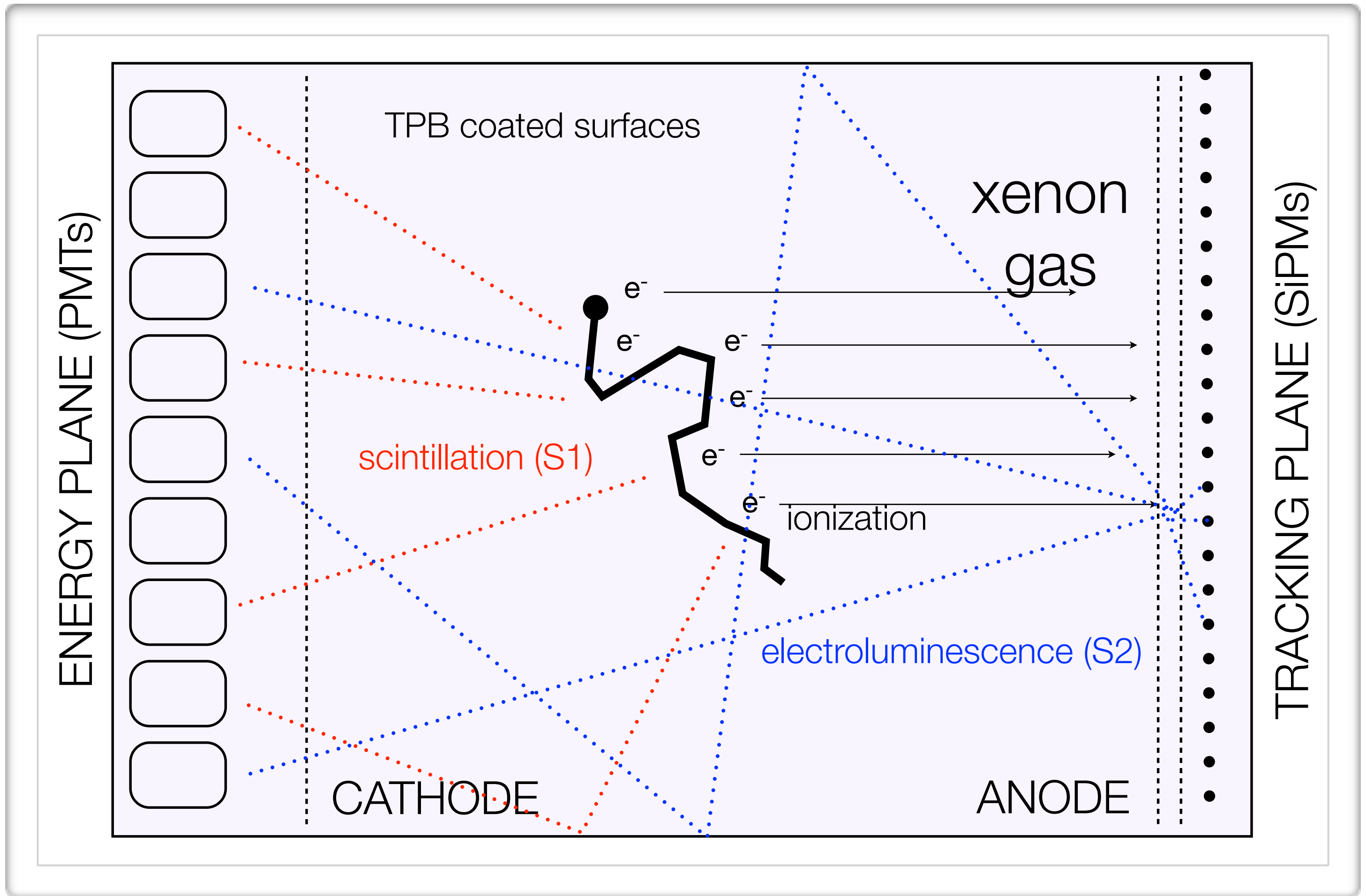
# The NEXT double beta decay experiment

Andrew Laing, IFIC (CSIC & UVEG)
*on behalf of the NEXT collaboration.*
*TAUP2015, Torino, 8/09/2015*

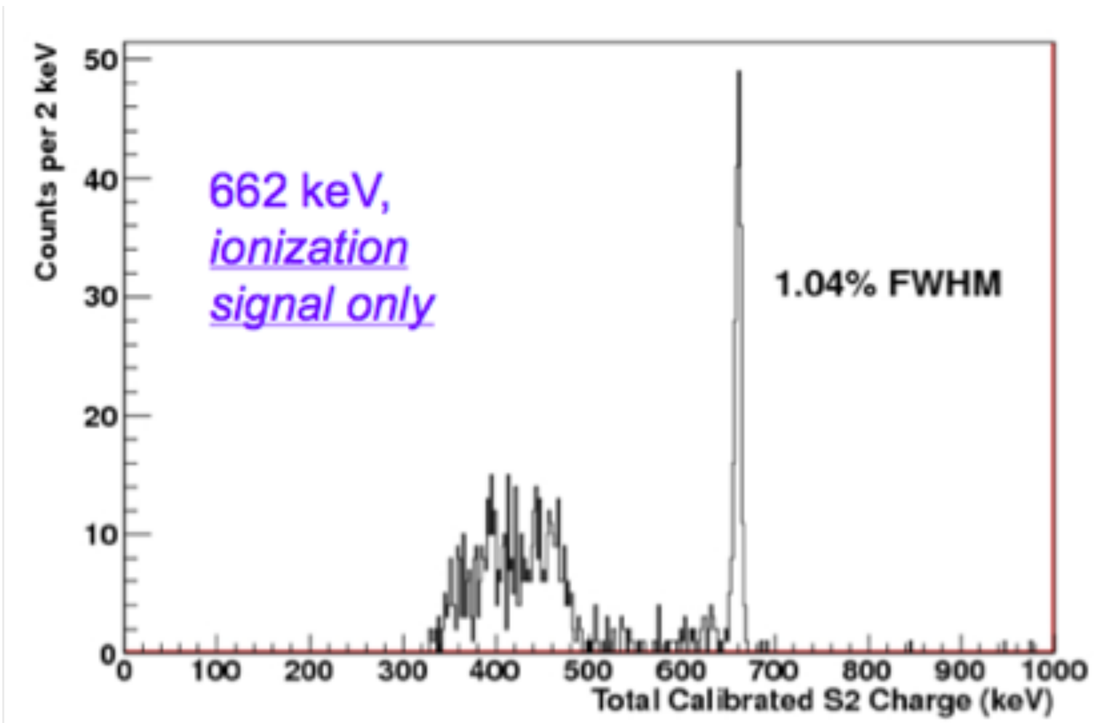
# NEXT: A light TPC

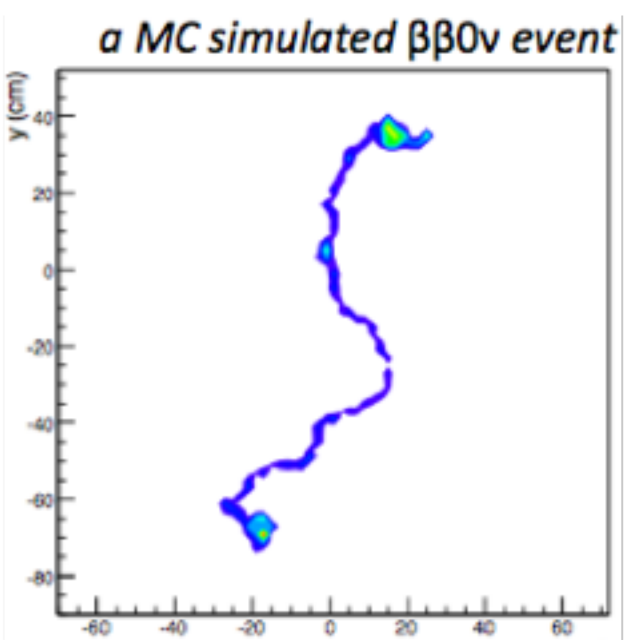


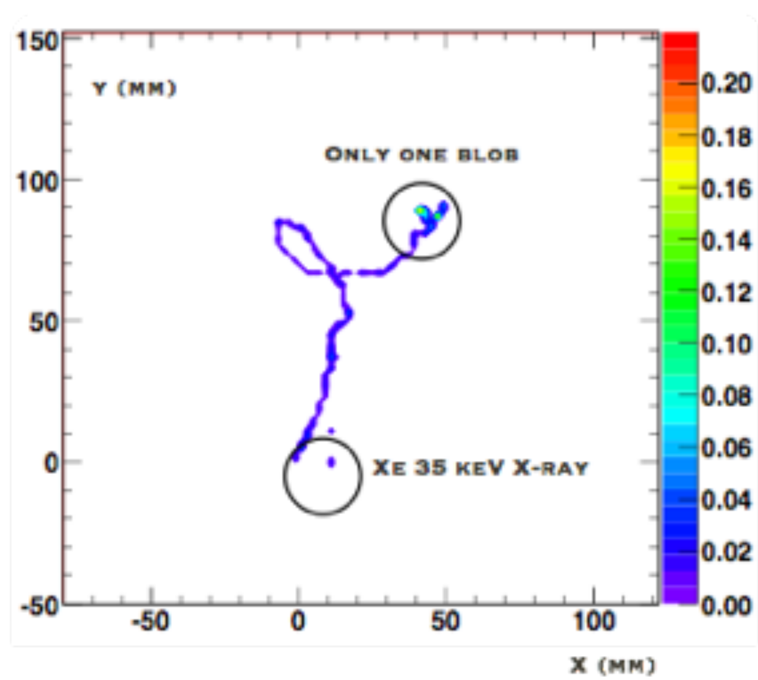

- A High Pressure Xenon (HPXe) TPC operating in EL mode.
- Filled with 100 kg of xenon enriched to 90% in Xe-136 (in stock) at a pressure of 15 bar.
- Event t0 is detected and its energy integrated by a plane of radiopure PMTs located behind a transparent cathode (energy plane).
- Event topology is reconstructed by a plane of radiopure silicon pixels (SiPMs) (tracking plane).

EL mode is essential for linear gain, avoiding avalanche fluctuations and fully exploiting the excellent Fano factor in gas

# NEXT: Advantages of technology

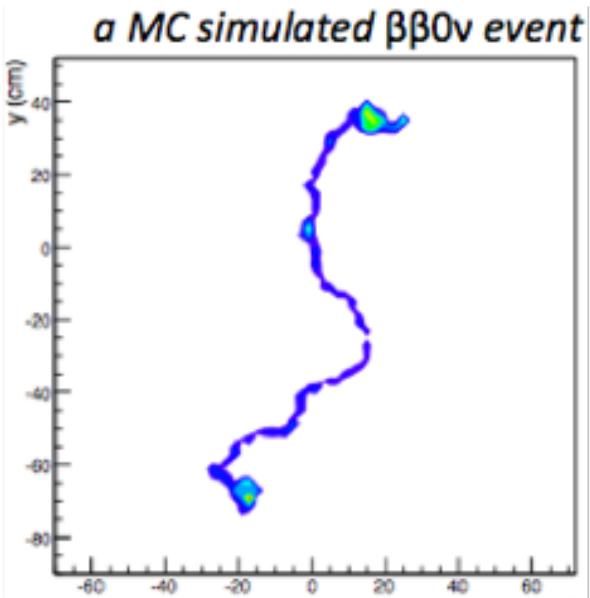


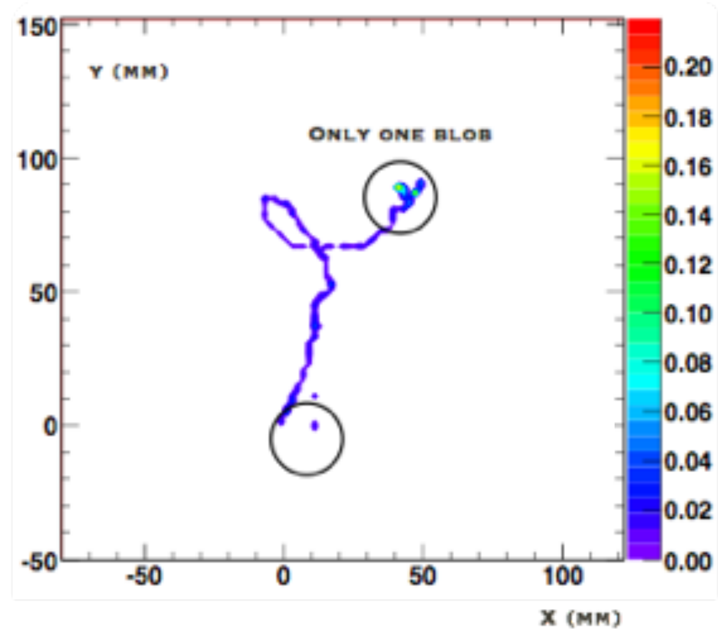



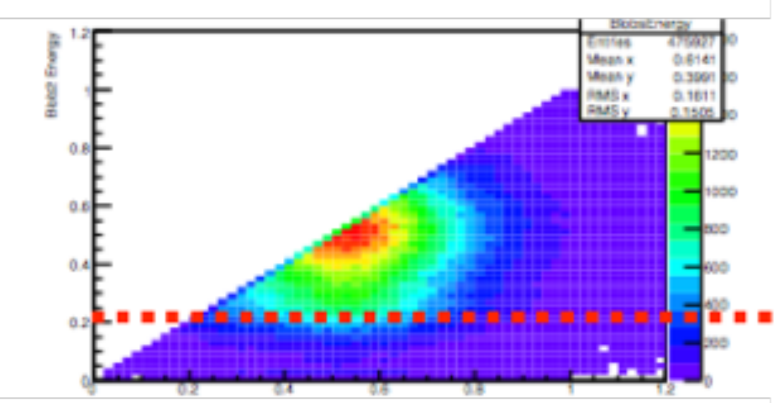

- Possible Excellent energy resolution due to low Fano factor in Xe gas.
  - ~1% FWHM measured at 662 keV by NEXT prototypes, extrapolates to 0.5 % FWHM at Qββ.
- Topological signature: the ability to distinguish between signal (“double electrons”) and background (“single electrons”).
- TPC: scalable. 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).

