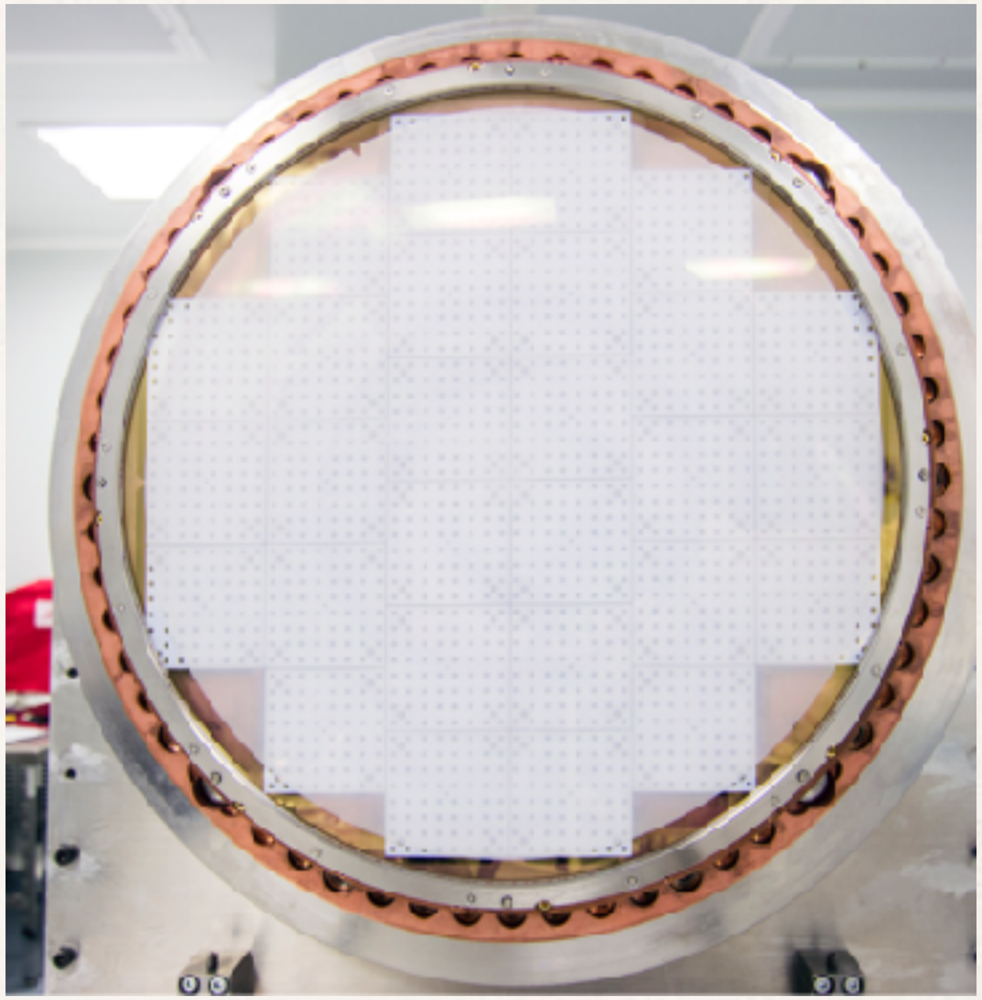



The NEXT experiment to search for the neutrinoless double beta decay of Xe-136

F. Monrabal & J.J. Gómez-Cadenas on behalf of the NEXT collaboration

November, 2016

State of the art

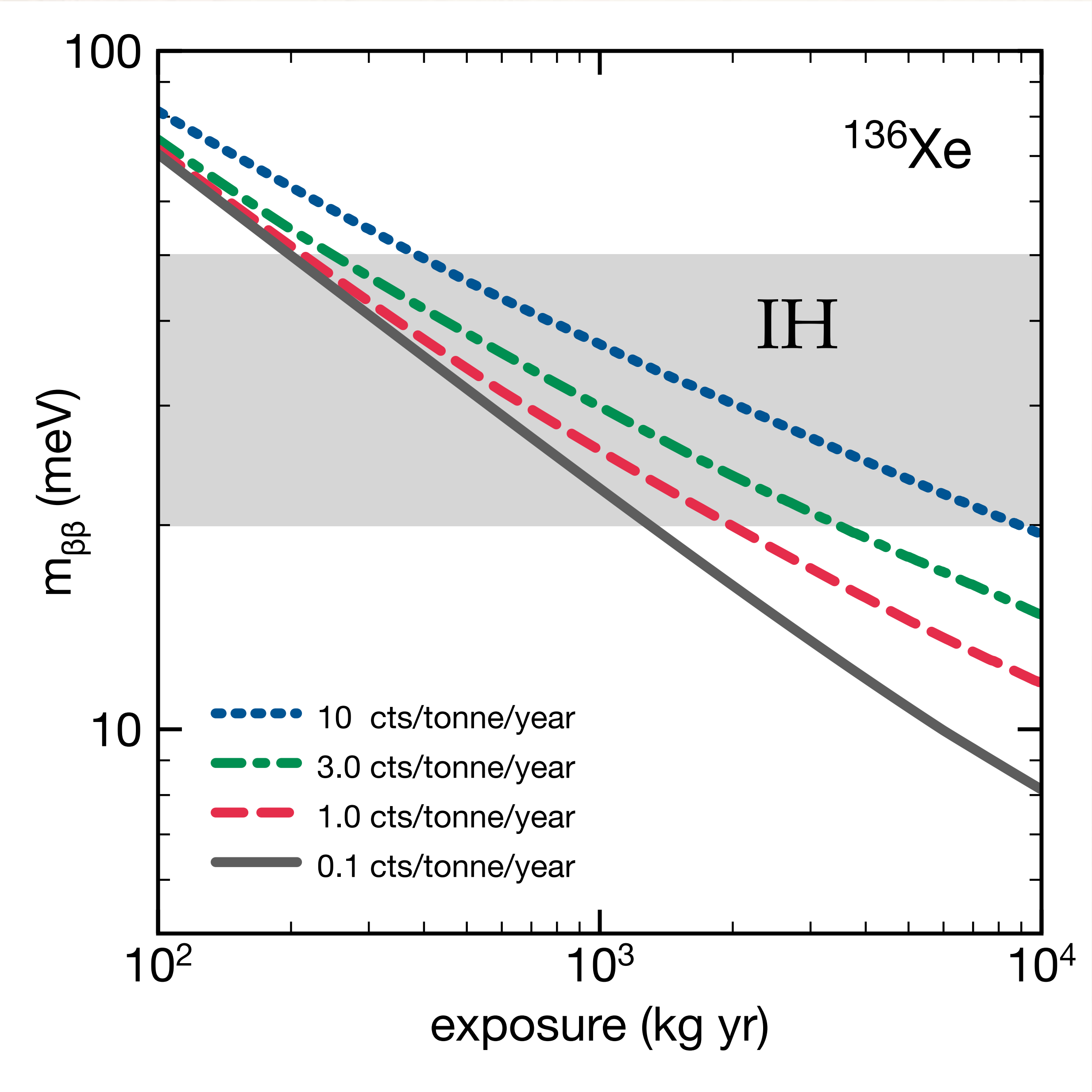
Table 1. Summary of comparison of leading $0\nu\beta\beta$ decay experiments. BIs are normalized per mass of the isotope of interest.

Experiment	Isotope mass, tonne	$T_{1/2}$ 90% C.L., 10^{25} yr	$m_{\beta\beta}$ 90% C.L., eV	BI, ROI^{-1}(isotope tonne)$^{-1}$yr^{-1}	ROI, keV
EXO-200	0.16	1.1	0.19-0.47	310	150 ($\pm 2\sigma$)
KamLAND-Zen	0.32	11	0.06-0.15	180	400
GERDA	0.018	2.1	0.24-0.41	58	5 (FWHM)
CUORE-0	0.013	0.4	0.26-0.71	890	5.1 (FWHM)

Exploration of the IH requires:

1) large masses (ton scale) : Technology must be scalable and cheap
2) BI in the range of 1 event (to cover the IH in a reasonable time) : large background reduction needed wrt to current state of the art

Exploring the IH



- Plot shows the sensitivity of a 100% efficient Xenon experiment (with a reasonable NME set).
- With a background ~10 cts/tonne/year and a mass of 1 ton, 10 years of run are required (e.g, 50 years for an efficiency of 20 %).
- With a background count of ~1 cts/tonne/year, "only" 2 years are required (10 years for an efficiency of 20%).

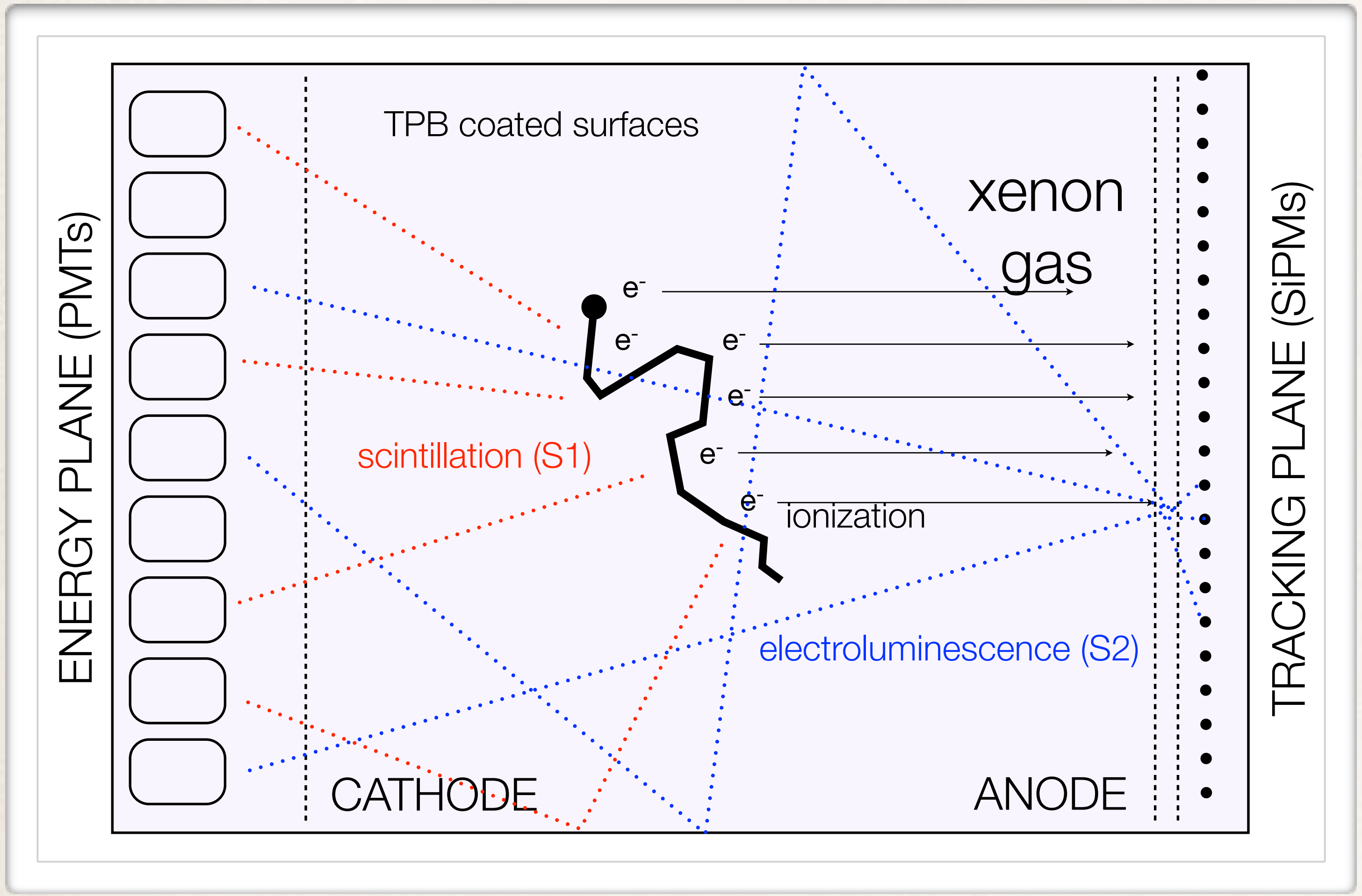
$$T_{1/2} = ln(2)\frac{N_A M t}{A N_{\beta\beta}}$$

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 m\beta\beta^2$$

Exploring the IH : the challenge

- Masses in the range of the ton are needed
  - This requires a "cheap" and easy to enrich isotope and scalable detectors (e.g, calorimeters, where source = detector)
  - Both KamLAND-ZEN and EXO can be scaled to large masses
  - But an HPXe TPC can also be scaled to large masses
- Background counts of **≤ 1 cts/tonne/year** are needed.
  - This is a factor ~180-310 of what has been currently achieved by KZ and EXO.
  - An HPXe with EL amplification of the signal has the potential of reaching the required very low background level.
  - NEXT sensitivity studies result in an expected BI of 10 cts/tonne/year (to be compared with 180-310 from KZ, EXO). We believe that a background of 1 cts/tonne/year is also possible.

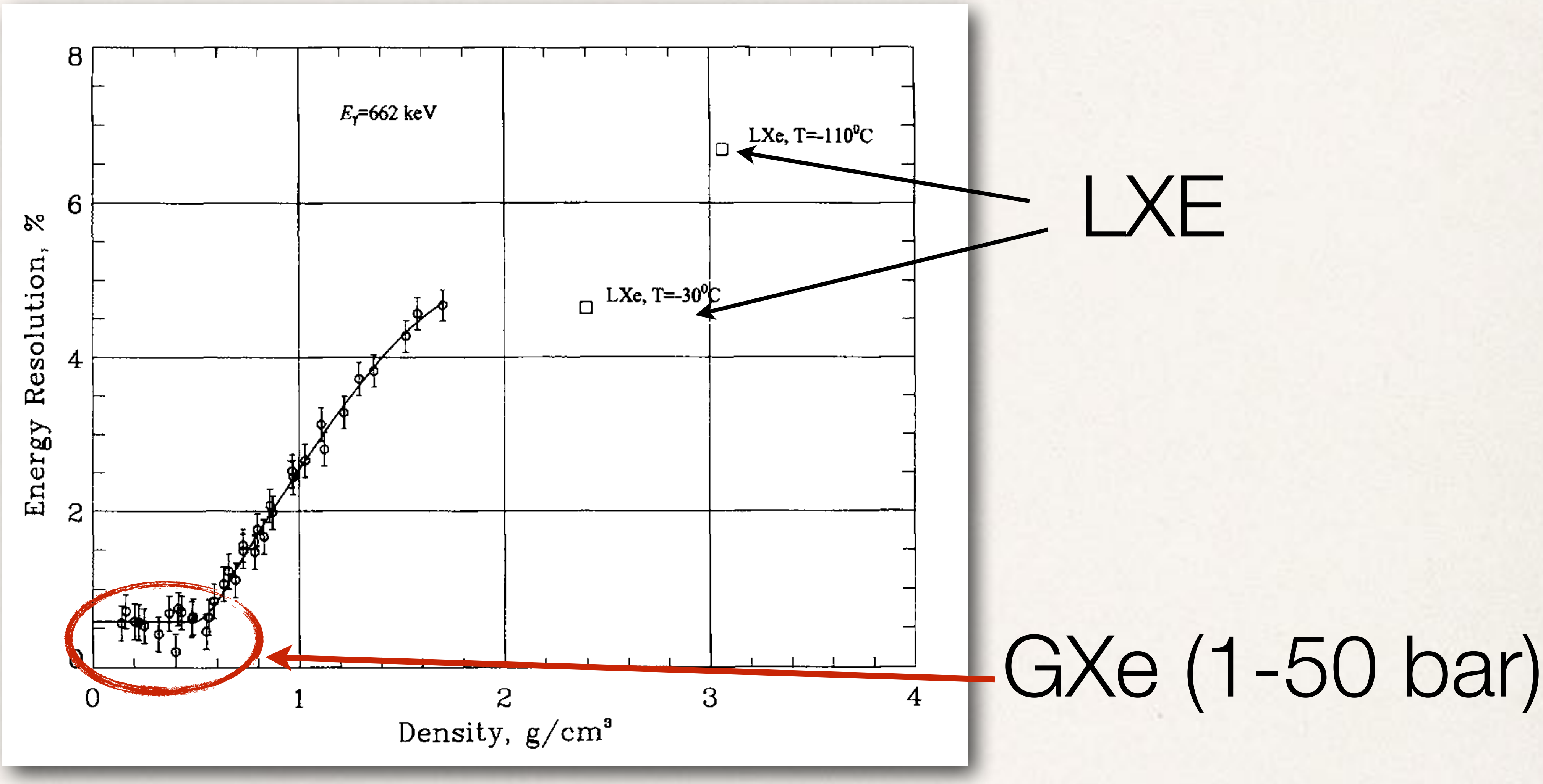
NEXT (HPXe EL TPC)



- Is a High Pressure Xenon TPC (operation 10-20 bar)
- Uses EL amplification to achieve excellent energy resolution (~0.5 % FWHM)
- Adds a topological signature (observation of two electrons) to further suppress the backgrounds.
- Is built with radio pure materials.

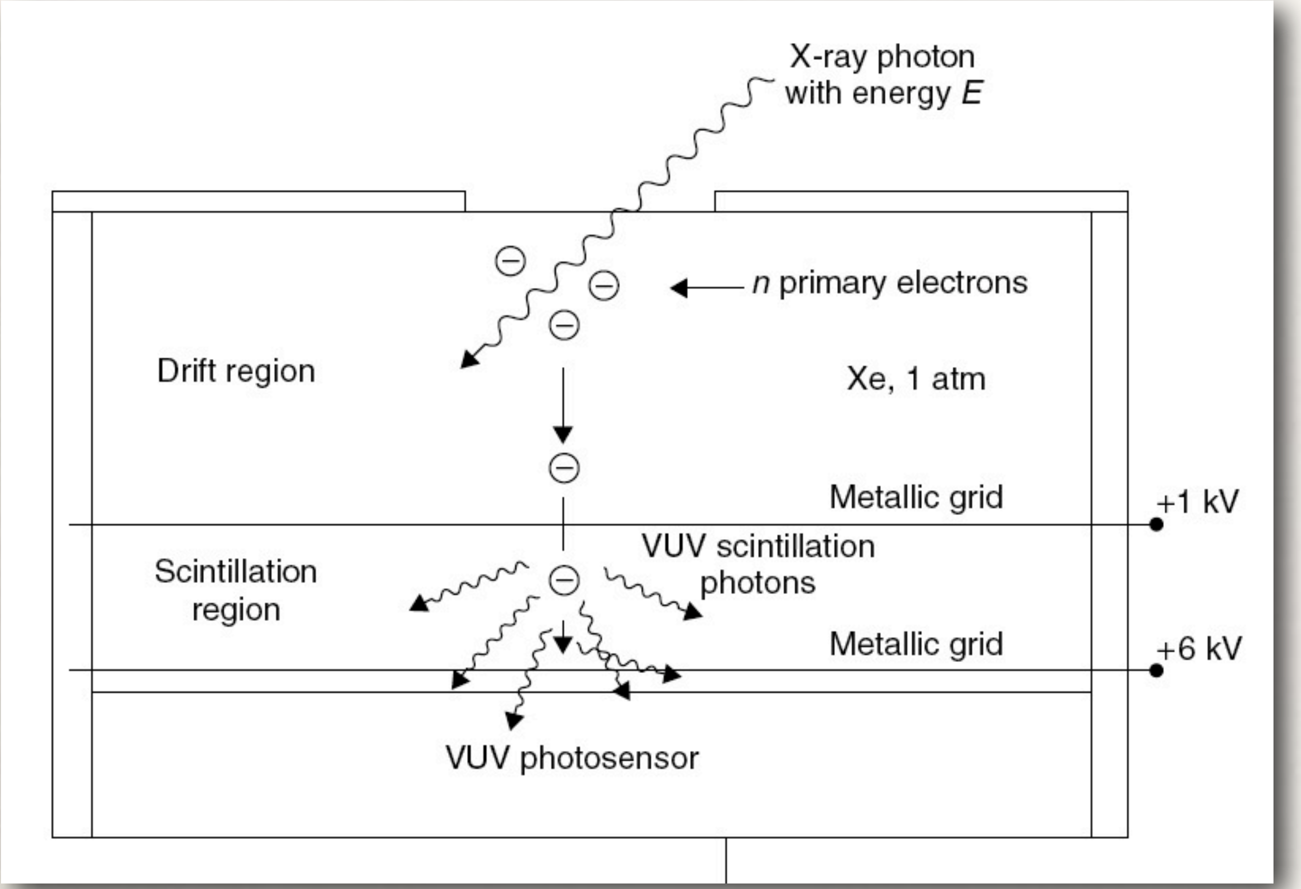
Energy resolution in Xe

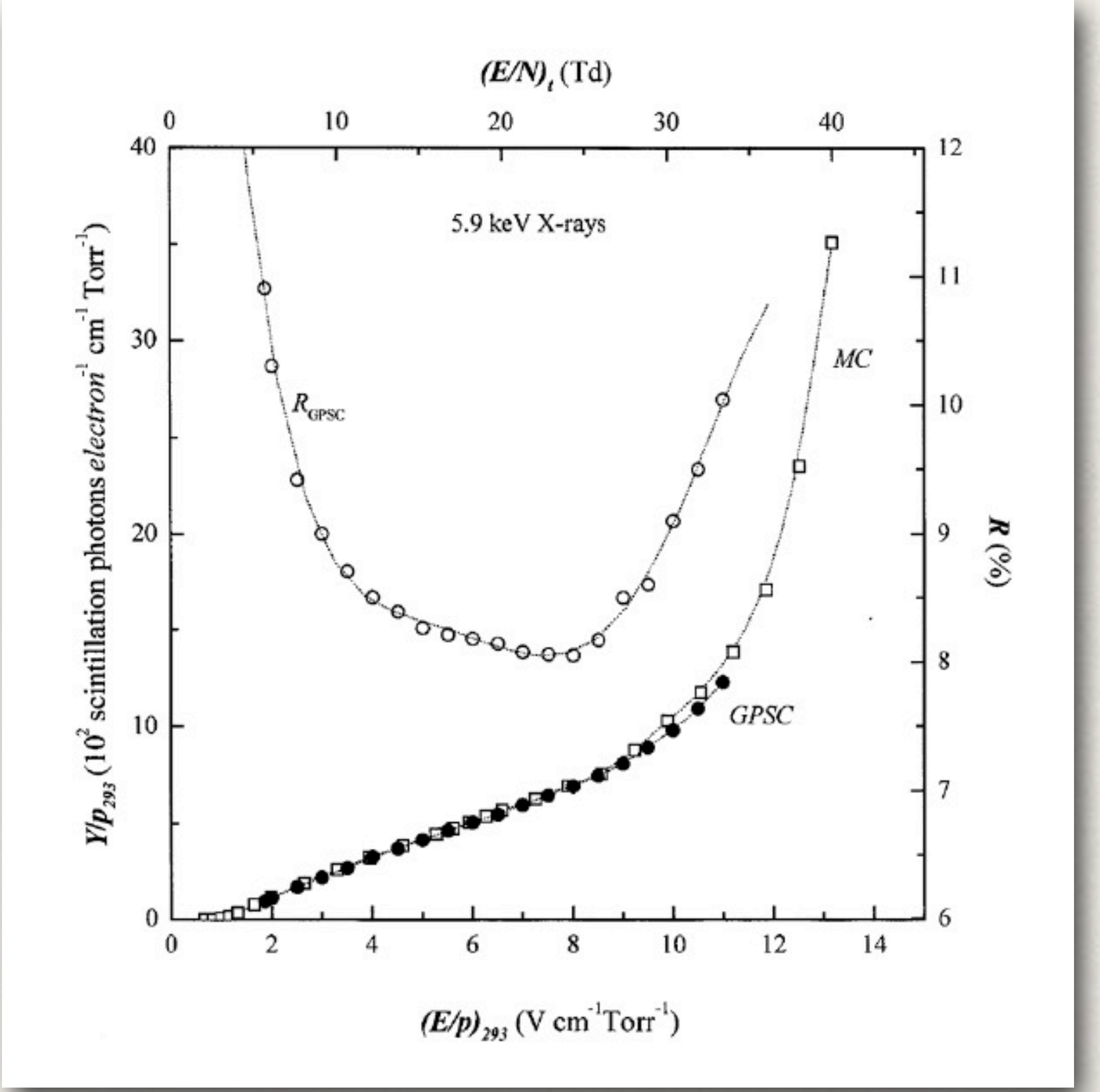
Bolotnikov and Ramsey, NIM A 396 (1997)



- Intrinsic resolution (Fano factor) at $Q_{\beta\beta}$ (2458 keV): 3×10^{-3} FWHM.
- Best experimental result: 0.6%@662keV. Extrapolates to 3×10^{-3} FWHM @ 2.5 MeV.
- NEXT target: ~0.5% FWHM @ 2.5 MeV already measured with prototypes.

