Characterization of Xe-TMA mixtures with NEXT-MM

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LS Canfranc, 27/05/2013

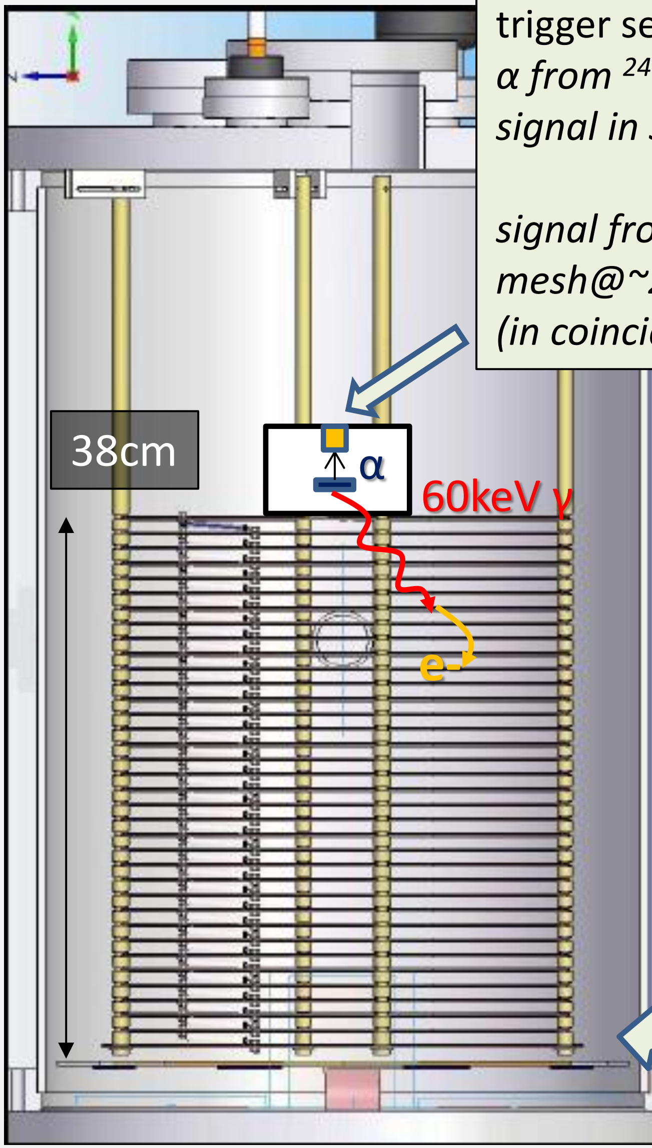
disclaimer:

A detailed description of the technical details of NEXT-MM will be circulated inside the collaboration soon.

I will focus here on the main results of potential interest for NEXT-100

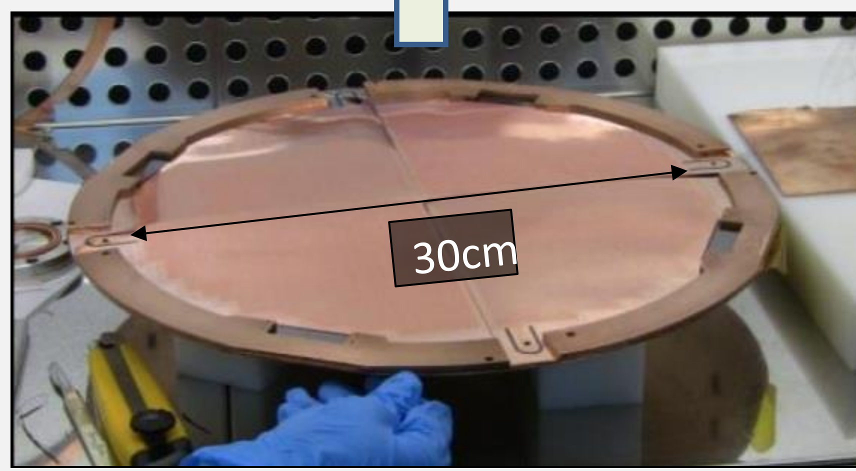
Part 1: system description

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



field-cage

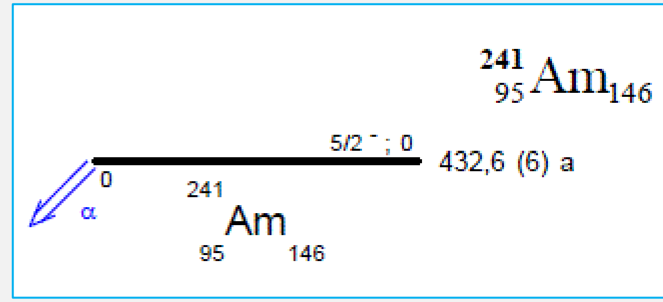
T2K *electronics* (based on the AFTER chip)

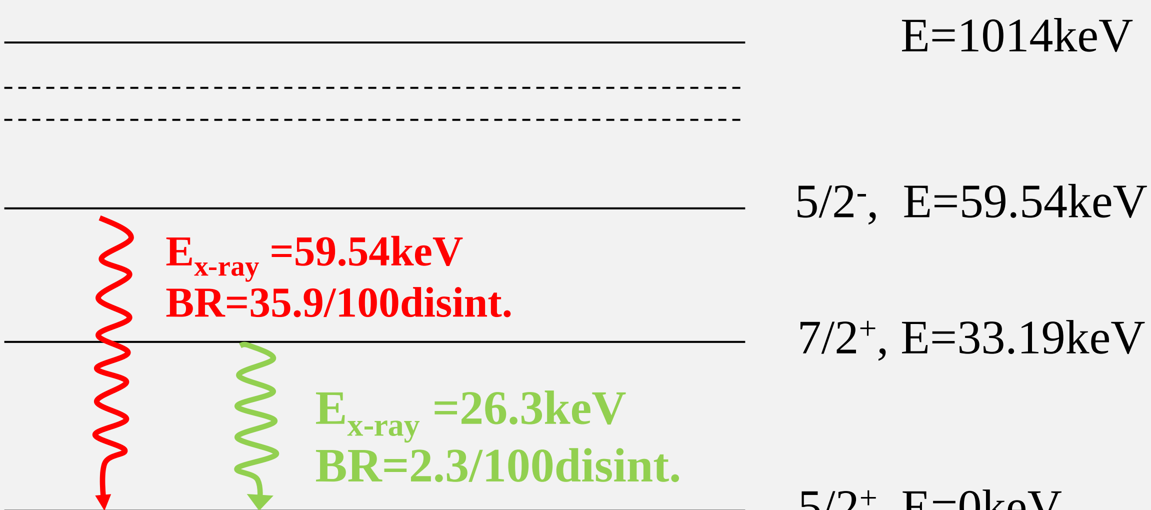


0.8cmx0.8cm pixelized *microbulk Micro-Megas*

E_α=5.578MeV(84.45%), 5.535MeV(13.23%)

$^{237}_{93}Np_{144}$
Q^α = 5637,82 keV
% α = 100





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
4. orphan K_α: 29.80 keV } → 3
5. escape K_β: 59.54-33.6 = 25.94 keV
6. full absorption secondary Am-peak: 26.3keV } → 4

Xe atomic properties

Edge energies, keV	
K	34.5820007
L_1	5.45200014
L_2	5.0999999
L_3	4.78100014
M	1.14300001
K-alpha	29.802
K-beta	33.644001
L-alpha	4.11100006
L-beta	4.42199993

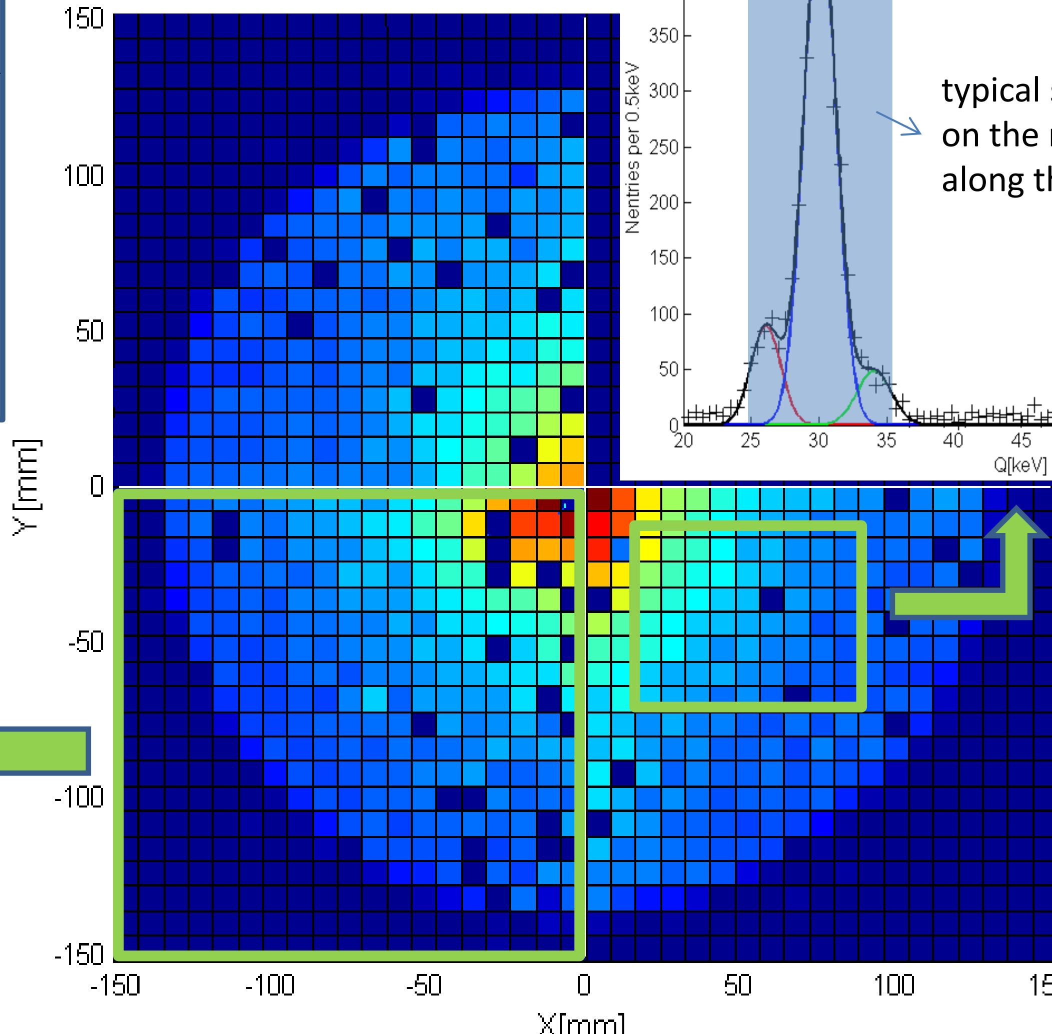
mixture: Xe/TMA (93/7)

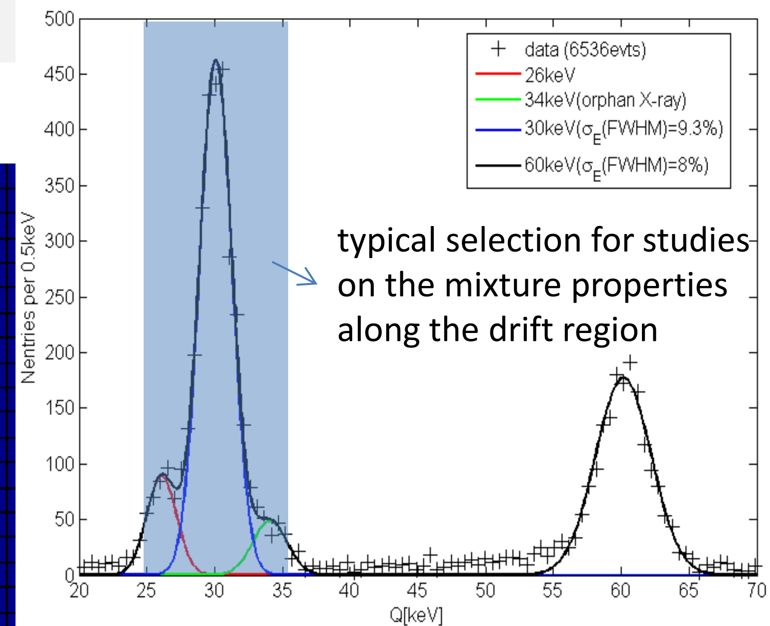
status as of today, before increasing pressure

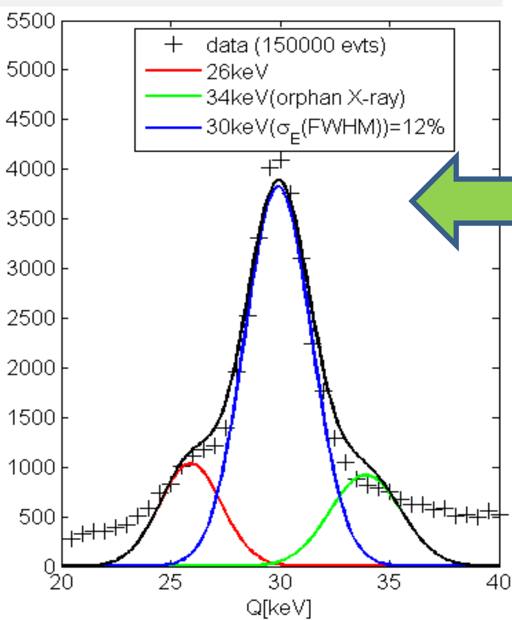
level of connectivity:	92%
unconnected pixels:	8%
of which	
unclear origin:	1%
understood(solvable):	5.2%
damaged pixels:	1.8%

sector 1 to be repaired for the HP-campaign

blob position at x-y plane

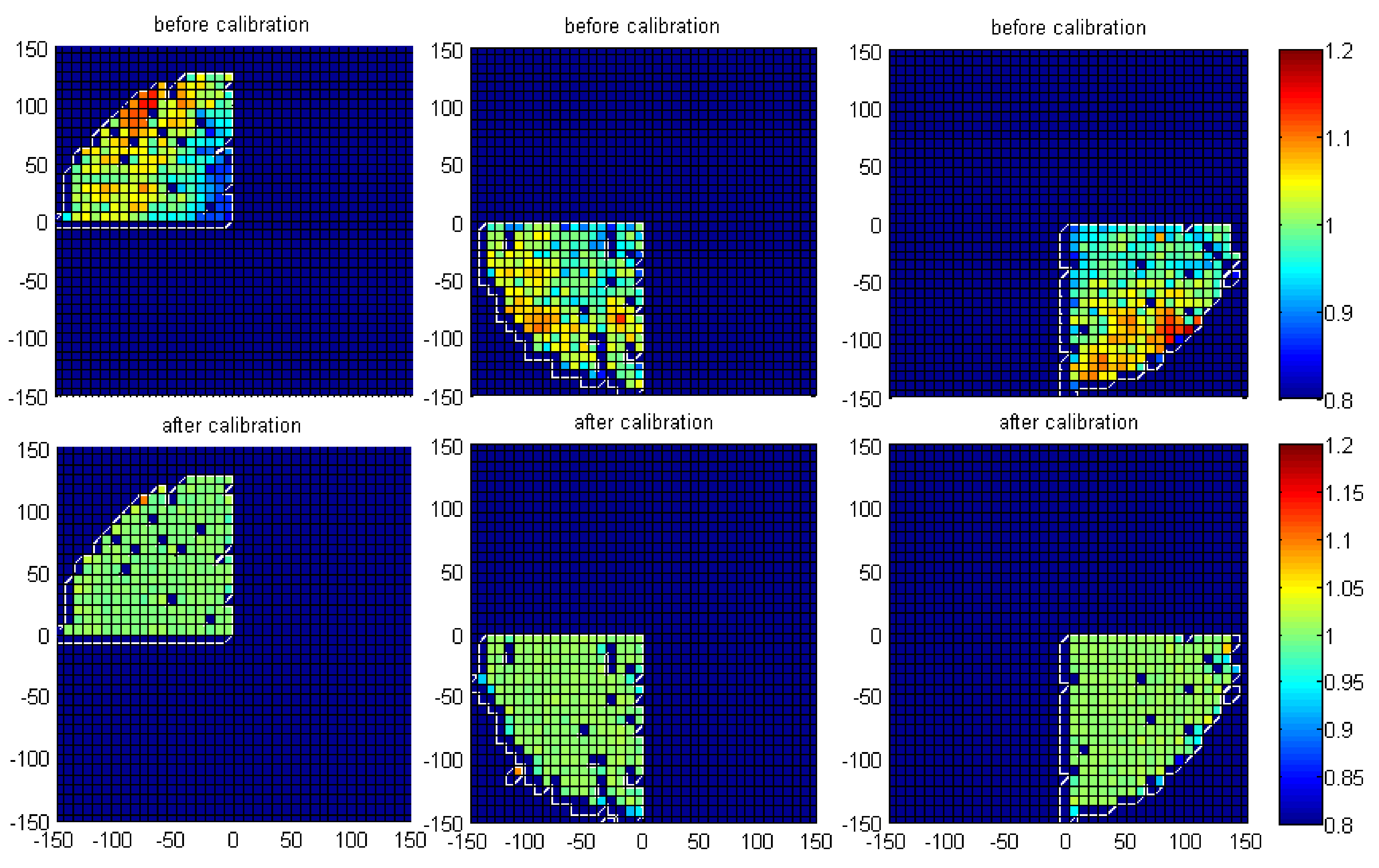






tails mainly due to i) field edge effects, ii) bad event containment, iii) to a minor extent to unconnected pixels

gain maps are necessary in order to achieve ultimate resolution



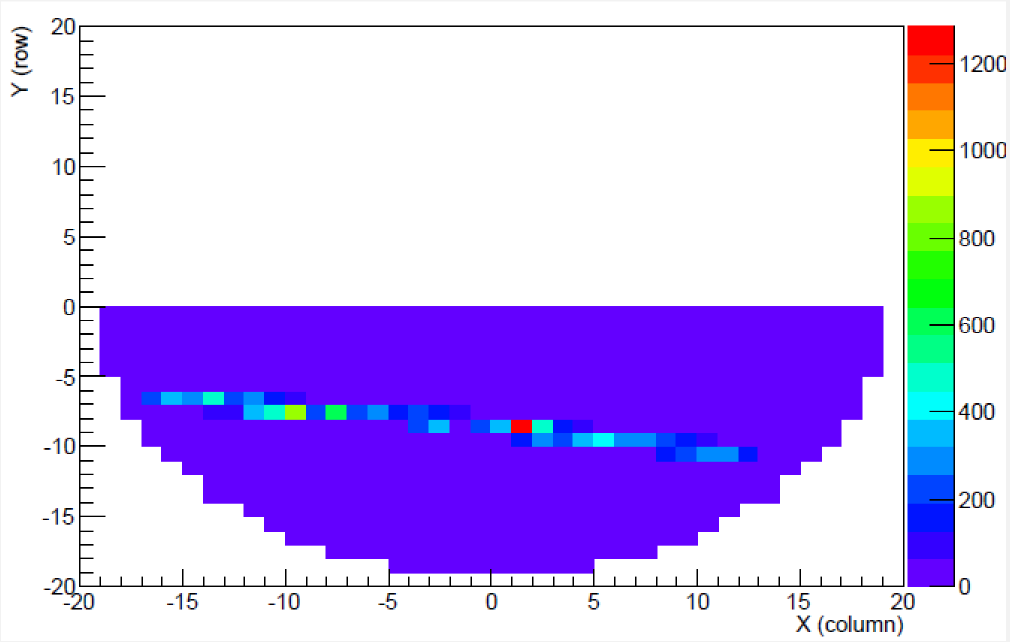
some typical events
(from old run: only lower half instrumented)

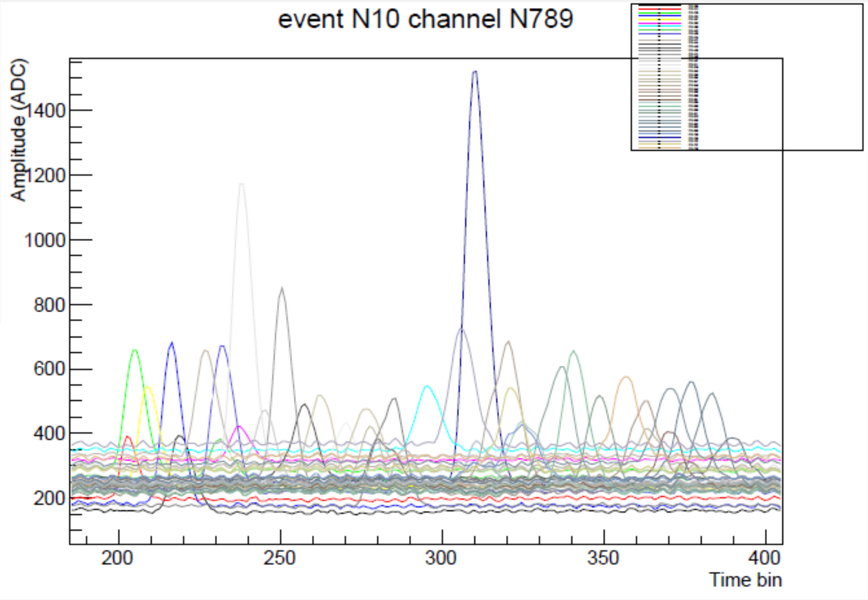
Pablo Pons

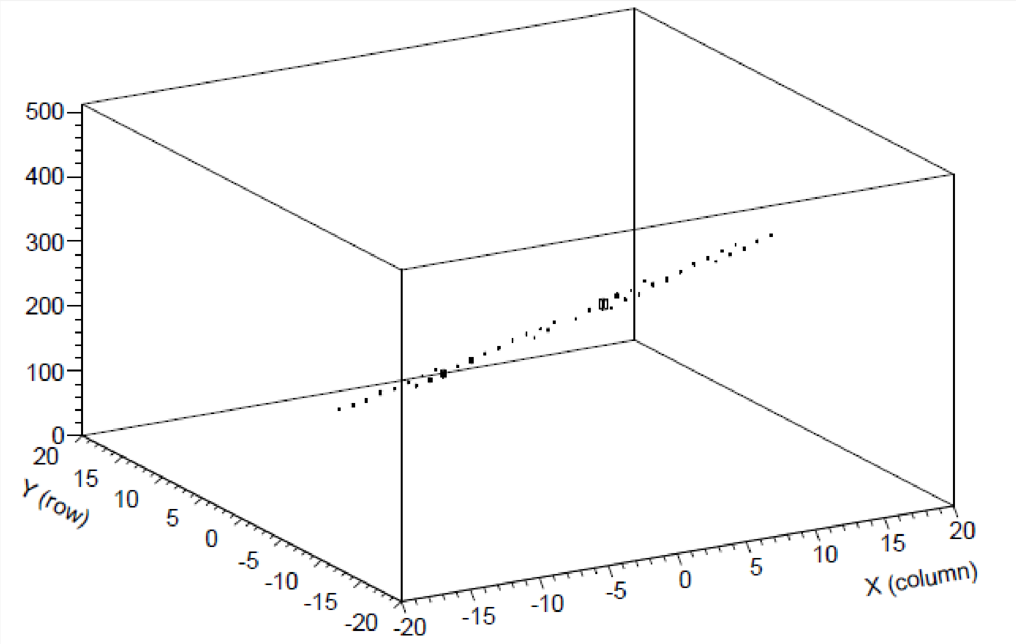
1. Muons

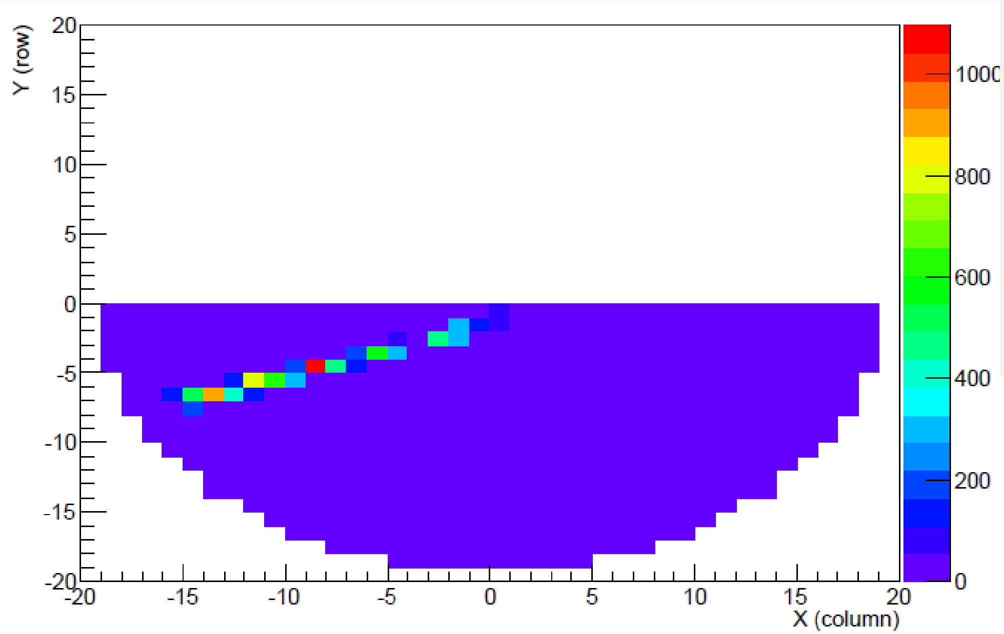
in random coincidence with trigger

(no analysis, just selection on the event display)

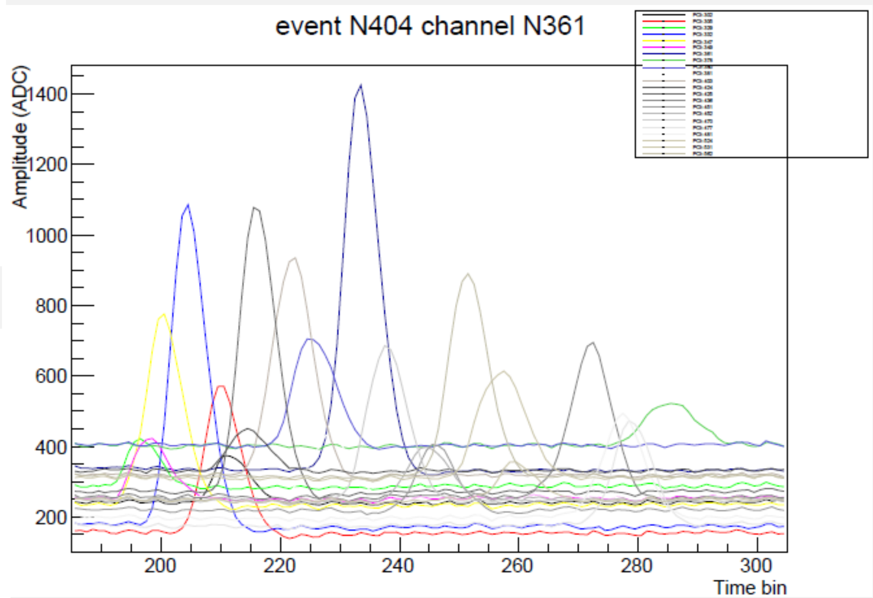

Y (row)
X (column)


event N10 channel N789
Amplitude (ADC)
Time bin

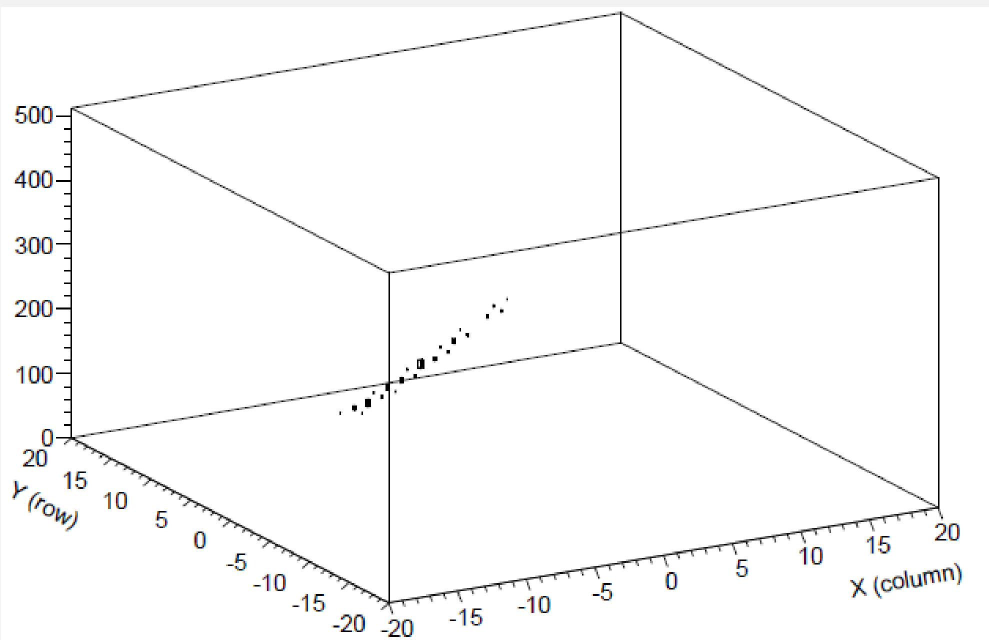

Y (row)
X (column)



