The NEXT experiment Status and prospects,

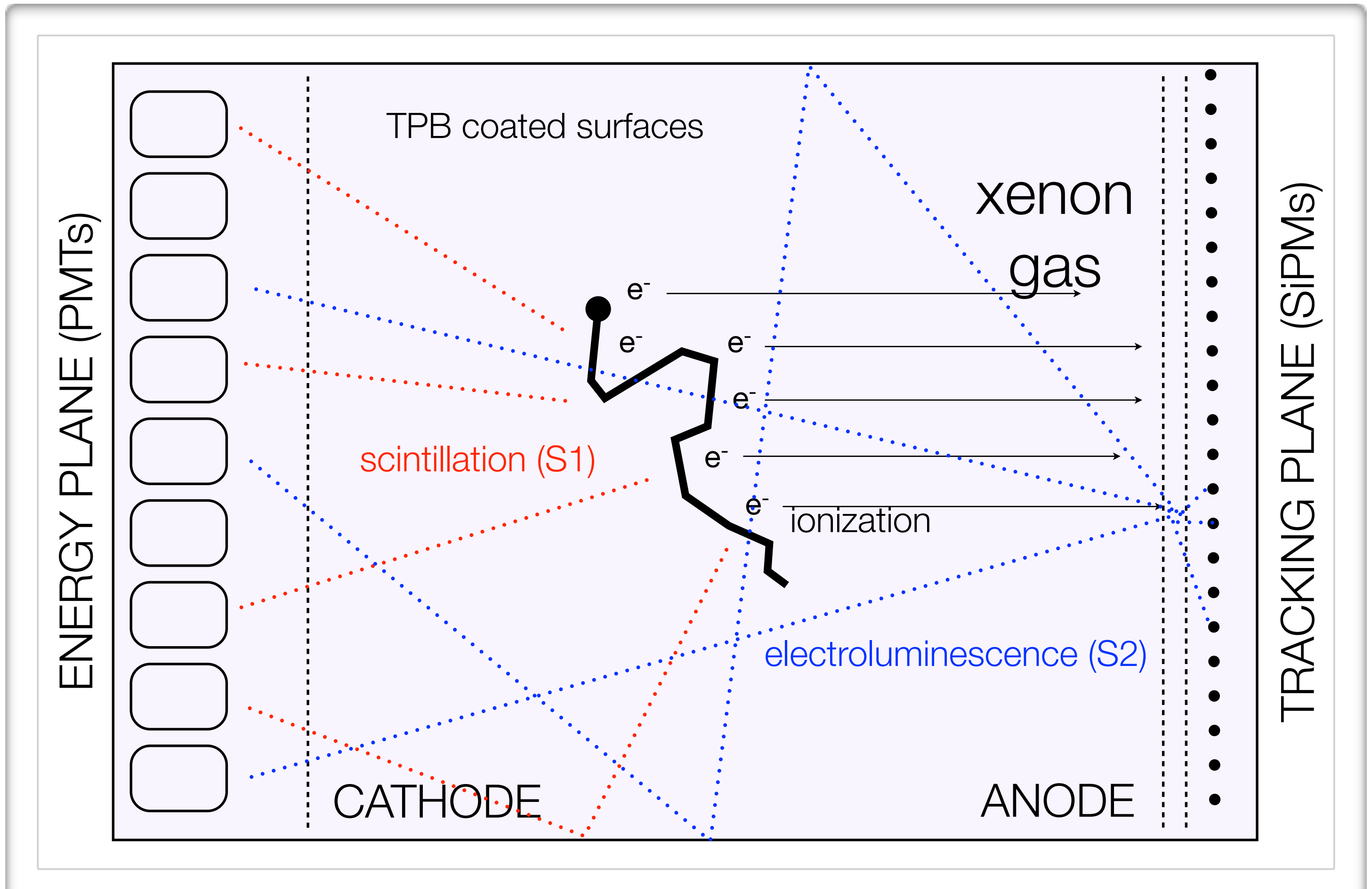
J.J. Gomez-Cadenas on behalf of the NEXT collaboration

October, 2015

NEXT: The collaboration

IFIC,UPV,US,UdG, UAM, UZ —Spain
UC, UA —Portugal
UTA, UT-A&M, Iowa S, LBNL, FNAL —USA

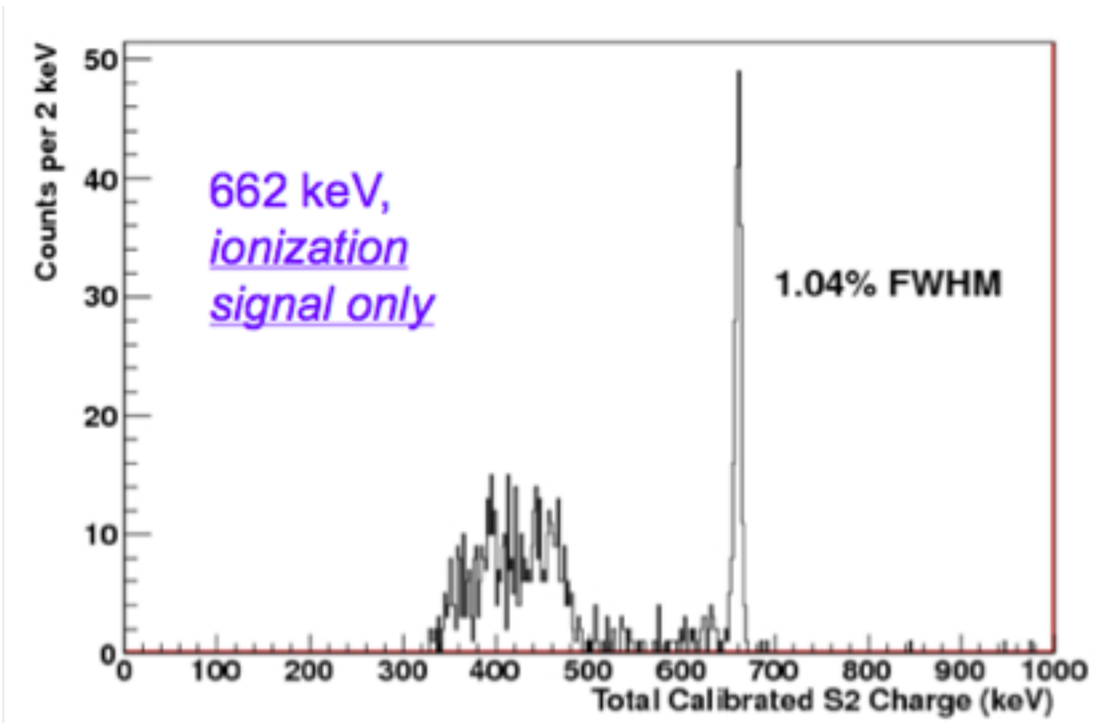
NEXT: A light TPC

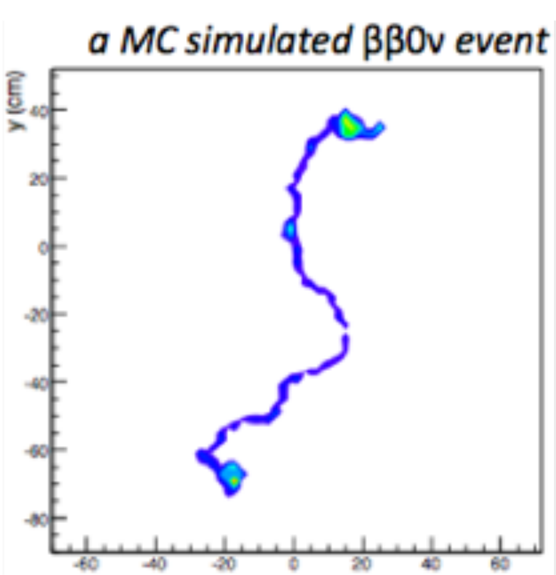


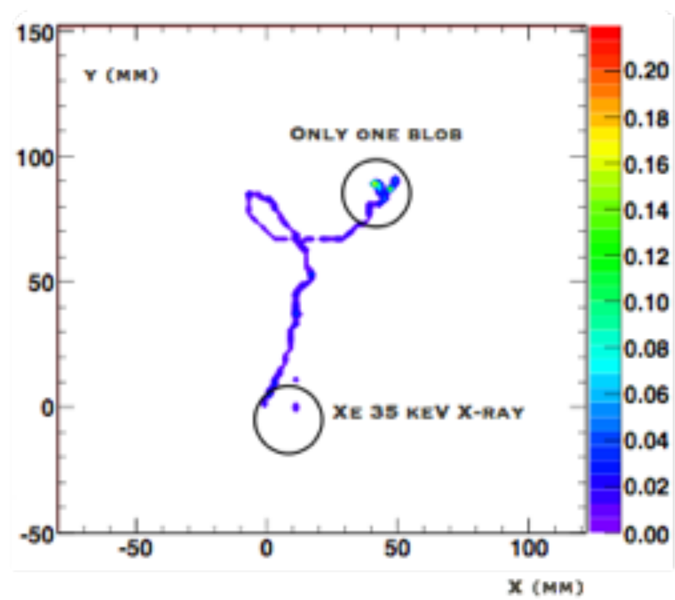
EL mode is essential to get lineal gain, therefore avoiding avalanche fluctuations and fully exploiting the excellent Fano factor in gas

- It is a High Pressure Xenon (HPXe) TPC operating in EL mode.
- It is filled with 100 kg of Xenon enriched at 90% in Xe-136 (in stock) at a pressure of 15 bar.
- 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 (MPPCs) (tracking plane).

NEXT: Salient features







- Excellent resolution (~1% FWHM measured at 662 keV by NEXT prototypes, extrapolates to 0.5 % FWHM at Qbb
- Topological signature (TPS), eg. the ability to distinguish between signal (“double electrons”) and background (“single electrons”).
- Target = detector. Fiducial region away from surfaces.
- TPC: scalable. Economy of scale (S/N increases linearly with L)
- Xenon: the cheapest isotope to enrich in the market (NEXT owns 100 kg of enriched xenon).

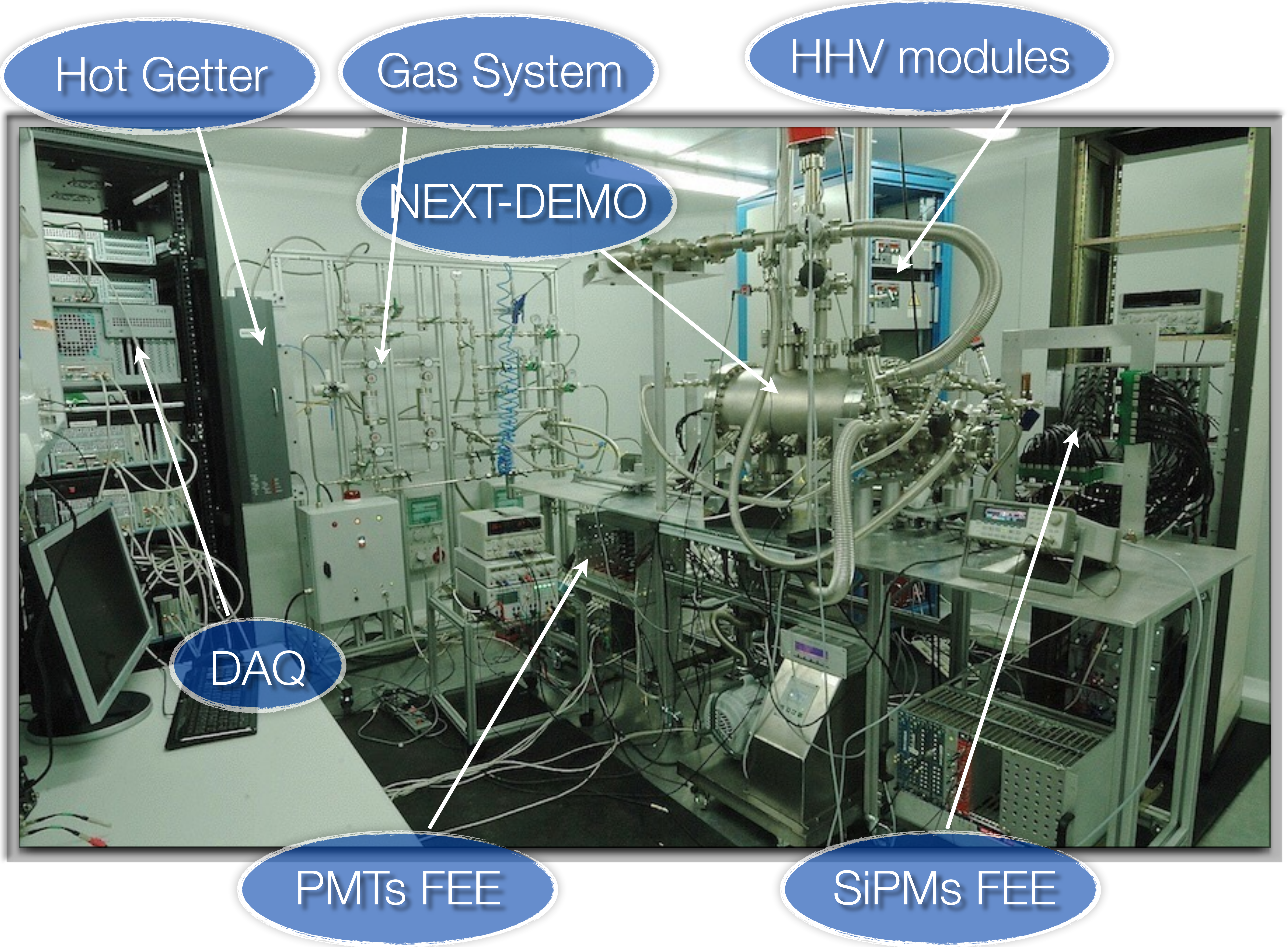
The NEXT program

(2010–2014)
Demonstration of detector concept

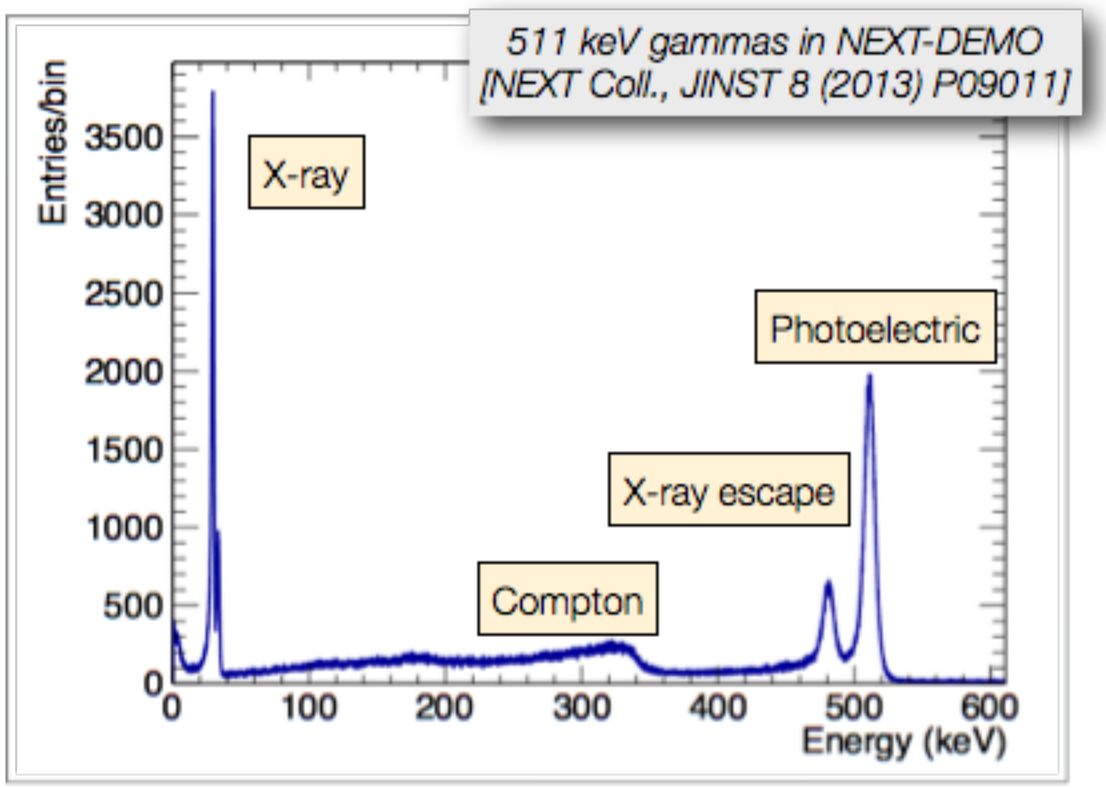
(2015–2017)
Test underground, radiopure operation