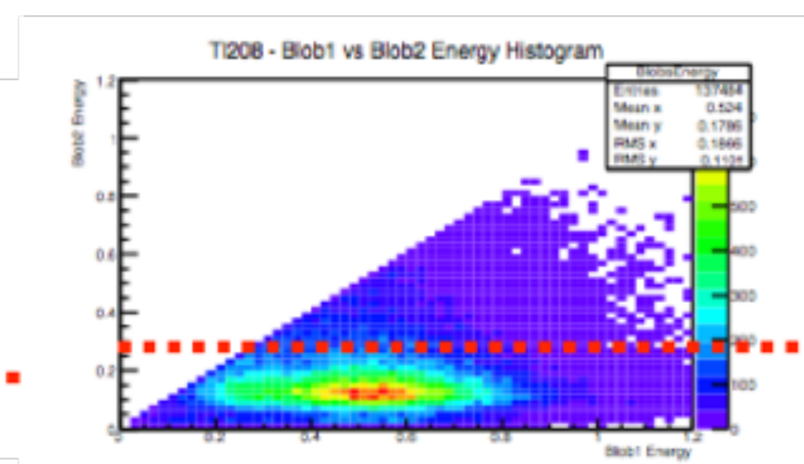
# Topological signature




- 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.

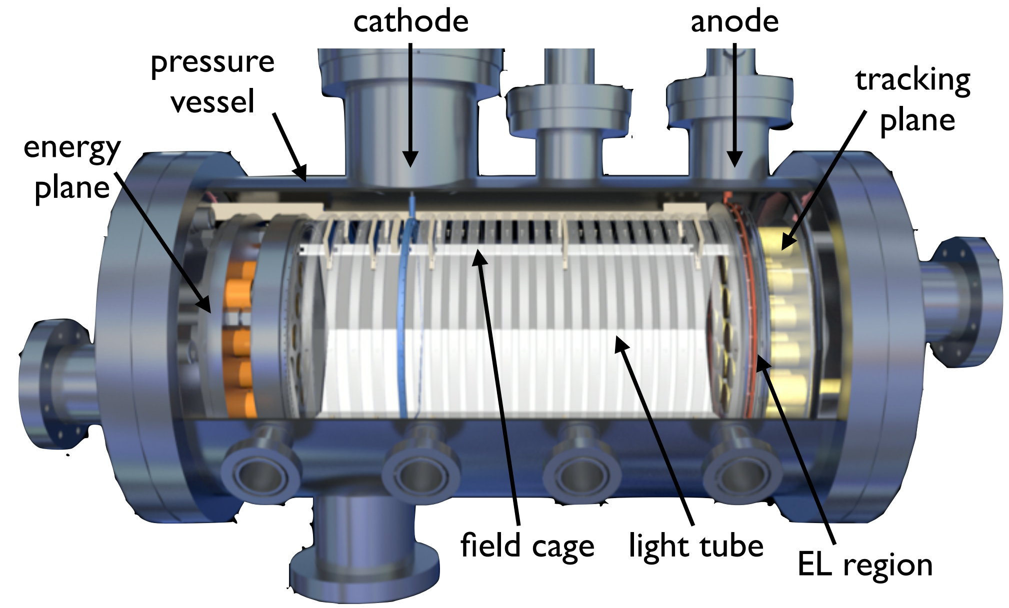


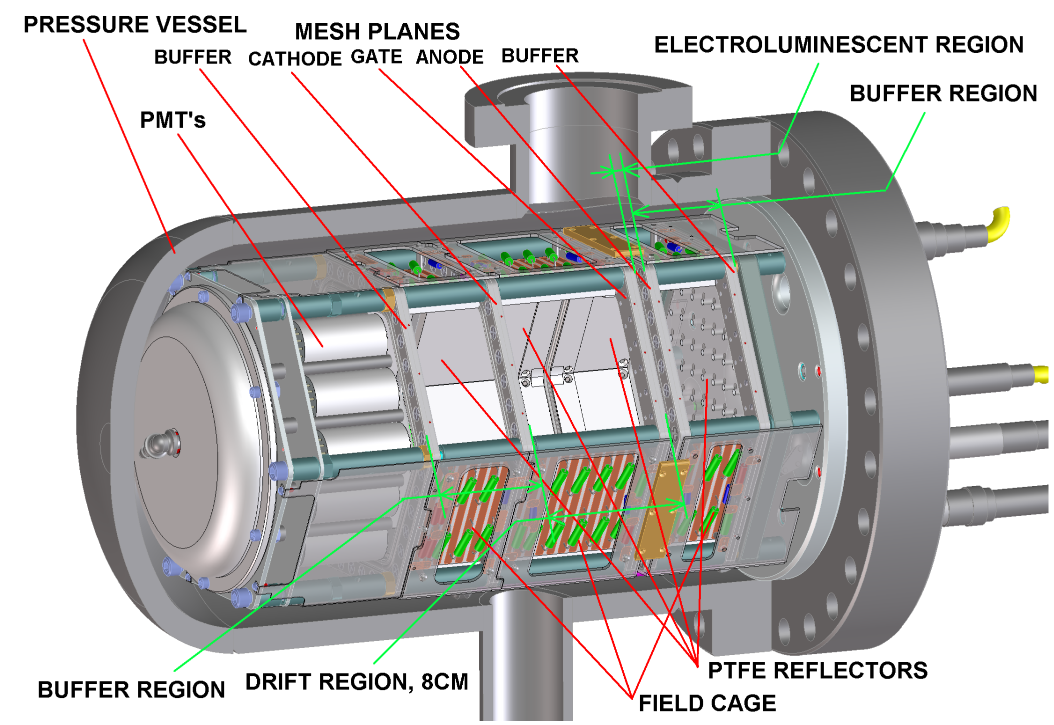



Topological signature: Identify ‘single tracks’ and compare the energies at the two end points to separate single from 2 electron tracks.

# R&D: Up to 2014

- **NEXT-DEMO:**
    - ~1.5 kg natural xenon at 10 bar.
    - 19 1 inch PMTs behind cathode.
    - Array of 256 SiPMs behind anode.
    - Internal surfaces coated with TPB.
- **NEXT-DBDM:**
    - ~1 kg natural xenon at 20 bar.
    - 19 1 inch PMTs behind cathode.
    - Reflective plate behind anode

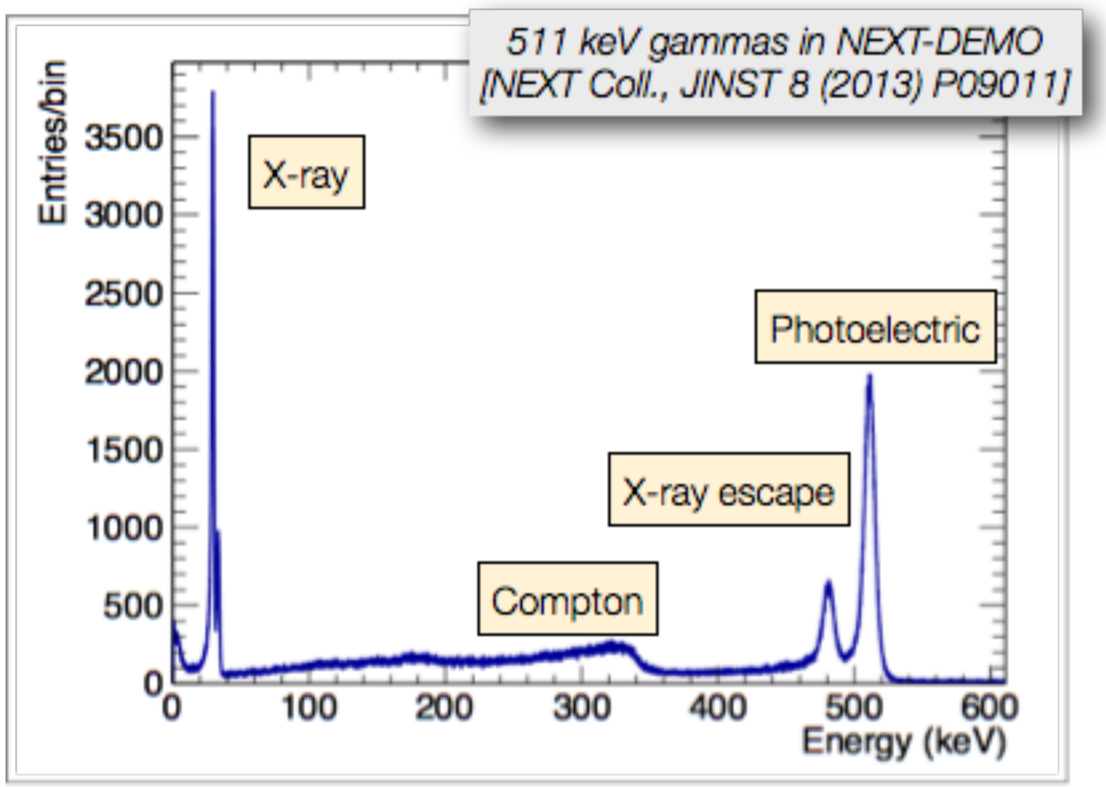


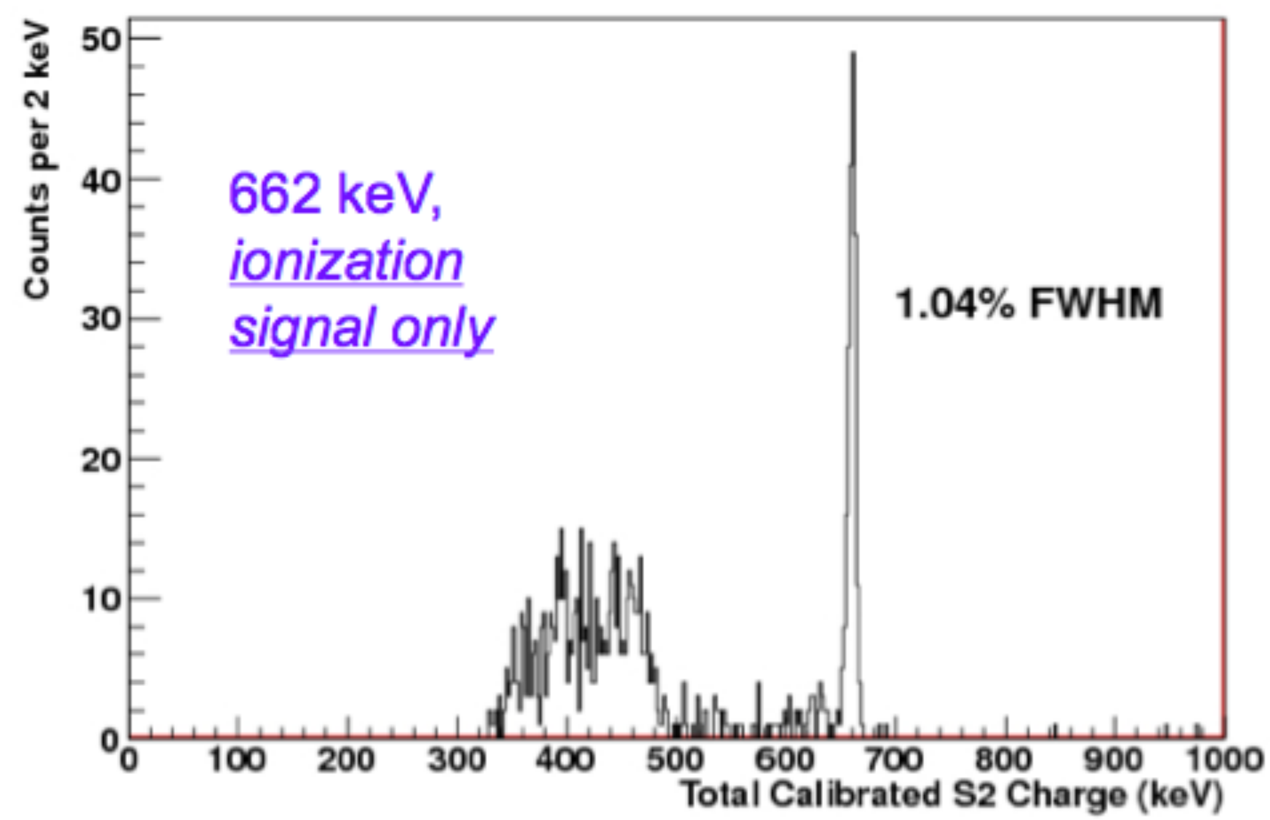




**Simultaneous running to verify technology and physics for electron, alpha and nuclear recoil detection.**

Nucl.Inst.Meth A708 (2013), JINST 8 (2013) P04002
JINST 8 (2013) P09011, JINST 10 (2015) 03, P03025
Nucl.Inst.Meth A793 (2015)

