DESY beam test test results part II

Ganna Dolinska, Ievgen Korol, Hanno Perrey,
Daniel Pitzl, Simon Spannagel

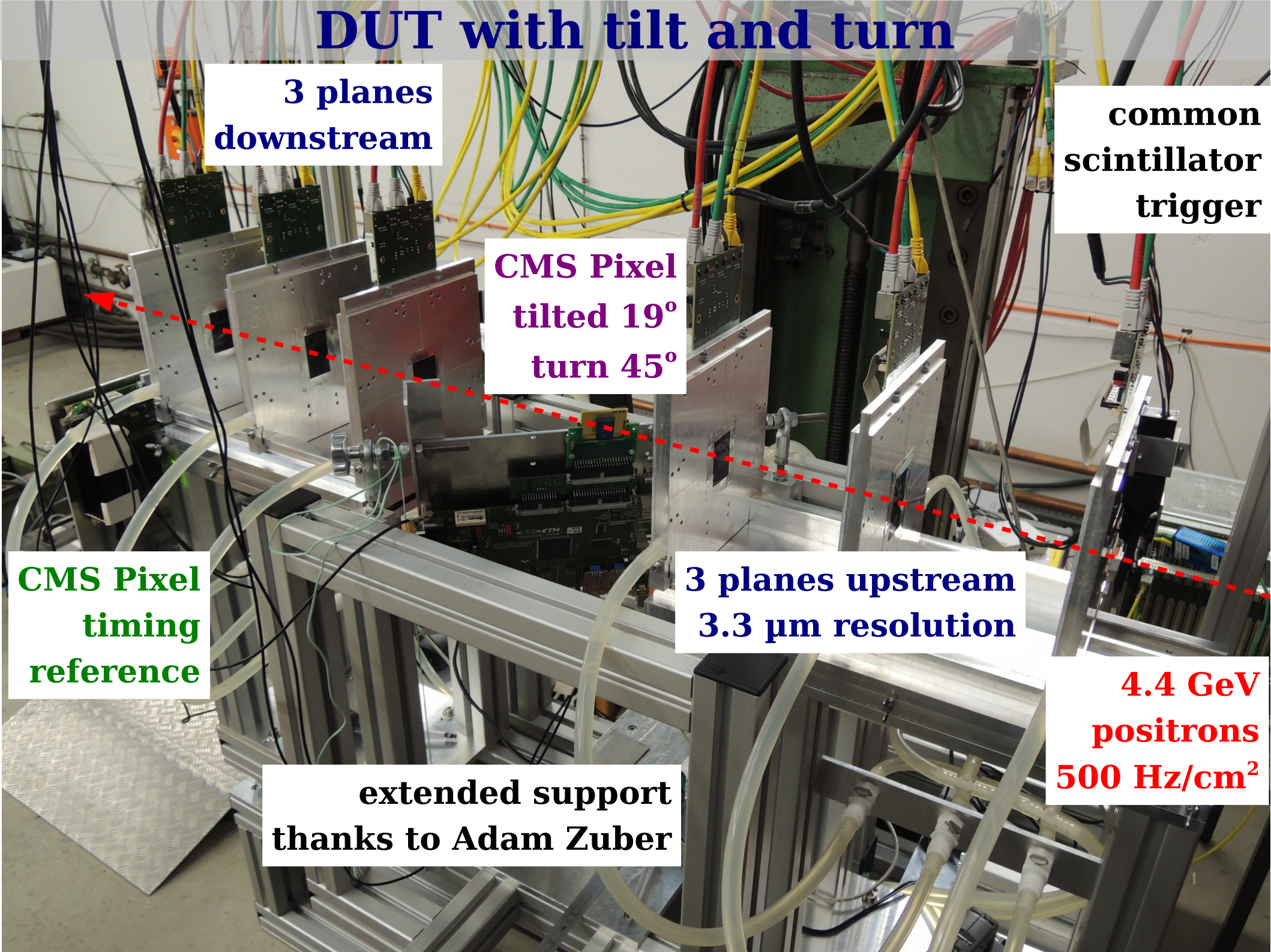
CMS Pixel Upgrade Plenary, 20.3.2013

- Setup improvements
- Column resolution with tilted and turned sensor
- Bias dot studies
- Threshold scans: tilt and turn
- Efficiency

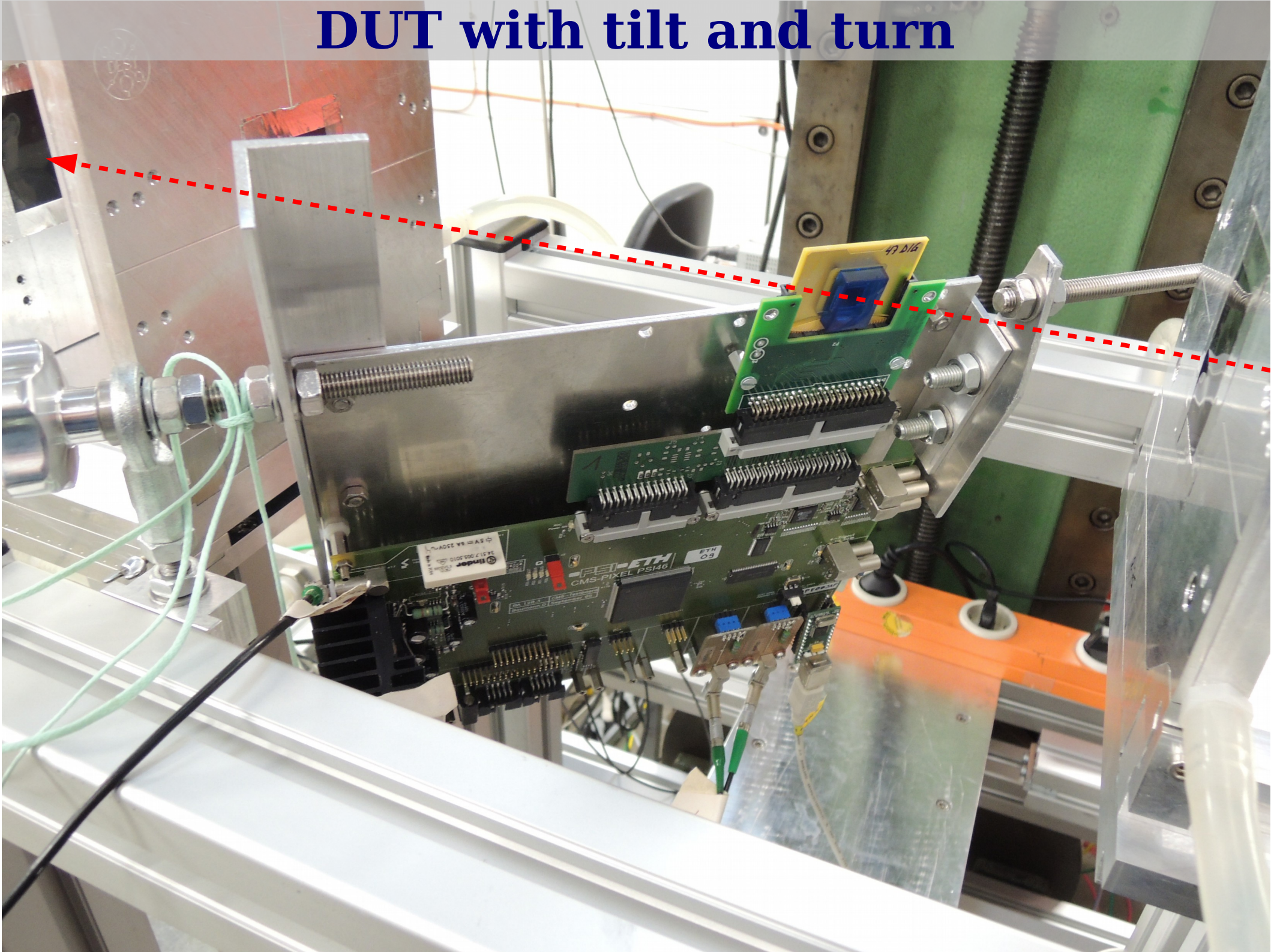
Improvements since Summer 2012

- Operate digital ROC at design analog current:
  - tune, trim, and operate at 25 mA (PSI default)
  - Aug and Sep beam test was done at 30-35 mA (relic of xdb problem)
  - in CMS: 35 mA/ROC is the power supply limit
- Operate at lowest threshold:
  - trim 24 = 1.2 ke, without noise; trim 22 becomes noisy
- More psi46dig chips (thanks to PSI for preparing):
  - 39, 47, 205

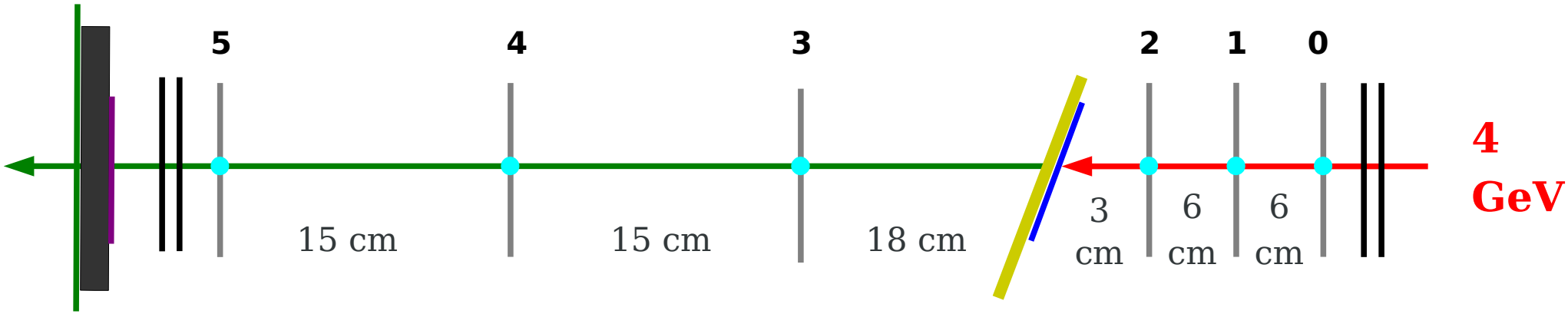
DUT with tilt and turn



DUT with tilt and turn

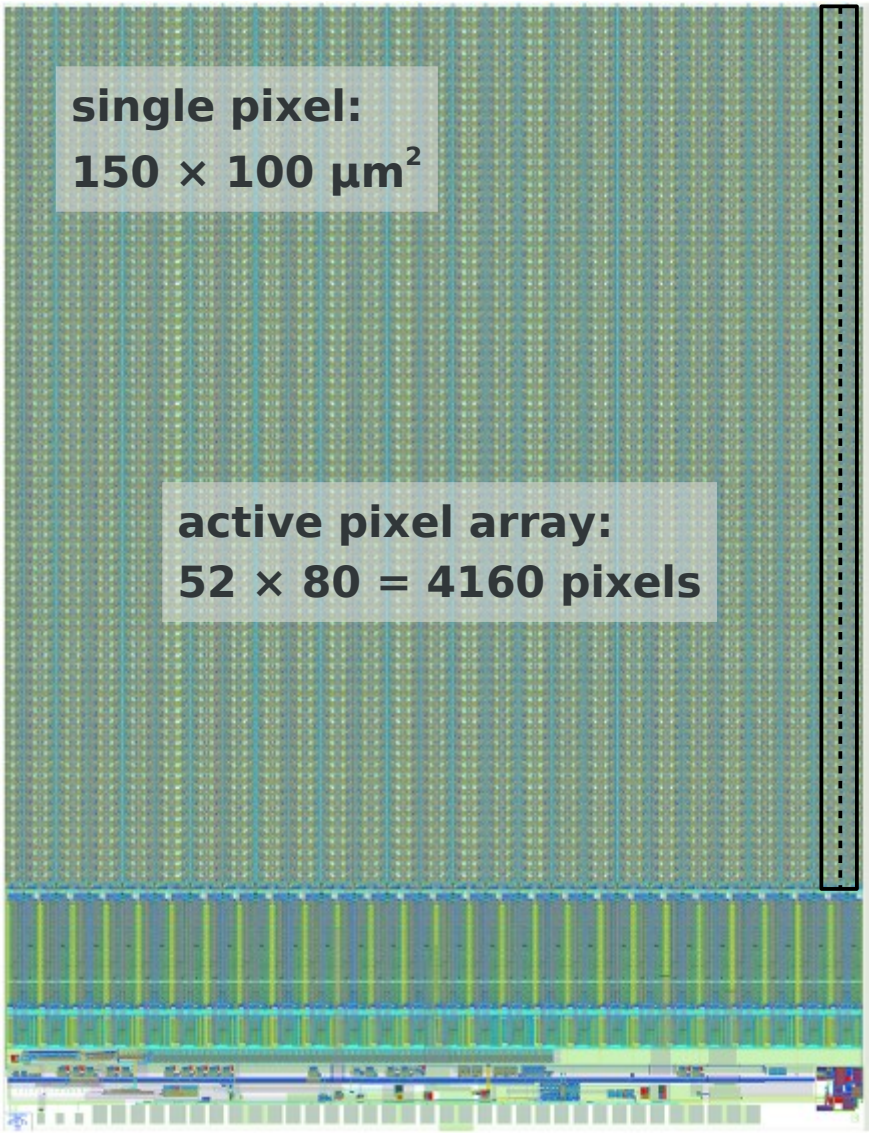


test beam set up

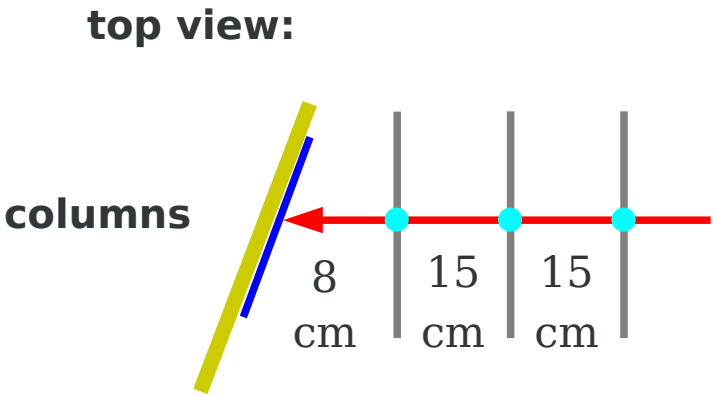


- Upstream arm 0-1-2:
  - as close as possible to DUT: 4.8 µm extrapolation error (at 4 GeV)
- DUT = single chip module, tilted by 19.3° = atan(100 µm / 285 µm)
- Downstream arm 3-4-5:
  - equally spaced between DUT and REF
- REF = single chip module for timing, as close as possible behind scint
- trigger: 4-fold scintillator coincidence, 2×1 cm^2 area

psi46dig pixel readout chip

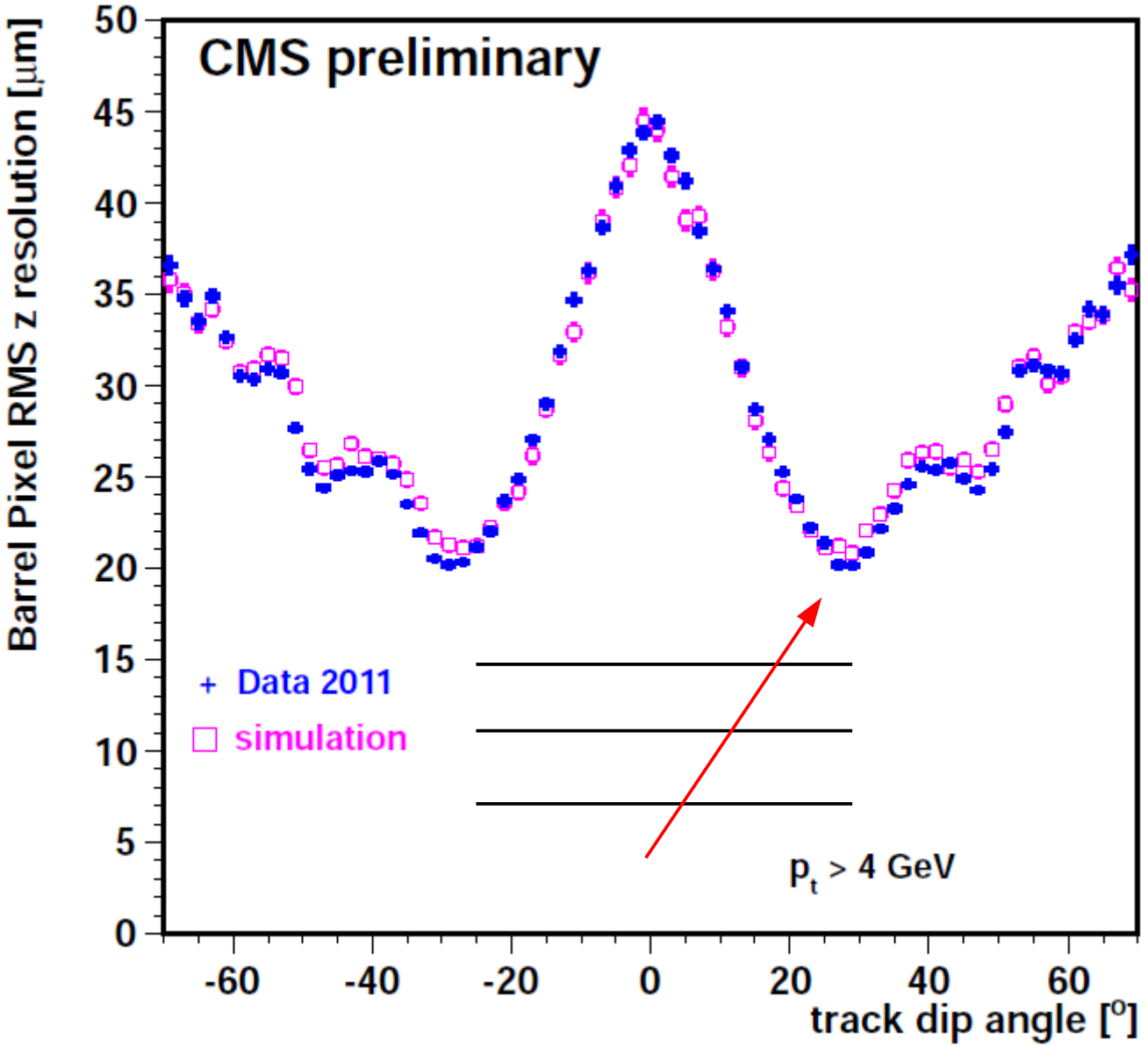


Turn Angle Scan: Column Resolution

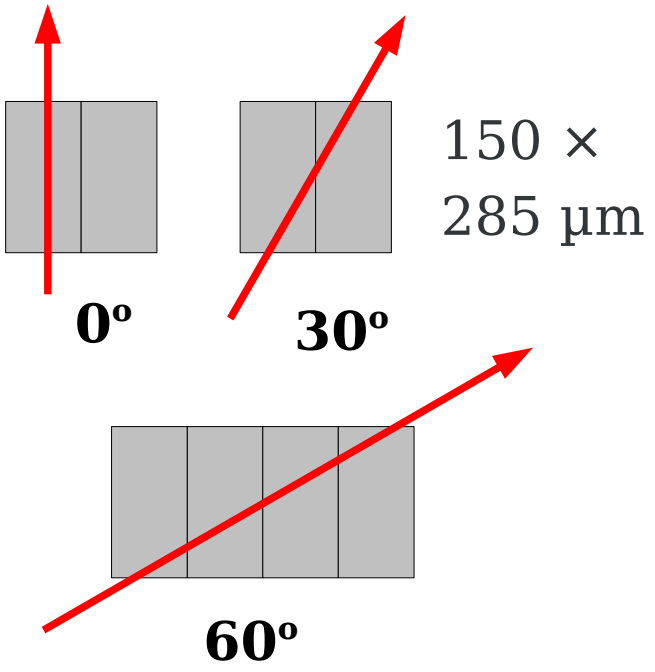


like dip angle in CMS...

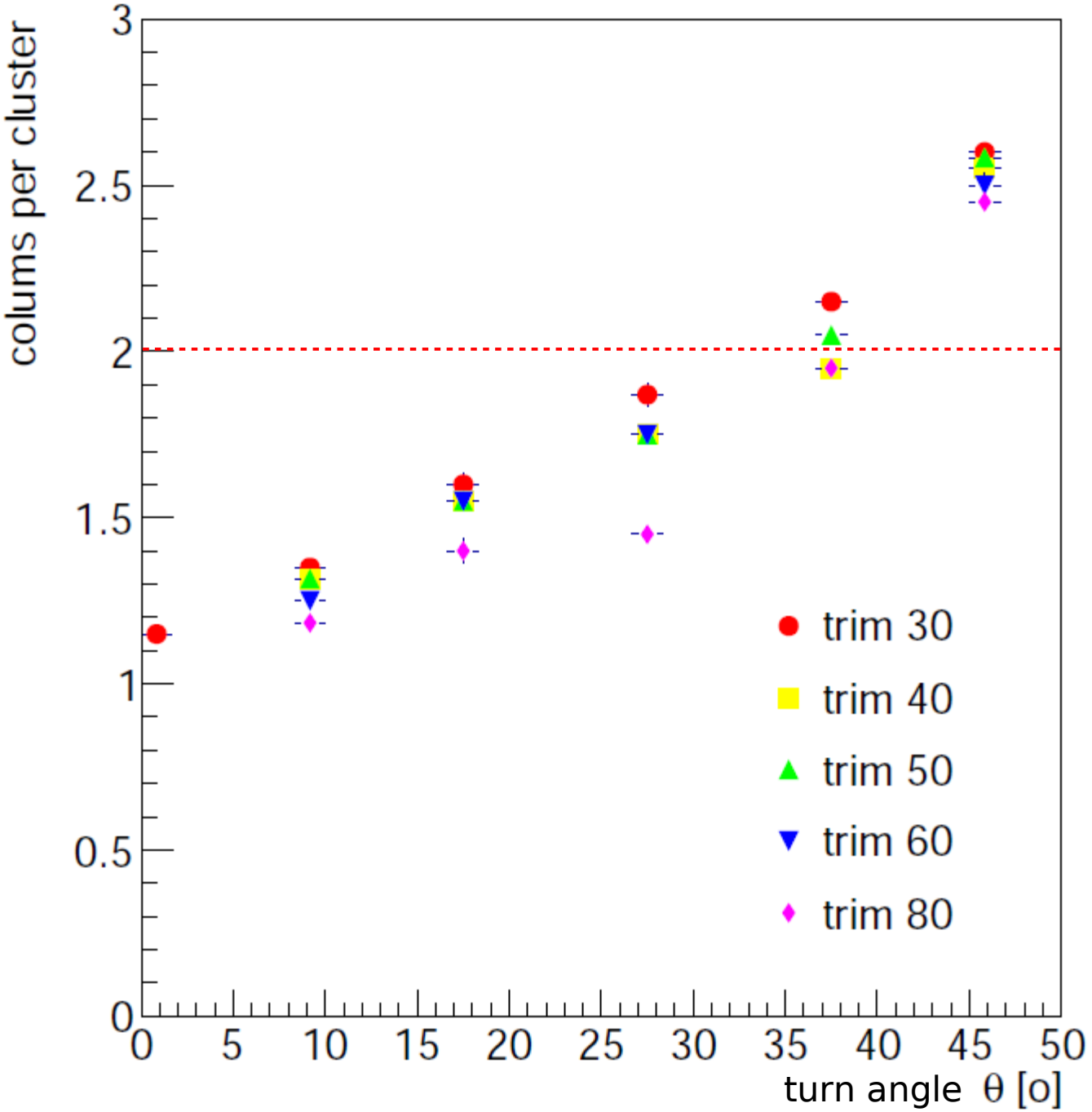
CMS: dip angle dependence of z resolution



- dip angle:
  - $\lambda = \pi/2 - \theta$.
- z = column direction
- optimal resolution at 28° = atan(150/285)
  - sharing between neighboring pixels

