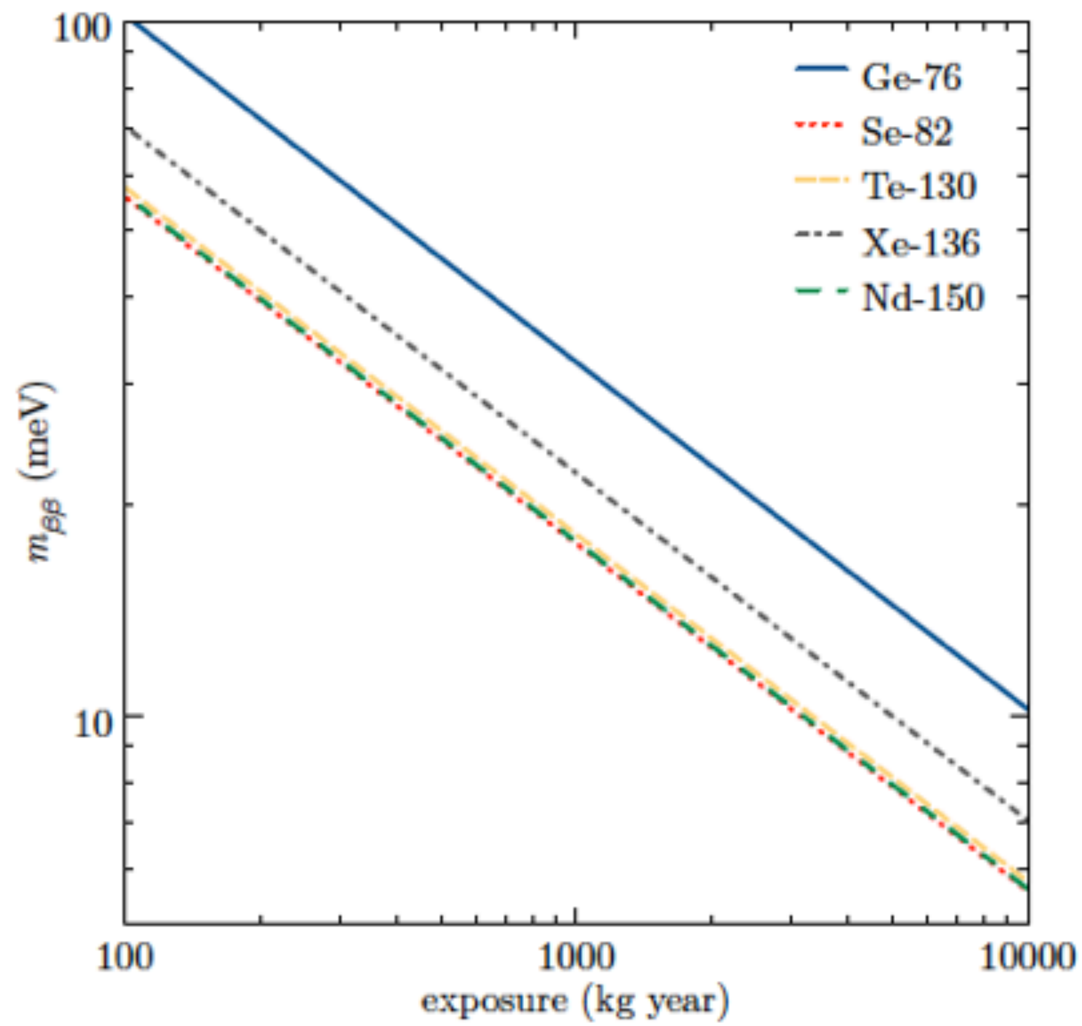
Ettore Majorana meets his shadow (IV)

J.J. Gómez-Cadenas
Instituto de Física Corpuscular
CSIC-U.Valencia

Xenon for DBD searches

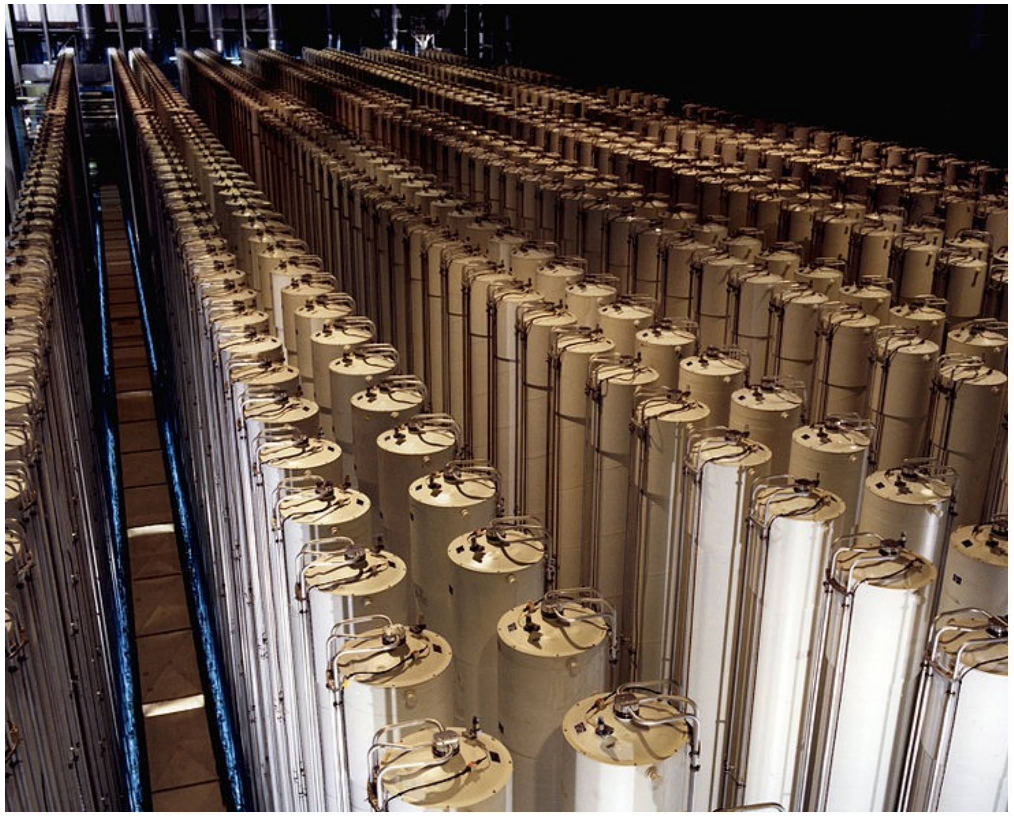
Yields



Good yield

- Twice better than Ge-76
- 50% worse than Se-82, Te-130 or Nd-150

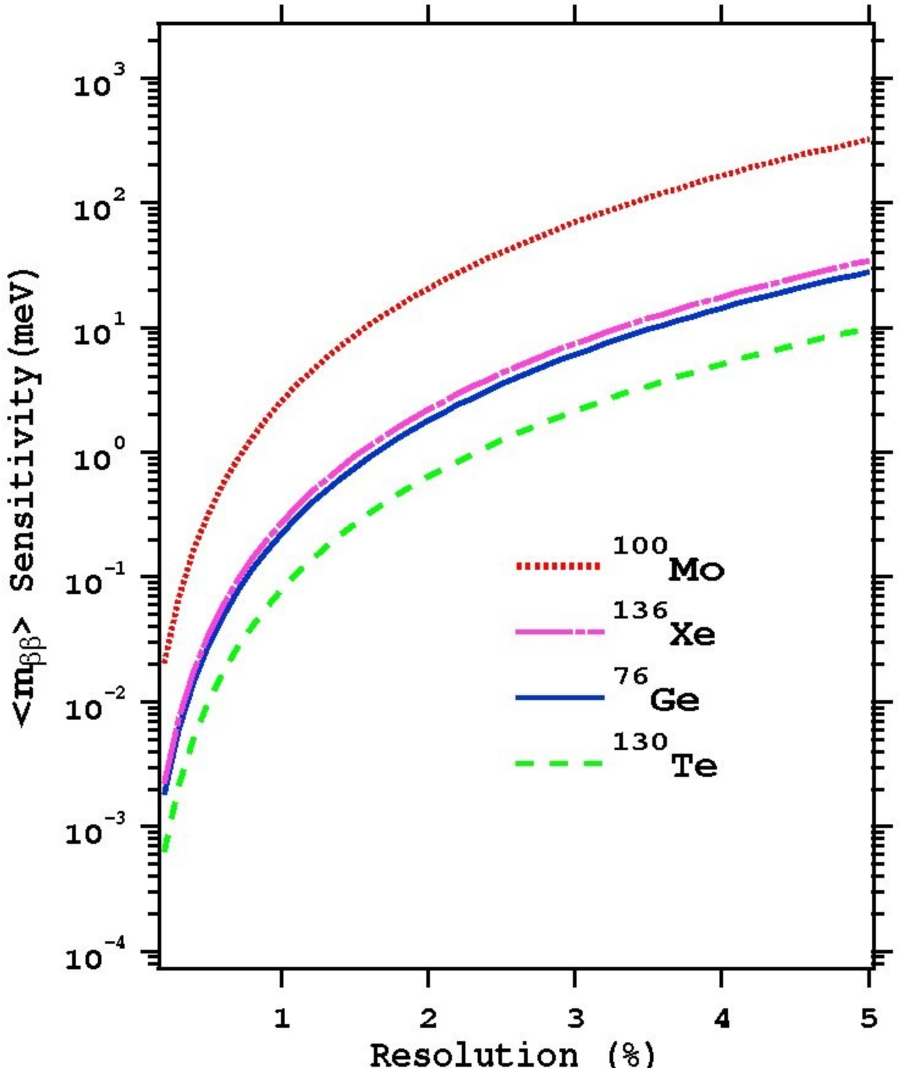
Easy to procure and enrich

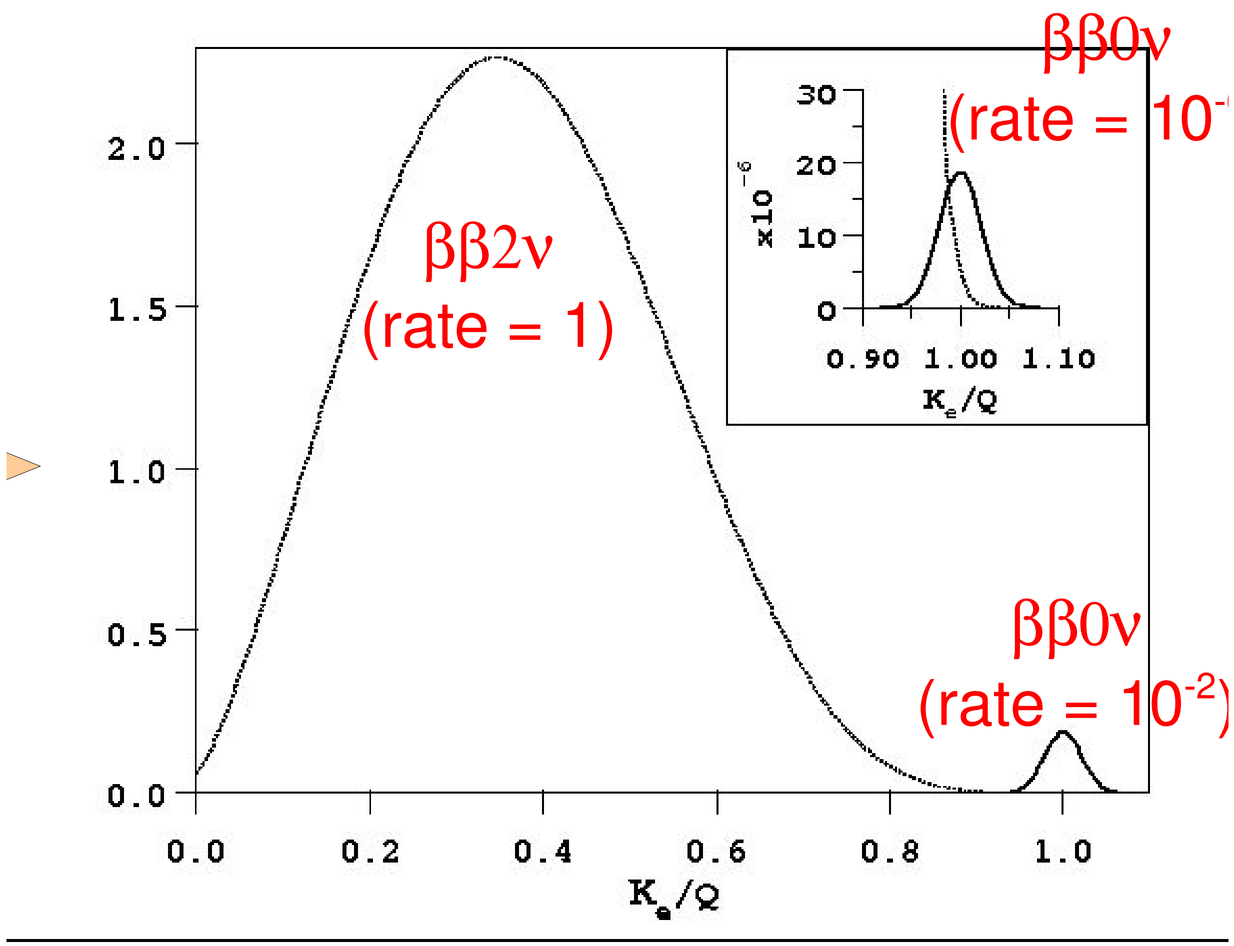


- Already 700 kg of Xe-136 in the world.
- 400 kg (KamLAND-ZEN)
- 200 kg EXO
- 100 kg NEXT

- Standard enrichment requires gasification of material and separation in centrifuges.
- Xe is a noble gas (no need to gasify) and Xe-136 the heaviest isotope (simplest case for mass separation in centrifuges).
- Compared with other isotopes Xe-136 is by far the easiest to procure and enrich
- In cost and difficulty about one order of magnitude less than other isotopes

Slow bb2nu mode



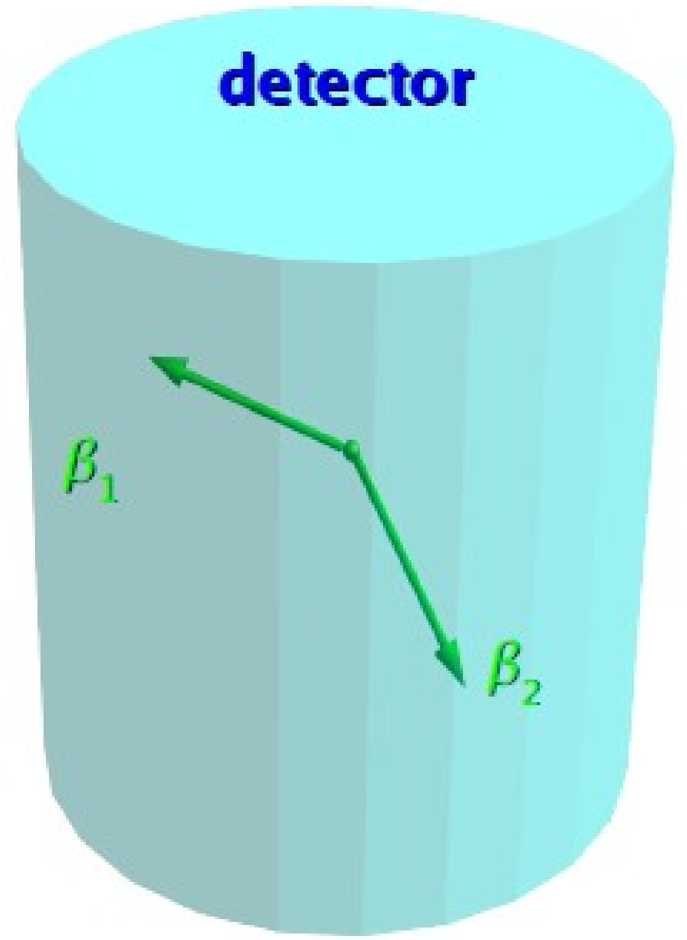


$$\langle m_{\beta\beta}\rangle^2 \sim \frac{7Q\delta^6}{m_e}\frac{G_{2\nu}}{G_{0\nu}}\frac{|M_{2\nu}|^2}{|M_{0\nu}|^2}$$

- Sensitivity limit for ββ2ν only, infinite statistics.

