Beam test with turn and tilt part III

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Hamburg CMS Pixel Upgrade meeting, 8.3.2013

- first tested Jan 18, 2013

- scheduled beam test Feb 4-9, 2013

- more beam time Feb 27 – Mar 3, 2013

- new psi46dig chip 205

- threshold scans

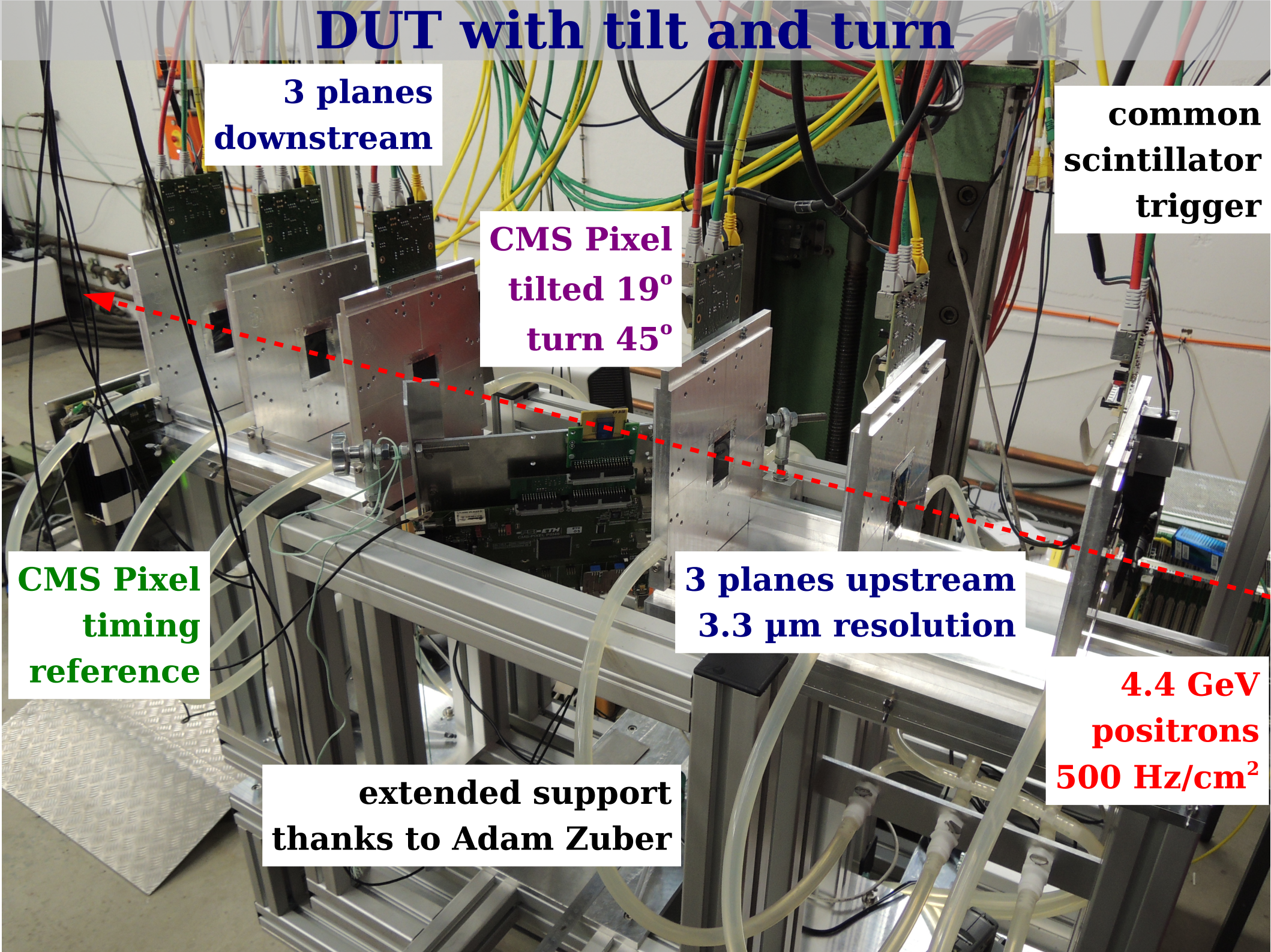# DUT with tilt and turn

3 planes
downstream

CMS Pixel
tilted 19°
turn 45°
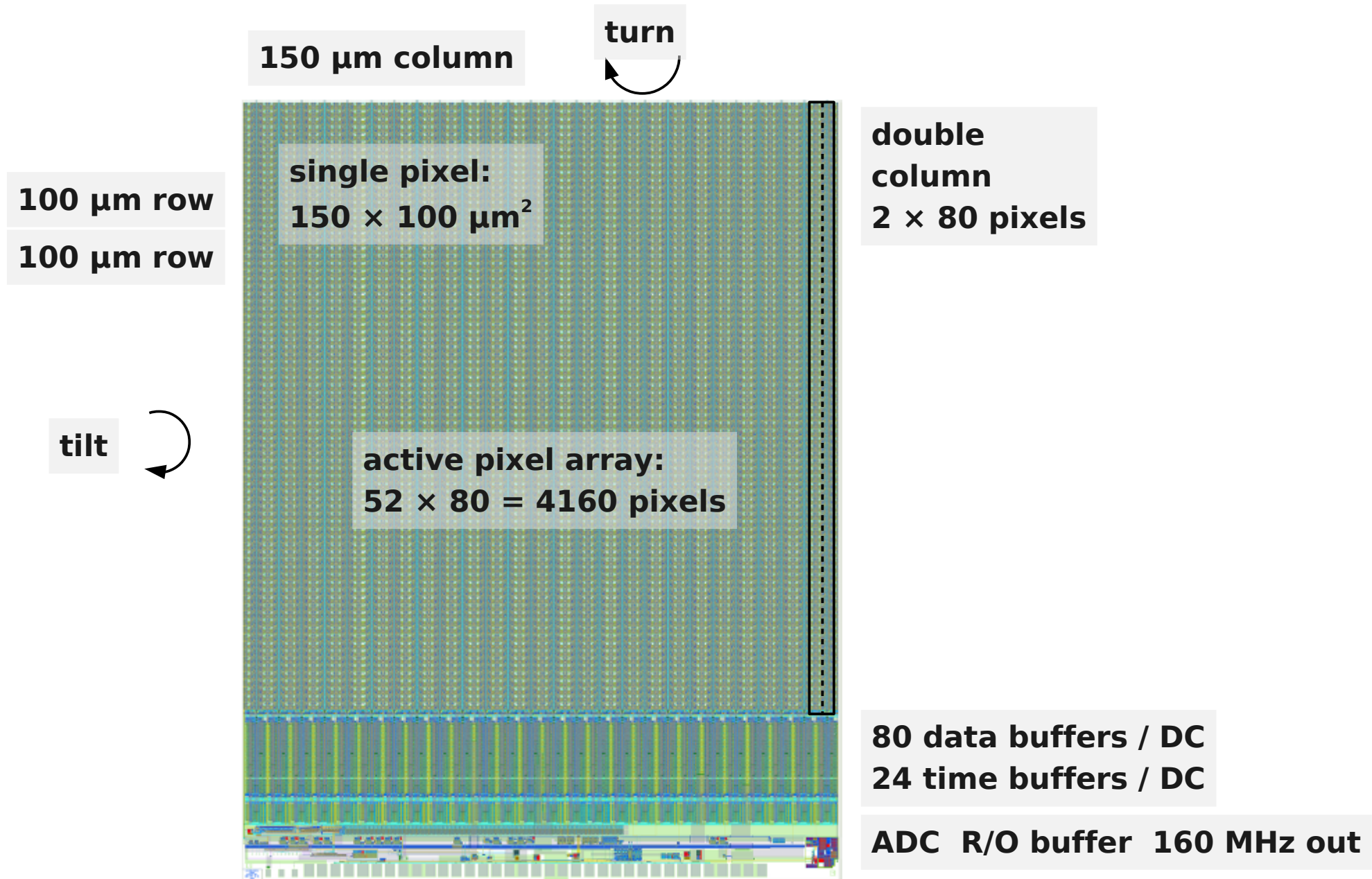
common
scintillator
trigger

CMS Pixel
timing
reference

3 planes upstream
3.3 μm resolution

4.4 GeV
positrons
500 Hz/cm²

extended support
thanks to Adam Zuber

psi46dig pixel readout chip

150 μm column

turn

100 μm row

100 μm row

single pixel:
150 × 100 μm²

double
column
2 × 80 pixels

tilt

active pixel array:
52 × 80 = 4160 pixels

80 data buffers / DC
24 time buffers / DC

ADC R/O buffer 160 MHz out
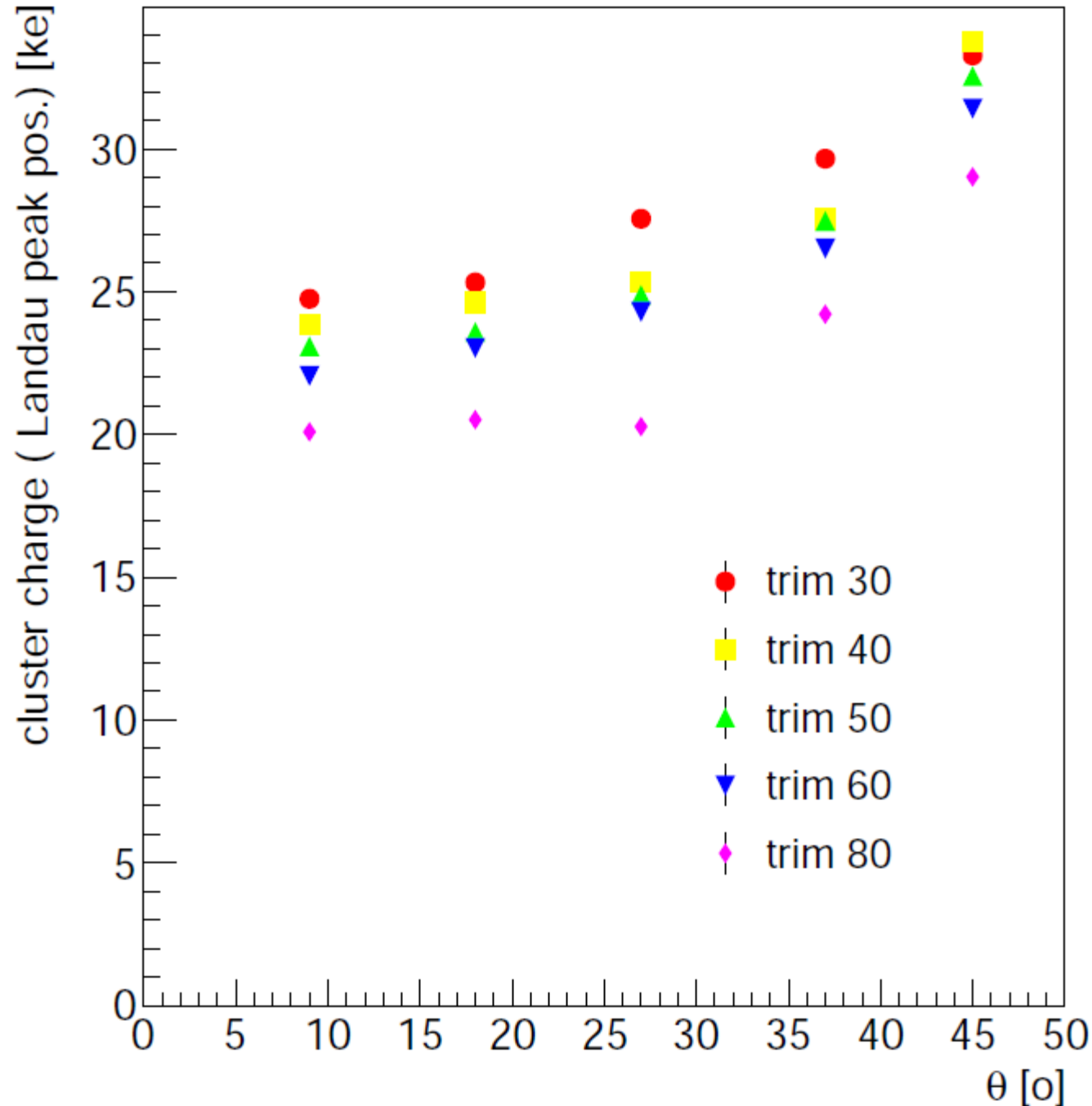
column resolution vs turn angle
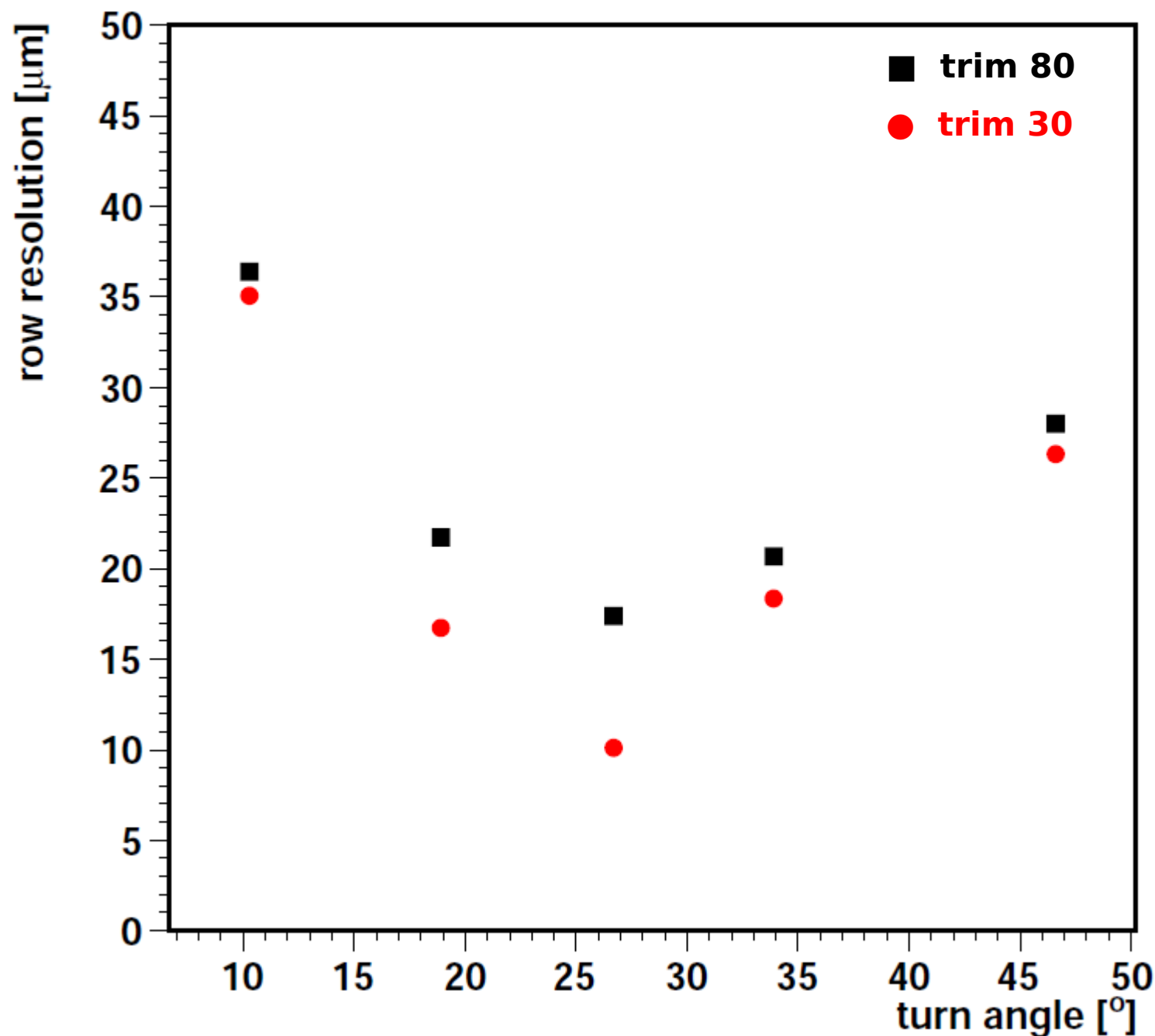
- **psi46dig chip 47:**
  - ‣ Ia 25 mA
- **optimal:**
  - ‣ 10 µm at 27° with lowest threshold
- Less threshold dependence at other angles

