PSI46xdb pixel chip beam test results

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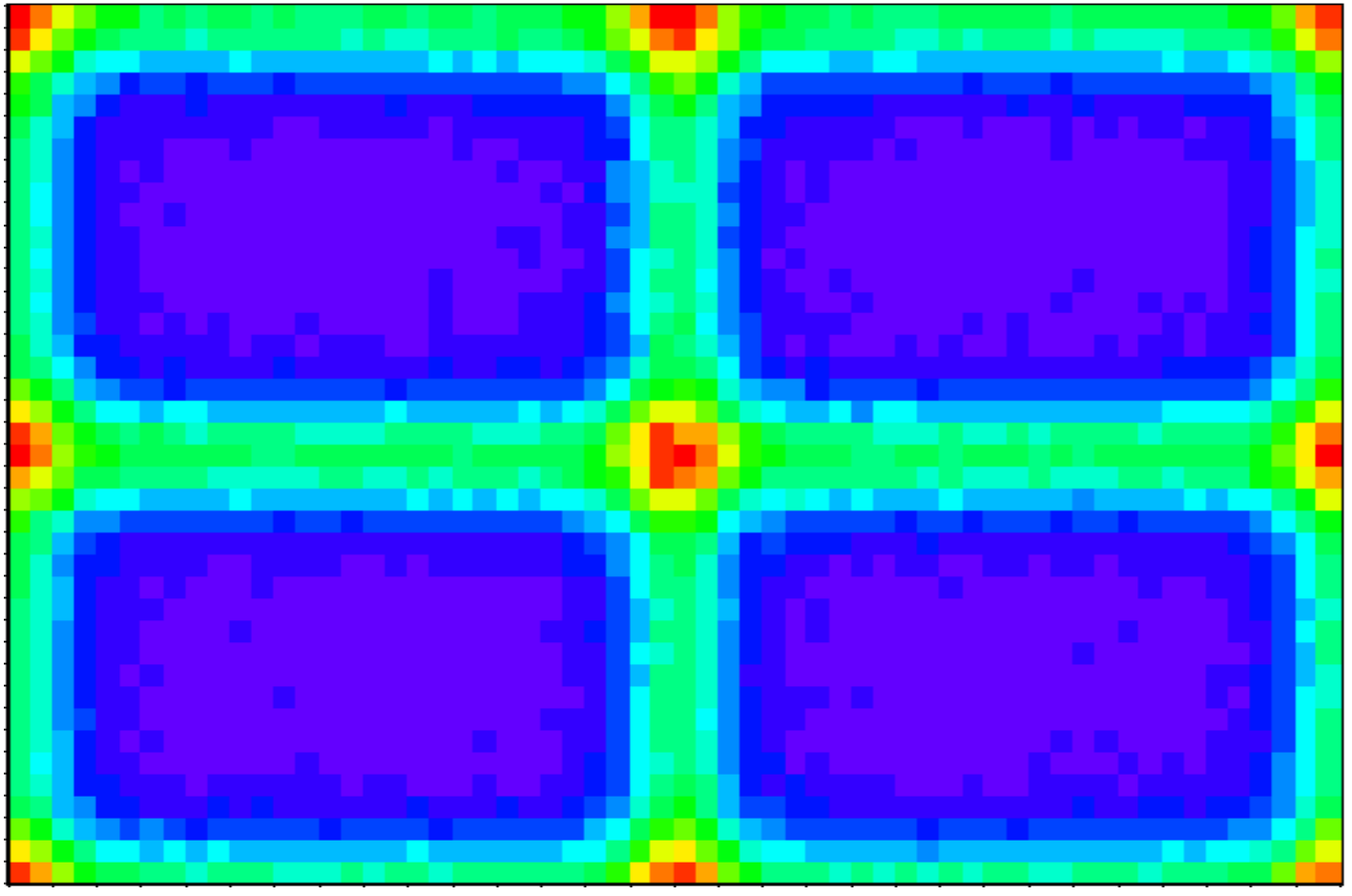
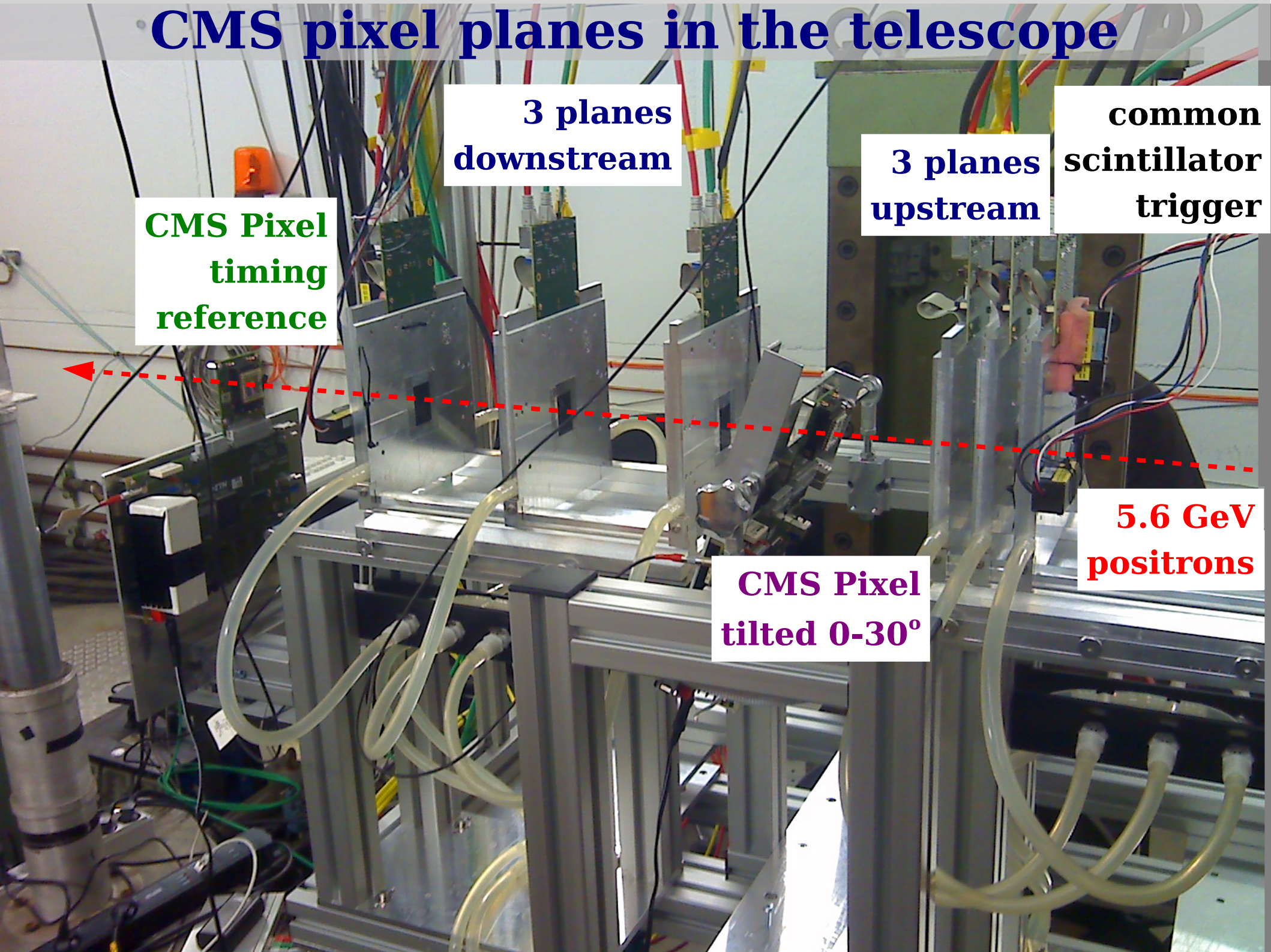
DESY CMS Phase I pixel upgrade, 27.7.2012