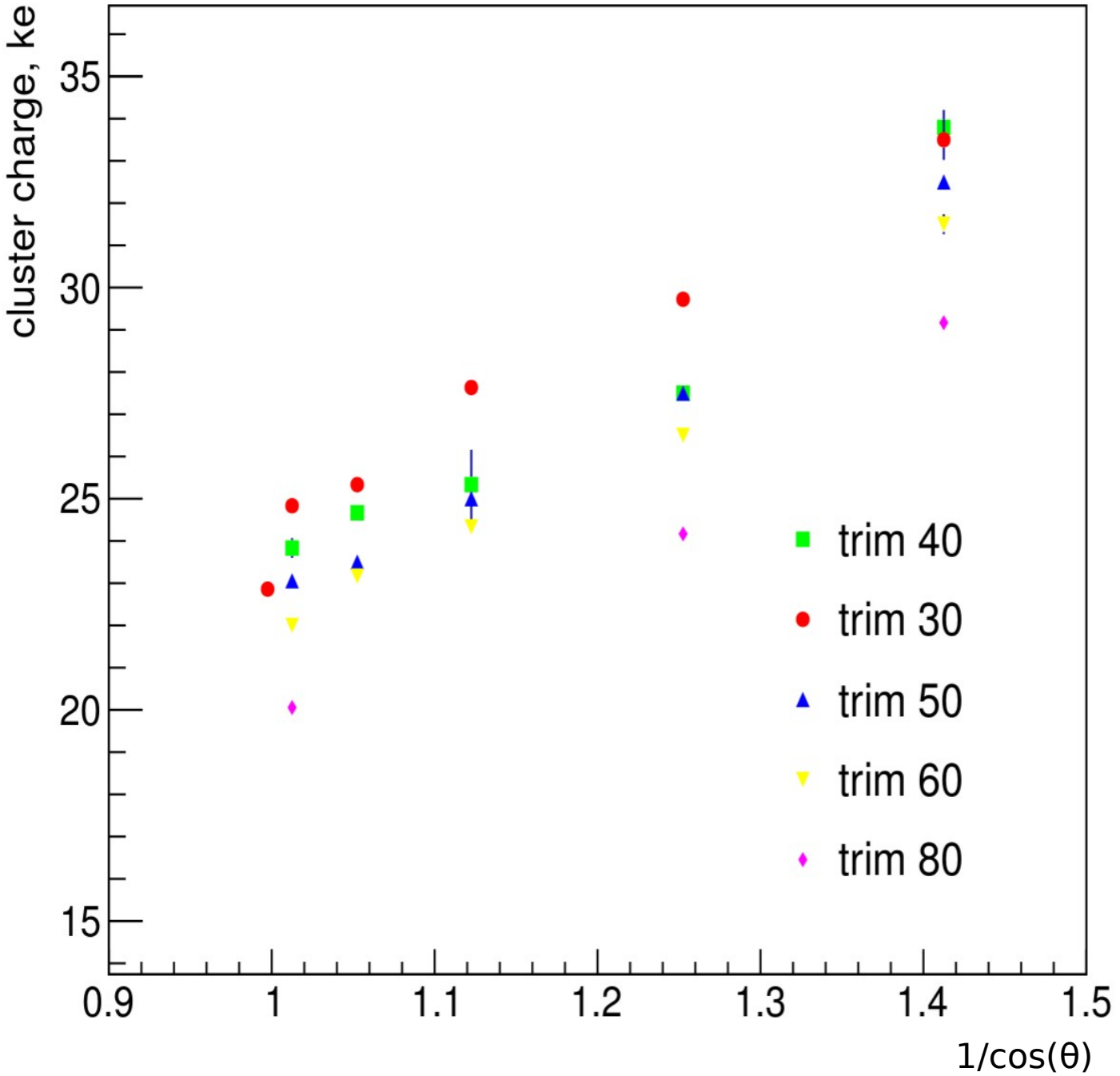


columns per cluster vs turn angle



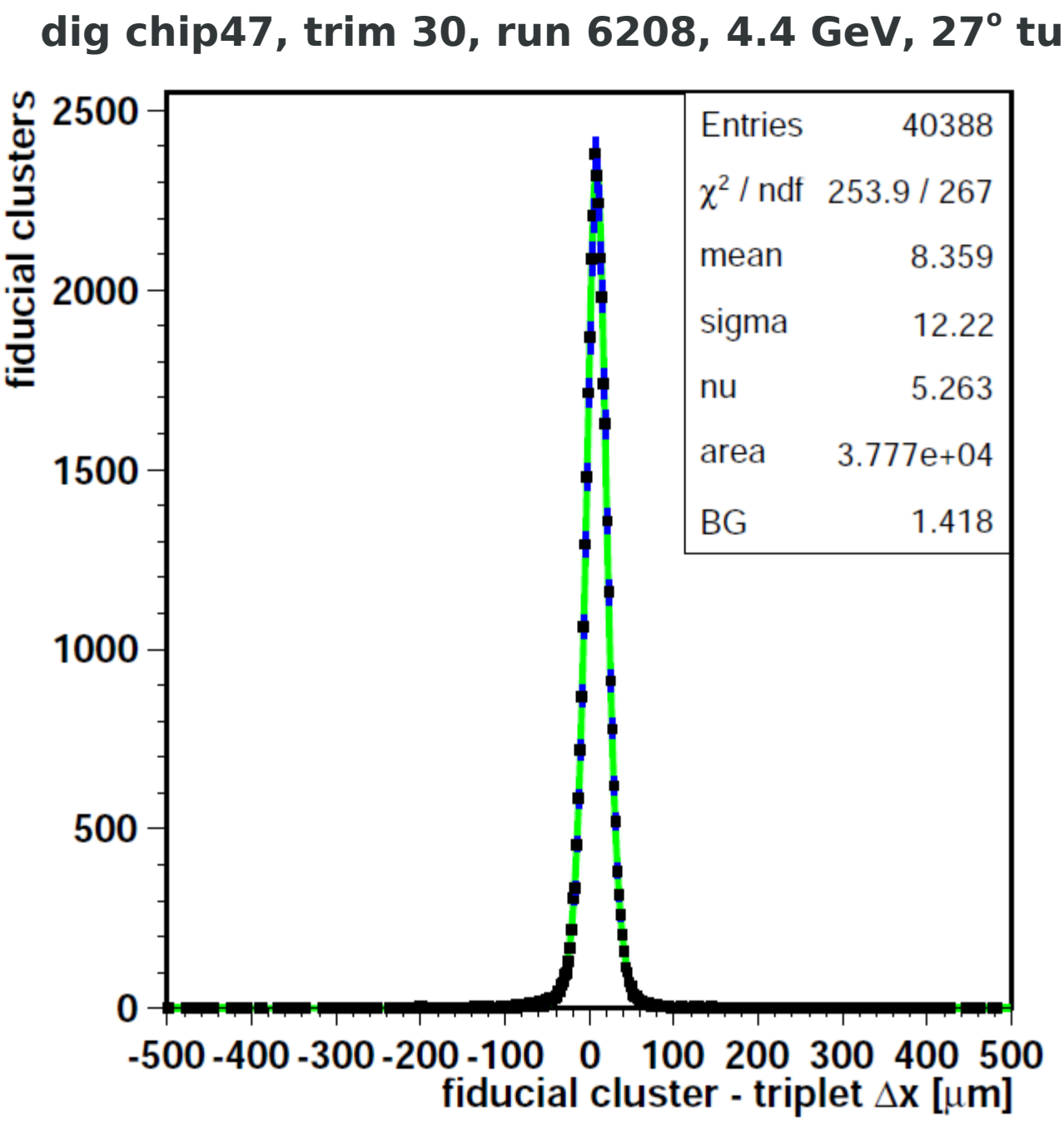
- psi46dig chip 47
  - Ia 25 mA
  - trim: ~50 e/DAC
- Optimum:
  - 2 columns/cluster
  - reached at 28 deg, as expected from geometry

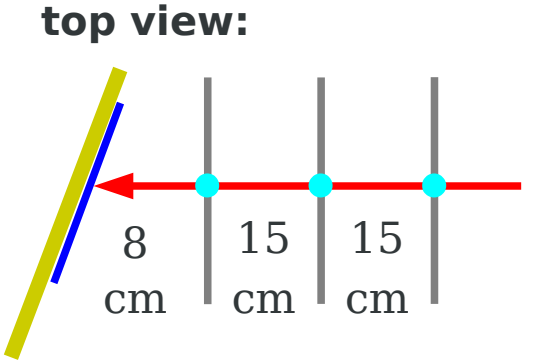
Landau peak position vs turn angle



- psi46dig chip 47
  - Ia 25 mA
  - nominal gain calibration: 50 e / DAC
- Geometry:
  - Q ~ 1 / cosθ
  - confirmed
- 20% loss at threshold 80 (4 ke)

column resolution with turn angle

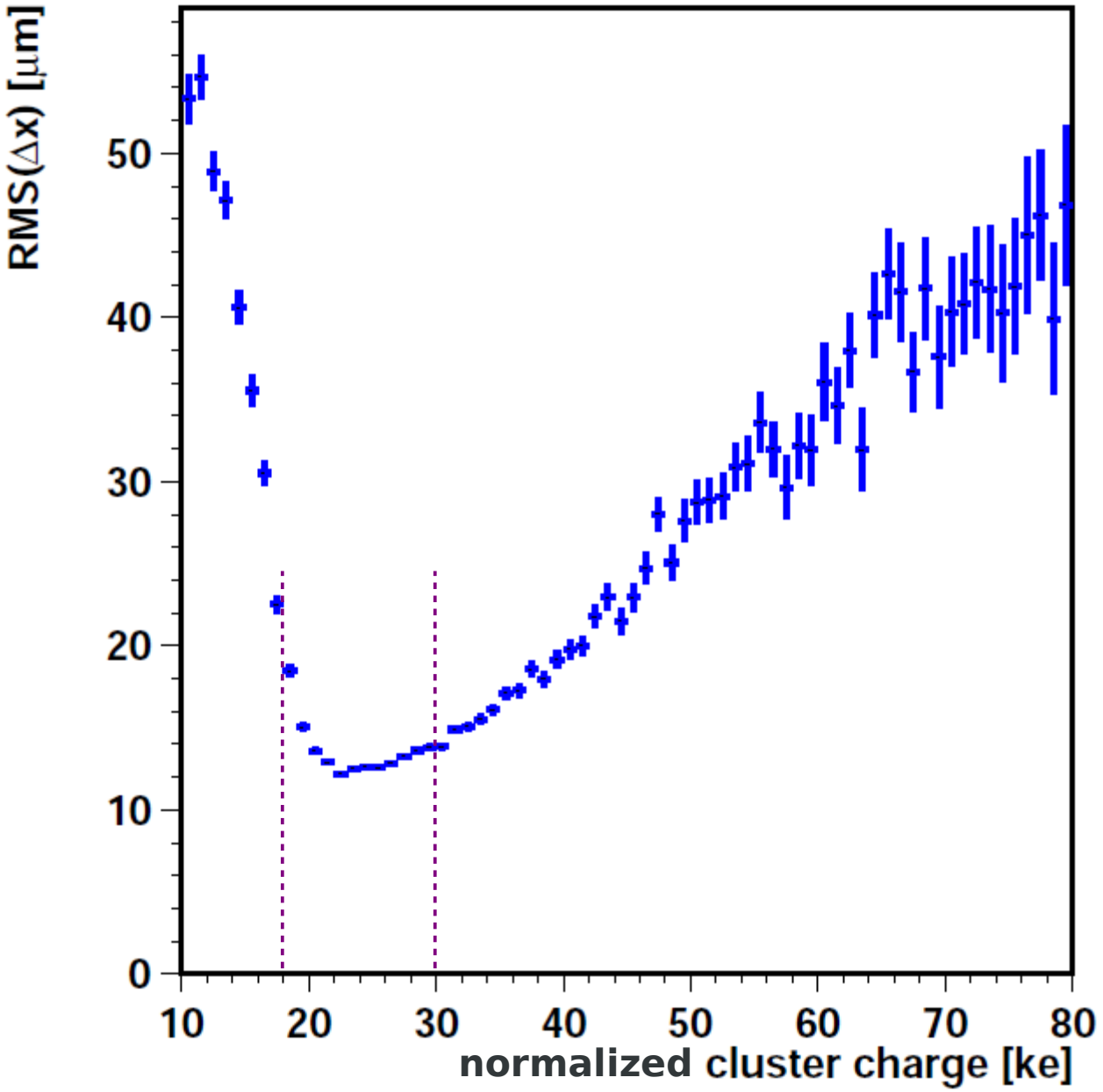


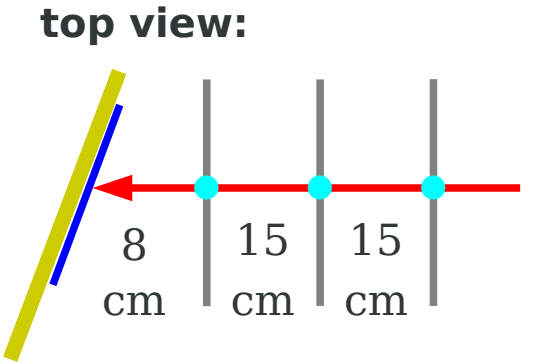


- Horizontal = columns
  - pixel width 150 µm
- turn angle:
  - charge sharing
  - residuals have Gaussian distribution
  - sigma = 12.2 µm
  - subtract telescope 7 µm
  - σ_{column} = 10 µm

column resolution vs cluster charge

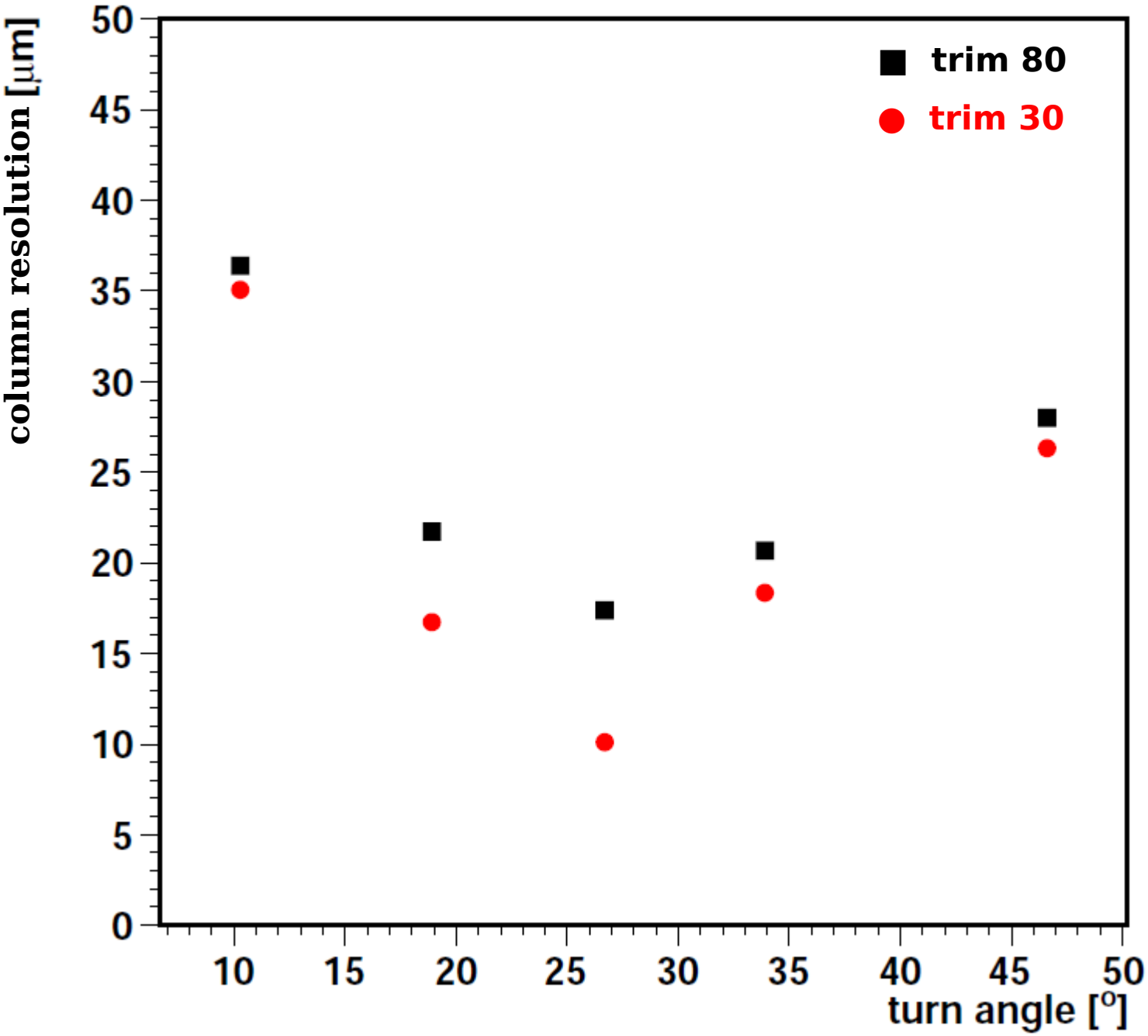
dig chip39, trim 24, run 5559, 4.4 GeV, 26° turn





- Best resolution for mips at the Landau peak around 22 ke
- Poor resolution below 18 ke:
  - broken clusters
- Poor resolution in Landau tail above 30 ke:
  - delta rays
- Select 18 < Q < 30 ke

column resolution vs turn angle



- psi46dig chip 47:
  - Ia 25 mA
- optimal:
  - 10 µm at 27° with lowest threshold
- Less threshold dependence at other angles

Bias Dot Studies

CMS barrel pixel sensor

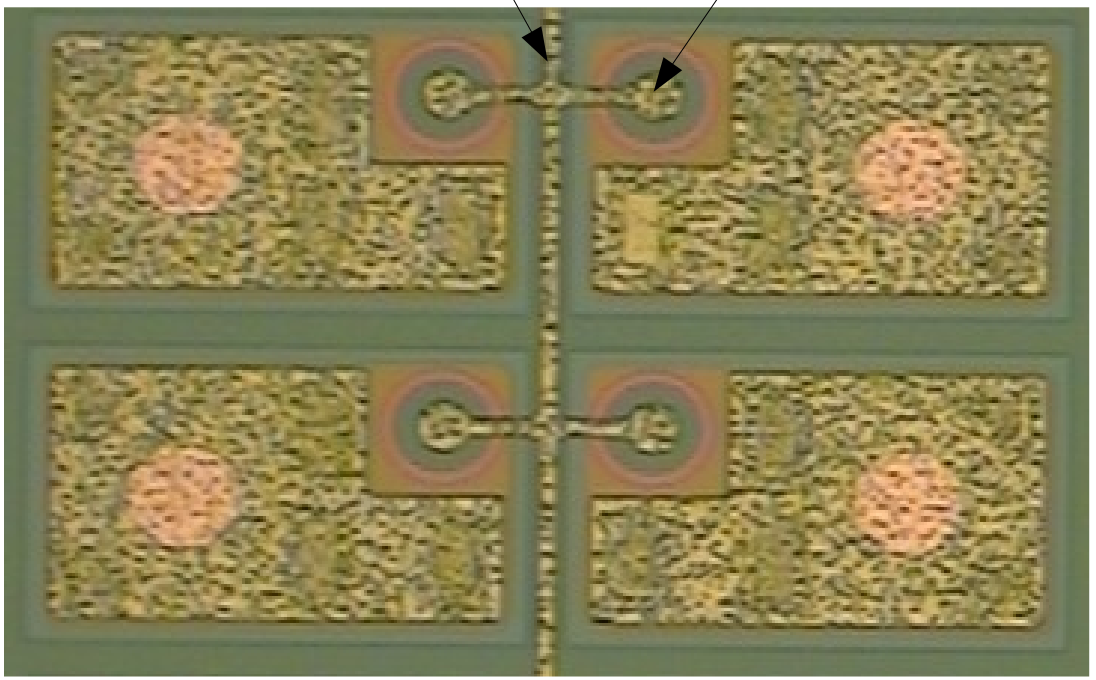
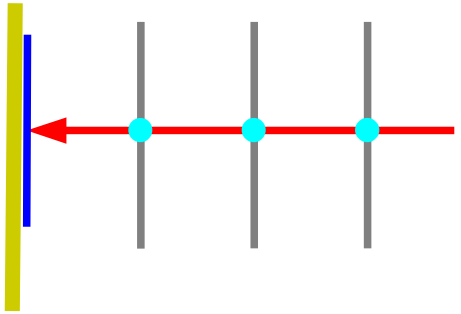


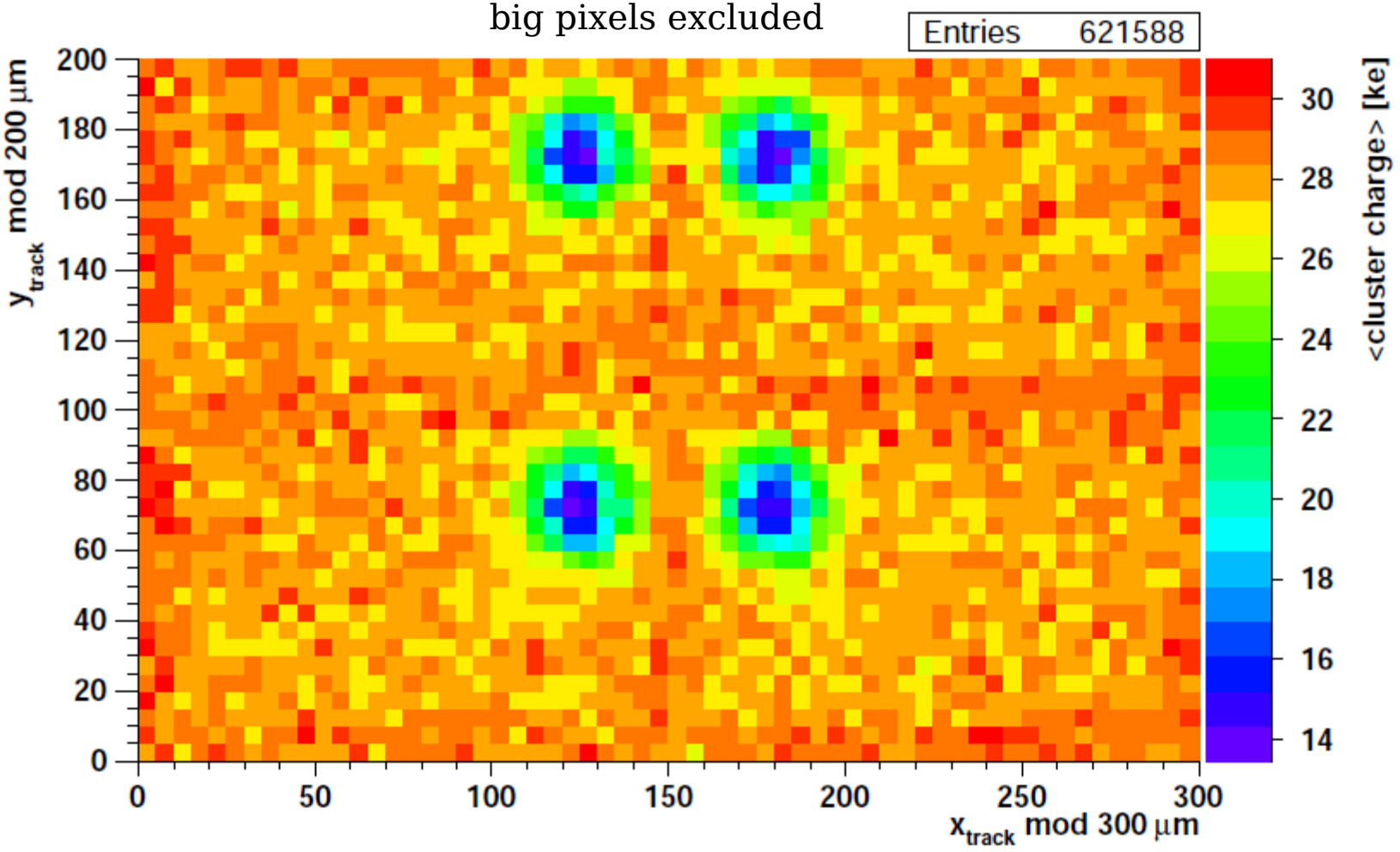
foto: Uni HH, 2012

cluster charge map at vertical incidence



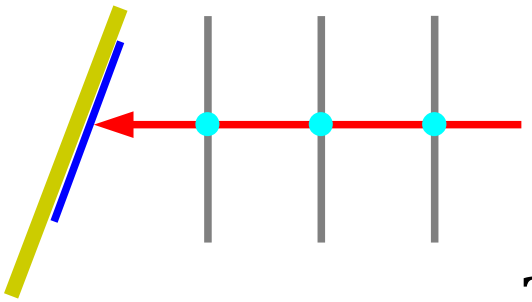
2×2 pixel map

big pixels excluded

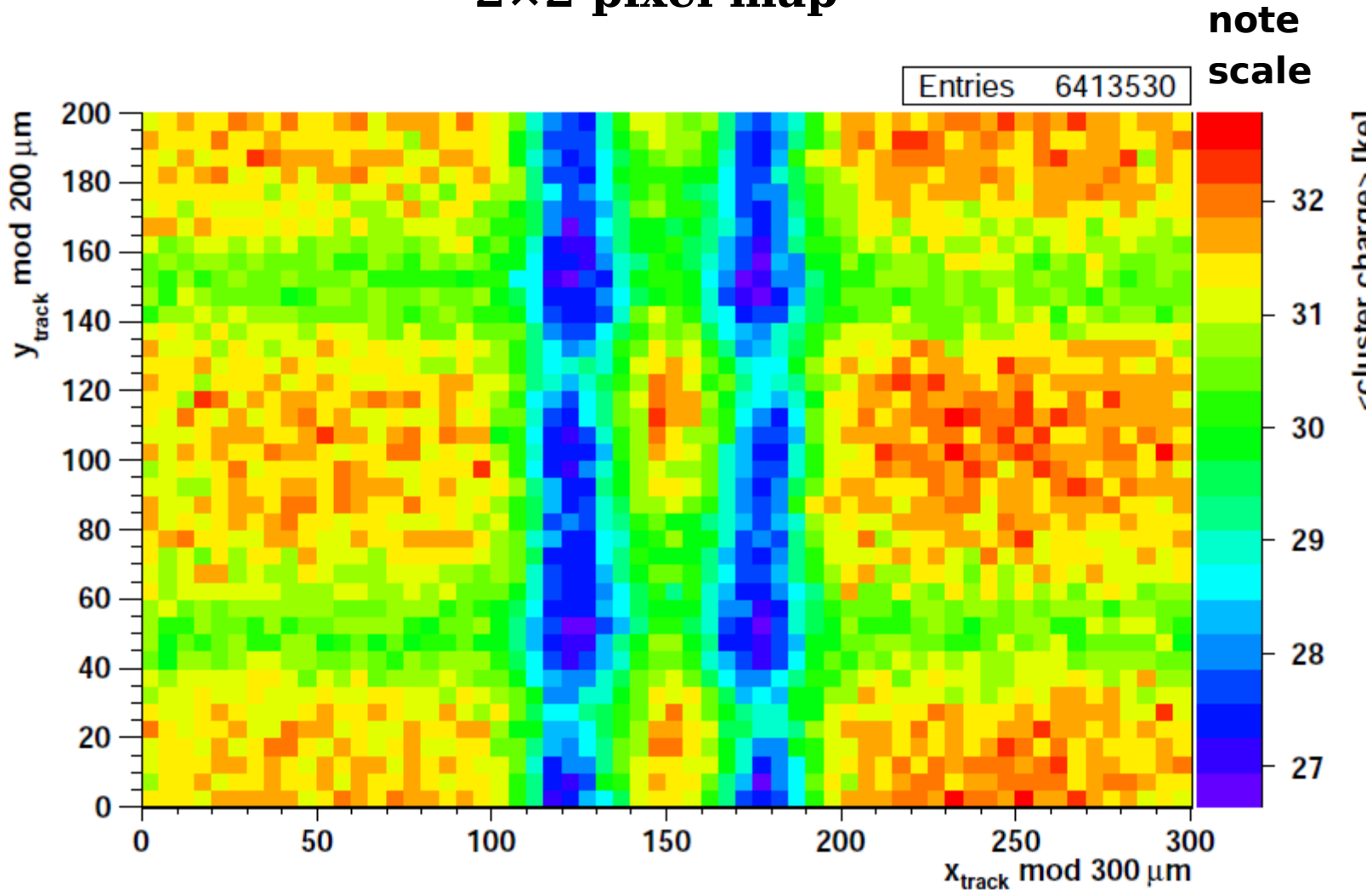


- psi46dig chip 205
- **0° tilt**
- trim 28 (1.4 ke)
- -150 V bias
- Telescope track: 4.5 µm precision
- **bias dots: charge deficit**