columns per cluster vs turn angle
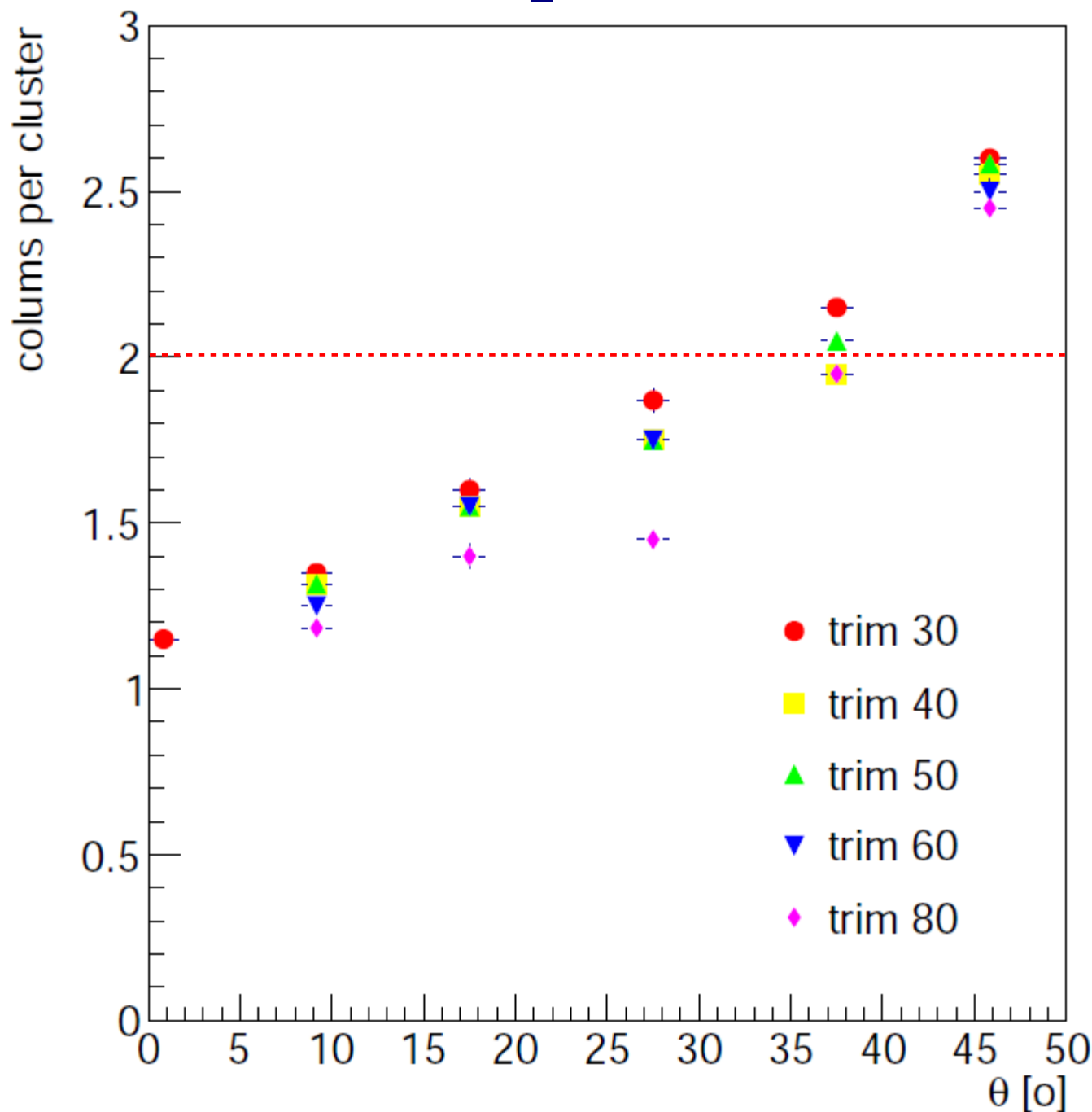
- psi46dig chip 47
  - ‣ Ia 25 mA
  - ‣ trim: ~50 e/DAC
- Optimum:
  - ‣ 2 columns/cluster
  - ‣ reached at 27 deg, as expected from geometry

Legend:
- ● trim 30
- ■ trim 40
- ▲ trim 50
- ▼ trim 60
- ◆ trim 80

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)

Legend (in plot):
- trim 30
- trim 40
- trim 50
- trim 60
- trim 80

Beam test program II

- problem (or outlier) at 28° turn and trim 80?

- focus on 28° turn:

  - repeat psi46dig chip 47

  - new psi46dig chip 205 (received from PSI in Feb 2013)

  - thresholds trimmed to 28, 30, 32, 35, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160 DAC (50 e/DAC)

  - higher thresholds require different WBC (comparator time walk)

  - bias -150 V

  - fixed tilt angle 19° (like Lorentz angle in CMS)

  - 4.4 GeV, typically 500 Hz telescope trigger rate with 9E9 e$^-$ in DESY

- data taken Feb 27 – Mar 3
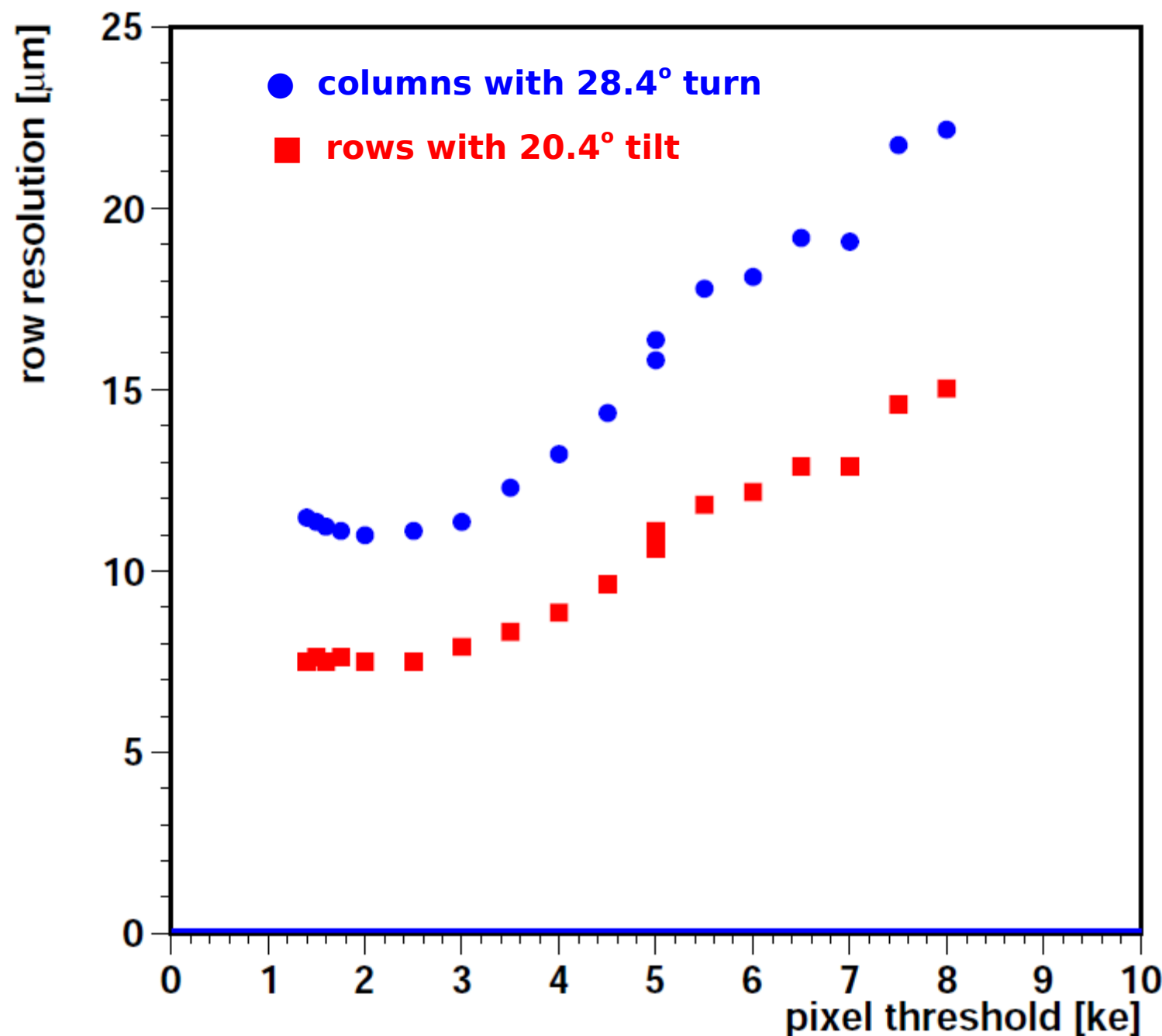
resolution vs threshold chip 47

- columns with 28.7° turn
- rows with 19.7° tilt
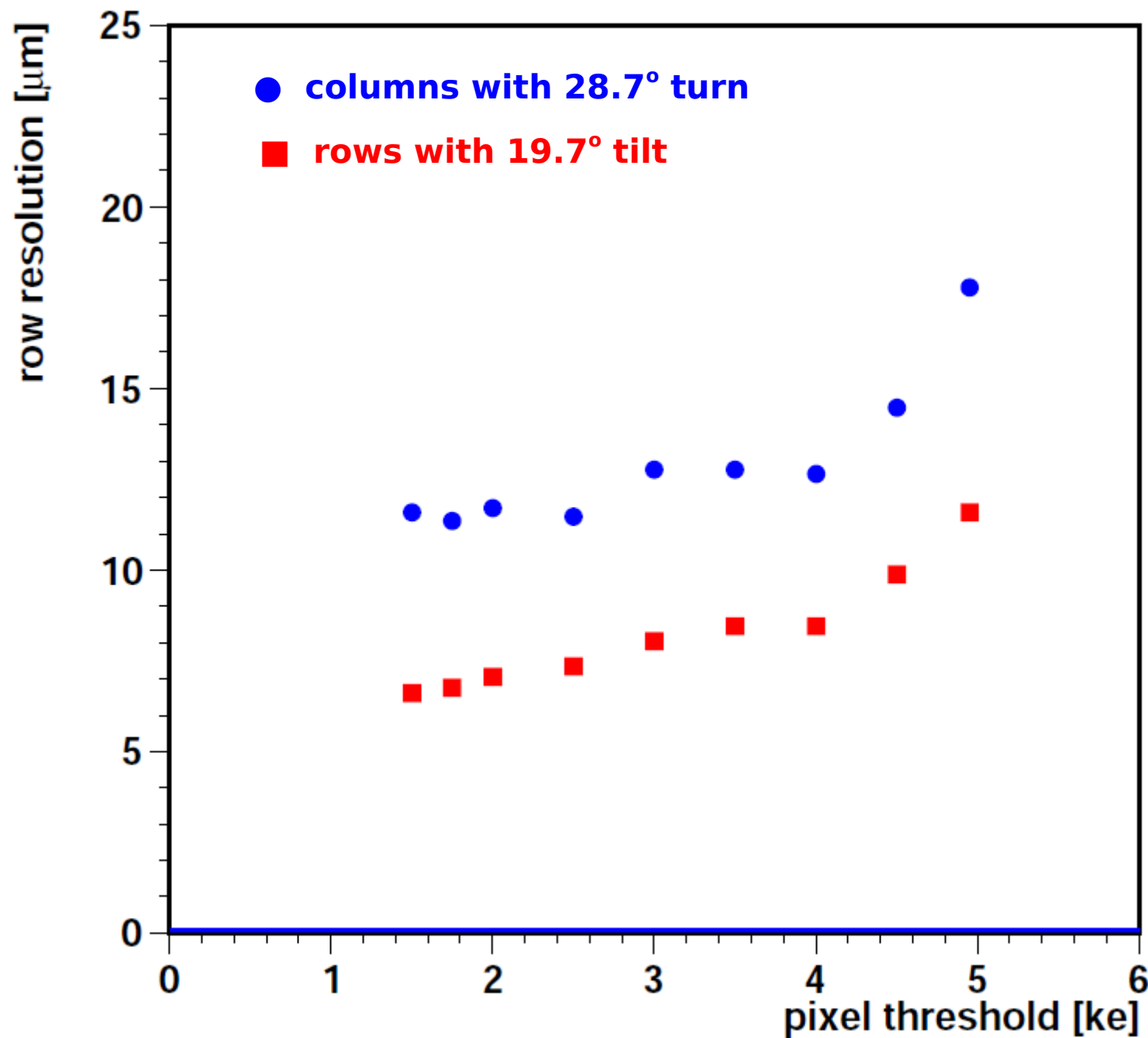
- psi46dig chip 47:
  ‣ Ia 25 mA
  ‣ 28.7° turn
  ‣ 19.7° tilt

