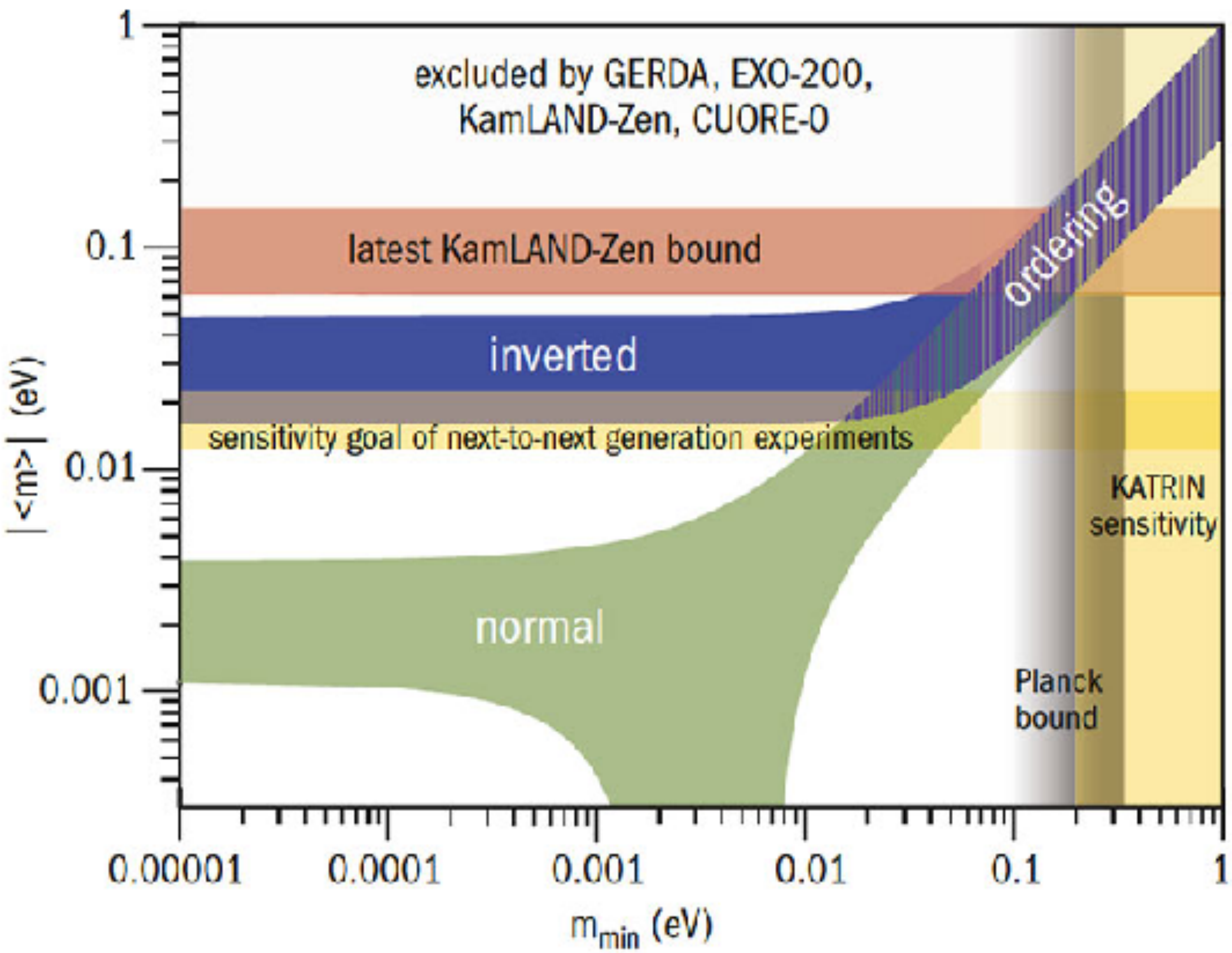
TONNE SCALE NEXT AT SNOLAB

F. Monrabal
University of Texas at Arlington
for the NEXT Collaboration

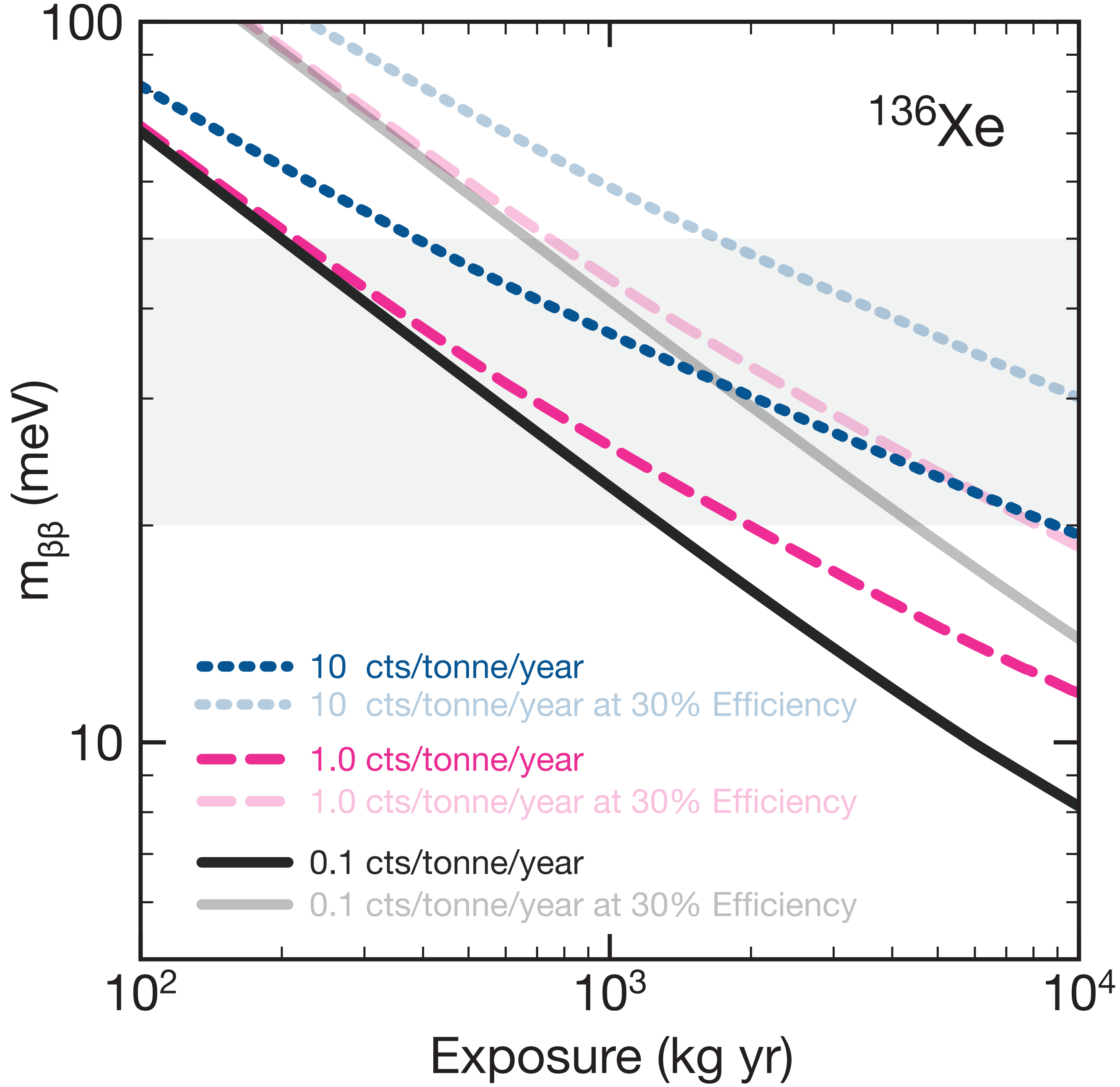
Future Projects Workshop

MAJORANA LANDSCAPE



- Latest results barely touching Inverse Hierarchy region.
- Need to reach $\sim 10^{27}$ years lifetimes.
- Ton scale experiments are needed to reach these lifetimes.
- Background rate objective <1 evt/tonne/year.

EXPLORING THE IH



100 % efficient Xe *experiment (using a "reasonable NME set"):*
2 ton year to explore IH with 1 background event per ton per year

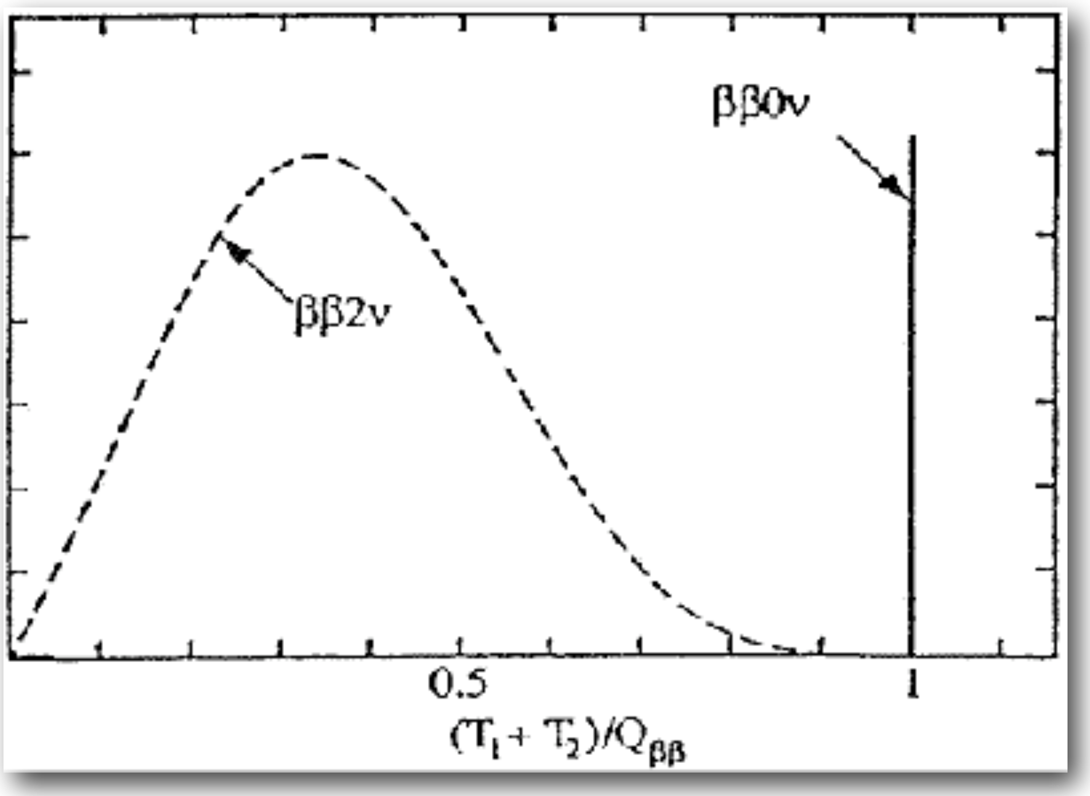
30 % efficient Xe *experiment:*

- *10 ton year to explore IH with 1 background event per ton per year*
- *4.5 ton year to explore IH with 0.1 background event per ton per year*

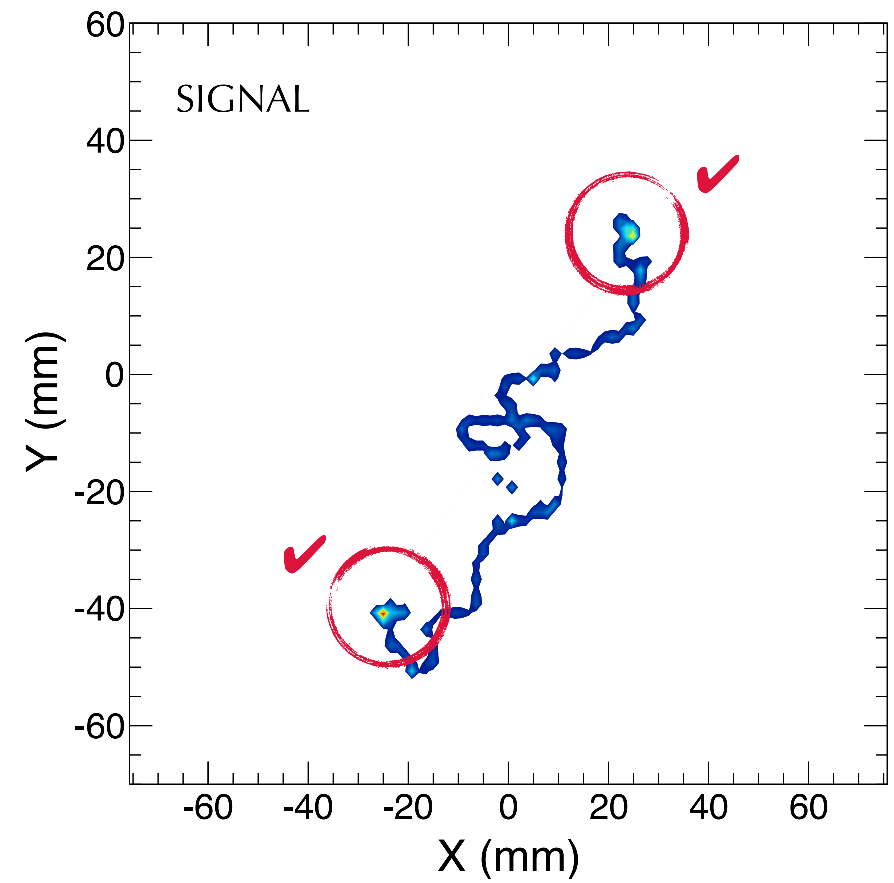
HPXE-EL TECHNOLOGY

Energy resolution

(Intrinsic Energy resolution 0.3%FWHM)



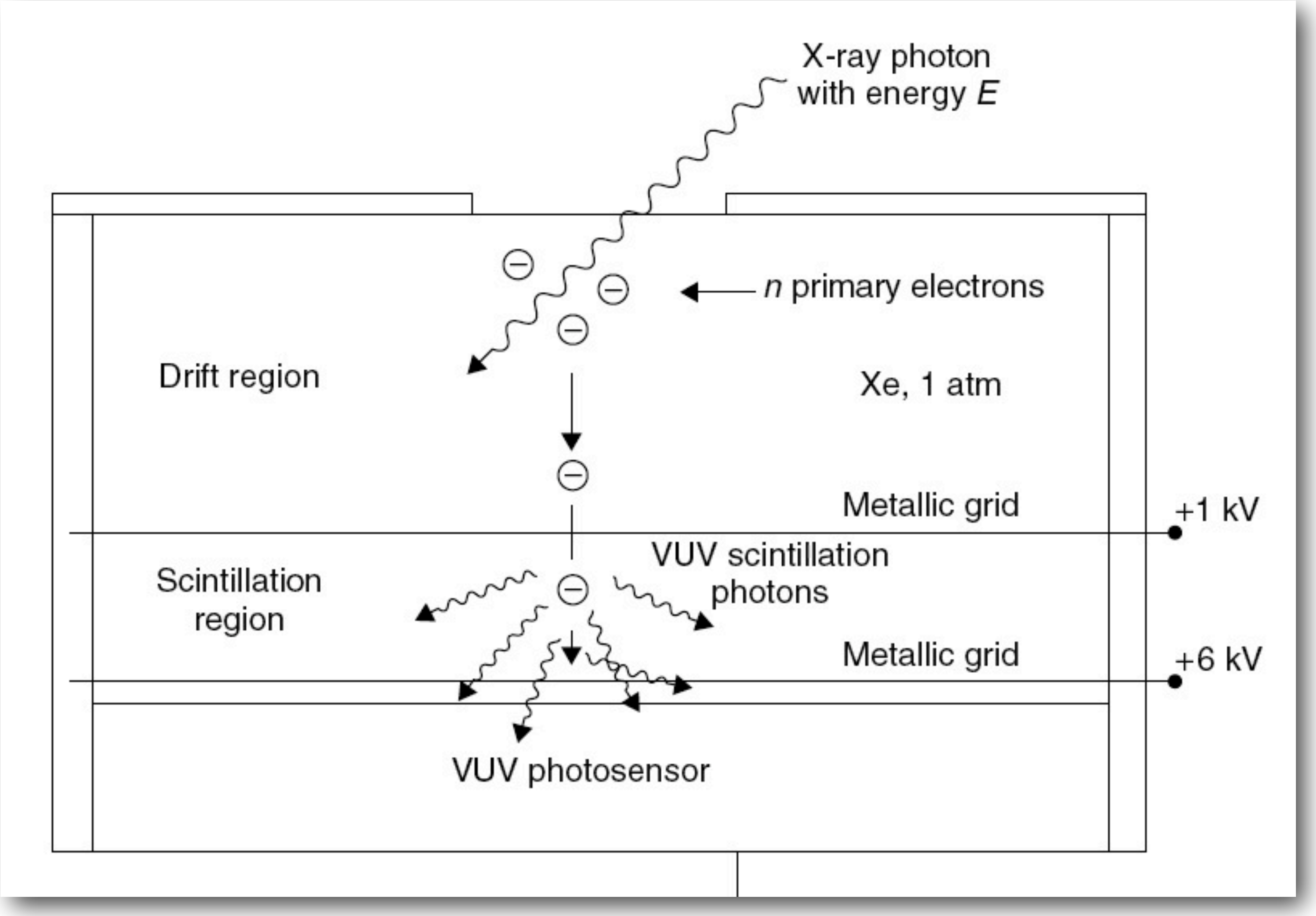
Topological signature



First target:
To demonstrate "background free" (<1 evt/year) @ 100 kg scale

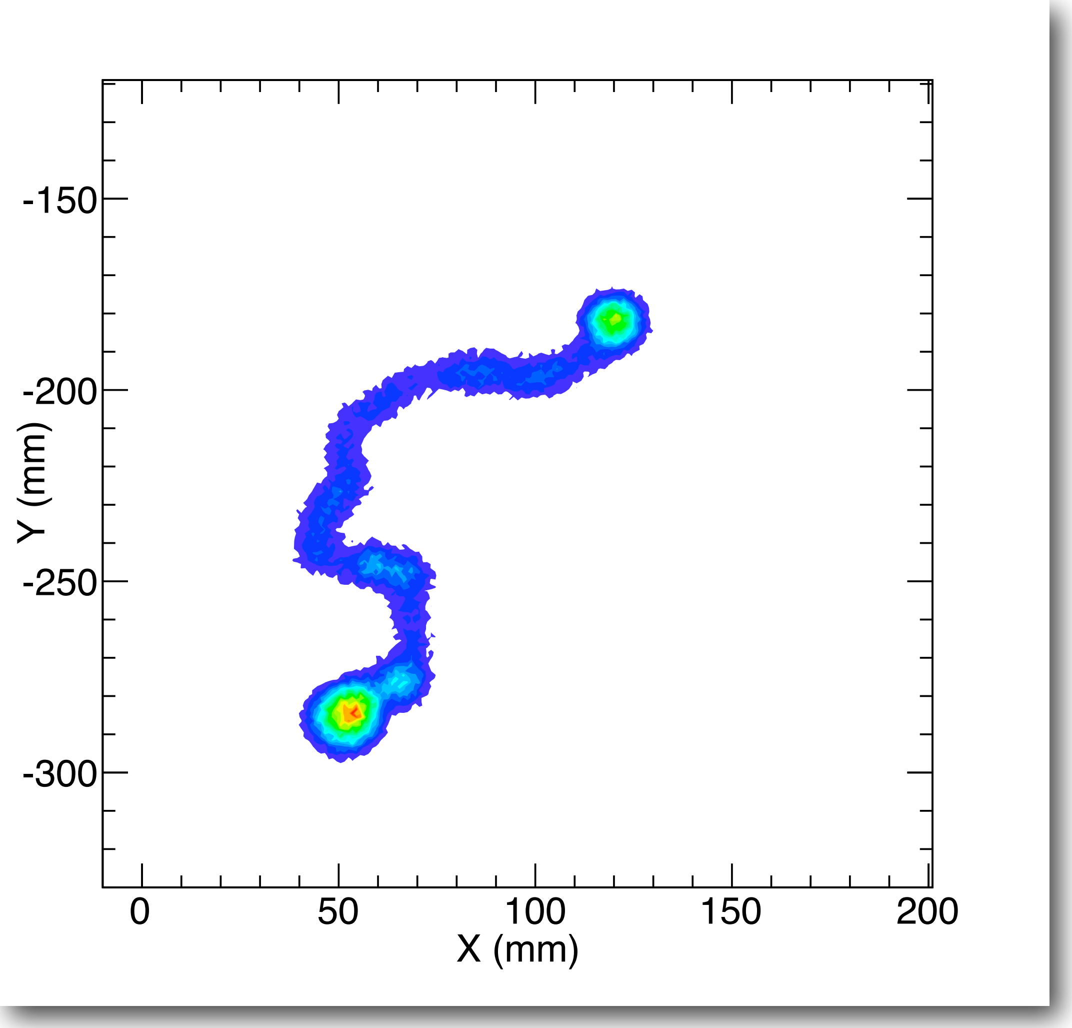
Ultimate target: *To upgrade the technology "background free" (<1 evt/year) @ 1 tonne scale*

NOISELESS GAIN WITH ELECTROLUMINESCENCE!



- Emission of scintillation light after atom excitation by a charge accelerated by a moderately large (no charge gain) electric field.
- Linear process, fluctuations suppressed (effective Fano factor ~0.01)
- Large gain (1500 ph./e-)
- Used in NEXT to amplify the ionization signal.

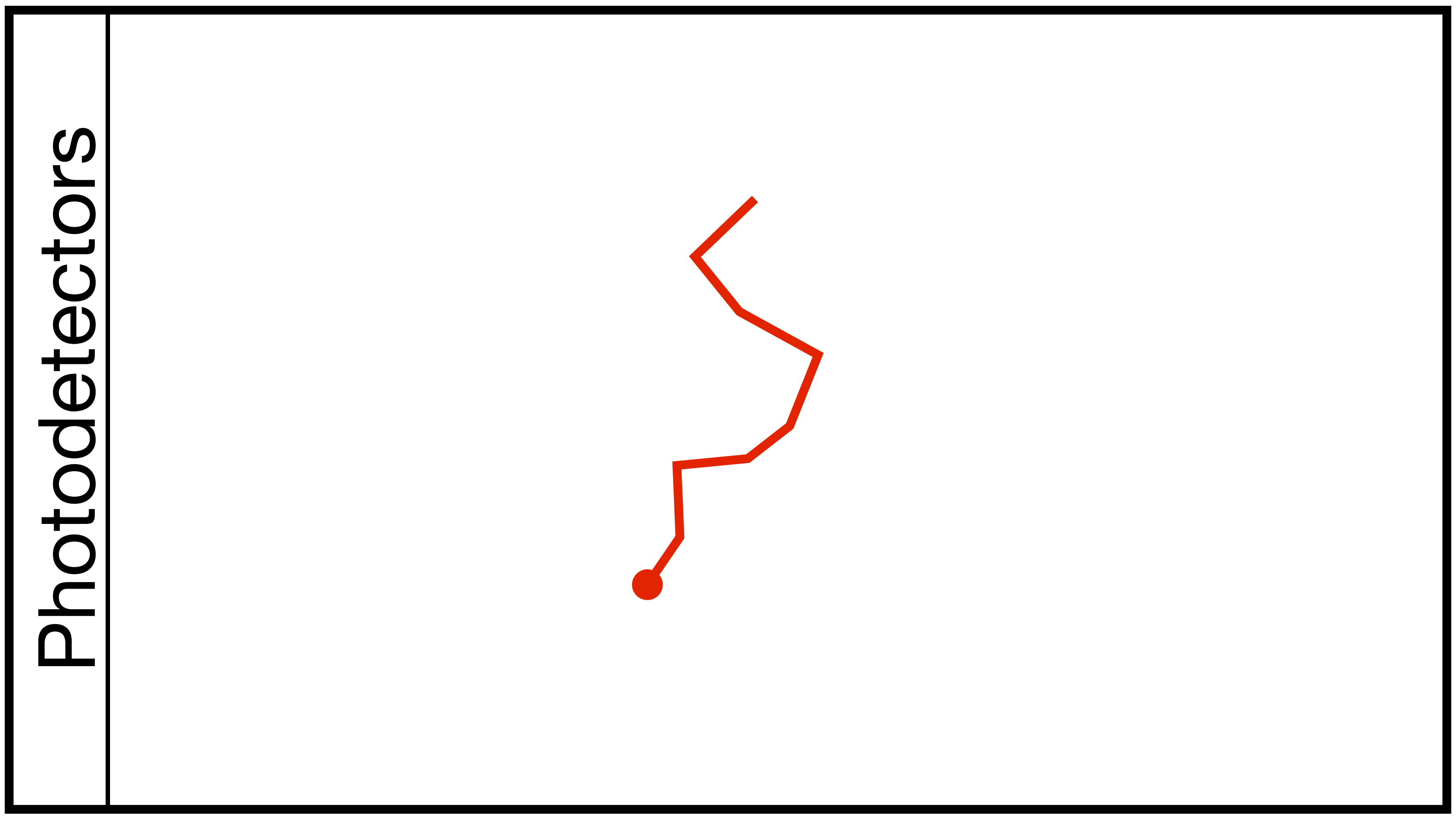
TRACKING IN HPXE



0vββ MC event

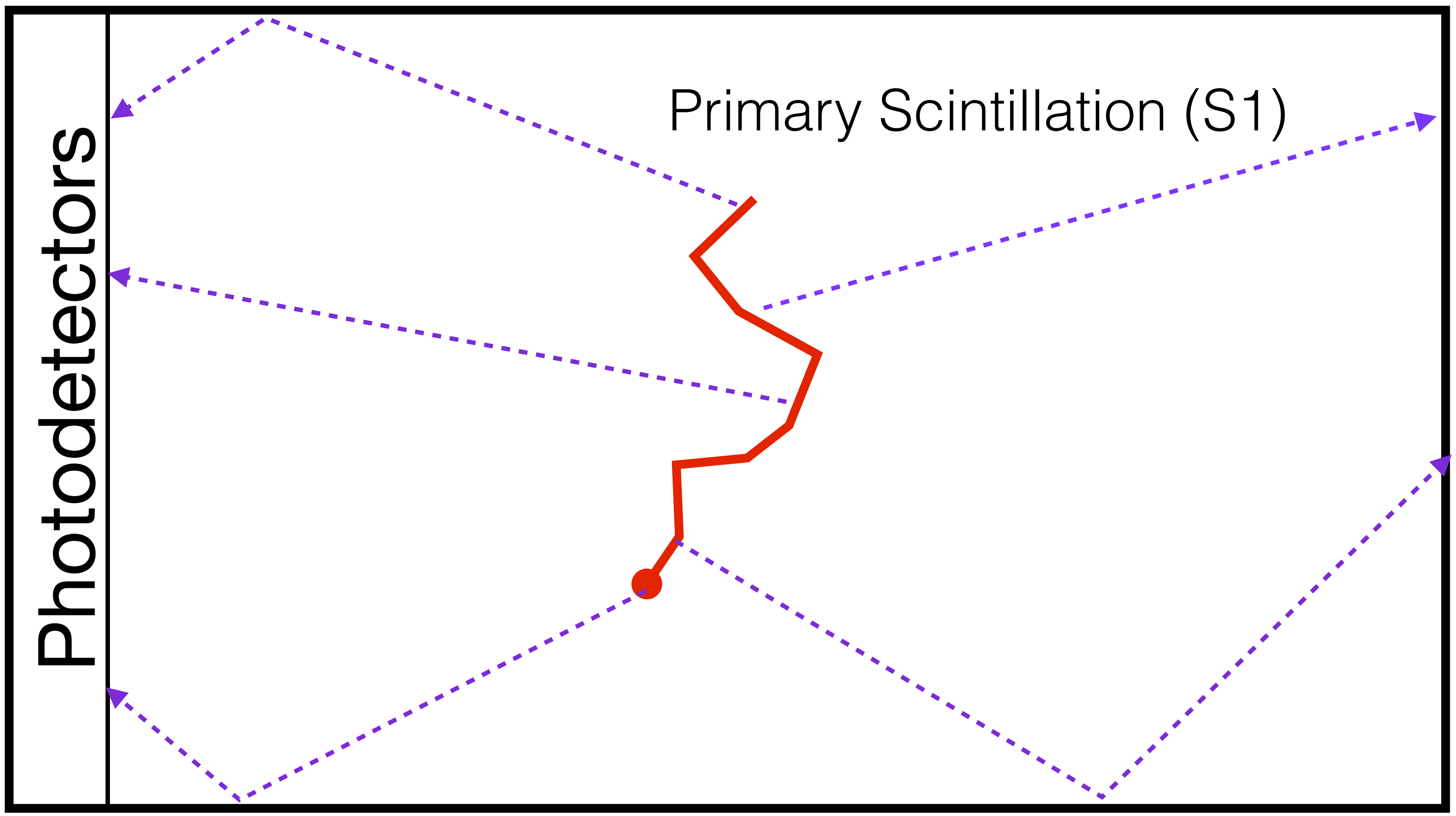
- *Electrons travel on average ~10 cm (15 bar) each.*
- *Trajectories highly affected by multiple scattering.*
- *Electrons travel with almost minimum dE/dx except at the end-points where they generate "blobs".*

