Neutrinoless Double Beta Decay

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Nov 22, 2015

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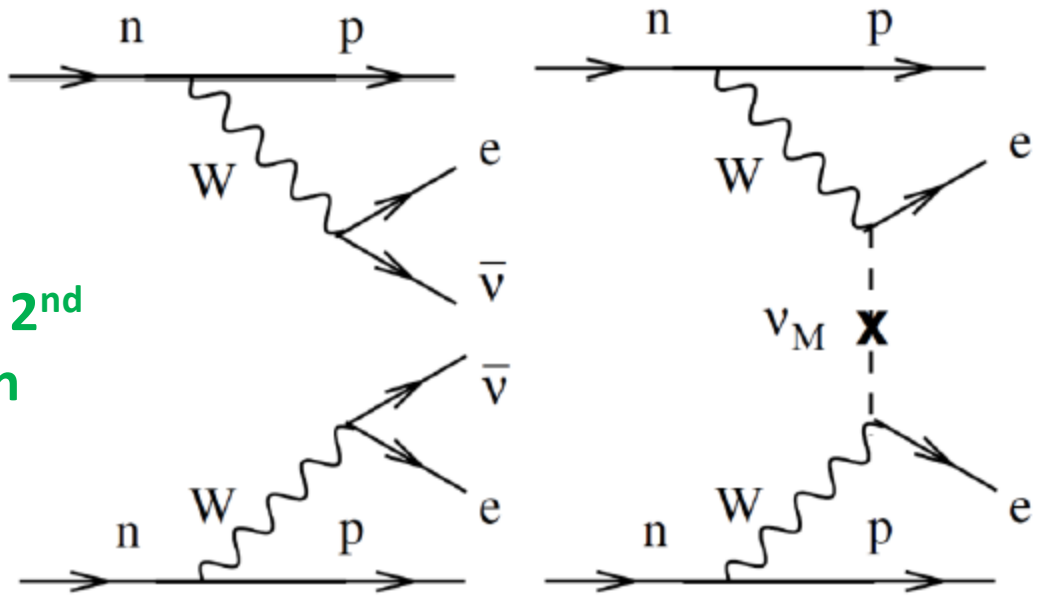
Double Beta Decay

2ν mode:

A conventional 2nd order process in nuclear physics



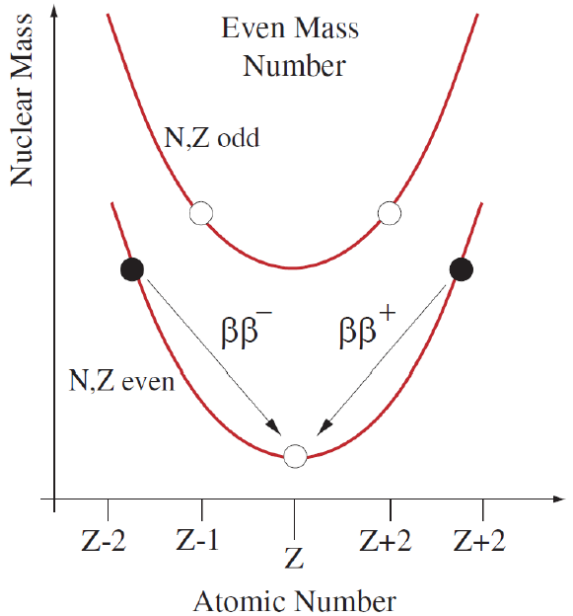
0ν mode:

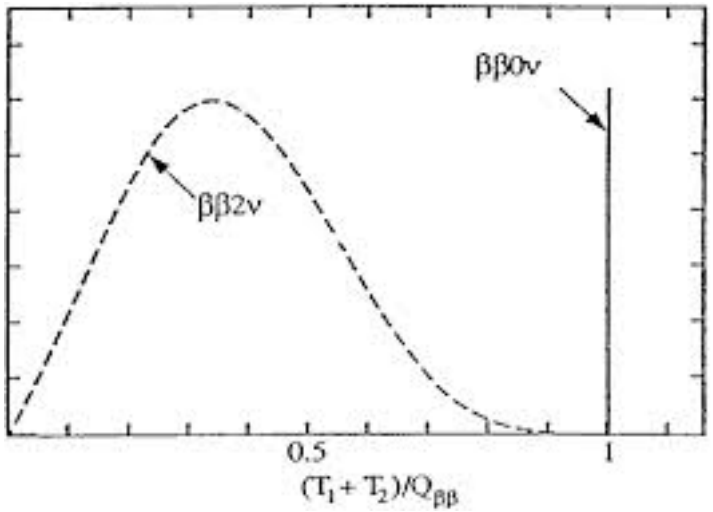
A hypothetical process that can happen only if:

$M_\nu \neq 0$, $\nu = \nu$

$|\Delta L|=2$,

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





An active and competitive community

Enriched Xenon Observatory
EXO
for double beta decay

Zero neutrino double beta decay search
KamLAND-Zen

nEXT

PANDA X

^{136}Xe

ββ
GERDA

^{76}Ge

CUORE

^{130}Te

supernemo
collaboration

^{82}Se
(^{130}Te, ^{116}Cd, ^{48}Ca, ^{96}Zr, ^{150}Nd, ^{100}Mo)

SNO+

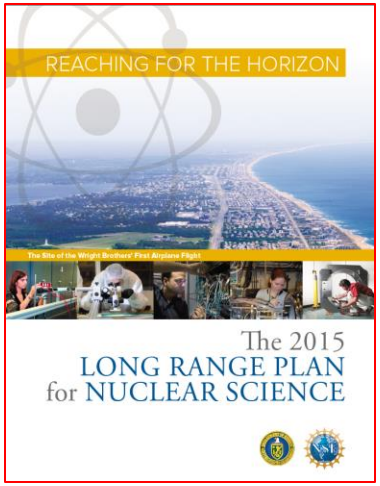
^{130}Te

LUCIFER

, ...

Ton-scale Neutrinoless Double Beta Decay (0νββ) - A Notional Timeline

Search for Lepton Number Violation



Current generation experiments

NSAC 0νββ decay Subcommittee

R&D: Pre-technology selection

R&D & Project Eng.: Post-technology selection

Ton-scale Construction

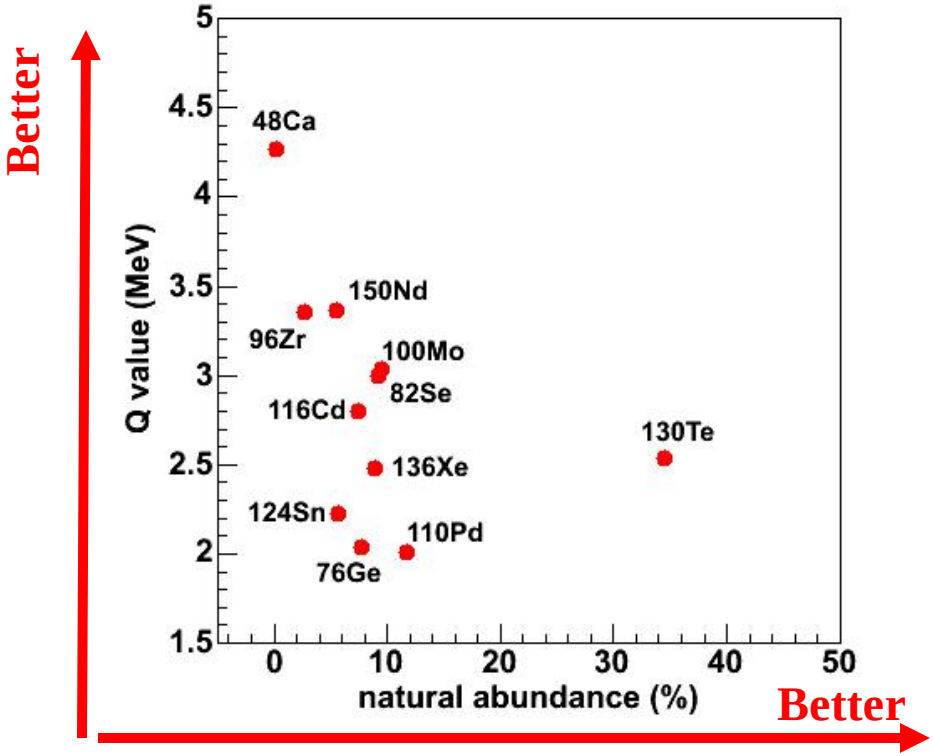
Data Taking

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

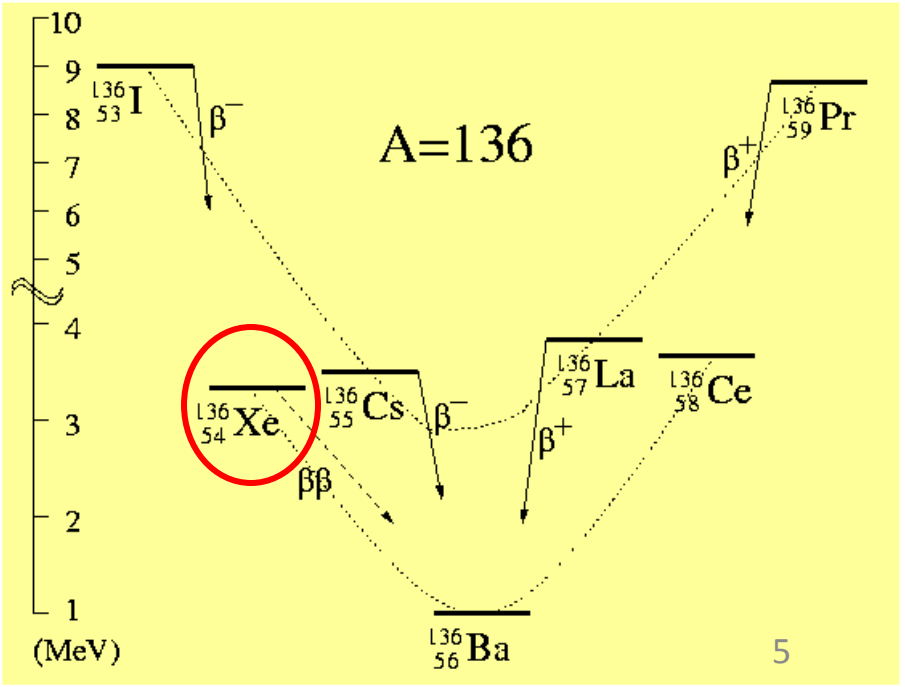
Ton-scale Milestones → Mission Decision → Technology Selection → Construction → Data

Xenon is ideal for a large $0\nu\beta\beta$ experiment

- More scalable. e.g, no need to grow crystals
- Can be re-purified during the experiment
- No long lived Xe isotopes to activate



- Can be easily transferred from one detector to another if new technologies become available
- Noble gas: easy(er) to purify
- ^{136}Xe enrichment easier and safer.
  - ✓ noble gas (no chemistry involved)



Keys in DBD Experiments

Sensitivity

N_B = number of background counts in the ROI along the measure time

$N_B \gg 1$

$$S_{1/2}^{0\nu} \propto \epsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot t_{meas}}{bkg \cdot \Delta E}}$$