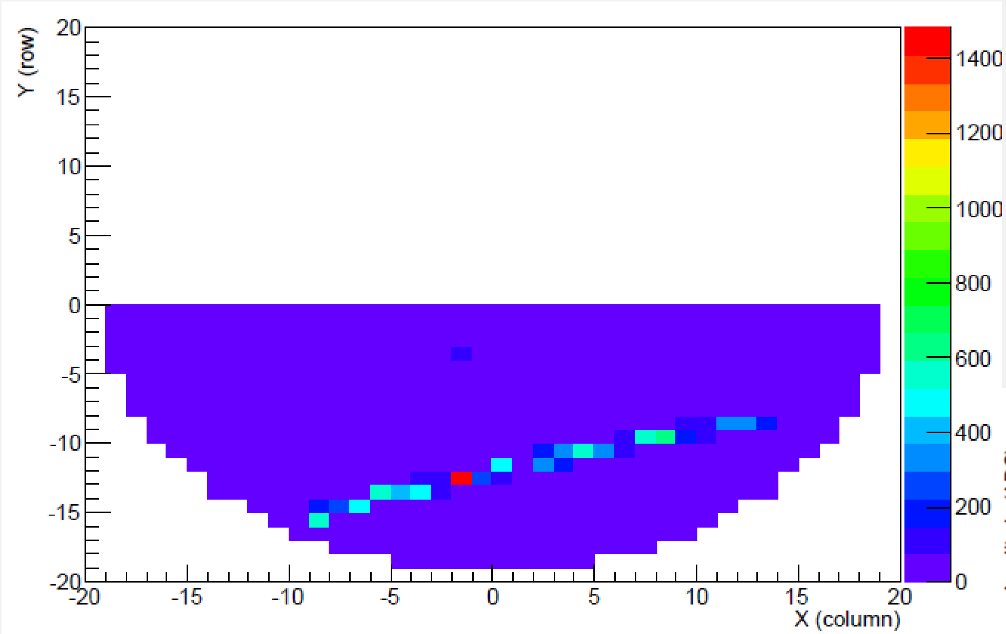
Y (row)
X (column)

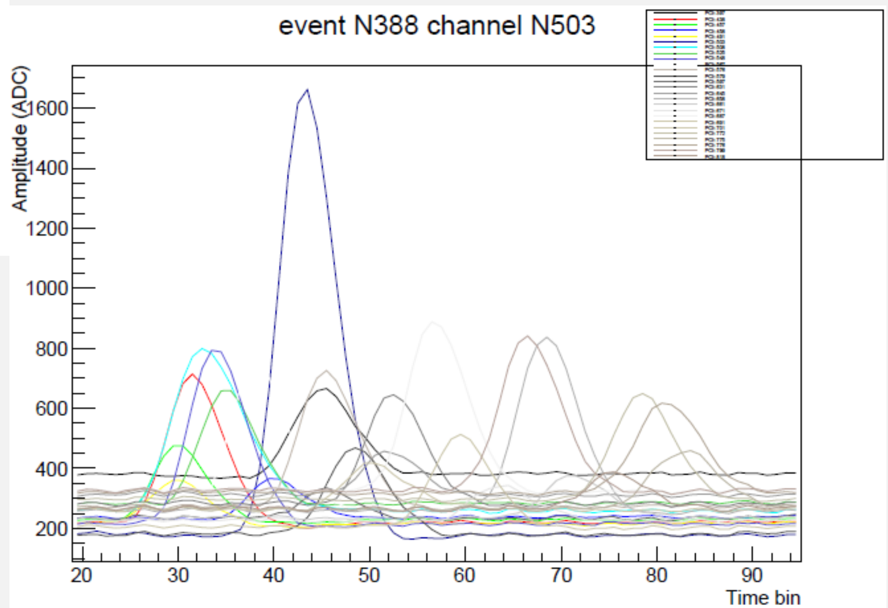


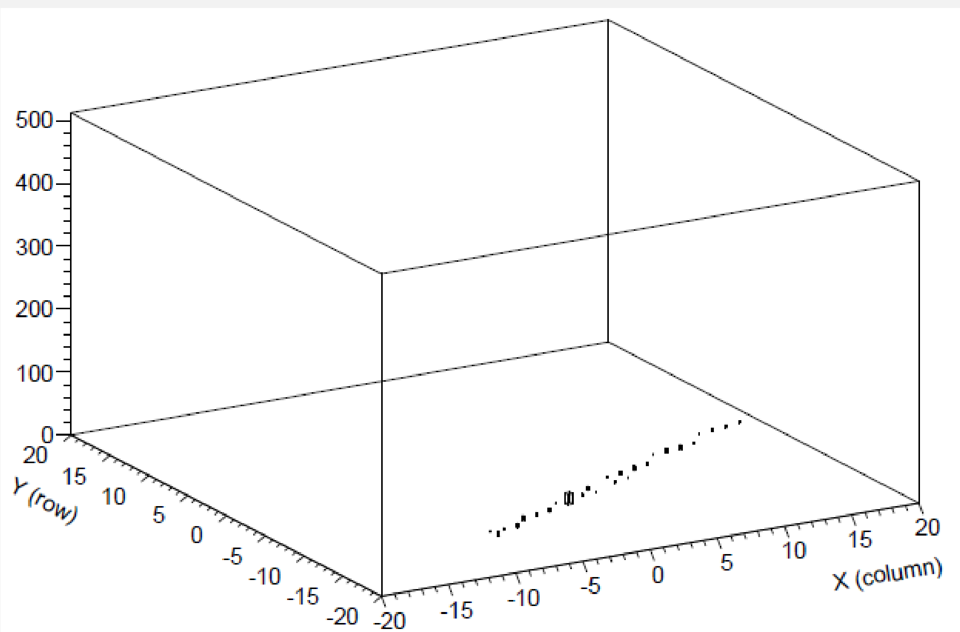
event N404 channel N361
Amplitude (ADC)
Time bin



Y (row)
X (column)


Y (row)
X (column)
20
15
10
5
0
-5
-10
-15
-20
1400
1200
1000
800
600
400
200
0

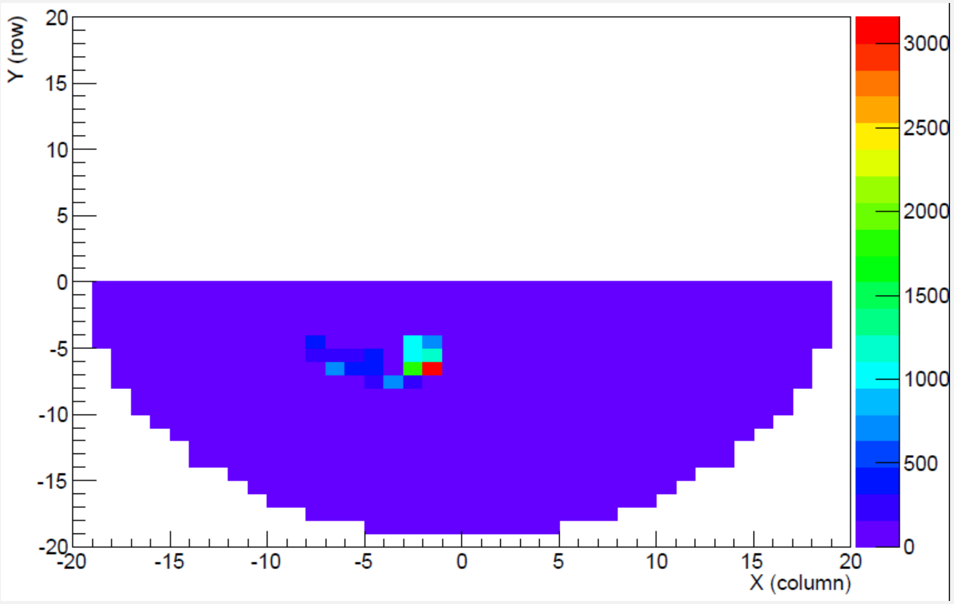

event N388 channel N503
Amplitude (ADC)
Time bin
1600
1400
1200
1000
800
600
400
200
20
30
40
50
60
70
80
90


500
400
300
200
100
0
Y (row)
X (column)
20
15
10
5
0
-5
-10
-15
-20

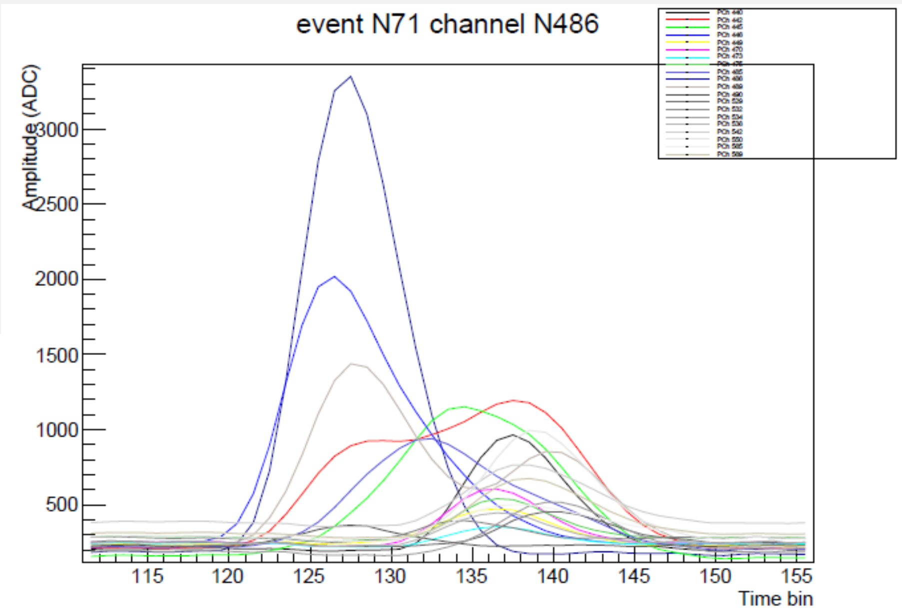
2. Low energy electrons

in random coincidence with trigger

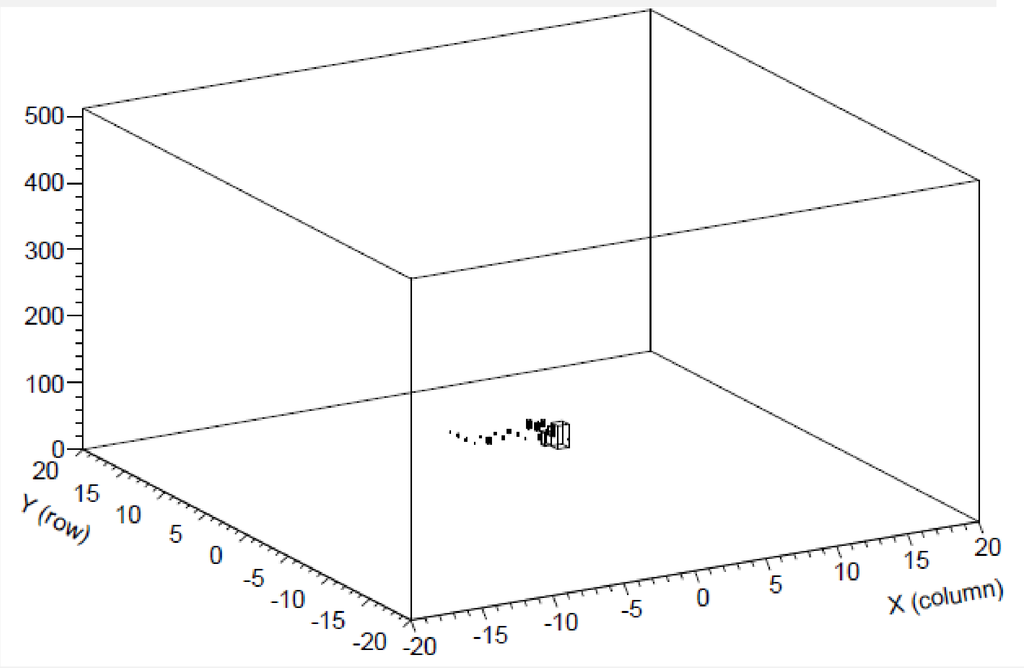
(no analysis, just selection on the event display)



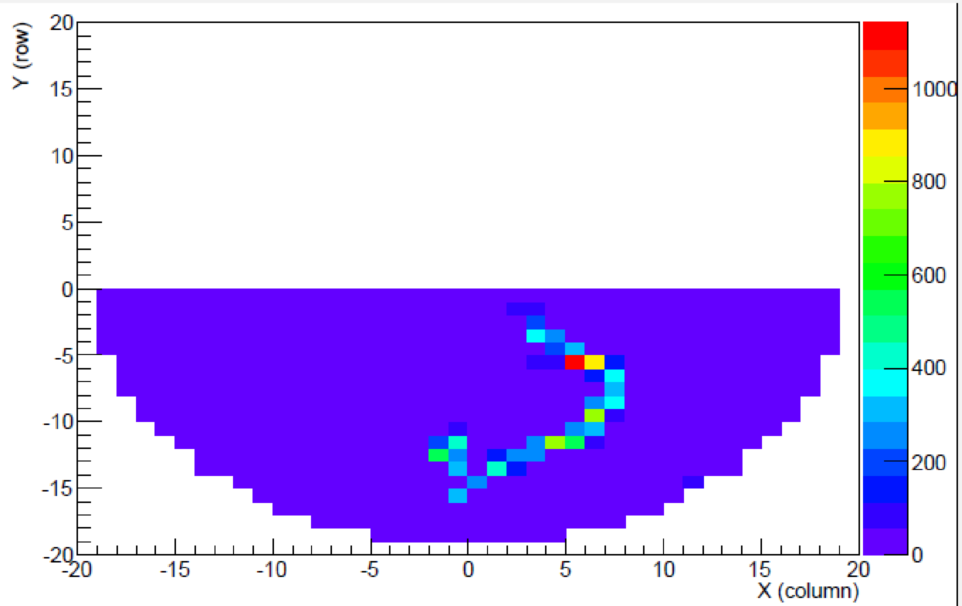
Y (row)
X (column)



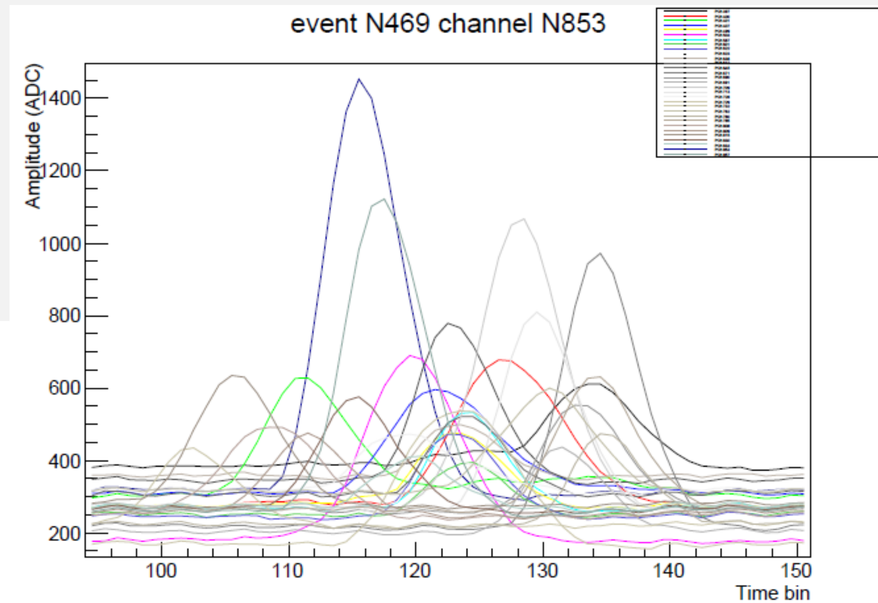
event N71 channel N486
Amplitude (ADC)
Time bin



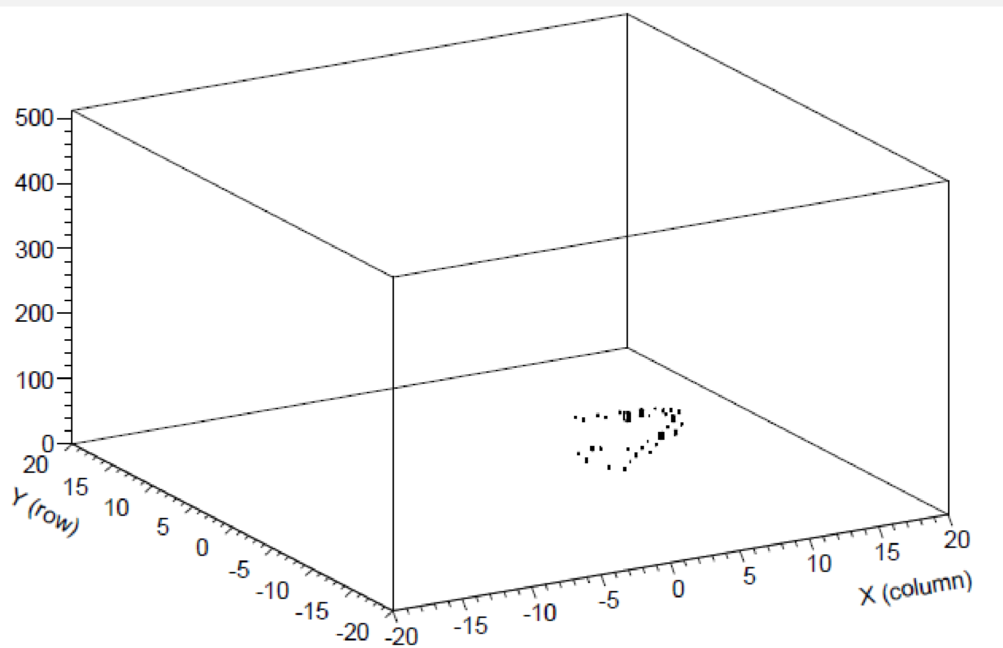
Y (row)
X (column)



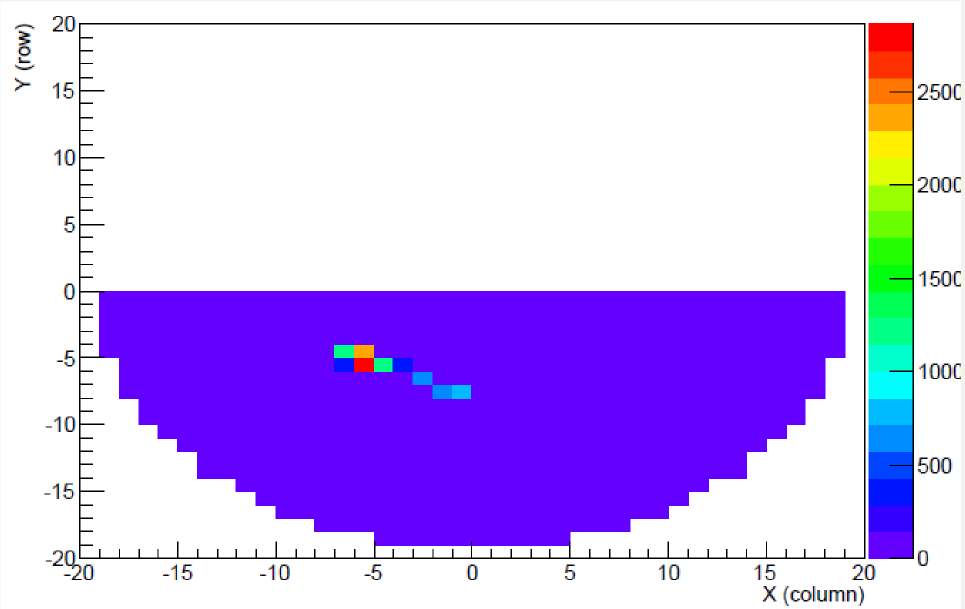
Y (row)
X (column)
20
15
10
5
0
-5
-10
-15
-20
1000
800
600
400
200
0

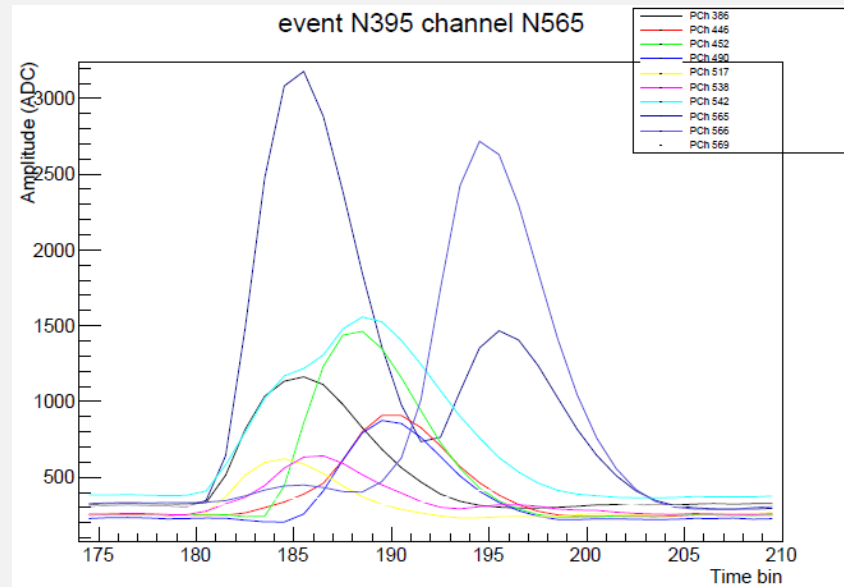


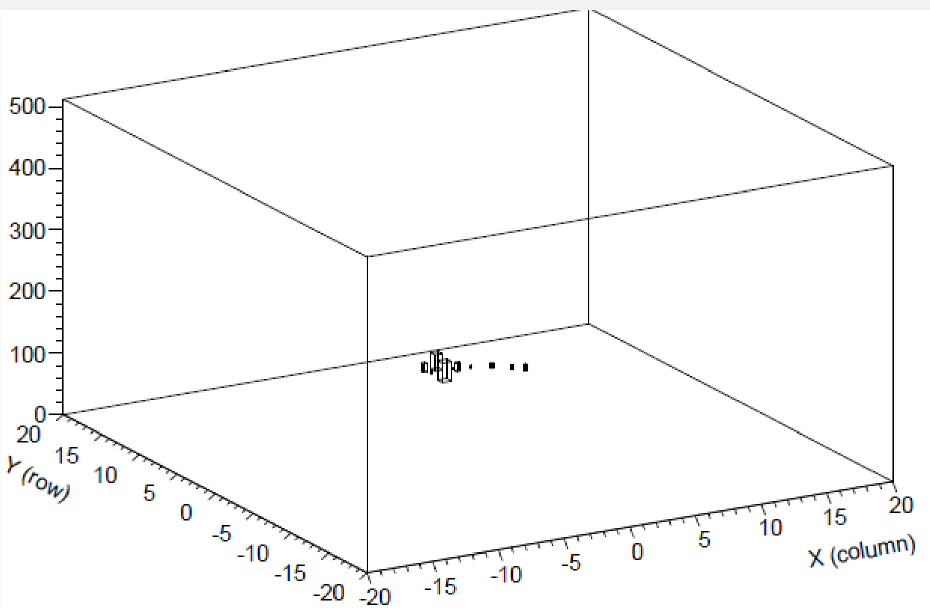
event N469 channel N853
Amplitude (ADC)
Time bin
1400
1200
1000
800
600
400
200
100
110
120
130
140
150



500
400
300
200
100
0
Y (row)
X (column)
20
15
10
5
0
-5
-10
-15
-20


Y (row)
X (column)

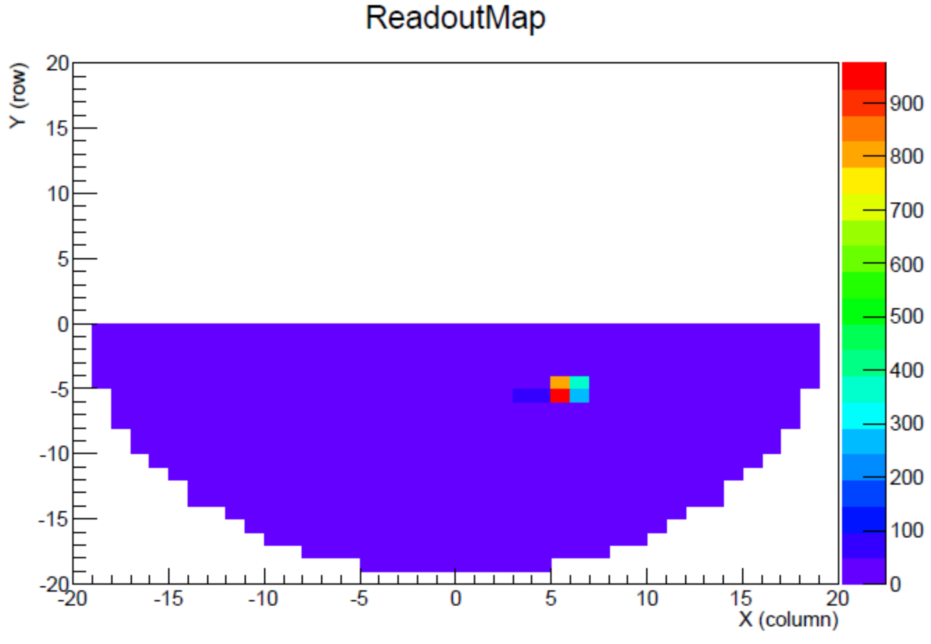

event N395 channel N565
Amplitude (ADC)
Time bin
PCh 386
PCh 446
PCh 452
PCh 490
PCh 517
PCh 538
PCh 542
PCh 565
PCh 566
PCh 569

