The Enriched Xenon Observatory (EXO)

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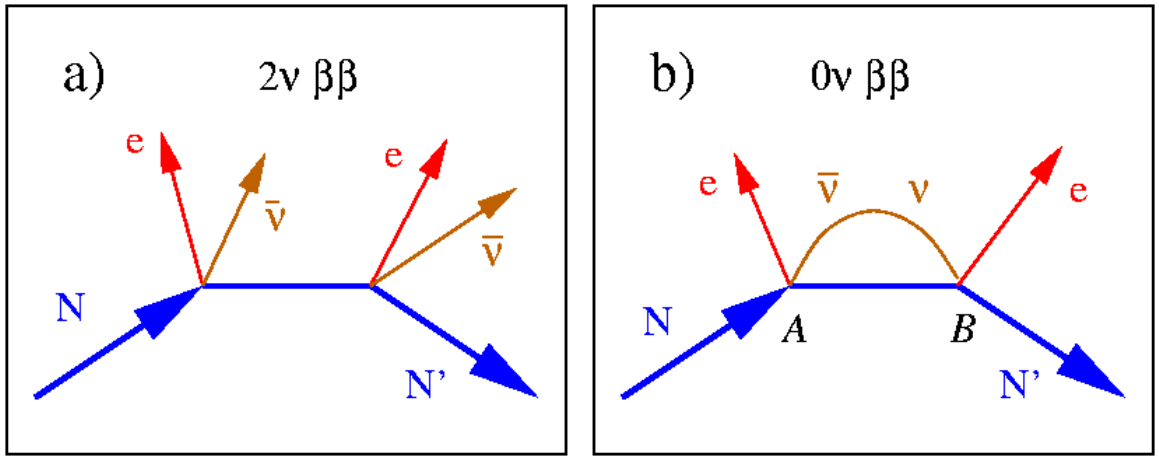
Outline

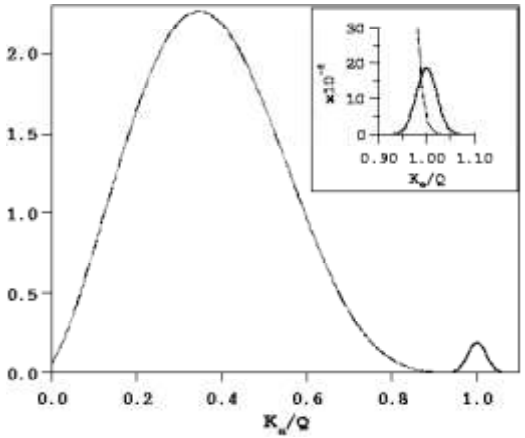
- Brief discussion of double beta decay
- Description and status of EXO-200 experiment
- Some results from Engineering run with natural xenon
- Preliminary results from barium tagging R&D efforts

Double Beta Decay



2ν mode:
a conventional
2nd order process
in Standard Model

0ν mode: a hypothetical process
can happen only if:
$M_\nu \neq 0$, $\nu = \overline{\nu}$ (non-zero Majorana mass)
$|\Delta L|=2$, $|\Delta(B-L)|=2$



Simulated double beta decay spectrum

To reach high measurement sensitivity for 0ν mode requires,

- High energy resolution
- Large Isotope mass
- Low background

Xenon is an Excellent Candidate for Double Beta Decay Search

Energy resolution is poorer than the crystalline devices (~ factor 10), but

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

Xenon is "reusable". Can be repurified & recycled into new detector (no crystal growth).

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

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

Energy resolution in LXe can be improved. Scintillation light/ionization correlation.

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

Enriched Xenon Observatory (EXO)

EXO is a multi-phase program to search for the neutrinoless double beta decay of ^{136}Xe.

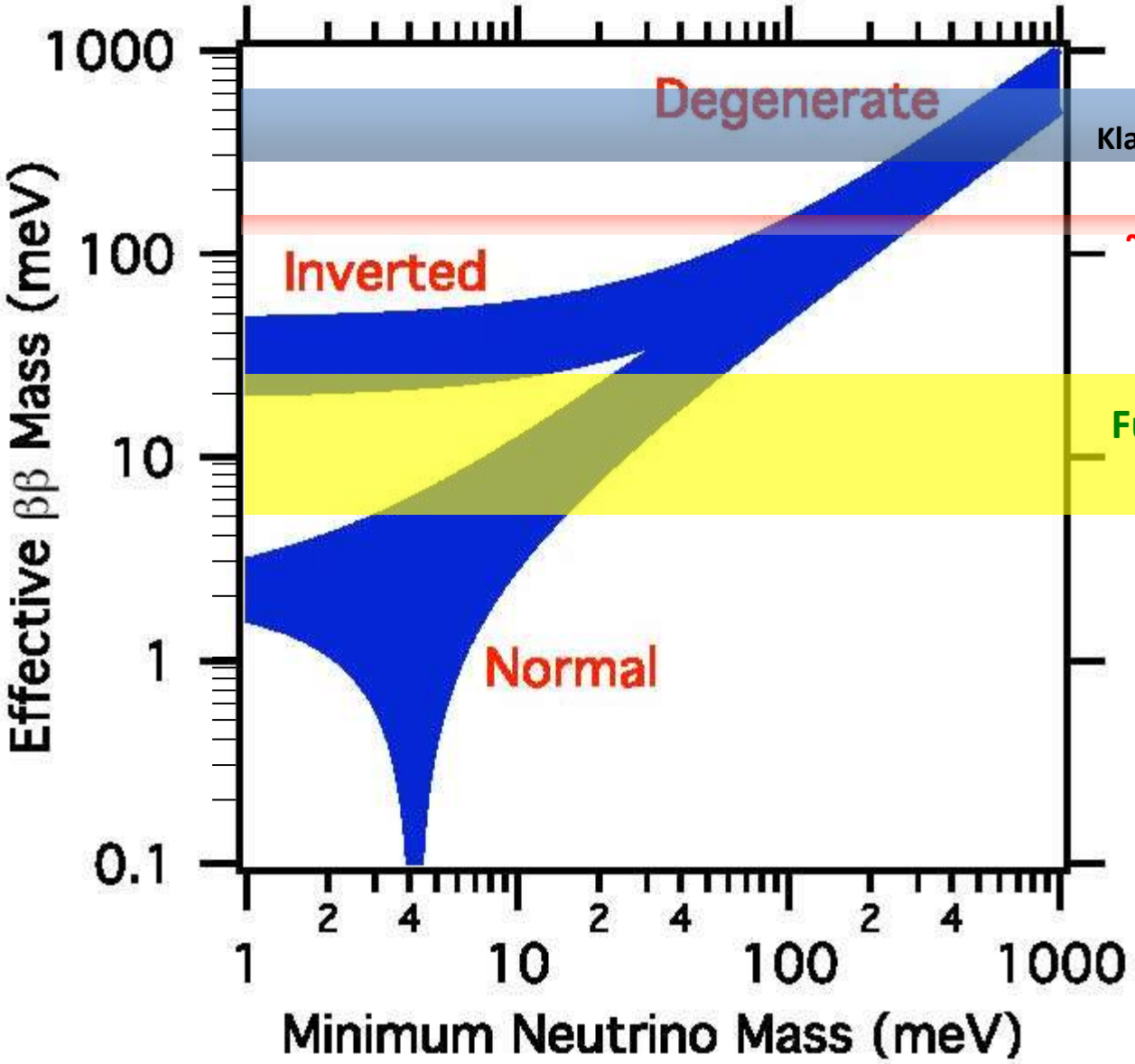
EXO-200 (first phase):

- A 200 kg liquid xenon detector currently operating underground
- Probe Majorana neutrino mass at 100-200 meV range
- Demonstrate technical feasibility of ton scale experiment

Full EXO (second phase):

- A proposed 1- 10 ton liquid or gas xenon detector
- Probe Majorana neutrino mass at 5 – 30 meV range
- R&D work for novel techniques for background suppression and energy resolution in progress

EXO Sensitivity



Klapdor et al. 0.24 – 0.58 eV

EXO-200
~109-135 meV sensit.

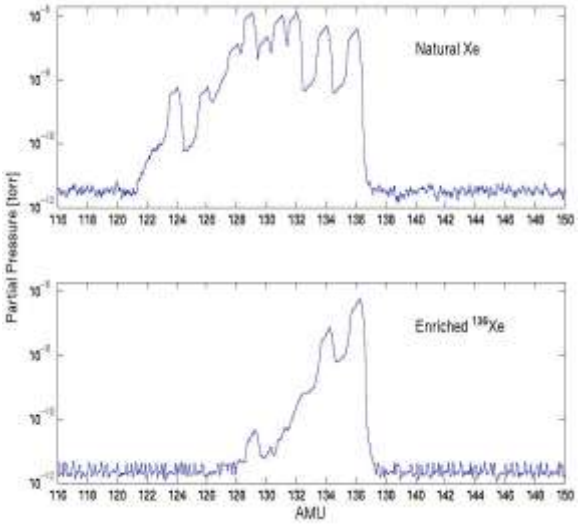
Full EXO 1ton – 10ton
5 - 25 meV

Assumptions:

Majorana neutrinos

EXO-200: the First 200kg Double Beta Decay Experiment

Centrifuge facility in Russia

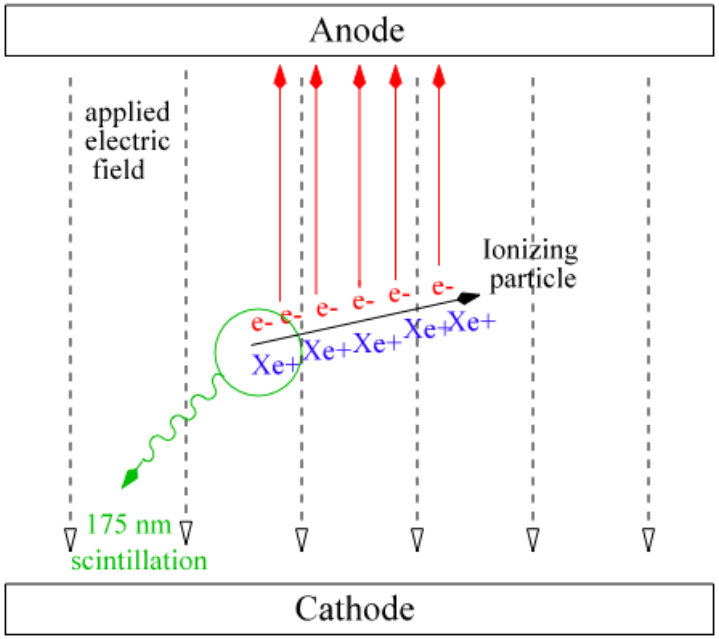


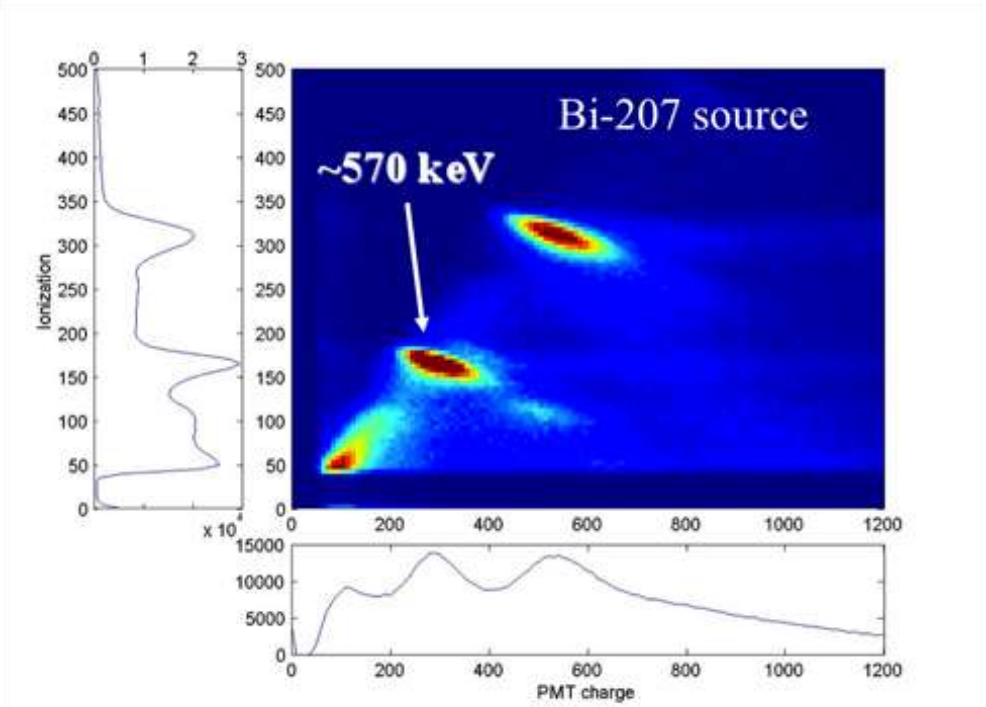
RGA mass scan of xenon samples

Enriched xenon storage bottles for EXO

EXO collaboration currently have 200 kg of xenon enriched to 80% = 160 kg of ^{136}Xe

