Experimental transport coefficients for electron swarms in Xe-TMA mixtures and ongoing activities towards modeling

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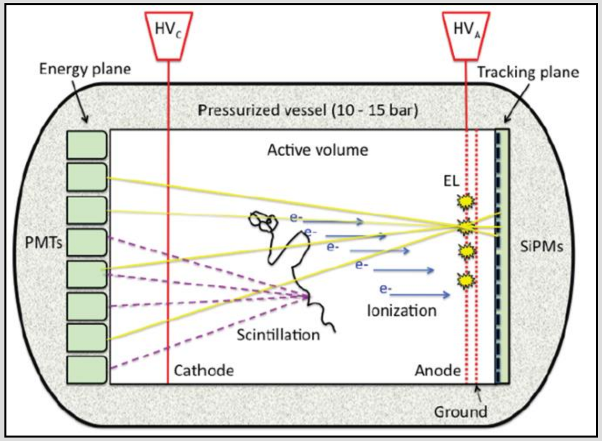
on behalf of the NEXT-100 collaboration
(diegogon@unizar.es)
CERN, **05-02-2014**

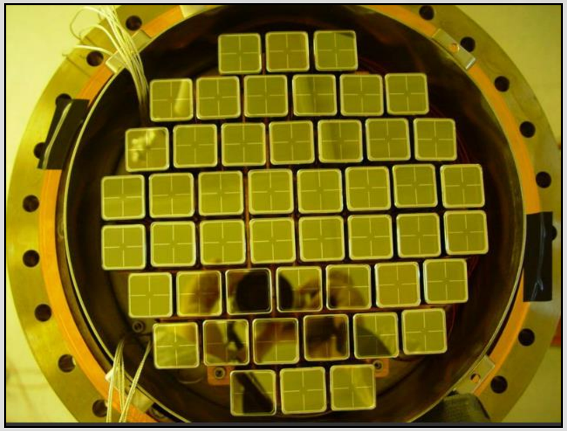
1.Introduction

(some) TPCs for rare event searches

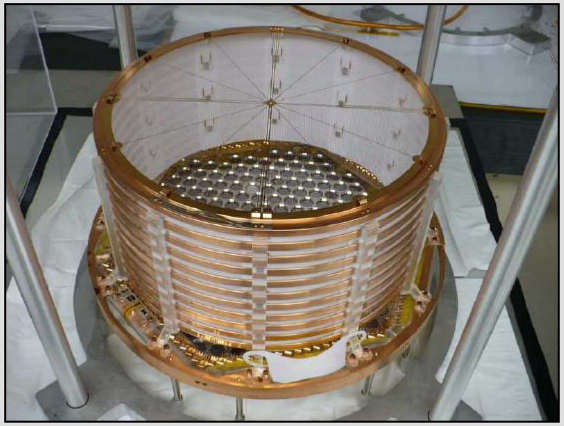
CAST (axion searches)



NEXT-100 (neutrino-less double beta decay)



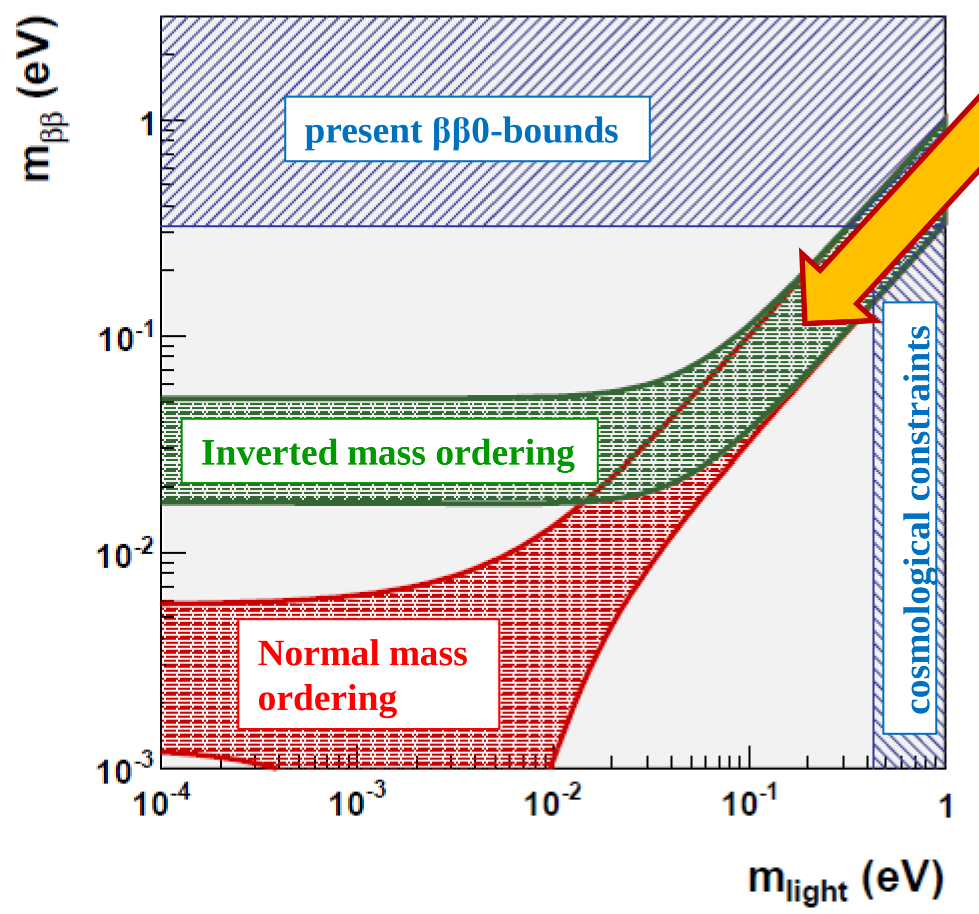
XENON (dark matter)



EXO-200 (neutrino-less double beta decay)

T-REX (directional dark matter)
ArgonDM (dark matter)
……….

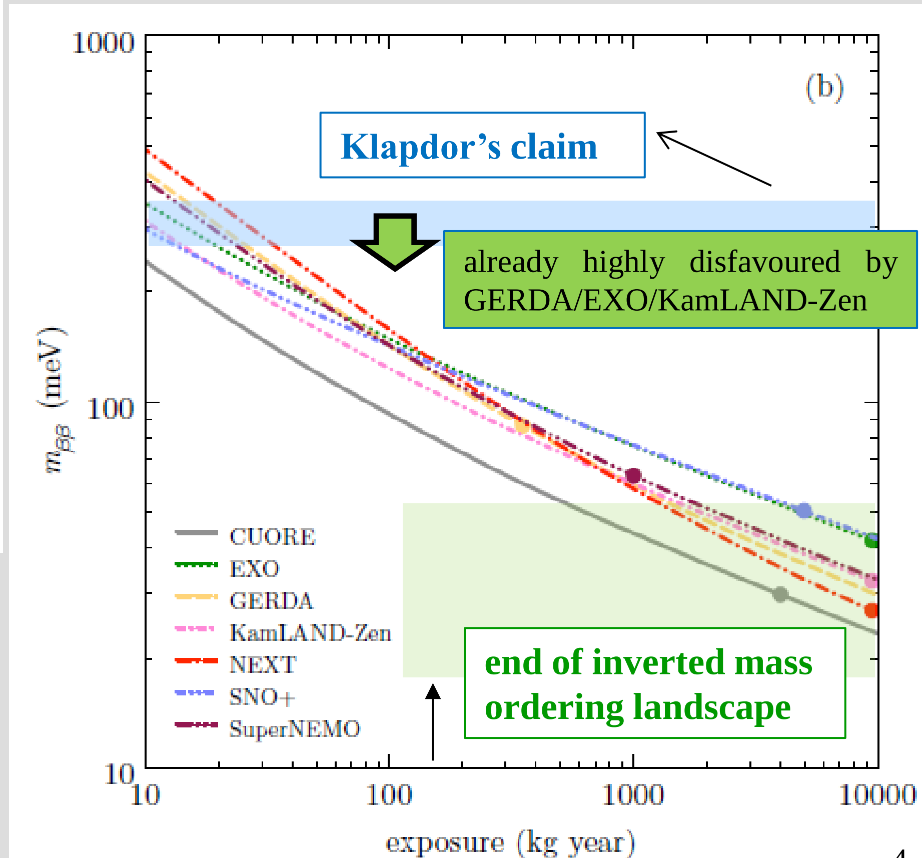
A sensible application for next-generation TPC experiments: *ββ0-decay*



$$m_{\beta\beta} \equiv \left| \sum_{i=1}^{3} m_i U_{ei}^2 \right|$$

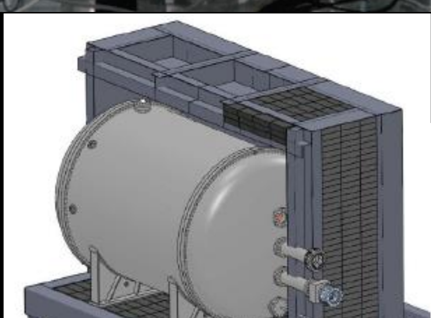
constrained by ν-oscillations

A relevant figure of merit. **Sensitivity to $m_{\beta\beta}$**: upper mass limit that can be claimed at 90%CL by a negative result in the next generation ββ0 experiments, as a function of their exposure.



J. J. Cadenas et al., *Sense and sensitivity of double beta decay experiments*, JCAP(2011)

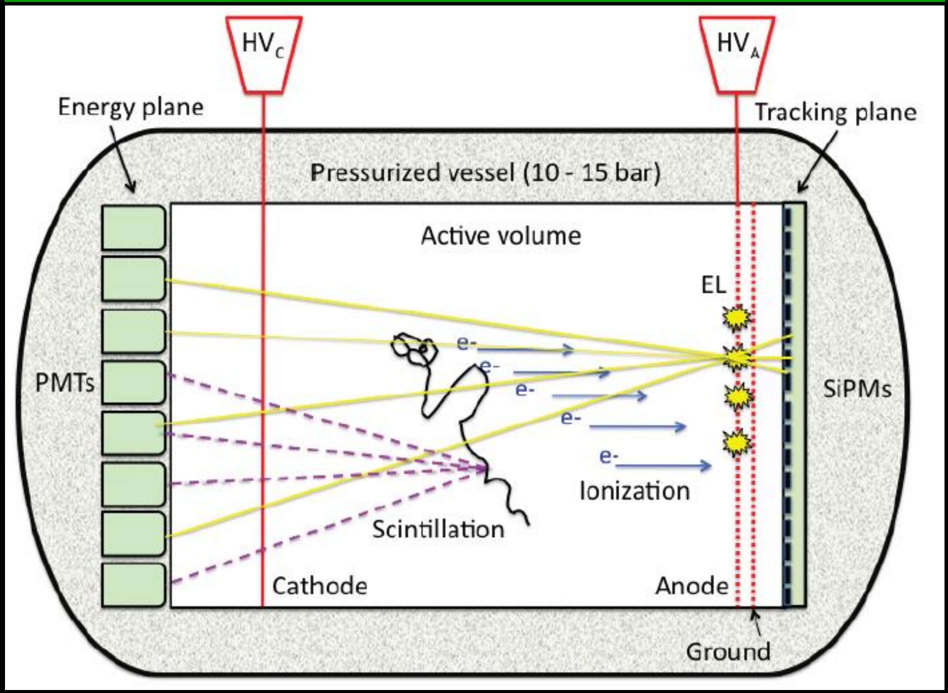
Canfranc
Underground Lab

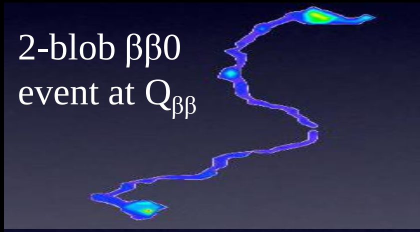


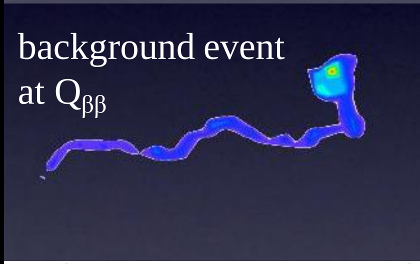
Why NEXT-100?

