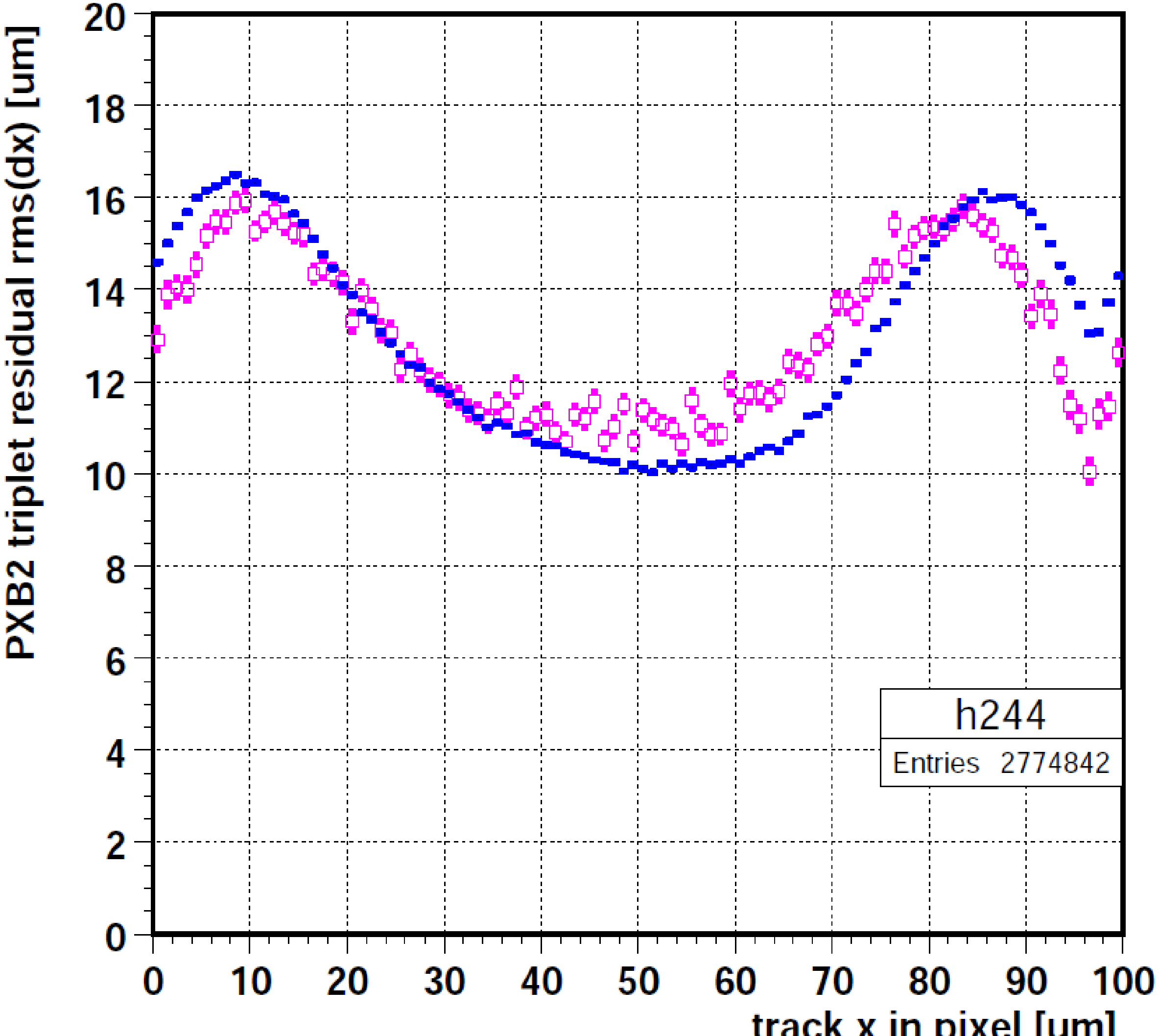
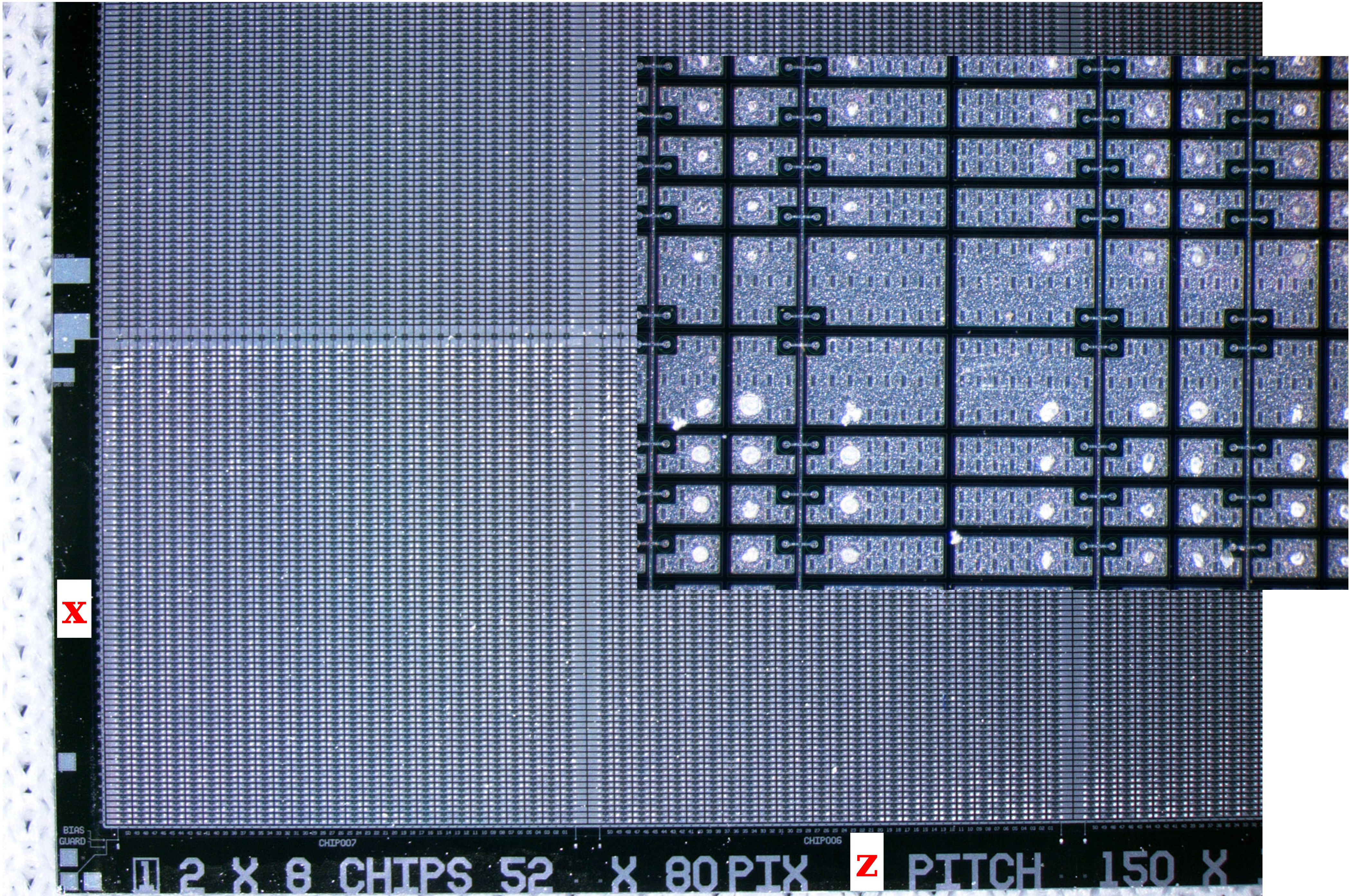
in-pixel resolution studies

Daniel Pitzl, DESY
CMS Pixel DPG, 30.6.2011



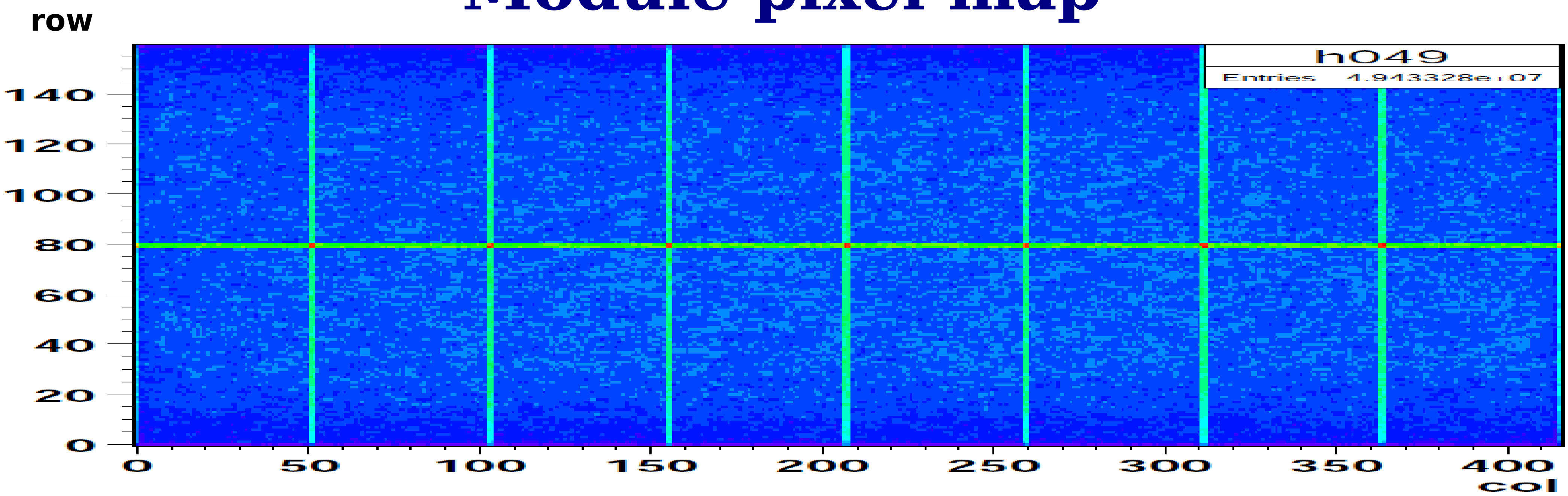
- Triplet residuals:
  - along module
- Lorentz drift
- Triplet residuals:
  - along pixel

