Operation of a 10bar/1kg Penning-Fluorescent Xenon TPC:

x- and γ-ray reconstruction in charge mode.

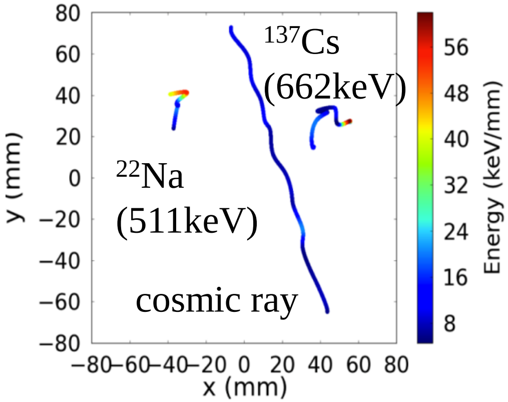
Diego Gonzalez Diaz

for the NEXT collaboration

11/12/2014

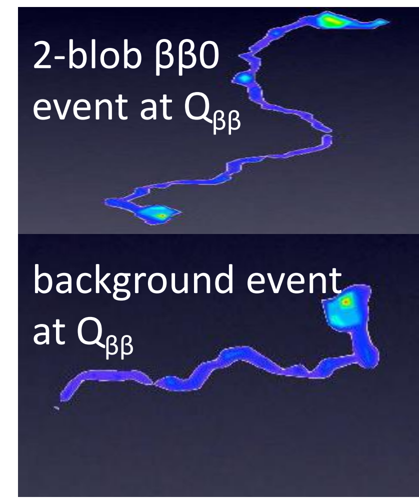
Conceived to simultaneously optimize energy resolution and tracking (specifically: double-blob recognition) for ββ0 reconstruction

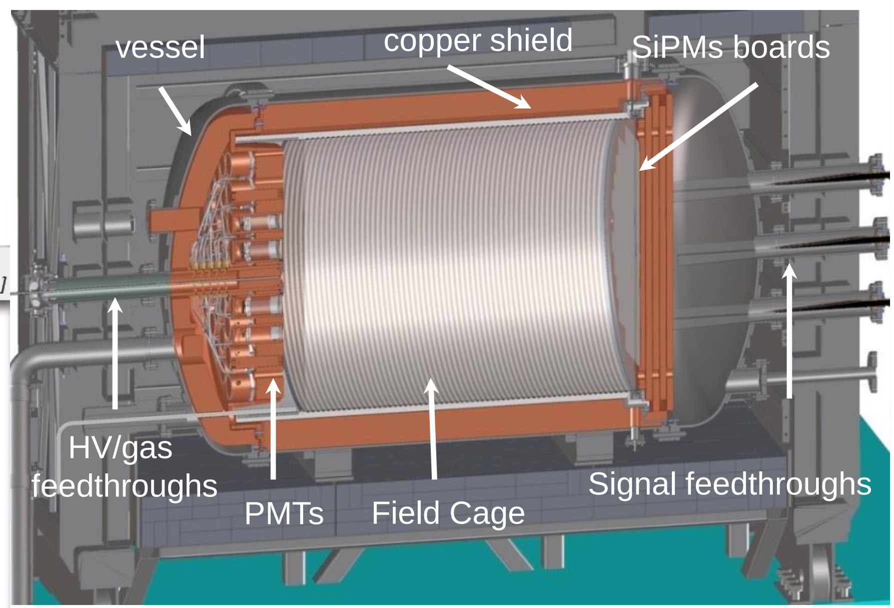
Neutrino Experiment with a Xenon TPC

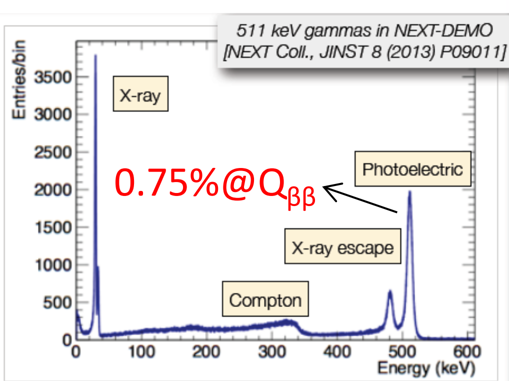


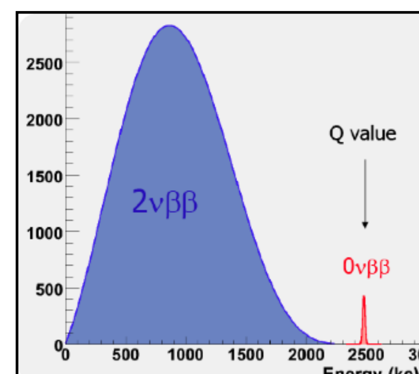
ββ0ν (100 meV)

(2016-2020)









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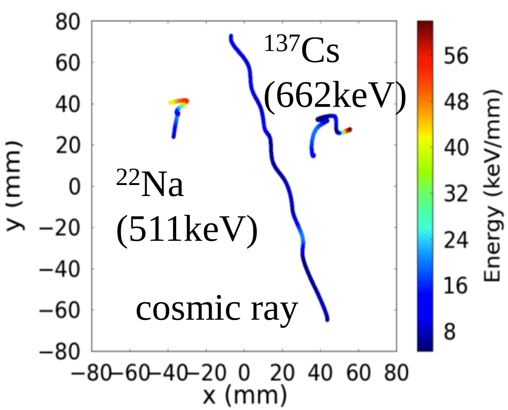
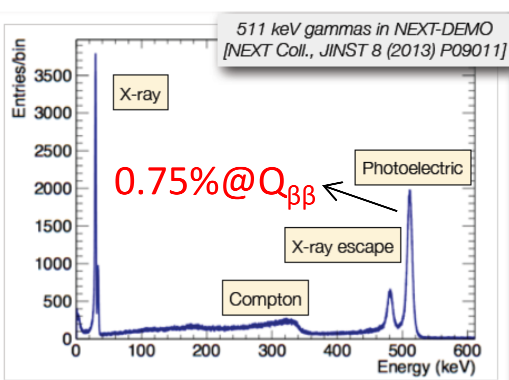
Neutrino Experiment with a Xenon TPC

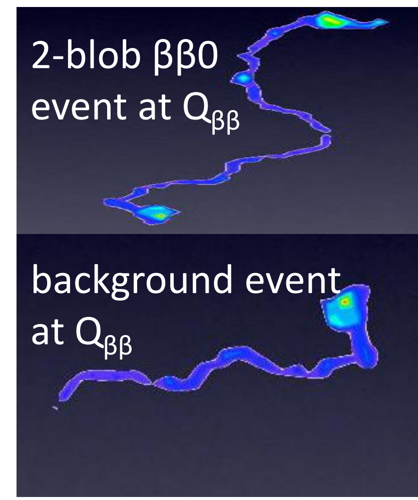


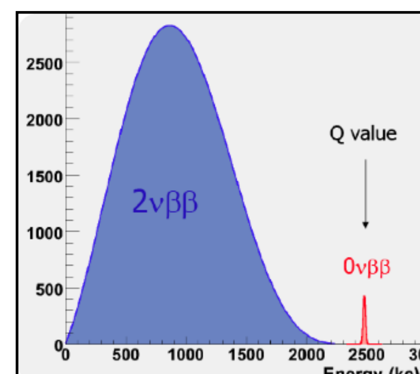
ββ0ν (20 meV)

(2020?)

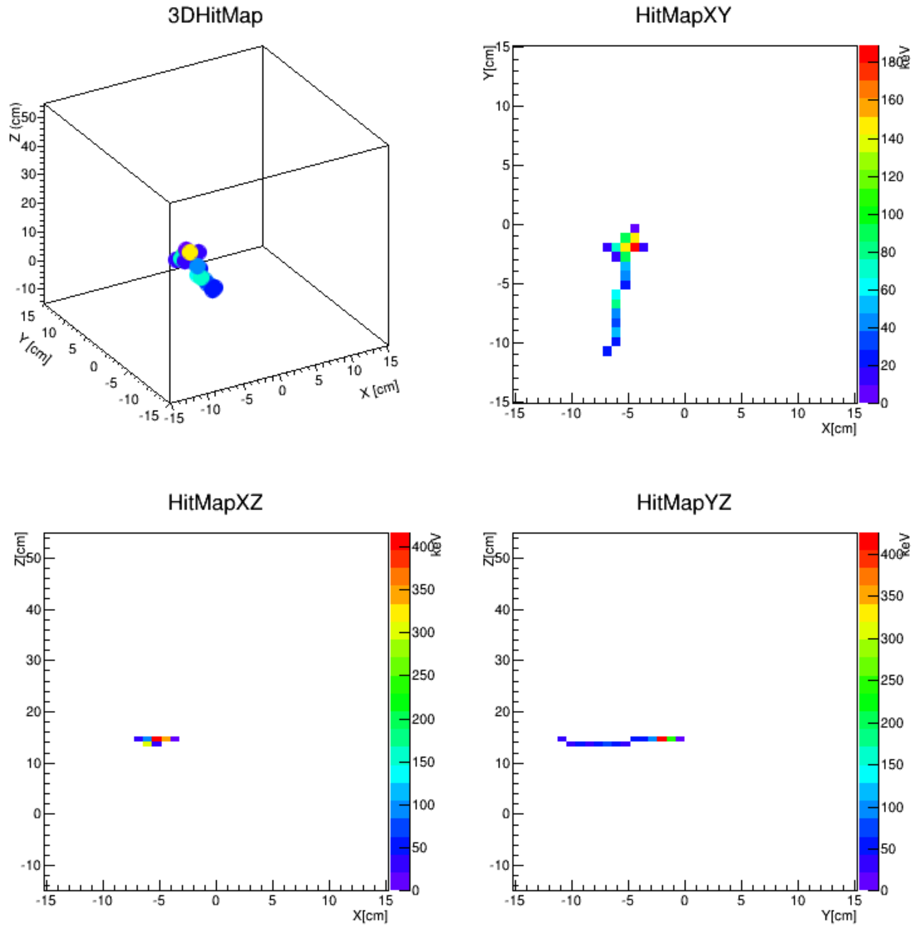


- Scale-up the concept, in principle possible.
- Optimize the gas mixture to boost topological information and/or energy resolution?.
- More exotic: Ba-Ta, B-field, others?.





this is how typical electrons with energy $\varepsilon = Q_{bb0}/2 \sim 1.25$MeV look like in 10bar Xe

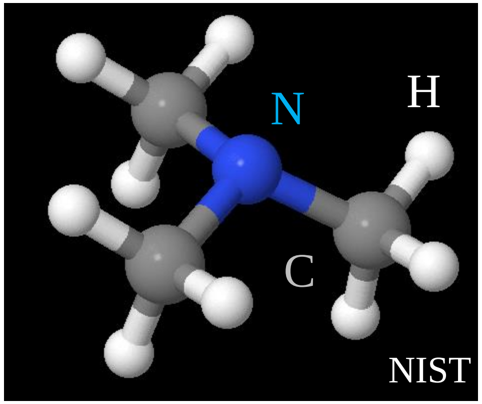


This is **not** a simulation!

TMA

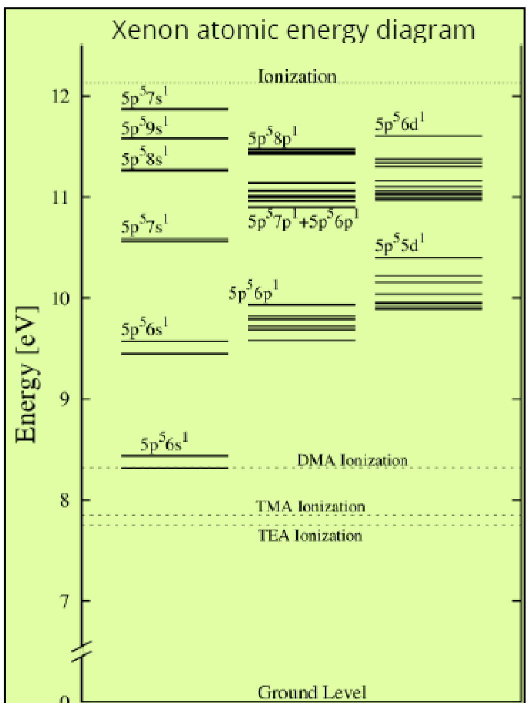
A family of mixtures with potential in ββ0-searches: ‘Penning-Fluorescent mixtures’

(Dave Nygren)



Trimethylamine (TMA)

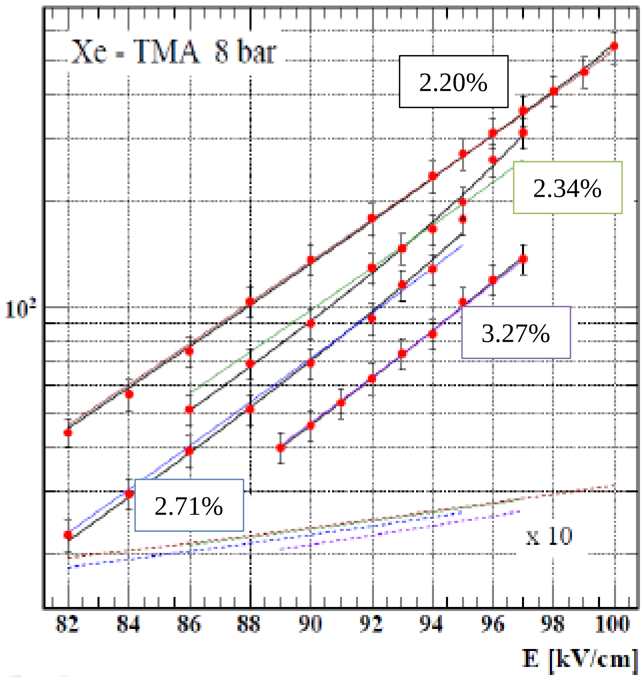
(the most readily usable at HP in virtue of its relatively high v.p.)

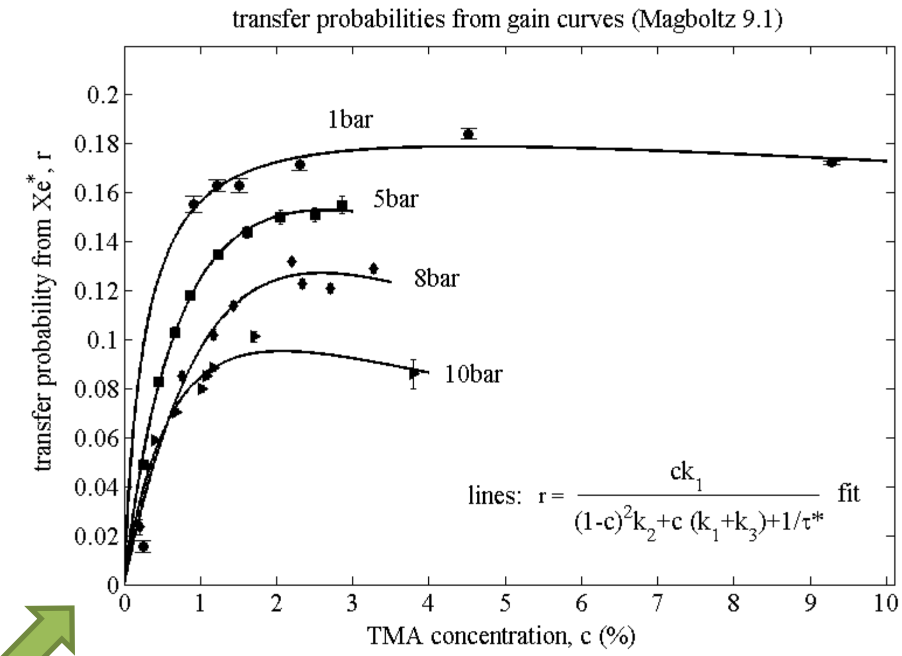


1. Suitable for Penning transfer. Can potentially reduce Fano factor.
2. Strongly fluorescent with large Stokes shift.
3. Able to reduce electron diffusion in gas.
4. UV-quencher, facilitates the imaging of the e- cloud.
5. May allow for EL due to low-lying TMA excited states.

Penning transfer rate in Xe-TMA

from Magboltz modeling (PPC approximation)





simplified 'toy-model'

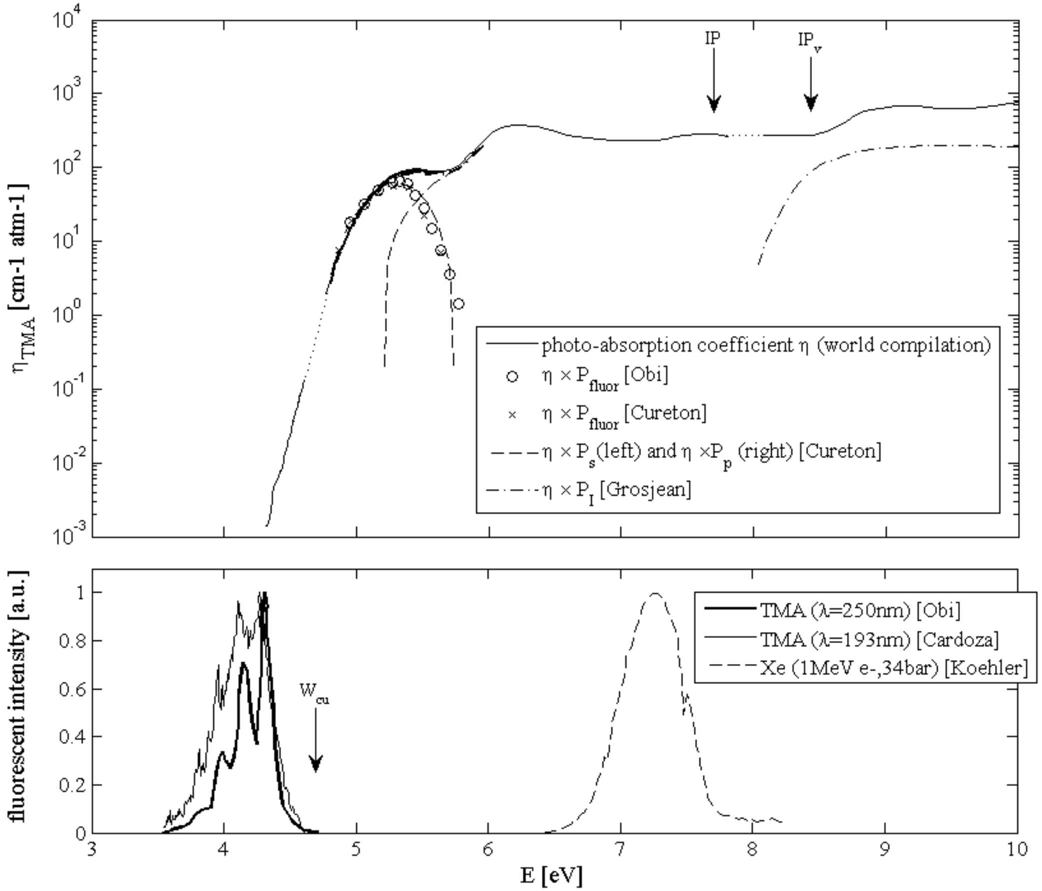
$$r = \frac{c k_1}{(1-c)^2 k_2 + c\,(k_1 + k_3) + \frac{1}{\tau^*}}$$

- k_1: Penning transfer rate (~P)
- k_2: Excimer formation rate (~P^2)
- k_3: quenching rate (~P)
- τ^*: effective life-time

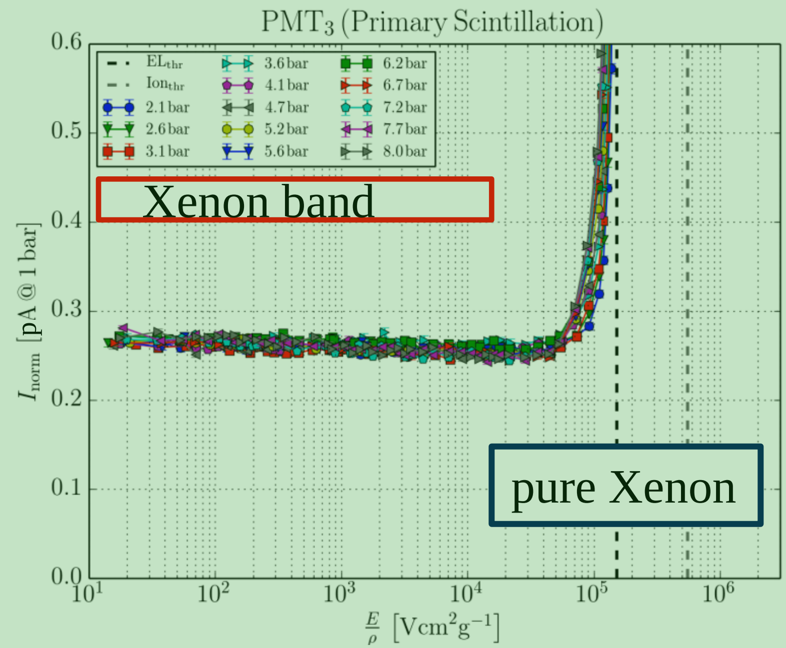
- Non-trivial decrease with P can be reproduced by the fit.
- Natural explanation in that Penning transfer from excimers disfavored due to energetic considerations ($E<IP_v$).
- Two-body collisions effectively represent a quenching channel for Penning transfer!!.

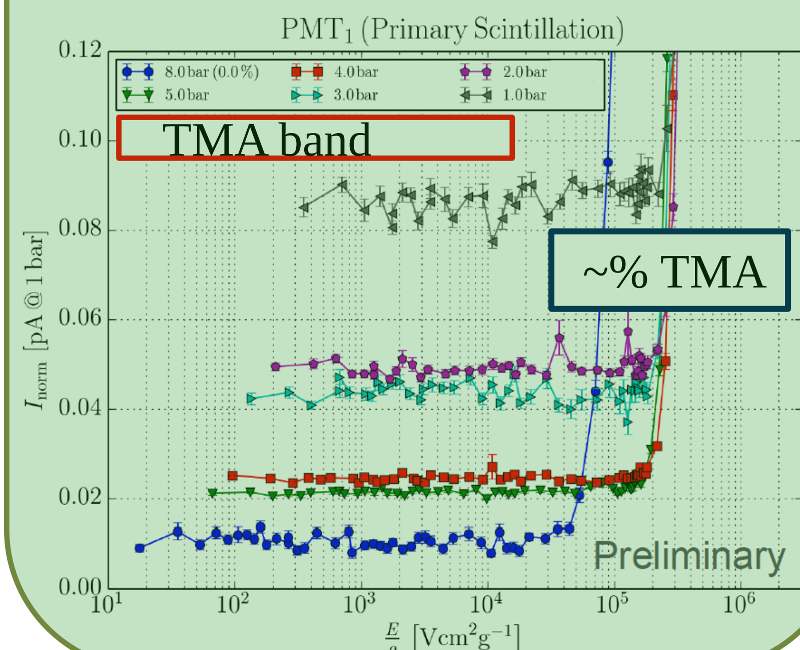
with O. Sahin, R. Veenhof (CERN-Bursa group)

primary scintillation light in Xe-TMA mixtures



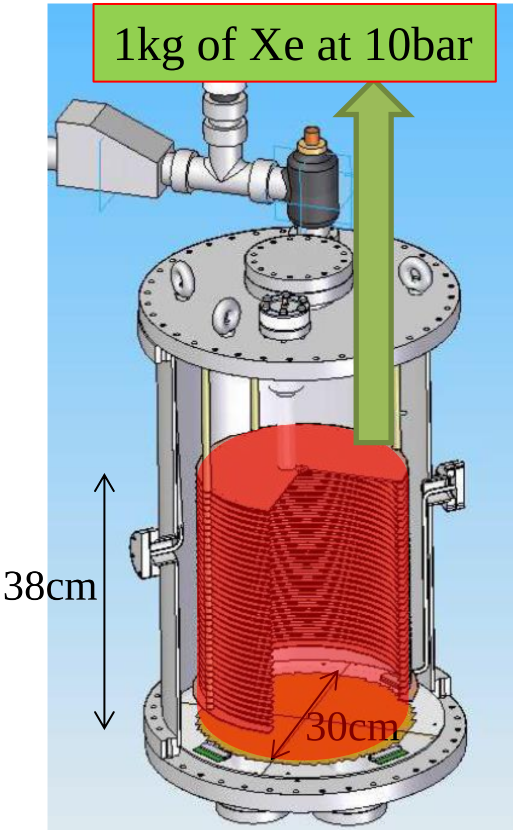
primary light (S_1)

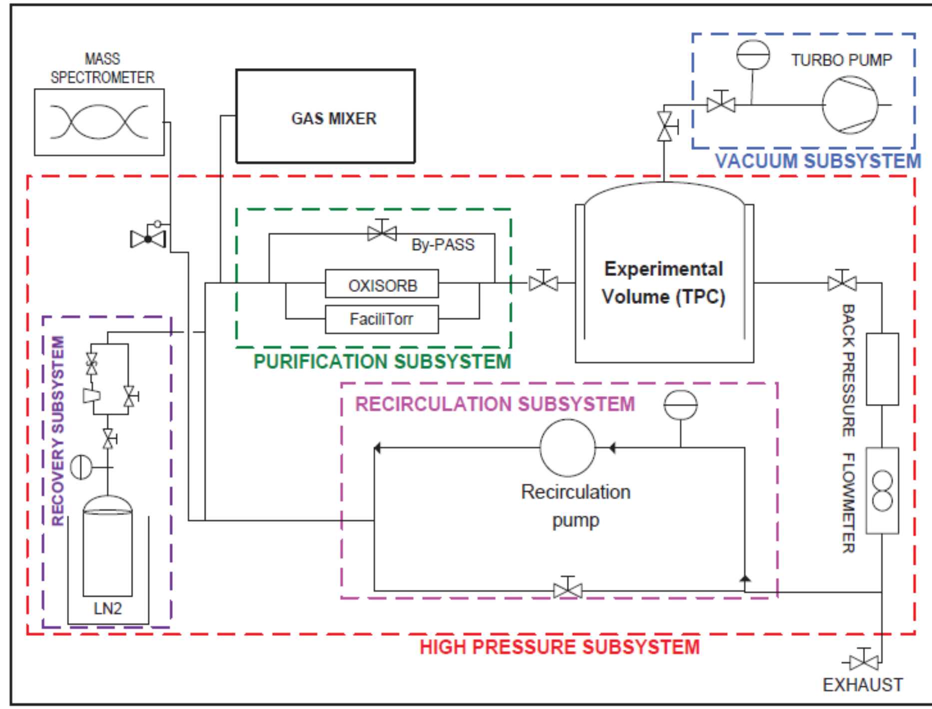


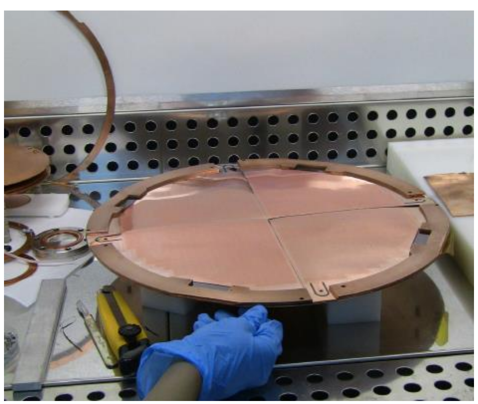


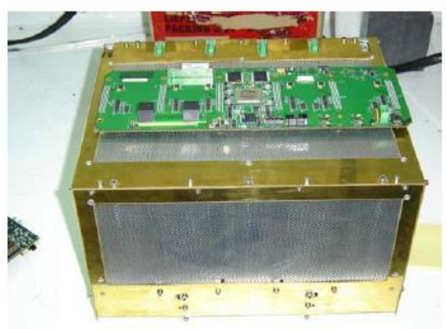
C. Oliveira, A. Goldschmidt, Y. Nakajima et al (LBL group)

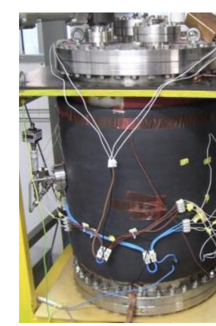
MM+TPC







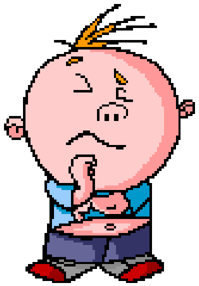


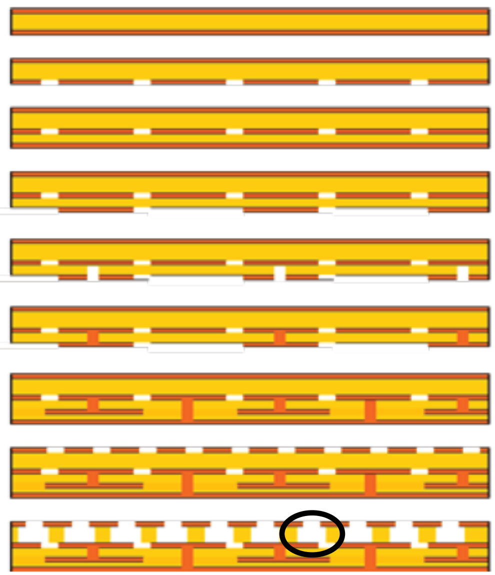


details in:

