CMS pixel resolution study in the DESY test beam telescope

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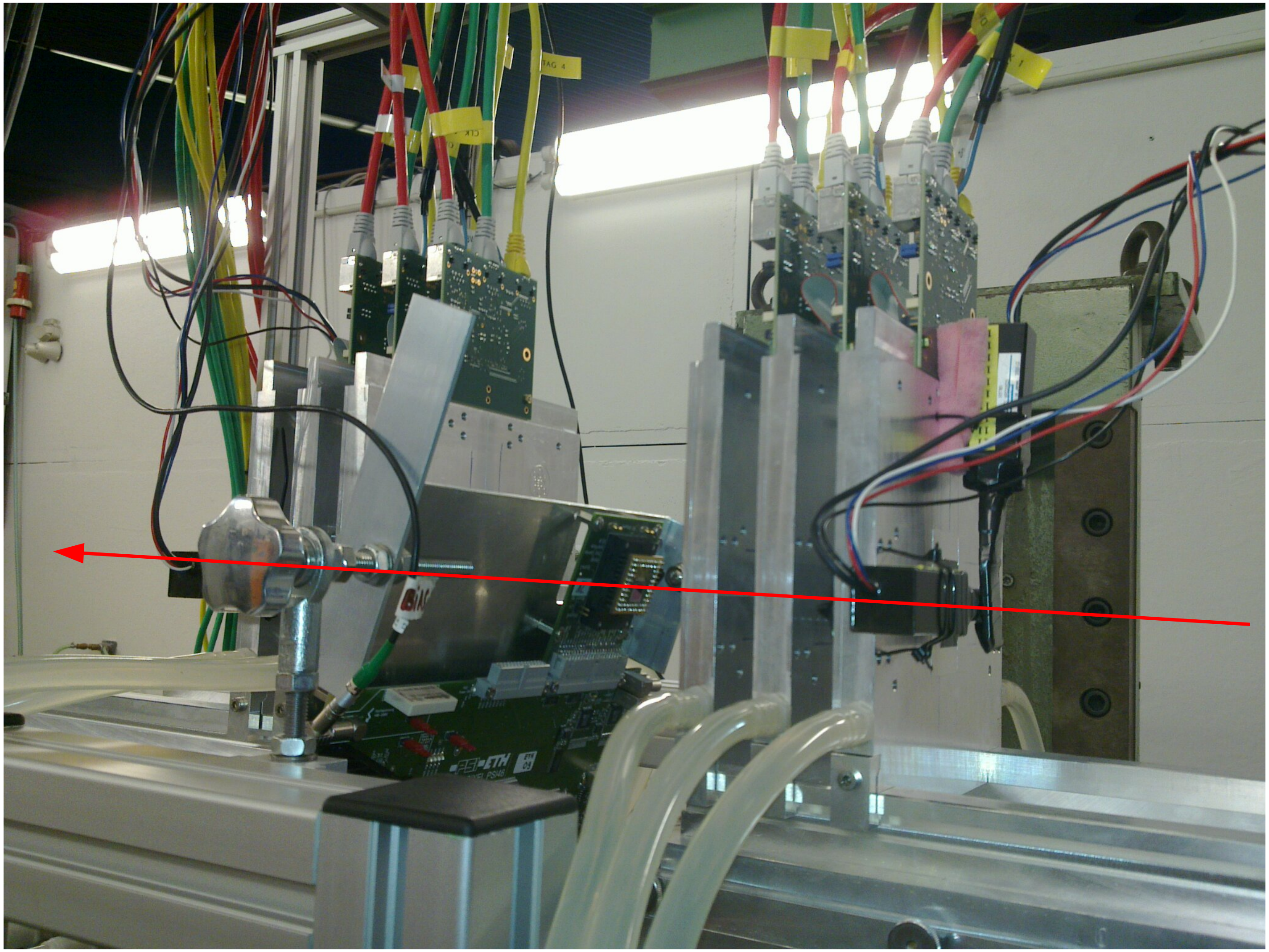
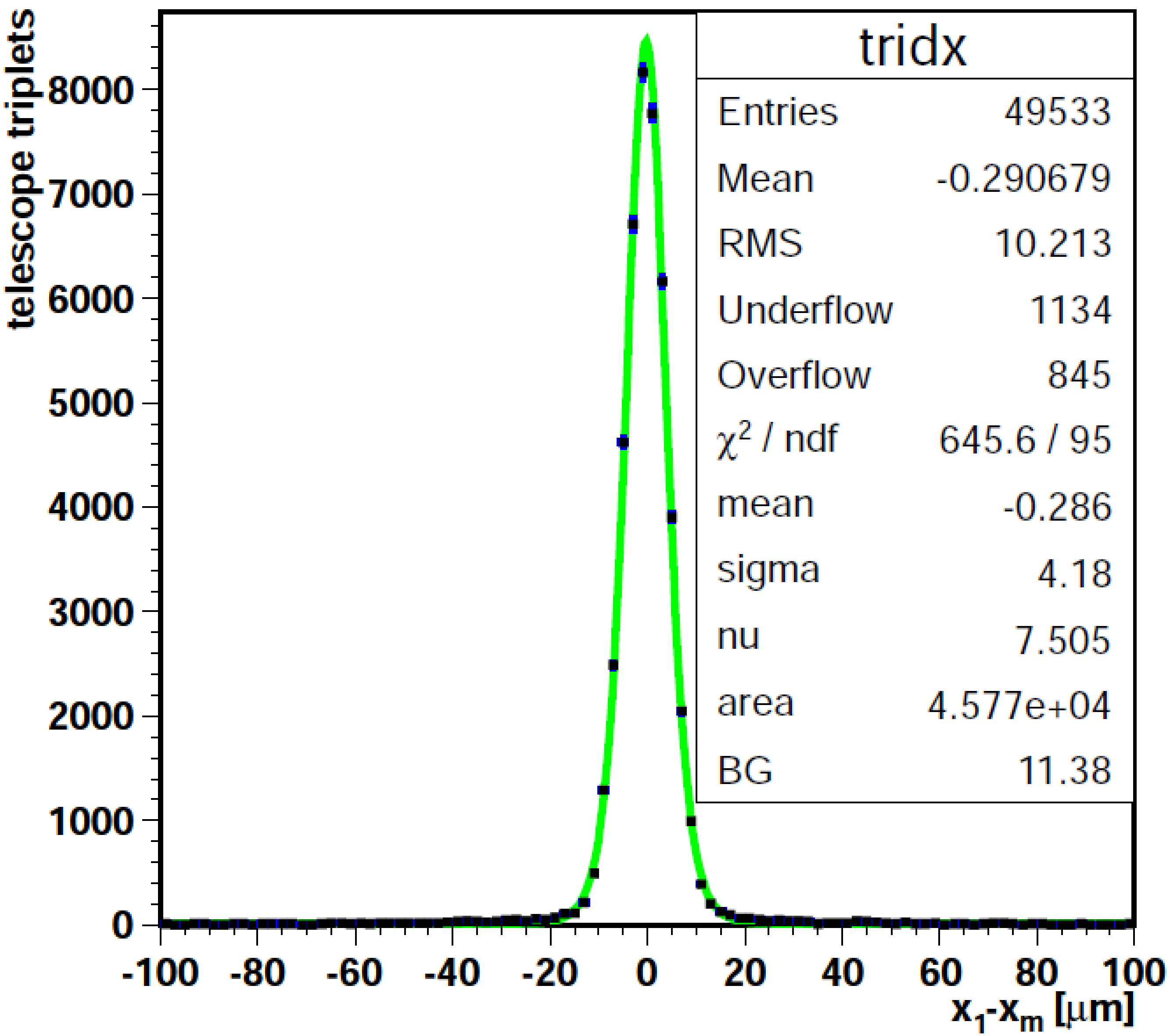
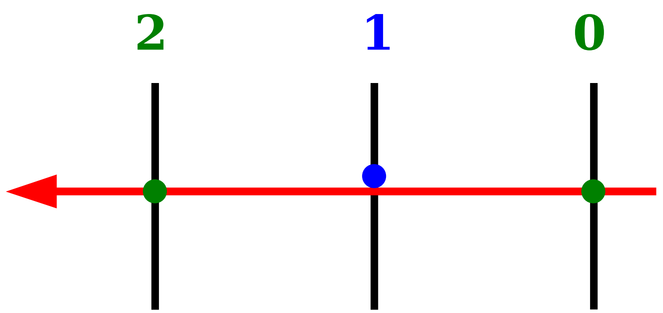
Pixel upgrade, 3.1.2012



- alignment
- tilted pixels
- charge sharing
- resolution

Telescope point resolution

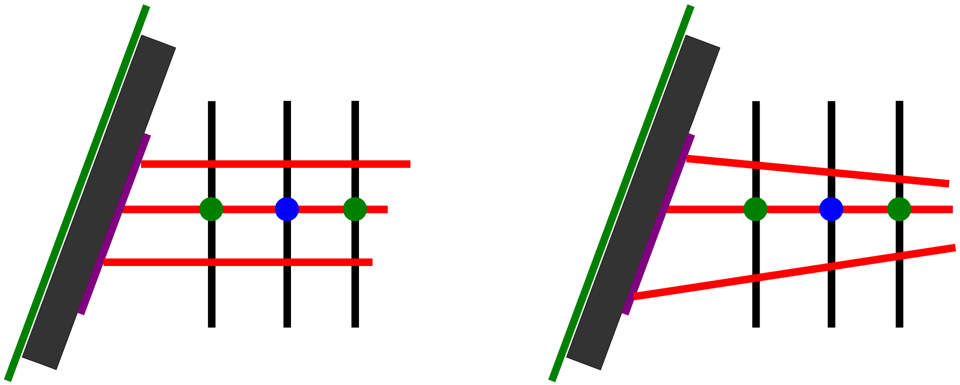




- 6 GeV e^+ beam.
- Triplet residuals:
  - 3 upstream planes,
  - hits in plane 0 and 2 form vector,
  - residual to hit in middle plane 1,
  - $\sigma_r = 4.2\ \mu m = \sqrt{(3/2)}\ \sigma_i$
  - $\boldsymbol{\sigma_i}$ **= 3.4 um**

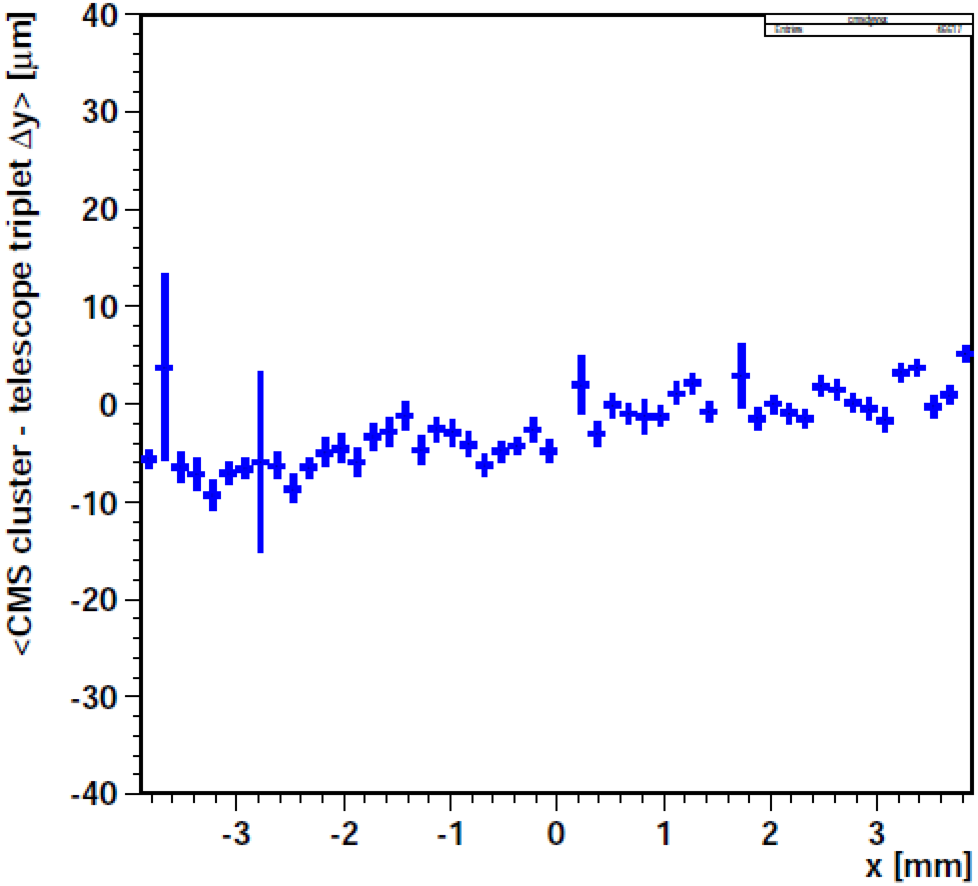
CMS pixel alignment w.r.t. telescope

- shift in x and y based on peak of residuals: `cmssxa`, `cmsdya`
- rotate by ϕ around z based on Δy vs x: `cmsdyvsx`
- adjust tilt angle α based on Δy vs y: `cmsdyvsy`
- adjust z shift based on Δy vs θ_y: `cmsdyvsty`
- to be automated:
  - include into telescope MillePede alignment, or
  - part of the general broken line track refit