Liquid Xenon Calorimetry





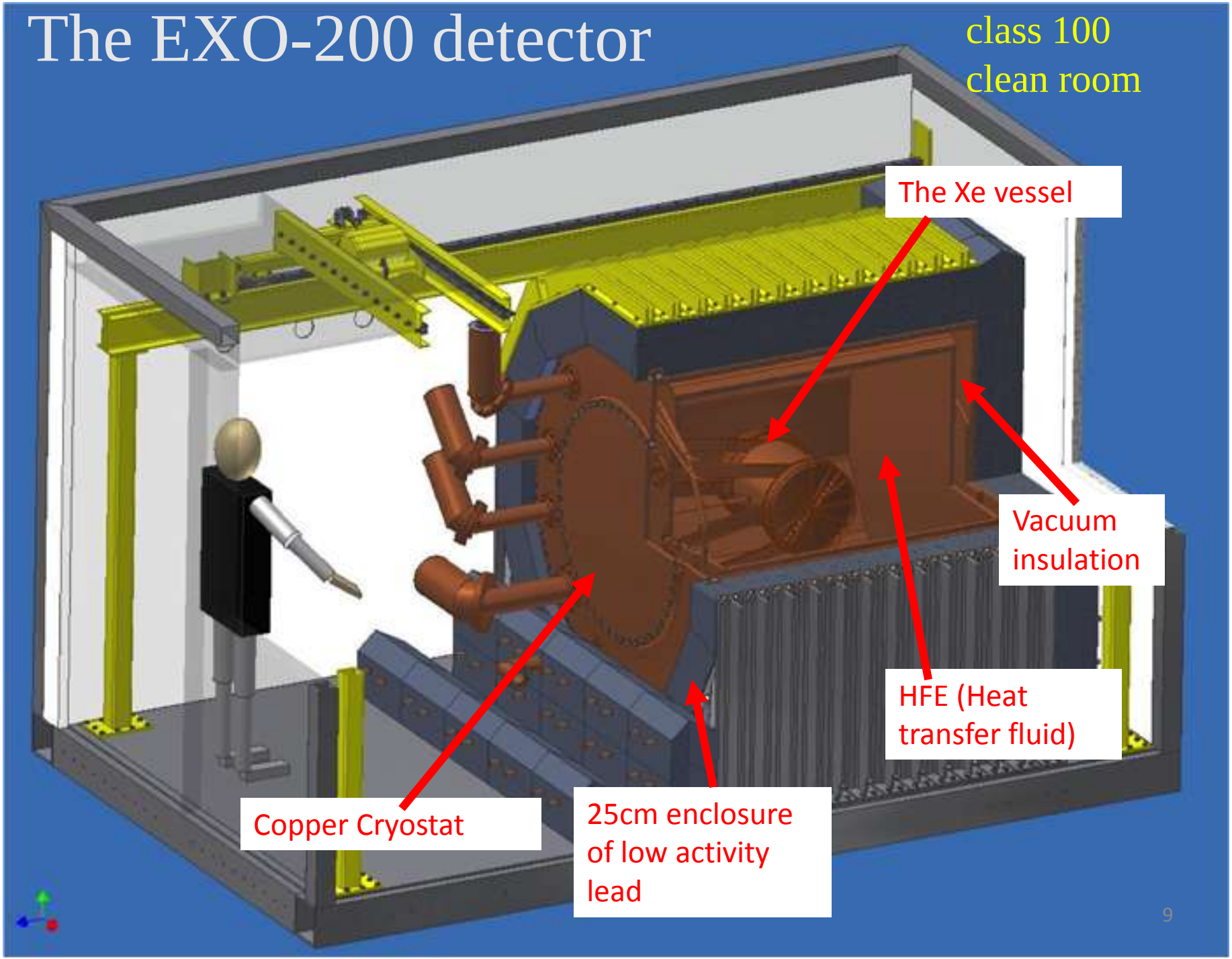
When ionizing radiation enters liquid xenon, it creates many Xe^+ and e^- pairs and Xe*, some of the Xe^+ and Xe* undergo recombination and give off 175nm VUV photons or heat.

Ionization alone: 3.8% @ 570 keV or 1.8 % @ Q(ββ)

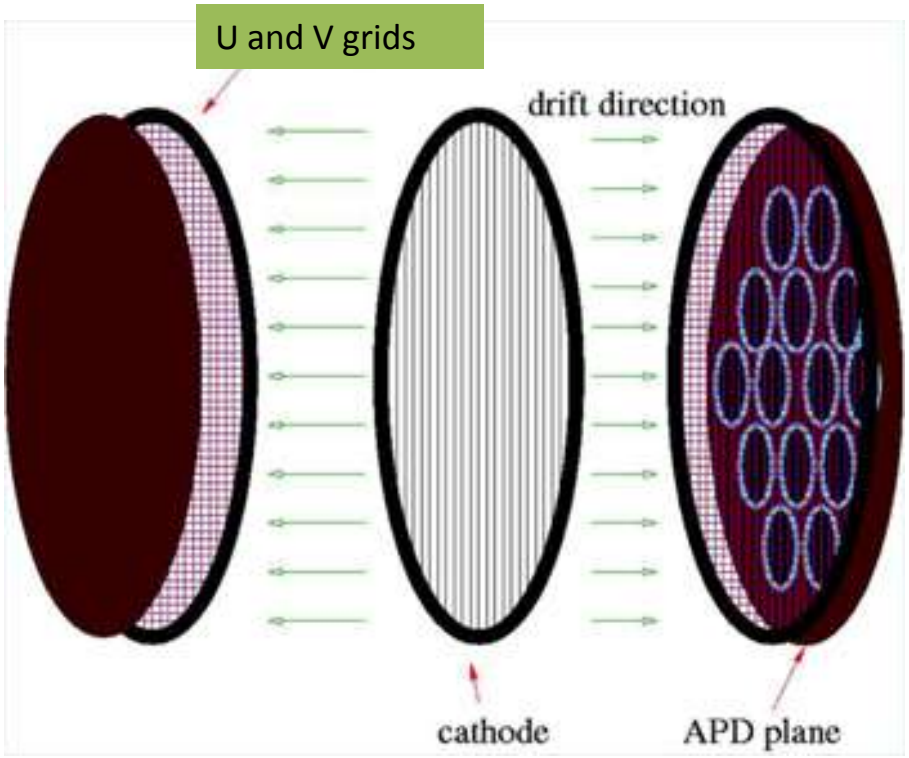
Ionization & Scintillation: 3.0% @ 570 keV or 1.4 % @ Q(ββ)

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

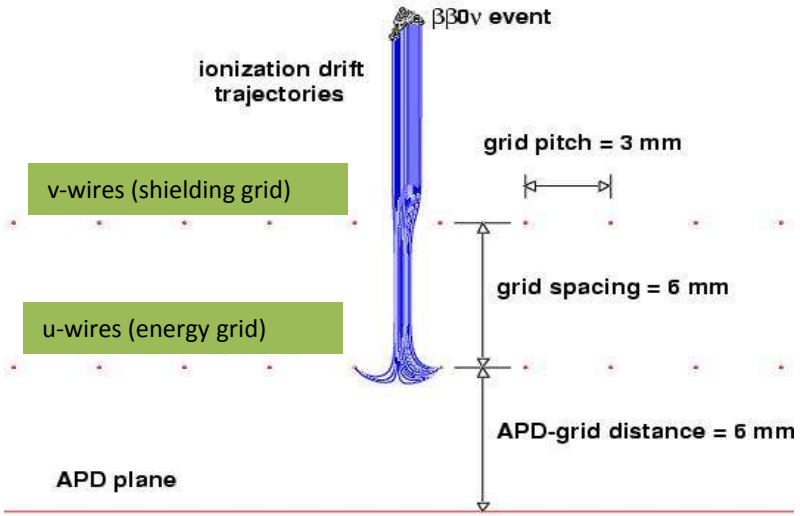
The EXO-200 detector



EXO-200 Time Projection Chamber (TPC) Basics



TPC Schematics



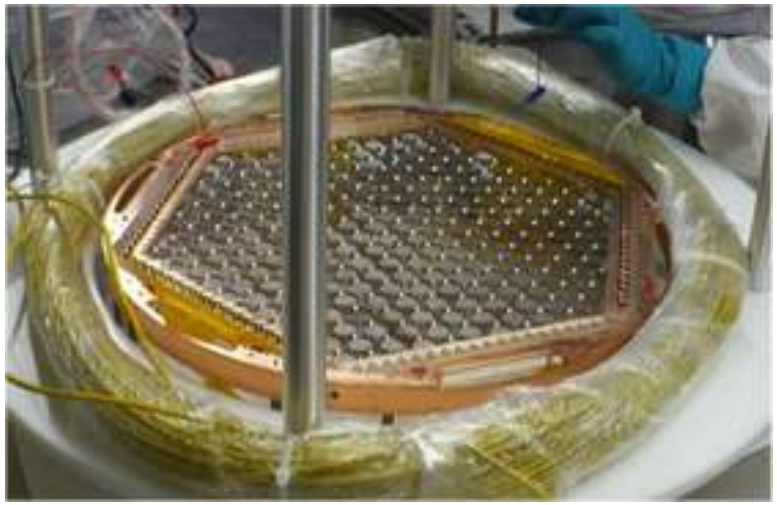
Simulation of Charge Drift

- Two TPC modules with common cathode in the middle.
- APD array observes prompt scintillation for drift time measurement.
- V-position given by induction signal on shielding grid.
- U-position and energy given by charge collection grid.

Ultra-low Activity Copper Vessel

- Very light (wall thickness 1.5 mm, total weight 15 kg), to minimize material.
- All parts machined under 7 ft of concrete shielding to reduce activation by cosmic rays.
- Different parts are e-beam welded together at Applied Fusion.

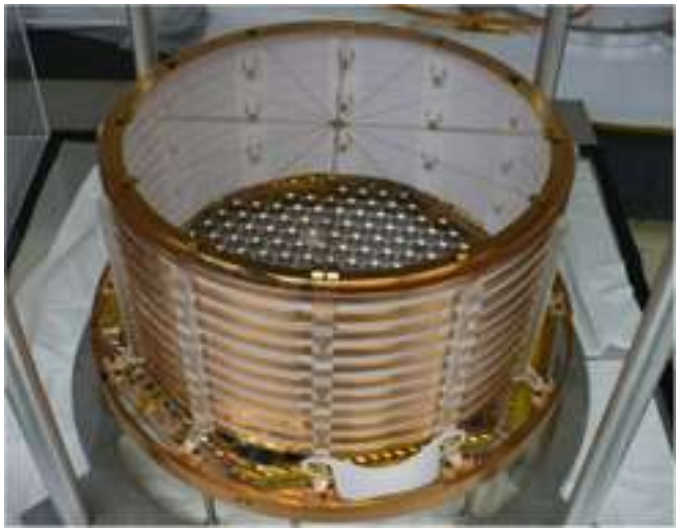
TPC Construction



Measuring wire tension

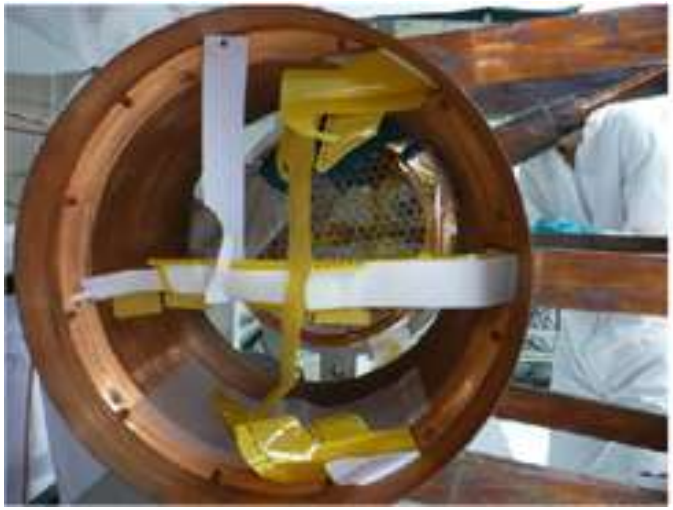
Installing field cages and teflon reflectors