JINST 9(2014)P03010, JINST 9(2014)C04015

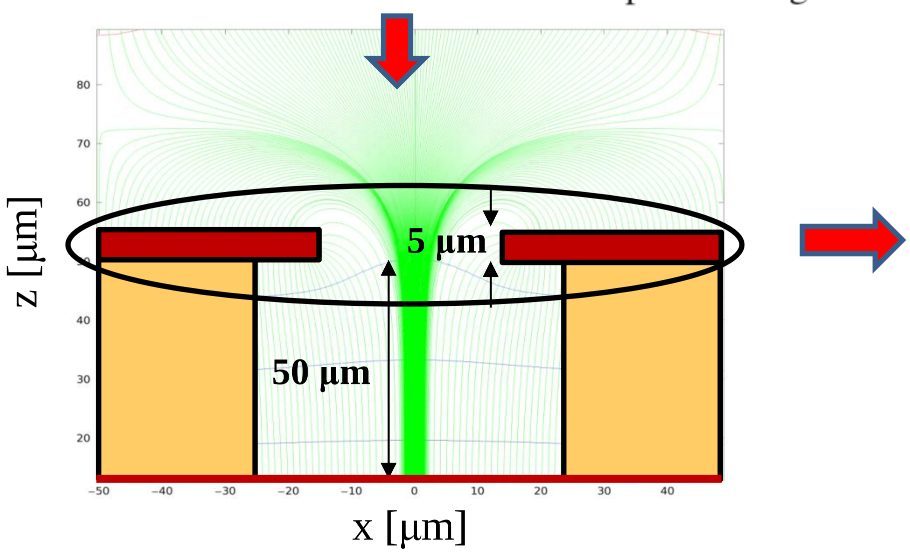
micro-pattern hole-amplification structure
(‘microbulk MicroMegas’)

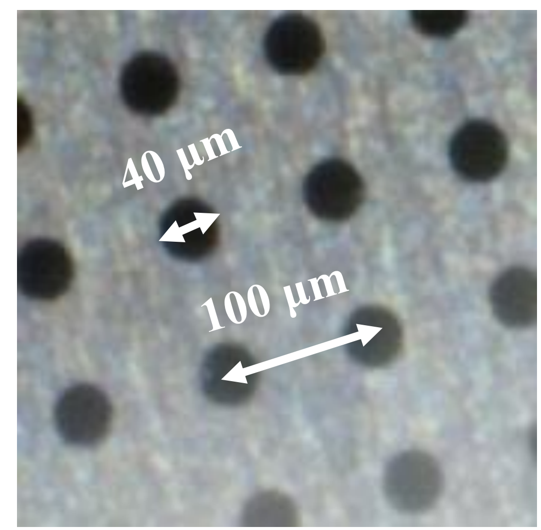




CERN workshop:
Rui de Oliveira et al

JINST 5(2010)P12001

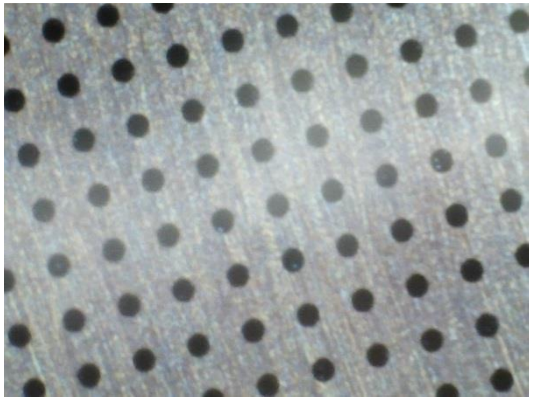




(highly radiopure: <30 μBq/cm^2 for ^{235}U, ^{238}U, ^{232}Th chains)

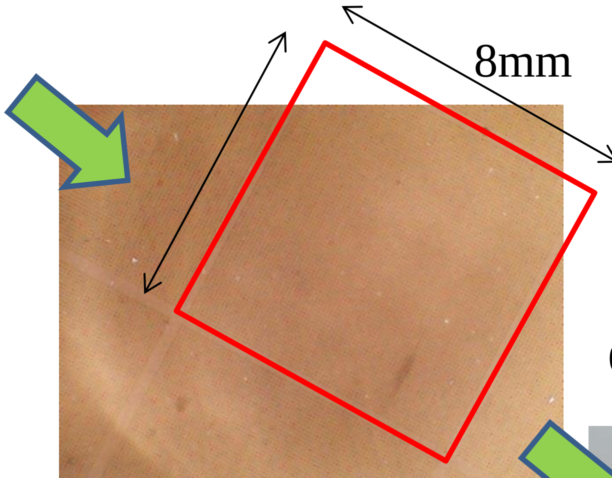
Astropart.Phys. 34 (2011) 354-359

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

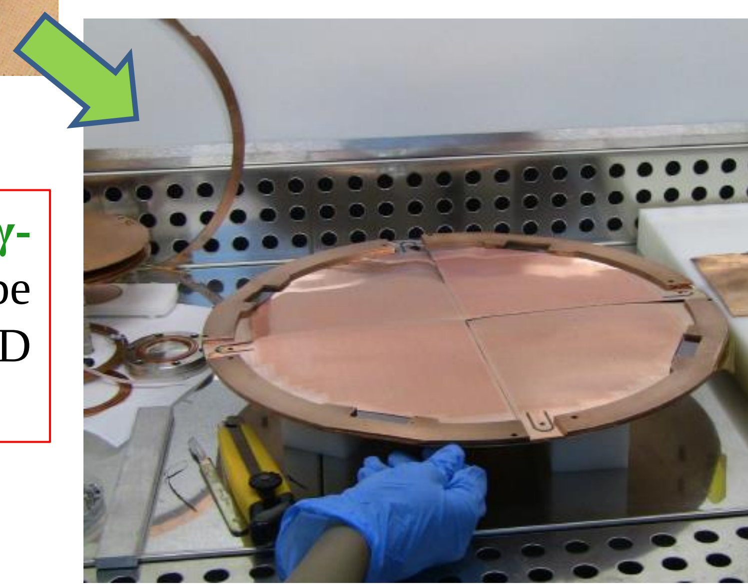


~100 holes

5900 holes/pixel



6796800 holes, 1152 pixels, 700cm^2



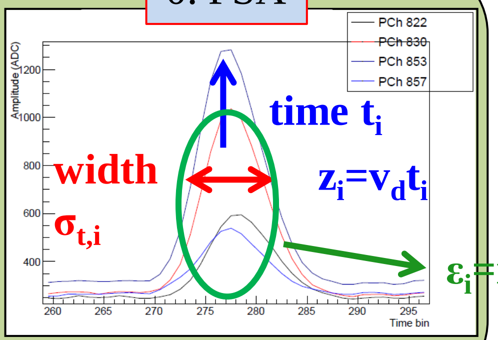
Would the technology allow extending to **m^2** and **γ-tracks** the excellent energy resolution that can be achieved under localized x-ray irradiation in R&D setups (~1%$Q_{\beta\beta,Xe}$ (extrap.)) ? JINST 8(2013)P01012

calibration and analysis strategy

procedure analogous to:
JINST 9(2014)C04015

based on Gaussian fits

0. PSA



typical x-ray event

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

start-time obtained from coincidence with ancillary detector

1. Calibration

(*on ~20keV<ε<~40keV isolated charge deposits*)

1. Determination of v_d and D_L.
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. Event energy in expected range.

3. Suppression of random coincidences

Impose a physical criteria (longitudinal diffusion) for the correlation between signal width and drift distance.

4. XYZ-fiducialization

Cut out external 2cm in z and R.

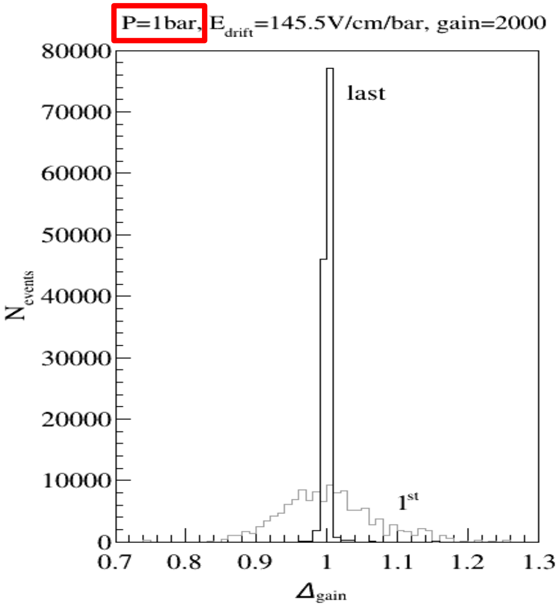
x-rays

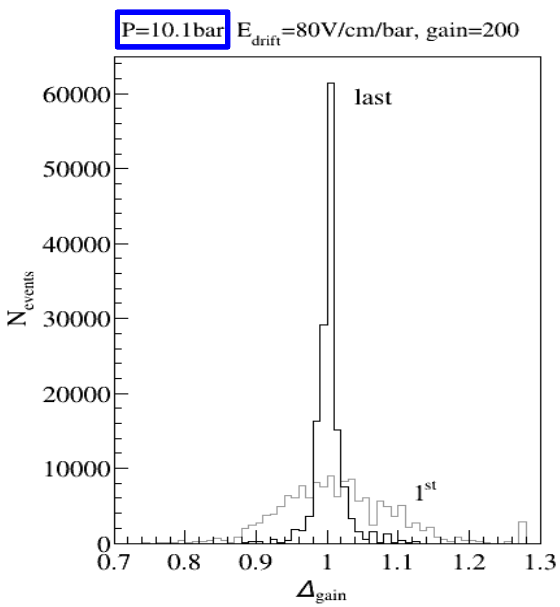
energy resolution for x-rays in the **30keV** region after calibration

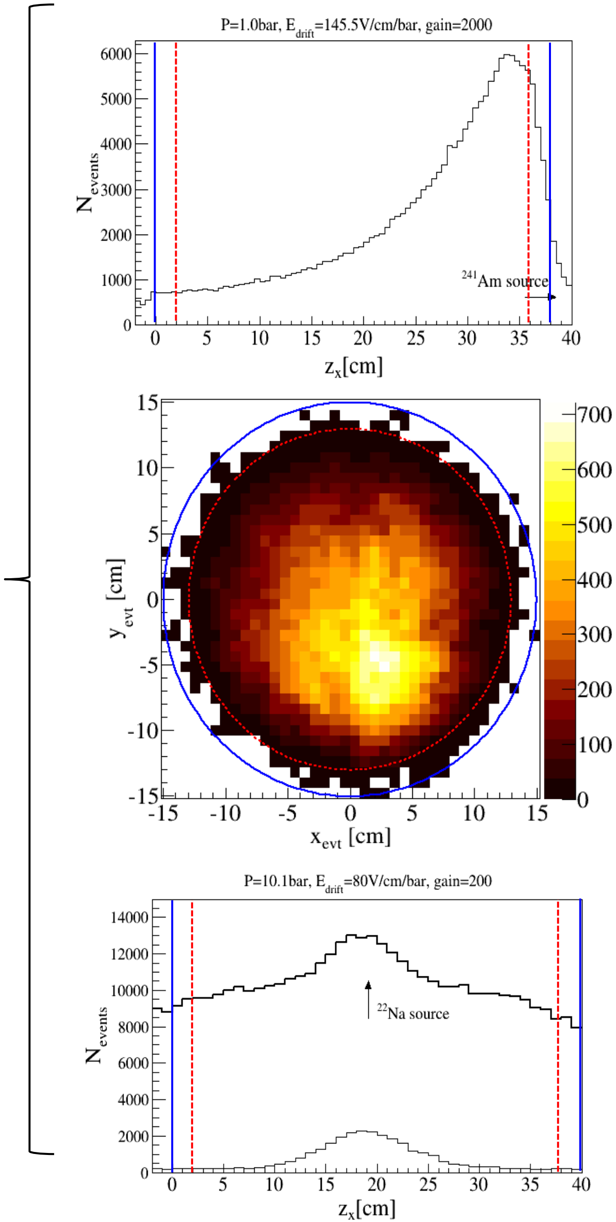
0-1.PSA+calibration

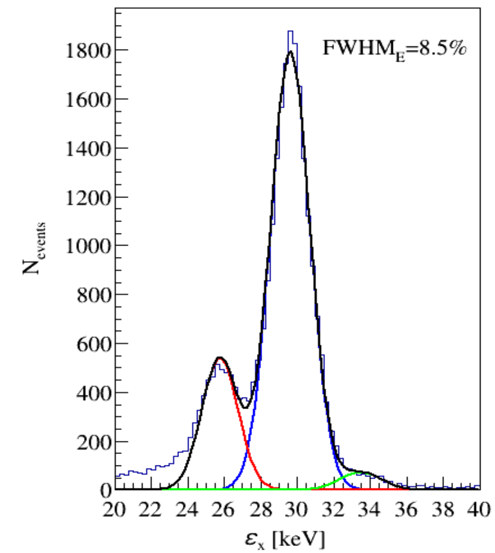
2-4. Track QC + suppress. random coinc. + fiducialization

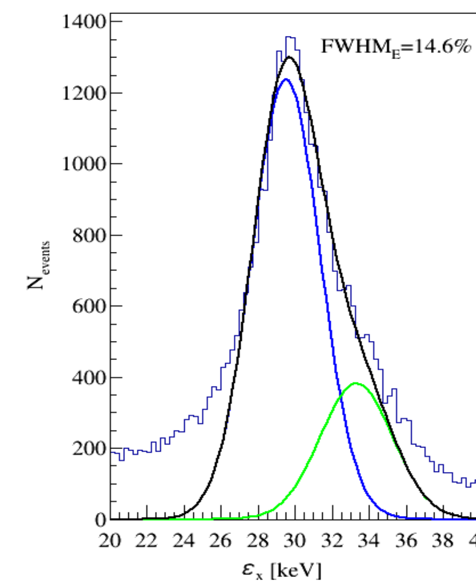
Final result (for isolated x-rays)



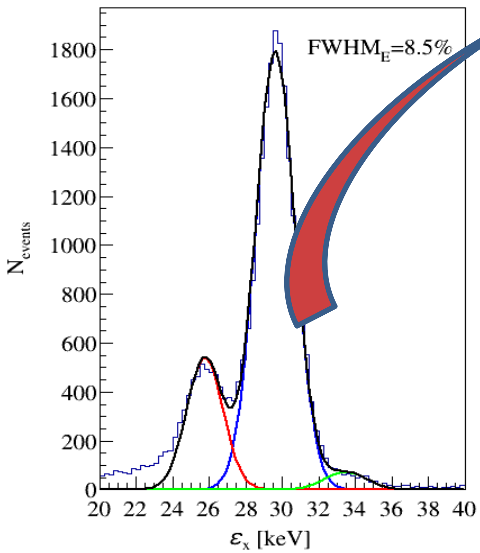


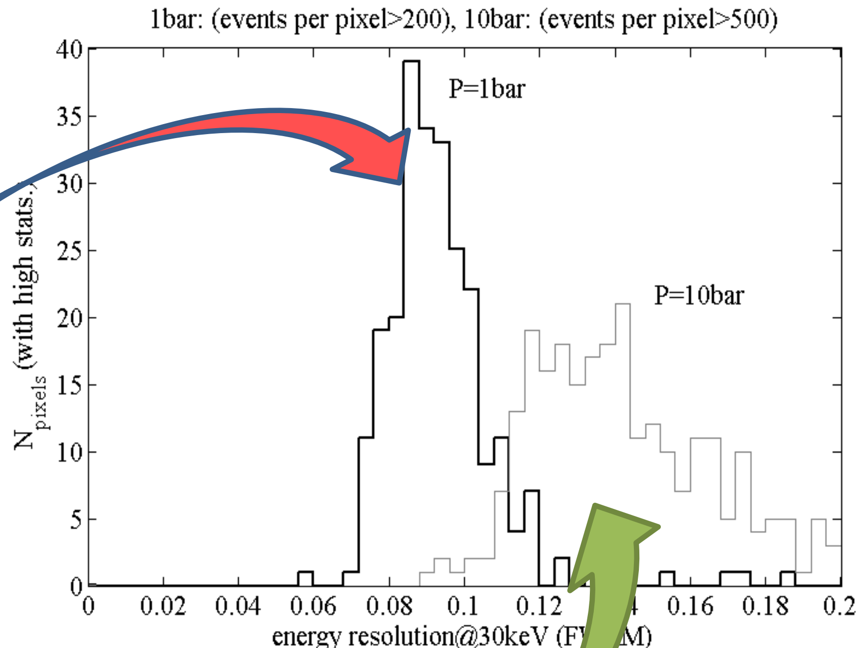




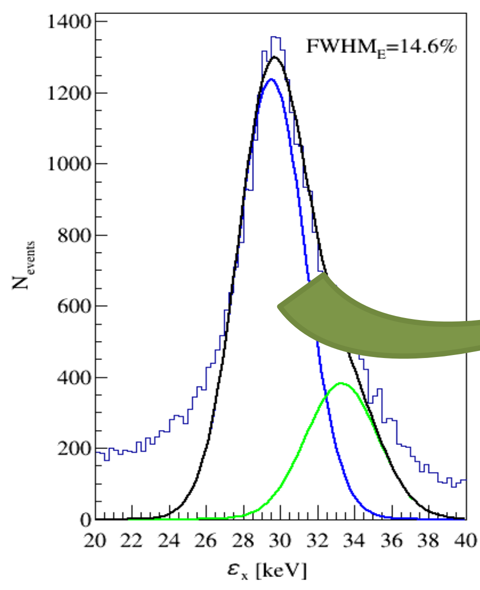


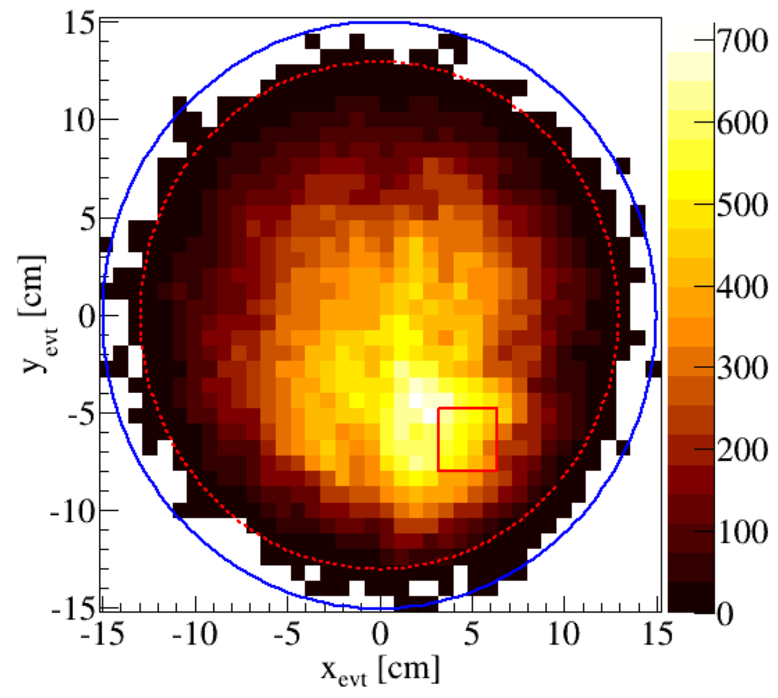
Final result
(for isolated x-rays)

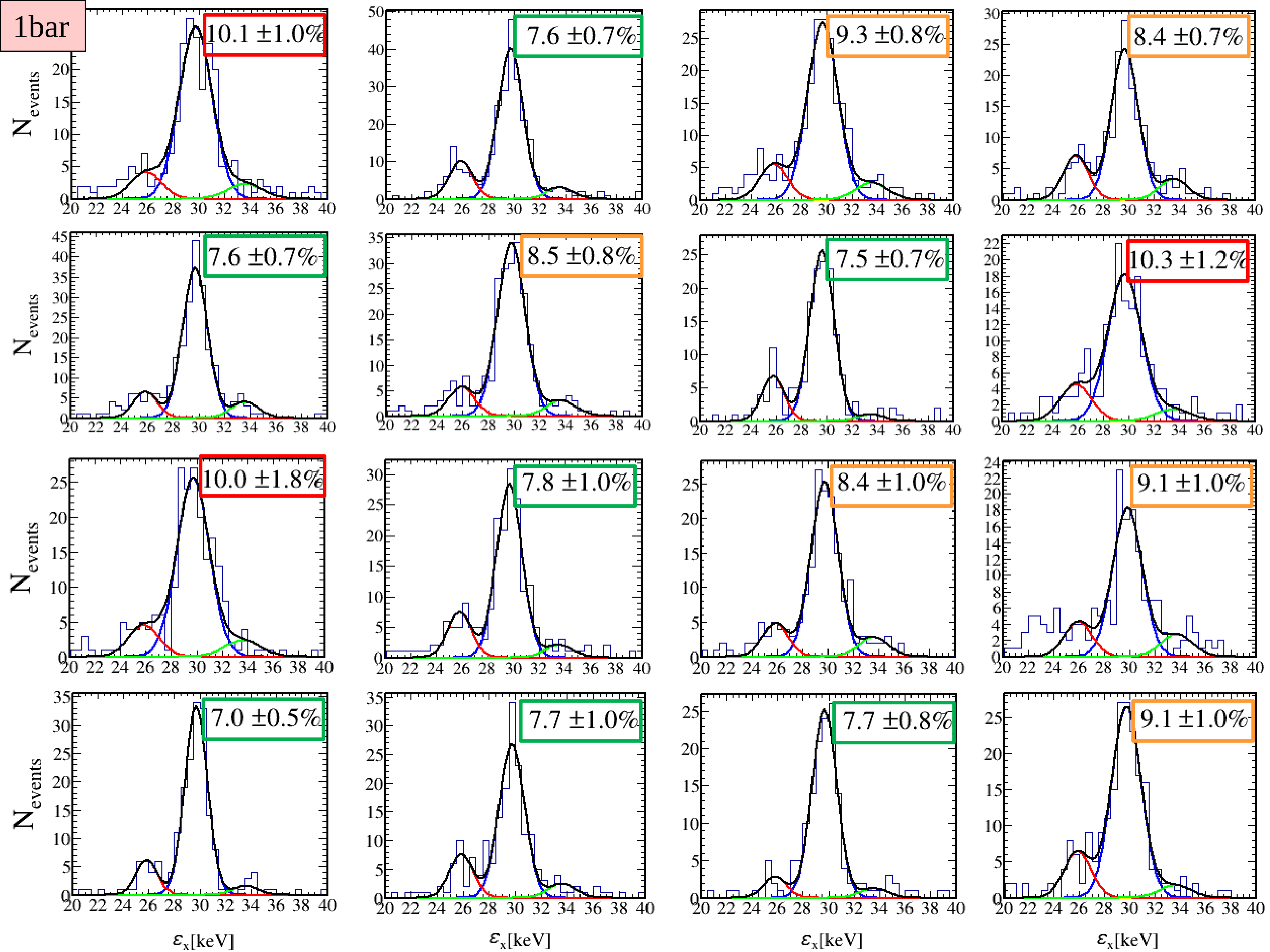


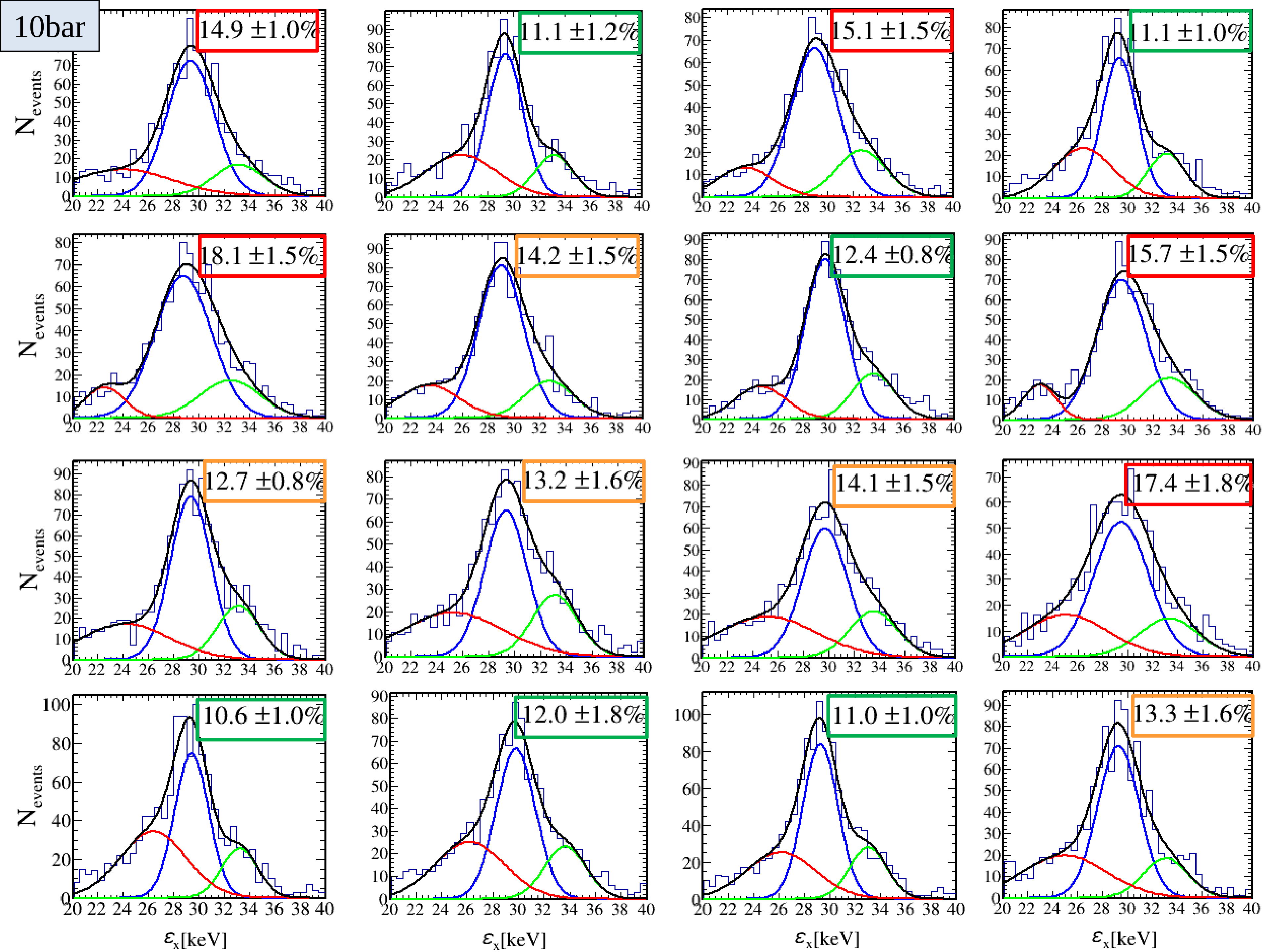


Energy resolution not just a number

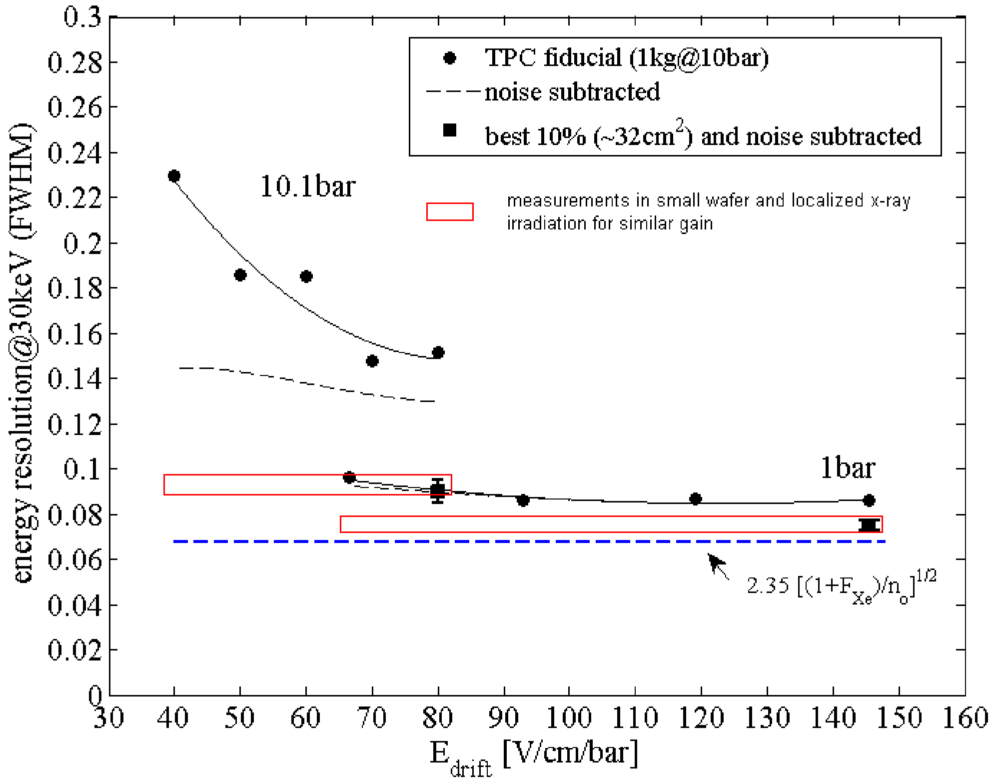




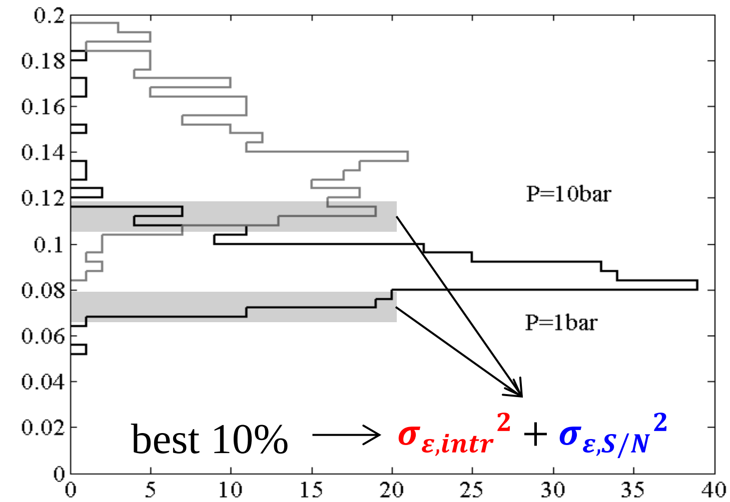

1bar
10.1 ±1.0%
7.6 ±0.7%
9.3 ±0.8%
8.4 ±0.7%
7.6 ±0.7%
8.5 ±0.8%
7.5 ±0.7%
10.3 ±1.2%
10.0 ±1.8%
7.8 ±1.0%
8.4 ±1.0%
9.1 ±1.0%
7.0 ±0.5%
7.7 ±1.0%
7.7 ±0.8%
9.1 ±1.0%
N_events
ε_x[keV]


