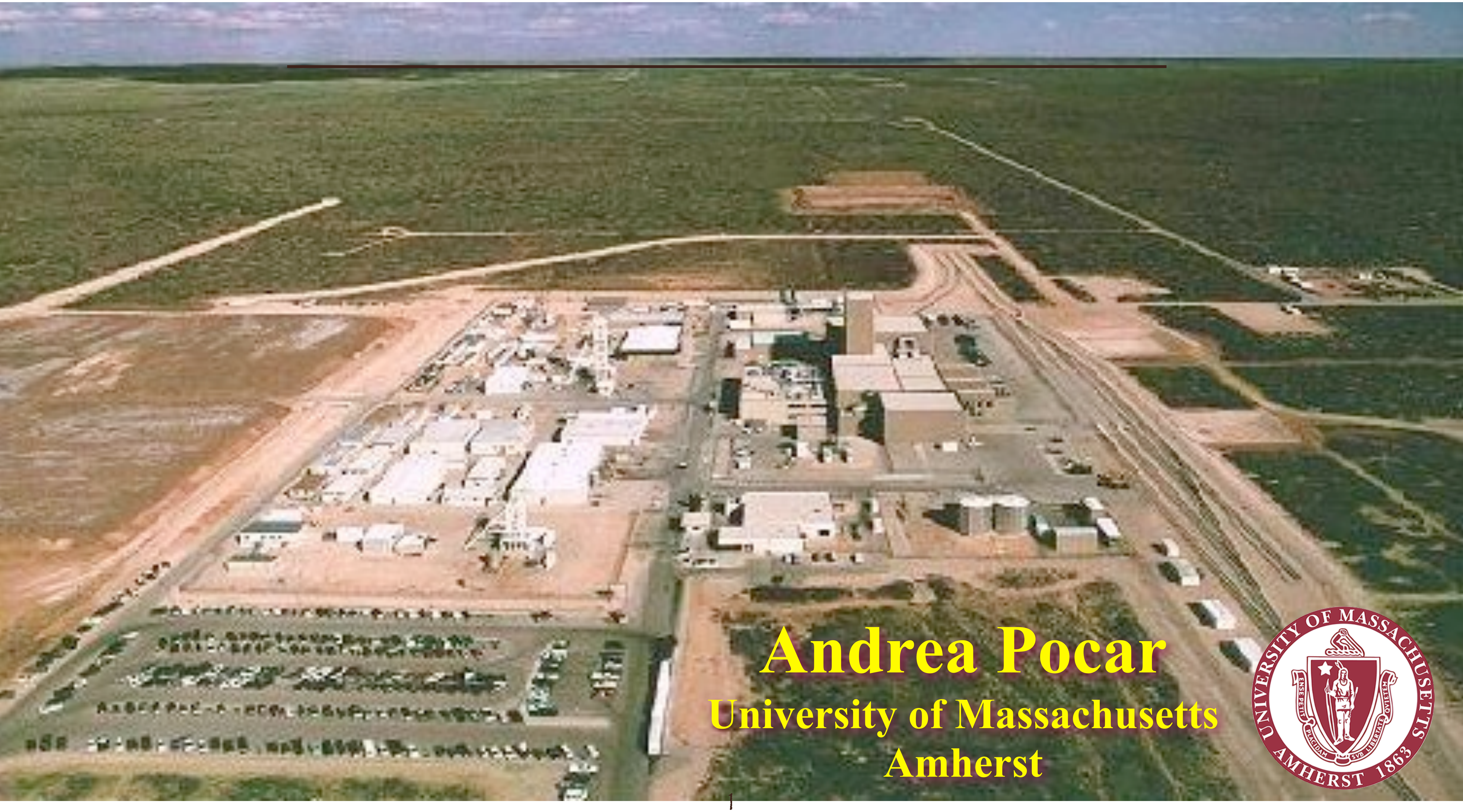
Enriched Xenon Observatory
for double beta decay

First data from the EXO-200 double beta decay experiment



Andrea Pocar
University of Massachusetts
Amherst

1. ***what & why***

   - ββ decay: 2ν and 0ν modes
   - link to new physics

2. ***how***

   - the EXO-200 detector
   - operations, calibrations, data analysis

3. ***results***

   - 2ν ββ measured by EXO-200
   - comparison with other measurements

4. ***what next?***

   - the EXO-200 program
   - (EXO plans beyond EXO-200)

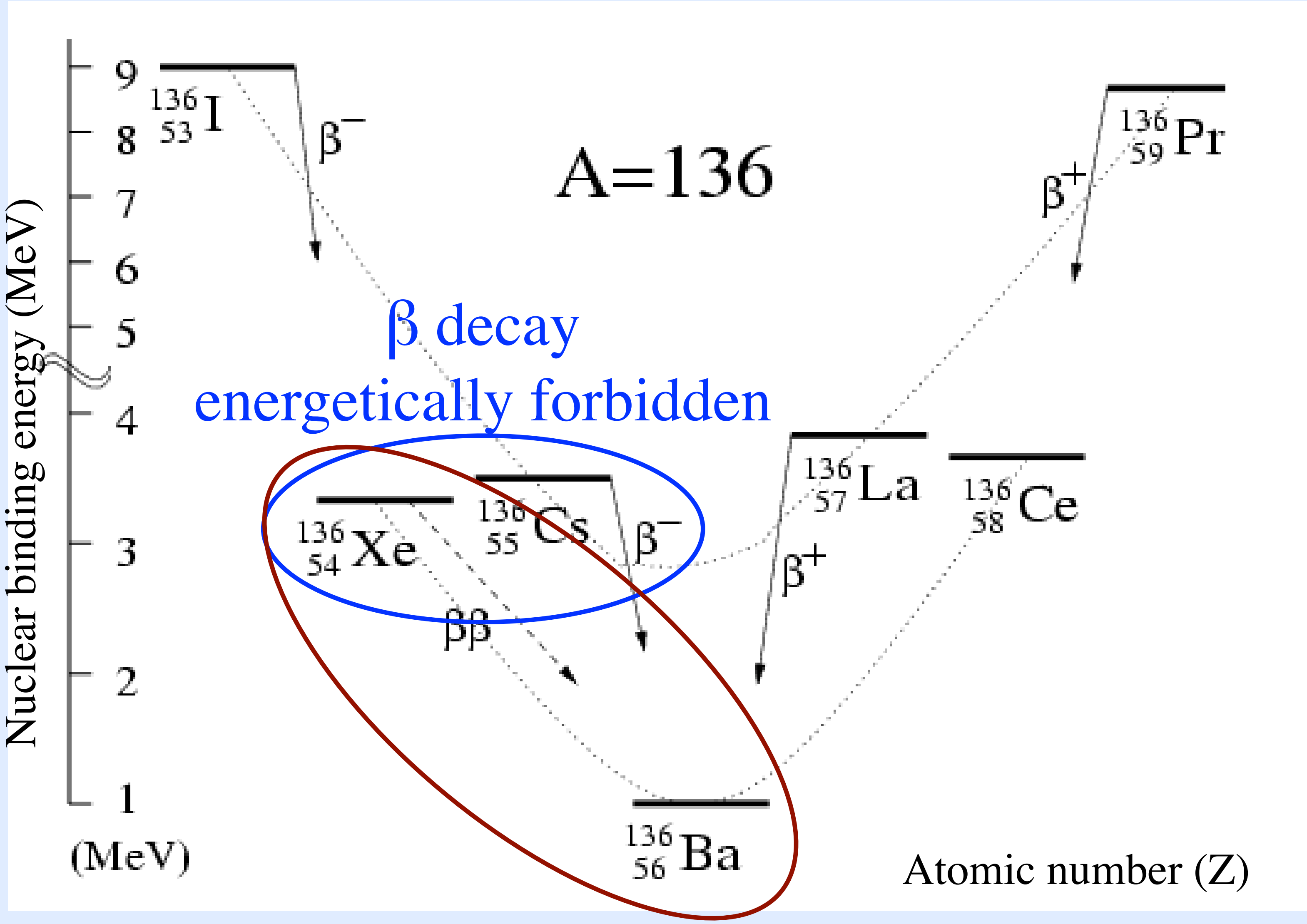
the back cover

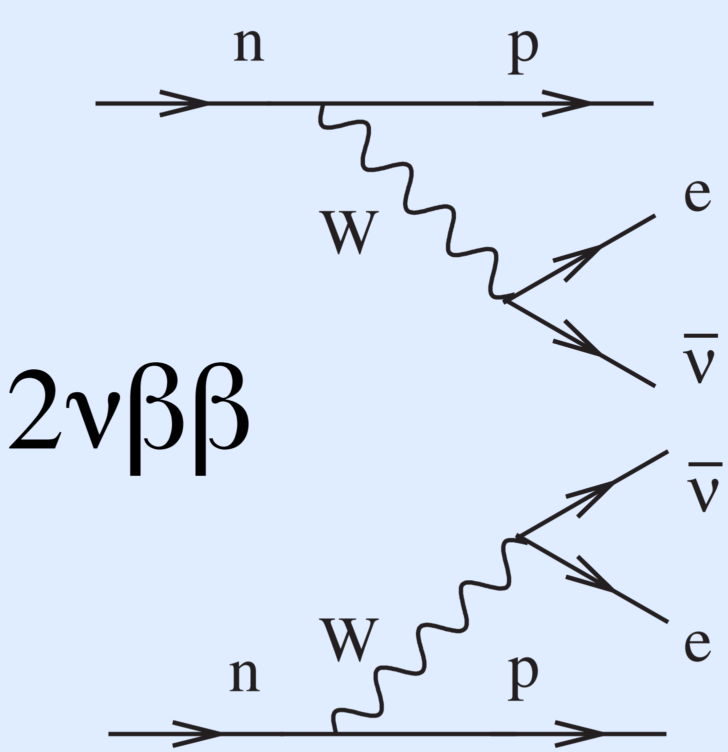
“ two nu’s is good news but no nu’s would be even better! ”

- Roger Blandford (Stanford University) -

double beta decay

- second order weak process (even-even nuclei)
- predicted in 1935 by Göppert-Meyer after Wigner's suggestion (~10^{17} years!)





possibility of non-standard 0νββ process

why study 0νββ decay?

its observation is associated with the discovery of:

- lepton number violation
- Majorana particles (neutrinos)

[Schechter and Valle, Phys. Rev. D 25 (1982) 2951]

and enables us to:

- measure the absolute mass scale of neutrinos
- define the mass ordering of neutrinos
- shed light on the matter/antimatter asymmetry (leptogenesis, ...)
- maybe

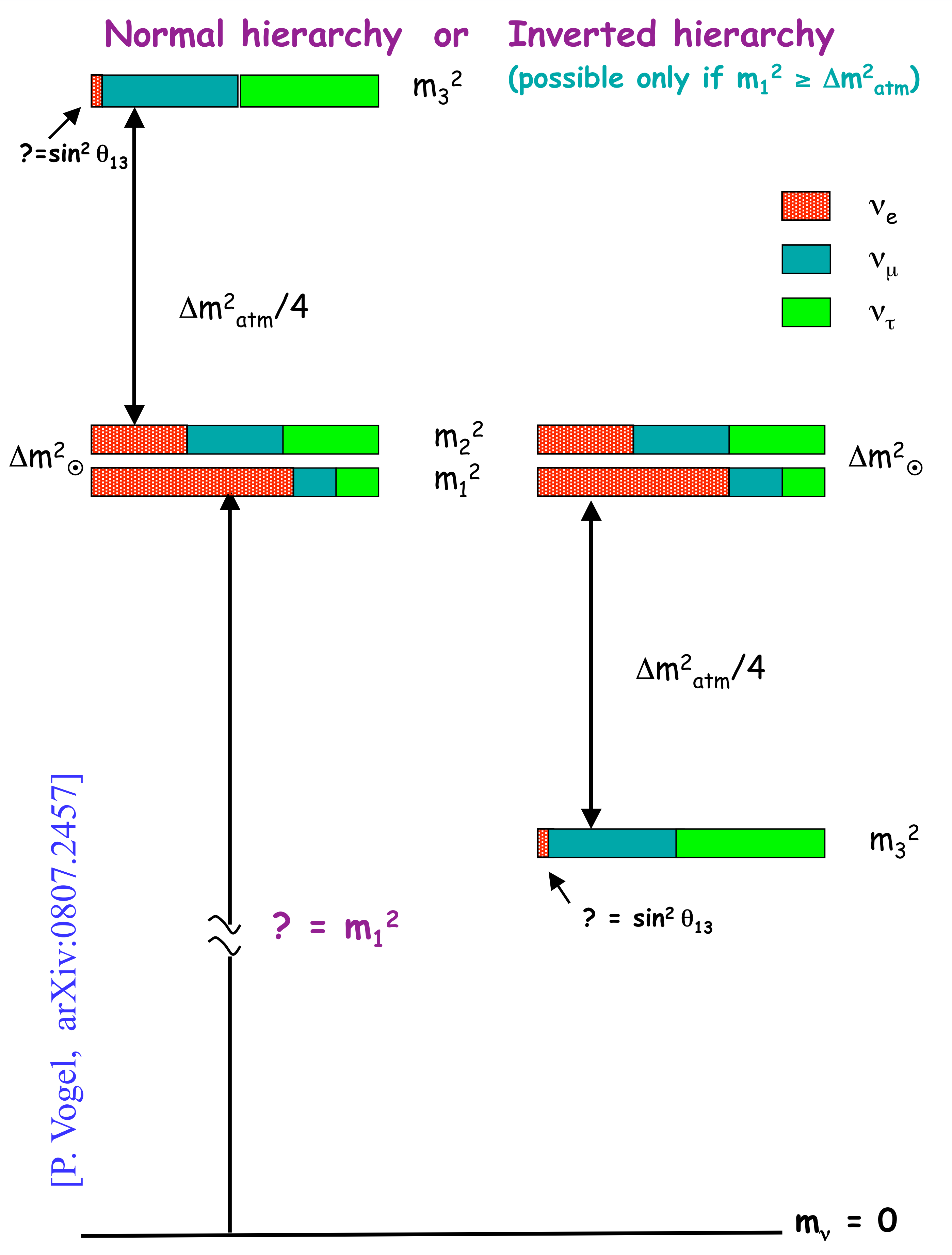
neutrino masses

from oscillation experiments:

- solar neutrinos + KamLAND (LMA-MSW): $\Delta m^2_{12} \sim 8\times10^{-5}$ eV^2, $\tan^2\theta_{12} \sim 0.4$
- atmospheric neutrinos + K2K/MINOS: $\Delta m^2_{23} \sim 3\times10^{-3}$ eV^2, $\sin^2 2\theta_{23} > 0.9$
- Chooz / Palo Verde: $\sin^2 2\theta_{13} < 0.2$

- only mass differences are measured

- at least one neutrino has a mass of ~50 meV



[P. Vogel, arXiv:0807.2457]

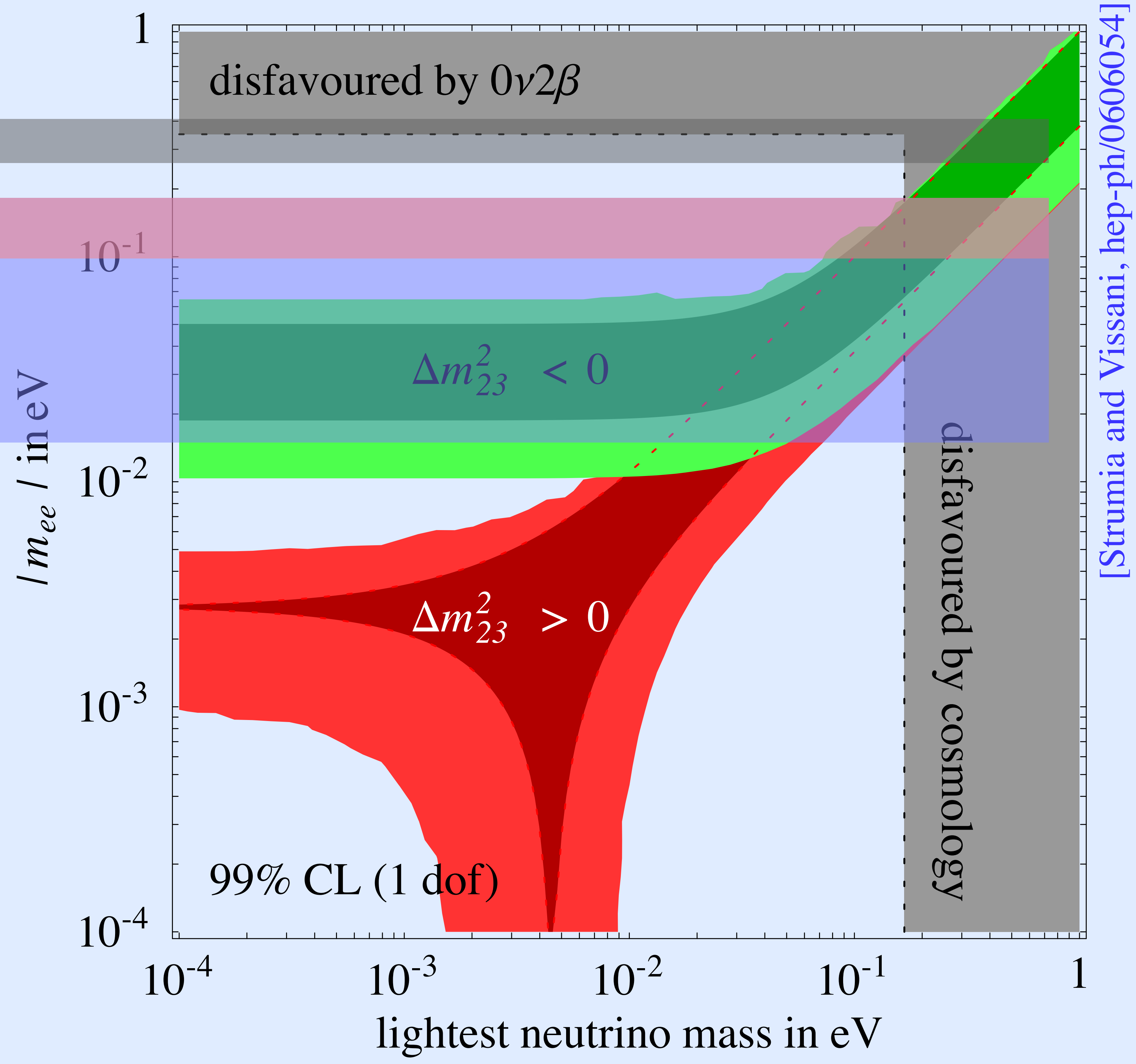
$0\nu\beta\beta$ and neutrino masses

[PLB 586(2004)198]

Klapdor et al.

EXO-200 (~100 meV)

current projects



[Strumia and Vissani, hep-ph/0606054]

m_{eff} ~ 50 meV: ~ 10^{27} years

(10^{27} nuclei ~ 10^3 moles ~ 100 kg)

measured quantity: half life (rate)

$$[T^{2\nu}_{1/2}]^{-1} = G_{2\nu}(Q_{\beta\beta}, Z)\left| M^{\mathrm{GT}}_{2\nu} - \frac{g_V^2}{g_A^2} M^F_{2\nu} \right|^2$$

directly measured quantity

calculable phase space factors

nuclear matrix elements
(calculated within particular nuclear models)

$$\frac{1}{T^{0\nu}_{1/2}} = G_{0\nu}(Q, Z)|M_{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$

Majorana neutrino mass
(can be zero !!)

$$\langle m_{\beta\beta} \rangle^2 = \left| \sum_i^N |U_{ei}|^2 e^{i\alpha_i} m_i \right|^2 \quad (\text{all } m_i \geqslant 0)$$

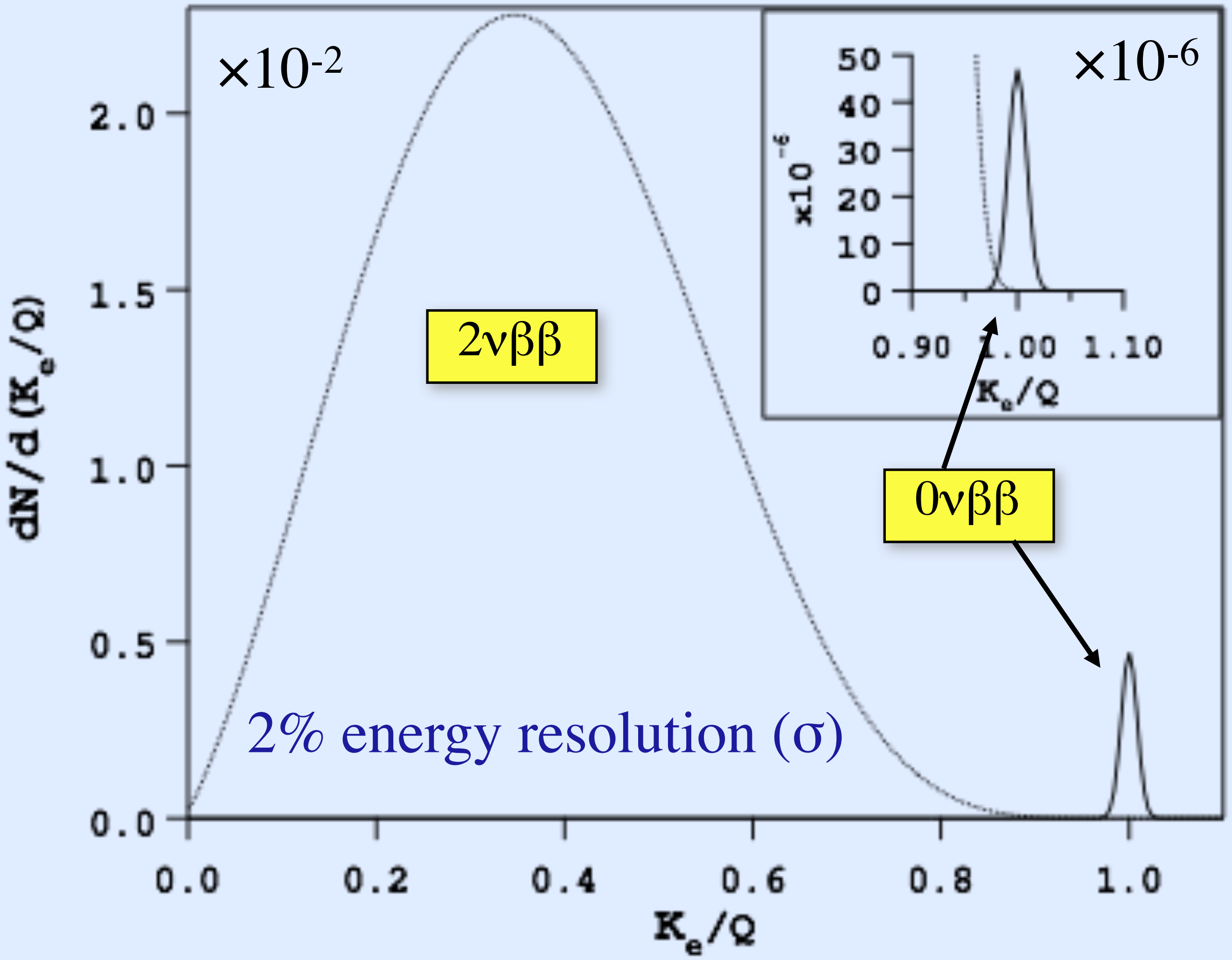
Nuclear physics is needed to connect different isotopes

how is 0νββ measured in the laboratory?

- very rare events: need to suppress non-ββ background with low radioactivity detectors (γ's in particular)

- large mass: large source, isotope enrichment

- energy resolution: separate 0νββ mono-energetic peak in the 2-electron energy spectrum and fewer non-ββ background events in the peak



2% energy resolution (σ)

[P. Vogel, arXiv:hep-ph/0611243]

- tracking: identify individual electron tracks to discriminate between single- and 2-electron events (discrimination of β and γ background radiation)

- multi-isotope: measure different isotopes with the same detector to cross-check results and reduce systematic and theoretical uncertainties

- decay product identification: unambiguously from ββ events

why xenon for EXO?

✓ known purification technology

✓ can be re-purified and transferred between detectors

✓ simplest enrichment (proven at the 100’s kg scale)

✓ scalable technology (dark matter experiments help!)

✓ source = detector, high detection efficiency

✓ allows for particle ID (α/β, single/multiple cluster)

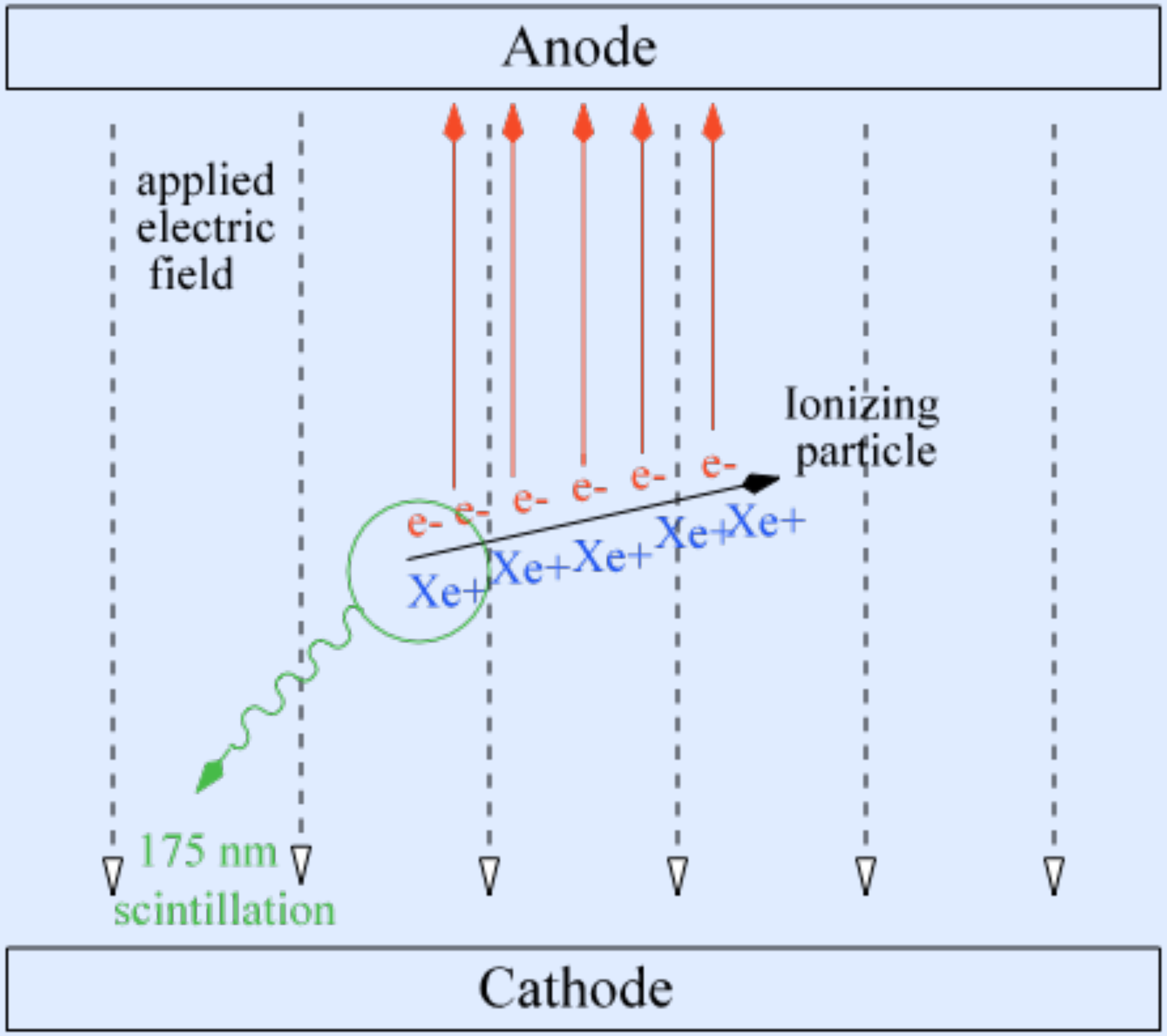
✓ standard $2\nu\beta\beta$ (just observed!) is very slow

($T^{0\nu}_{1/2} = 2.11 \times 10^{21}$ y) [Ackerman et al., PRL 107, 212501 (2011); arXiv:1108.4193]

✳ energy resolution: GXe > LXe > scintillator

LXe TPC design

dual readout of ionization and scintillation for position and energy measurement



Ionizing radiation interacting with liquid (or gaseous) xenon locally separates charge along it’s path

Electric field drifts some of it away
The rest recombines producing scintillation (175 nm), via Xe_2 dimer de-excitation

Event energy: ionization and scintillation light (used as t=0 for z)

Position of the event: crossed wires at the anode (x-y) and drift time (z)

✓excellent technology for rare, low energy events!