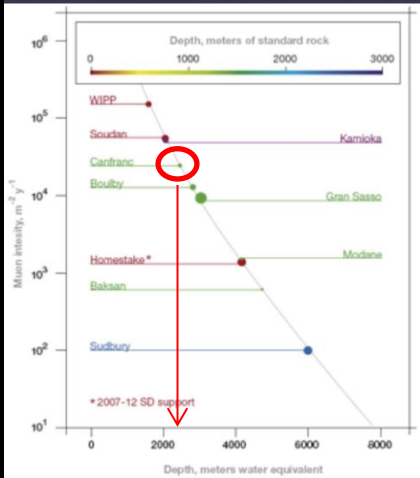
It covers a 'technological gap', providing simultaneously:

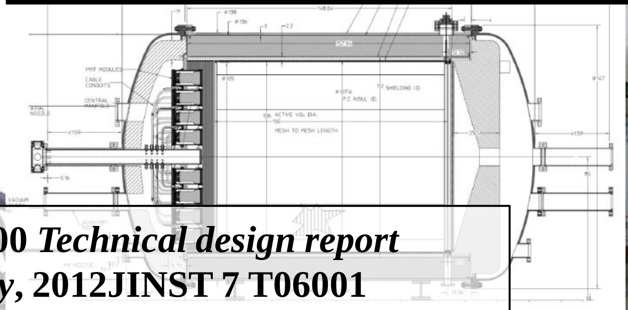
- **Good topological information.**
- **Good energy resolution** down to 0.5-1%FWHM@$Q_{\beta\beta}$.
- Good prospects for **scalability to 1Ton.**

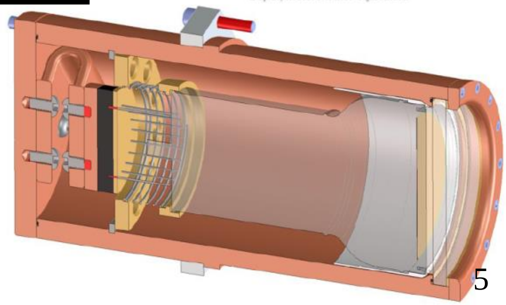




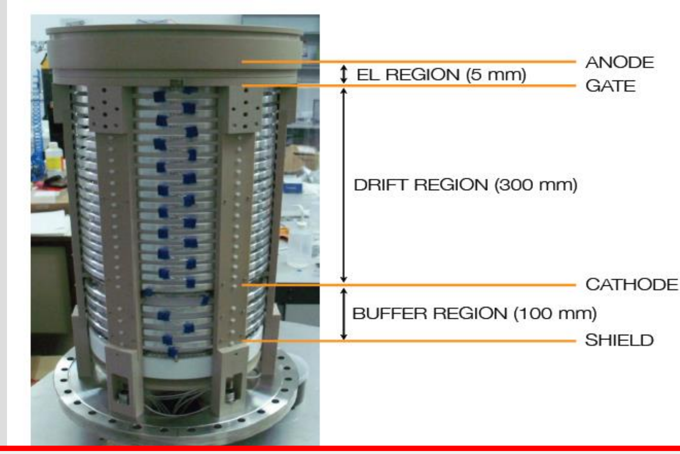






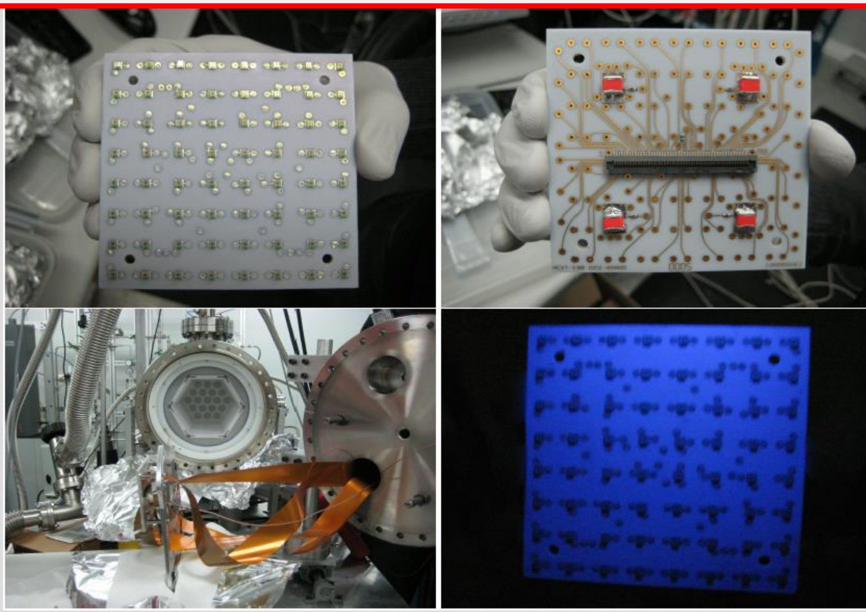


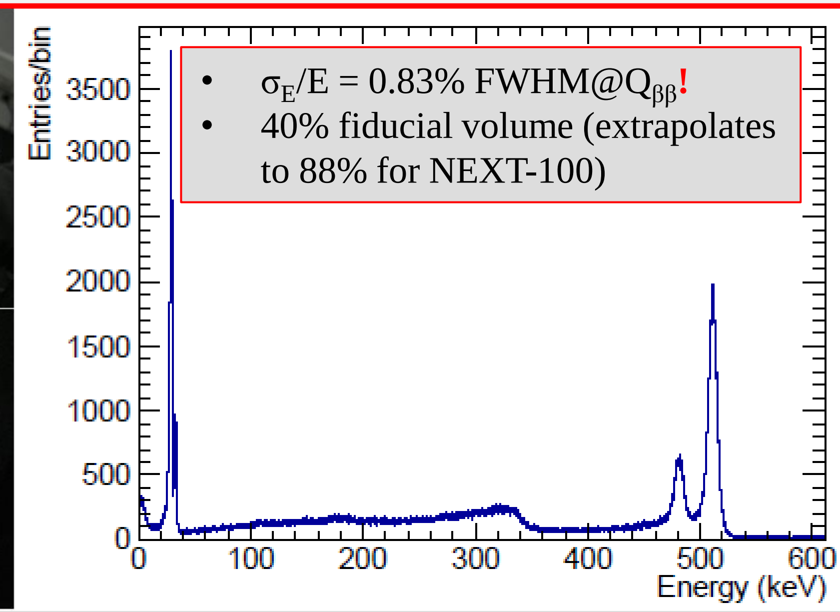
V. Alvarez et al., NEXT-100 *Technical design report (TDR). Executive summary*, 2012JINST 7 T06001



From: **Operation and first results of the NEXT-DEMO prototype using a silicon photomultiplier tracking array**

http://arxiv.org/pdf/1306.0471.pdf





see also:

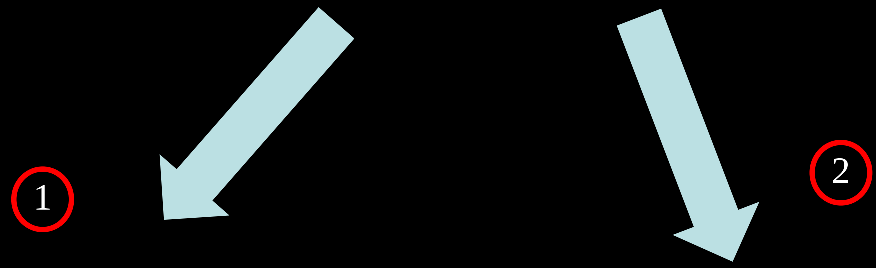
Near-intrinsic energy resolution for 30-662keV gamma rays in a high pressure Xenon TPC, NIM A 708(2013)101

Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment, JINST 8 (2013) P04002

Ionization and scintillation response of high-pressure xenon gas to alpha particles, JINST 1305 (2013) P05025

2.Microbulk Micromegas

Why a microbulk Micromegas HP Xenon-TPC *now*?



MM-TPCs??

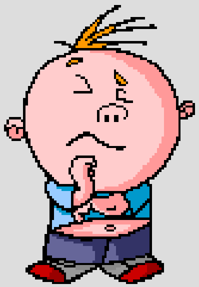
1. **There is *interest on understanding the performance of MMs in HP-Xenon* as a possible upgrade towards the ton-scale.**

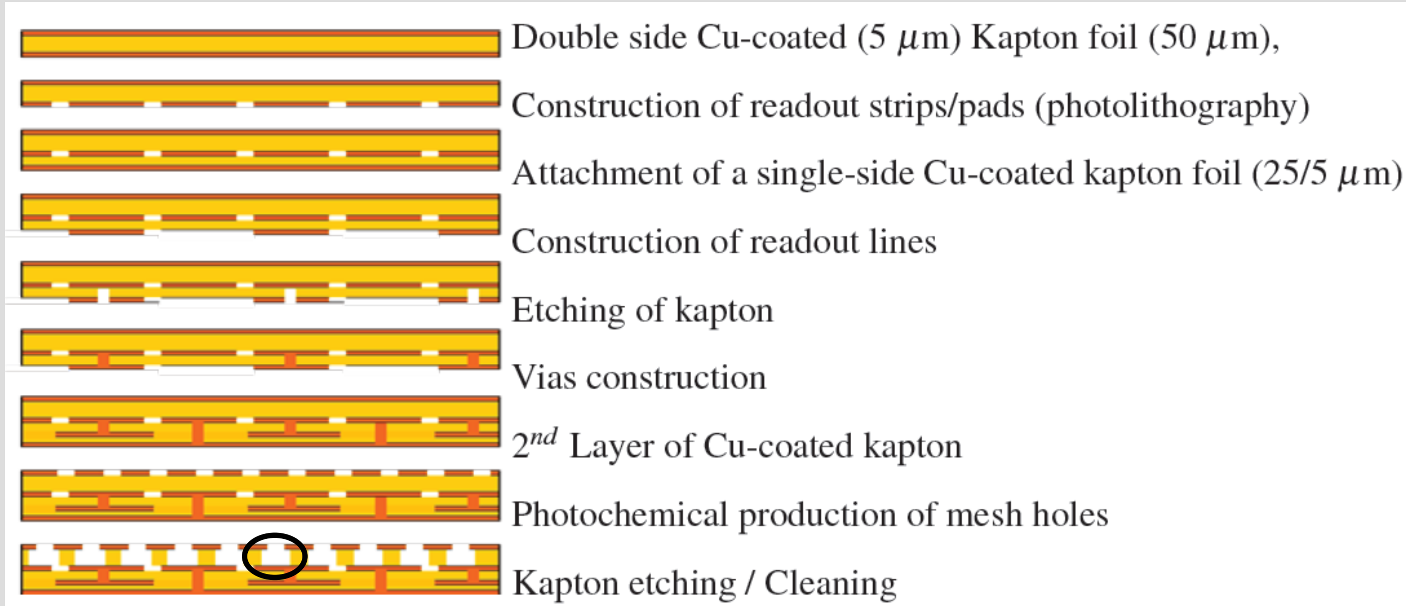
Xe+TMA TPCs??