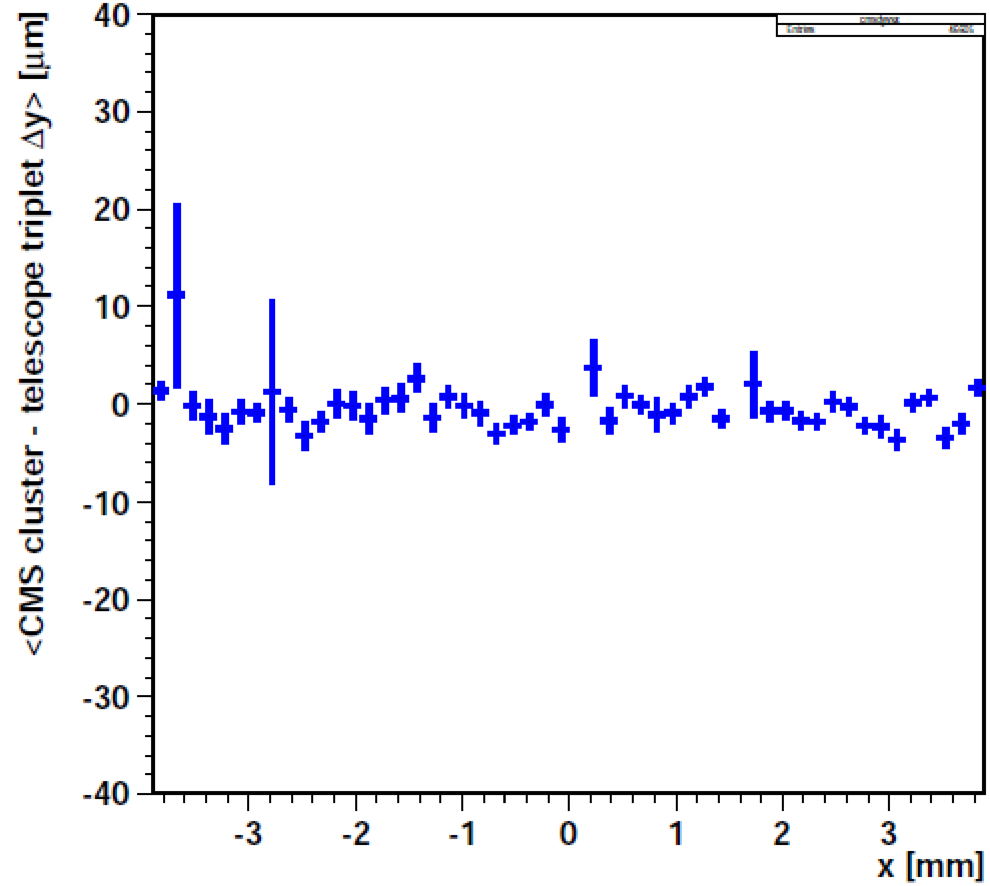


rotate pixel around *z*

ϕ = 20 mrad

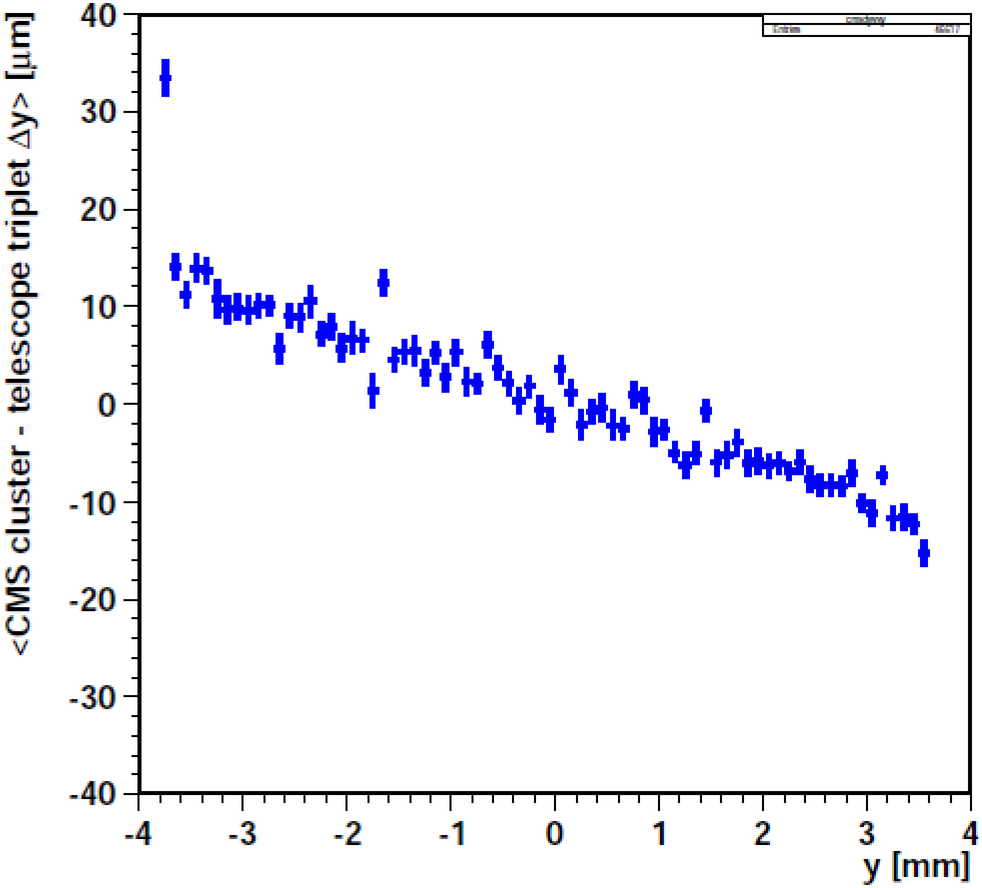


ϕ = 30 mrad

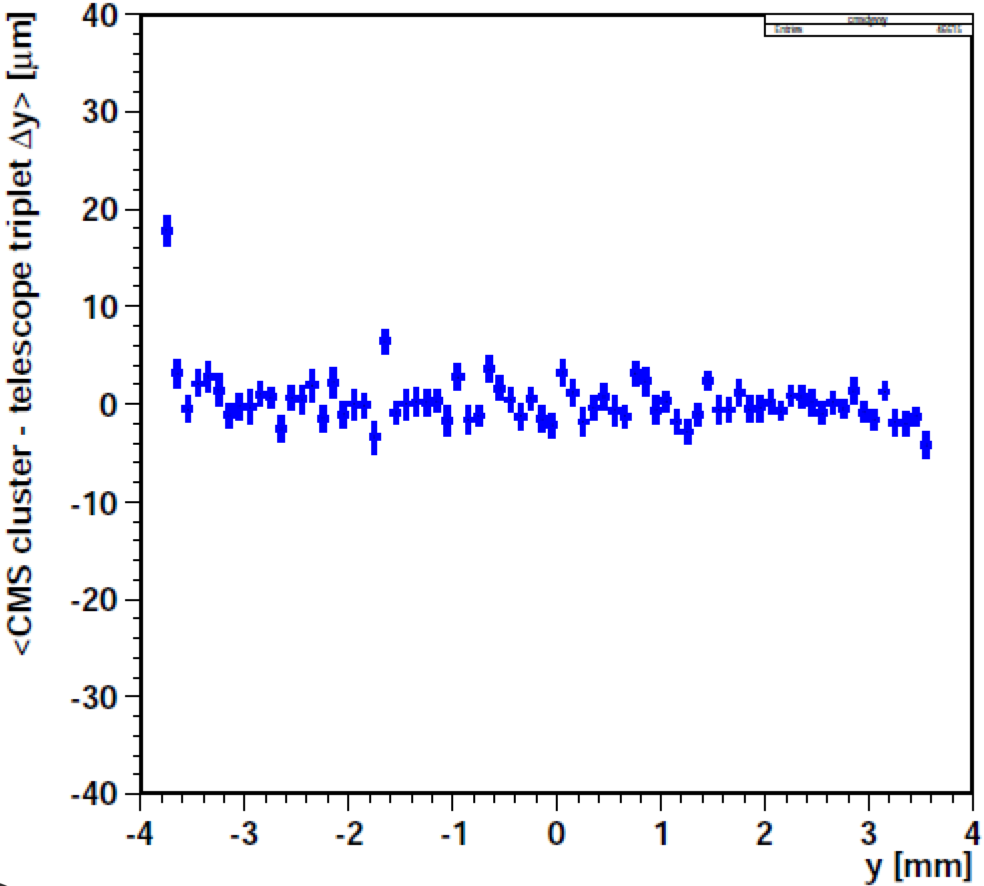


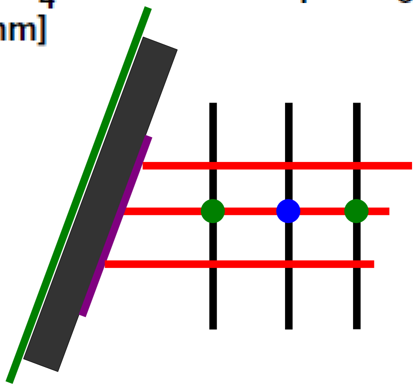
adjust tilt angle

α = 20.5°



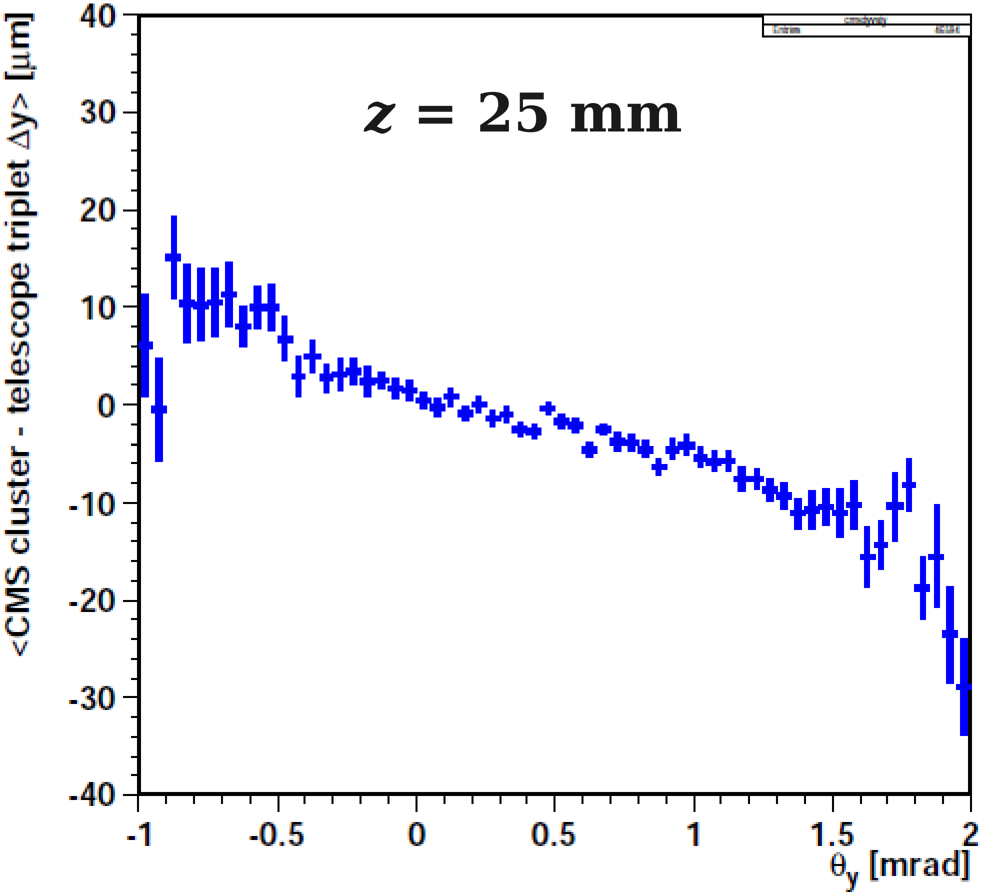
α = 20.0°

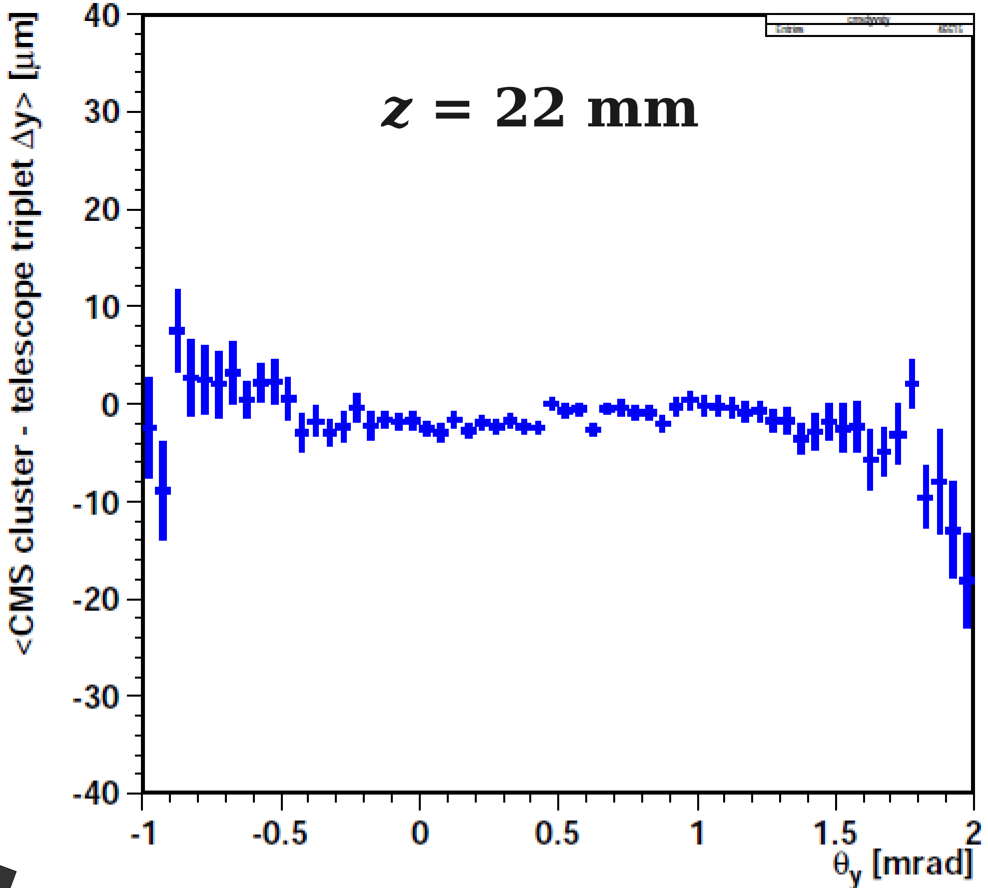


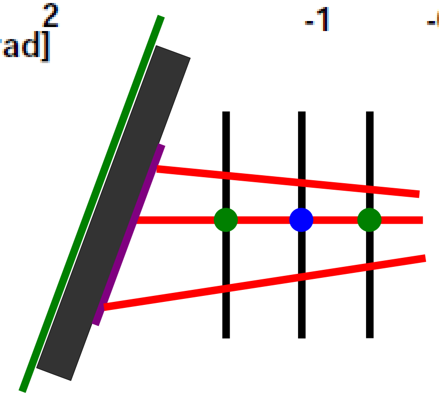


