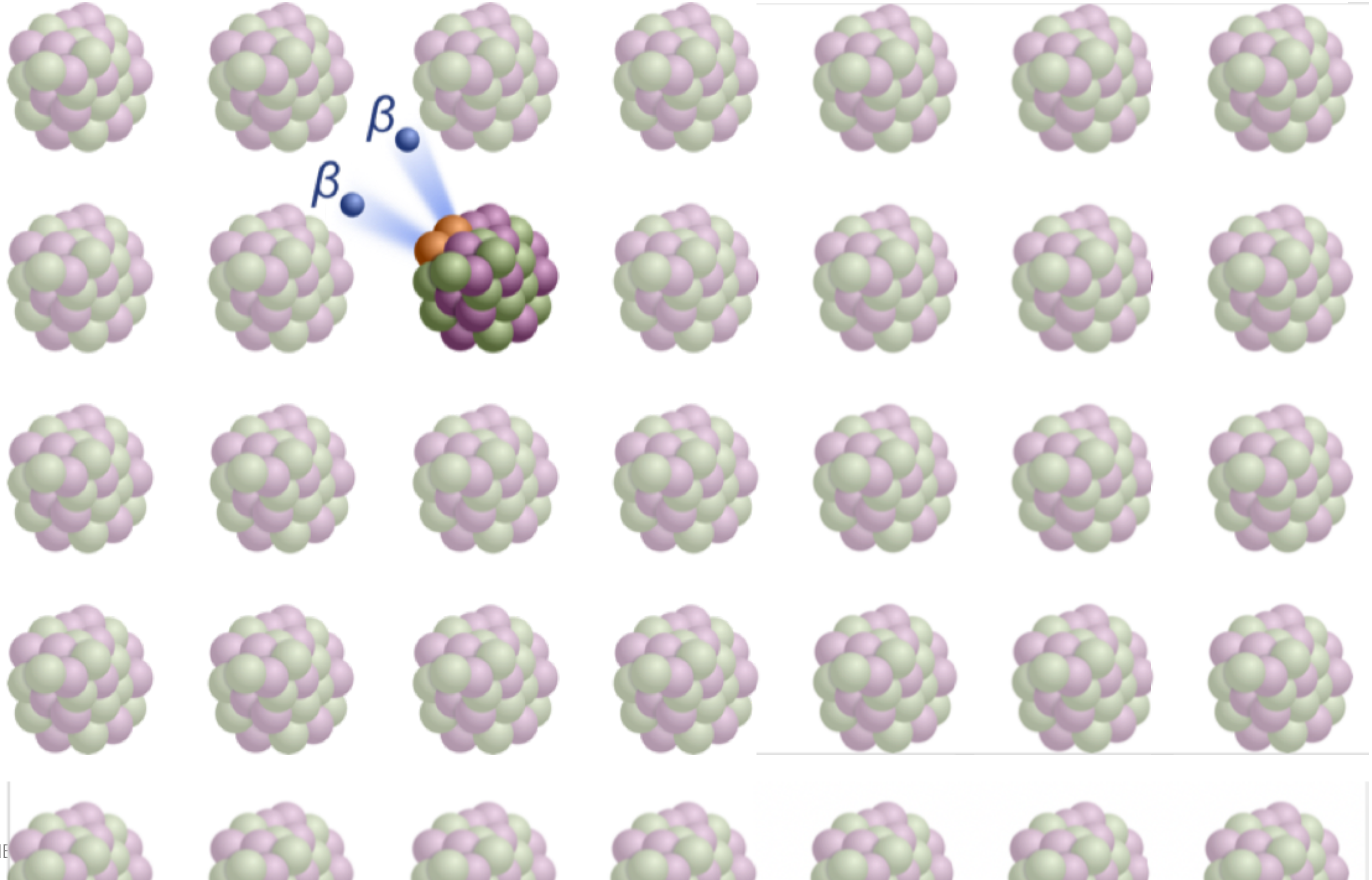


$$\sum_i m_i$$

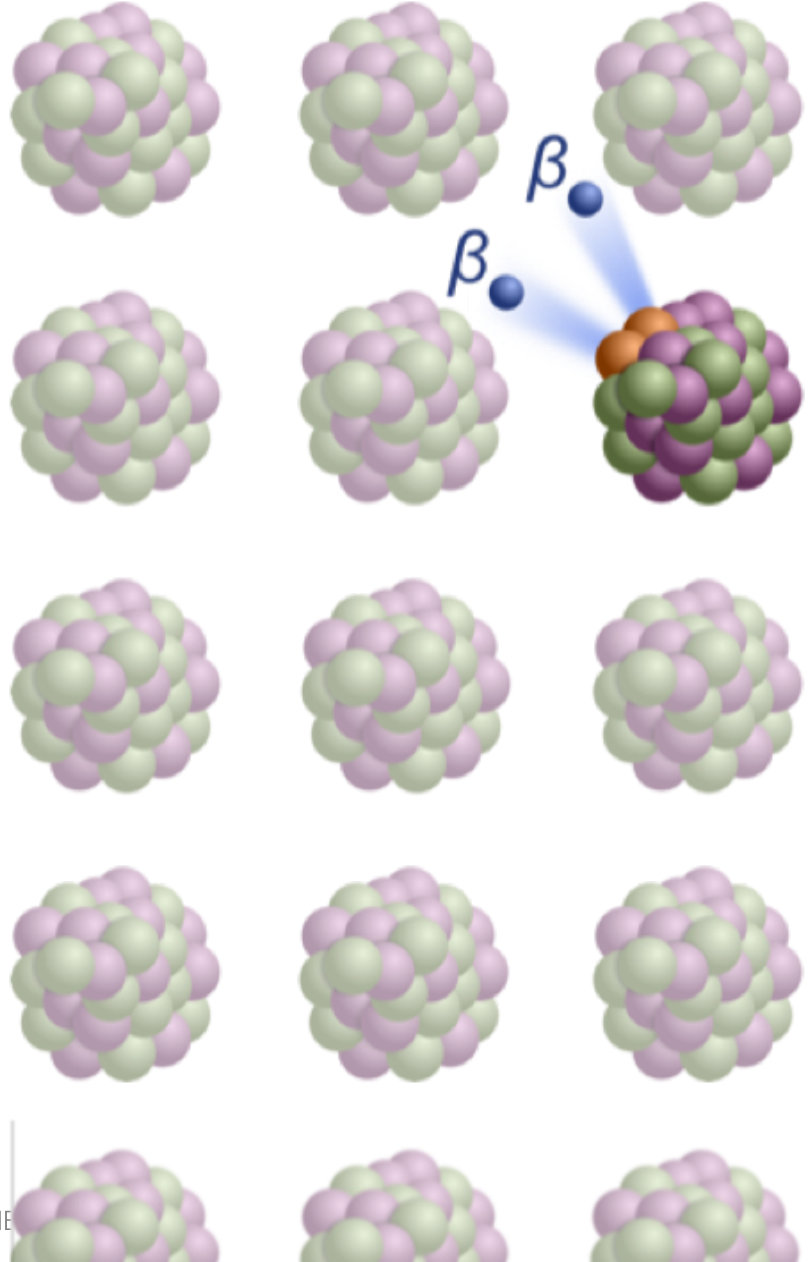
$0\nu\beta\beta$ decay



0νββ decay

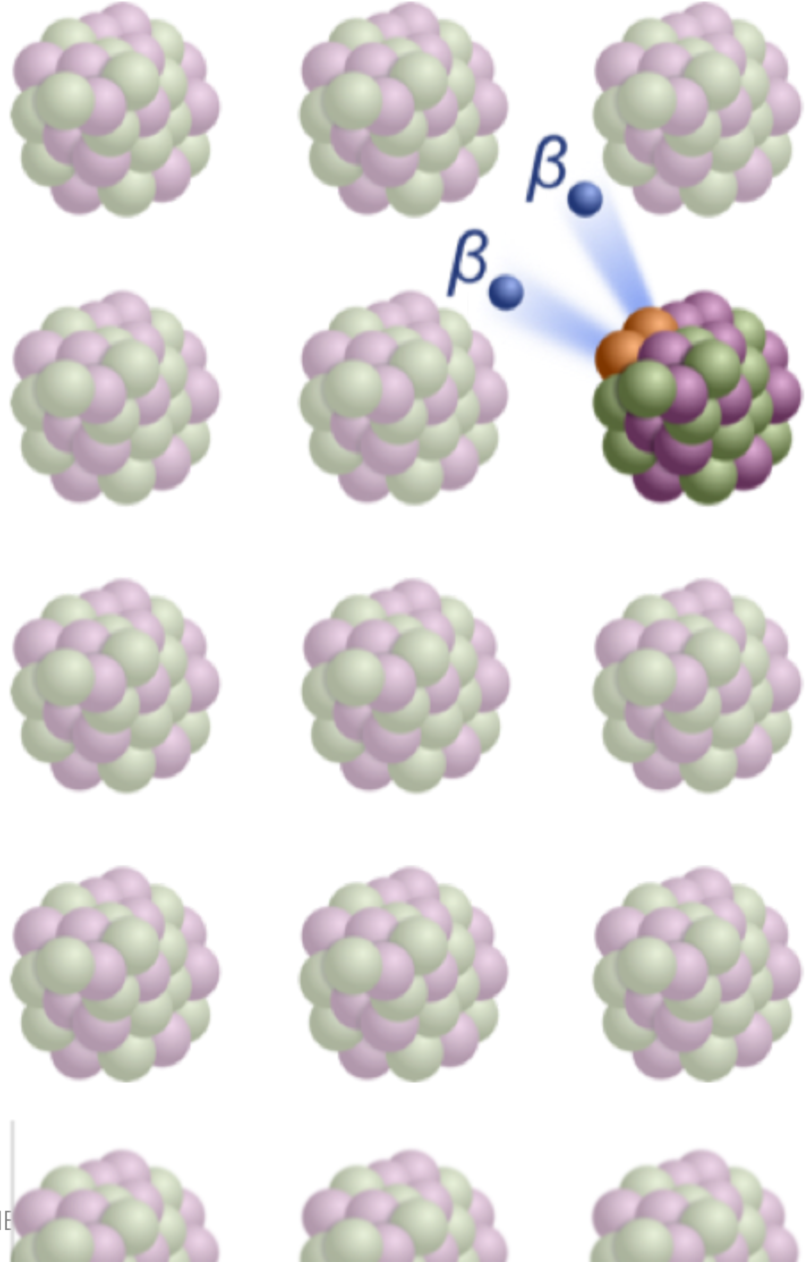


0νββ decay



- Creation of matter without balancing emission of anti-matter (Vissani)
- $(A,Z) \rightarrow (A,Z+2) + 2e^-$
- Lepton number violating process ($\Delta L=2$)
- Majorana neutrinos generate 0νββ
- Majorana neutrinos would explain small neutrino masses (See-Saw)
- Key ingredient for explanation of matter-antimatter asymmetry
- In general: $\Delta L=2$ (BSM) operators can generate 0νββ
- Discovery of 0νββ always imply new physics

0νββ decay



Current best sensitivity (GERDA):

$T_{1/2} \sim 10^{26}$ yr

Next generation:

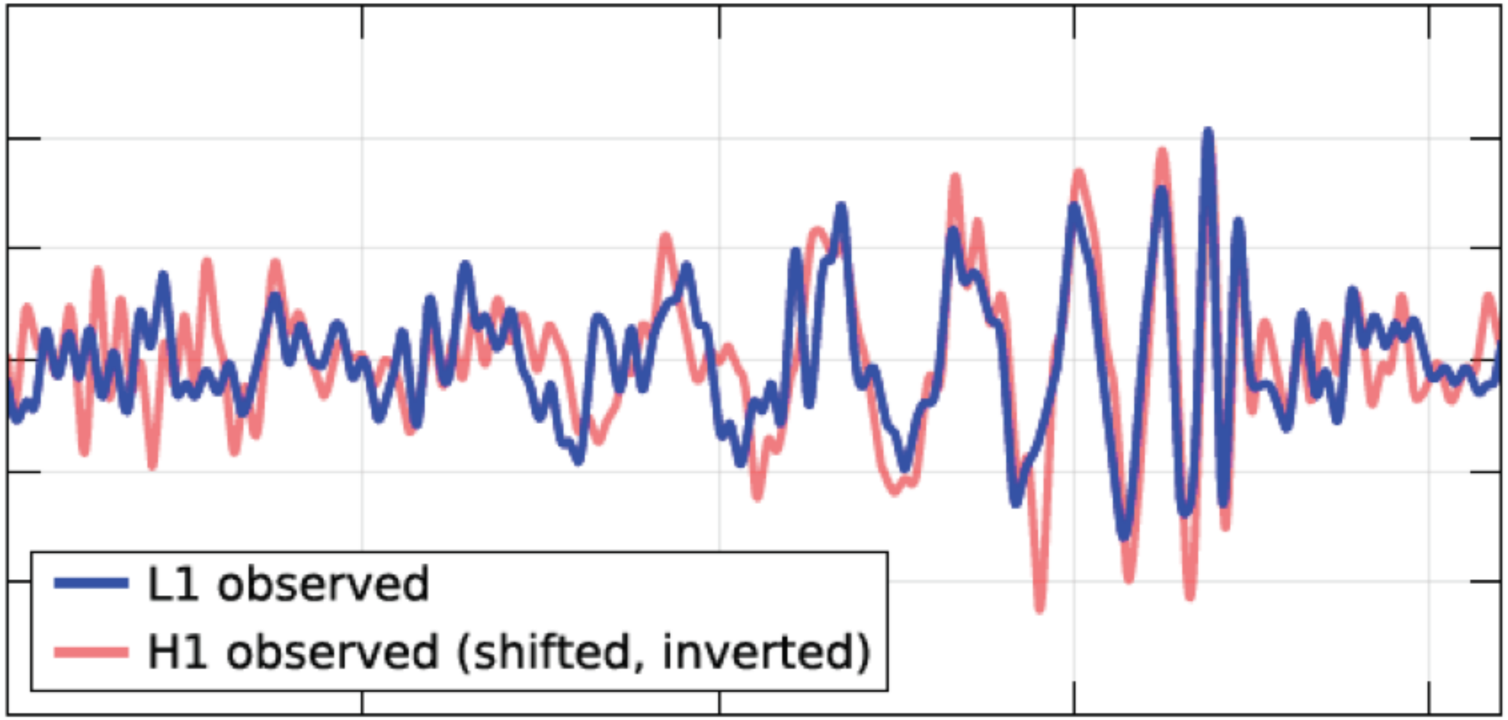
$T_{1/2} \sim 10^{28}$ yr (x 100 increase)

Challenge:

~1 decay per 10^4 Mol and year

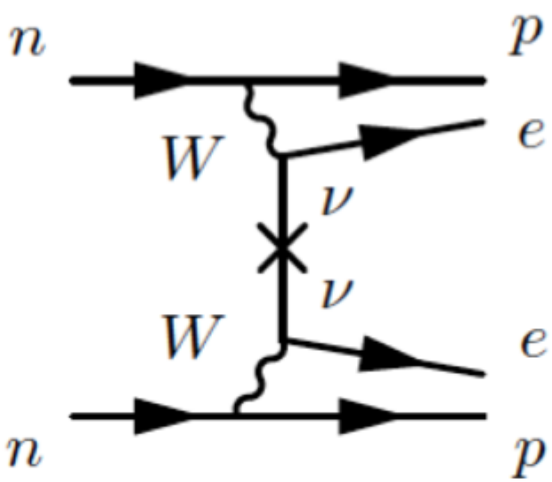
How many events are needed for a discovery?

…this depends obviously on the number of background events!



LIGO: discovery potential with single event
Time coincidence between two highly specific signals

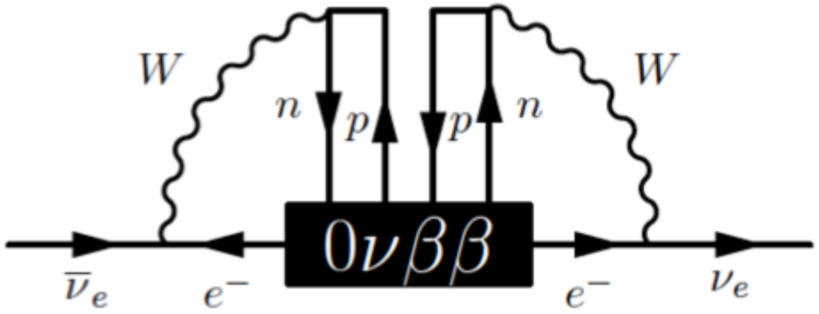
0νββ



Standard paradigm: exchange of
light Majorana neutrinos

$$\langle m_{ee} \rangle = \left| \sum_i U_{ei}^2 \, m_i \right|$$

PMNS-matrix ν-mass

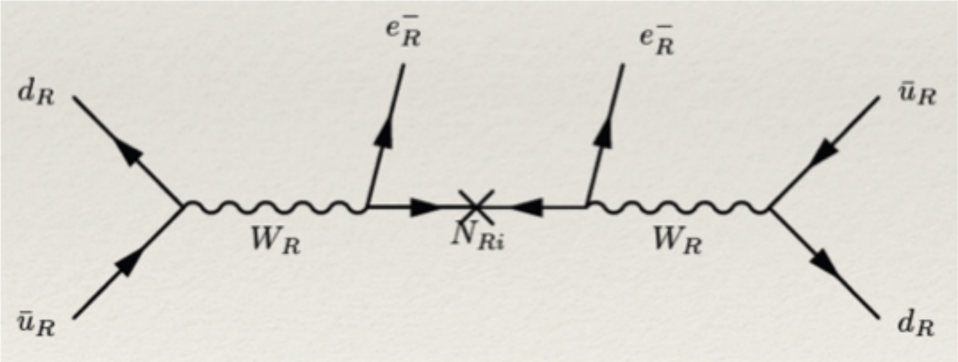


Any 0νββ decay process induces a $\overline{\nu_e}$-ν_e transition, ie. an effective **Majorana mass term**
Schechter, Valle Phys.Rev. D25 (1982)

Numerical values tiny; other leading contributions to neutrino mass must exist
Duerr, Merle, Lindner: JHEP 1106 (2011)