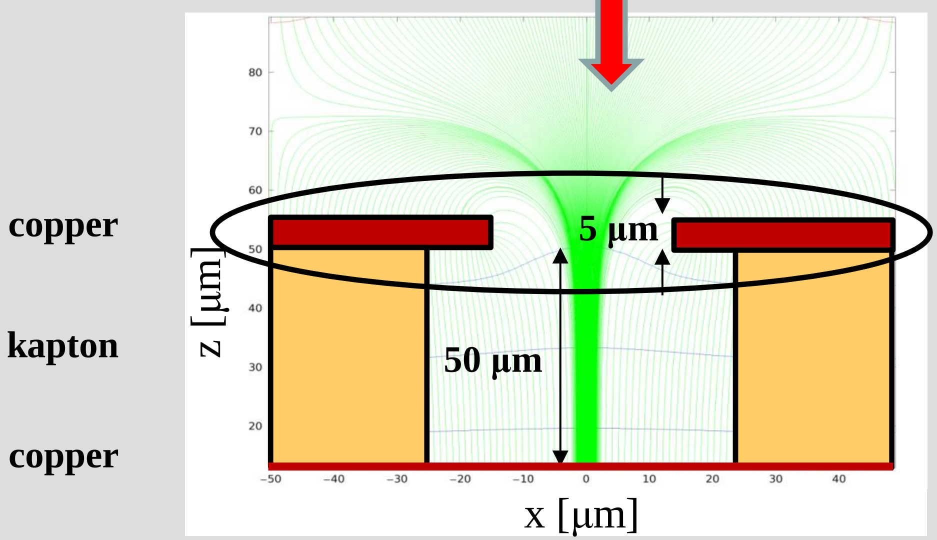
1. **Xe+TMA is believed to constitute a *Penning mixture*, that is a desirable feature for energy resolution in gaseous detectors (this talk)**
2. **It increases drift velocity and *reduces diffusion*, enhancing the topological signatures (this talk).**
3. **It may allow for a novel idea to search for *Dark Matter directionality* (this talk and Megan Long's)**
4. **It may provide an S_1 signal (initial scintillation) through *fluorescence in the more convenient near-visible range* as well as easing light-amplification for S_2 (work ongoing at LBNL – Carlos Oliveira).**

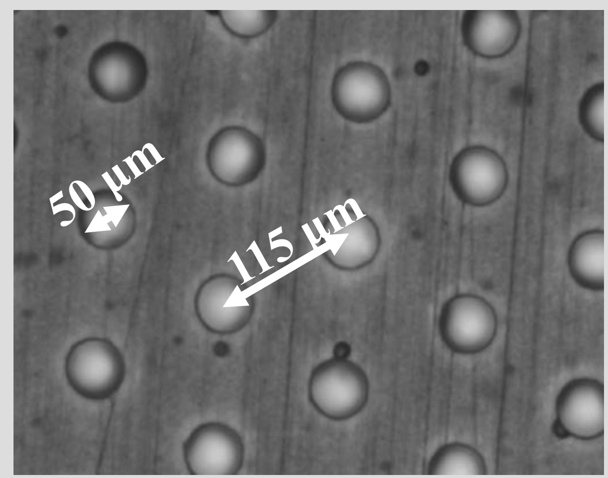
High-end micro-pattern single-gap amplification structure (‘microbulk MicroMegas’)

CERN workshop: thanks to Rui et al









side view

up view

3. Parameters of the swarm in Xe-TMA mixtures (1-3bar)

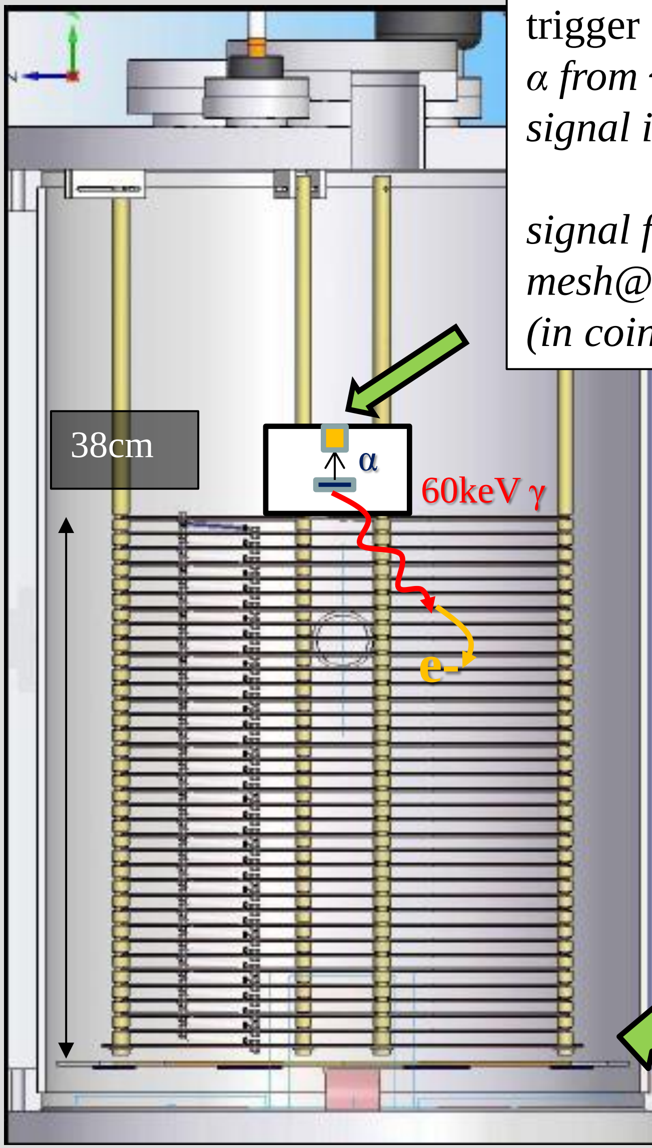
this and more in:

Characterization of a medium size Xe/TMA TPC instrumented with microbulk Micromegas, using low-energy γ-rays

The NEXT Collaboration (V. Alvarez et al.). Nov 14, 2013. 22 pp.
e-Print: arXiv:1311.3535 [physics.ins-det]

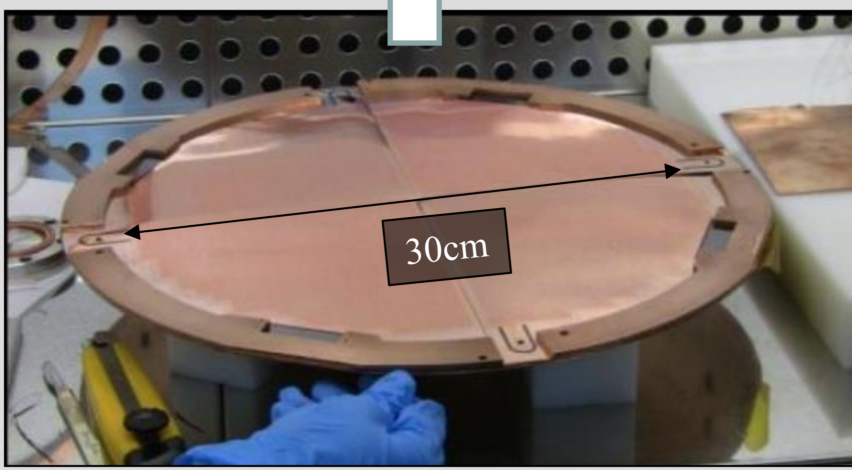
setup used for these measurements

trigger setup:
α from ^{241}Am creates signal in Si-diode
+
signal from MM-mesh@~20keV threshold (in coincidence)



field-cage

T2K *electronics* (based on the AFTER chip)

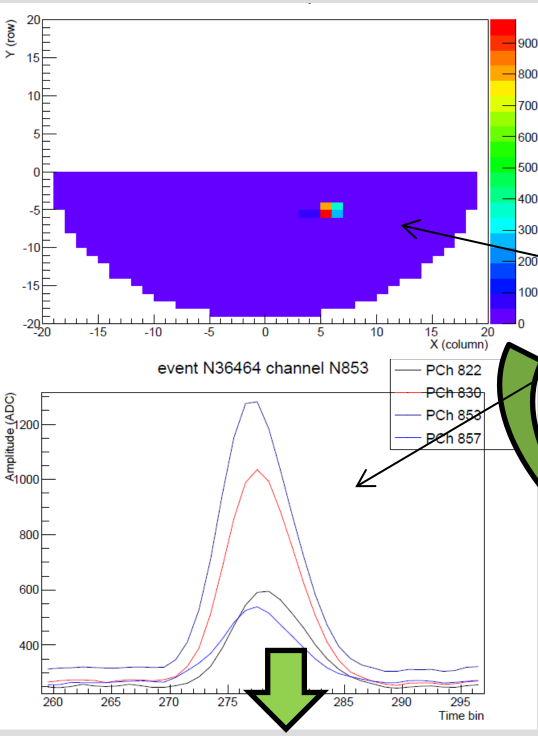


0.8cmx0.8cm pixelized *microbulk Micromegas*

mixture: Xe/TMA (~98/2)

experimental summary

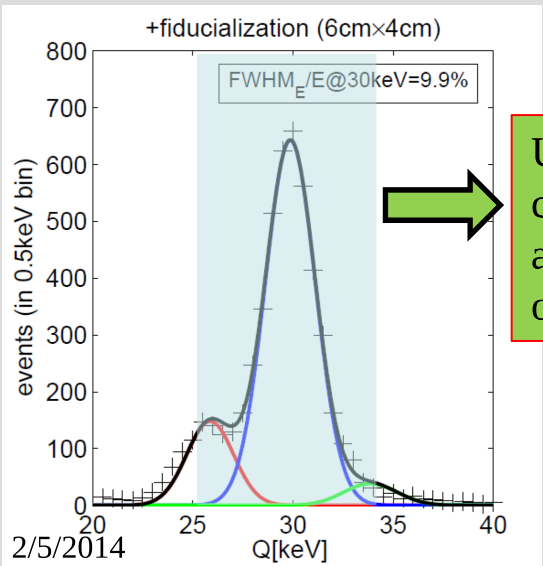
fully digitized pulses



list of observable x-ray photons (~above 1% probability)

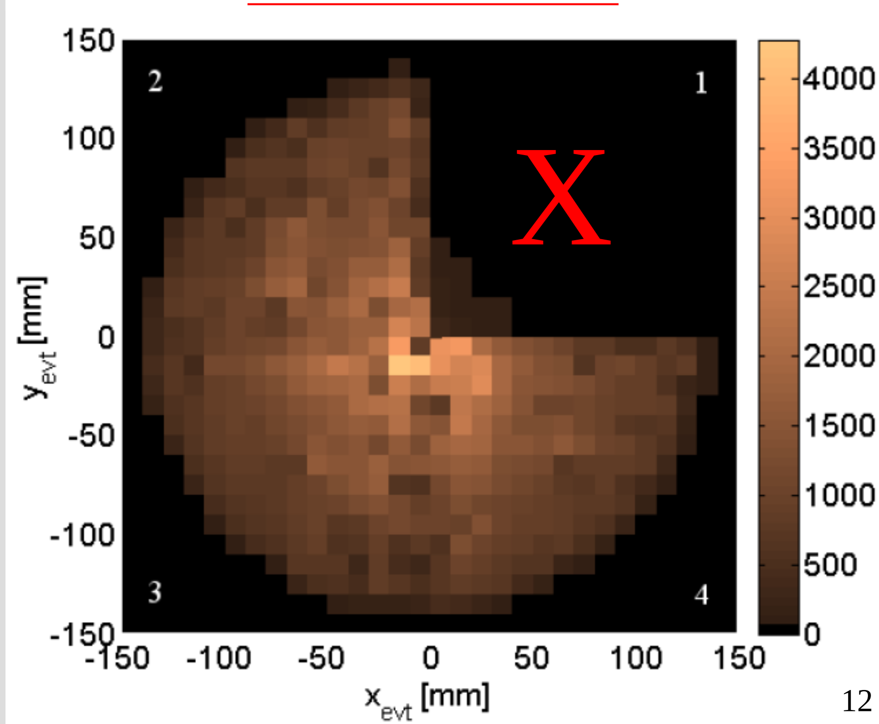
1.	**full absorption main Am-peak:**	**59.54 keV**	→ **1**
2.	orphan K_β:	33.64 keV	→ 2
3.	escape K_α:	59.54-29.8 = 29.74 keV	} → 3
4.	orphan K_α:	29.80 keV	} → 3
5.	escape K_β:	59.54-33.6 = 25.94 keV	} → 4
6.	full absorption secondary Am-peak:	26.3keV	} → 4

energy reconstruction



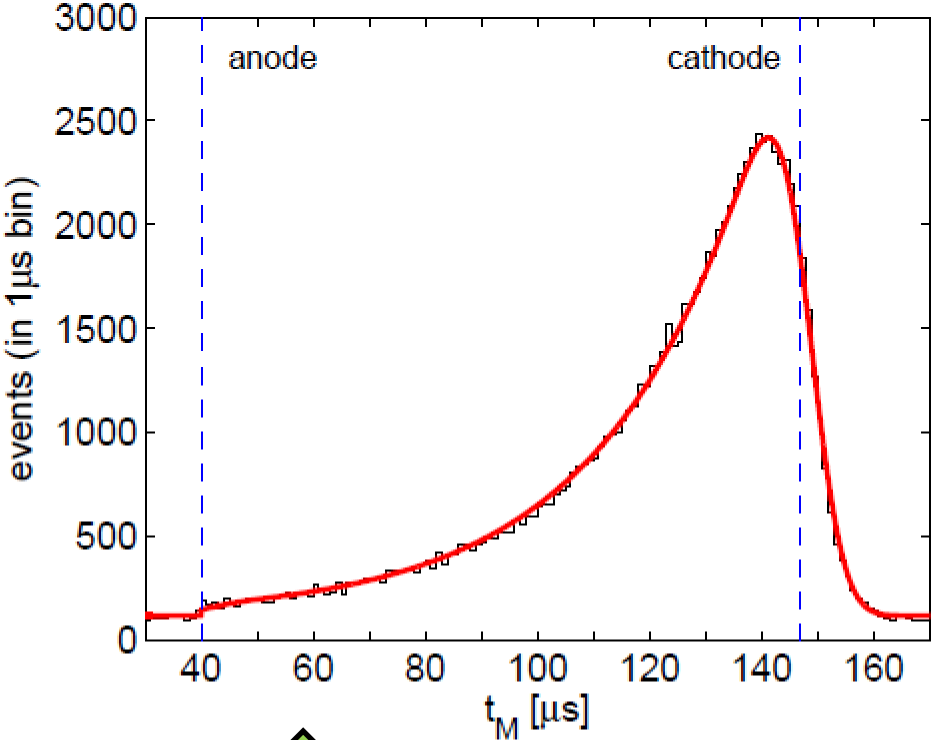
Use these ionization clouds for experimentally accessing the parameters of the swarm.