- resolution degrades with higher thresholds
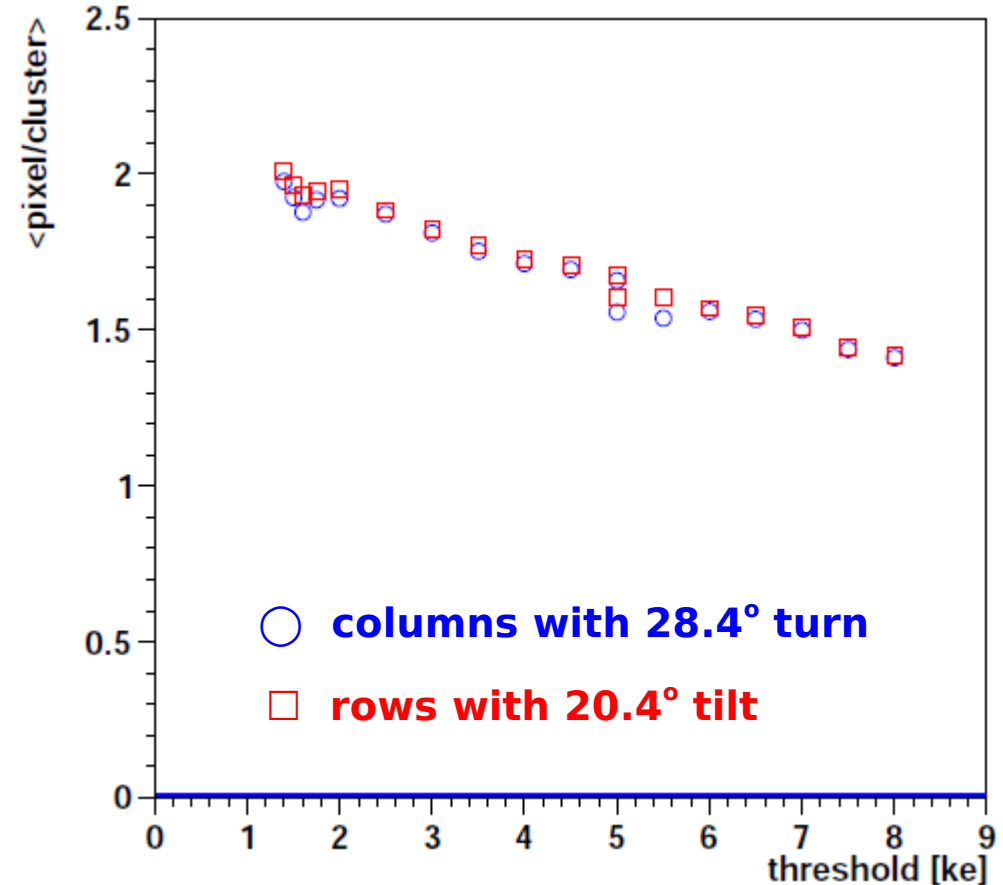
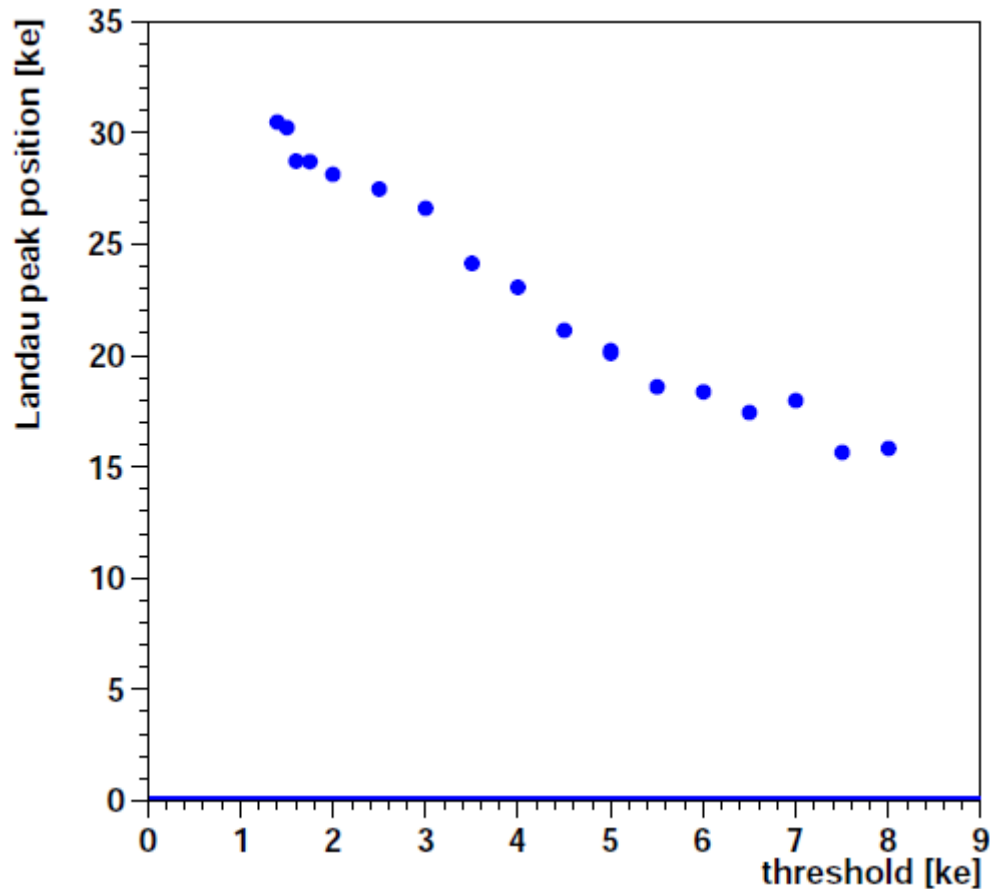# threshold scan with chip 47
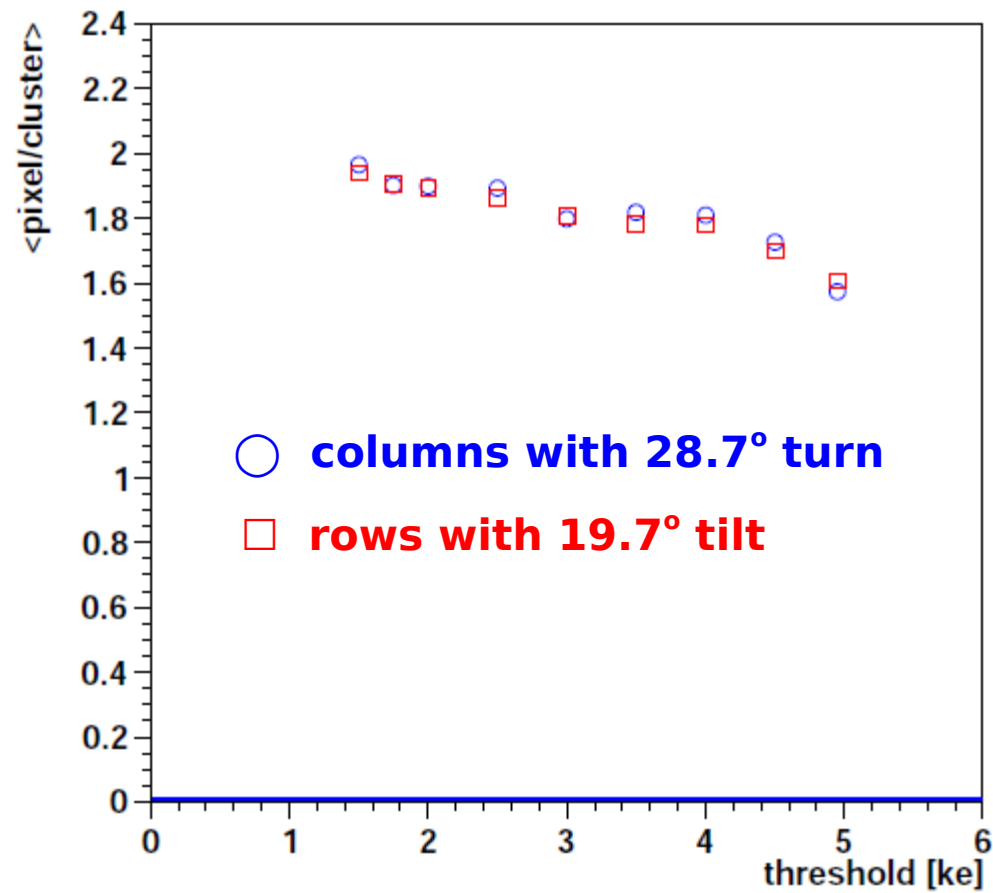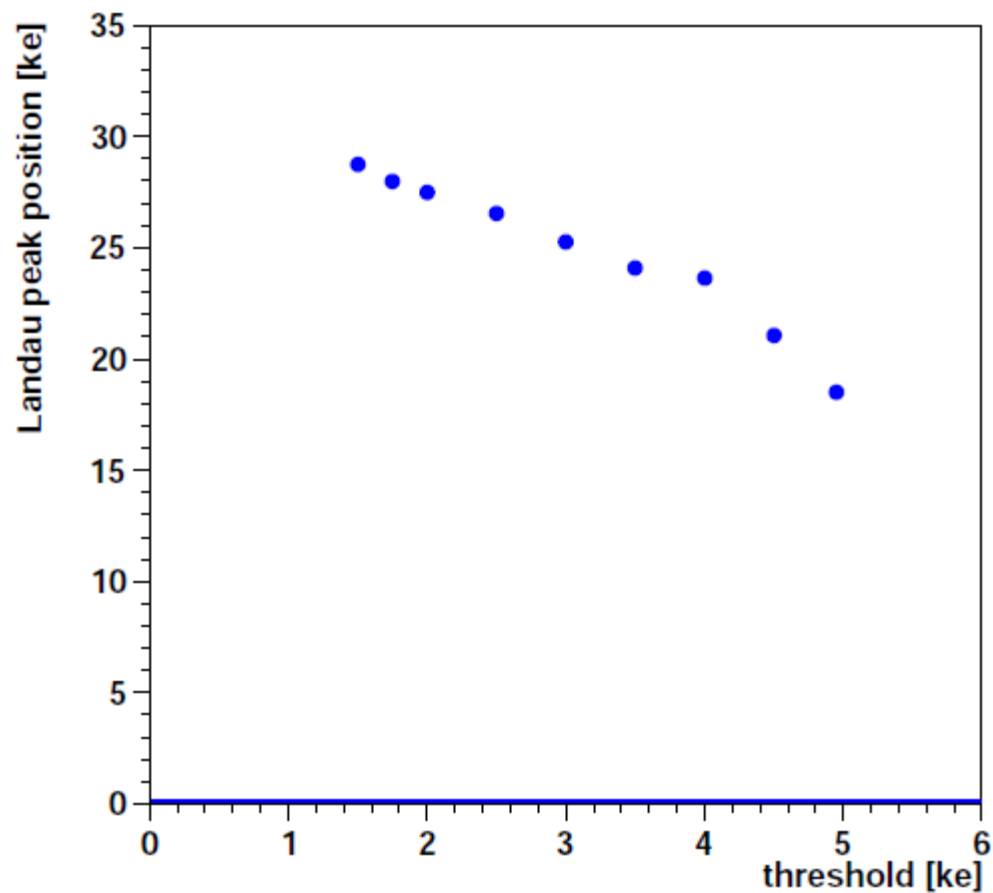
resolution vs threshold chip 205

- psi46dig chip 205:
  - Ia 25 mA
  - 28.4° turn
  - 20.4° tilt

- resolution degrades with higher thresholds

- small degradation at lowest threshold?

threshold scan with chip 205

○ **columns with 28.4° turn**

□ **rows with 20.4° tilt**

Summary

- Beam test at 28° turn and 19° tilt:

  ‣ threshold scans with psi46dig chips 47 and 205

- Results from first beam test confirmed and extended:

  ‣ resolution degrades with threshold

  ‣ smaller clusters at higher thresholds

  ‣ reduced cluster charge at higher thresholds

- Precision data, should be compared to a simulation

Back up

Beam test program

- single chip module with psi46dig chip 47

  ‣ bump and wire bonded at PSI

  ‣ thresholds trimmed to 25, 30, 35, 40, 50, 60, 80 DACs (50 e)

  ‣ bias -150 V

  ‣ fixed tilt angle 19° (like Lorentz angle in CMS)

  ‣ 4.4 GeV, typically 500 Hz telescope trigger rate with 9E9 e$^-$ in DESY

- Vary turn angle:

  ‣ 27°, 18°, 45°, 36°, 9°, 0°.