DETECTION CONCEPT



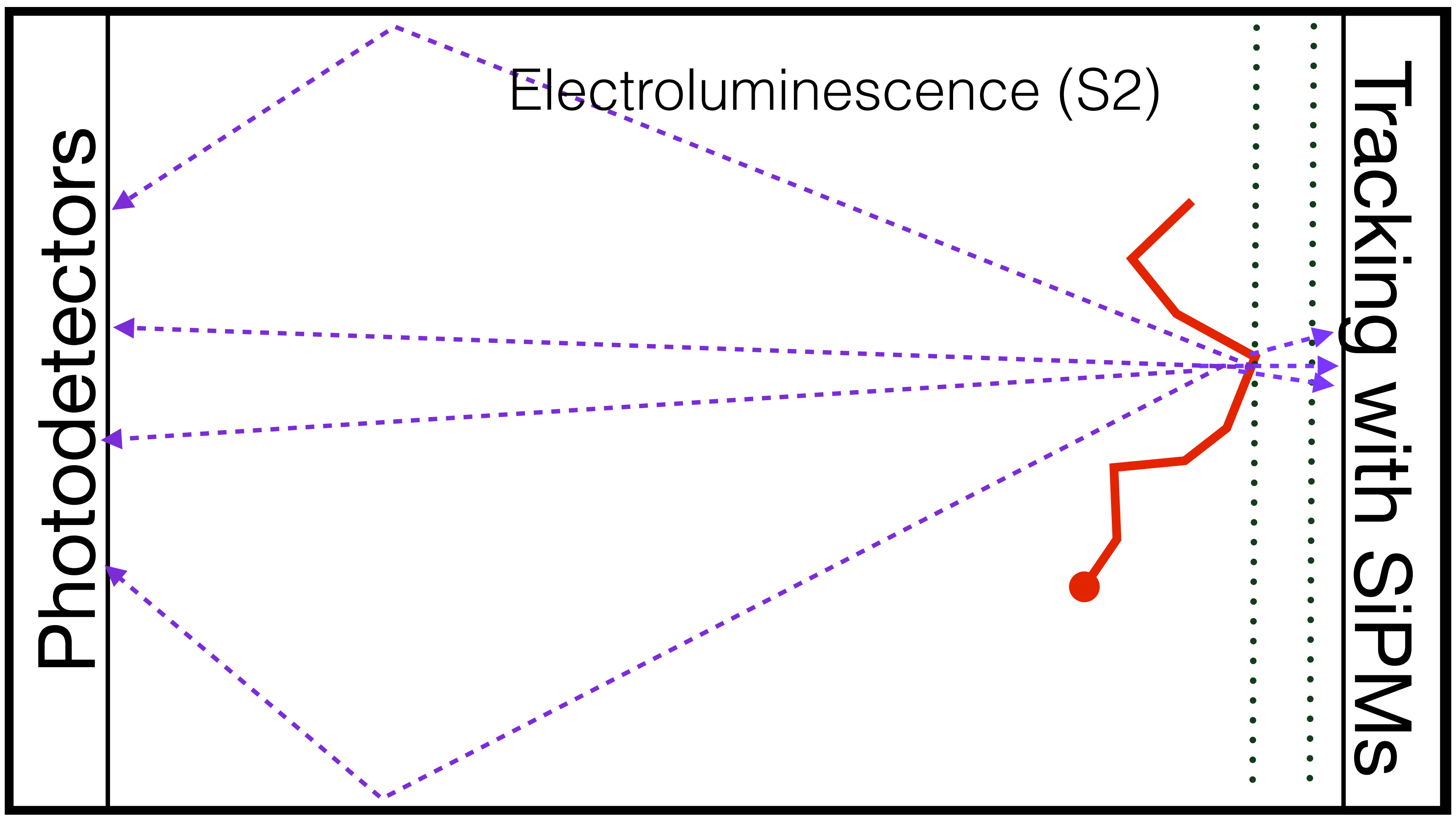
- *It is a High Pressure Xenon (**HPXe**) TPC operating in EL mode.*
- *It is filled with Xe enriched at 90% in Xe-136 (in stock) at a pressure of 15 bar.*

DETECTION CONCEPT



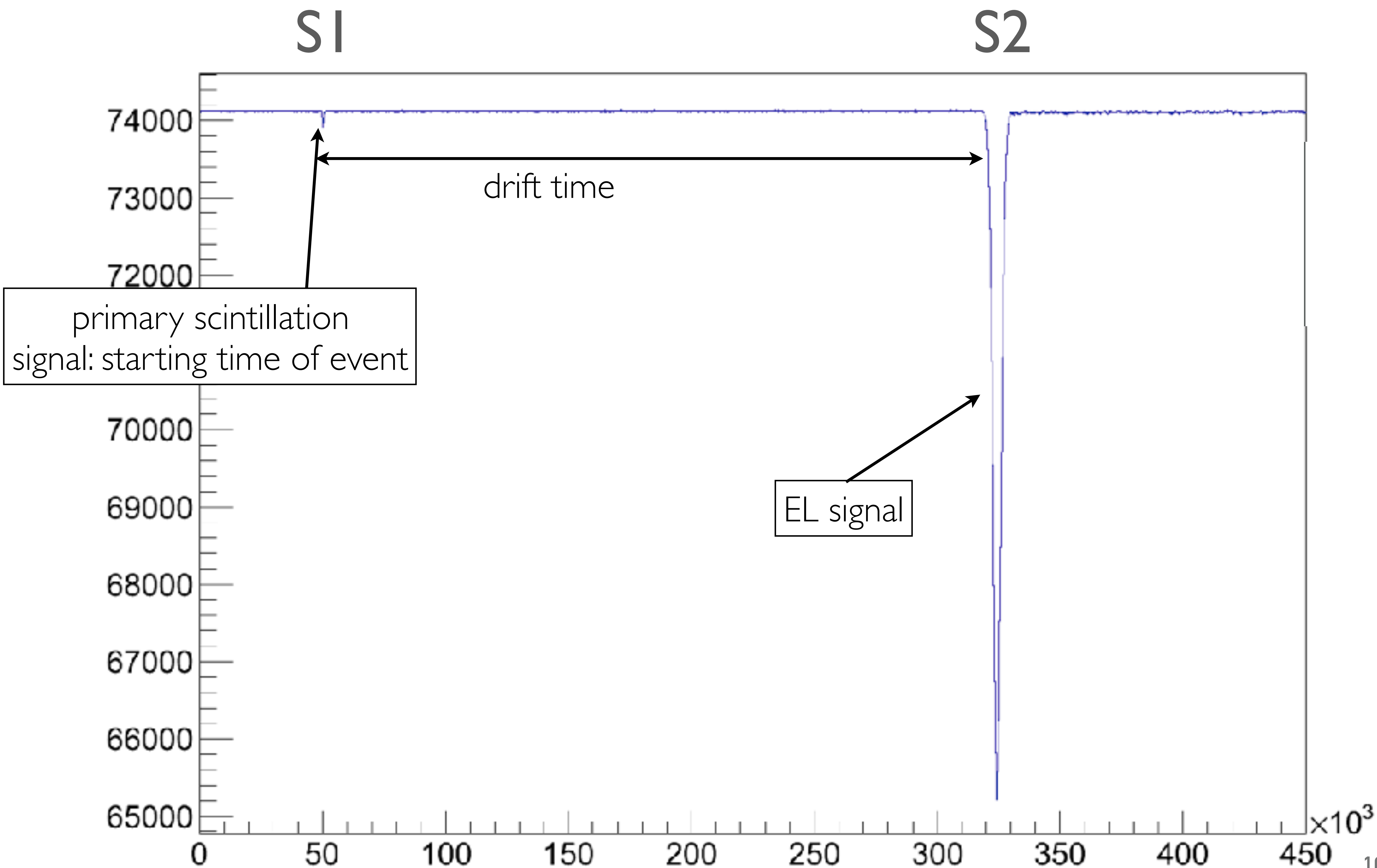
Primary Scintillation light is detected by a plane of photosensors. It gives t_0 of the event and the z position.

DETECTION CONCEPT



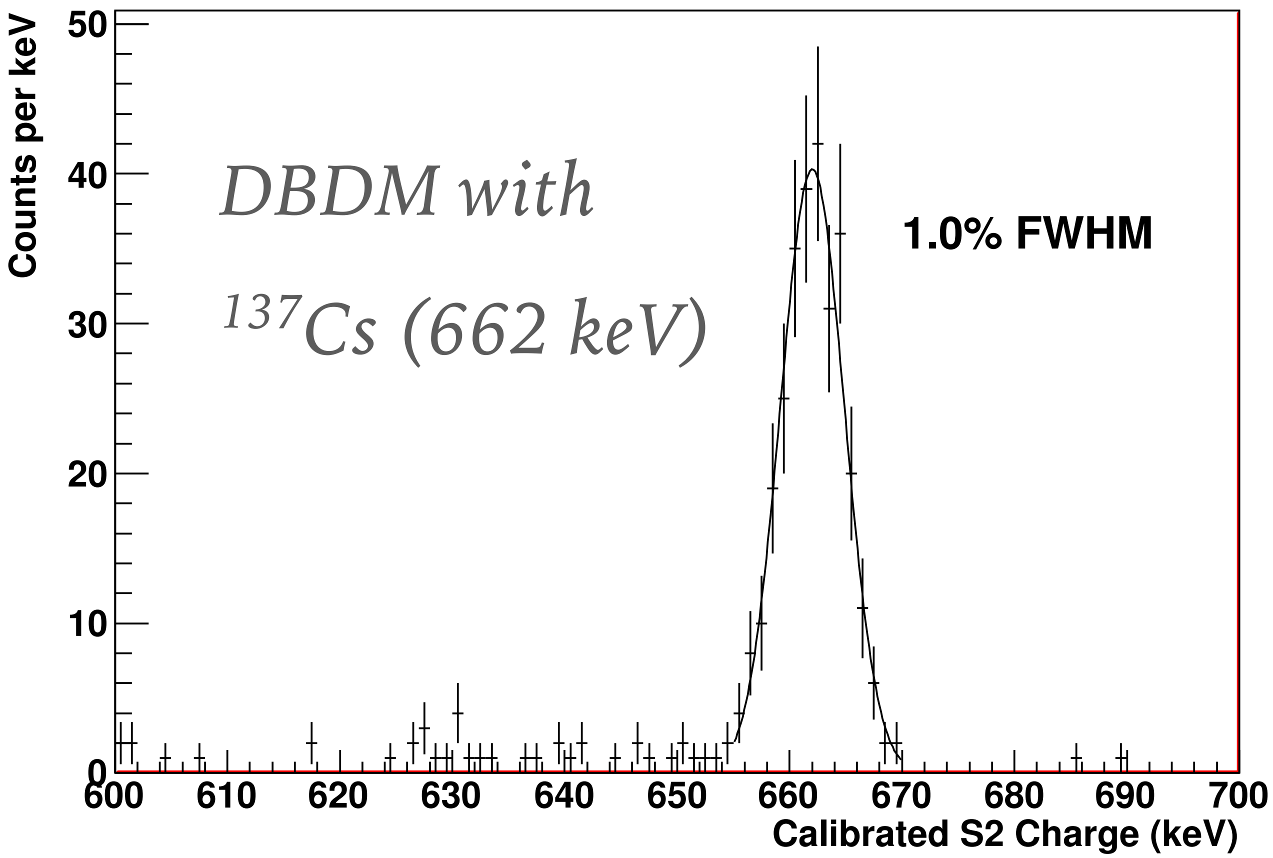
- *The event energy is integrated by a plane of radiopure PMTs located behind a transparent cathode (energy plane), which also provide t0.*
- *The event topology is reconstructed by a plane of radiopure silicon pixels (SiPMs) (tracking plane).*

WAVEFORMS IN NEXT

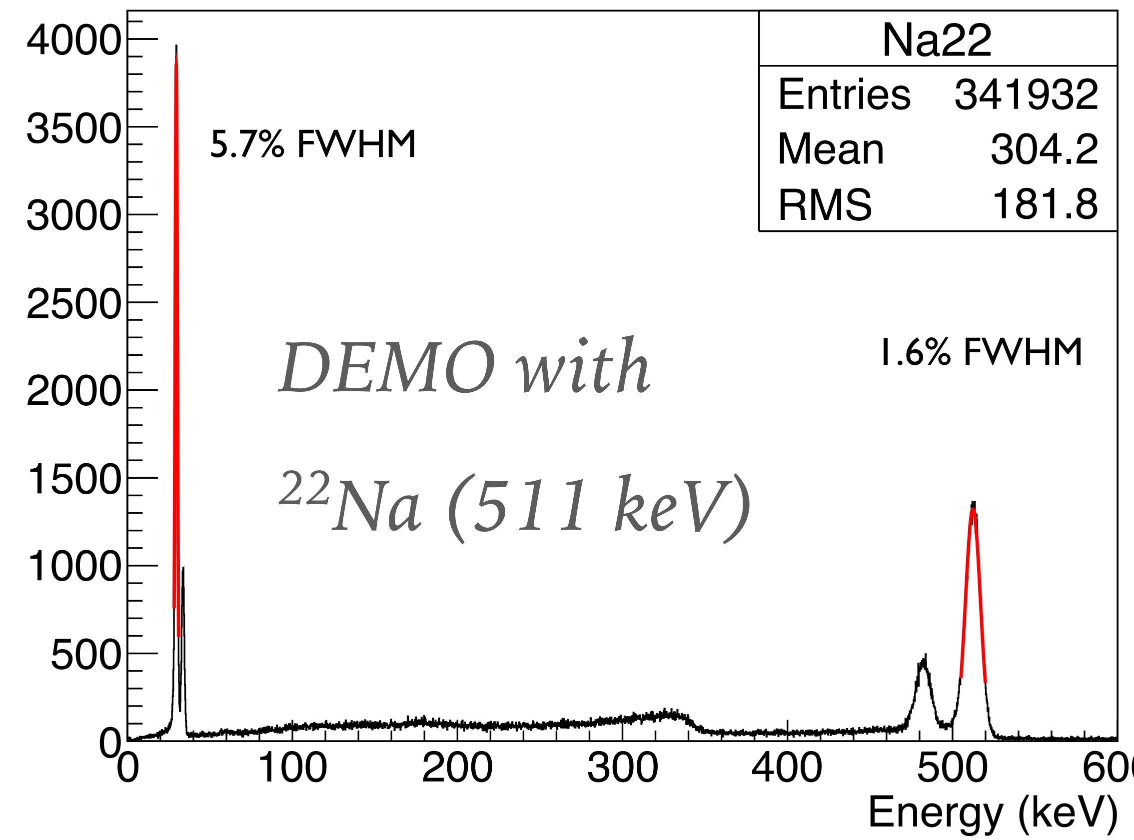


ENERGY RESOLUTION

Nucl. Instrum. Meth. A708 (2013) 101-114



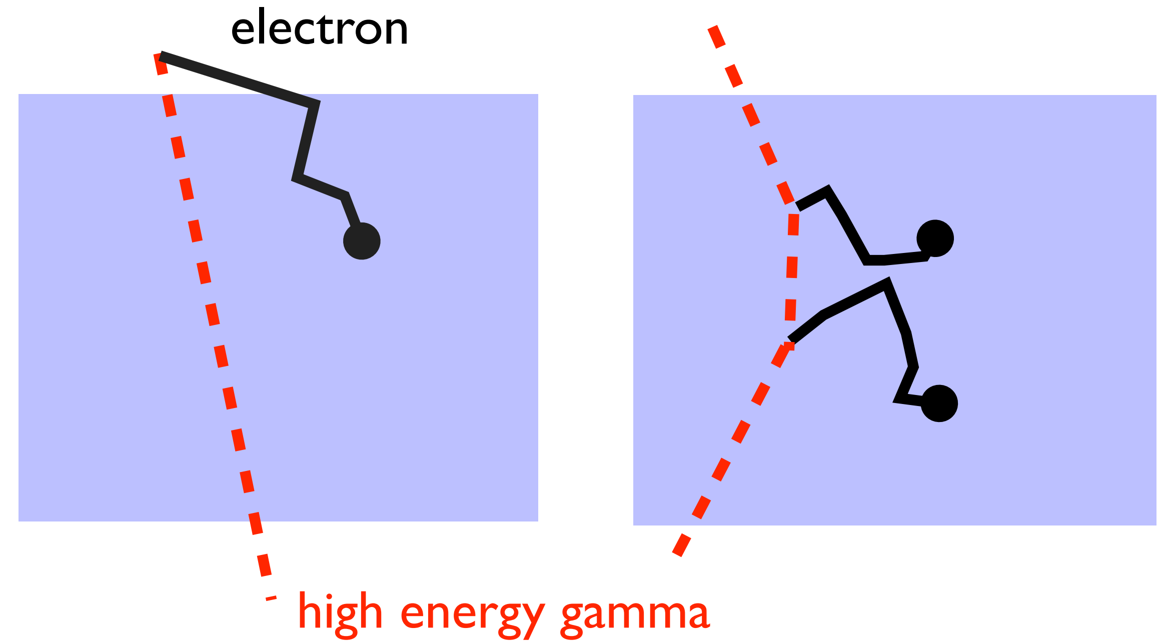
JINST 9 (2014) no.10, P10007

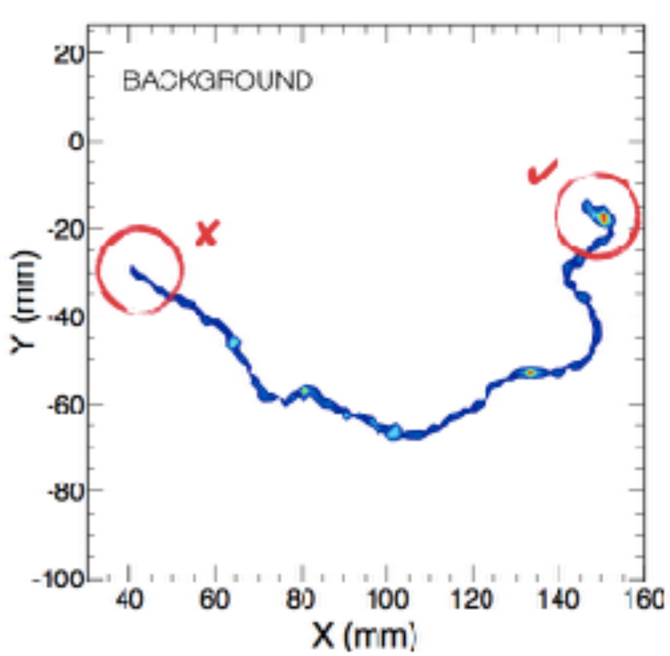


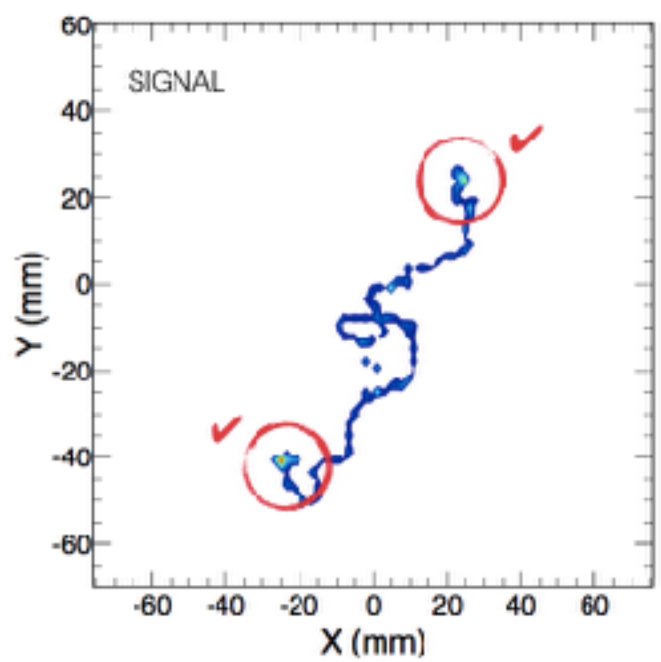
Direct 1/Sqrt(E) Energy resolution extrapolation from NEXT prototypes: 0.5-0.7% FWHM at $Q_{\beta\beta}$

TOPOLOGY

- *Electrons leave extended tracks in gas, which can be used 1) to veto beta electrons coming from outside, 2) to identify events with more than one track (typically background).*







- *Electron energy loss in gas is constant until the end of the trajectory (Bragg peak).*
- *Signal: spaghetti with two "meat balls".*
- *Background: spaghetti with one "meat ball".*

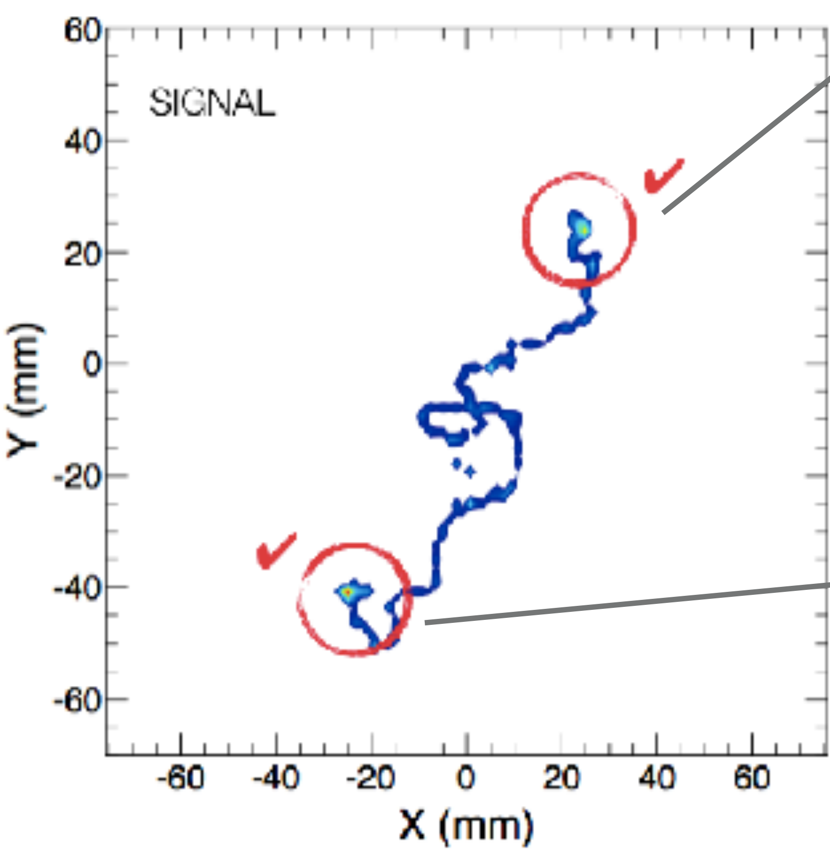
THE POWER OF TOPOLOGY (MC)

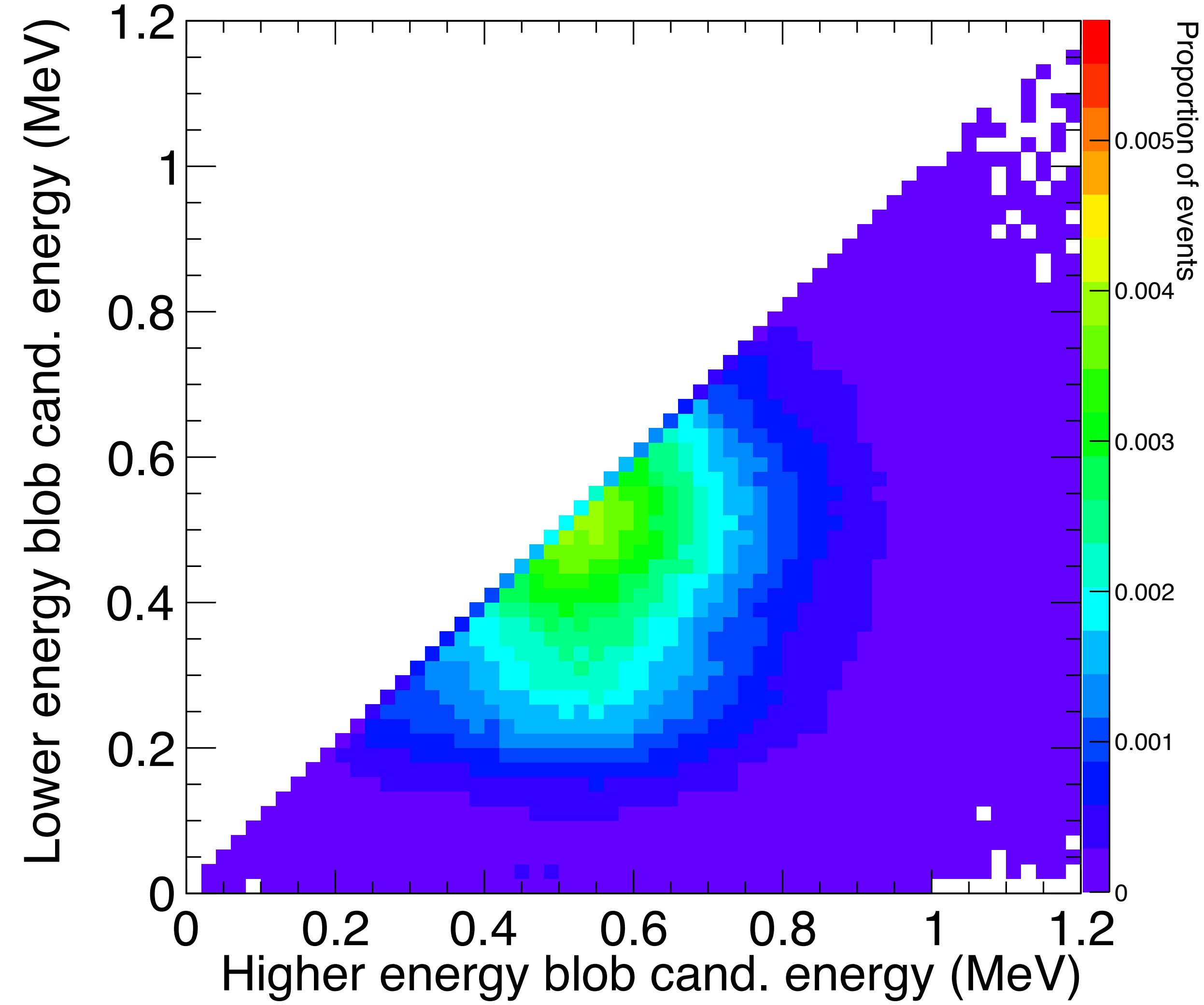
Double electrons signals

(^{208}Tl double escape peak)