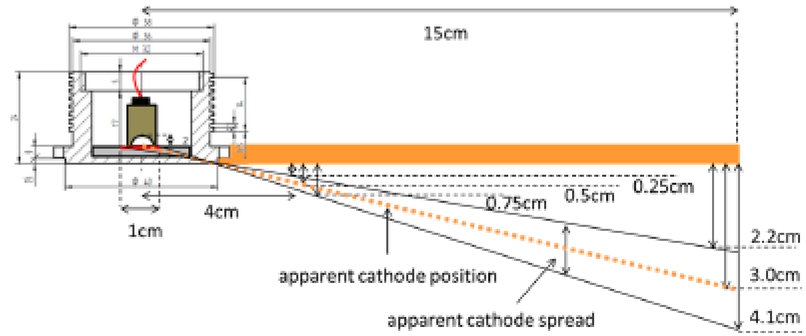
mean position of the event

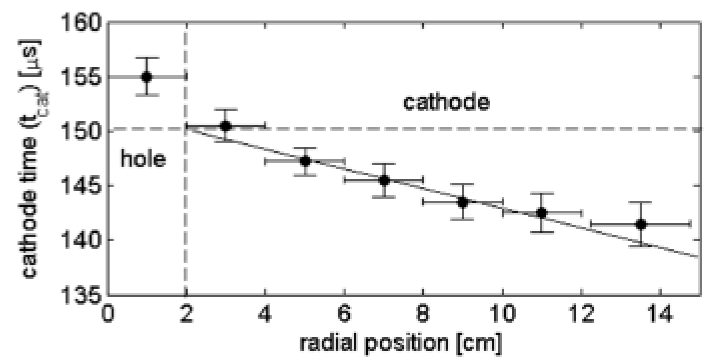


determining the total drift time (and hence the drift velocity)

(sharp) (smeared due to extended source)







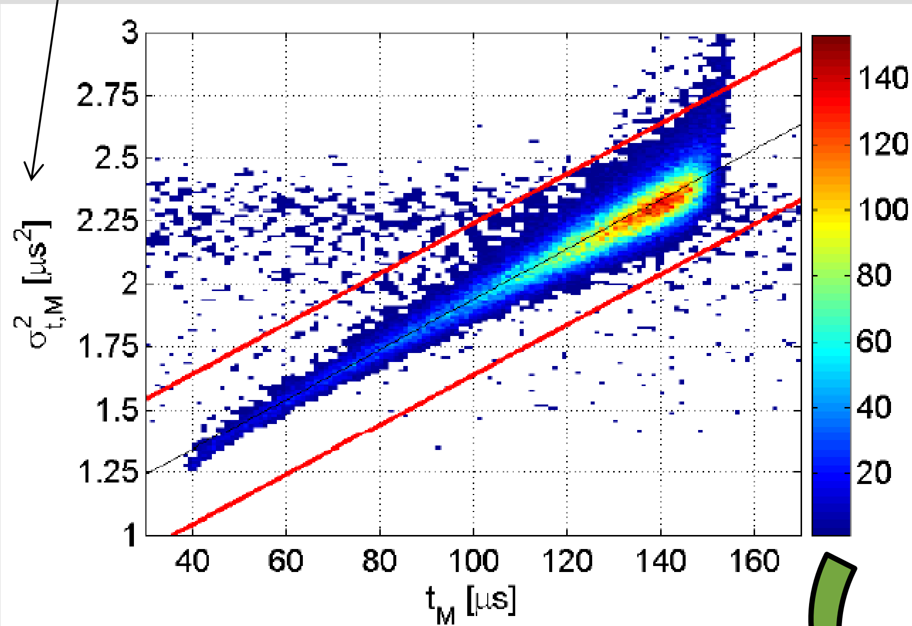
operational fit to exponential convoluted with Gauss

$$v_d = \frac{t_{cat} - t_{ano}}{D(= 38cm)}$$

$$f(t_M) = \mathscr{C} e^{t_M/\tau^*} \left[\mathrm{erf}\left(\frac{t_{cat} - \sigma_g^2/\tau^* - t_M}{\sqrt{2}\sigma_g} \right) - \mathrm{erf}\left(\frac{t_{ano} - \sigma_g^2/\tau^* - t_M}{\sqrt{2}\sigma_g} \right) \right] \Theta(t_M - t_{ano}) + B$$

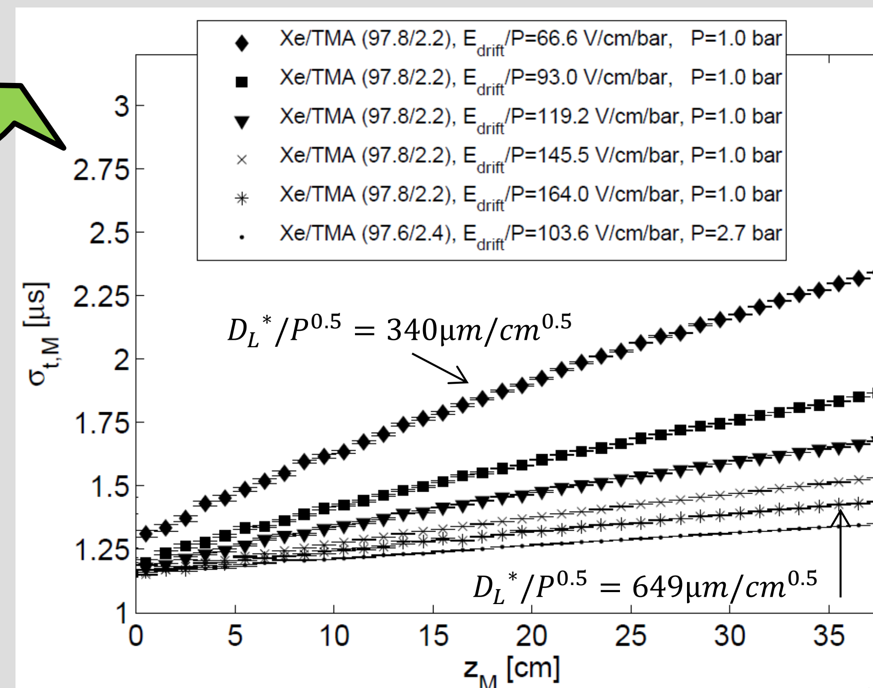
longitudinal diffusion

pulse width:



diffusion law:

$$\sigma^2_{t,M} = \sigma_0^2 + \frac{2D_L}{v_d^2}(t_M - t_{ano})$$

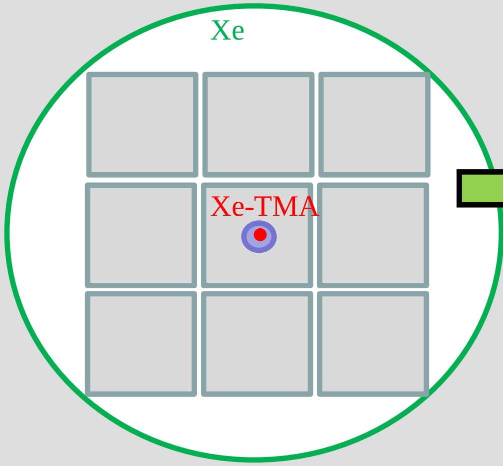


for convenience, we adopt the following convention:

$$D_L^* = \sqrt{\frac{T_0}{T}\frac{2P\,D_L}{v_d}} \quad [\frac{\mu m}{\sqrt{cm}} \times \sqrt{bar}]$$

$$\sigma_{L,T} = D^*_{L,T}\frac{\sqrt{z}}{\sqrt{P}}$$

transverse diffusion

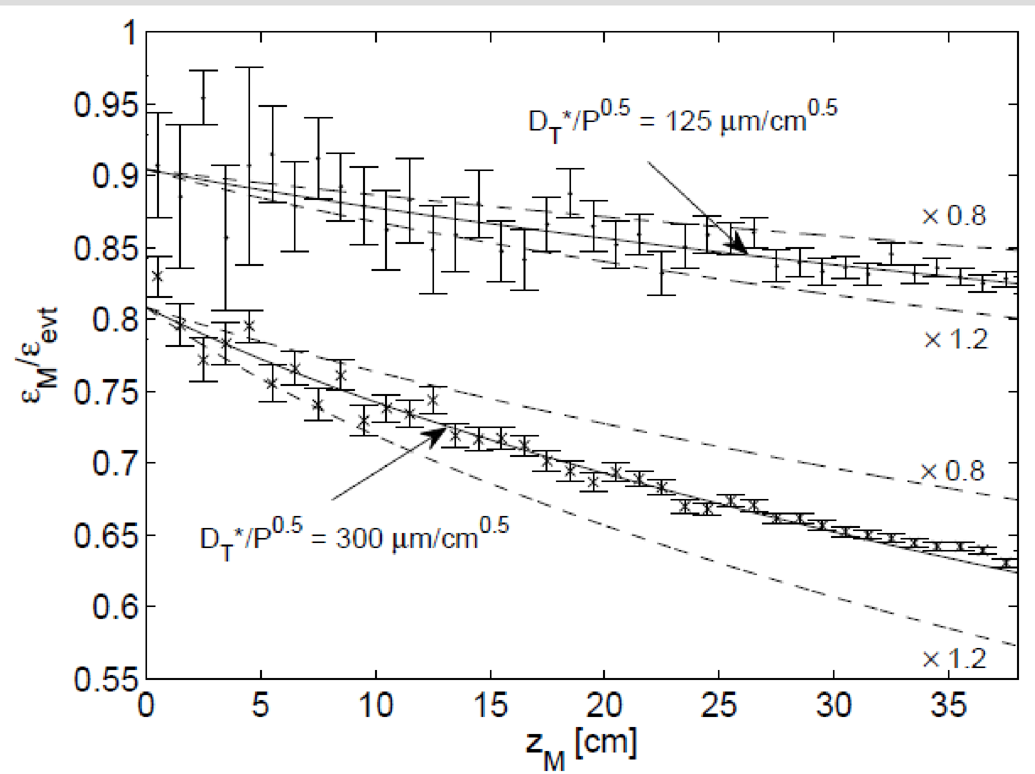


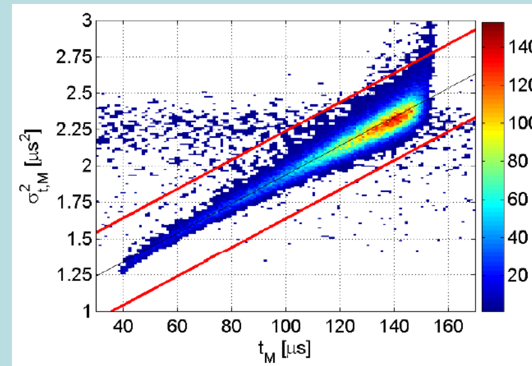
Typical transverse size of the ionization cloud for 38cm drift @1bar (1-σ) according to Magboltz. Difficult to estimate the charge spread!

