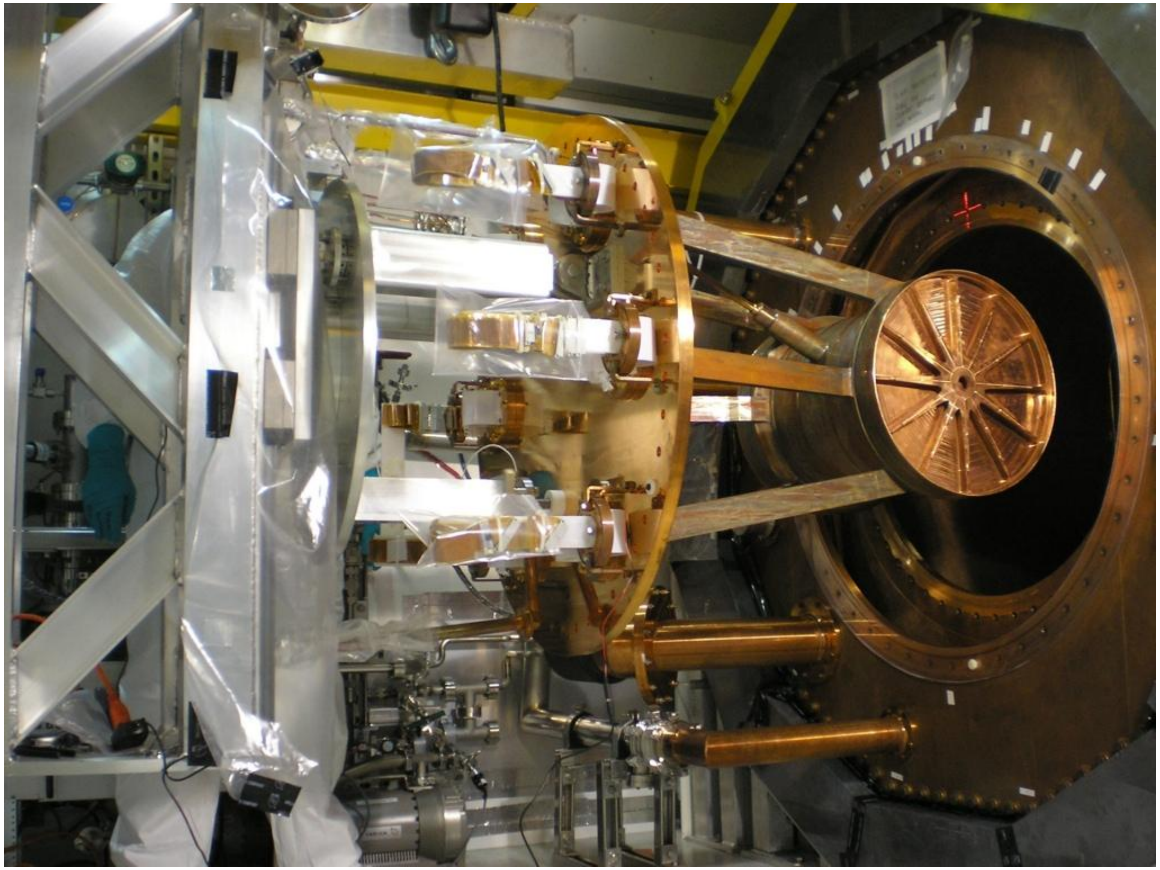
EXO-200 Results

Russell Neilson, University of Chicago

for the EXO Collaboration



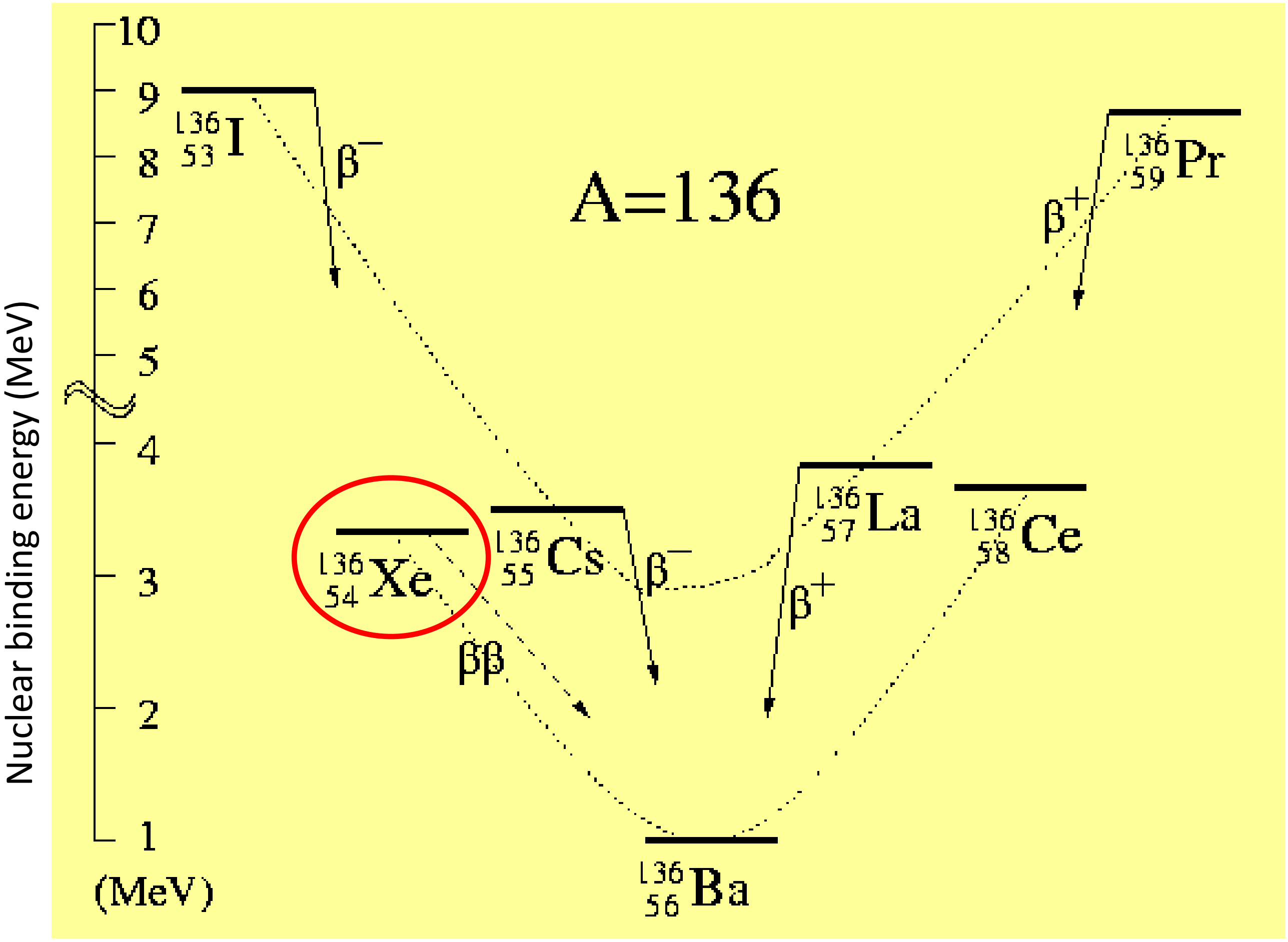
NDM12 Nara June 9, 2012

Double beta decay

Extremely rare nuclear decay where two neutrons decay into two protons simultaneously.

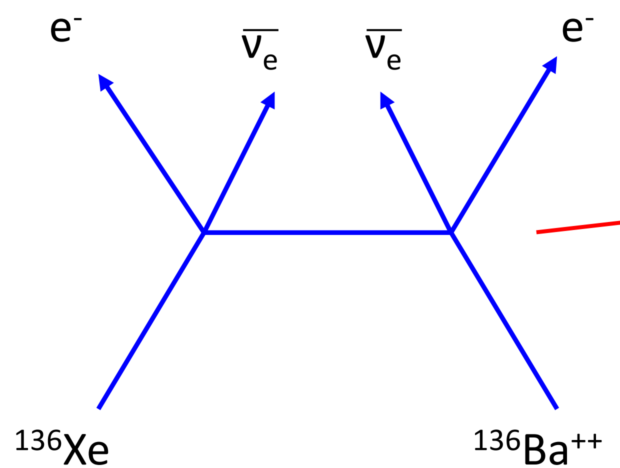
$(A,Z) \rightarrow (A,Z+2) + 2e^- \; (+2\overline{\nu}_e)$

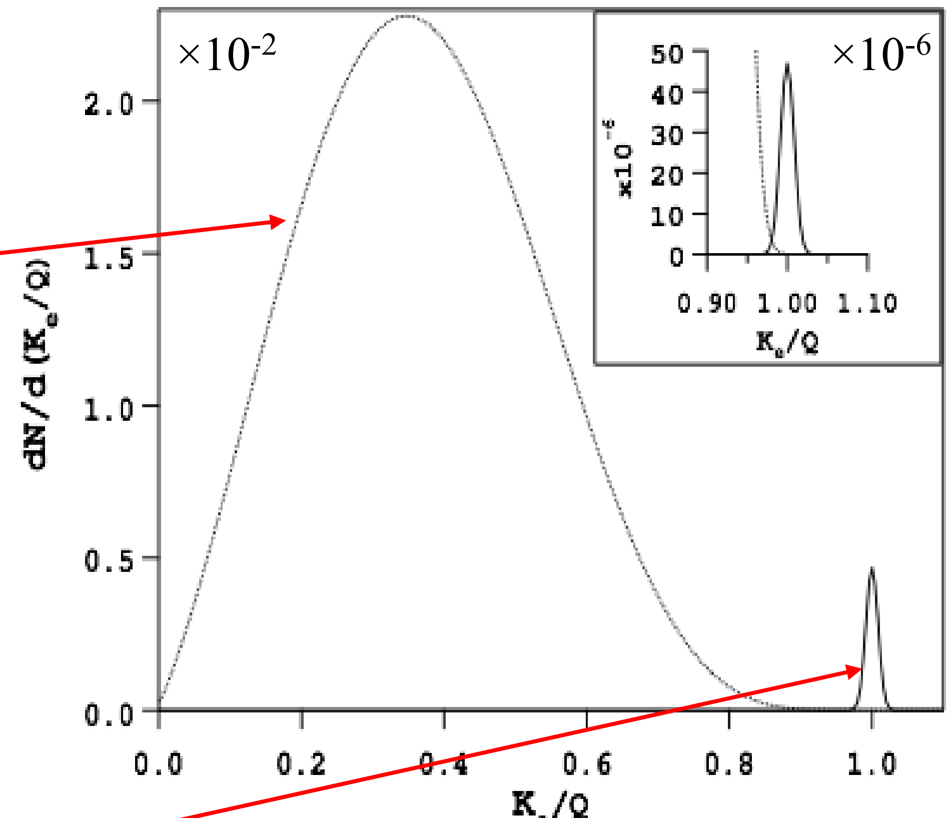
Only observable when single beta decay is energetically forbidden.



Two types of double beta decay

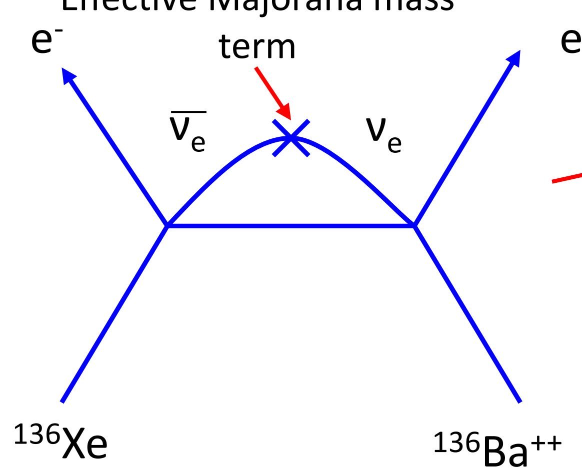
Two neutrino double beta decay





[P. Vogel, arXiv:hep-ph/0611243;
S.R. Elliot and P. Vogel, arXiv:hep-ph/0202264]

Neutrinoless double beta decay



$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = G_{0\nu\beta\beta}(Q_{\beta\beta}, Z)\left|M_{0\nu\beta\beta}\right|^2 \langle m_{\beta\beta}\rangle^2$$

Why use xenon?

Xenon isotopic enrichment is easier. Xenon is a gas & ^{136}Xe is the heaviest isotope.

Xenon is "reusable". Can be repurified & recycled into new detector.

Monolithic detector. LXe is self shielding, surface contamination minimized.

Minimal cosmogenic activation. No long lived radioactive isotopes of xenon.

Energy resolution. Is improved by scintillation light/ionization correlation.

… admits a novel coincidence technique. Background reduction by barium daughter tagging.

Enriched Xenon Observatory

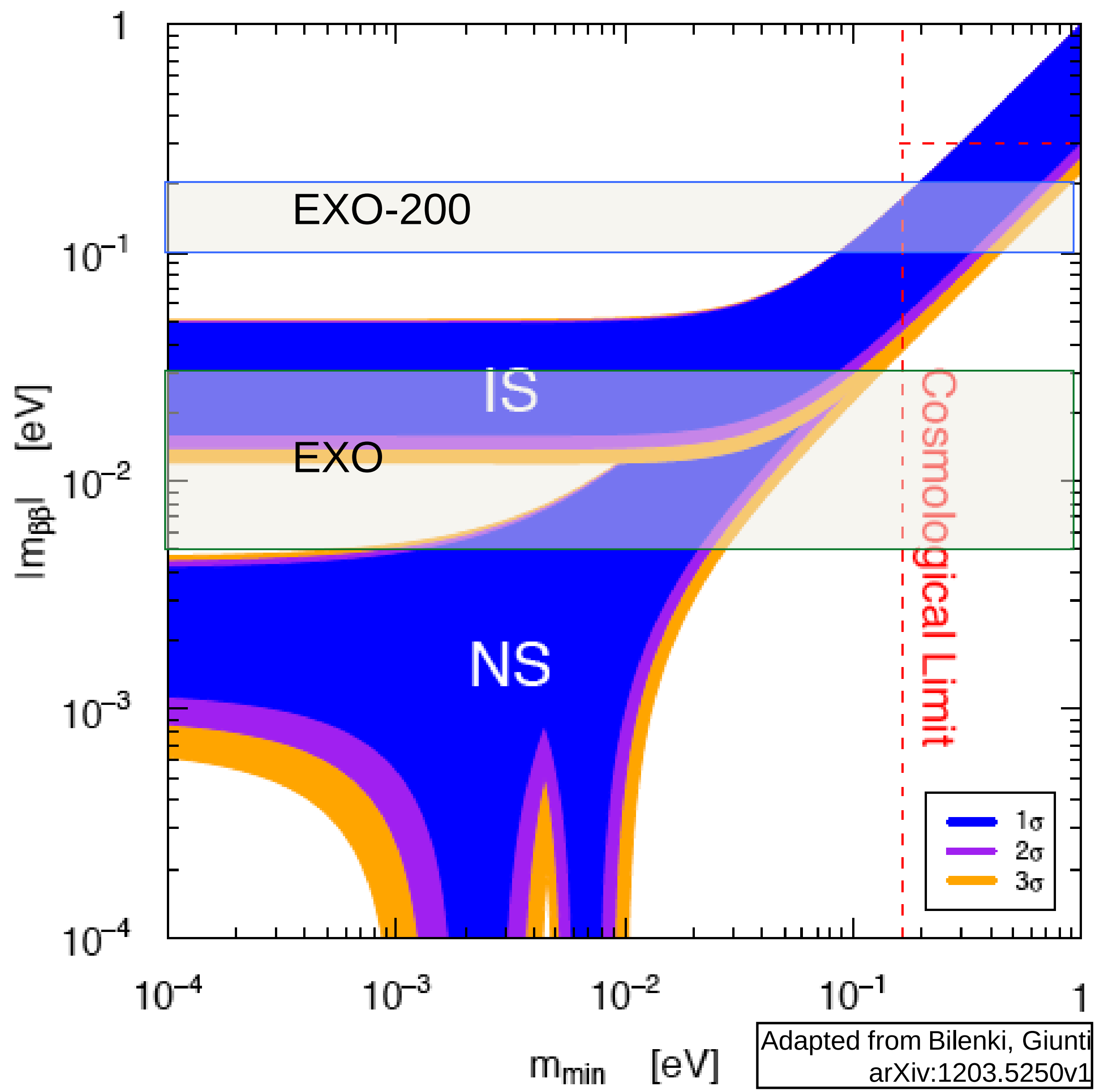
Multi-phase program

EXO-200, in operation:

- 200 kg LXe
- Sensitivity: 100-200 meV

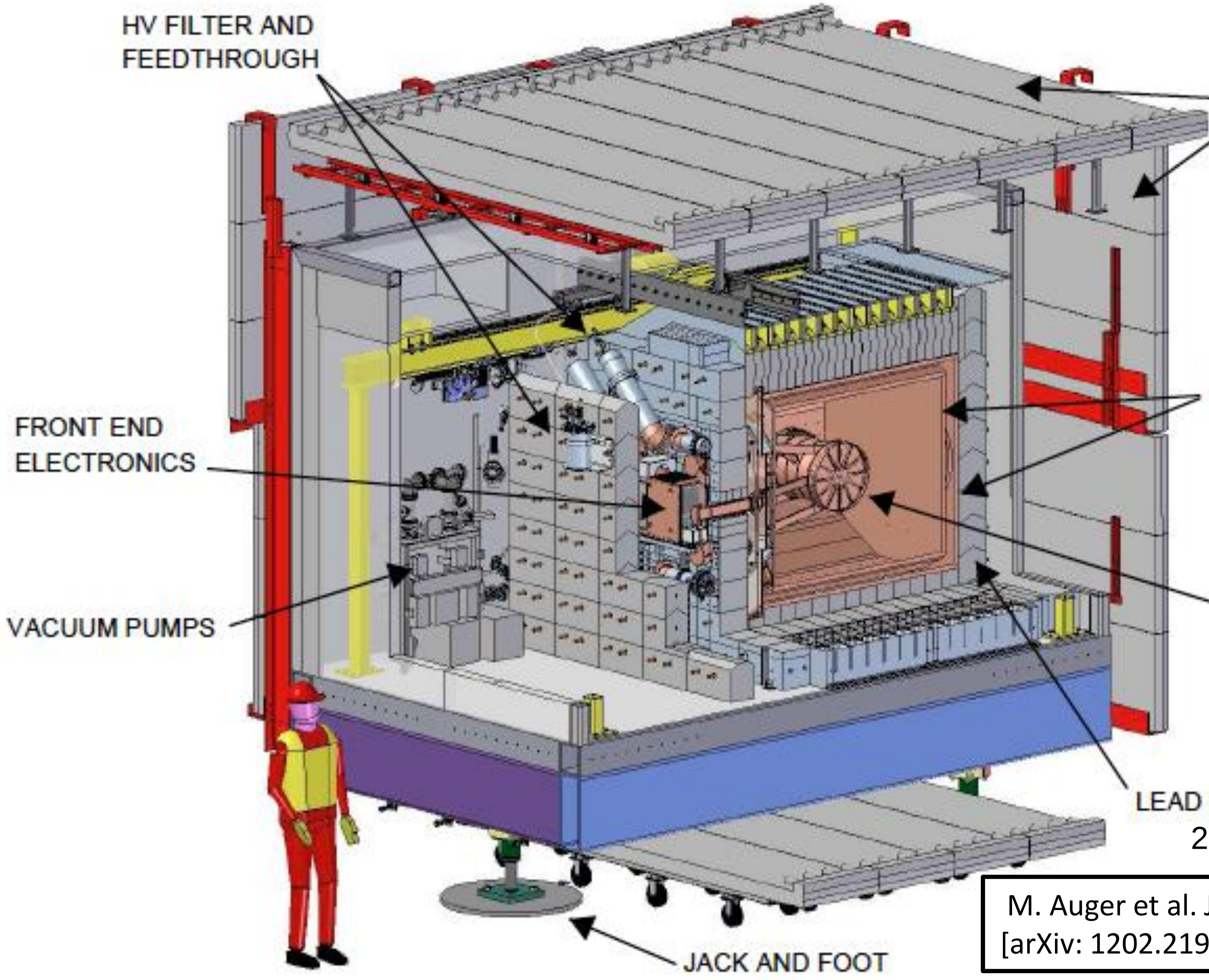
Multi-ton EXO, R&D underway:

- 1-10 ton liquid/gas Xe
- Sensitivity: 5-30 meV
- Improved techniques for background suppression and possibly Ba^{++} tagging



Adapted from Bilenki, Giunti arXiv:1203.5250v1

EXO-200



High purity
HFE7000
> 50 cm

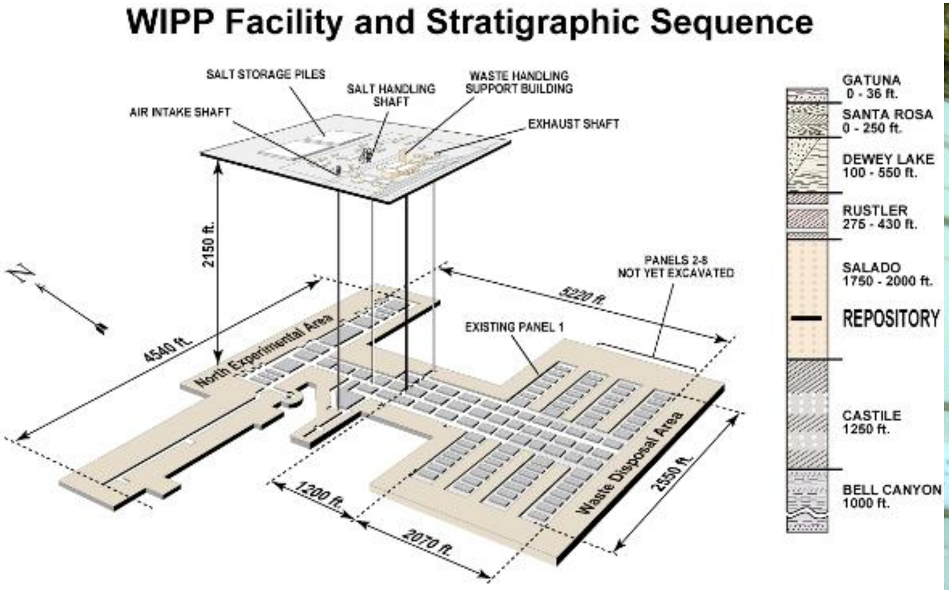
Enr Lxe: 80.6% ^{136}Xe
T = 167 K
P = 147 kPa
ρ = 3.0 g/cm^3

25 cm

M. Auger et al. JINST 7 (2012) P05010
[arXiv: 1202.2192]

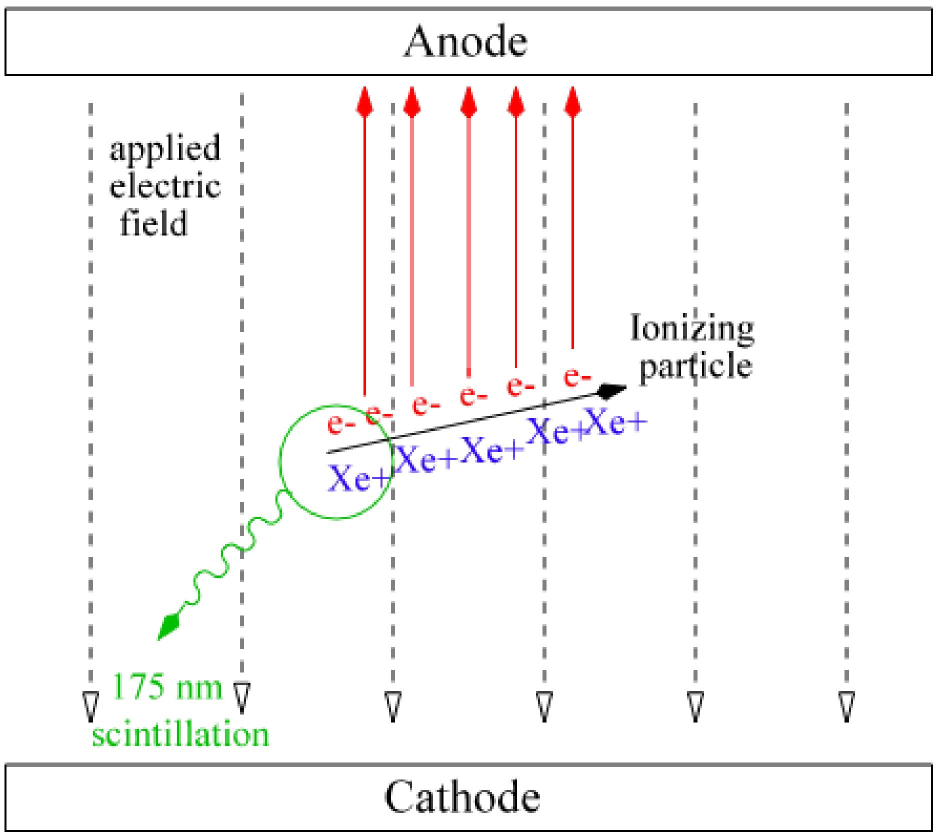
WIPP underground facility

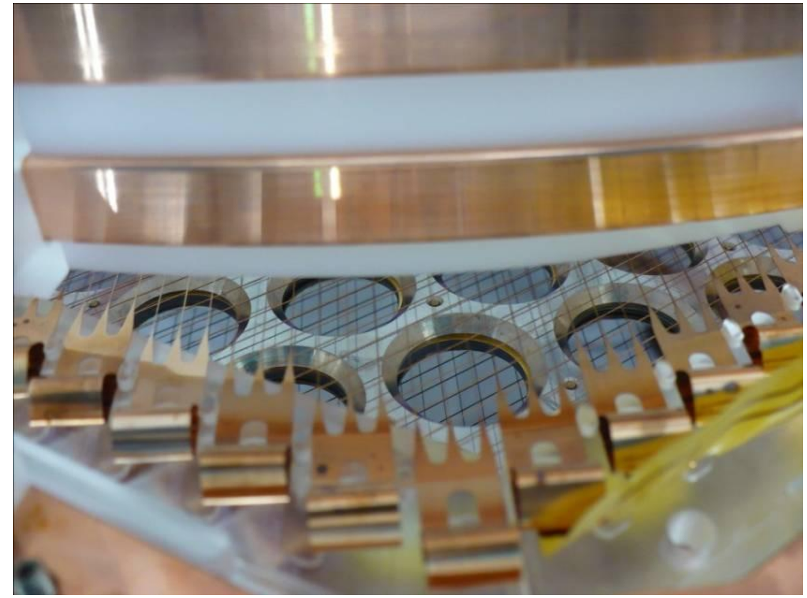
EXO-200 is located 2150 feet underground at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM.



1600m water equivalent depth

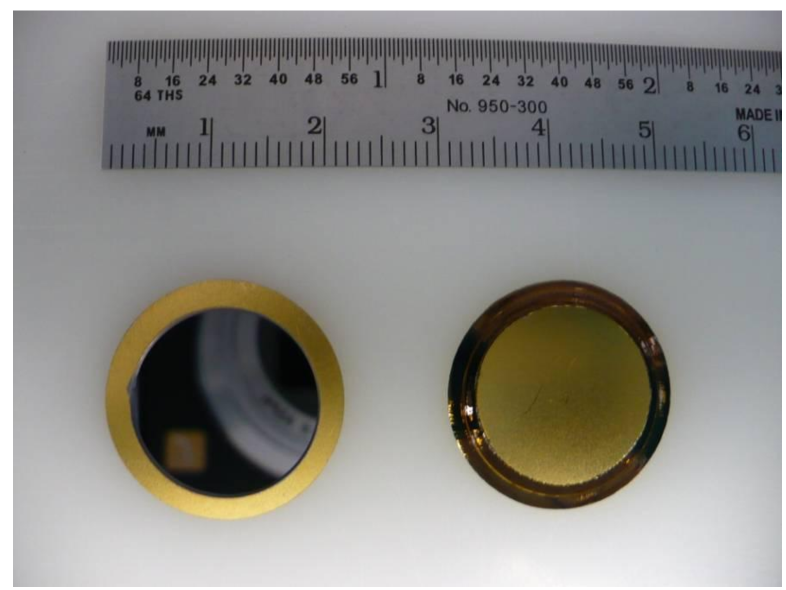
Liquid xenon as source and detector





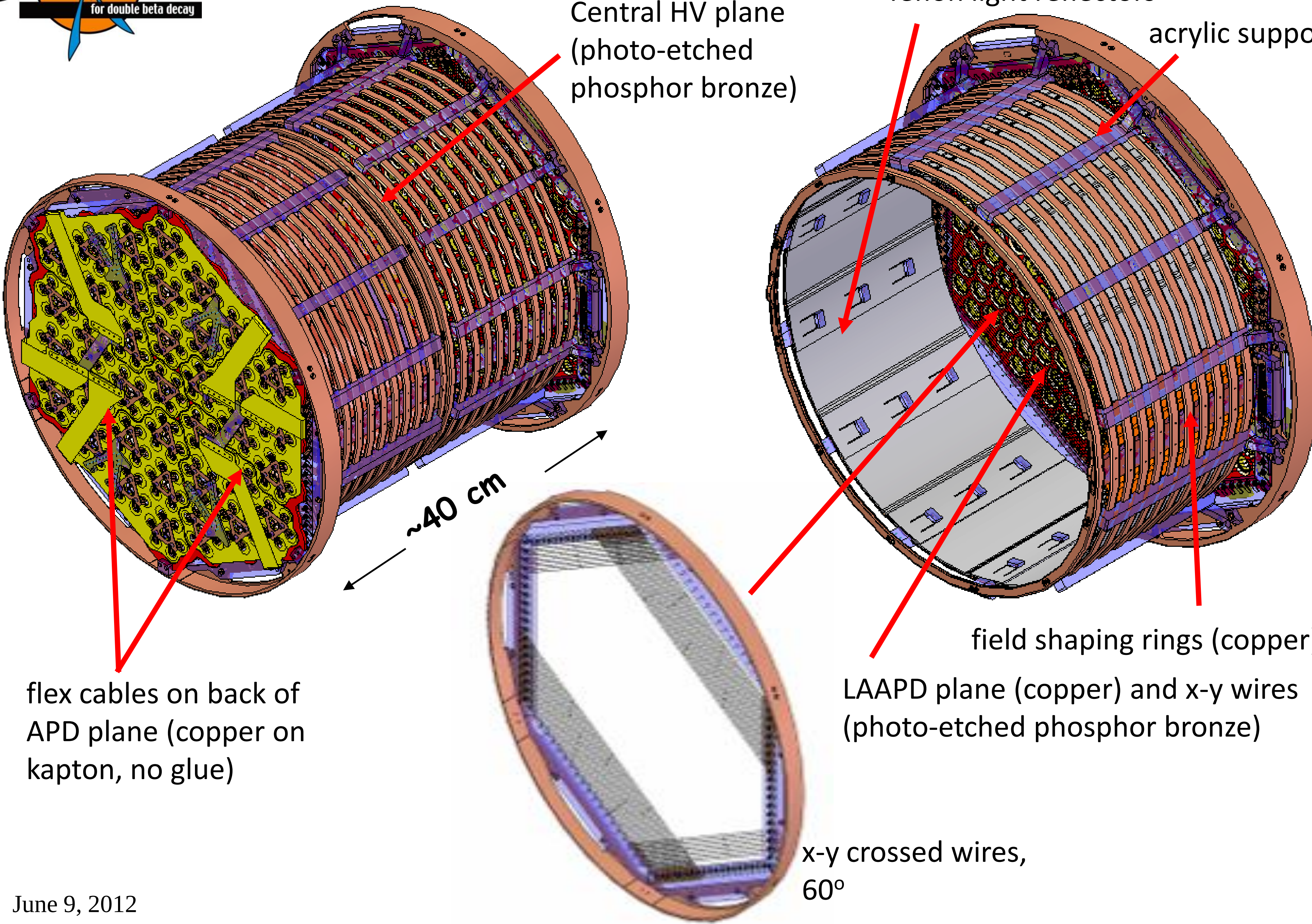
Crossed wire grid collects ionization charge.