  ‣ take threshold scan at each angle

  ‣ at least two good 5 min runs (150 k events) per point
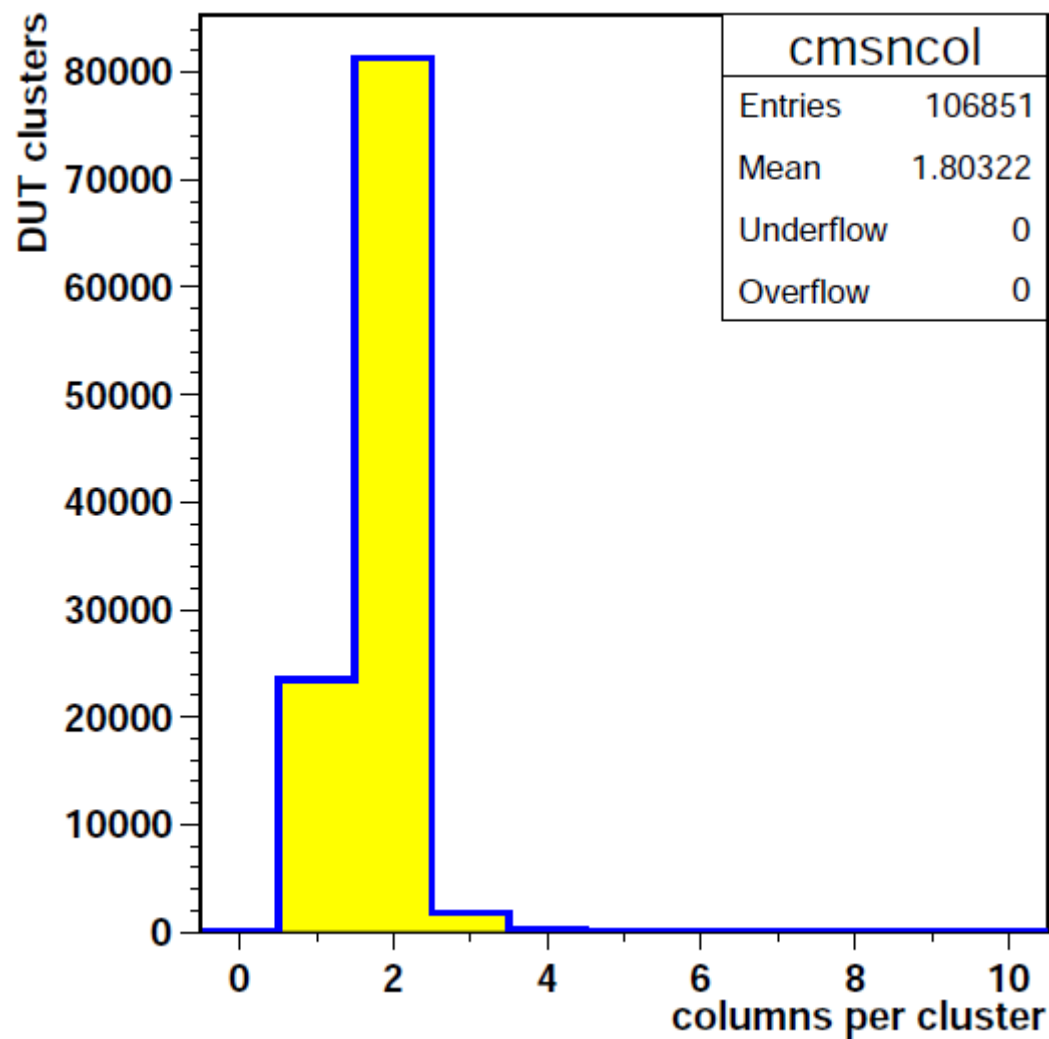
- Achieved in 11 shifts of 4 hours
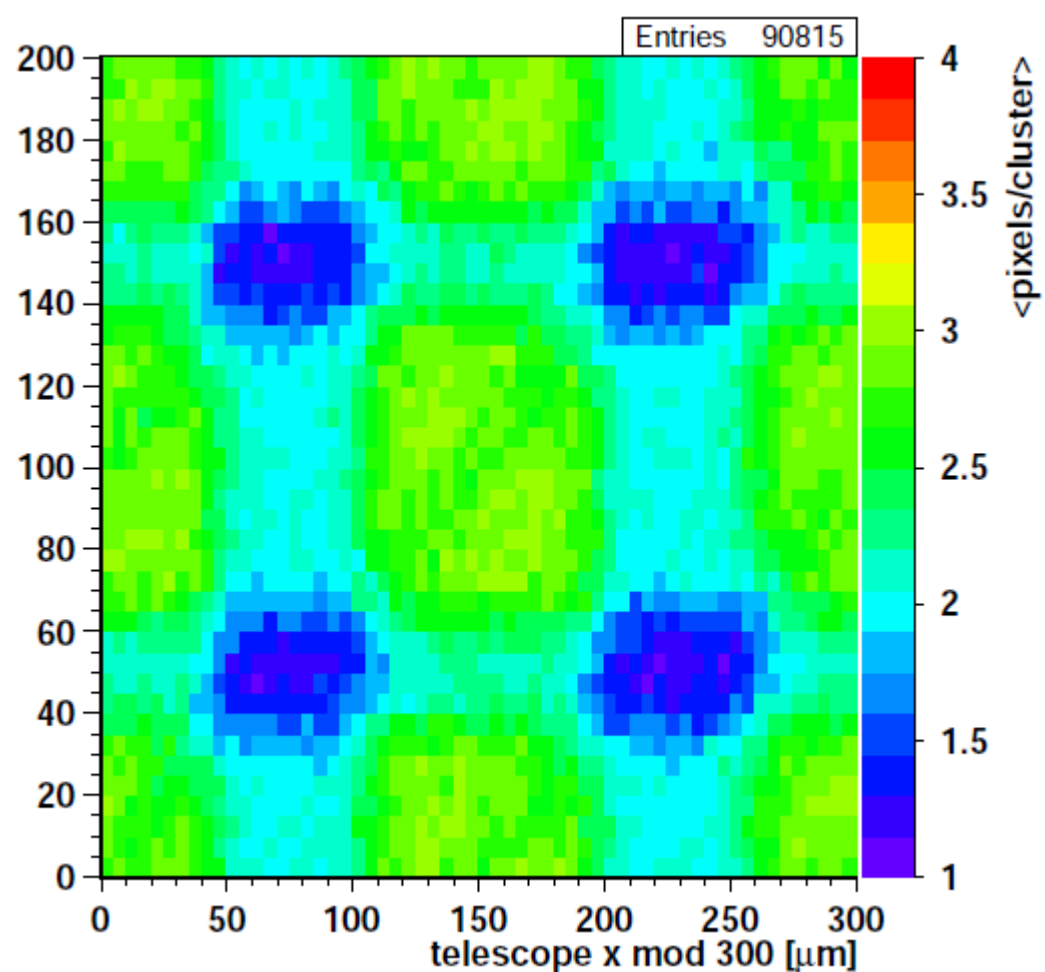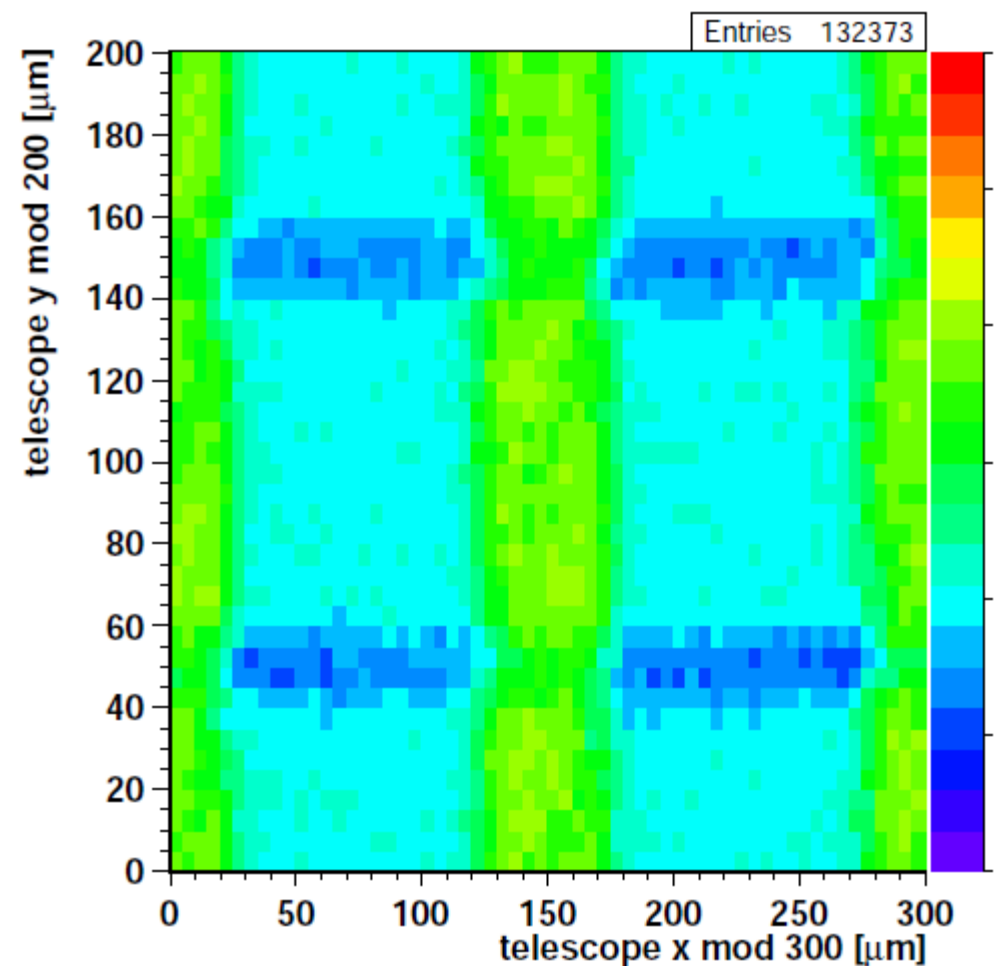
columns per cluster

trim 30 (1.5 ke)

