Modelling the response of microbulk Micromegas in Xe-TMA admixtures

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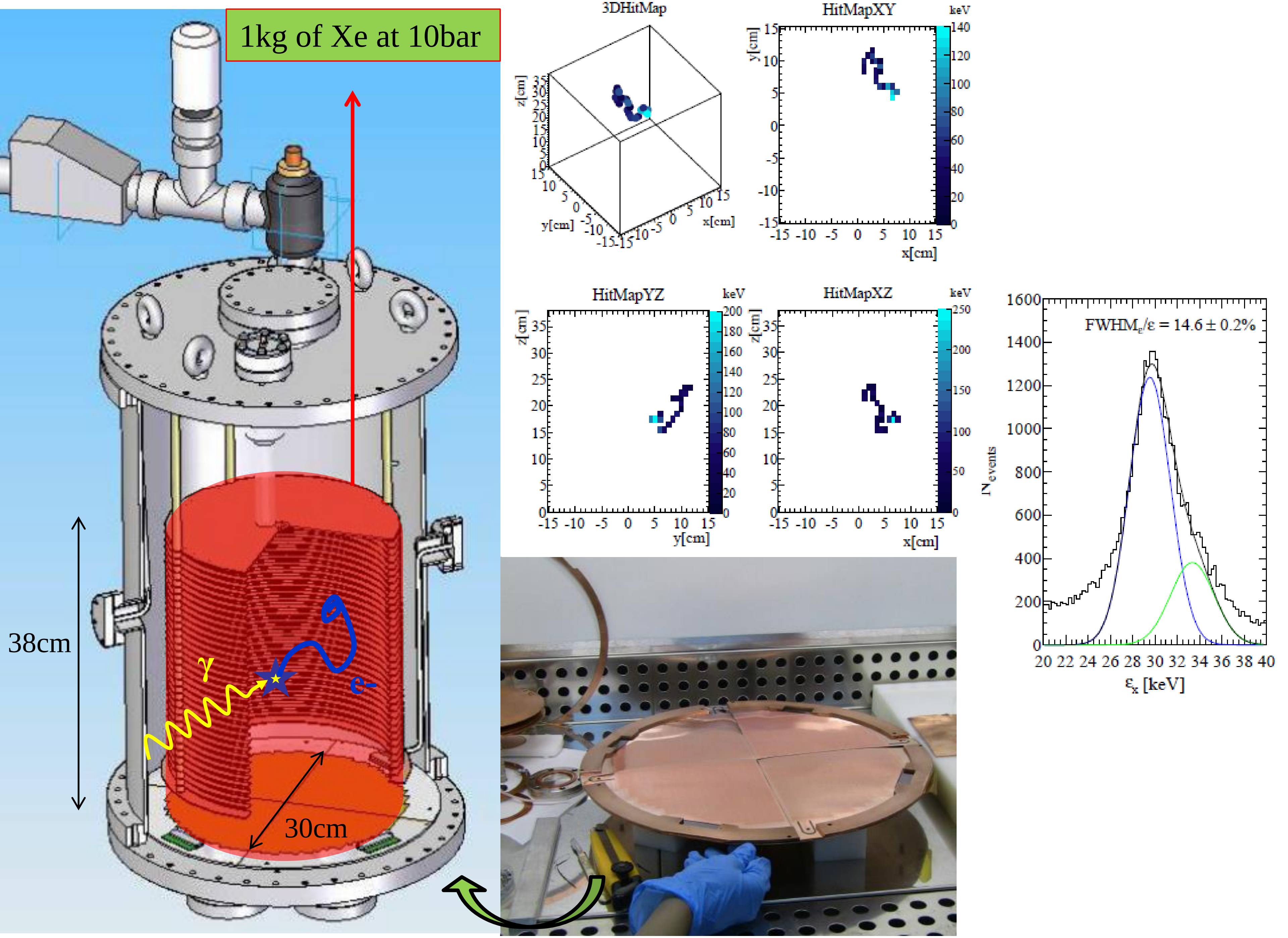
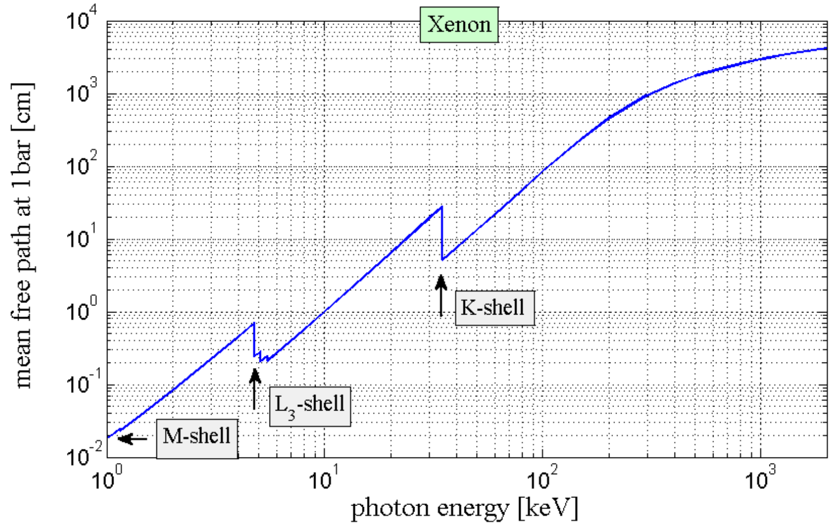
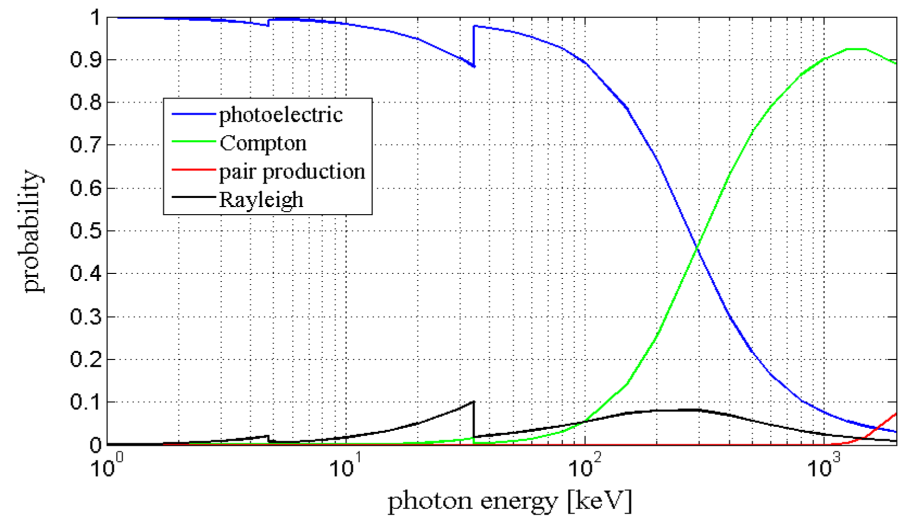
CERN, **12-06-2015**

what we wanted to understand:


1kg of Xe at 10bar
38cm
30cm
γ
e-
3DHitMap
z[cm]
y[cm]
x[cm]
HitMapXY
y[cm]
x[cm]
keV
HitMapYZ
z[cm]
y[cm]
keV
HitMapXZ
z[cm]
x[cm]
keV
FWHM$_ε$/ε = 14.6 ± 0.2%
N$_{events}$
ε$_x$ [keV]

What we knew:





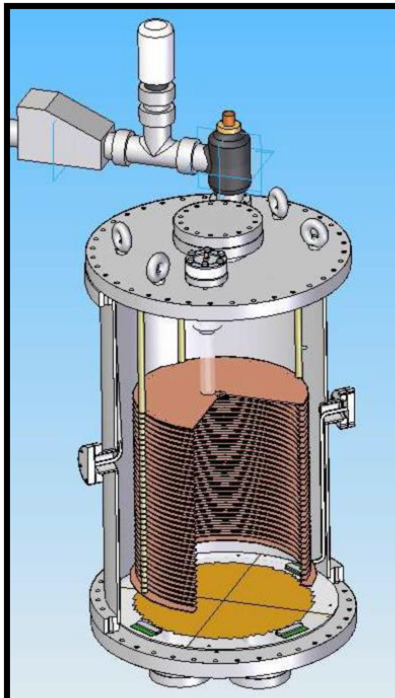
What we did not know:

simulation code

1. Track topology ↔ Characteristics of the primary electron ionization trail. (DEGRAD)
2. Drift properties ↔ Properties of electron ionization trail in electric field: *diffusion*, *drift*, *attachment*. Magboltz
3. Readout properties ↔ Properties of multiplication structures: *transmission*, *energy resolution*, *gain*. Garfield++

+ recombination and Penning transfer processes

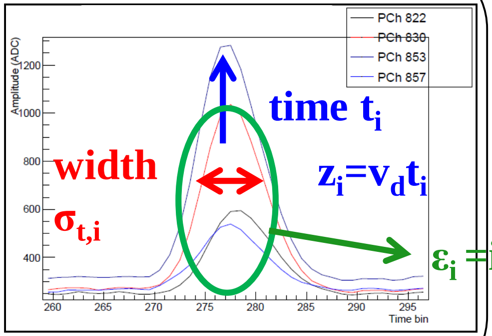
1. Drift data from the 38cm x 700cm^2-setup (NEXT-MM)



drift properties

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

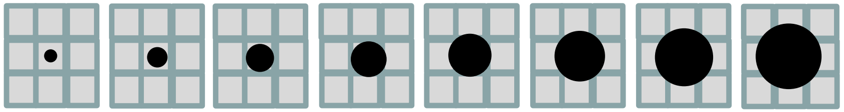
$$\sigma_{L,T} = D_{L,T}^* \frac{\sqrt{z}}{\sqrt{P}}$$

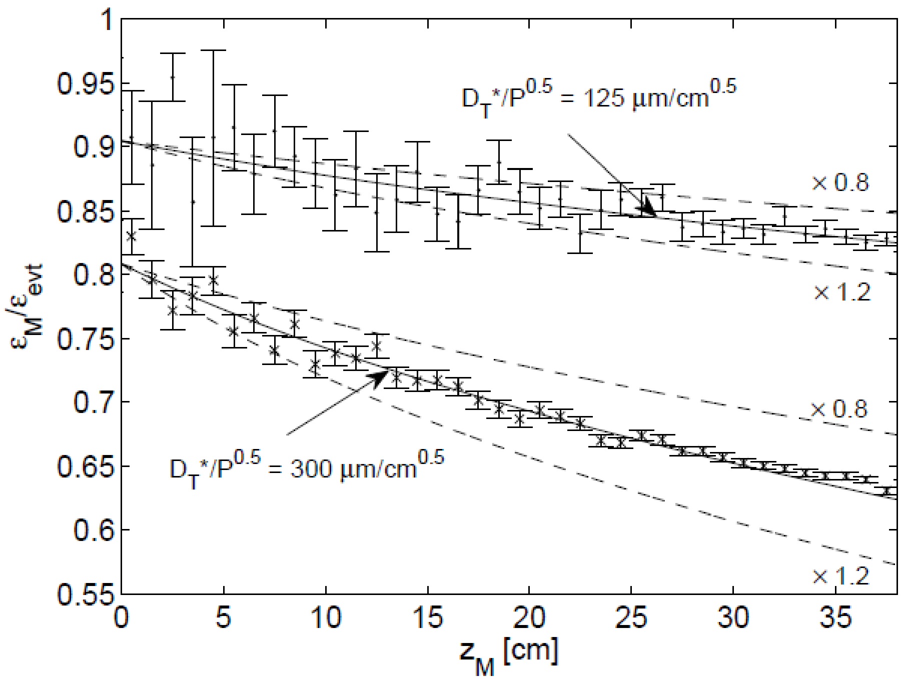


typical x-ray event

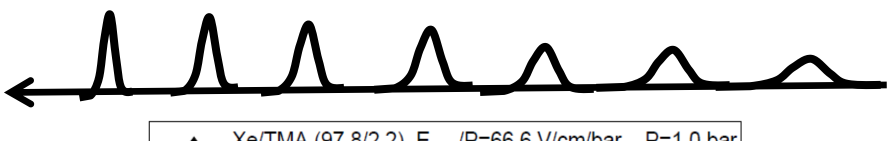
agreement with Magboltz??