Chose a convenient variable (**maximum fraction of charge contained in a pixel**)

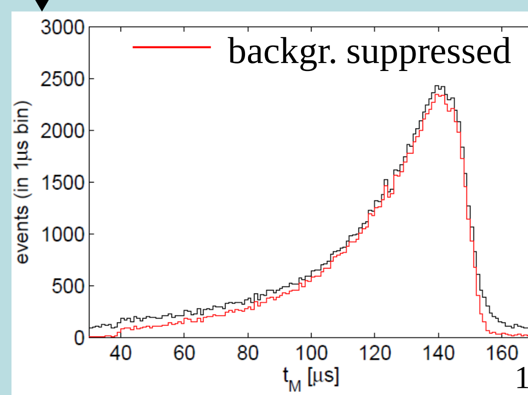
$$<\frac{\varepsilon_M}{\varepsilon_{evt}}>=\frac{\left[2\hat{v}_r\left(e^{-\frac{L^2}{2\hat{v}_r}}-1\right)+\sqrt{2\pi}L\sqrt{\hat{v}_r}\mathrm{erf}\left(\frac{L}{\sqrt{2\hat{v}_r}}\right)\right]^2}{2\pi L^2\hat{v}_r}$$

$$\hat{v}_r = {D_T^*}^2 \times \frac{z_M}{P} + \hat{v}_{r,0}$$

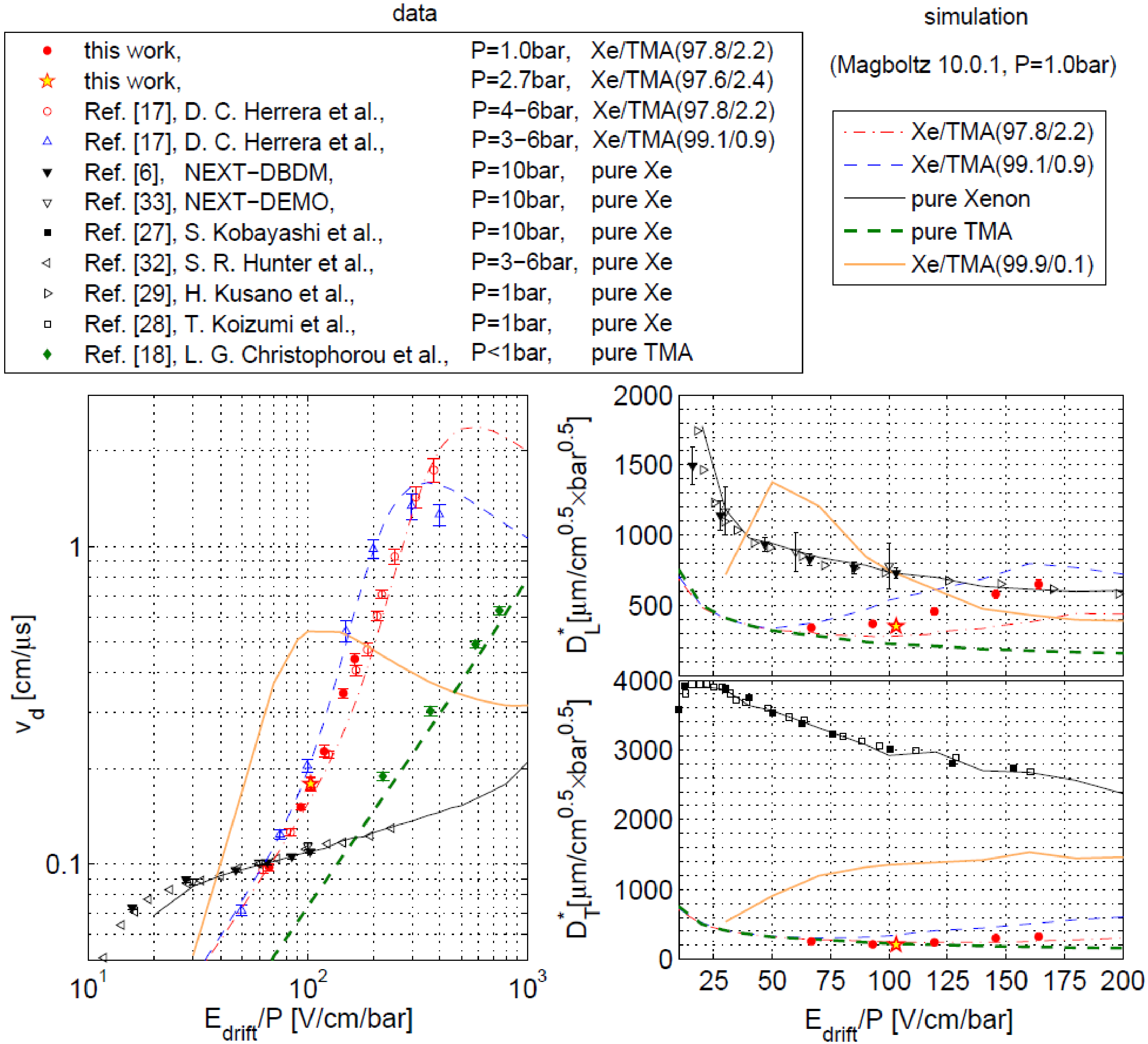




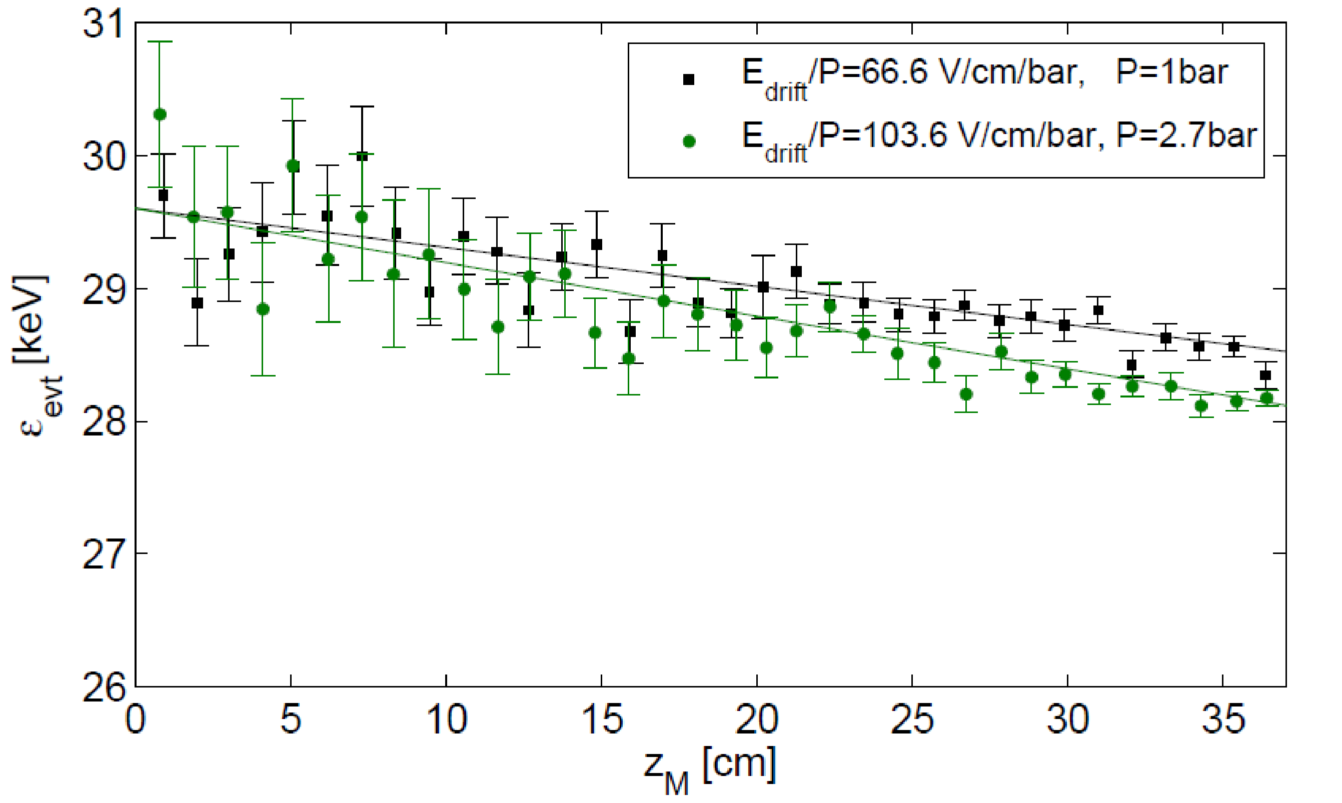
Impose correlation band to avoid biasing effects from random coincidences!



Xe-TMA properties in a nut-shell

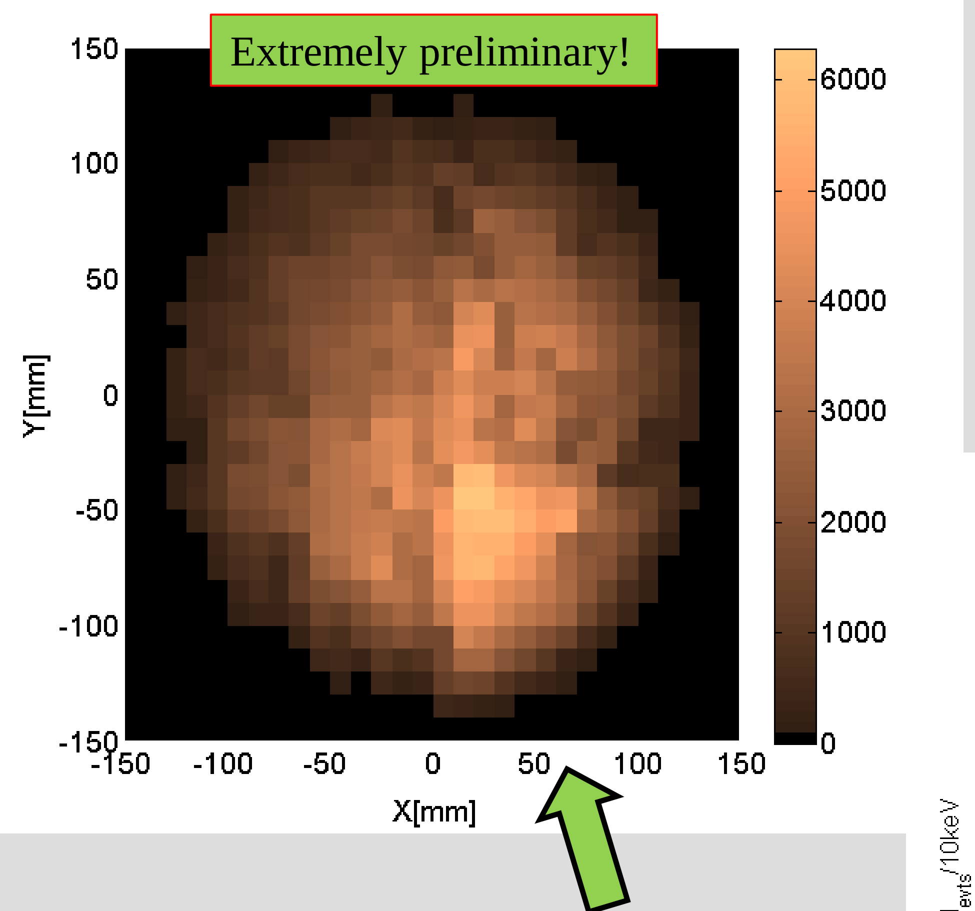


attachment coefficient



E/P[V/cm/bar]	v_d[cm/μs]	$D_L^*[\mu m/\sqrt{cm}\times\sqrt{bar}]$	$\eta[m^{-1}]$	TMA(%)	P[bar]
66.6 ± 1.3	0.097 ± 0.005	340 ± 19	0.10 ± 0.01	2.2	1.0
93.0 ± 1.9	0.151 ± 0.007	368 ± 20	0.08 ± 0.02	2.2	1.0
119.2 ± 2.4	0.227 ± 0.011	456 ± 25	0.08 ± 0.01	2.2	1.0
145.5 ± 2.9	0.345 ± 0.017	579 ± 32	0.10 ± 0.01	2.2	1.0
164.0 ± 3.3	0.442 ± 0.022	649 ± 36	0.07 ± 0.04	2.2	1.0
103.6 ± 2.1	0.179 ± 0.009	351 ± 18	0.14 ± 0.01	2.4	2.7

bonus slide



Illumination with ^{22}Na from this side

Xe-TMA (99/1)