Complementarity of LHC and 0νββ decay

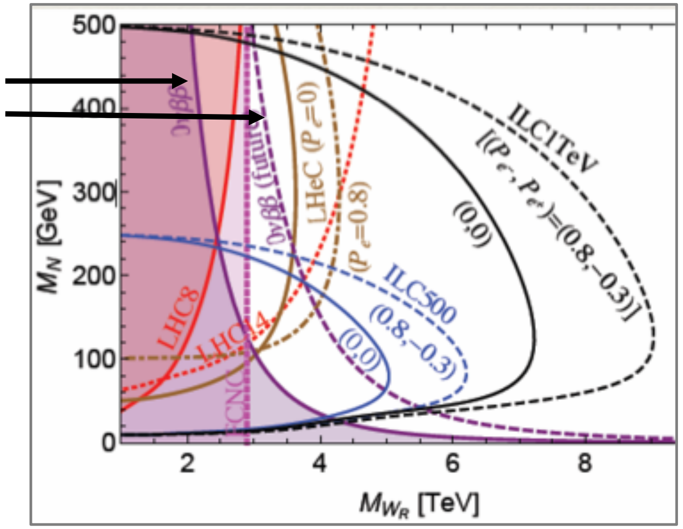
Probing the TeV scale with same-sign di-leptons in 0νββ and LHC:



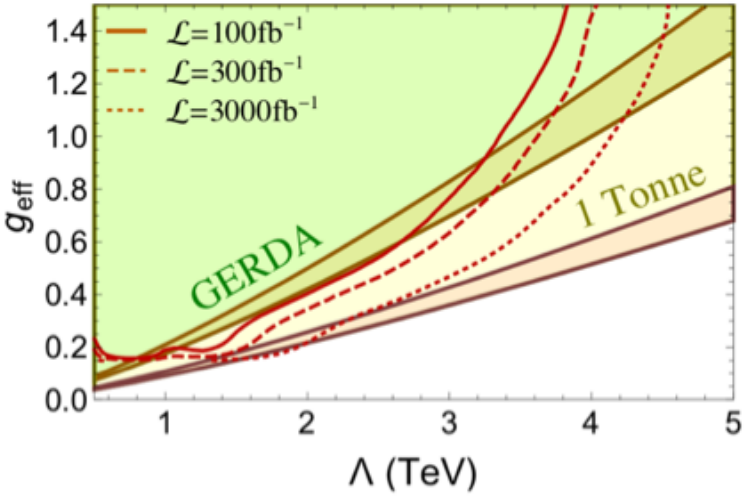
$$G_F^2 \frac{|m_{ee}|^2}{q^2} = \frac{1}{\Lambda^5} \text{ for } |m_{ee}| \sim \text{eV and } \Lambda \sim \text{TeV}$$

"eV = TeV"

0νββ



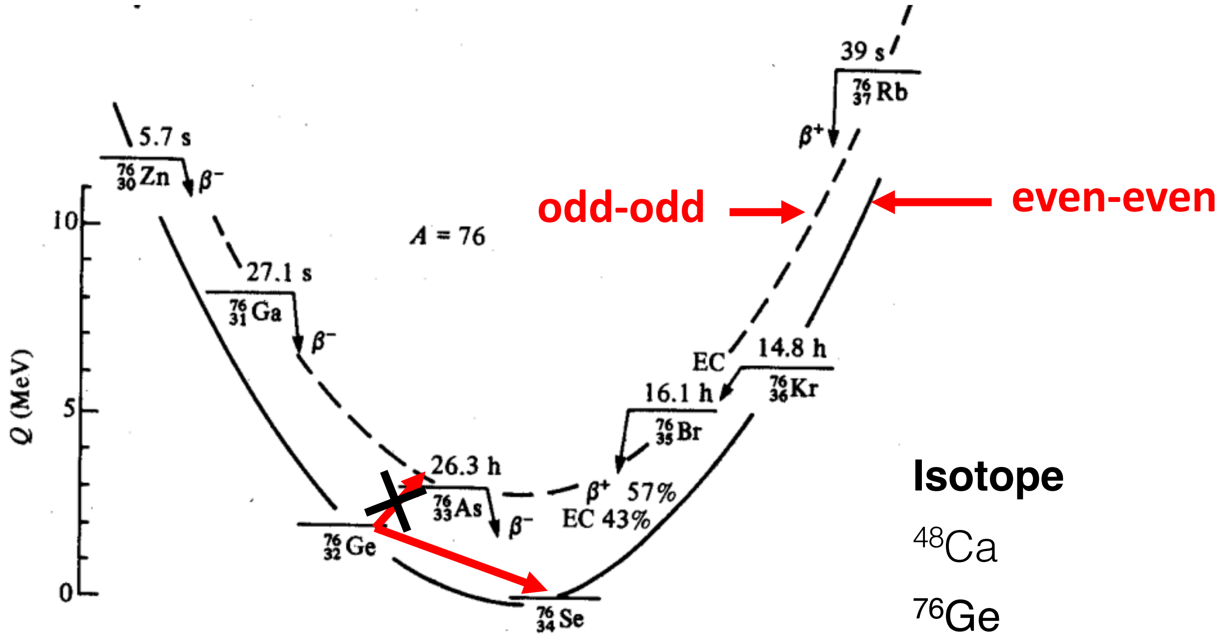
Biswal, Dev, 1701.08751



Ramsey-Musolf et al., 1508.04444

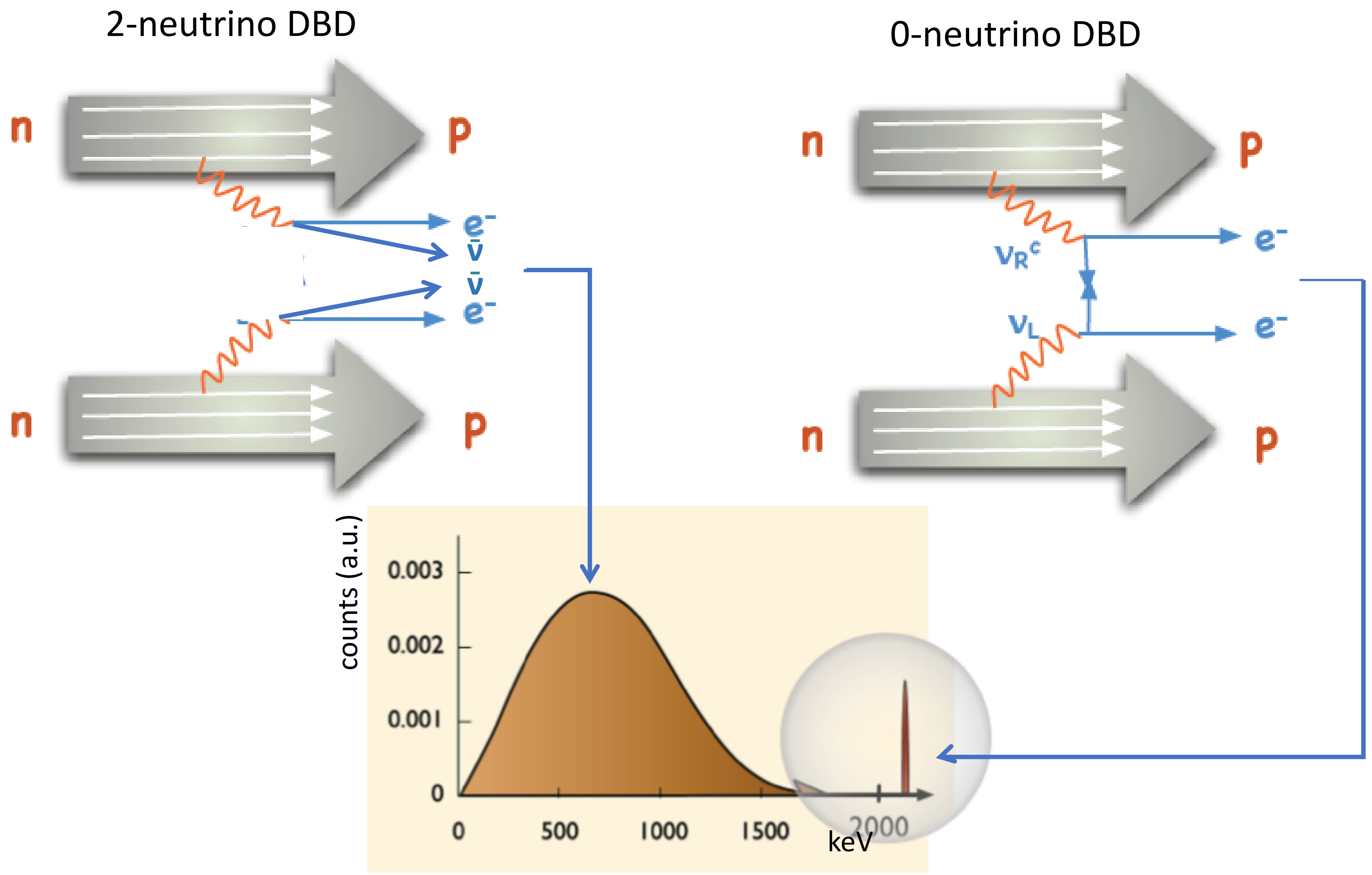
See also: Hirsch et al., 1511.03945

Double beta decay isotopes



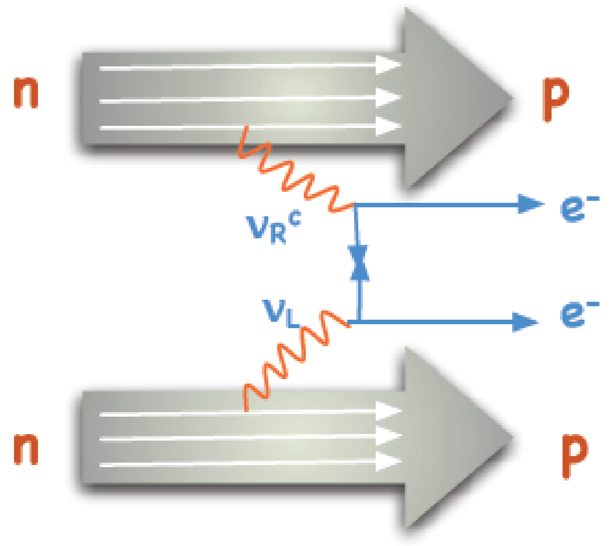
Isotope	Nat ab.	$Q_{\beta\beta}$
^{48}Ca	0.19 %	4262.96(84) keV
^{76}Ge	**7.6%**	**2039.04(16) keV**
^{82}Se	**8.7%**	**2997.9(3) keV**
^{96}Zr	2.8%	3356.097(86) keV
^{100}Mo	**9.6%**	**3034.40(17) keV**
^{116}Cd	7.5%	2813.50(13) keV
^{130}Te	**34.5%**	**2526.97(23) keV**
^{136}Xe	**8.9%**	**2457.83(37) keV**
^{150}Nd	5.6%	3371.38(20) keV

2νββ and 0νββ decay



2-electron spectra

0νββ decay and neutrino mass



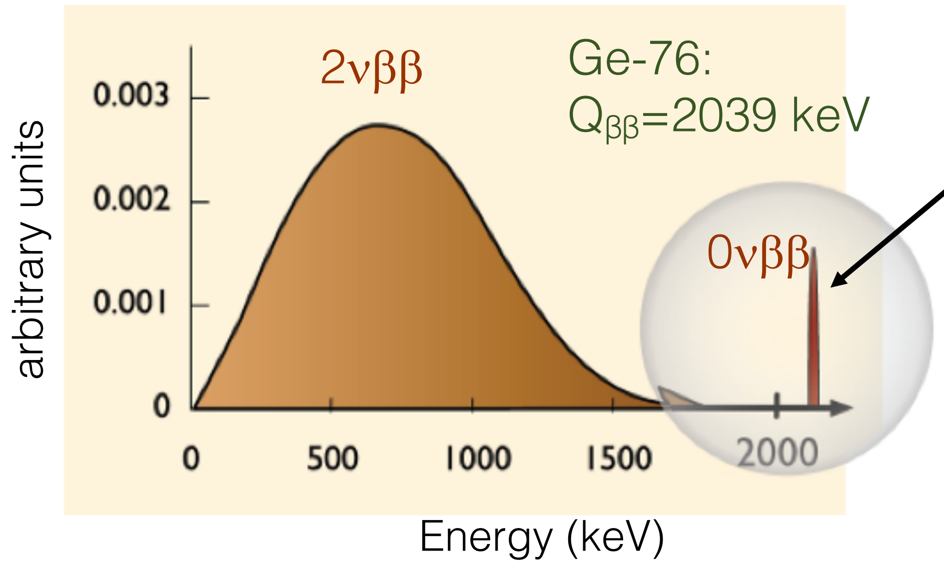
Expected decay rate:

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

Phase space integral   Nuclear matrix element

$$\langle m_{ee}\rangle = \left|\sum_i U_{ei}^2\, m_i\right|$$ Effective neutrino mass

U_{ei} Elements of (complex) PMNS mixing matrix



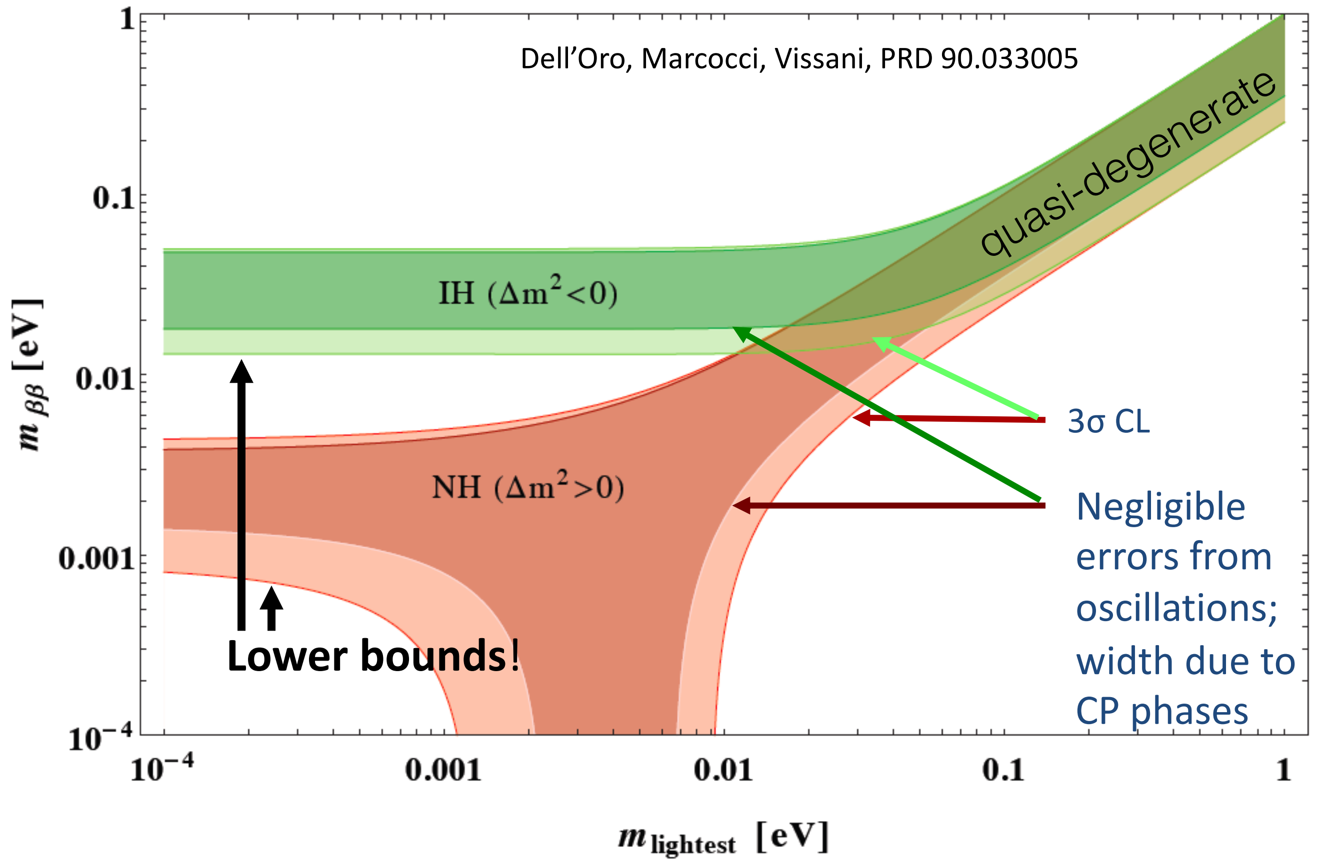
Experimental signatures:
- peak at $Q_{\beta\beta}$
- two electrons from vertex

Discovery would imply:
- lepton number violation ΔL = 2
- ν's have Majorana character
- mass scale
- physics beyond the standard model

$0\nu\beta\beta$: Range of m_{ee} from oscillation experiments

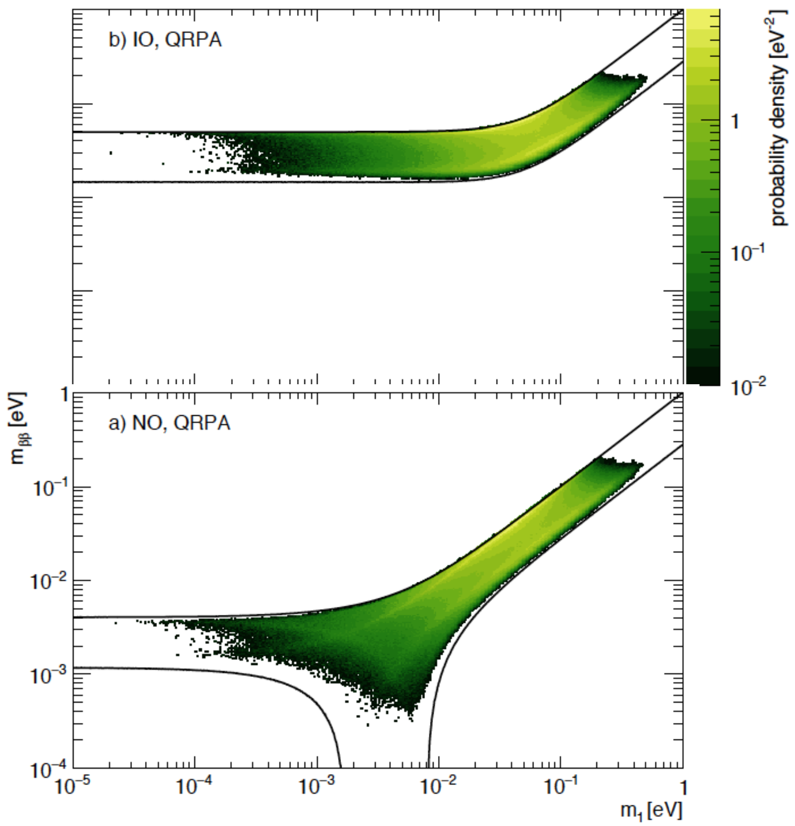
$$m_{ee} = f(m_1, \underbrace{\Delta m^2_{sol}, \Delta m^2_{atm}, \theta_{12}, \theta_{13}}_{\text{from oscillation experiments}}, \alpha\text{-}\beta)$$