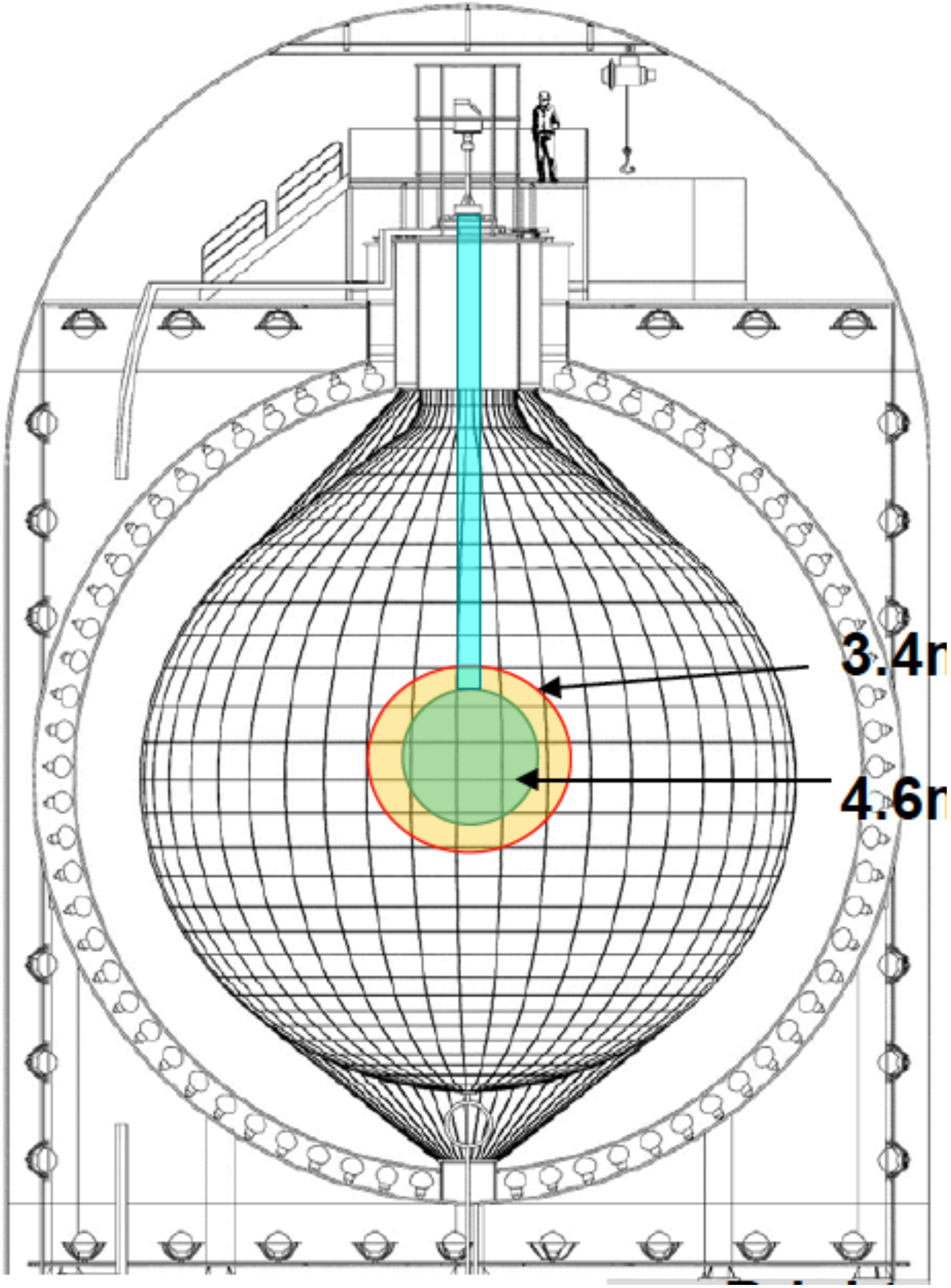
Slow bb2nu mode

Source = Detector



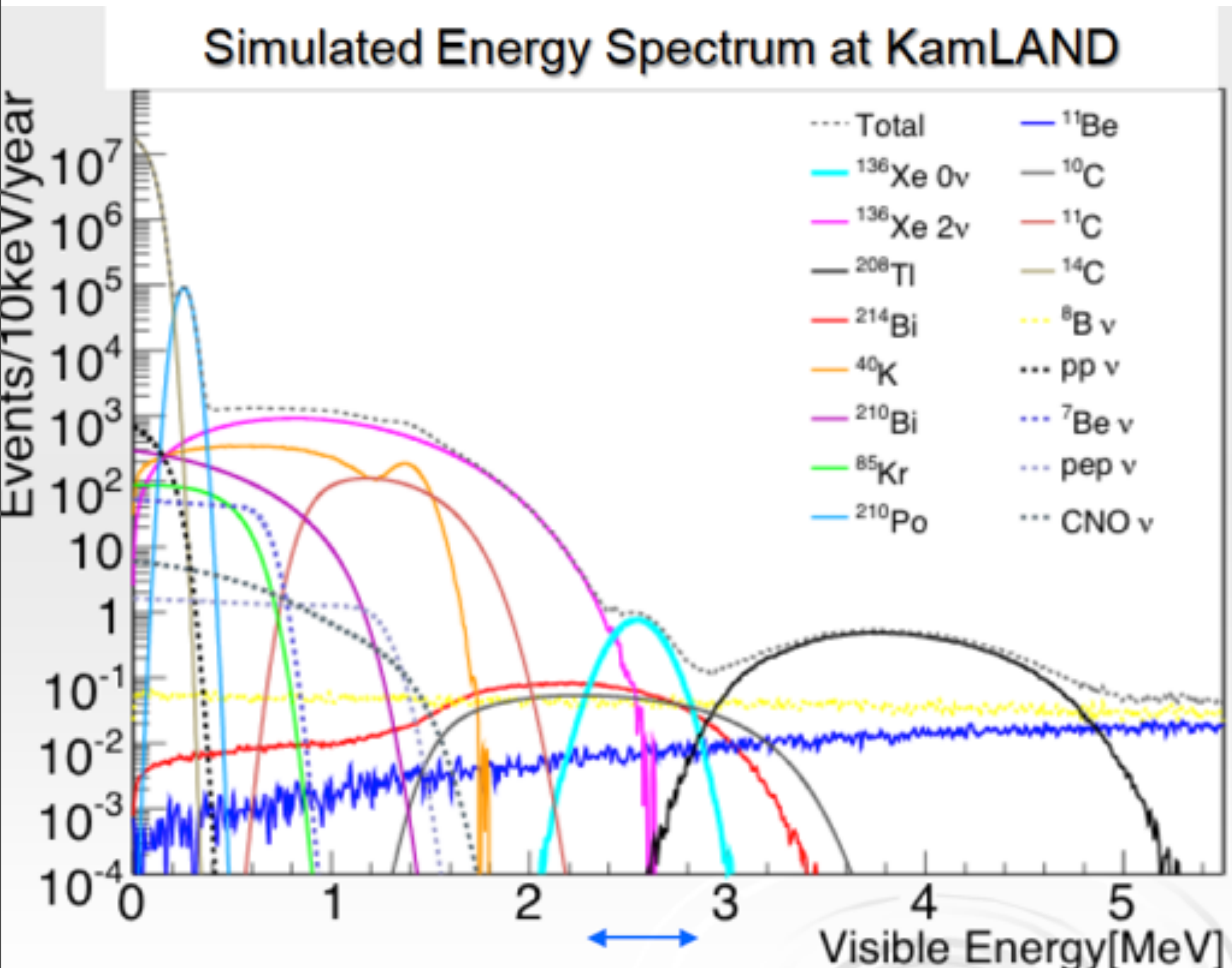
- Large detectors
- Mass goes with L^3
- Large mass and good fiduciality

Kamland-Zen



- Xenon dissolved in liquid scintillator.
- Very radiopure balloon of 2 m radius
- High efficiency (~80%)
- Phase I 400 kg of Xenon.
- PHASE-II 1 ton of Xenon.
- Poor resolution (about 10% at Qbb)
- claims b~10^{-4} ckky (self-shielding)
- Diffusion through balloon?

Background model



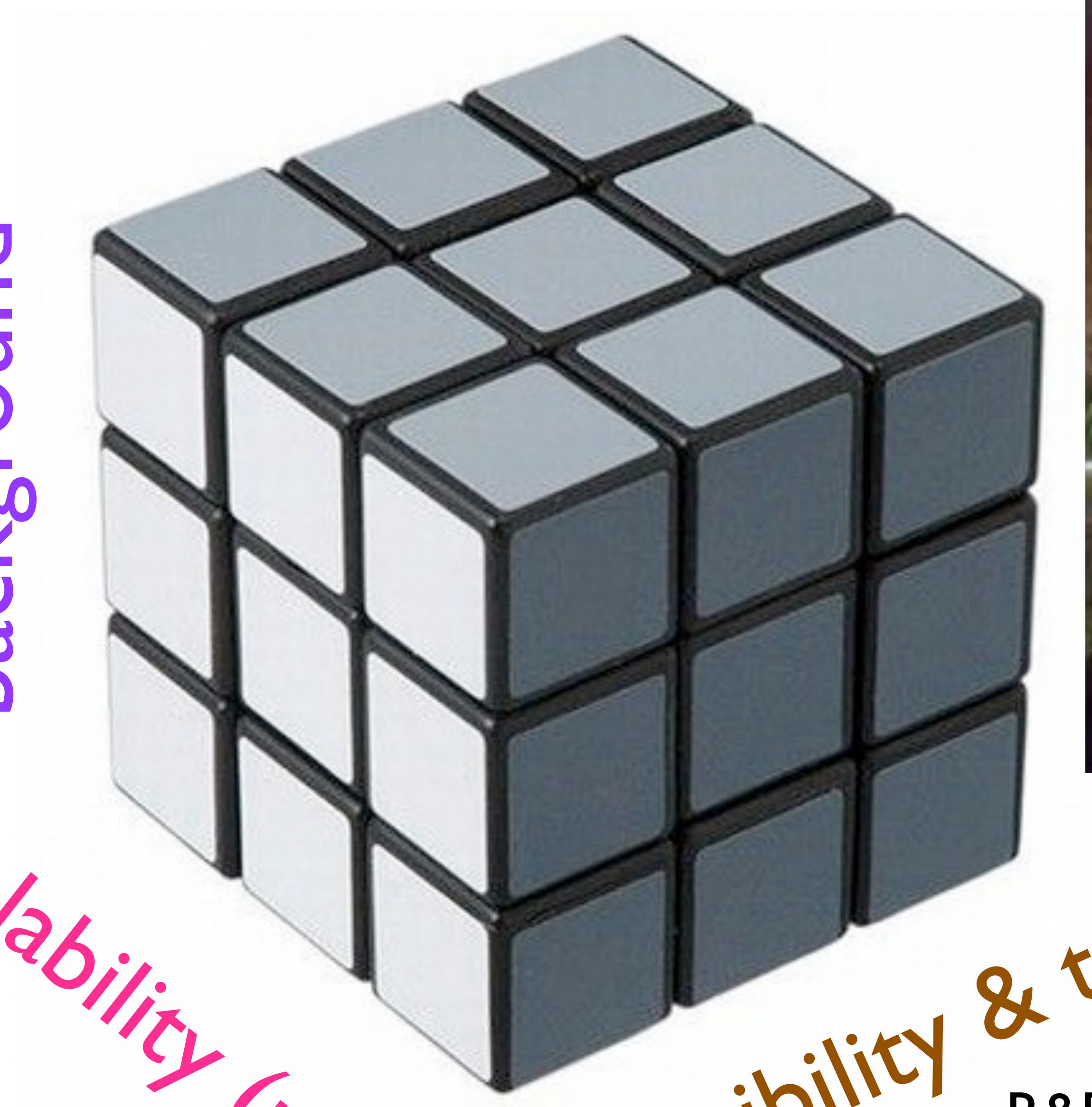
Summary of BG and signal in signal region

^{136}Xe 2ν	^{208}Tl	^{214}Bi	^{10}C	^{11}Be	^{8}B	Total	^{136}Xe 0ν
2.08 ±0.15	1.86×10^{-2} $\pm0.13\times10^{-2}$	2.40 ±0.01	3.09 ±0.01	0.26 ±0.01	1.52 ±0.03	9.35 ±0.23	18.08 ±0.02

[events/year]

- Purely MC studies.
- Backgrounds can increase sizably if bb2nu for Xenon is faster than 10^{22} y
- Aggressive assumptions for tagging capabilities (90% 10C, 60% 214Bi)
- Assumes extreme radiopurity of both scintillator and balloon (10^{-12} g/g in U and Th).
- results in $b\sim10^{-4}$ ckky

Kamland-ZEN cube



background

scalability (mass, cost)

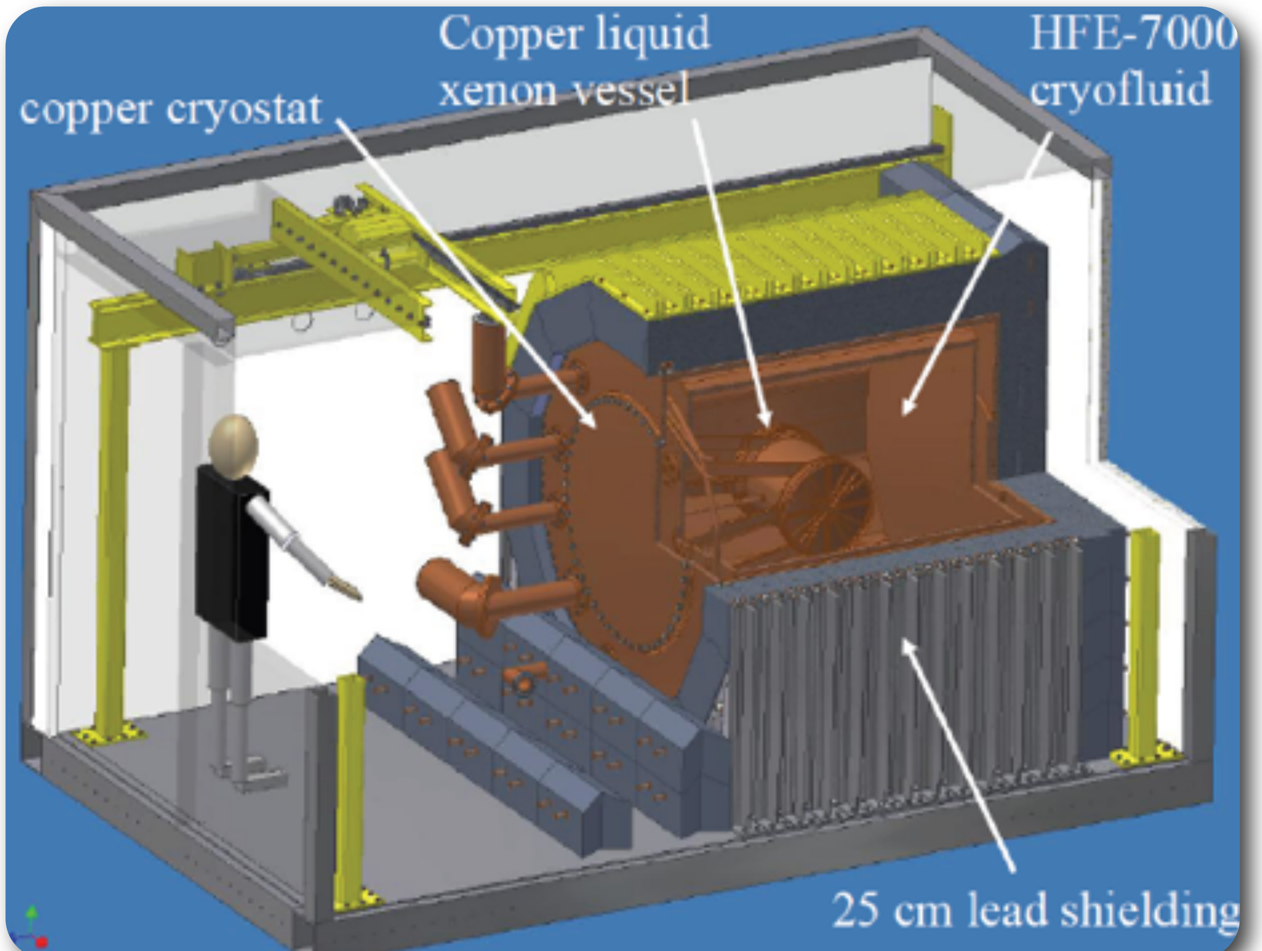
feasibility & t0

~(2-5) x10^{-4}
ckky

350-1000 kg

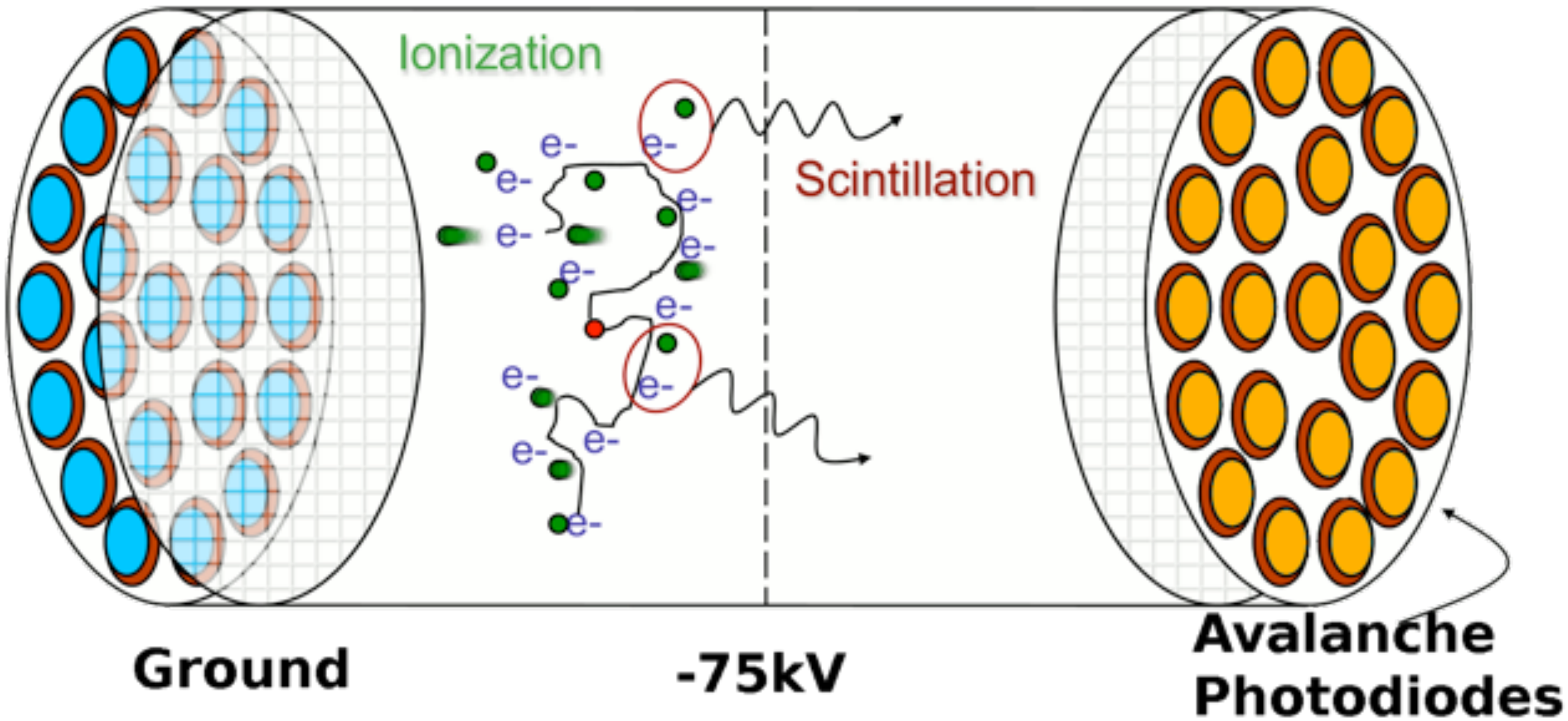
R&D on radiopure balloon
liquid scintillator
readout electronics
starts in 2012? 2013?

