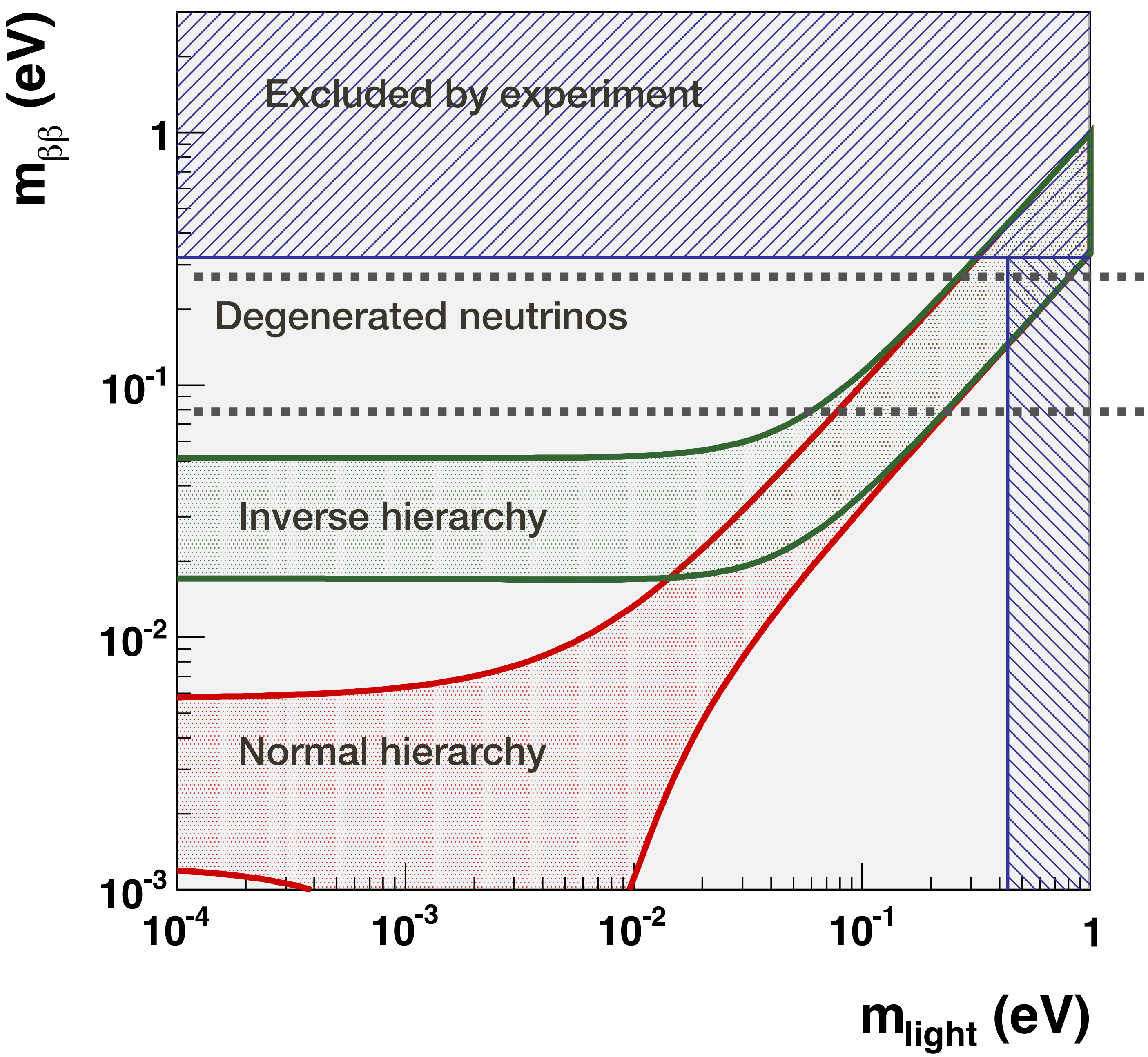
THE next NEUTRINOLESS DOUBLE BETA DECAY EXPERIMENT

JJ Gomez-Cadenas on behalf of the NEXT collaboration

XVII International Workshop on Neutrino Telescopes
March 13-17 2017

The Majorana landscape

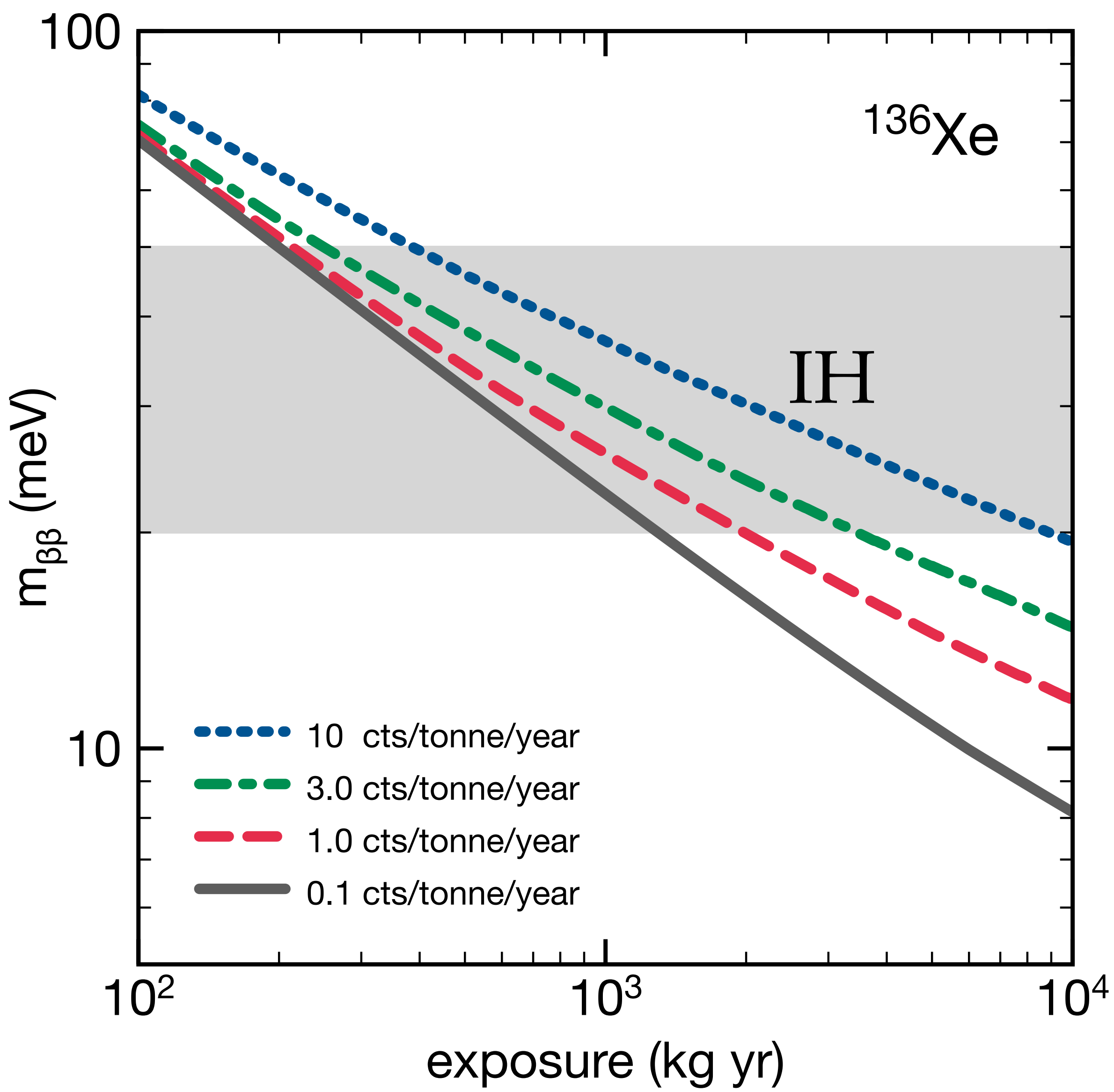


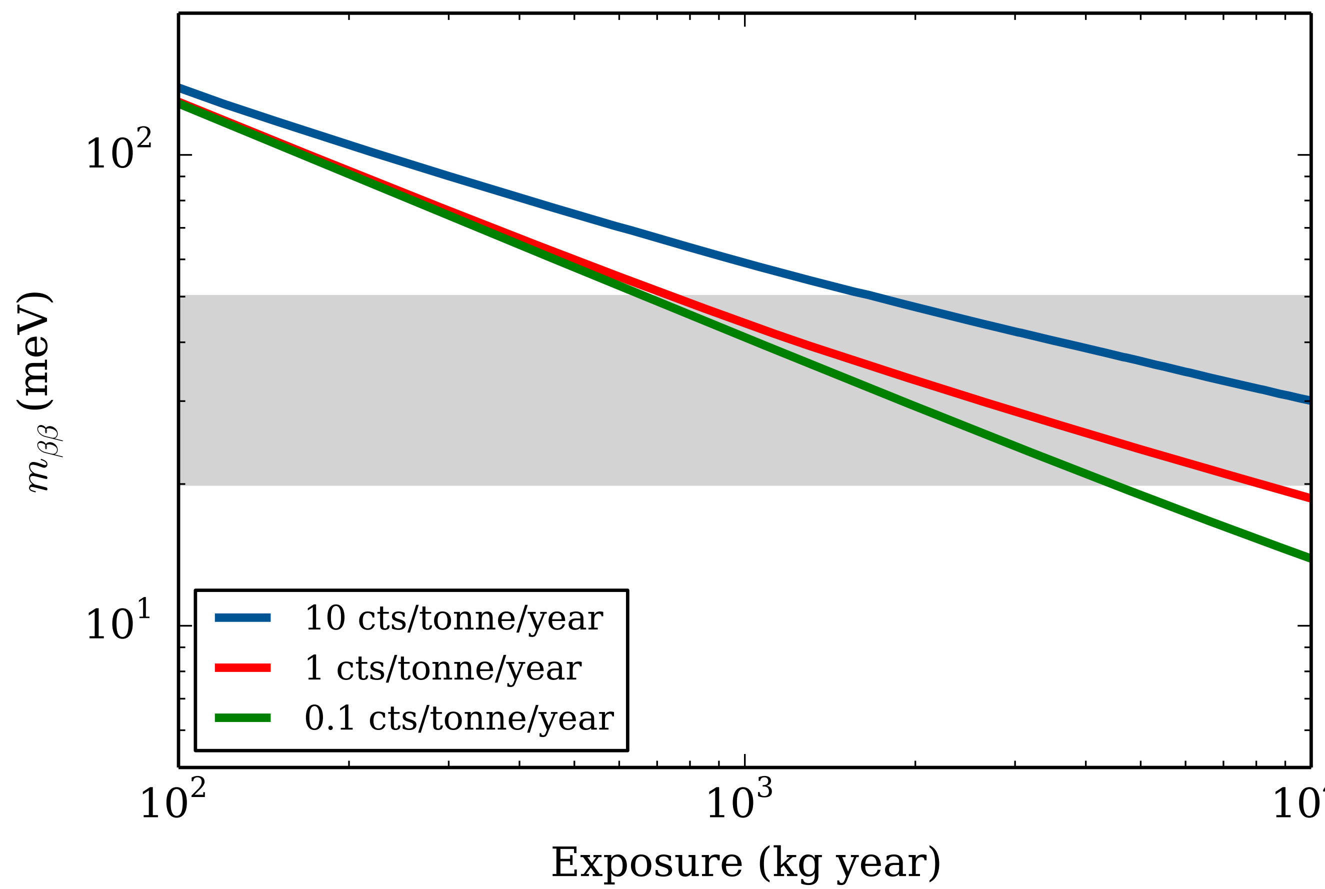
Results from GERDA, CUORE KamLAND-ZEN, EXO barely scratching IH

exploring IH : T~ 10^{27}y

"Background free" experiments

Exploring the IH

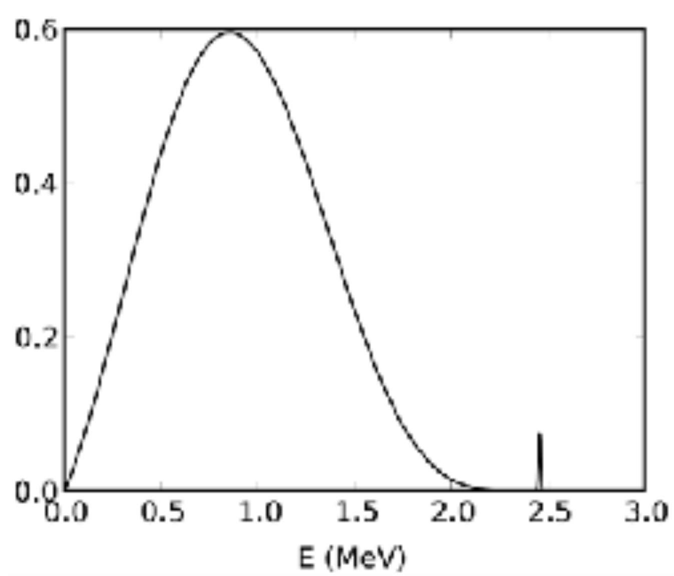




100 % efficient Xe experiment (using a "reasonable NME set") 2 ton year to explore IH with 1 background event per ton per year

30 % efficient Xe experiment (using a "reasonable NME set") 6 ton year to explore IH with 1 background event per ton per year

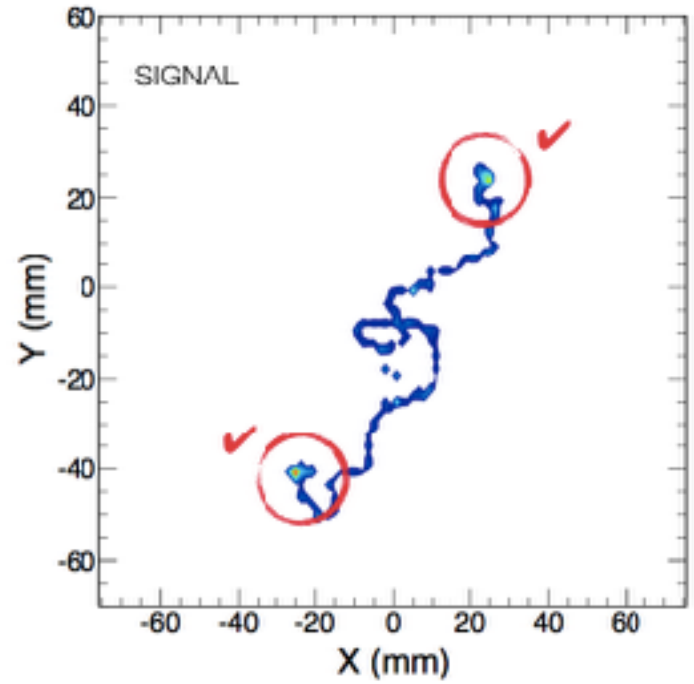
HPXe-EL technology



Energy Resolution

- **0.5 % FWHM**

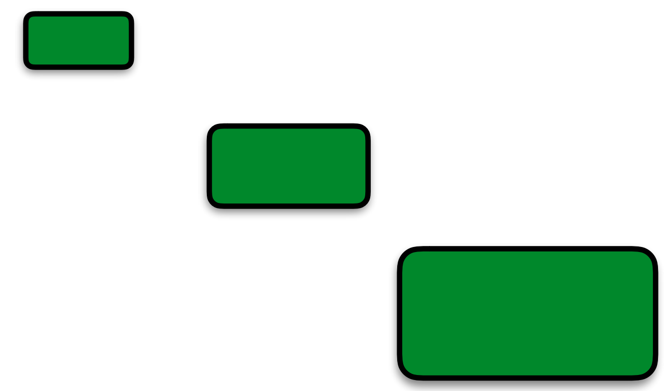
Intrinsic (Fano): ~0.3 %



Topological Signature

c ~5 x 10^{-4} ckky

c < 10^{-4} ckky low diffusion?



Cost and Scalability
(Least Expensive ßß Isotope)
(Source = detector)

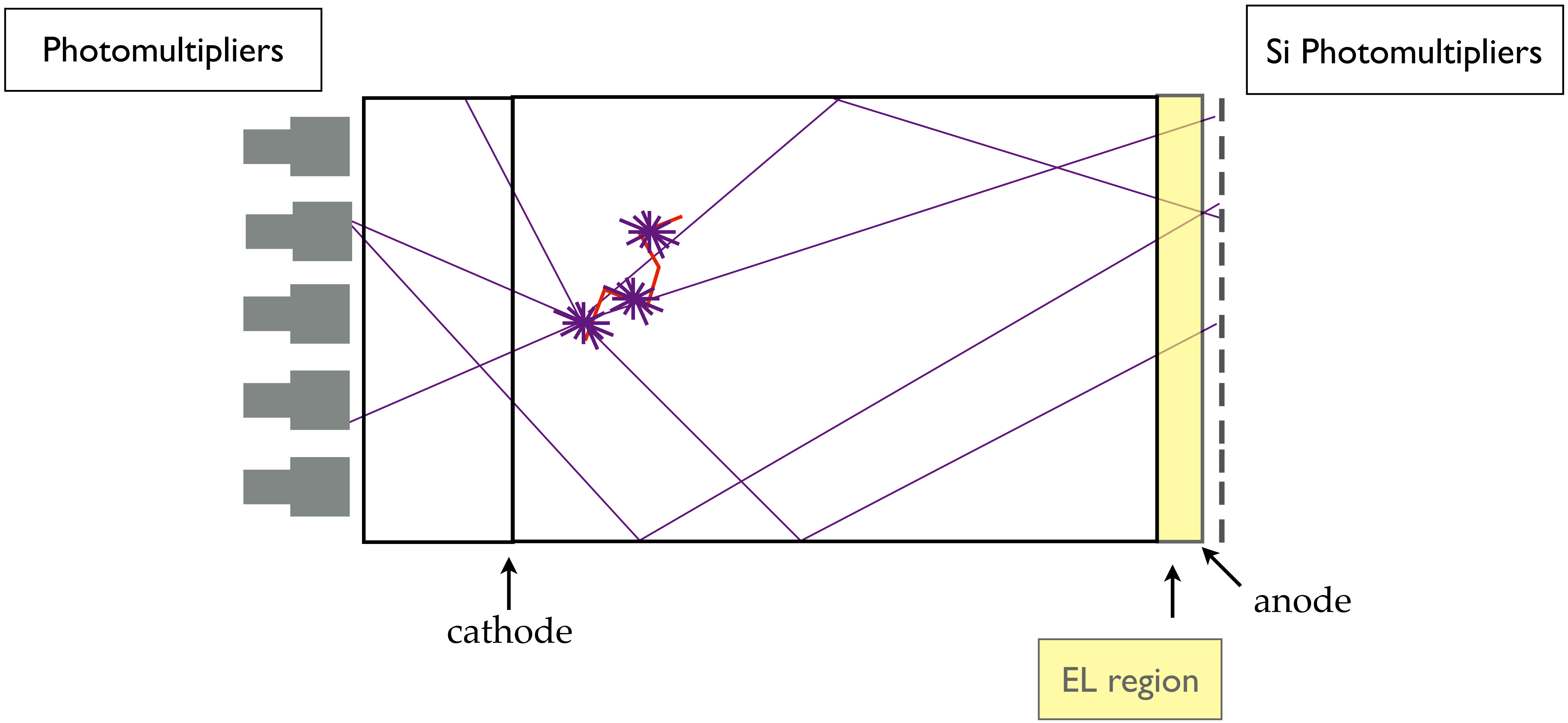
extrapolate to large (ton) masses

First target: To demonstrate "background free" at 100 kg scale (e.g, <~1 count per 100 kg per year

Ultimate target: To develop a technology "background free" at ton scale (e.g, <~1 count per ton per year

THE NEXT CONCEPT

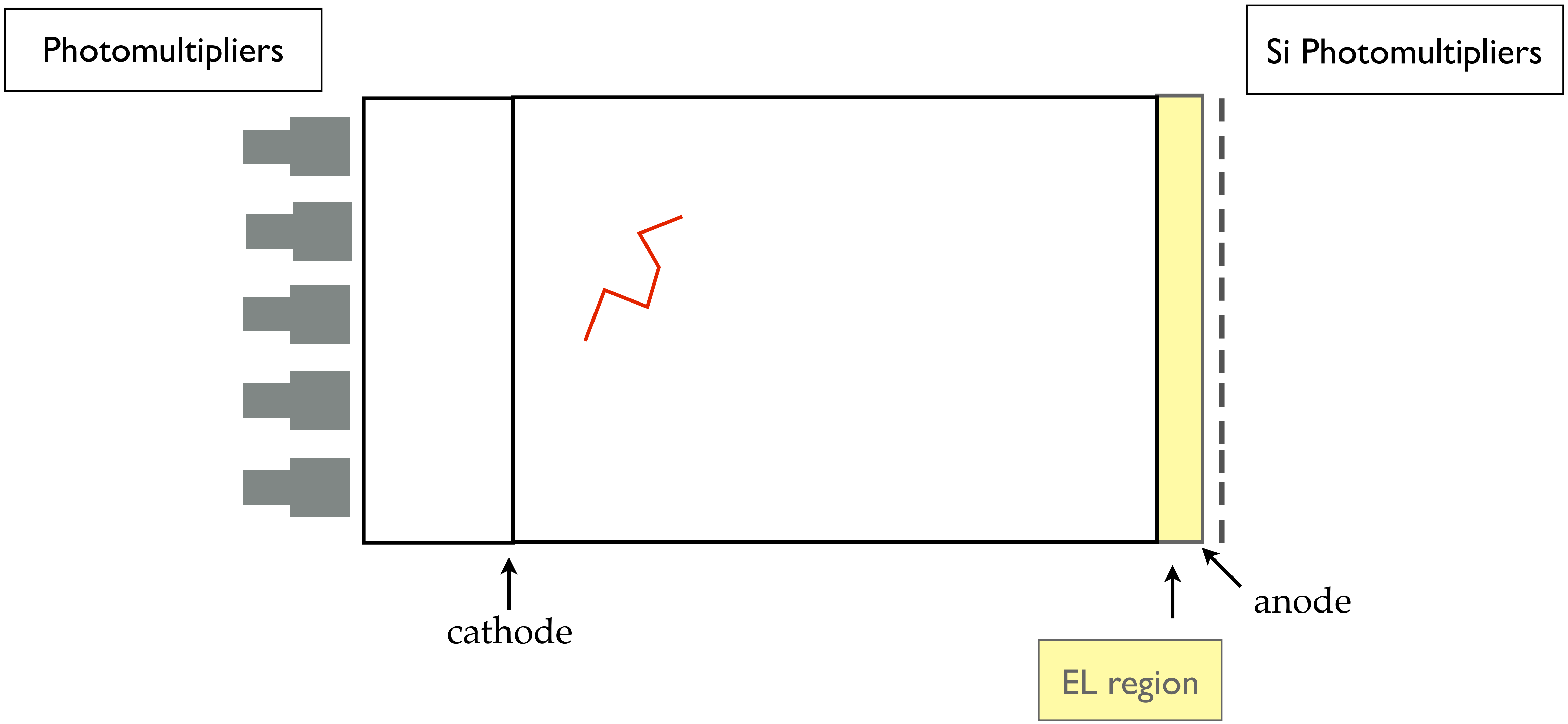
Scintillation



UV scintillation (~10 000 photons/MeV in gas xenon) gives the starting time of the event.