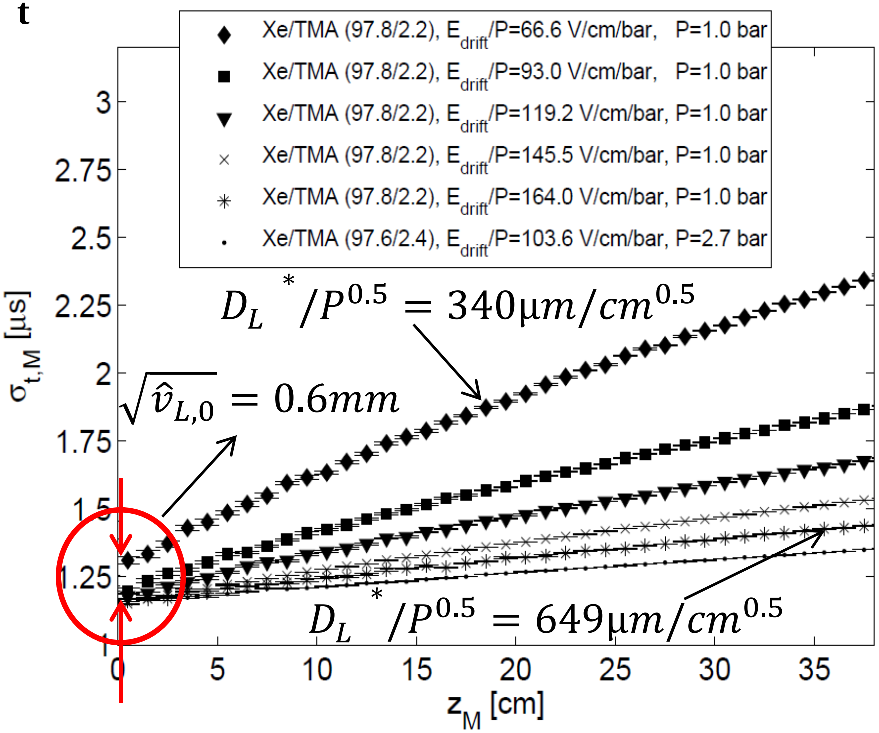
across the field





along the field

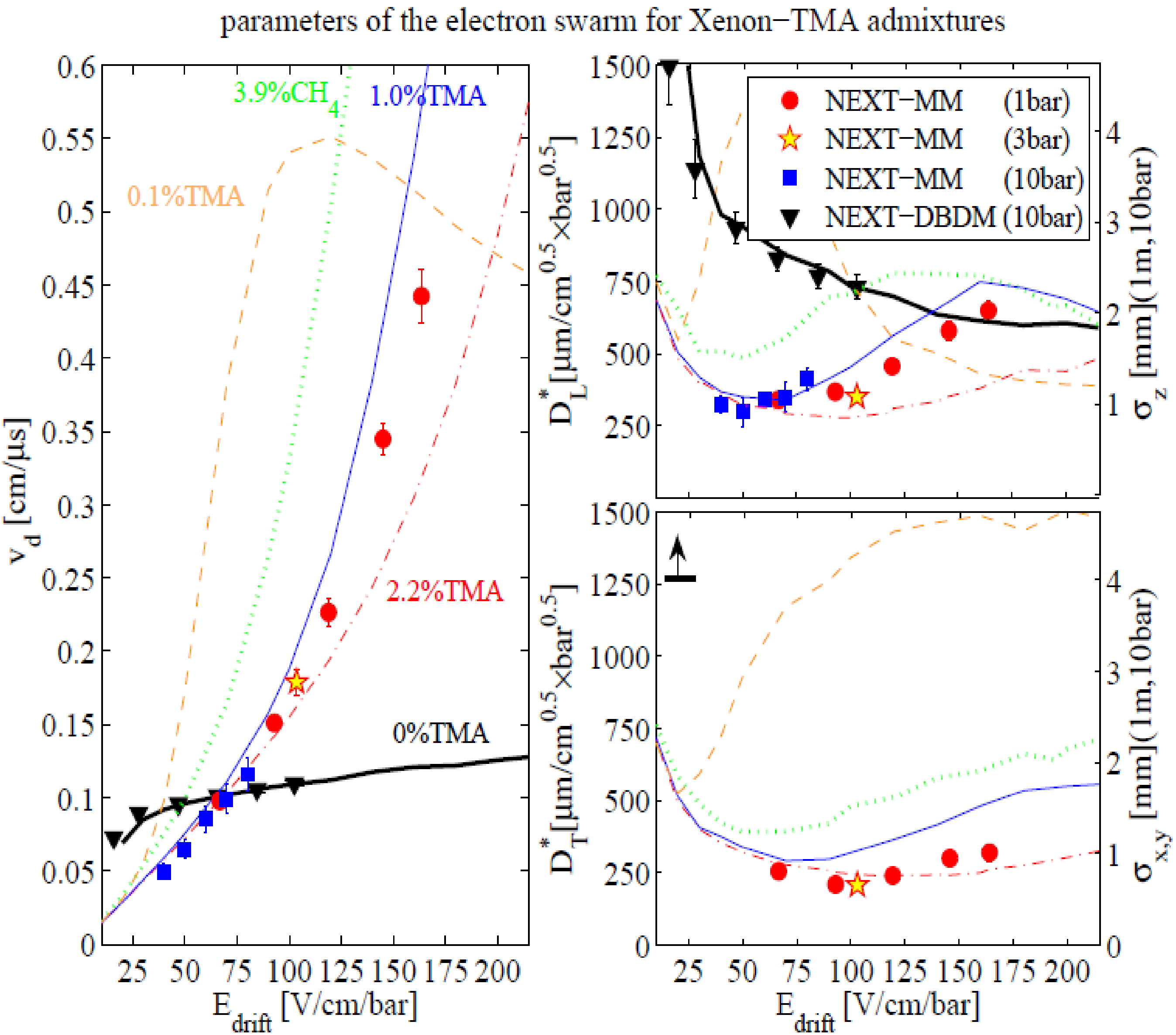




$$< \frac{\varepsilon_M}{\varepsilon_{evt}} >= \frac{\left[2\hat{v}_r\left(e^{-\frac{L^2}{2\hat{v}_r}}-1\right)+\sqrt{2\pi}L\sqrt{\hat{v}_r}\,\mathrm{erf}\left(\frac{L}{\sqrt{2\hat{v}_r}}\right)\right]^2}{2\pi L^2 \hat{v}_r}$$

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

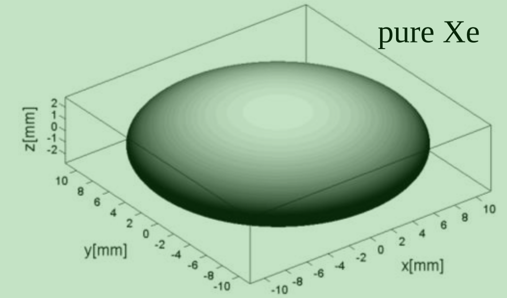
drift properties (data and Magboltz simulation)

