Recherche de la désintégration beta double du ^{136}Xe avec EXO

—

Search for $0\nu\beta\beta$ decay in ^{136}Xe with EXO

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For the EXO collaboration

CPPM 4 Juin 2013

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Double-beta decay

There are two varieties of ββ decay

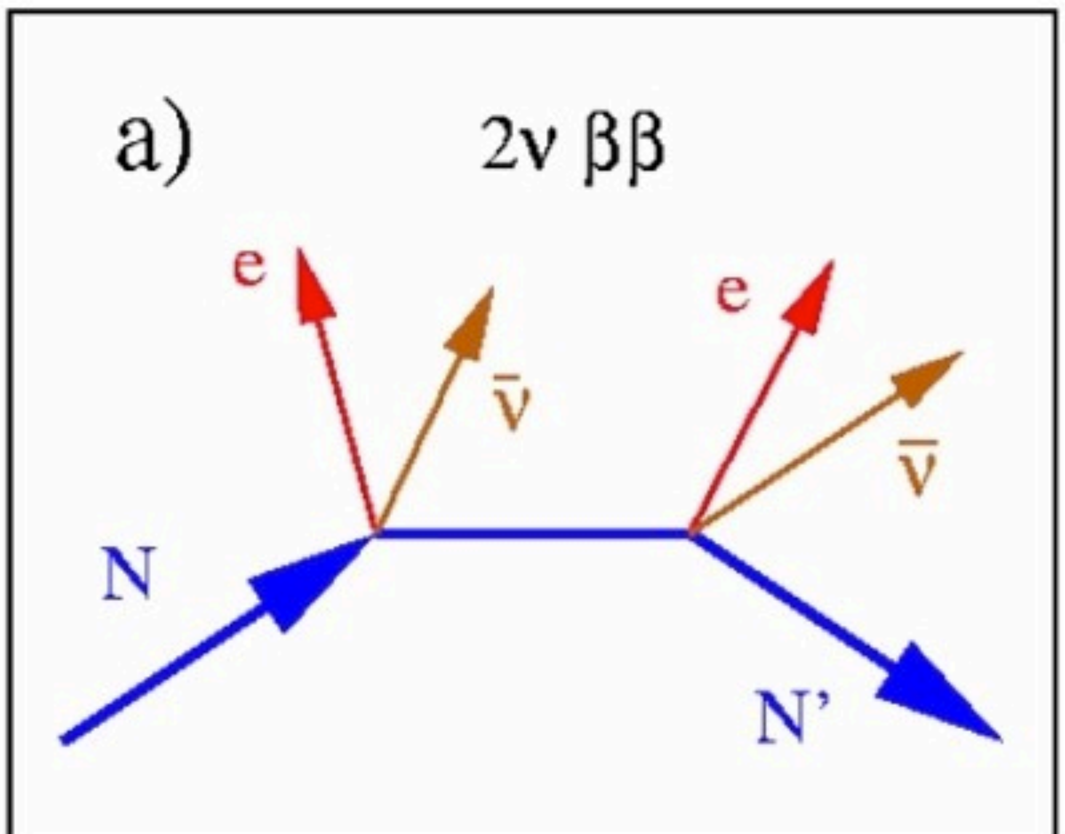
2ν mode:
a conventional
2^{nd} order process
in nuclear physics

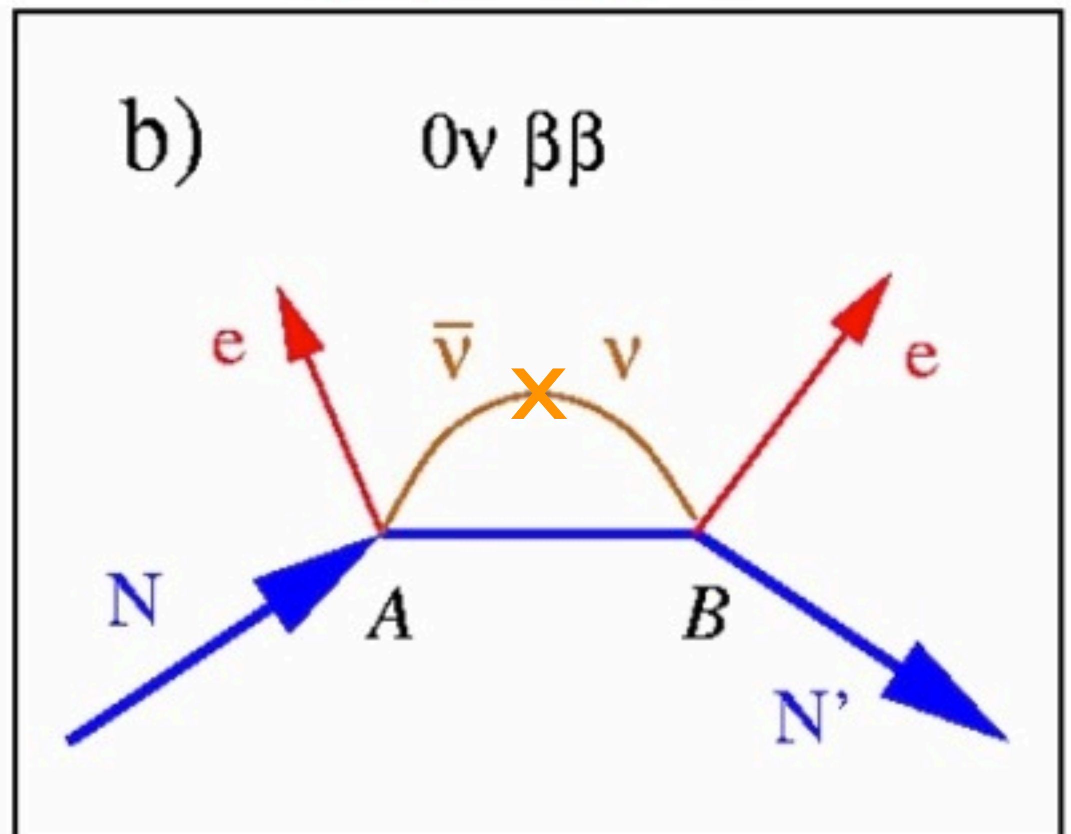
0ν mode: a hypothetical process can happen only if:

$M_\nu \neq 0$, $\nu = \bar{\nu}$ — Since helicity has to "flip"

$|\Delta L| = 2$

$|\Delta(B-L)| = 2$





Decay rate and neutrino properties

Measured $0\nu\beta\beta$ rate

Phase space $\propto Q^5$

Nuclear matrix element

Effective Majorana mass

$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = G^{0\nu}\left|M_{nucl}\right|^2 m_{ee}^2$$

$$m_{ee} = \left|\sum_i e^{i\alpha_i}\left|U_{ei}^2\right| m(\nu_i)\right|$$

Majorana + possible CP-violating phases

Mixing matrix

In the last 10 years there has been a transition

1) From a few kg detectors to 100s or 1000s kg detectors
→ Think big: qualitative transition from cottage industry to large experiments

2) From "random shooting" to the knowledge that at least the inverted hierarchy will be tested

Discovering 0νββ decay:

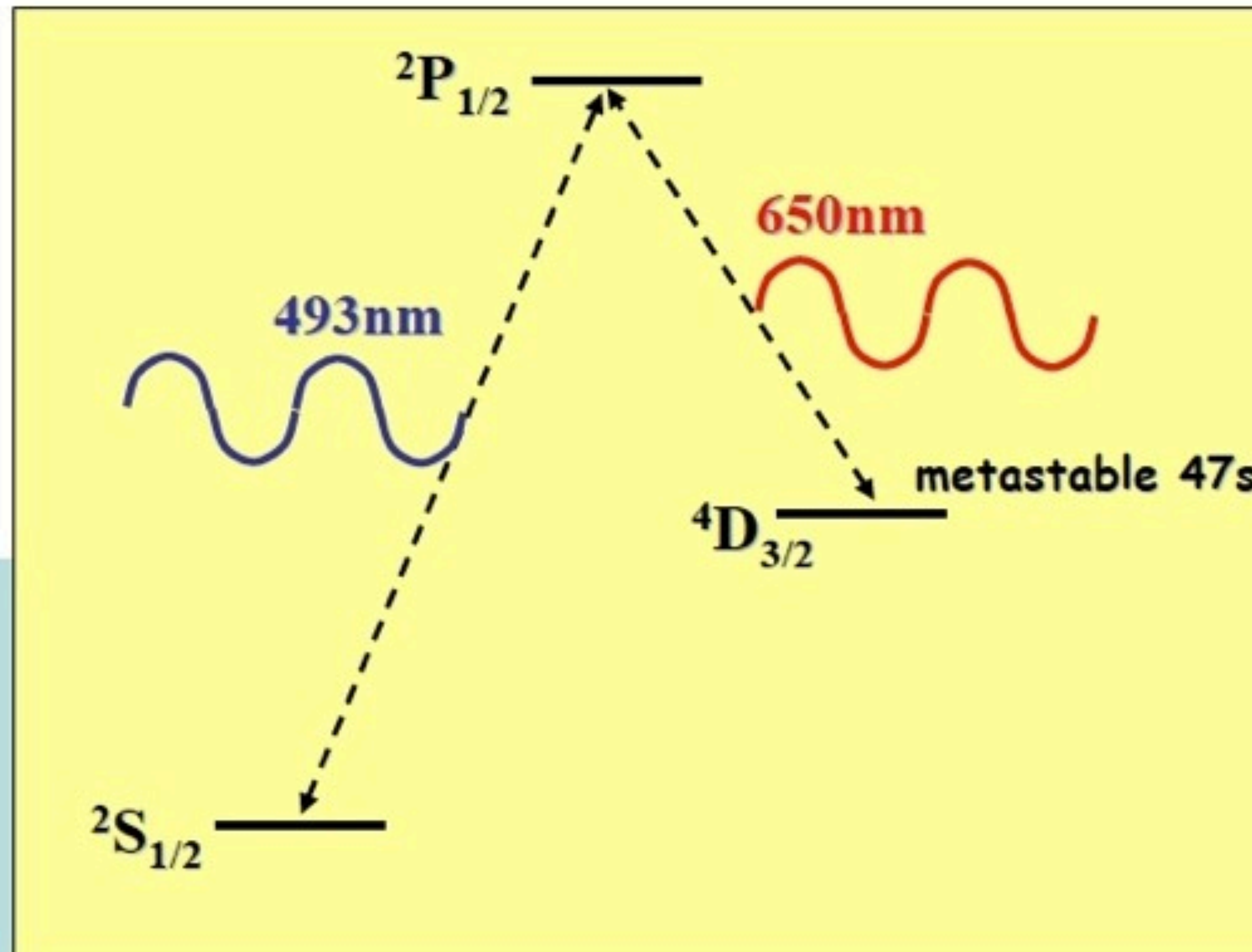
→ Discovery of the neutrino mass scale
→ Discovery of Majorana particles
→ Discovery of lepton number violation

The EXO Program

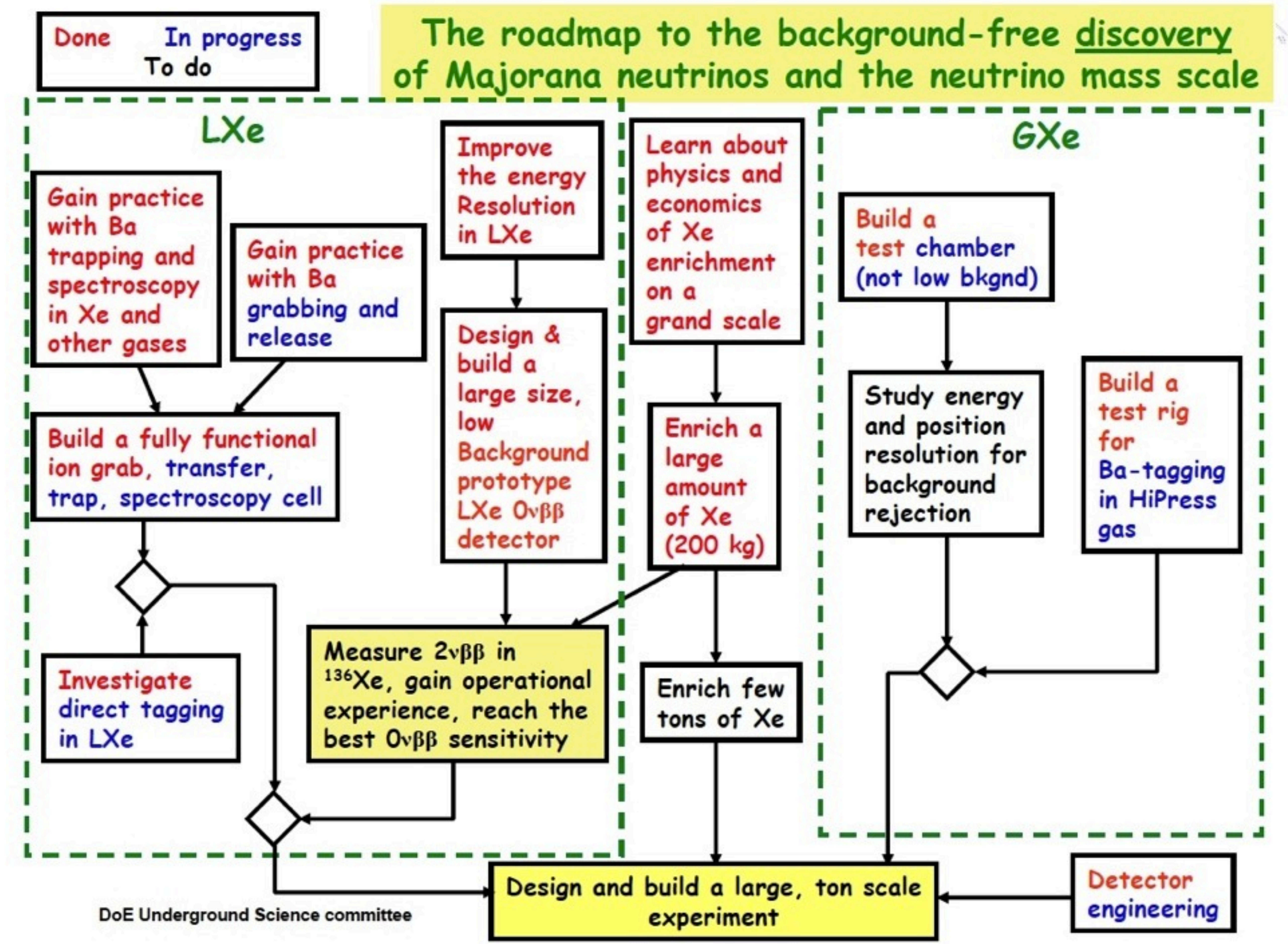
- EXO is a multi-phase program to search for the neutrinoless double beta decay of ^{136}Xe
- The ultimate goal is a ton-scale experiment with ~10 meV sensitivity to the Majorana mass as well as positive identification of the barium daughter ion
- EXO-200 is a prototype experiment to acquire experience with LXe. Its physics goals were the measurement of the 2νββ decay and an improved limit on m_{ee} (up to 4 years LT)
- In parallel, the collaboration is gaining experience with a 10kg GXe detector based on electroluminescence

Xe offers a qualitatively new tool against background: $^{136}Xe \rightarrow {}^{136}Ba^{++} e^- e^-$ final state can be identified using optical spectroscopy (M.Moe PRC44 (1991) 931)

Ba^+ system best studied
(Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)
Very specific signature "shelving"
Single ions can be detected from a photon rate of 10^7/s



- Important additional constraint
- Drastic background reduction
- May be required to reach the ultimate m_ν sensitivity


Done
In progress
To do
The roadmap to the background-free discovery of Majorana neutrinos and the neutrino mass scale
LXe
Gain practice with Ba trapping and spectroscopy in Xe and other gases
Gain practice with Ba grabbing and release
Improve the energy Resolution in LXe
Design & build a large size, low Background prototype LXe 0νββ detector
Build a fully functional ion grab, transfer, trap, spectroscopy cell
Investigate direct tagging in LXe
Measure 2νββ in ¹³⁶Xe, gain operational experience, reach the best 0νββ sensitivity
Learn about physics and economics of Xe enrichment on a grand scale
Enrich a large amount of Xe (200 kg)
Enrich few tons of Xe
GXe
Build a test chamber (not low bkgnd)
Study energy and position resolution for background rejection
Build a test rig for Ba-tagging in HiPress gas
Design and build a large, ton scale experiment
Detector engineering
DoE Underground Science committee

EXO–200

A LXe TPC

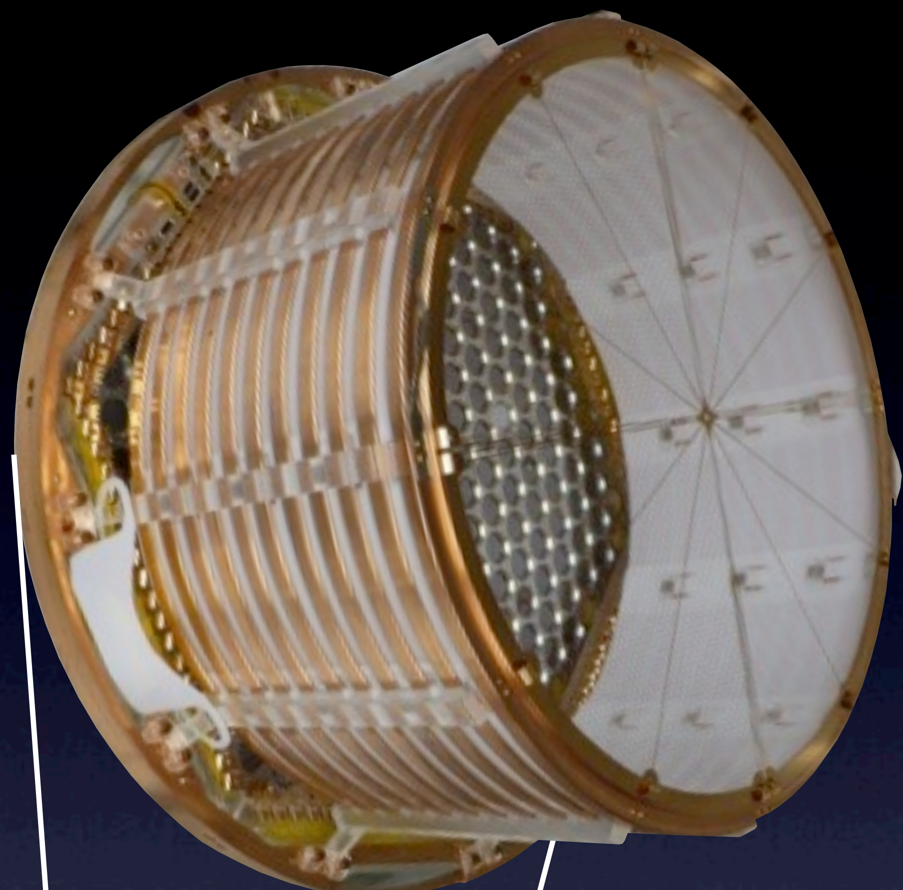
200kg ^{enr}Xe

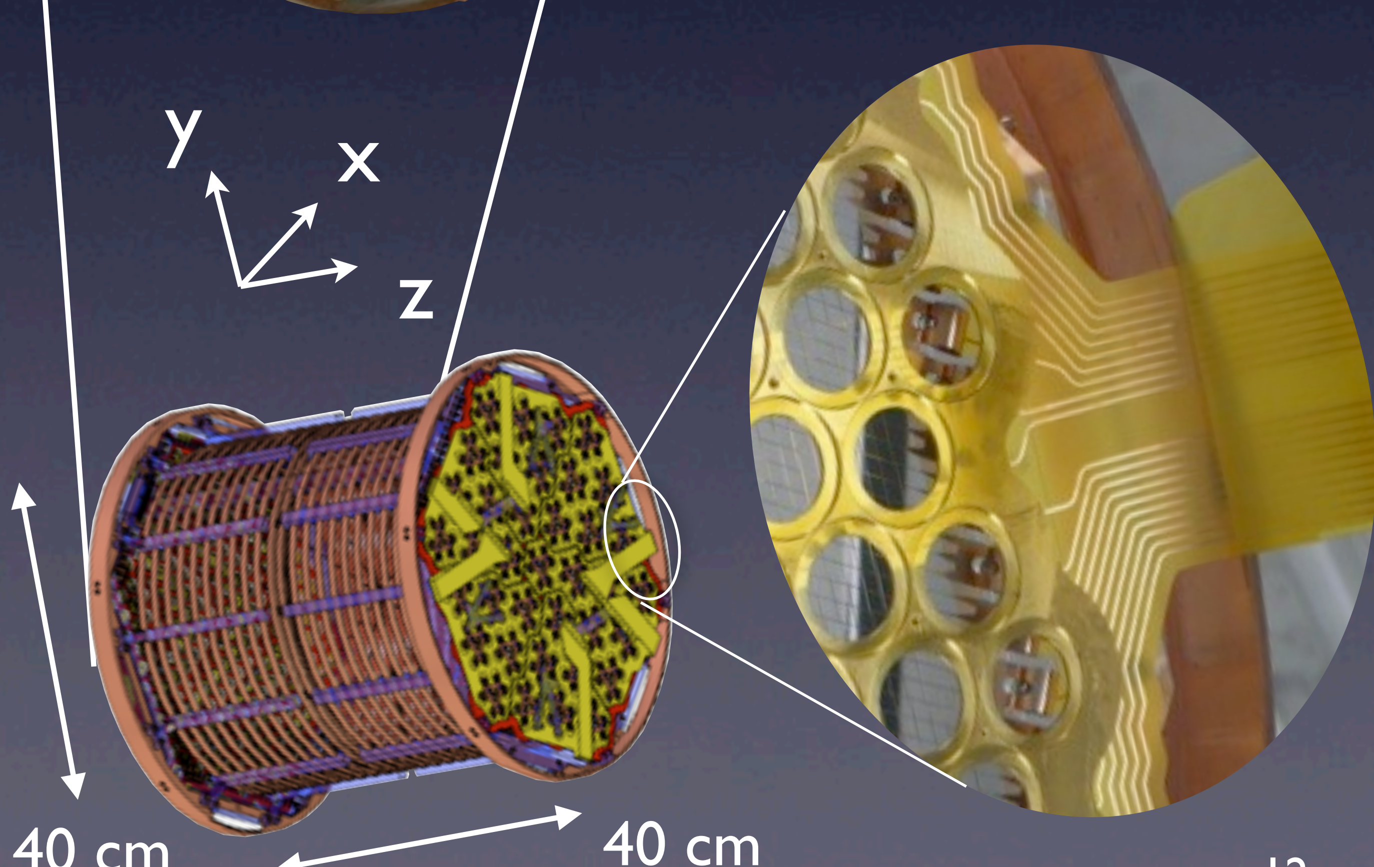
No Ba tagging

The EXO-200 TPC

Two almost identical halves reading ionization and 178 nm scintillation, each with:

- 38 U triplet wire channels (charge)
- 38 V triplet wire channels, crossed at 60° (induction)
- 234 large area avalanche photodiodes (APDs, light in groups of 7)
- Wire pitch 3 mm (9 mm per channel)
- Wire planes 6 mm apart and 6 mm from APD plane
- All signals digitized at 1 MS/s, ±1024S around trigger
- Drift field 376 V/cm