adjust z shift

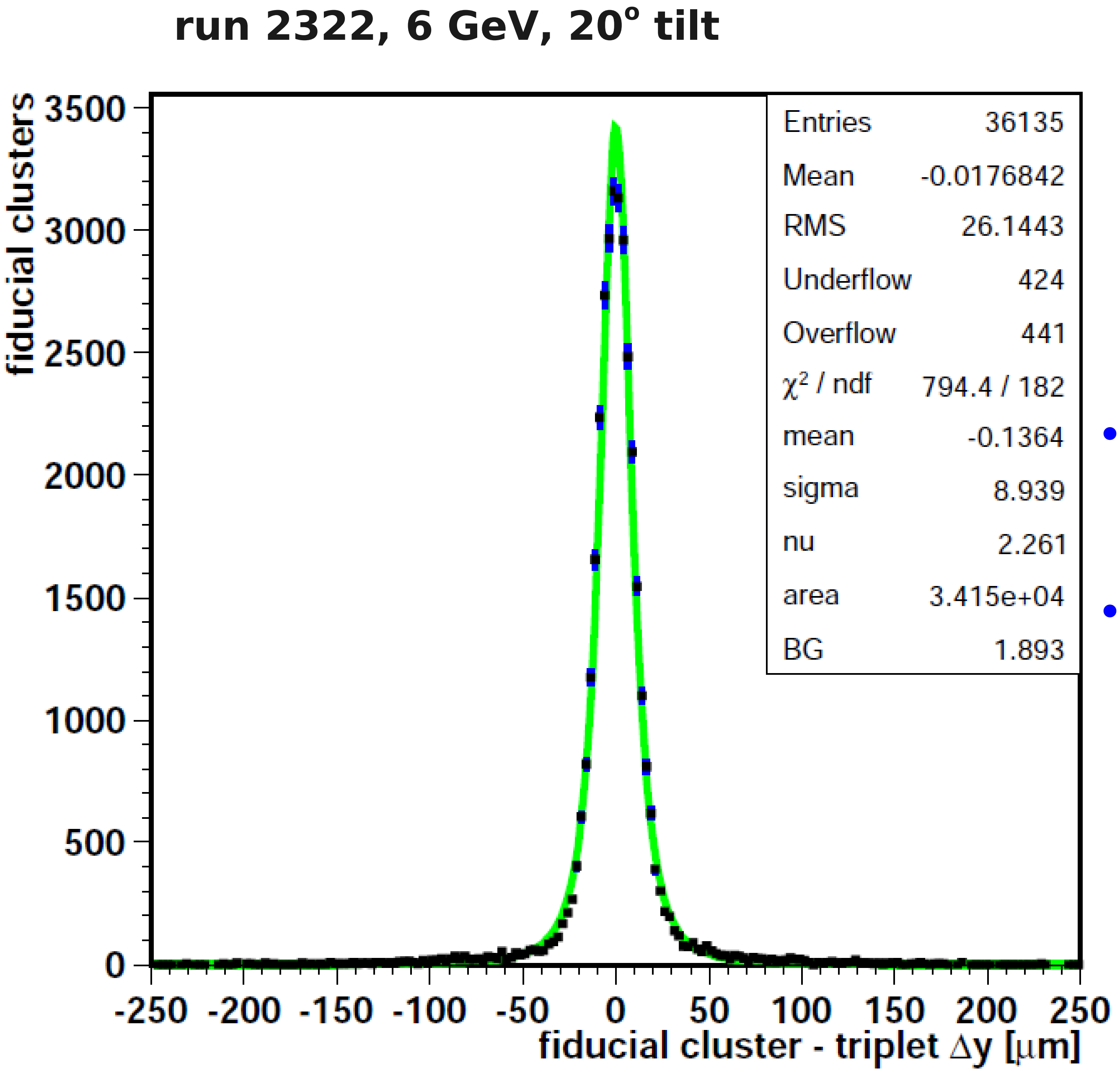
z position of CMS pixel w.r.t. telescope plane 2

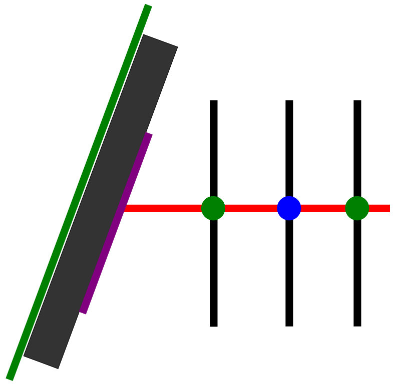






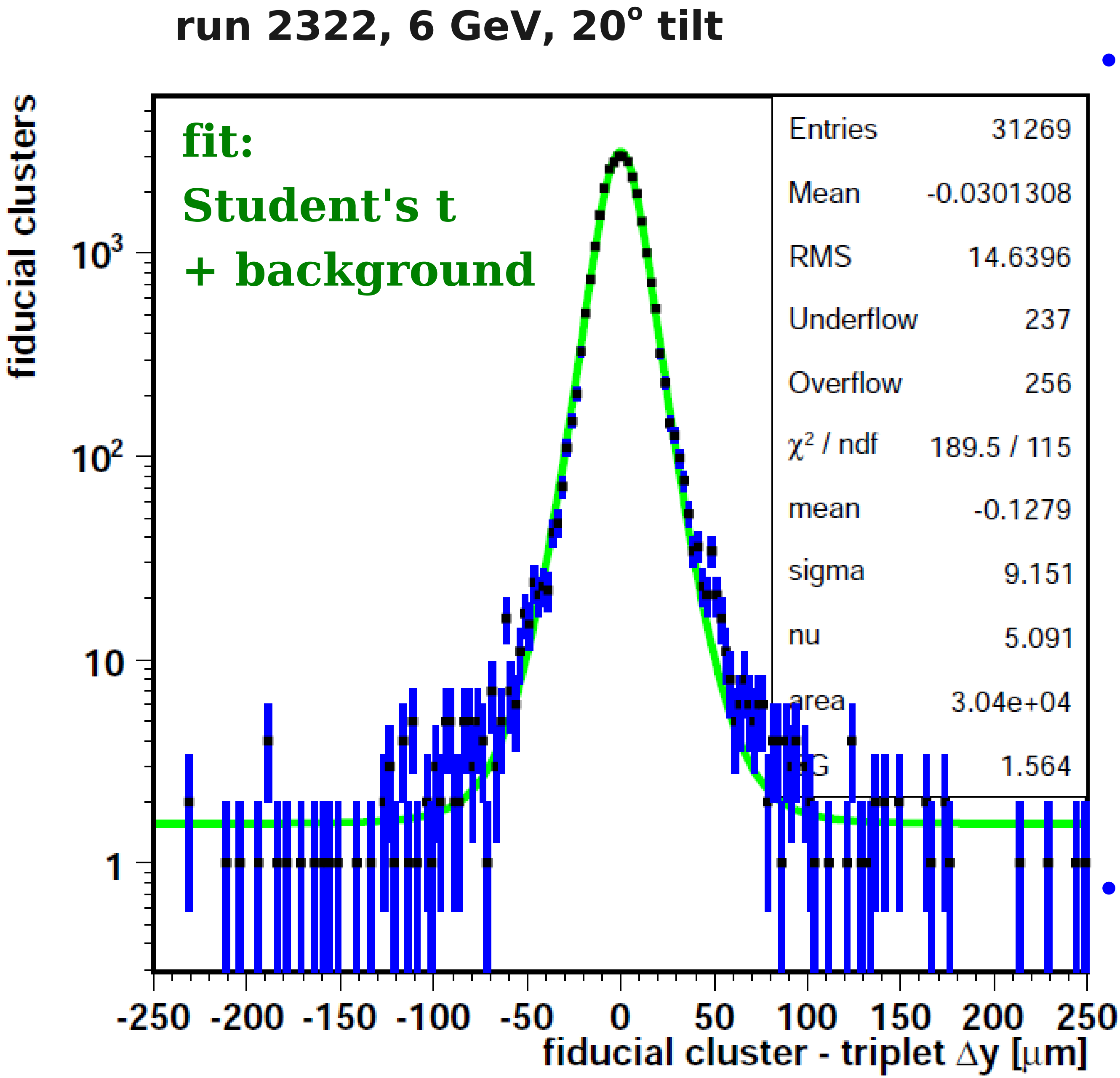
CMS pixel row resolution





- Vertical = rows
  - CMS pixel = 100 μm.
- Residual:
  - σ = 9 μm,
  - telescope extrapolation: 4.5 μm,
  - **CMS resolution: 8 μm.**