no turn
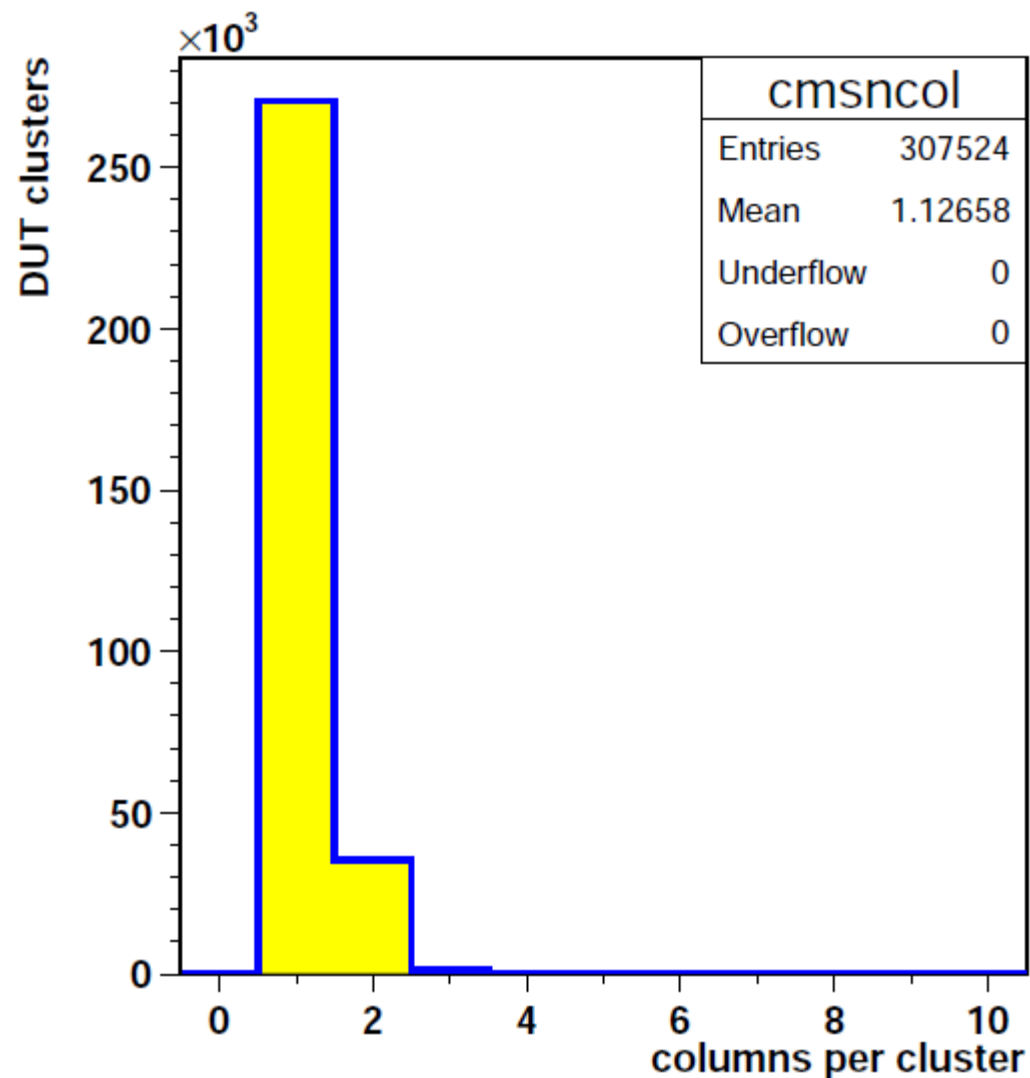
26° turn

pixels per cluster

trim 30
2 × 2 pixels

turn 10º, tilt 20º

turn 19º, tilt 17º

pixels per cluster

trim 30

2 × 2 pixels

turn 27º, tilt 19º
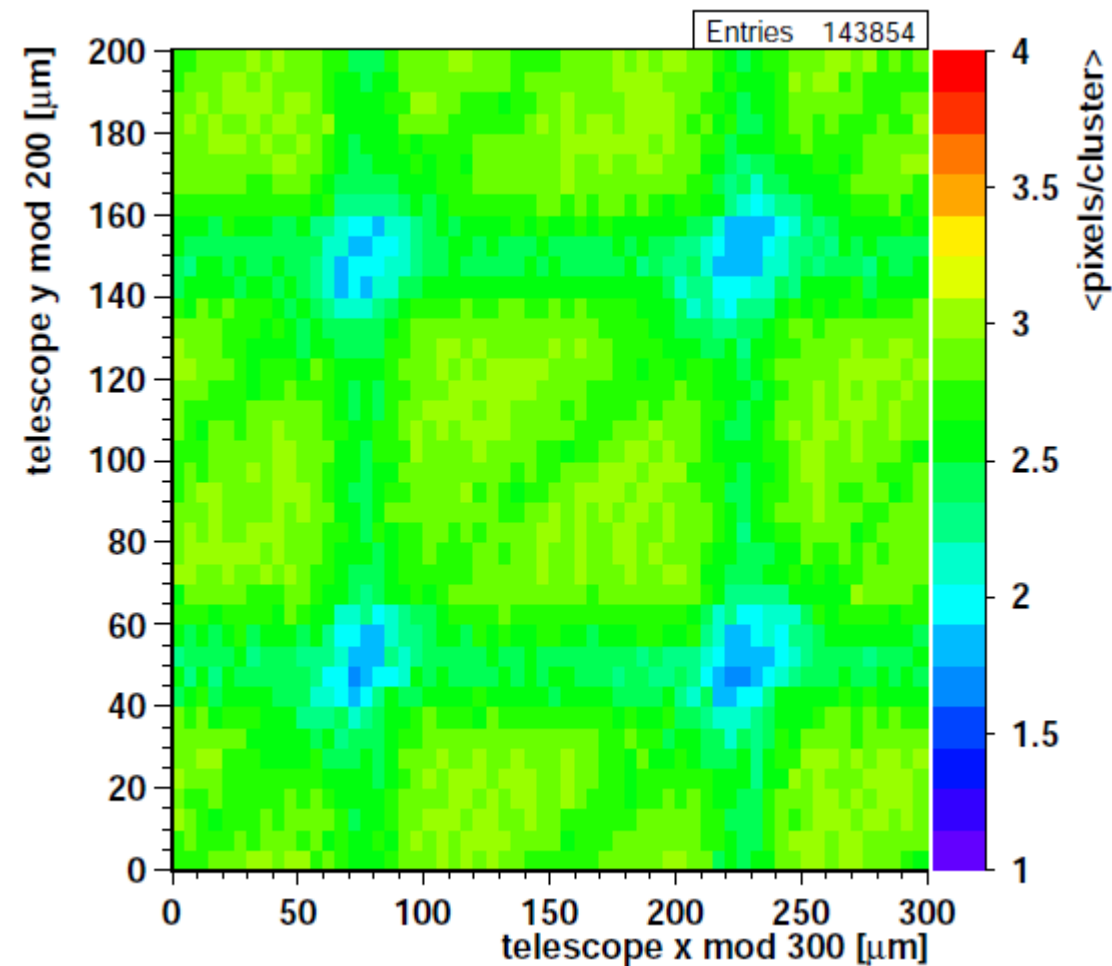
pixels per cluster

trim 30

2 × 2 pixels

turn 34º, tilt 19º

turn 47º, tilt 21º
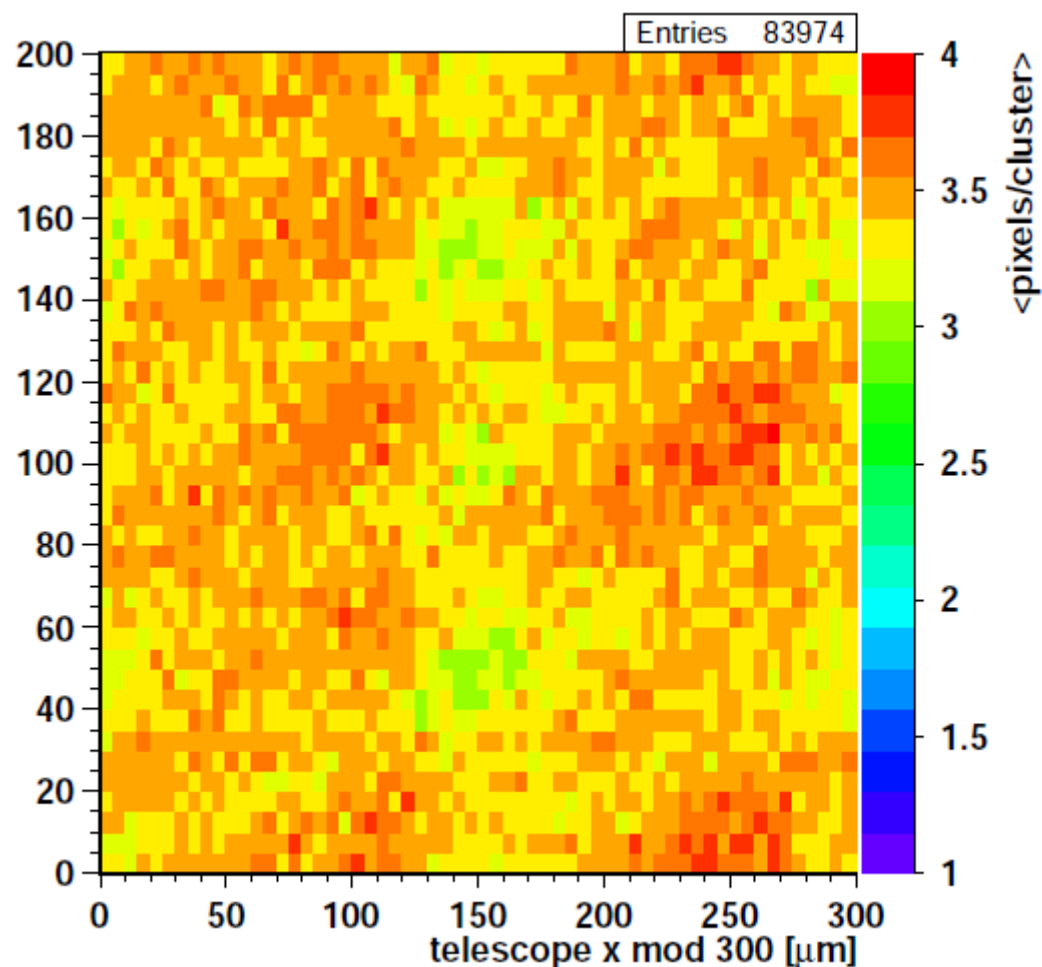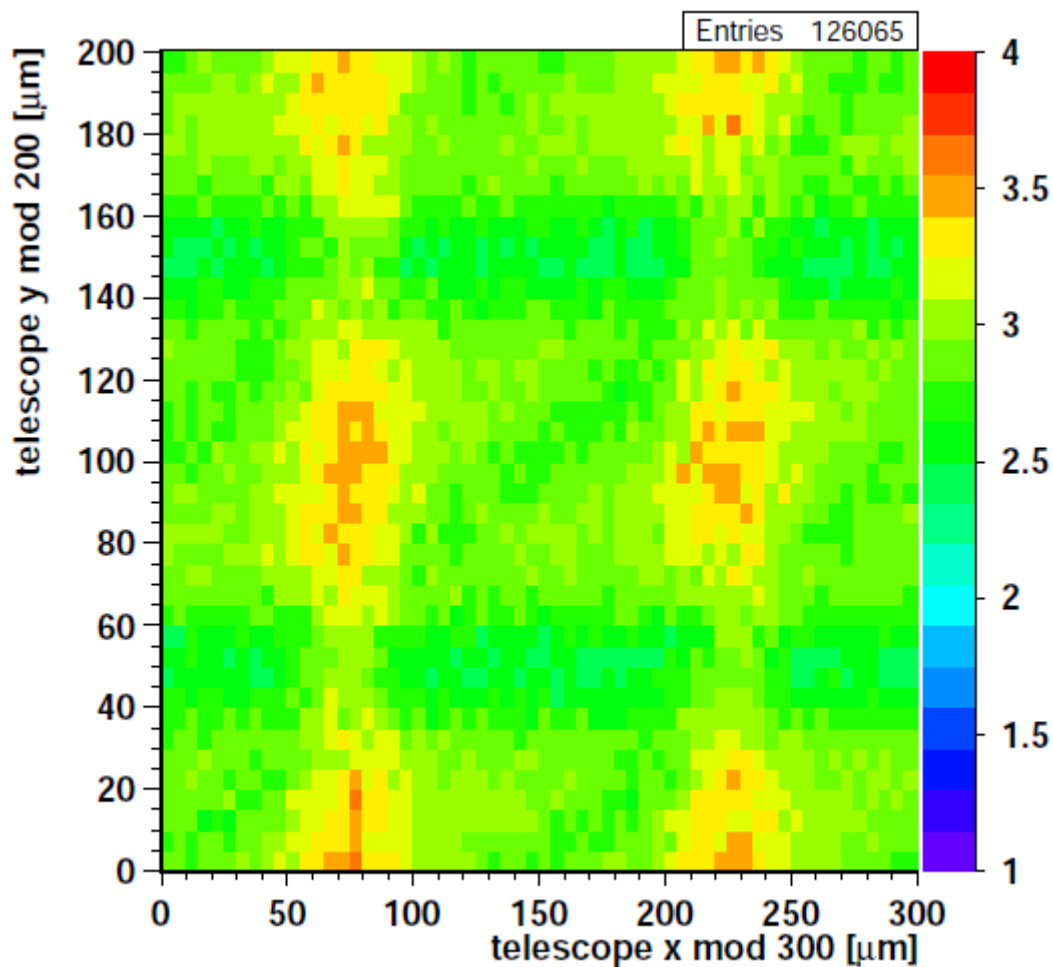
pixels per cluster

turn 27°, tilt 19°

2 × 2 pixels
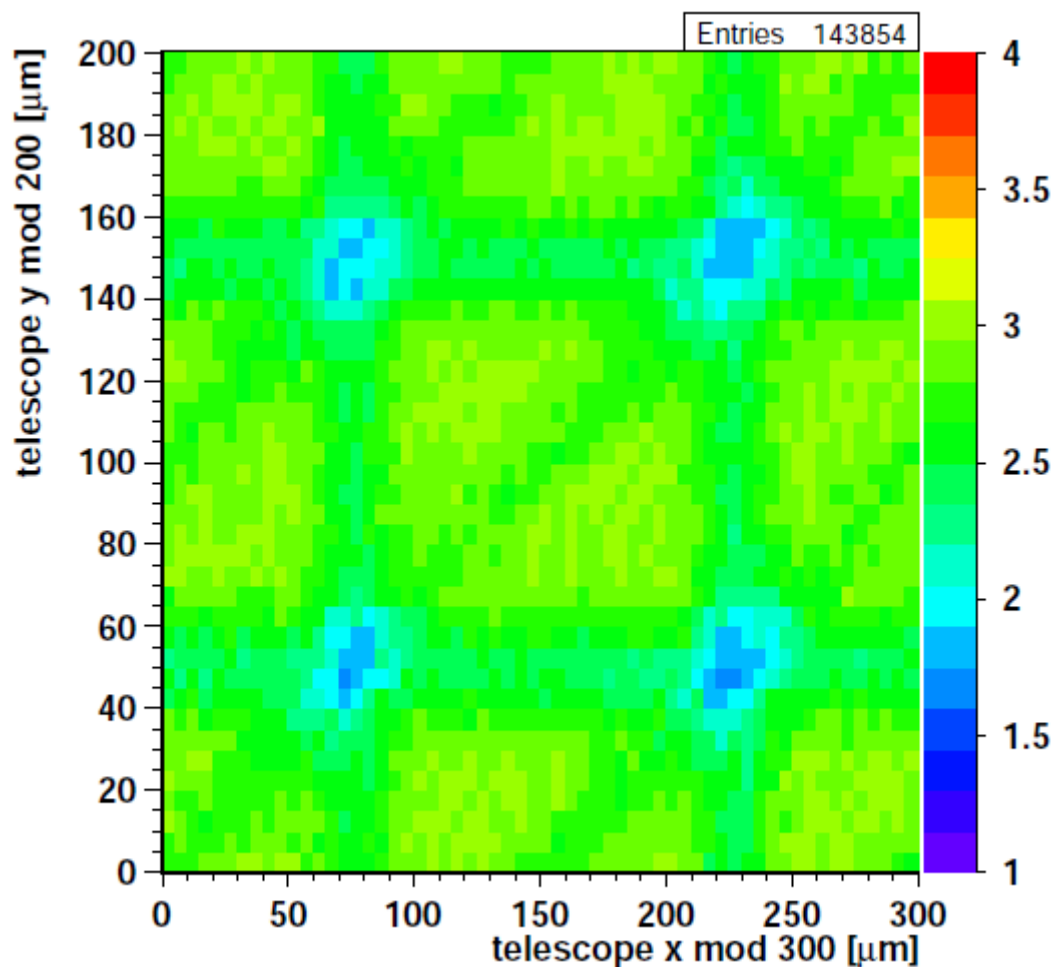
trim 30   **trim 80**
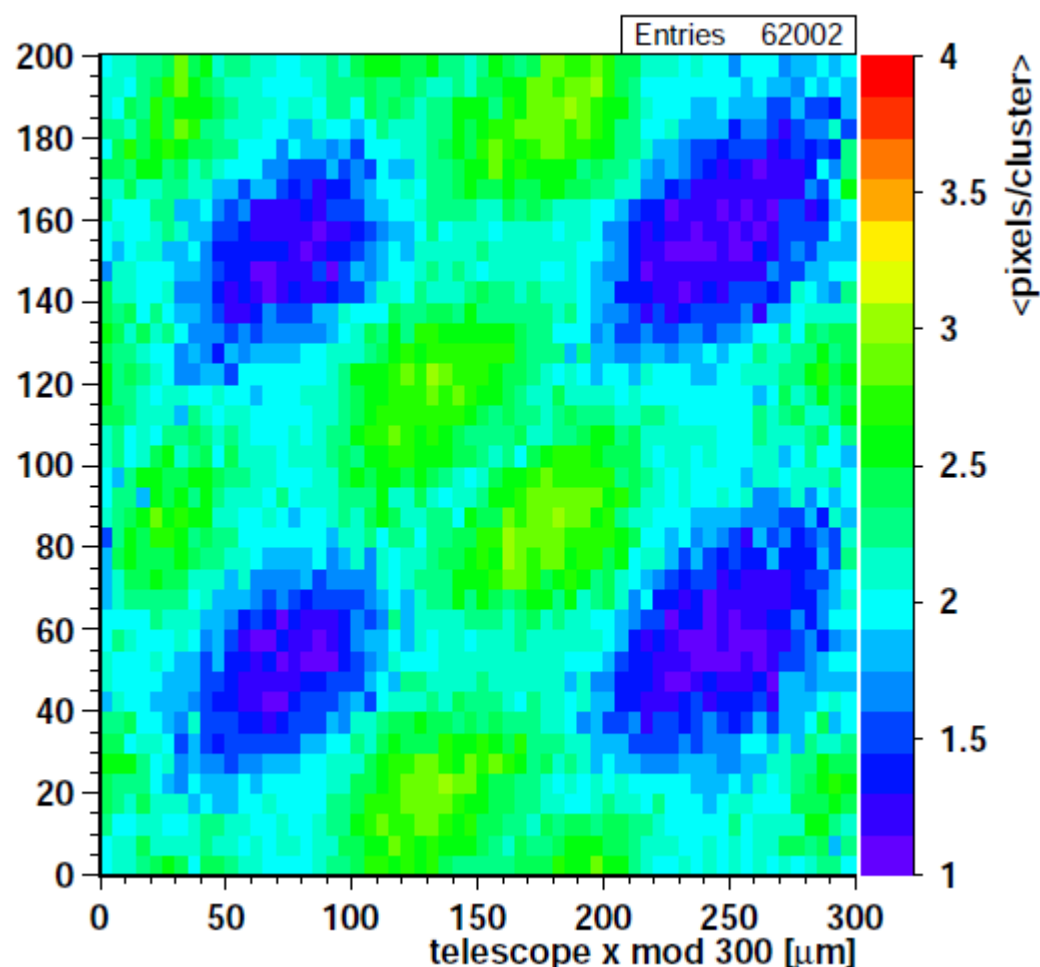
fodder for a simulation?

Landau distribution chip 47

cmsq0f	
Entries	106851
χ^2 / ndf	28.94 / 19
peak	23.1
sigma	1.759
area	1.042e+05
smear	2.423
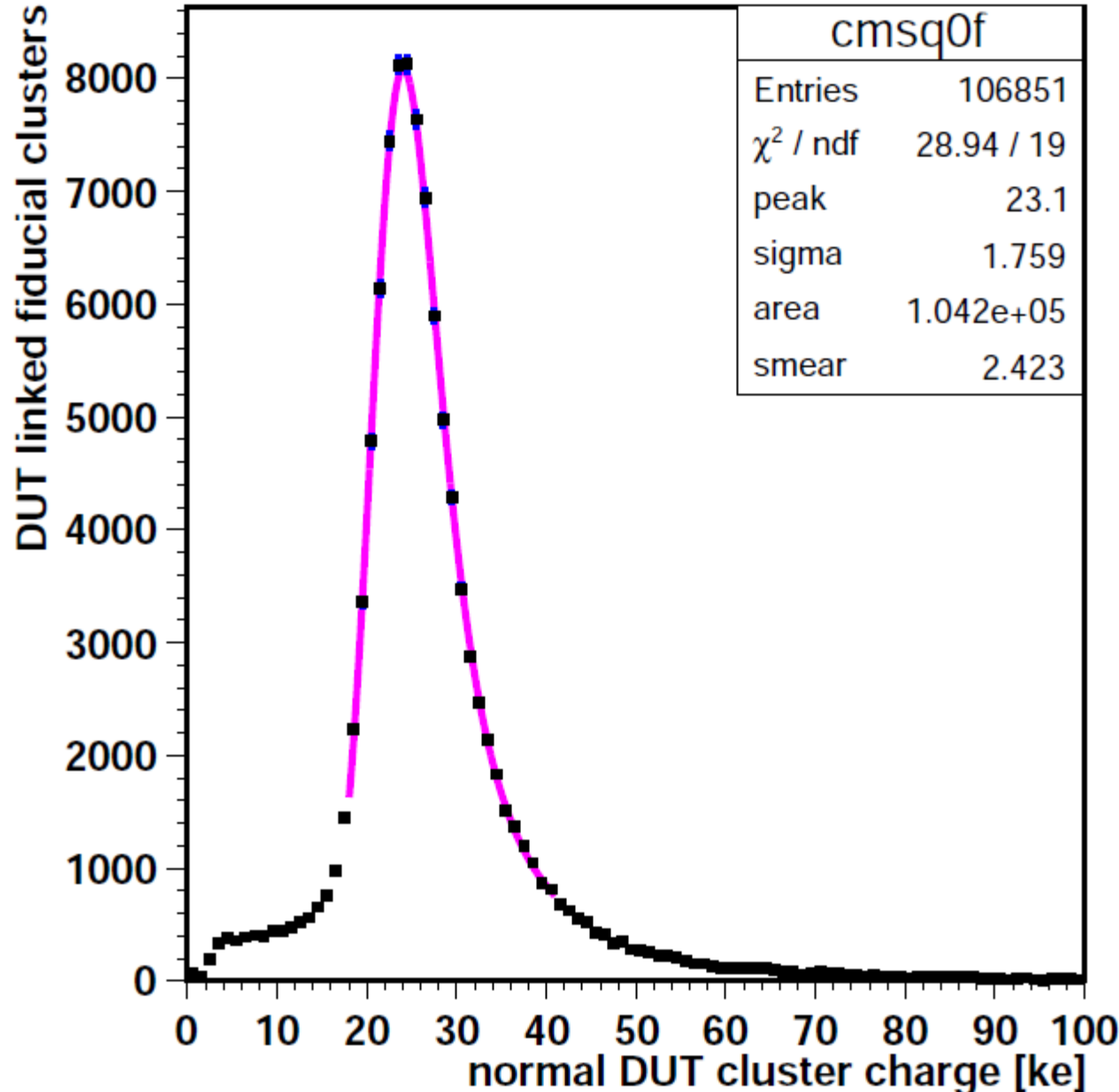
- digital chip 47