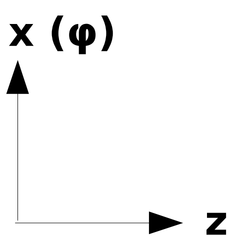
pixel sensor: wide and long pixels

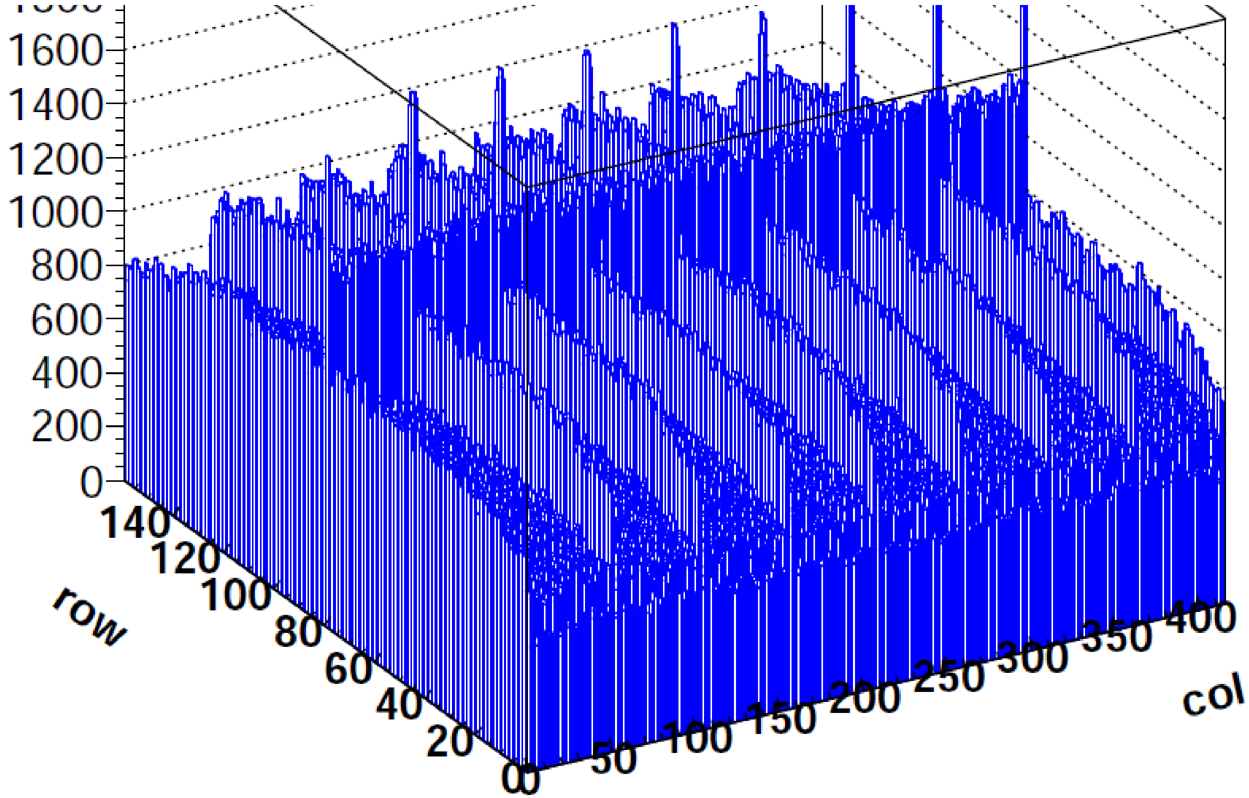


6.2011

Module pixel map



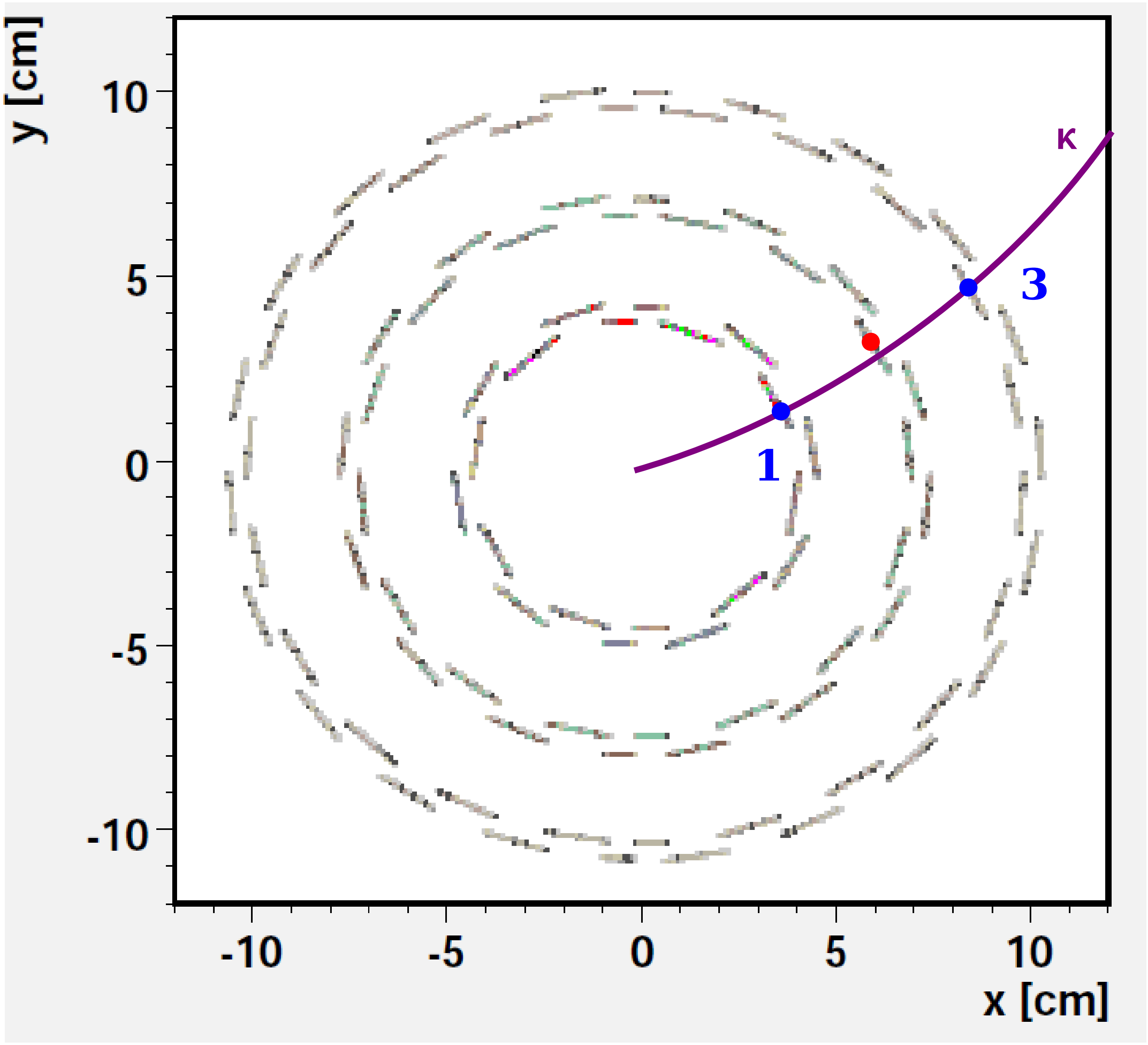




rows 79 and 80: wide pixels: 200 instead of100 µm to cover the ROC edge.

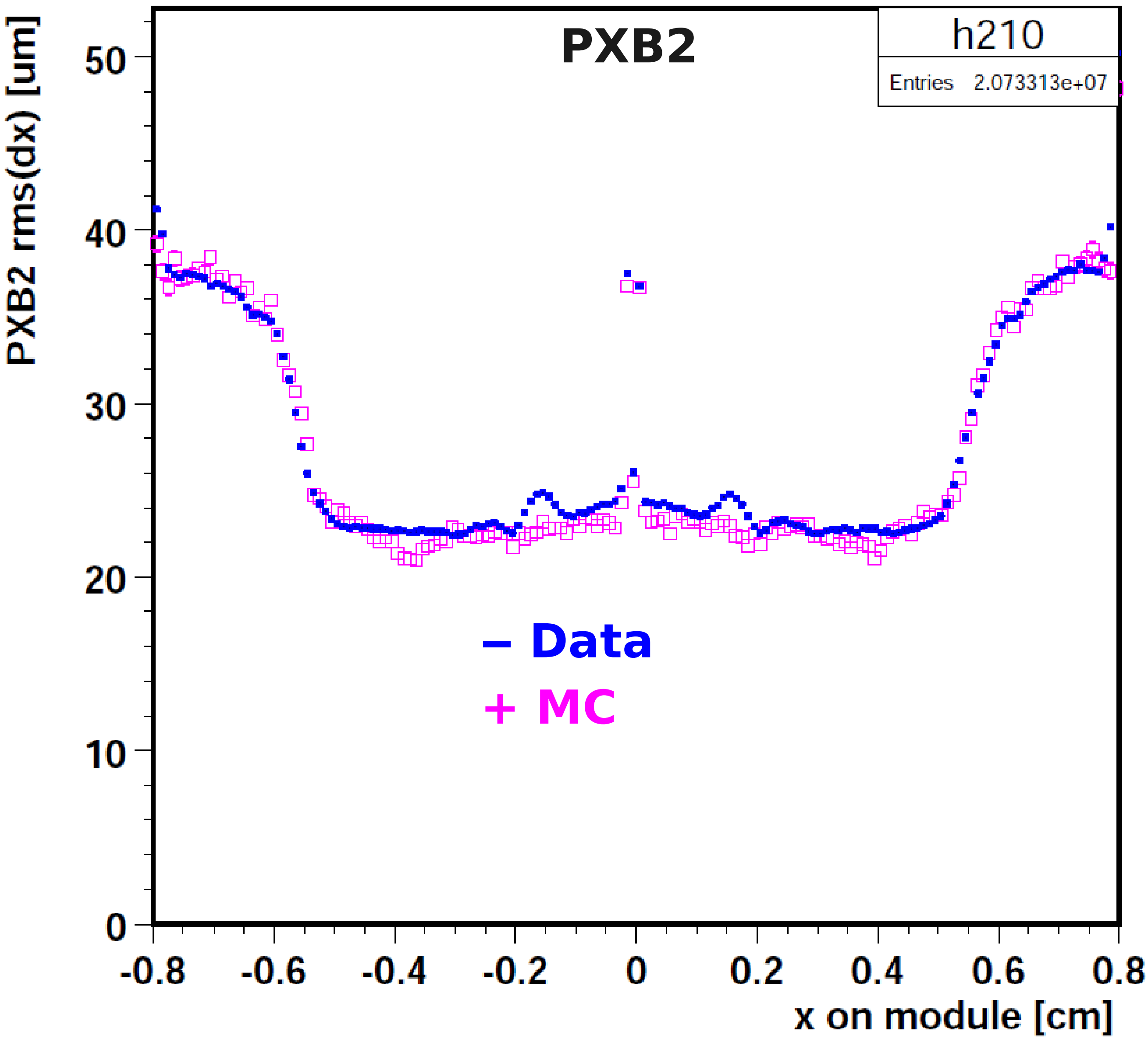
colums 51, 52: 300 µm instead 150 µm.

Pixel triplets



- Select tracks with hits in 3 pixel layers.
- Redefine track:
  - curvature κ from full tracker,
  - position and angles from hits 1 and 3.
  - analytic code from J. Gassner 1996.
- Interpolate to middle layer:
  - residual between track and hit.
  - rms = resolution.

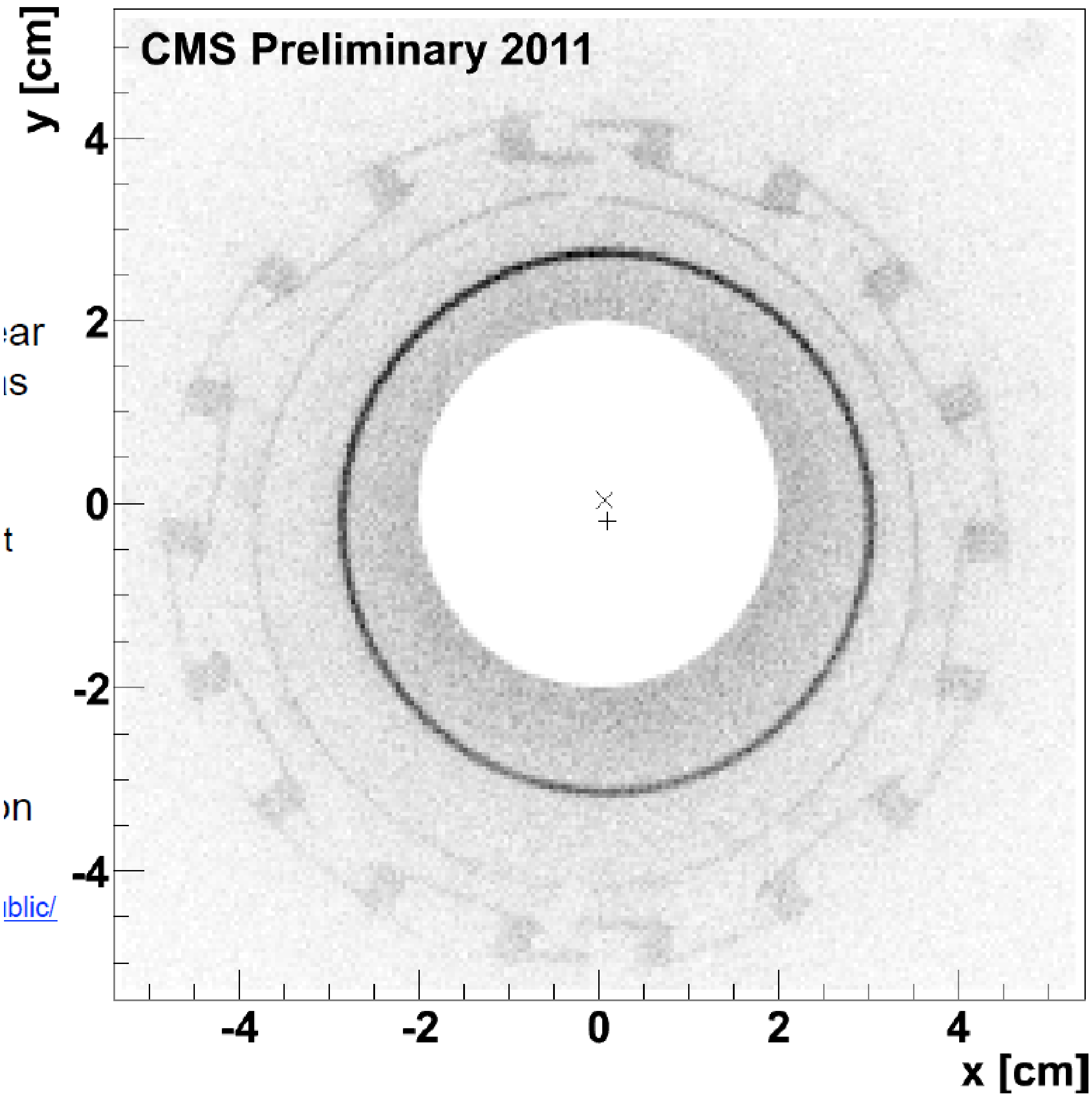
local *x* resolution at low p_t



$0.8 < p_t < 1.2$ GeV

- Multiple scattering dominates at low p_t.
- Flat valley:
  - only silicon at mid-module.
- Peak at center:
  - wide pixels.
- Edges:
  - SiN base strips, cooling pipes.
- Well described by simulation. No phase shift when plotted in this way.