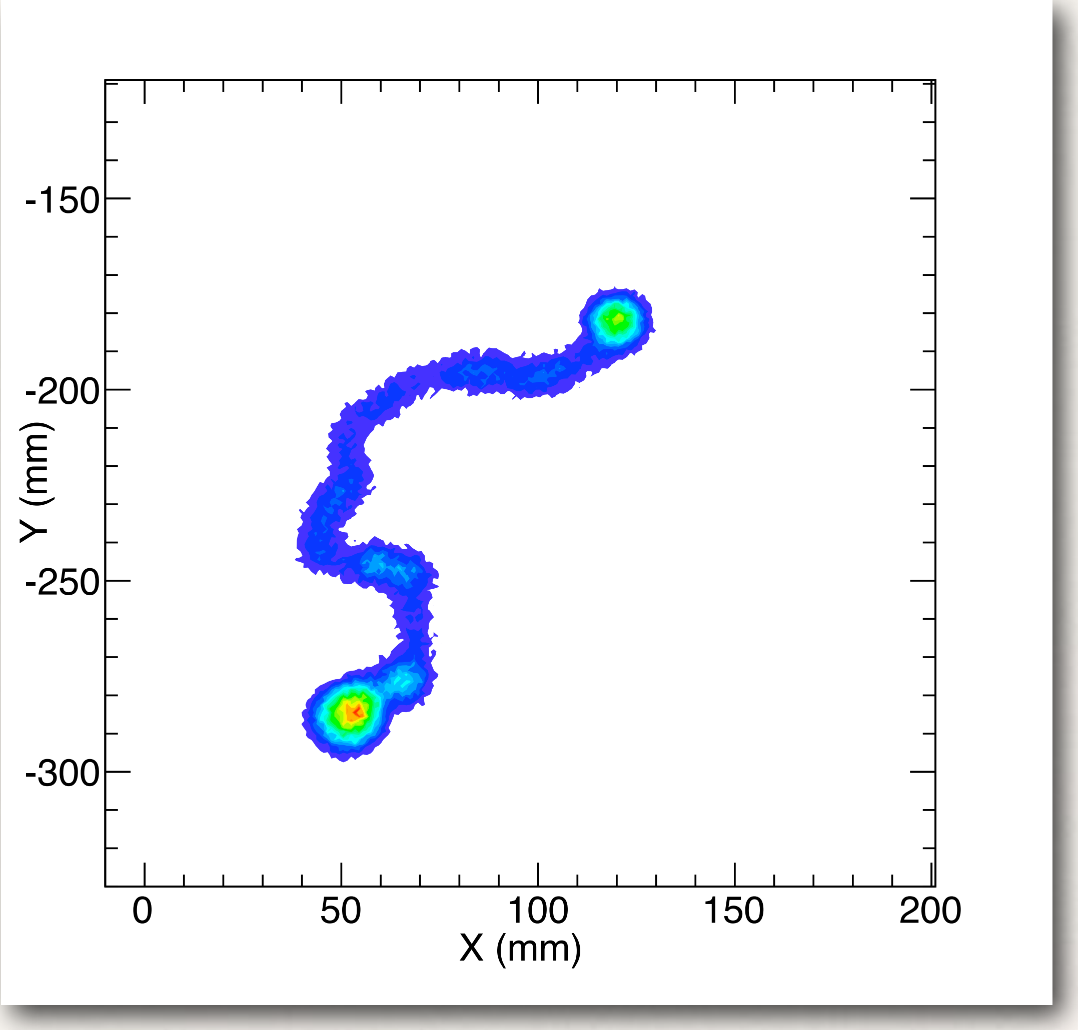
Electroluminescence





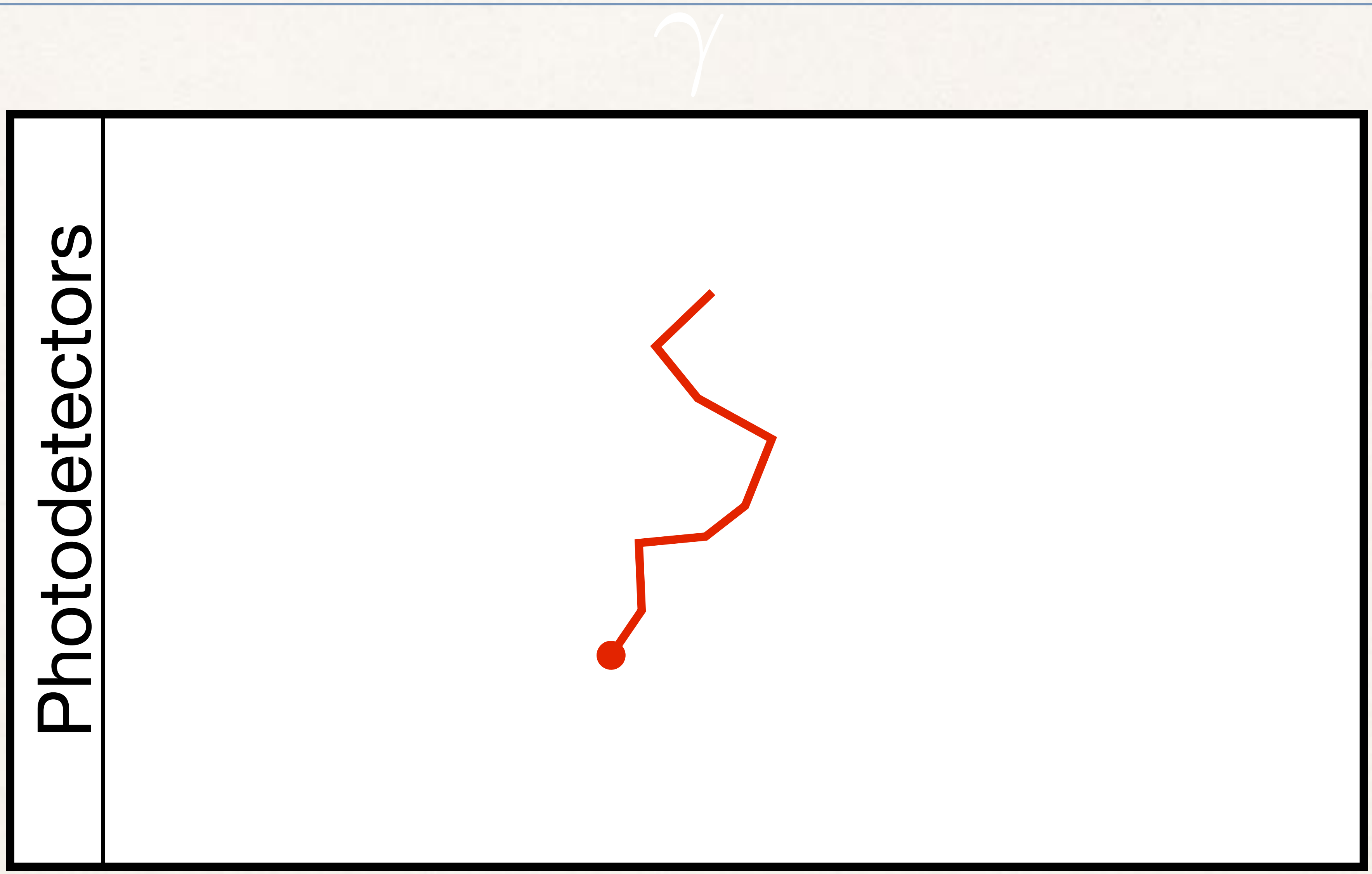
- Emission of scintillation light after atom excitation by a charge accelerated by a moderately large (no charge gain) electric field.
- Used in NEXT to amplify the ionisation signal.
- Linear process, huge gain (1500 ph./e-) at 3 < E/p < 6 kV/cm/bar.

Tracking in HPXe



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

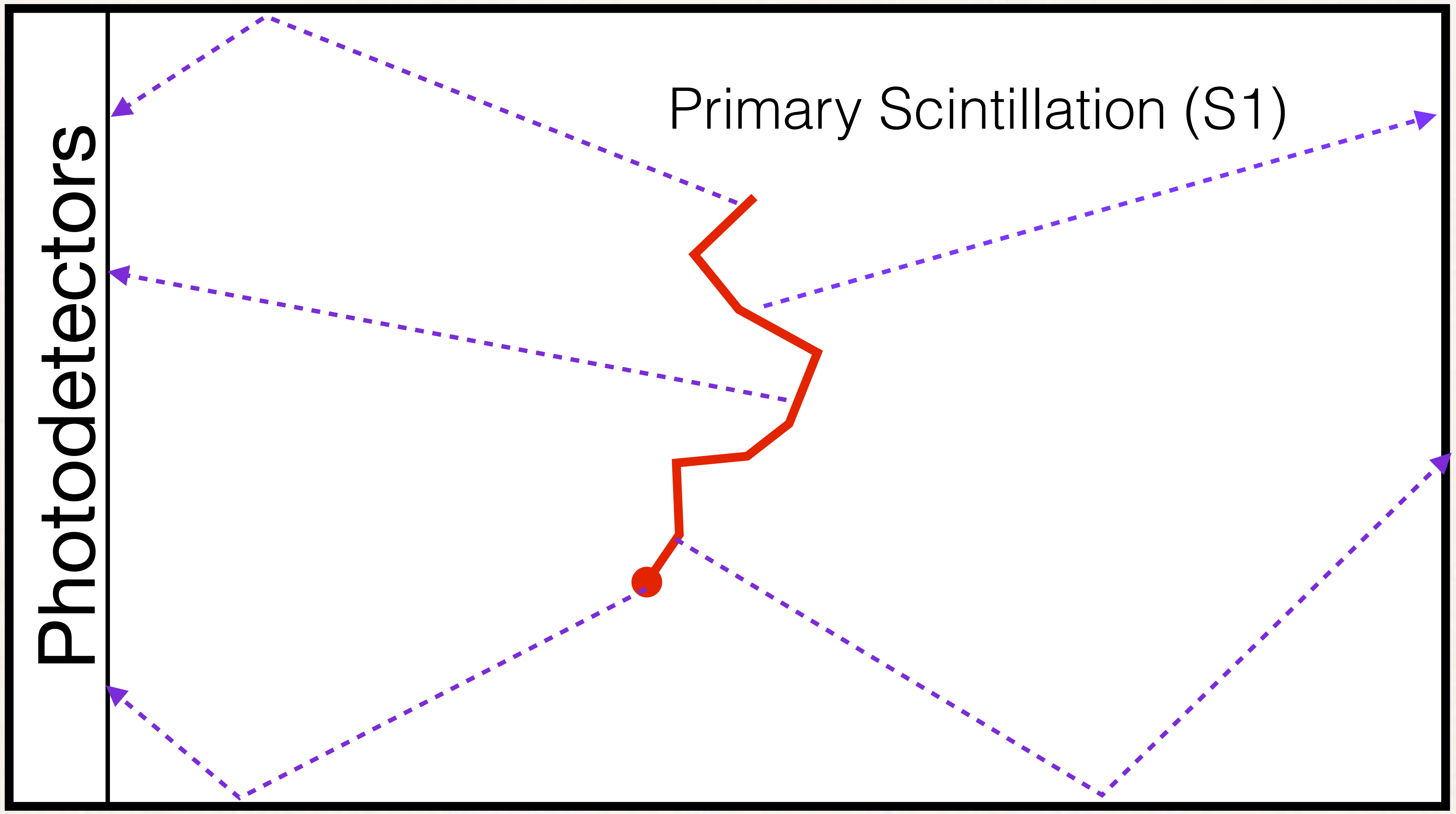
Detection concept



- 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.

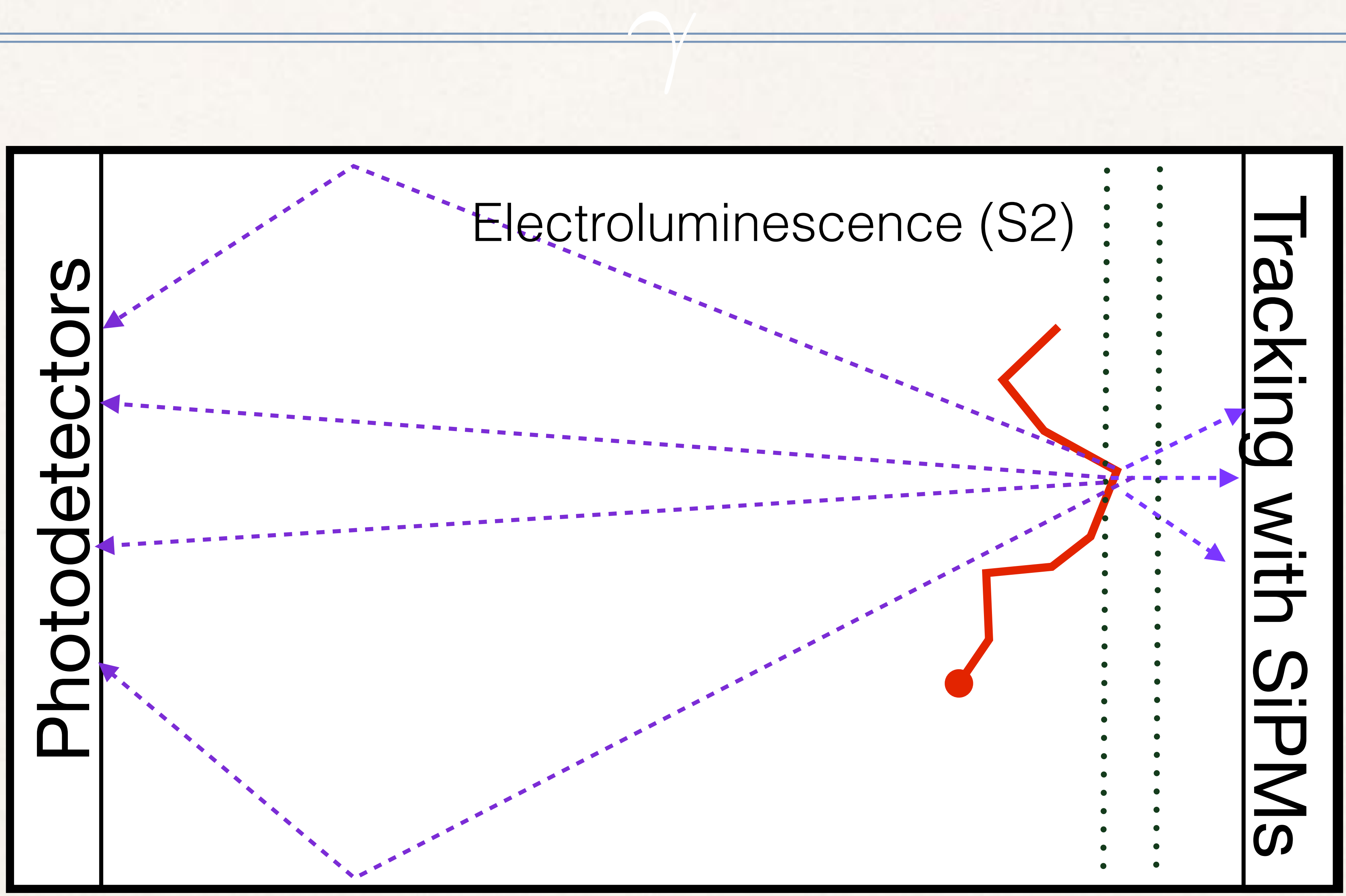
Detection concept

γ



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

Detection concept

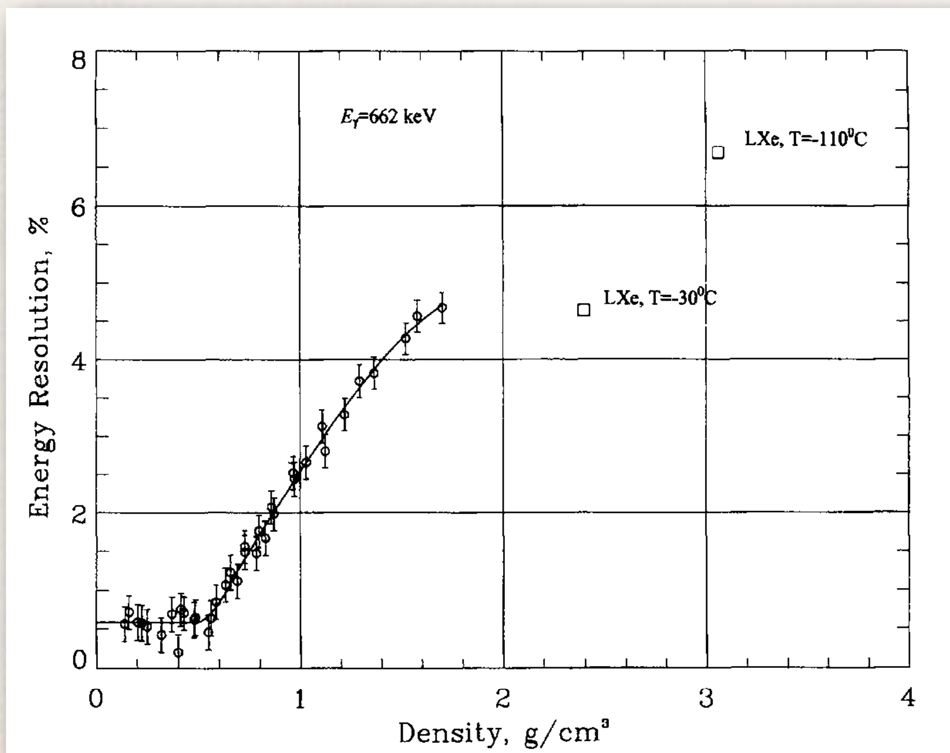


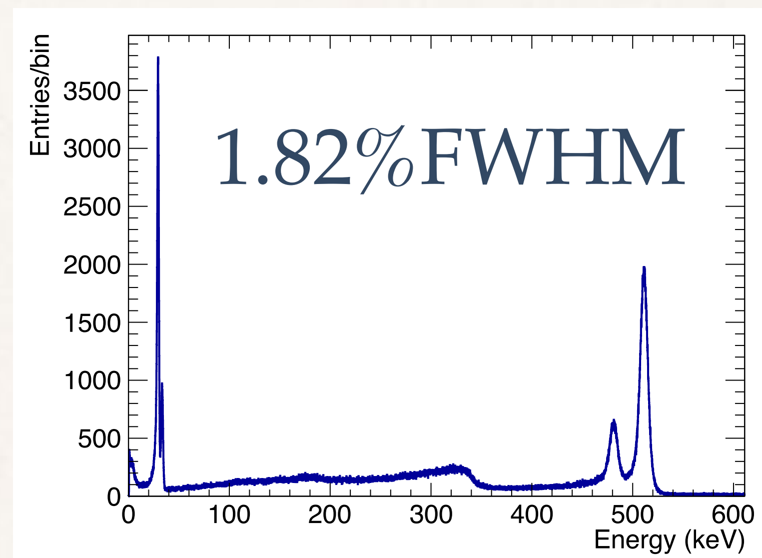
- The event energy is integrated by a plane of radiopure PMTs located behind a transparent cathode (**energy plane**), which also provide t0.
- The event topology is reconstructed by a plane of radiopure silicon pixels (SiPMs) (**tracking plane**).