THE NEXT CONCEPT

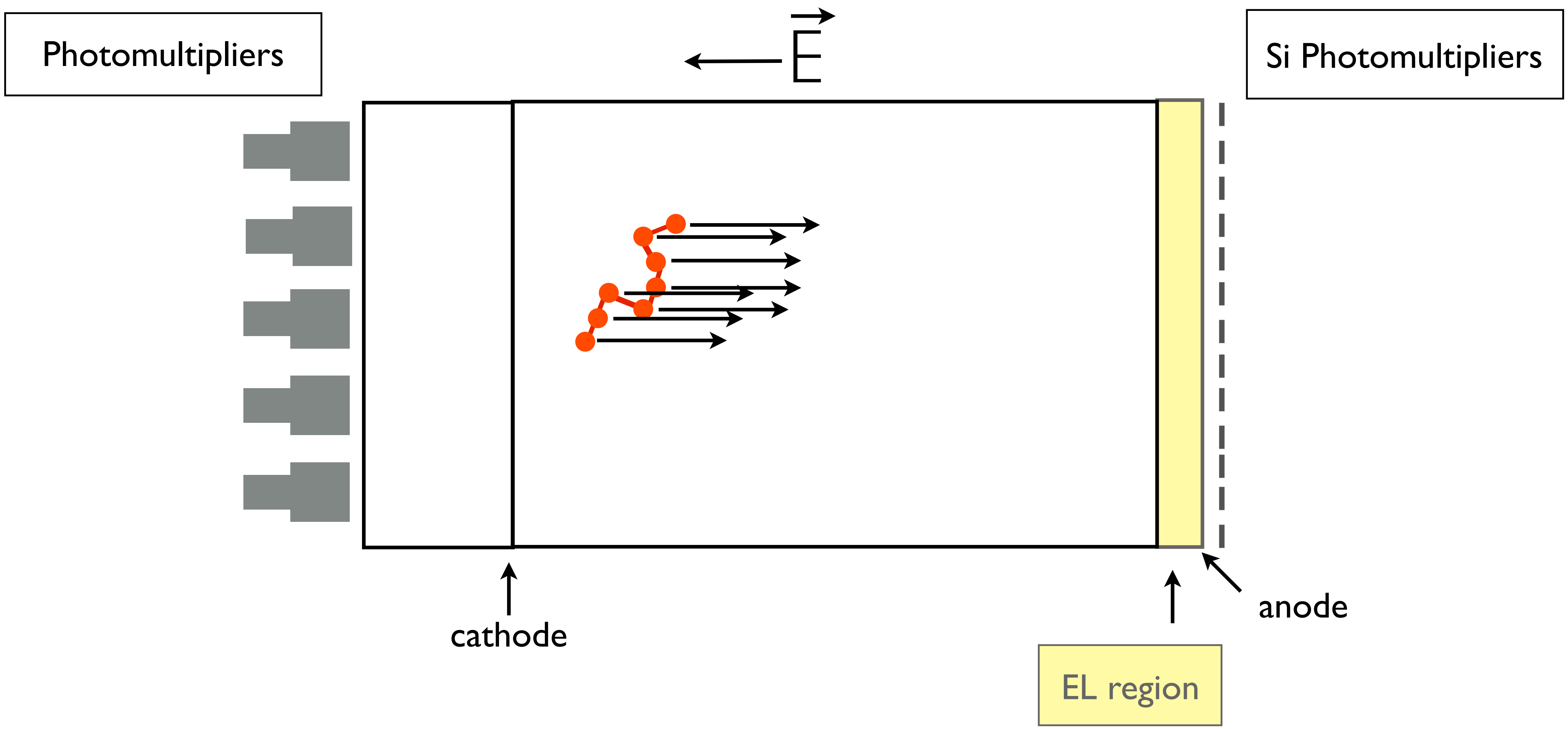
High pressure xenon Time Projection Chamber with electroluminescence amplification of signal.



A charged particle in gas releases its energy through scintillation and ionization of the atoms of gas.

THE NEXT CONCEPT

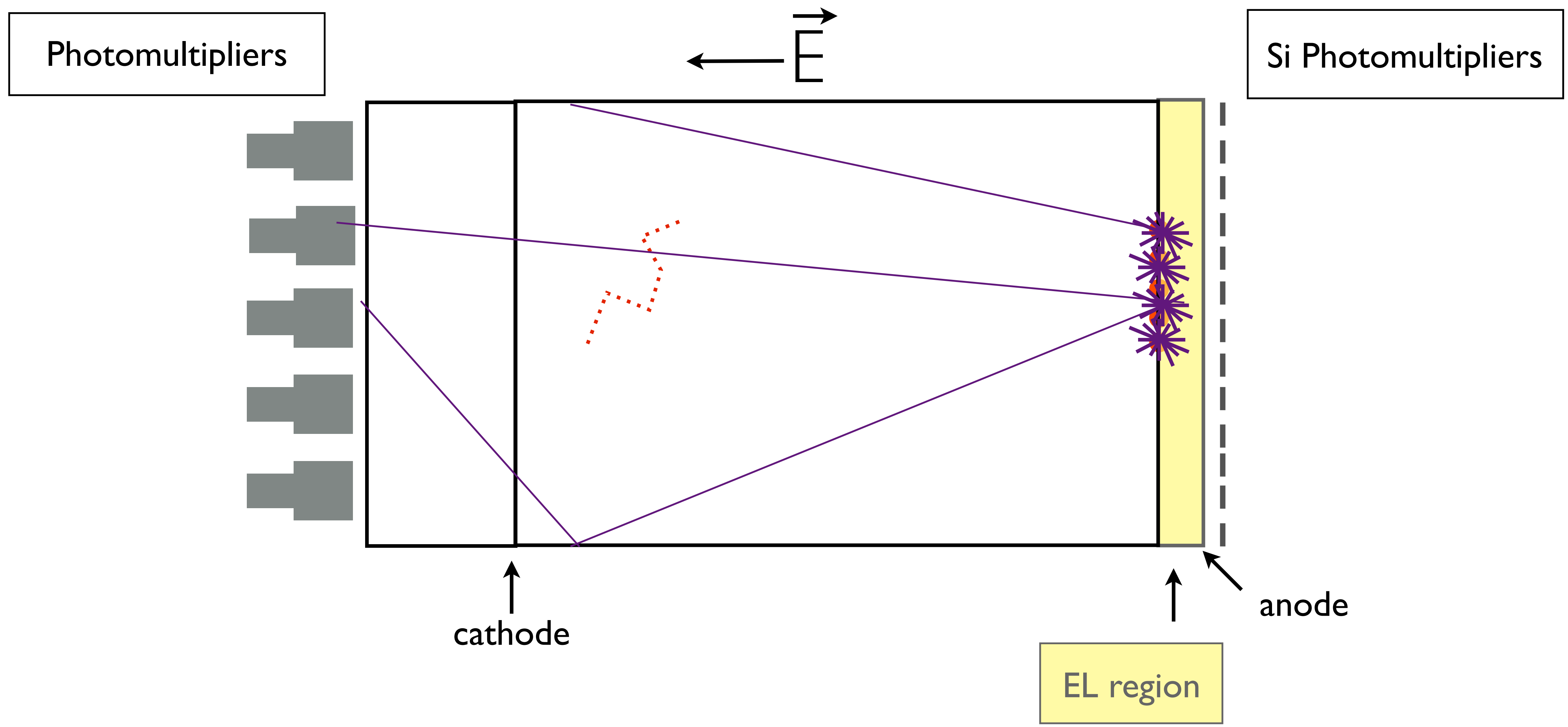
Ionization and drift



Ionization electrons are drifted by an electric field towards the anode, with a drift velocity of ~1mm/microsecond in a ~500 V/cm field.

THE NEXT CONCEPT

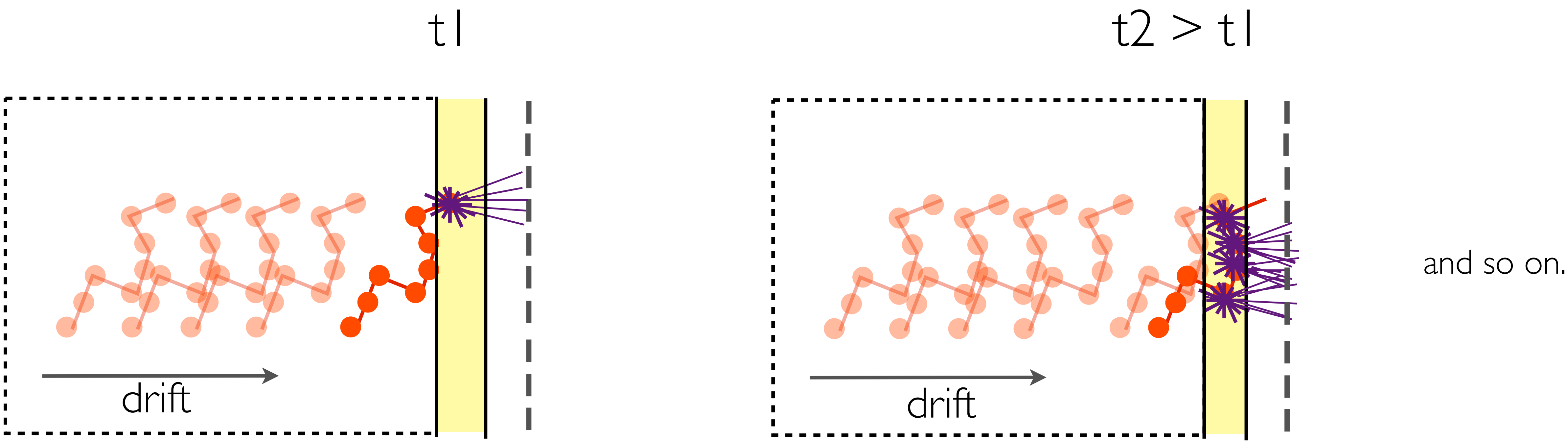
Electroluminescence: energy



Ionization electrons enter a moderately high electric field where they produce secondary scintillation (EL), with a linear gain of ~10^3 photons per electron. PMTs give a measurement of the energy of the event.

THE NEXT CONCEPT

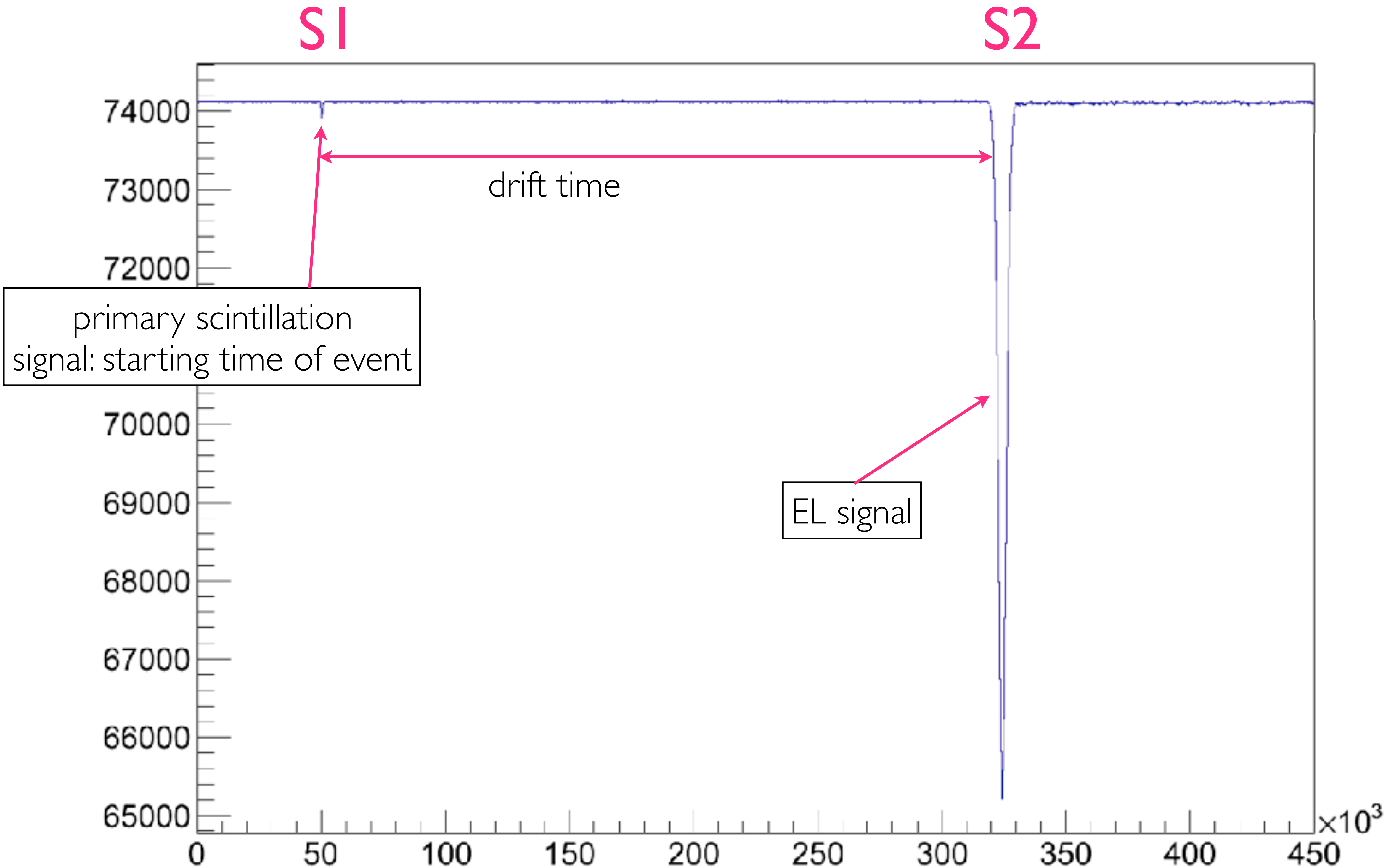
Electroluminescence: tracking



The distribution of light on the sensors in the anode is, at any moment, a 2D picture of the track at a given position along the axis.

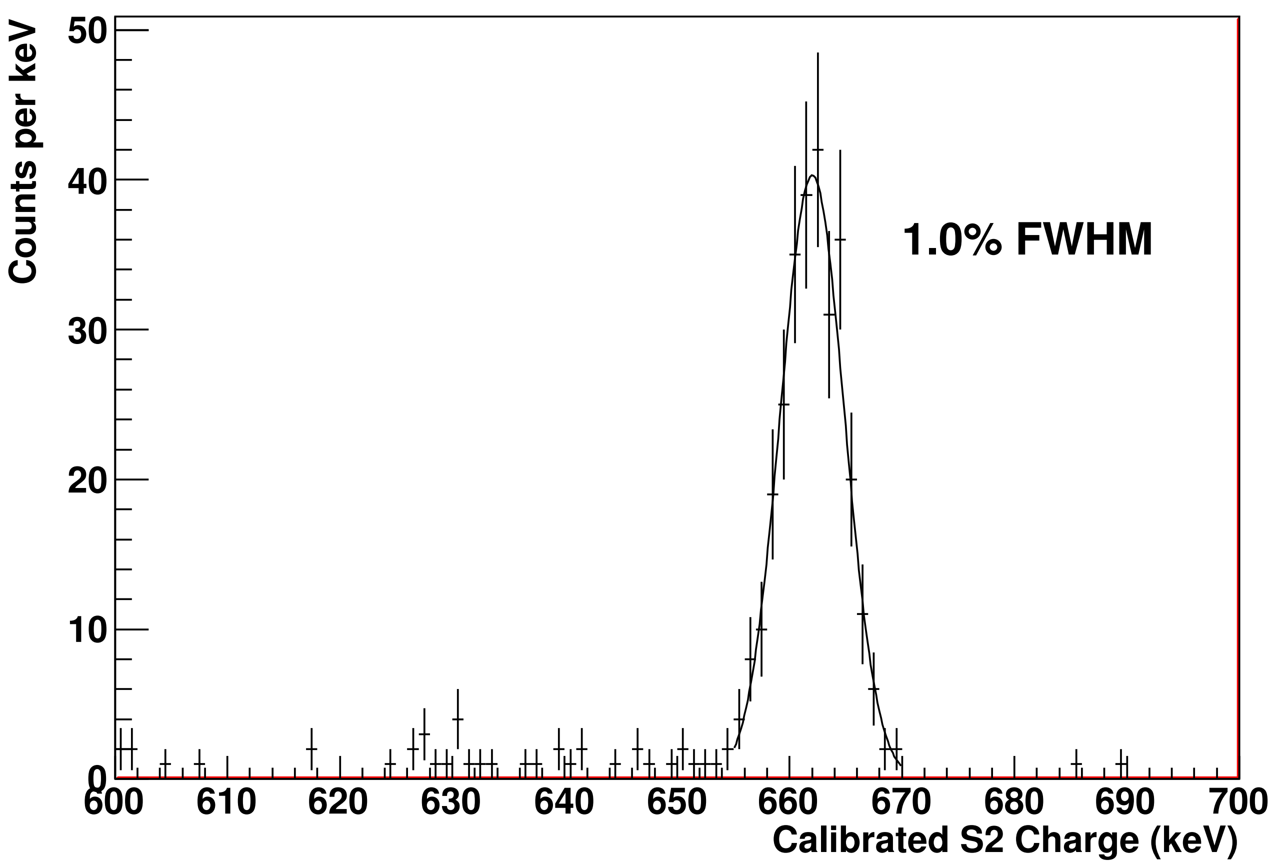
Knowing t0, the absolute position along the axis is also reconstructed.

