30, 511, 1200 keV e- track reconstruction from a 1kg, 10bar Xe-TMA TPC with microbulk readout

Diego Gonzalez Diaz (diegogon@unizar.es)
for the NEXT collaboration

16/06/2014

Index

- Short overview of NEXT.
- The Micromegas-TPC (NEXT-MM).
- Results for 1-3bar (and extraction of electron-swarm parameters).
- Results for 10bar.
- Long-term stability.
- Supra-intrinsic resolution in Xe-TMA?, situation and prospects.
- Conclusions and scope.

IS NEUTRINO MAJORANA OR DIRAC (-TYPE)?

Majorana

Keep it simple:
reduce the degrees of freedom!

Dirac

Keep it simple:
respect analogy with charged leptons and conserve lepton number!

Baryogenesis

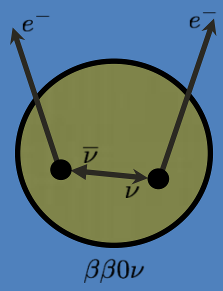
+non-thermal equilibrium.
+CP violation sources.
+sphaleron process.

Smallness of neutrino mass scale

+see-saw mechanism

How to answer?

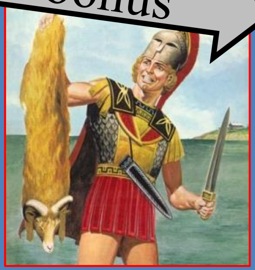
Most promising way:
Study neutrino-less double beta decay (ββ0ν) for checking the Majorana hypothesis!



+Neutrino oscillations.
All neutrino flavors are massive!
"***If it is** (Majorana-type), **it will happen** (bb0ν)*"

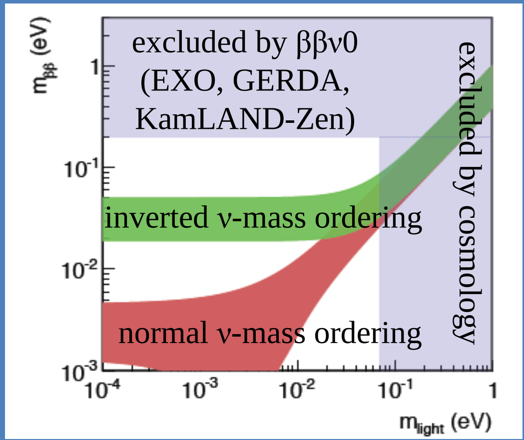
+Black box theorem (Schechter-Valle, 1982):
"***If it happens** (bb0ν), **it is** (Majorana-type)*"

bonus



Access to the neutrino mass scale

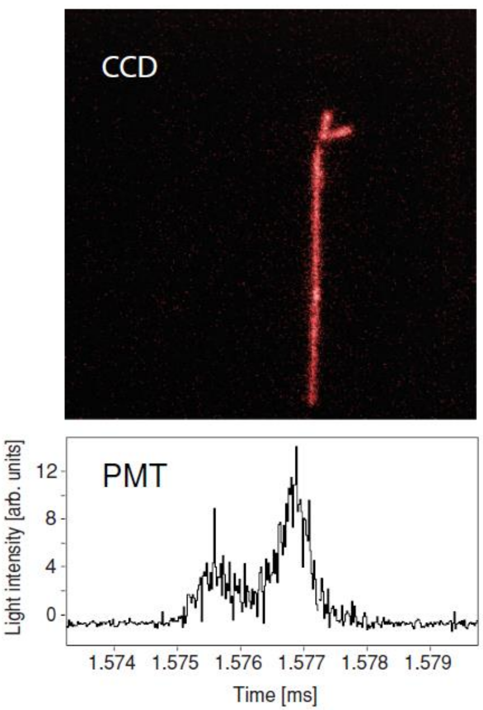
+Nuclear physics.
+Physics beyond SM.
+Accurate measurements.

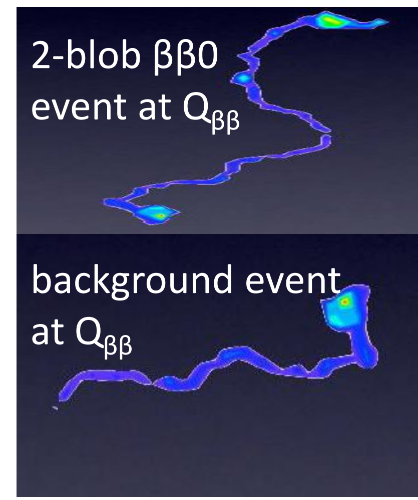


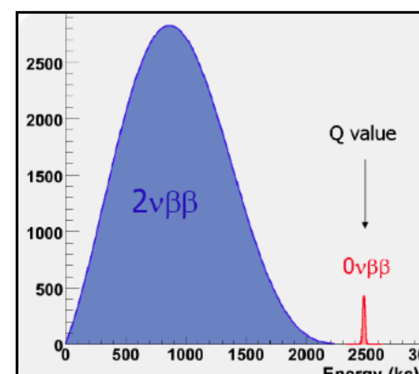
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

Neutrino Experiment with a Xenon TPC

M. Pomorski et al., 'First observation of two-proton radioactivity in ^{48}Ni', Phys. Rev. C 83, 061303(R), 2011





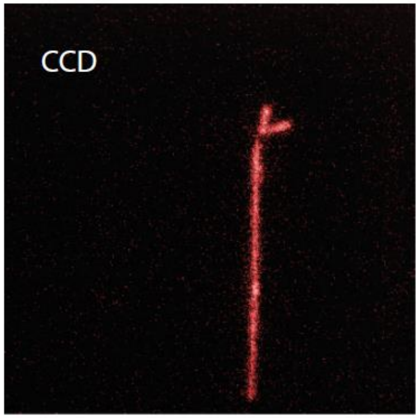


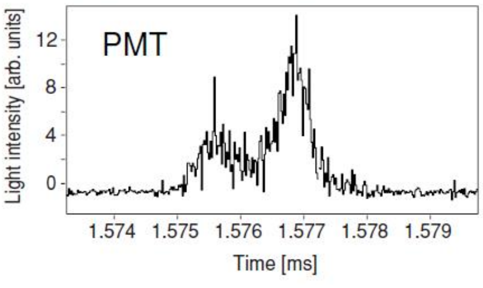
next

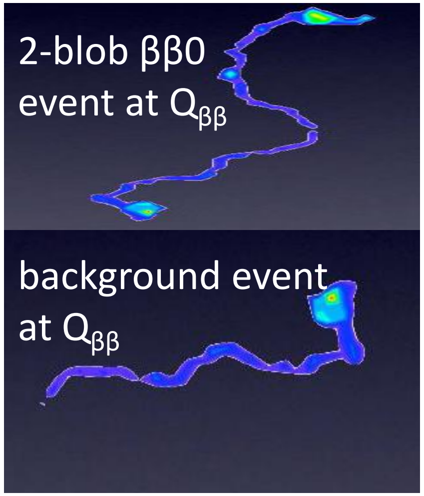
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

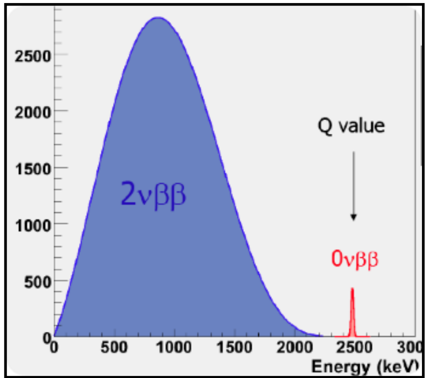
Neutrino Experiment with a Xenon TPC

M. Pomorski et al., 'First observation of two-proton radioactivity in ^{48}Ni', Phys. Rev. C 83, 061303(R), 2011





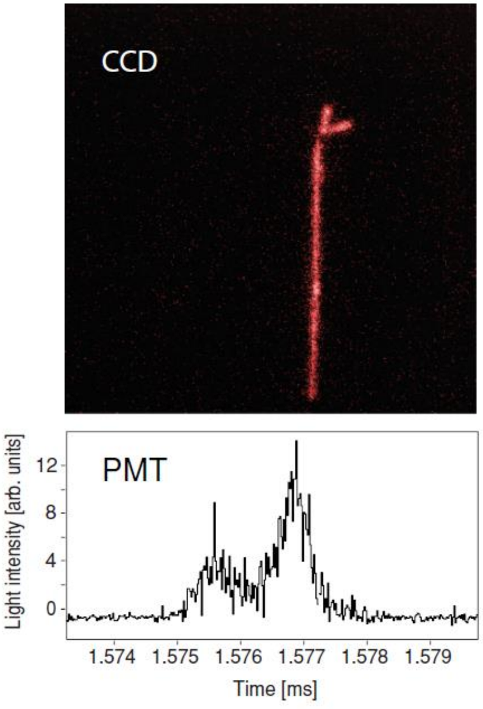




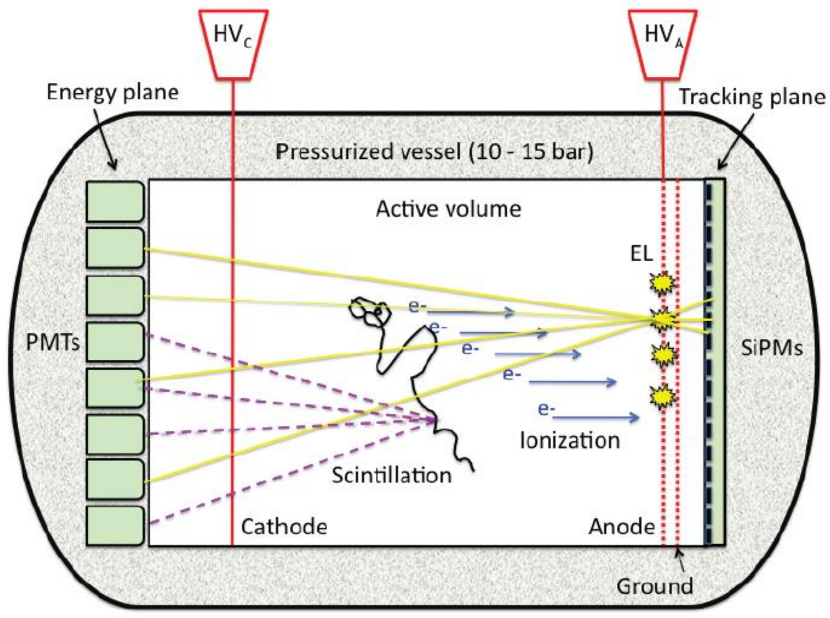
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

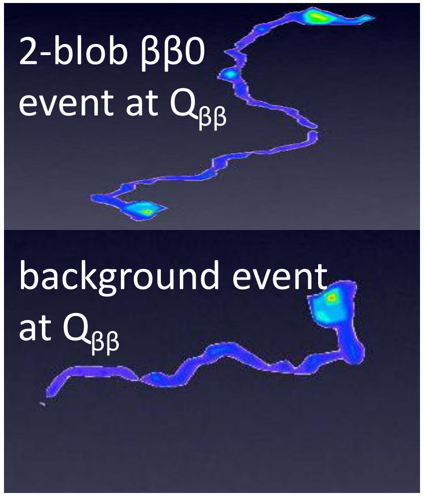
Neutrino Experiment with a Xenon TPC

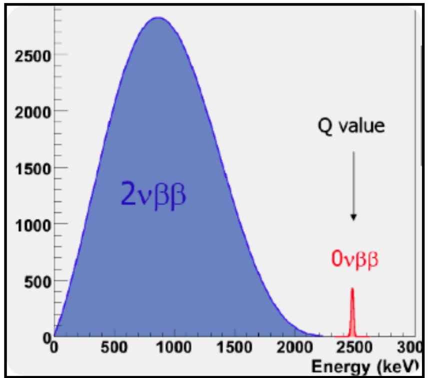
M. Pomorski et al., ‘First observation of two-proton radioactivity in ^{48}Ni’, Phys. Rev. C 83, 061303(R), 2011



The NEXT concept



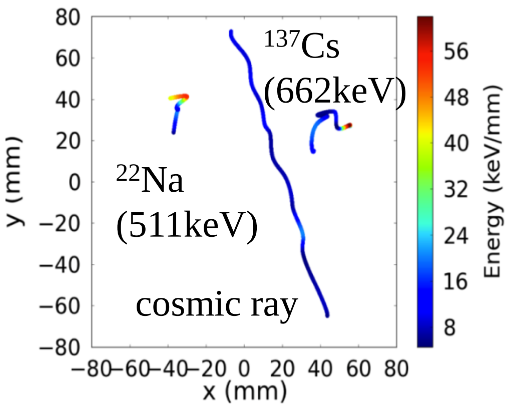




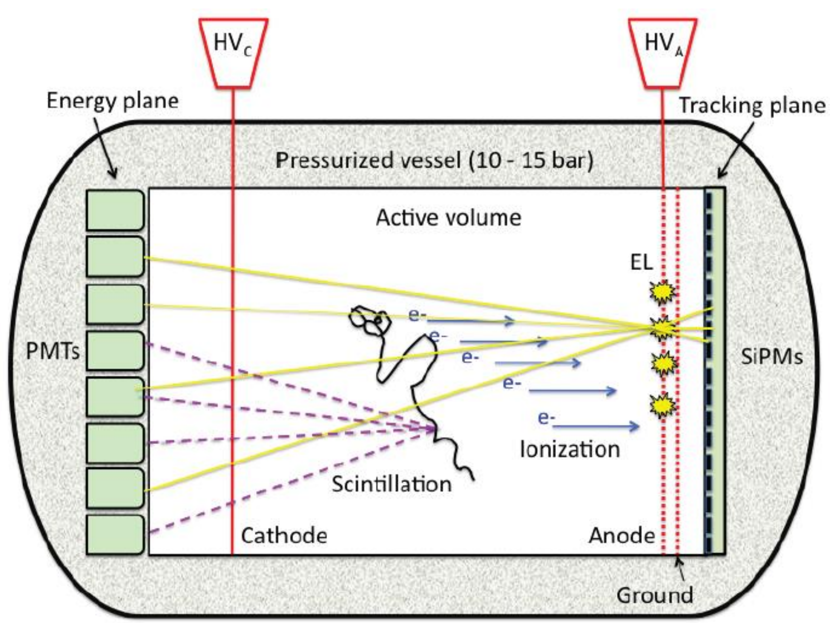
next

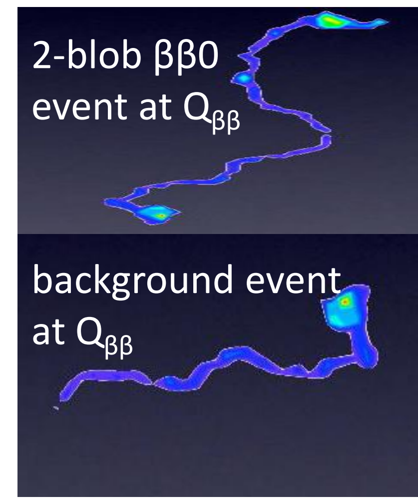
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

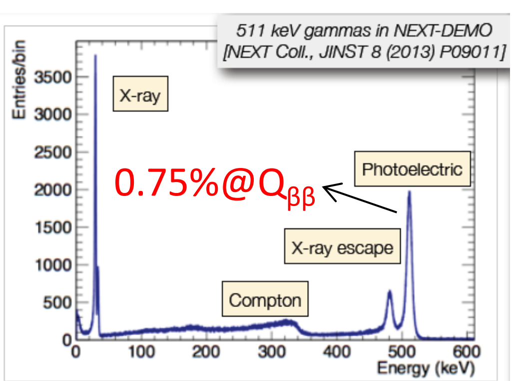
Neutrino Experiment with a Xenon TPC

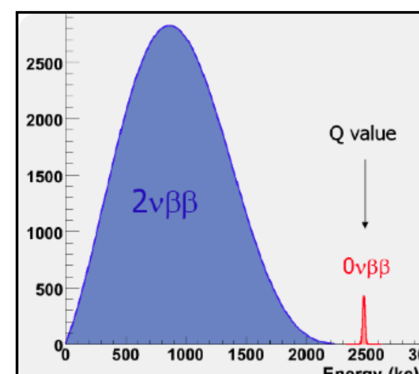


The NEXT concept



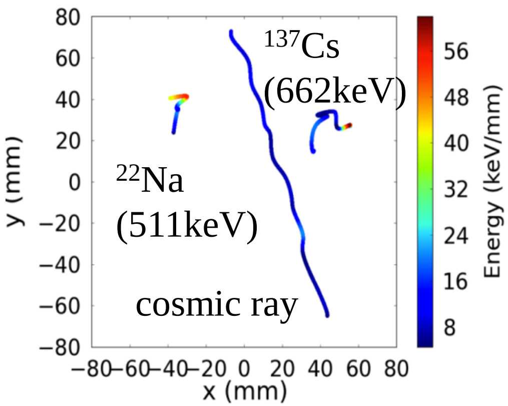


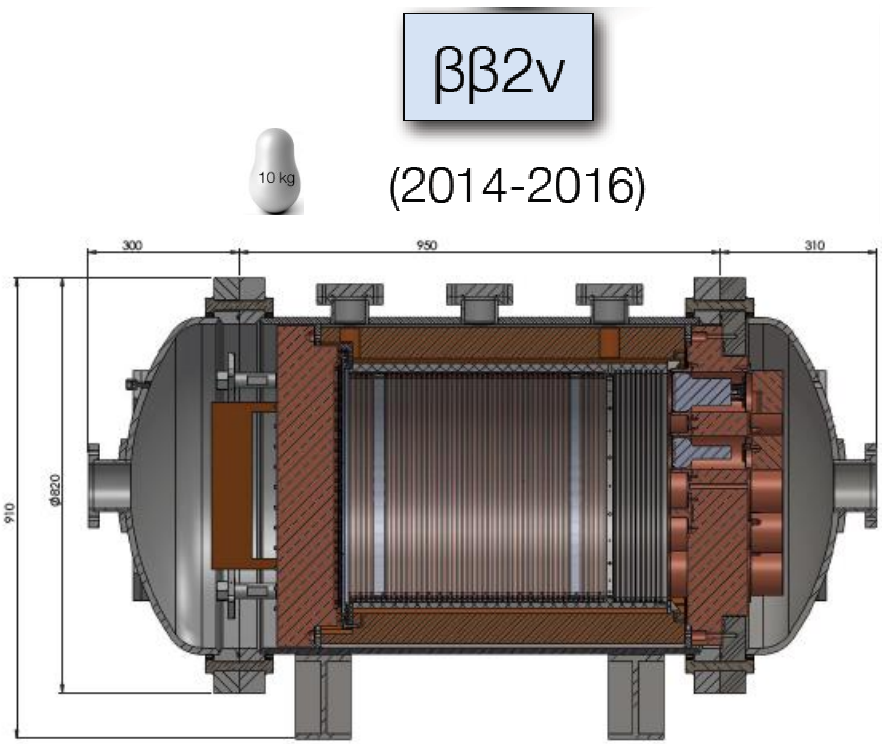


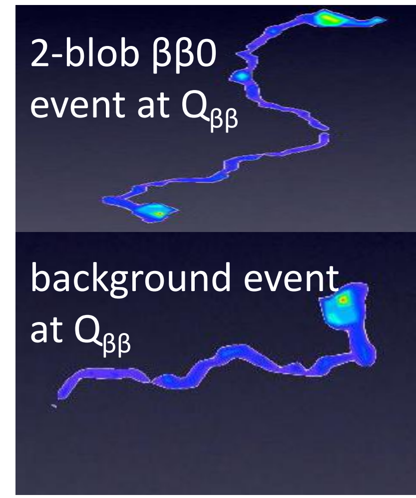


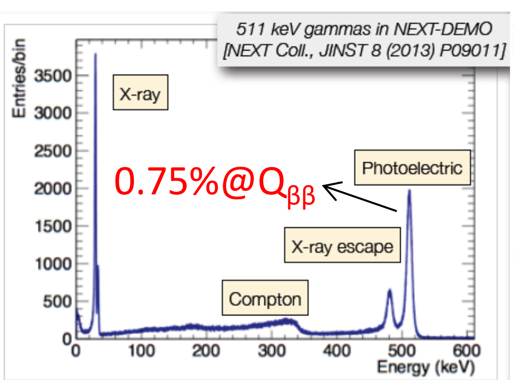
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

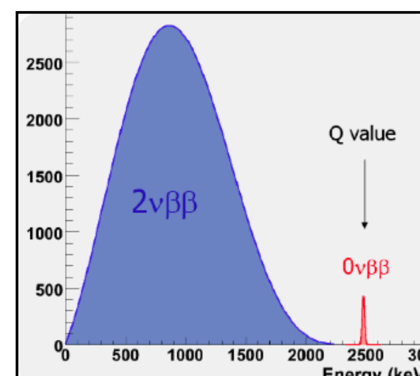
Neutrino Experiment with a Xenon TPC





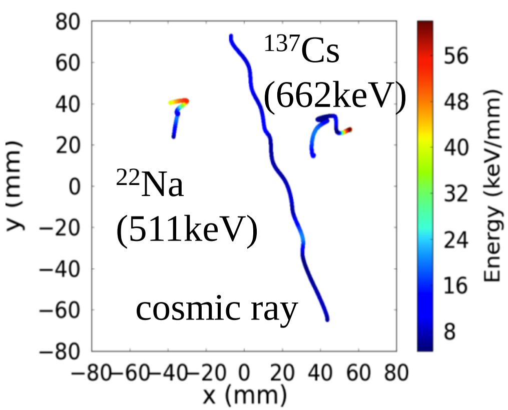






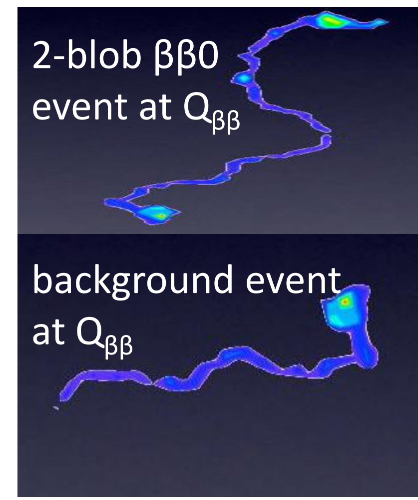
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

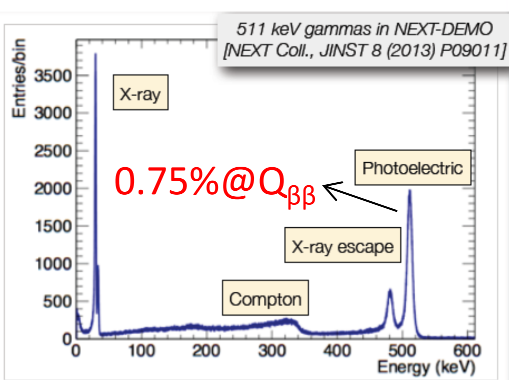
Neutrino Experiment with a Xenon TPC

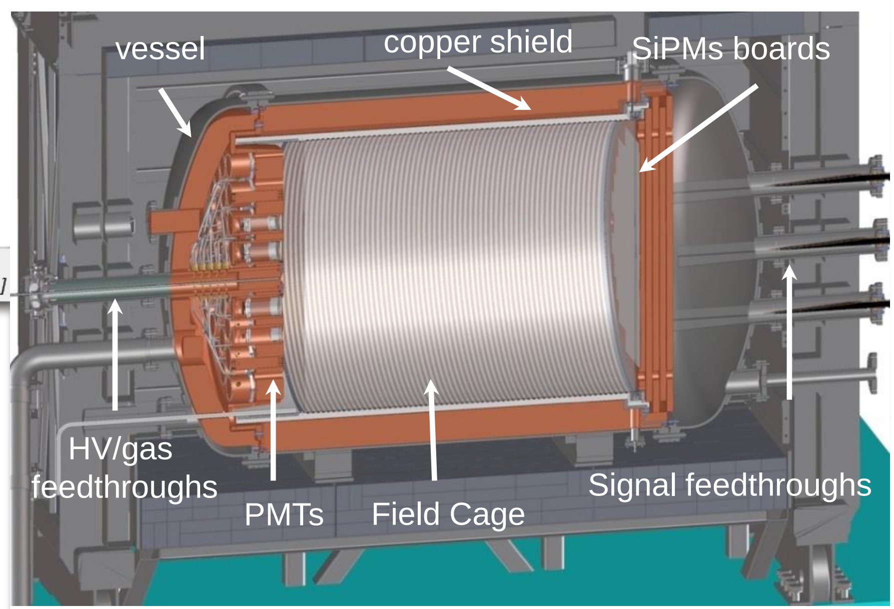


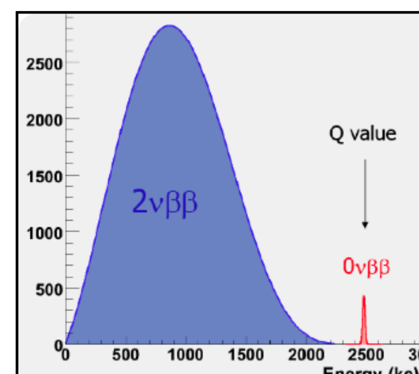
ββ0ν (100 meV)

(2016-2020)



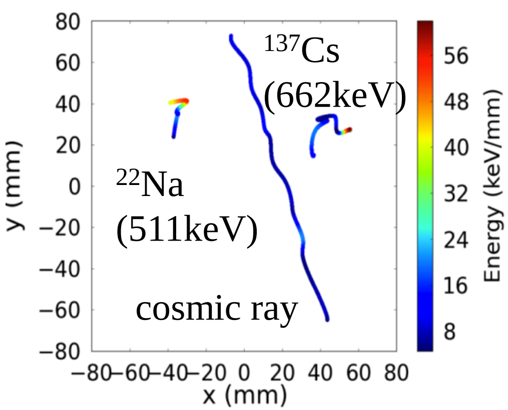






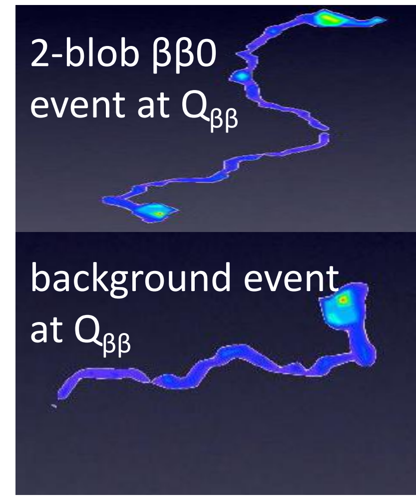
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

Neutrino Experiment with a Xenon TPC

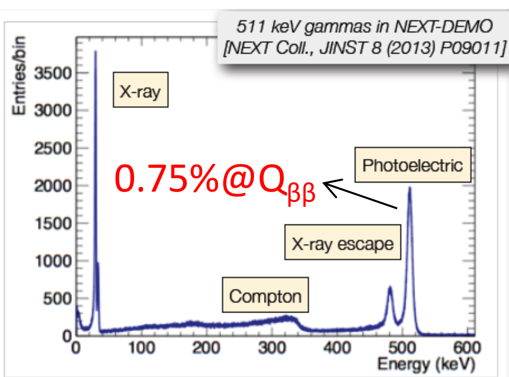


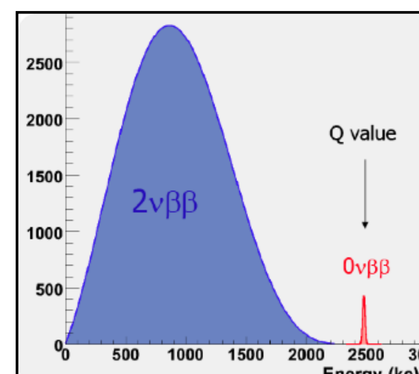
ββ0ν (20 meV)

(2020?)

