A 1kg (10bar) Xenon-TMA TPC for Rare Event Searches: system aspects and electron swarm behaviour

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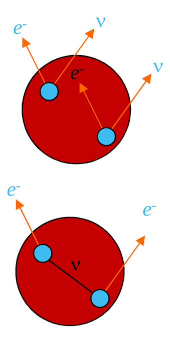
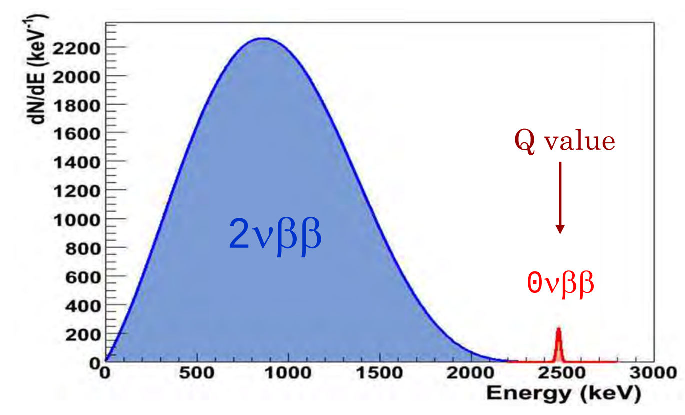
Double beta decay



2νββ: Standard process, observed in ~10 isotopes so far

0νββ: Only possible if the neutrino has a mass and is Majorana. Yet to be seen



Requirements

Excellent energy resolution

Very low background ($<10^{-3}$ cts keV^{-1} kg^{-1}y^{-1})

The NEXT experiment in the Underground Laboratory of Canfranc (LSC): an electroluminescence TPC to look for the 0ν-double beta decay of ^{136}Xe

See JJ Gomez-Cadenas's talk on NEXT and posters on: backgrounds & sensitivity, event reconstruction, radiopurity campaign, NEXT-DEMO and NEXT-NEW

T-REX: R&D on equipping the TPC with microbulk Micromegas and measure in charge collection mode.

Microbulk Micromegas

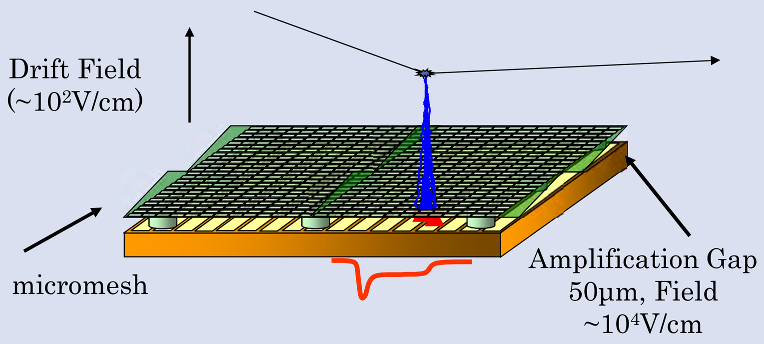
Readout plane + mesh all in one

S. Andriamonje et al., JINST 5 P02001

- High gap homogeneity
- Very good energy resolution
- High granularity
- Big surface construction feasible
- Radiopure