- 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 a little low.

column resolution with turn angle

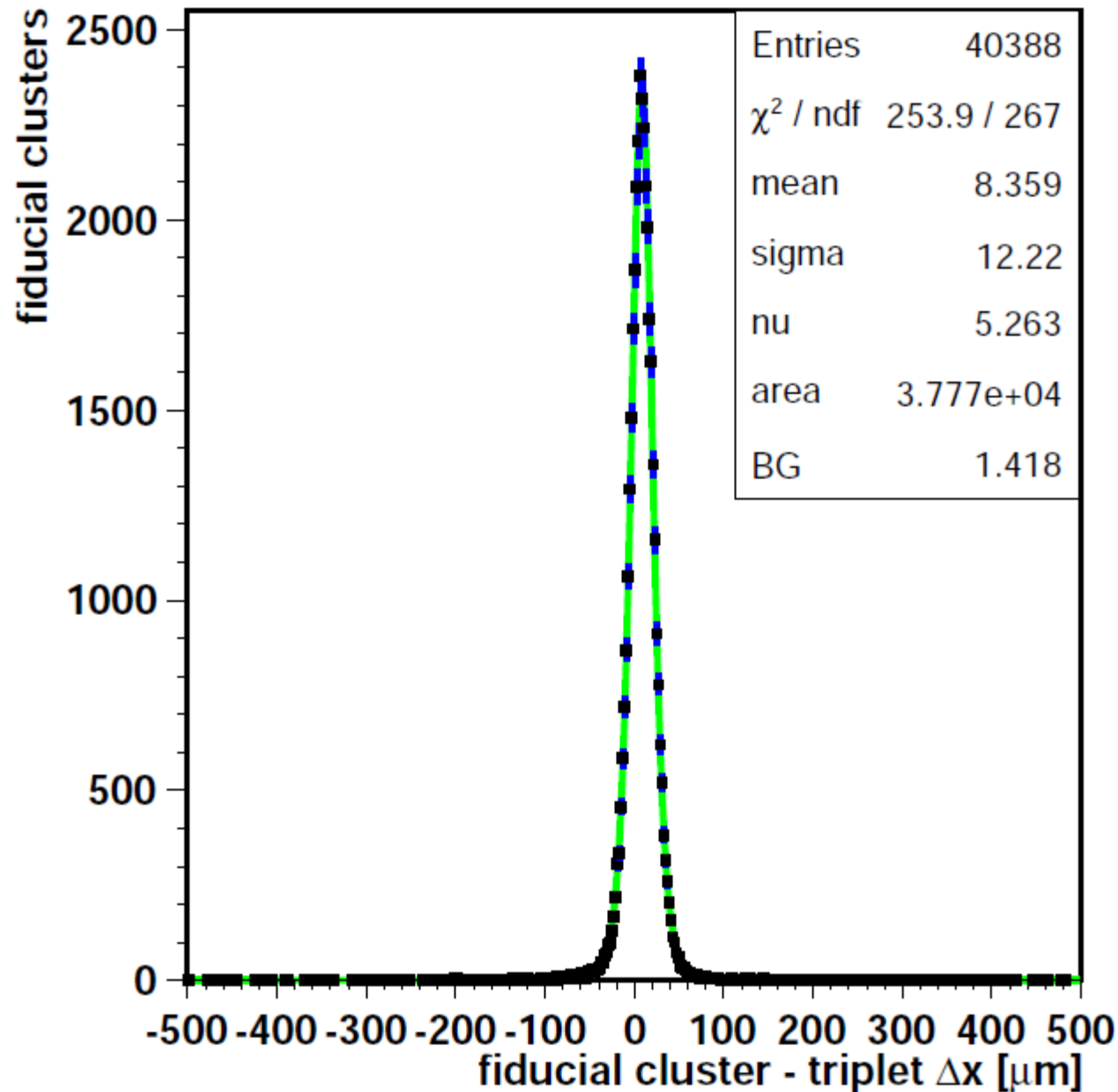**dig chip47, trim 30, run 6208, 4.4 GeV, 27° turn**

top view:

Entries	40388
χ^2 / ndf	253.9 / 267
mean	8.359
sigma	12.22
nu	5.263
area	3.777e+04
BG	1.418
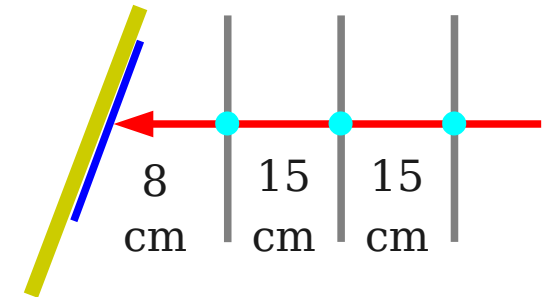
- Horizontal = columns
  - ▸ pixel width 150 μm

- turn angle:
  - ▸ charge sharing
  - ▸ residuals have Gaussian distribution
  - ▸ sigma = 12.2 μm
  - ▸ subtract telescope 7 μm
  - ▸ σ_{column} = 10 μm

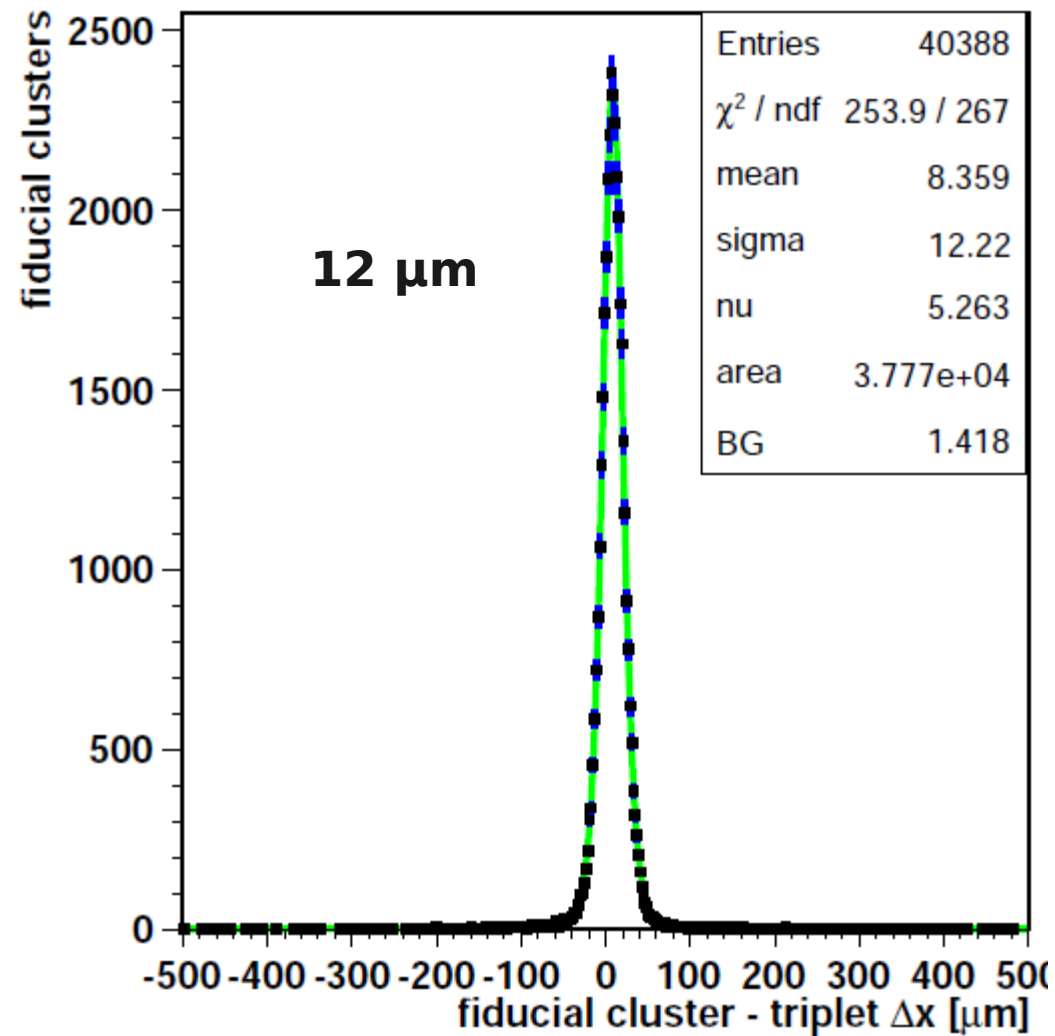# column resolution at 27°

trim 30 (1.5 ke), run 6208

trim 80 (4 ke), run 6200
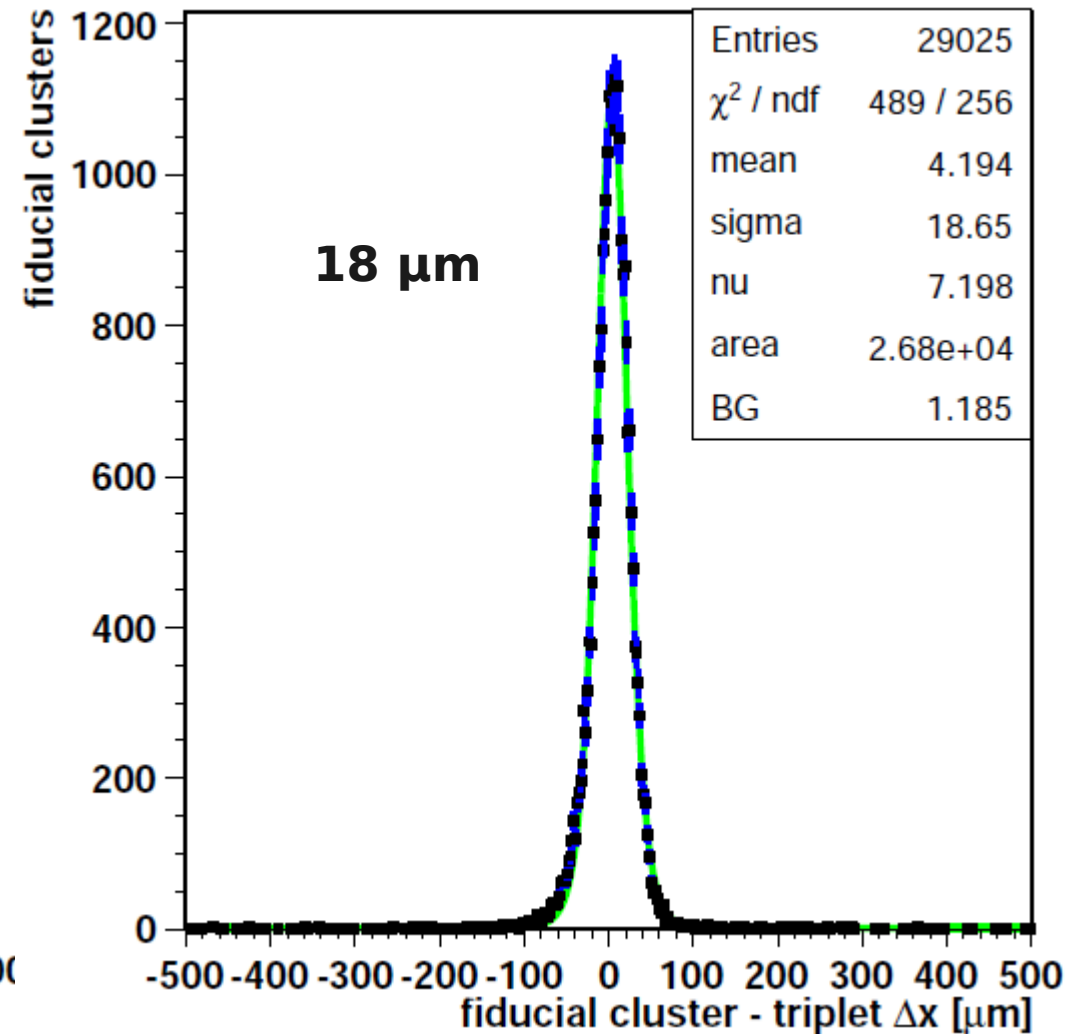
column resolution vs cluster charge

dig chip39, trim 24, run 5559, 4.4 GeV, 26° turn
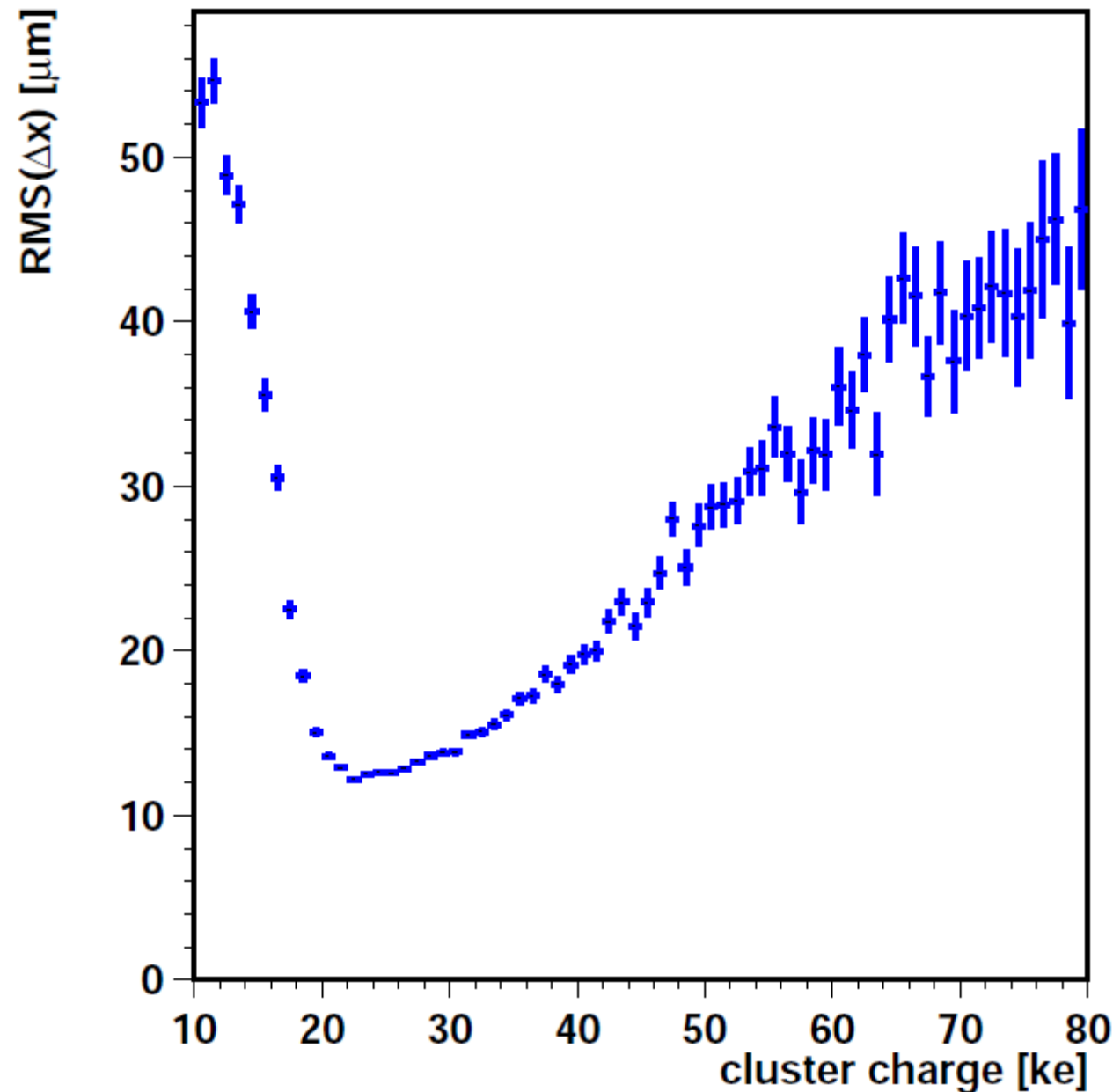
top view:
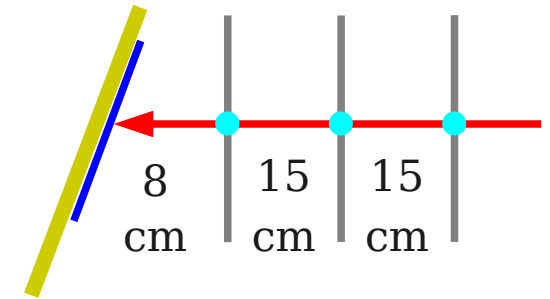
- Best resolution for mips at the Landau peak around 24 ke