$N_B \leq O(1)$ → "zero

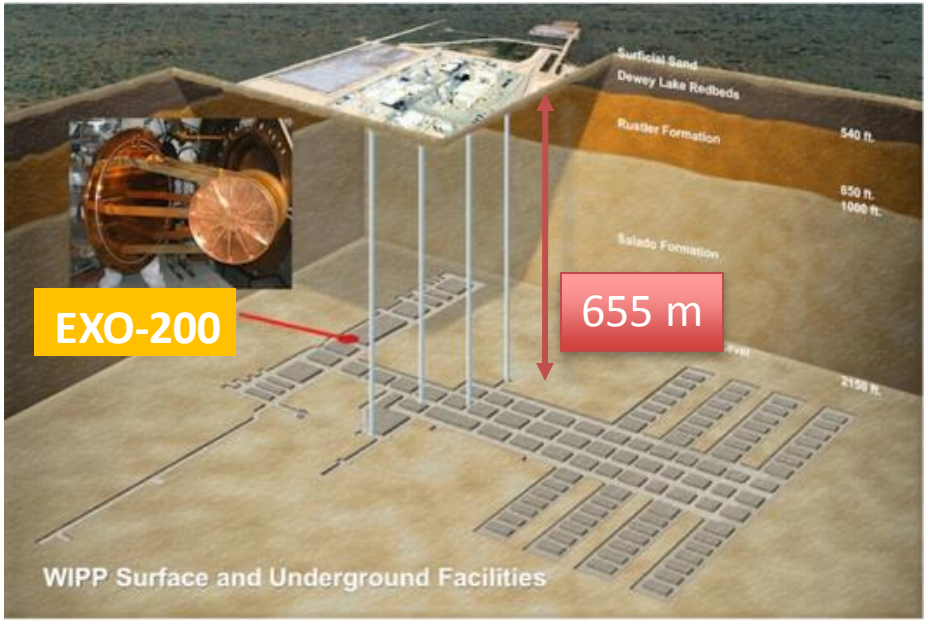
$$S_{1/2}^{0\nu} \propto \epsilon \frac{i.a.}{A} M \cdot t_{meas}$$

- t_{meas} measuring time [y]
- ☆ **M** detector mass [kg]
- **ε** detector efficiency
- ☆ **i.a.** isotopic abundance
- **A** atomic number
- ★ **ΔE** energy resolution [keV]
- ★★ **bkg** background [c/keV/y/kg]

- For "background-free" experiment → factor of 50 in $T_{1/2}$ needs factor of 50 in M
- For experiment with background → factor of 50 in $T_{1/2}$ needs factor of 50 in M

EXO Enriched Xenon Observatory

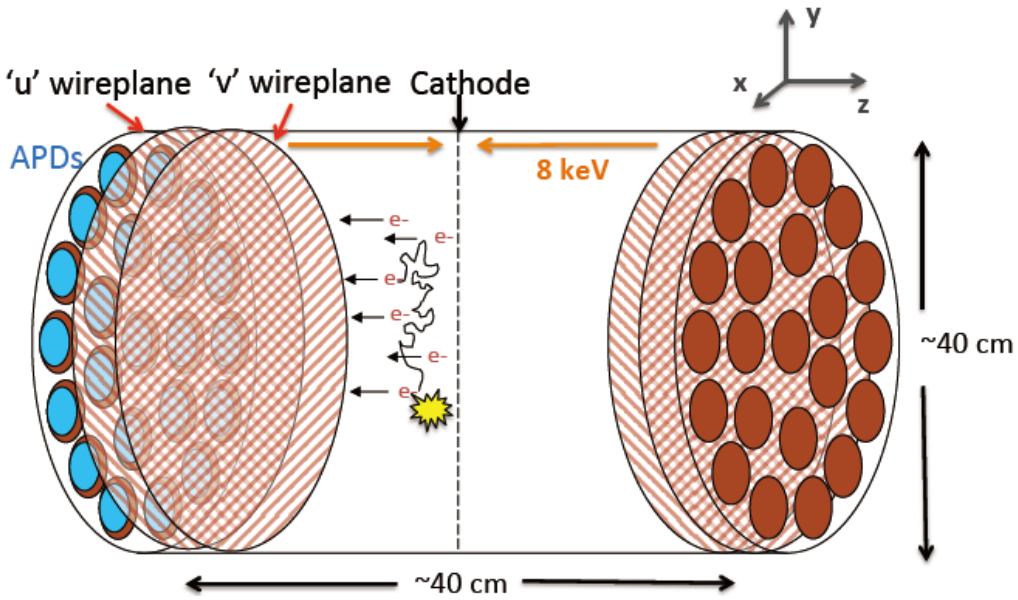
- Liquid Xe Time Projection Chamber (TPC)
- Enriched ^{136}Xe to 80.6%
- Q-value 2458 keV
- Located at Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM, USA



Liquid Xenon – Decent Resolution

- **Energy meas.** → Combine Light and Ionization

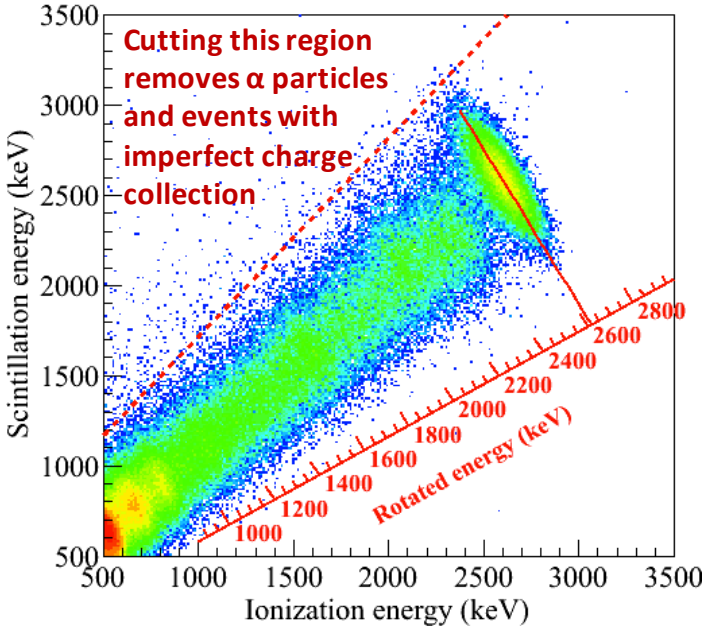
*E. Conti et al. Phys. Rev. B 68 (2003) 054201

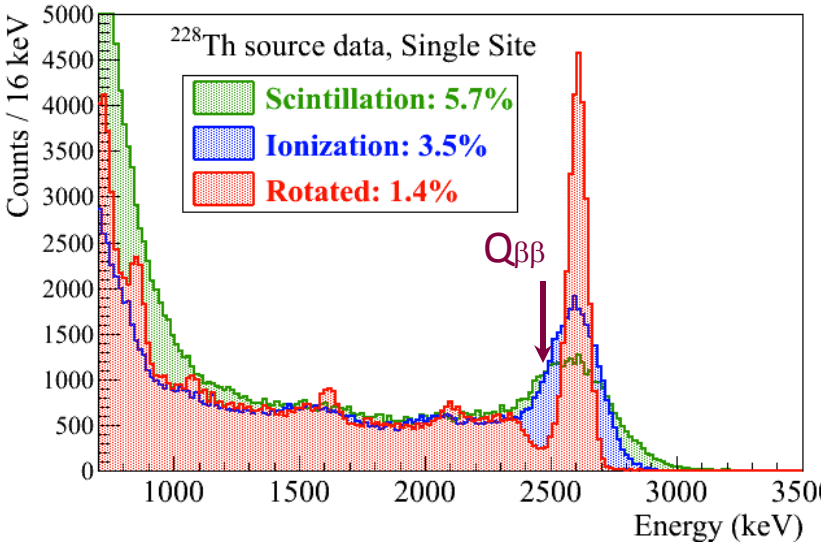


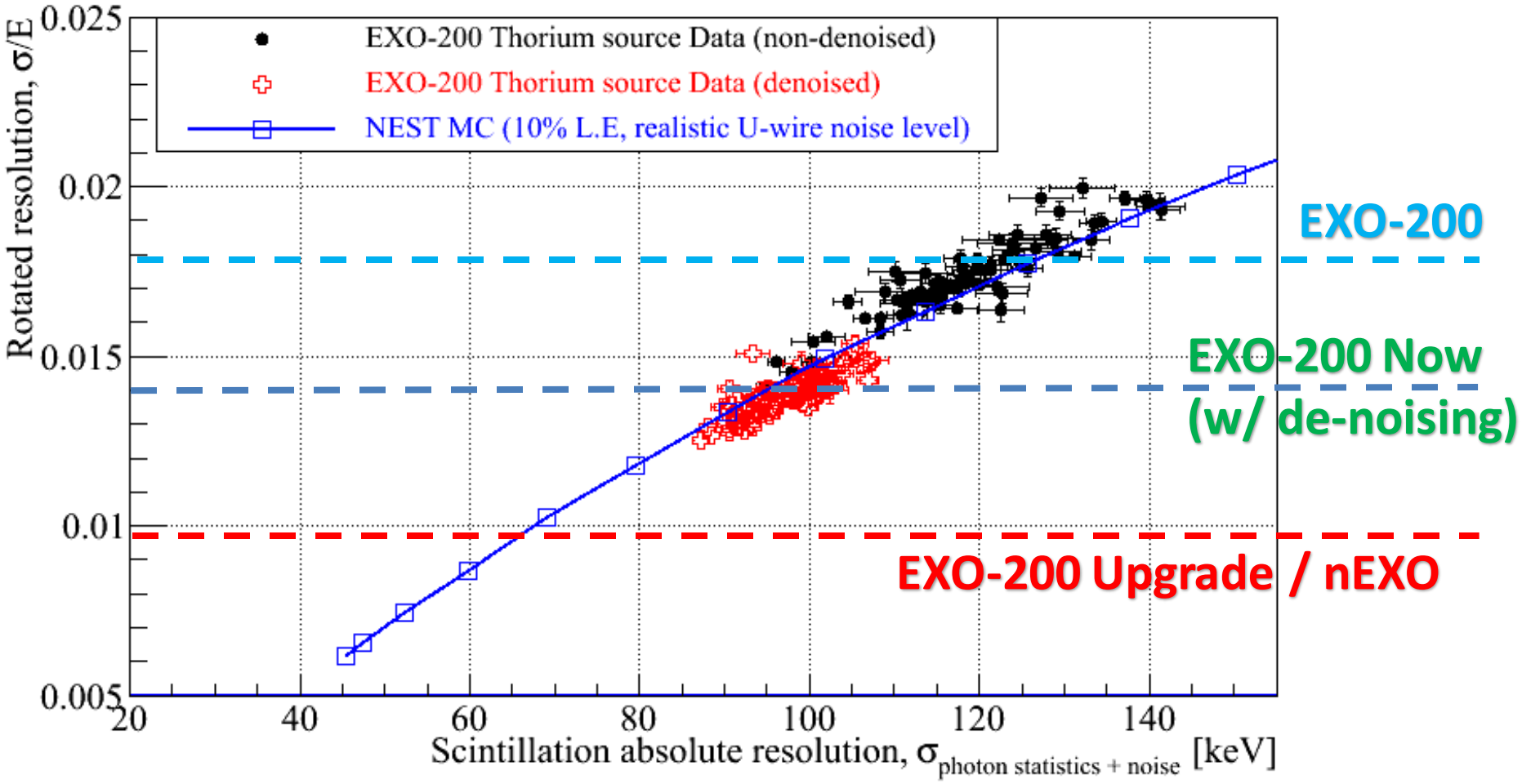
Schematic plot of **EXO-200** Time Drift Chamber

Current EXO-200: 1.4% @ 2.615 MeV

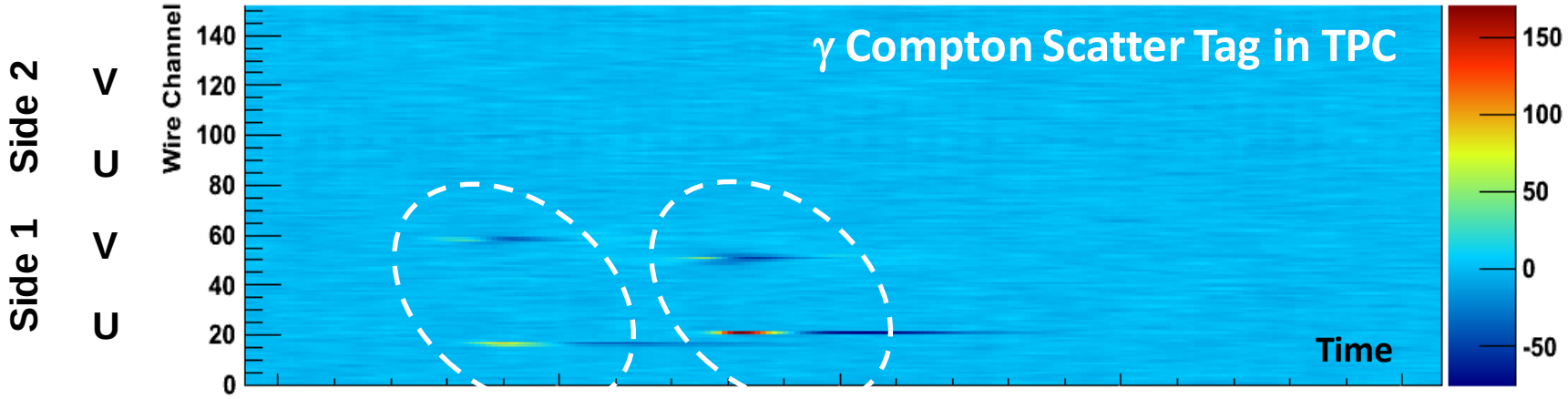
Future nEXO project: <1% (low noise electronics)