cluster charge map with 19° tilt

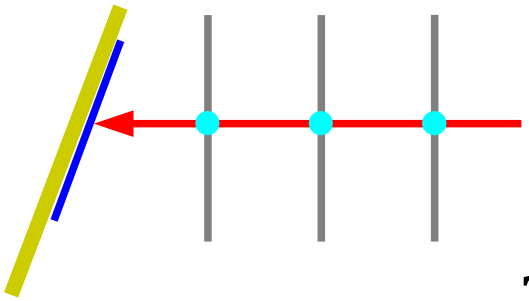


2×2 pixel map

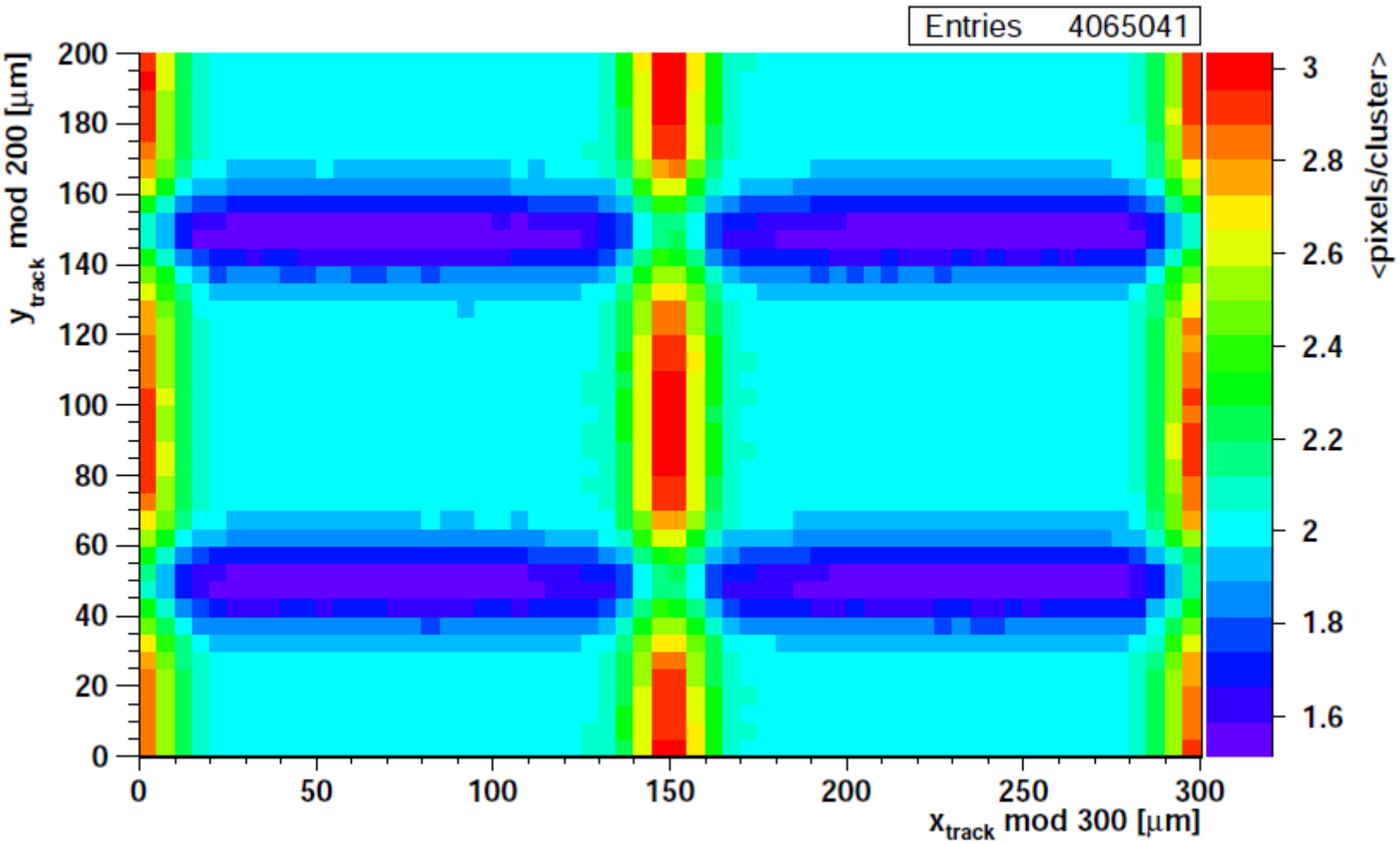


- psi46dig chip 39
- **19° tilt**
- trim 28 (1.4 ke)
- -150 V bias
- Telescope track: 4.5 µm precision
- **bias dots stretched**
- **threshold effect**

cluster size map with 19° tilt

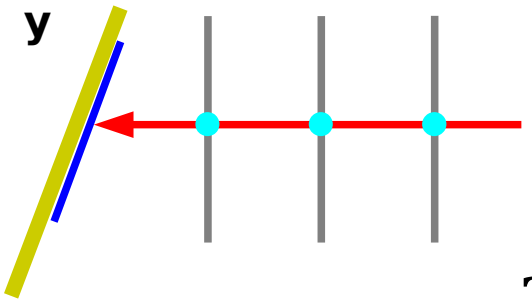


2×2 pixel map



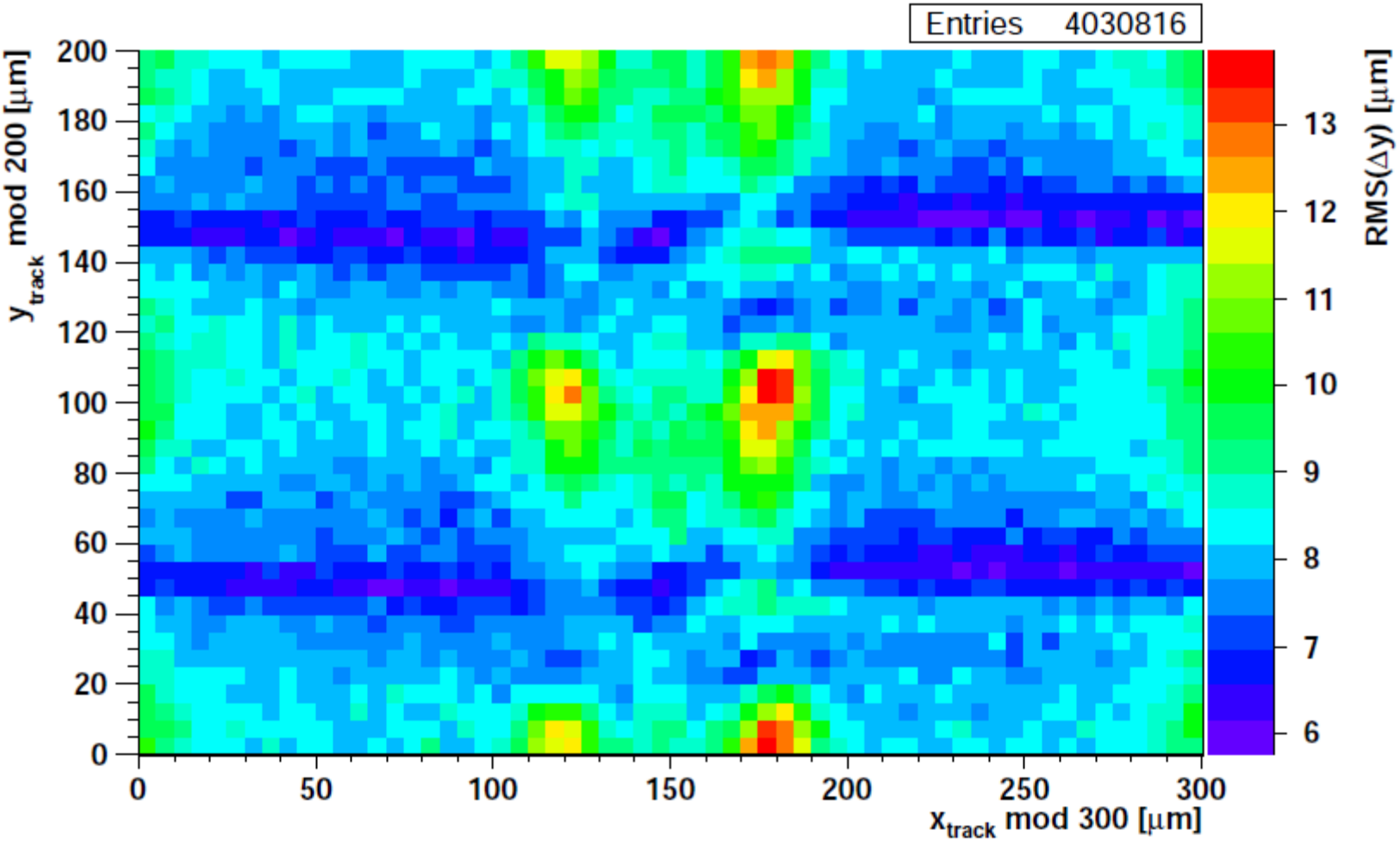
- psi46dig chip 39
- **19° tilt**
- trim 28 (1.4 ke)
- -150 V bias
- Telescope track: 4.5 µm precision
- **tilt leads to 2-row clusters**

row resolution map with 19° tilt



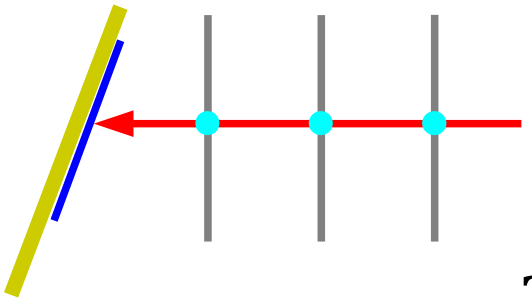
2×2 pixel map

RMS of residual in row direction

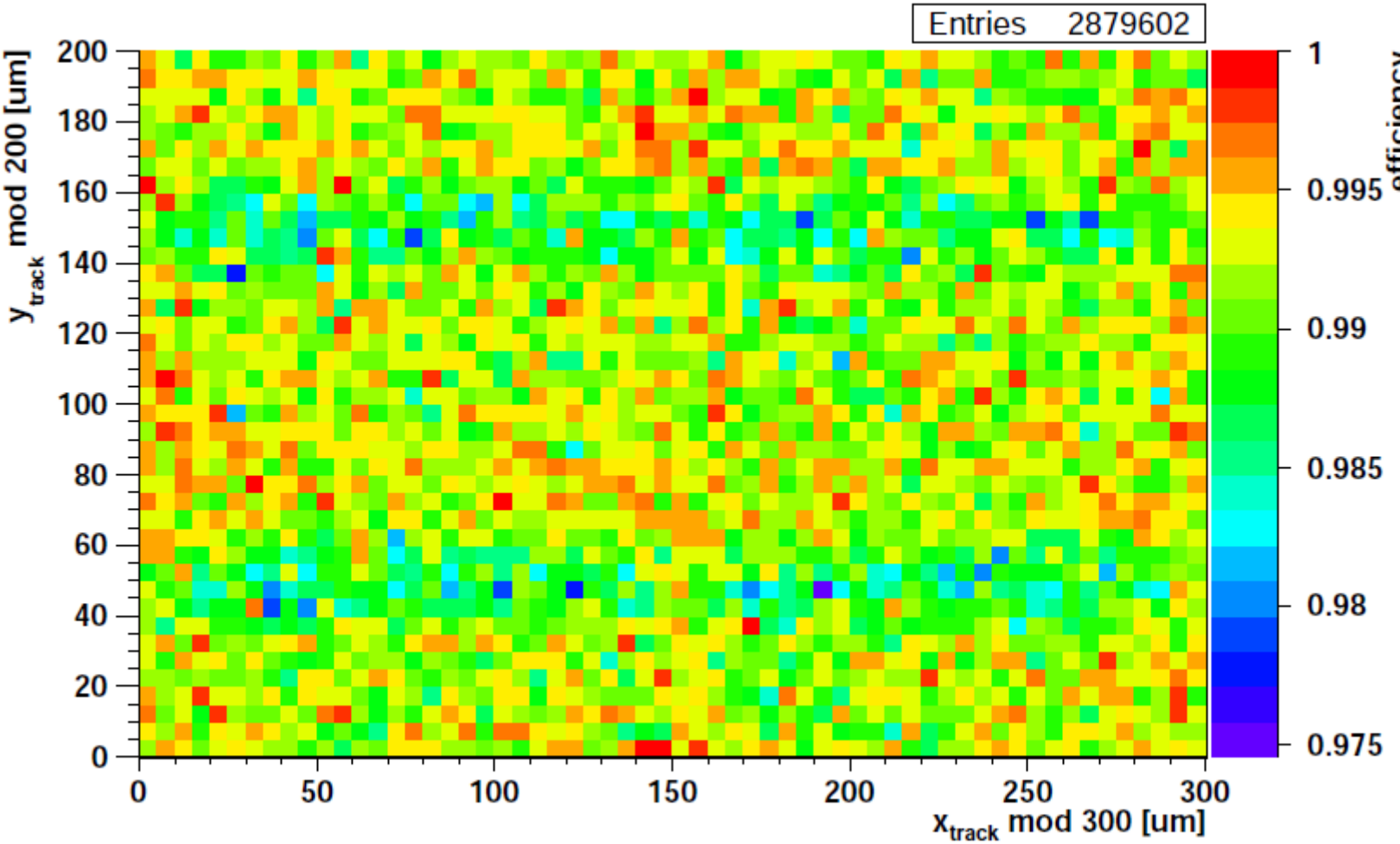


- psi46dig chip 39
- **19° tilt**
- trim 28 (1.4 ke)
- -150 V bias
- Telescope track: 4.5 µm precision
- **bias dots deteriorate**
- **best resolution in 1-pixels**

efficiency map with 19° tilt

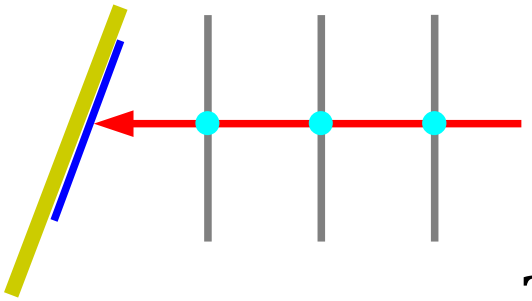


2×2 pixel map

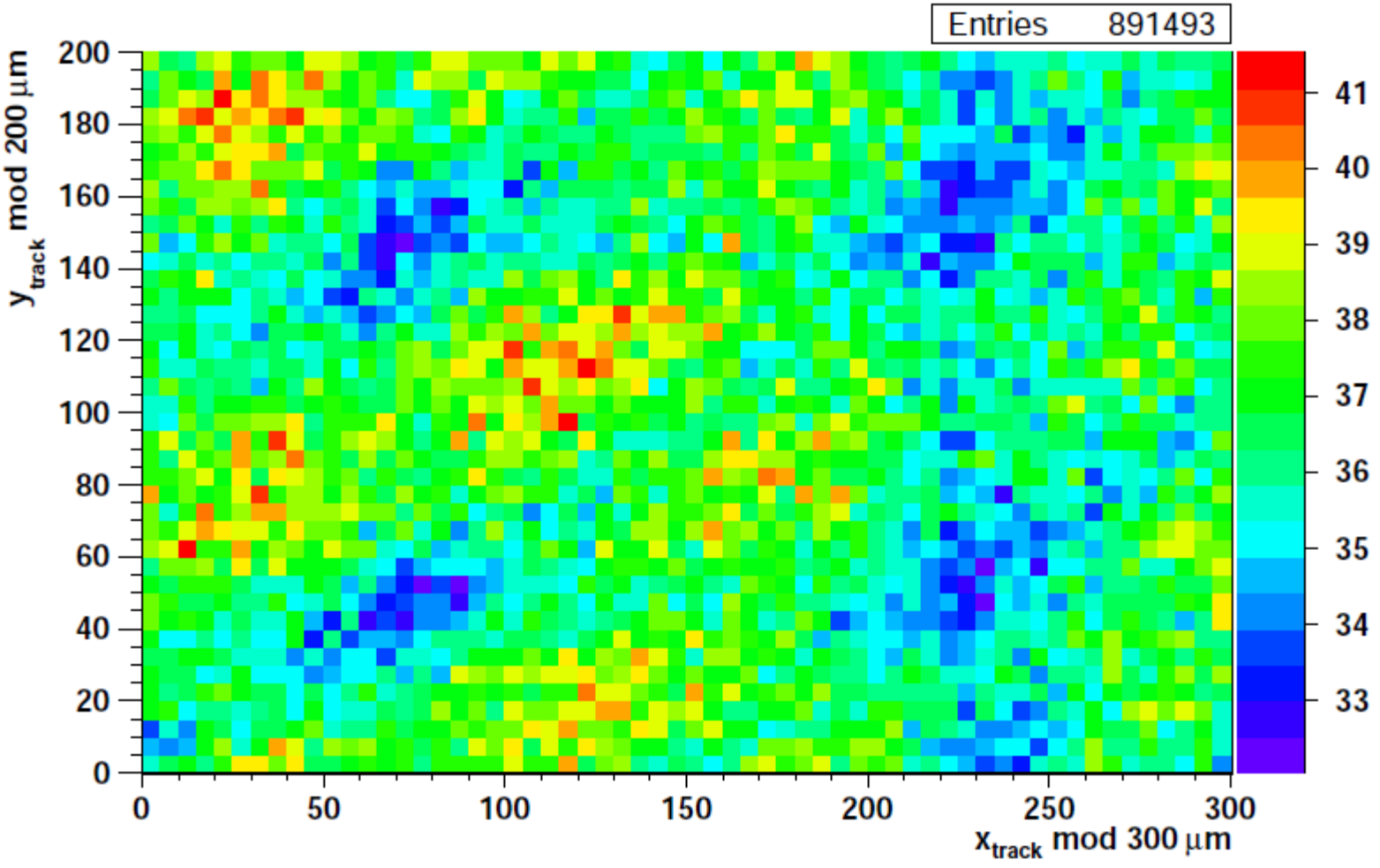


- psi46dig chip 39
- **19° tilt**
- trim 28 (1.4 ke)
- -150 V bias
- Telescope track: 4.5 µm precision
- **bias dots don't give inefficiency**

cluster charge map with tilt and turn

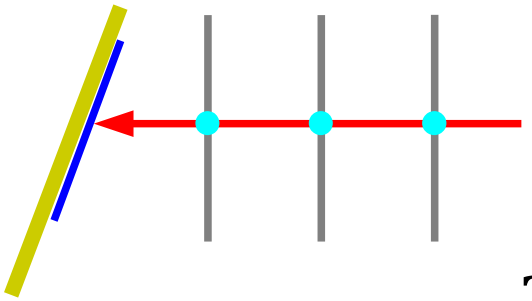


2×2 pixel map

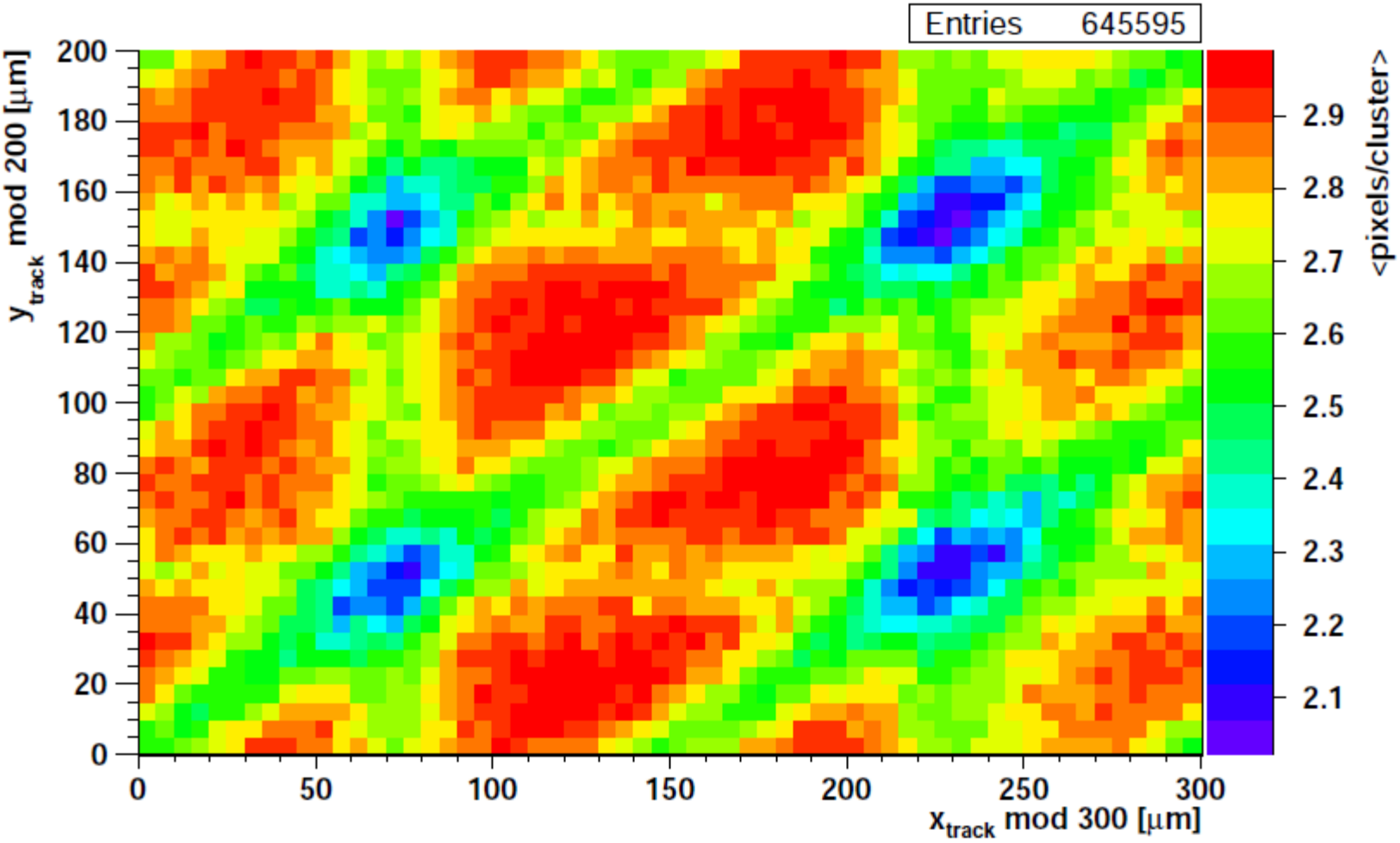


- psi46dig chip 205
- **19° tilt**
- **28° turn**
- trim 30 (1.5 ke)
- -150 V bias
- Telescope track: 7.5 µm precision
- **structure due to threshold effects?**

cluster size map with tilt and turn



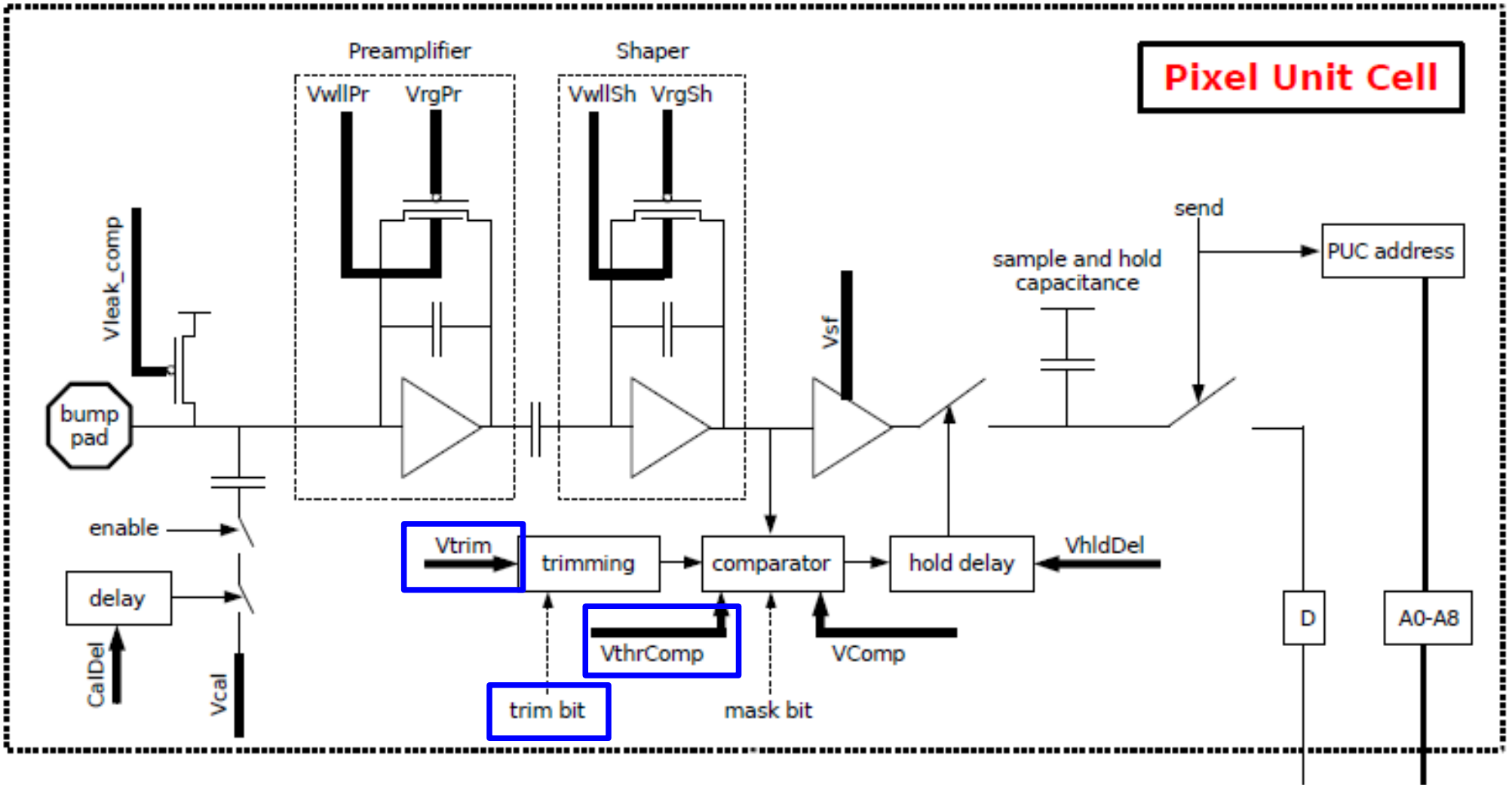
2×2 pixel map



- psi46dig chip 205
- **19° tilt**
- **28° turn**
- trim 30 (1.5 ke)
- Telescope track: 7.5 µm precision
- **structure due to threshold effects?**