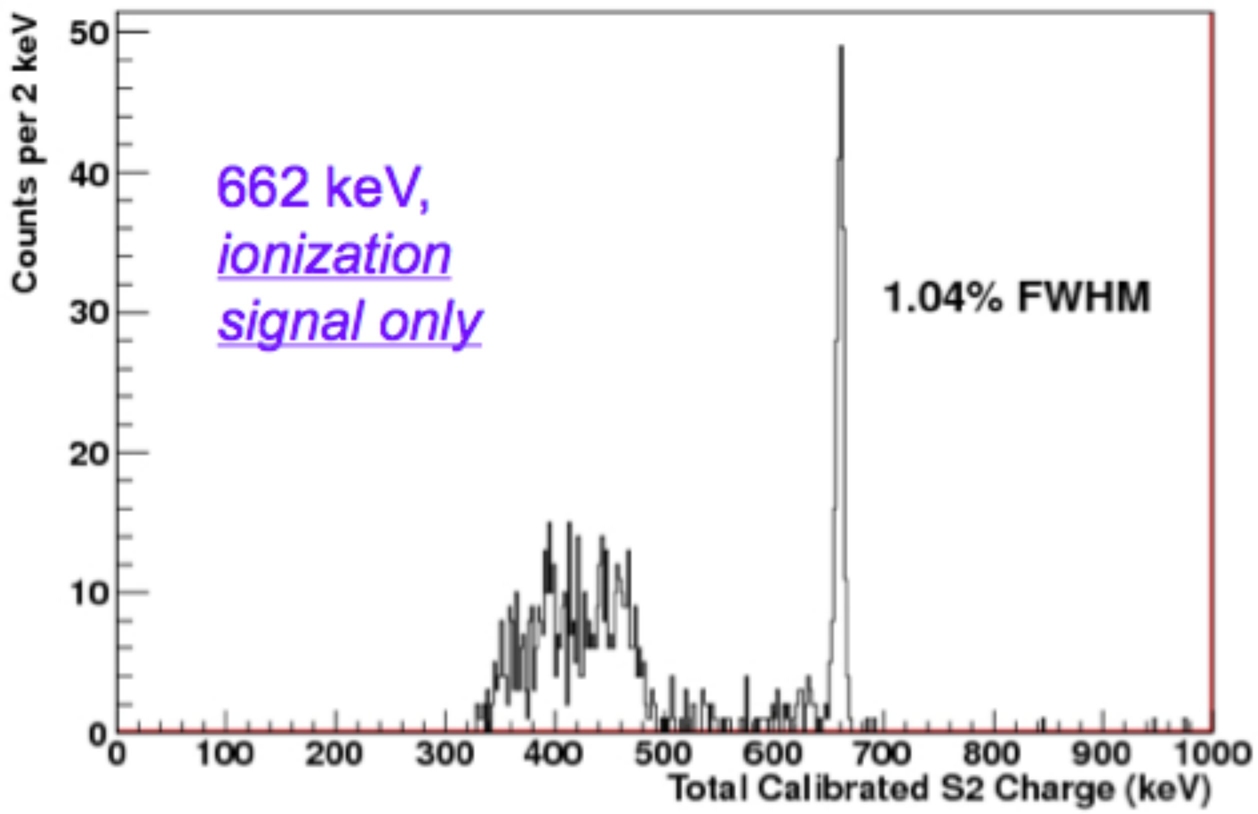
(2018–2020)
Neutrinoless double beta decay searches


DEMO
(1 kg)


Hot Getter
Gas System
HHV modules
NEXT-DEMO
DAQ
PMTs FEE
SiPMs FEE

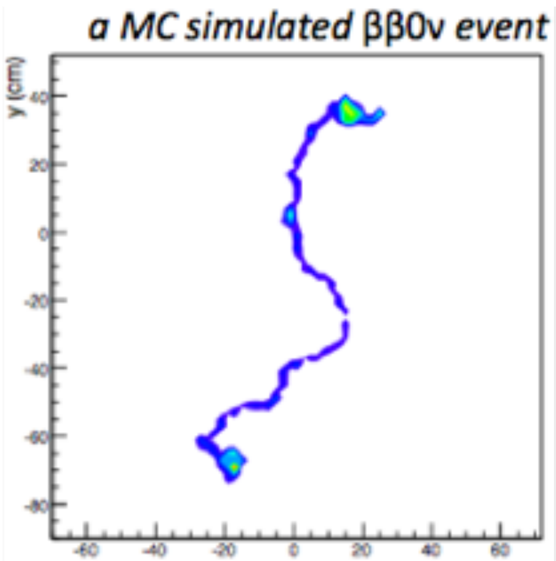
Energy Resolution

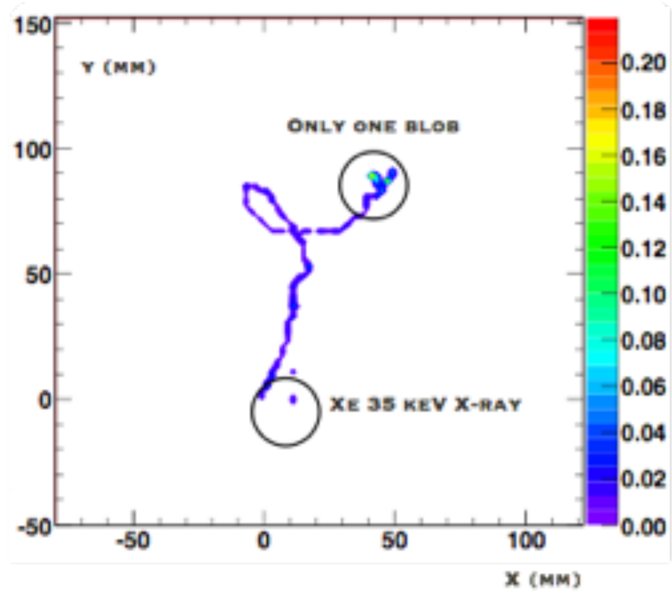


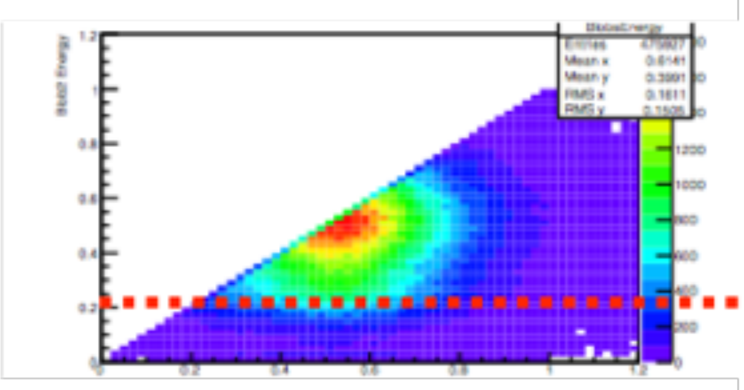


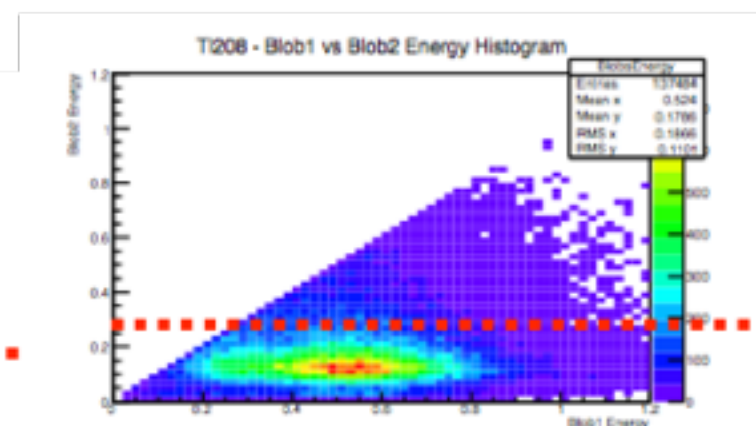
Energy resolution measured with prototypes DEMO (IFIC) DBDM (LBNL) extrapolates to 0.5 — 0.7 % FWHM at Qbb

Topological signature









- Signal events (bb0nu): TOP left MC event, two energetic blobs at the end of each electron (Bragg peak).
- Background events (Bi-214, Tl-208), single energetic electron, single blob, often with X-ray (xenon de-excitation)
- Bottom left, for signal event the energy of both blobs is high.
- Bottom right, for background events only one energetic blob.

Topological signature: “single track” (no floating x-rays) with two energetic blobs: Signal efficiency ~50 %, background suppression 1%

Validation of TPS with DEMO

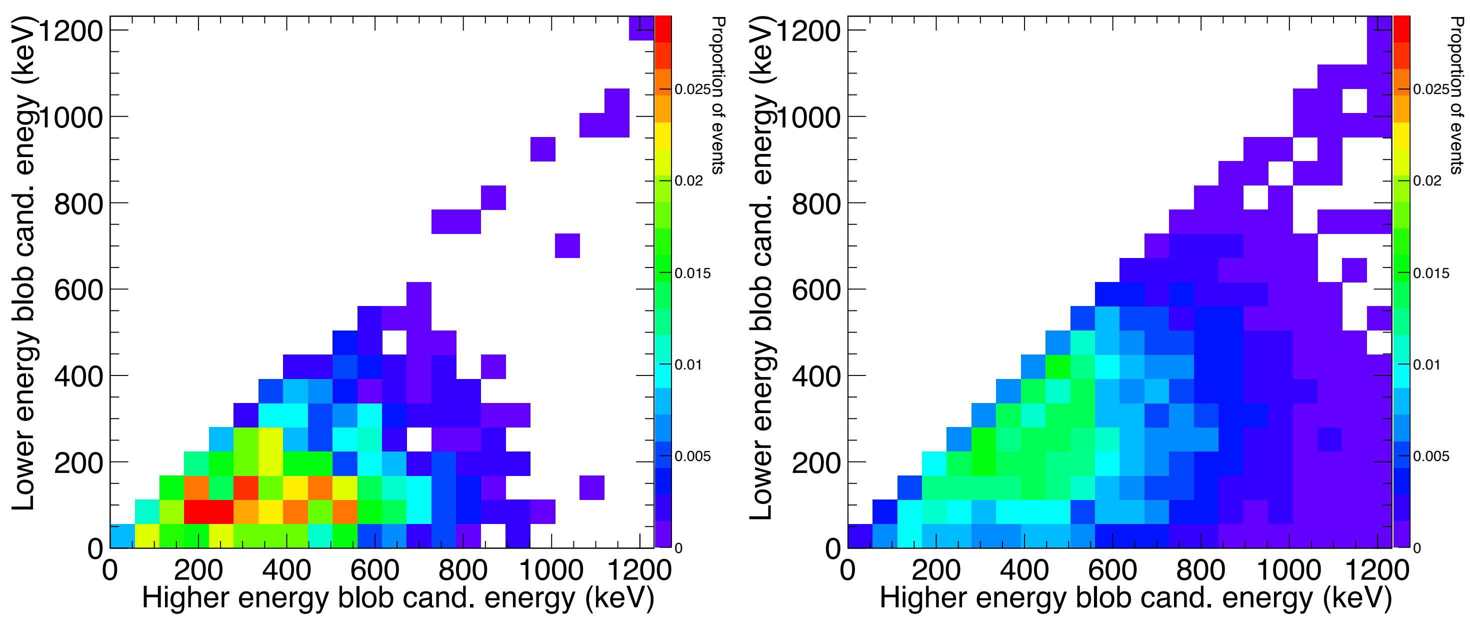


Figure 5. Energy distribution at the end-points of the tracks coming from ^{22}Na decay (left) and those coming from the ^{228}Th decay (right) for 2 cm radius blob candidates.

TPS measured with DEMO data: "background", Na-22 gammas, giving single electrons, 1.275 MeV, "signal"; Tl-208 "double electrons" (e- e+, double escape peak), 1. 592 MeV

Analysis performed in Data and Monte Carlo simulation of DEMO with good agreement! First robust validation of Monte Carlo analysis for NEXT-100.

1. **First proof of topological signature in high pressure xenon gas with electroluminescence amplification**
   NEXT Collaboration (P. Ferrario *et al.*). Jul 21, 2015. 18 pp.
   e-Print: **arXiv:1507.05902 [physics.ins-det] | PDF**

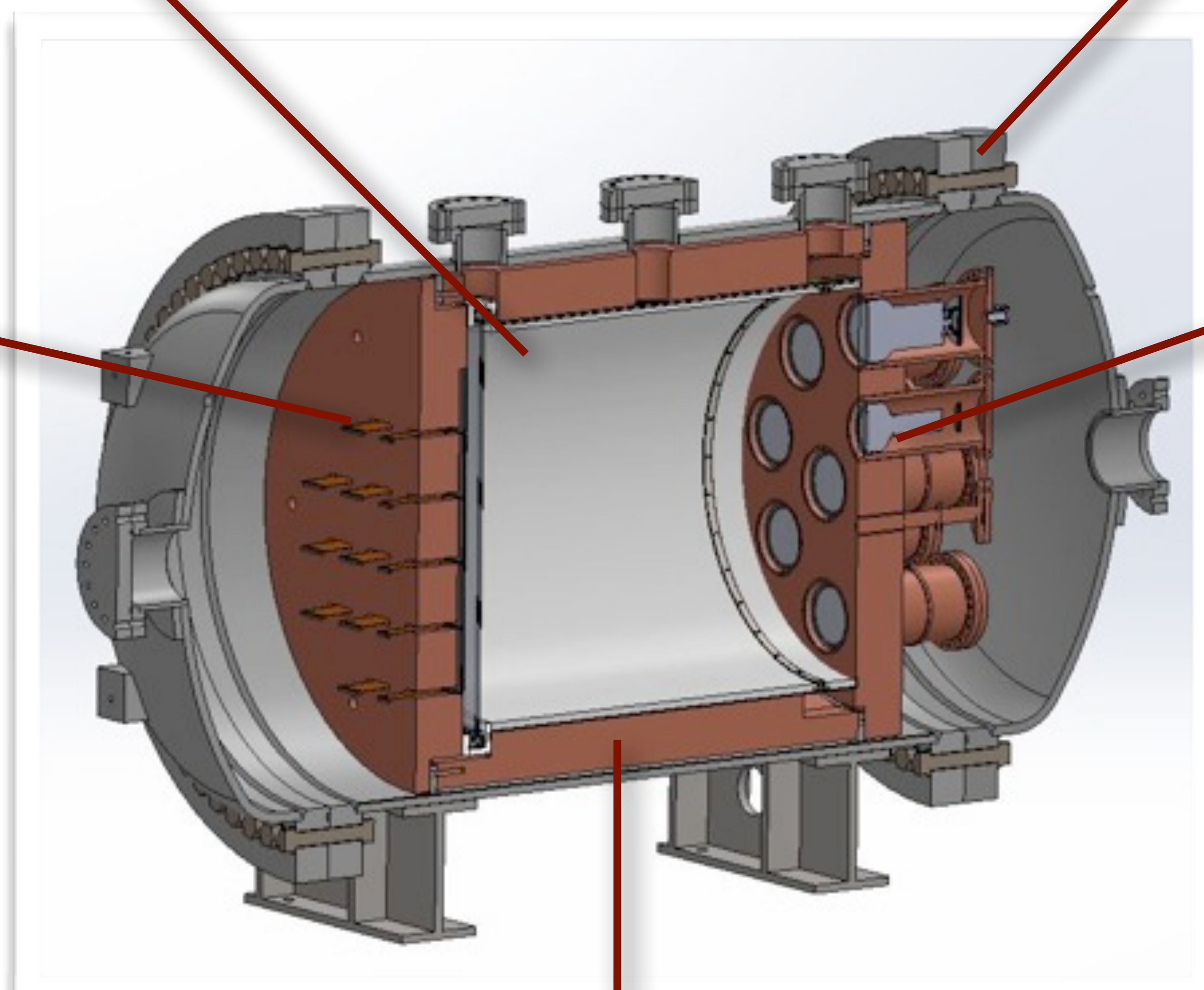

NEW
(10 kg)

NEW (NEXT-WHITE) at glance

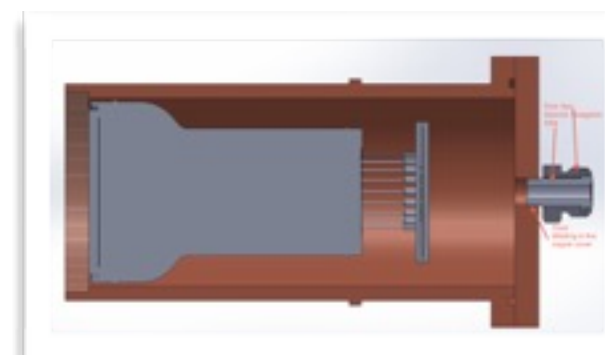
Time Projection Chamber:
10 kg active region, 50 cm drift length