WAVEFORMS IN NEXT

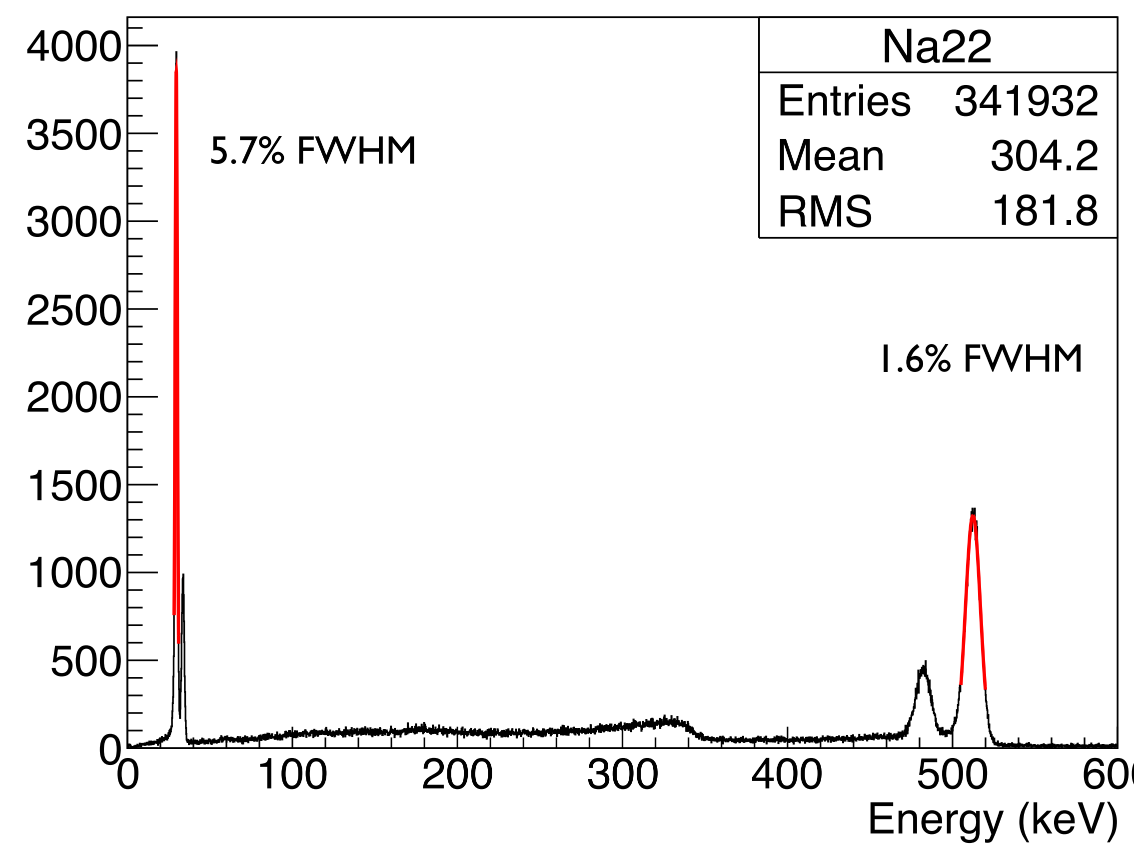


Energy resolution

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



JINST 9 (2014) no.10, P10007



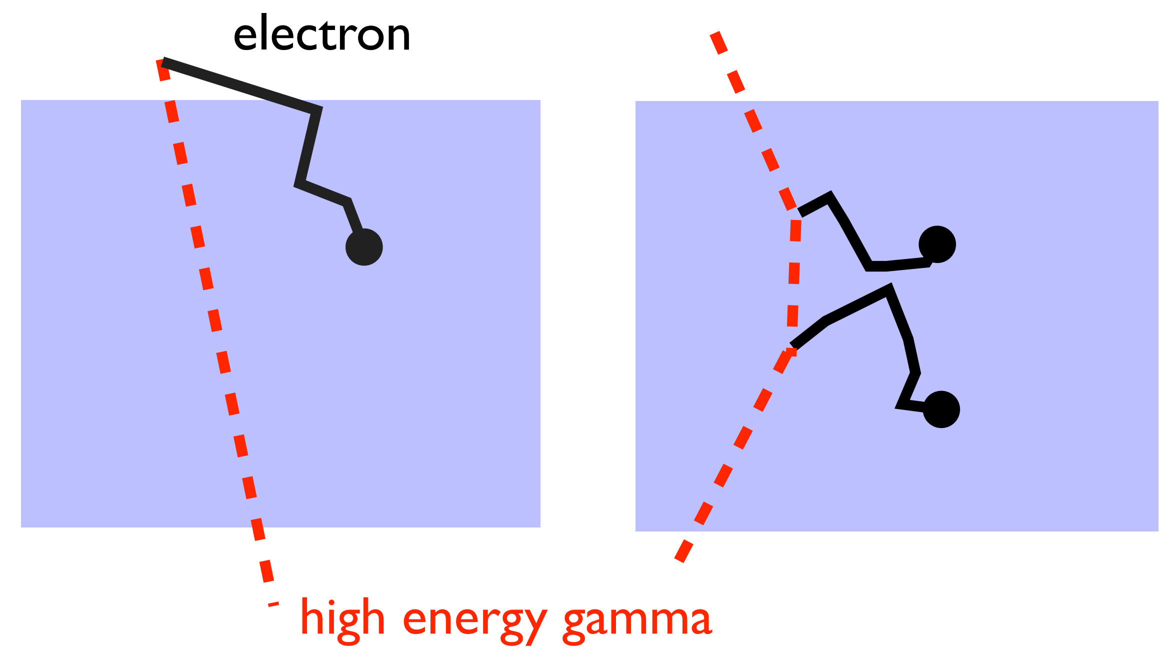
DBDM: 0.5 % FWHM Qbb

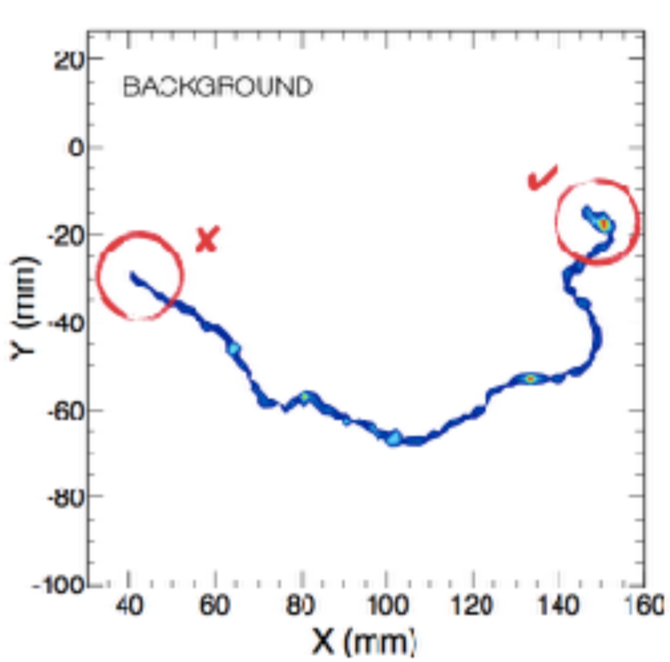
DEMO: 0.7 % FWHM Qbb

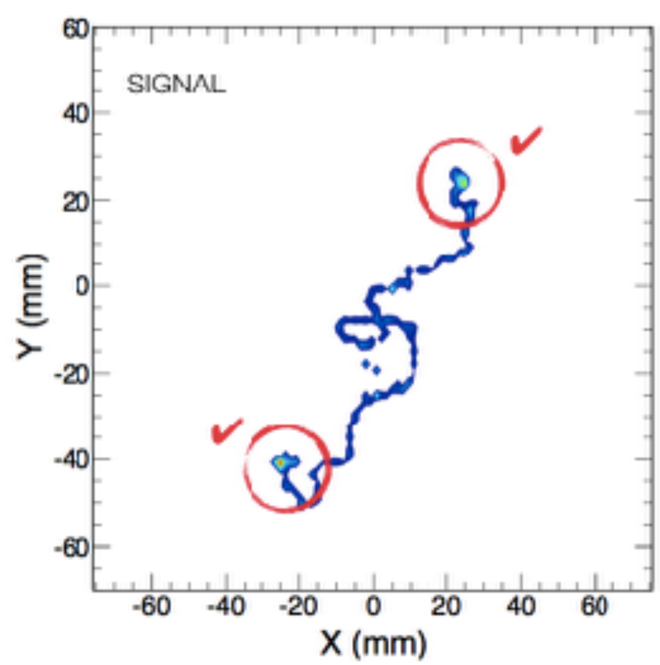
Energy resolution NEXT prototypes: 0.5-0.7% FWHM at $Q_{\beta\beta}$

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).

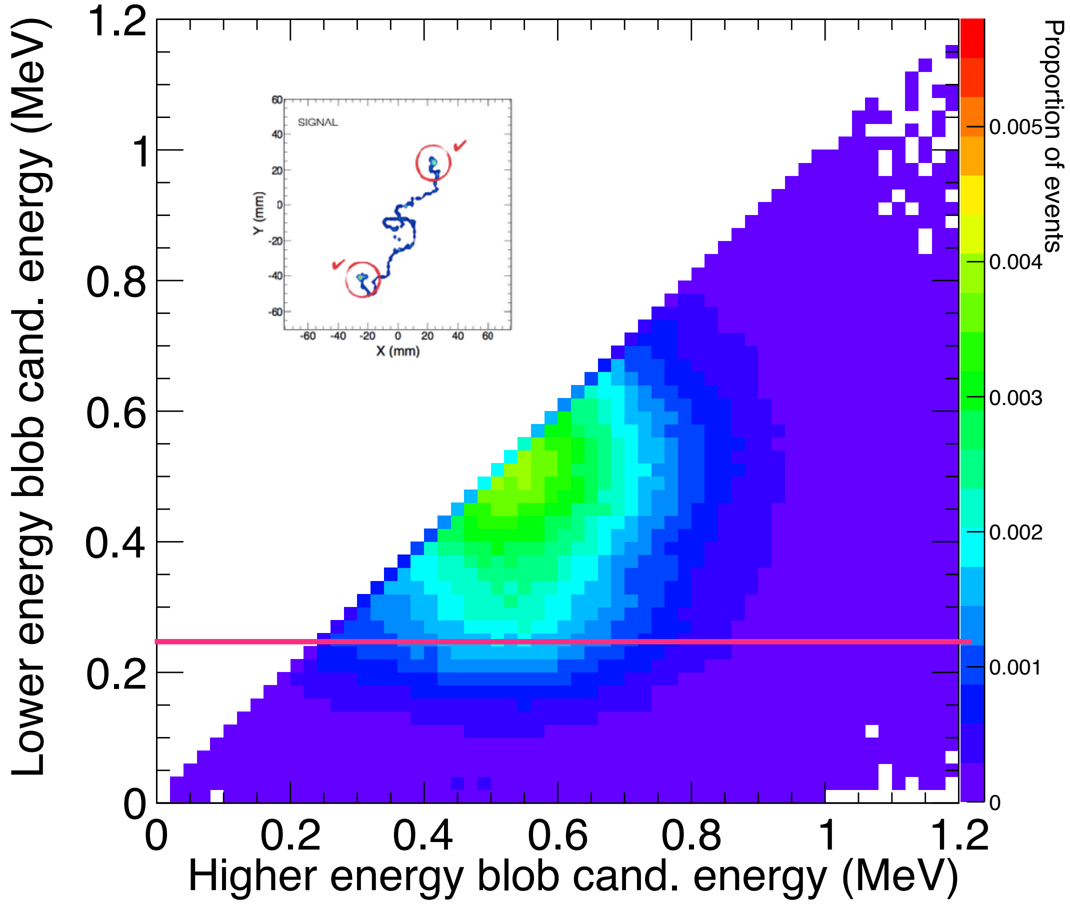


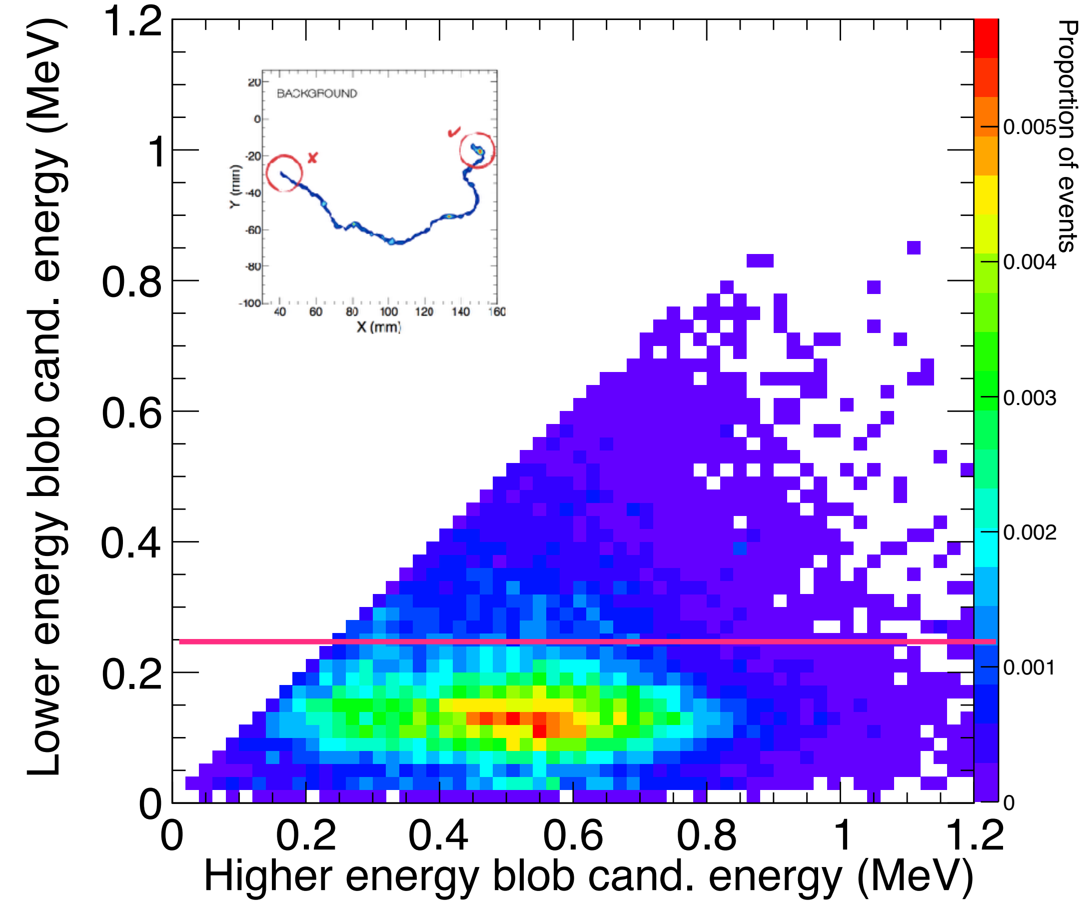




- Electron energy loss in gas is constant until the end of the trajectory (Bragg peak).
- Signal: spaghetti with two "meat balls".
- Background: spaghetti with one "meat ball".

THE POWER OF TOPOLOGY





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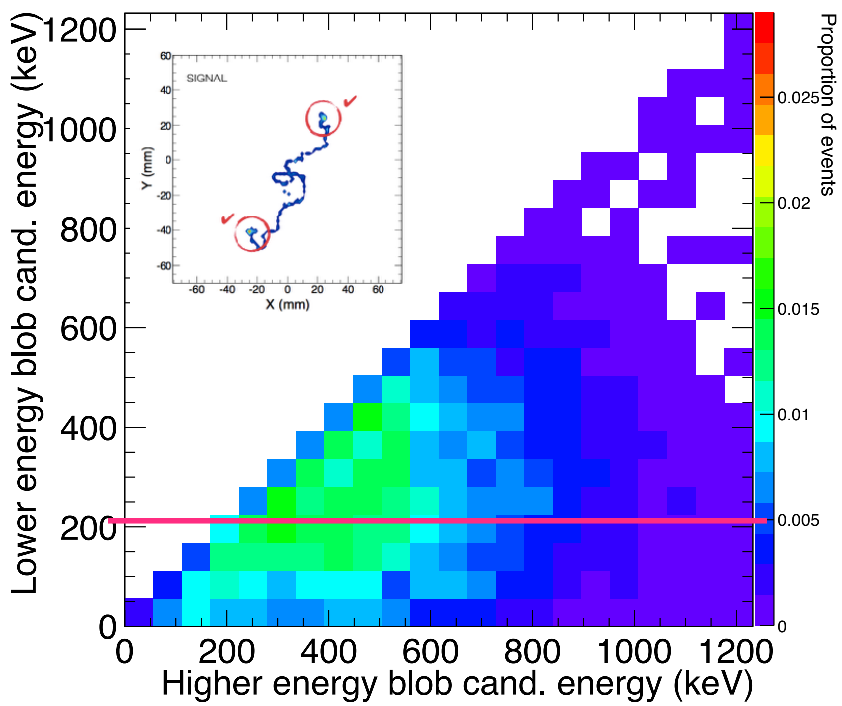
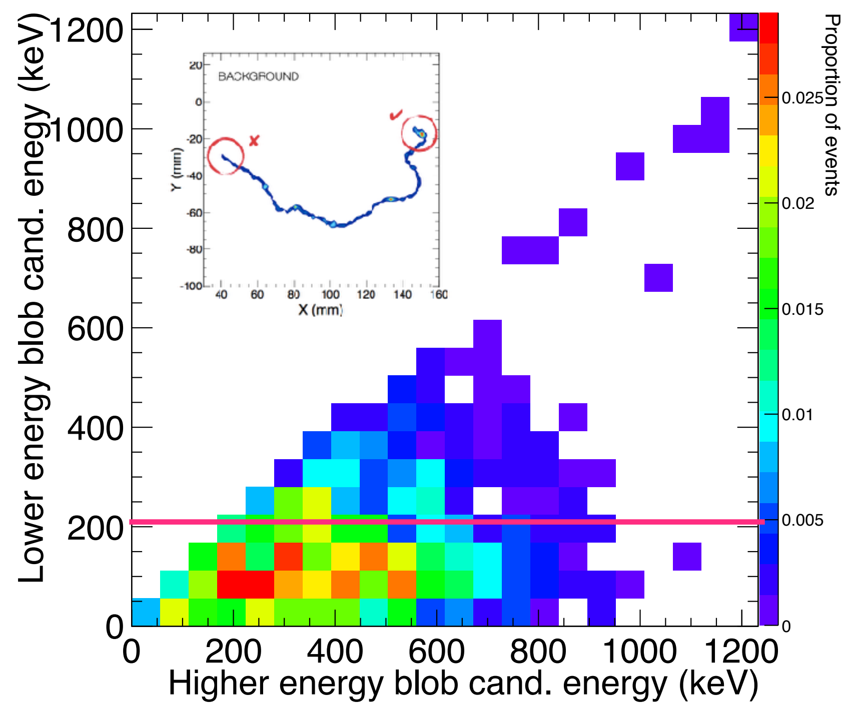
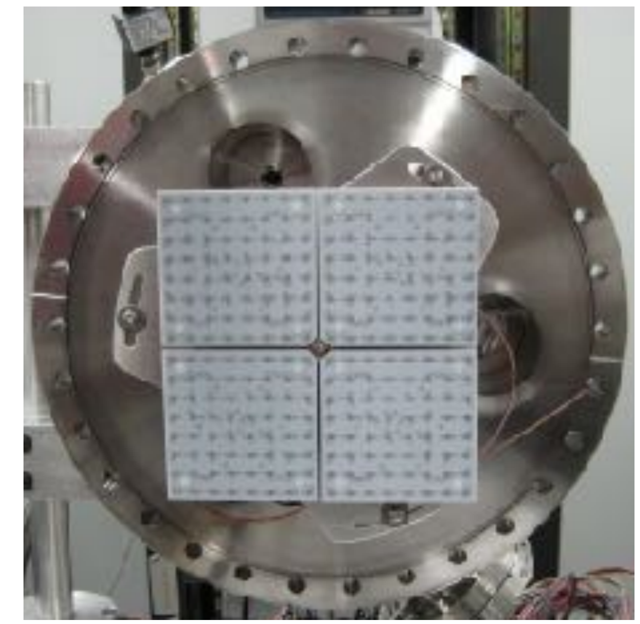
- Distribution of the energy at the end-points of the track, Geant4 MC.
- High discrimination power.