Energy blob 2

(Lower energy)





Energy blob 1 (Higher energy)

Two electrons events: Both electrons have similar energies at the end-point

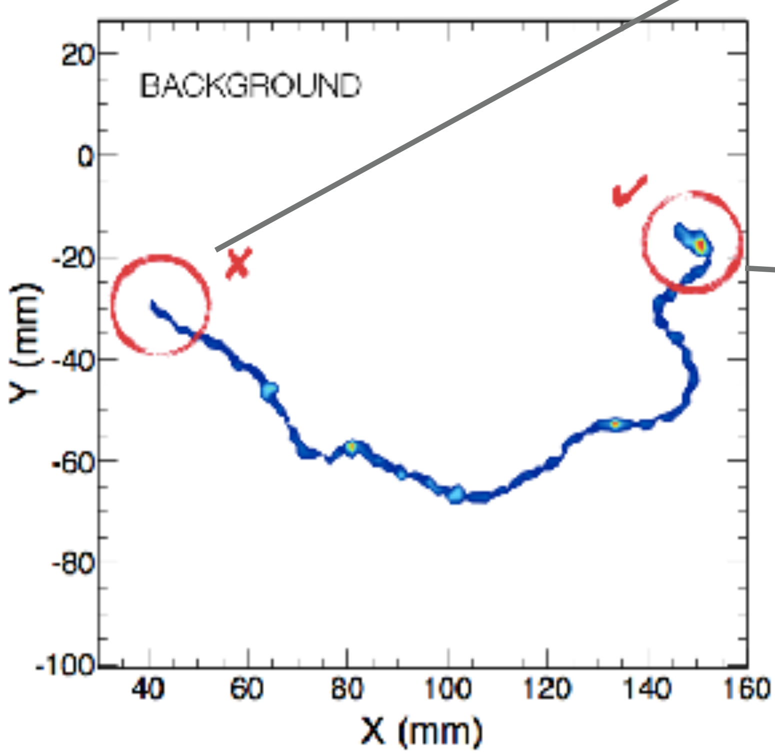
THE POWER OF TOPOLOGY (MC)

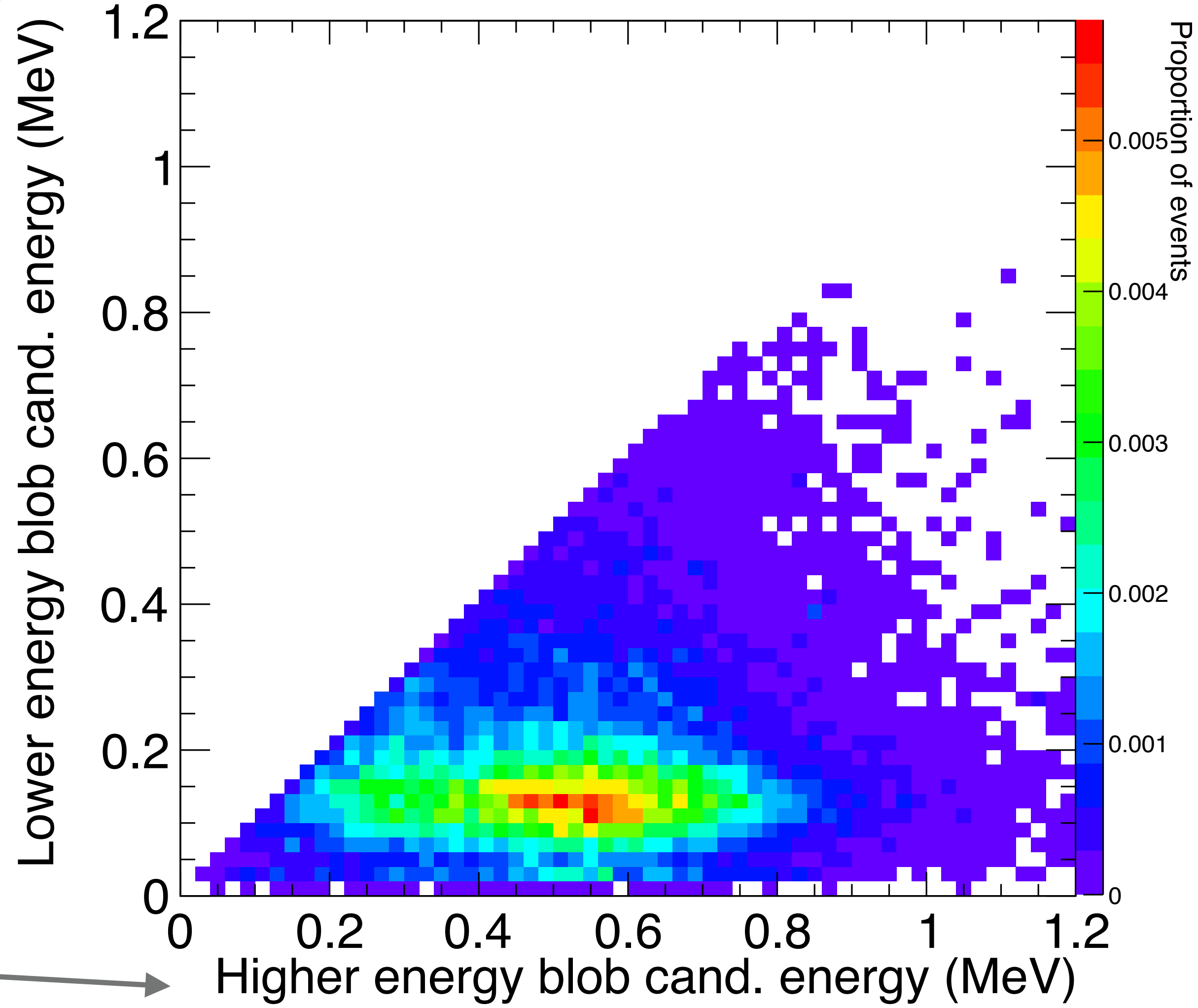
Single electrons signals

(^{22}Na 1.2 MeV gamma)

End-point Energy 2

(Lower energy)

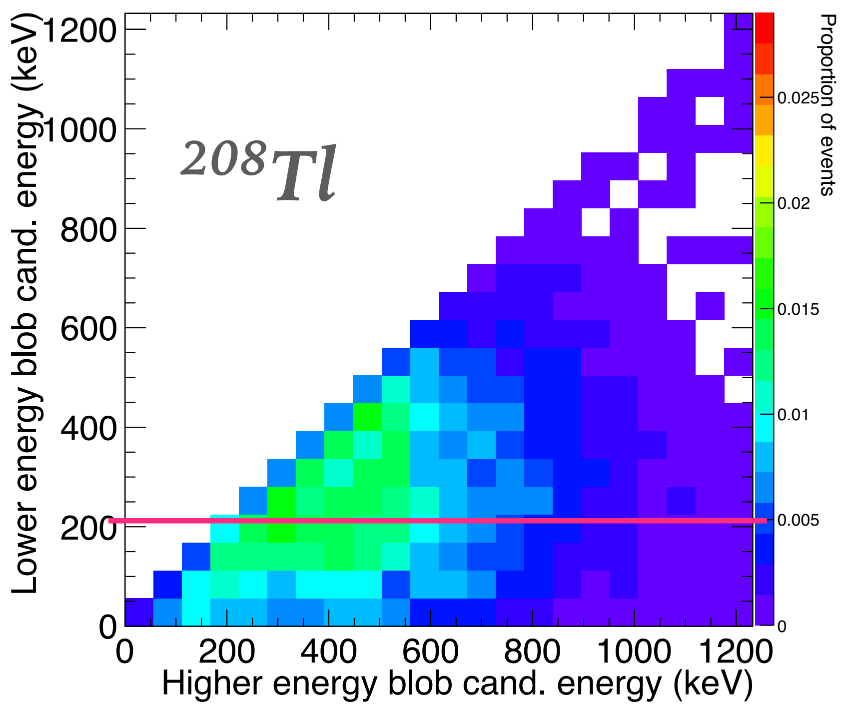


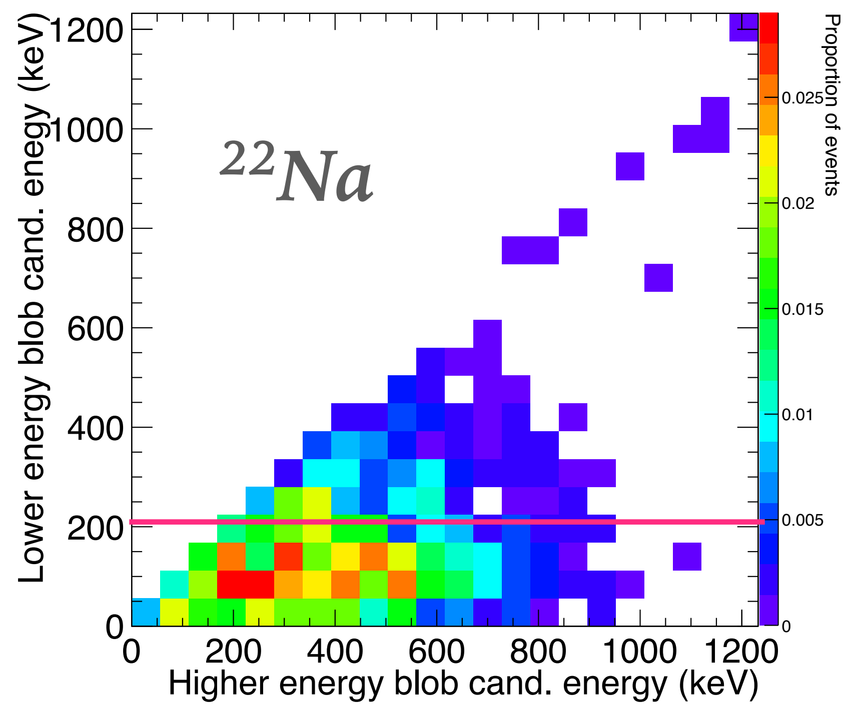


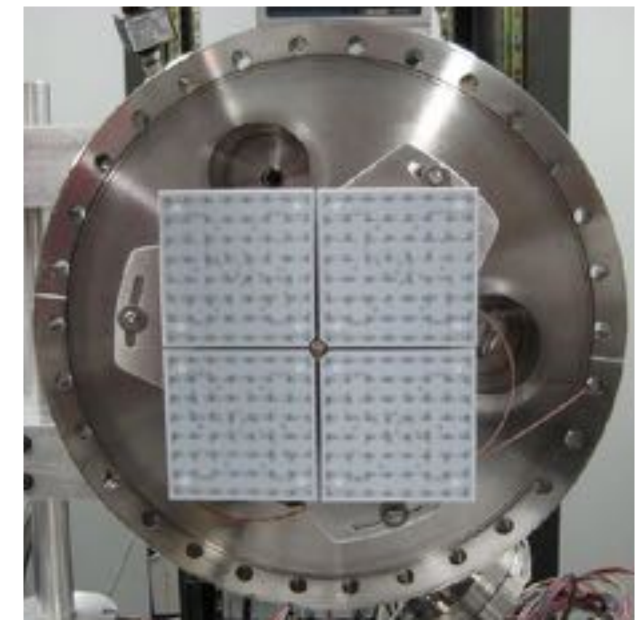
End-point Energy 1 (Higher energy)

One electron events: Very different energies at end-points.

TOPOLOGY: DEMO DATA







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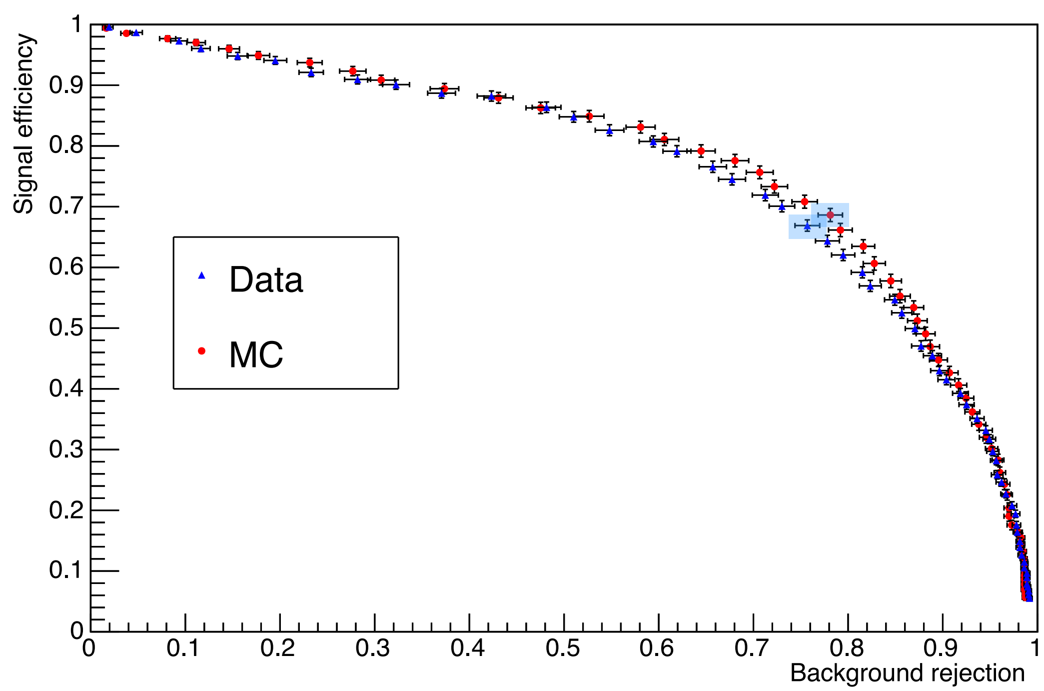
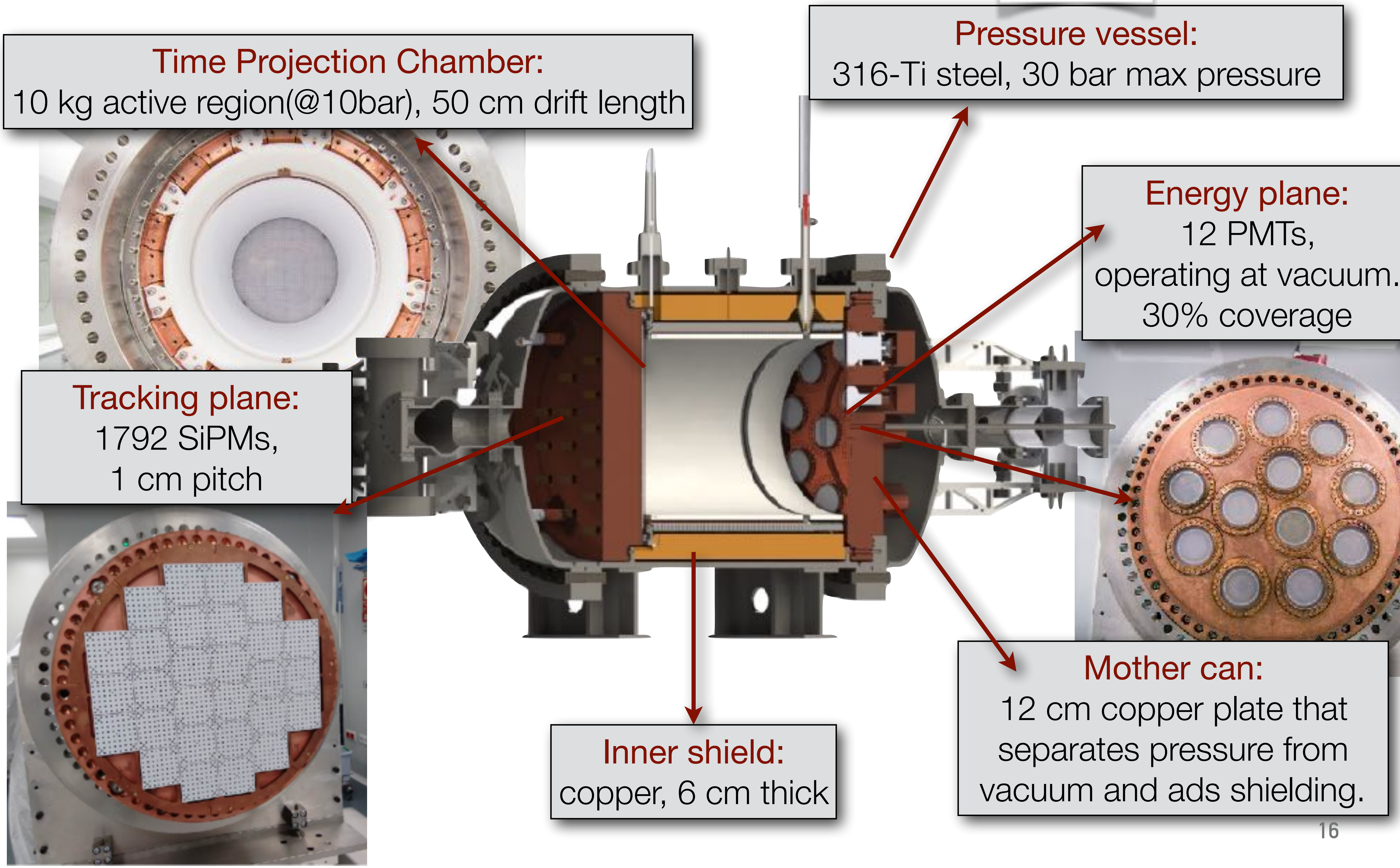


Tracking capabilities of NEXT DEMO

- *Double escape peak of Tl-208 and high energy gamma photopeak of Na-22 used to mimic signal and background.*
- *Discrimination power of topological cut demonstrated in data: 68% signal efficiency for 24% background acceptance.*
- ***Limitations due to small chamber compared with track length.***
- *Better performance expected in larger detectors.*
- *Validation of Monte Carlo.*

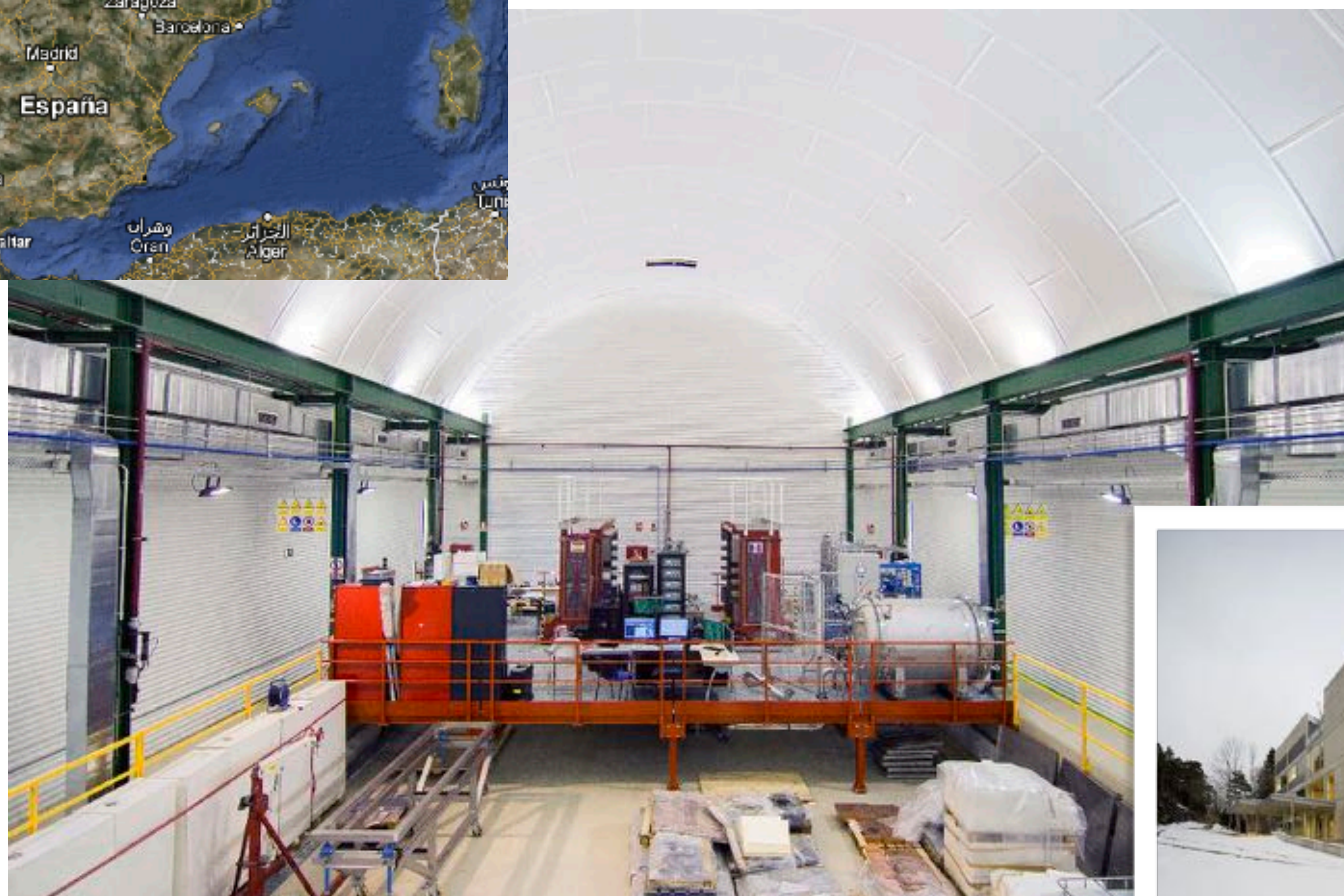
DECONSTRUCTING NEXT-WHITE

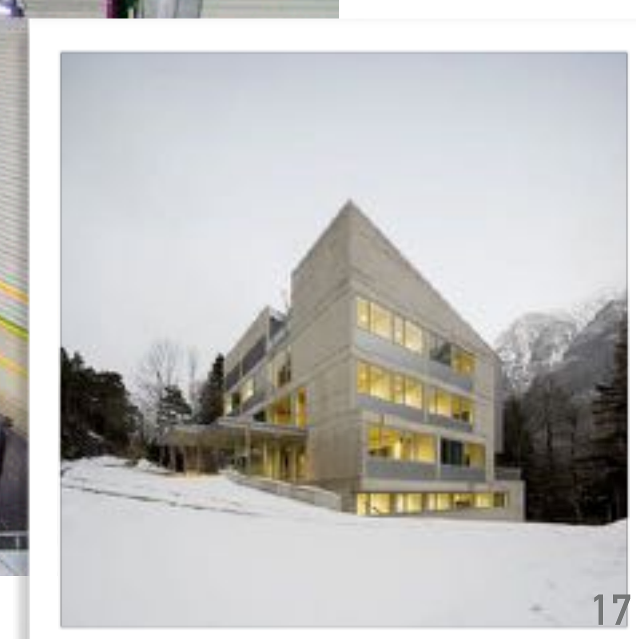


THE CANFRANC UNDERGROUND LABORATORY

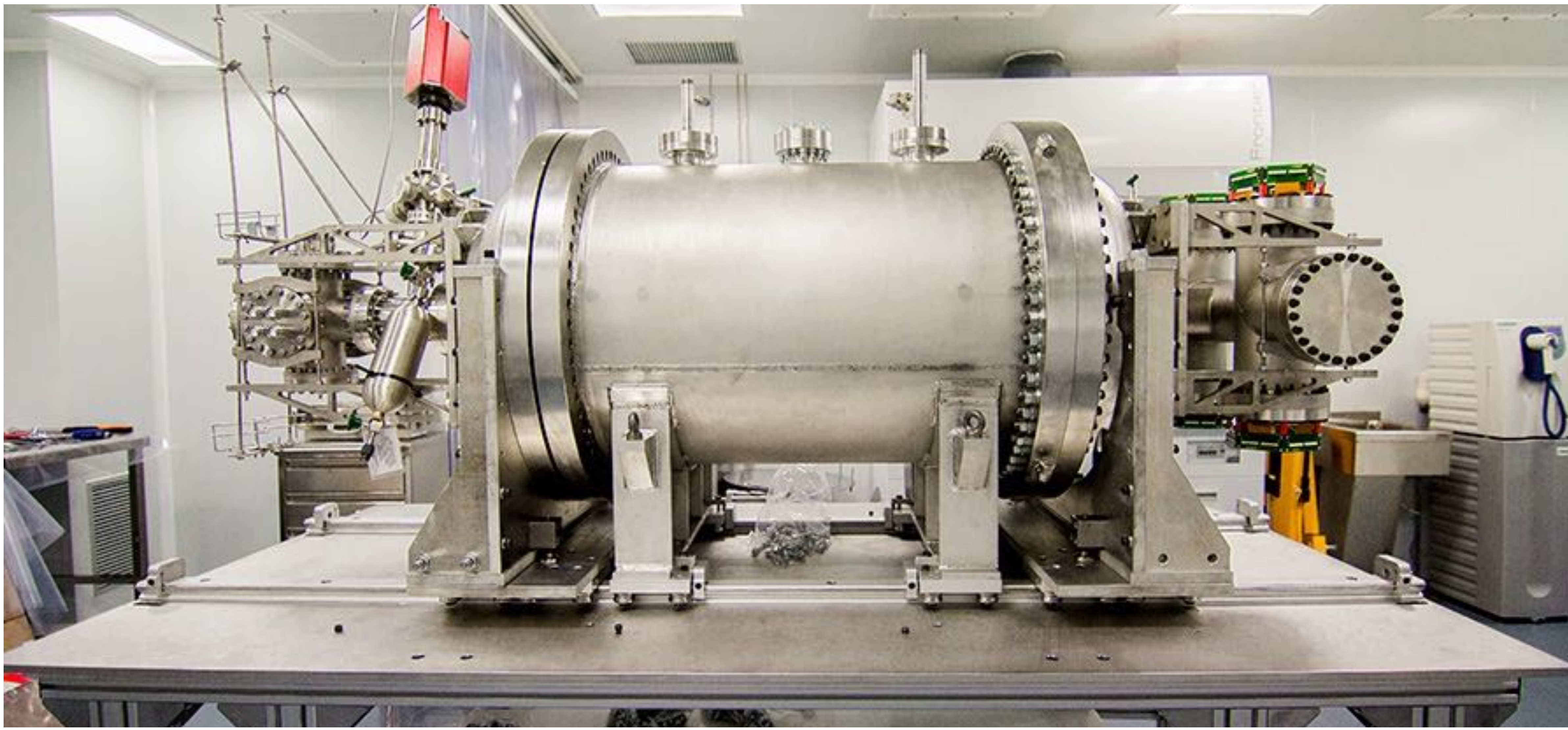
LSC
Laboratorio Subterráneo de Canfranc

2500 wme





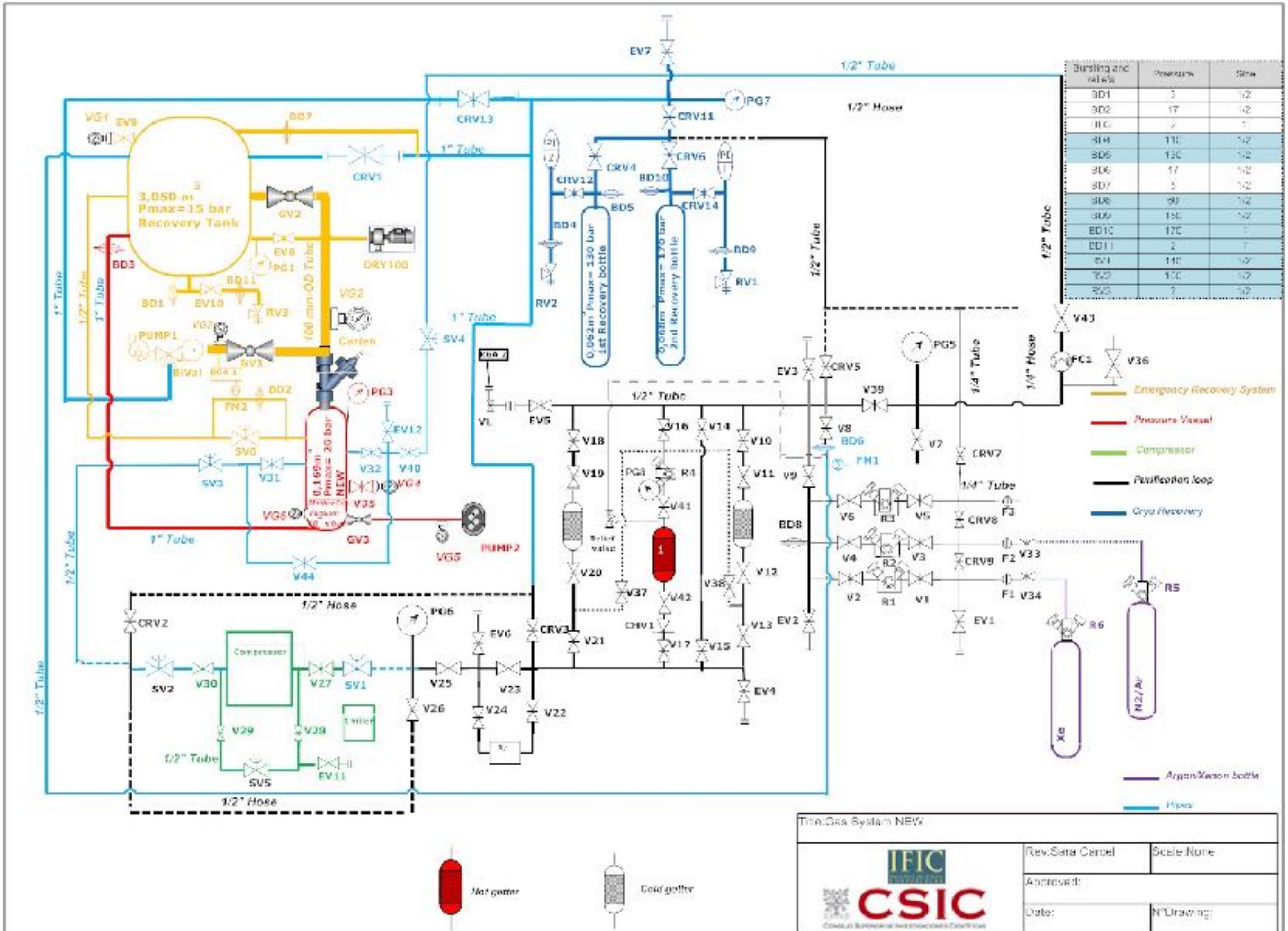
PRESSURE VESSEL



Stainless Steel 316 alloy.

