HP TPC READOUT OPTIONS

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KEYS OF THE EXPERIMENT

- Figure of merit of 0vDBB

$$m_{\beta\beta} \propto \sqrt{1/\varepsilon}\left(\frac{b\,\delta E}{M\,t}\right)^{1/4}$$

- HP Xenon TPC: combination of good energy resolution (δE) and high background rejection property via tracking (b)

INTRINSIC RESOLUTION OF HP XENON

$$\delta E/E = 2.35\sqrt{FW_{\mathrm{i}}/E} \quad \text{(FWHM)}$$

- F: Fano factor = 0.14 in GXe
- W_i: about 25 eV, function of drift field and pressure
- Intrinsic resolution at $E_{\beta\beta}$ is 0.3%!

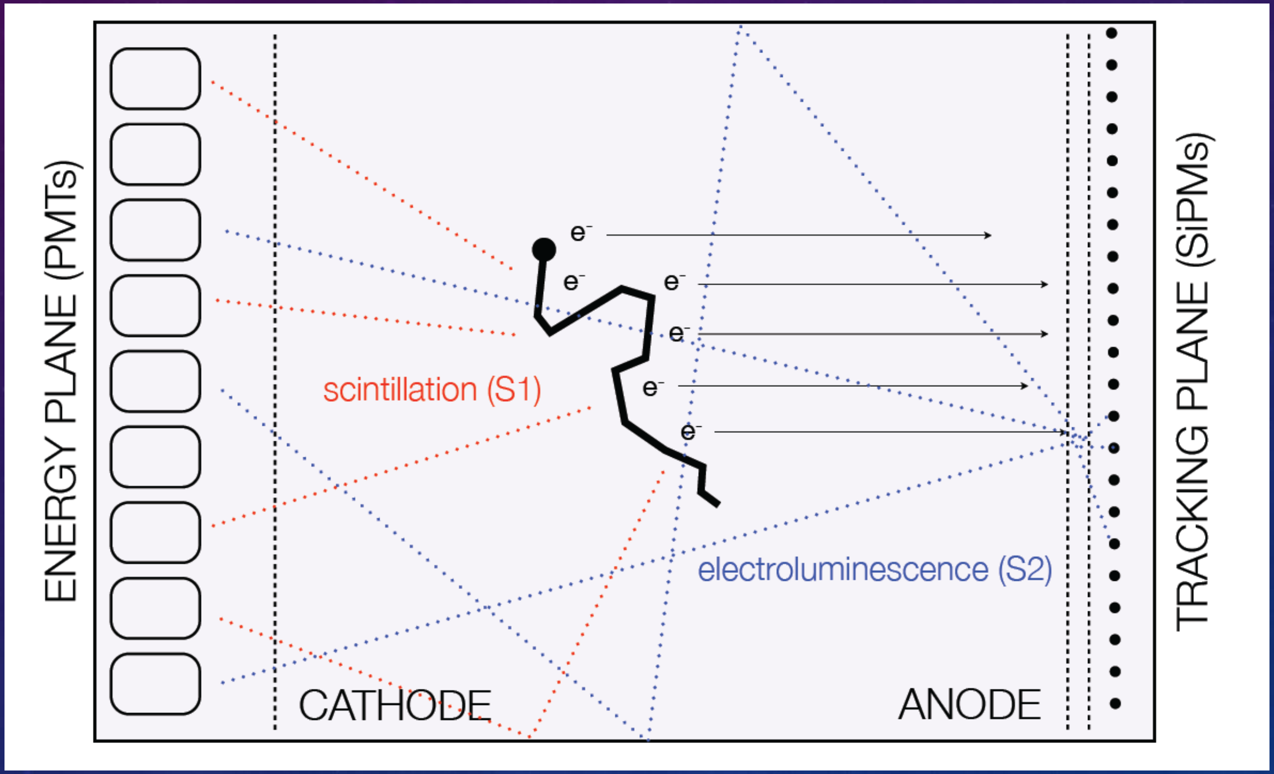
SIGNALS IN TPC

- Two betas each at 1.2 MeV, each travels about 15 cm before being stopped (10 bar)
  - Primary scintillation light (T=0 trigger signal)
    - For a drift field of 370 V/cm, light yield is about 61 eV per photon (40,000 photons @ $E_{\beta\beta}$) arXiv:1409.2853
  - Ionizing electrons (energy, track)
    - Charge yield = 2459 keV/24.8 eV ~ 100, 000 electrons