# Energy Resolution

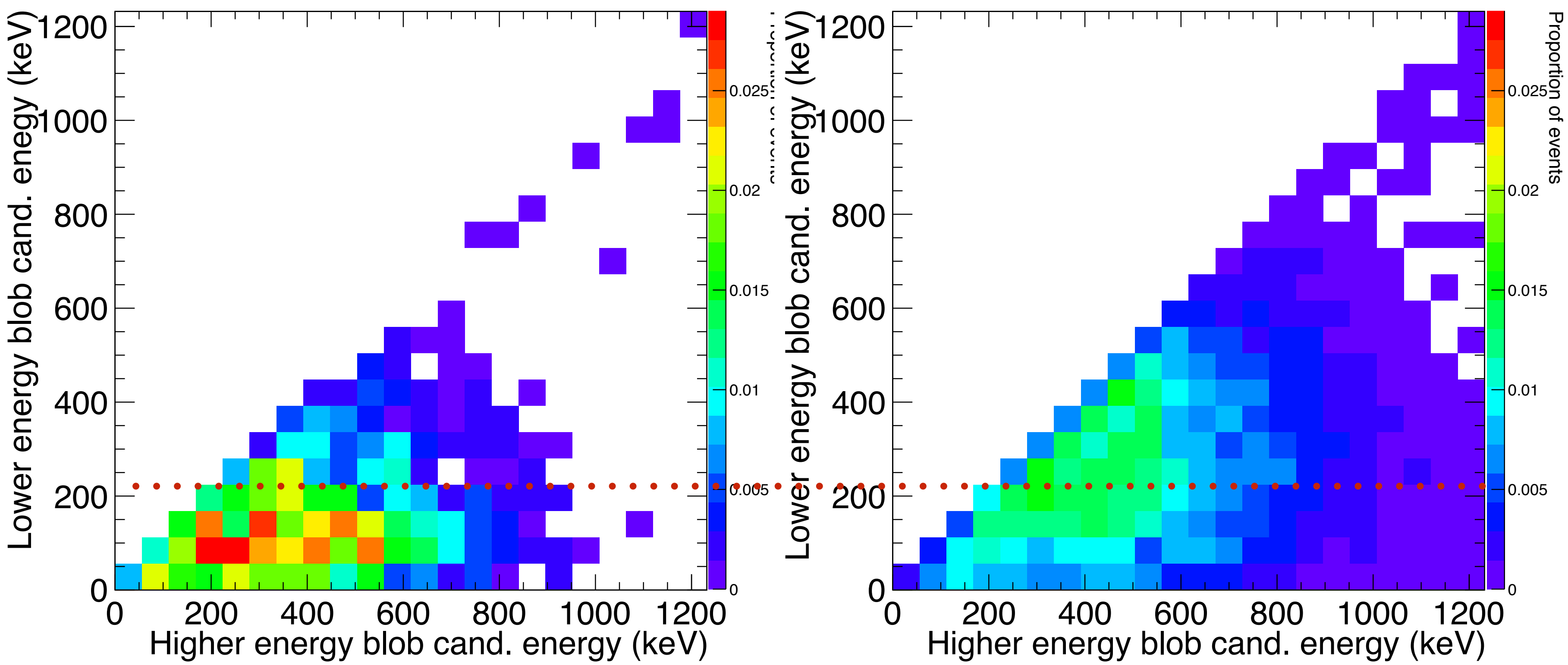



Energy resolution measured with prototypes DEMO (IFIC) DBDM (LBNL) extrapolates to 0.5 — 0.7 % FWHM at $Q_{\beta\beta}$

Energetic reconstruction performed using a calibration using point like deposits: X-ray or Krypton run: JINST 9 (2014) 10, P10007

# Validation of Topological signal with DEMO




**Basic two blob separation in data for (left) 1.275 MeV gammas and (right) pair production + Compton gammas.**

Topological rejection has been verified using DEMO data.

Used $e^+e^-$ events in the Tl-208 double escape peak at 1.592 MeV as a model signal and Na-22 1.275 MeV gammas as model background.

3D reconstruction in 1x1x1 $cm^3$ voxels. Simple clustering algorithm.

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

75% background rejection consistent with the 90% prediction for the 0νββ ROI according to simulation.

arXiv:1507.05902, submitted to JHEP

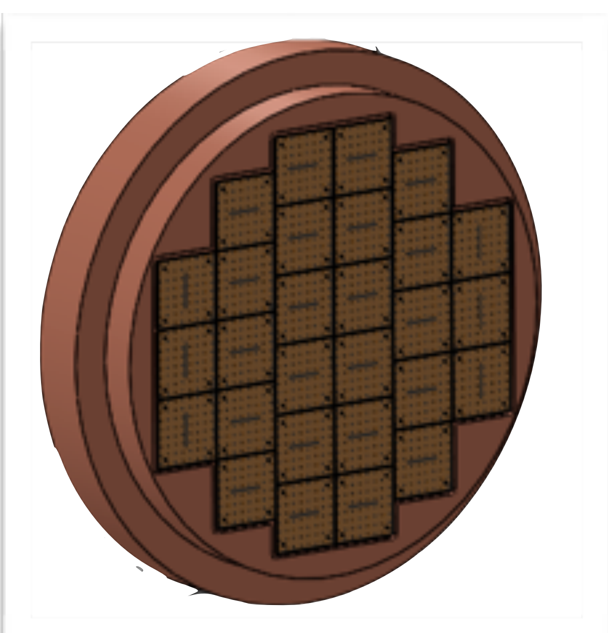
# NEW (NEXT-WHITE) at glance

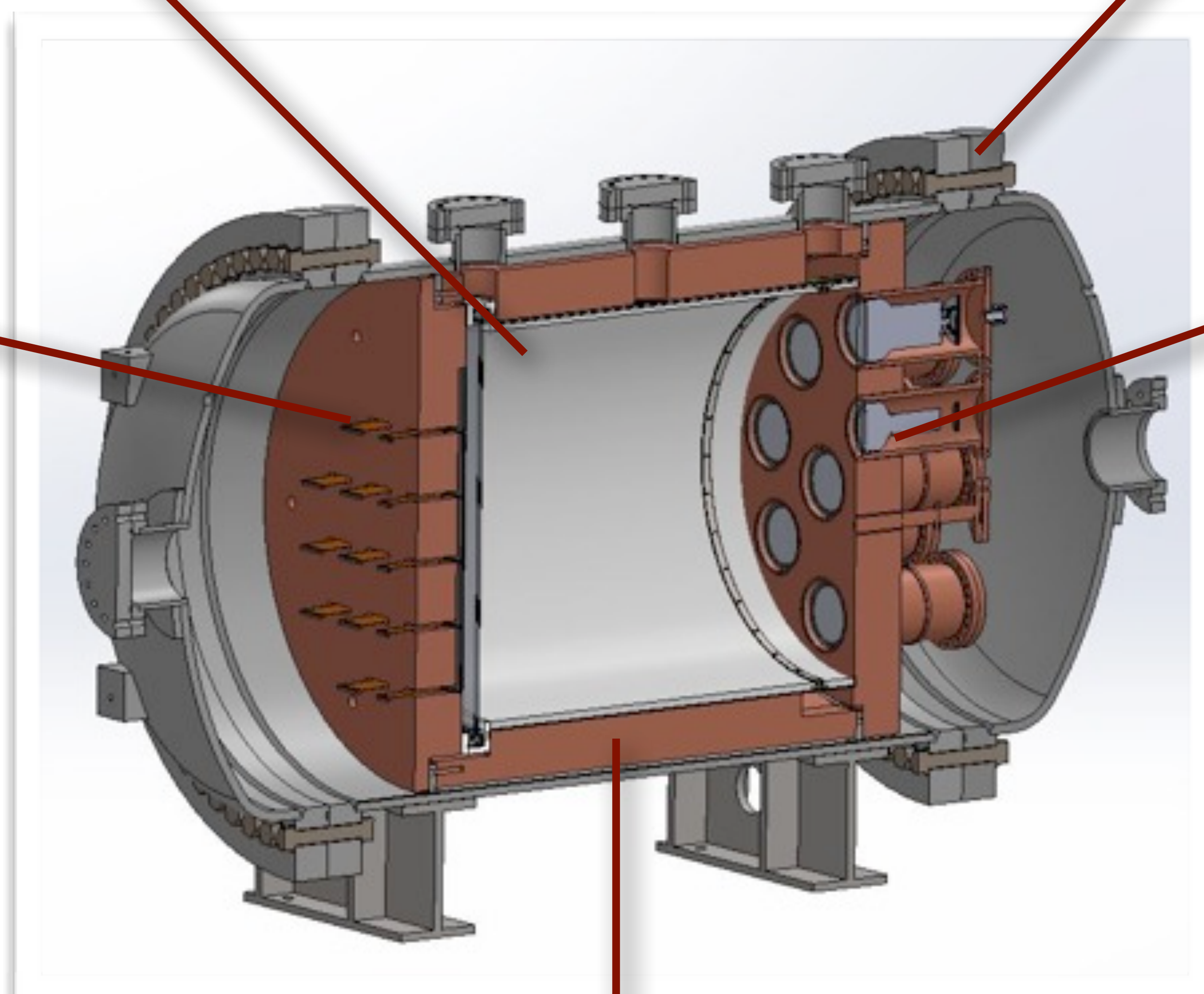
**Time Projection Chamber:**
10 kg active region, 50 cm drift length