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

Tracking plane:
1,800 SiPMs,
1 cm pitch

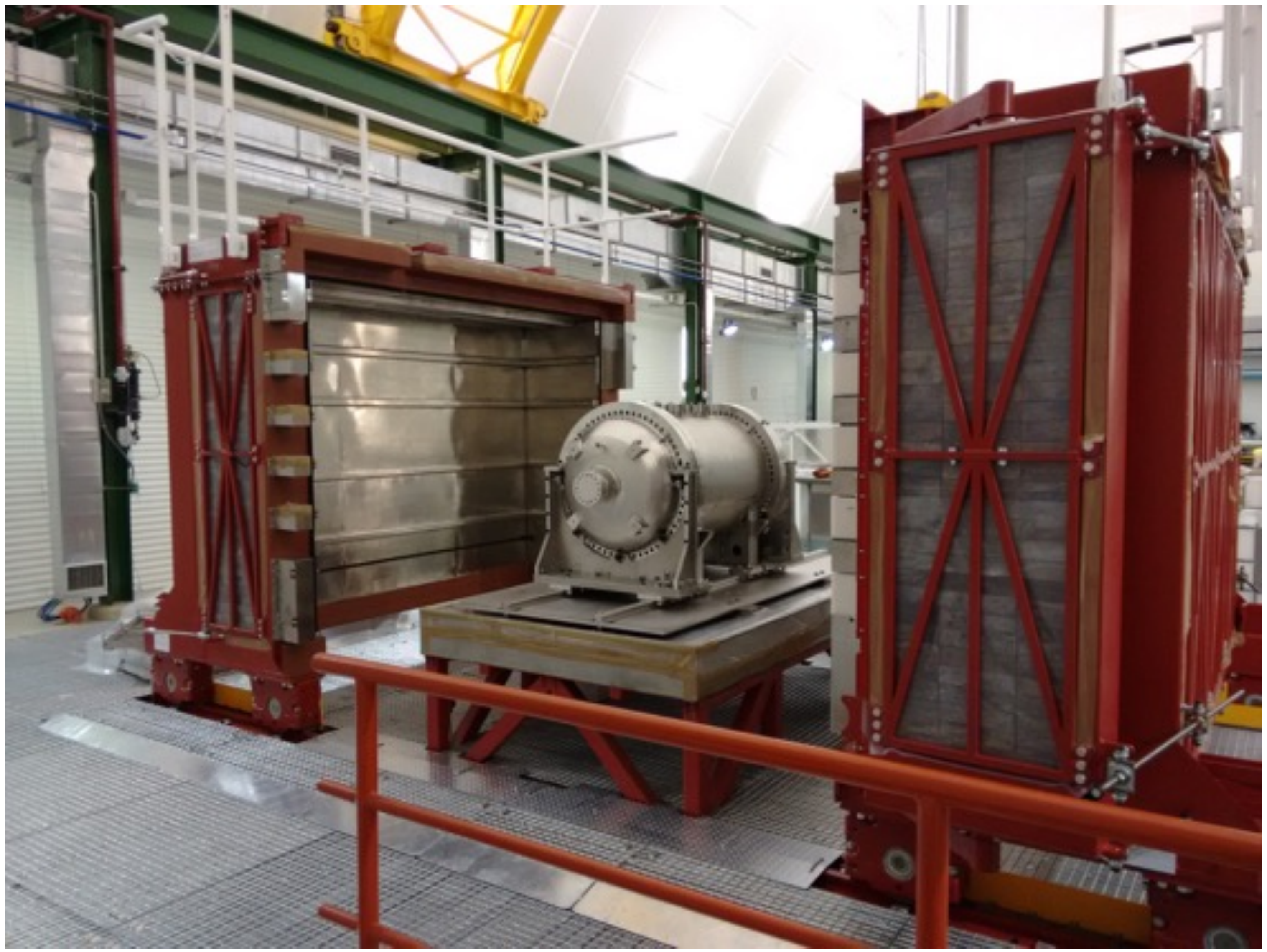


Energy plane:
12 PMTs,
30% coverage



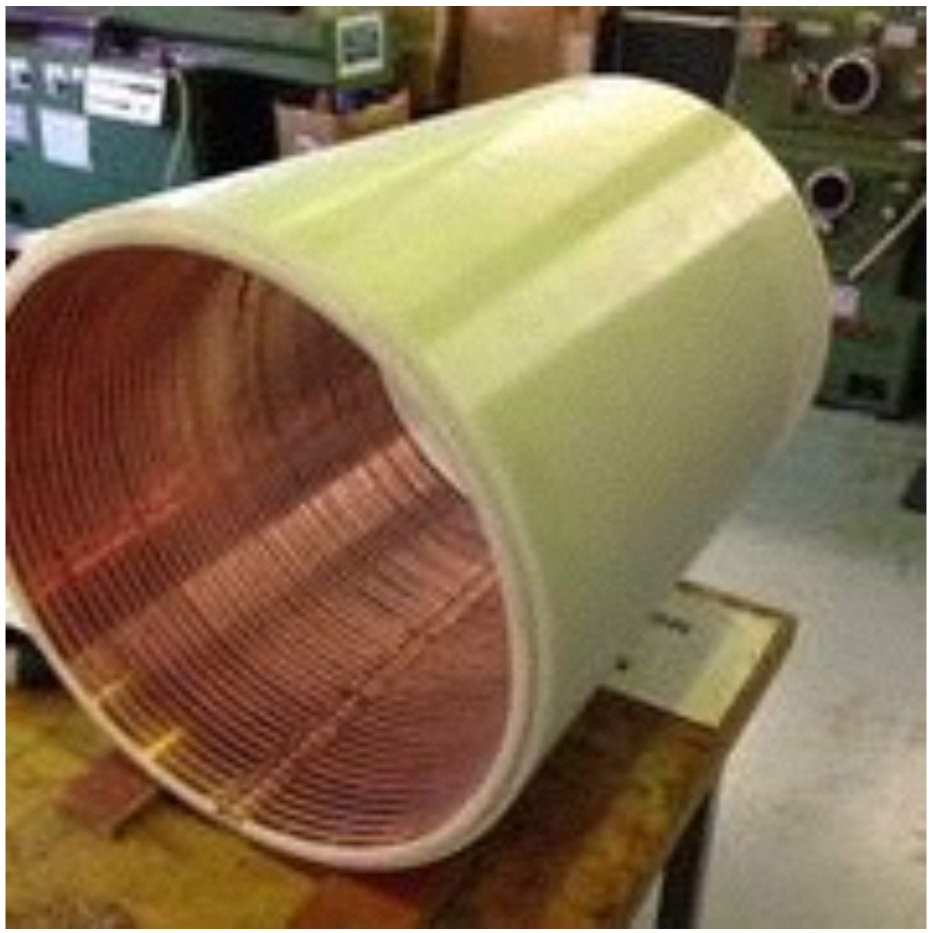
Inner shield:
copper, 6 cm thick

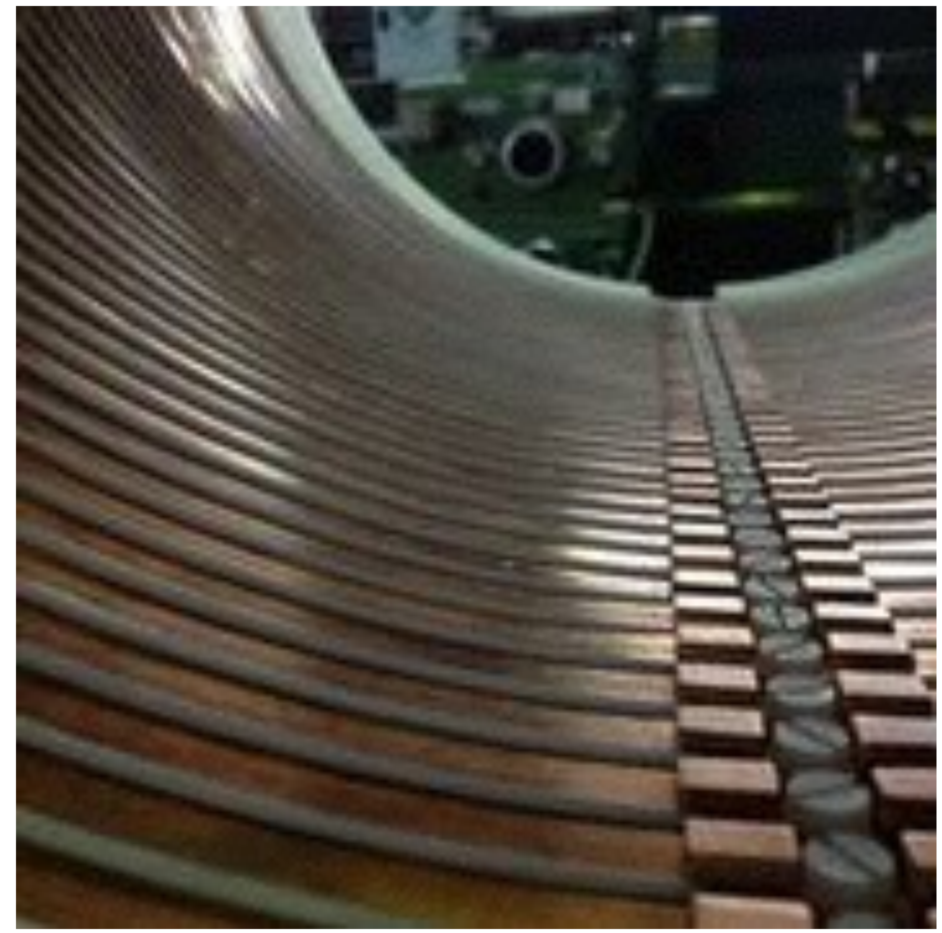
NEW (NEXT-WHITE) at the LSC



NEW on the seismic support table, inside the Lead Castle at the LSC

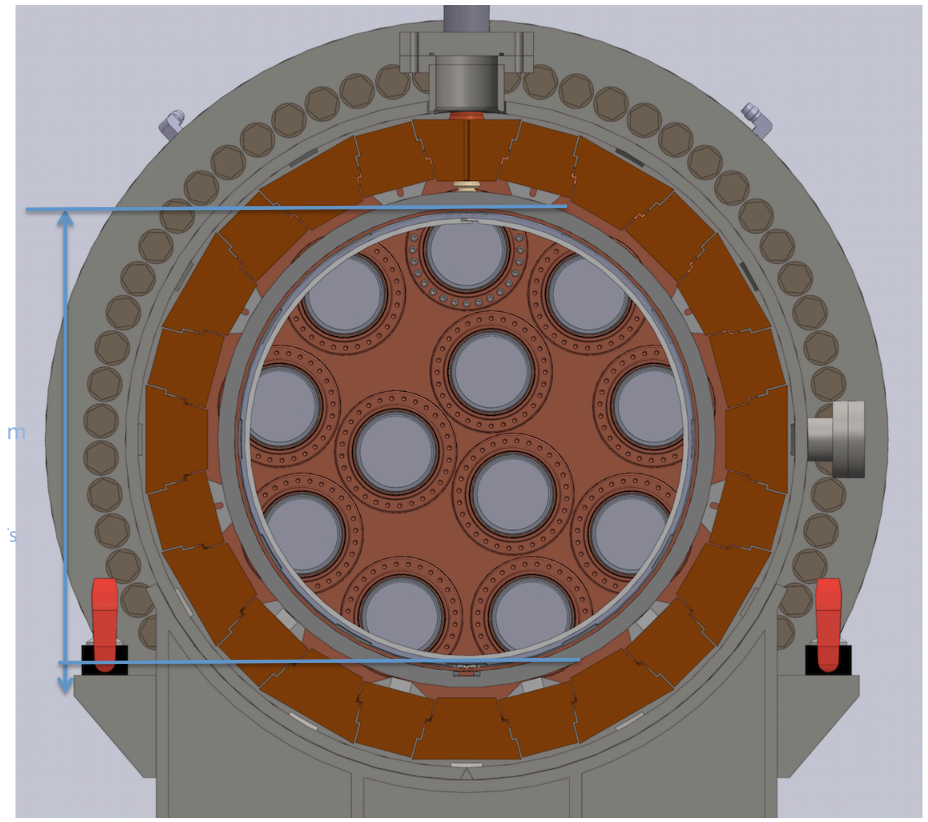
NEW field cage

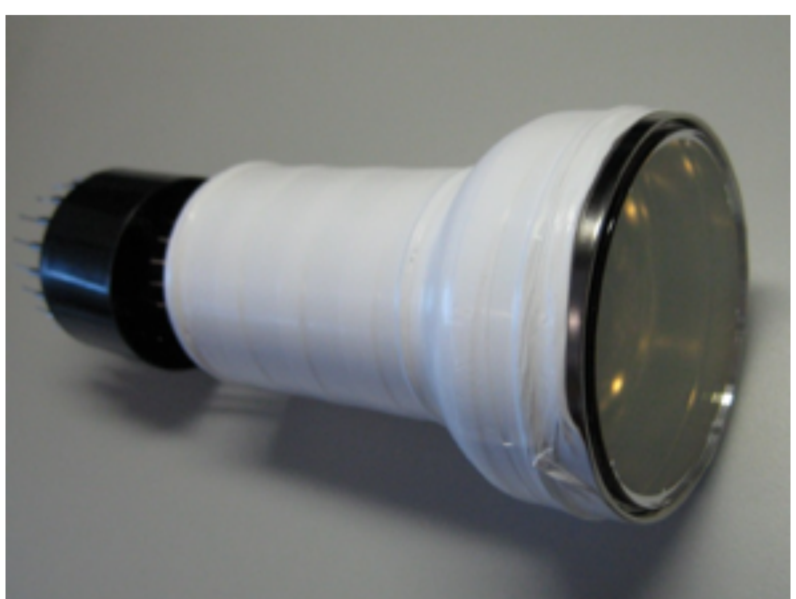




Field cage: 50 cm diameter, 50 cm drift length
Poly boy, copper rings connected by low-background resistors

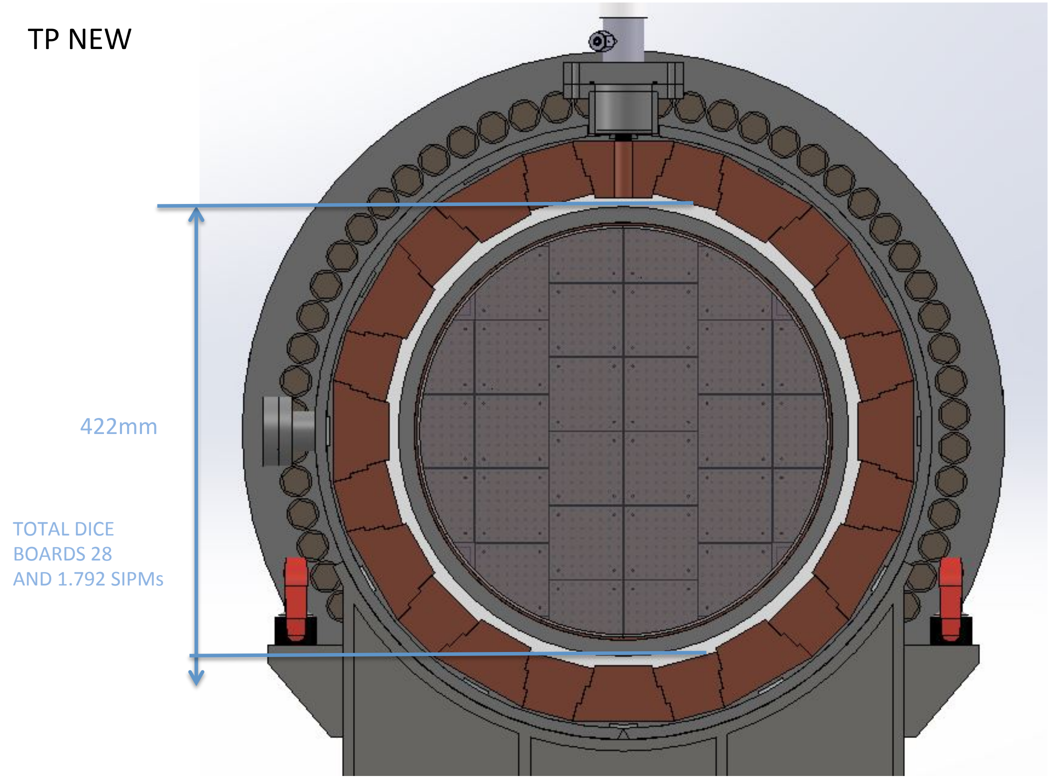
Energy plane





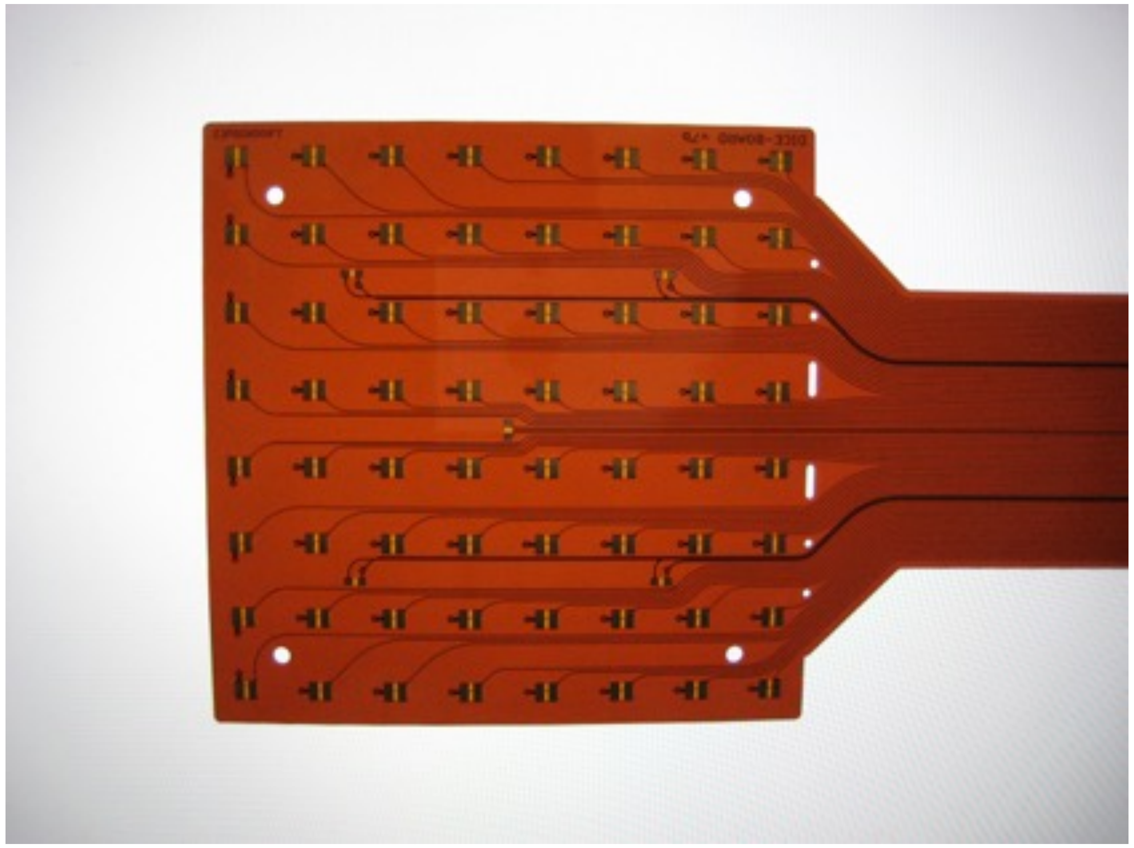
12 R11410-10 PMTs (Hamamatsu)
NEXT 100 will have 60
Excellent response (low noise very low dark current) in gas.
Radiopure (less than 1 mBq/PMT in Tl-208 and Bi-214)