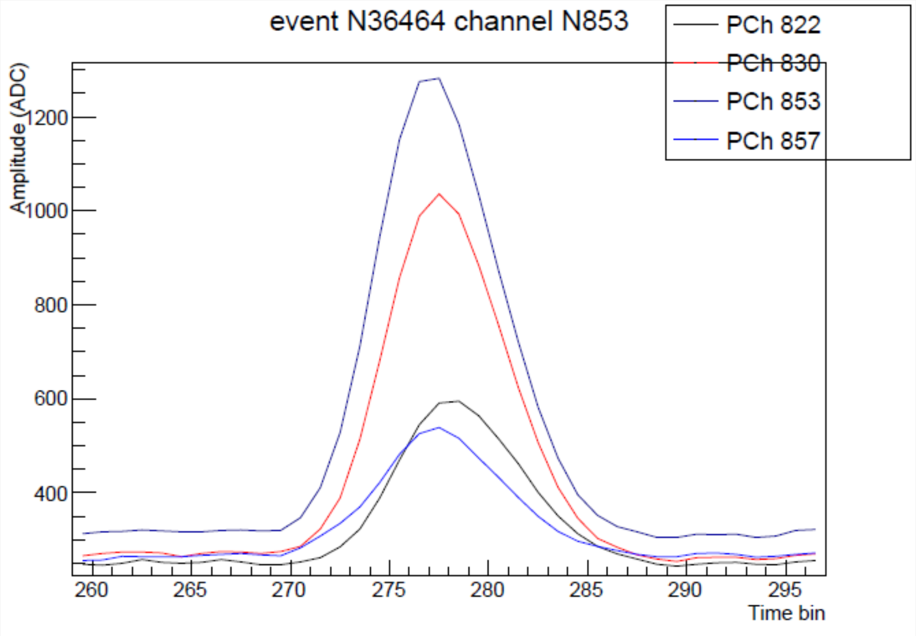

Y (row)
X (column)

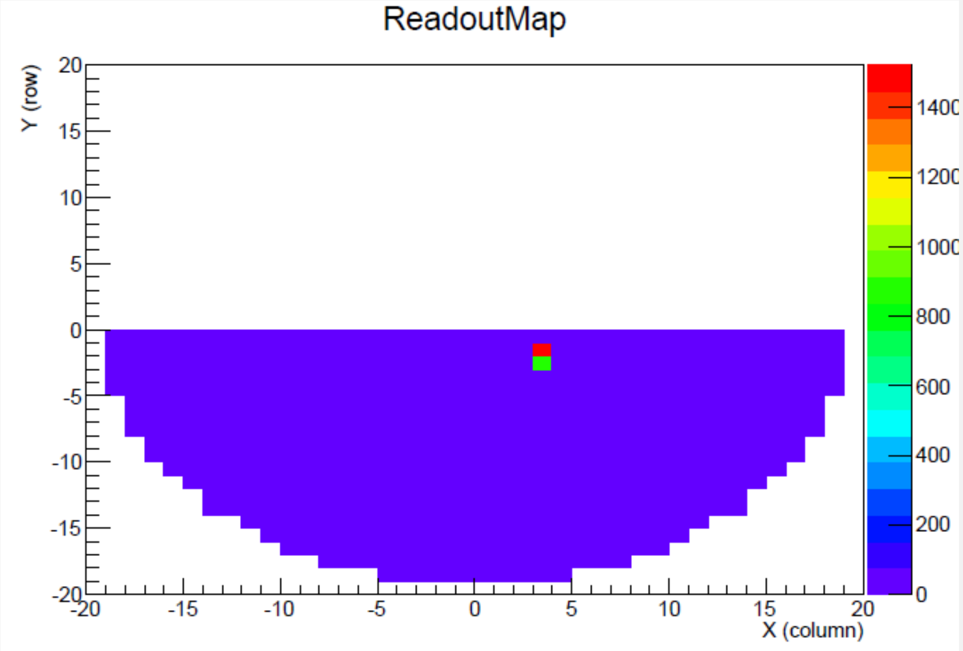
3. ~30keV escape-peak photons

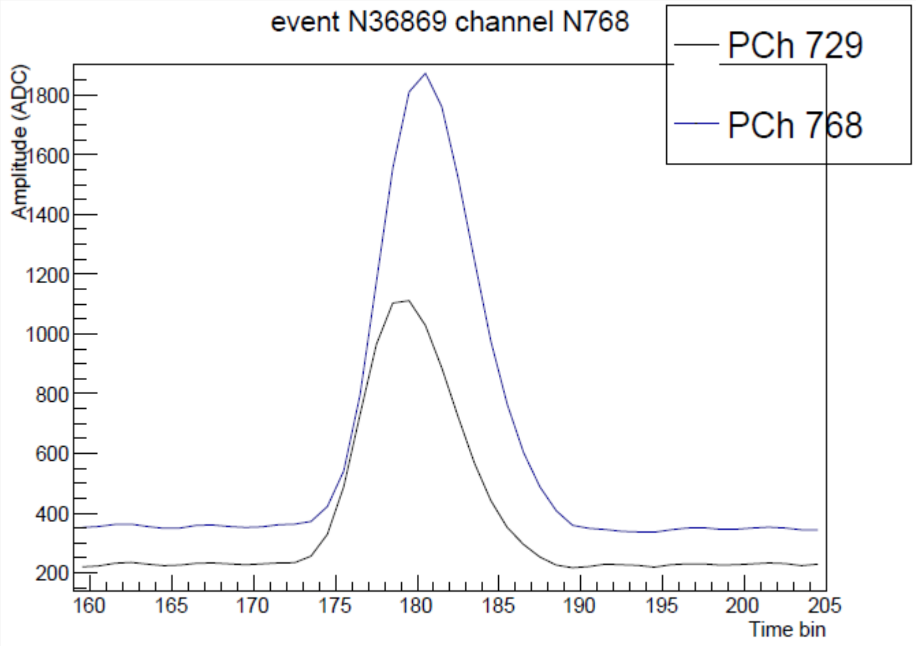
(59.5keV-[29.8-33.6]keV K-shell)

(selection after analysis)


ReadoutMap
Y (row)
X (column)


event N36464 channel N853
PCh 822
PCh 830
PCh 853
PCh 857
Amplitude (ADC)
Time bin

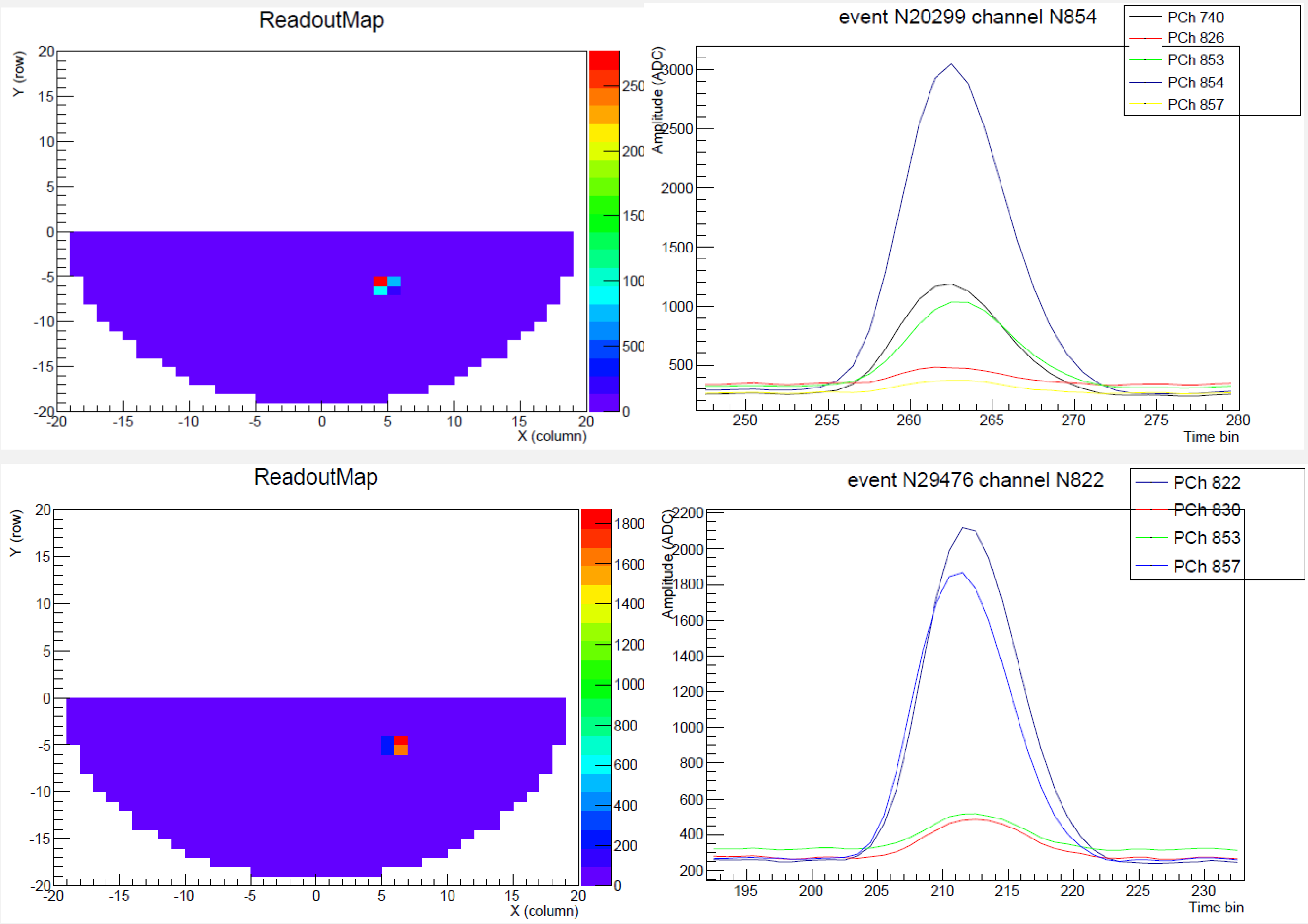

ReadoutMap
Y (row)
X (column)


event N36869 channel N768
PCh 729
PCh 768
Amplitude (ADC)
Time bin

4. Full absorption 59.5keV (1blob)

(after ***a)*** Auger cascade following ionization of K-shell or ***b)*** ionization from external shells, or ***c)*** $K_{\alpha,\beta}$ re-absorbed in the local neighborhood)

(selection after analysis)

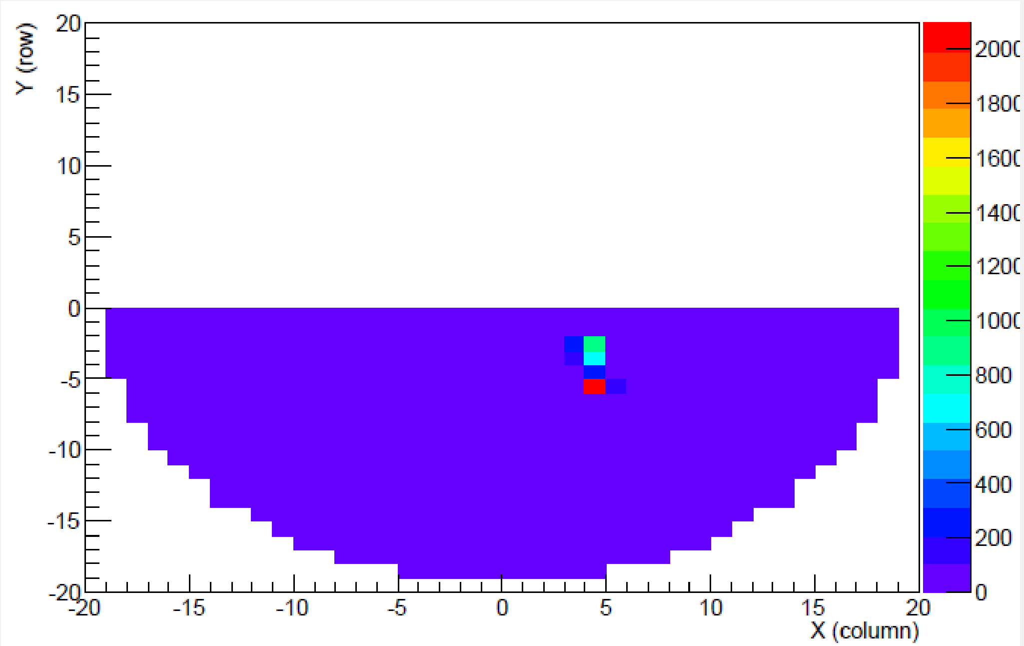


ReadoutMap
Y (row)
X (column)
event N20299 channel N854
PCh 740
PCh 826
PCh 853
PCh 854
PCh 857
Amplitude (ADC)
Time bin
ReadoutMap
Y (row)
X (column)
event N29476 channel N822
PCh 822
PCh 830
PCh 853
PCh 857
Amplitude (ADC)
Time bin

5. Full absorption 59.5 keV (2blobs)

($K_{\alpha,\beta}$ re-absorbed at a distant position)

(selection after analysis)


Y (row)
X (column)
20
15
10
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0
-5
-10
-15
-20
2000
1800
1600
1400
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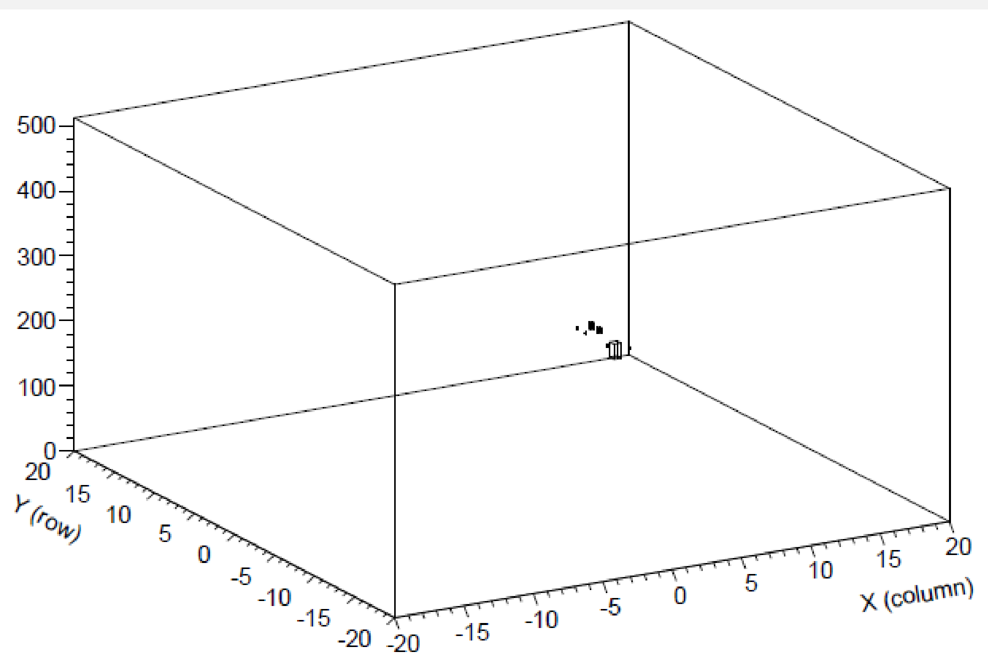
800
600
400
200
0


500
400
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100
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Y (row)
X (column)
20
15
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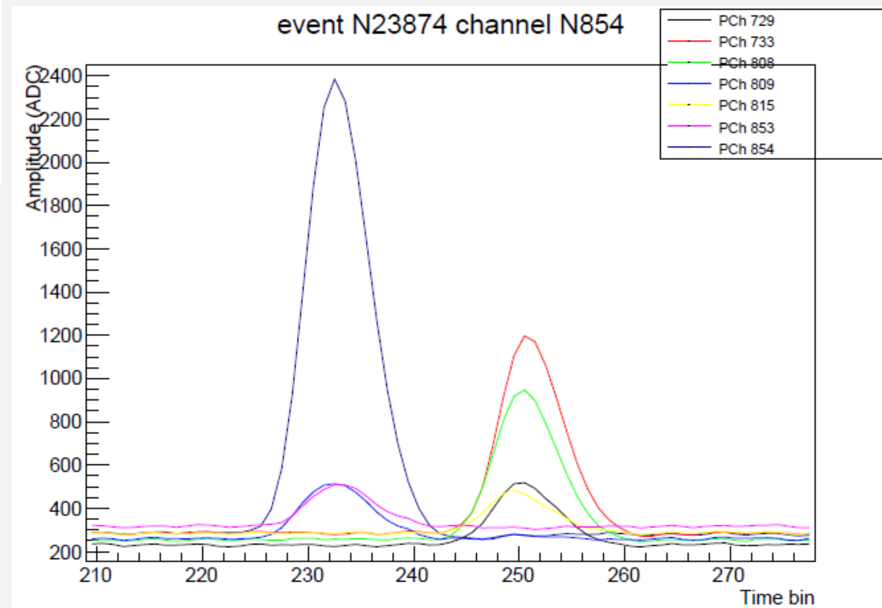
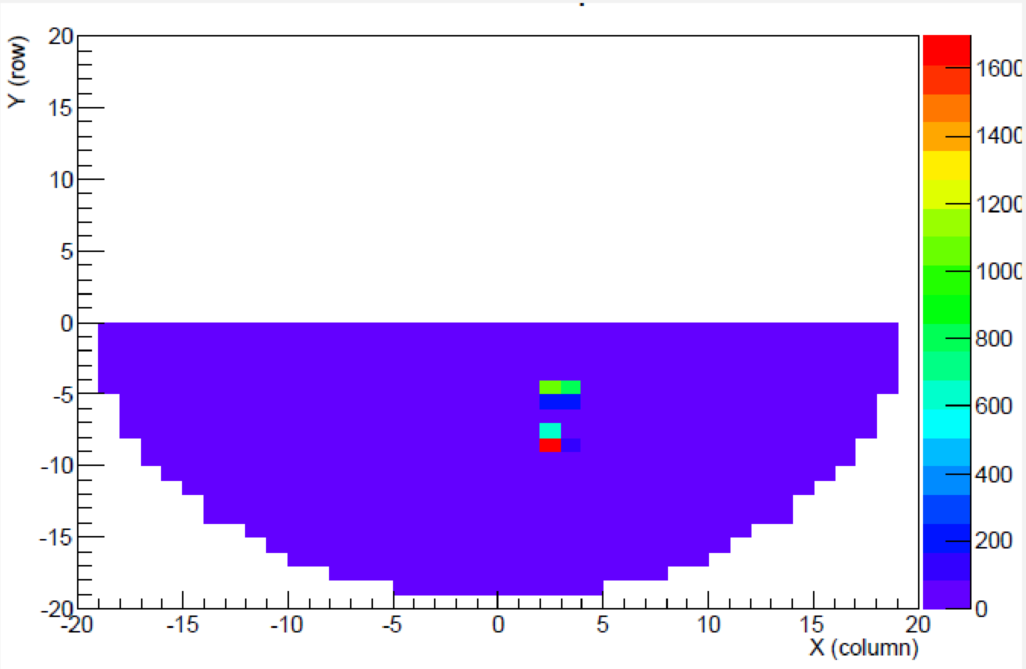
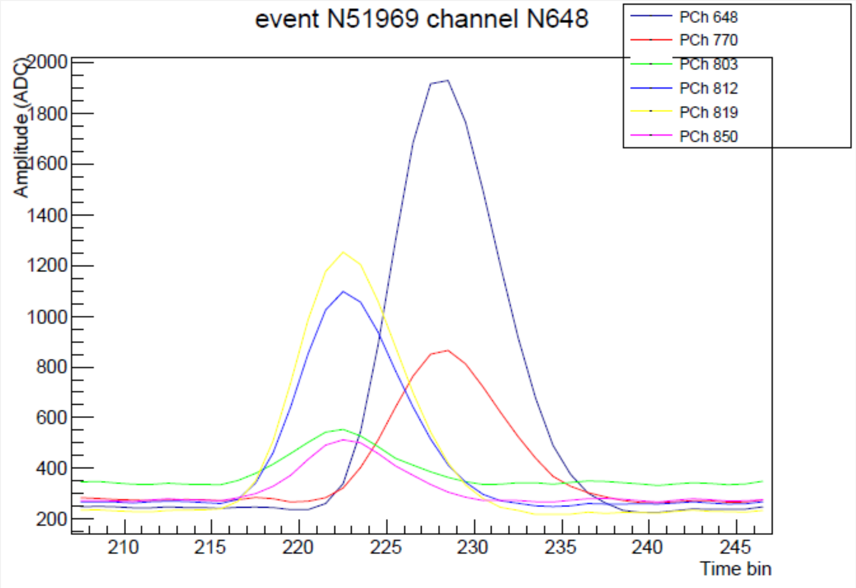
-5
-10
-15
-20

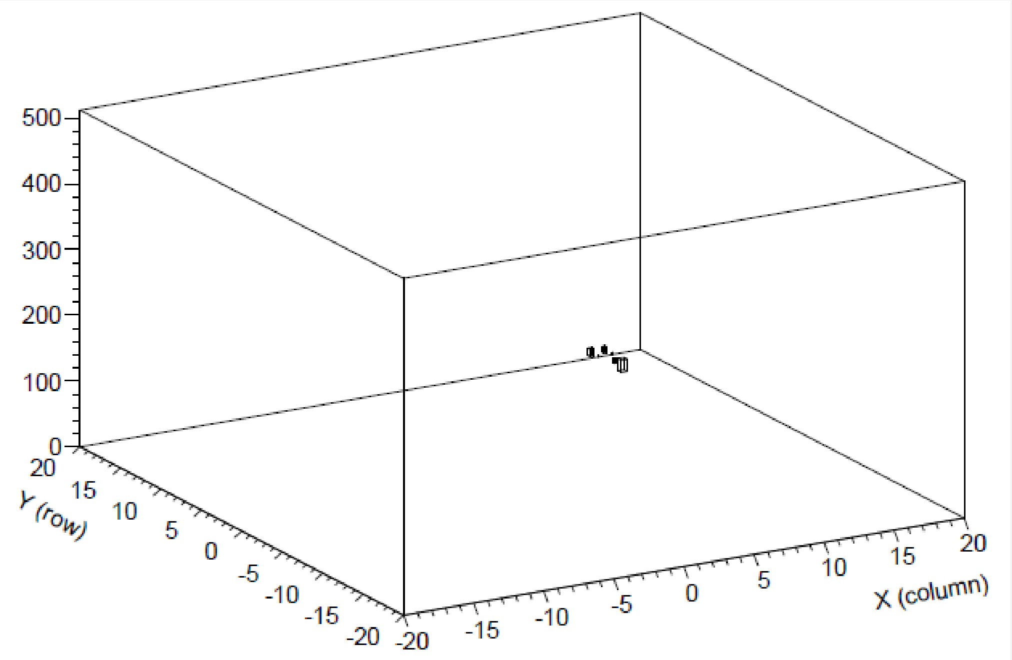

event N23874 channel N854
PCh 729
PCh 733
PCh 808
PCh 809
PCh 815
PCh 853
PCh 854
Amplitude (ADC)
Time bin
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
210
220
230
240
250
260
270



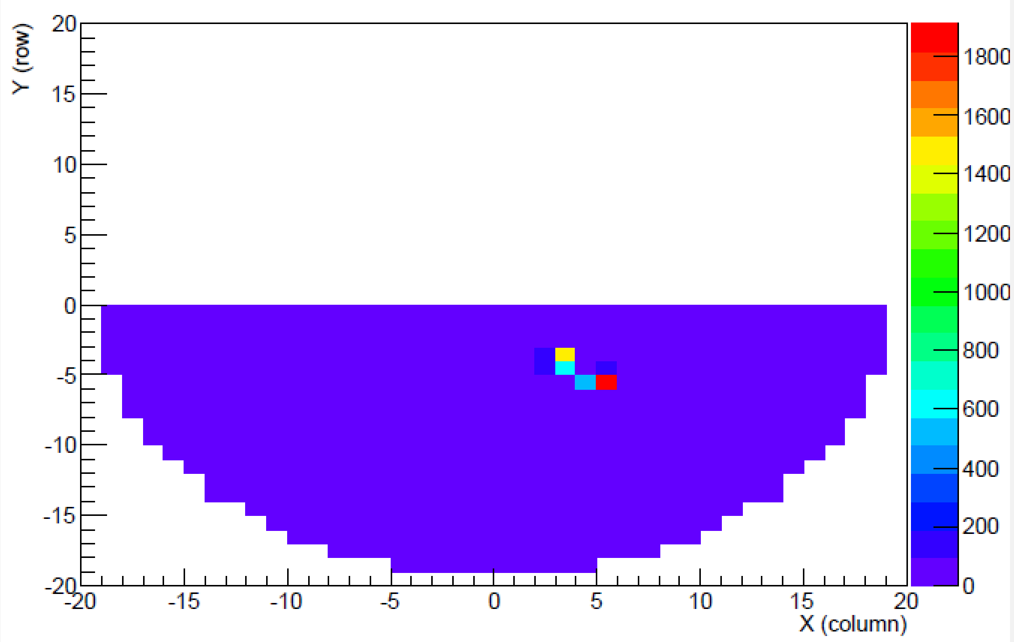
Y (row)
X (column)



event N51969 channel N648
PCh 648
PCh 770
PCh 803
PCh 812
PCh 819
PCh 850
Amplitude (ADC)
Time bin



Y (row)
X (column)