Loading APDs

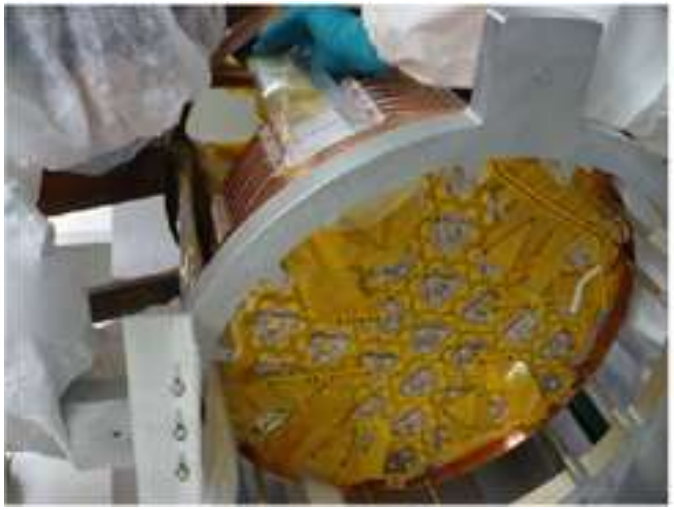


Completed TPC module

TPC Insertion and Cabling



Flex cables inserted in the chamber



TPC insertion

Detector Wiring

Completed Detector

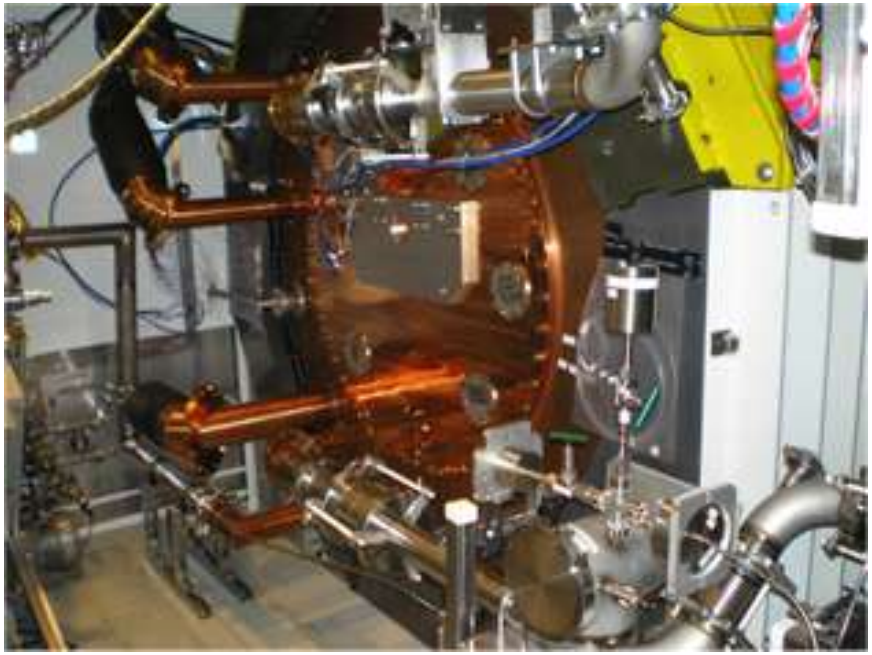
EXO-200 Installation Site: WIPP

EXO area at WIPP in 2007

- EXO-200 is installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- U.S. DOE salt mine for radioactive waste storage
- Salt “rock” low activity relative to hard-rock mine

EXO-200 Facility at WIPP

Cleanrooms at WIPP drift



Cryostat and Pb Shielding

- Cleanroom installed on adjustable stands to compensate salt movements.
- Cryogenic system fully commissioned using a dummy vessel.
- Active pressure compensating system insured no large pressure differential across the detector vessel.

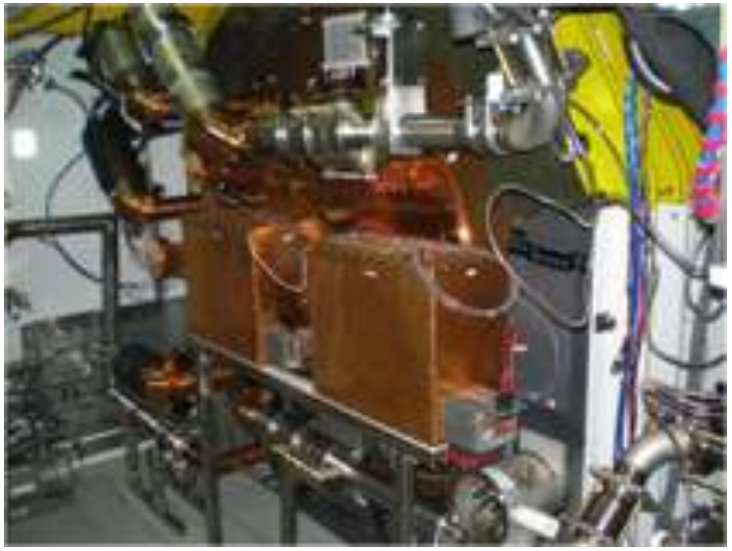
EXO-200 Engineering Run in 2010

- EXO-200 was filled with Natural Xe in the fall 2010 and we took a variety of engineering runs in Dec 2010.

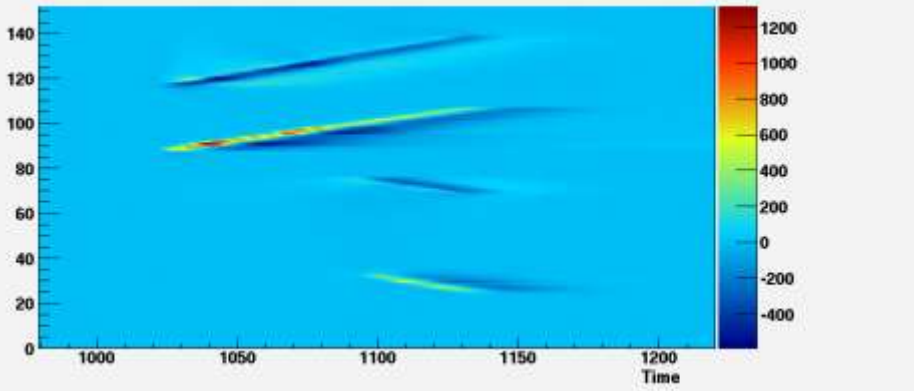
- The data collected were used to make a first assessment of the performance of the detector and perform a first round of calibrations:

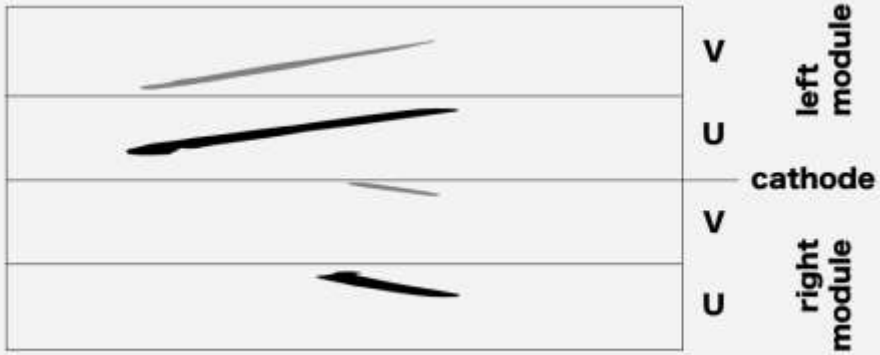
- Check stability of all LXe/GXe systems
- Check Xe purity
- Check electronics
- Generally test detector performance
- Test Xe emergency recovery

- No front shielding
- No Rn enclosure
- No Rn trap in Xe system
- No veto counter

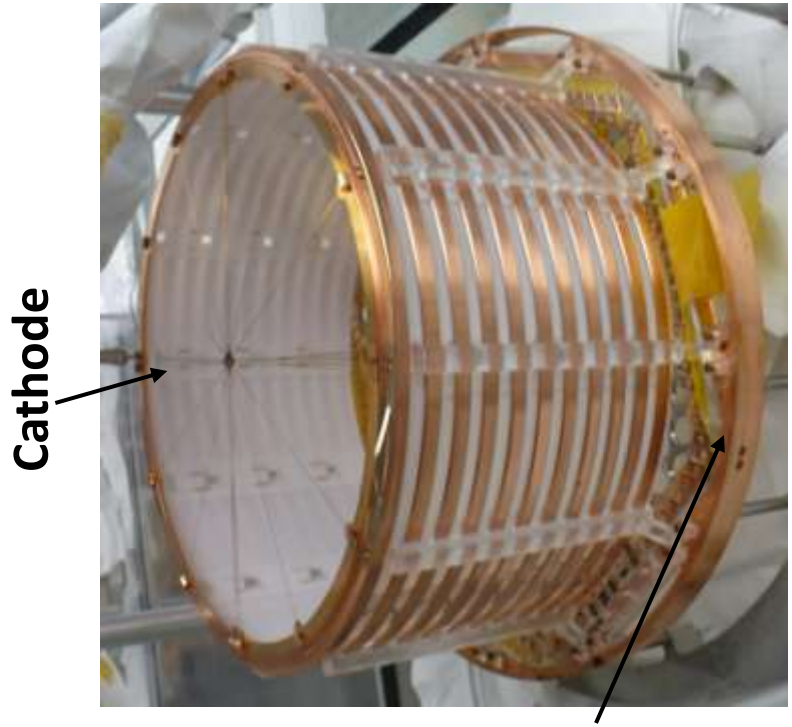


Muon track in EXO-200



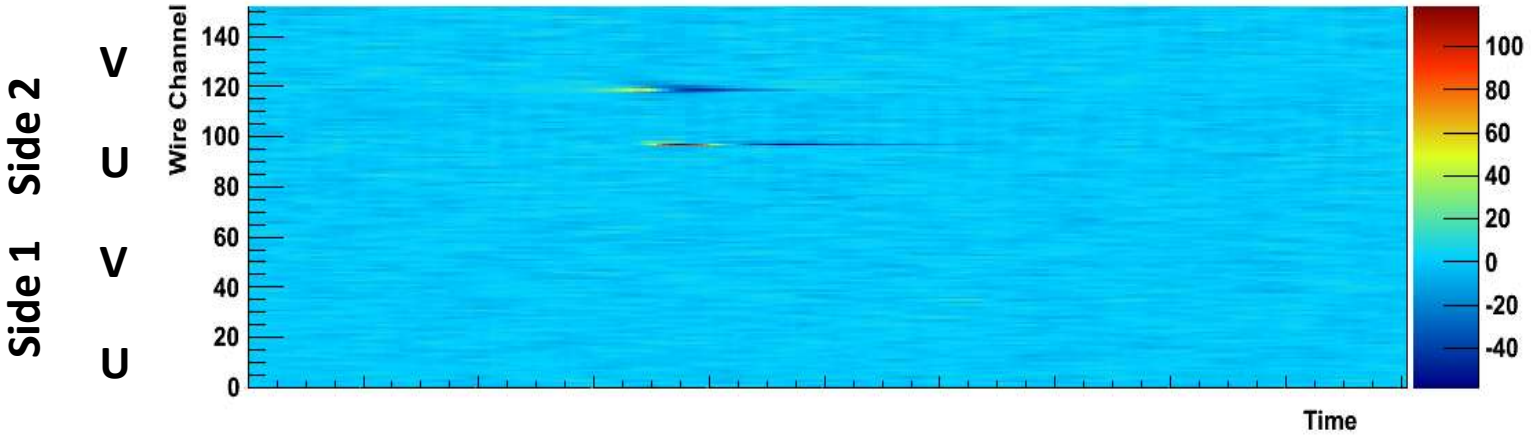


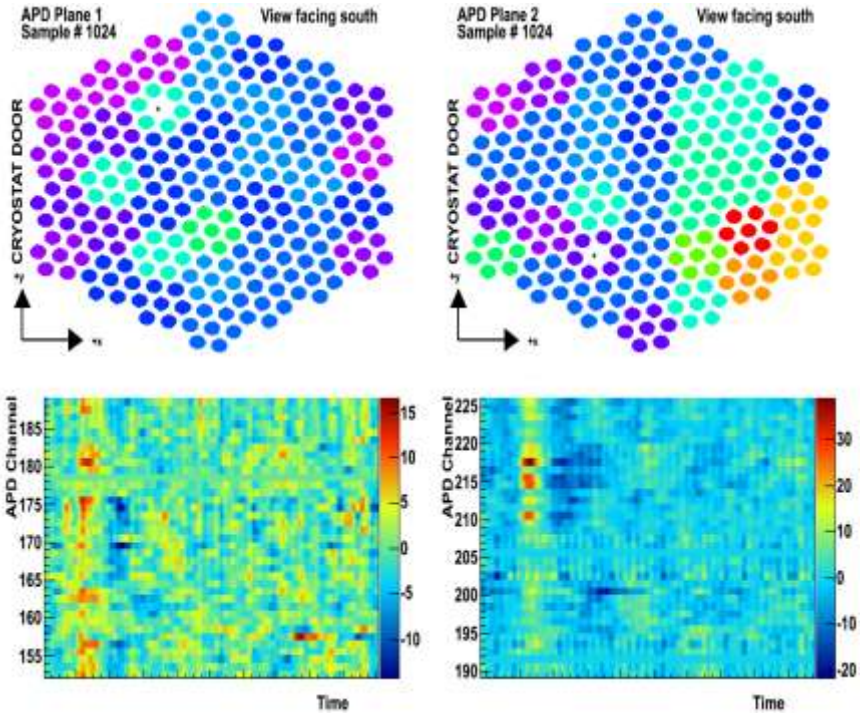
One of the two TPC modules



A track from a cosmic-ray muon in EXO-200. The horizontal axis represents time (uncalibrated for now) while the vertical is the wire position (see sketch). V wires see inductive signals while U wires collects the charge.
The muon in the present event traverses the cathode grid, leaving a long track in one TPC module and a shorter one in the other.

Single Site Event in EXO-200





Top display is charge readout (V are induction wires and U are collection wires).

Left display is light readout. APD map refers to the sample with max signal.

Scintillation light is seen from both sides, although more intense and localized on side 2, where the event occurred.

Small depositions produce induction signals on more than one V wires but are collected by a single U wire. V signal always comes before U.