CMS pixel residual distribution



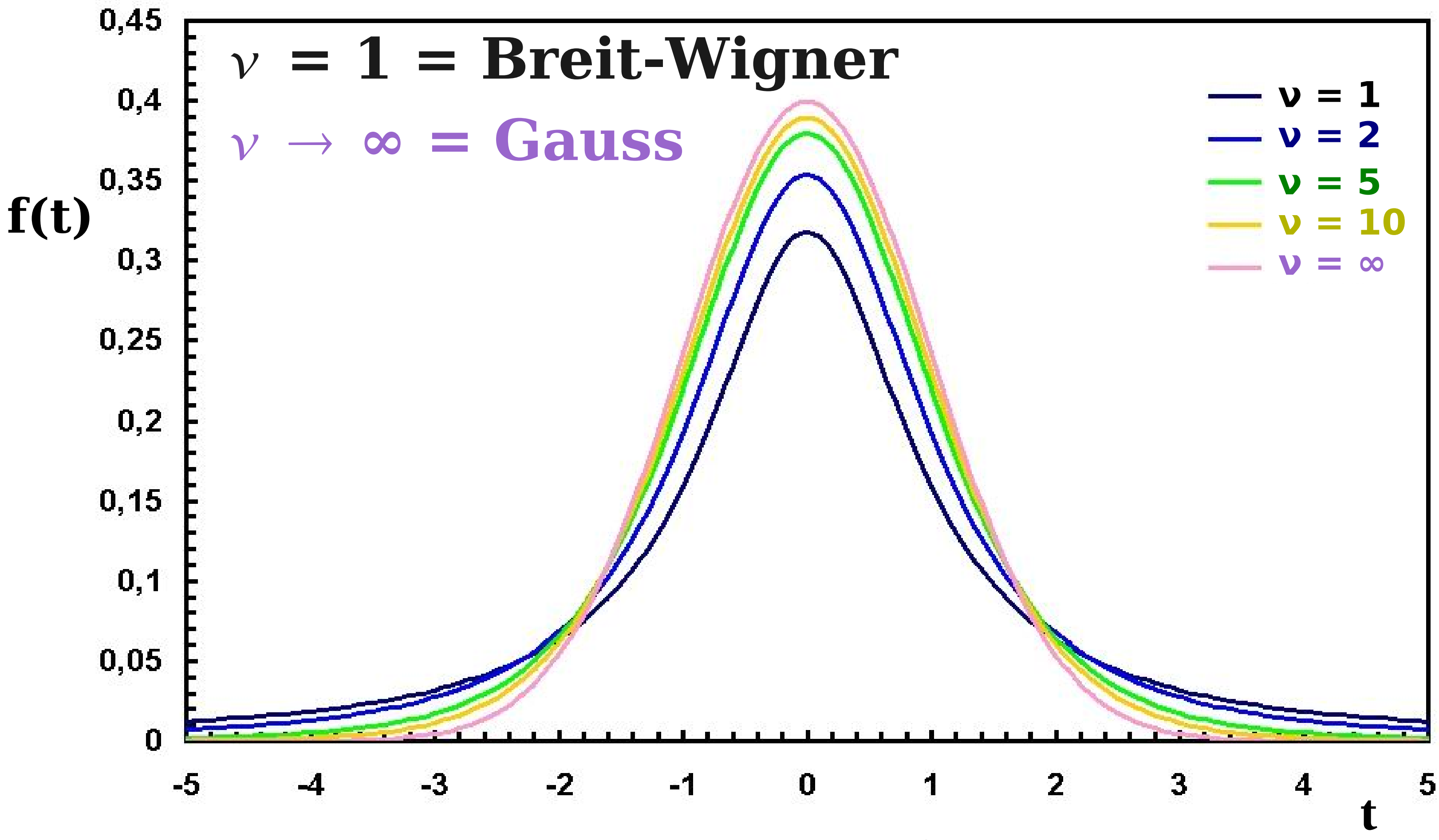
- cleaning cuts:
  - cluster one pixel away from edges and dead columns,
  - $|\Delta x| < 0.15$ mm,
  - only 1- and 2-row clusters (against δ-rays)
  - cluster charge > 18 ke (against wrong timing),
  - | track angle | < 2 mrad (against scattering).
- Result:
  - less tails, more Gaussian

Fitting peaks with Student's *t*

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

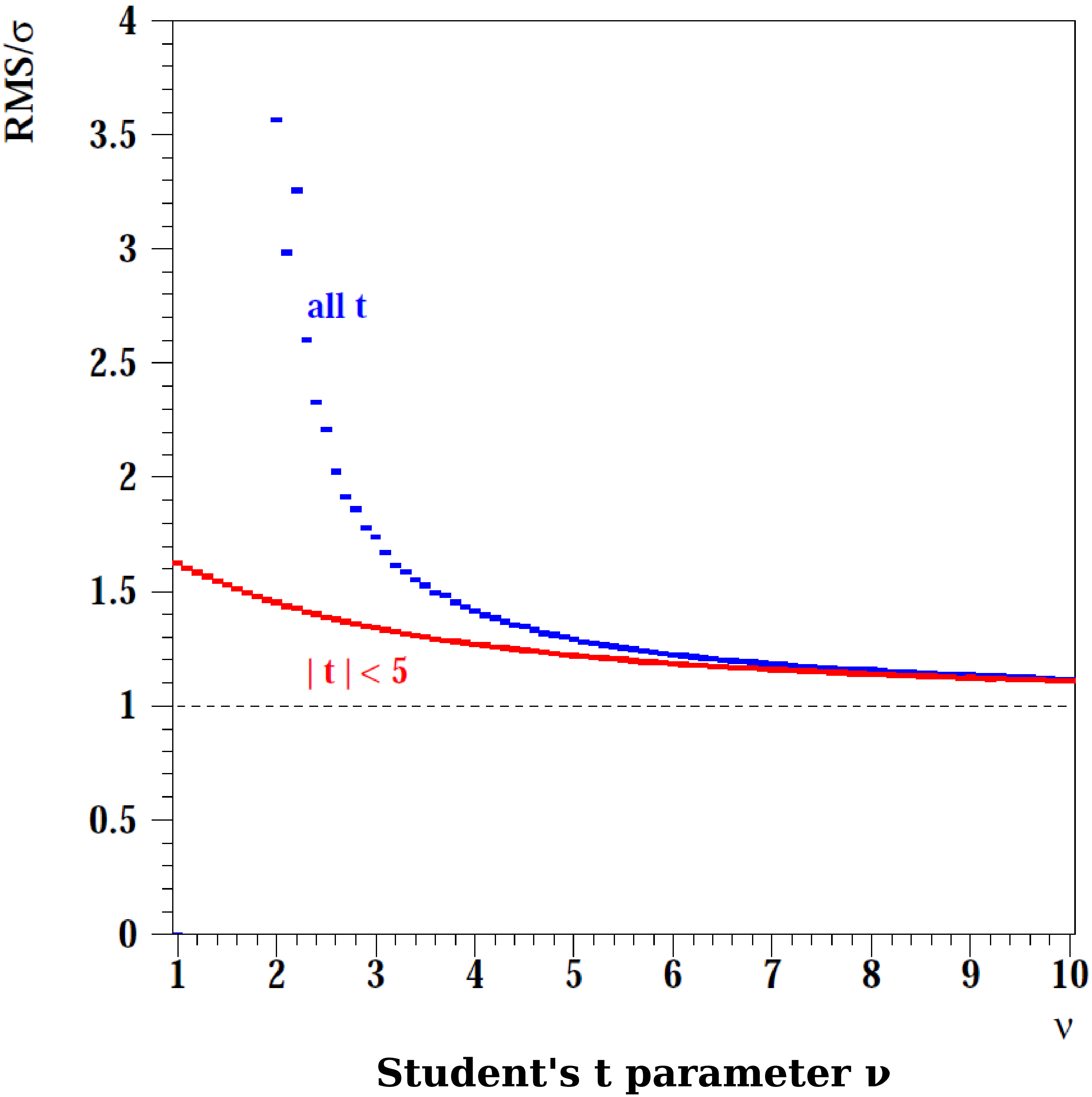
$$\boxed{f(t) = \frac{\Gamma((\nu+1)/2)}{\sqrt{\nu\pi}\,\Gamma(\nu/2)}(1+t^2/\nu)^{-(\nu+1)/2}}$$

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



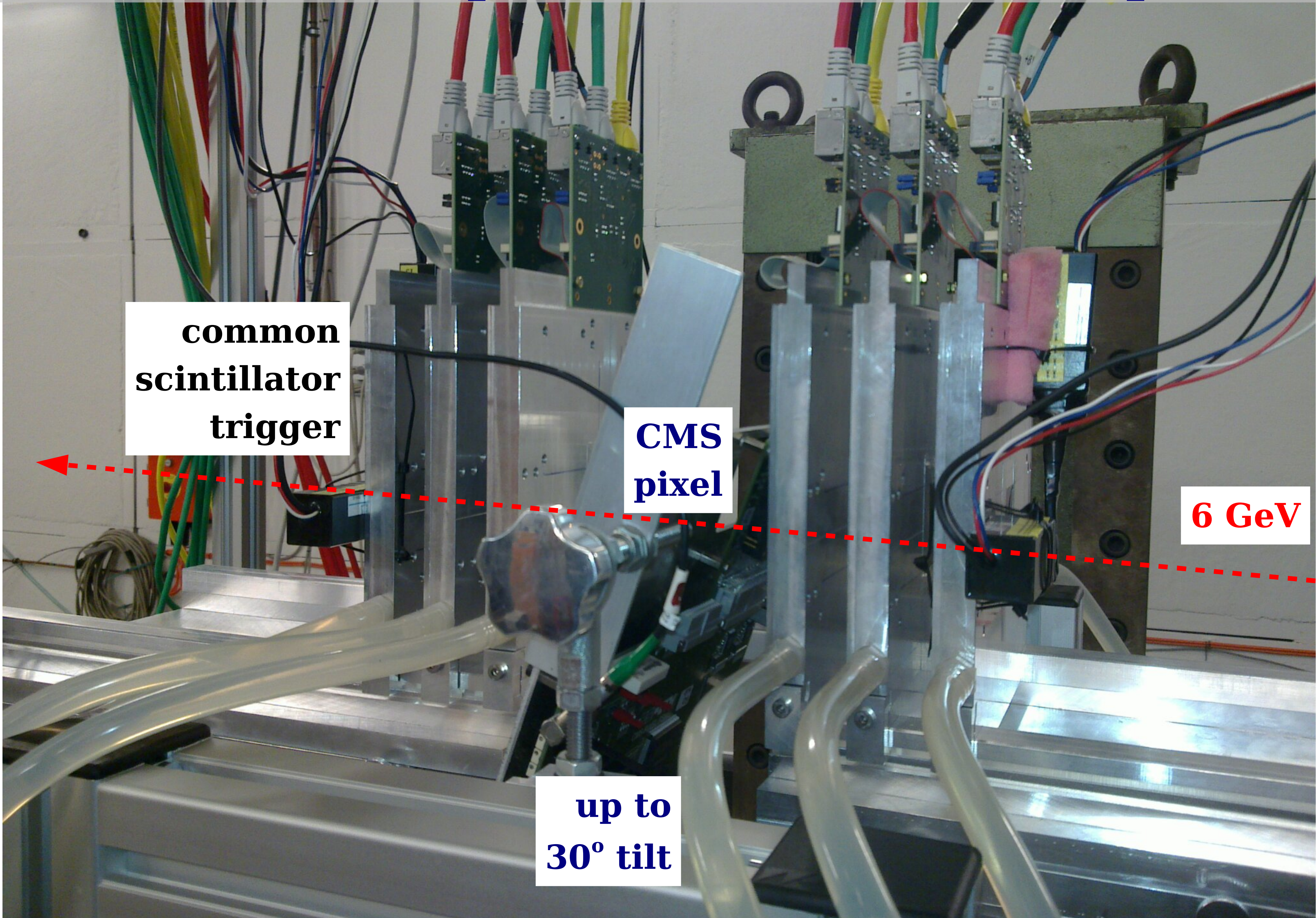
Parameter ν interpolates between Gaussian and Breit-Wigner.