TOPOLOGY: DEMONSTRATION







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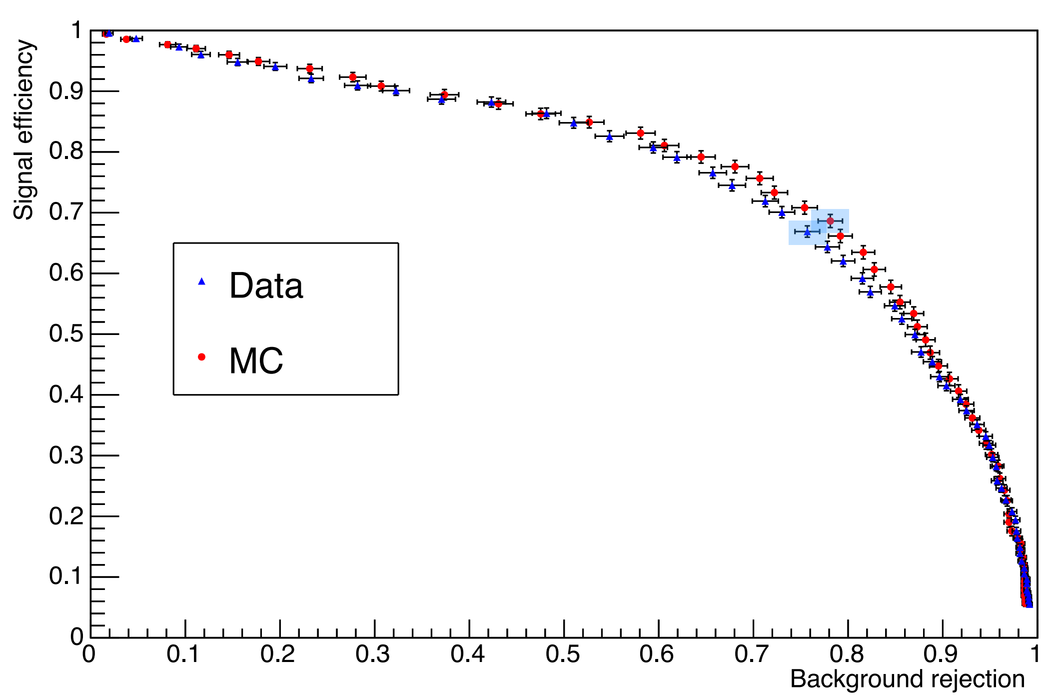


Tracking capabilities of NEXT DEMO

- 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. Better performance expected in NEW.
- Validation of Monte Carlo.

THE NEXT DETECTORS

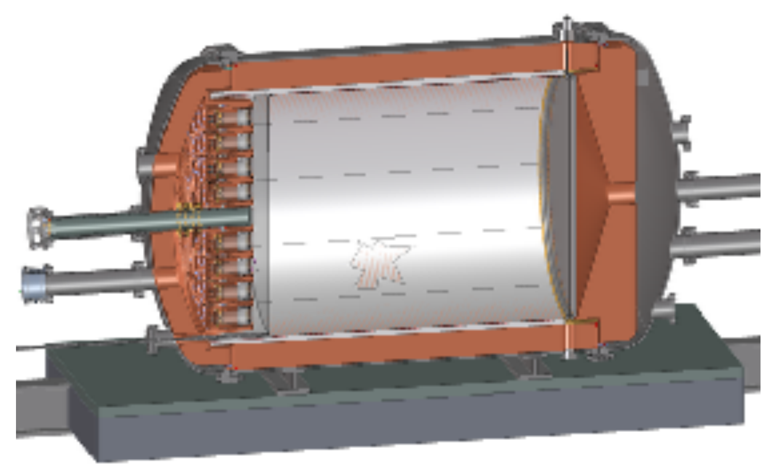
Prototypes (2009-2014)

- ~1 **kg** of mass
- Demonstration of technology

First stage - NEW (2015-2019)

- **~10 kg** of mass
- Underground operation
- **Background** and **ββ2ν** measurements

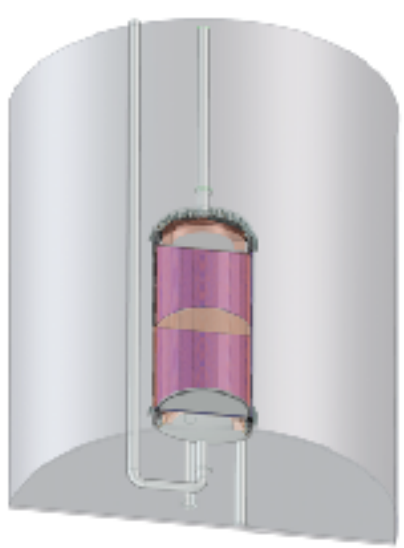
NEXT-100 (2019-)



- **100 kg** of mass
- **ββ0ν** search

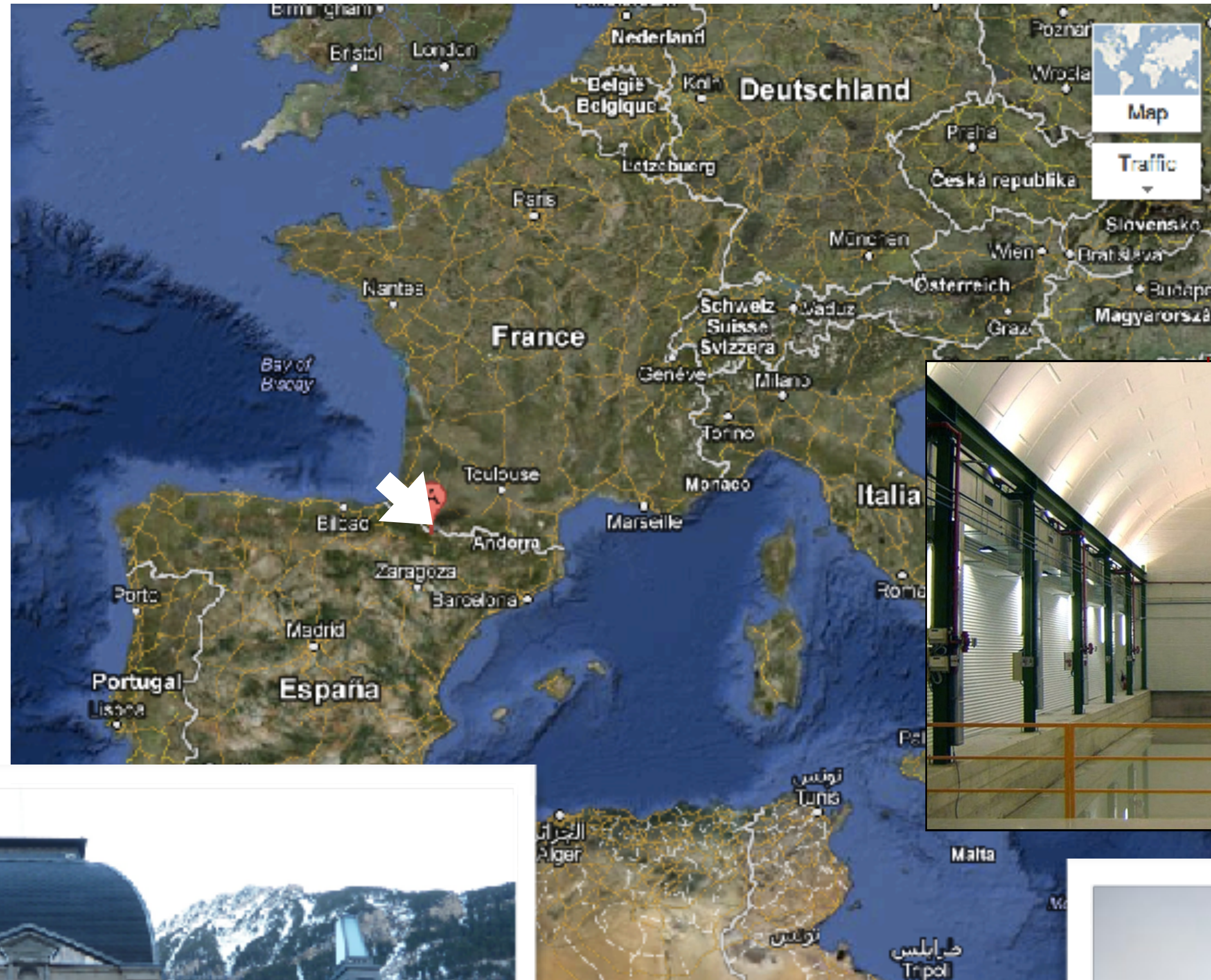
NEXT-ton (NAUSICAA)

- **1000 kg** of mass
- **ββ0ν** search



THE CANFRANC UNDERGROUND LABORATORY

- 2500 m water equivalent



LSC
Laboratorio Subterráneo de Canfranc

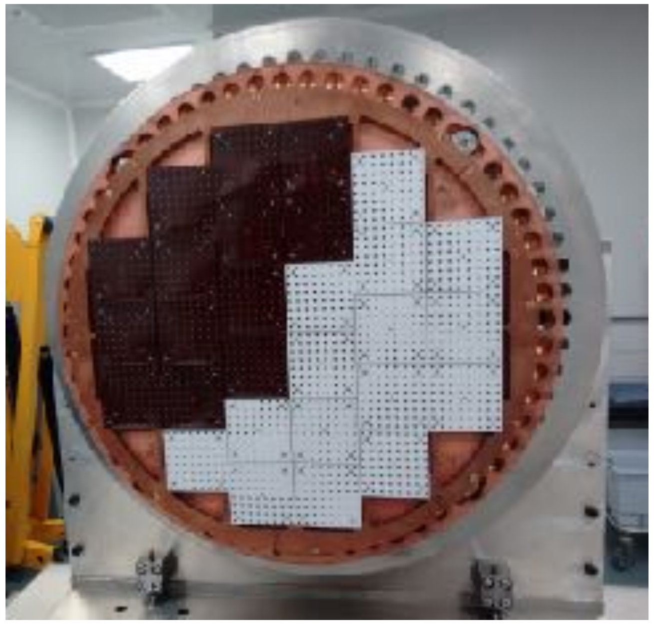
NEXT working platform (2017)

In honour of
our friend
and mentor
James White

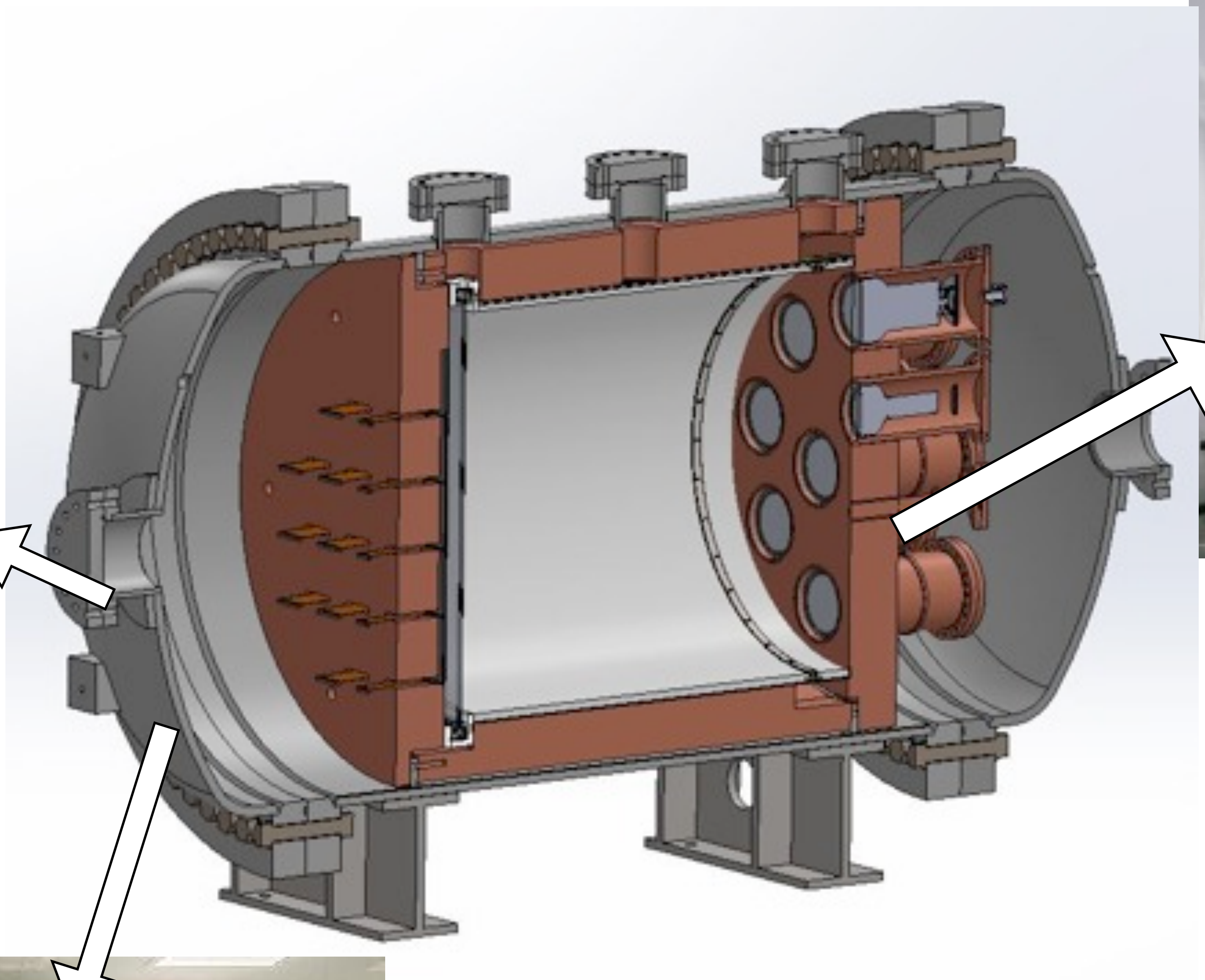
NEXT-WHITE (NEW)

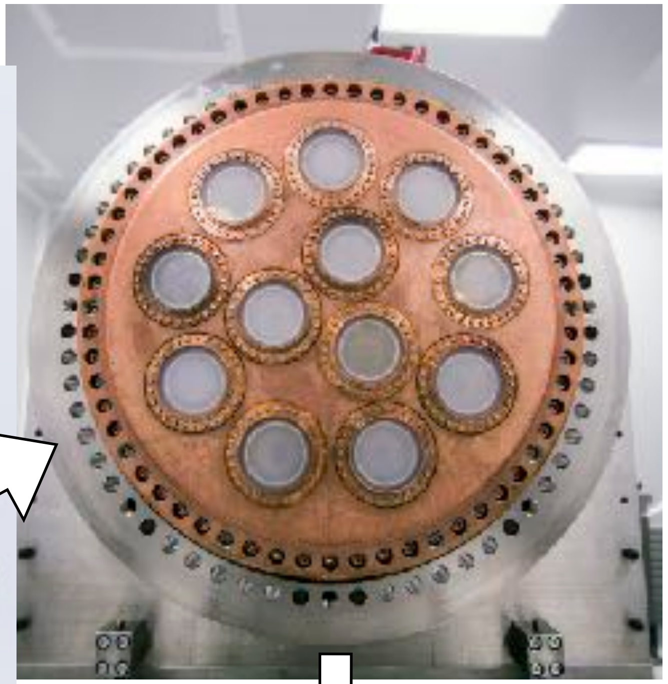
- First stage of the NEXT experiment at LSC.
- 10 kg of xenon at 15 bar, 54 cm of drift length, 40 cm of diameter.
- Purpose: acquire technological know-how, understand backgrounds

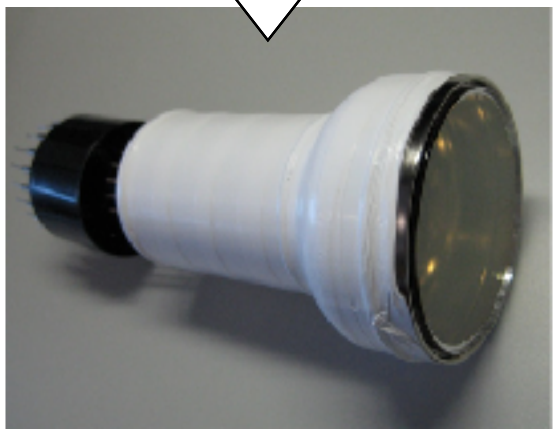
NEXT-WHITE (NEW)



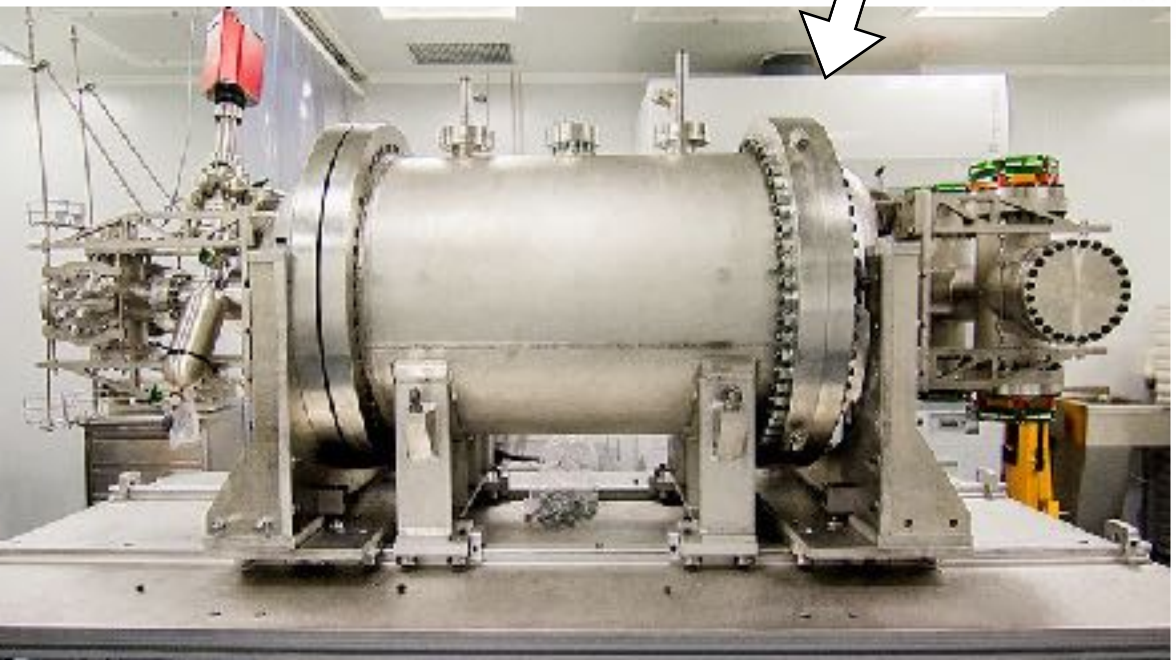
Tracking plane
~1800 SiPMs
1 cm pitch, Kapton boards