Ionizing radiation produces many Xe^{+}/e^{-} pairs. Some recombine, giving off 175nm photons.

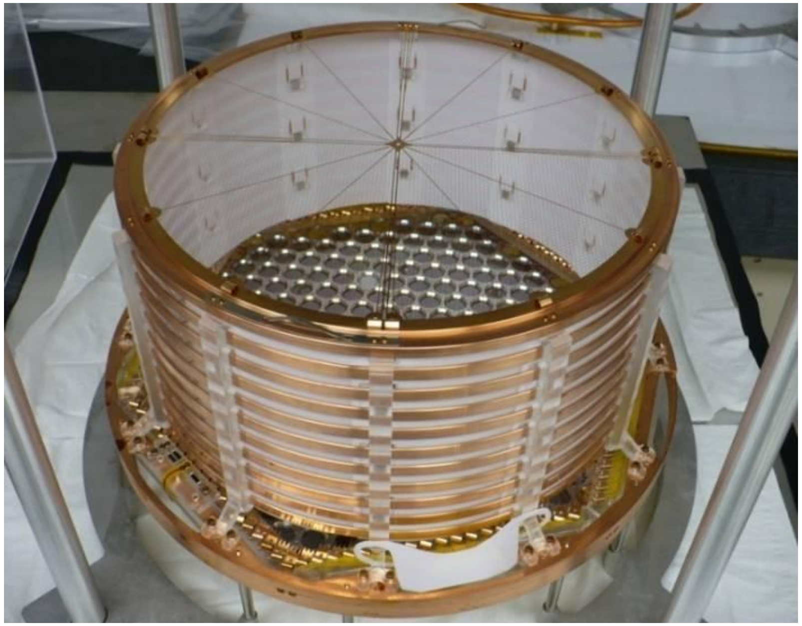


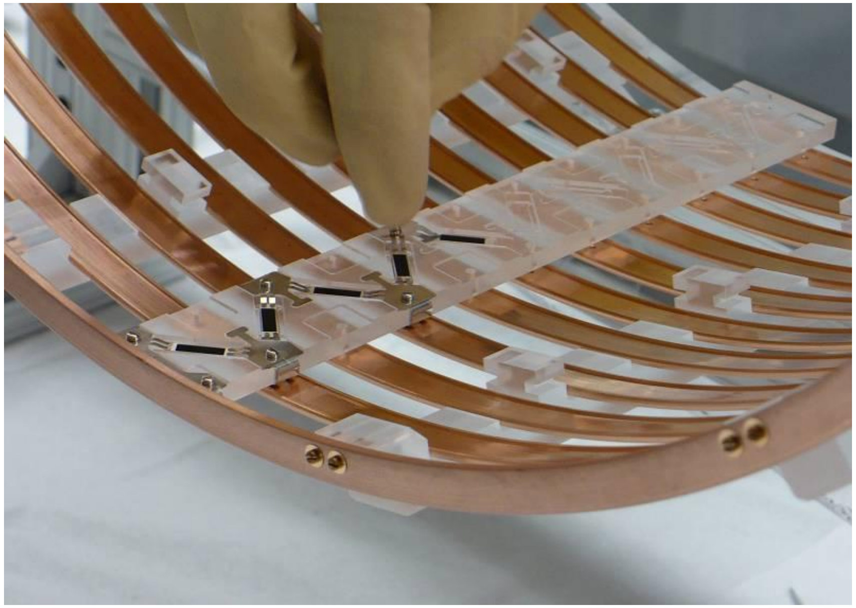
468 LAAPDs detect 175nm scintillation light.

EXO-200 double-TPC



LXe TPC

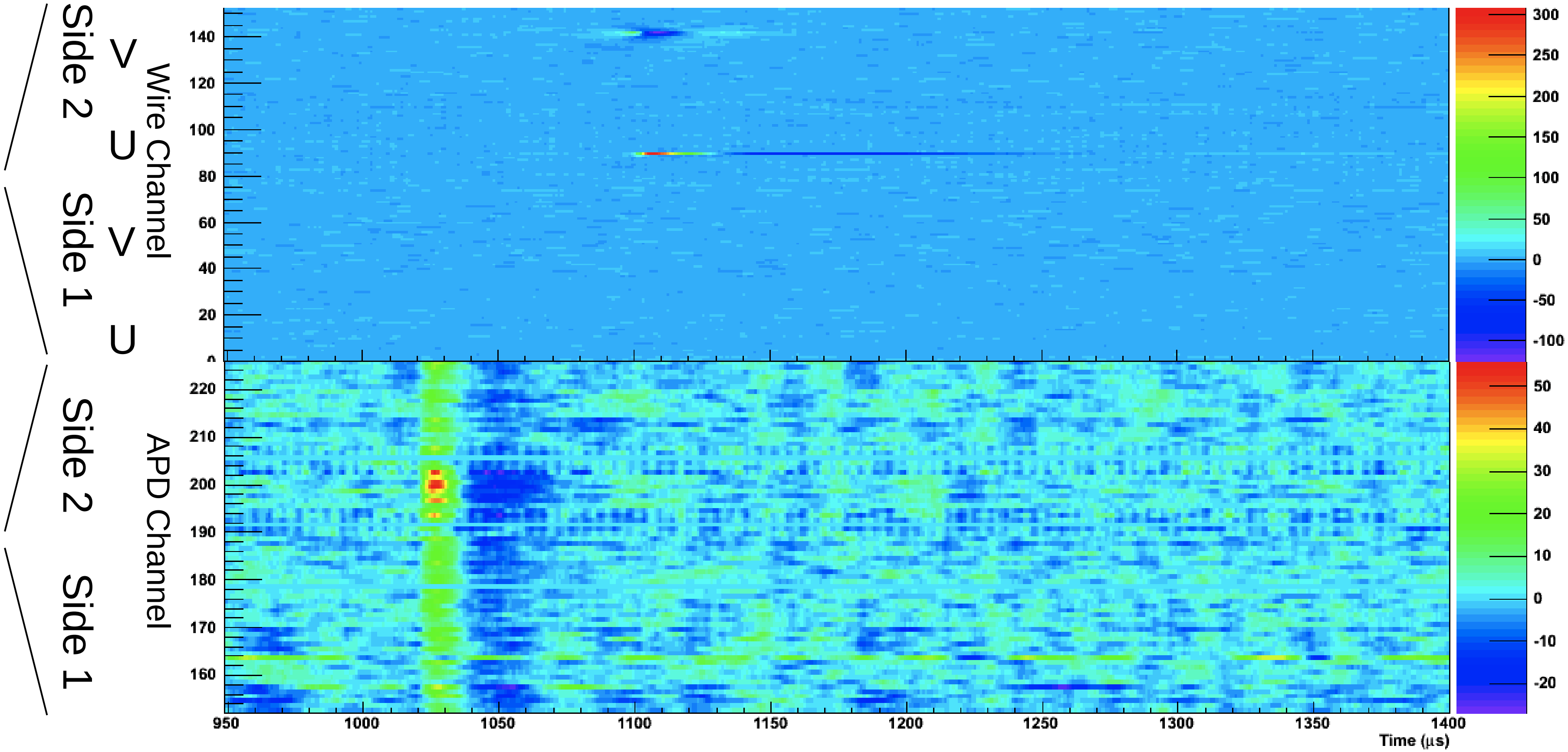




A single-site energy deposition in EXO-200

Charge readout
V: Induction
U: Collection

Light readout



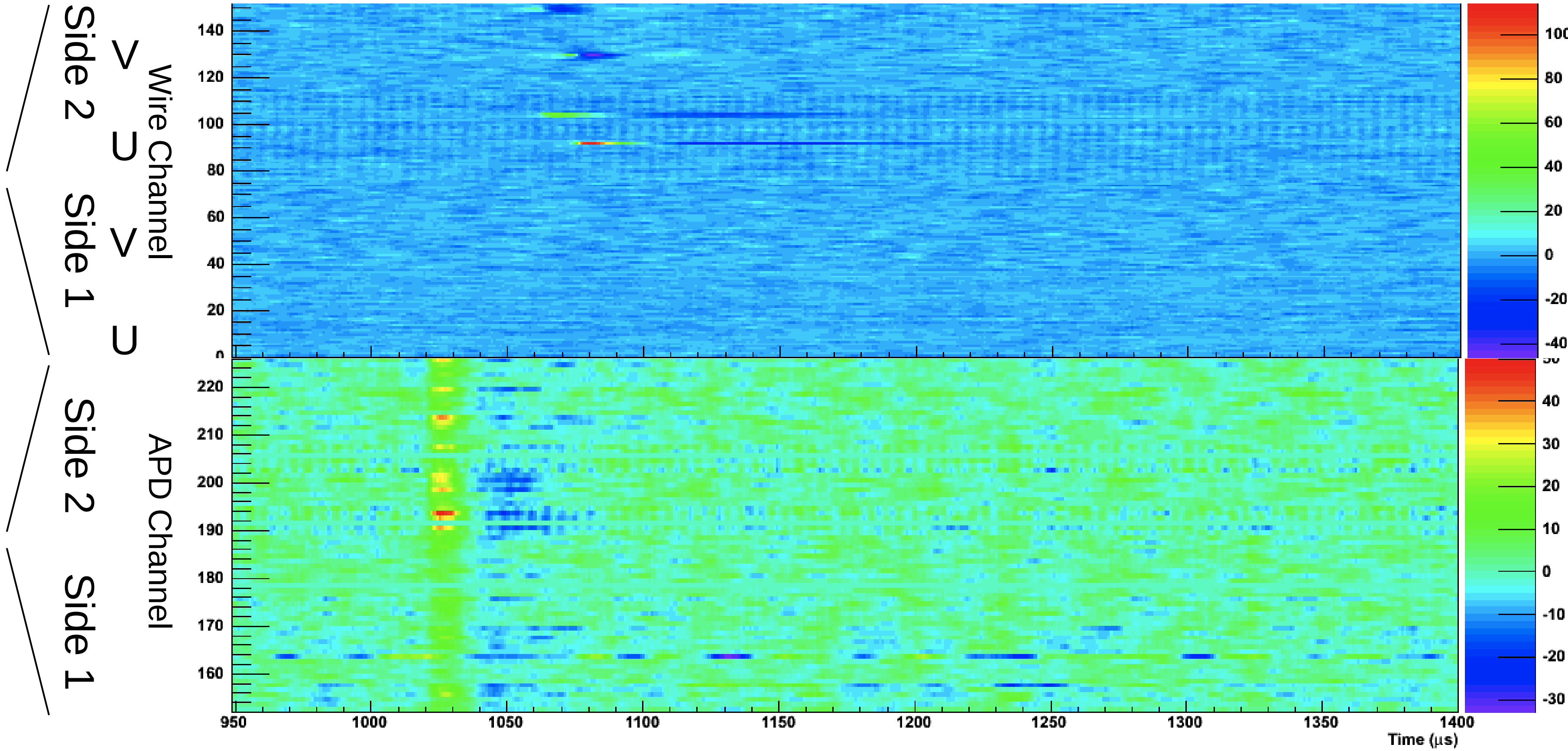
Scintillation light is seen at both sides. The light is more diffuse on side 1 and more localized on side 2, where the event occurred.

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

A two-site Compton-scattering event

Charge readout
V: Induction
U: Collection

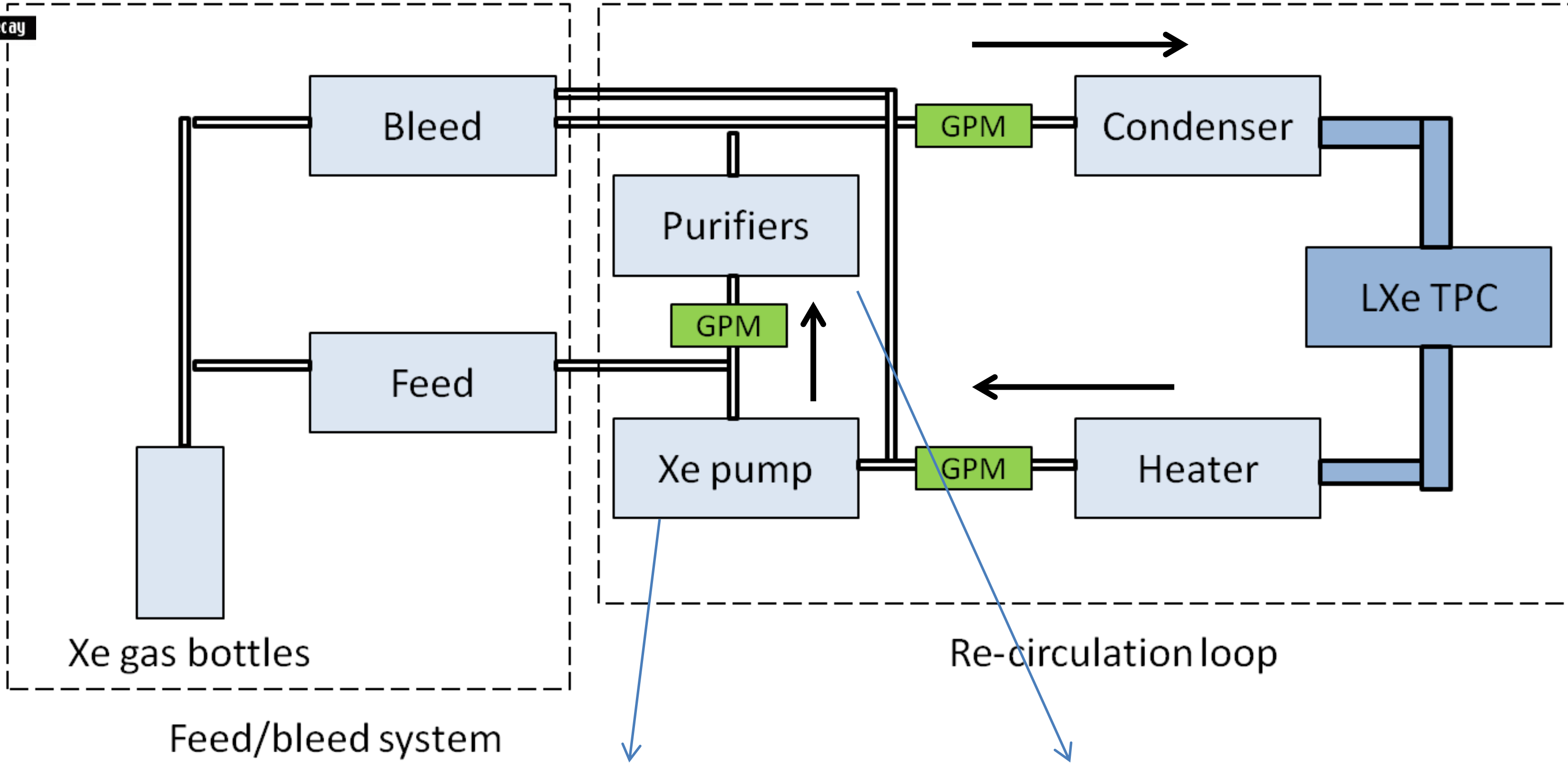
Light readout



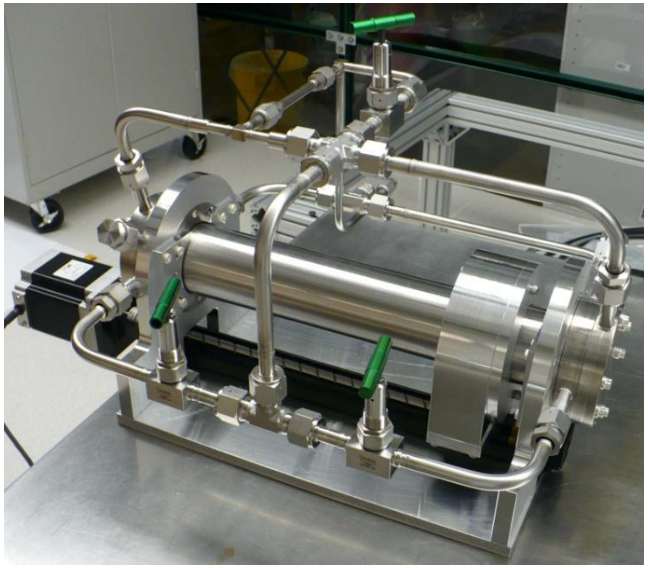
All scintillation light arrives at the same time, indicating that the two energy depositions are simultaneous.