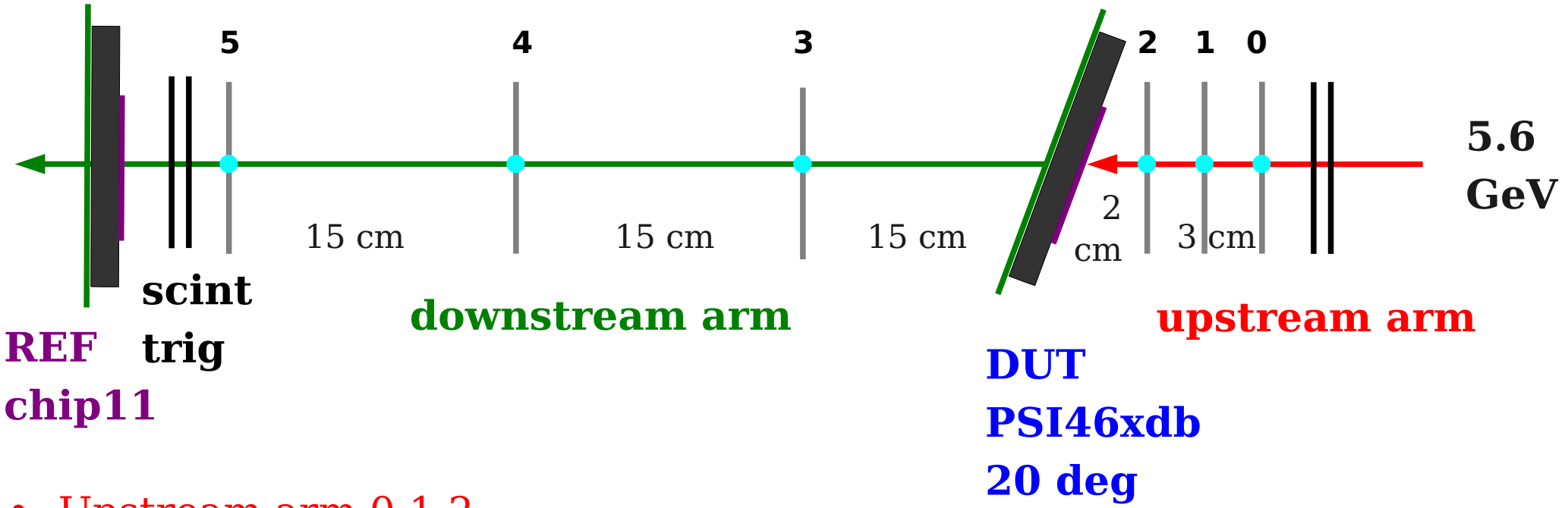


- efficiency
- clusters
- tilt scan
- threshold scan

CMS pixel planes in the telescope



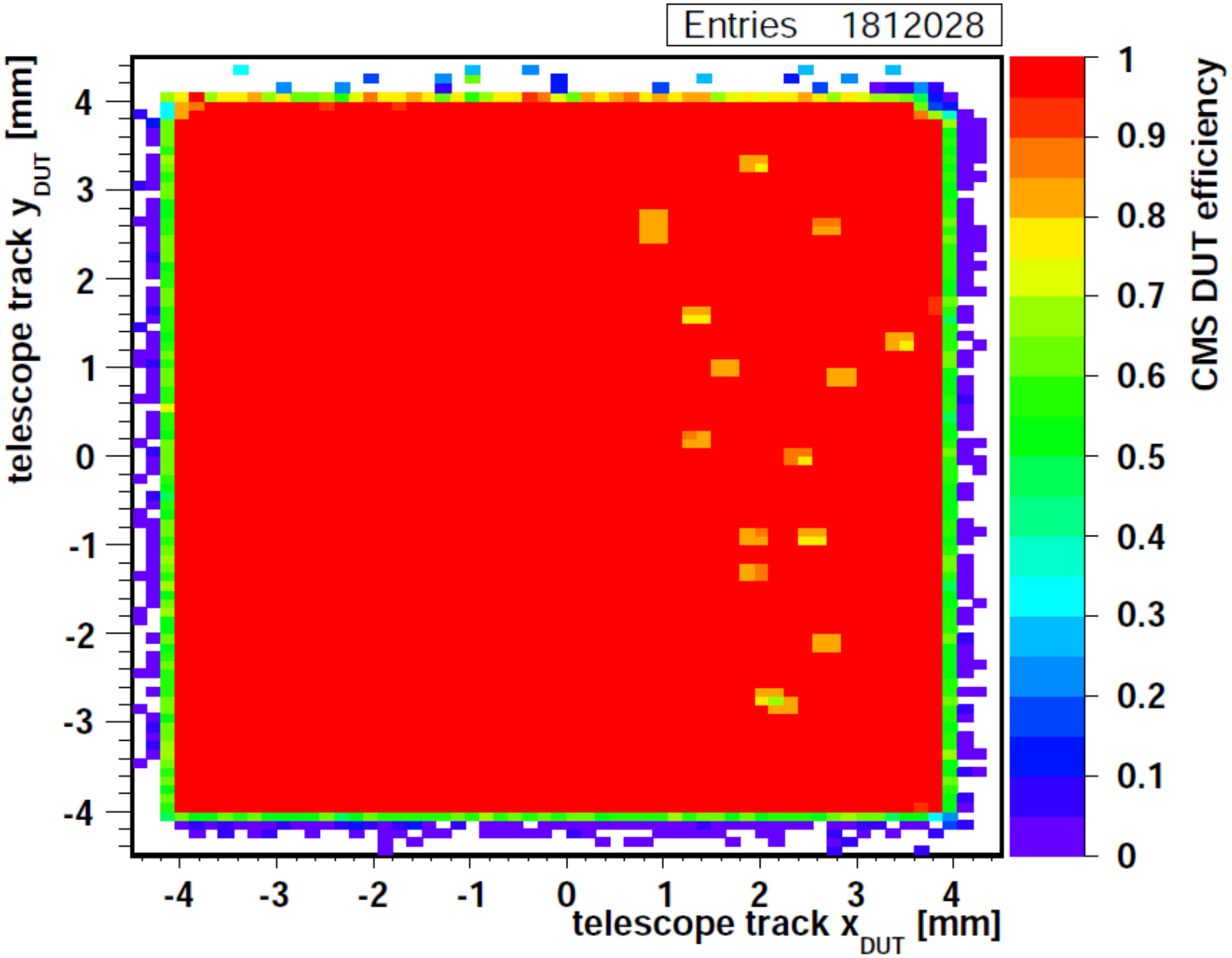
Default set up



- Upstream arm 0-1-2:
  - as close as possible to DUT, but allow for tilting
- DUT = single chip module, tilted by up to 30°,
- Downstream arm 3-4-5:
  - equally spaced between DUT and REF, allow for DUT tilting
- REF = single chip module for timing, as close as possible behind scint
- trigger: 3-fold coincidence 1+2+4 (config: TLU AndMask 11)

xdb efficiency map

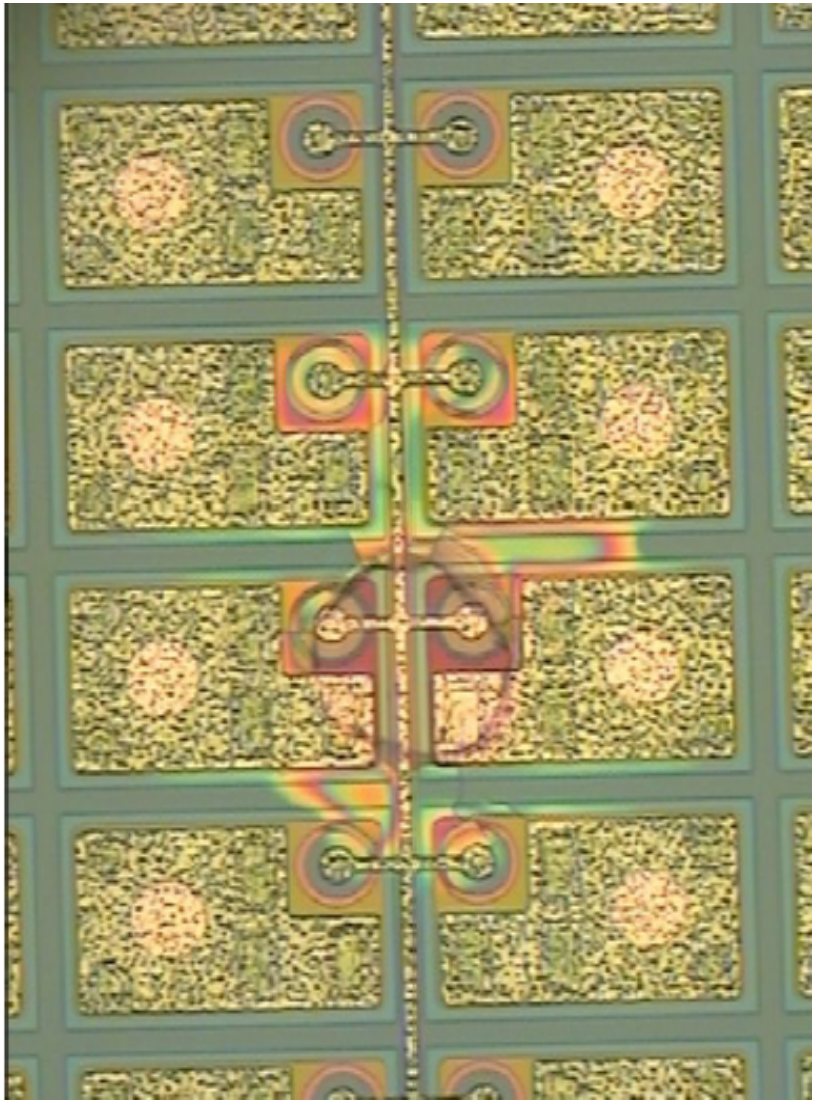
eff = (xdb linked clusters) / (telescope tracks with REF cluster)



- xdb 2
  - I_A 35 mA
  - trim 41
- runs 4248-4269
- tilt 0^o
- **99.1% in fiducial volume**
- **16 dead pixels**