Y (row)
X (column)
20
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200
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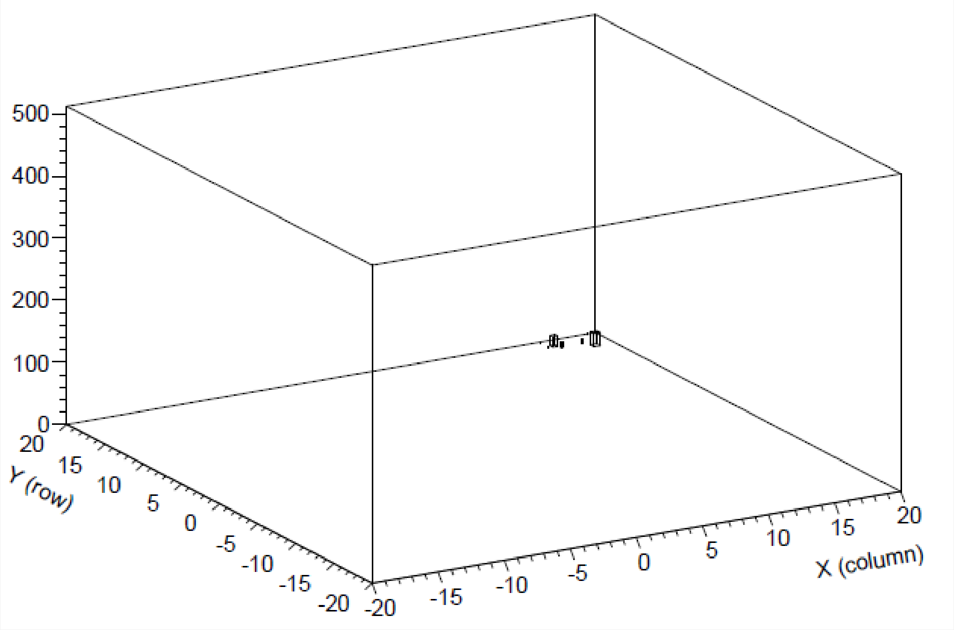
500
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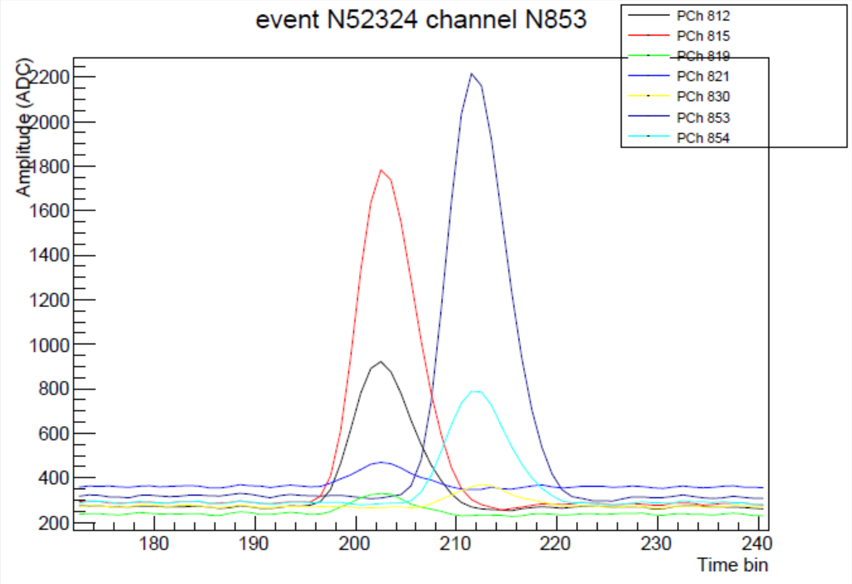
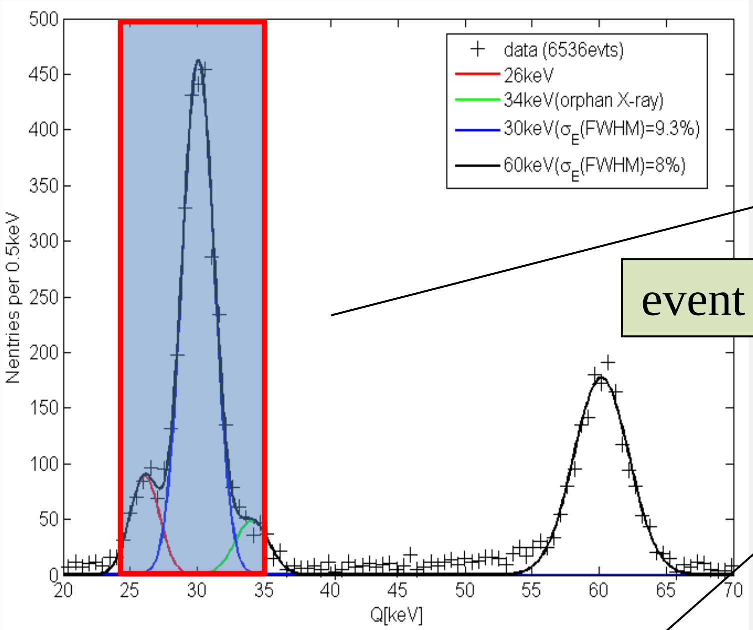
300
200
100
0
Y (row)
X (column)


event N52324 channel N853
PCh 812
PCh 815
PCh 819
PCh 821
PCh 830
PCh 853
PCh 854
Amplitude (ADC)
Time bin

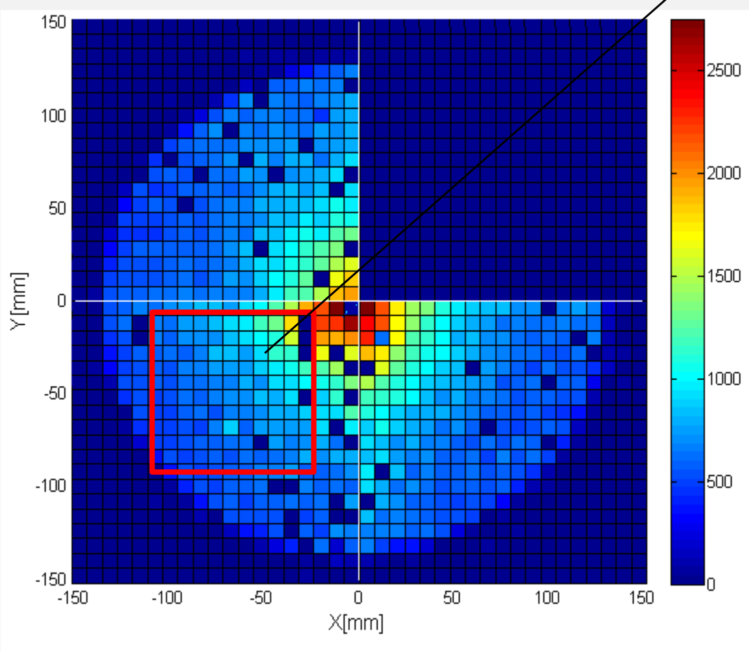
Part 2: identifying the relevant parameters of the electron swarm with the commissioned system.

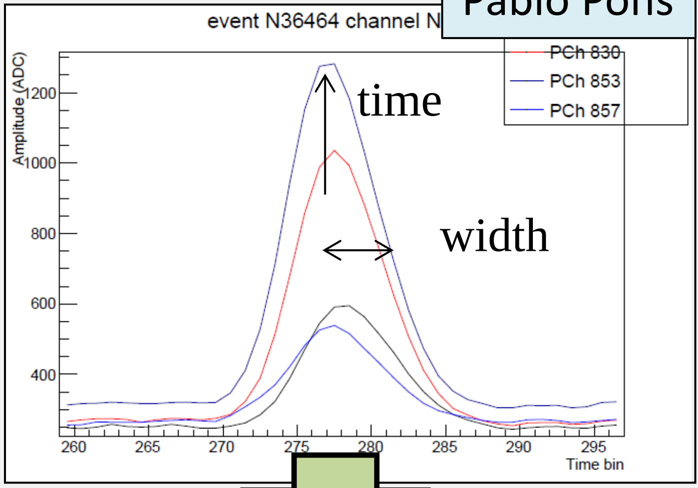
Pablo Pons

Simple (standard) pulse shape analysis (Gaussian fit)

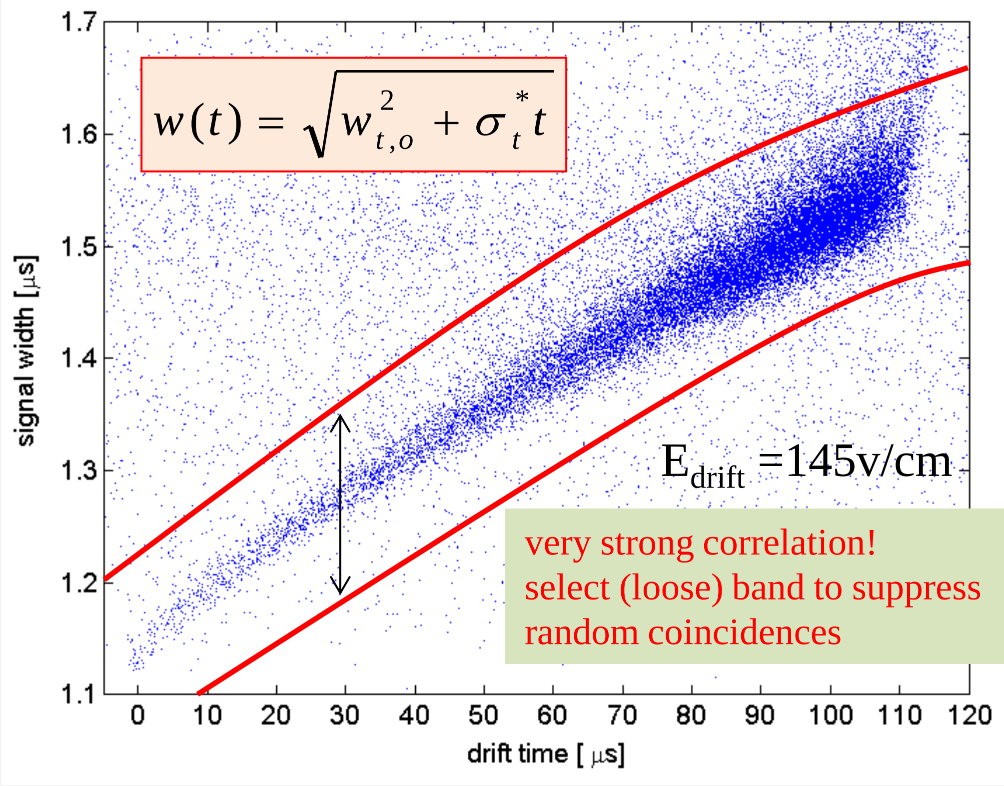


event selection



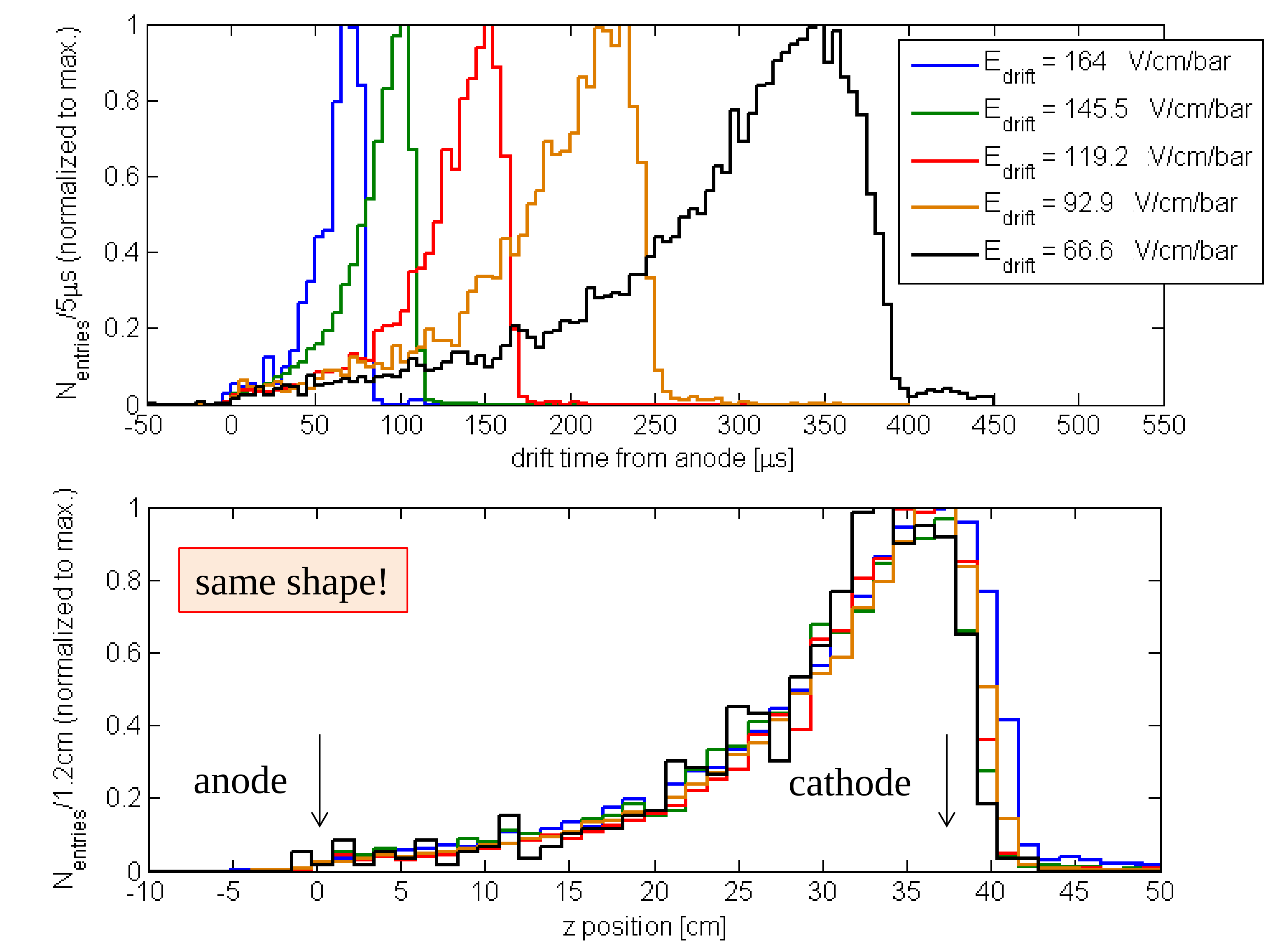


behavior of pulse containing the highest charge

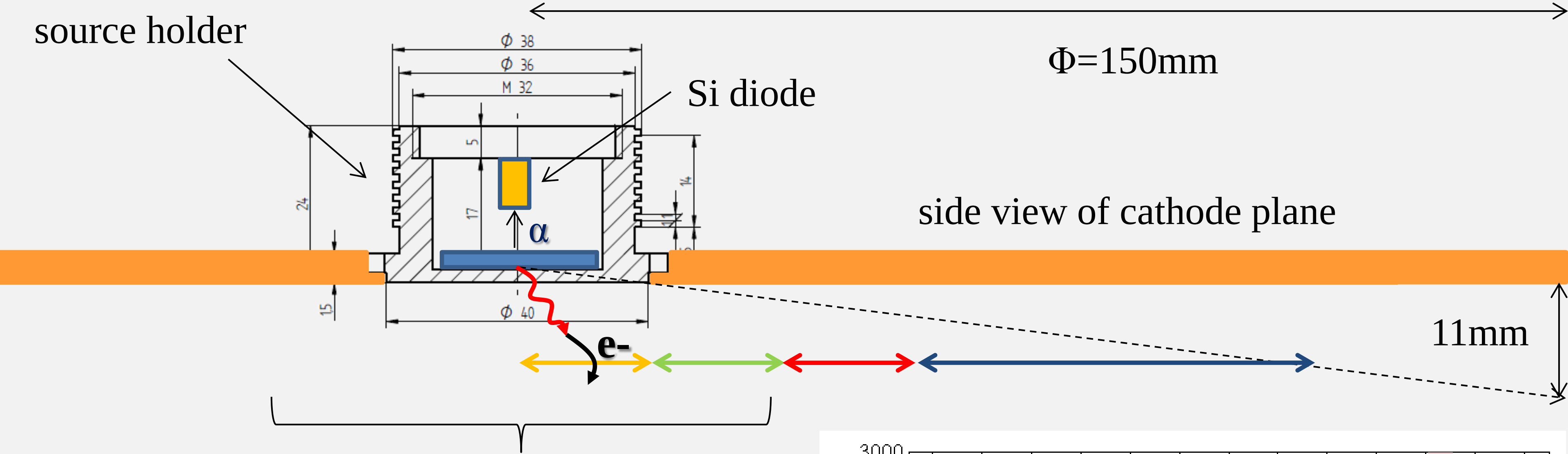


Part 2.1: drift velocity

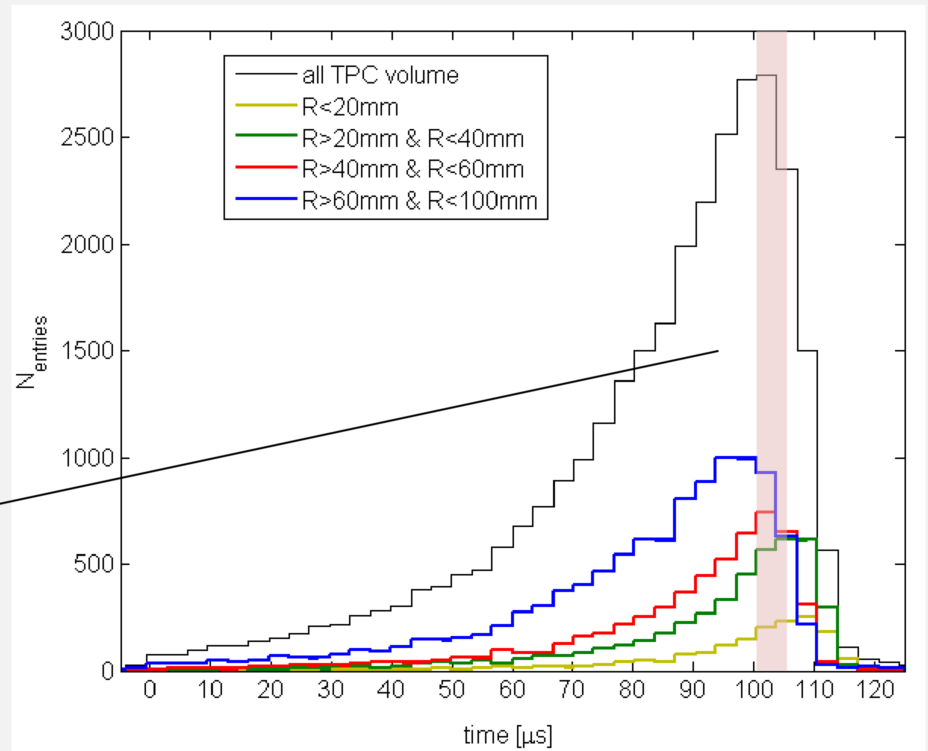
1. Obtain drift velocity by re-scaling time-distributions to a common z-profile



2. Systematic uncertainties involved in drift velocity calculation (dependence with radial position)



Region where fringe fields are important (they create tails towards delayed times)

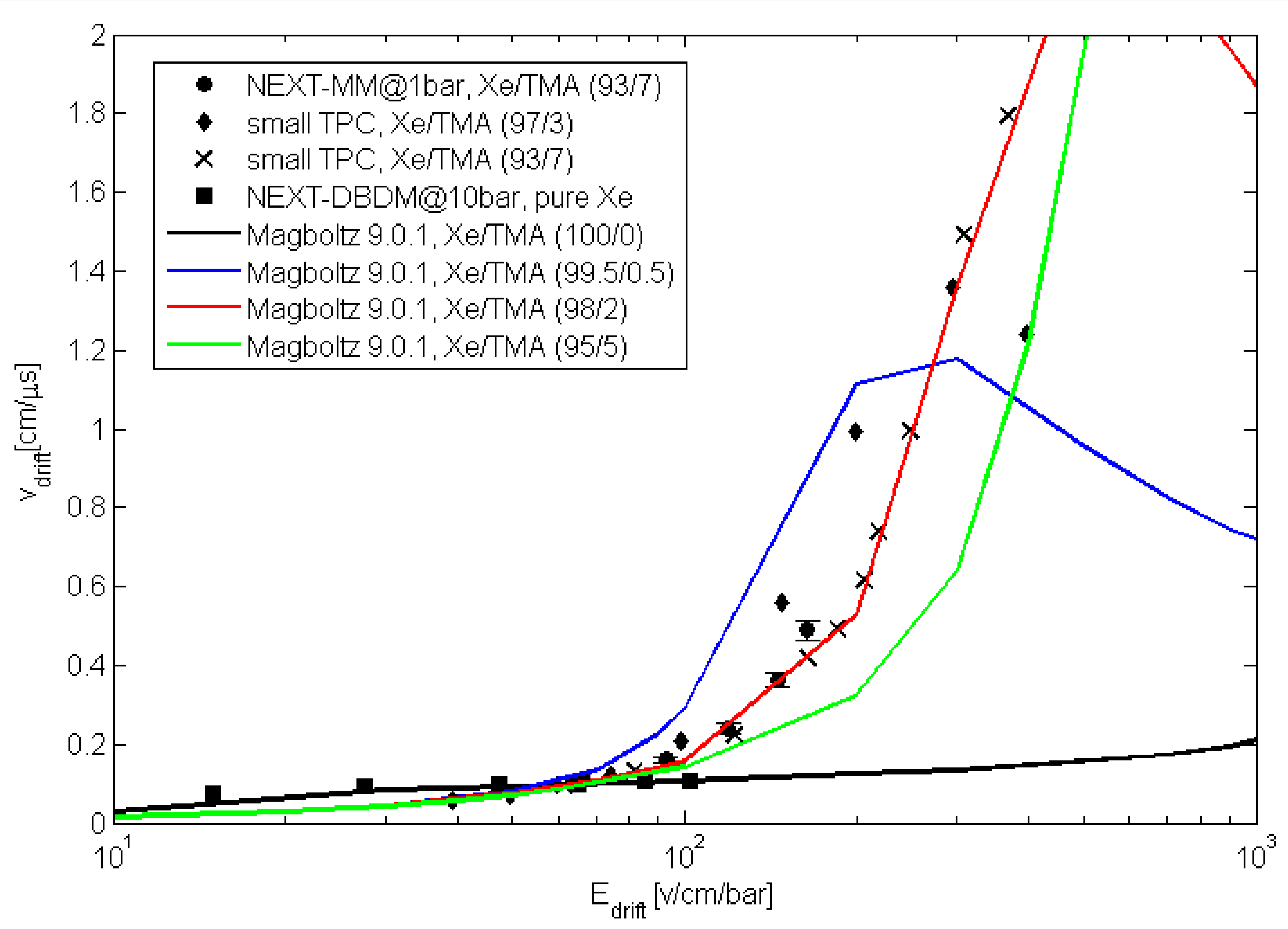


- We assign a **5% uncertainty** to the definition of the z-position of the cathode due to this geometrical effect.
- $R_{e,csda}$=6mm@1bar (very small residual effect: 6mm/380mm=1.5%)

τ_e >2ms for all measurements

drift velocity compilation

Monitors of O_2 and H_2O to be installed soon!



very strong discrepancy with Magboltz 9.0.1.!

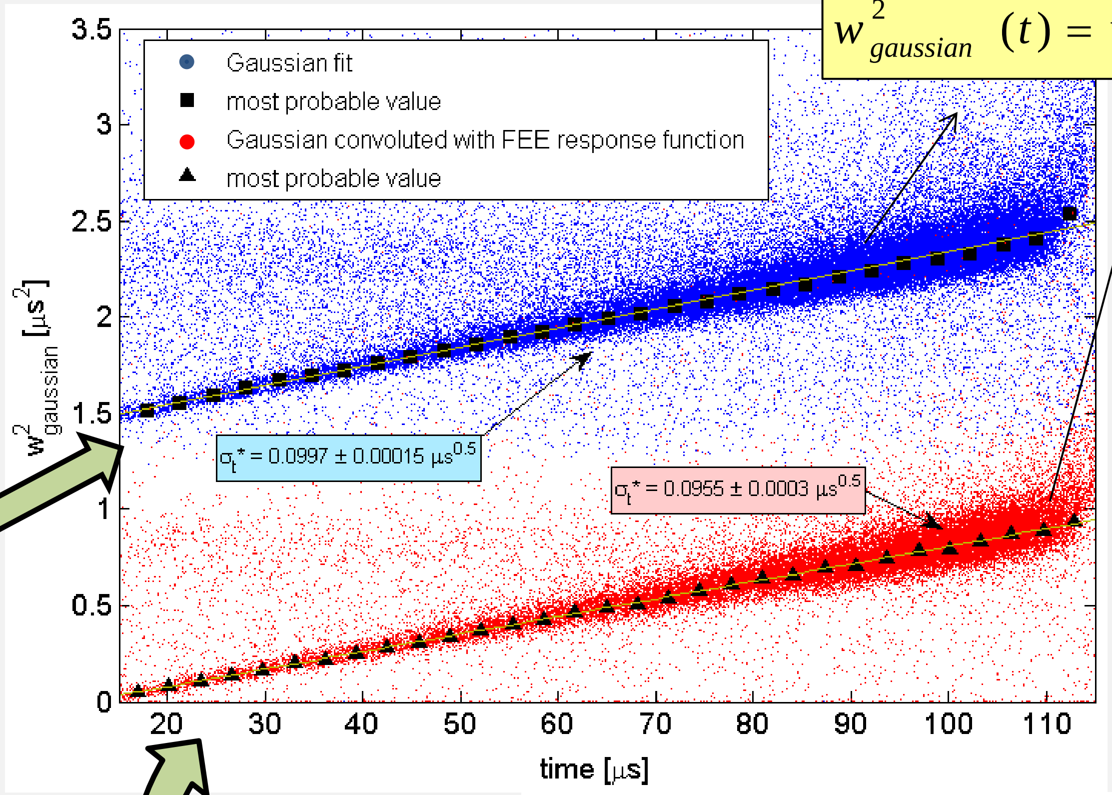
Part 2.2: longitudinal diffusion

τ_e >2ms for all measurements

Pablo Pons

1. Study 2 different analysis procedures

$$w^2_{gaussian}(t) = w_o^2 + \left(\sigma_t^*\right)^2 \cdot t$$

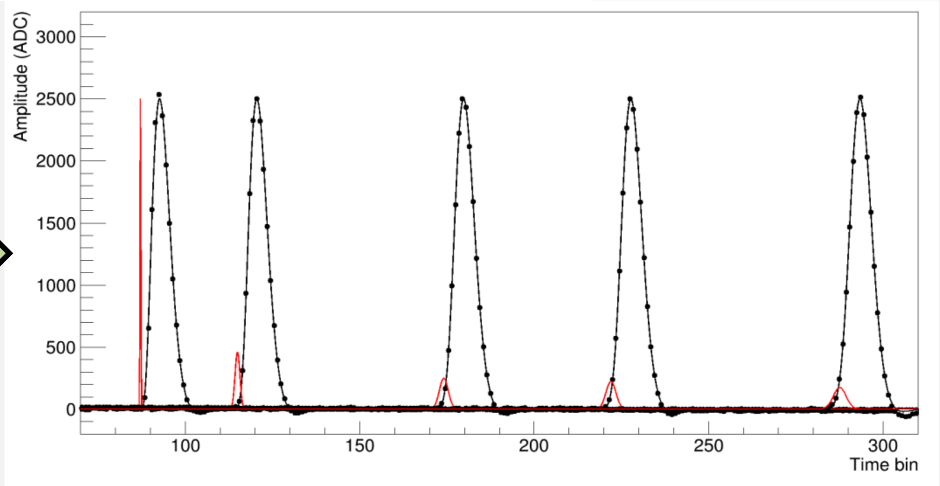


<5% systematic uncertainty!

1. width obtained from simple Gaussian fit (default analysis)

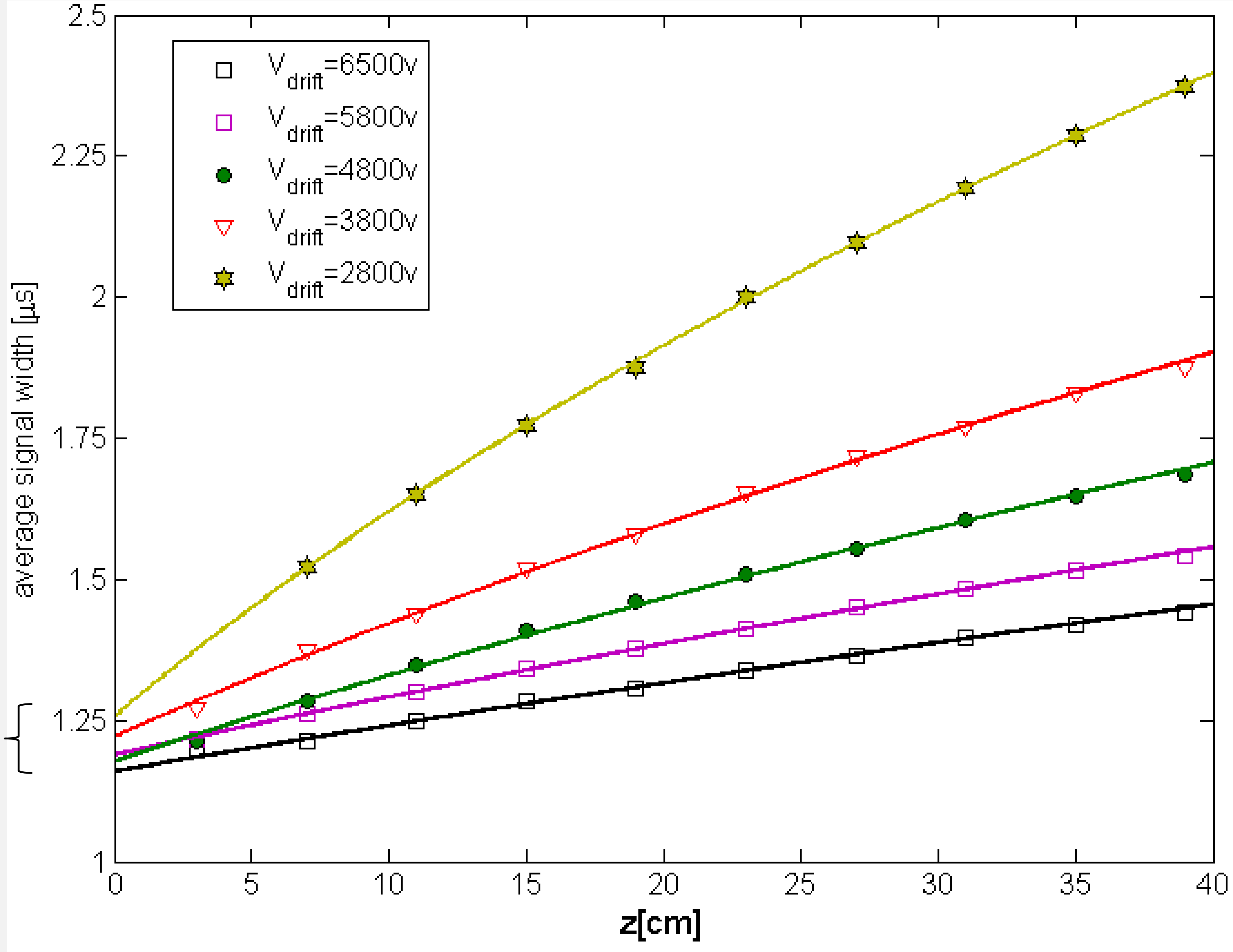
2. width obtained from convolution of Gaussian to FEE response function (numerically costly):

$$f(t) = e^{-3t/\tau}(t/\tau)^3 \sin(t/\tau) \otimes e^{-(t-t_o)^2/2\sigma_t(t)^2}$$



τ_e >2ms for all measurements

2. Fit the most probable values to the expected behavior



$Width_o$ depending on:

-Ion transit time.