PXB1 in nuclear interactions

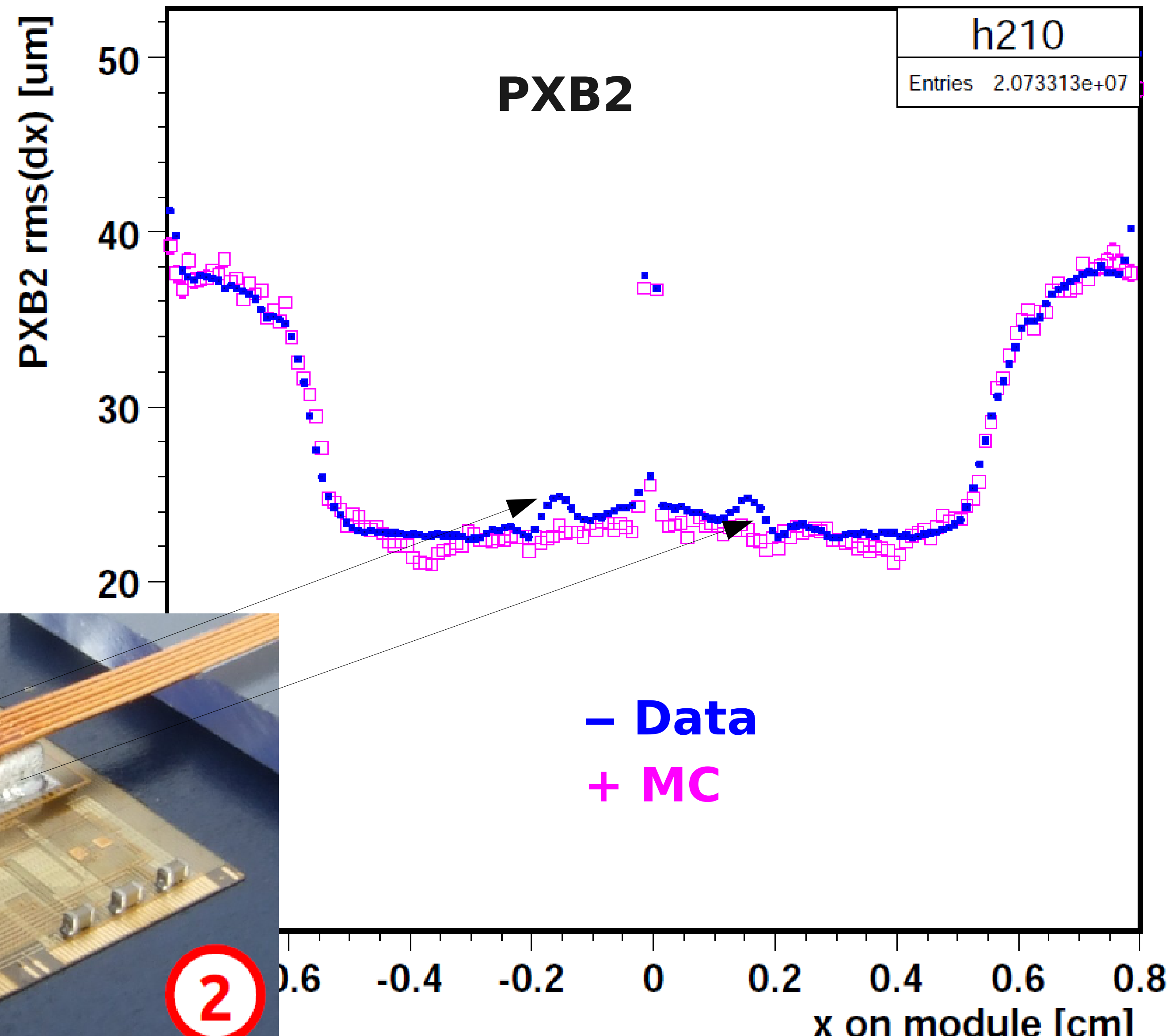


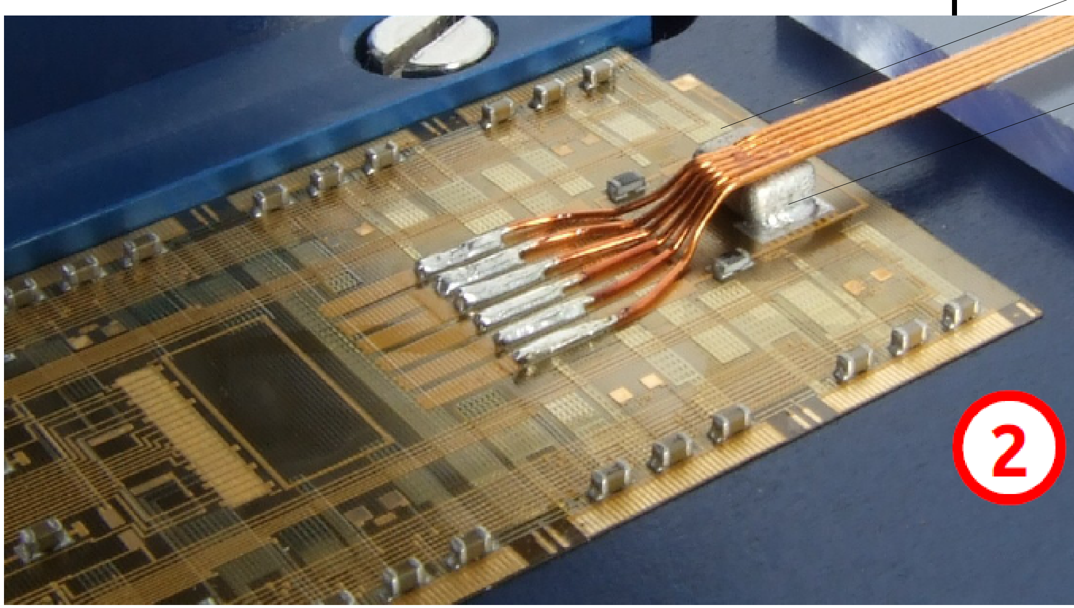
- Nuclear interaction vertices (M. Gouzevitch, G. Squazzoni).
- https://indico.cern.ch/conferenceDisplay.py?confId=123717
- First pixel barrel layer with 18 cooling pipes clearly visible.

local x resolution at low p_t

resolution humps at ±0.15 cm due to HV filter capacitor?

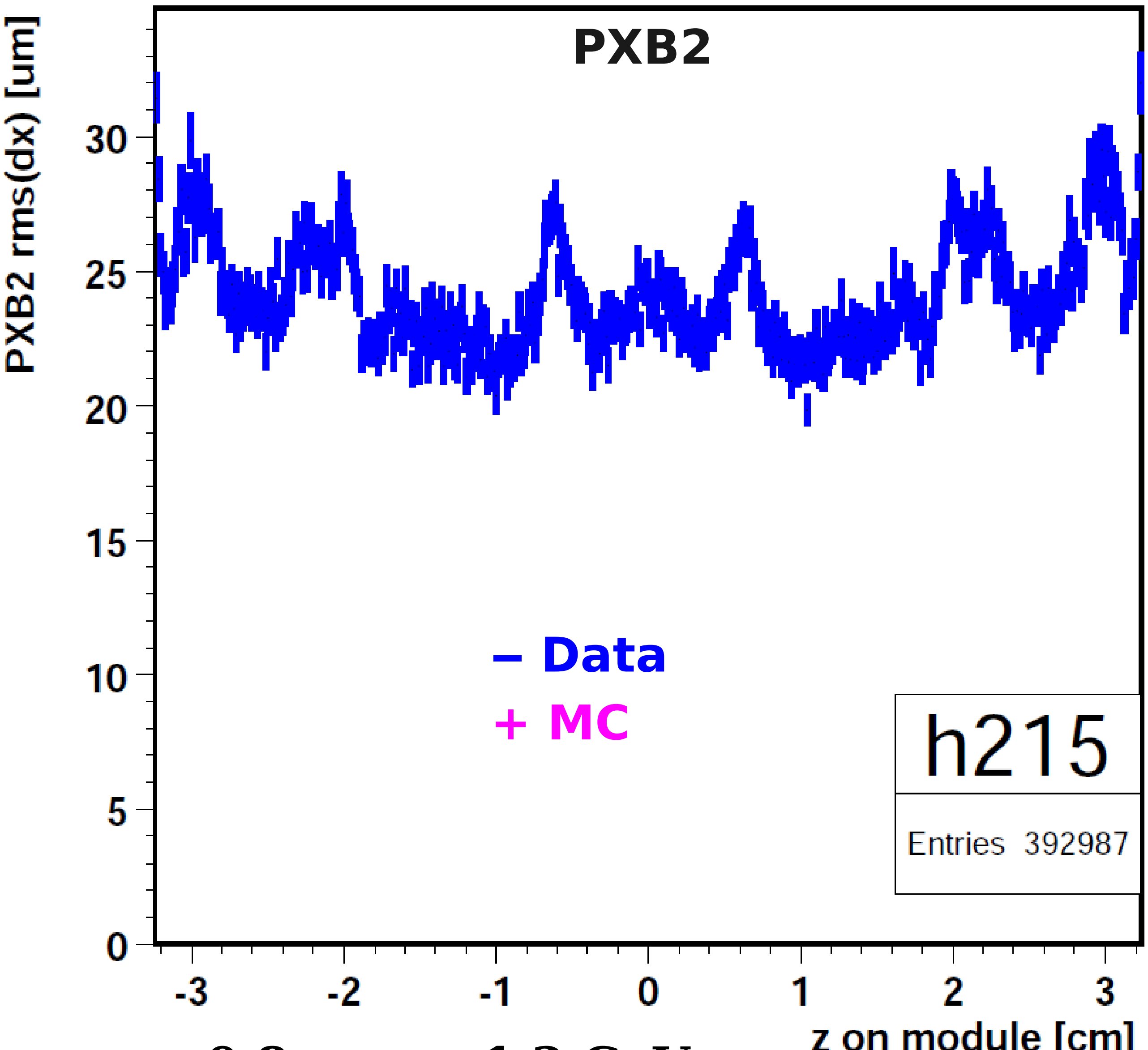
Make z profile in x-slices!