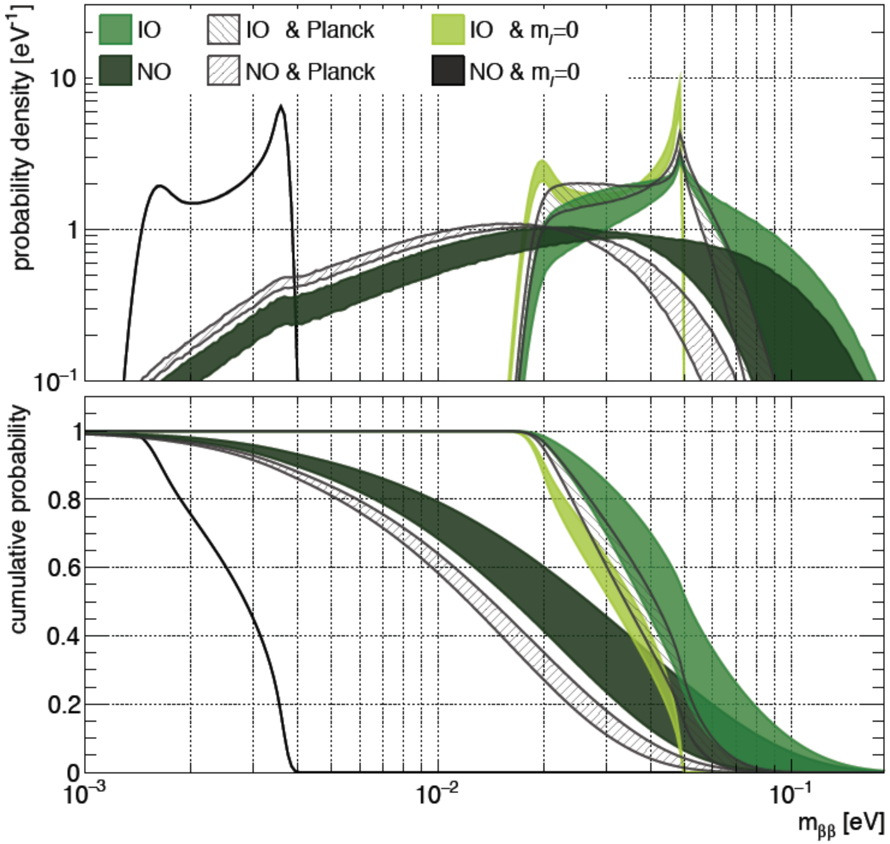
Goal of next generation experiments:



Discovery probabilities

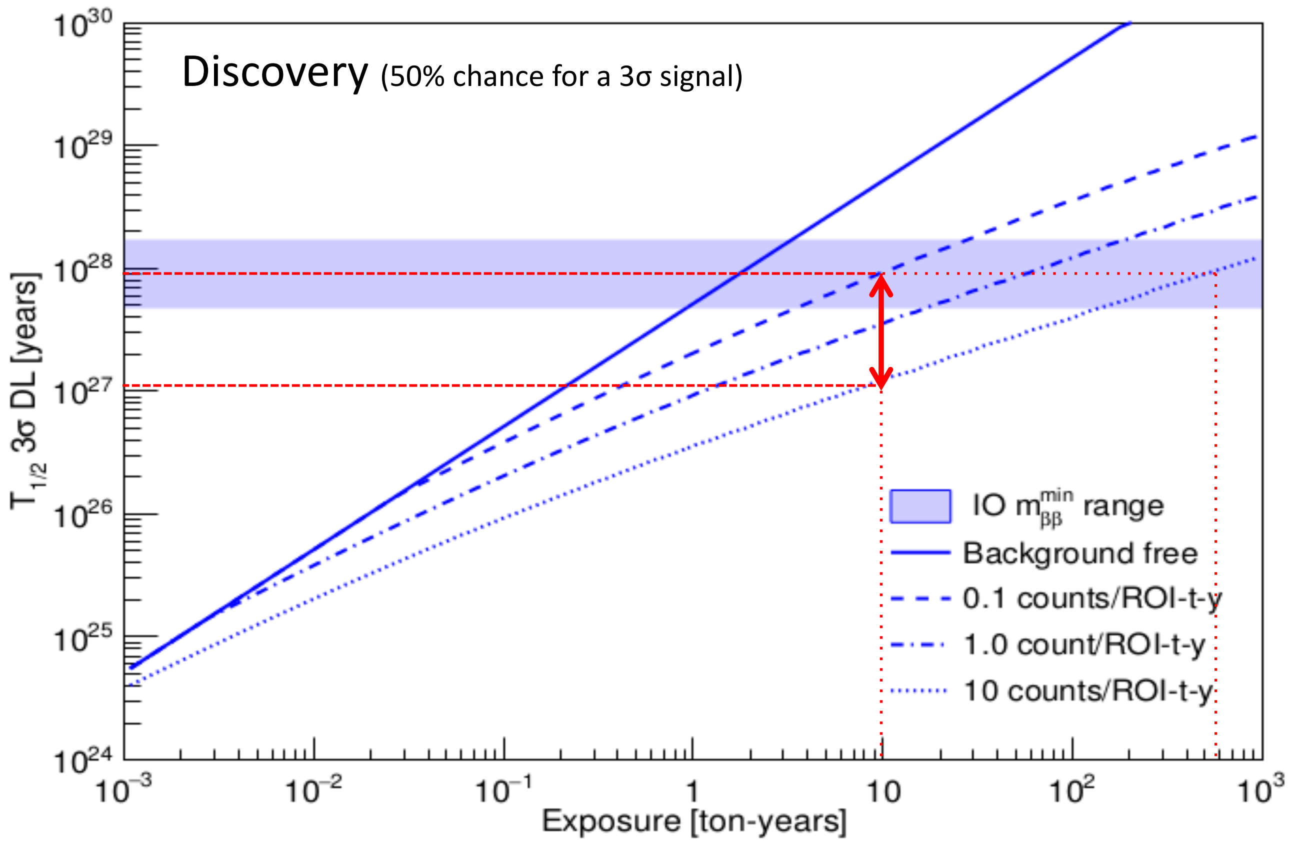
- Global Bayesian analysis including ν-oscillation, m_β $m_{\beta\beta}$, Σ
- Priors:
  - Majorana phases (flat)
  - m_1 (scale invariant)





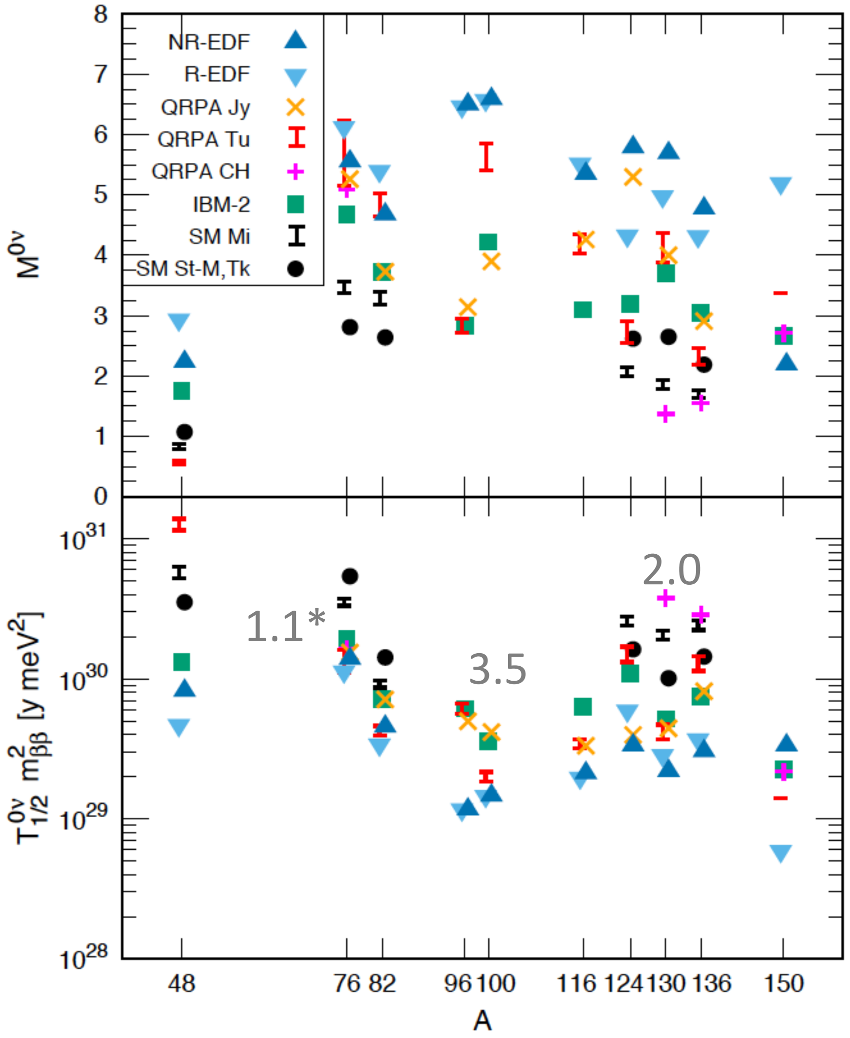
Agostini, Benato, Detwiler arXiv:1705.02996

Discovery sensitivity vs. background



Courtesy J. Detwiler

Nuclear matrix elements



Spread about x2

No isotope significantly preferred when comparing decay rate per mass

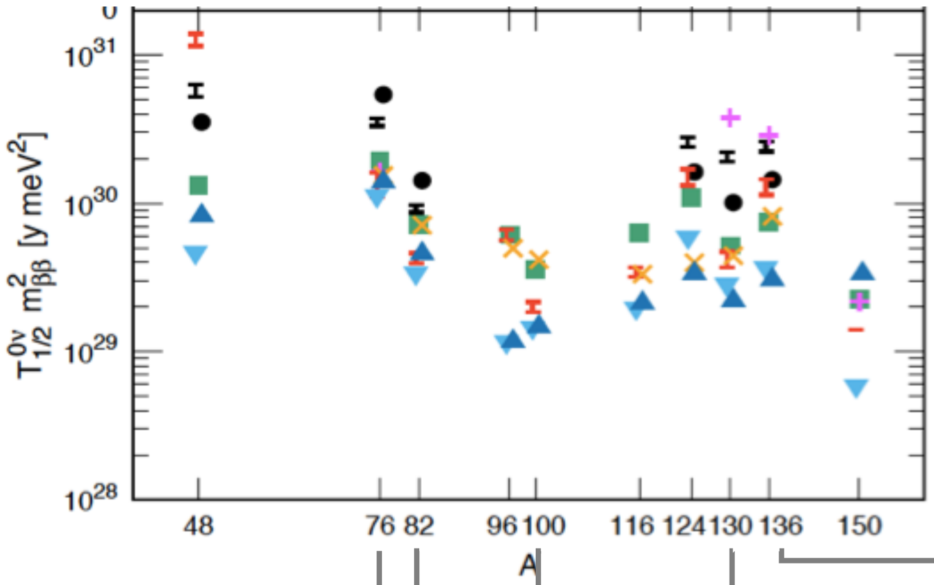
Choice mainly driven by experimental considerations

*number = signal rate per 1000 kg yr exposure & for middle of NME values for For $<m_{ee}>$ = 17.5 meV ('bottom of IH' for g_A=1.25, $\sin^2\theta_{12}$ = 0.318)

Engel & Menédez

arXiv:1610.06548v2

Experiments



LXe TPC:	EXO-200 / nEXO
gas-Xe TPC:	NEXT, PandaX-III
Xe-loaded LS:	KamLAND-Zen

Te-loaded LS:	SNO+
Te-bolometers:	CUORE / CUPID-Te

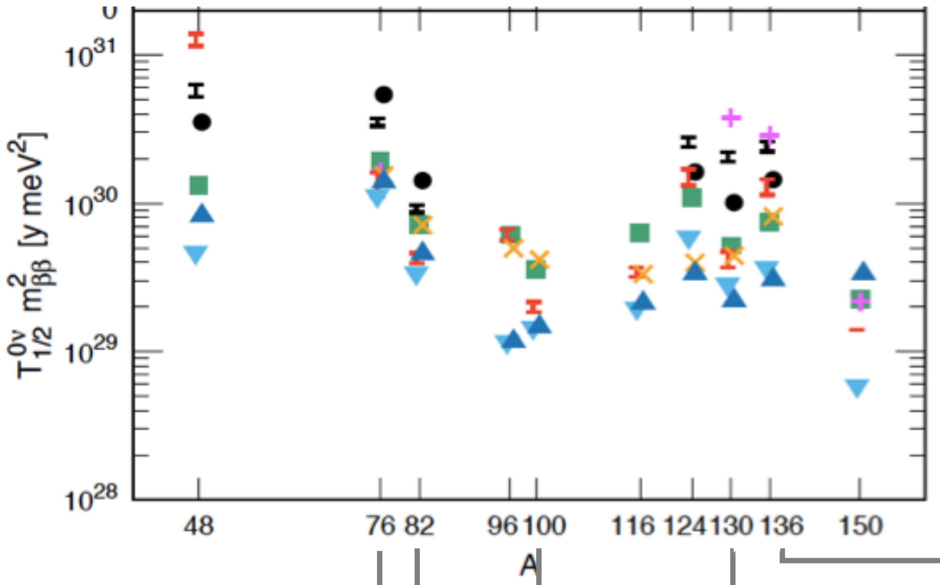
Mo-bolometers: CUPID-Mo / AMoRE

Se-bolometers:	CUPID-0 (ex Lucifer)
Se-calo-tracko:	SuperNEMO

Ge-semiconductor: GERDA, MJD, LEGEND

& other interesting, but less advanced R&D; ^{48}Ca, ^{150}Nd not available in large quantities

Experiments



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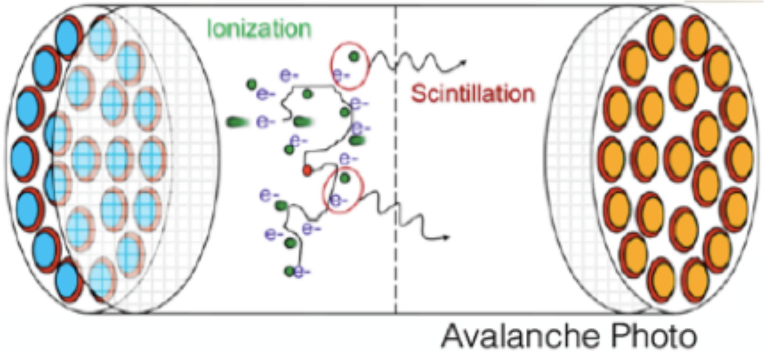
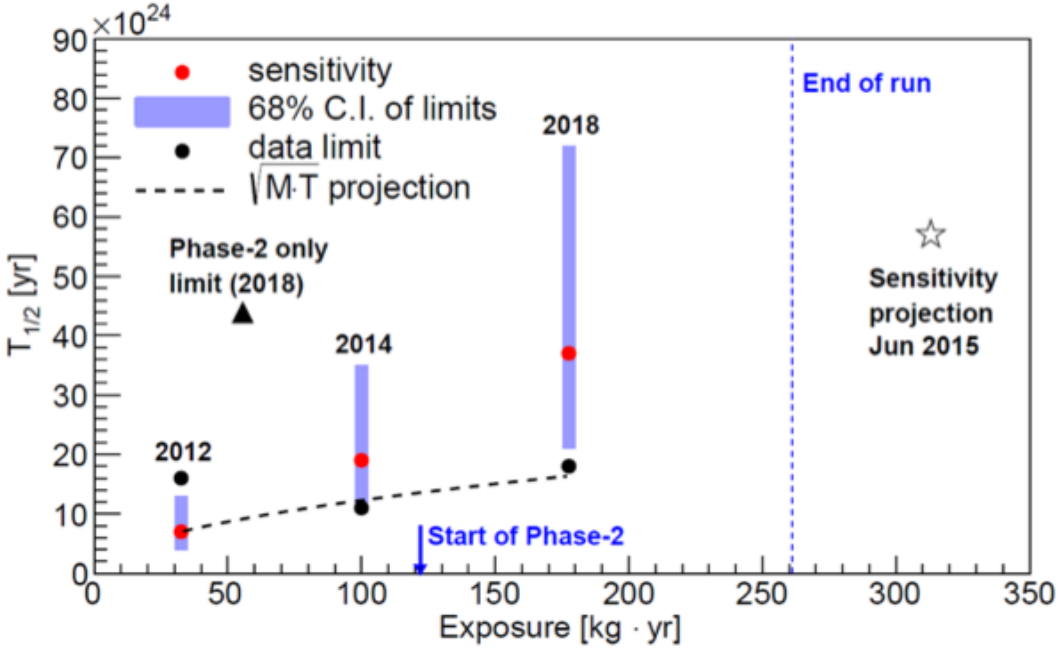
Xenon Experiments: EXO-200