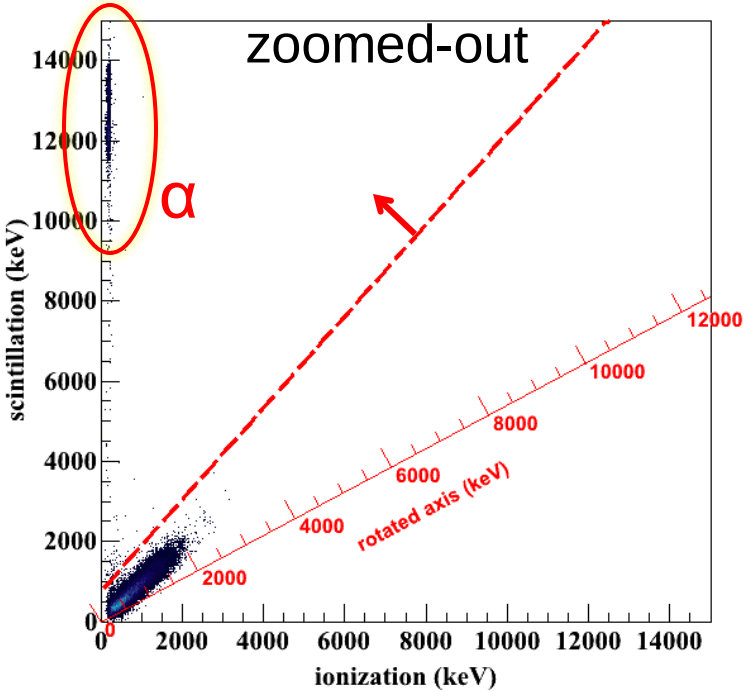


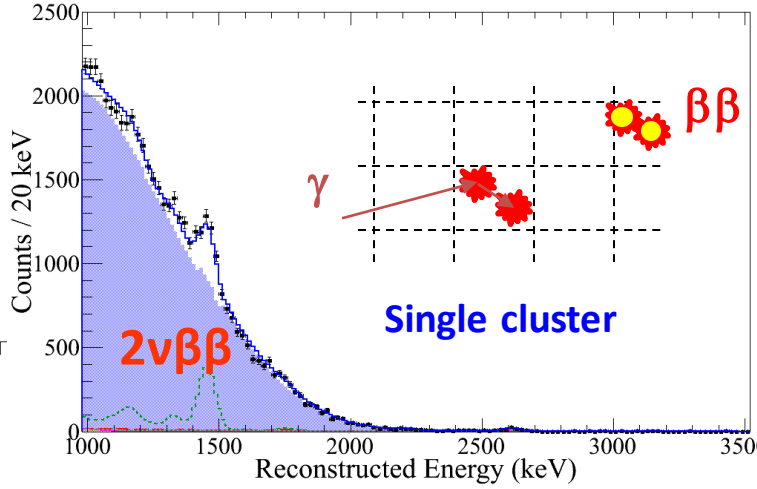


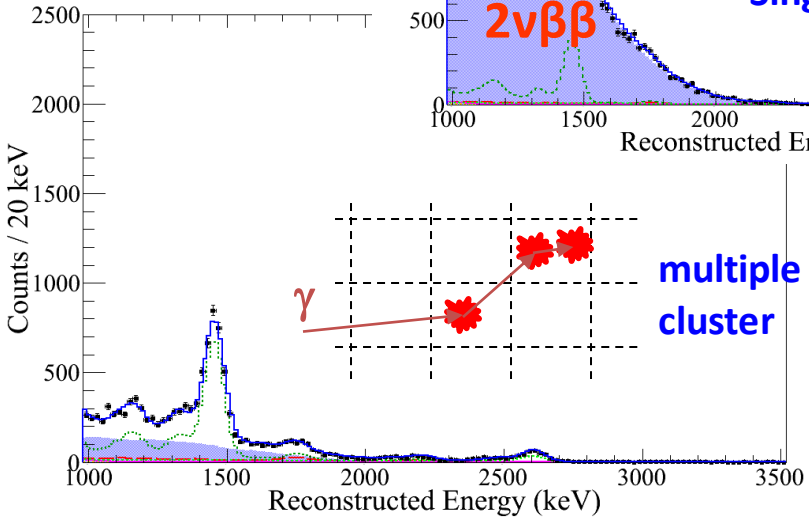

EXO-200 Thorium source Data (non-denoised)
EXO-200 Thorium source Data (denoised)
NEST MC (10% L.E, realistic U-wire noise level)
Rotated resolution, σ/E
0.025
0.02
0.015
0.01
0.005
20
40
60
80
100
120
140
Scintillation absolute resolution, σ photon statistics + noise [keV]
EXO-200
EXO-200 Now
(w/ de-noising)
EXO-200 Upgrade / nEXO

Liquid Xenon – NOT A Pure Calorimeter

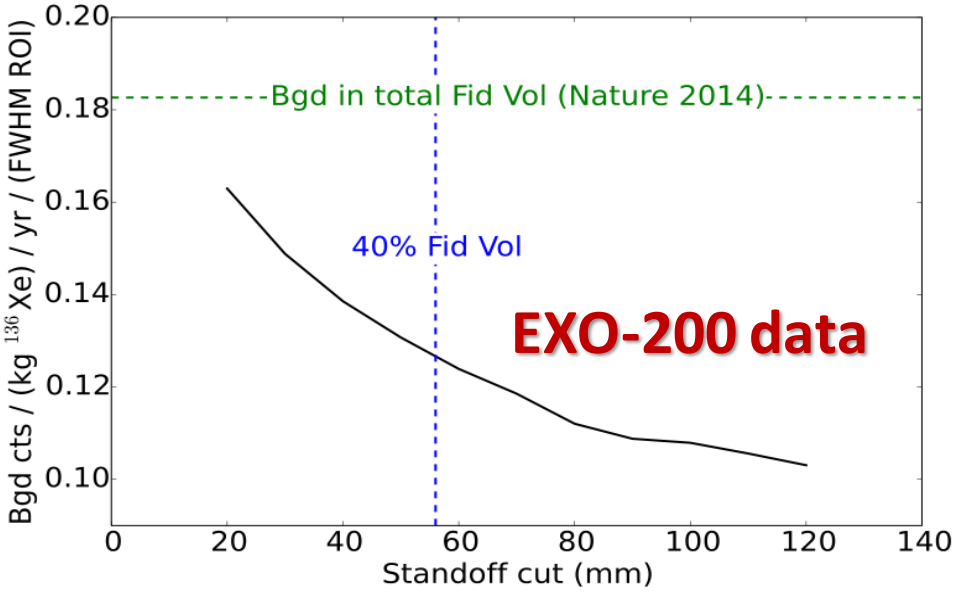


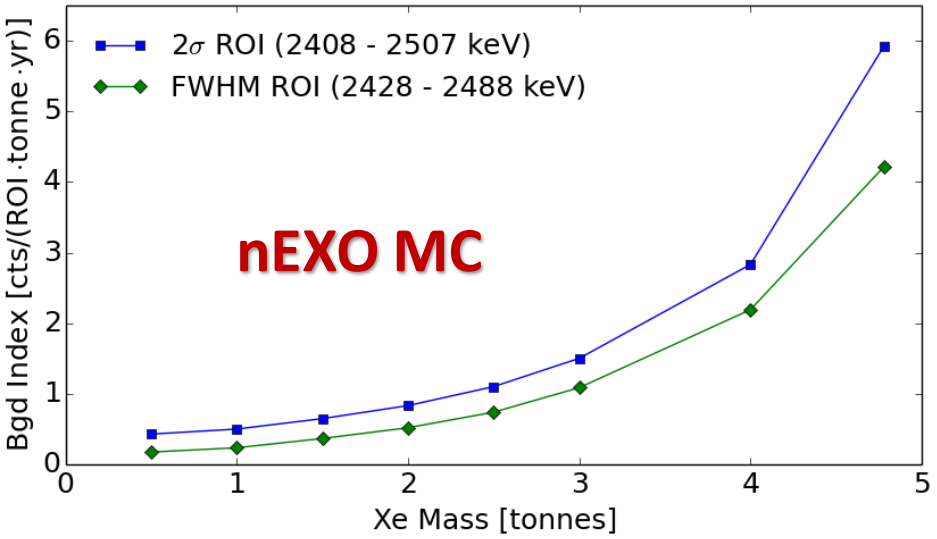


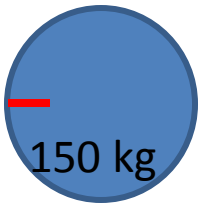




Liquid Xenon – Homogeneity is Essential

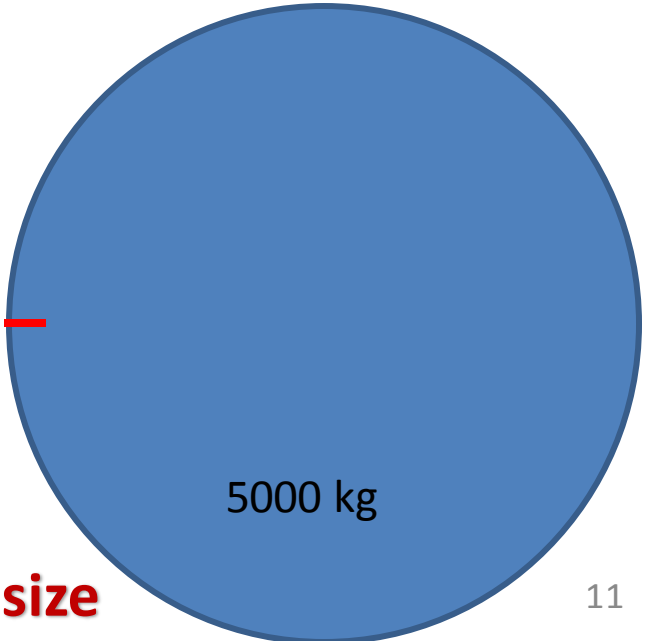






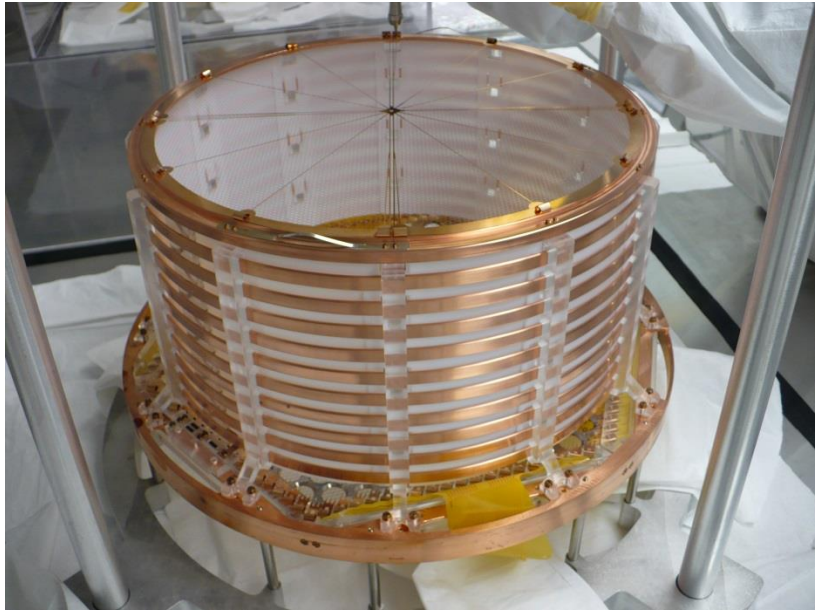
~EXO-200 size

2.5MeV γ attenuation length (8.5cm)