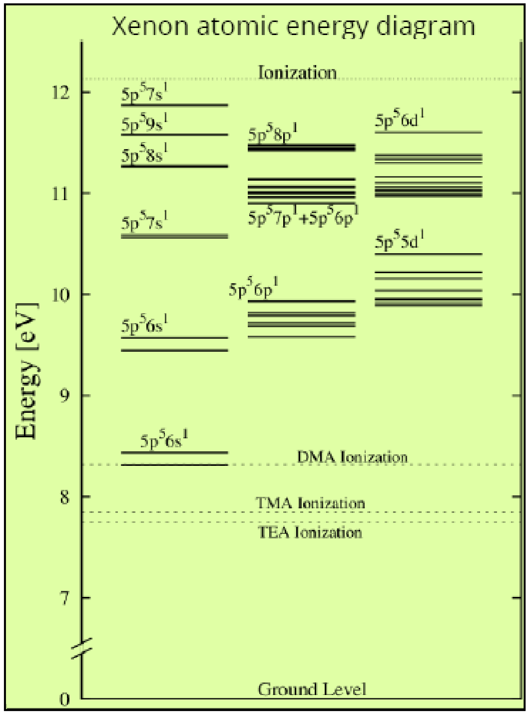


- Scale-up the concept, in principle possible.
- Optimize the gas mixture to boost topological information and/or energy resolution?.
- More exotic: Ba-Ta, B-field, others?.

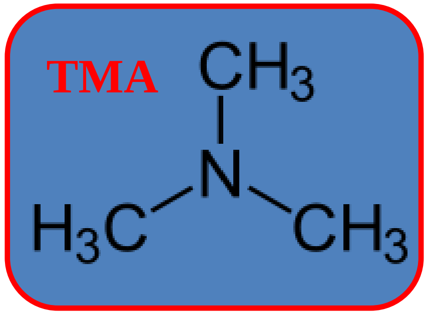




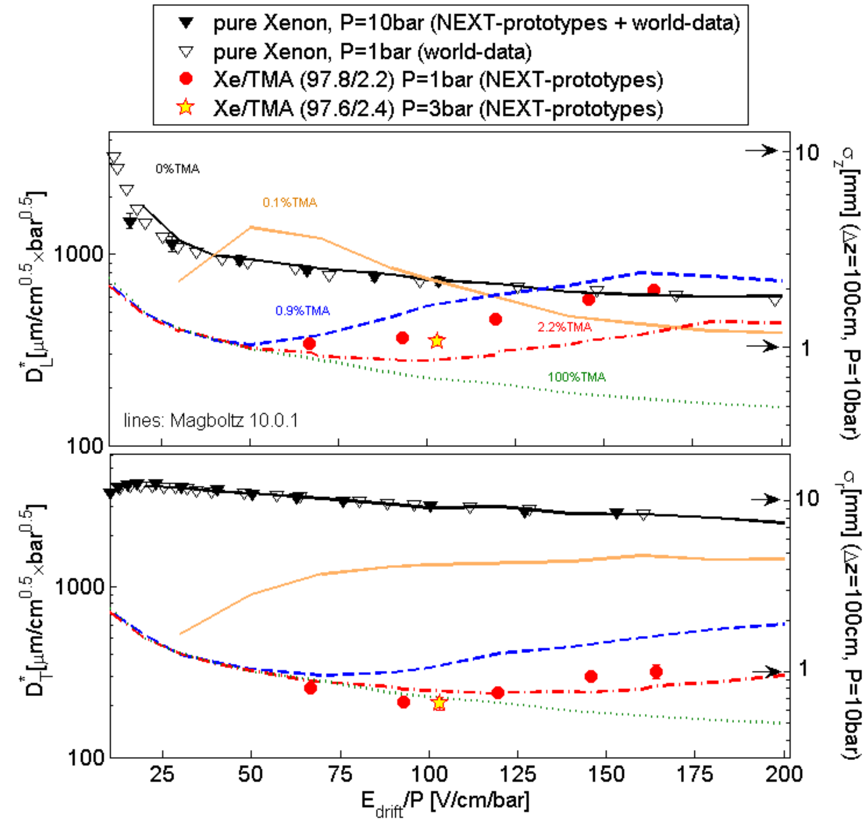
Slowly emerging new idea
'Fluorescent Penning-mixtures'

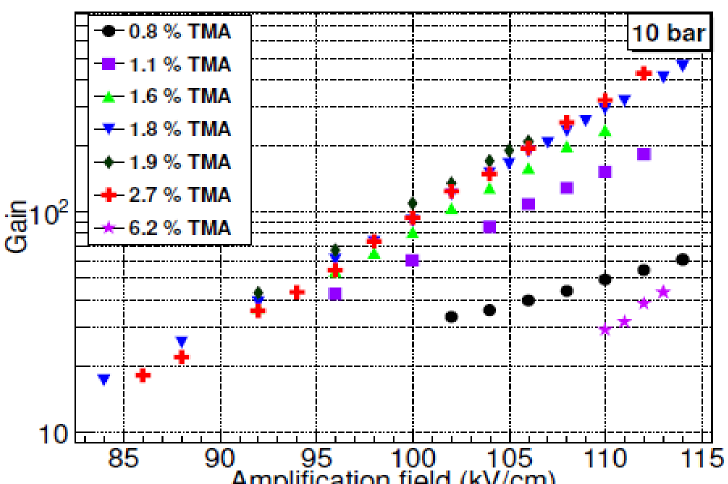


1. Suitable for Penning transfer. (Indirect evidence from gain curves ☺)
2. Strongly fluorescent. (Yields in Xe-mixtures unknown. In progress 😐)
3. Able to reduce electron diffusion in gas. (Verified ☺)
4. UV-quencher, facilitates the imaging of the e- cloud. (Verified ☺)
5. May lower the EL-threshold and ease operation. (In progress 😐)

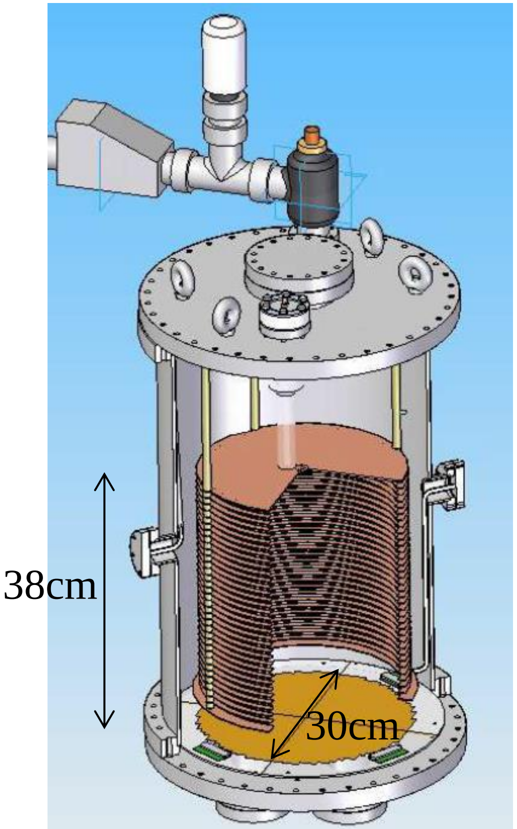


(from C.A.B. Oliveira)

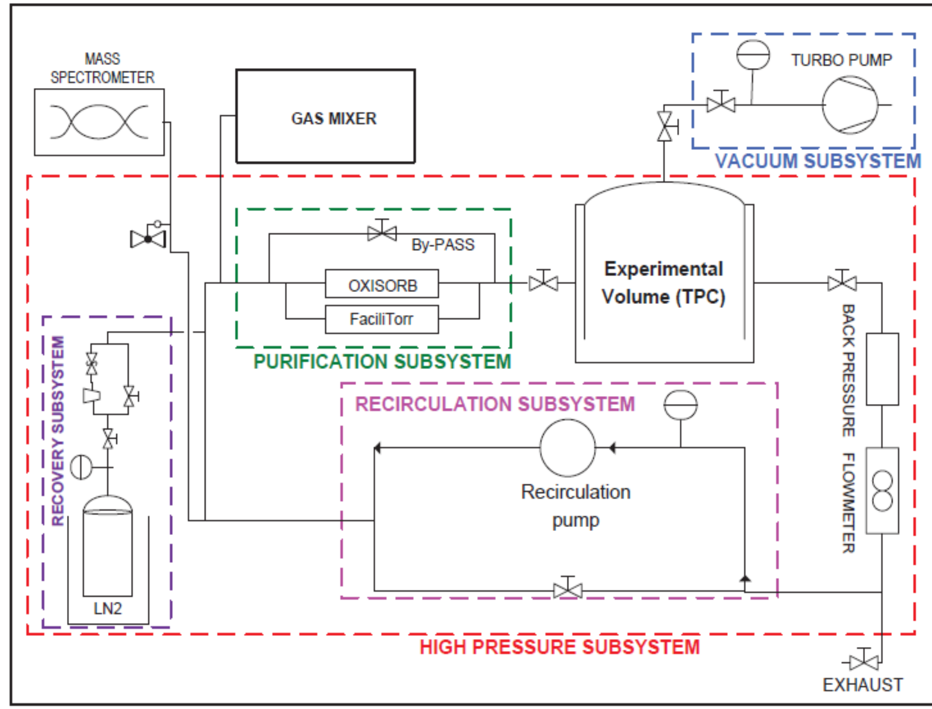


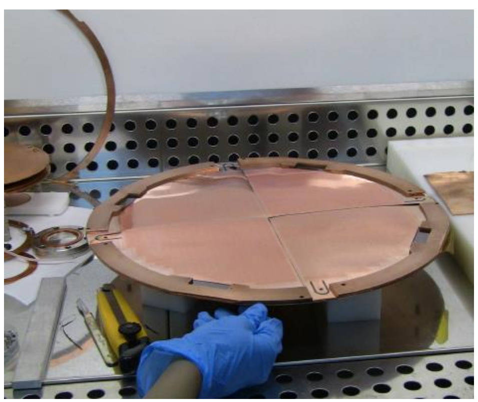
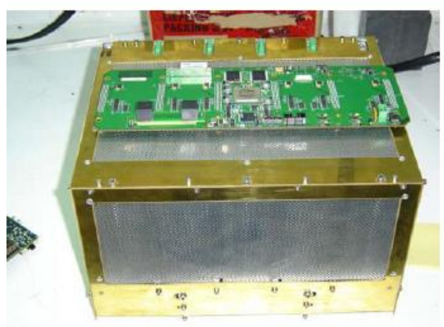


B. Ramsey, P. Agrawal, NIM A 576(1989)278; S. Cebrian et al. JINST 8 (2013) P01012







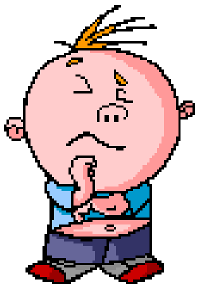




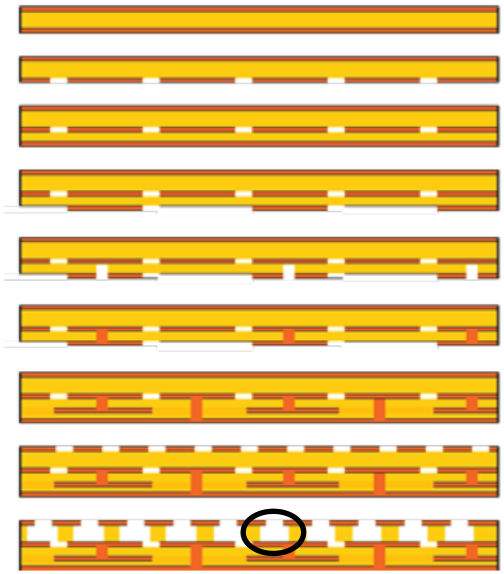
Description and commissioning of ***NEXT-MM*** *prototype*

JINST 9 P03010

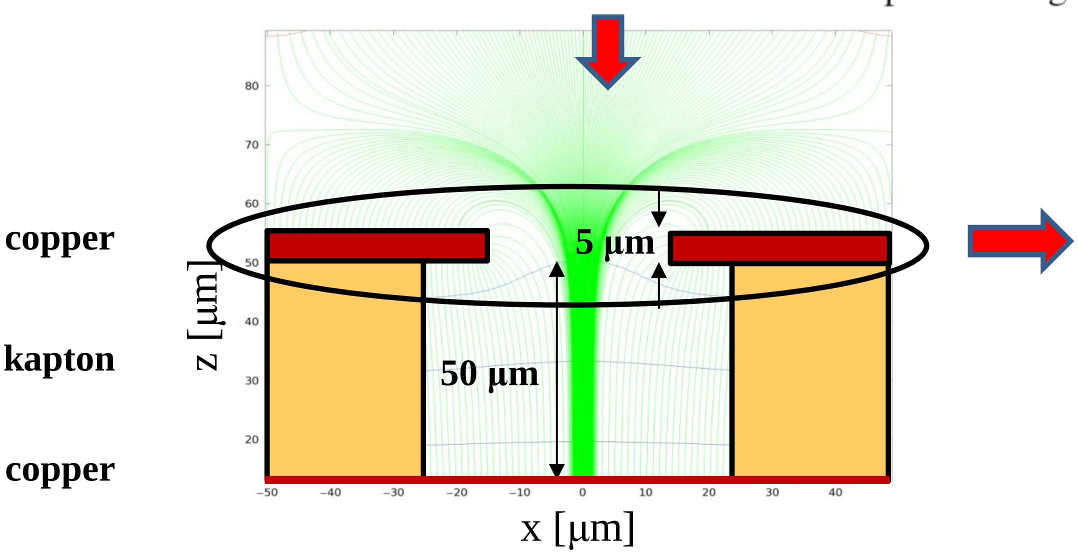
High-end micro-pattern single-gap amplification structure (‘microbulk MicroMegas’)

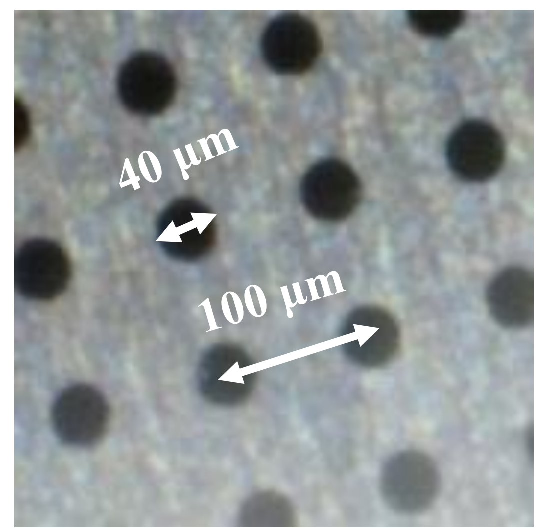
CERN workshop: Rui de Oliveira et al





- Double side Cu-coated (5 μm) Kapton foil (50 μm),
- Construction of readout strips/pads (photolithography)
- Attachment of a single-side Cu-coated kapton foil (25/5 μm)
- Construction of readout lines
- Etching of kapton
- Vias construction
- 2^{nd} Layer of Cu-coated kapton
- Photochemical production of mesh holes
- Kapton etching / Cleaning

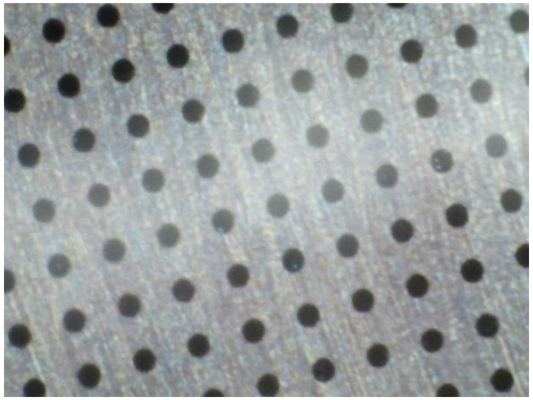




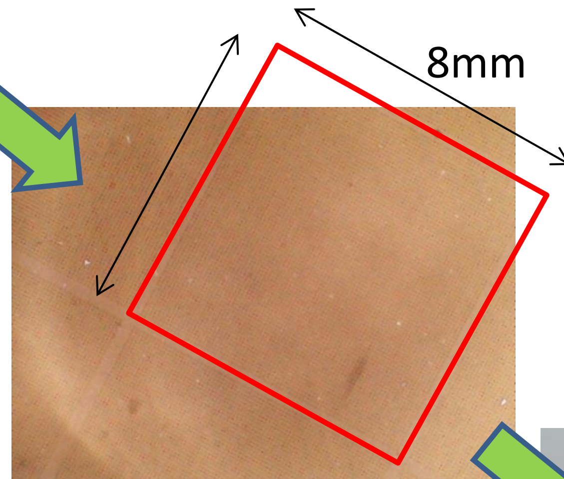
up view

(Radiopure: <30 μBq/cm^2 for ^{235}U, ^{238}U, ^{232}Th chains)

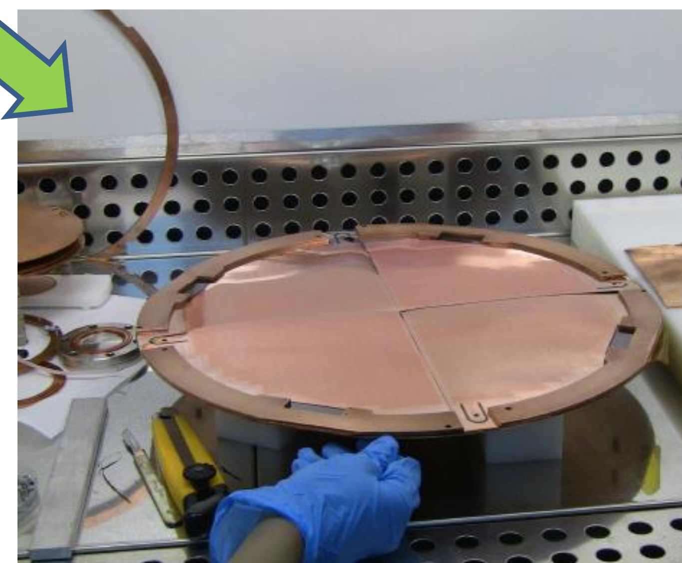
~100 holes



5900 holes/pixel

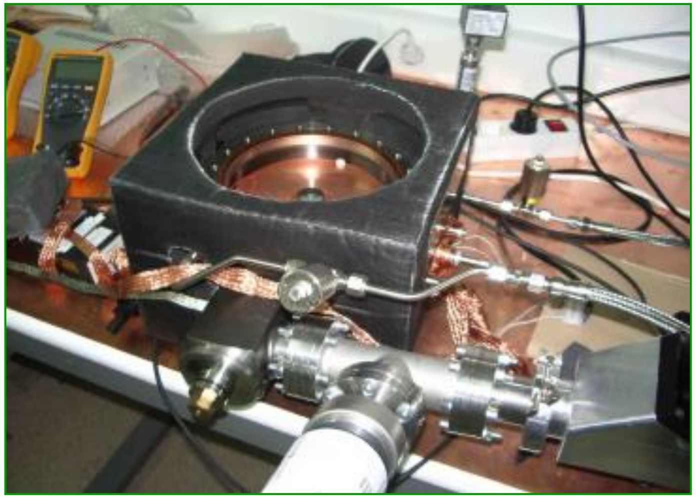


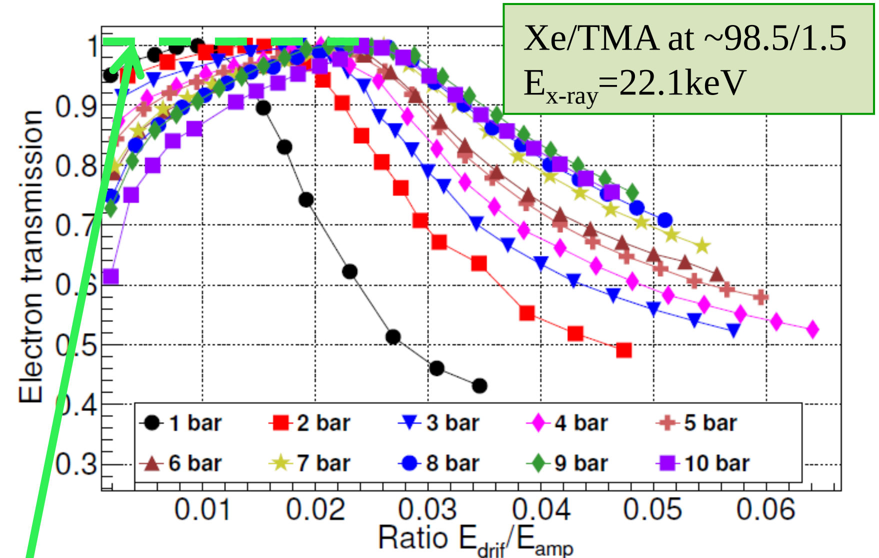
6796800 holes/readout plane

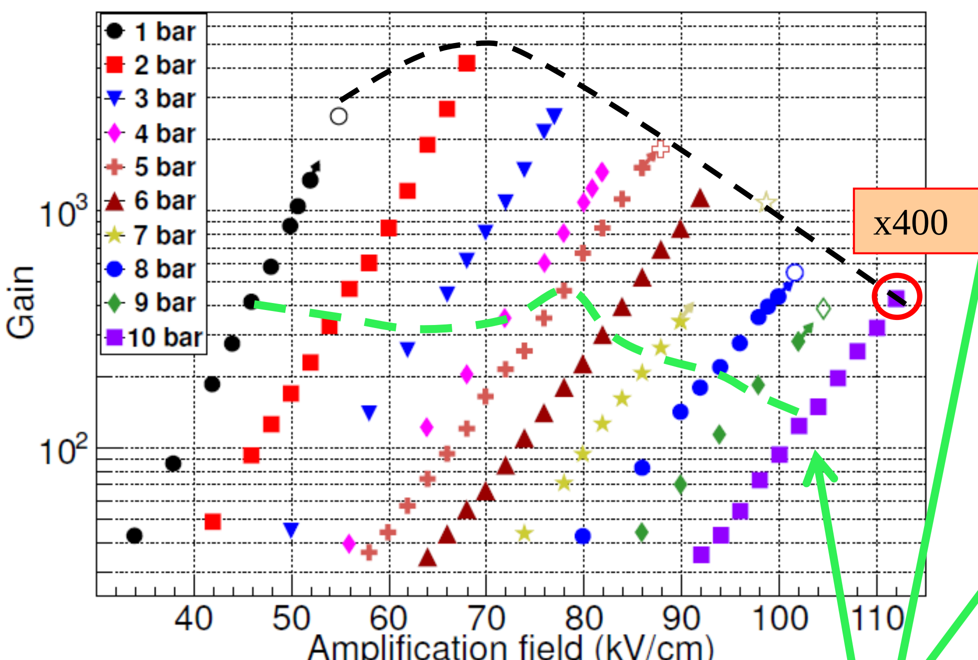


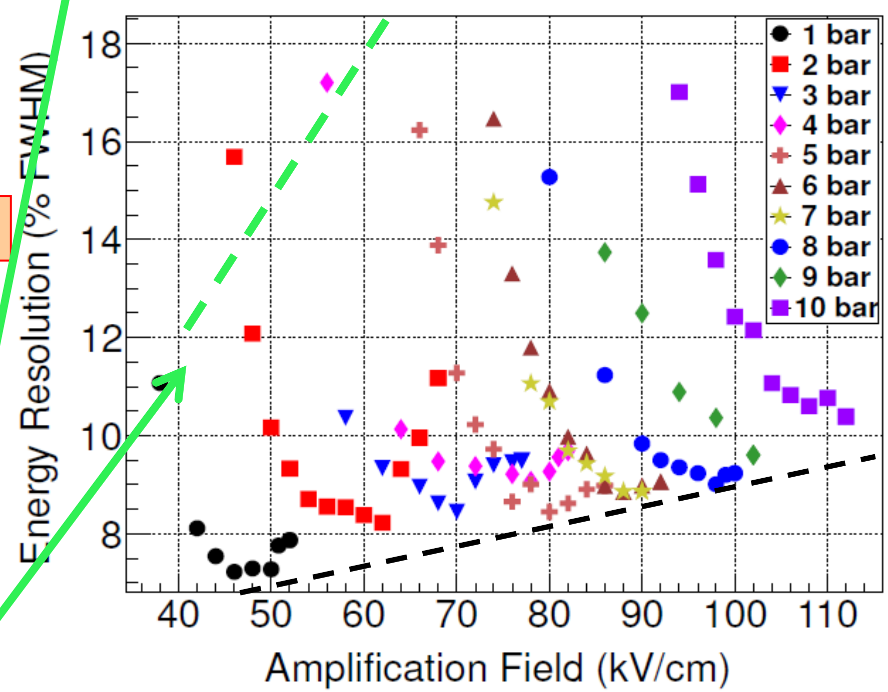
Largest Micromegas manufactured in the microbulk.
No existing experience in a similar system.