-Track geometry.

-FEE response.

Very little dependent on drift voltage!

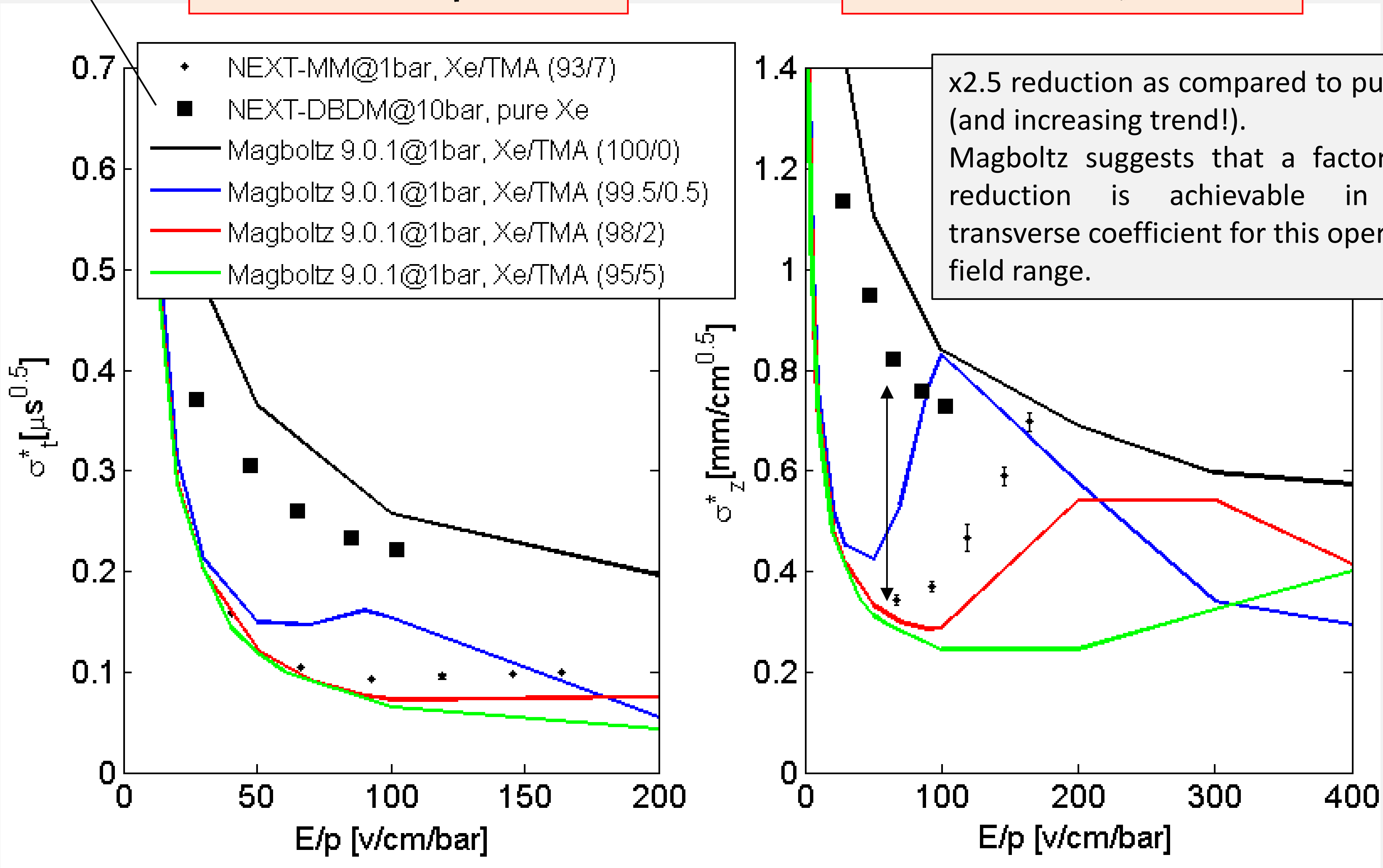
τ_e >2ms for all measurements

longitudinal diffusion compilation

Scaled up by √P to 1bar

$$\sigma_t = \sigma_t^* \sqrt{t} = \sqrt{\frac{2D_L}{v_d^2}} \sqrt{t}$$

$$\sigma_z = \sigma_z^* \sqrt{z} = \sqrt{\frac{2D_L}{v_d}} \sqrt{z}$$



x2.5 reduction as compared to pure Xe (and increasing trend!). Magboltz suggests that a factor x10 reduction is achievable in the transverse coefficient for this operating field range.

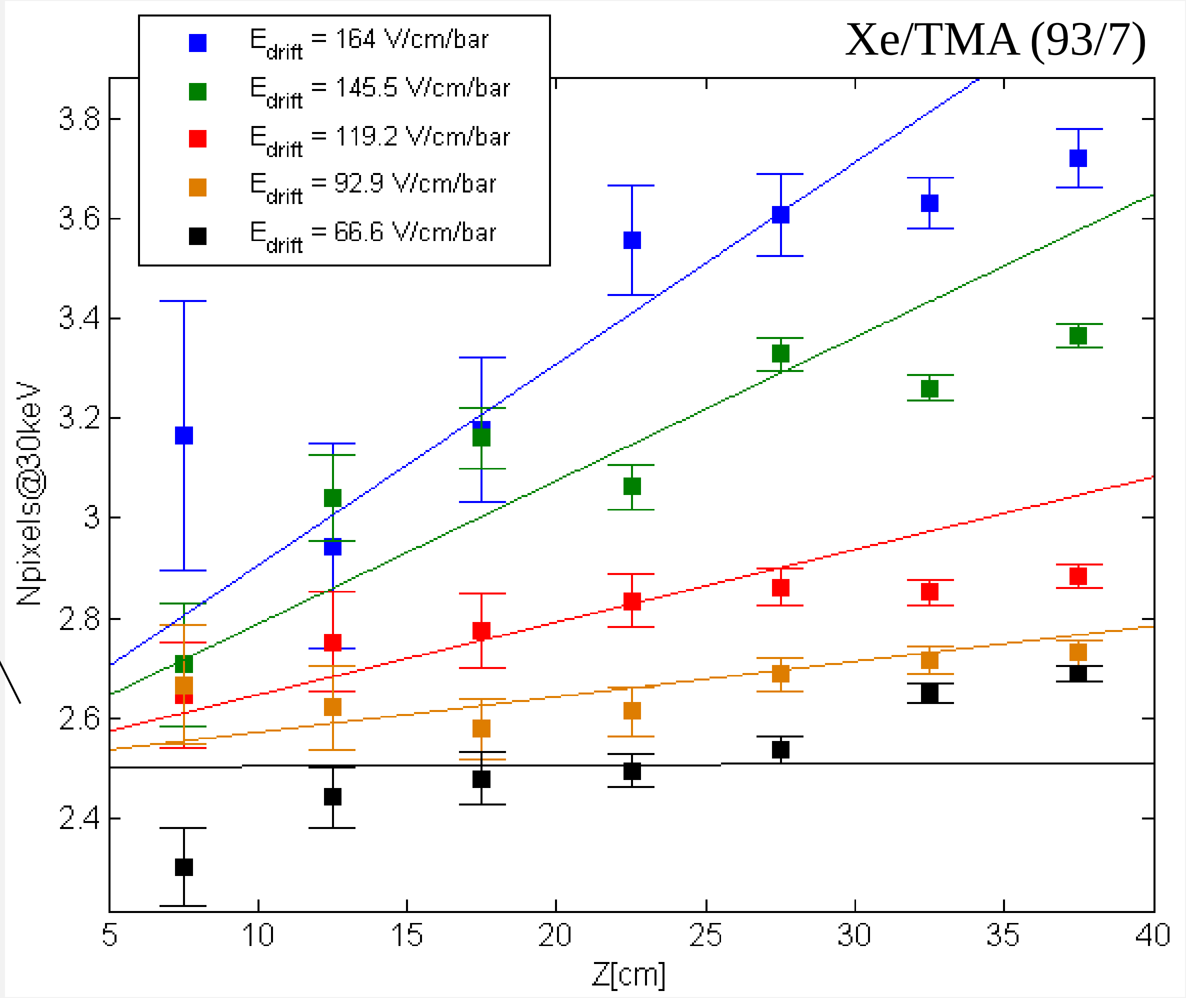
Very strong discrepancy with Magboltz 9.0.1!.

Part 2.3: transverse diffusion (expectedly a strength of this setup)

τ_e >2ms for all measurements

pixel multiplicity

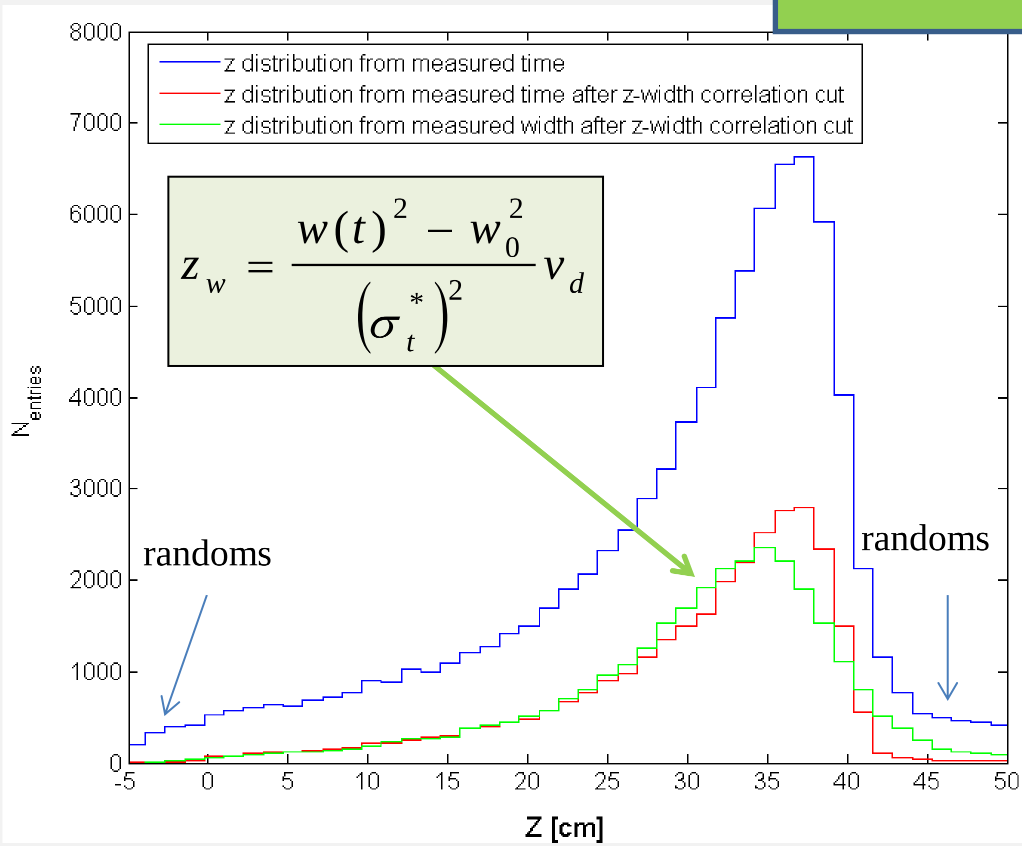
linear fit
(bound to 2.5)



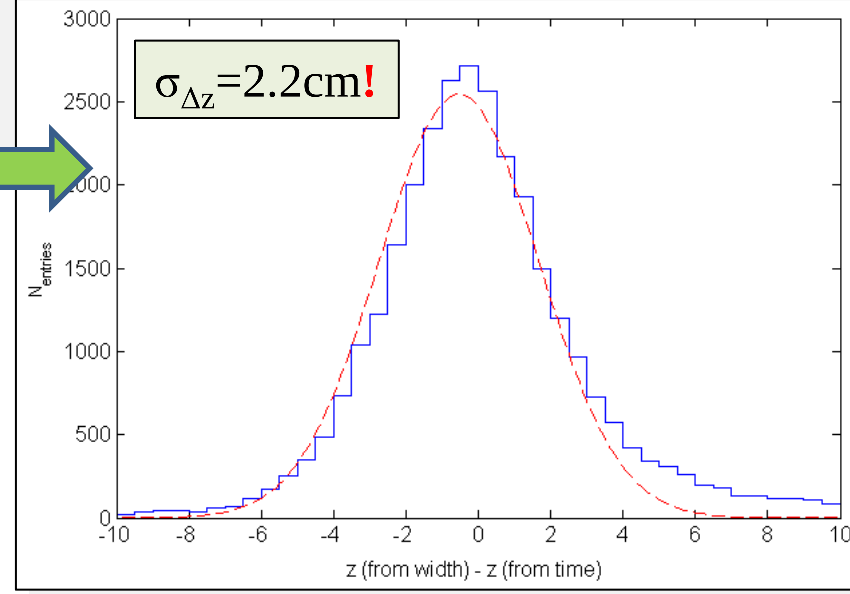
Similar to σ^*_z [mm/√cm], the transverse diffusion σ^*_r [mm/√cm], clearly increases with the drift field in this operating range. However, extracting its value seems to require of a full simulation (ongoing), due to the very low hit multiplicity, or some smart idea…

Part 2.4: extras

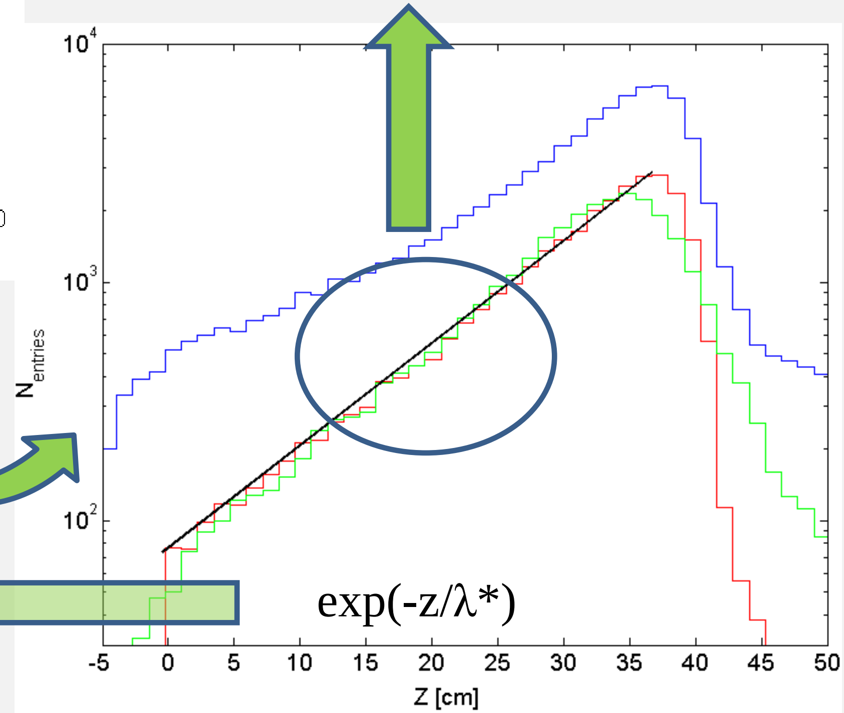
Position resolution estimated from signal width for a nearly point-like deposit (30keV@1bar)



$$z_w = \frac{w(t)^2 - w_0^2}{\left(\sigma_t^*\right)^2} v_d$$

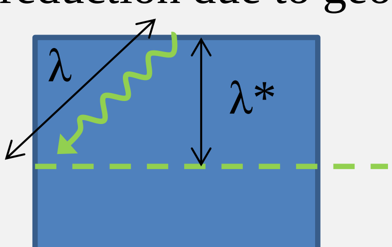


very small dip due to reduced escape probability at the center of the chamber



$\lambda^* \approx 1/2\ \lambda_{59.5keV}$ x-ray @ pure Xe

effective reduction due to geometry!

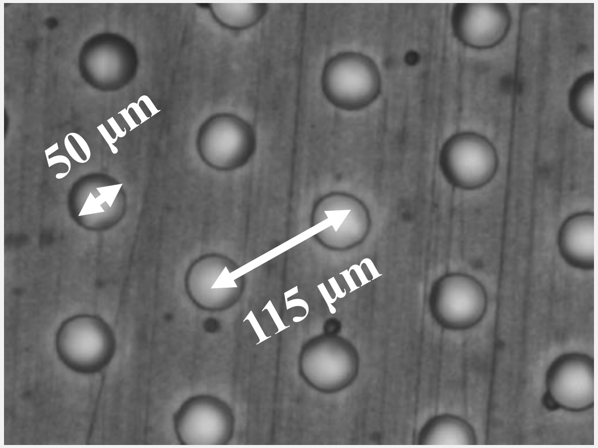


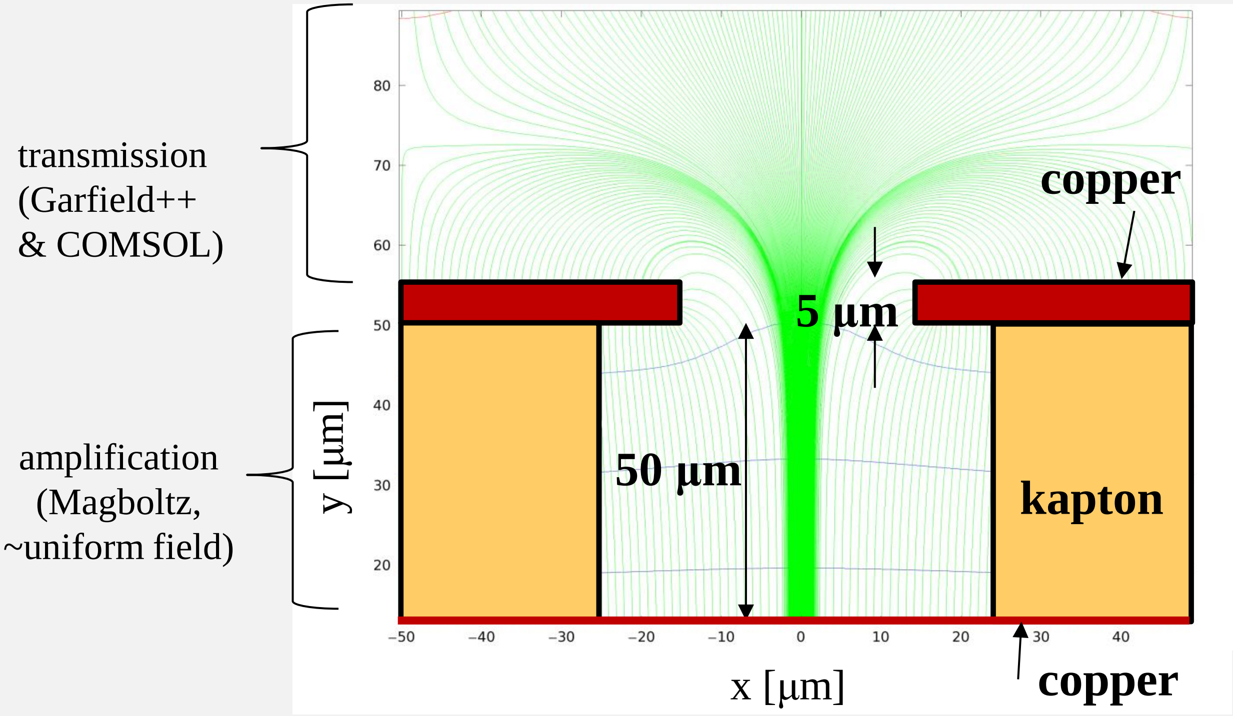
All TMA values from here on must be multiplied roughly by a factor x2 to correct for a calibration problem.

Part 3: Penning effect and energy resolution

- A proper simulation of the electrons' drift through the field lines precludes a pure hydrodynamic modeling based merely on the parameters of the swarm.
- The short scale at which the electric field varies in the transition region between the drift region and the amplifying gap is comparable to the electrons' mean free path.
- Electrons will not fully achieve (in general) statistical equilibrium before the field orientation and module changes appreciably.
- A microscopic modeling is enforced -> Garfield++.

We have preliminary separated the problem in two parts:





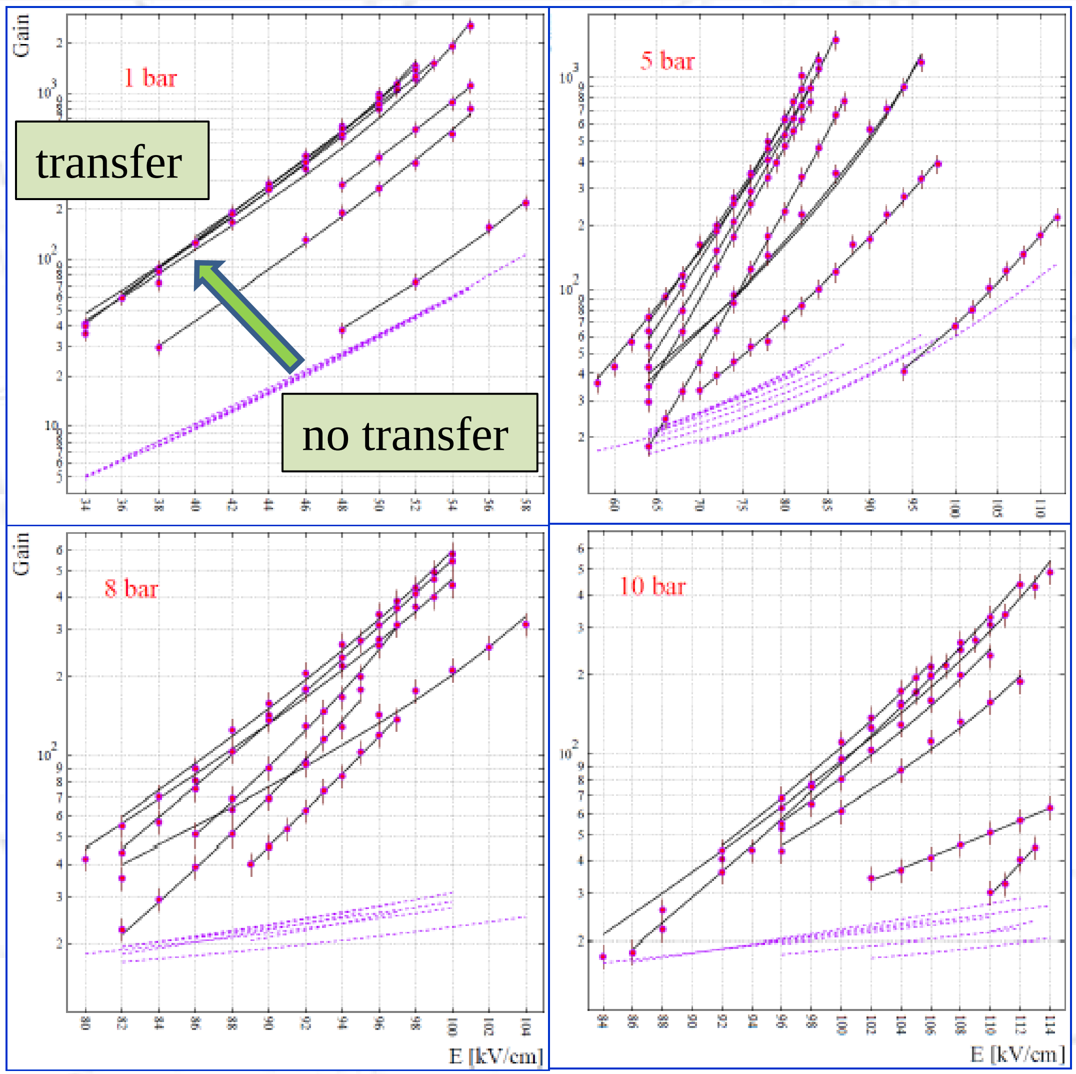
Part 3.1: the amplification region

Ozkan Sahin

$$m(E) = \exp(\alpha_{r=0}(E)\left[1 + r\frac{N_{ex,0}}{N_{I,0}}(E)\right]gap)$$

transfer coefficient -r-:
(**effective** probability that a excited state of the main gas ionizes TMA, **field-independent** in first order)

lines: simulation
points: data (at different %TMA)

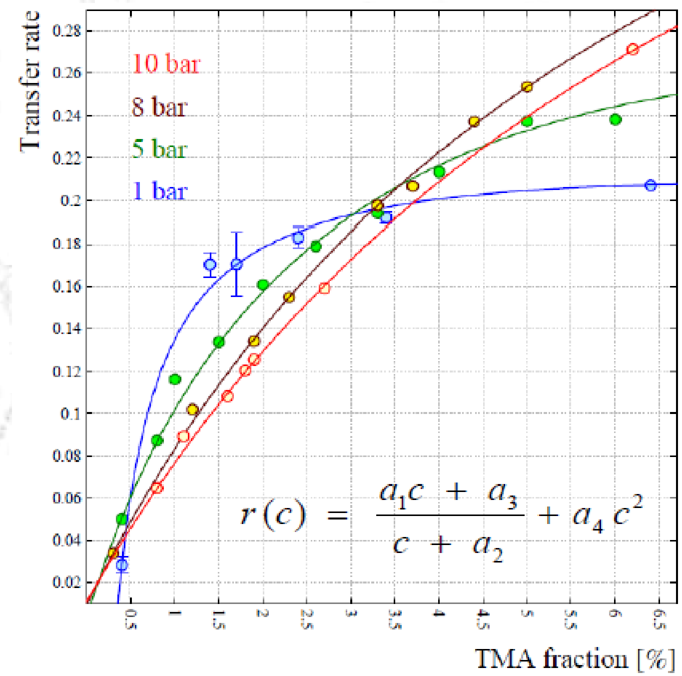


'classic' Magboltz

Status as of April at RD51 mini-week

Ozkan Sahin

- All the fits using the proposed model
- It describes transfer curves sufficiently well
- **BUT**; $\mathbf{a_2}$ and $\mathbf{a_3}$ negative at higher pressures than 5 bar



- 3 – body interactions only happen for large TMA fractions at low pressures ???
- Should be checked, with gain measurements at large TMA concentrations at high pressures
- What is the physical meaning of $\mathbf{a_4}$ parameter, which mechanism(s) leads to drop on transfer curve; in progress.