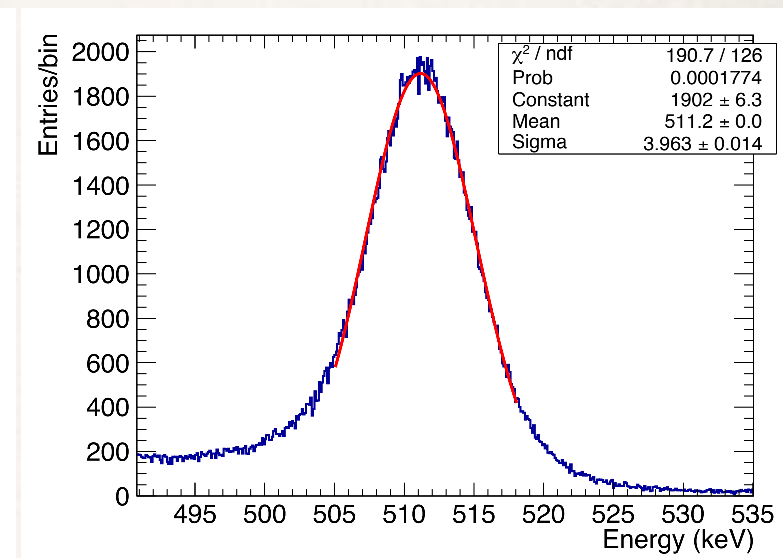
Energy resolution in NEXT

Fano Factor is 0.3%@Qbb

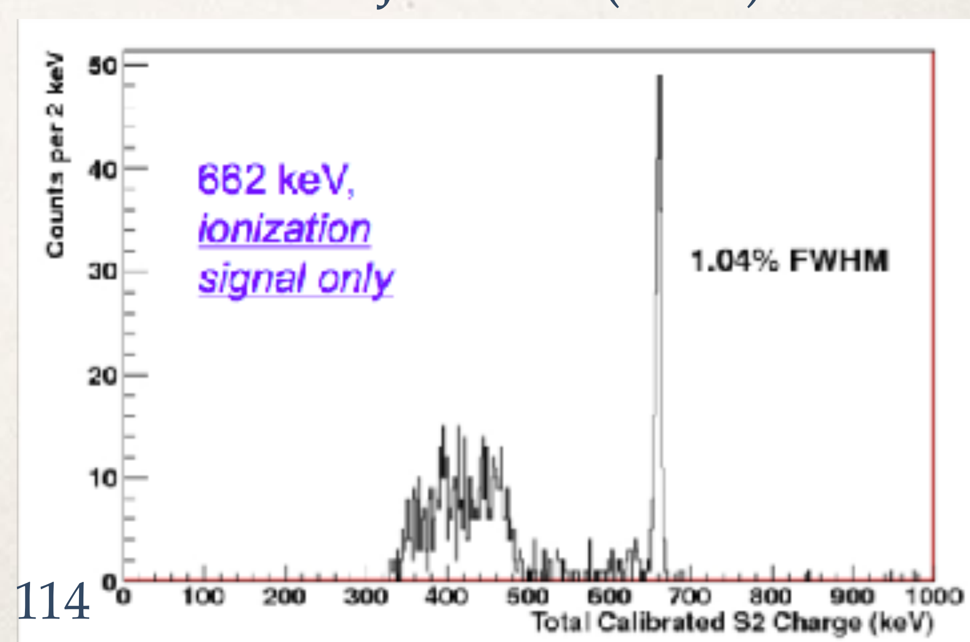
NEXT Prototypes (DBDM&DEMO)







JINST 8 (2013) P09011

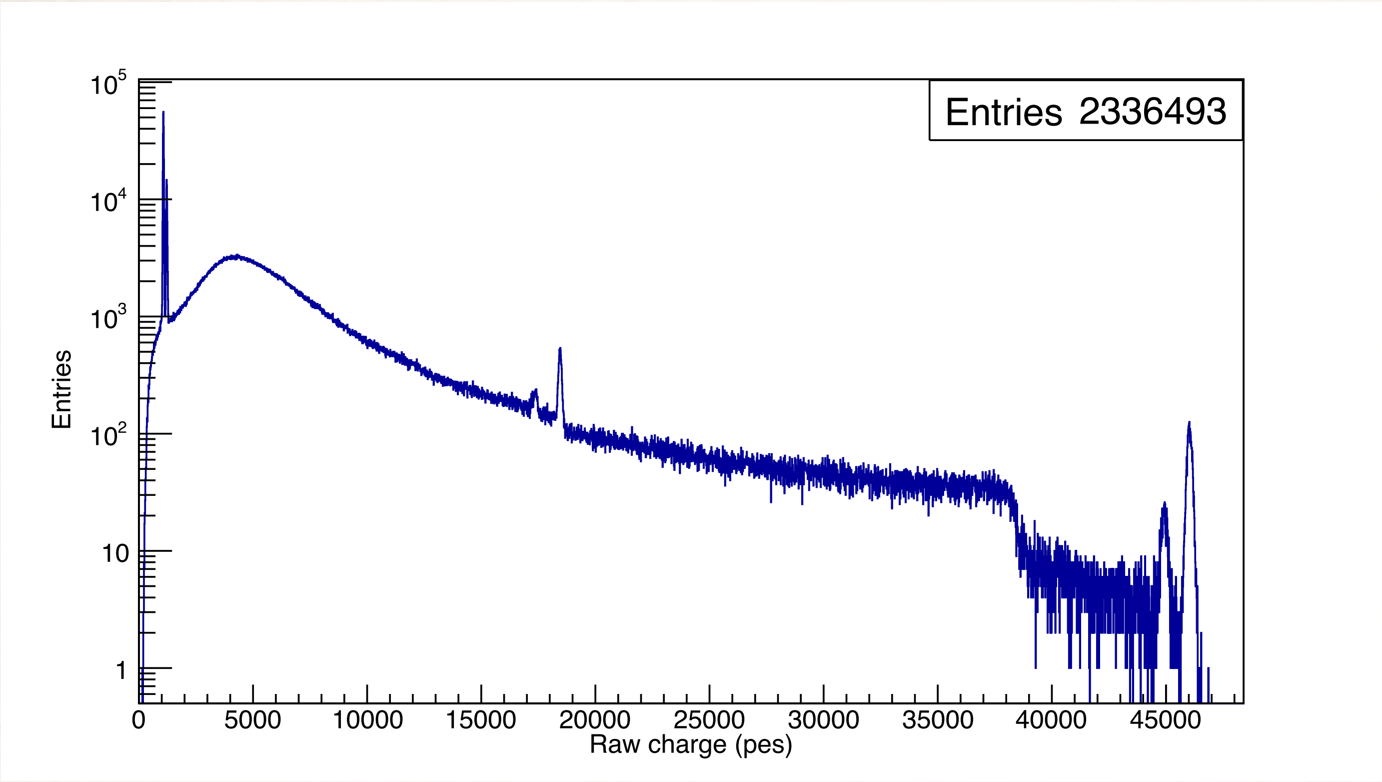


Results from DEMO extrapolates to 0.82%FWHM@Qbb

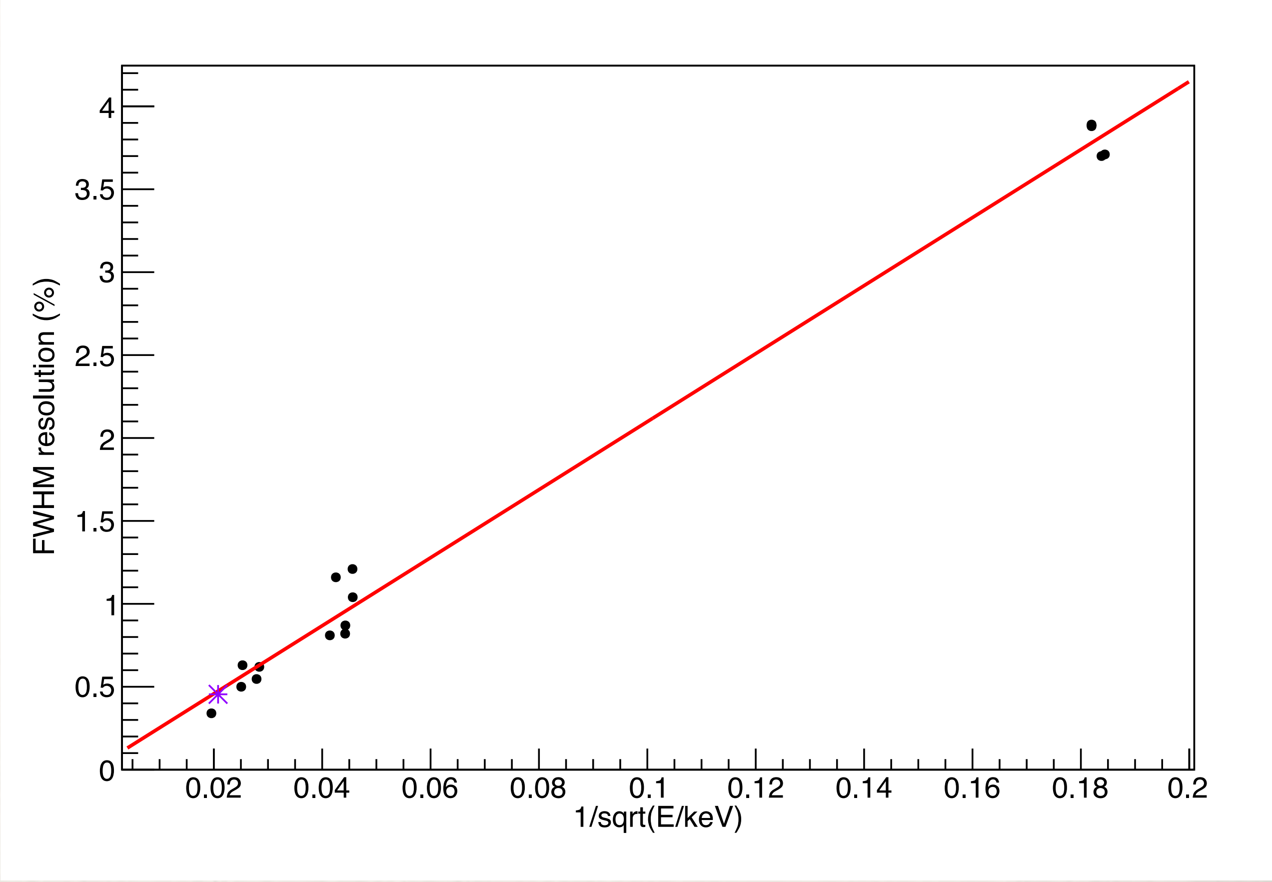
Results from DBDM extrapolates to 0.54%FWHM@Qbb

Nuclear Inst. and Methods in Physics Research A (2013), pp. 101, 114

Energy resolution in NEXT

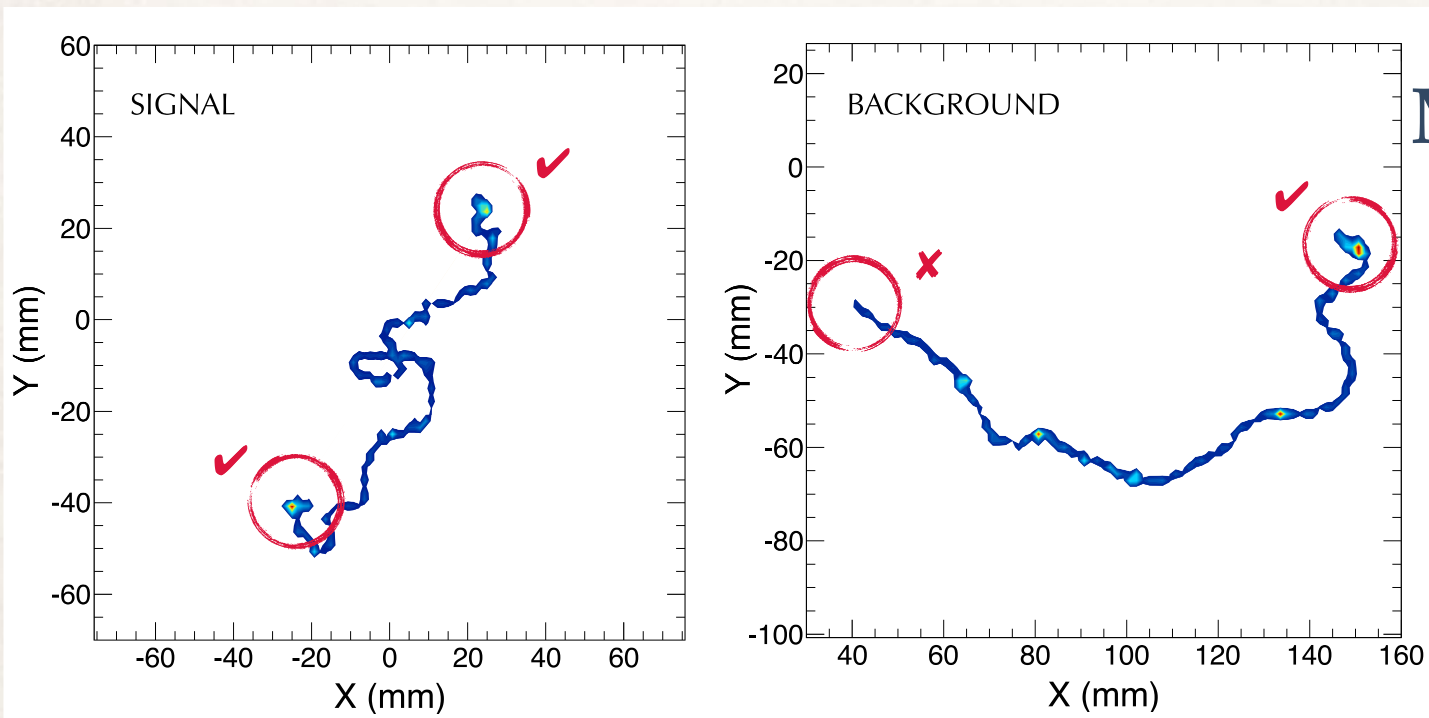


NEXT **MC** predicts an energy resolution of ~0.34%FWHM@Qbb



NEXT objective is to demonstrate <0.5%FWHM@Qbb

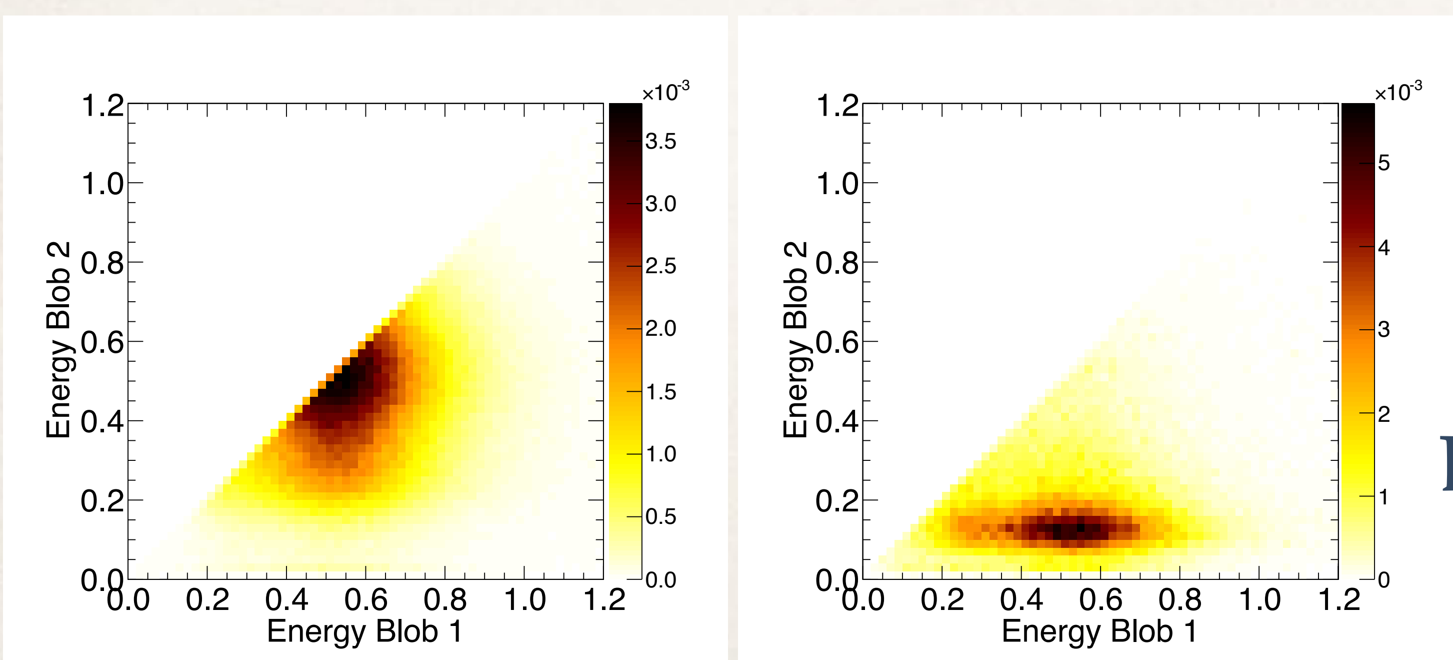
Topological signature in NEXT



MC

Two separated topology cuts:

- Single track selection.
- 2 “blobs” selection



DATA

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Topological signature in NEXT

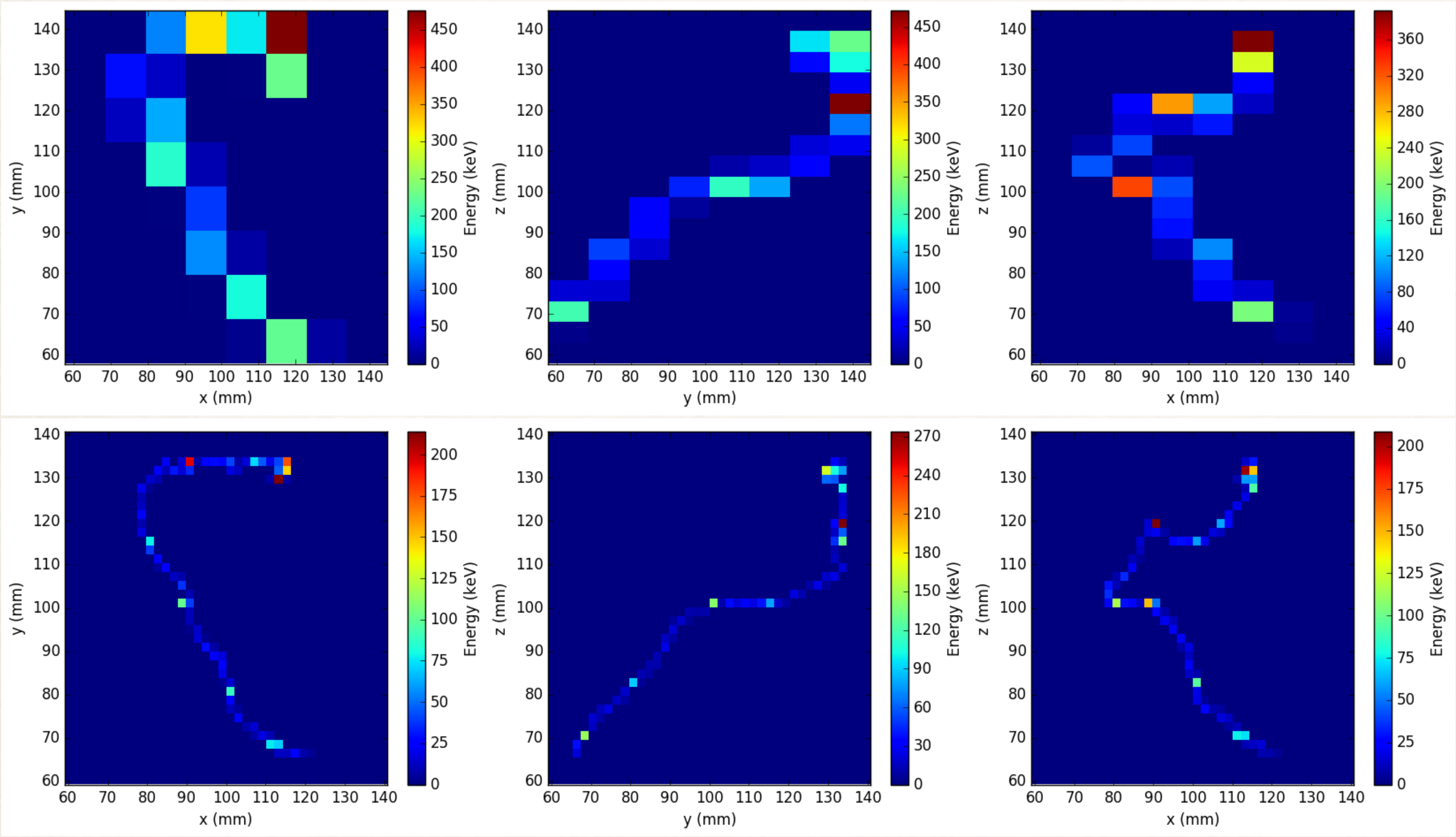


Figure 4. Projections in xy, yz, and xz for an example background event voxelized with $10 \times 10 \times 5$ mm^3 voxels (above) and with $2 \times 2 \times 2$ mm^3 voxels (below).

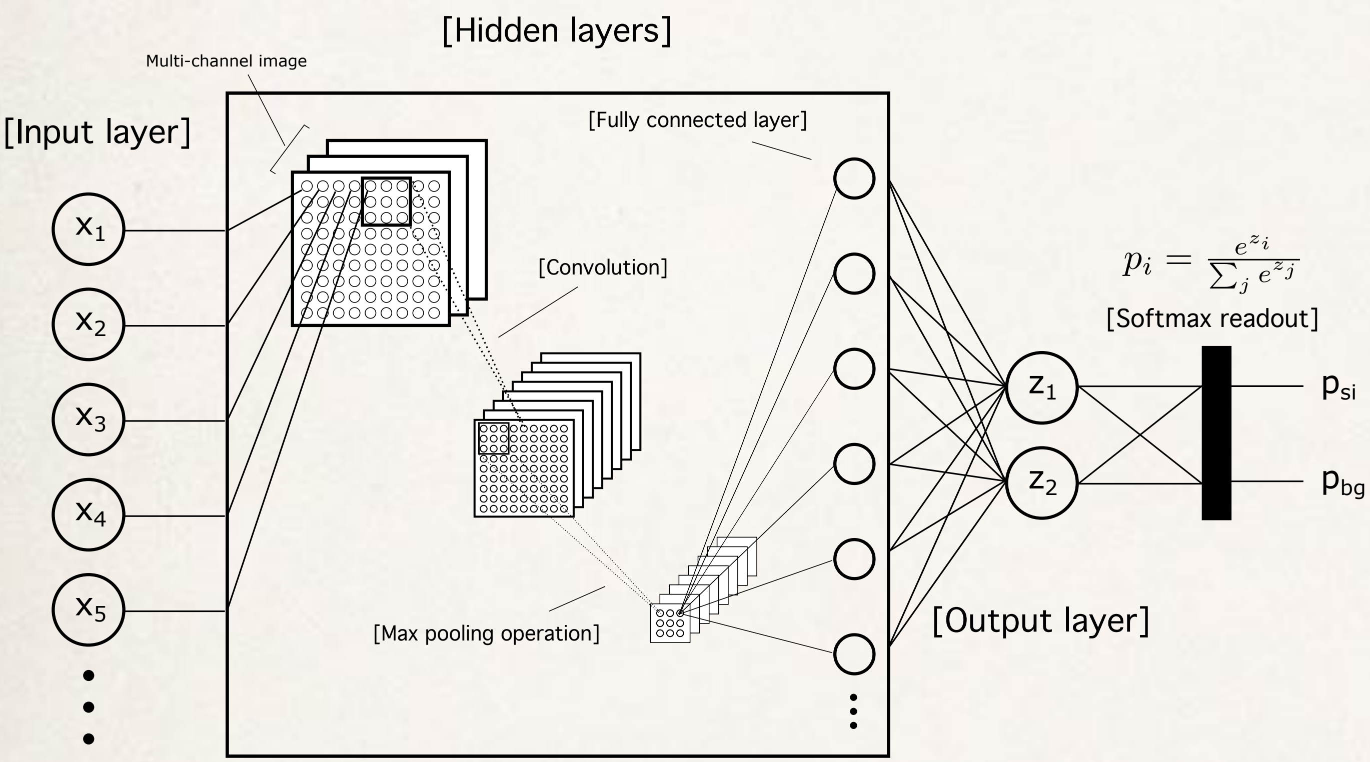
- Effect of diffusion.
- As diffusion decreases, event pictures become sharper and identification of features is easier.