step 0: measurements in a small setup and general behavior









Measurements in pure Xe (Universidade Coimbra+Saclay)

Commissioning strategy

- HV, vacuum and pressure tests.
- Preliminary studies with alphas in Ar-ibutane.
- Studies with low energy γ-rays and characterization of the e-cloud properties in the pressure range 1-3bar for Xe-TMA. (~30 live days)
- Run at 10bar with γ-rays (511keV, 1275keV) close to $Q_{\beta\beta}/2$. (~40 live days+)

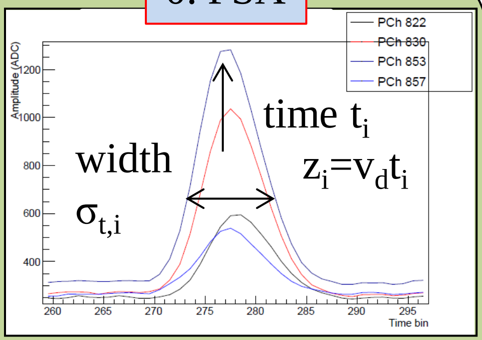
1-3bar

Analysis strategy [1-3bar]

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

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

0. PSA



typical event

1. Calibration

(*on ~15keV<ε<~45keV sample*)

1. Determination of v_d
2. Sector equalization (10-20%)
3. Pixel equalization (10%)
4. Transient correction (5-10%)

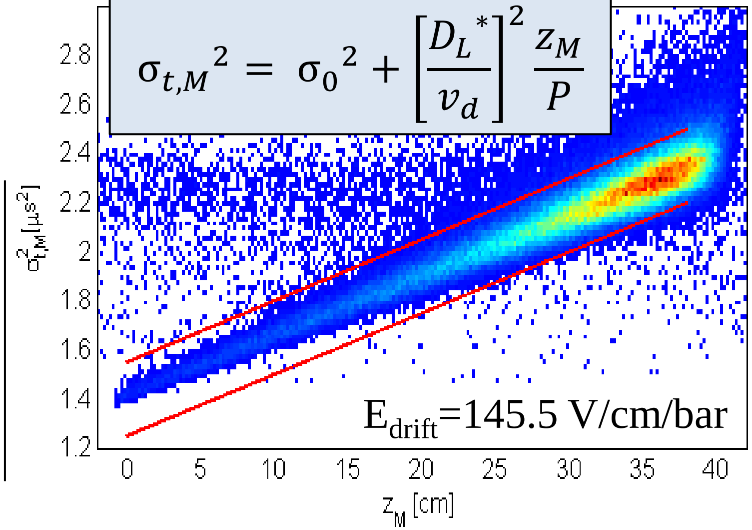
2. Track quality cut

(*on the sample to analyze*)

1. Cosmic ray cut (z-extension<5cm).
2. Baseline quality.
3. Forming a single-track (in XY-plane).

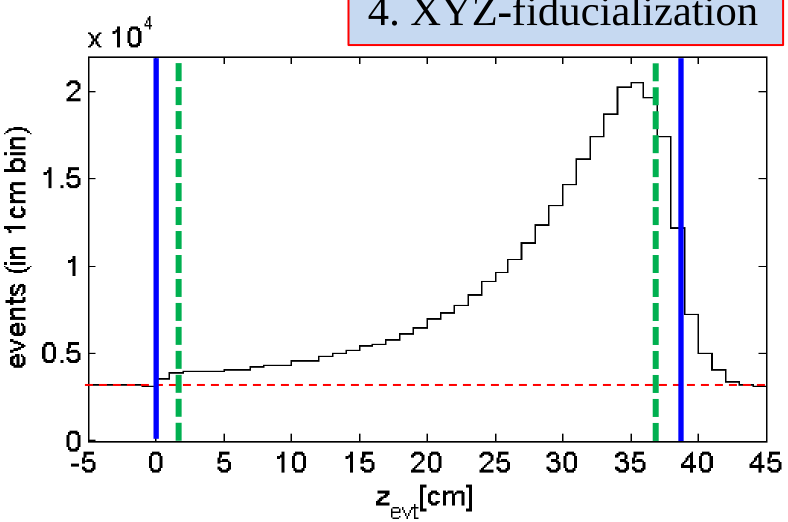
3. Suppression of random coincidences

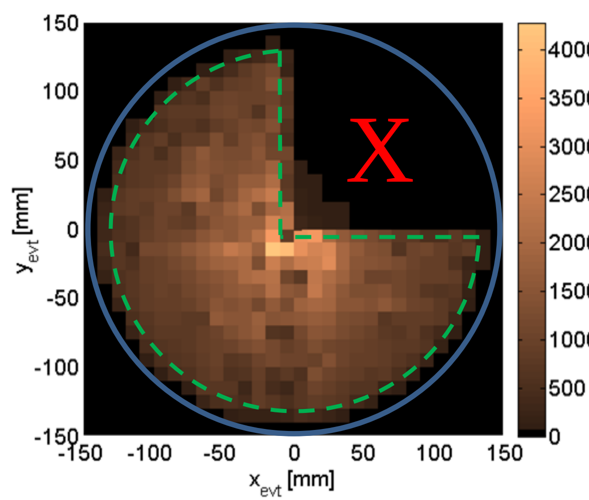
$$\sigma_{t,M}^2 = \sigma_0^2 + \left[\frac{D_L^*}{v_d}\right]^2 \frac{z_M}{P}$$

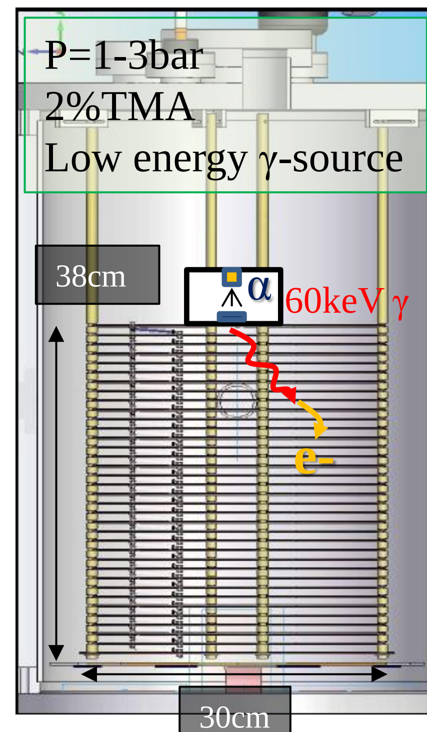


Physical criteria for longitudinal diffusion

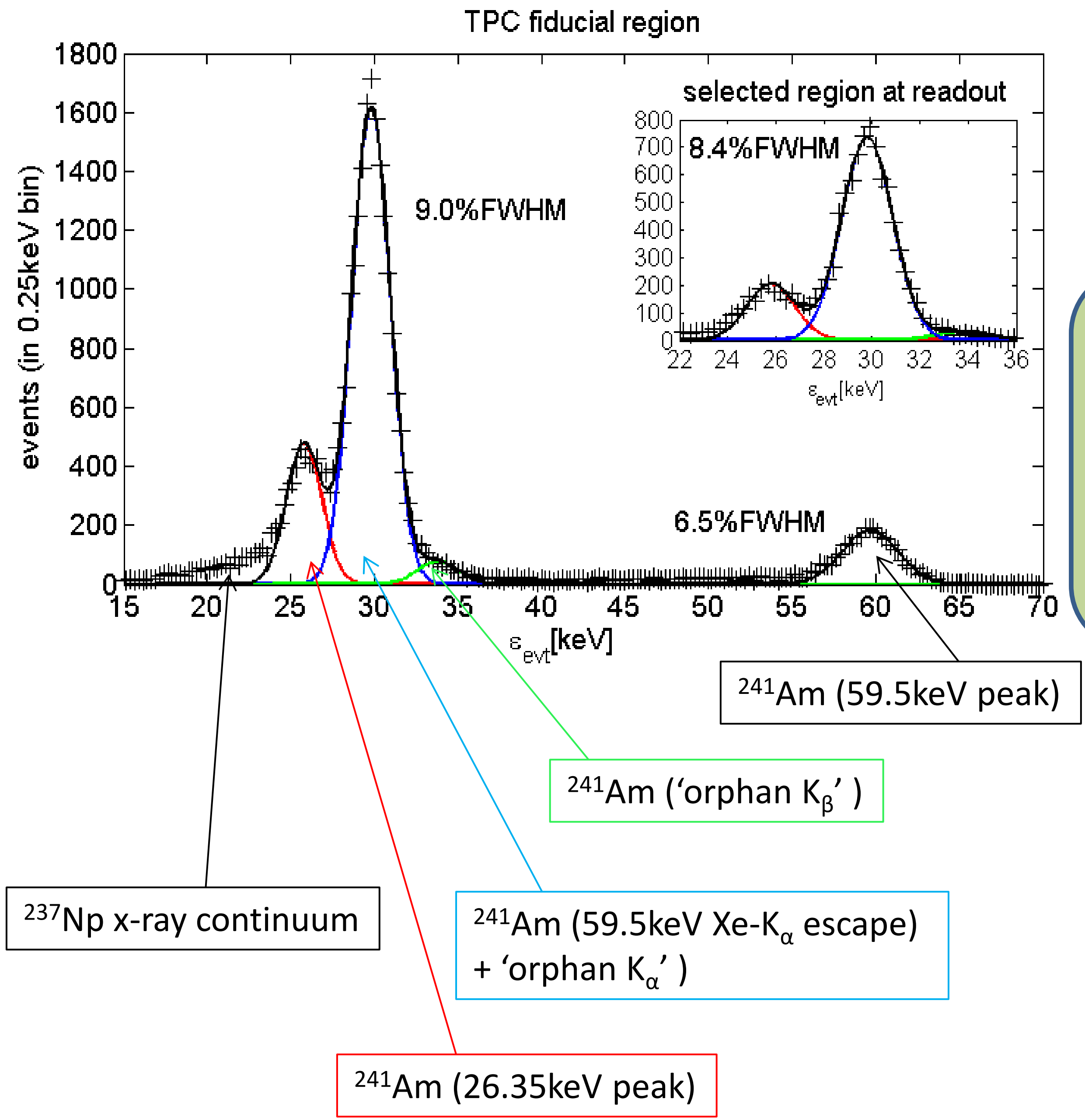
4. XYZ-fiducialization





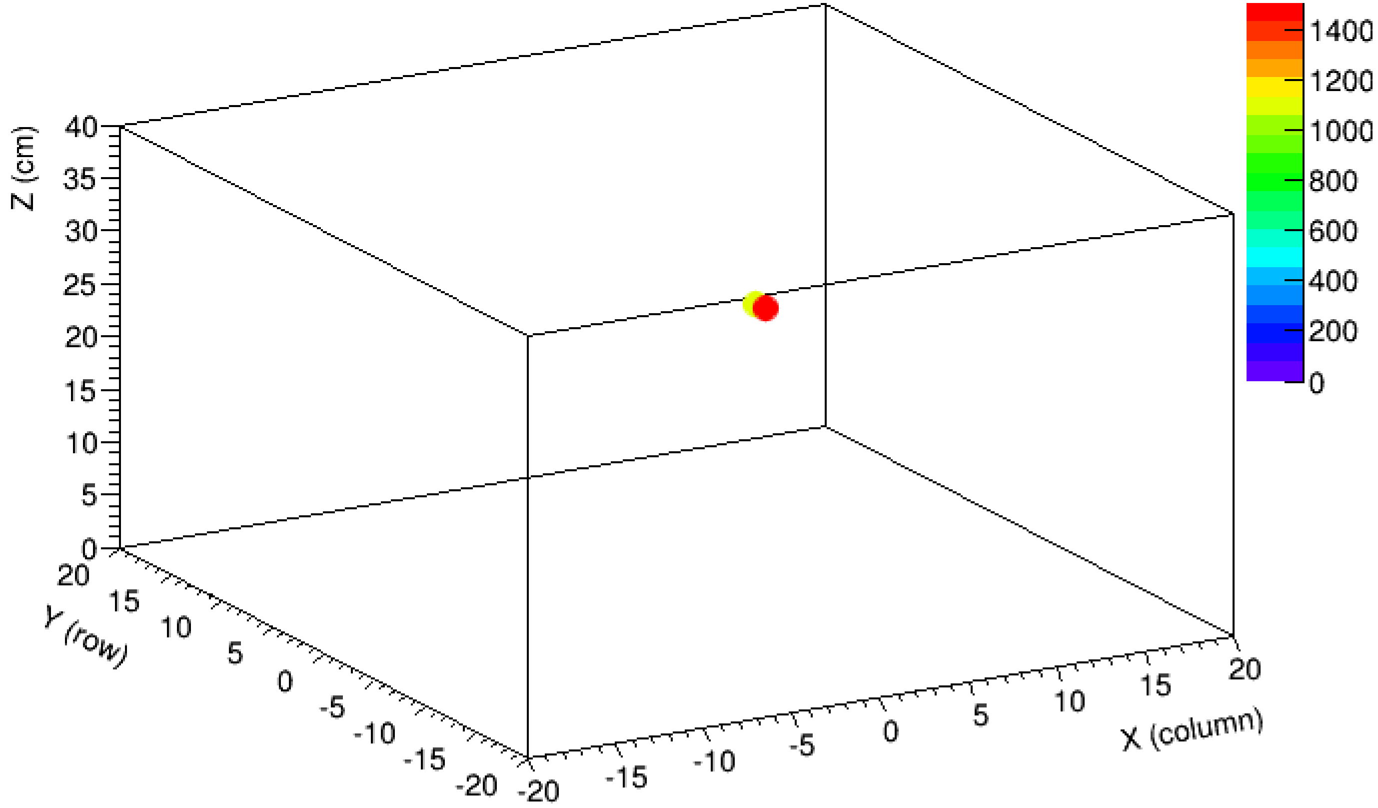


Calibrated energy spectrum at 1-3bar

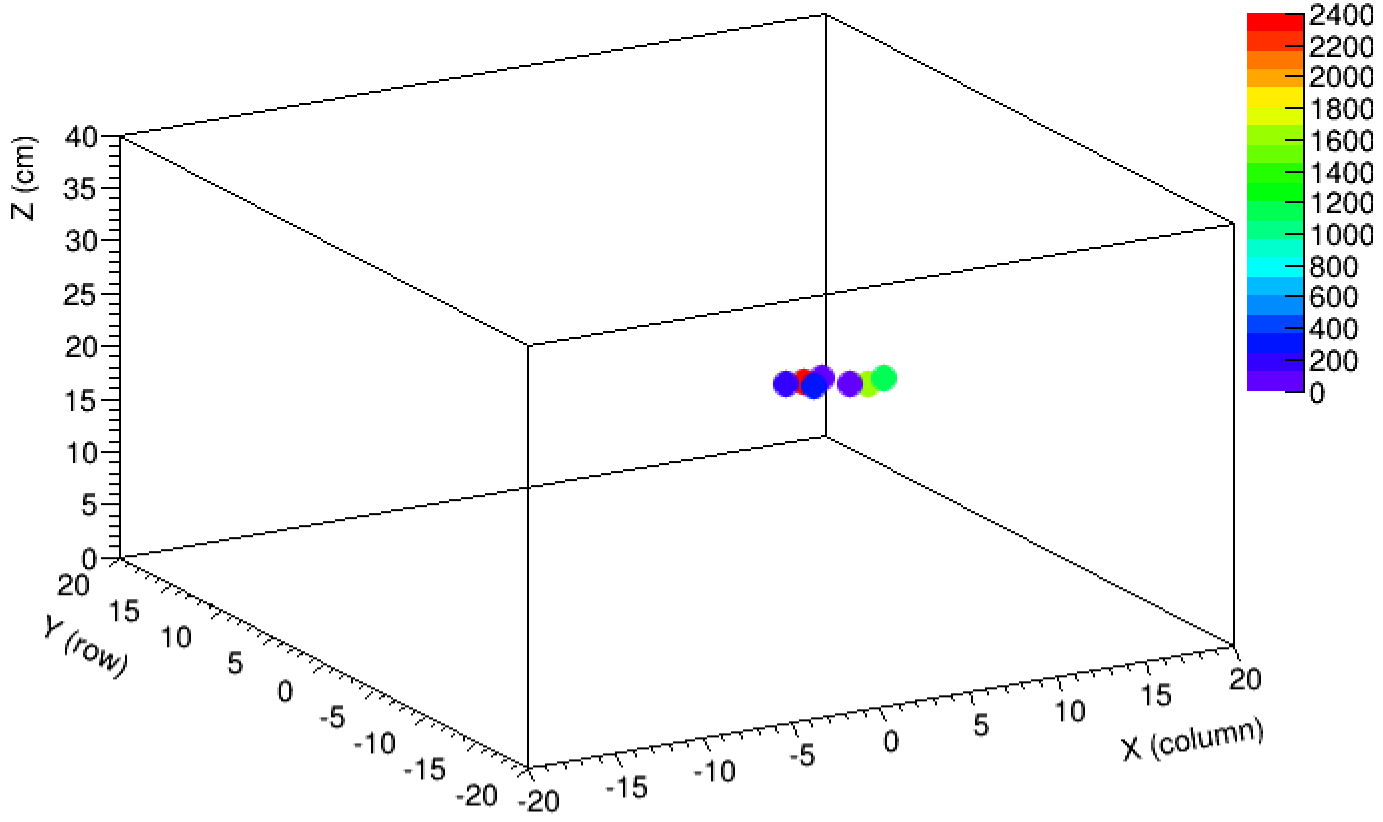


- Mixture: Xe-TMA (97.8/2.2)
- Micromegas gain: 2000
- FEE ENC: <0.12keV(95%ch)
- Pixels' threshold, ε_{th} : ~0.5keV
- Trigger threshold: 10-15keV
- E_{drift}=145.5V/cm/bar
- P=1.0bar
- Electron attachment: <10%/m

30keV clusters at 1bar

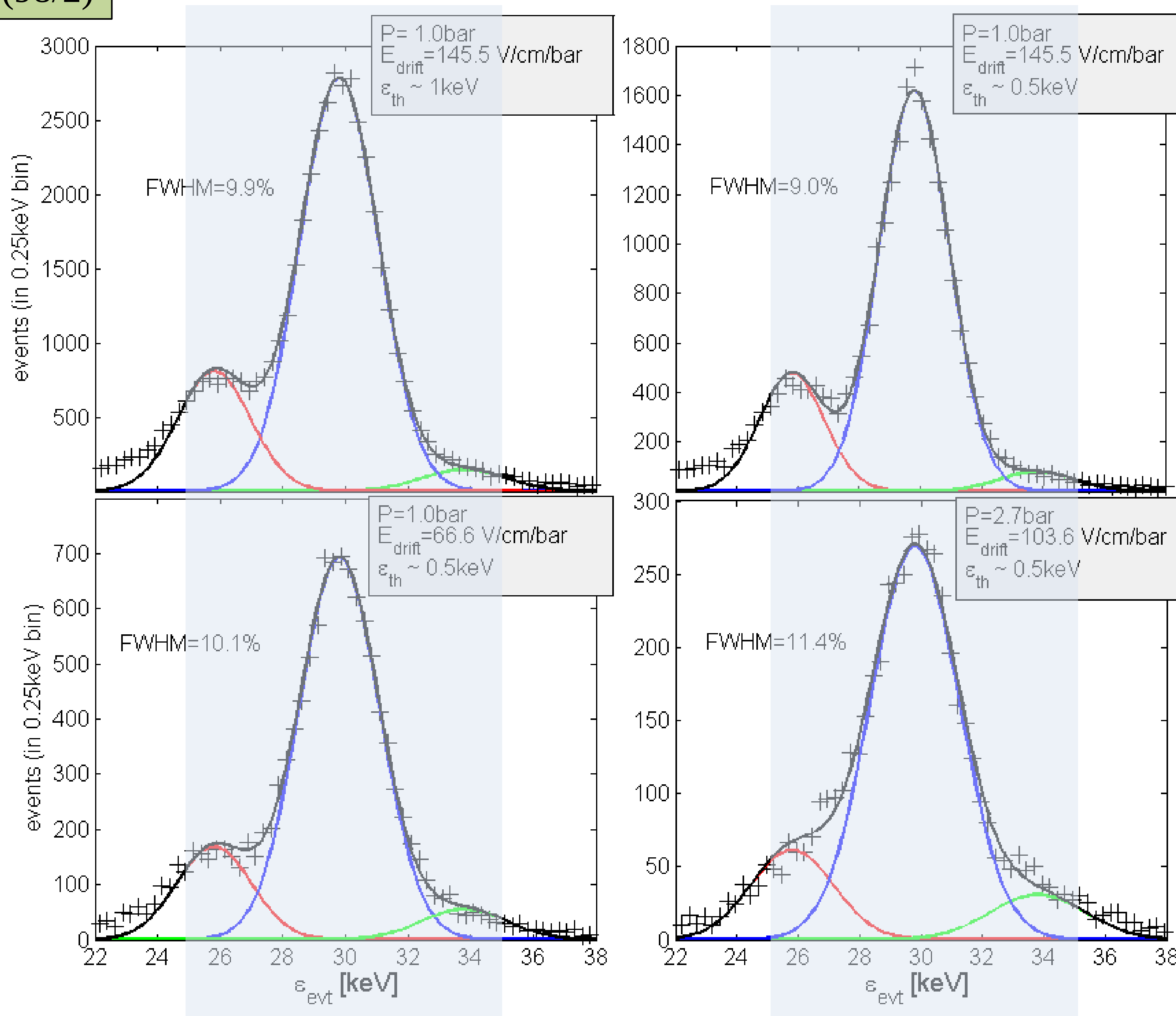


59.5keV clusters at 1bar



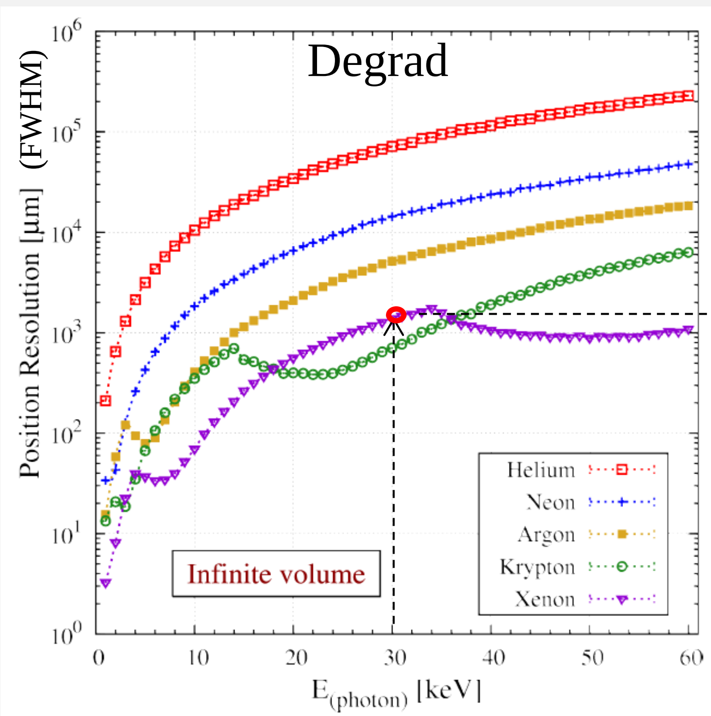
Xenon escape peaks for ^{241}Am in various conditions

Xe/TMA (98/2)