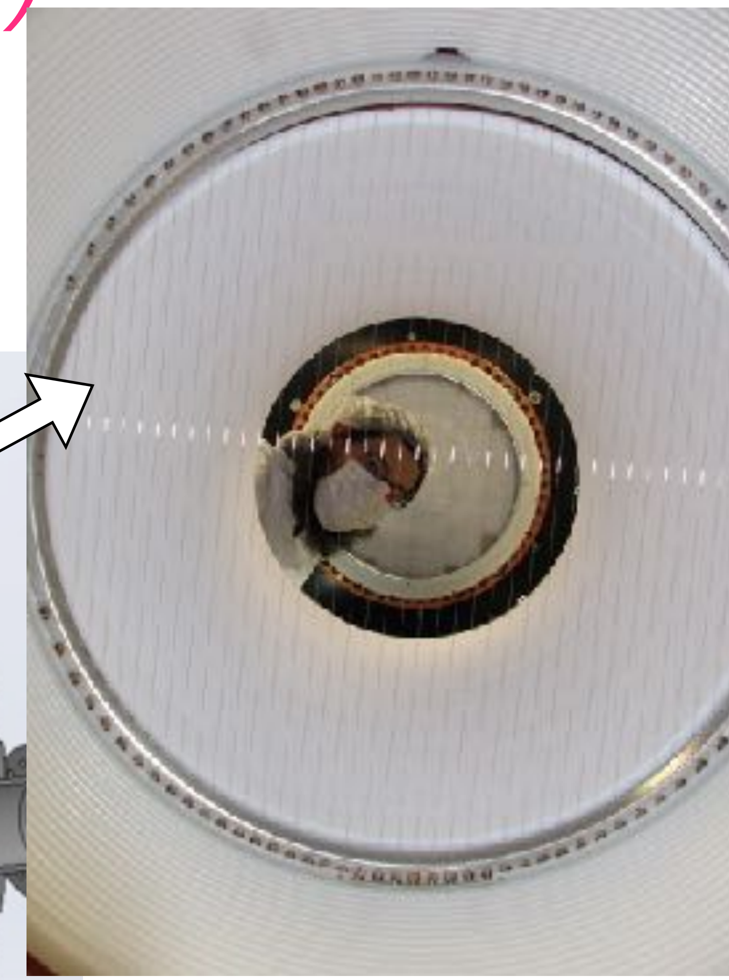
12 PMTs, 30% coverage



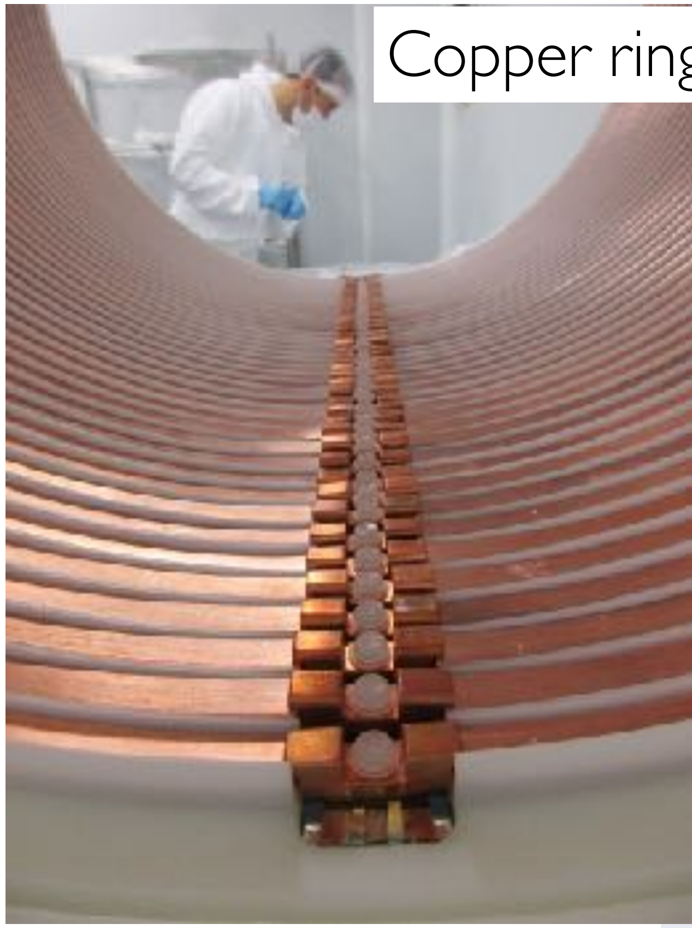
Pressure vessel
Designed to stand up to 30 bar

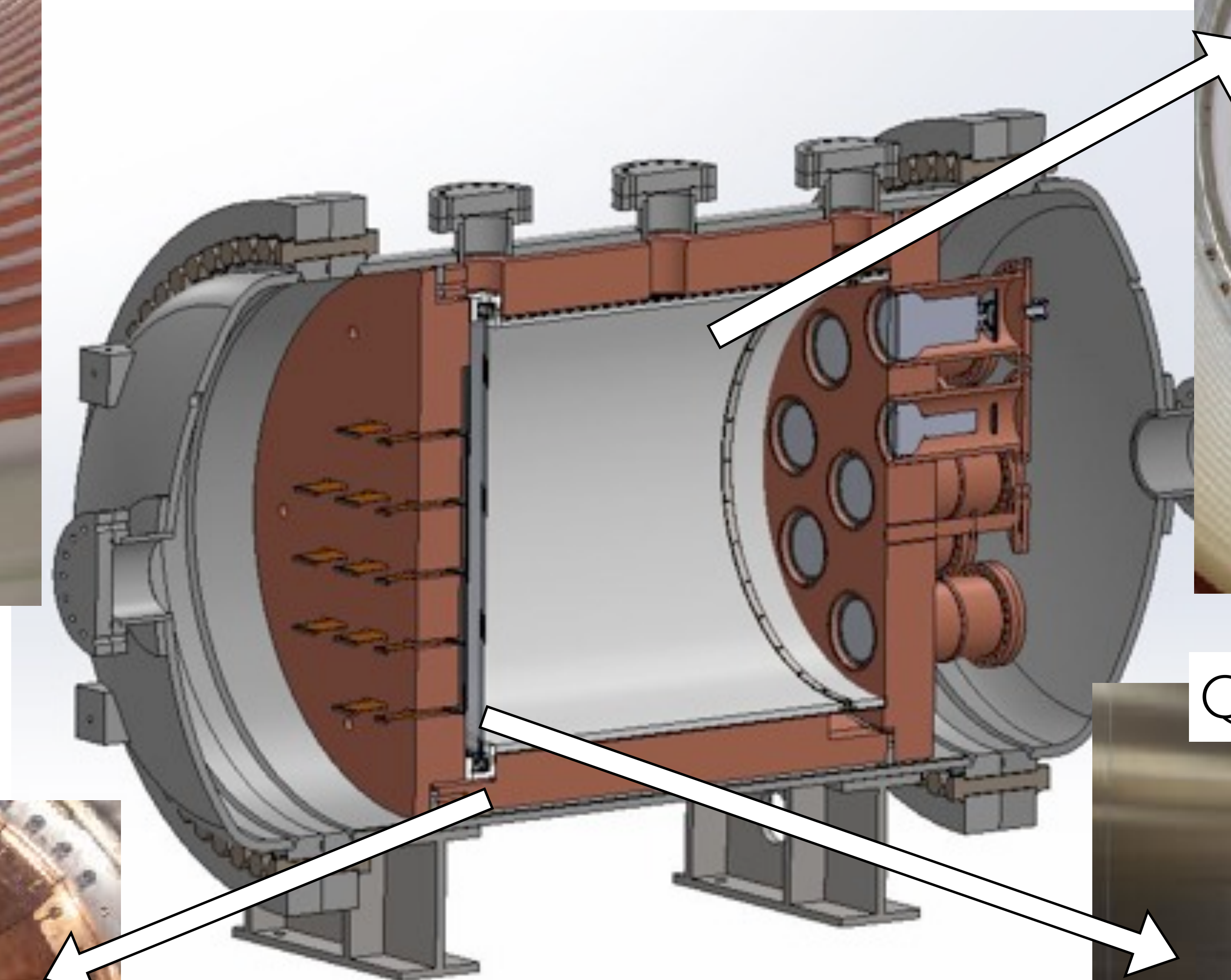
NEXT-WHITE (NEW)

HDPE field cage
+ teflon reflector



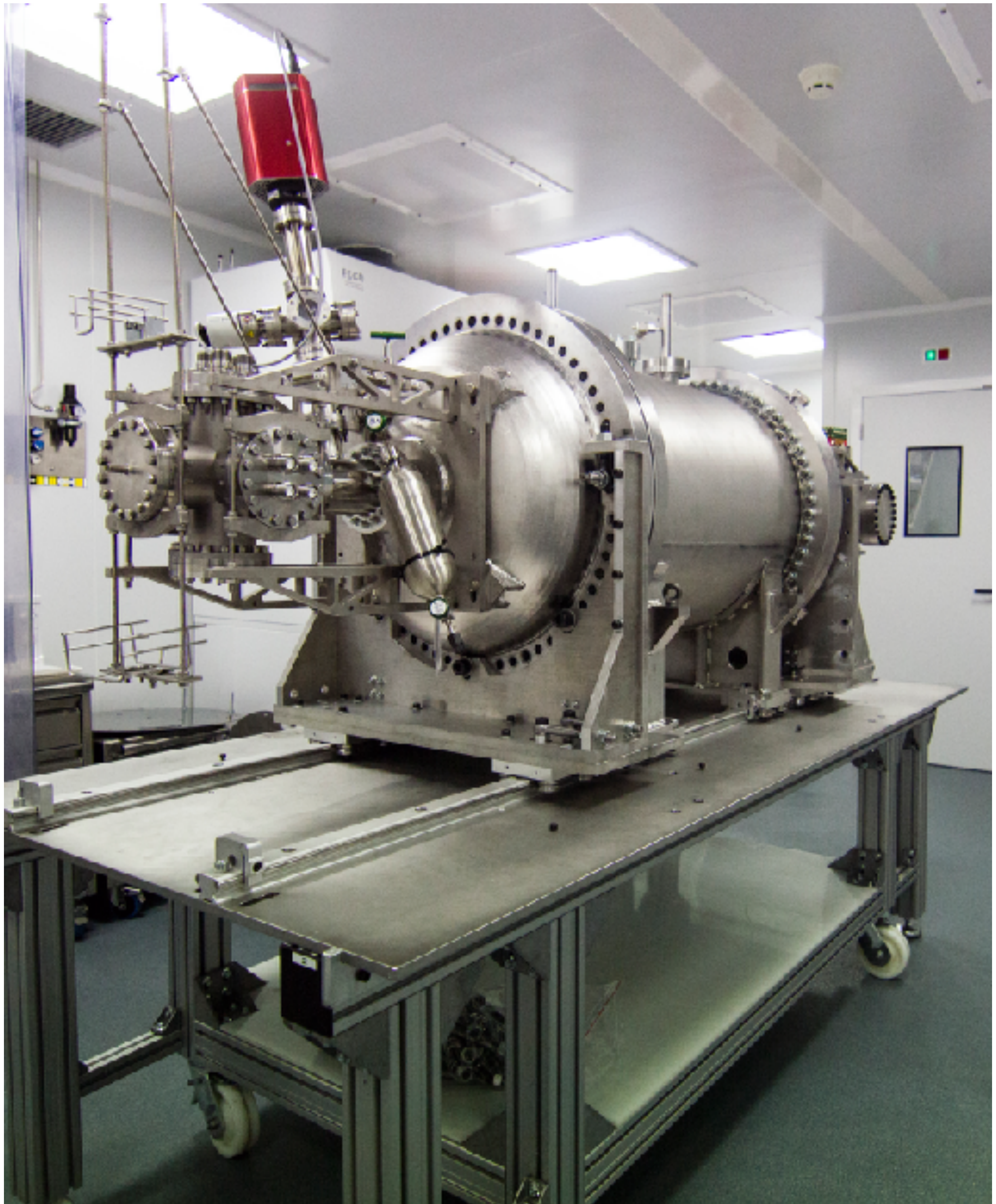
Copper rings

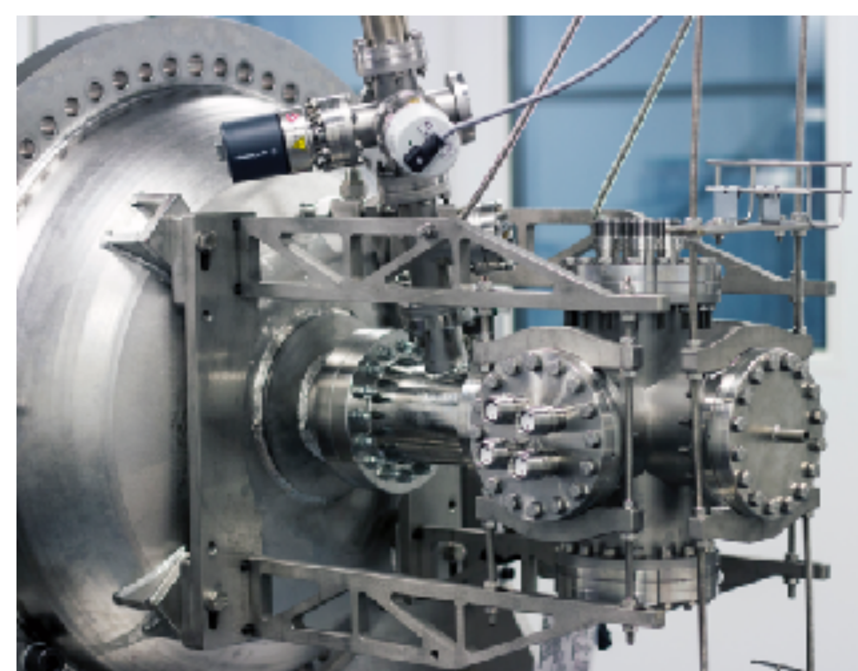


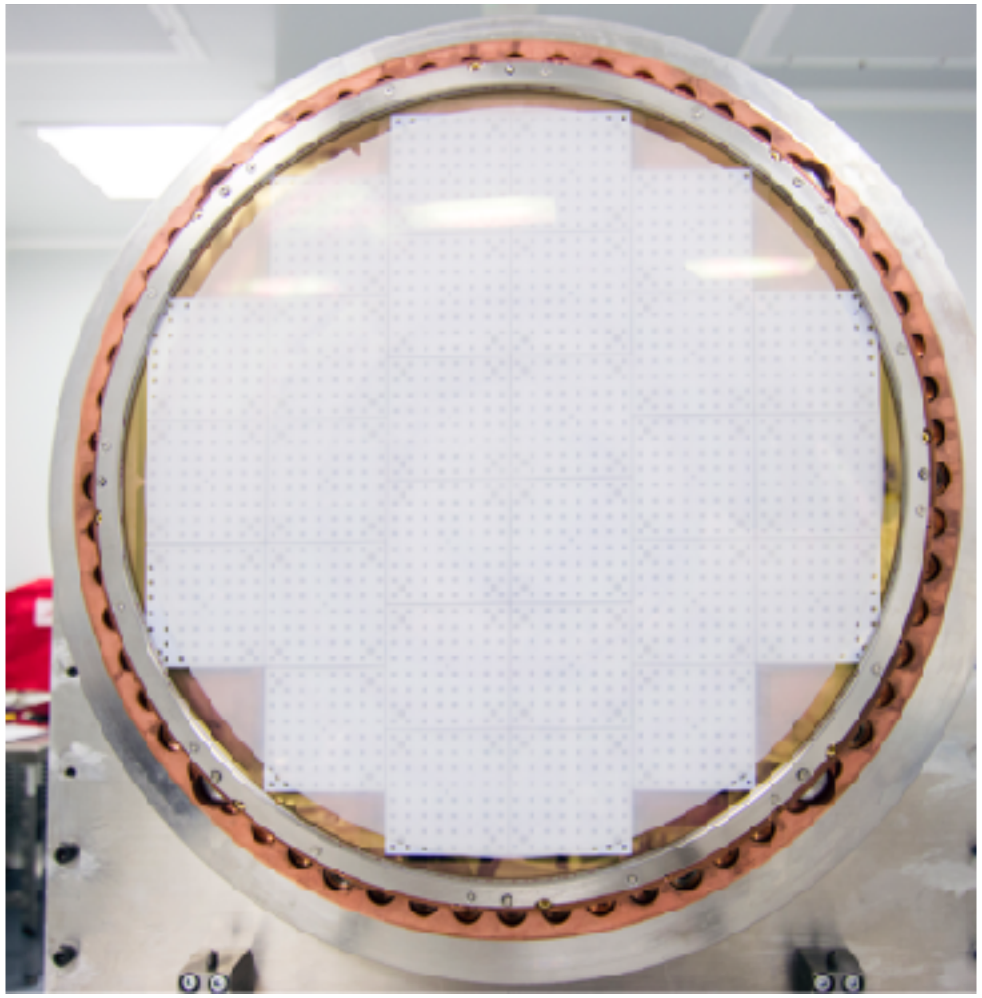


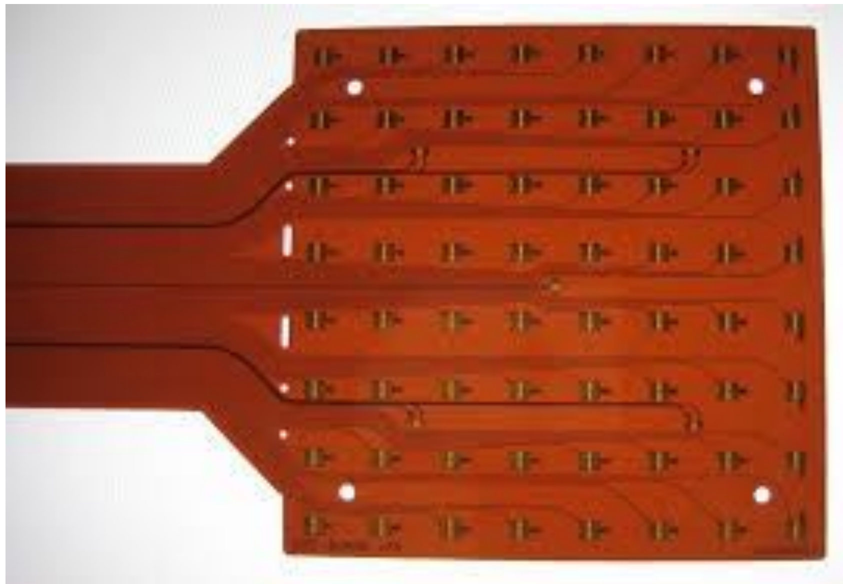
Quartz plate for the anode

Inner copper shield
6 cm thick





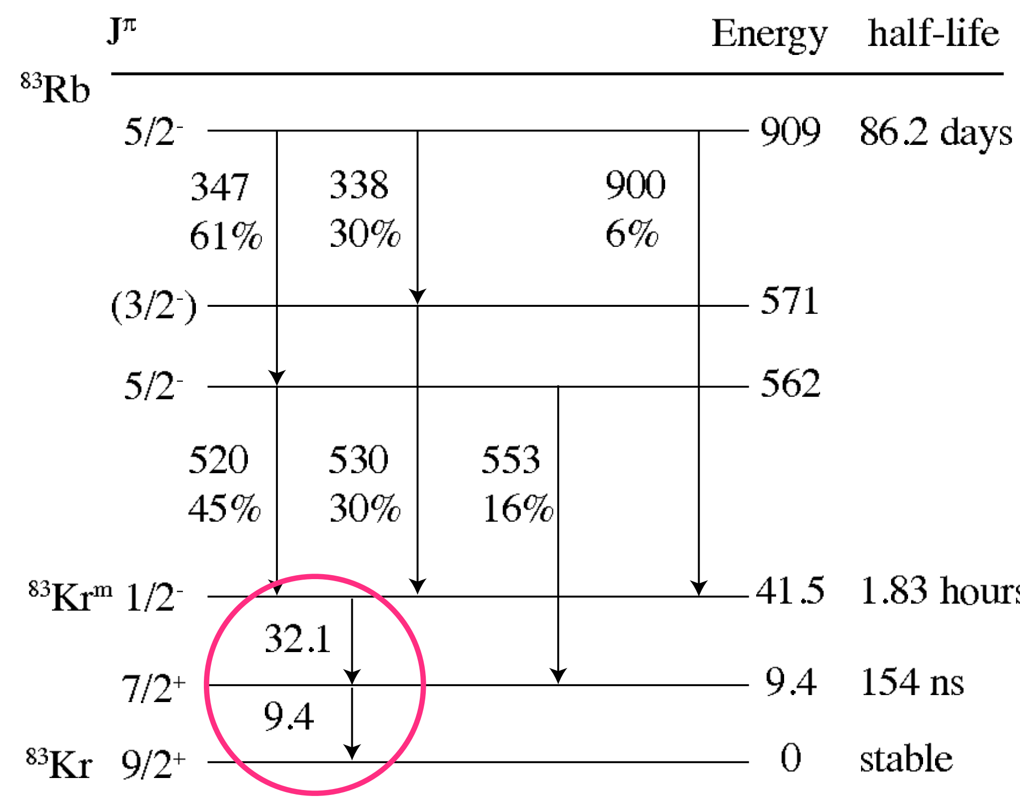





FIRST RESULTS

PRELIMINARY

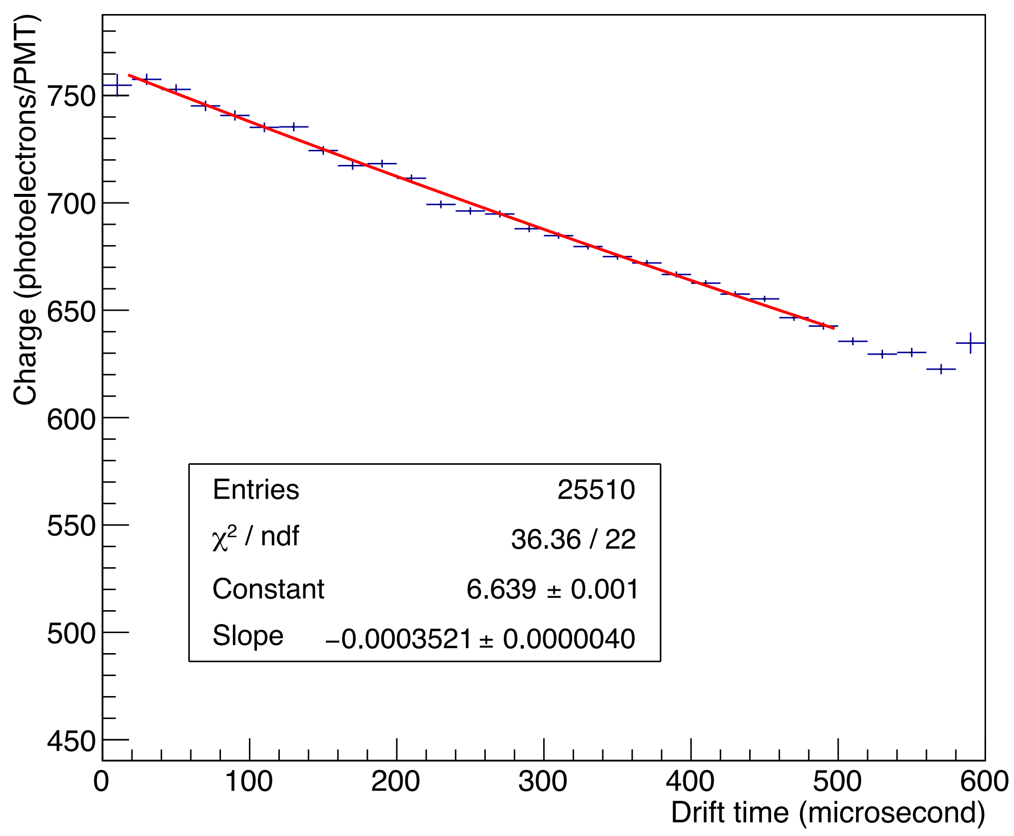
- Source of **Rb-83** inserted in the gas system inside a capsule.
- It decays with a half-life of 86 days to an excited state of **Kr-83**, which diffuses in the whole system and eventually reaches the chamber.
- Kr-83 goes to ground state emitting electrons with total energy of ~41.5 keV.
- Almost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