S. Cebrian et al., Astropart. Phys 34 (2011) 354-359

Principle of operation



Working with Xe-based mixtures — NEXT-MM

Equipped with low outgassing materials

Stainless Steel vessel

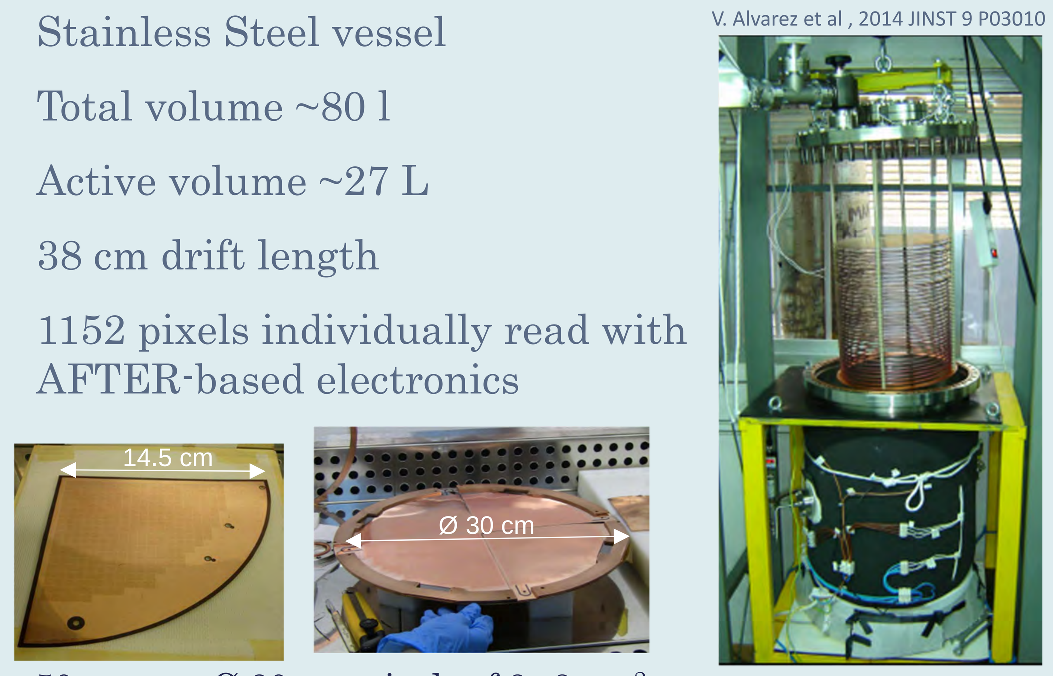
Total volume ~80 l

Active volume ~27 L

38 cm drift length

1152 pixels individually read with AFTER-based electronics

V. Alvarez et al , 2014 JINST 9 P03010



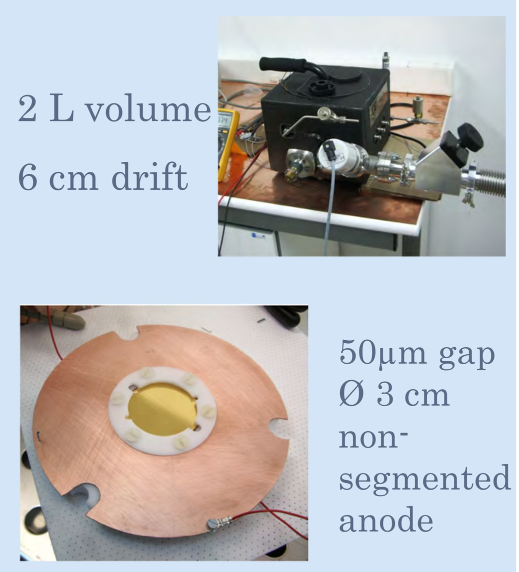
50μm gap, Ø 30 cm, pixels of 8×8mm²

Small TPC

First test with microbulks at High Pressures

2 L volume

6 cm drift

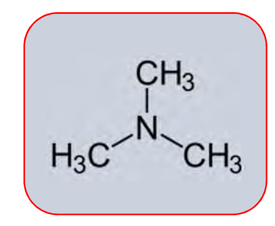


50μm gap, Ø 3 cm, non-segmented anode

Tri-methyl-amine as an additive

D. Nygren, 2011 J. Phys.: Conf. Ser. 309 012006

TMA



- Is a quencher
  - ✓ Increases maximum gain
- Could form a Penning mixture
  $Xe^{*} + TMA \rightarrow Xe + TMA^{+} + e^{-}$
  - ✓ Improves energy resolution
- Fluoresces
  - ✓ If in visible could still create electroluminescence and keep t_0 information
- Reduces electron diffusion
  - ✓ Promising for topology
  - ✓ May allow for exotic ideas such as using columnar recombination to infer the directionality of dark matter

