Measurements of electron-ion recombination in high-pressure xenon gas using NEXT-DEMO

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The NEXT detector

A high-pressure gaseous Xenon, electroluminescent TPC for neutrinoless double beta decay searches.

Advantages of Xenon detectors for bb:

- Noble gas: easy to enrich, purify and to scale.
- Good Q_{bb} and slow two-neutrino mode ~ 2.2×10^{21} y

Unique features of NEXT among Xenon detectors:

- Near intrinsic energy resolution (0.5 - 1% FWHM at Qbb)
- Event topology information (not possible in liquid)

NEXT 100:

- 100 kg of Xe 136, detector under construction at the Laboratorio Subterráneo de Canfranc (LSC, Spain)

NEXT Detection Concept

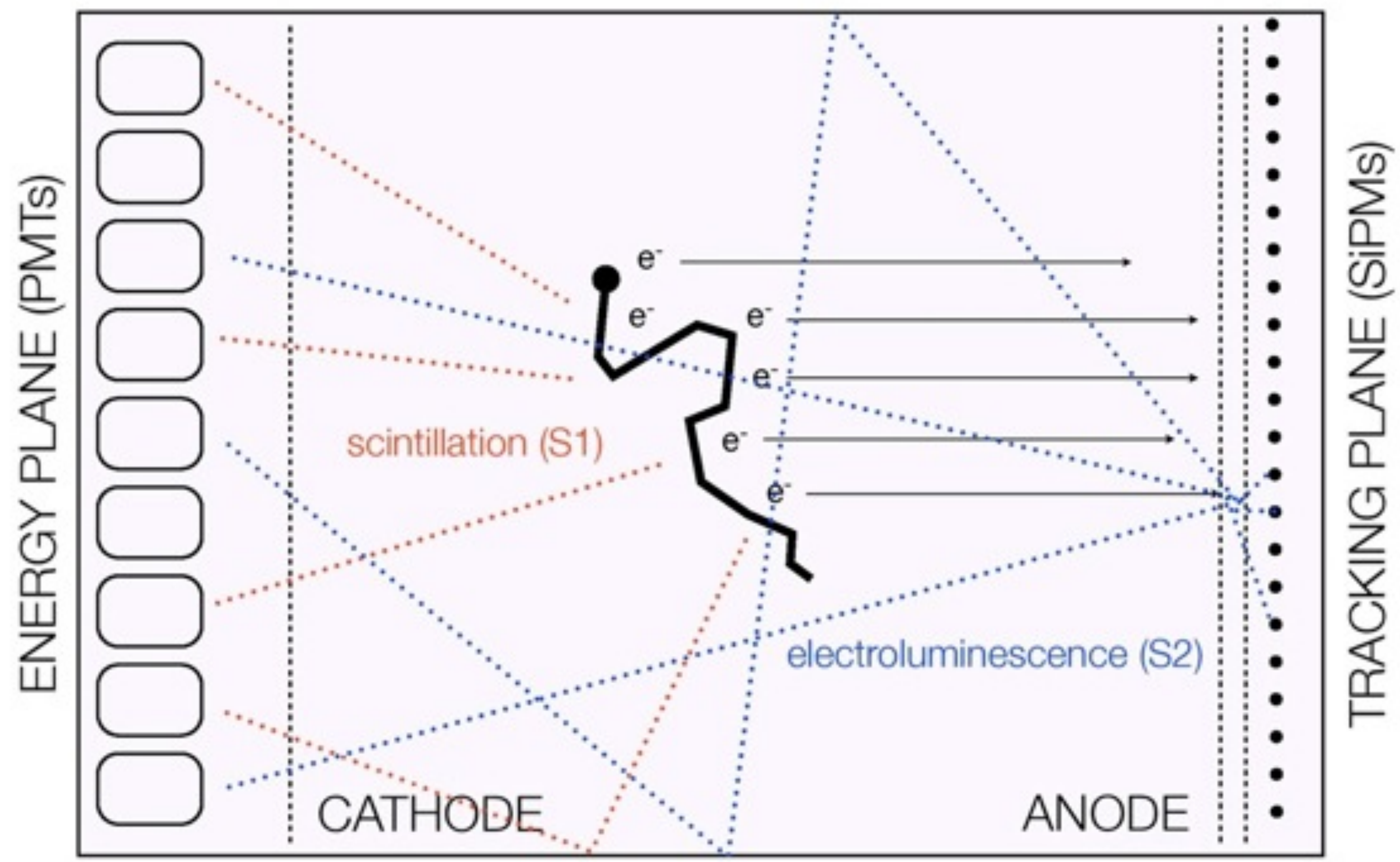
Concept 1:
Use a xenon gas TPC

Concept 2:
Use electroluminiscence to amplify ionization signal

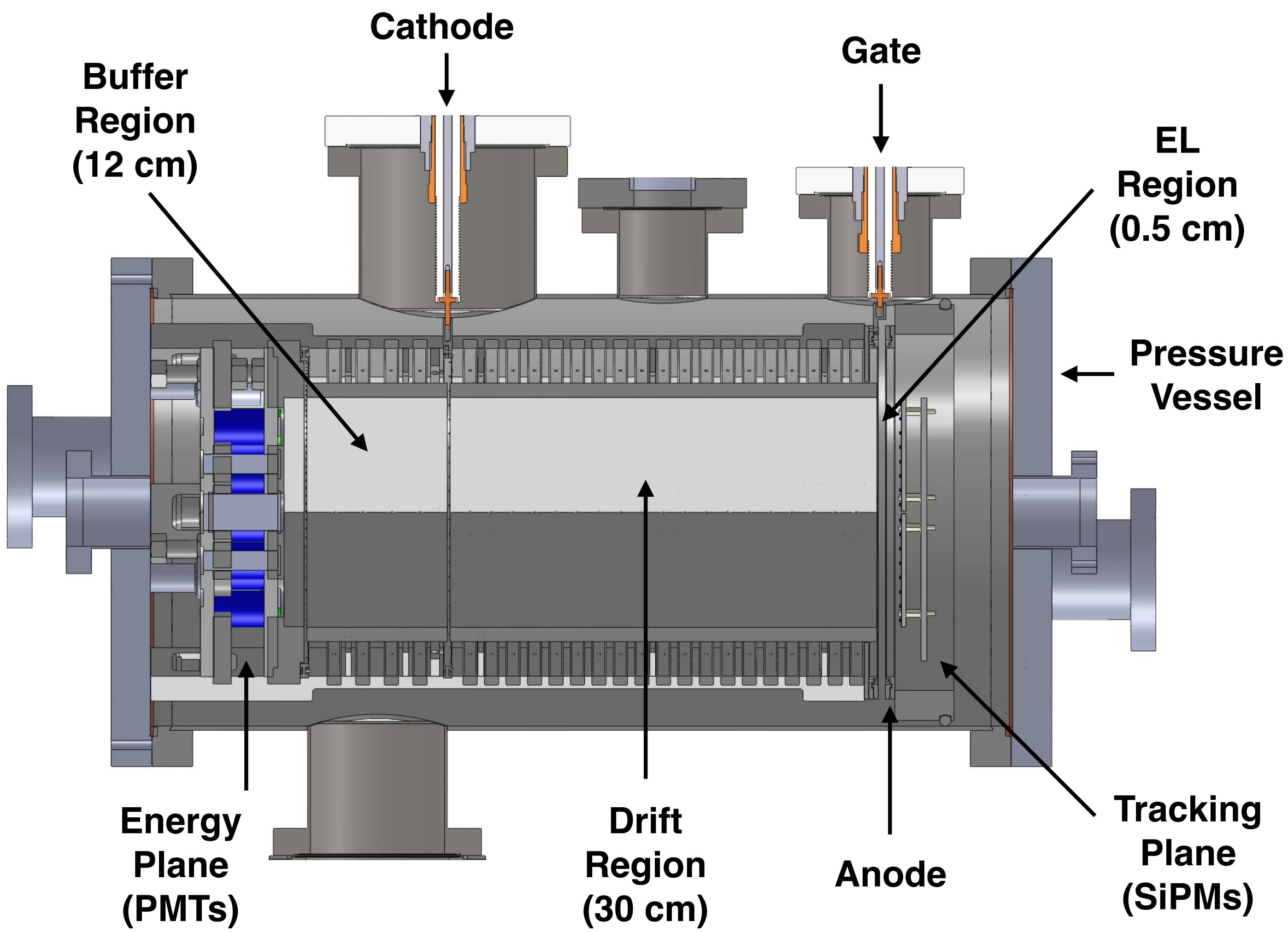
Concept 3:
Ionization used for separated energy and tracking measurements