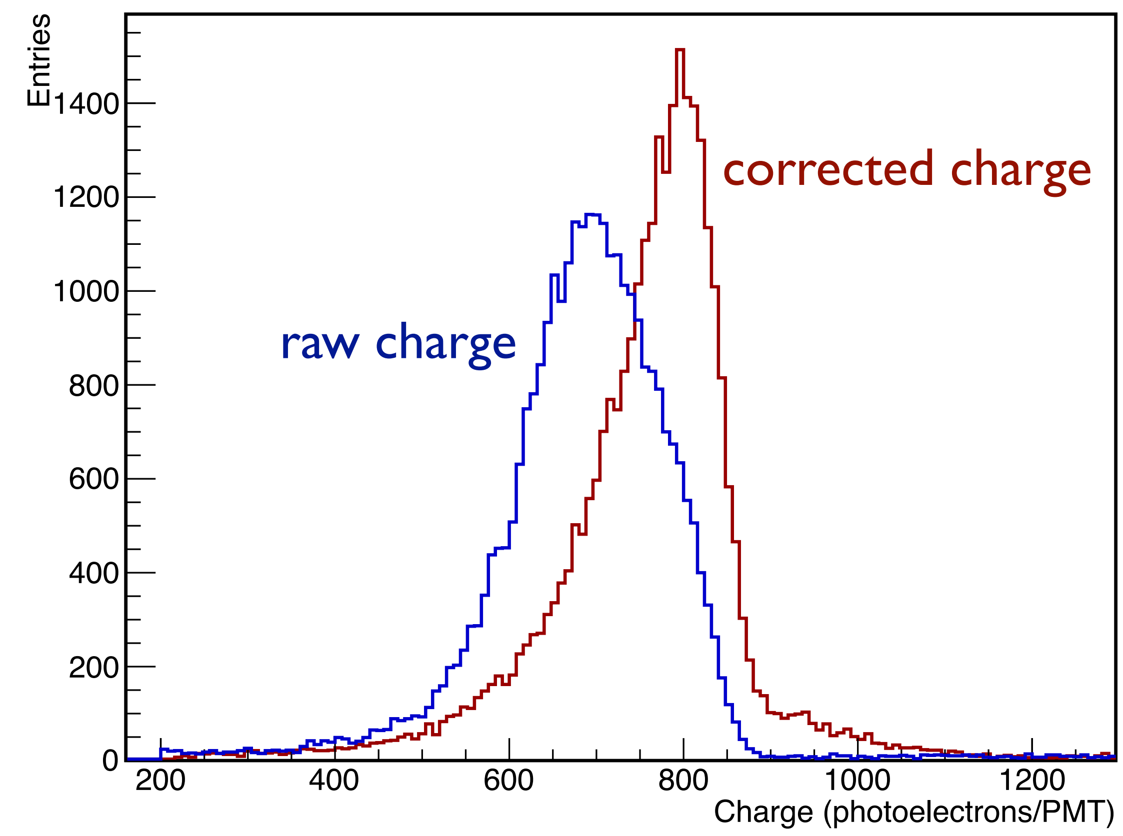


ELECTRON LIFETIME

PRELIMINARY

- Gas impurities (H_2O, N_2…) absorb ionization electrons during drift.
- Detected charge decreases exponentially.



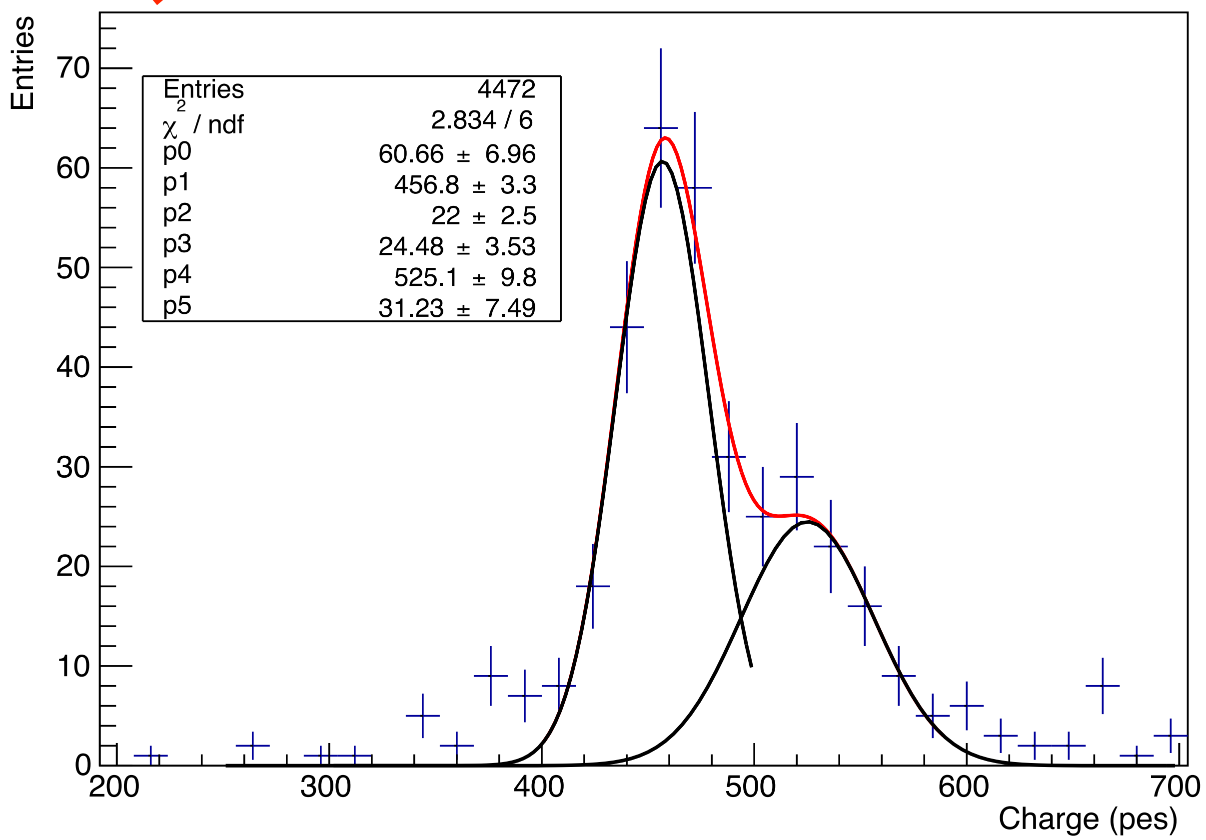


- The inverse of the slope of the exponential is the electron lifetime.
- 3 ms at the beginning of operation around ~7 ms at the end of the run.

raw: ~26% FWHM
after attachment correction: ~13% FWHM

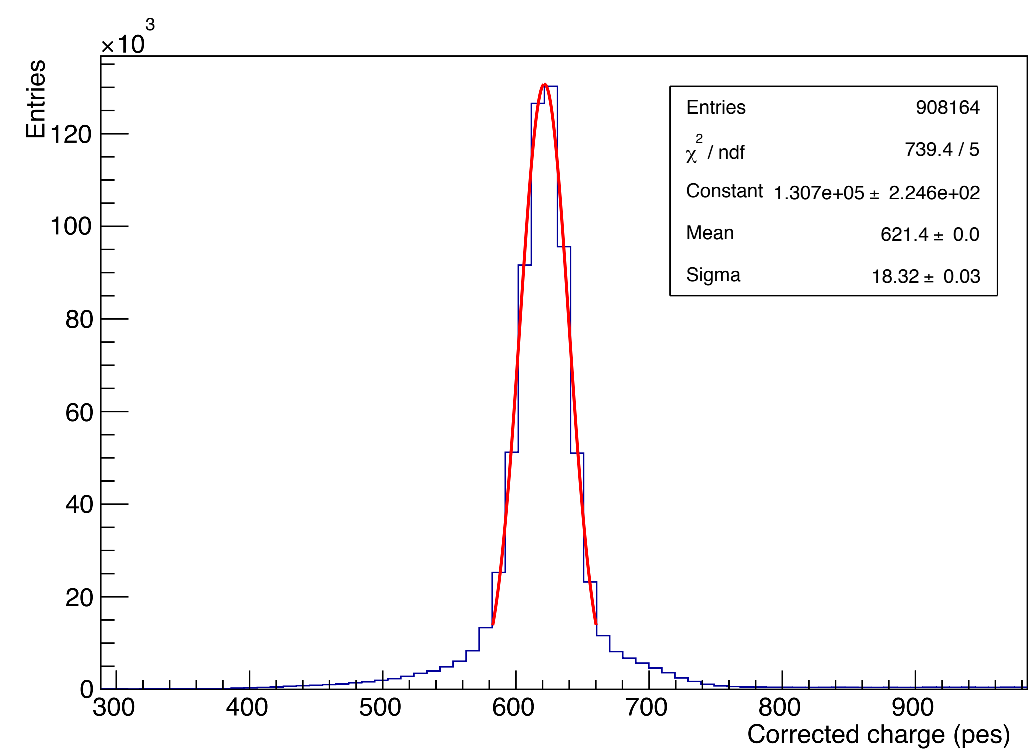
Energy resolution in NEXT

PRELIMINARY



- **Initial results from NEW** (December 2016 run)
- 11.0% FWHM for Xenon X-rays
- Extrapolates to <1% FWHM at $Q_{\beta\beta}$

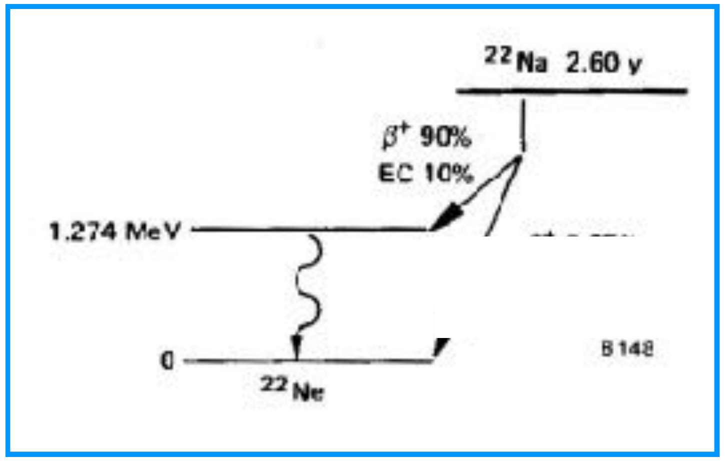
- **Initial results from NEW** (December 2016 run)
- 7.0% FWHM for Krypton X-rays
- Extrapolates to <1% FWHM at $Q_{\beta\beta}$ (~2.5 MeV)



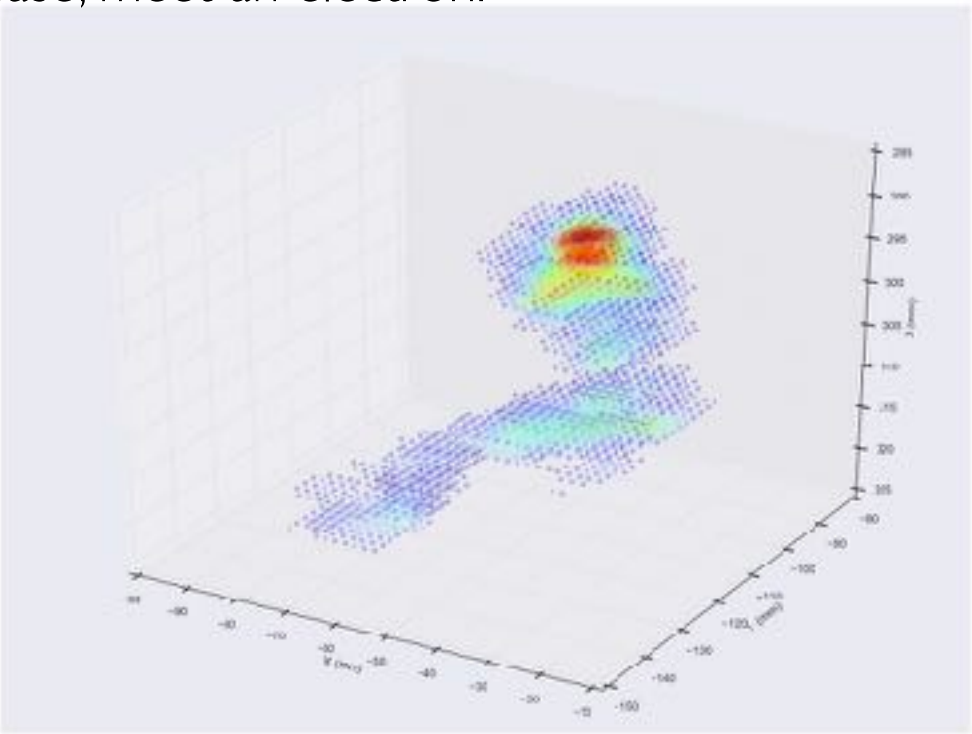
PRELIMINARY

SODIUM SOURCE

- Na-22 calibration source in lateral port.
- Na-22 decays emitting a positron —> two 511-keV gammas emitted back-to-back from positron annihilation + disexcitation emitting isotropic 1275-keV gamma.
- A NaI scintillator with a PMT is placed behind the source to tag the 511-keV backward gamma.
- A trigger is raised if a coincidence of the two gammas (in the chamber and in the external scintillator) is found within 250 ns.



Please, meet an electron!

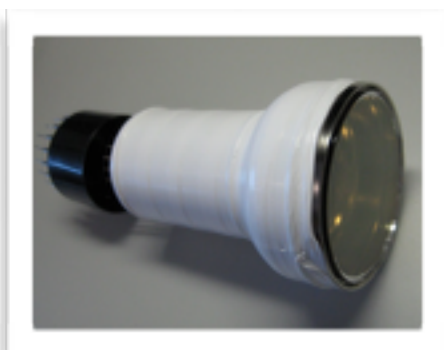


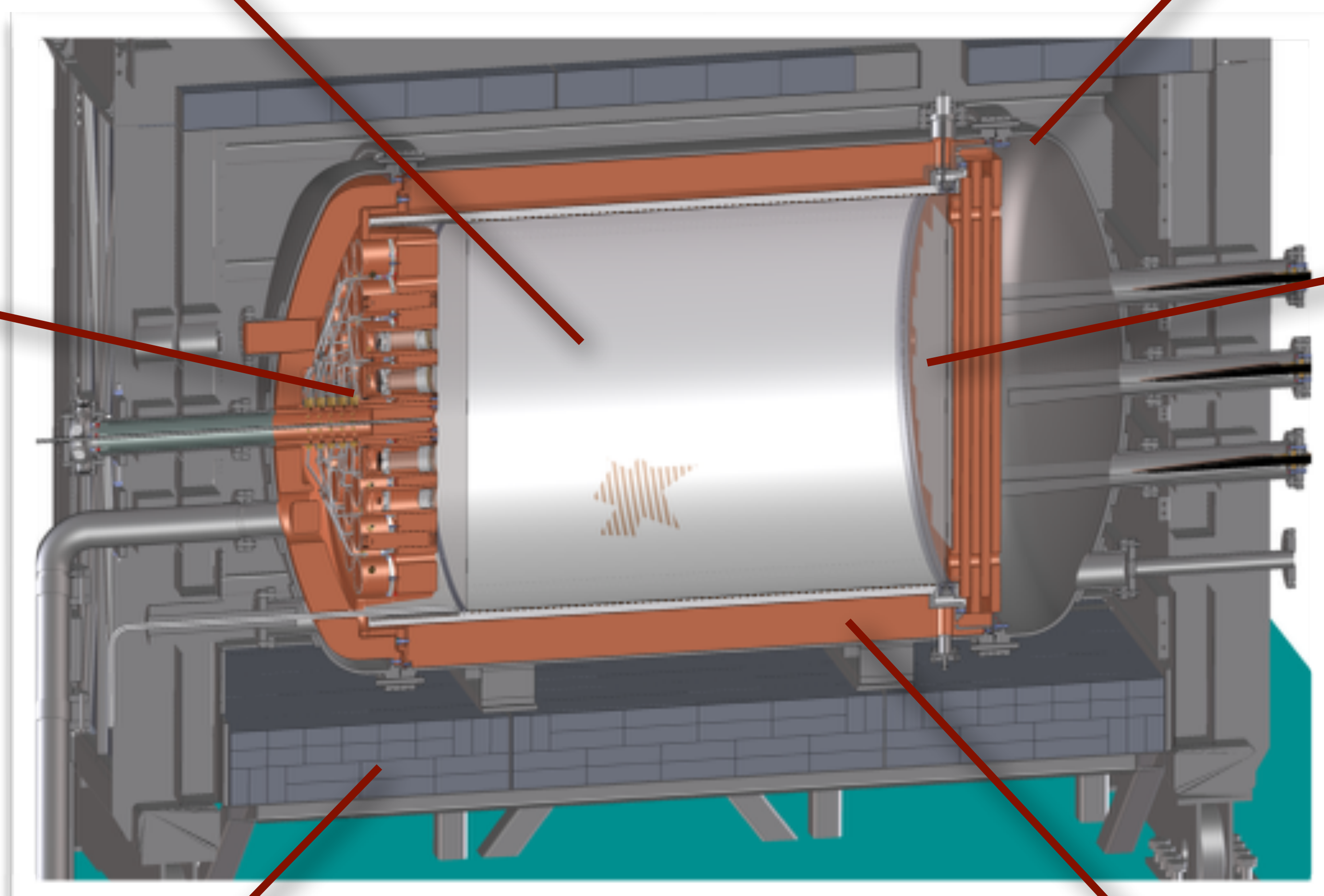
NEXT-100 (2019)

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

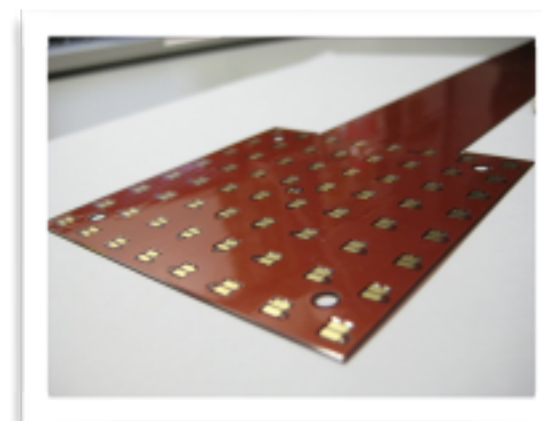
Pressure vessel:
stainless steel,15 bar max pressure

Energy plane:
60 PMTs,
30% coverage





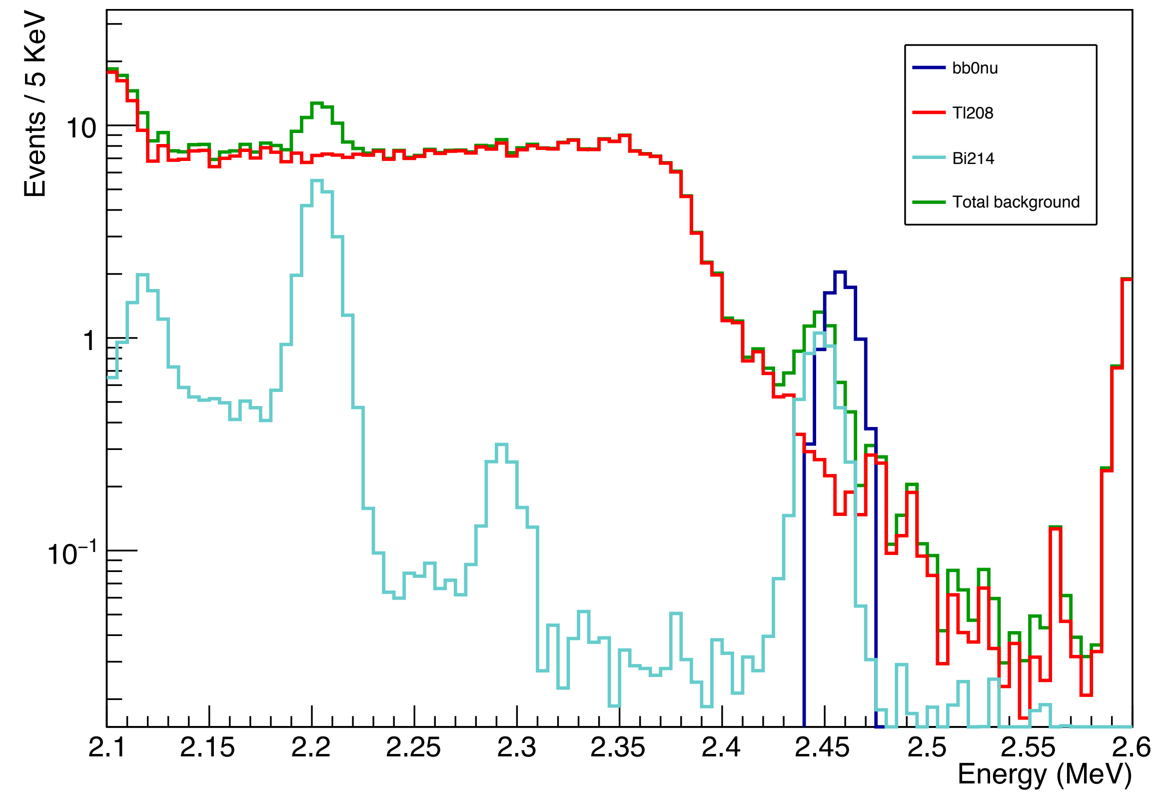
Tracking plane:
7,000 SiPMs,
1 cm pitch



Outer shield:
lead, 20 cm thick

Inner shield:
copper, 12 cm thick

REJECTION OF BACKGROUND



Main backgrounds:
Tl-208 - Compton tail of 2.6 MeV gamma.
Bi-214 - Photopeak of 2.447 gamma, very close to Qbb!!!.