D. Nygren, 2013 J. Phys.: Conf. Ser. 406 012006

Xe-TMA mixtures: Gain, Penning, Diffusion

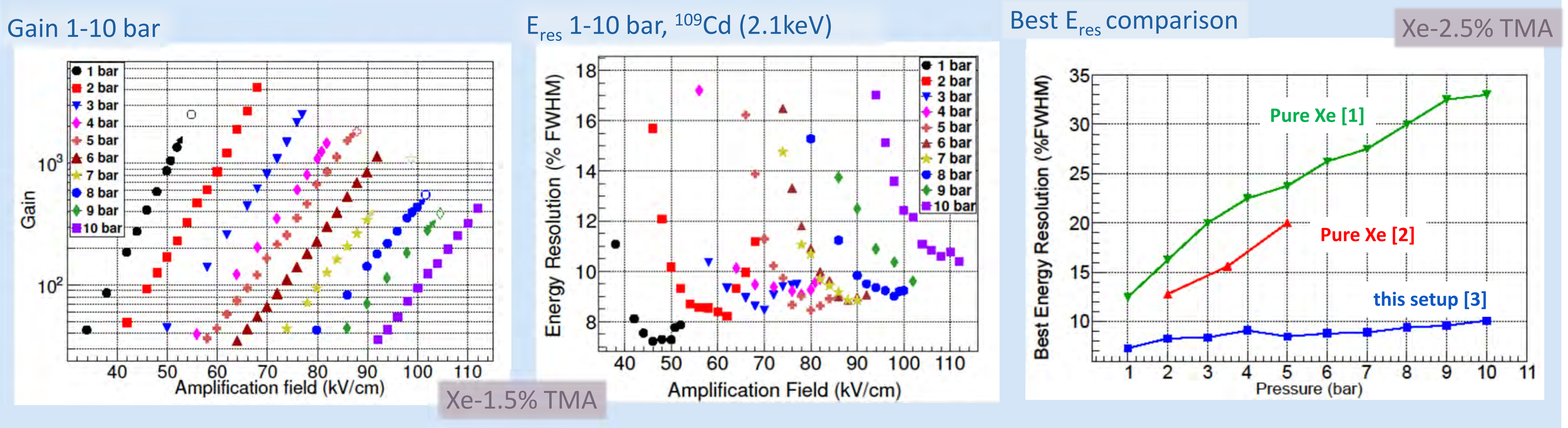
- Gain: exponential decrease in the maximum gain achieved as pressure increases
- Energy resolution degradation for higher pressures
- Best energy resolutions achieved with Micromegas in optimized mixture of Xe 97.5%-TMA 2.5% are considerably better than in pure Xe.

[1] C. Balan et al, 2011 JINST 6 P02006, [2] T. Dafni et al., J. Phys.:Conf. Ser. 309 (2011)012009, [3] S. Cebrian et al., 2013 JINST 8 P01012

Gain 1-10 bar

E_{res} 1-10 bar, ^{109}Cd (2.1keV)

Best E_{res} comparison



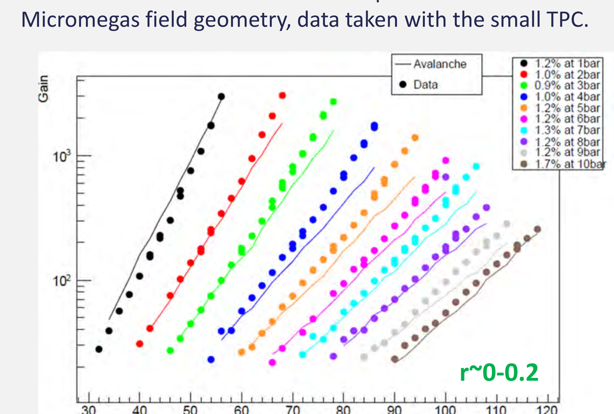
Penning mixture

The Penning effect will decrease W as long as recombination stays low and does not over-compensate

Gain comparison

Gain vs. amplification field: agreement introducing r~0-0.2

Gain calculated with a microscopic simulation of the Micromegas field geometry, data taken with the small TPC.