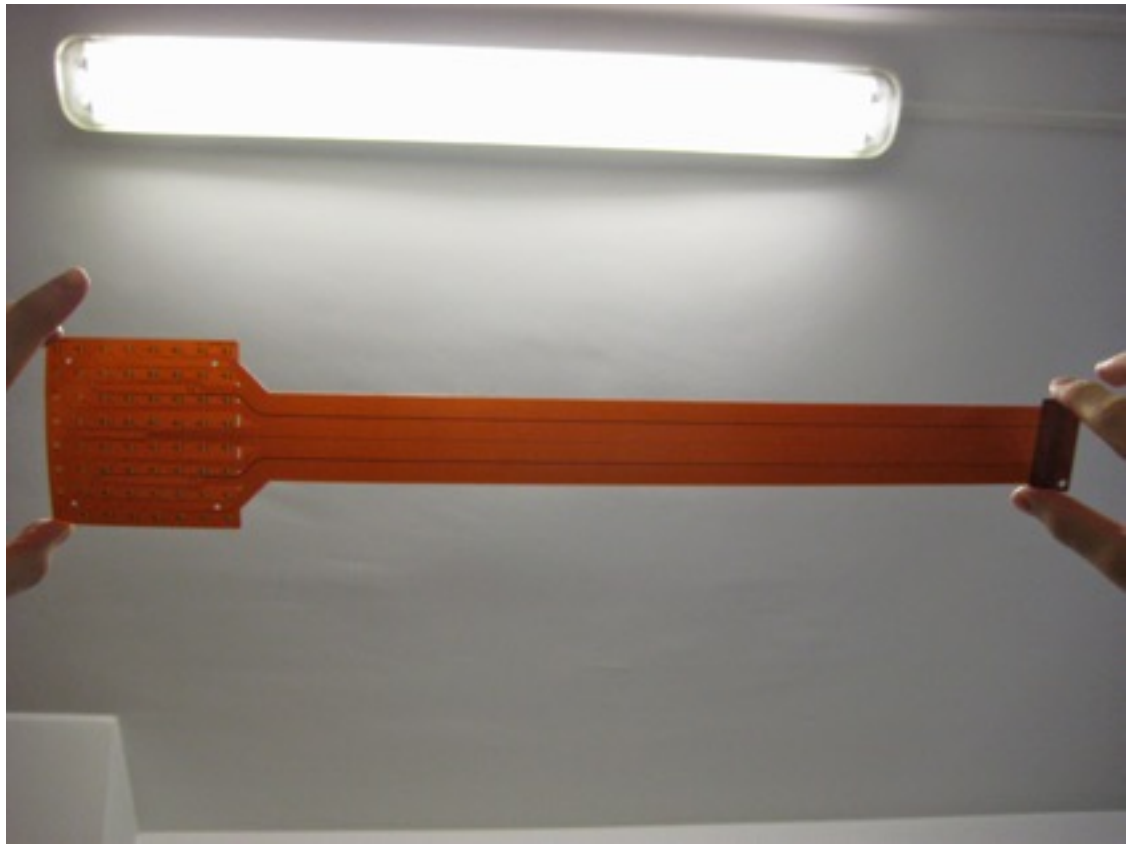
Tracking plane



28 Kapton Dice Boards (KDBs) NEXT 100 will have ~100
Each KDB has 64 SiPMs from SENSL (thus, about 1,800 SiPms)
SENSL SiPMs are the most radiopure currently in market,

Tracking plane: KDBs



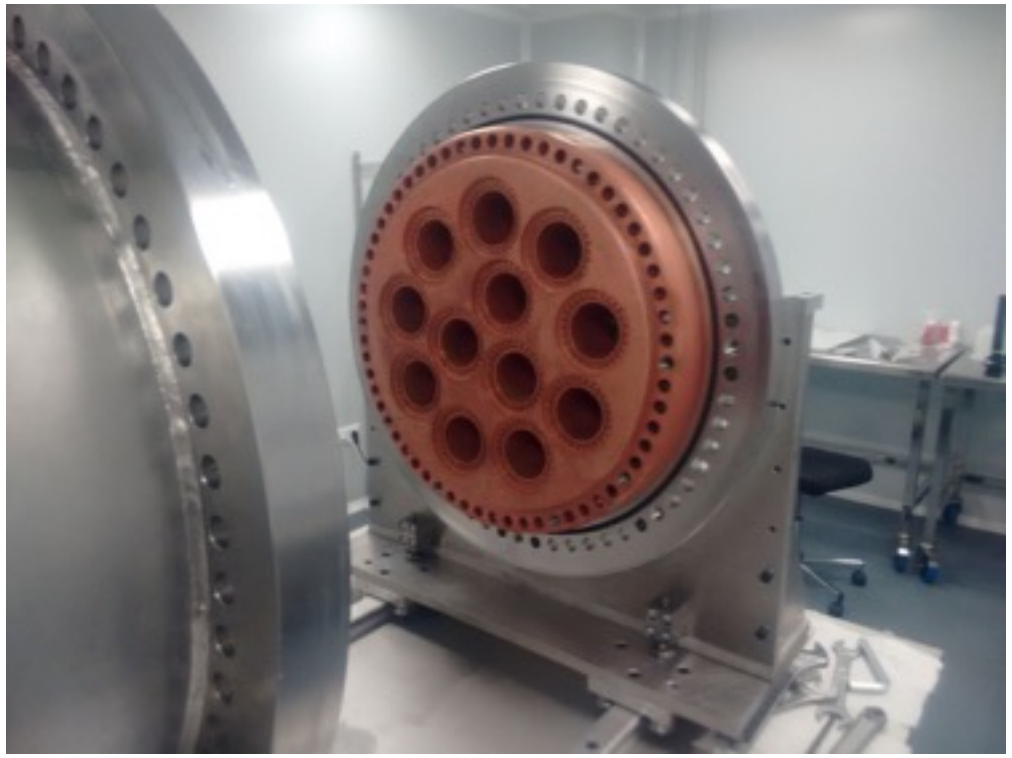


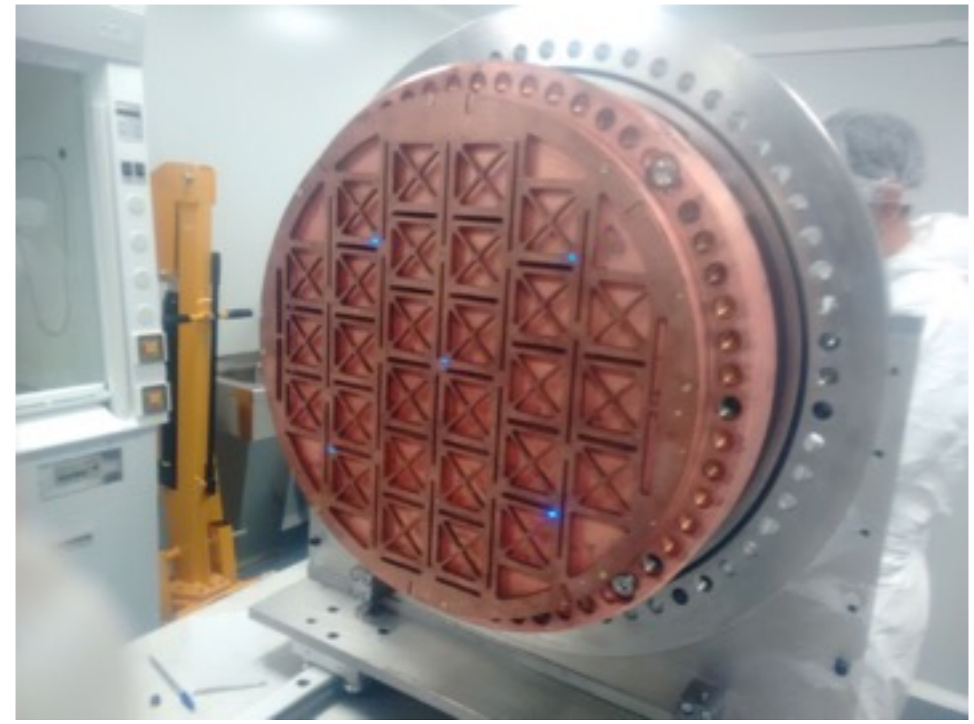
Made of low-background Kapton
Long pigtail runs through 12 cm of copper shield.
Connector BEHIND copper shield

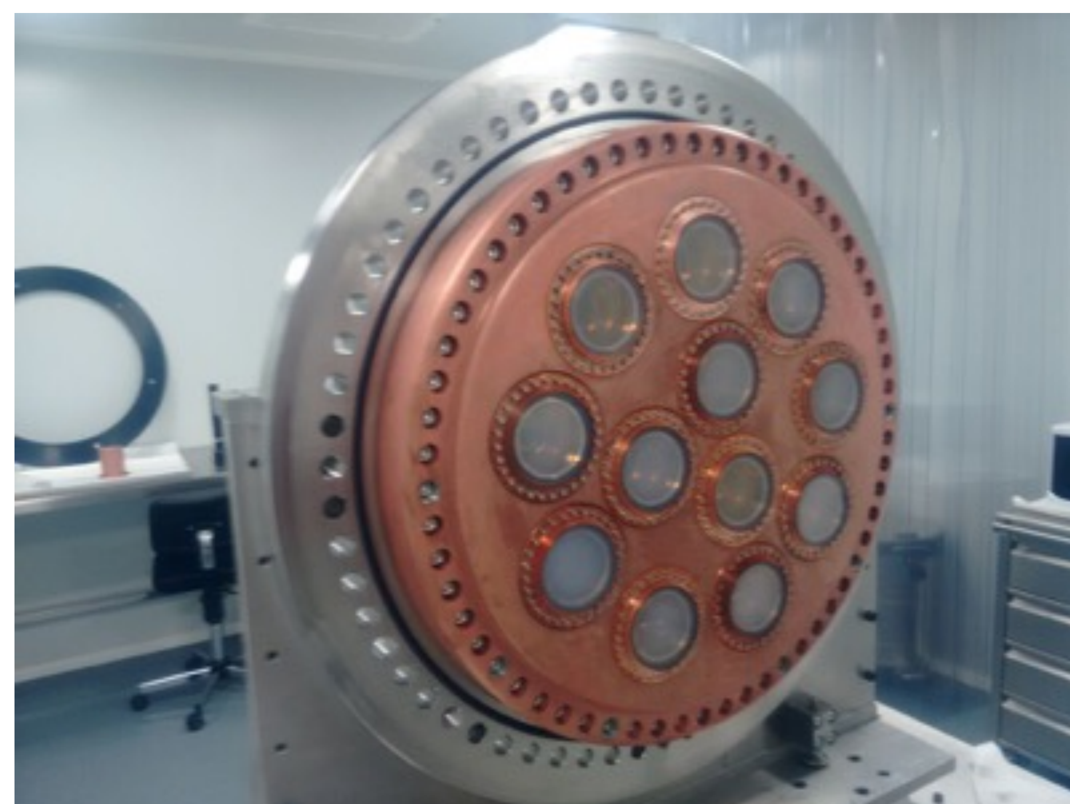
NEW Schedule

- Energy plane (EP) installed in July
- Commissioning of EP in September.
- Tracking plane installation and commissioning October — Mid November.
- Field Cage installation and commissioning: Mid November —End of year.
- Commissioning run (full detector): First Quarter (Q1) 2016.
- Calibration run (energy resolution, topological signature, gas mixtures): Q2-Q4 2016.
- Physics run (background model, bb2nu): Q1-Q4 2017.

Energy Plane installation (July 2015)







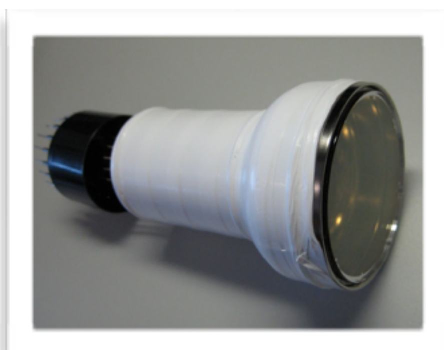

NEXT-100
(10O kg)

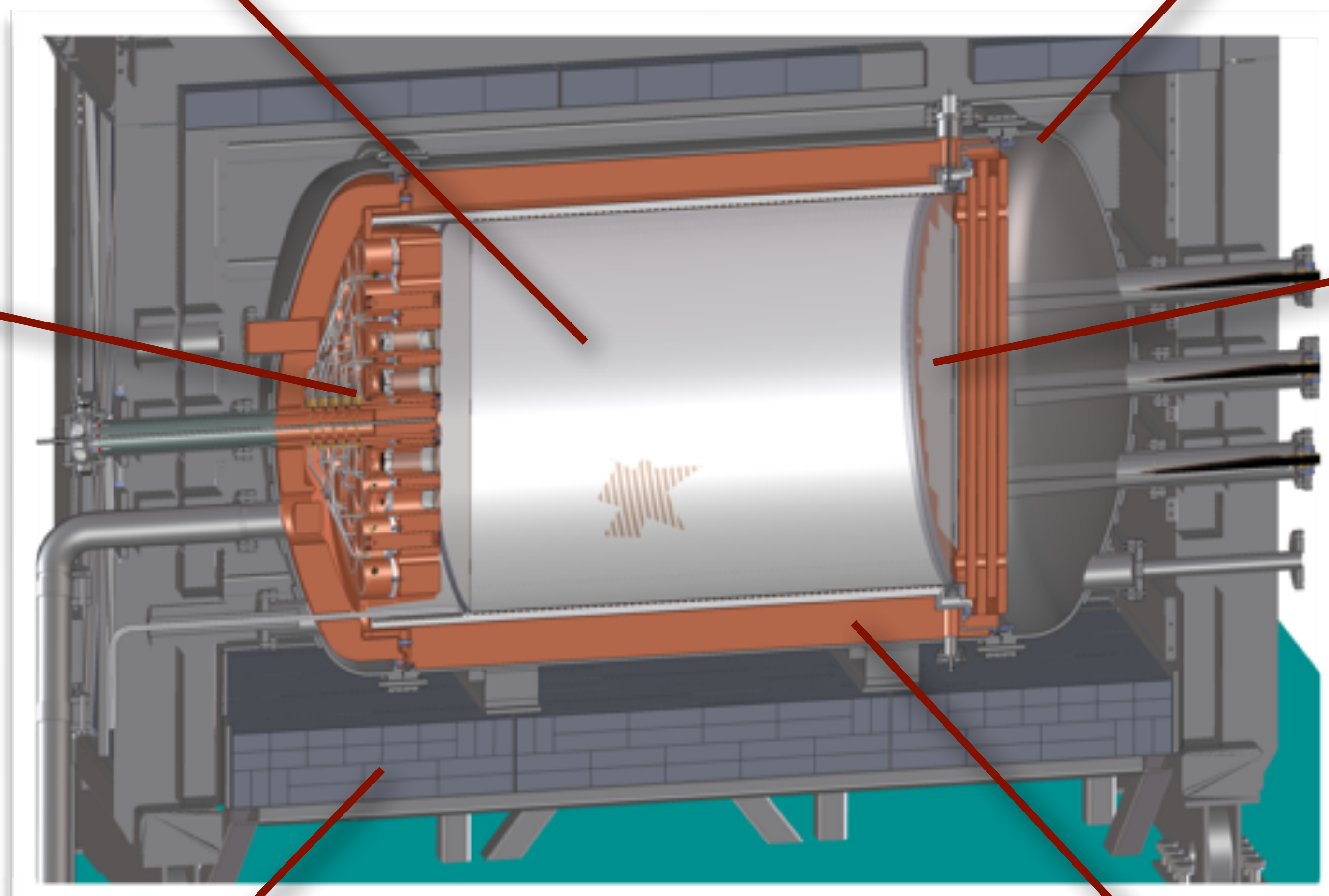
NEXT 100 kg detector at LSC: main features

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

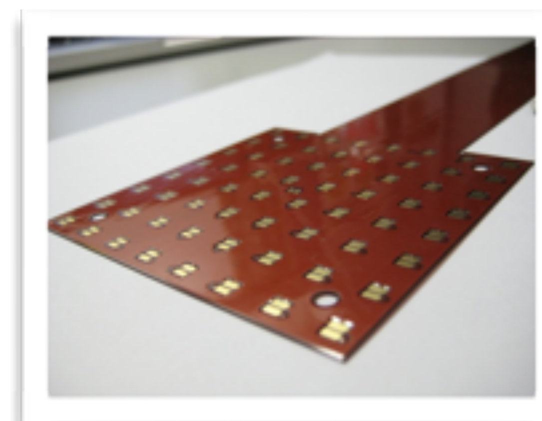
Pressure vessel:
stainless steel,15 bar max pressure