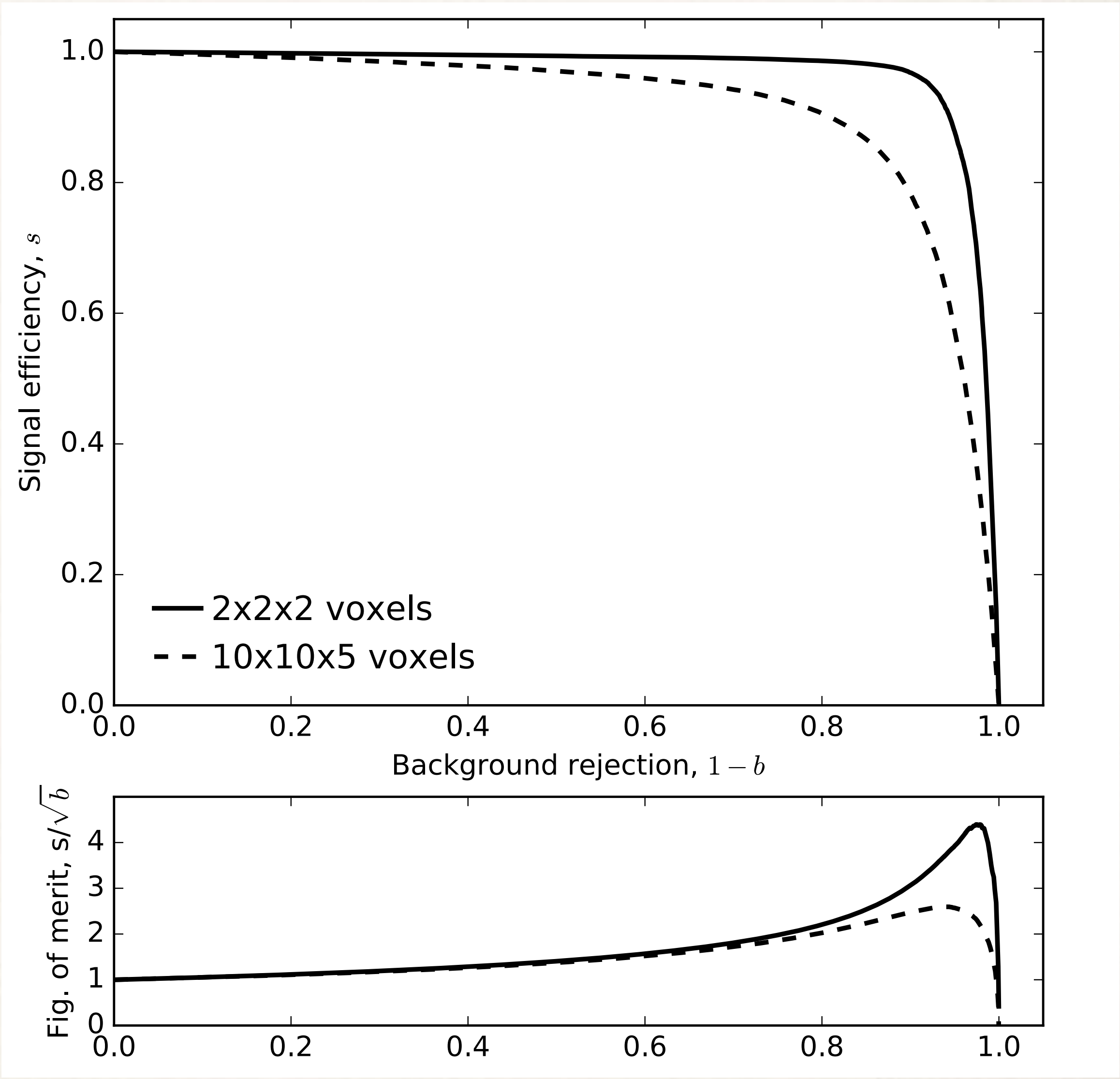
Topological signature in NEXT

Cut	Signal Events		BG Events (^{208}Tl)		BG Events (^{214}Bi)	
	$2\times2\times2$	$10\times10\times5$	$2\times2\times2$	$10\times10\times5$	$2\times2\times2$	$10\times10\times5$
(Initial events)	1.0	1.0	1.0	1.0	1.0	1.0
Energy	7.59×10^{-1}	7.59×10^{-1}	2.27×10^{-3}	2.27×10^{-3}	1.42×10^{-4}	1.42×10^{-4}
Fiducial	6.71×10^{-1}	6.68×10^{-1}	1.19×10^{-3}	1.17×10^{-3}	8.62×10^{-5}	8.54×10^{-5}
Single-Track	3.75×10^{-1}	4.79×10^{-1}	7.90×10^{-6}	1.81×10^{-5}	3.84×10^{-6}	8.75×10^{-6}
Classification*	3.23×10^{-1}	3.67×10^{-1}	7.70×10^{-7}	2.41×10^{-6}	2.90×10^{-7}	9.59×10^{-7}

- Power of topological signature increases with reduced diffusion.
- "Classical NEXT analysis" (analytical track reconstruction) yields the results in table (Monte Carlo simulation)
- Pure Xenon (10 mm/Sqrt(m) gives a combined rejection power for TPS (single-track + 2 blobs) of ~1/100
- Reduced diffusion (2 mm/Sqrt(m)) rejection factor to ~1/300

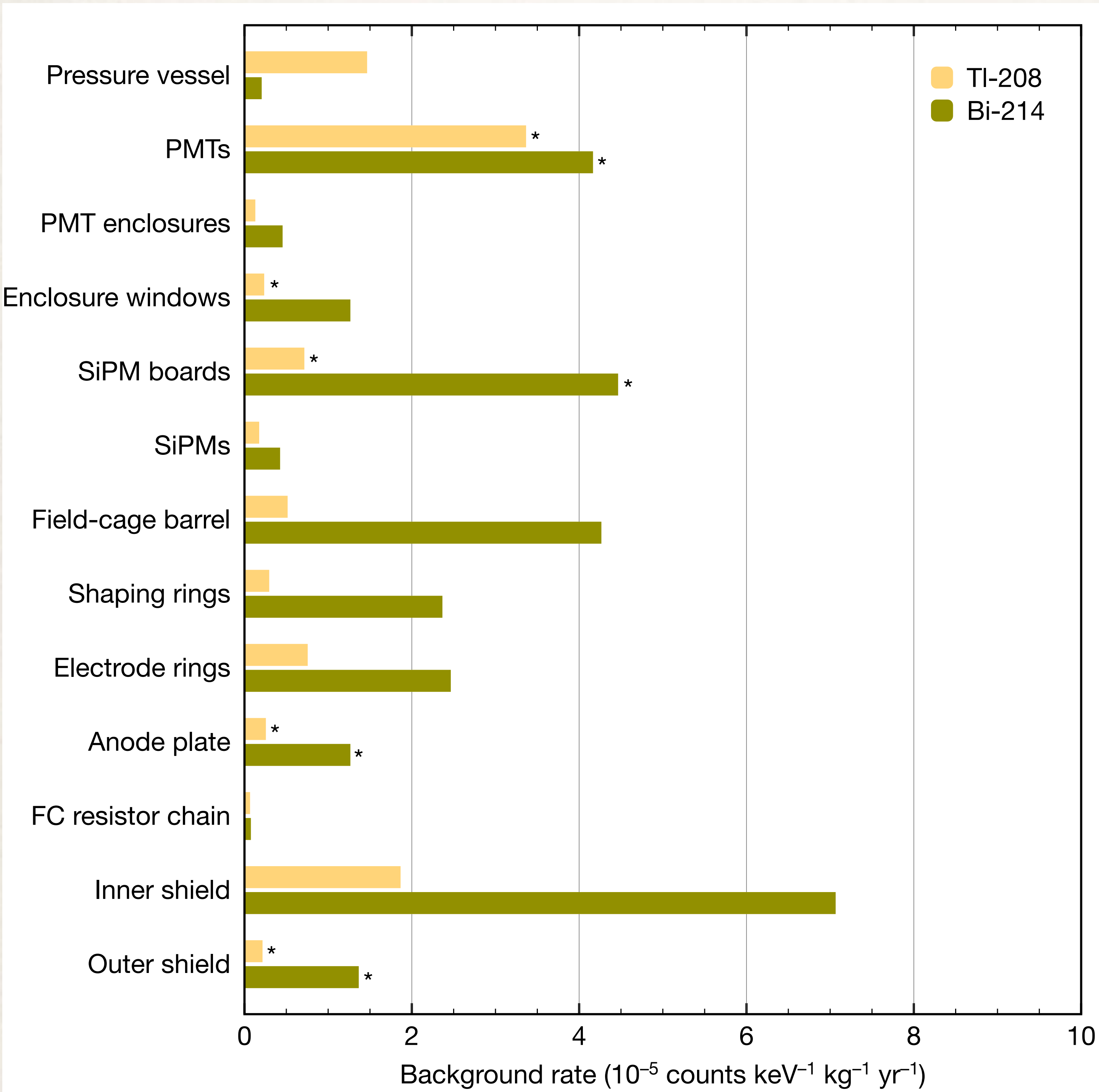
Topological signature in NEXT





- Power of topological signature increases with improved algorithms.
- "DNN NEXT analysis" yields an improvement of 2 wrt classical analysis (high diffusion). Combined low diffusion and DNN yields an improvement of 4.

Background budget



- Expected background rate: 4 x 10^{-4} ckky (8 events in ROI per ton and year)
- Leading sources: PMTs and SiPM boards (KDBs), which contribute with equal amounts. PMTs + KDBs ~10^{-4} CKKY in Bi-214
- Contribution of field cage and inner shield: only upper limits measured (taken as actual values, a conservative approach)

https://inspirehep.net/record/1407146

The NEXT program

- Demonstrate energy resolution at the level of 0.5 % FWHM (NEW)
- Demonstrate rejection power of TPS in pure xenon (NEW)
- Measure backgrounds and compare with NEXT background model (NEW).
- Demonstrate scalability of technology (NEXT-100)
- Demonstrate rejection power of TPS in xenon + low diffusion additives (NEXT-100)
- Refine radio purity (NEXT-100)

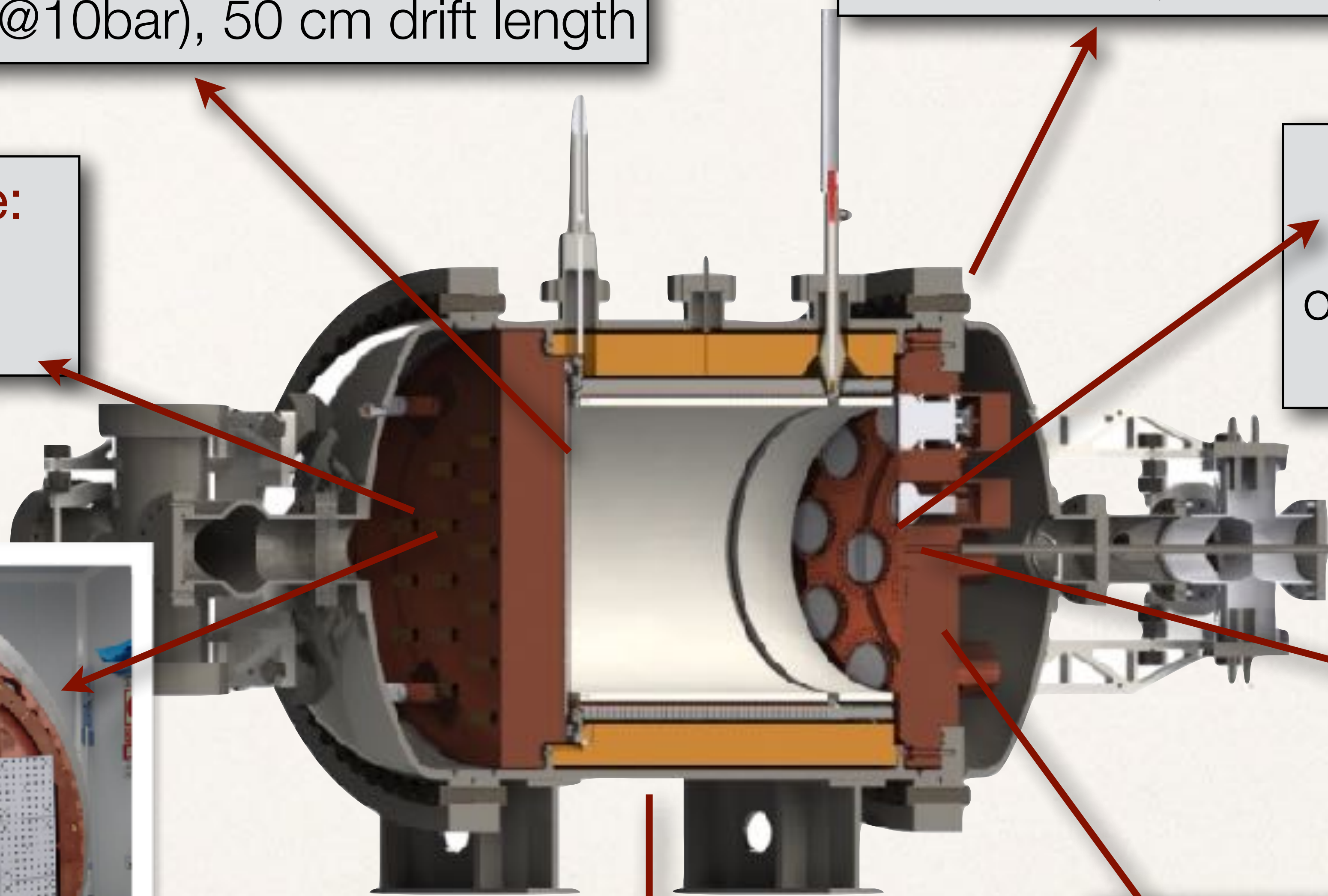
NEW (NEXT-WHITE) at glance

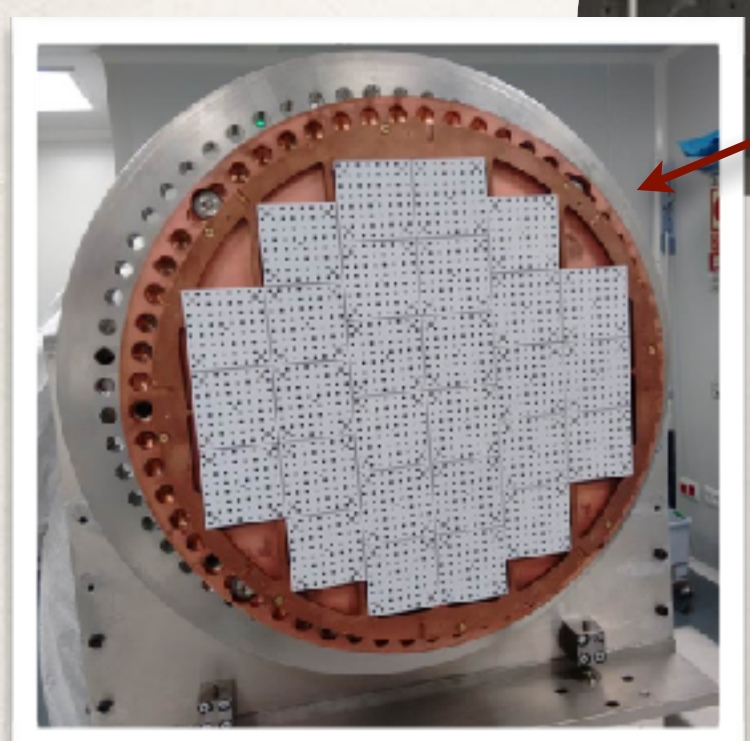
Time Projection Chamber:
10 kg active region(@10bar), 50 cm drift length

Pressure vessel:
316-Ti steel, 30 bar max pressure

Tracking plane:
1,800 SiPMs,
1 cm pitch

Energy plane:
12 PMTs,
operating at vacuum.
30% coverage

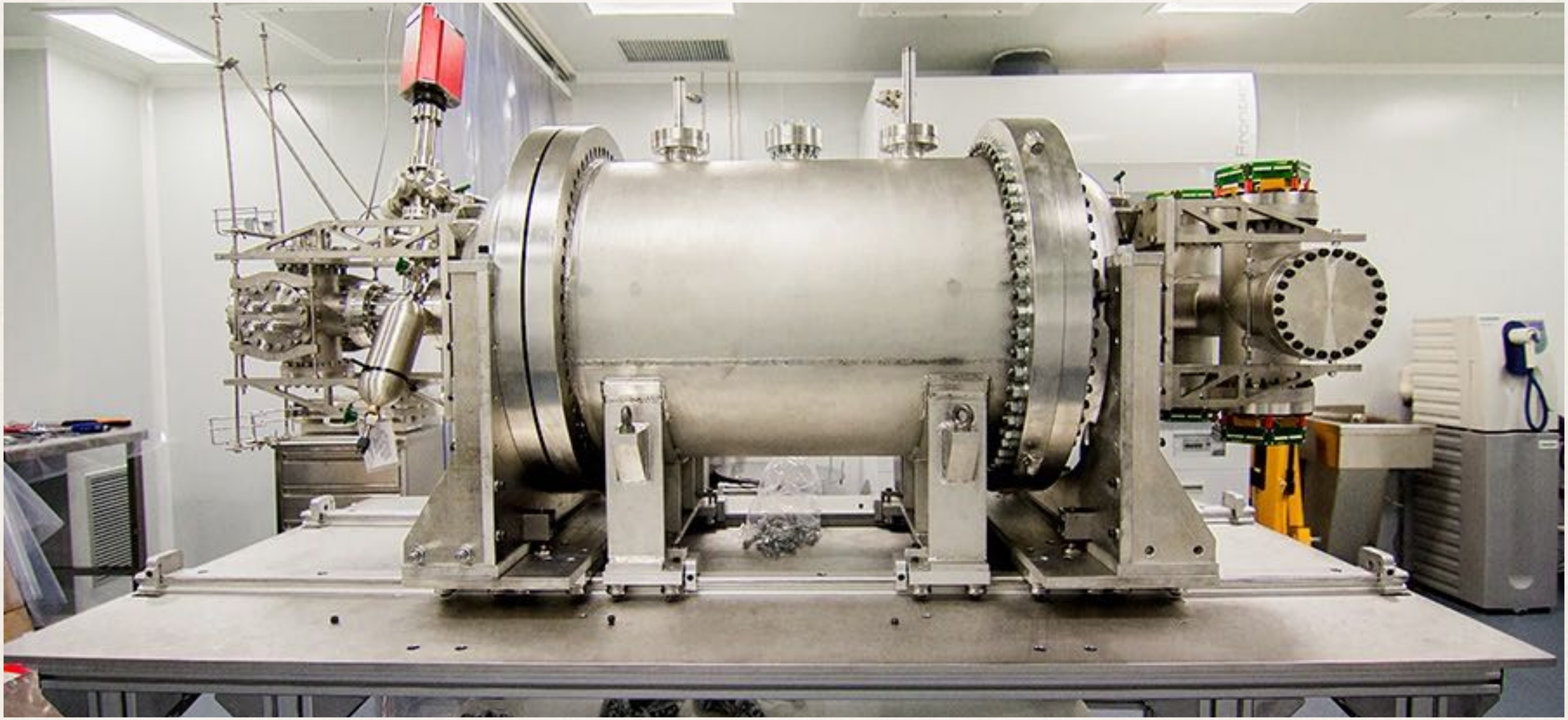




Mother can:
12 cm copper plate that separates pressure from vacuum and ads shielding.

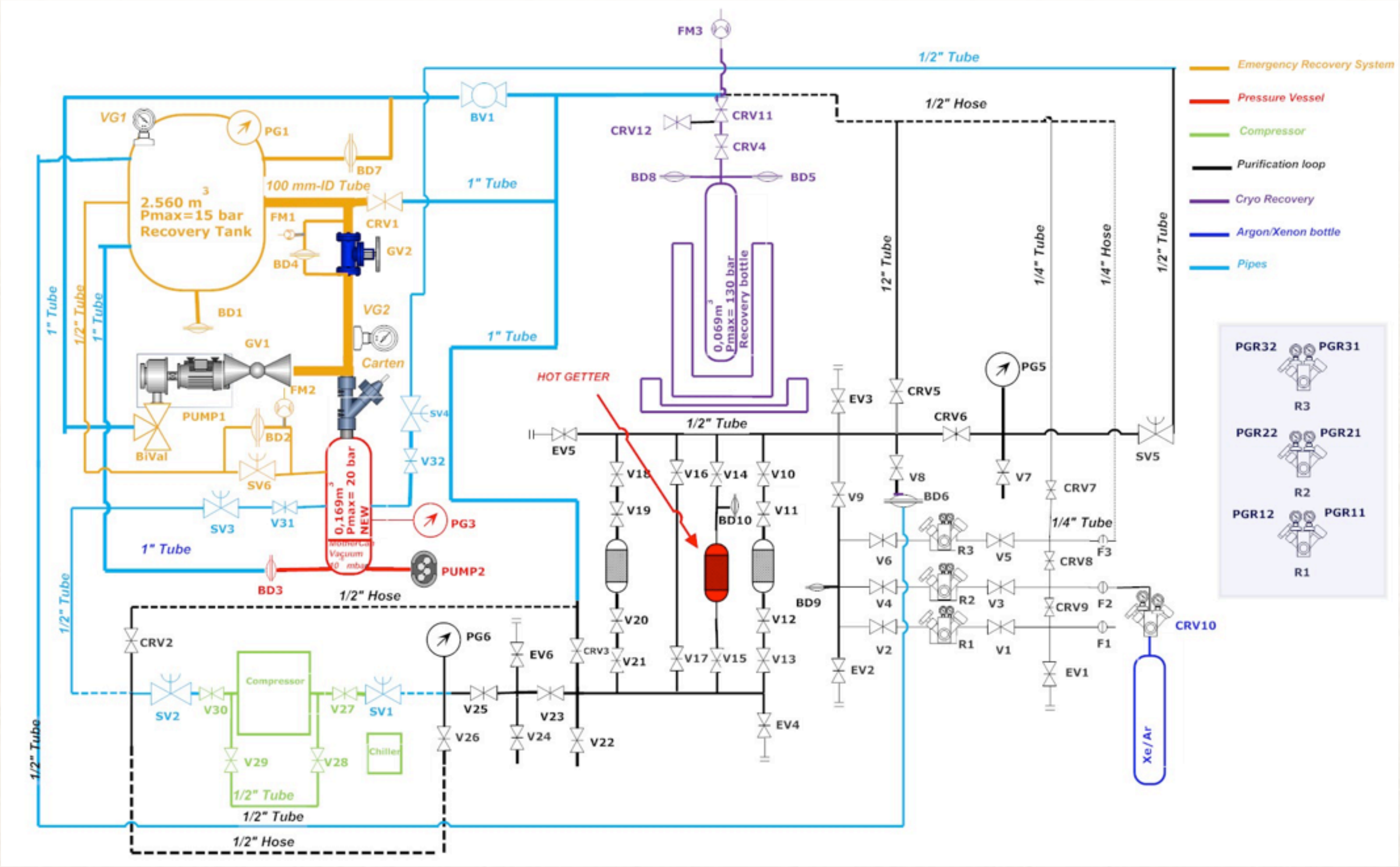
Inner shield:
copper, 6 cm thick

Pressure vessel



Stainless Steel 316 alloy.
Radiopure and light

Gas system (same for NEXT-100)