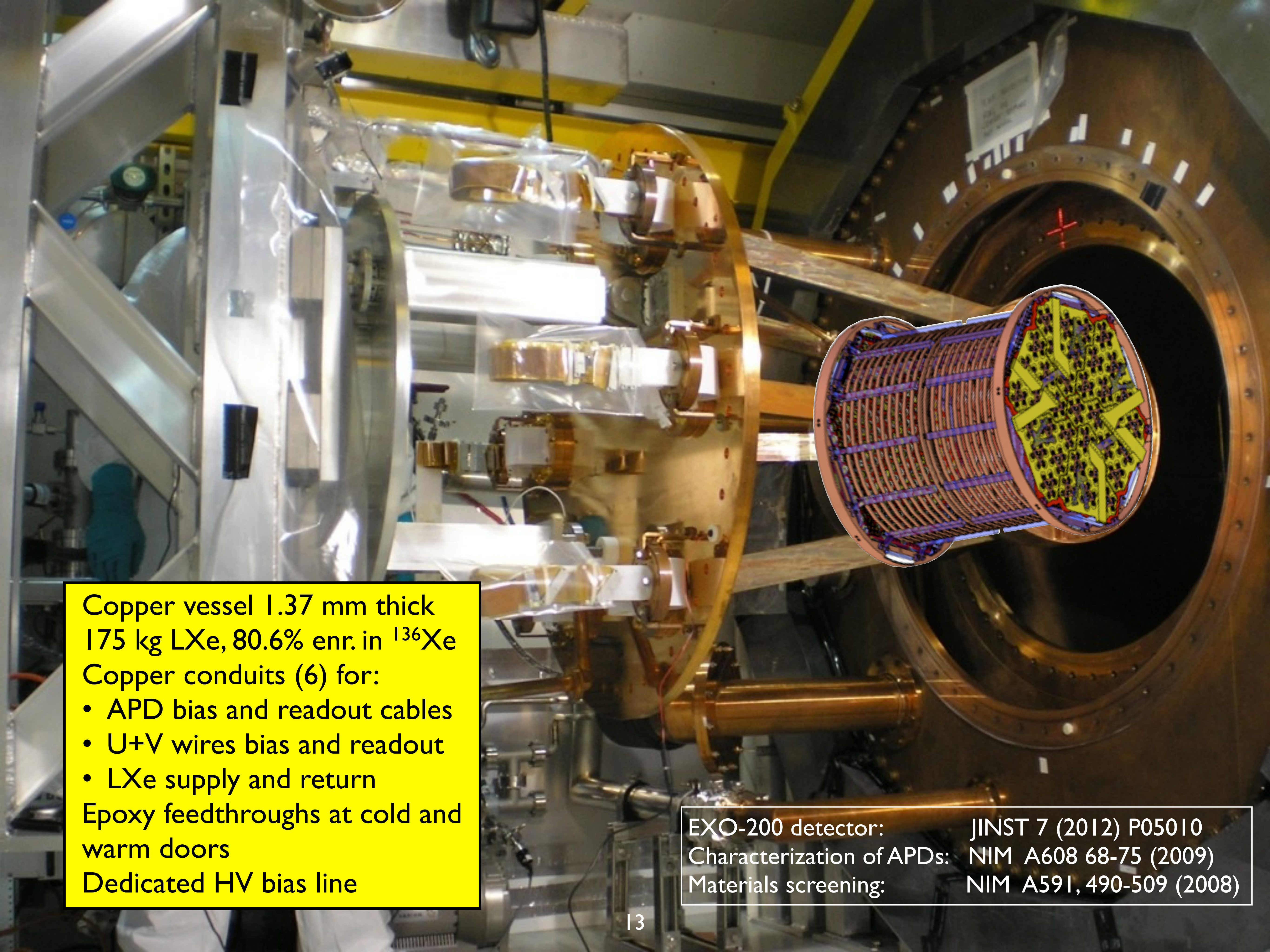




- Field shaping rings: copper
- Supports: acrylic
- Light reflectors/diffusers: Teflon
- APD support plane: copper; Au (Al) coated for contact (light reflection)
- Central cathode, U+V wires: photo-etched phosphor bronze
- Flex cables for bias/readout: copper on kapton, no glue

Comprehensive material screening program

Goal: 40 cnts/2y in 0νββ ±2σ ROI, 140 kg LXe



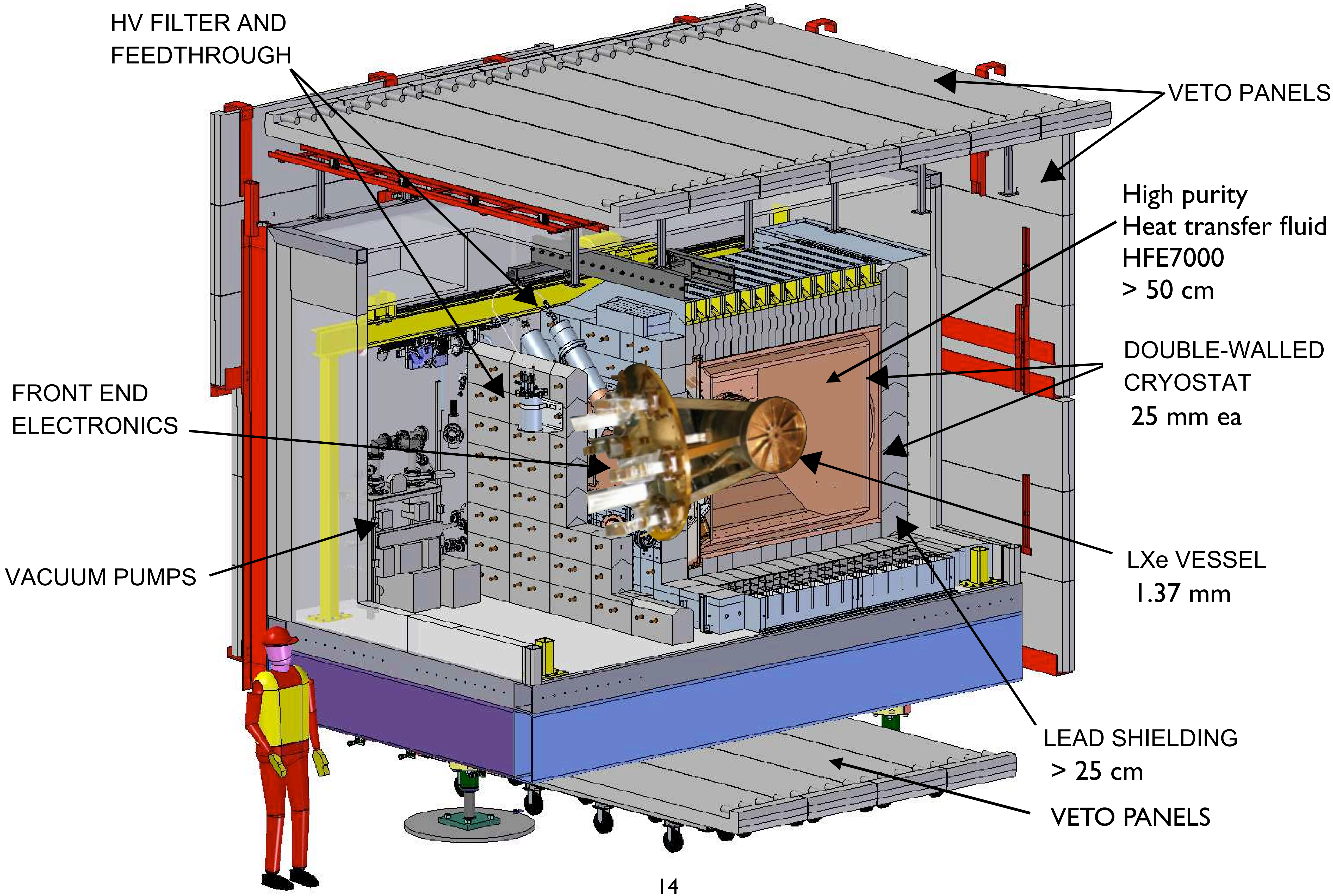
Copper vessel 1.37 mm thick
175 kg LXe, 80.6% enr. in ^{136}Xe
Copper conduits (6) for:

- APD bias and readout cables
- U+V wires bias and readout
- LXe supply and return

Epoxy feedthroughs at cold and warm doors
Dedicated HV bias line

EXO-200 detector:	JINST 7 (2012) P05010
Characterization of APDs:	NIM A608 68-75 (2009)
Materials screening:	NIM A591, 490-509 (2008)

The EXO-200 Detector



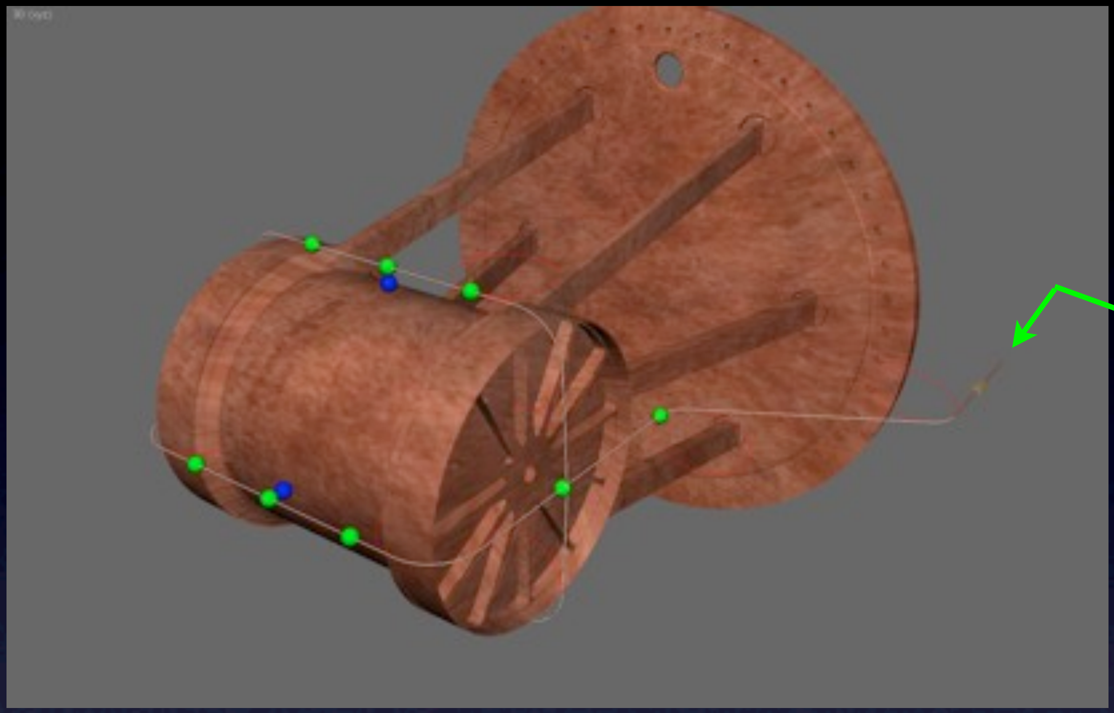
Muon veto

- 50 mm thick plastic scintillator panels
- surrounding TPC on four sides.
- 95.5 ± 0.6 % efficiency

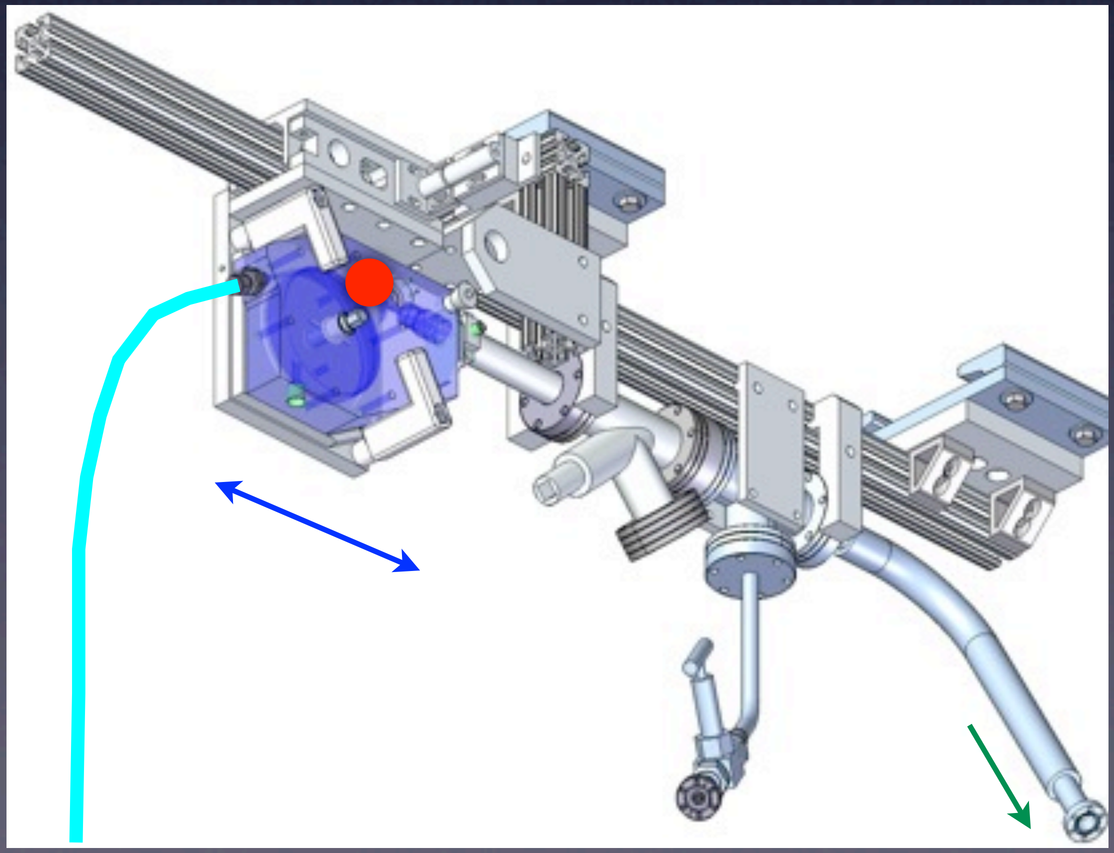
Veto cuts (8.6% combined dead time)

- 25 ms after muon veto hit
- 60 s after muon track in TPC
- 1 s after every TPC event

Calibrations Hardware

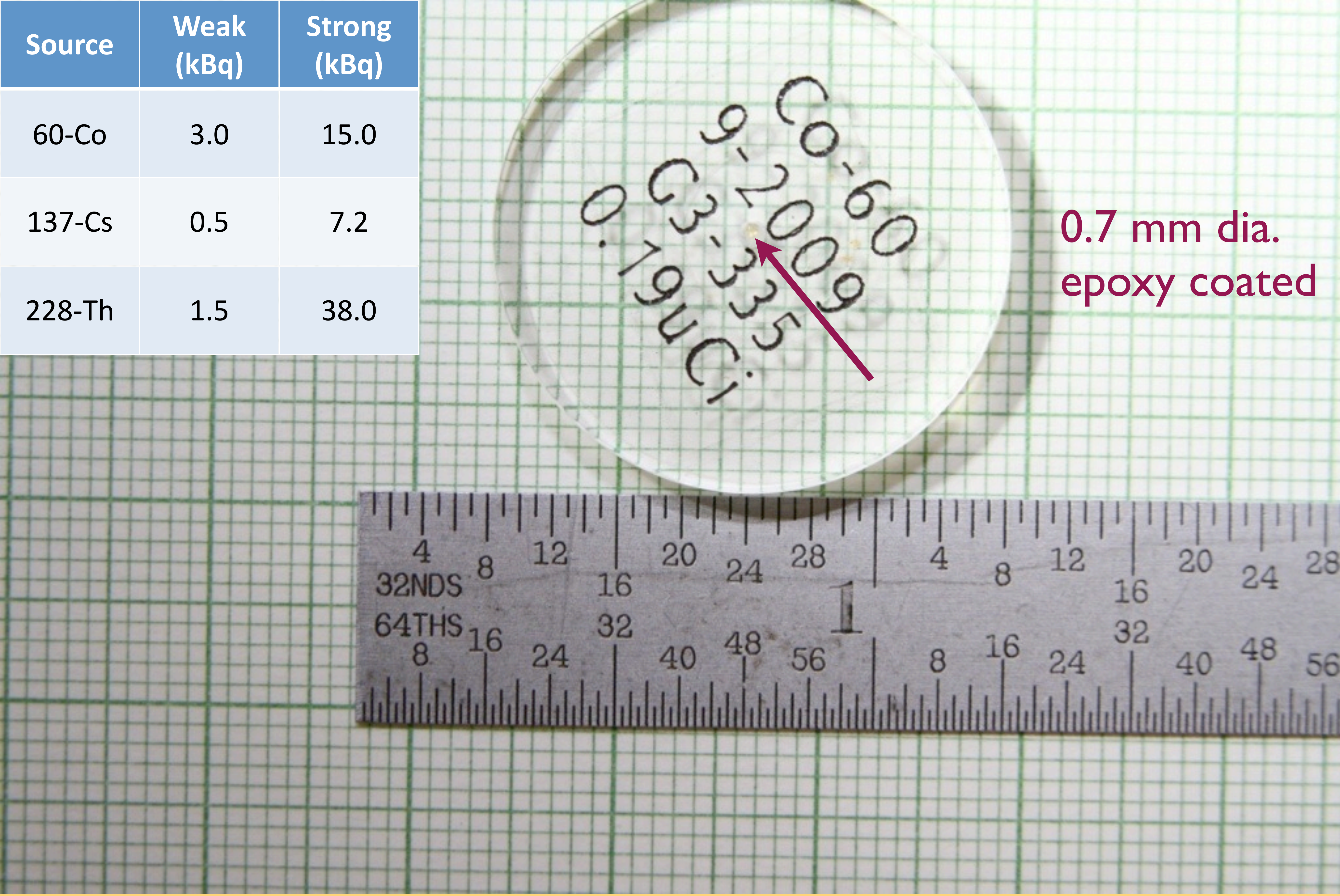


- Encapsulated gamma source
- Attached to ~ 8m long guide wire
- Deployed inside Guide Tube convoluted around TPC

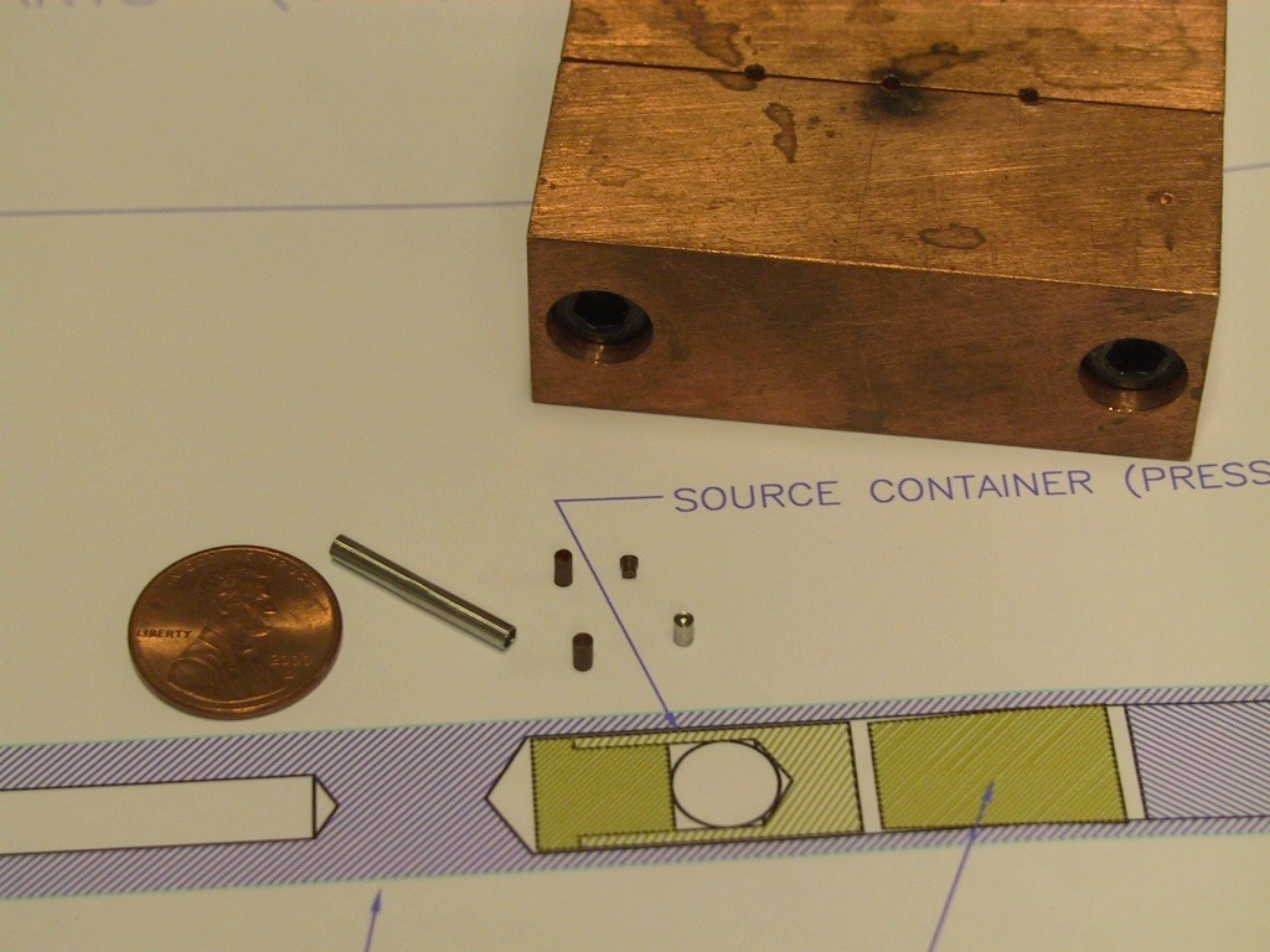


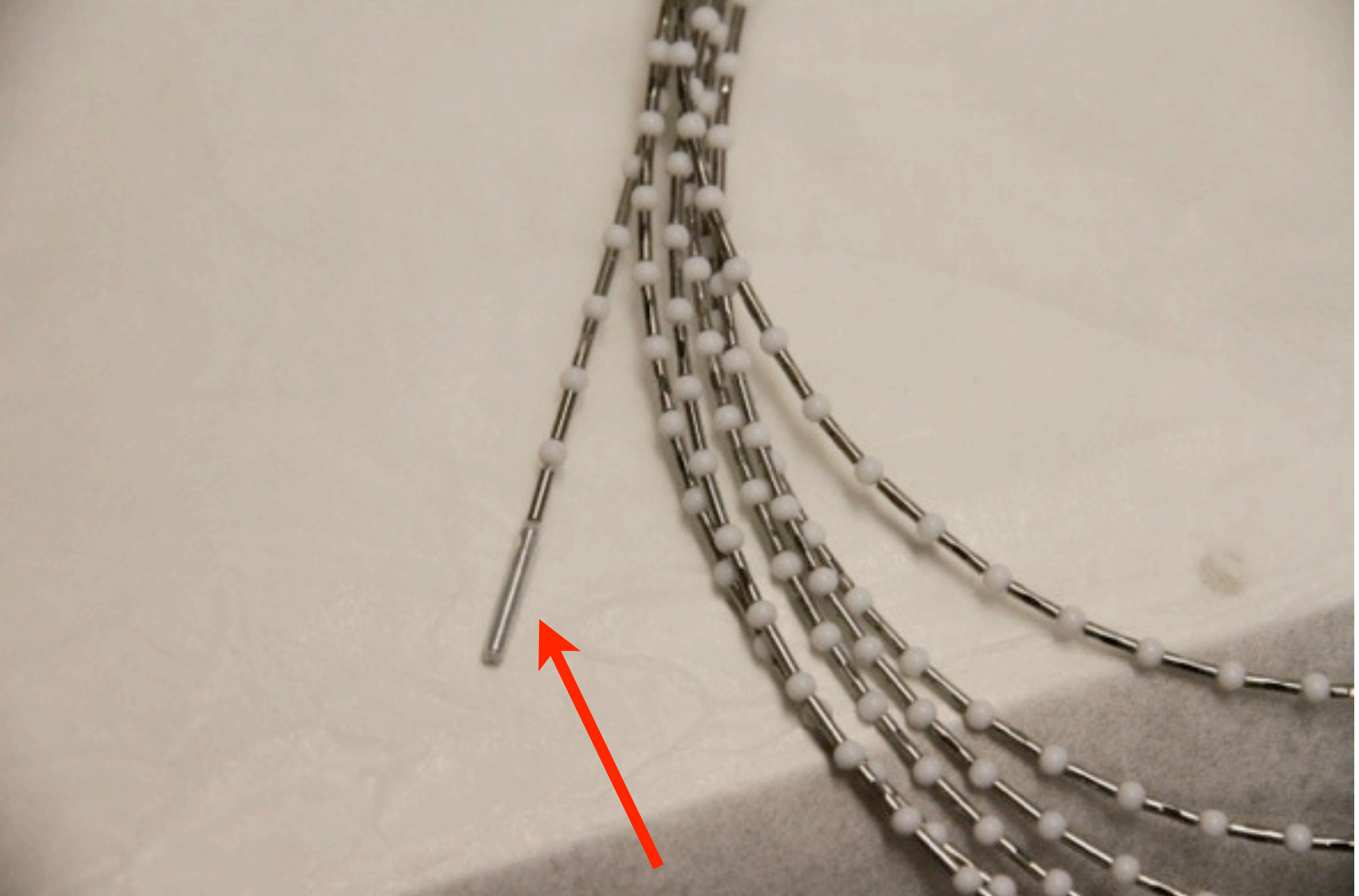
- Design driven by background from Guide Tube, and by friction
- Sources stored in cassettes; guide wire stored in PTFE tubing
- Cassettes mounted on carriage, slides in deployment hardware
- Sprocket drives guide wire