CMS barrel pixel sensor

punch through bias dot



bump pad

n pixel

p-spray

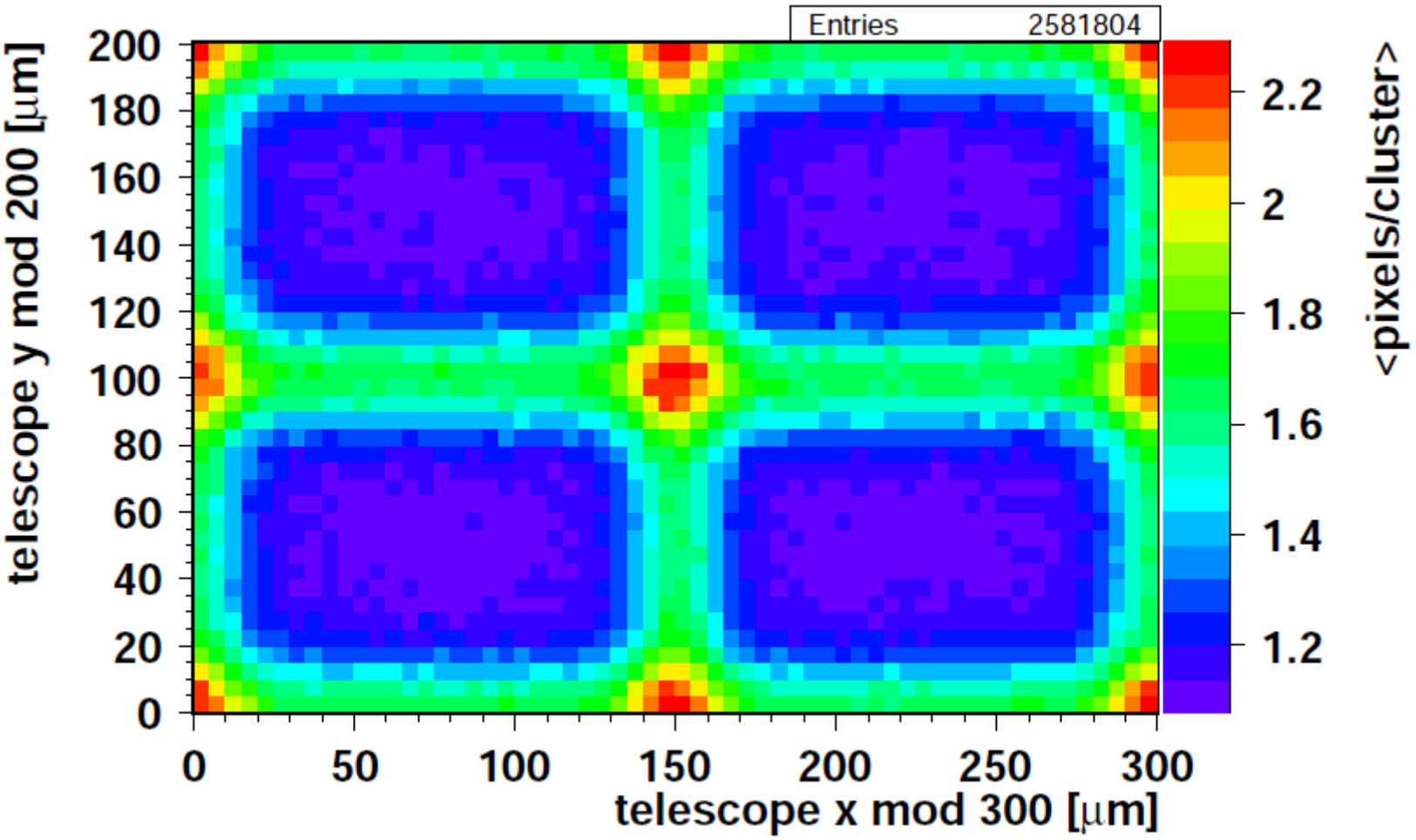
100 µm

150 µm **bias grid**

Uni HH, 2012

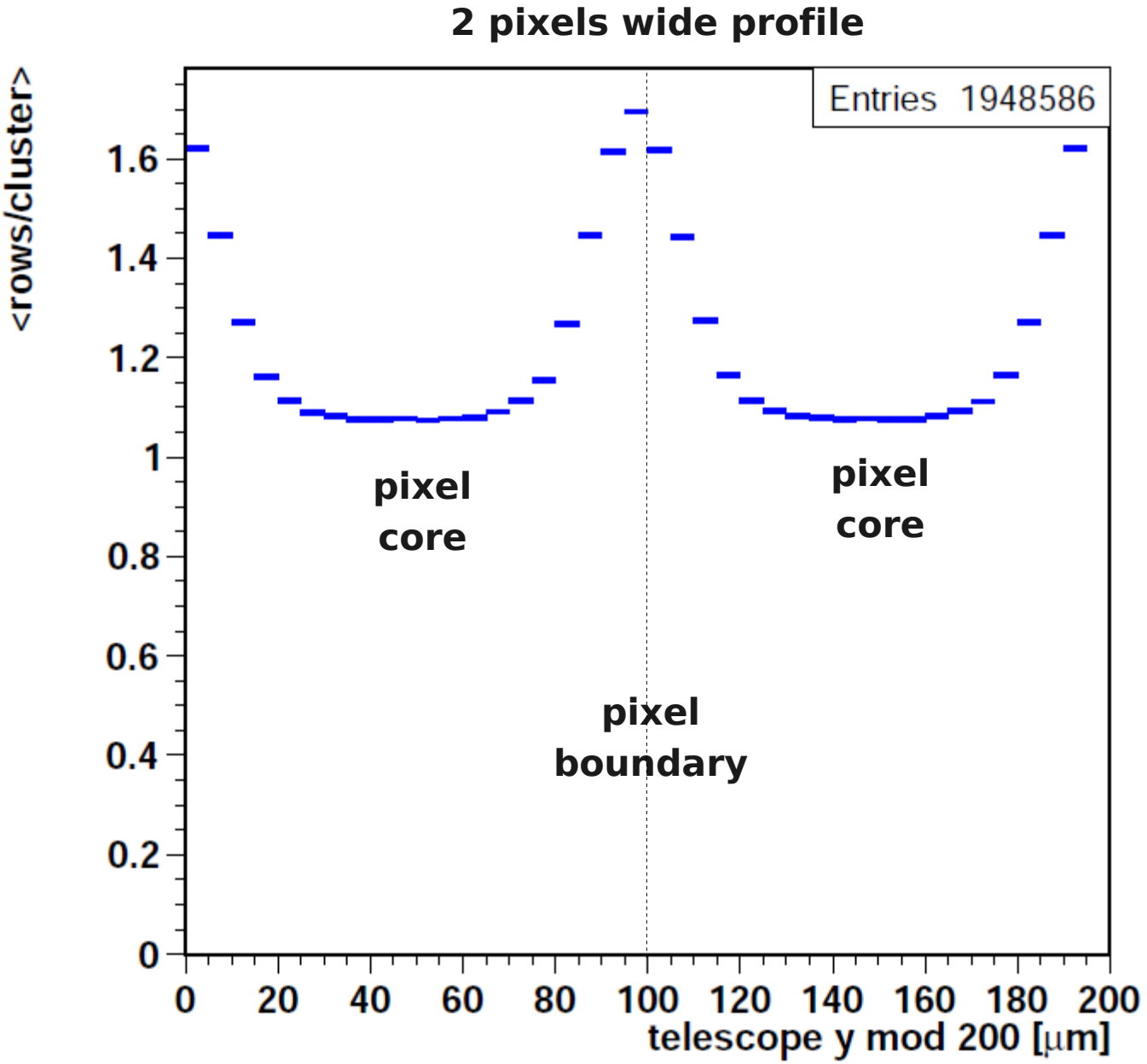
cluster size map with xdb

2×2 pixel map



- xdb2, **0º tilt**
- 4.8 GeV runs 4249-4269
- Telescope track has 6 μm precision
- **pixel core**
- **pixel edge**
- **pixel corner**
- **Charge diffusion radius is about 10 μm.**

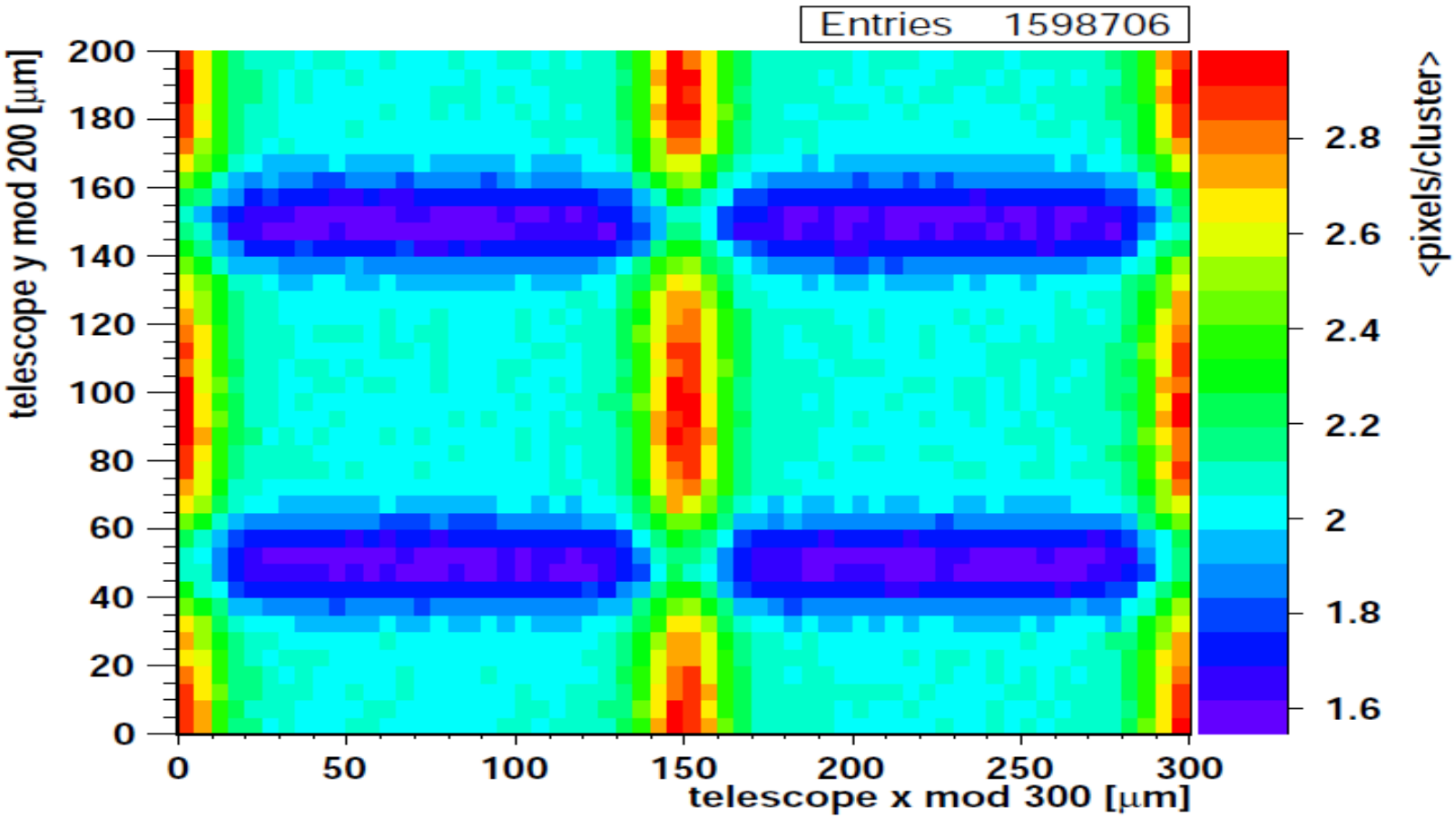
vertical cluster size profile with xdb



- xdb2, **0° tilt**
- 4.8 GeV runs 4249-4269
- Telescope track has 6 µm precision
- **pixel core:**
  - **minimal cluster size**
- **pixel boundary:**
  - **larger clusters due to charge diffusion**
  - **diffusion radius about 10 µm**

cluster size map with xdb

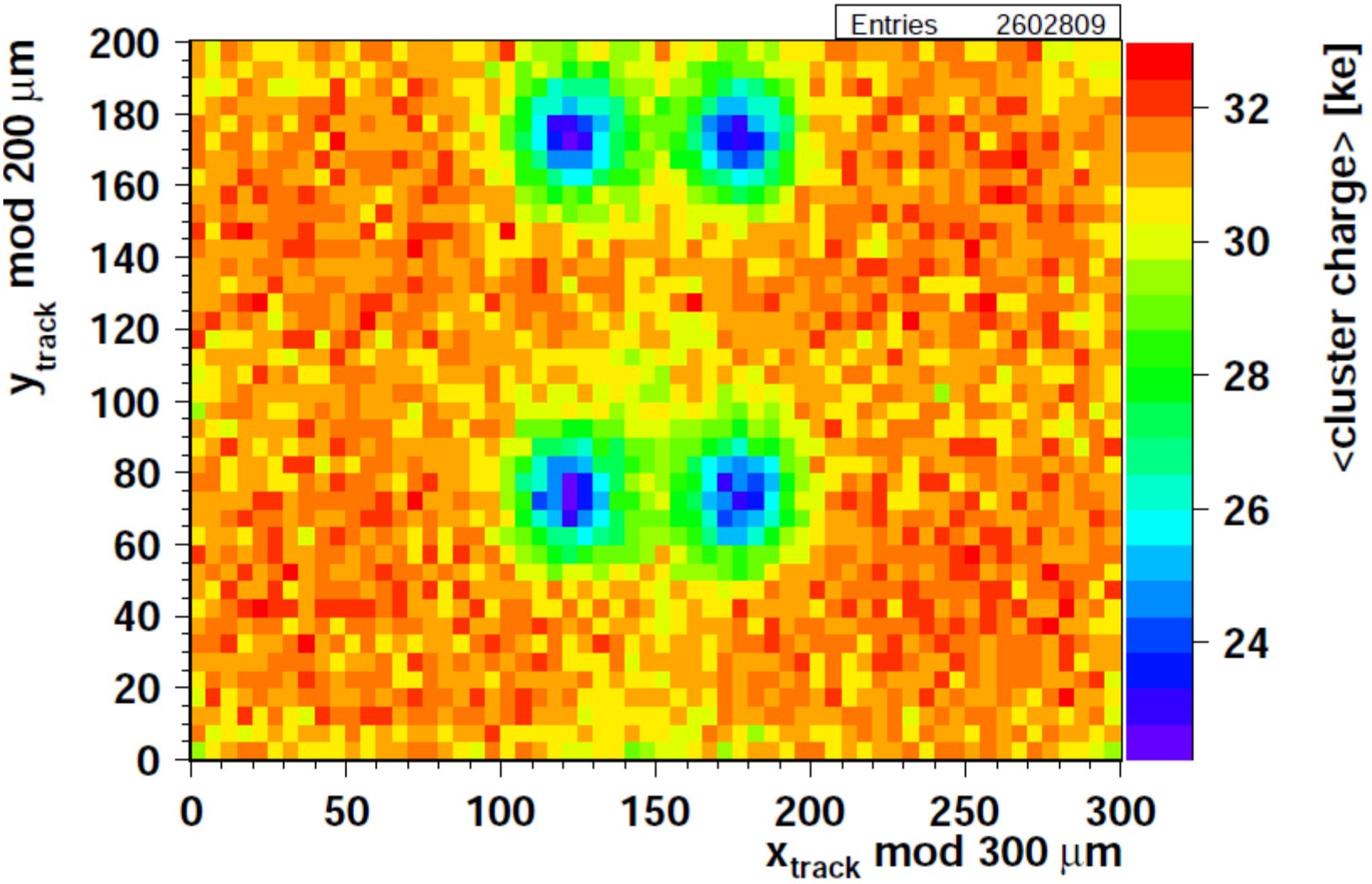
2×2 pixel map



- xdb2, **18° tilt**
- 4.8 GeV runs 4211-4231
- **pixel core:**
  - **2-pix clus**
  - **tilt**
- **row edge:**
  - **1-pix clus**
  - **threshold**
- **col edge:**
  - **diffusion**