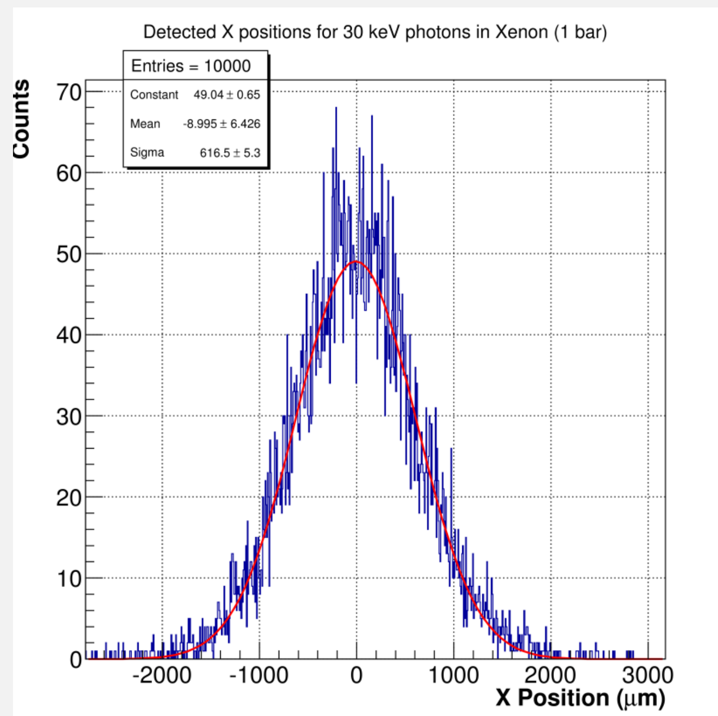


Short digression

(estimate of the parameters of the electron swarm using 30keV ‘quasi-point like’ charge deposits)



(Carlos Azevedo, Feb2014 RD51 mini-week)



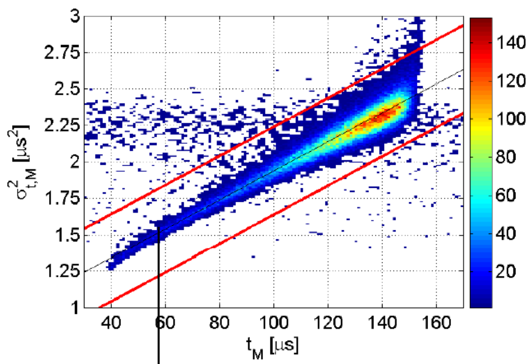
(courtesy of Carlos Azevedo)

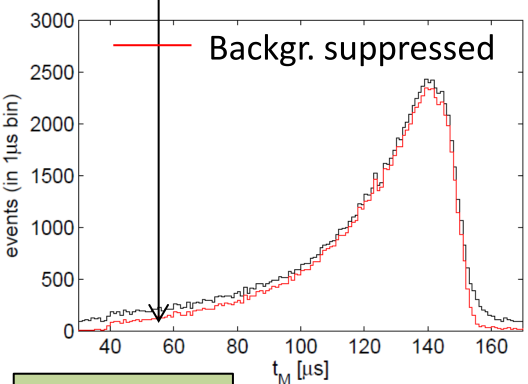
Extraction of diffusion coefficients at 1-3bar

use the following convention

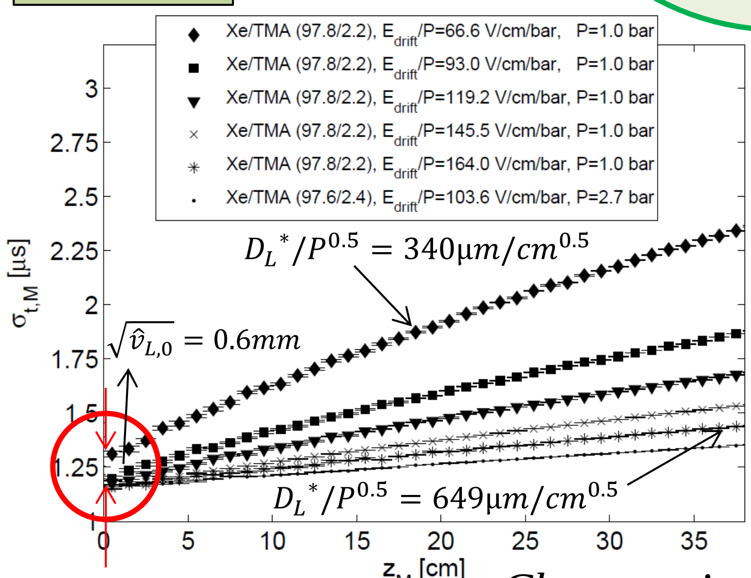
$$D_L^* = \sqrt{\frac{T_0}{T}\frac{2P\,D_L}{v_d}} \quad [\frac{\mu m}{\sqrt{cm}} \times \sqrt{bar}]$$

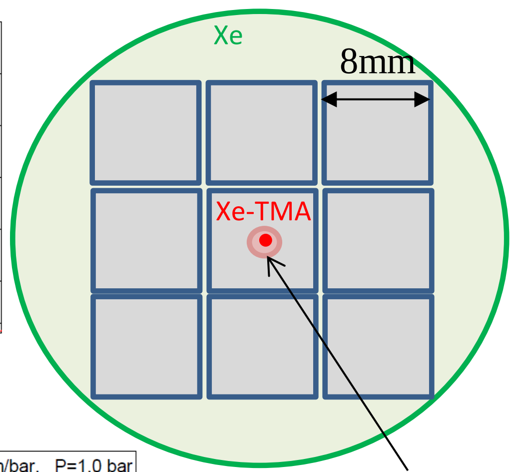
$$\sigma_{L,T} = D_{L,T}^* \frac{\sqrt{z}}{\sqrt{P}}$$



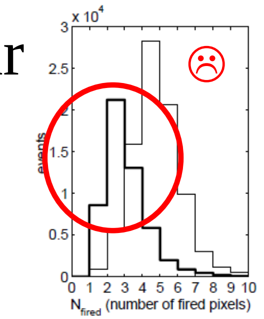


longitudinal

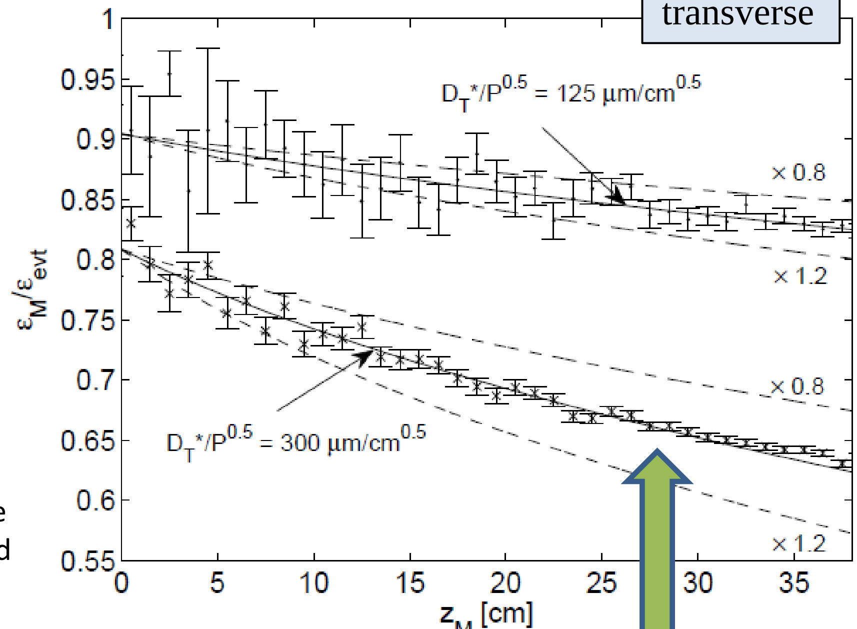




Typical transverse size of the ionization cloud for 38cm drift @1bar (1-σ)



transverse



$$< \frac{\varepsilon_M}{\varepsilon_{evt}} >= \left[\frac{1}{L}\int_{-L/2}^{L/2} dx \int_{-L/2}^{L/2} \frac{1}{\sqrt{2\pi\hat{v}_r}}\, e^{-\frac{(x-x_0)^2}{2\hat{v}_r}}\, dx_0\right]^2$$

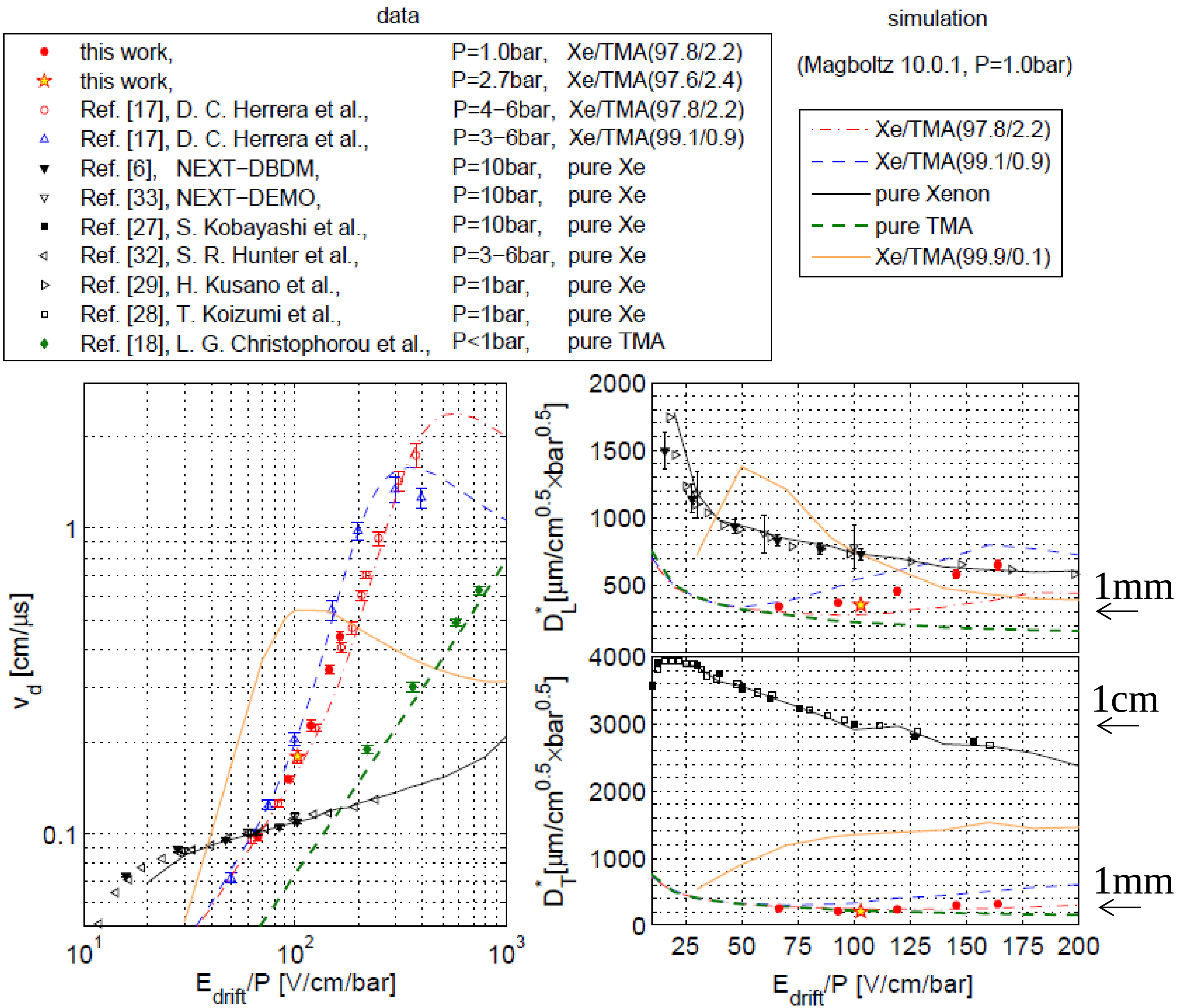
$$< \frac{\varepsilon_M}{\varepsilon_{evt}} >= \frac{\left[2\hat{v}_r\left(e^{-\frac{L^2}{2\hat{v}_r}} - 1\right) + \sqrt{2\pi}L\sqrt{\hat{v}_r}\,\mathrm{erf}\left(\frac{L}{\sqrt{2\hat{v}_r}}\right)\right]^2}{2\pi L^2 \hat{v}_r}$$

$$\hat{v}_r = {D_T^*}^2 \times \frac{z_M}{P} + \hat{v}_{r,0} \longrightarrow \sqrt{\hat{v}_{r,0}} = 1 \pm 0.1mm$$

Characterization of a medium size Xe-TMA TPC, JINST 9(2014)C04015

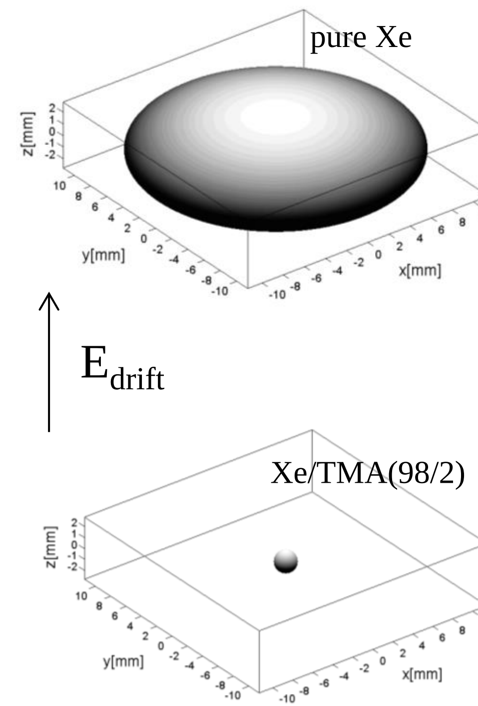
Drift velocity and diffusion systematics

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



point-like ionization

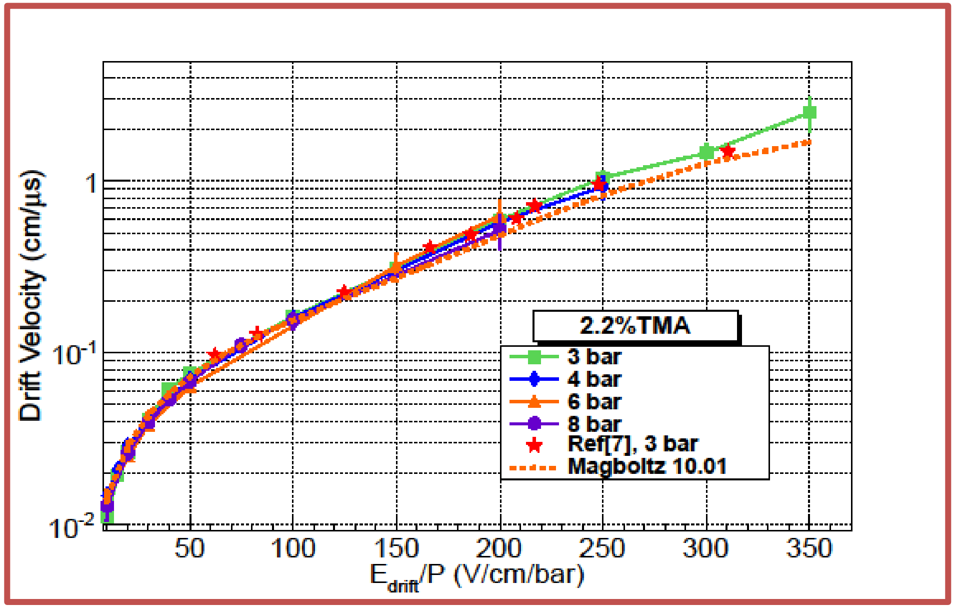
z_{drift}=100cm, P=10bar

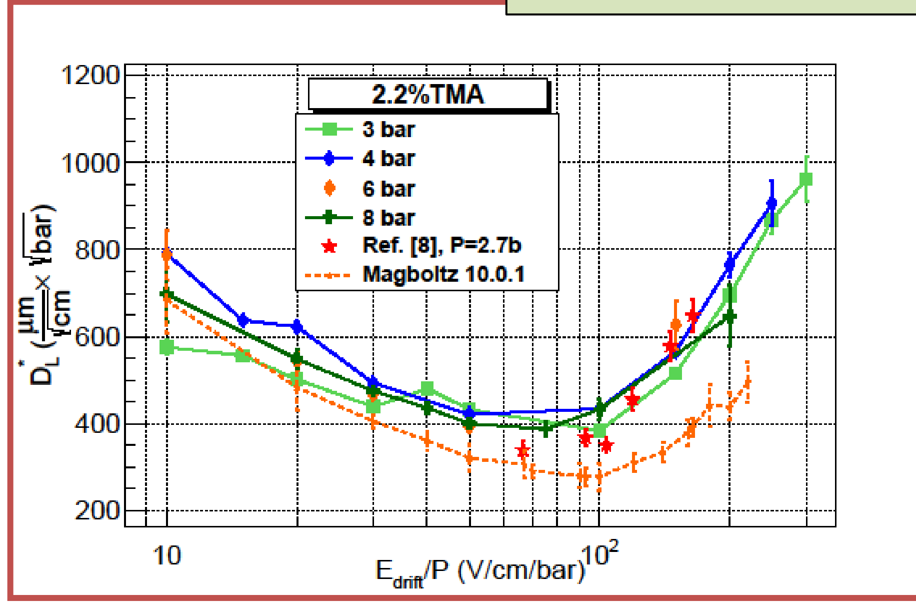


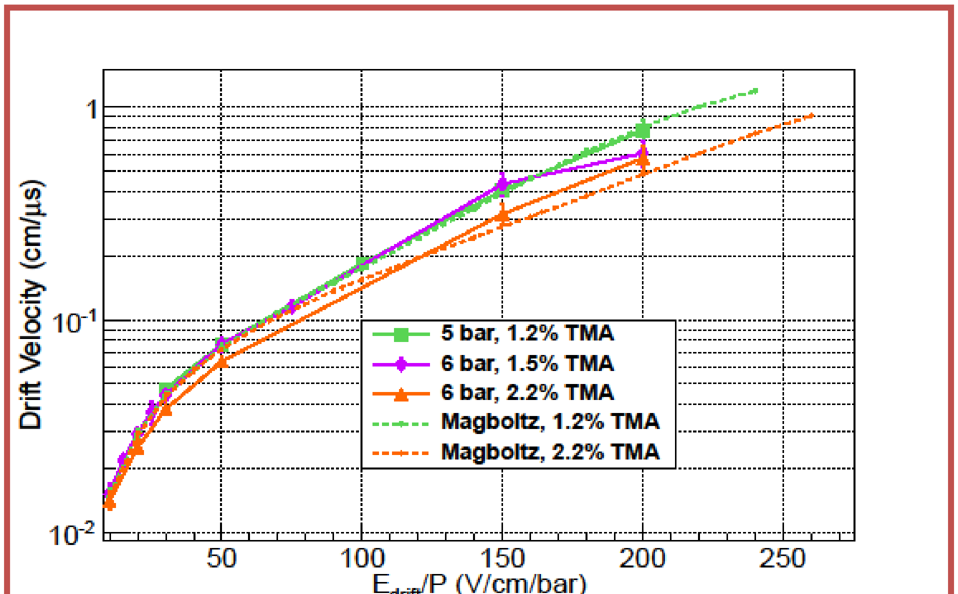
Characterization of a medium size Xe-TMA TPC, JINST 9(2014)C04015

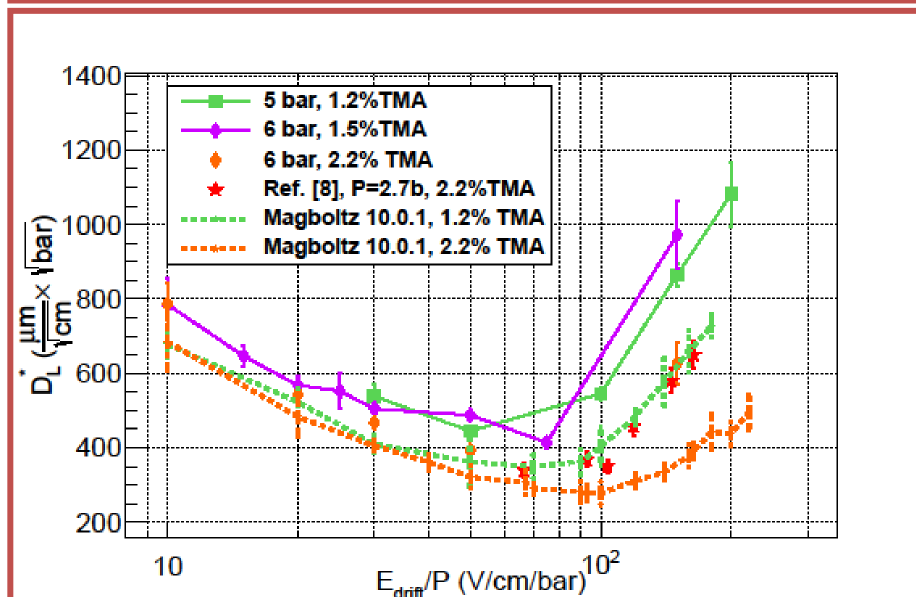
New data from small setup (with α-tracks)

See D. C. Herrera's talk at WG2









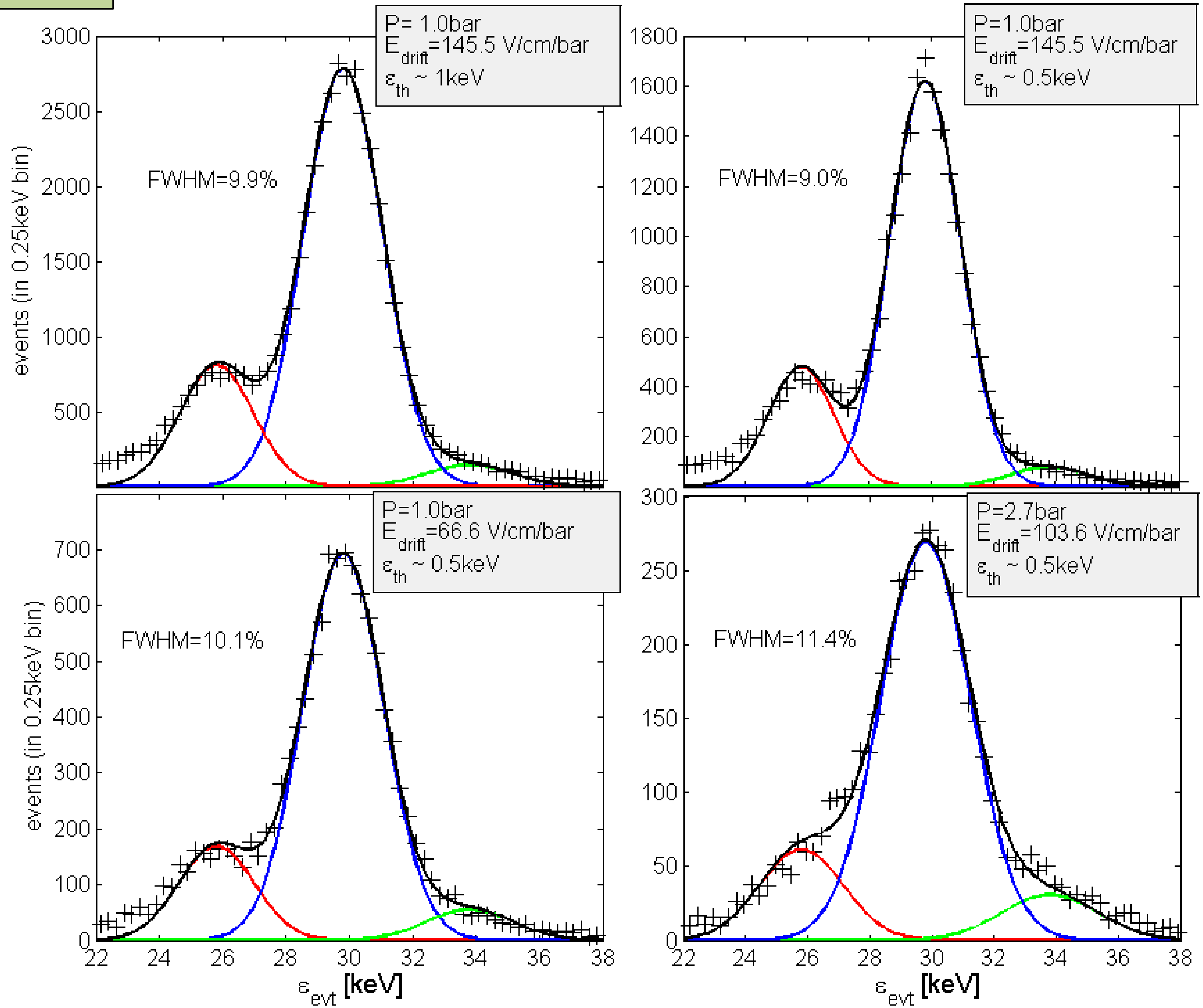
[7] D.C. Herrera , J. Phys. Conf. Ser. **460** (2013) 012012