Anti-correlated ionization and scintillation improves the energy resolution in LXe

Ionization alone:

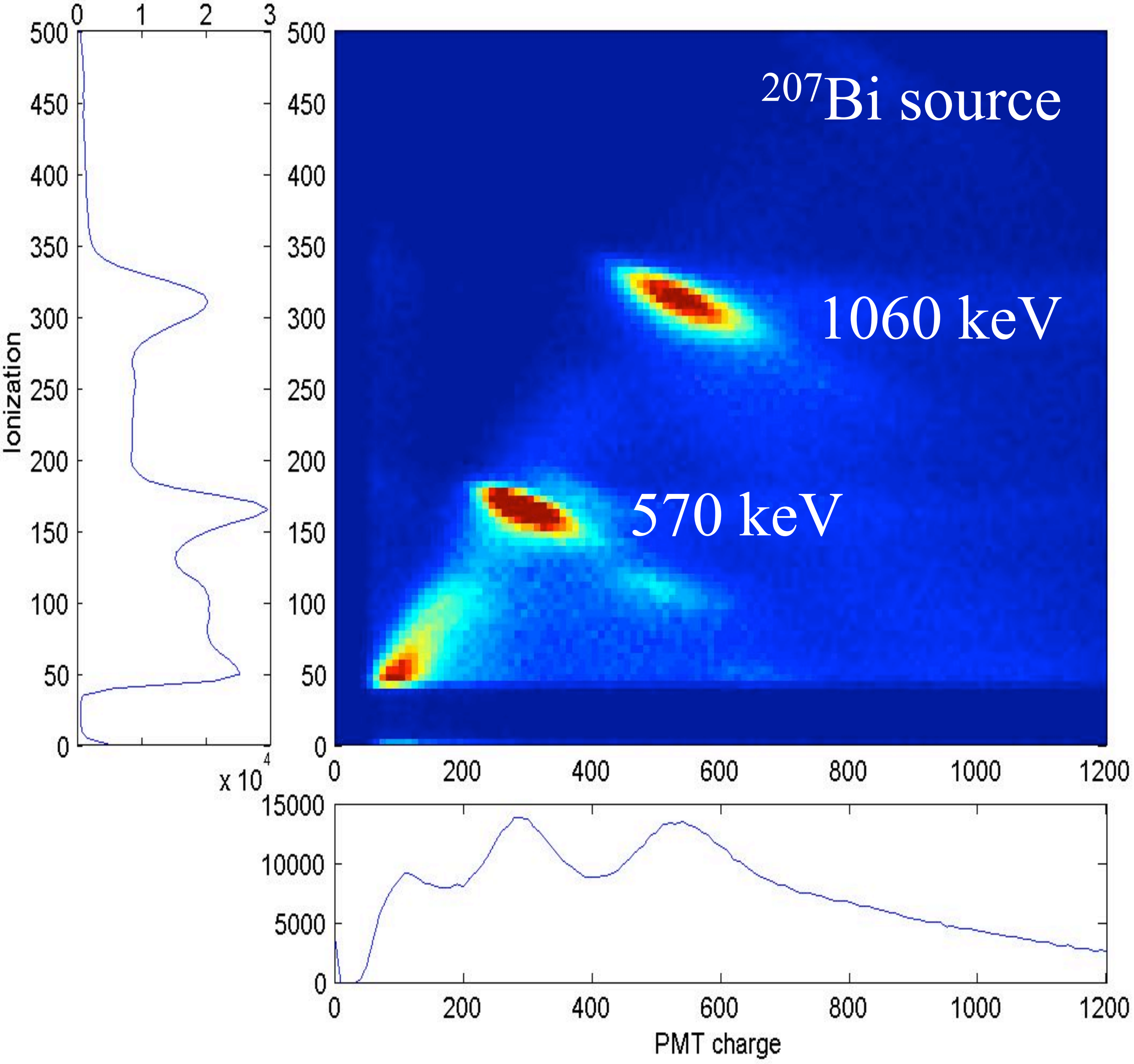
$\sigma(E)/E = 3.8\%$ @ 570 keV

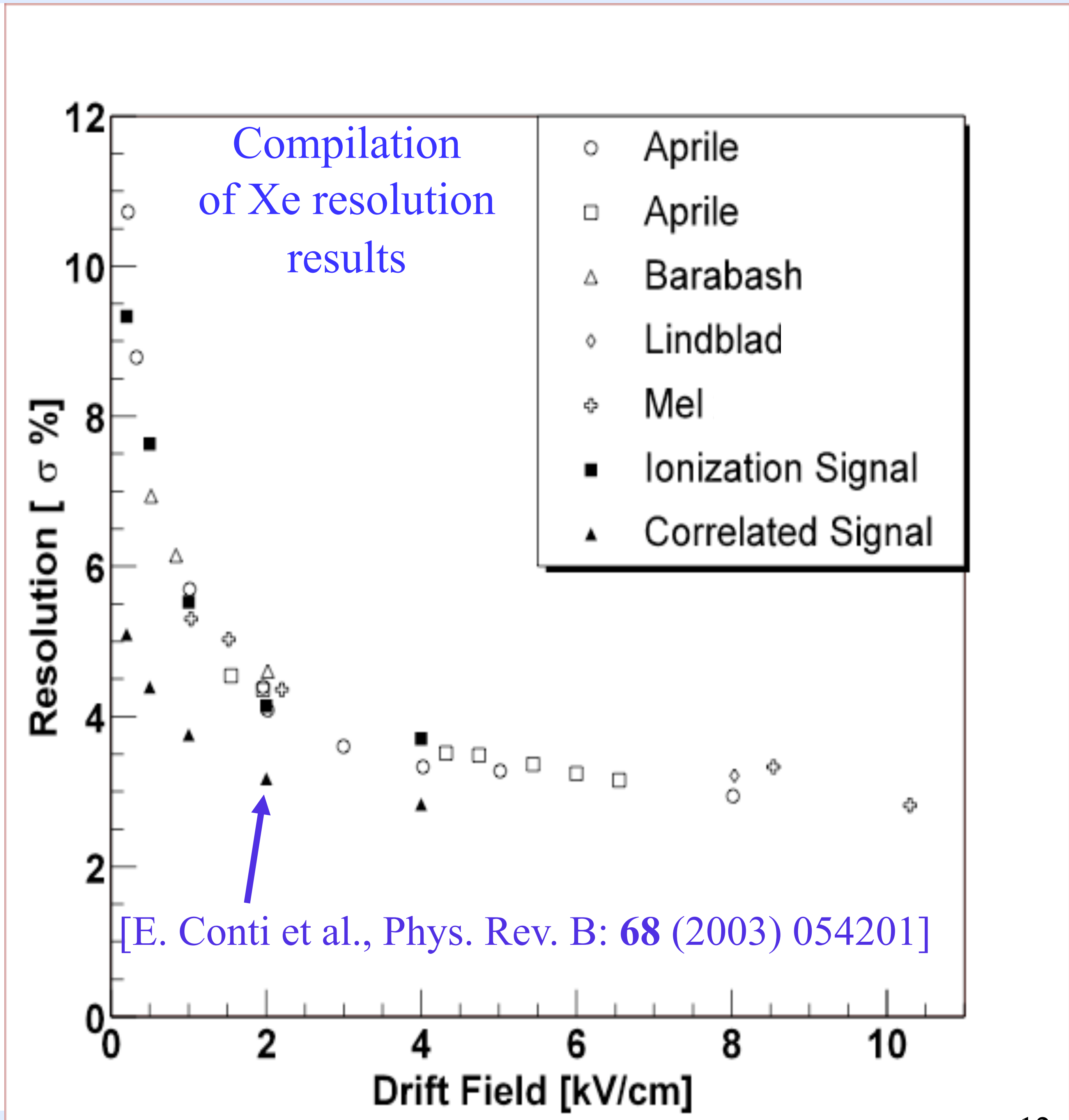
or 1.8% @ $Q_{\beta\beta}$

Ionization + Scintillation:

$\sigma(E)/E = 3.0\%$ @ 570 keV

or 1.4% @ $Q_{\beta\beta}$





Compilation of Xe resolution results

[E. Conti et al., Phys. Rev. B: **68** (2003) 054201]

the EXO program

"EXO is a program aimed at building a xenon double beta decay experiment with a one or more ton ^{136}Xe source, with the particular ability to detect the two electrons emitted in the decay in coincidence with the positive identification of the ^{136}Ba daughter via optical spectroscopy for unprecedentedly low background"

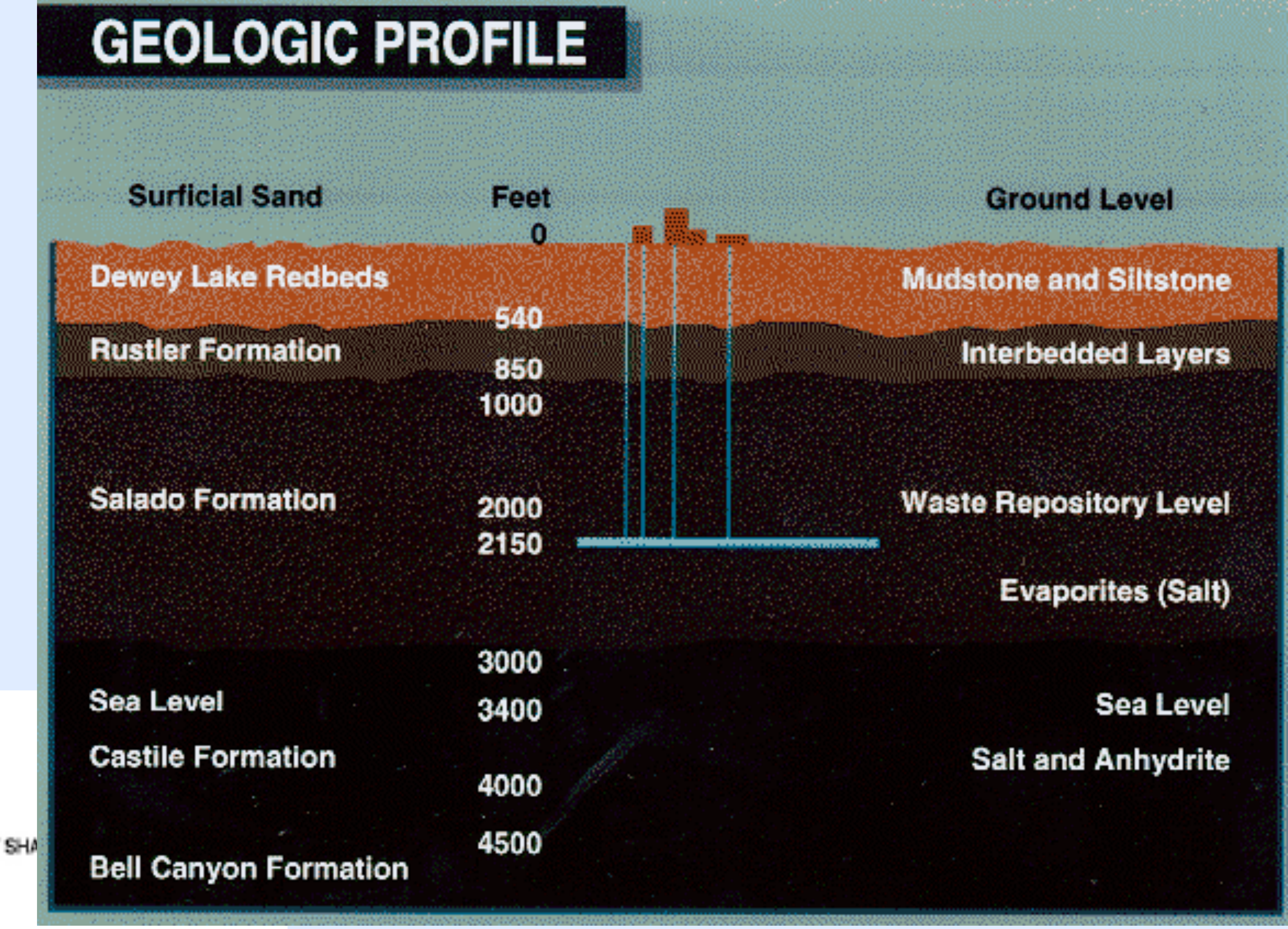
EXO-200

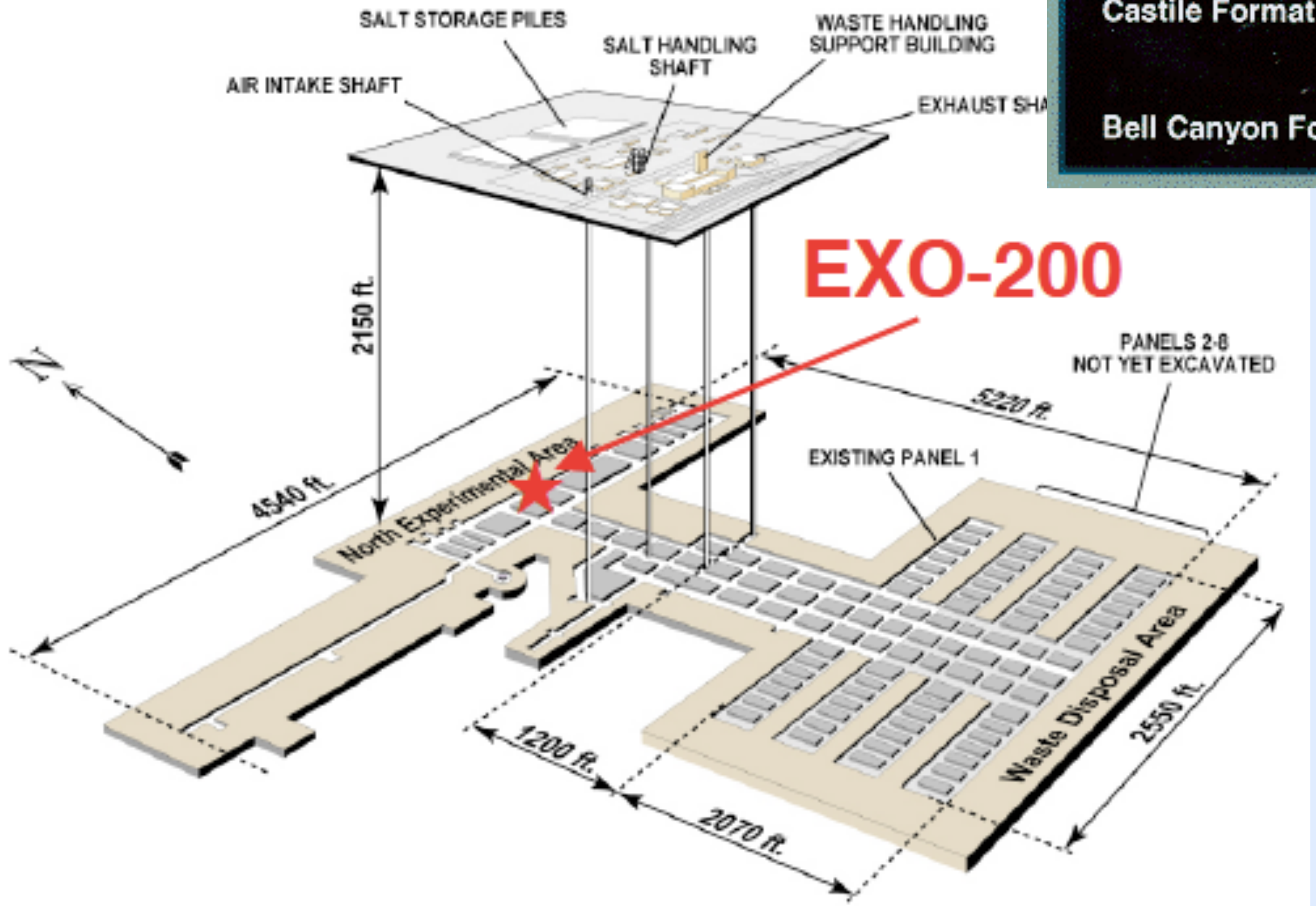
EXO-200 is a large single phase LXe TPC with scintillation light readout. It uses a source of 200 kg of enriched xenon (80% ^{136}Xe)

- measure the standard $2\nu\beta\beta$ decay of ^{136}Xe (done!) [Ackerman et al.., PRL 107, 212501 (2011); arXiv:1108.4193]
- look for $0\nu\beta\beta$ decay of ^{136}Xe with competitive sensitivity (current limit: $T^{0\nu}_{1/2} > 1.2 \times 10^{24}$ y) [R. Bernabei et al., Phys. Lett. B 546 (2002) 23]

- test backgrounds of large LXe detector at ~2000 m.w.e. depth
- test LXe technology and enrichment on a large scale
- test TPC components, light readout (~500 LAAPDs), and radioactivity of materials, xenon handling and purification, energy resolution

EXO-200 at WIPP



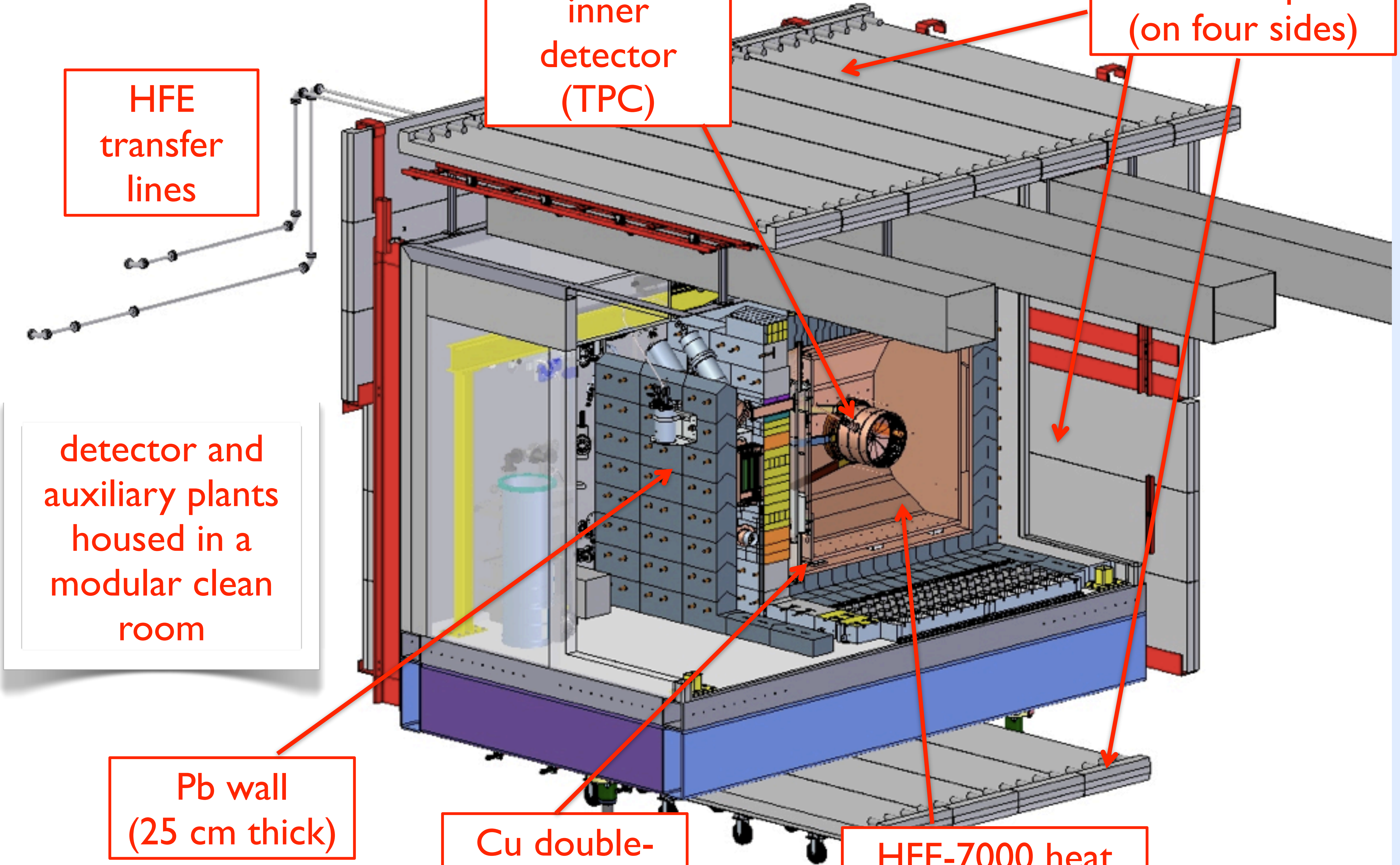


- ~1600 m.w.e. overburden (650 meters or rock + salt)

  [Esch et al., NIM A 538, 516 (2005)]

- <100 ppb U,Th
- ~20 Bq/m^3 radon

EXO-200



inner detector (TPC)

muon veto panels (on four sides)

HFE transfer lines

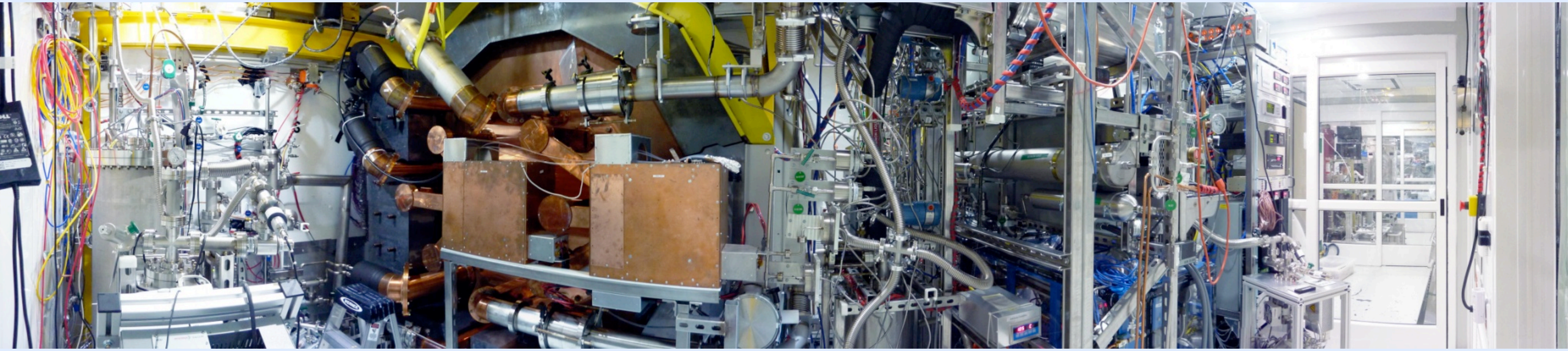
detector and auxiliary plants housed in a modular clean room

Pb wall (25 cm thick)

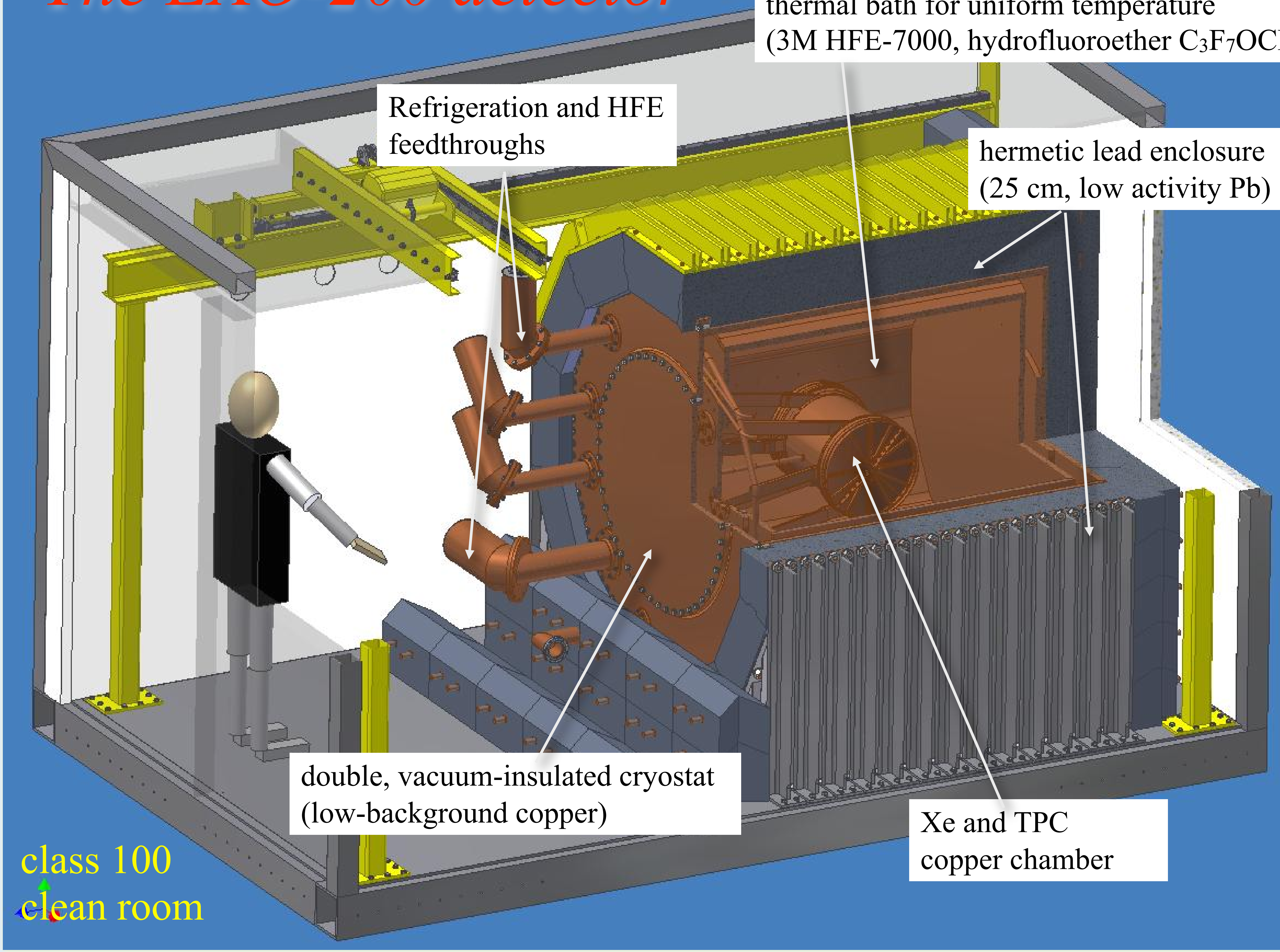
Cu double-walled cryostat

HFE-7000 heat transfer fluid (~3 tonnes)

EXO-200 @ WIPP



The EXO-200 detector



50 cm of ultra pure cryofluid, providing large thermal bath for uniform temperature (3M HFE-7000, hydrofluoroether $C_3F_7OCH_3$)

Refrigeration and HFE feedthroughs

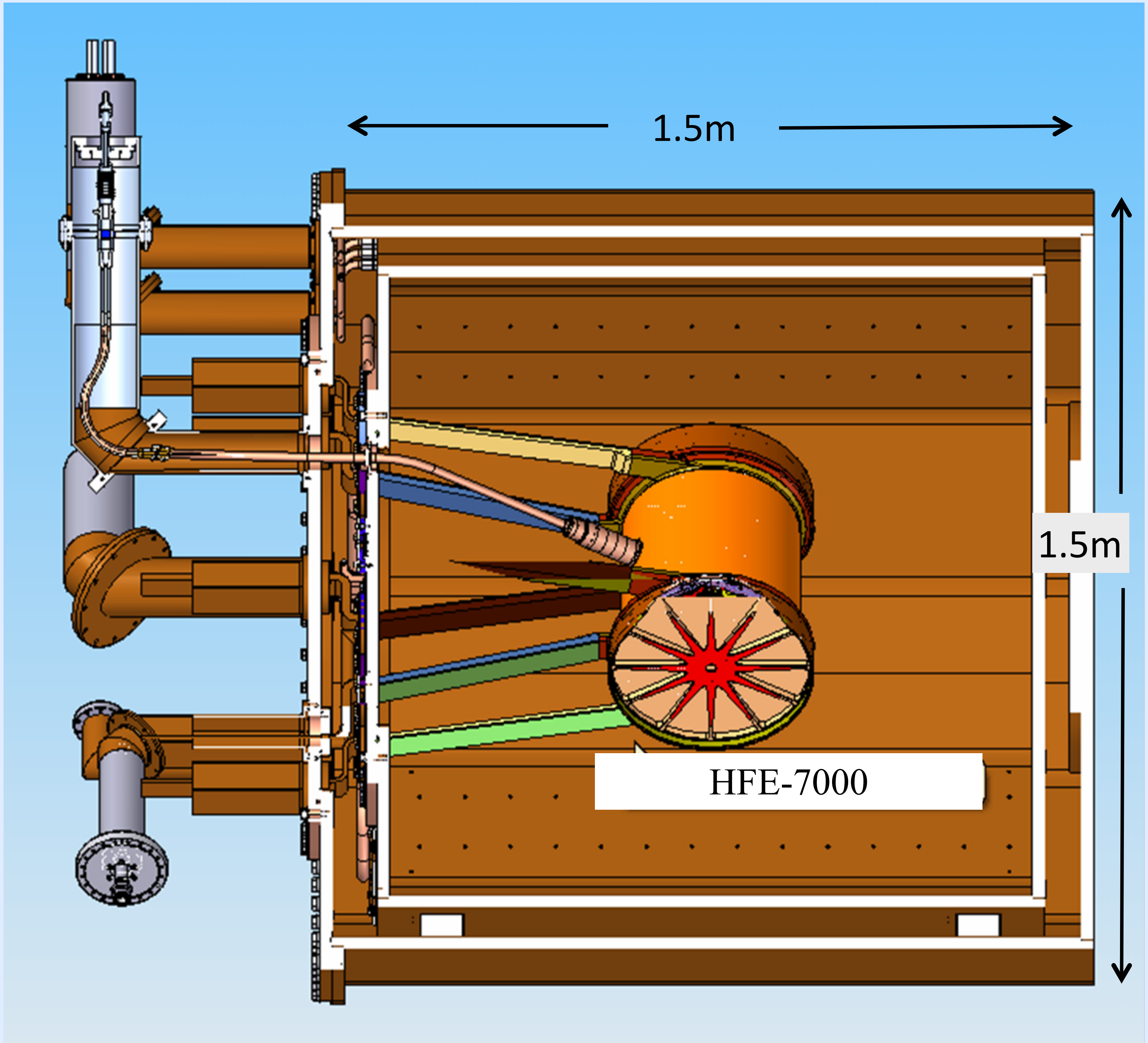
hermetic lead enclosure (25 cm, low activity Pb)

double, vacuum-insulated cryostat (low-background copper)

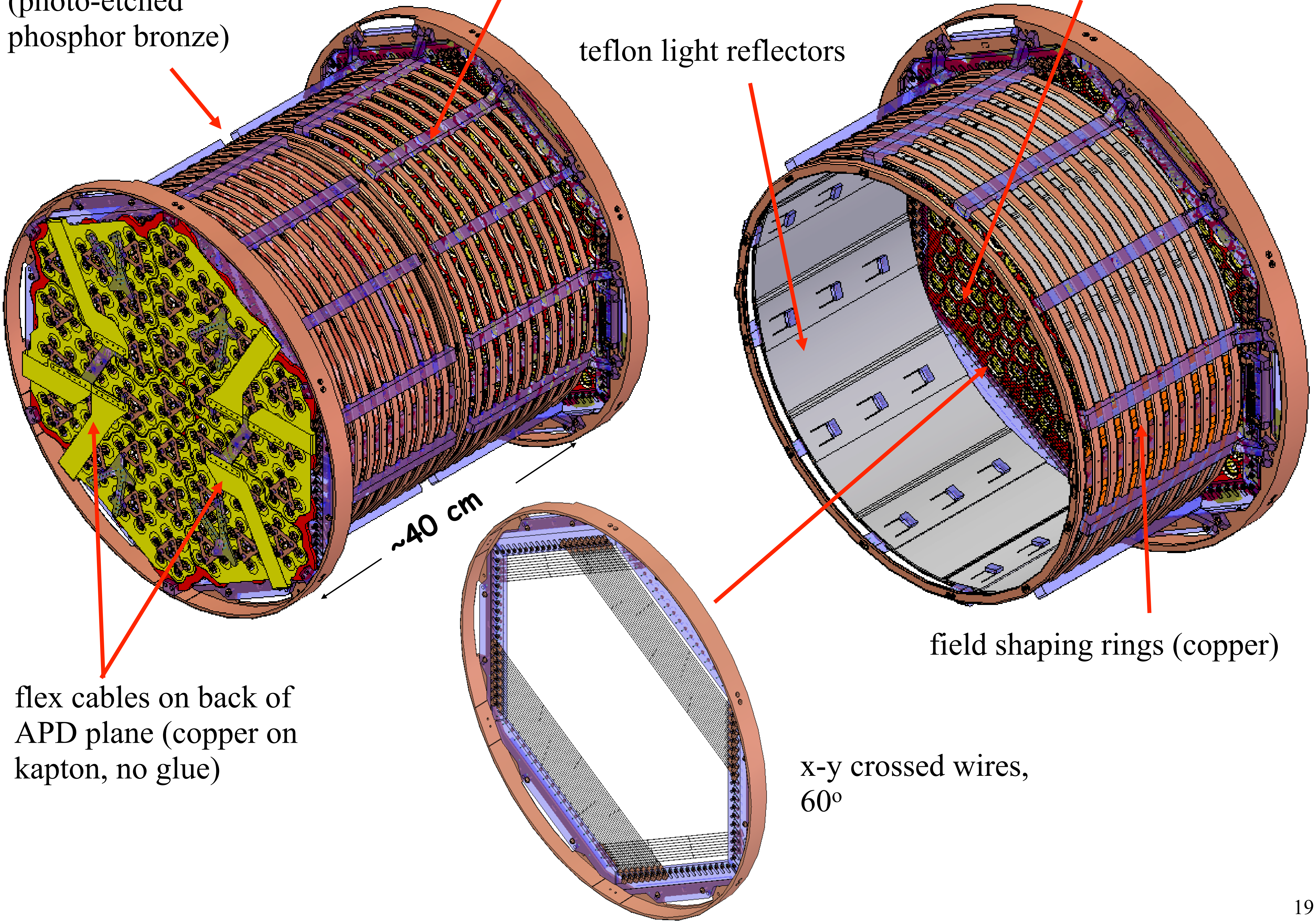
Xe and TPC copper chamber

class 100 clean room

The EXO-200 detector



HFE-loaded cryostat is cooled via closed-loop refrigerant chilled by external refrigerators and circulating in heat exchangers