Light signals precede in time the charge ones

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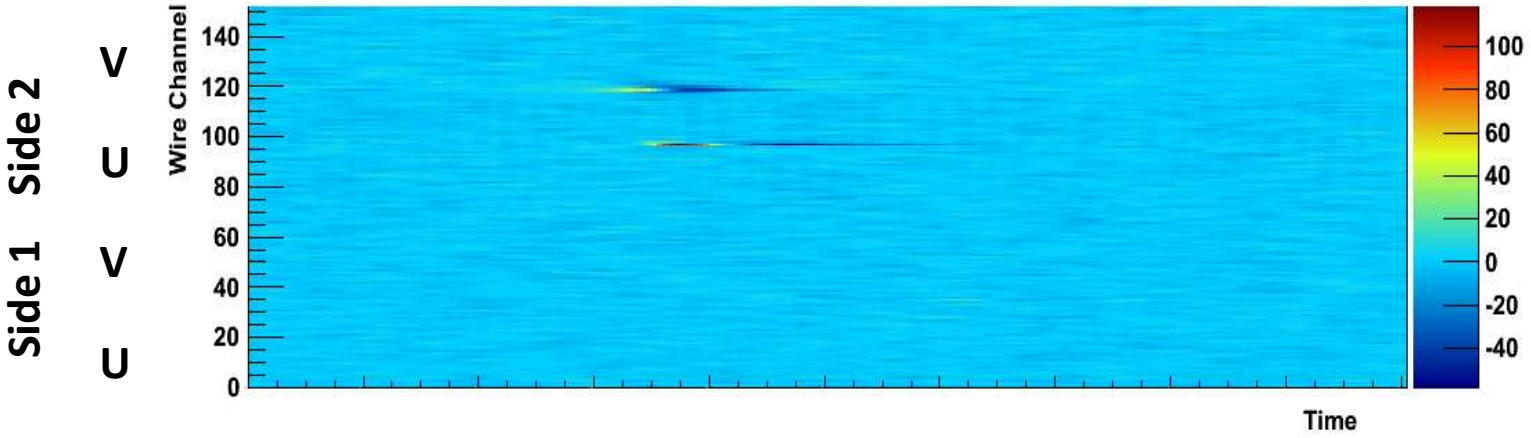

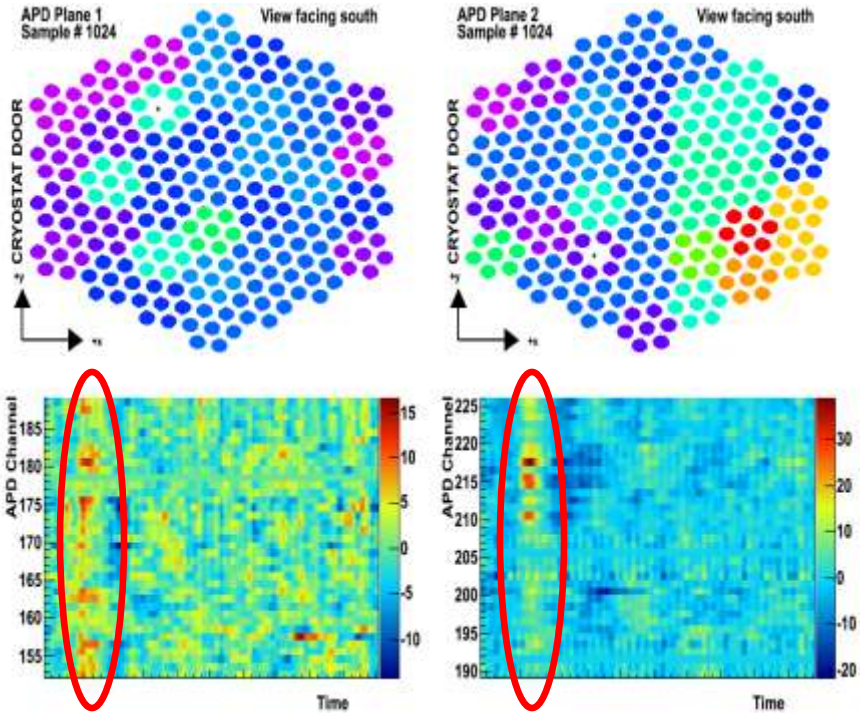

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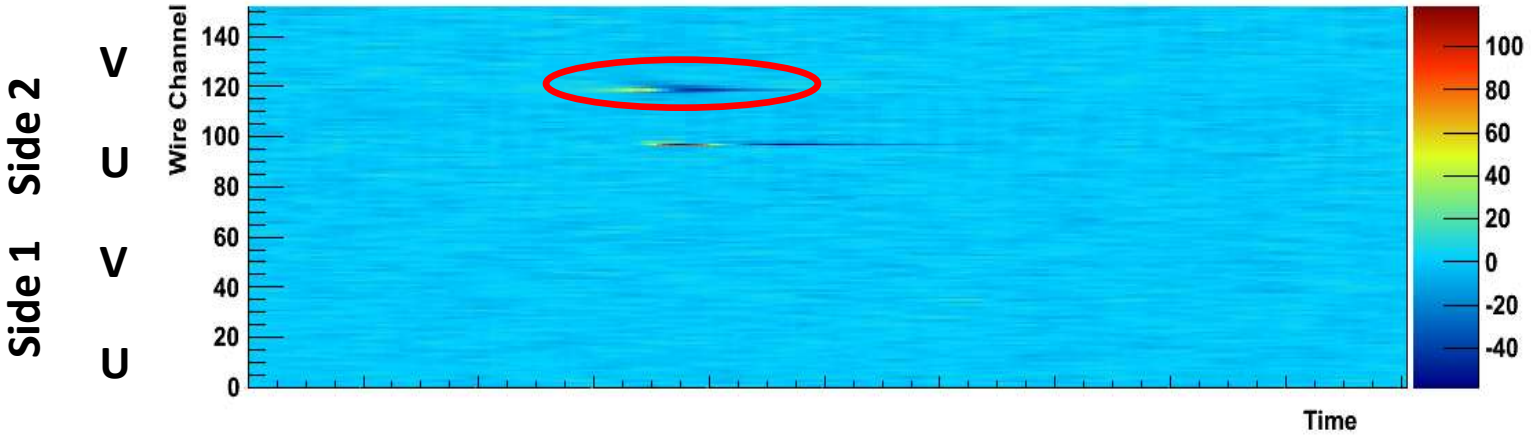

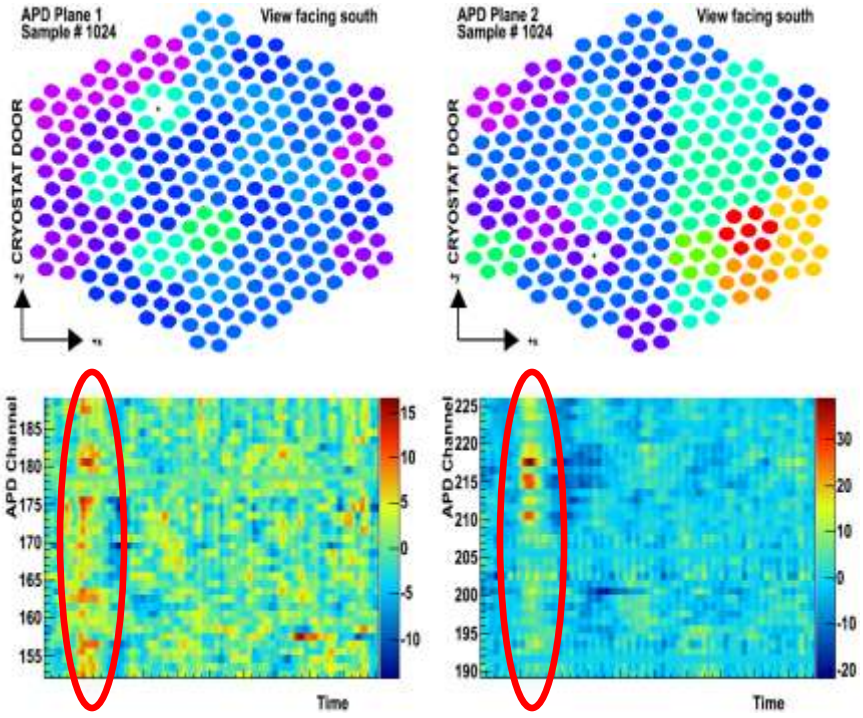

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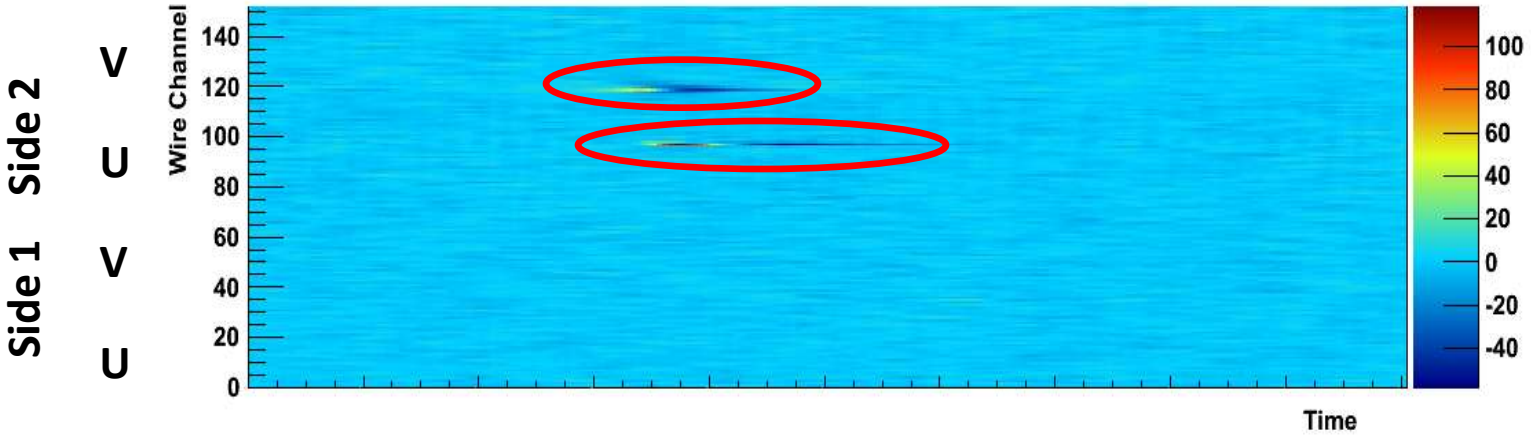

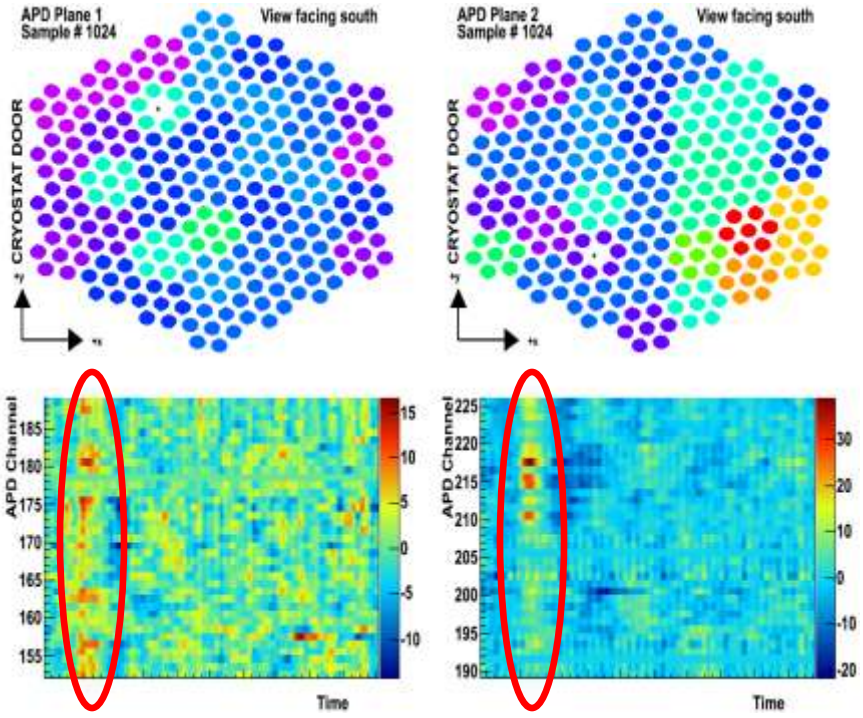

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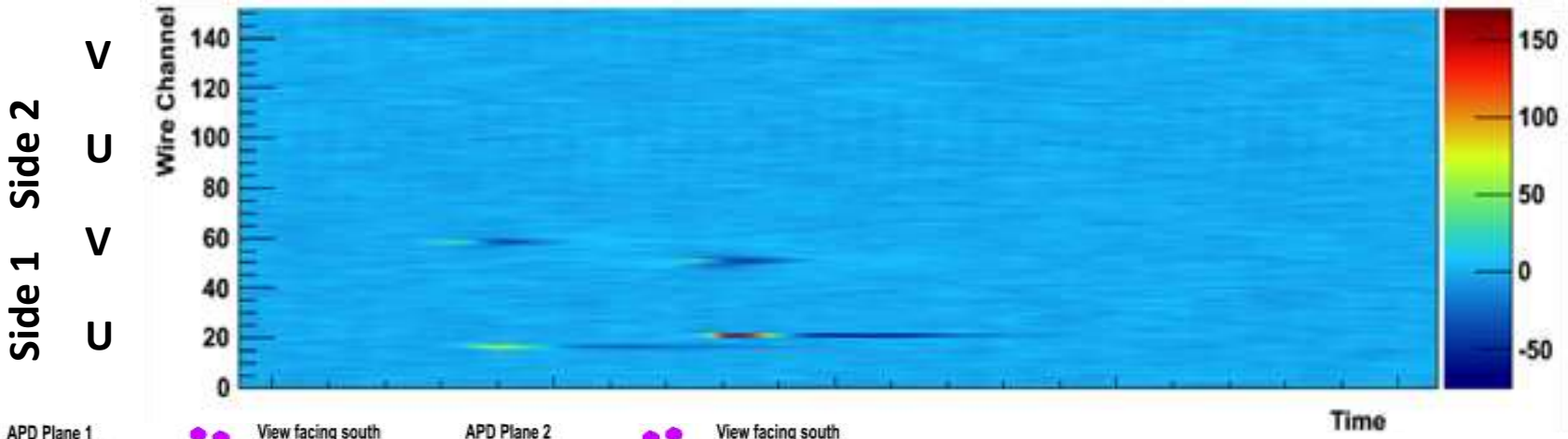