Radiopure and light

GAS SYSTEM



1/2" Tube
1/2" Hose
1" Tube
1/4" Tube
1/4" Hose
3,050 m³
Pmax=15 bar
Recovery Tank
0,062m³ Pmax= 130 bar
1st Recovery bottle
2nd Recovery bottle
0,169m³
Pmax= 20 bar
NEW
PUMP1
PUMP2
DRY100
Compressor
Emergency Recovery System
Pressure Vessel
Compressor
Purification loop
Cryo Recovery
Argon/Xenon bottle
Pipes
Hot getter
Cold getter
Xe
N2/Ar
Title:Gas System NEW
Rev:Sara Carcel
Scale:None
Approved:
Date:
N°Drawing:
IFIC
CSIC

GAS SYSTEM

cryo-recovery bottle

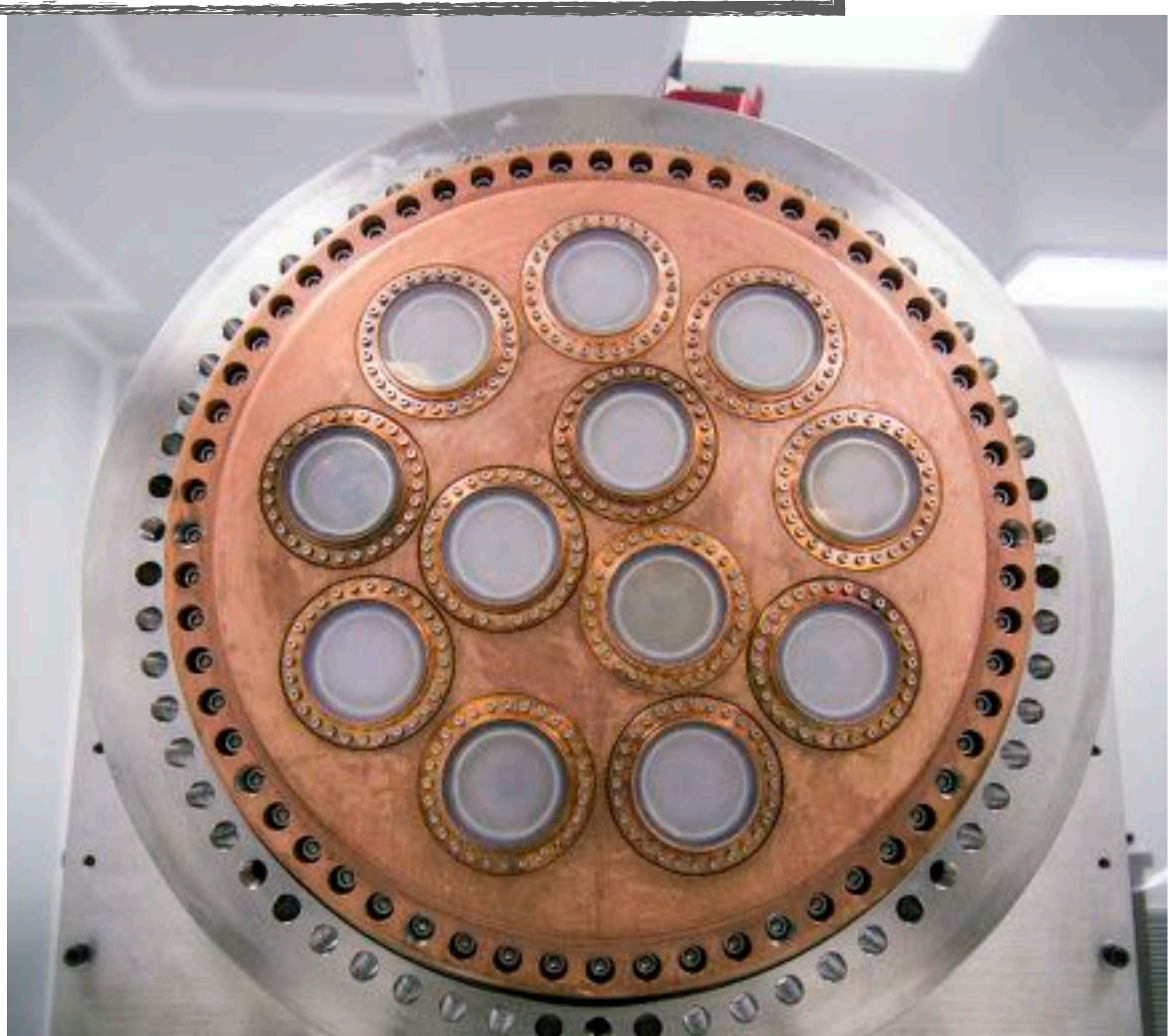
getters

Triple diaphragm compressor to prevent leaks

ENERGY PLANE

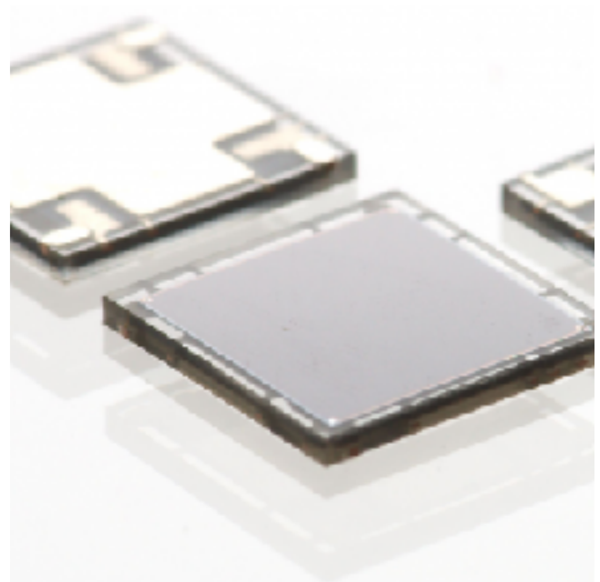
HAMATSU R11410 low radioactivity PMT

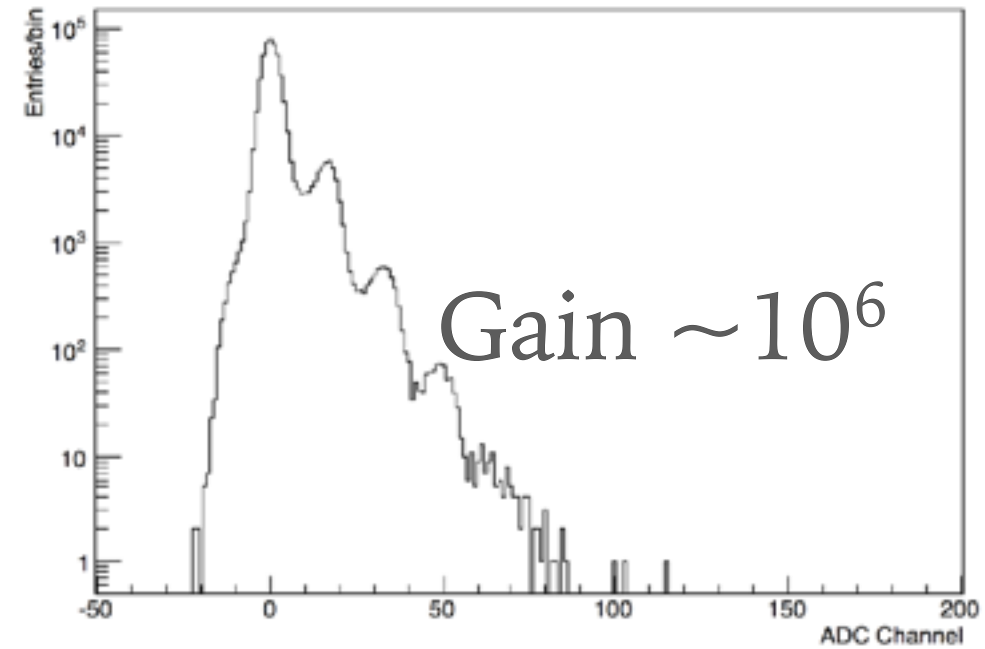
Copper plate to shield and protect PMTs



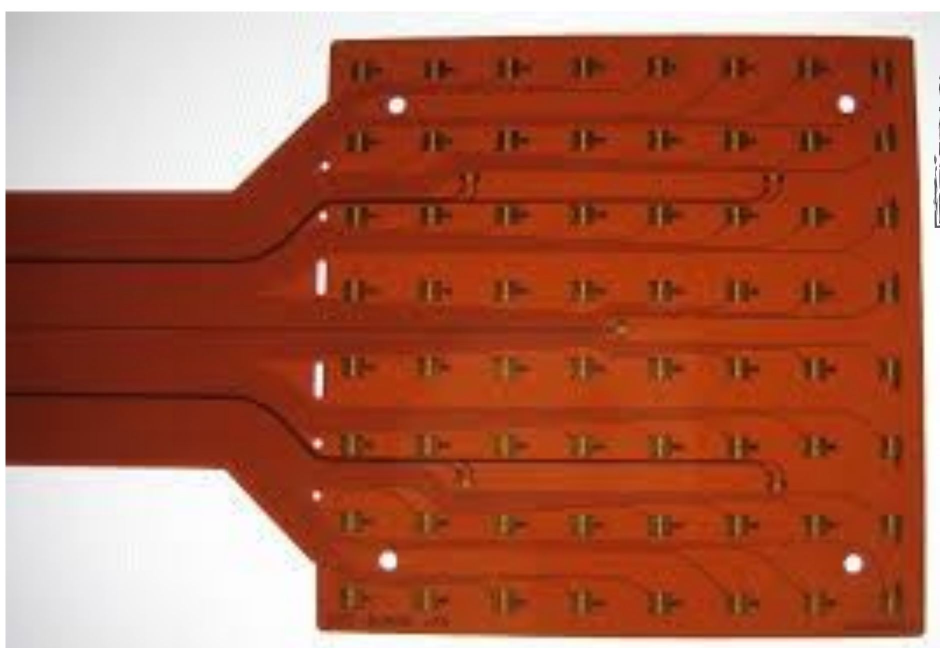
TRACKING PLANE

SensL series-C
low radioactivity



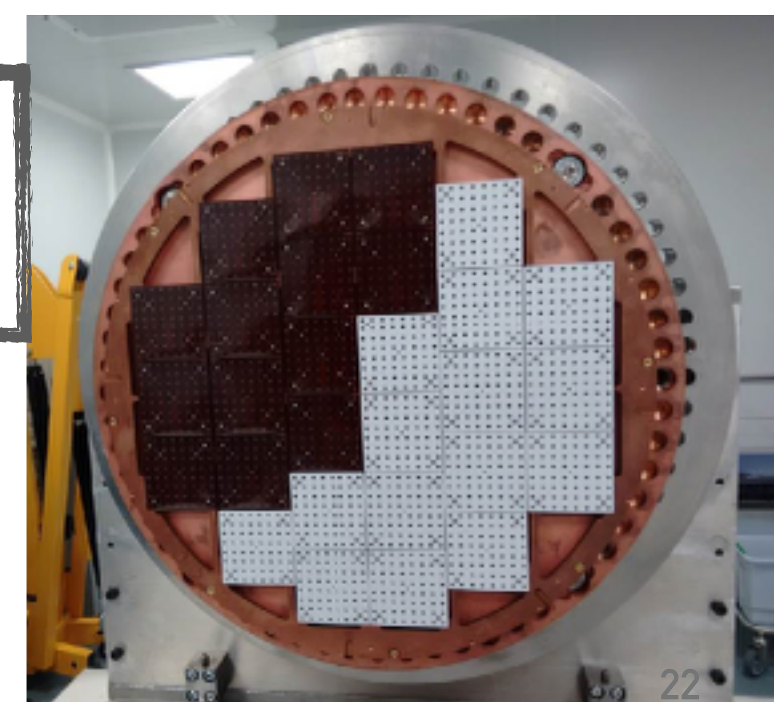


Gain $\sim 10^6$



1cm pitch between sensors

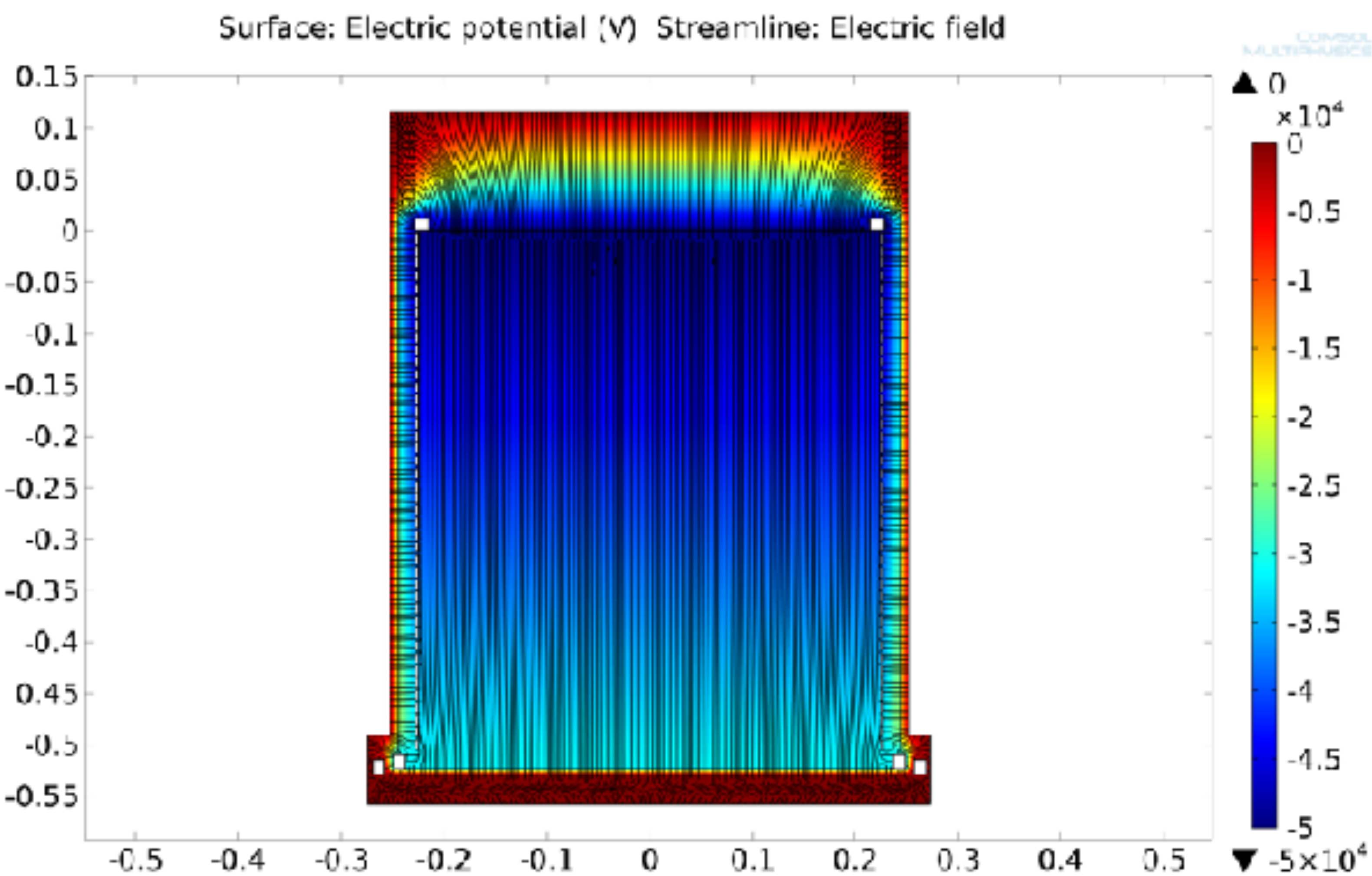
Teflon panels for extra reflection

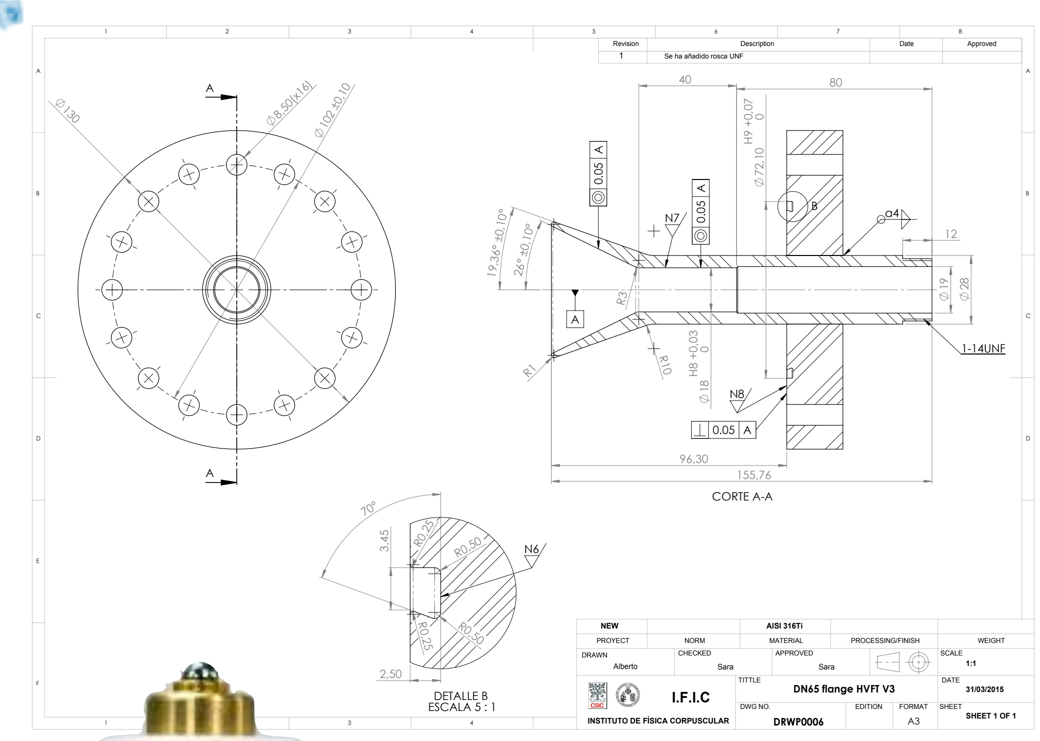


kapton boards for radiopurity and allowing connexions behind the shielding

FIELD CAGE AND HIGH VOLTAGE FEEDTHROUGH

Design and electric field simulation of the field cage and HVFT



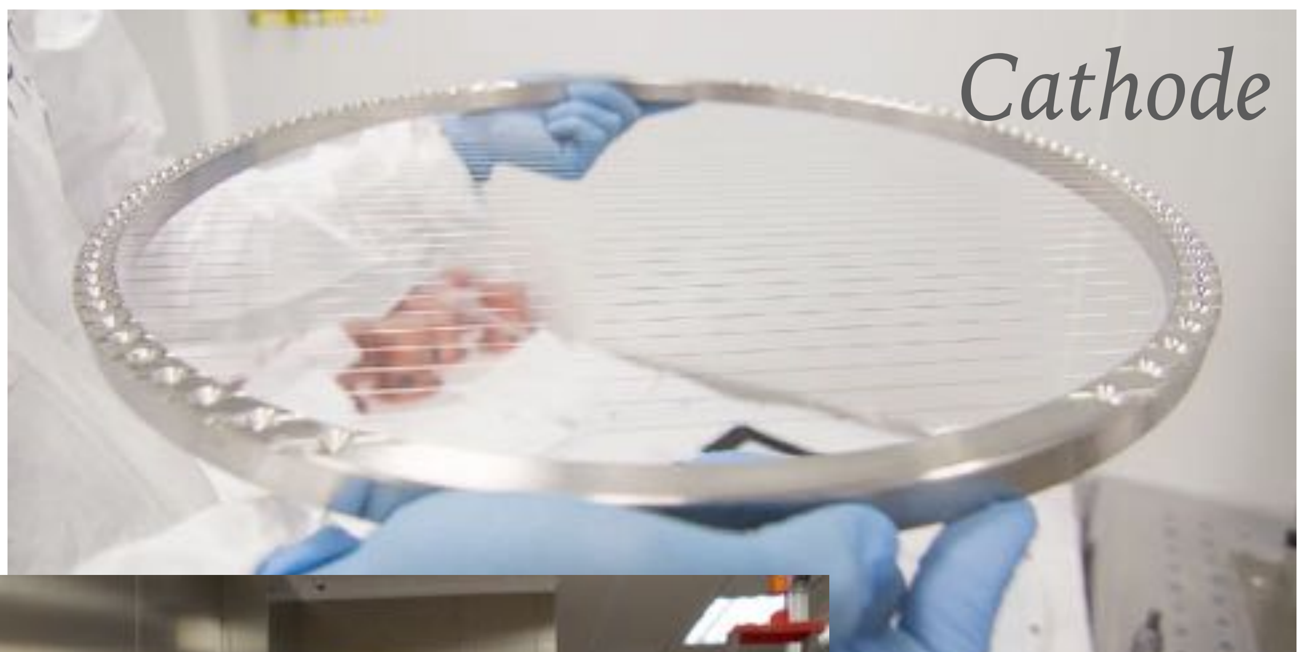


Field cage produces uniform electric field over the active volume.