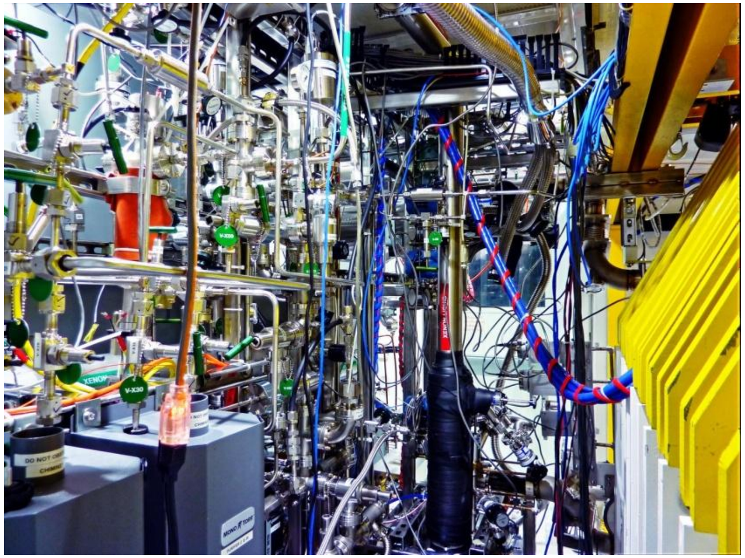
In this case, the gamma ray occurred on side 2. The light hitting side 2 is more localized, while the light hitting side 1 is more diffuse across the plane.

Continuous xenon recirculation



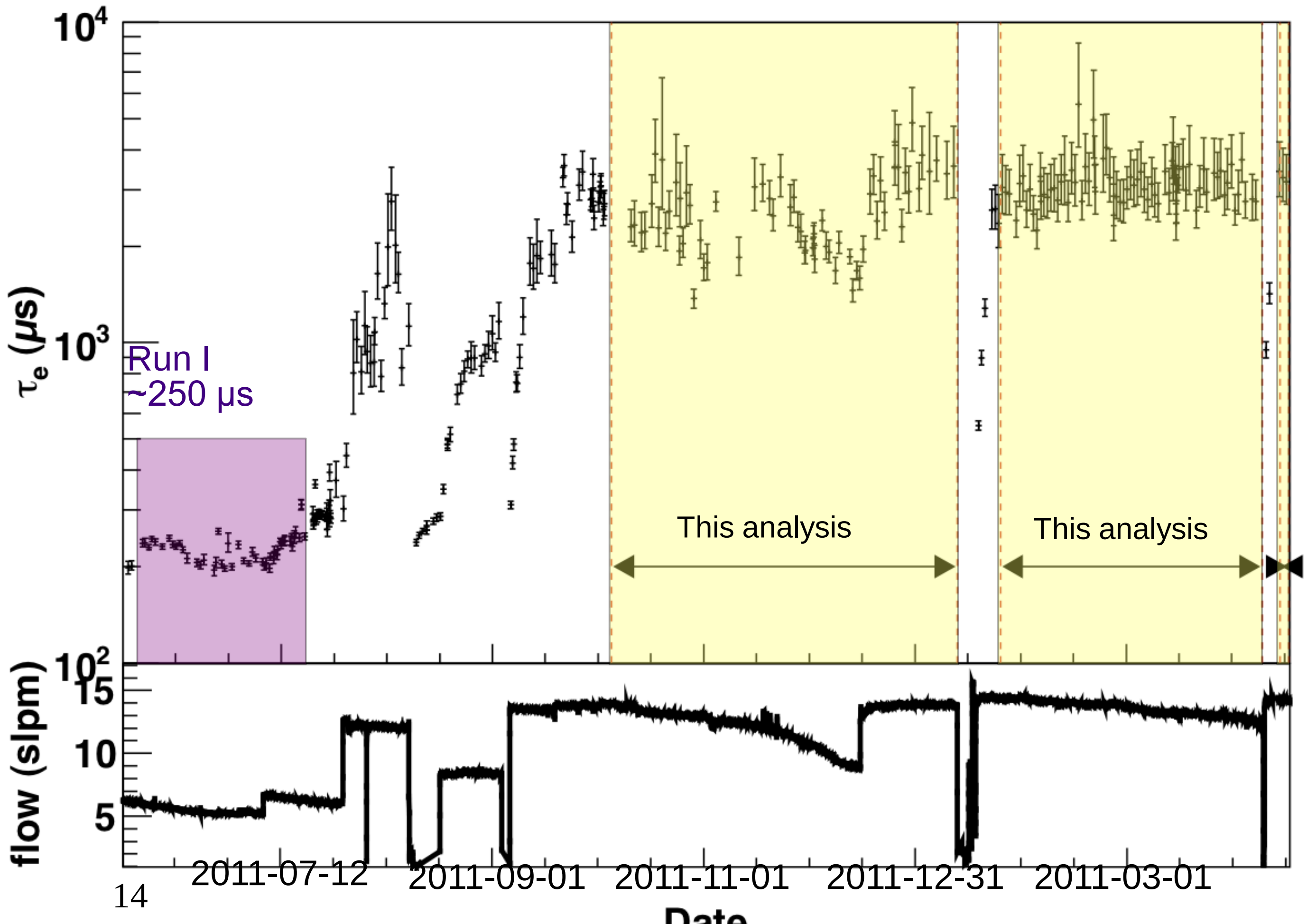
Magnetically coupled ultra-clean piston pump: Rev Sci Instrum. 82(10):105114





Data taking phases and xenon purity

	Run I	Run 2 (this analysis)
Period	May 21, 11 – Jul 9, 11	Sep 22, 11 – Apr 15,12
Live Time	752.7 hr	2,896.6 hr
^{136}Xe exposure	4.4 kg-yr	26.2 kg-yr



Sep 2011 – Hardware upgrades
- APD gain increase by factor 2
- improved U-wire shaping
- added outer lead shield

Purity

Electron lifetime τ_e is determined by measuring the attenuation of the ionization signal as a function of drift time for the full-absorption peak of gamma ray sources

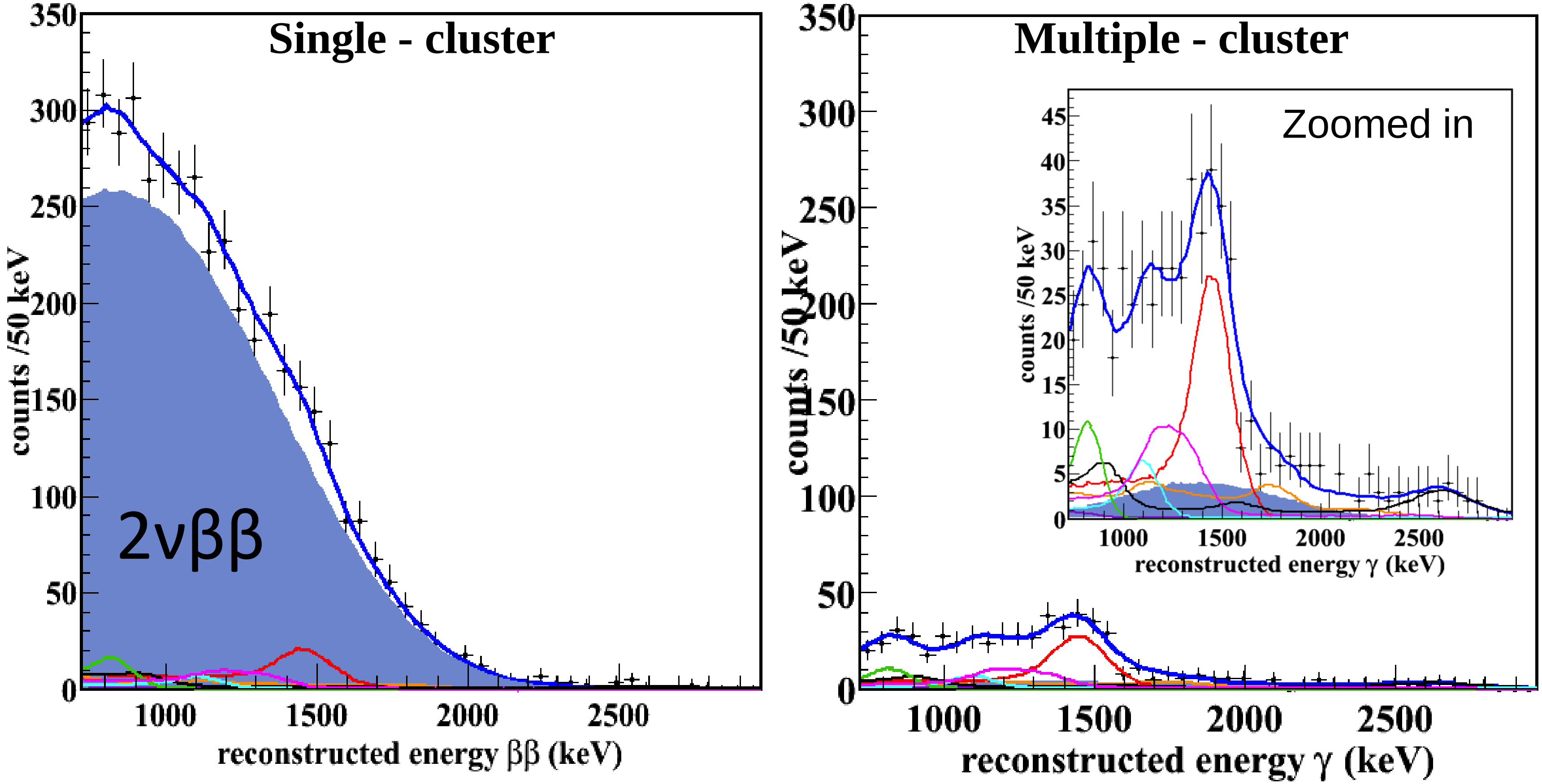
For this analysis, the recirculation rate was increased to 14 slpm, leading to long electron lifetimes in the TPC

At τ_e = 3 ms:
- max. drift time ~110 μs
- loss of charge is 3.6% at full drift length

2011 EXO-200 2νββ Measurement

PRL 107 (2011) 212501

R. Neilson, PhD (2011) “Discovery of the two-neutrino double-beta decay of xenon-136 with EXO-200”, Stanford University

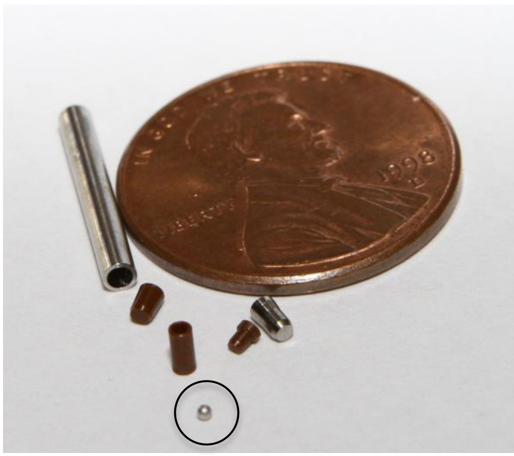


31 live-days of data, 63 kg active mass

$T_{1/2}$ = 2.11 · 10^{21} yr (± 0.04 stat) (± 0.21 syst)

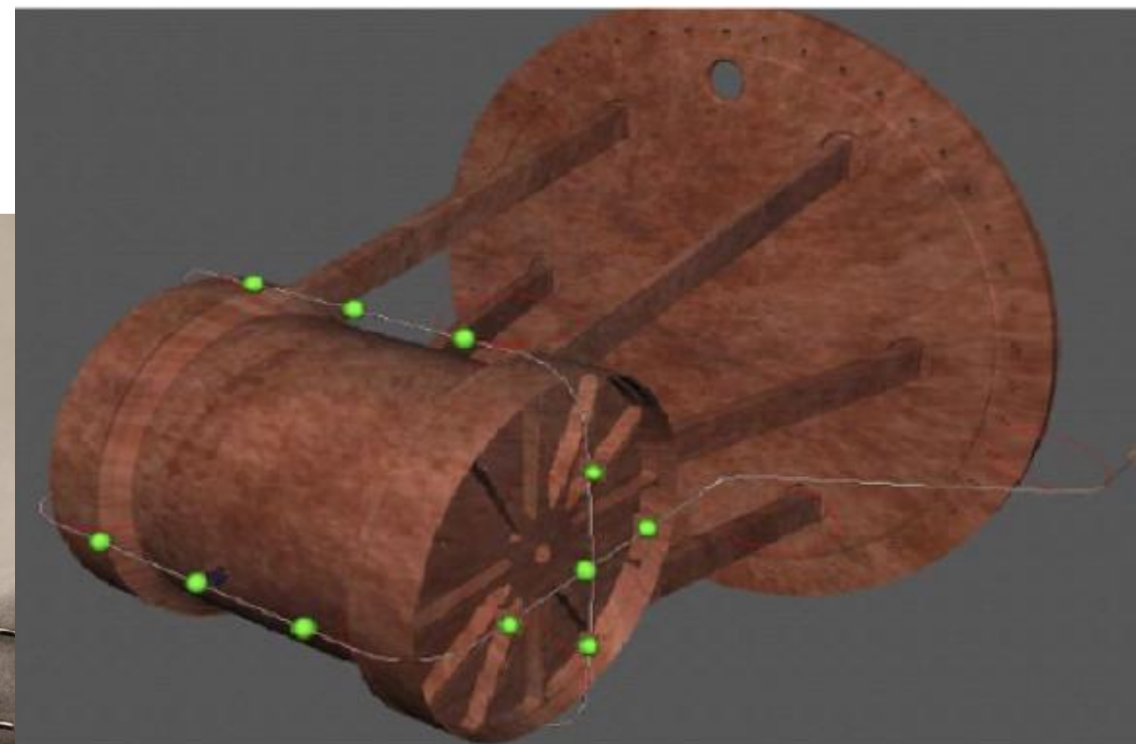
Calibration sources in EXO-200

Calibration sources can be deployed at several positions around the TPC

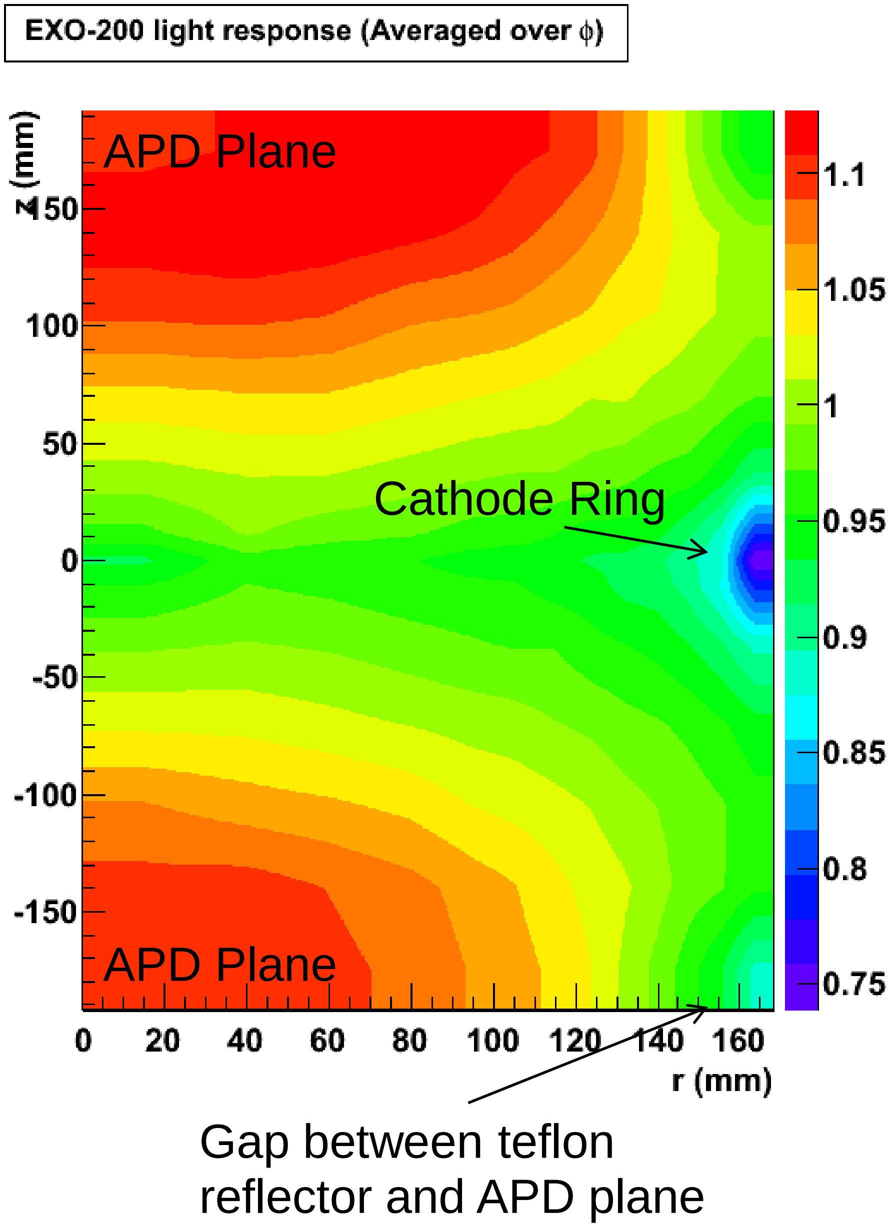


Source – 0.7mm diameter

Source	“Weak” [kBq]	“Strong” [kBq]	Gamma line [keV]
^{137}Cs	3kBq	15kBq	661.657
^{60}Co	0.5	7.2	1173.228, 1332.492
^{228}Th	1.5	38	2614.511