*[8] V Álvarez et al, JINST **9** C04015 (2014)*

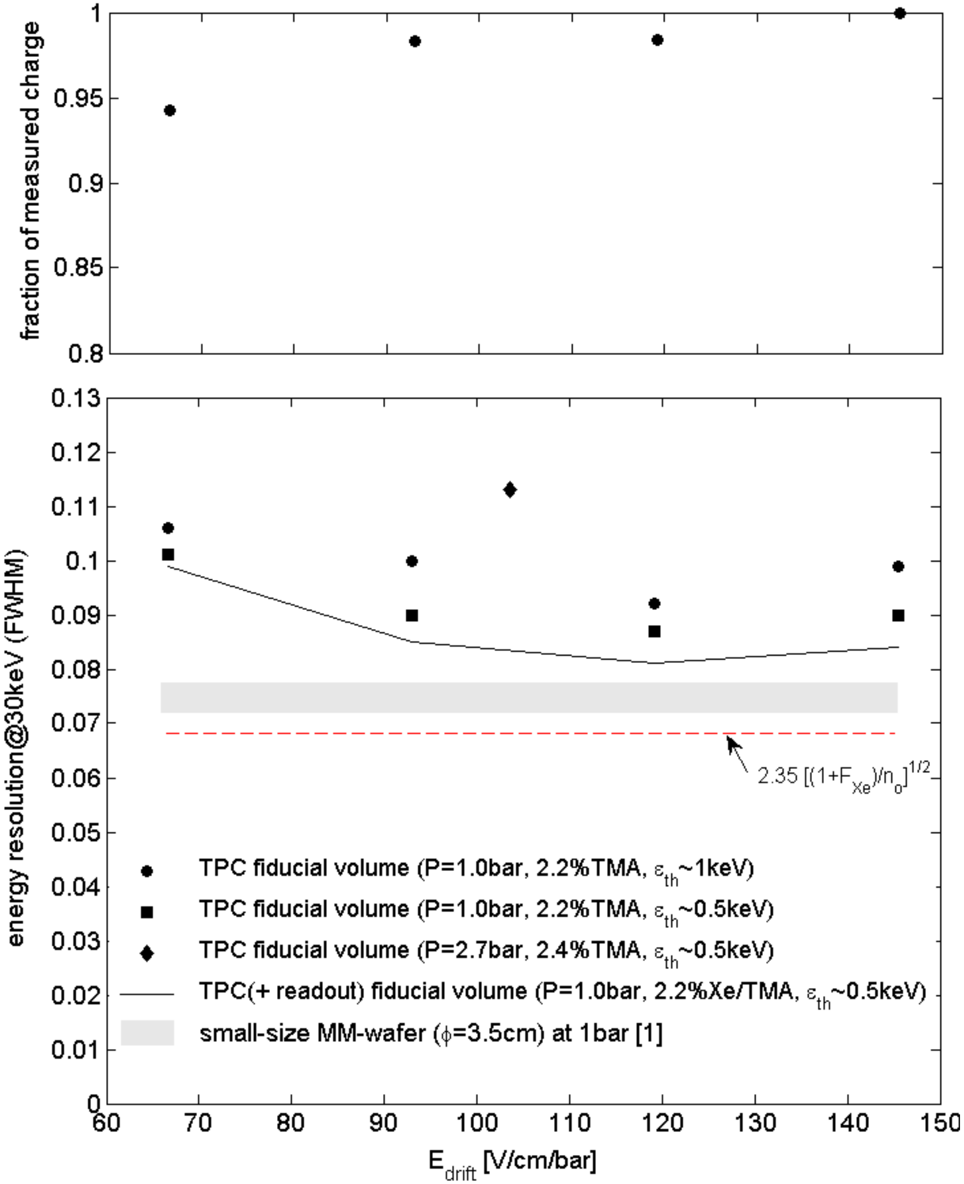
back to system performance

Xenon escape peaks for ^{241}Am in various conditions

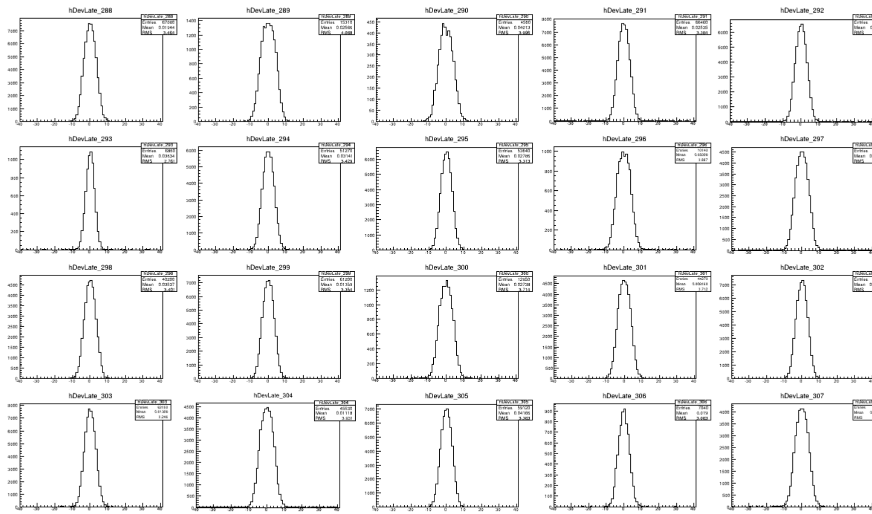
Xe/TMA (98/2)



Drift field systematics in the pressure range 1-3bar



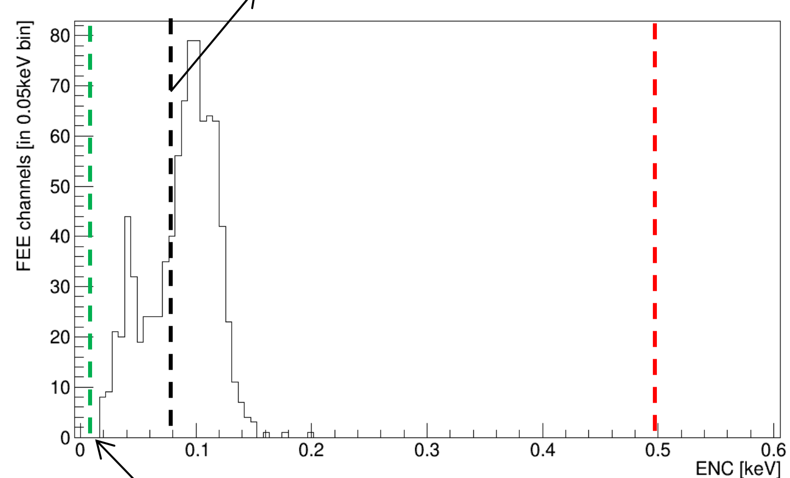
Base-line spread for 20 random FEE channels



#ADC channels

<ENC>=7000e-

threshold



Typical AFTER values (1000e-) for optimized system

10bar

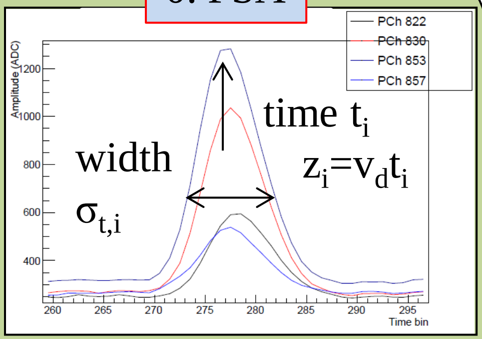
Analysis strategy [10bar]

3. No suppression of random coincidences (yet)

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

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

0. PSA



typical event

1. Calibration

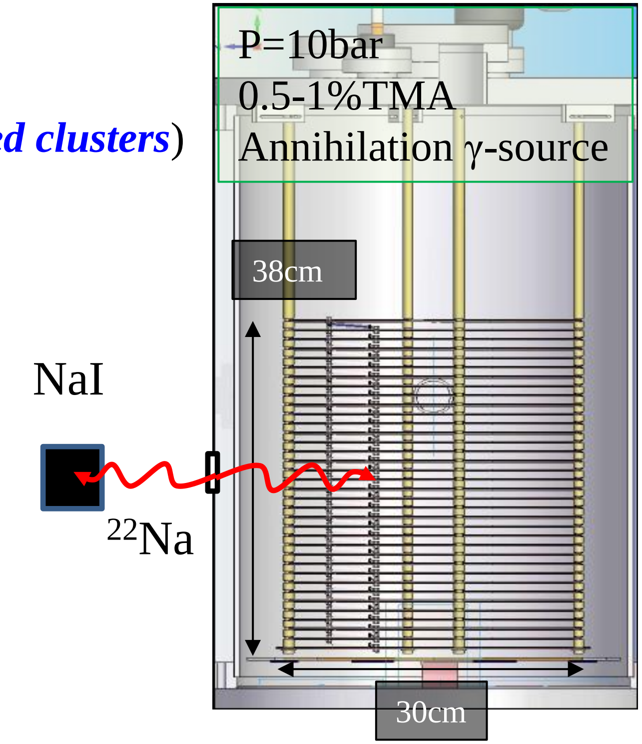
(*on ~15keV<ε<~45keV sample –>* ***isolated clusters***)

1. Determination of v_d
2. Sector equalization (10-20%)
3. Pixel equalization (10%)
4. Transient correction (5-10%)

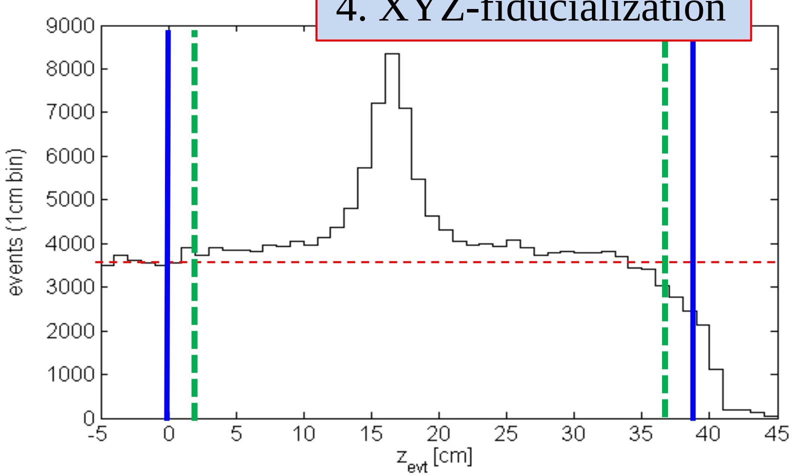
2. Track quality cut

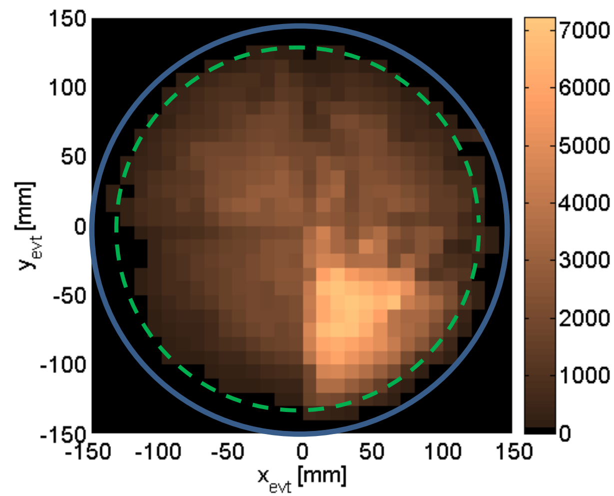
(*on the sample to analyze*)

1. Cosmic ray cut (z-extension<5cm).
2. Baseline quality.
3. ***Tracks with 1-3 clusters.***



4. XYZ-fiducialization





approximate source position

Energy spectrum after calibration at 10bar

Compton edge (^{22}Na, 511keV)

photo-peak (^{22}Na, 511keV)

Compton edge (^{22}Ne*, 1275keV)

- Mixture: Xe-TMA (99.0/1.0)
- Micromegas gain: 150-250
- FEE ENC: <2keV(95%ch)
- Pixels' threshold, ε_{th} : ~7.5keV
- Trigger threshold: 250-300keV
- Edrift=80V/cm/bar
- P=10.1bar
- Electron attachment: small (prelim.)

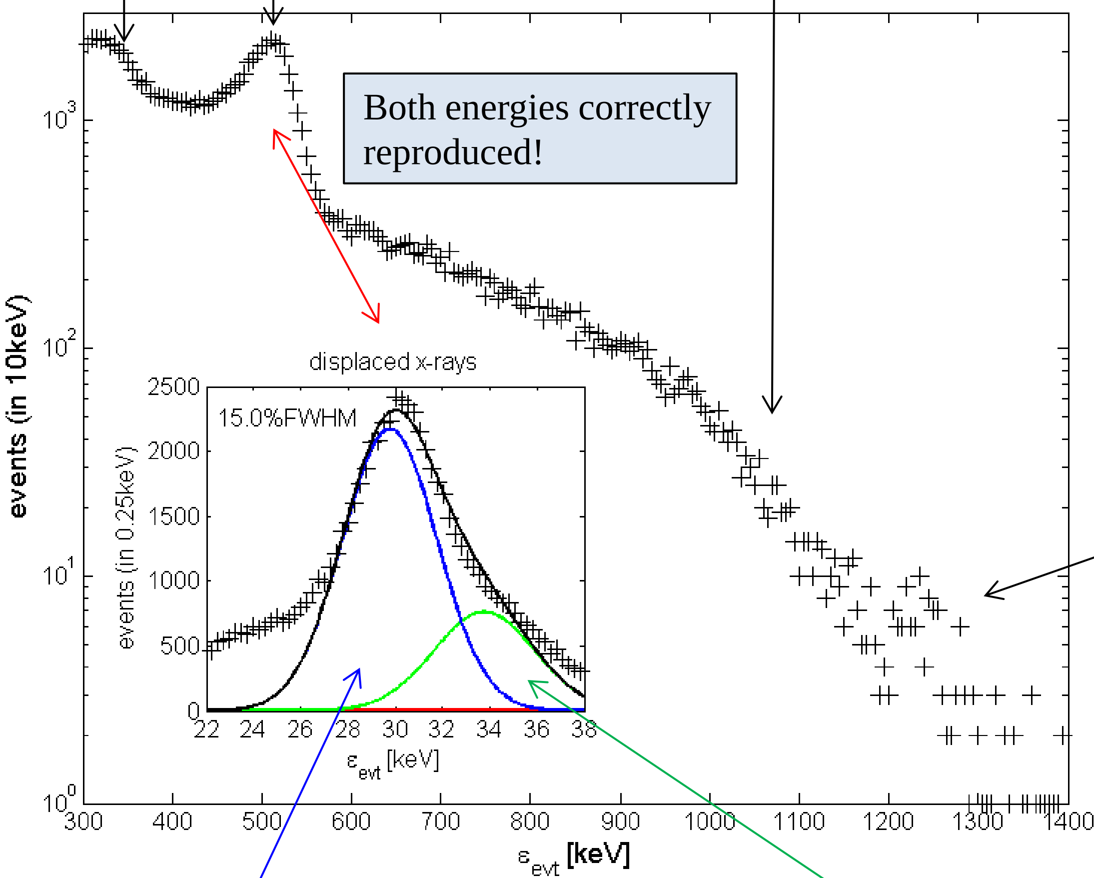


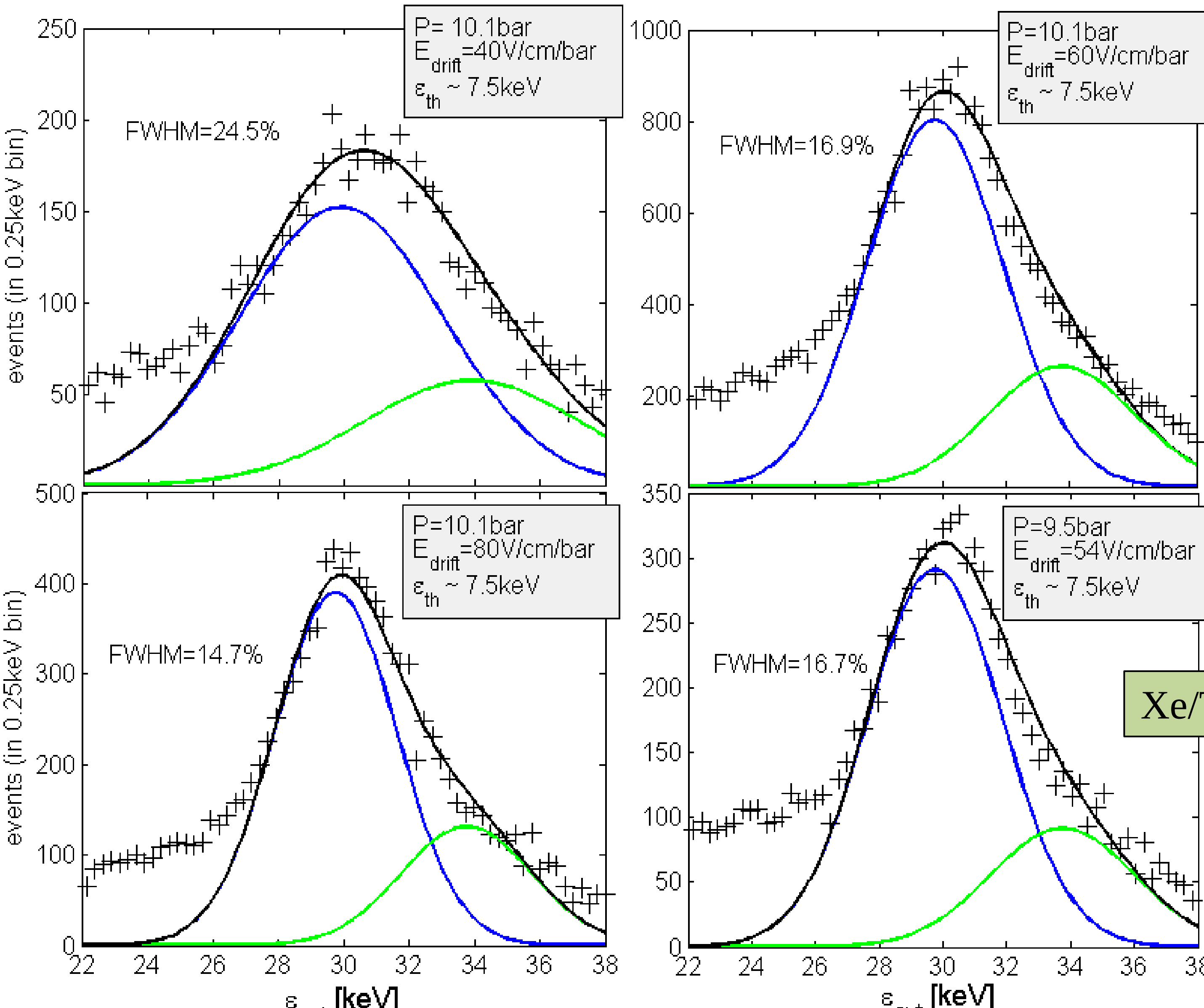
photo-peak (^{22}Ne*, 1275keV)

(29.8keV Xe-K$_\alpha$ emission)

(33.64keV Xe-K$_\alpha$ emission)

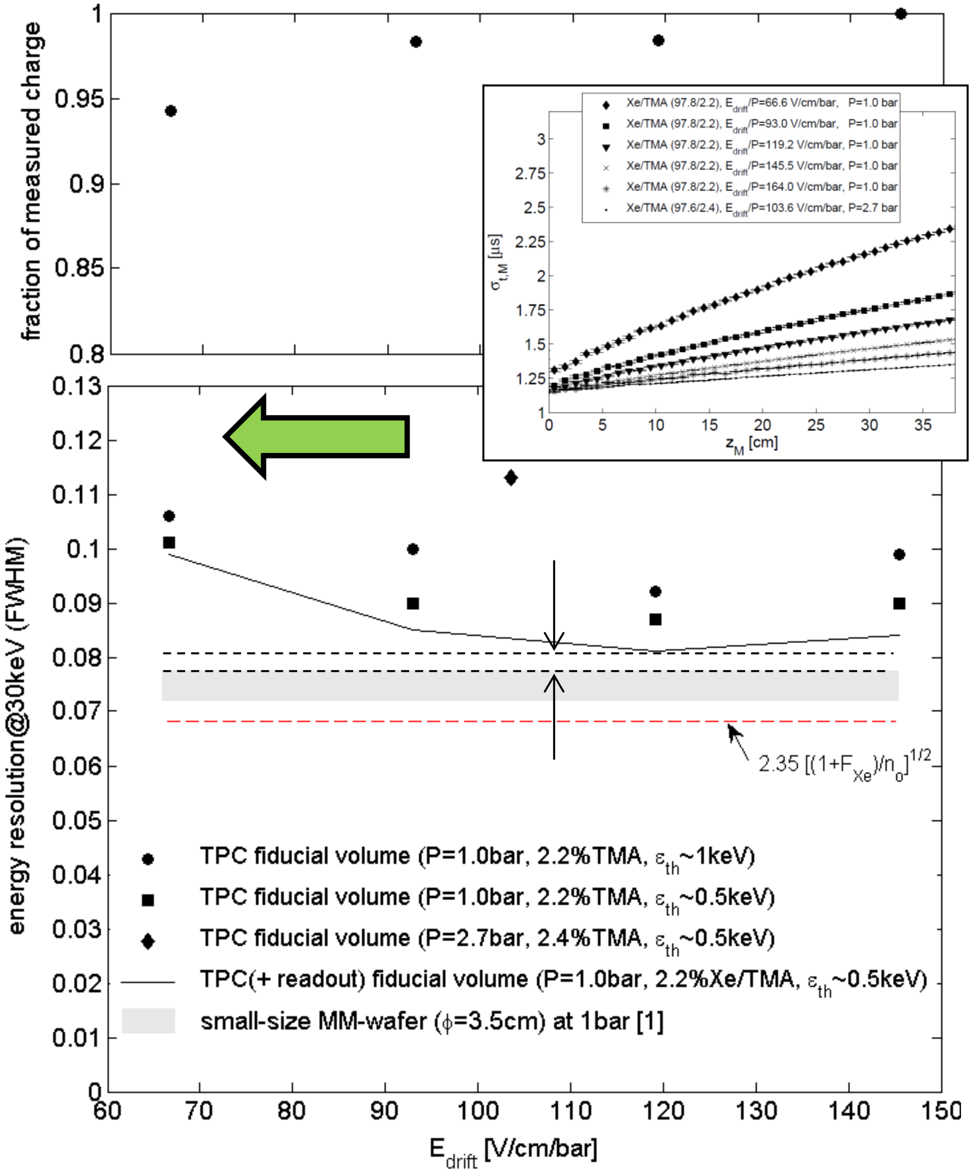
Xe characteristic $K_{\alpha,\beta}$ peaks (isolated clusters) for various conditions

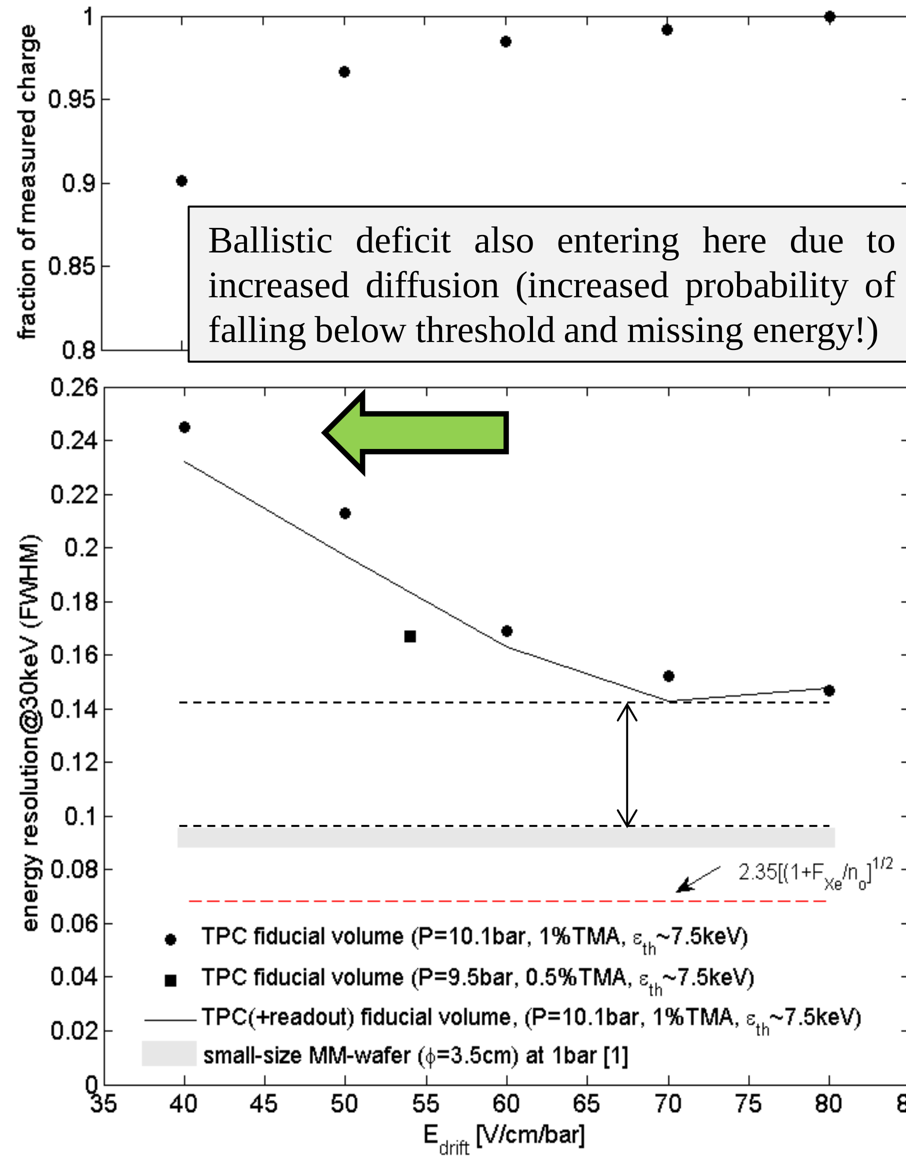
Xe/TMA (99/1)