EXO-200



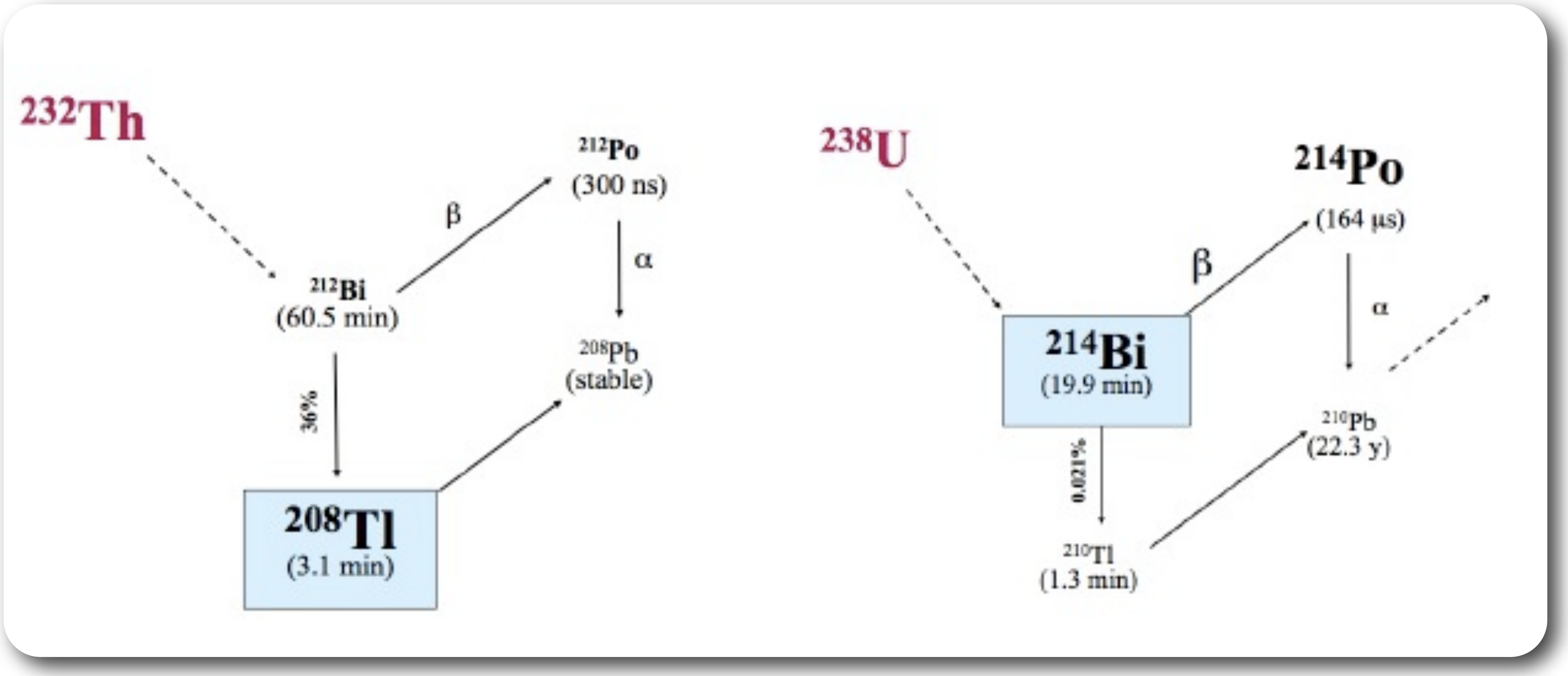
- 200 kg of liquid Xenon (enrichment at 80%)
- High efficiency (~70%)
- Mediocre resolution (about 4% at Qbb), but excellent self shielding.
- b~10^{-3} ckky (background model not very detailed in literature)

SIGNALS in EXO



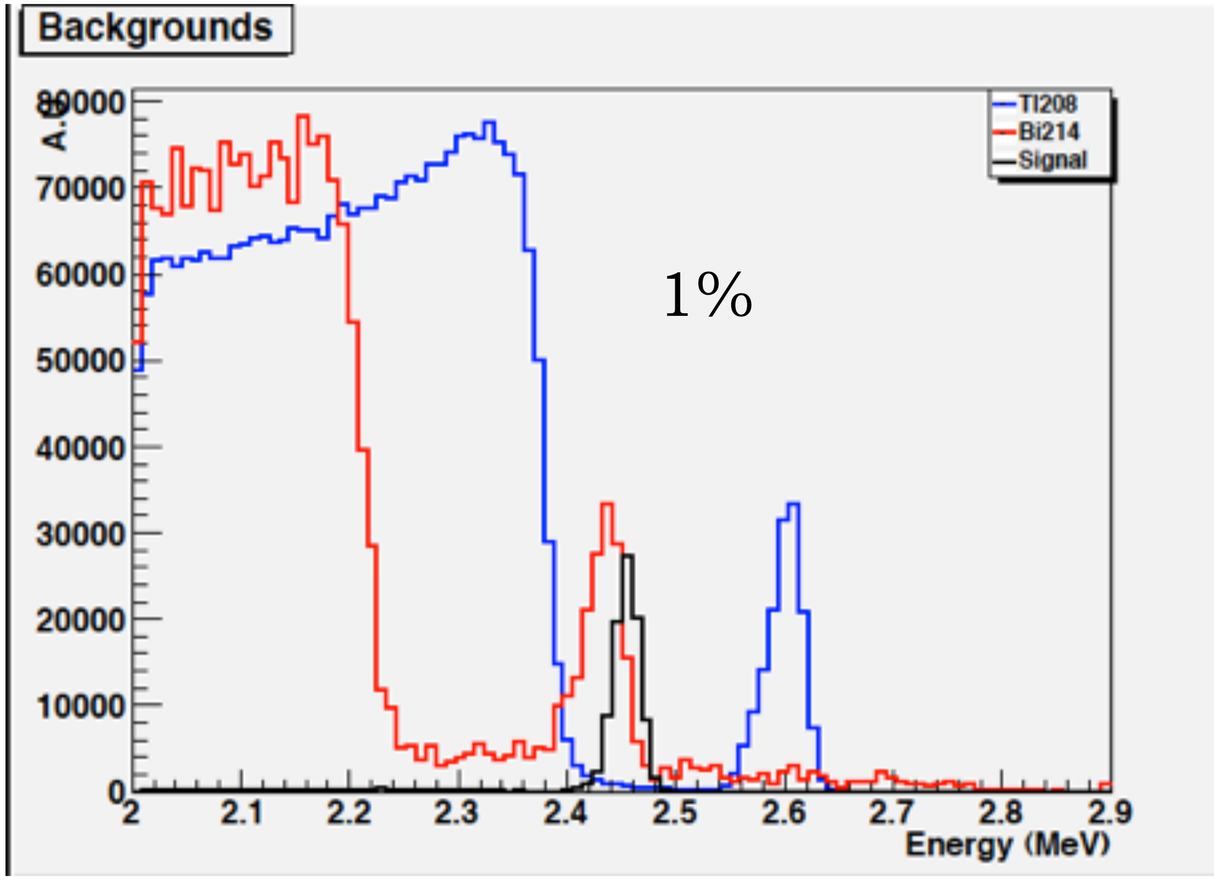
- Fast scintillation (S1) is used to locate the event t0.
- In LXe scintillation also provides a measurement of energy.
- Ionization charge drifts under the action of electric field andis read by wires. It provides a second measurement of the energy.
- A resolution of about 4% FWHM is obtained combining both measurements.

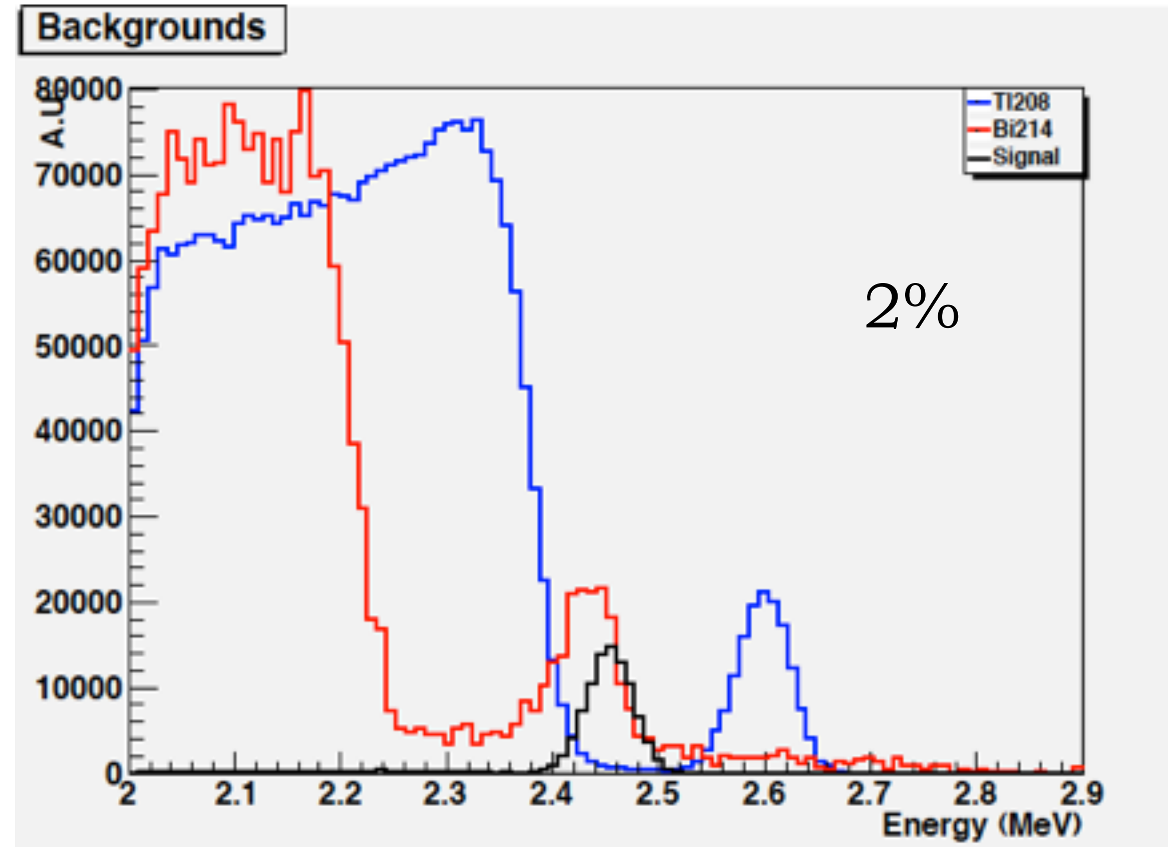
Backgrounds for EXO (and for NEXT)

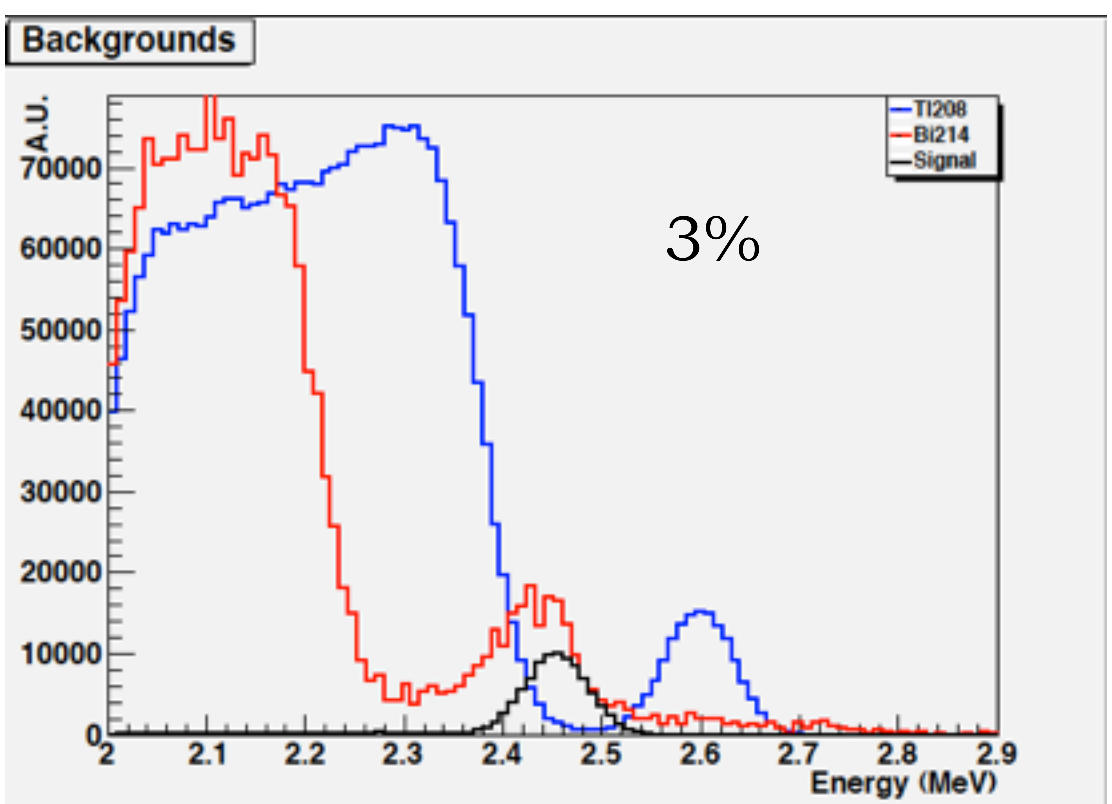


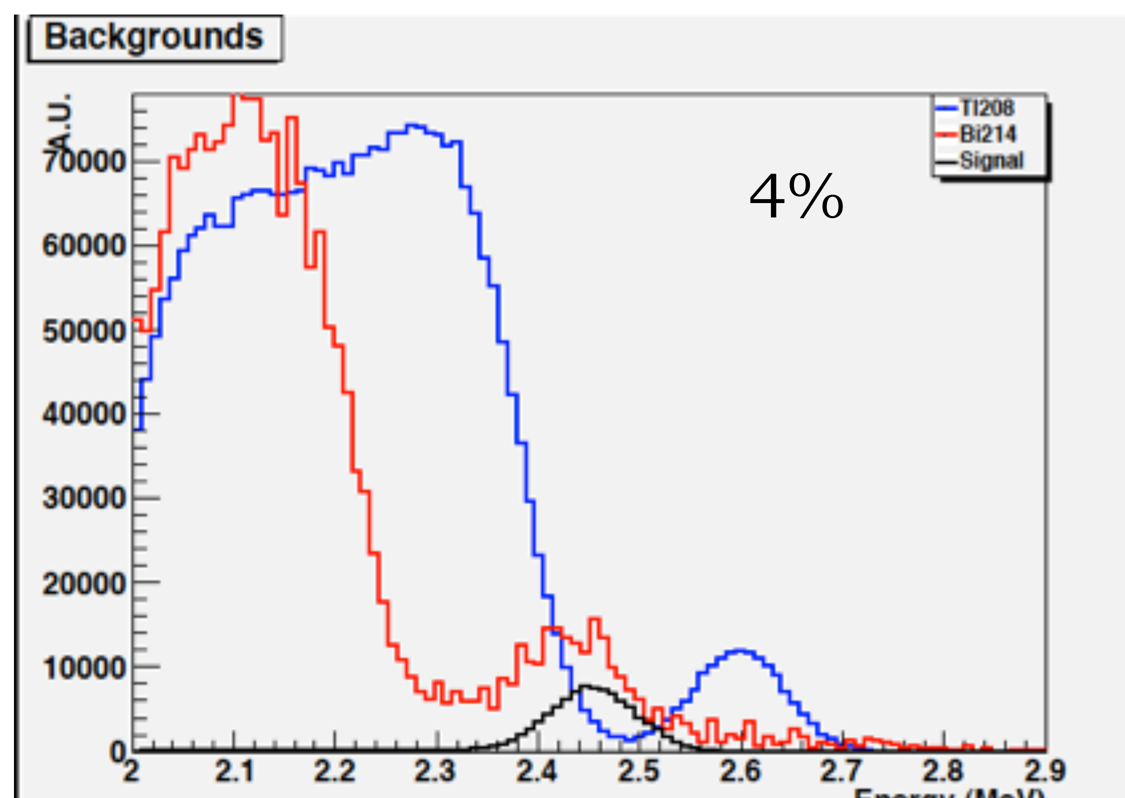
Xe TPCs are mostly affected by external backgrounds. Surface backgrounds are greatly reduced by defining a strict fiducial volume.

The Xenon landscape & resolution

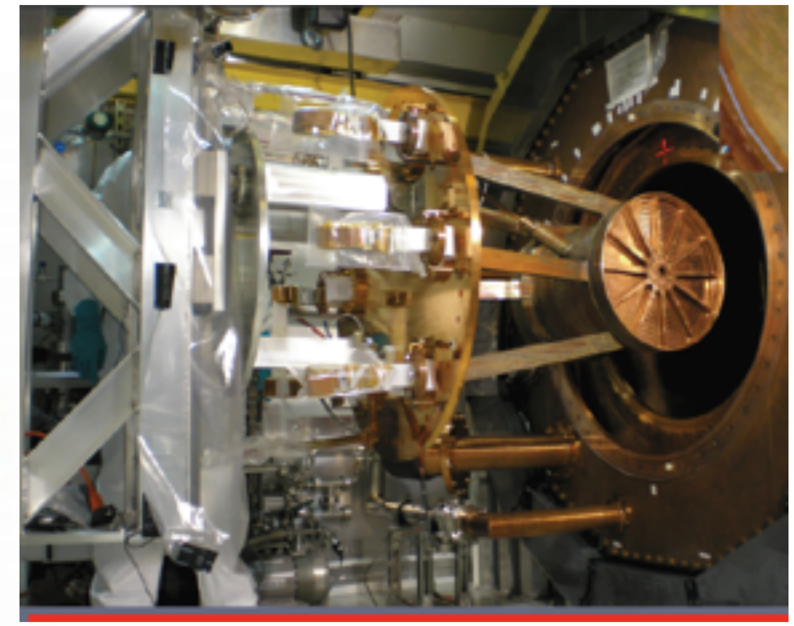








EXO cube



10^{-3} ckky

background

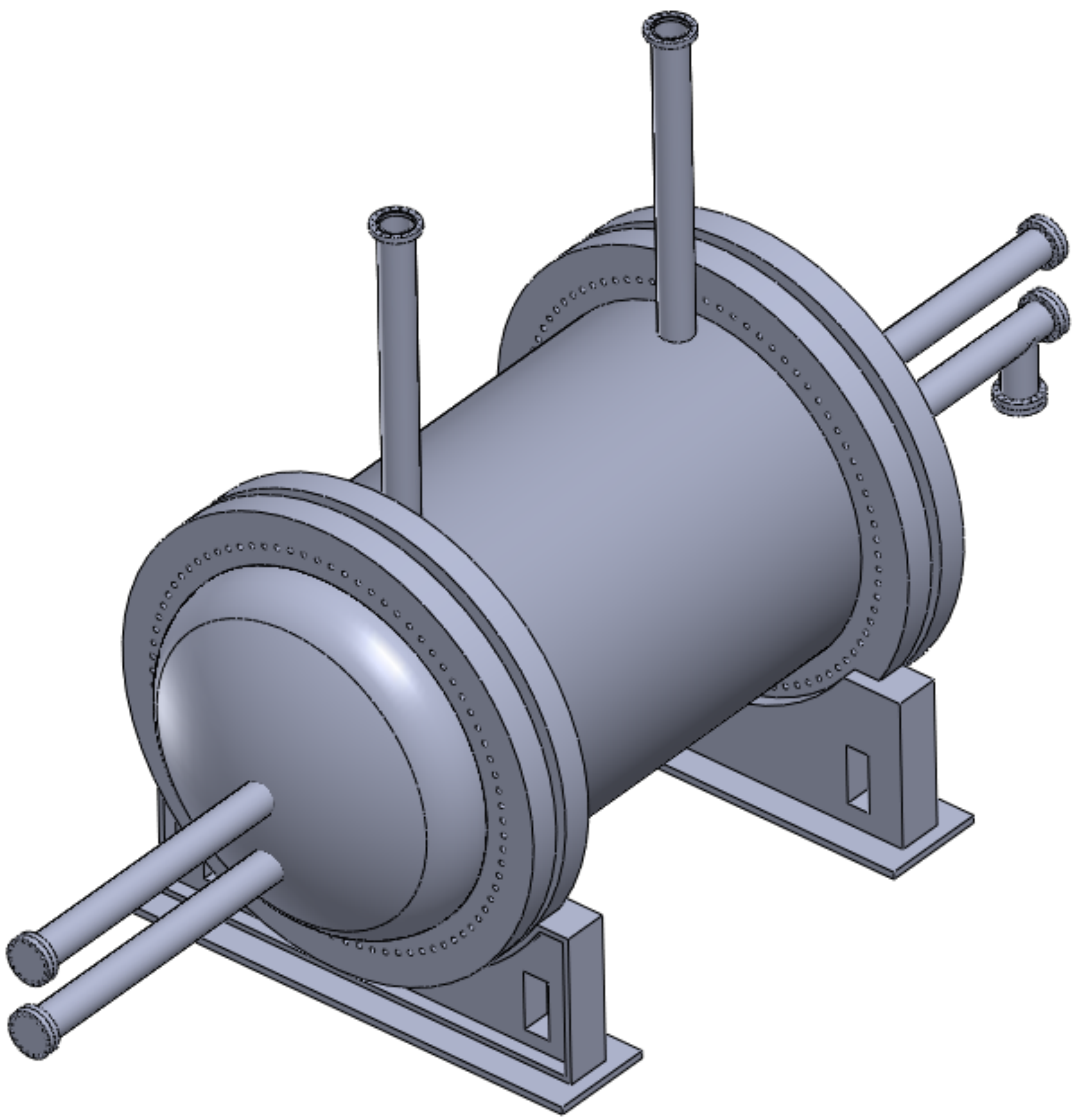
scalability (mass, cost)