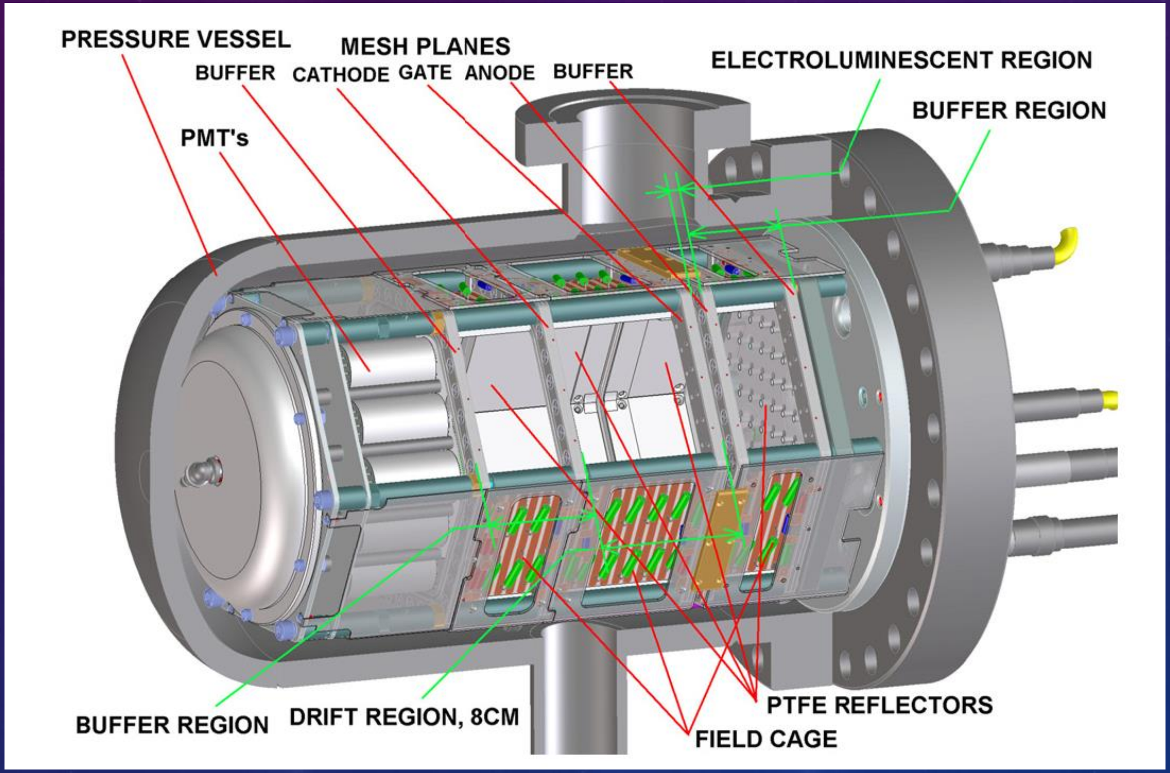
SURVEY OF OPTIONS BY NEXT

- History: NEXT Collaboration have constructed four prototypes in total, NEXT-DEMO, NEXT-DBDM, NEXT-0-MM, NEXT-MM
- References:
  - NEXT-100 TDR: JINST 7 T06001
  - NEXT-DBDM, NIMA 708 (2013) 101–114
  - NEXT-0-MM, Journal of Physics: Conference Series **460** (2013) 012012
  - NEXT-MM: JINST 9 C04015
- They have decided their baseline technology for NEXT-100
  - Asymmetric TPC with separate energy and track measurement devices, both via electroluminescence (SOFT)
  - Charge readout via MicroMEGAS as the R&D option for future upgrade.

SOFT TPC


ENERGY PLANE (PMTs)
TRACKING PLANE (SiPMs)
scintillation (S1)
electroluminescence (S2)
e⁻
e⁻
e⁻
e⁻
e⁻
e⁻
CATHODE
ANODE

NEXT-DBDM (DEMONSTRATOR)



TPC dimension

- 12 cm diameter
- 14 cm long

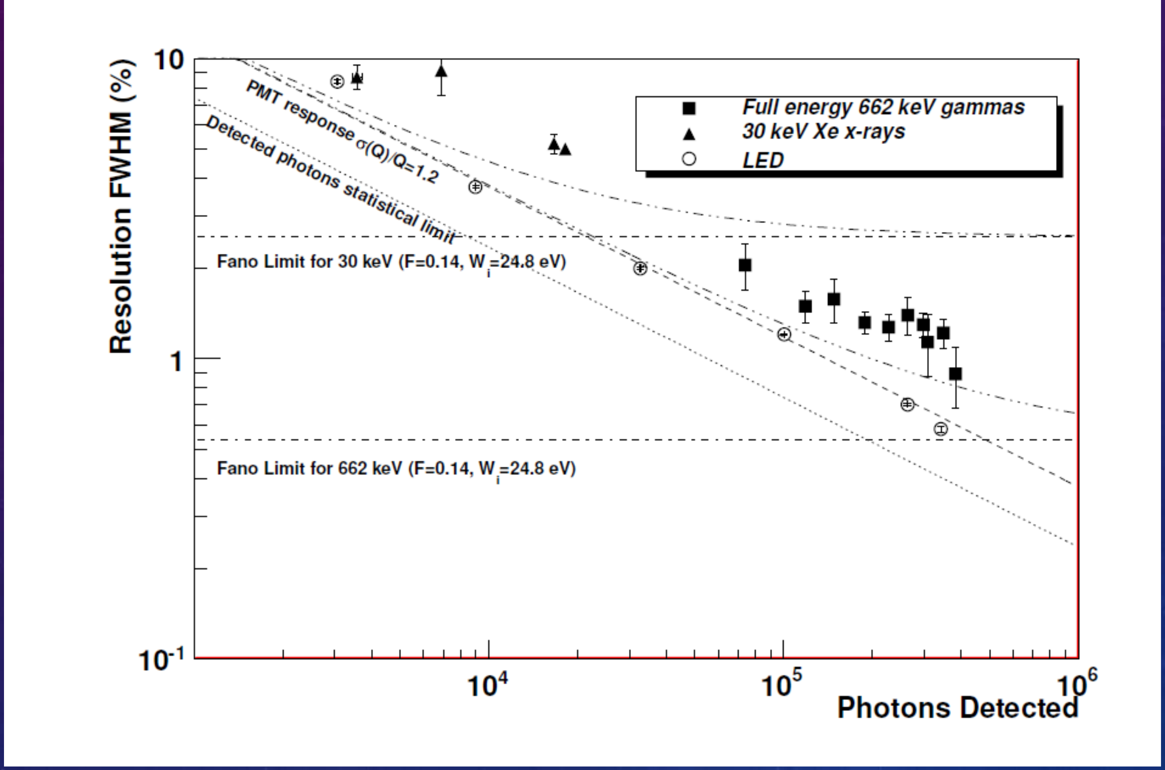
INTRINSIC RESOLUTION WITH ELECTROLUMINESCENCE