Problems and next steps:

- **Microscopic modeling needed!** (will mainly mimic a smaller gap, and increase the necessary –r-).
- **Problem with TMA calibration.** Repeated. Concentration is approximately doubled, as compared to published data (erratum to be submitted soon). Will also likely increase –r-, due to the stronger e- cooling.
- Interpretation of atomic-molecular parameters $a_{1 \ldots n}$ cumbersome in the presence of excimers…. (**work ongoing**)

details in

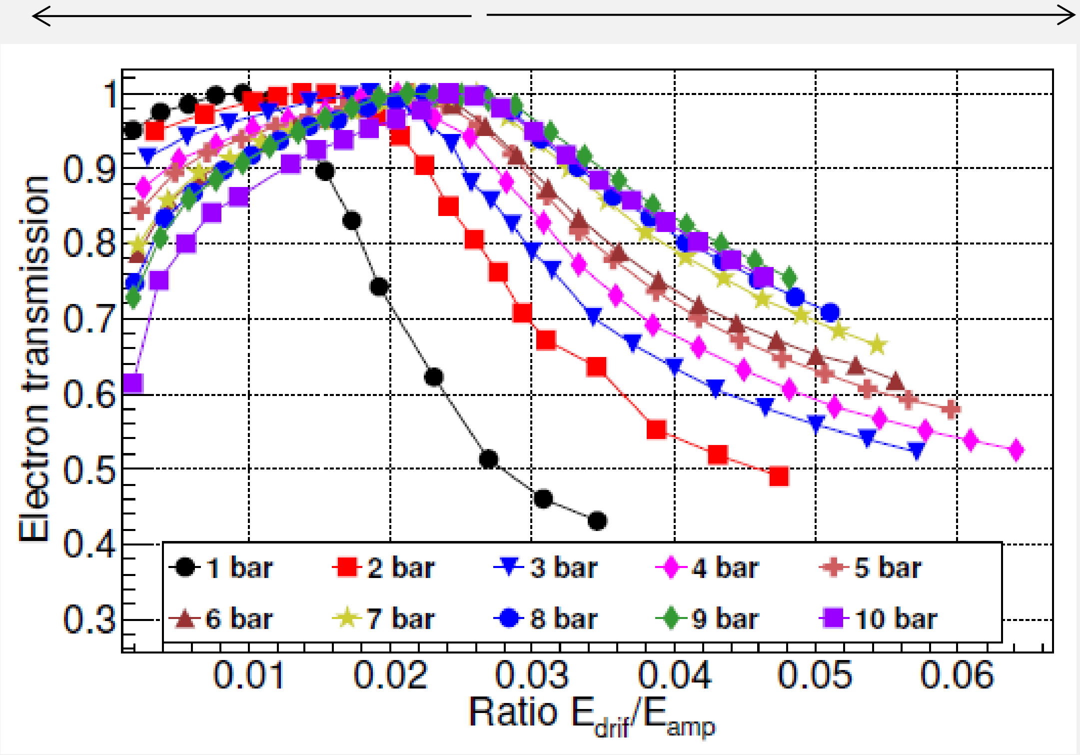
http://indico.cern.ch/getFile.py/access?contribId=37&sessionId=5&resId=1&materialId=slides&confId=245535

Part 3.2: the transmission region

The experimental situation

Too low drift field:
losses due to recombination or attachment.

Too high drift field:
loss of transparency. Electrons 'crash' against the mesh.



(S. Cebrian et al. JINST 8 (2013) P01012)

Is the observed effect compatible with recombination?

1) Fit the left-side to the standard 'Jaffe+Onsager' model as proposed by Ramsey/Agrawal

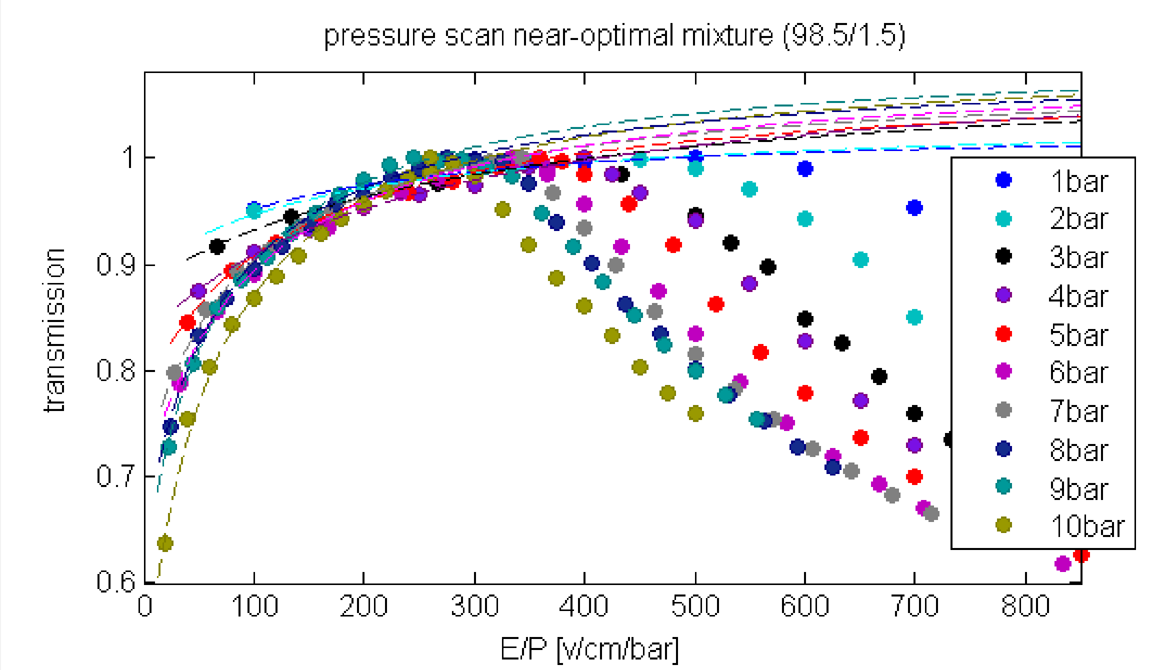
$$Q = Q_0 + \frac{Q_\infty - Q_0}{1 + K/E}$$

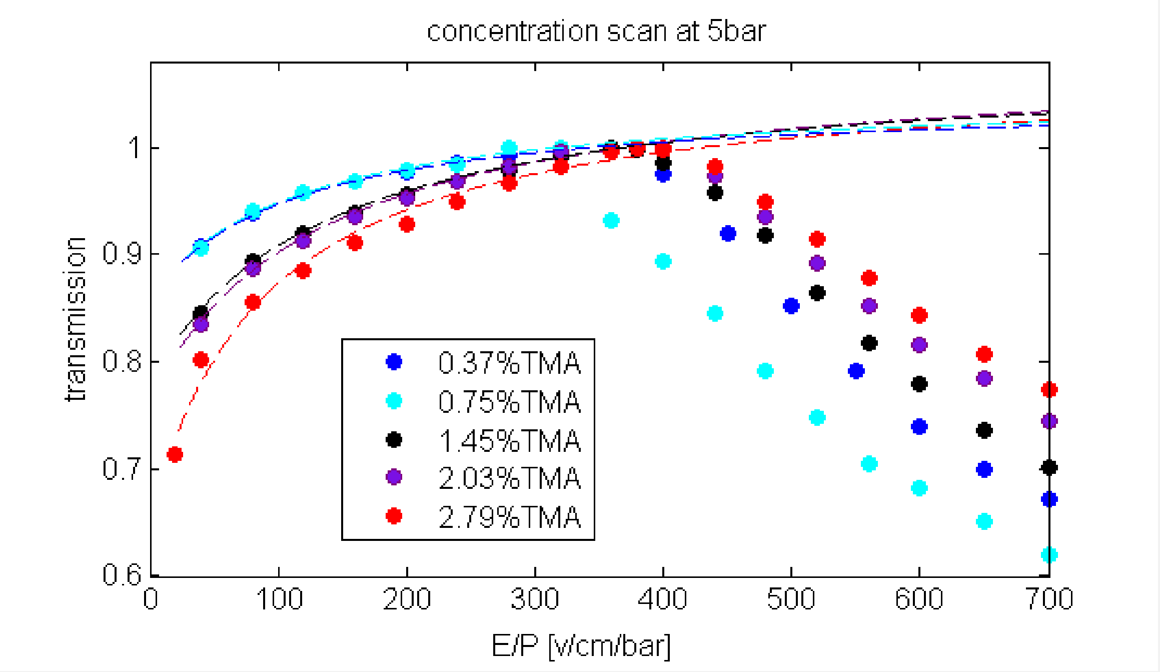
2) Attachment can be excluded up to 6bar and down to 50V/cm/bar (measured: **τ_e>3ms after recirculation! (***measurements done on 1cm drift***))**.

3) The observed effect is systematically increasing with increased quencher and increased pressure (intuitive).

4) The behavior to the right of the maximum is a complex interplay between field geometry and diffusion and depends strongly on the behavior of the Micromegas.

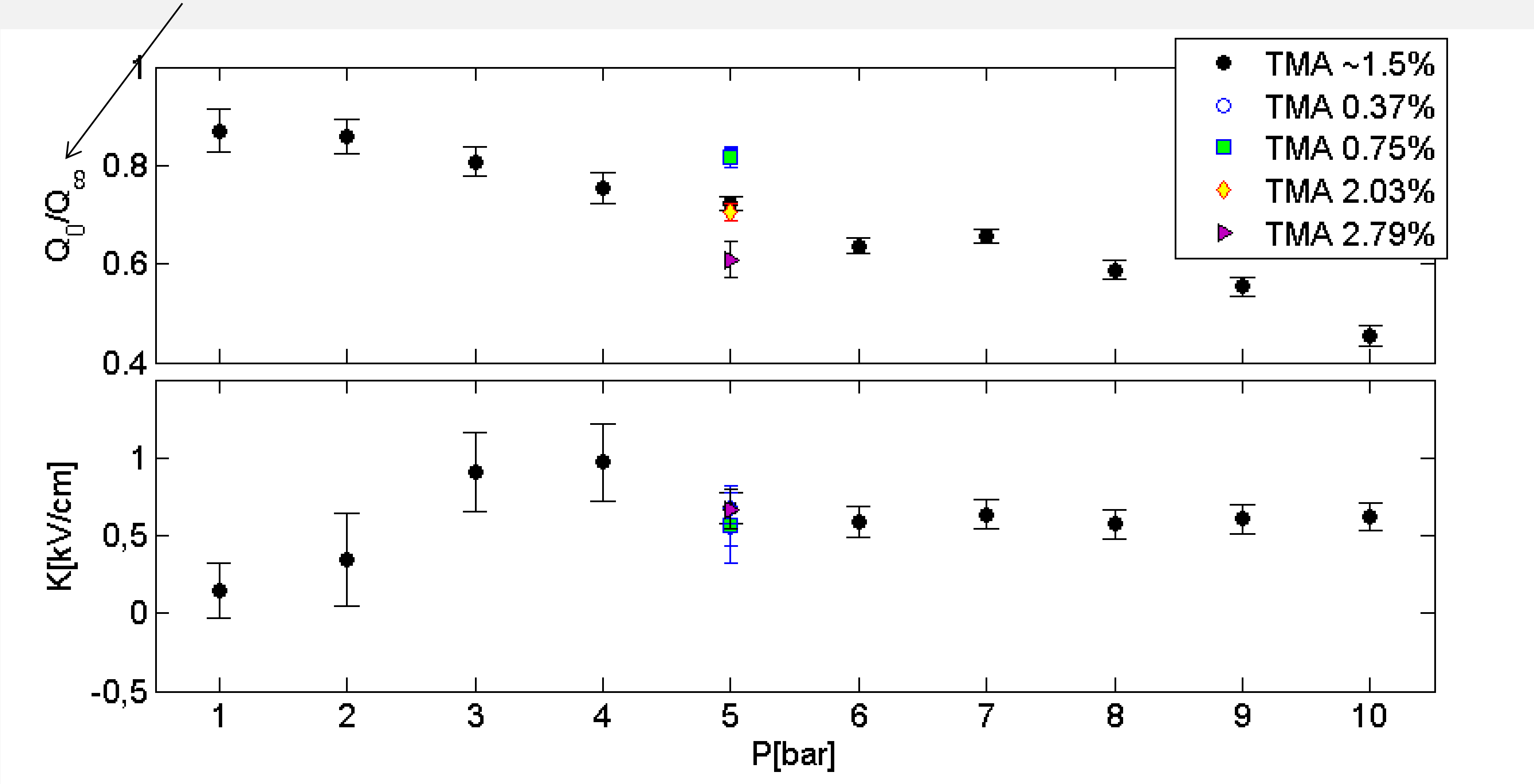
5) In the absence of recombination or attachment the behavior to the left of the maximum is expected not to depend on the micromegas, equaling one (preliminary studies based on microscopic simulations are given later).





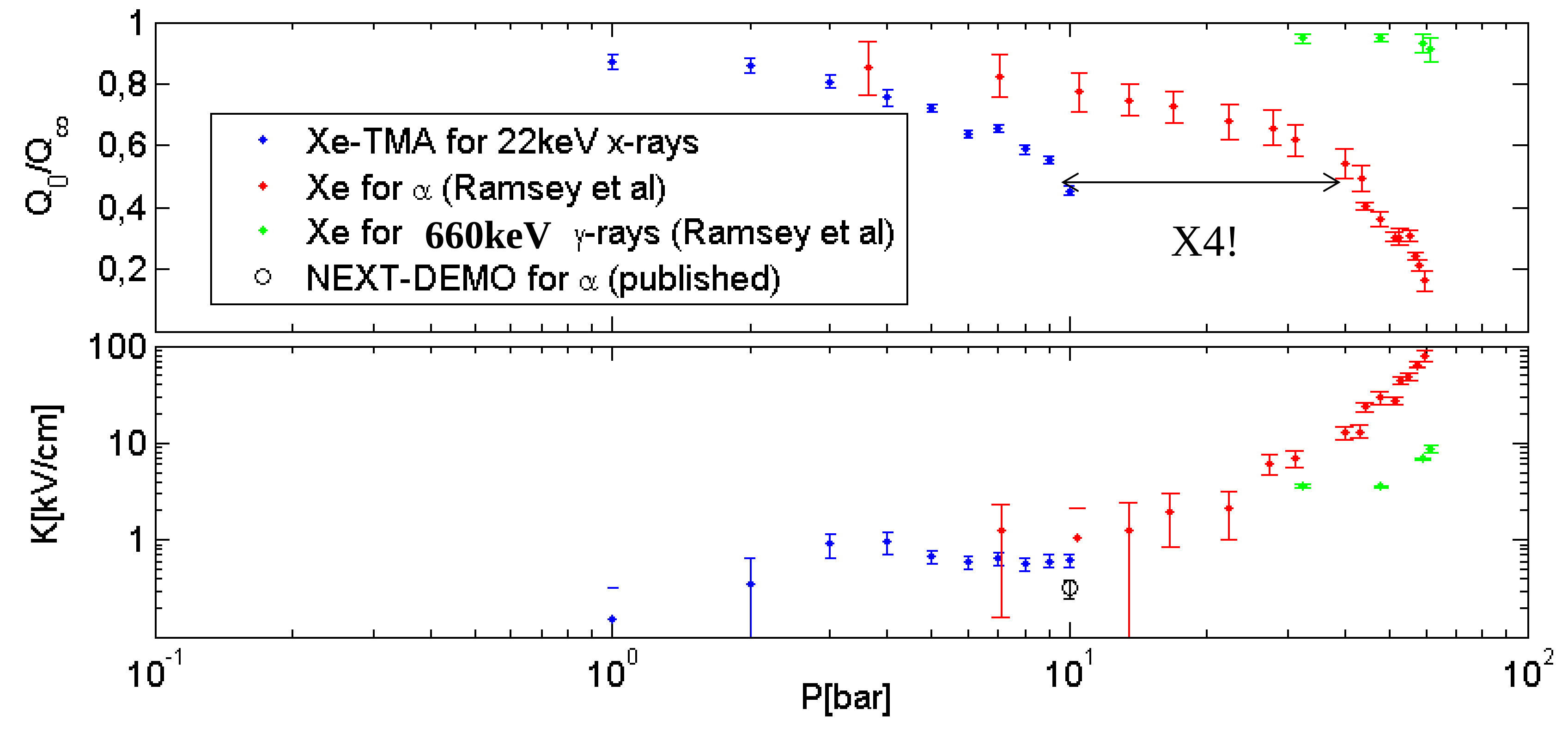
A compilation of the main figures in the Onsager/Jaffe model

fraction of charge that escapes recombination at zero field



Quantitative explanation still missing, but it behaves as intuitively expected. The higher the quencher and the pressure the faster the thermalization, the lower the charge that escapes initial recombination. However…

The observed effect is much more serious than for alphas in pure Xe!



Is this purely an effect of the faster thermalization of the initial electron in the presence of quencher or is Penning also somehow involved??

We tried to understand if this loss of transparency at low fields can be caused by the transition to the micromegas amplifying region (Garfield++ and Comsol simulations).

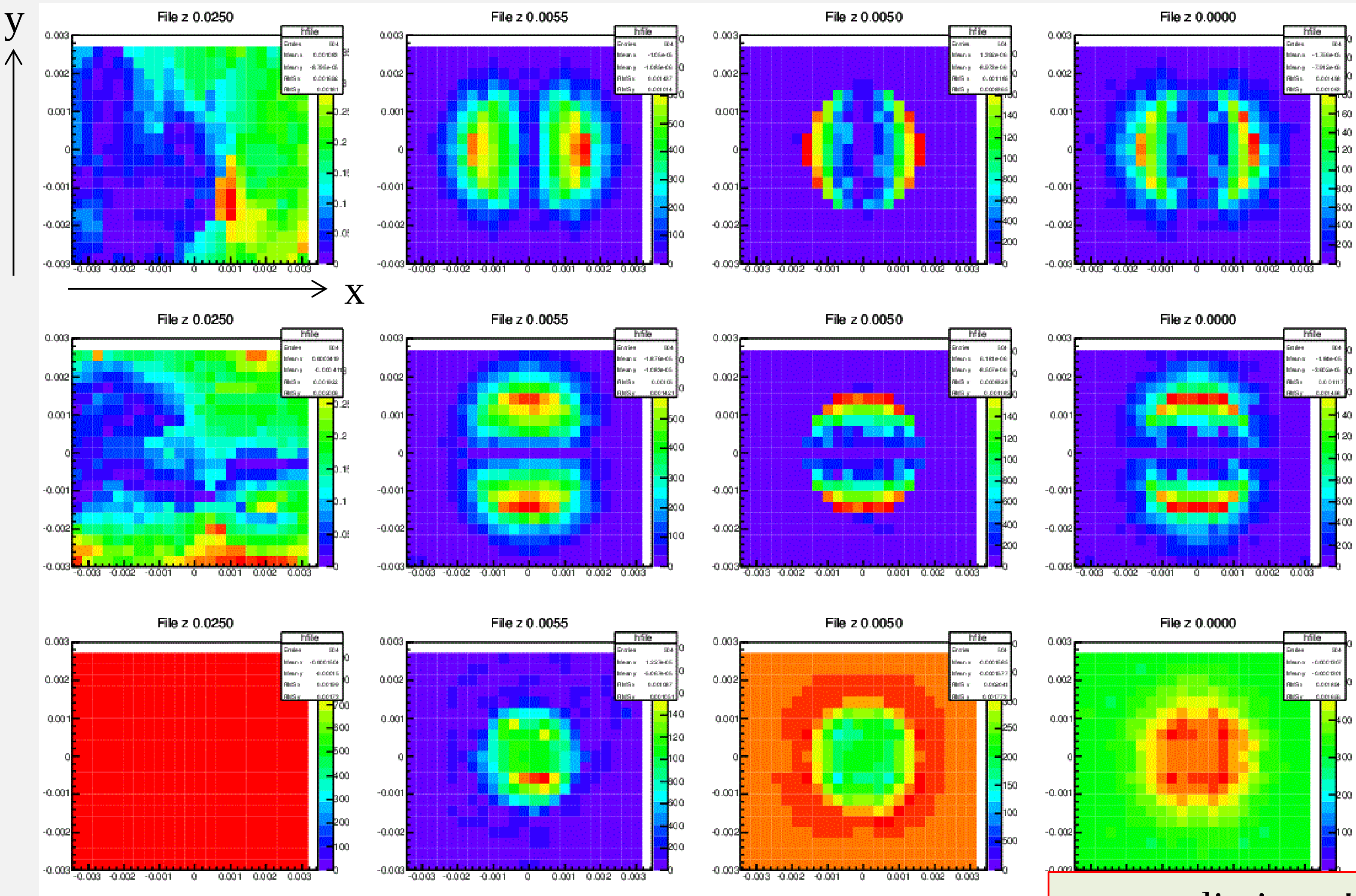
Alicia Diago

z=0.25mm (drift)	z=0.55mm (above mesh)	z=0.50mm (mesh)	z=0mm (anode)

E_x

E_y

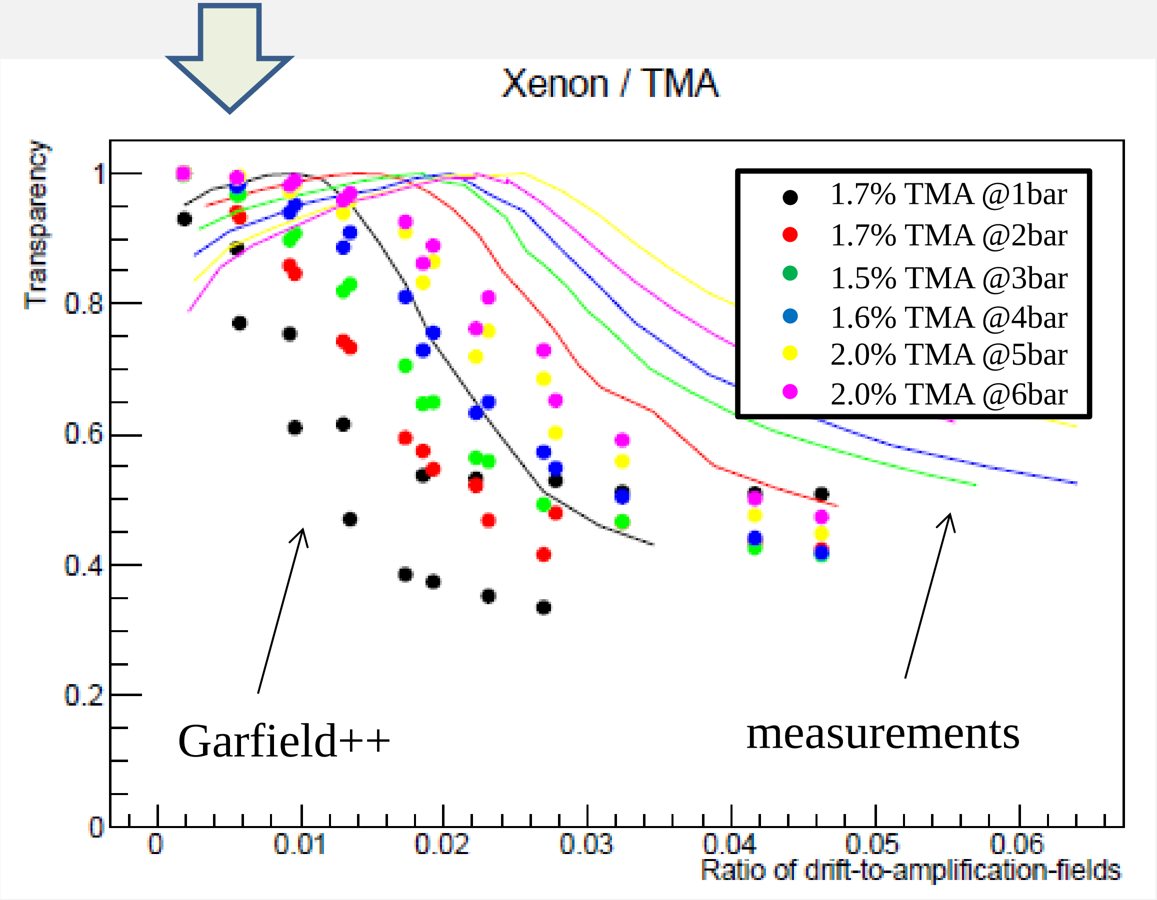
E_z



very preliminary!

Alicia Diago

No drop at low fields in simulation.
Trend for high drift field correctly captured!



arbitrary normalization!. Curves around the operating plateau differ by to 20% (under investigation)

very preliminary!

Part 3.3: energy resolution

First order formula used in the CDR (valid for large charge collection efficiency)

$$\frac{\sigma_E}{E} \cong 2.35\sqrt{F^* + f + (1-T) + (1-Q/Q_\infty)}\,\frac{1}{T\times Q/Q_\infty}\,\frac{1}{\sqrt{n_o}}$$

<0.15

0.3-1 (simulation)
(single-electron variance)

(0-0.2 ->simulation)

(0-0.2->from measurements)

$$F^* \cong F_{xe}(1-r) + rF_1$$

from simulation

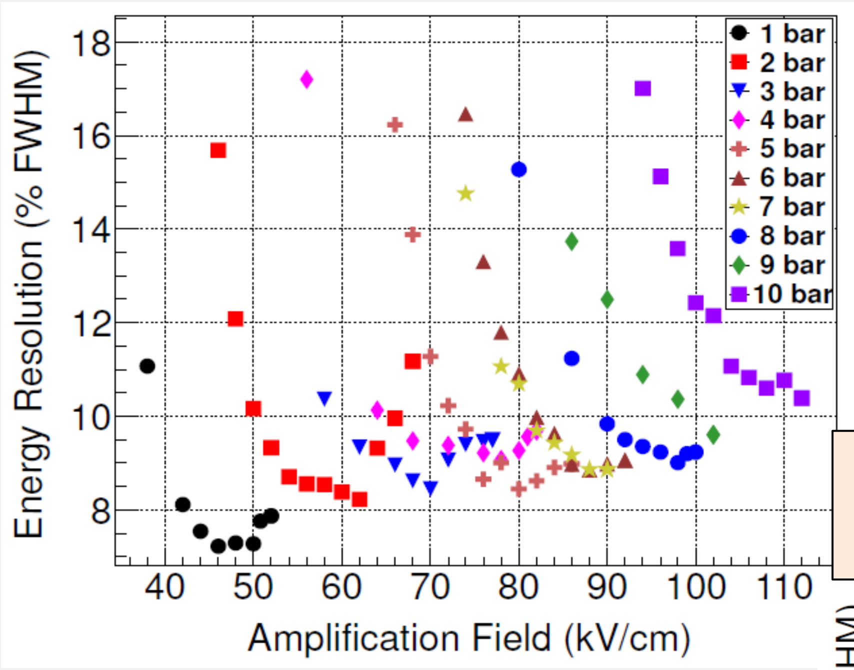
G. D. Alkhazov, A. P. Komar, A. A. Vorobeb, *Ionization fluctuations and resolution of ionization chambers and semi-conductor detectors*, NIM A, 1966.
(Eq. 11)

-> $\mathbf{F_1}$ is a complex (**defined-positive**) function.