10bar
14.9 ±1.0%
11.1 ±1.2%
15.1 ±1.5%
11.1 ±1.0%
18.1 ±1.5%
14.2 ±1.5%
12.4 ±0.8%
15.7 ±1.5%
12.7 ±0.8%
13.2 ±1.6%
14.1 ±1.5%
17.4 ±1.8%
10.6 ±1.0%
12.0 ±1.8%
11.0 ±1.0%
13.3 ±1.6%
N_events
ε_x[keV]

energy resolution for x-rays in a nutshell



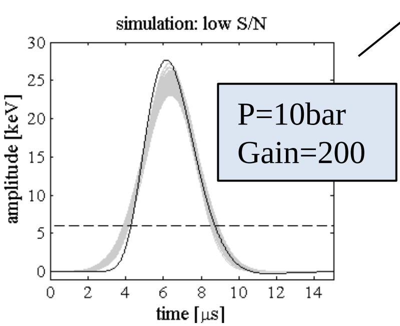
energy resolution pixel by pixel

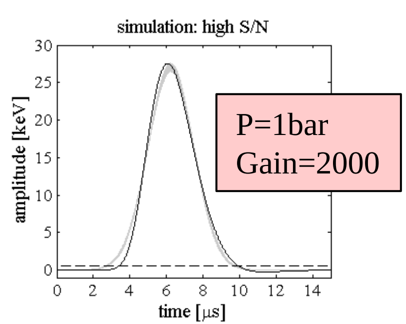


1bar	$\sigma_\varepsilon{}^2 = \sigma_{\varepsilon,intr}{}^2 + \sigma_{\varepsilon,S/N}{}^2 + \sigma_{\varepsilon,pixel-to-pixel}{}^2$
10bar	$\sigma_\varepsilon{}^2 = \sigma_{\varepsilon,intr}{}^2 + \sigma_{\varepsilon,S/N}{}^2 + \sigma_{\varepsilon,pixel-to-pixel}{}^2$

(0.075, 0.002, 0.035)

(0.09, 0.07, 0.09)



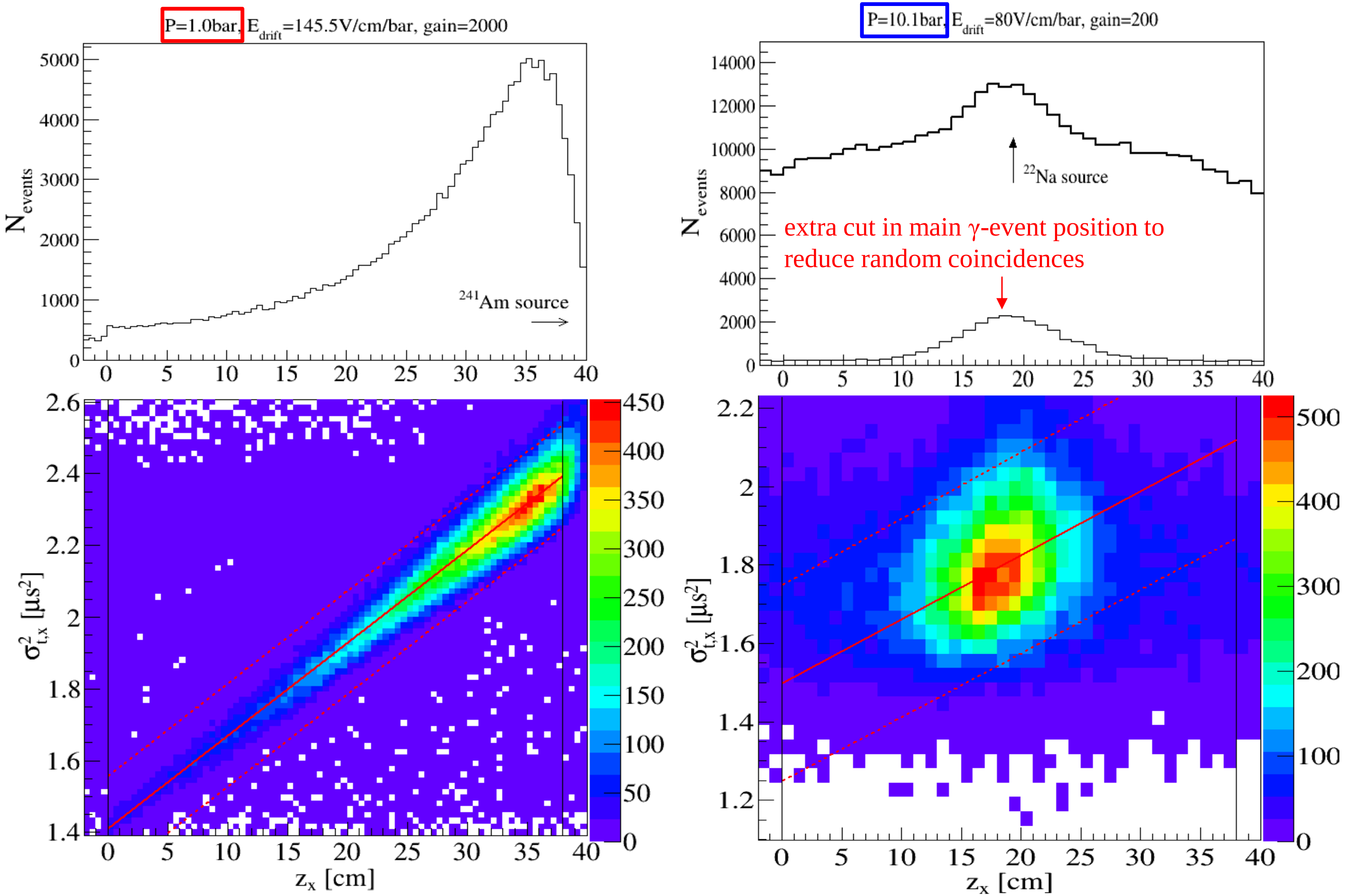


being **point-like** events and their response reasonably **understood**, use them to characterize the TPC

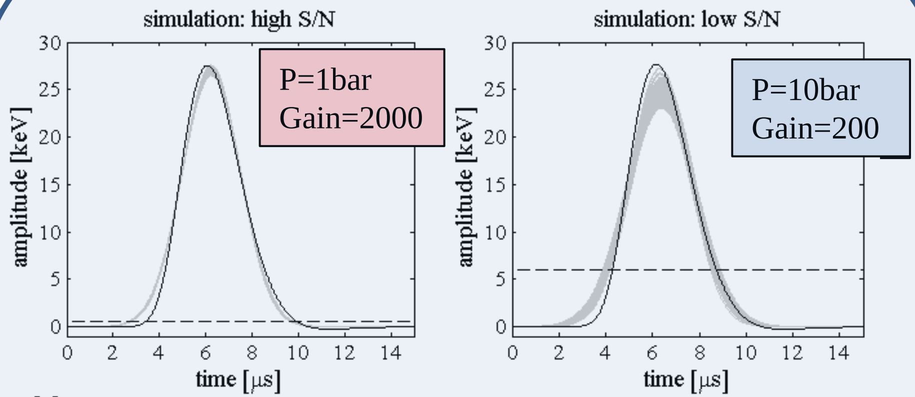
electron drift properties in Xe-TMA

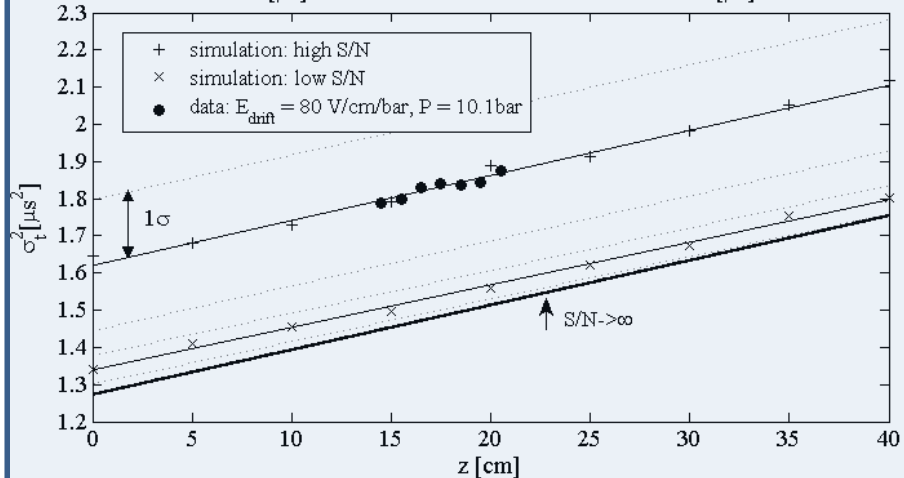
procedure analogous to:
JINST 9(2014)C04015

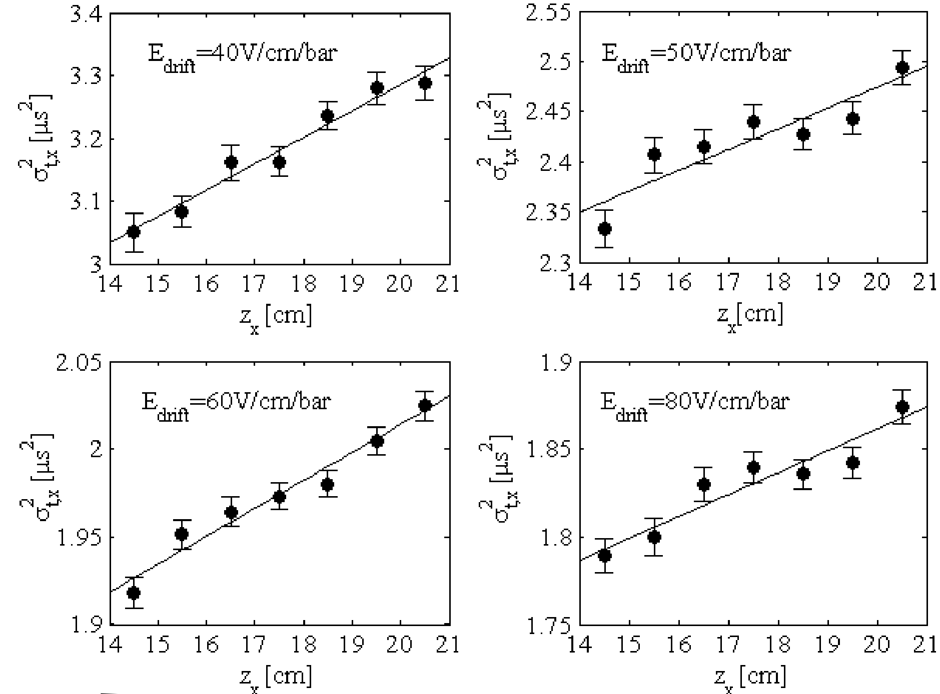
$$\sigma_t^{\,2} = \sigma_0^{\,2} + \left[\frac{D_L^{\,*}}{v_d}\right]^2 \frac{z_x}{P}$$



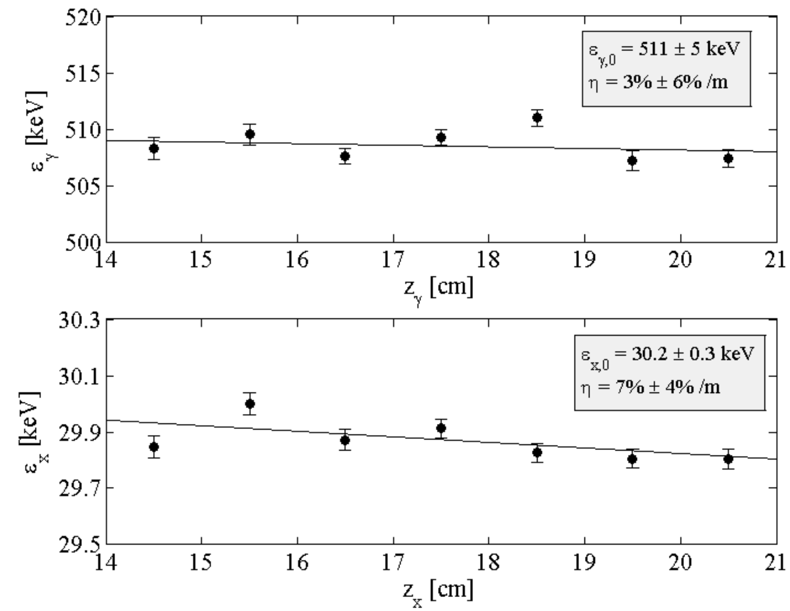
electron drift properties (analysis)





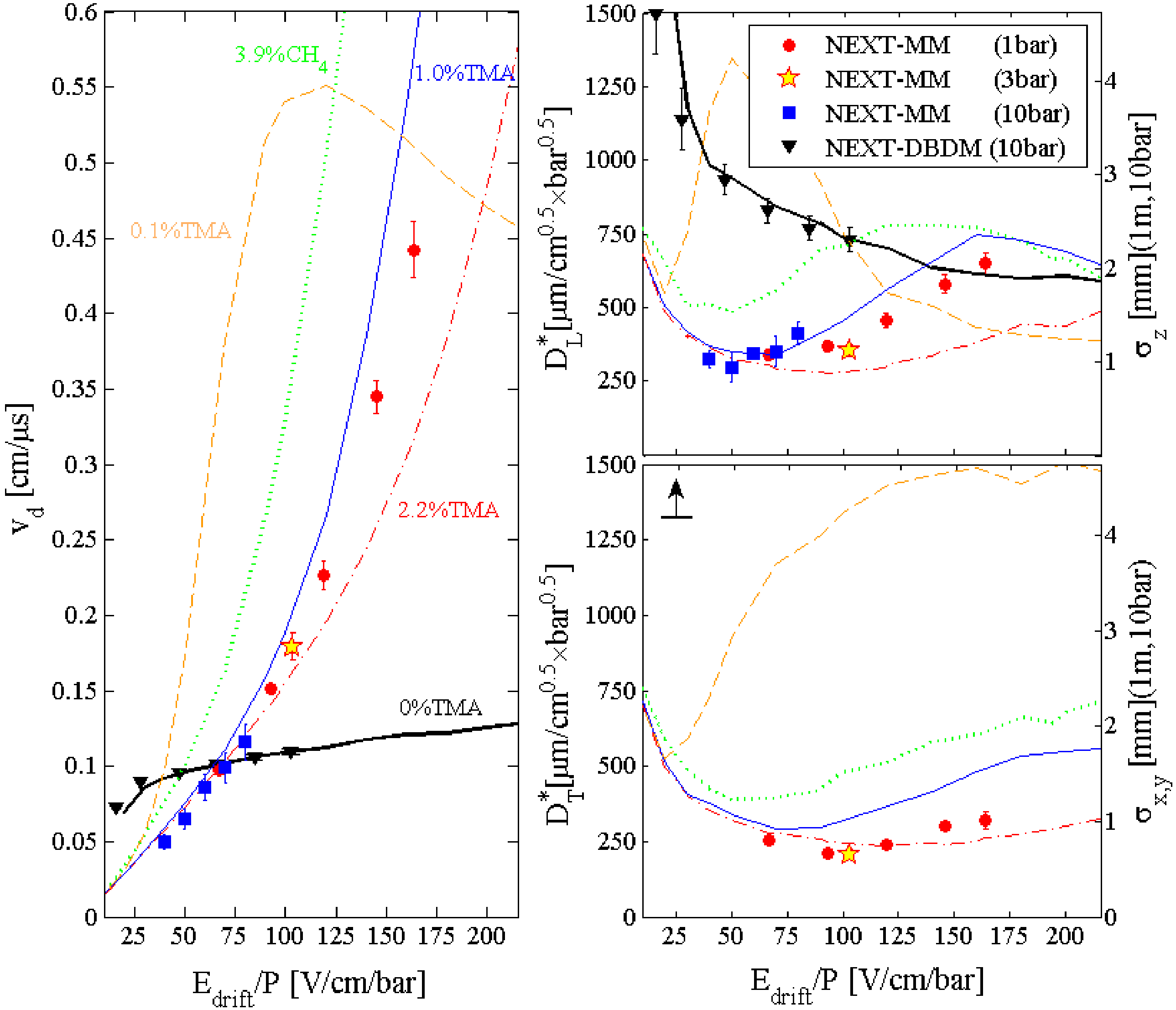


Suppress random coincidences with σ-z correlation cut



reduced S/N at high P increases minimum signal width and widens correlation stemming from diffusion, but leaves it unaffected.

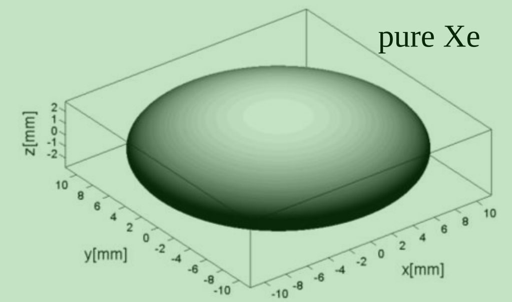
electron drift properties in Xe-TMA in a nutshell

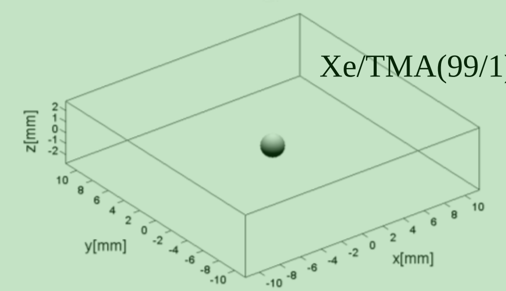


$$\sigma_{z,xy} = D^*_{L,T}\frac{\sqrt{z}}{\sqrt{P}}$$

Spatial spread of point-like charge deposits

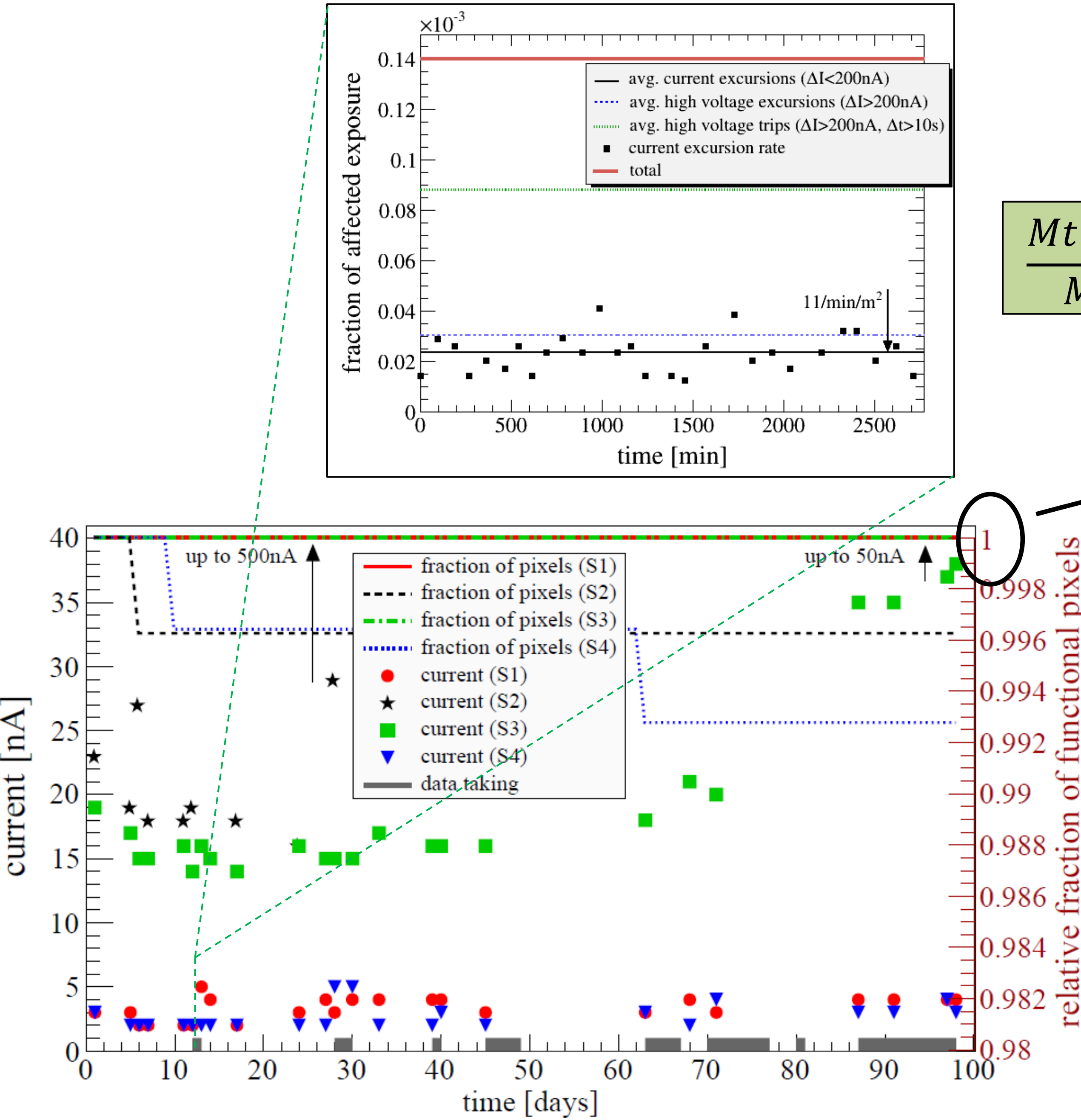
z_{drift}=100cm, P=10bar





E_{drift}~50-100V/cm/bar

stability of readout plane (continuously running for 100days+)



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

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

level of instrumented pixels at start of 10bar campaign: **~90%**

non-instrumented pixels: **~10%**

unclear origin: **1%**

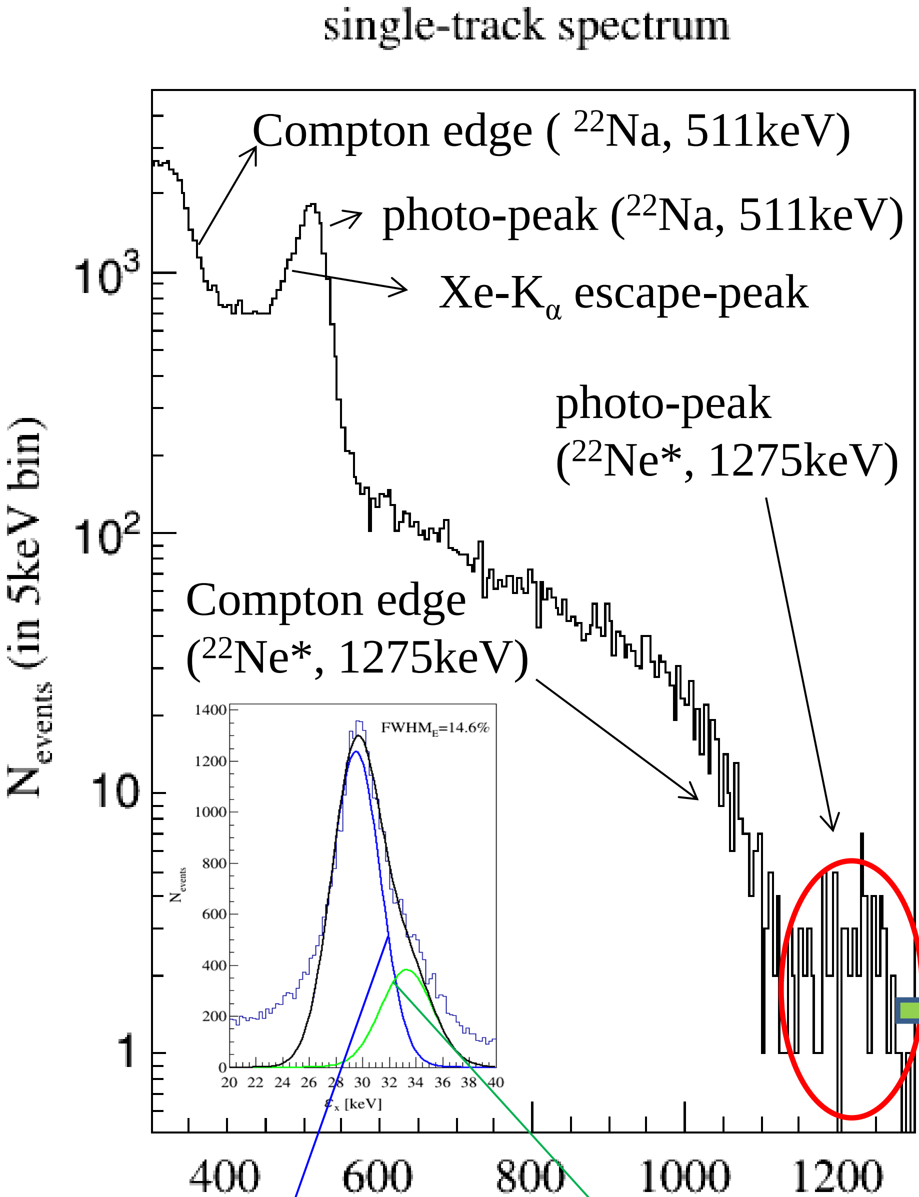
connections + cables: **4.5%**

damaged pixels: **4.5%**

rate of new damage: **~1%/yr**

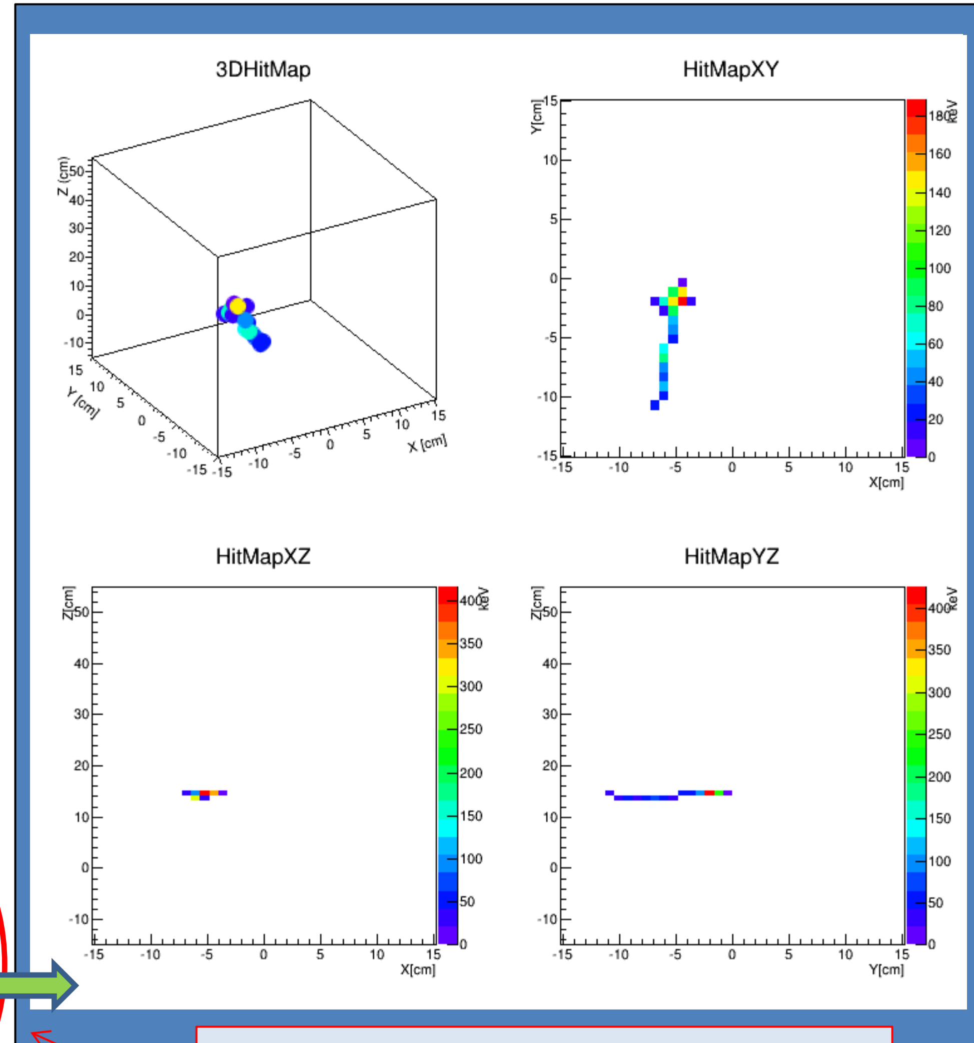
(with calibration source on)