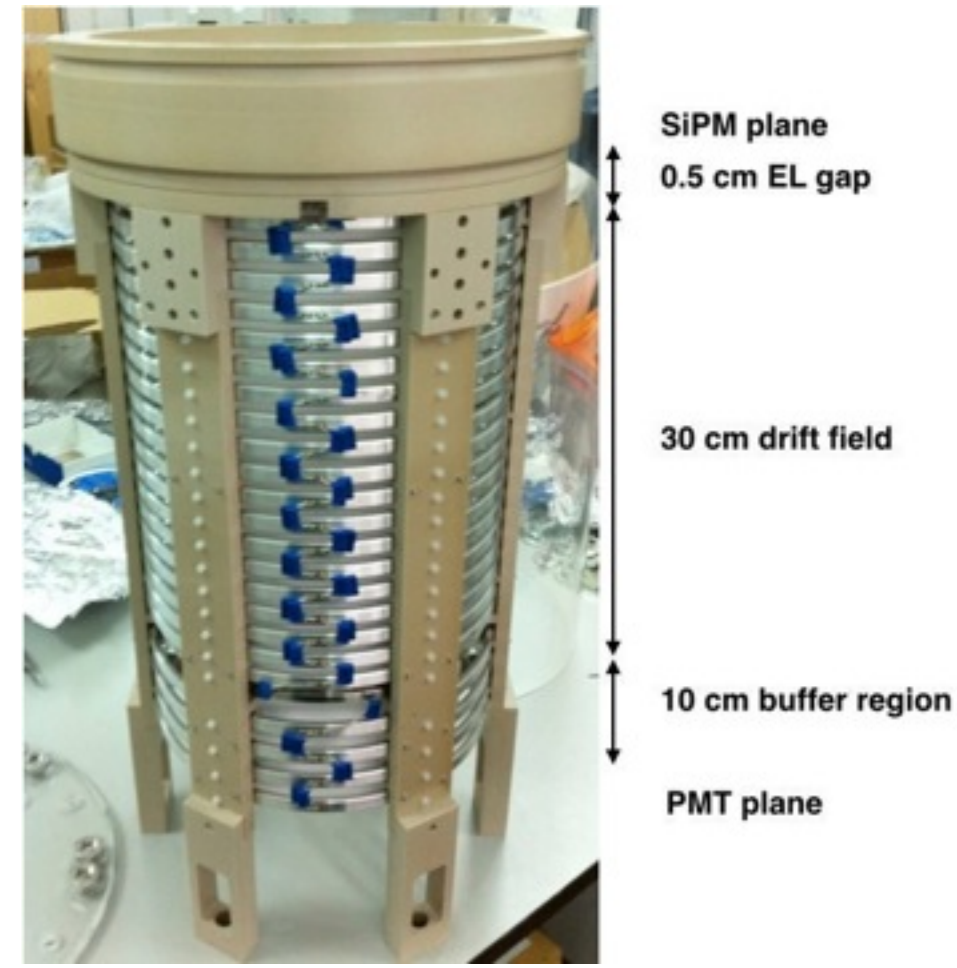
Concept 4:
Energy sensors detect also primary scintillation for t0 determination

Concept 5:
Shift 170 nm Xe light to longer wavelength



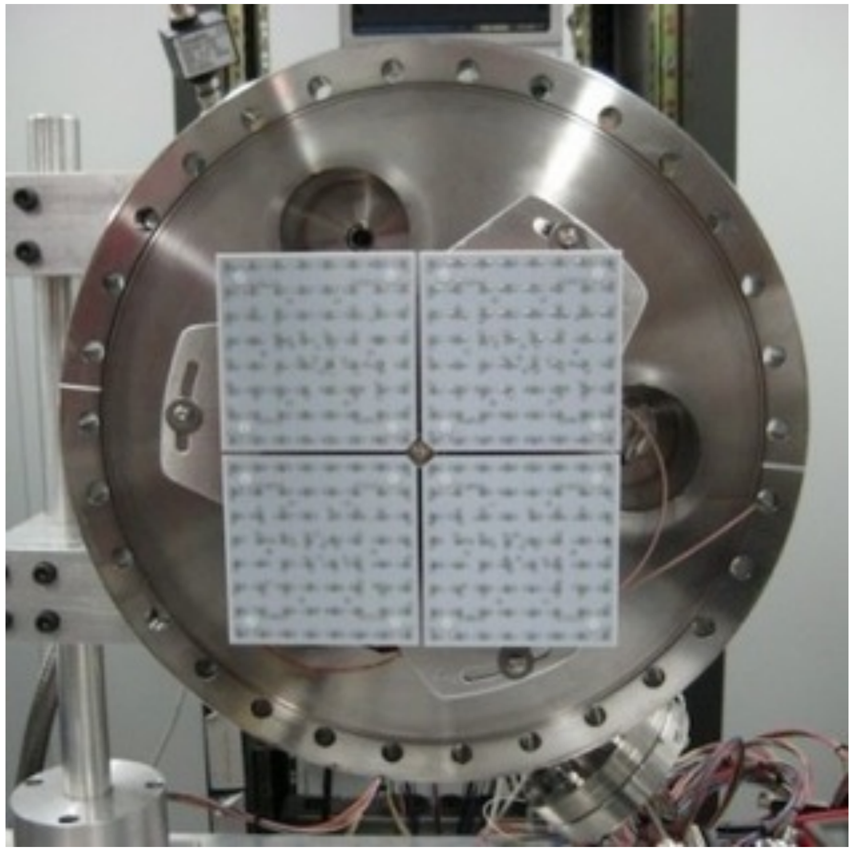
NEXT-DEMO detector





- 10 bar xenon gas TPC
- 19 PMT energy plane
- 256 SiPM tracking plane
- Coating with TPB wavelength shifter
- Optical gain of 100 photons/electron
- Drift field 0.3-1 kV/cm

Readout planes

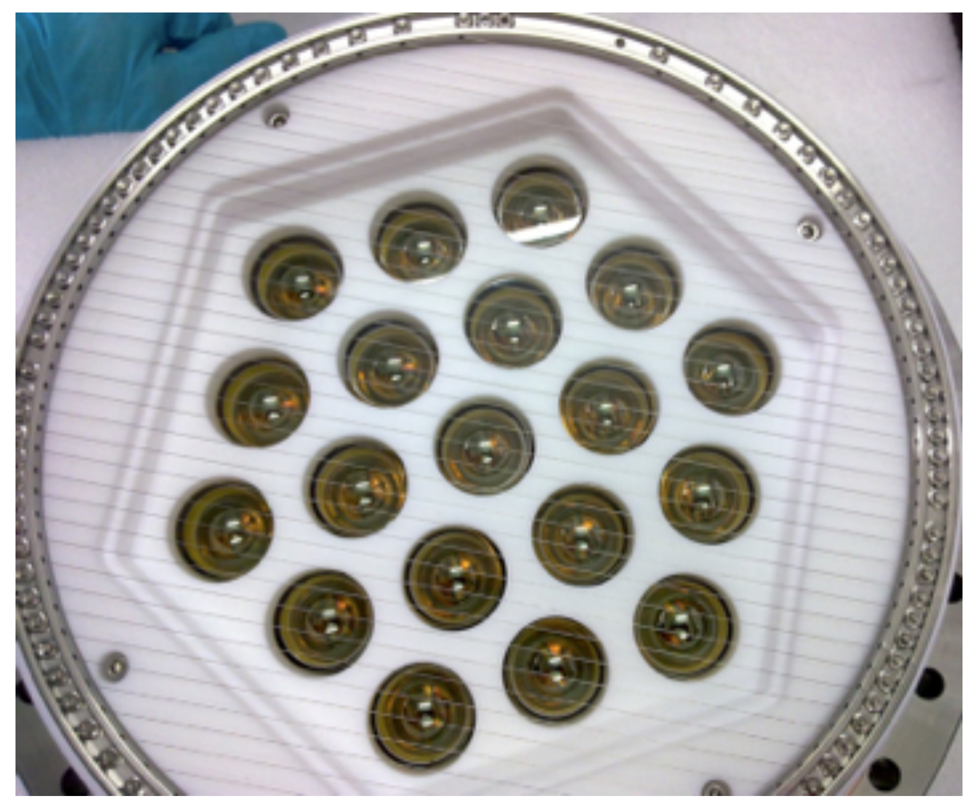


Tracking plane

- 256 Hamamatsu SiPM
- 1 cm pitch
- 2D signal reconstruction

Energy plane

- 19 Hamamatsu PMT
- Energy resolution better than 1% FWHM
- Sensitive to both primary and secondary scintillation light