$$\delta E/E = 2.35\sqrt{((F+G)W_{\mathrm{i}}/E)} \quad \mathrm{(FWHM)}$$

$$G = 1/\eta + (1+\sigma_{\mathrm{pd}}^2)/n_{\mathrm{pe}}$$

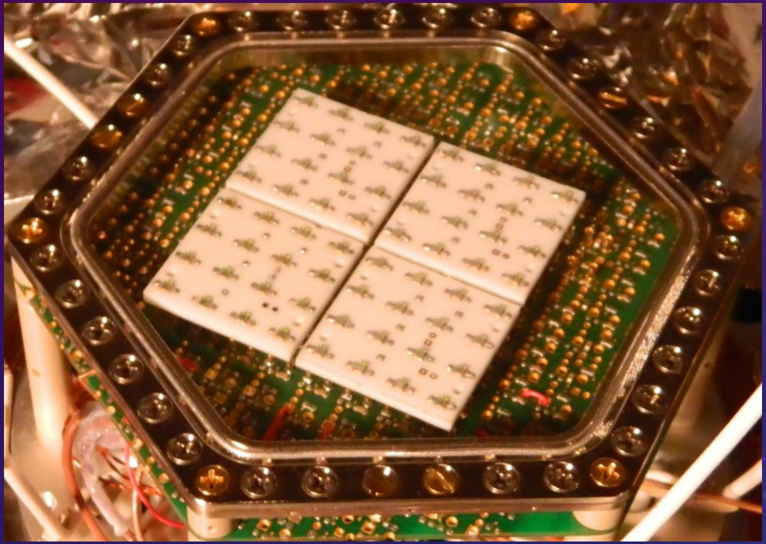
- F: Fano factor = 0.14 in GXe
- η: optical gain per electron, depending on the EL voltage and pressure, O(1000)
- σ_{pd}: single PE resolution (1.2! due to afterpulsing)
- N_{pe}: number of photoelectron per electron, 0(10)
- Note: position dependent gas gain uniformity should also be in G, VERY relevant for a large detector, critical to have superb resolution in position

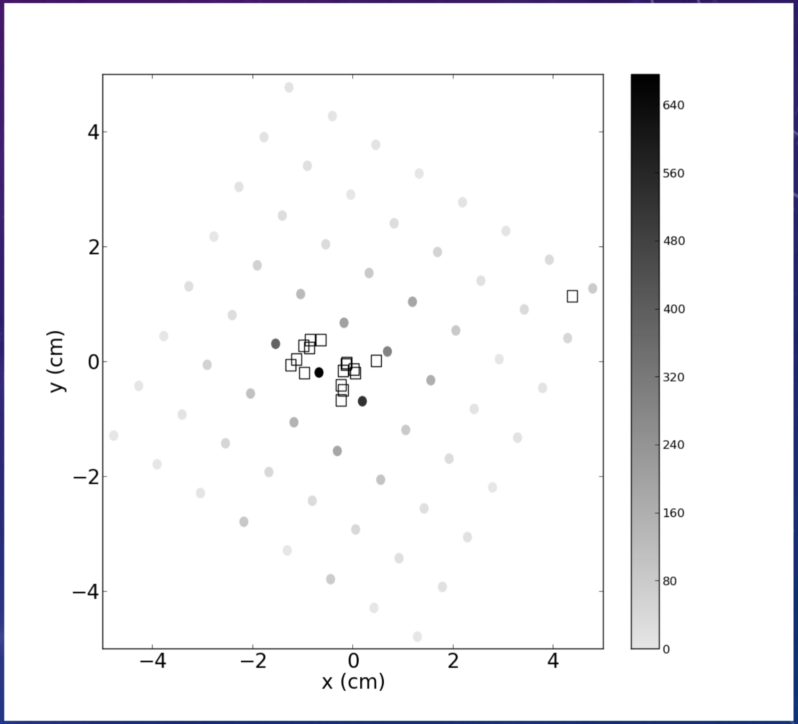
NEARLY INTRINSIC RESOLUTION



Extrapolated to 0.5% FWHM resolution at $E_{\beta\beta}$

TRACKING ABILITY (8X8 SIPM)