Gas system

cryo-recovery bottle

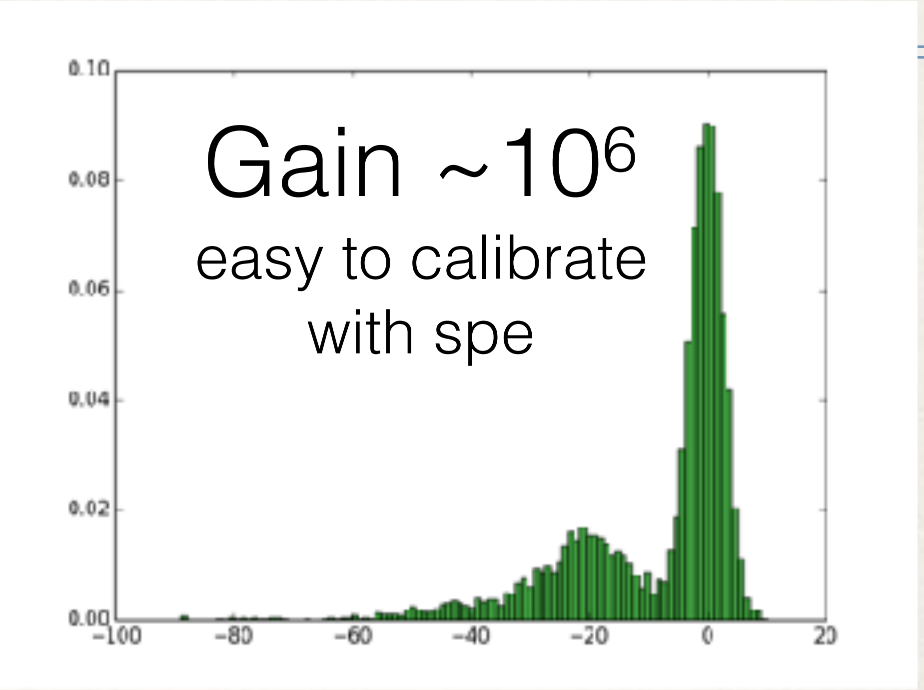
getters

Triple diaphragm compressor to prevent leaks

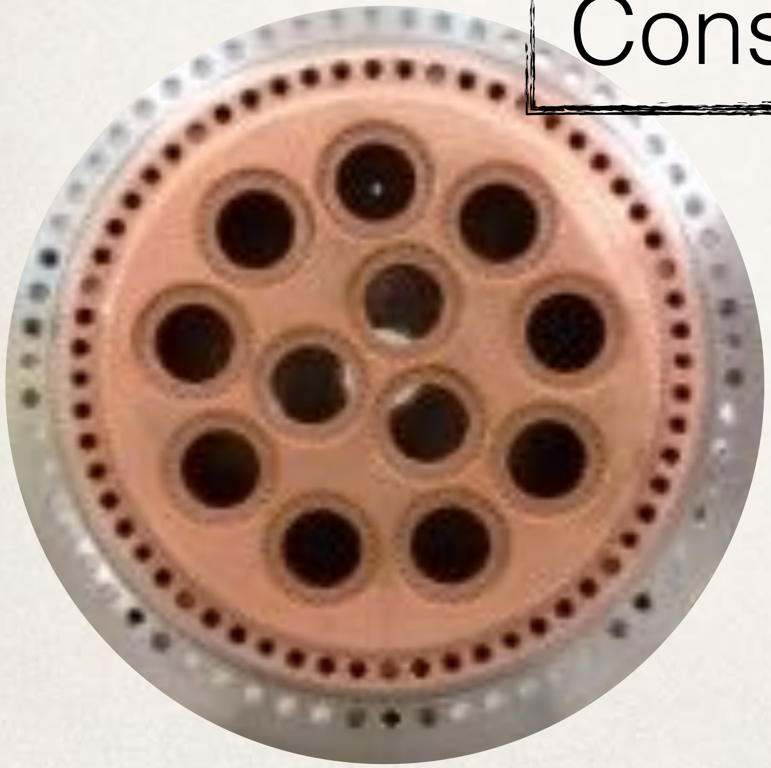
Energy plane

Find the right PMTs

HAMATSU R11410
low radioactivity PMT



Construct the support

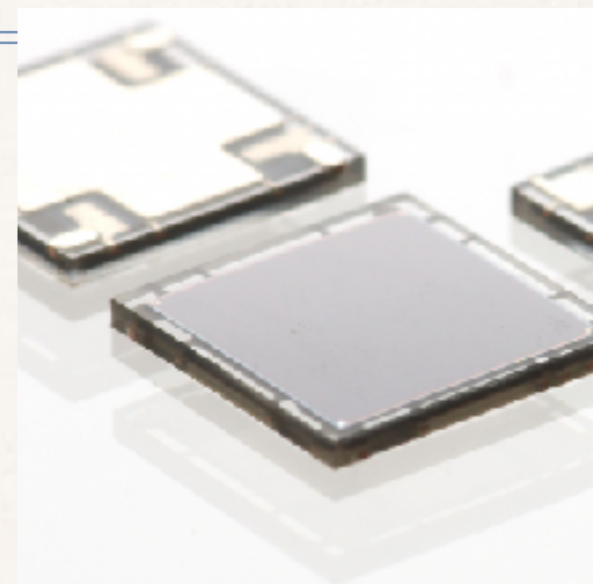


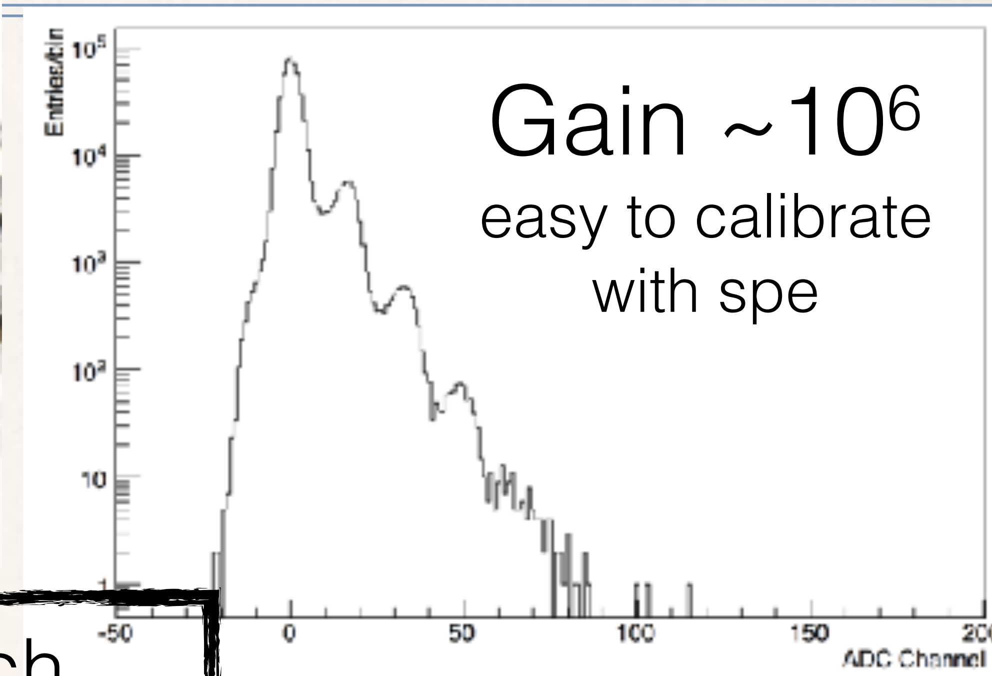
Assembly
the PMTs

Tracking plane

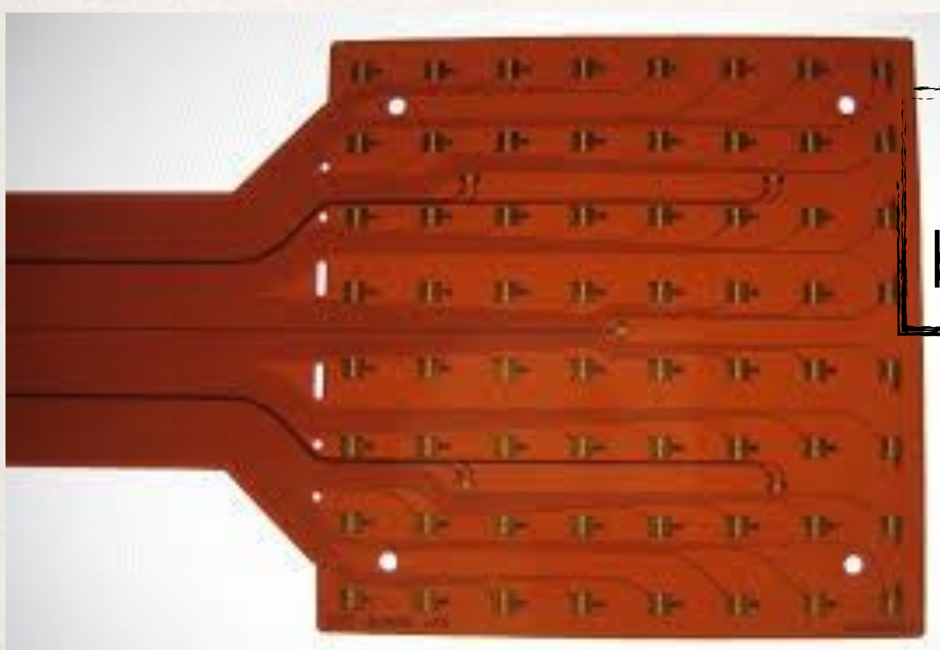
Find the right MPPC

SensL series-C
low radioactivity



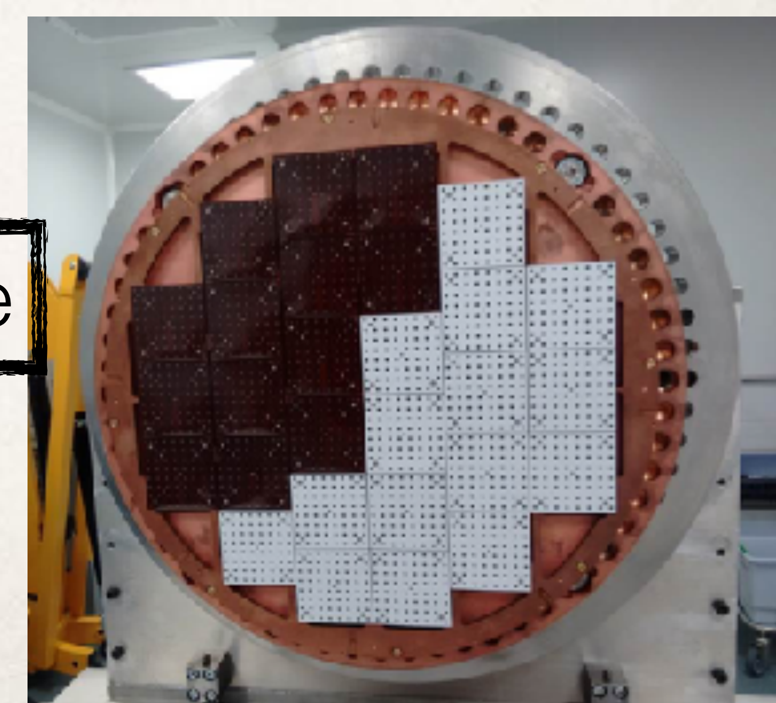


Gain ~10^6
easy to calibrate
with spe



Decide the pitch
between sensors (1cm)

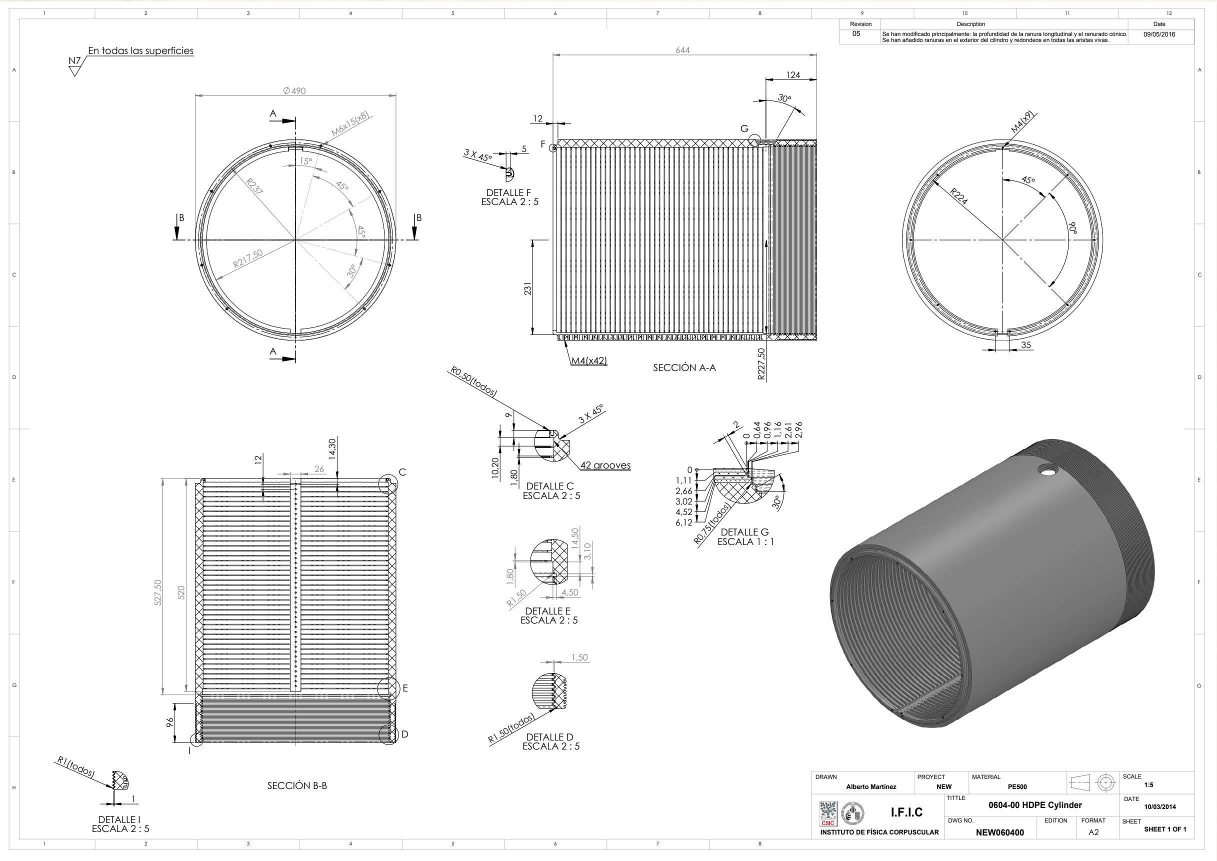
Assembly the plane



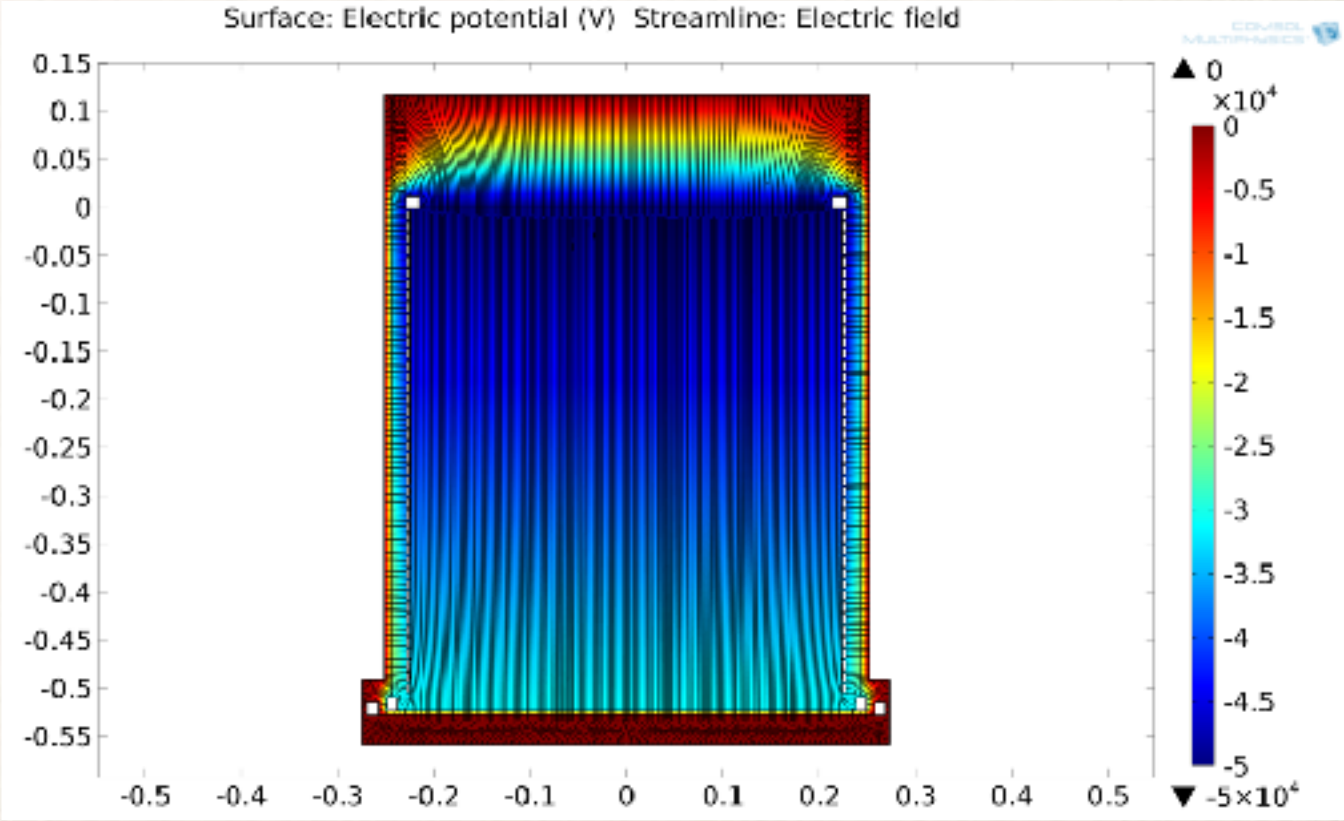
Find a radiopure material for the board (kapton)