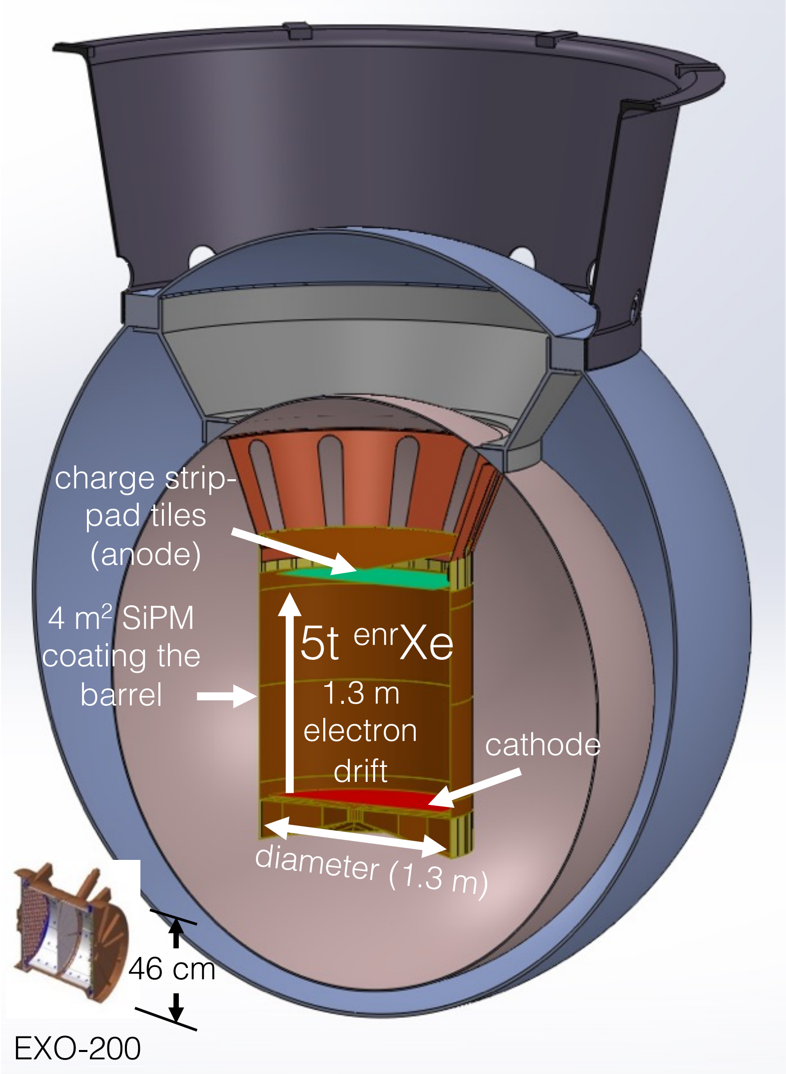


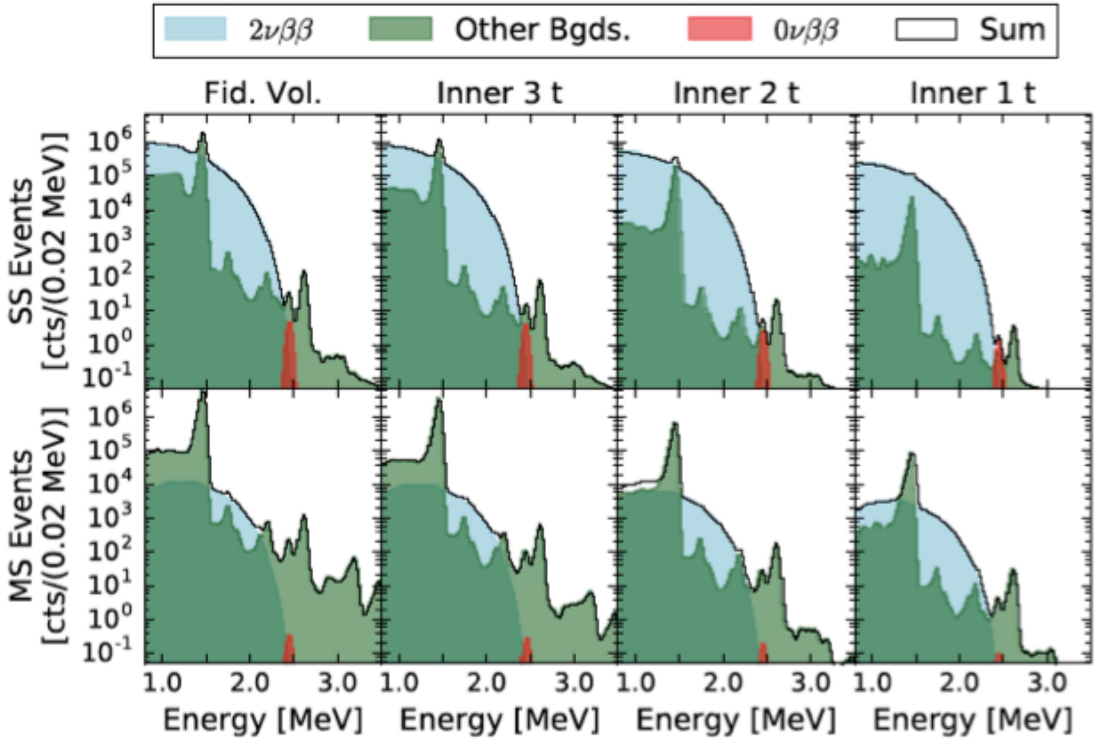
- ^{136}Xe: $Q_{\beta\beta}$ = 2458 keV
- Liquid Xe TPC (80.6% ^{136}Xe)
- 75 kg ^{136}Xe in FV

	Sensitivity (yr)	90% CL Limit (yr)	$\langle m_{\beta\beta}\rangle$ (meV)
PRL 109, 032505 (2012)	0.7×10^{25}	1.6×10^{25}	
Nature 510, 229 (2014)	1.9×10^{25}	1.1×10^{25}	
PRL 120 072701 (2018)	3.8×10^{25}	1.8×10^{25}	147-398

Courtesy G. Gratta

Xenon Experiments: nEXO



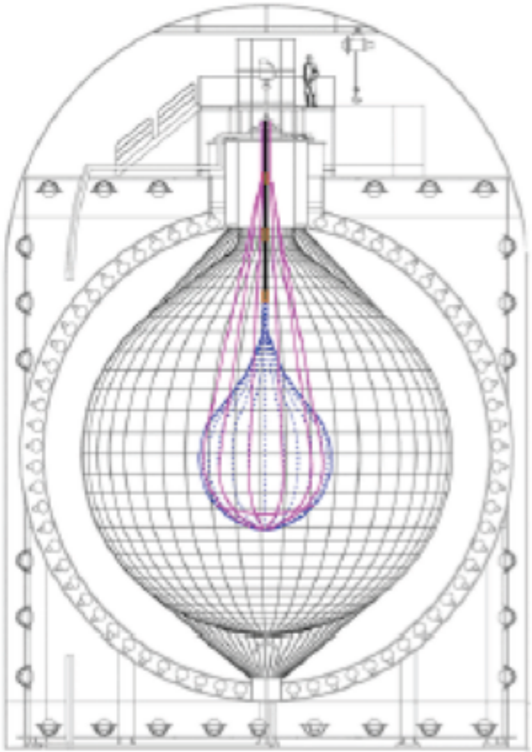


Discovery sensitivity (3σ, 50%) after 10 yr
$T_{1/2}^{0\nu\beta\beta}$ = 5.5x10^{27} yr

If ^{136}Ba-tagging can be implemented:
$T_{1/2}^{0\nu\beta\beta}$ = 1.6x10^{28} yr

Courtesy G. Gratta

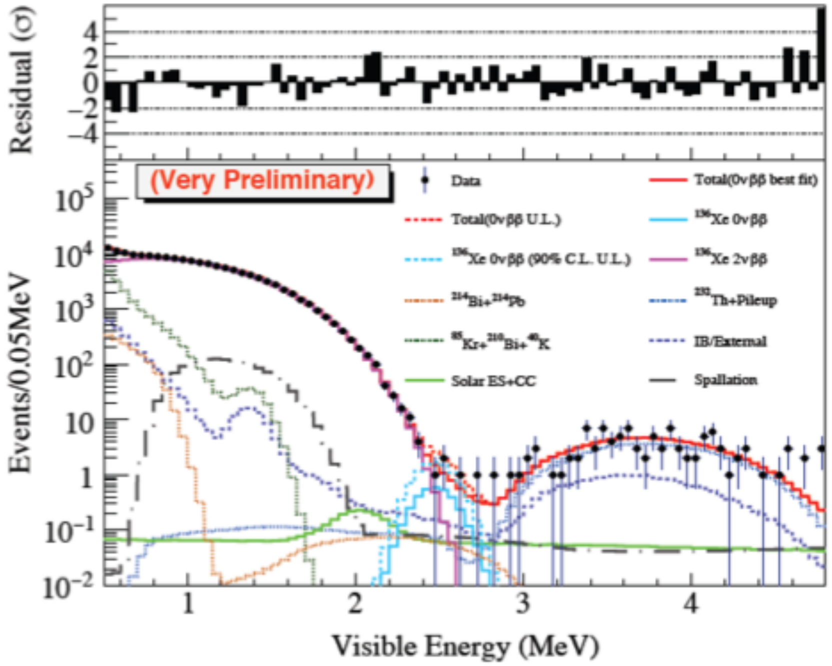
Xenon Exp's: KamLAND-Zen



KamLAND-Zen 800

R = 1.90m mini-balloon

745 kg enriched Xenon
-start Jan 2019



Best fit : 2.1 events/day/kton-XeLS

90% Upper limit : < 6.0 events/day/kton-XeLS

$T^{0\nu}_{1/2} > 4 \times 10^{25}$ year (90% C.L.)

Summary of observed & best-fit events in ROI

Observed events	8
Best-fit total events	10.7
$0\nu\beta\beta$	2.8
$2\nu\beta\beta$	5.1
^{214}Bi in LS	0.4
^{212}Bi-^{212}Po pile-up	0.4
Film BG (^{214}Bi)	0.9
Spallation (^{10}C)	0.2
Spallation (^{137}Xe)	0.1
Spallation (short-lived)	0.2
Solar ^{8}B ν	0.4

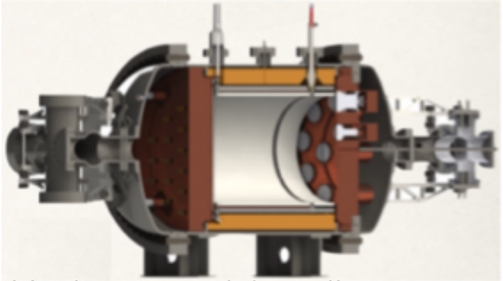
Very preliminary

Gando, Taup 2019

Xenon Experiments: next

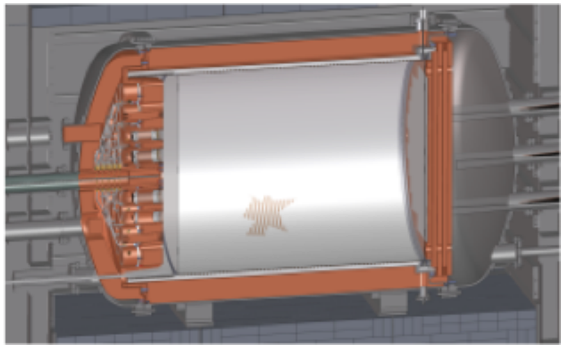
^{136}Xe high-pressure (10-15 bar) TPC

NEXT-NEW (5 kg) 2015-2018



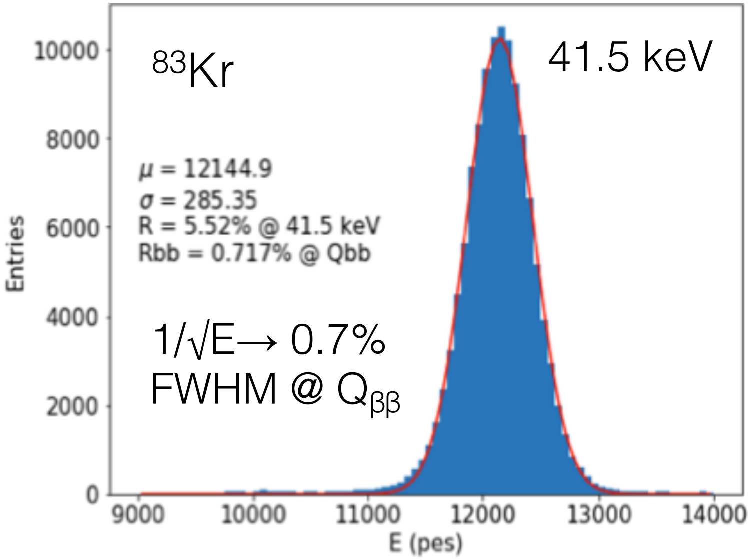
Underground & radio-pure operations, background, $2\nu\beta\beta$

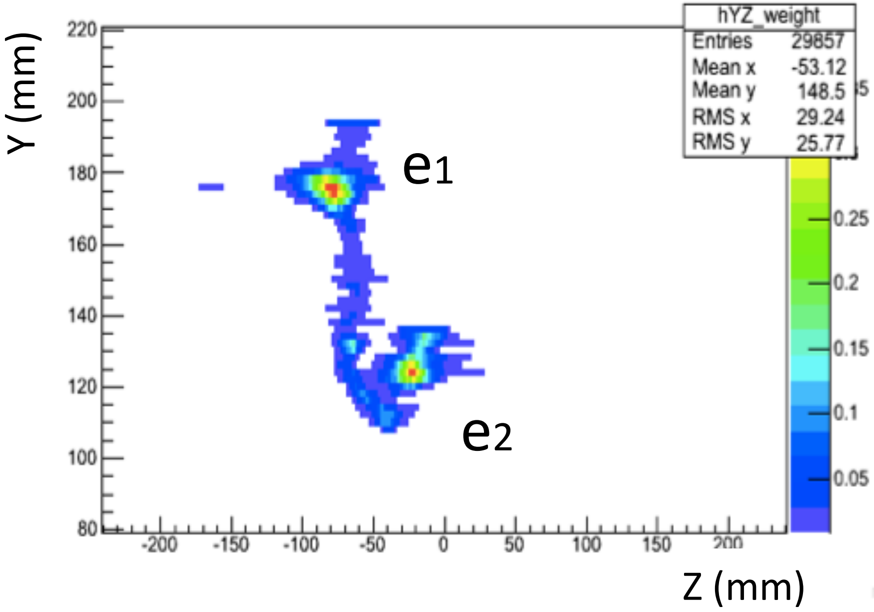
NEXT-100 (100 kg) 2018-2020's



$0\nu\beta\beta$ search

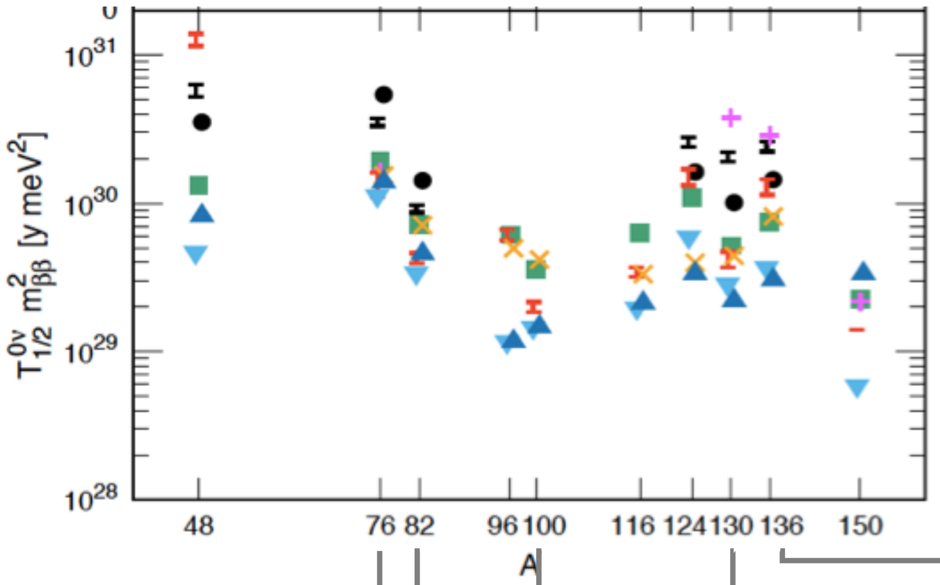
→ NEXT-ton





Courtesy JJ Gomez Cadenas

Experiments



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Se-calo-tracko:	SuperNEMO

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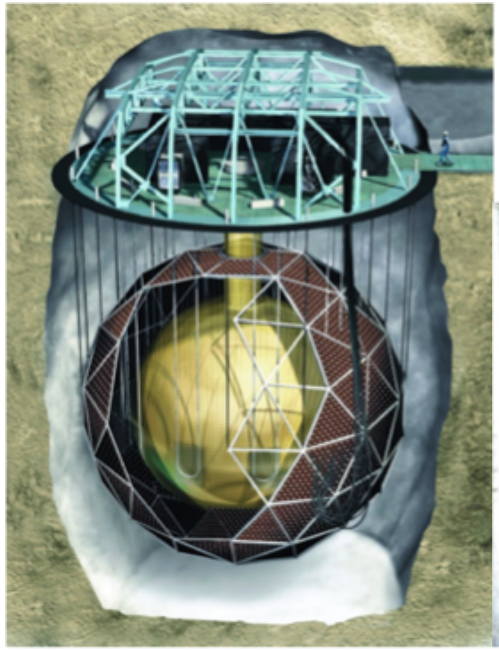
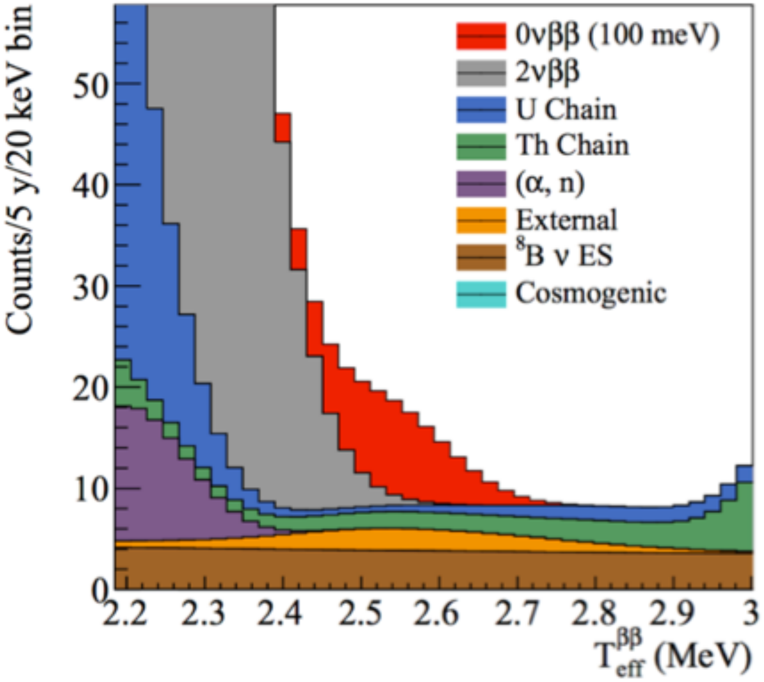
& other interesting, but less advanced R&D; ^{48}Ca, ^{150}Nd not available in large quantities

SNO+

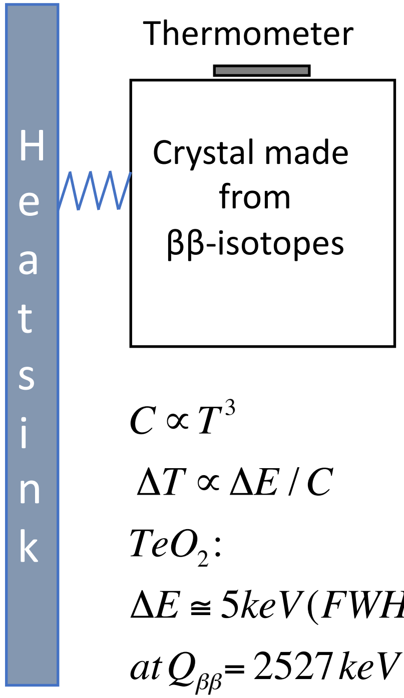


- 3.9 t Te
- 780 t LAB(+PPO+Te-ButaneDiol)
- 0.5% loading → 1300 kg ^{130}Te



Sensitivity (limit setting) after 5 yr:
$T_{1/2} > 2\times10^{26}$ yr (90% CL)