γ-rays



(29.8keV Xe-K_α emission)

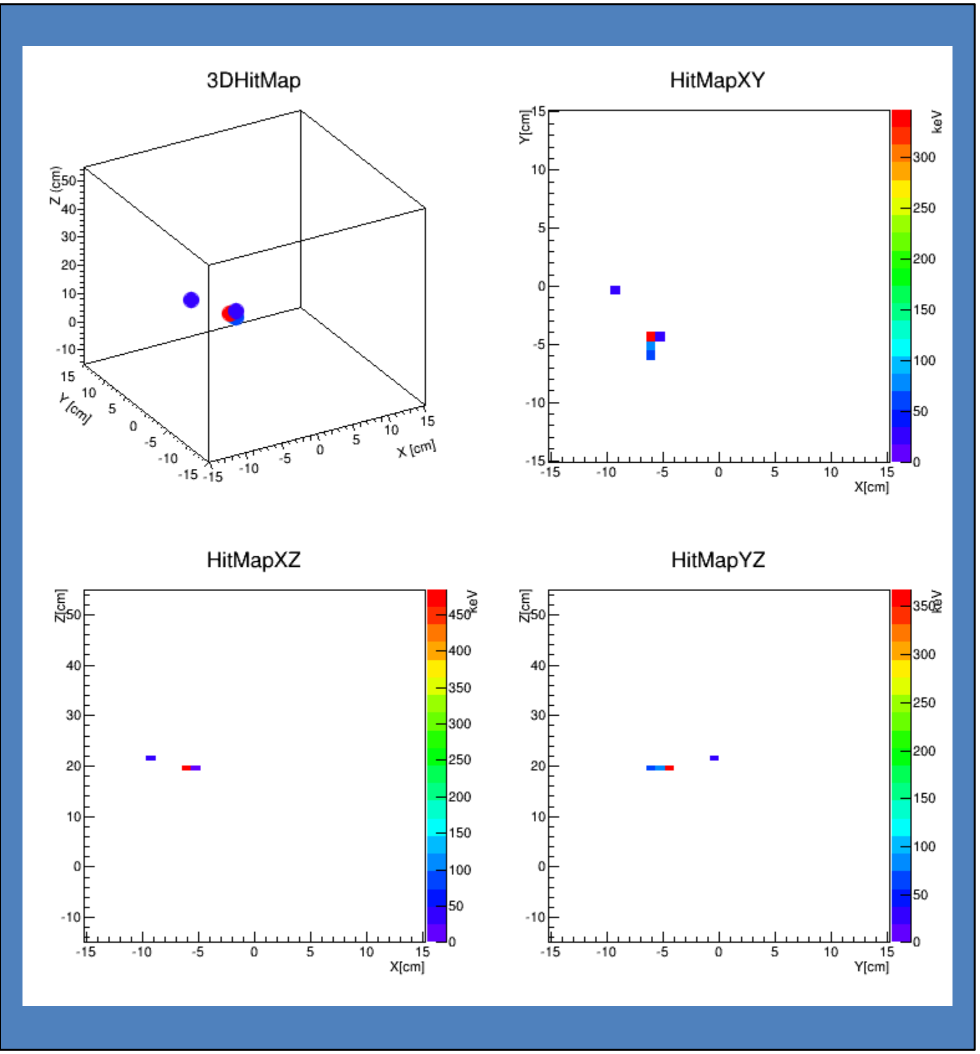
(33.64keV Xe-K_α emission)

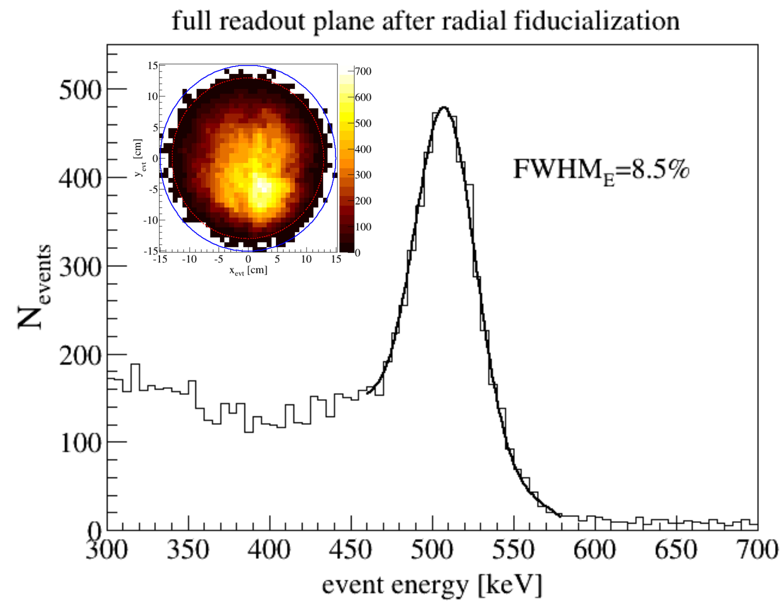


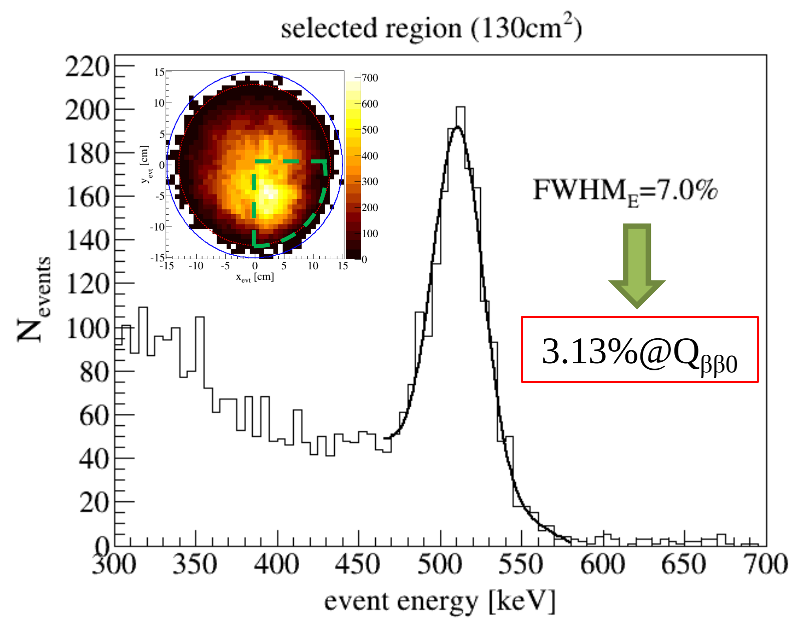
about the typical energy carried out by each electron at Xe^{136} $Q_{\beta\beta0}$!.

All peak energies correctly reproduced after calibration within 2%

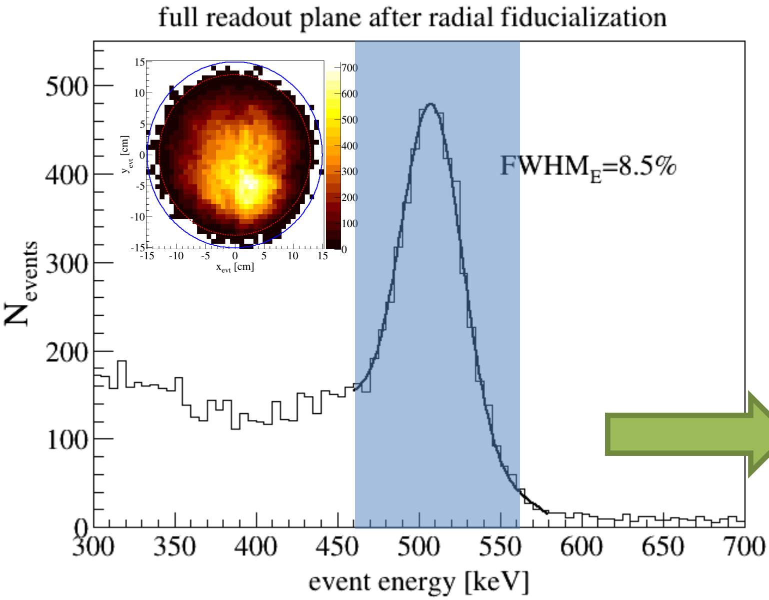
For analysis select 511 events with displaced x-ray

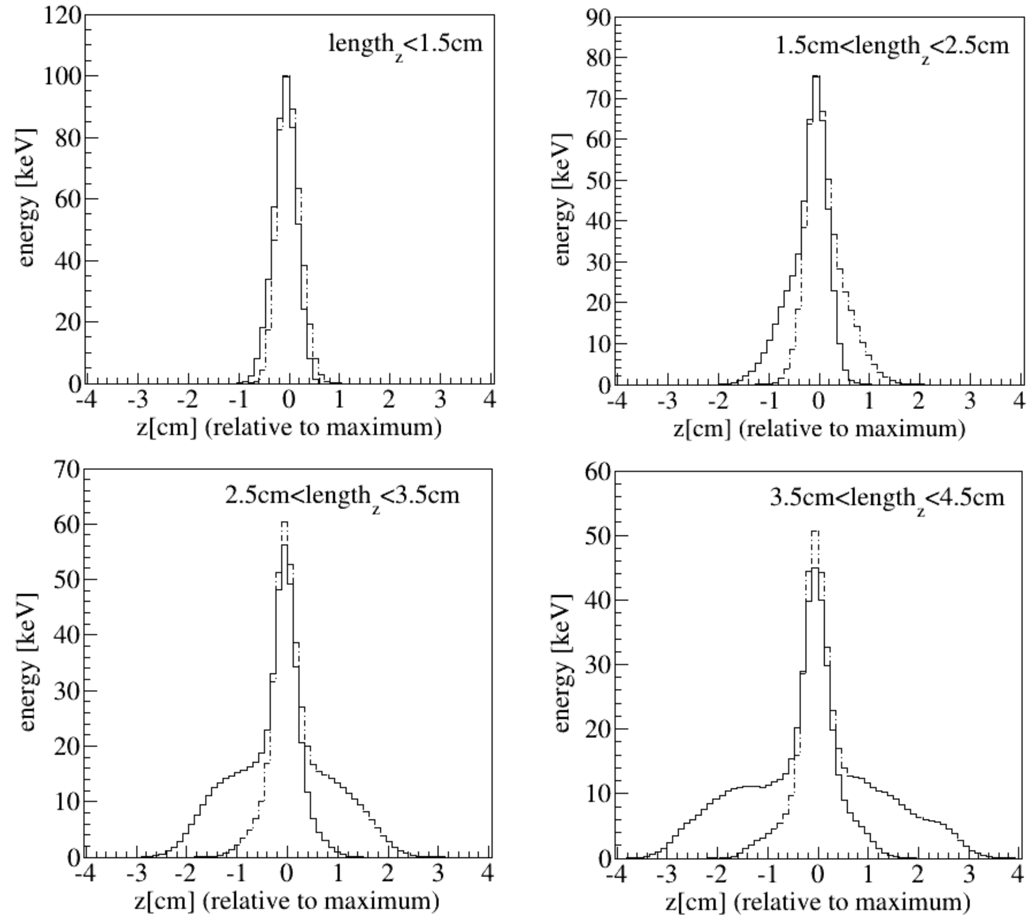




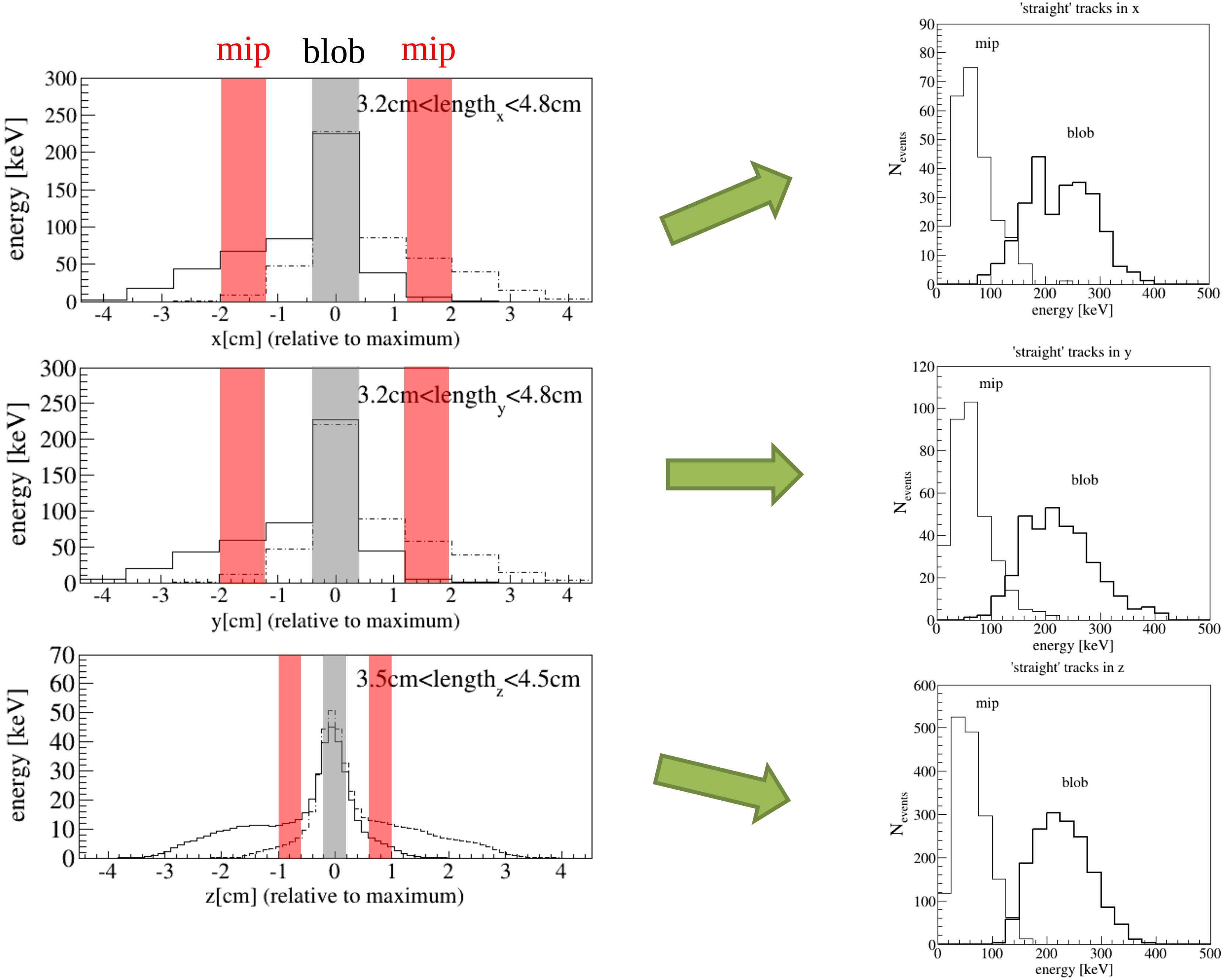


Separation between blob and mip region for straight tracks (I)





Separation between blob and mip region for straight tracks (II)



conclusions

1. NEXT-MM is truly a 'Penning-fluorescent Xenon-TPC', housing 1kg of Xenon in its active region, and operating at 10bar.

2. As compared to Gotthard's approach, **Xe-TMA + Micromegas +AFTER-FEE** offers lower electron-diffusion, better energy resolution (a factor x2 at 511keV), better z-sampling (x5) true x-y readout and (limited) primary scintillation at ~300nm, as well as ability to work at higher pressure. A clear mip-blob separation is visible in all x,y,z projections for 511keV tracks.

3. The achieved value extrapolates to 3.1%$Q_{\beta\beta0}$. There is some indication of the influence of noise in this value. If the nominal ENC noise of the AFTER chip (x3 lower) could be achieved by proper cable+connection design, a value closer to the anticipated 1-1.5%$Q_{\beta\beta0}$ might be obtained. MM-optimization (e.g. gain-compensation) could bring this value slightly down.

4. About 5% of the readout plane was damaged during commissioning. This fact, together with the observed variations in response from pixel-to-pixel suggest the implementation of tighter QA procedures.

5. Blob and mip region clearly recognizable for 511keV energy deposits in z and (although limited due to lower granularity) also in x-y plane. A slightly finer segmentation will help to improve on this + decrease the fraction of damaged area.

6. Chamber operating stable over 100+ days with more than 99% live time.

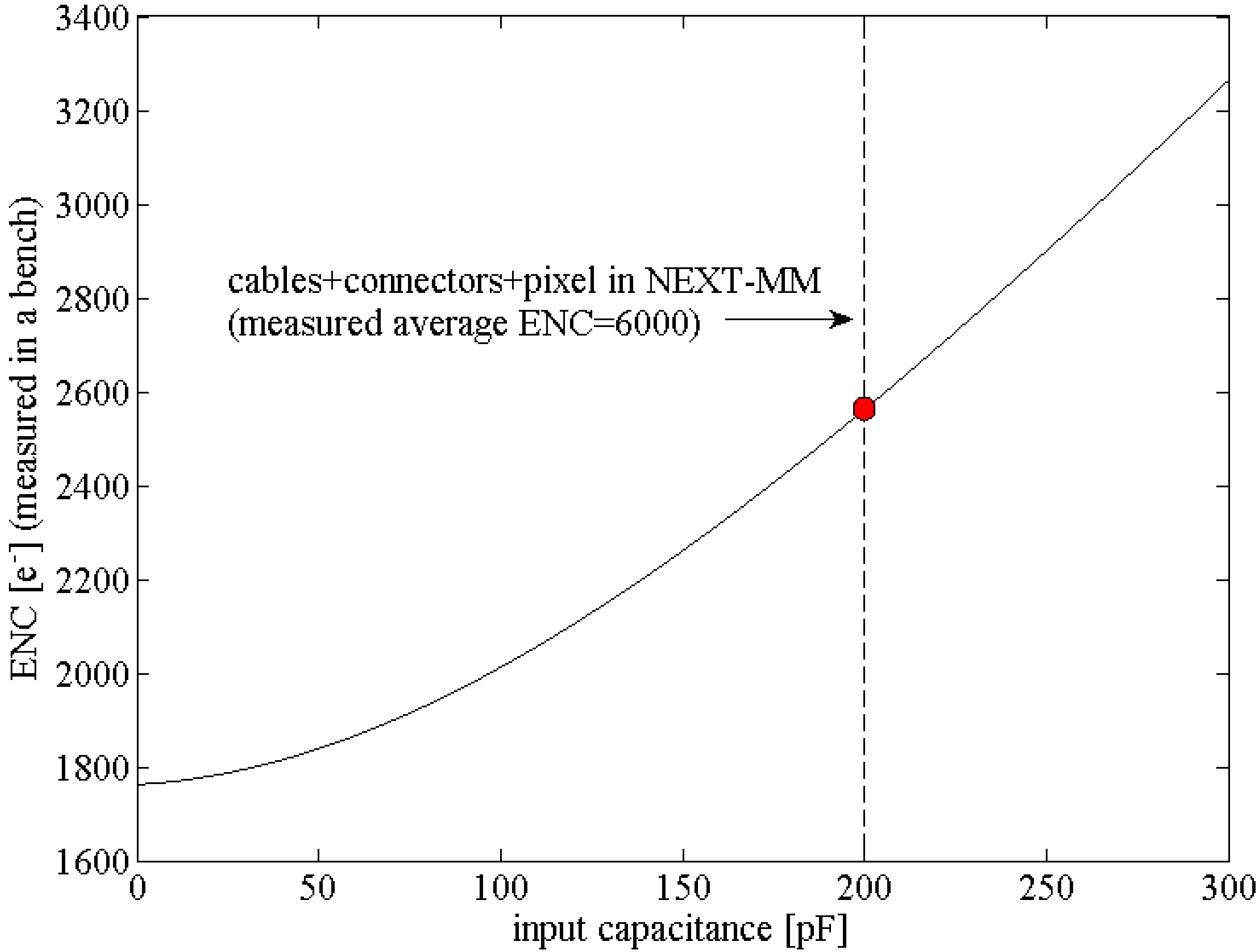
scope

1. MM truly a fantastic tracking device for high pressure Xenon already with today's performance. Would be great to include it in a future NEXT-1T if the remaining system performances (e.g. electroluminescence yield and variance) can be kept when using admixtures.

2. In any case, these results suggest more than ever that for obtaining near-intrinsic energy resolutions in gas and over large areas one has to operate in conditions where dead channels and noise have no impact on performance. Electroluminescence suffers only marginally from those.

Thanks for your attention!

appendix



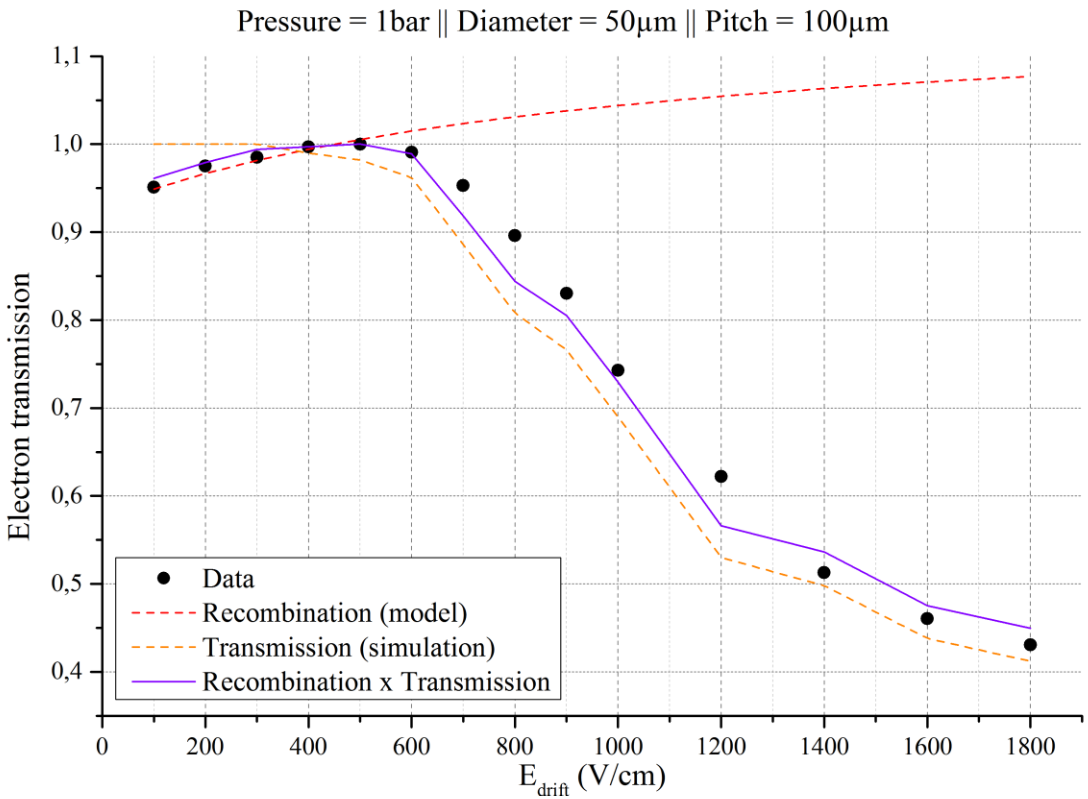
cables+connectors+pixel in NEXT-MM
(measured average ENC=6000)
ENC [e-] (measured in a bench)
input capacitance [pF]
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
0
50
100
150
200
250
300

energy resolution for x-rays in a nutshell

$$\sigma_{\varepsilon,intr}{}^2 = \sigma_{\varepsilon,MM-gain}{}^2 + \sigma_{\varepsilon,Fano}{}^2 + \sigma_{\varepsilon,reco}{}^2$$