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

**Tracking plane:**
1,800 SiPMs,
1 cm pitch

**Energy plane:**
12 PMTs,
30% coverage

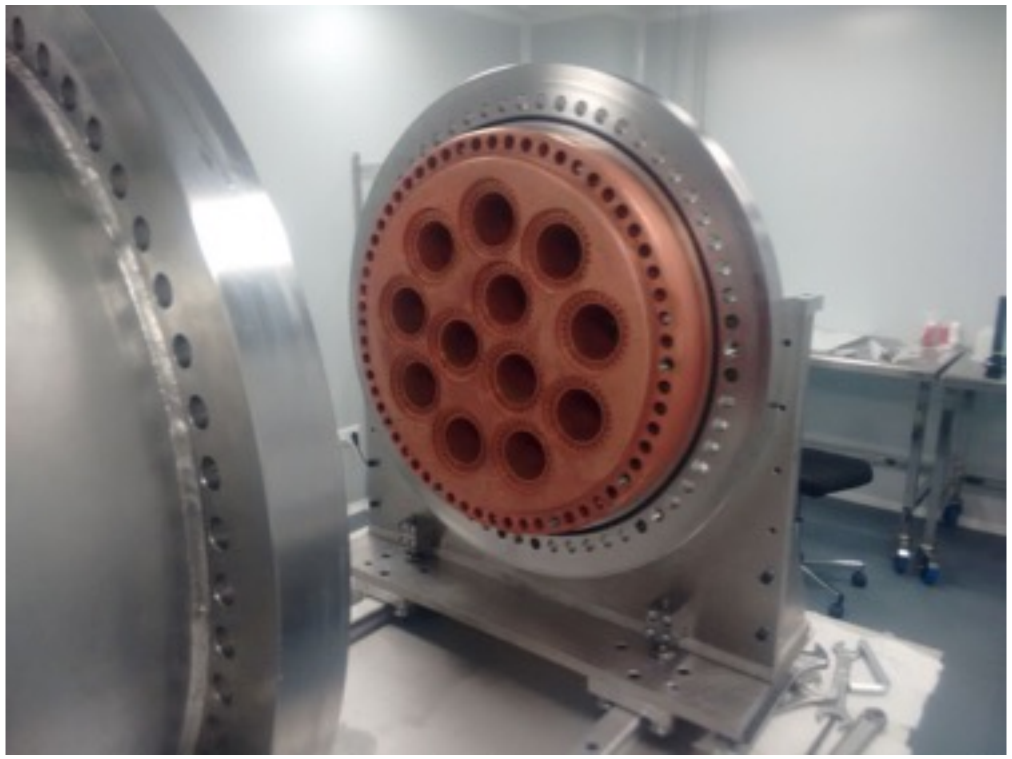


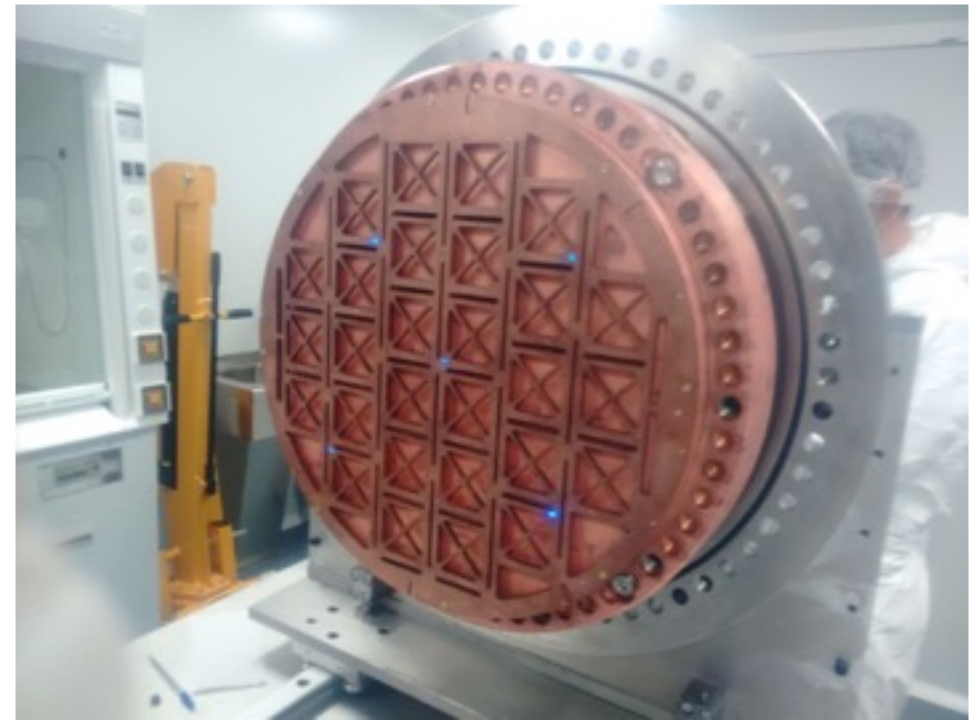


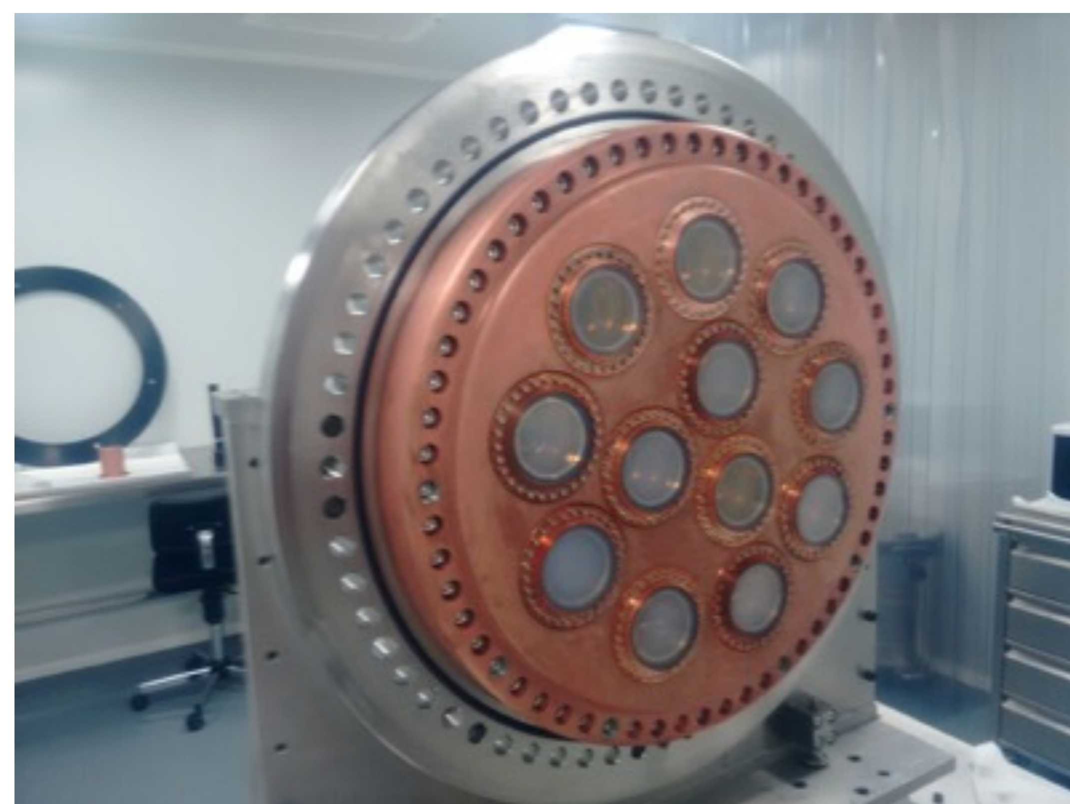
**Inner shield:**
copper, 6 cm thick

Installation well underway at LSC

# Energy Plane installation (July 2015)







# NEW at LSC

- Installation begun:
  - Energy plane (EP) installed July 2015.
  - Commissioning of EP Sept. 2015.
  - Tracking plane installation Oct. 2015.
  - Field cage installation Nov. 2015.
- Commissioning of full set-up in December.
- Calibration in first half of 2016.

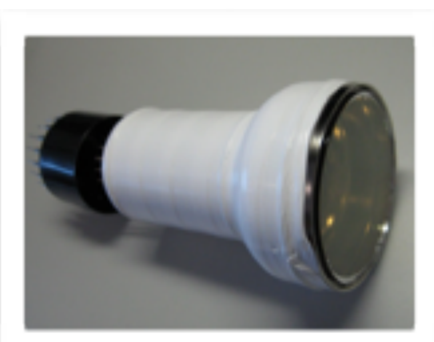
- NEW will be used to verify calibration and resolution studies in radiopure detector and make first analysis of 2 neutrino decay.
  - Is the background model good?

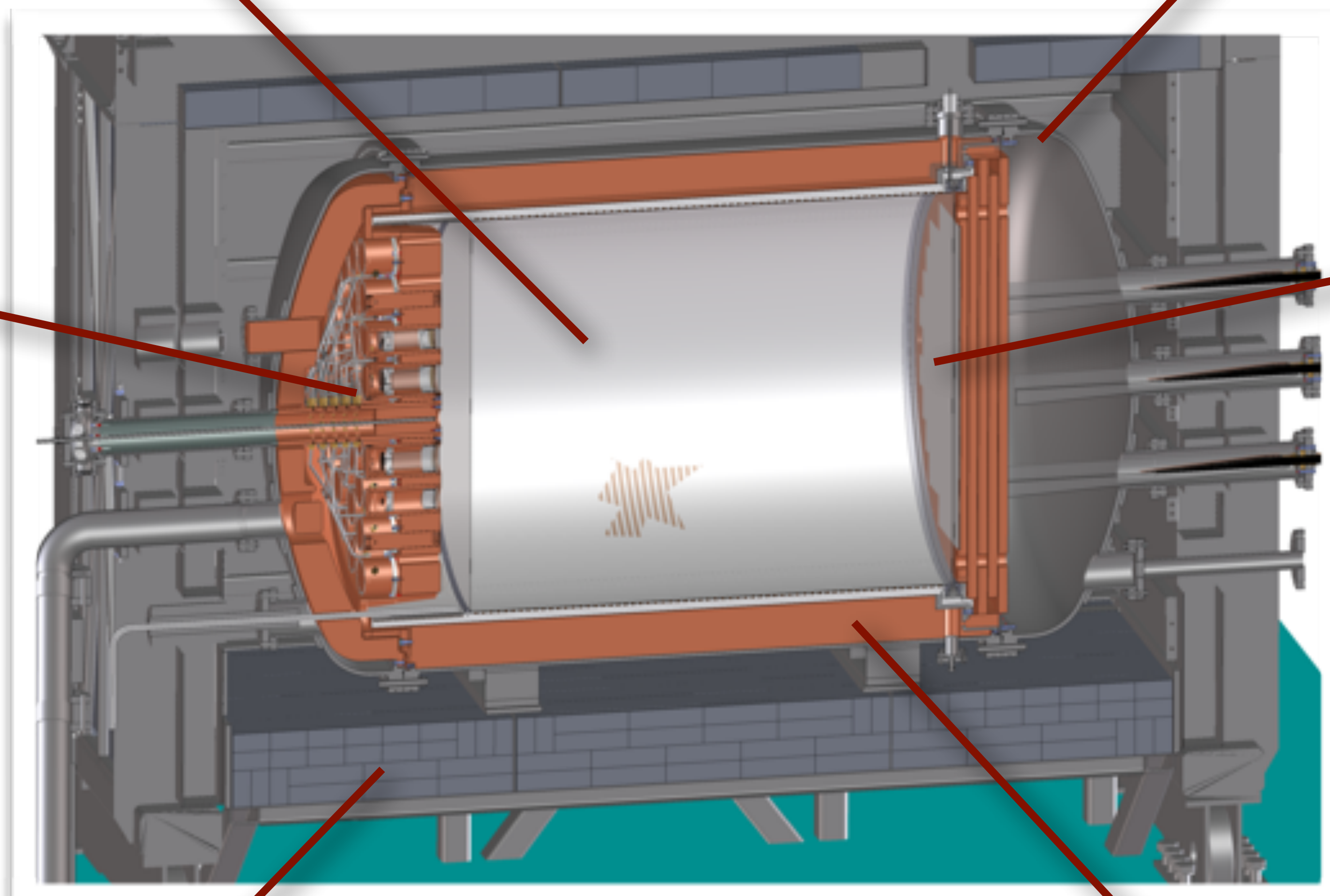
# NEXT 100 kg detector at LSC: main features

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

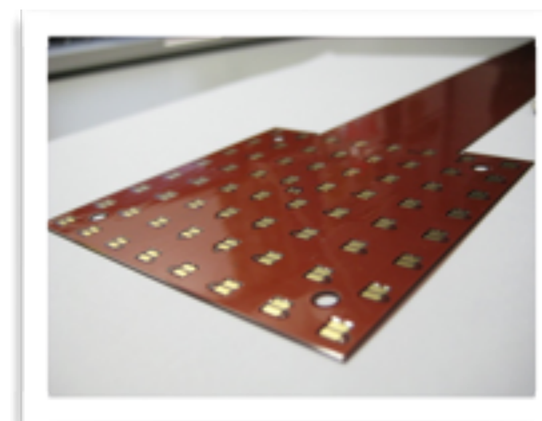
**Pressure vessel:**
stainless steel,15 bar max pressure

**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

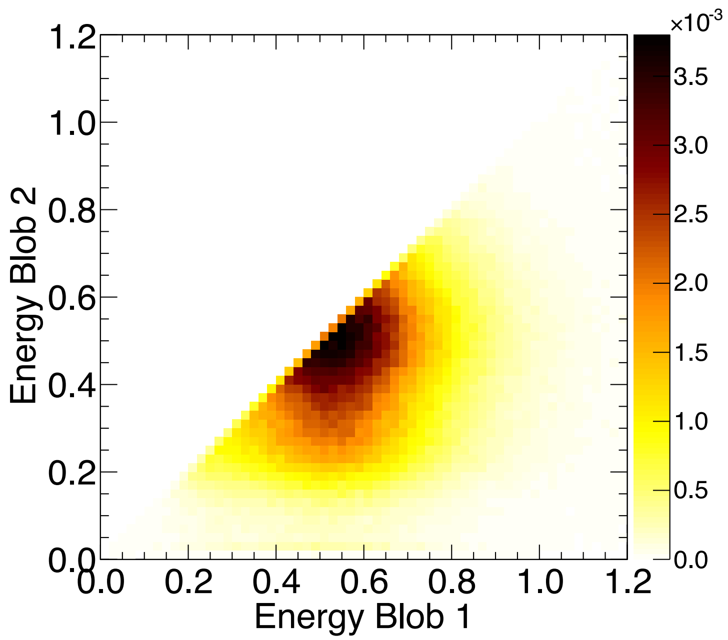
# NEXT-100 material screening

An extensive screening of materials for NEXT-100 (and NEW) has been performed by the collaboration

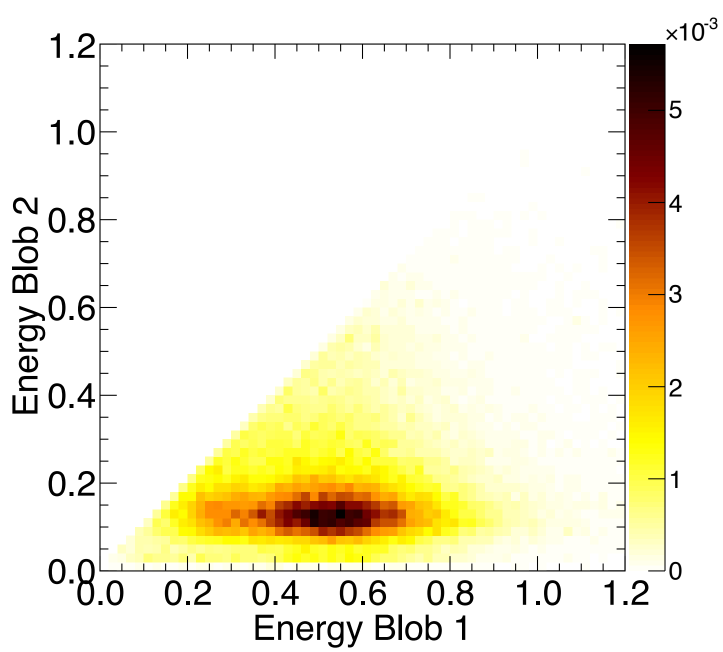
| Material | Subsystem | Technique | Units | $^{208}$Tl | $^{214}$Bi |
|---|---|---|---|---|---|
| Copper (CuA1) | IS, EP, FC | GDMS | mBq/kg | $< 0.0014$ | $< 0.012$ |
| Fused silica | FC | NAA | mBq/kg | 0.034(4) | 0.21(5) |
| Kapton board | TP | HPGe | mBq/unit | 0.0104(11) | 0.070(5) |
| Lead | OS | GDMS | mBq/kg | 0.034(7) | 0.35(7) |
| PMT R11410-10 | EP | HPGe | mBq/PMT | 0.30(9) | $< 0.94$ |
| Polyethelene | FC | ICPMS | mBq/kg | $< 0.0076$ | $< 0.062$ |
| Resistor (1 G$\Omega$) | FC | HPGe | mBq/unit | 0.000011(6) | 0.00009(4) |
| Sapphire | EP | NAA | mBq/unit | 0.04(1) | $< 0.31$ |
| Steel (316Ti) | PV | GDMS, HPGe | mBq/kg | $< 0.15$ | $< 0.46$ |
| SiPM SensL | TP | HPGe | mBq/unit | $< 0.00003$ | $< 0.00009$ |

Screening campaign in NEXT: results for main components Summarised in JINST 10 (2015) 05, P05006.