Xe/TMA (99.5/0.5)

Comparison for 30keV charge deposits (1-10bar)



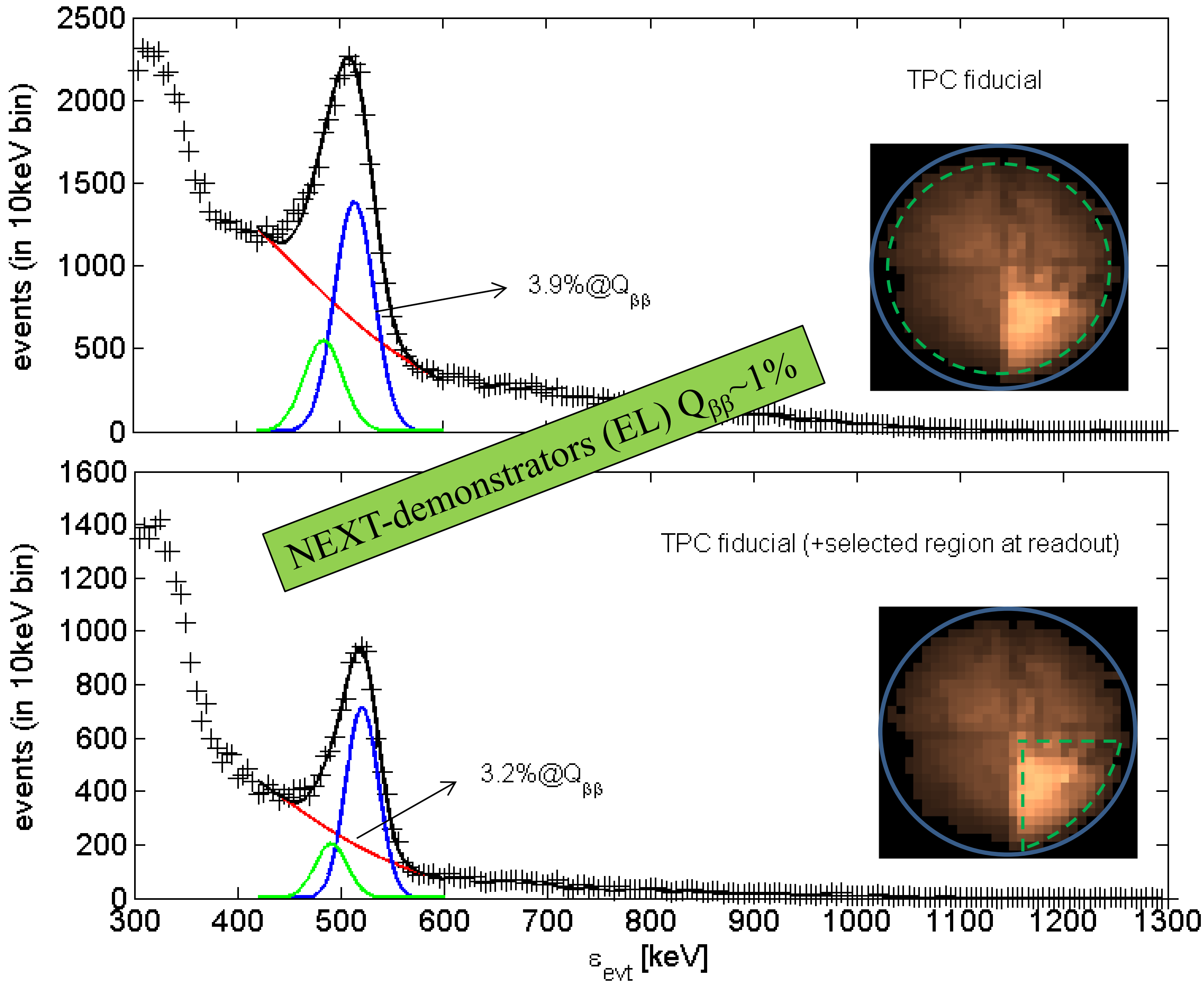


Ballistic deficit also entering here due to increased diffusion (increased probability of falling below threshold and missing energy!)

Deterioration already at the level of small variations in the technological process

Deterioration presumably coming from both missing energy (ε_{th}~7.5keV) and higher recombination at HP

Energy resolution at the 511 annihilation peak

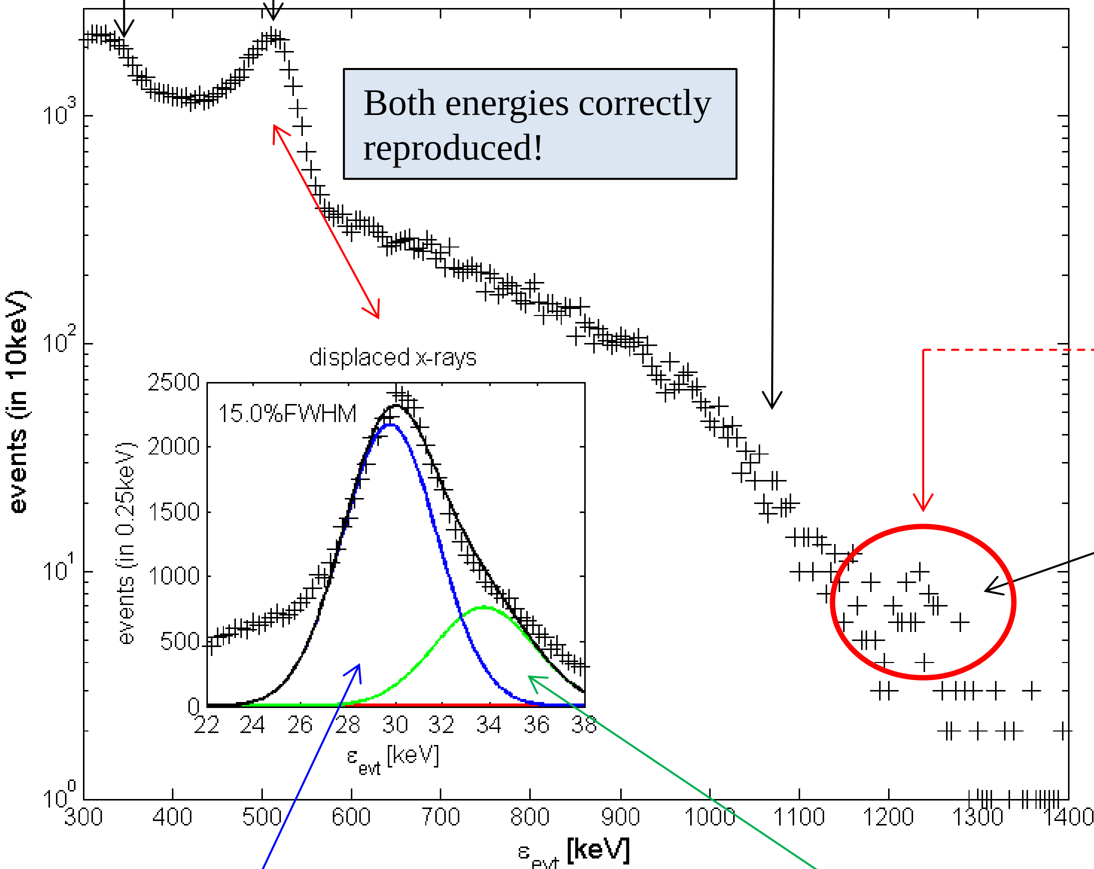


Energy spectrum after calibration at 10bar (reminder)

Compton edge (^{22}Na, 511keV)

photo-peak (^{22}Na, 511keV)

Compton edge (^{22}Ne*, 1275keV)



Both energies correctly reproduced!

- Mixture: Xe-TMA (99.0/1.0)
- Micromegas gain: 150-250
- FEE ENC: <2keV(95%ch)
- Pixels' threshold, ε_{th} : ~7.5keV
- Trigger threshold: 250-300keV
- Edrift=80V/cm/bar
- P=10.1bar
- Electron attachment: small (?)

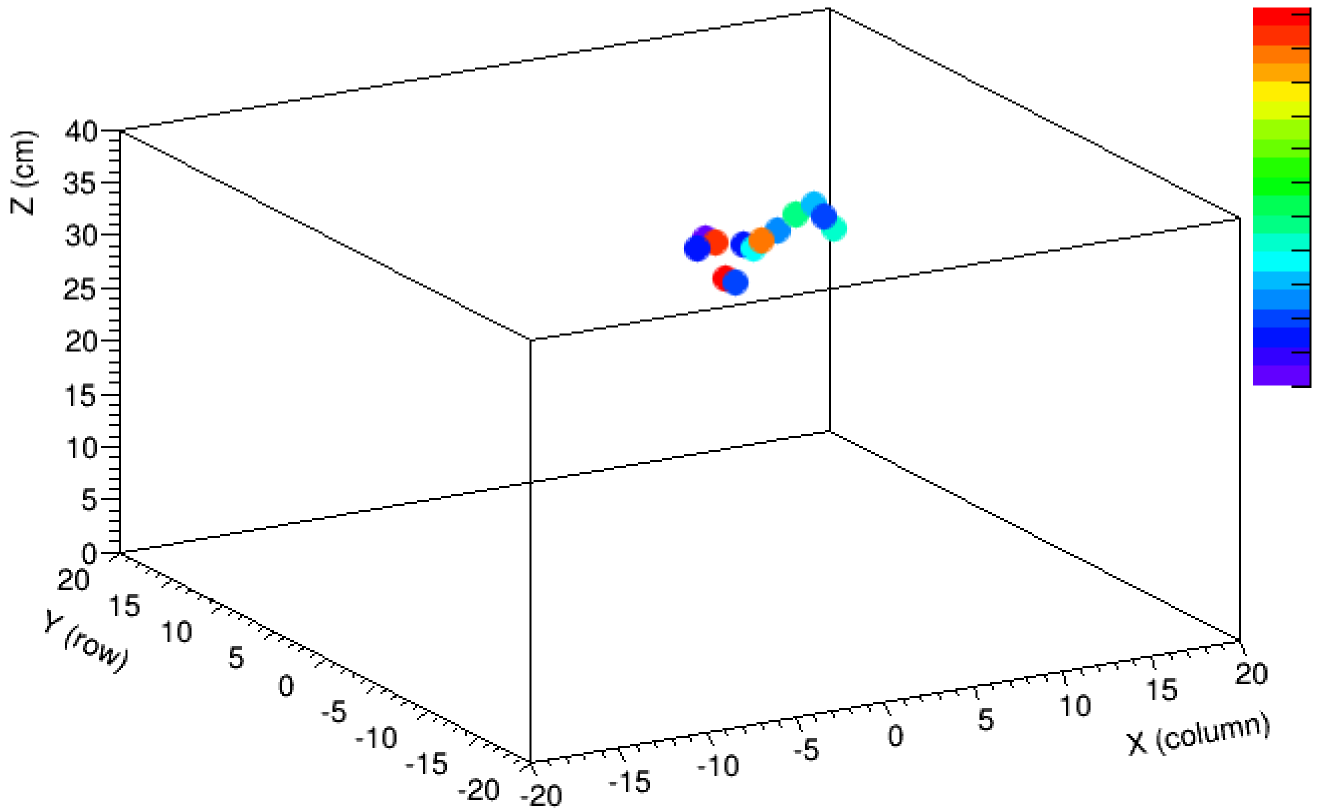
$Q_{\beta\beta,\ 136Xe}/2$

photo-peak (^{22}Ne*, 1275keV)

(29.8keV Xe-K$_\alpha$ emission)

(33.64keV Xe-K$_\alpha$ emission)

selected events in the 1.2MeV region (from $^{22}Ne^*$)



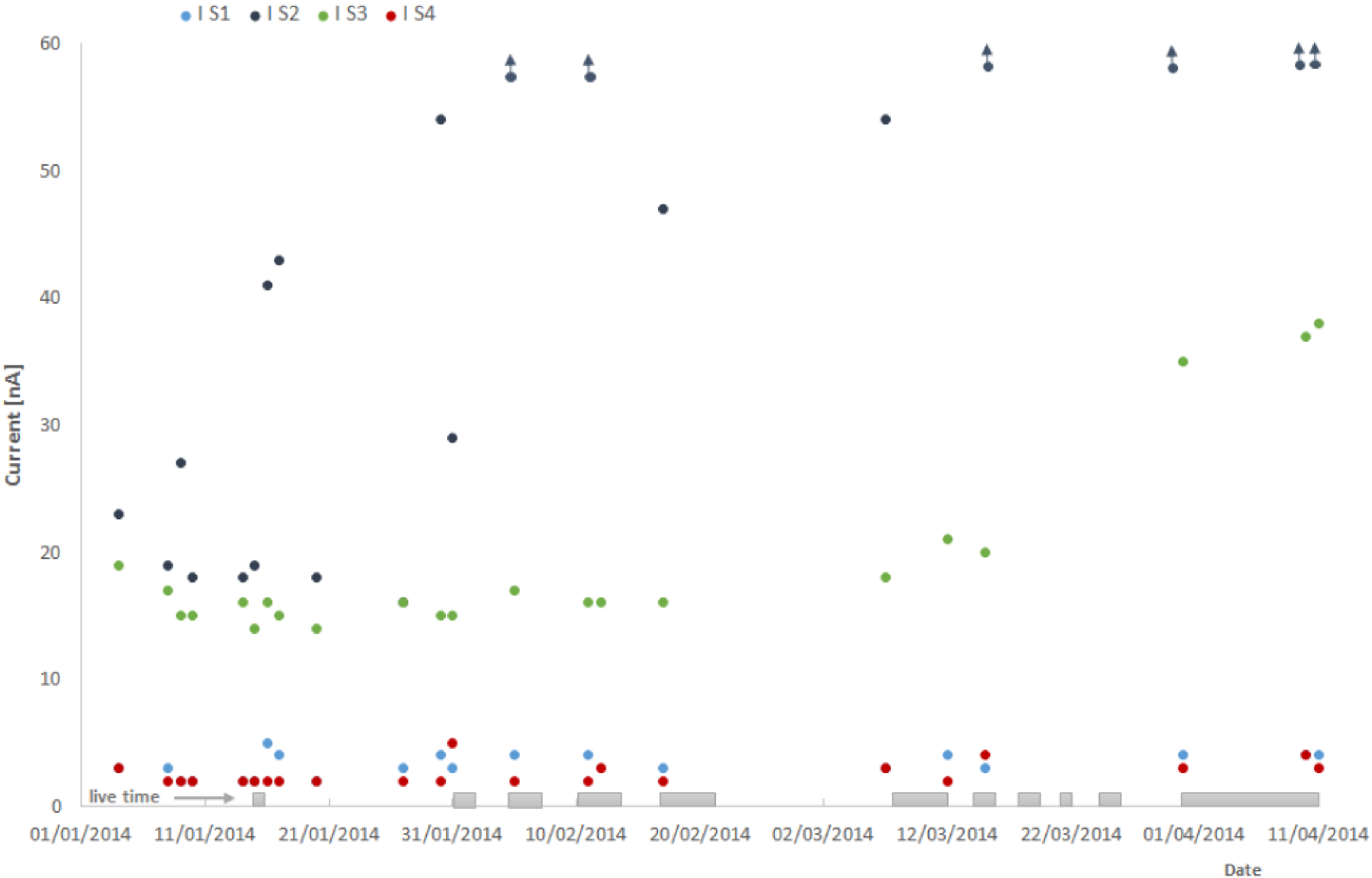
End-blob clearly identified

Status

1-3bar campaigns (6months/30live days)	HP campaigns (3months/40live days)
level of connectivity: **92%**	level of connectivity: **90%**
unconnected pixels: **8%**	unconnected pixels: **10%**
of which	of which
unclear origin: **1%**	unclear origin: **1%**
understood(solvable): **5.2%**	understood(solvable): **4.5%**
damaged pixels: **1.8%**	damaged pixels: **4.5%**
sector 1 **not functional.**	**full plane operative**
P=1-2.7bar	P=9.5-10bar
%TMA=2.2-2.4	%TMA=0.45-1%
E_{drift}=66-170 V/cm/bar	E_{drift}=40-80 V/cm/bar
gain=1600-2000	gain=200
η<10%/m	η= no strong indication
Am-source (30-60keV)	Na-source (511-1270keV)

running continuously at the moment!

Behavior of current with time



Stability and effective exposure

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{\boxed{Mt}}{\Delta E \cdot B}}$$

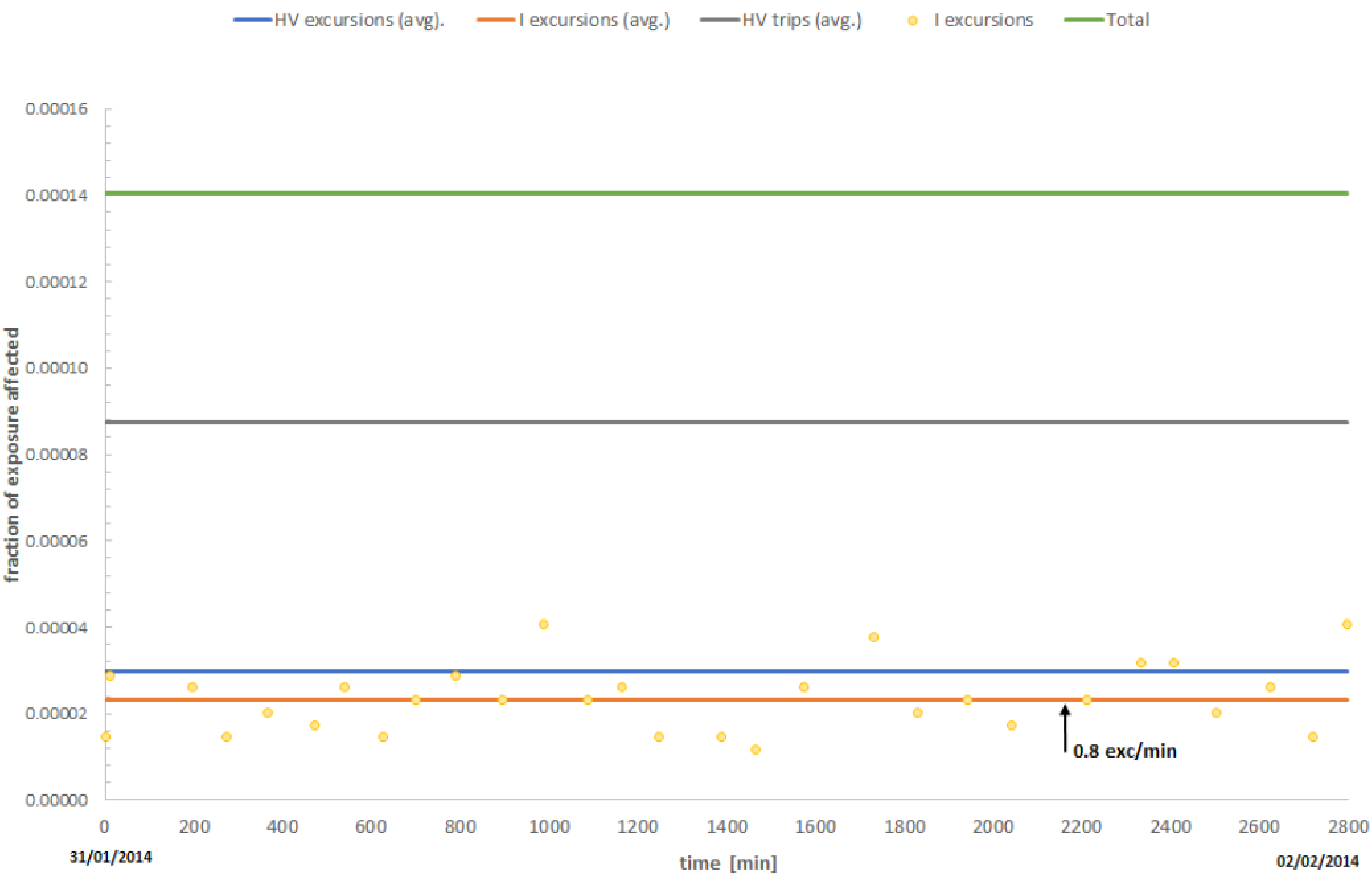
← exposure

Besides general maintenance and calibration activities, assume 3 main sources of loss of exposure connected to the readout plane:

- Current excursions. Only one hole/pixel is affected during ~2s.
- HV excursions. The voltage of a whole sector ramps down for ~5-10s.
- HV trips. Full ramp-down/up cycle needed, ~1-2min.

$$\frac{Mt|_{loss}}{Mt} \cong \frac{A_{affected} \times \Delta t_{affected}}{A \times t}$$

Stability and effective exposure



Supra-intrinsic energy resolution in Xe-TMA

The basic idea (details omitted)

$$\frac{W_{xe-TMA}}{W_{xe}} \cong \frac{1}{(1 + rN_{ex}/N_I)(1 - R)}$$

Recombination (electron dynamics)

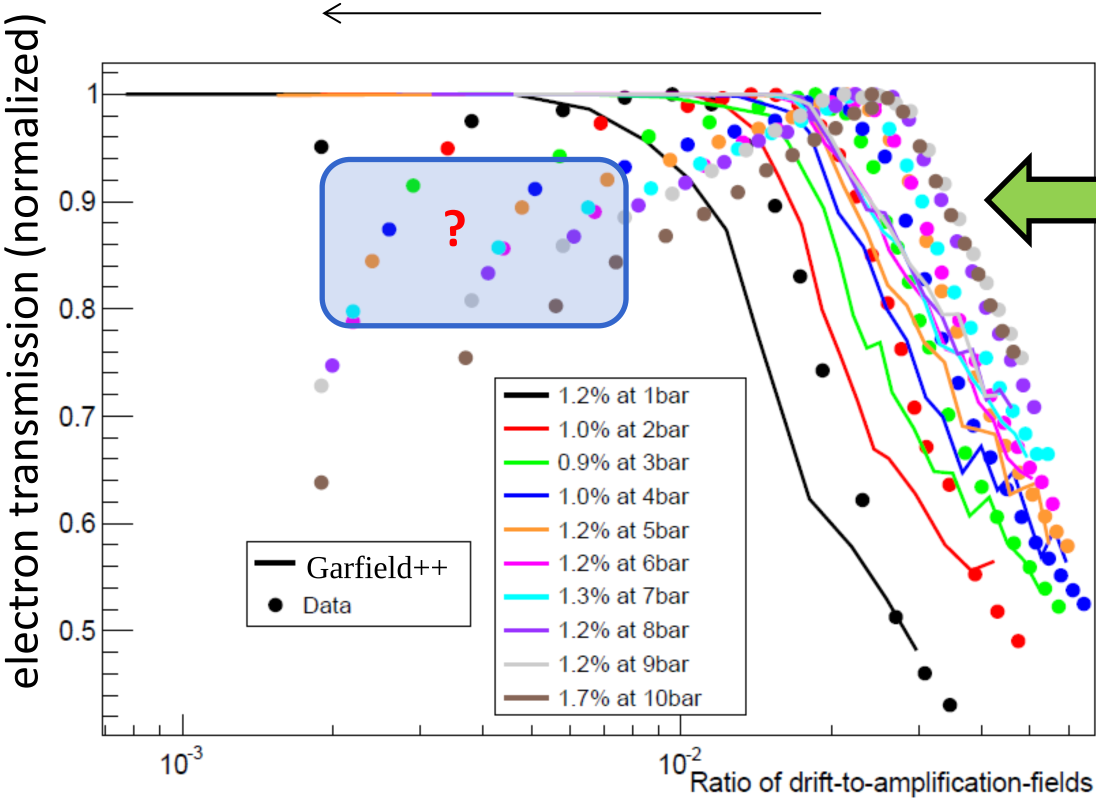
Penning transfer (ion dynamics)

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

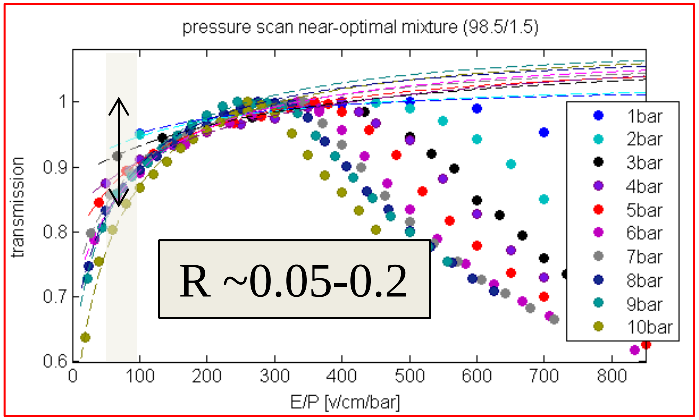
$$\frac{\sigma_{xe-TMA}}{\sigma_{xe}} \geq \sqrt{(1 - r) + R/F_{Xe}}$$