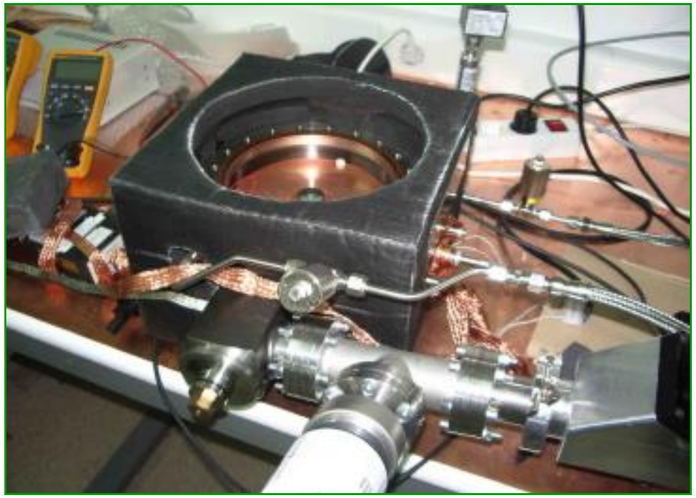
inherent to the mixture

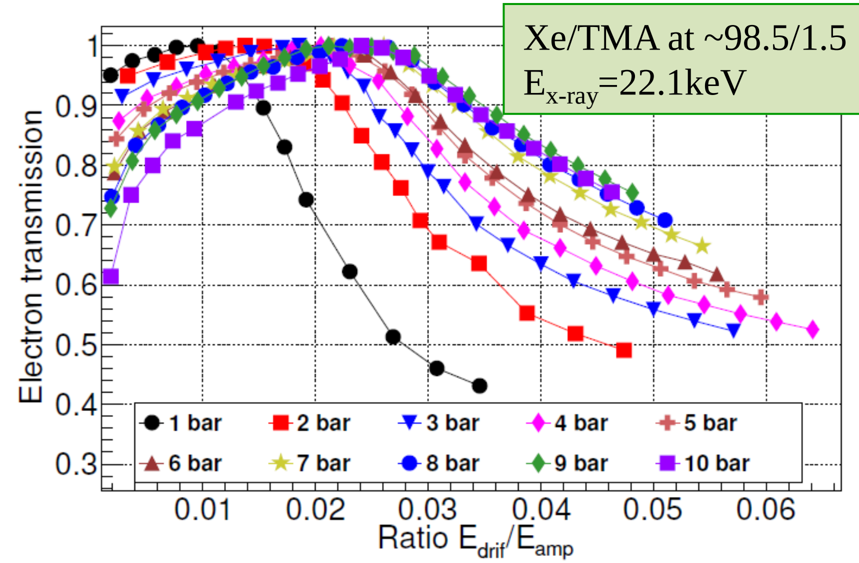
10bar

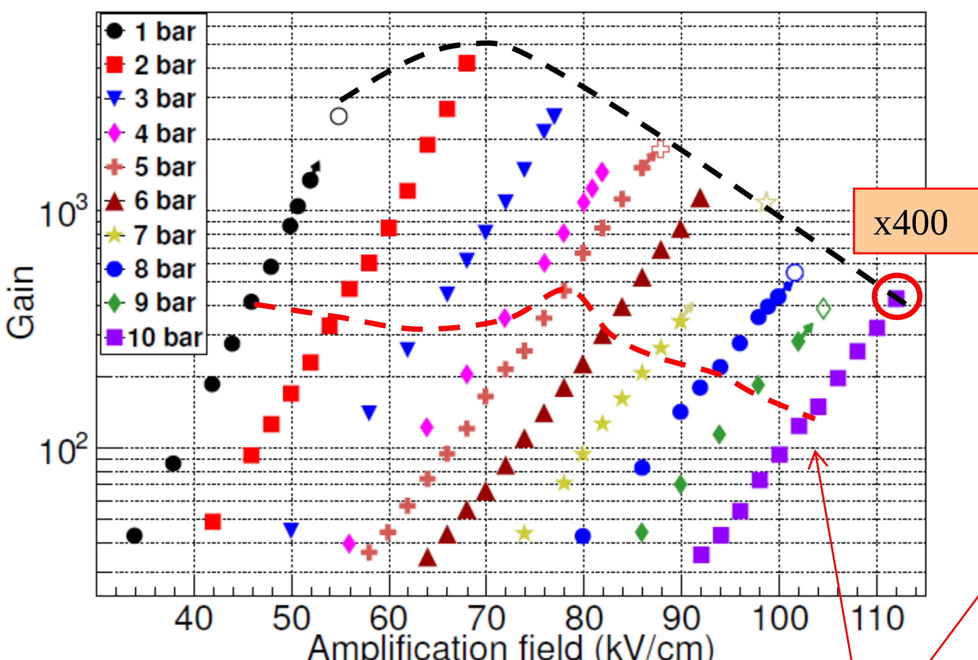


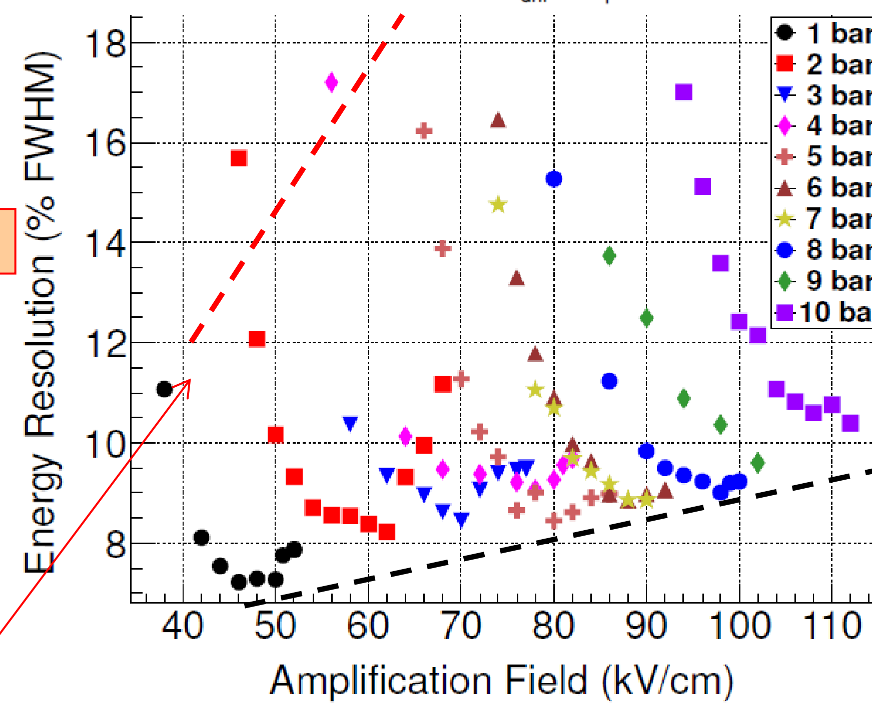
work in progress

step 0: measurements in a small setup and general behavior



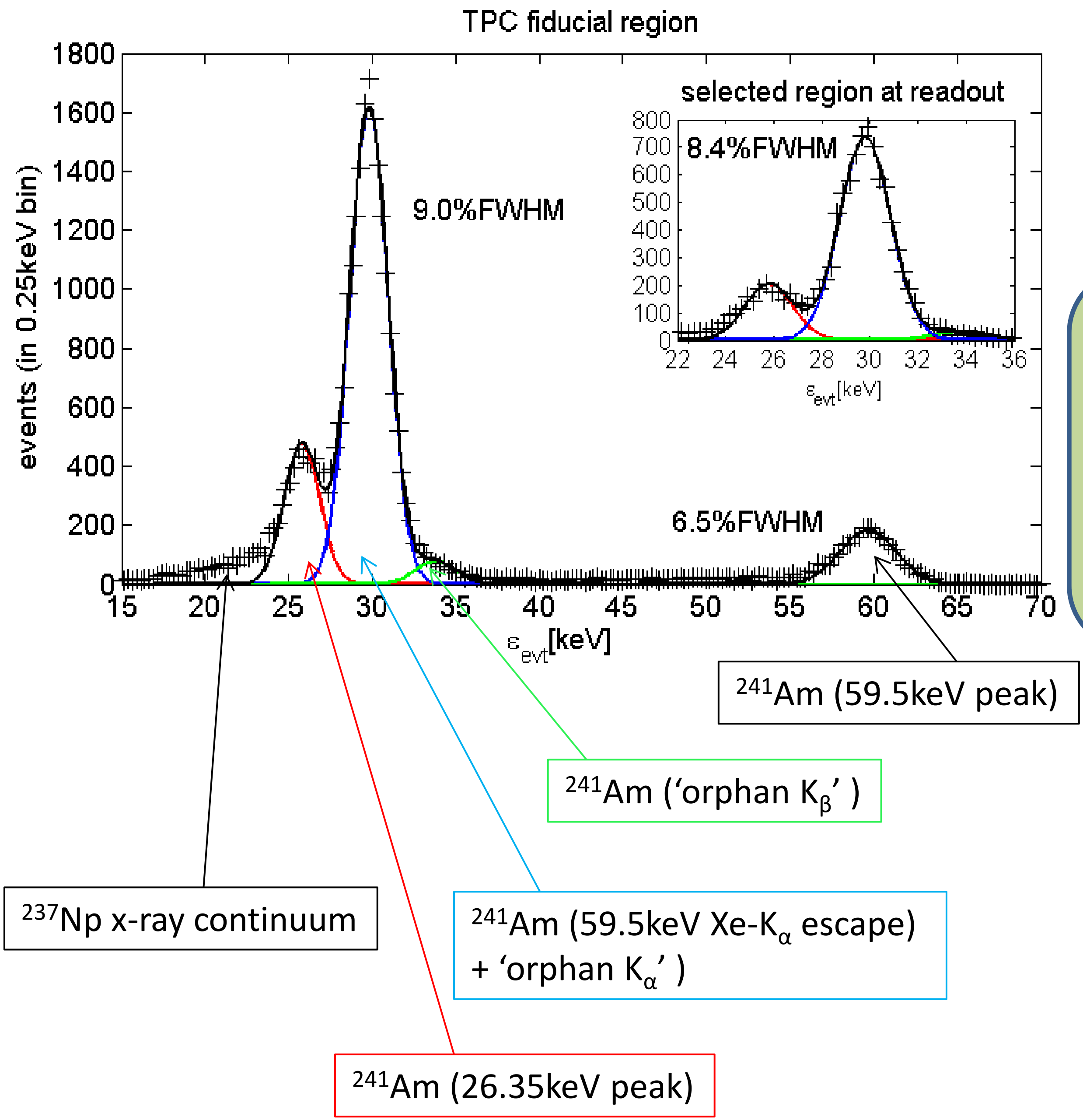






Measurements in pure Xe (Coimbra+Saclay)

Calibrated energy spectrum at 1-3bar



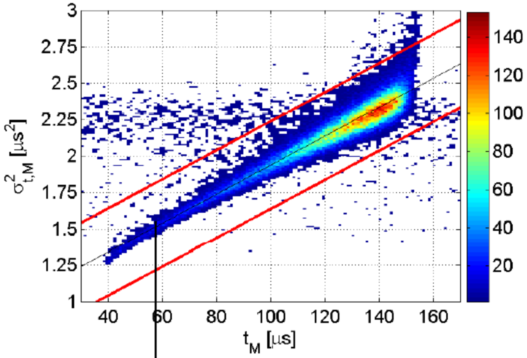
- Mixture: Xe-TMA (97.8/2.2)
- Micromegas gain: 2000
- FEE ENC: <0.12keV(95%ch)
- Pixels' threshold, ε_{th} : ~0.5keV
- Trigger threshold: 10-15keV
- E_{drift}=145.5V/cm/bar
- P=1.0bar
- Electron attachment: <10%/m

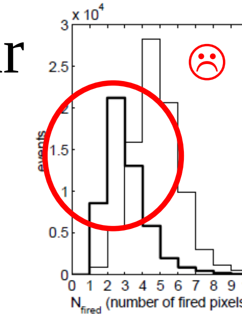
Extraction of diffusion coefficients at 1-3bar

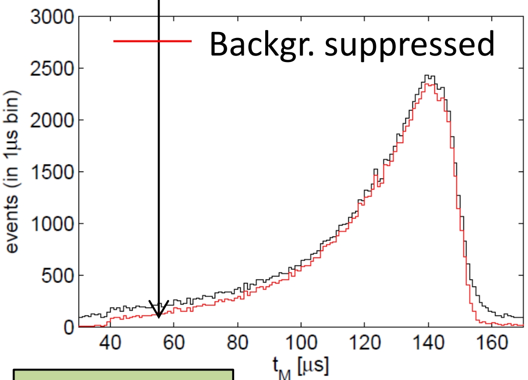
use the following convention

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

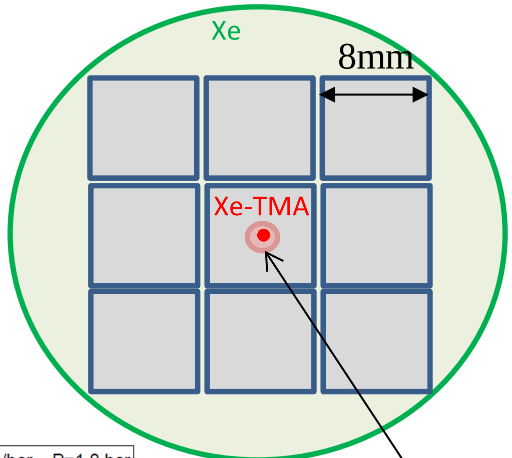
$$\sigma_{L,T} = D_{L,T}^* \frac{\sqrt{z}}{\sqrt{P}}$$





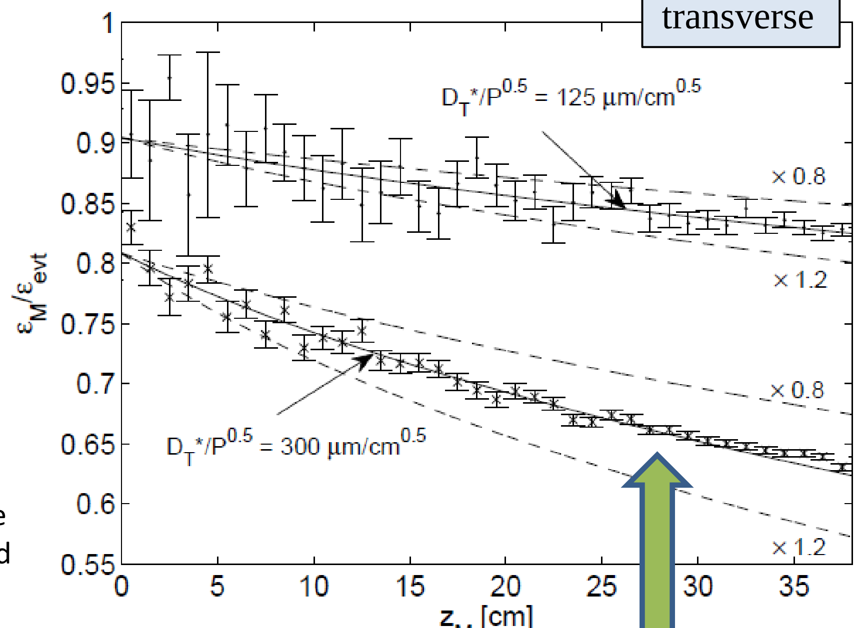


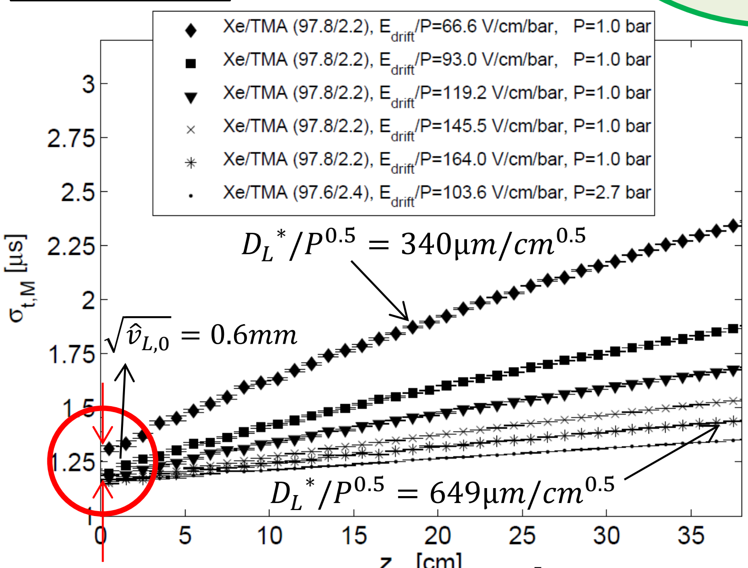
longitudinal



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

transverse





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

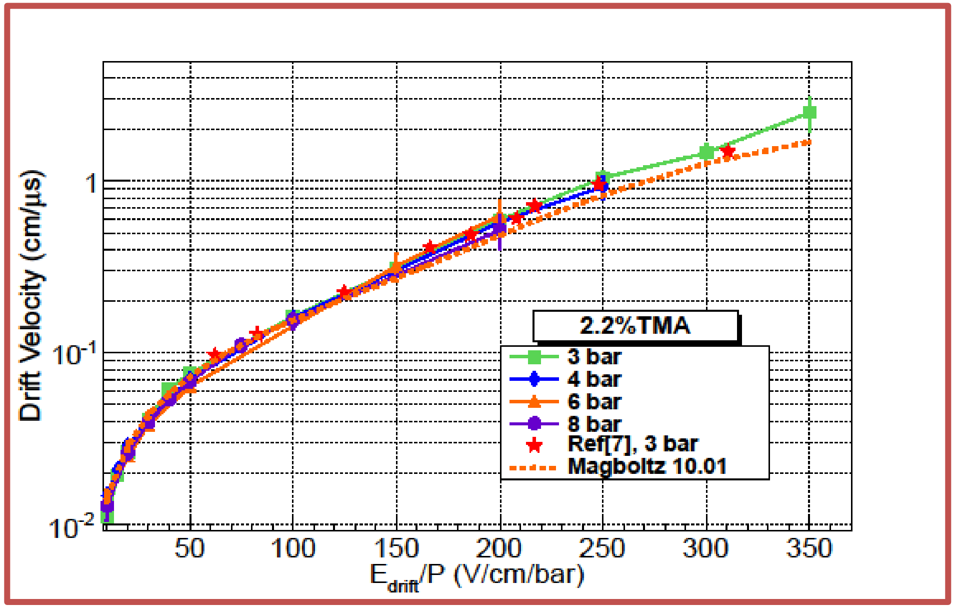
$$<\frac{\varepsilon_M}{\varepsilon_{evt}}> = \frac{\left[2\hat{v}_r\left(e^{-\frac{L^2}{2\hat{v}_r}} - 1\right) + \sqrt{2\pi}L\sqrt{\hat{v}_r}\,\mathrm{erf}\left(\frac{L}{\sqrt{2\hat{v}_r}}\right)\right]^2}{2\pi L^2 \hat{v}_r}$$

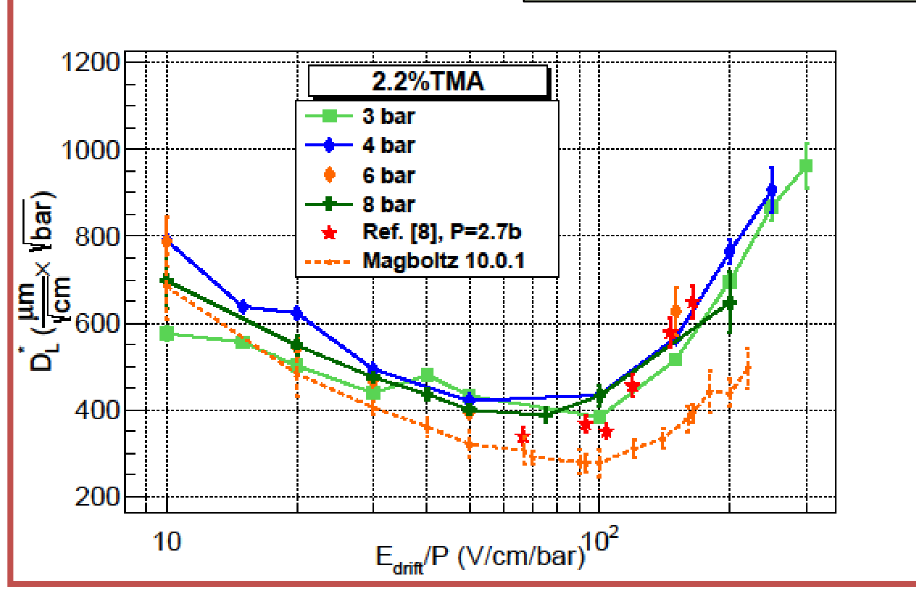
$$\hat{v}_r = D_T^{*\,2} \times \frac{z_M}{P} + \hat{v}_{r,0} \longrightarrow \sqrt{\hat{v}_{r,0}} = 1 \pm 0.1mm$$

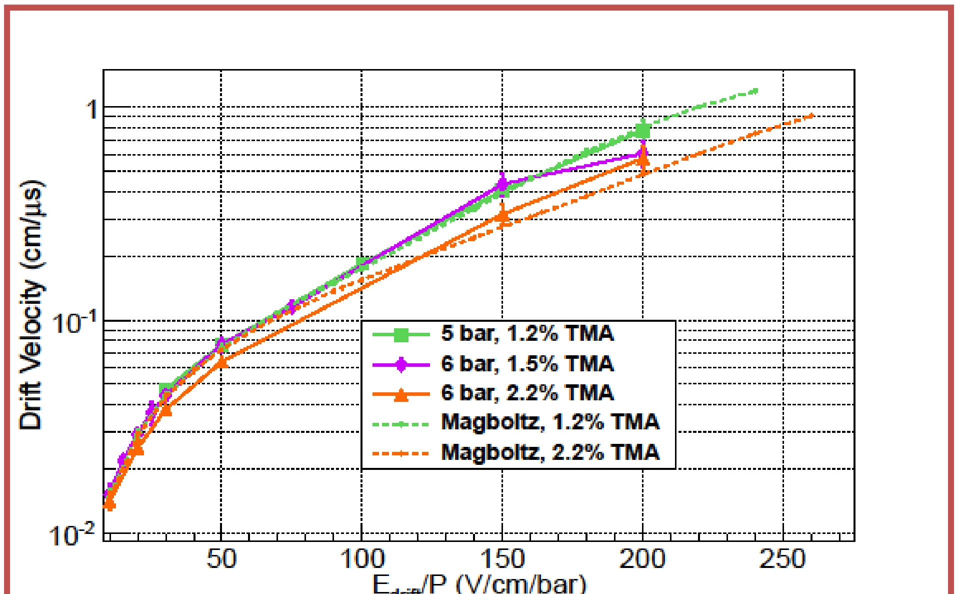
Characterization of a medium size Xe-TMA TPC, JINST 9(2014)C04015

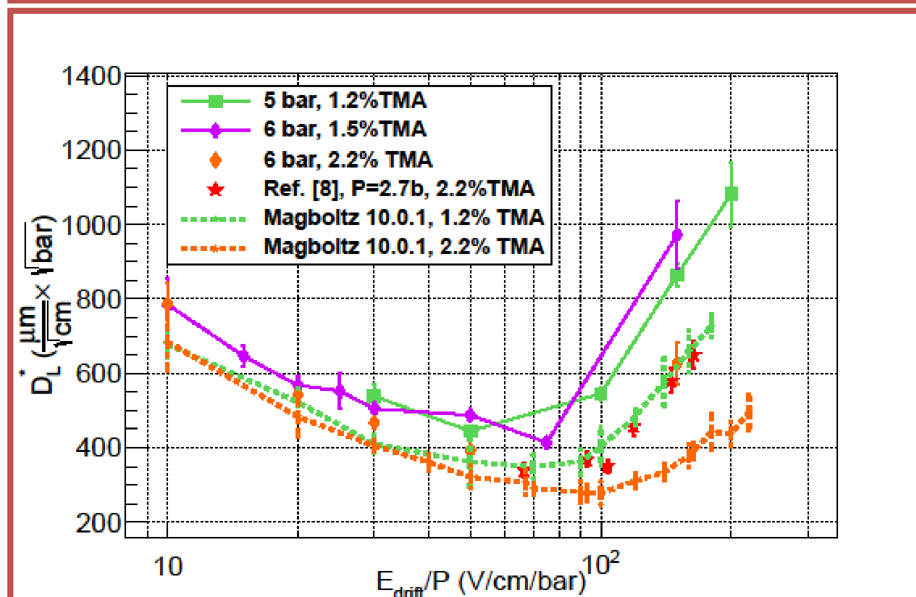
New data from small setup (with α-tracks)

See D. C. Herrera's talk at WG2







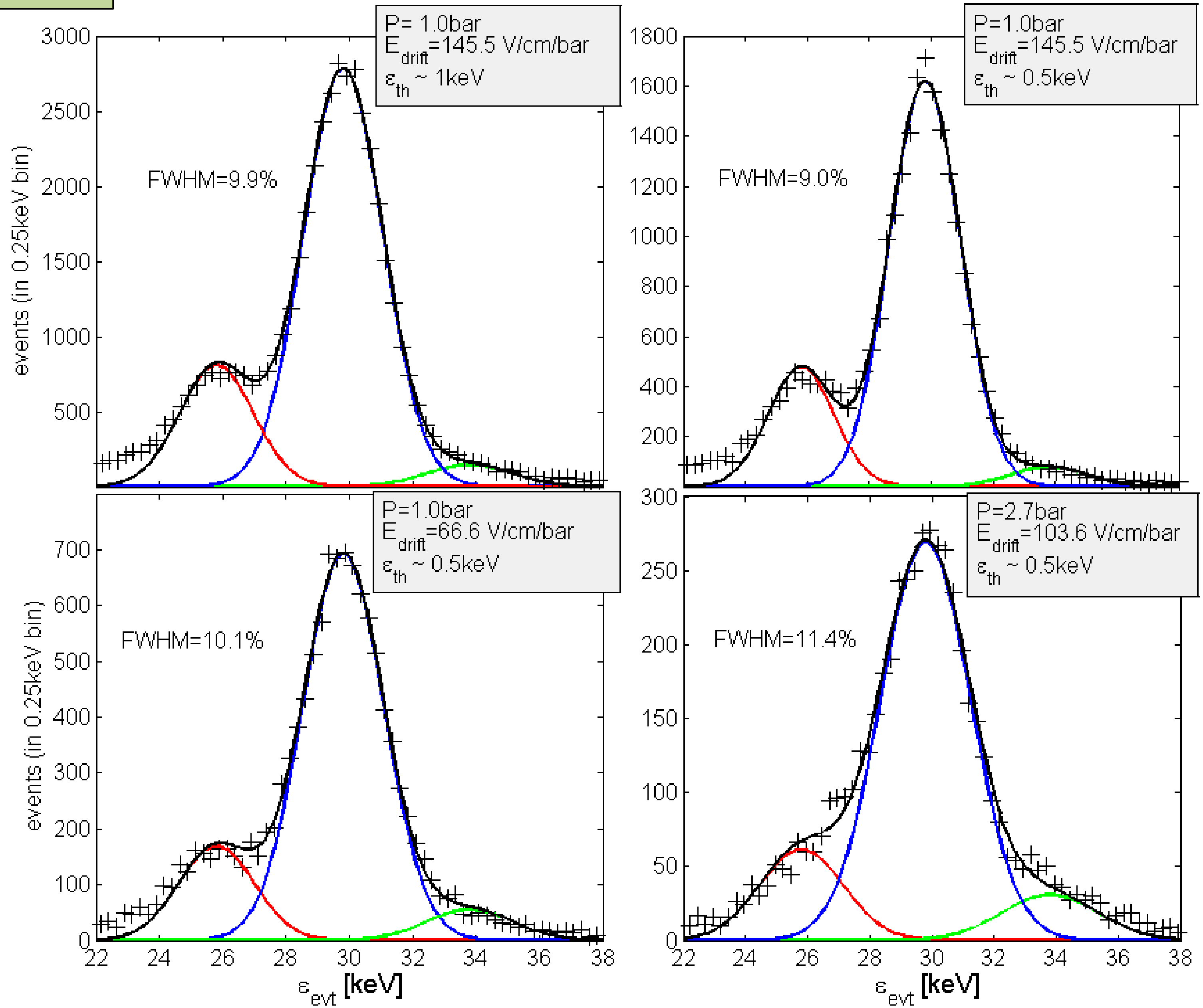


[7] D.C. Herrera , J. Phys. Conf. Ser. **460** (2013) 012012

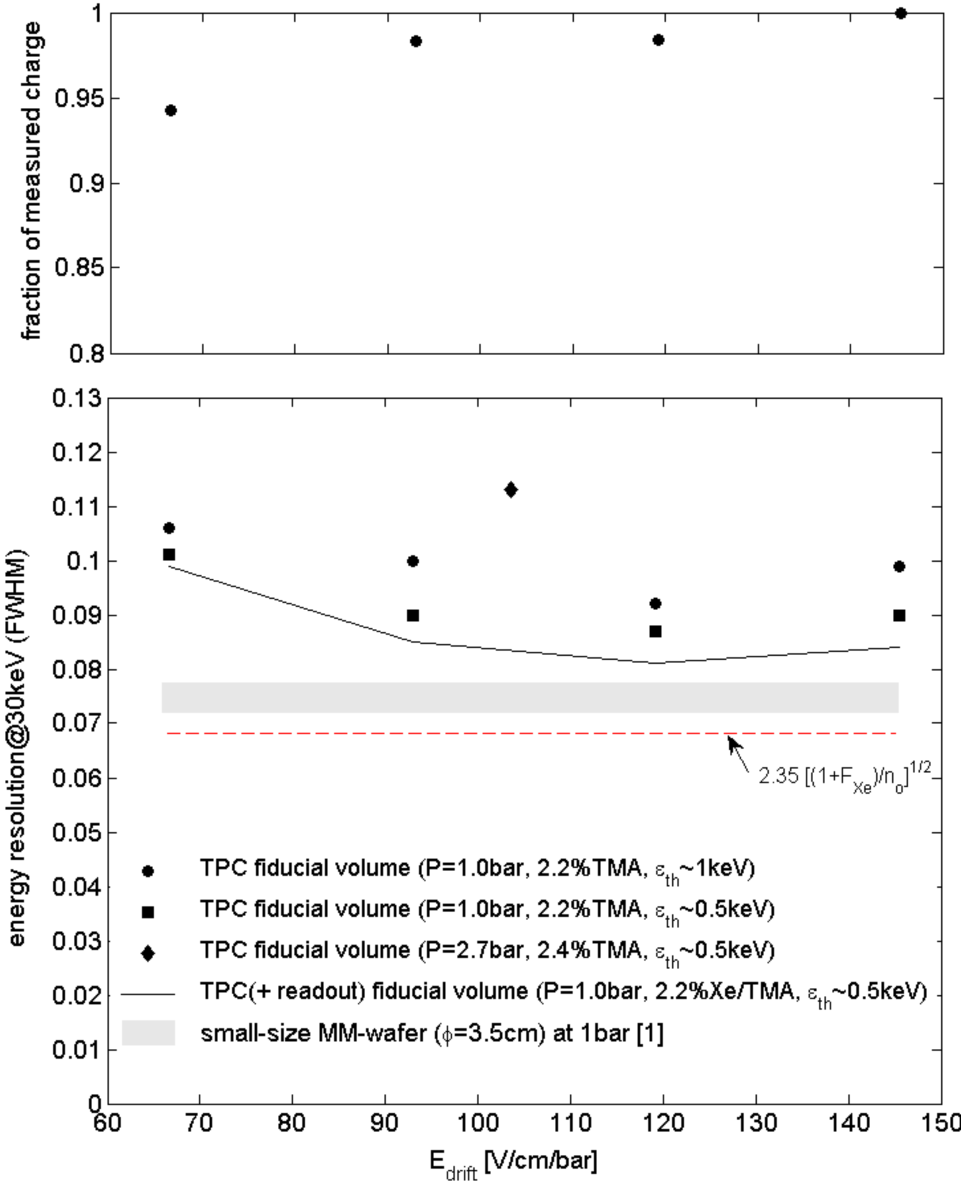
[8] V Álvarez et al, JINST ***9*** *C04015 (2014)*

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

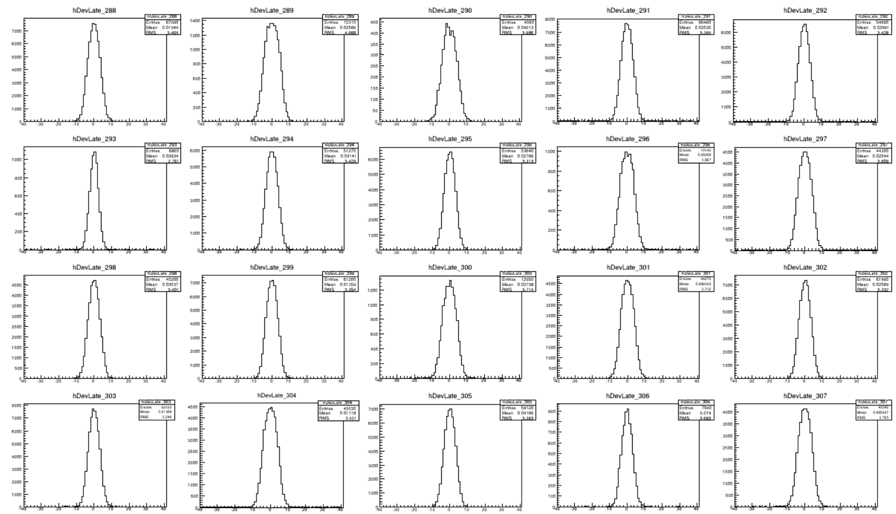
Xe/TMA (98/2)



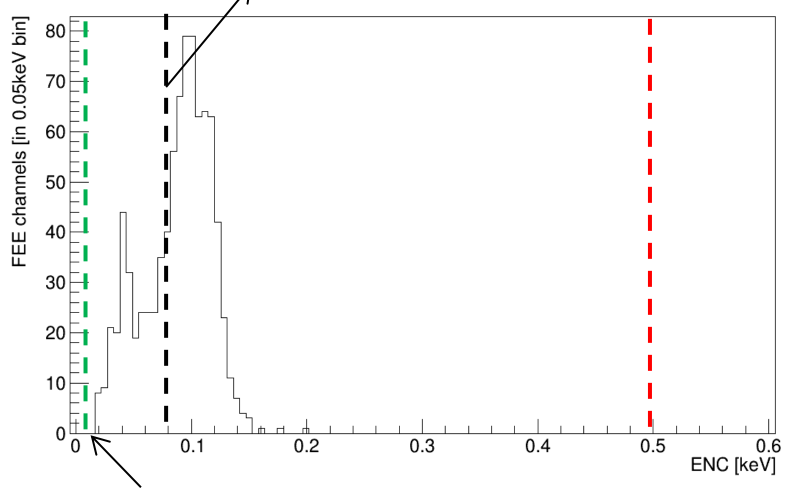
Drift field systematics in the pressure range 1-3bar



Base-line spread for 20 random FEE channels



#ADC channels



Typical AFTER values (1000e-) for optimized system

10bar

Energy spectrum after calibration at 1-3bar

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 (?)