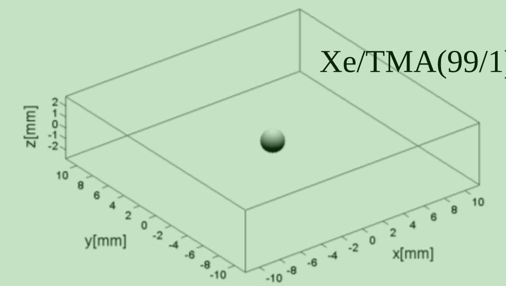


$$\sigma_{z,xy} = D^*_{L,T}\frac{\sqrt{z}}{\sqrt{P}}$$

Spatial spread of point-like charge deposits

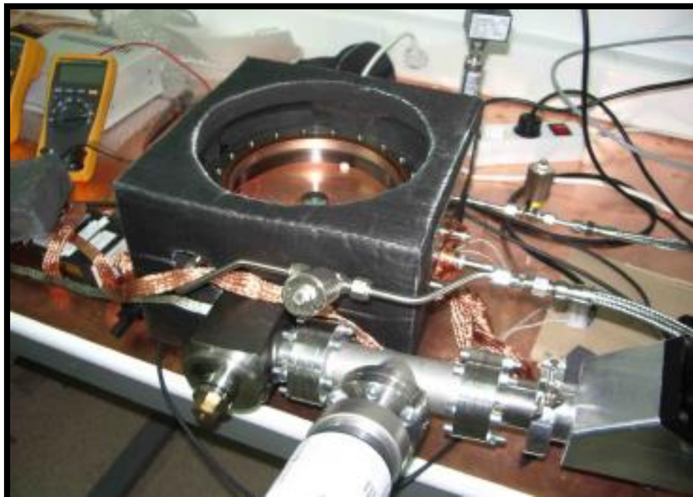
z_{drift}=100cm, P=10bar





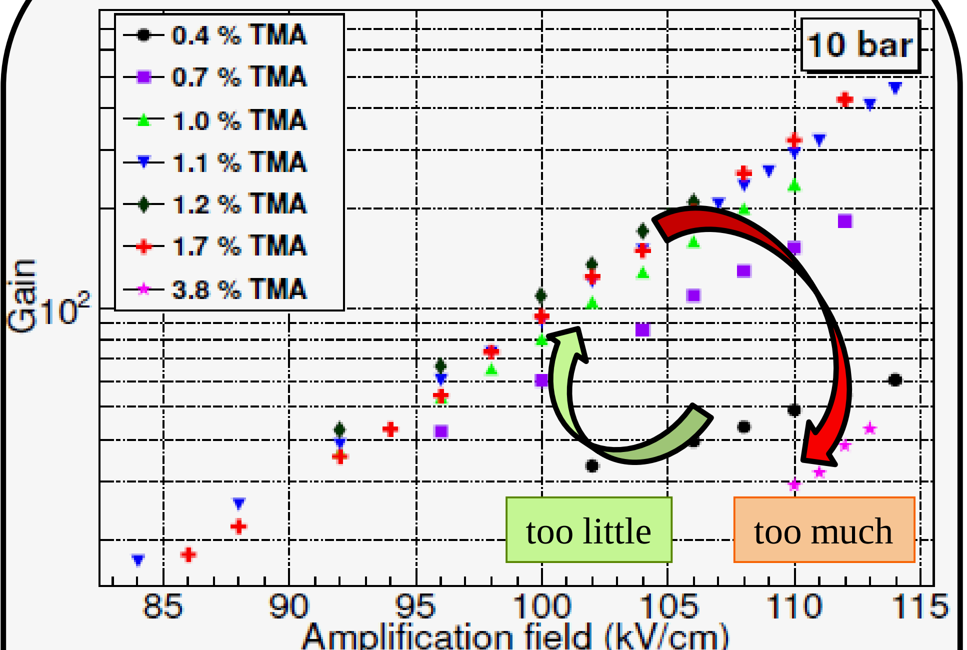
E_{drift}~50-100V/cm/bar

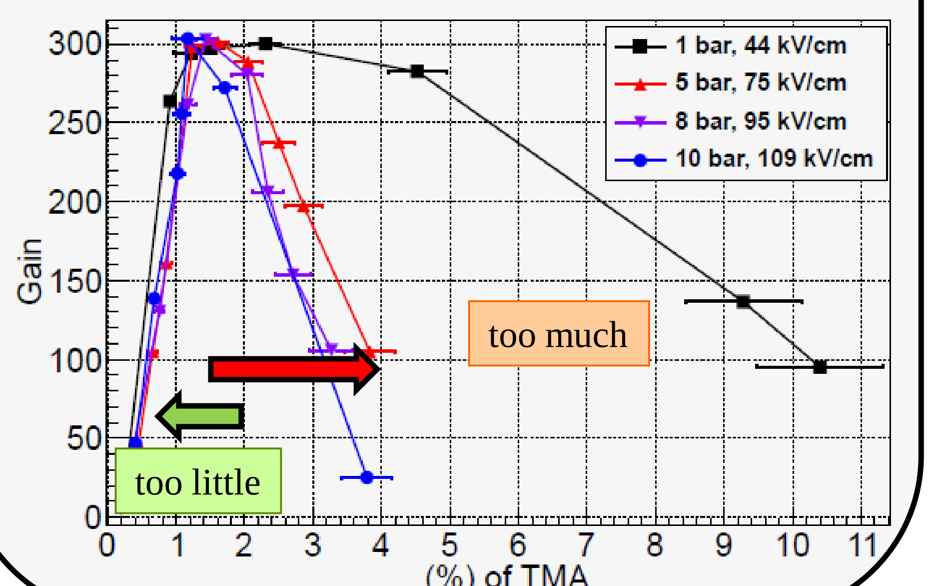
2. Data from the 1cm x 10cm^2-setup (NEXT-MM0)



charge readout properties

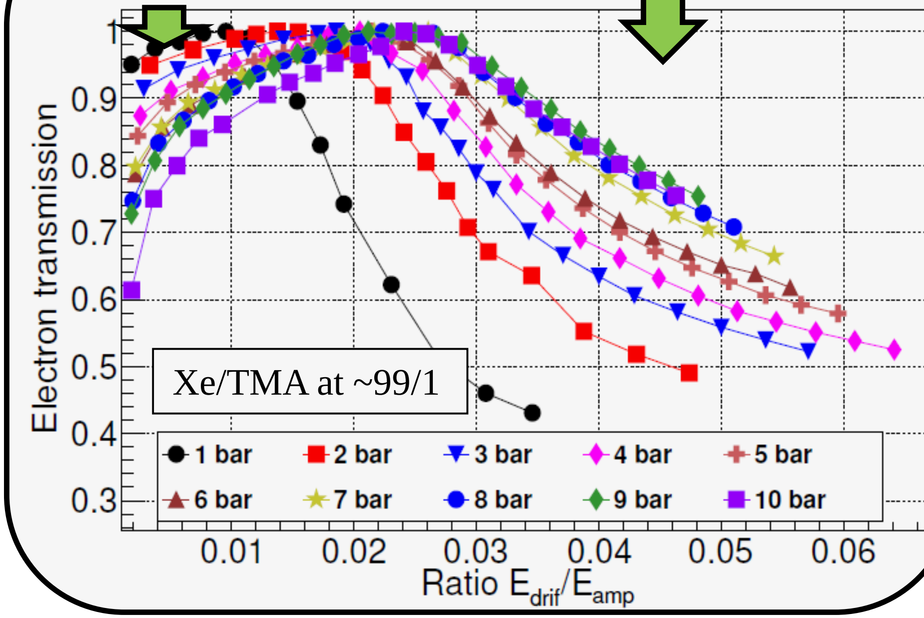
clear indication of *Penning* effect!



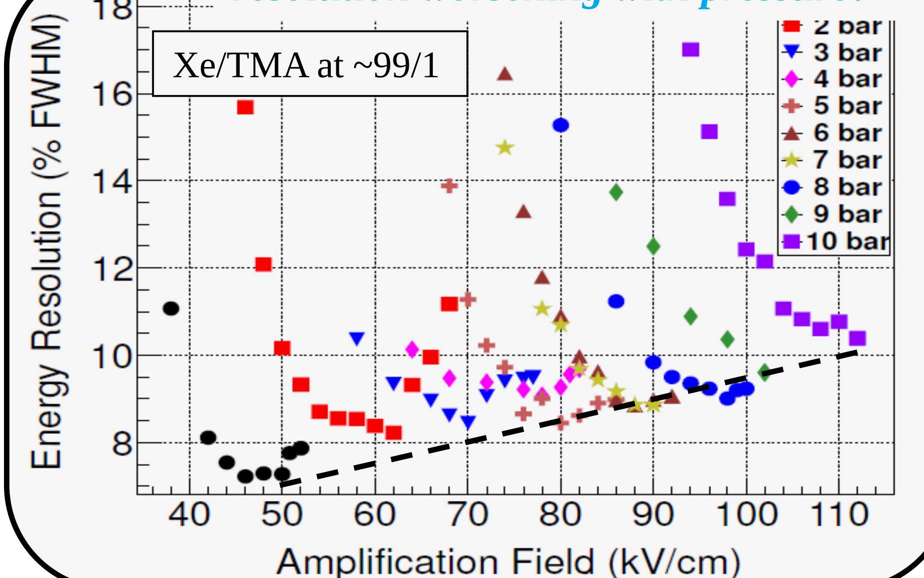


reduction of field flux through holes?

recombination?



resolution worsening with pressure?



electric field modelling (3D) and Garfield++

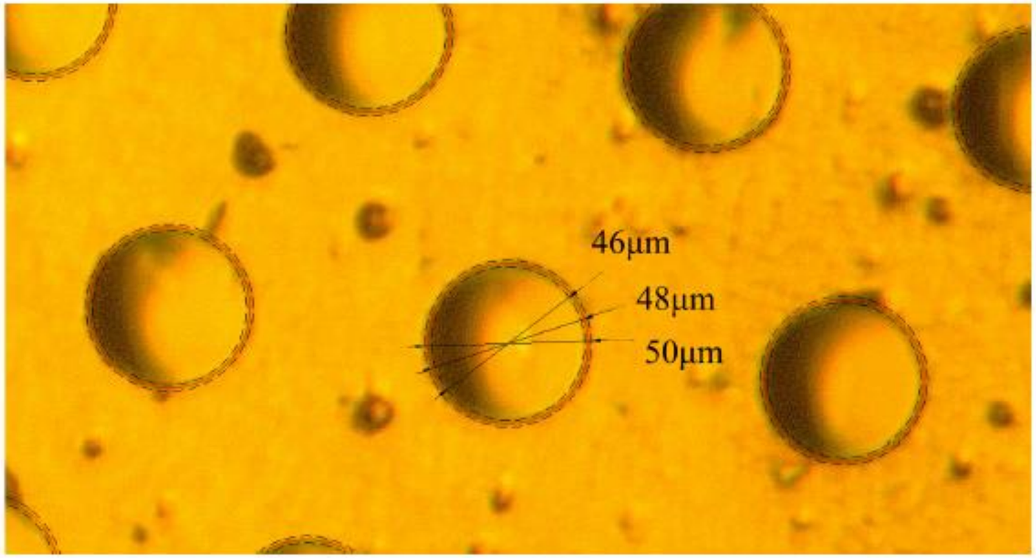
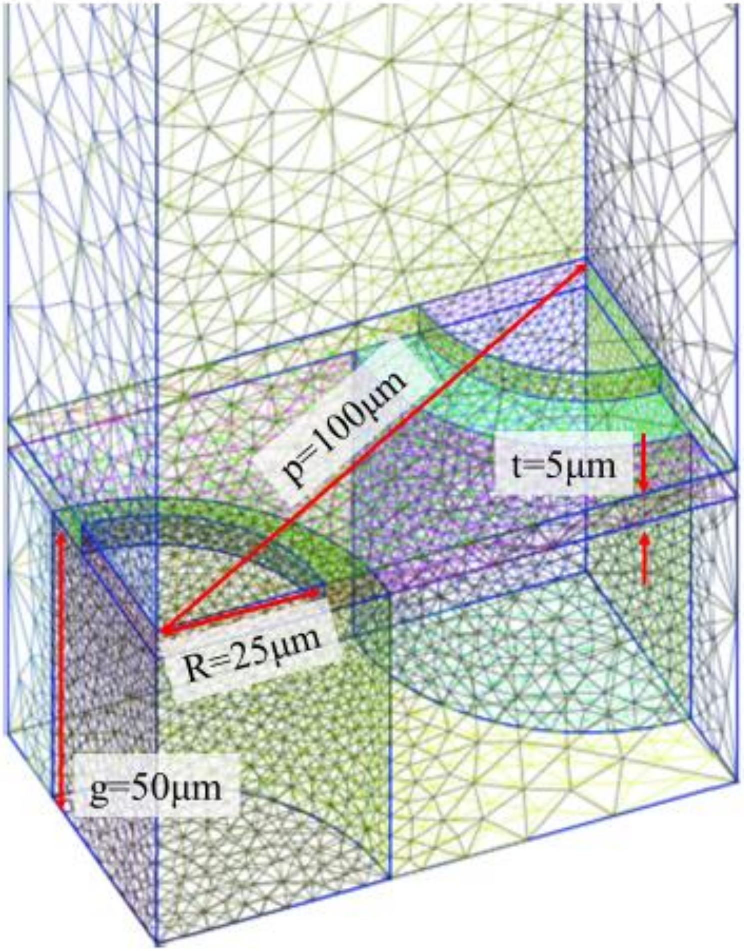
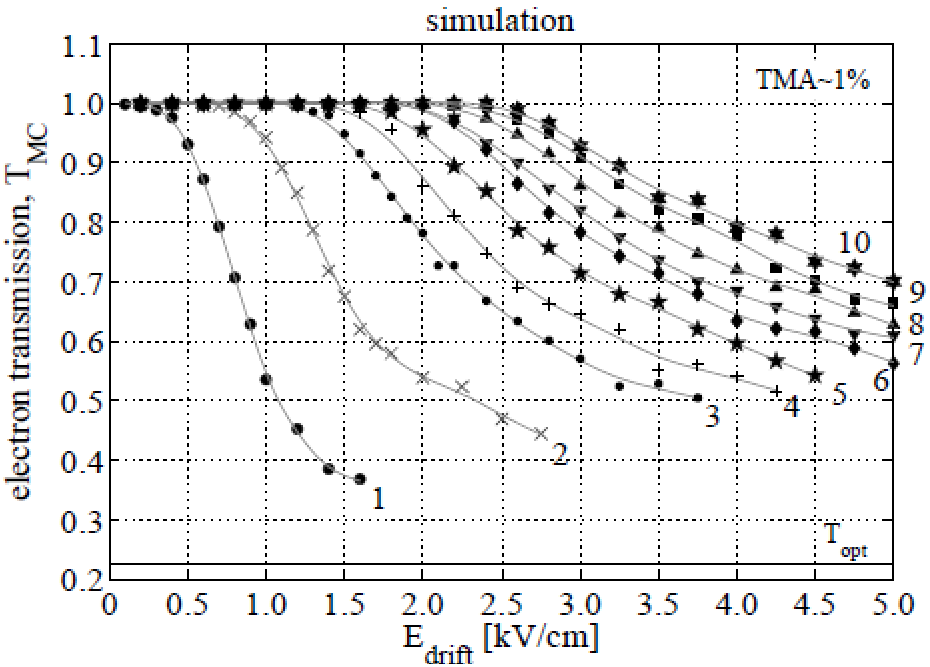