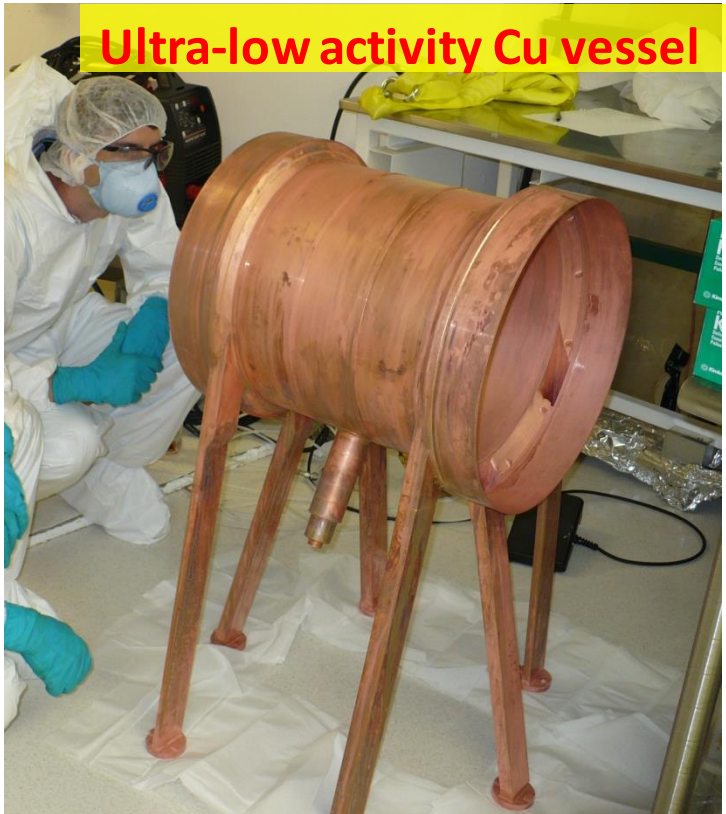


~nEXO size

~500 “Bare” LAAPD



Ultra-low activity Cu vessel



Material radioactivity qualification

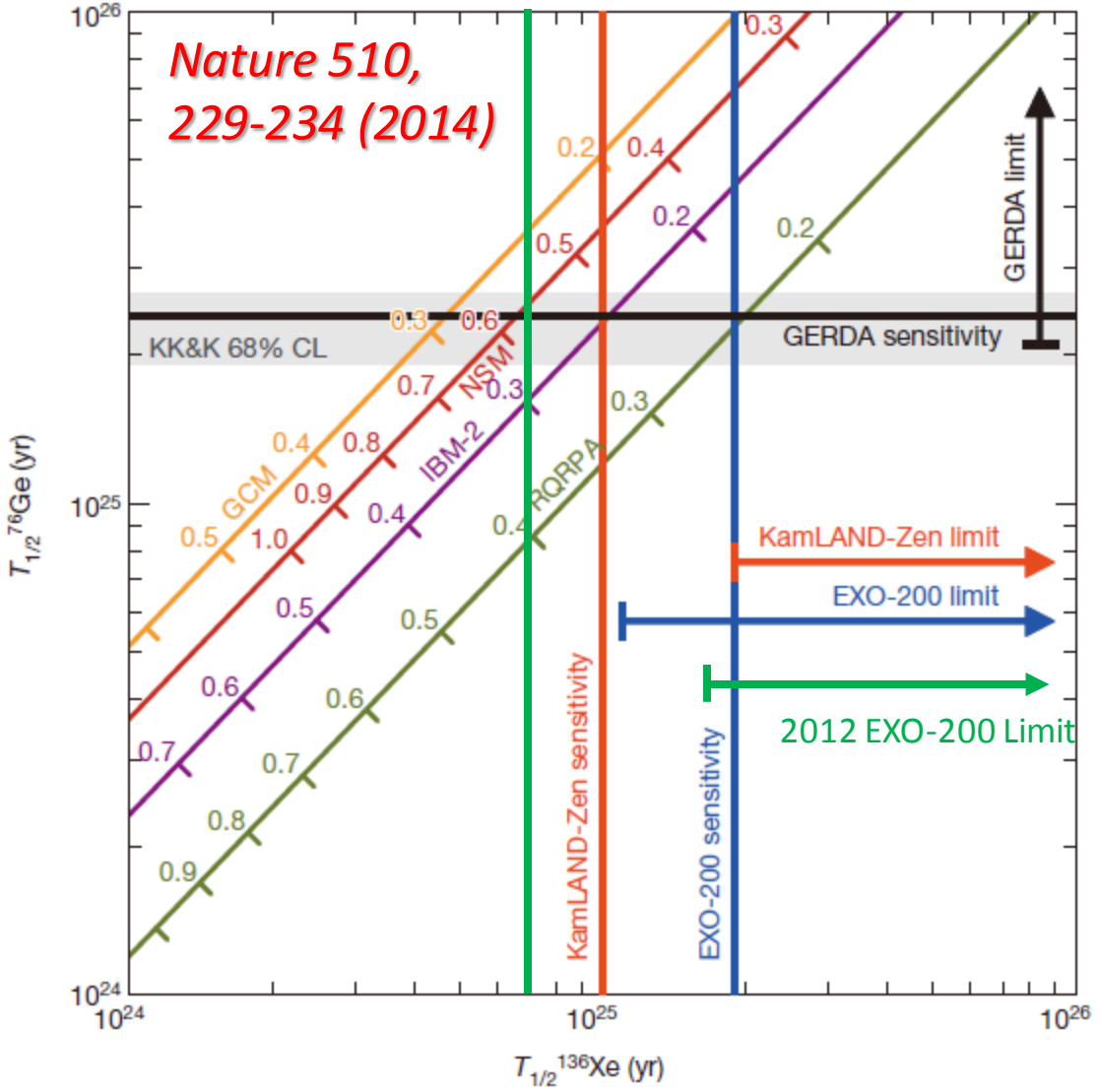
- Neutron Active Analysis
- Low background γ-spectroscopy
- α-counting
- Radon counting
- High performance GD-MS and ICP-MS

(D.S. Leonard et al., Nucl. Ins. Meth. A 591, 490(2008))

The impact of every screw within the Pb shielding is evaluated before acceptance

→ Goal: 40 cnts/2yr in the 0νββ ±2σ ROI in 140kg of LXe

Search for 0νββ Search of ^{136}Xe



EXO-200 limit:

$T_{1/2}^{0\nu\beta\beta} > 1.1 \times 10^{25}$ yr (90%CL)

$\langle m_{\beta\beta} \rangle < 190 - 450$ meV

EXO-200 $T_{1/2}^{0\nu\beta\beta}$ sensitivity: $1.9 \cdot 10^{25}$ yr

[Nature, 510, 229-234 (2014)]

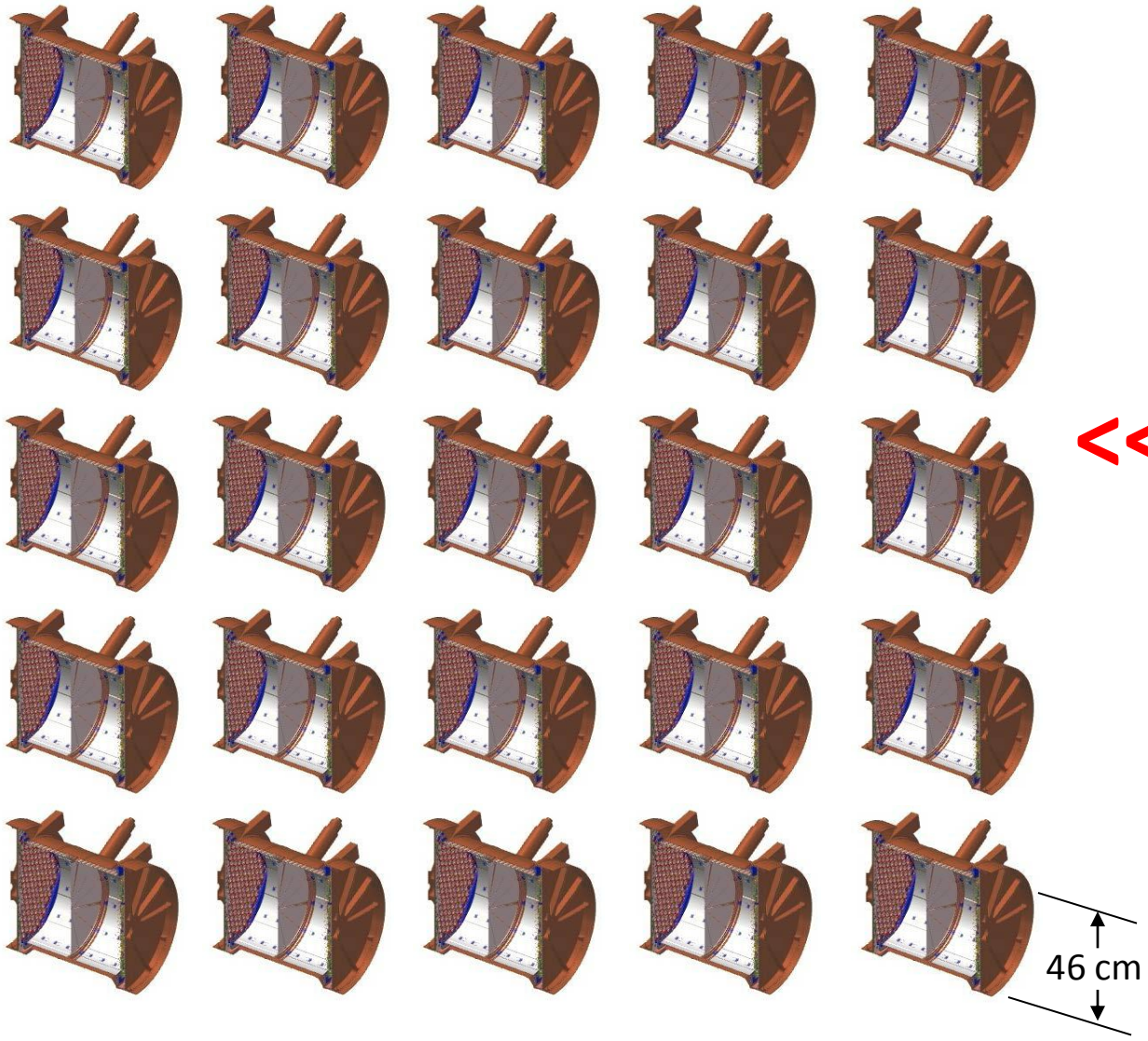
[GERDA: PRL 111, 122503 (2013)]

[KL-Zen: PRL 110, 062502 (2013)]

[PRL 109, 032505 (2012)]