Threshold Scan with Tilt Angle

Threshold scan

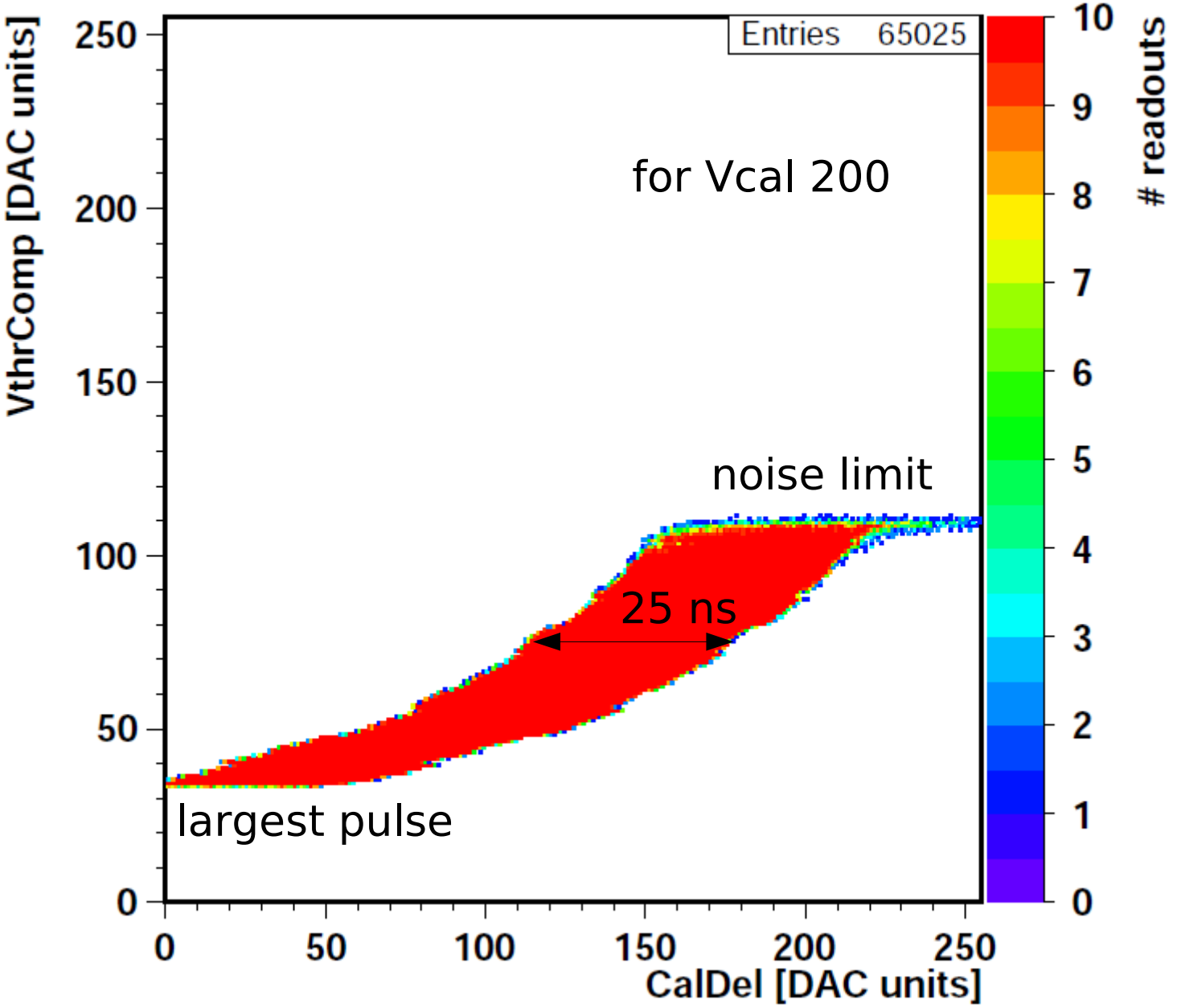


Threshold = VthrComp – Vtrim · (15 – trimbits)

Harder threshold: loose small pulses

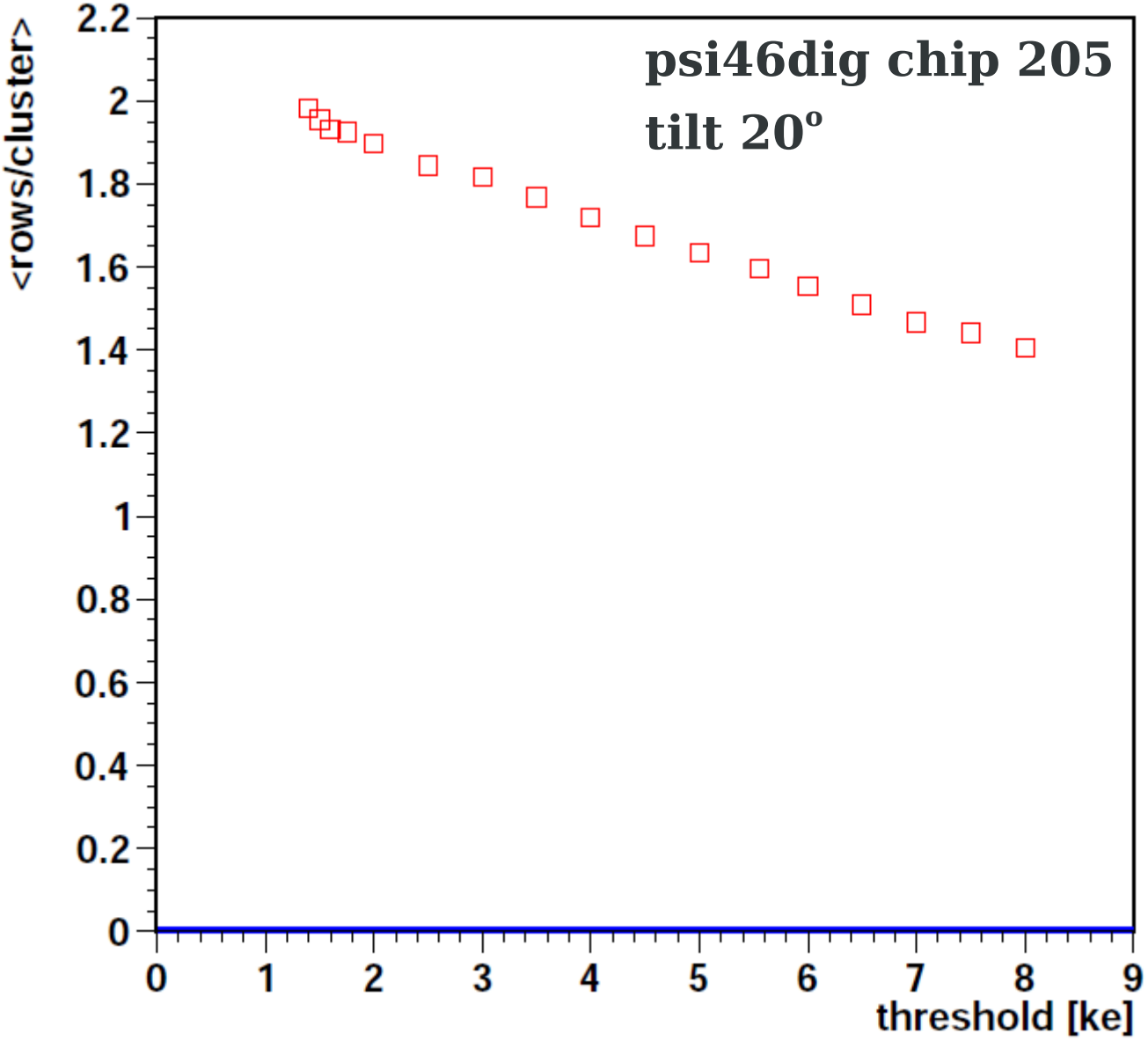
Simulates reduced charge collection (radiation damage)

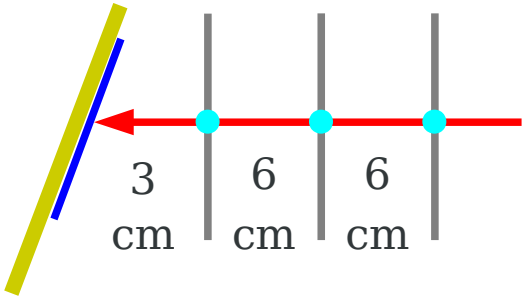
ROC timing changes with threshold setting



- Digital Chip 202
  - Ia 30 mA
  - pixel (2, 2)
  - Vcal 200
- Changing the comparator threshold affects the timing by up to 3 clock cycles
- We adjust WBC and timing during data taking

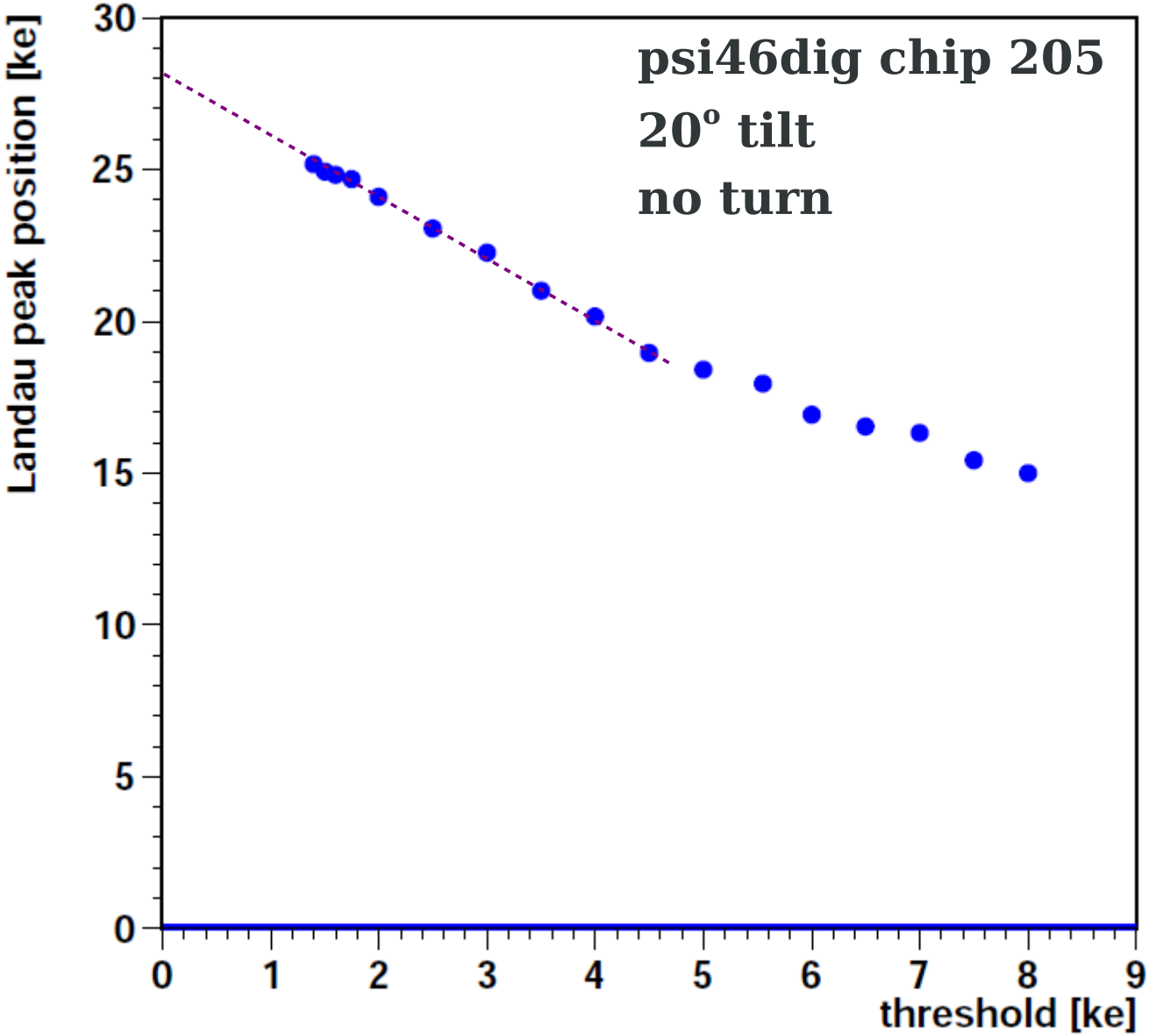
cluster size vs threshold at 20° tilt

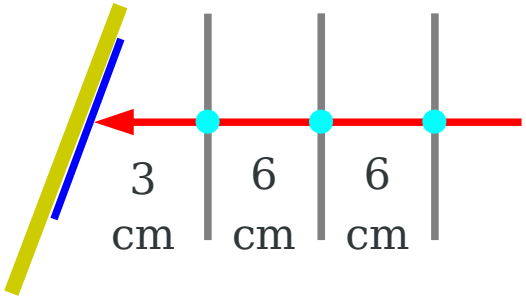




- Digital ROC 205:
  - 20° tilt
  - no turn
  - -150 V bias
- rows per cluster:
  - decreases linearly with threshold
  - good indicator for threshold

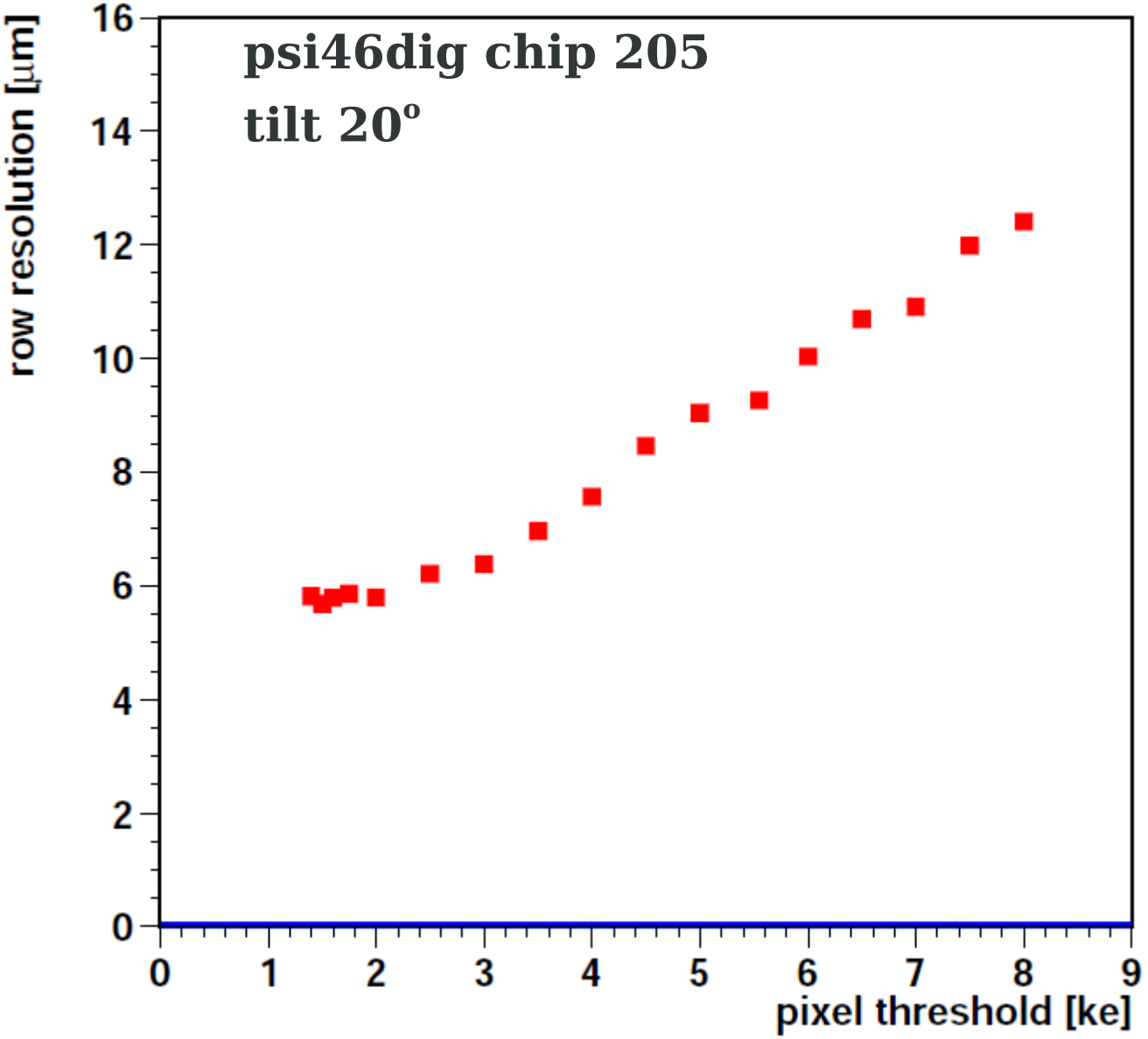
cluster charge vs threshold at 20° tilt

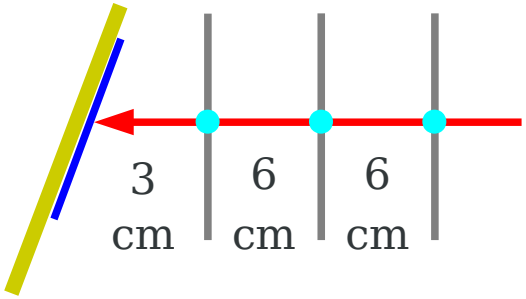




- Digital ROC 205, 20° tilt
- nominal calibration:
  - 50 e / Vcal DAC
- cluster charge:
  - decreases ~linearly with threshold
  - extrapolate to zero threshold for total charge

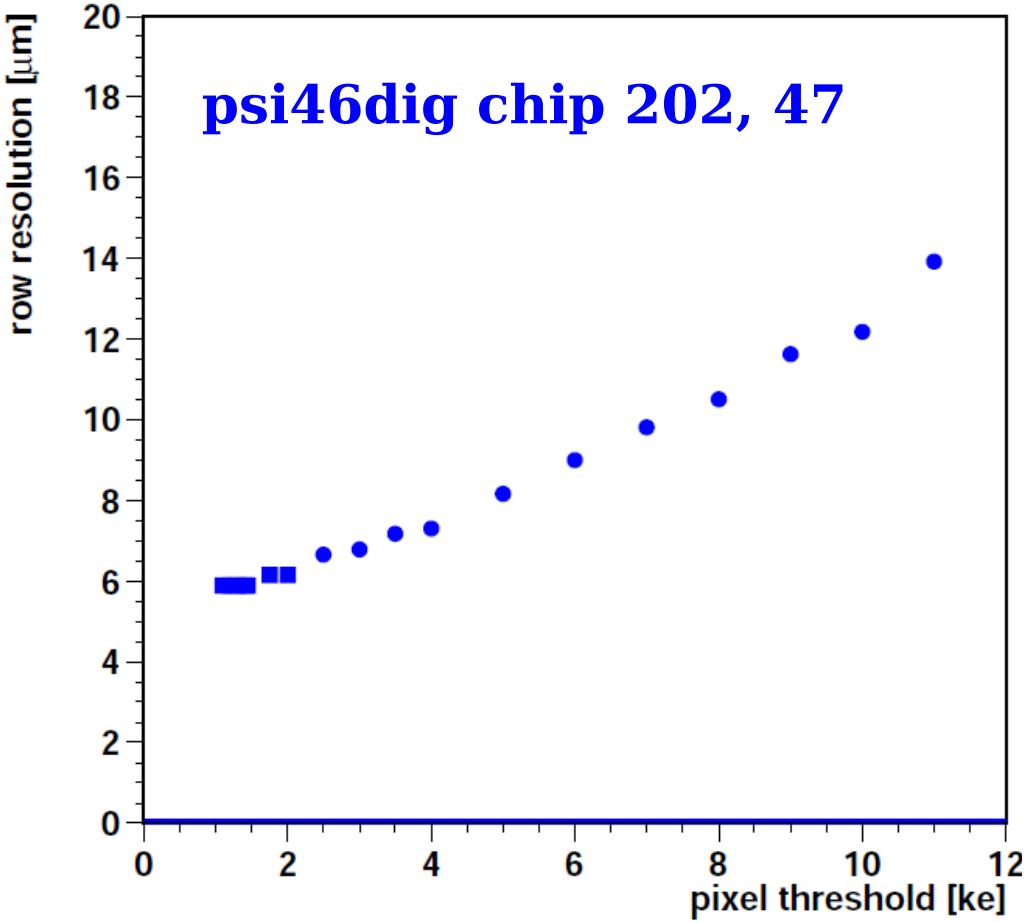
row resolution vs threshold at 20° tilt

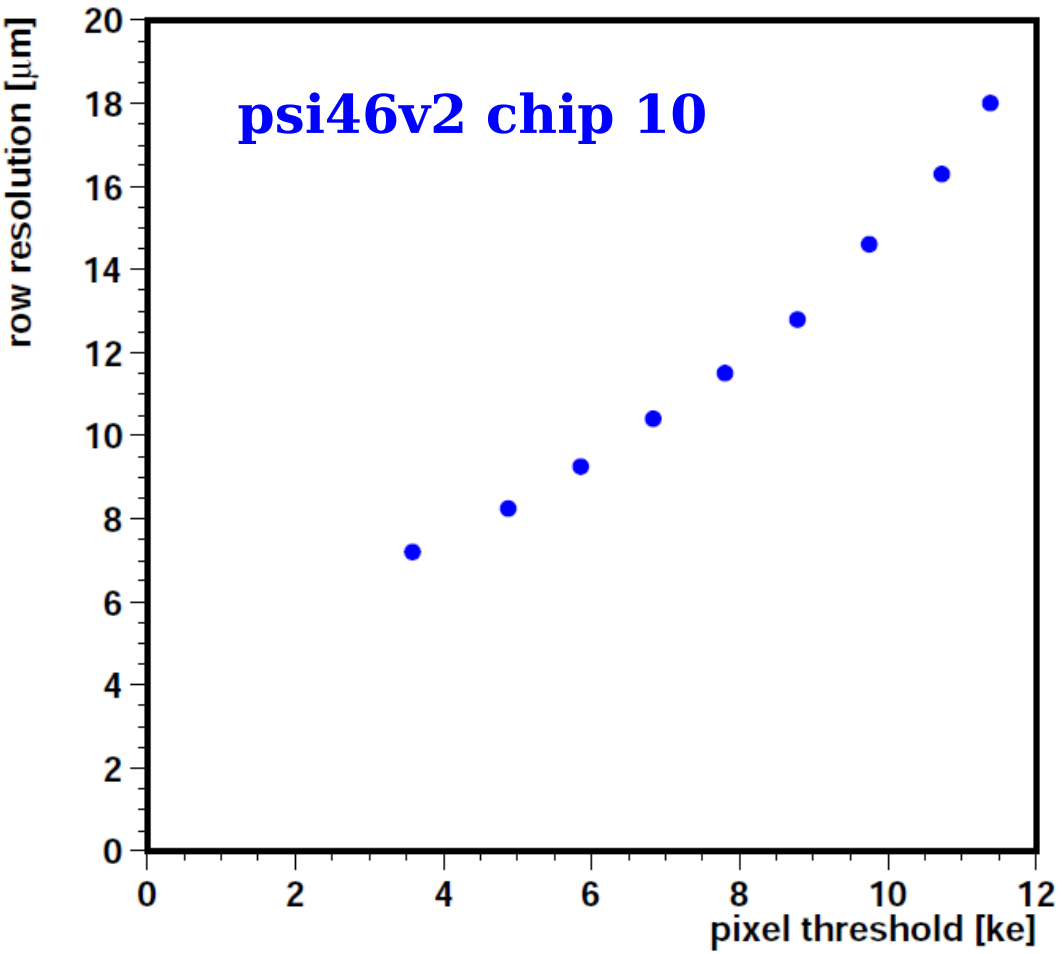




- Digital ROC 205, 20° tilt
- 4.4 GeV, telescope extrapolation uncertainty subtracted.
- lower threshold:
  - resolution seems to saturate at 6 µm below 2.5 ke.

row resolution vs threshold

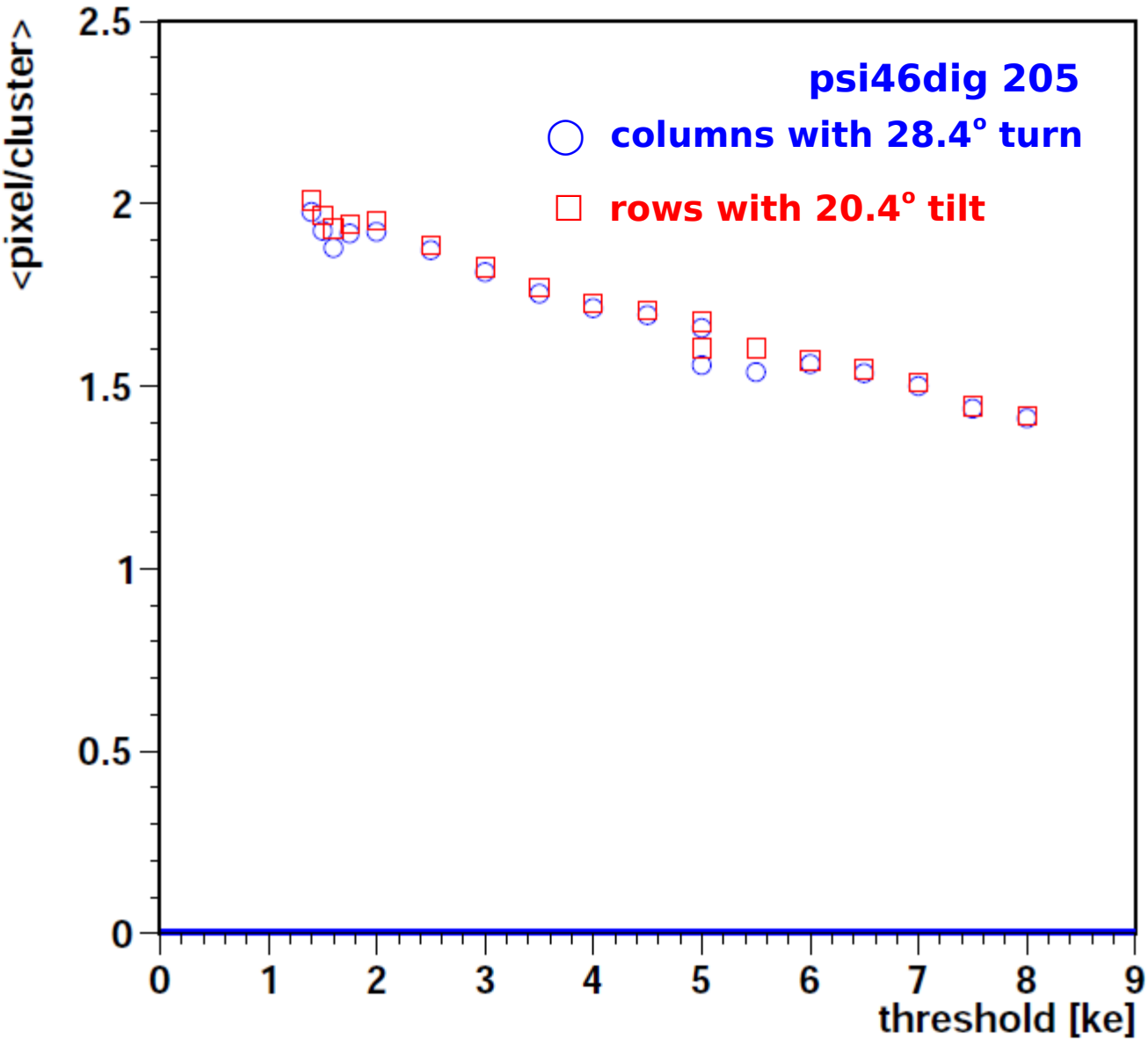


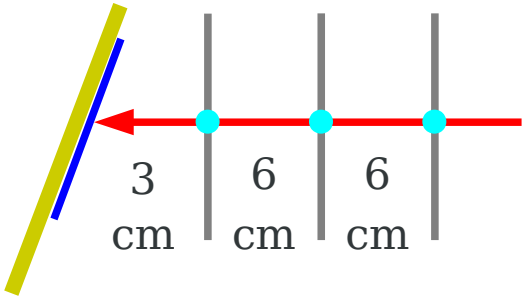


steeper slope due to timewalk?