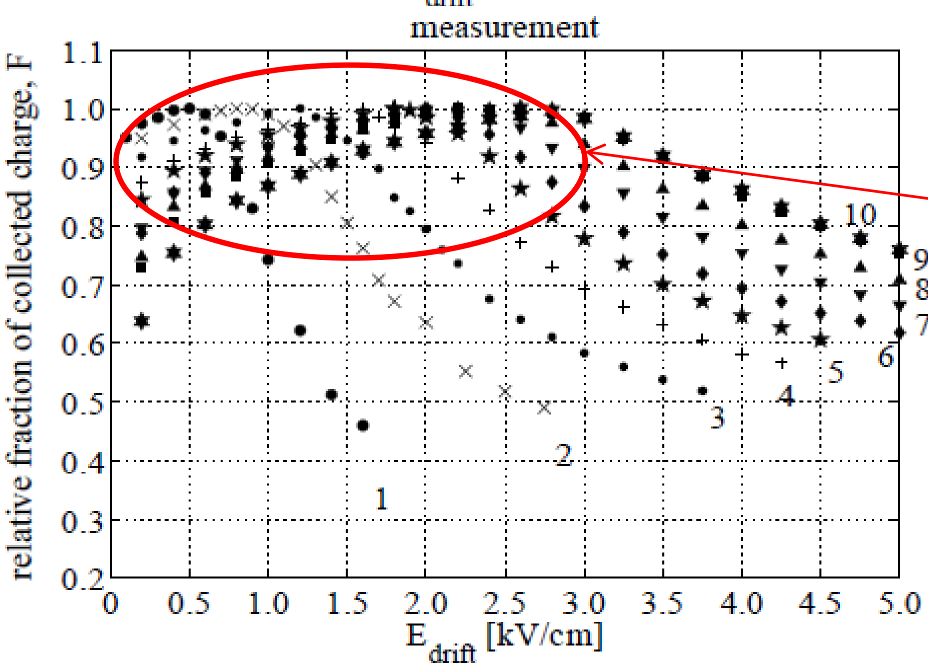
Fig. 1. Microscope image of the surface of the microbulk Micromegas whose performance has been simulated in this work. The surface characteristics are determined by the gold coating. The dashed circles represent the biggest and smallest circles compatible with the hole foot-print. The (red) continuous circle has the average diameter of both, yielding an estimate of $\phi = 48\mu m \pm 2\mu m$.

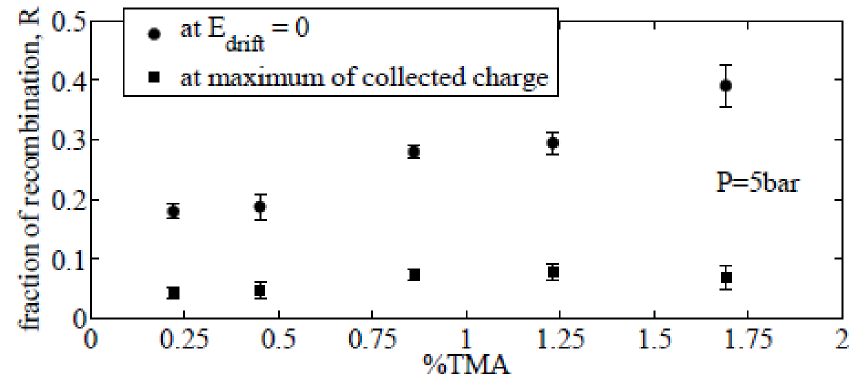


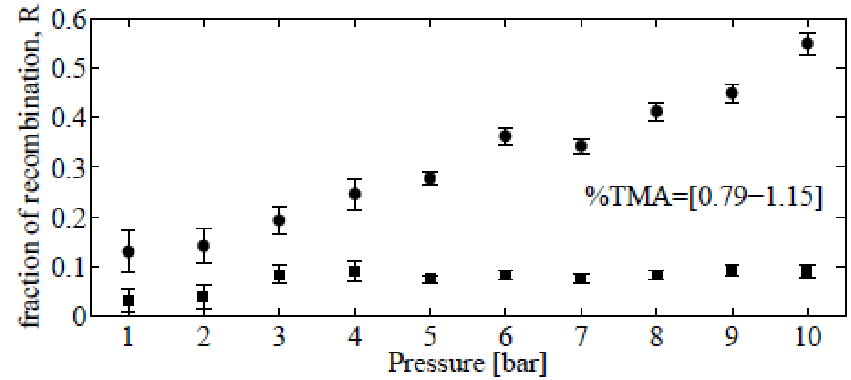
Gmsh + ELMER
(Garfield++ interface provided by J. Renner)

fraction of collected charge/electron transmission







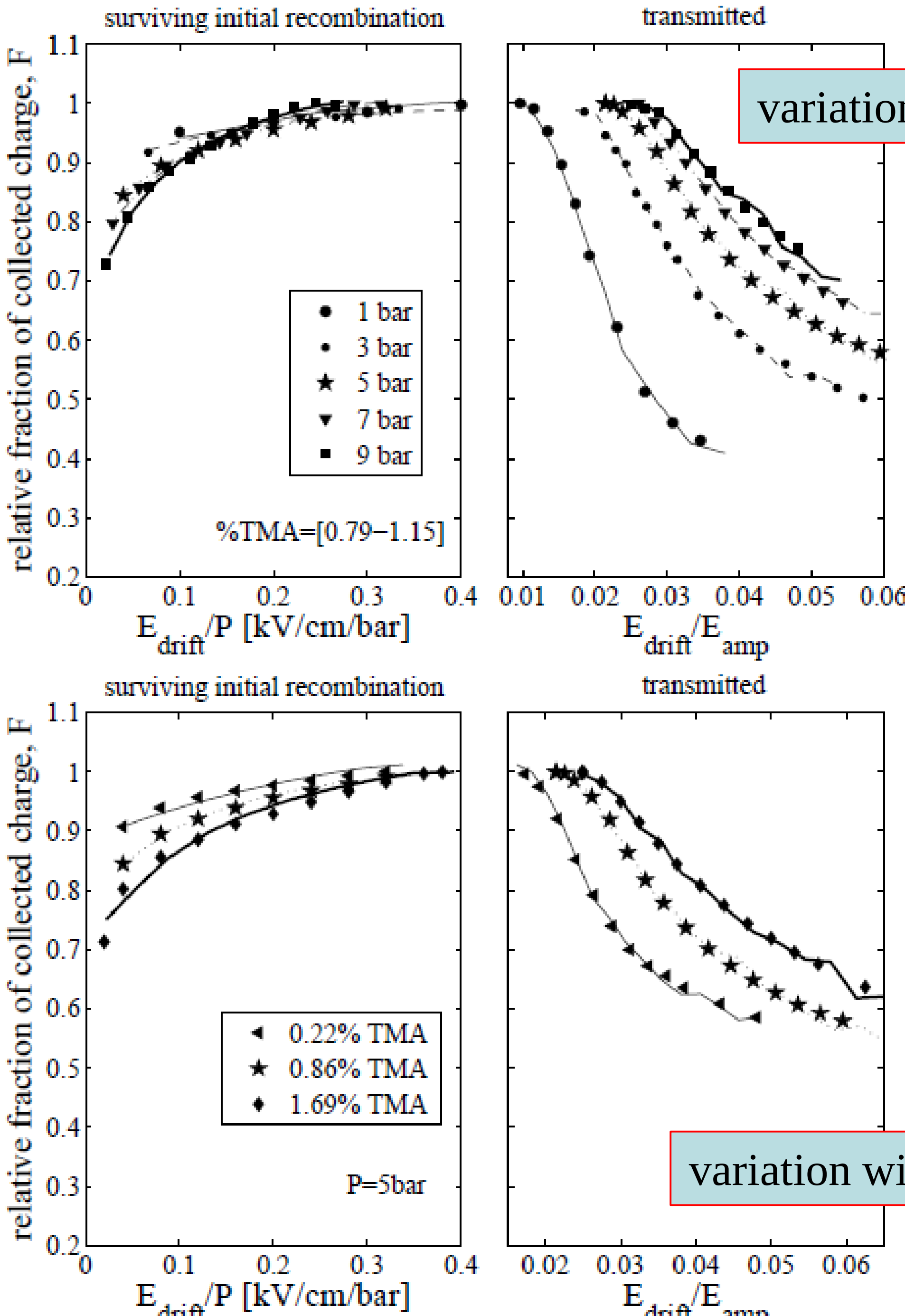


$$\mathcal{R}(E_d/P) = (1 - \frac{Q_0}{Q_\infty})(1 - \frac{1}{1 + kP/E_d})$$

(measured attachment <0.1%)

$$\mathcal{F}(E_d, E_a) = \frac{(1-\mathcal{R})\mathcal{T}}{\max[(1-\mathcal{R})\mathcal{T}]}$$

?