Field cage

Make a design

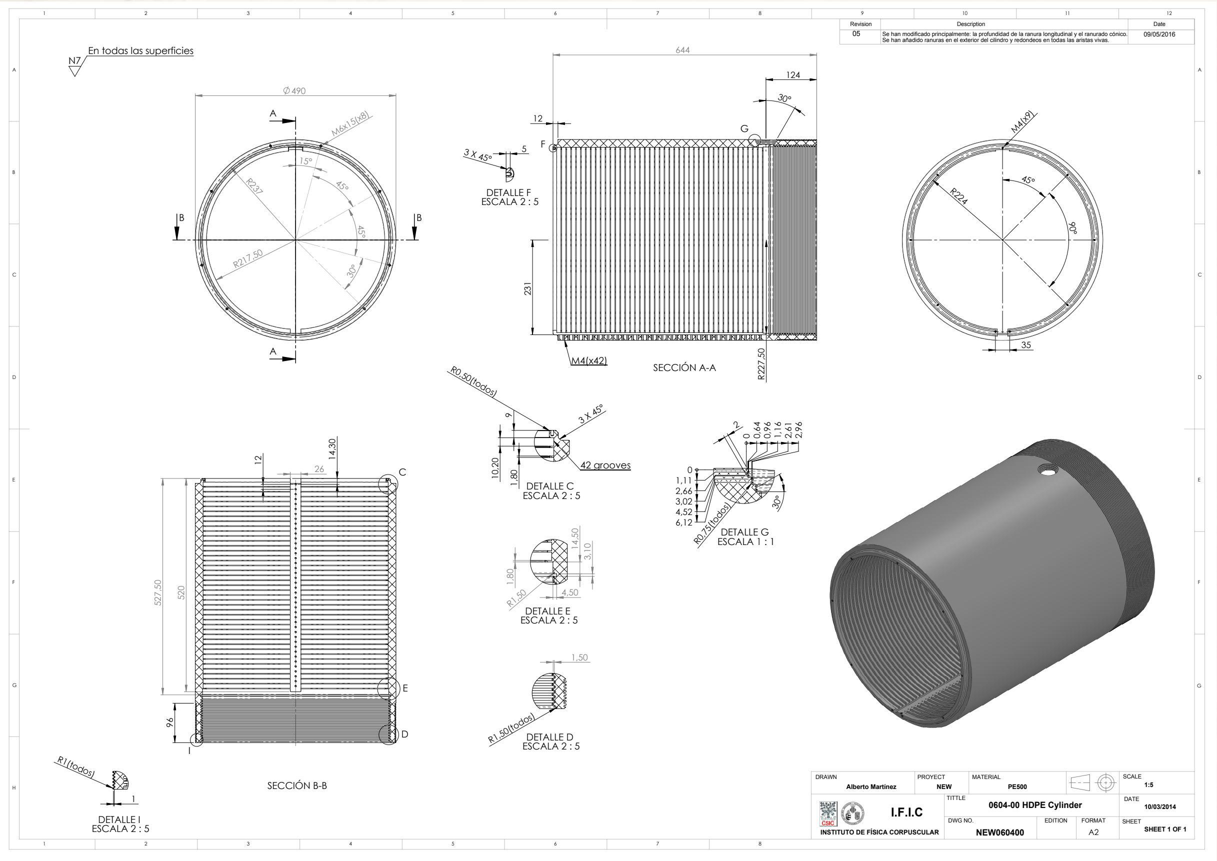


Simulate the electric field

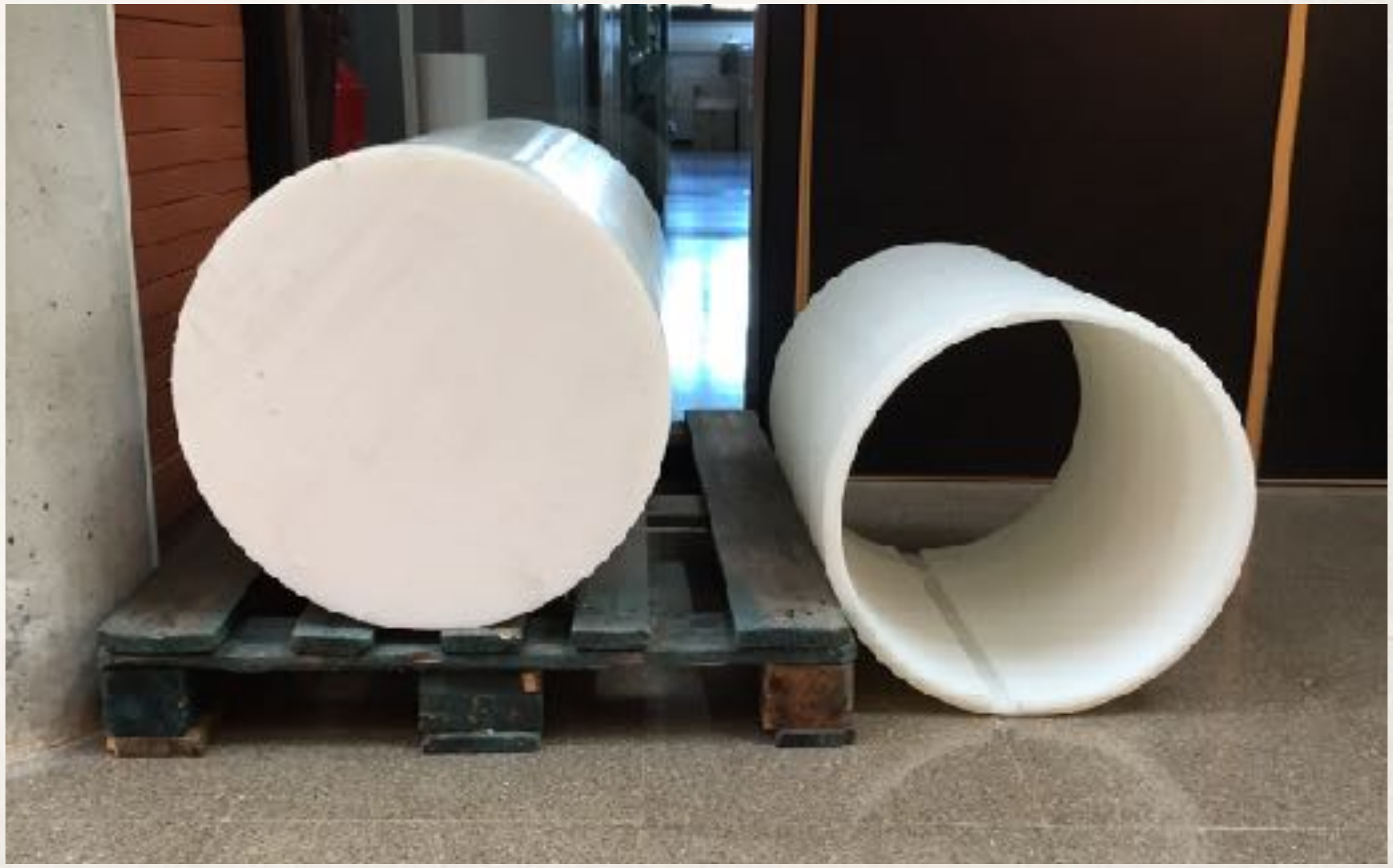


Field cage

Make a design

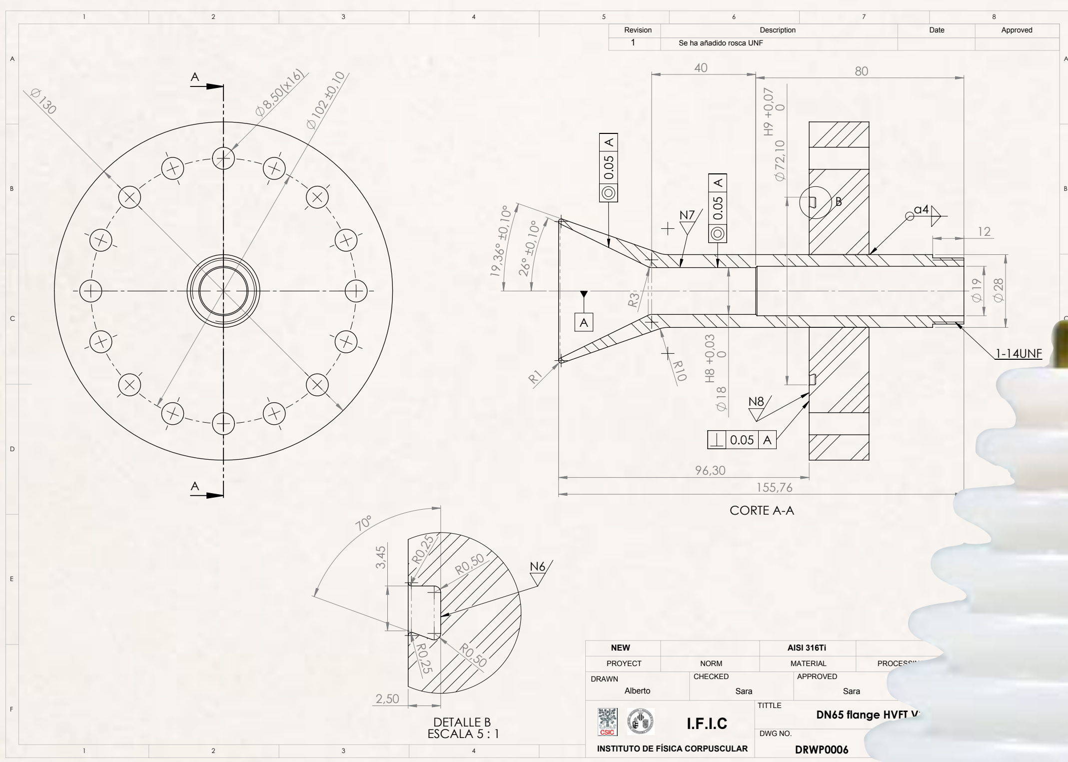


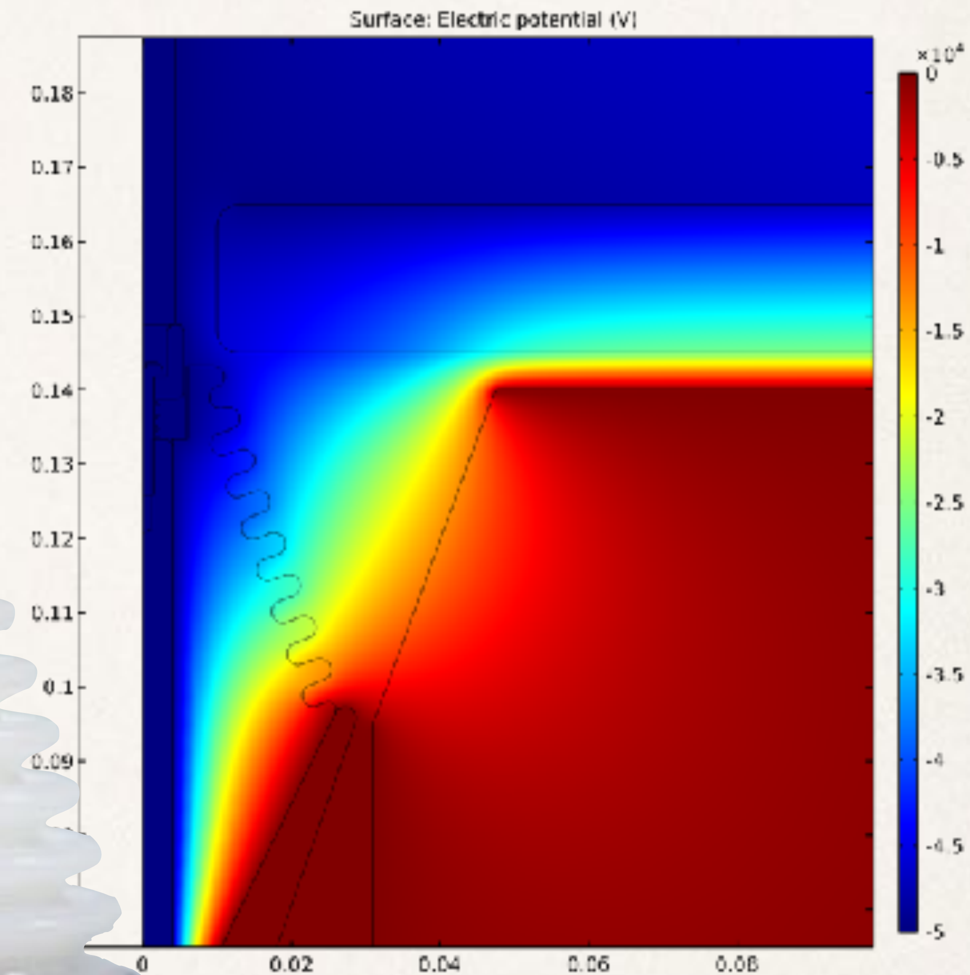
Fabricate



Field cage

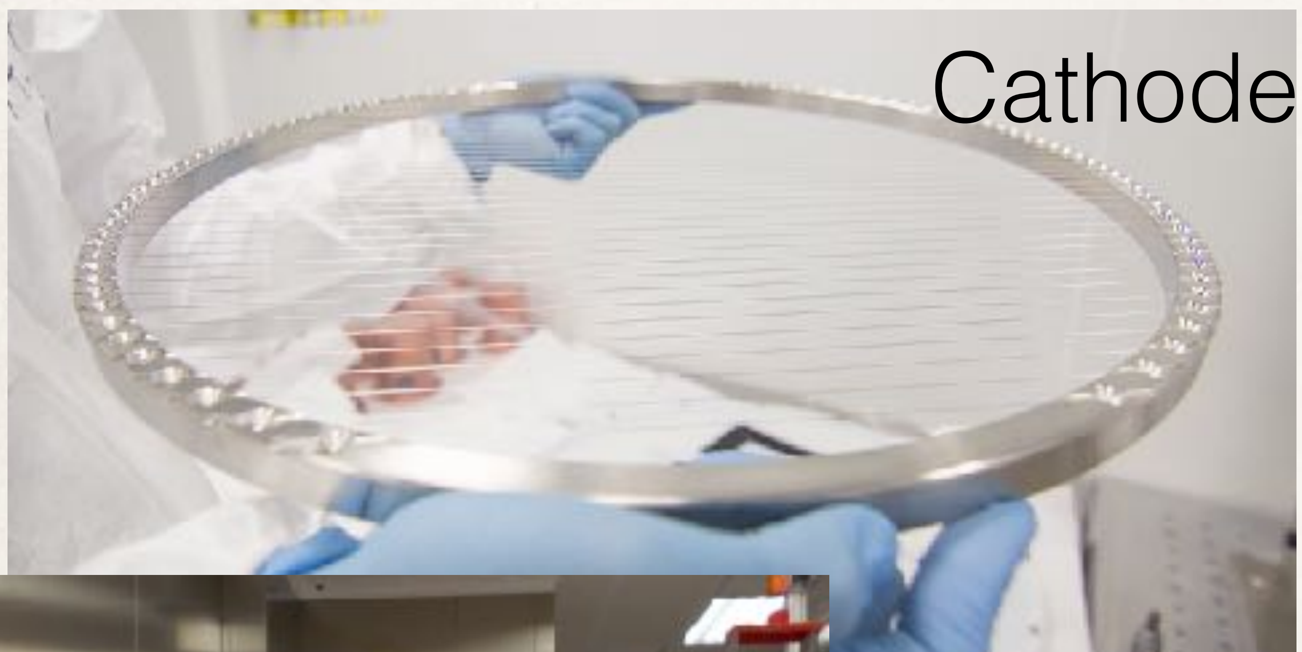
Repeat process for HVFT

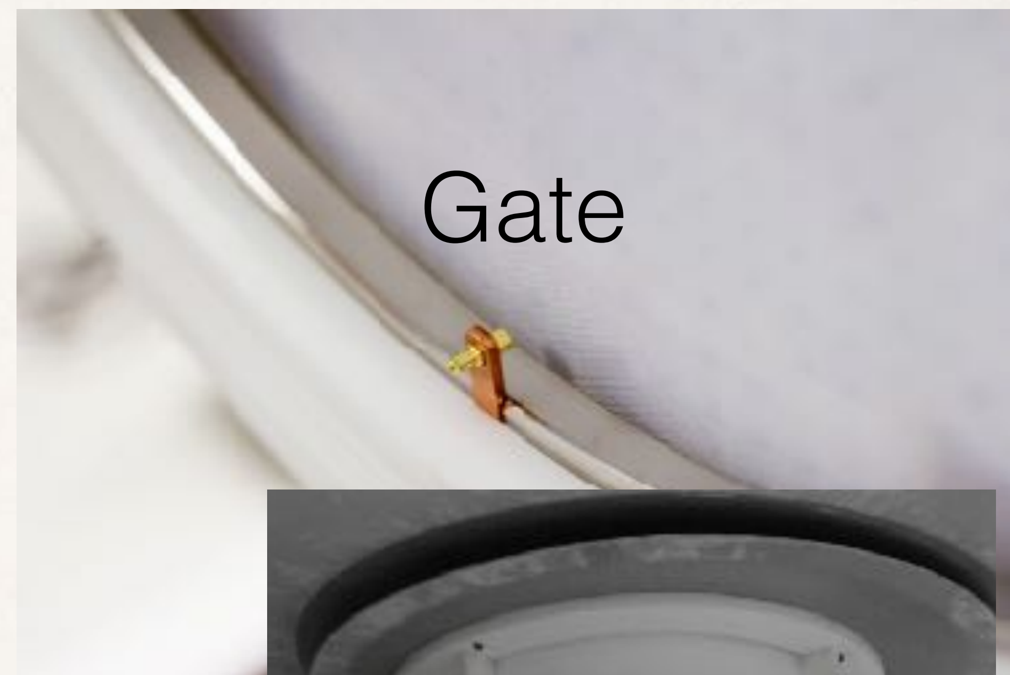




Field cage

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

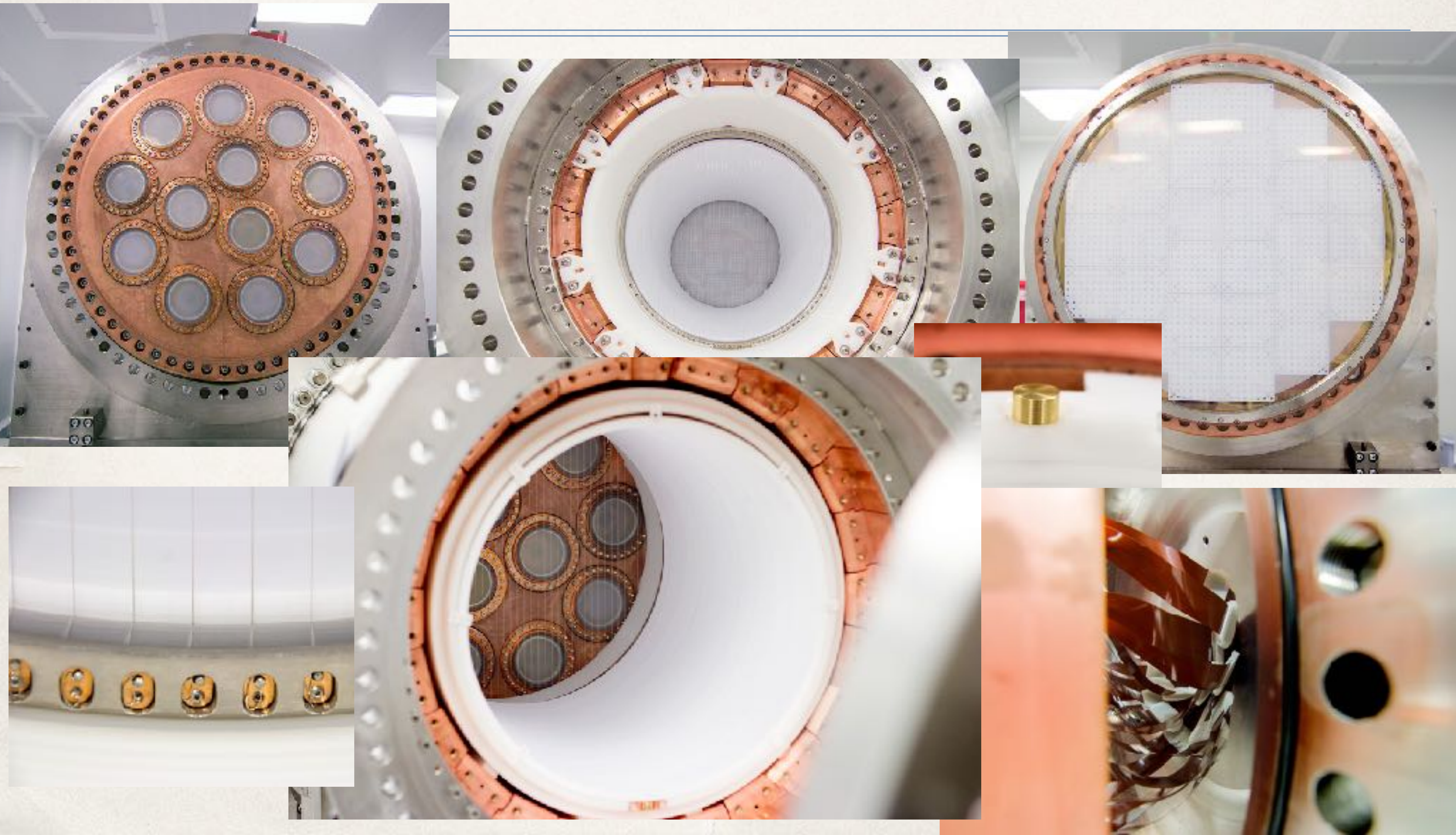




Anode plate

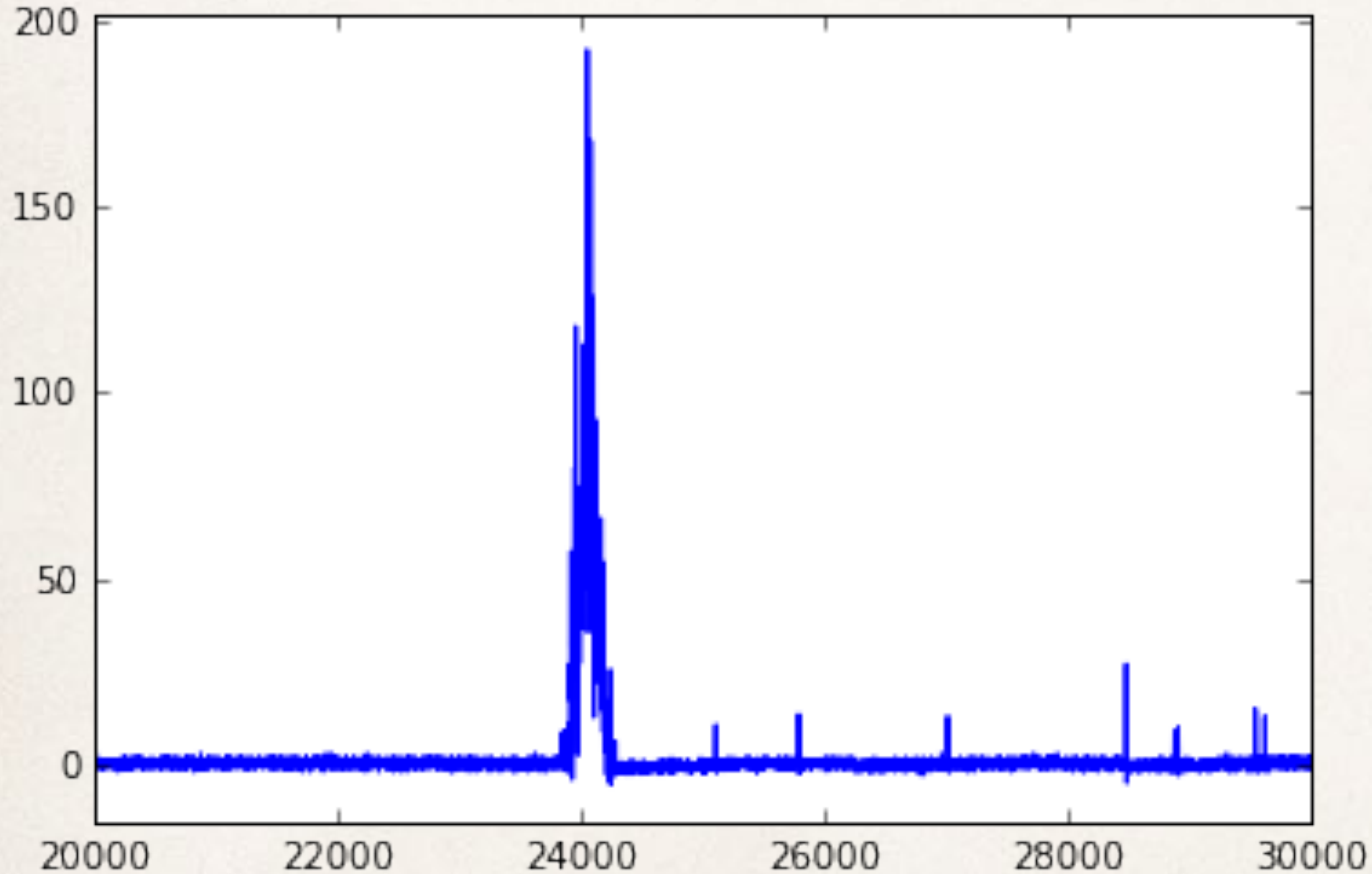
Light tube

Assembly all the pieces



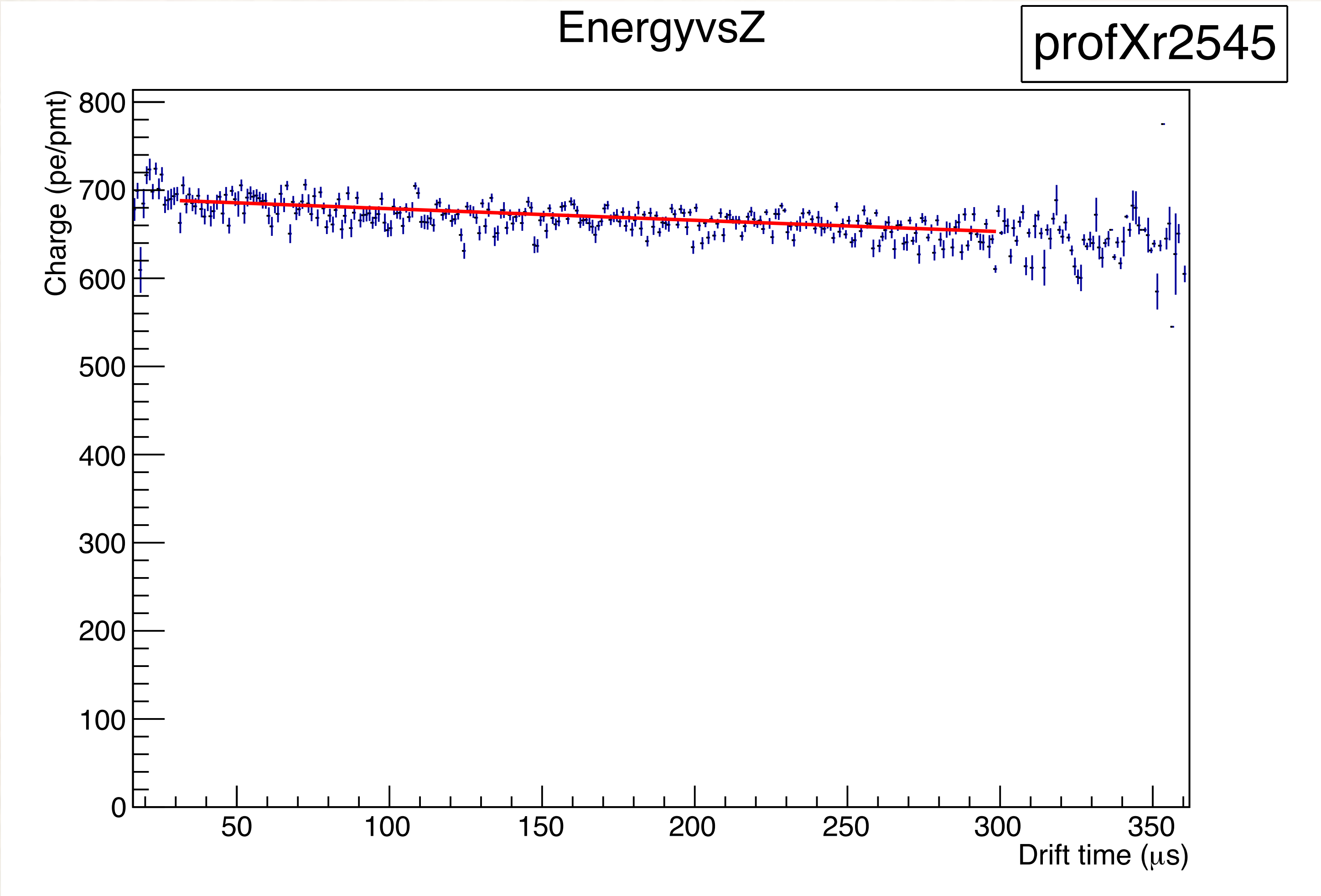
Detector operating with Xenon in the Canfranc Underground Laboratory

NEW is alive!