rms/σ for Student's t

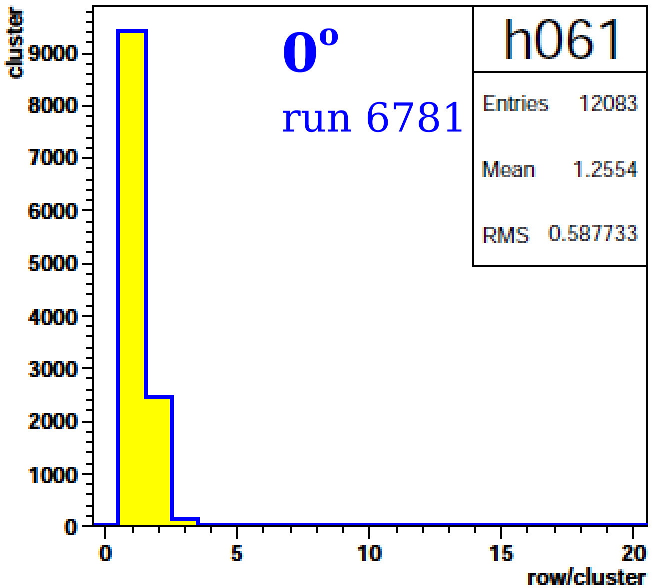


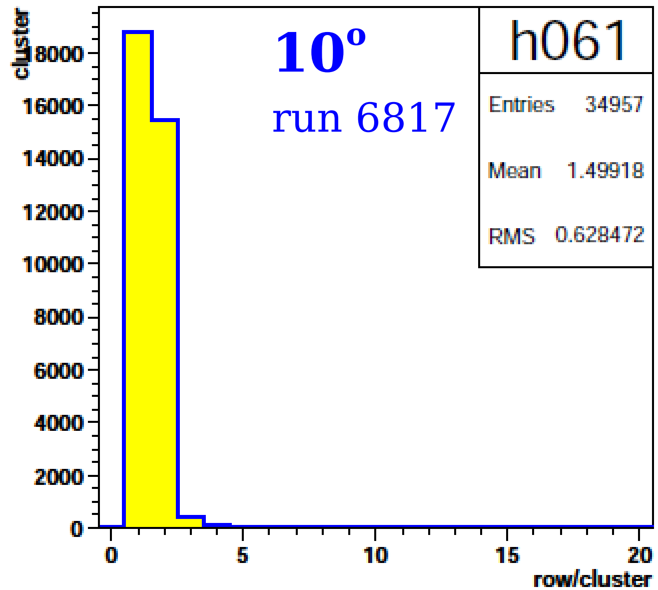
- Generate random numbers according to Student's t for different ν (see W. Hoermann, Computing 81 (2007) 317).
- calculate rms:
  - for all t. (rms diverges for $\nu = 1$).
  - for | t | < 5. (rms stays below 1.62 for all $\nu \geq 1$).
- Asymptotic value (rms/σ = 1) slowly approached.