Threshold Scan with Tilt and Turn

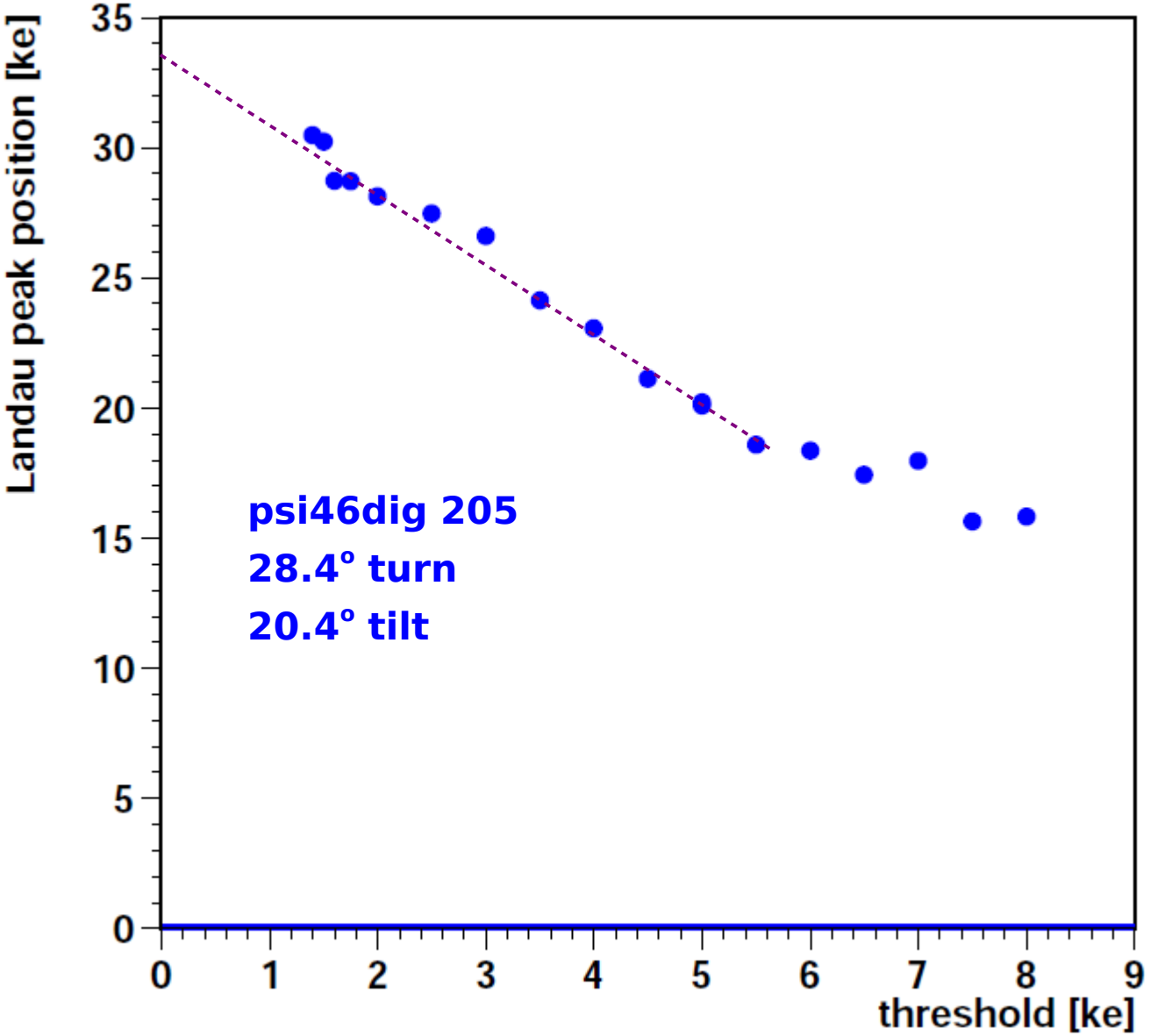
cluster size vs threshold 20° tilt 28° turn

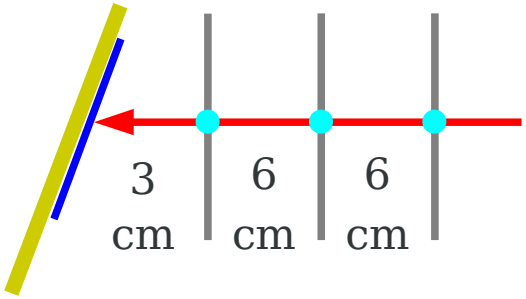




- Digital ROC 205
  - 20.4° tilt
  - 28.4° turn
  - -150 V bias
- rows and columns per cluster:
  - decrease linearly with threshold
  - similar at these angles

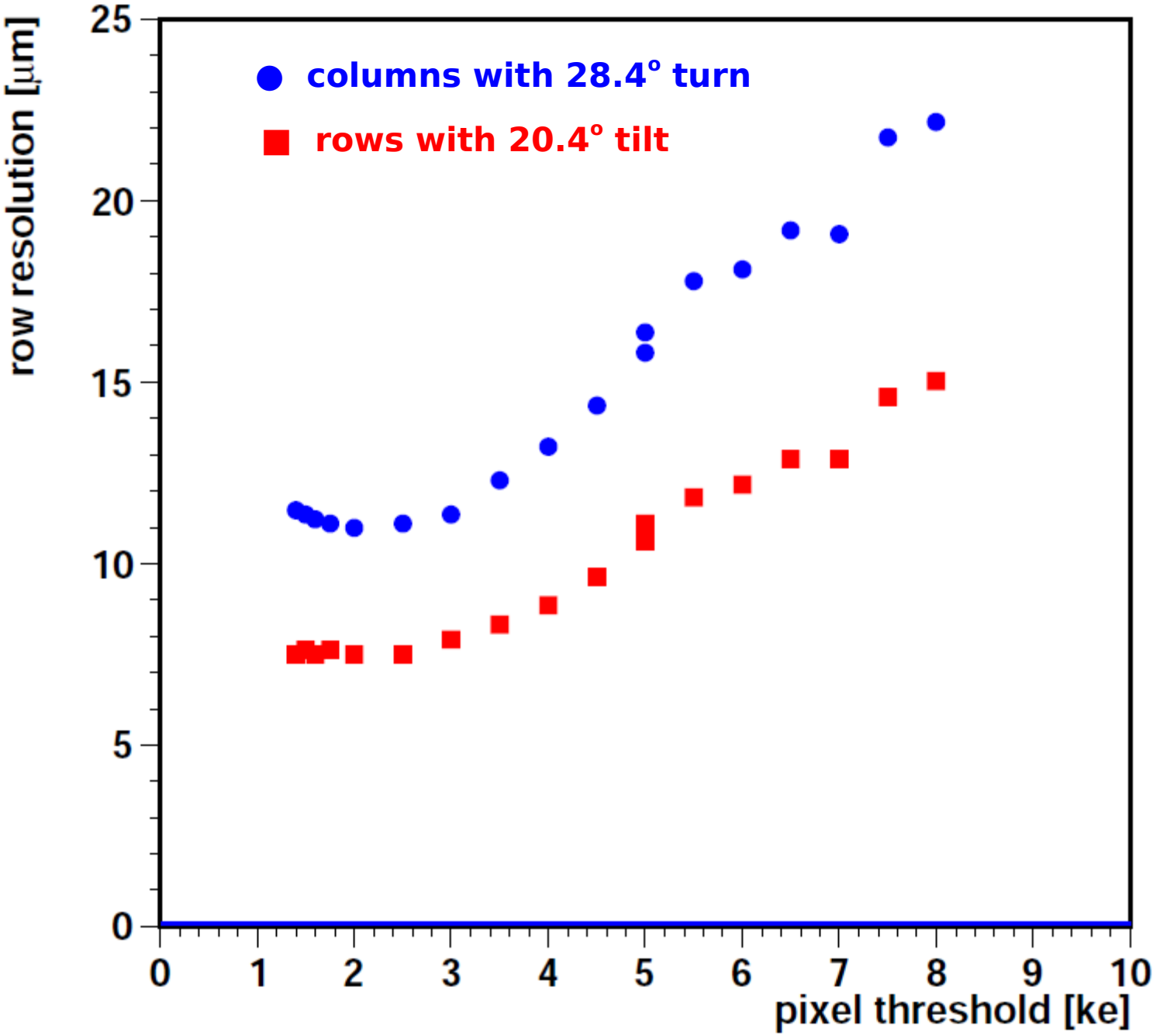
cluster charge vs threshold 20° tilt 28° turn





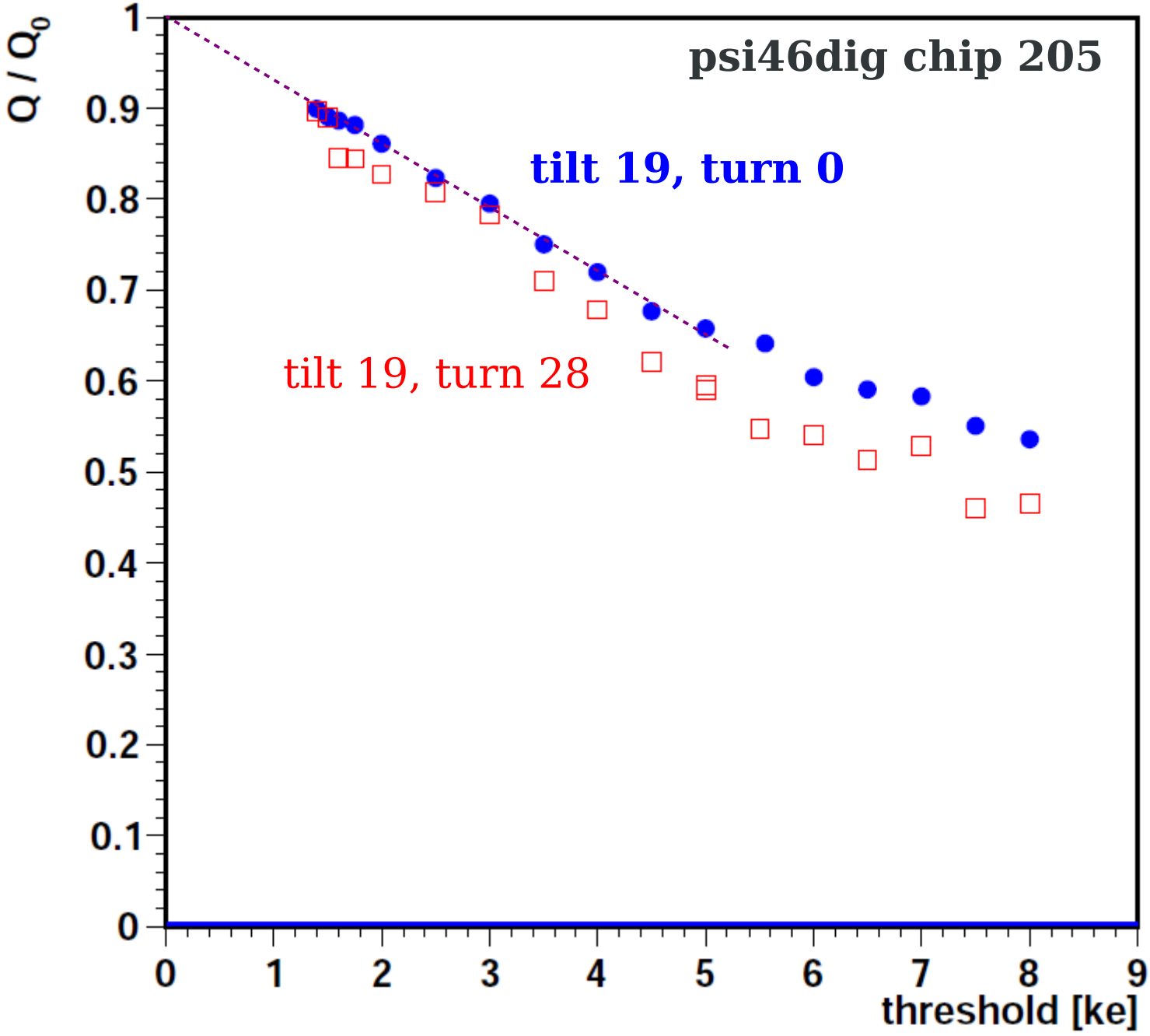
- Digital ROC 205
  - 20.4° tilt
  - 28.4° turn
  - -150 V bias
- Nominal gain of 50 e / Vcal DAC applied
- Charge deficit with threshold

resolution vs threshold chip 205



- psi46dig chip 205:
  - Ia 25 mA
  - 28.4° turn
  - 20.4° tilt
- resolution degrades with higher thresholds
- small degradation at lowest threshold?

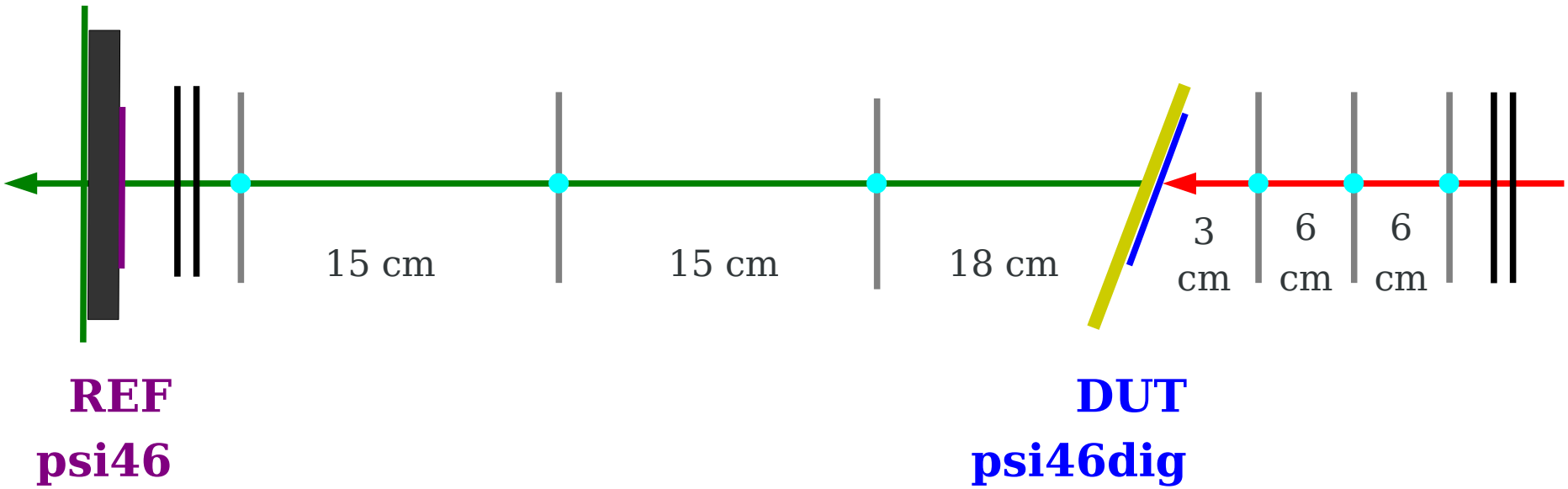
cluster charge vs threshold



- psi46dig chip 205
  - Ia 25 mA
  - -150 V bias
  - tilt angle 19°
  - turn angle 0 and 28°
- Charge normalized to extrapolated value at zero threshold
- **How strong is this effect with X-rays?**

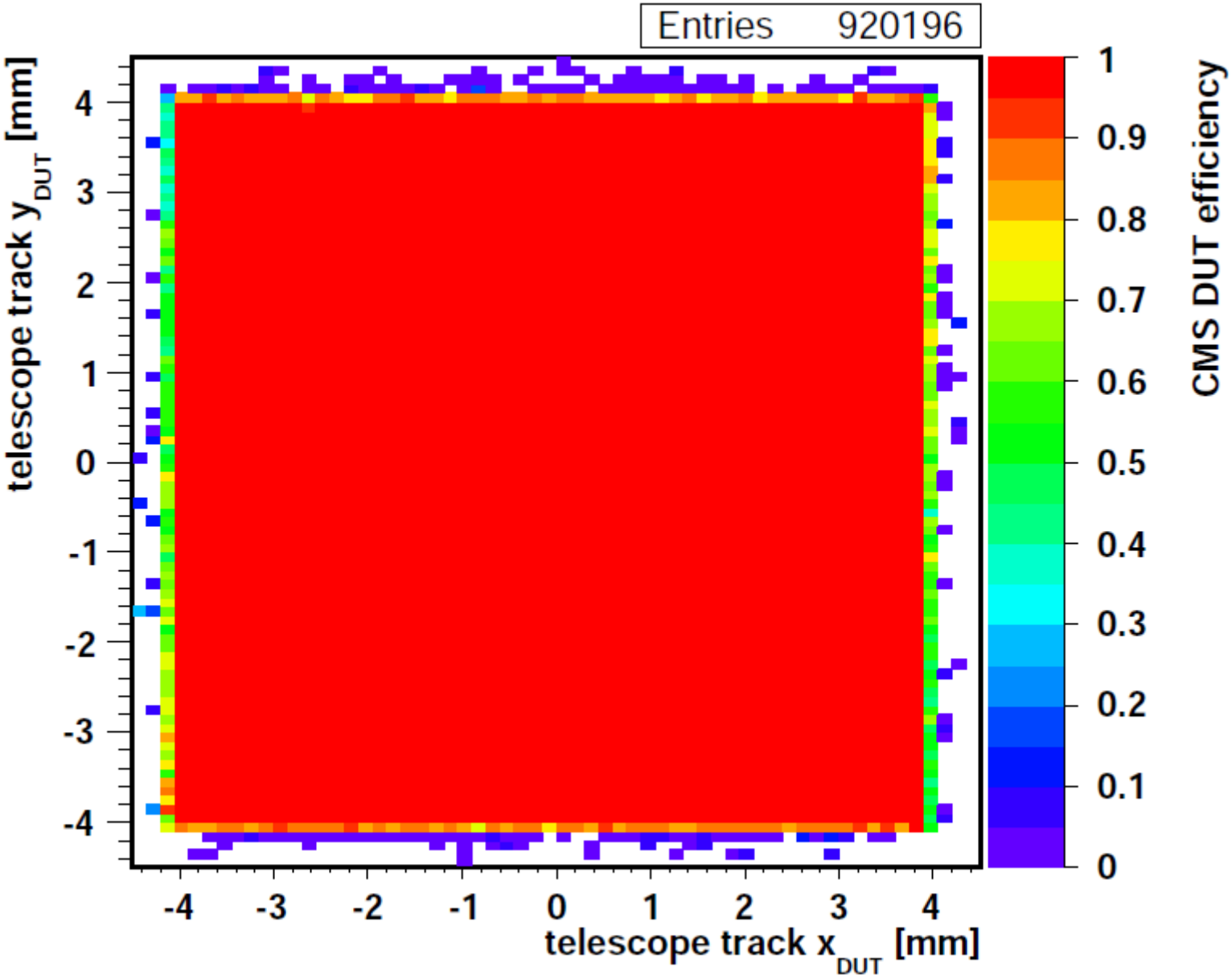
Efficiency

eff = (DUT linked clusters) / (telescope tracks with REF cluster)



efficiency map

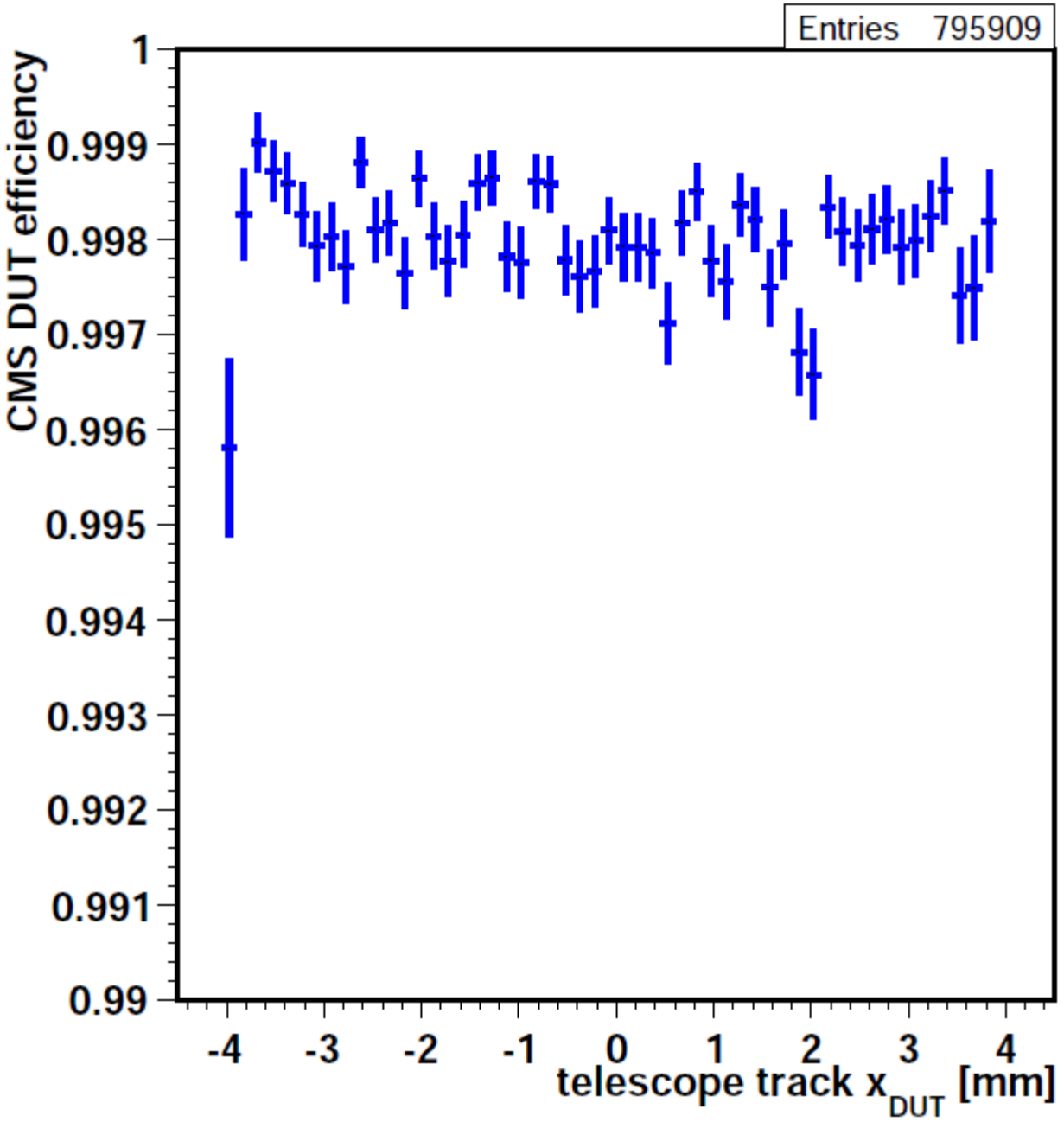
eff = (DUT linked clusters) / (telescope tracks with REF cluster)



- chip 205
  - I_A 25 mA
  - trim 30
  - tilt 17°
  - turn 0°
- runs 6701-6814, selected
- **99.6% in fiducial volume**

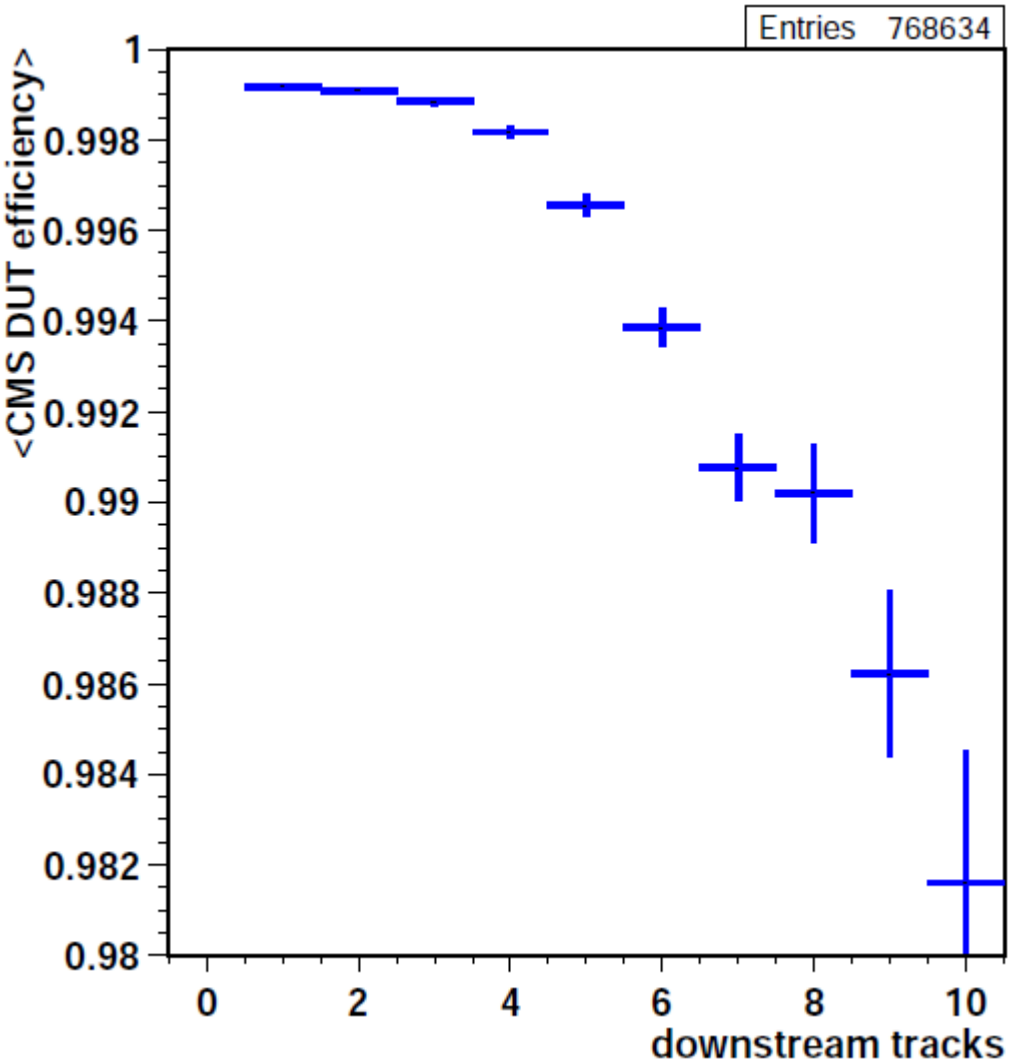
efficiency per column

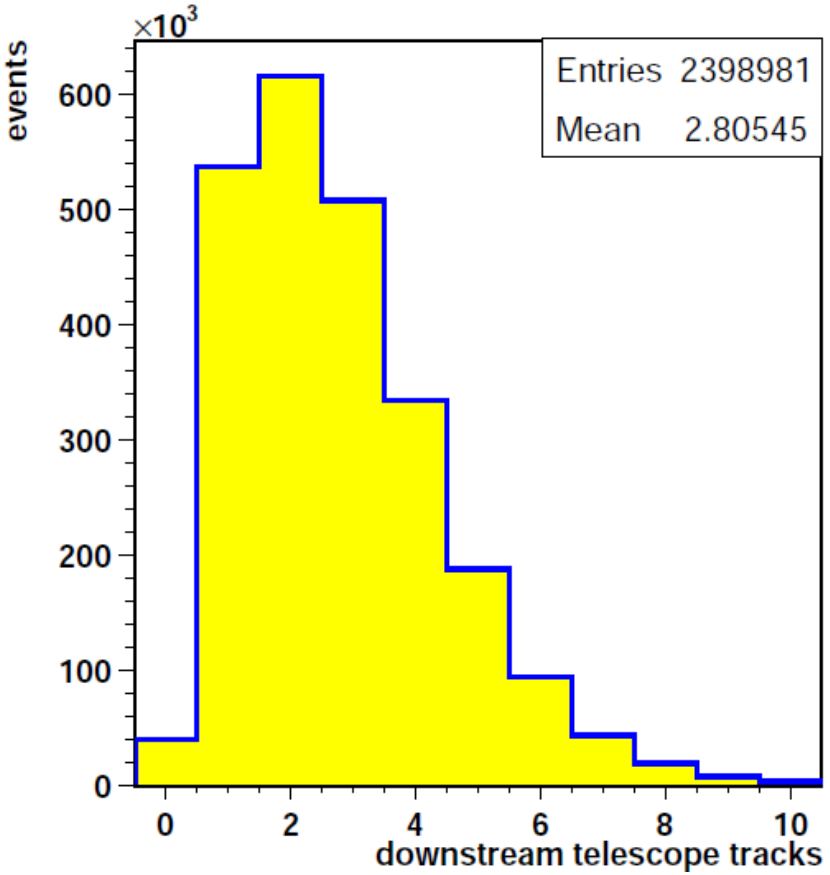
eff = (DUT linked clusters) / (telescope tracks with REF cluster)