Source	Weak (kBq)	Strong (kBq)
60-Co	3.0	15.0
137-Cs	0.5	7.2
228-Th	1.5	38.0



Source bead used in first capsule Co-60 19nCi


SOURCE CONTAINER (PRESS



Clear tube insertion test
(2" and 3" rad)

Practice cable with
PTFE coated dummy source

Tested in dedicated cold box

Guide Tube Installed 12/09 – 01/10

Background control

Material Screening

Goal: 40 cnts/2y in $0\nu\beta\beta$ $\pm 2\sigma$ ROI, 140 kg LXe && MC

n activation (Alabama)

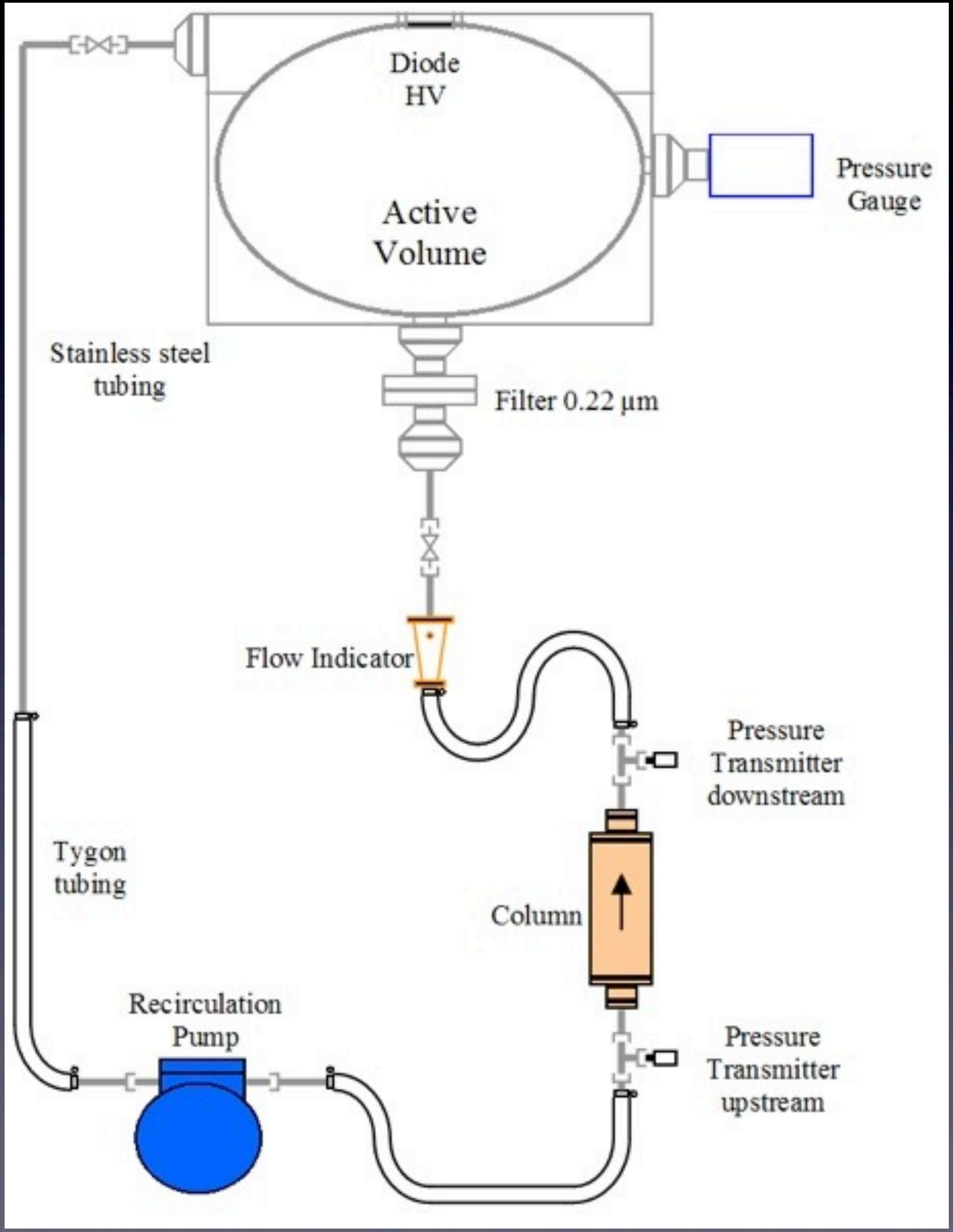
γ HPGe (Alabama, Neuchâtel, SNOLAB)

Rn emanation ESCs (Laurentian)

α surface counting (Carleton)

NIM A591, 490-509 (2008)

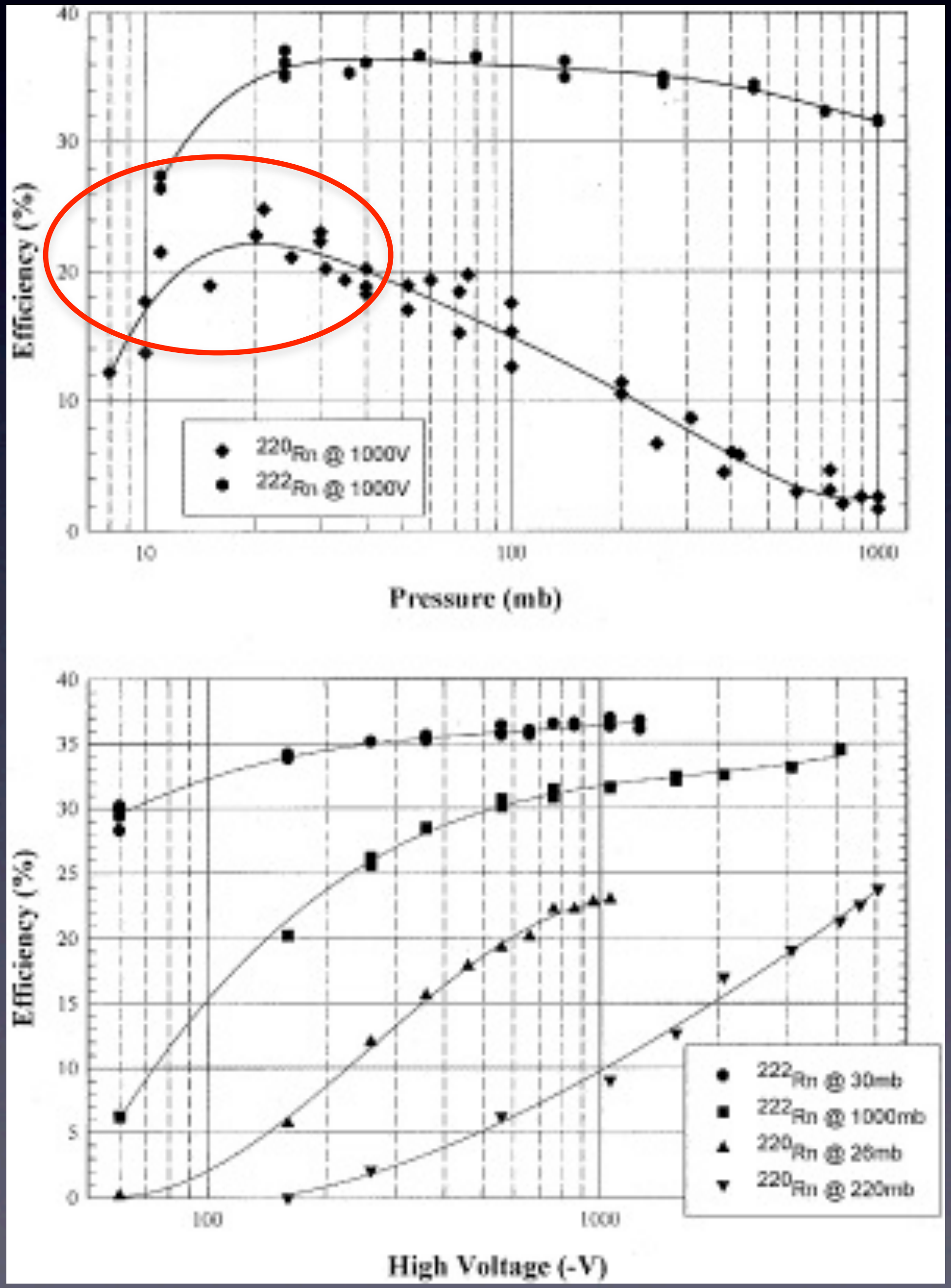
ElectroStatic Counters (ESCs) Developed to Measure ^{224}Ra, ^{226}Ra in SNO

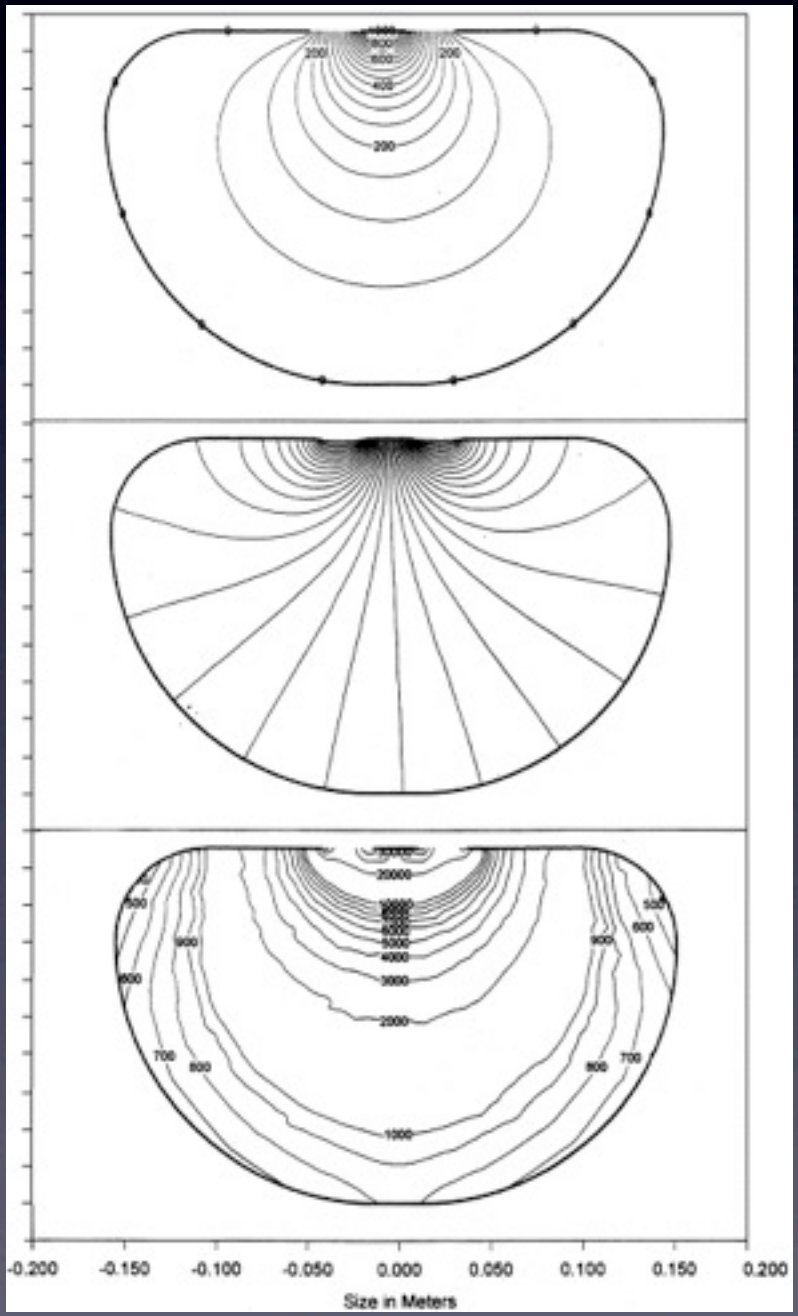


- A recirculation pump forces a carrier gas gas through the sample and into the ESC for analysis.
- 10L Decay Chamber, filled with Electrostatic field
- 70% of Rn daughters +charged
- Rn daughters precipitate onto Si PIN diode
- Alpha spectroscopy
- Time series analysis returns ^{220}Rn, ^{226}Ra, ^{228}Th and ^{224}Ra at time zero

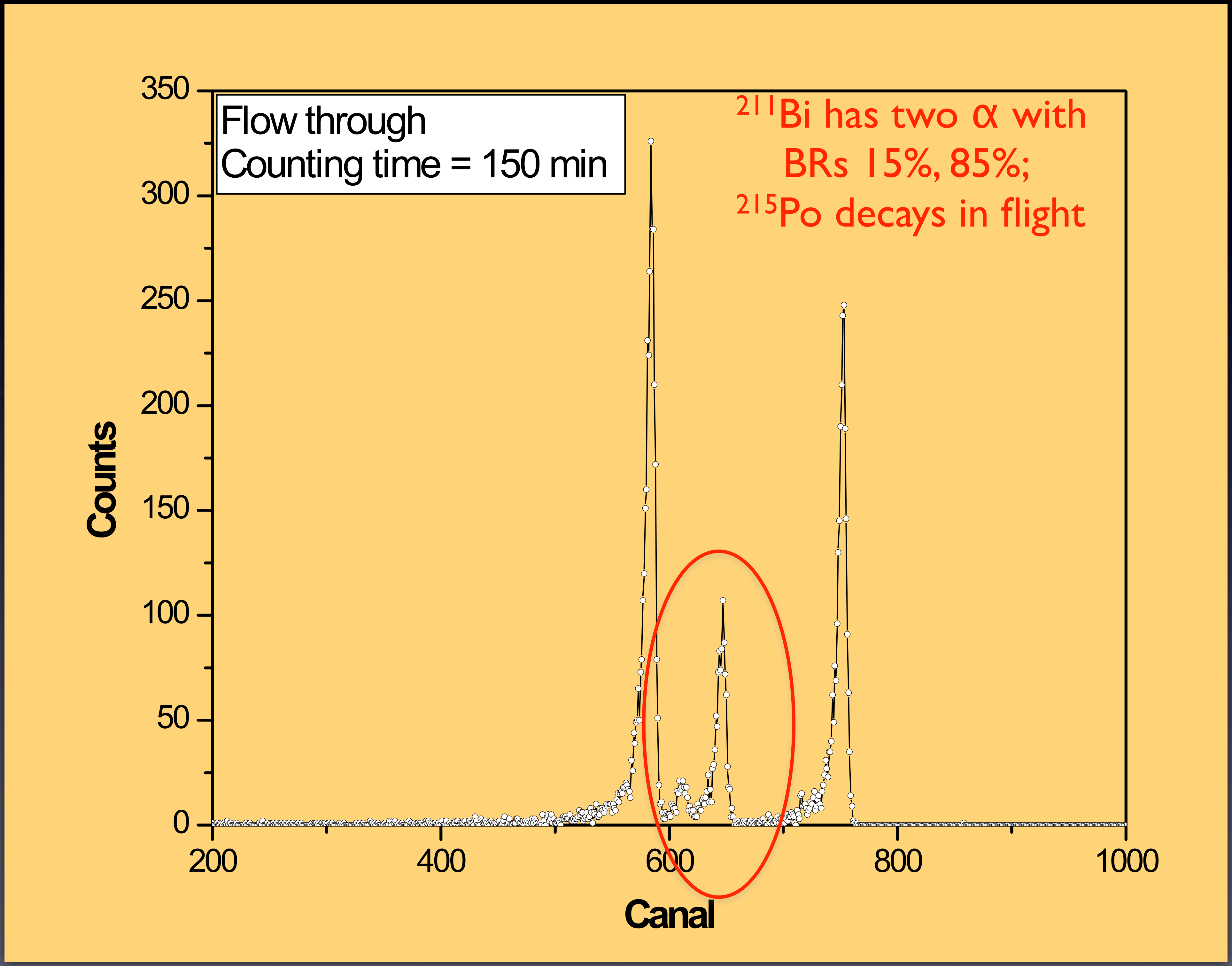
Designed specifically for high ^{220}Rn detection efficiency: 22.5% @ 25mbar N_2

J.X. Wang et.al., NIM A 421 (1999) 601
T.C. Andersen et.al., NIM A 501 (2003) 399–417





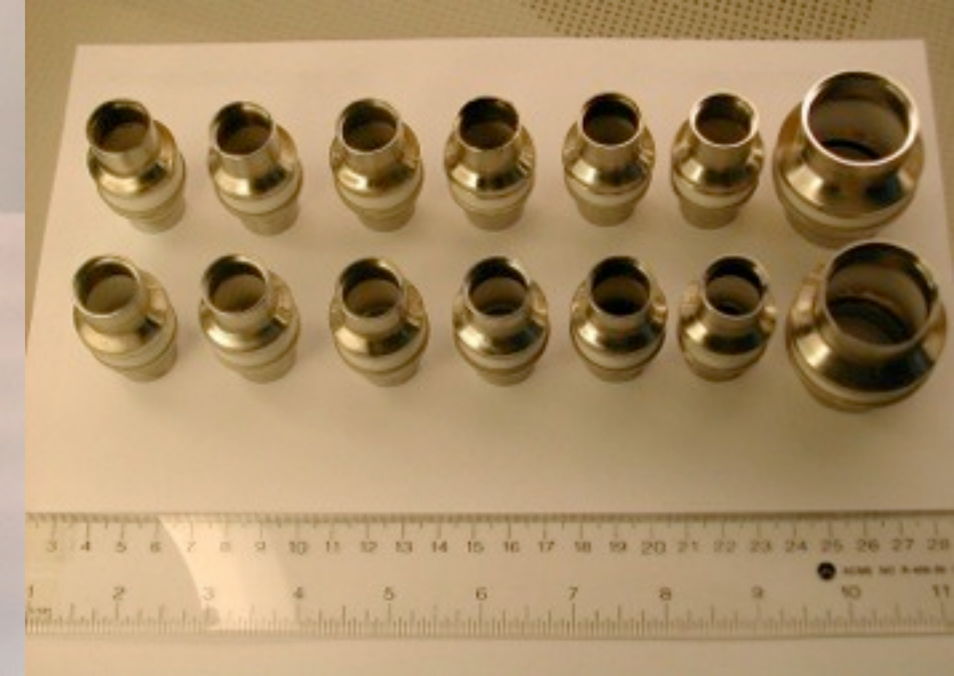
Sensitivity to ^{219}Rn through ^{211}Bi

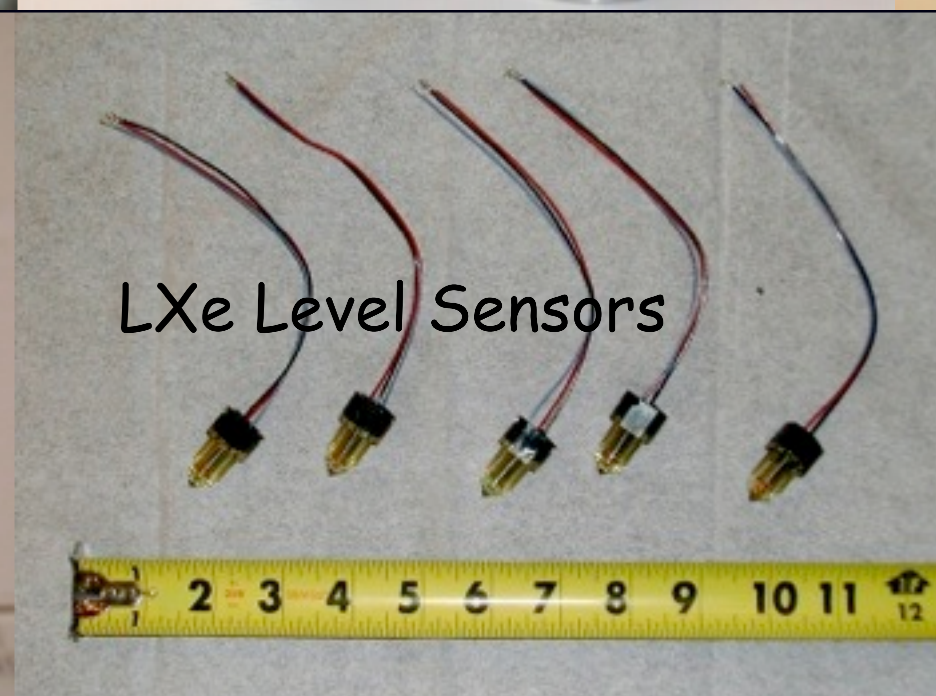


ESC Farm operated by LU at SNOLAB

- Measure radon from U / Th / Act chains, in N_2, Ar, Xe
- From 9 counters down to 6 for general emanation studies (still 8 in use for EXO)
  - ESC#5 moved to WIPP (and well used for Emanation, Rn tent,..)
  - ESC#7 lent to Alberta (SNO+ Rn–free air)
  - ESC#3 dedicated to Rn trap work
- Worked hard to reduce backgrounds further
  - routine sensitivity:

^{222}Rn	^{220}Rn	^{219}Rn
~10 at/d	~5 at/d	~10 at/d





SAES Purifier II - SLAC Spare

DuPont Teflon TE-6472 Lot# 0503830033 APT drum #041 - DuPont Teflon TE-6472 Lot# 0506830001 Sealed drum, DuPont - Espanex sheet for flat cable (from A. Piepke) - Ceramics electrical breaks 9998-06-W(12) + 17199-01-W(2) - LXe Level Sensors (from P. Rowson) - Valve seats for GXe systems (from C. Hall) - Teflon coated o-rings (compressors) (from C. Hall) - Phosphor Bronze Spiders for APDs (from A. Pocar) MD152.B.1 - Copper plates (from A. Pocar) MD152.A.1 - Copper plates (from A. Pocar) MD152.A.1 - Macor rods (from V. Stekanov) MD197 - Epoxy for cables F/T (from L. Yang) MD196, MD99 - SAES Purifier I (Carleton) MT-PS4 - SAES Purifier II (MT-PS4 SLAC #2/2 Spare) - SAES Purifier III (PF4C3R1 - Cartrige only) - SAES Purifier IV (MT-PS4 SLAC #1/2 Original) - NuPure Eliminator CG (from Al Odian) - Mott Filter 1 of 3 (MD198) - Mott Filters 2+3 of 3 (MD198)

EXO Radon Emanation Measurements Summary

http://thoron.phys.laurentian.ca/~jfarine/exo/RnEmanResults.html

EXO Radon Emanation Measurements Summary

Last update 23 July 2008
J. Farine, Laurentian University

Radon yields when given in atoms/day are always total, as measured.

All dates are in the 6-digit format YYMMDD.