variation with pressure

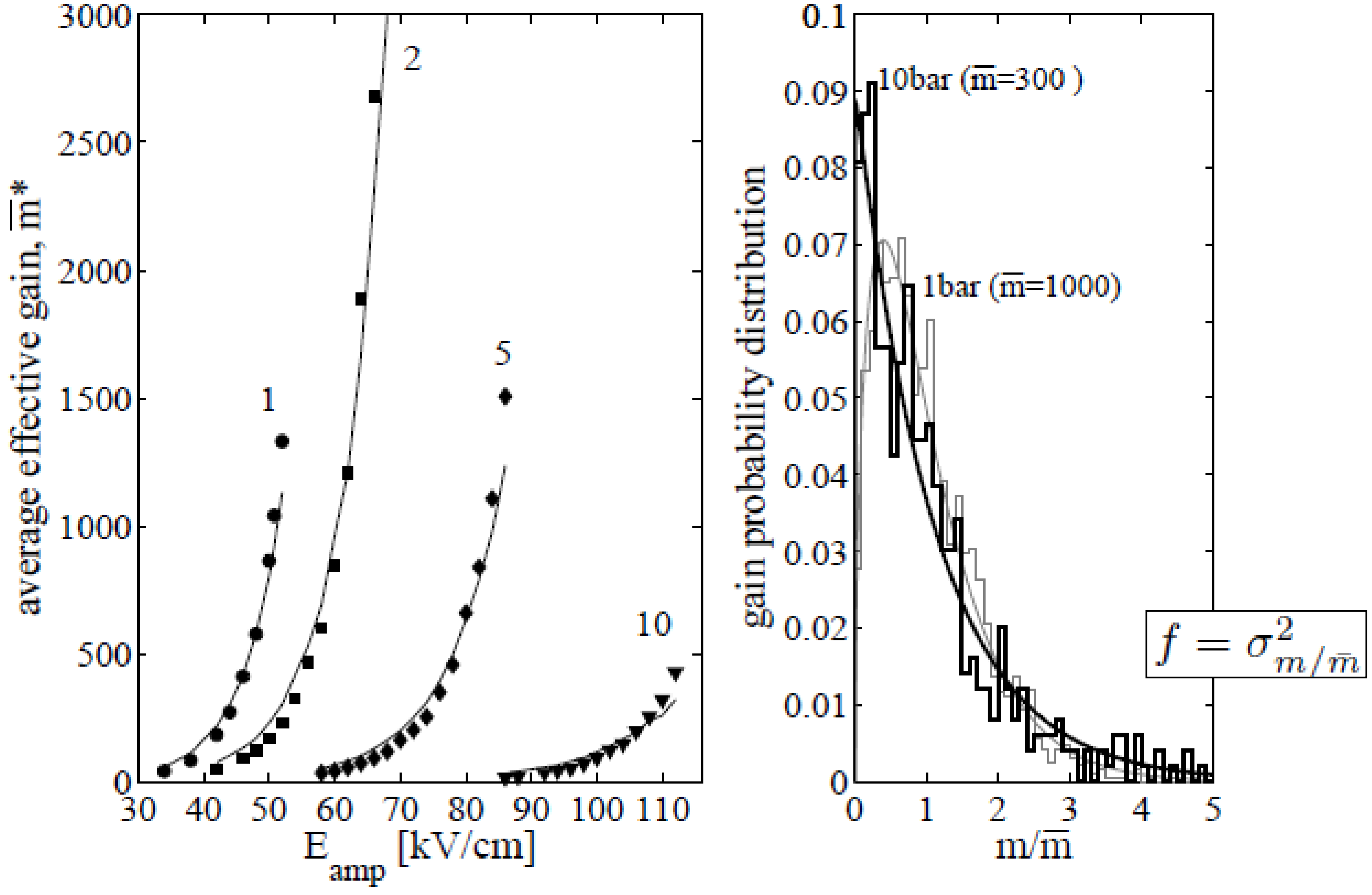
variation with concentration

(global fit to data)

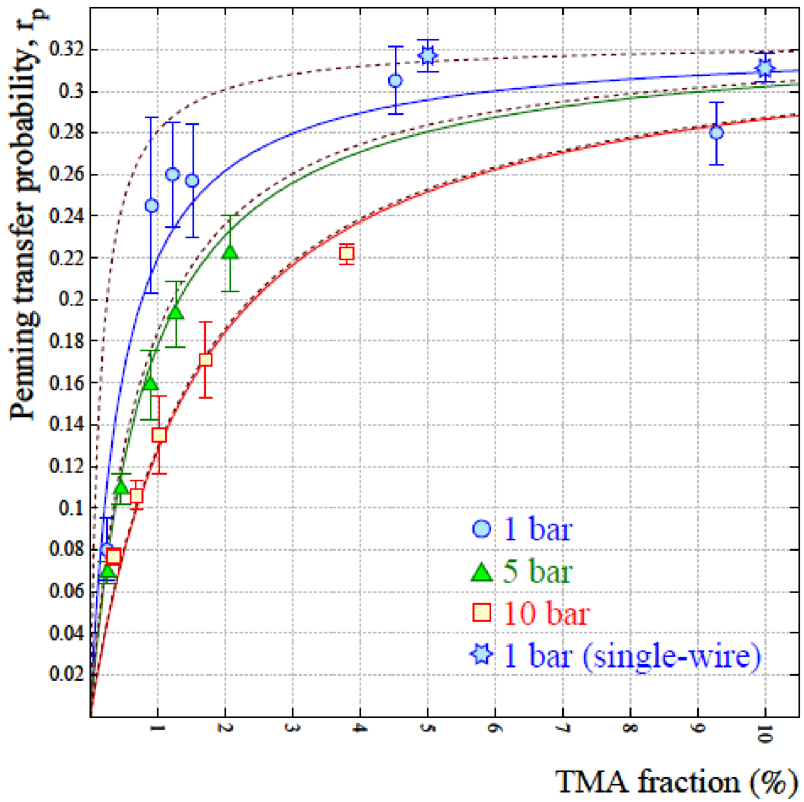
$$\mathcal{F}(E_d, E_a) = \frac{(1-\mathcal{R})\mathcal{T}}{\max[(1-\mathcal{R})\mathcal{T}]}$$

effective gain

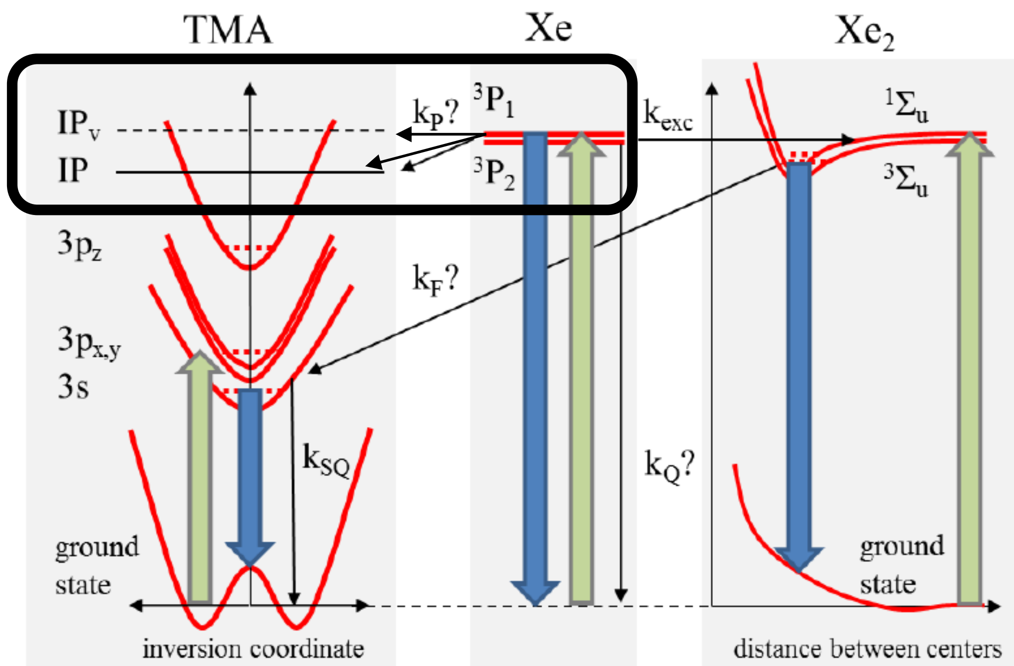
$$\bar{m}^* = \mathcal{T}(1-\mathcal{R}) \times \bar{m} \qquad (\,\bar{m} \equiv f(r_p)\,)$$



Penning transfer probability



simplified level diagram including only low-lying states



Simplified model (only Xe* singlet-state can make the transfer):

$$r_p = \frac{cP}{(1-c)^2P^2a_1 + cPa_2 + a_3}$$

$$\tau_1^* = \frac{a_1}{a_3}\frac{1}{k_{exc,1}} = 9.2 \pm 2.5\text{ns}$$

$$r_p = f_1\frac{cPk_{p,1}}{(1-c)^2P^2k_{exc,1} + cP(k_{p,1}+k_{Q,1}) + 1/\tau_1^*} + f_3\frac{cPk_{p,3}}{(1-c)^2P^2k_{exc,3} + cP(k_{p,3}+k_{Q,3})}$$

energy resolution (for 22keV X-rays)

Not viable to simulate 22keV/W_I~900 primary electrons, we assume independent fluctuations:

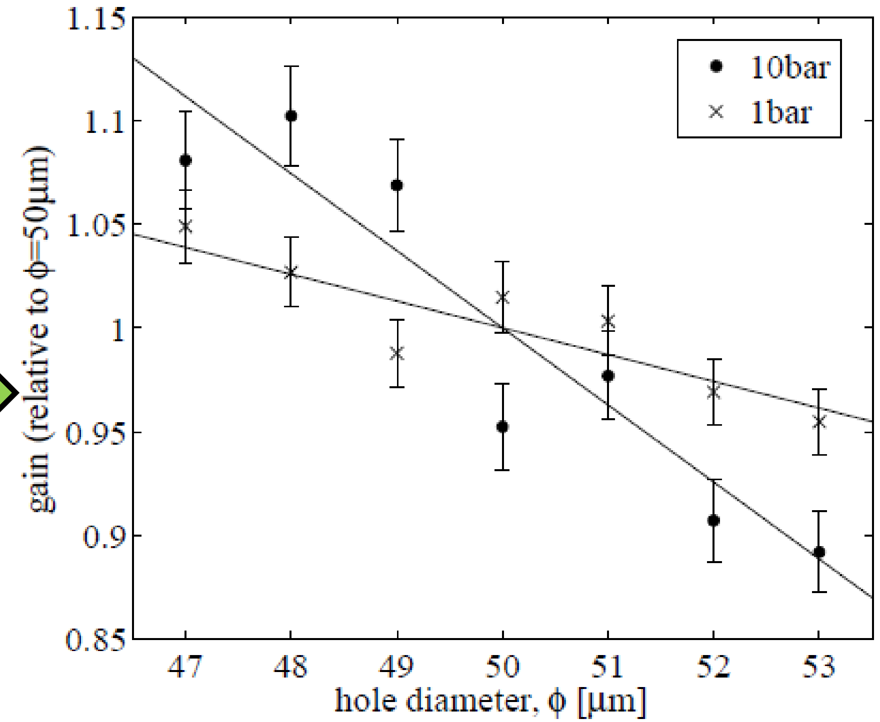
$$\mathfrak{R} = 2.35\sqrt{\sigma_{int}^2 + \sigma_{mech}^2 + \sigma_{S/N}^2}$$

$$\sigma_{int} = \sqrt{F + f + \mathcal{T}\mathcal{R} + (1-\mathcal{T})}\frac{1}{\sqrt{n_e}}$$