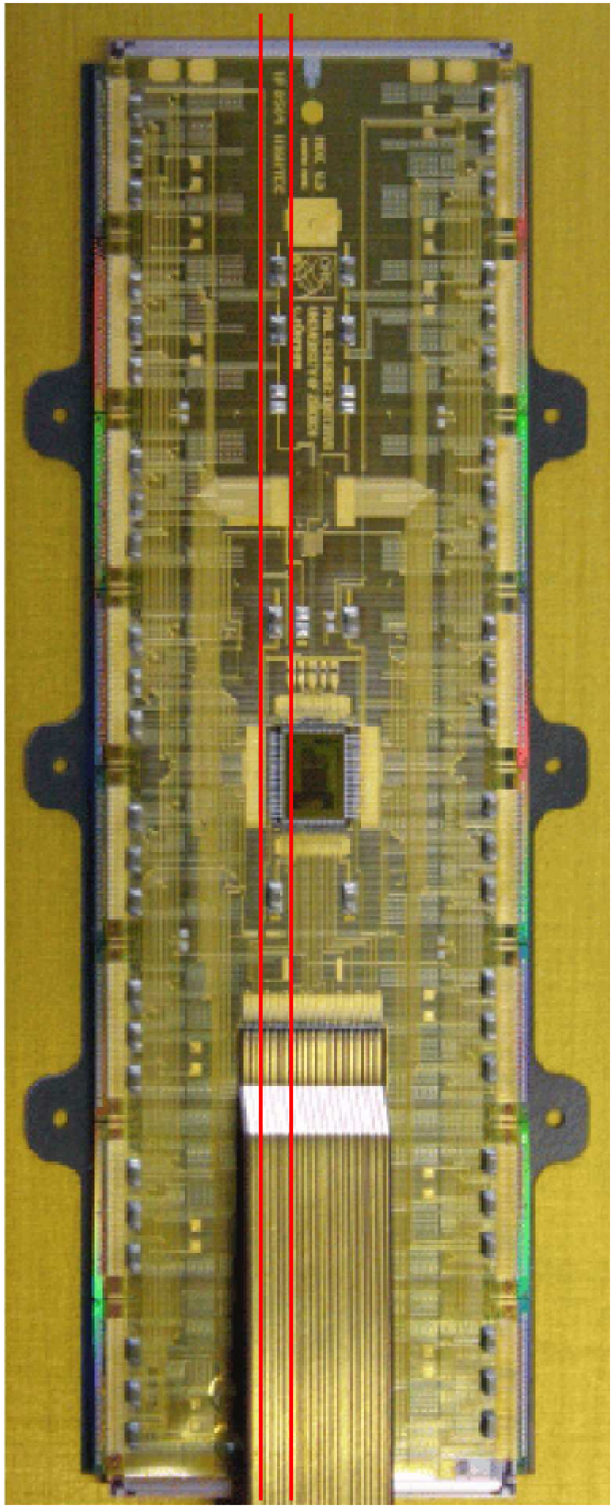




$0.8 < p_t < 1.2$ GeV

local x resolution at low p_t

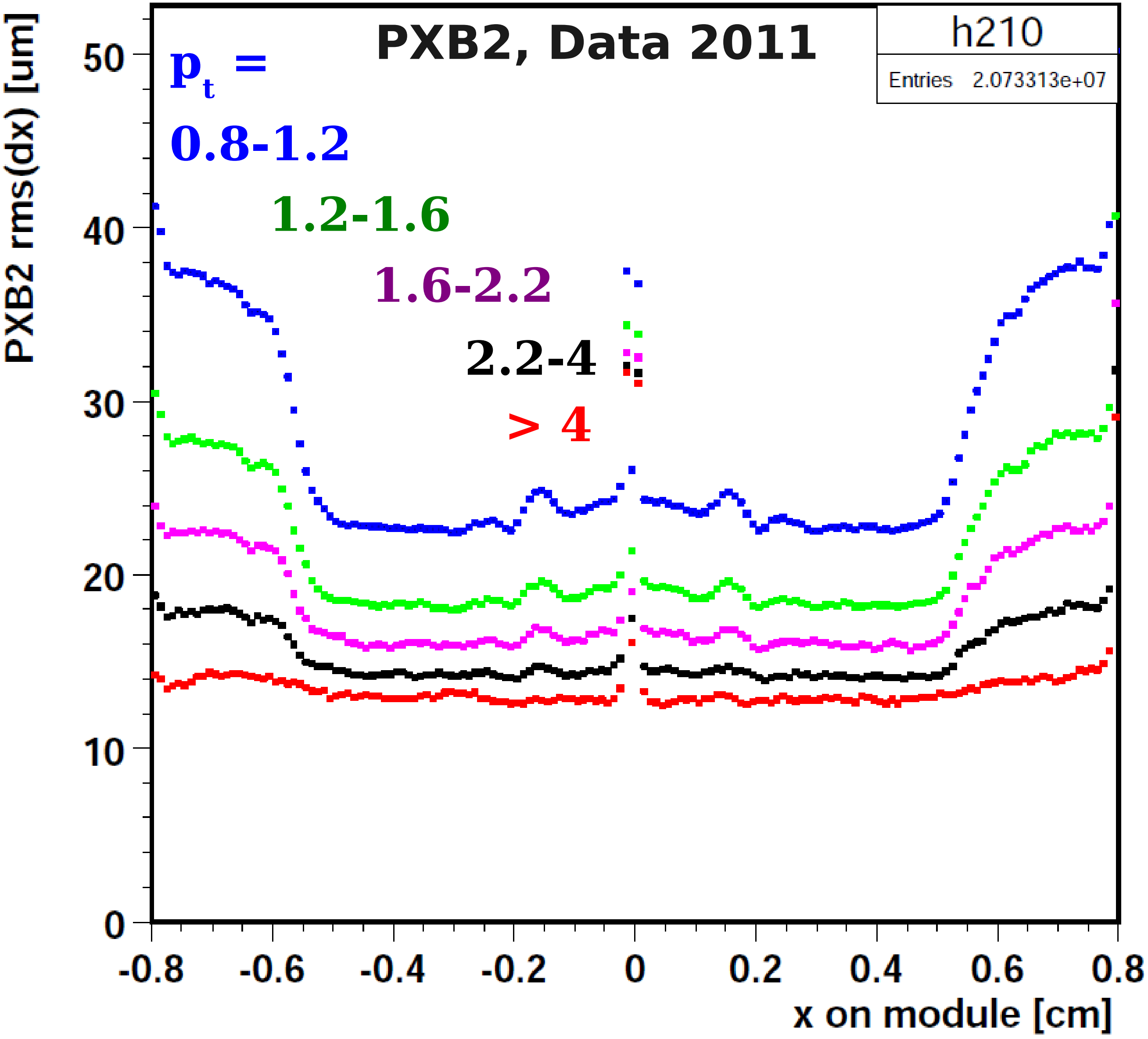




$0.8 < p_t < 1.2$ GeV

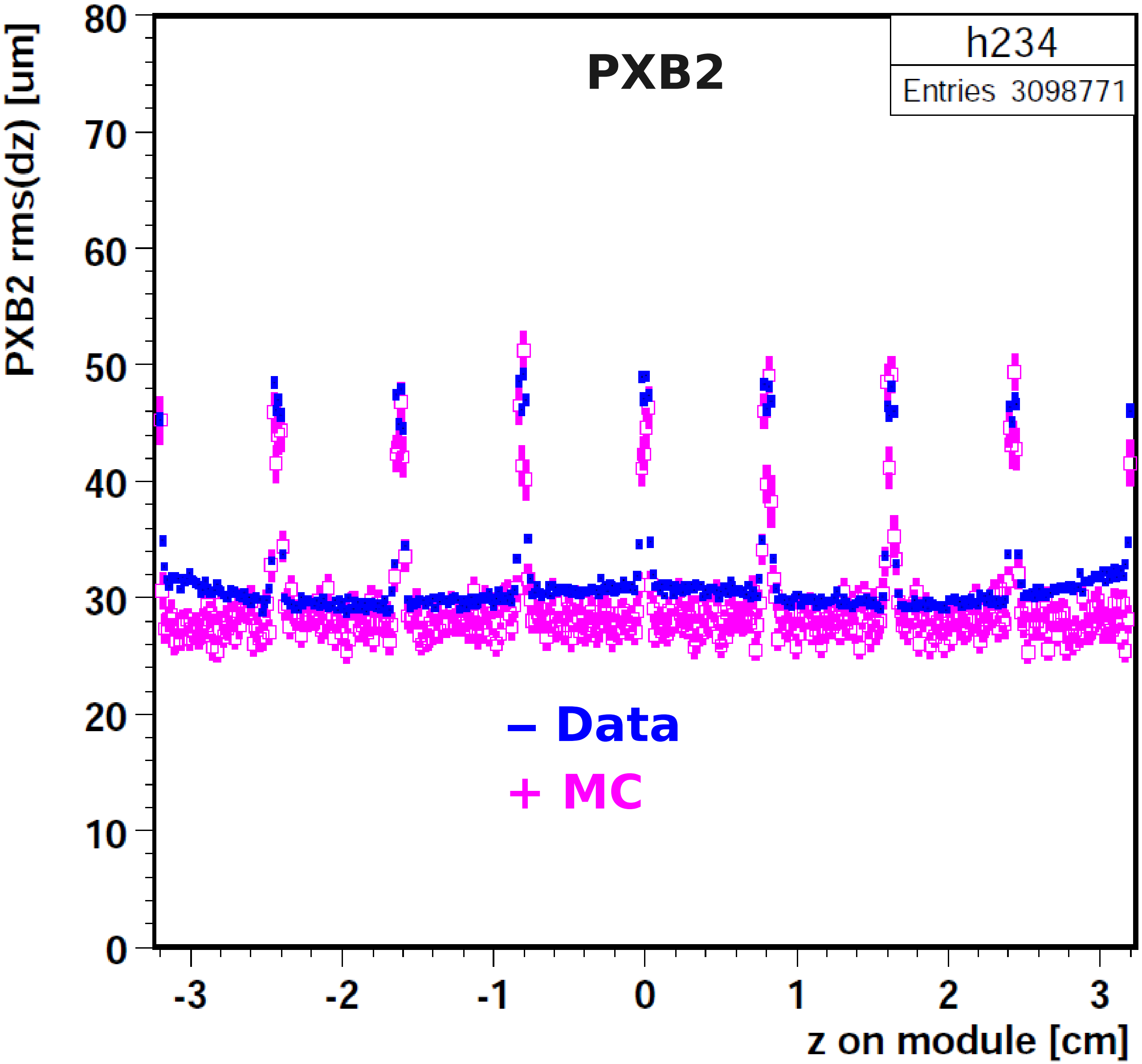
$0.1 < |x_{loc}| < 0.2$ cm

local *x* resolution vs p_t



- Need p_t > 4 to reach intrinsic resolution.