feasibility & t0

160-1000 kg

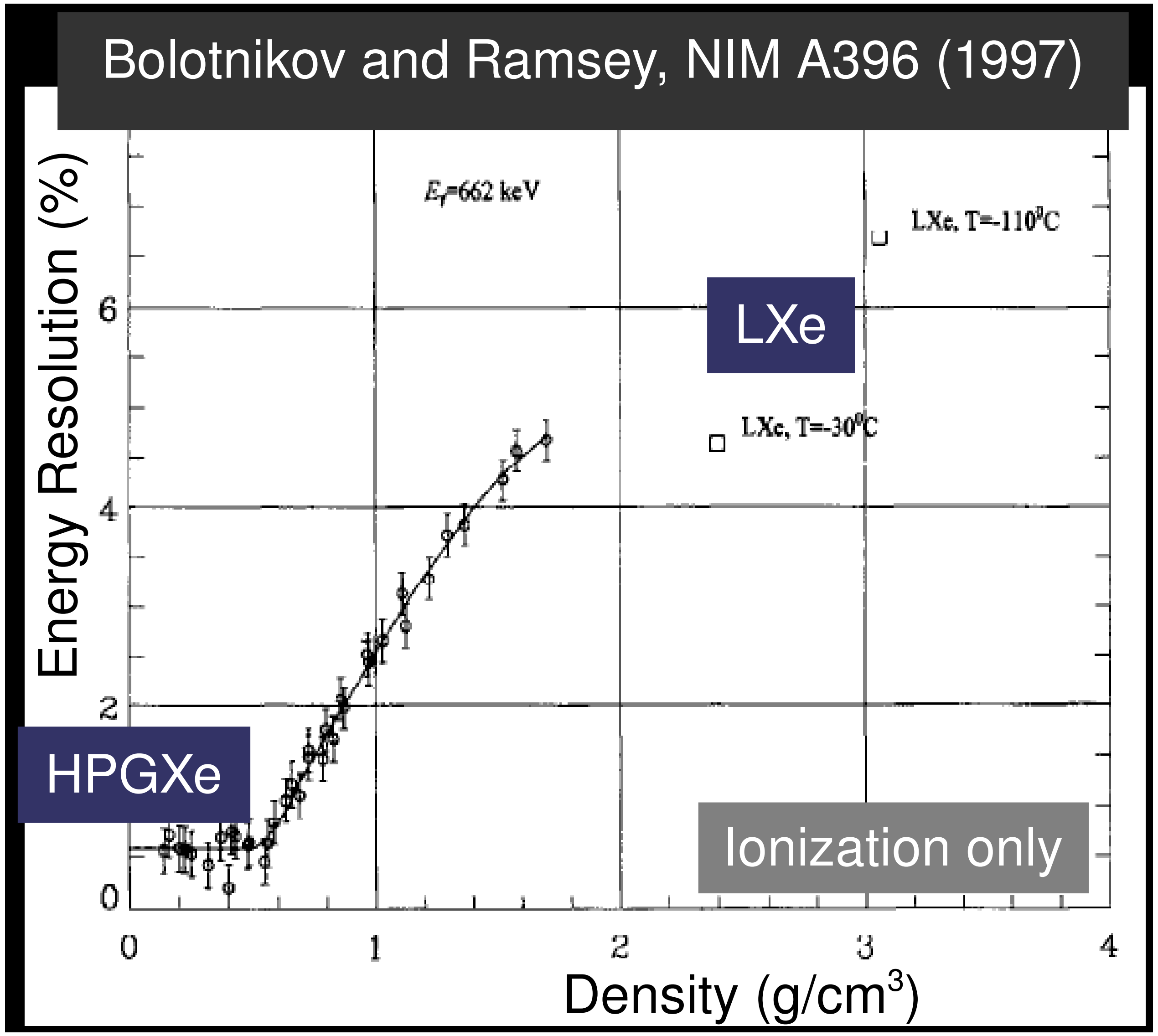
Running!

NEXT



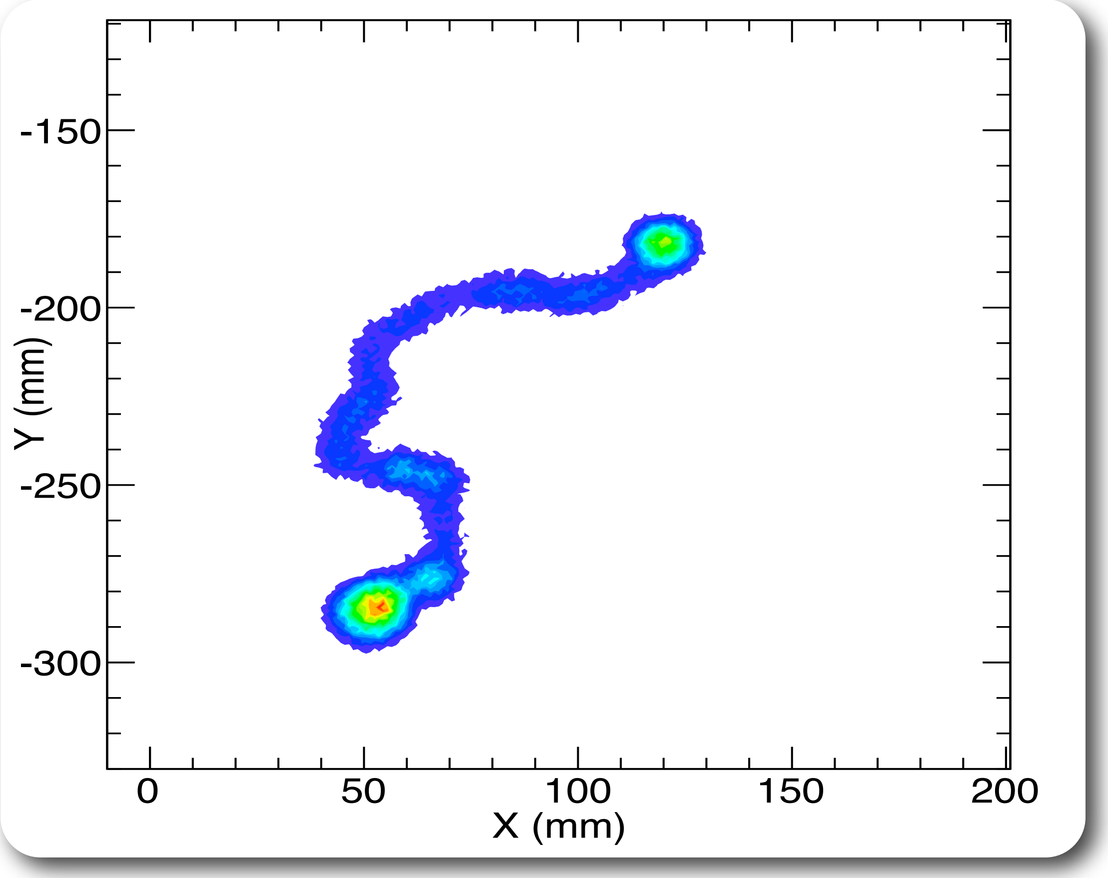
- 100 kg of pressurized Xenon (enrichment at >90%), P=15 bar
- Moderate efficiency (~30%)
- Good resolution (better than 1% at Qbb).
- Transparent to background
- b~10^{-4} ckky (purely MC calculation)

Energy resolution



- Intrinsic energy resolution in gas phase ~ 0.5%
- Liquid: much worse resolution due to anomalous Fano Factor.

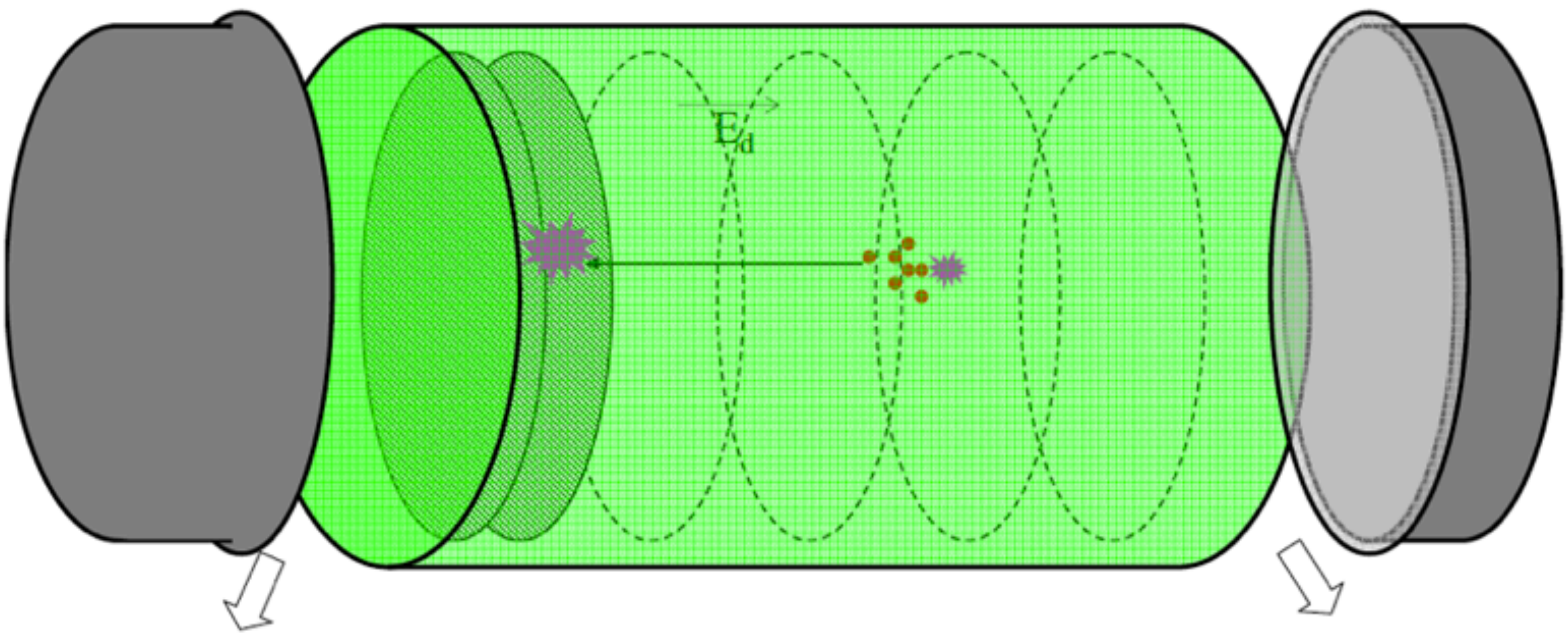
Extra handles

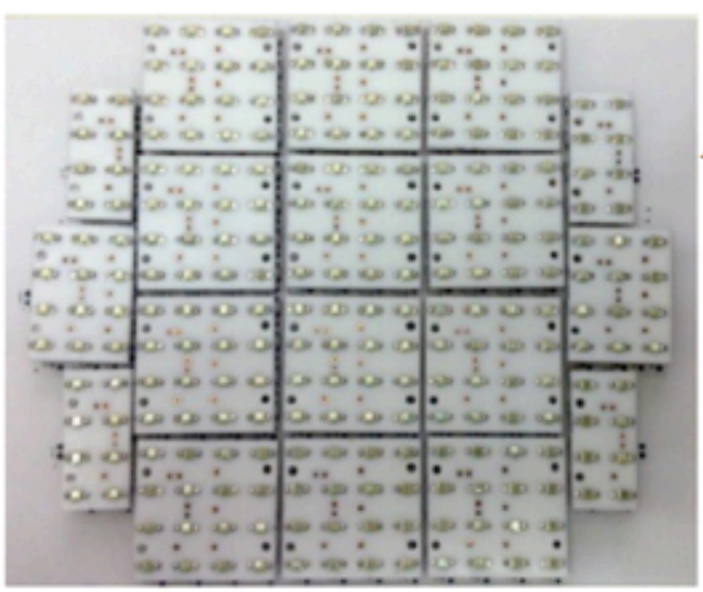


- Topological signature (tracking of the two electrons) available in NEXT!