$$\sigma_{mech} = \left|\frac{1}{\bar{m}}\frac{dm}{d\phi}\right|\sigma_\phi$$

$$\sigma_{S/N} = \frac{ENC}{\bar{m}}\frac{1}{n_e}$$

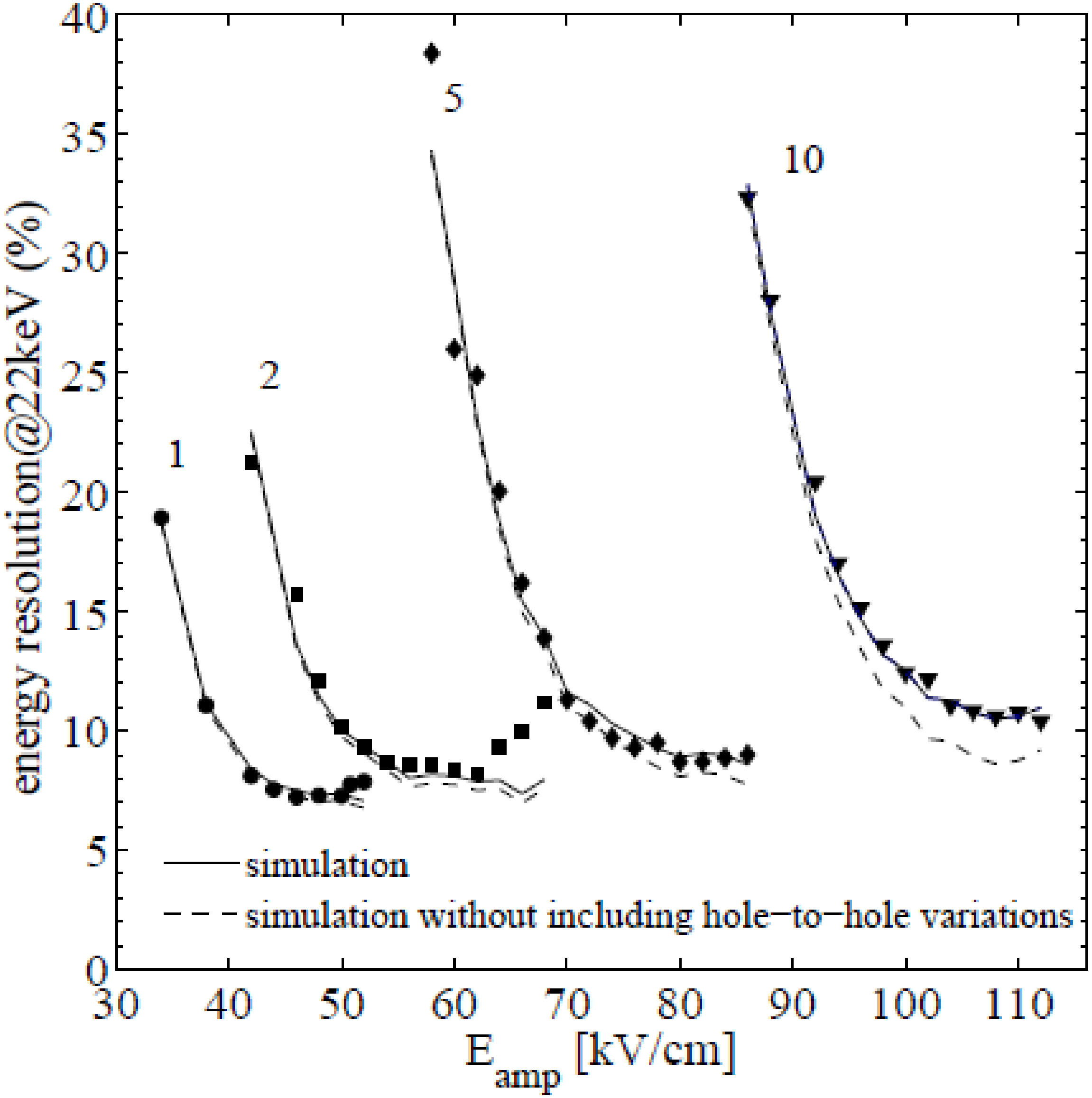
$$n_e = (1-\mathcal{R})\mathcal{T}\frac{\varepsilon}{W_I}$$



P[bar]	gain	$-\frac{1}{\bar{m}}\frac{dm}{d\phi}$ [%/μm]
1	350	1.1 ± 0.3
1	1350	1.3 ± 0.4
10	100	3.0 ± 0.6
10	150	3.7 ± 0.8

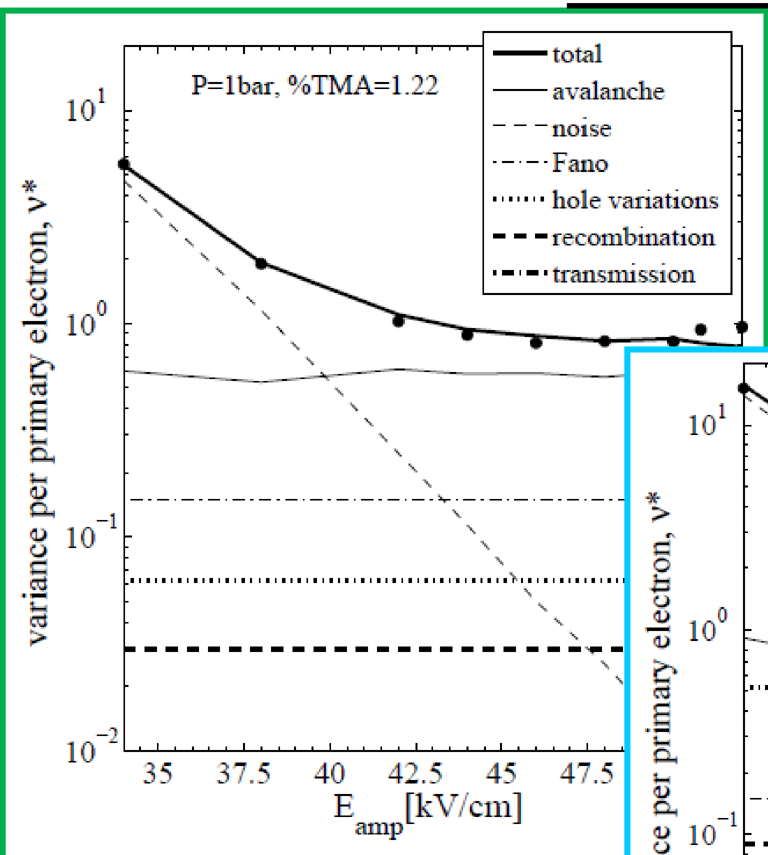
Higher sensitivity at high pressure!

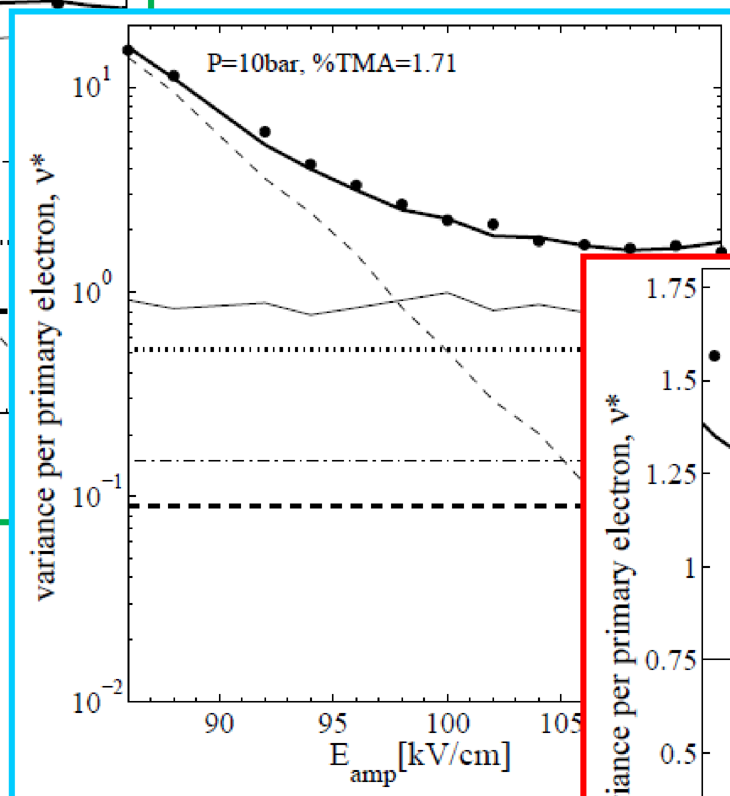
comparison with data (I)

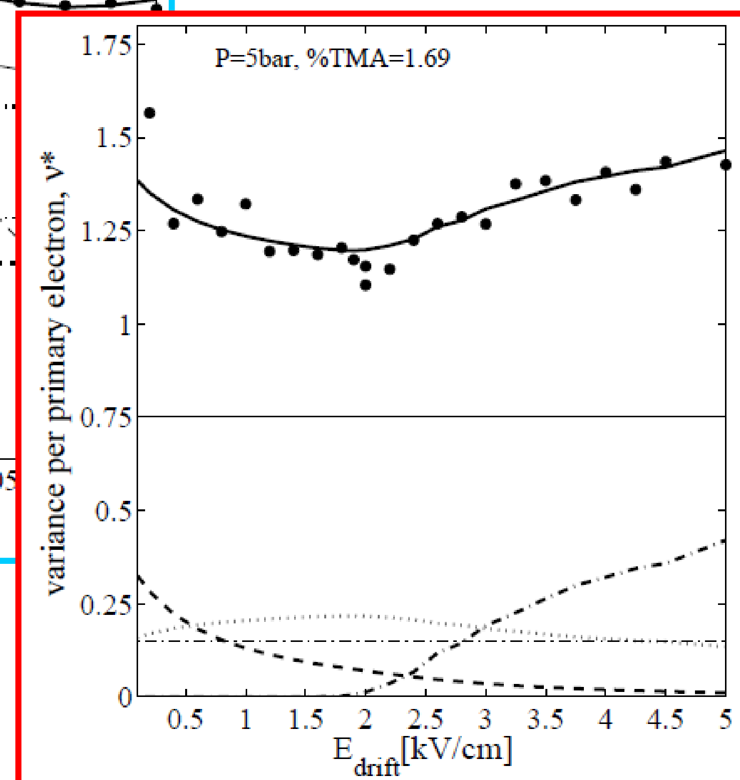


σ_{φ}=0.6μm

comparison with data (II)







$$v^* = \left(\frac{\Re}{2.35}\right)^2 n_e$$

extraction of Fano factor (1bar)

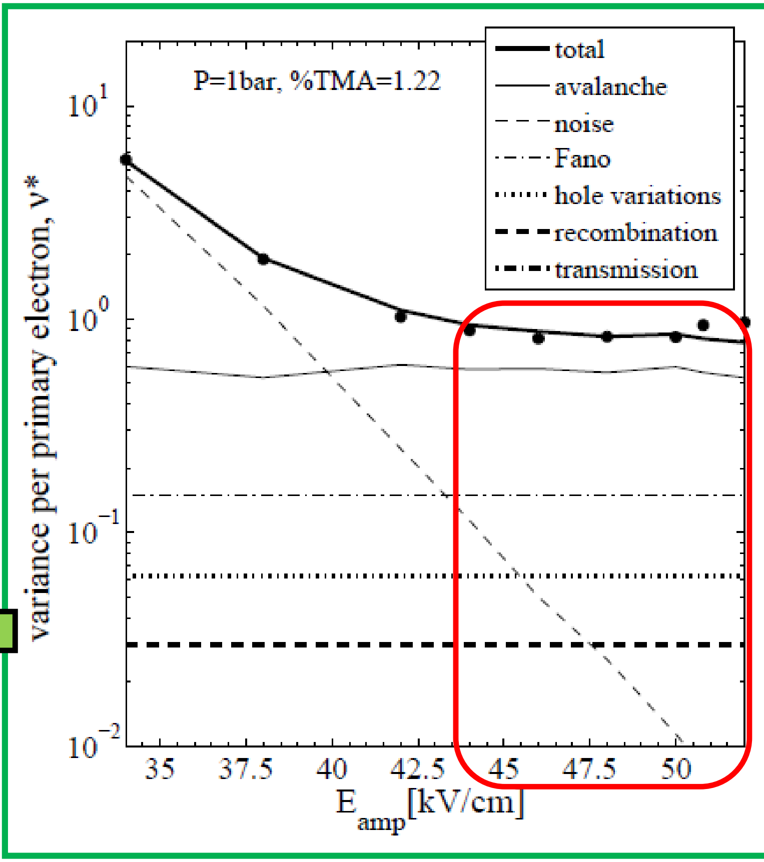
$$v^* = \left(\frac{\Re}{2.35}\right)^2 n_e$$

$$\Re_p = \sqrt{\frac{n_e}{n_{e,p}}\Re^2 - 2.35^2\frac{(F-F_p)}{n_{e,p}}}$$

$$\frac{n_{e,p}}{n_e} = 1 + \frac{N_{ex}}{N_I} r_p(E_d)$$

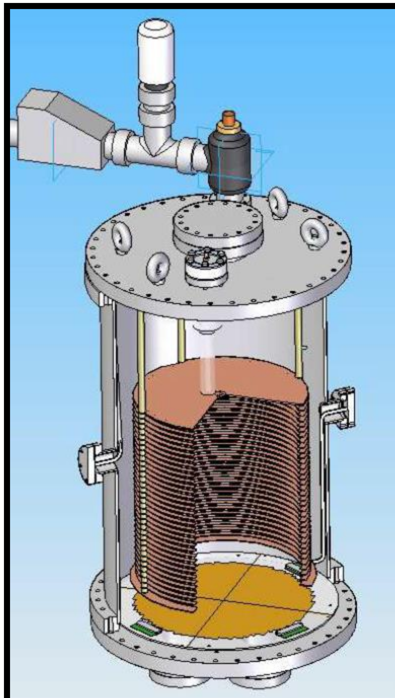
$$\frac{n_{e,p}}{n_e} = 1 + \frac{W_I}{W_{sc}} r_p = 1.10 \pm 0.04$$

$$F_p = \frac{n_{e,p}}{n_e} v^* - f - \mathcal{T}\mathcal{R} - (1-\mathcal{T}) - \sigma_{mech} - \sigma_{S/N} = 0.20 \pm 0.06$$



$$\Re_{0,Xe-TMA} = 2.35\sqrt{\frac{F_p}{n_{e,p}}} = (0.50\% \pm 0.08\%)\sqrt{\frac{1\text{MeV}}{\varepsilon}}$$