Cryogenic Detectors: CUORE



$C \propto T^3$

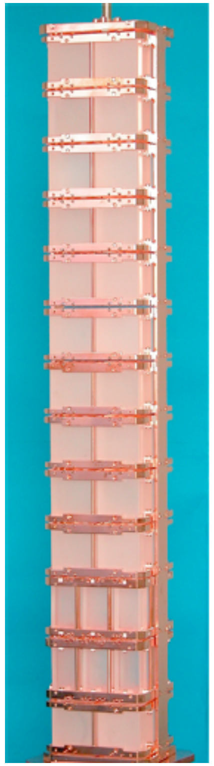
$\Delta T \propto \Delta E / C$

TeO_2:

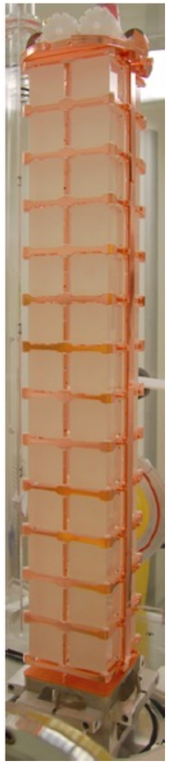
$\Delta E \cong 5 keV (FWHM)$

at $Q_{\beta\beta} = 2527\, keV$

Cuoricino
2003

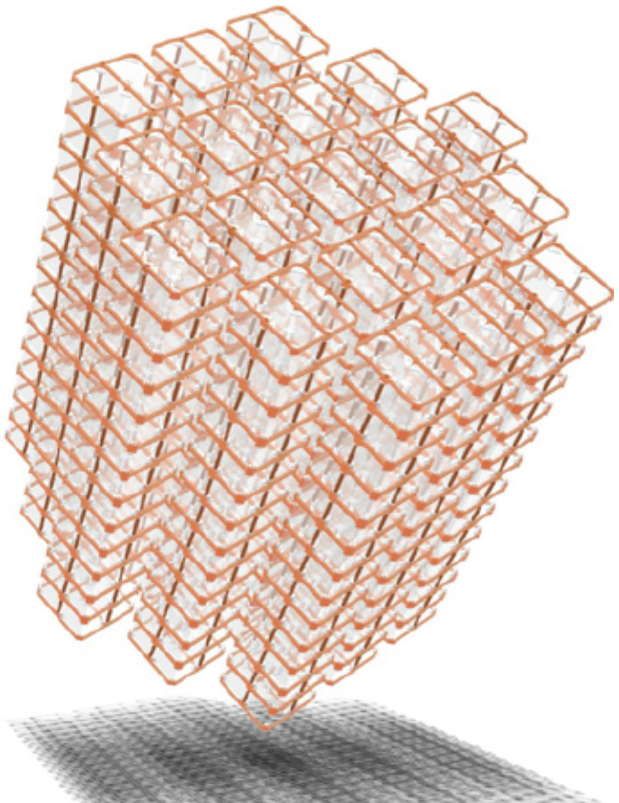


Cuore-0
2012



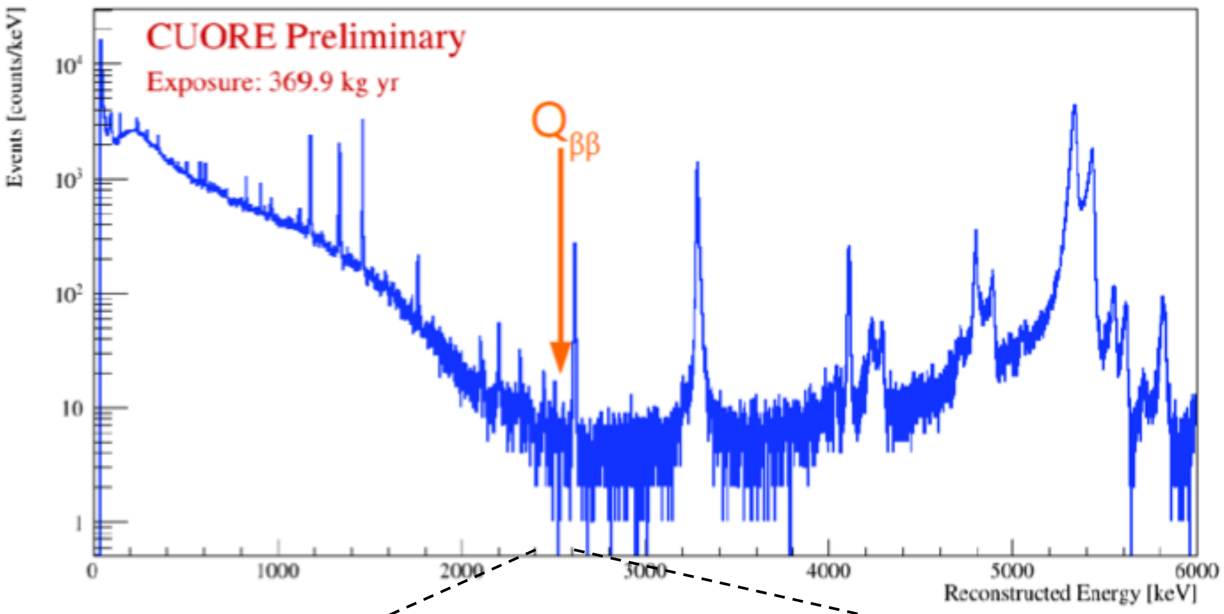
39 kg
(11 kg ^{130}Te)

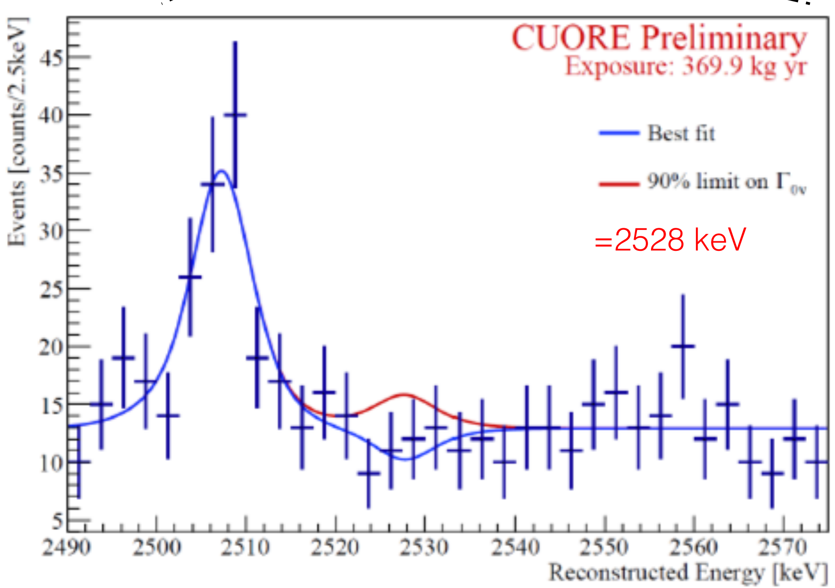
CUORE
2016



741 kg
(206 kg ^{130}Te)

Cryogenic Detectors: CUORE





BI: 1.4 x10^{-2} cts/(keV kg y)

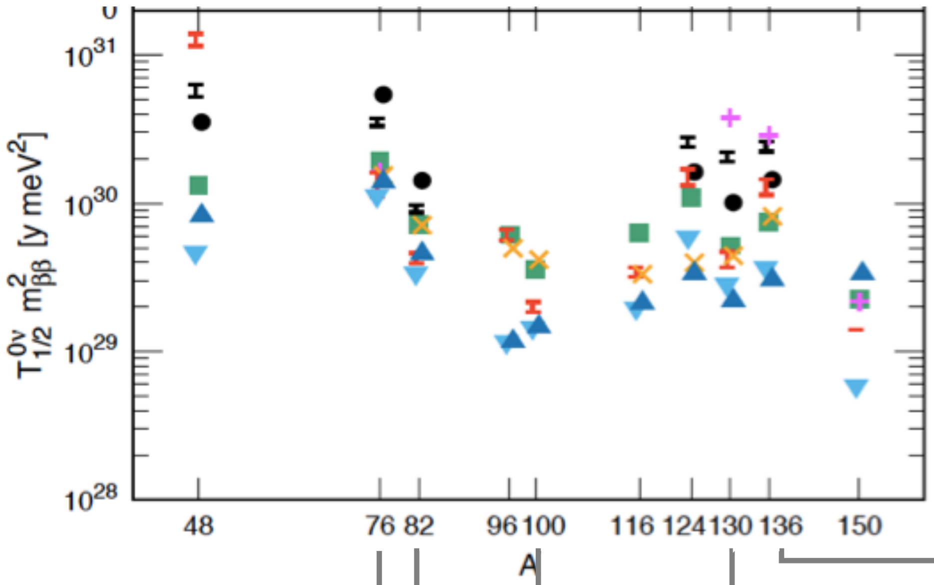
Sensitivity (90% C.L): 1.5 x 10^{25} yr

Limit (90% C.L): 2.3 x 10^{25} yr

$m_{\beta\beta}$ < 0.09-0.42 eV

S. Pozzi, Taup 2019

Experiments



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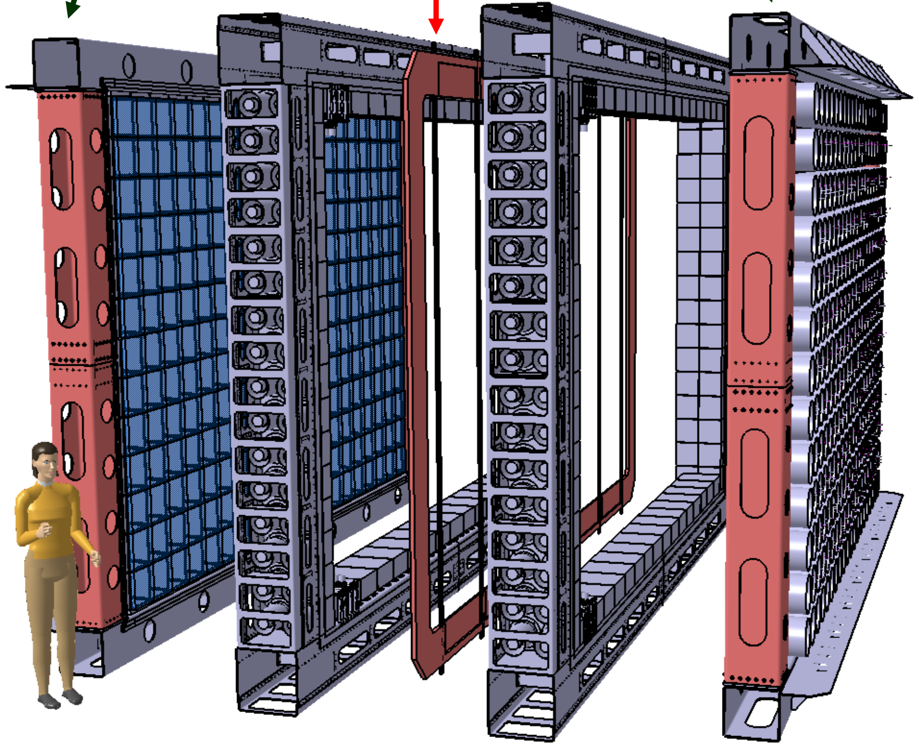
& other interesting, but less advanced R&D; ^{48}Ca, ^{150}Nd not available in large quantities

SuperNemo Demonstrator



Demonstrator Module

Status:

All detector parts underground at LSM

Half-detector fully assembled and undergoing testing/commissioning

Source foil fabrication (7kg of ^{82}Se) complete within next few months

SuperNEMO Demonstrator Module fully assembled by end-2017

Physics data-taking starts in 2018

Expected sensitivity:

17.5 kg×yr initial exposure (2.5 yr):

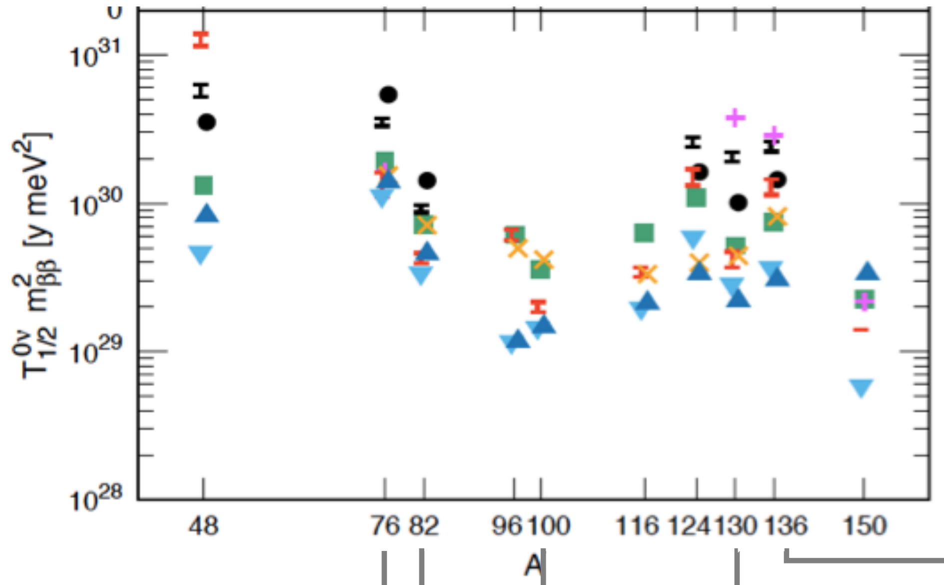
$T_{1/2}^{0\nu} > 6.5 \times 10^{24}$ yr $\langle m_\nu \rangle < 0.20 - 0.40$ eV

SuperNEMO (100 kg ^{82}Se, 20 mod., 500 kgxyr)

$T_{1/2}^{0\nu} > 10^{26}$ yr $\langle m_\nu \rangle < 50 - 100$ meV

Courtesy D. Waters

Experiments



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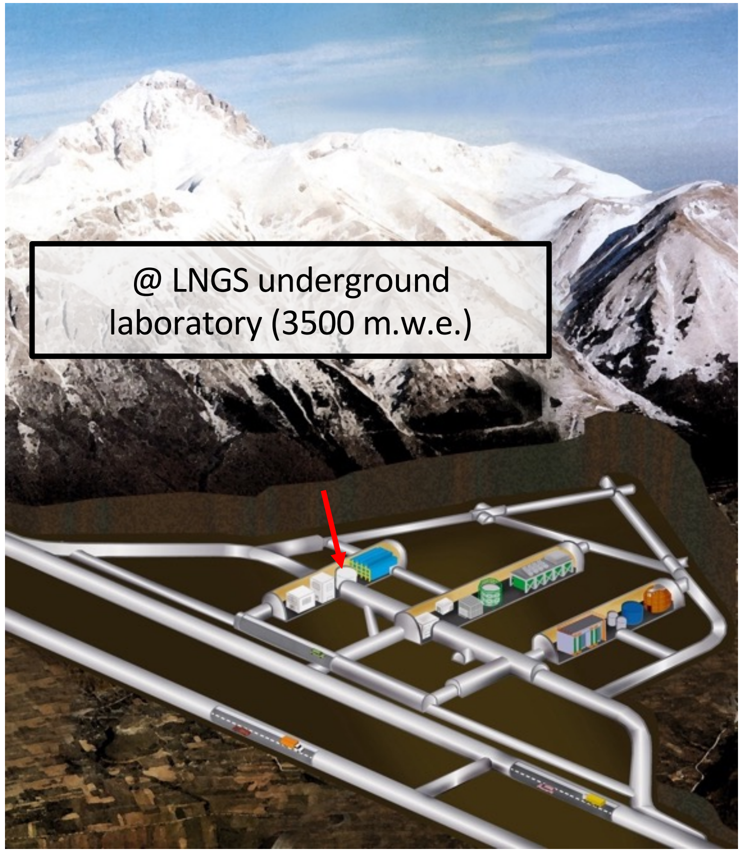
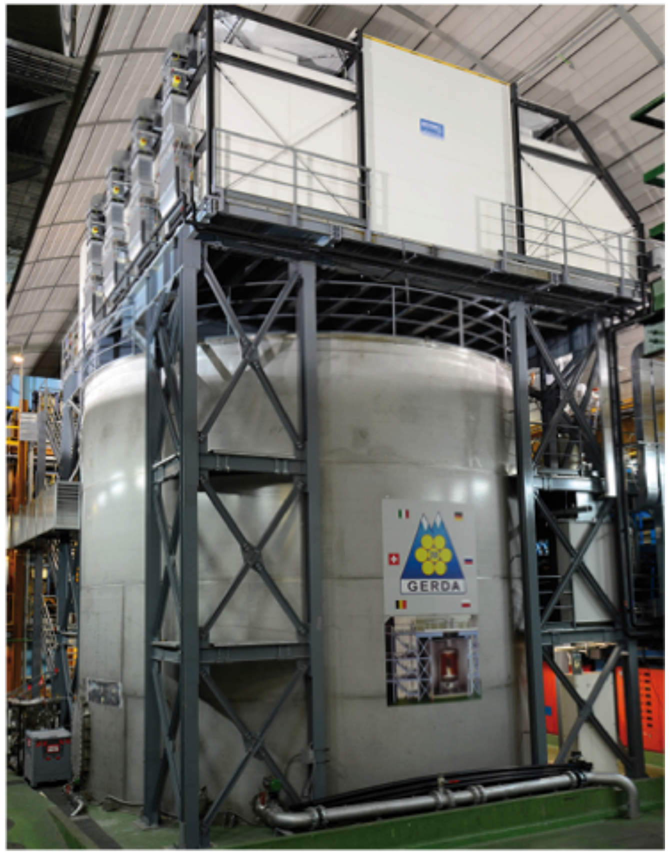
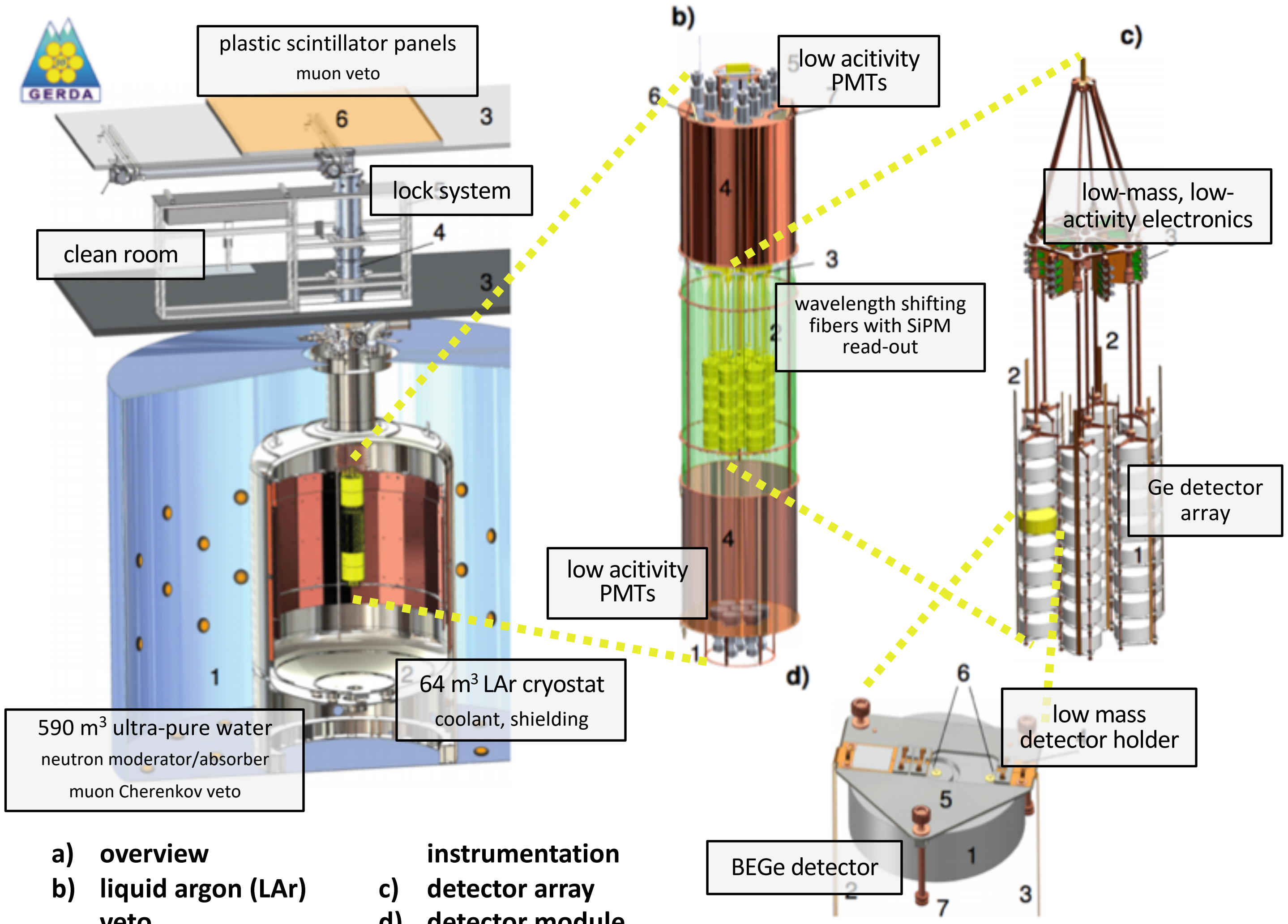
GERDA experimental setup at LNGS