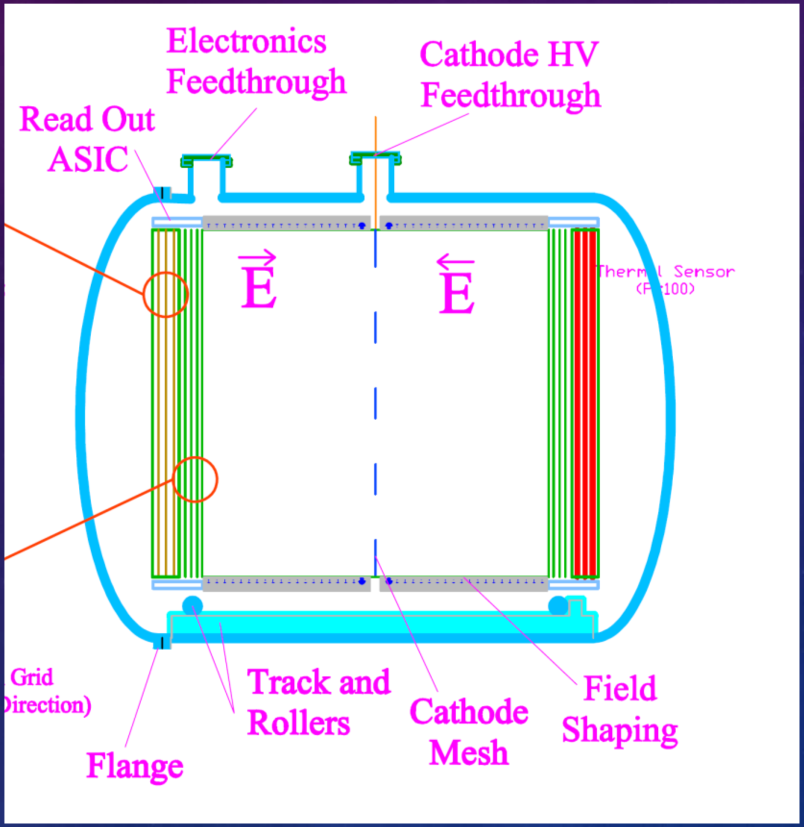




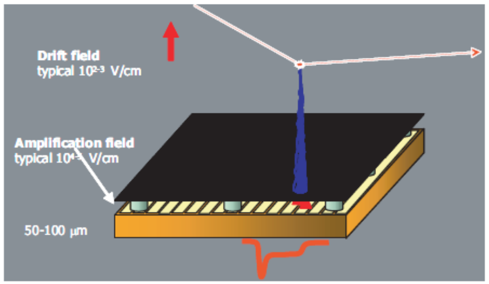
POTENTIAL ISSUES WITH NEXT BASELINE DESIGN

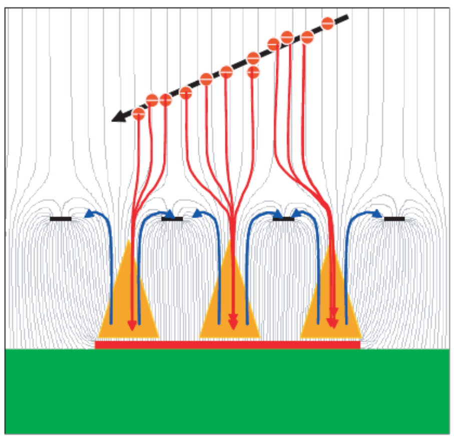
- Photomultipliers are known to be radioactive (Bi214 and Tl208 are from the U/Th chain!)
- High uniformity of EL gain a challenge
- SiPM tracking for a m^2 coverage is EXPENSIVE
- Large EL light can saturate SiPM, causing inaccuracy in tracking and uniformity correction
- Asymmetric TPC: drift field requirement x 2 higher than a symmetric TPC with cathode in the middle

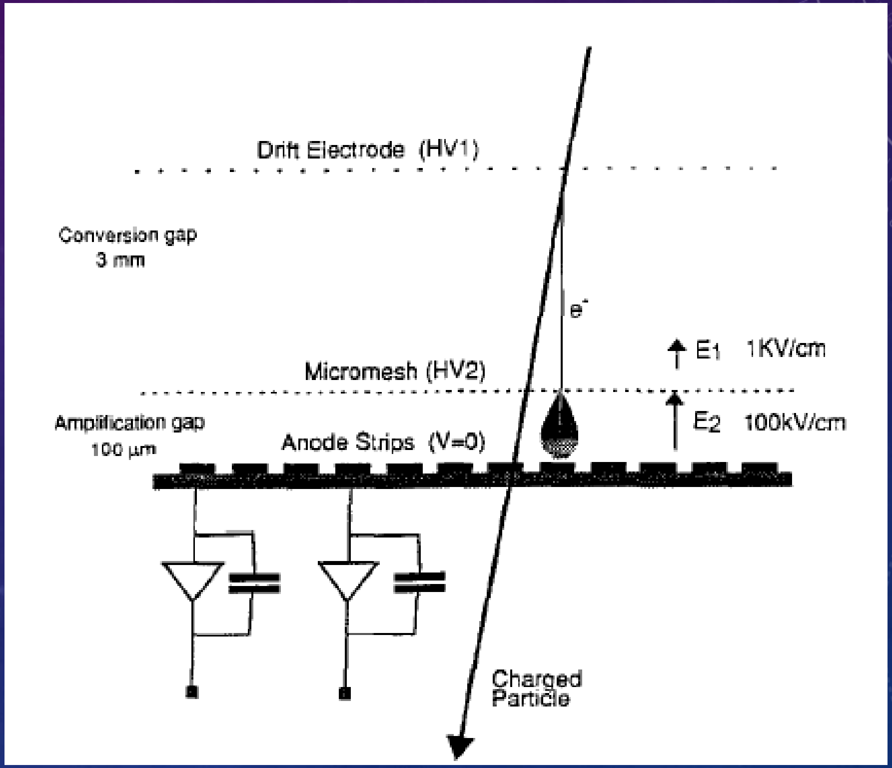
SYMMETRIC TPC CONCEPT



MICROMEGAS (MICRO MESH GASEOUS STRUCTURE)