Parallel plate approximation

$$m \sim exp(\alpha[1 + r\, N_{exc}/N_I] \times gap)$$

$$\frac{W_{Xe-TMA}}{W_{Xe}} \cong \frac{1}{(1 + r\, N_{exc}/N_I)(1 - R)}$$

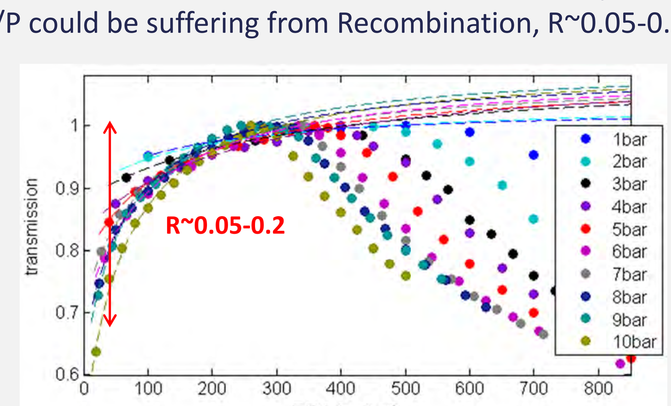
$$\frac{\sigma_{Xe-TMA}}{\sigma_{Xe}} \geq \sqrt{(1 - r) + R/F_{Xe}}$$

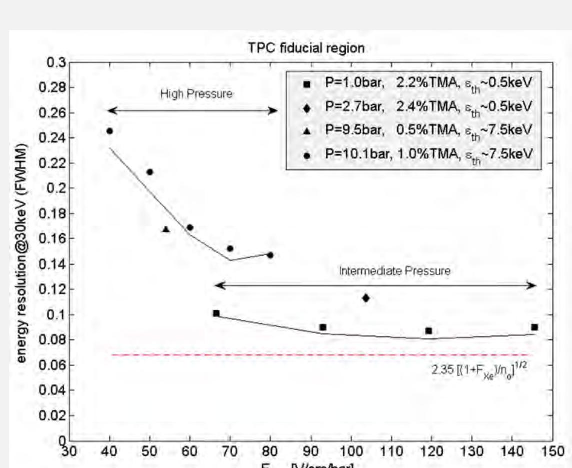
Energy resolution limits

E resolution vs. drift field at 1bar and 10 bar: deterioration due to missing energy (ε_{thres}~7.5keV) and recombination, especially at higher pressures

Electron transmission

Electron transmission vs. reduced field : the left part at low E/P could be suffering from Recombination, R~0.05-0.2

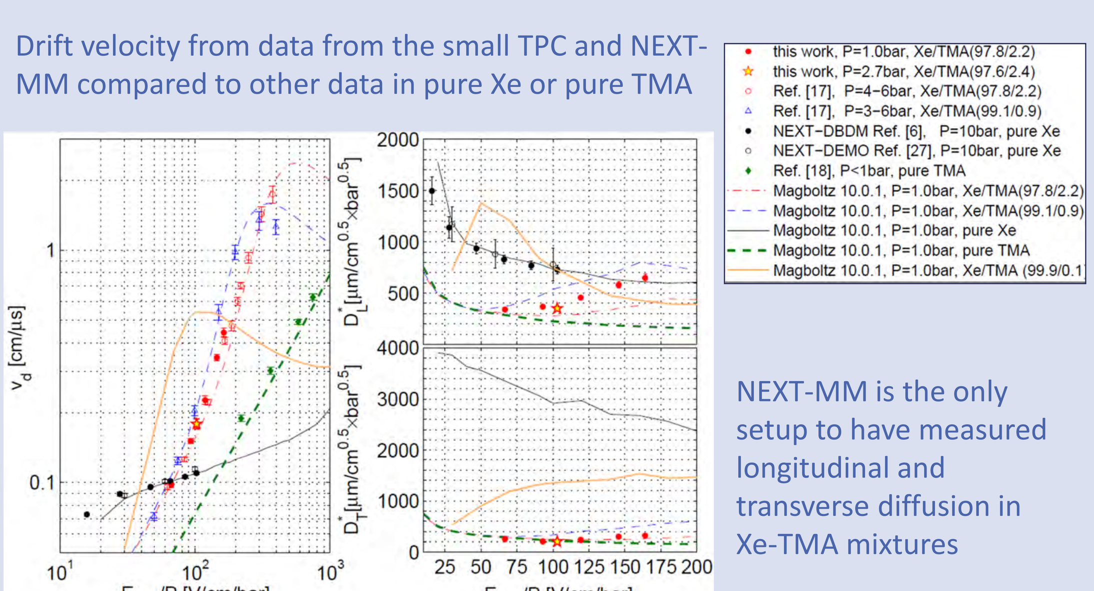




Drift velocity and Diffusion

V. Alvarez et al., 2014 JINST 9 C04015

Drift velocity from data from the small TPC and NEXT-MM compared to other data in pure Xe or pure TMA