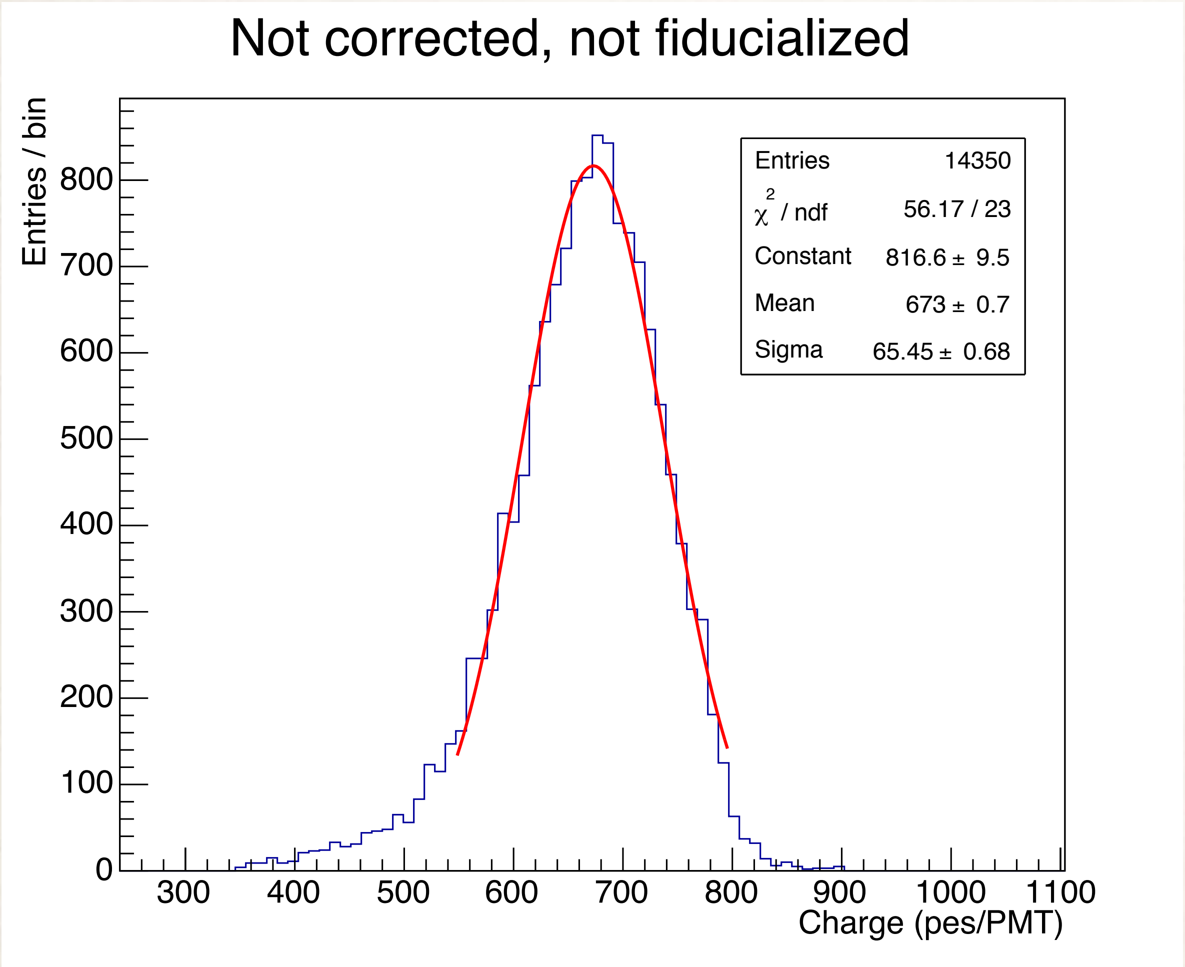
- A kripton signal
- baseline noise well below 1/20th pes.
- Curious S1-like signals after S2 (not yet understood… maybe TPB in anode plate?)

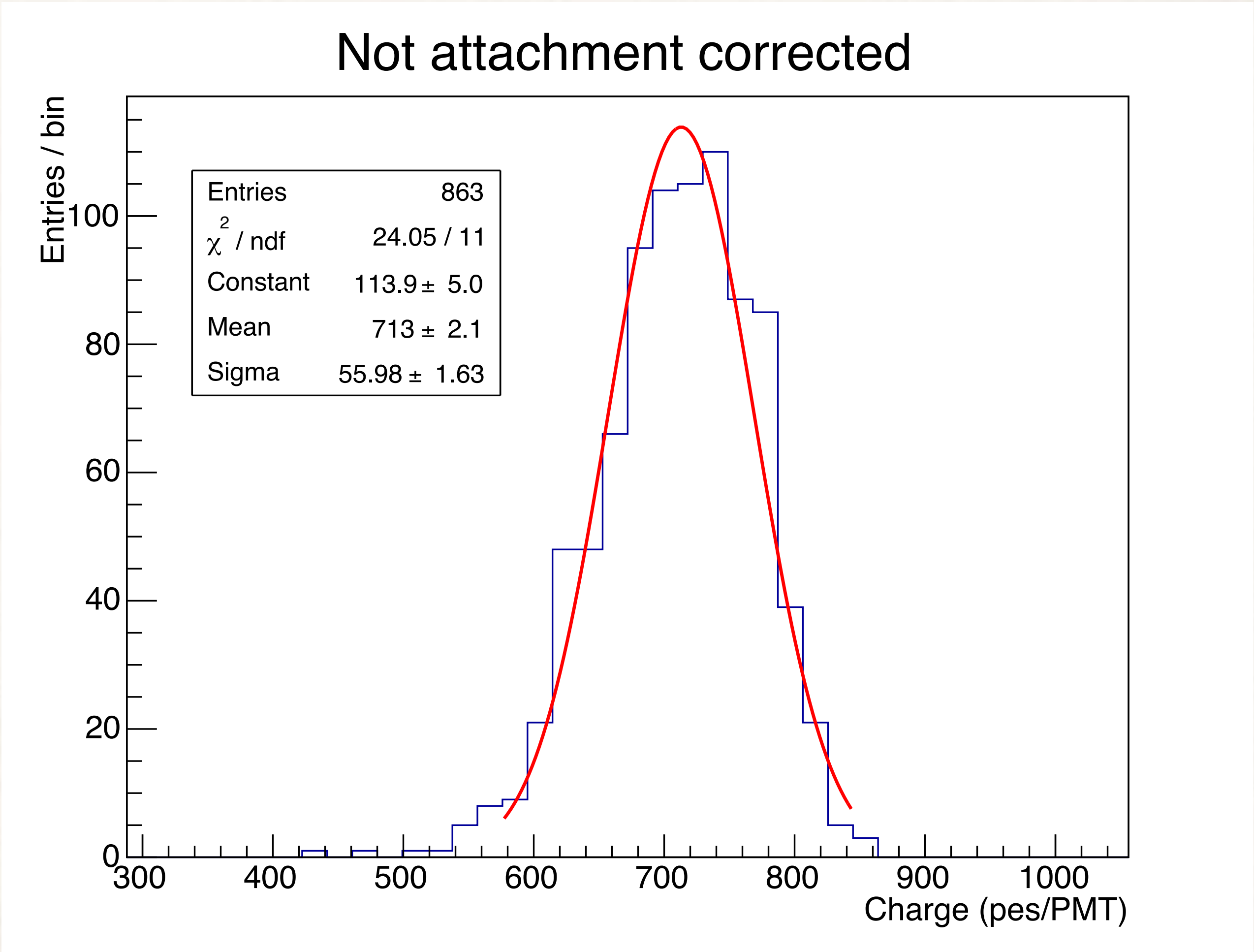
NEW is alive!



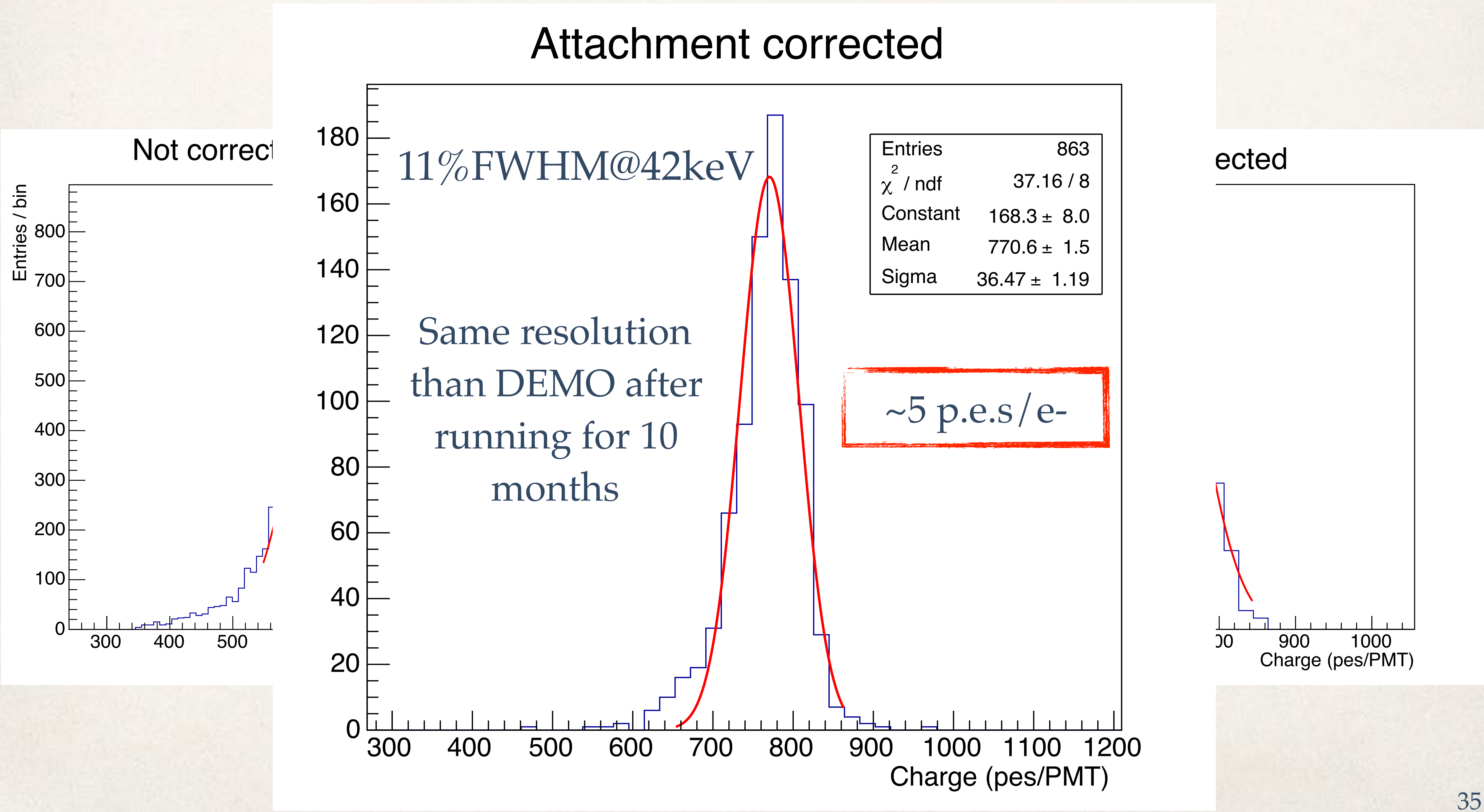
- Electron lifetime ~5 ms after a few days of running with hot getter
- Lifetime should improve to 20 ms or better as gas keeps circulating in system and degassing decreases

NEW is alive!


Not corrected, not fiducialized
Entries / bin
Charge (pes/PMT)
Entries 14350
χ2 / ndf 56.17 / 23
Constant 816.6 ± 9.5
Mean 673 ± 0.7
Sigma 65.45 ± 0.68
0
100
200
300
400
500
600
700
800
300
400
500
600
700
800
900
1000
1100

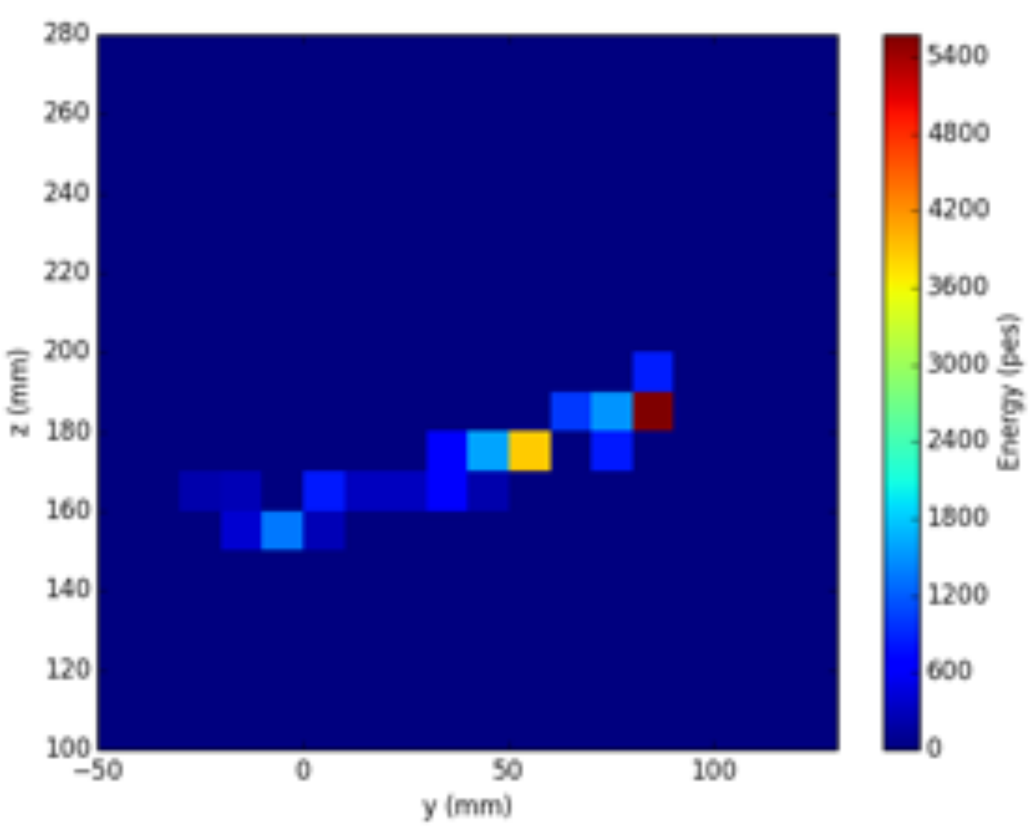

Not attachment corrected
Entries / bin
Charge (pes/PMT)
Entries 863
χ2 / ndf 24.05 / 11
Constant 113.9 ± 5.0
Mean 713 ± 2.1
Sigma 55.98 ± 1.63
0
20
40
60
80
100
300
400
500
600
700
800
900
1000

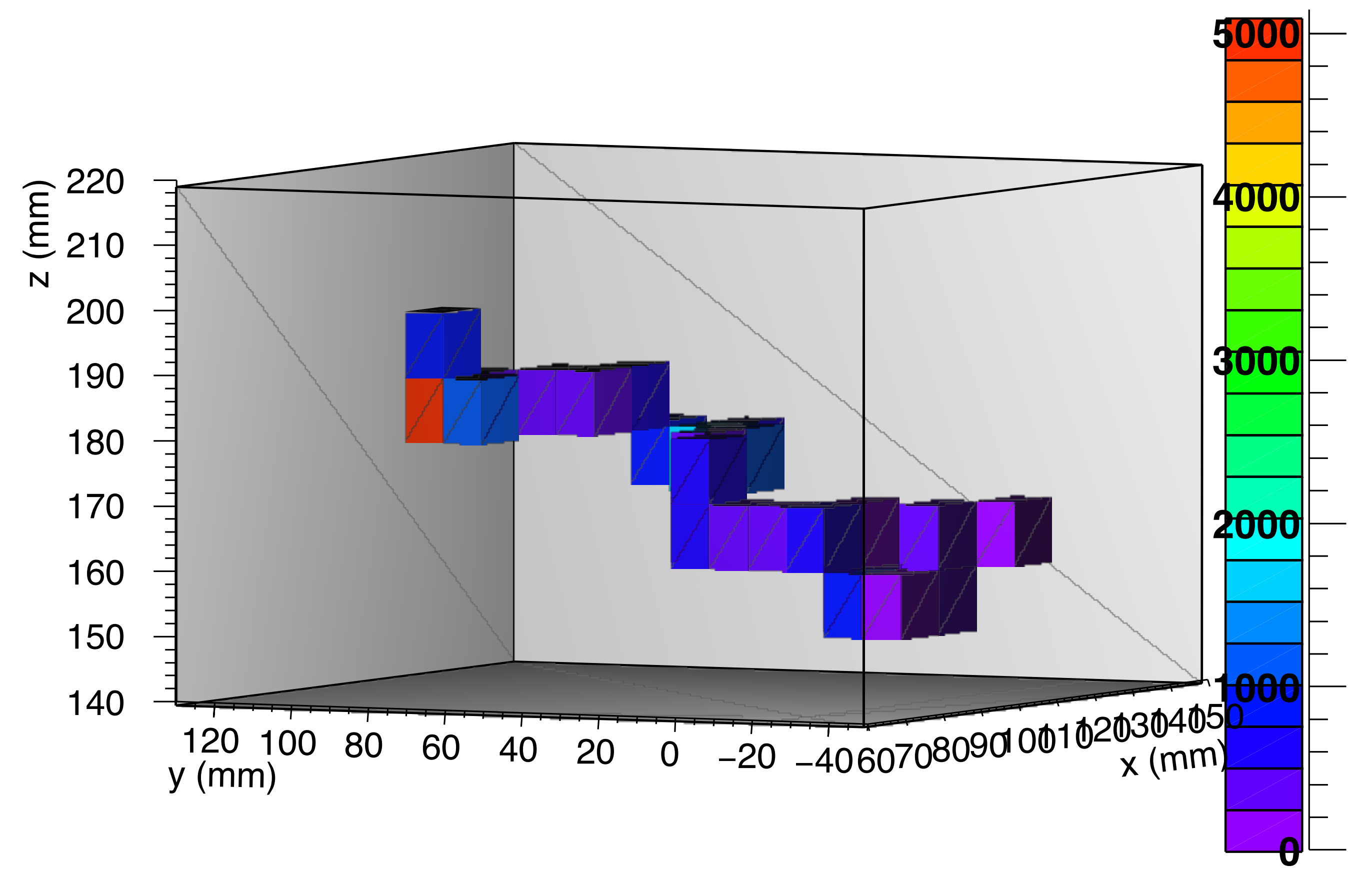
NEW is alive!


Not correct
Entries / bin
Attachment corrected
11%FWHM@42keV
Entries 863
χ^2 / ndf 37.16 / 8
Constant 168.3 ± 8.0
Mean 770.6 ± 1.5
Sigma 36.47 ± 1.19
Same resolution than DEMO after running for 10 months
~5 p.e.s/e-
Charge (pes/PMT)
ected
Charge (pes/PMT)

NEW is alive!

511 keV electron produced by the Na22 annihilation gamma





NEW Schedule

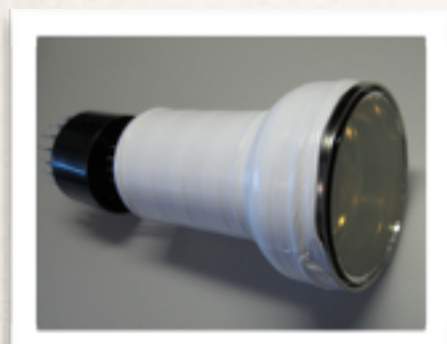
- Detector up and running in stable conditions.
- Initial run (March 2017): Initial calibrations with radioactive sources.
- March & April: Detector upgrades.
- May-: Run at higher pressures (10-15 bar).
- Low background run starting ~summer 2017.

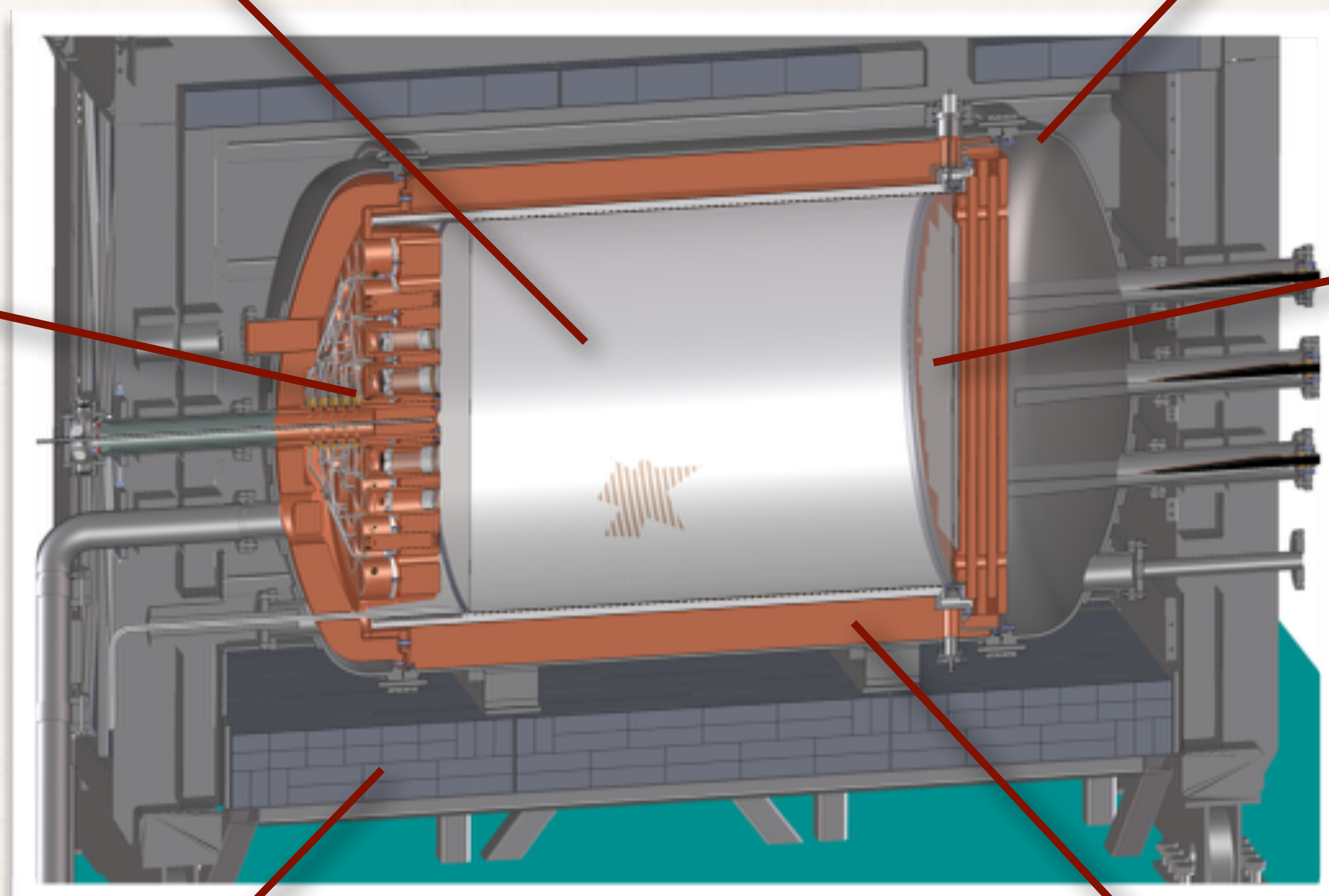
NEXT 100 kg detector at LSC: main features

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

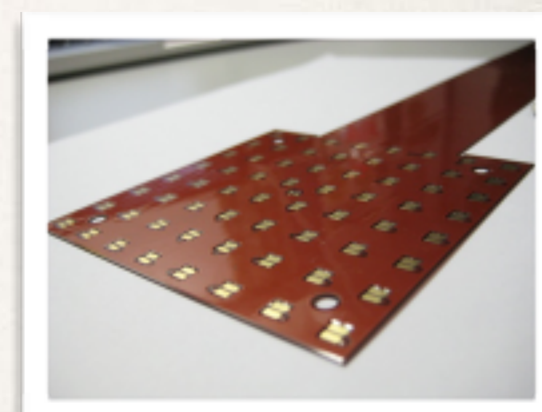
Pressure vessel:
stainless steel,15 bar max pressure