Picture of a bb0nu experiment

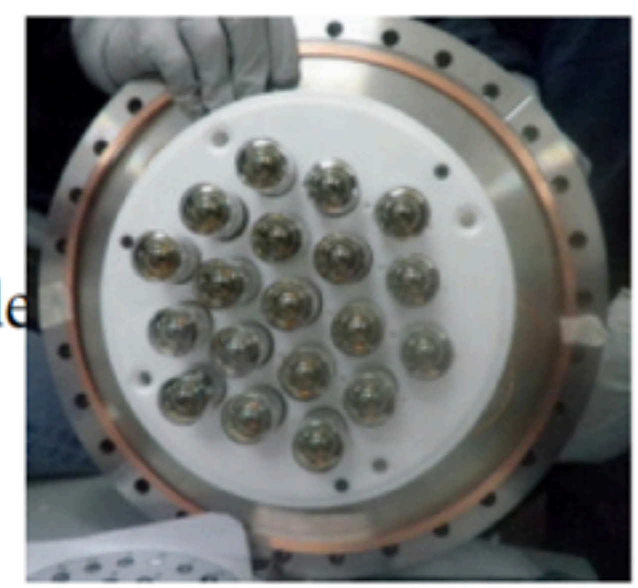
Electroluminescence & TPC



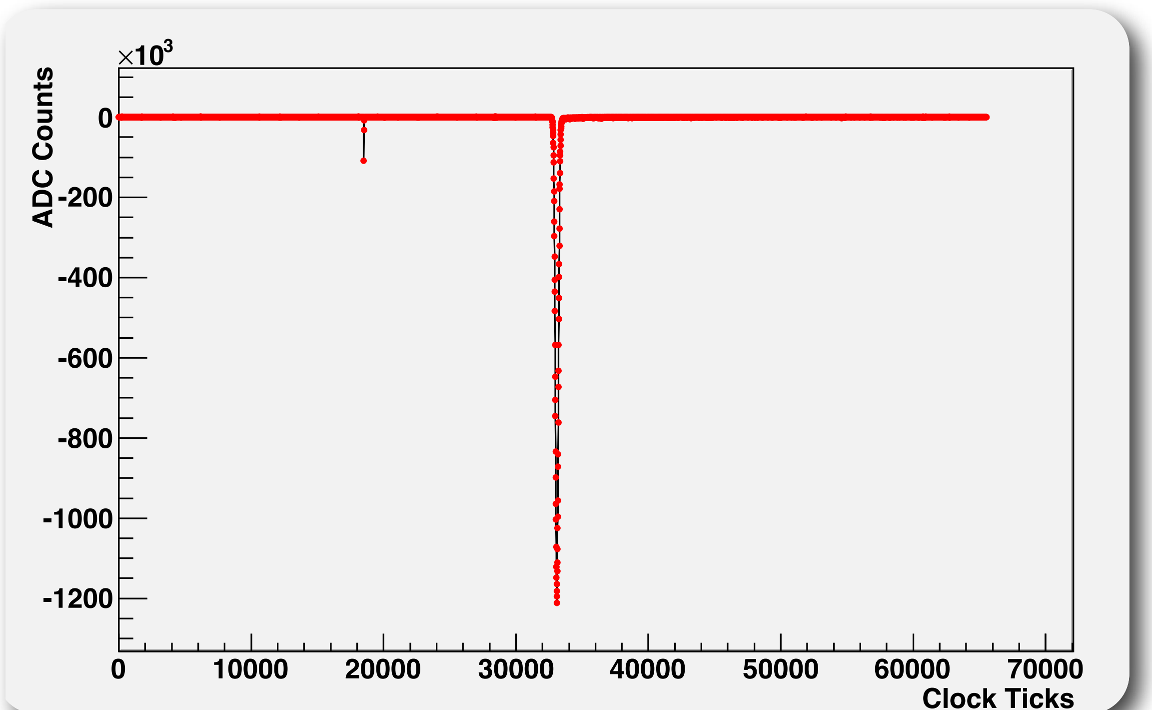


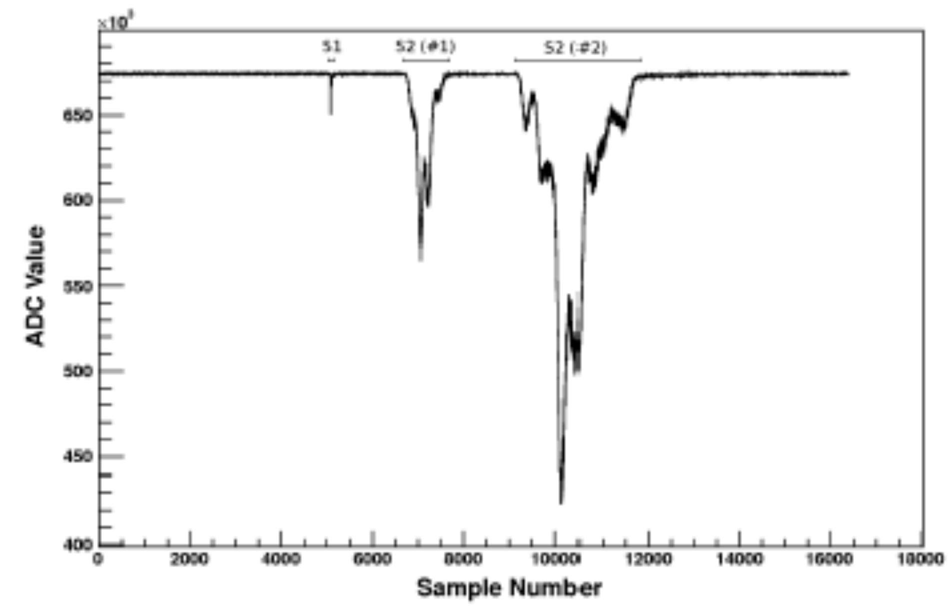
Anode → tracking

Energy & t0 ← Cathode



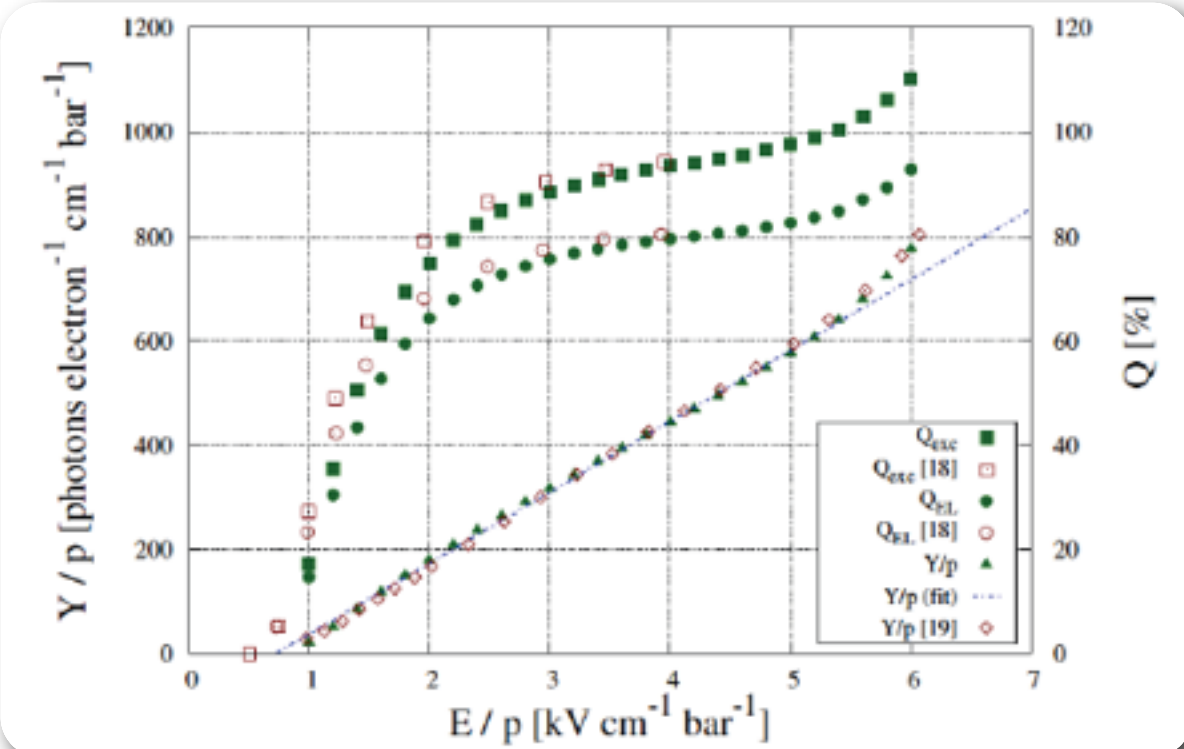
Signals in a light Xenon TPC

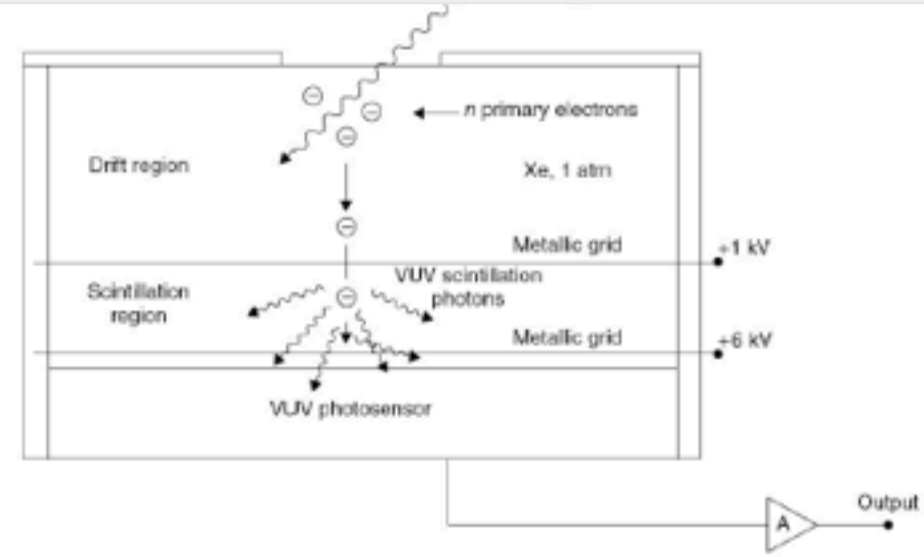


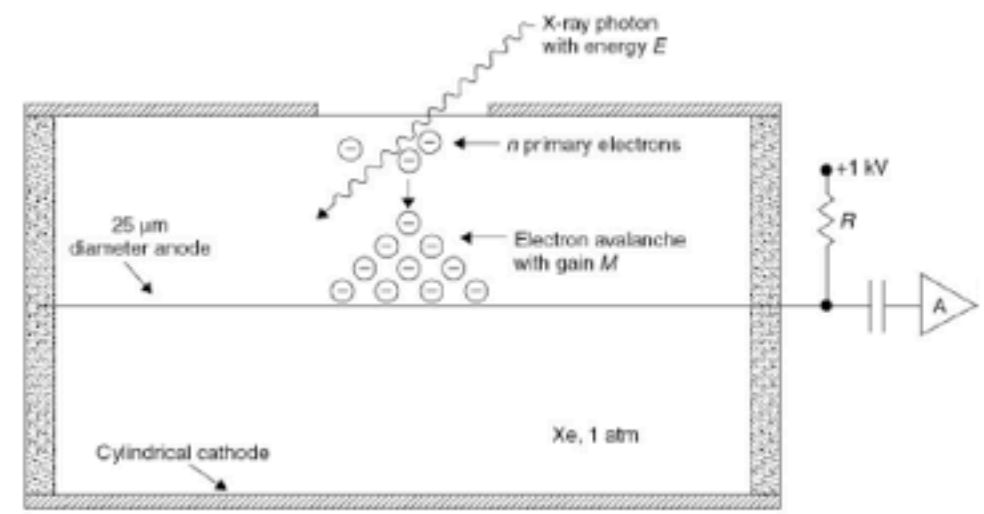


- Xe scintillates as response to charged particles. A fast response (S1) that can be used to define z position of the event.
- The ionization charge drifts to the anode. There charge is transformed in light when it is accelerated through an EL mesh (electroluminescence). A second, large signal (S2) appears.

Electroluminescence

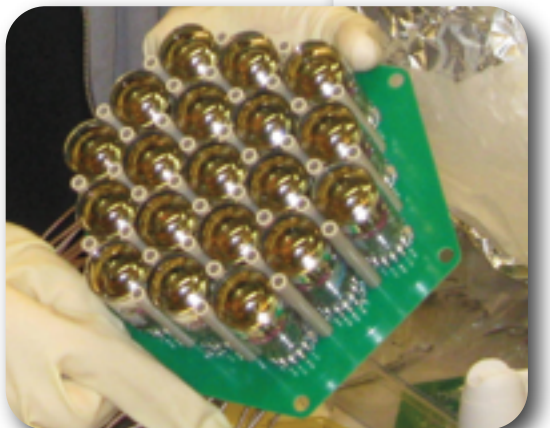


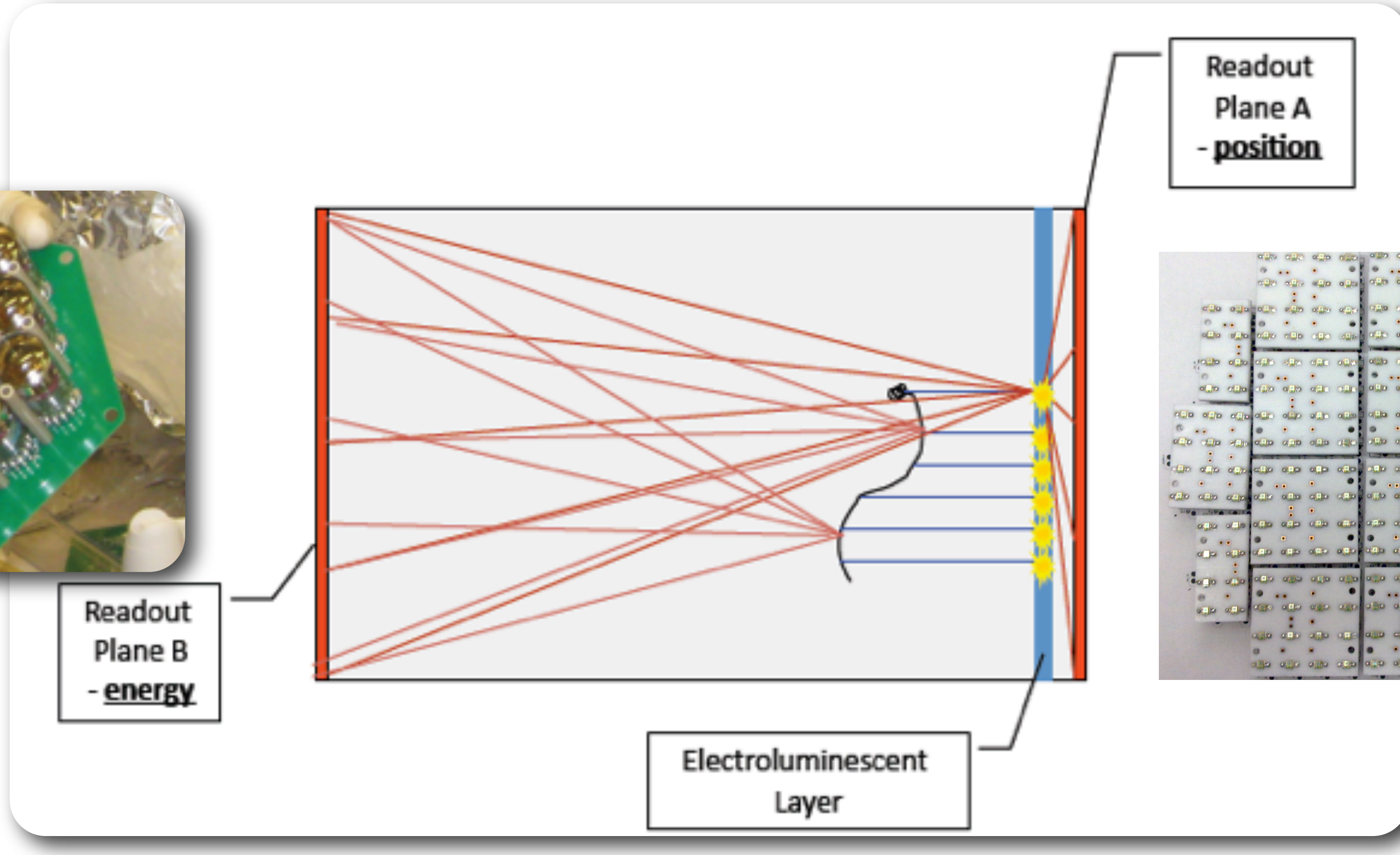


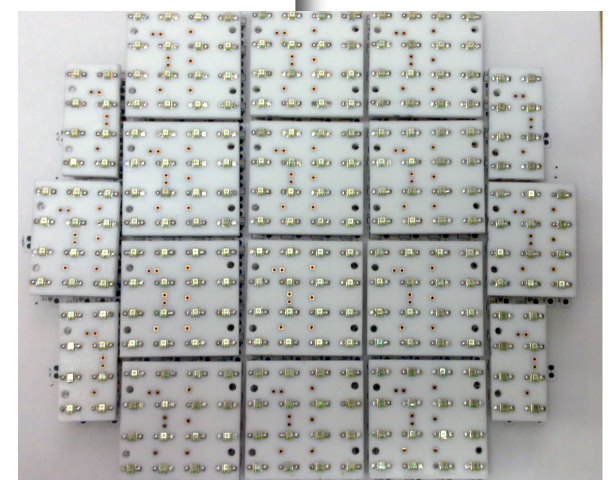


- At 15 bar with 0.5 cm spacing and E/P~3.5 kV/cm/bar
- G~3000 photons/electrons
- Linear gain. Resolution limited, a priory only by Fano's Factor.

SOFT





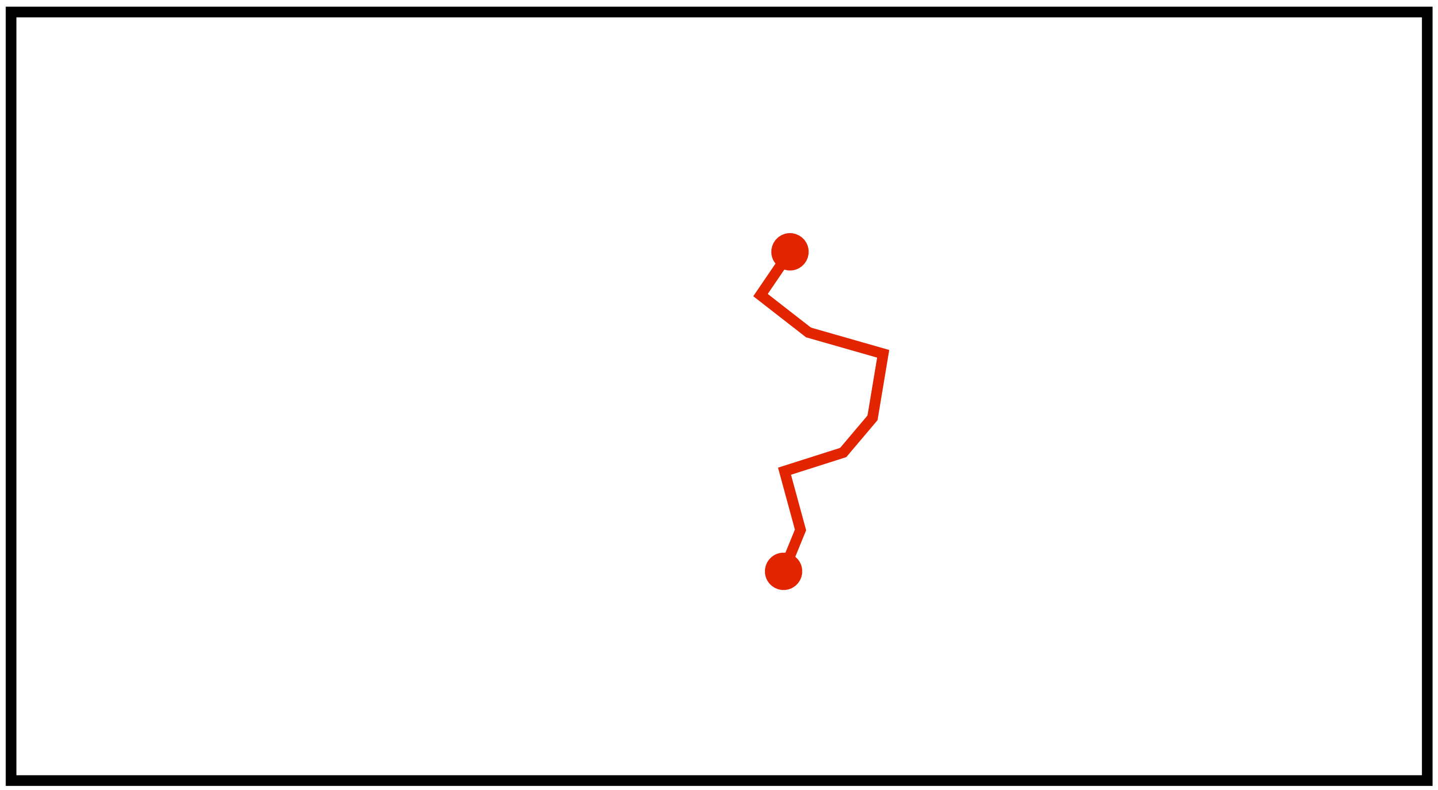


- Anode: sensors optimized for tracking (e.g, SiPMs)
- Cathode: sensors optimized for energy measurement (PMTs).
- Energy sensors also measure S1 (t0)

Detection process

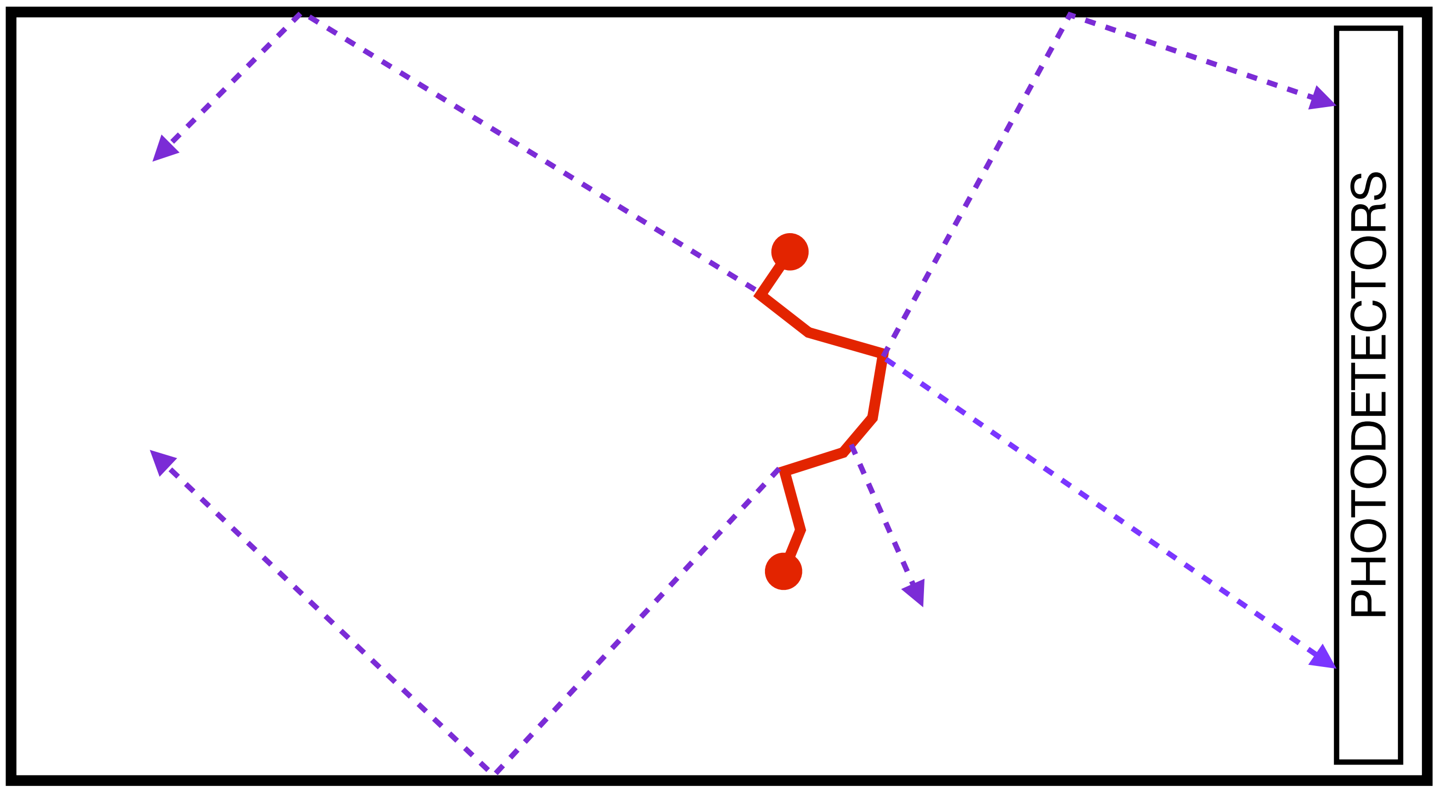
- TPC filled with highly enriched (>90%) ^{136}Xe gas at 10 bar pressure.
- Chamber walls lined with material highly reflective to UV light.
- Baseline detector with ~100 kg fiducial mass (2 m^3): NEXT-100.