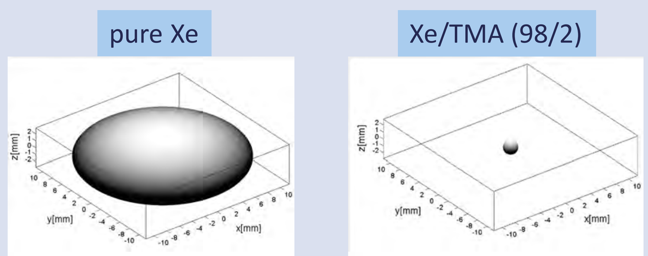
NEXT-MM is the only setup to have measured longitudinal and transverse diffusion in Xe-TMA mixtures

Diffusion

$$D^{*}_{L,T} = \sqrt{\frac{2PD_L}{v_d}}\left[\frac{\mu m}{\sqrt{cm}} \times \sqrt{bar}\right] \qquad \sigma_{L,T} = D^{*}_{L,T}\frac{\sqrt{z}}{\sqrt{P}}$$

A point-like ionization deposit after drifting z_{drift}=100cm at 10bar

pure Xe — Xe/TMA (98/2)



~20×20mm² — ~2×2mm²

Operation at 1-3 bar

V. Alvarez et al., 2014 JINST 9 C04015

^{241}Am source inside:

➢ α detected by Si-diode gives T_0

Analysis steps:

- ✓ Pulse shape analysis: info on t, σ, z
- ✓ Calibrations: sectors, pixels, transient
- ✓ Track: baseline, cosmics rejection, single-cluster (30keV), multi-cluster (>60keV)
- ✓ Random coincidences suppression (not yet easy for 10 bar)
- ✓ XYZ fiducialization

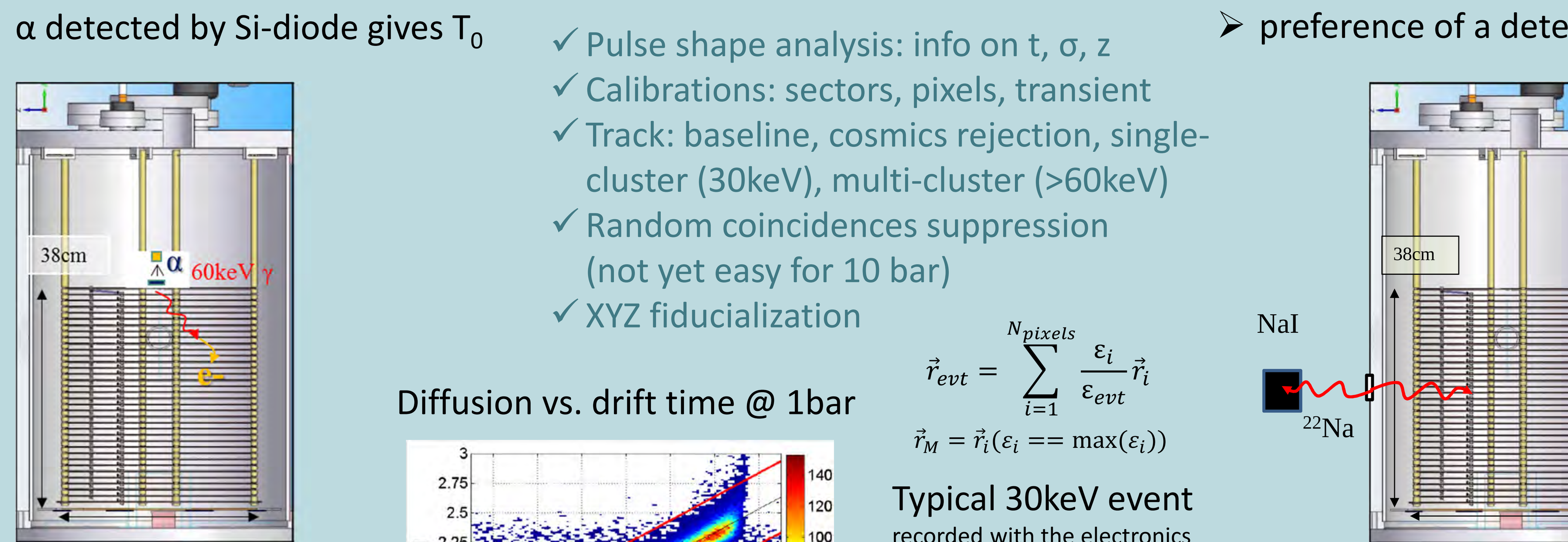
$$\vec{r}_{evt} = \sum_{i=1}^{N_{pixels}} \frac{\varepsilon_i}{\varepsilon_{evt}} \vec{r}_i$$