PENNING-ADDITIVES

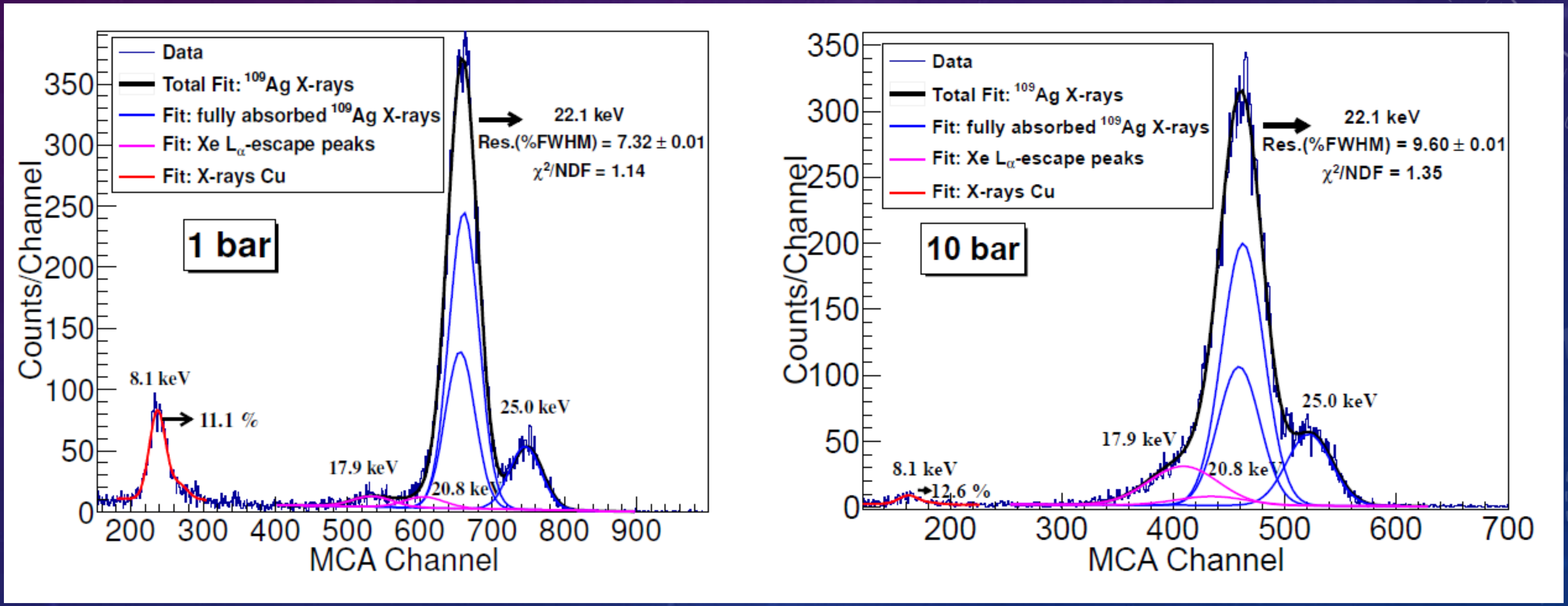
- Early measurements indicated that micromegas in pure Xe has insufficiency resolution
- In 2011, Nygren reported in J. Phys. Conf. Ser., **309**(2011)012006 that additive of Penning trimethylamine (TMA) can greatly enhance the gas electronic properties: resolution, gain, diffusion, etc

NEXT-0-MM

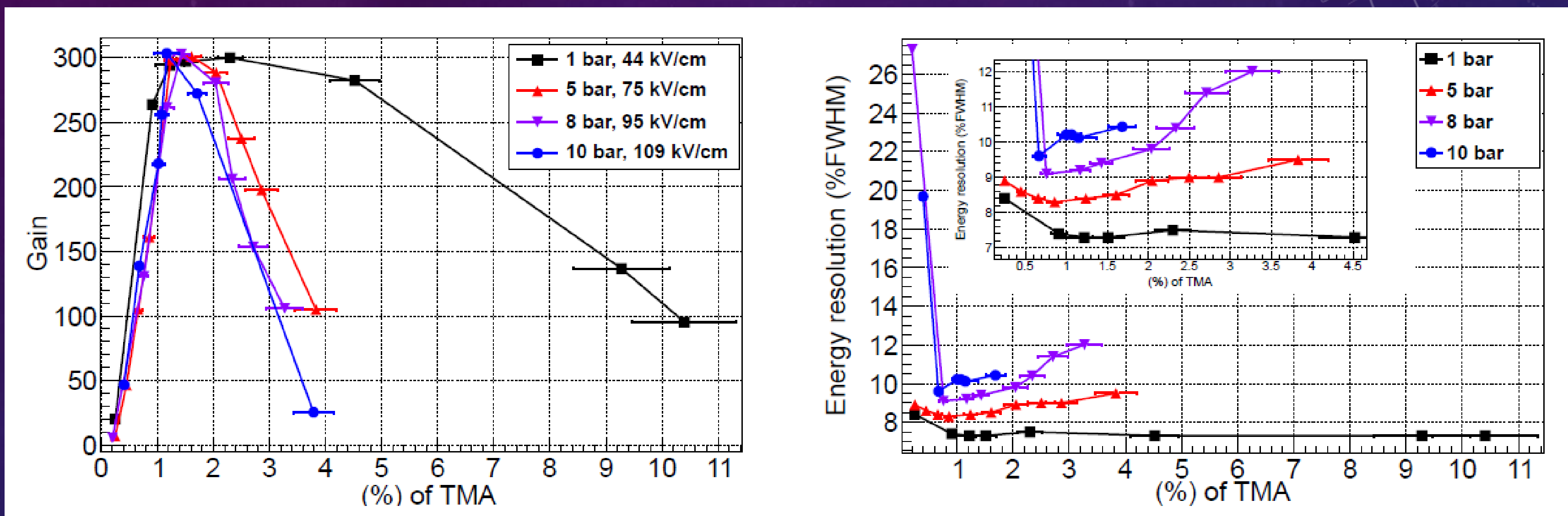
- 2.4 l small prototype with micromegas readout
- Xe:TMA mixture studies
- Penning transfer observed with TMA concentration between 0.9% and 1.7%