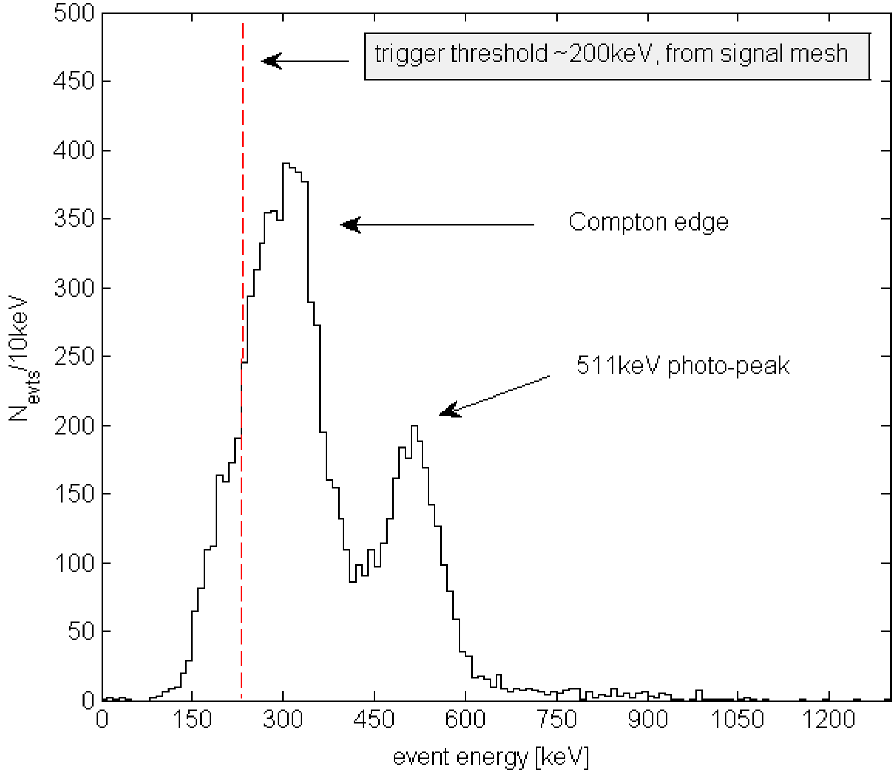
P=10.1bar

Gain~200

E_{drift}~50V/cm/bar

Non-stop data-taken for about 52h (~1.5Mio events)

Raw spectrum (sector 4) for a fraction of the data, using just a global calibration factor



4. Results from small setups

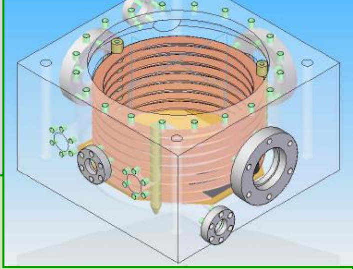
see also:

Micromegas TPC operation at high pressure in Xenon-trimethylamine mixtures

S. Cebrián et al., JINST 8(2013)P01012
and
D. C. Herrera et al., J. of Phys.: Conf. Ser. 460(2013)012012

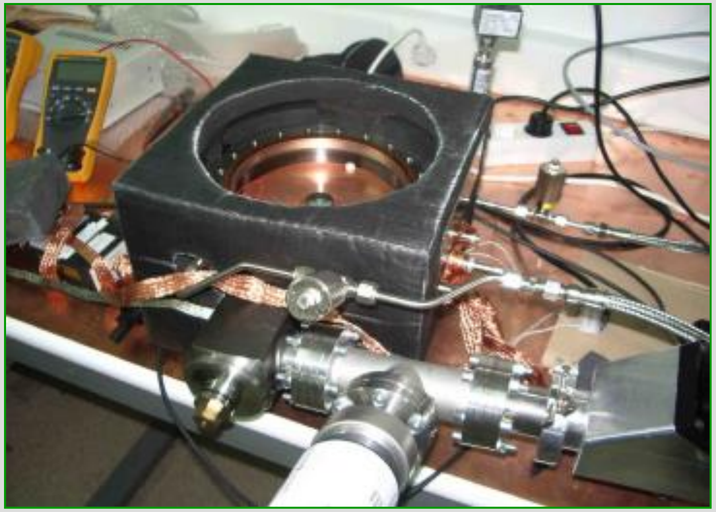
Note: *Erratum in preparation due to ~x0.5-0.7 correction of TMA calibration factor!*

general-purpose chamber for R&D studies



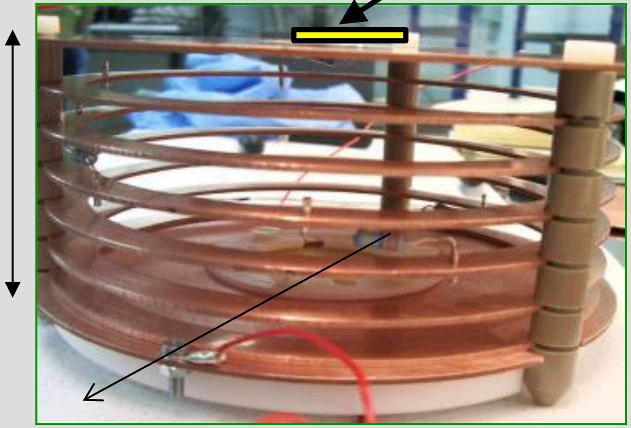
Main characteristics:

- Fully **stainless-steel** vessel: h=10cm, ϕ=16cm.
- Designed for standing pressures in the range 0-**15bar**.
- Mini-TPC with **microbulk Micromegas** as anode.
- Bake out system + turbo pump, allowing for vacuum down to **10^{-6}mbar** after full TPC assembly.
- Outgassing below **5×10^{-5} mbar l/s** before gas filling.
- Gas recirculation through **SAES FaciliTorr + Messer Oxysorb getters**.
- Characterization of system composition with a Pfeiffer OmniStar **mass spectrometer**.
- Achievable electron life-time during operation in the order of 2ms at least.
- Acquisition with:
  1) Canberra 2004/2022 amplifying chain + multichannel analyzer Amptek MCA 8000A.
  2) Oscilloscope.



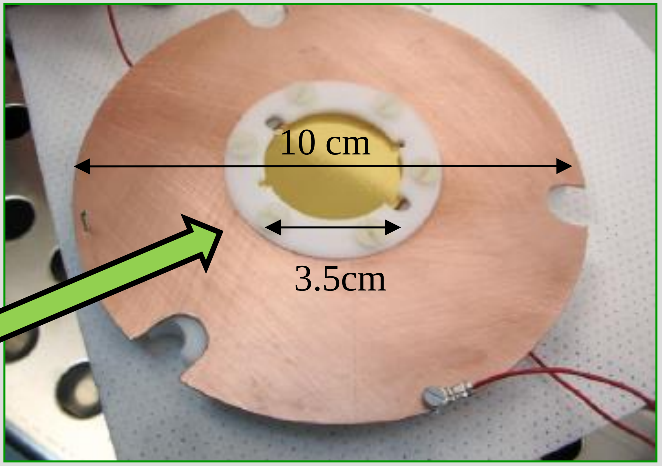
Field cage:
h= 1-6cm

radioactive source goes here

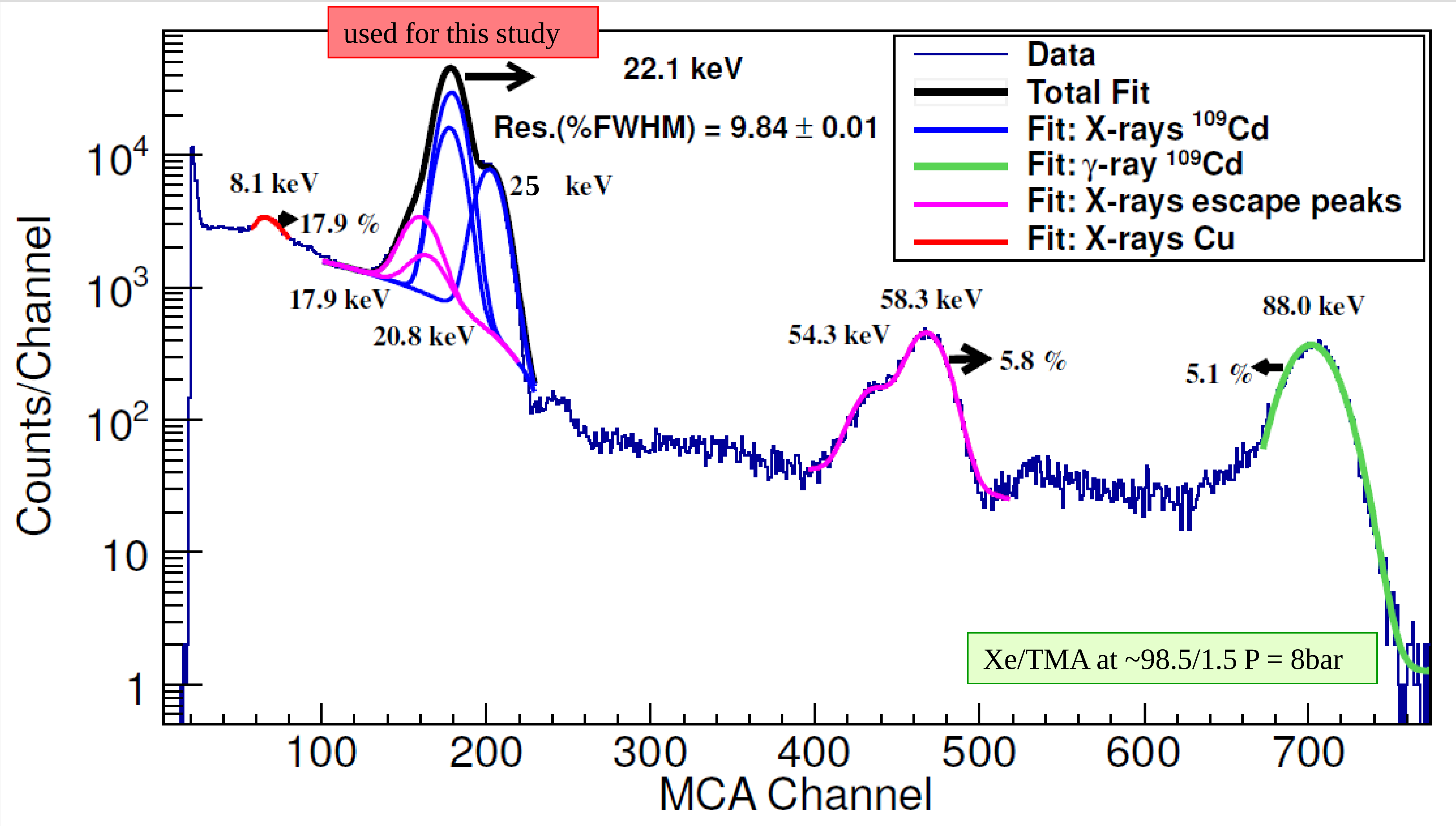


10MΩ/resistors

Micromegas
(50μm gap, 50μm holes, 115 μm pitch)