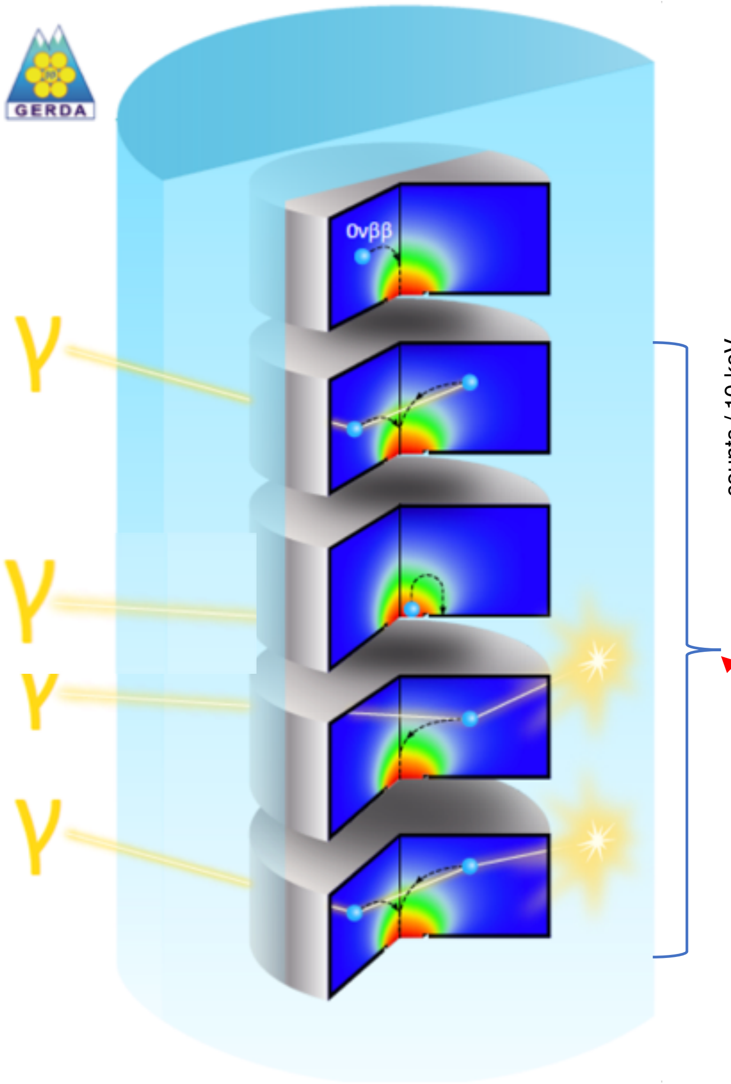


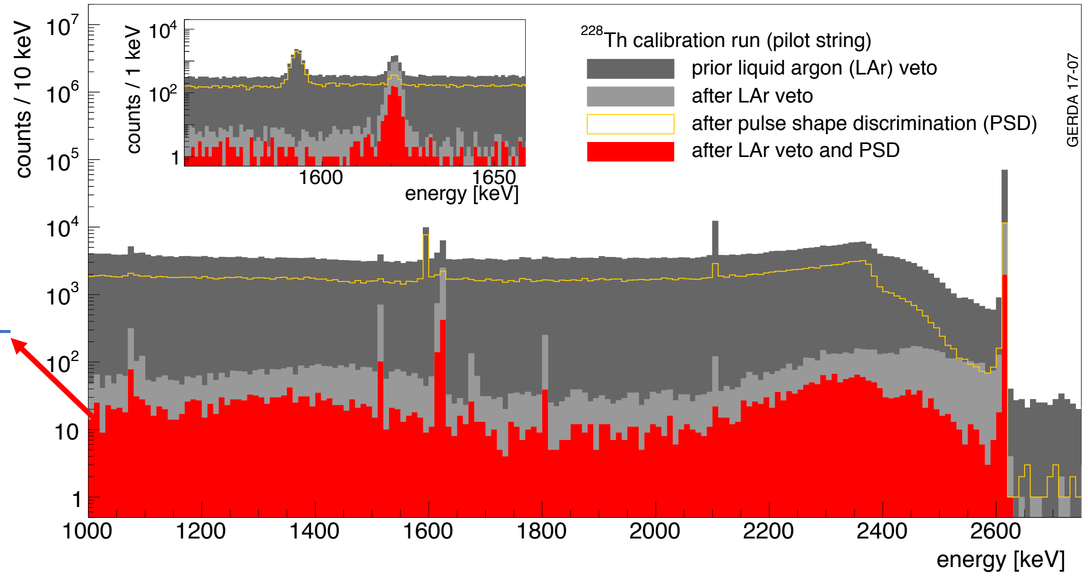


a) overview
b) liquid argon (LAr) veto instrumentation
c) detector array
d) detector module

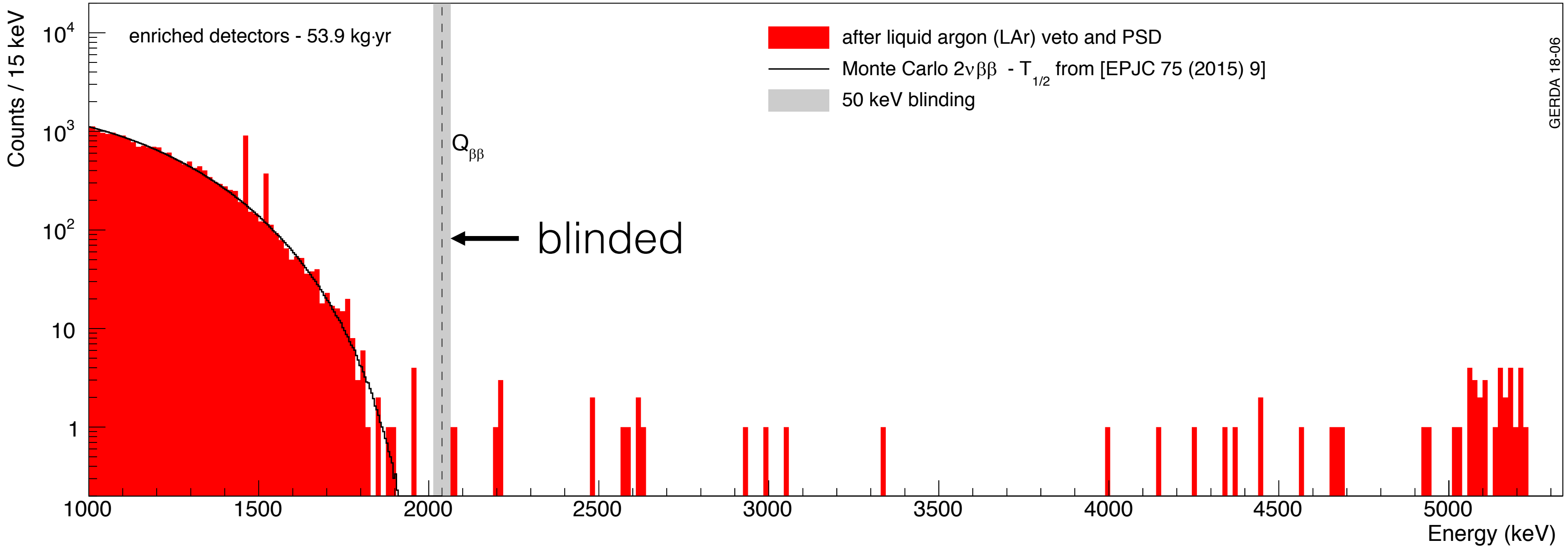
Interplay between PSD and LAr Veto

^{228}Th calibration source





The full energy range – after PSD and LAr



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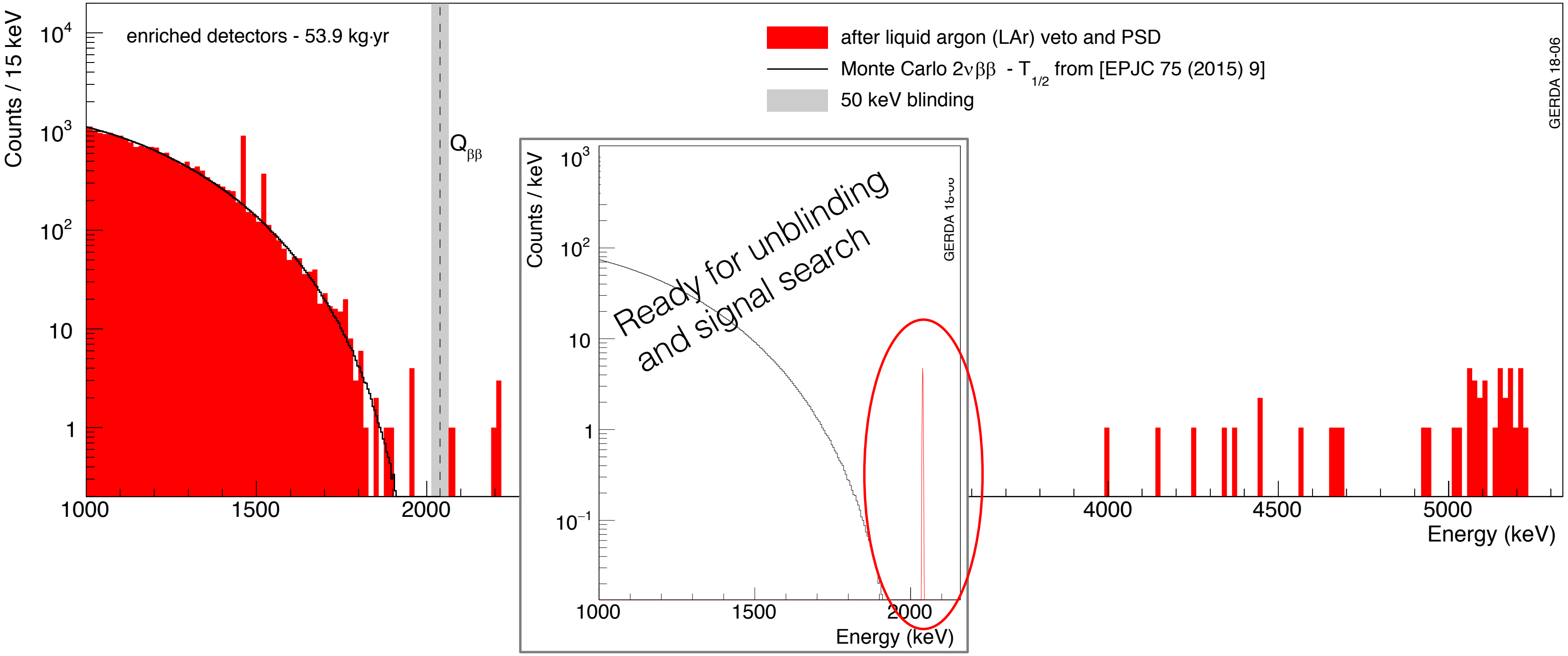
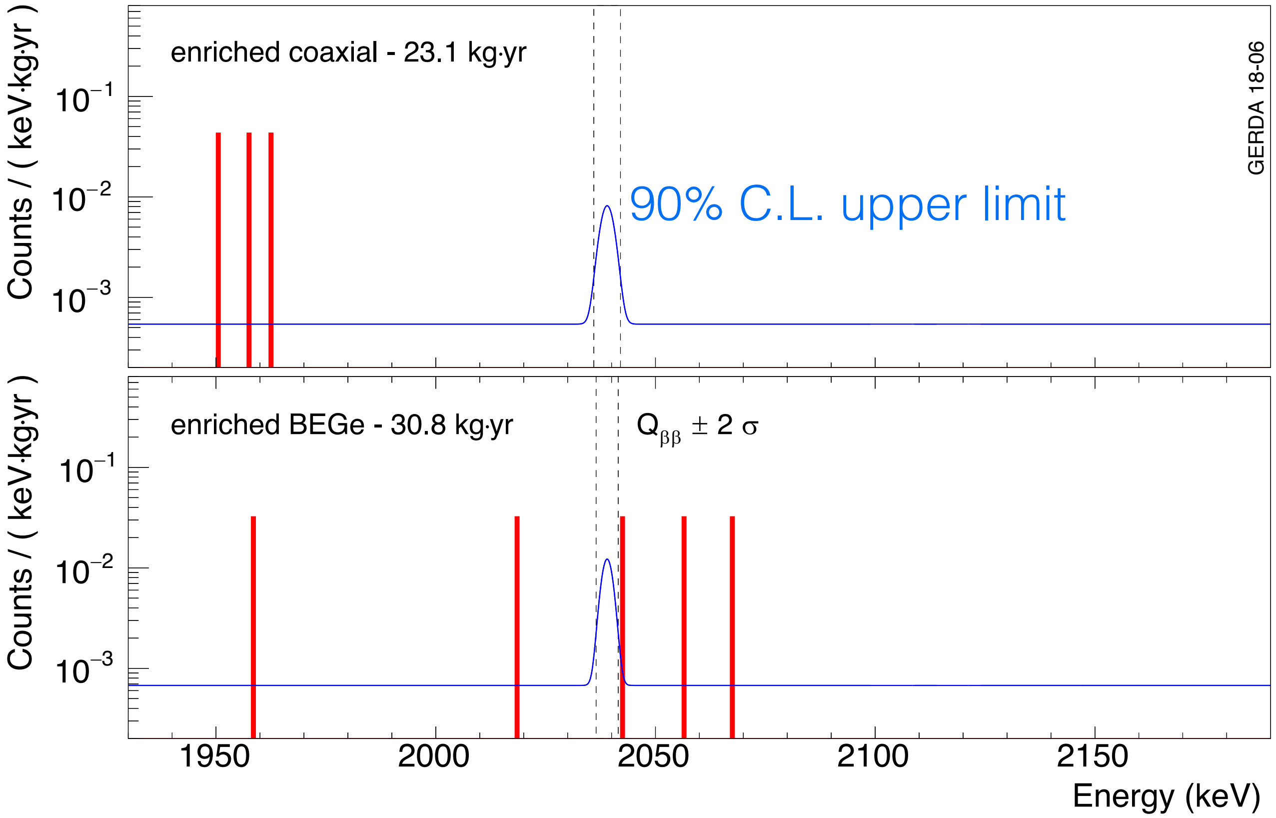


Fit to full GERDA data sets



<u>Frequentist:</u>
Best fit $N^{0\nu} = 0$
$T^{0\nu}_{1/2} > 0.9 \cdot 10^{26}$ yr (90% C.L.)
Median sensitivity (NO Signal)
$T^{0\nu}_{1/2} > 1.1 \cdot 10^{26}$ yr (90% C.L.)
63% of MC realizations yield limit stronger than data

$m_{\beta\beta} < 0.11 – 0.25$ eV,
with NME: 2.8–6.1, g_A=1.27

<u>Bayesian:</u>
$T^{0\nu}_{1/2} > 0.8 \cdot 10^{26}$ yr (90% C.I.)
Median sensitivity:
$T^{0\nu}_{1/2} > 0.8 \cdot 10^{26}$ yr (90% C.I.)
59% of MC realizations yield limit stronger than data

<u>Bayes factor</u>: P(H1)/P(H0) = 0.054
where:
H1:signal+background hypothesis
H0: background only hypothesis

Science, 05 September 2019

LEGEND: the collaboration

Univ. New Mexico
L'Aquila Univ. and INFN
Gran Sasso Science Inst.
Lab. Naz. Gran Sasso
Univ. Texas
Tsinghua Univ.
Lawrence Berkeley Natl. Lab.
Leibniz Inst. Crystal Growth
Comenius Univ.
Lab. Naz. Sud
Univ. of North Carolina
Sichuan Univ.
Univ. of South Carolina
Jagiellonian Univ.
Banaras Hindu Univ.
Univ. of Dortmund
Tech. Univ. – Dresden
Joint Inst. Nucl. Res. Inst.
Nucl. Res. Russian Acad. Sci.
Joint Res. Centre, Geel

Chalmers Univ. Tech.
Max Planck Inst., Heidelberg
Dokuz Eylul Univ
Queens Univ.