Detection process



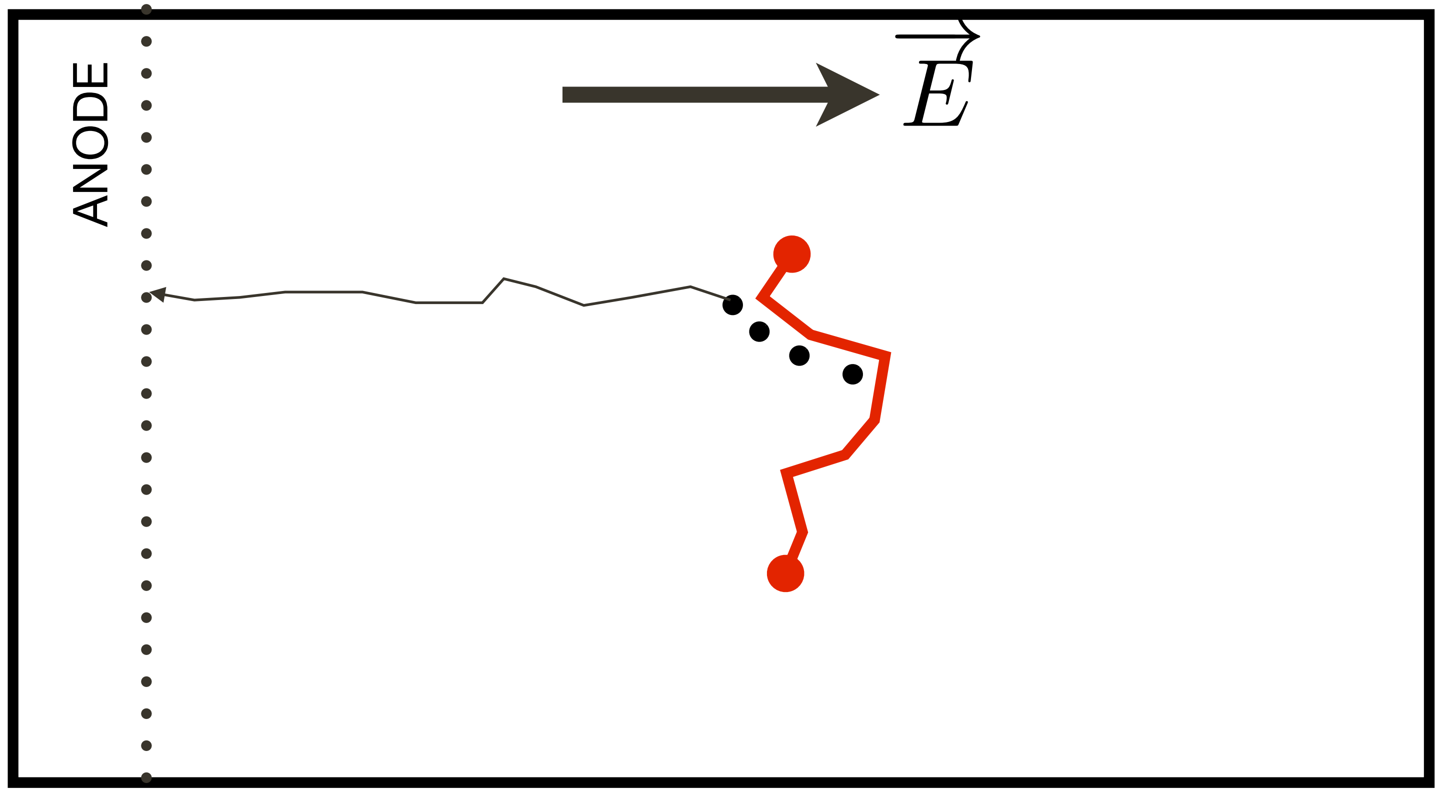
- A 136Xe isotope decays emitting the two electrons.
- They propagate through the HPXe ionizing and exciting its atoms.

Detection process



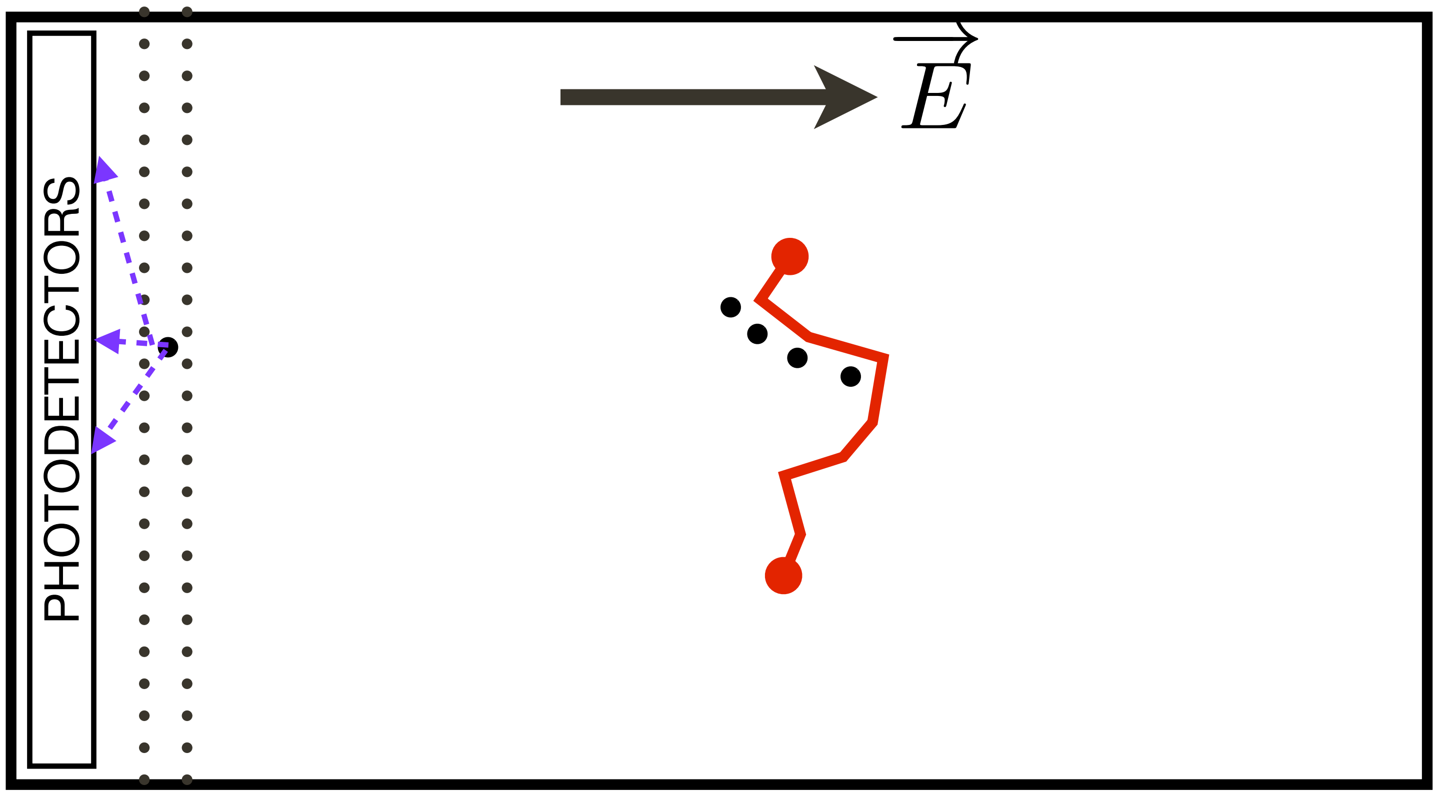
- Prompt primary scintillation light emission in VUV (~175 nm). About 100 eV needed to create a primary scintillation photon.
- Detect faint signal via sensitive photo-detectors (PMTs) behind transparent cathode.
- Determine t_0 and therefore event position along drift.

Detection process



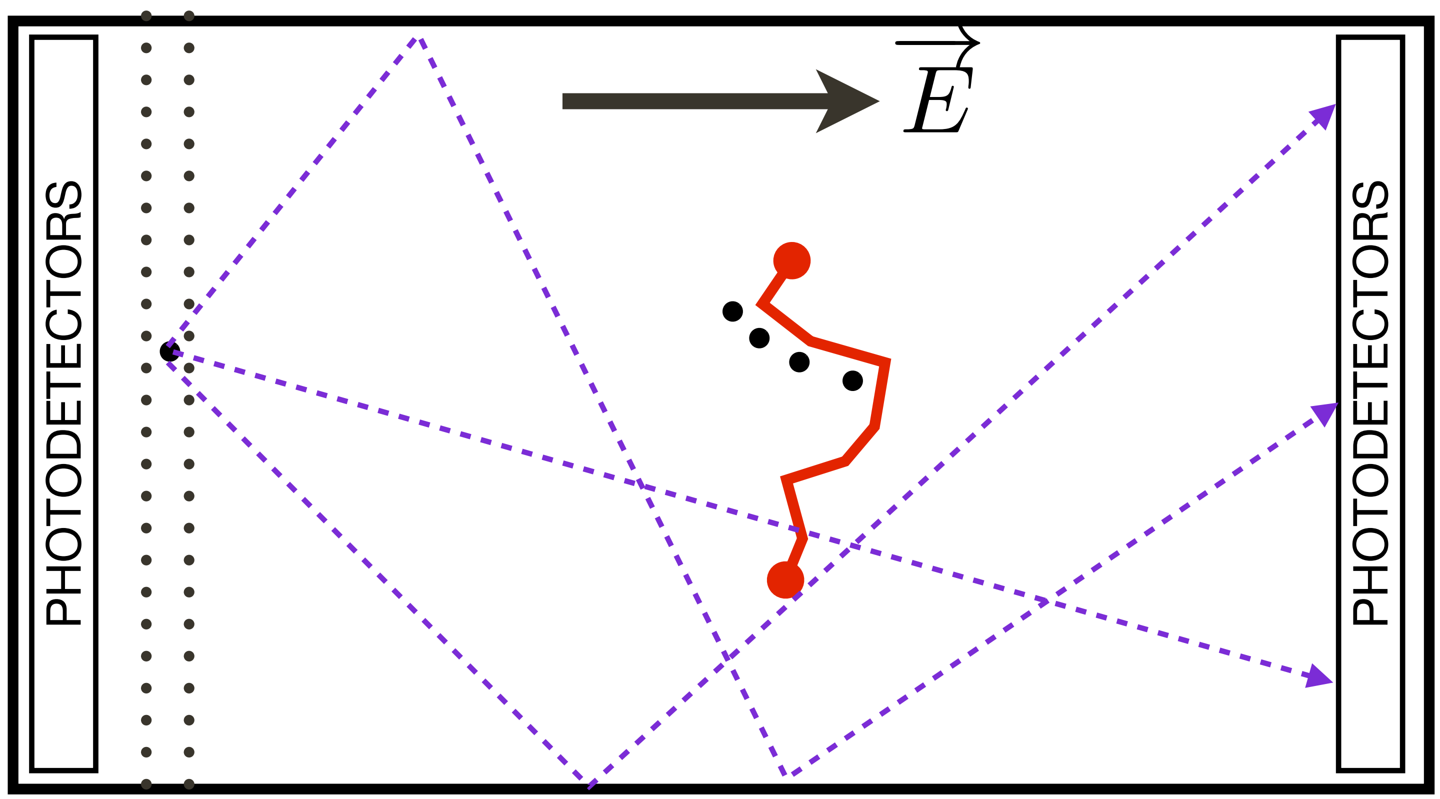
- Create ionization charge in Xe: ~25 eV to create one electron-ion pair.
- Electrons drift toward anode with velocity ~1 mm/us in a ~1kV/cm electric drift.
- At 10 bar pressure, non-negligible diffusion: 9 mm/√m transverse, 4 mm/√m longitudinal).

Detection process



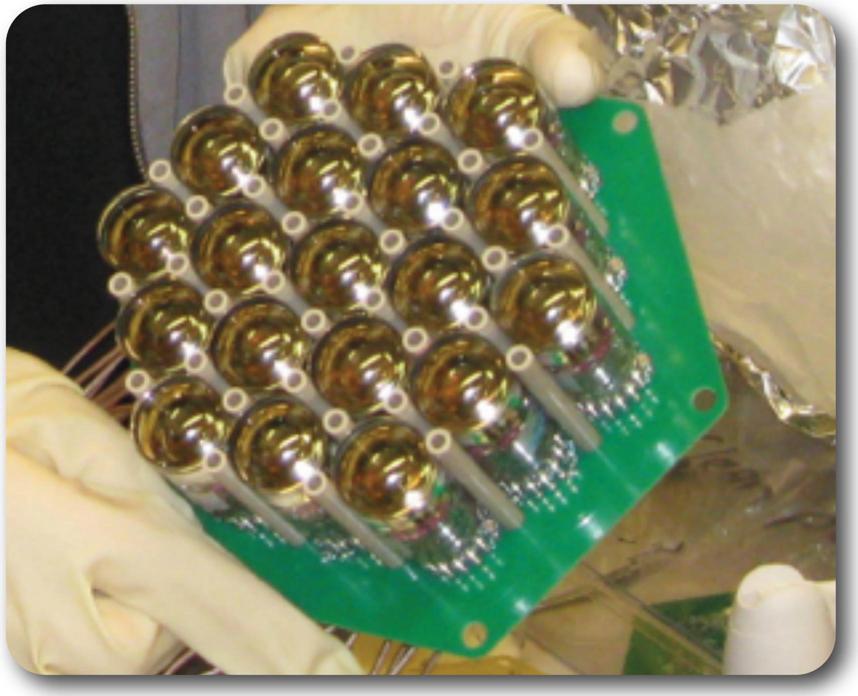
- Additional grid in front of anode creates ~0.5 mm thick region of more intense field: E/p ~4 kV/cm/bar.
- Secondary scintillation light (electroluminescence) created in between grids by atomic de-excitation, with very linear gain of order 10^3 and over a ~2us interval.
- Finely segmented photo-detector plane (MPPCs) just behind anode performs “tracking”.

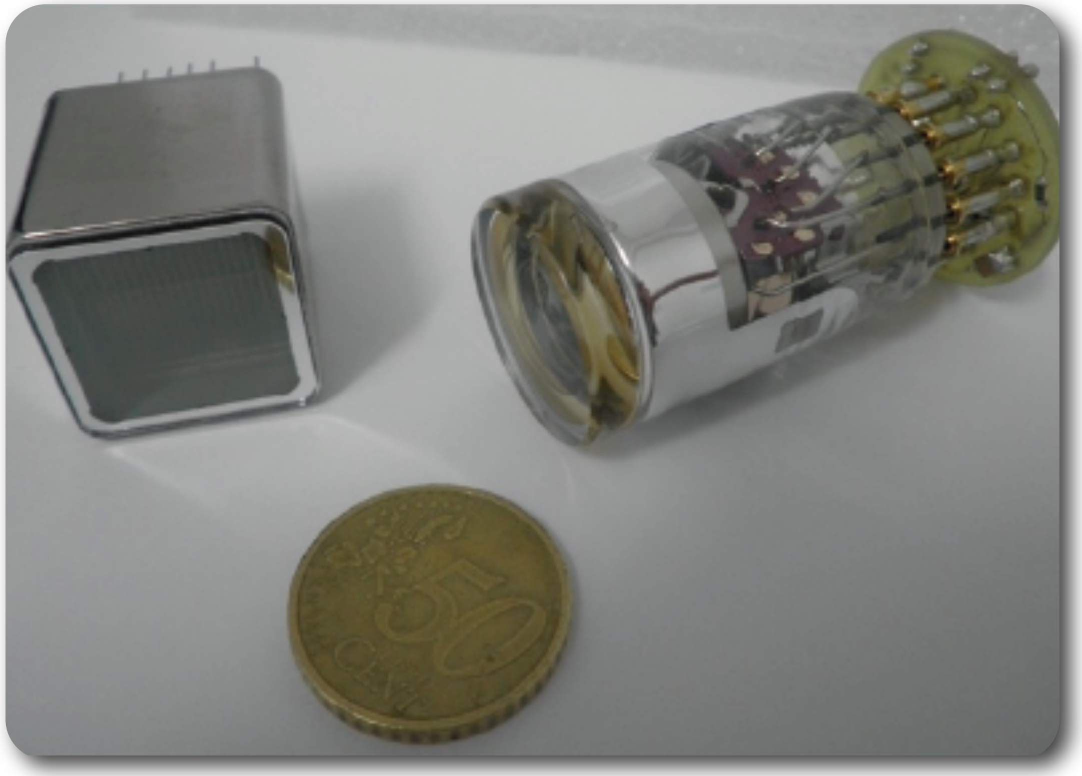
Detection process



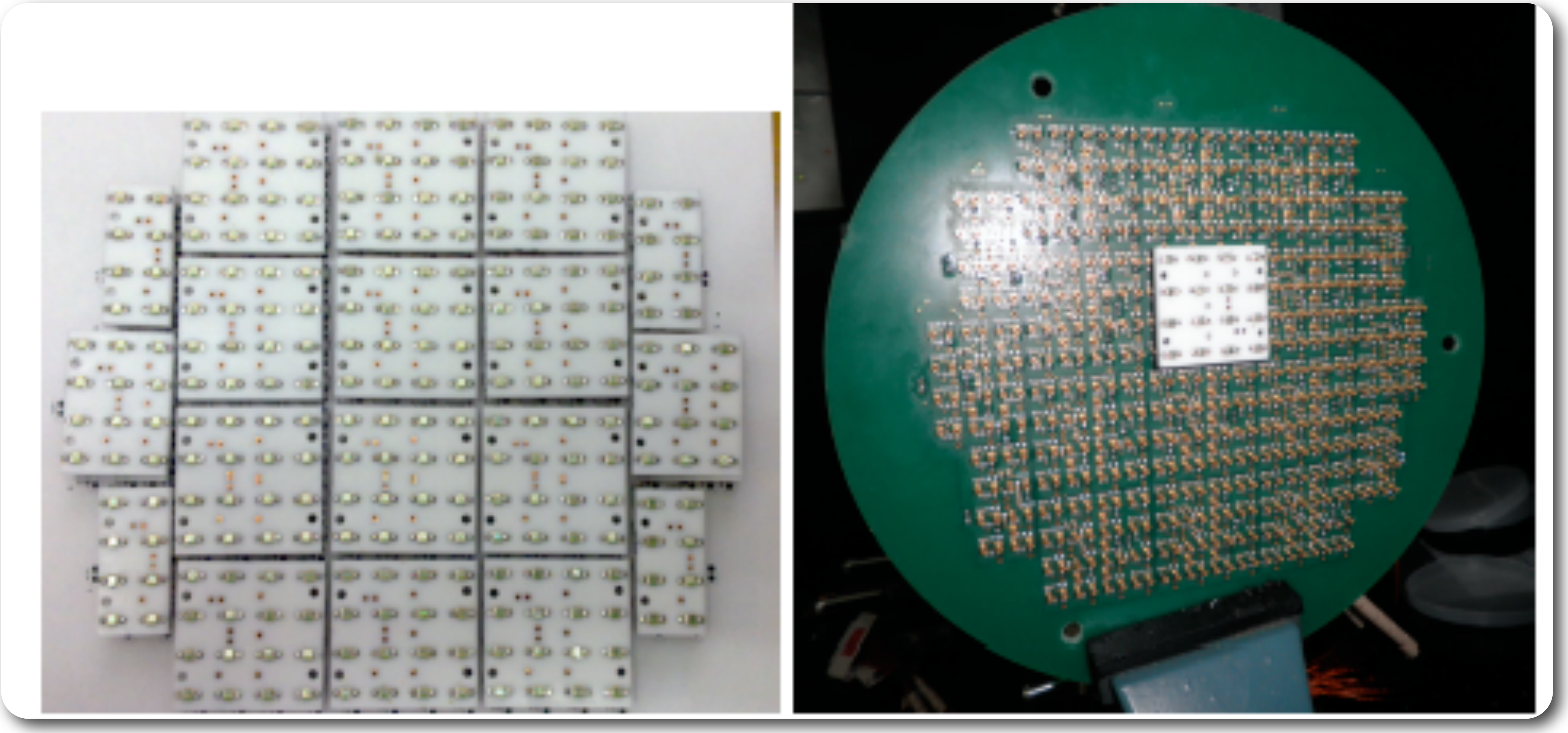
- Electroluminescence, emitted isotropically, also reaches cathode.
- Same array of photo-detectors used for t_0 measurement is also used for accurate calorimetry.