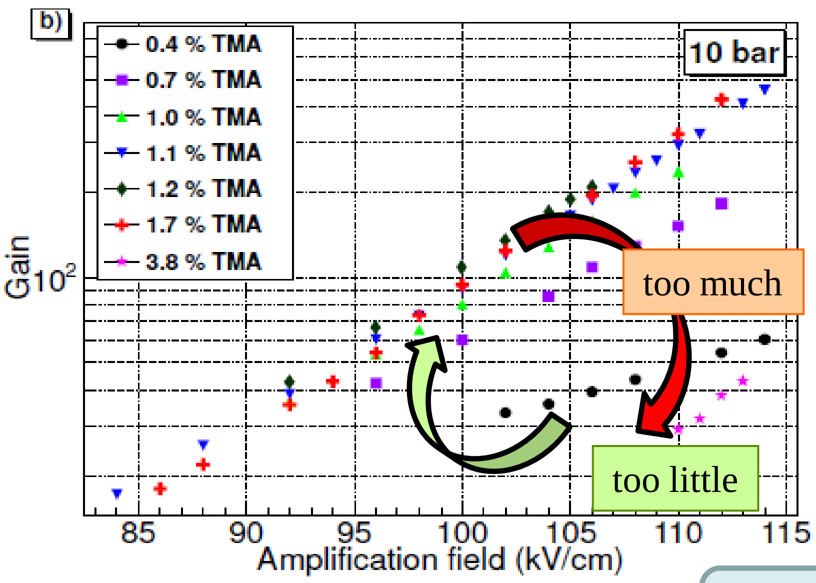


operation of Micromegas in Xe+TMA mixtures. General properties

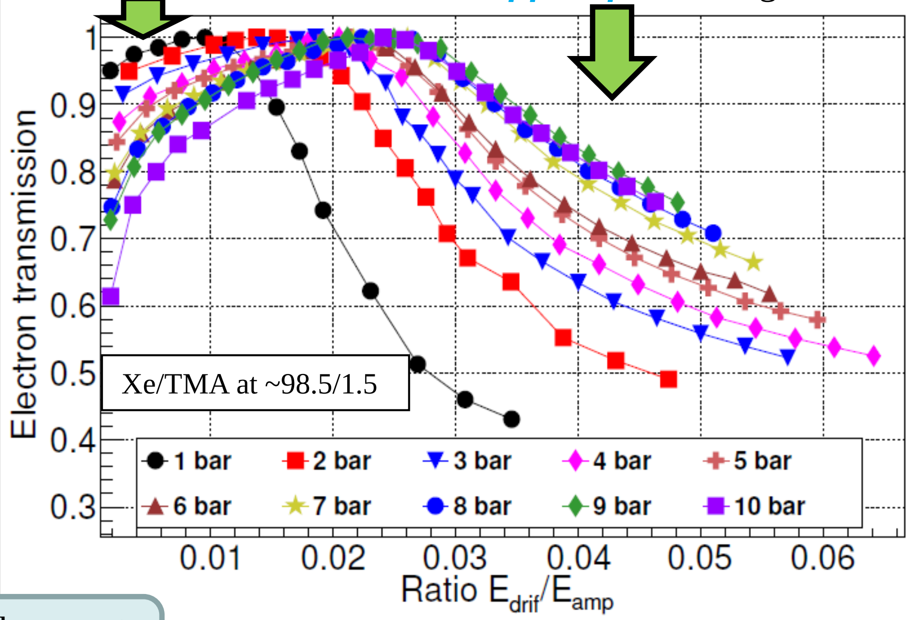


what are we trying to model?

Clear indication of ***Penning*** effect!

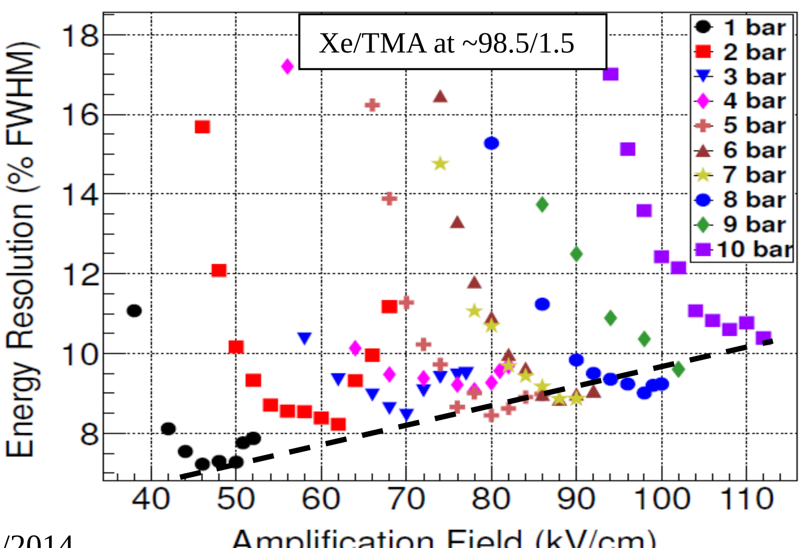


recombination? ***Reduction of field flux*** through holes?

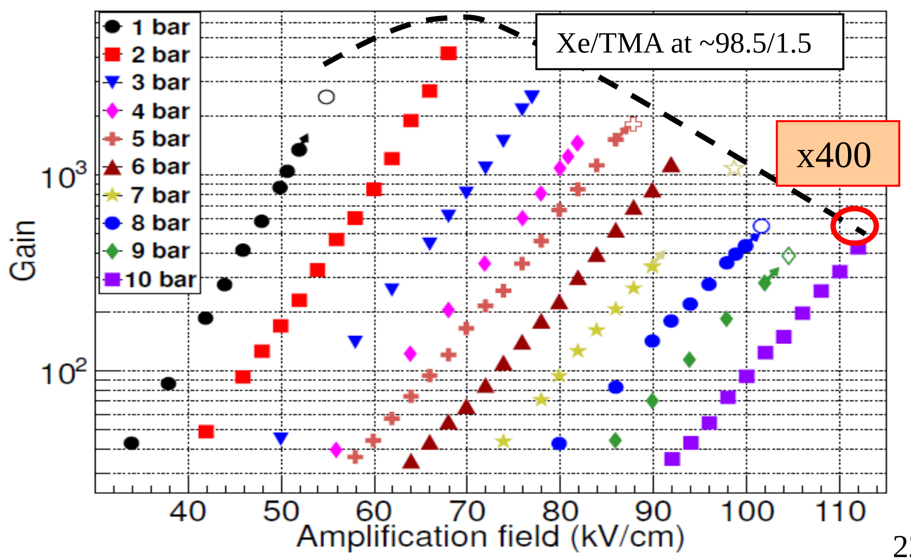


focus on these two for this talk

resolution worsening with pressure?

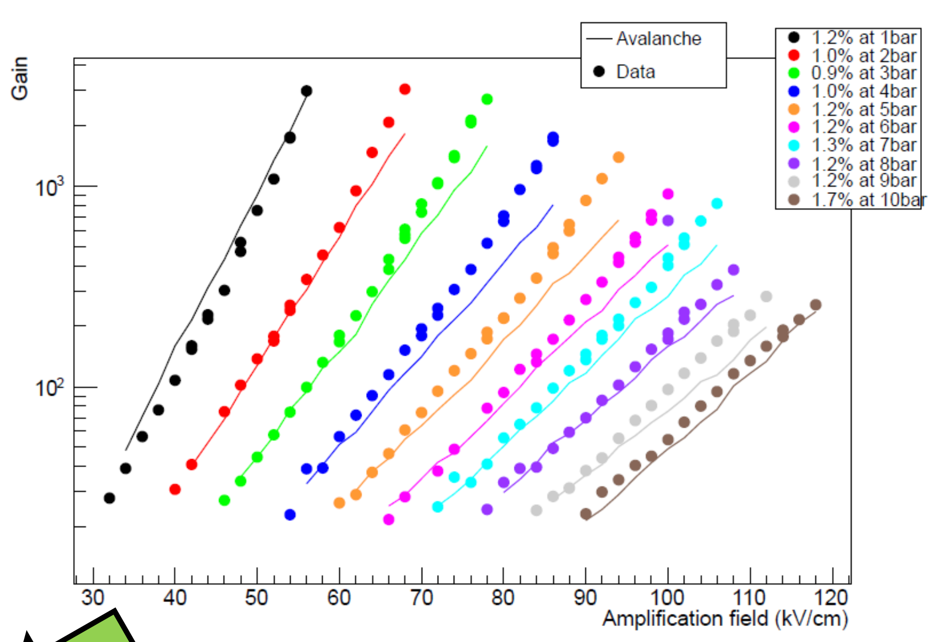


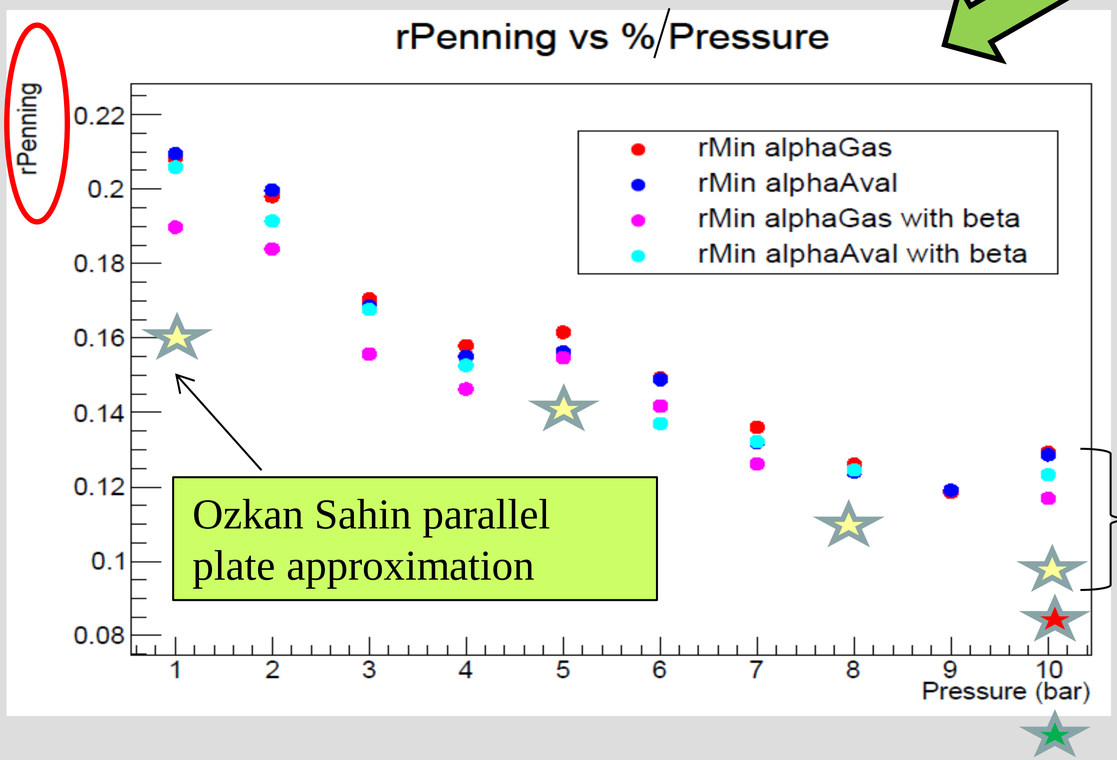
Reduction of maximum gain with pressure?



gain behaviour (Garfield++)

reasonable description of gain curves if including Penning transfer!





Decreasing trend with Pressure and %TMA??

But opposite behavior seen for Argon-based Penning mixtures!