Univ. Tennessee
Argonne Natl. lab.
Univ. Liverpool
Univ. College London

Los Alamos Natl. Lab.
Lund Univ.
INFN Milano Bicocca
Milano Univ. and Milano INFN
Natl. Res. Center Kurchatov Inst.
Lab. for Exper. Nucl. Phy. MEPhI
Max Planck Inst., Munich
Technical Univ. Munich
Oak Ridge Natl. Lab.
Padova Univ. and Padova INFN
Czech Tech. Univ. Prague
Princeton Univ.
North Carolina State Univ.
South Dakota School Mines Tech.
Univ. Washington
Academia Sinica
Univ. Tuebingen
Univ. South Dakota
Univ. Zurich

LEGEND

Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

Foundations: GERDA & MAJORANA

GERDA

Bare ^{enr}Ge detectors immersed in instrumented LAr shield

MAJORANA DEMONSTRATOR

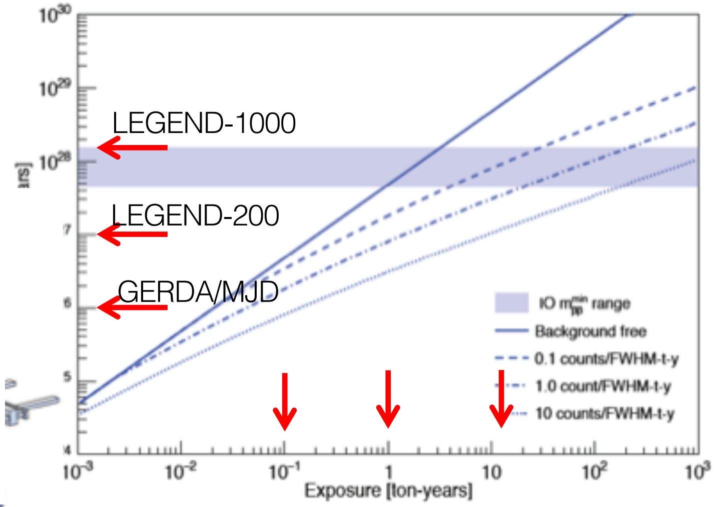
^{enr}Ge detectors operated in vacuum cryostats in a passive graded shield with ultra-clean copper

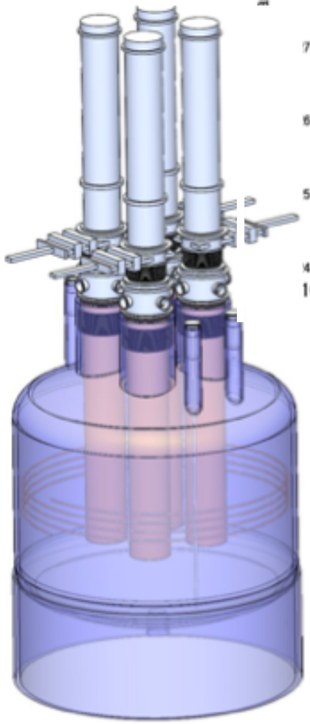
The LEGEND program

Large Enriched Germanium Experiment for Neutrinoless ββ Decay

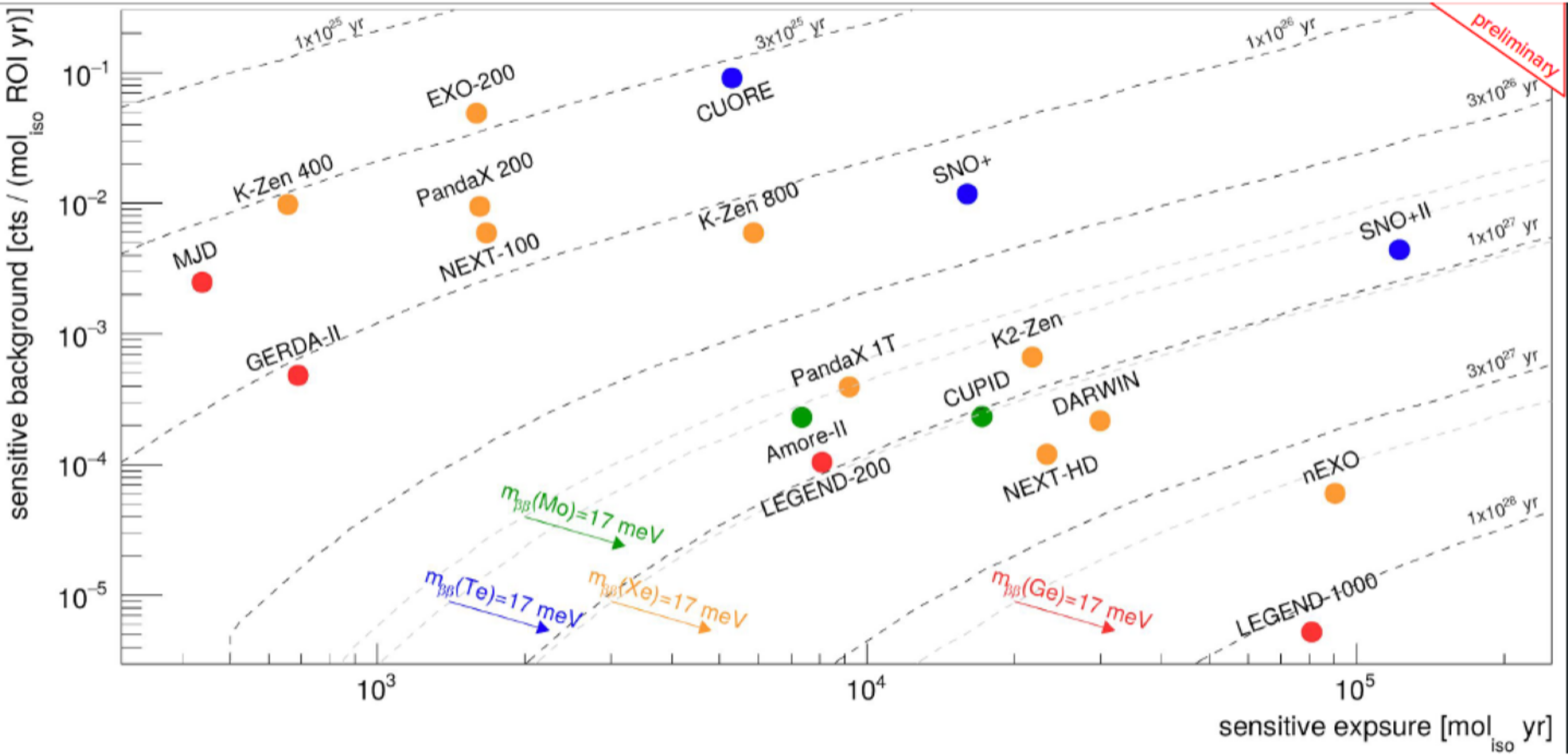
LEGEND-200 (first phase):
- up to 200 kg of detectors
- BI ~0.6 cts/(FWHM t yr)
- use existing GERDA infrastructure at LNGS
- design exposure: 1 t yr
- Sensitivity 10^{27} yr
- Isotope procurement ongoing
- Start in 2021

Sensitivity for 3σ signal **discovery**



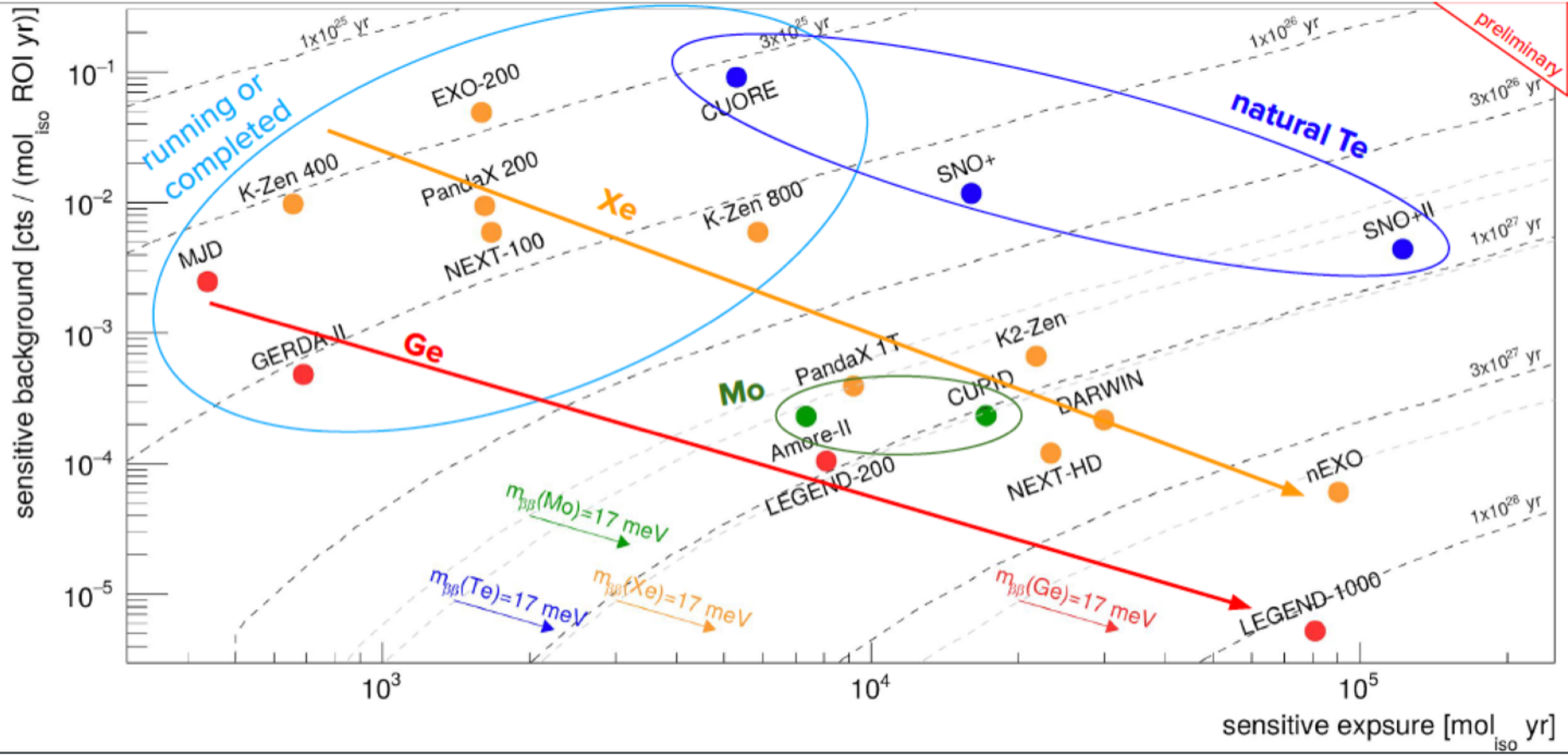


LEGEND-1000 (second phase):
- 1000 kg of detectors (deployed in stages)
- BI <0.1 cts/(FWHM t yr)
- Location tbd
- Design exposure 12 t yr
- 1.2×10^{28} yr



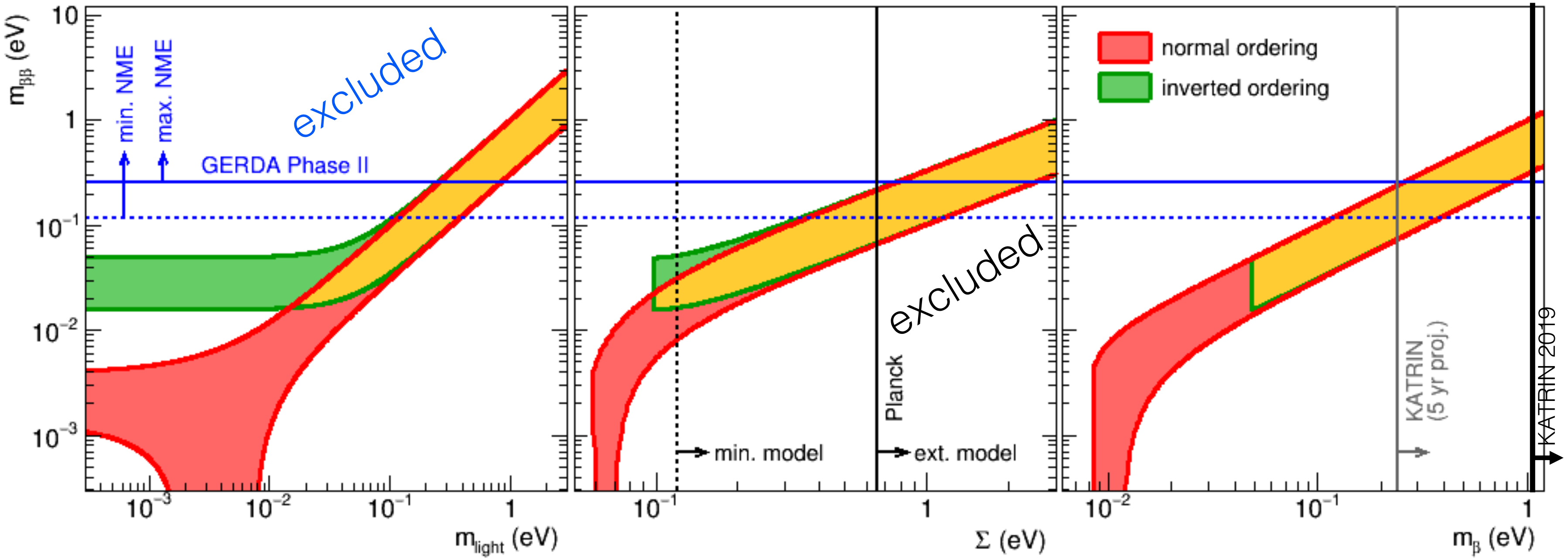
Stefan Schönert, UK HEP Forum 2019

M. Agostini (TU Munich), Taup 2019



M. Agostini (TU Munich), Taup 2019

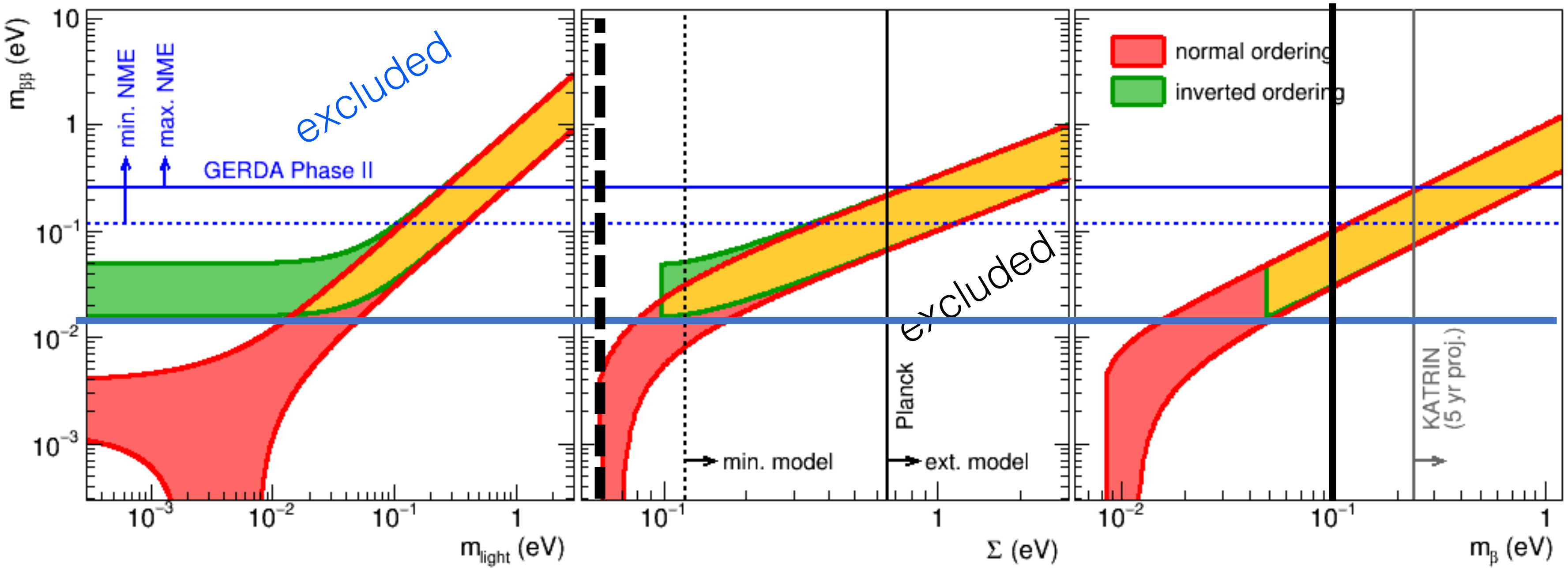
Current sensitivities probe quasi-degenerate mass spectrum