NEXT-0-MM

Calibration source Cd109 with 22.1 keV x-rays (Ag109)

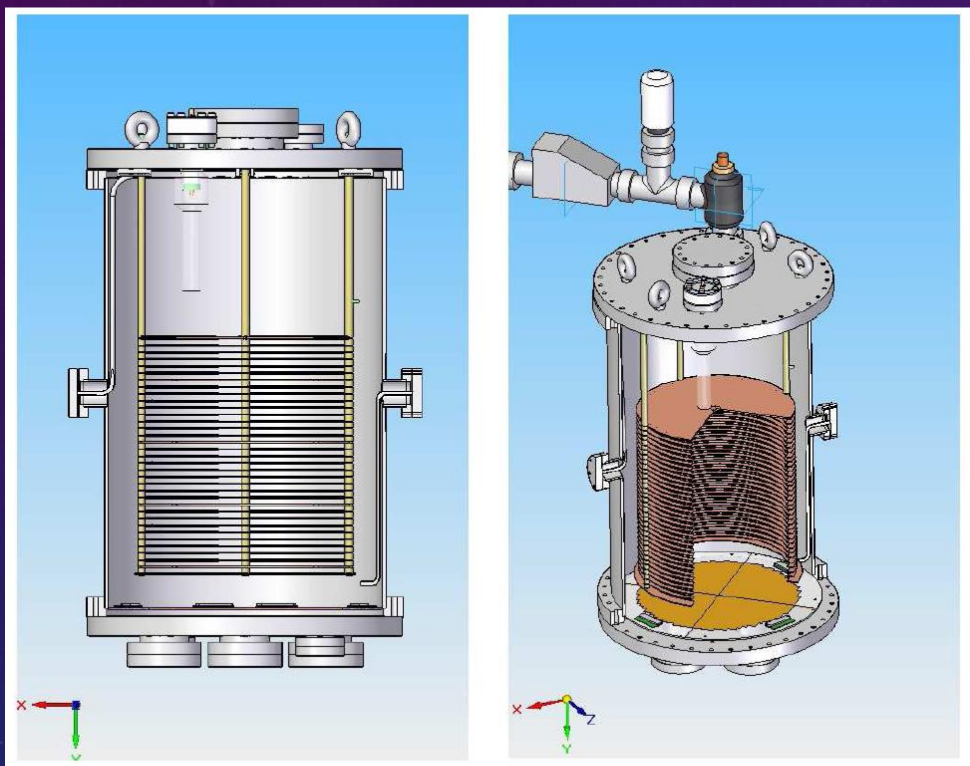


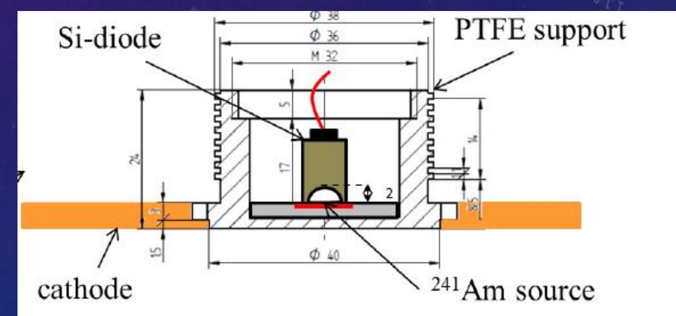
NEXT-0-MM RESULTS



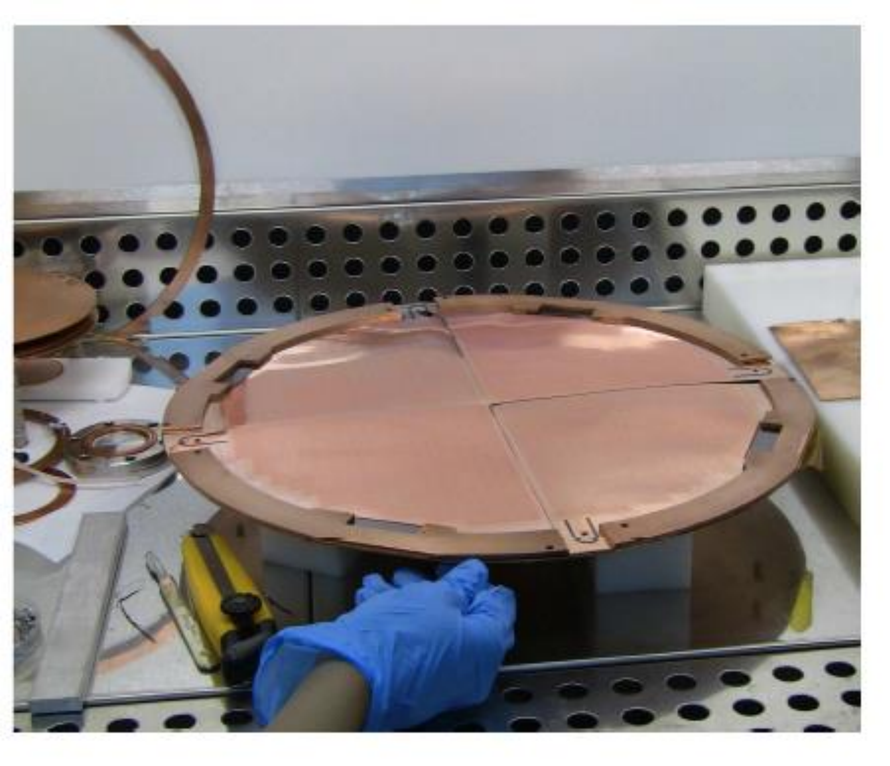
- 10 bar results extrapolated to 1% at $E_{\beta\beta}$