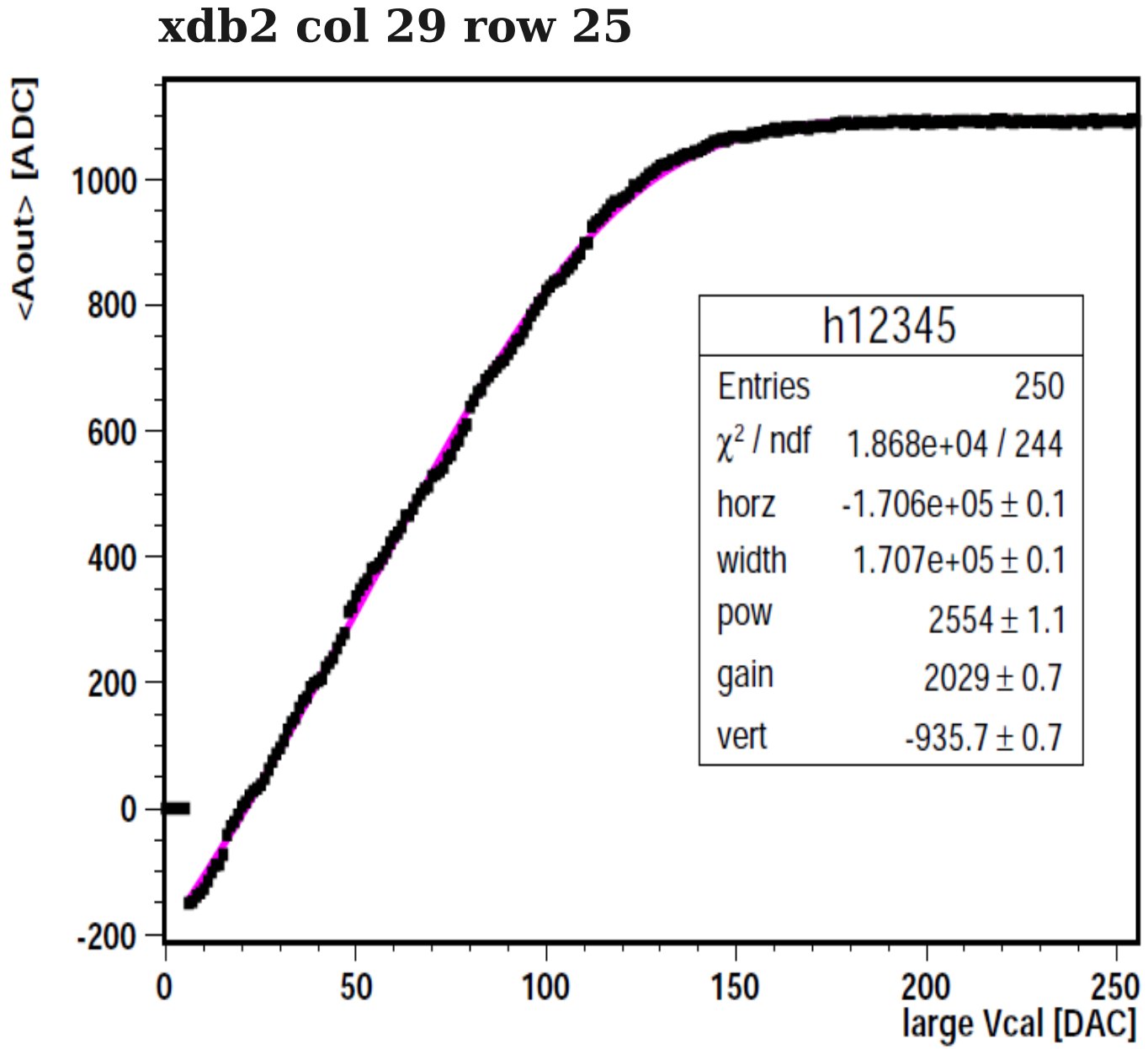
charge map with xdb

2×2 pixel map



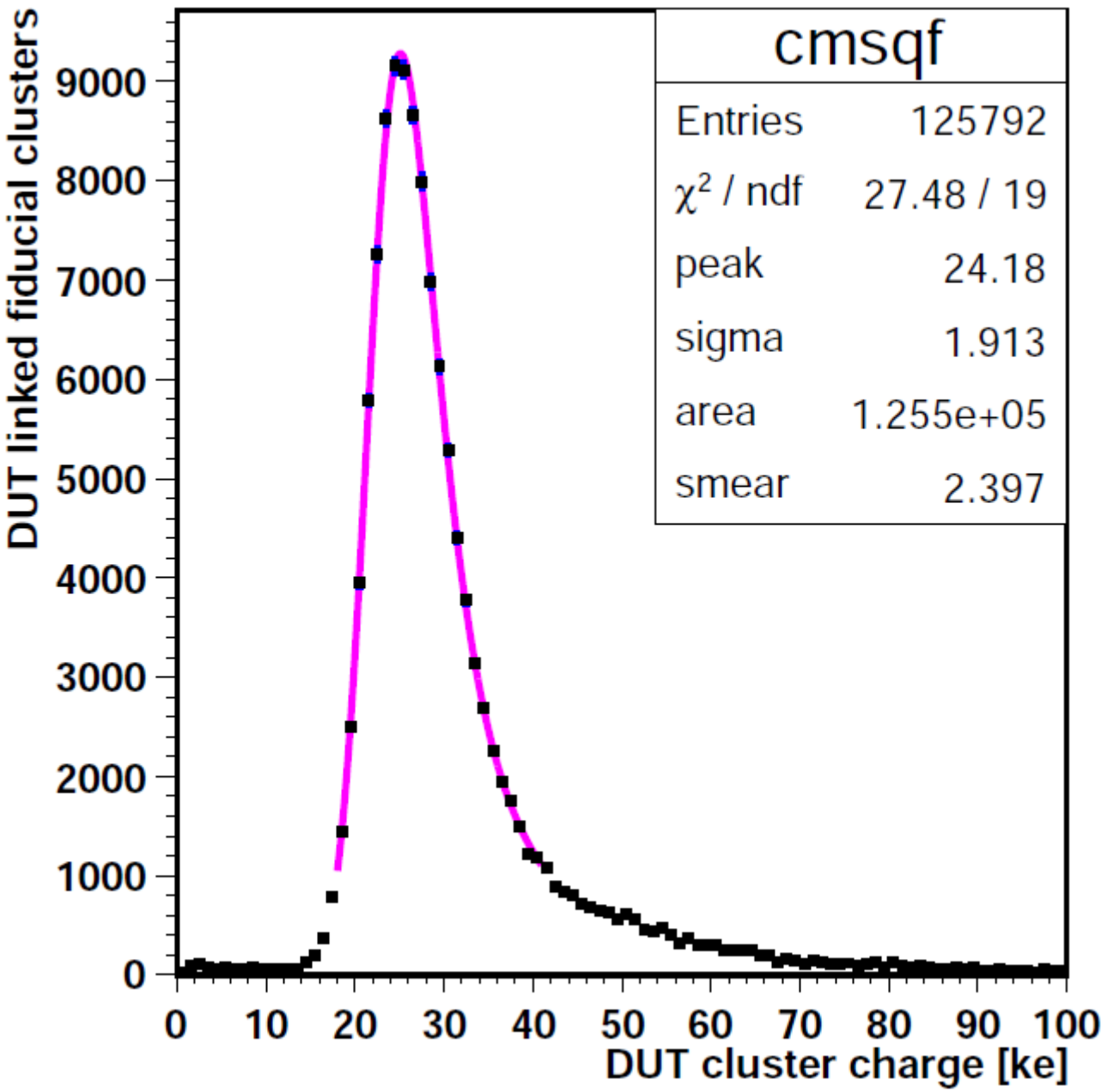
- xdb2, 0° tilt
- 4.8 GeV runs 4249-4269
- Test pulse gain calibration applied (Weibull fit)
- Telescope track position
- **bias dots: charge deficit**

xdb2 Aout vs Vcal gain curve



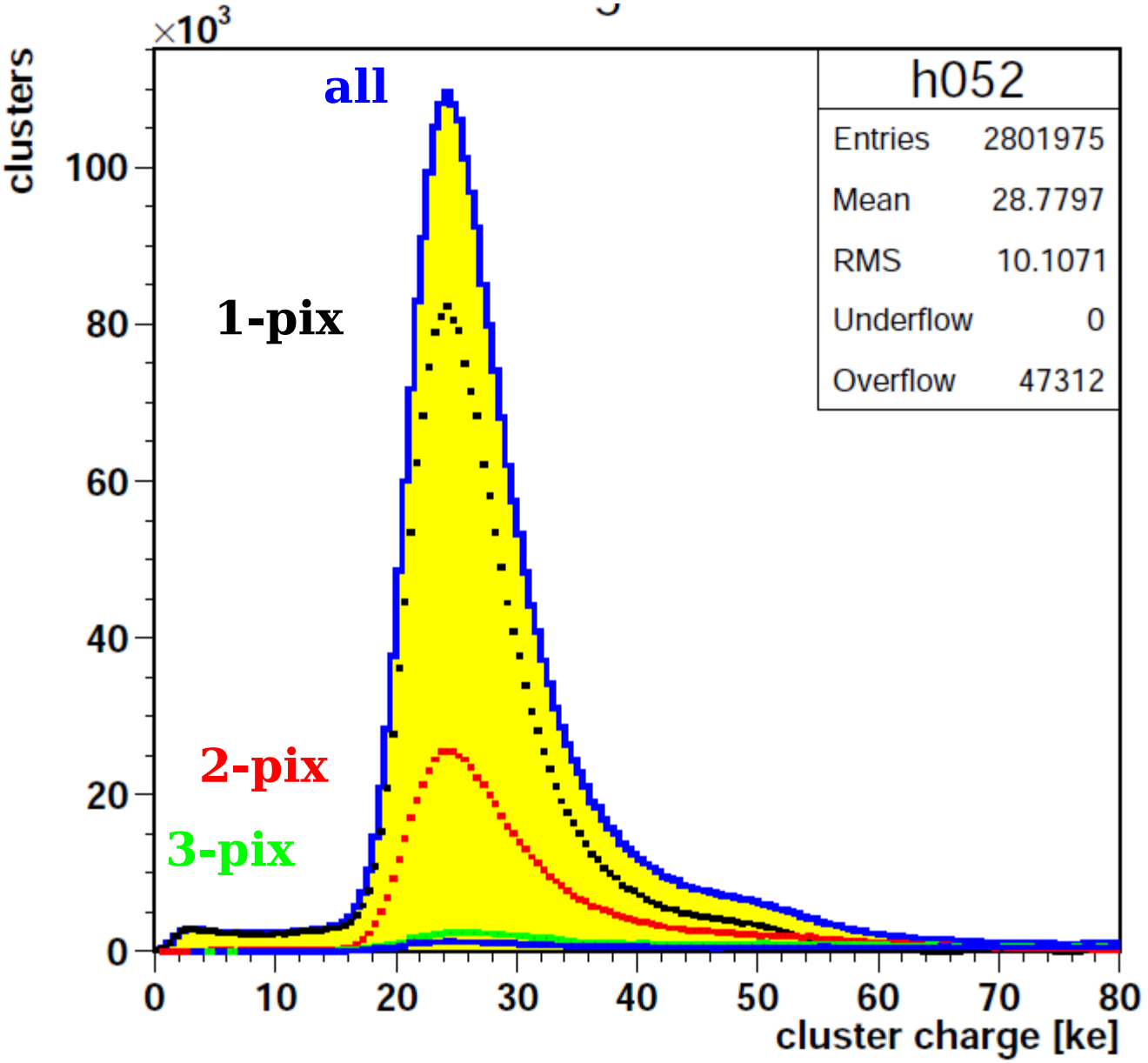
- xdb2
- for each pixel
- gainmap with disarm instead disable
- large Vcal:
  - 380 e / DAC (Landau calibration)
- Fit by Weibull function