Energy plane



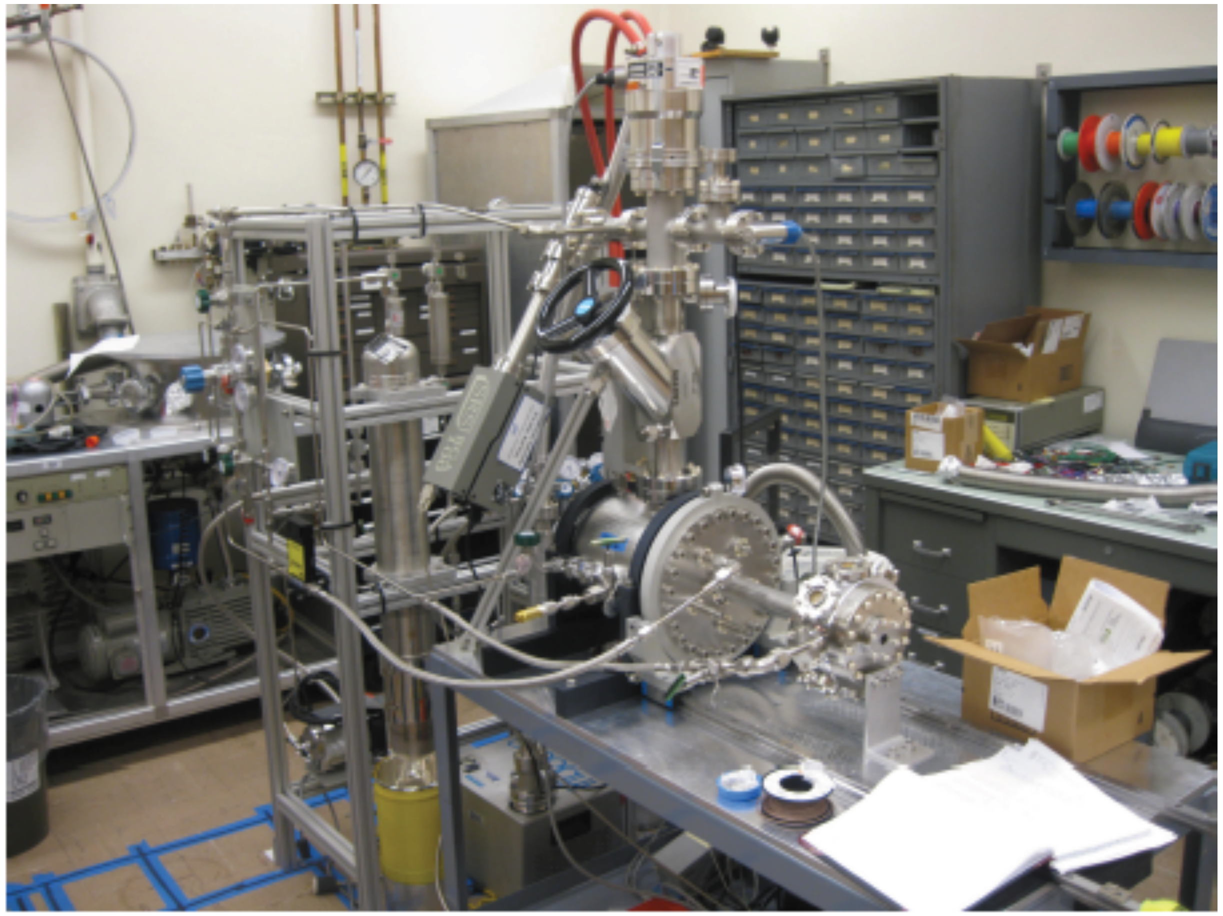


Tracking plane

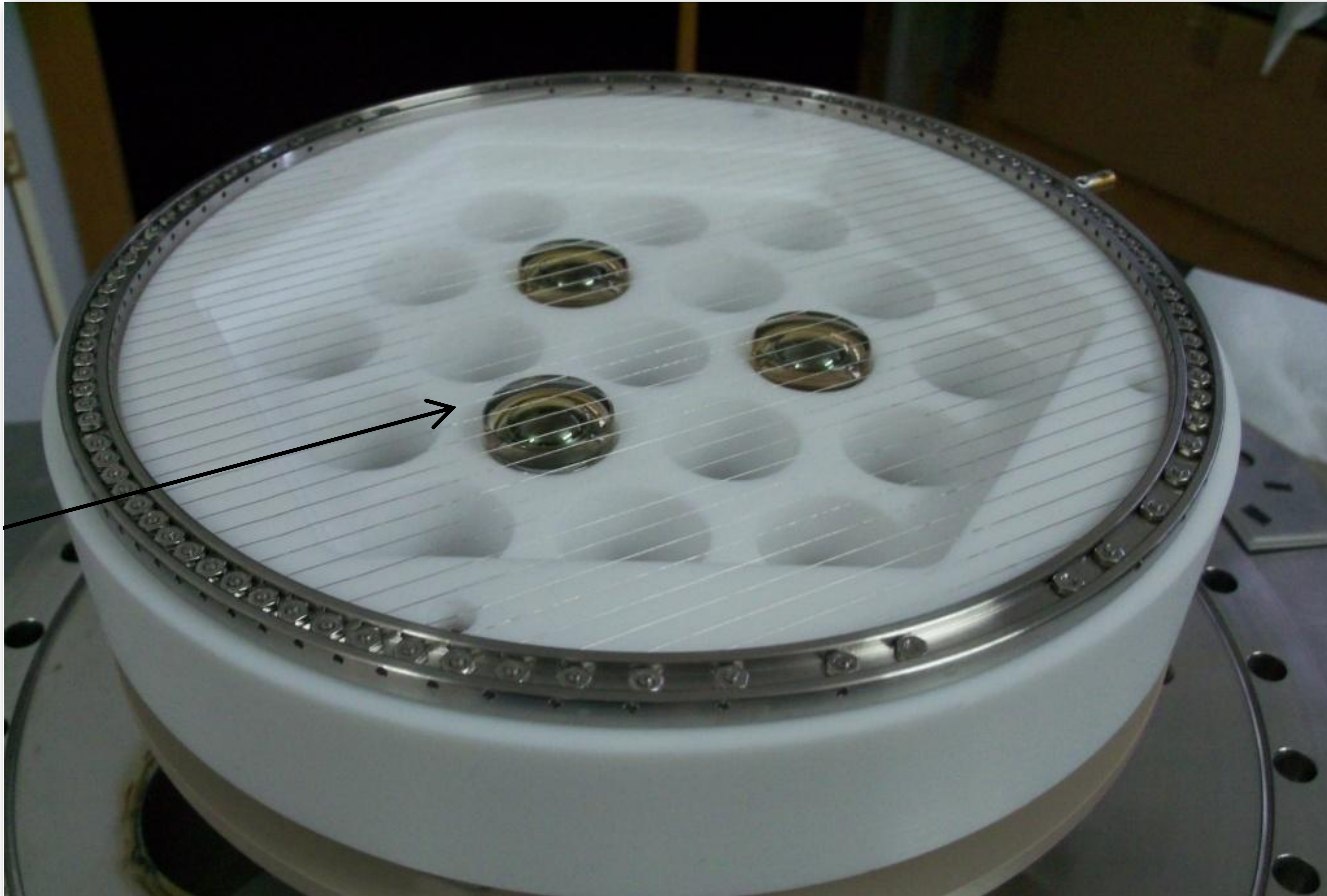


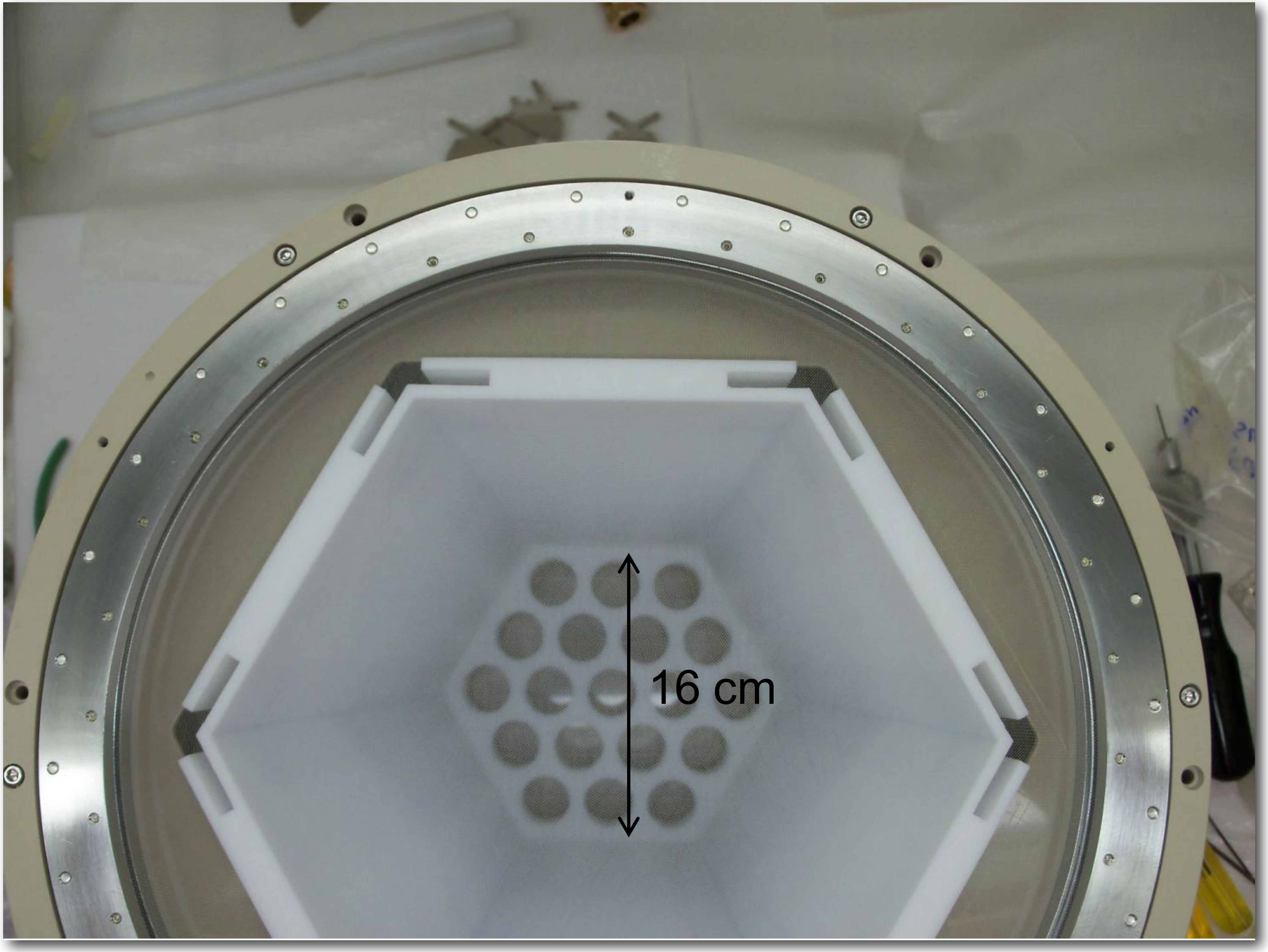
NEXT-1 SiPM tracking plane-->NEXT100 is a larger version, same concept

Large scale prototypes

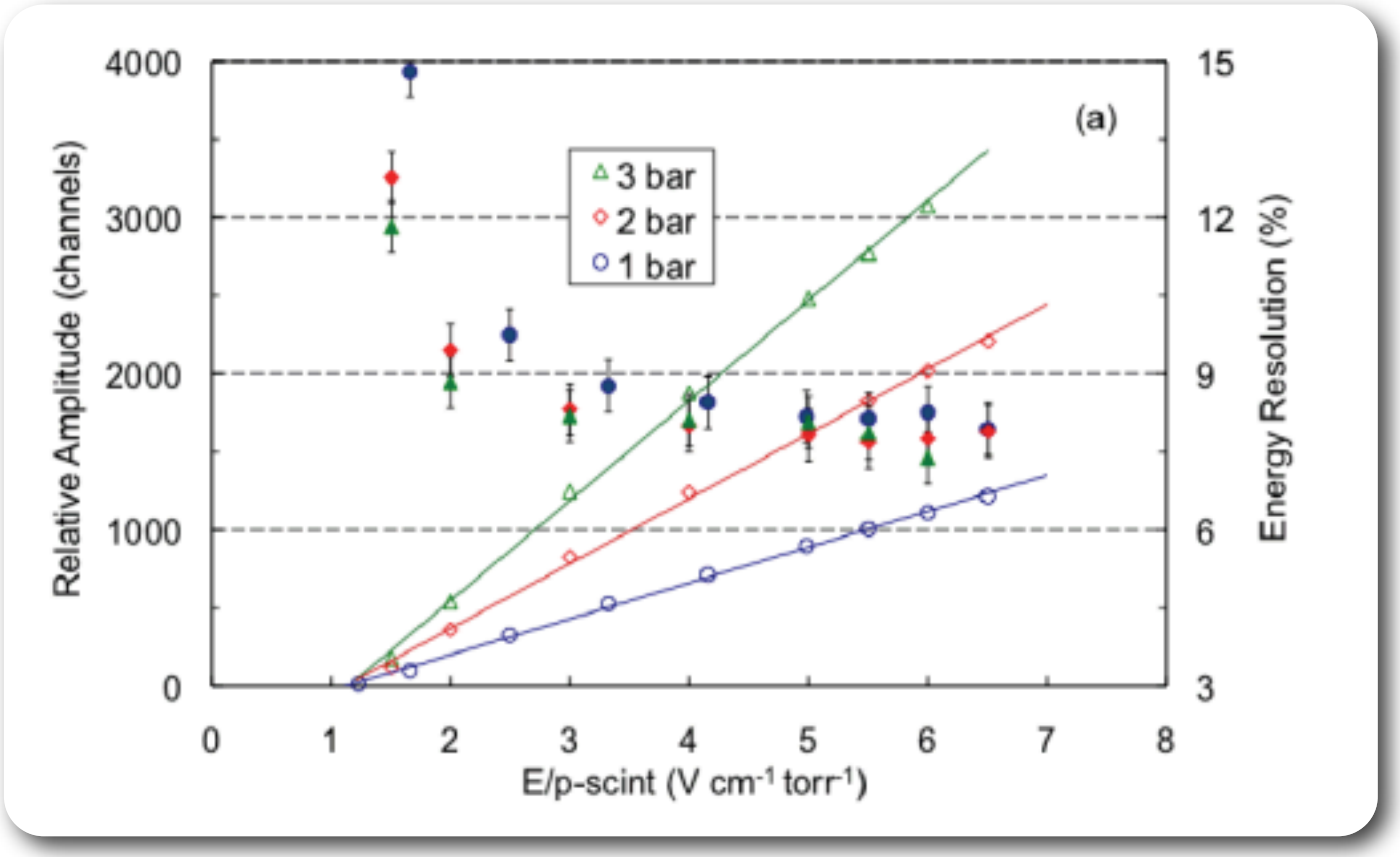


- Prototypes at LBNL & IFIC




16 cm

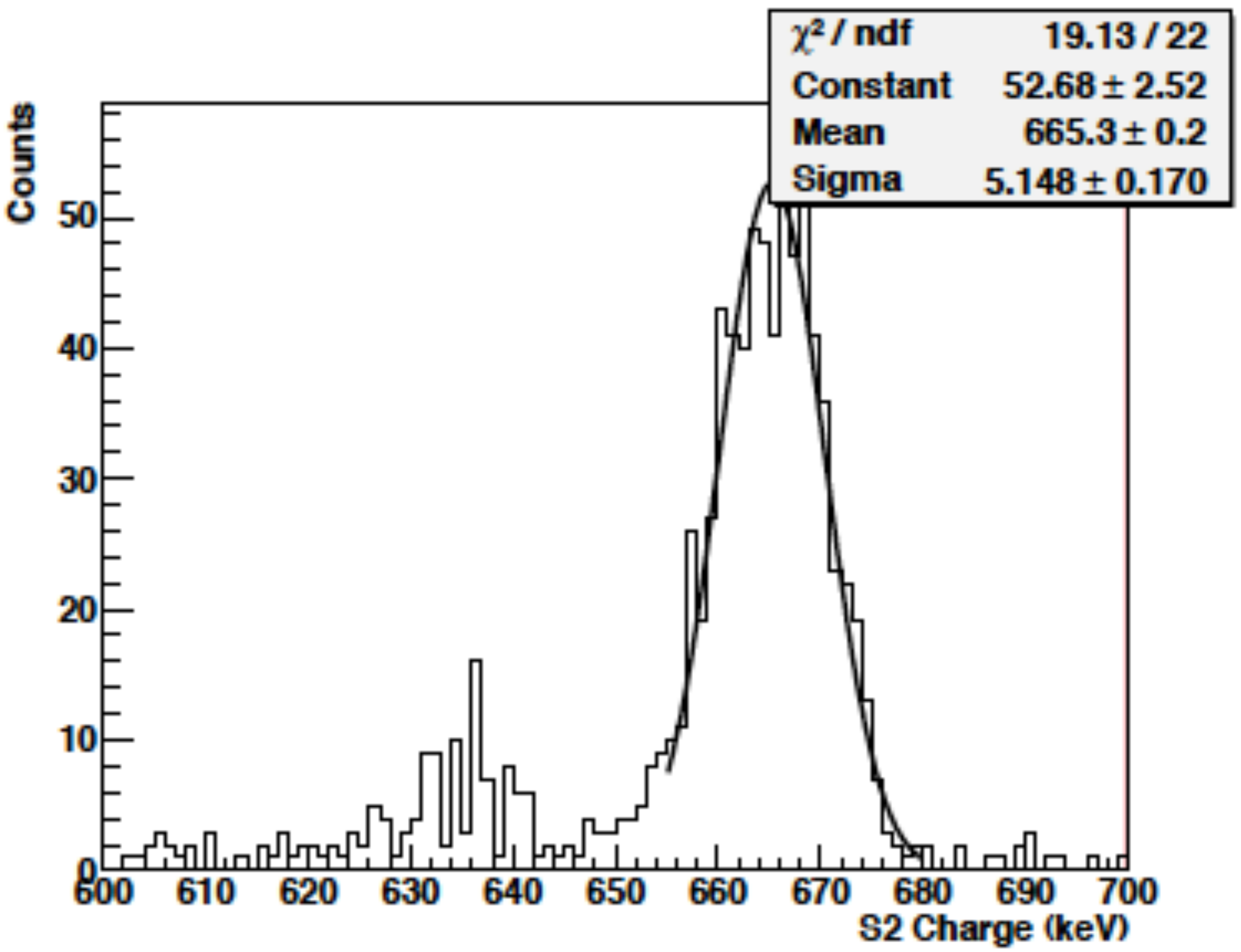
Energy resolution



With small setups, intrinsic resolution using EL close to fano factor
NEXT has measured 0.4 % (Qbb) resolution

Measured by NEXT!