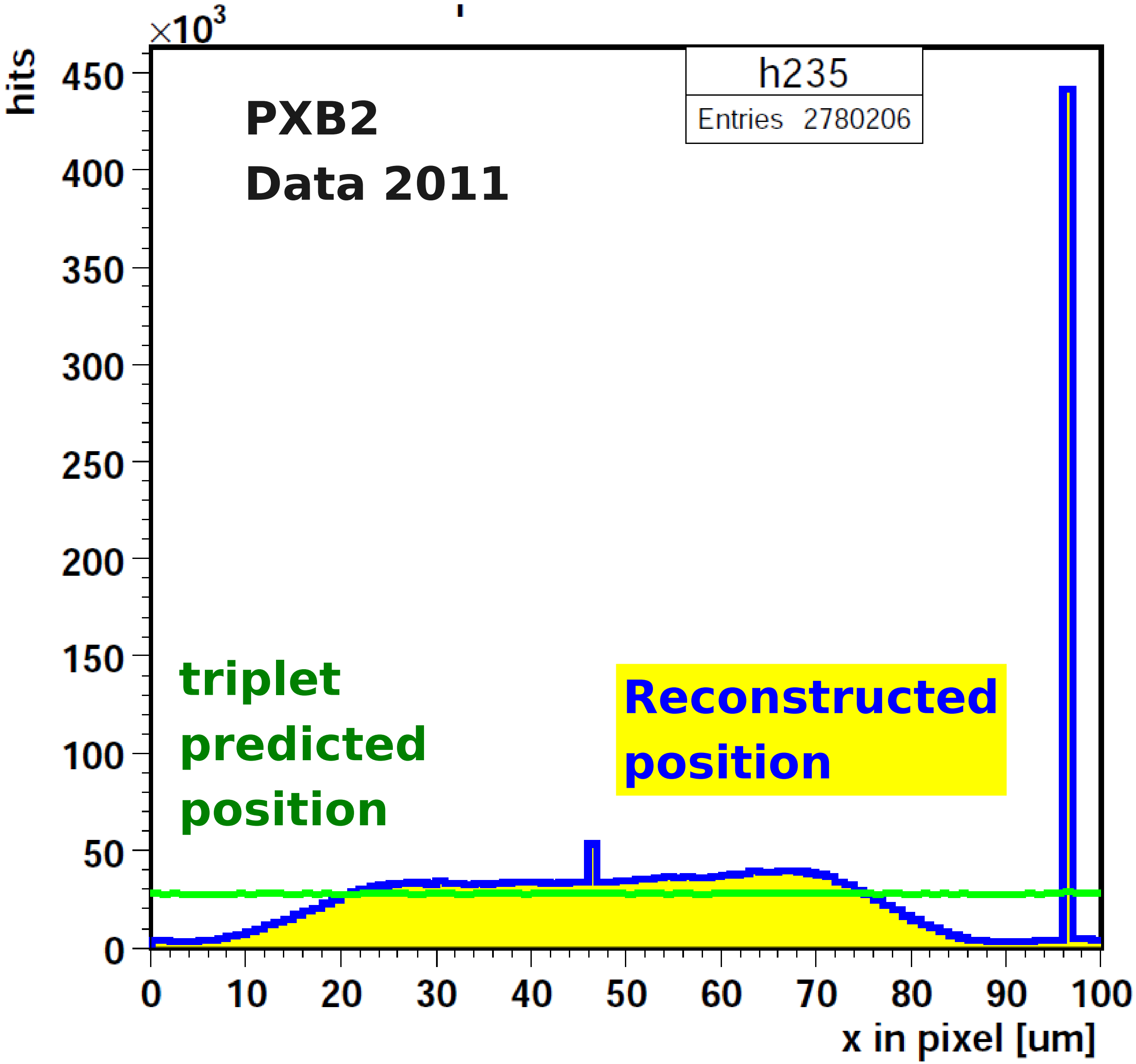
local z resolution along module



p_t > 4 GeV

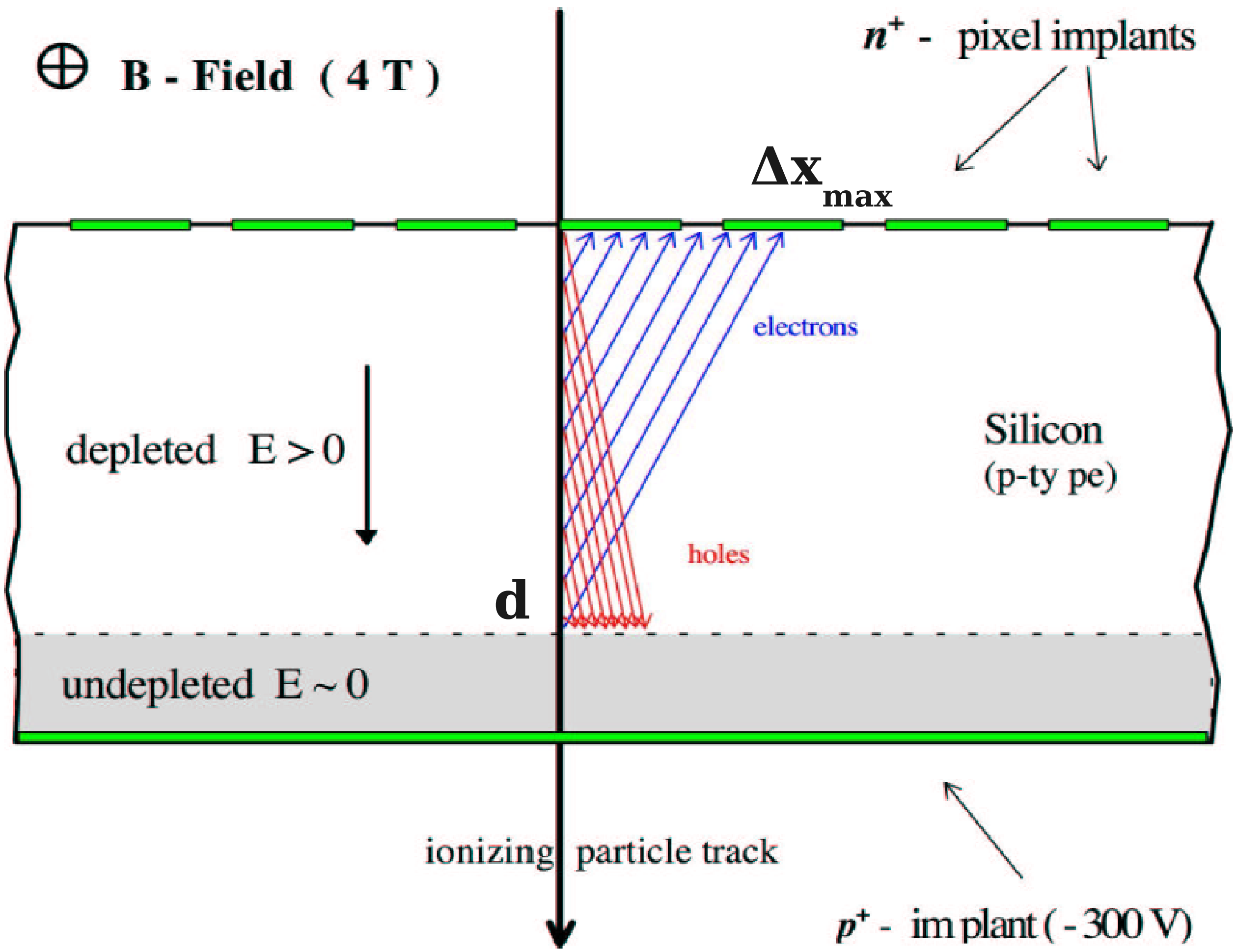
- Triplet z residual rms.
- All angles, p_t > 4 GeV.
- Peaks every 0.8 cm:
  - long pixels at ROC edges.
- MC z resolution is slightly too optimistic.

zoom into pixel



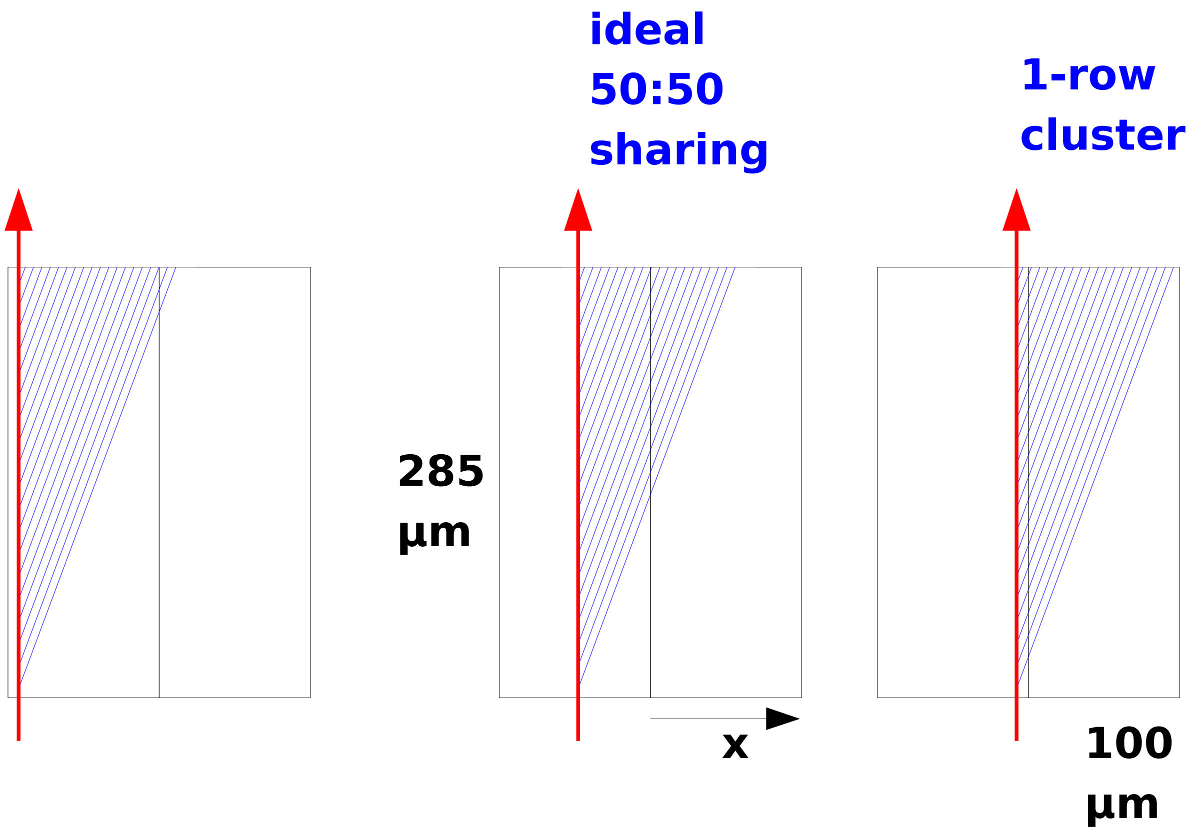
- $x_{pix} = \text{fmod}(\ x_{loc}+0.8,\ 0.01)$.
- Predicted distribution is flat, as expected.
- Reconstructed position from Pixel-CPE-with-Templates:
  - peak at 97 from 1-row clusters,
  - peak at 46 µm?
  - almost flat between 22 and 74 µm.

Lorentz drift



- $\tan\alpha_L = \mu B$
- pixel at 3.8 T:
  - $\tan\alpha_L = 0.398$
- pixel sensors:
  - $d = 285\ \mu m$
  - $\Delta x_{max} = d \tan\alpha_L$
    $= 114\ \mu m$
  - $\Delta x_{mid} = 0.5\ d \tan\alpha_L$
    $= 57\ \mu m$

Lorentz drift



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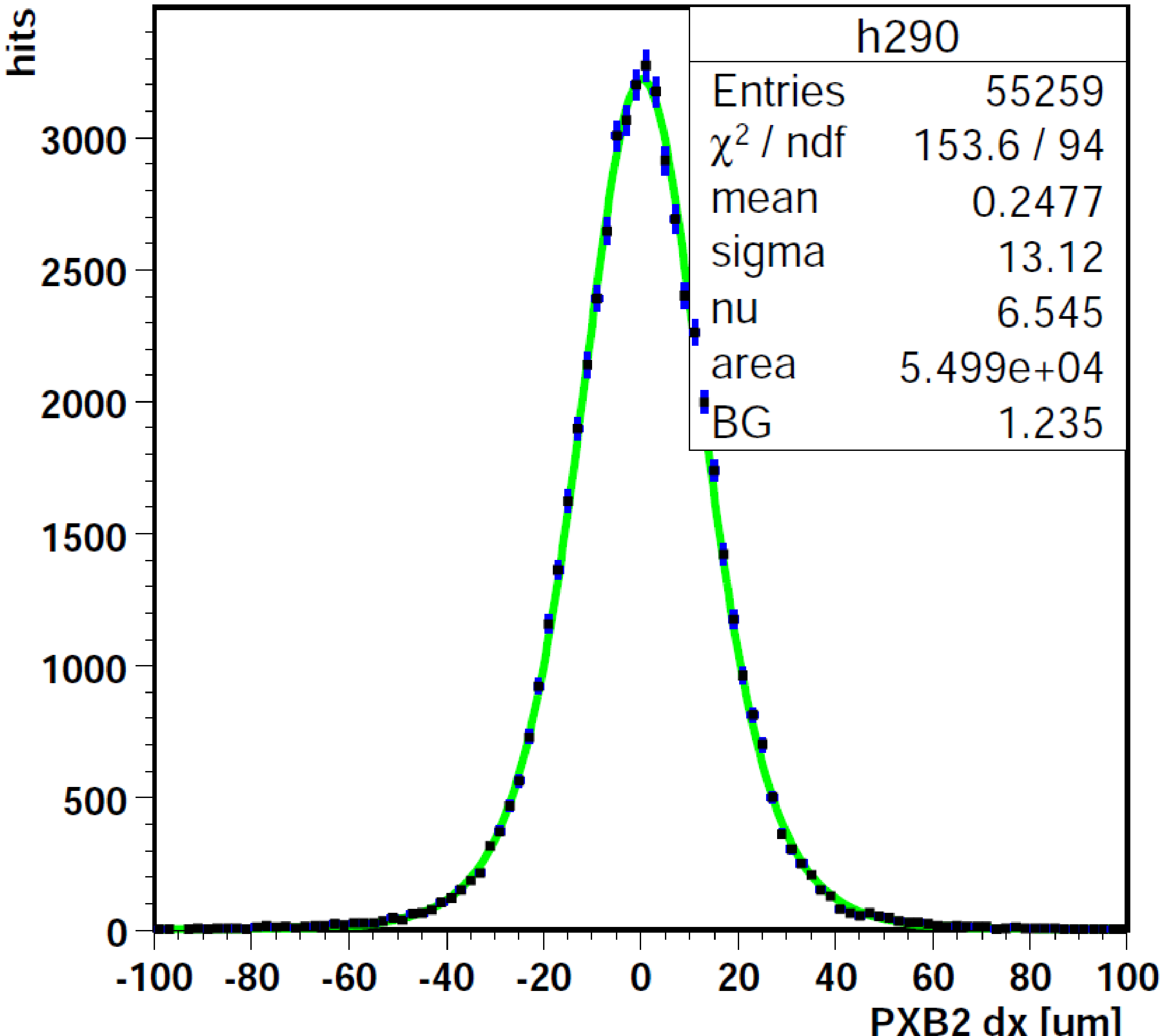
triplet *x* residuals for 1-row clusters