Energy plane:
60 PMTs,
30% coverage





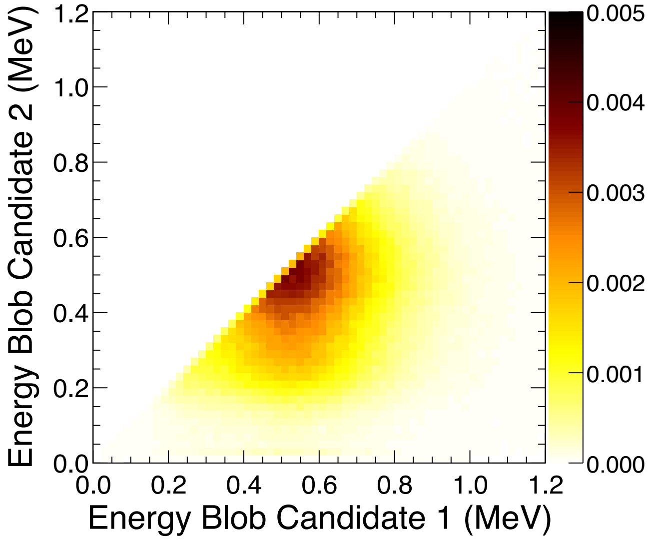
Tracking plane:
7,000 SiPMs,
1 cm pitch

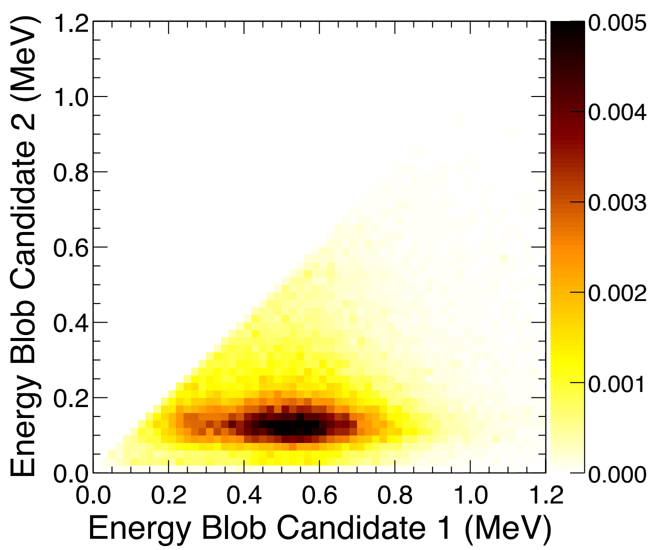


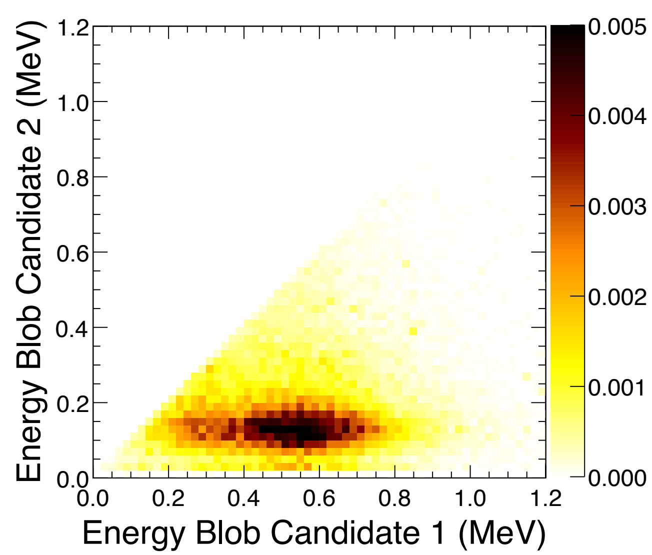
Outer shield:
lead, 20 cm thick

Inner shield:
copper, 12 cm thick

PERFORMANCE







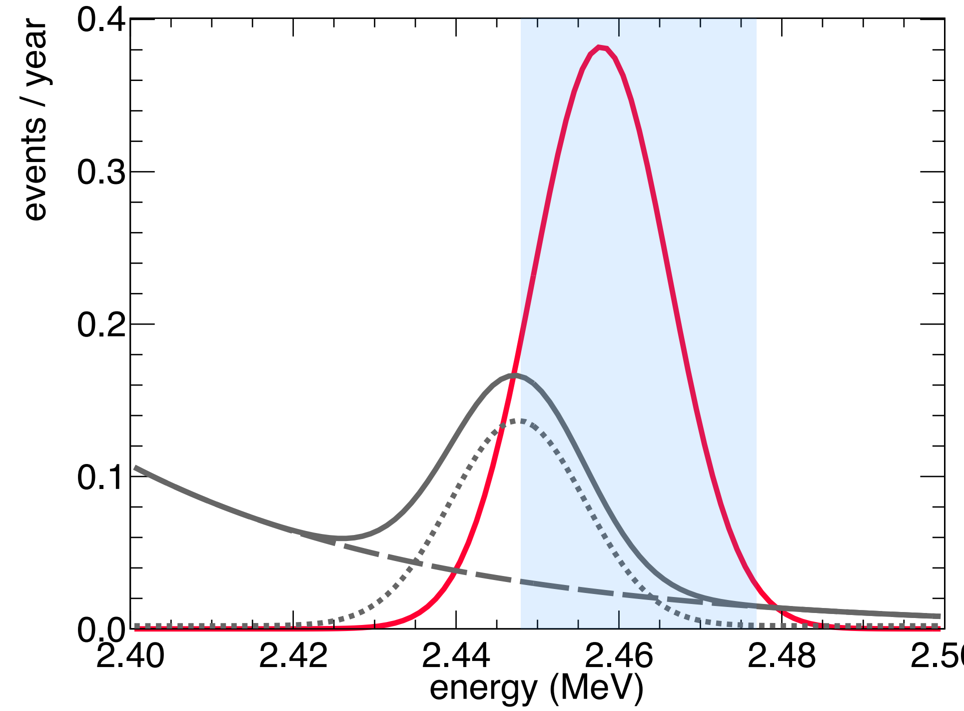


Figure 8. Energy spectra of signal (red, solid curve) and background (^{208}Tl: grey, dashed distribution; ^{214}Bi: grey, dotted distribution; total: grey, solid distribution) in the region of interest (ROI) around $Q_{\beta\beta}$. The optimal ROI (the one that maximizes the ratio of the signal efficiency over the square root of the background rate) is indicated by the shaded, blue region. The signal strength represented here corresponds to a neutrino Majorana mass of 200 meV, while the backgrounds are scaled to their expected values in NEXT-100 (6×10^{-4} counts/(keV kg y)), assuming an exposure of 91 kg yr.

Selection criterion	$0\nu\beta\beta$	$2\nu\beta\beta$	^{208}Tl	^{214}Bi
Fiducial, single track $E \in [2.4, 2.5]$ MeV	0.4759	8.06×10^{-9}	2.83×10^{-5}	1.04×10^{-5}
Track with 2 blobs	0.6851	0.6851	0.1141	0.105
Energy ROI	0.8661	3.89×10^{-5}	0.150	0.457
Total	0.2824	2.15×10^{-13}	4.9×10^{-7}	4.9×10^{-7}

Table 4. Acceptance of the selection criteria for $0\nu\beta\beta$-decay events described in the text. The values for ^{208}Tl and ^{214}Bi correspond to one of the dominant sources of background in the detector.

Background rate

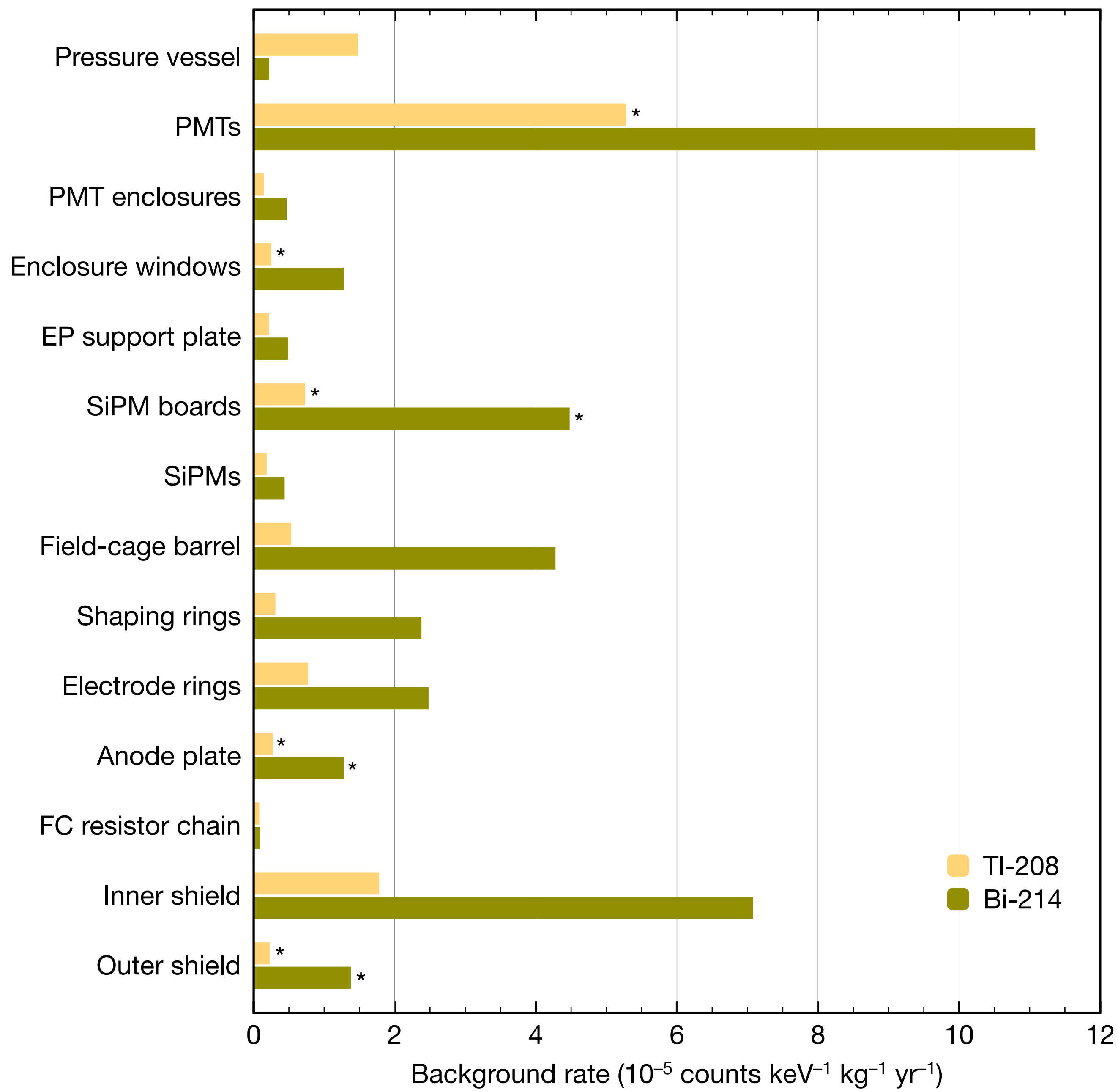


Figure 9. Contribution to the background rate of NEXT-100 of the different detector subsystems considered in our background model. An asterisk (*) next to a bar indicates that the contribution corresponds to a positive measurement of the activity of the material.

Table 6 shows the contributions grouped into six major subsystems. The background from ^{214}Bi is 4.3 times more abundant than the background from ^{208}Tl. The overall background rate estimated for NEXT-100 is

$$< 5 \times 10^{-4} \text{ counts/(keV kg year)}. \tag{7.1}$$

This rate includes only radioactive backgrounds from detector materials and components. All other sources of background are expected to contribute at the level of 10^{-5} keV^{-1} kg^{-1} yr^{-1} or below:

background rate: 5×10^{-4} ckky
WARNING: rate computed taking upper limits as actual values (a very conservative approach)

Radon

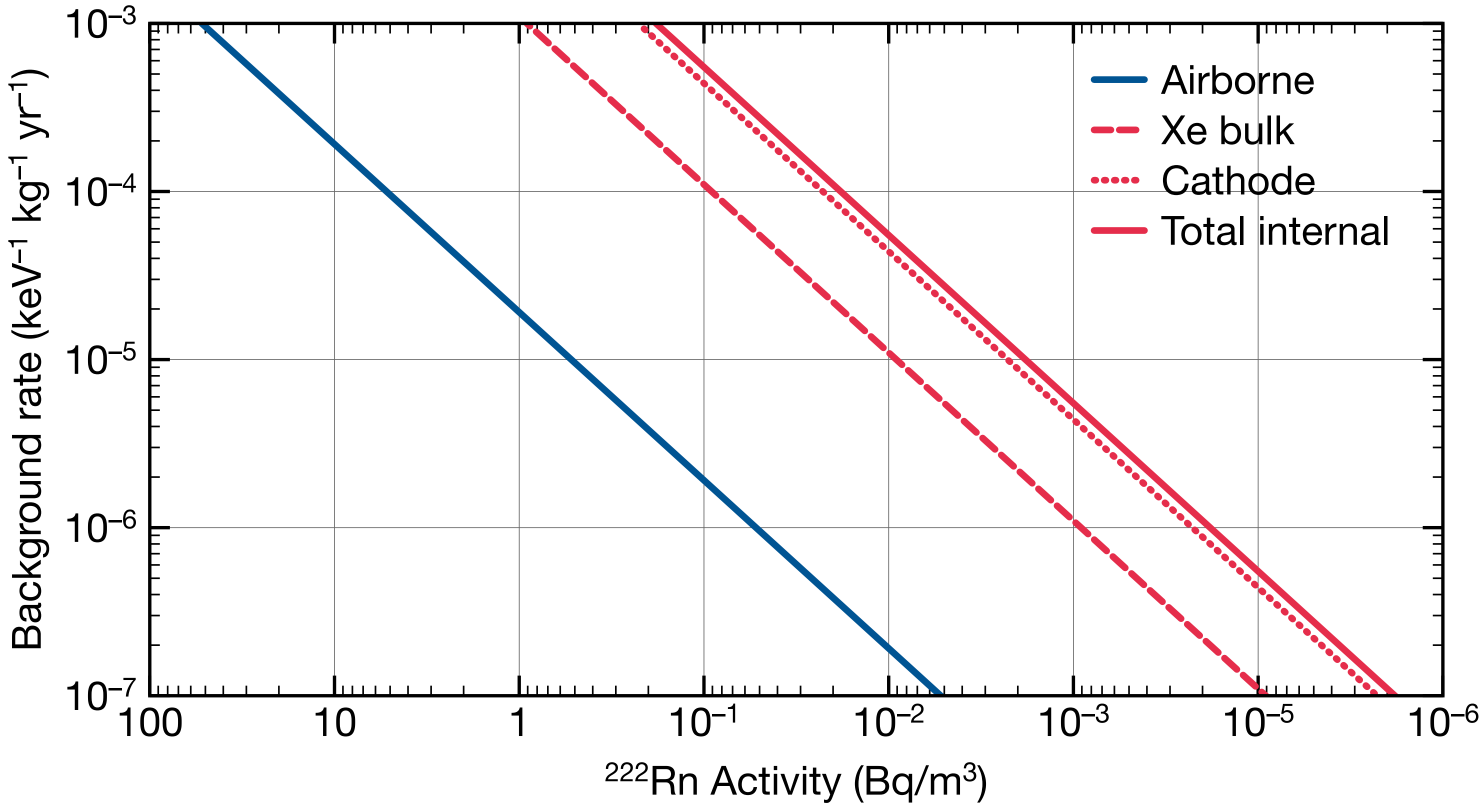
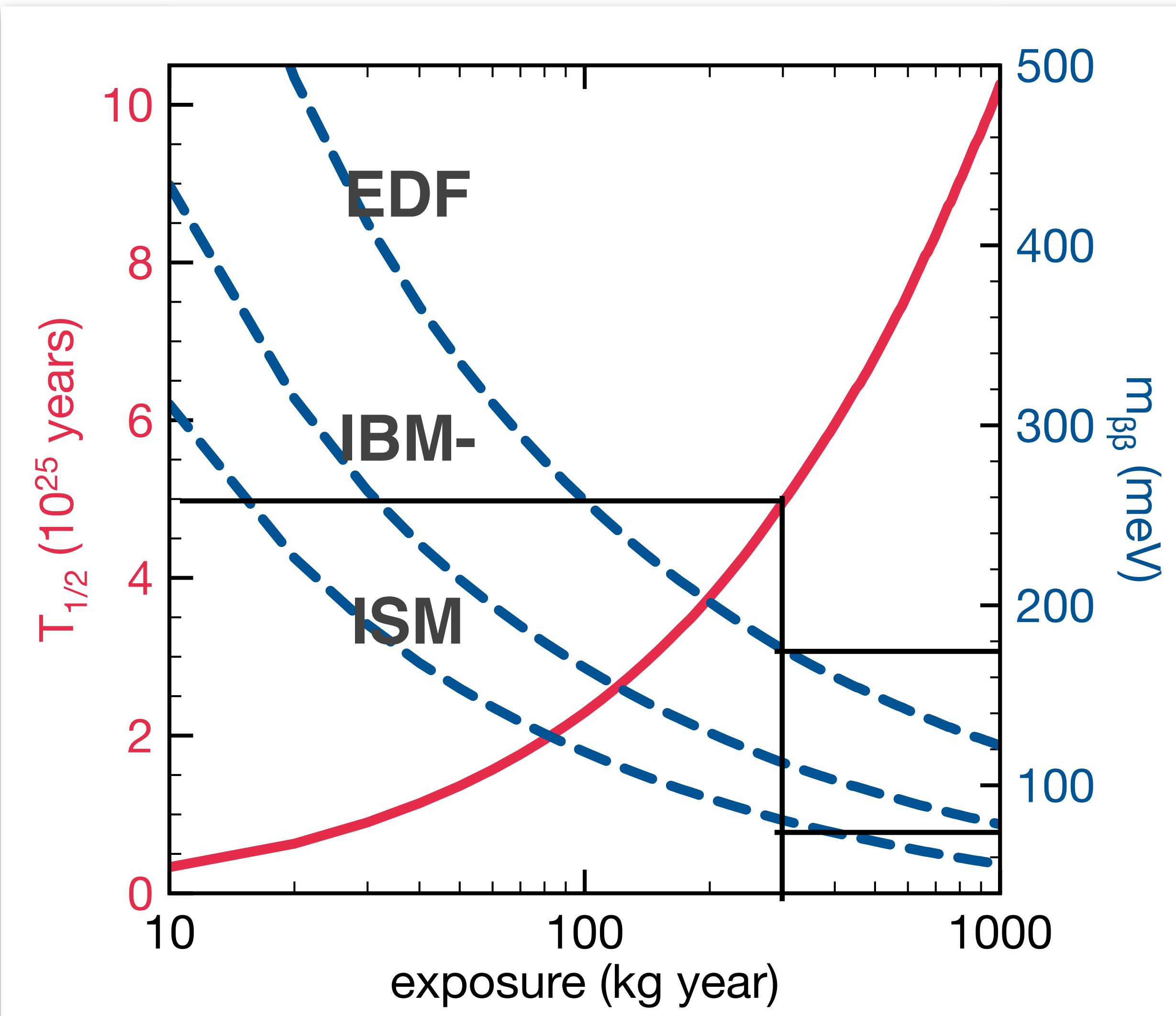


Figure 10. Background rate induced in NEXT-100 by airborne radon and radon contamination in the xenon gas (labelled as *internal*) in terms of the activity of ^{222}Rn.