NEXT-MM PROTOTYPE





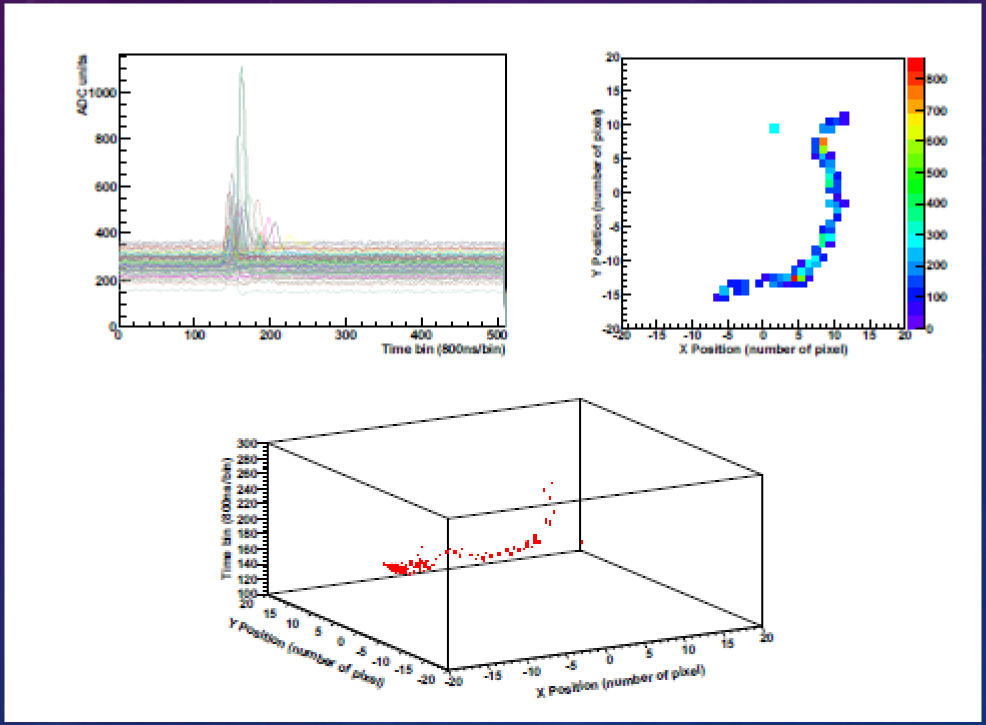
MICROBULK MICROMEGAS



Mesh: 50 um gap, 35 um hole, 100 um pitch
Anode: 8 mm x 8 mm pixels
Method HV: 270 V!
Electron multiplication: 2000

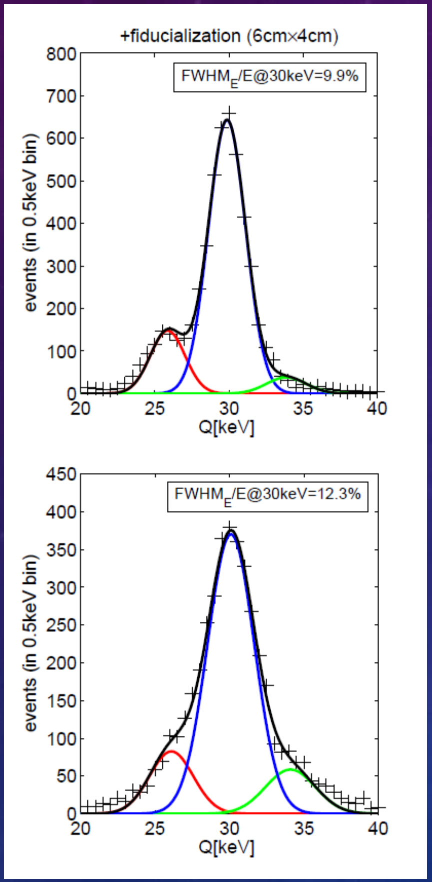
Better field homogeneity, radiopure (double-sided Cu plated kapton)