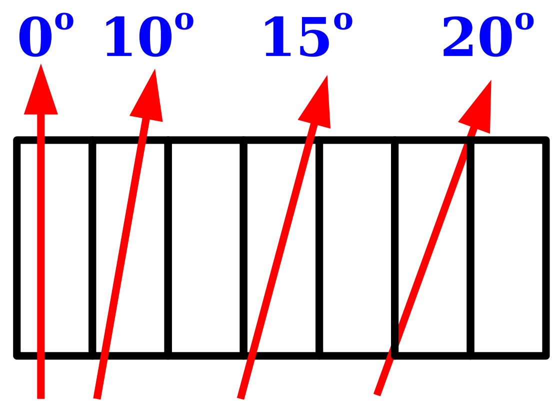
Tilted CMS pixel in the EuTelescope



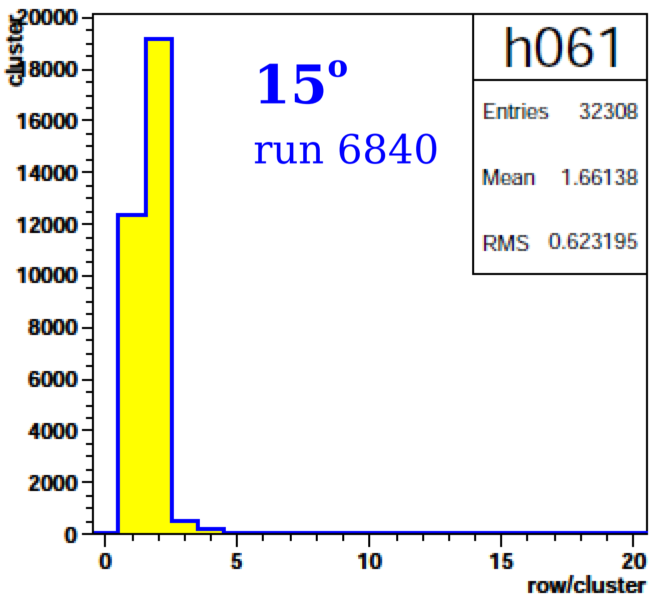
cluster size vs tilt angle

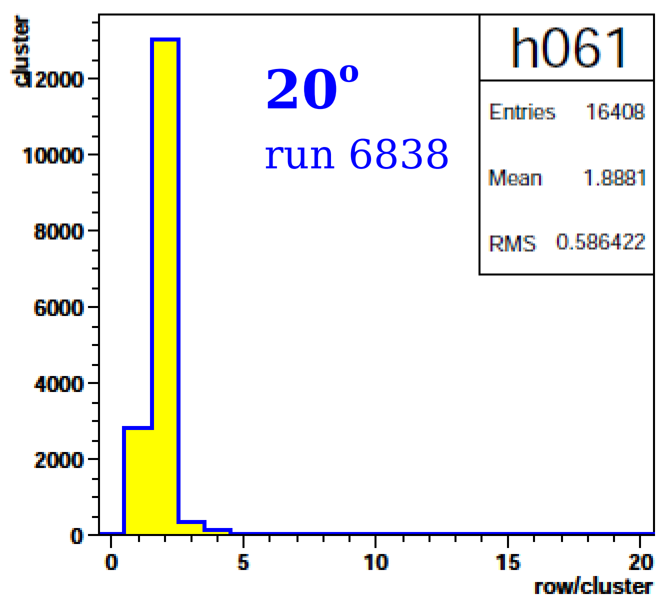


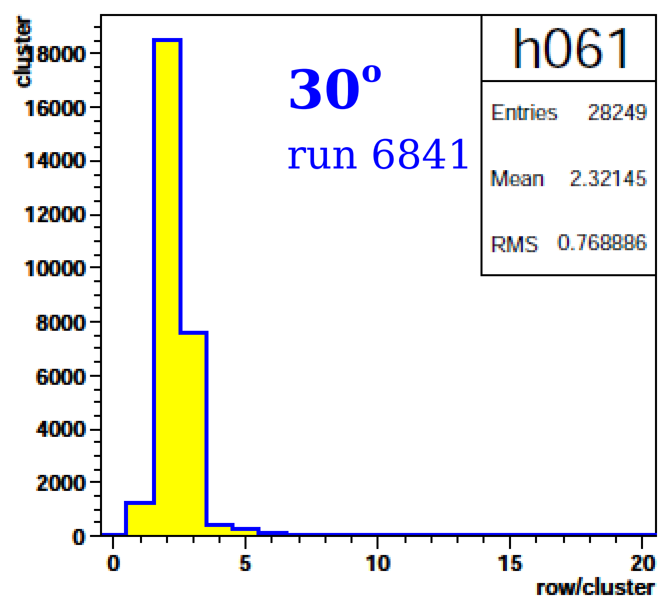




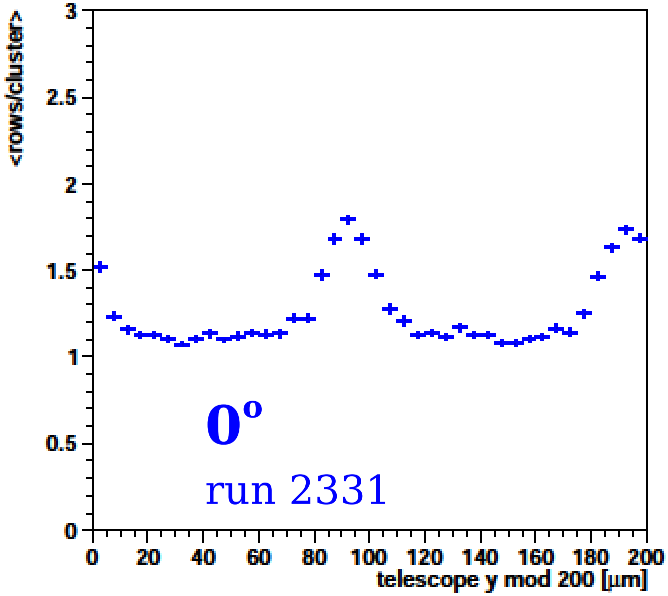
atan(100/285) = 19.3°

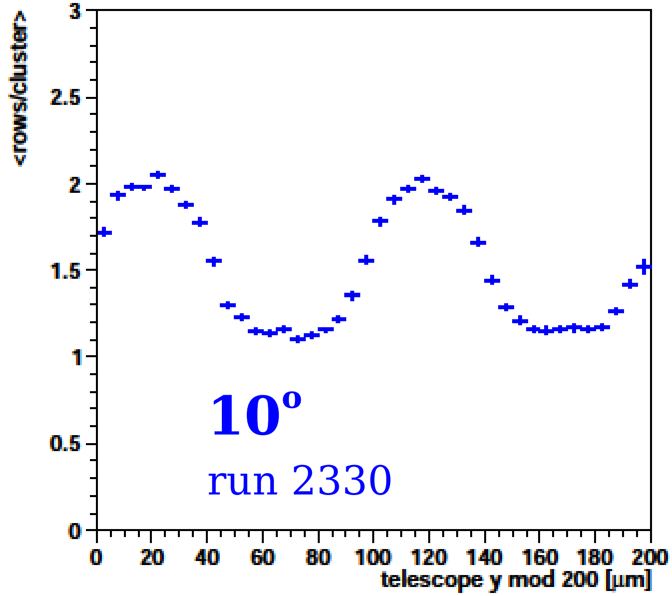


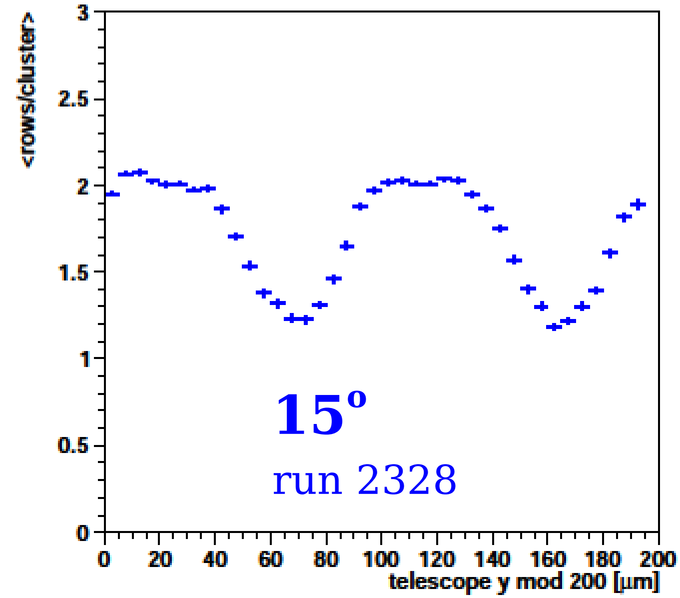




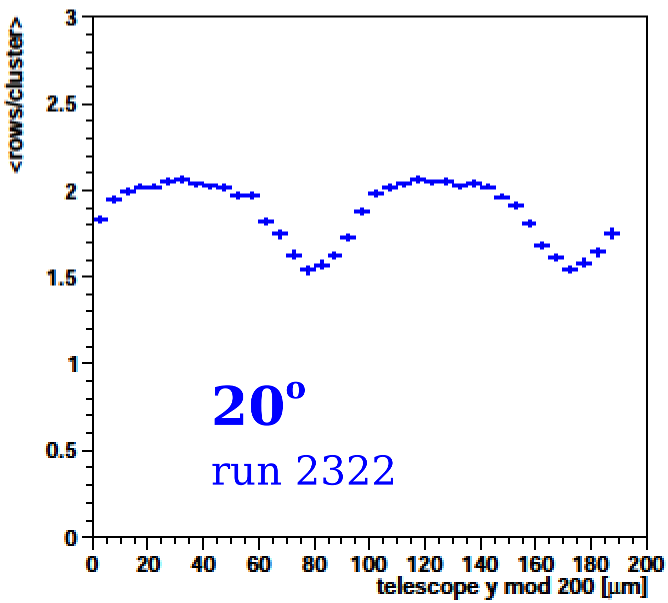
cluster size vs impact point and tilt angle

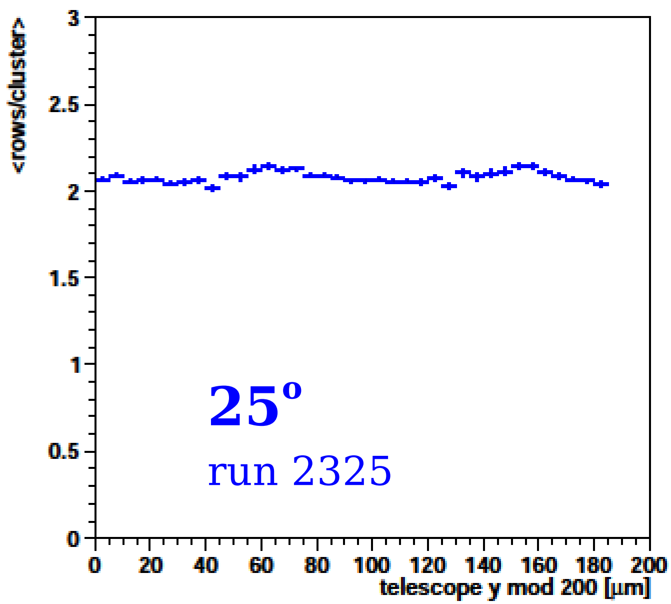


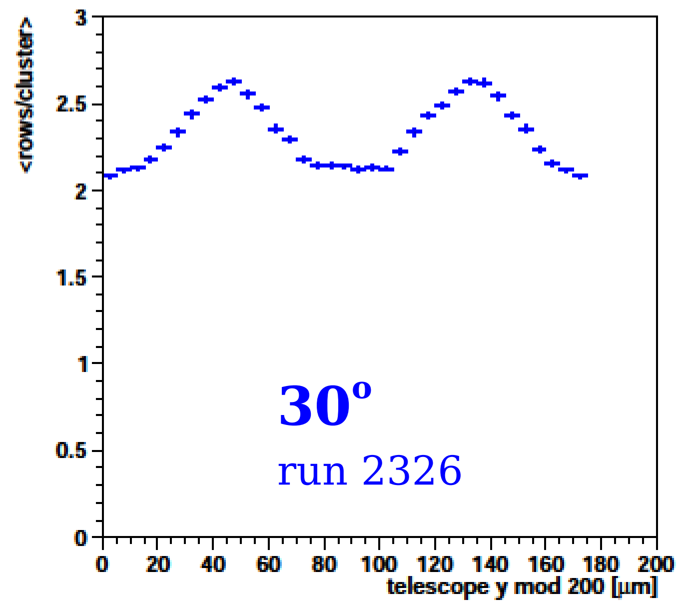




y_{impact} mod 200 μm: 2 pixels

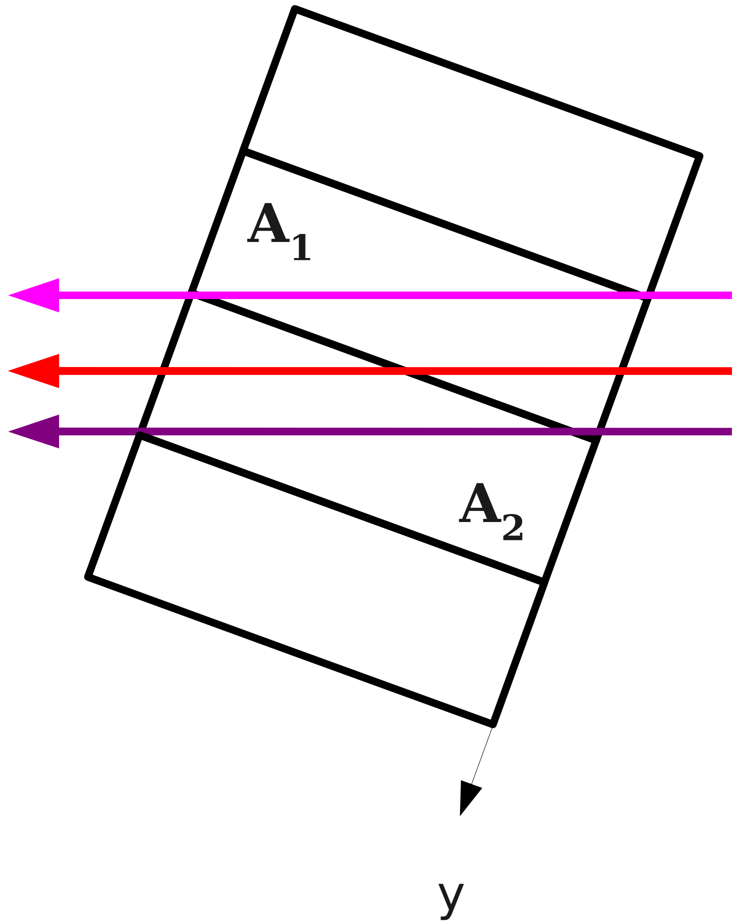






charge sharing: η

at 20°:



$$\eta = (A_1 - A_2) / (A_1 + A_2)$$

1.0

0.0

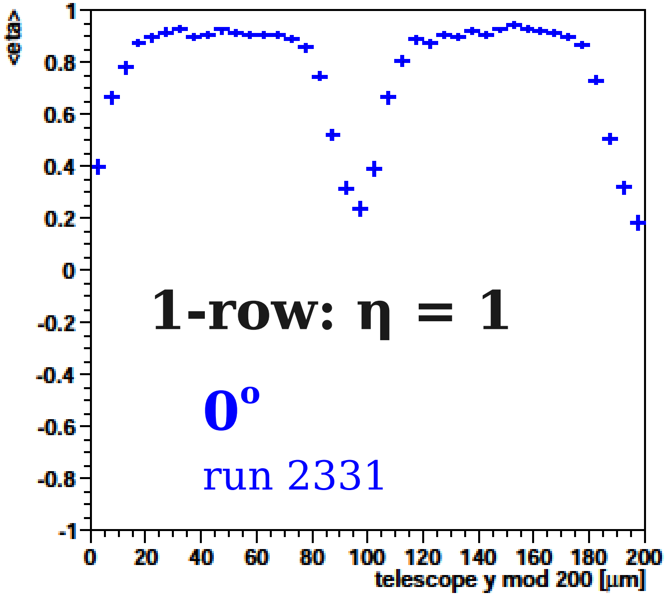
(-1.0)

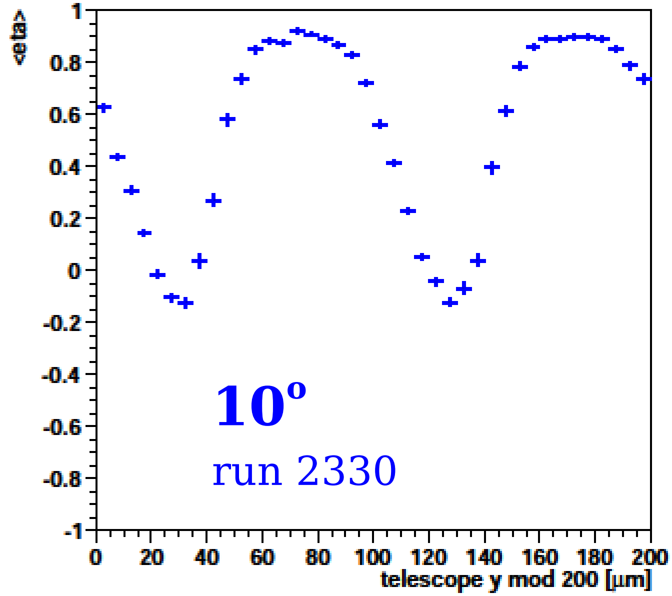
1-row clusters have η = 1.