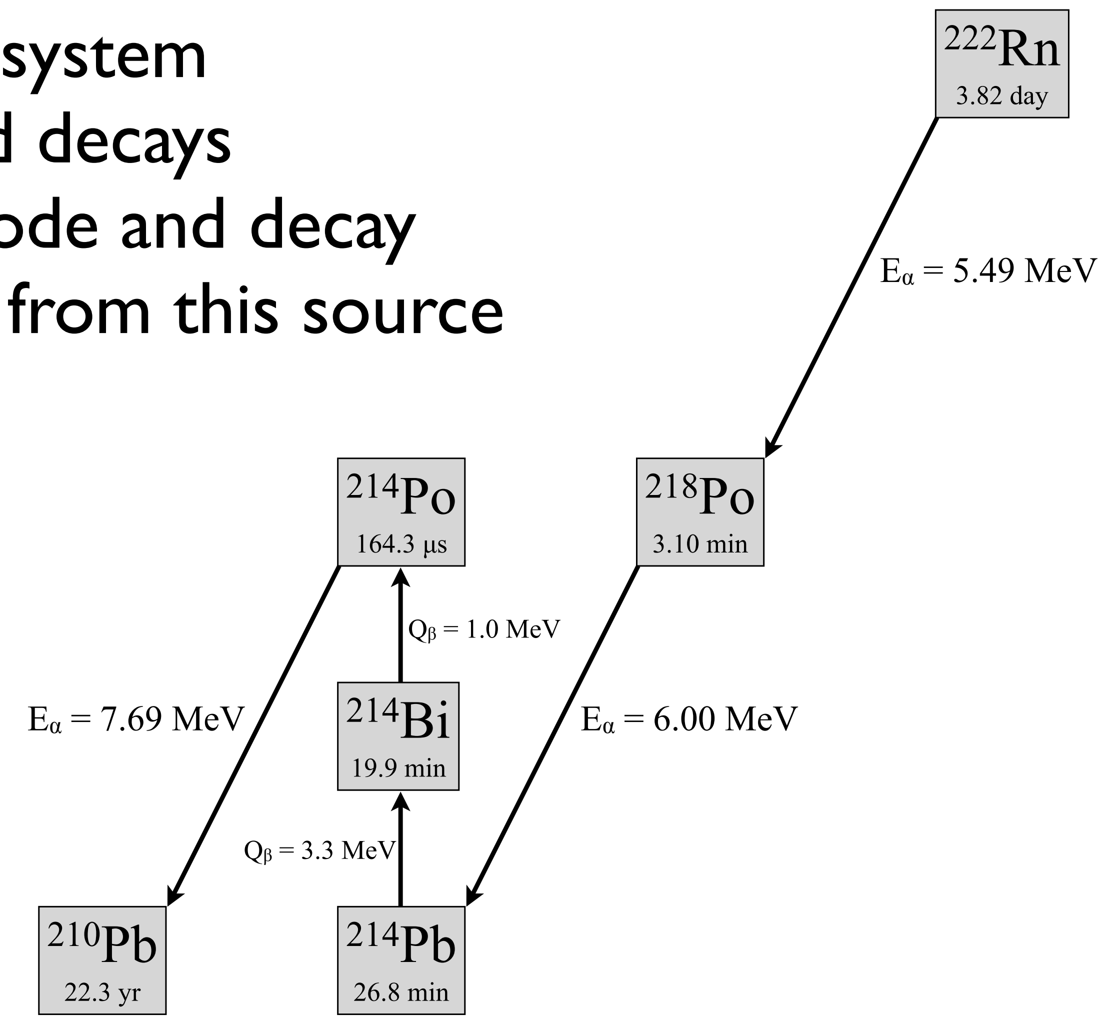
Shifting Xe light to blue

Sensors and inner part of the field cage coated with Tetraphenyl Butadiene (TPB)

Light is shifted from VUV to blue which can be detected in the tracking plane

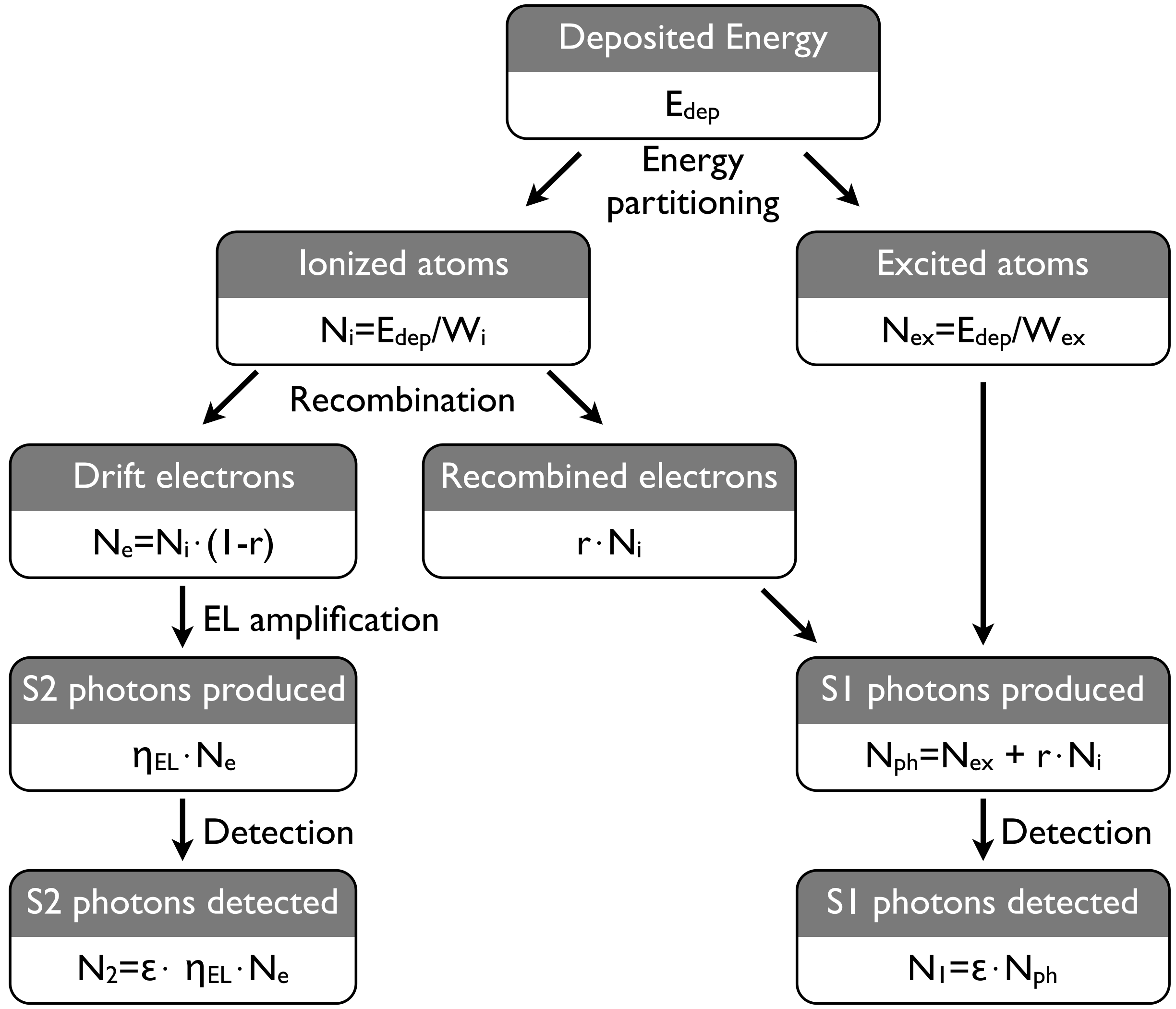
Alpha decay

- Ra-226 source attached to the gas system
- Rn-222 flows into the detector and decays
- Po-218 ions drift towards the cathode and decay
- Two alpha decays can be measured from this source