- All detector materials are being screened to measure their radioactive budget or set limits.
- High pure Ge detectors, GDMS techniques.

REJECTION OF BACKGROUND

Fraction of events left after each analysis cut

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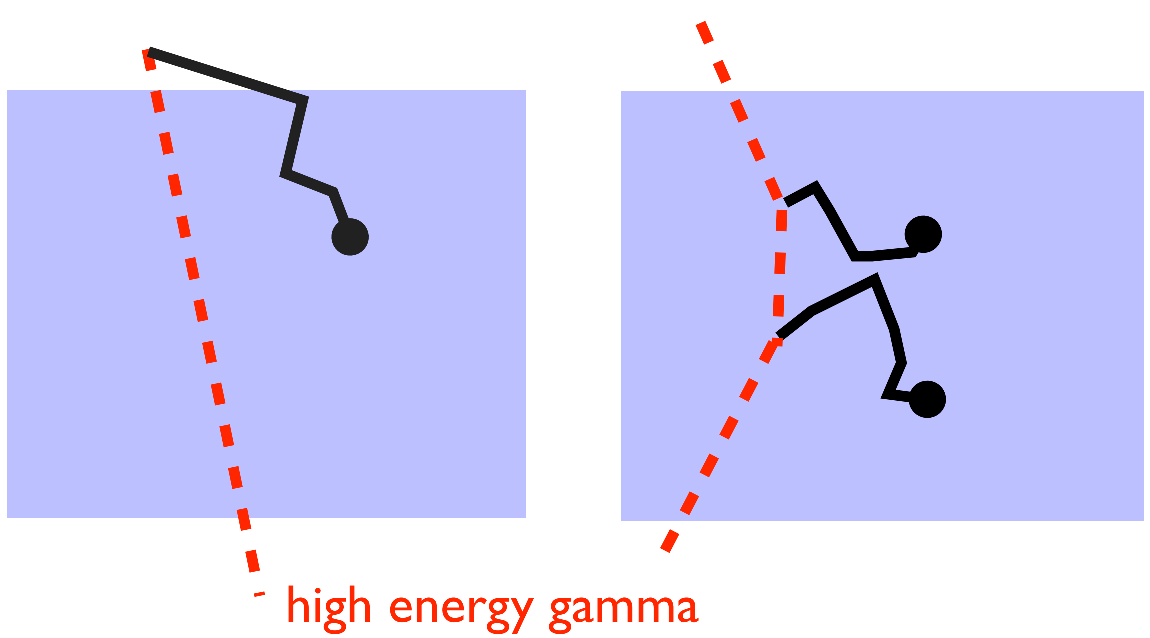
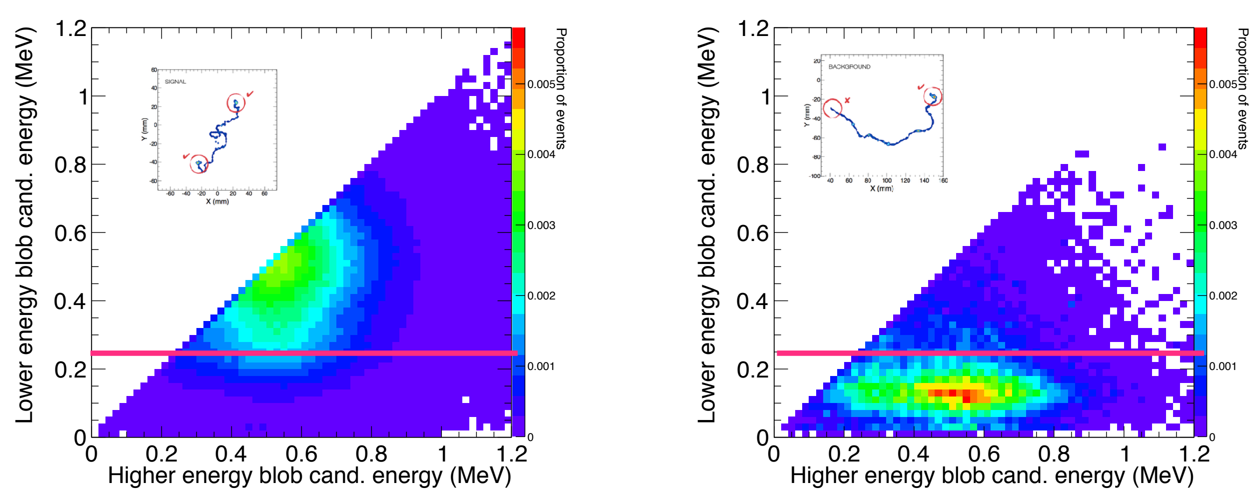
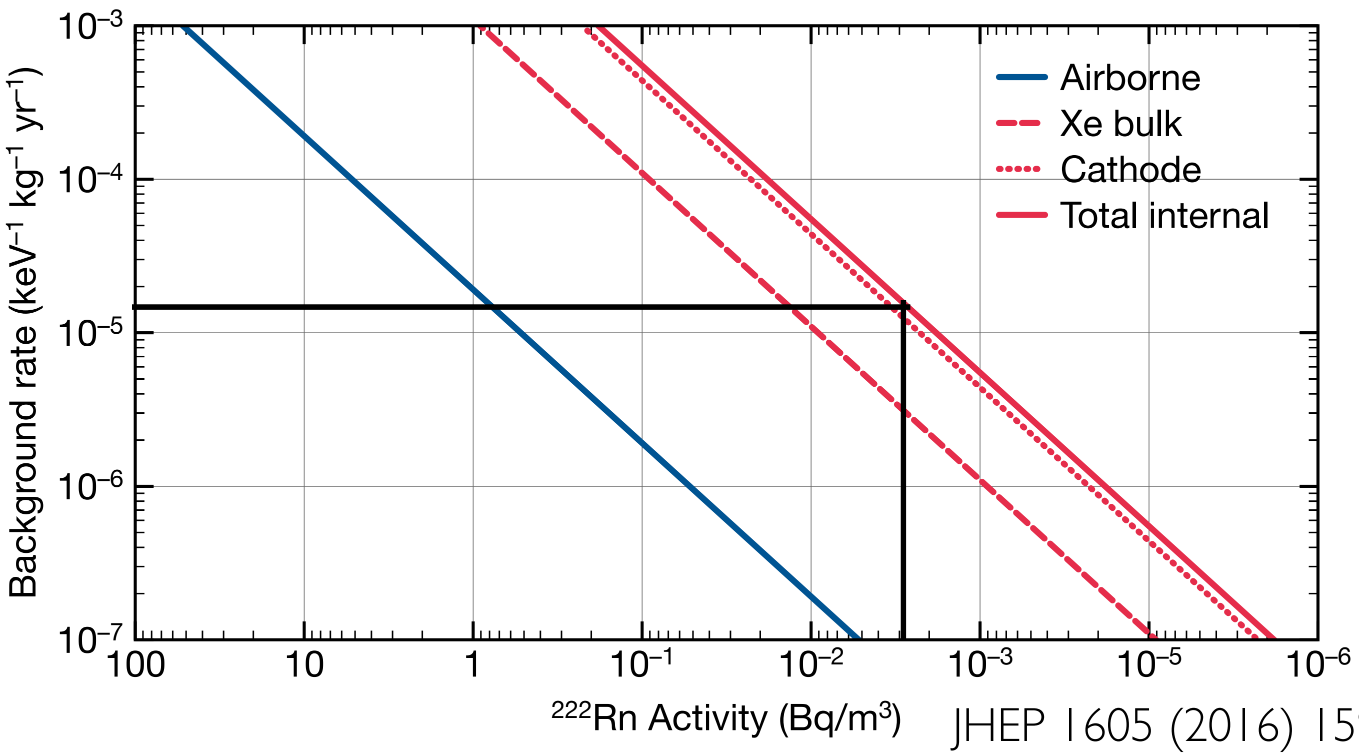
	$0\nu\beta\beta$	Tl-208	Bi-214
Fiducial + E $\in$ [2.4, 2.5] MeV	0.664	3.5×10^{-4}	2.9×10^{-5}
1 track	0.476	1.41×10^{-5}	3.44×10^{-6}
2 "blobs"	0.354	1.57×10^{-6}	3.39×10^{-7}
Energy ROI	0.320	2.54×10^{-7}	1.46×10^{-7}





RADON

- Rn gas produces Bi-214 and Tl-208, very dangerous.
- Airborne Rn in the lab can be reduced by a radon abatement system down to ~ mBq/m^3.



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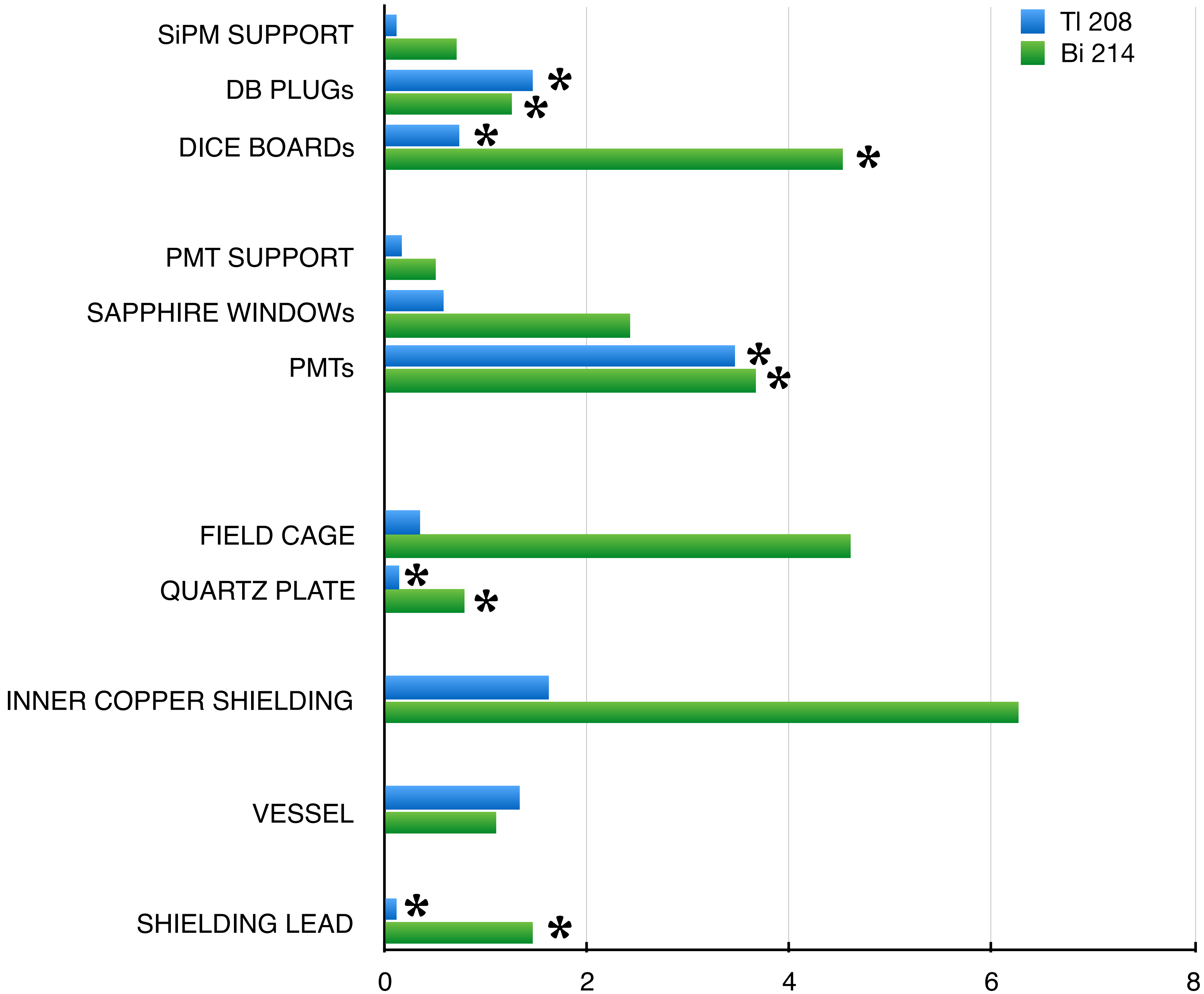
- Radon emanation measurements for all detector materials.
- Alternatives to high sources of Rn such as SAES hot getters are explored (e.g., Ca-based chips).

- Rn emanation from detector components and getters gets into active volume.
- Rn charged daughters stick to internal surfaces.
- A reduction to few mBq/m^3 would lower Rn contribution to the level of the rest of background.

REJECTION OF BACKGROUND



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

- Main measured contribution: PMTs (21 and 11 mBq in total) and kapton boards (glue between layers).
- Limits on copper and hdpe.

Total expected background rate

< 4 x 10^{-4} cts / (keV kg year)

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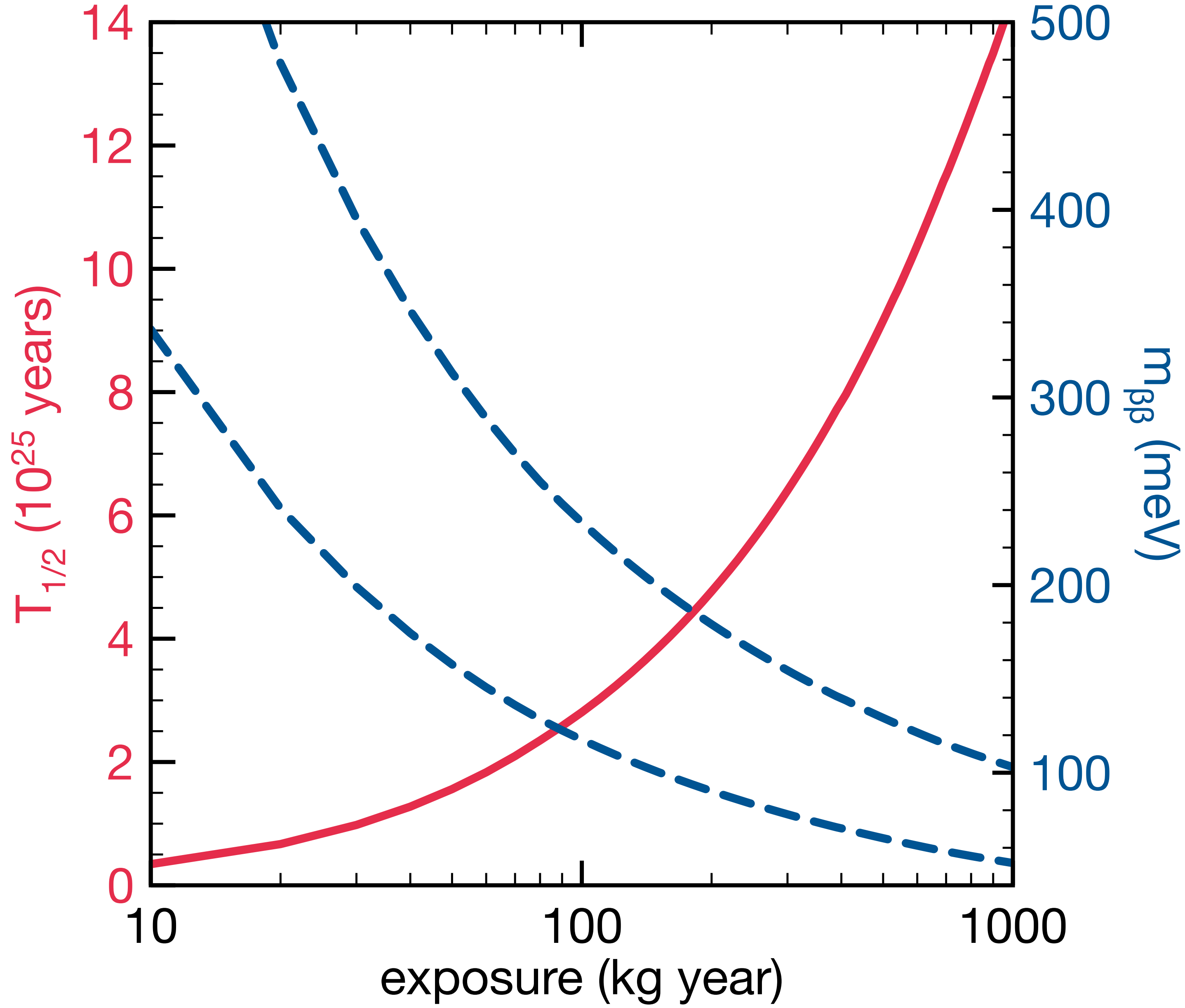
- Essential step towards the tonne scale.

NEXT-100 SENSITIVITY



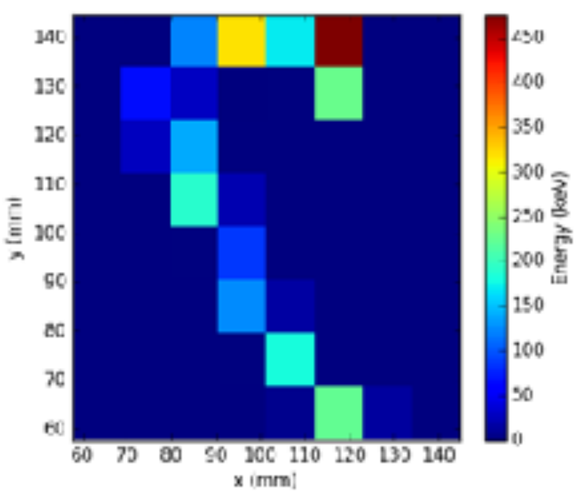
- For an exposure of 275 kg yr a half-life up to 6 x 10^{25} years can be explored.
- Room for improvement (background rate is reduced or reconstruction and analysis improved).