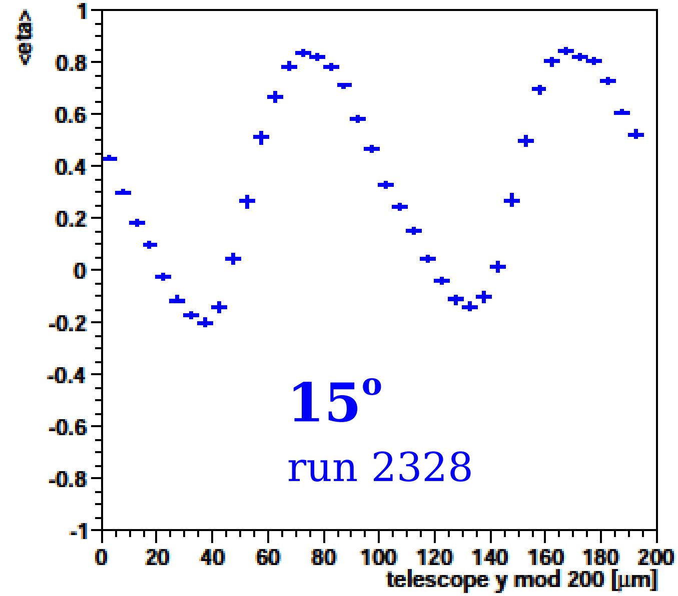
ideal:
linear η vs y
(saw tooth)