Central HV plane
(photo-etched
phosphor bronze)

acrylic supports

LAAPD plane (copper) and x-y wires
(photo-etched phosphor bronze)

teflon light reflectors

field shaping rings (copper)

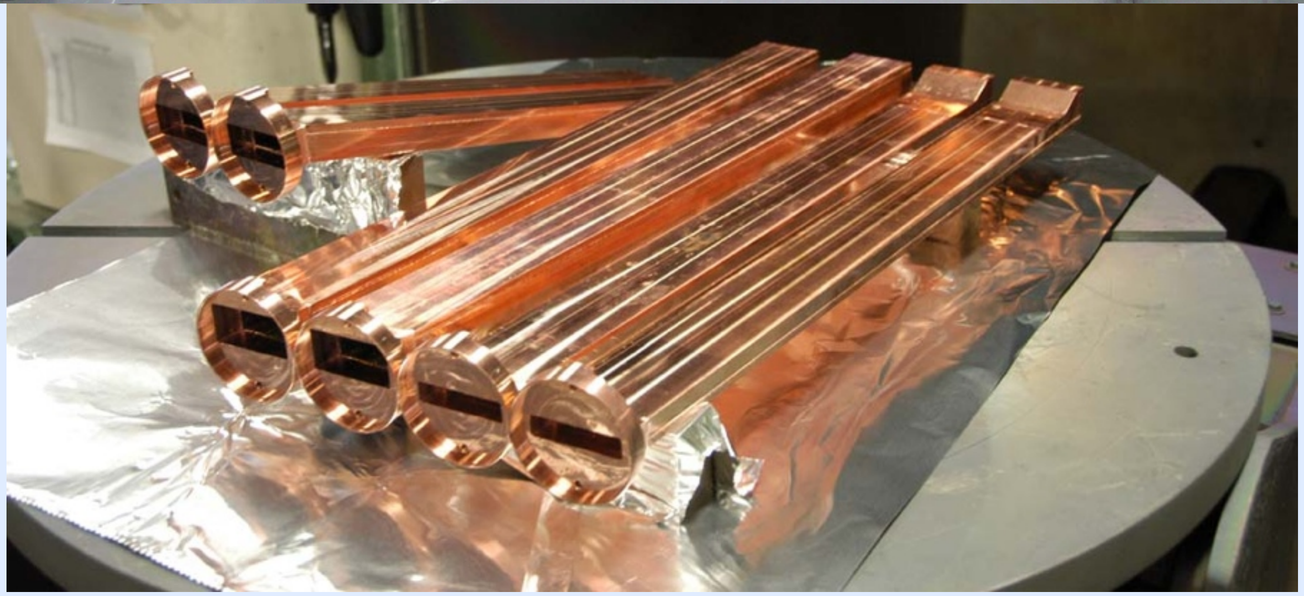
flex cables on back of
APD plane (copper on
kapton, no glue)

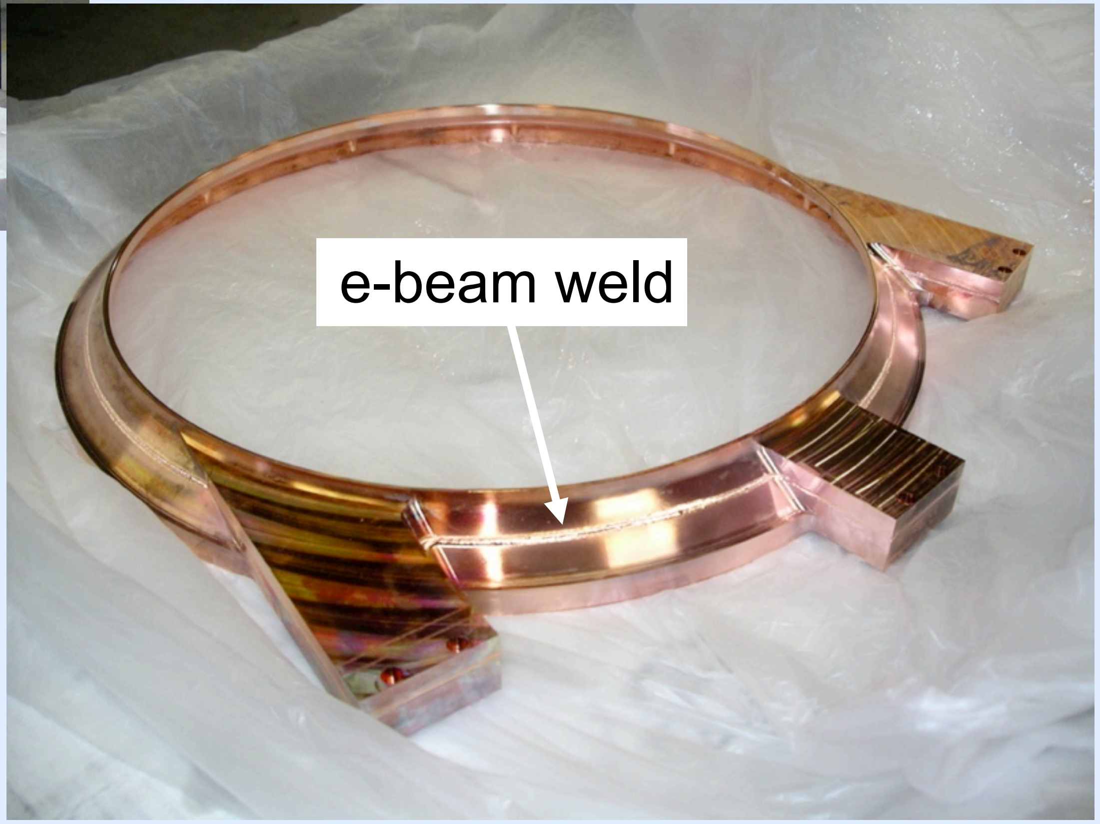
x-y crossed wires,
60°

EXO-200 xenon vessel

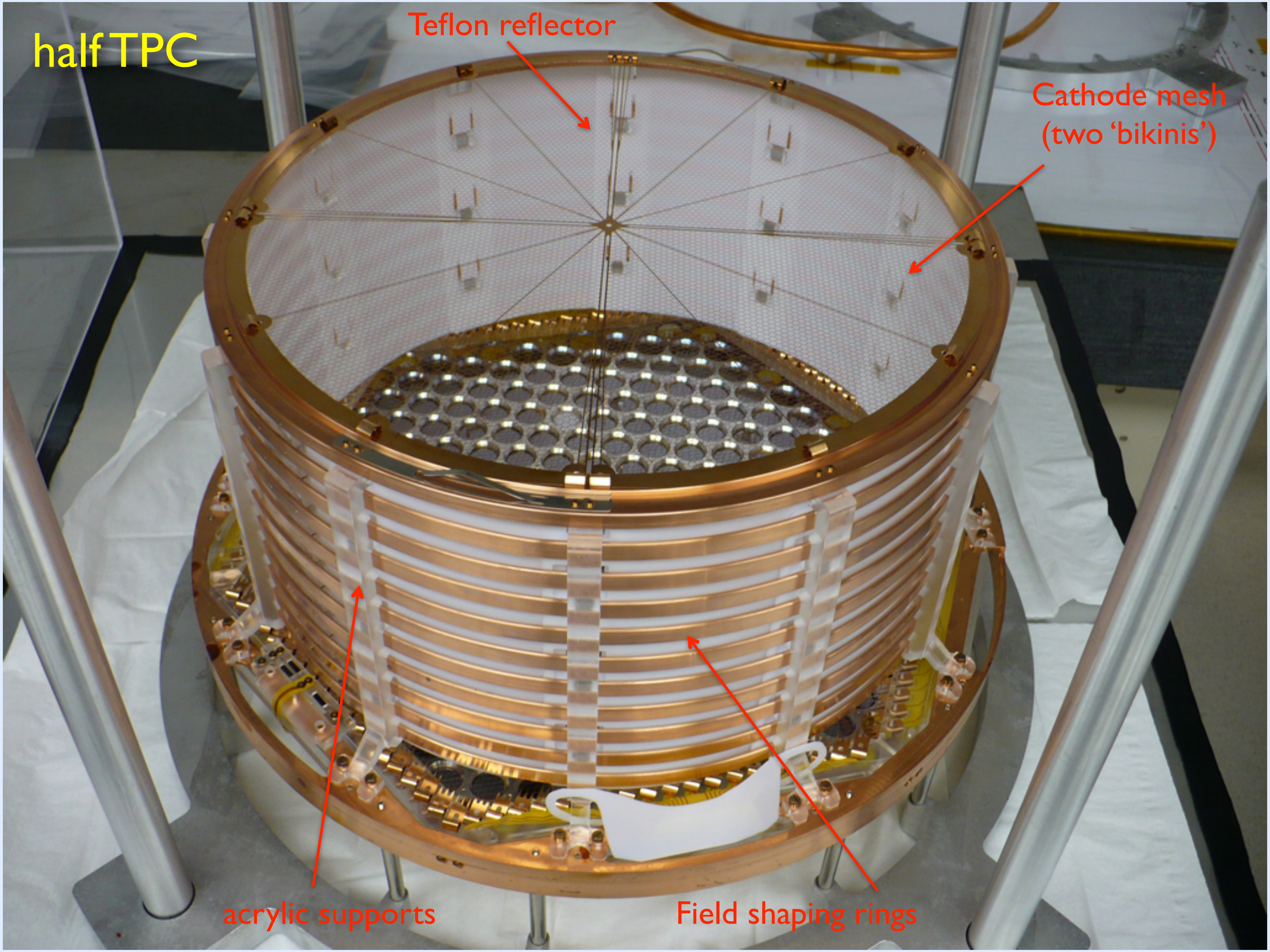
- ultra-pure copper
- 1.5 mm thick
- mostly e-beam welded

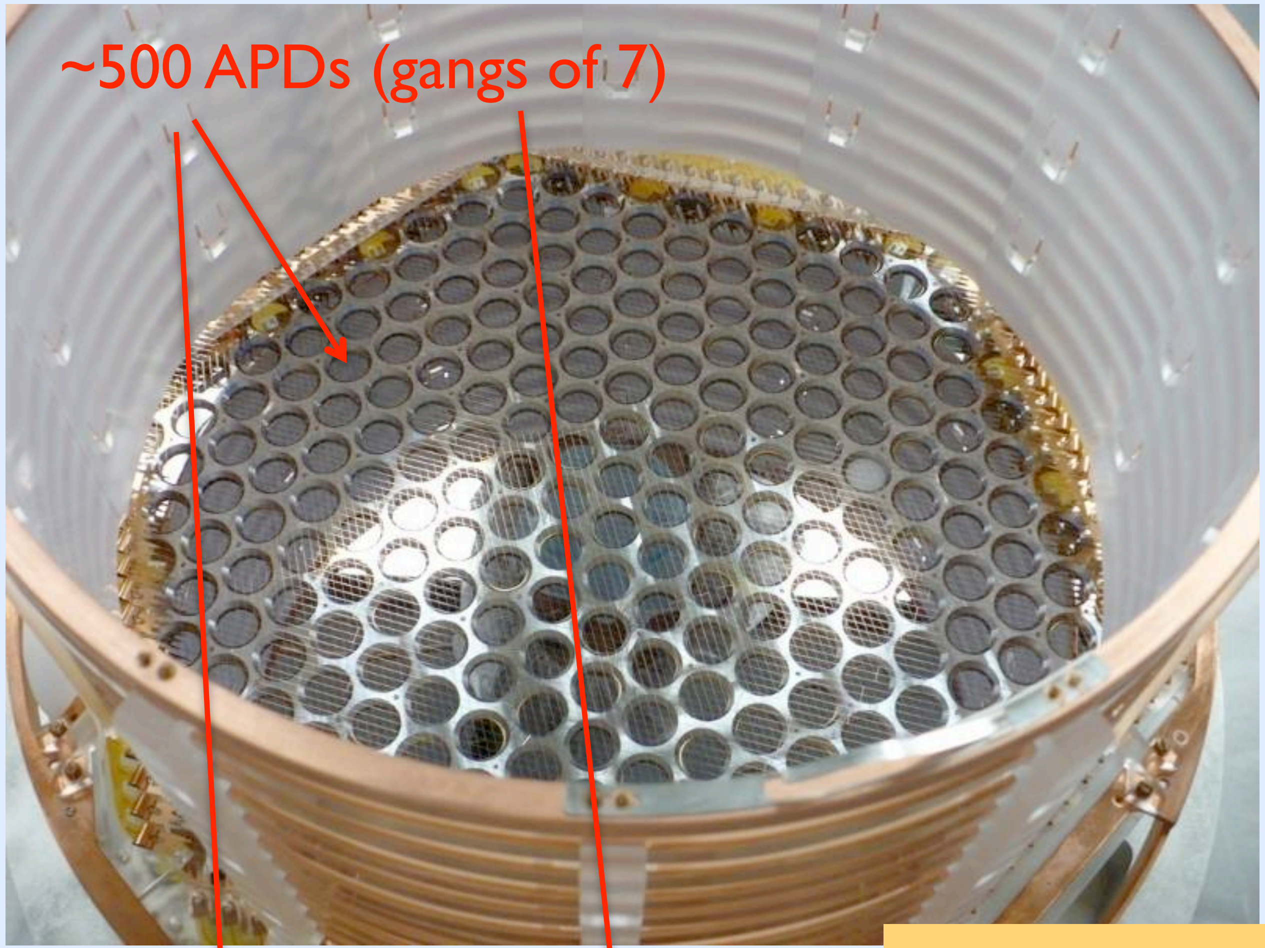
- machined and stored shallow underground (2 m of concrete)



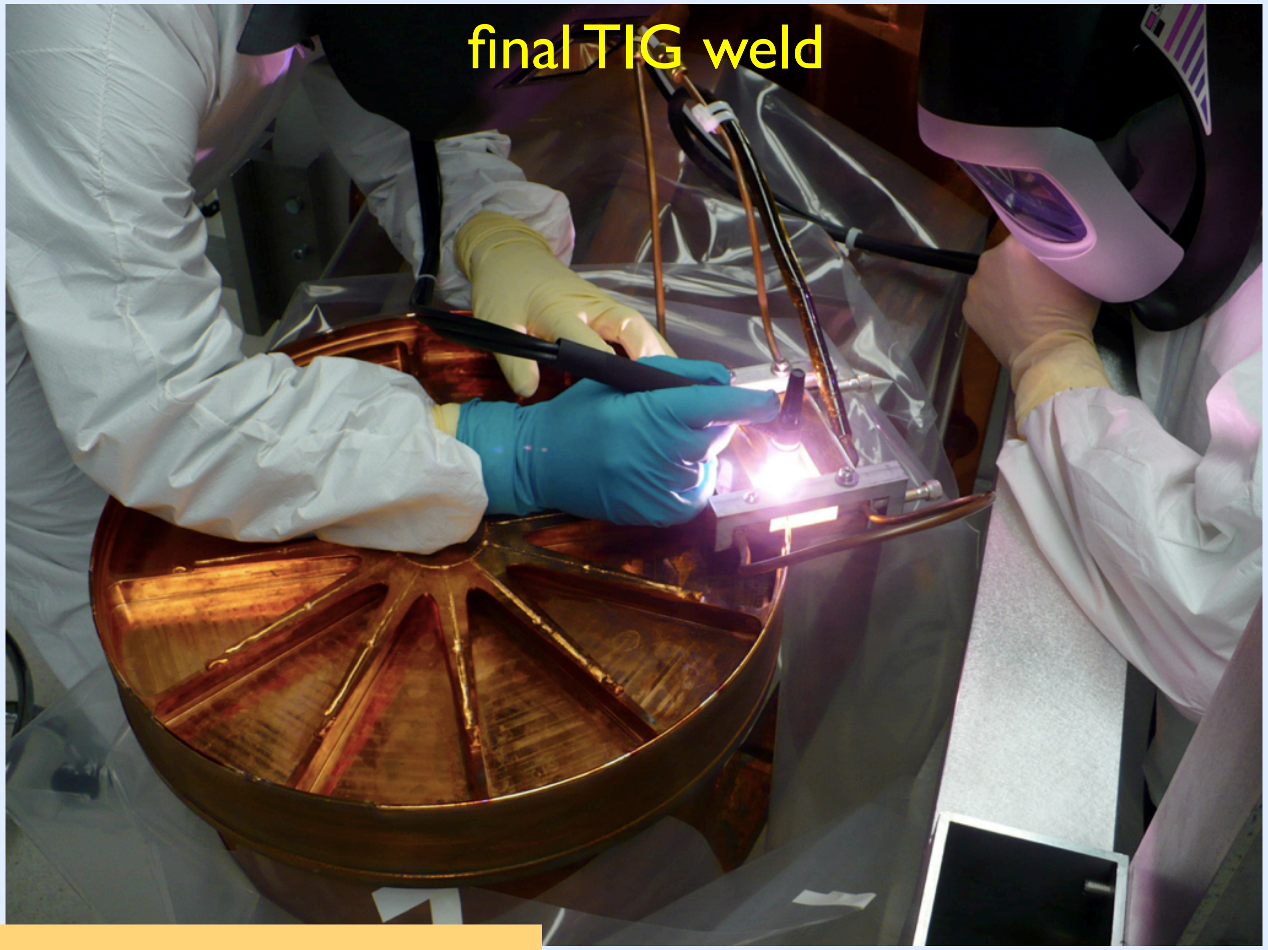


the EXO-200 TPC



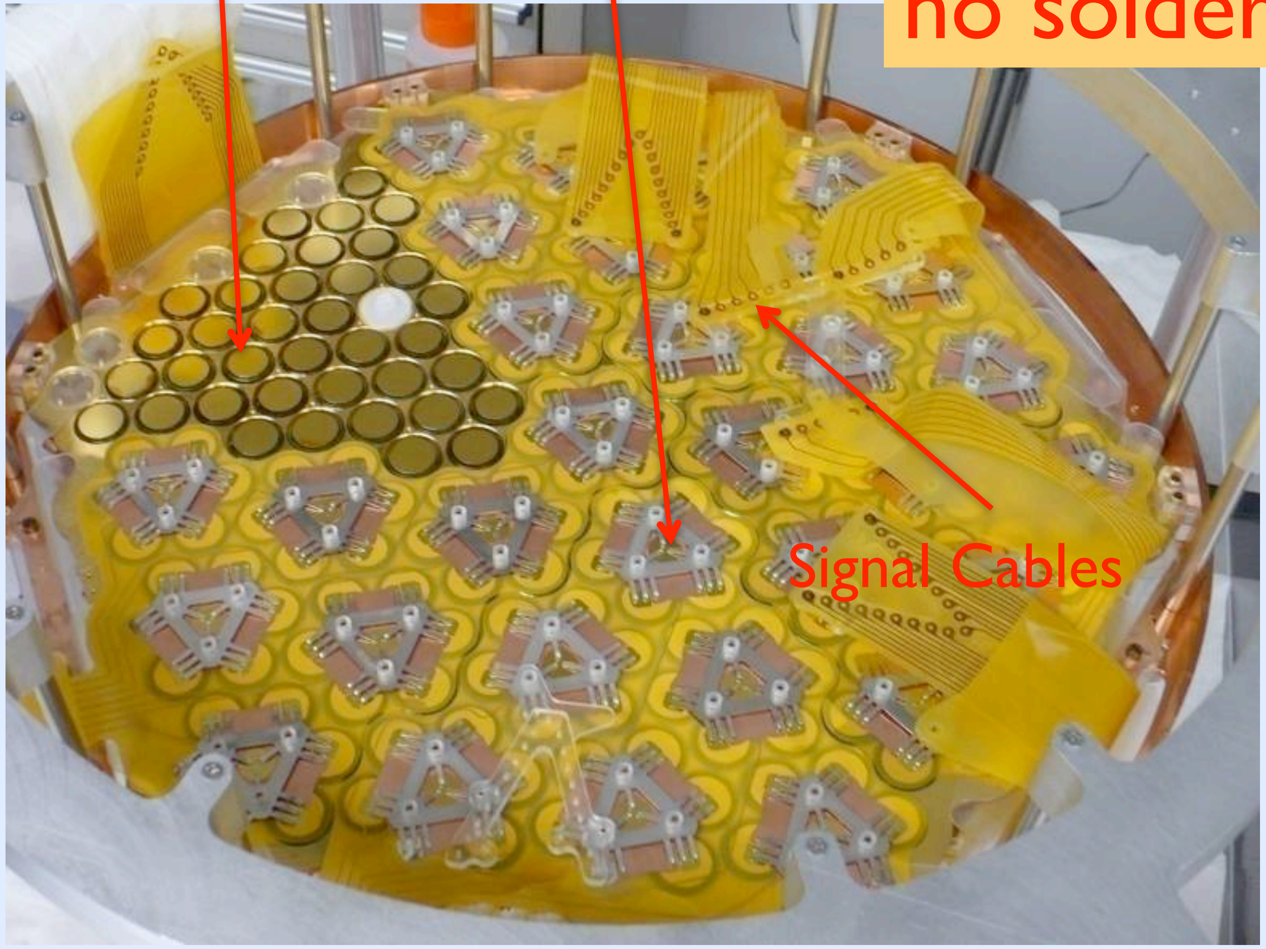


~500 APDs (gangs of 7)