Object	References (author date)	Sample characteristics				Emanation rates				^{224}Ra conc. (10^{-12} gTh_{eq}/g)	^{226}Ra conc. (10^{-12} gU_{eq}/g)
		MD#	Mass (g)	Area (m^2)	# of items	Total		Per unit area			
						^{220}Rn/d	^{222}Rn/d	^{220}Rn/m^{2}d	^{222}Rn/m^{2}d		
SAMPLES											
DuPont Teflon TE-6472 Lot# 0503830033 Taken from APT drum #041 by APT on 3 August 2005	BA051020 BA060104 BA,JF051110	TBD	602.1	(3.8)		< 5	36 ± 7	< 1	9.5 ± 1.8	< 25 ‡	56 ± 10 ‡
DuPont Teflon TE-6472 Lot# 0506830001 Sealed drum from DuPont. Samples collected in UA clean room	BA051020 BA060104 BA,JF051110	MD11	718.2	(4.5)		< 5	< 12	< 1	< 3	< 20 ‡	< 16 ‡
Espanex sheet for flat cable (from A. Piepke)	JF060707	MD1, MD52		1.60		< 10	< 10	< 6.3	< 6.3		
Ceramics electrical breaks (from V. Strickland). Part#(qty): 9998-06-W(12) +	JF060330			7.9E-2 (29%	12+2	< 9.5	< 8.2	< 121	< 105		

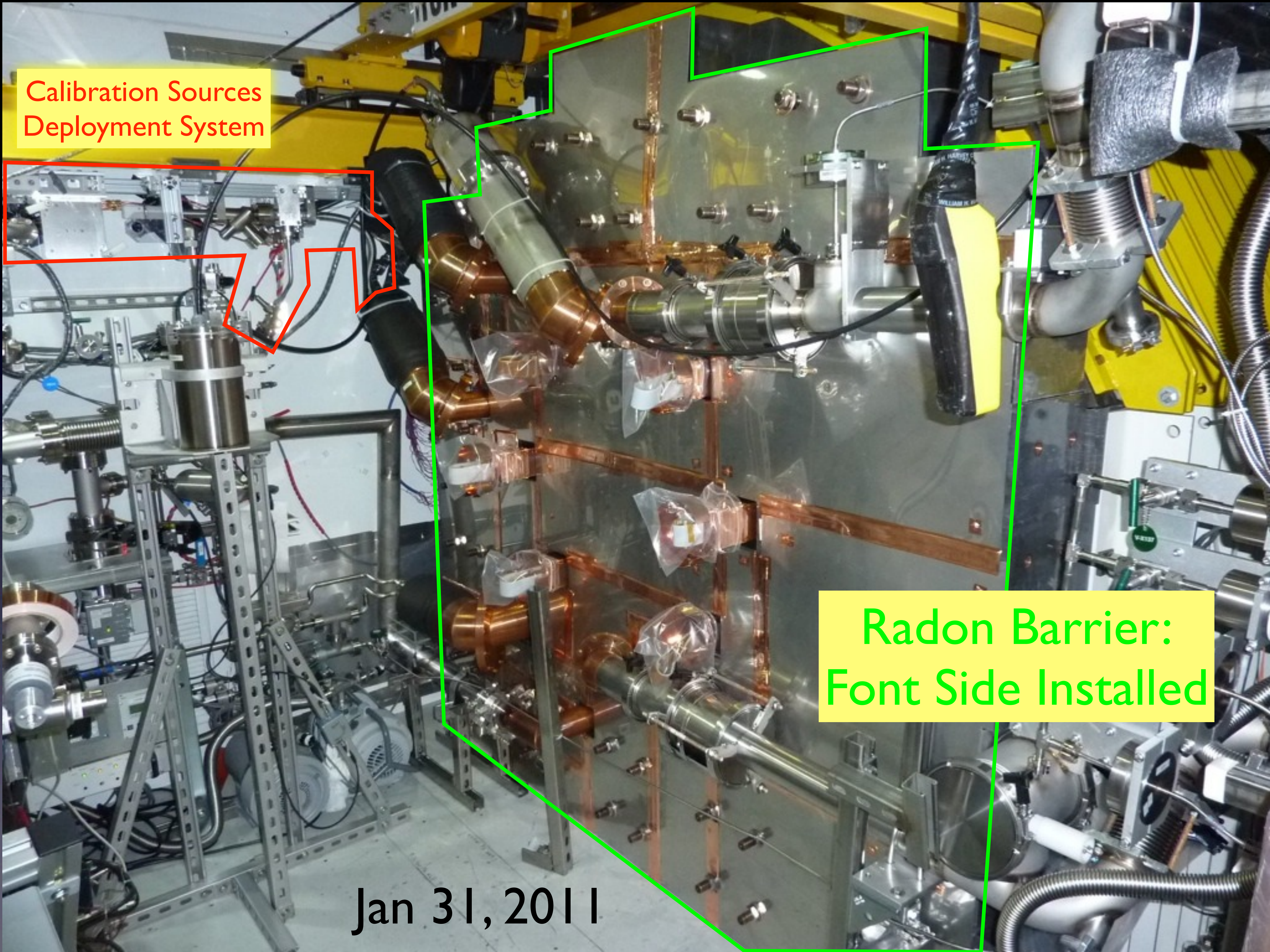
Upcoming updates to EXO radioactivity measurements and Rn results

Radon barrier

Background mitigation – Rn Barrier

Stainless sheets + butyl rubber

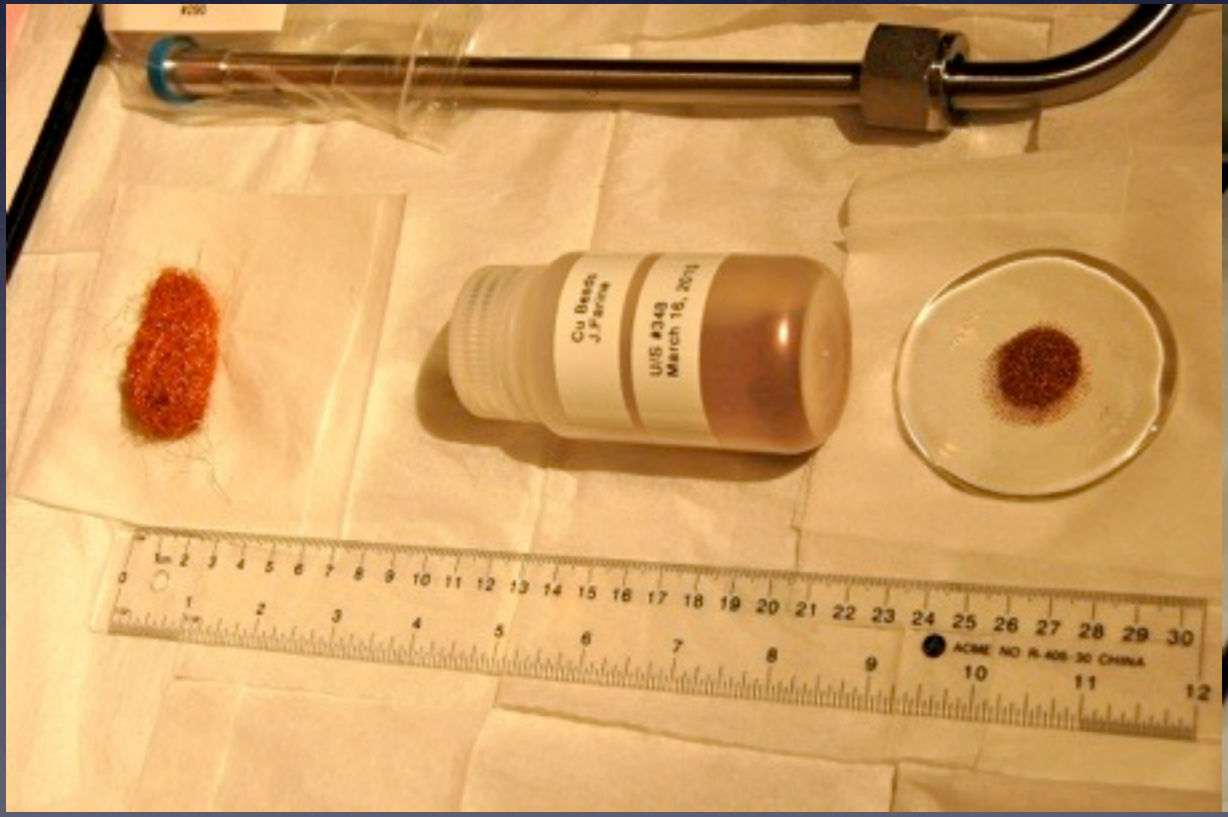
- Mine air Rn 15 Bq/m3 (spikes up to 37); Simulations: factor 10 less (2 Bq/m3) @ cryostat would account for 10% target Bgnd
- Can eliminate this source of ^{214}Bi γ altogether with a barrier !
- Target 20 mBq/m3 inside barrier – use aged dry air (safety)
- LU maintains low bgnd counter (ESC) at WIPP, dedicated to on-site Rn work; thoroughly leak-checked; sensitivity 6 mBq/m3
- Determined Rn budget inside barrier. Ingress by diffusion is negligible if polymers are required to be self-supporting
- Choose stainless steel for fire safety. Butyl rubber for seams
- Measured Rn from std bottles: 3 runs, consistent 662+-58 Rn/d
- Tent now in service. Upgrade to High Flow is needed, in progress


Calibration Sources
Deployment System
Radon Barrier:
Font Side Installed
Jan 31, 2011

Radon Trap

Background mitigation – Rn Trap

- Dedicated system at SNOLAB for development, a LU responsibility
- Target radon retention rate is 99.99% at 10 LPM, 1 atm
- Test copper wool, then copper spheres; compare with existing models (analytical + simulation). Also test nickel wool
- EXO–200 trap: Envelope design done; cooling capacity at hand; can swap traps with minimal disruption.



Upgraded Radon Source

DAQ & DAN

Data taking phases and Xenon Purity

	Run 1	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
Exposure (^{136}Xe)	4.4 kg-yr	26.3 kg-yr
Publ.	PRL 107 (2011) 212501	arXiv:1205.5608

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

Run 1 Results:

$$T_{1/2}^{2\nu\beta\beta}\,(^{136}Xe) = (2.11 \pm 0.04\ \text{stat} \pm 0.21\ \text{sys}) \cdot 10^{21}\ \text{yr}$$

In disagreement with previously reported limits by

R. Bernabei et al. Phys. Lett. B 546 (2002) 23, and
Yu. M. Gavriljuk et al. , Phys. Atom Nucl. 69 (2006)

This was also a measurement of a nuclear matrix element
of 0.019 MeV^{-1}, the smallest measured among the $2\nu\beta\beta$ emitters

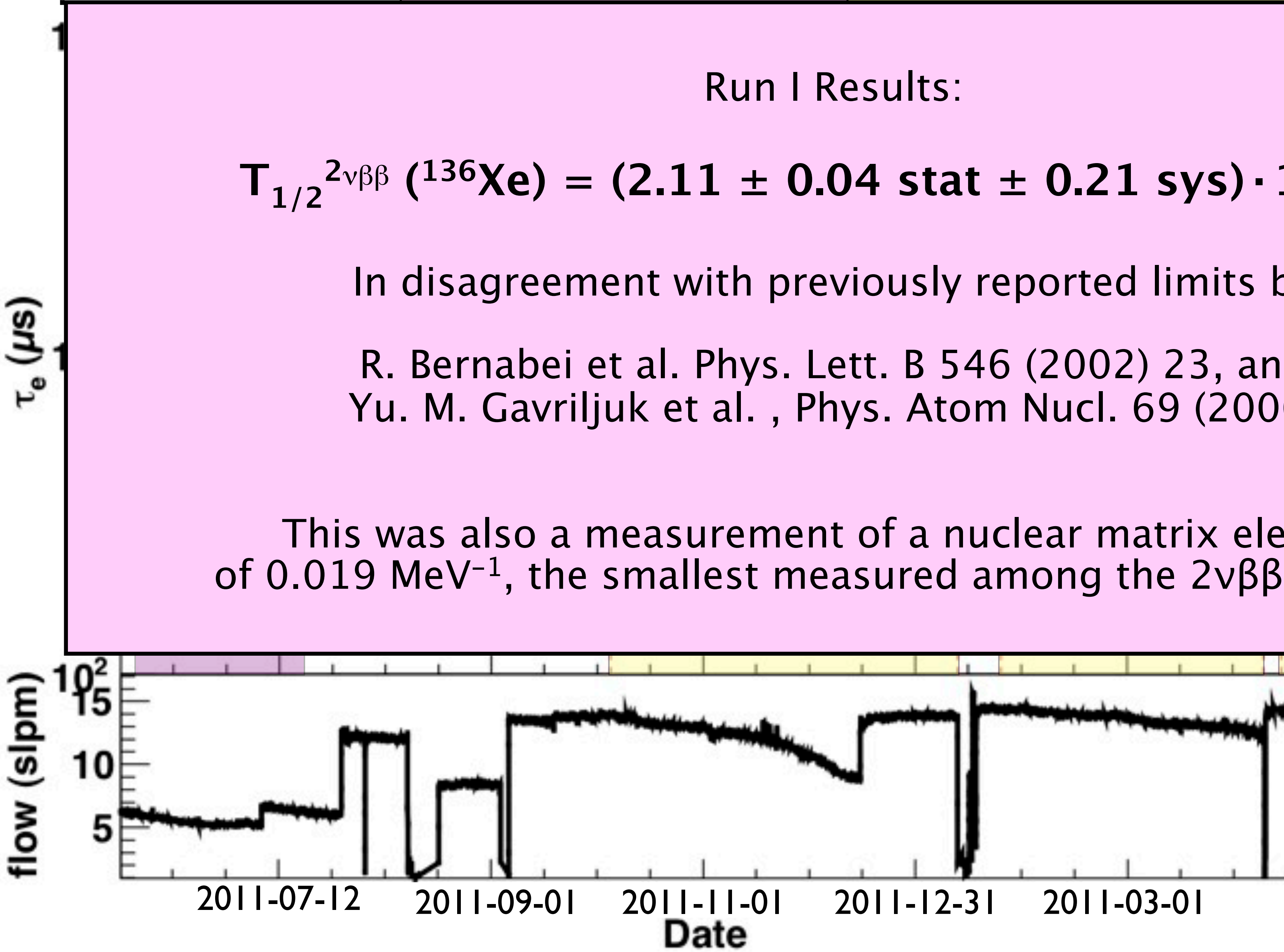
Purity

...rced through heated
...tom ultraclean

... τ_e is determined
...e attenuation of the
... as a function of
...e full-absorption
...ray sources

..., the recirculation
...ed to 14 slpm,
...electron lifetimes in

...me ~110 μs
...ge is 3.6% at full



Ultraclean pump:
Rev Sci Instrum. 82(10):105114
Xenon purity with mas spectroscopy:
NIM A675 (2012) 40-46
Gas purity monitors:
NIM A659 (2011) 215-228

Event reconstruction

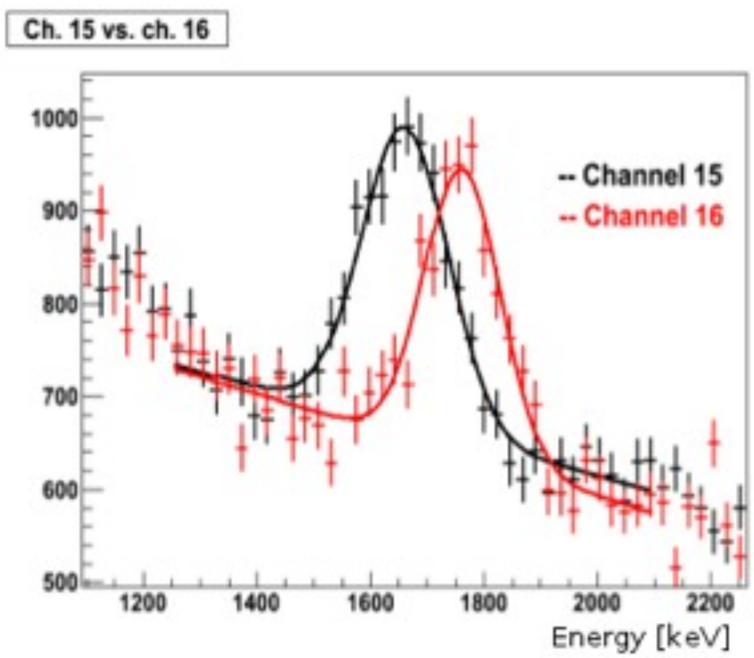
- Signal finding – matched filters applied on U,V and APDs waveforms
- Signal parameter estimation (t, E) for charge and light
- Cluster finding – assignment to Single Site (SS) or Multiple Site (MS): resolution 18mm in X and Y and 6 mm in Z

Amplitudes corrected by channel for gain variation

Require events to be fully reconstructed in 3D

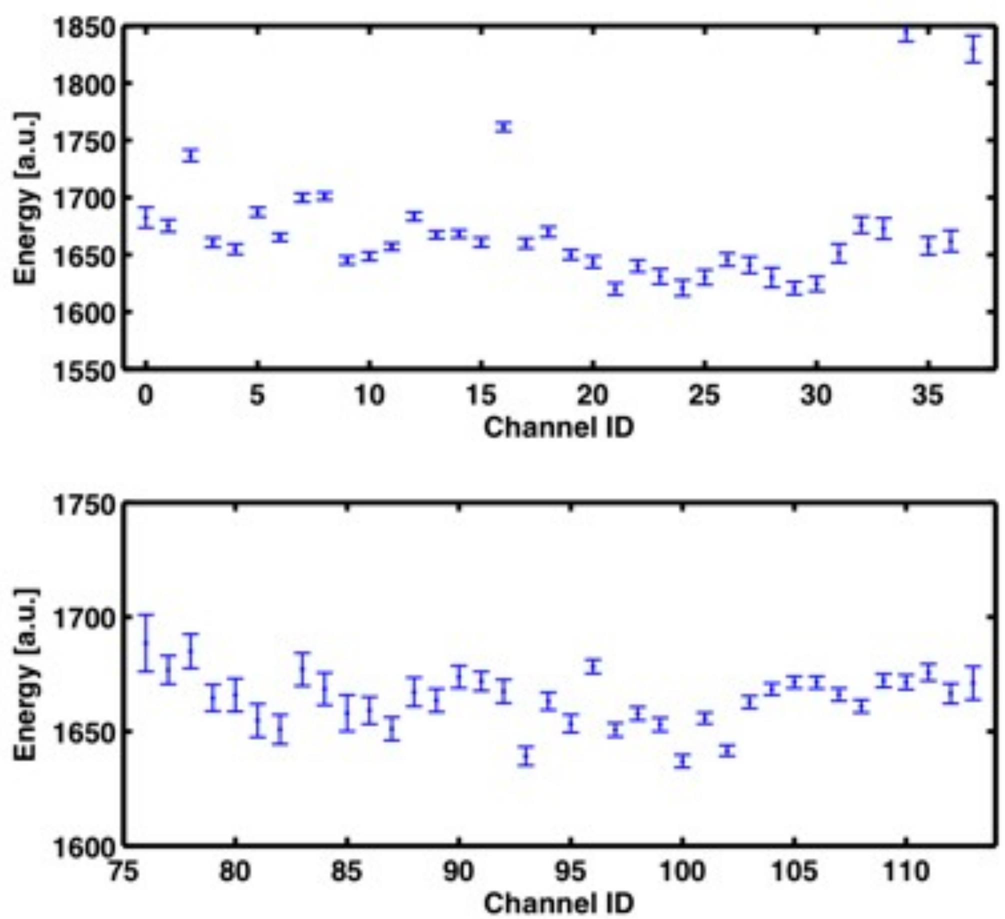
Reconstruction efficiency for $0\nu\beta\beta$ is 71% – estimated by MC and verified by comparing the $2\nu\beta\beta$ MC efficiency with low background data, over a broad range in energy

Wire Gains

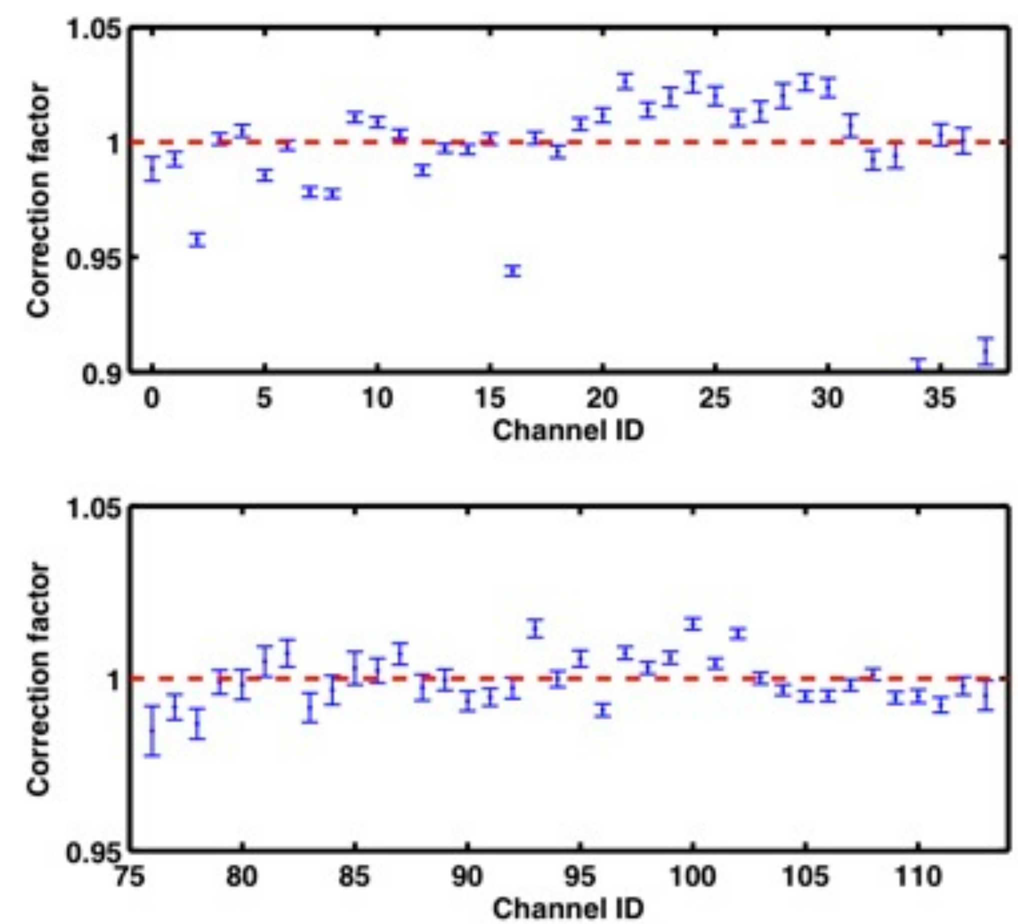


- Gains of wire channels measured with charge calibrations
- This is further corrected using the pair production peak (1593 keV) from ^{232}Th 2615 keV gamma depositions.
- Have also individually measured the electronic transfer function of each channel, which are used to reconstruction the charge signals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