$$\vec{r}_M = \vec{r}_i(\varepsilon_i == \max(\varepsilon_i))$$

Operation at 10 bar

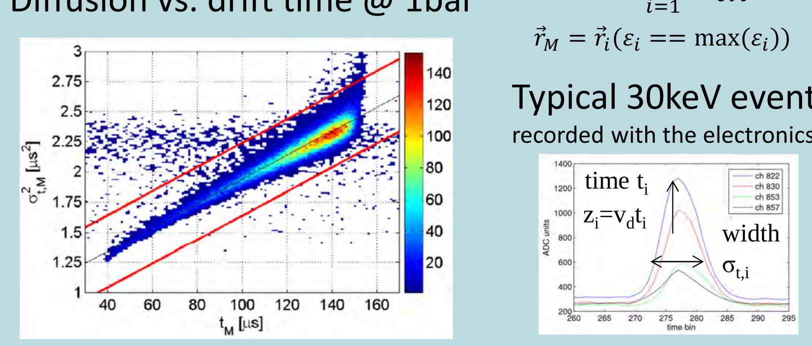
^{22}Na source in coincidence with NaI:

➢ preference of a determined z



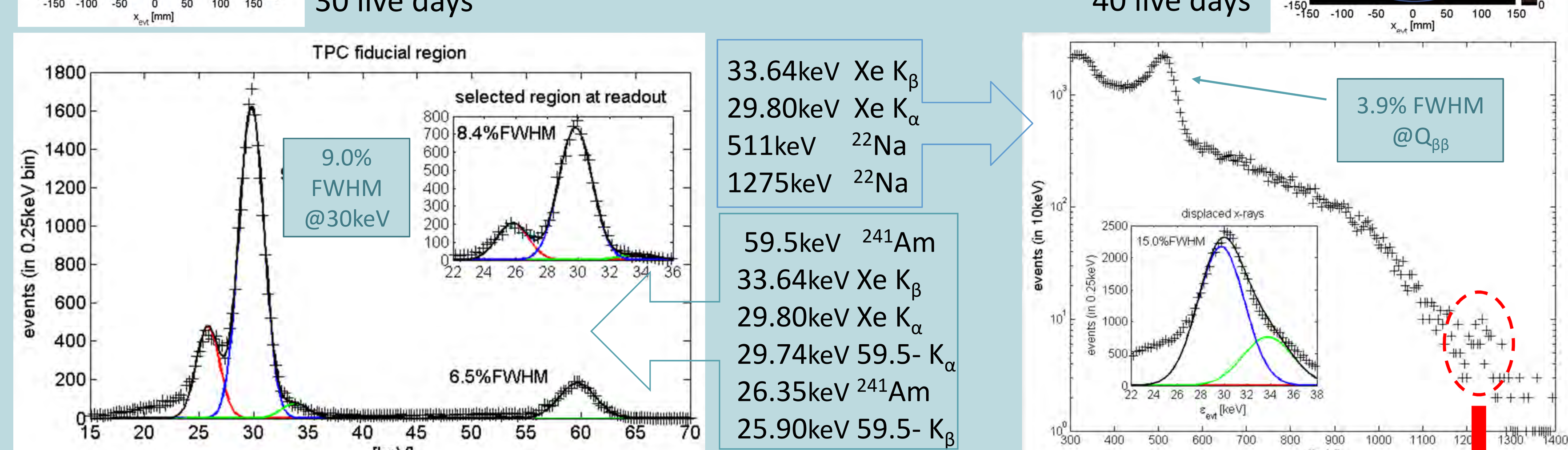
Diffusion vs. drift time @ 1bar

Typical 30keV event recorded with the electronics



3 microbulks active, 30 live days

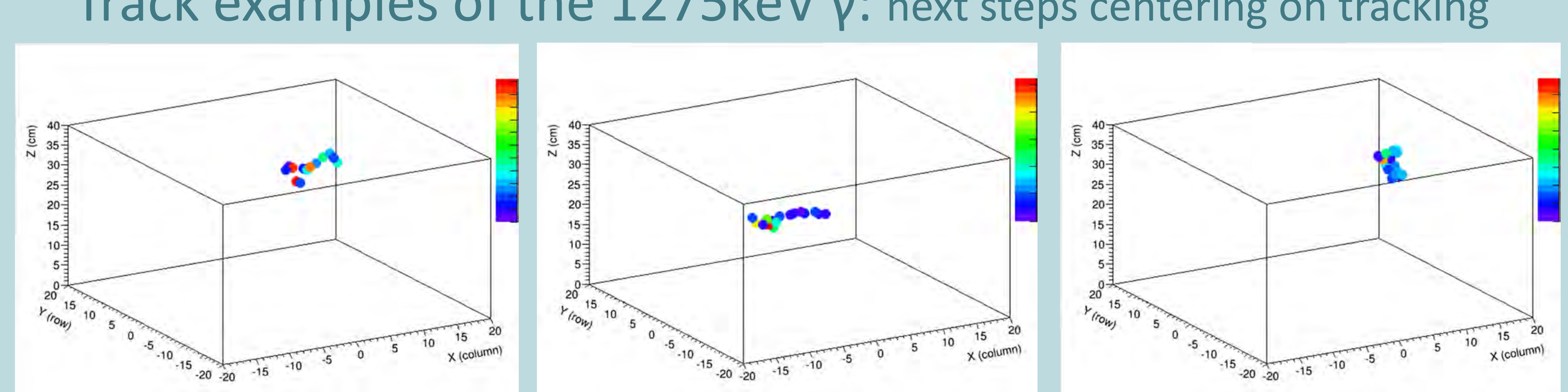
4 microbulks active, 40 live days



33.64keV	Xe K_β
29.80keV	Xe K_α
511keV	^{22}Na
1275keV	^{22}Na

59.5keV	^{241}Am
33.64keV	Xe K_β
29.80keV	Xe K_α
29.74keV	59.5- K_α
26.35keV	^{241}Am
25.90keV	59.5- K_β

Track examples of the 1275keV γ: next steps centering on tracking



Conclusions

Xe-TMA mixtures

- ✓ increase substantially the gain and the energy resolution with Micromegas vs. results in pure Xe.
- ✓ reduce electron diffusion, especially the transversal component.

NEXT-MM

- ✓ has been built as part of the R&D program of the NEXT experiment, and is currently focused on the study of the topological characteristics on low-diffusion gases through charge collection.
- ✓ is equipped with the largest surface of microbulk Micromegas to-date.
- ✓ is working stable for more than 60 live days in a Xe-1% TMA mixture.
- ✓ has achieved (so far) a 3.9% FWHM @ $Q_{\beta\beta}$ at 10 bar in Xe-1% TMA.
- ✓ has measured drift velocity, longitudinal and transversal diffusion in Xe-TMA mixtures.
- ✓ excellent for topological studies of MeV e$^-$ tracks in low-diffusion Xenon-mixtures.

Next steps

- ✓ study and identify limitations on the measured energy resolution.
- ✓ focus on topological capabilities, studying 2-blob vs. 1-blob of high-energy γ-induced e$^-$ tracks.
- ✓ complete simulation efforts on modelling Xe-TMA mixtures (Penning, recombination, Fano).
- ✓ study S1 and EL yields in Xe-TMA mixtures (LIP Coimbra, LBL).