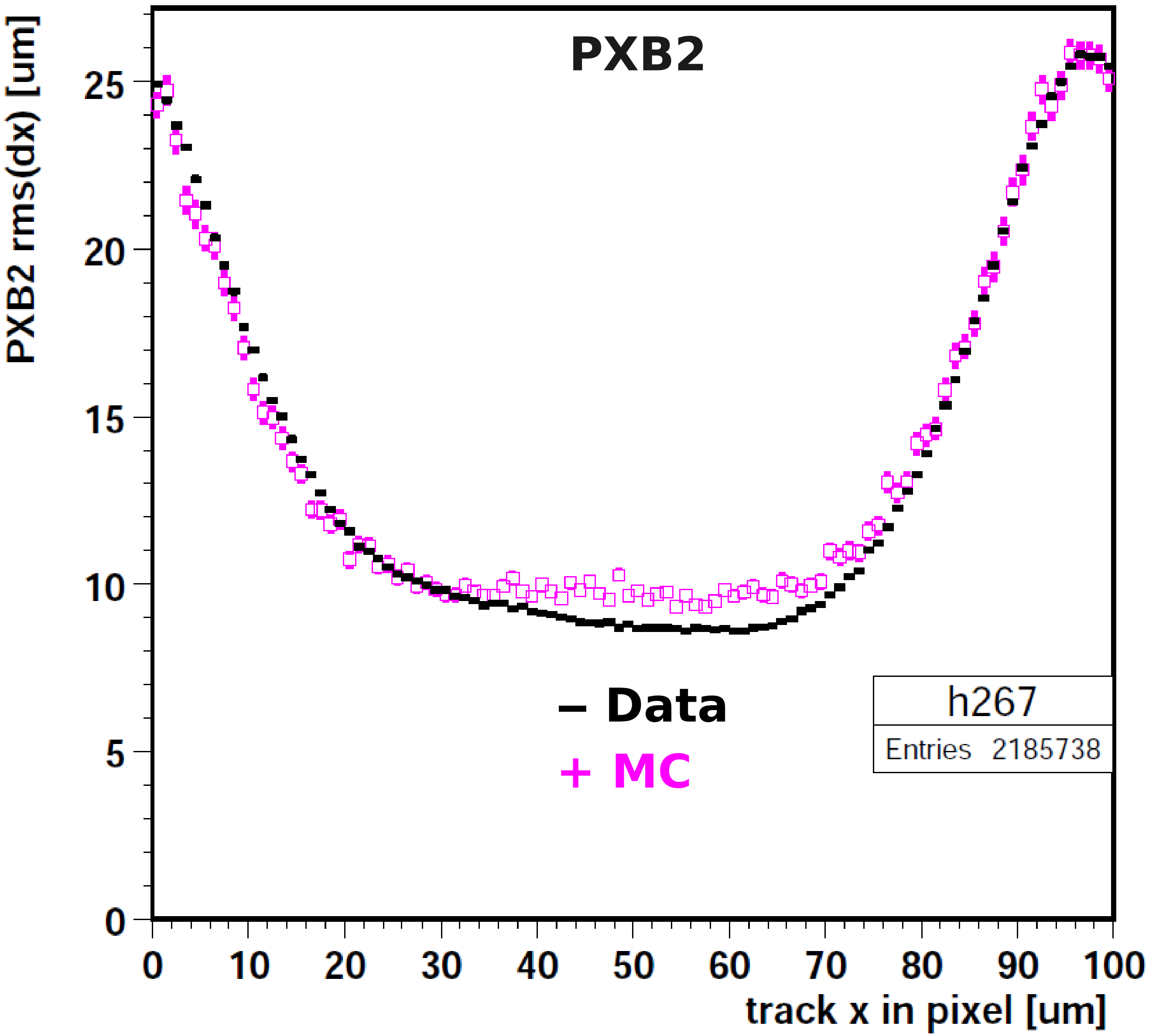


p_t > 12 GeV

1-row clusters

- Data Mar 2011
- Mean of the residual distribution is zero:
  - no bias, alignment OK.
- Width of the residual distribution at high p_t:
  - σ_r = 13 μm.
  - OK.
- Upgrade:
  - ROC with lower thresholds
  - less 1-row clusters.

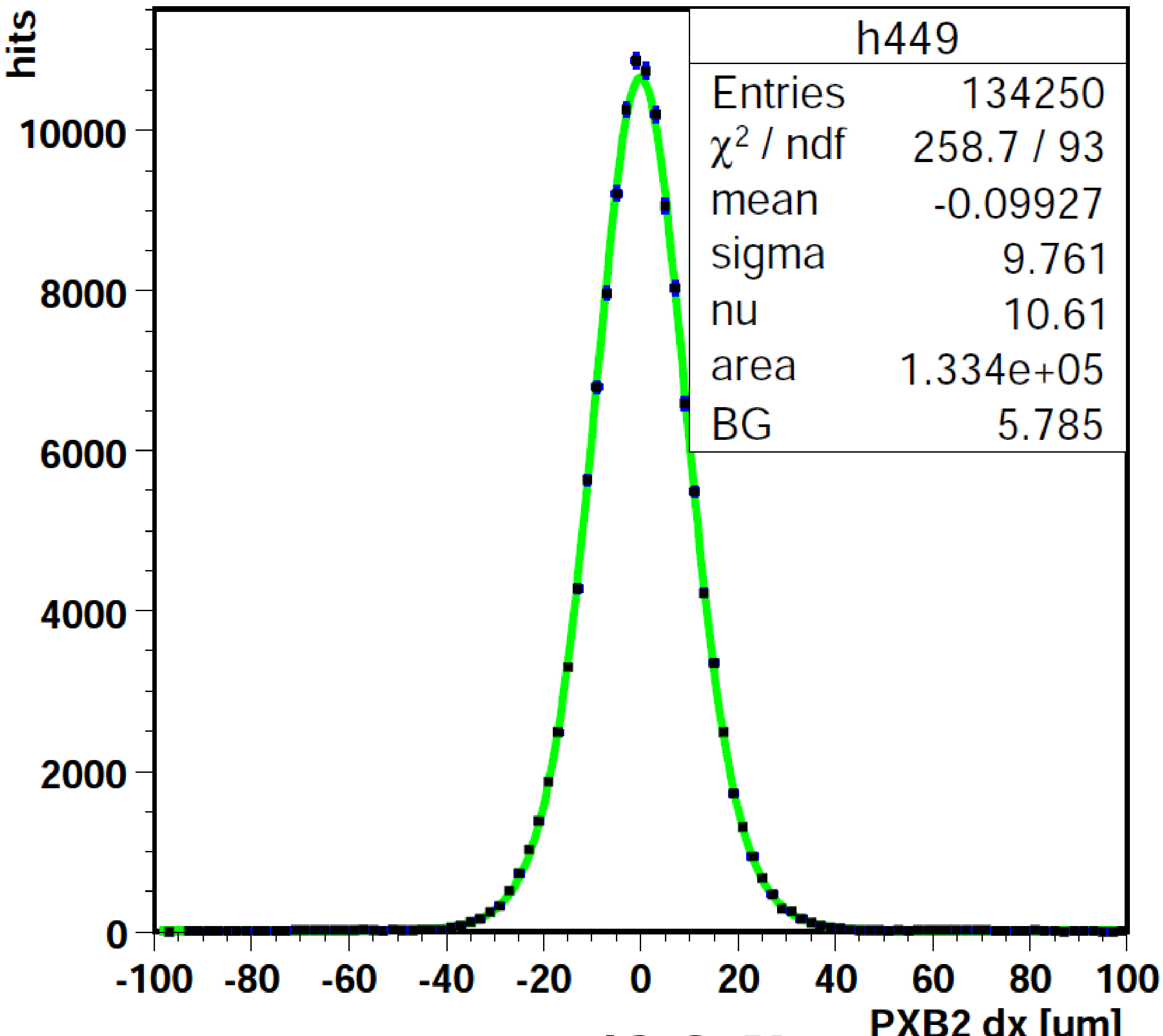
local *x* resolution in pixel



p_t > 4 GeV, 2-row clusters

- Triplet *x* rms as function of predicted *x* in pixel at high p_t.
- Strong resolution variation from 9 to 25 µm:
  - best resolution at pixel center,
  - worst resolution near pixel edges.
- Well described by the simulation.

triplet *x* residuals at pixel mid



p_t > 12 GeV,

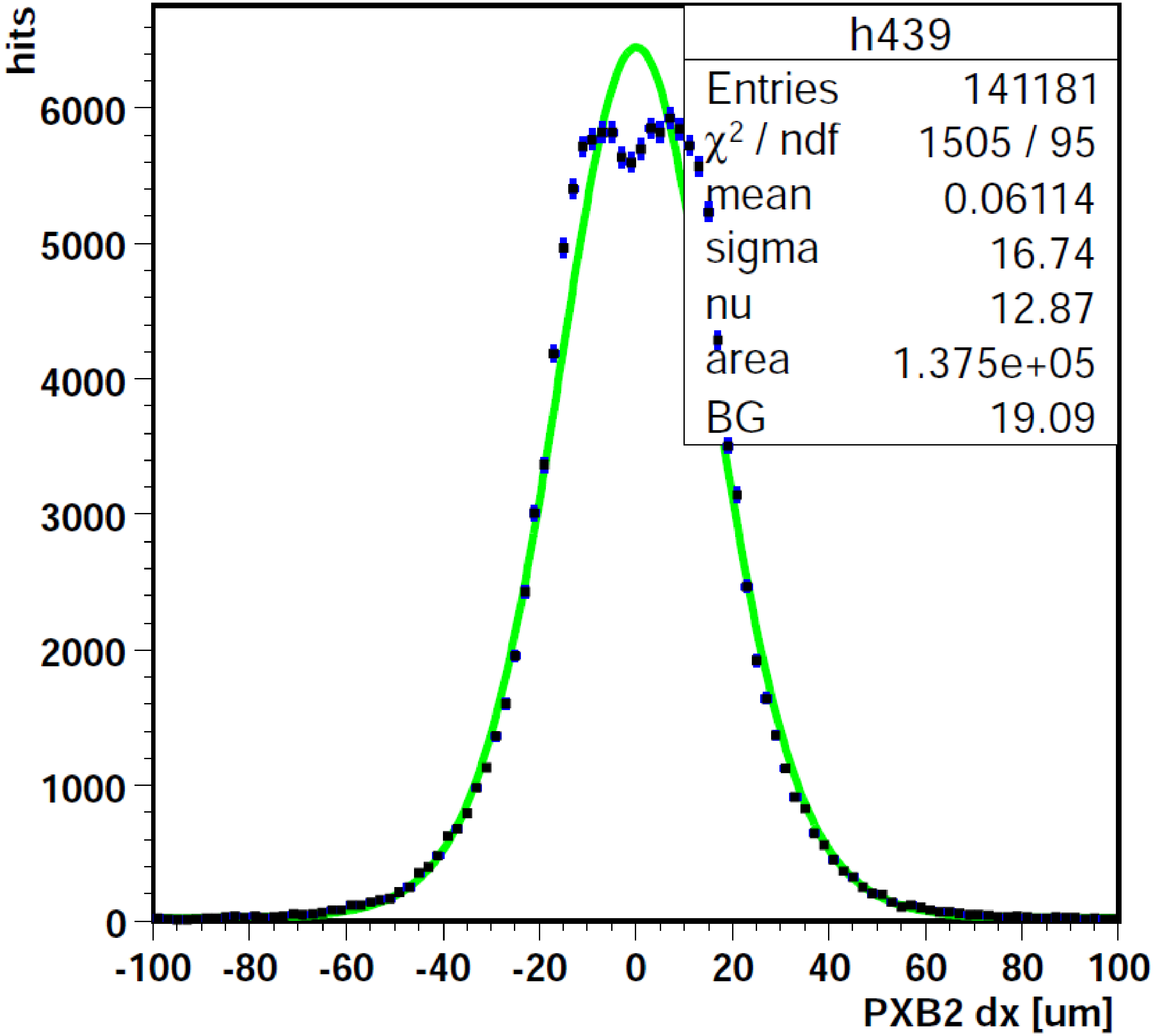
2-row clusters, 30 < x_{pix} < 70 µm.