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

NEXT-100 scalability to tonne scale

- NEXT-100 MC calculations (energy resolution 0.7% FWHM, high diffusion) yield 8 events/tonne/year.
- We need to reduce the background rate by an order of magnitude:
  - Improve energy resolution from 0.7% to 0.5% FWHM will reduce the dominant background (Bi214) by a factor **2**.
  - Gaseous mixtures can provide low diffusion, improving rejection by a factor ~4
- Therefore NEXT-100 can demonstrate ~ 1 event/tonne/year

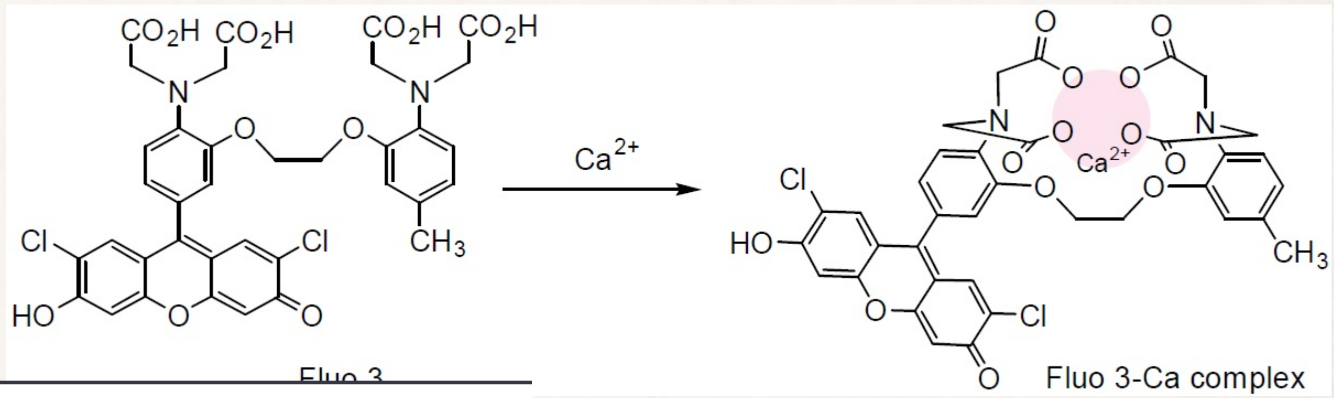
Towards the ton scale

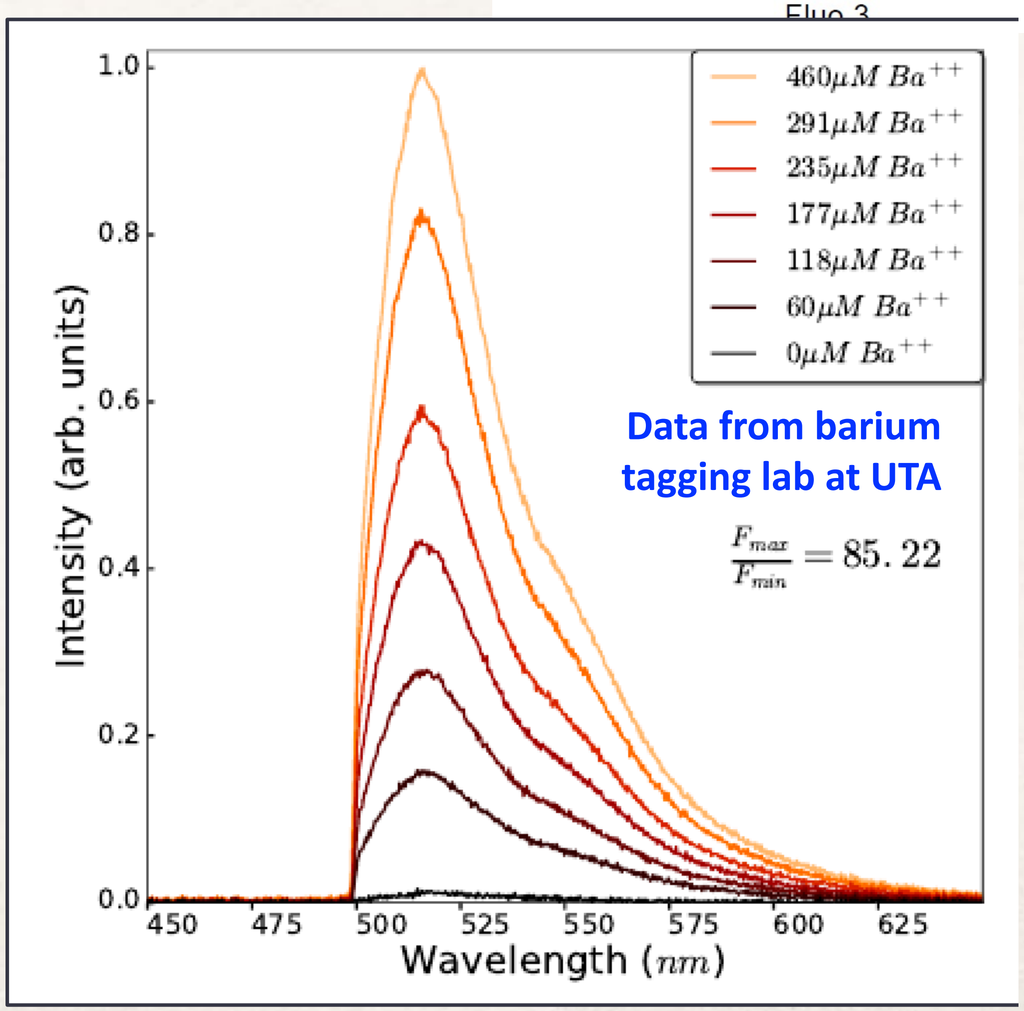
- NEXT-100 can demonstrate a background rate near 1 cts/ton/year in ROI.
- Further improvement may be achieved by building a x2 larger detector (S/N improves linearly with size) and by reducing the radioactive budget
  - Symmetric detector. x2 in z
  - R&D to increase diameter.
  - SiPM in both planes can reduce the background budget.
- Last but not leat gas Xenon can provide a technique (SMFI) for a background free experiment.

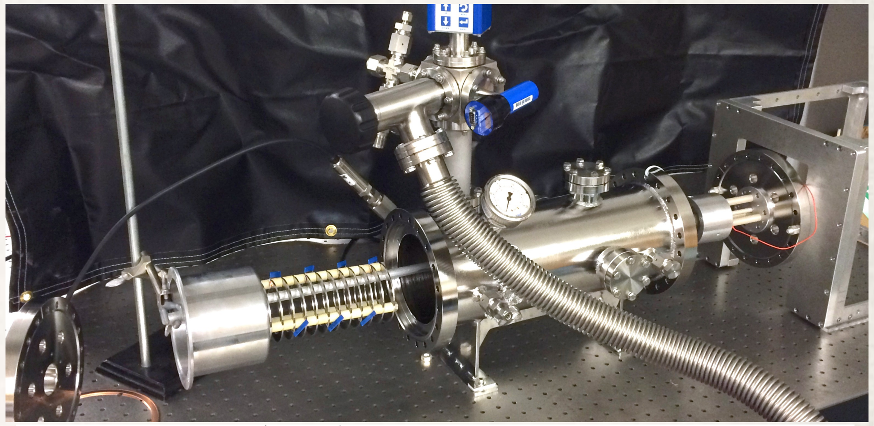
Towards a background free experiment: Single Molecule Fluorescent Imaging

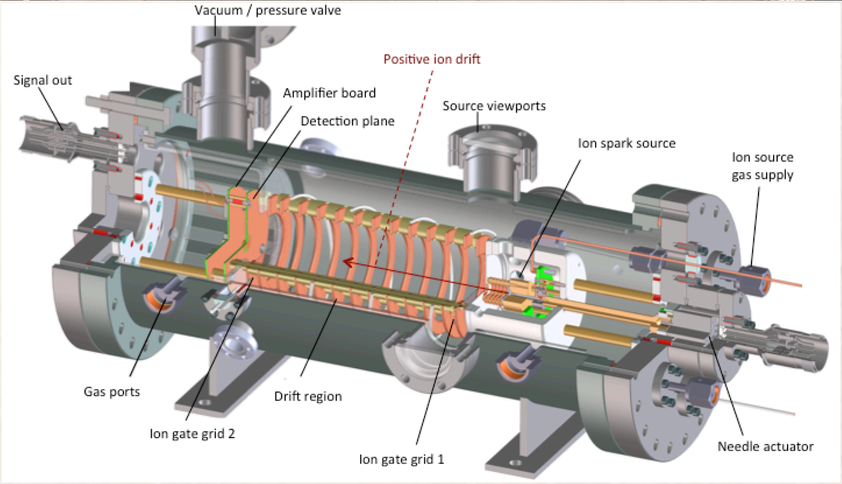
- SMFI is a technique from biochemistry with demonstrated single-ion sensitivity.
- We are exploring its use in xenon gas for barium ion tagging
- If efficient barium tagging can be achieved, a zero background experiment can be realised.

Not fluorescent **Fluorescent**









Summary & Outlook

- NEXT R&D phase completed with great success
- Operation underground started. NEW operation foreseen in 2017 and 2018
- The goal of NEXT-100 is to reach a sensitivity competitive with the best experiments in the 100 kg scale and demonstrate ultra low background (BI ~1 cts/ton/year in ROI)
- Excellent prospects for ton scale scalability.

Thanks for your attention!
The NEXT Collaboration

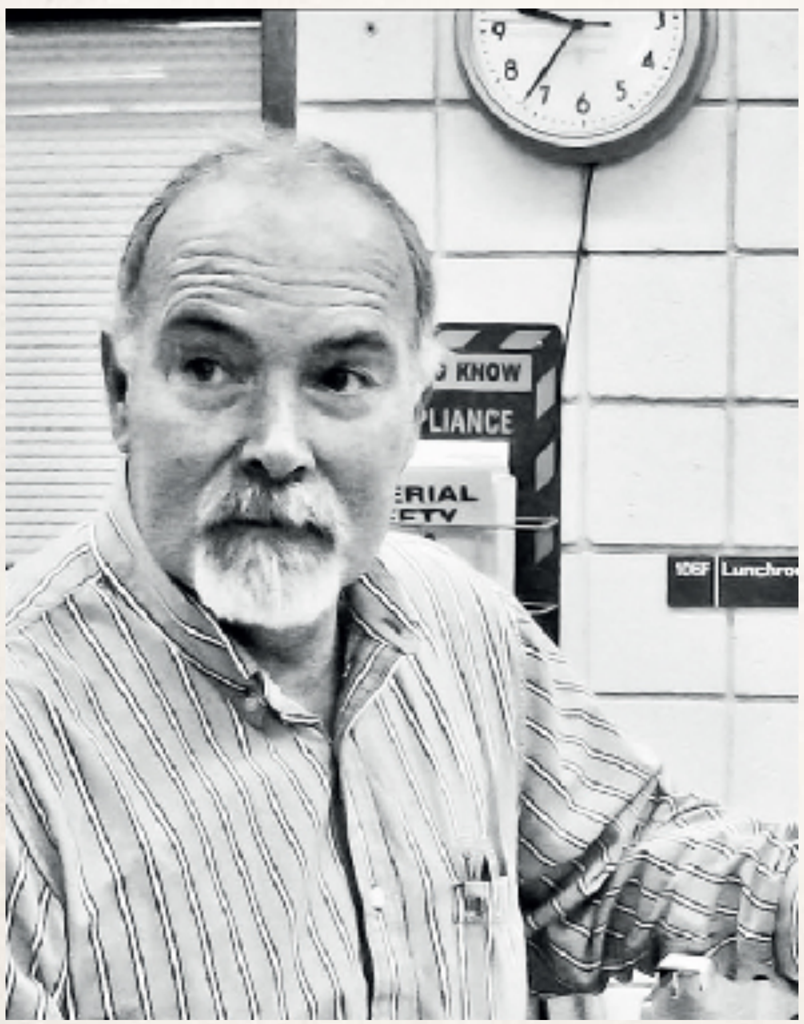
IFIC Valencia • Zaragoza • Politécnica Valencia • Santiago de Compostela • Girona • Madrid

• Texas A&M• Texas UTA

Coimbra • Aveiro

JINR

A. Nariño



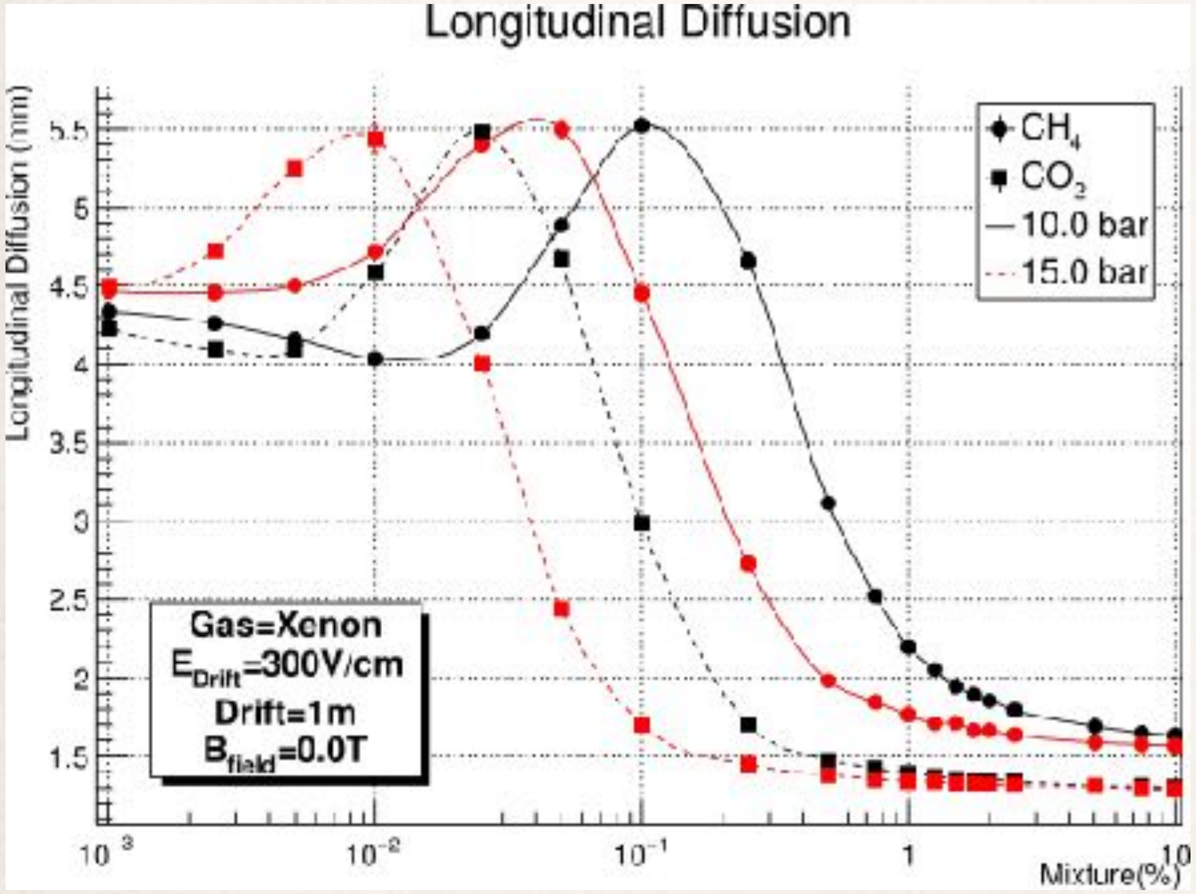
To our friend and mentor
James White, in memoriam.

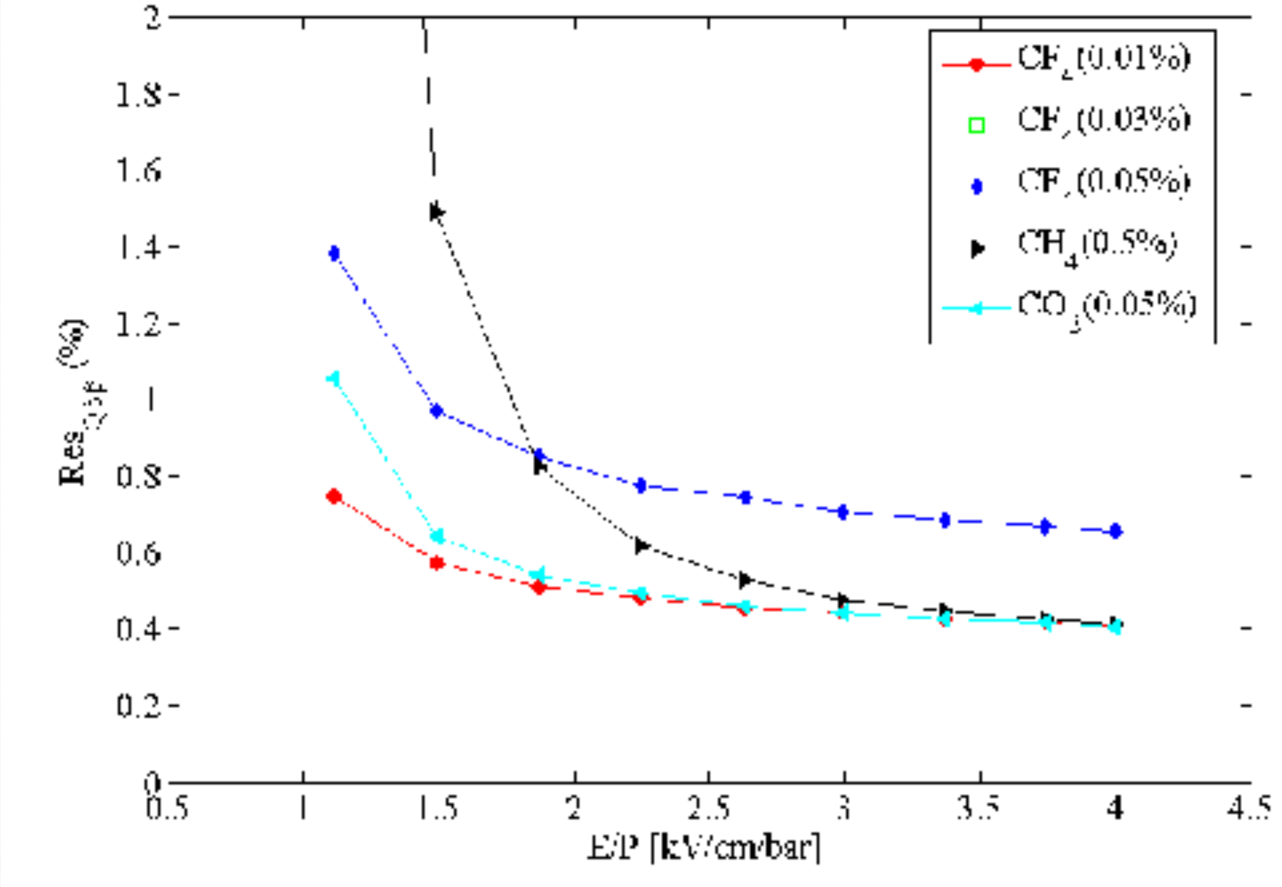
co-spokespersons: D. Nygren (USA) and J.J. Gomez-Cadenas (Spain)

Back-up

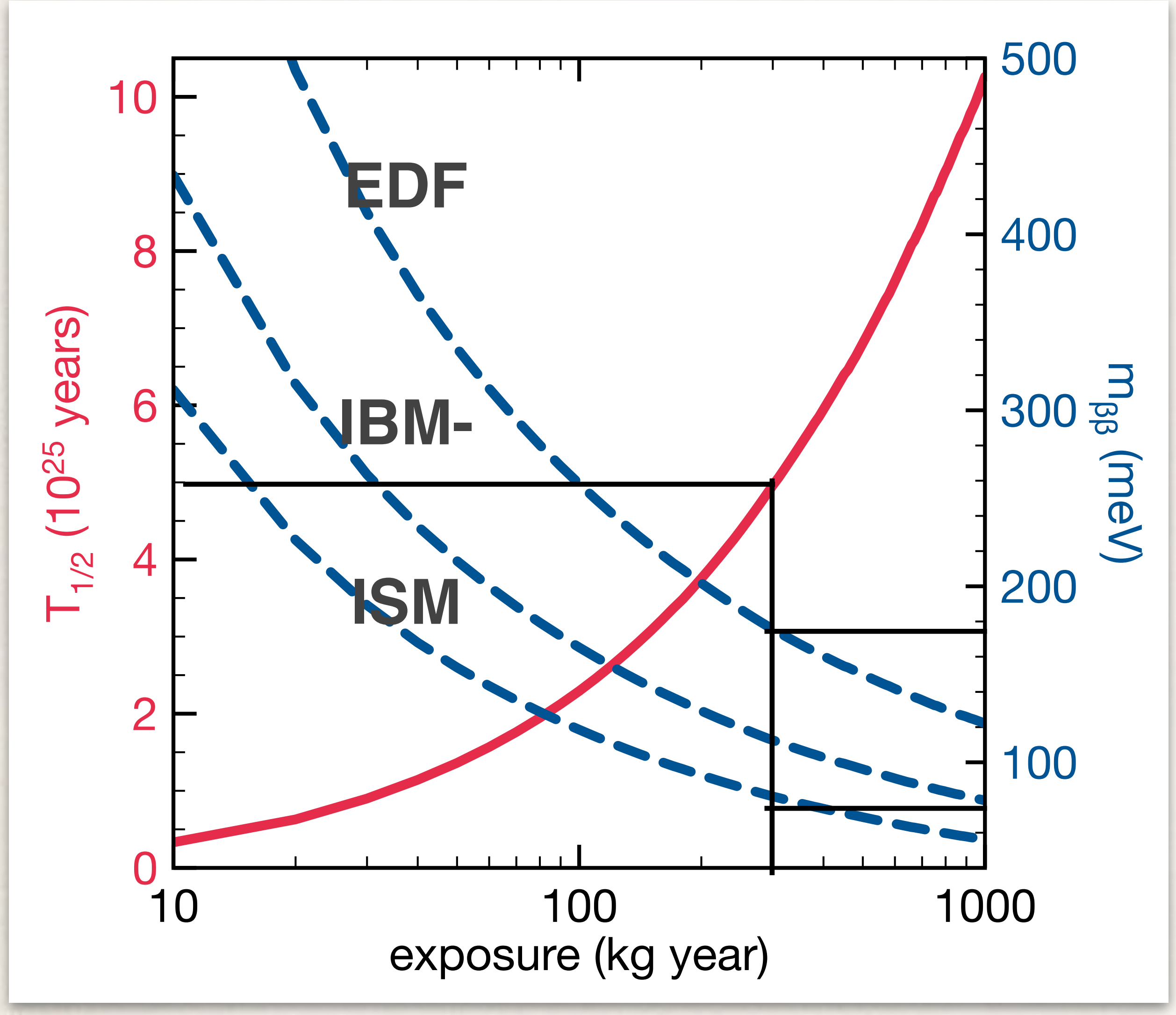
How to improve topological signature?

Some gas mixtures allow for a small diffusion without losing energy resolution





Sensitivity



- Expect 5 x 10^{25} y in 3 years run (2018-2020).
- mbb ~[90-180] meV depending on NME

Sensitivity of NEXT-100 to neutrinoless double beta decay
NEXT Collaboration (J. Martin-Albo (Valencia U., IFIC) *et al.*). Nov 30, 2015. 29 pp.
e-Print: **arXiv:1511.09246 [physics.ins-det] | PDF**