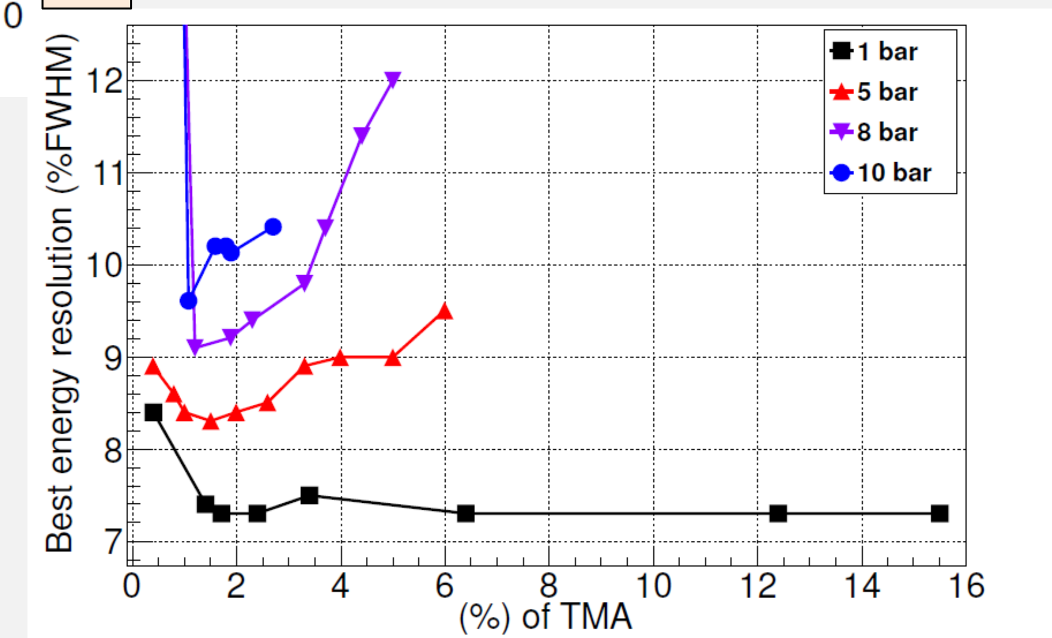
-> $\boldsymbol{\sigma}$ is the probability that an excited state causes an ionization by photo-ionization or Penning. ('probability of de-excitation followed by additional ionization', in Alkhazov words–*this old reference is still used by Aprile and Knoll*). Here it has been replaced by r in first order.

Extremely difficult to isolate all contributions…, but we do not give up!

the goal (stay tuned)



?



Conclusions and outlook

- ***System at 1bar well understood and operation stable****.*
- *Detailed assessment of unconnected pixels performed and situation understood.*
- *Basic analysis tools developed.*
- *Calibration preliminary implemented. System response very democratic at the moment.*
- *Previously 12%FWHM@30keV energy resolution on 1000evts and small area extended to the whole readout plane for over 100kevts.*
- *Energy resolution asymptotically approaching the NEXT-0 (small TPC) levels (6%), showing regularly 9.5% and hints of 8% for very small regions (~1000evts).*
- ***Looking forward to the 3bar-campaing!*** *(a necessary step before going to 10bar).*

- *Analysis of Xe-TMA parameters (diffusion and drift velocity):*
  - ***A calibration problem affecting the TMA determination was identified and solved.***
  - ***Measurements of the longitudinal coefficient and drift velocity of Xe-TMA mixtures (93/7, 97/3) in strong disagreement with Magboltz 9.0.1.***
  - ***Modeling of the Penning effect and microscopic modeling of Micromegas started.***
  - ***Simulation results preliminary indicate that the presence of excimers is necessary to describe the transfer probability, as expected.***
  - ***Strong hints of loss of transparency (from simulation) and recombination, that may explain the deterioration with pressure and %TMA.***
  - ***A common picture emerging… but some work ahead .***

Appendix

Description of the electron cloud in a (standard) hydrodynamic model

avalanche equation

$$-\frac{\partial n}{\partial t} + \alpha v_d n + D\left(\frac{\partial^2}{\partial x^2} n + \frac{\partial^2}{\partial y^2} n\right) + D_L \frac{\partial^2}{\partial z^2} n - W \frac{\partial}{\partial z} n = 0$$

solution for a point-like release of n_o electrons

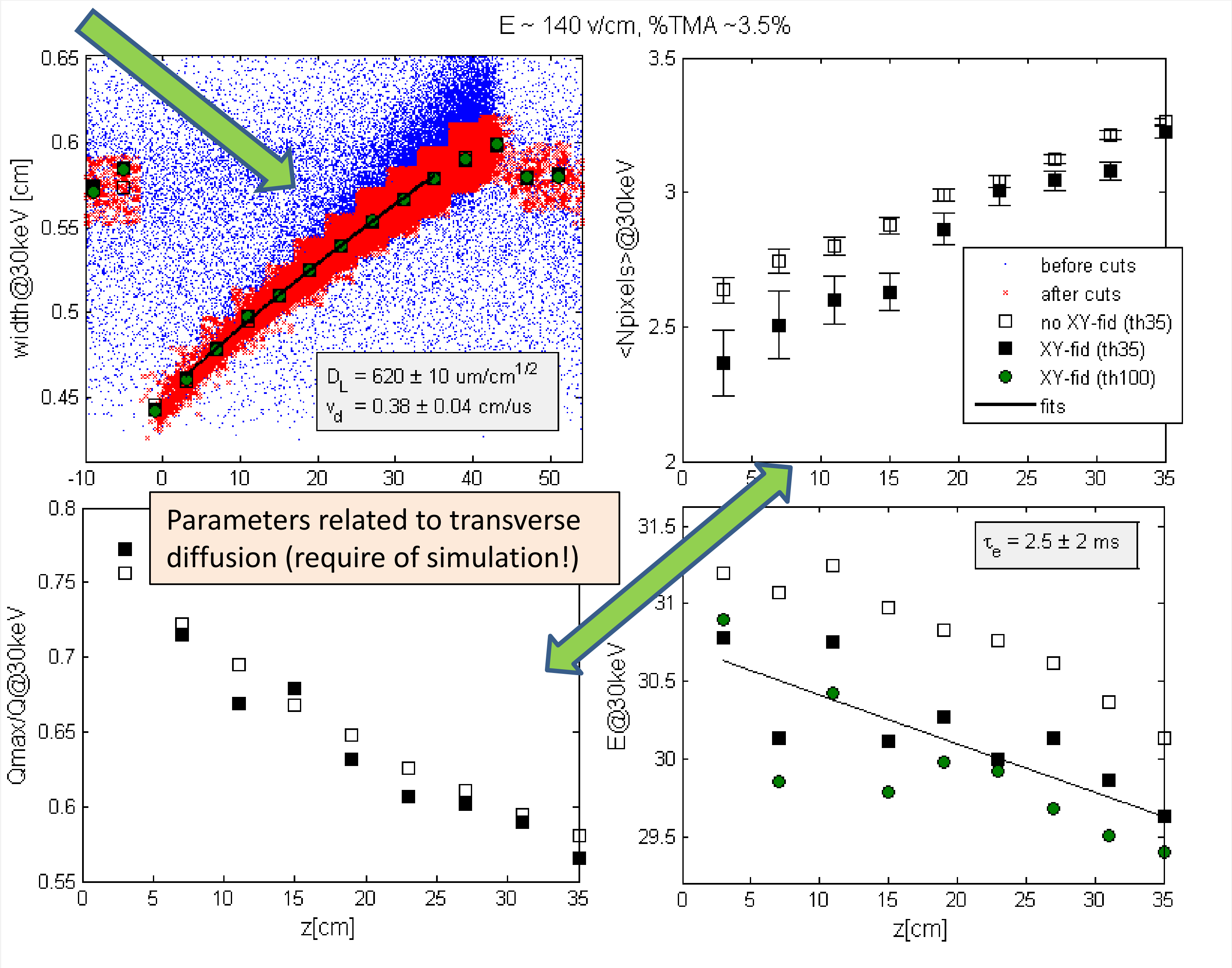
$$n(r,z,t) = \frac{n_0 \exp\left(-r^2 / 4Dt\right)}{v_d t (4\pi Dt)(4\pi D_L t)^{1/2}} \times \exp\left(-\frac{r^2}{4 D_T t}\right) \times \exp\left(-\frac{(z - v_d t)^2}{4 D_L t}\right) \times \exp\left[\alpha v_d t\right]$$

standard Magboltz re-definition

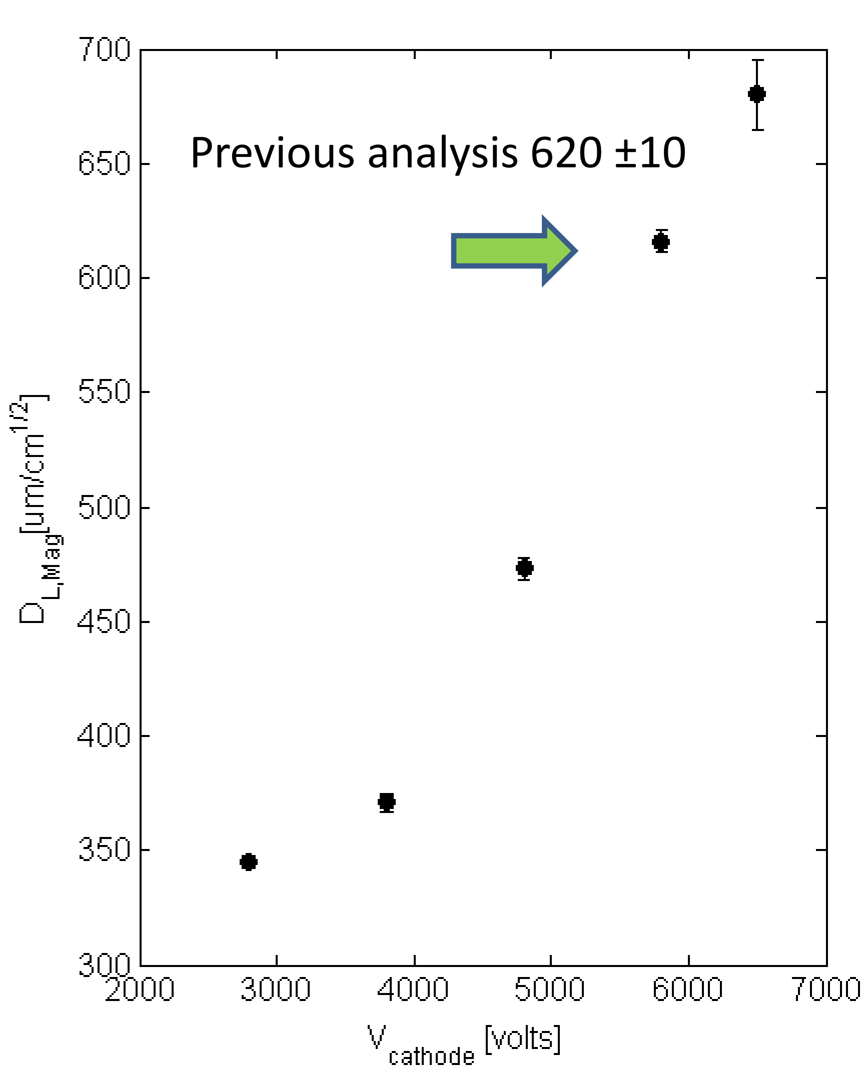
$$4 D_{L,T} t = 2\sigma_z^2 = 2\left(D_{L,T(Mag)} \sqrt{z}\right)^2$$

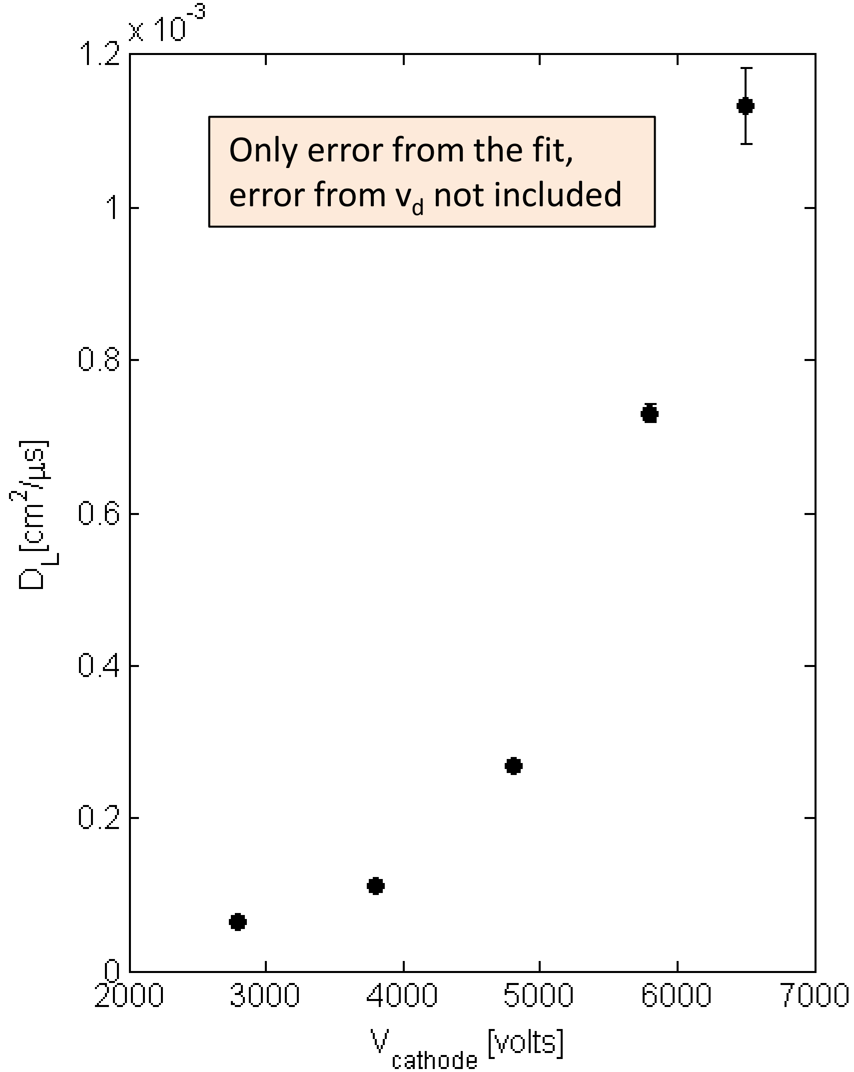
$$D_{L,T(Mag)} = \left(\frac{2 D_{L,T}}{v_d}\right)^{0.5}$$

parameters of drift region (old analysis (very high statistics))



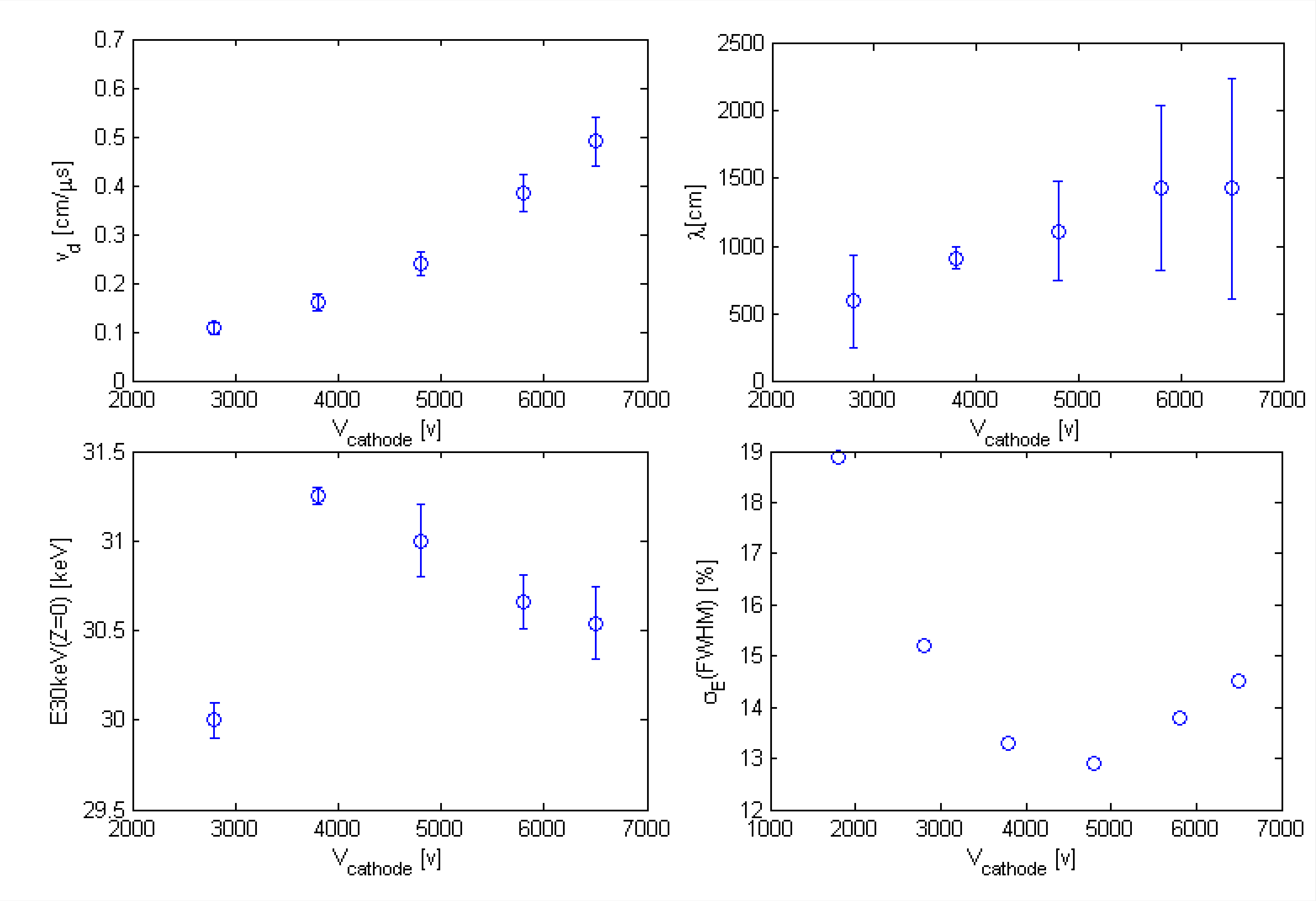
Results for the diffusion coefficient



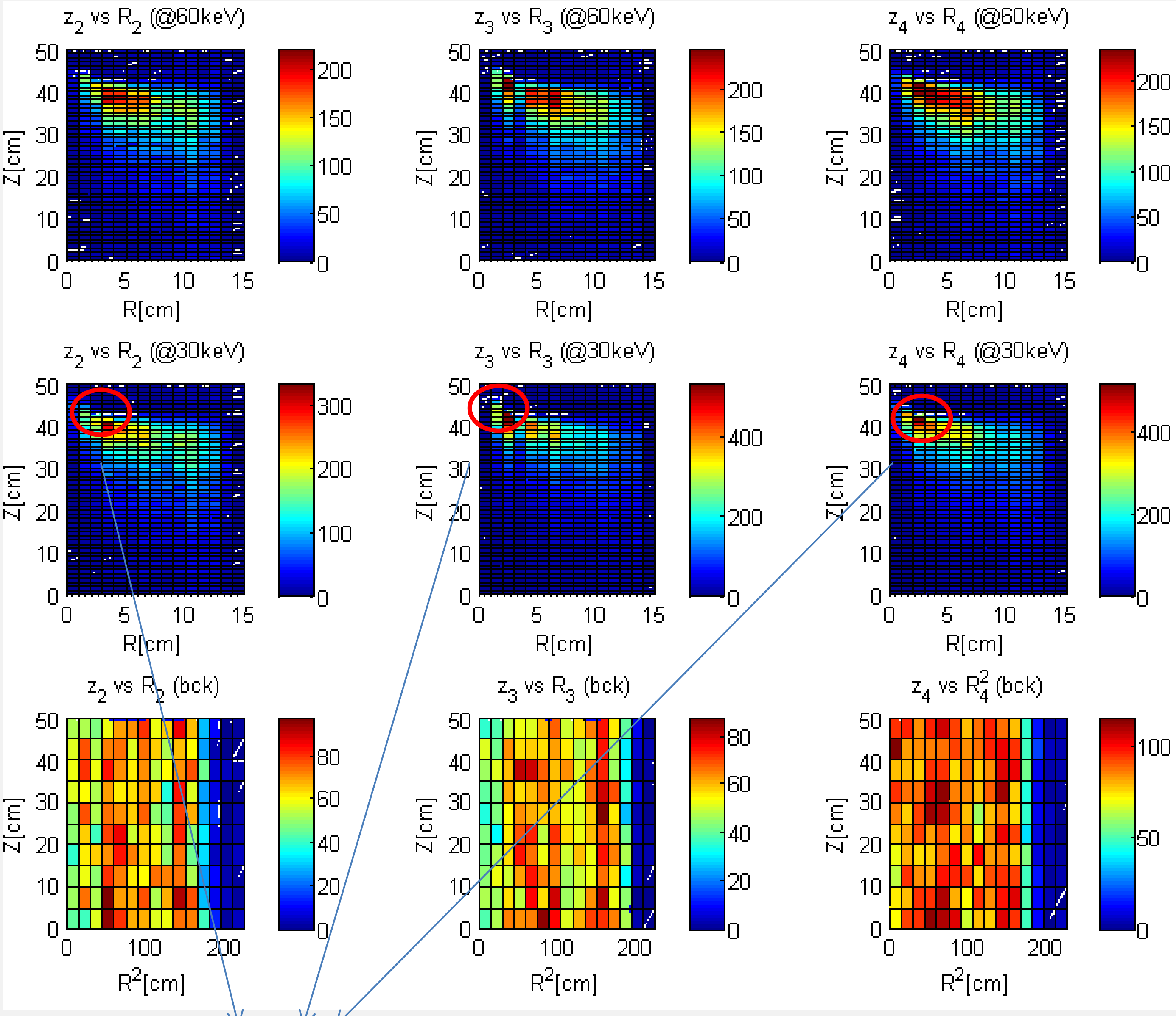


This experimental parameter depends very weakly on the chosen XY-region and threshold used for the analysis, very robust!!

Other relevant parameters as a function of voltage



Small effects to correct for

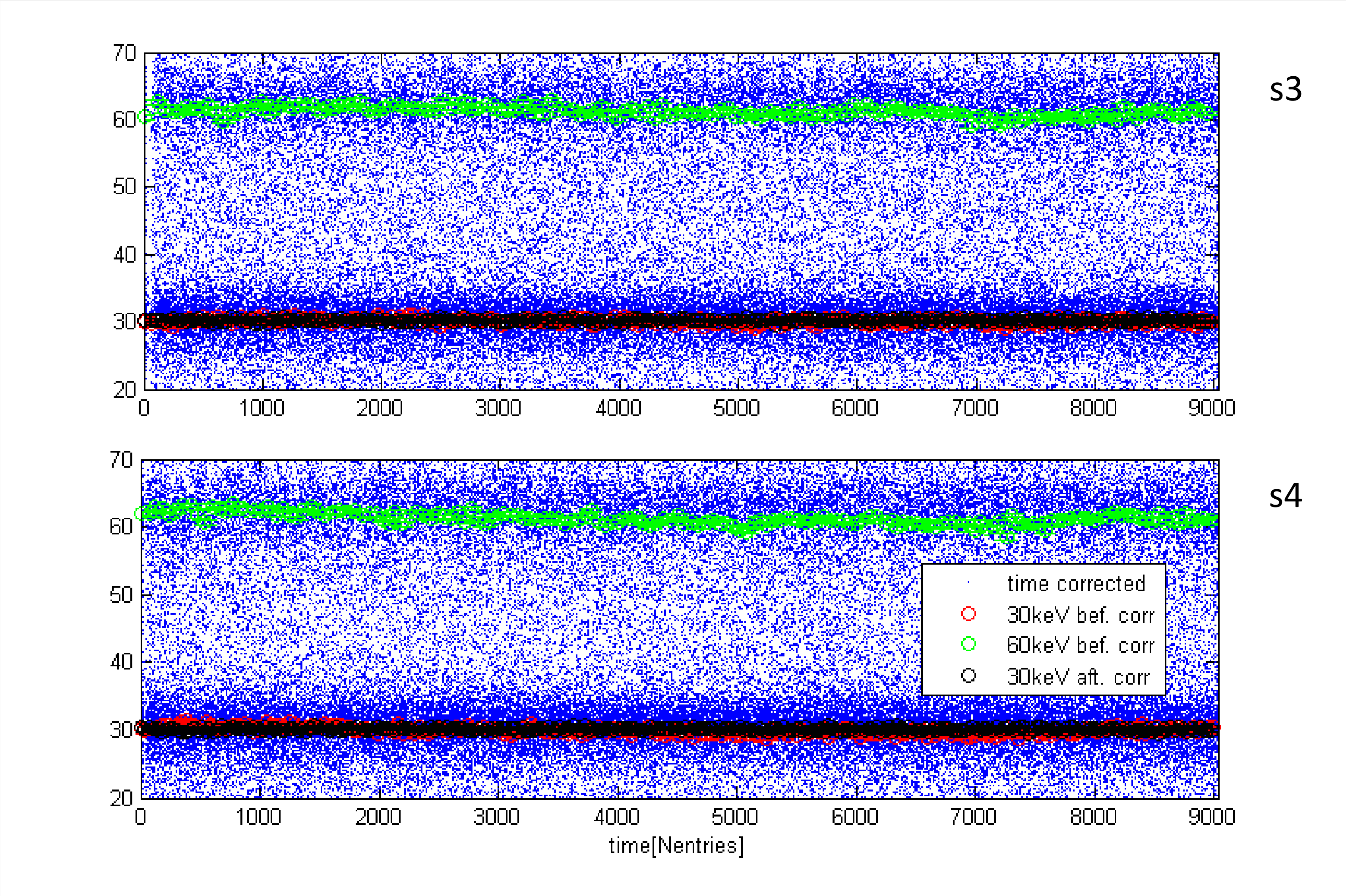


field deformation due to collimator hole (4cm ϕ)