Behavior in the drift region (recombination)

~(1-R)



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

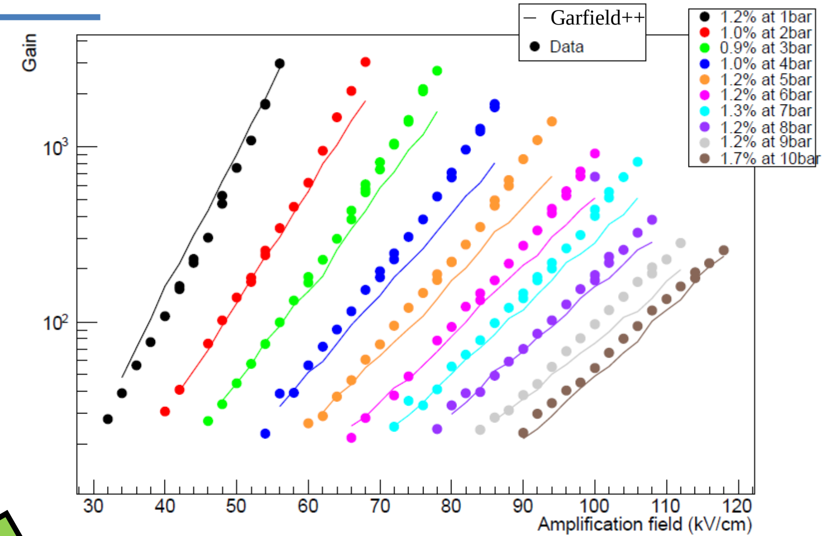


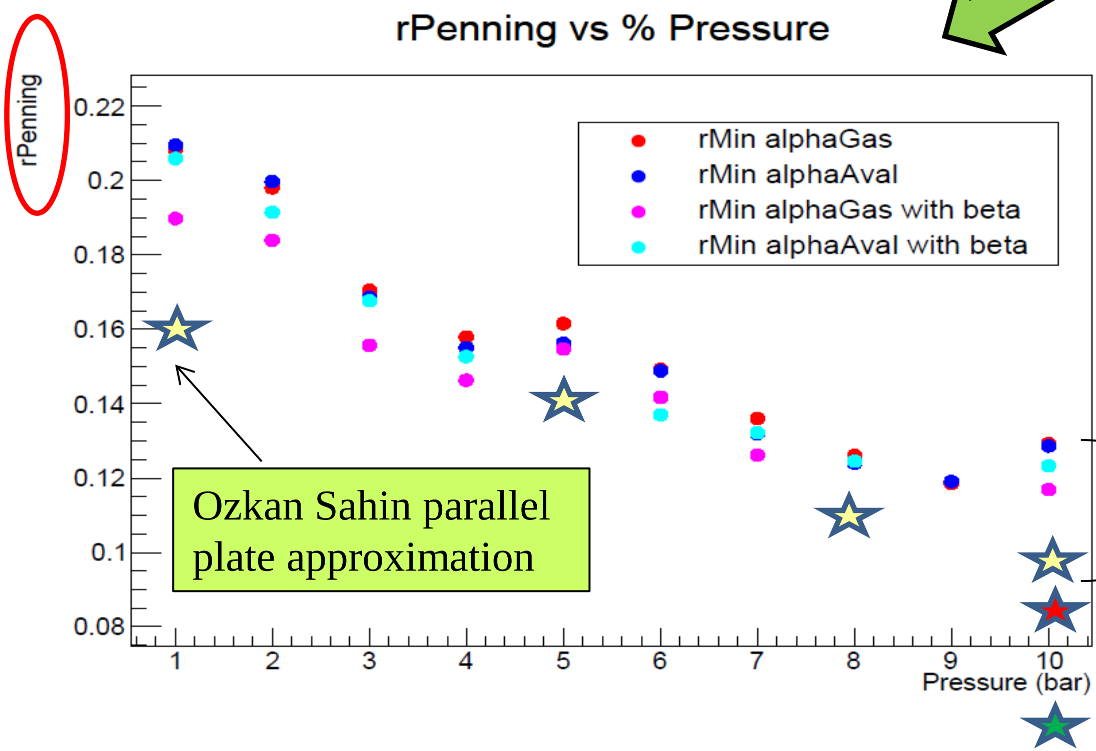
Region at low fields connected to recombination (see talk of D. C. Herrera at WG2).

Behaviour in the gain region (Penning)

reasonable description of gain curves if including Penning transfer!

r~0-0.2





Decreasing trend with pressure!

%TMA=1.5%

%TMA=3.8%

%TMA=0.4%

r~0-0.2

R ~0.05-0.2

Plenty of room for recombination compensating Penning at the drift fields (25-100V/cm/bar) and pressures (P~10bar) of interest ☹.

Was nature so unfair to us or are we missing something?

An experimental campaign with INGRID foreseen in order to answer the question through a direct measurement!.

Conclusions and outlook

1. NEXT-MM working **stable** (24/7) at 10bar, for 40 live days+, in a Xe/TMA mixture at 99/1. Virtually no experiment-shifts except for safety (pressure, high voltage, leaks). Loss of exposure due to instrument imperfections (damaged pixels, excursions, HV-trips) quantified to be **0.014%**.

2. Assigning the observed pixel damage (**4.5%**) to defects in the micro-fabrication of the sensor, it translates to a probability of a defect of **8ppm**. A further reduction can be envisaged, specially since part of the damage was certainly caused during sensor manipulation. *Higher pixelization will reduce the probability of pixel damage proportionally.* ***An inspiring option!.***

3. Energy resolution a bit shy of **$3\%Q_{\beta\beta}$**, a factor x2 far from the $1/\sqrt{E}$ scaling. Improved PSA and track-geometry studies will follow to clarify if the limitation comes from the drift region or the MM-sensor (recombination, finite threshold or calibration). It is unclear whether MM can contribute to the energy estimate coming from the EL region in NEXT, however it offers an unparalleled performance as a tracking plane.

4. NEXT-MM is probably **the best possible test-bed to date (?)** for topological studies of high energy e- tracks in low-diffusion Xenon-mixtures. There is a claim that this particular setup can increase the γ-suppression in at least a factor x3 as compared to pure Xenon [J. Phys. G: Nucl. Part. Phys. 40 125203], ***encouraging***!.

5. **Ongoing experimental and simulation efforts towards modelling** Xe-TMA mixtures in order to address the ultimate energy resolution for this Penning mixture (Penning, recombination, Fano). However, some (small) discrepancies with Magboltz existing at the moment.

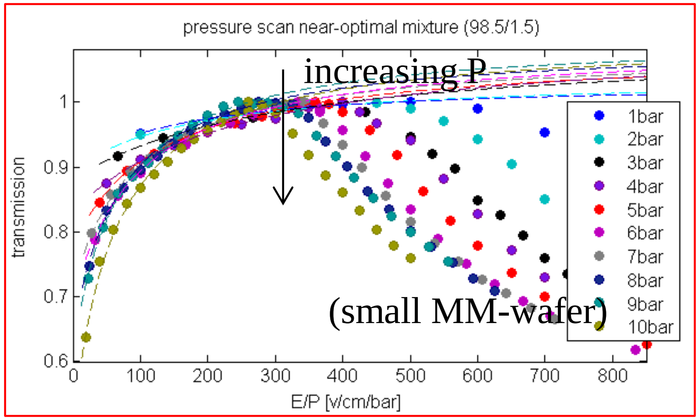
6. Light measurements (S_1, S_2) ongoing (LBNL, LIP-Coimbra).

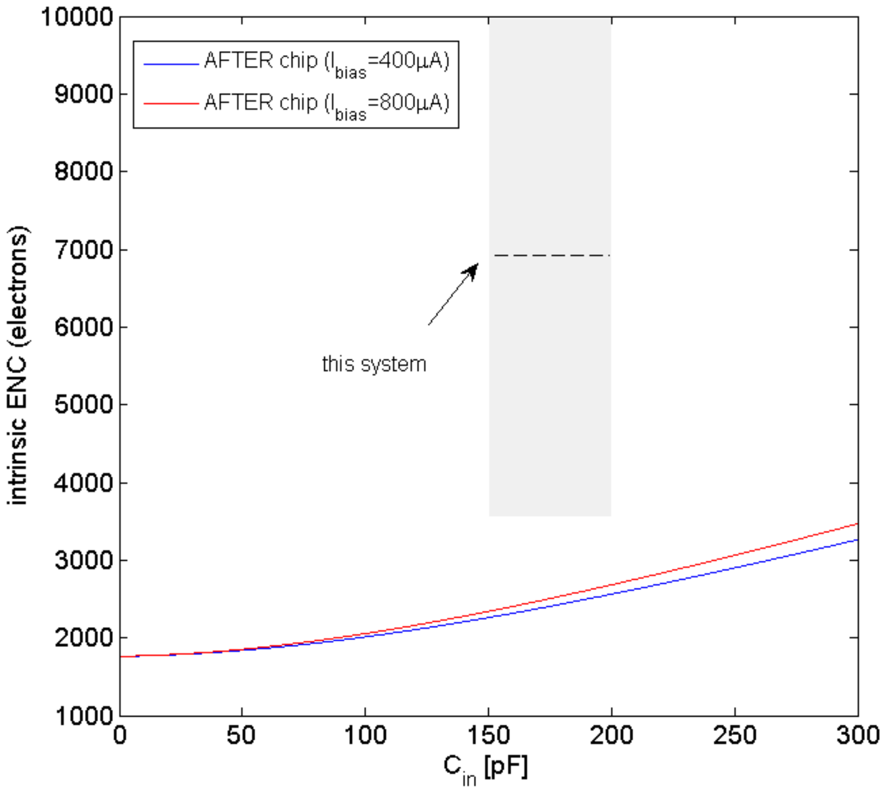
the Zaragoza group

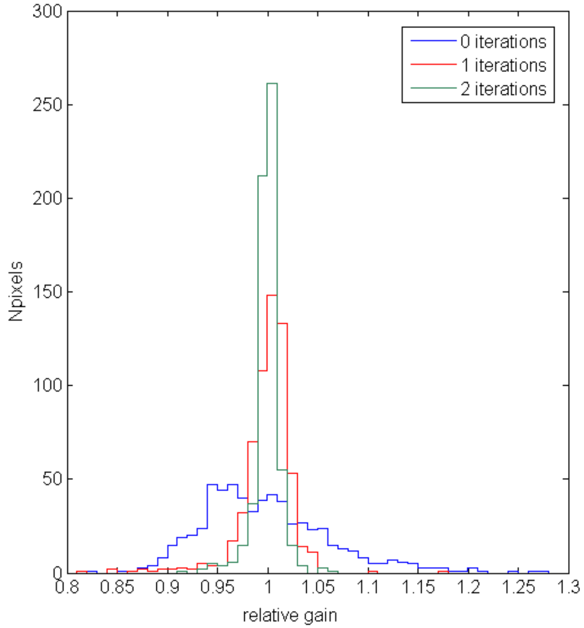
Theopisti Dafni
Igor Irastorza
Juan Antonio Garcia
Juan Castel
Angel Lagraba
Diego Gonzalez-Diaz
Francisco Iguaz
Gloria Luzon
Susana Cebrian
Elisa Choliz
Javier Gracia
Diana Carolina Herrera

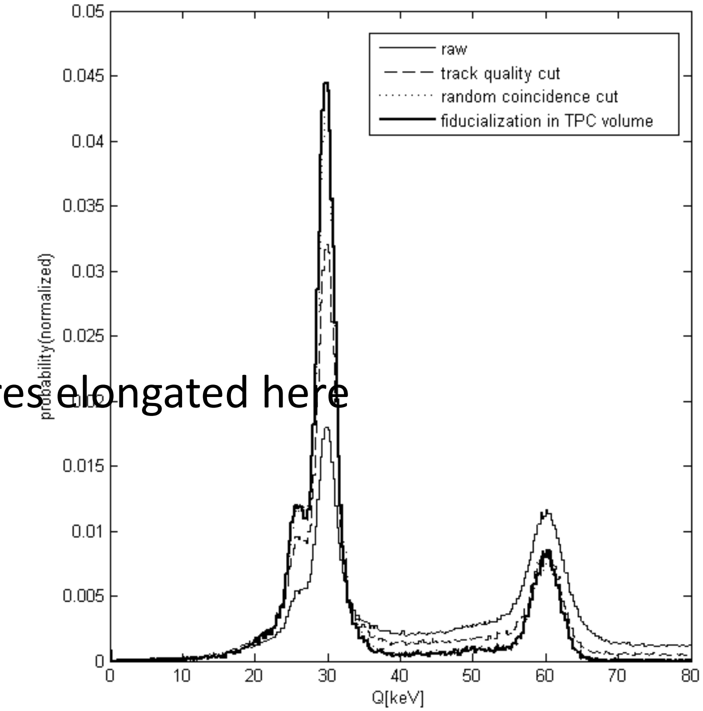
special thanks to Saclay-IRFU and to the CERN workshop

appendix

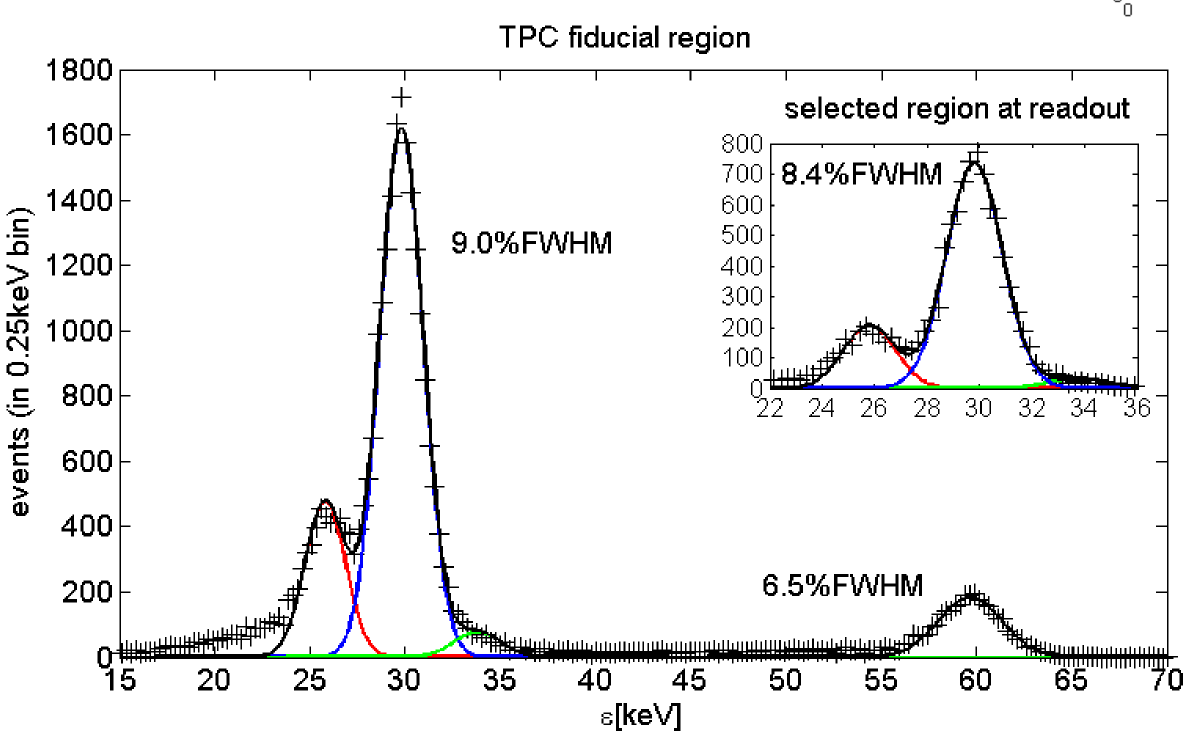

pressure scan near-optimal mixture (98.5/1.5)
increasing P
(small MM-wafer)
transmission
E/P [v/cm/bar]
1bar
2bar
3bar
4bar
5bar
6bar
7bar
8bar
9bar
10bar


AFTER chip (I_bias=400µA)
AFTER chip (I_bias=800µA)
this system
intrinsic ENC (electrons)
C_in [pF]



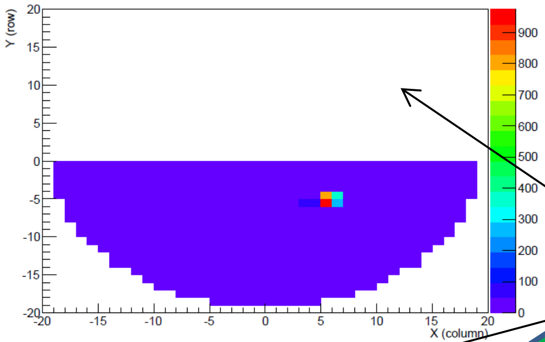


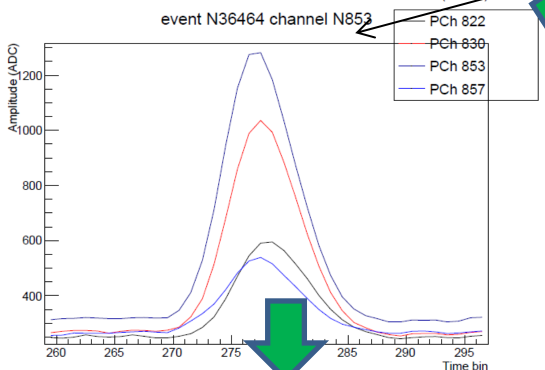
Make figures elongated here



Mixture: Xe-TMA (97.8/2.2)
Micromegas gain 2000
FEE ENC<0.12keV(95%ch):
FEE threshold: 0.5keV
Edrift=bla
P=1bla

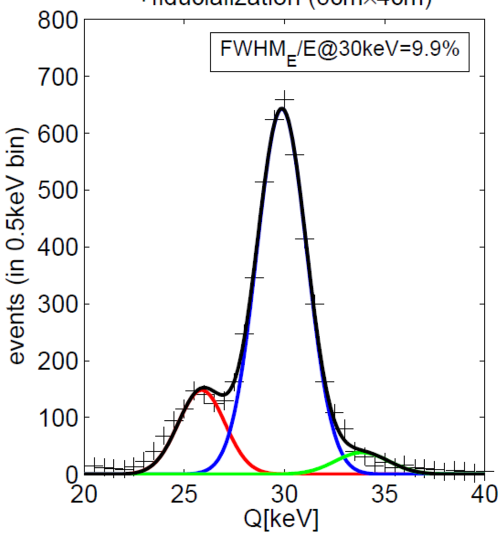
fully digitized pulses





energy resolution

+fiducialization (6cm×4cm)



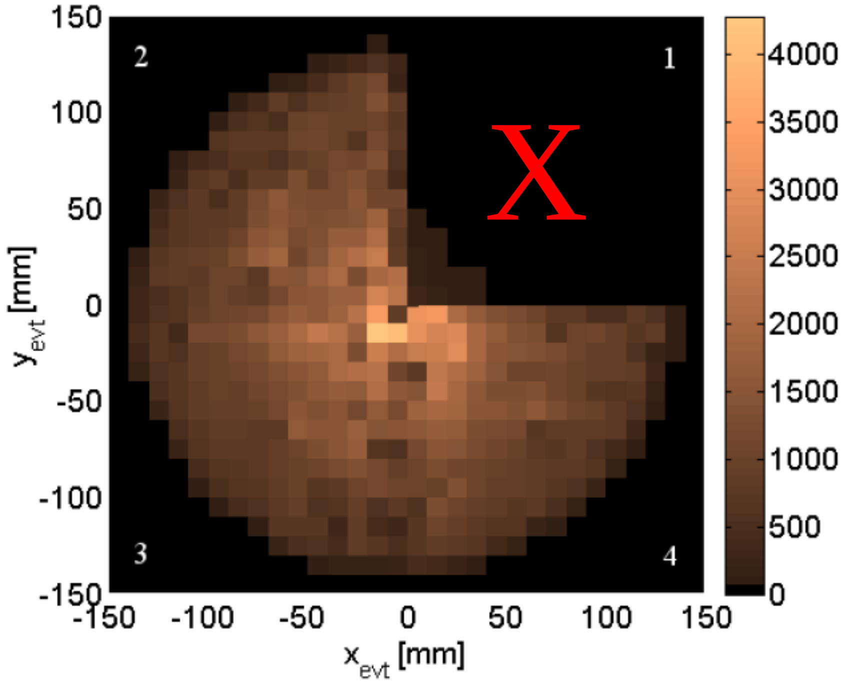
summary (reminder)

mixture: Xe/TMA (~98/2)

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

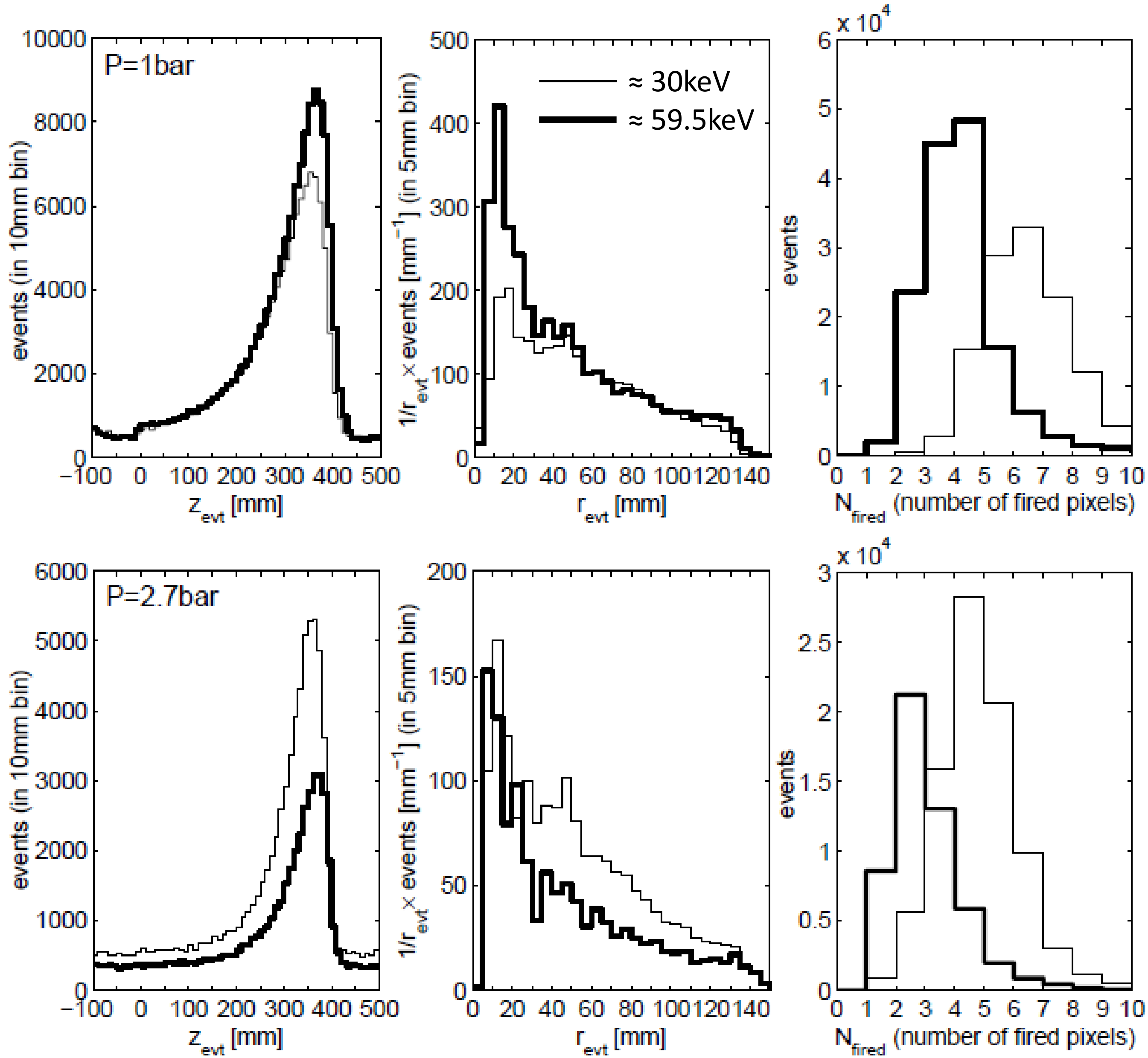
mean position of the event



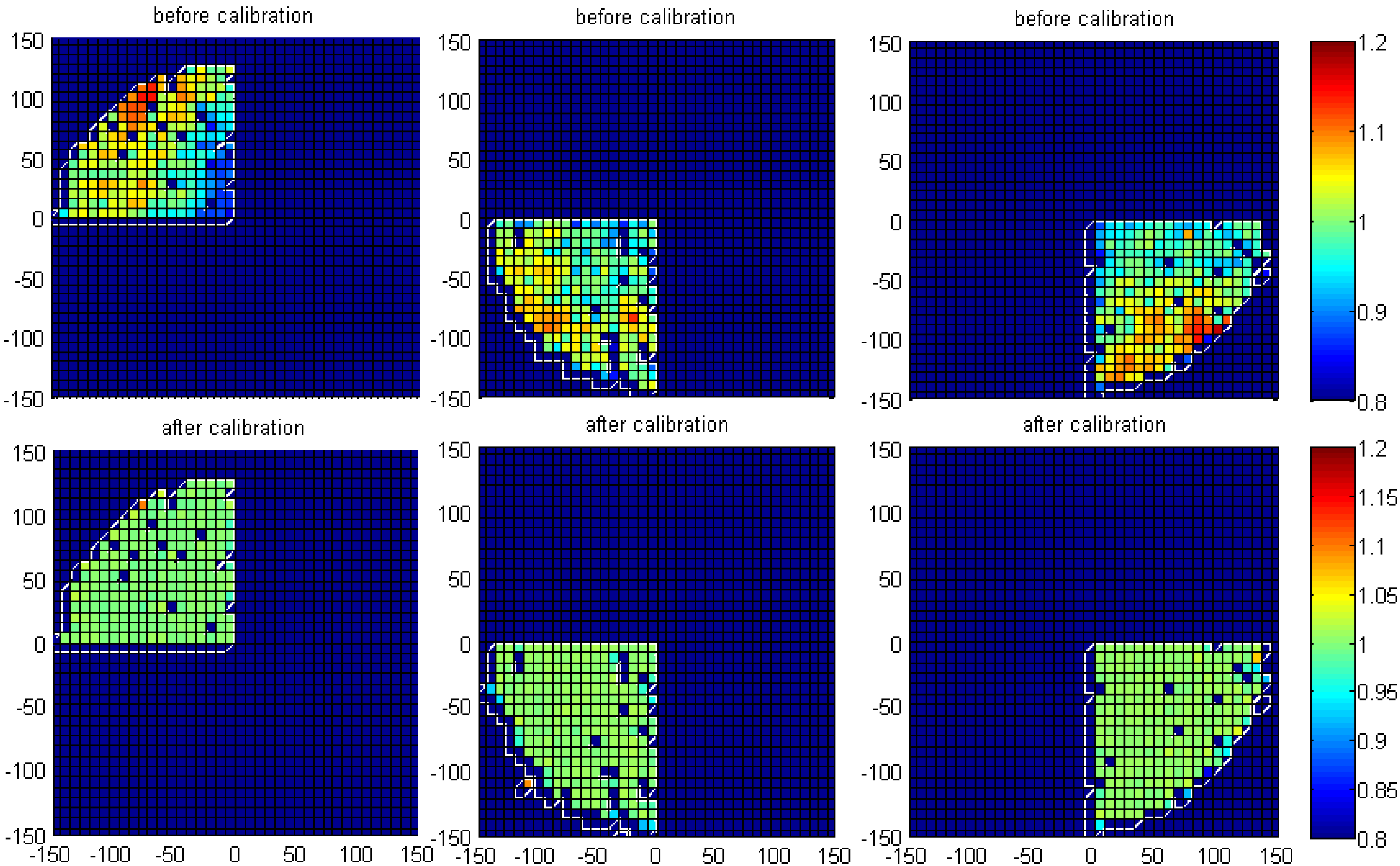
level of connectivity:	92%
unconnected pixels:	8%
of which	
unclear origin:	1%
understood(solvable):	5.2%
damaged pixels:	1.8%