HVFT operating at 28 kV at 7bar in pure Xenon

FIELD CAGE

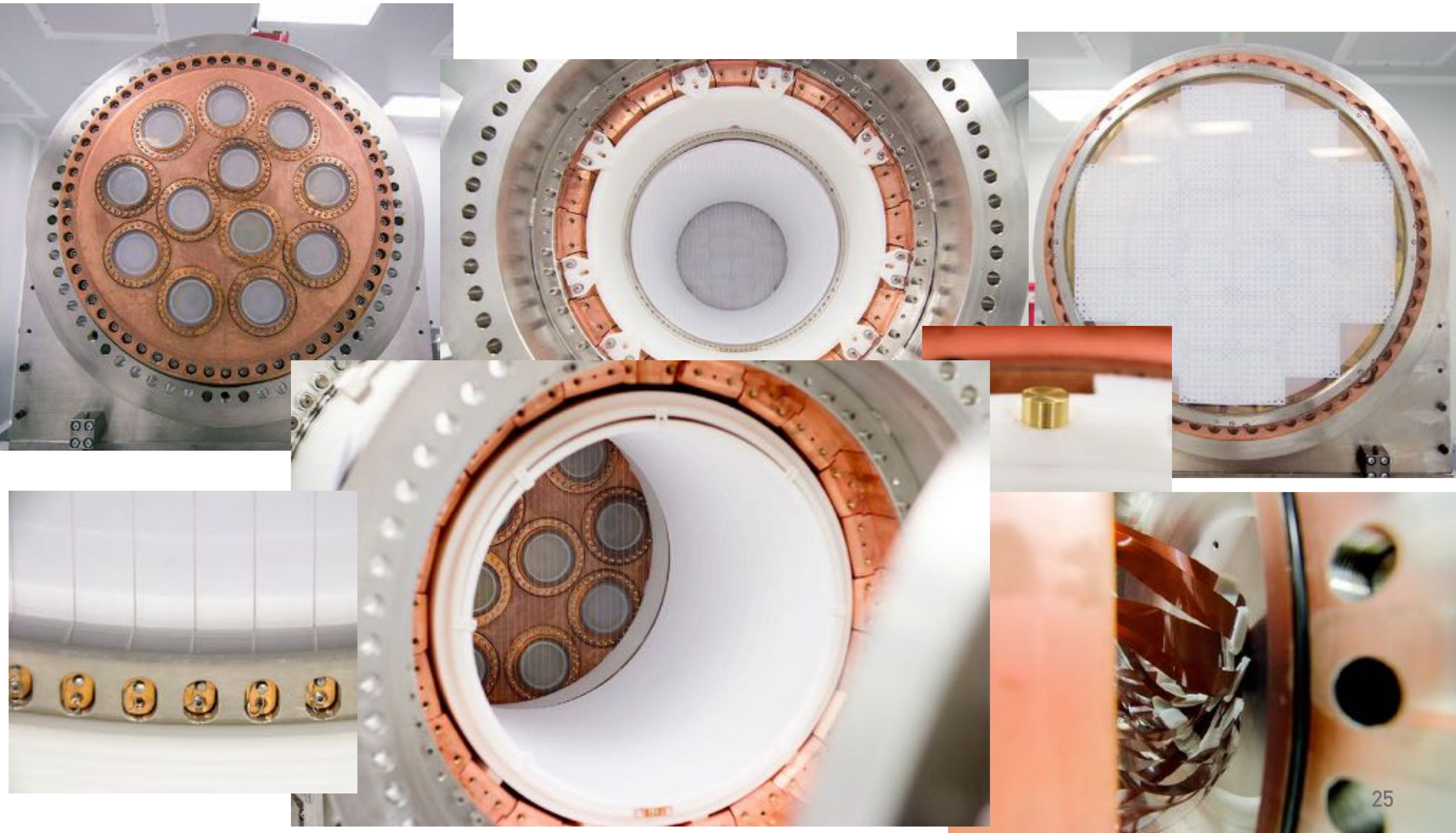
Cathode, Gate, tpb coating for the anode and light reflector tube



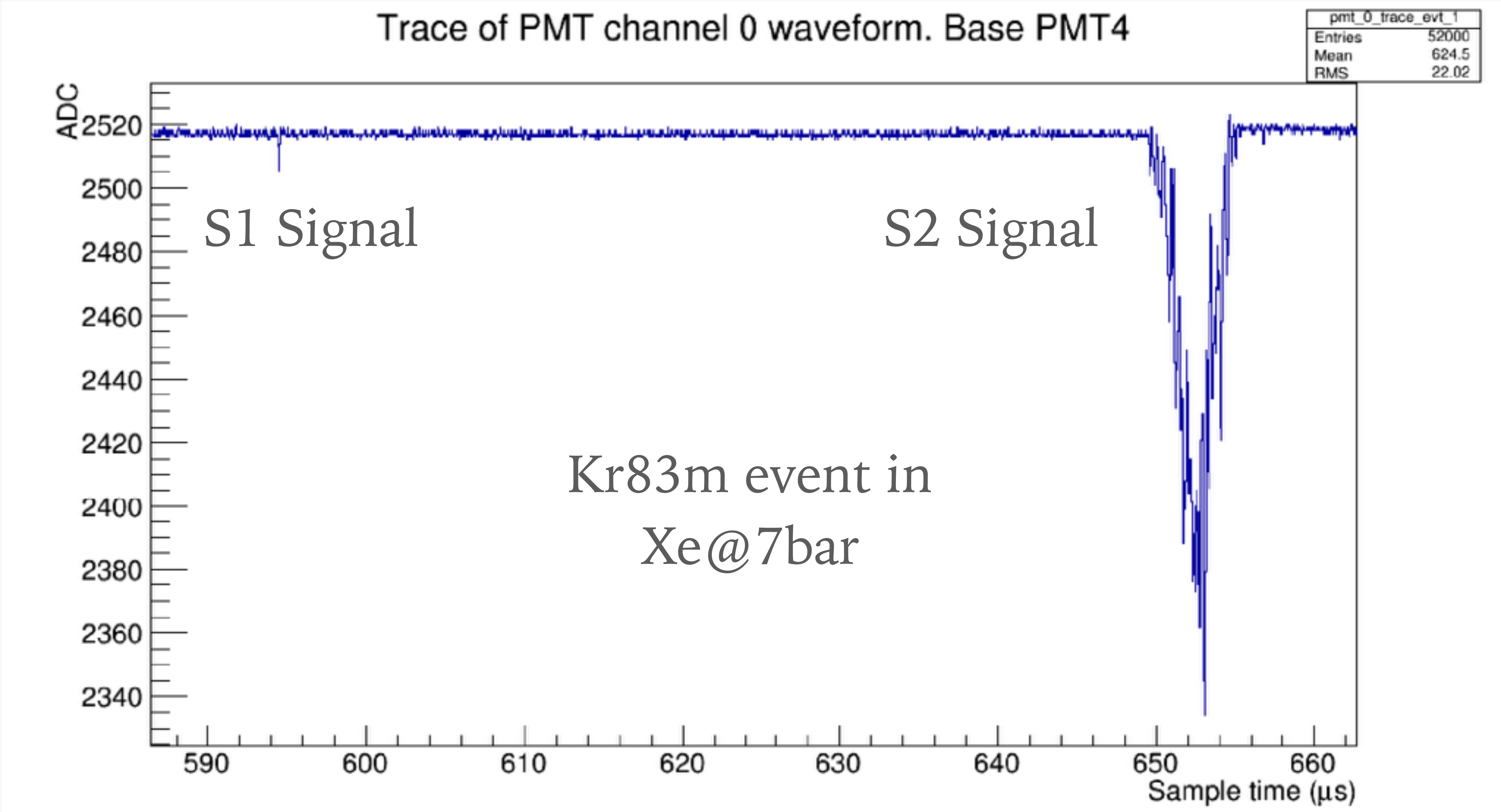
Anode plate

Light tube

INSIDE NEXT-WHITE

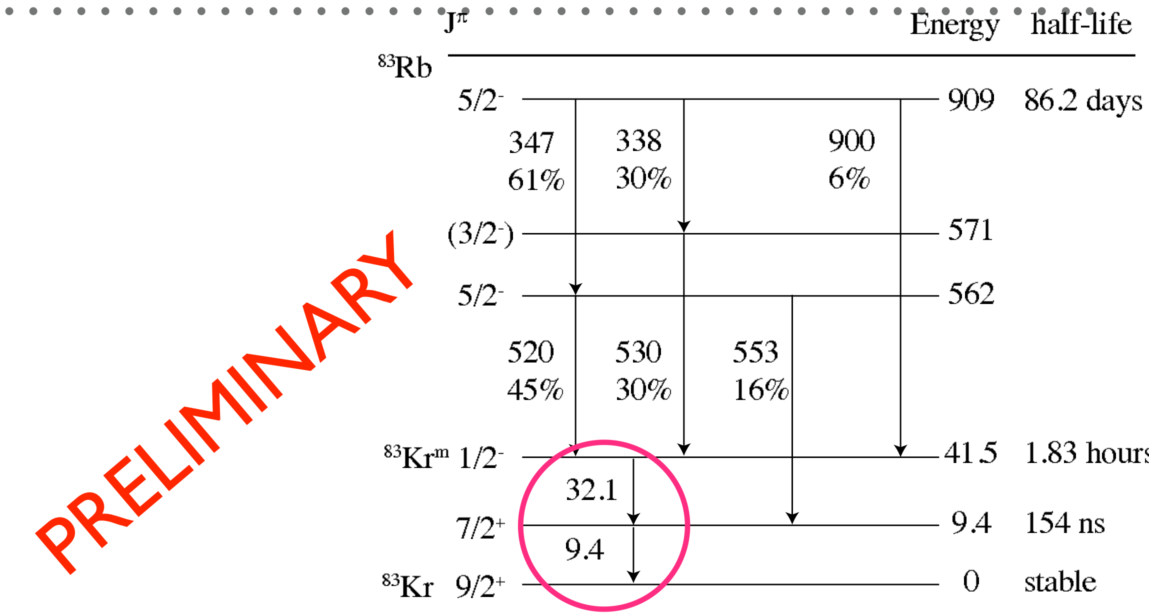


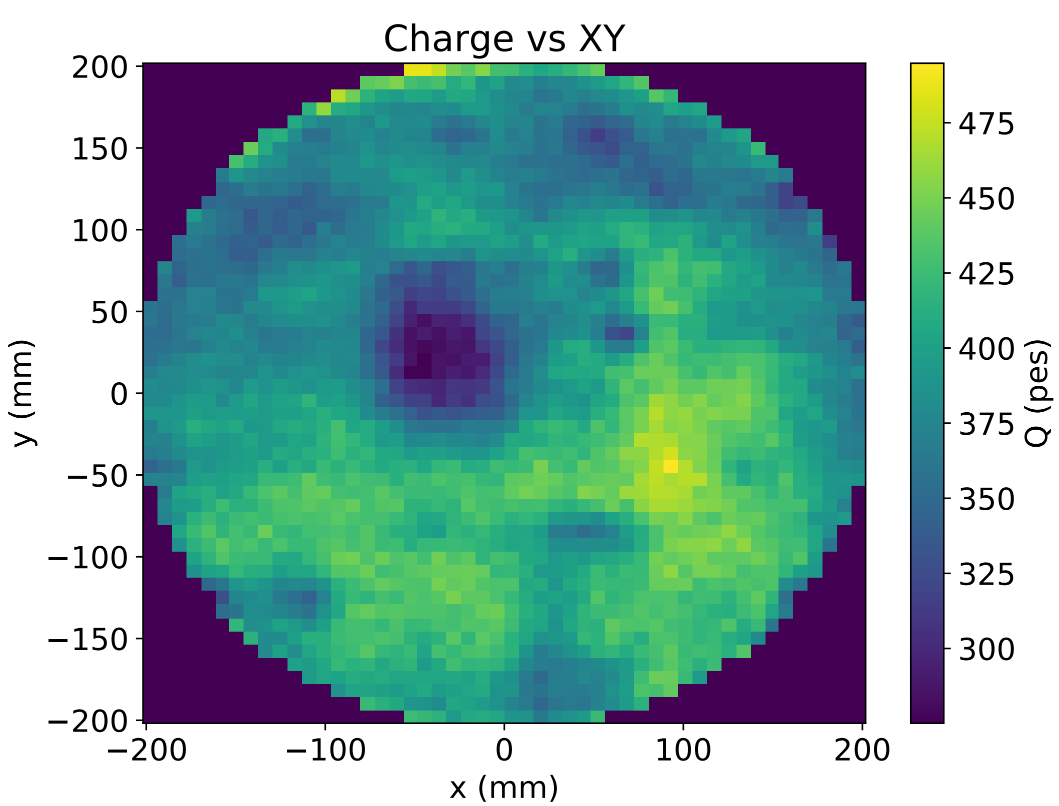
FIRST WAVEFORMS

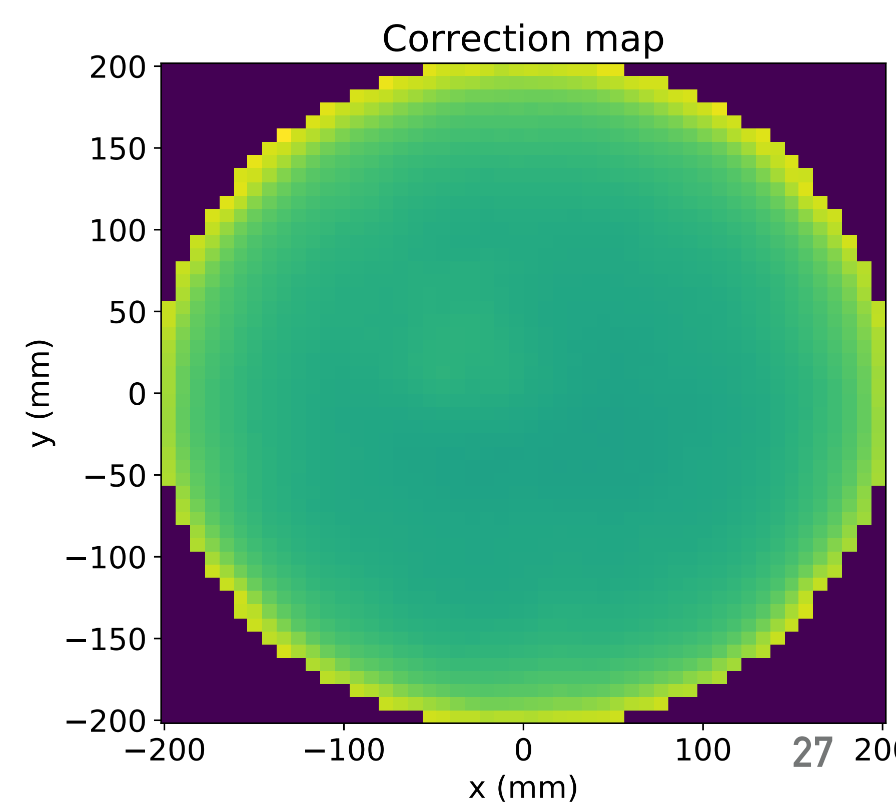


FIRST RESULTS

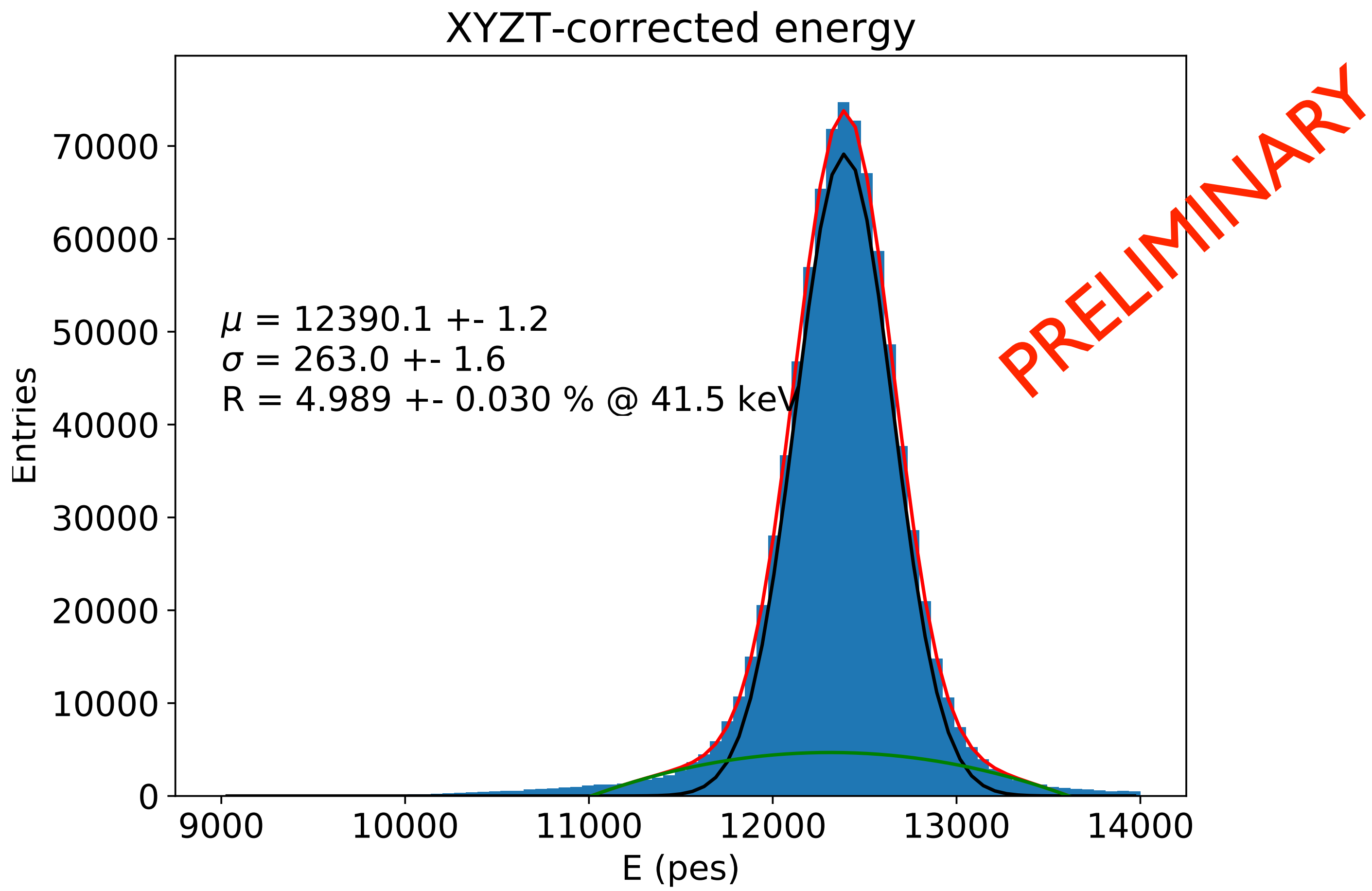
- *Source of Rb-83 inserted in the gas system inside a capsule.*
- *It decays with a half-life of 86 days to an excited state of Kr-83, which diffuses in the whole system and eventually reaches the chamber.*
- *Kr-83 goes to ground state emitting electrons with total energy of ~41.5 keV.*
- *Almost point-like depositions, very useful to characterize the detector: electron attachment and drift velocity, geometric corrections.*



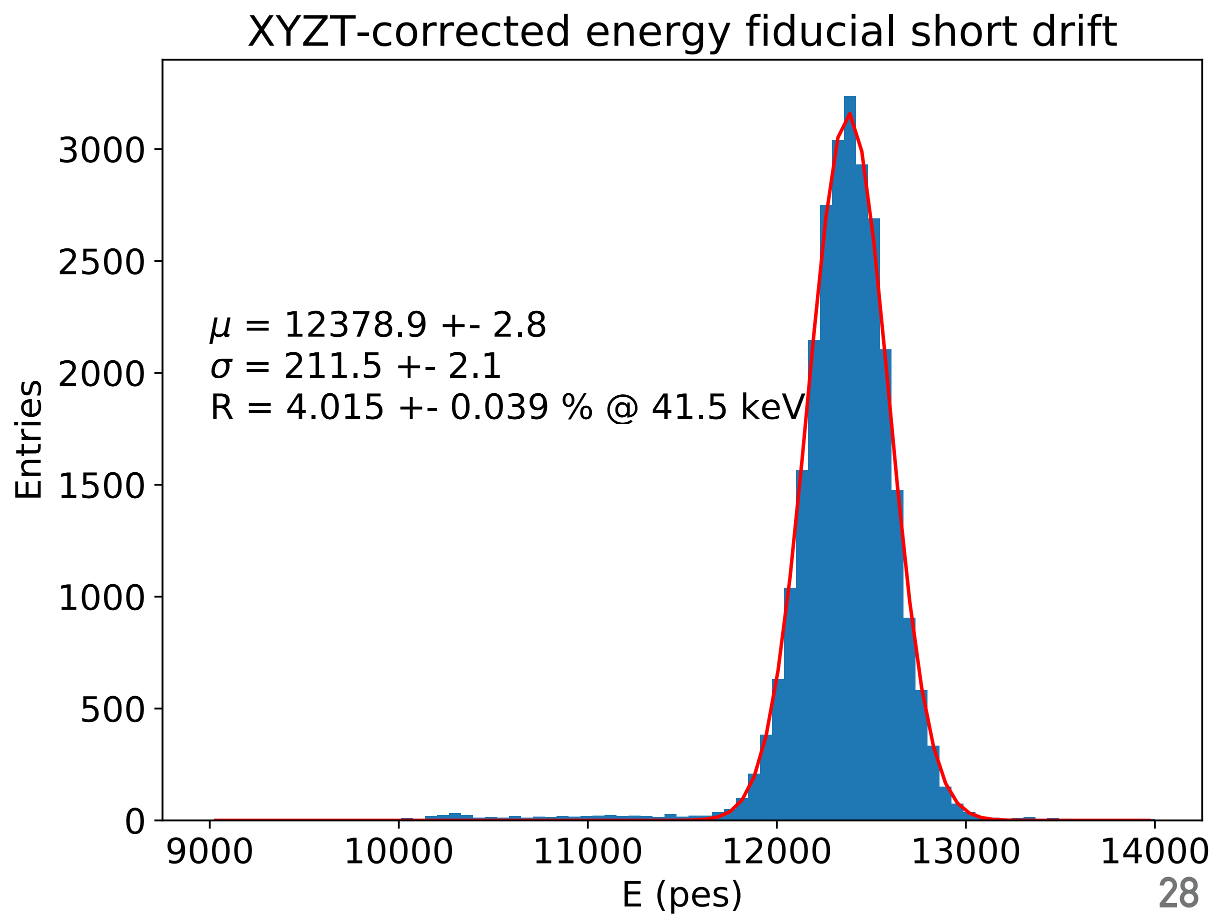




^{83}Kr

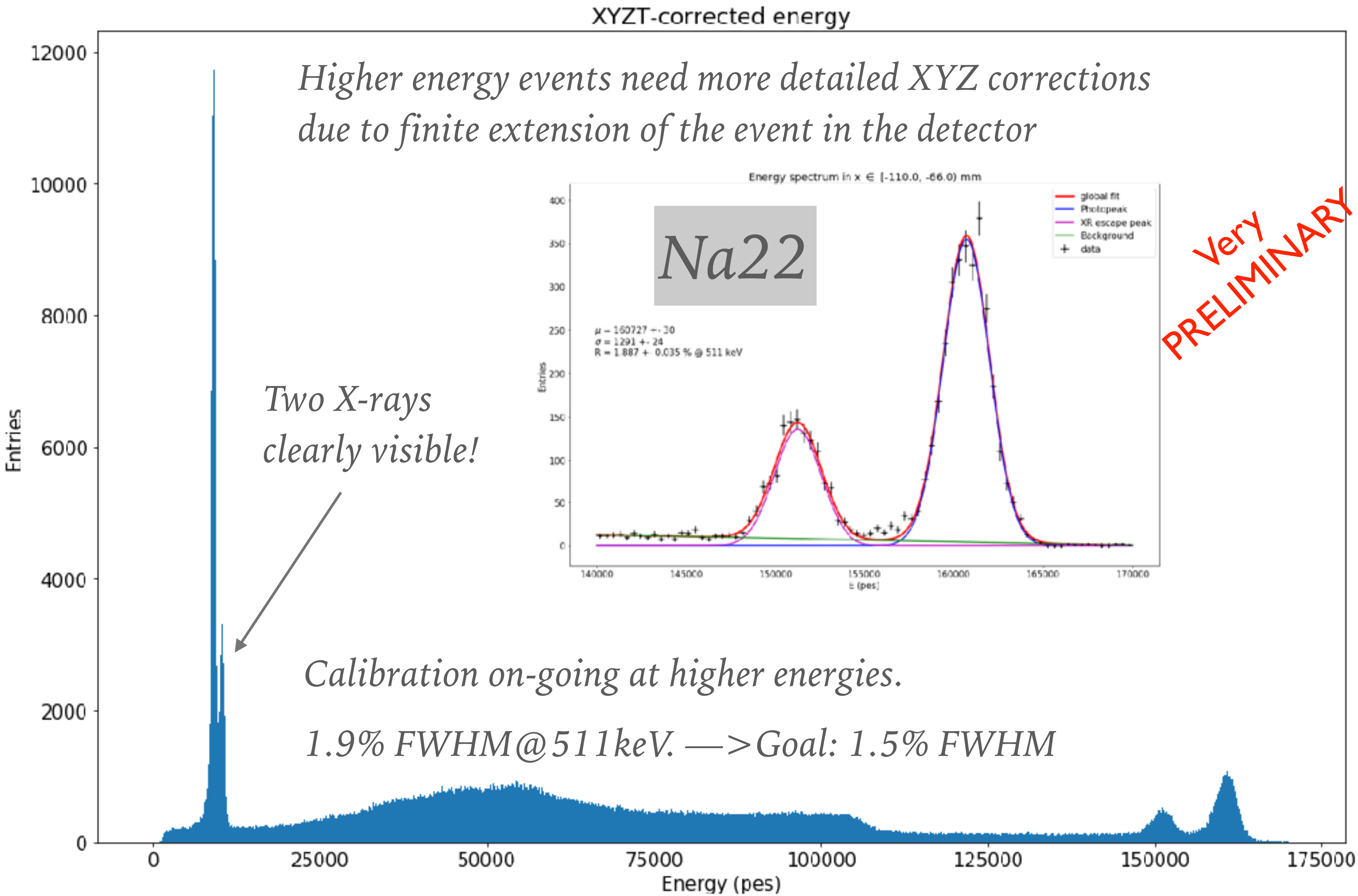


Energy resolution at low energies matches previous results in prototypes

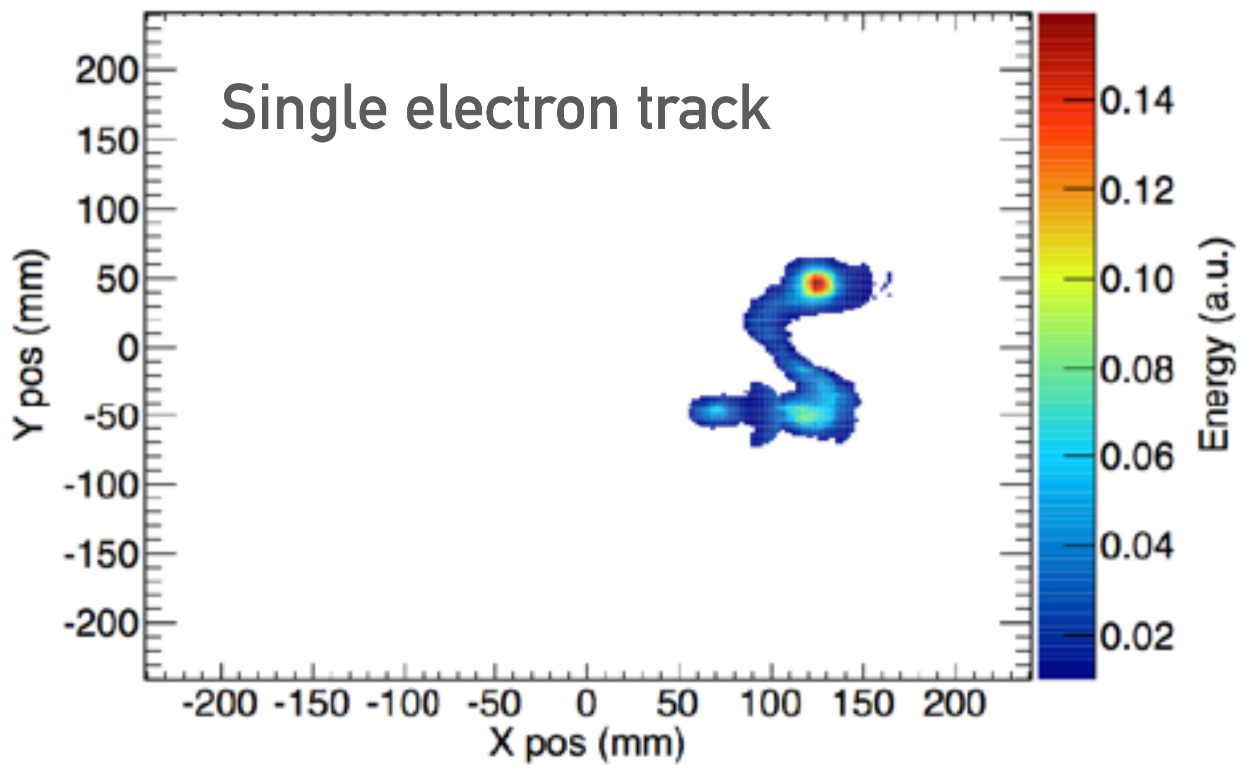


Still some radial dependance:

Room for improvement!