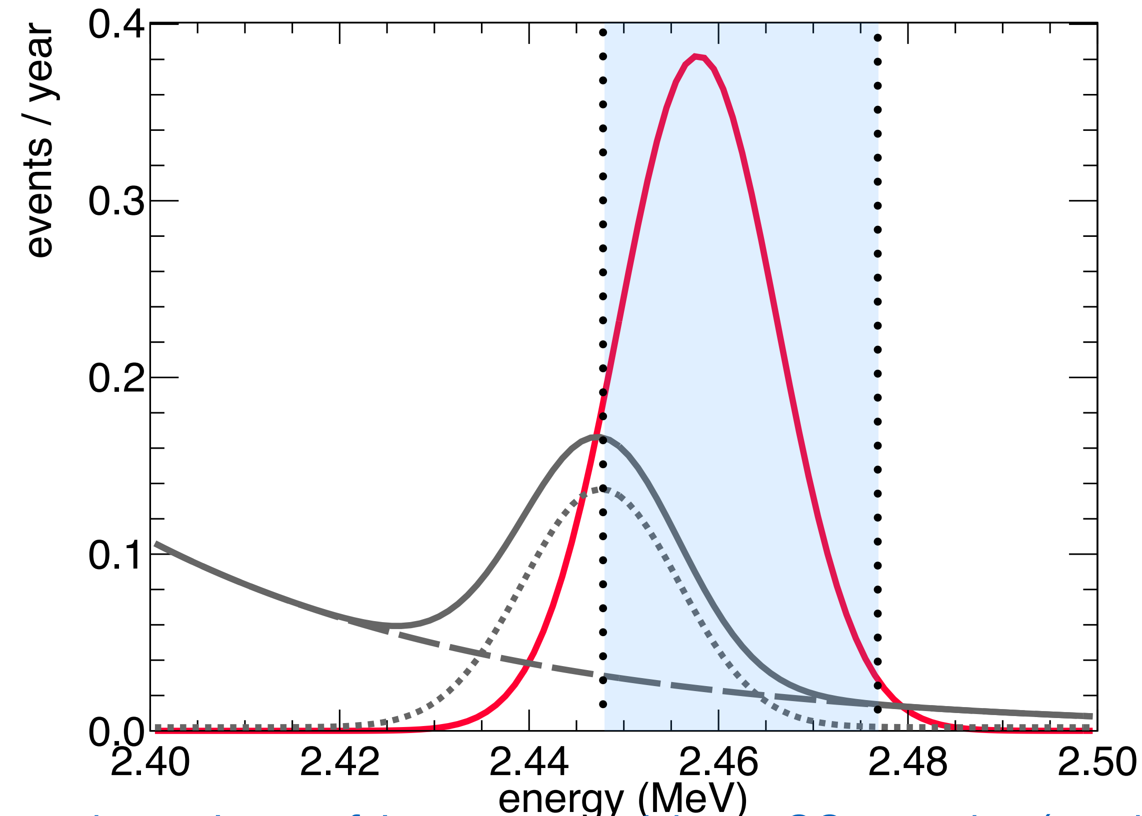
# PERFORMANCE




End point energies for signal




End point energies for single gamma background

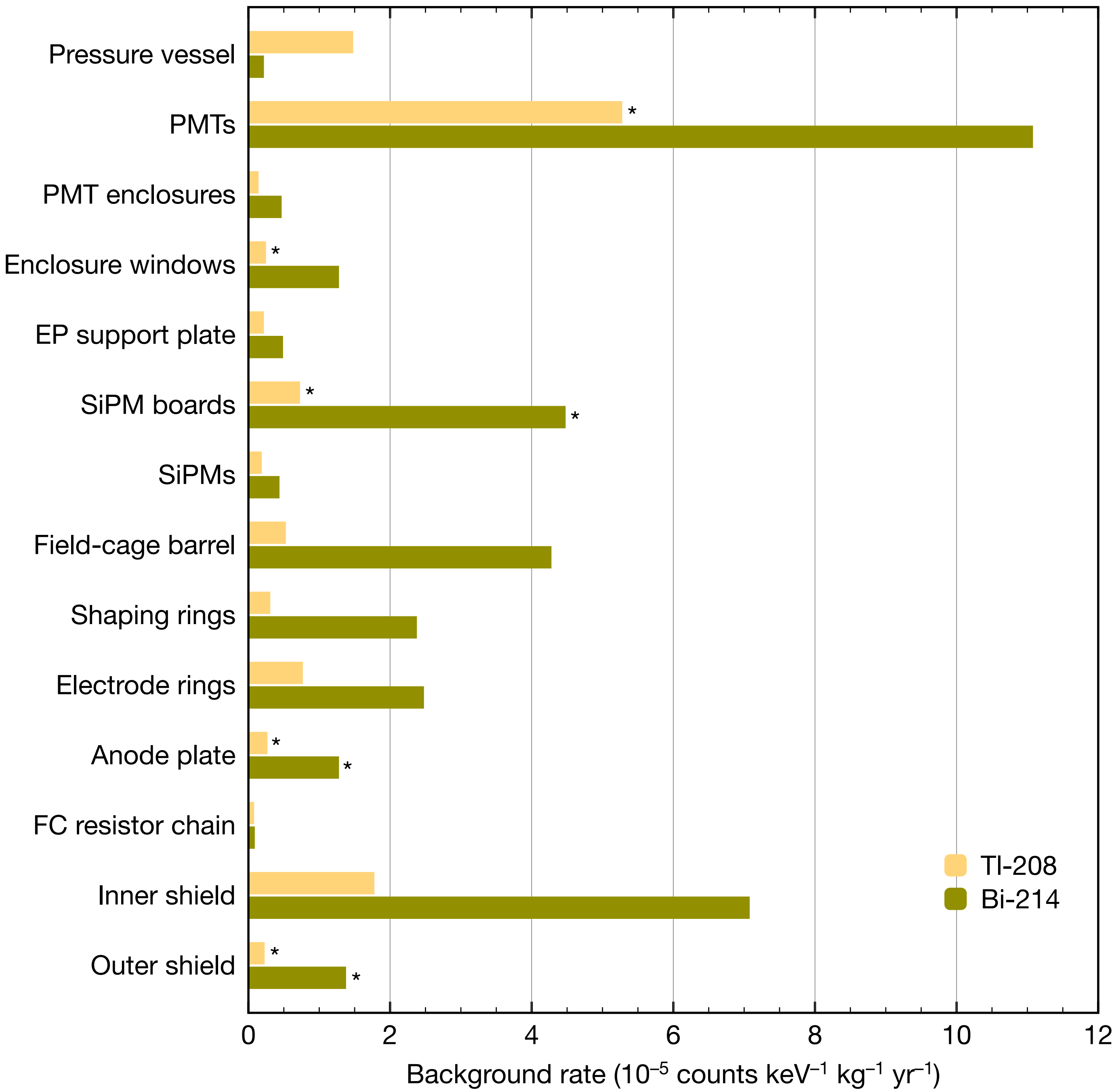



Selected region of interest with $0\nu\beta\beta$ peak (red) and backgrounds from Th and Bi gammas (grey dash, dot resp.) scaled for expectation for an exposure of 91 kg yr for $m_{\beta\beta}$ = 200 meV. Resolution 75% FWHM at $Q_{\beta\beta}$

| 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 | $8.06 \times 10^{-9}$ | $2.83 \times 10^{-5}$ | $1.04 \times 10^{-5}$ |
| Track with 2 blobs | 0.6851 | 0.6851 | 0.1141 | 0.105 |
| Energy ROI | 0.8661 | $3.89 \times 10^{-5}$ | 0.150 | 0.457 |
| *Total* | 0.2824 | $2.15 \times 10^{-13}$ | $4.9 \times 10^{-7}$ | $4.9 \times 10^{-7}$ |

**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



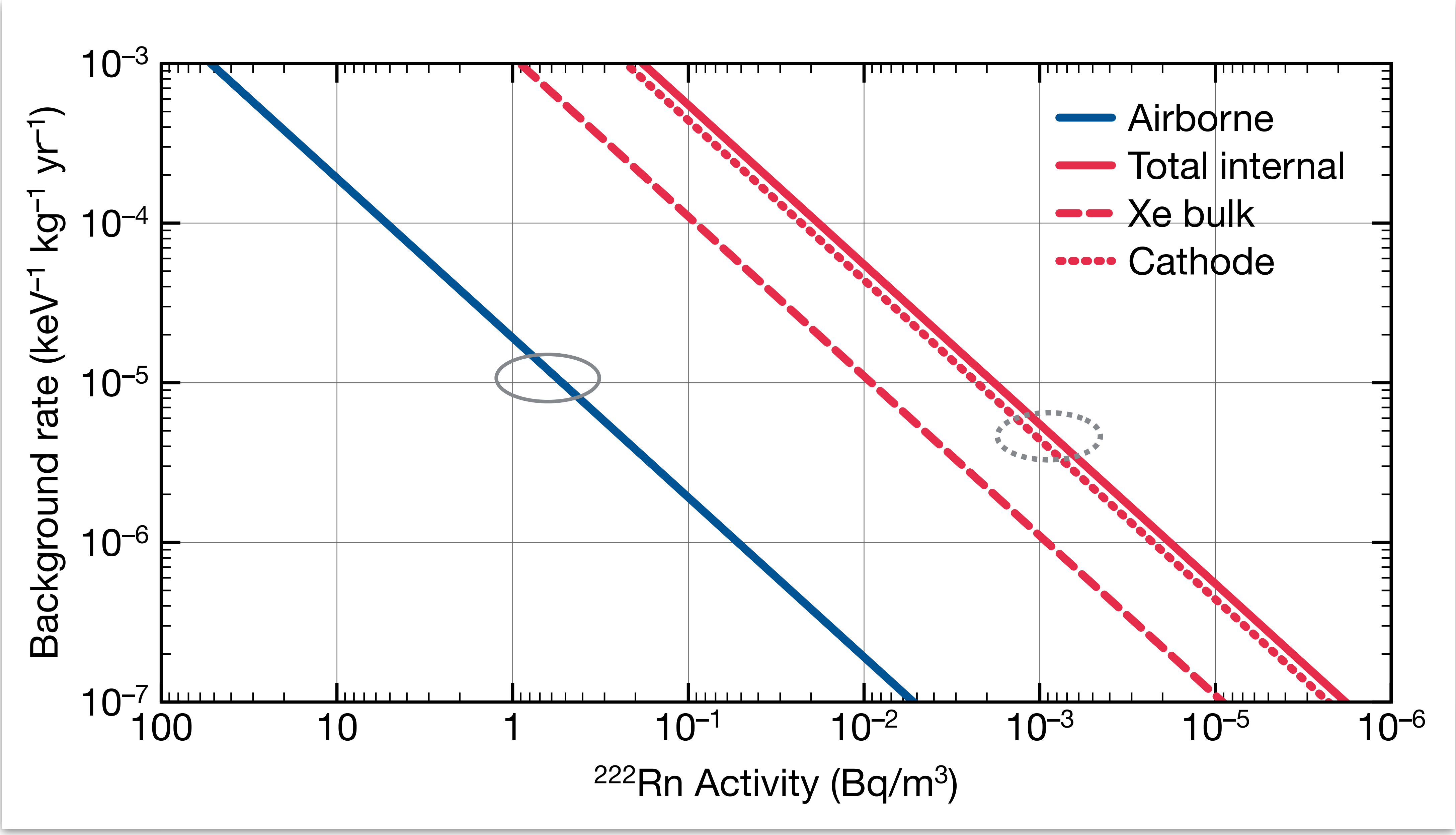

Overall background rate estimated at < 5 x $10^{-4}$ ckky

Largest contributions (particularly from Bismuth) come from components where only an upper limit on activity known.

Conservative limit set here. Improvements will be made with NEW and NEXT-100 data.

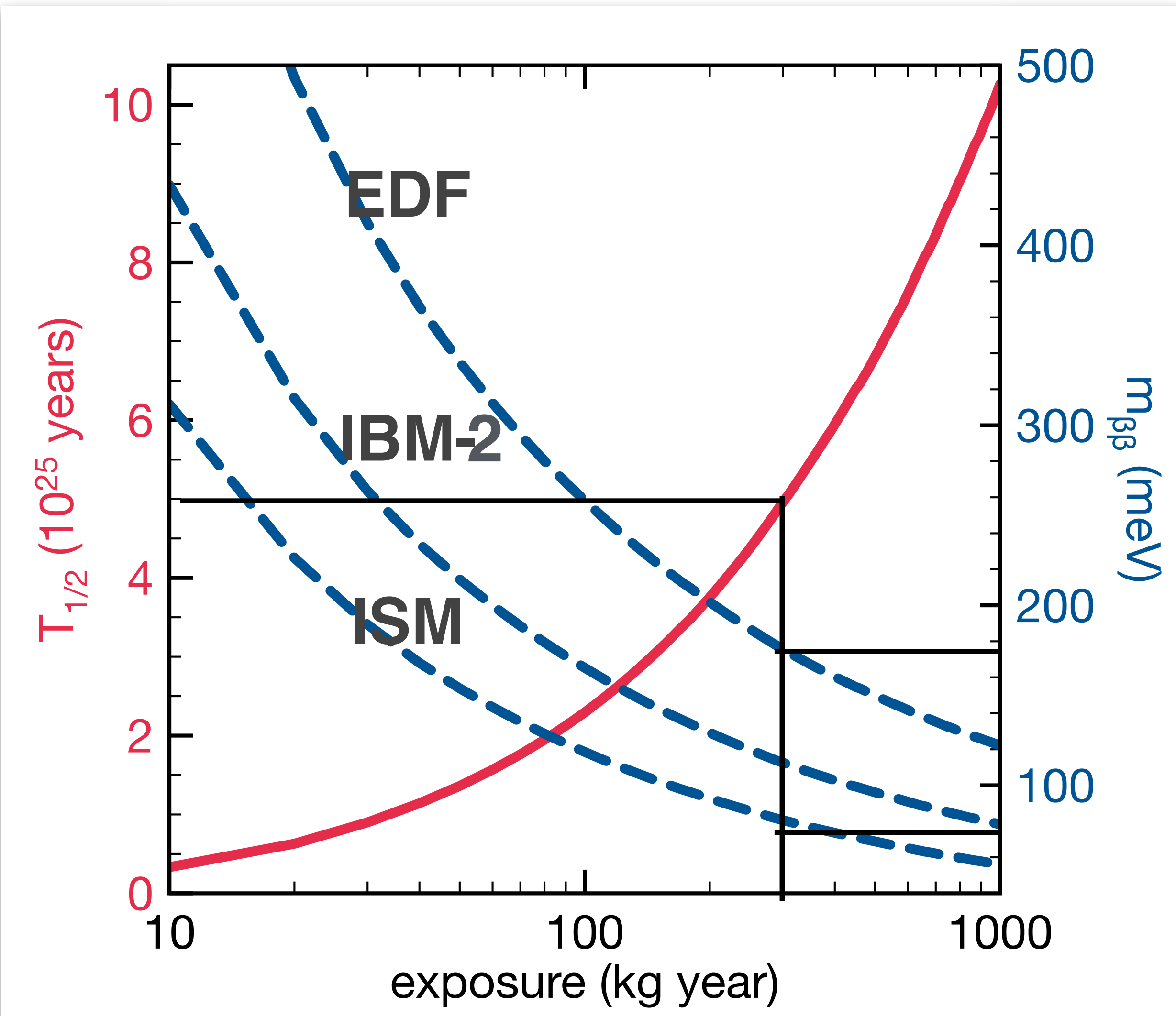
Contributions to background from major components. Contributions marked with an **asterisk** correspond to components where a **positive measurement** of activity has been made.