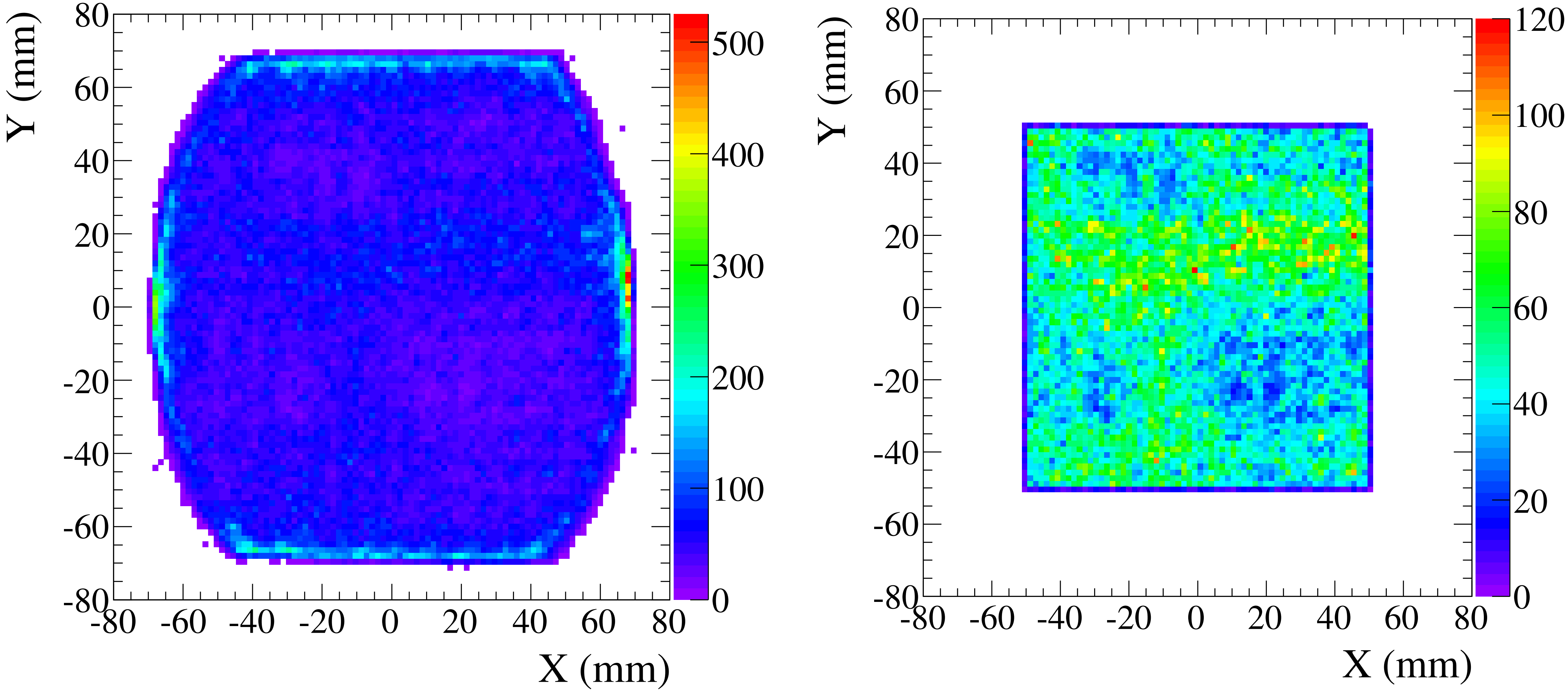
- Radon inside and outside the detector is a main source of background for double beta decay experiments

Alpha decay energy partitioning



- For every recombination a scintillation photon is produced
- Anti-correlation between S1 and S2 can be used to improve energy resolution
- Measurement in gas only with high recombination signals. In this work alpha particles

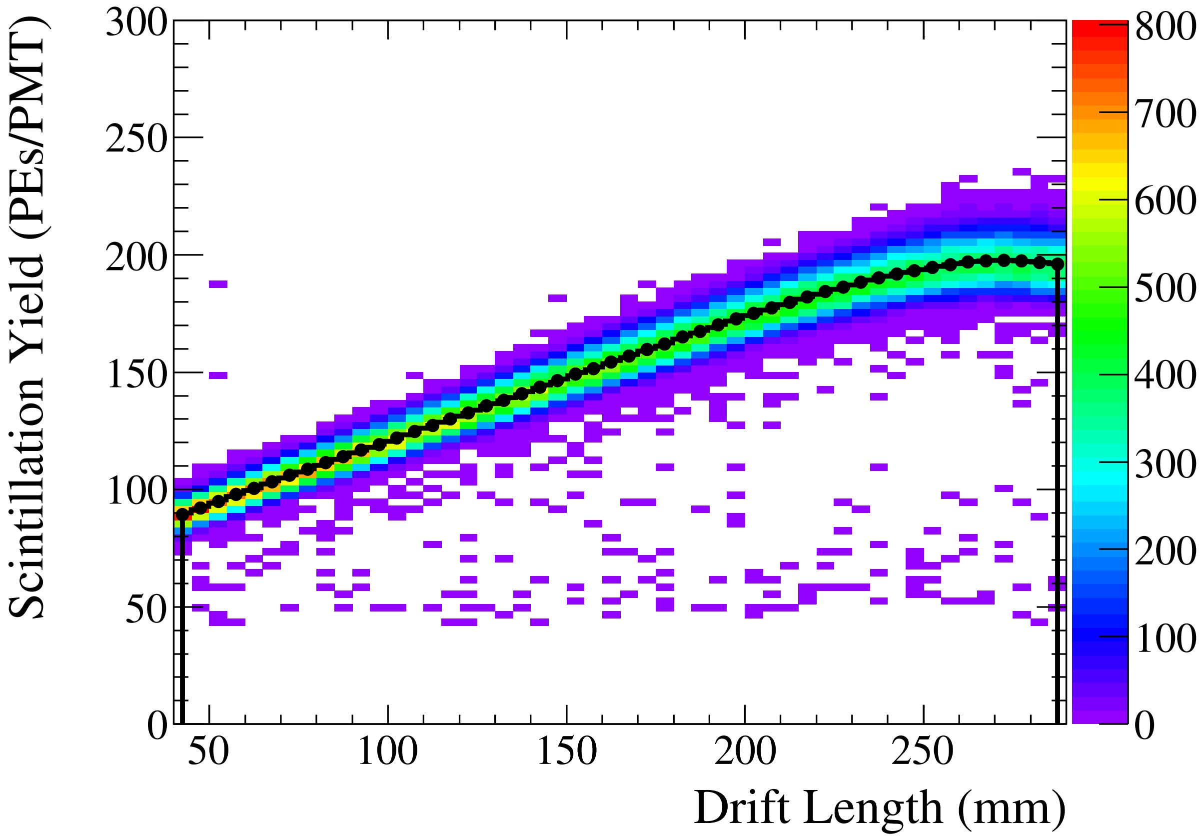
Selection of events



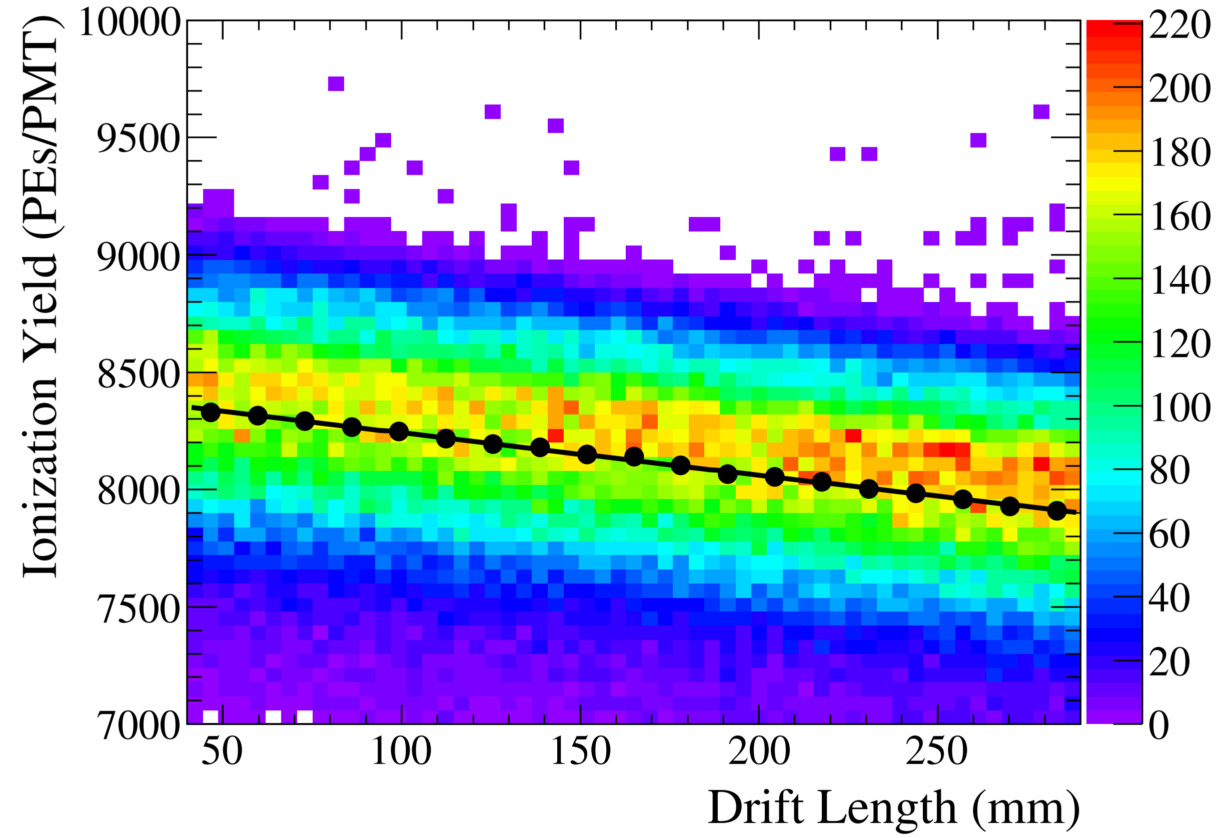
- Large S1 and S2 to isolate alpha events
- Single S1 peak in the event
- S2 width lower than 30 μs (avoid muons)
- |x,y|< 50 mm. Only fully contained events
- Drift length 40 < z (mm) < 290