XYZT-corrected energy
Higher energy events need more detailed XYZ corrections
due to finite extension of the event in the detector
Energy spectrum in x ∈ [-110.0, -66.0) mm
Na22
global fit
Photopeak
XR escape peak
Background
data
μ = 160727 +- 30
σ = 1291 +- 24
R = 1.887 +- 0.035 % @ 511 keV
Entries
E (pes)
Very
PRELIMINARY
Two X-rays
clearly visible!
Calibration on-going at higher energies.
1.9% FWHM@511keV. —>Goal: 1.5% FWHM
Entries
Energy (pes)

TRACKING RECONSTRUCTION



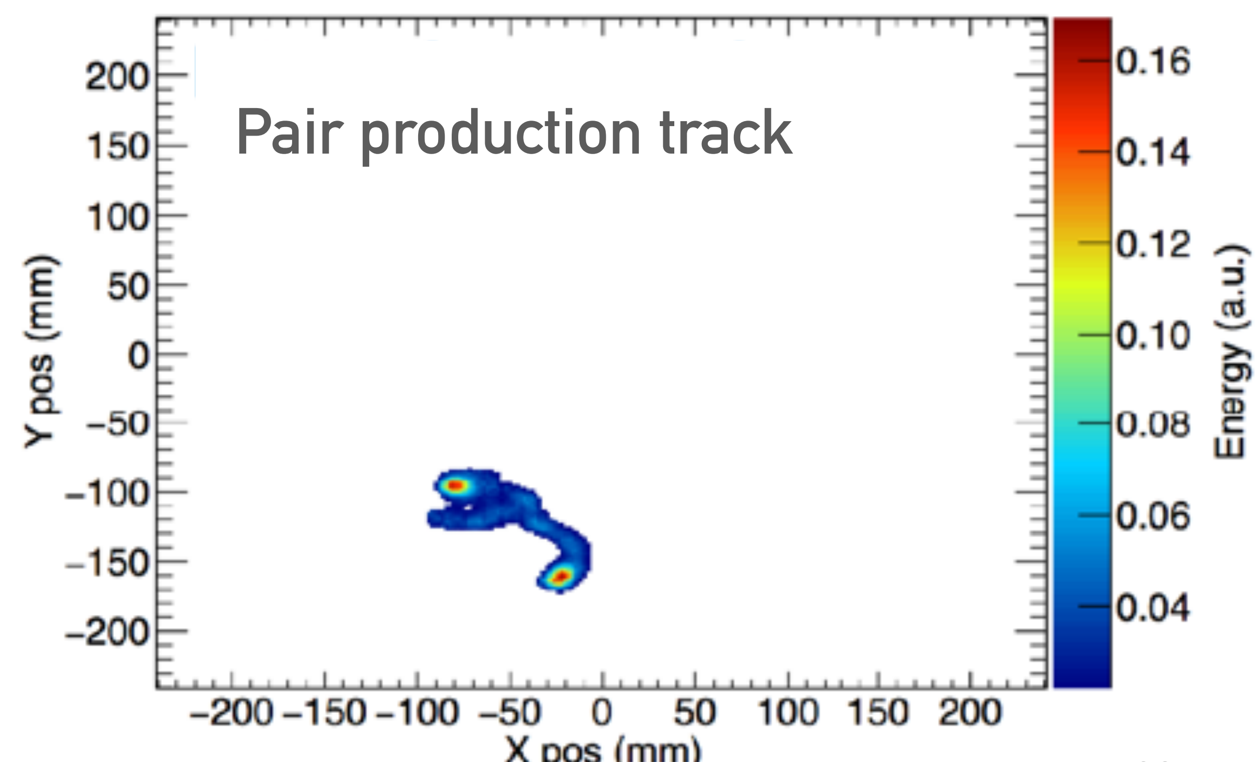
^{228}Th source emits 2.6 MeV gamma from ^{208}Tl.

This gamma has a double escape peak from pair production that produces signal-like events with two electrons.

Topology algorithms to be tested with this data.

Background rejection of the topology can be measured using this source.

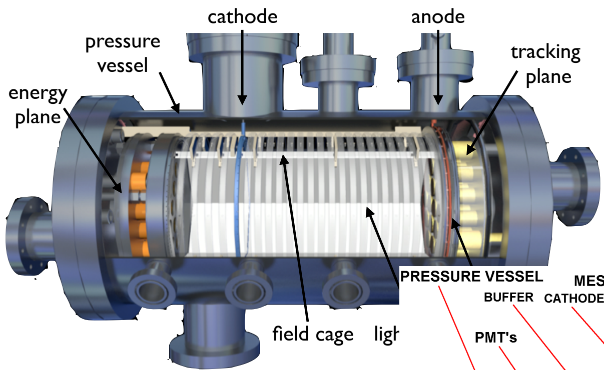
Large rejection factors may be possible.

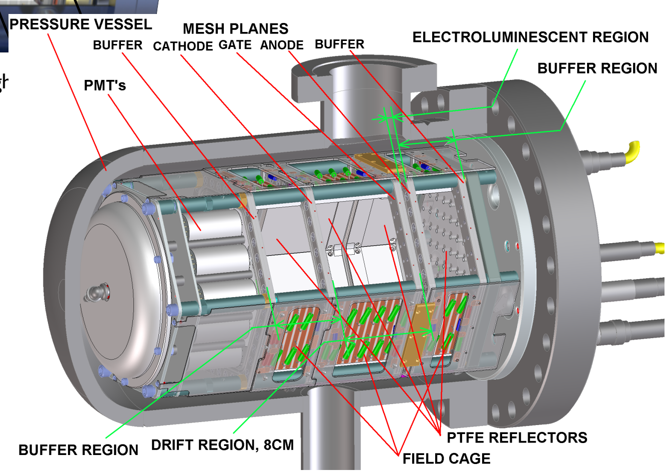


NEXT-WHITE SCHEDULE

- *Detector completed.*
  - *Calibration data with radioactive sources on-going.*
- *Physics run (background model, bb2nu): Q4 2017.*

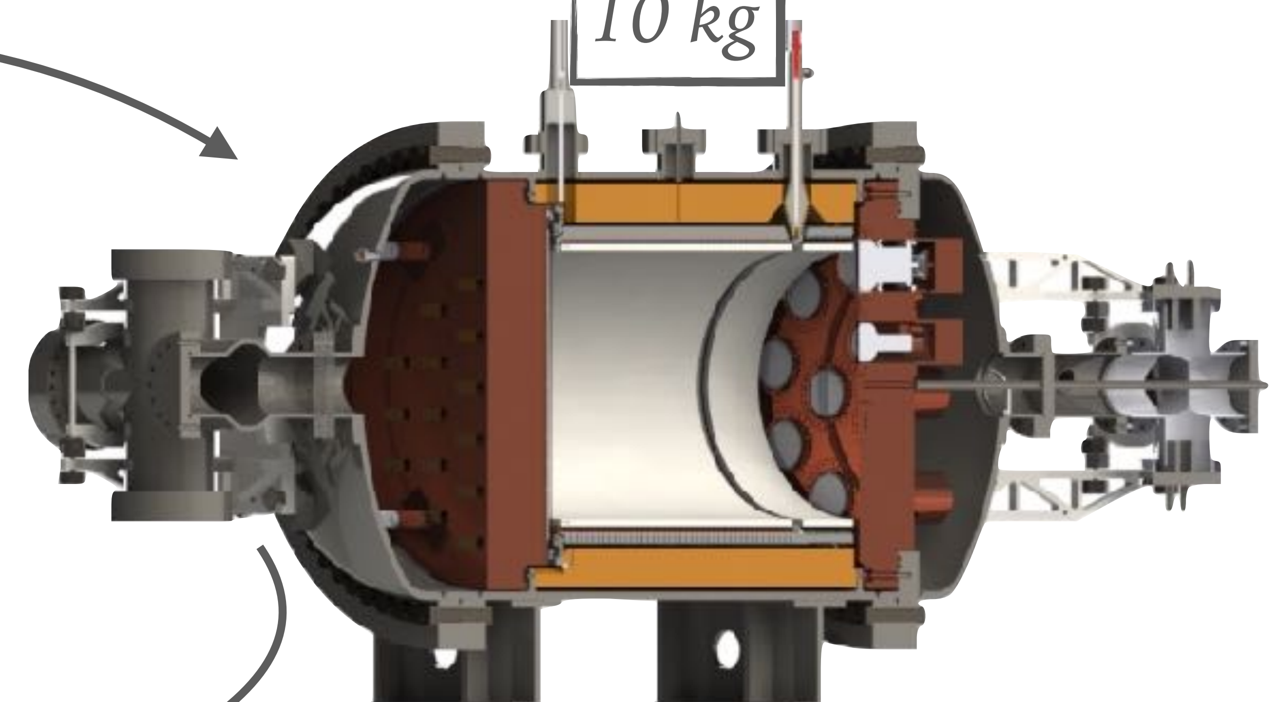
NEXT STEPS:



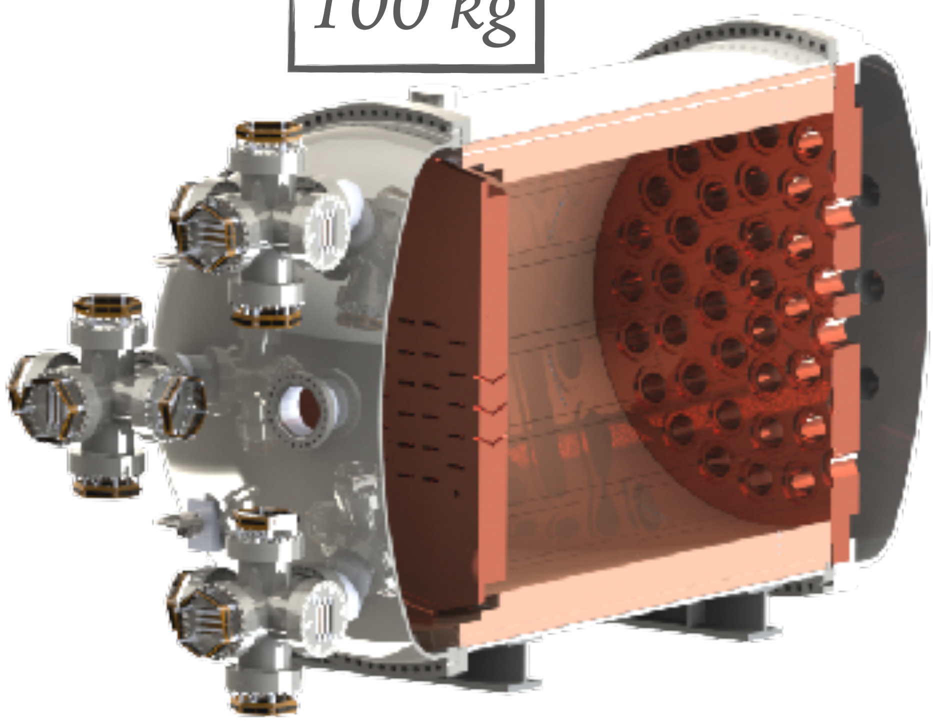


1 kg

10 kg



100 kg



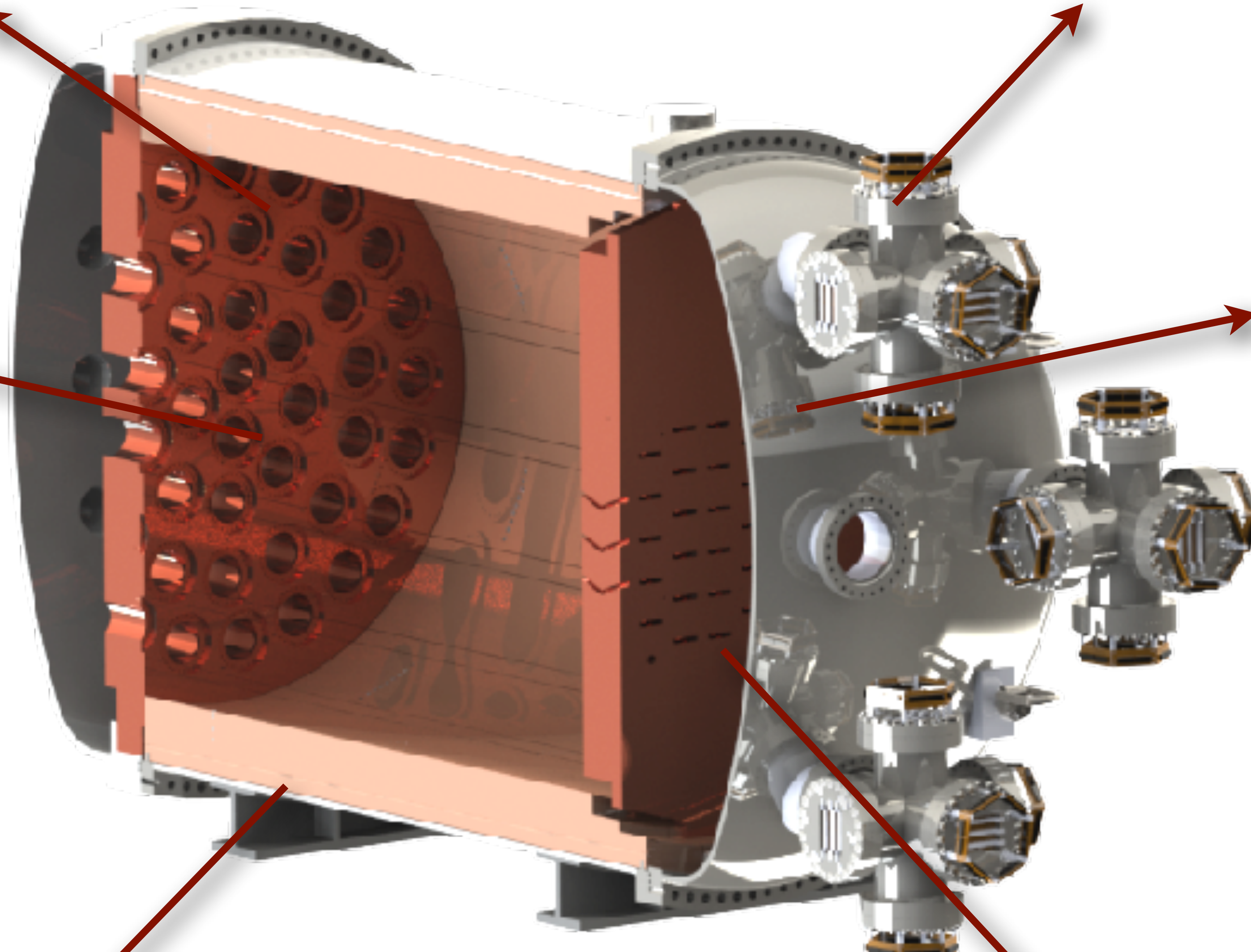
NEXT-ton

NEXT 100 kg detector at LSC: main features

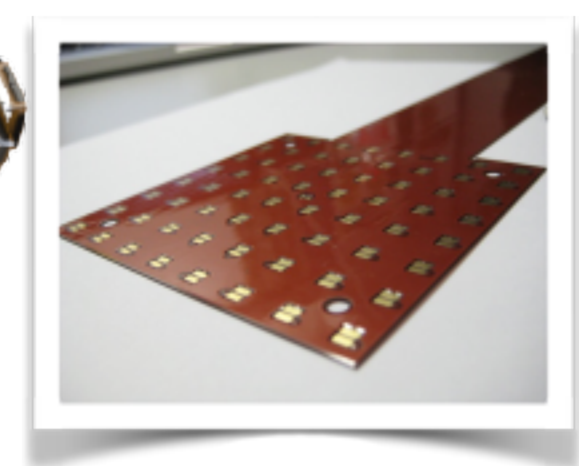
Time Projection Chamber:
100 kg active region, 130 cm drift length

Pressure vessel:
stainless steel,15 bar max pressure

Energy plane:
60 PMTs,
30% coverage



Tracking plane:
7,000 SiPMs,
1 cm pitch



Outer shield:
lead, 20 cm thick

Inner shield:
copper, 12 cm thick

BACKGROUNDS IN NEXT-100

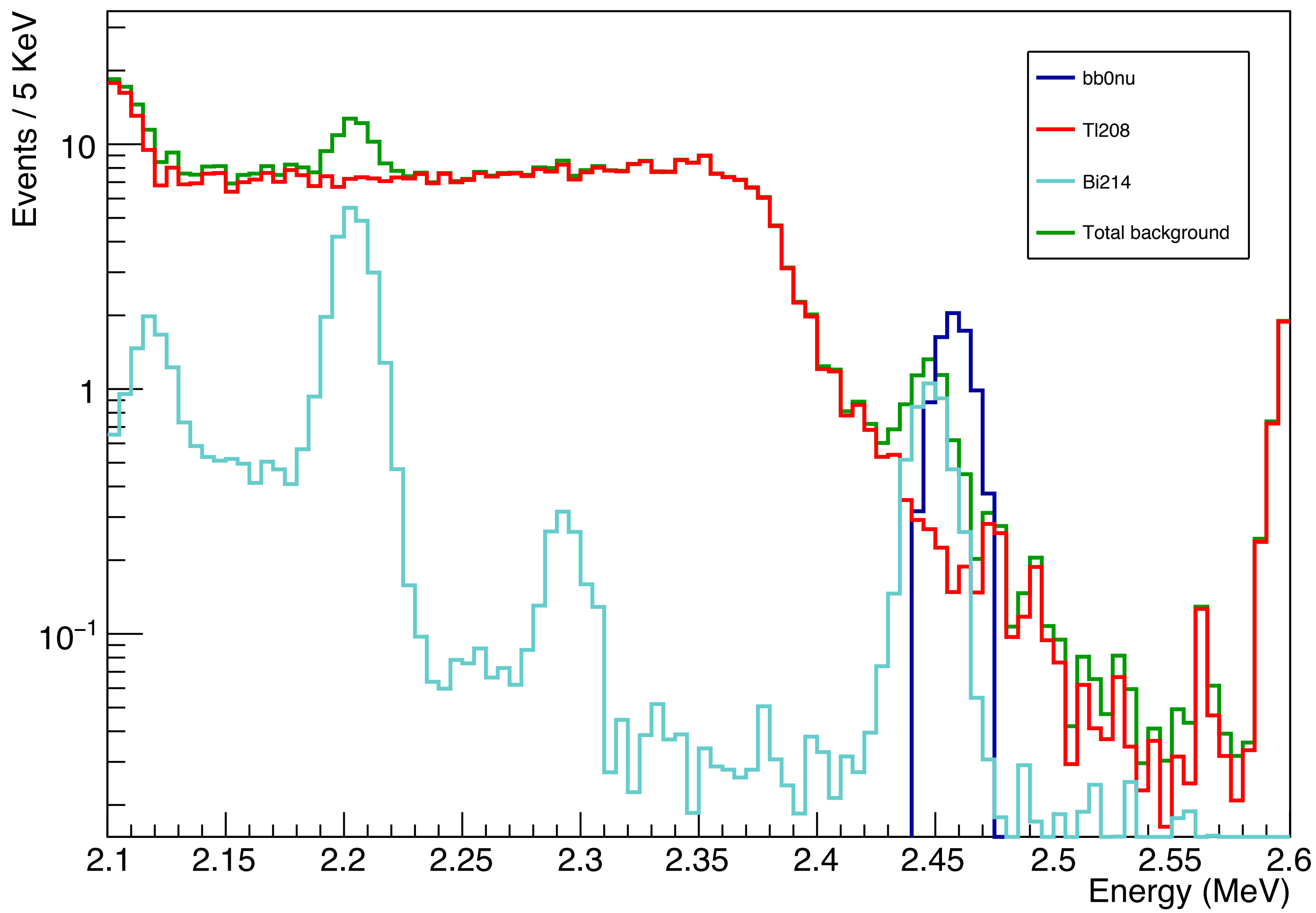
Main backgrounds:

*^{208}**Tl:** 2.6 MeV gamma.*

*^{214}**Bi:** 2.447 gamma.*

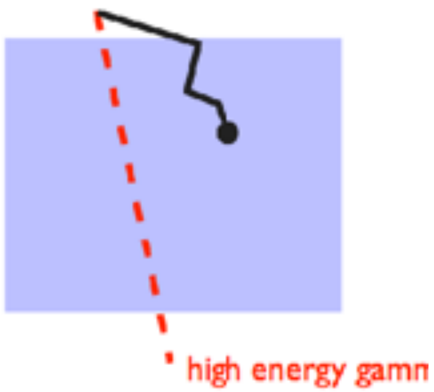
All materials used for NEXT-100 construction have been screened:

Ge detectors, GDMS techniques,…



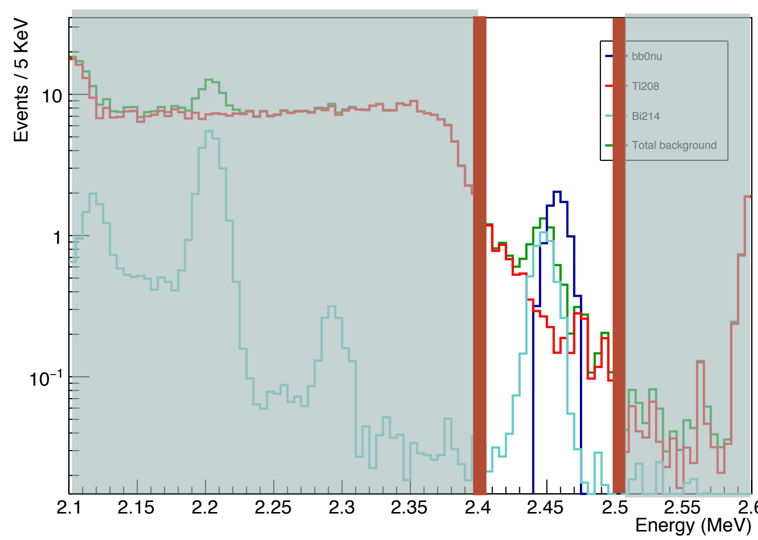
Simulated spectra near the $Q_{\beta\beta}$ for Xe