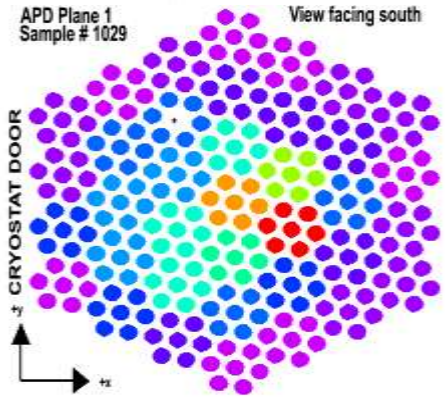

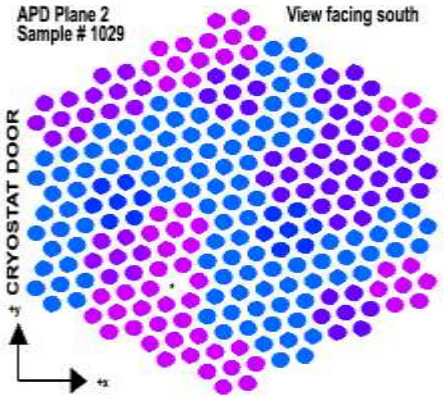

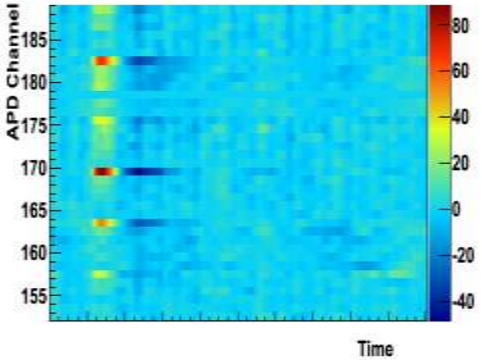

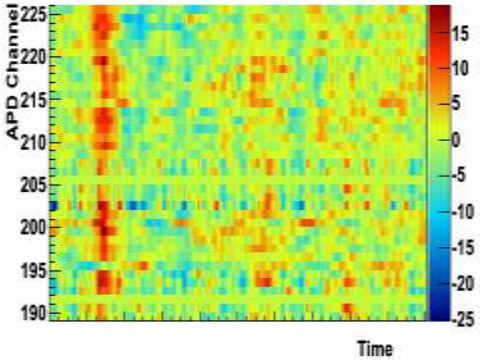

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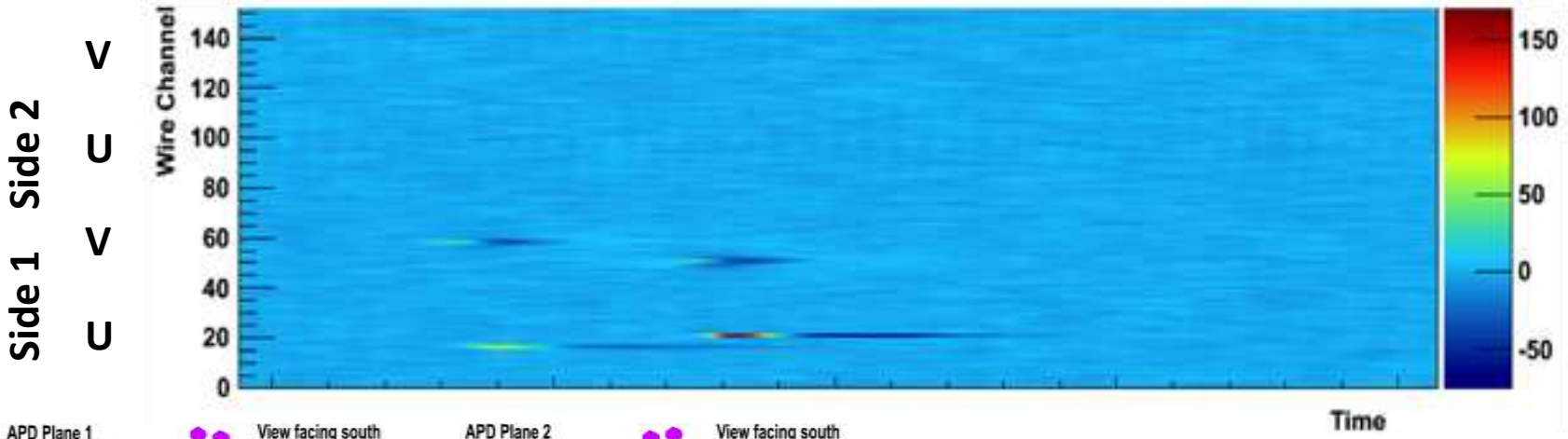

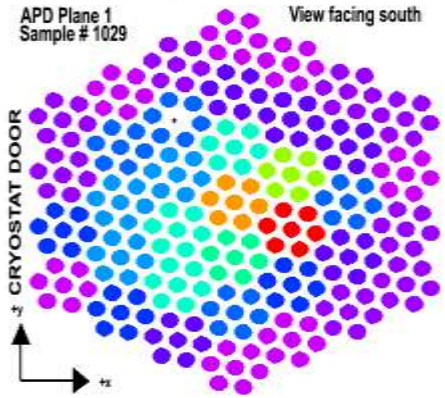

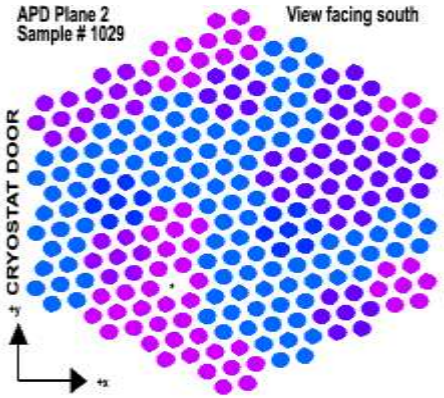

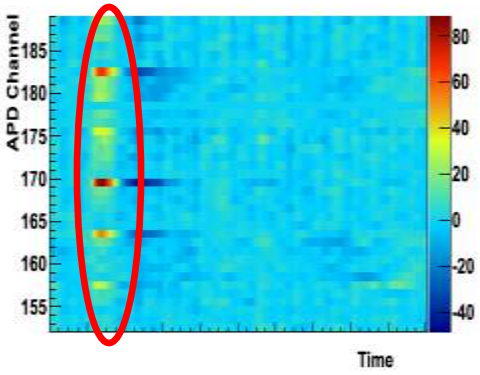

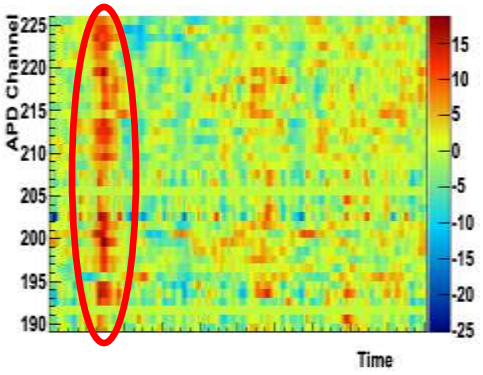

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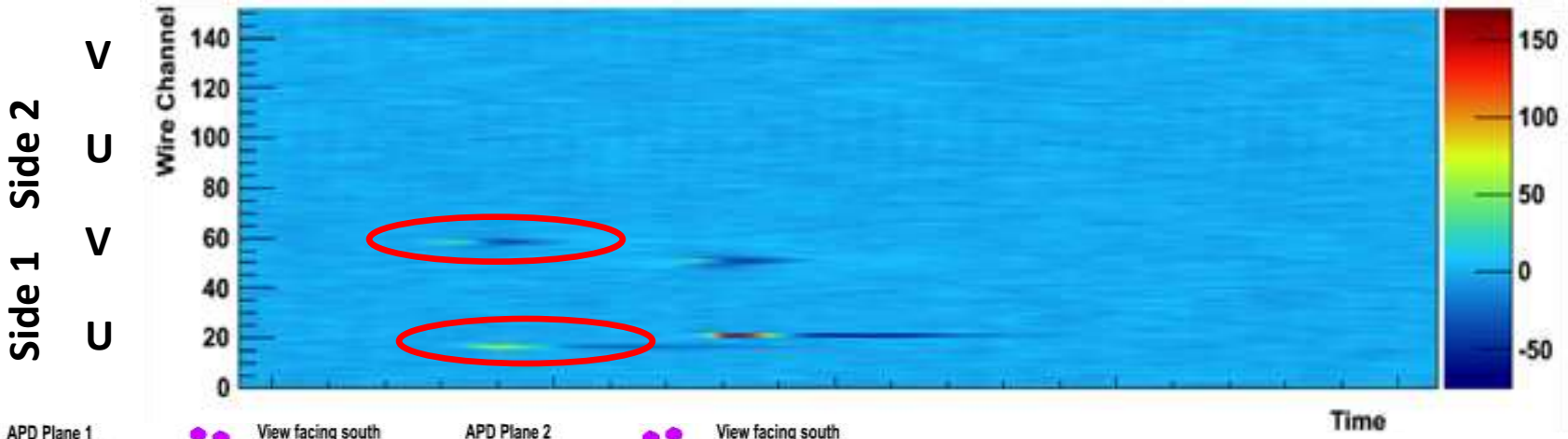