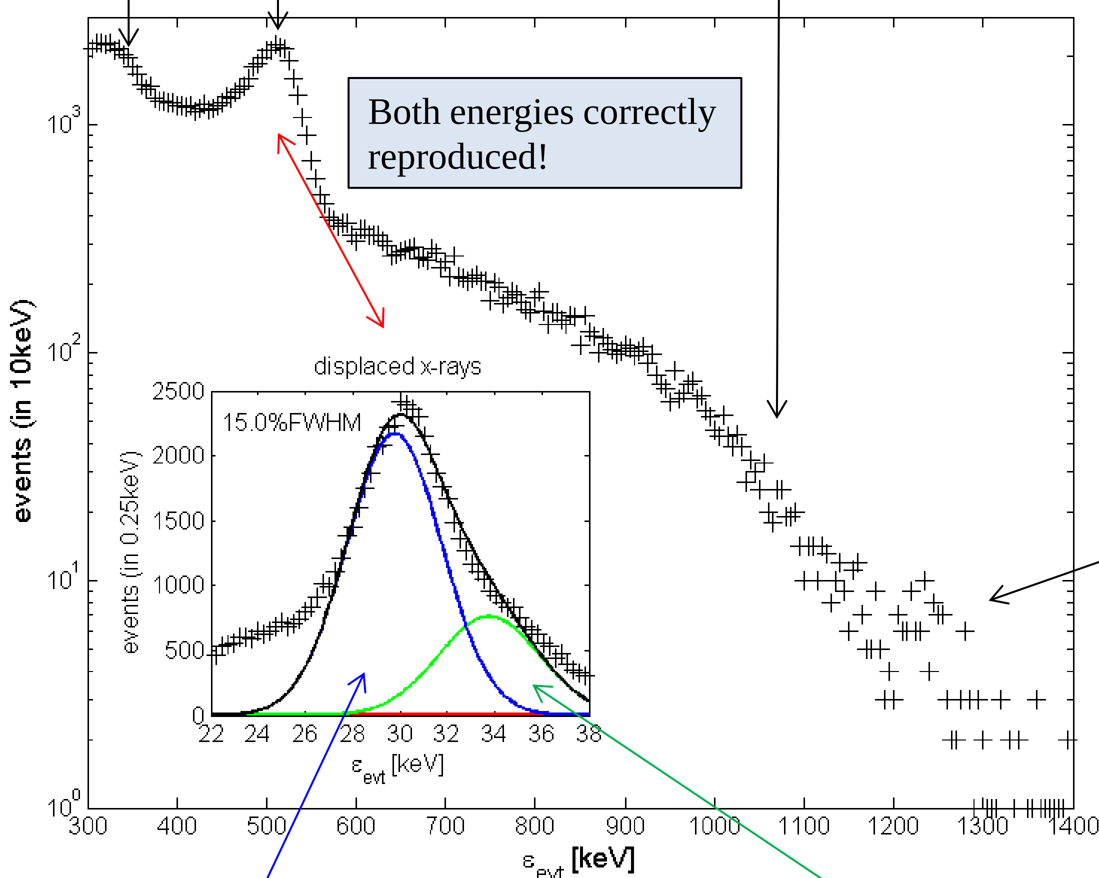


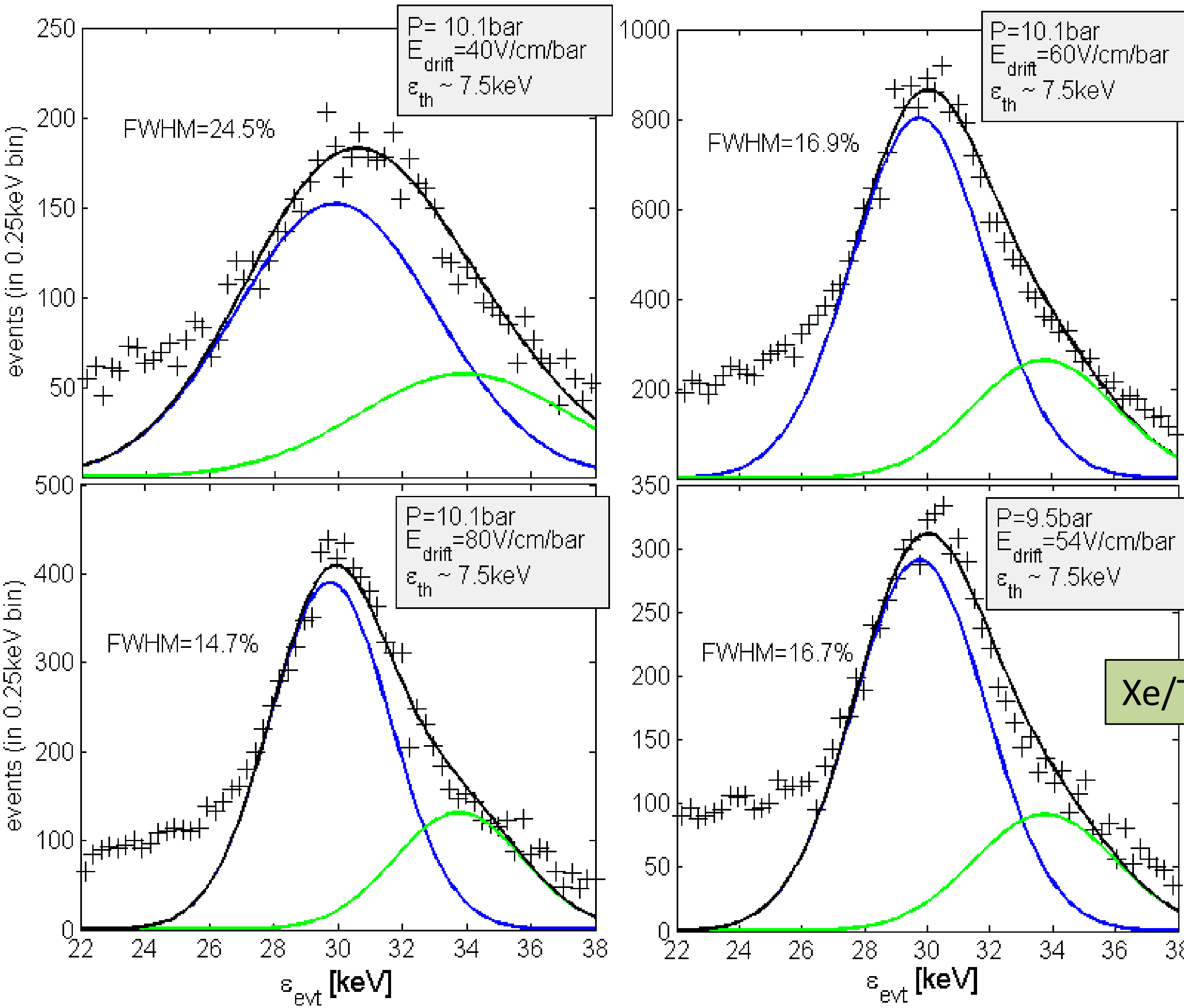
photo-peak (^{22}Ne*, 1275keV)

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

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

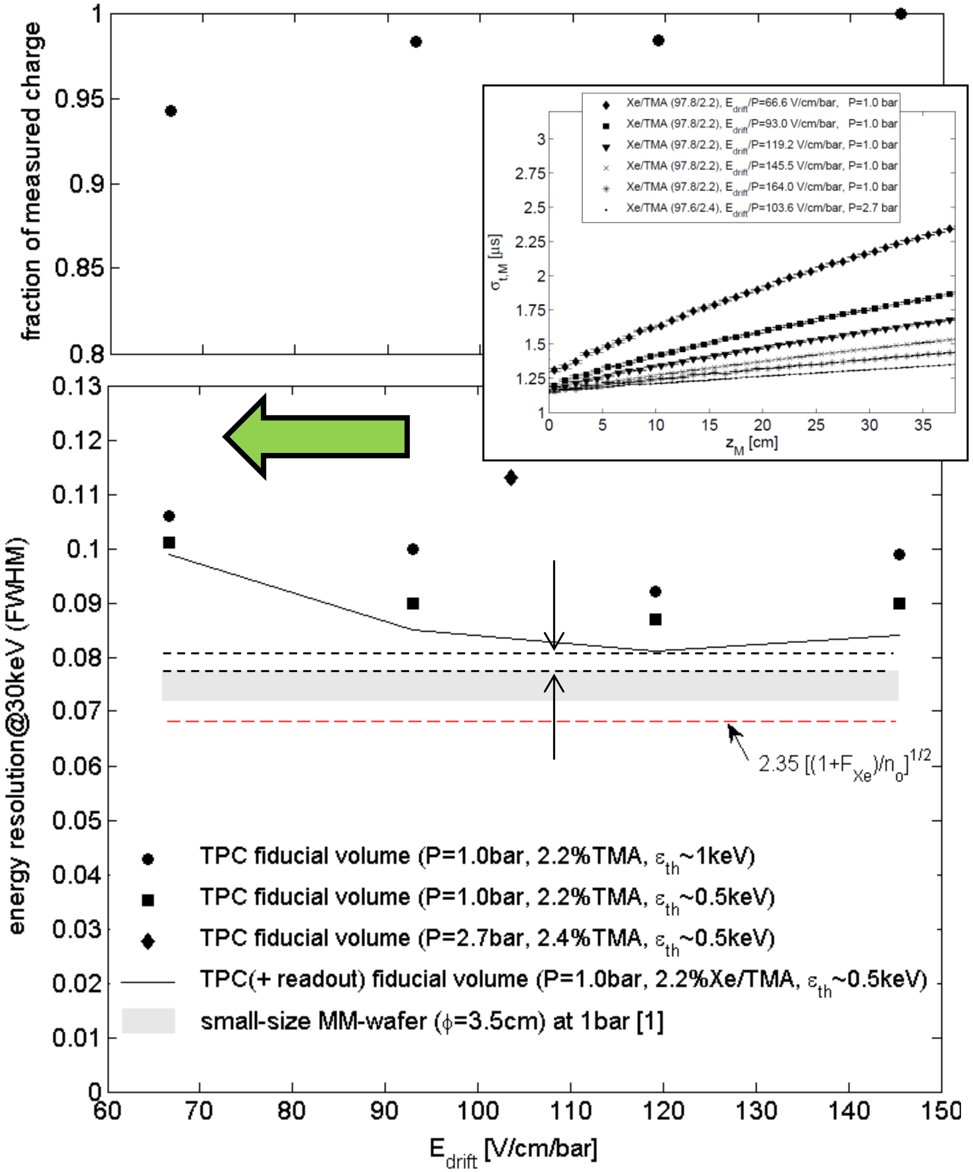
Xe characteristic $K_{\alpha,\beta}$ peaks (isolated clusters) for various conditions

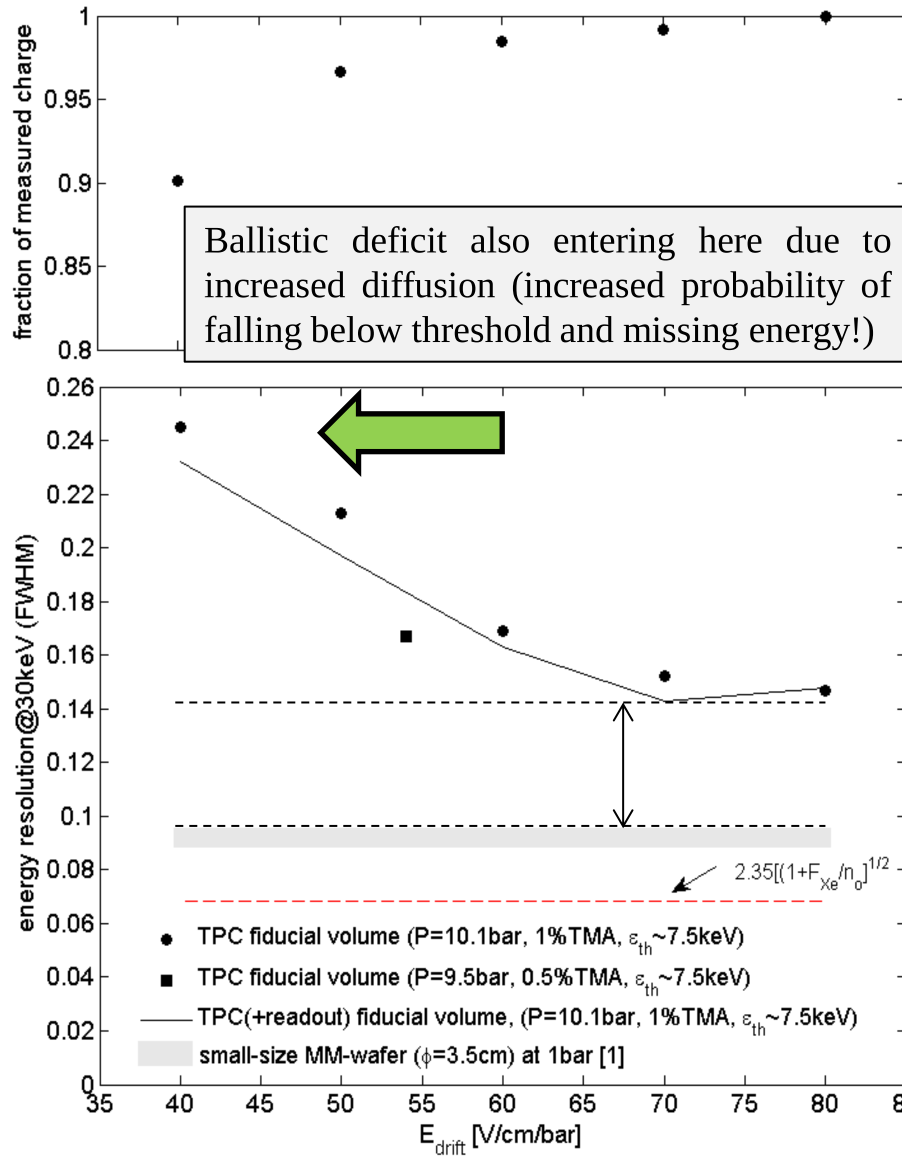
Xe/TMA (99/1)



Xe/TMA (99.5/0.5)

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



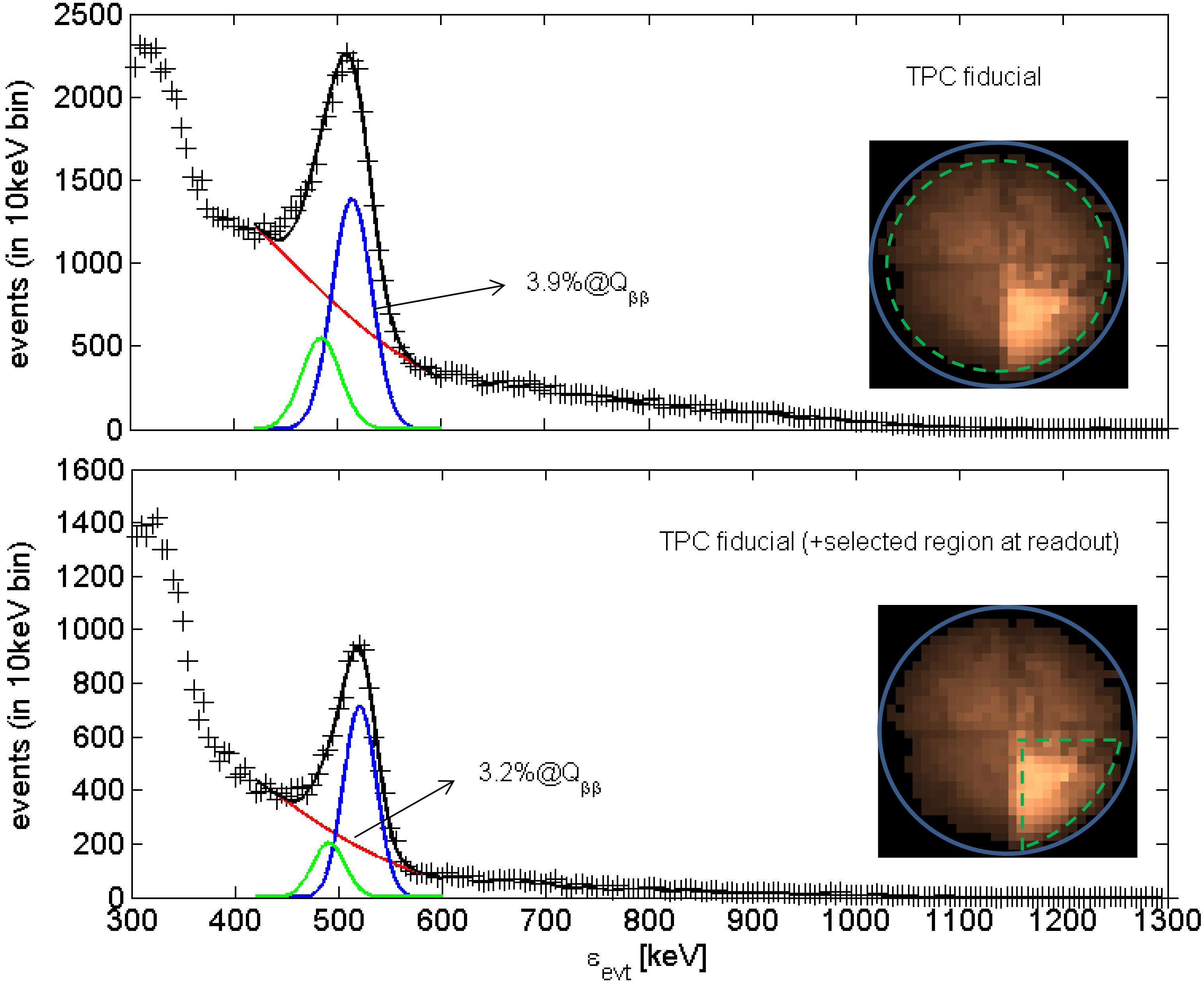


Ballistic deficit also entering here due to increased diffusion (increased probability of falling below threshold and missing energy!)

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



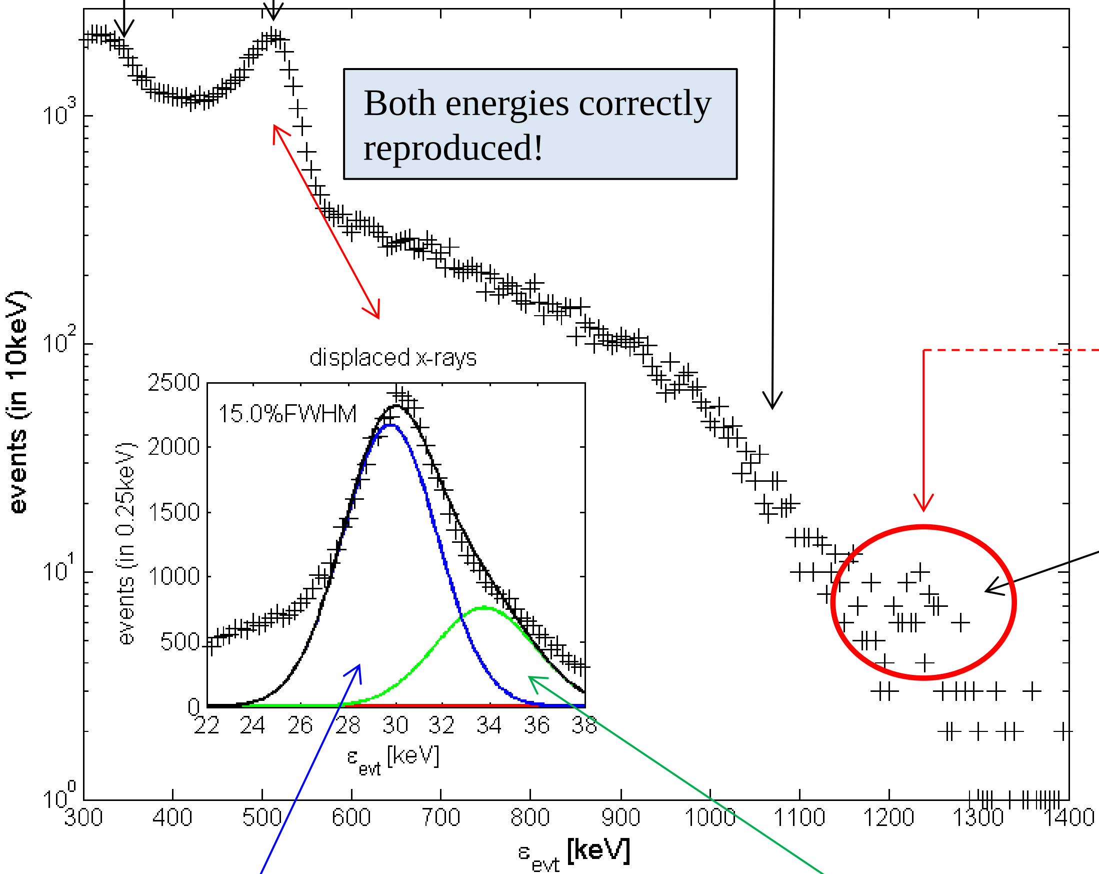
Energy spectrum after calibration at 1-3bar (reminder)

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 (?)



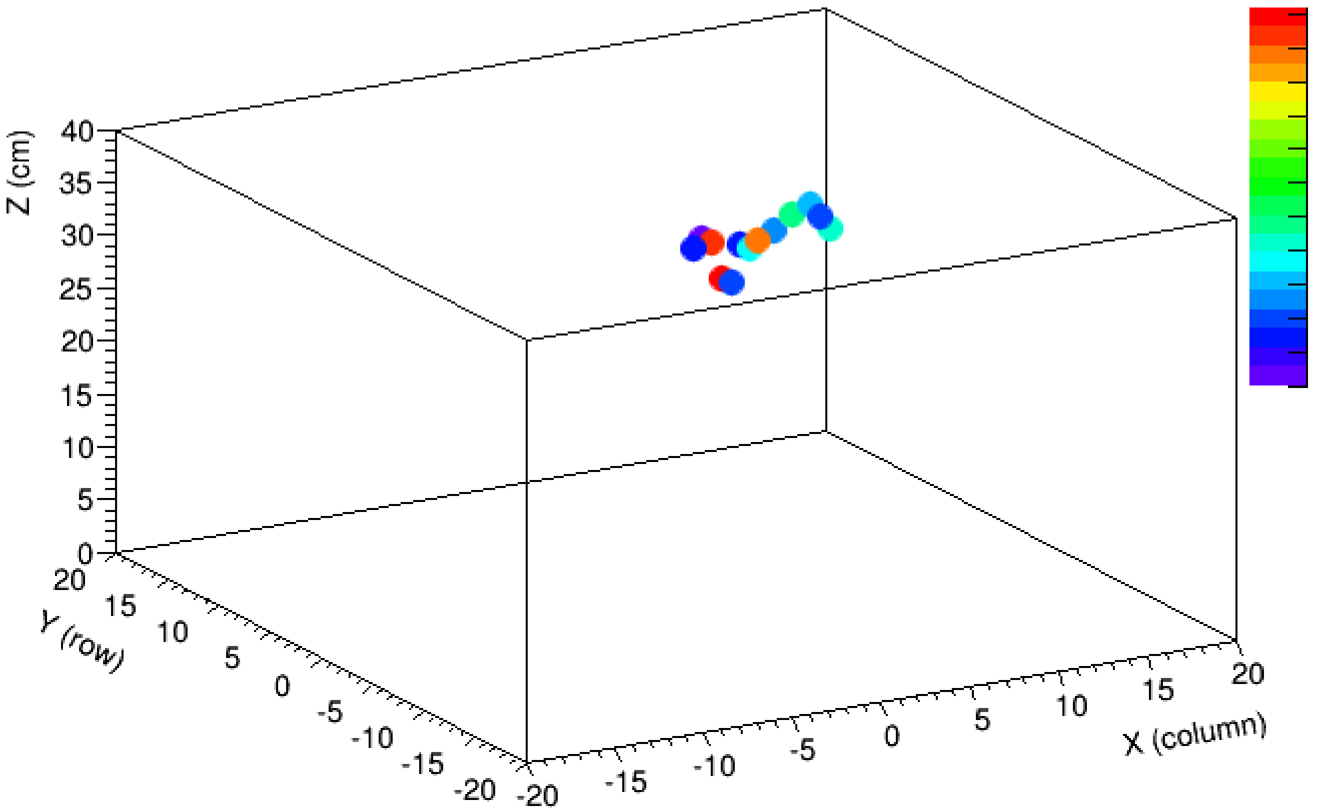
$Q_{\beta\beta,\ ^{136}Xe}/2$

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

(29.8keV Xe-K_α emission)

(33.64keV Xe-K_α emission)

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



End-blob clearly identified

Status

1-3bar campaigns (6months/30live days)

level of connectivity: **92%**

unconnected pixels: **8%**

of which

unclear origin: **1%**

understood(solvable): **5.2%**

damaged pixels: **1.8%**

sector 1 **not functional.**

P=1-2.7bar

%TMA=2.2-2.4

E_{drift}=66-170 V/cm/bar

gain=1600-2000

η<10%/m

Am-source (30-60keV)

HP campaigns (3months/40live days)

level of connectivity: **~90%**

unconnected pixels: **10%**

of which

unclear origin: **1%**

understood(solvable): **4.5%**

damaged pixels: **4.5%**

full plane operative

P=9.5-10bar

%TMA=0.45-1%

E_{drift}=40-80 V/cm/bar

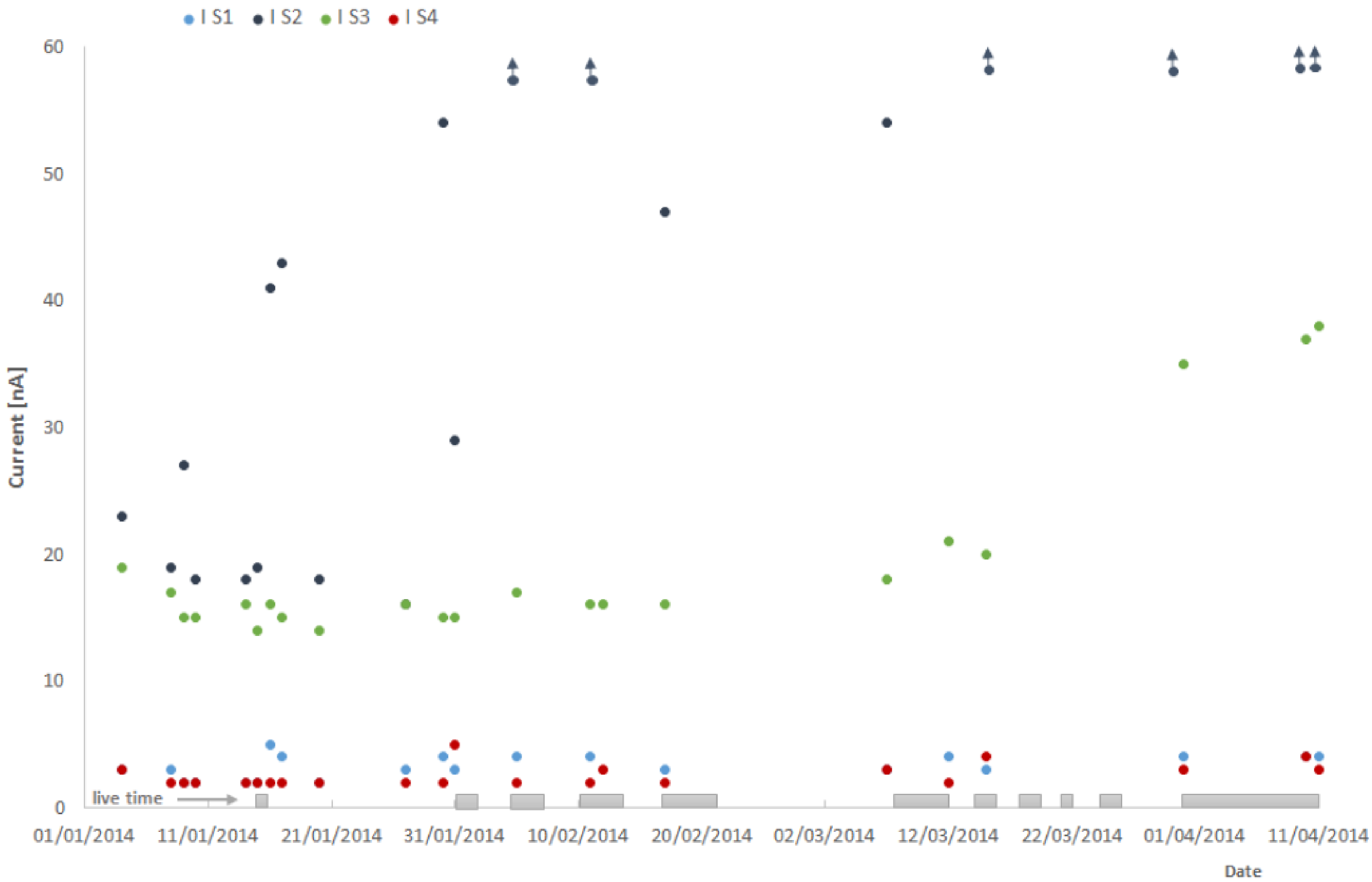
gain=200

η=**?** (no strong indications)

Na-source (511-1270keV)

running continuously at the moment!