- chip 205
  - I_A 25 mA
  - trim 30
  - tilt 19°
  - turn 0°
- runs 6701-6814, selected
- events with readout errors skipped (0.2%)
- **99.8% in fiducial volume**

efficiency vs track multiplicity





- Mimosa telescope has pile up:
  - 120 µs readout
  - 2.8 tracks/event
- **99.9% for 1-track events**

Summary

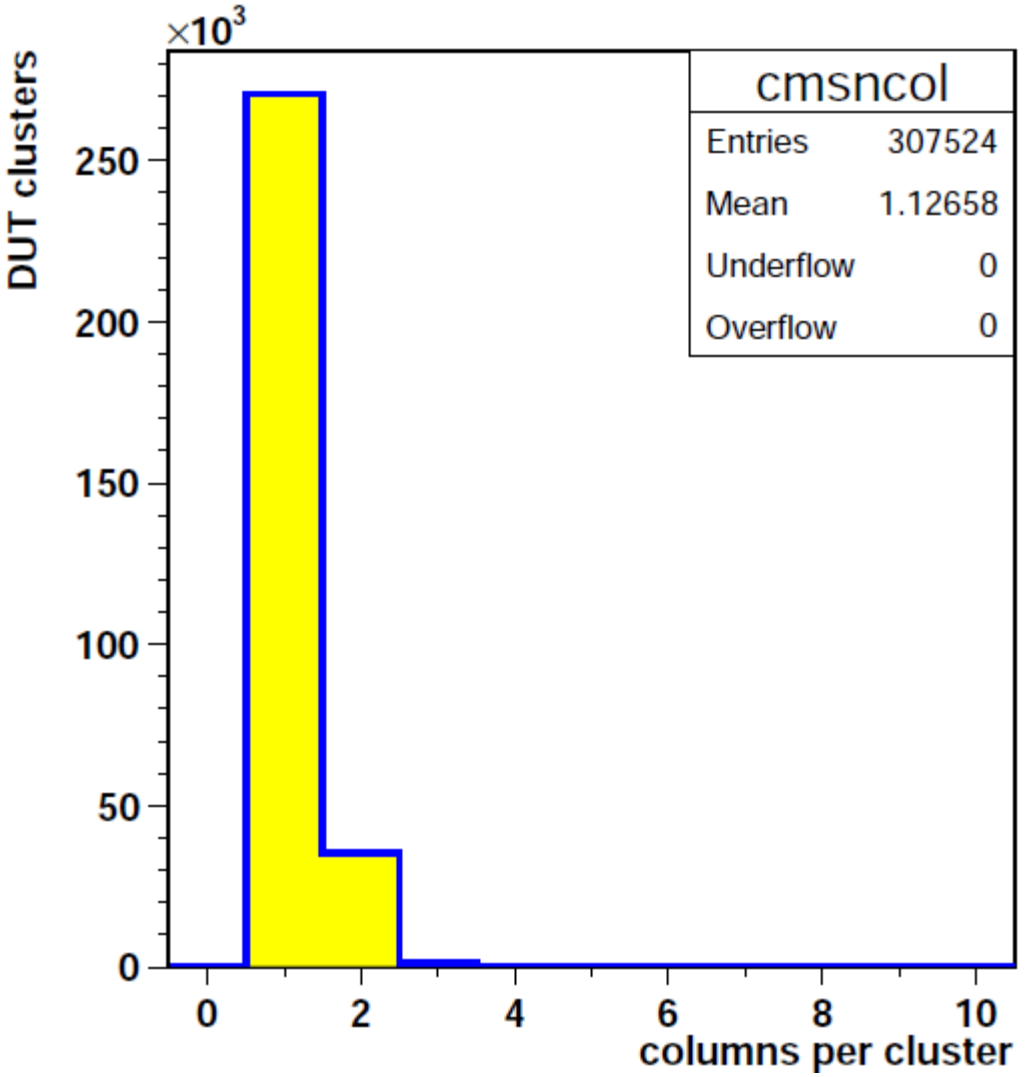
- DESY beam tests continued with psi46dig single chip modules:
  - ROC tuned to 25 mA analog current and trimmed to 1.4 ke threshold
- Best resolutions (in the Landau peak, 285 µm sensors):
  - 6 µm in the row direction with 19° tilt
  - 10 µm in the column direction with 28° turn
  - resolutions saturate for thresholds below 2.5 ke
- Charge collection uniformity:
  - influence of the bias dot gets smeared out with tilt and turn angles
  - Precision data, should be compared to a simulation
- Threshold scans:
  - 10% charge deficit even at 1.5 ke threshold
  - resolution degrades with higher thresholds
- Irradiated ROCs and sensors (3 and 13 MRad) to be measured in April

Back up

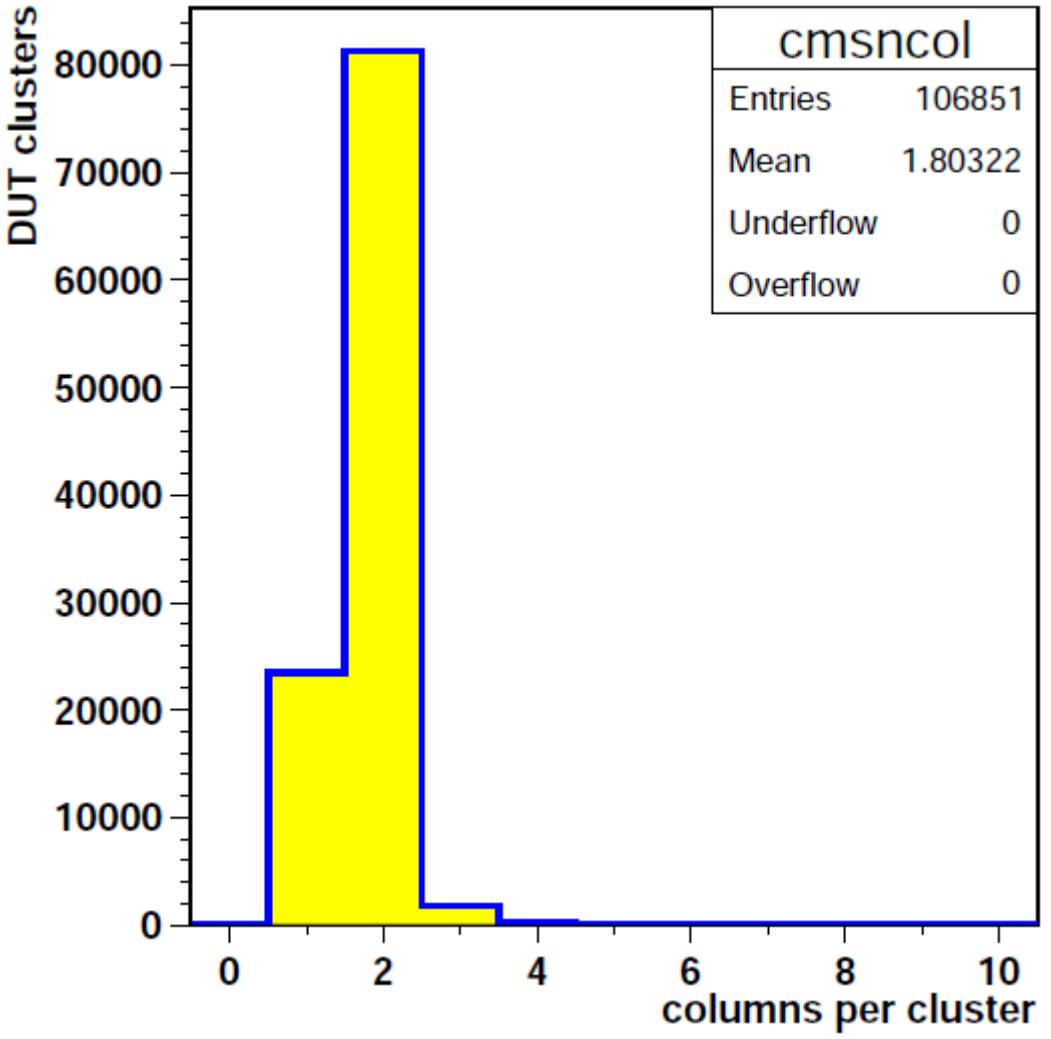
columns per cluster

trim 30 (1.5 ke)