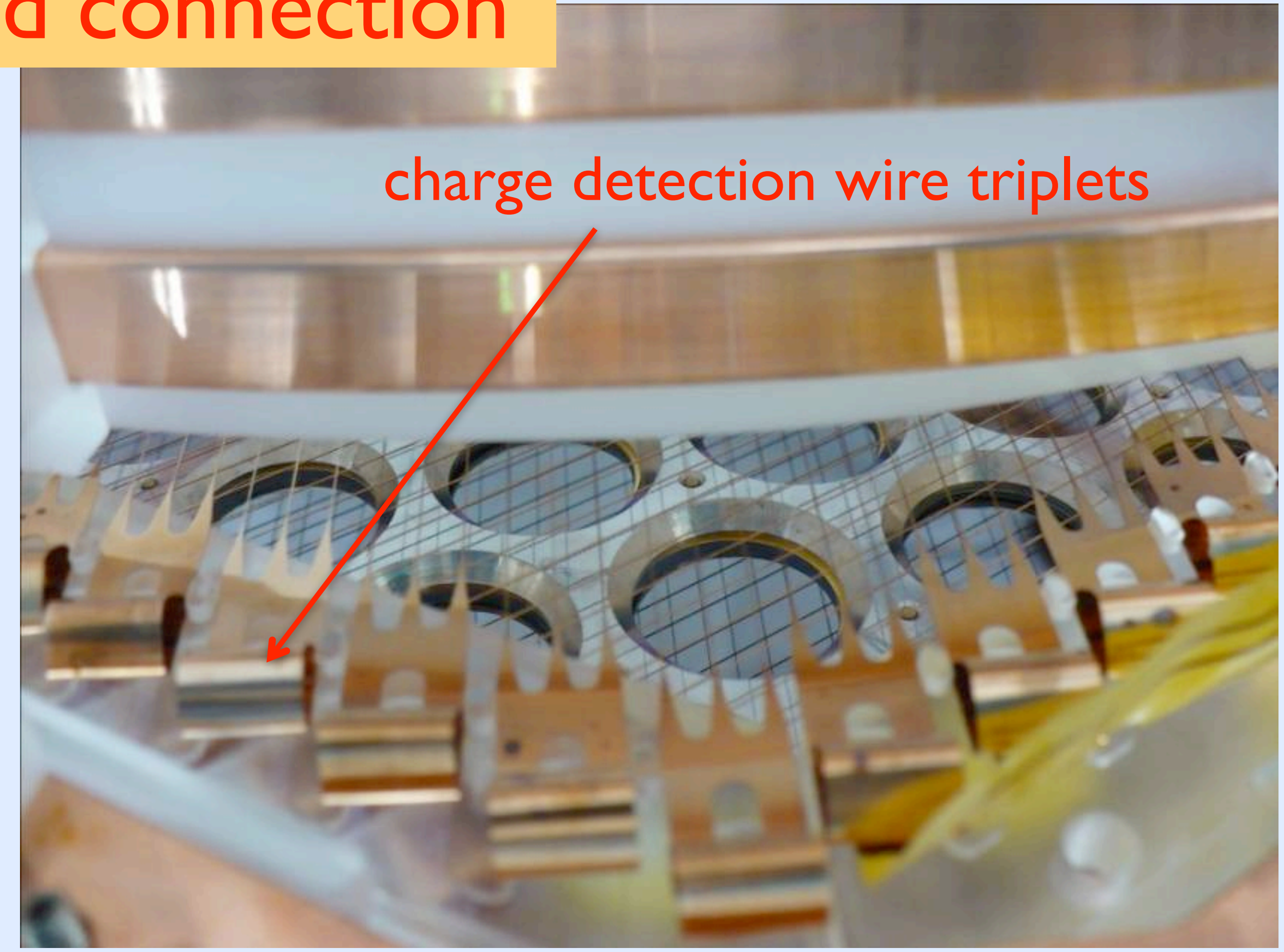


final TIG weld

no soldered connection

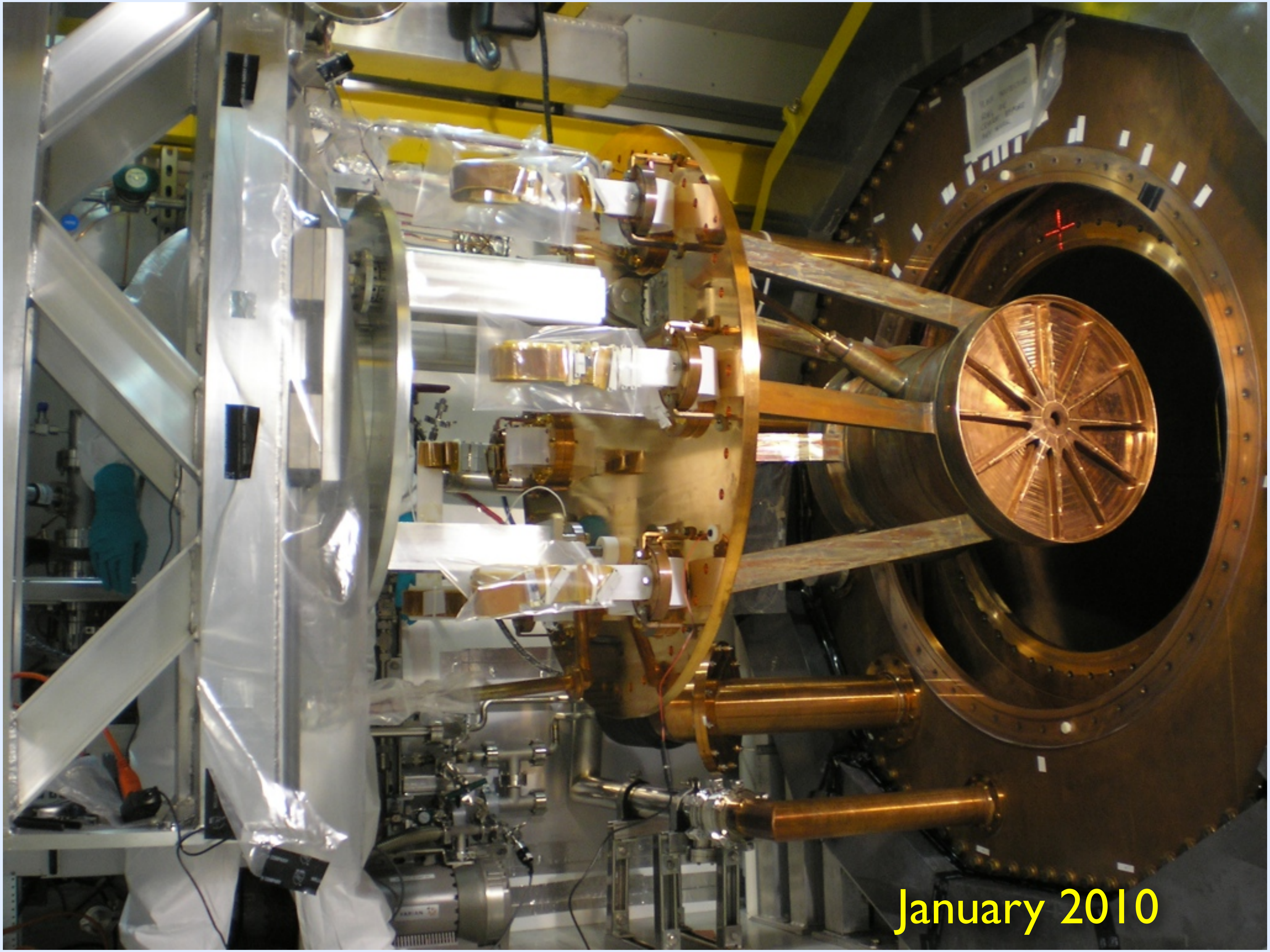


Signal Cables



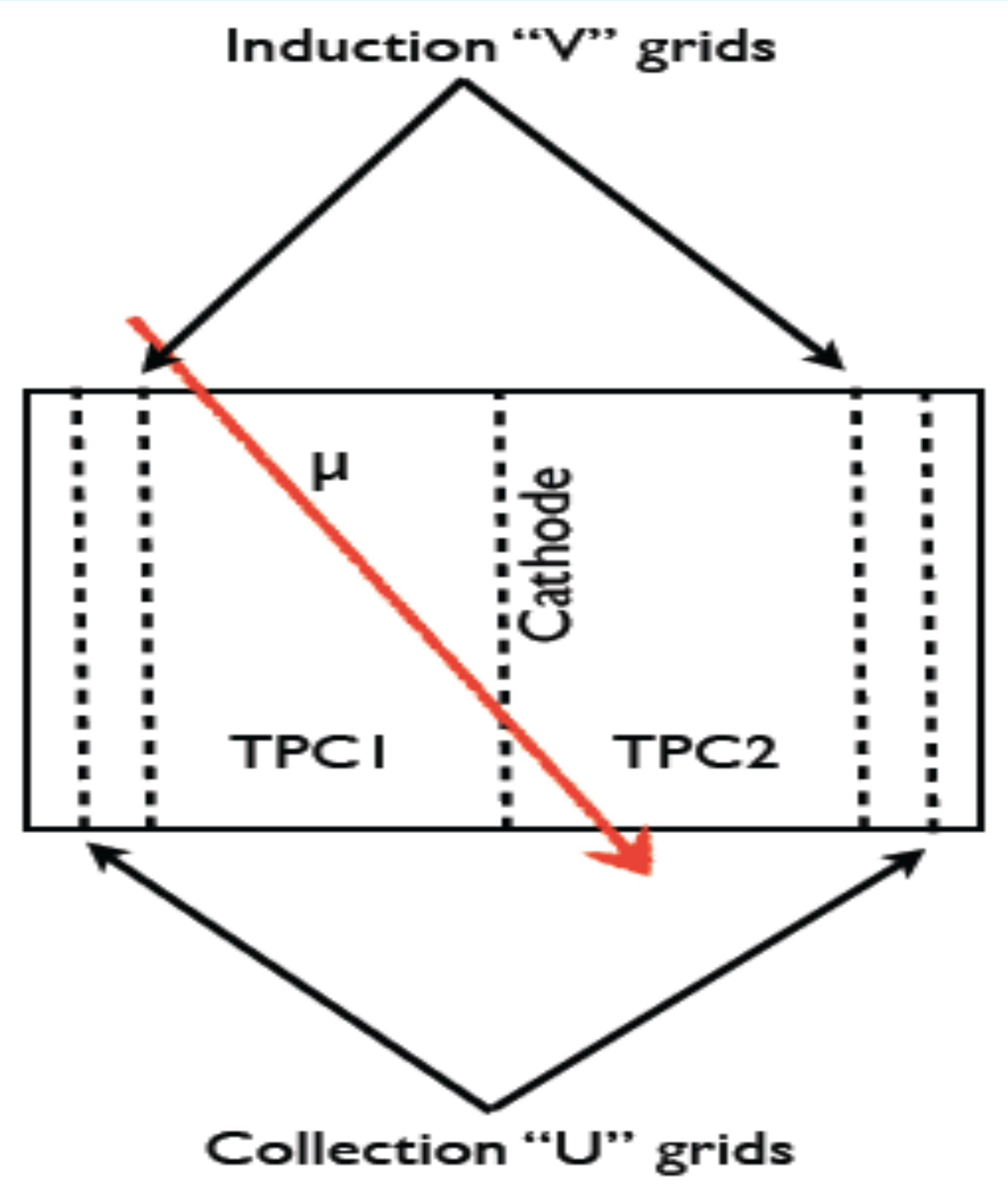
charge detection wire triplets

EXO-200



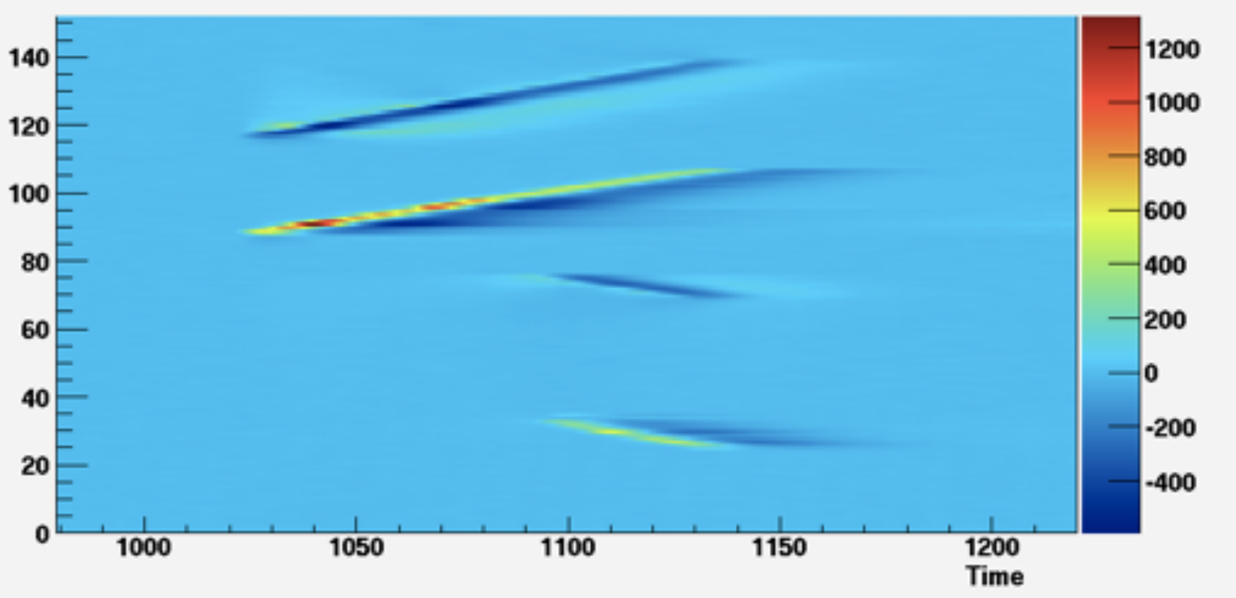
January 2010

EXO-200 engineering run (Dec 2010)

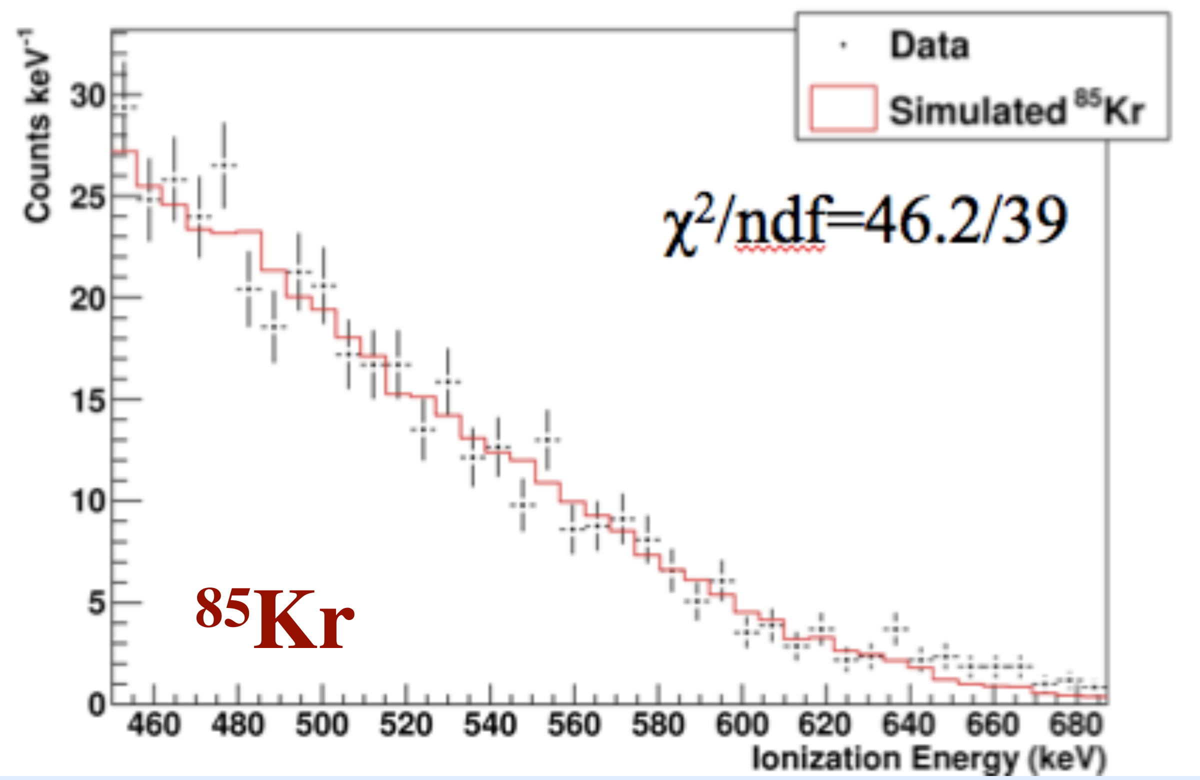


- ✓ natural xenon
- ✓ test stability of LXe/GXe systems
- ✓ measure Xe purity
- ✓ generally test detector performance
- ✓ test source calibration system
- ✓ test Xe emergency recovery
- ✳ no front Pb shield
- ✳ no Rn-suppressed enclosure
- ✳ no Rn trap in Xe system
- ✳ no muon veto

a muon event:



some known offenders (in ^{nat}Xe)

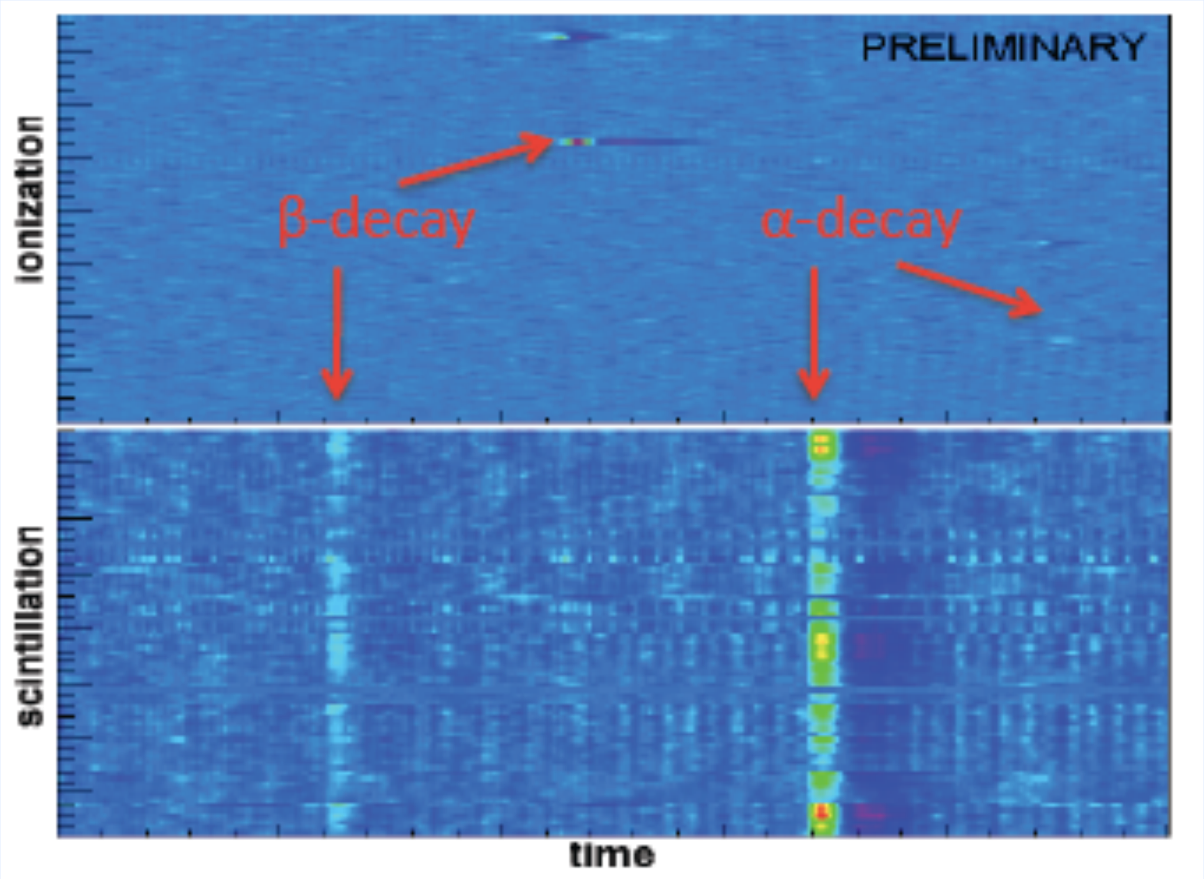


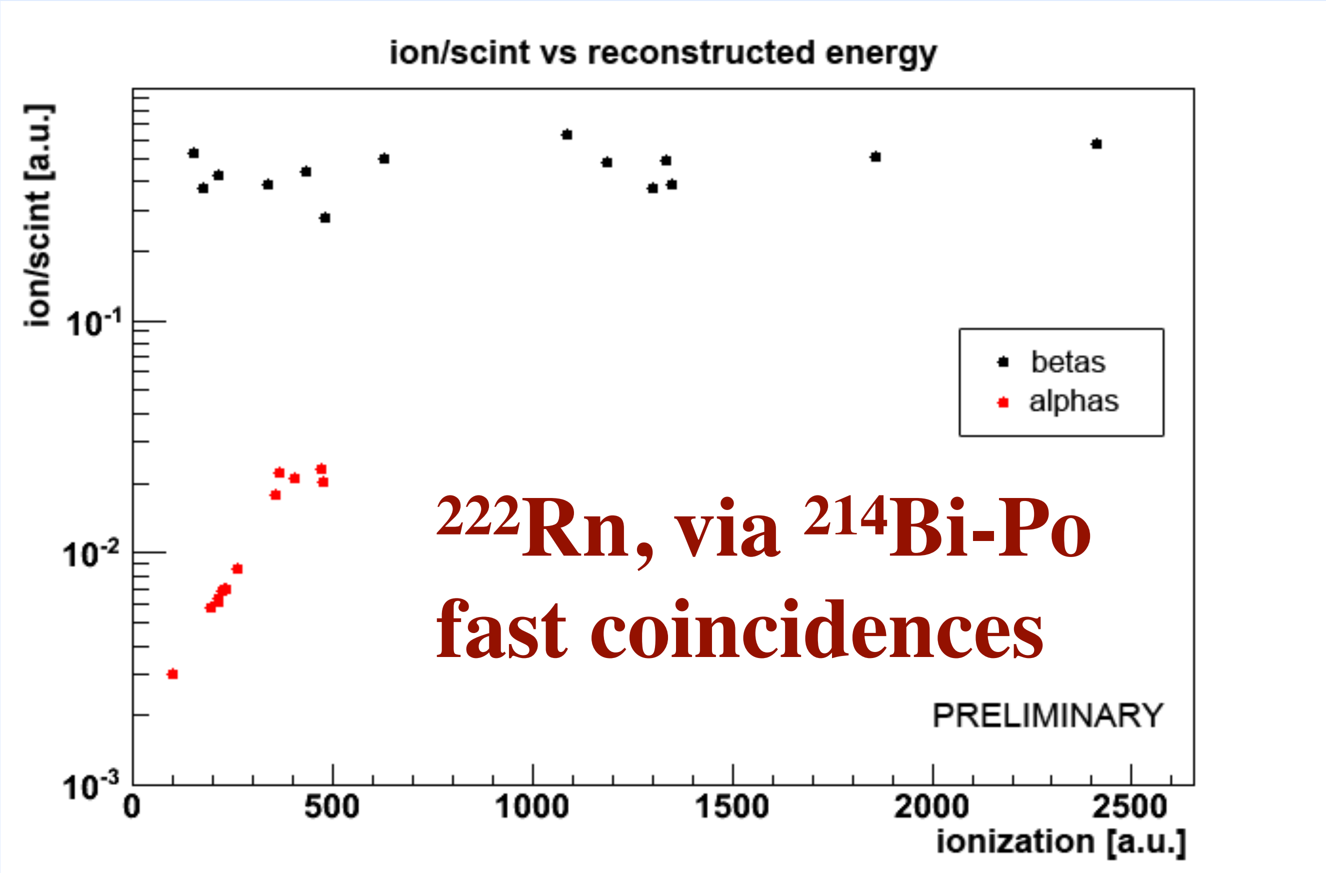
the total Kr concentration in the ^{nat}Xe was measured to be, using a special technique involving mass-spectroscopic analysis in the gas phase,

$$(42.6 \pm 5.7) \cdot 10^{-9} \text{ g/g}$$

[A. Dobi et al., arXiv:1103.2714v1]

→ consistent with Mass Spec result assuming standard ^{85}Kr/Kr concentration of ~10^{-11}

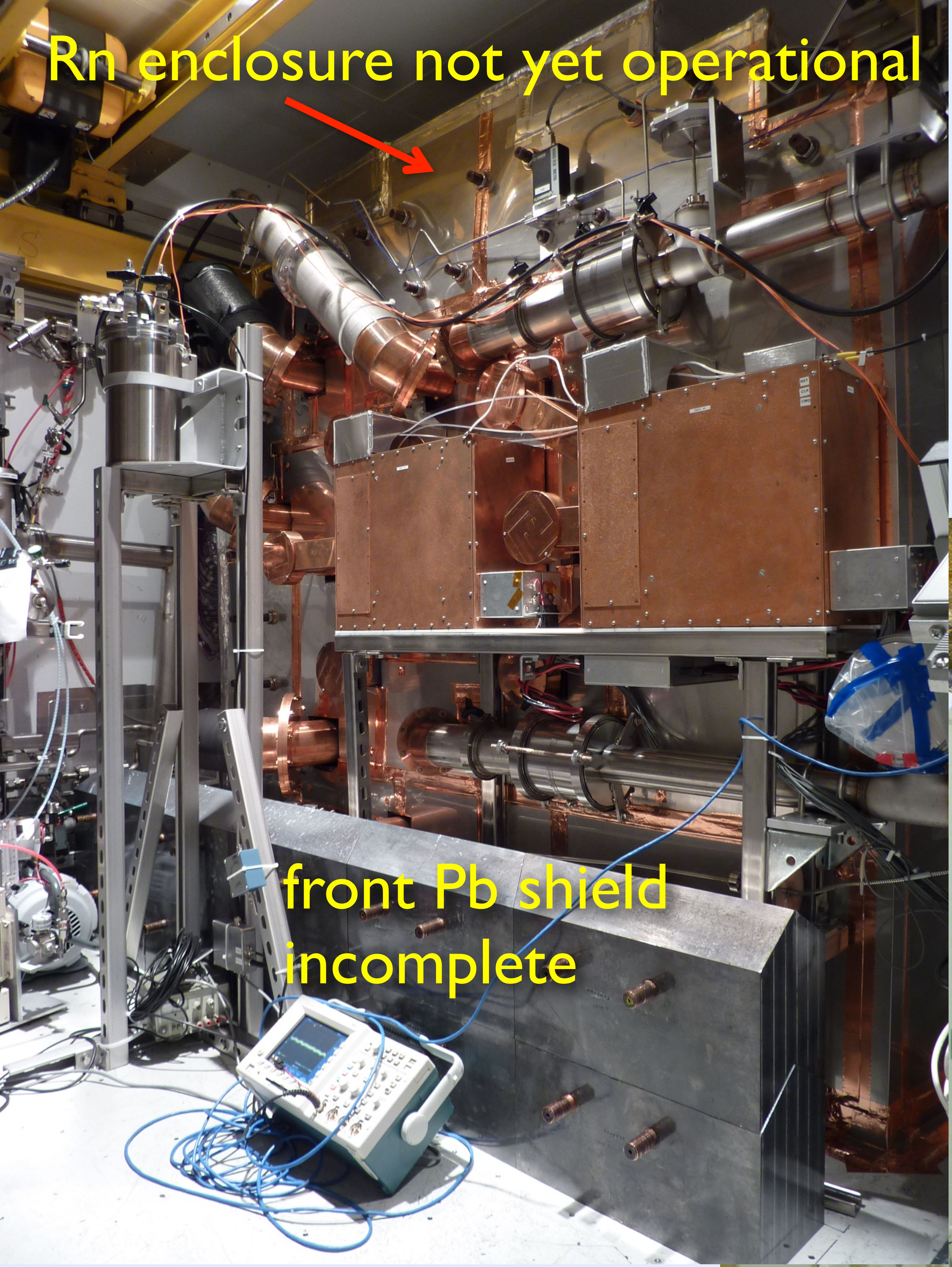




^{222}Rn, via ^{214}Bi-Po fast coincidences

status of EXO-200

running with enriched xenon since spring 2011



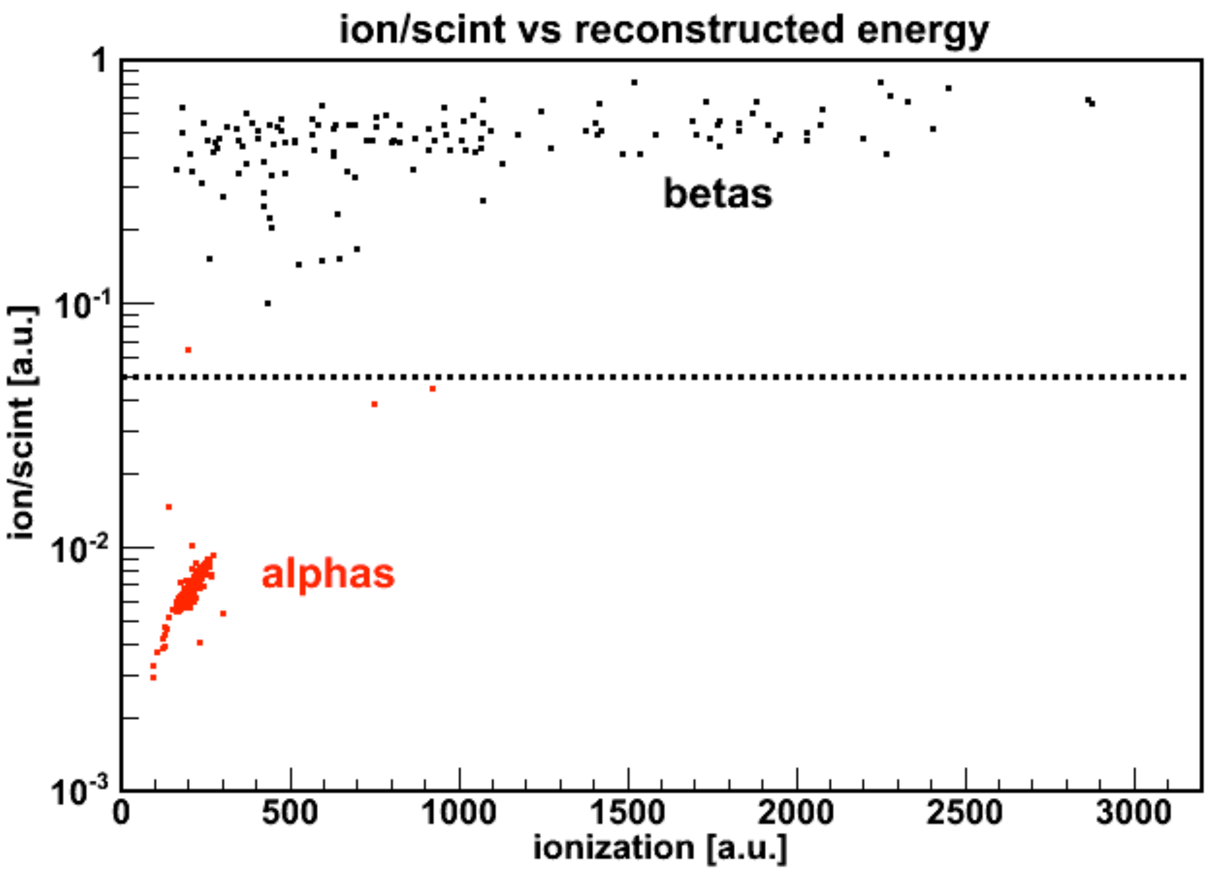
Rn enclosure not yet operational

front Pb shield incomplete

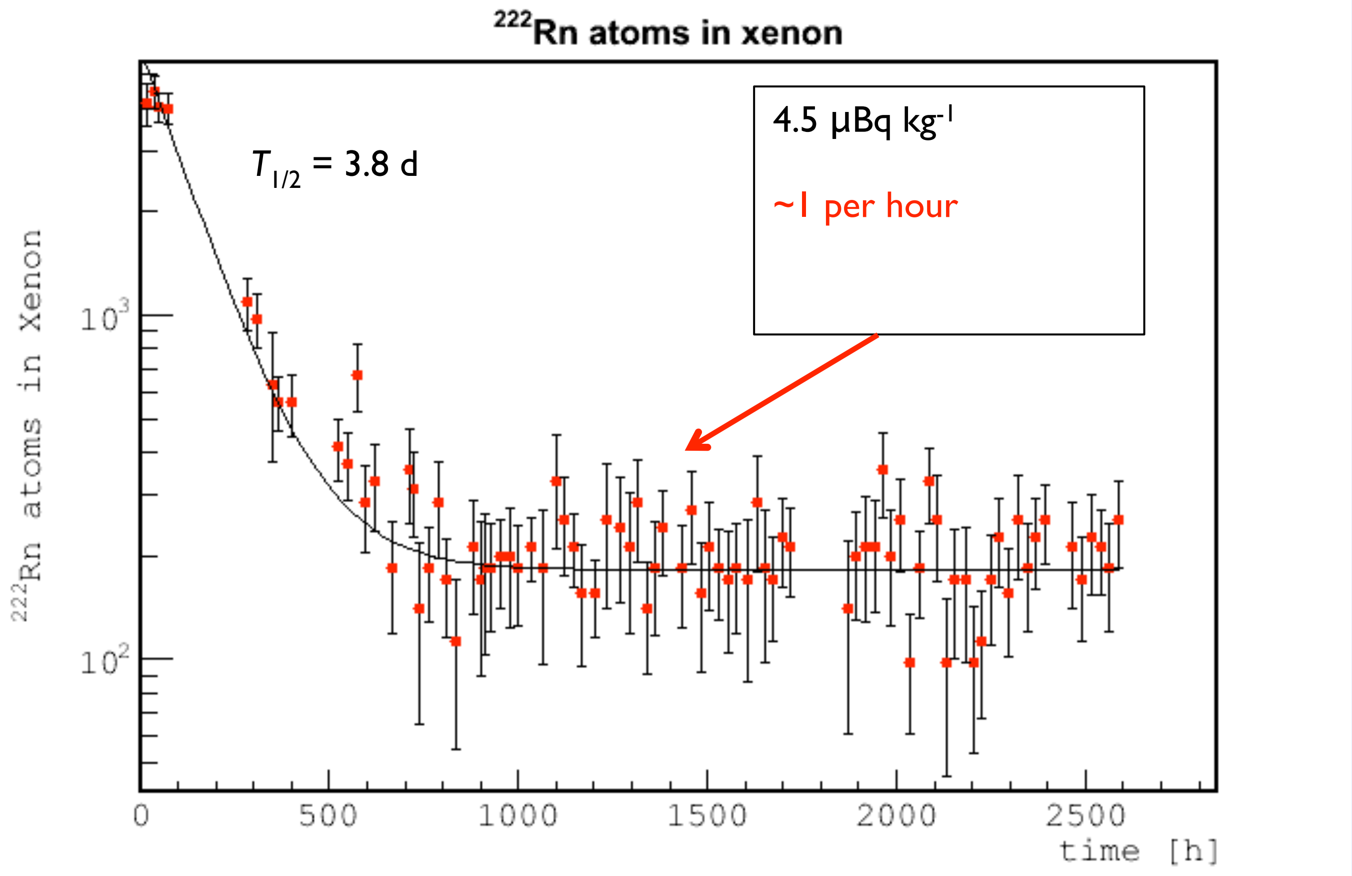
no Rn trap in Xe system

Veto counter now running

Rn content and alpha discrimination


ion/scint vs reconstructed energy

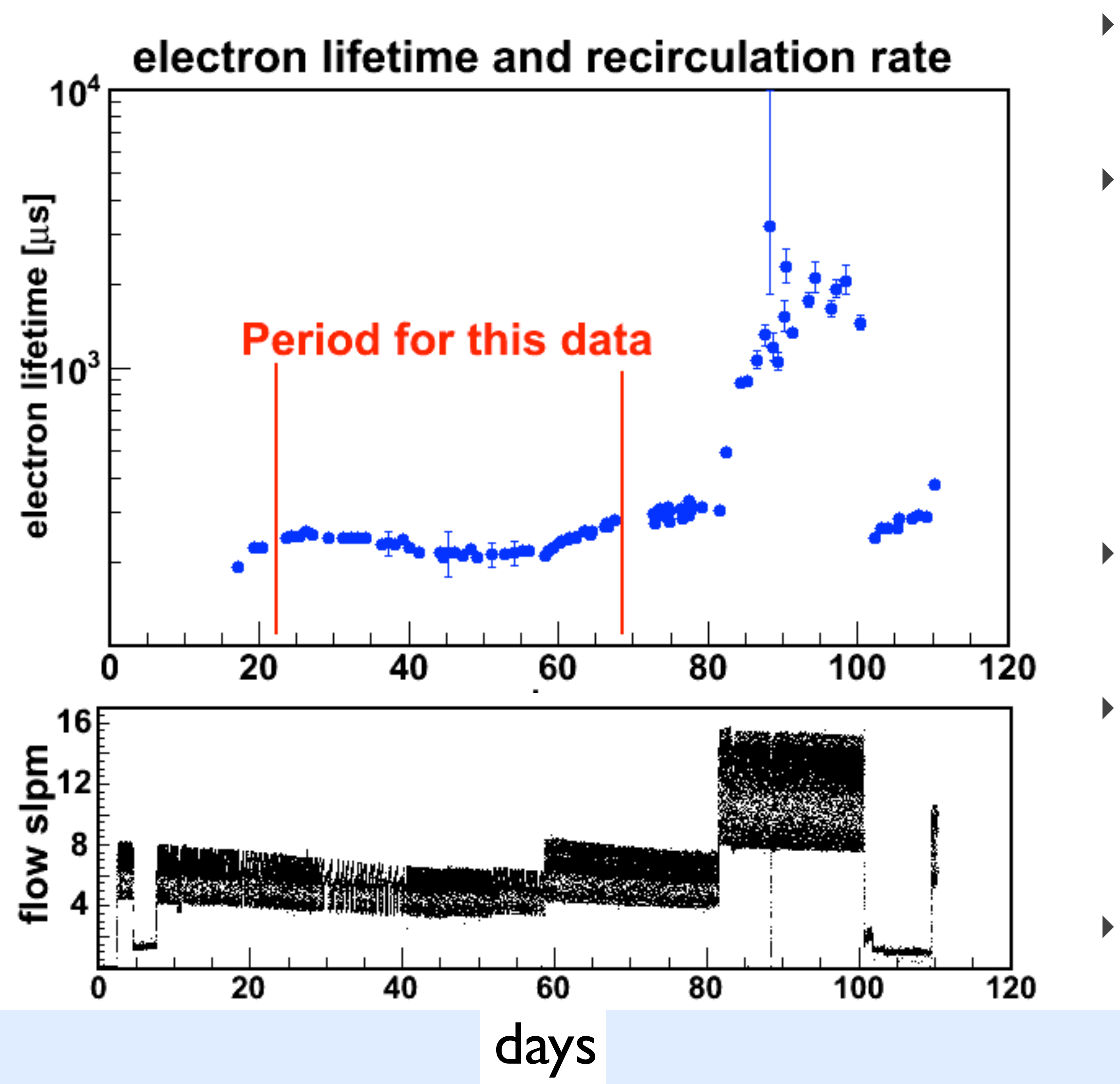
α: strong light signal, weak charge signal
β: weak light signal, strong charge signal


^{222}Rn atoms in xenon

^{214}Bi–^{214}Po correlations in the EXO-200 detector

Using the Bi-Po (Rn daughter) coincidence technique, we can estimate the Rn content in our detector. The ^{214}Bi decay rate is consistent with measurements from alpha-spectroscopy and the expectation before the Rn trap is commissioned.