BACKGROUNDS IN NEXT-100: CUTS

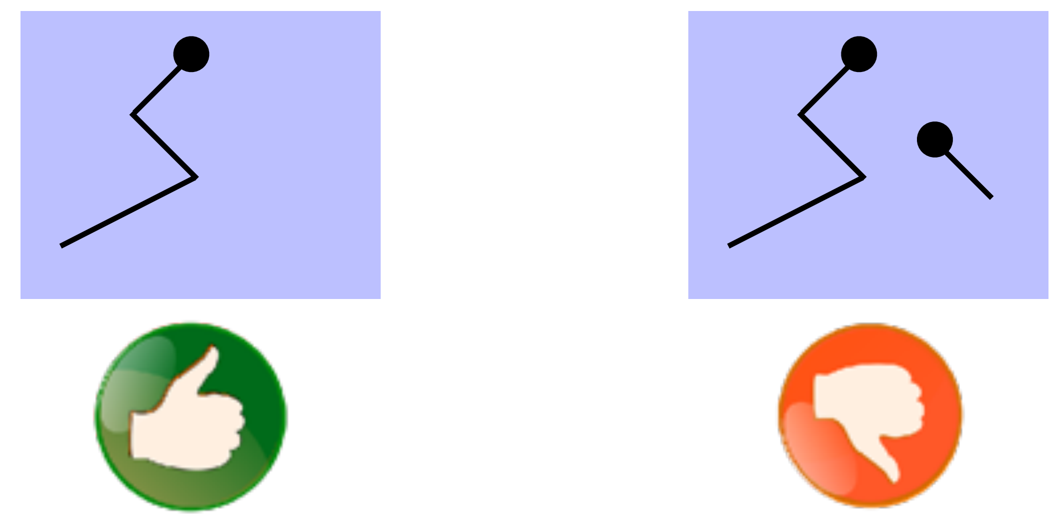


fiducial cut

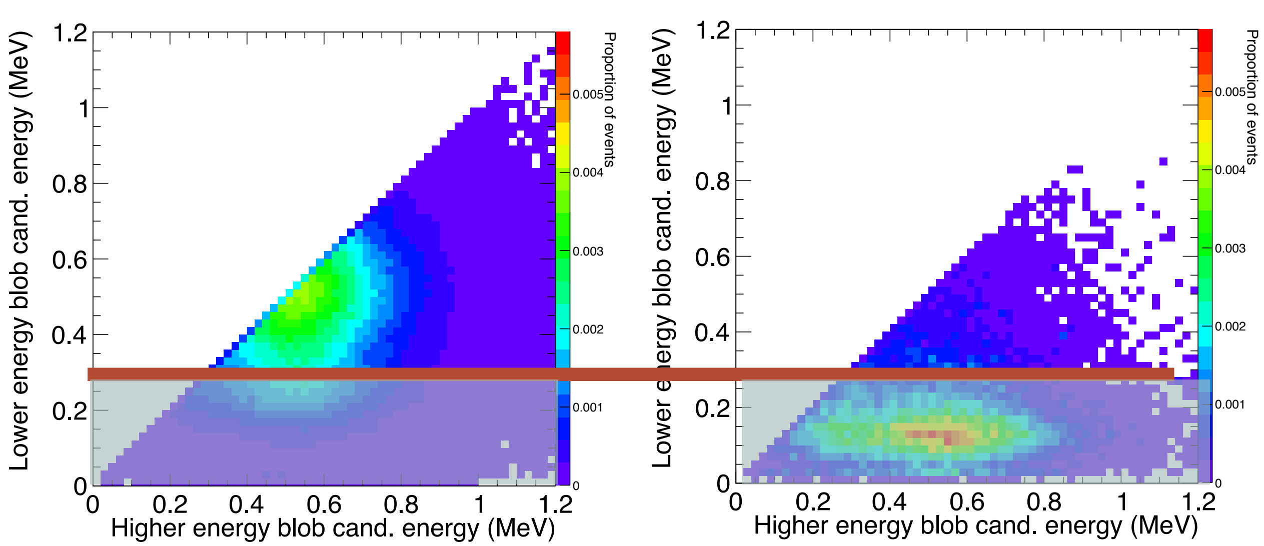
Wide energy cut between 2.4 and 2.5 MeV



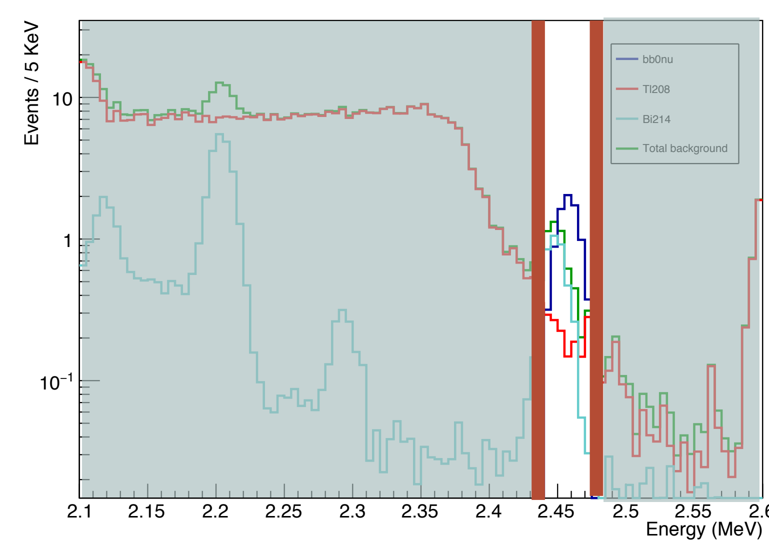
Single energy deposition



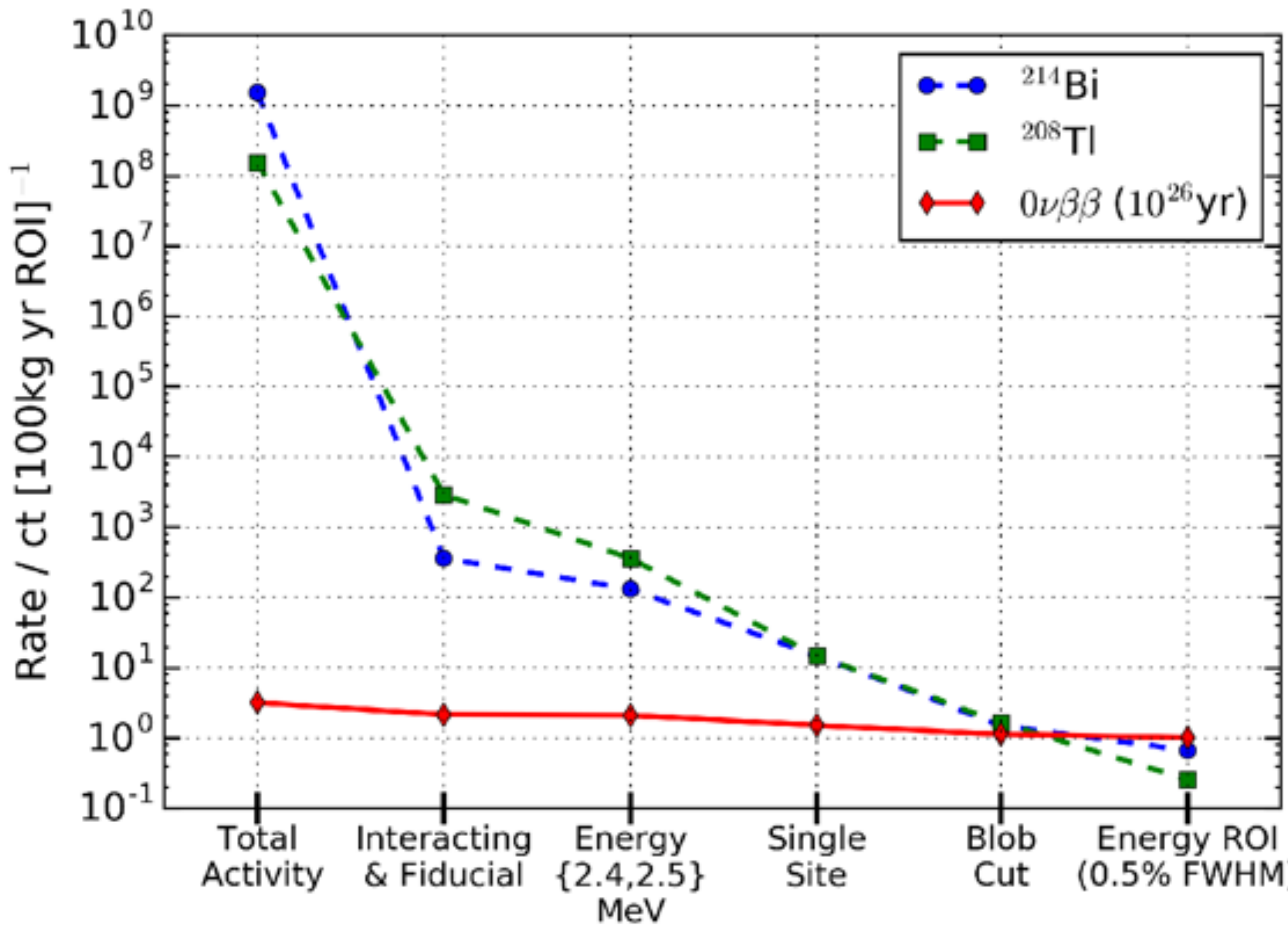
Two vs one blob



Region of interest

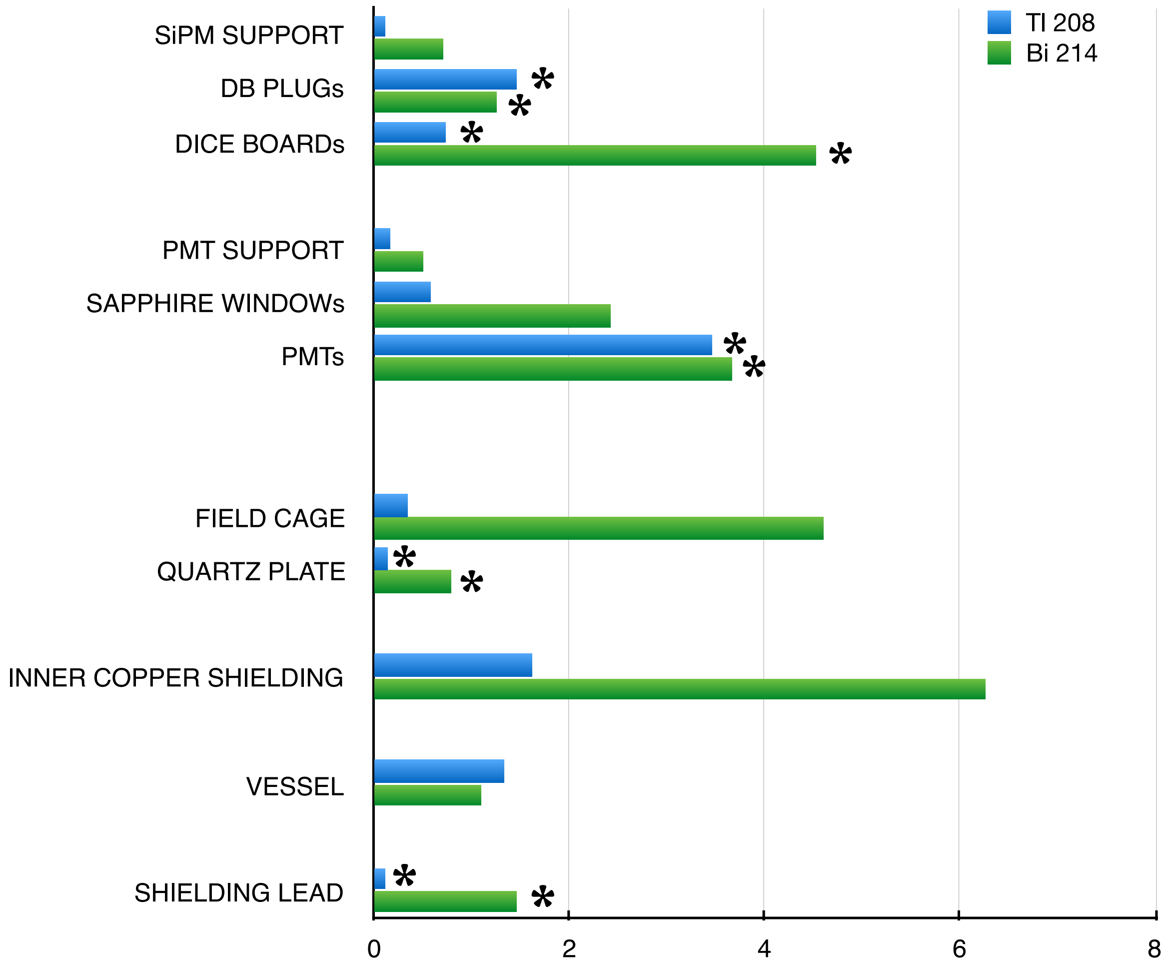


BACKGROUNDS IN NEXT-100: CUTS

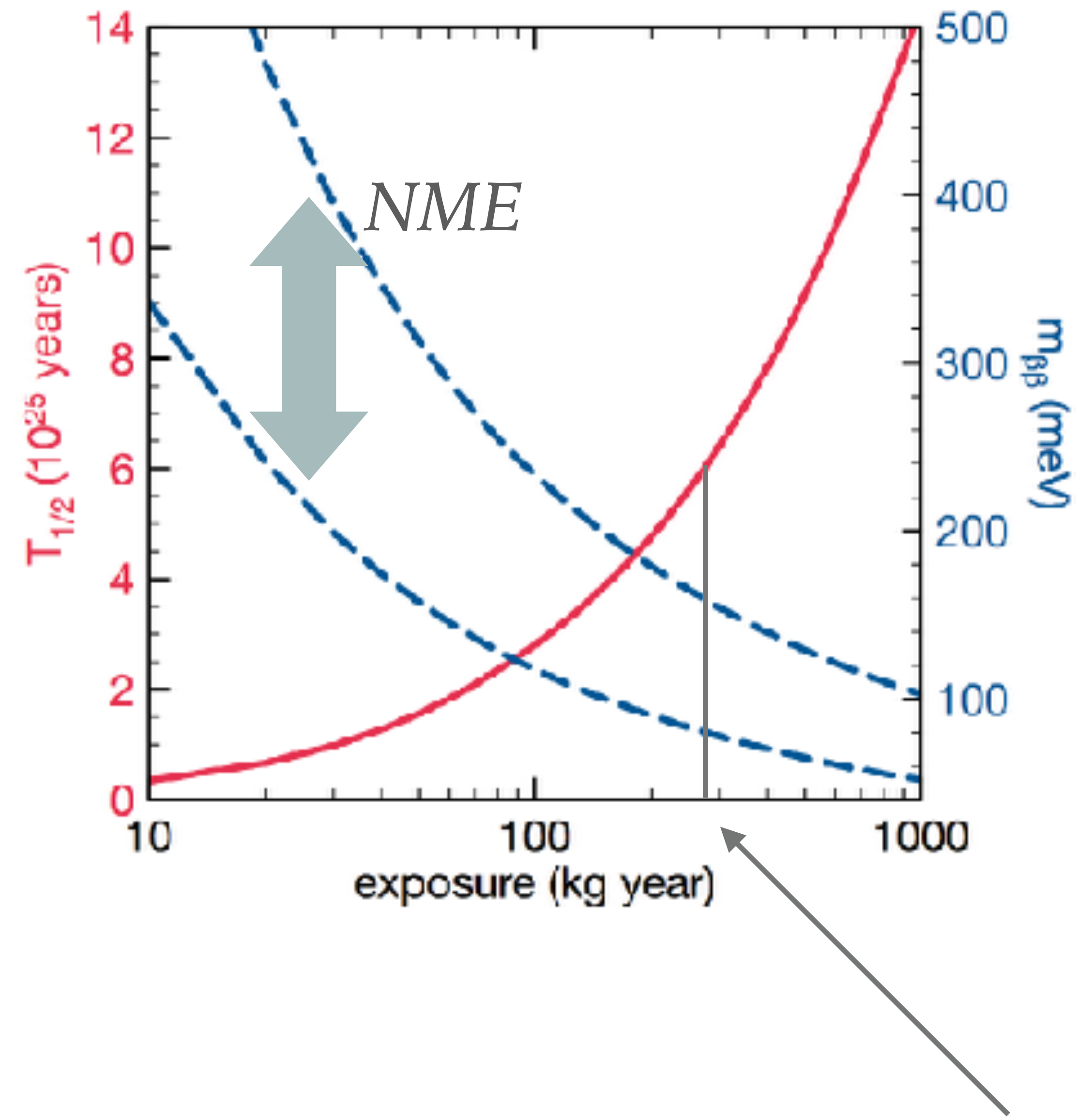


- *Signal simulated in the active volume.*
- *Tl and Bi simulated in the different components of the detector.*
- *Most of the background gammas either do not interact with the detector or deposit energy far from ROI.*

BACKGROUND REJECTION IN NEXT-100



NEXT-100 background rate x 10^{-5} counts/(keV kg year).
* come from actual measurements (otherwise are limit).



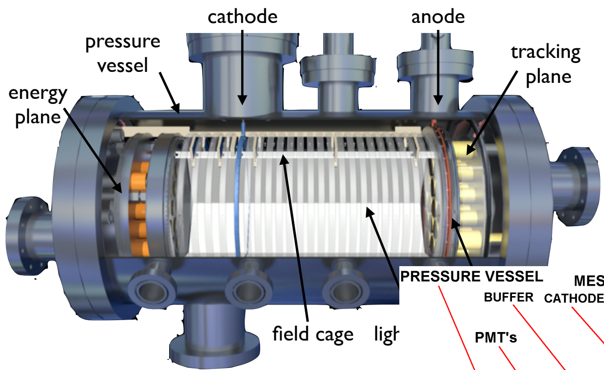
- *All known background sources are included except ^{137}Xe (TBD).*
- *Total expected background rate : $<4\cdot10^{-4}$ evt/keV kg year*

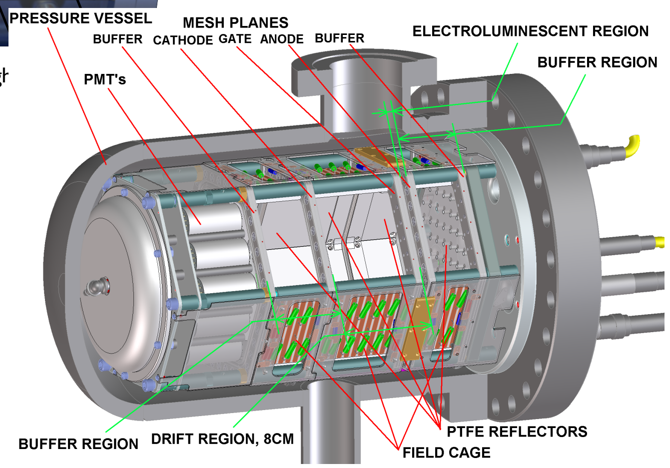
- *Expect a half life sensitivity of $6\cdot10^{25}$ with an exposure of 275 kg·year.*
- *$m_{\beta\beta}$ ~[90-180] meV.*

NEXT-100 GOALS

- Extend NEXT technology towards near tonne scale.
- Measurement of background index at the 100 kg scale.
- Physics run:
  - Precise measurement of 2 neutrino mode.
  - Competitive sensitivity to neutrino-less process.

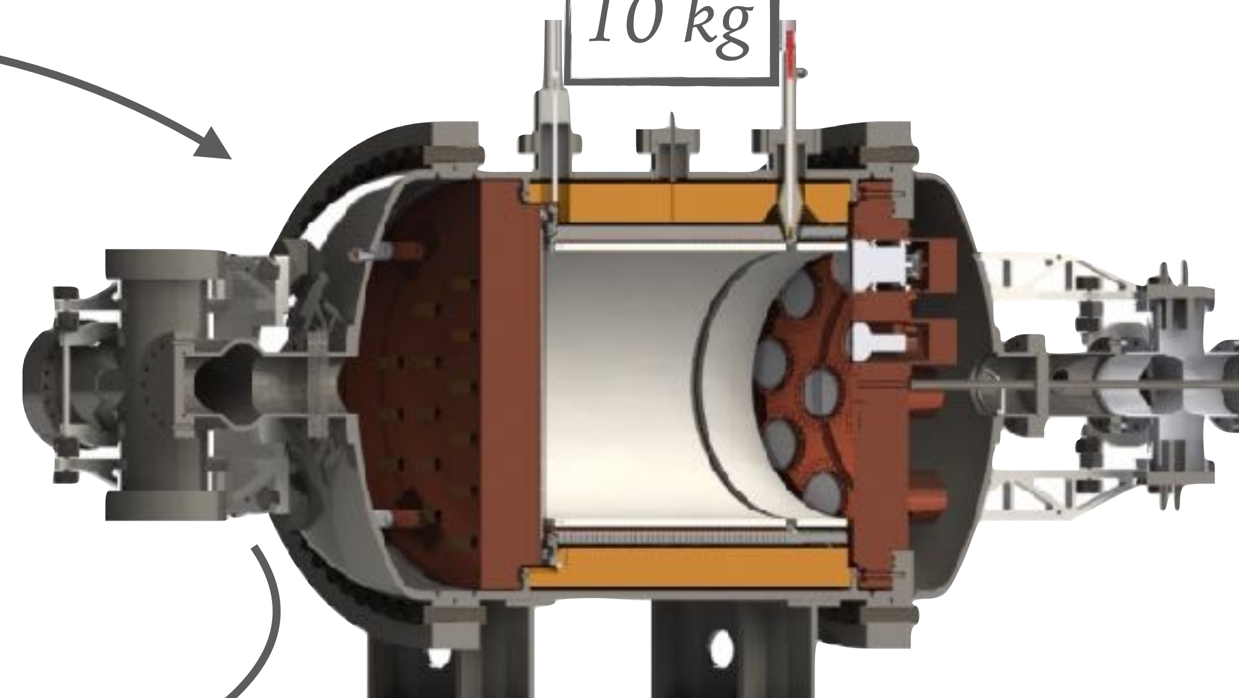
NEXT STEPS:



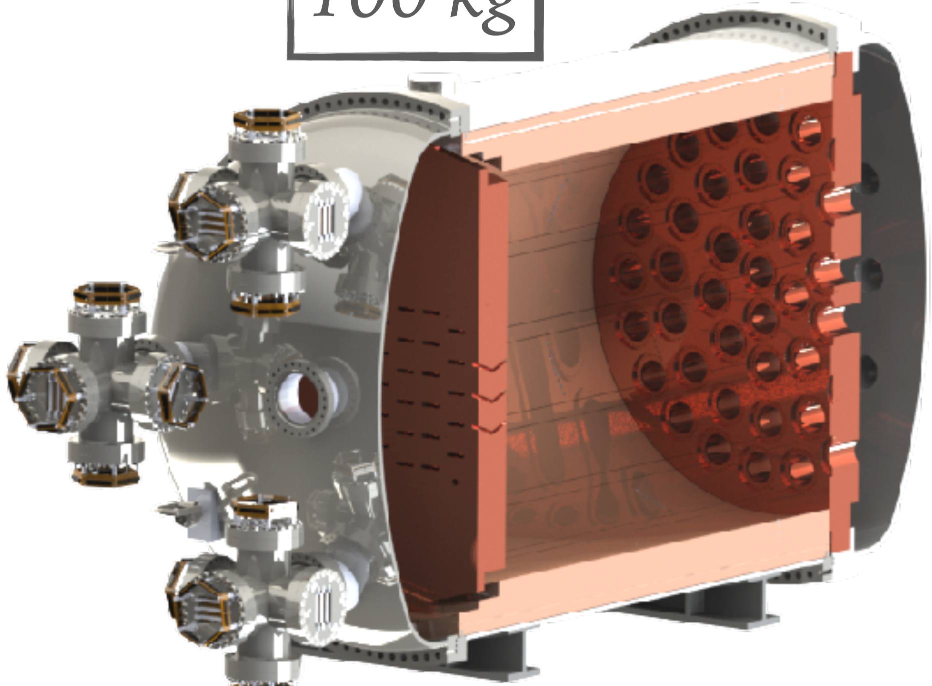


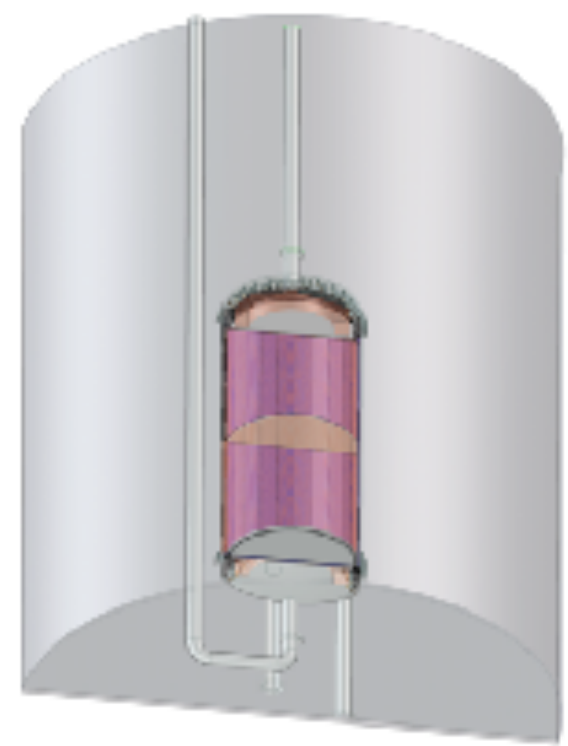
1 kg

10 kg



100 kg





NEXT-ton

NEXT-TON:

- **Goal:** Reach "background free" ~ton scale active volume.
- **Approach:** Multi-site multi-modular detectors.
    - *Simplify construction.*
    - *Minimize single-point failure risk.*
    - *Reduce uncertainty in case of a discovery.*
    - *Possible operation of enriched and depleted Xenon in different modules.*
- **Possible locations:** Europe (LSC, Gran Sasso), North America (SNOlab, SURF) and Australia (Stawell) or South America (Andes).

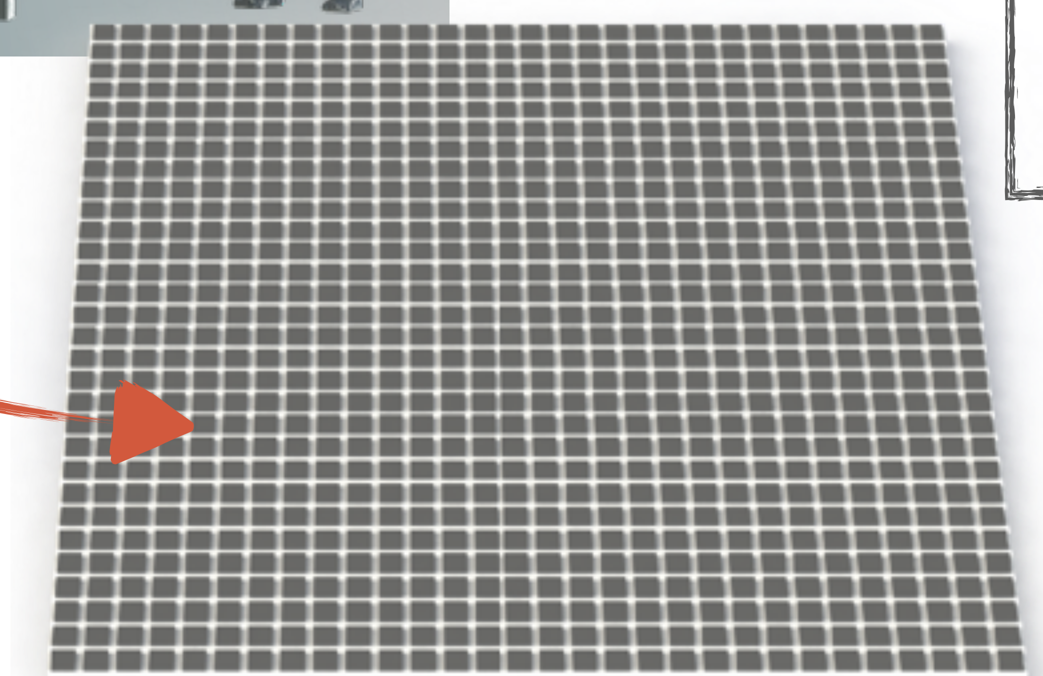
NEXT-TON: WHAT DOES THE DETECTOR LOOK LIKE?

Symmetric TPC with two EL regions:

- *1.5 meter diameter*
- *2 times 1.5 meter drift length*
- *~500 kg of enriched Xenon*

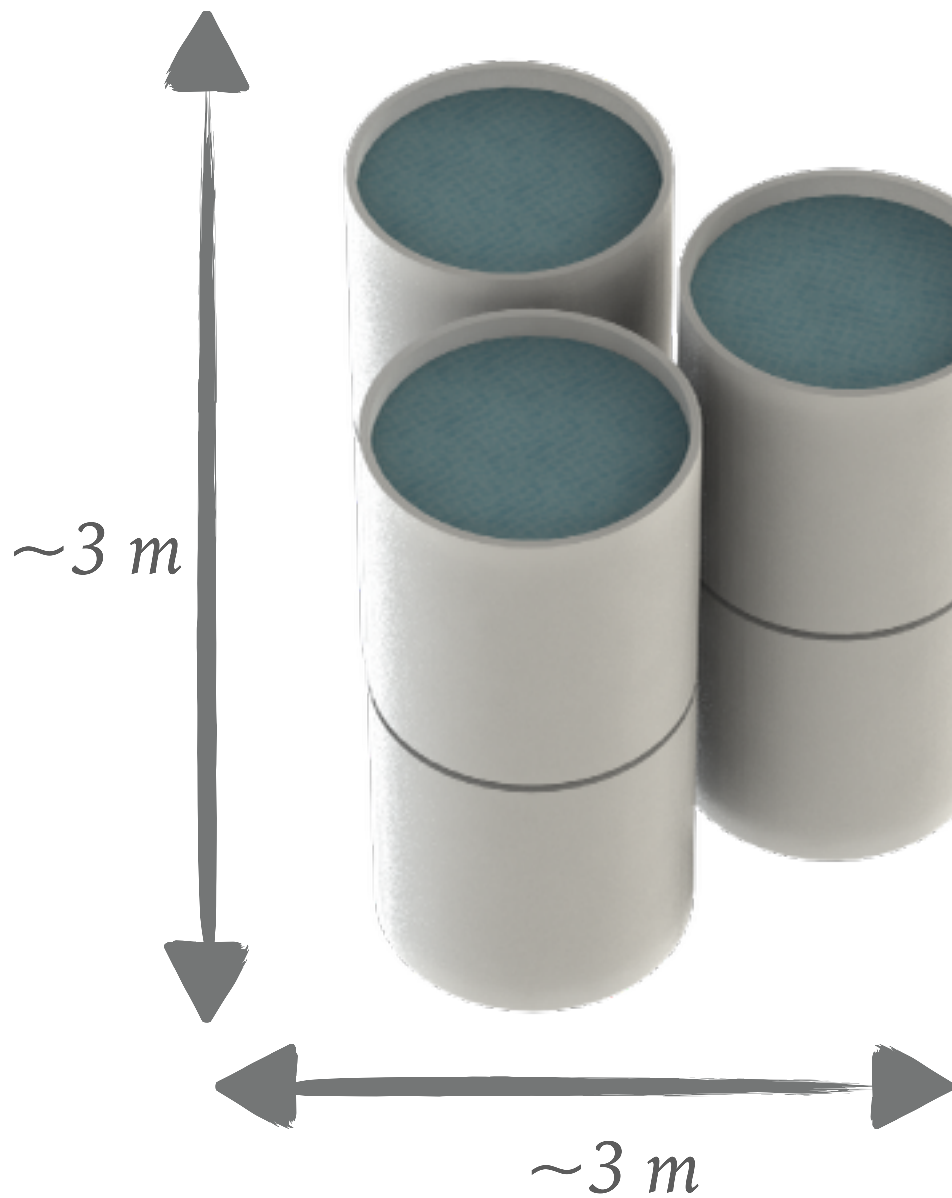
All SiPM read-out:

- *Improved radio purity*
- *Better topological signature*



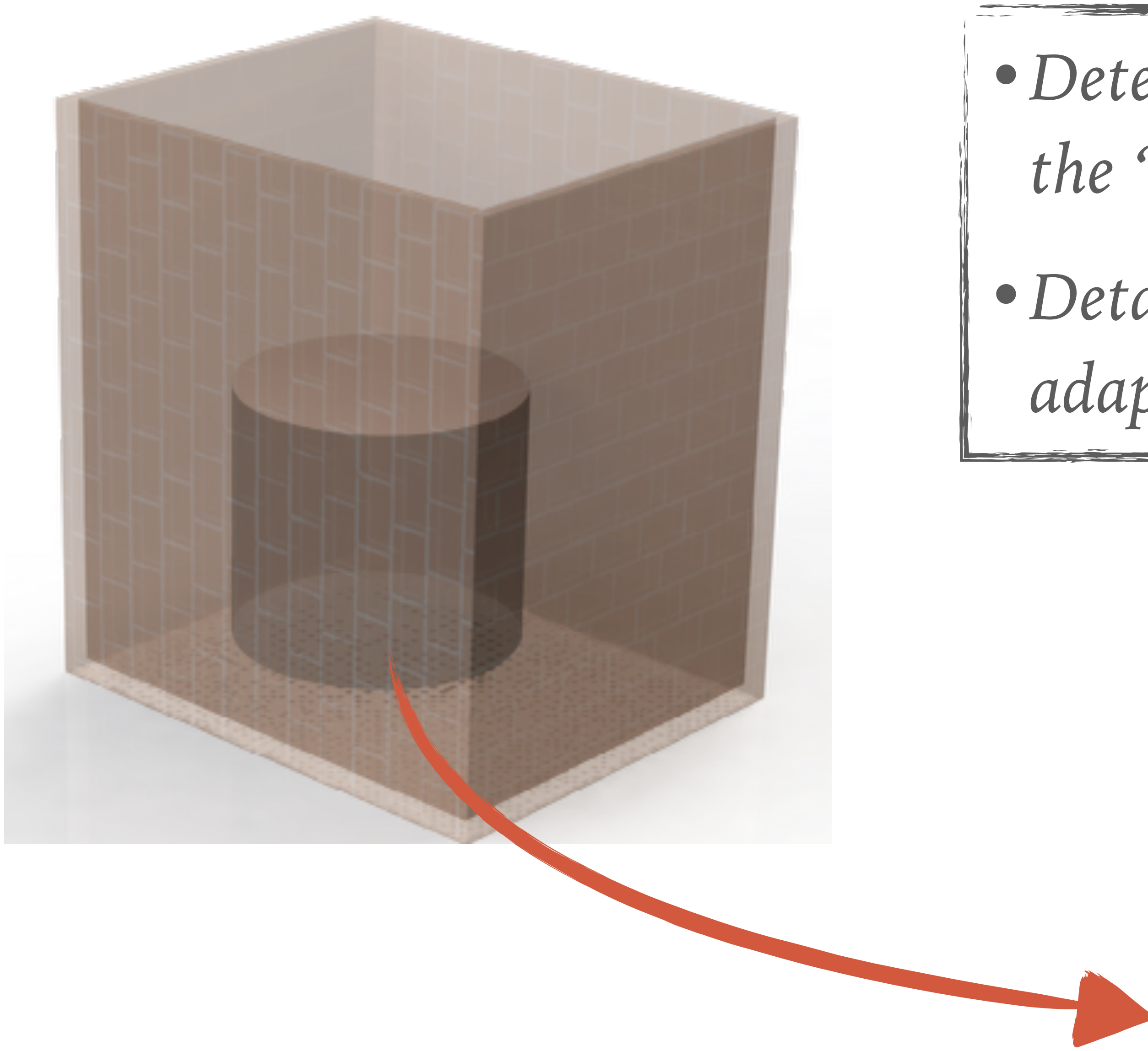
Example of 3x3 mm^2 SiPMs at 5mm pitch

NEXT-TON: WHAT DOES THE DETECTOR LOOK LIKE?