no turn



26° turn

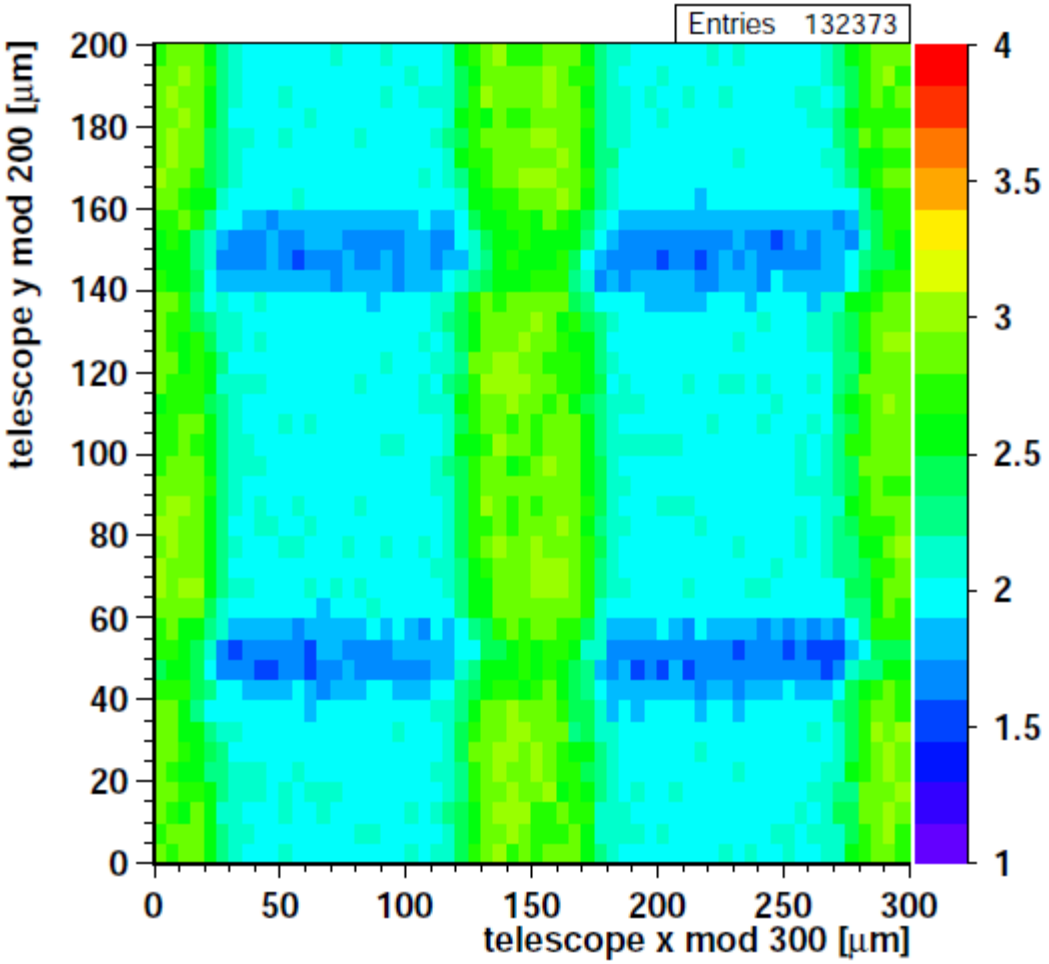


pixels per cluster

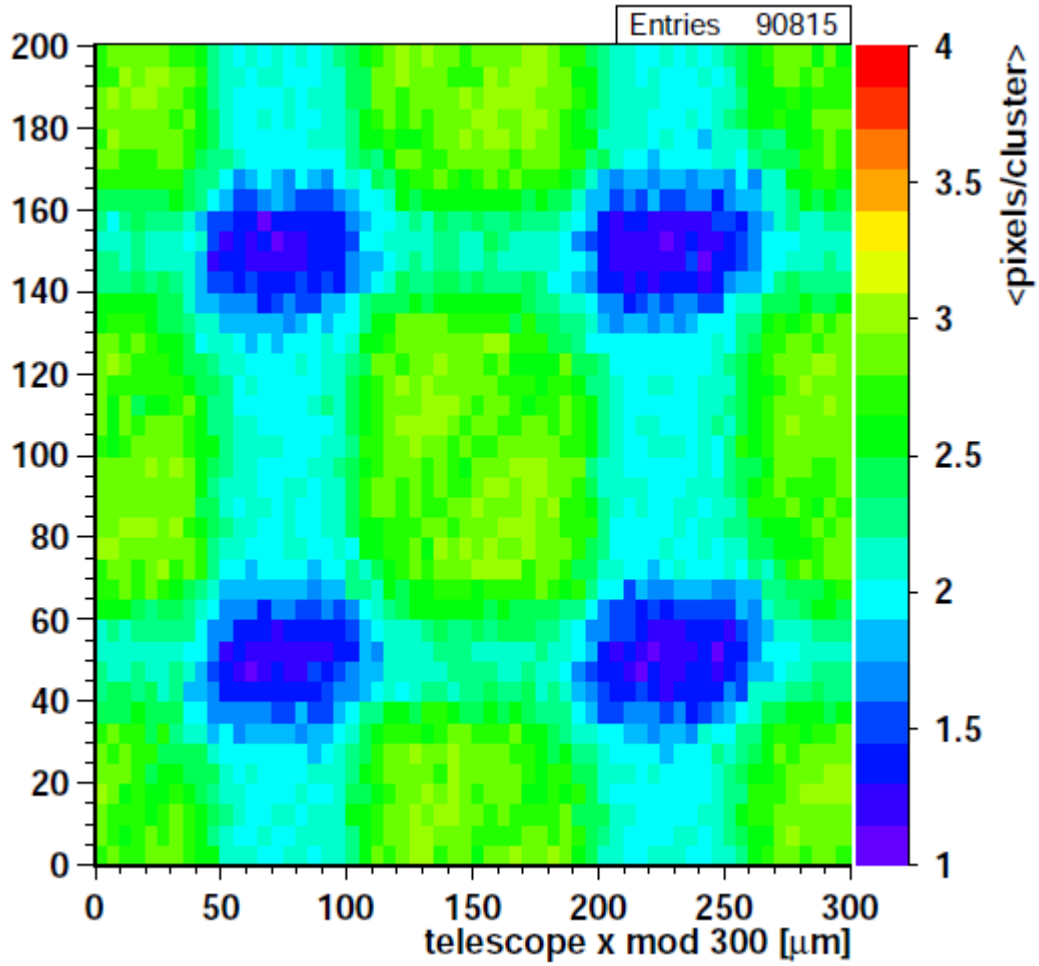
trim 30

2 × 2 pixels

turn 10°, tilt 20°



turn 19°, tilt 17°

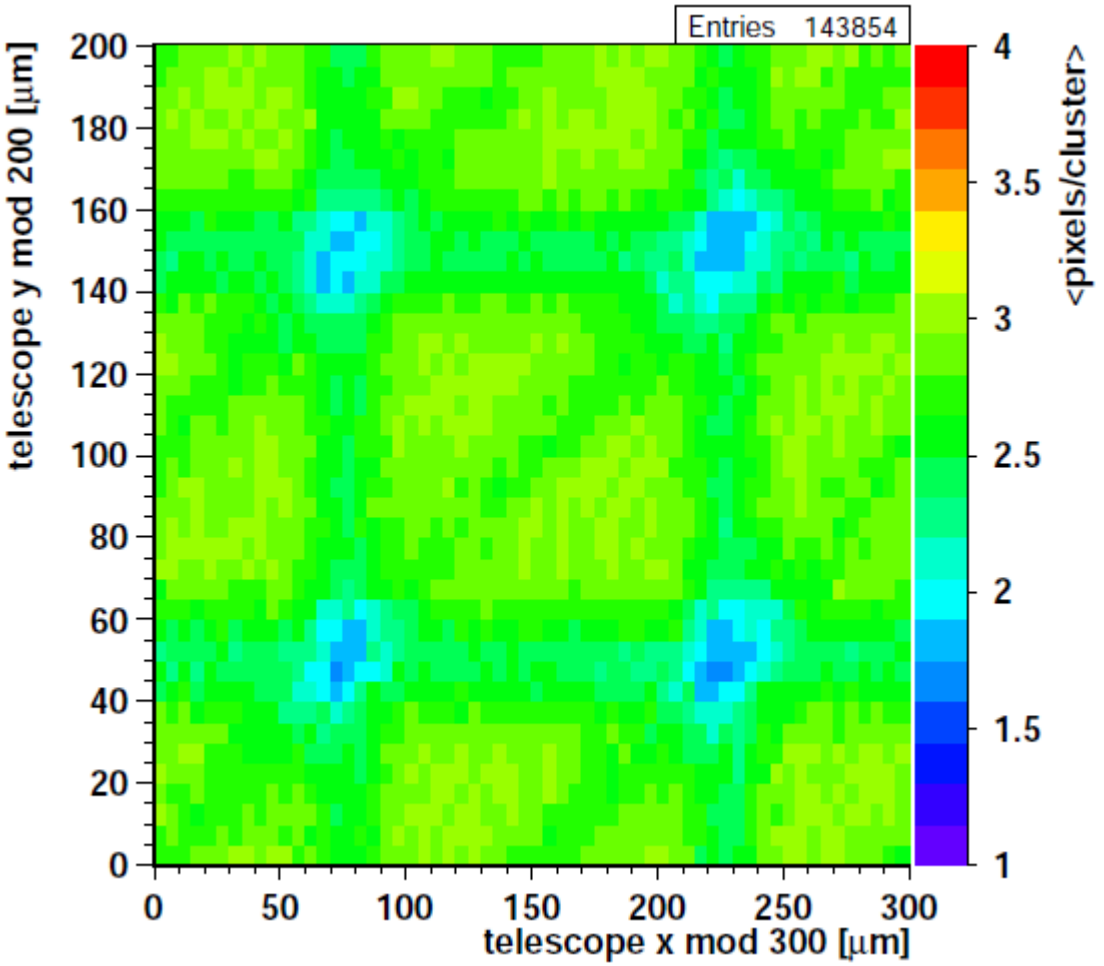


pixels per cluster

trim 30

2 × 2 pixels

turn 27°, tilt 19°

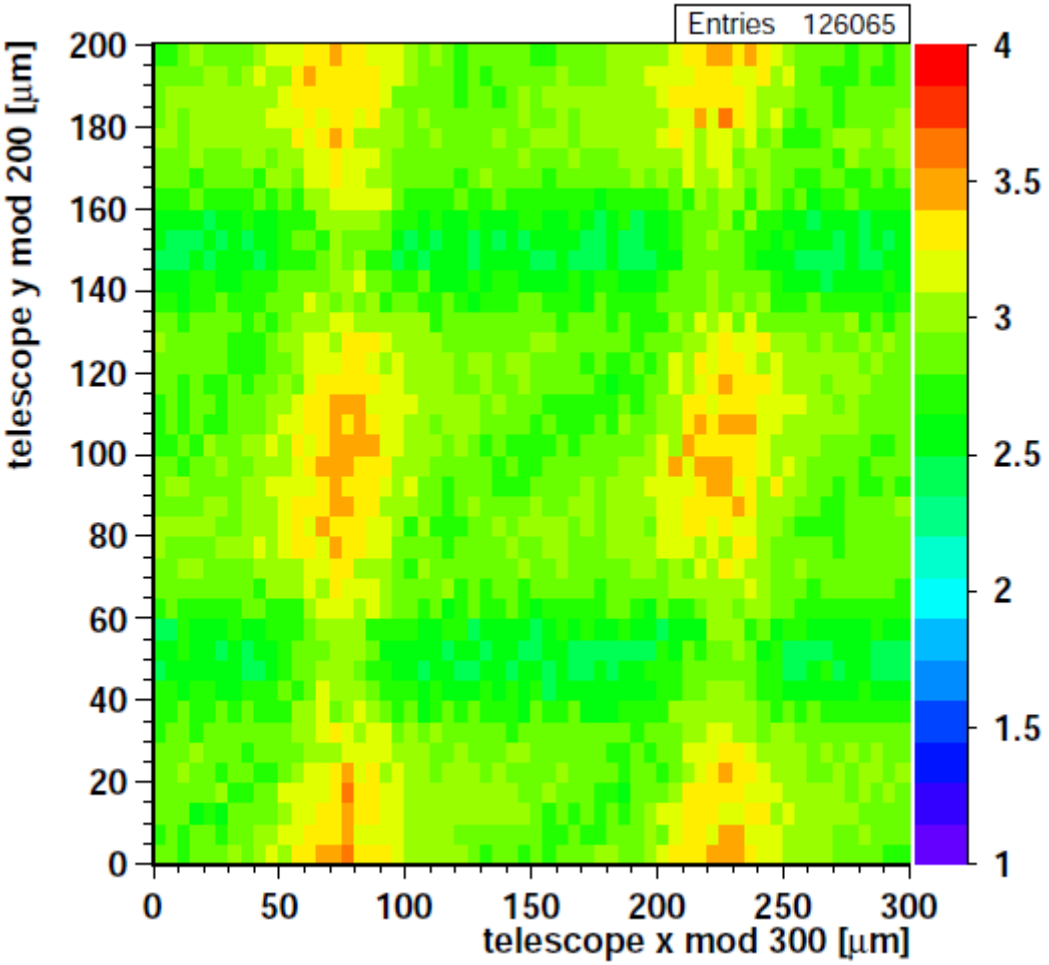


pixels per cluster

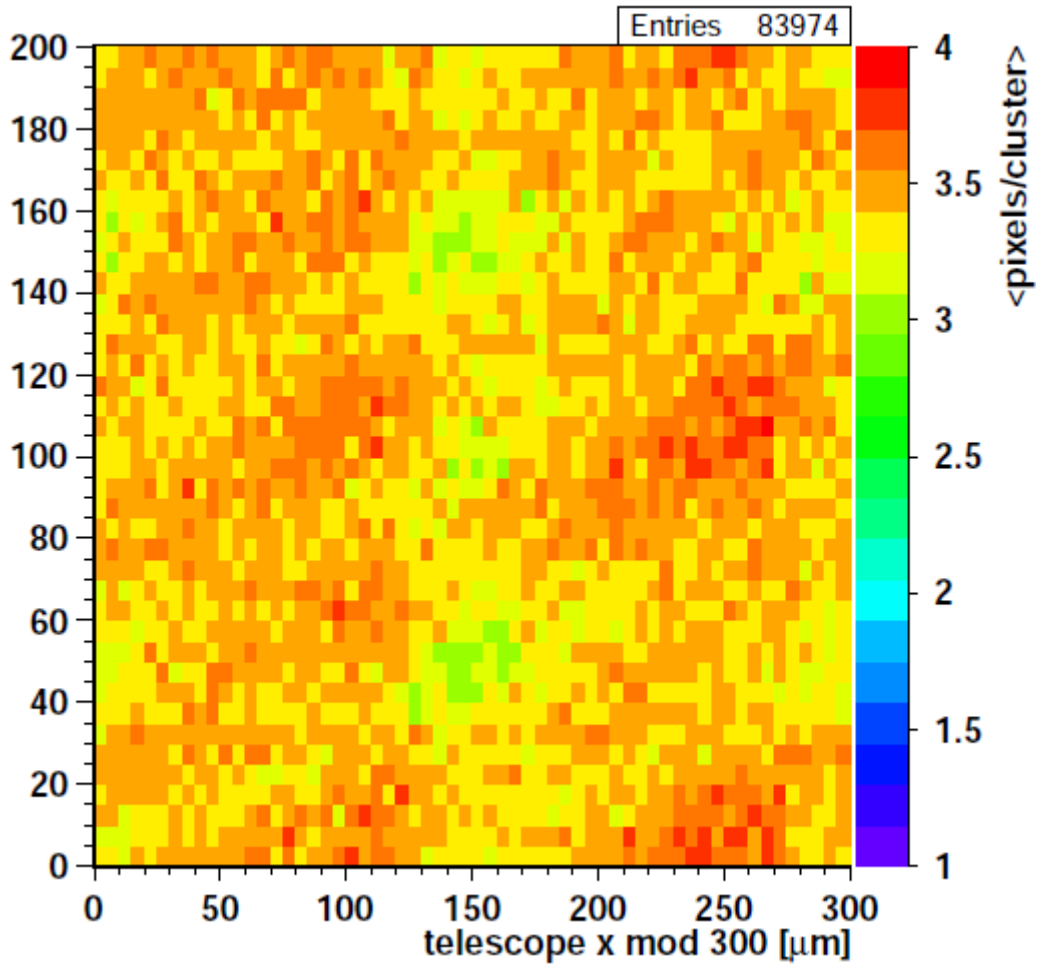
trim 30

2 × 2 pixels

turn 34°, tilt 19°



turn 47°, tilt 21°

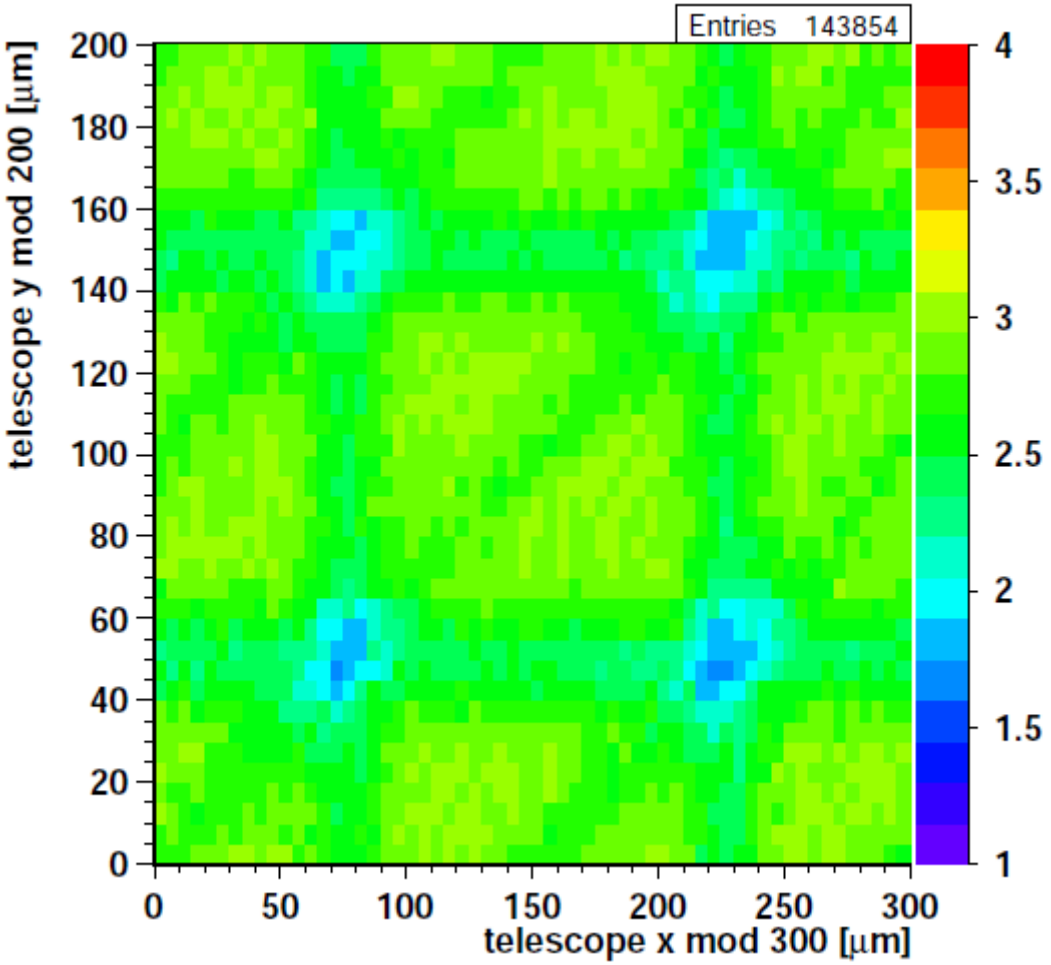


pixels per cluster

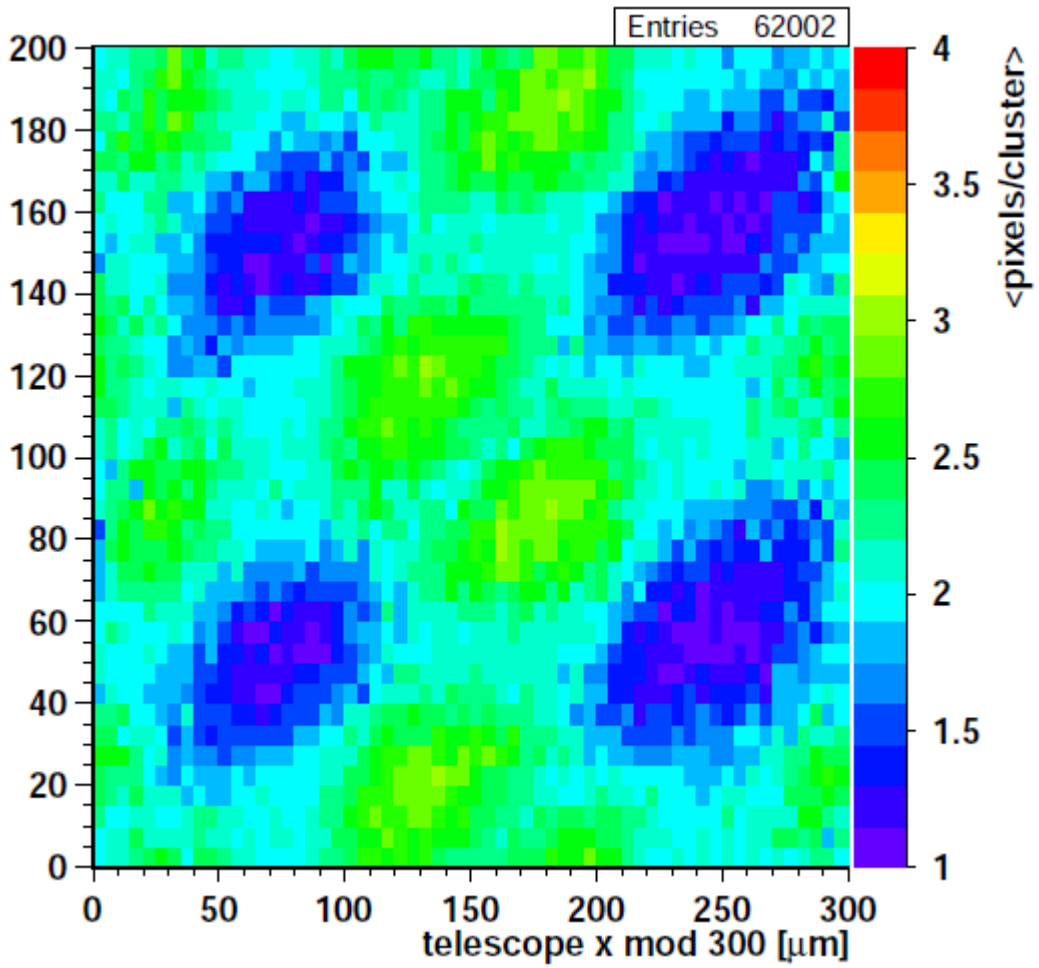
turn 27°, tilt 19°

2 × 2 pixels

trim 30

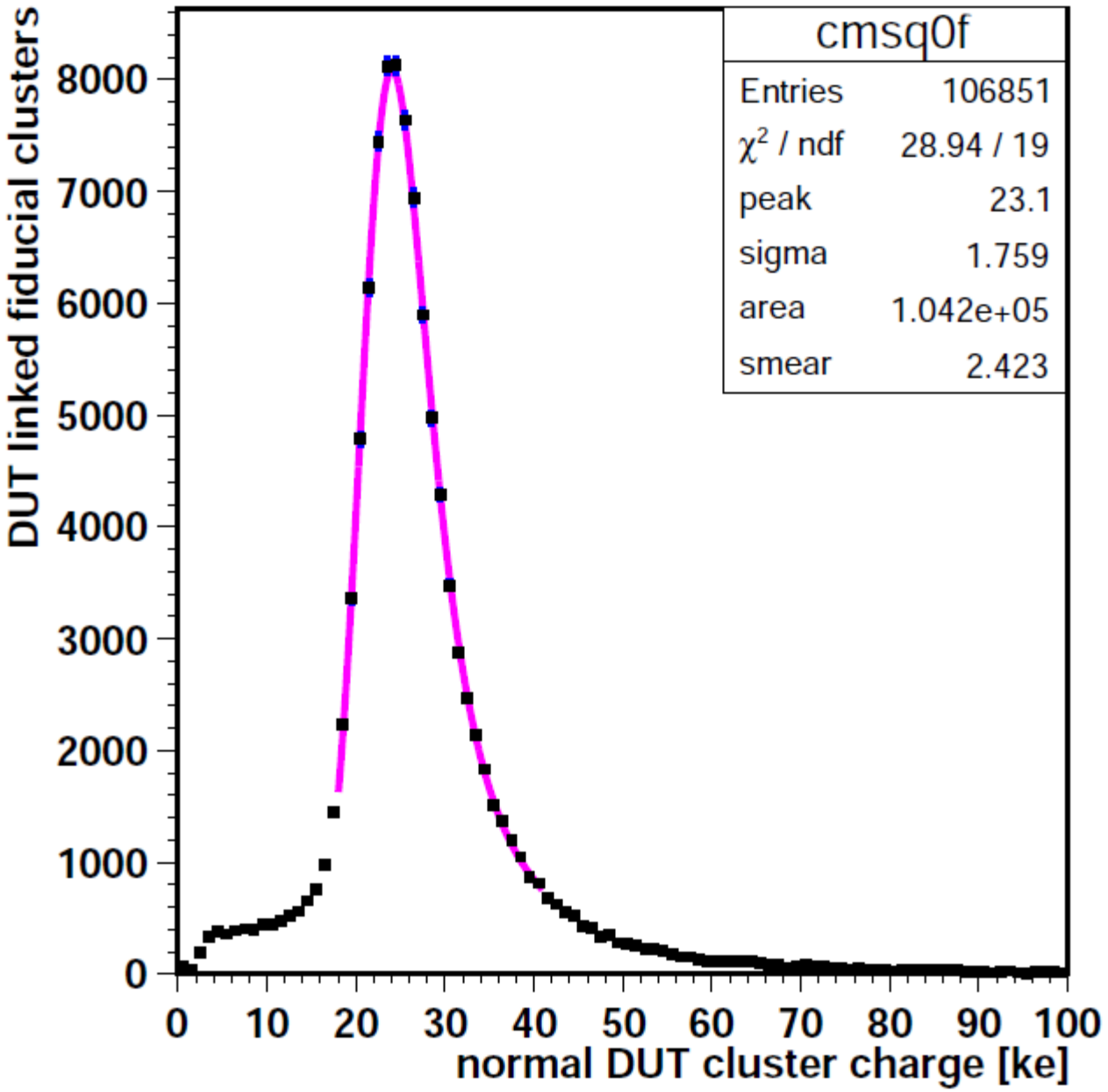


trim 80



fodder for a simulation?

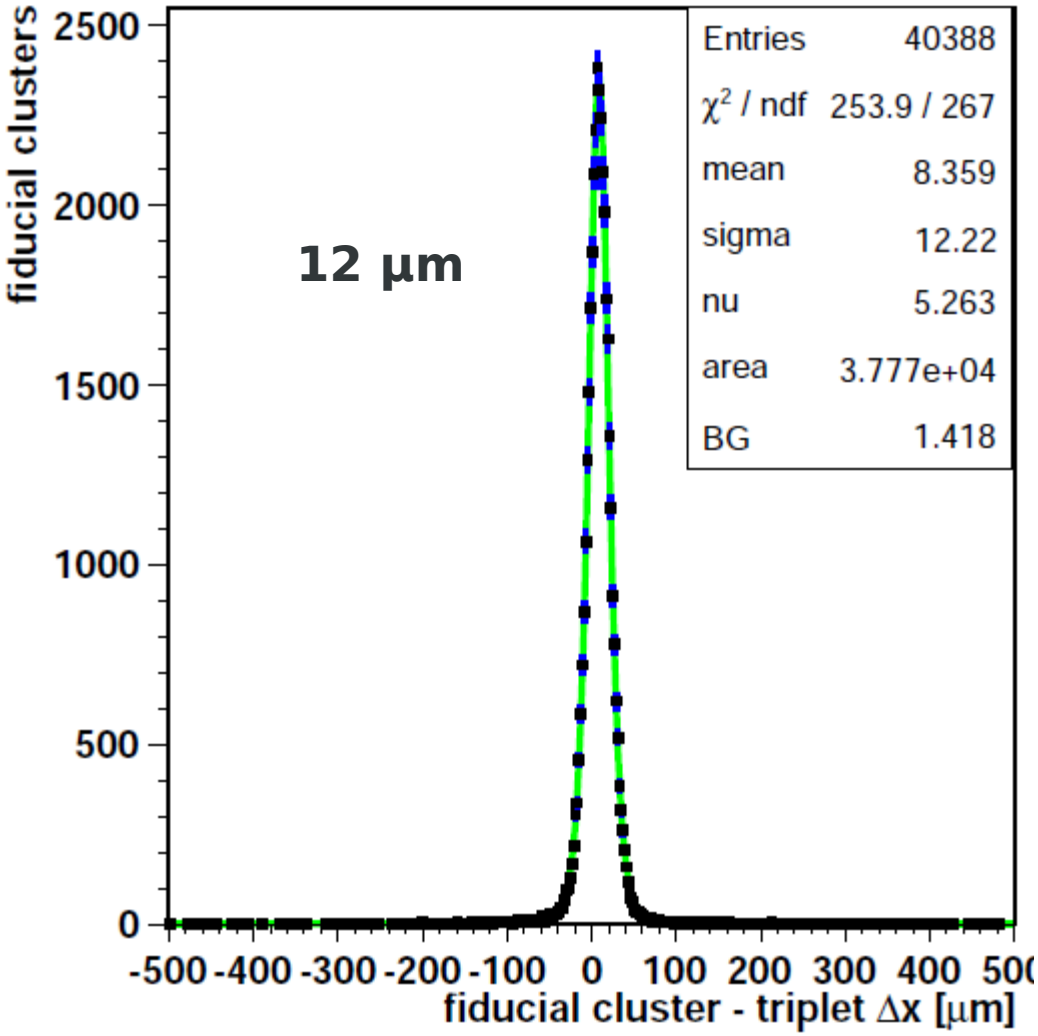
Landau distribution with tilt and turn



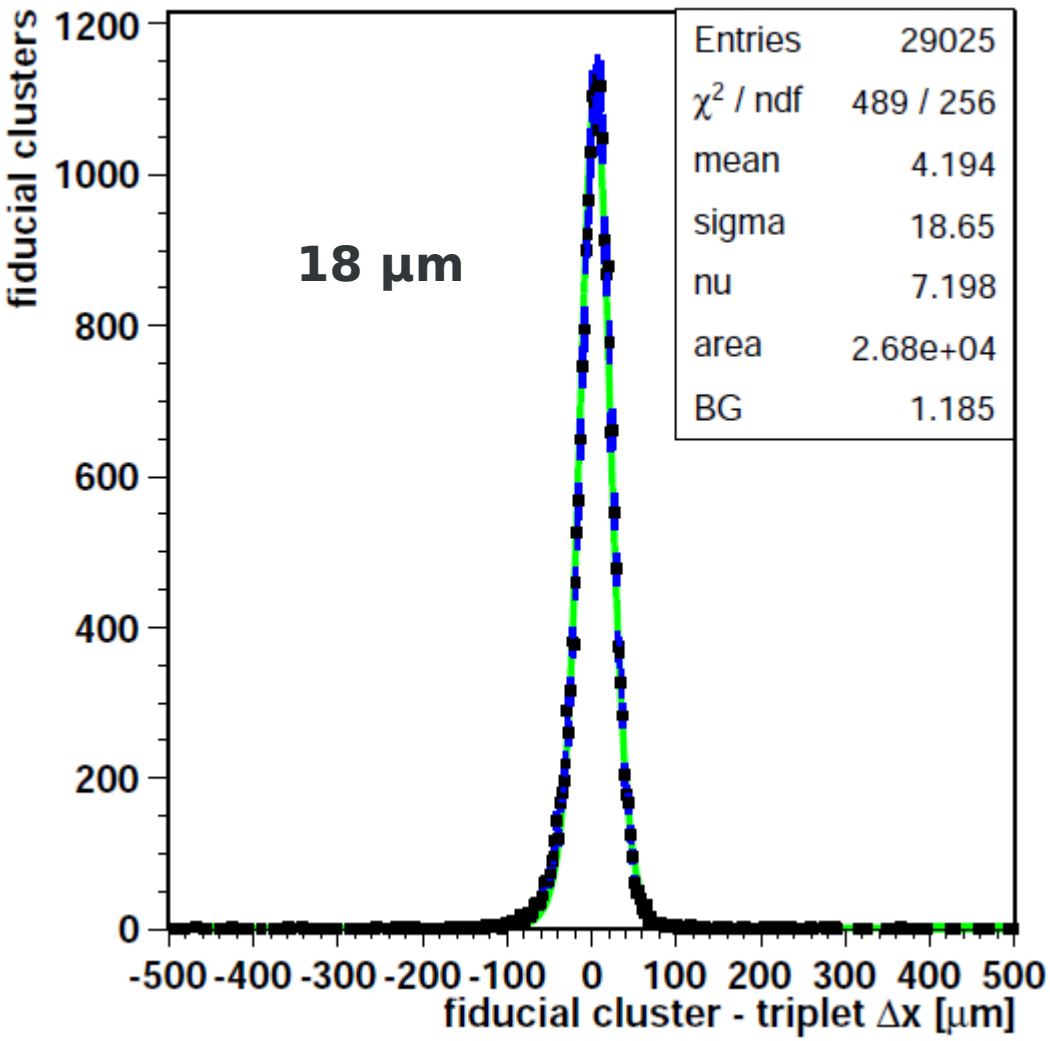
- digital chip 47
- Telescope run 5559:
  - bias -150V
  - turn 26°, tilt 19°
  - **normalized to vertical incidence**
- Gain calibration: Weibull fit, nominal gain 50e/DAC used.
- Cluster charge distribution fit by Landau ⊗ Gauss
  - **peak at 23.1 ke.**

column resolution at 27°

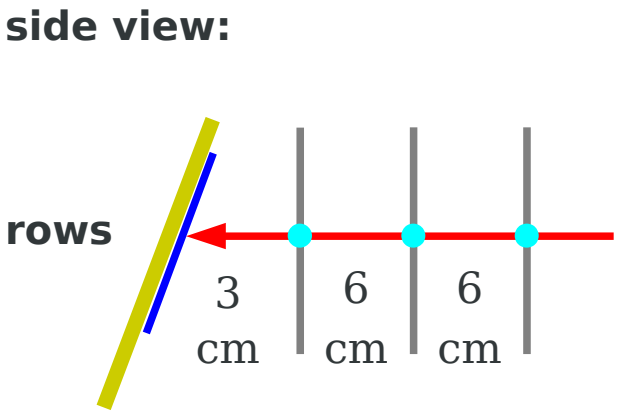
trim 30 (1.5 ke), run 6208



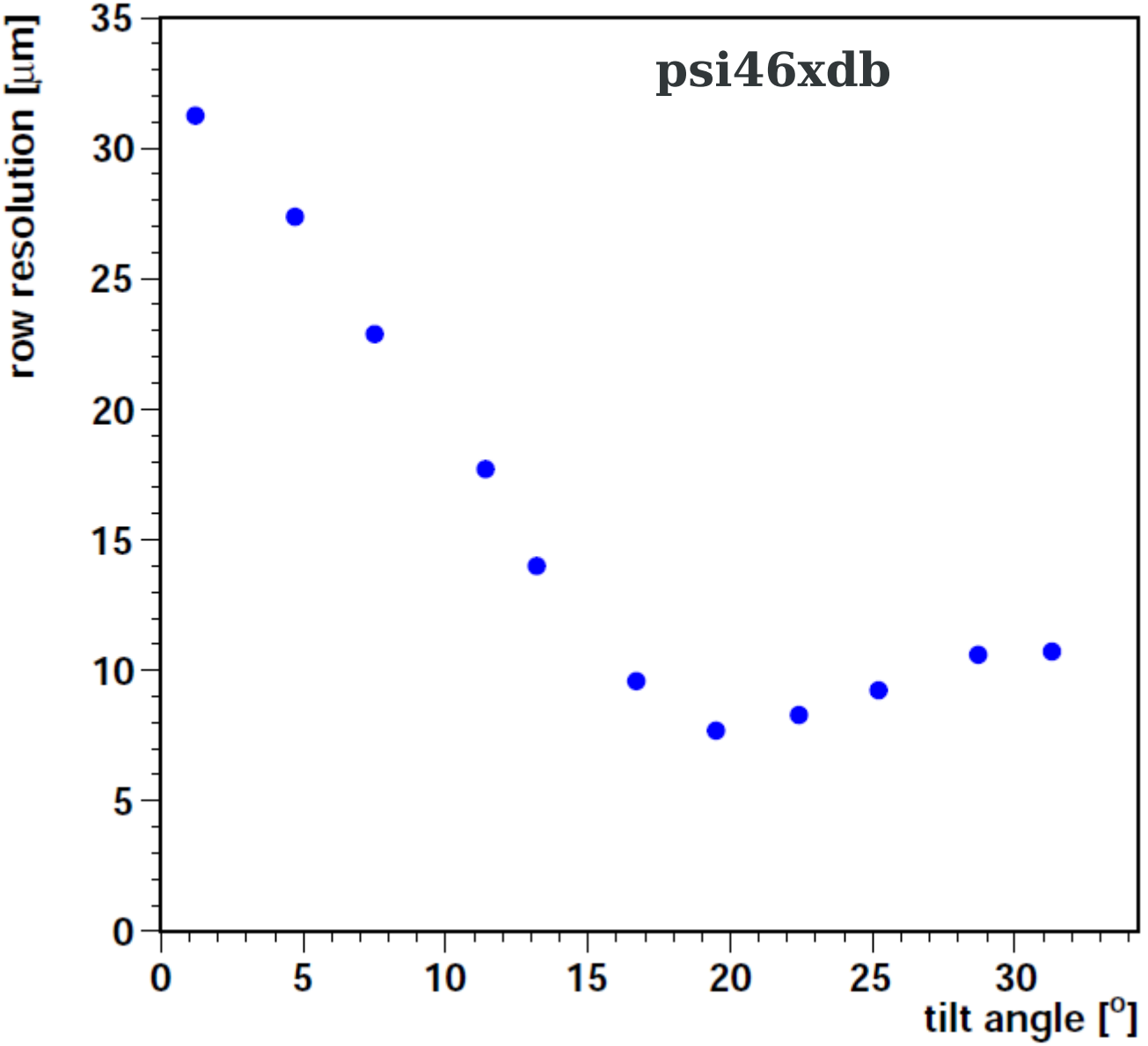
trim 80 (4 ke), run 6200

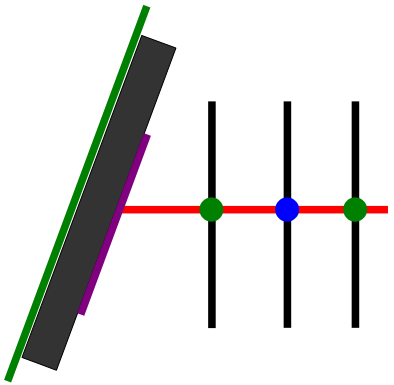


row resolution vs tilt angle



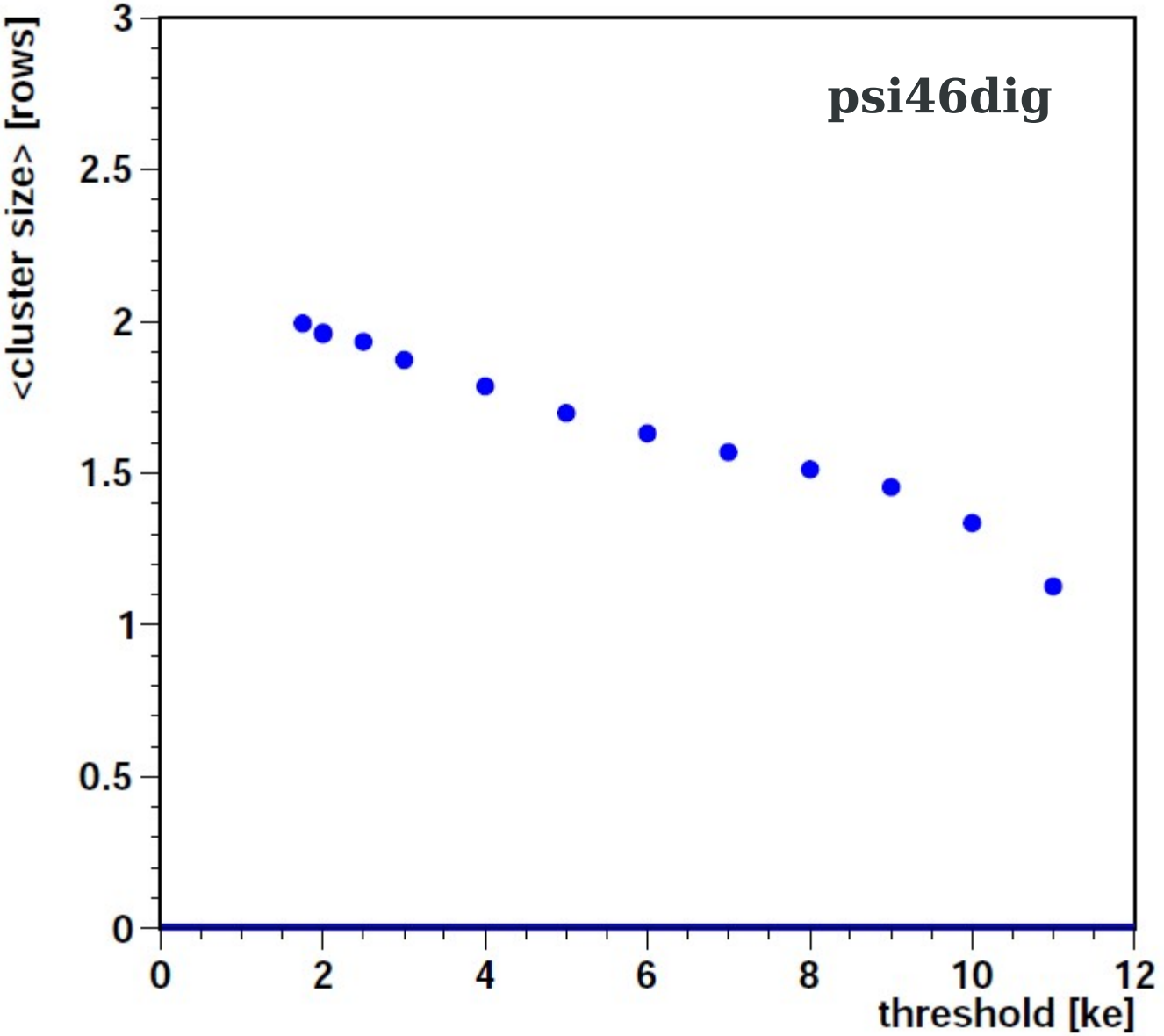
xdb row resolution vs tilt angle

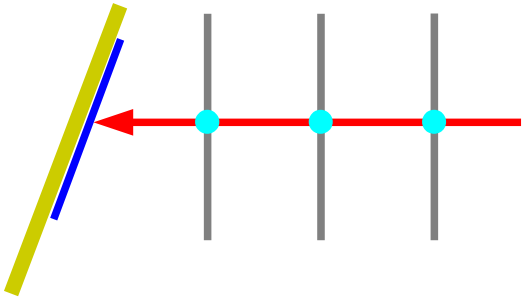




- Chip xdb2, 5.6 GeV, telescope extrapolation uncertainty subtracted.
- row pixels = 100 μm.
- At 0°:
  - σ = 100 / √12 = 29 μm
- Optimal angle 19.5°:
  - σ = 7 μm.
- Similar to psi46