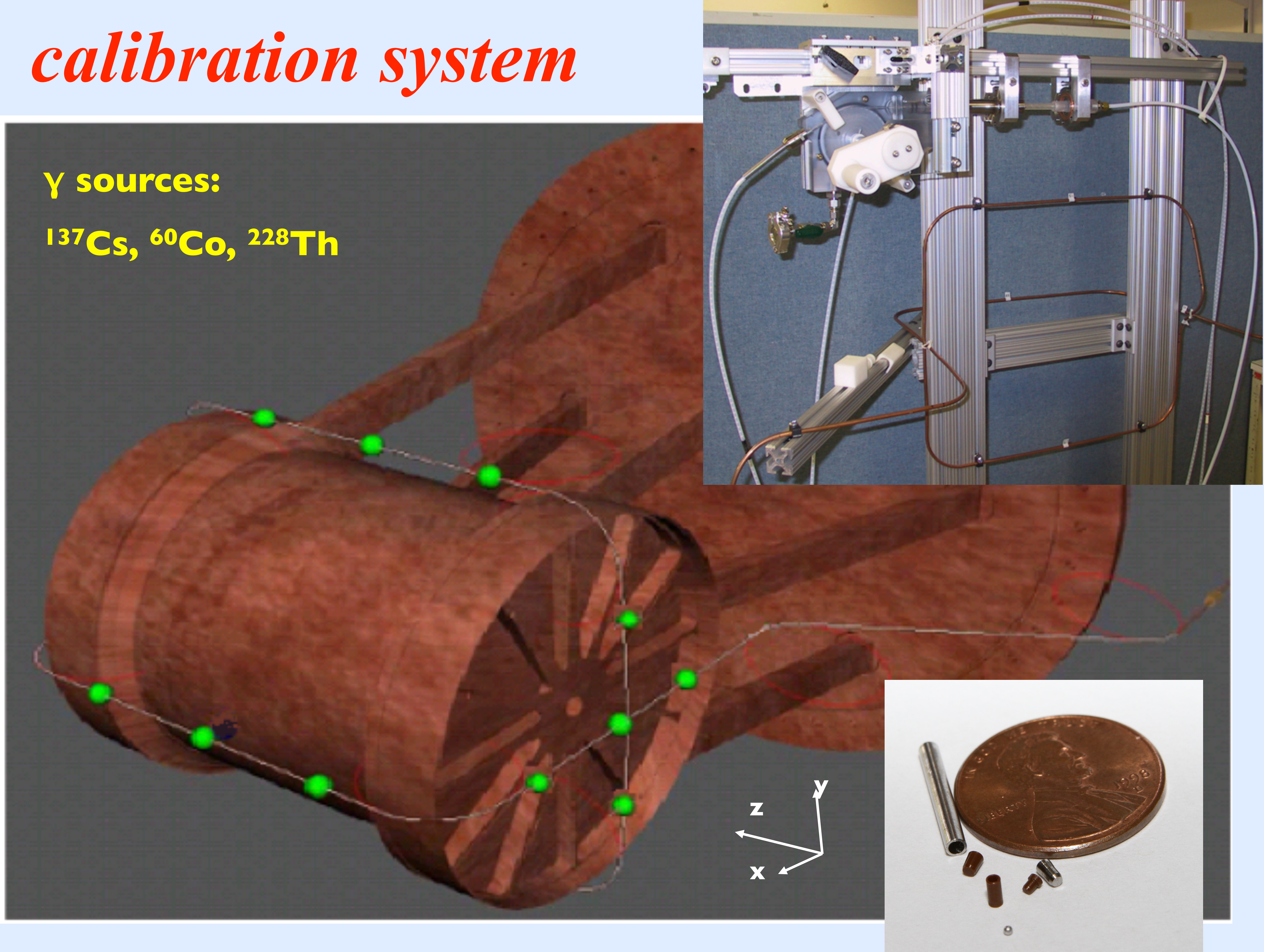
xenon purity



- deployed γ sources around the TPC
- measured the purity of LXe during continuous recirculation with a piston pump

  [R. Neilson et al., arXiv:1104.5041v1]
- purity measured by 3 methods
- determined the energy scale in the relevant range of interest
- shown rapid achievement of ms electron lifetime

calibration system



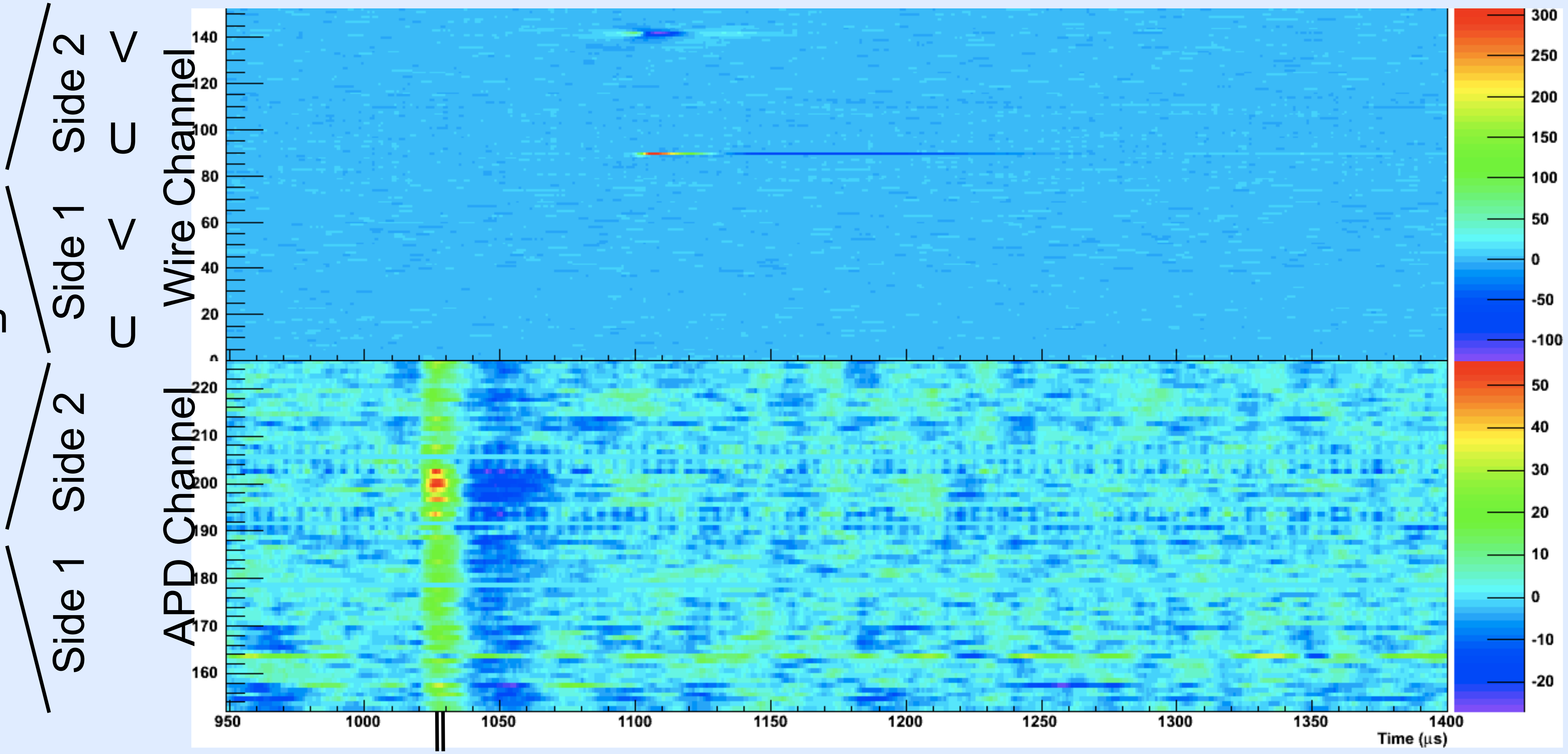
γ sources:

^{137}Cs, ^{60}Co, ^{228}Th

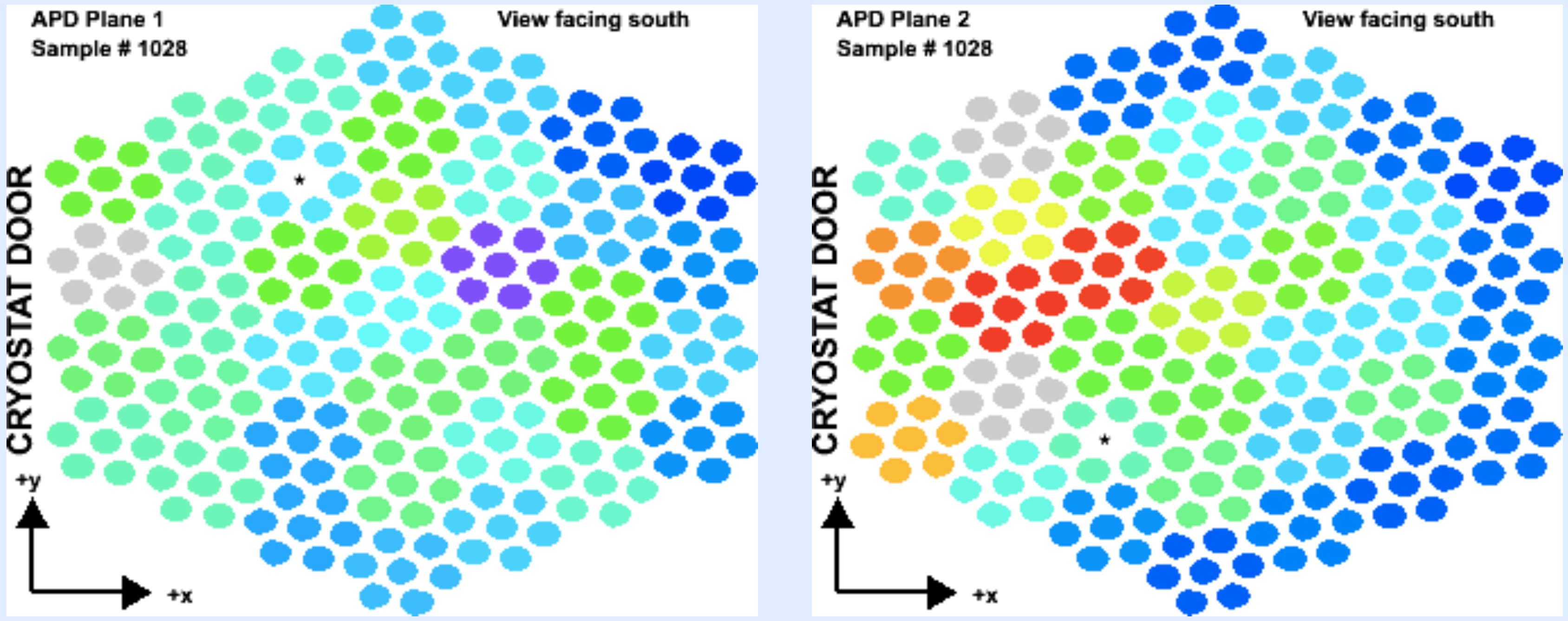
Charge readout

V: Induction
U: Collection

Light readout



one sample

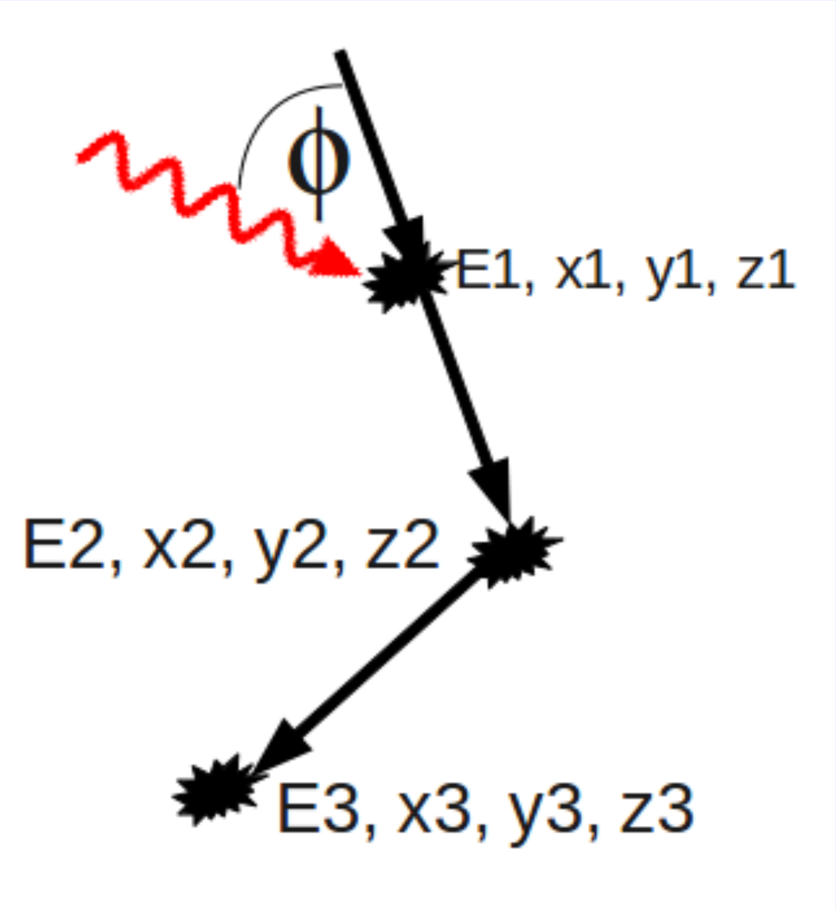


A single-site energy deposition in EXO-200

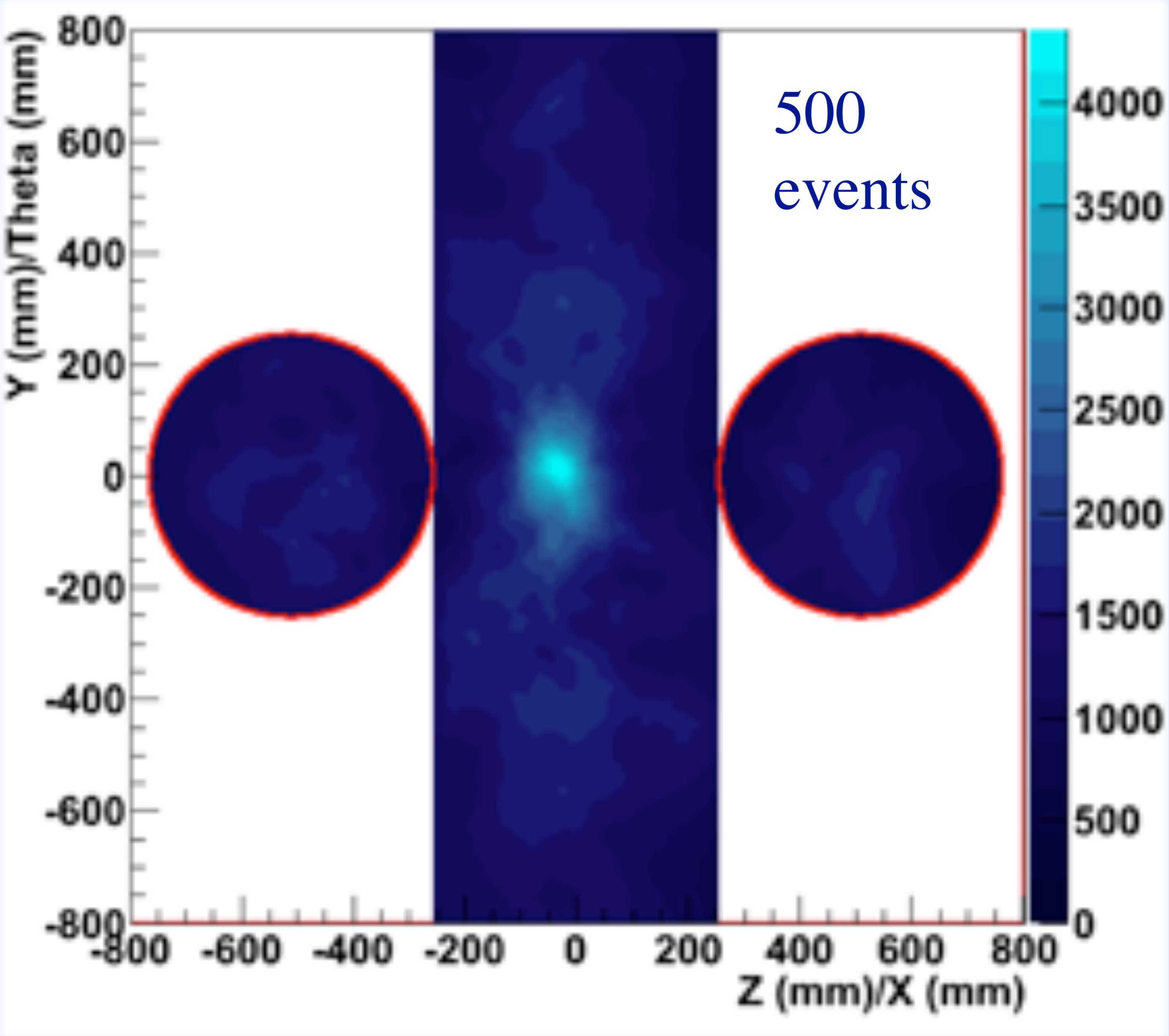
Scintillation light is seen at both sides. The light is more diffuse on side 1 and more localized on side 2, where the event occurred.

The light signal always precedes both charge signals. The induction (V) signal precedes the collection (U) signal.

source position: Compton telescope



$$\phi = arccos\left[1 - m_e c^2 \cdot \left(\frac{1}{E_\gamma - E_1} - \frac{1}{E_1}\right)\right]$$



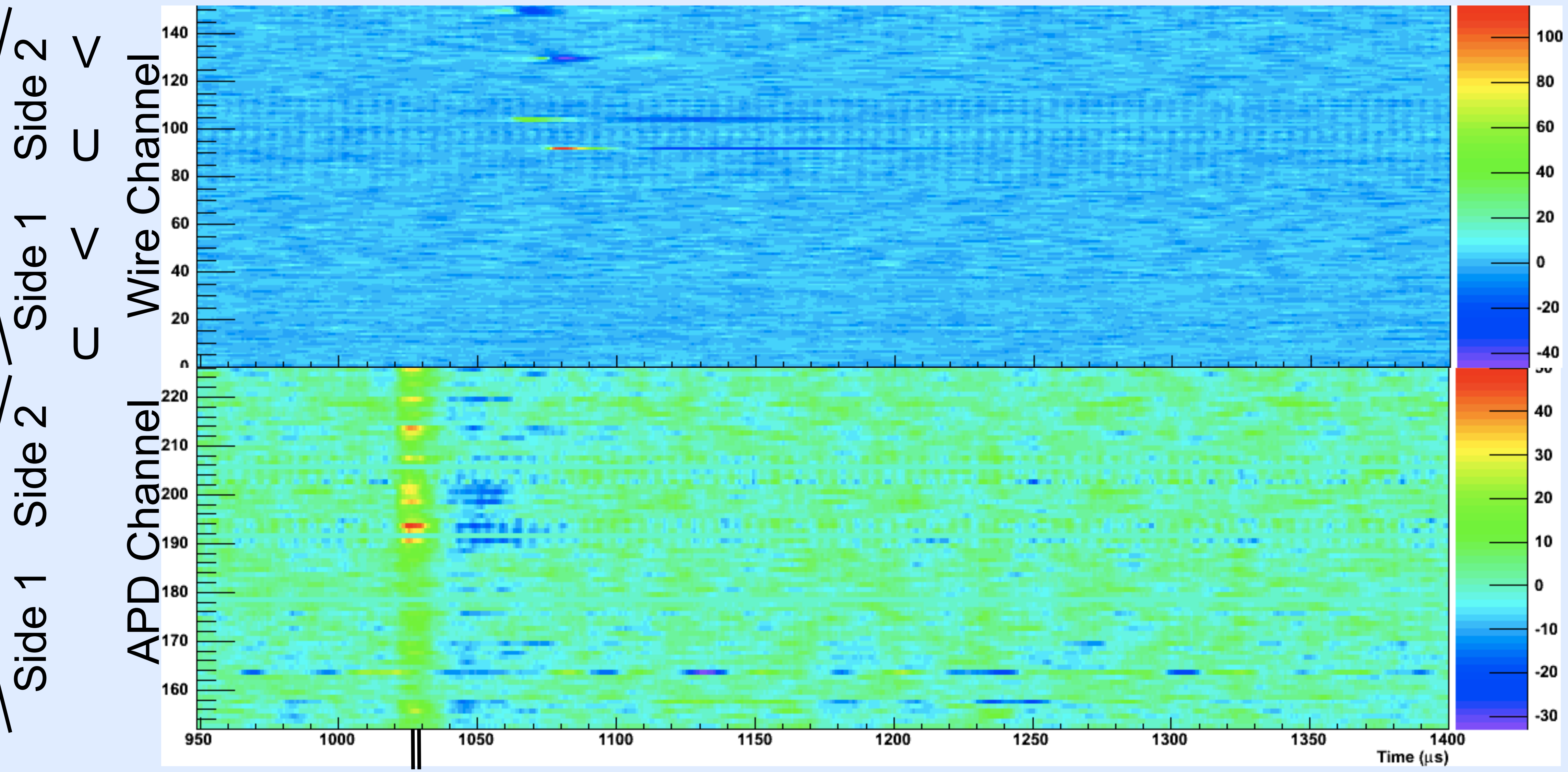
500 events

- measure energy and position of each event
- from each site a cone is drawn and the sum of all the cones produces the image to the right

Charge readout

V: Induction
U: Collection

Light readout

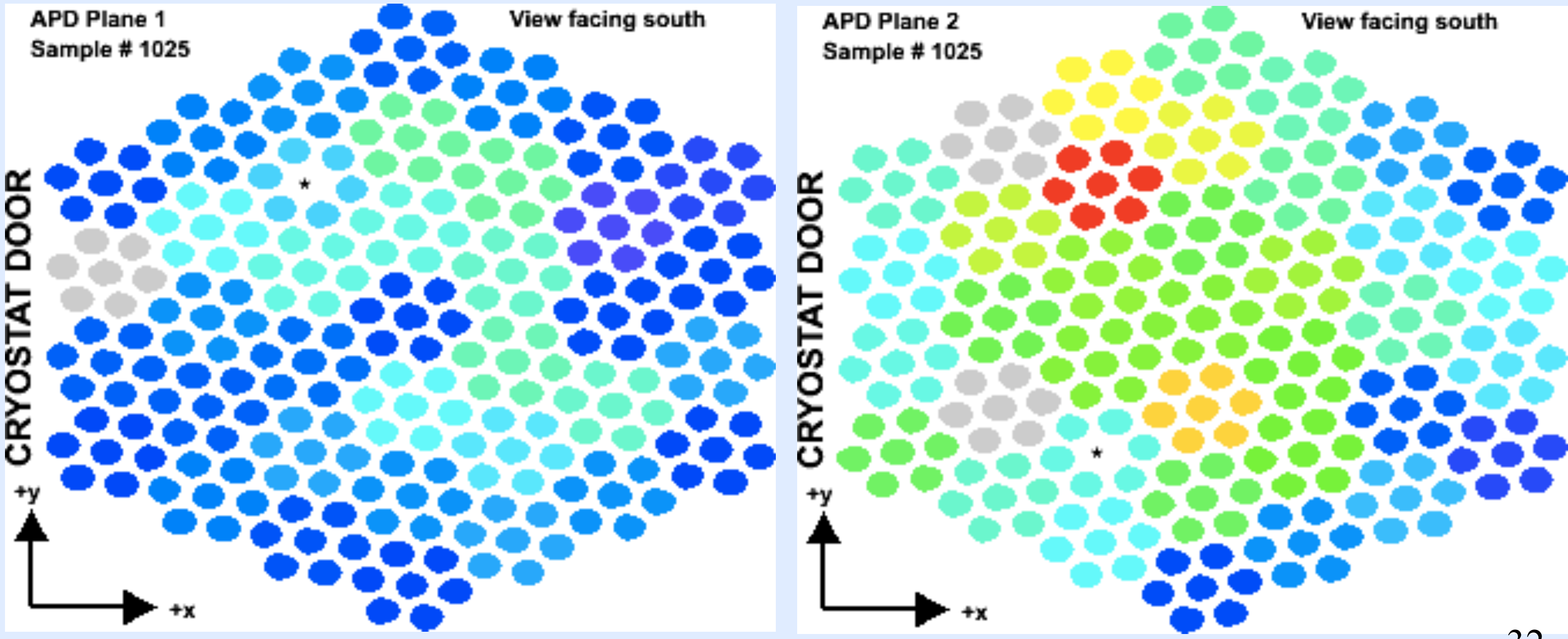


A two-site Compton scattering event

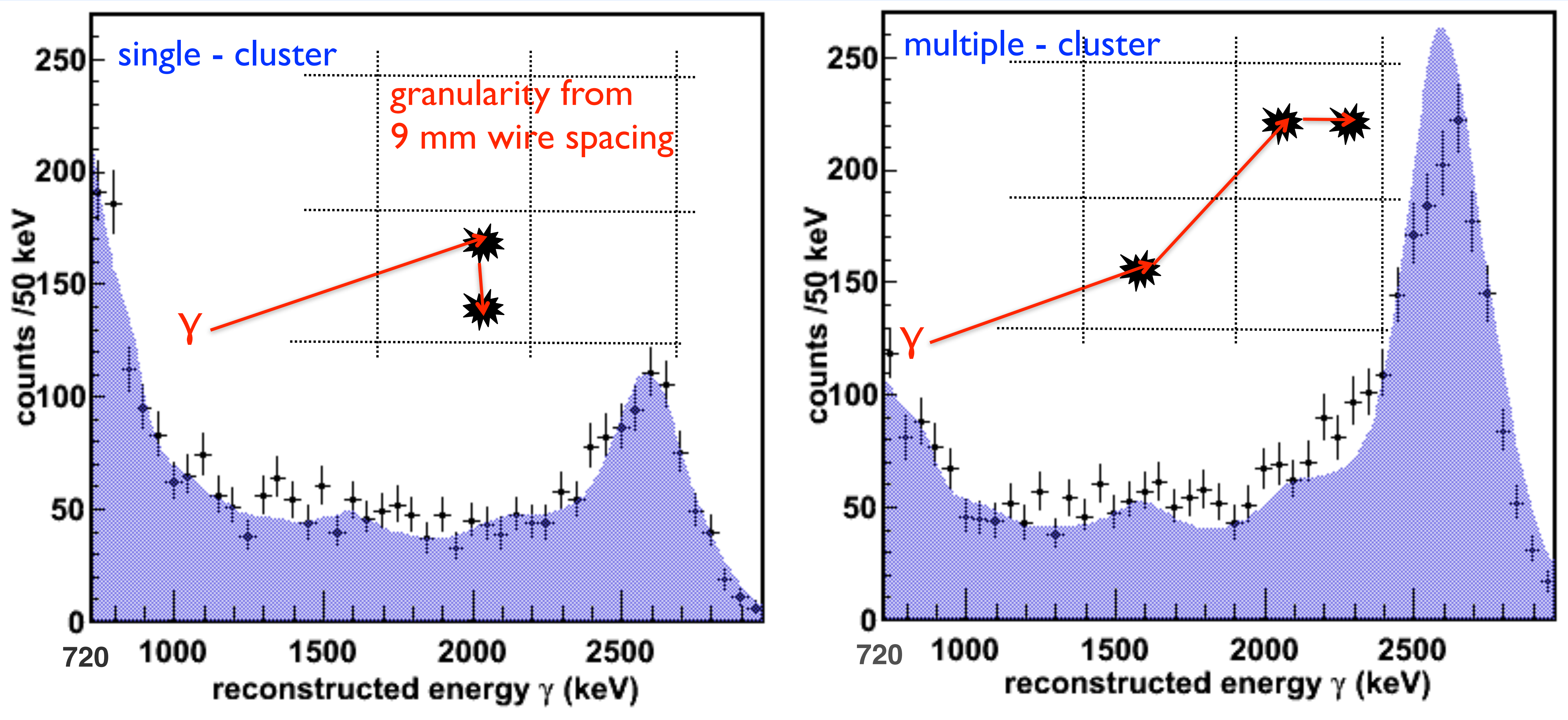
All scintillation light arrives at the same time, indicating that the two energy depositions are simultaneous.