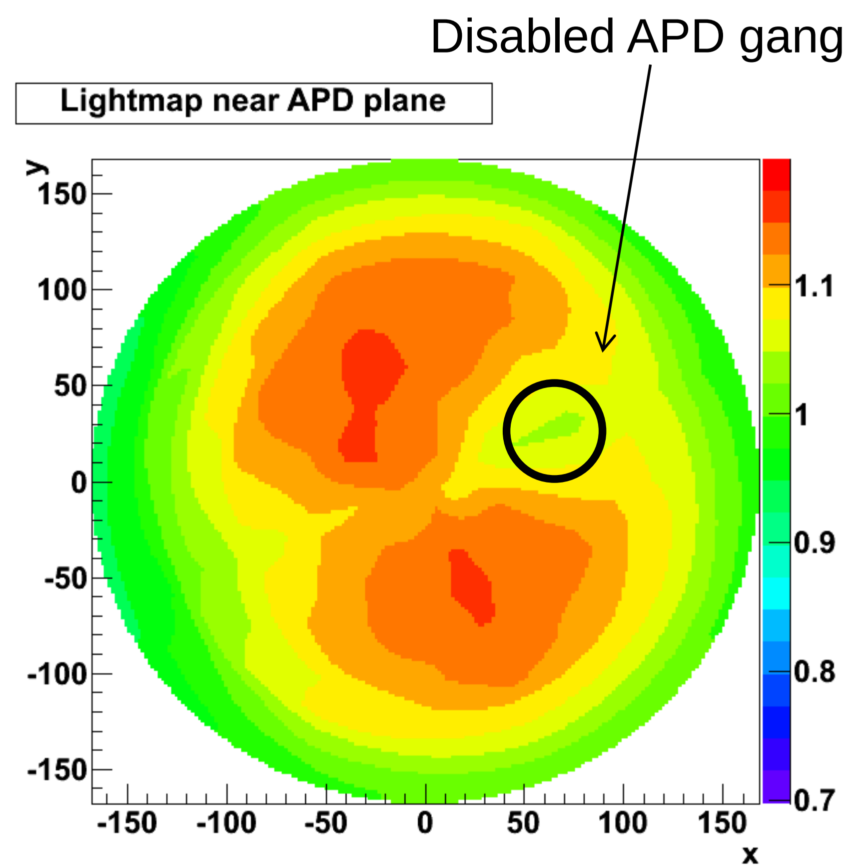


Correcting for light response

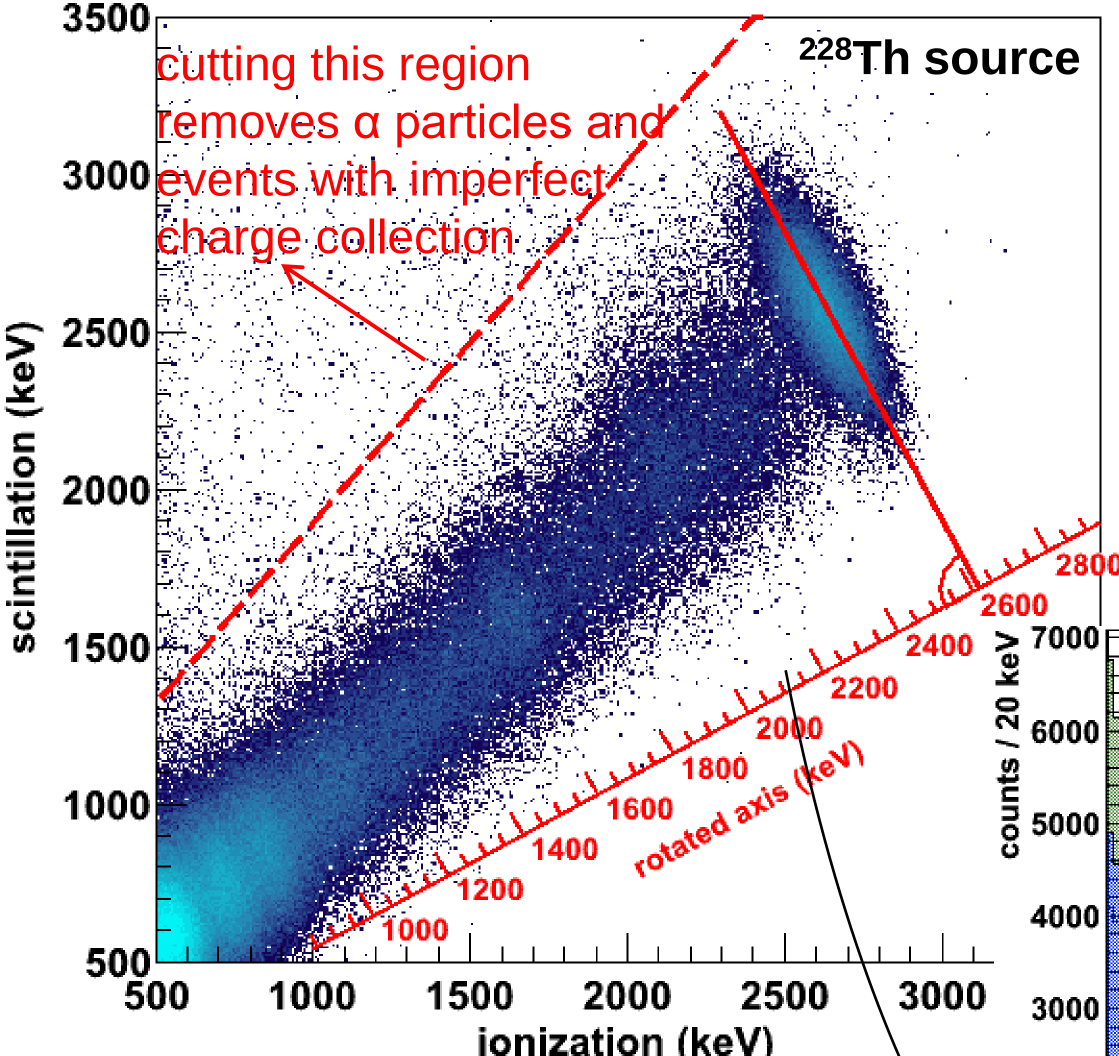


Use full absorption peak of 2615 keV gamma from 208Tl to map light response in TPC

Linearly interpolate between 1352 voxels



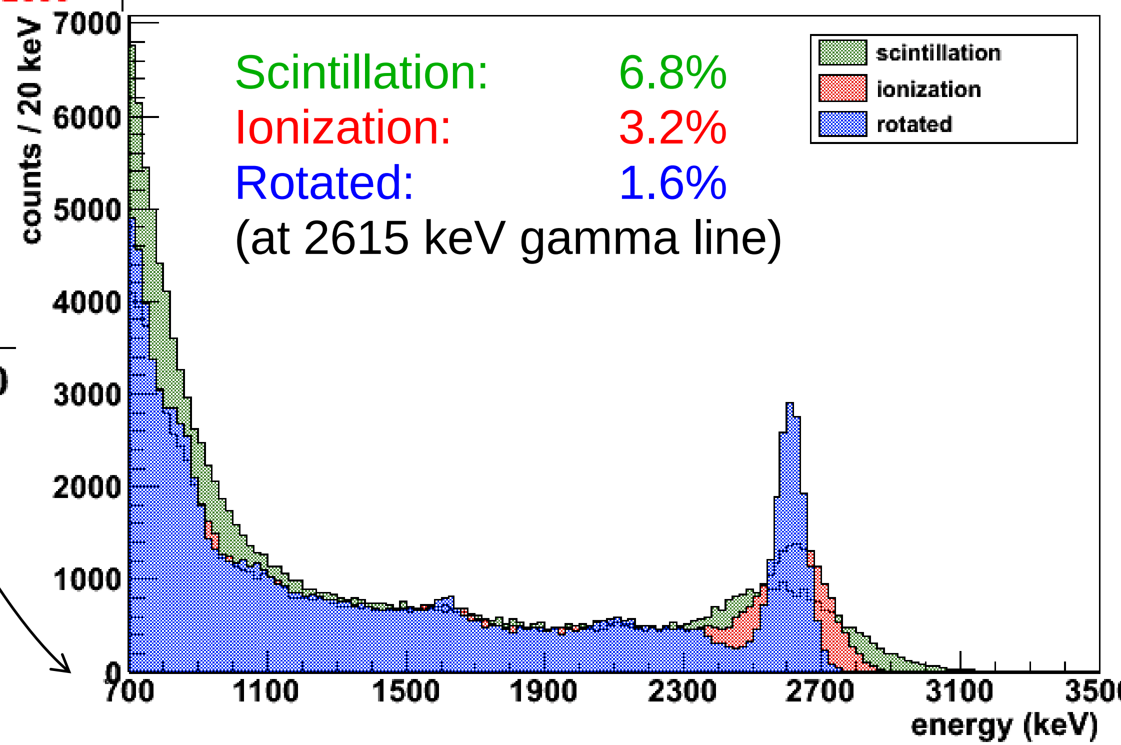
Combining ionization and scintillation



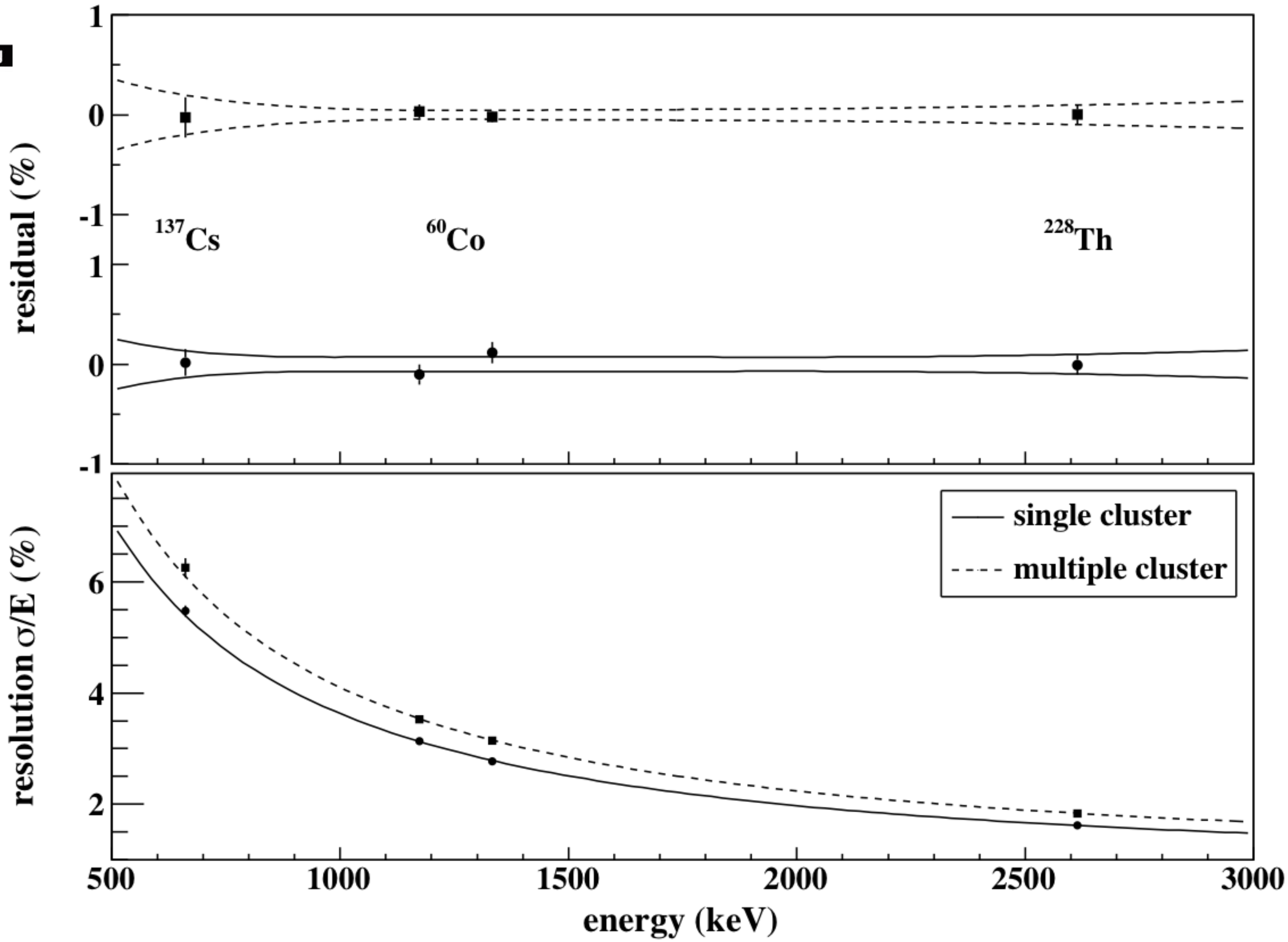
Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa)†