xdb2 Landau distribution



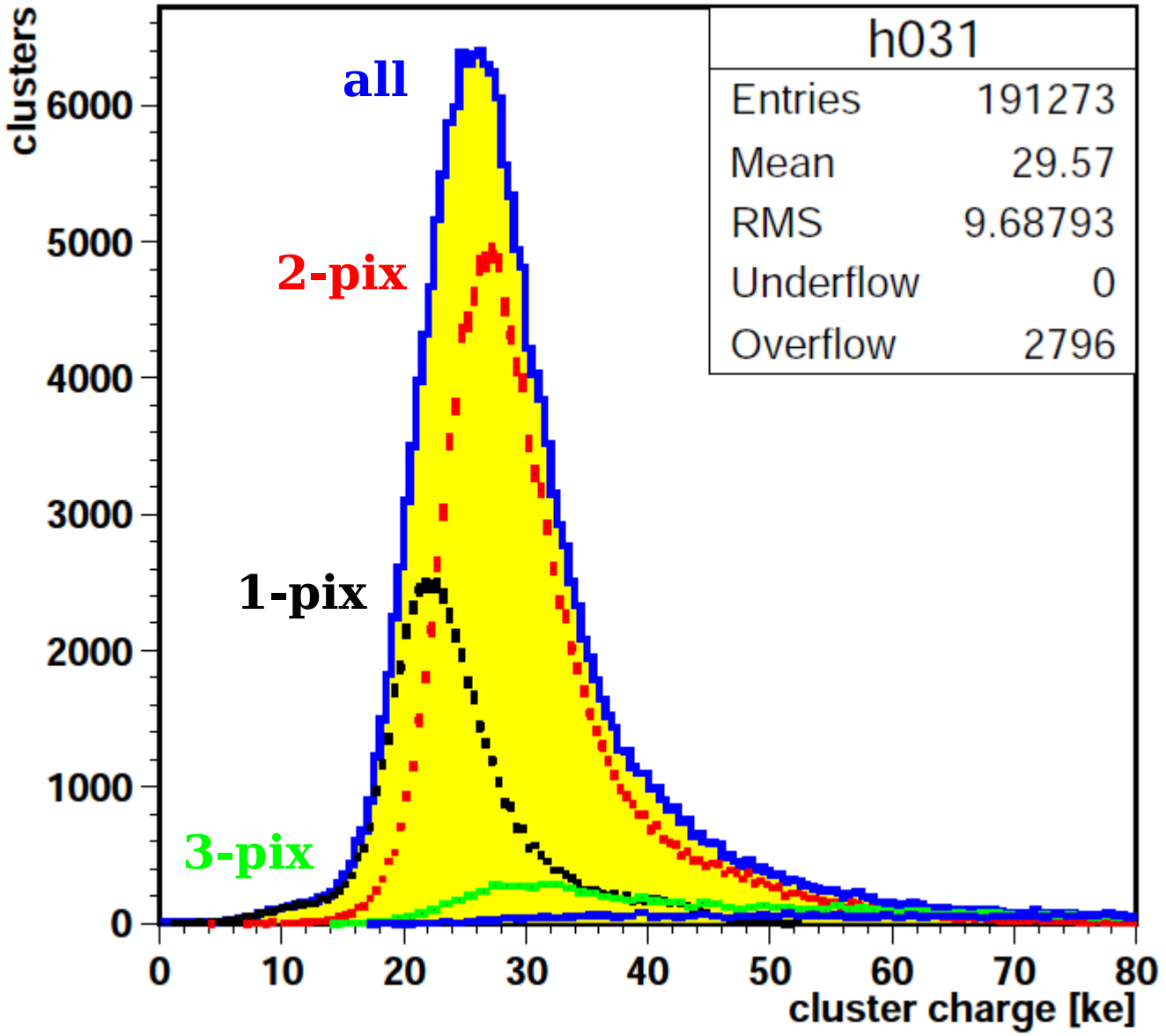
- xdb2
- run 4211:
  - bias -150V
  - threshold 1.8 ke
  - tilt 19°
- Weibull gain calibration applied
- Cluster charge distribution fit by Landau ⊗ Gauss
  - peak position and width OK
  - Gaussian smearing needed

Cluster charge vs size for xdb



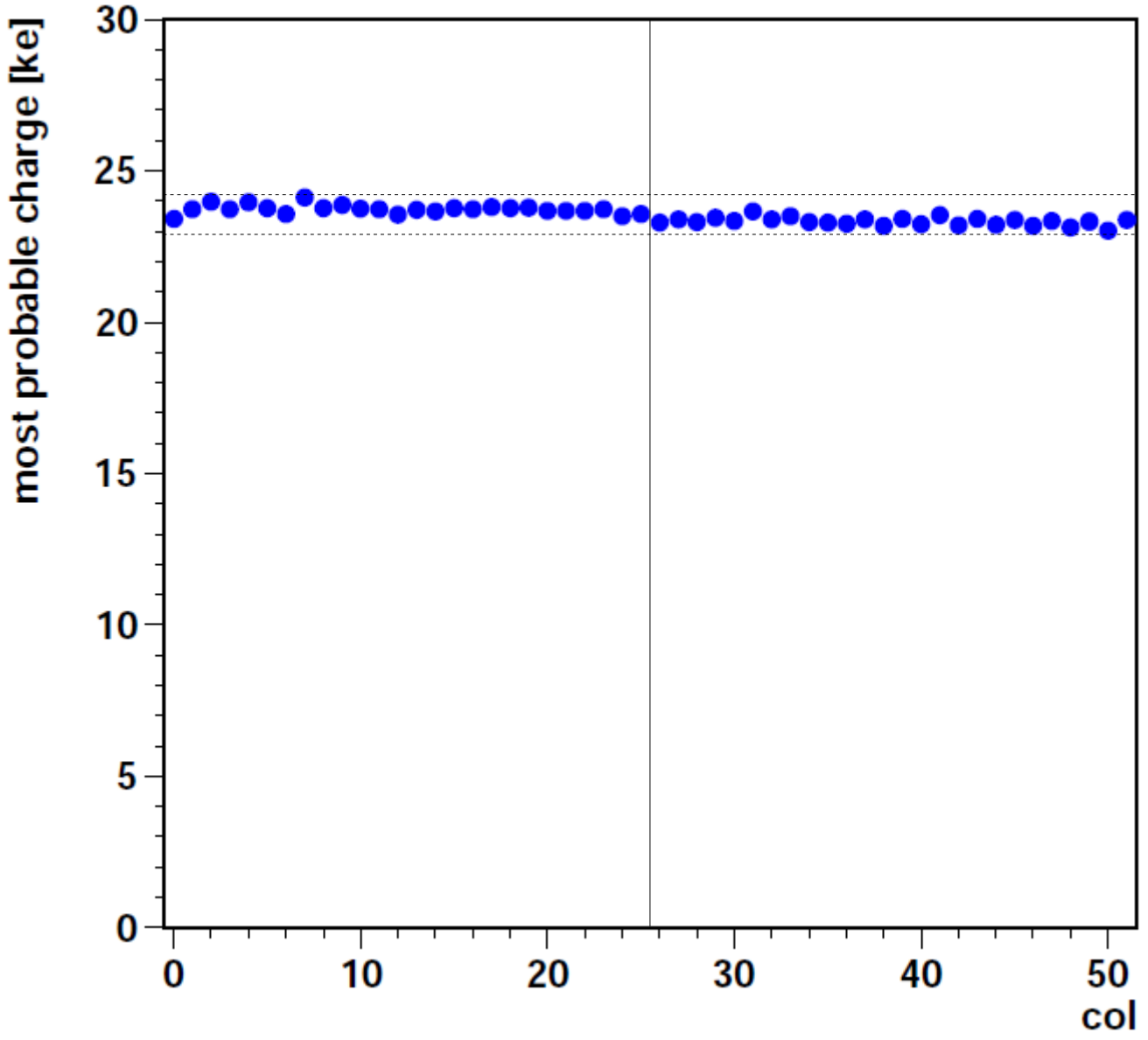
- xdb2
- 0^{o} tilt
- 4.8 GeV, runs 4249-4269
- Test pulse gain calibration (Weibull fit): gainweib.dat
- 1-pixel and 2-pixel clusters have same Landau peak:
  - no large loss due to threshold