In this case, the gamma ray occurred on side 2. The light hitting side 2 is more localized, while the light hitting side 1 is more diffuse across the plane.

one sample



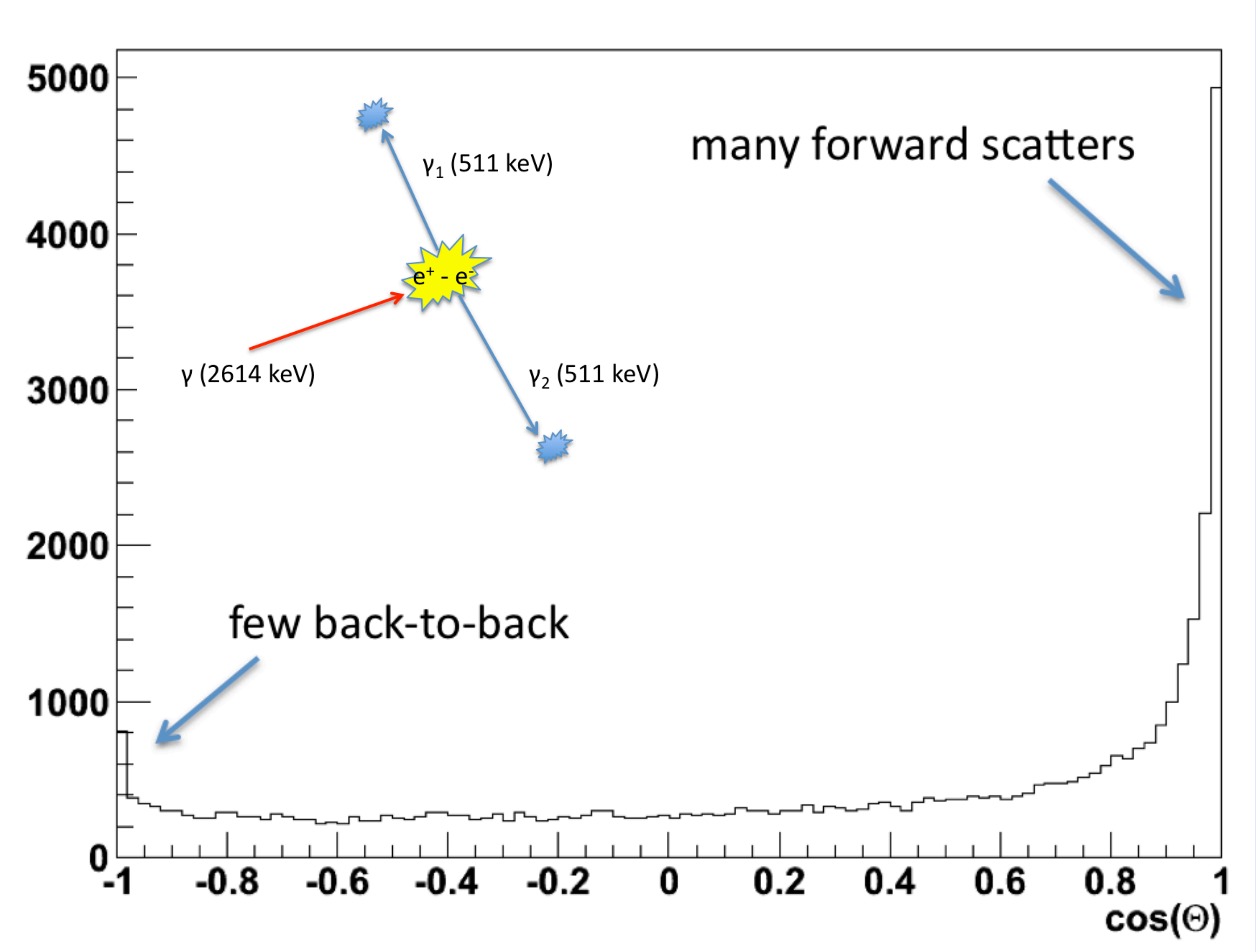
^{228}Th source calibrations



- Calibration runs compared to simulation
  - GEANT4 based simulation
  - charge propagation
  - scintillation propagation
  - signal generation
  - energy resolution parameterization is added in after the fact
- There are no free parameters for these comparisons (worst agreement is +8%)

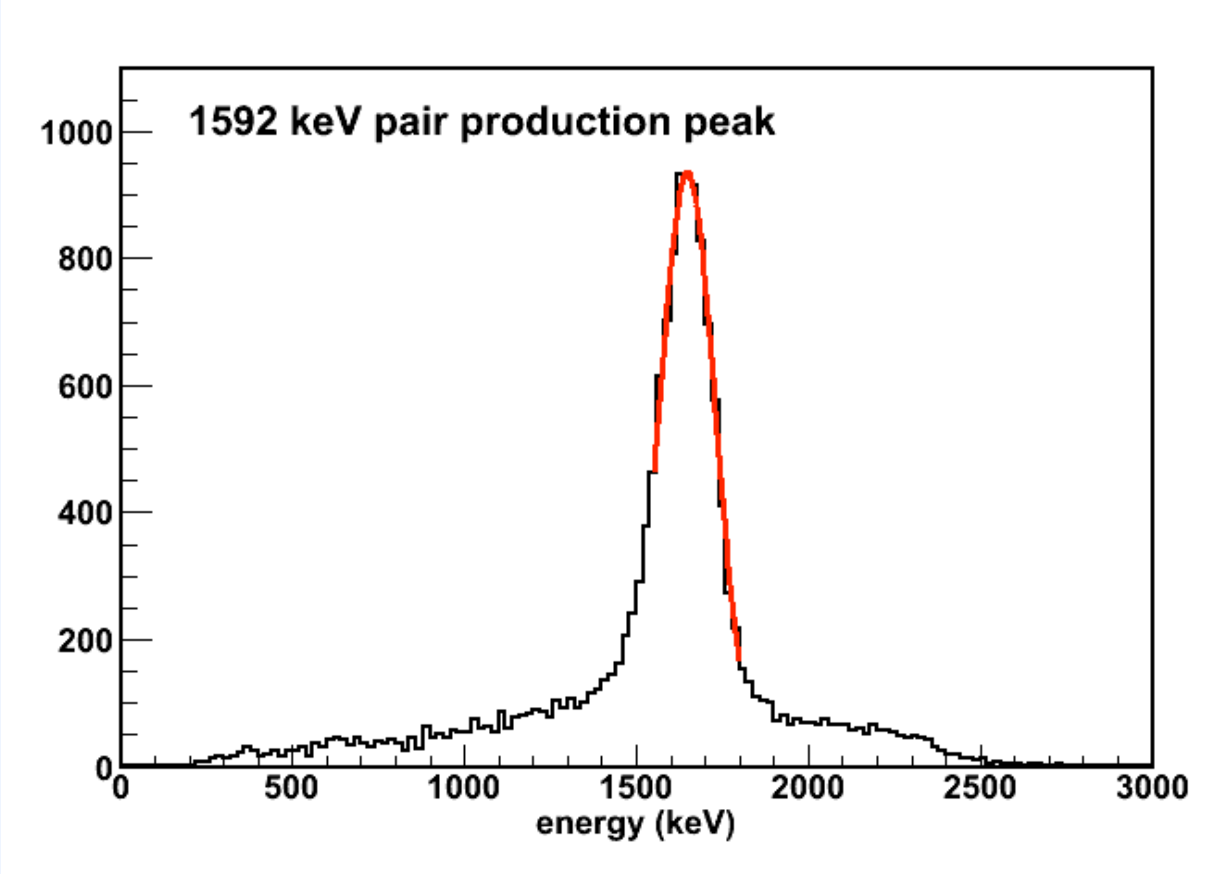
charge-only analysis

energy calibration: pair production

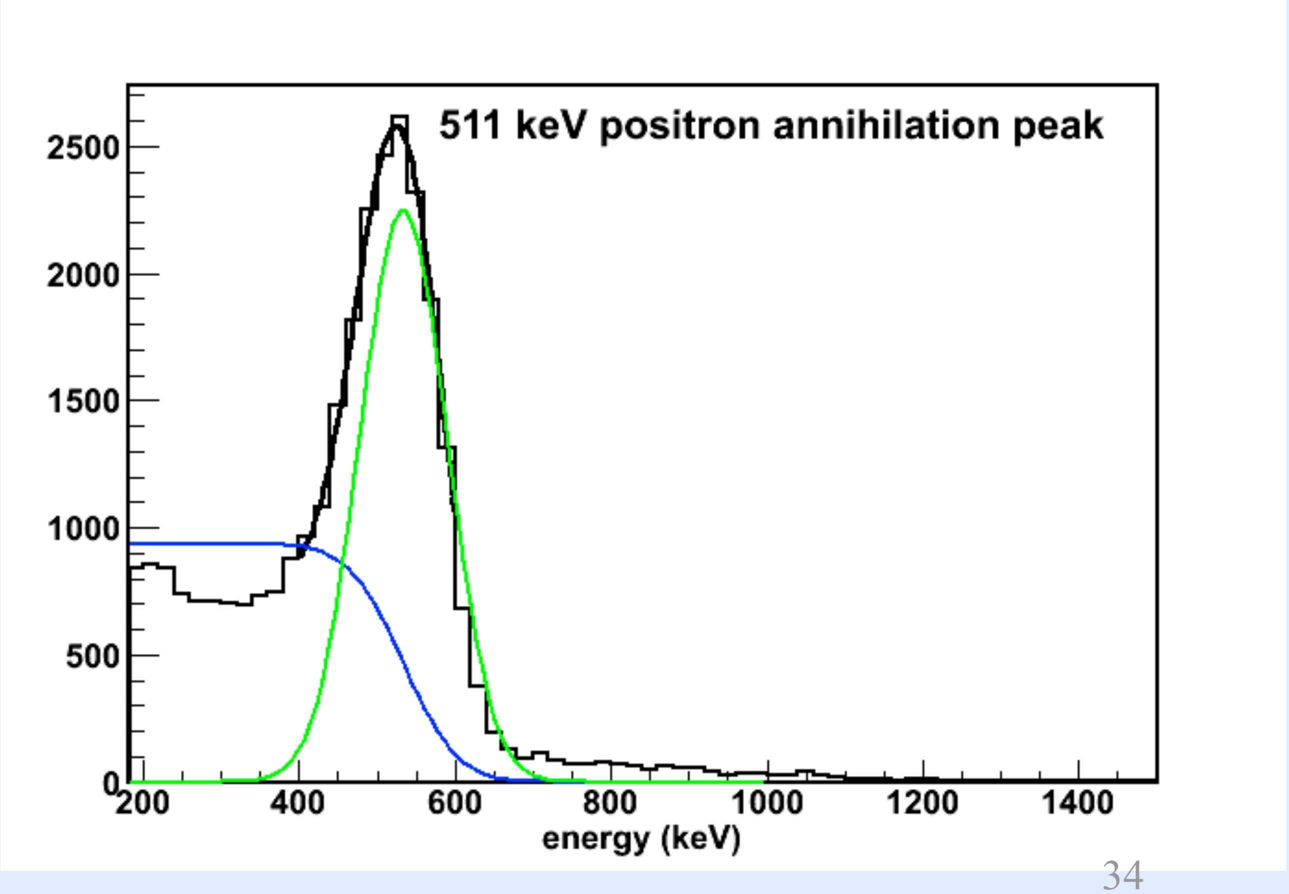


many forward scatters

few back-to-back



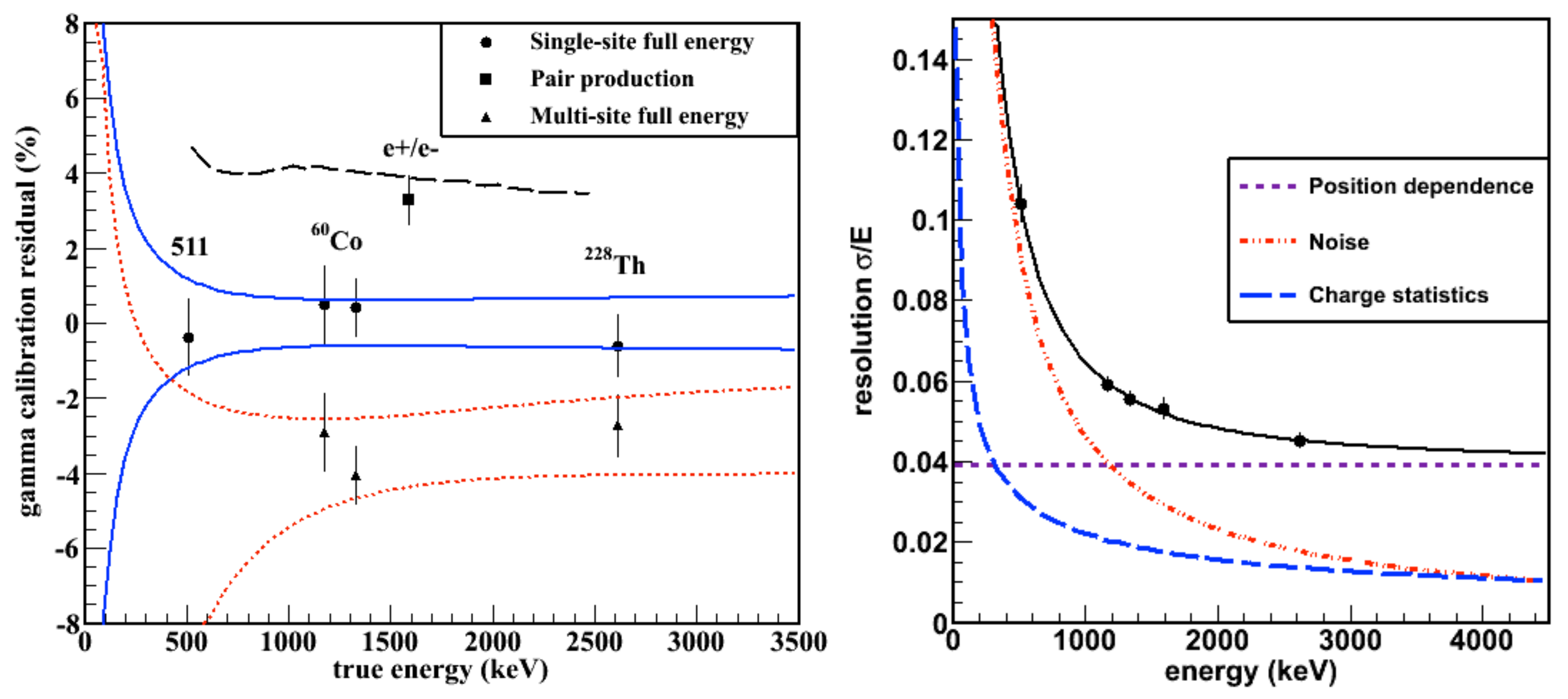
1592 keV pair production peak



511 keV positron annihilation peak

- identify 3-site events (pair-production + 2 annihilation γ's)
- 511 keV are our lowest energy calibration point
- 1592 keV pair production mimics ββ event

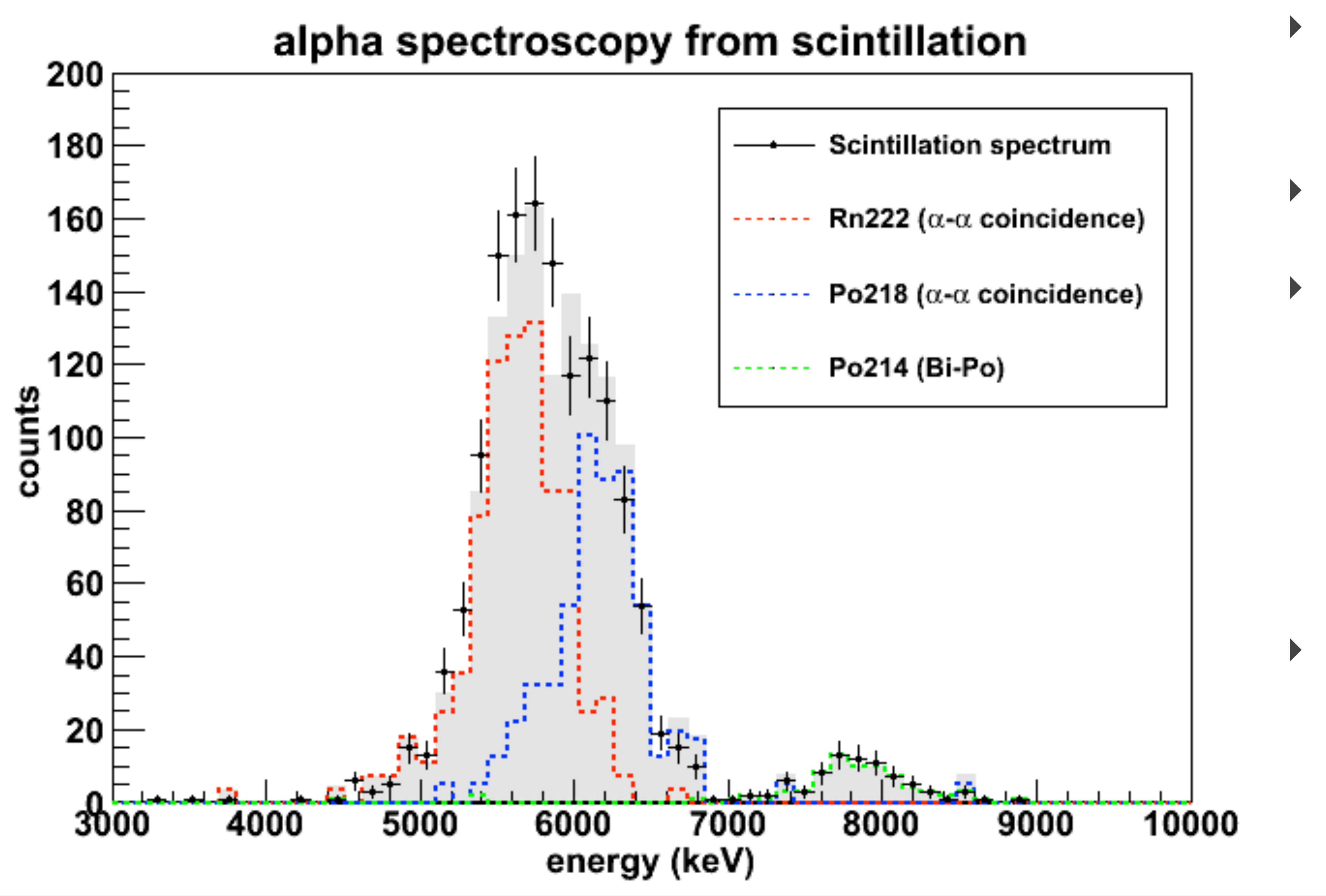
energy calibration



- After purity correction, calibrated single and multiple cluster peaks across energy region of interest (511 to 2615 keV)
  - -uncertainty bands are systematic
- Point-like depositions have large reconstructed energies due to induction effects
  - - observed for pair-production site (similar to β and ββ decays)
  - - reproduced in simulation
- Peak widths also recorded and their dependence on energy is parameterized.

constraints from alpha spectroscopy

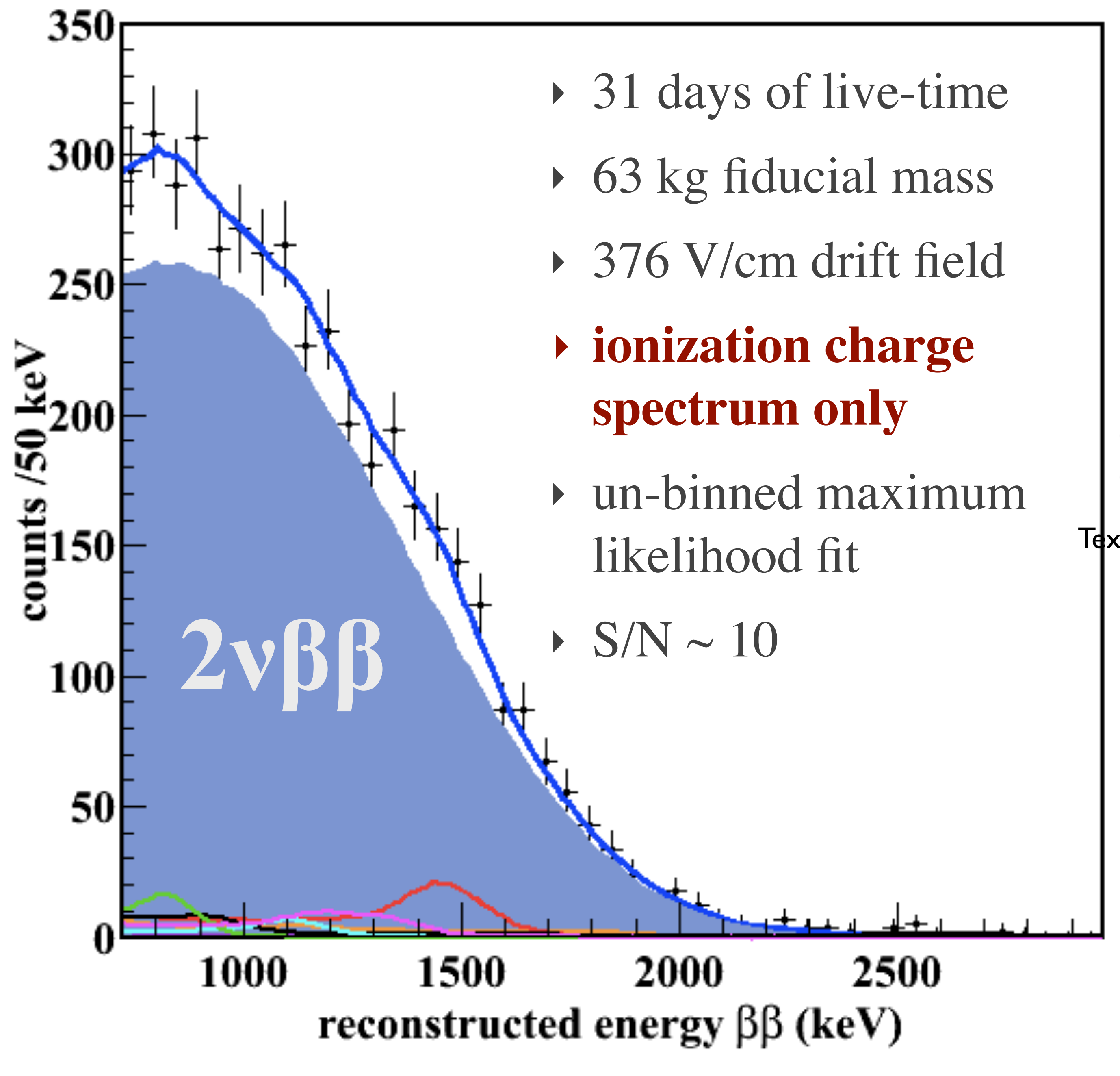
use well-identifiable α decays to constrain plausible backgrounds



- look for α decays in the ^{238}U chain, above ^{222}Rn
- use Rn alphas to calibrate
- can constrain ^{238}U contamination by setting a limit on 4.5 MeV α's (<0.3 counts/day in fiducial volume)
- same limit applies to its daughter ^{234m}Pa, which with its Q=2195 keV β's could be a background (but isn't)

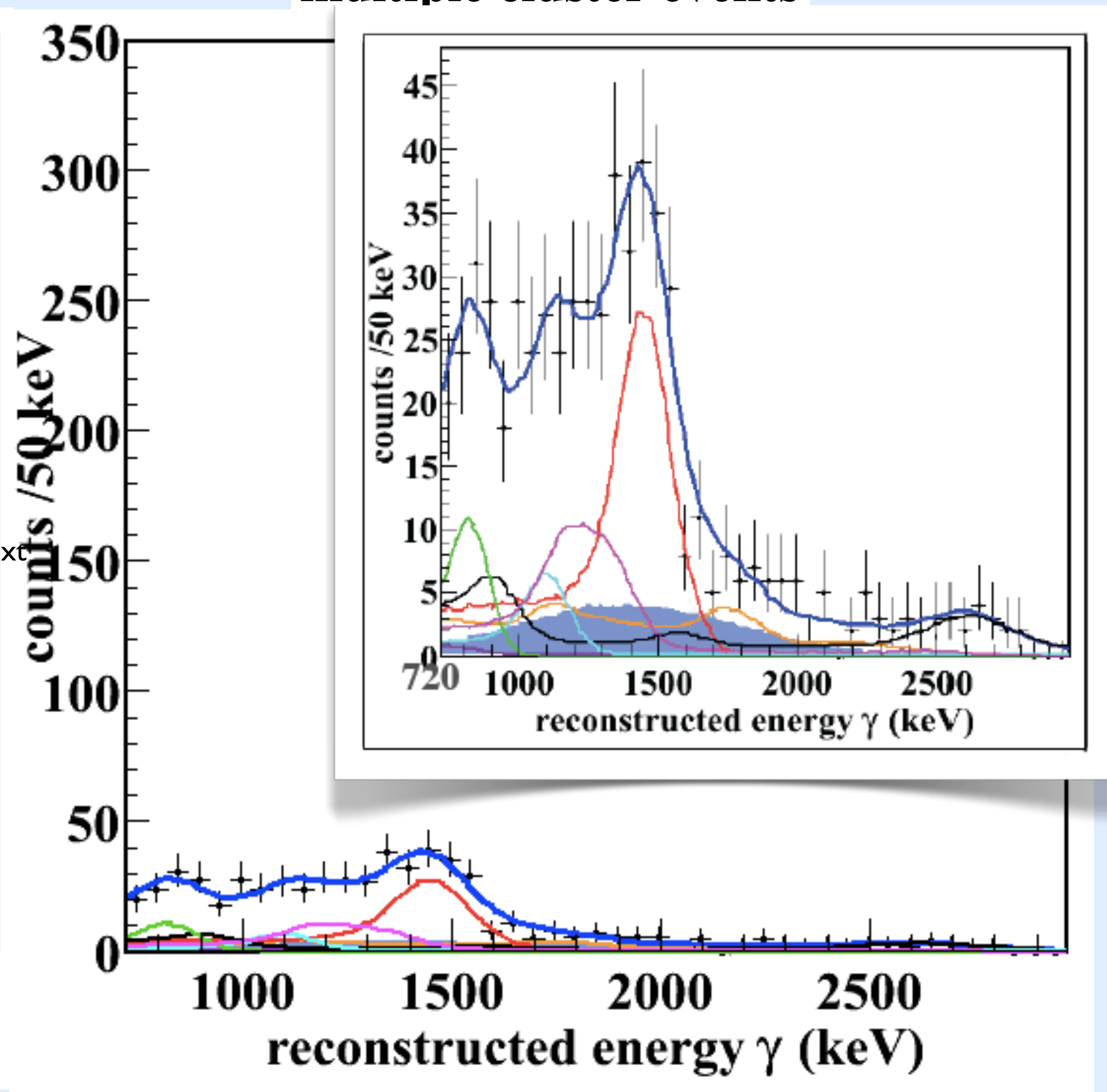
first observation of $2\nu\beta\beta$ of ^{136}Xe

single cluster events



- 31 days of live-time
- 63 kg fiducial mass
- 376 V/cm drift field
- **ionization charge spectrum only**
- un-binned maximum likelihood fit
- S/N ~ 10

multiple cluster events



$$T^{2\nu}_{1/2} = (\mathbf{2.11} \pm \mathbf{0.04}(\mathbf{stat}) \pm \mathbf{0.21}(\mathbf{syst})) \times \mathbf{10^{21}}\ \text{years}$$

[PRL 107, 212501 (2011); arXiv:1108.4193]

$2\nu\beta\beta$ decay matrix elements

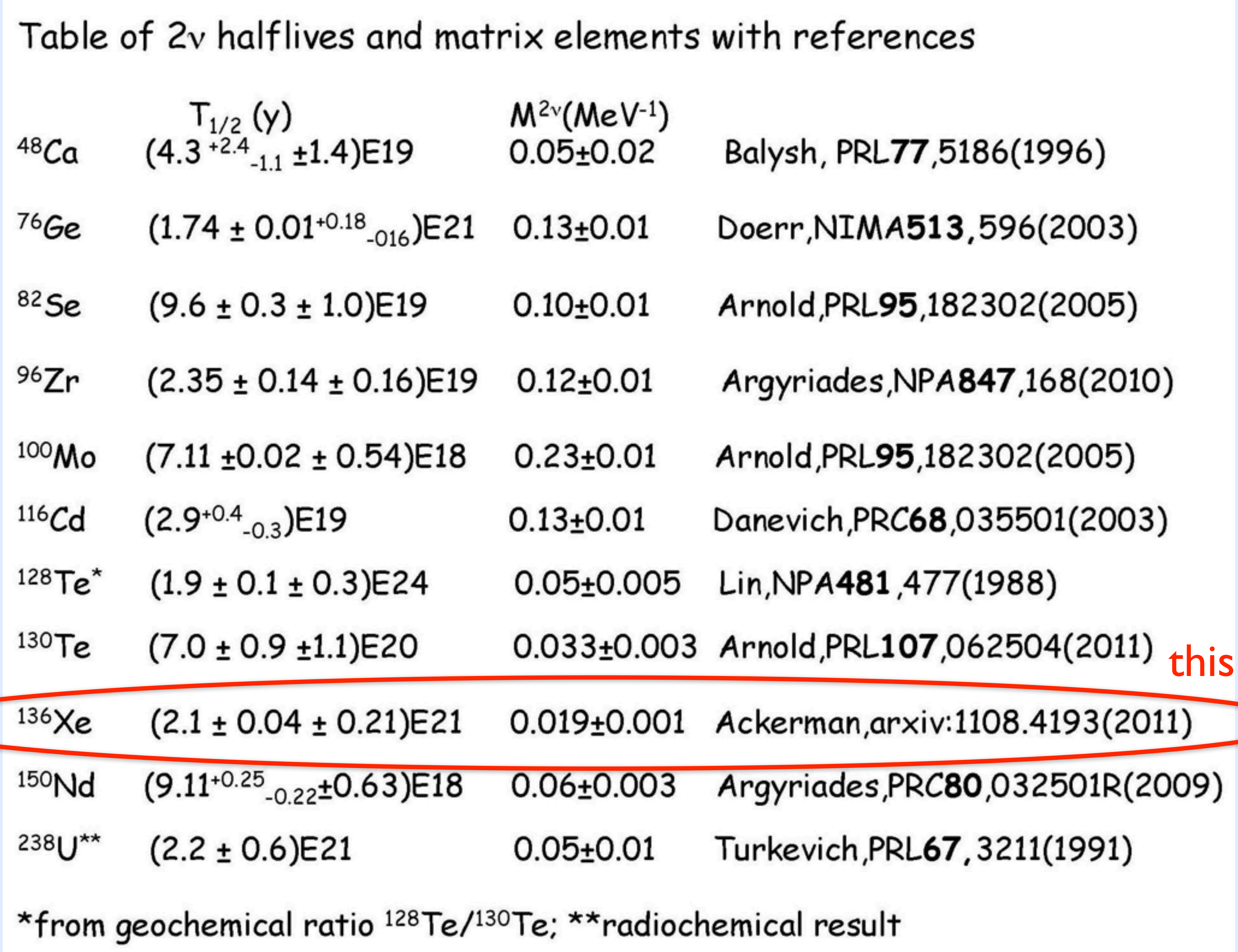


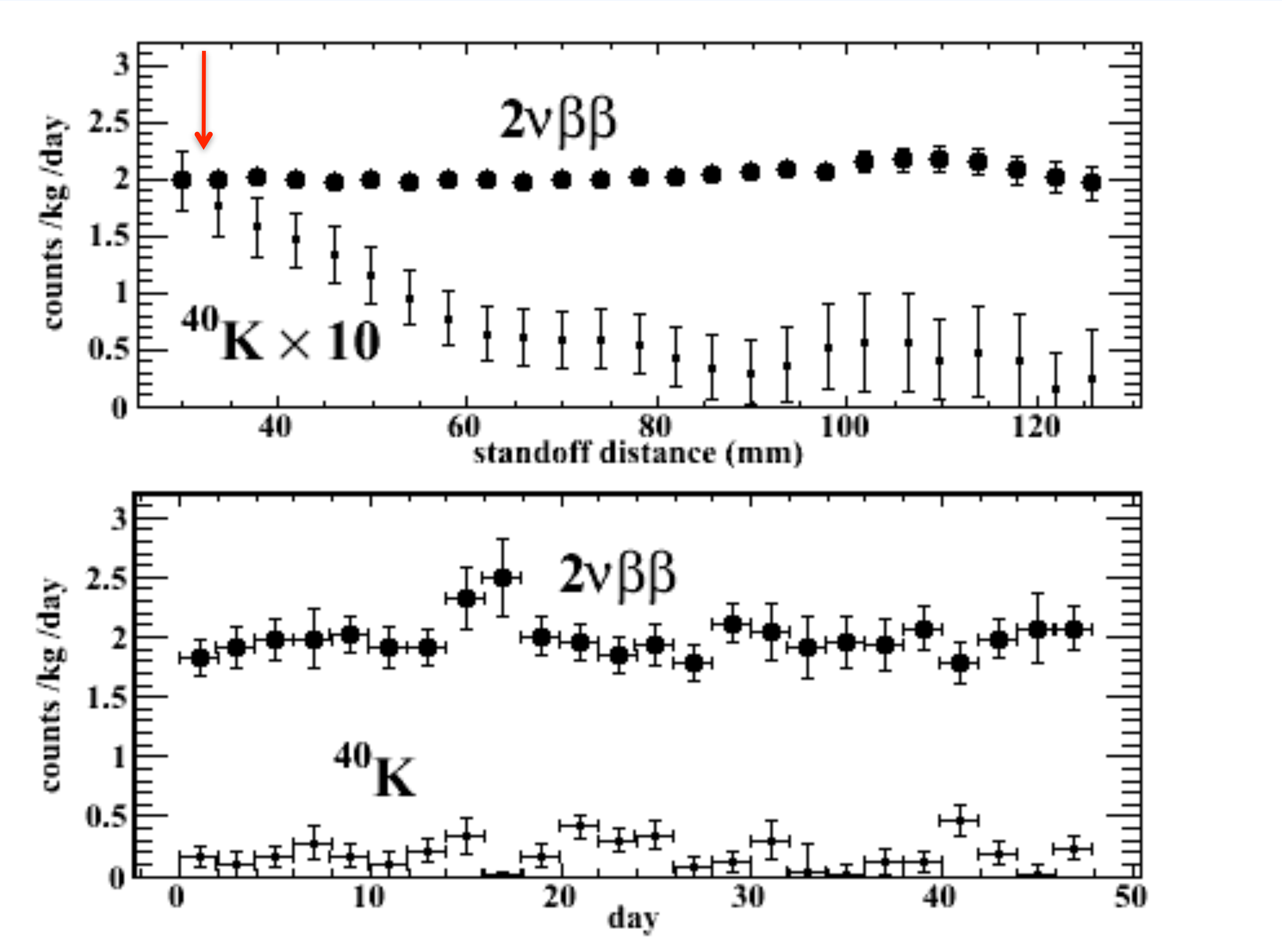
Table of 2ν halflives and matrix elements with references