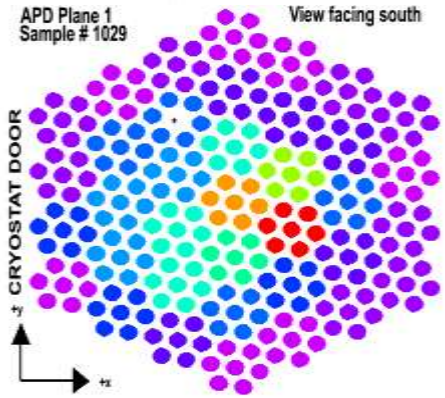

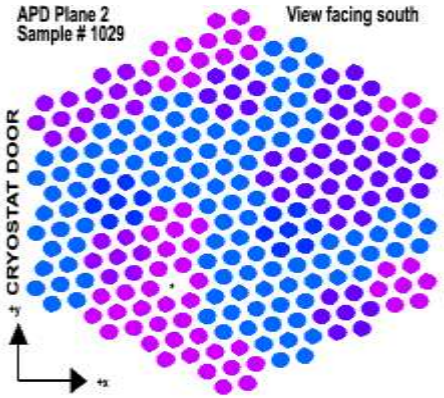

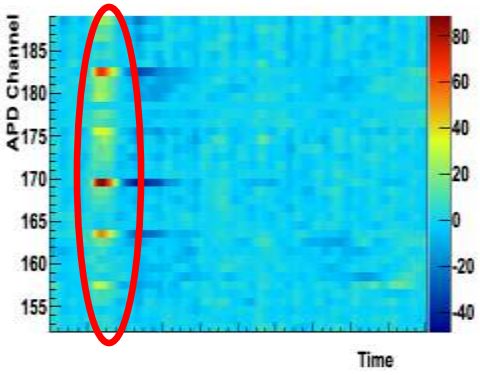

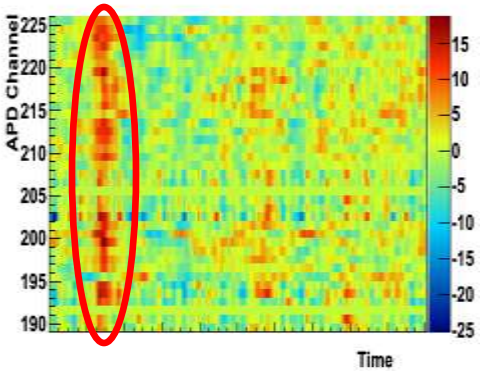

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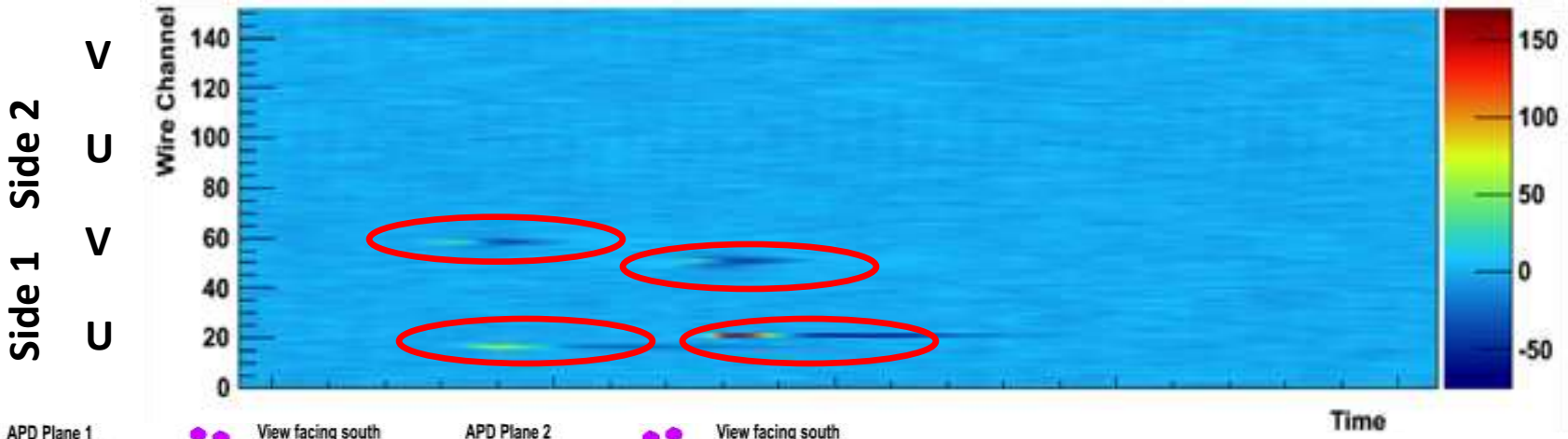
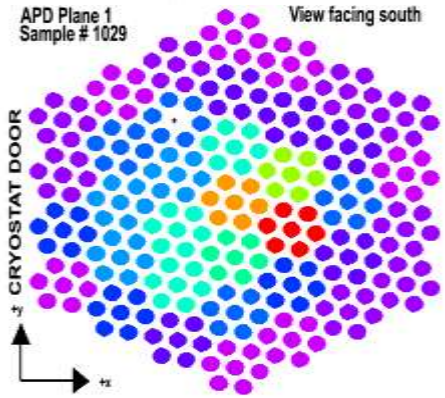
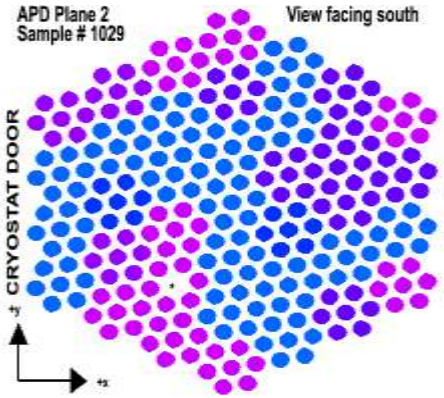
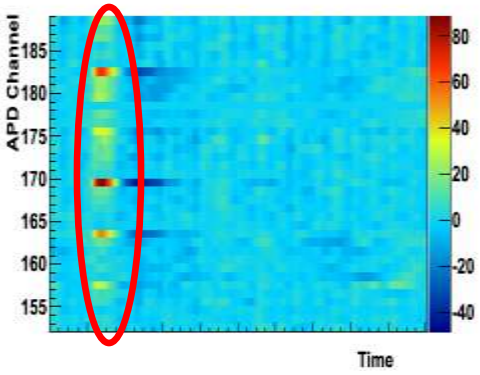
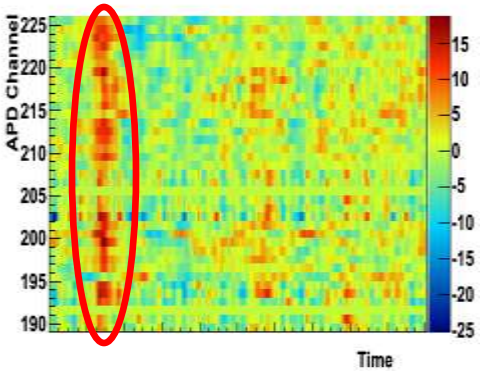






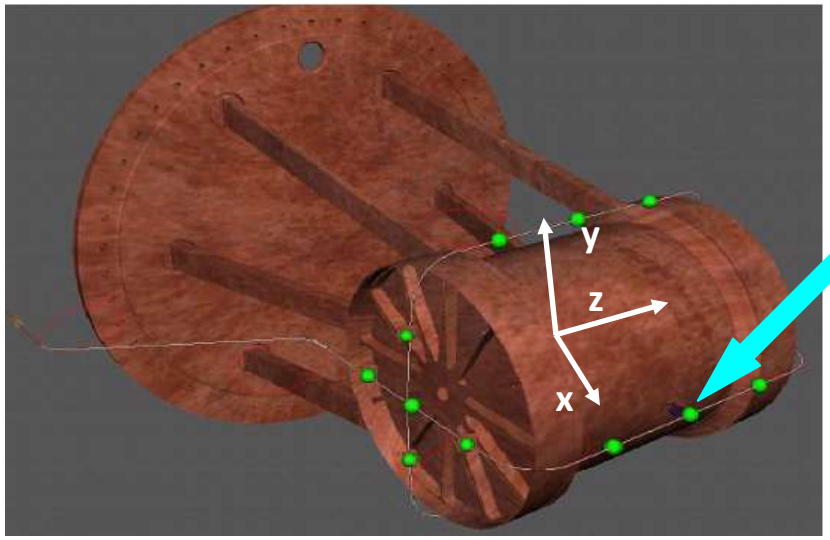




All scintillation light arrives at the same time, indicating that the two energy depositions are simultaneous.

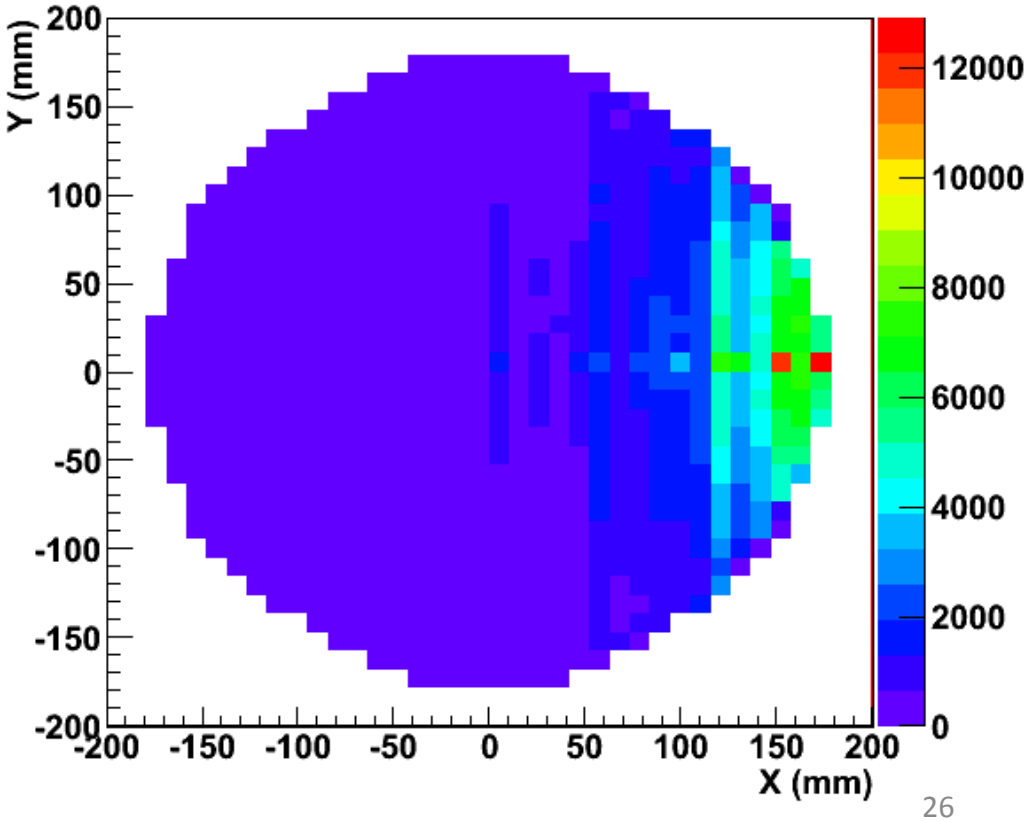
The scintillation light is brighter and more localized on Side 1 where the scattering occurs

Early Calibration Source Run



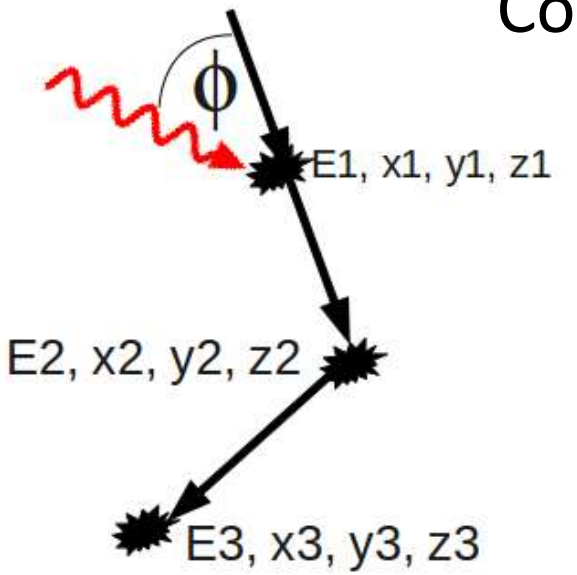
^{60}Co source

Various calibration sources can be brought to several positions just outside the detector

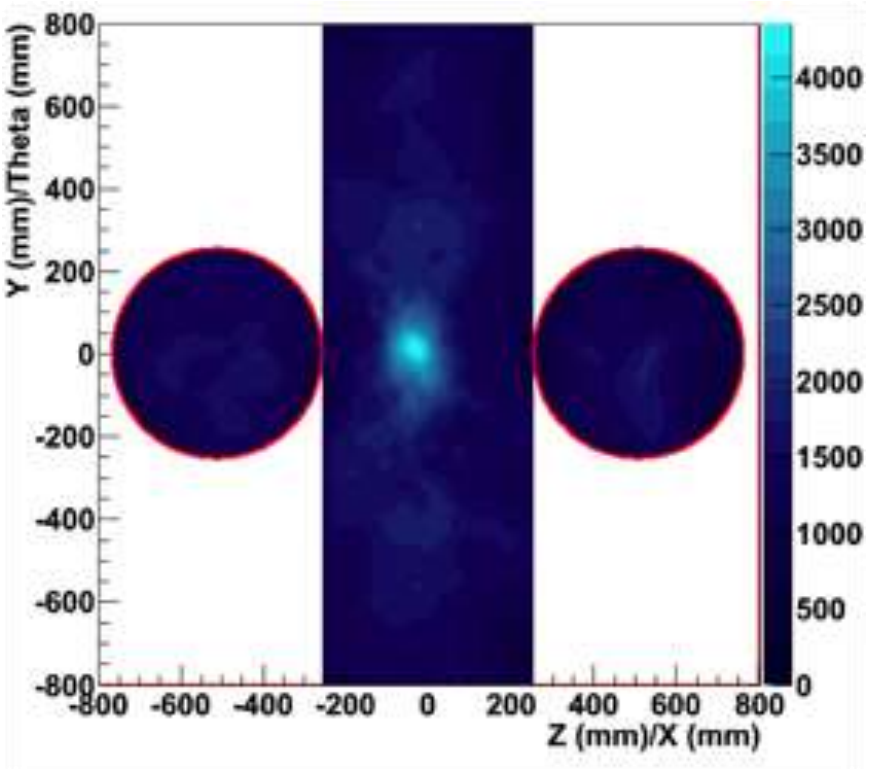


x-y distribution of events clearly shows excess near the source location

Pinpoint Source Location using a Compton telescope technique



500 events

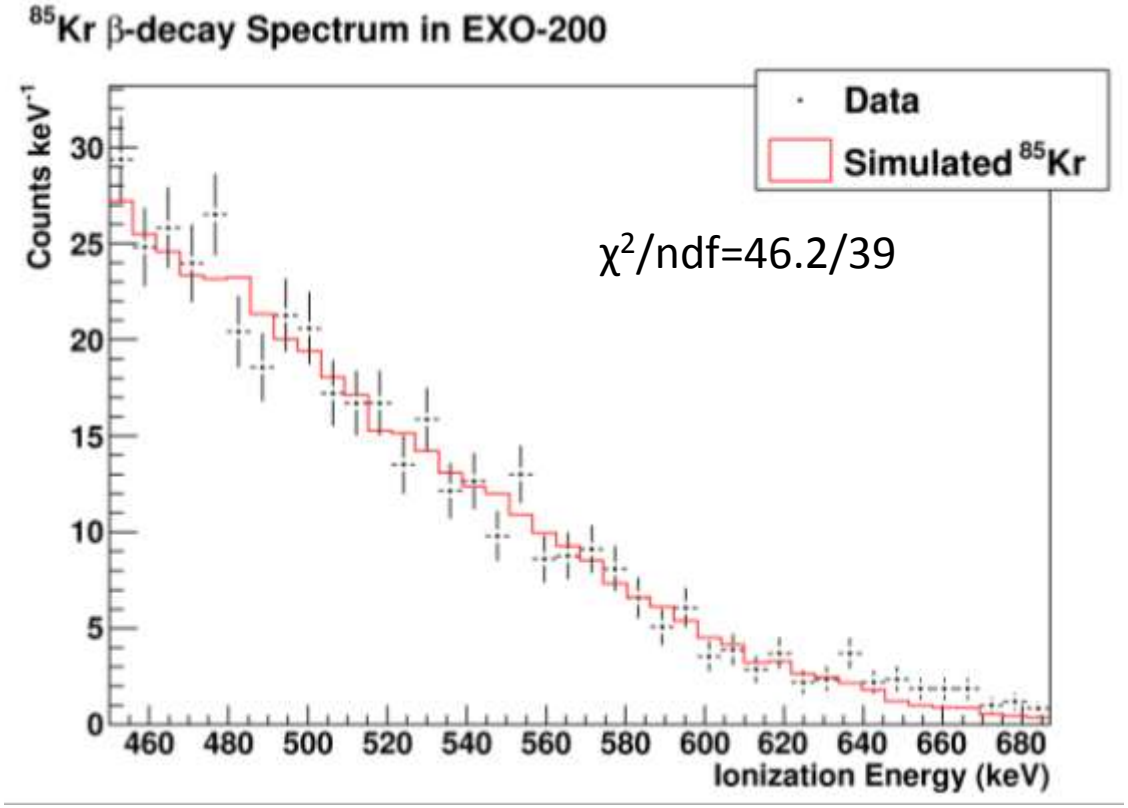


- Detector measures E, x, y, z for each site
- Use scattering formula

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

- From each site a cone is drawn and adding up these cones produces the image to the right