Cluster charge vs size for psi46



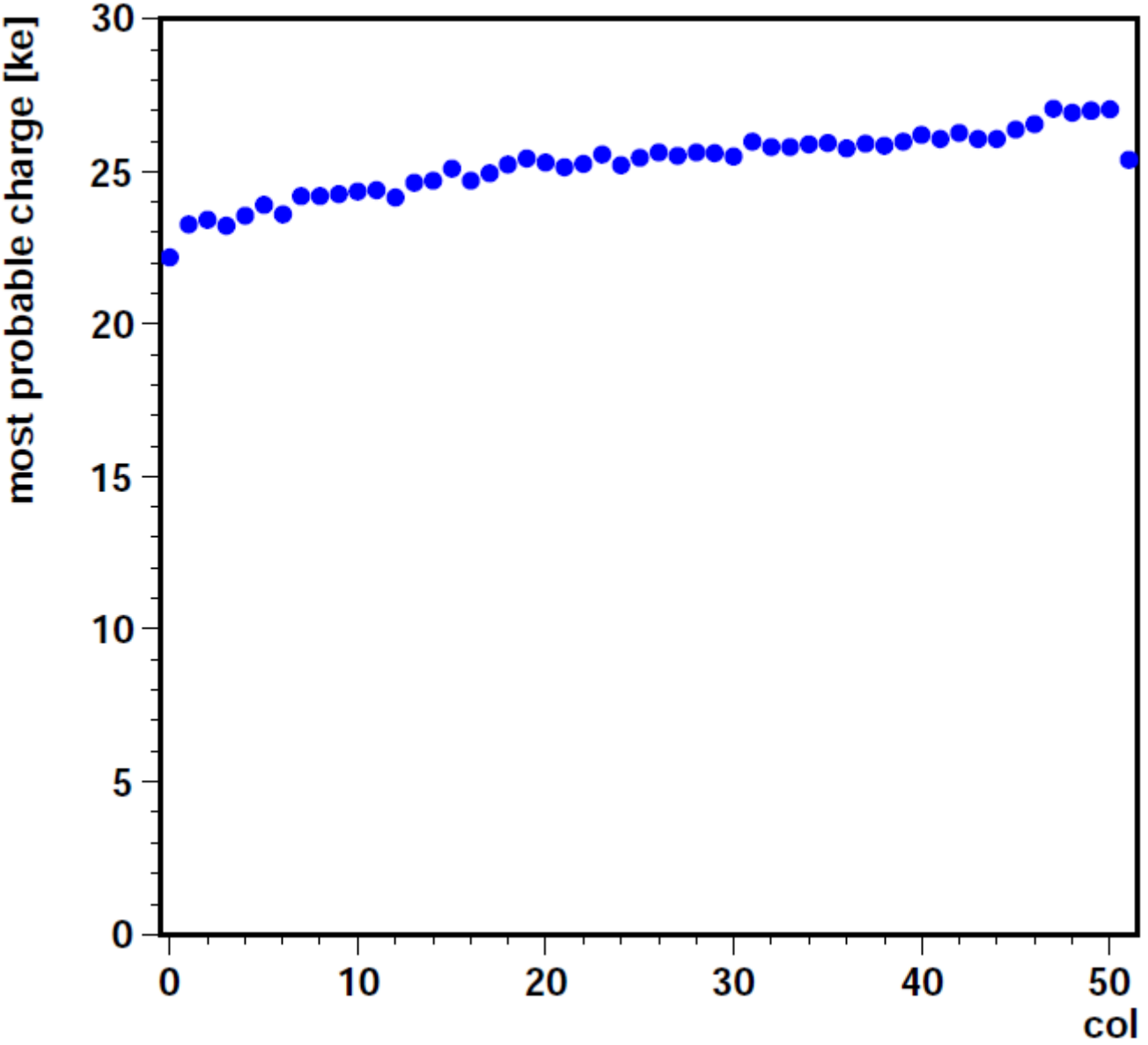
- 4 GeV e-, run 2880, chip 10, 20° tilt
- Test pulse gain calibration applied (tanh fit)
- 1-pixel clusters have lower Landau peak:
  - charge loss due to threshold?

Cluster charge profile xdb



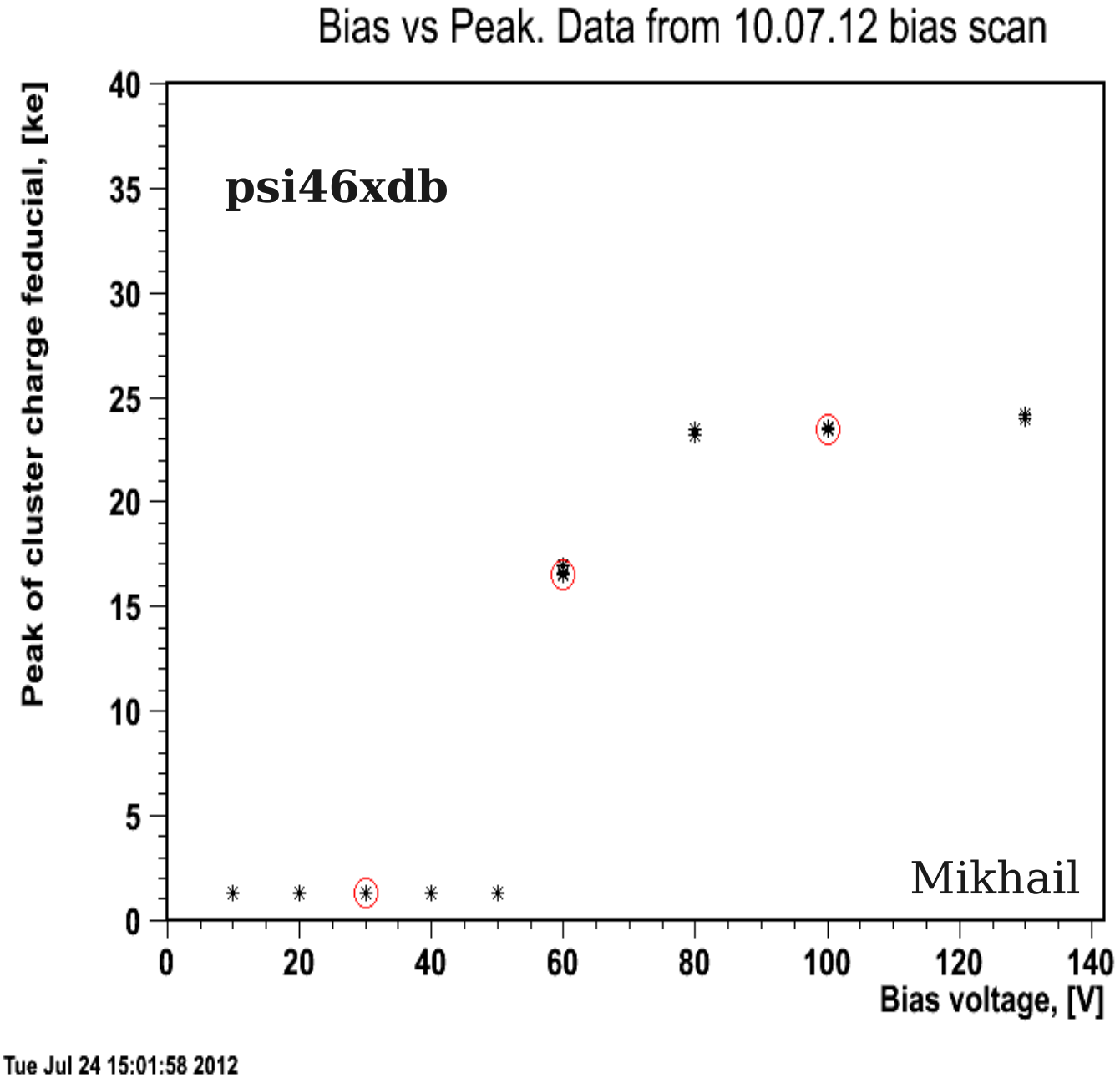
- xdb2, 0^{o} tilt
- 4.8 GeV, runs 3903-3947
- Test pulse gain calibration applied (Weibull fit)
- Landau peak per column
- **Flat within ±2%**
  - small difference between left and right half?
- Mean value is adjusted to 24 ke for e^{+} in 285 µm Si
  - 350 e / large Vcal DAC

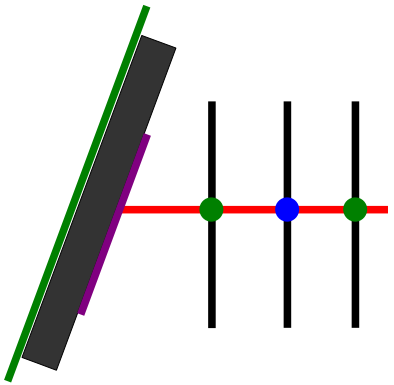
Cluster charge profile psi46



- 4 GeV e^-
- chip 10, 20° tilt
- Test pulse gain calibration applied (tanh fit)
- peak charge
- **Observe ±8% gain variation across the chip**