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

Use projection onto a rotated axis to determine event energy

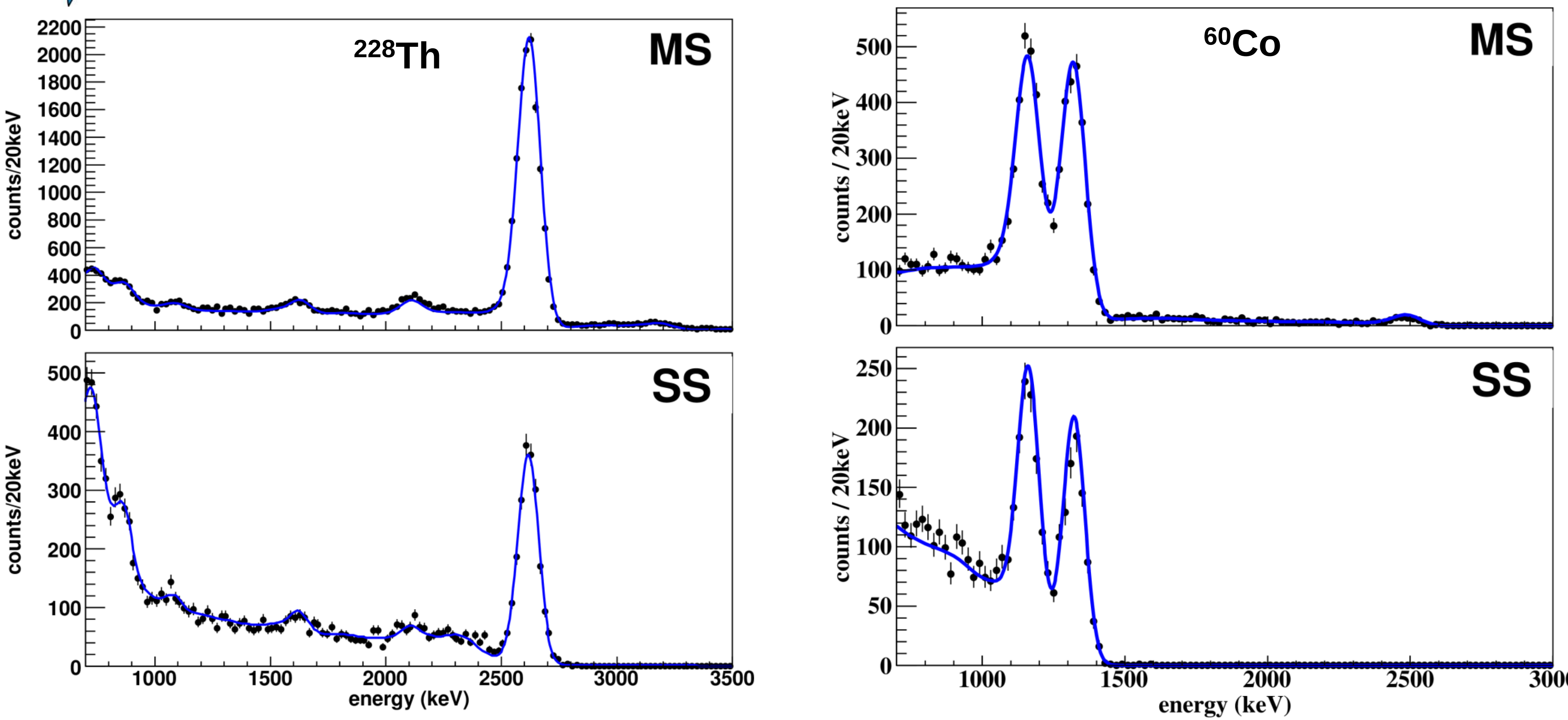


Calibrations



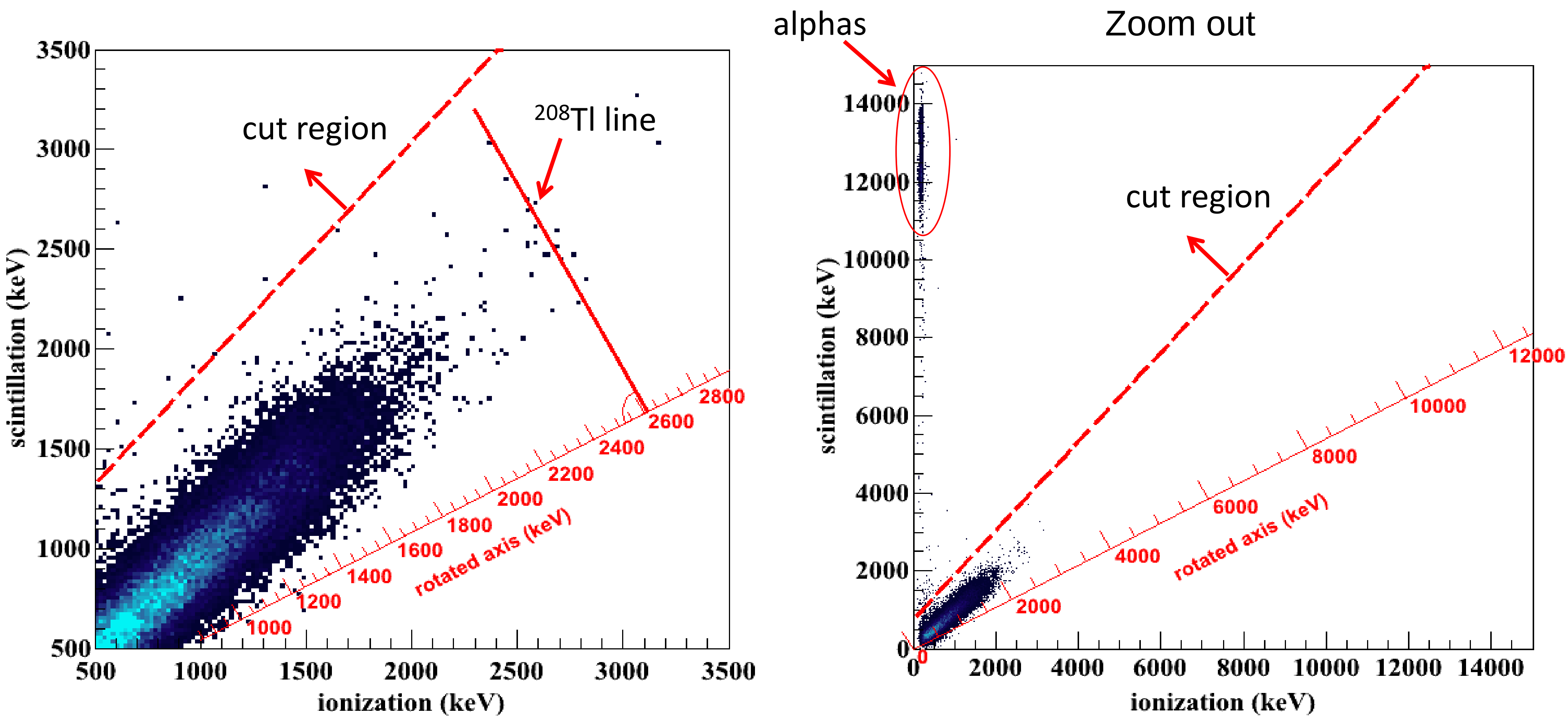
- Energy calibration residuals uncertainties constrained to be less than 0.1%
- Energy resolution at the Q-value (2458 keV) is 1.67% (1.84%) in the SS (MS) spectrum

Calibration source spectrum agreement



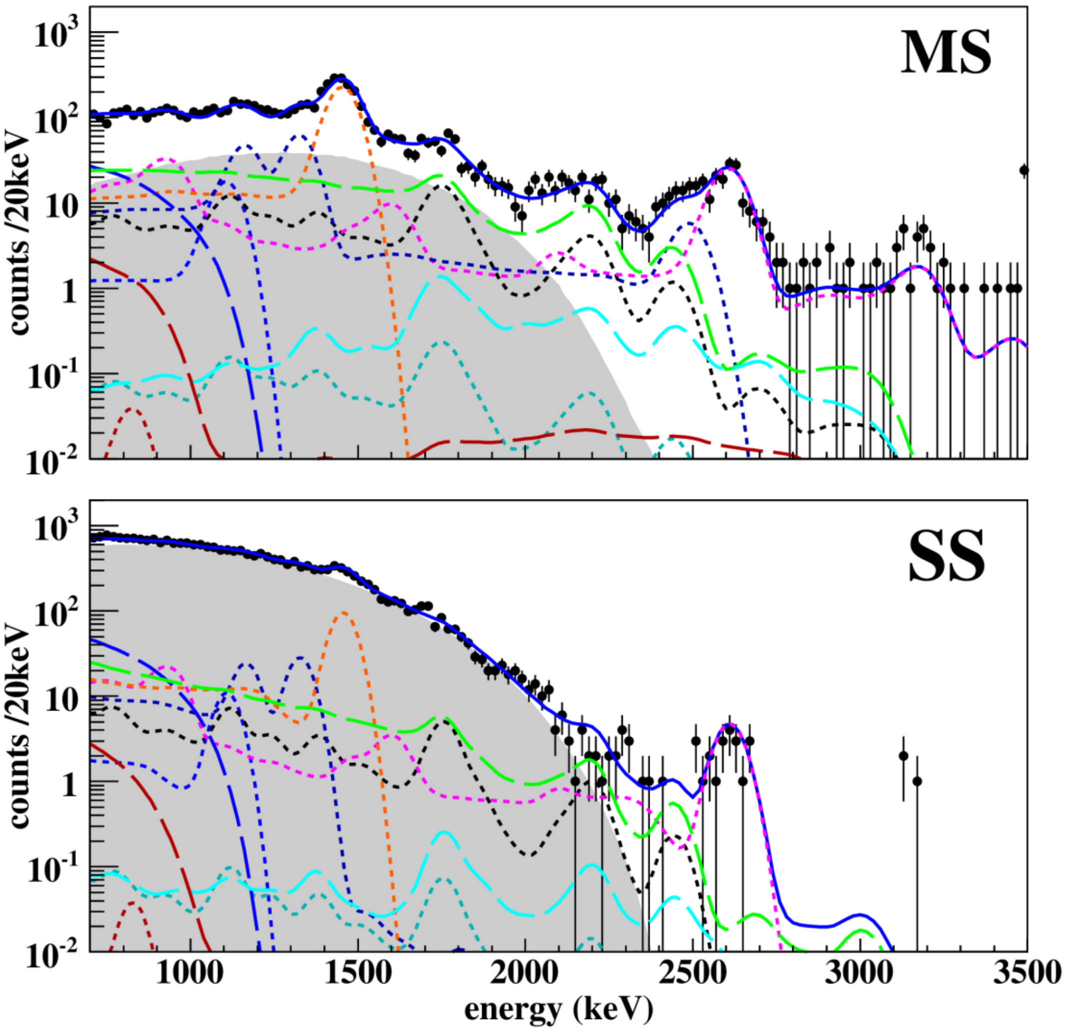
- Multi site (MS) and single site (SS) data (black points) are compared to model (blue curves)
- Single site fraction agrees to within 8.5%
- Can measure source activities to within 9.4%

Low background 2D single-site spectrum



Low background data

Maximum likelihood fit

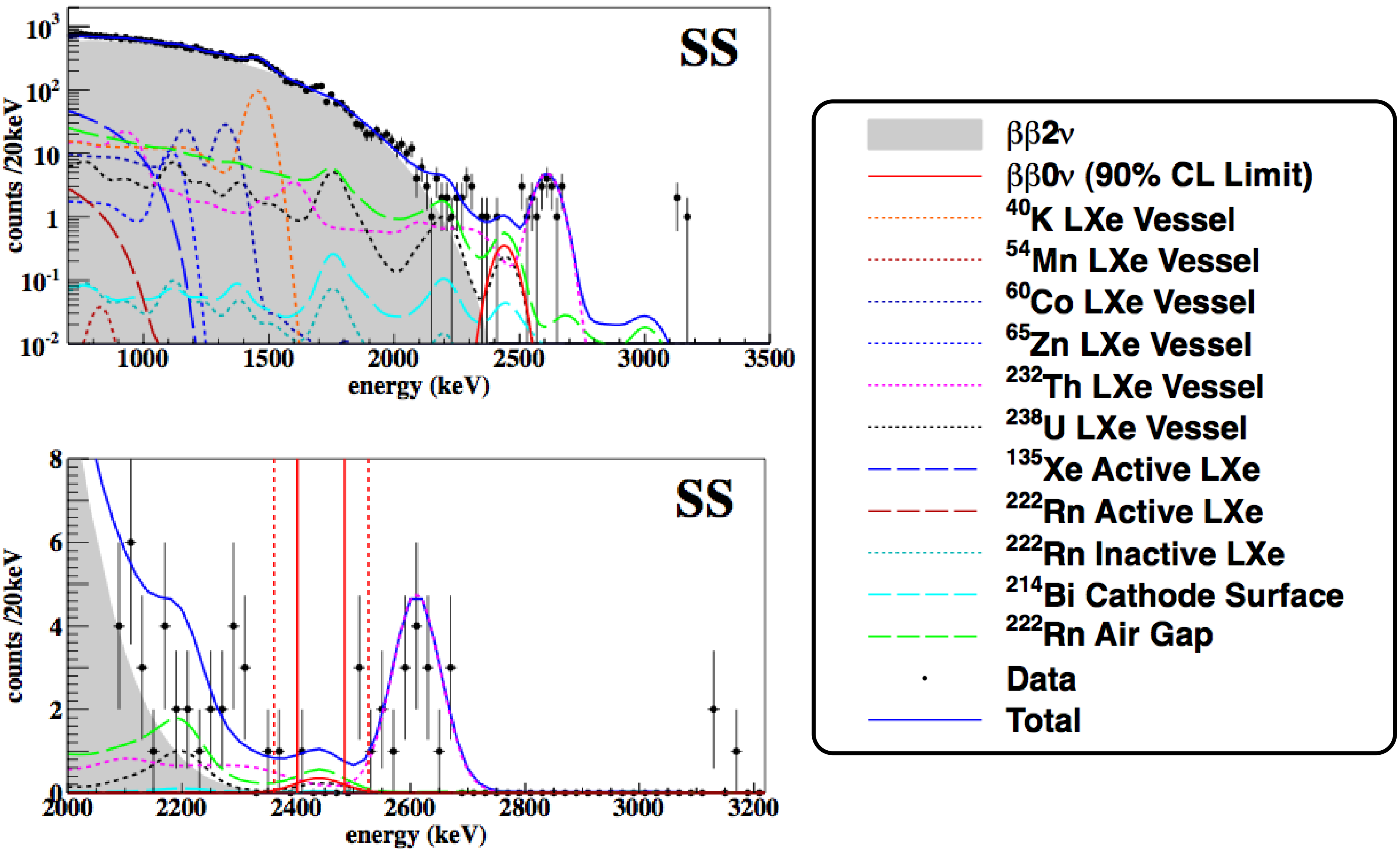


- Trigger fully efficient above 700 keV
- Low background run livetime: **120.7 days**
- Active mass: **98.5 kg LXe (79.4 kg ^{136}LXe)**
- ^{136}Xe exposure: **26.2 kg·yr**
- Total dead time (vetos): 8.6%
- Various background PDFs fitted along with 2νββ and 0νββ PDFs

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

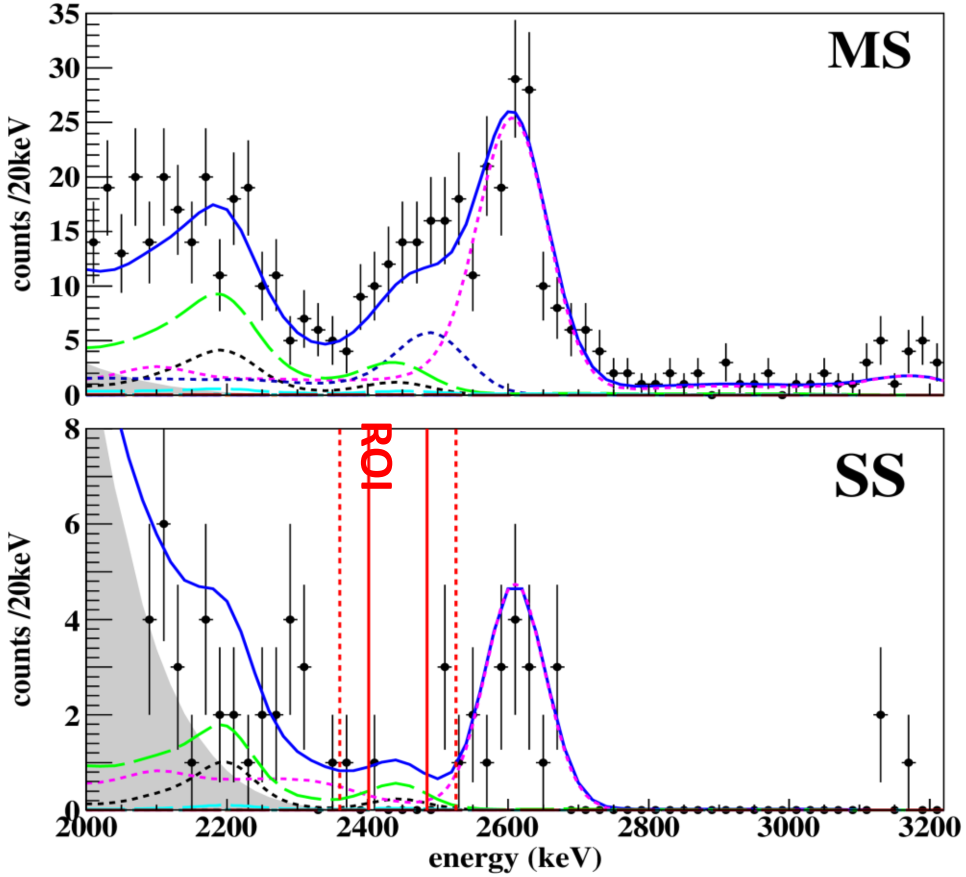
(In agreement with previously reported value by EXO-200 and KamLAND-ZEN collaborations)