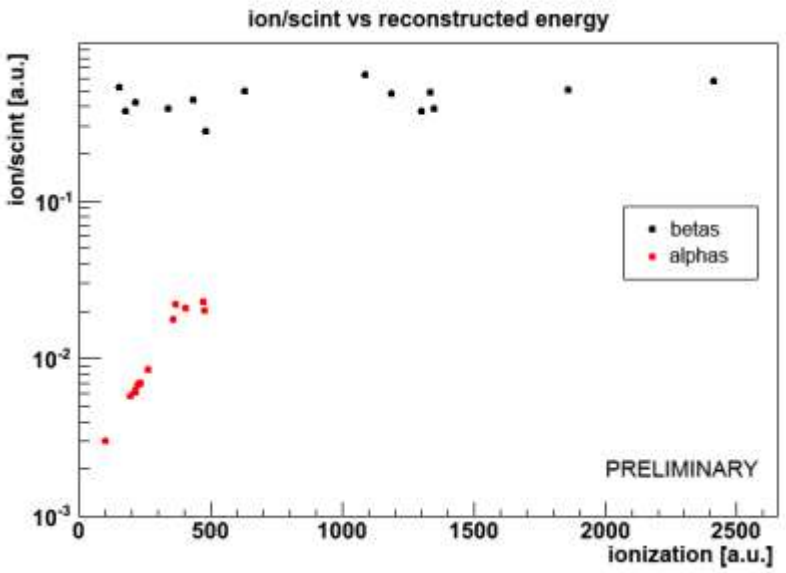
Measuring Kr Concentration in Natural Xenon



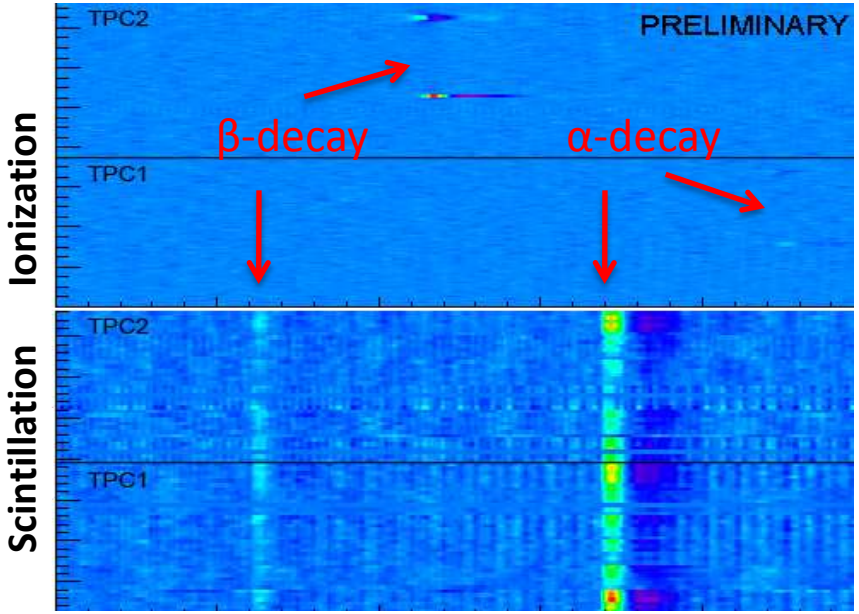
• The ^{85}Kr fraction of the Kr in the detector can be seen in the low energy spectrum (using charge readout only). Spectral shape of data match well with simulation.

• Adjust ^{85}Kr simulation to match the data in the integral from 450keV to the Q value (687keV). Consistent with Mass Spec result of total Kr concentration of $(42.6\pm5.7)\cdot10^{-9}$ g/g in the ^{nat}Xe, and assuming standard ^{85}Kr/Kr concentration of ~10^{-11}

Rn Content in Xenon



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



^{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. Accurate detection efficiency still under study, but the 214Bi decay rate is consistent with expectation before the Rn trap is commissioned.

Expect Enriched Xenon Results soon….

Front shield
& Rn enclosure

Veto counter installed
and commissioned

Low background data taking with enriched Xe started in the spring 2011

EXO-200 Sensitivity Projections

We expect a low but finite radioactive background: 20 events/year in the ±2σ interval centered around the 2.458 MeV endpoint

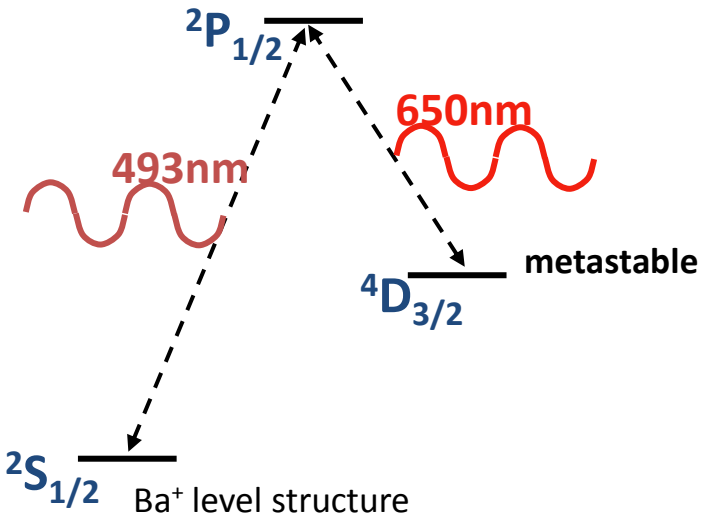
The background from 2νββ will be negligible ($T_{1/2}>1\cdot10^{22}$ yr R.Bernabei et al. measurement)

The expected energy resolution is σ(E)/E = 1.6%

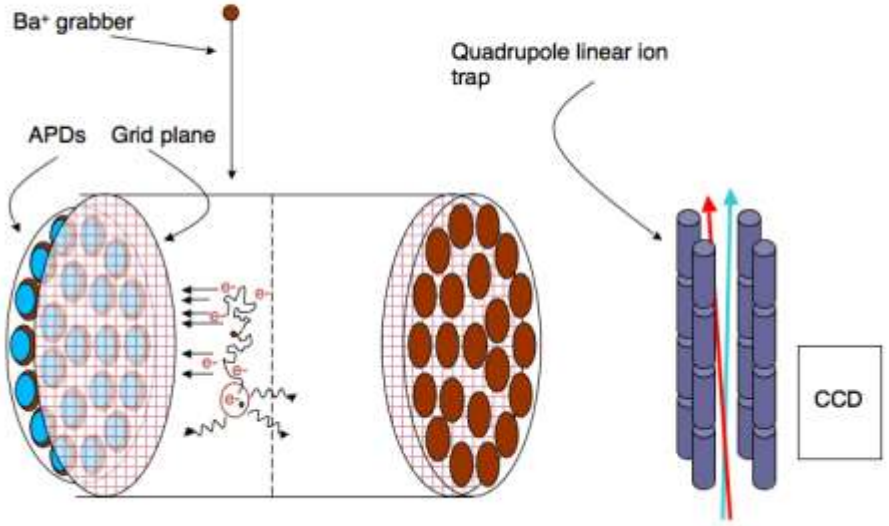
Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu}$ (yr, 90%CL)	Majorana mass (meV) QRPA (NSM)	
EXO200	0.2	70	2	1.6*	40	$6.4*10^{25}$	109[1]	(135)[2]

1. Simkovic et al., *Phys. Rev.* C**79**, 055501(2009); 2. Menendez et al., *Nucl. Phys.* A**818**, 139(2009)

Barium Tagging R&D Summary



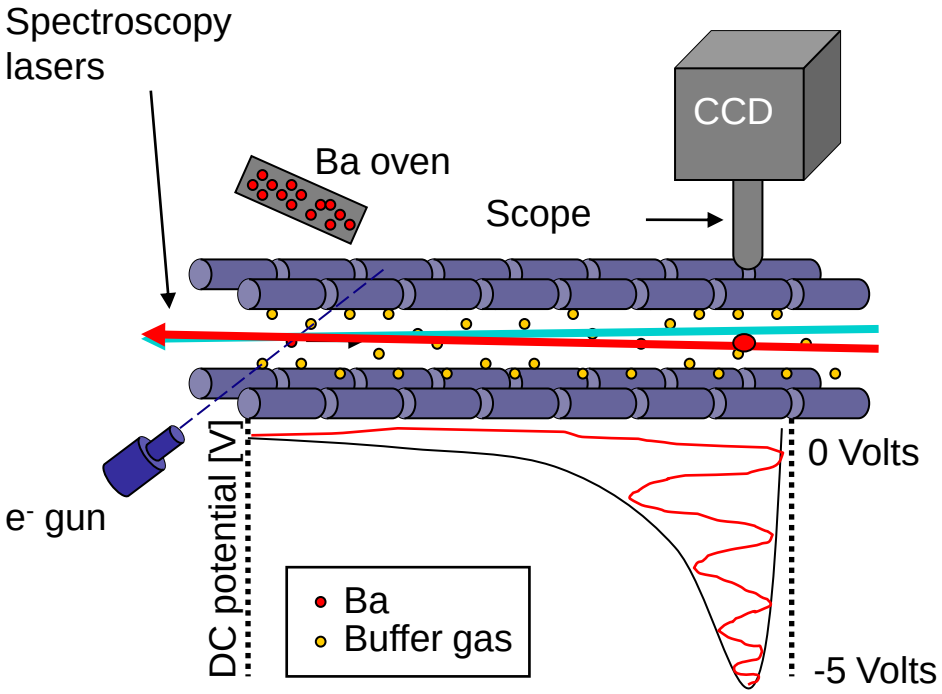
Ba^+ level structure

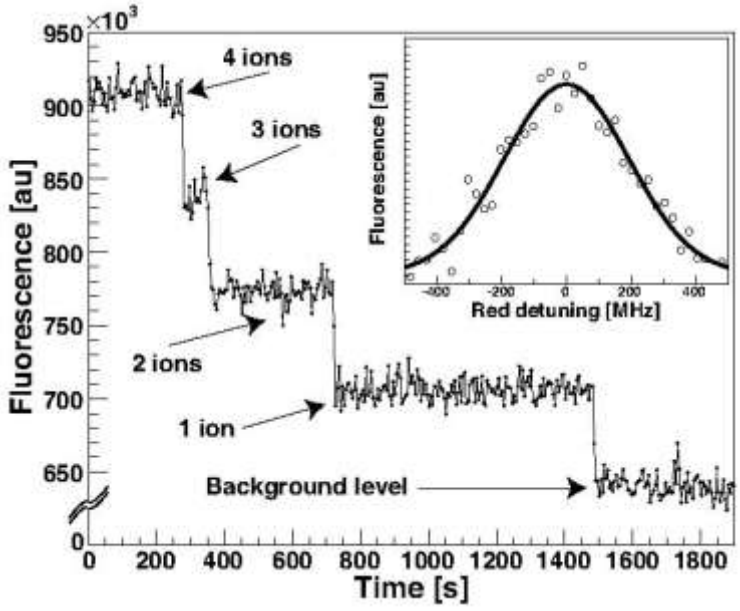


One proposed barium tagging scheme

Method	Summary
RIS probe	Desorb and resonantly ionize Ba from probe tip, then identify with laser spectroscopy in ion trap
Hot probe	Release neutral by heating and ionize with hot surface, then identify with laser spectroscopy in ion trap
Solid Xe probe	Storage and spectroscopy of Ba^+ in Xe ice
Direct tag in liquid	Laser identification of Ba^+ in liquid Xe
Gas Xe extraction	Guide ions from high pressure (10 bar) Xe to low pressure trapping region, then identify with laser spectroscopy