- *2-4modules will fit in moderate laboratory space.*
- *1-2 tonnes of Xenon active volume per site.*

NEXT-TON: WHAT DOES THE DETECTOR LOOK LIKE?

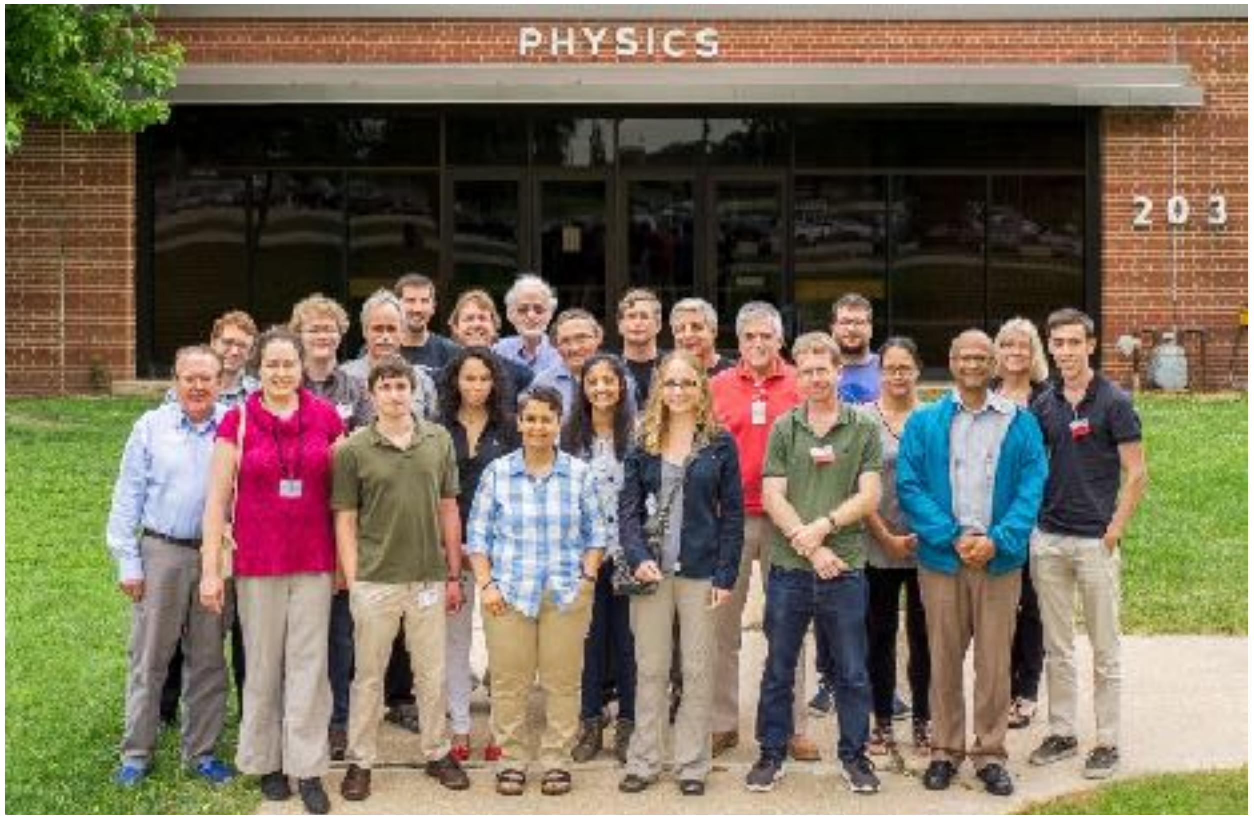


- *Detectors plus shielding will easily fit in the "Cube Hall" or "Cryopit" at SNO.*
- *Details of external/shielding veto will be adapted to the specific lab characteristics.*

NEXT PLANS

- Final design and construction of NEXT-100 in the next 18 months.
- DOE R&D funds for one year:
  - Develop EL region and HVFT to allow good performance in large detectors.
- Broad R&D for improved performance and technological advances.
  - Replace PMTs by SiPMs
  - Improve topological background rejection: Improved tracking resolution.
  - Barium tagging by Single Molecule Fluorescence Imaging.
  - …

THANKS FOR YOUR ATTENTION!



IFIC (Valencia), Santiago de Compostela, Girona, Politécnica Valencia, Autónoma Madrid

Coimbra GIAN, Coimbra LIP, Aveiro

JINR (Dubna)

ANL, FNAL, Iowa State, Ohio State, Texas A&M, Texas Arlington, Harvard

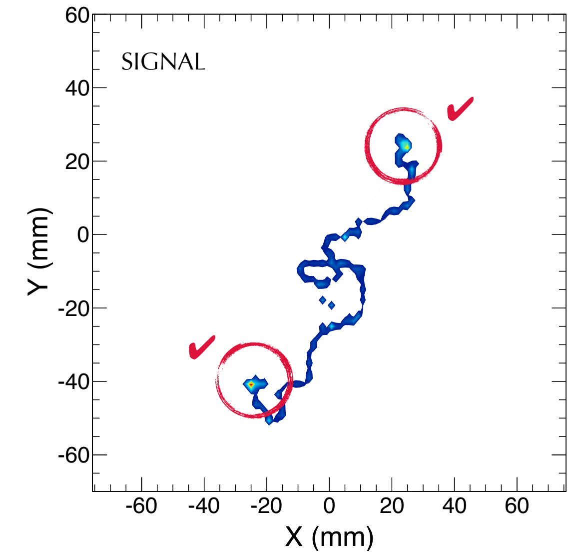
A.Nariño (Bogotá)

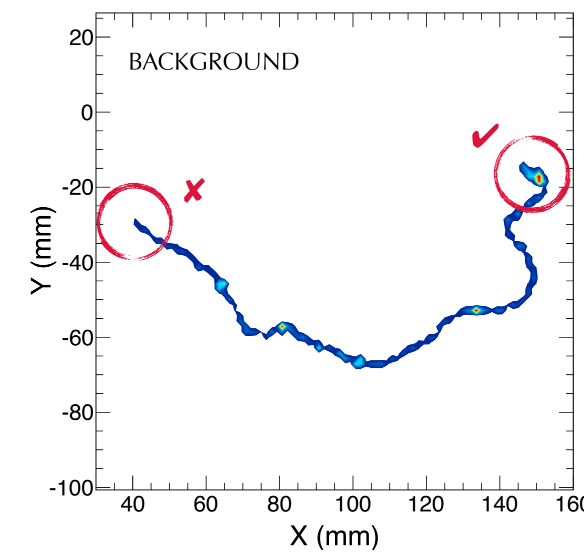
Ben-Gurion University

BACK-UP

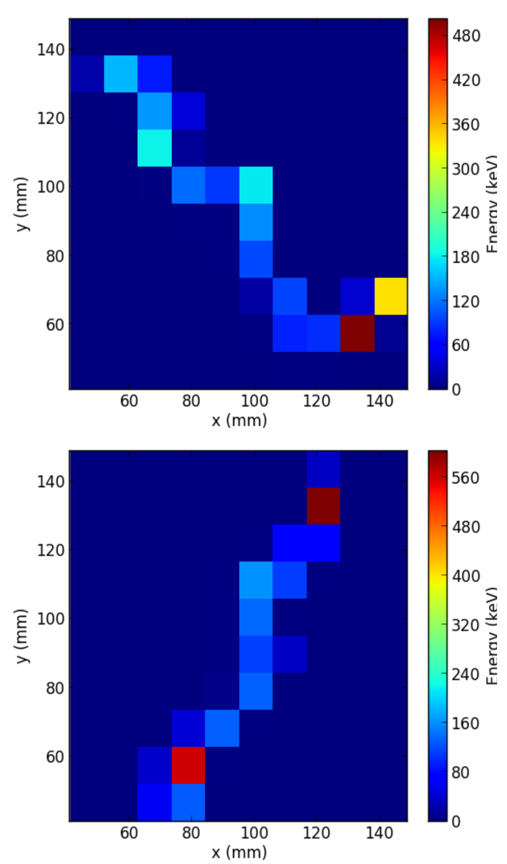
HOW TO IMPROVE TOPOLOGICAL SIGNATURE?

Effect of diffusion

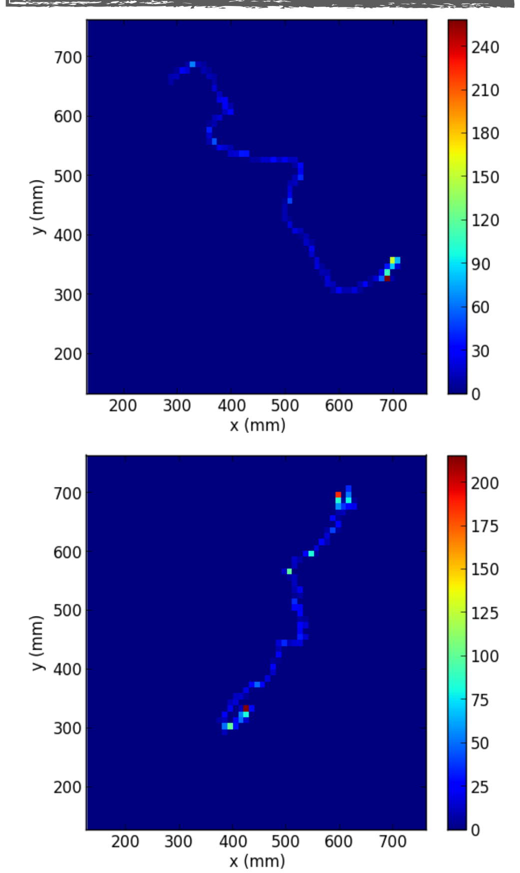


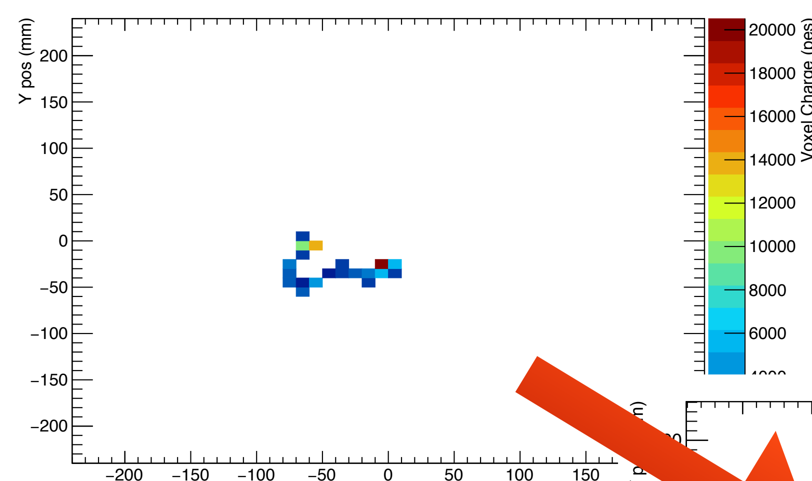


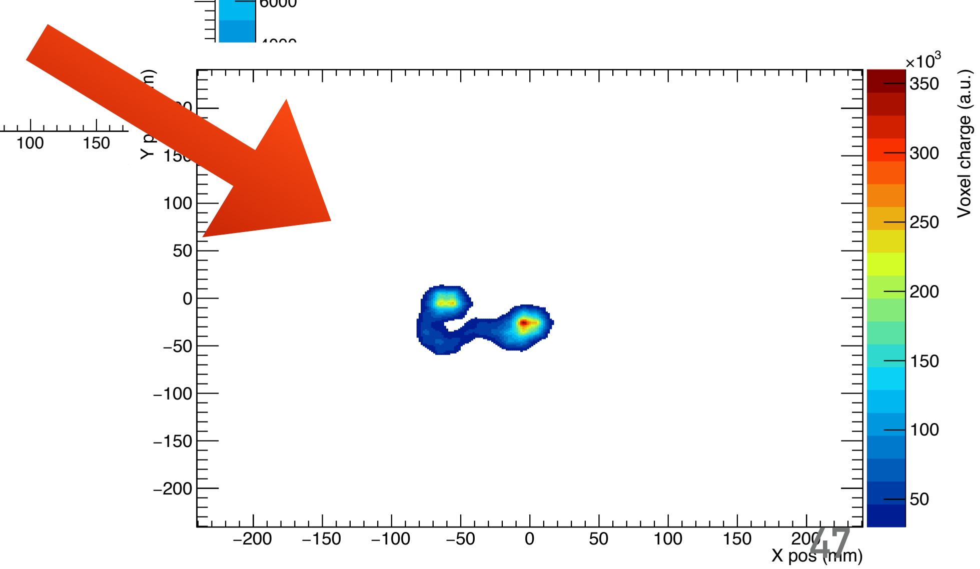
10mm voxels



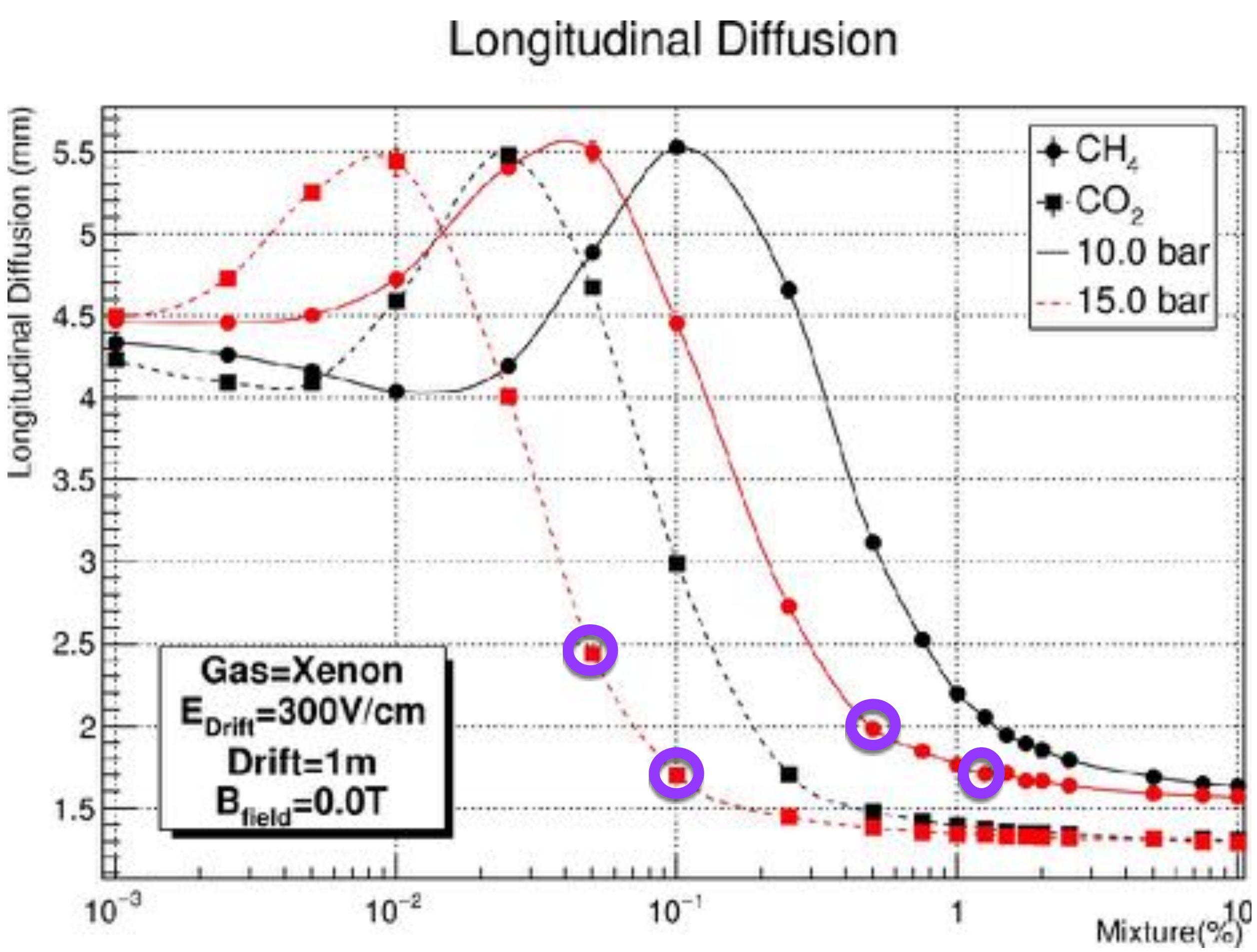
2mm voxels







SOME GAS MIXTURES REDUCE DIFFUSION



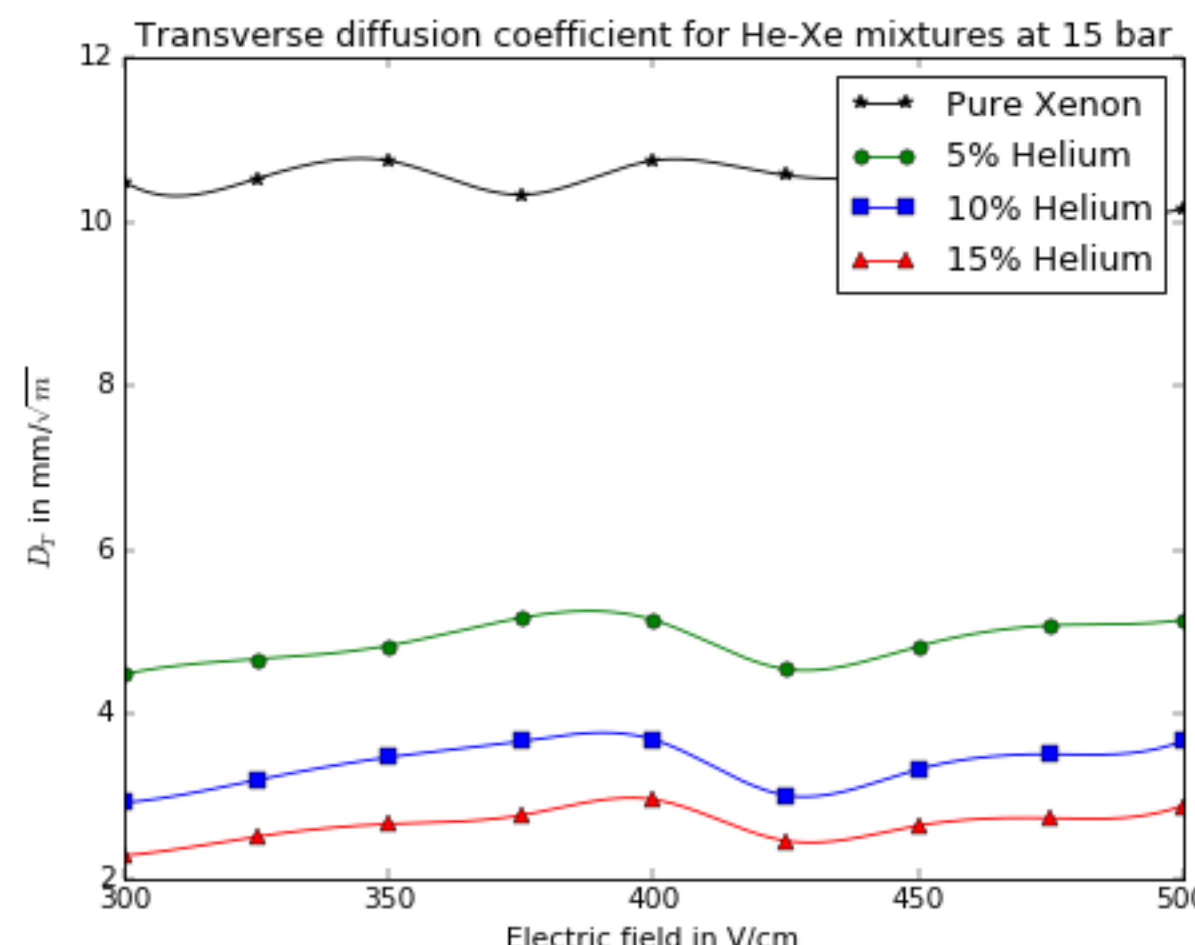
CO_2: 0.1% (CH_4: 1%) ->LD<2 mm

CO_2: 0.05% (CH_4: 0.5%) ->LD<2.5 mm

Molecular mixtures will reduce scintillation and EL light

***Helium** at larger concentrations (>10%) LD ~ 3 mm.*

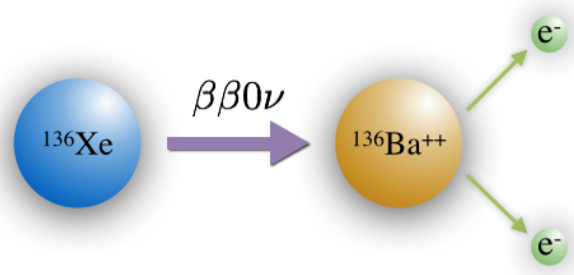
***Helium** won't affect light production.*



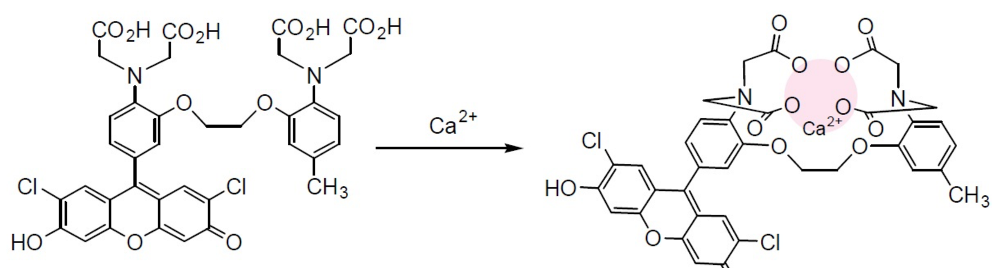
HOW TO IMPROVE RESOLUTION

- Resolution is dominated by longitudinal and transverse diffusion.
- It can be improved with gaseous mixtures
- **CO_2** and **CH_4** are good candidates.
- **He** is very promising as it will simplify gas system operations and won't reduce EL production.
- Read-out plane will need to be improved.

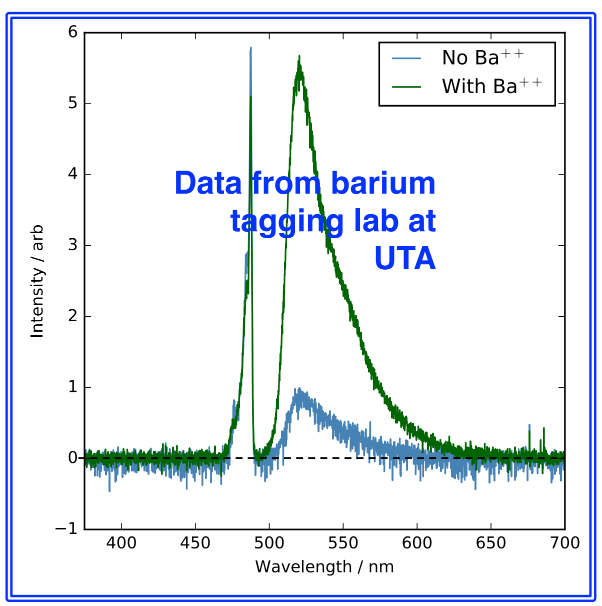
BA-TAGGING



Not fluorescent **Fluorescent**



Fluo 3 Fluo 3-Ca complex



- Xe-136 decays produce Ba++
- Ba++ will drift towards cathode (hopefully without recombining)
- Coat cathode with PSMA molecule, which will capture BA++ (**Dave Nygren's proposal)**
- PSMA + BA++ will fluoresce when illuminated with 342 nm light (broad band, 360-430… can design a system to detect blue light. Interrogation rate at ~100 kHz.
- This idea is a new form of Ba-tagging in gas which does not involve extracting the Ba++ ion to vacuum.
- Potentially: background free experiment.