	$T_{1/2}$ (y)	$M^{2\nu}$(MeV^{-1})	
^{48}Ca	$(4.3^{+2.4}_{-1.1} \pm 1.4)$E19	0.05±0.02	Balysh, PRL**77**,5186(1996)
^{76}Ge	$(1.74 \pm 0.01^{+0.18}_{-016})$E21	0.13±0.01	Doerr,NIMA**513**,596(2003)
^{82}Se	(9.6 ± 0.3 ± 1.0)E19	0.10±0.01	Arnold,PRL**95**,182302(2005)
^{96}Zr	(2.35 ± 0.14 ± 0.16)E19	0.12±0.01	Argyriades,NPA**847**,168(2010)
^{100}Mo	(7.11 ±0.02 ± 0.54)E18	0.23±0.01	Arnold,PRL**95**,182302(2005)
^{116}Cd	$(2.9^{+0.4}_{-0.3})$E19	0.13±0.01	Danevich,PRC**68**,035501(2003)
^{128}Te*	(1.9 ± 0.1 ± 0.3)E24	0.05±0.005	Lin,NPA**481**,477(1988)
^{130}Te	(7.0 ± 0.9 ±1.1)E20	0.033±0.003	Arnold,PRL**107**,062504(2011)
^{136}Xe	(2.1 ± 0.04 ± 0.21)E21	0.019±0.001	Ackerman,arxiv:1108.4193(2011)
^{150}Nd	$(9.11^{+0.25}_{-0.22} \pm 0.63)$E18	0.06±0.003	Argyriades,PRC**80**,032501R(2009)
^{238}U**	(2.2 ± 0.6)E21	0.05±0.01	Turkevich,PRL**67**,3211(1991)

*from geochemical ratio ^{128}Te/^{130}Te; **radiochemical result

this work

low background spectra



- signal constant in time
  - signal is uniform throughout the LXe bulk
    - gamma backgrounds are suppressed towards the center of the detector

Systematic error budget for spring 2011 $2\nu\beta\beta$ analysis

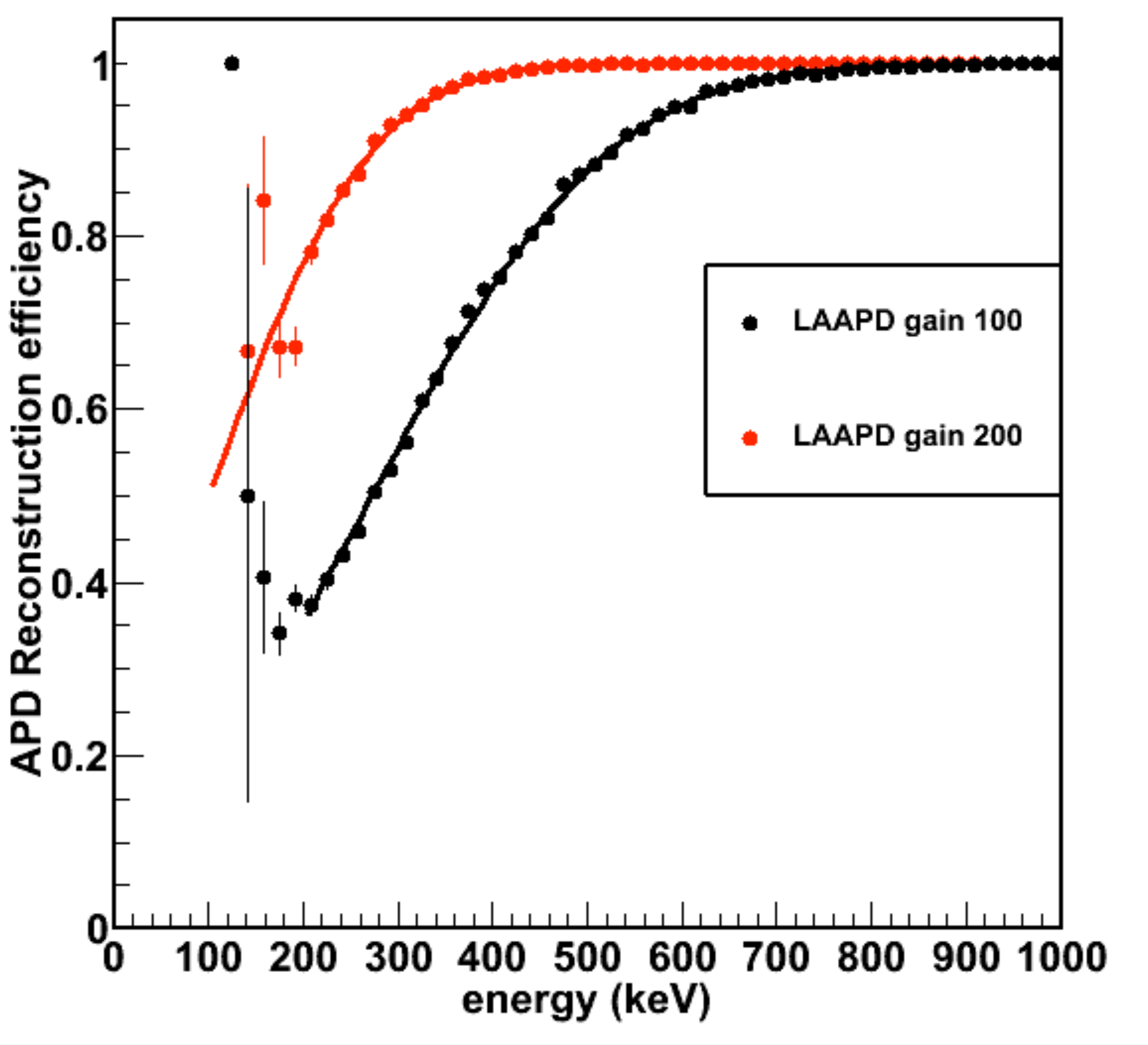
$T^{2\nu\beta\beta}_{1/2} = 2.11\times10^{21}$ yr (± 0.04 stat) (± 0.21 sys)

- Fiducial volume 9.3%
- Multiplicity assignment 3.0 %
- Energy calibration 1.8%
- Background models 0.6%

- Working hard to reduce these for upcoming analyses

3D reconstruction, energy threshold

- events above 100 keV are well above the charge trigger and reconstruction threshold
- 3D reconstruction requires the drift time from the scintillation trigger
- measure reconstruction efficiency by comparing the ratio of fully reconstructed to triggered events
- 700 keV software threshold (for the paper, LAAPD gain = 100)
- currently obtaining much lower threshold (~350 keV) with higher LAAPD gain of 200

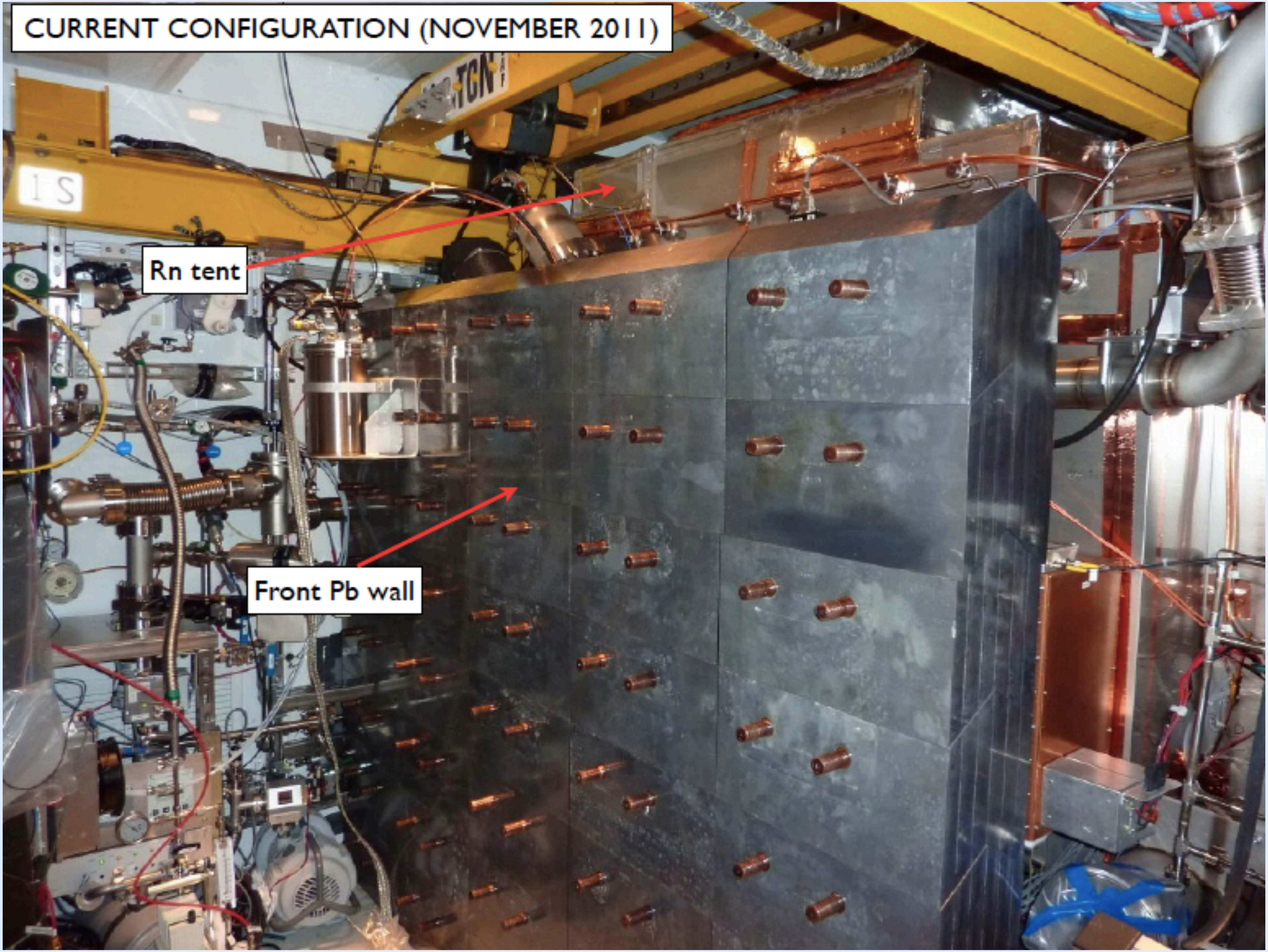


what's ahead

our background at $Q_{\beta\beta}$ = 2458 keV for this analysis was
~0.004 counts/(kg keV y)

- complete front Pb wall (done)
- flush radon-suppression tent around cryostat
- install radon trap on xenon input
- upgrade electronics, improve clustering
- increase LAAPD gain, reduce energy threshold
- 3D multiple site discrimination
- ionization + scintillation anticorrelation

CURRENT CONFIGURATION (NOVEMBER 2011)



EXO-200 sensitivity

Case	**Mass (ton)**	**Eff. (%)**	**Run Time (yr)**	**σ_E/E @ 2.5MeV (%)**	**Radioactive Background (events)**	**$T_{1/2}^{0\nu}$ (yr, 90%CL)**	**Majorana mass (meV)**	
							QRPA[1]	**NSM[2]**
EXO-200	**0.2**	**70**	**2**	**1.6***	**40**	**6.4×10^{25}**	**109**	**135**

** σ(E)/E = 1.4% obtained in EXO R&D, Conti et al., Phys. Rev. B 68 (2003) 054201*

[1] Simkovic et al. Phys. Rev. C79, 055501(2009) [use RQRPA and g_A= 1.25]

[2] Menendez et al., Nucl. Phys. A818, 139(2009), use UCOM results

improves sensitivity for ^{136}Xe 0νββ by one order of magnitude

detected 2νββ of ^{136}Xe (|$M^{2\nu}$|=0.019 MeV^{-1})

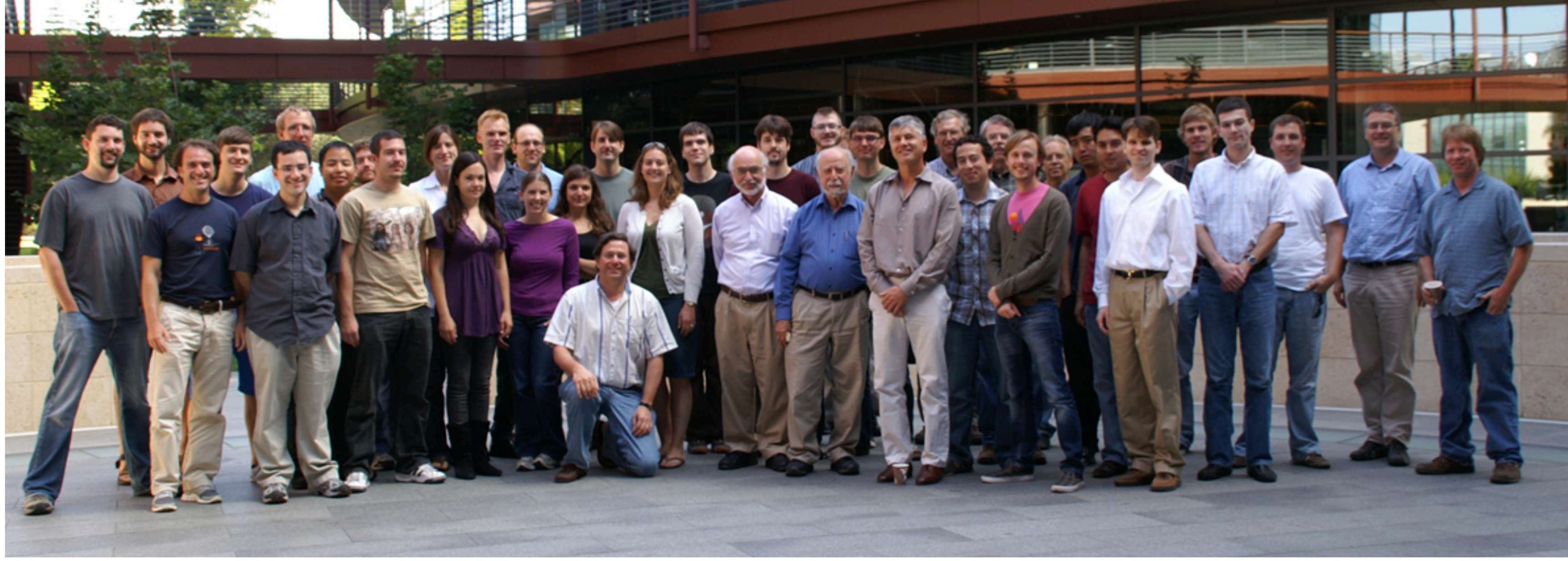
(reference: 10^{25} years lifetime => 440 events/year/ton of ^{136}Xe)

discovery claim in ^{76}Ge: $T_{1/2} = 2.23^{+0.44}_{-0.31} \times 10^{25}$y

46/170 (QRPA/NSM) events above 40 bg: confirm or rule out at 5/11.7 σ

The EXO Collaboration

Enriched Xenon Observatory
EXO
for double beta decay



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University of Illinois, Urbana-Champaign IL, USA - J. Walton, L. Yang

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Stanford University, Stanford CA, USA - P.S. Barbeau, T. Brunner, J. Davis, R. DeVoe, M.J. Dolinski, G. Gratta, M. Montero-Díez, A.R. Müller, R. Neilson, I. Ostrovskiy, K. O'Sullivan, A. Rivas, A. Sabourov, D. Tosi, K. Twelker

Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino

disagreement with previous results

- two experiments have published experimental limits for 2νββ of 136 Xe which are incompatible with EXO-200

- DAMA-LXe @ Gran Sasso (6.5 kg, enriched LXe, 3 PMTs):

$$\mathbf{T^{2\nu}_{1/2} > 1.0 \cdot 10^{22}} \text{ years} \quad \mathbf{(90\%\ C.L.)}$$

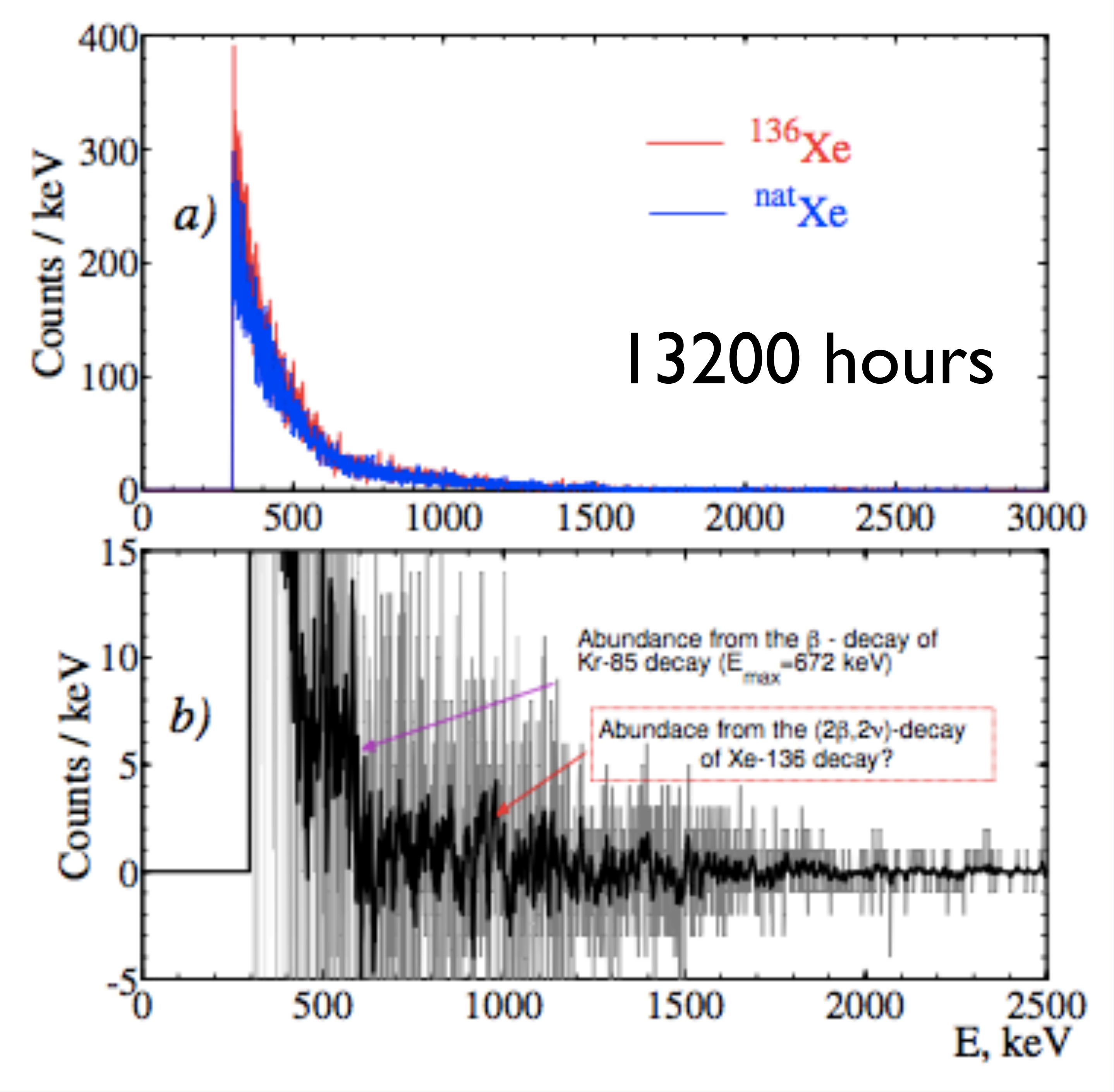
[R. Bernabei et al., Phys. Lett. B: **546**, 23 (2002)]

- Baksan (800g, enriched GXe, 15 bar, 2 proportional counters)

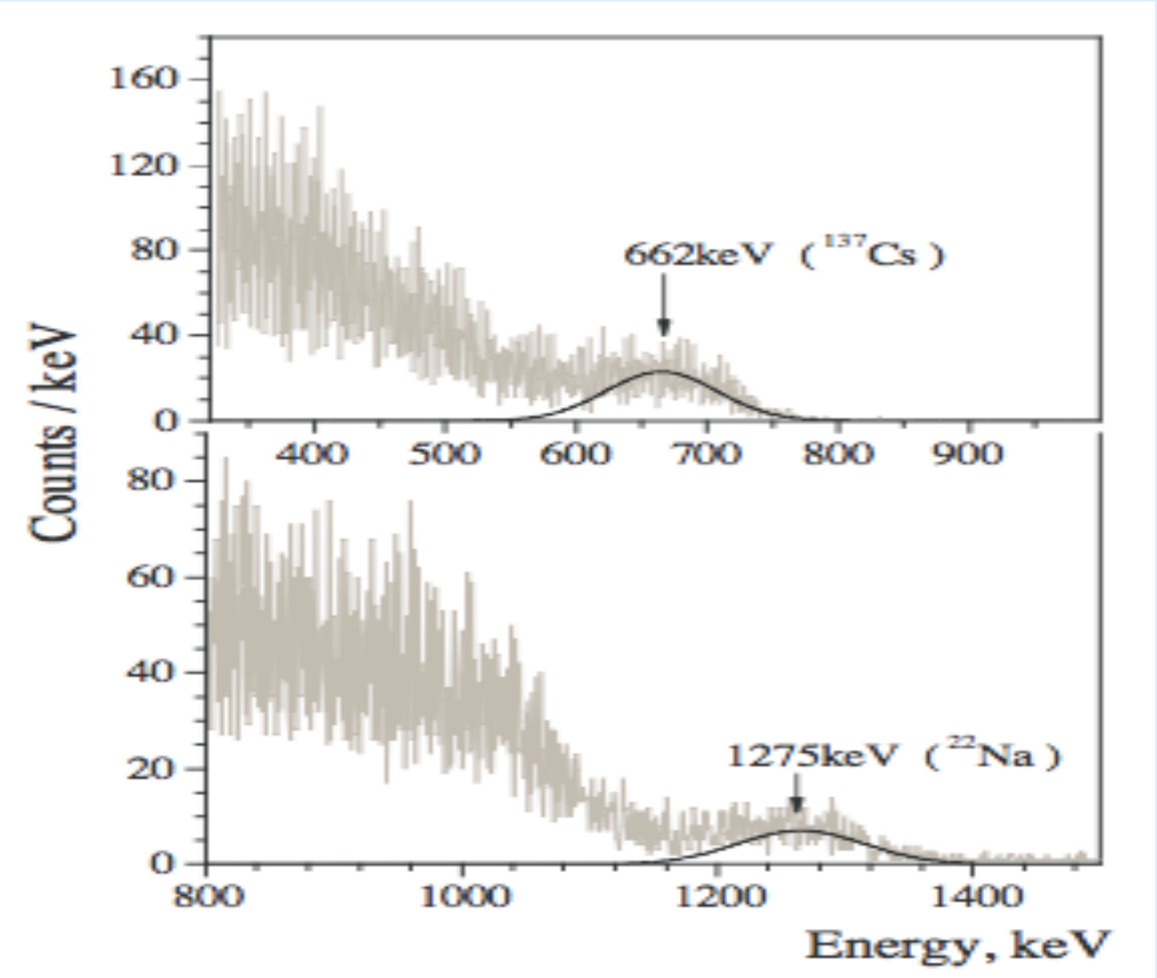
$$\mathbf{T^{2\nu}_{1/2} > 8.5 \cdot 10^{21}} \text{ y} \quad \mathbf{(90\%\ C.L.)}$$

[Yu.M. Gavriljuk et al., Phys. Atom. Nucl: **69**, 2129 (2006) - arXiv:nucl-ex/0510071]

Baksan re-analysis



13200 hours



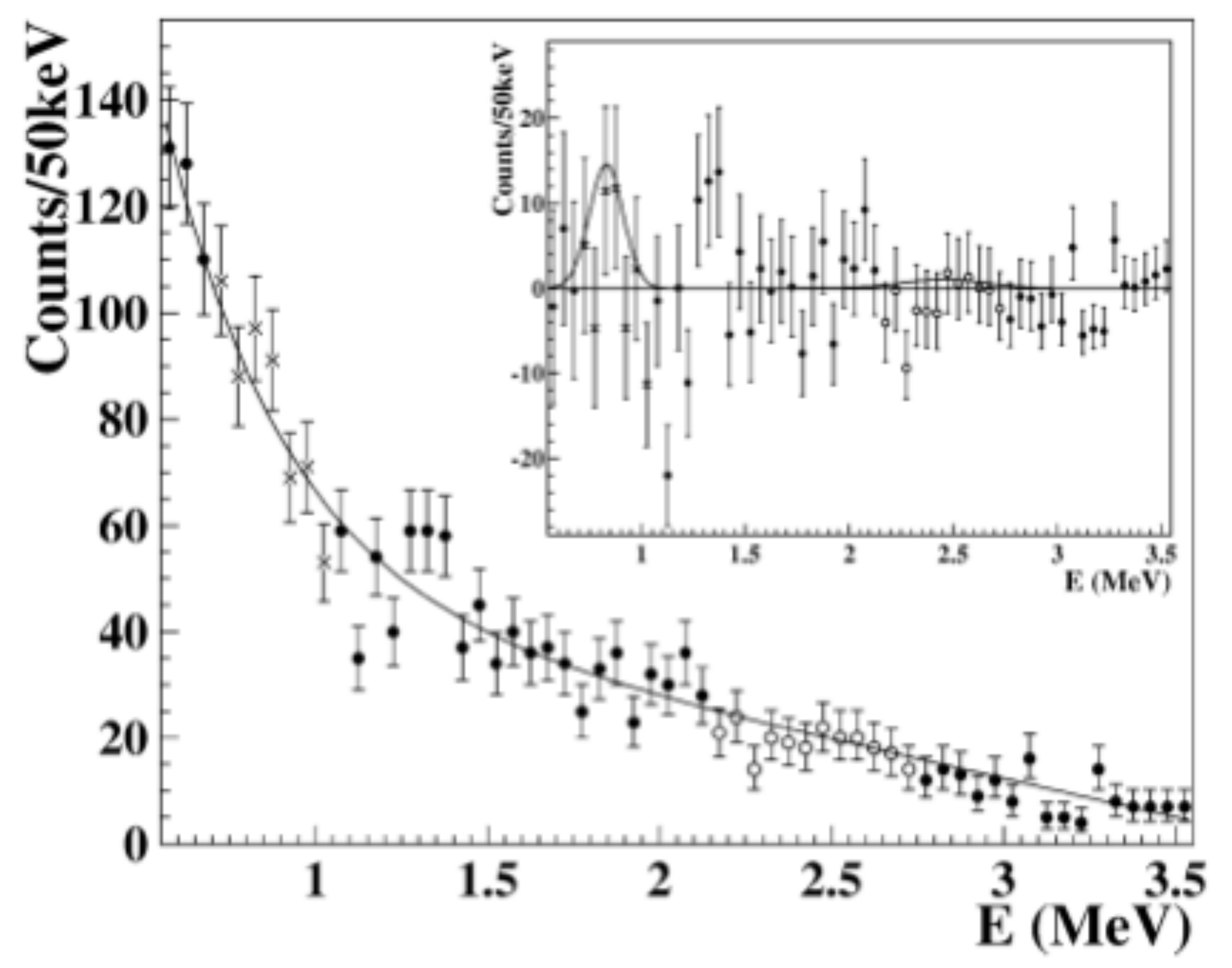
$$\mathbf{T^{2\nu}_{1/2} = 5.5^{+4.5}_{-1.7} \times 10^{21}} \quad (67\% \text{ C.L.})$$