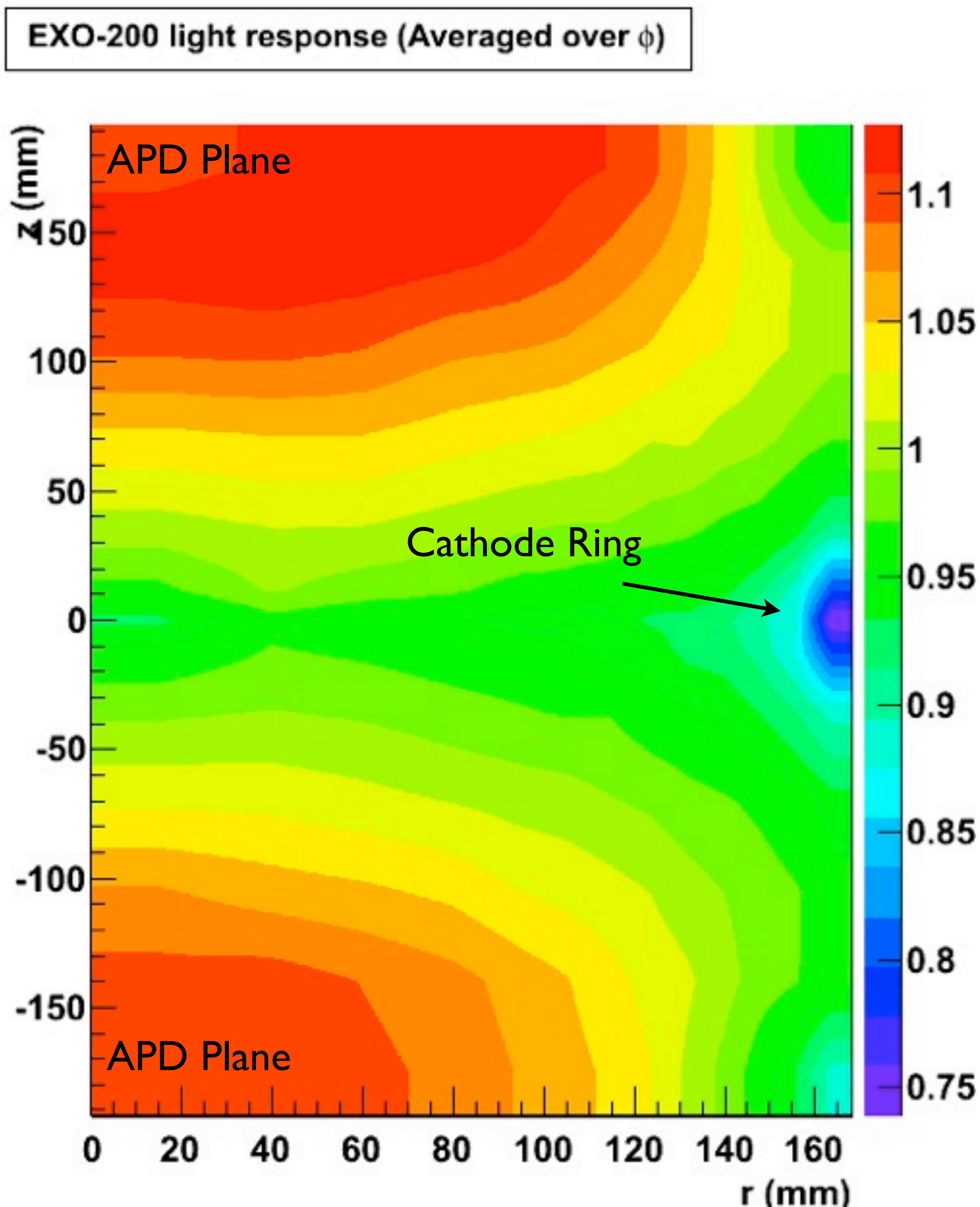
Peak Location



Correction Factor

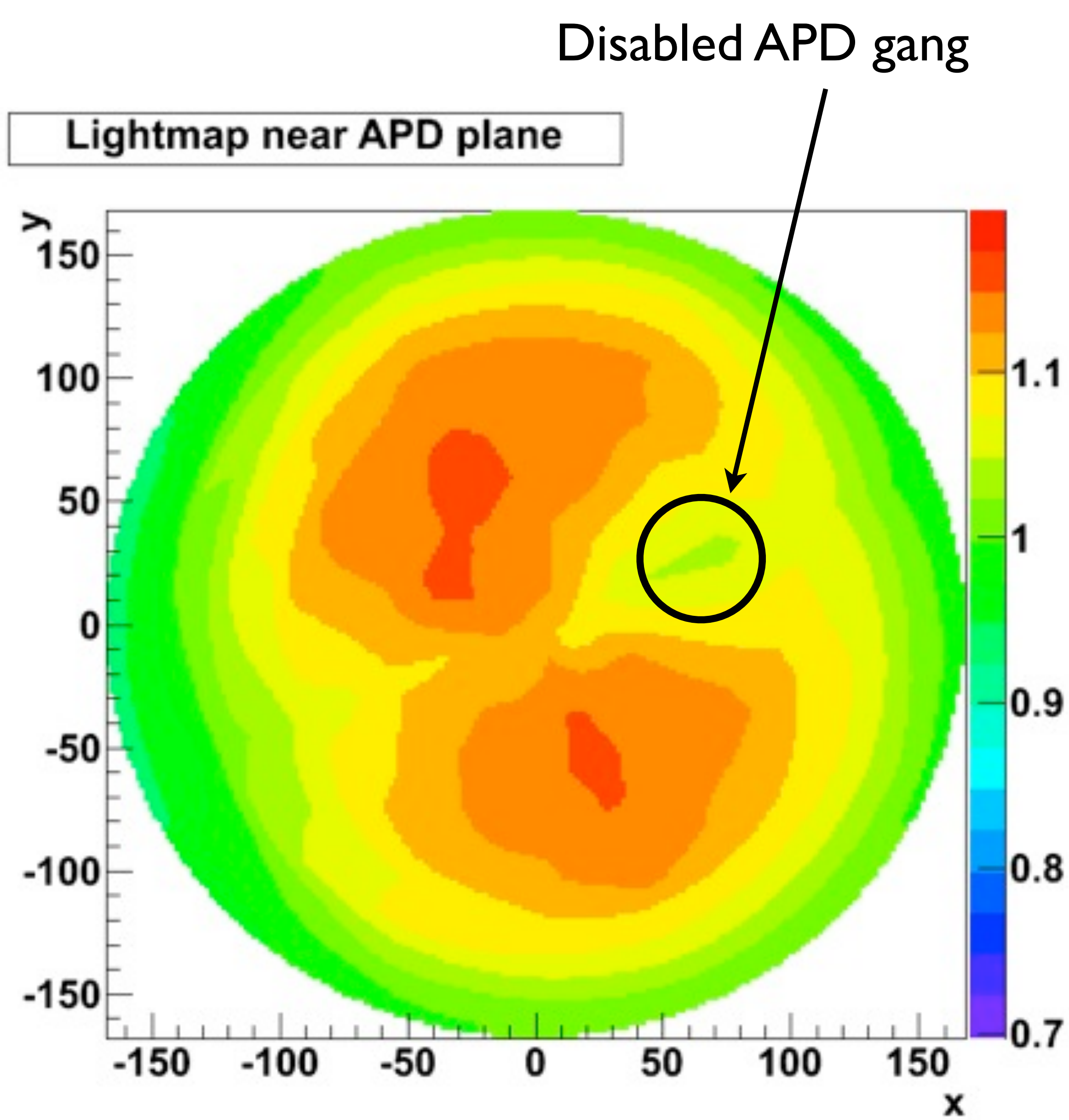


Correcting for light response

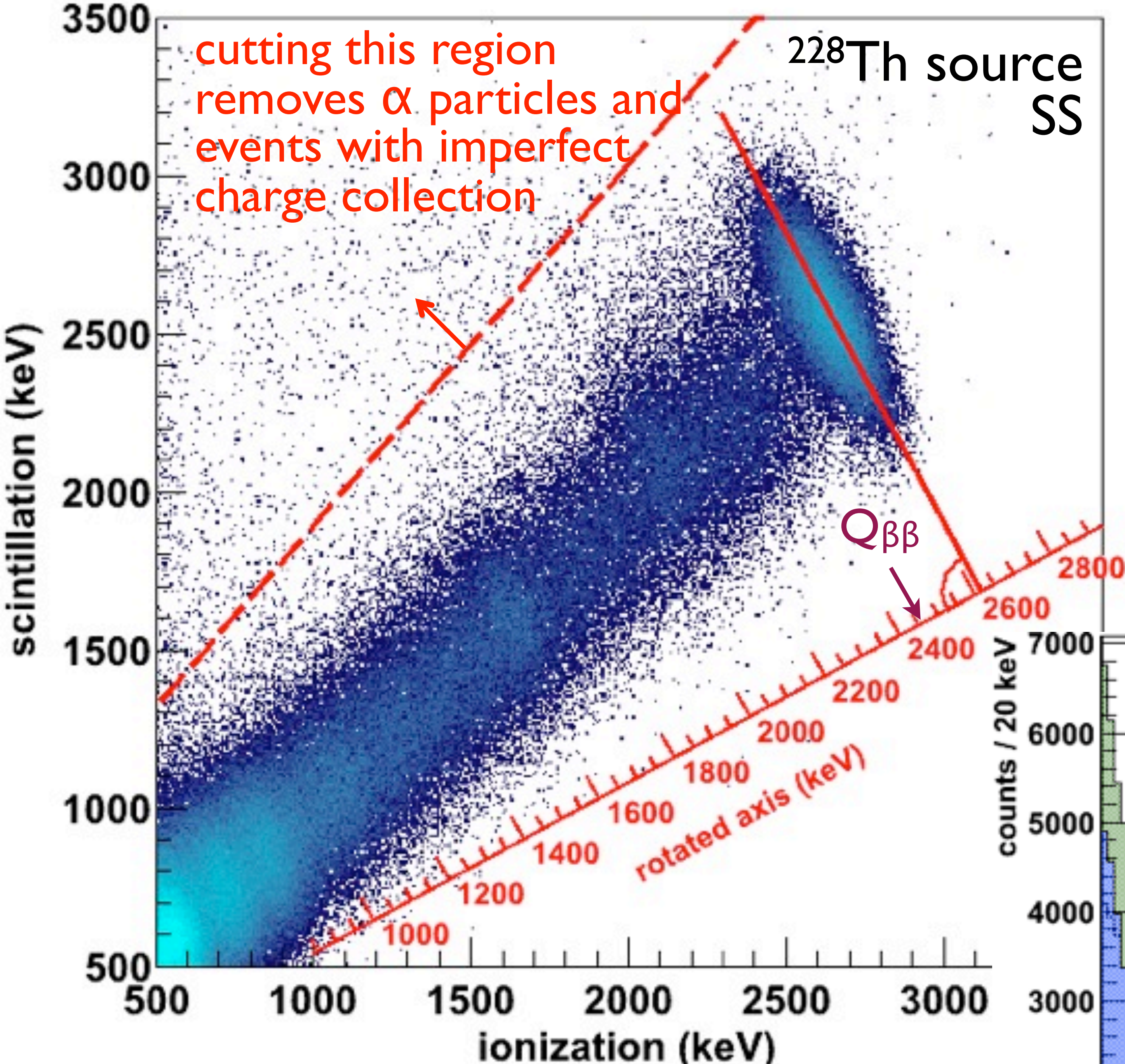


Use full absorption peak of 2615 keV gamma from ^{208}Tl to map light response in TPC

Linearly interpolate between 1352 voxels



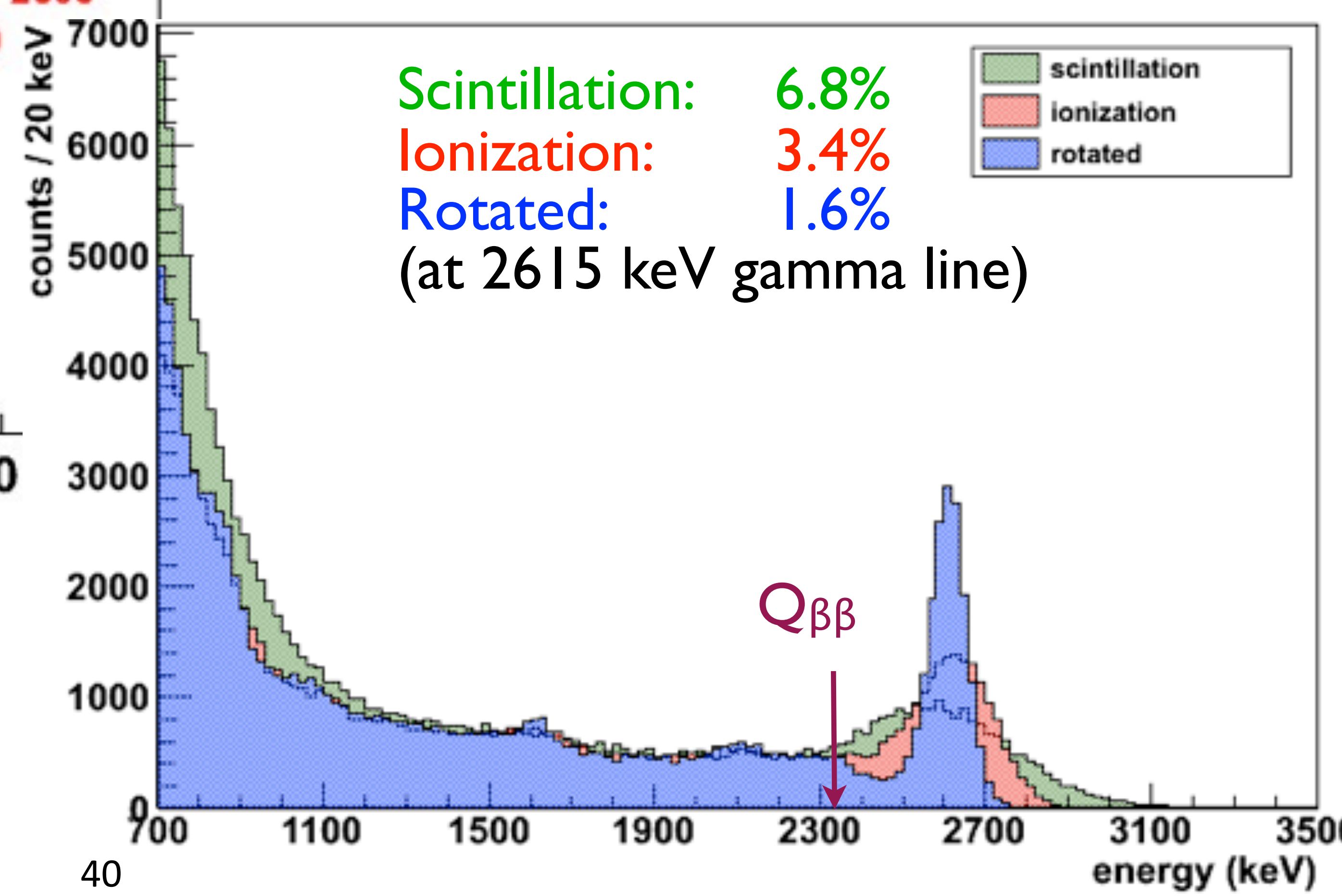
Combining Ionization and Scintillation



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

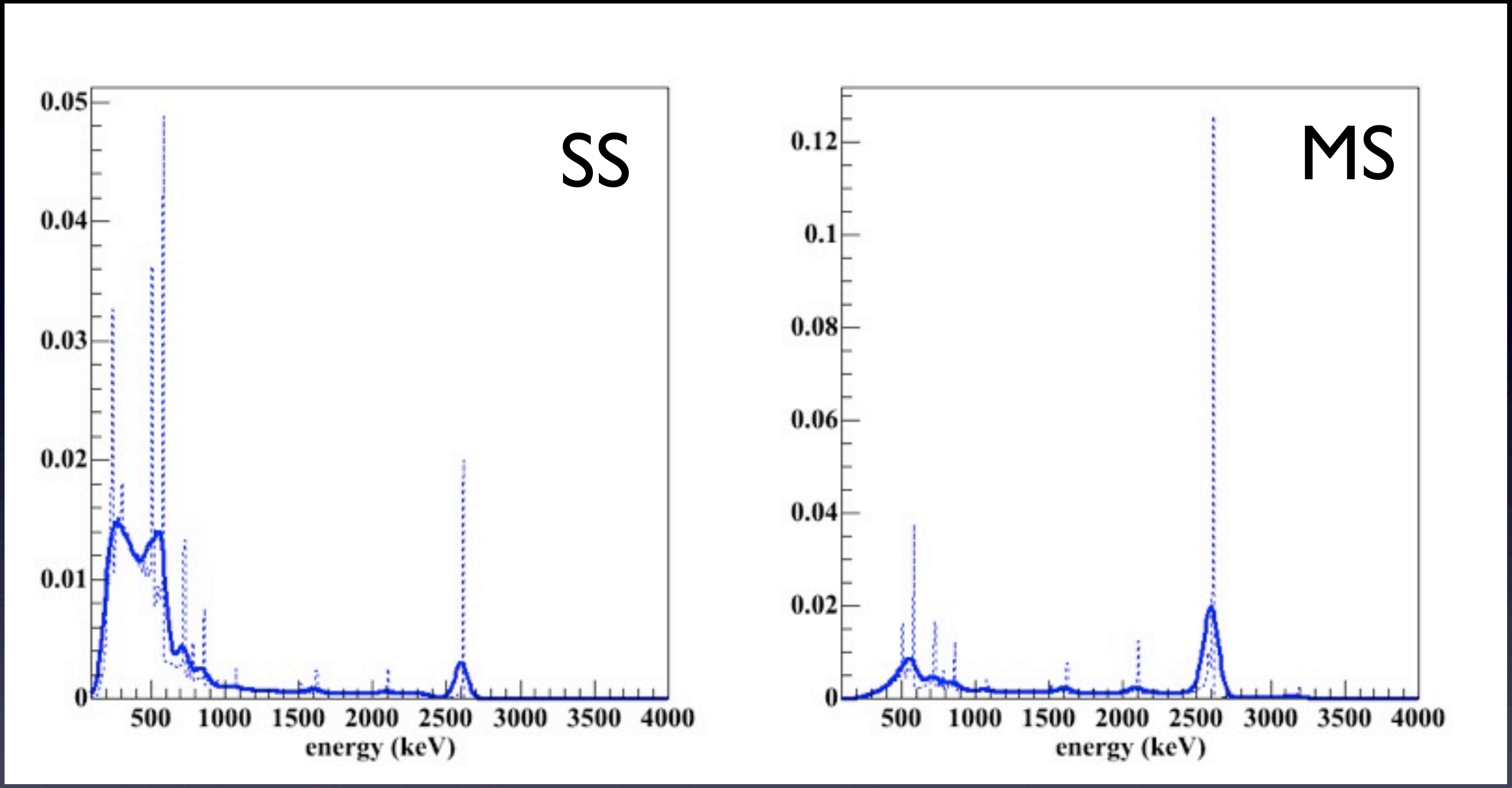
E. Conti et al. Phys. Rev. B 68 (2003) 054201

Use projection onto a rotated axis to determine event energy



Rotation angle chosen to optimize energy resolution at 2615 keV

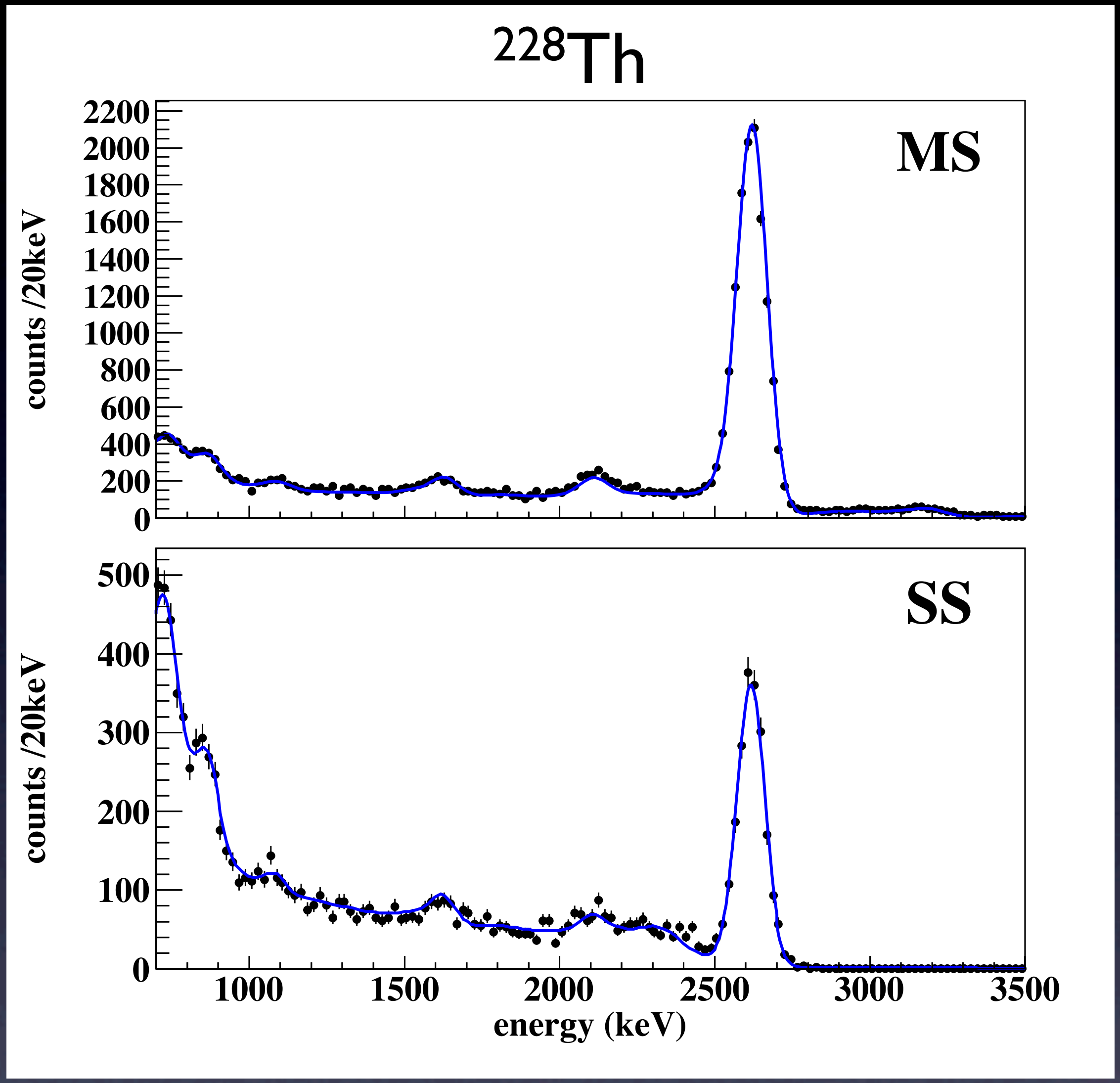
Simulated spectra generation

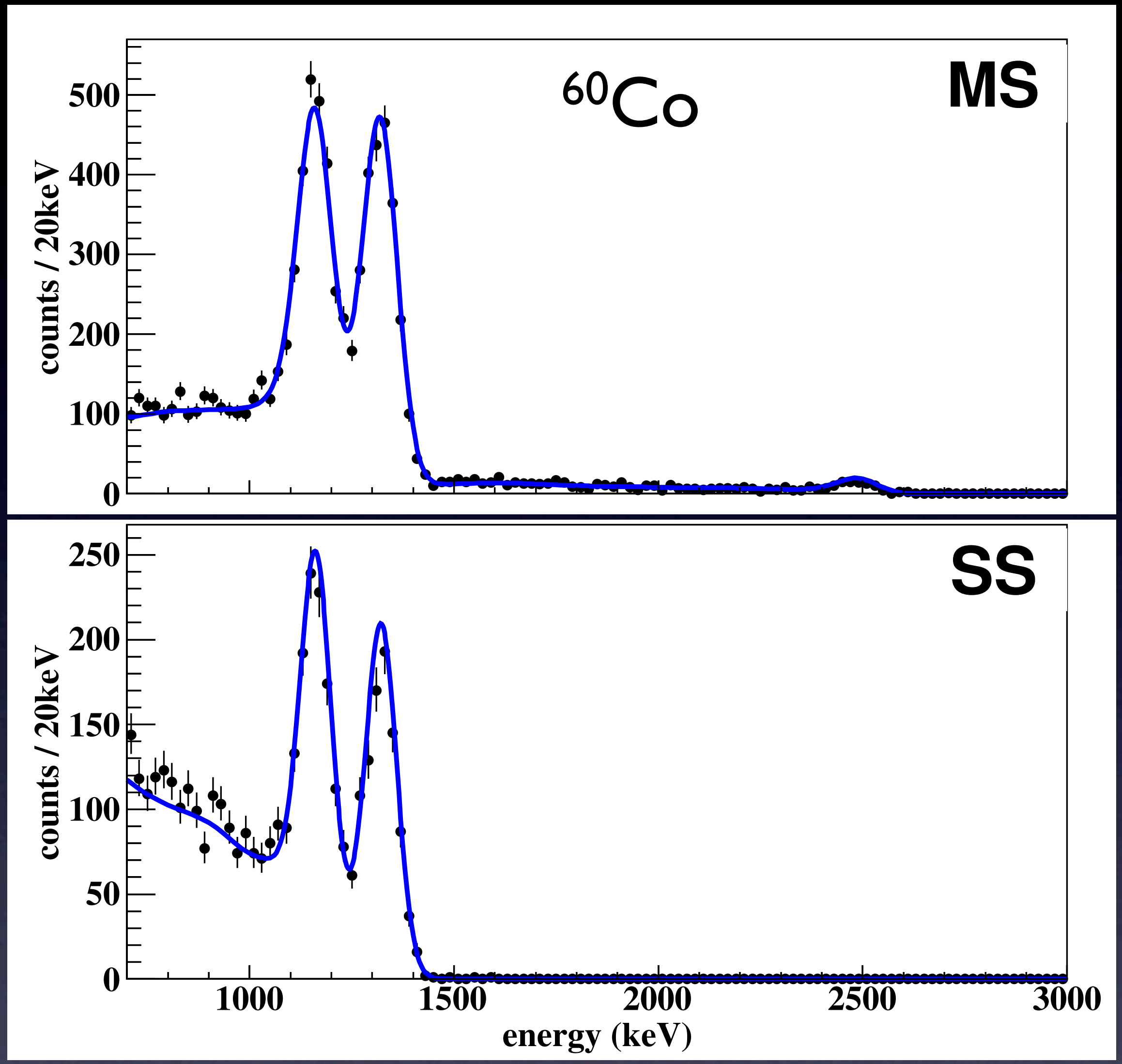


Dotted line is Geant4 simulated energy deposition from ^{228}Th source.