Drift length correction

S1 Z dependence



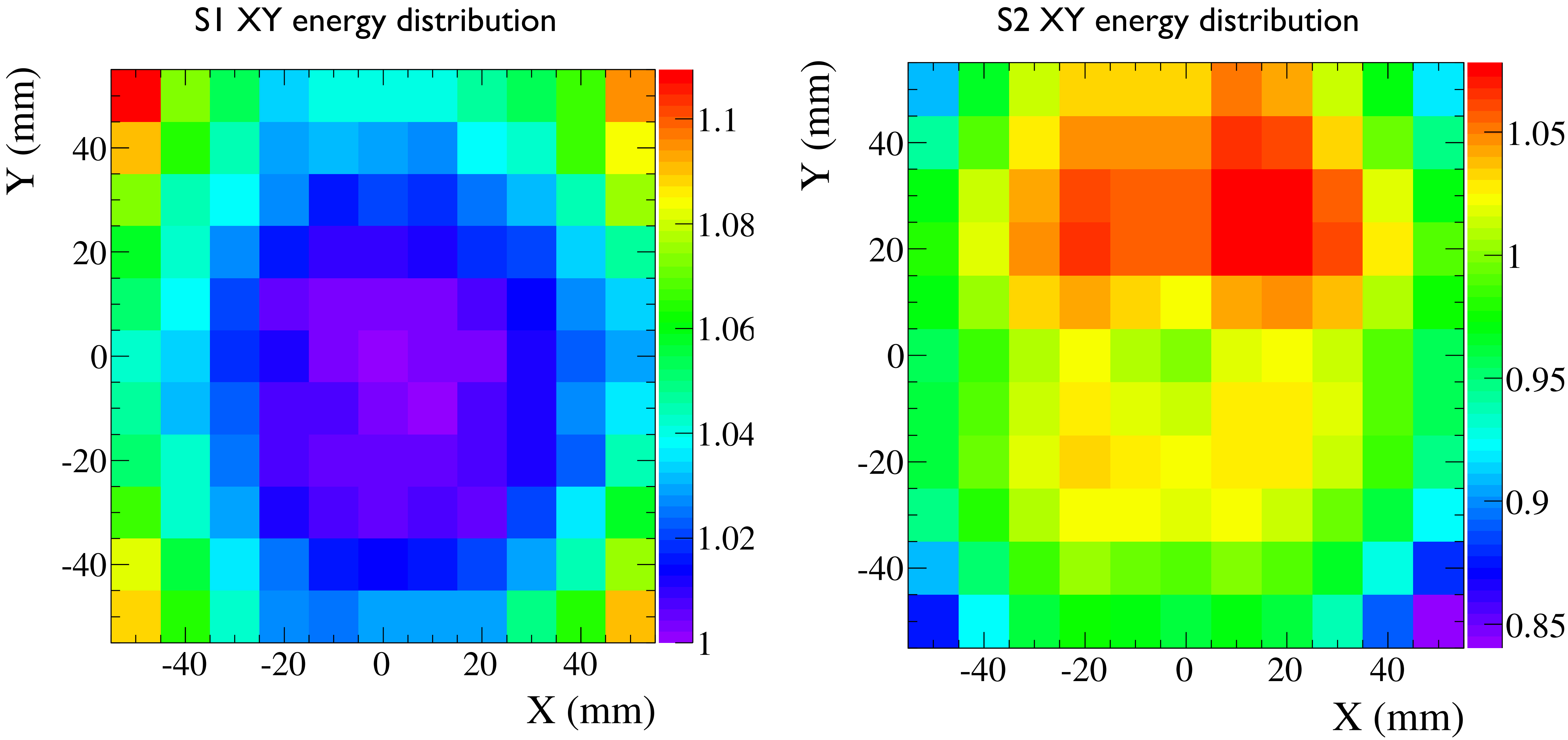
S2 Z dependence



• S1 Z dependence due to detector properties.
• Difference of 100% in signal strength due to position
• Correction using spline

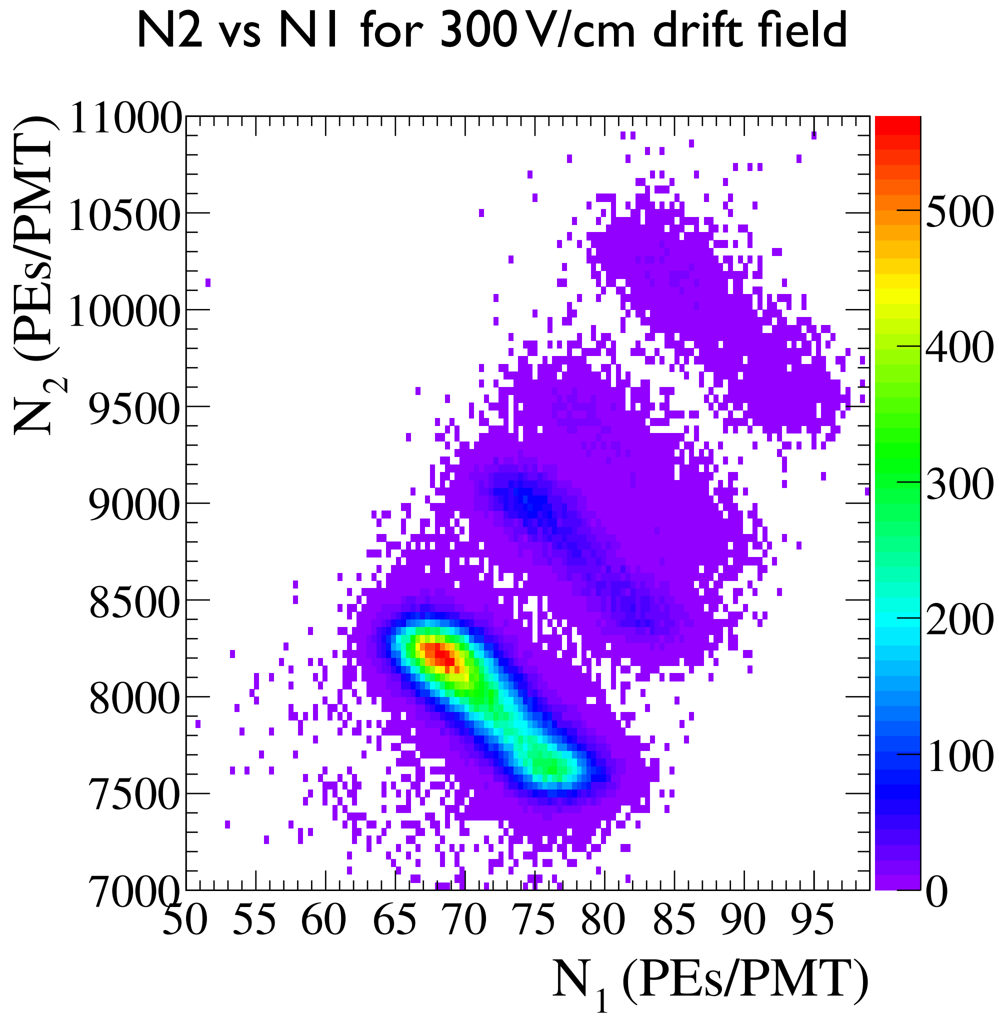
• S2 Z dependence due to attachment in gas
• Correction using exponential
• Attachment can be used to measure gas impurities