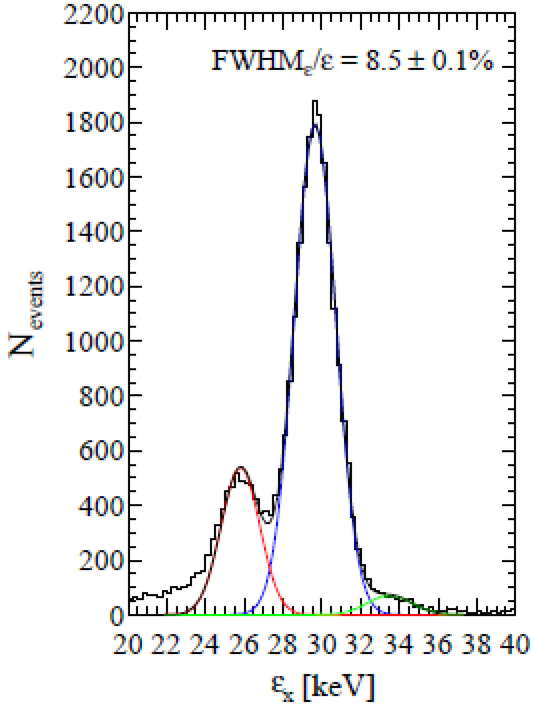
3. Energy resolution data from the 38cm x 700cm^2-setup (NEXT-MM)



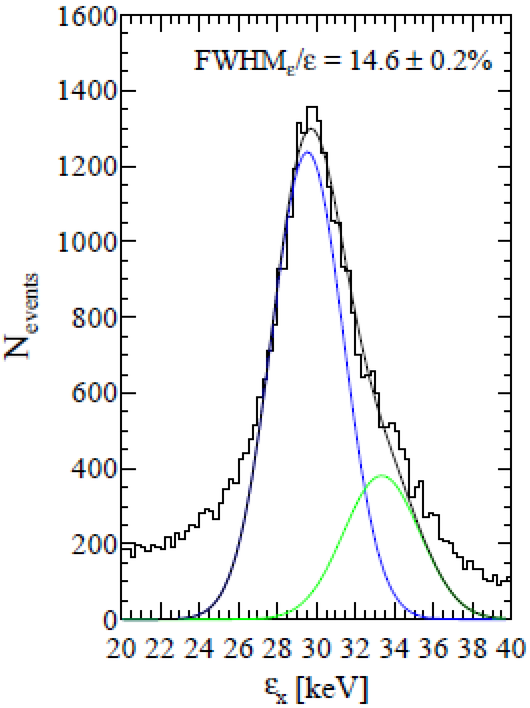
understanding the energy resolution in a realistic system (I)

$$\mathfrak{R} = 2.35\sqrt{\sigma^2_{int} + \sigma^2_{mech} + \sigma^2_{S/N}}$$

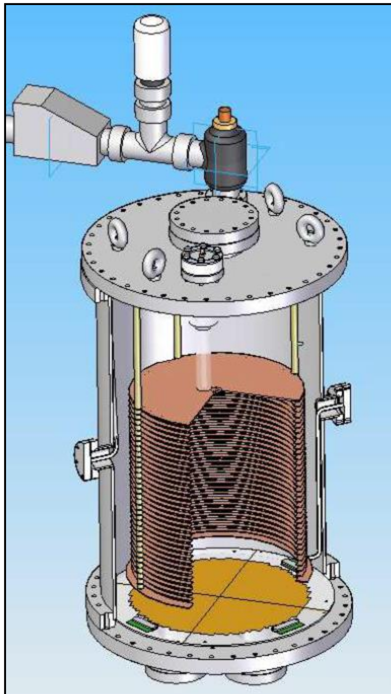
P=1bar



P=10bar

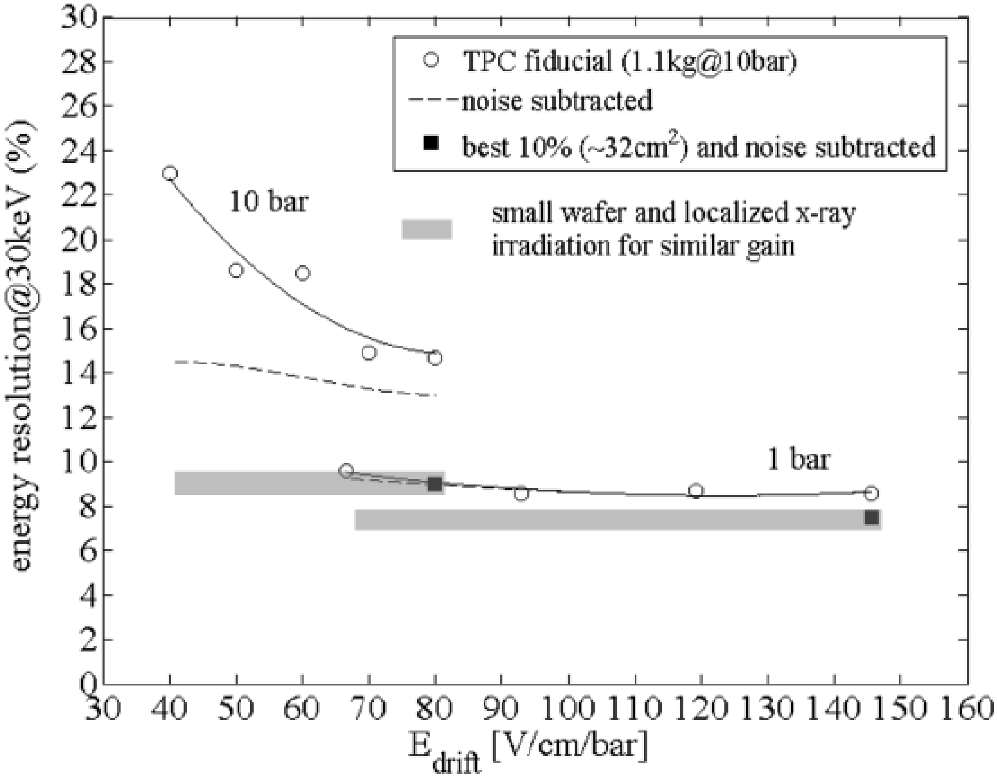


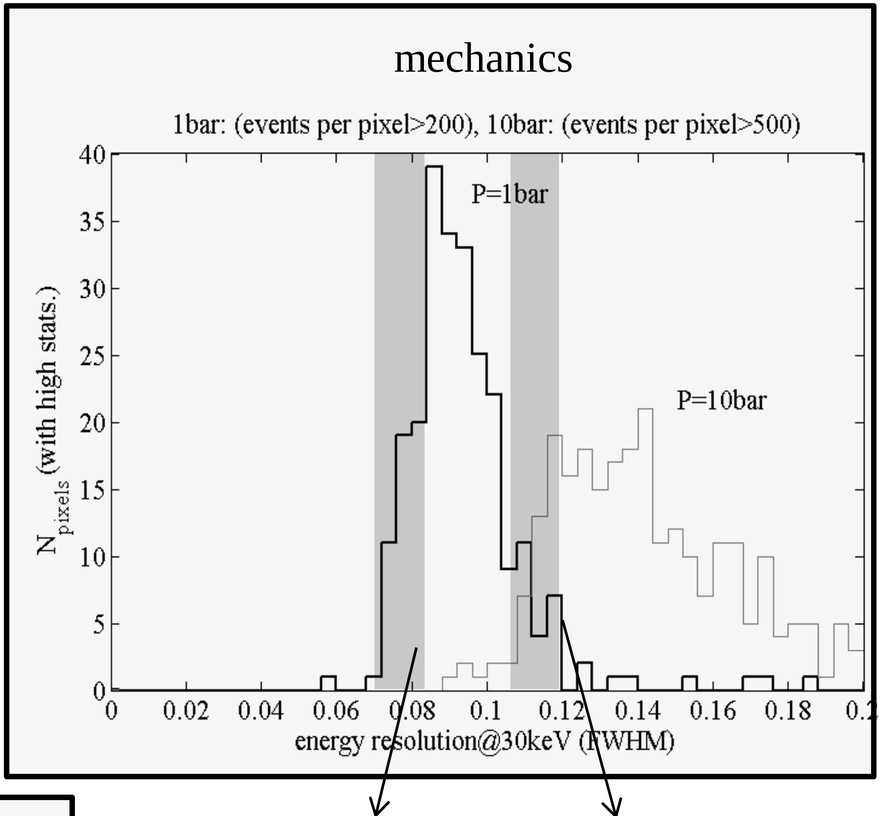
NEXT-MM

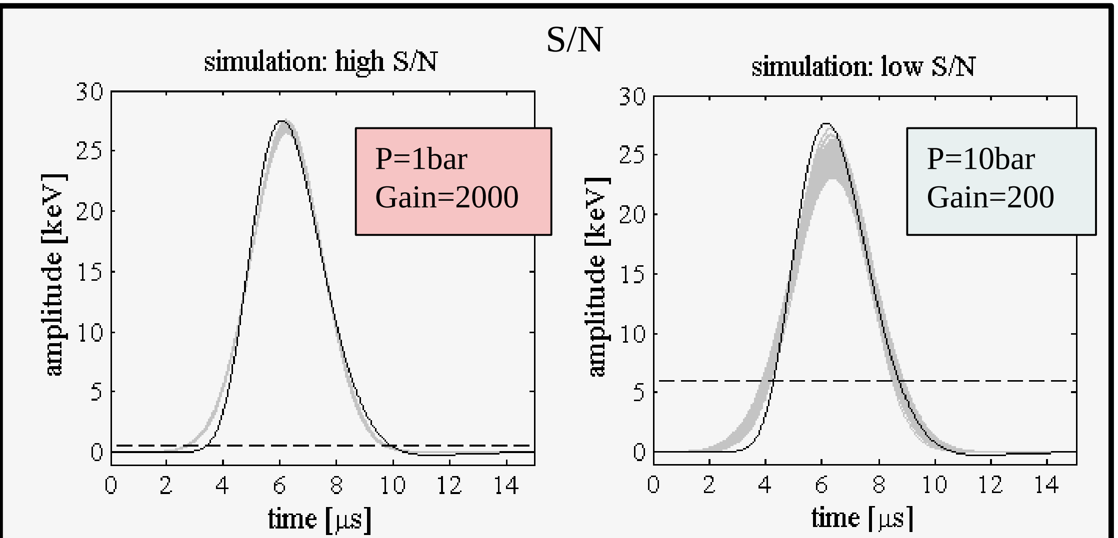


can be understood in terms of the contributions identified in the small setup **?**

understanding the energy resolution in a realistic system (II)