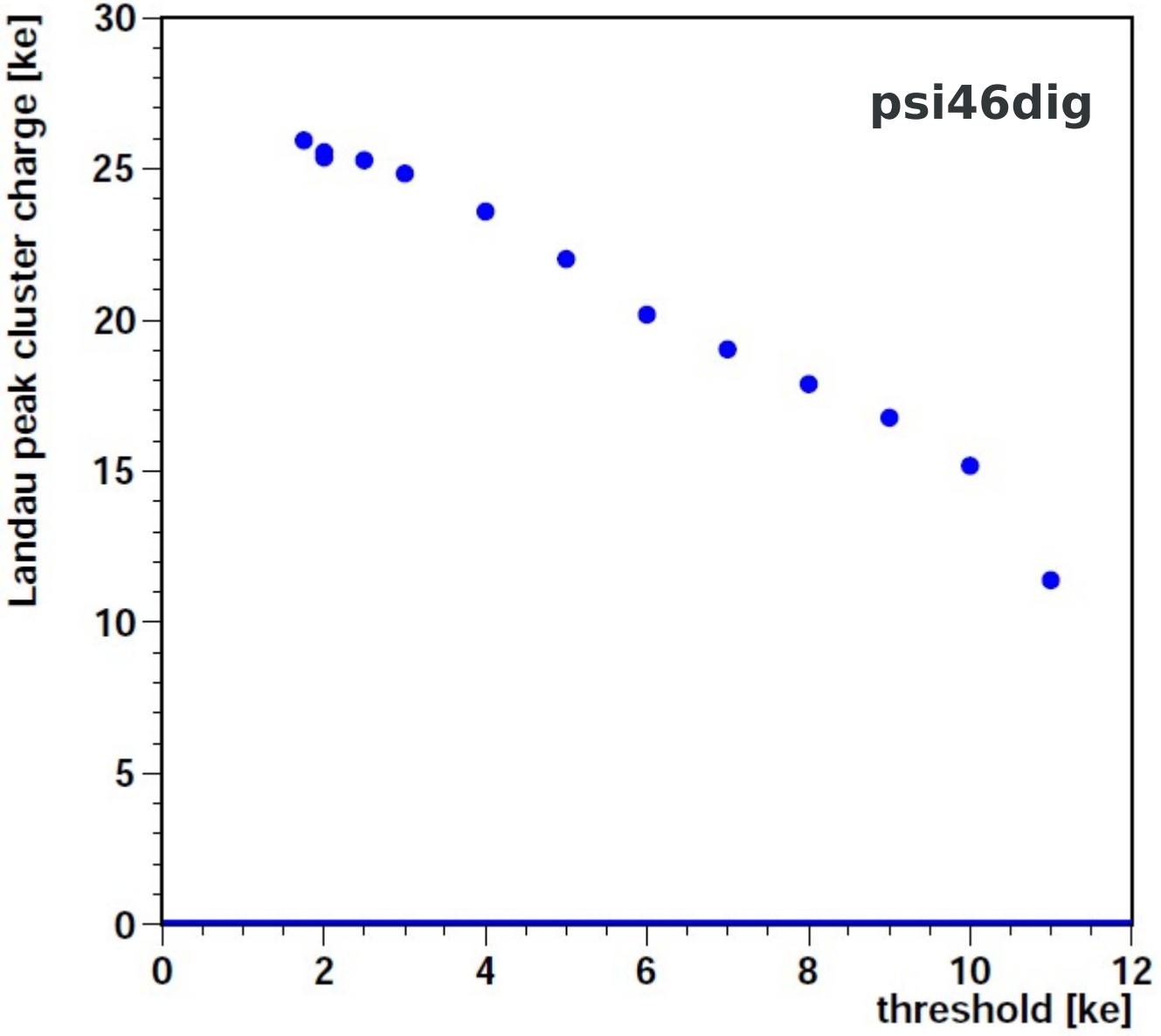
Cluster size vs threshold at 19° tilt

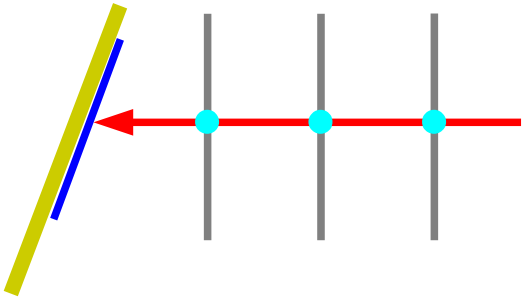




- Digital Chip 202, -150V, 20° tilt, Ia 30 mA
  - runs 5310-5384
- Threshold and delay adjusted together
- rows per cluster:
  - decreases with harder threshold

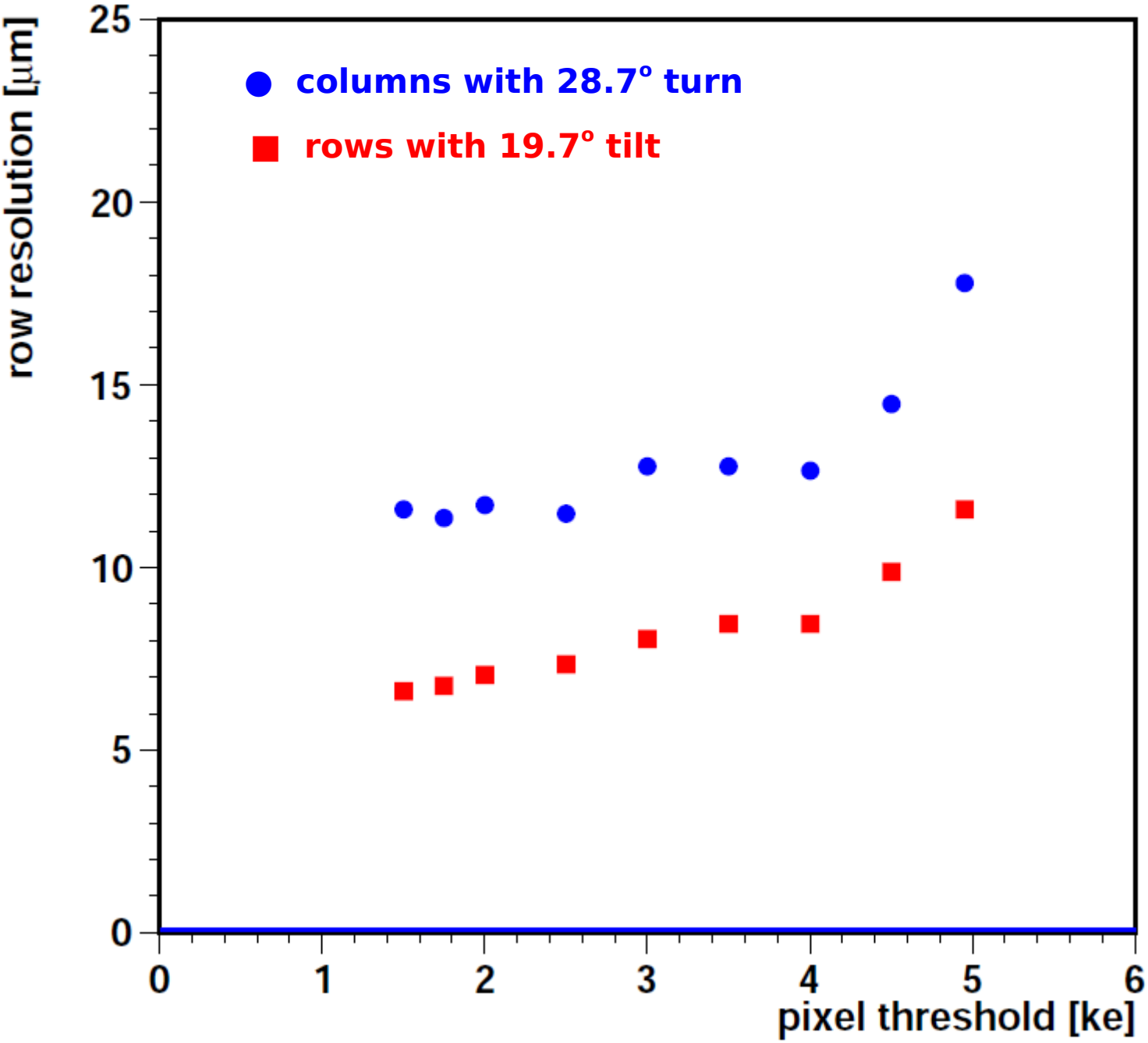
Cluster charge vs threshold at 19° tilt





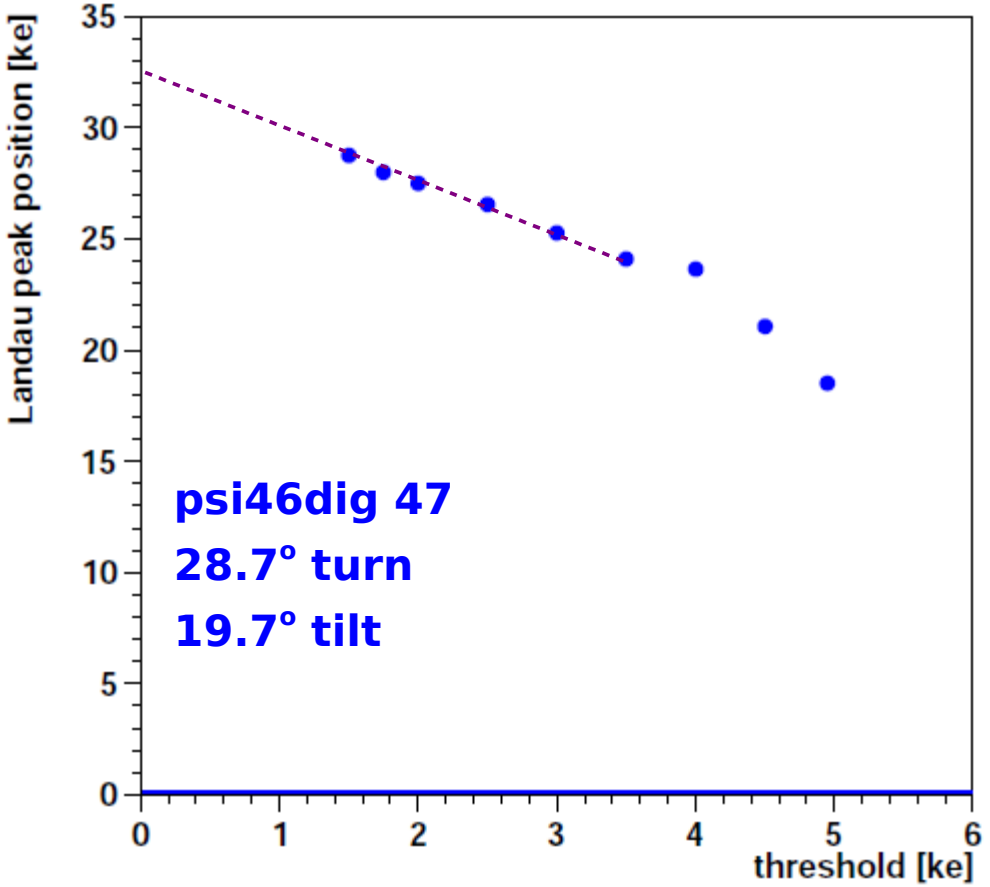
- Digital Chip 202, -150V, 20° tilt, Ia 30 mA
  - runs 5310-5384
- Threshold and delay adjusted together
- Position of Landau peak
  - decreases with harder threshold

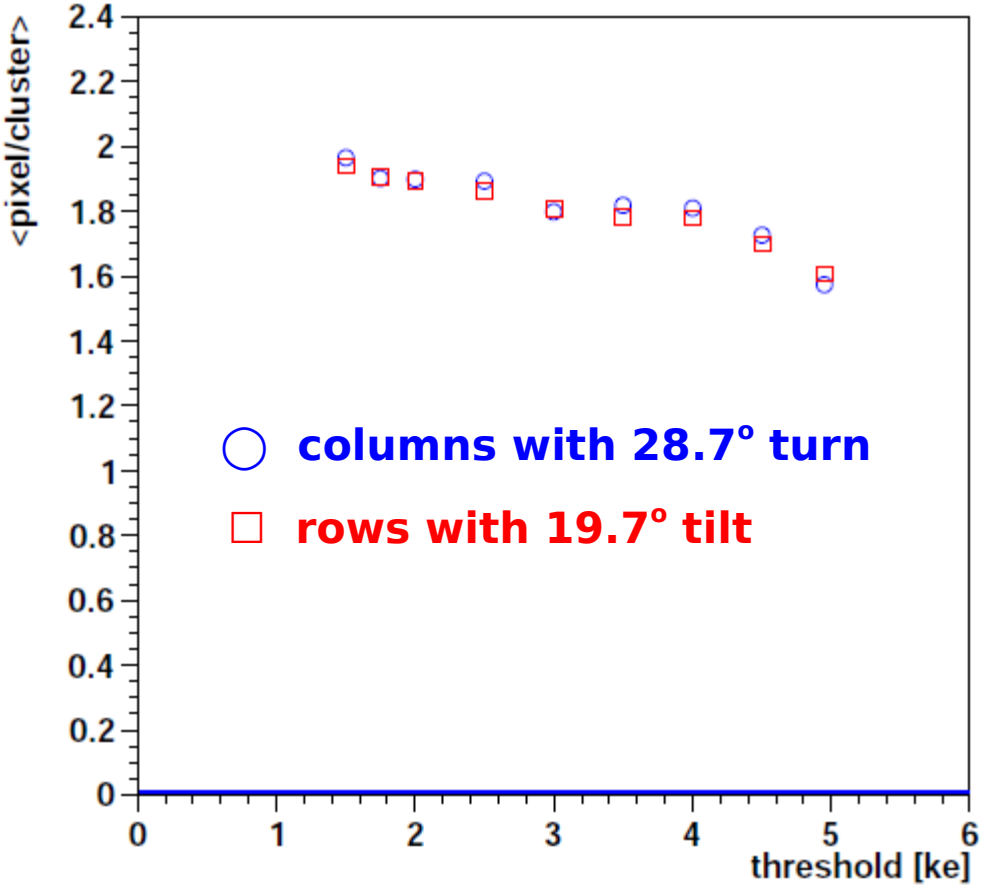
resolution vs threshold chip 47



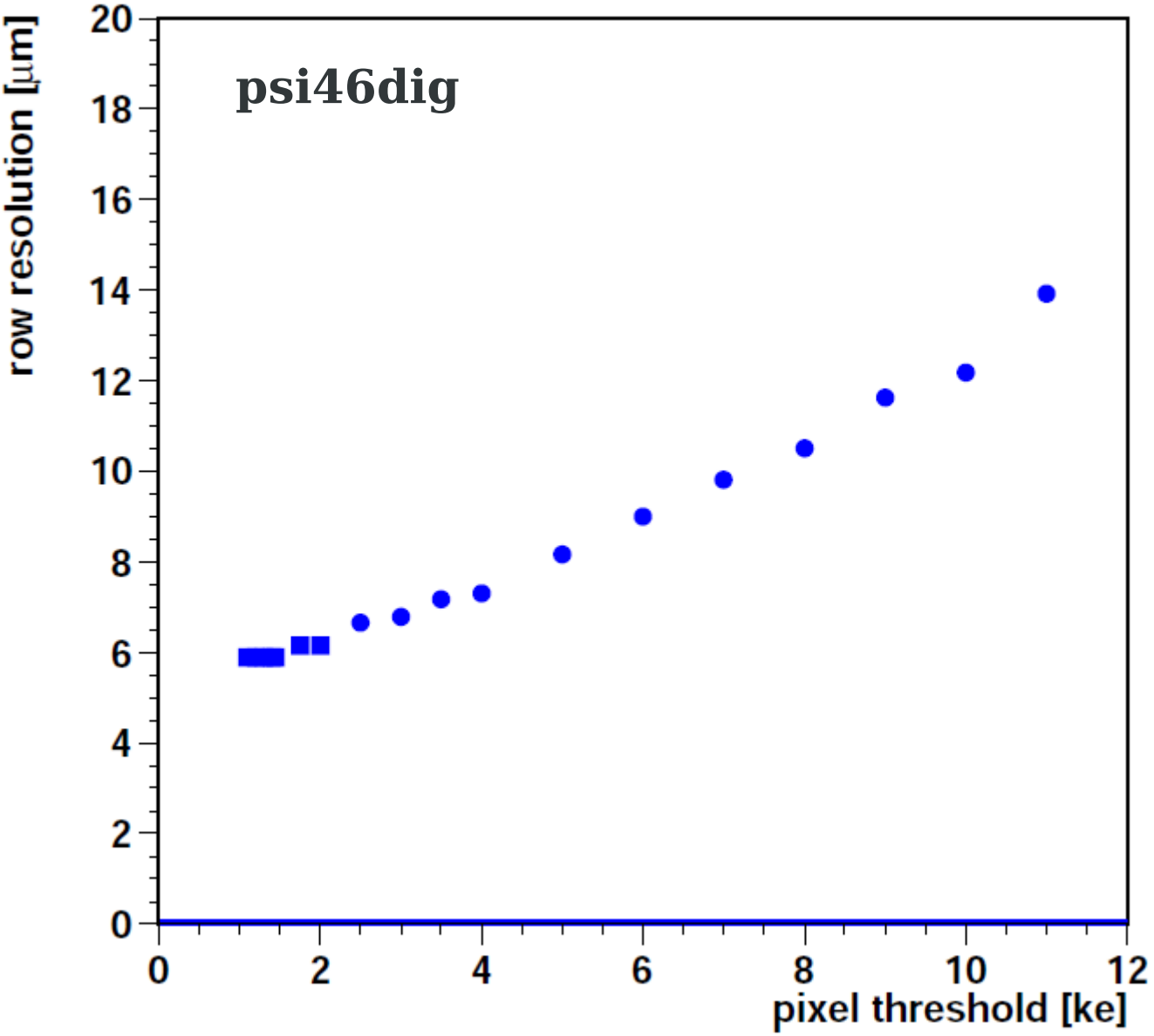
- psi46dig chip 47:
  - Ia 25 mA
  - 28.7° turn
  - 19.7° tilt
- resolution degrades with higher thresholds

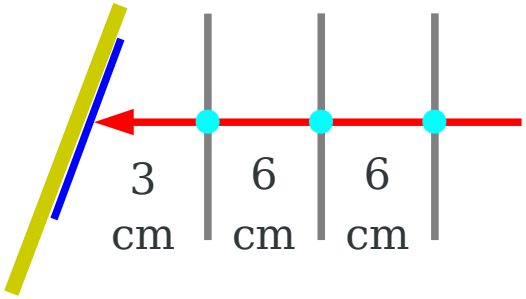
threshold scan with chip 47





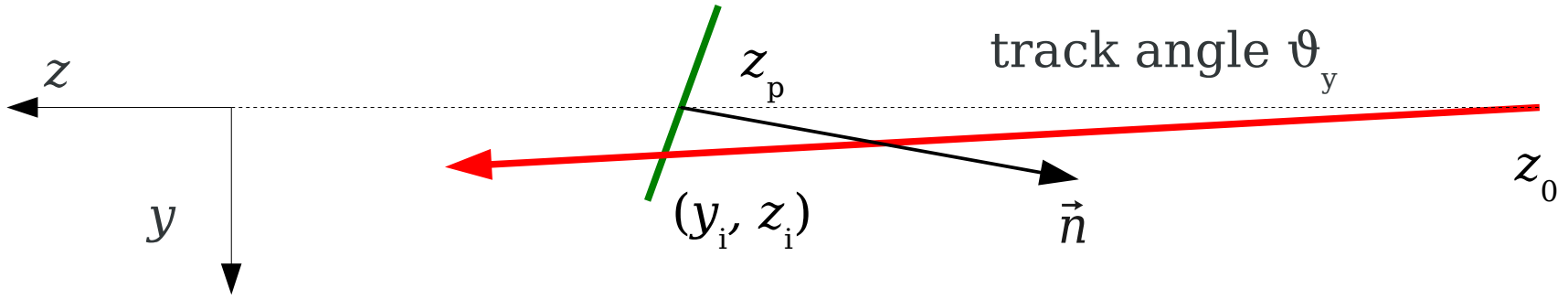
row resolution vs threshold at 19° tilt





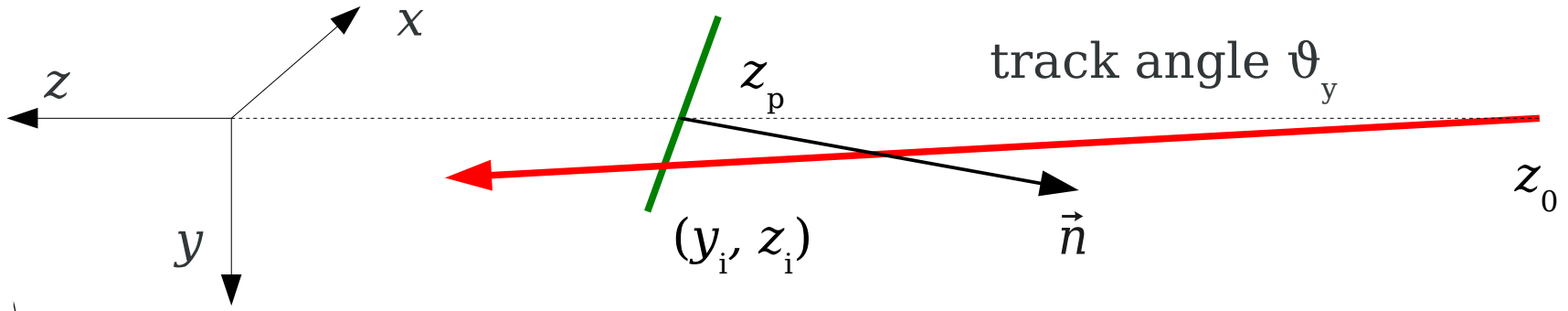
- Digital ROC 203 and 239, 20° tilt
- 4.4 GeV, telescope extrapolation uncertainty subtracted.
- lower threshold:
  - resolution seems to saturate at 6 μm below 2 ke.

intersection



- inclined track:
  - $x = x_0 + (z - z_0) \tan\vartheta_x$
  - $y = y_0 + (z - z_0) \tan\vartheta_y$
- sensor plane at z_p defined by normal vector $\vec{n} = (n_x, n_y, n_z)$
- plane equation: $\{ \vec{r} \mid \vec{n}(\vec{r} - \vec{r}_p) = 0 \}$
- insert track equation into plane equation to get intersect:
  - $z_i - z_0 = \left(n_z(z_p - z_0) - n_y y_0 - n_x x_0\right) / \left(n_x t_x + n_y t_y + n_z\right)$
  - get x_i and y_i by inserting z_i into track equations

Rotations and transformations



$$\begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix} = R_y(\omega)\ R_x(\alpha) \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$R_y(\omega) = \begin{pmatrix} \cos\omega & 0 & \sin\omega \\ 0 & 1 & 0 \\ -\sin\omega & 0 & \cos\omega \end{pmatrix} \qquad R_x(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{pmatrix}$$

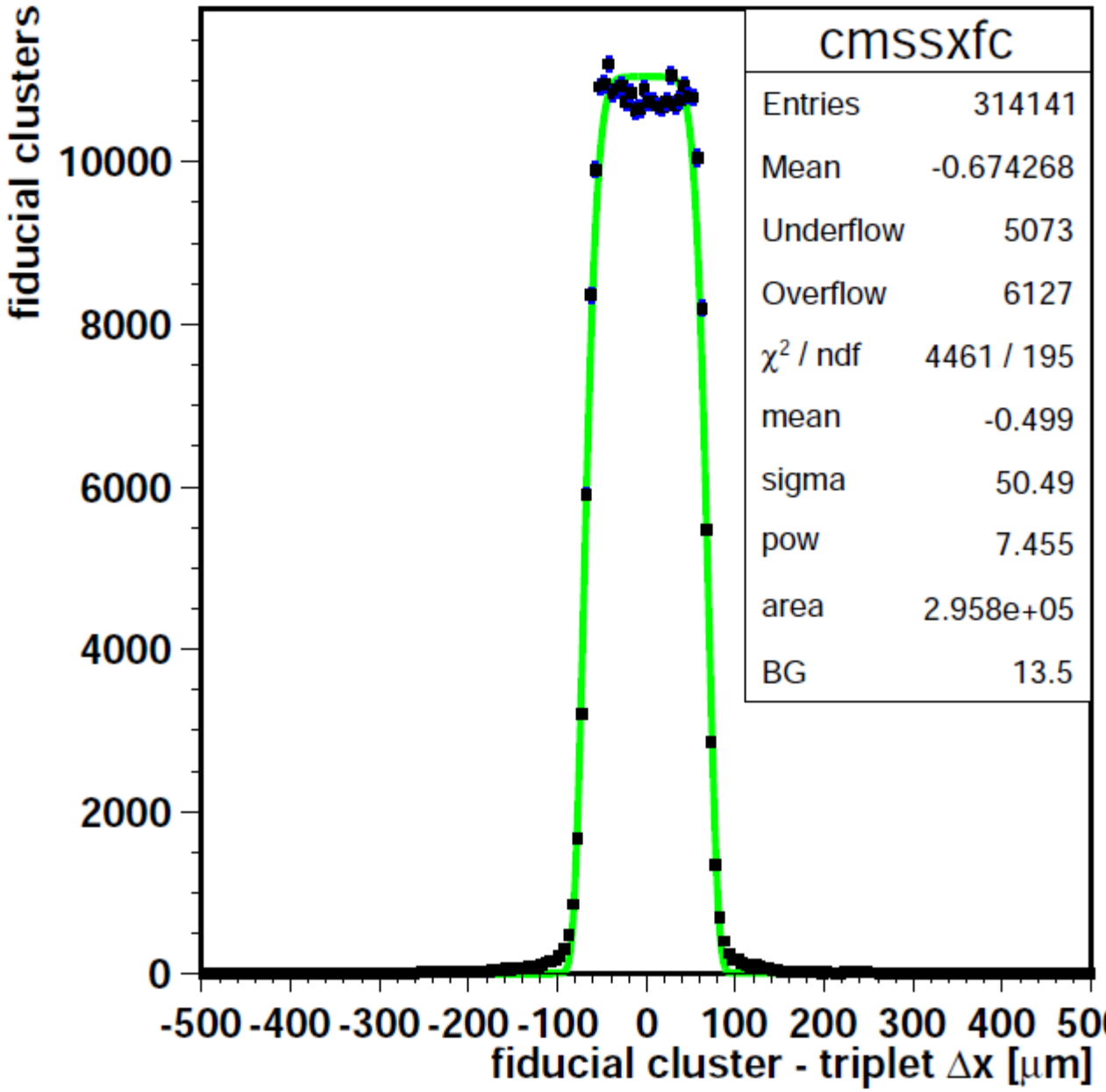
Transform intersect point into sensor coordinates:

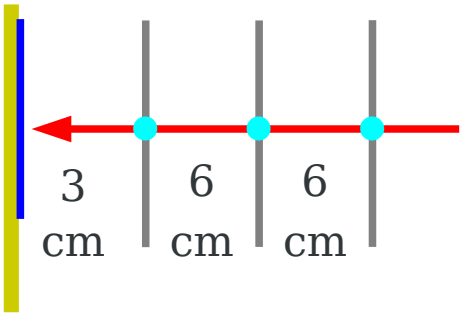
$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = R_z(\varphi)\ R_x(-\alpha)\ R_x(-\omega) \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} + \begin{pmatrix} a_x \\ a_y \\ 0 \end{pmatrix} \qquad \text{where} \quad z' = 0$$

with alignment parameters ϕ, α, ω, a_x, a_y.

column resolution at vertical incidence

dig chip47, trim 24, run 5474, 4 GeV, 0° turn





- Horizontal = columns
  - pixel width 150 µm
- Vertical incidence:
  - no charge sharing
  - residuals have box distribution
- Fit with generalized error function
  - Residual: 50 µm,