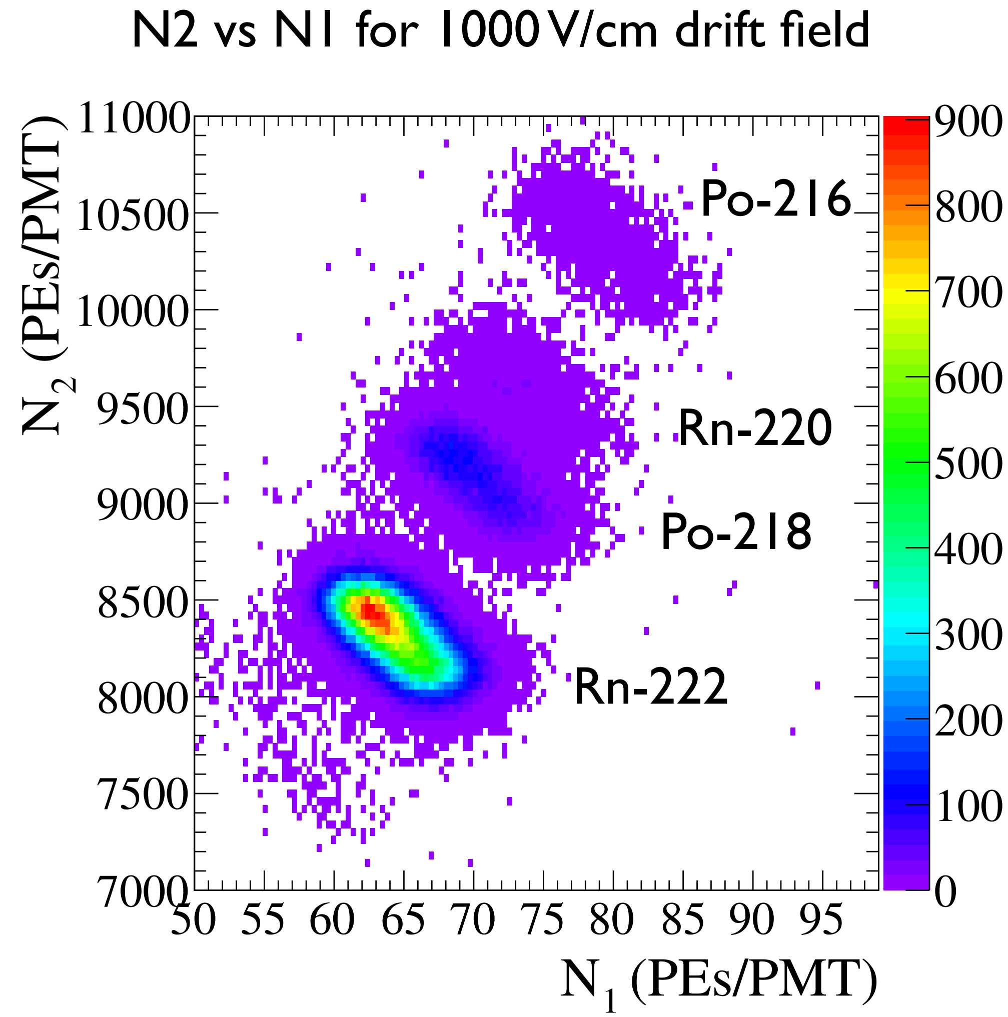
XY calibration



- 10 mm wide bins used to measure XY response
- Energy compared to central bin (0,0)
- Single XY correction for S2
- 5 slices in Z for S1, one each 50 mm

Results: S1-S2 anti-correlation

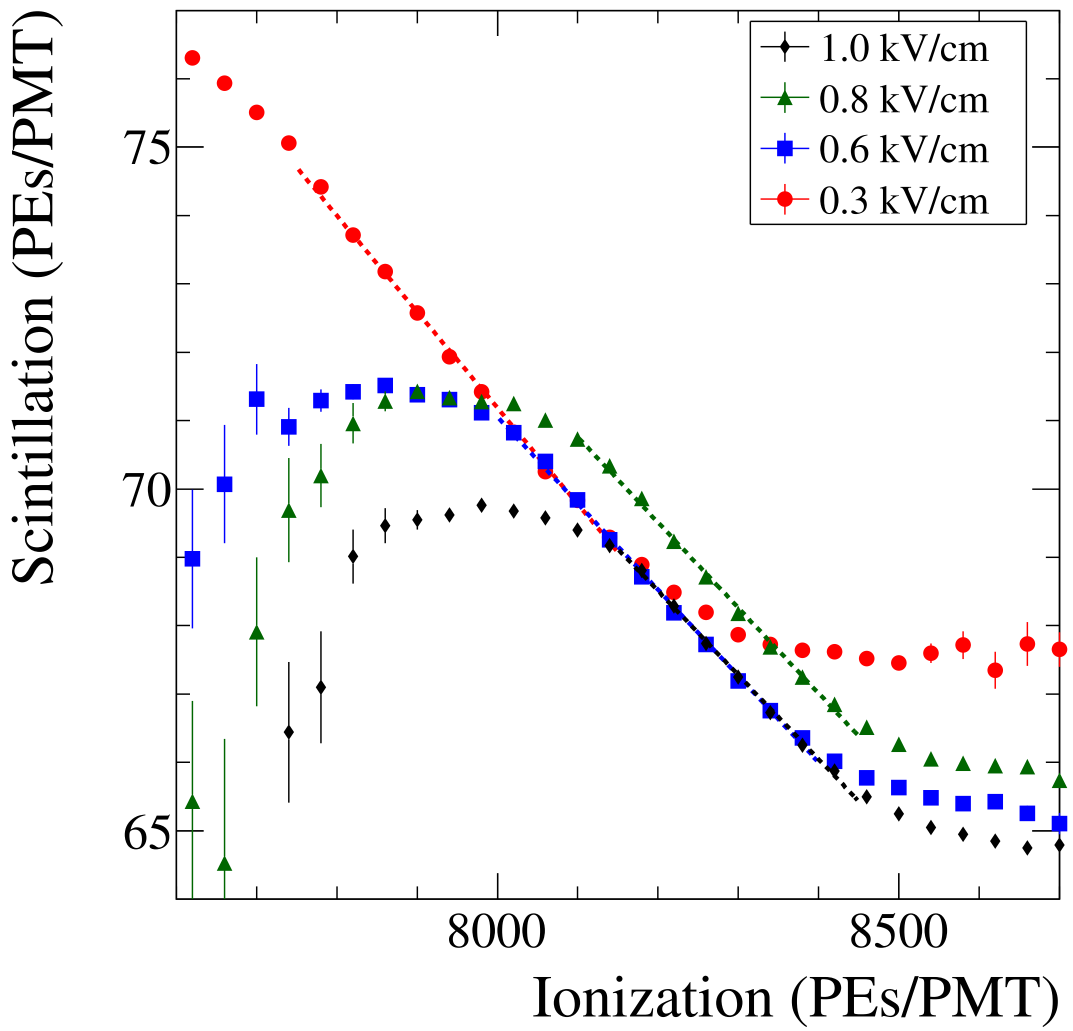




- At lower field recombination is higher
- Correlation coefficients between -0.80 (300 V/cm) and -0.56 (1 kV/cm)
- Coefficients different from -1 due to instrumental effects
- Improvement in correlation measurement compared to previous work with alpha particles (**JINST 8, P05025 (2013)**)