# Radon




Grey ovoids show expected rates with basic countermeasures. The levels will be more fully understood with NEW data. Improvements to suppression methods are under study.

# Sensitivity




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

# Scalability and upgrade

- Technology scalable to the tonne scale
  - Larger vessel already gives better surface/volume ratio.
  - Fiducial cuts remove smaller proportion of events.
  - Large drift lengths possible and possibility to make TPC symmetric.
- Shielding in a water tank to decrease entering backgrounds.
- Magnetic field for increased background rejection?
  - Gas additives to reduce diffusion without degrading energy resolution?
- Full instrumentation with SiPMs? Read-out with WLS fibres?

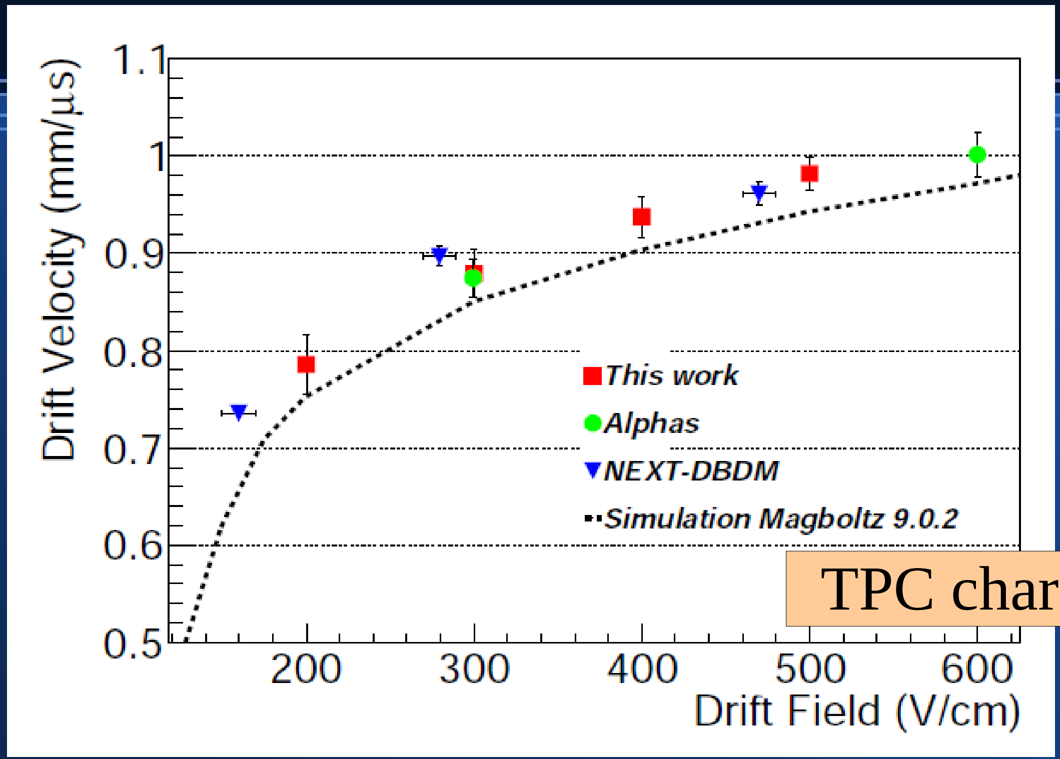
# Summary

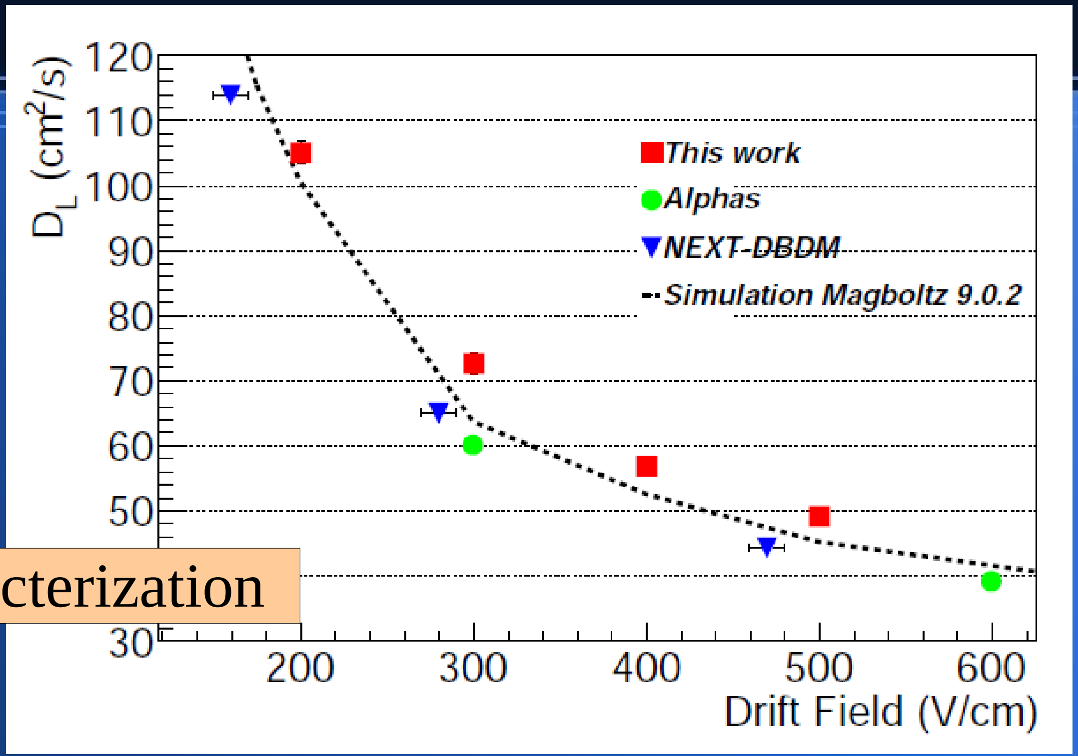
- R&D indicates energy resolution of below 1% is possible at $Q_{\beta\beta}$.
    - Major advantage of high pressure gas, technology takes advantage of low Fano factor.
- Topological rejection using simple algorithms can reject 75% of remaining backgrounds from single electrons at lower energies and up to 90% in the 0νββ ROI.
- Background from simulation at level of $5 \times 10^{-4}$ ckky
    - Conservative activity used with simple analysis, further improvement possible.
- Sensitivity to half life of $5 \times 10^{25}$ years with 3 years running.
    - Competitive with active experiments complementing and improving on sensitivities.
- Path to larger scale detectors clear, studies underway.