sector 1 to be **damaged** (**repaired** for the 10bar-campaign)

main characteristics of low-energy X-ray deposits at 1-2.7bar

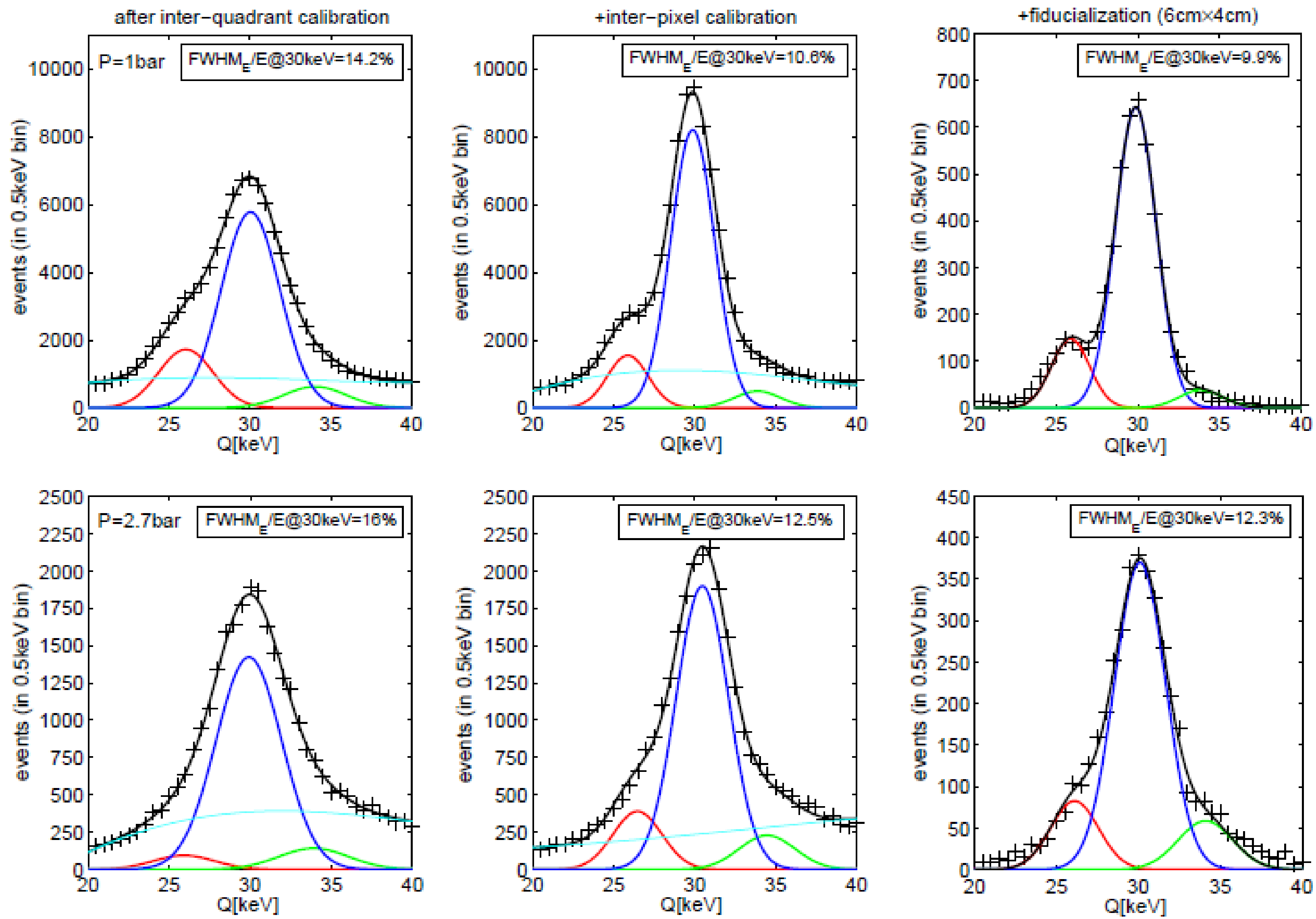


gain maps are necessary in order to achieve ultimate resolution

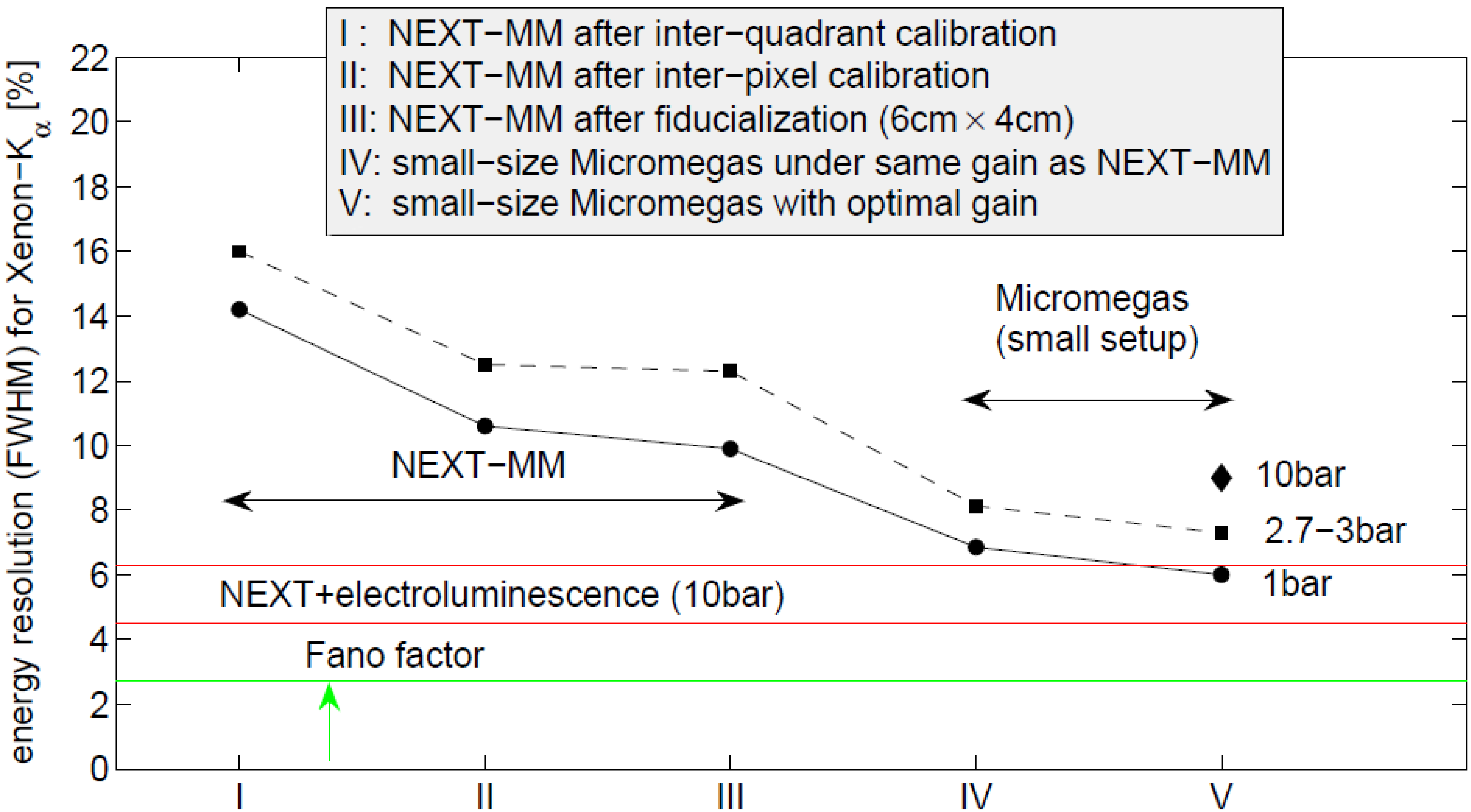


obtained by aligning the 30keV peak pixel by pixel

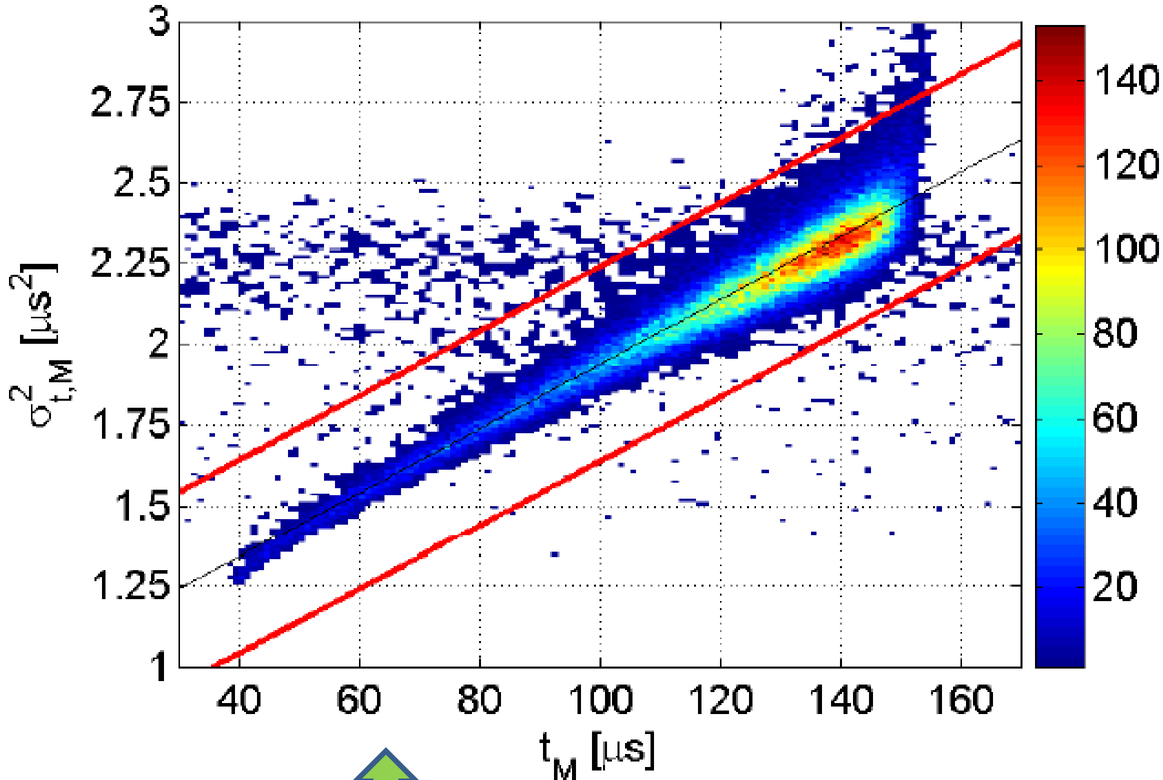
main performance with low energy X-rays in the 1-2.7bar regime

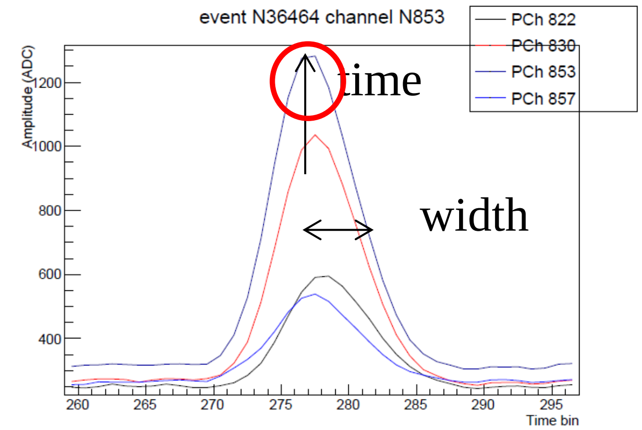


half-way performance cross-comparison (with a grain of salt)



time-width pulse correlations through drift & longitudinal diffusion



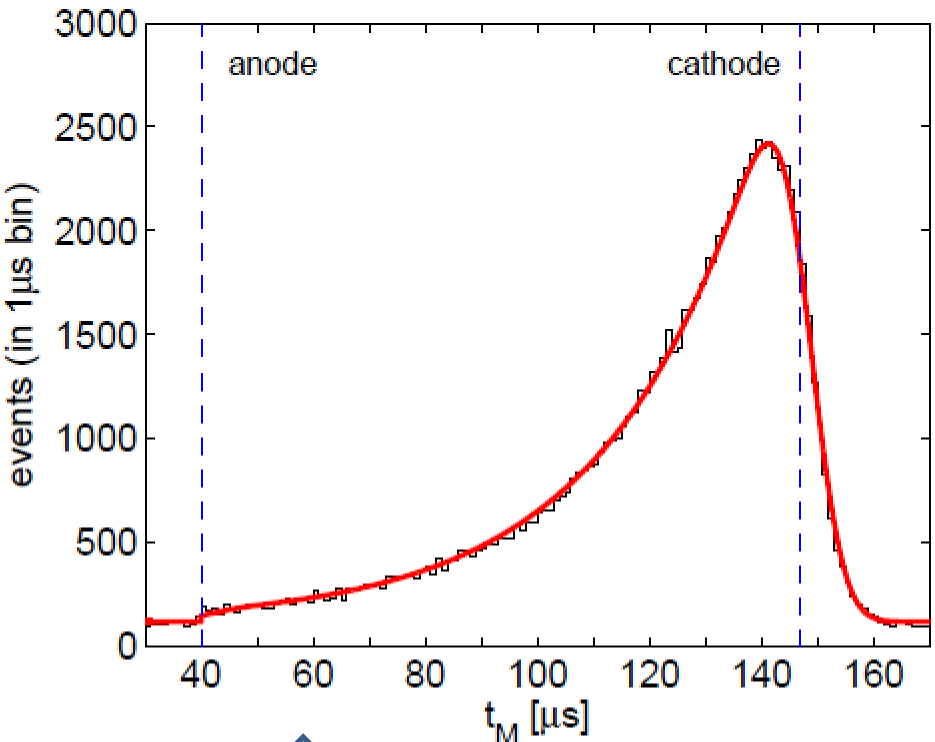


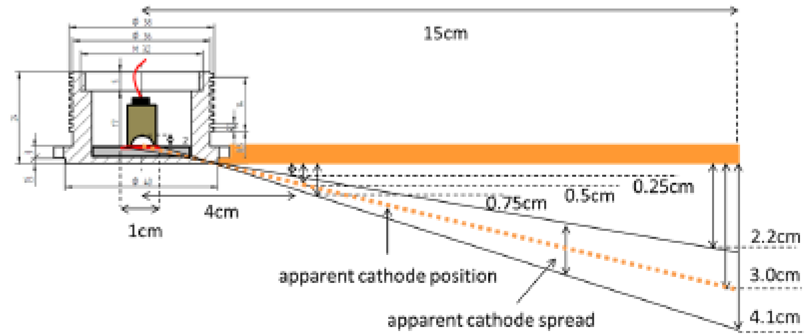
- Select **30keV events**.
- Take pulse with highest charge.
- Take a fiducial distance of 2.5cm with respect to the chamber edge

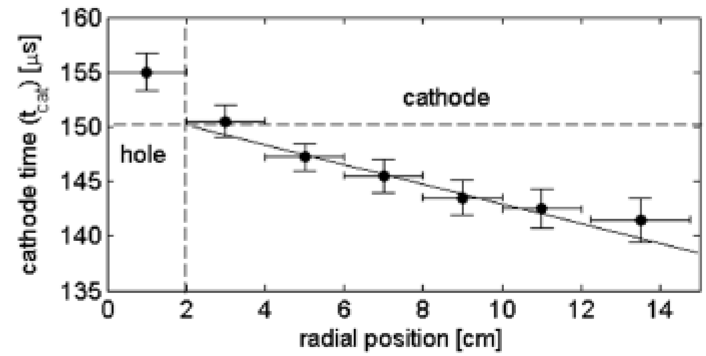
$$\sigma^2_{t,M} = \sigma^2_0 + \frac{2D_L}{v_d^2} t_M$$

electronics response function + size of ionization cloud (+ ion transit time) determining the total drift time (and hence the drift velocity)

(sharp) (smeared due to extended source)





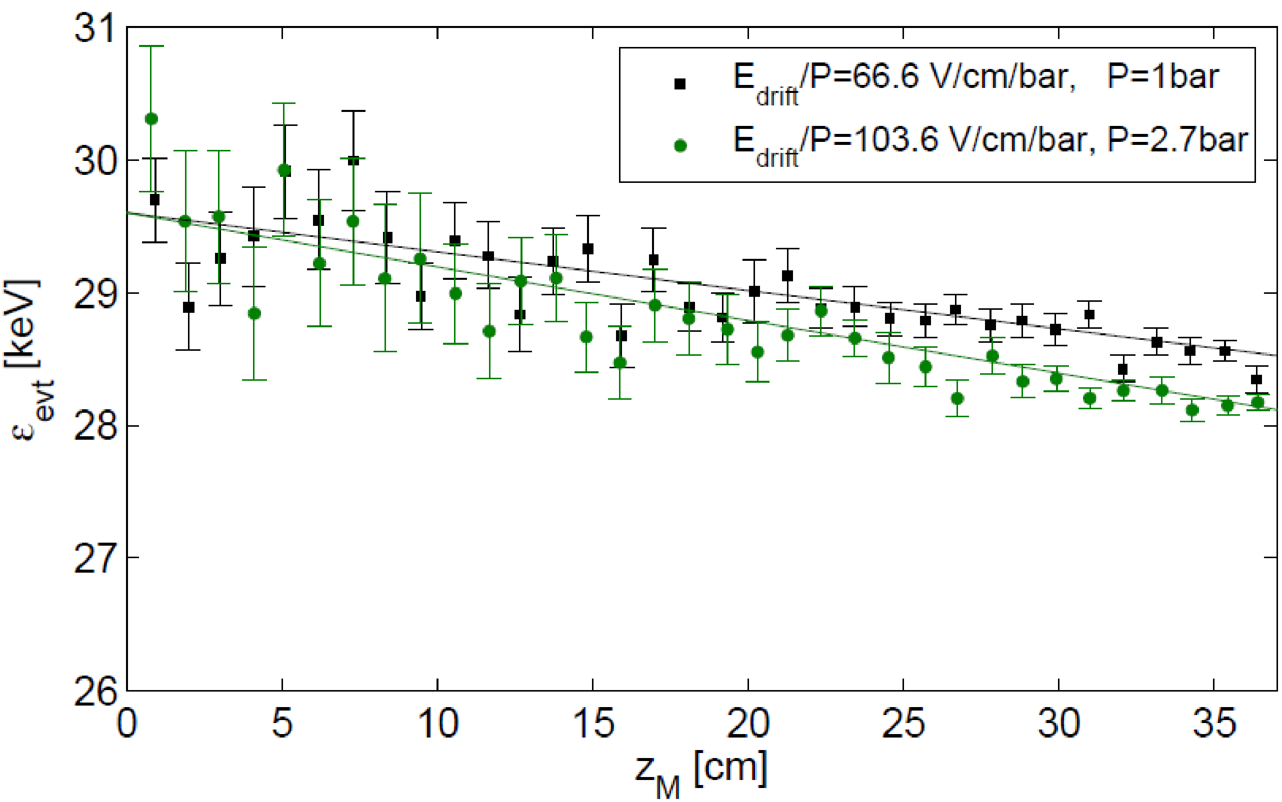


operational fit to exponential convoluted with Gauss

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

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

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

new hardware

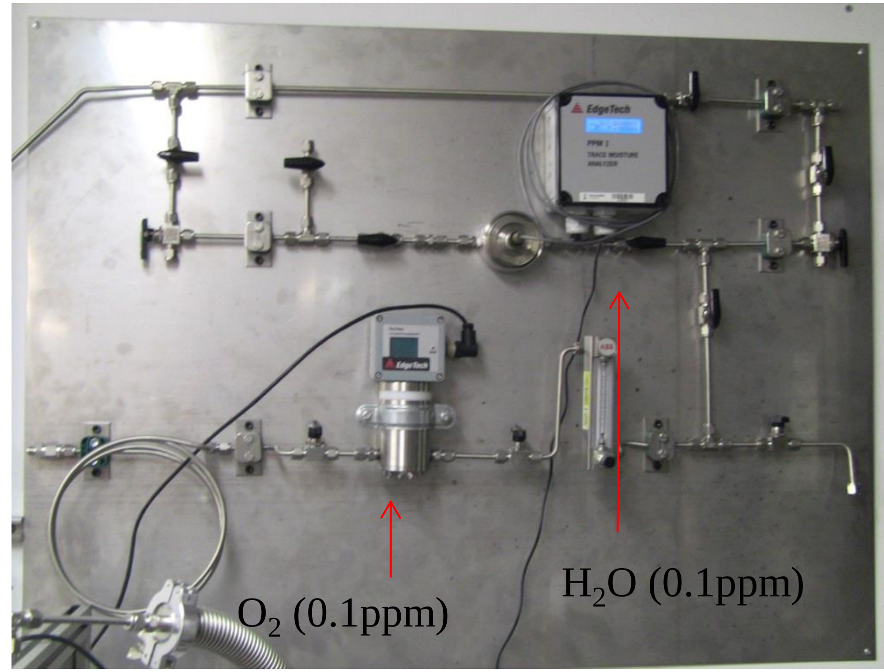
new bottles and piping

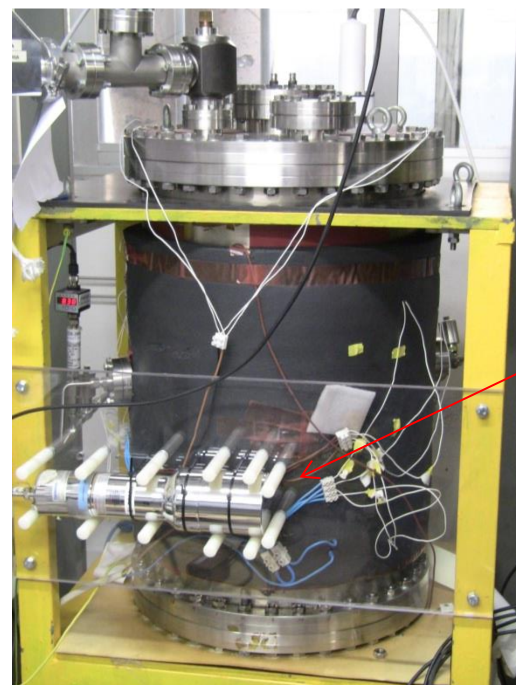
TREX-light (pure Xenon line)

NEXT-MM recovery bottle

NEXT-MM expansion chamber

sensor panel





NaI detector and Na source