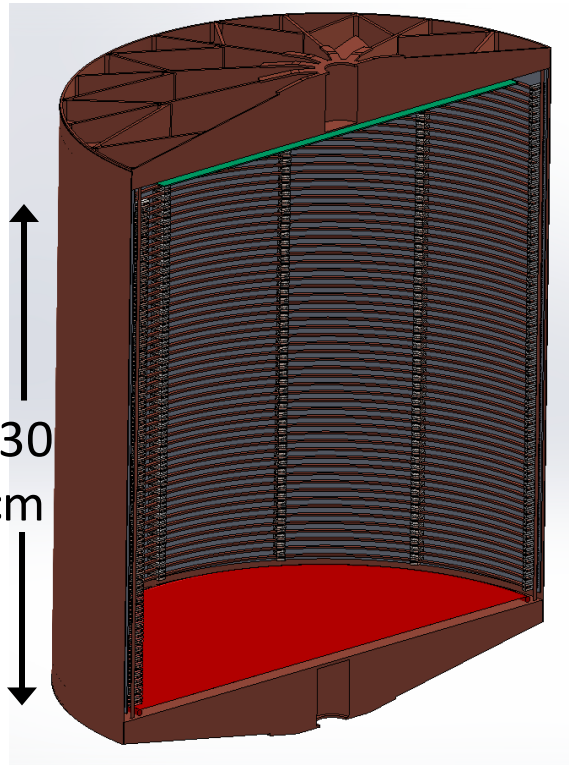
KK&K Claim: Mod. Phys. Lett., A21 (2006) 1547

Ton-scale LXe Experiment



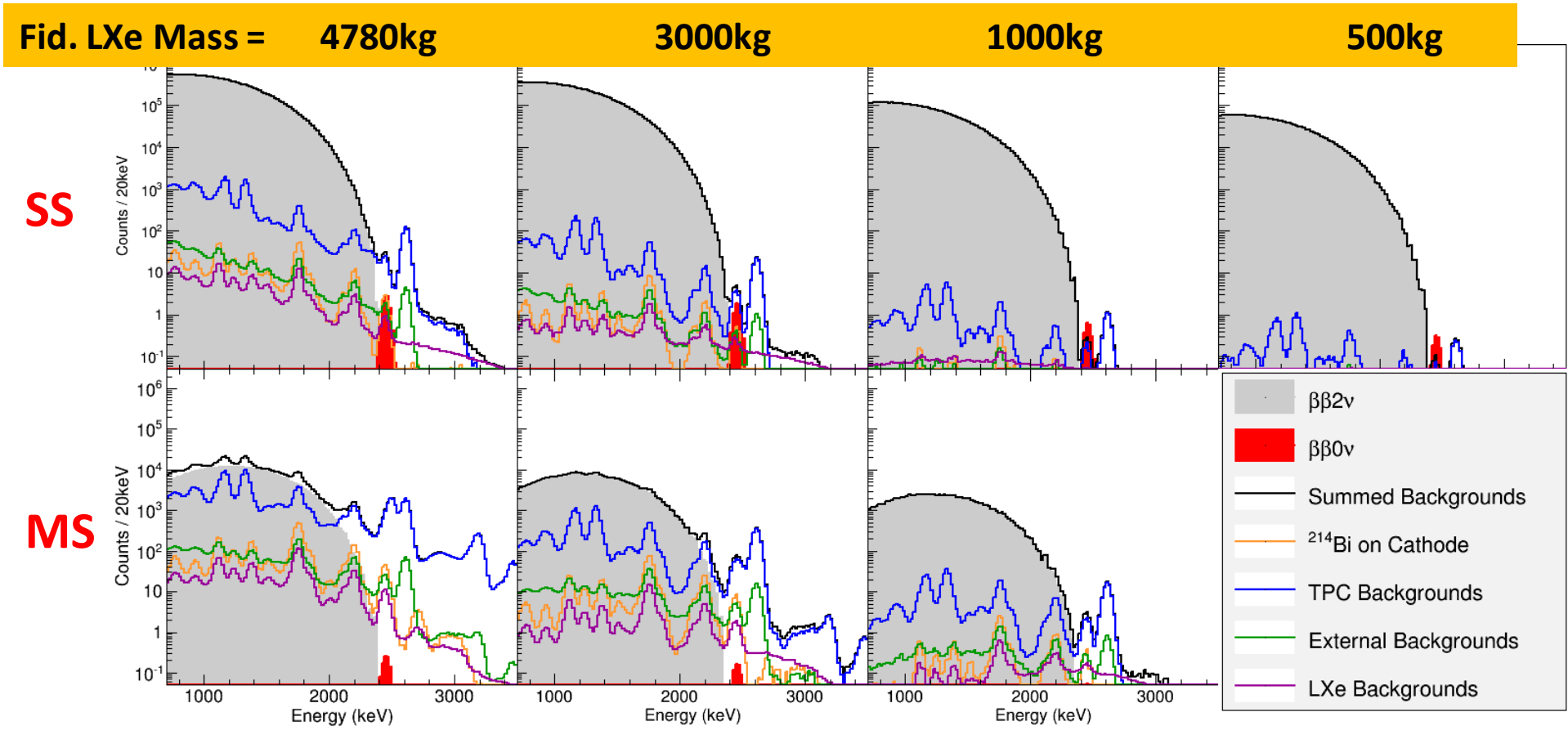
25 * 200 kg

<<



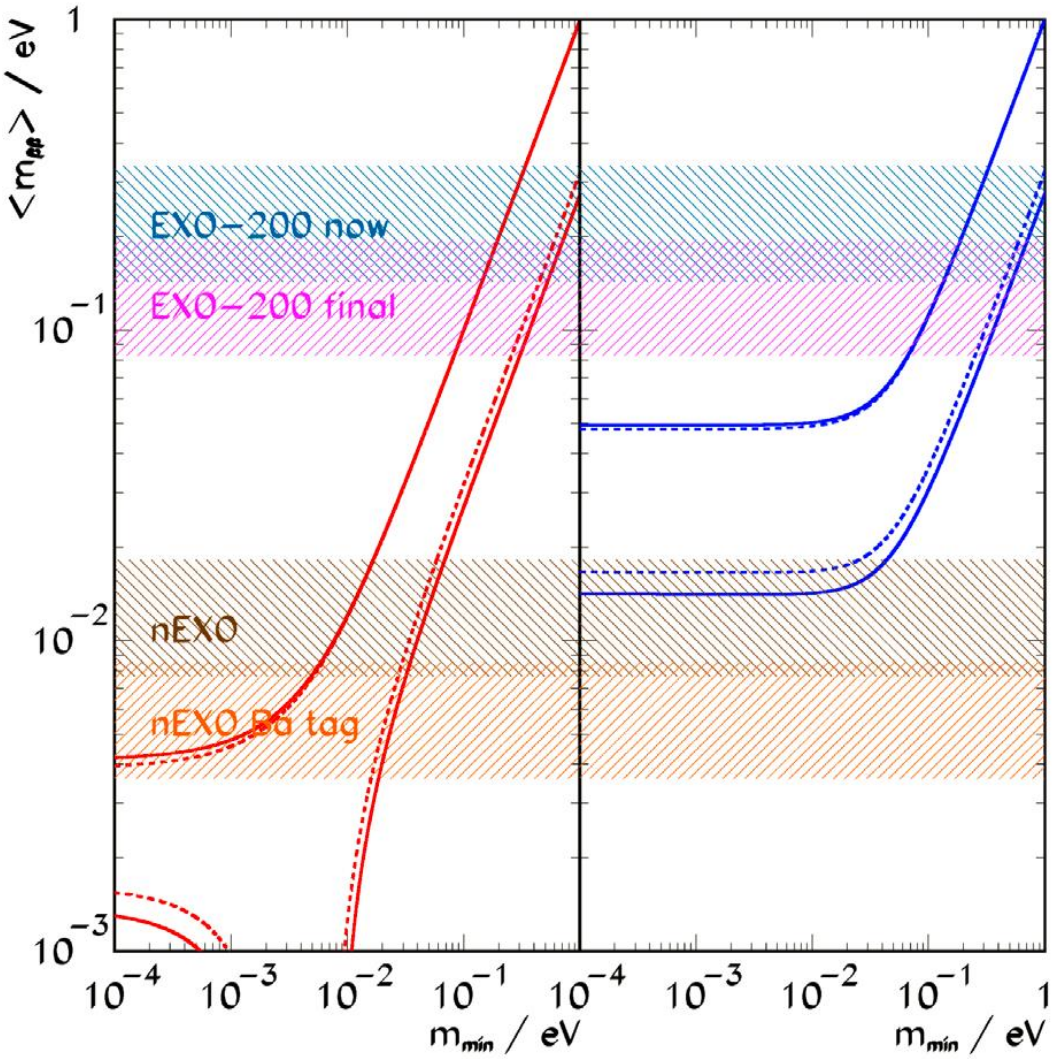
~5 ton

SS/MS spectra in nEXO



Example: nEXO, 5 yr data, 0νββ @ $T_{1/2}$=6.6x10^{27} yr, projected backgrounds from subsets of the total volume

nEXO Sensitivity



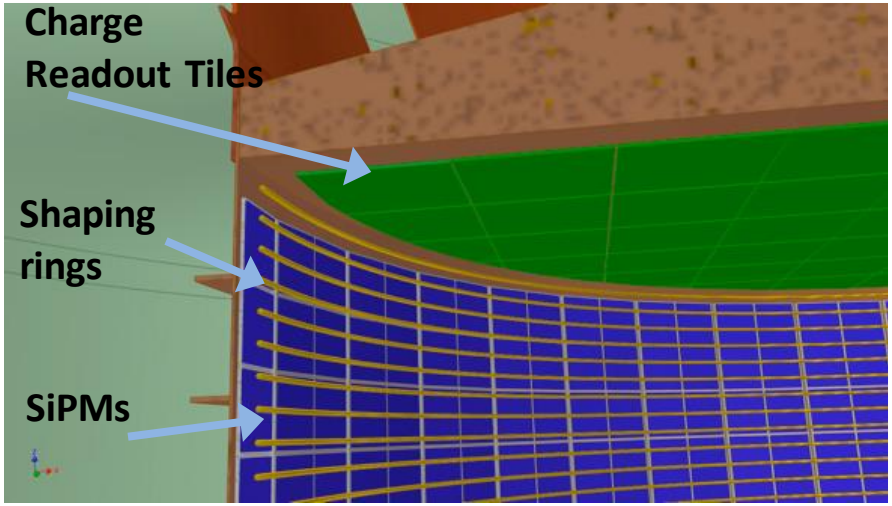
nEXO 5 yr 90% CL sensitivity: $T_{1/2} > 6.6 \cdot 10^{27}$ yr

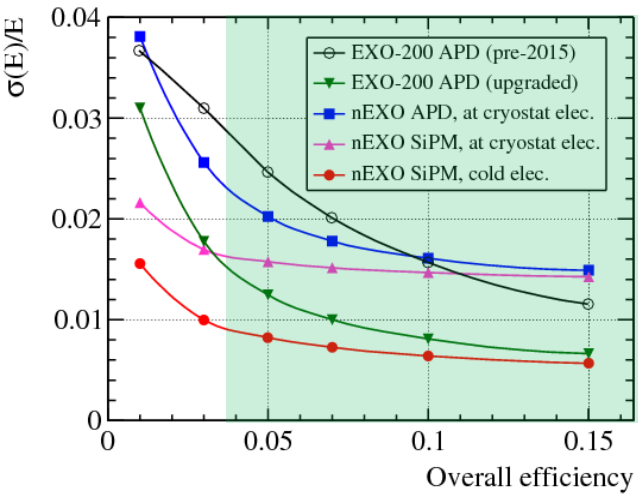
NH and IH bands are also 90%CL

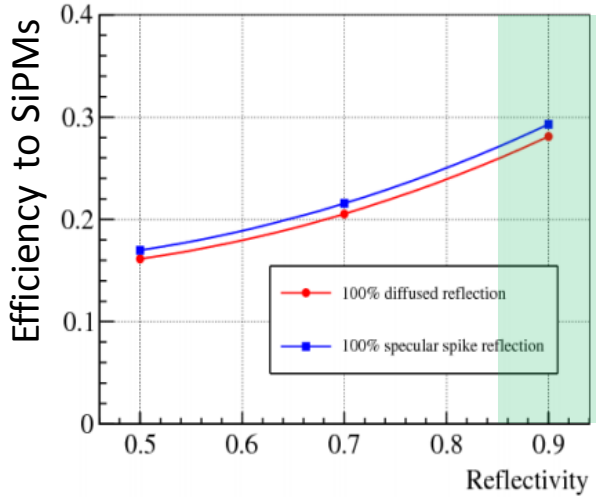
Forero et al., PRD 90 (2014) 093006
Forero et al., Private Comm.