Low background data



0νββ limit

Zoomed around 0νββ region of interest (ROI)



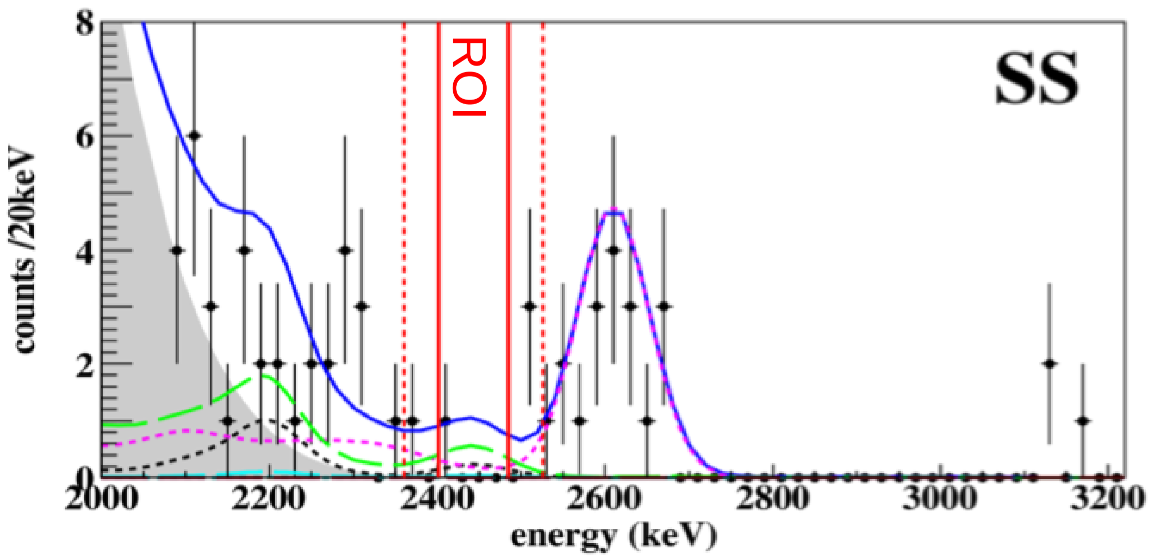
- No signal observed
- Background in ROI:

$1.5 \cdot 10^{-3} \pm 0.1$ $kg^{-1}yr^{-1}keV^{-1}$ in $\pm 1\sigma$ ROI

- **Profile likelihood study to extract limits for $T_{1/2}^{0\nu\beta\beta}$**

$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > $1.6 \cdot 10^{25}$ yr (90% C.L.) [arXiv:1205.5608]

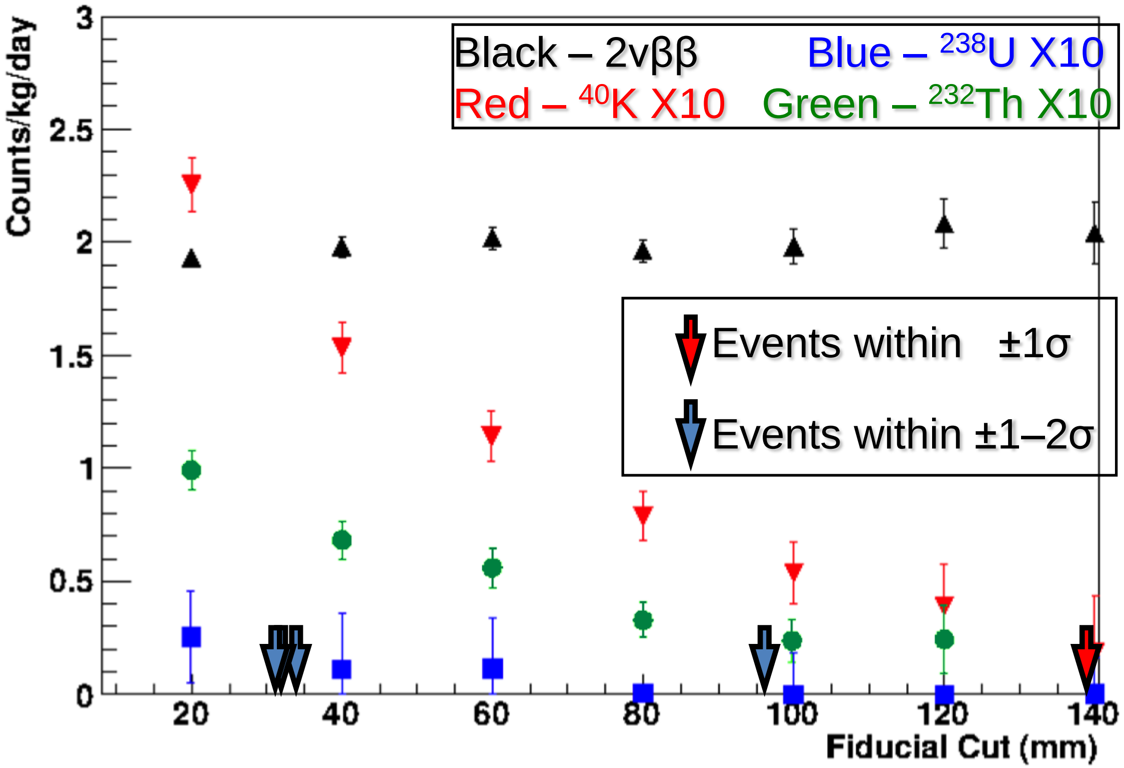
Background counts in ±1,2 σ ROI

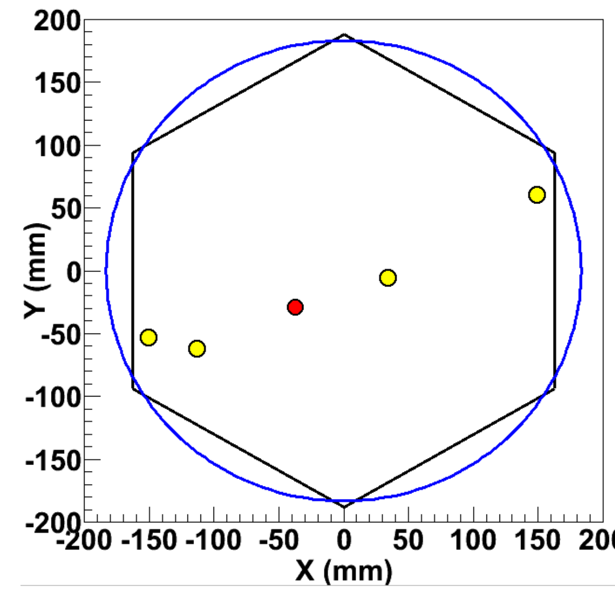


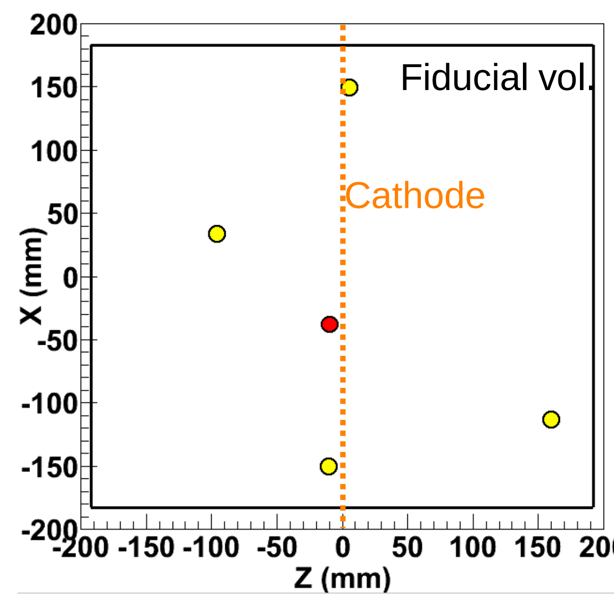
	Expected events from fit			
	±1 σ		±2 σ	
^{222}Rn in cryostat air-gap	1.9	±0.2	2.9	±0.3
^{238}U in LXe Vessel	0.9	±0.2	1.3	±0.3
^{232}Th in LXe Vessel	0.9	±0.1	2.9	±0.3
^{214}Bi on Cathode	0.2	±0.01	0.3	±0.02
All Others	~0.2		~0.2	
Total	4.1	±0.3	7.5	±0.5
Observed	1		5	
Background rate ($kg^{-1}yr^{-1}keV^{-1}$)	$1.5\cdot10^{-3} \pm 0.1$		$1.4\cdot10^{-3} \pm 0.1$	

Background goal for this exposure was 4.6 counts in ±2σ ROI

Spatial distributions





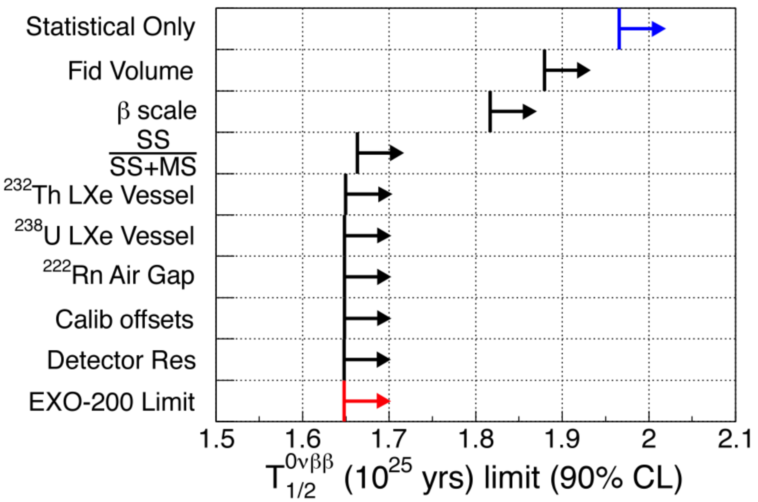


2νββ rate does not change with fiducial volume

Background gammas rates drop towards the inside of the detector

Events in the ±1,2σ ROIs: statistics is too low to conclude on their parent distribution

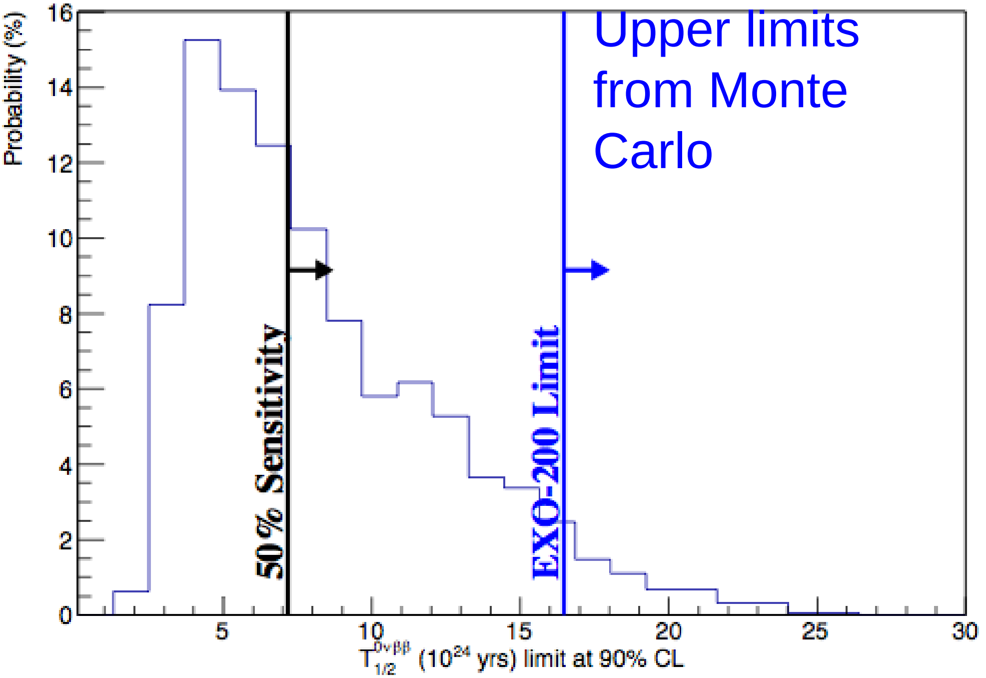
Systematics and sensitivity



Error breakout: expected 90% CL limit given absolute knowledge (0 error) of a given parameter or set of parameters

Term	%
Fiducial Volume	12.34
β scale	9.32
SS / (SS + MS)	0.93
^{232}Th LXe Vessel	0.11
^{238}U LXe Vessel	0.04
^{222}Rn Air Gap	0.04
Calibration offsets	0.04

Distribution of 0νββ $T_{1/2}$ 90% CL

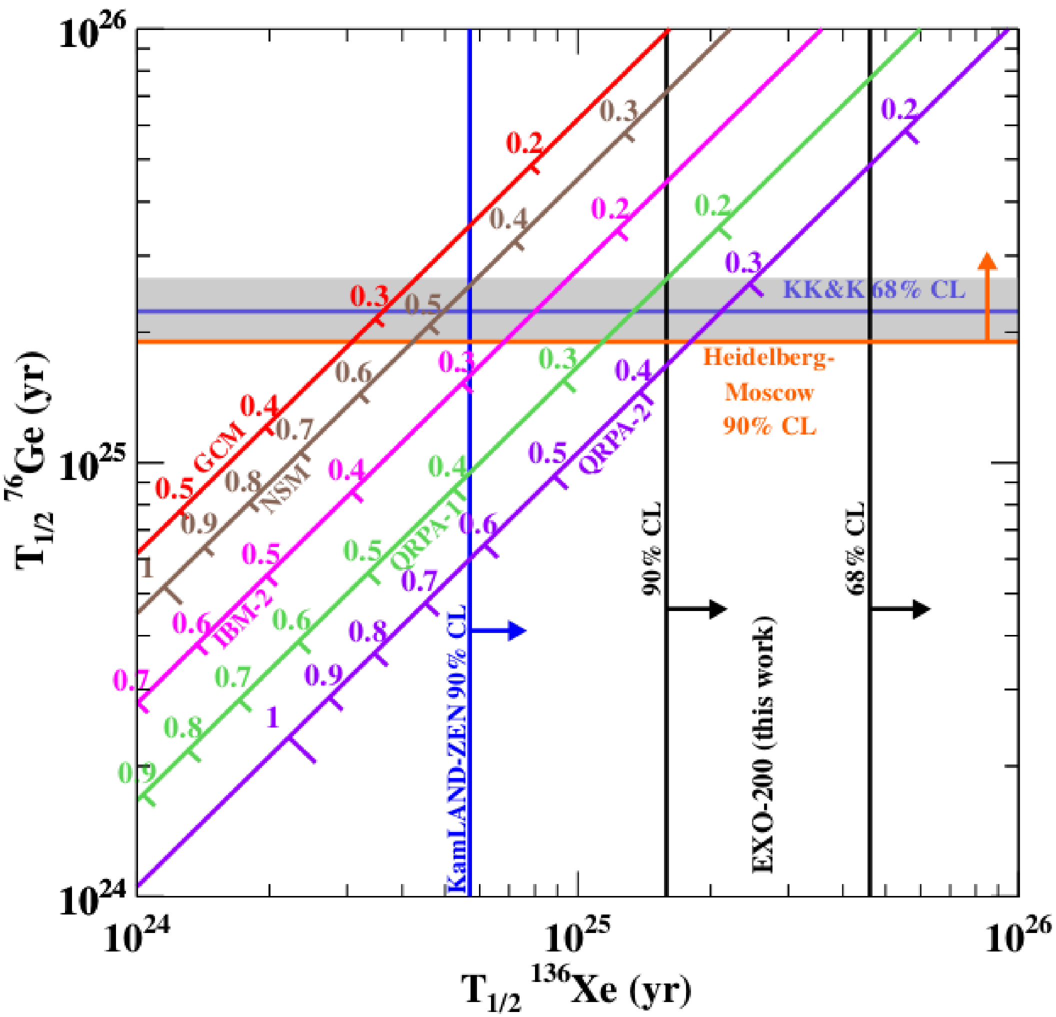


From estimated background, expect to quote a 90% CL upper limit on $T_{1/2}$:

≥ 1.6 x 10^{25} yr 6.5% of the time

≥ 7 x 10^{24} yr 50% of the time

Limits on 0νββ



$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > 1.6·10^{25} yr

〈$m_{\beta\beta}$〉 < 140–380 meV

(90% C.L.)