Results: Optical gain

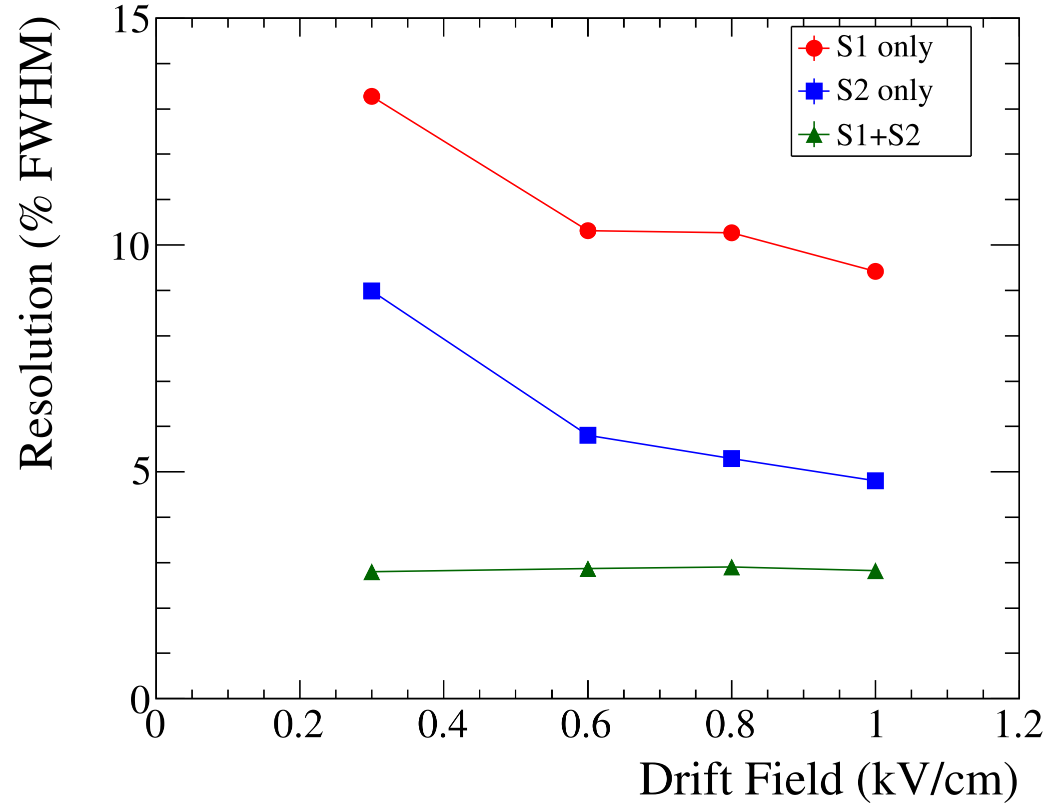
N2 vs N1 profile for 4 drift fields



- N1 depends linearly on N2
- Slope is 1 over optical gain, ηEL
- Important parameter for any TPC
- Only Rn-222 is used to obtain ηEL

Experimental ηEL = (75 ± 5)
Theoretical ηEL = (87 ± 25)