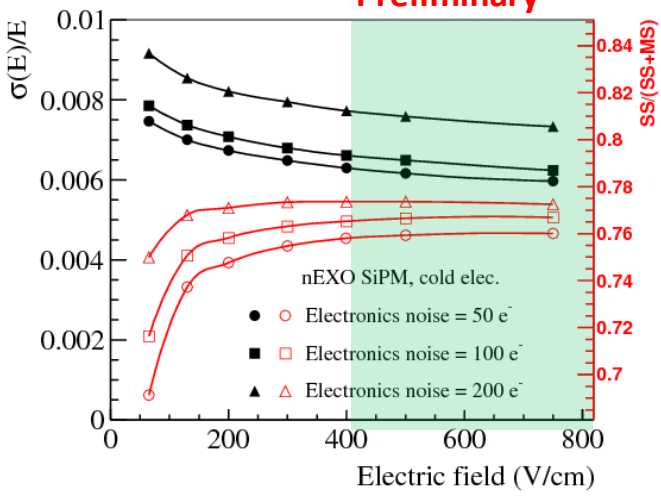
Photodetector

- Extensive MC *(NEST)* studies
  - Light collection efficiency
  - Operation field
  - Noise from SiPM sensor
  - Readout Electronic Noise, threshold effect





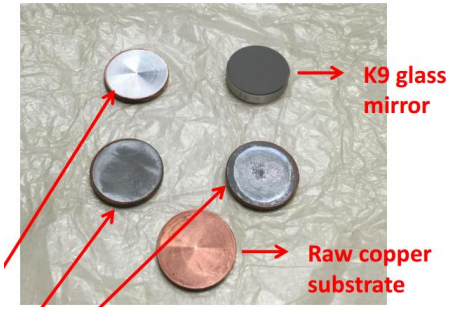


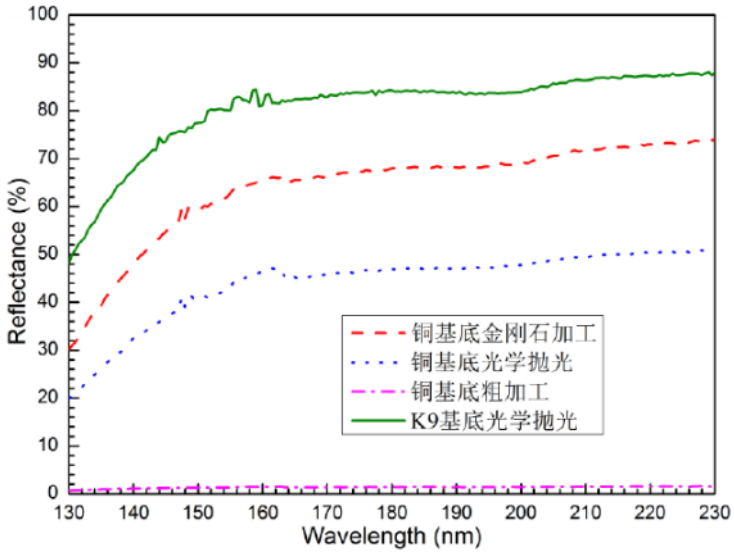


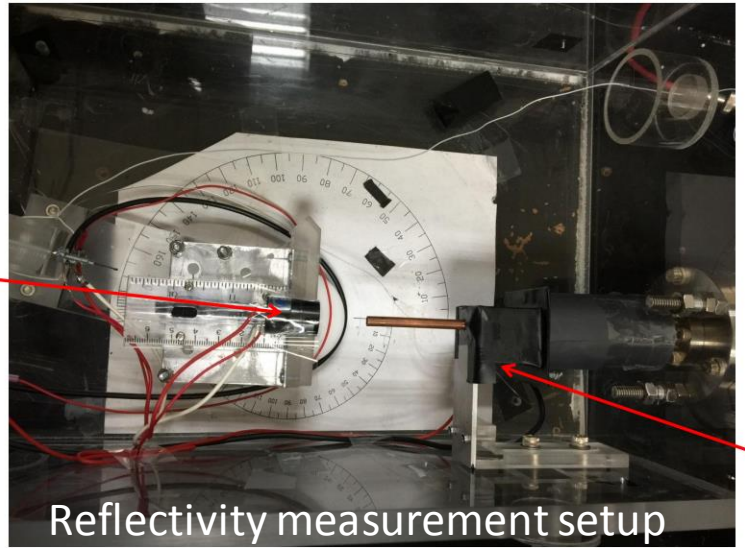
SiPMs D.E ~ 15%@175nm

Mirror R&D

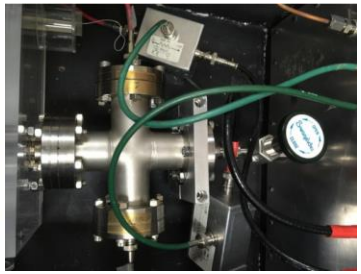
- Teflon (used on EXO-200)
  - Outgassing, LXe purity issue
  - Charge build-up
- Al + MgF_2 *(LiF, AlF, etc)* on OFHC
  - ~1.2m cathode, shaping rings
  - Challenge: large coating machines, radio-purity







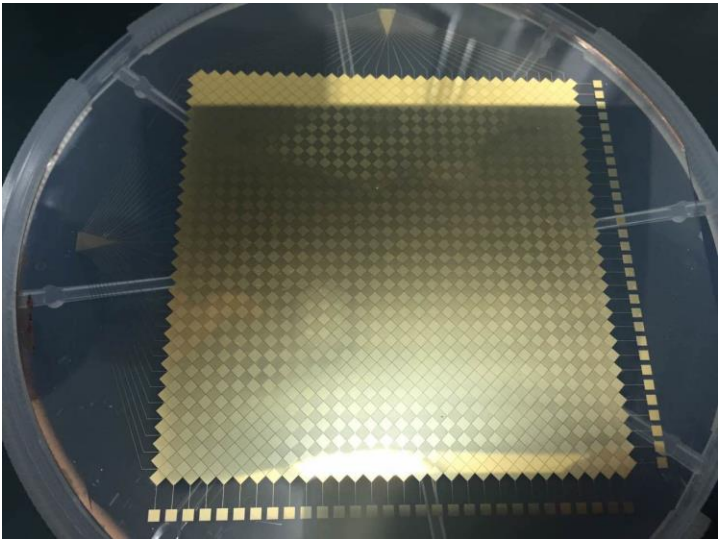
GXe light source

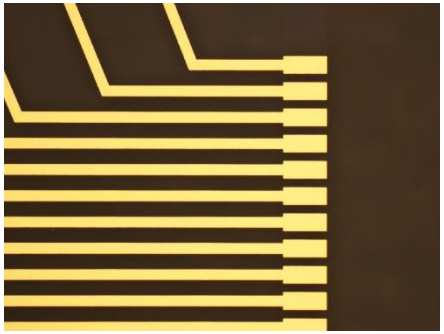


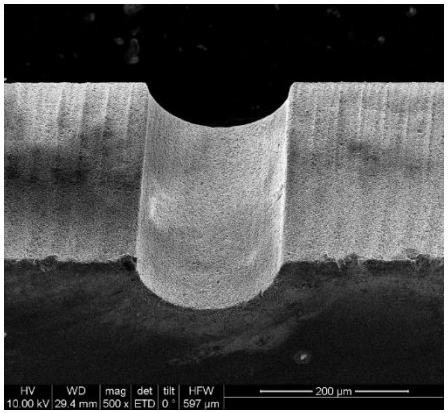
PMT under collimator for monitoring

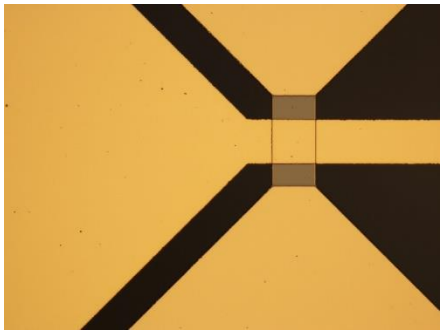
Charge Readout Tile

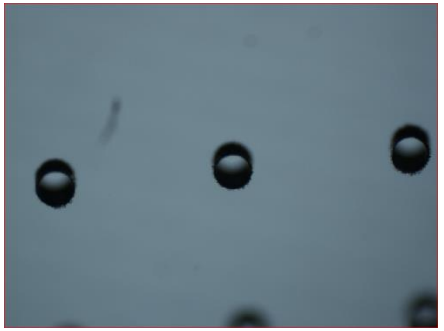
- Ultra-low background, low noise charge readout tile
  - X- and Y- chain of small pads
  - 2μm SiO_2 layer between X-, Y- crossing
  - Pad size: 3mm diagonal, can be optimized
  - (Cu + Ni/Au) or Au
  - Metalized vias