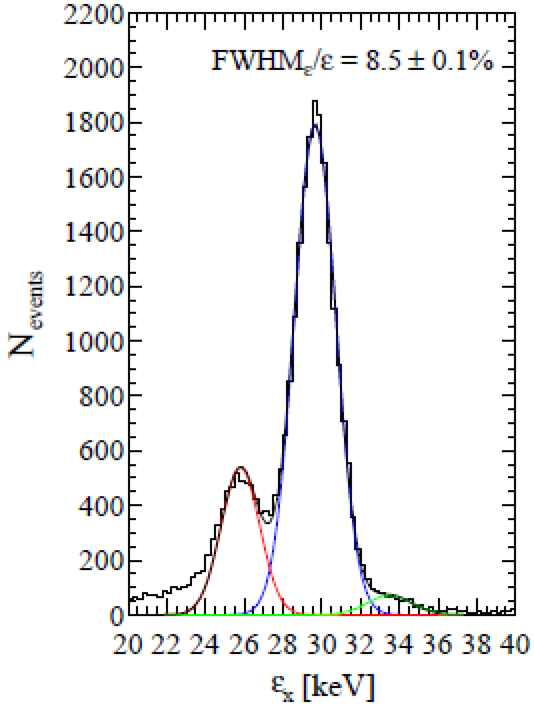


best 10% $\longrightarrow \sigma_{intr}^2 + \sigma_{S/N}^2$

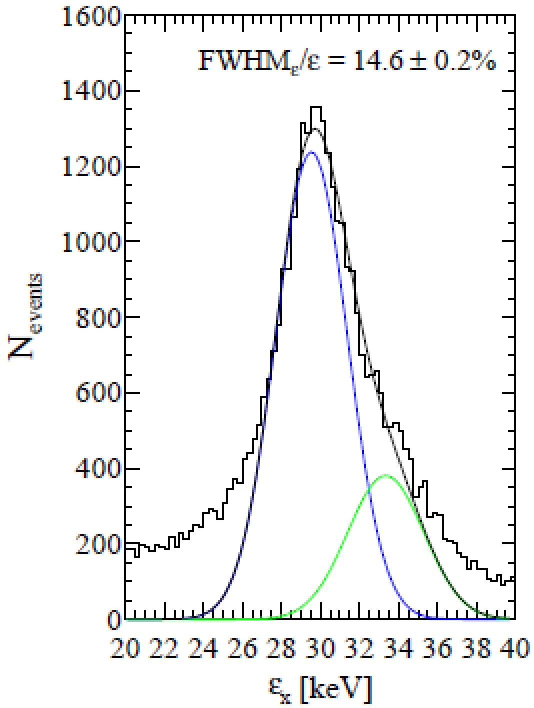
understanding the energy resolution in a realistic system (III)

$$\Re = 2.35\sqrt{\sigma_{int}^2 + \sigma_{mech}^2 + \sigma_{S/N}^2}$$

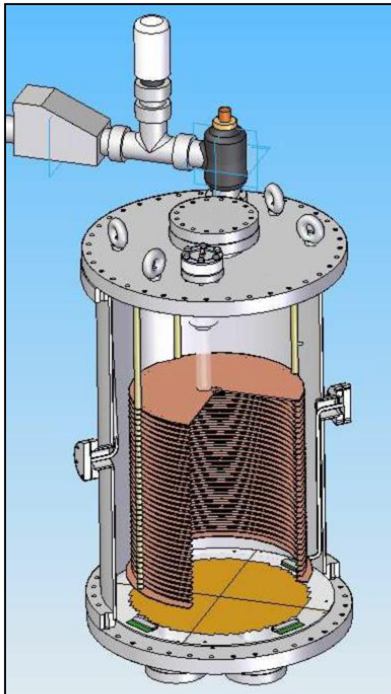
P=1bar



P=10bar



NEXT-MM



P=1bar	P=10bar
$\sigma_{int} = 0.075$	$\sigma_{int} = 0.09$
$\sigma_{S/N} = 0.002$	$\sigma_{S/N} = 0.07$
$\sigma_{mech} = 0.035$	$\sigma_{mech} = 0.09$

σ_φ=1.0μm →

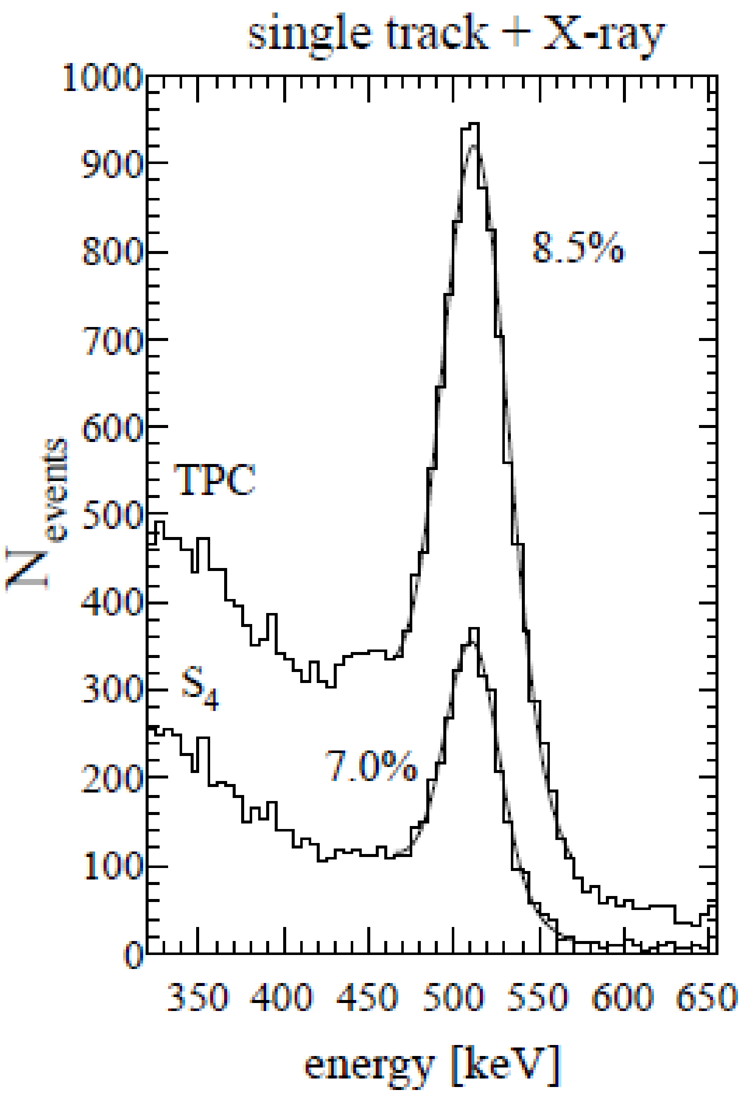
conclusions

1. 'Electron transmission' at high pressures requires both recombination (drift region) and hole-transmission (readout region) to be included. Measured data can be described by combining a recombination model (Bolotnikov, Ramsey) and the simulated electron transmission.

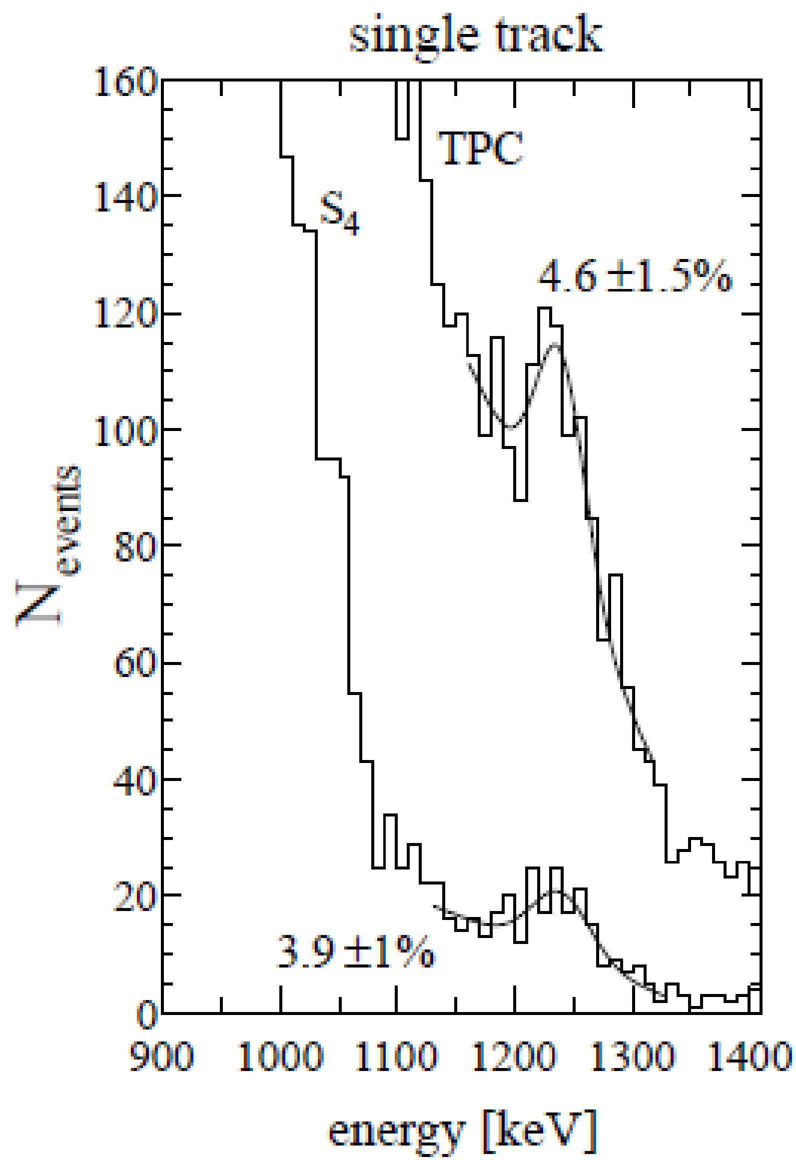
2. Penning-effect in Xe-TMA can be interpreted through a simple model that assumes resonant energy transfer from the Xe^* singlet state to TMA.

3. Energy resolution well explained by known sources except for a small deviation at high pressure.

Strong evidence of sensitivity to mechanical variations in the hole diameter at 0.5μm level! (important at 10bar) appendix



single track + X-ray
TPC
S4
8.5%
7.0%
Nevents
energy [keV]



single track
TPC
S4
4.6 ±1.5%
3.9 ±1%
Nevents
energy [keV]