NEXT-100 will operate inside Radon-suppression tent (a la NEMO): expect ~200 mBq/m3 in air. Best guess for internal is tens of mBq/m3. Contribution of Radon appears tolerable but needs to be understood by NEW operation

Sensitivity



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

Summary

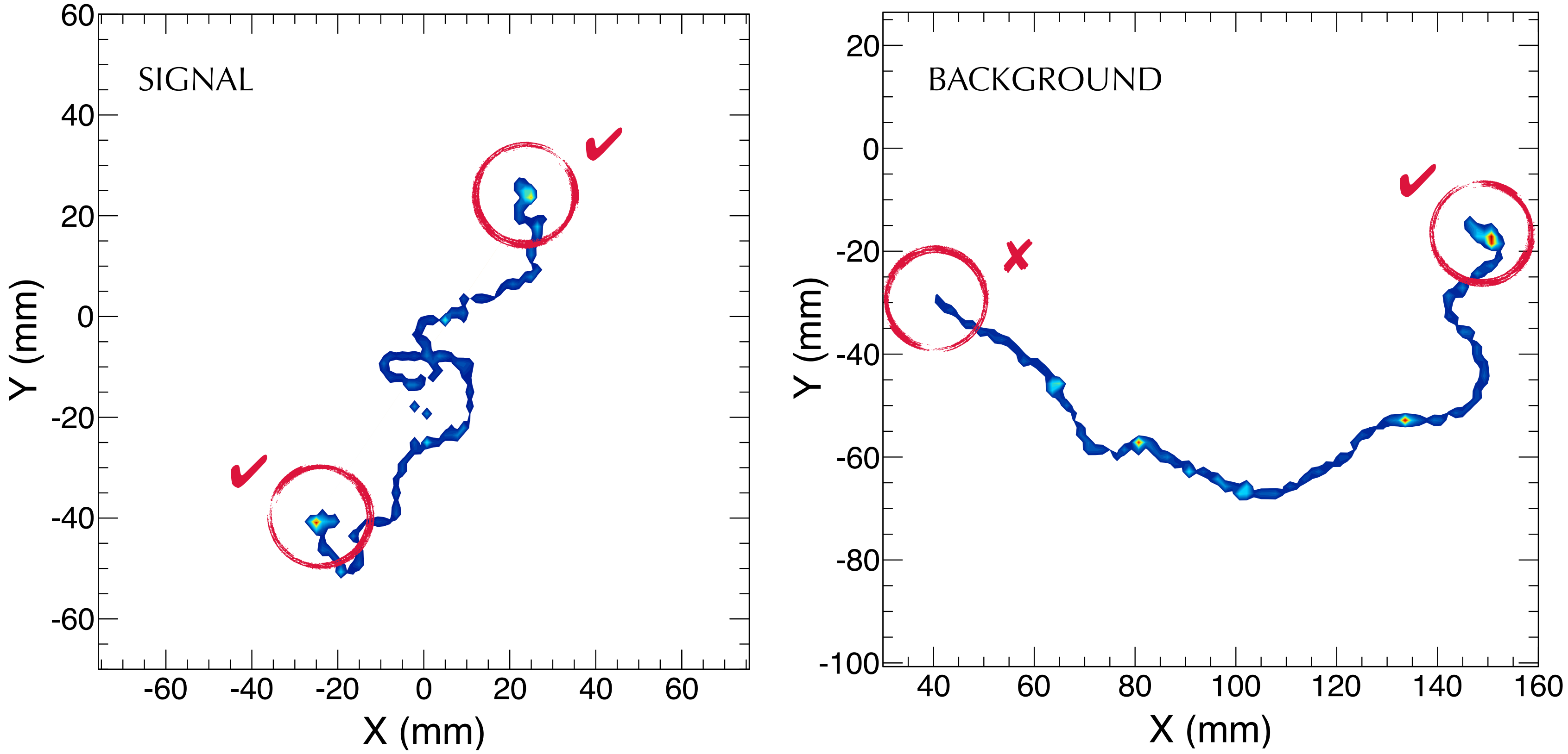
- NEW at LSC: commissioning in 2015, operation in 2016 and 2017.
- DEMO analysis of Tl-208/Na-22 data with DEMO shows good topological separation and validates Monte Carlo calculations.
- NEXT sensitivity evaluated with last background model, results consistent with previous estimations.
- Expect a sensitivity to the period of 10^{25} y which translates in mbb ~[90-180] meV

The Future


BE READY FOR
THE ROAD NEXT TRAVELLED
ENTER HERE
Colonial
First State


R&D

How to improve the topological signature?



Diffusion

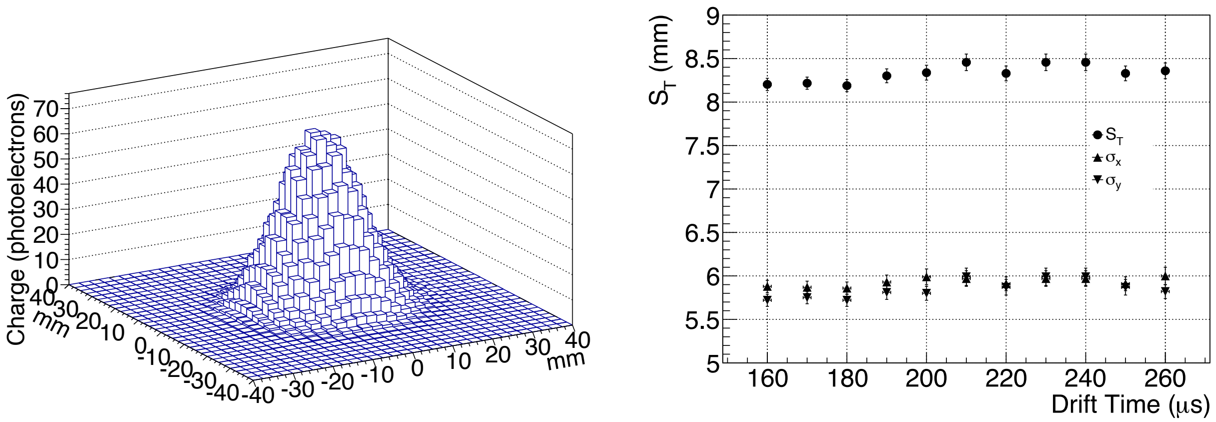
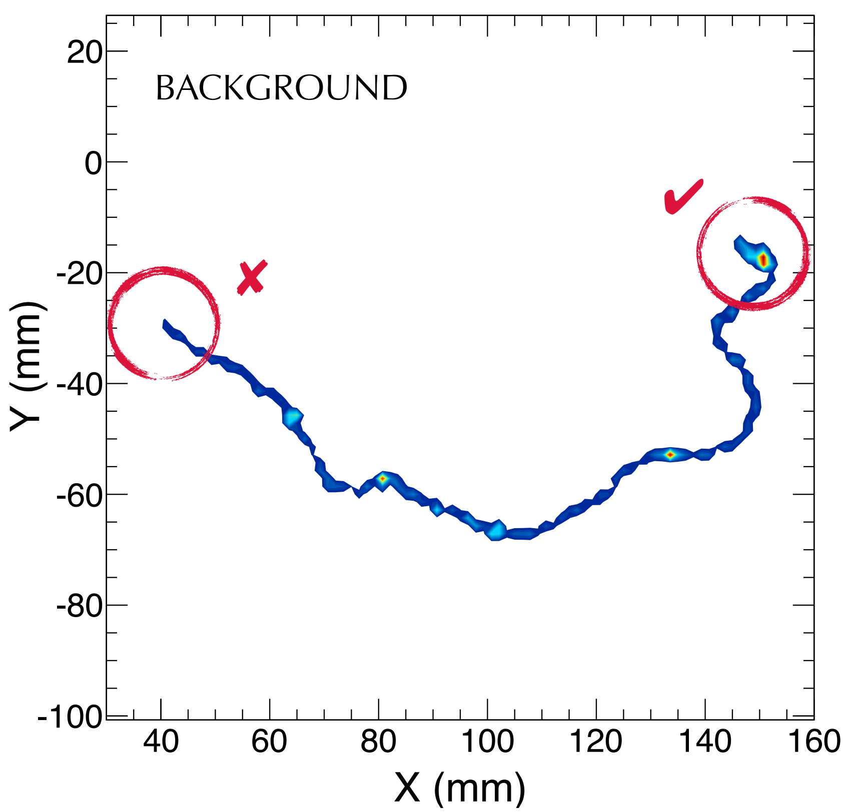


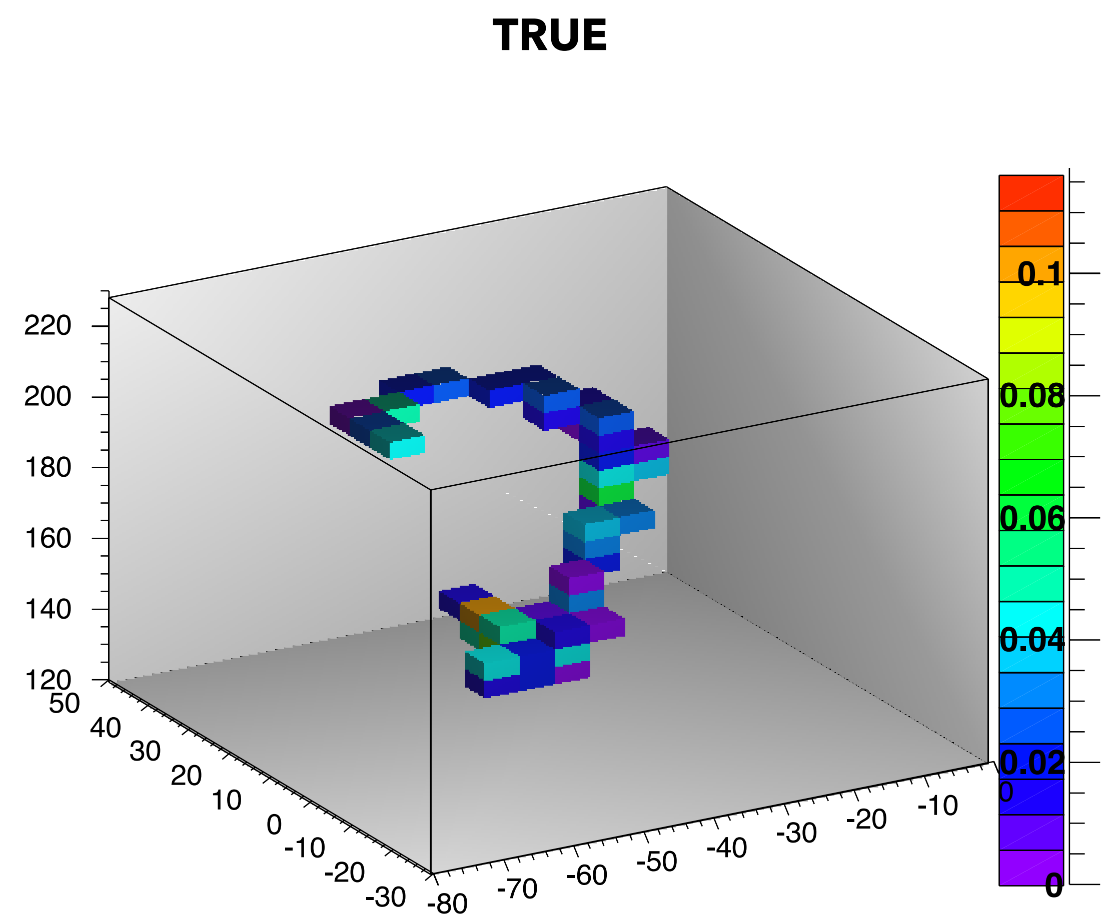
Figure 15. Left: Average 3D charge distribution of a x-ray event from its barycenter. Right: S_T, σ_x and σ_y of charge distribution gaussian fit versus Drift Length.

σ_xy ~10mm/√m

σ_z ~5 mm/√m

- In pure xenon diffusion of drifting electrons is very large.
- After 1 m drift, the electron cloud has a transverse rms of the order of 10 mm and a longitudinal rms of the order of 5 mm
- Resolution is totally dominated by diffusion in NEXT.



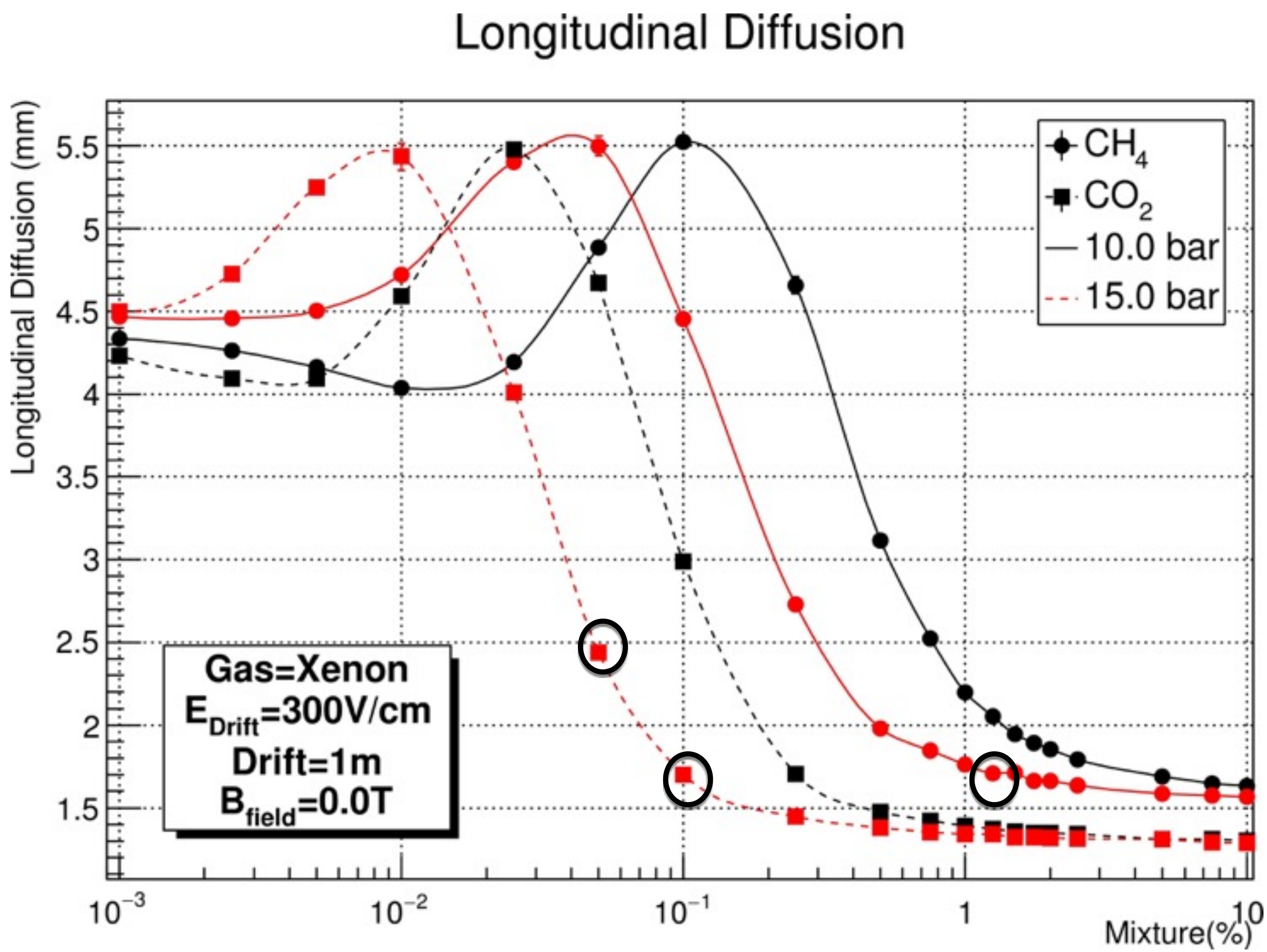


- Diffusion blurs the track reconstruction: The sharp “wire with a blob” of left panel gets blurred as diffusion increases.