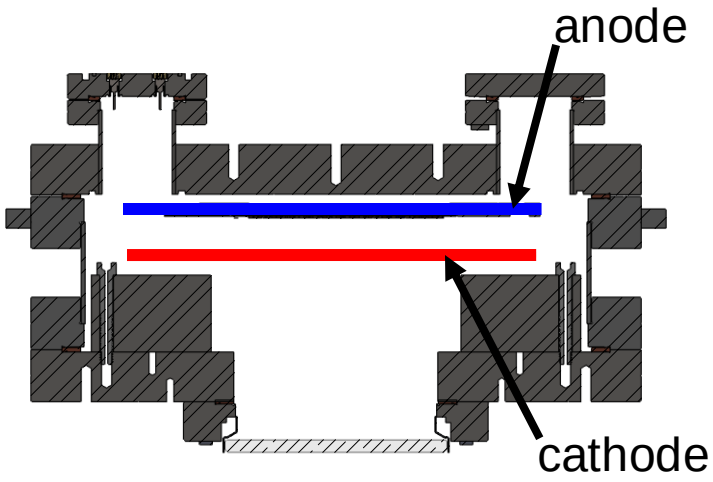






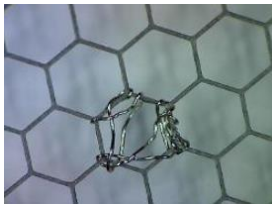


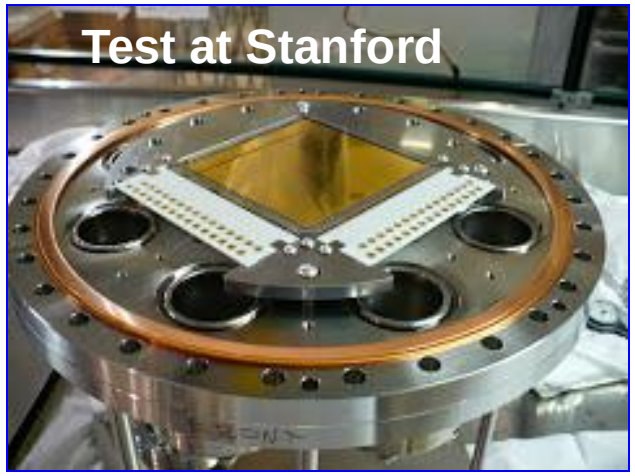
First Data in LXe at Stanford

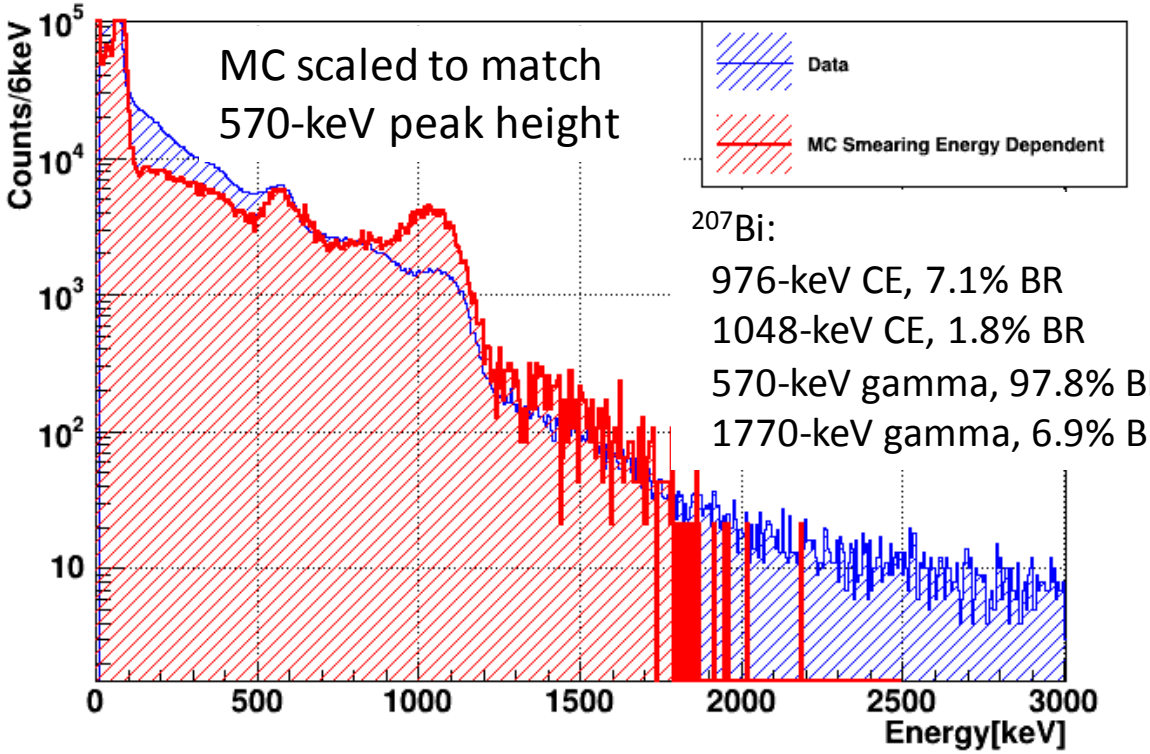


1.7-cm drift length

Field: 1kV/cm







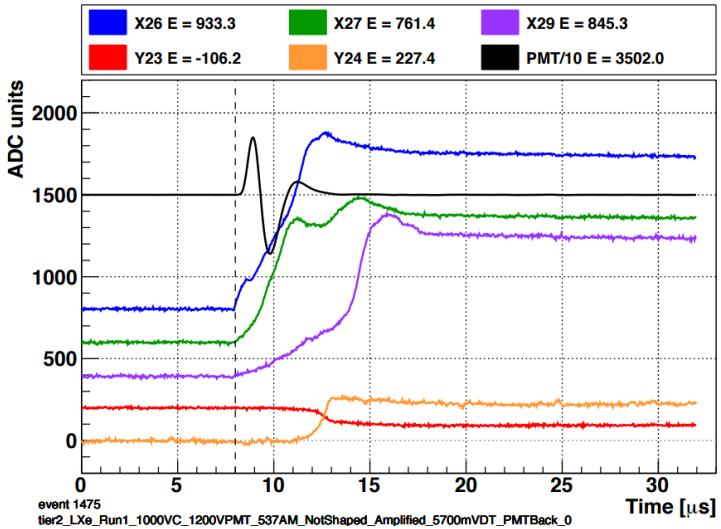
^{207}Bi:

976-keV CE, 7.1% BR

1048-keV CE, 1.8% BR

570-keV gamma, 97.8% BR

1770-keV gamma, 6.9% BR

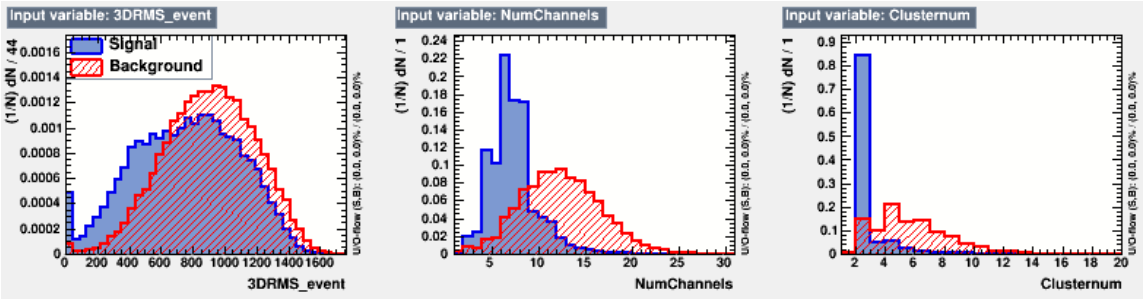


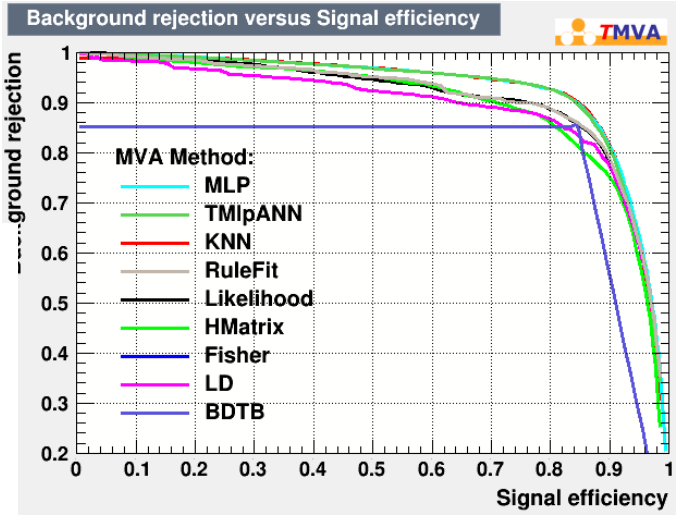
Charge Readout Simulation

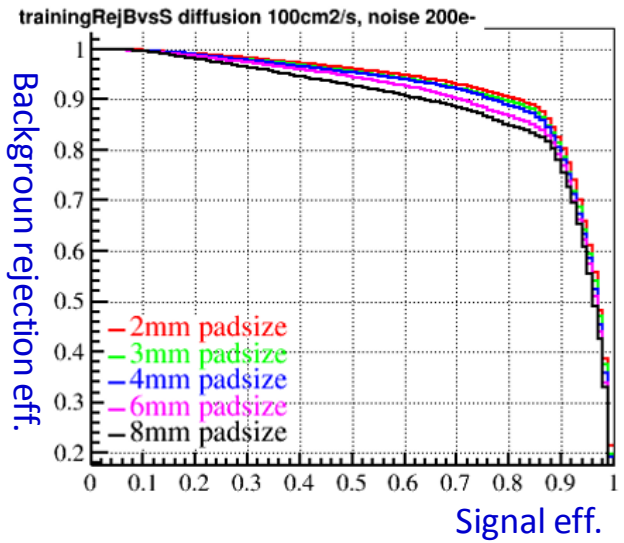
- Issues
  - Optimal pitch size
  - Noise requirement
  - Diffusion impact
  - e-/γ discrimination
  - *Induction impact*

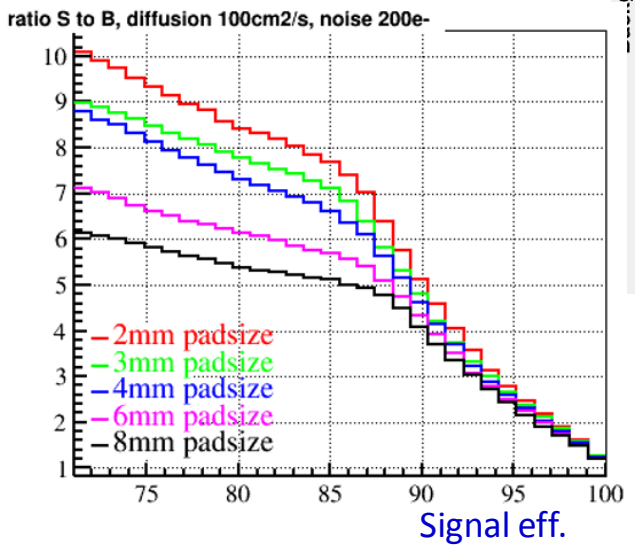
X-cluster and Y-clusters: ΔD<3mm, $\Delta T<1\mu s$

SS event: $N_X<=1$ && $N_Y<=1$







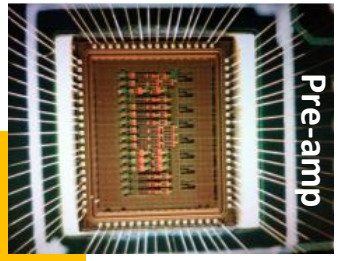


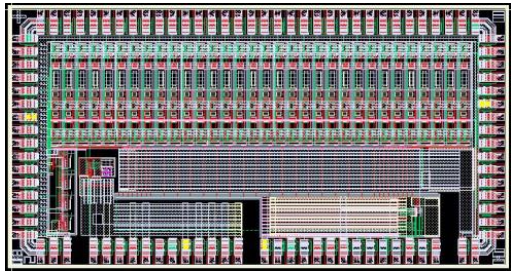
Cold ASIC electronics

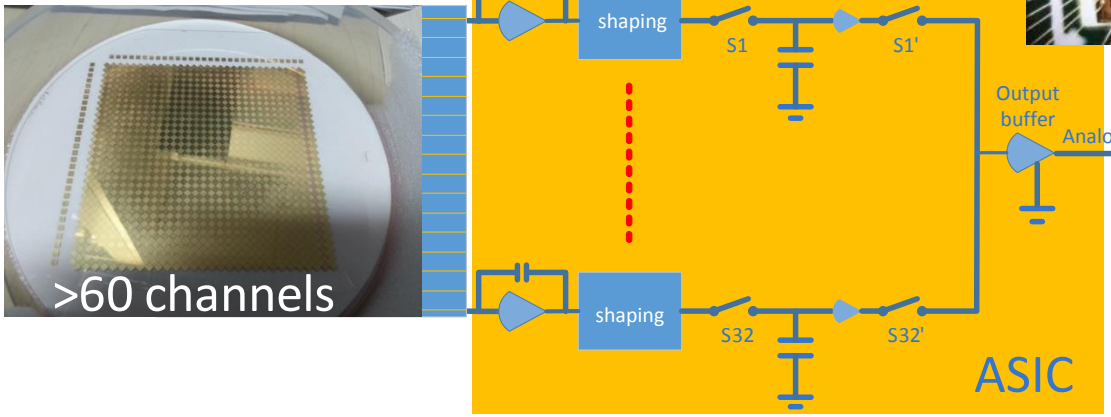
- Two schemes
  - Digital multiplexing
    - Analog + Digital in cold
  - Analog serialization output
    - Sampling first then hold on the capacitor
    - Serially readout ch.-by-ch.
    - External ADC, less EM interference