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

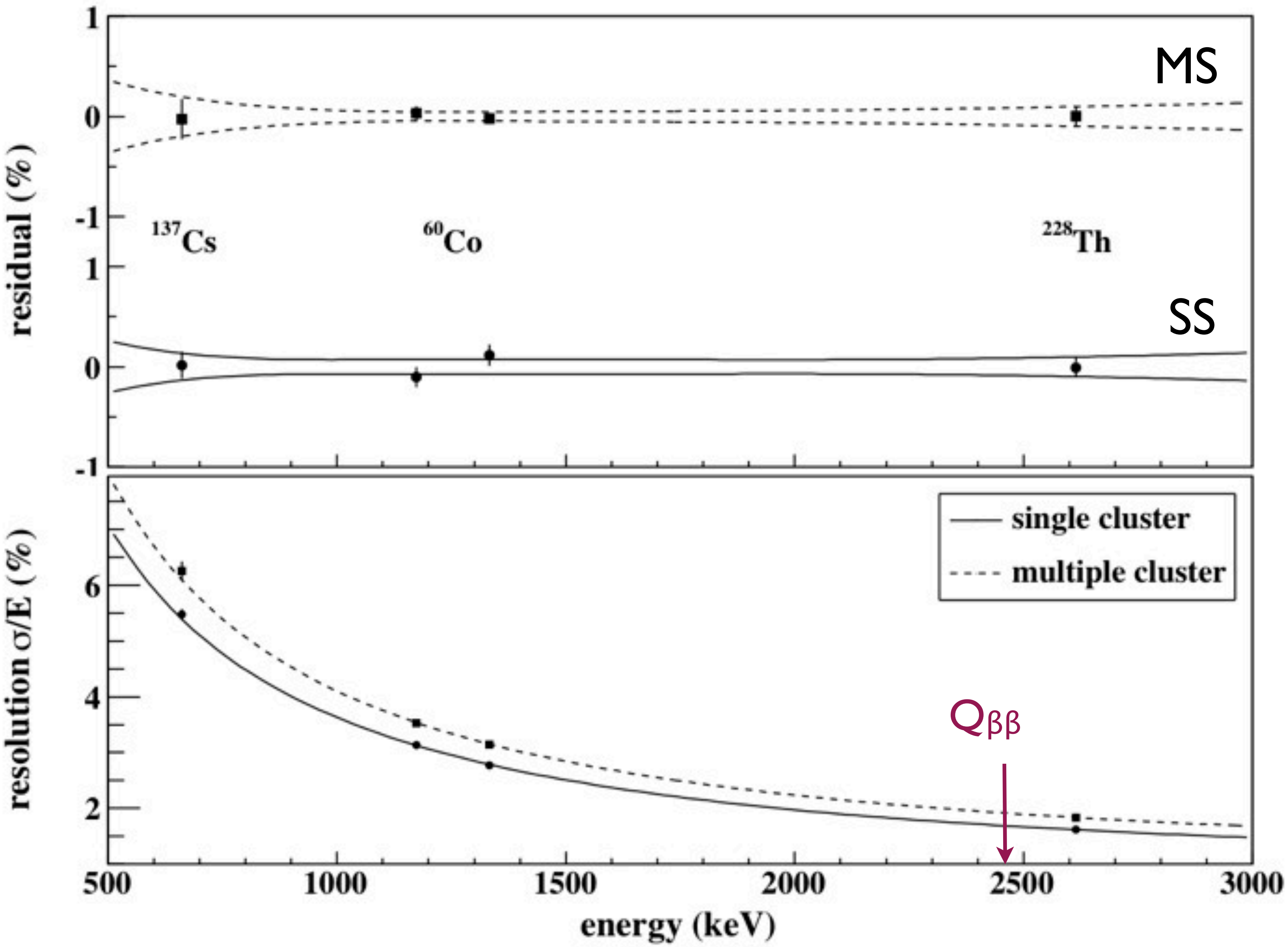
Source Data/MC Agreement





- Multi site (MS) and single site (SS) data (black points) are compared to model (blue curve)
- Single site fraction agrees to within 8.5%
- Source activities measured to within 9.4%

Calibrations



Using quadratic model for energy calibration, single- and multi-site
Residual are < 0.1%

Energy resolution model:

$$\sigma^2_{Tot} = p_0^2 E + p_1^2 + p_2^2 E^2$$

Resolution dominated by constant (noise) term p_1

At $Q_{\beta\beta}$ (2458 keV):
σ/E = 1.67 % (SS)
σ/E = 1.84 % (MS)

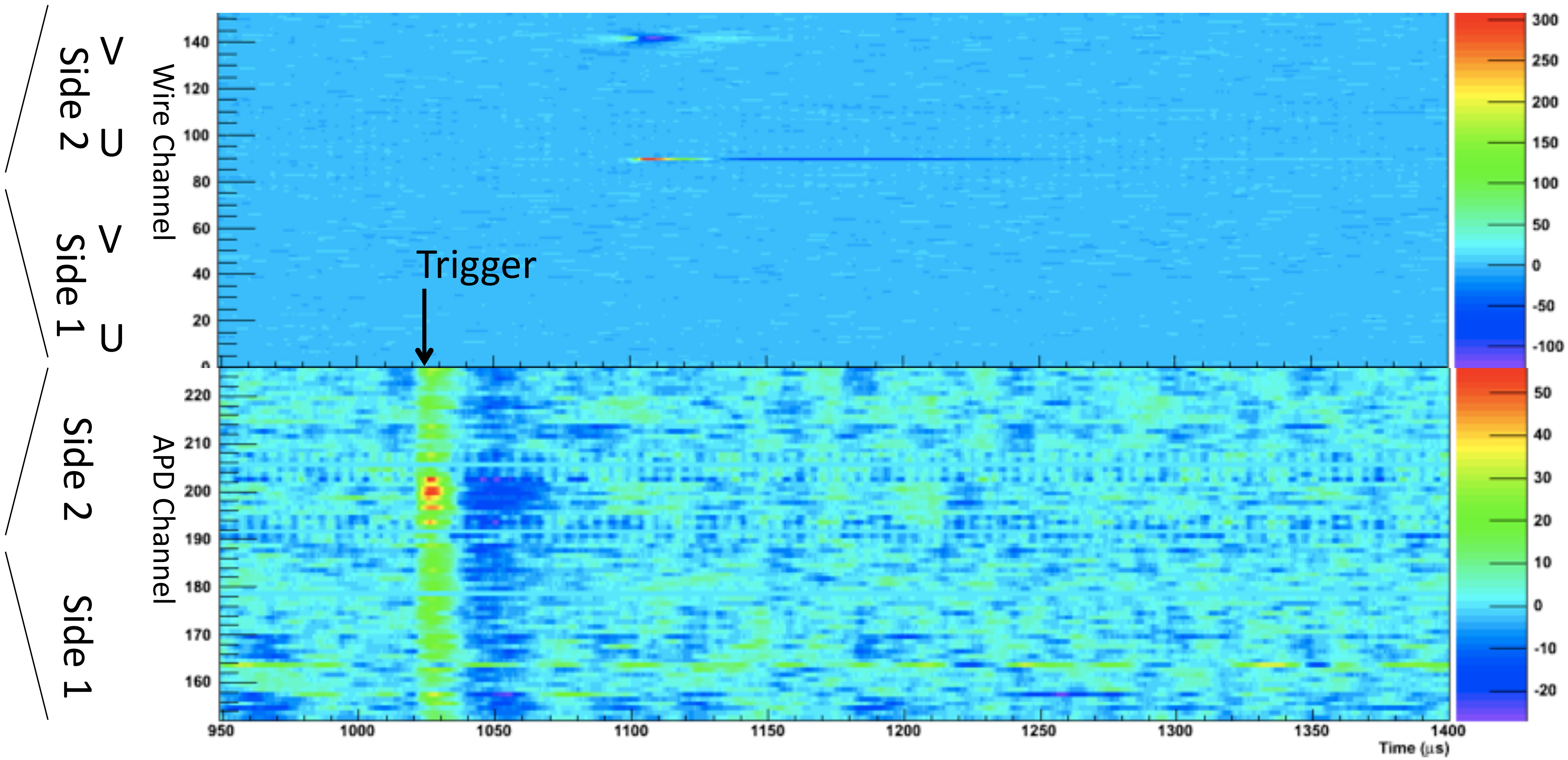
A single-site event in EXO-200

Ionization readout

V: Induction

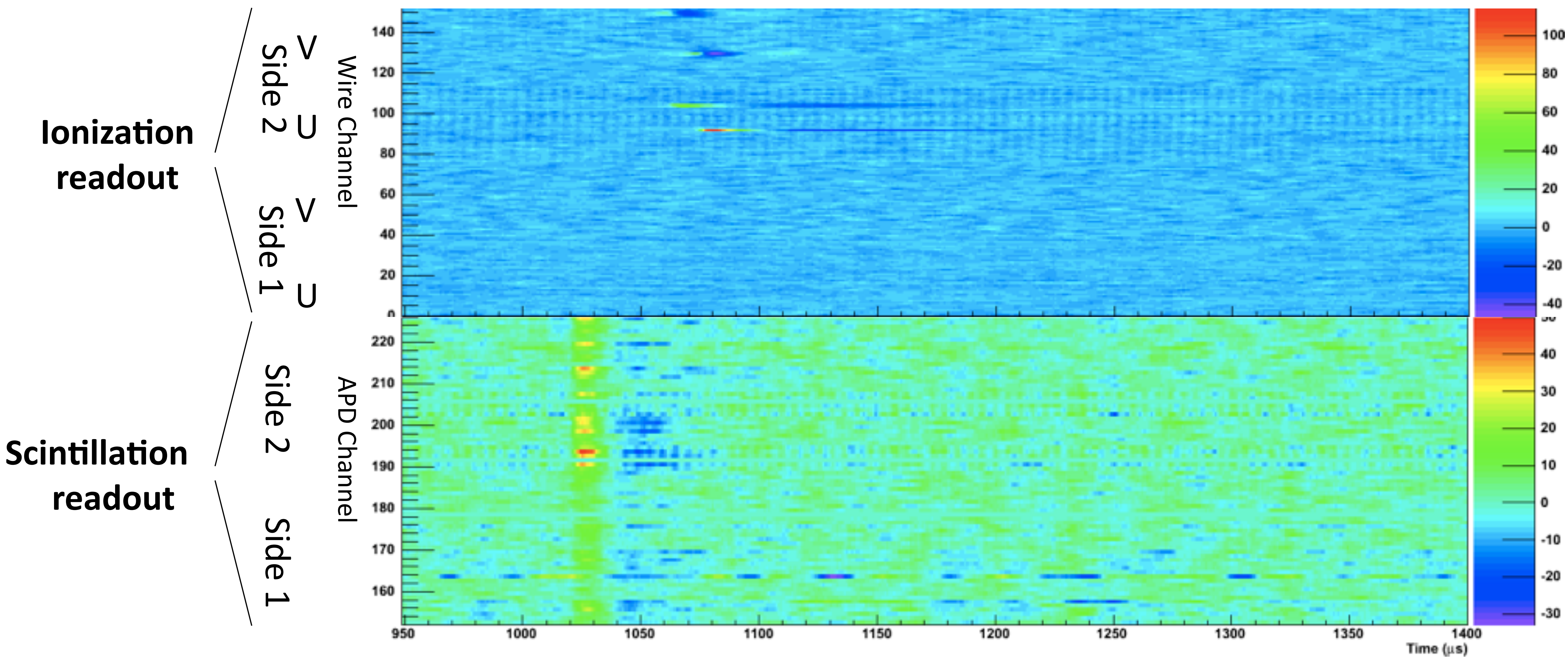
U: Collection

Scintillation readout



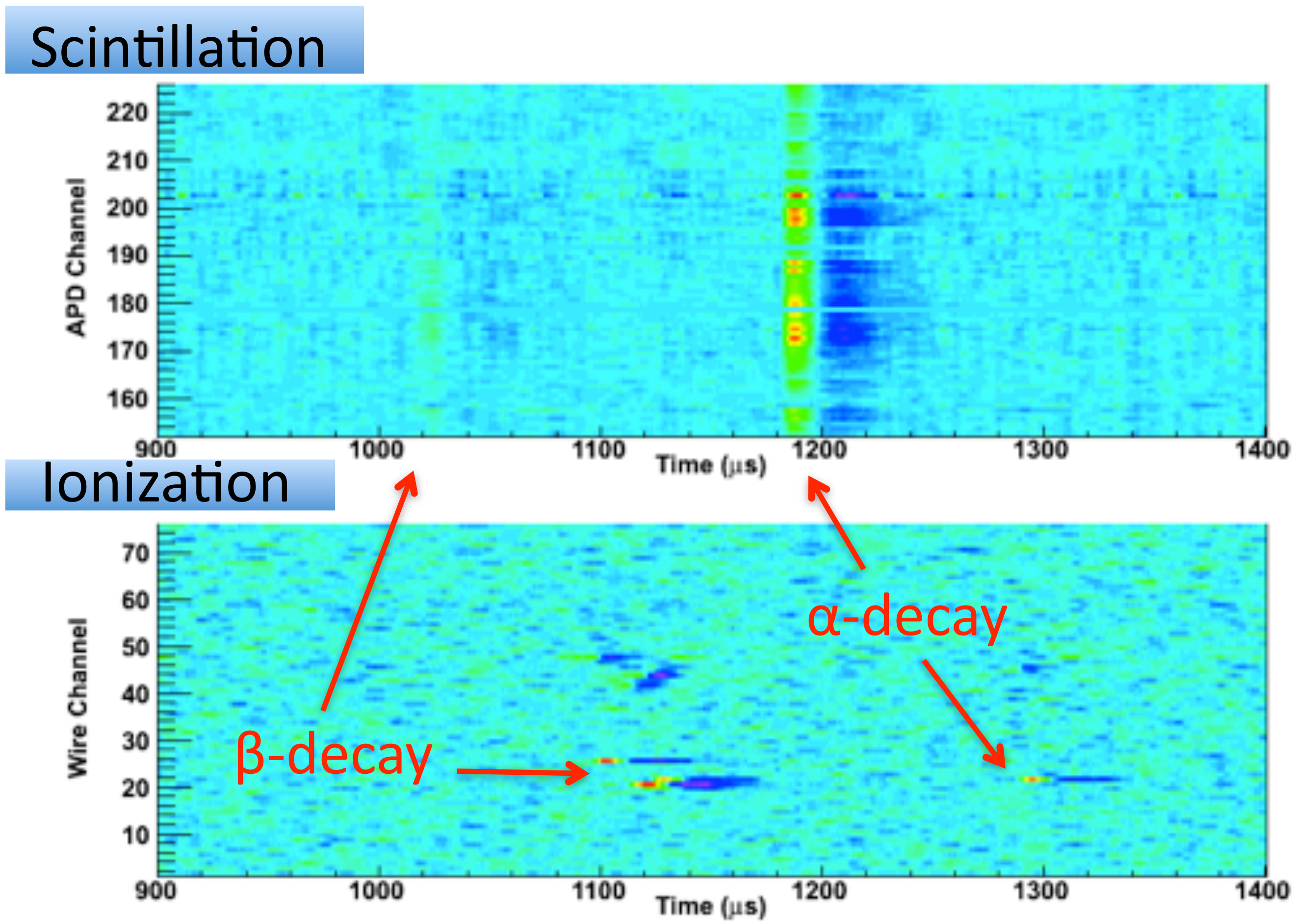
- Scintillation signal
  - Observed in both sides (but more localized in side 2)
  - Precedes ionization signal
- Ionization signal
  - Observed on both wire planes in side 2

A two-site Compton scattering event

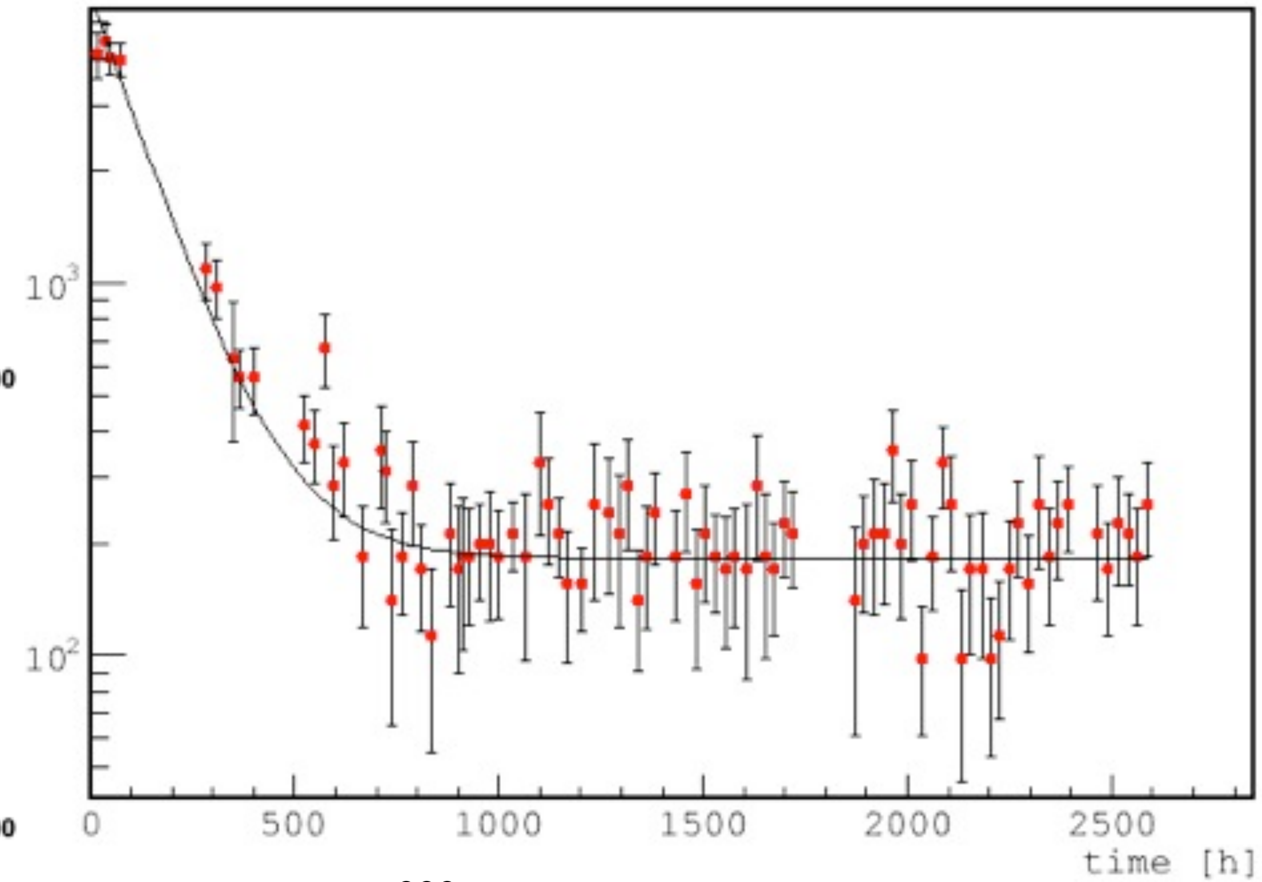


- All scintillation light arrives at a single time, indicating the two energy depositions were simultaneous
- Two separate ionization signals visible in side 2

Rn Content in Xenon



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

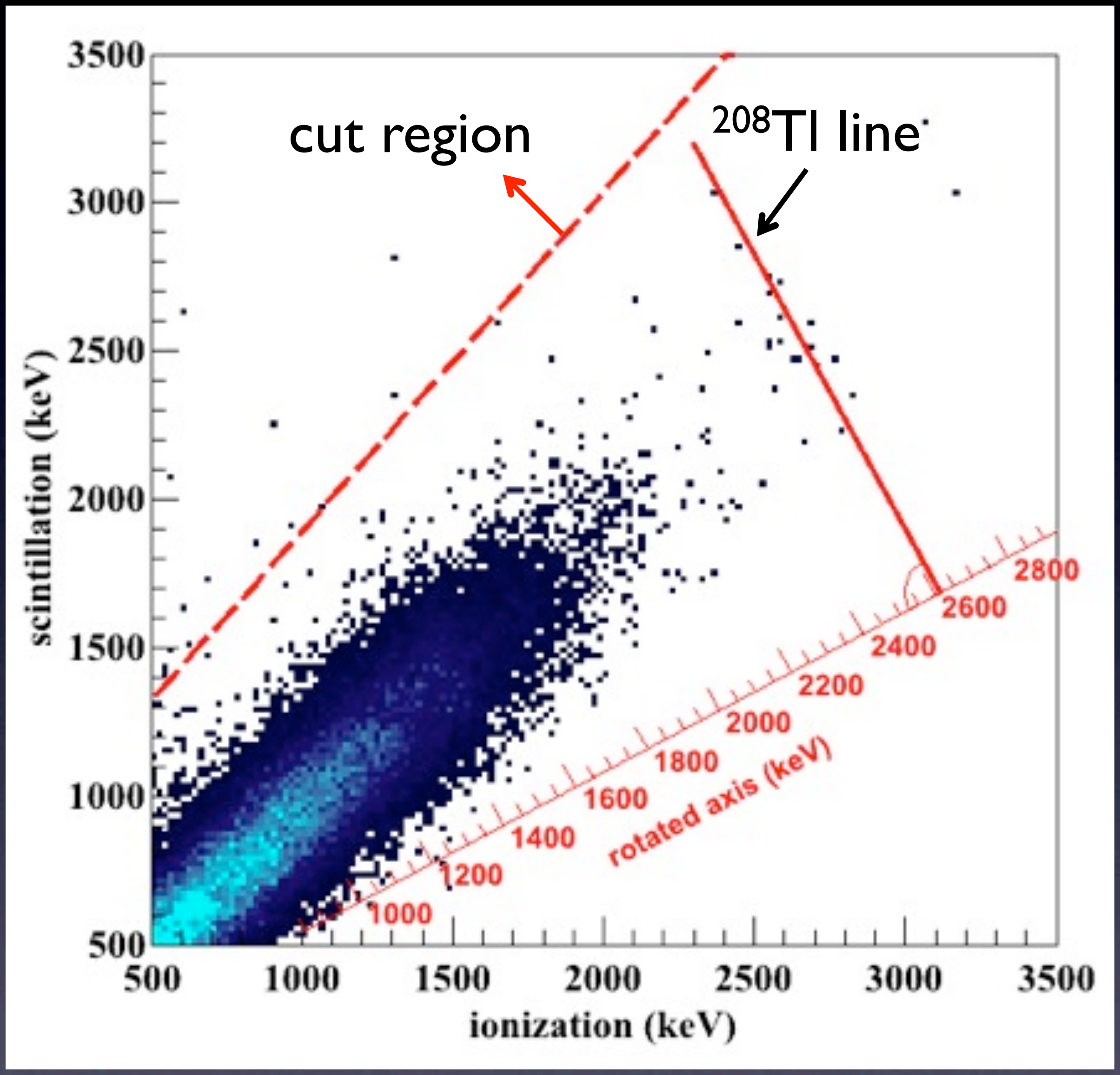


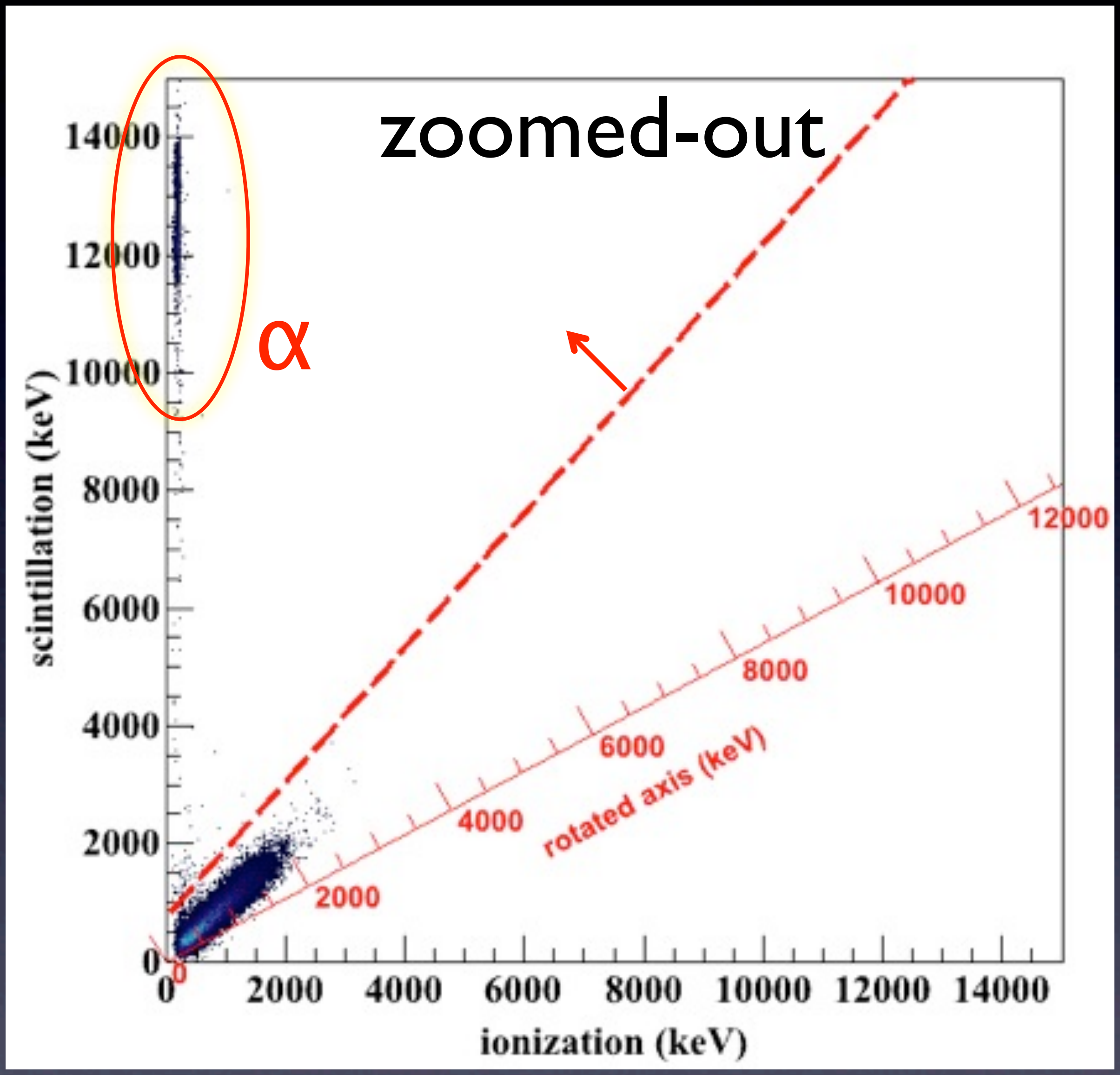
Total ^{222}Rn in LXe after initial fill

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.)