- Poor resolution below 18 ke:
  - ▸ broken clusters

- Poor resolution in Landau tail above 40 ke:
  - ▸ delta rays

- Select 18 < Q < 30 ke

efficiency psi46dig chip47

eff = (dig linked clusters) / (telescope tracks with REF cluster)
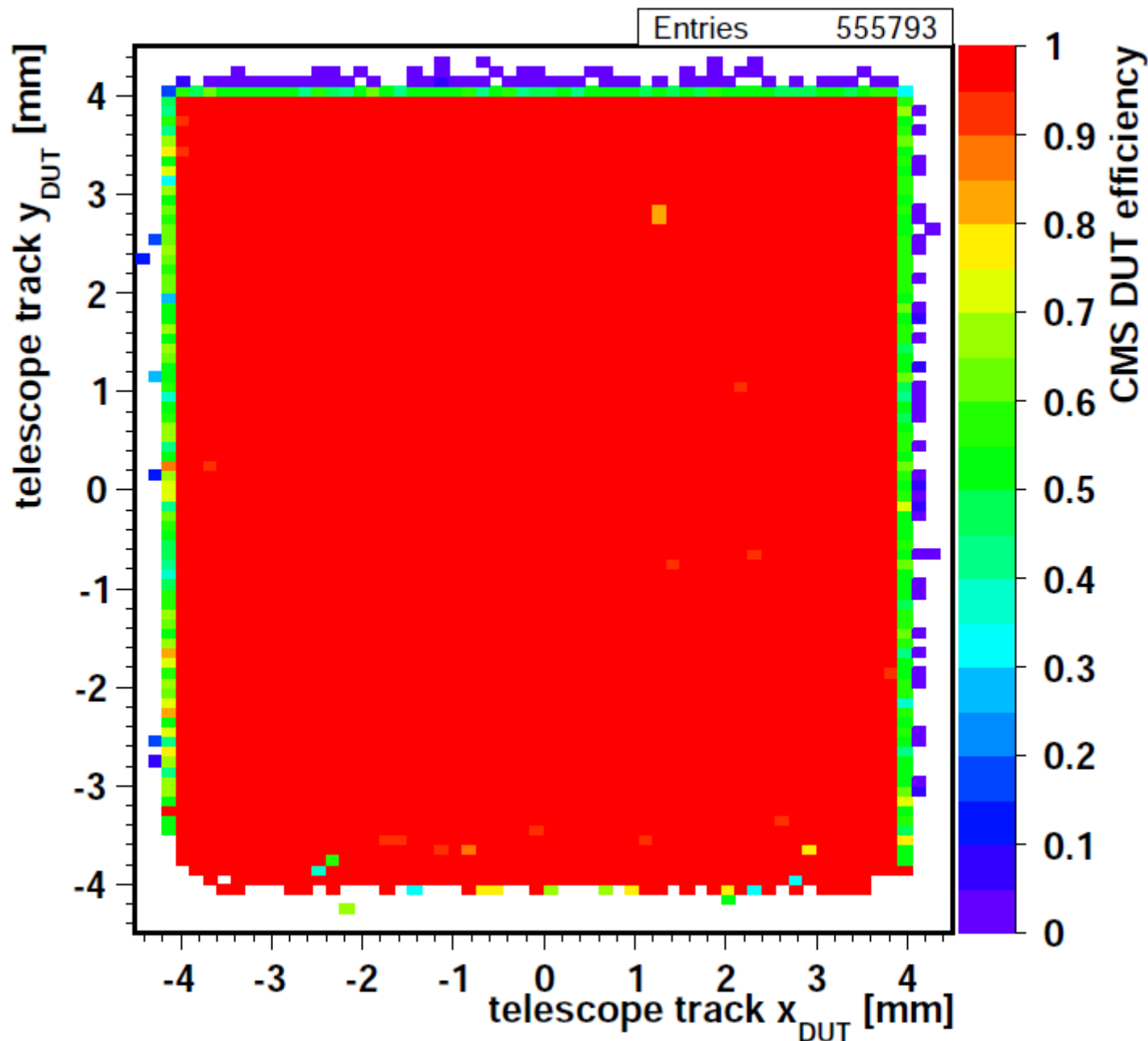
- chip 47
  ▸ I_A 25 mA
  ▸ trim 30
  ▸ tilt 0°
  ▸ turn 0°

- runs 6352-6371, selected

- **99.4% in fiducial volume**

Summary

- Our test beam setup allows turning in addition to tilting

  ‣ study charge sharing in column direction

  ‣ extended up to 45° turn angle

- Optimal resolution at 27°:

  ‣ 30% improvement by reducing threshold from 4 to 1.5 ke.

- Less improvement at other angles

- More studies possible:

  ‣ efficiency

  ‣ charge sharing vs track impact point

  ‣ different cluster algorithms

CMS: dip angle dependence of *z* resolution
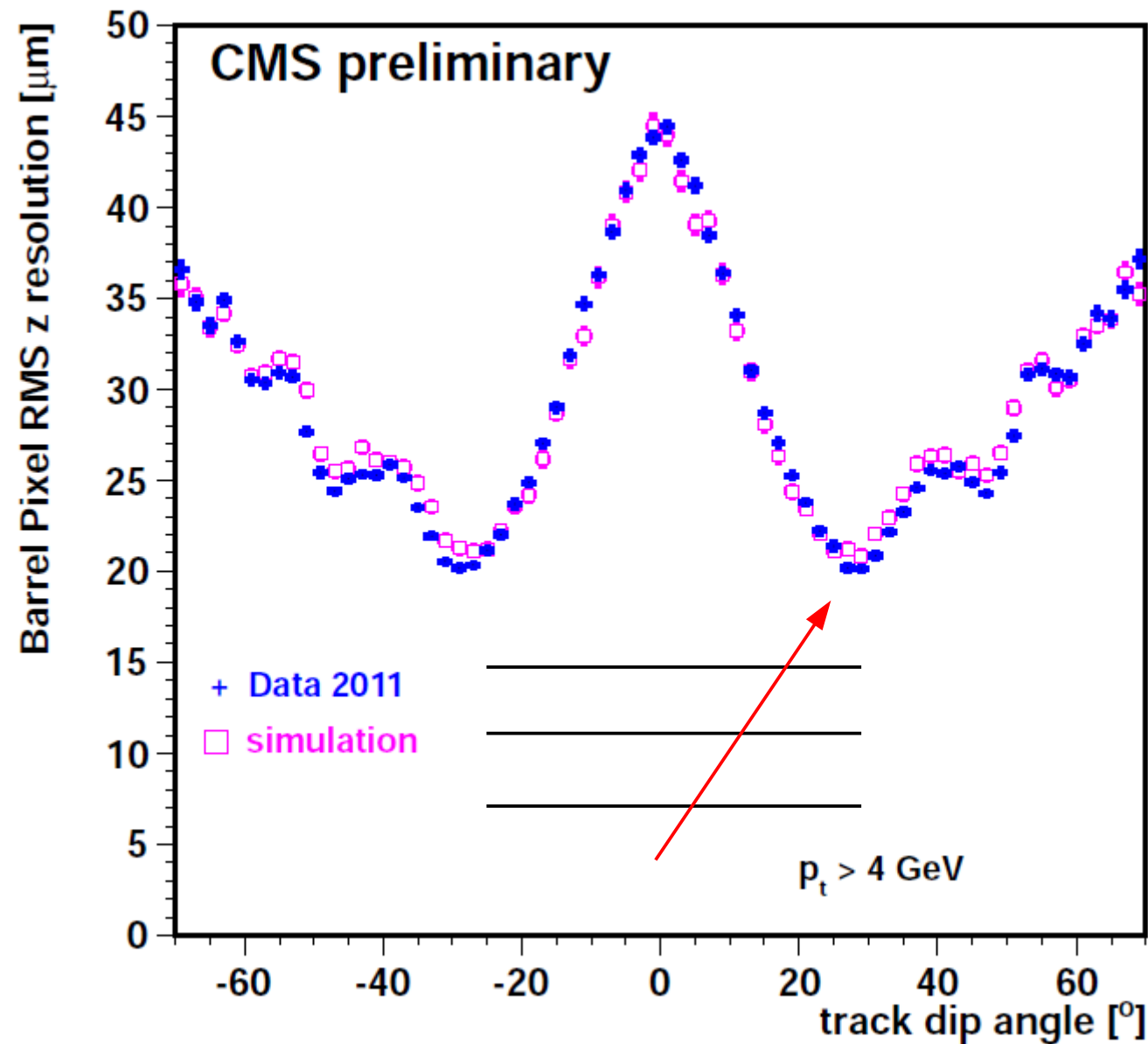
- dip angle:
  - ‣ $\lambda = \pi/2 - \theta$.

- *z* = column direction

- optimal resolution at $28^\circ = \text{atan}(150/285)$
  - ‣ sharing between neighboring pixels

150 × 285 μm
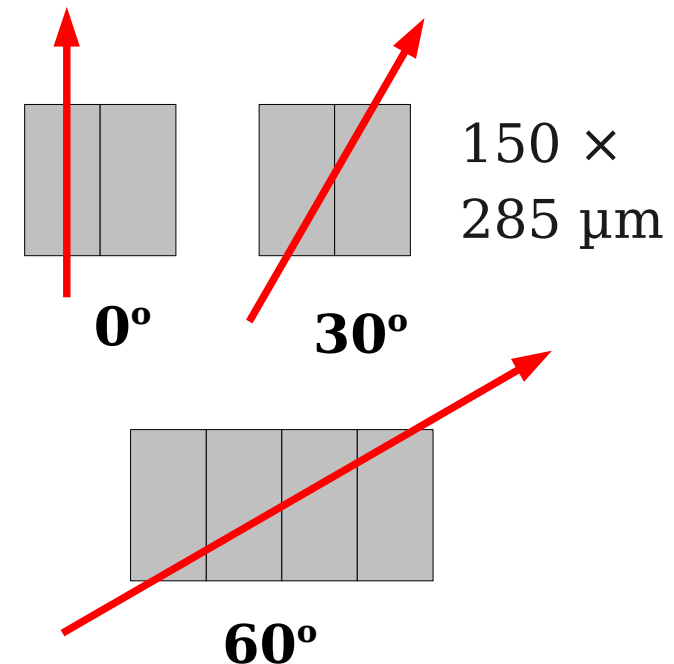
DESY Testbeam Schedule 2013 - version of December 14 2012

swapped

|	Week		TB21		TB22		TB24/1		TB24
			DATURA (telescope)	none	Telescope	CAL	Telescope PCMAG	PCMAG	none
	2		---	---	---	---	---	---	---
14-Jan	3		---	ITER	Tele setup				
	4		X0		---	CALICE AHCAL			
	5	swapped	CMS Pix-irrad	---	---	CALICE AHCAL	---	TPC MMG	ECAL
2-Feb	6	order	CMS Pix-fwd	---	ATLASPix	---	---	TPC MMG	
	7		CLICpix	---	---	SiPM	LorAngle	---	---
	8		---	SiW ECAL	---	SiPM	LorAngle	---	---
	9		---	Sc ECAL	EUTelescope	---	---	DESY TPC	
4-Mar	10								
	11		ALICE ITS	---	MuPix 2	---	---	DESY TPC	---
	12		CMS Pix-irrad	---	APIX PPS	---	---	DESY TPC	---
	13		CMS Pix-KA	---	APIX PPS	---	---	LCTPC Time	
1-Apr	14		---	GRPC-SDHCAL	APIX IBL	---	---	LCTPC Time	---
	15		---	GRPC-SDHCAL	APIX DBM	---			
	16		X0		ILCPOL				
	17		---	SiW ECAL	ILCPOL		SBS GEM		
	18		---	SC ECAL	---	RD50	SBS GEM		
6-May	19		DEPFET	---	---	RD50	LorAngle		
	20		FE-I4		---	CAL MMG	---	GridPix	---
	21		CMS Pix-ro		---	CAL MMG	---	---	Belle 2 PID
	22		X0			CALICE AHCAL			
3-Jun	23		CLICpix	---	---	CALICE AHCAL			
	24		CLICpix	---	MuPix 3	CALICE AHCAL			
	25		ALICE ITS	---	APIX 3D		---	---	PICSEL
	26		CMS Trk II	---	DIA-SiGe		---	---	PICSEL