How to improve resolution

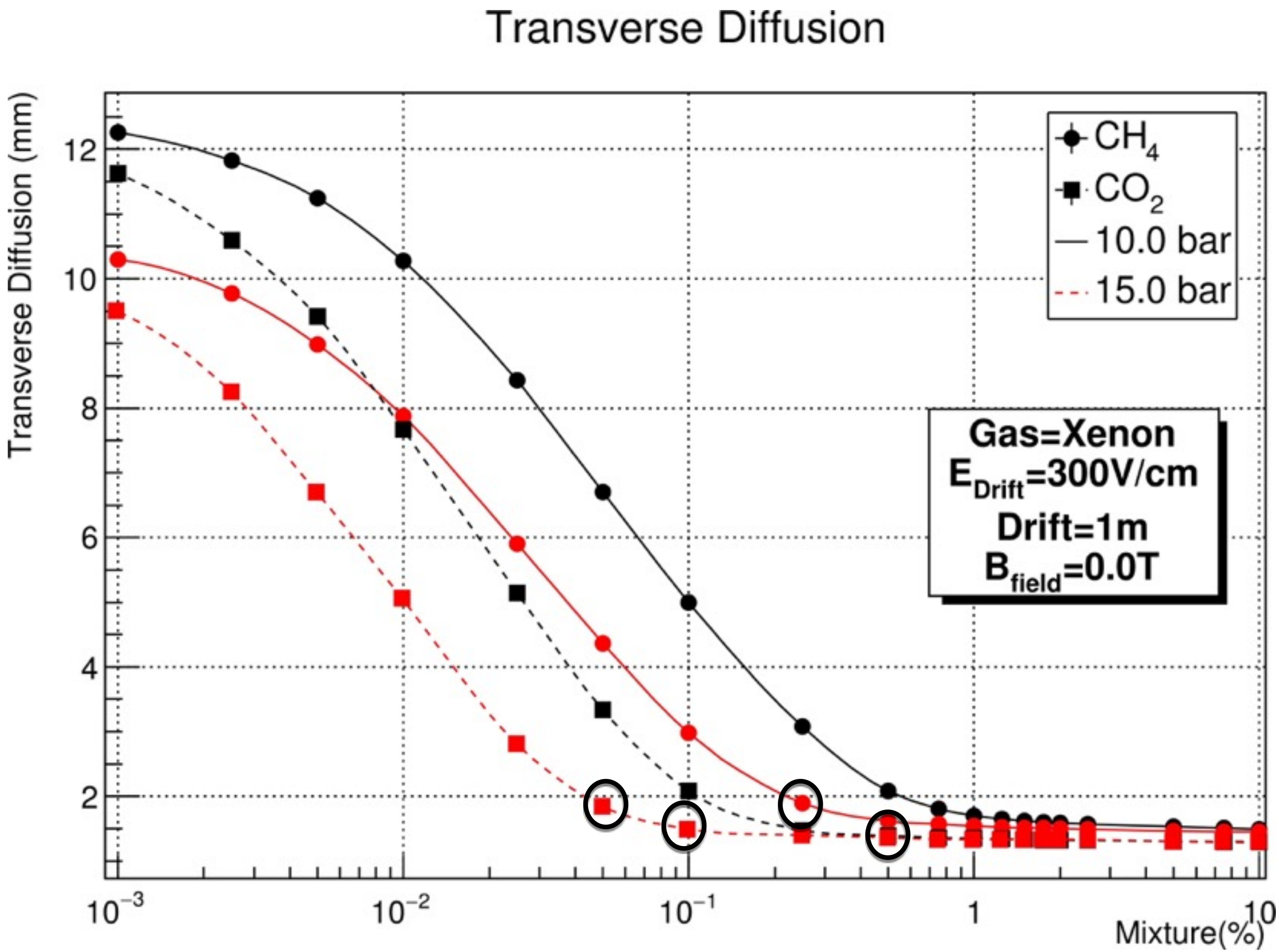
- Resolution is dominated by longitudinal and transverse diffusion.

- It can be improved by adding small amounts of CO2. CH4 and CF4 may also be possible, but CH4 requires larger fractions of additive, which quenches more the light, and CF4 has side effects, such as dissociative attachment, TMA is excellent to reduce the diffusion but it appears to quench completely the xenon scintillation



CO2: 0.1 % (CH4: 1%) —> DL < 2 mm

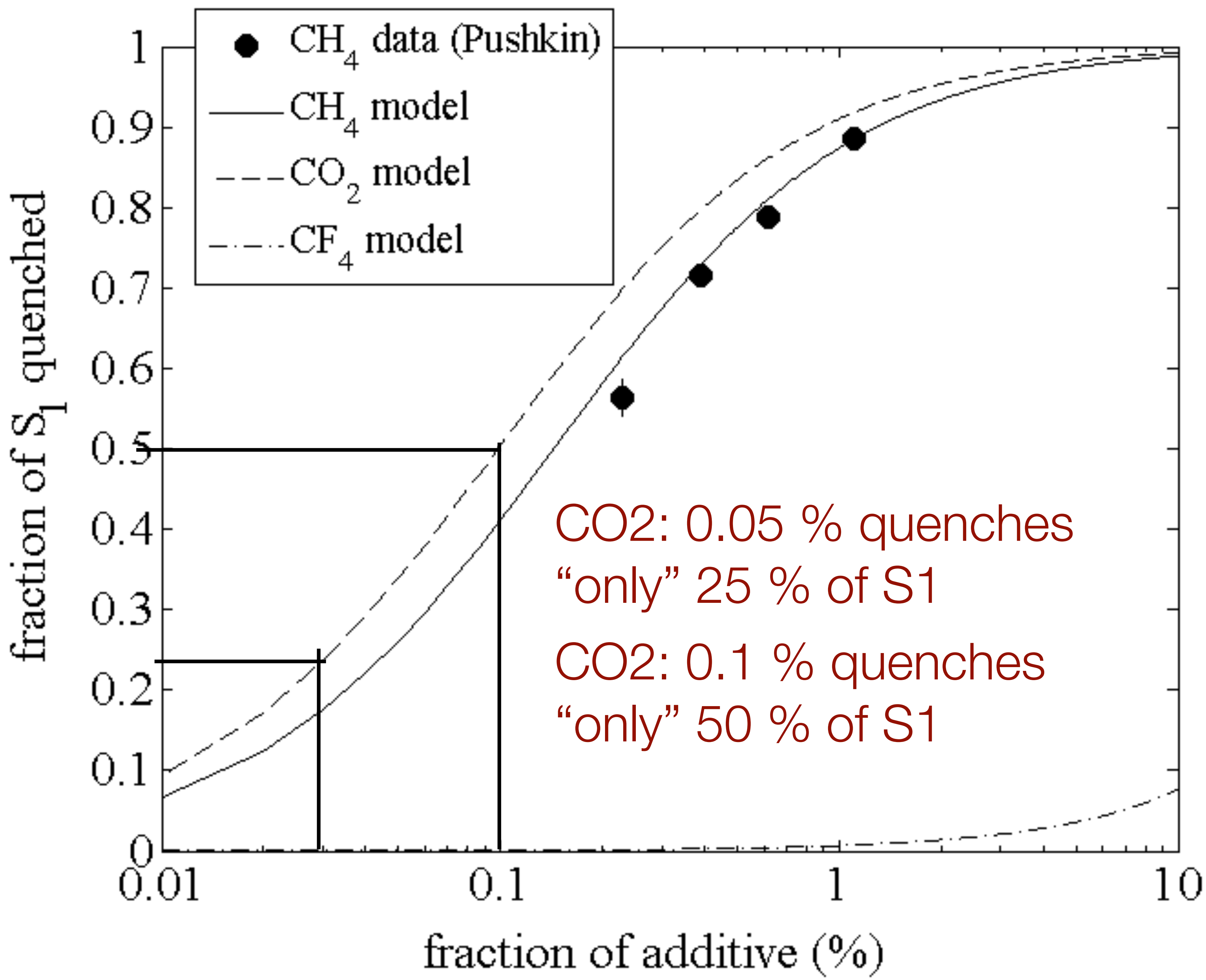
CO2: 0.05 % (CH4: 0.5%) —> DL < 2.5 mm



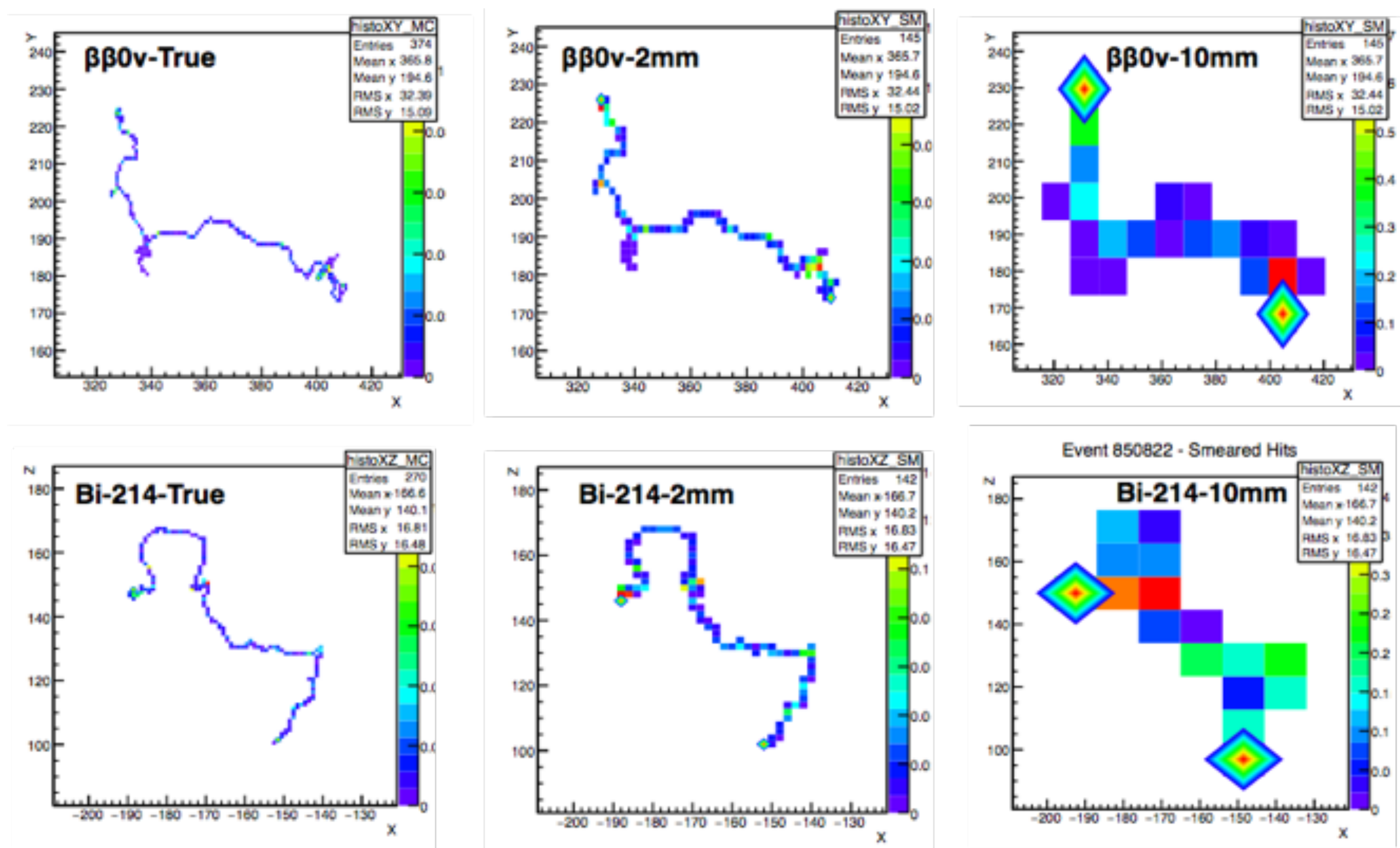
CO_2: 0.1 % (CH_4: 0.5 %) —> DT < 1.5 mm

CO_2: 0.05 % (CH_4: 0.25 %) —> DT < 2 mm

Quenching of light



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

Mixtures: summary

- Overall, it appears possible to reduce diffusion to ~2 mm by adding 0.05 % of CO_2.

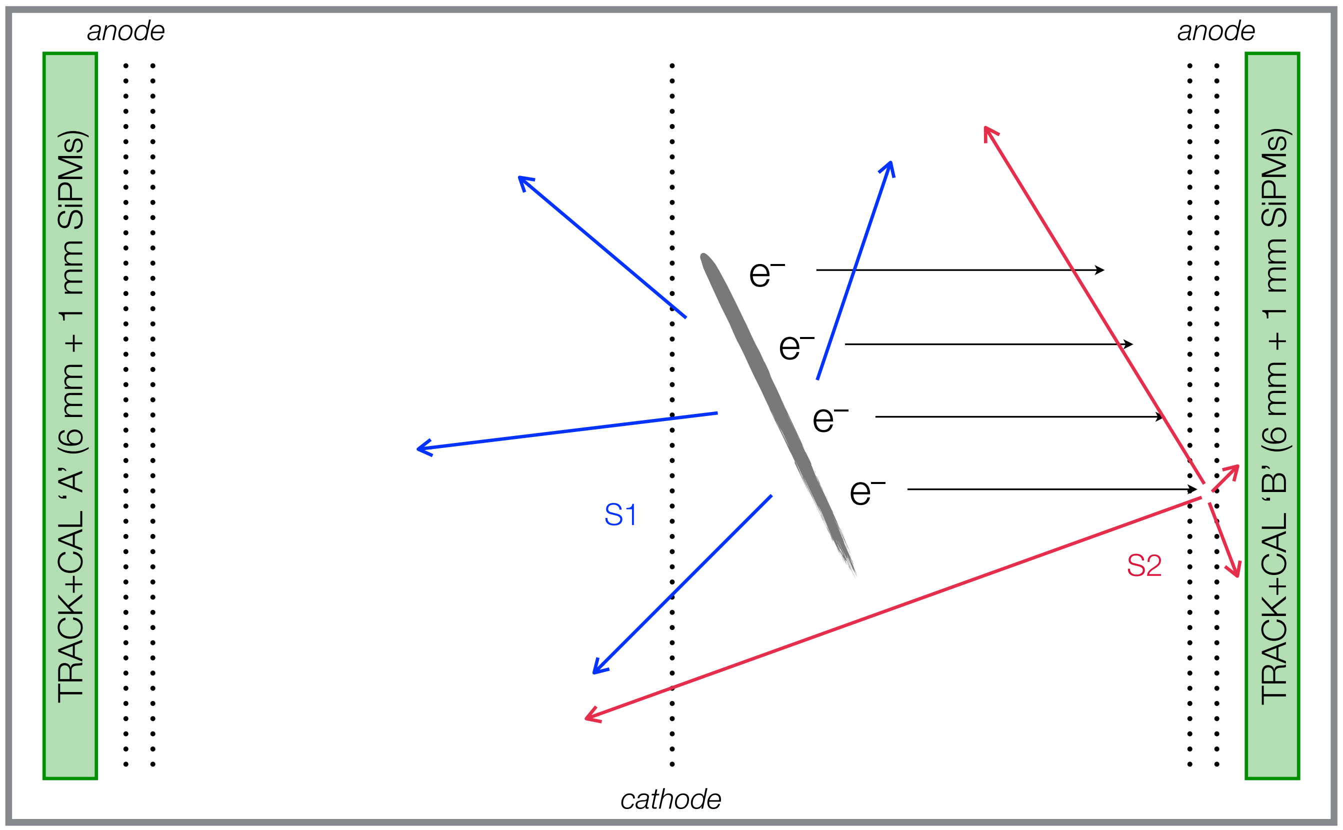
- The side effects on reduction of S1 and drift velocity appear tolerable.

- R&D campaign foreseen for the next 6 months: Detailed study of the effect of gas mixtures (CO_2, CH_4) in NEXT performance. What is the compromise between diffusion and energy resolution?

Replace PMTs by SiPMs

- PMTs are rather radioactive, do not tolerate well high pressure and do not work in a magnetic field.
- But recent developments in SiPM technology make it possible to replace them!
- New generation SiPMs have dark current and dark noise at the level of 50-100 kHz/mm^2 at ambient temperature.
- Dark current decreases a factor 2 per 10 degrees celsius colder. Cooling SiPMs to -10 degrees appears feasible and results in ~10 kHz/mm^2. OK for energy resolution

Symmetric TPC



- Replacing PMTs by SiPMs also allows to merge tracking and energy functions, by alternating SiPms of 1 mm^2 (for tracking) and 6 mm^2 (for energy).
- When an event is produced in the EL grid in front of plane B, SiPMs of 1 mm^2 (at a pitch of 7 mm) are readout for tracking, while SiPMs of 6 mm^2 (at a pitch of 7 mm) are readout for energy in plane A
- S1 is readout by both planes and gives extra information of the localisation of the event (in addition to t0)