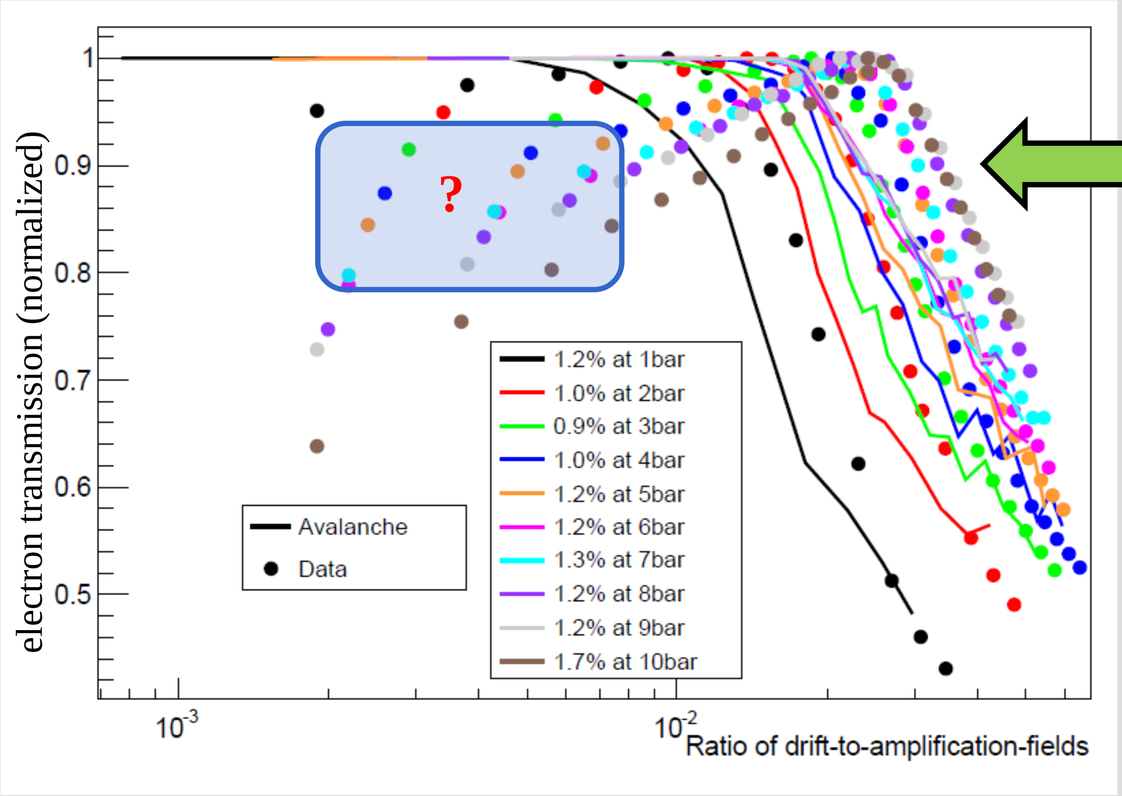
Penning transfer in Argon based mixtures, O. Sahin et al., 5, JINST(2010) P05002

%TMA=1.5%

%TMA=3.8%

%TMA=0.4%

electron transmission from Garfield++ (electric fields from Comsol)



Reasonable description of electron transmission at high fields!, But some tweak seems to be needed (x-sections or geometry?)

How to understand the origin of the observed effect at low electric fields??

Take better data!

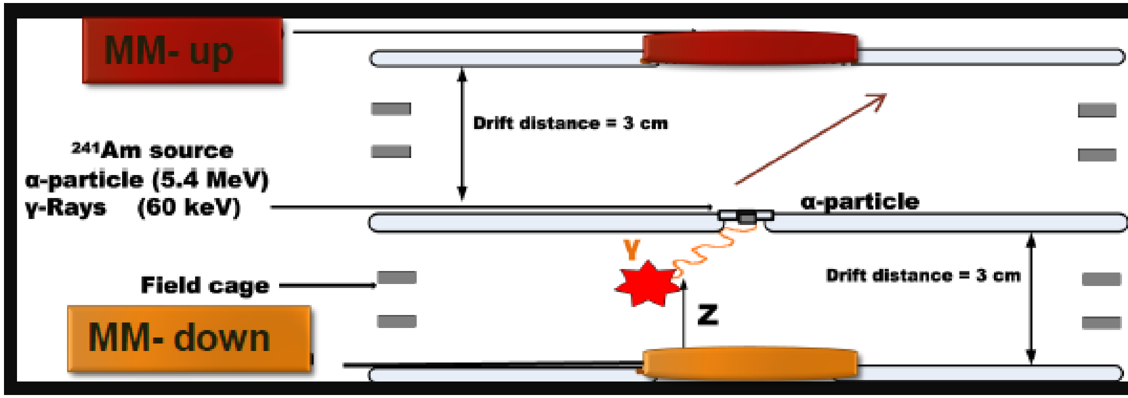
a dedicated setup for studying the angular dependence of recombination

from D. C. Herrera

Setup consists in a TPC of 2 l formed by two symmetric drift regions of 3 cm.

α- and γ-particles emited in coincidence by a ^{241}Am source is measured:
By means of 2 microbulk Micromegas (MM) placed in each anode.

α –particles → MM- up
γ-particle → MM –down



Two configurations

1

MM- up →pre-am +oscilloscope
MM-down →pre-am+amp+MCA

1. **Q versus EF for α- and γ- particles**
2. **Q versus φ for α- particles**

Rate= 130 Hz

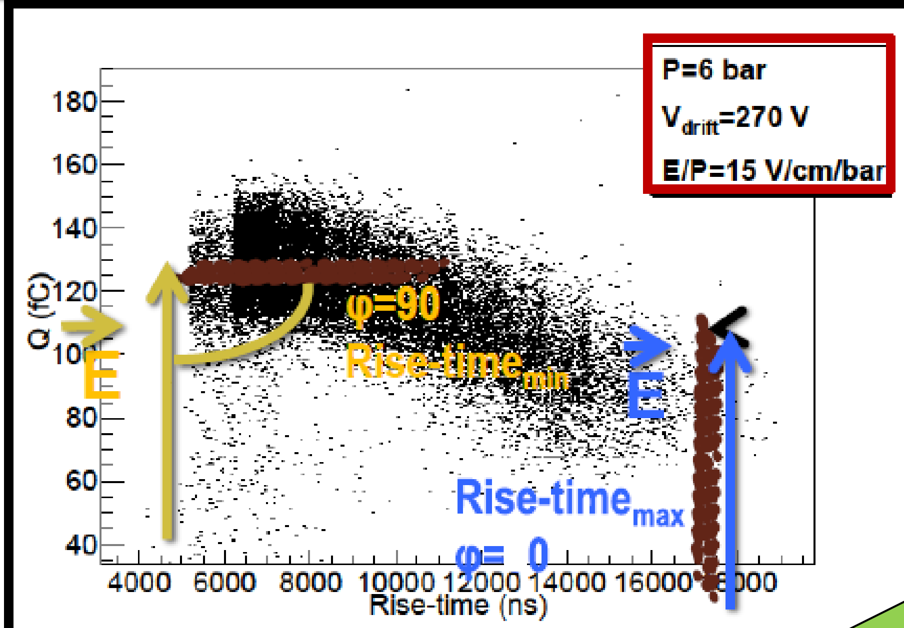
2

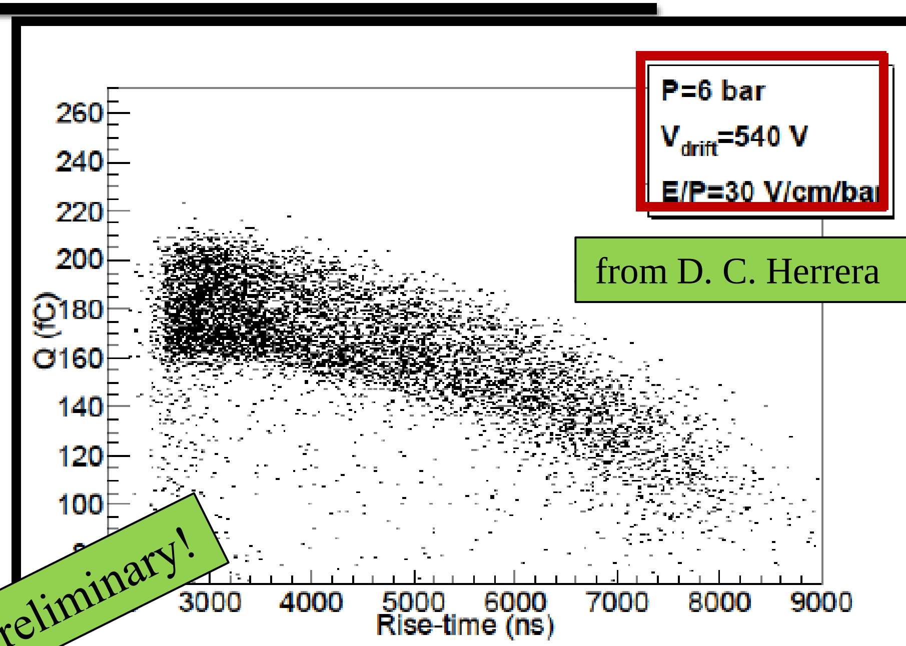
MM- up →pre-am +oscilloscope
MM-down →pre-am+oscilloscope

1. **Q versus EF for α- and γ- particles**
2. **Vdrift and attachment**

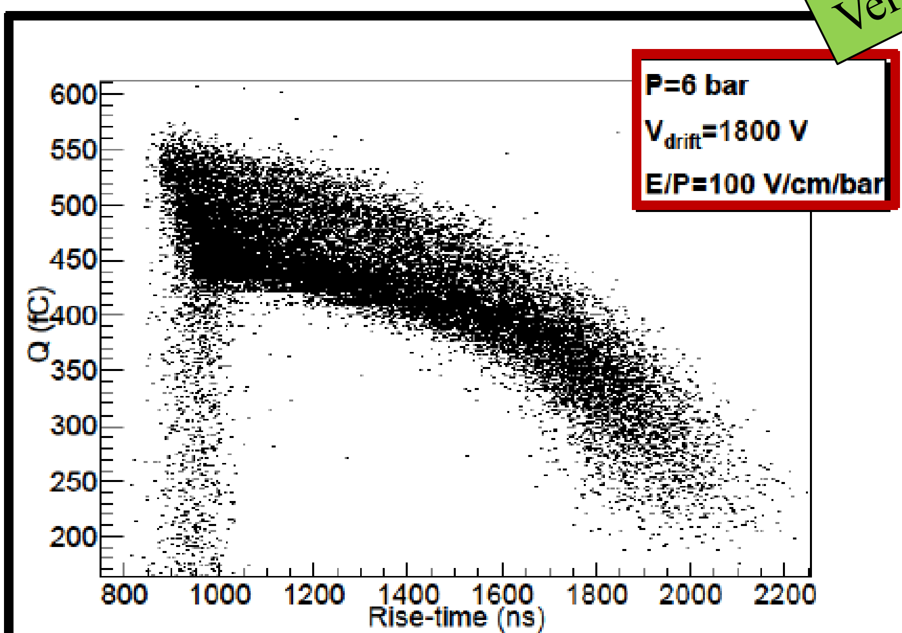
Rate <1 Hz

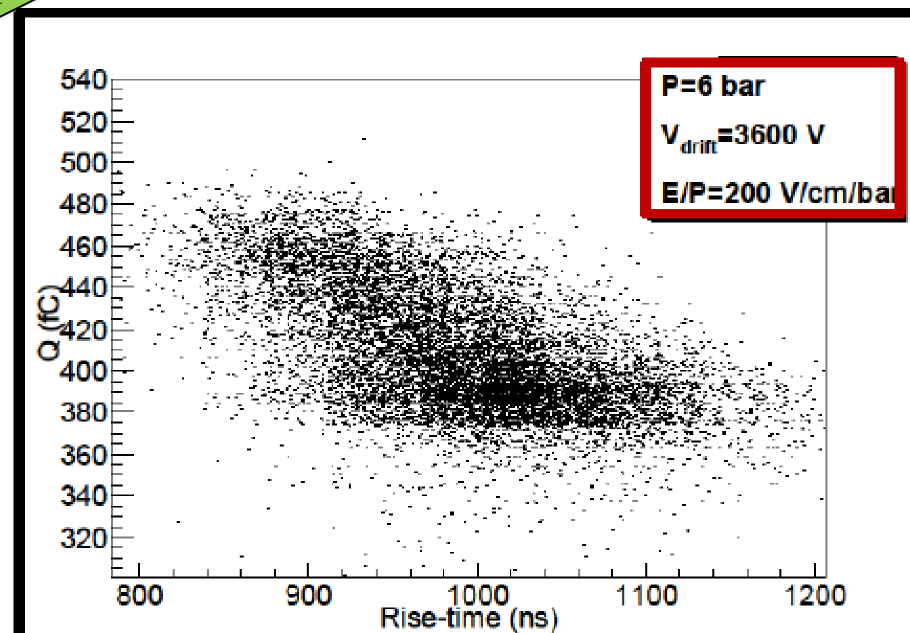
Results: Q versus Rise-time at 6 bar





Very preliminary!





conclusions

- NEXT-MM presently a good test bench for characterizing Xe mixtures and addressing the ultimate capabilities of MM in HP-Xenon, system-wise.
- Currently working at 10bar a about x200 gain. No problems.
- Final data analysis to be presented in the RD51 coll. meet.

- Hints of decreasing Penning with %TMA and P, contrary to Argon-based mixtures. A good explanation currently missing!.

- Indications of geminate and columnar recombination in data. Work in progress/stay tuned. Usable as a discriminating signal for DM directionality?? ->quite some work to do.

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