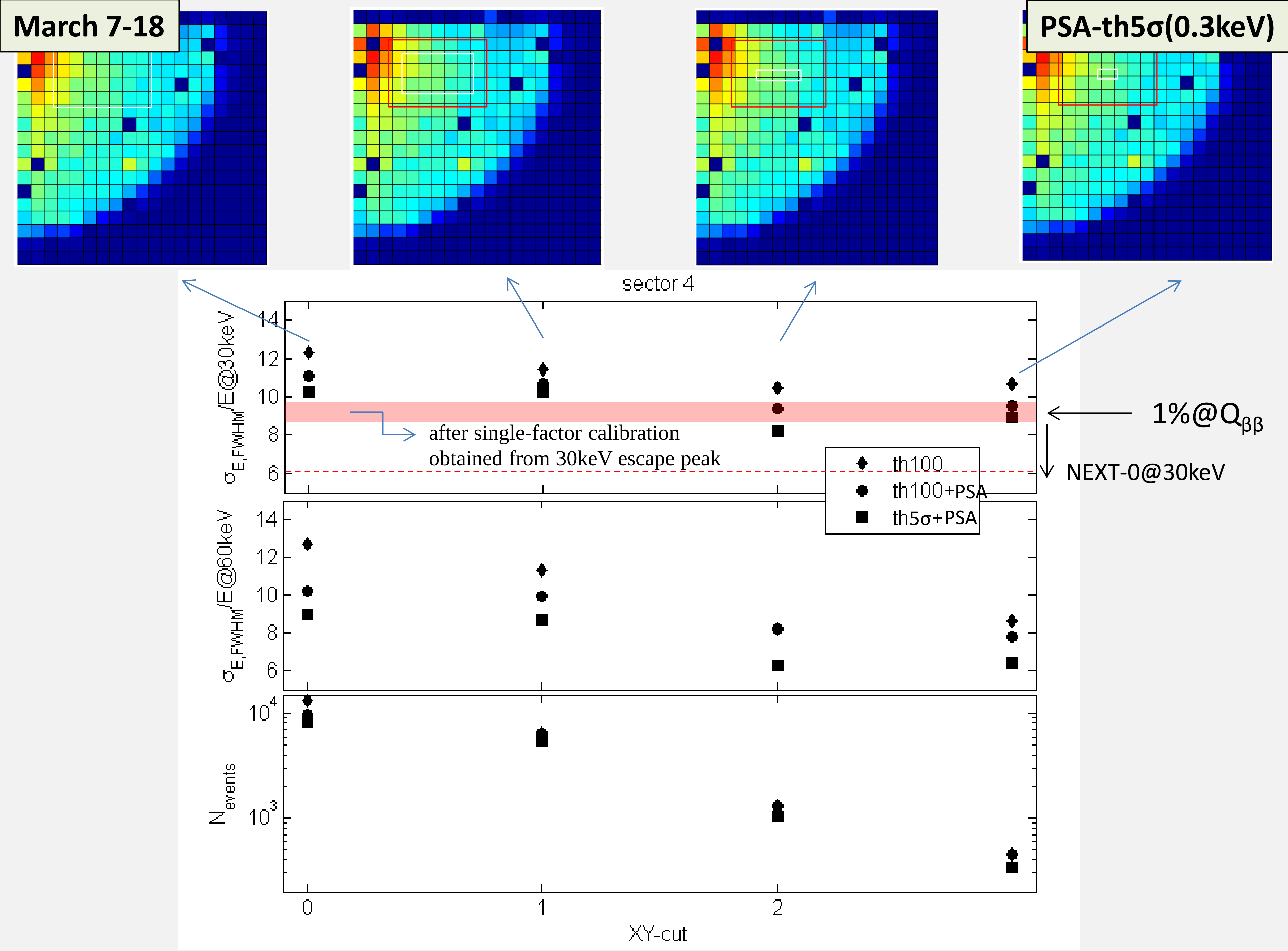
March 28

PSA-th100(1.2keV)

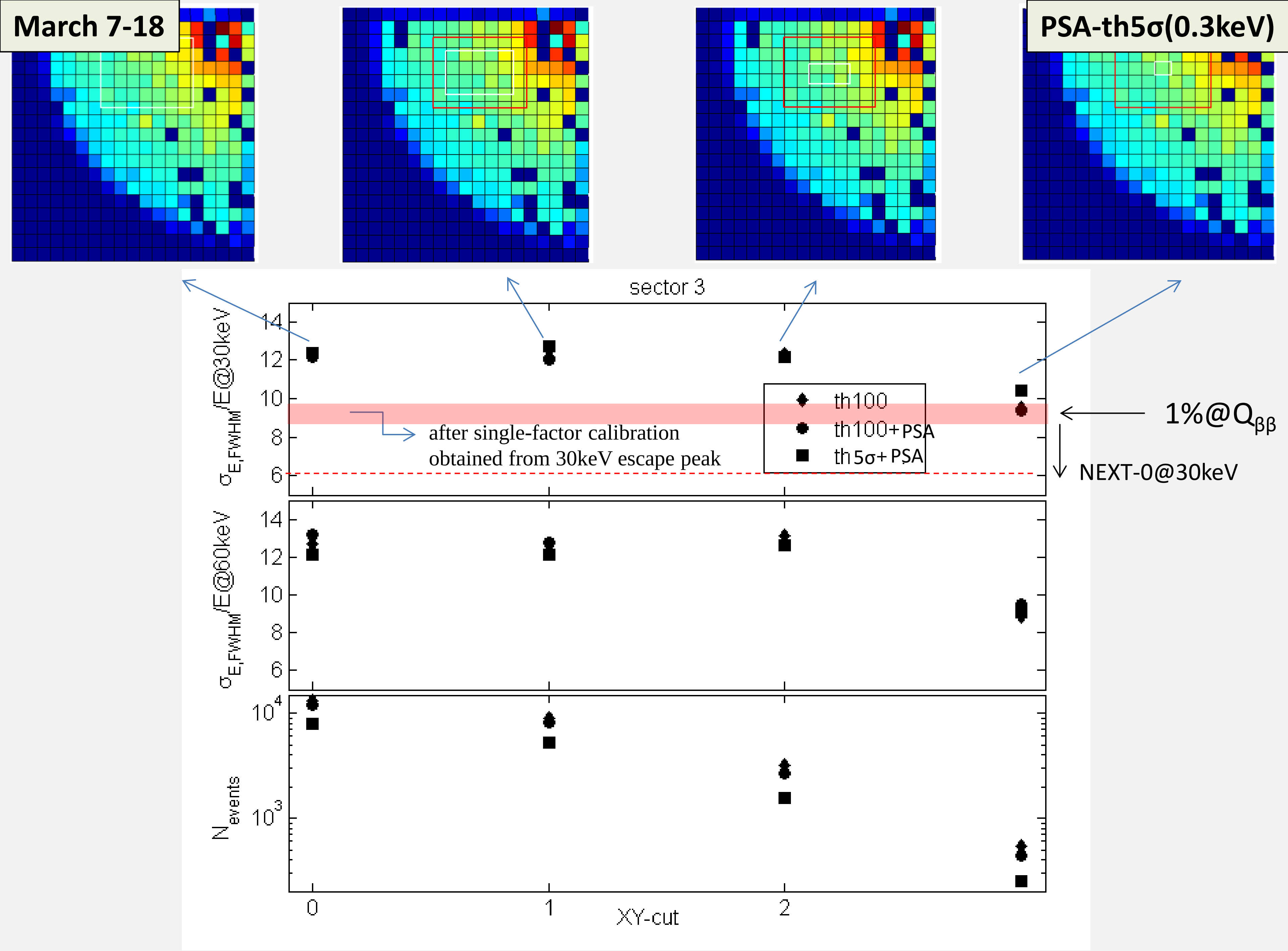
gain excursions (before and after correction)



Excursions much smaller with the new power supplies!



March 7-18
PSA-th5σ(0.3keV)
sector 4
after single-factor calibration
obtained from 30keV escape peak
1%@Qββ
NEXT-0@30keV
th100
th100+PSA
th5σ+PSA
σE,FWHM/E@30keV
σE,FWHM/E@60keV
Nevents
XY-cut

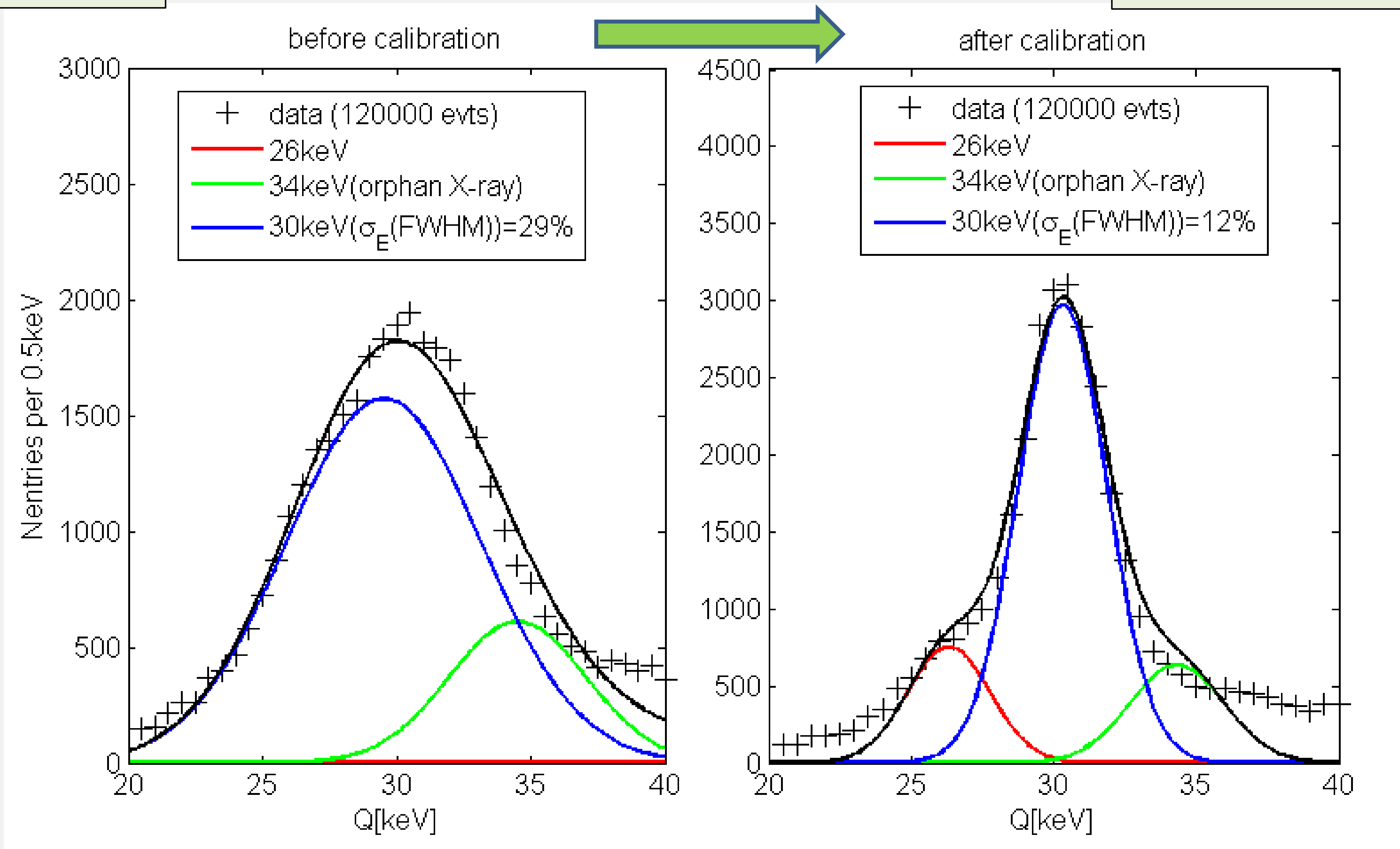


March 7-18
PSA-th5σ(0.3keV)
sector 3
σE,FWHM/E@30keV
σE,FWHM/E@60keV
Nevents
XY-cut
0
1
2
14
12
10
8
6
10^4
10^3
th100
th100+PSA
th5σ+PSA
after single-factor calibration
obtained from 30keV escape peak
1%@Qββ
NEXT-0@30keV

March 28

Results for **full sector 2** after calibration **(no cuts!)**

PSA-th100(1.2keV)

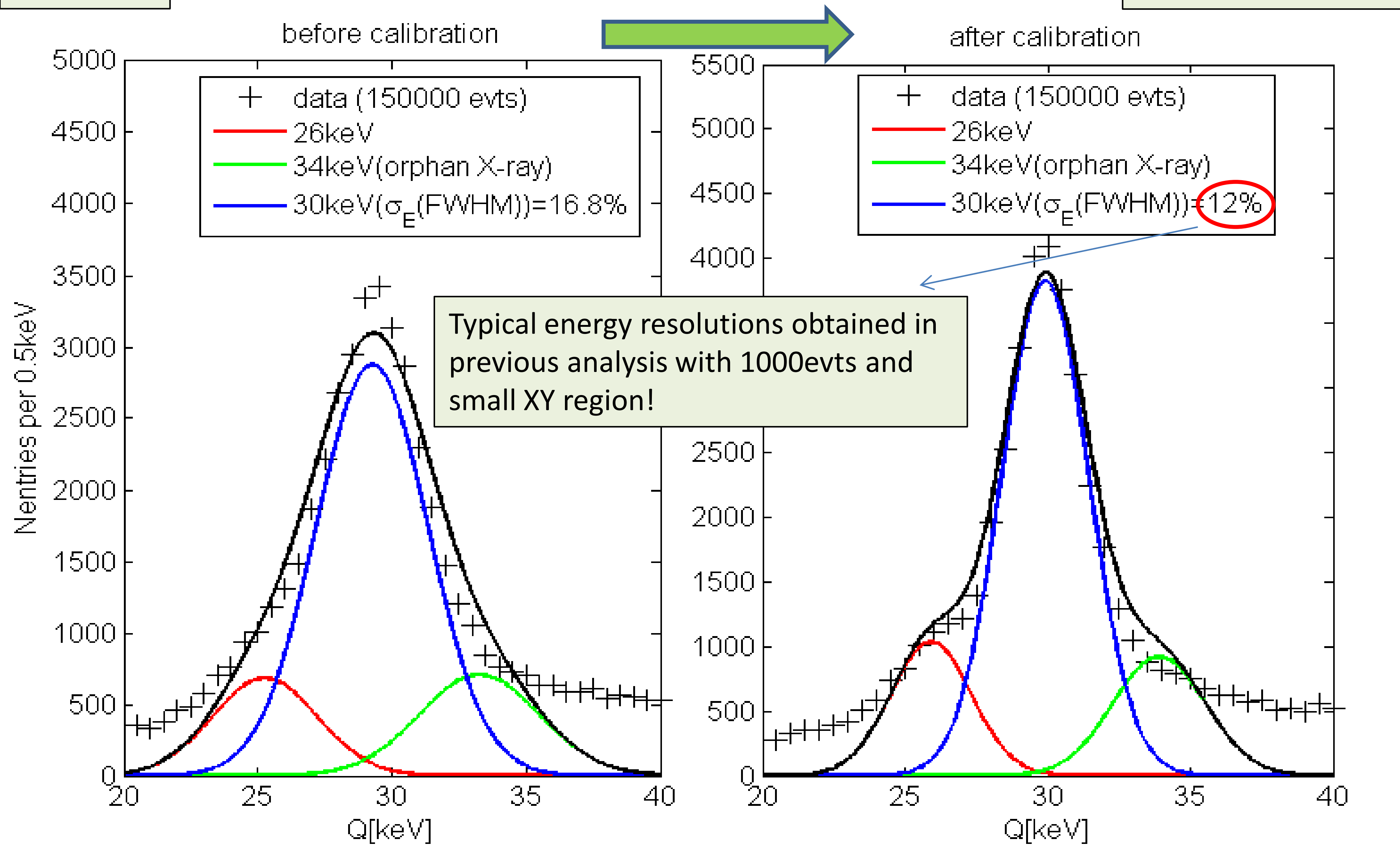


NOTE: cut in signal width should suppress backgrounds.
calibration works better for 30keV, since ~70% of the energy goes to one pixel

March 28

Results for **full sector 3** after calibration **(no cuts!)**

PSA-th100(1.2keV)

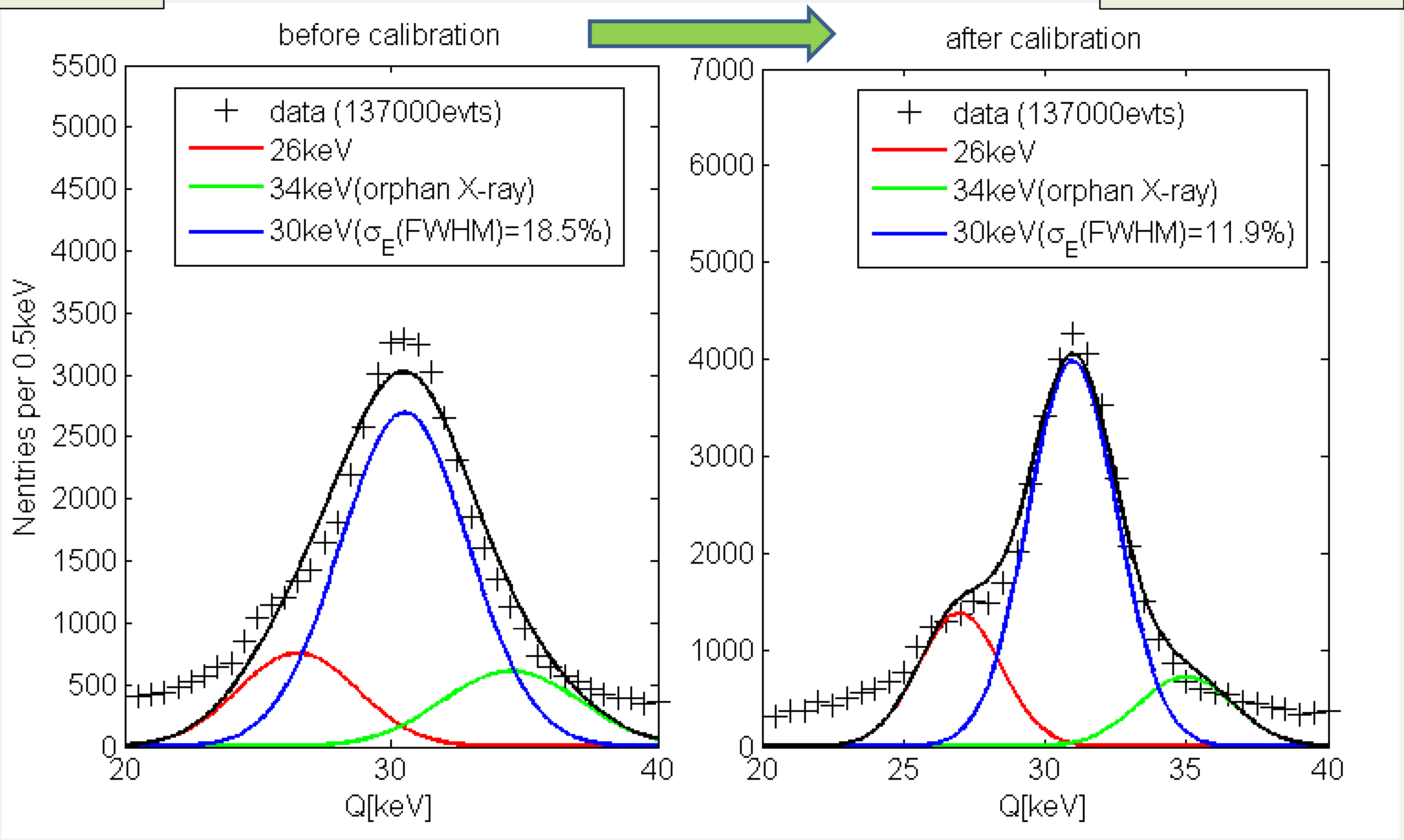


NOTE: cut in signal width should suppress backgrounds and improve resolution.
calibration works better for 30keV, since ~70% of the energy goes to one pixel

March 28

Results for **full sector 4** after calibration **(no cuts!)**

PSA-th100(1.2keV)

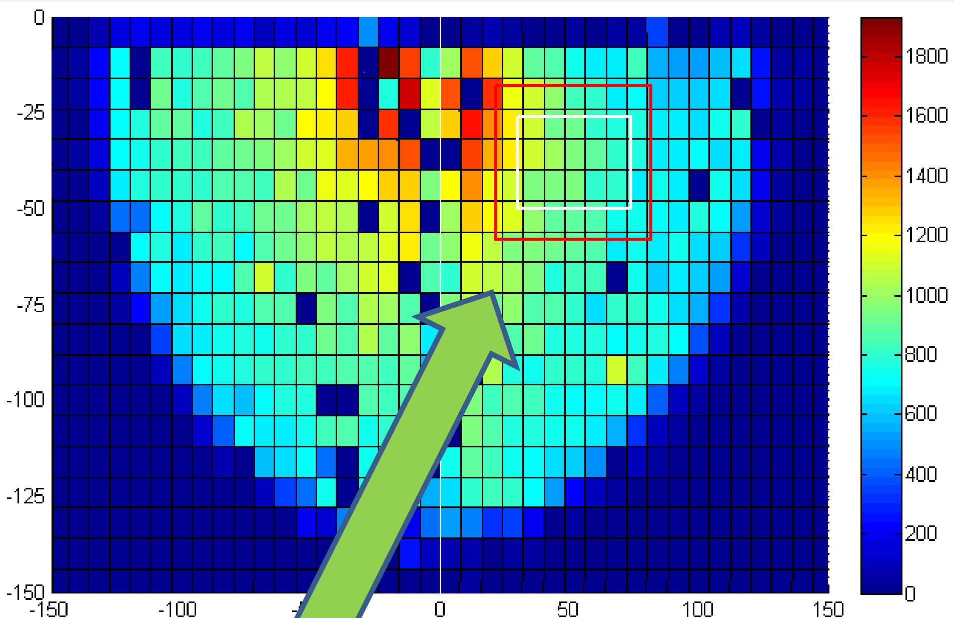


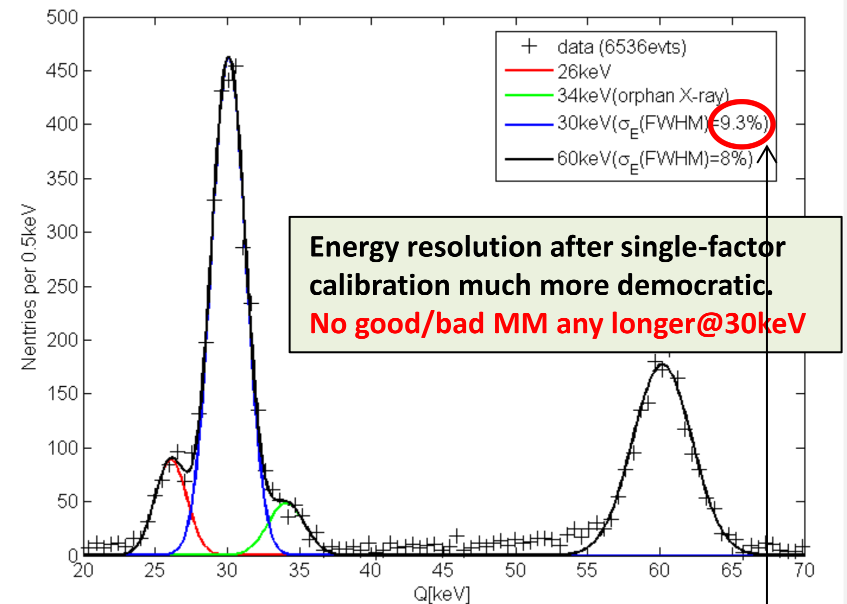
NOTE: cut in signal width should suppress backgrounds and improve resolution.
calibration works better for 30keV, since ~70% of the energy goes to one pixel

March 7-18

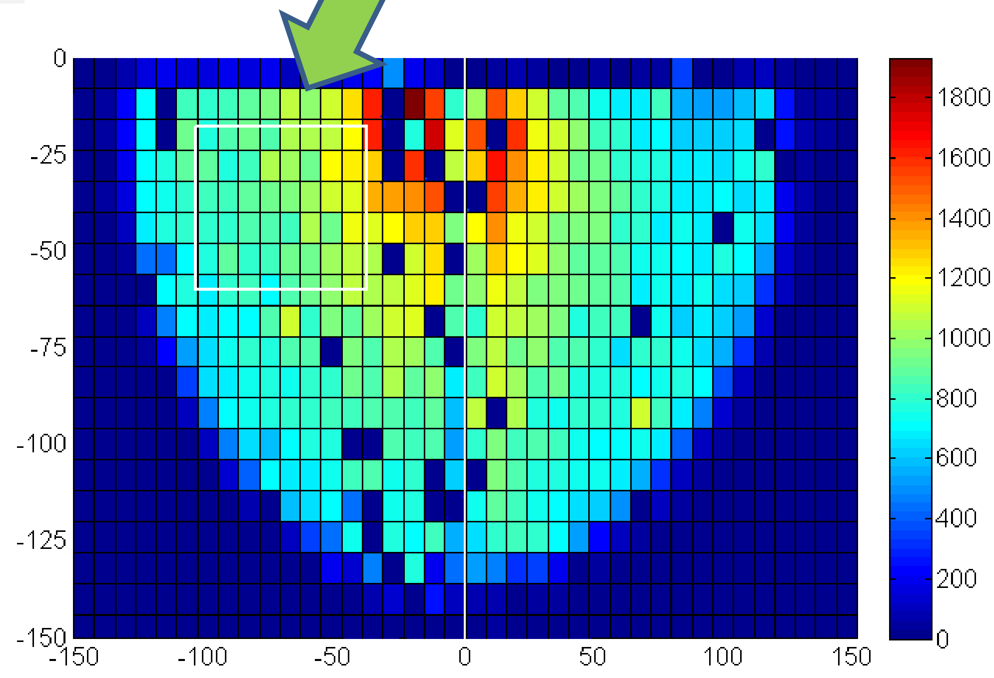
resolution's best
(after preliminary single-factor calibration)

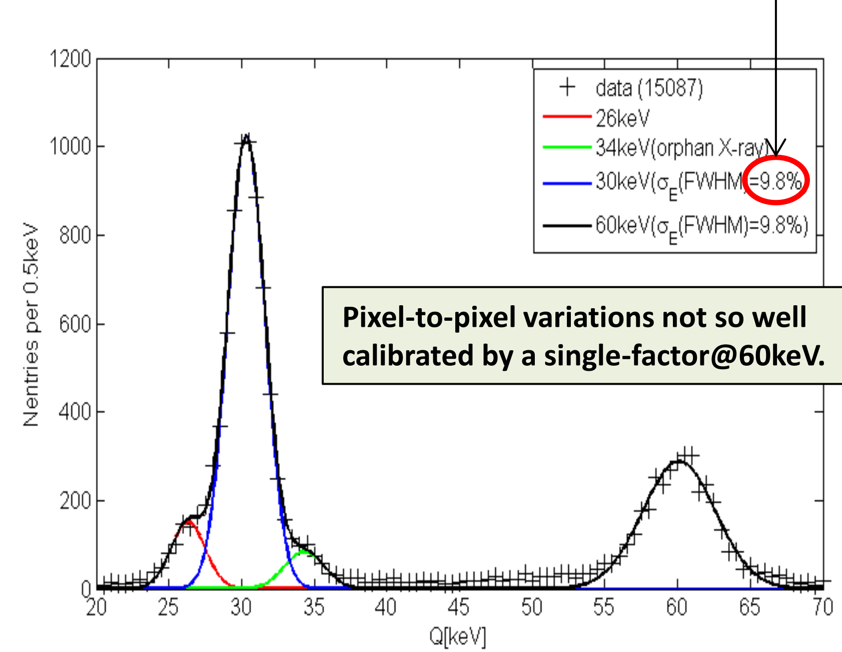
PSA-th5σ(0.3keV)





Energy resolution after single-factor calibration much more democratic.
No good/bad MM any longer@30keV





Pixel-to-pixel variations not so well calibrated by a single-factor@60keV.

Summary of NEXT-MM analysis@1bar

	PSA th1.2keV + phys(old soft) + Matlab	PSA th1.2keV + phys(old soft) + Matlab	**PSA th1.2keV + phys(old soft) + Matlab**	PSA th1.2keV + phys(old soft) + Matlab	???
Before calibration (30keV)	17%(S3) -30%(S2)	13-15%	11-13%	8-9%	NEXT0 6%
After calibration (30keV)	**12%** tails visible	10.3-10.5% small tails	**9.3-9.9%** ~no tails	8-9% ~no tails	With further analysis we can certainly approach **7%**
Typical Number of events	120000-150000evts	50000evts	5000-10000evts	500-1000evts	?
Typical size	**1 sector**	9cm x 8cm	5cm x 5cm	1cm x 1cm	5cm x 5cm
Typical problems	**unconnected pixels, fringe fields, bad containment**	unconnected pixels (some ~5% -typical)	**1.03-1.1%@$Q_{\beta\beta}$**	~single-pixel limit. Little statistics **PSAth0.3keV** analysis makes a difference	
Notes			**Standard analysis (fast)**		