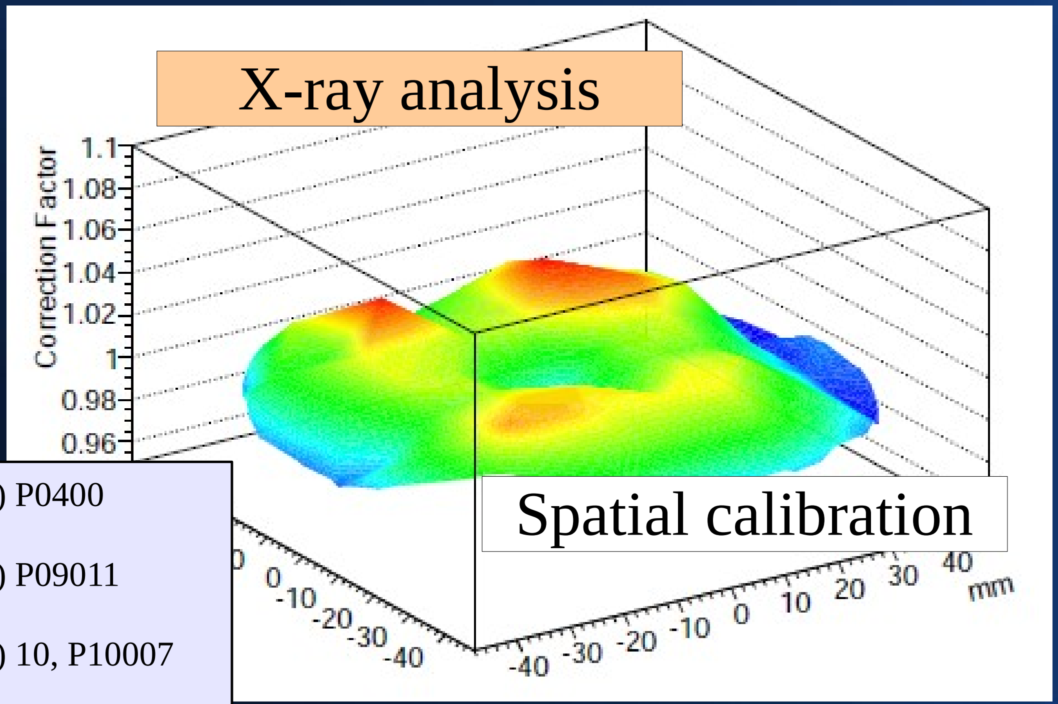
# Backup

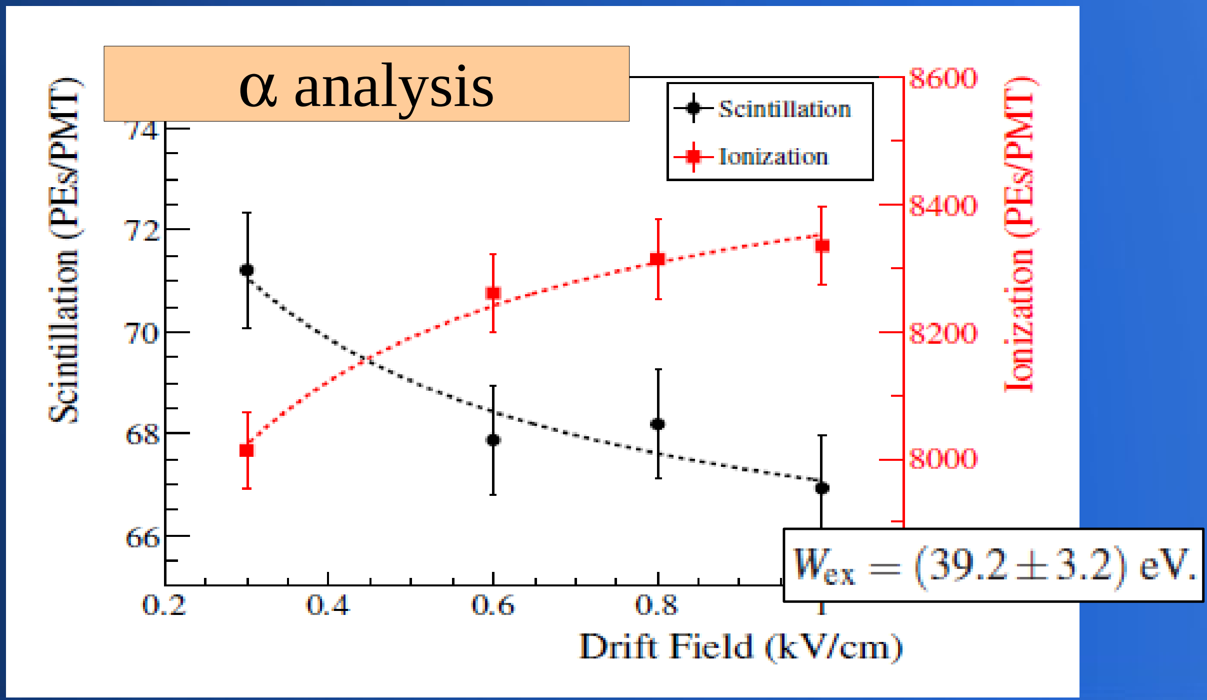
# Gas properties

# NEXT-DEMO Results





JINST 8 (2013) P0400

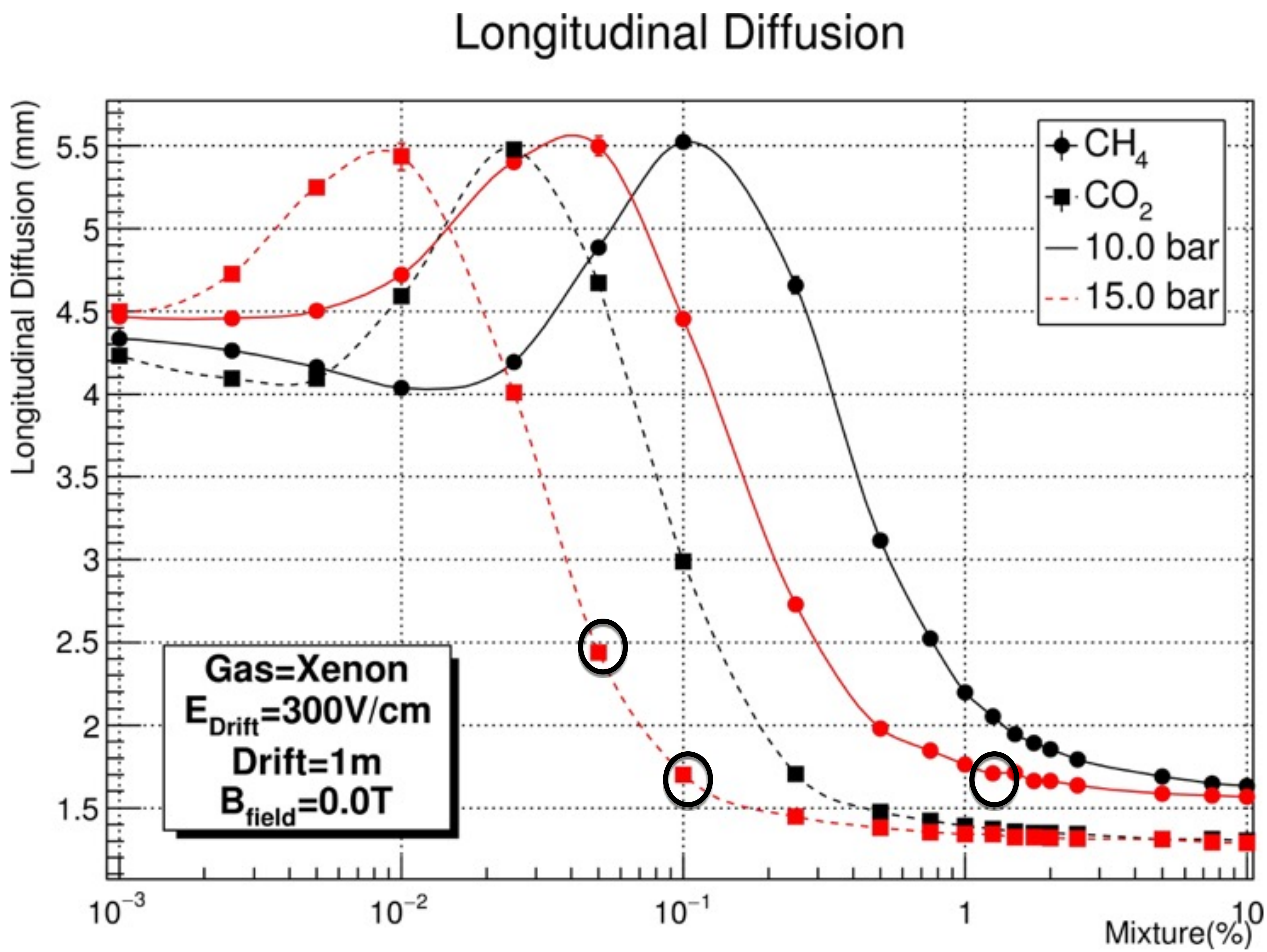
JINST 8 (2013) P09011

JINST 9 (2014) 10, P10007

JINST 8 (2013) P05025

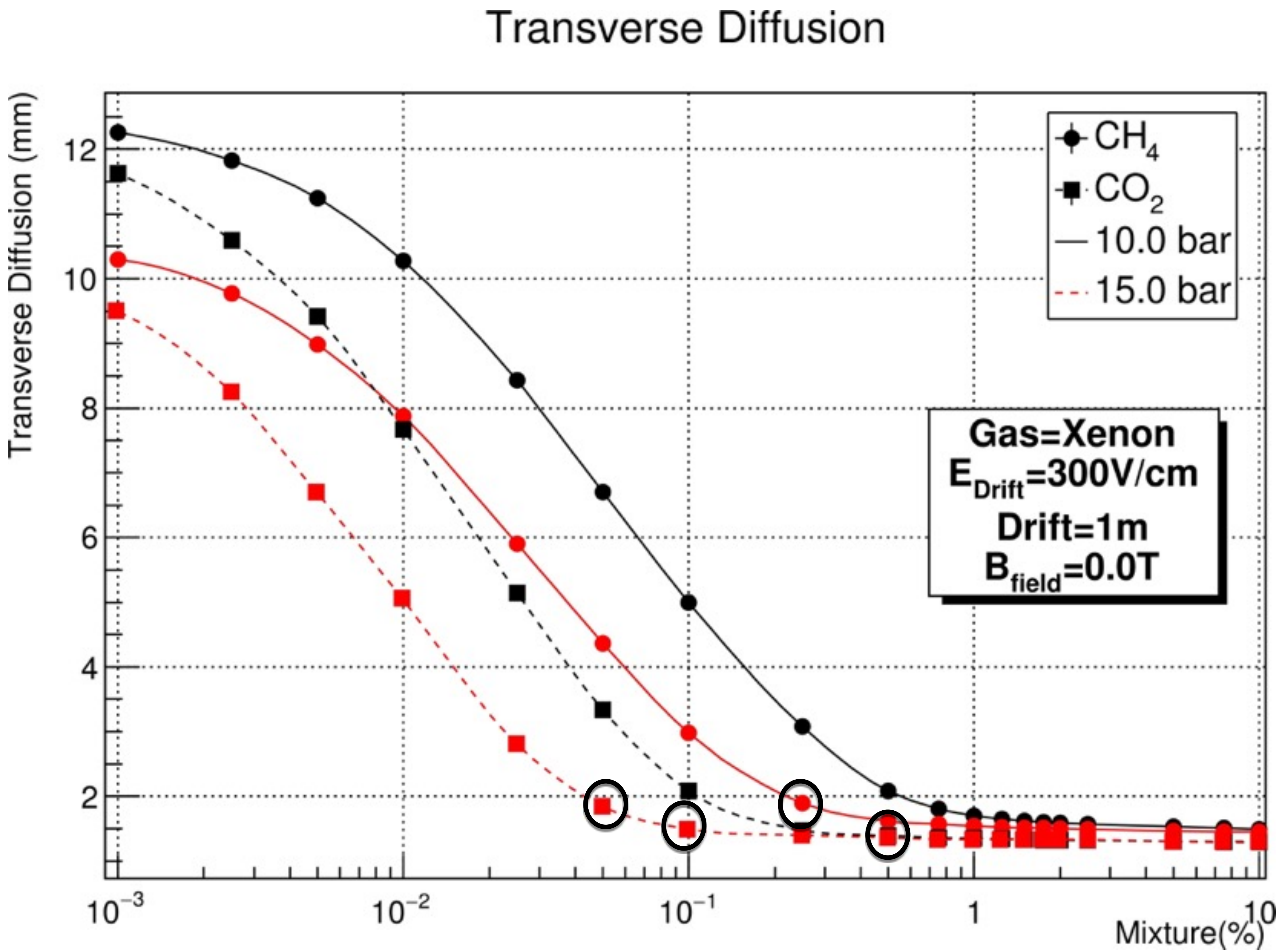
JINST 10 (2015) 03, P03025

# Additives




CO2: 0.1 % (CH4: 1%) —> DL < 2 mm

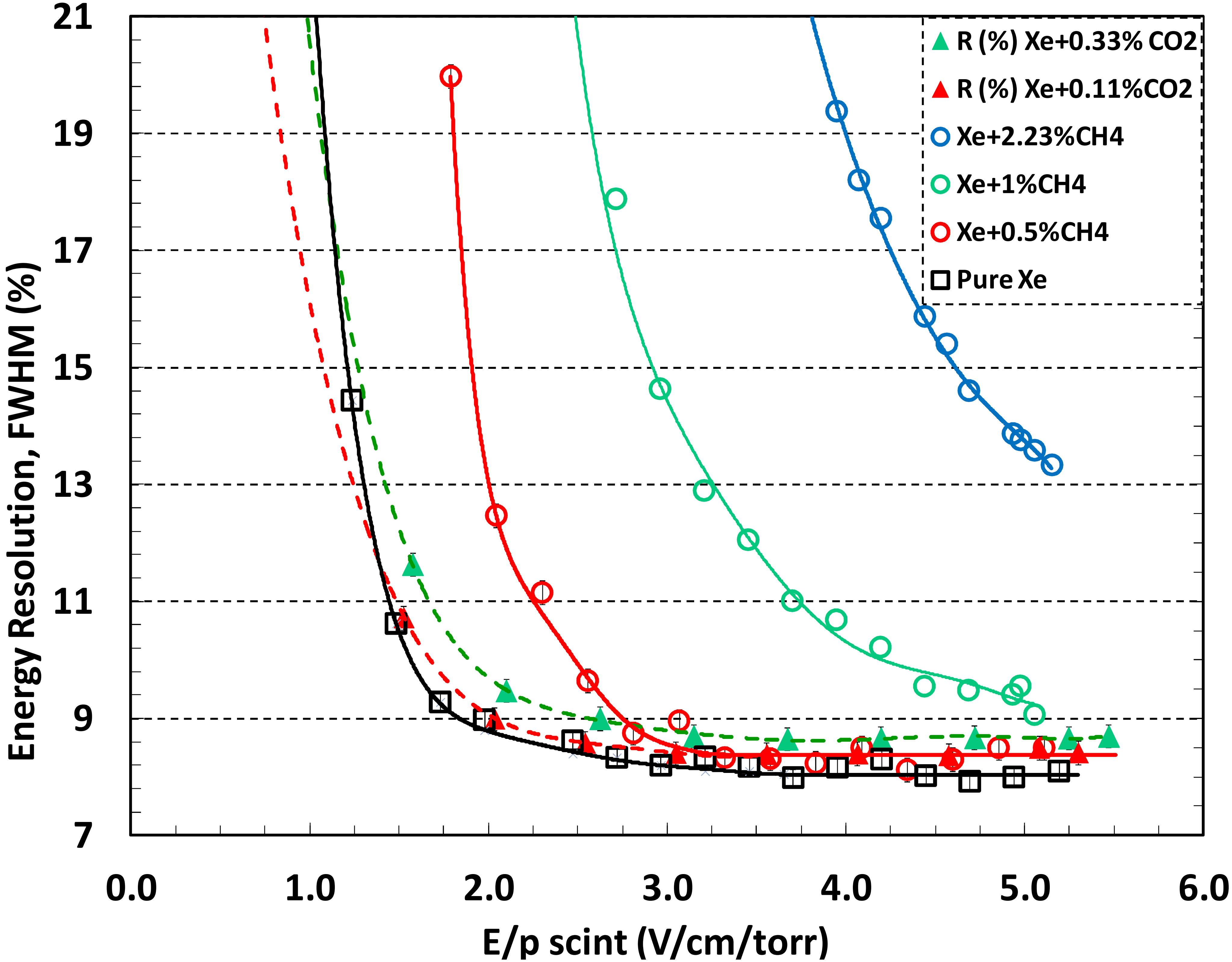
CO2: 0.05 % (CH4: 0.5%) —> DL < 2.5 mm




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

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

# FWHM (%)



R (%) Xe+0.33% CO2
R (%) Xe+0.11%CO2
Xe+2.23%CH4
Xe+1%CH4
Xe+0.5%CH4
Pure Xe
Energy Resolution, FWHM (%)
E/p scint (V/cm/torr)
21
19
17
15
13
11
9
7
0.0
1.0
2.0
3.0
4.0
5.0
6.0