- Data Mar 2011
- Width of the residual distribution at high p_t:
- σ_r = 9.8 µm.

$$\sigma_r^2 = \sigma_2^2 + (\sigma_1/2)^2 + (\sigma_3/2)^2$$

- Other layers have average σ_i = 10.5 µm.
- Result:
  - σ_2 = 6.4 µm at pixel mid.

triplet *x* residuals at pixel edge



p_t > 12 GeV

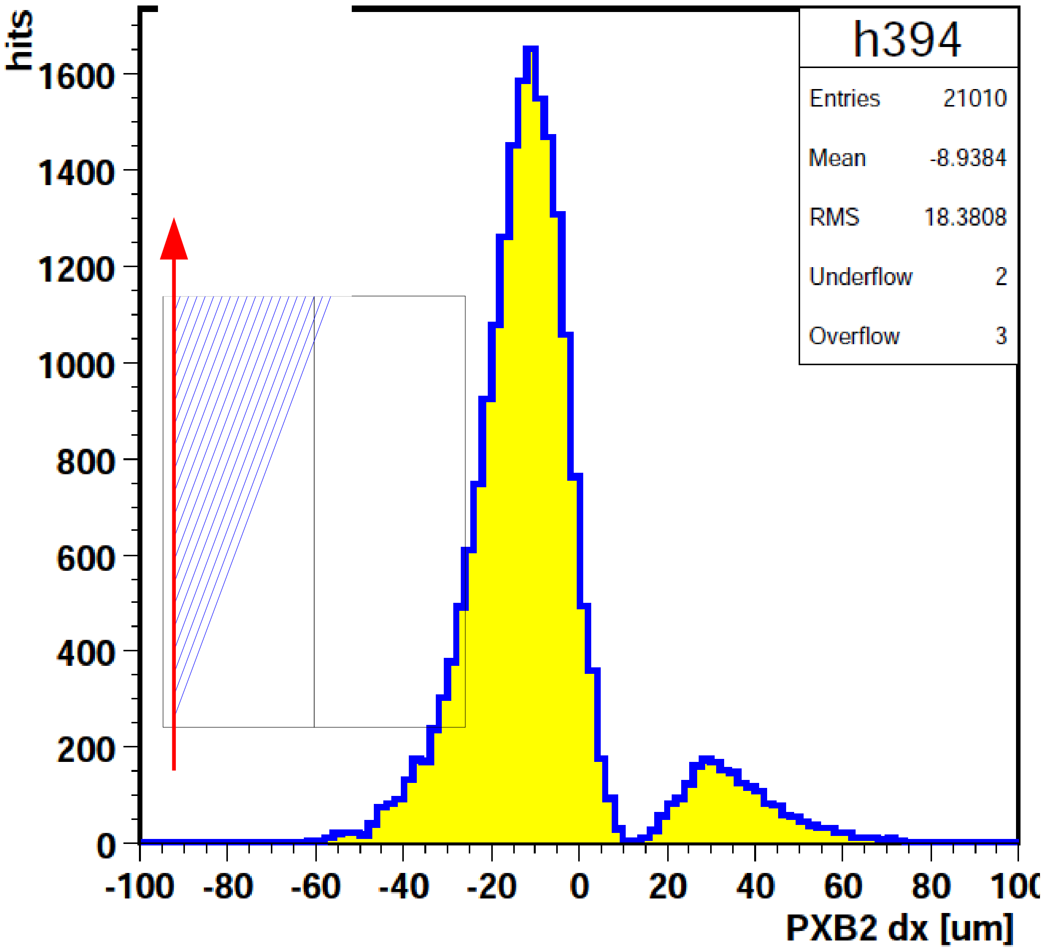
x_{pix} < 20 or > 80 µm.

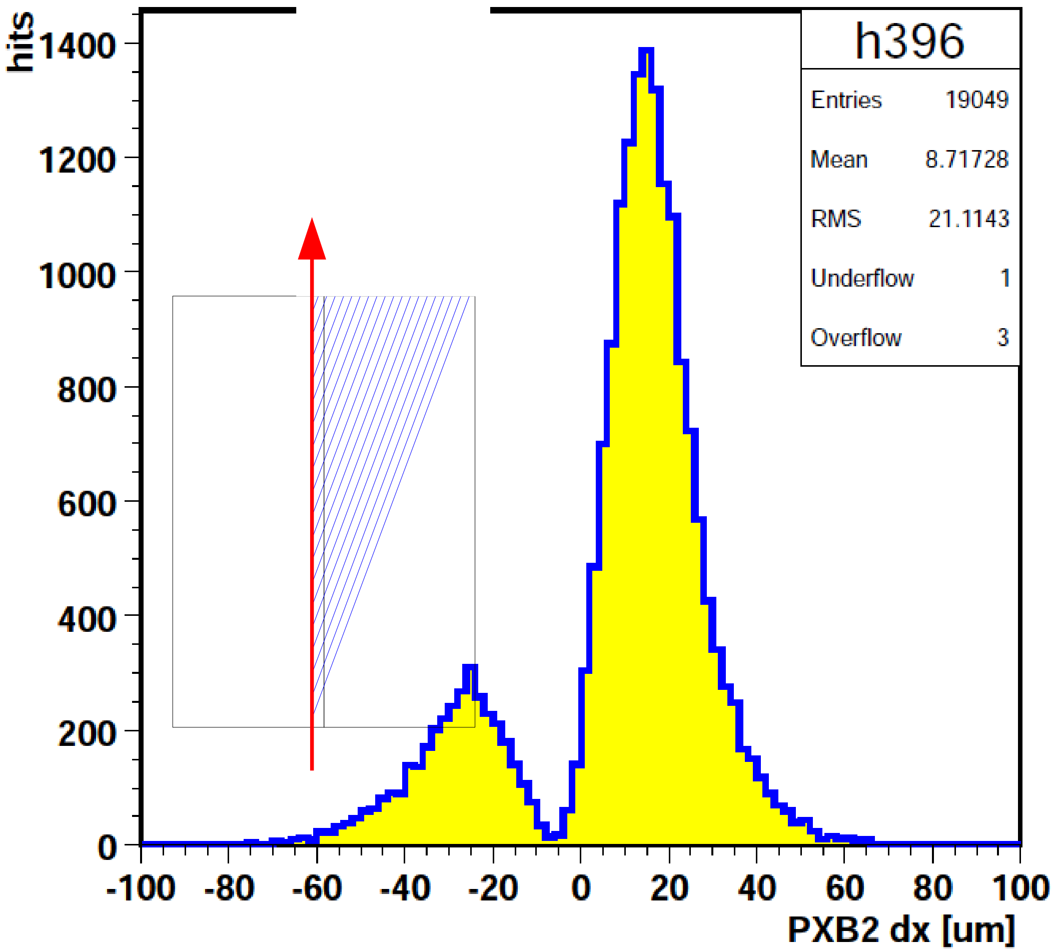
- Data Mar 2011
- Width of the residual distribution at high p_t:
- σ_r = 16.8 µm.

$$\sigma_r^2 = \sigma_2^2 + (\sigma_1/2)^2 + (\sigma_3/2)^2$$

- Other layers have average σ_i = 10.5 µm.
- Result:
  - σ_2 = 15 µm at pixel edge,
  - double peak?

triplet *x* residuals at pixel edge





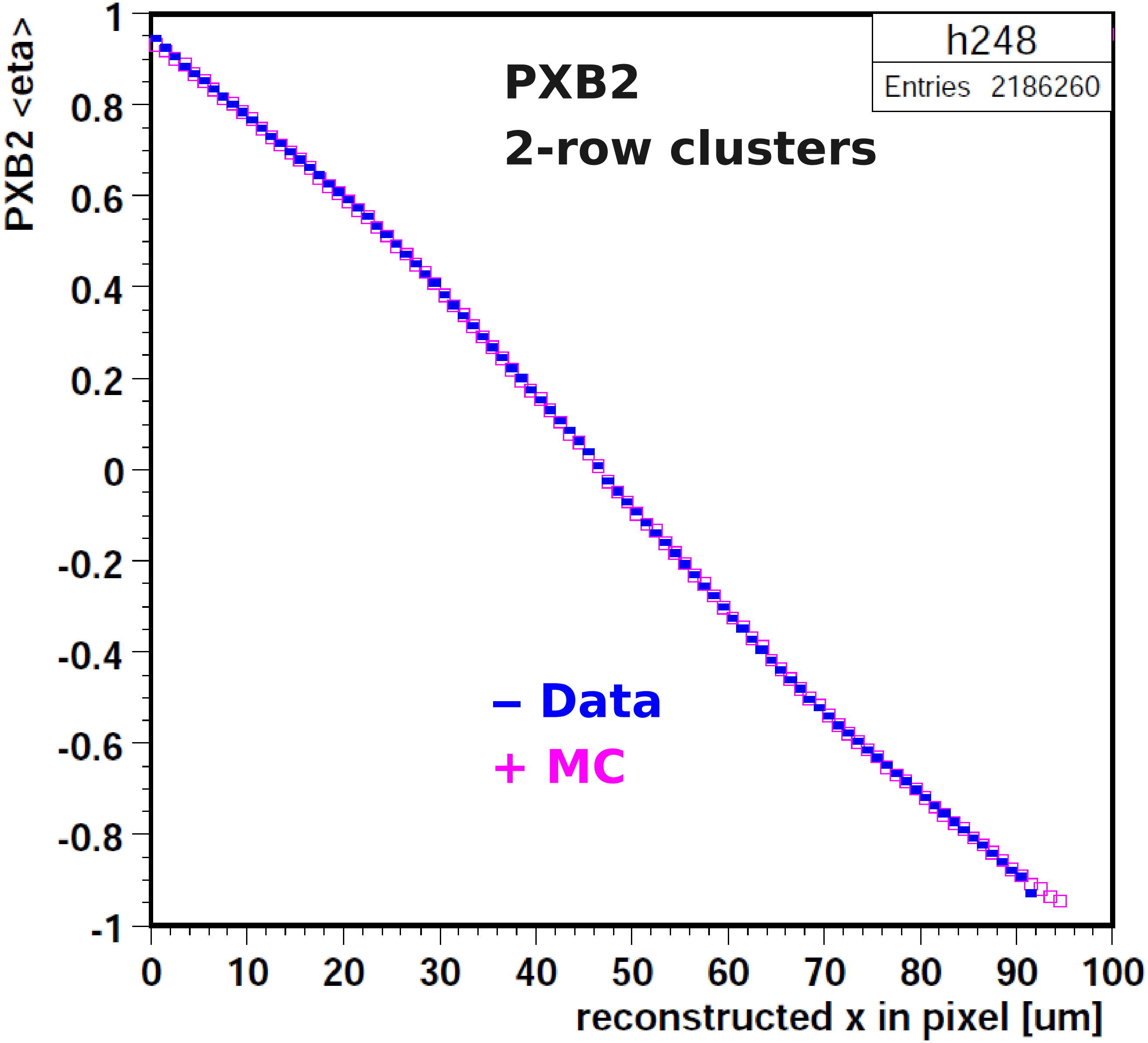
p_t > 12 GeV, 2-row cluster

x_{pix} < 20 µm, outward module

p_t > 12 GeV, 2-row cluster

x_{pix} > 80 µm, outward module

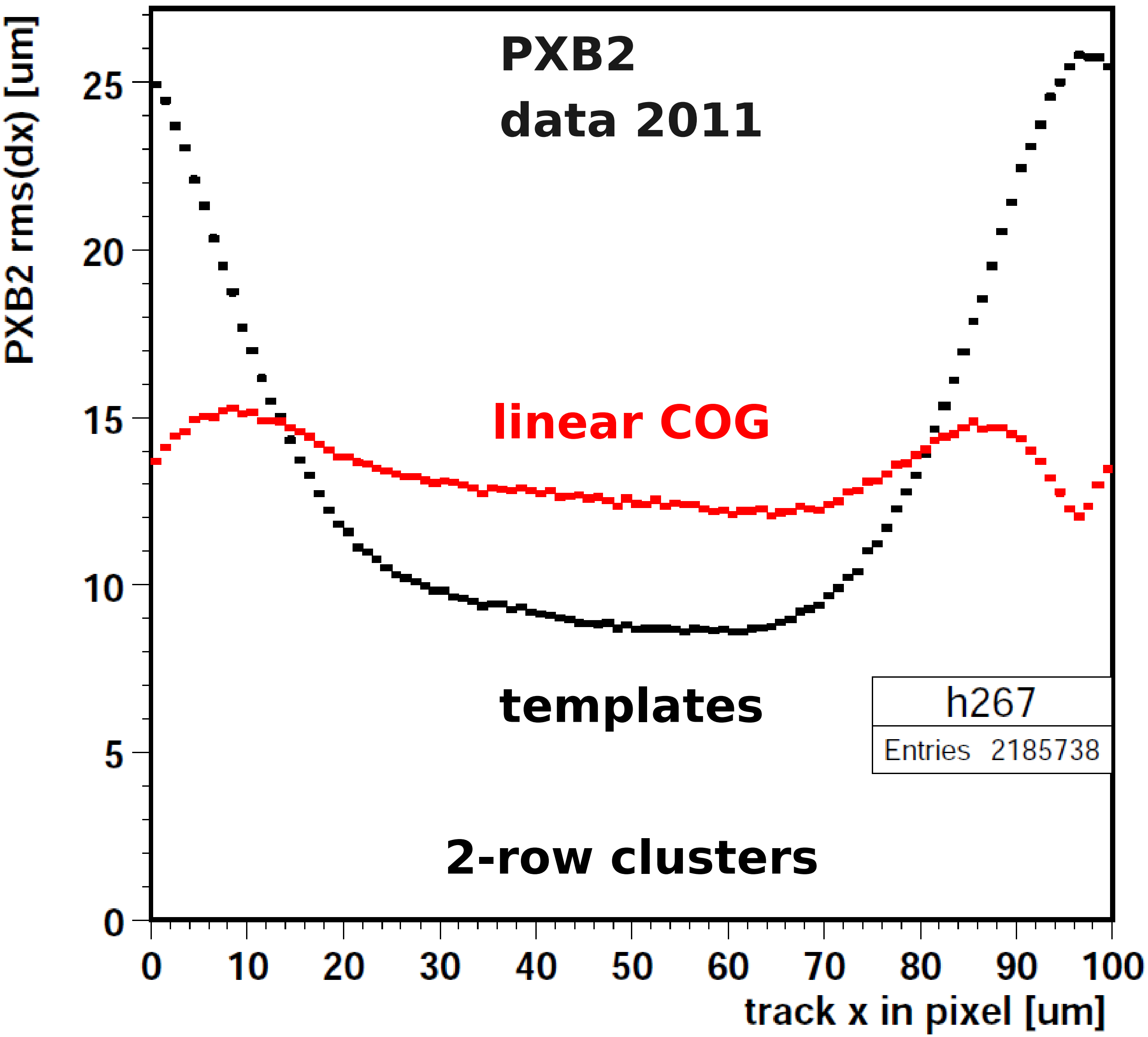
charge sharing



p_t > 4 GeV

- 2-row clusters:
  - $\eta = (Q_L - Q_R) / Q_{tot}$
- almost linear:
  - uniform charge sharing due to Lorentz drift.
- x > 90 µm:
  - only 1-row clusters.
- Perfect description by MC:
  - algorithm tuned to MC.

local *x* resolution in pixel



$p_t > 4$ GeV

- Triplet *x* rms as function of predicted *x* in pixel at high p_t.
- Strong resolution variation from 9 to 25 µm with standard template CPE.
- Simple cluster center-of-gravity algorithm:
  - worse resolution at pixel center,
  - better resolution near pixel edges.