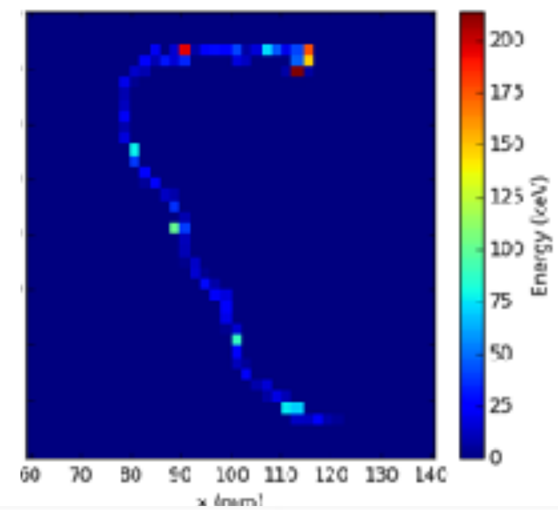
NAUSICAA

- **NAUSICAA (Next Array aparatUS with Improved CApAbilities)**
- ~3 detectors with masses 0.5-1 ton, distributed across the World (why not Canfranc, LNGS and SURF?)
- Distributed array: large mass, better control of systematics, more cross-checks.

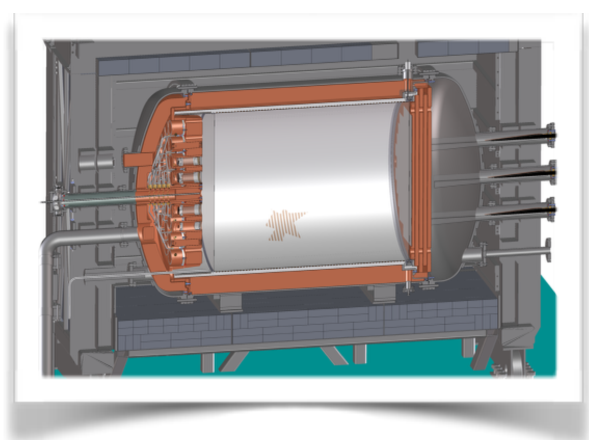
NAUSICAA would be a truly international effort that could lead to a discovery!

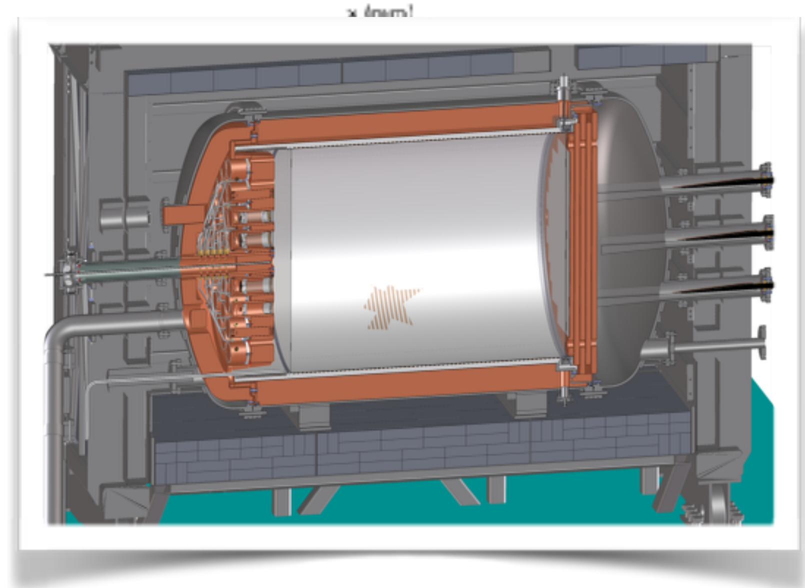
FROM NEXT TO NAUSICAA



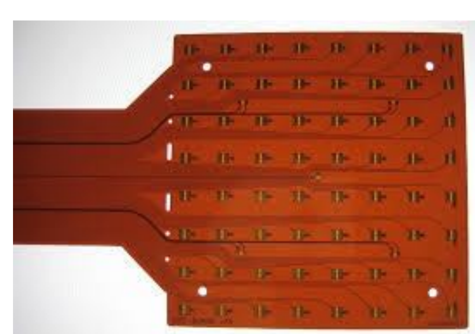


Low diffusion: f ~(1/5)



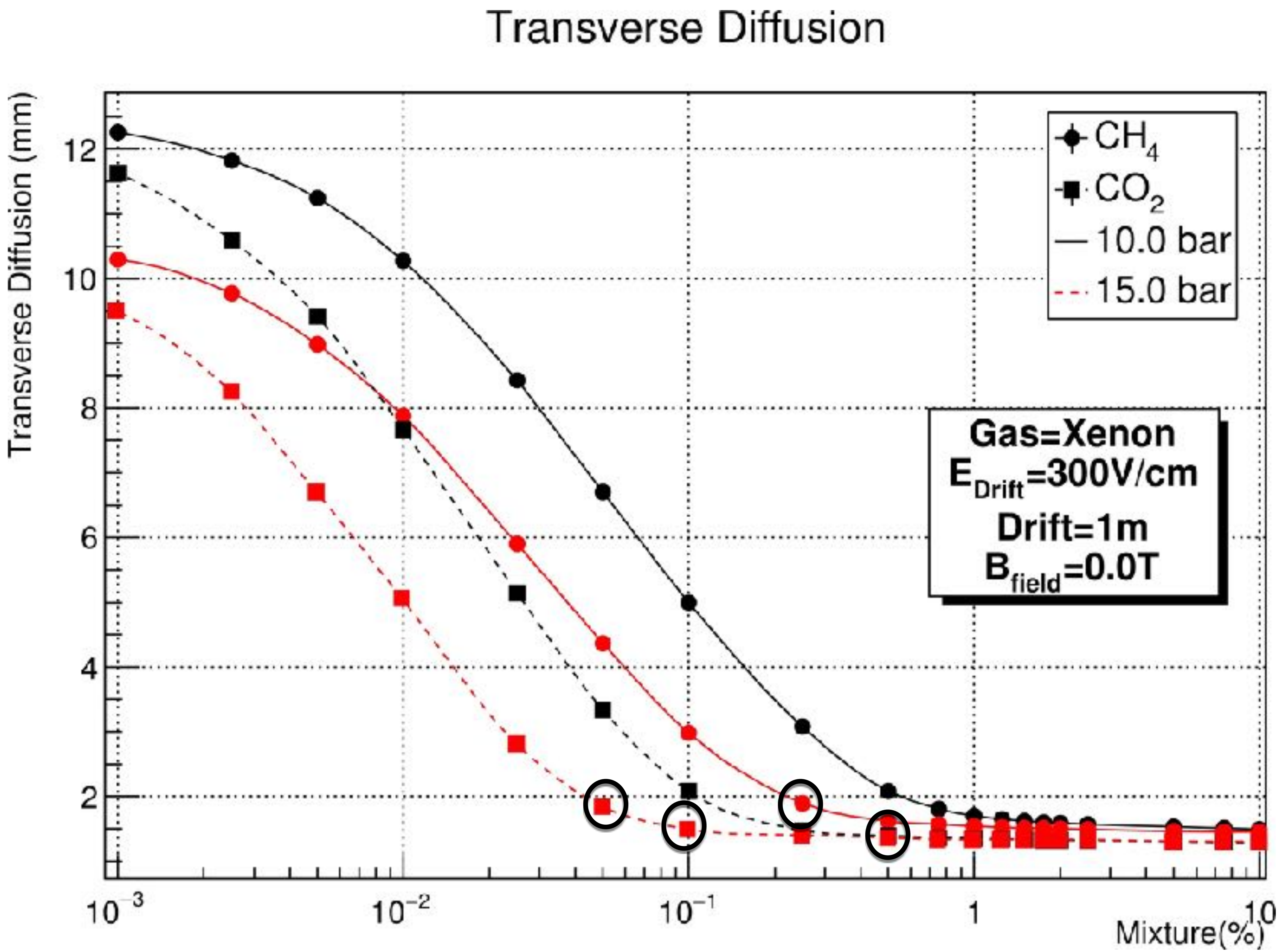


Scale: f ~(1/2)



Radiopurity: f ~(1/2)

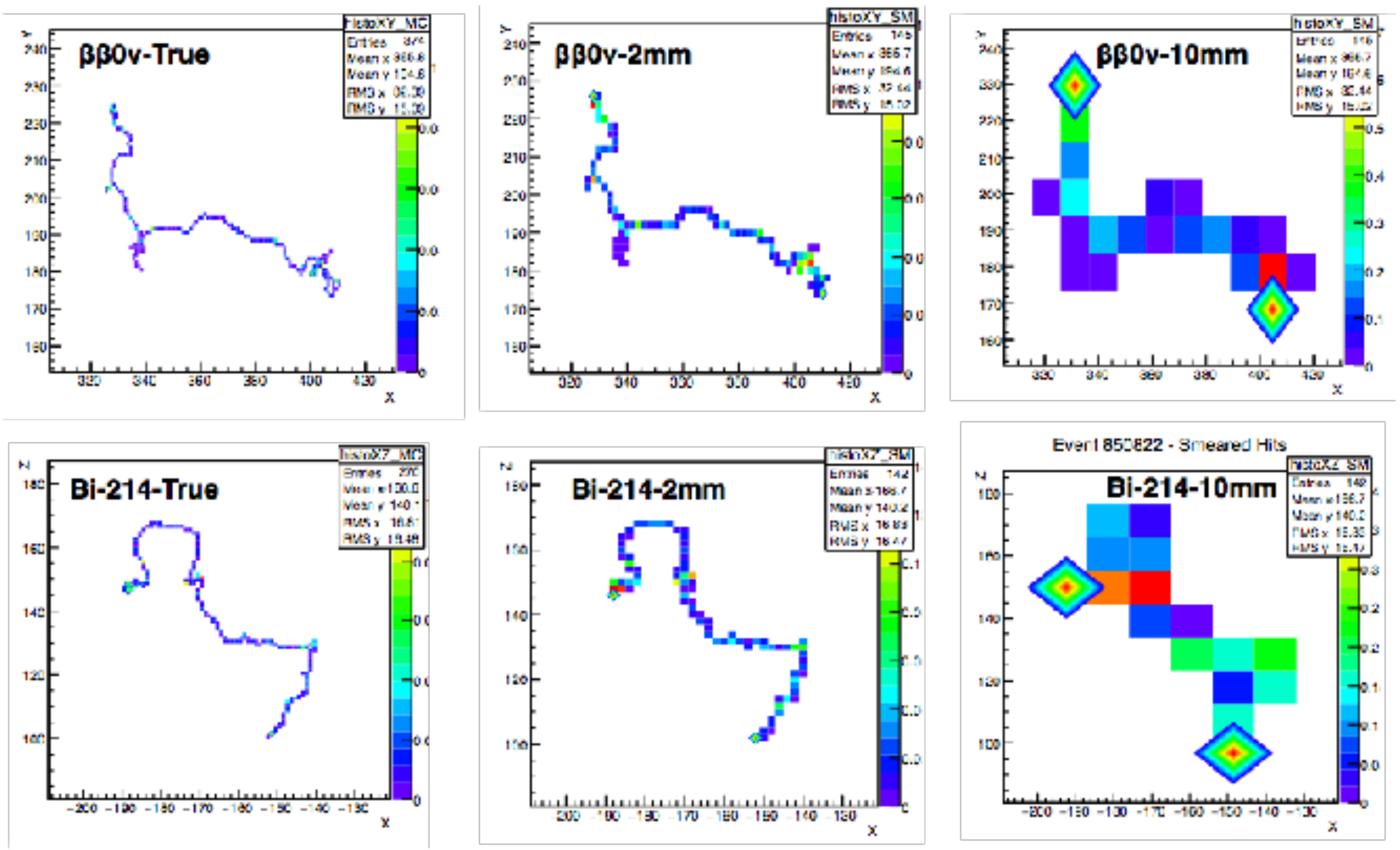
- **Reaching 1 event ton/year in the ROI appears possible.**



CO2: 0.1 % (CH4: 0.5 %) —> DT < 1.5 mm

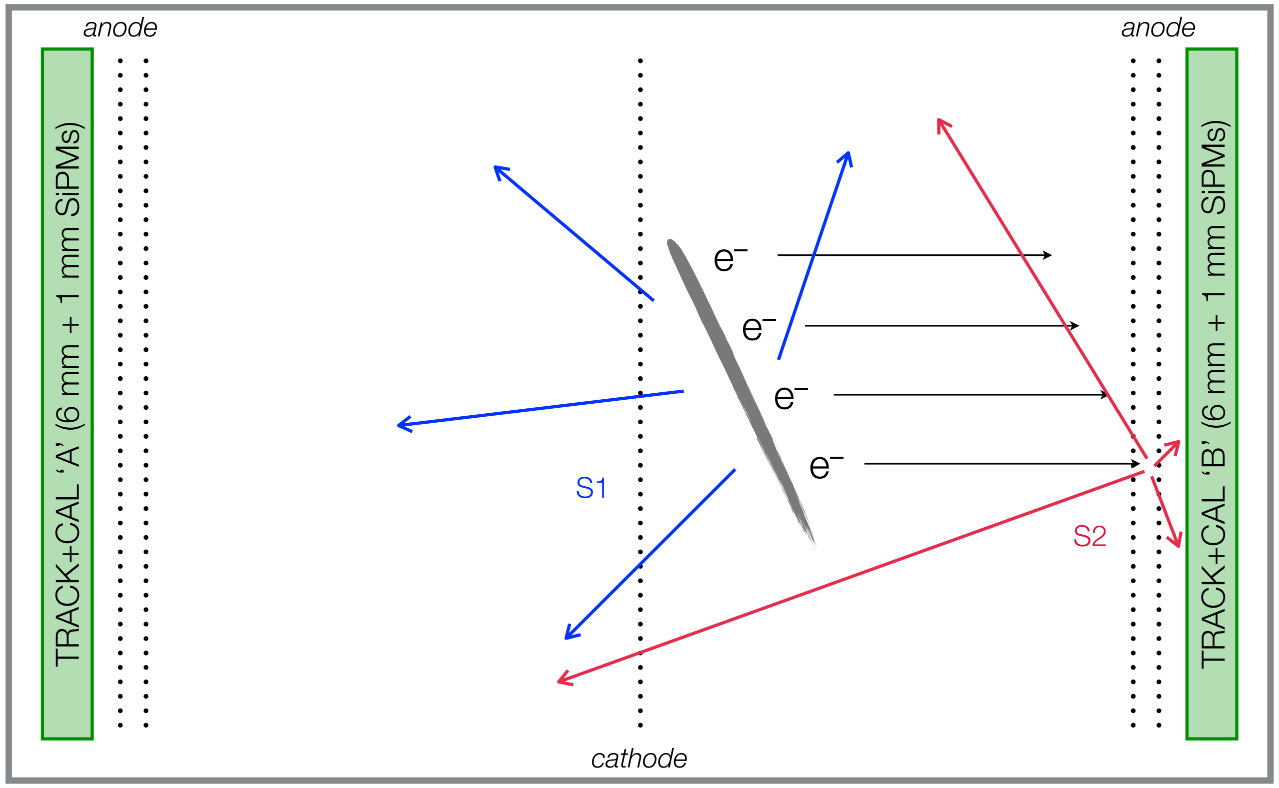
CO2: 0.05 % (CH4: 0.25 %) —> DT < 2 mm

The effect of difusion



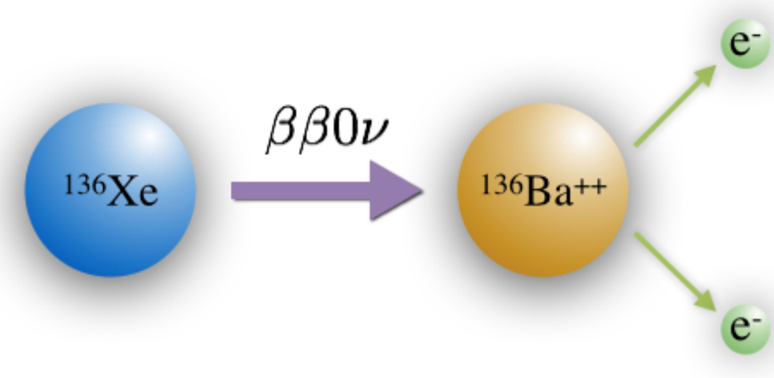
The effect of blurring the "true" track (left) by 2 mm diffusion (center) or 10 mm diffusion (right). In the example, the algorithm finds a fake blob in Bi-214 event for 10 mm diffusion but not for 2 mm diffusion

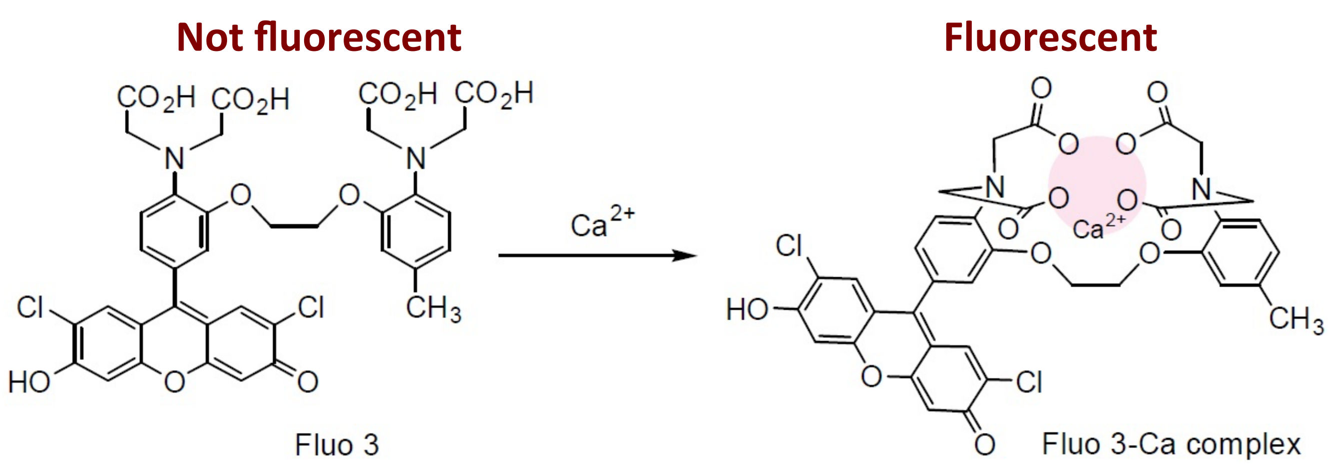
Symmetric TPC

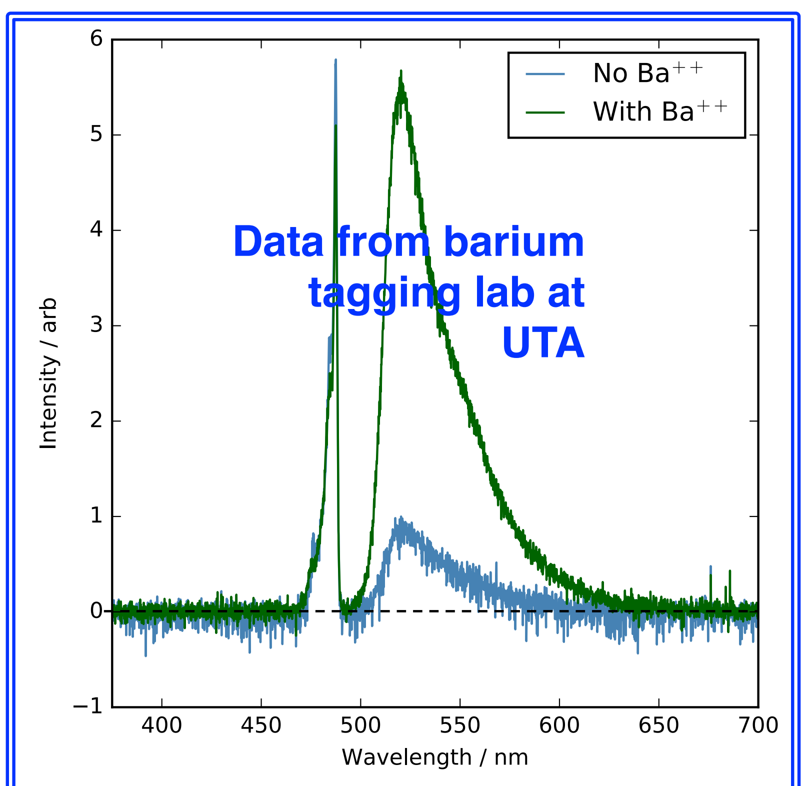


- L = 2 m, R = 1.5 m.
- ~30,000 SiPMs
- P = 10 bar: —> 815 kg
- P = 15 bar: —> 1220 kg

BA-TAGGING







- 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.

THANKS FOR YOUR ATTENTION!

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

Coimbra GIAN, Coimbra LIP, Aveiro

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