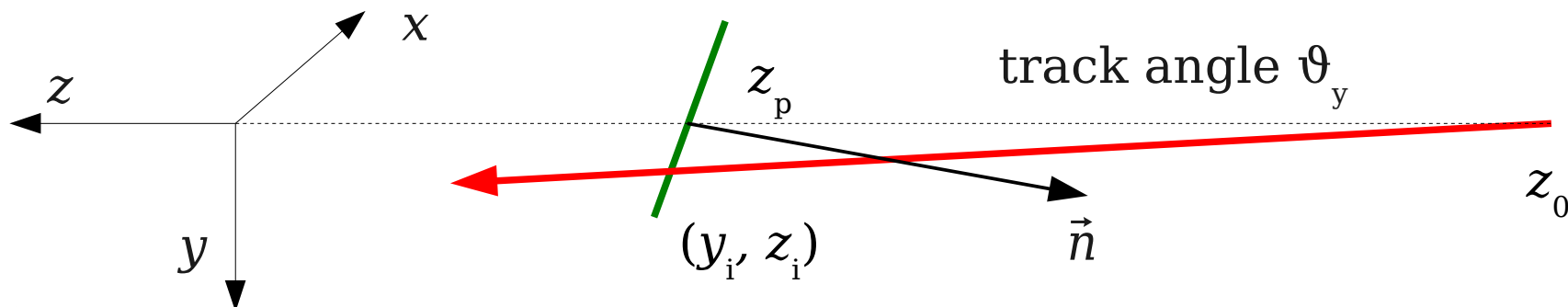*swapped order*

DUT with tilt and turn
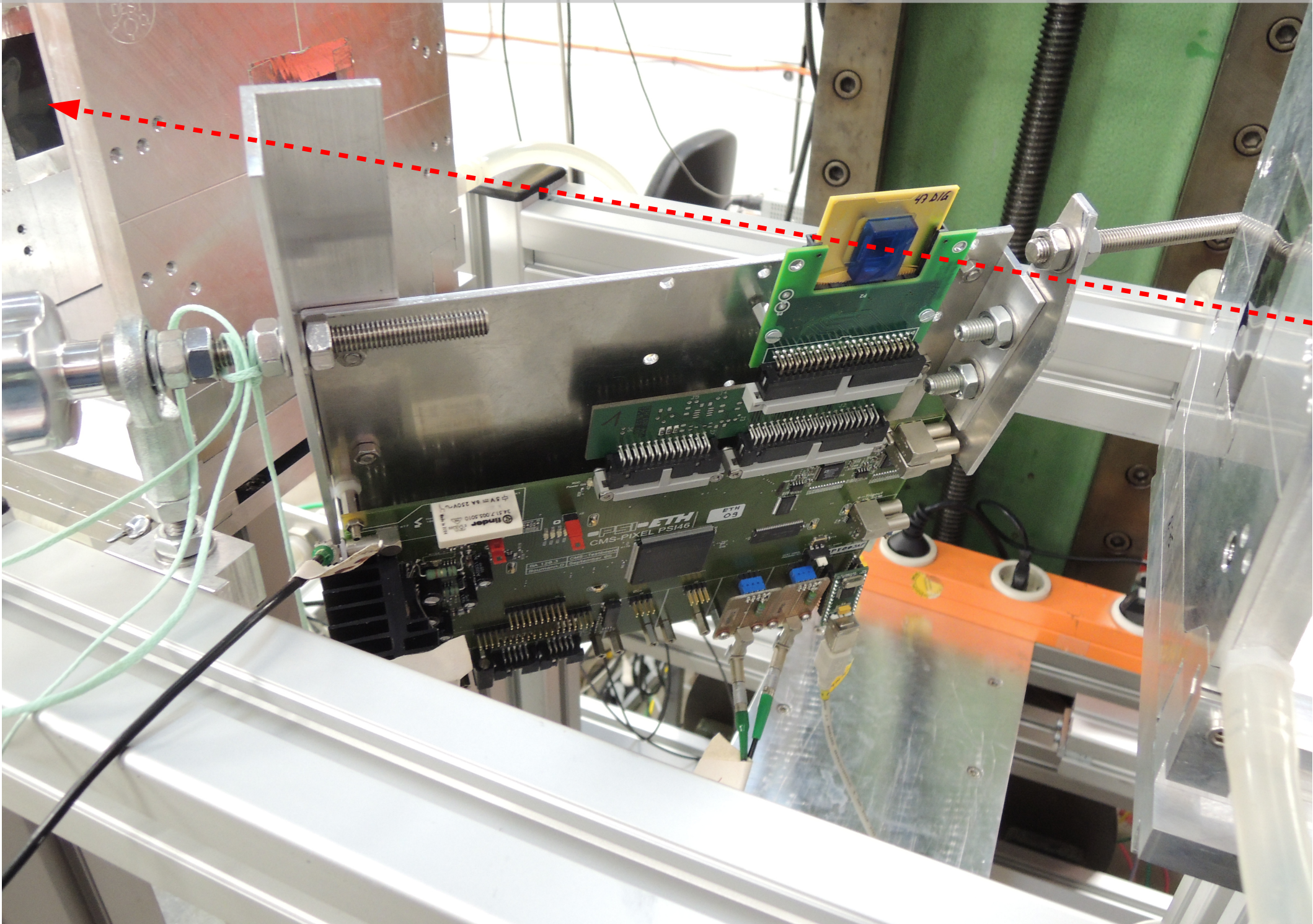
changes to EUTelescope code
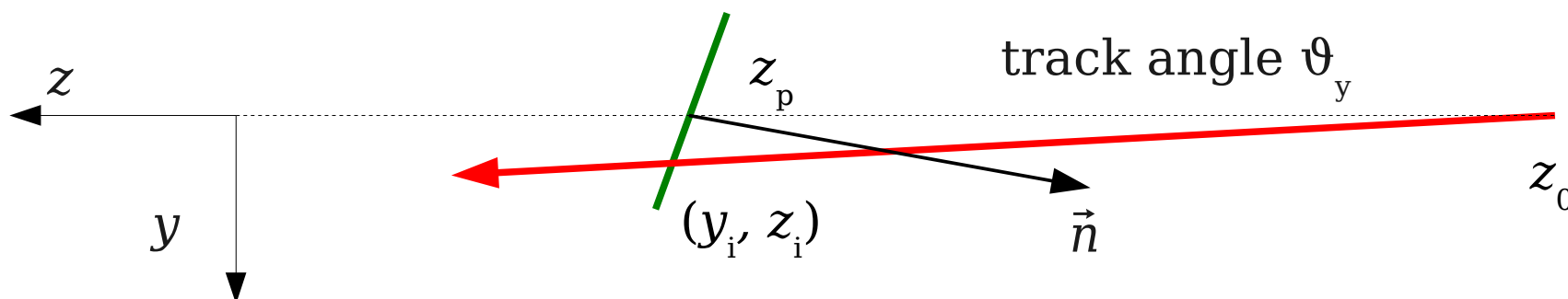
- inclined track:

    ‣ $x = x_0 + (z - z_0) \tan\vartheta_x$

    ‣ $y = y_0 + (z - z_0) \tan\vartheta_y$

- 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

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

$$R_y(\omega) = \begin{pmatrix} \cos\omega & 0 & \sin\omega \\ 0 & 1 & 0 \\ -\sin\omega & 0 & \cos\omega \end{pmatrix} \qquad R_x(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{pmatrix}$$
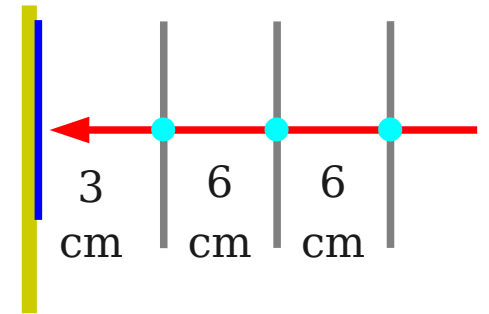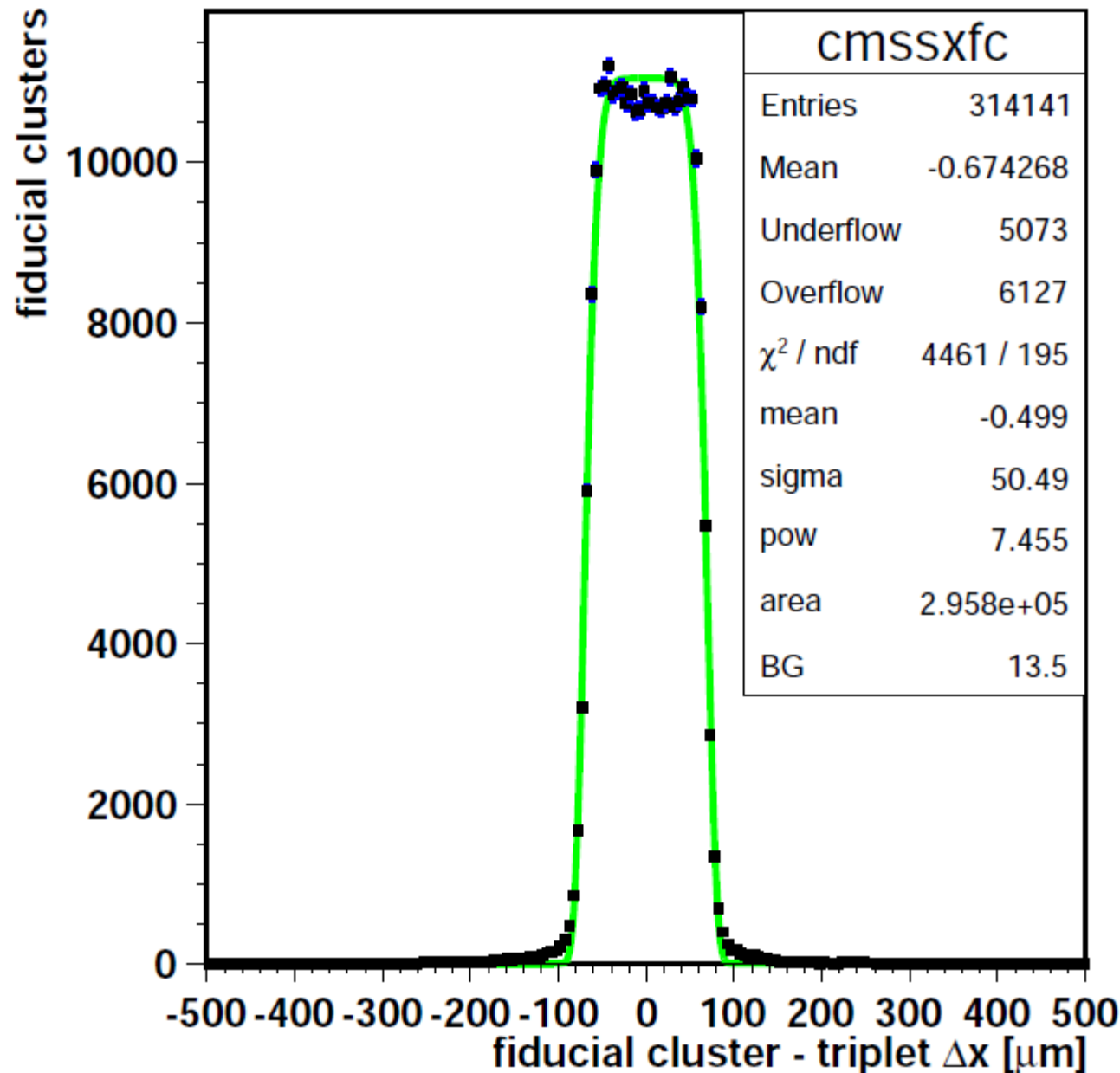
Transform intersect point into sensor coordinates:

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

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

cmssxfc	
Entries	314141
Mean	-0.674268
Underflow	5073
Overflow	6127
χ^2 / ndf	4461 / 195
mean	-0.499
sigma	50.49
pow	7.455
area	2.958e+05
BG	13.5

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

beam test vs CMS
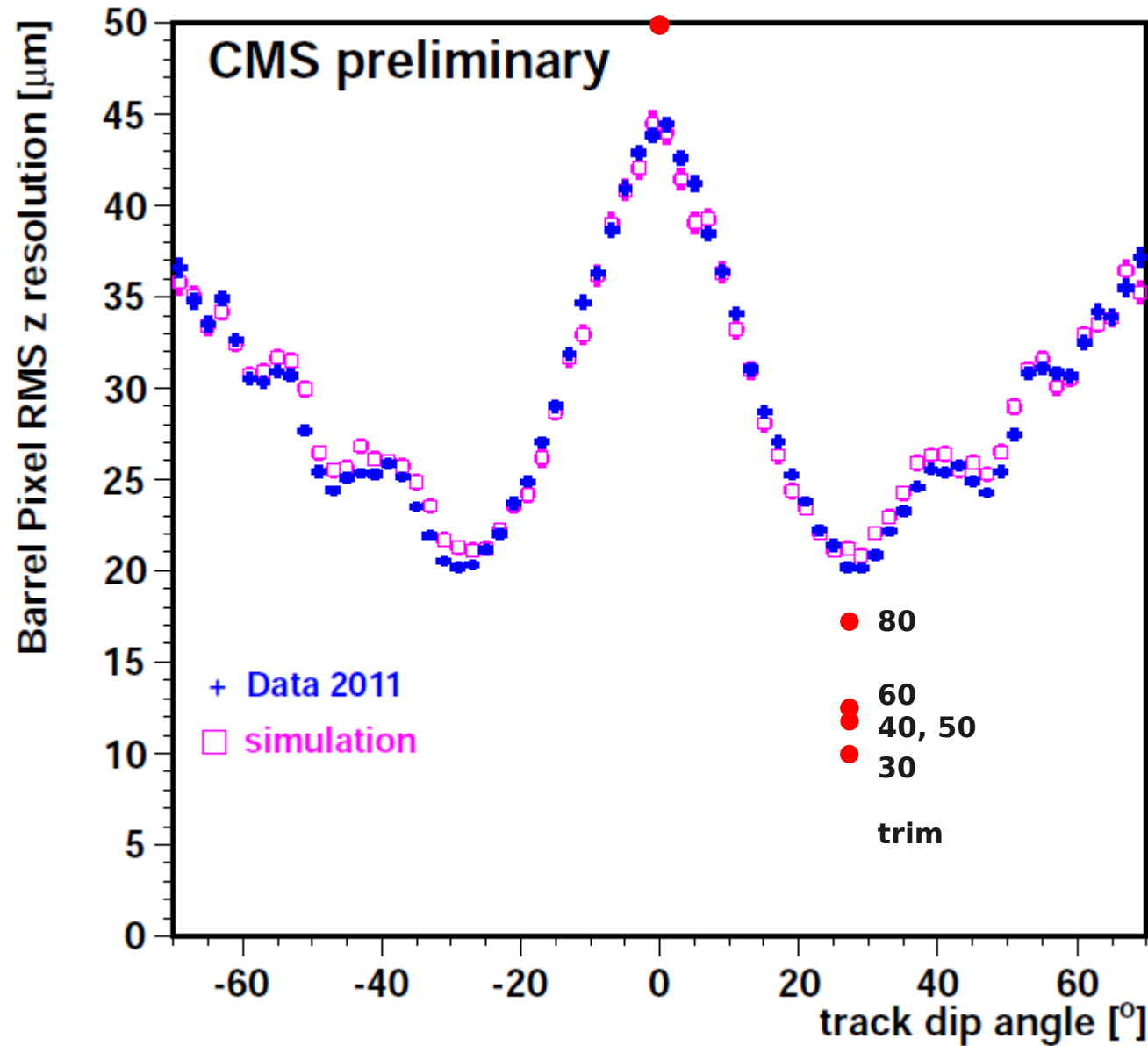
- caveat: truncated RMS vs Student's t fit

- data at 9°, 18°, 36°, 45° to be analyzed...