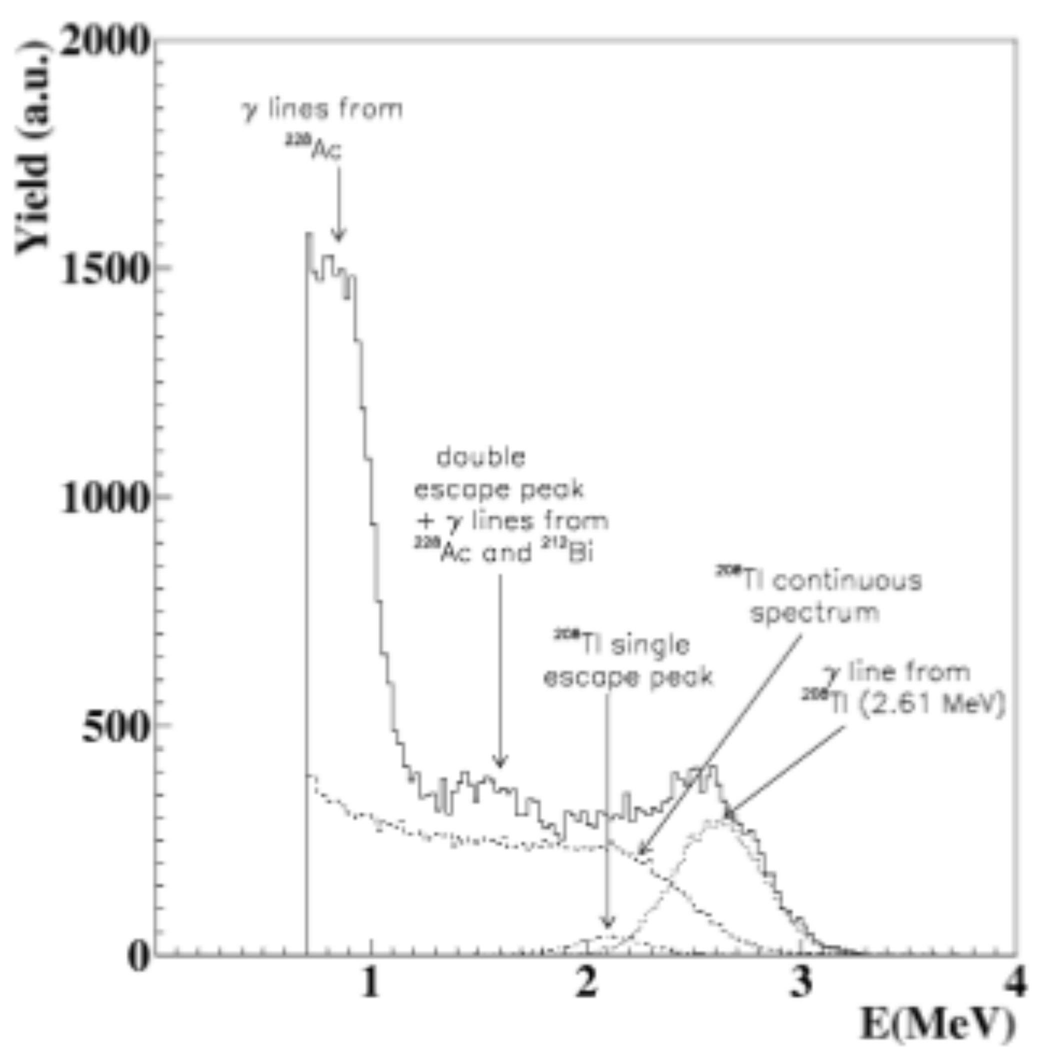
- 800g GXe, 15 bar
- 2 proportional counters
- analysis based on the subtraction between enriched and natural xenon runs

[Ju.M. Gavriljuk et al., arXiv:1112.0859]

DAMA - LXe @ LNGS

- 6.5 kg, enriched LXe
- OFHC copper chamber
- 3 PMTs
- MgF_2 windows





$$\mathbf{T^{2\nu}_{1/2} > 1.0 \cdot 10^{22}}\ \text{years} \quad \mathbf{(90\%\ C.L.)}$$

[R. Bernabei et al., Phys. Lett. B: **546**, 23 (2002)]

comparison with DAMA-LXe

- energy scale was calibrated with source(s)
- DAMA-LXe's limit:

$$\mathbf{T^{2\nu}_{1/2} > 1.0 \cdot 10^{22}\ y \quad (90\%\ C.L.)}$$

- real vs live time?
- ln2 factor from numerator to denominator?
- wrong enrichement factor?

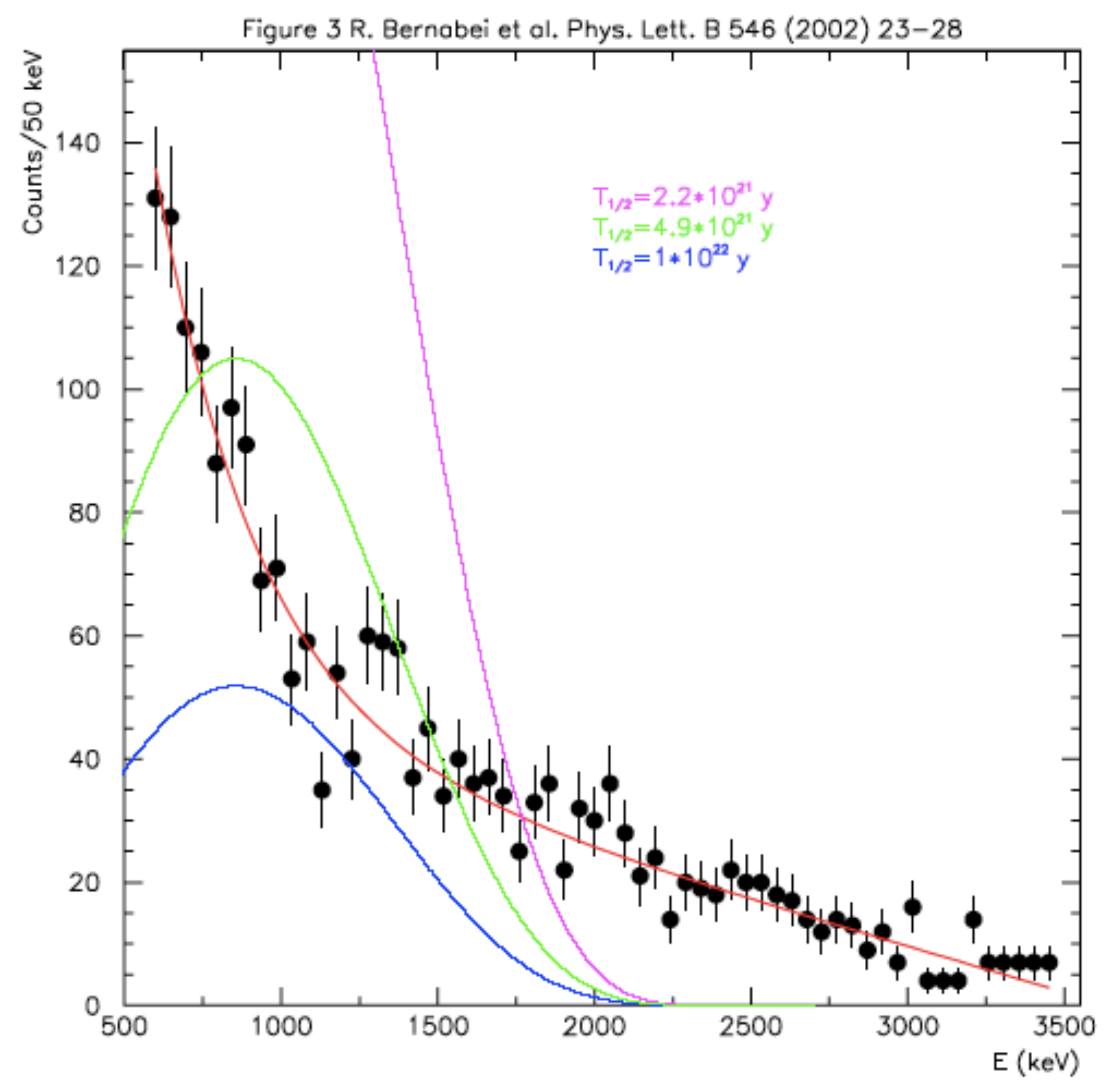
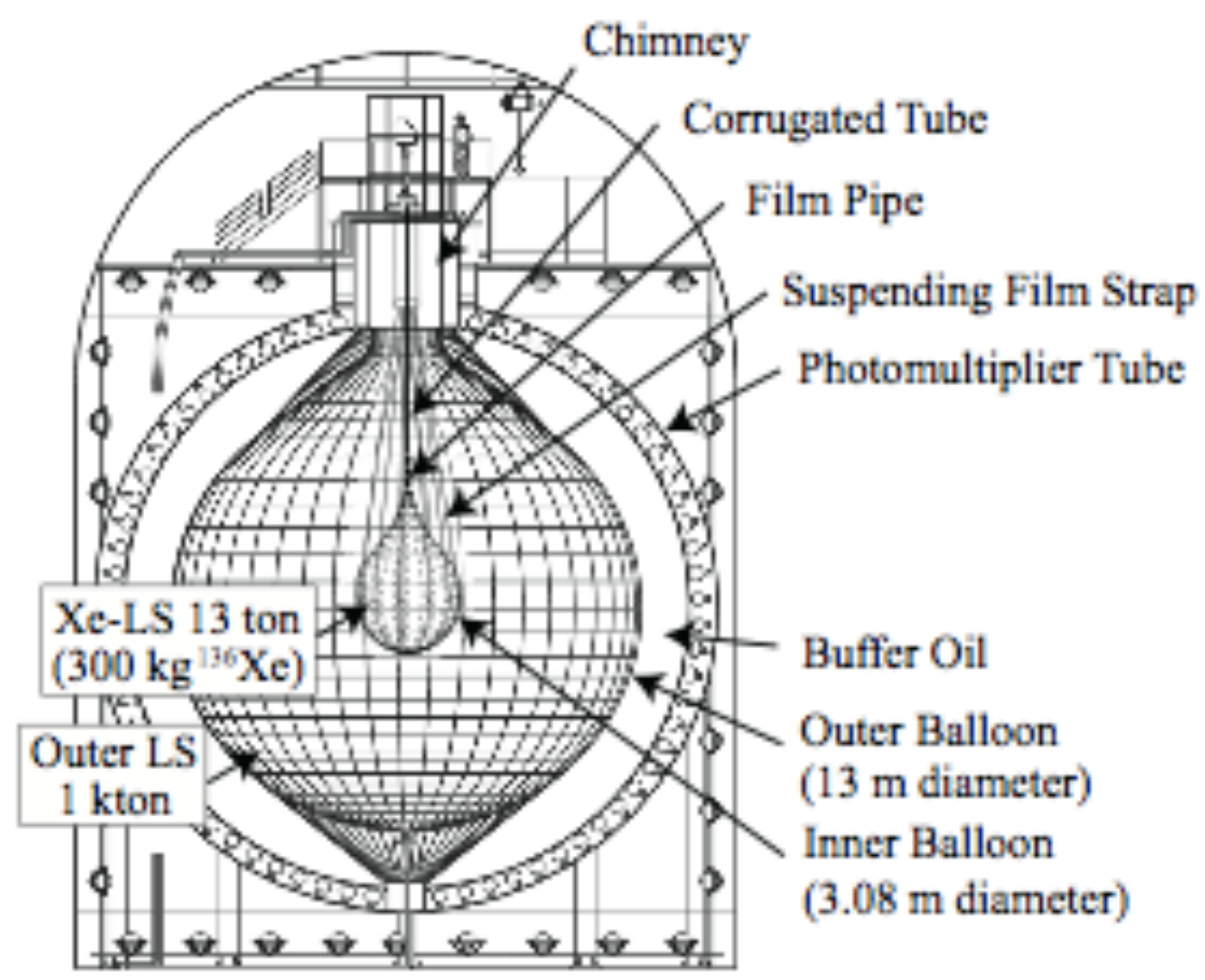
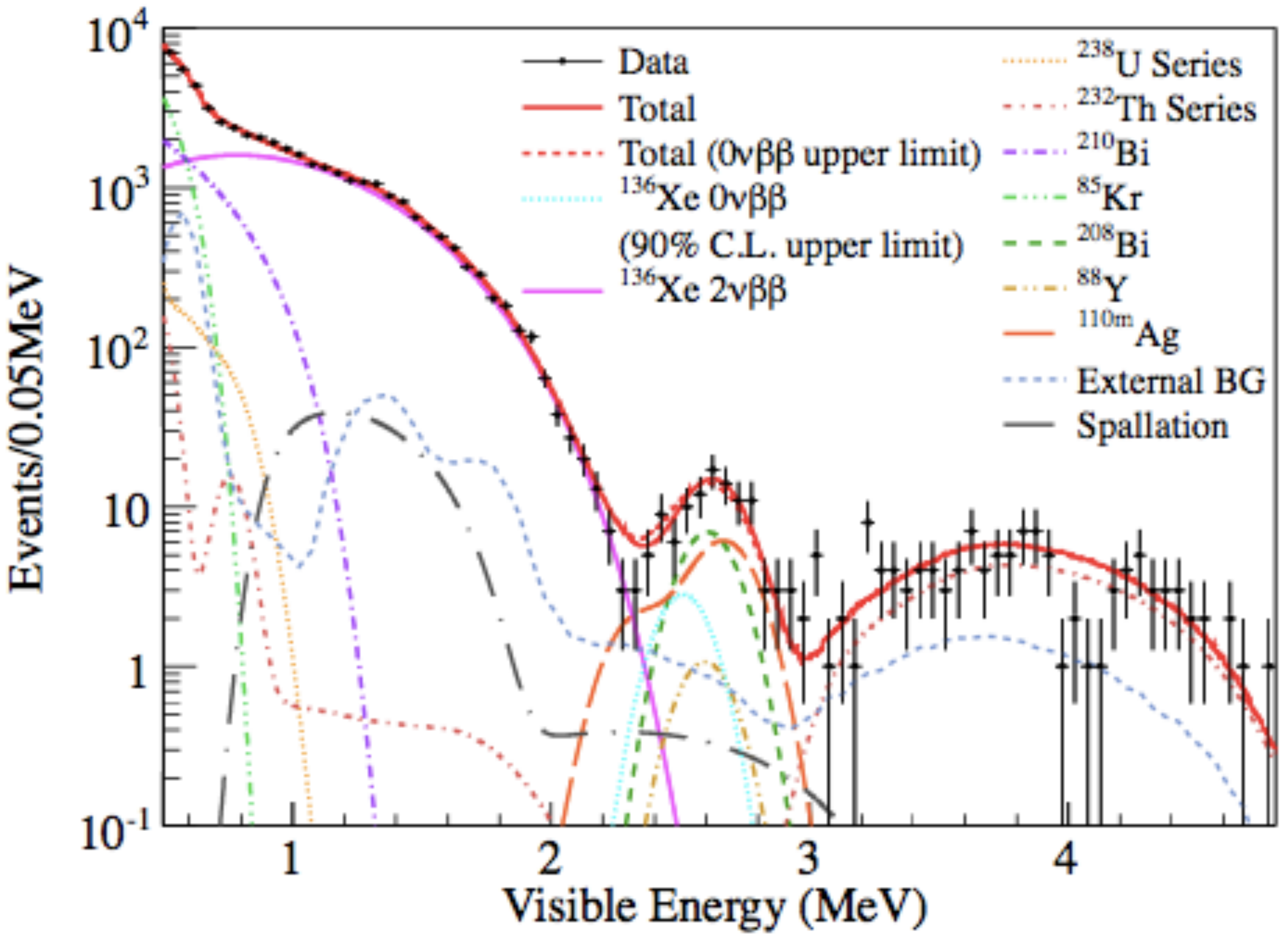


Figure 3 R. Bernabei et al. Phys. Lett. B 546 (2002) 23–28

KamLAND-Zen





- 300 kg of 90%-^{enr}Xe dissolved in 13 tons of liquid scintillator (2.5% concentration)

$$\mathbf{T^{2\nu}_{1/2} = 2.38 \pm 0.02\ (stat) \pm 0.14\ (syst) \times 10^{22}}\ \mathrm{y}$$

$$\mathbf{T^{2\nu}_{1/2} > 5.7 \times 10^{24}}\ \mathrm{y}\ \ (90\%\ \mathrm{C.L.})$$

A. Gando et al., arXiv:1201.4664

a ton-scale EXO

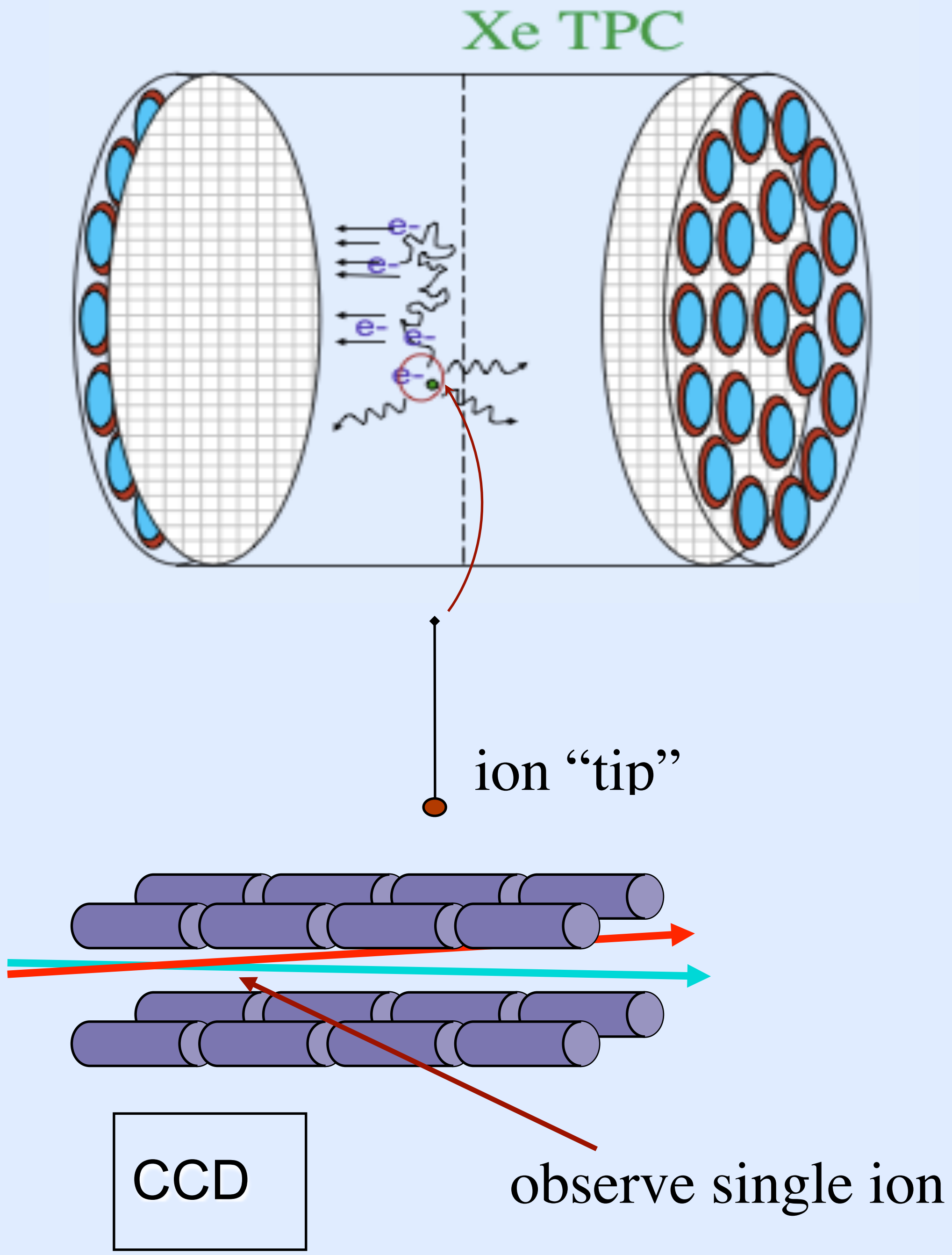
xenon admits a novel coincidence technique:
drastic background reduction by Ba daughter tagging!

detect the 2 electrons
(ionization + scintillation in xenon detector)

$$^{136}\text{Xe} \rightarrow {}^{136}\text{Ba}^{++} + 2e^{-}\ (+\ 2\nu_e)$$

positively identify daughter via
optical spectroscopy of Ba^+

other Ba^+ identification strategies are being
investigated within the EXO collaboration



[M. Moe, Phys. Rev. C 44 (1991) R931]

0νββ and neutrino masses

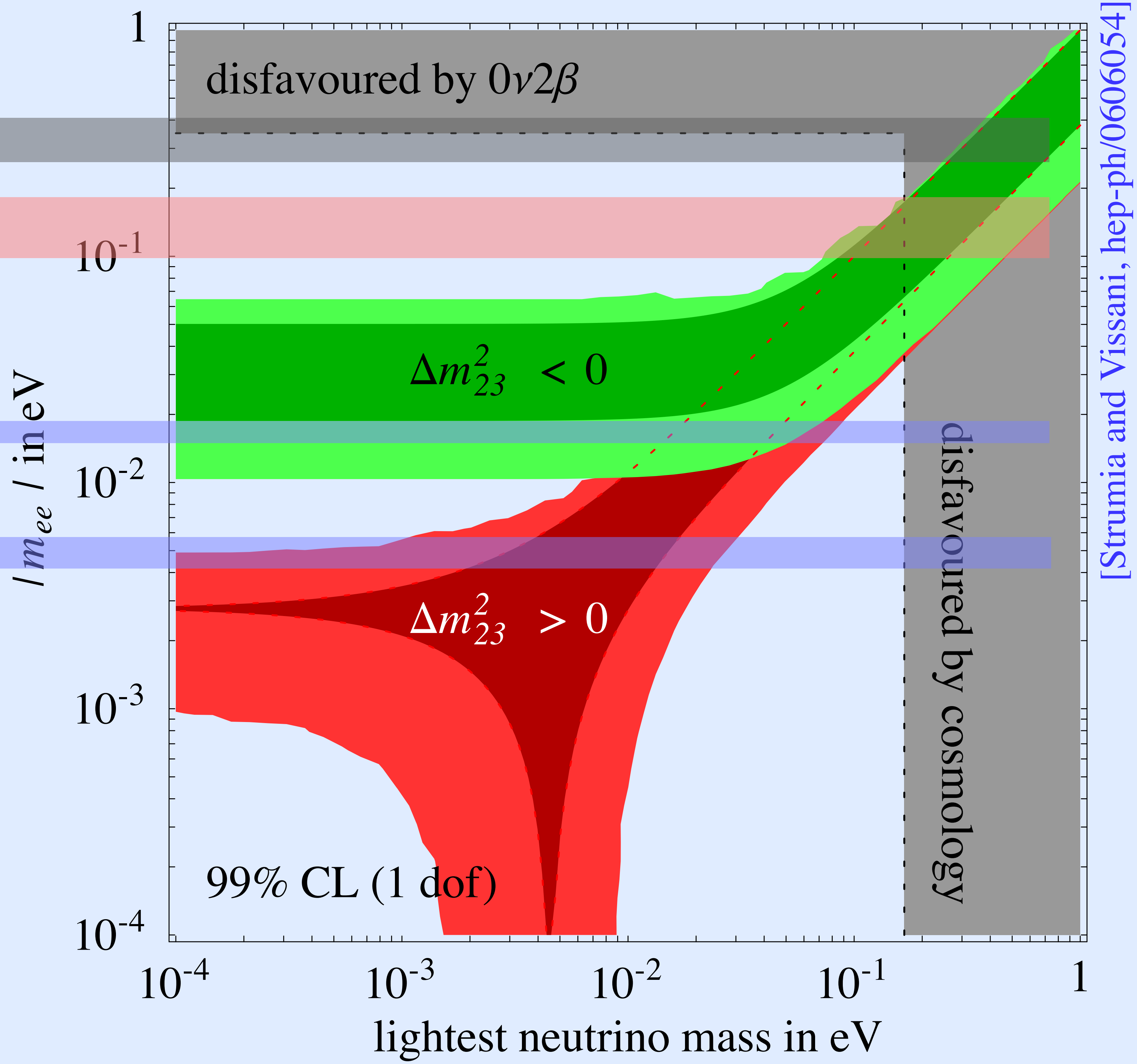
[PLB 586(2004)198]

Klapdor et al.

EXO-200 (~100 meV)

EXO (2 tons, 5 years, ~18 meV)

EXO (10 tons, 10 years, ~5meV)



[Strumia and Vissani, hep-ph/0606054]

m_{eff} ~ 50 meV: ~ 10^{27} years

(10^{27} nuclei ~ 10^3 moles ~ 100 kg)

sensitivity of ton-scale EXO with barium tagging

Assumptions:

1. 80% enrichment in Xe-136
2. 68% overall efficiency: 95% energy cut * 80% tracking effic * 90% lifetime fraction from EXO-200 analysis
3. Intrinsic low background + Ba tagging eliminate all radioactive background
4. Energy resolution only used to separate the 0ν from 2ν modes: select 0ν events in a ±2σ interval centered around the 2.458 MeV endpoint
5. Use for $2\nu\beta\beta$ $T_{1/2}=2.11\times10^{22}$yr (Ackerman et al., arXiv:1108.4193, 21 August 2011)

Case	Mass (ton)	Eff. (%)	Run Time (y)	σ_E/E @ 2.5MeV (%)	$2\nu\beta\beta$ Background (events)	$T_{1/2}^{0\nu}$ (y) (90% CL)	Majorana mass (meV)	
							QRPA[1]	NSM[2]
large	2	68	5	1.6*	5	$2.4*10^{27}$	16	20
very large	10	68	10	1†	3.4	$3.5*10^{28}$	4.7	5.8

[*] σ(E)/E = 1.6% obtained in EXO R&D, Conti et al Phys Rev B68 (2003) 054201

[†] σ(E)/E = 1.0% considered as an aggressive but realistic guess with large light collection area

[1] Šimkovic et al., Phys. Rev. C79 055501 (2009) [use RQRPA with $g_A=1.25$]

[2] Menendez et al., Nucl. Phys. A818 139 (2009) [use UCOM results]

summary

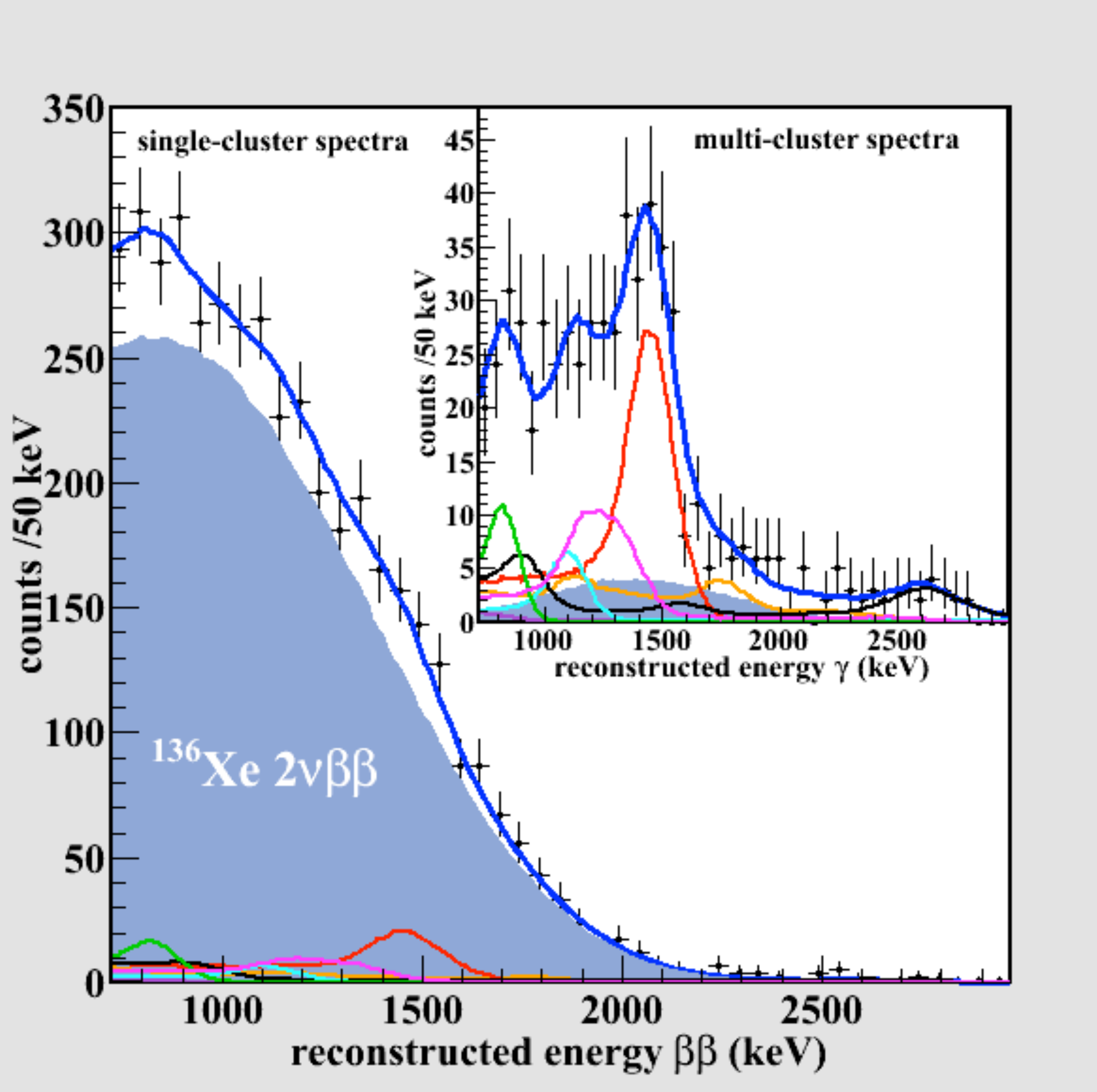
- EXO-200 (200 kg of enriched xenon) has recently measured $2\nu\beta\beta$ decay of ^{136}Xe and is performing very well

- a good start, improved purity and lower energy threshold define a promising path ahead

- full understanding of the energy resolution to come

- hopefully a $0\nu\beta\beta$ decay result for ^{136}Xe will arrive soon

- (and ... we are working on a future, larger detector too)



The Final State(ment)

THANK YOU