Behavior of current with time



Stability and effective exposure

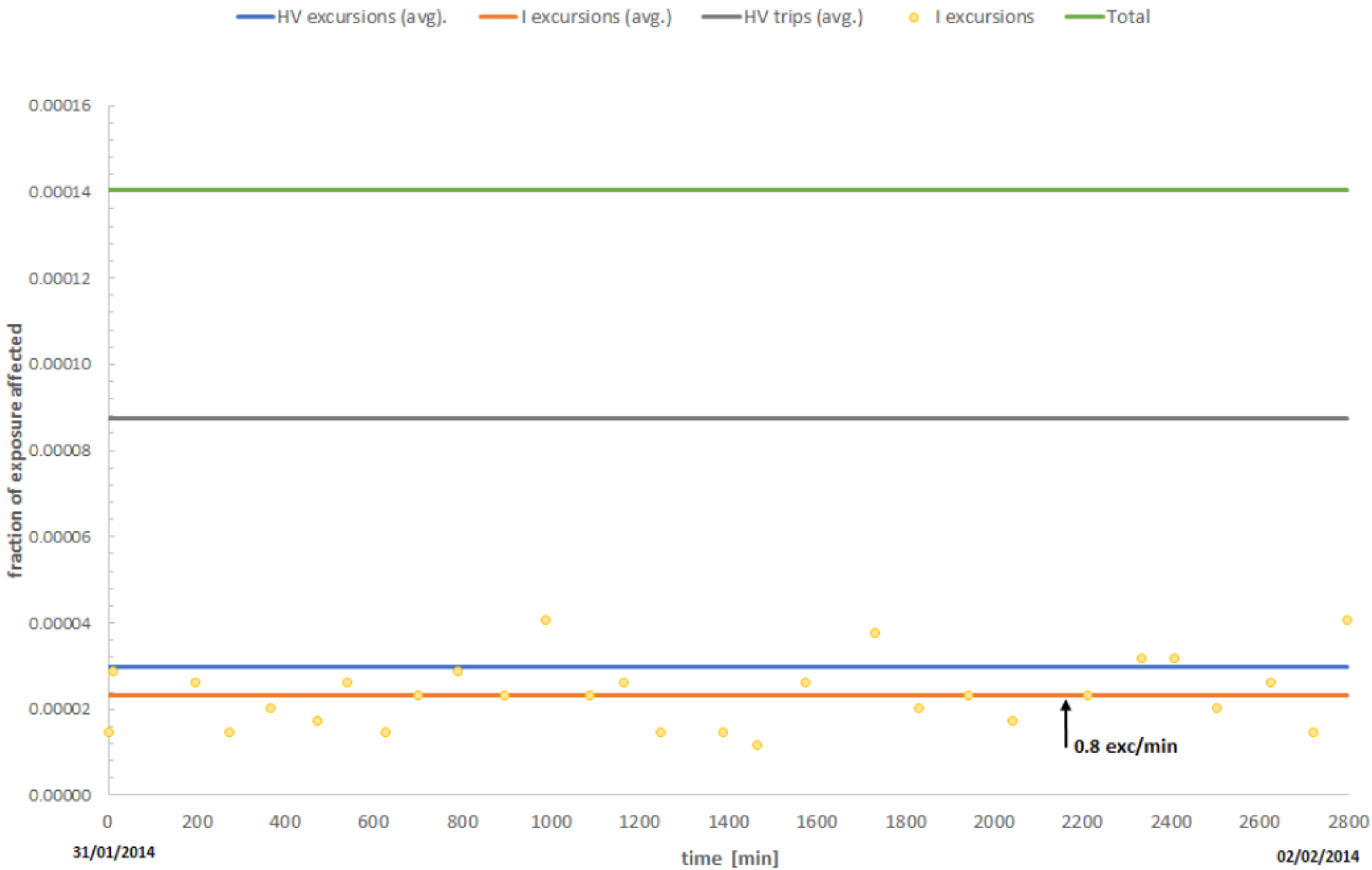
$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{\boxed{Mt}}{\Delta E \cdot B}}$$ ← exposure

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

- Current excursions. Only a 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)

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

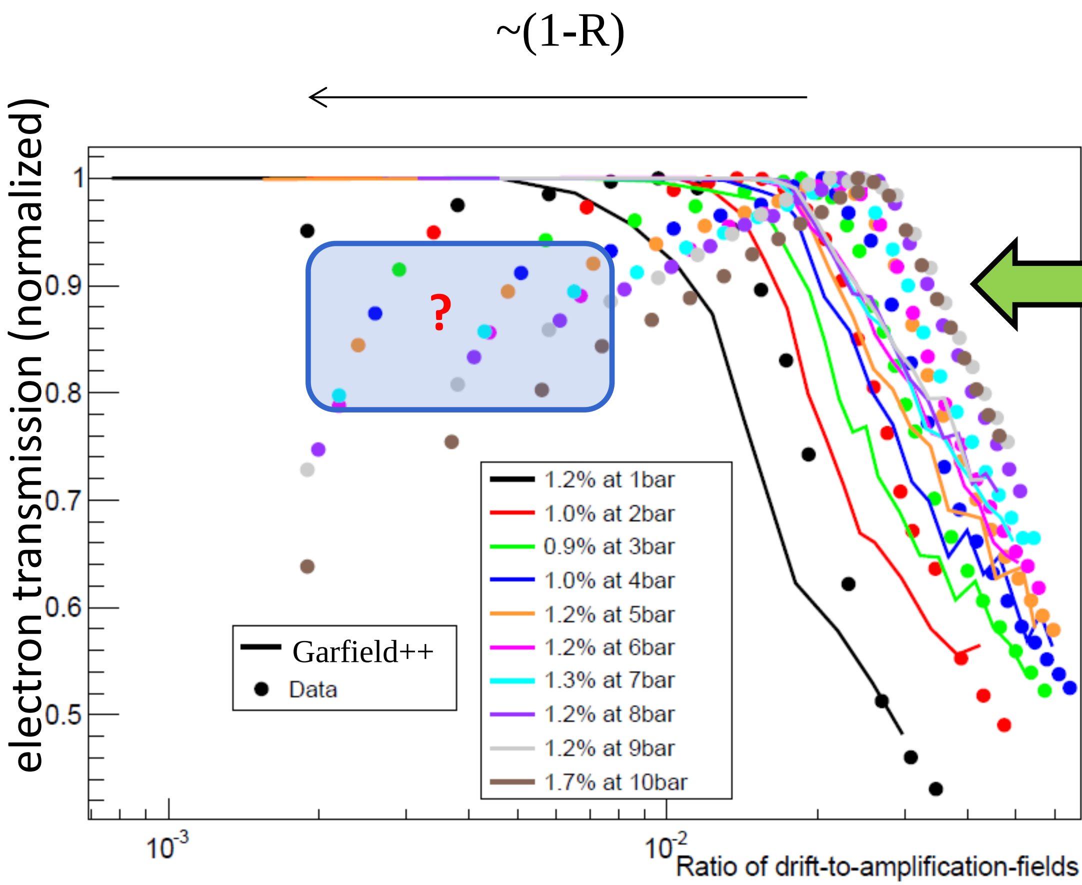
Recombination (electron dynamics)

Penning transfer (ion dynamics)

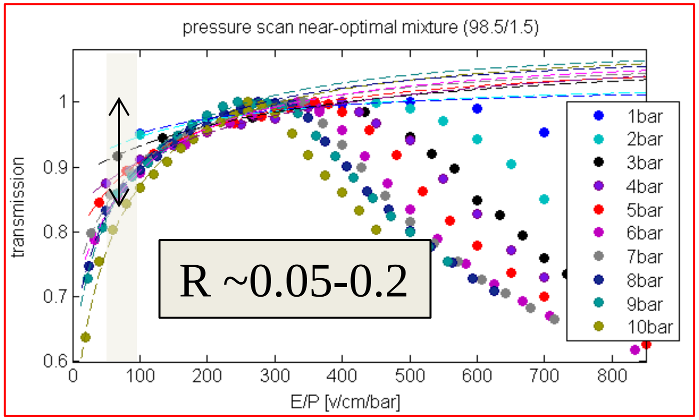
Penning will decrease W as long as recombination stays low and does not over-compensate

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

Behavior in the drift region (recombination)



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

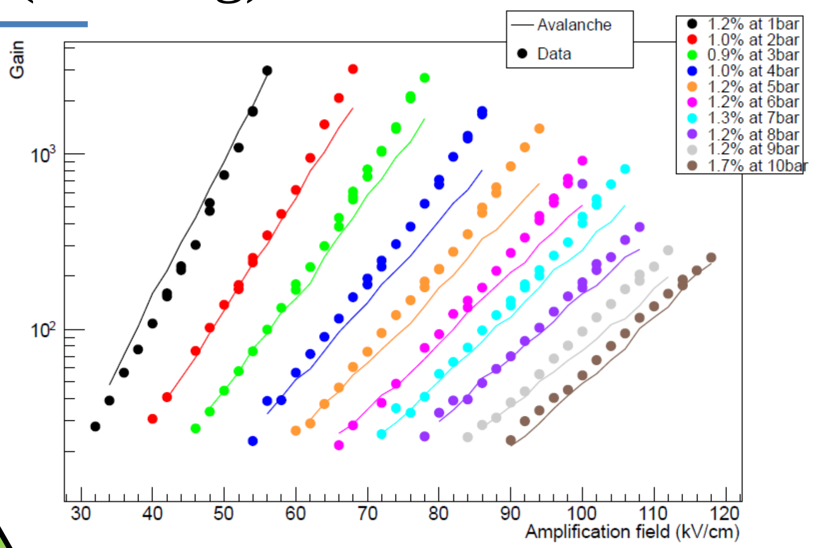


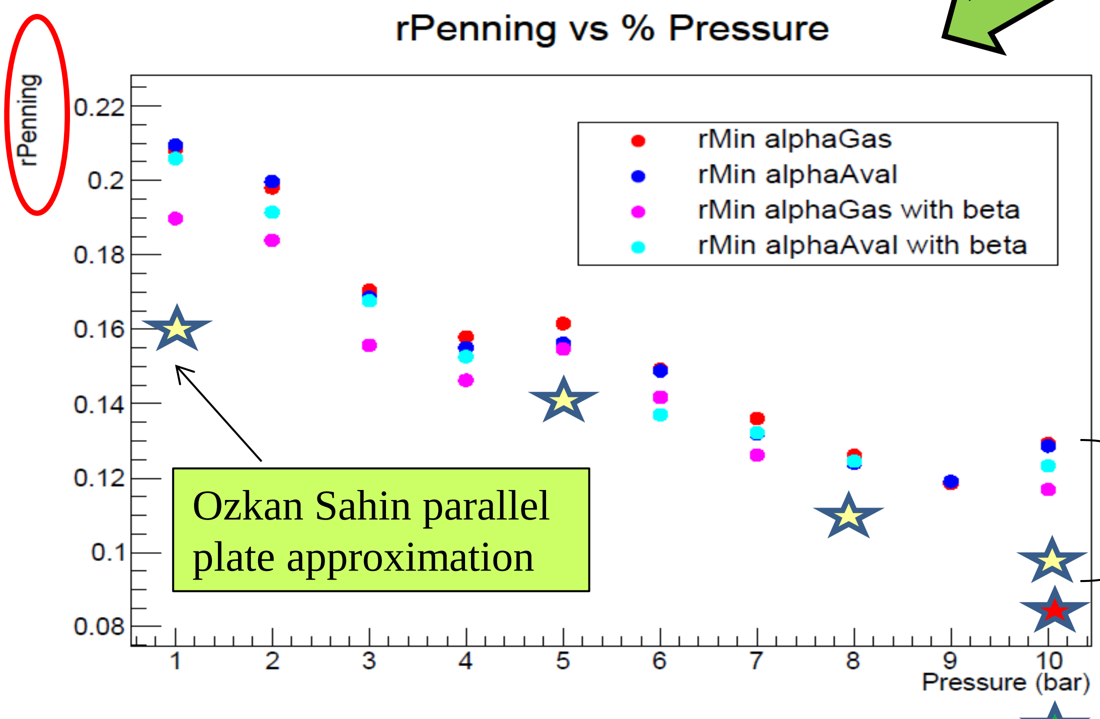
Region at low fields connected to recombination (see talk of D. C. Herrera at WG2).

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 ☹.

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

An experimental campaign with INGRID foreseen!.

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 damaged 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 excellent 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***!.

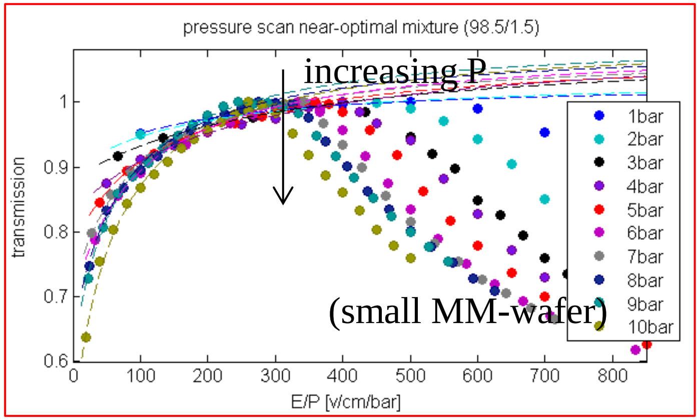
5. **Ongoing experimental and simulation efforts towards modelling** Xe-TMA mixtures in order to address the ultimate energy resolution for this Penning mixture (Penning, recombination, Fano). However, some (small) discrepancies with Magboltz existing at the moment.

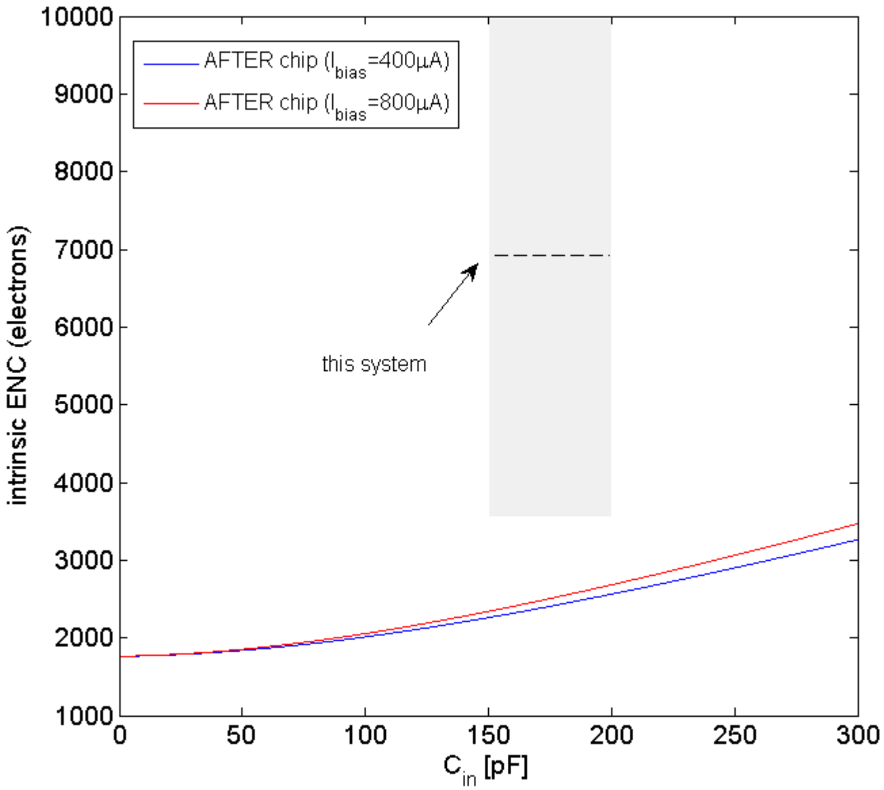
the Zaragoza group

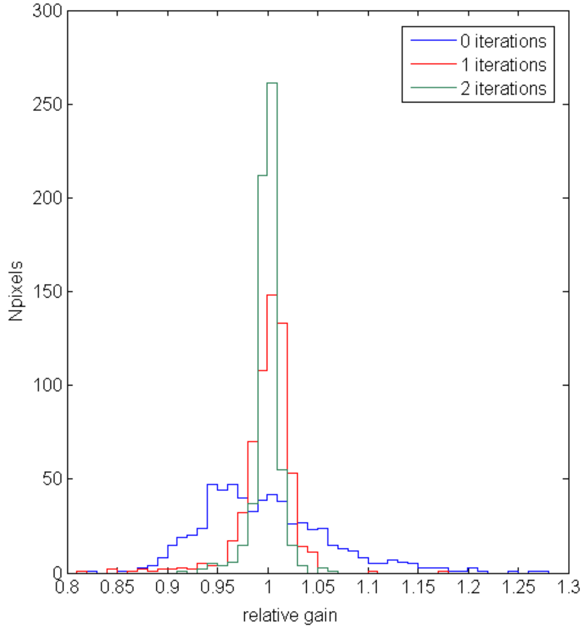
Theopisti Dafni
Igor Irastorza
Juan Antonio Garcia
Juan Castel
Angel Lagraba
Diego Gonzalez-Diaz
Francisco Iguaz
Gloria Luzon
Susana Cebrian
Elisa Choliz
Javier Gracia
Diana Carolina Herrera

special thanks to Saclay-IRFU and to the CERN workshop

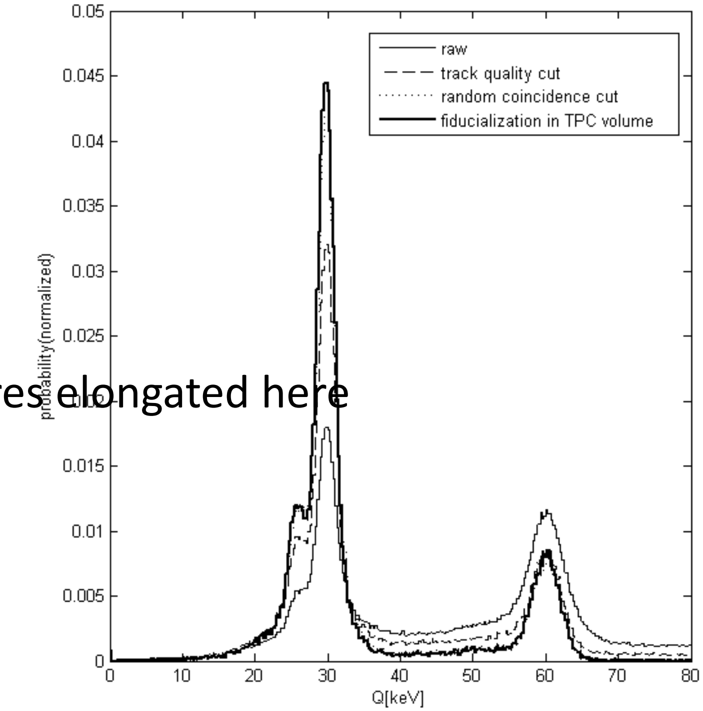
appendix

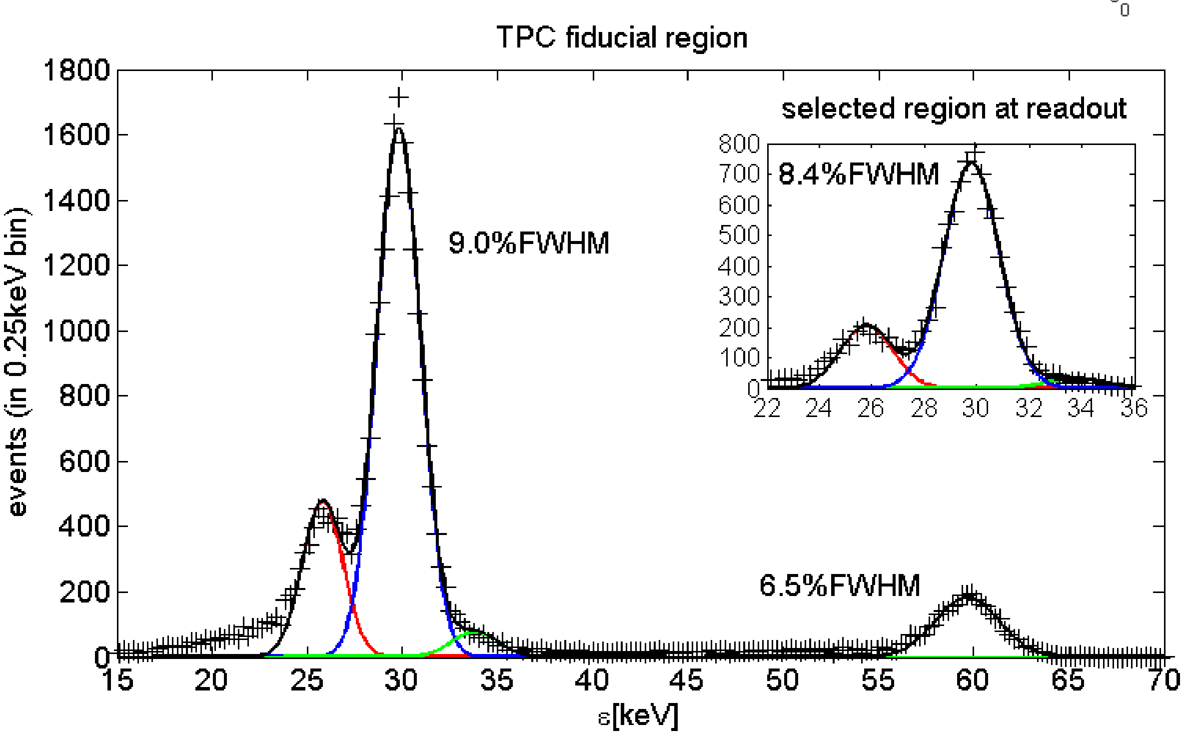

pressure scan near-optimal mixture (98.5/1.5)
increasing P
(small MM-wafer)
transmission
E/P [v/cm/bar]
1bar
2bar
3bar
4bar
5bar
6bar
7bar
8bar
9bar
10bar


AFTER chip (I$_{bias}$=400µA)
AFTER chip (I$_{bias}$=800µA)
this system
intrinsic ENC (electrons)
C$_{in}$ [pF]



Make figures elongated here

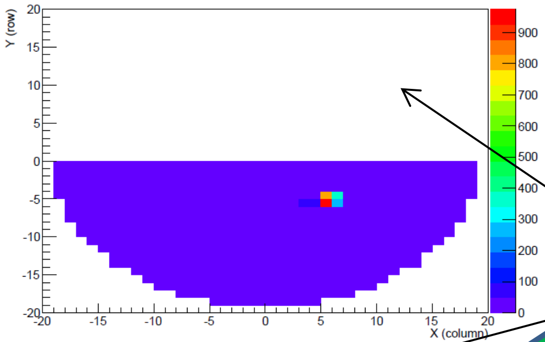


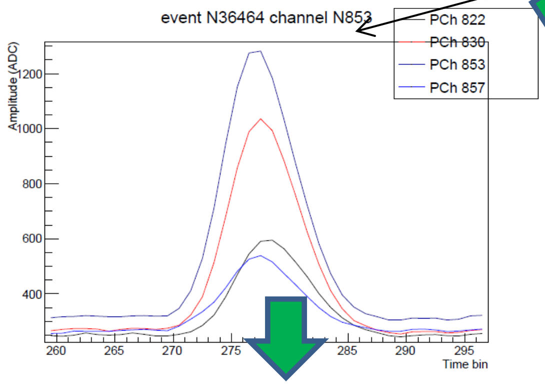


Mixture: Xe-TMA (97.8/2.2)
Micromegas gain 2000
FEE ENC<0.12keV(95%ch):
FEE threshold: 0.5keV
Edrift=bla
P=1bla

mixture: Xe/TMA (~98/2)

fully digitized pulses



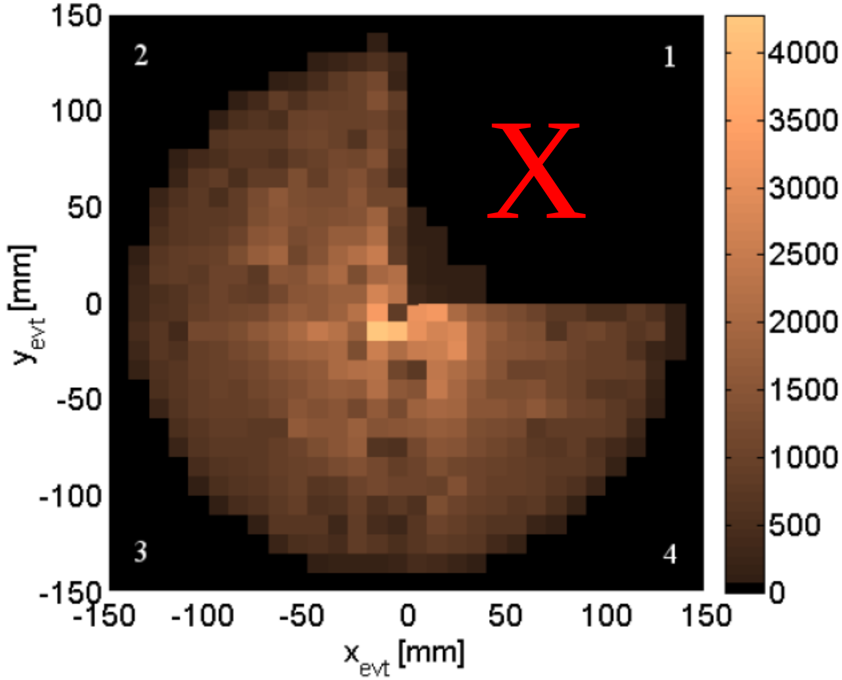


summary (reminder)