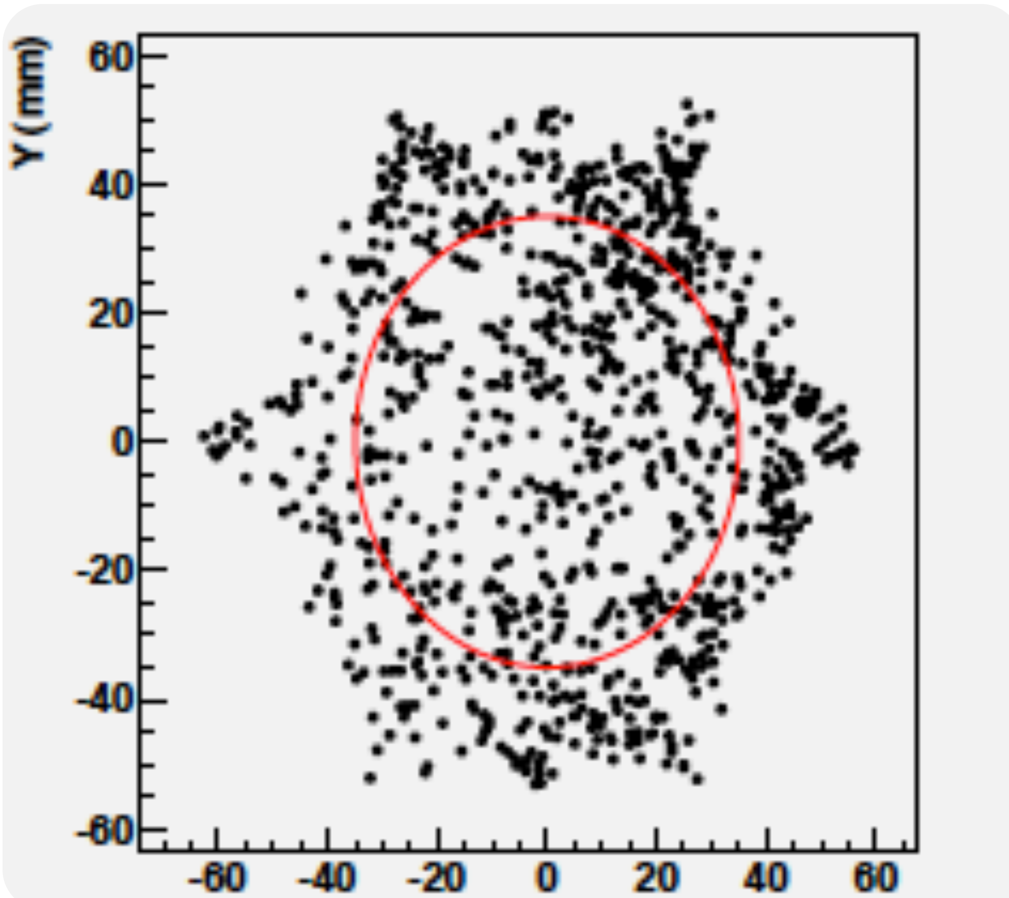
Energy resolution

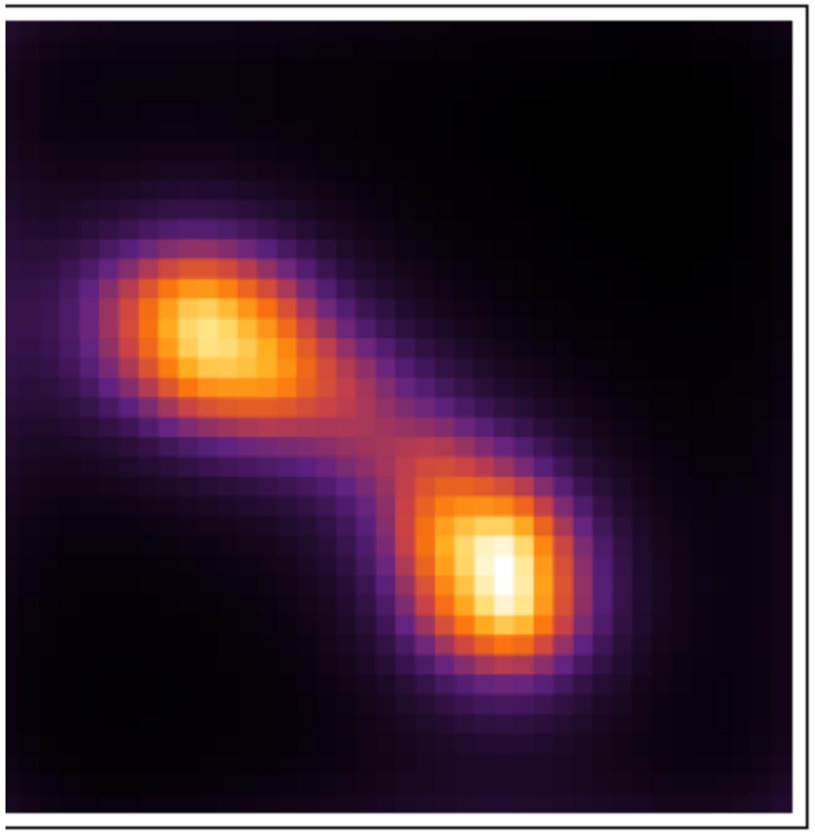


- Energy resolution measured with NEXT-1 (LBNL prototype) is 1.8% FWHM
- This extrapolates to better than 1% (NEXT target value)
- We hope to improve this number in the next year or so to intrinsic resolution.

Measured by NEXT!

Tracking



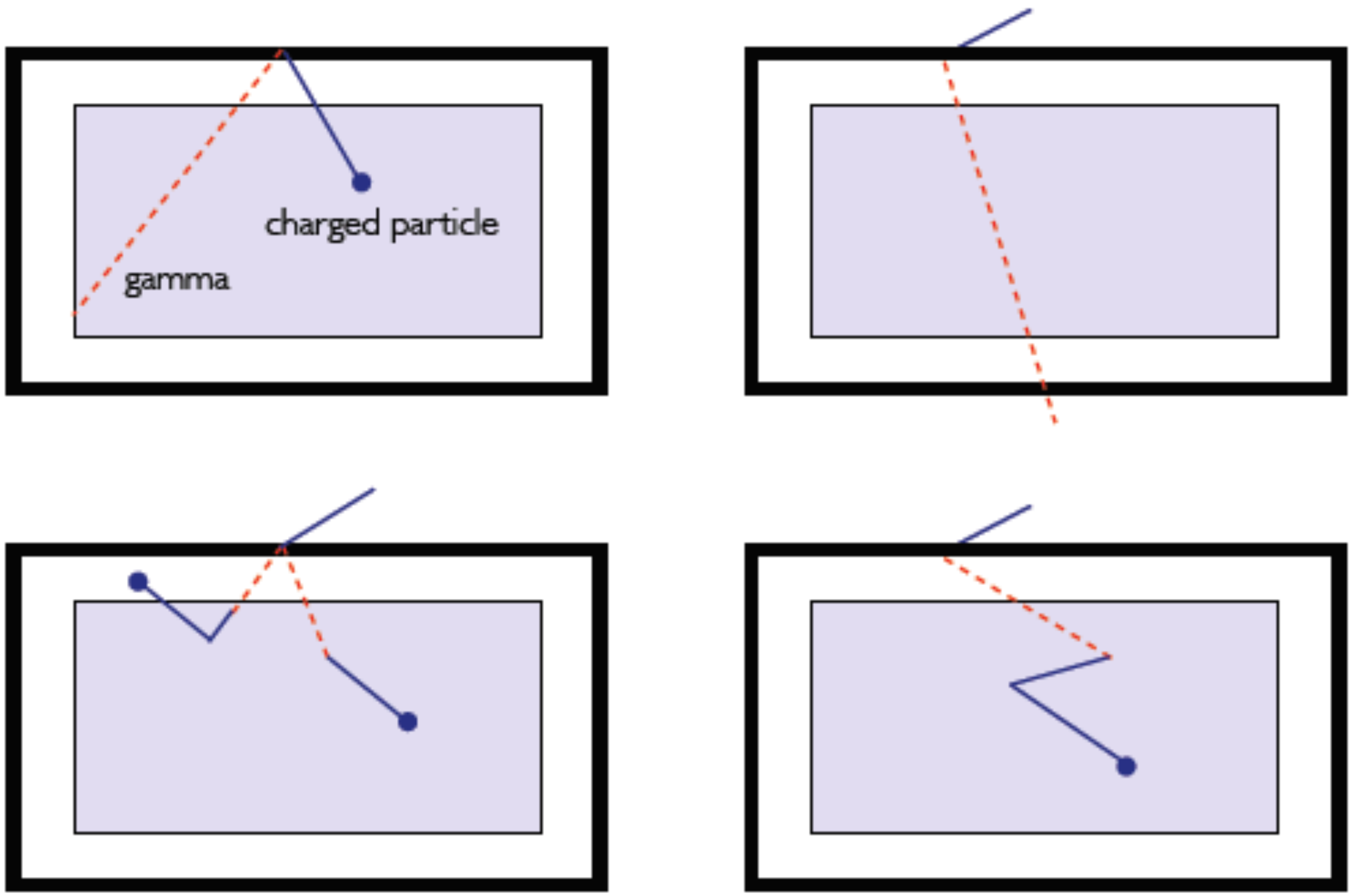


- alpha-graphy of NEXT1-IFIC field cage

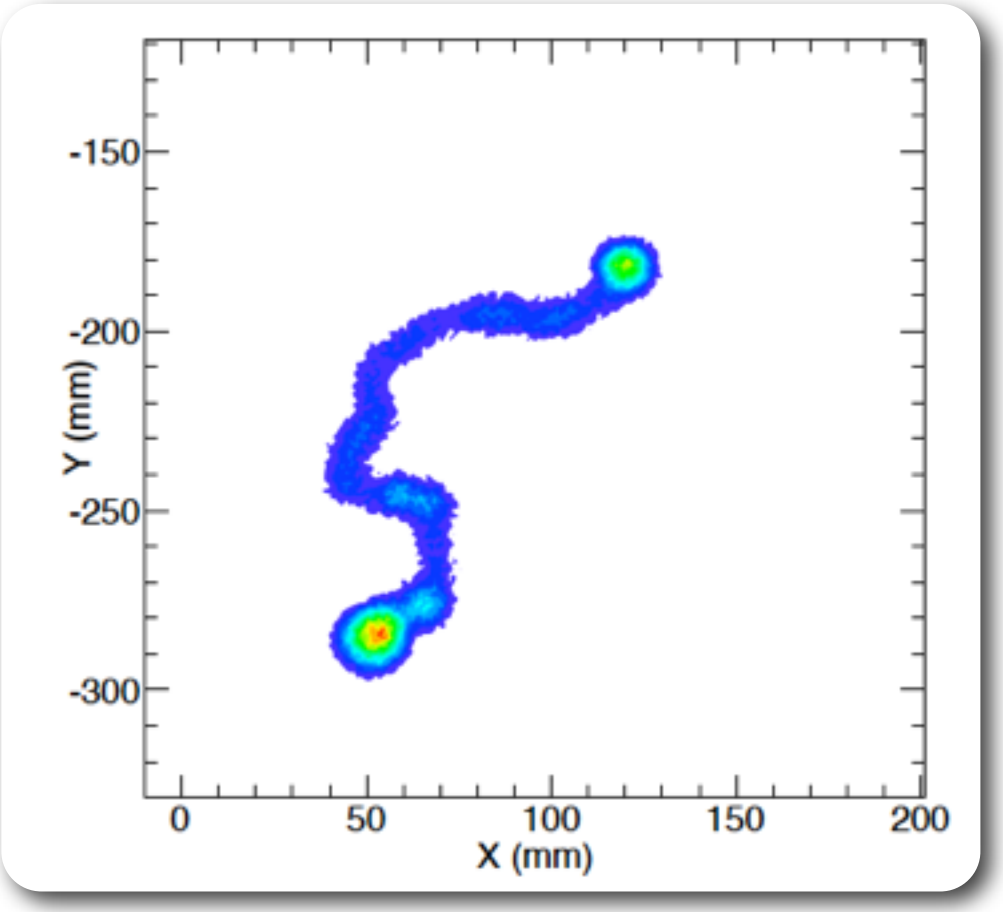
Measured by NEXT!

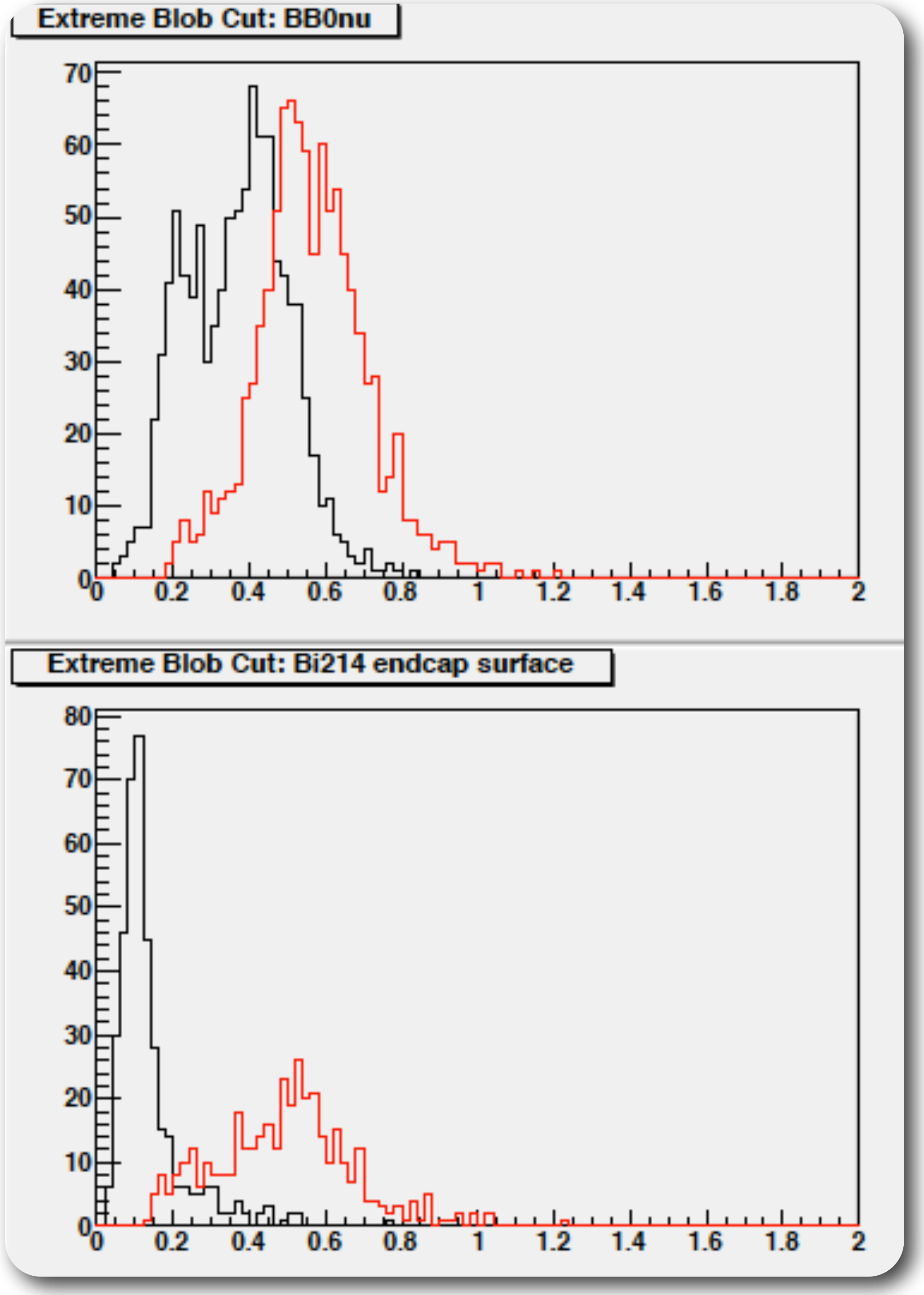
- MC reconstruction of a bb0nu event in NEXT1 (notice the two ionization balls)

Backgrounds



Extreme blob cut





NEXT cube

~<10^{-4} ckky

background

90-1000 kg

scalability (mass, cost)

feasibility & t0

starts in 2014