Low Background 2D SS Spectrum

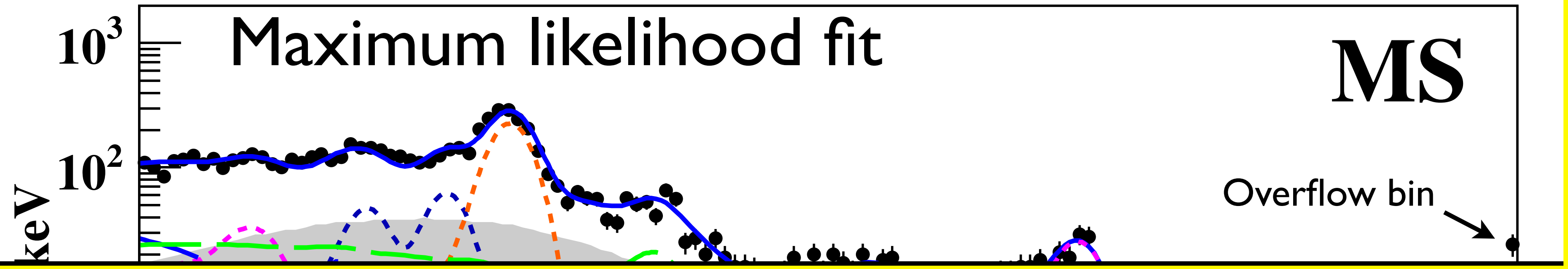




Events removed by diagonal cut:

- alpha events (they leave large ionization density, which leads to more recombination, which means more scintillation light)
- events near edge of detector, where not all the charge ends up on the collection wires

Low Background Spectrum



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

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

In agreement with previously reported value by

EXO-200 Phys.Rev.Lett. 107 (2011) 212501

and

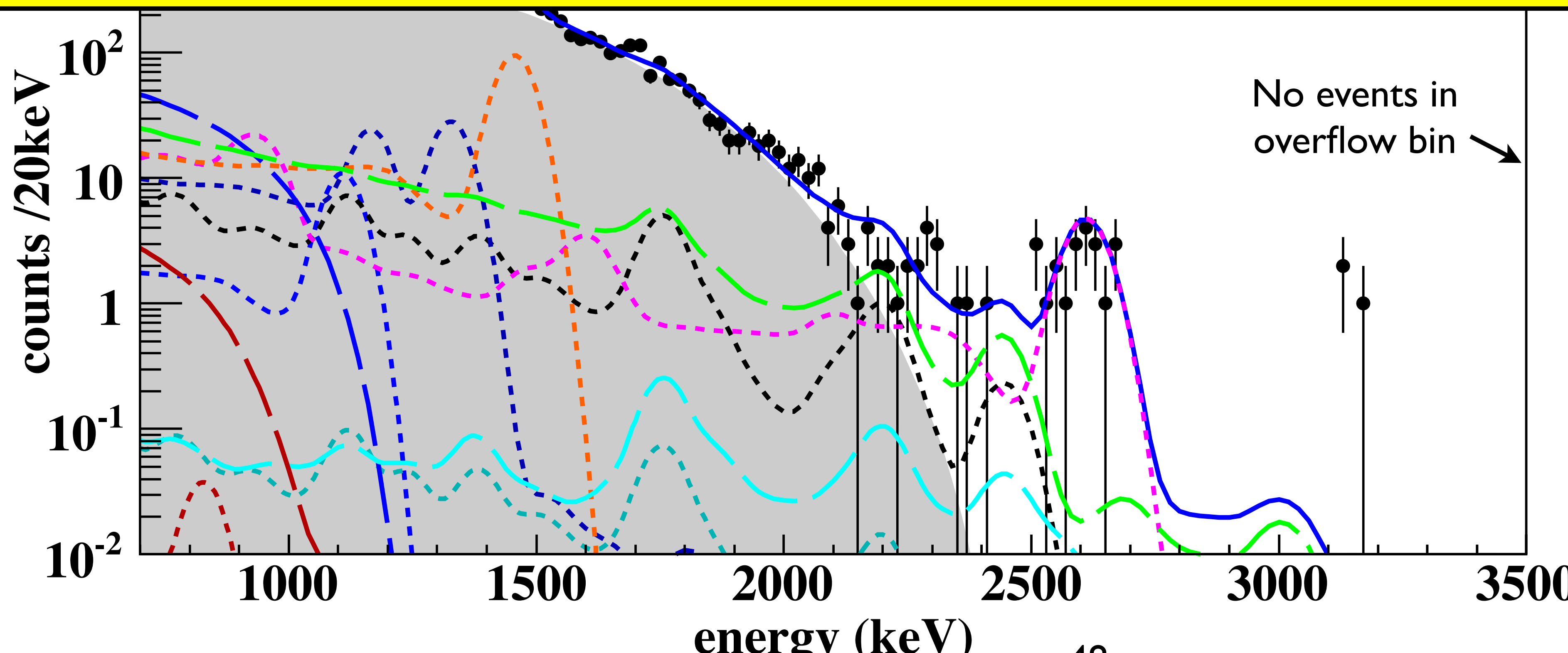
KamLAND-ZEN Phys.Rev.C85:045504,2012)

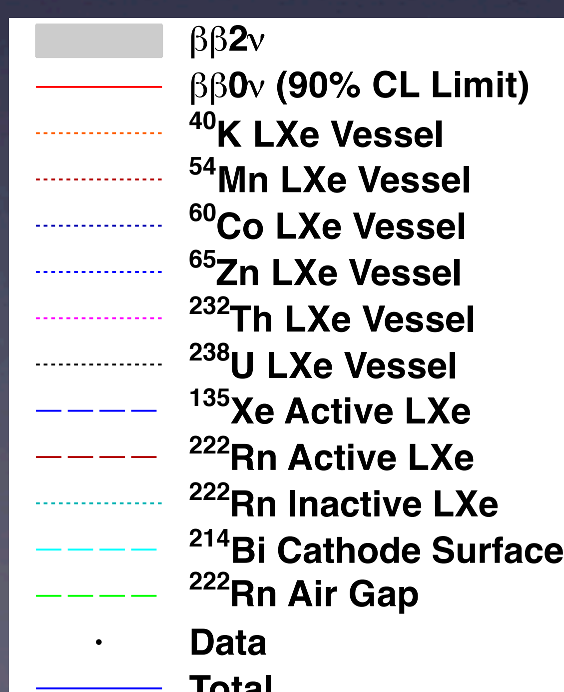
98.5 kg LXe
(79.4 kg ^{136}LXe)

xposure 32.5 kg.yr

otal dead time from vetos: 8.6%

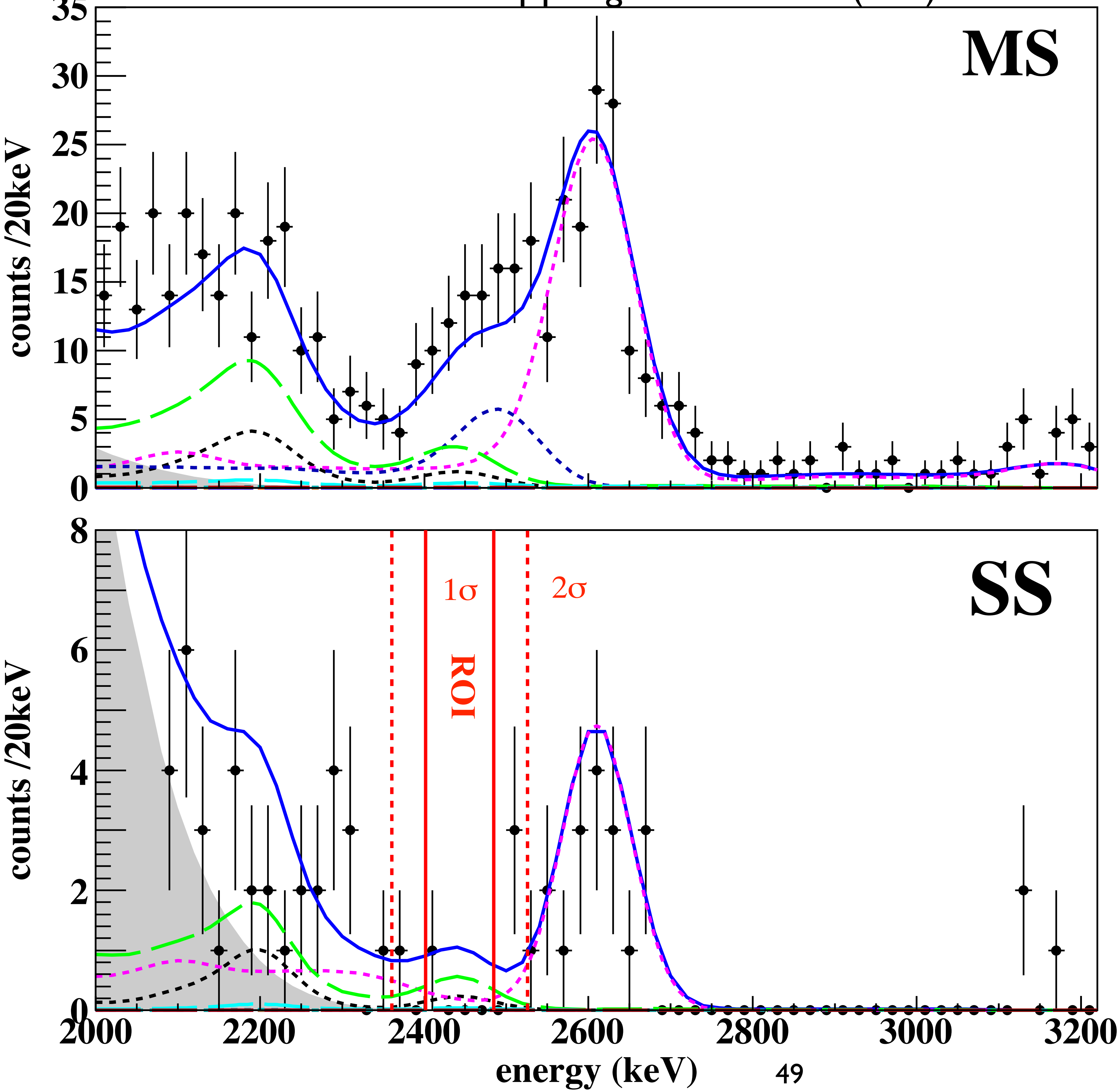
arious background DFs fitted along with 2νββ and 0νββ PDFs

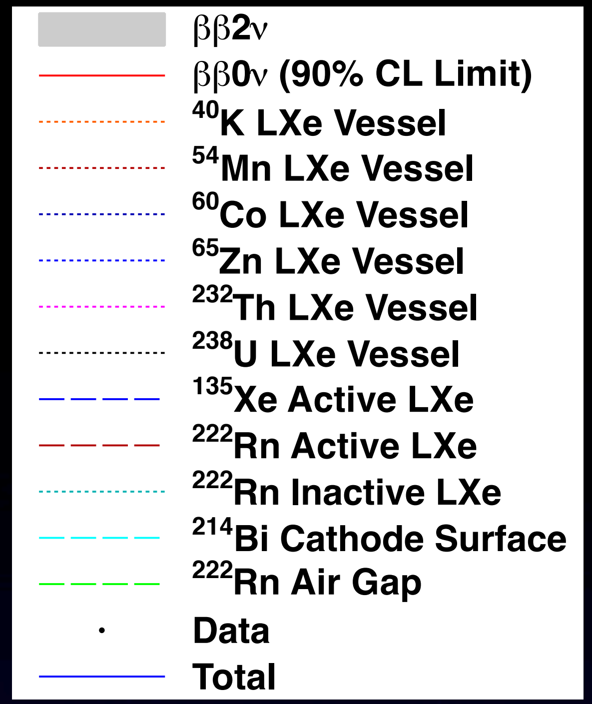




Low Background Spectrum

Zoomed around 0νββ region of interest (ROI)





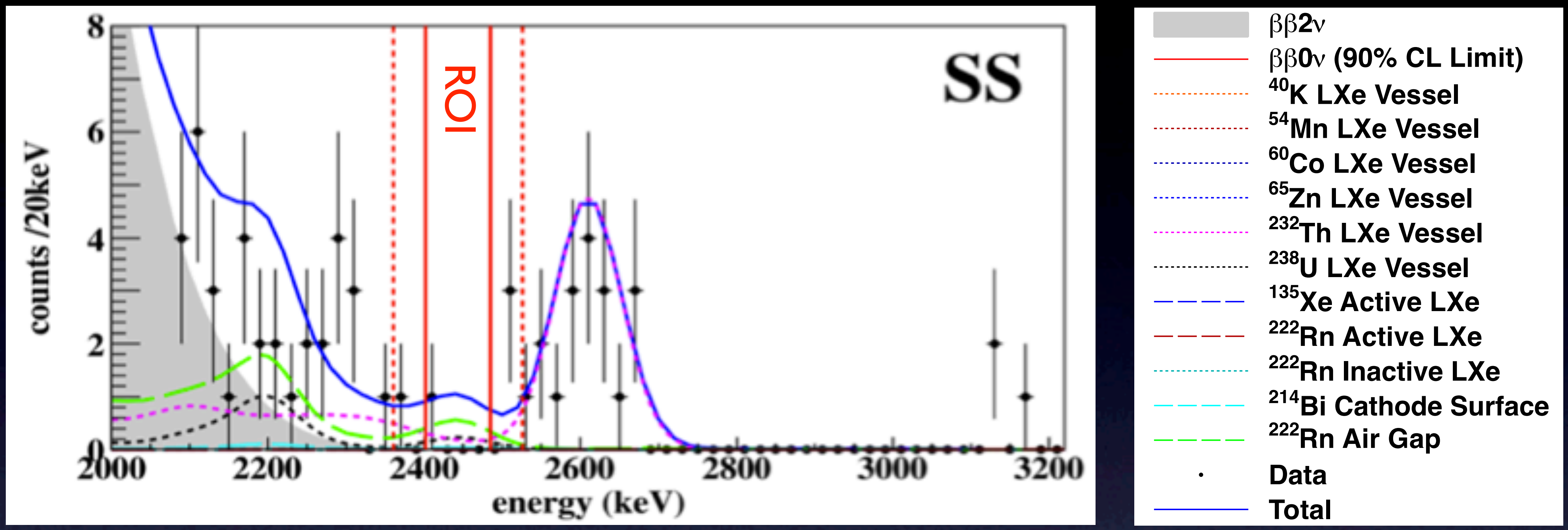
Constraints:

- SS to MS ratio within ±8.5% of values predicted by MC (set by largest variations in source data)
- other systematic uncertainties

Profile likelihood fit to entire SS and MS spectra to extract limits for $T_{1/2}^{0\nu\beta\beta}$

No 0ν signal observed

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 index b ($kg^{-1}yr^{-1}keV^{-1}$)	$1.5 \cdot 10^{-3}$ ± 0.1		$1.4 \cdot 10^{-3}$ ± 0.1	

EXO-200 goal (slide 3):

40 cnts/2y in ±2σ ROI, 140 kg LXe

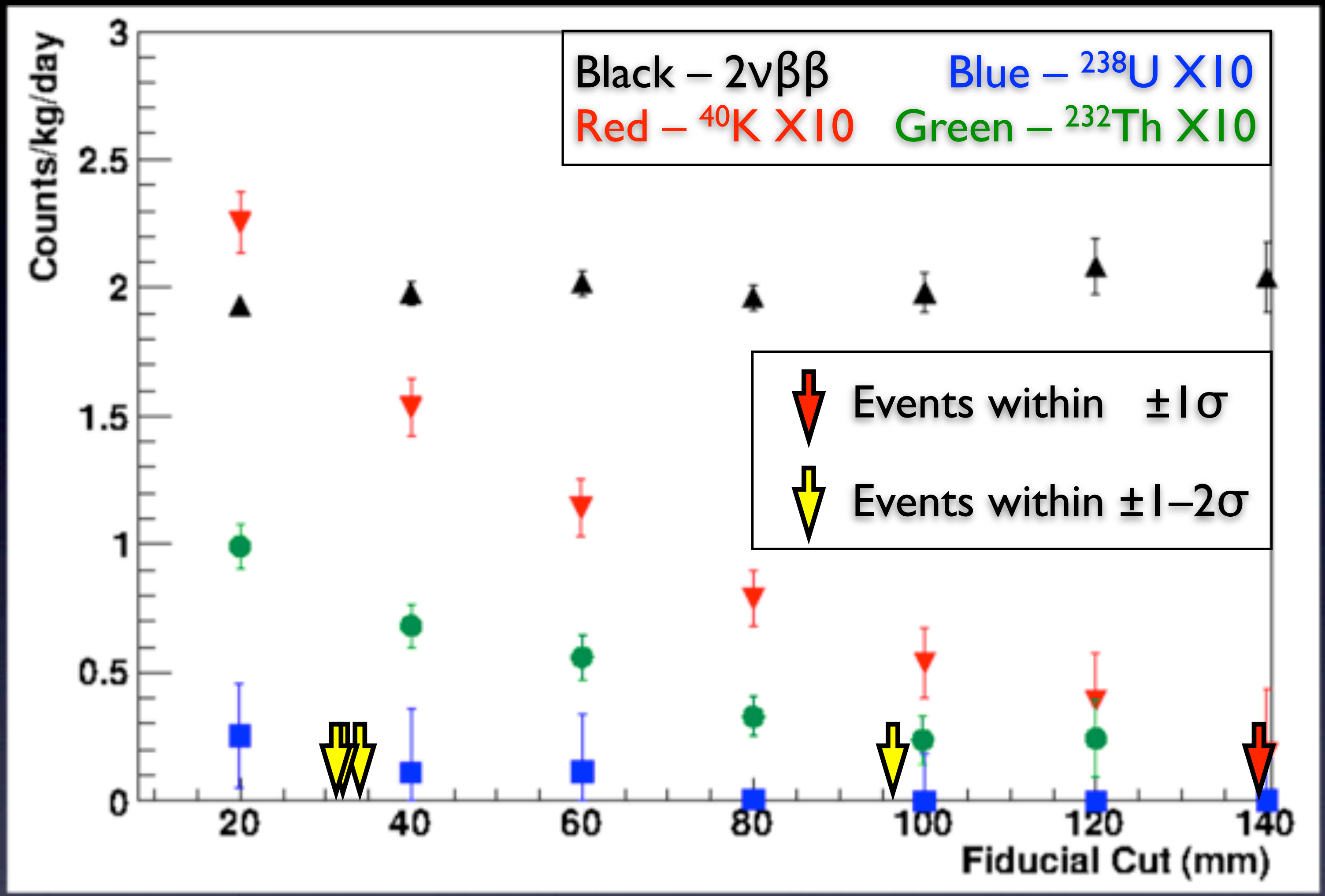
In this data 120 days, 98.5 kg, this would be: 4.6