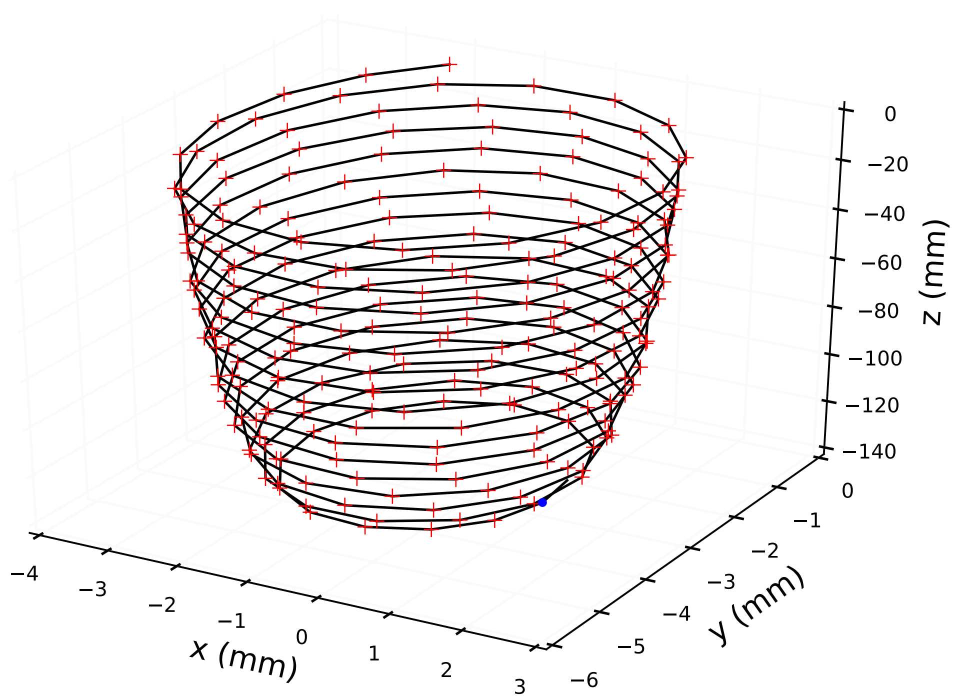
# Magnetic field

# The effect of a magnetic field

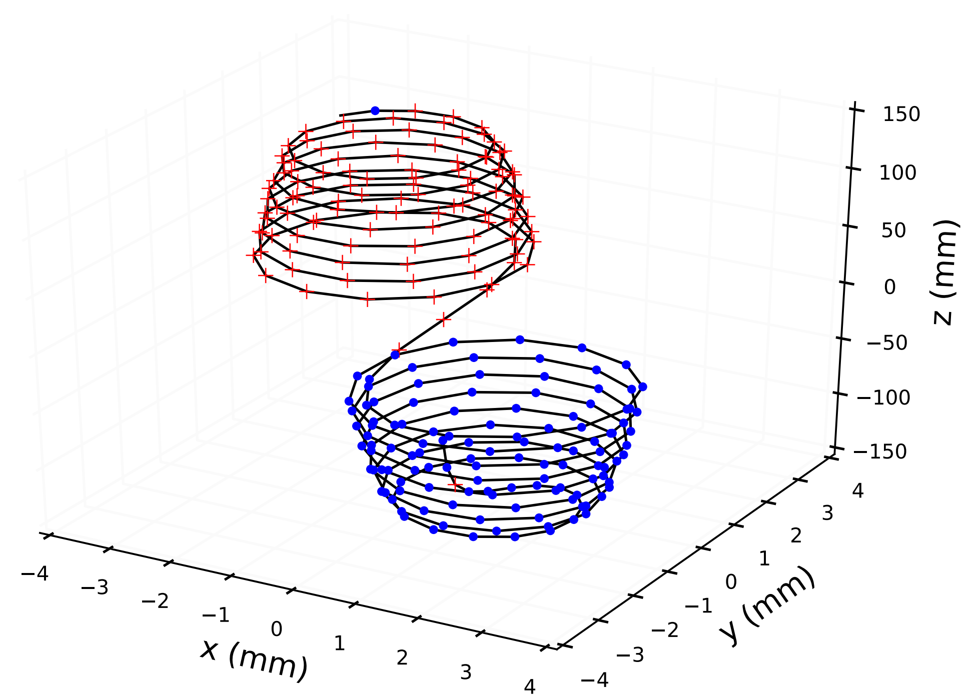
- In the absence of Multiple Scattering, a single, energetic electron of 2.5 MeV kinetic energy (thus in the Qbb window) moving in a solenoidal field describes a helix.

- The signal (2 electrons which kinetic energies add up to 2.5 MeV) describes a double helix.

- In the absence of a magnetic field the separation between signal and background when adding a magnetic field is striking (~= perfect).




**single electron**



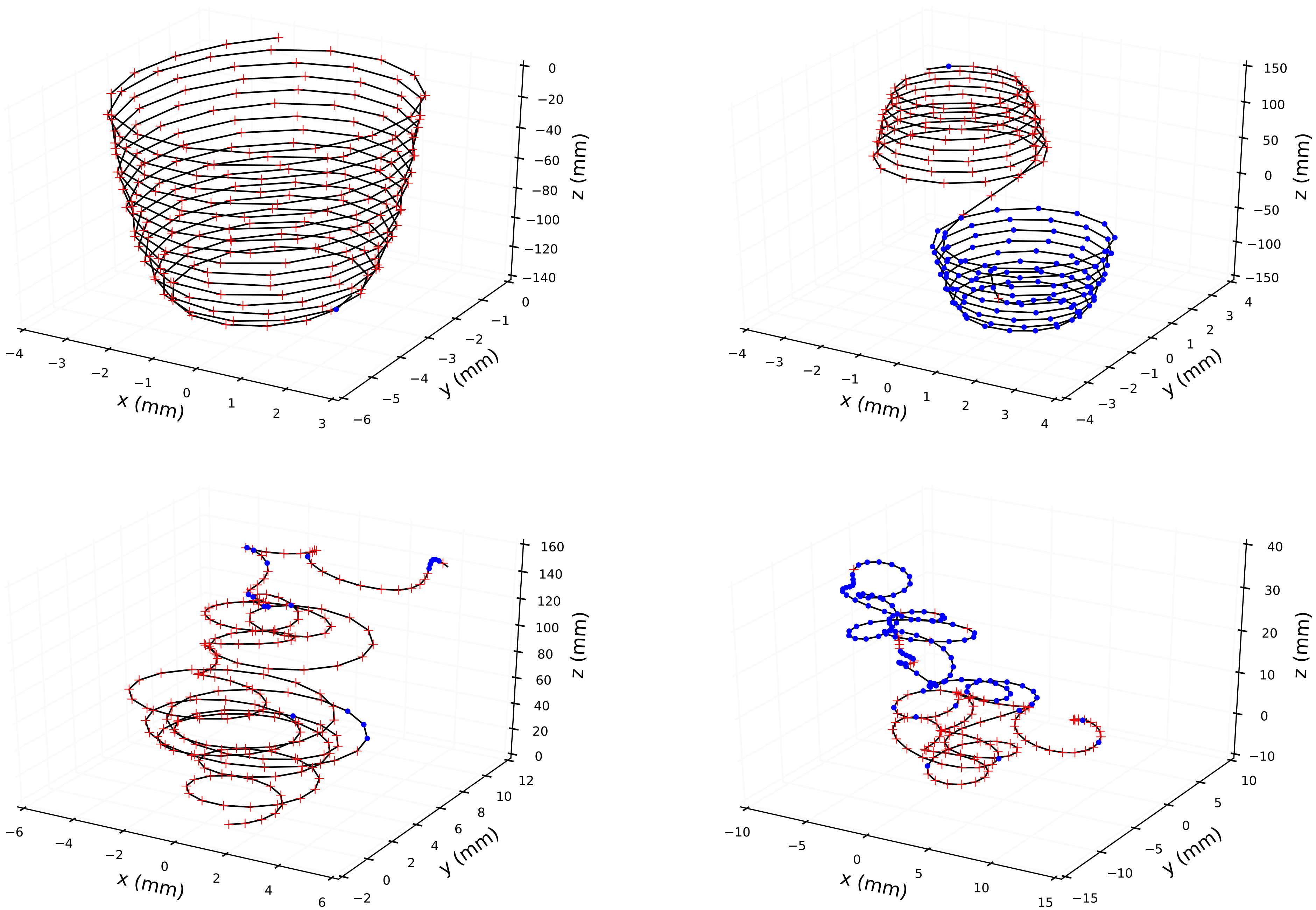

**2 electrons**

# The effect of a magnetic field

- In a HPXe TPC, multiple scattering is very high.
- The pretty picture of 1 vs 2 helices is (alas) lost.
- Visual inspection of tracks clearly shows that 1 vs 2 electrons cannot be separated on a track-by-track basis.
- However, locally, the SIGN of the curvature still follows a trend which is different for single and double electrons

**single electron no MS**

**2 electrons MS**



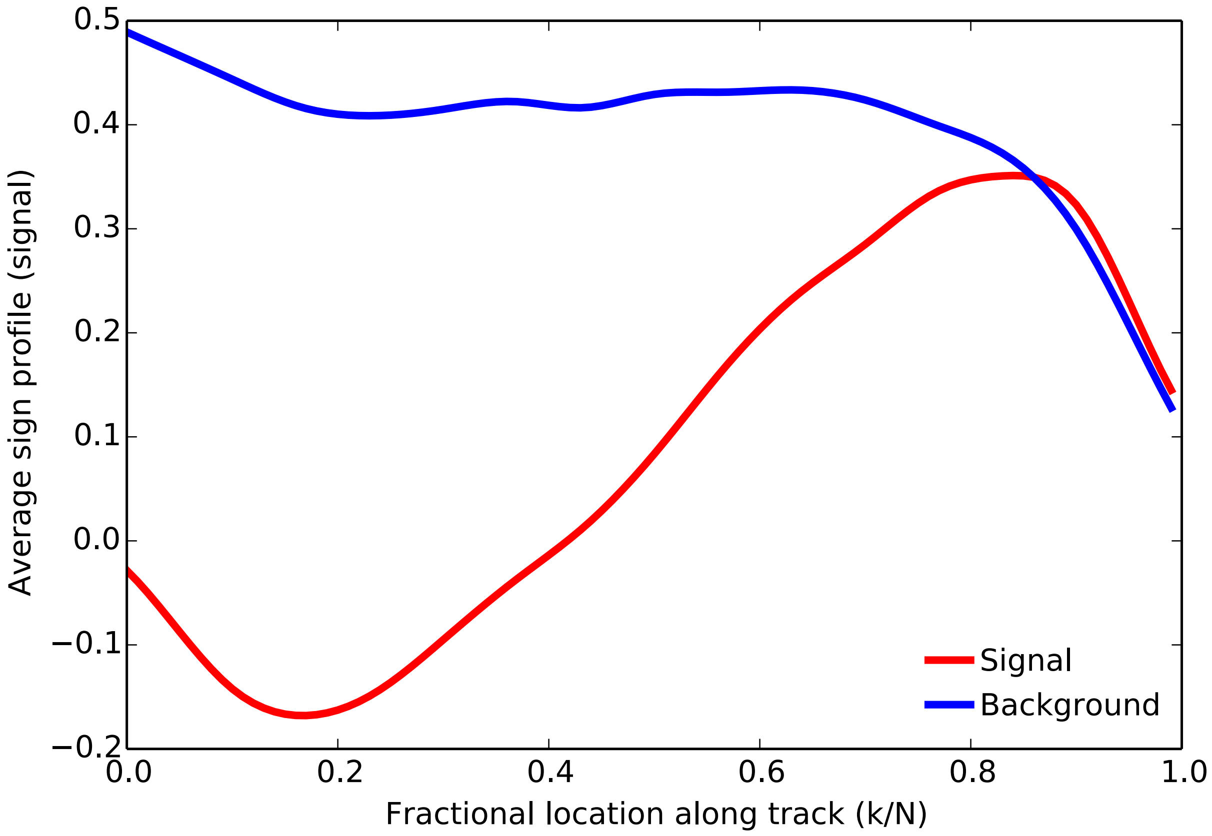

**single electron MS**

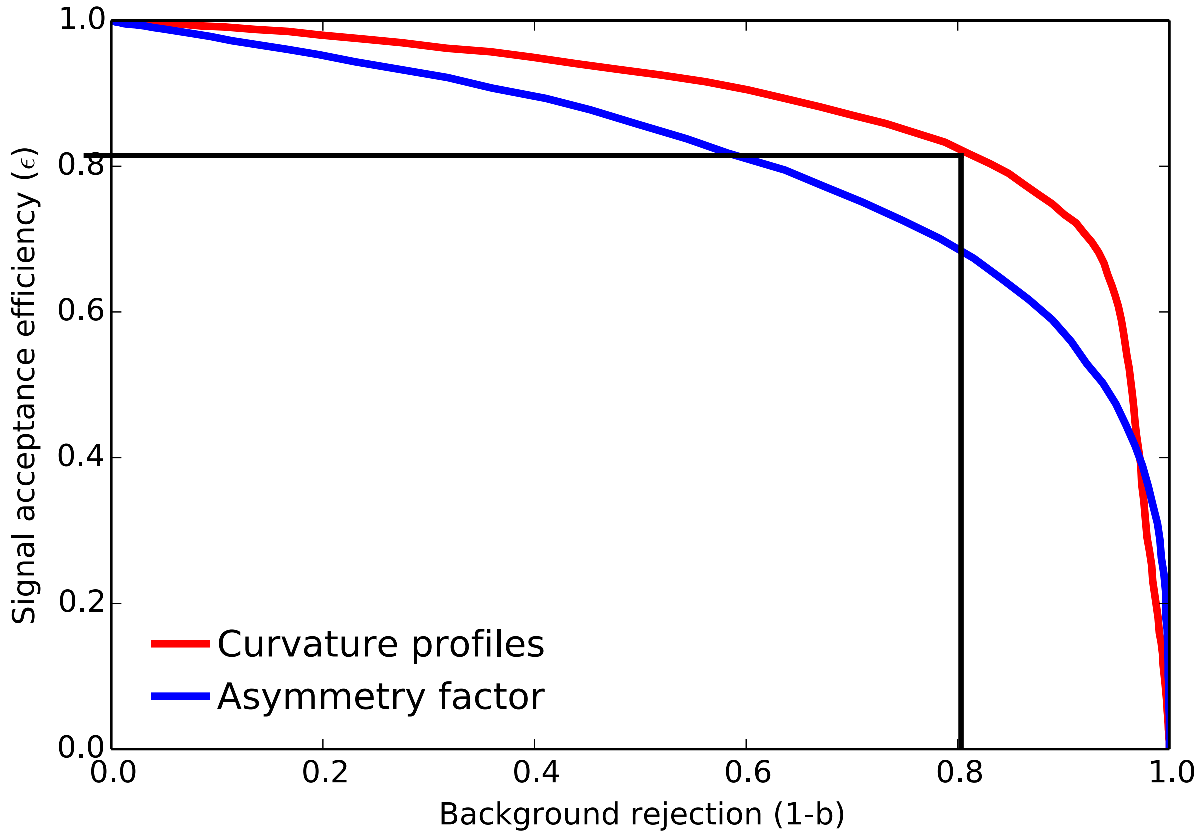
**2 electron MS**

# Sign profile

- The average curvature of “single electrons” (background) and “double electrons” (signal) is rather different.
- One can compute those profiles and compare them with any track moving in a magnetic field (an even simpler criterium is to compute an asymmetric between the first and the last part of the track)
- The result is a clear separation between single and double electrons.

# Sign profile




Sign profile discrimination may yield a 1/5 rejection factor at a cost of 80% efficiency (P = 10 bar, B=0.5 T)