$0\nu\beta\beta$ cosmology tritium beta decay

Science, 05 September 2019

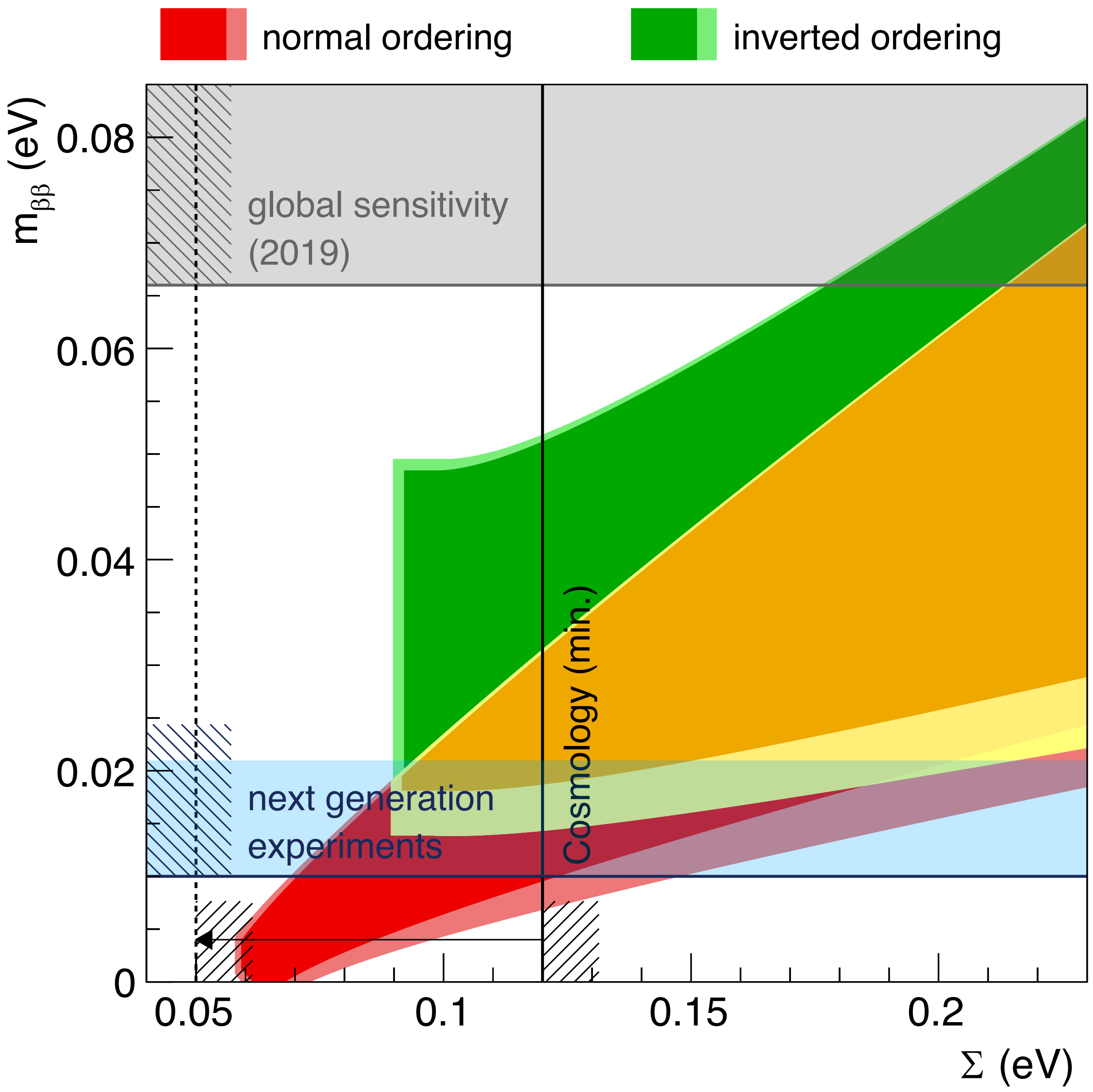
Next decade: large phase space for discoveries

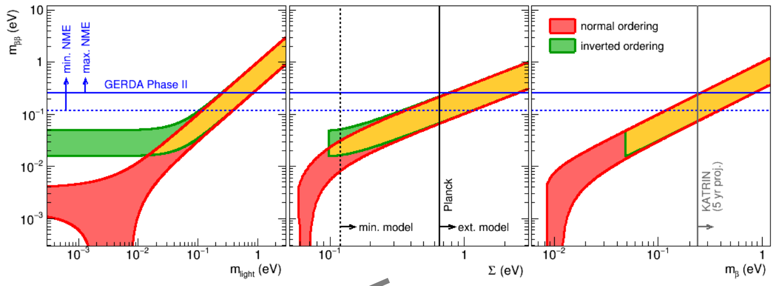


$0\nu\beta\beta$ cosmology tritium beta decay

Science, 05 September 2019

Next decade: large phase space for discoveries





Linear projection

Summary & Outlook

- $0\nu\beta\beta$ experiments, cosmology (now) and KATRIN (soon) are probing **quasi-degenerate ν-masses**
- SB reactor (now) and accelerator (soon) experiments will clarify **eV-scale sterile** ν conjecture
- Quasi-degenerate mass scale and/or sterile eV-ν's would require **extensions to ΛCDM**
- Upcoming cosmology observations has potential to **measure Σ** given the measured mass splitting from ν–oscillation experiments
- Strong activities world-wide for preparation of **ton-scale** $0\nu\beta\beta$ experiments (x100 improvement in $T_{1/2}$)
- Large **discovery potential** from direct ν-mass, $0\nu\beta\beta$ and cosmology during next decade
- **Null results** (laboratory) would be less exciting, but not less relevant!
- Laboratory experiments and cosmology **highly synergetic** (not only) on ν-mass search

APPEC Community Meeting on Neutrinoless Double Beta Decay

31 October 2019
Hallam Conference Centre, London, UK
Europe/London timezone

Search...

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Sponsors
- Venue Information

This meeting aims at discussing and collecting the input of the community on the roadmap document (to follow) prepared by the Double Beta Decay APPEC Committee for the APPEC SAC on the future neutrinoless double beta decay experimental programme in Europe. The ultimate goal is to maintain a leading role in this scientifically important quest, in line with APPEC Roadmap recommendations (https://www.appec.org/wp-content/uploads/Documents/Current-docs/APPEC-Strategy-Book-Proof-19-Feb-2018.pdf). We will assess the existing, planned and proposed technologies, their discovery potential and technical challenges, making a critical examination of resources and schedules. We will also review the theoretical issues and the status and uncertainties on the nuclear matrix element evaluation.

Starts 31 Oct 2019, 10:00
Ends 31 Oct 2019, 17:00
Europe/London

Hallam Conference Centre, London, UK
44 Hallam Street, London W1W 6JJ, UK

Silvia Pascoli

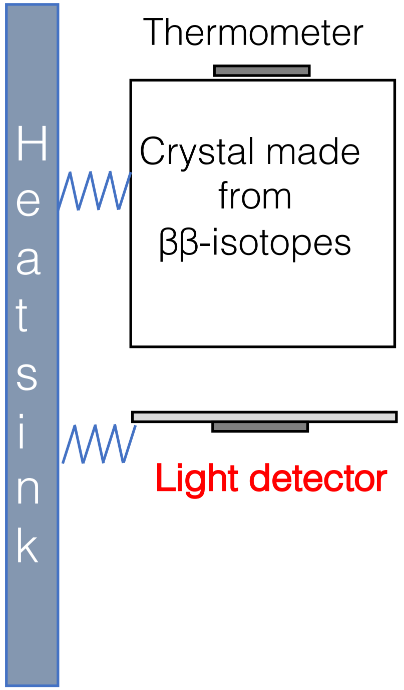
Double Beta Decay APPEC Committee (DBDAC) members: Andrea Giuliani, J.J. Gomez Cadenas, Silvia Pascoli (chair), Ezio Previtali, Ruben Saakyan, Karoline Schaeffner and Stefan Schoenert.

Registration
Registration for this event is currently open.
Register now

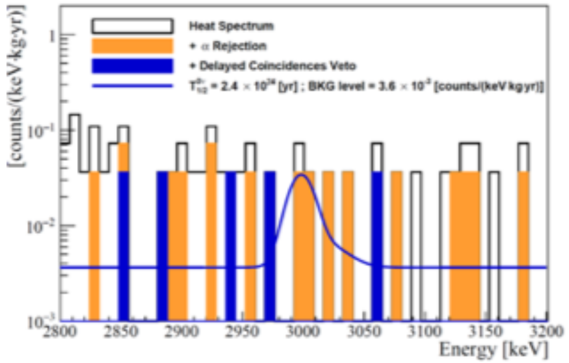
https://indico.cern.ch/event/832454/overview

Extra slides

Cryogenic Detectors: CUPID



CUPID-0: ZnSe
@ LNGS
5.2 kg ^{82}Se

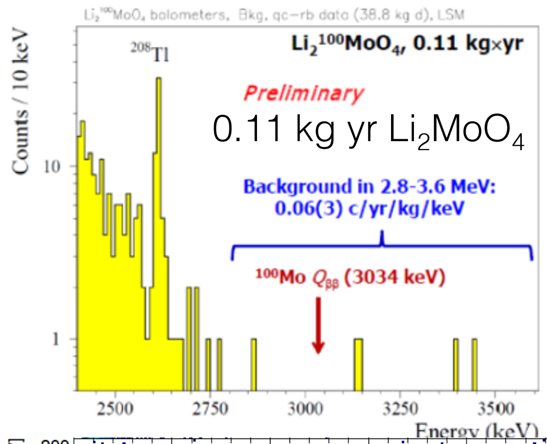


$T_{1/2}$> 2.4x10^{24} y
(90%C.I.)

BI = 3.6x10^{-3}
cts/(keV kg y)

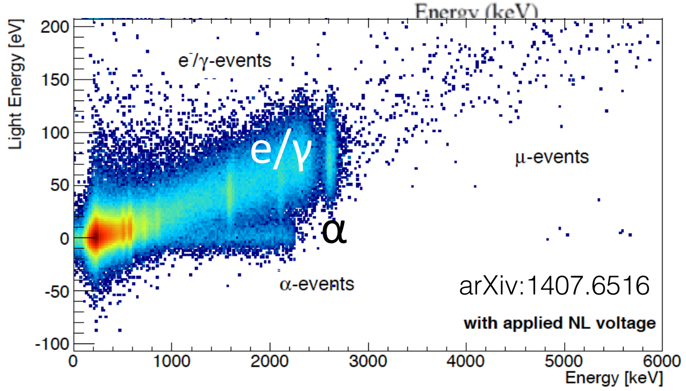
S. Pirro, NDM2018

CUPID-Mo: Li_2MoO_4
(ex Lumineu)
Demonstrator @ LSM
2.34 kg ^{100}Mo, 2018

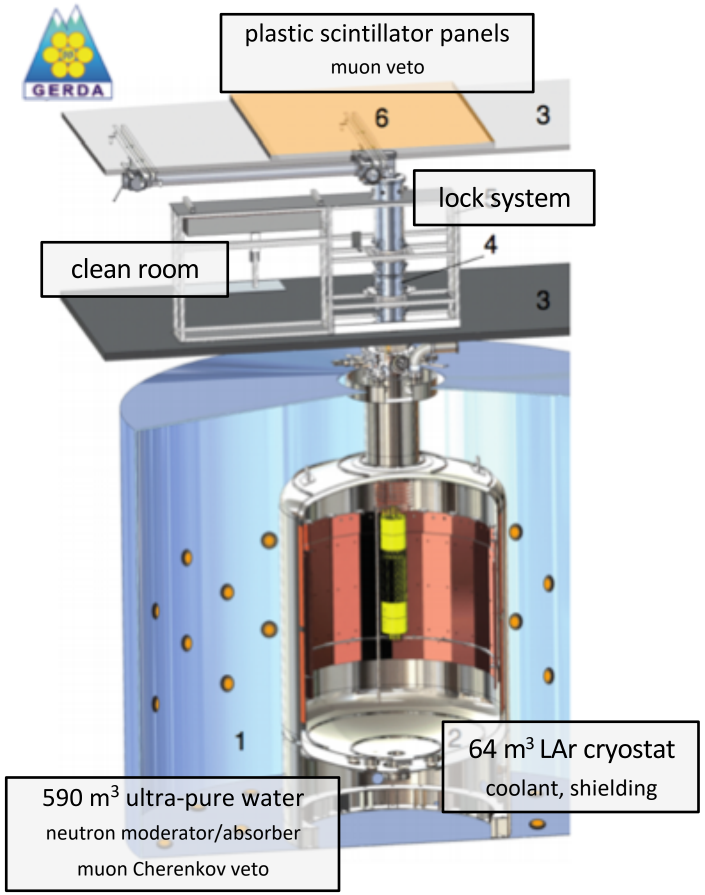


Courtesy
A. Giuliani

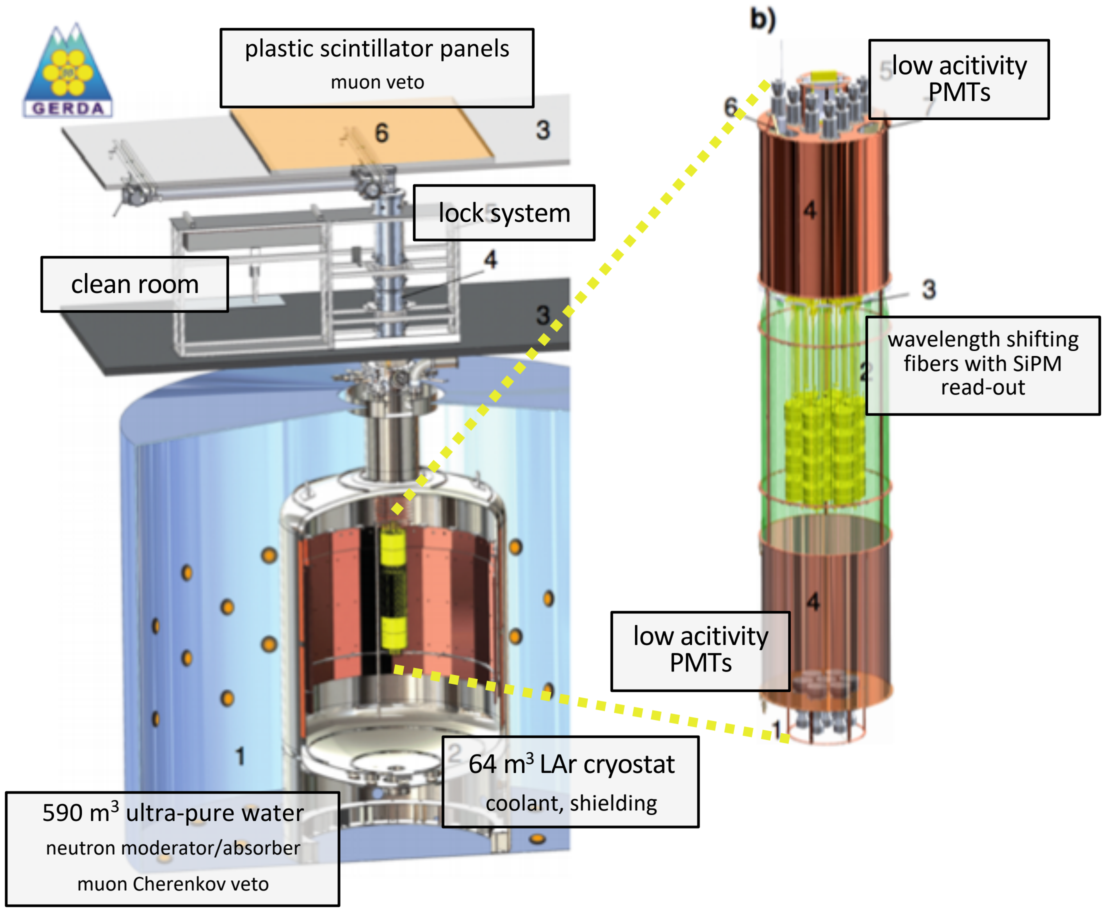
CUPID-Te:TeO_2
(with Cherenkov)
Demonstrator @ LNGS



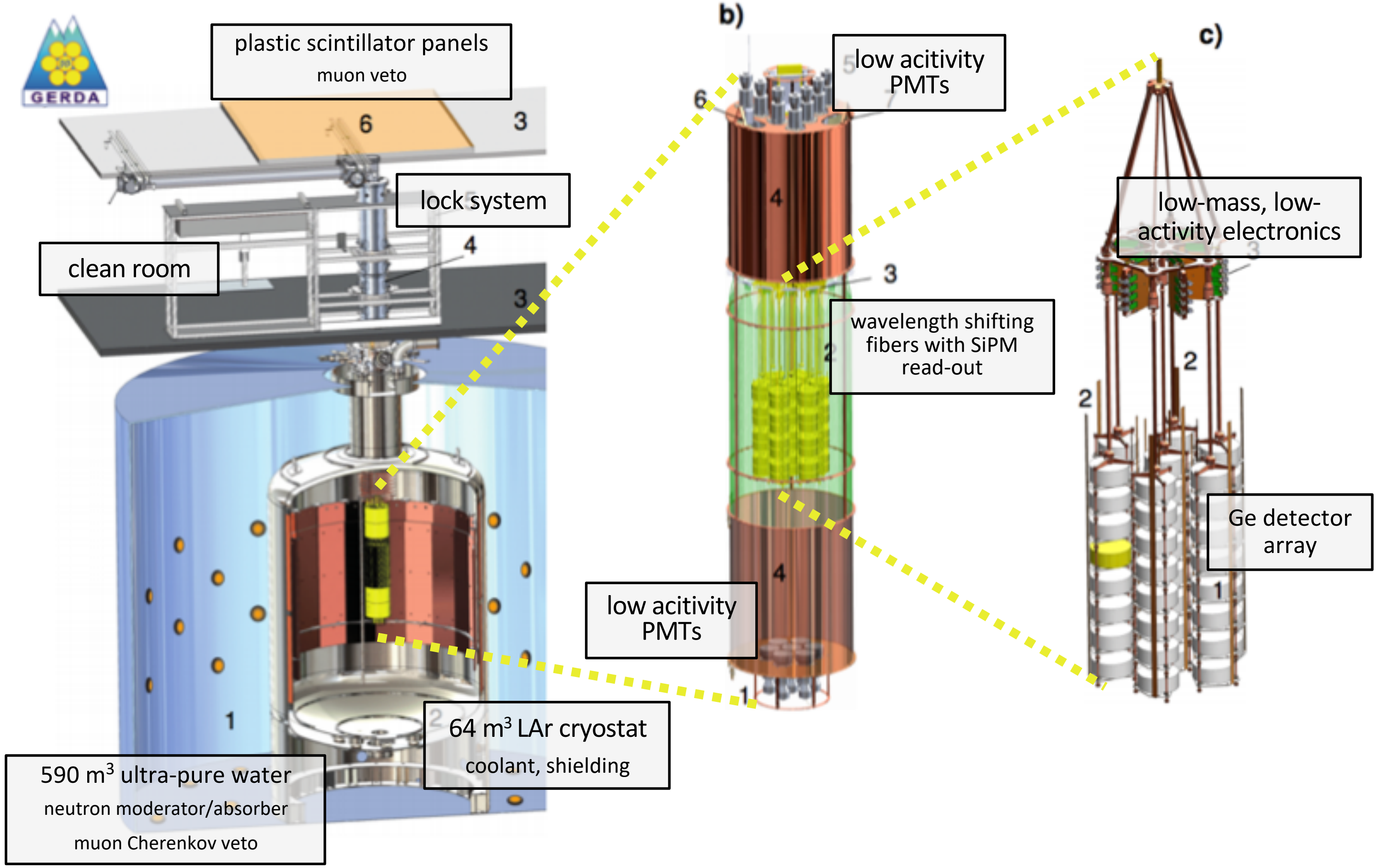
GERDA experimental setup at LNGS



a) overview



a) overview **veto**
b) liquid argon (LAr) **instrumentation**



a) overview

b) liquid argon (LAr) veto

instrumentation

c) detector array