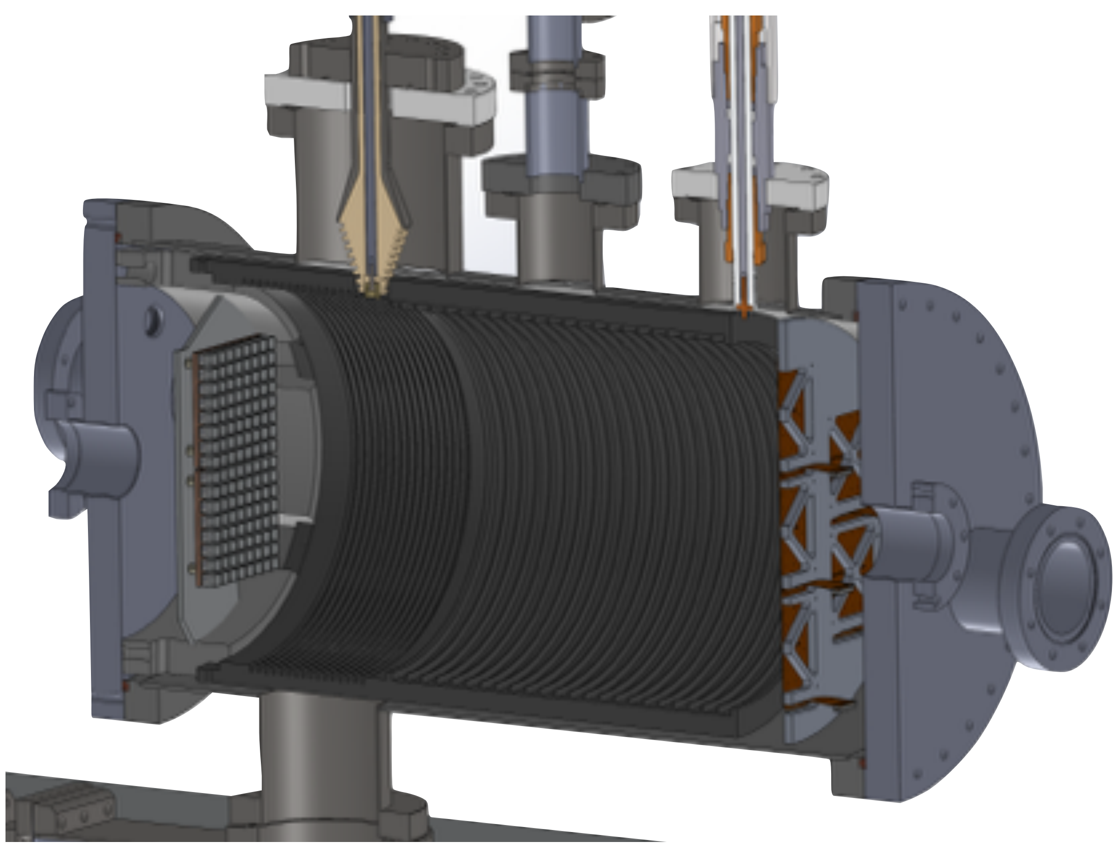
Upgrade NEXT

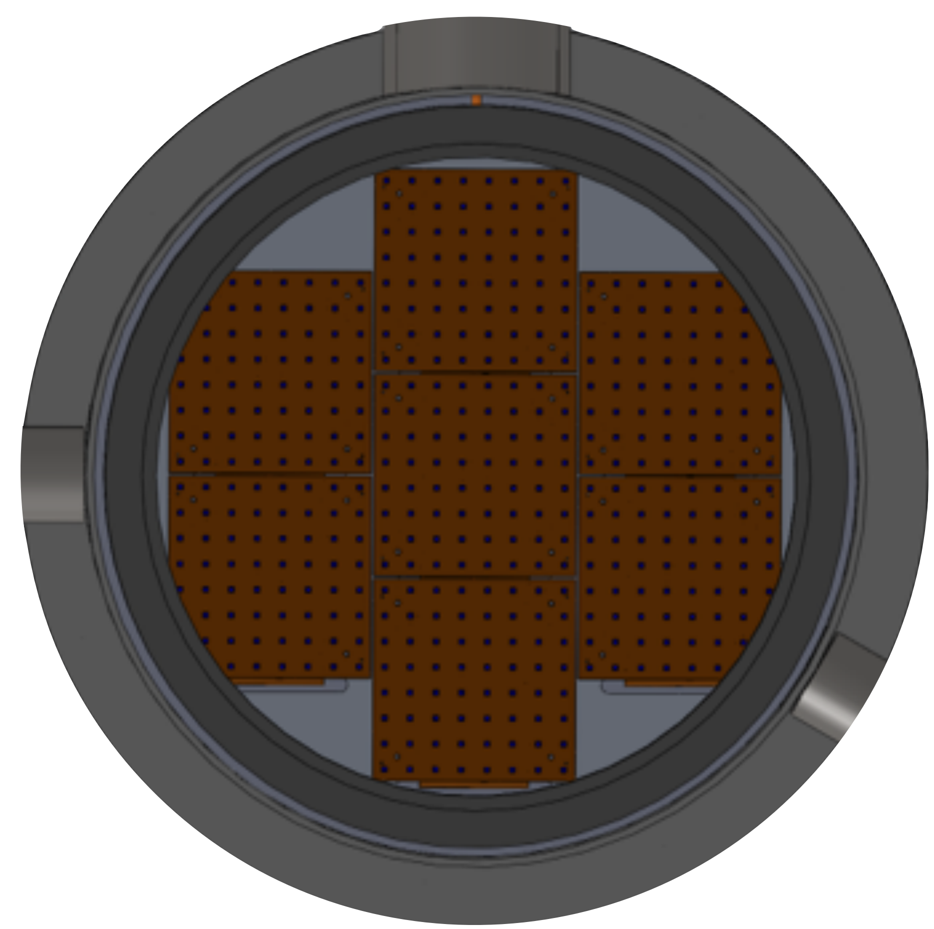
- Reduce diffusion to some 2 mm (e.g, 0.05 % of CO2)
- Symmetric TPC with mixed function planes.
- MC calculation shows that improvement of topological signature decreases background rate by a factor 4.
- PMTs are the dominant source in the background model. Replacing them by SiPMs could buy an extra factor of 2-3.
- Overall an addition rejection factor of 10, reaching 5x 10^{-5} ckky appears possible.

DEMO++

- Field Cage and HVFT using NEW design to increase active volume.

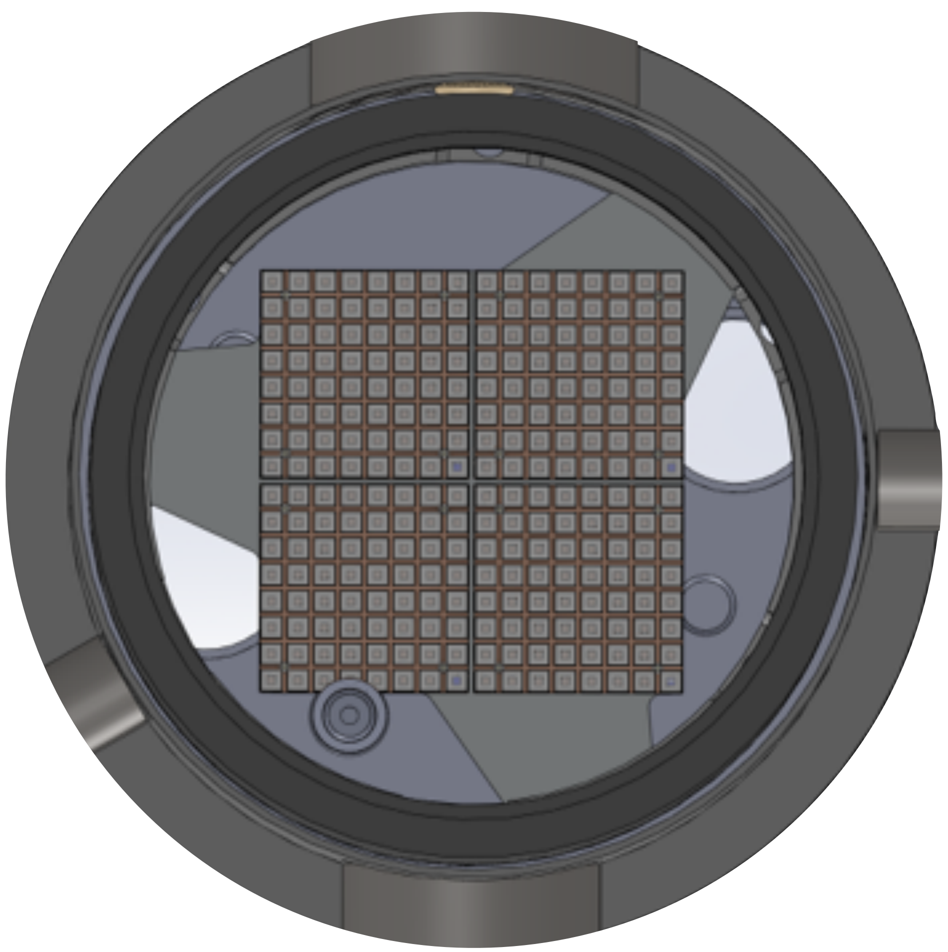
- Tracking plane with 7 DICE boards for a better coverage of the active volume.

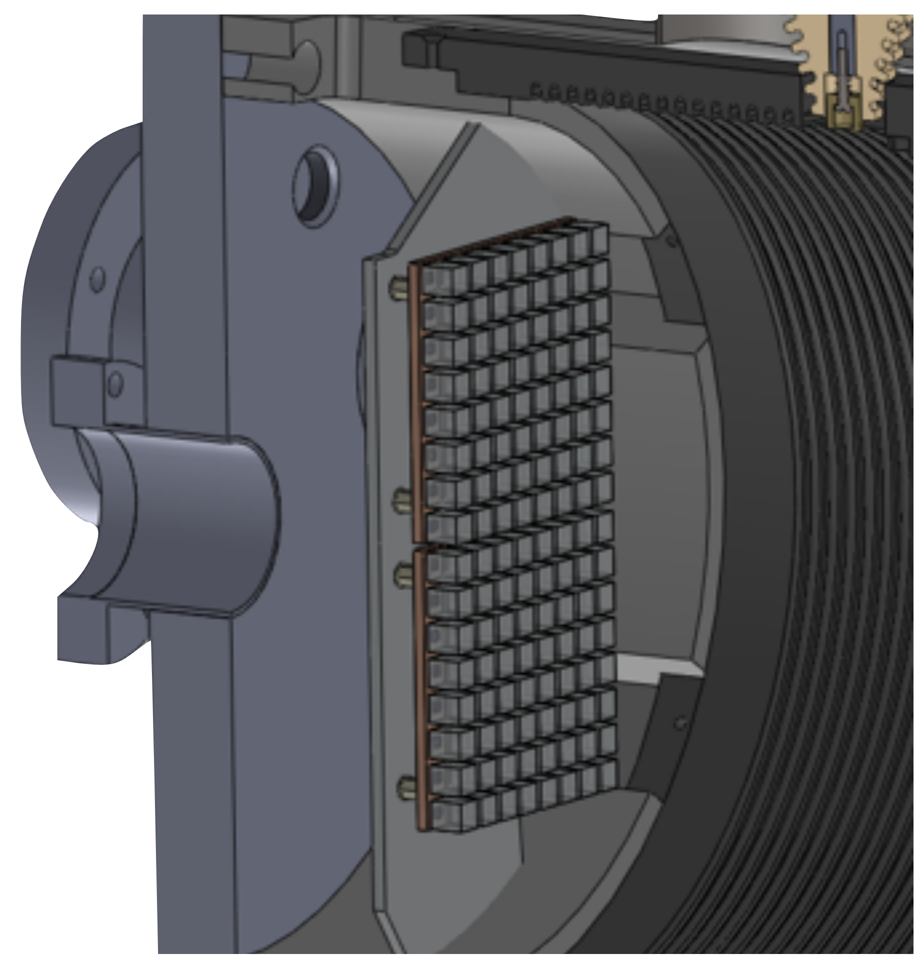




DEMO++

- Only SiPM inside the detector.
- Energy measurement performed using 3x3mm^2 SiPMs.
- Light concentrators (Wiston cones/lenses)





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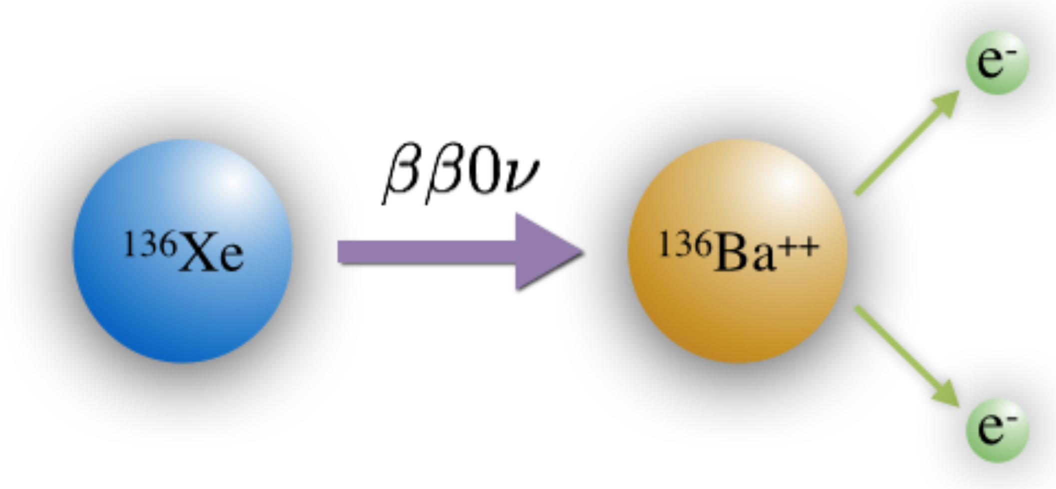

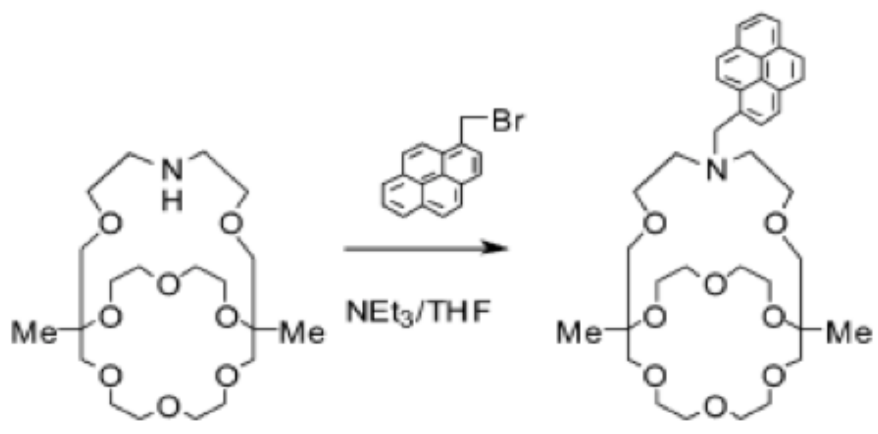

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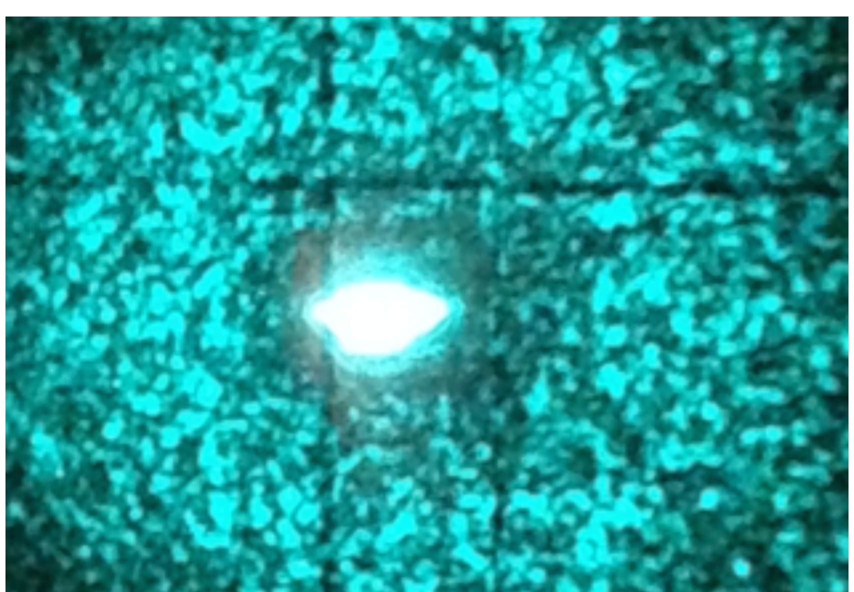
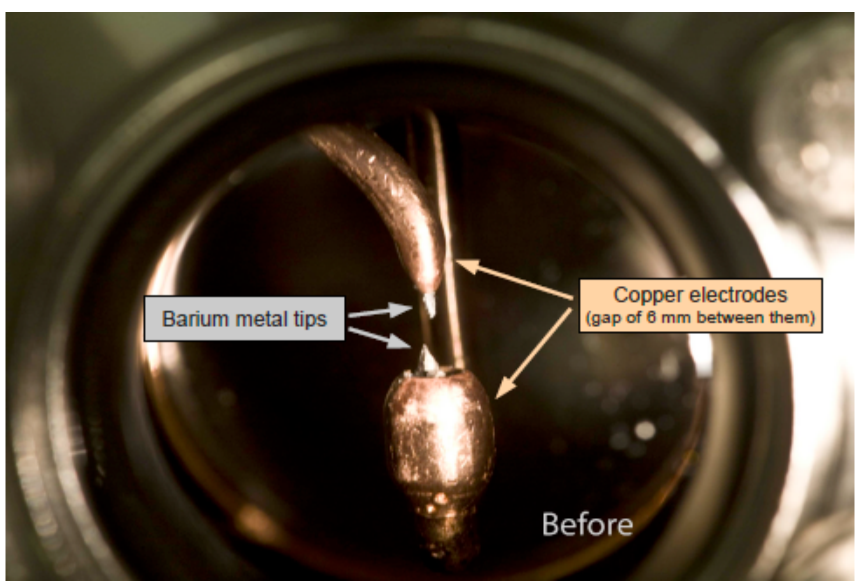


- Xe-136 decays produce Ba++
- Ba++ will drift towards cathode (hopefully without recombining)
- Coat cathode with PSMA molecule, which will capture BA++
- PSMA + BA++ will fluoresce when illuminated with 342 nm light (broad band, 360-430… can design a system to detect blue light. Interrogation rate 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.

MAGIX



- Experimental tests planned by 2016
- Ba++ by sparking Ba coated tips.
- Let Ba++ drift towards walls of a HP sphere.
- Illuminate with 330 nm led, and try to read 400 nm light.

Summary

- The NEXT project is moving forward. In particular, we have started the underground campaign with the commissioning of the NEW detector. New funding from Spanish ministry has been secured (1 M€). This adds to the existing AdG/ERC grant. Funds from the USA (U. Texas at UTA— Nygren) have also been made available at a significant level, reinforcing the very important US participation in the project.

- NEW will take data in 2016 and 2017. NEW will start operations in 2018.

- R&D on-going to understand effect of gas mixtures in TPS and the upgrade to a symmetric TPC readout by SiPMs only (upgrade DEMO prototype in 2016 and carry on studies). Test of performance in a magnetic field will follow (late 2016 or 2017). Also, start tests to understand the feasibility of the Molecule tagging concept.

- Even the most conservative upgrade (improving the TPS by reducing the diffusion, symmetric TPC) will result in a competitive detector for ton scale. Magnetic field or Molecule may result in a background free detector at the ton scale.

- The NEXT collaboration is seeking new partners to carry this ambitious program.