90% C.L. limit compared with recent ^{136}Xe constraints (KamLAND-ZEN) >2.5 factor improvement.

EXO-200 contradicts Klapdor-Kleingrothaus and Krivosheina claim at the 90% C.L. for most matrix element calculations.

What's next for EXO-200

- EXO-200 is approved to run for 4 more years.
- New radon purge for the air between the cryostat and the lead shield.
- Upgraded laser pulser for improved LAAPD response calibrations.
- Energy resolution improvements on the horizon.
- Improvements to 3D reconstruction for gamma background rejection.

Conclusions

▪EXO-200 has set a world-best lower limit on the decay half-life

$T_{1/2}^{0nbb}$ (^{136}Xe) > 1.6·10^{25} yr (90% C.L.) .

▪Corresponding limit on Majorana neutrino mass

$m_{\beta\beta}$ < 140-380 meV (90% C.L.).

▪Achieved energy resolution by combining ionization and scintillation of **σ/E = 1.67%** at $Q_{\beta\beta}$, with future improvement likely.

▪Achieved background of **1.5·10^{-3} keV^{-1} $kg^{-1}yr^{-1}$**, and are working on reducing this.

The EXO Collaboration

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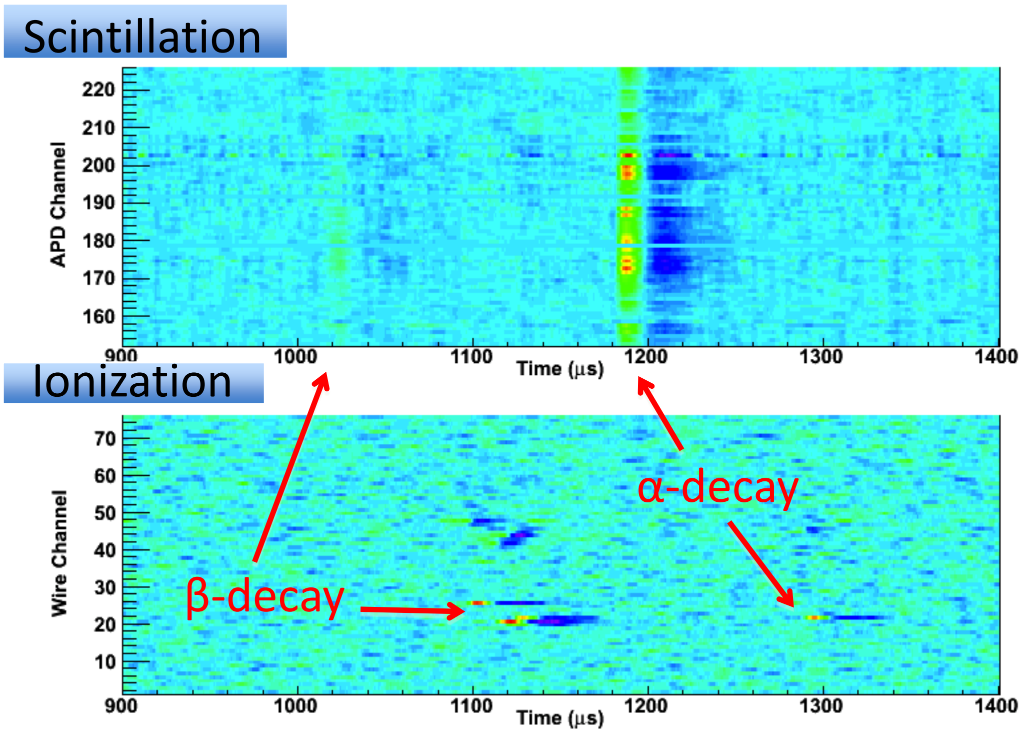
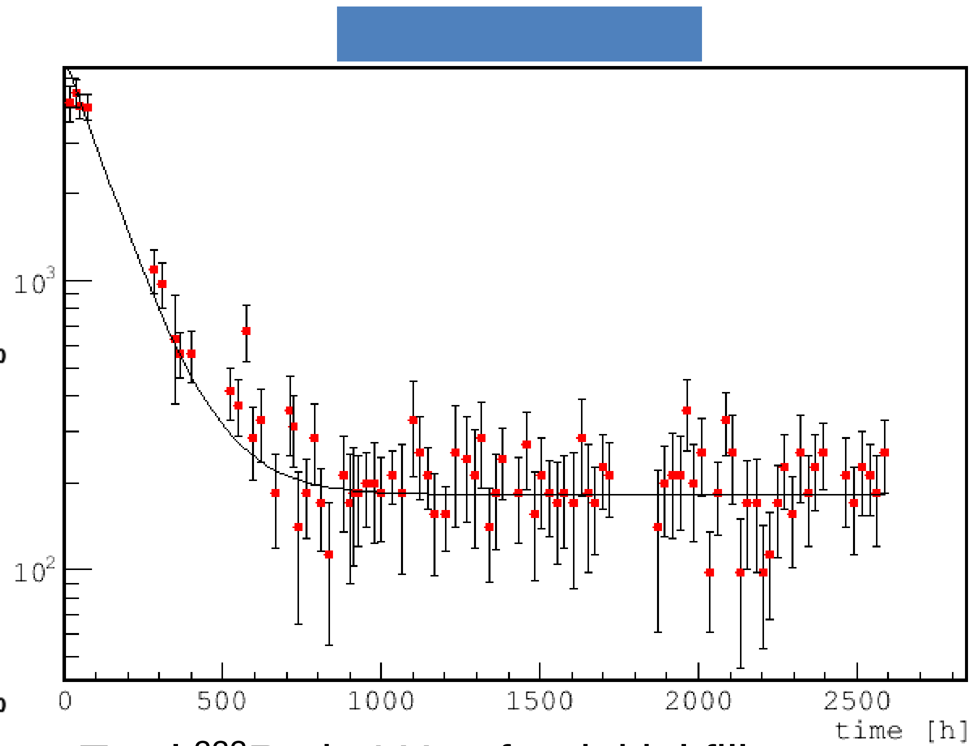
Extra Slides

Rn Content in Xenon



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

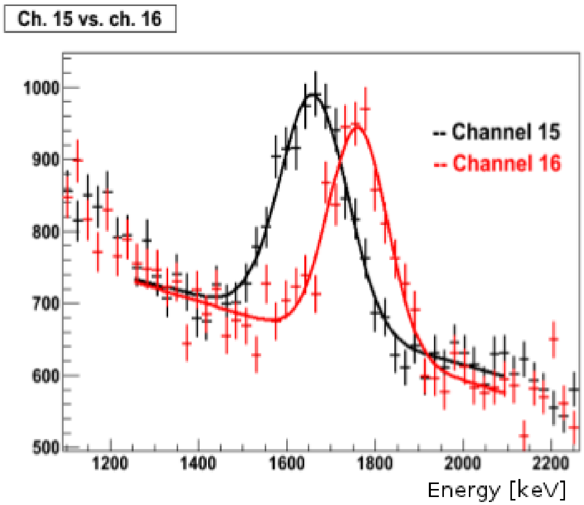


Total ^{222}Rn in LXe after initial fill

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.

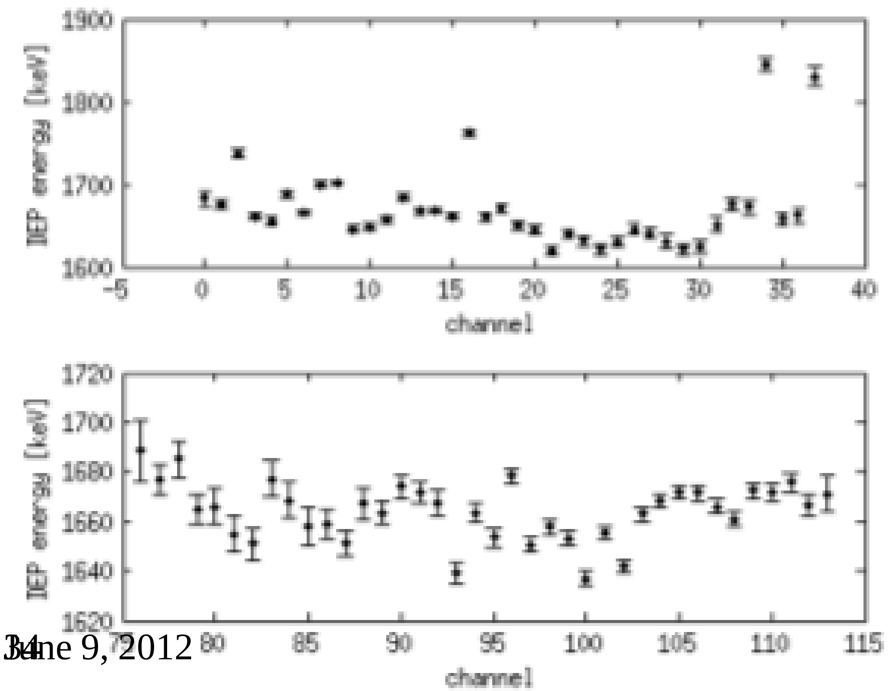
Long-term study shows a constant source of ^{222}Rn dissolving in ^{enr}LXe: 360 ± 65 µBq (Fid. vol.)

Wire Gains

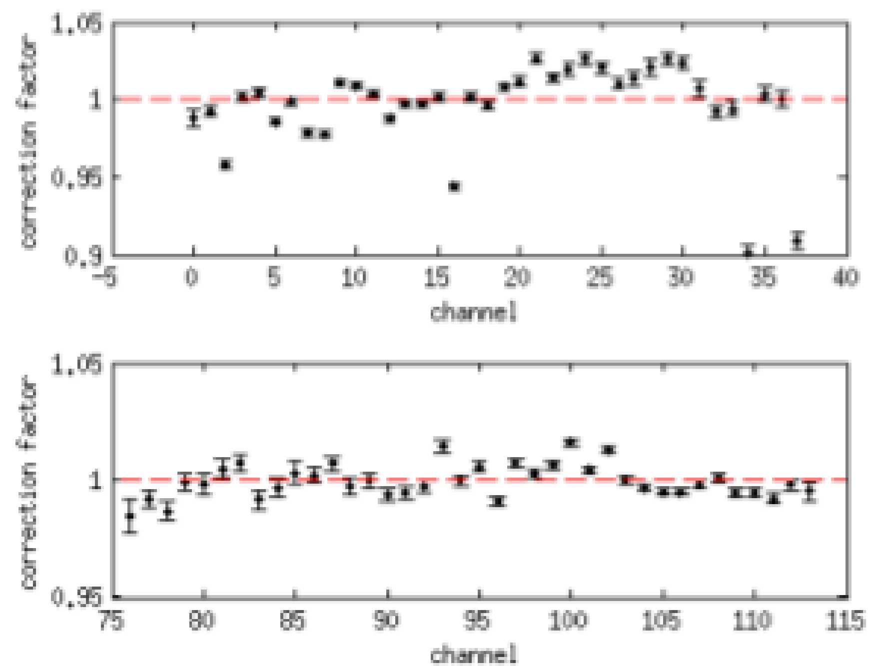


- gains of wire channels measured with charge calibrations
- This is further corrected using the pair production peak (1593 keV) from ^{232}Th 2615 keV gamma depositions.
- Have also individually measured the electronic transfer function of each channel, which are used to reconstruction the charge signals
- With all this, and the excellent purity, the charge resolution improved from 4.5% to 3.4% at 2615 keV

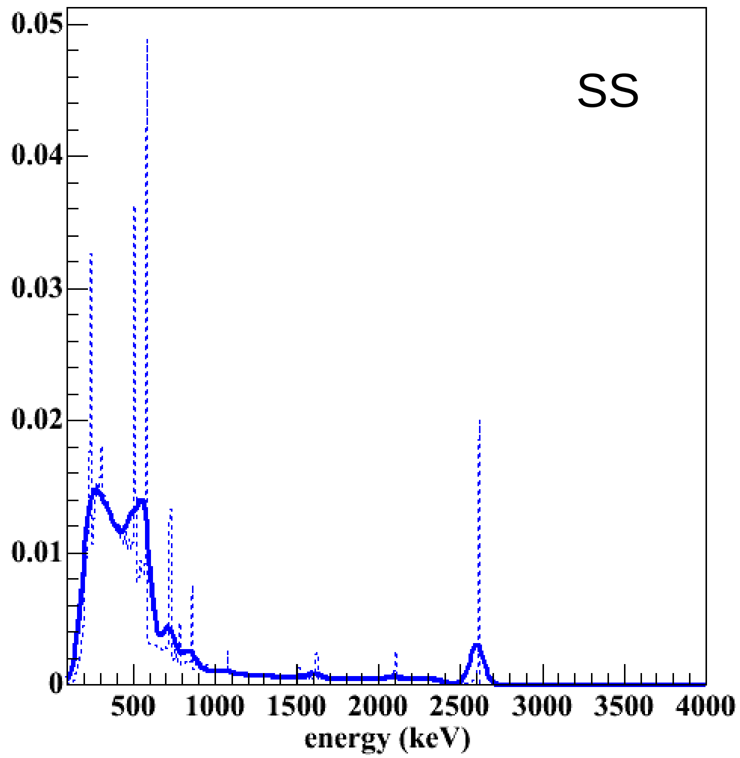
DEP position

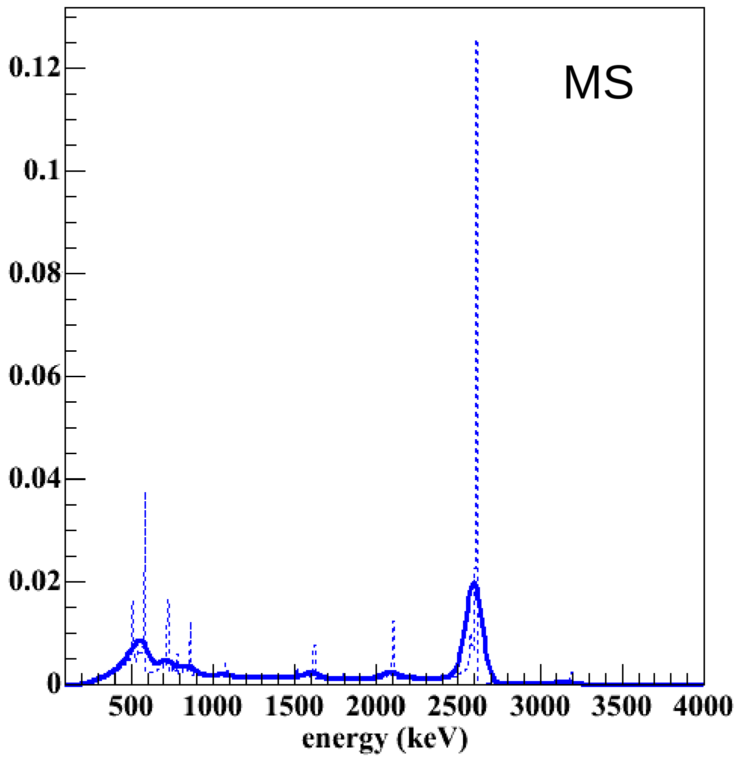


Correction factor



Simulated spectra generation





Dotted line is Geant4 simulated energy deposition from ^{228}Th source.

Solid line is energy spectra resulting from the convolution of the MC energy deposition with the energy resolution model.