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

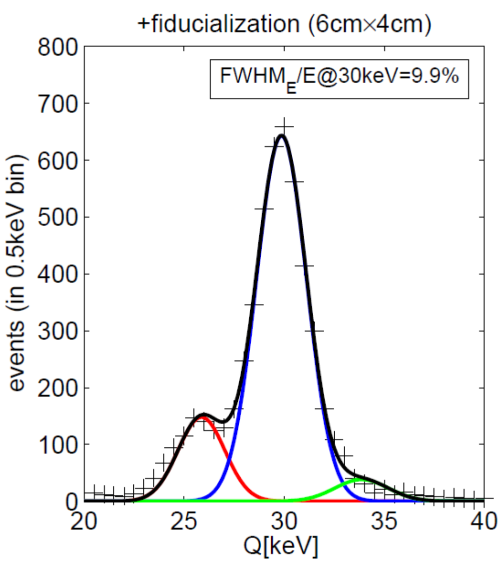
unclear origin: 1%

understood(solvable): 5.2%

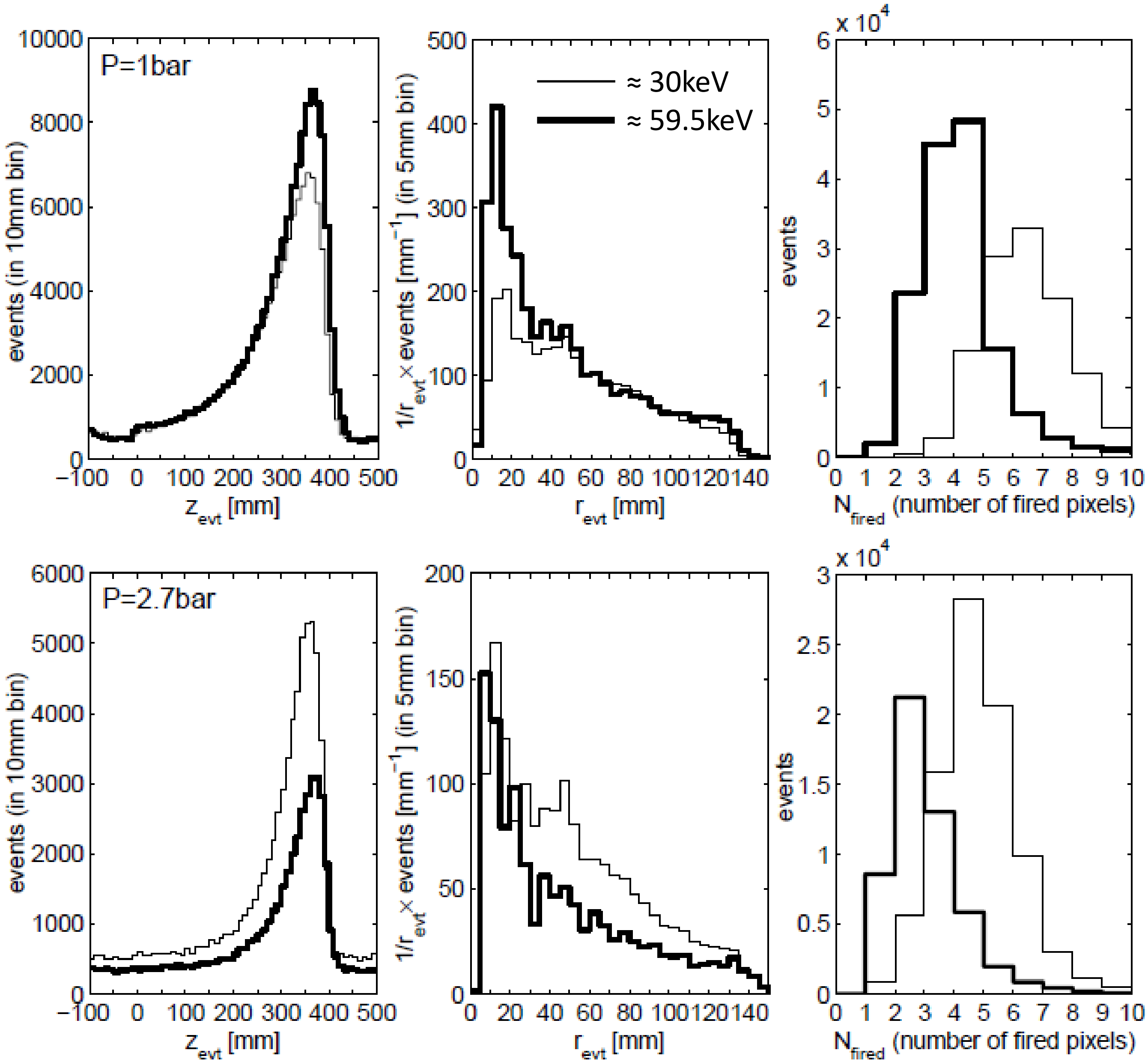
damaged pixels: 1.8%

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

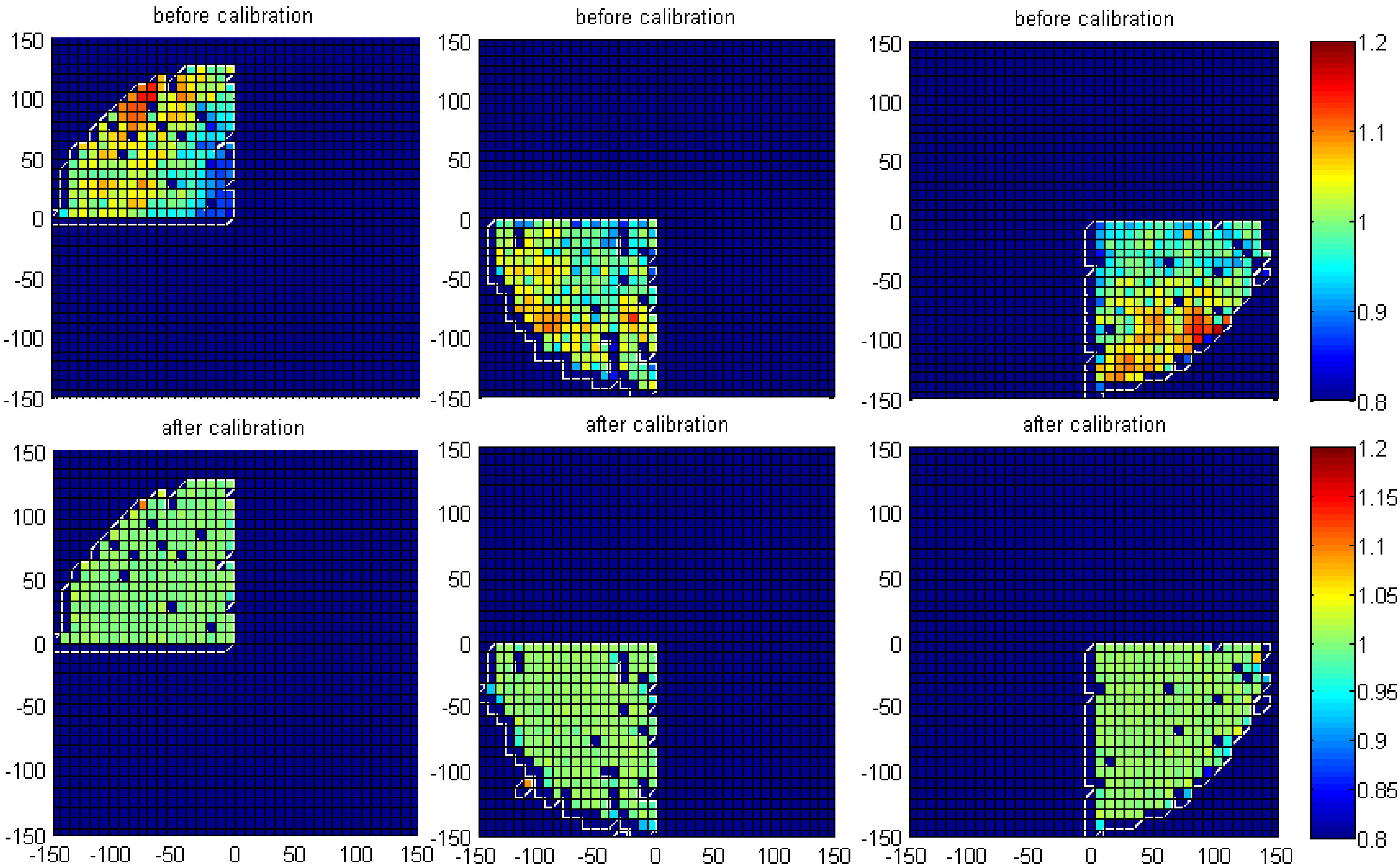
energy resolution



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

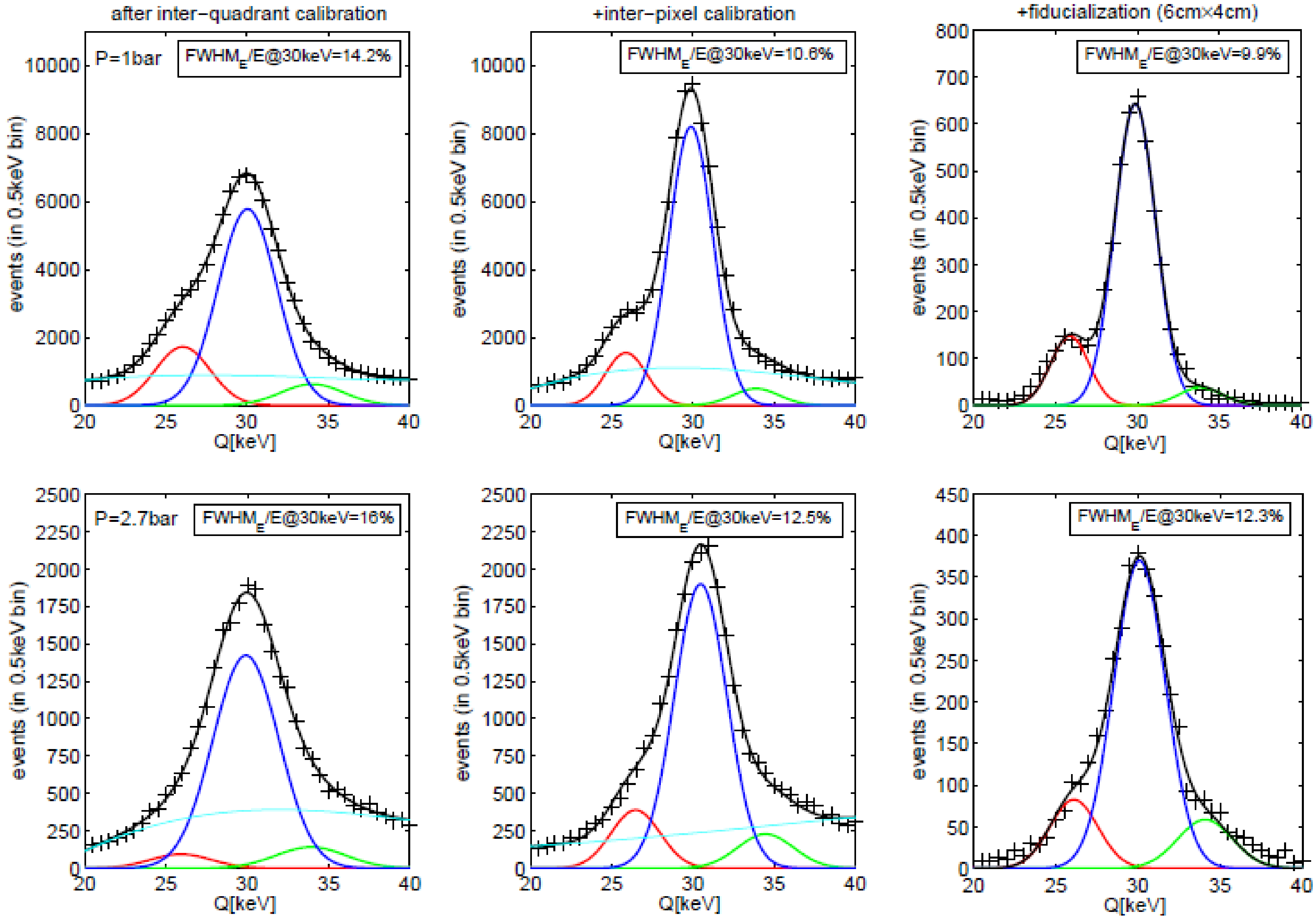


gain maps are necessary in order to achieve ultimate resolution

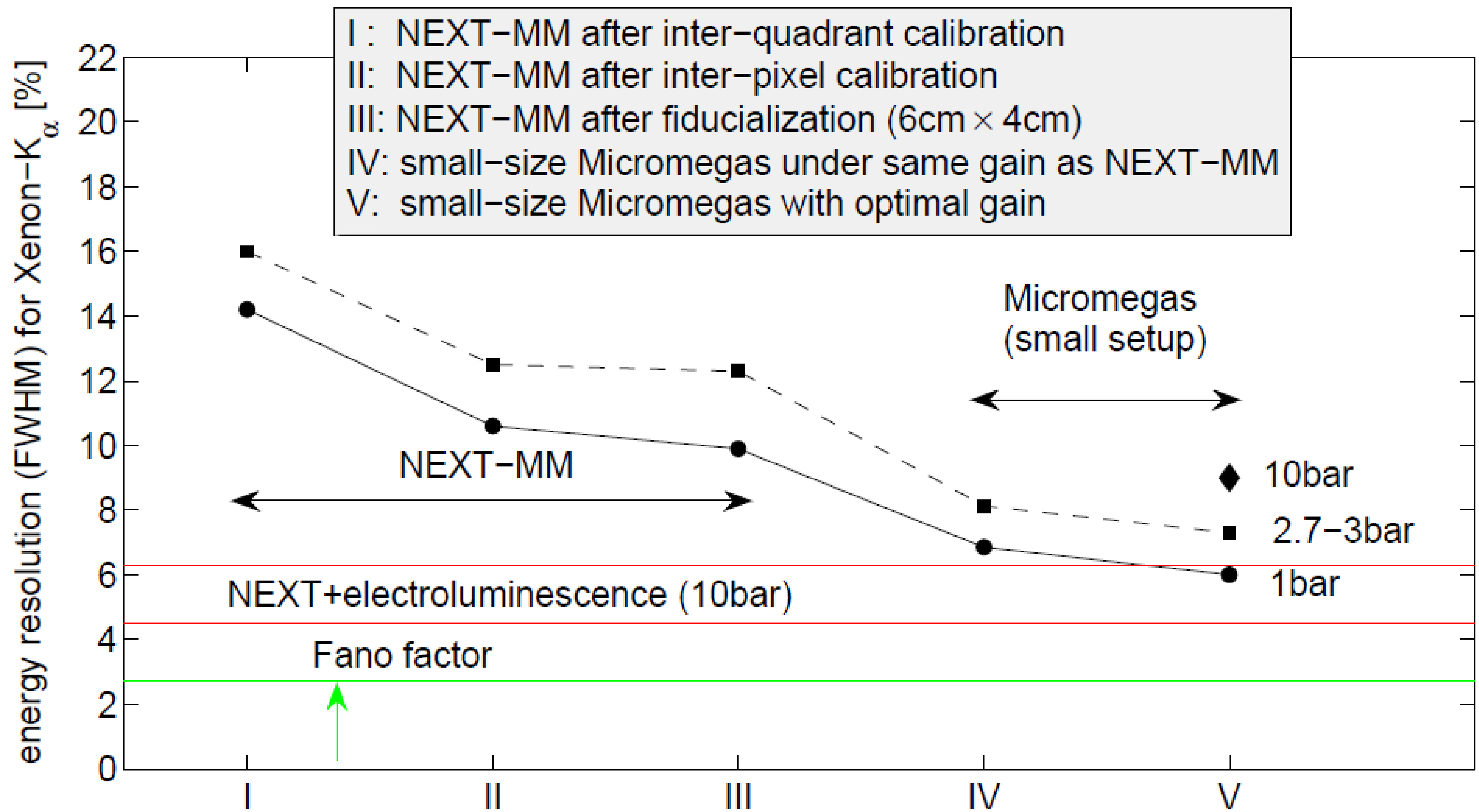


obtained by aligning the 30keV peak pixel by pixel

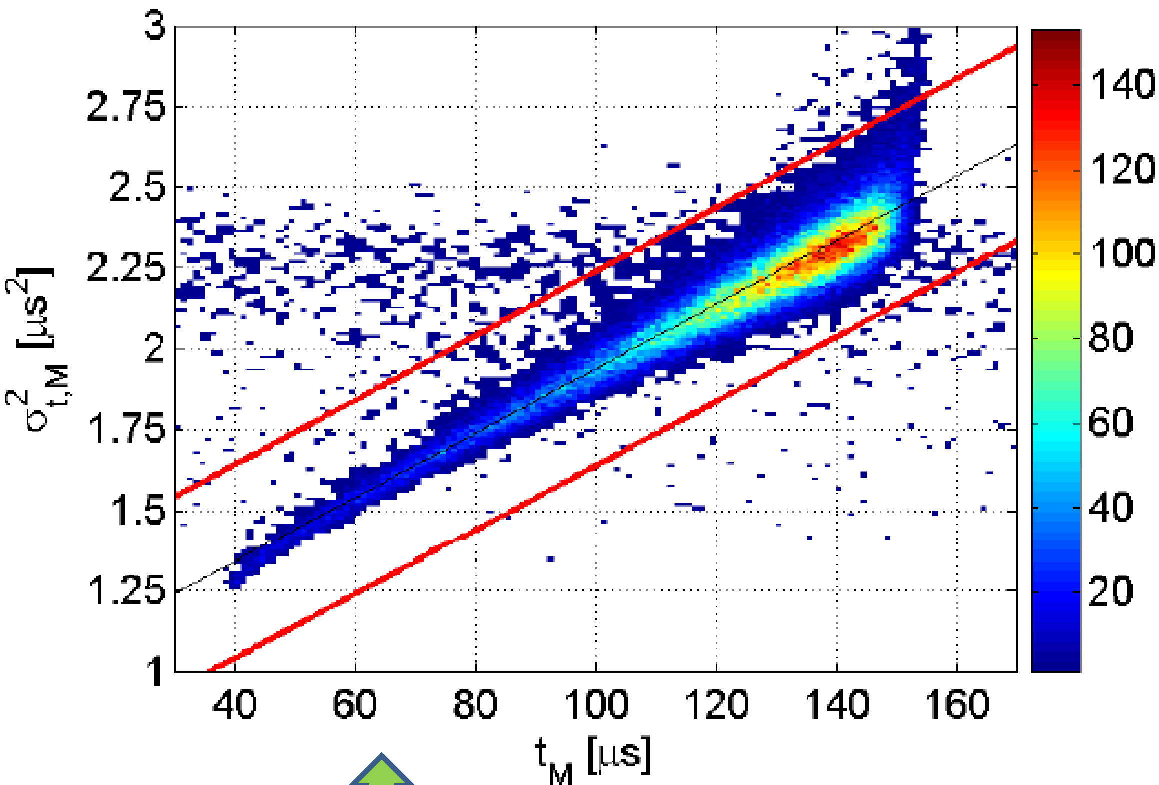
main performance with low energy X-rays in the 1-2.7bar regime

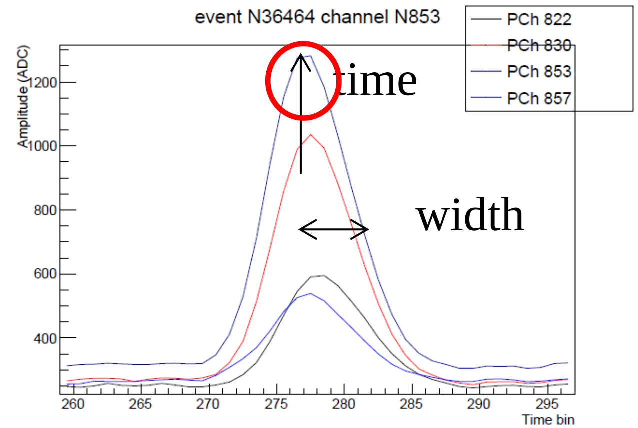


half-way performance cross-comparison (with a grain of salt)



time-width pulse correlations through drift & longitudinal diffusion



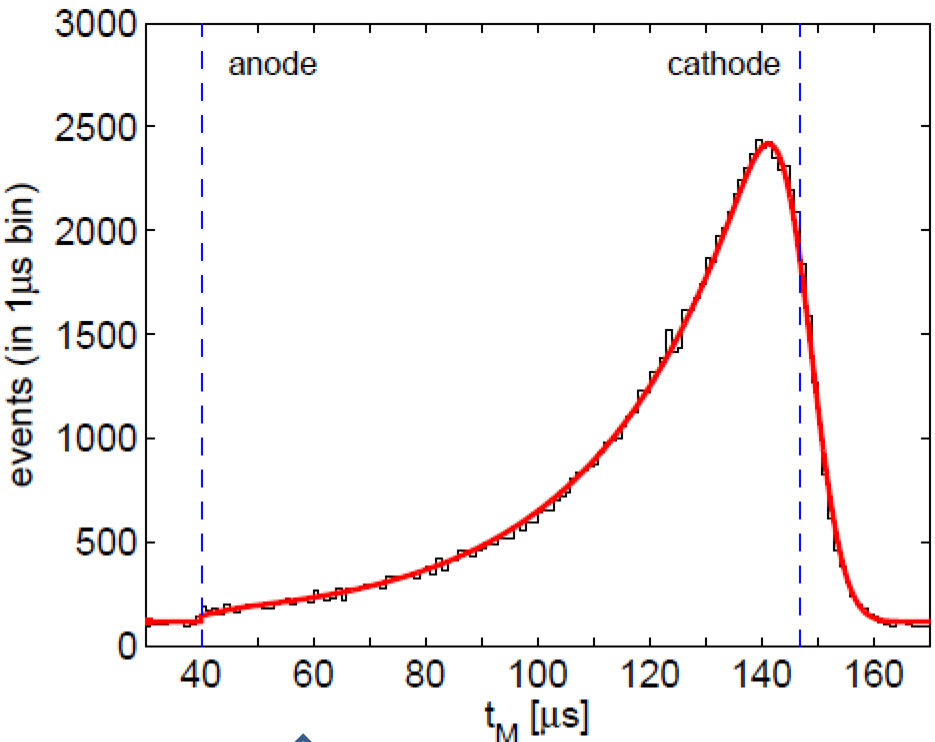


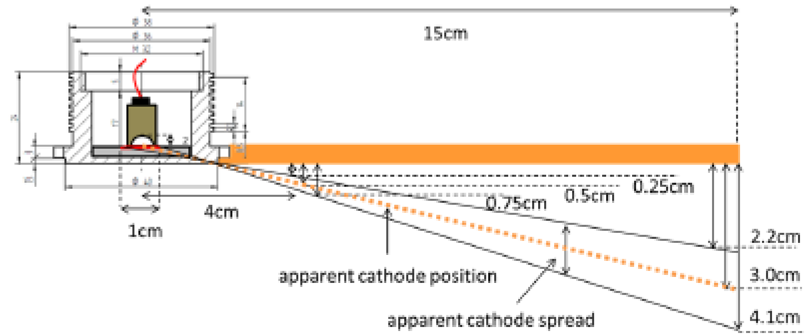
- Select **30keV events**.
- Take pulse with highest charge.
- Take a fiducial distance of 2.5cm with respect to the chamber edge

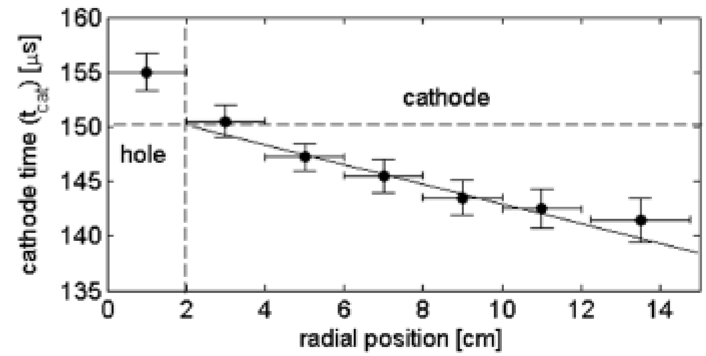
$$\sigma_{t,M}^2 = \sigma_0^2 + \frac{2D_L}{v_d^2} t_M$$

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)





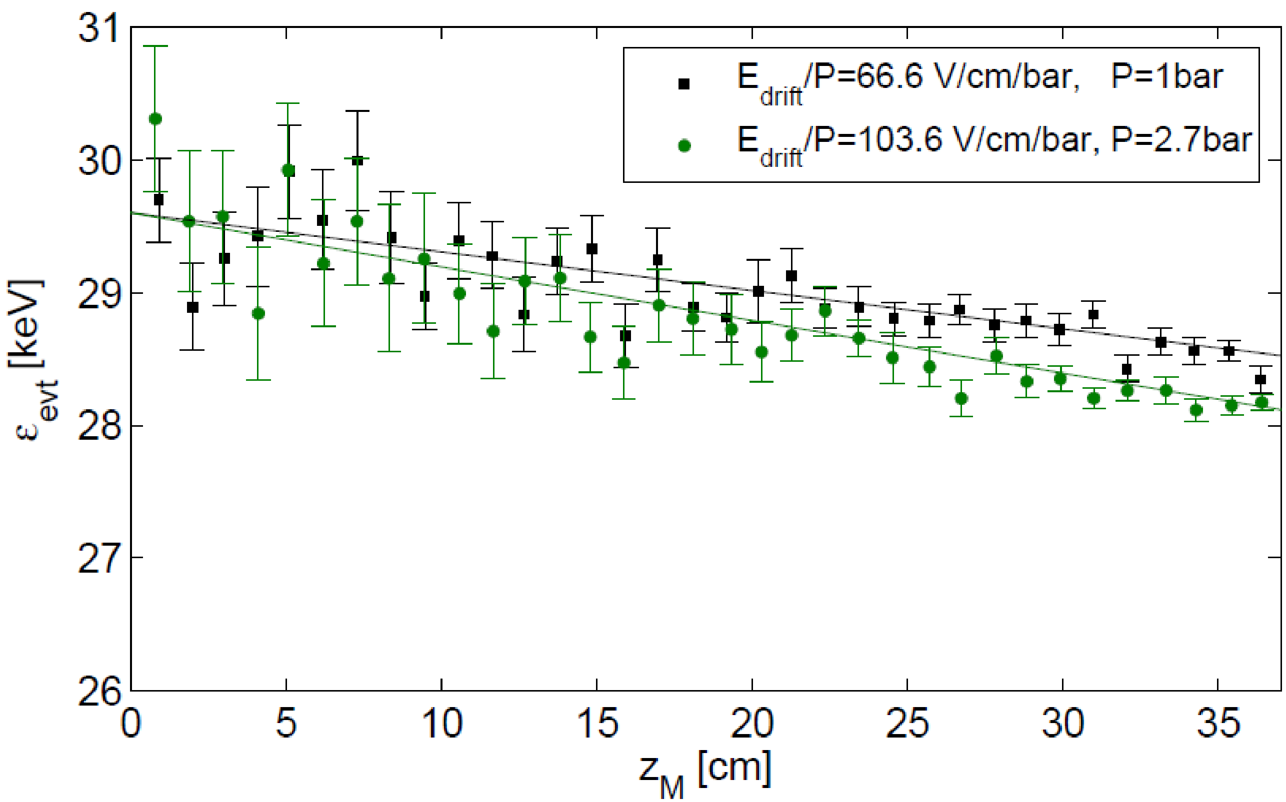


operational fit to exponential convoluted with Gauss

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

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

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

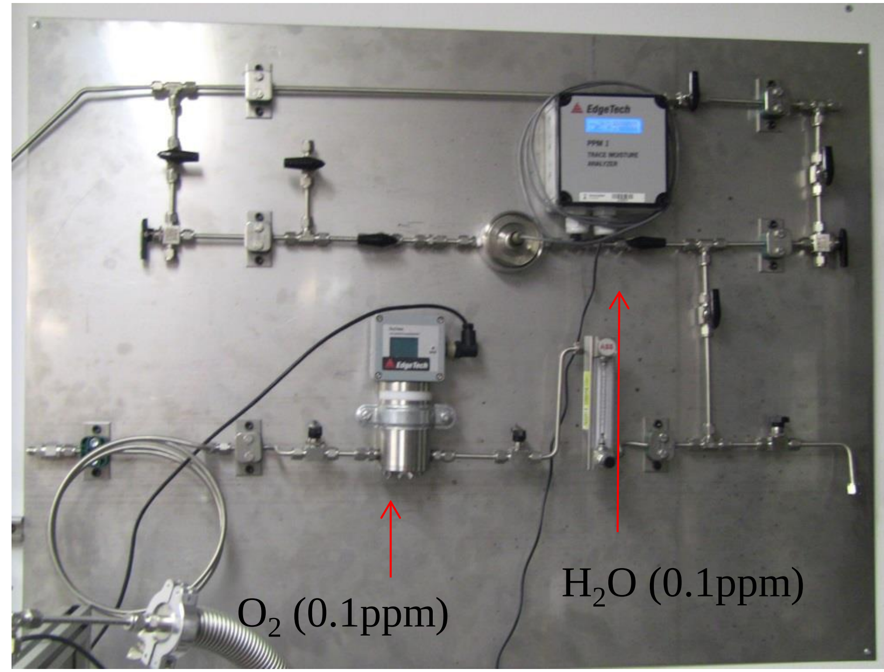
new bottles and piping

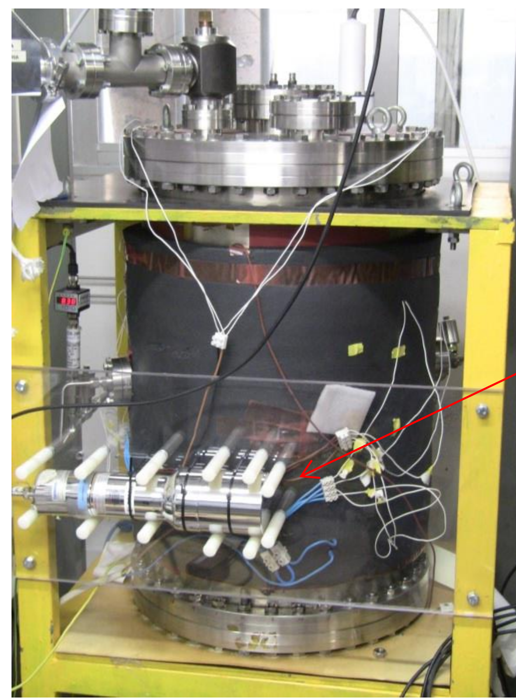
TREX-light (pure Xenon line)

NEXT-MM recovery bottle

NEXT-MM expansion chamber

sensor panel





NaI detector
and Na source