Summary

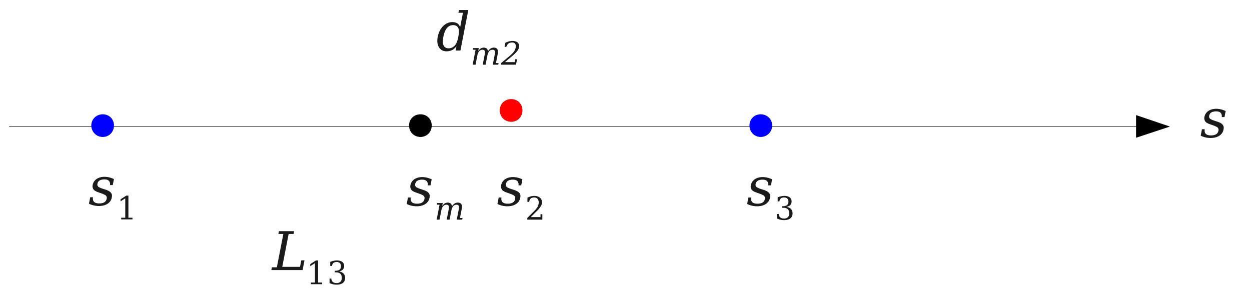
- Triplet method for pixel hit residuals:
  - x and z resolutions across a module well described by simulation
  - x resolution varies strongly across one pixel:
  - best resolution at pixel mid (optimal charge sharing under Lorentz drift),
  - worst resolution near pixel edges (especially for 2-row clusters). Improvement possible?
  - Resolution of 10.5 µm previously observed seems to be a mixture of 6.4 µm at best and 15 µm at worst.
  - quite well described by simulation.
- Upgrade:
  - new ROC with lower thresholds
  - less 1-row clusters?
  - wider plateau with optimal resolution?

triplet resolution function

Propagation of the intrinsic resolution at high p_t:

$$\sigma_r^2 = \sigma_2^2 + \frac{\sigma_1^2}{4} + \frac{\sigma_3^2}{4} + \frac{d_{m2}^2}{L_{13}^2}\left(\sigma_1^2 + \sigma_3^2\right)$$

$L_{13} = s_3 - s_1$	length of base line
$d_{m2} = s_2 - s_m$	distance of point 2 from mid point
$s_m = (s_1 + s_3)/2$	mid point
s	radial coordinate (arc length)



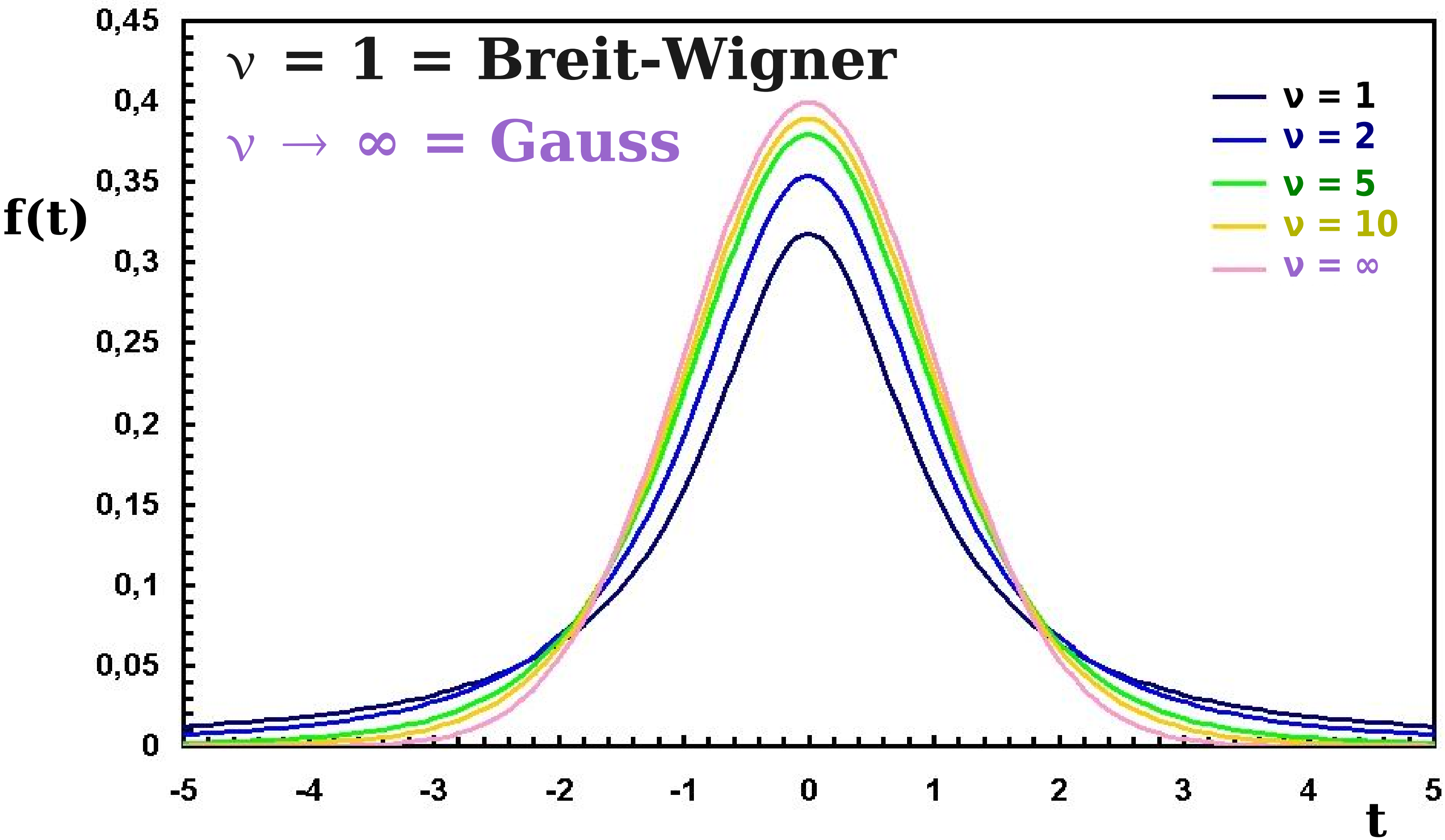
like for a straight line developed around its center, where offset and slope are uncorrelated.

Fitting peaks with Student's *t*

$t = (x - x_0)/\sigma$ = normalized residual.

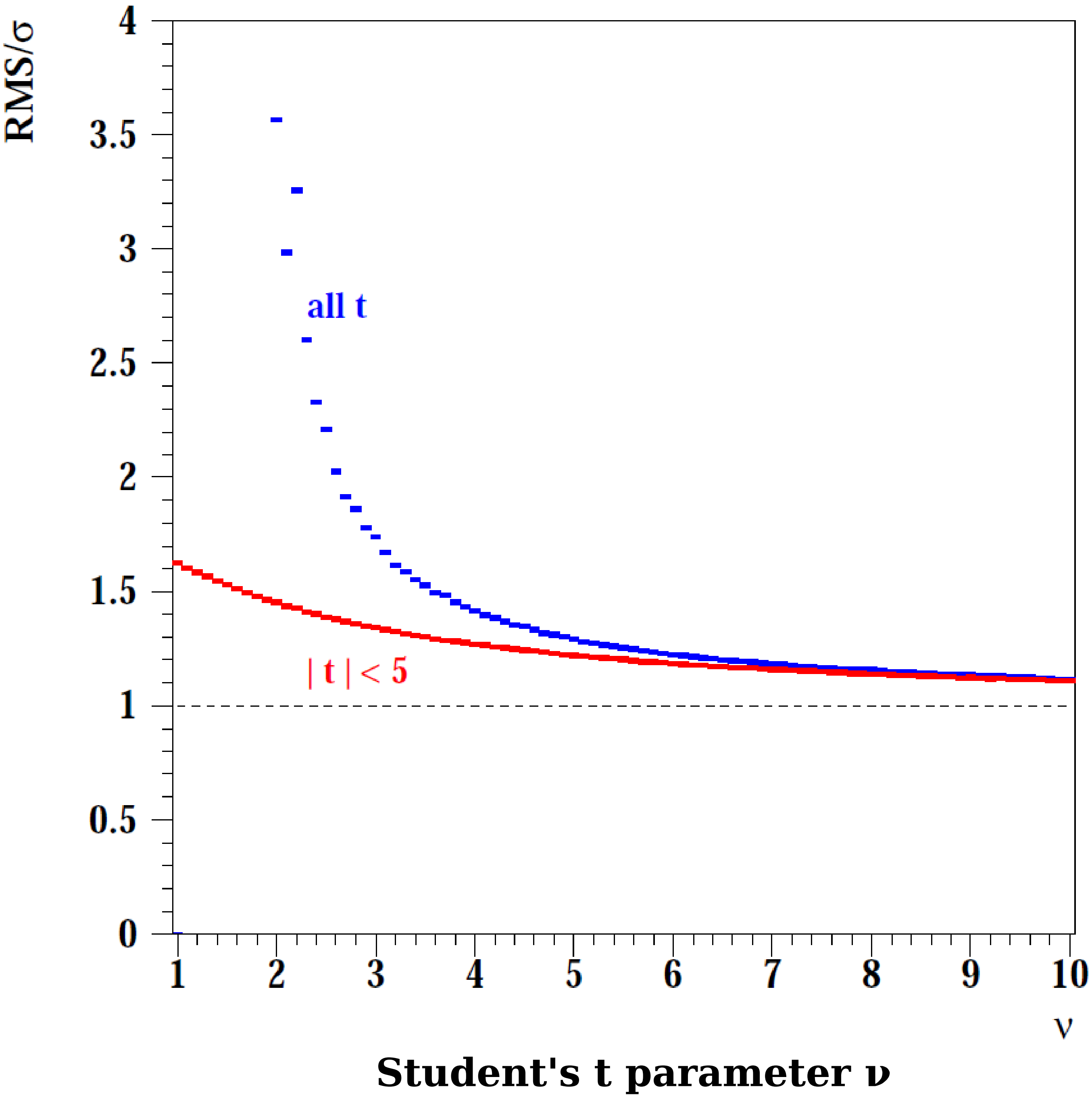
$$\boxed{f(t) = \frac{\Gamma((\nu+1)/2)}{\sqrt{\nu\pi}\,\Gamma(\nu/2)}(1+t^2/\nu)^{-(\nu+1)/2}}$$

f(t) is a normalized probability density.
Γ function is in PAW, ROOT.



Parameter ν interpolates between Gaussian and Breit-Wigner.

rms/σ for Student's t



- Generate random numbers according to Student's t for different ν (see W. Hoermann, Computing 81 (2007) 317).
- calculate rms:
  - for all t. (rms diverges for $\nu = 1$).
  - for | t | < 5. (rms stays below 1.62 for all $\nu \geq 1$).
- Asymptotic value (rms/σ = 1) slowly approached.