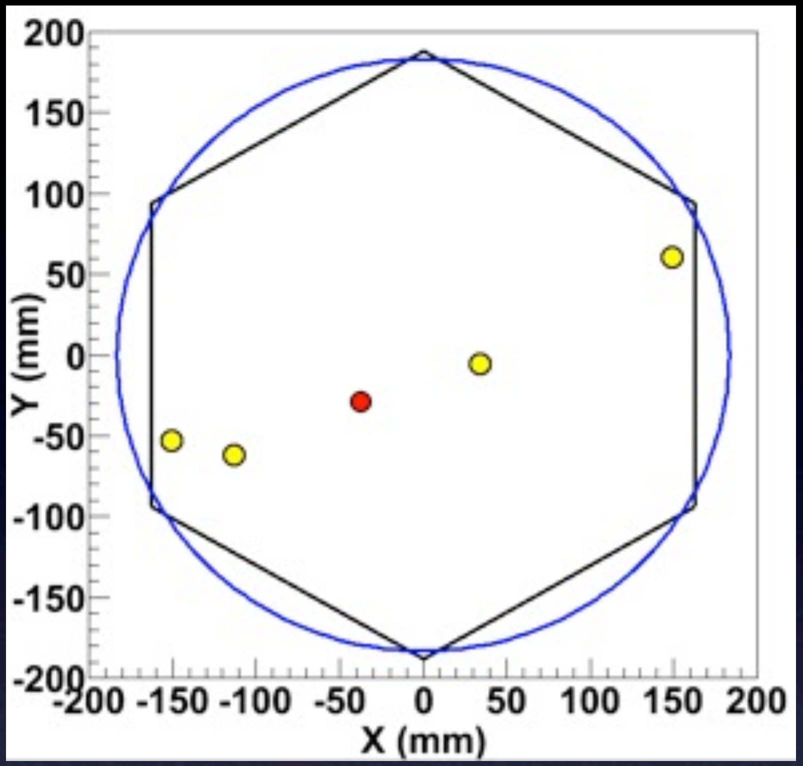
Expected from the fit: 7.5

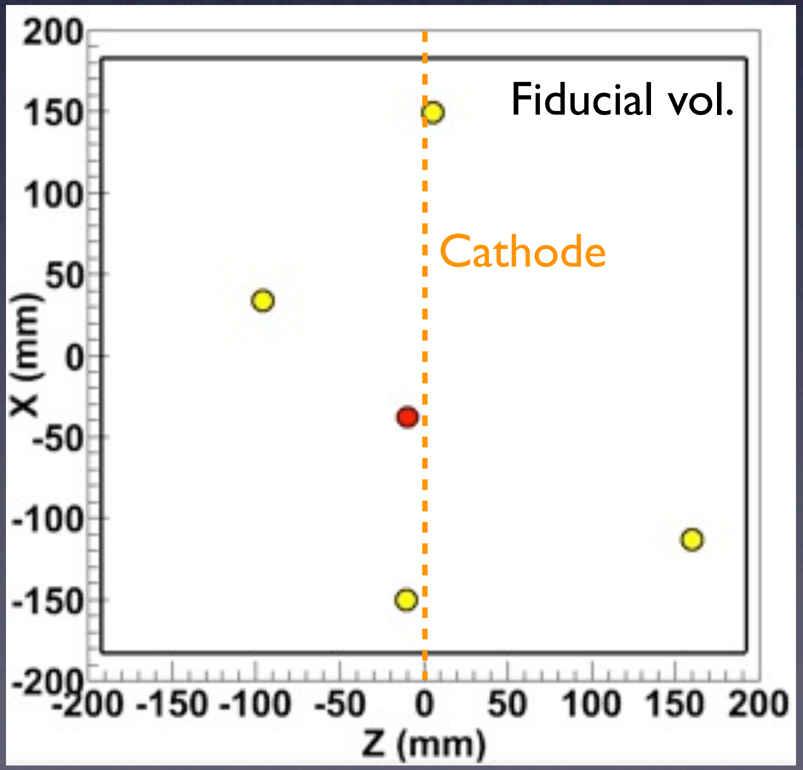
Observed: 5

Background within expectation

Spatial distributions

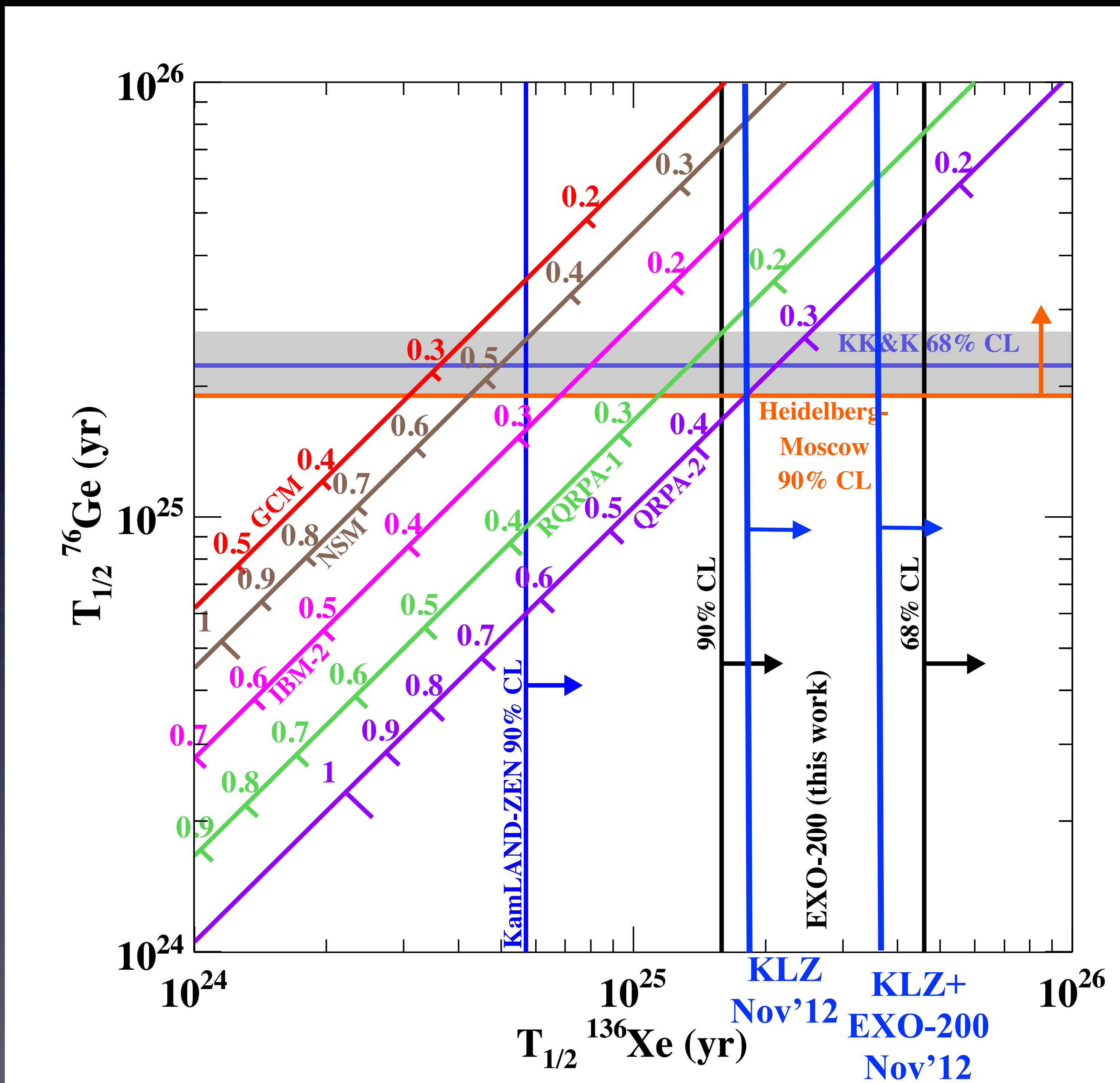






- 2νββ rate does not change with fiducial volume
- Background gammas rates drop towards the inside of the detector
- Events in the ±1,2σ ROIs: statistics is too low to conclude on their parent distribution

Limits on $T_{1/2}^{0\nu\beta\beta}$ and $\langle m_{\beta\beta}\rangle$



Interpret as lepton number violating process with effective Marojana mass $\langle m_{\beta\beta}\rangle$:

$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = G^{0\nu}\left|M_{nucl}\right|^2 \langle m_{\beta\beta}\rangle^2$$

From profile likelihood:

$T_{1/2}^{0\nu\beta\beta} > 1.6 \cdot 10^{25}$ yr

$\langle m_{\beta\beta}\rangle < 140–380$ meV

(90% C.L.)

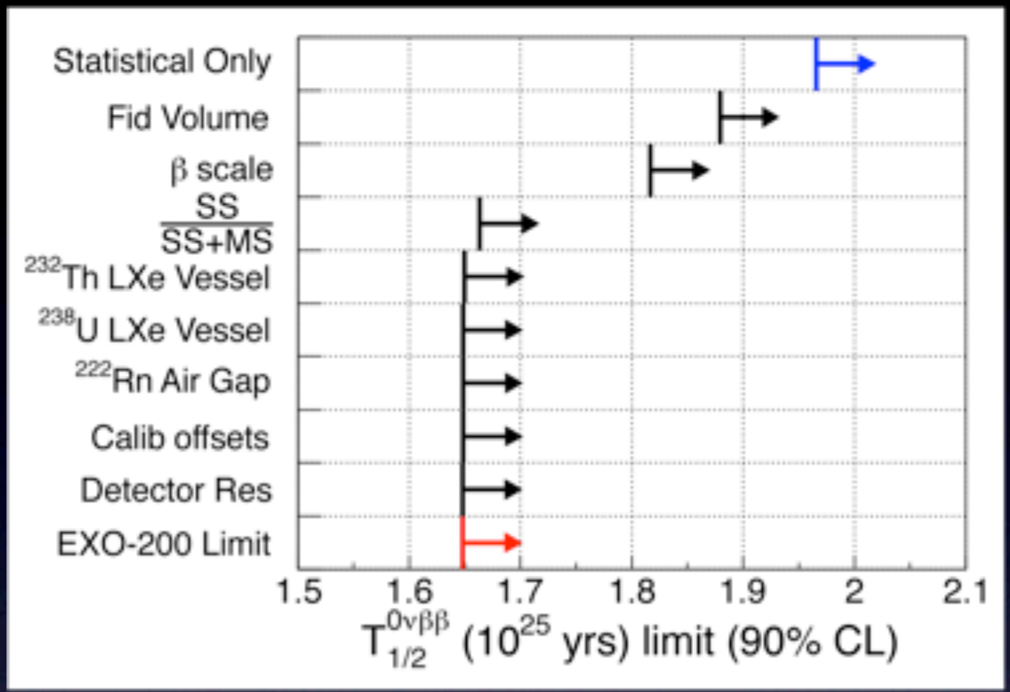
Phys. Rev. Lett. 109 (2012) 032505

A. Gando et al. Phys. Rev. C 85 (2012) 045504

H.V. Klapdor-Kleingrothaus et.al. Eur. Phys. J. A12 (2001) 147

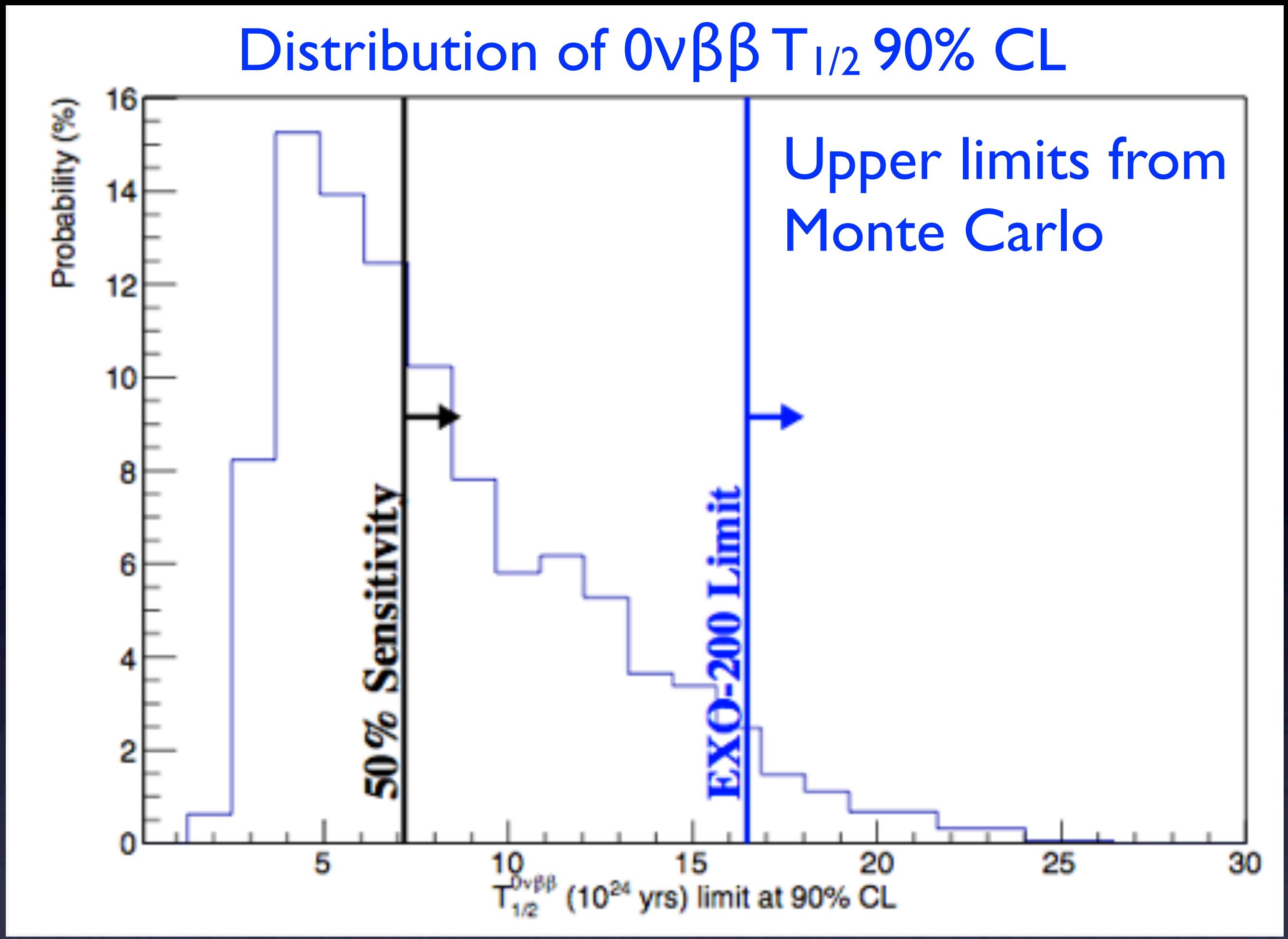
H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, Mod. Phys. Lett., A21 (2006) 1547.

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

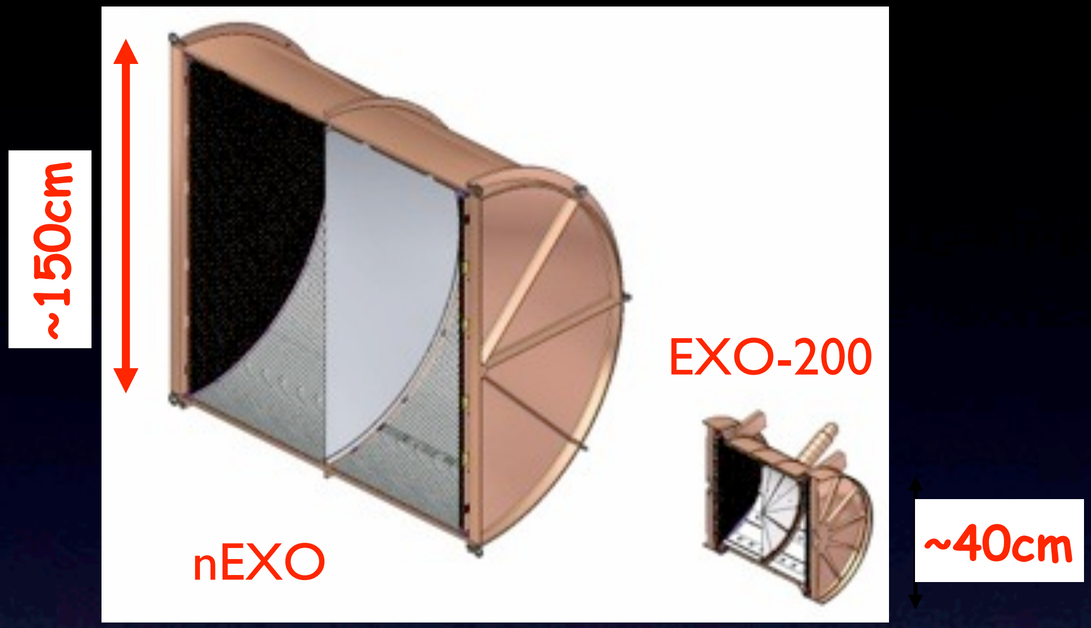


From estimated background, expect to quote a 90% CL upper limit on $T_{1/2}$:

- $\geq 1.6 \times 10^{25}$ yr 6.5% of the time
- $\geq 7 \times 10^{24}$ yr 50% of the time

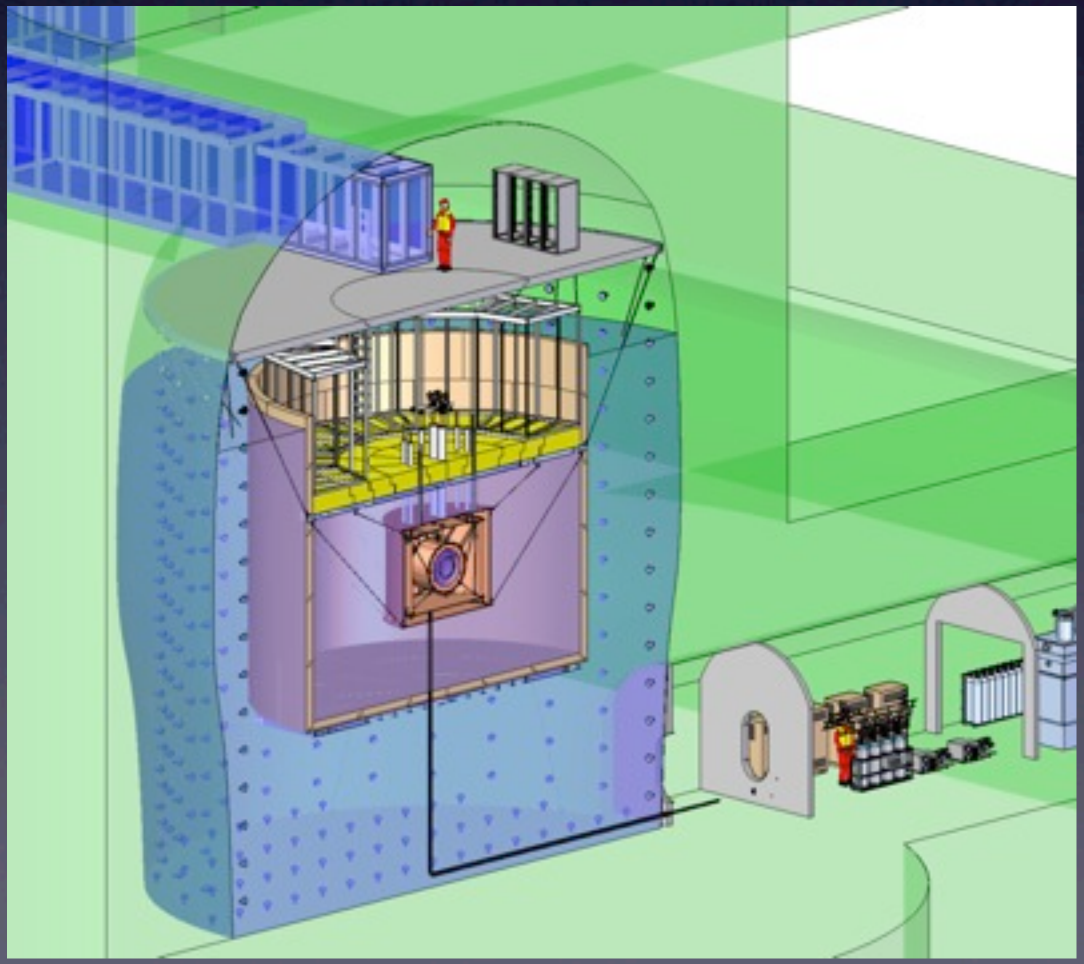
nEXO

nEXO



- 5 tonne LXe TPC "As similar to EXO-200 as possible"
- Access ports for possible later upgrade to Ba tagging

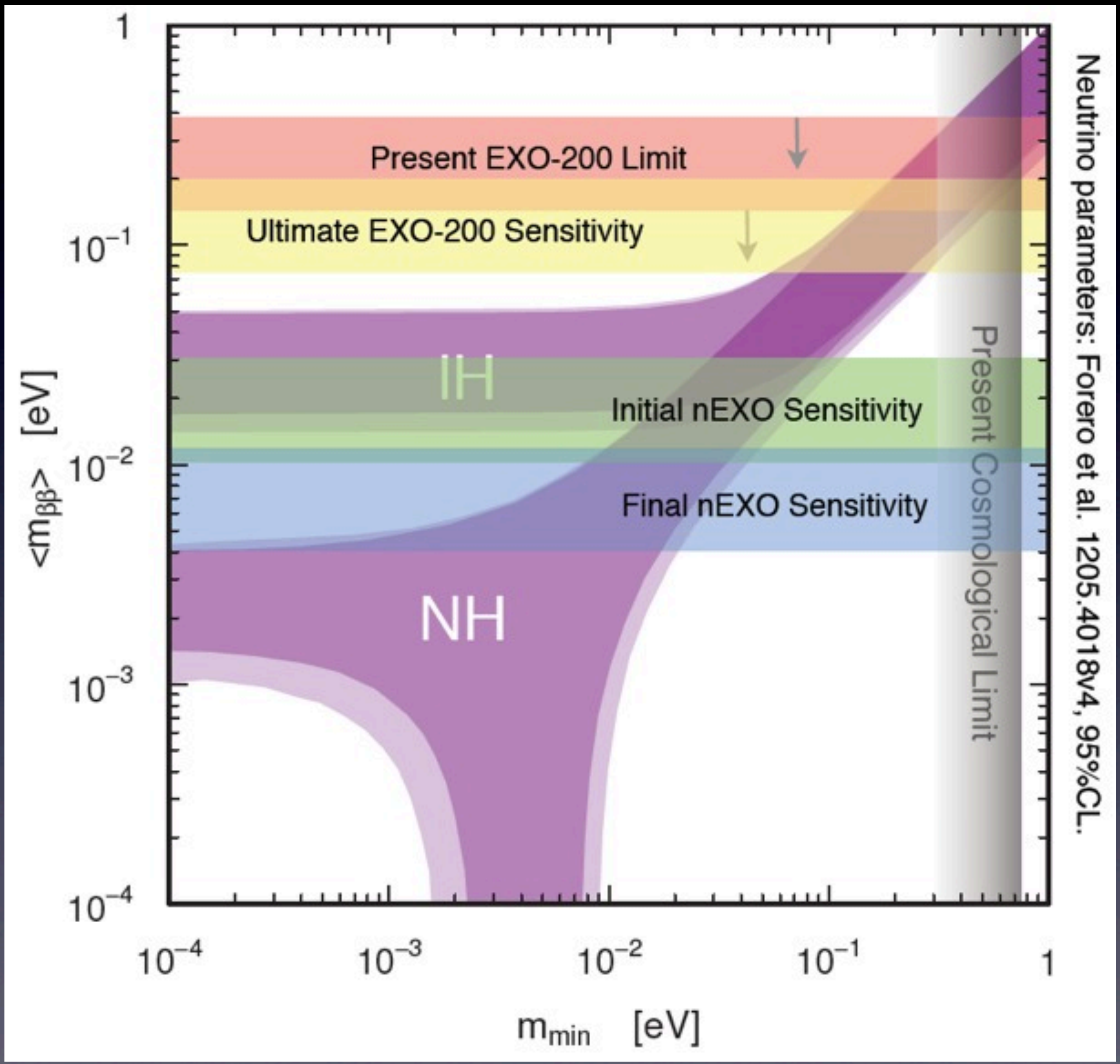
nEXO in the SNOlab Cryopit



R+D items

- Understand HV issues (a common problem to all LXe detectors ?)
- Low background, cryo-electronics (⬇noise, ⬆chnls)
- SiPM photodetectors (no HV, ⬇mass, ⬆gain)
- Alternative charge collection scheme (no wires, ⬇background, ⬆reconstruction)

EXO-200 and nEXO projected sensitivities



Purple bands are 95%CL from oscillation experiments for "Inverted" and "Normal" Hierarchy (exterior outlines)

The EXO-200 "Present limit" is the 90%CL envelope of Limits (for different NMEs) from PRL 109 (2012) 032505

The EXO-200 "Ultimate" sensitivity: 90%CL for no signal in 4 yrs livetime with new analysis & Rn removal

The "Initial nEXO" band refers to a detector directly scaled from EXO-200, including its measured background and 10yr livetime.

The "Final nEXO" band refers to the same detector and no background other than 2ν

EXO-200 and nEXO projected sensitivities

Band	Fiducial Mass (tonne)	Livetime (yr)	$T_{1/2}$ sensitivity (yr)	Bracketing NMEs		Conditions
				QRPA-2 (meV)	GCM (meV)	
EXO-200 "Ultimate"	0.1	4	$5.5 \cdot 10^{25}$	200	75	EXO-200 with Rn removal and new analysis
Initial nEXO	4.5	10	$2.5 \cdot 10^{27}$	30	11	Extrapolation from EXO-200 using EXO-200 backgrounds
Final nEXO	4.5	5+5	$2.2 \cdot 10^{28}$	10	4	Second 5 yr background-free (e.g. Ba tagging)

The final sensitivity of EXO-200 may surpass "Ultimate" with a possible electronics upgrade currently under discussion.

GCM: T.R. Rodriguez and G. Martinez-Pinedo, Phys. Rev. Lett. 105 (2010) 252503.
NSM: J. Menendez et al., Nucl. Phys. A 818 (2009) 139.
IBM2: J. Barea and F. Iachello, Phys. Rev. C79 (2009) 044301 and private communication.
R-QRPA-1: F. Simkovic et al., Phys. Rev. C 79 (2009) 055501.
QRPA-2: A. Staudt, K. Muto and H.V. Klapdor-Kleingrothaus, Europhys. Lett. 13 (1990) 31.

Summary

- EXO-200 is taking low background data since June 2011
- Already reached nominal performance for resolution and background:
  - Energy resolution: 1.67% at $Q_{\beta\beta}$
  - Background: 1.5×10^{-3} $kg^{-1}keV^{-1}yr^{-1}$
  - 1 (5) counts in 1σ (2σ) 0νββ ROI
- EXO-200 approved to run for 3 more years
- Discovered the 2νββ decay in ^{136}Xe
- Very competitive limit on the 0νββ decay
- With the first 4 month of data: almost exclude the Klapdor claim
- More data acquired, better performance (σ, b, ..), new papers soon
- nEXO taking shape

- Next few years will be very interesting!

Thank You


THIS IS WONDERFUL— A COMPLETELY DUST-FREE LAB. WHAT DO YOU STUDY HERE?
Dust.
S. Harris