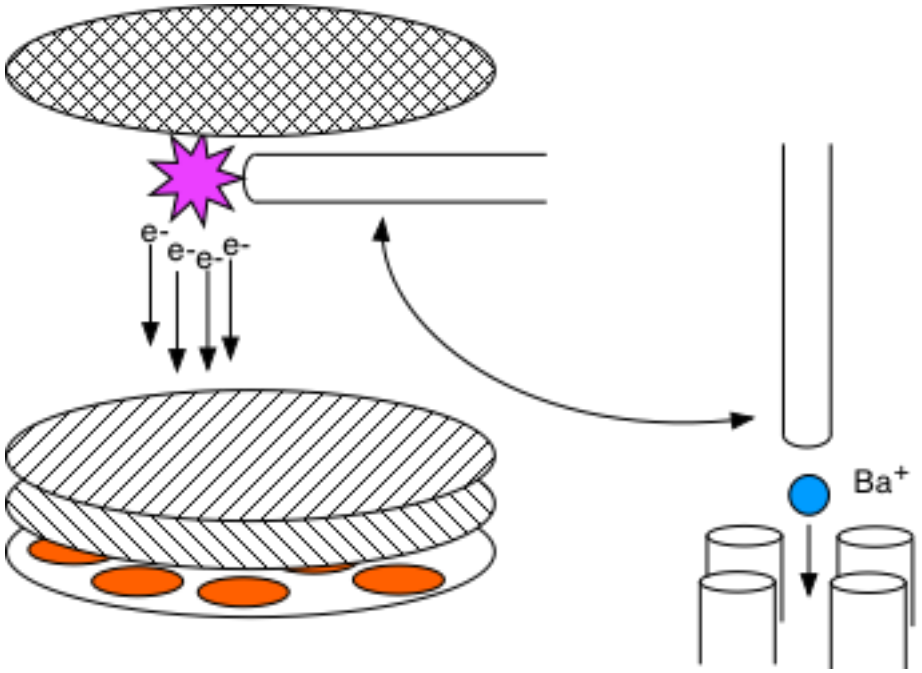
Barium Ion Trapping in Buffer Gas Environment

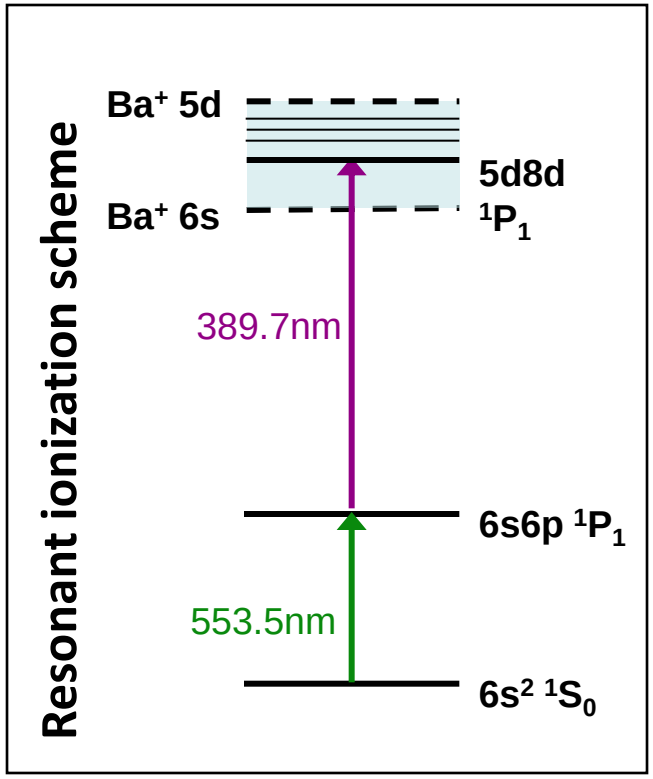




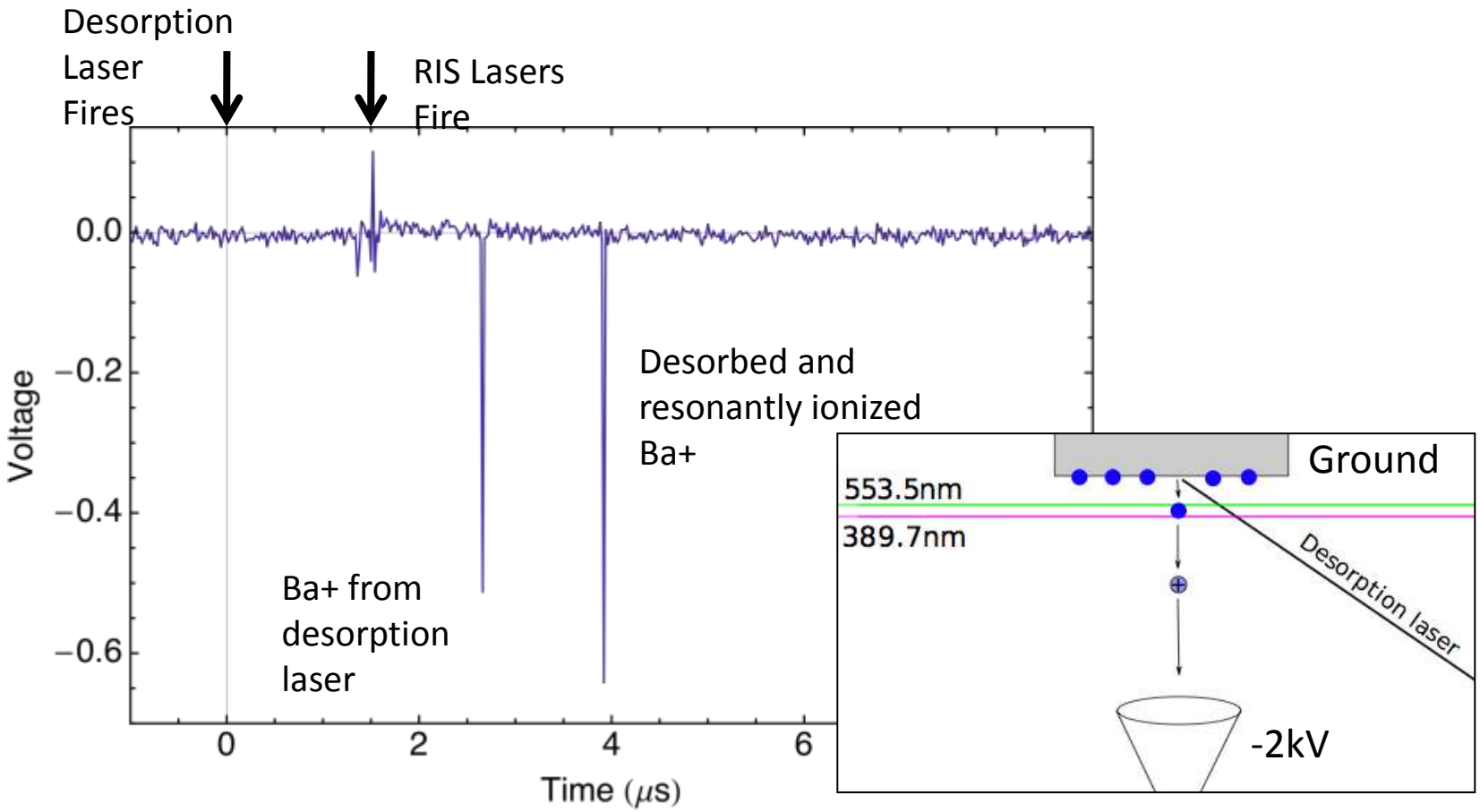
- Have developed techniques for detecting single barium ion in a buffer gas filled ion trap (~ 10^{-3} torr He, some Xe).
- ~ 9σ observation at 25s storage time.
- R&D efforts currently focus on develop a suitable probe to take barium from the liquid xenon bath and deliver it into the ion trap.

Resonance Ionization Spectroscopy as a release technique





RIS Technique Preliminary Results

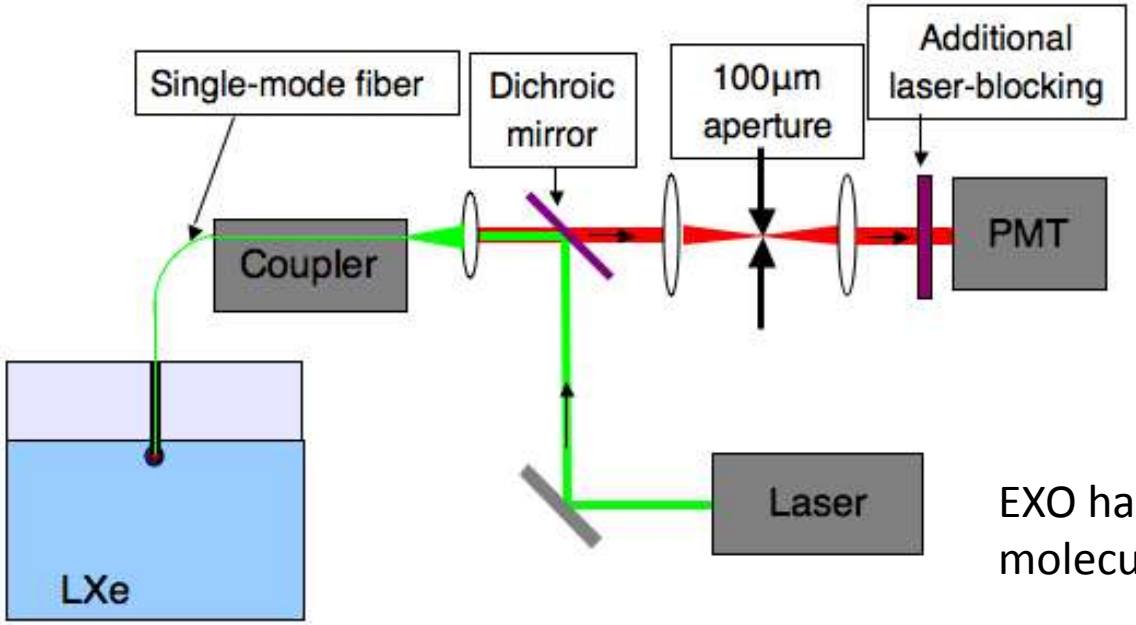


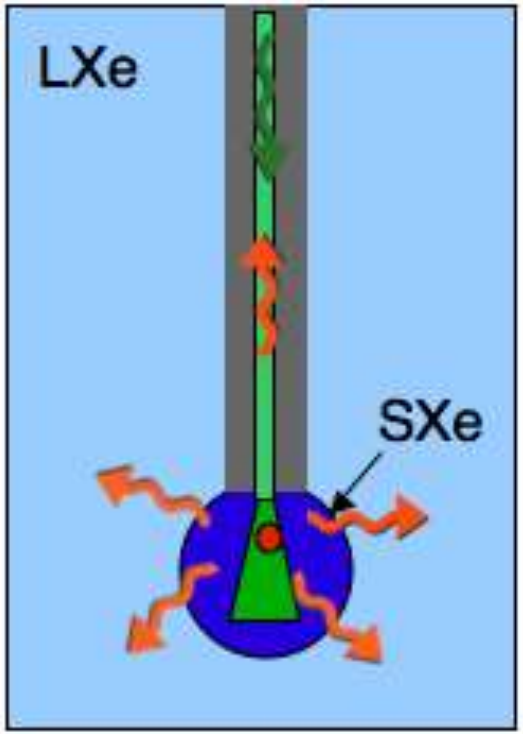
Firing RIS lasers after desorption laser consistently returns barium ions as measuring by time of flight. Absolute efficiency under study.

Detecting Ba while still in LXe

Ions could be trapped in solid xenon frozen on the end of an optical fiber.

The fiber could be used to both illuminate the ion and capture fluorescence from the ion.





EXO has already achieved single dye molecule detection with fiber

Full EXO Sensitivity

Case	Mass (tonne)	Efficiency (%)	Run time (yr)	$\sigma(E)/E$ @ 2.5 MeV (%)	$2\nu\beta\beta$ background (events)	$T_{1/2}^{0\nu}$, 90% C.L. (yr)	Majorana mass (meV)	
							RQRPA[1]	NSM[2]
Conservative	1	70	5	1.6	0.5 (use 1)	2×10^{27}	19	24
Aggressive	10	70	10	1	0.7 (use 1)	4.1×10^{28}	4.3	5.3

1. Simkovic et al., *Phys. Rev.* C**79**, 055501(2009) [g_A= 1.25]; 2. Menendez et al., *Nucl. Phys.* A**818**, 139(2009) [UCOM results]

Assumptions:

- 80% enrichment in ^{136}Xe
- Intrinsic low background and Ba tagging to eliminate all radioactive background
- Energy resolution only used to separate the 0ν from 2ν modes: Select 0ν events in a $\pm 2\sigma$ interval centered around the 2458 keV endpoint
- Use for $2\nu \rightarrow T_{1/2} > 1 \times 10^{22}$ yr (Bernabei et al.)

Conclusions

- All subsystems of EXO-200 are working
- With natural xenon runs, we were able to measure both Kr-85 and Rn contamination inside the xenon.
- Low background physics data taking with enriched xenon has begun, results coming soon.
- R&D efforts for barium tagging techniques have shown promising initial results.

Stay Tuned….

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