deviations:
- **diffusion**
- **thresholds**
- **trapping**
- **delta-rays**

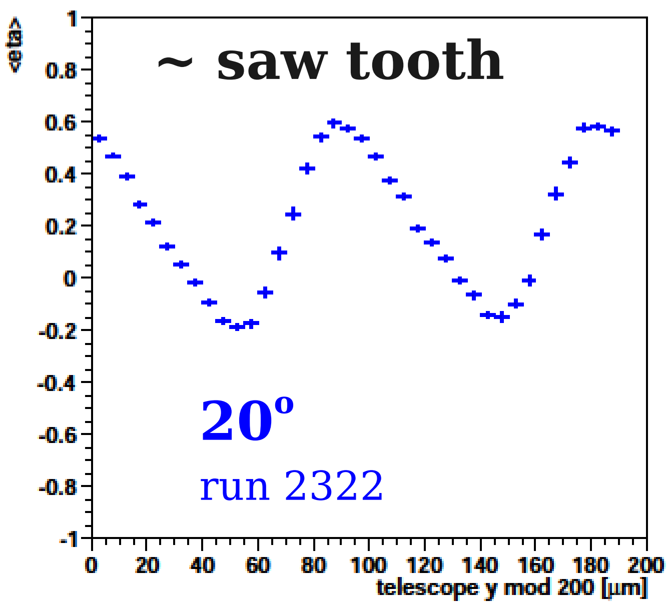
charge sharing vs tilt angle

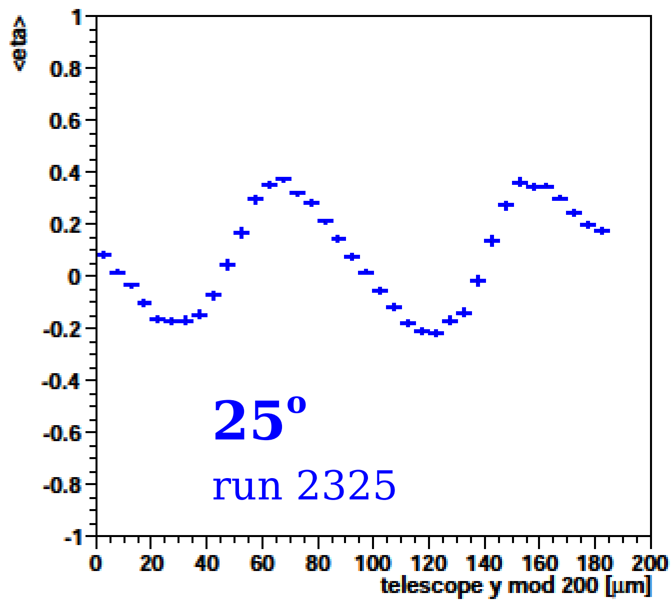


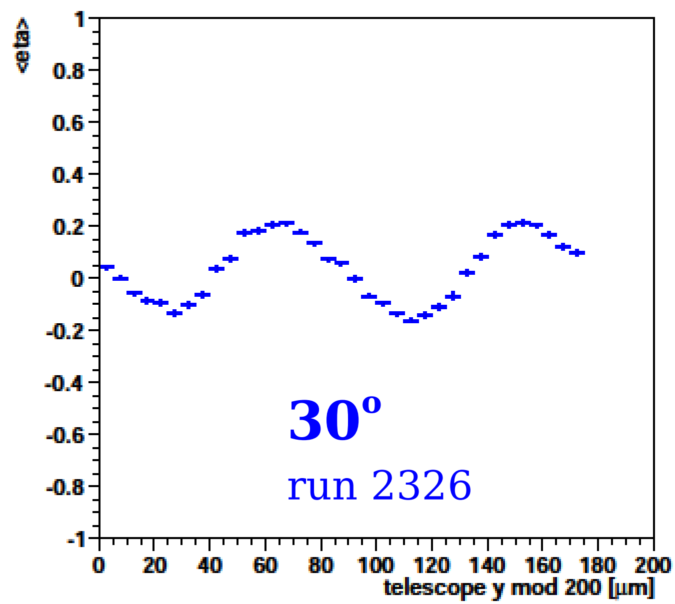




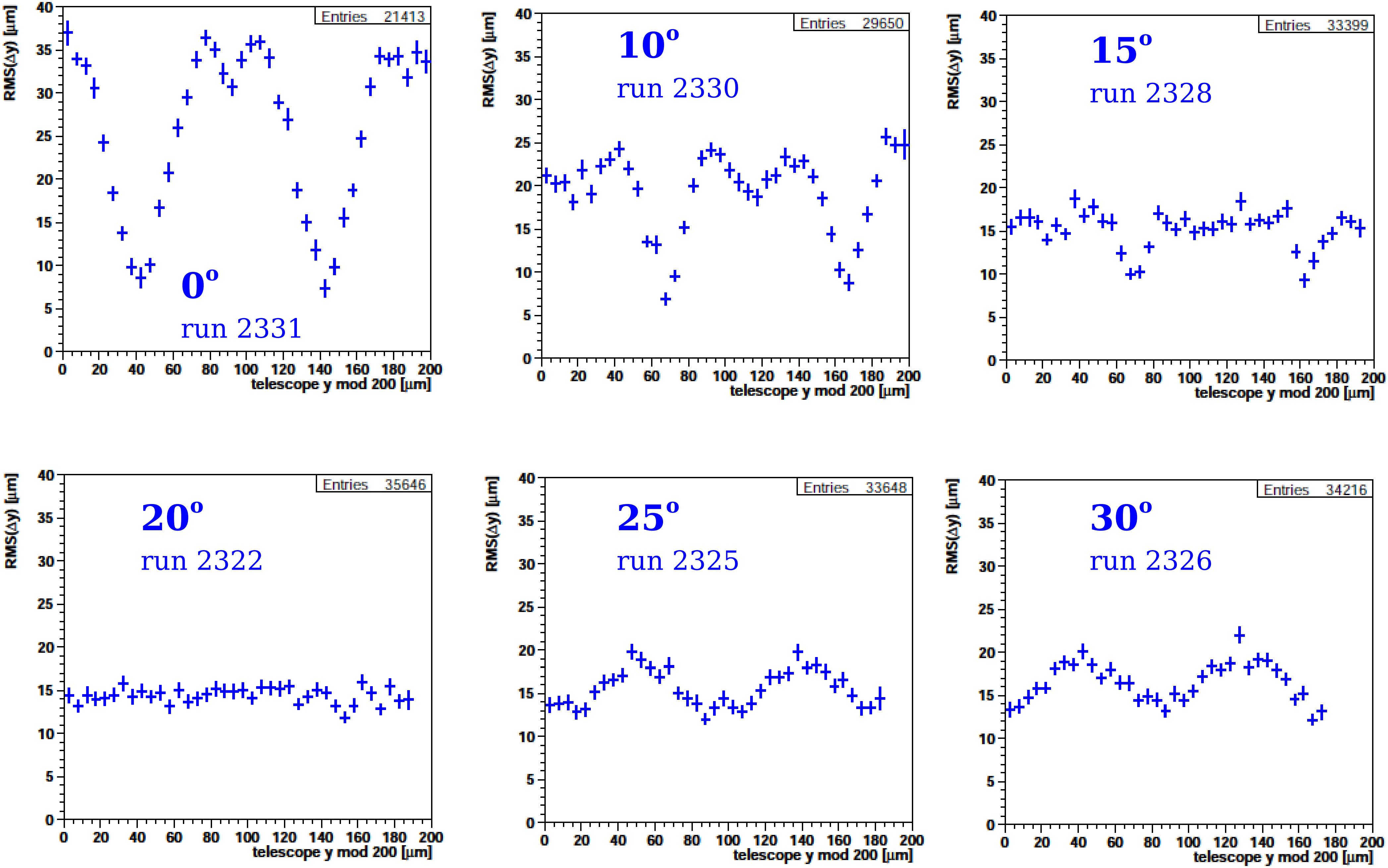
y_{impact} **mod 200 µm: 2 pixels**



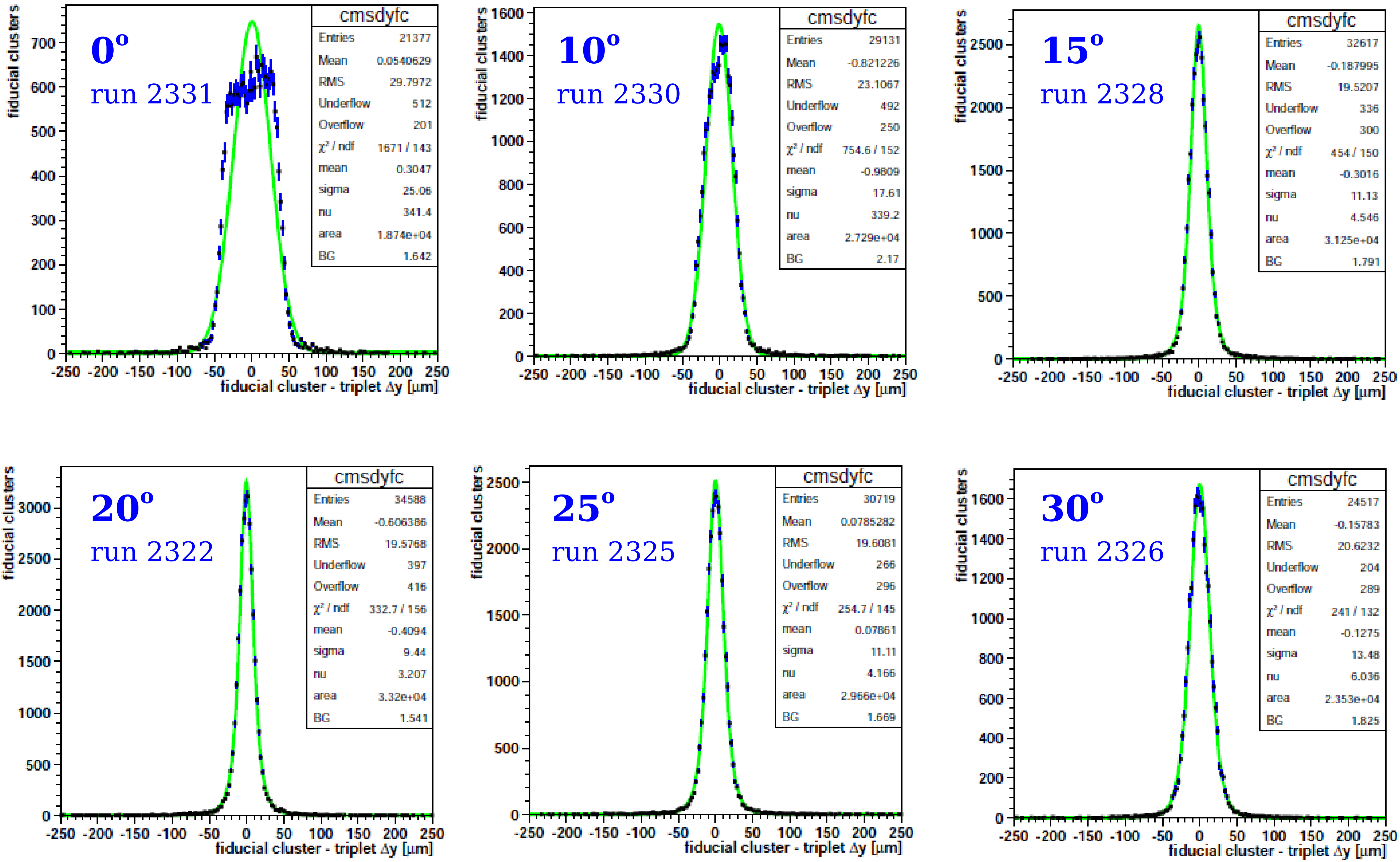




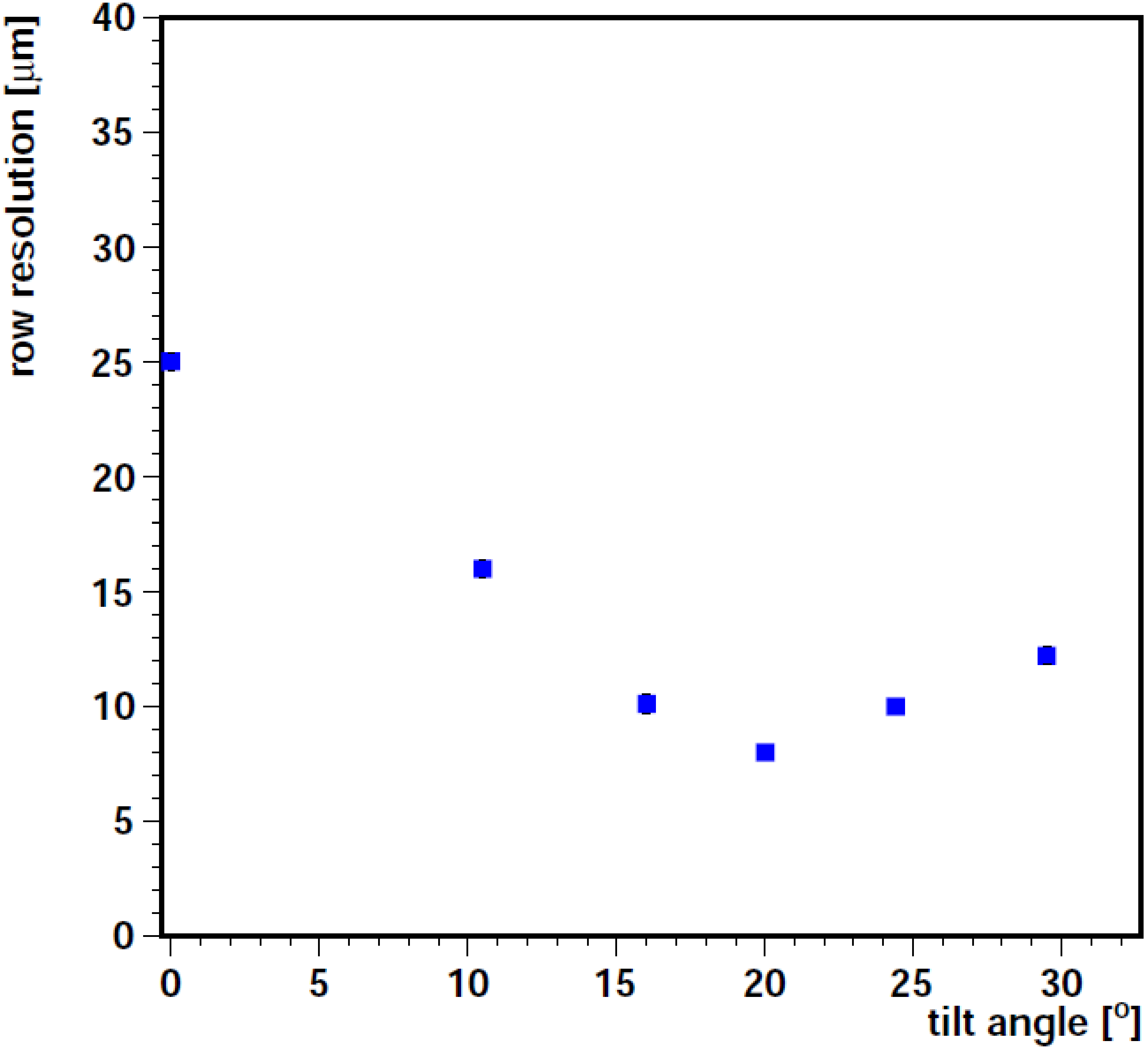
resolution profile vs tilt angle

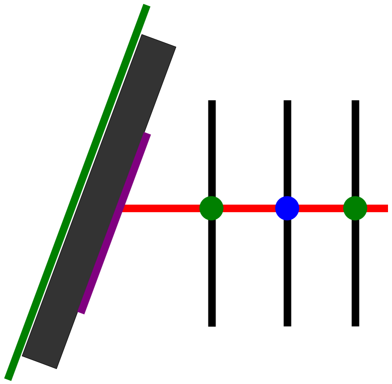


CMS pixel resolution vs tilt angle



CMS pixel row resolution vs tilt angle



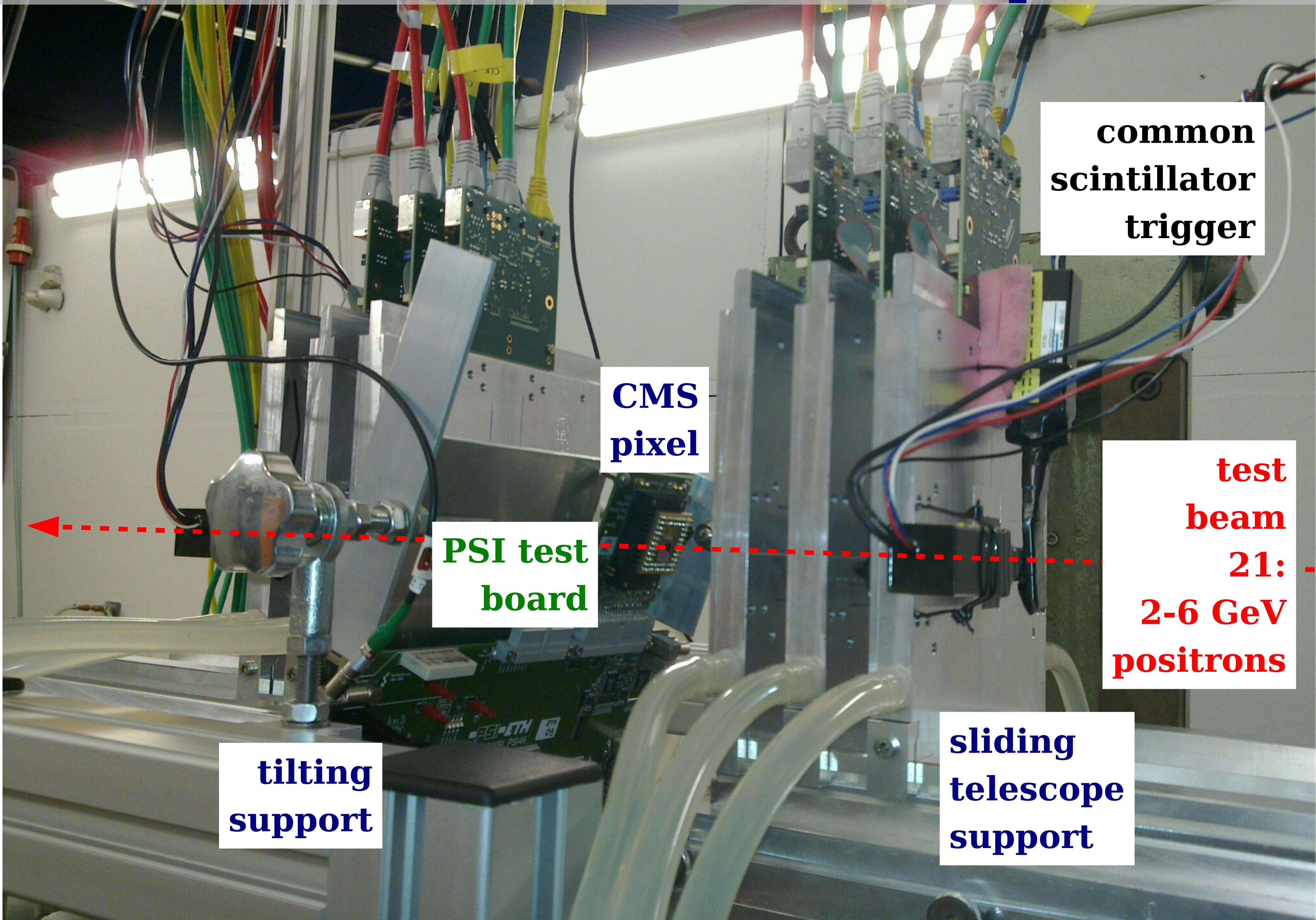


- 6 GeV, telescope extrapolation uncertainty subtracted.
- row pixels = 100 μm.
- Binary:
  - $\sigma = 100 / \sqrt{12} = 29$ μm
- Optimal angle 19°:
  - $\sigma = 8$ μm.

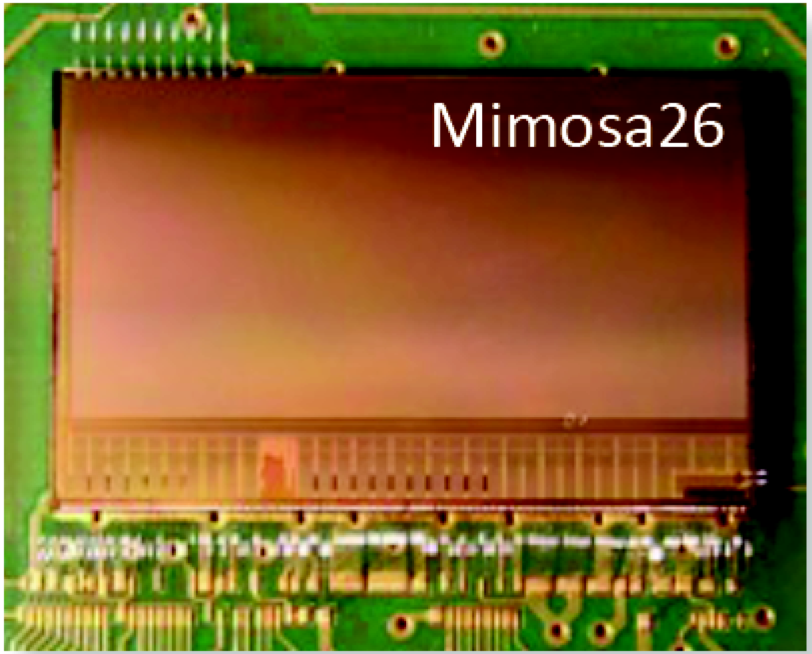
Summary

- CMS pixel sensor aligned in the EUDET beam telescope.
- CMS pixel resolution measured as function of tilt angle:
  - Optimal resolution 8 µm at 20^{o},
  - charge sharing appears almost linear at 20^{o},
  - can we improve on the simple center-of-gravity cluster algorithm?
  - CMS uses template matching.
- Expect further improvements from the new ROC:
  - lower threshold
  - less 1-row clusters
  - even better resolution

CMS Pixel with EuTelescope



Mimosa26 ILC pixel chip



- Mimosa26 monolithic active pixel sensors (Strasburg, 2009):
- thinned to 50 µm,
- 18.4×18.4 µm^2 pixel size,
- $1152 \times 576 = 663$k pixels,
- 10.6×21.2 mm^2 active area,
- binary readout,
- integration time 115 µs.

EuTelescope software

step	data.format	constants
0. EUDAQ data taking: 900s	**native.bin,** e.g. 200 MB 500k triggers	
1. convert, find hot pixels: 70s	**raw.lcio,** e.g. 200 MB	**hotpixel.db**
2. clustering: 240s	**clusters.lcio,** e.g. 400 MB	**offset.db**
3. hits, coarse align: 250s	**hits.lcio,** e.g. 600 MB	**pre-align.db**
4. Millepede alignment: 12s	**pede.bin,** e.g. 120 MB	**align.db**
5. track fitting: 270s	**tracks.lcio,** e.g. 25 MB	

script `submit-all.sh run energy` by Armin Burgmeier

All steps produce ROOT histograms for monitoring.

Steps 1-5 require a geometry file defining the telescope.

Parameters are passed from xml files. Code in svnsrv cmspixelupgrade.