Critical requirement:
<200 e- noise @160K

Analog multiplexing readout

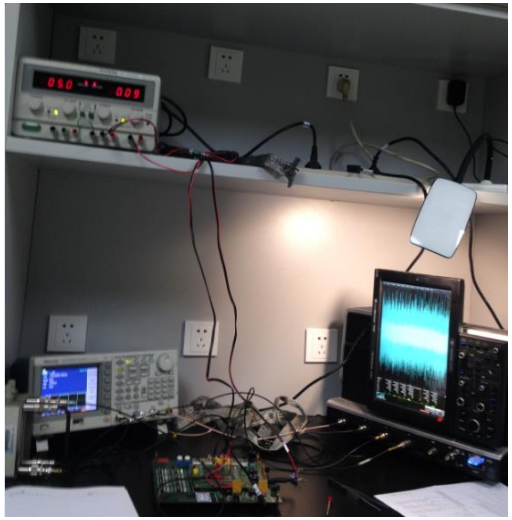


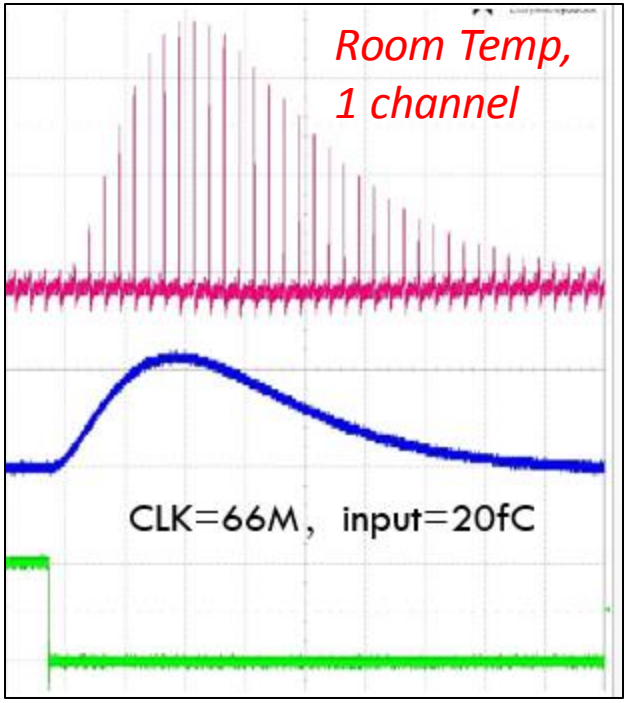


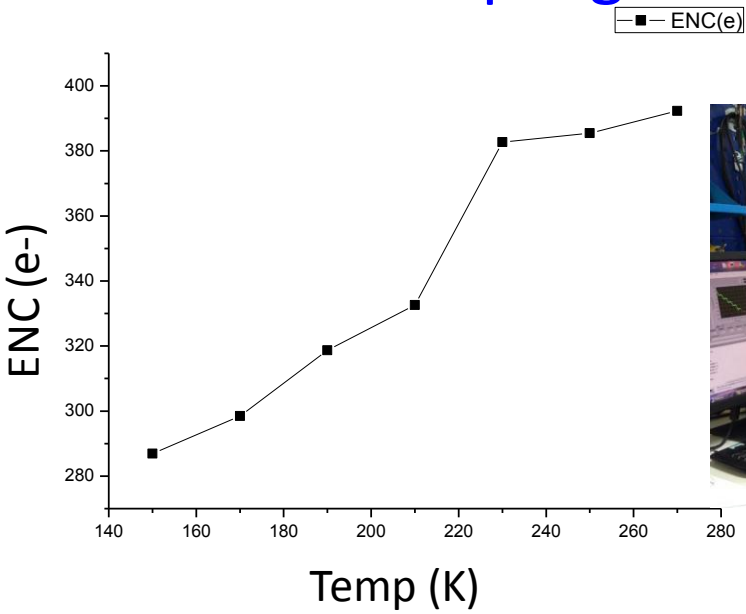


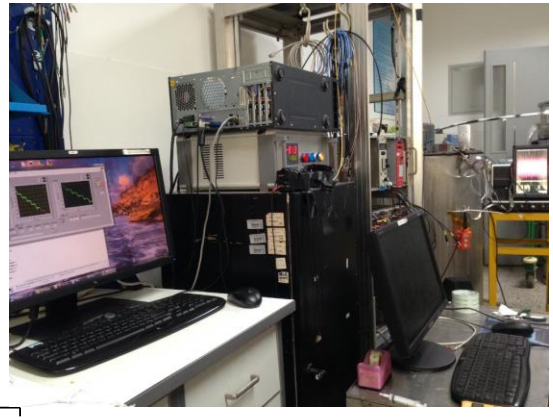
Preliminary Tests

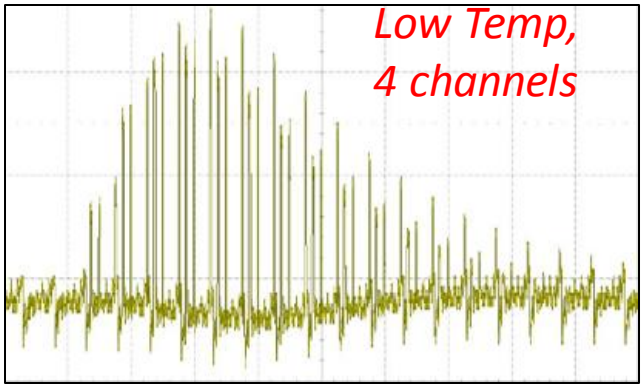
- Noise (preliminary)
  - ~380 e- @ 295K
  - ~280 e- @ 160K
- gain: ~12.8mV/fC
- Analog INL < 1.5%
- 2MHz sampling



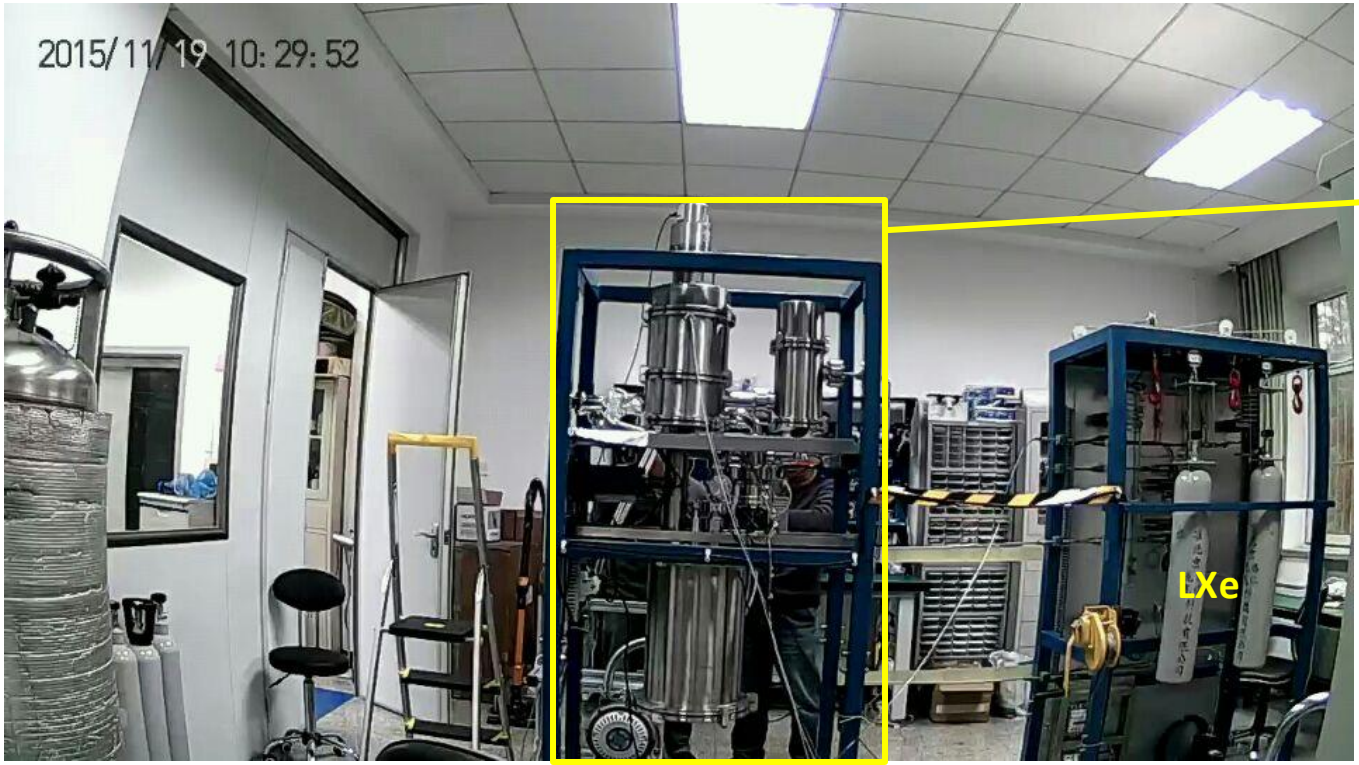


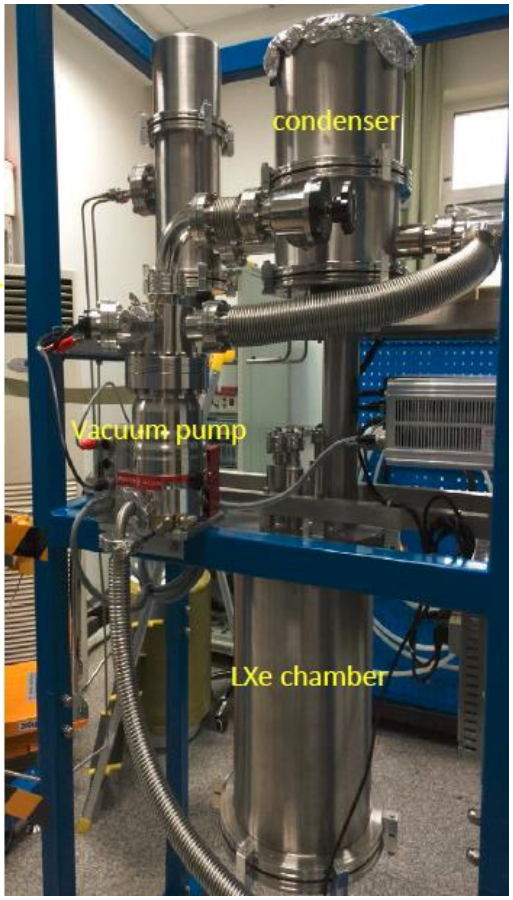




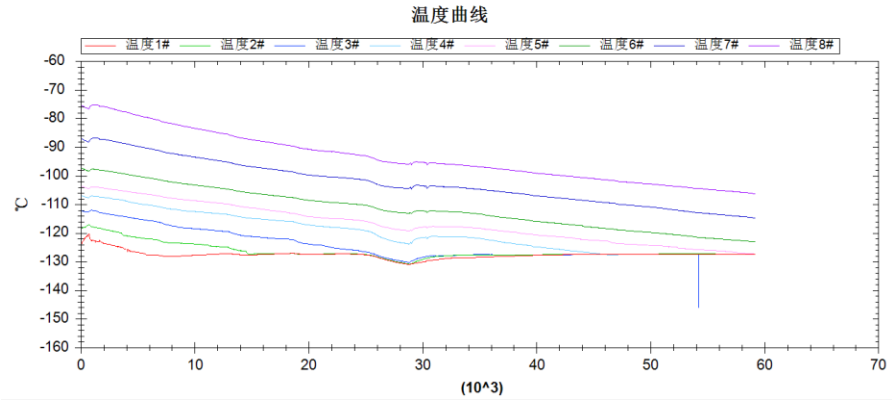


LXe Test System





First successful liquification with CF_4



A multi- purpose setup:

- ✓ charge tile
- ✓ SiPM under HV
- ✓ mirrors
- ✓ Anti-correlation MC validation

ICP-MS Lab

ICP-MS: Thermo Element iCAP Qc
Ultra-pure water: Millipore Milli-Q® Reference
Sample Digestion: Milestone ETHOS UP
Ultra-pure acid: Acid distillation equipment

Initial target sensitivity: U/Th < 10^{-13} g/g,
Develop extremely careful sample treatment

Commissioning next week.

Radio-purity screening for EXO, JUNO, other low background experiment

Summary

- nEXO has robust discovery potential of $0\nu\beta\beta$. Its detector configuration & technique was validated by EXO-200
- IHEP is a new player in $0\nu\beta\beta$ field and we expect to play an important role EXO-200/nEXO
  - 2~3 FTE at EXO-200 *(L.J.W analysis coordinator),* ~ 5 FTE @ nEXO *(G.F.C photo-detector L2)*
  - Active R&Ds at IHEP
    - 2D Charge readout tile
    - Ultra-low background assay using ICP-MS technique
    - Cold ASIC electronics
    - VUV reflective mirror on Cu cathode & shaping
    - Detector Simulation
    - nEXO M&S: Funding: $240k/yr, 2015-2017
- Enrichment: possible in China? Collaboration with other Country?

Thanks!