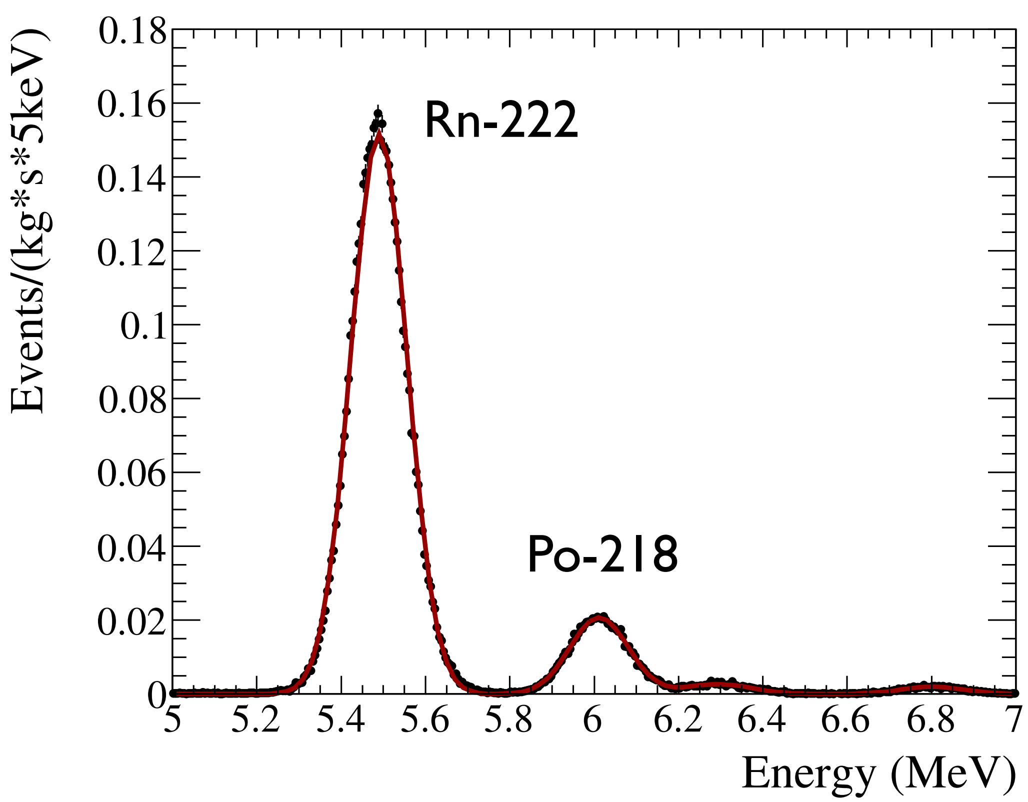
Results: Energy reconstruction

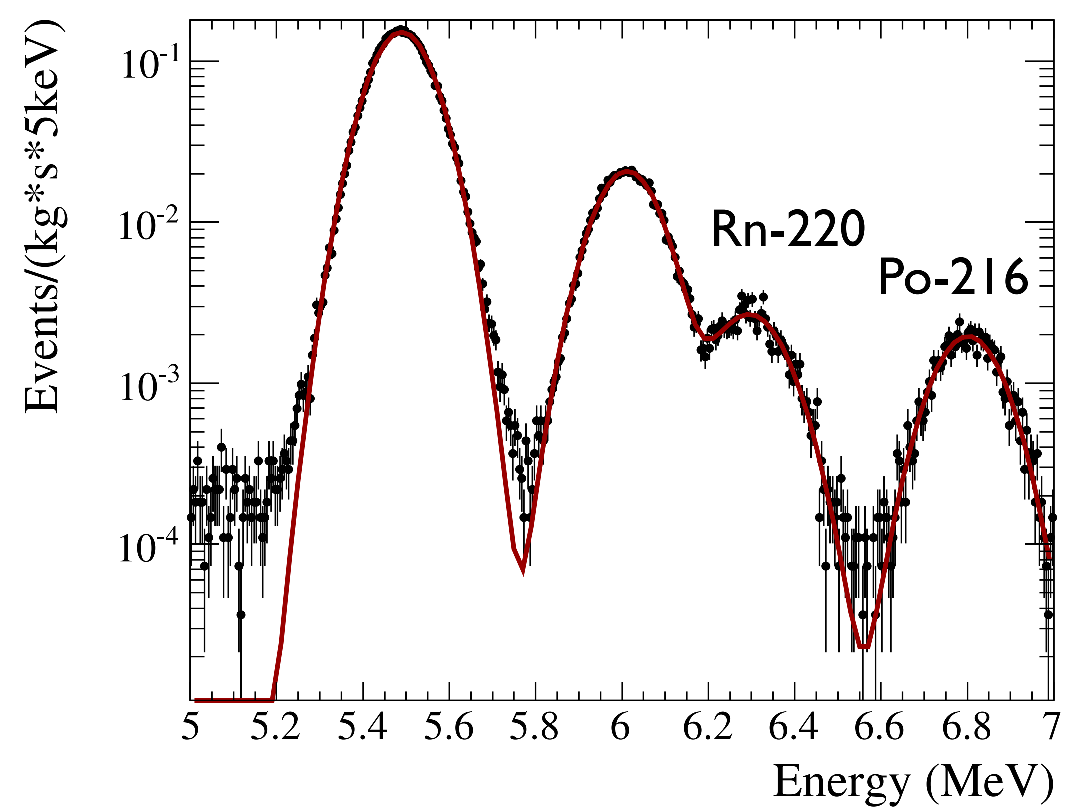


- Energy is defined as

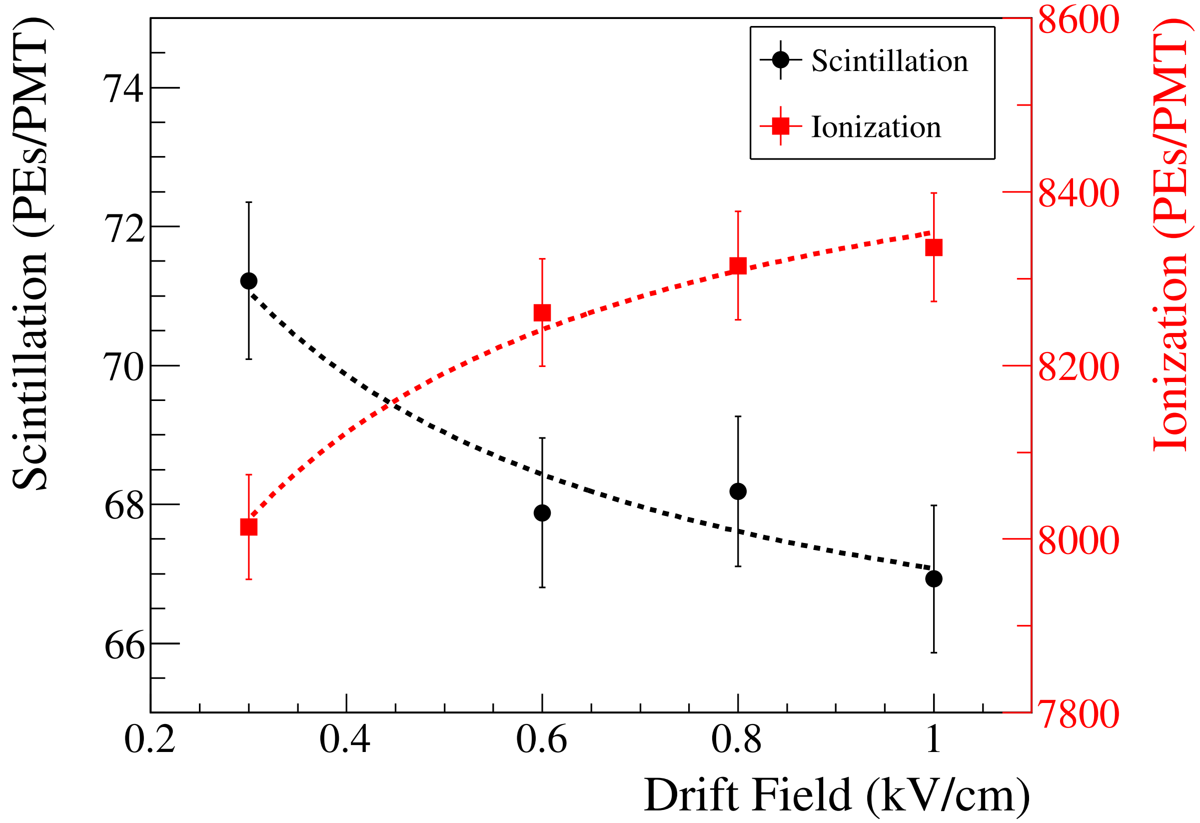
$$E = \lambda(N1 + N2/\eta EL)$$

- N1 and N2 dominated by recombination fluctuations
- Resolution independent on drift field
- Natural radon-220 chain detected
- 2.8 % FWHM obtained for Rn-222
- Previous work result: 8 % FWHM





Results: S1 and S2 energy partitioning



- Electron-ion recombination probability at 1 kV/cm $r = (0.026 \pm 0.013)$
- Ionization increases with drift field
- Scintillation lowers with drift field
- We measure Nex/Ni = (0.561 ± 0.045).
- Considering Wi = 22 eV

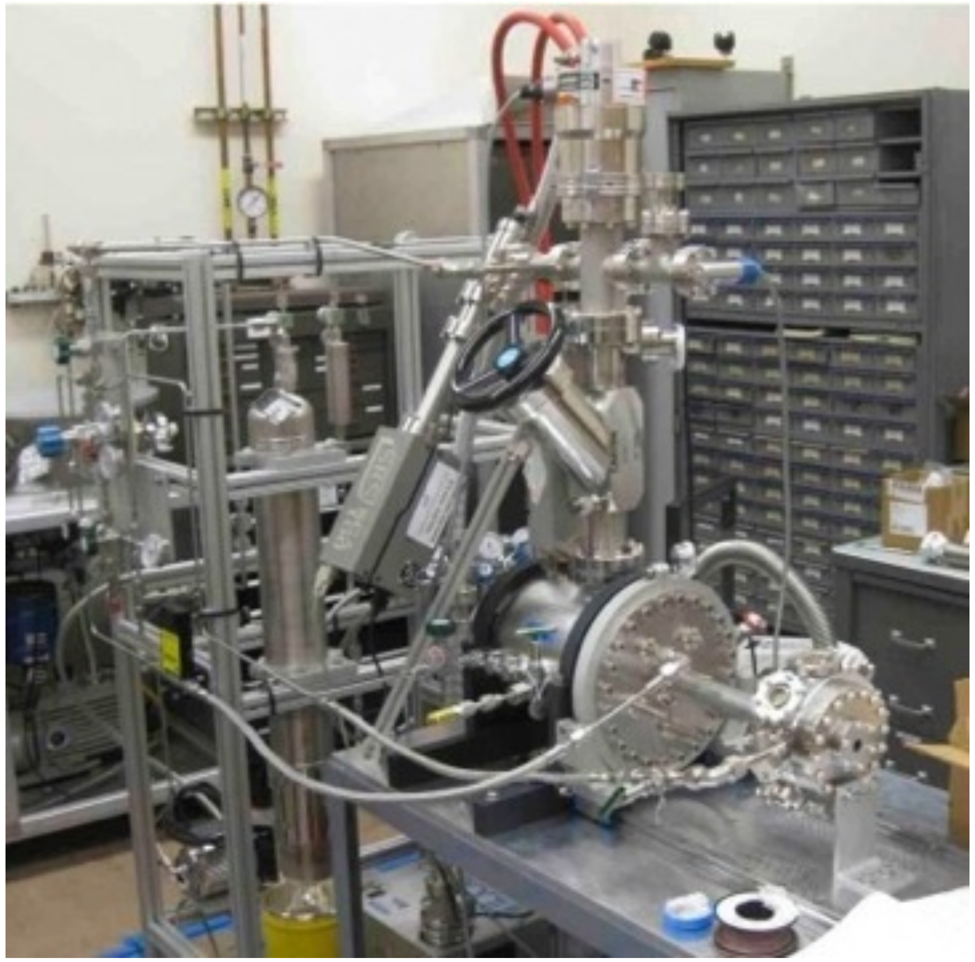
$$W_{ex} = (39.2 \pm 3.2)\ \text{eV}$$

Compatible with results obtained from other works with alpha particles

$W_{ex} = (34.5 \pm 1.4)$ eV **K. Saito *et al.*, IEEE Trans. Nucl. Sci. 50, 2452 (2003).**

$W_{ex} = (34.1 \pm 2.4)$ eV **M. Mimura *et al.*, Jpn. J. Appl. Phys. 48, 076501 (2009).**

NEXT DBDM Results



- NEXT prototype at LBNL
- Using Cs-137 662 keV gamma rays
- Assuming Wi = 24.7 ± 1.1 eV
- Work on arXiv:1409.2853

$$W_{ex} = (61.4 \pm 18)\ \text{eV}$$

Wex for X and gamma rays is higher than Wex for alpha particles:

$W_{ex} = (111 \pm 16)$ eV **S.J.C. do Carmo, F.I.G.M. Borges, F.P. Santos, T.H.V.T. Dias and C.A.N. Conde, JINST 3, P07004 (2008).**

$W_{ex} = (72 \pm 6)$ eV **L. M. P. Fernandes *et al.*, JINST 5, P09006 (2010) [Erratum-ibid. 5, A12001 (2010)]**

$W_{ex} = (76 \pm 12)$ eV **A. Parsons, T. K. Edberg, B. Sadoulet, S. Weiss, J. F. Wilkerson, K. Hurley, R. P. Lin and G. Smith, IEEE Trans. Nucl. Sci. 37, 541 (1990) [Proc. SPIE Int. Soc. Opt. Eng. 1159, 45 (1989)].**

Conclusions

- We have used a Rn-222 alpha source to study electron-ion recombination and energy partitioning between ionization and scintillation in NEXT-DEMO

- We have measured strongest S1-S2 correlation coefficients at low drift fields where recombination is higher

- Anti-correlation between scintillation and ionization provides a better energy estimator. This can be used in liquid xenon detectors as well.

- Best energy resolution is 2.8 % FWHM and optical gain $\eta EL = (75 \pm 5)$. Natural Rn-220 chain detected in this study not coming from source.

- We obtain $W_{ex} = (39.2 \pm 3.2)$ eV, compatible with previous works

- Work have been accepted in JINST (JINST_026P_1214)