AN MEASURED ELECTRON TRACK



1 bar

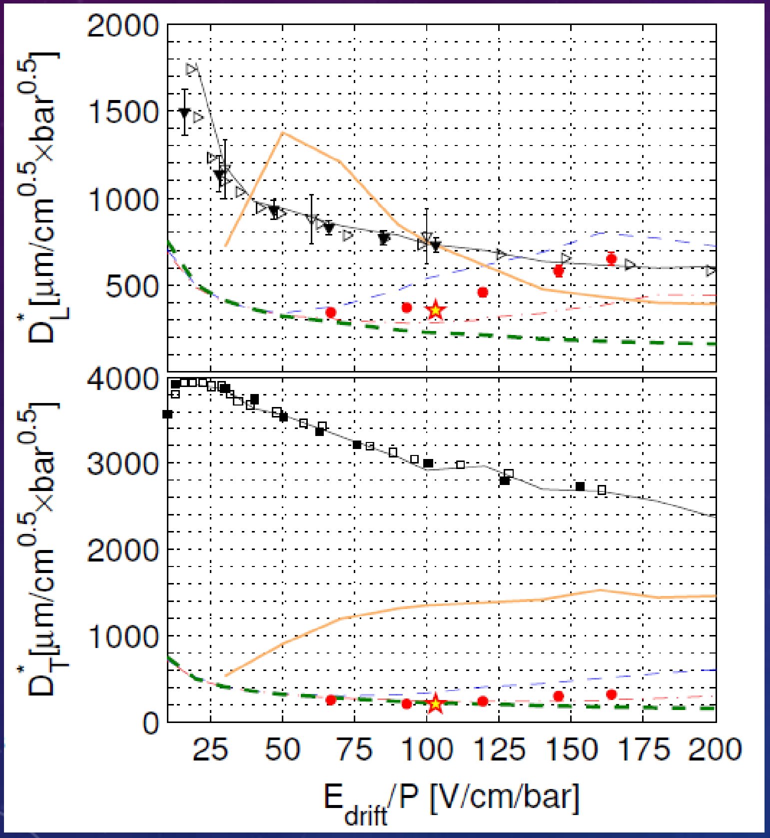
RESOLUTION @ 30 keV

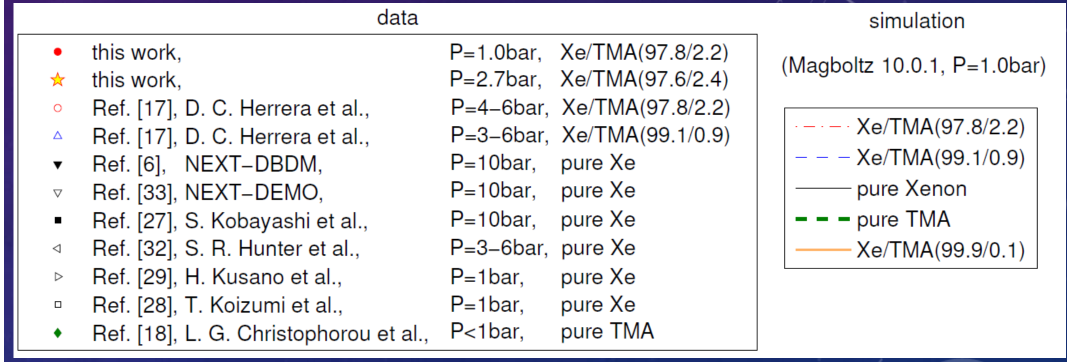


1 bar

2.7 bar

DIFFUSION CHARACTERS IN XENON-TMA (98%:2%)





VERY encouraging!

RADIOACTIVITY

Table 2
Radioactivity levels (in μBq/cm^2) measured for a Micromegas without mesh, a *microbulk*-Micromegas, a kapton–copper raw material foil, a copper–kapton–copper raw material foil and those in a PMT used in XENON experiment, taken from [30].

Sample	^{232}Th	^{235}U	^{238}U	^{40}K	^{60}Co
Micromegas without mesh	4.6 ± 1.6	<6.2	<40.3	<46.5	<3.1[a]
Microbulk-Micromegas	<9.3	<13.9	26.3 ± 13.9	57.3 ± 24.8	<3.1[a]
Kapton–copper foil	<4.6[a]	<3.1[a]	<10.8	<7.7[a]	<1.6[a]
Copper–kapton–copper foil	<4.6[a]	<3.1[a]	<10.8	<7.7[a]	<1.6[a]
Hamamatsu R8520-06 PMT [30]	27.9 ± 9.3	–	<37.2	1705.0 ± 310.0	93.0 ± 15.5

CHALLENGES AND OPEN QUESTIONS

- Can the energy resolution be improved (>= 10 bar)?
- Additive mixture be optimized?
- Improve the position uniformity of the micromegas?
- With the TMA additive, normally the scintillation yield is quenched. How to get an effective trigger?

A WORD ON THGEM

JINST
PUBLISHED BY INSTITUTE OF PHYSICS PUBLISHING AND SISSA
RECEIVED: *December 4, 2007*
ACCEPTED: *December 26, 2007*
PUBLISHED: *January 29, 2008*

Operation of a Thick Gas Electron Multiplier (THGEM) in Ar, Xe and Ar-Xe

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Seemed to have a larger resolution

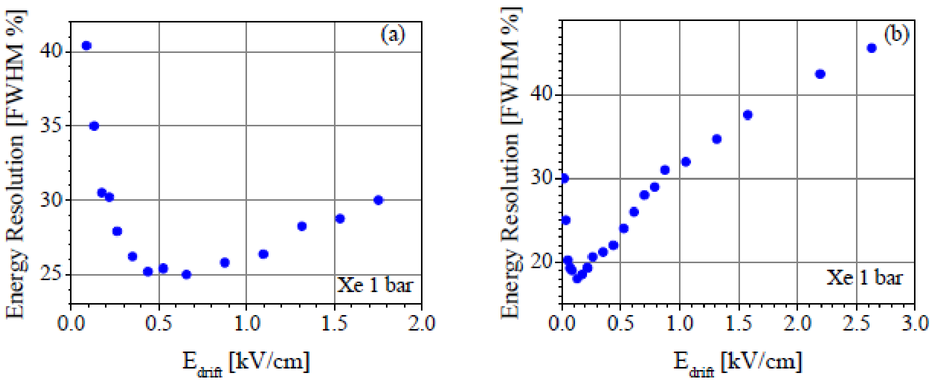

Figure 9. Energy resolution of a single-THGEM versus drift field, measured in 1 bar Xe: (a) 5.9 keV x-rays, t=0.8mm, d=0.4mm, a=1.2mm; (b) 22.1 keV x-rays, t=0.4mm, d=0.3mm, a=1mm. Detector gain ~10^3.

FINAL REMARKS

- Charge readout with micromegas in HP Xe TPC promising (with TMA mixture), overcoming several fundamental problems with the EL approach in the DBD search
- Good approach for a interim 100-kg Xe136 DBD project
- Great project to develop a generic low background, high resolution, large-area tracking detector, applicable to, e.g. dark matter direction detector