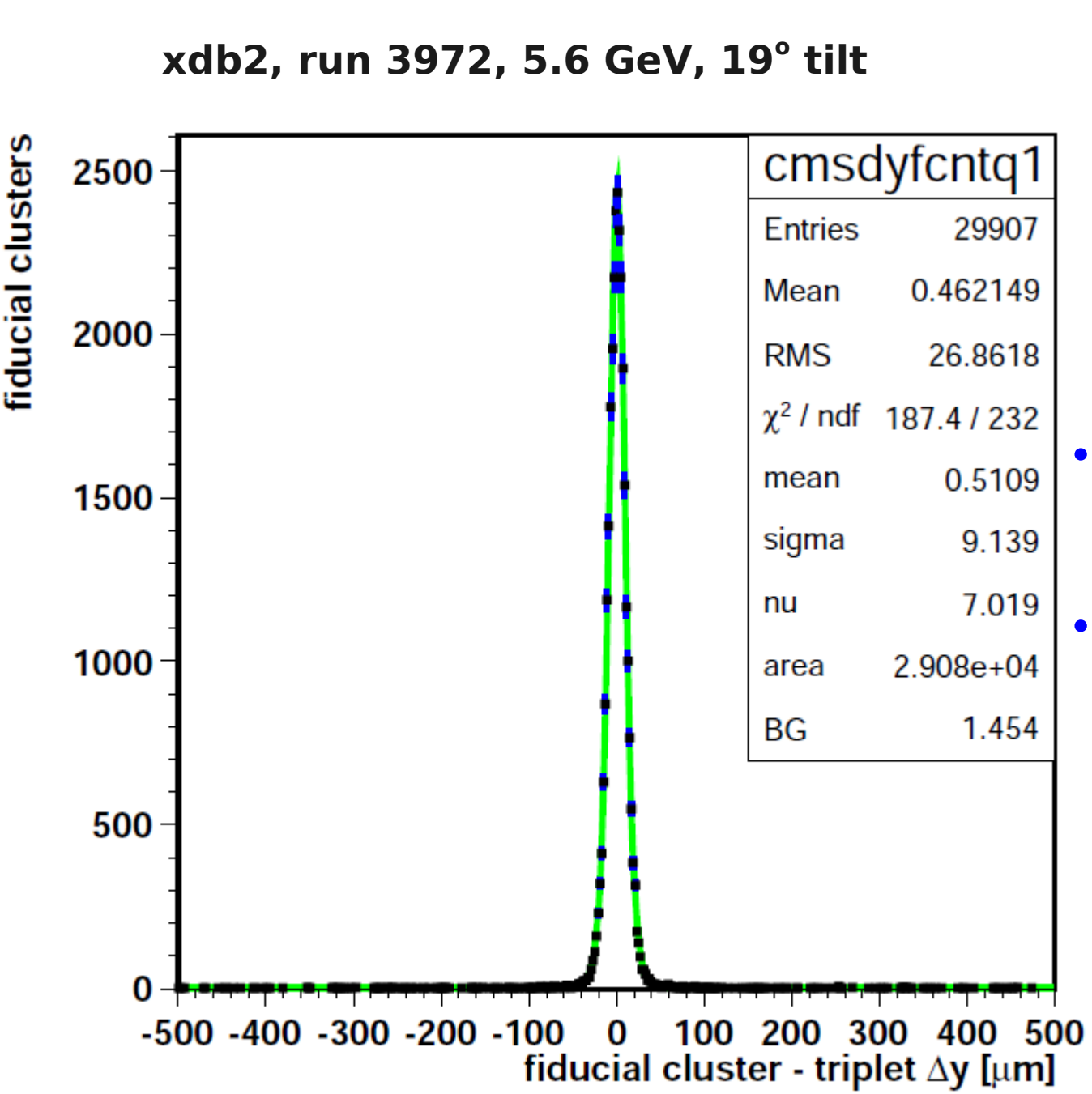
charge vs bias voltage

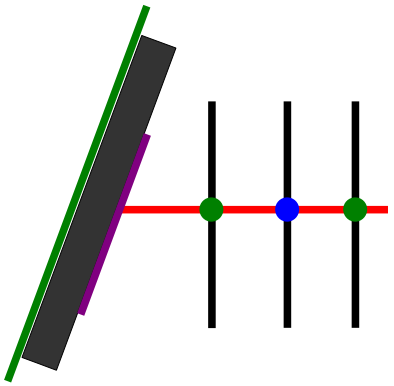




- Chip xdb2, 19° tilt
- bias voltage scan
  - need >70 V for full depletion

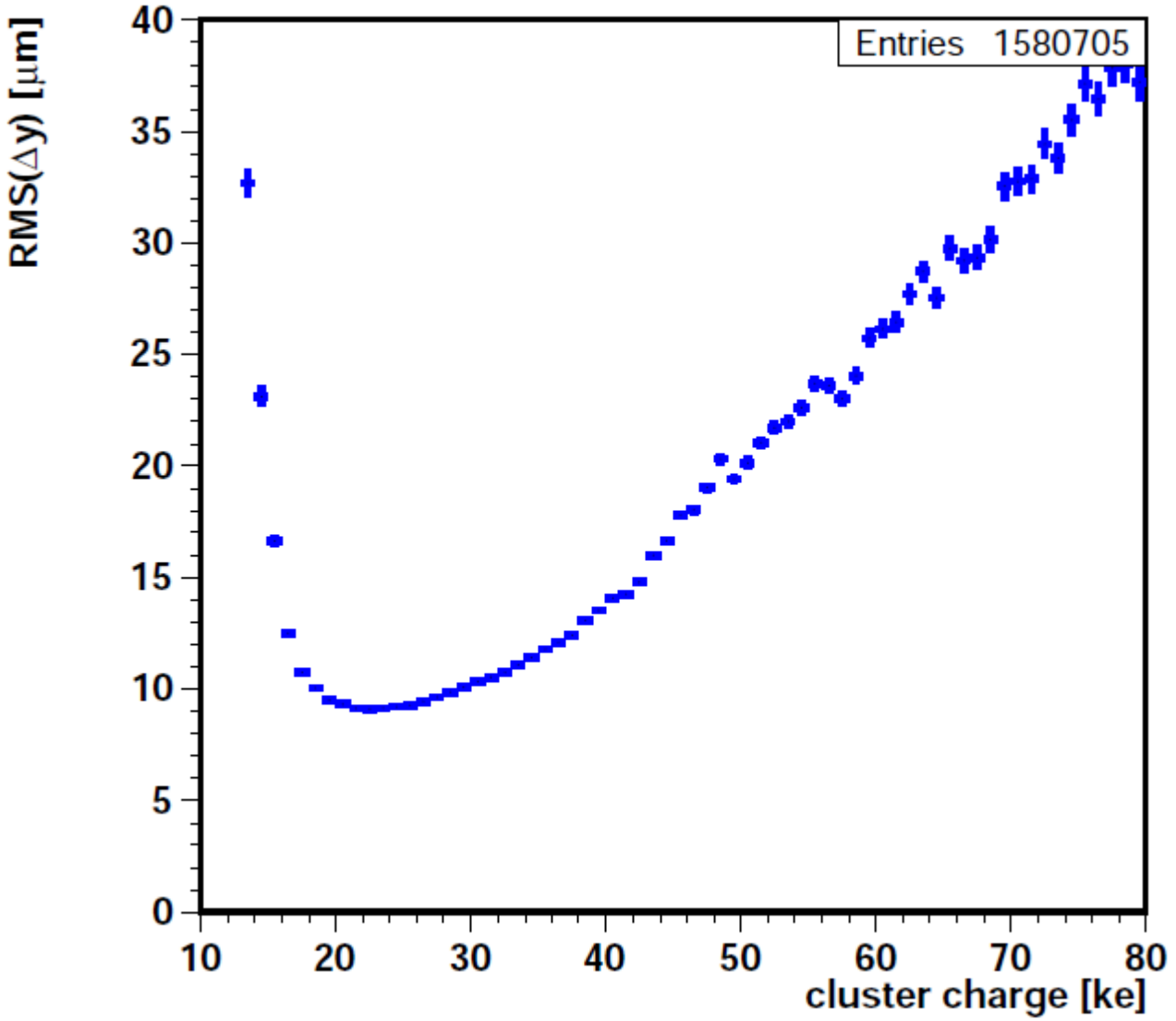
row resolution

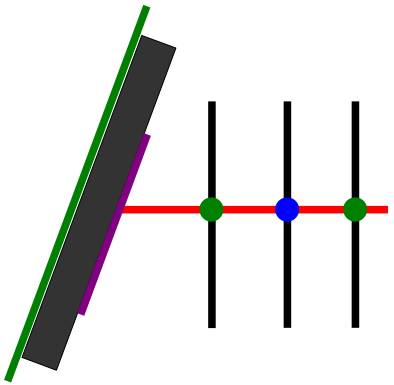




- Vertical = rows
  - CMS pixel = 100 µm.
- Residual:
  - σ = 9.1 µm,
  - telescope extrapolation: 5.7 µm,
  - **xdb resolution: 7 µm**
  - **similar to psi46**

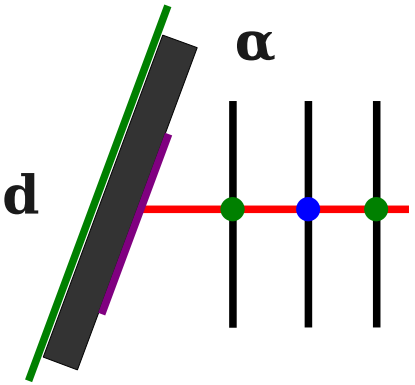
row resolution vs cluster charge

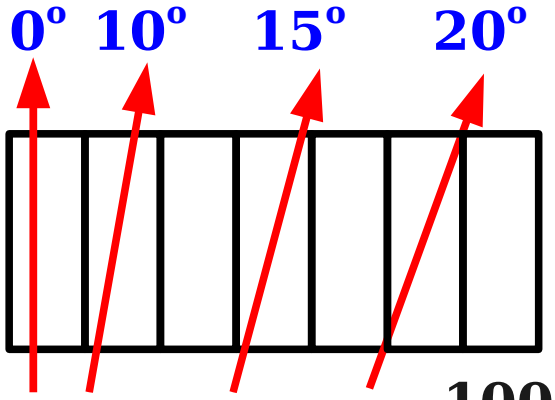




- Best resolution for mips at the Landau peak around 24 ke
- Poor resolution below 18 ke:
  - broken clusters
- Poor resolution in Landau tail above 40 ke:
  - delta rays

tilt angle





sensor thickness

285 µm

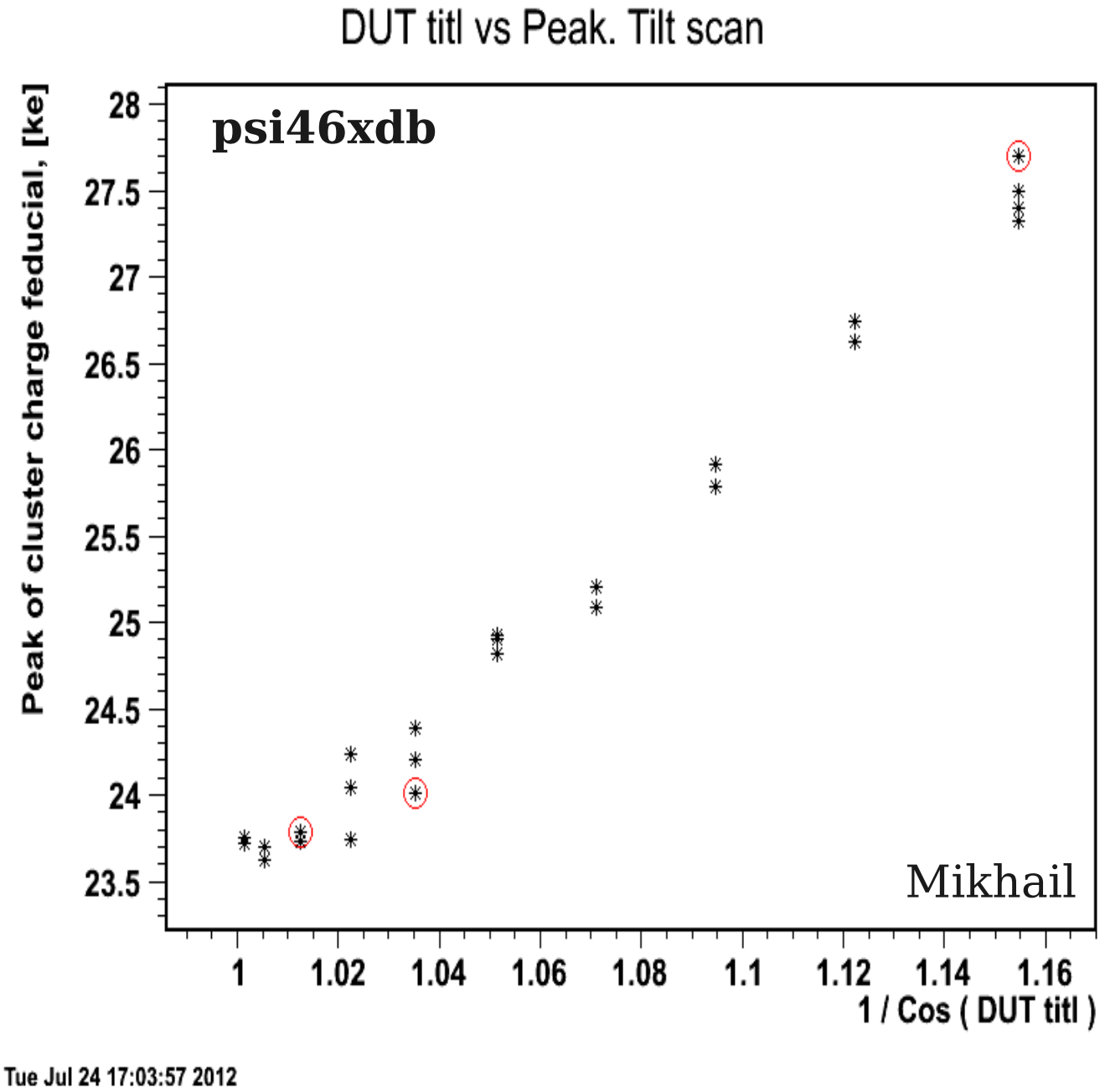
100 µm

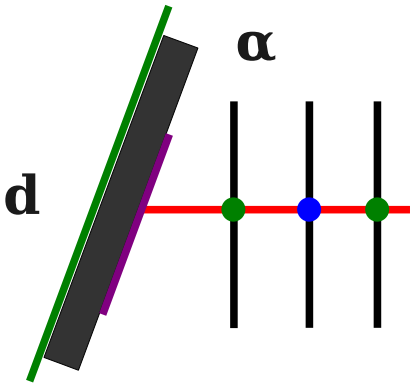
pixel size

optimal angle:

atan(100/285) = 19.3°

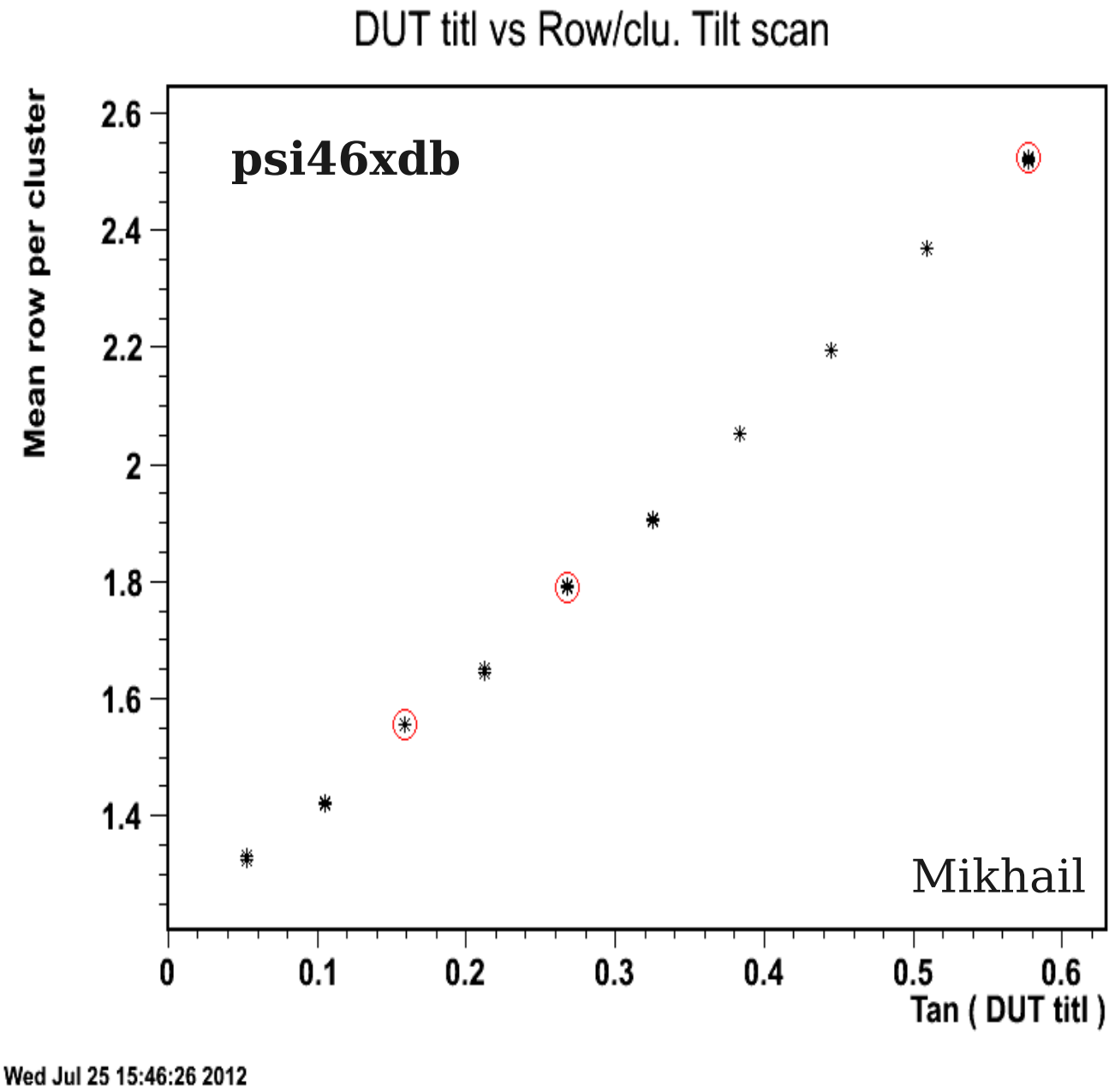
Cluster charge vs tilt angle

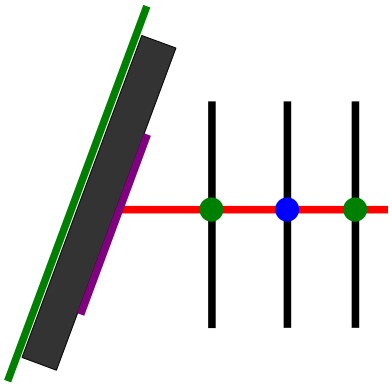




- Chip xdb2, -150V
- effective sensor thickness:
  - $d = 285\ \mu m / \cos \alpha$
- position of the Landau peak should be linear in d

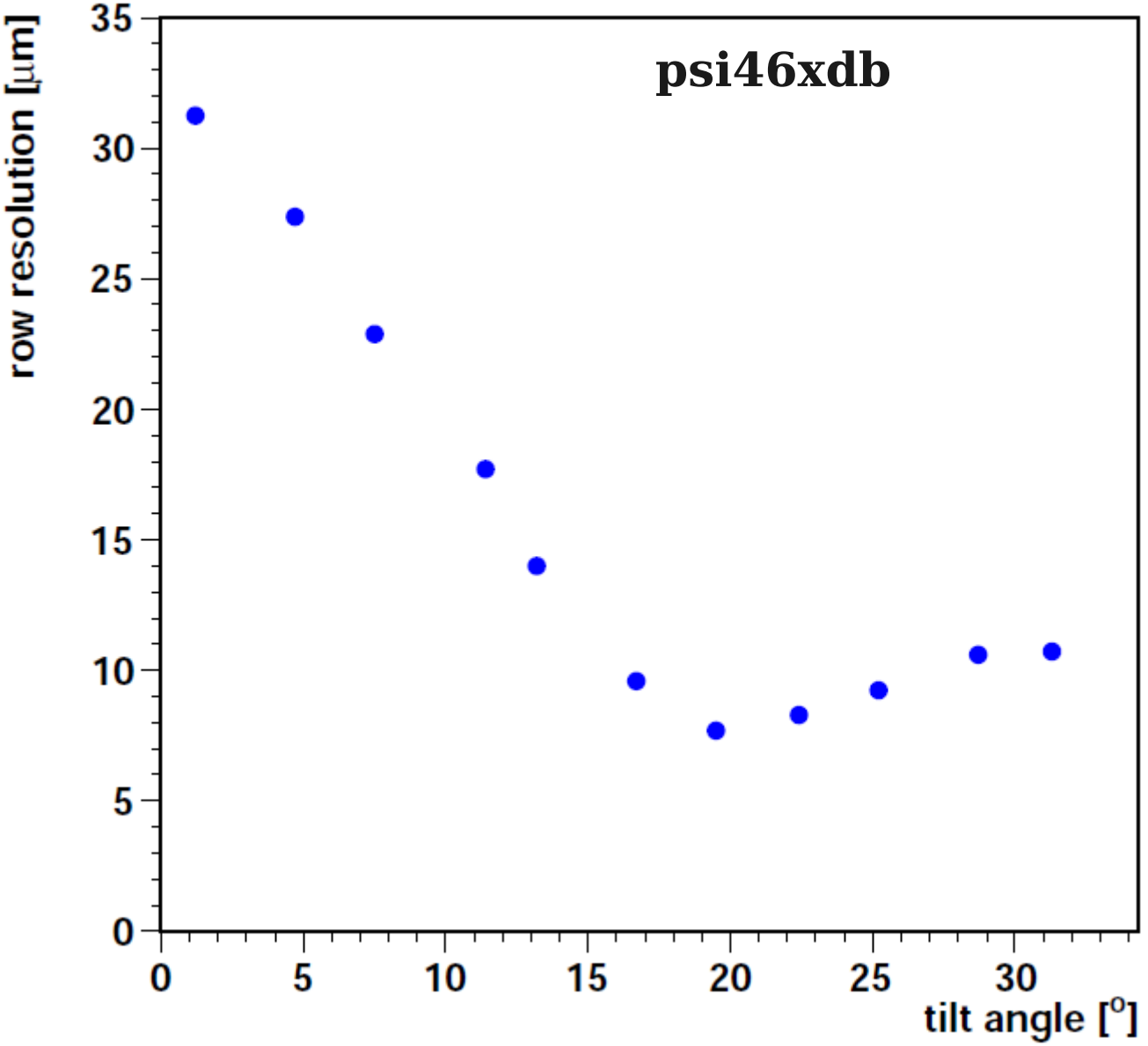
xdb cluster size vs tilt angle

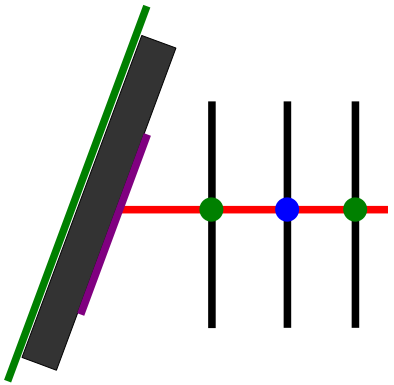




- Chip xdb2, -150V
- rows per cluster:
  - scales with tan(tilt)

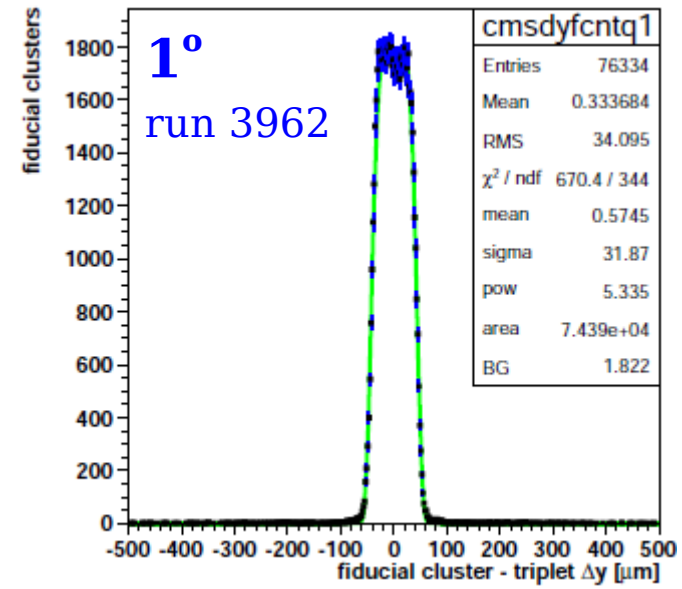
xdb row resolution vs tilt angle

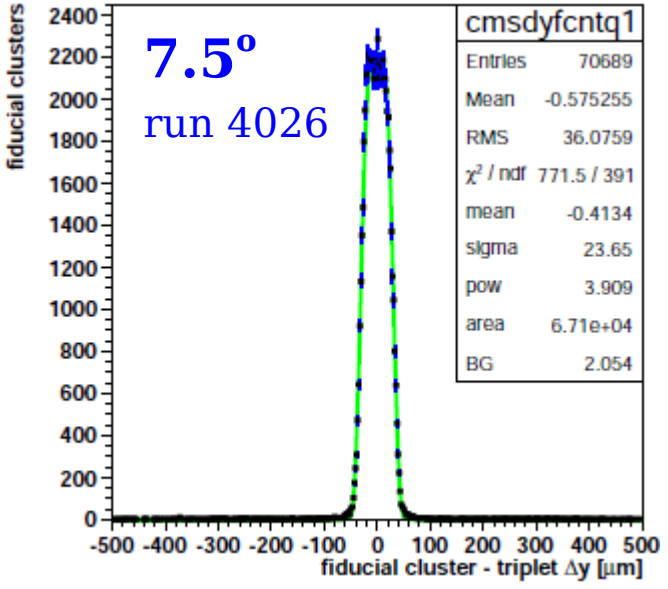


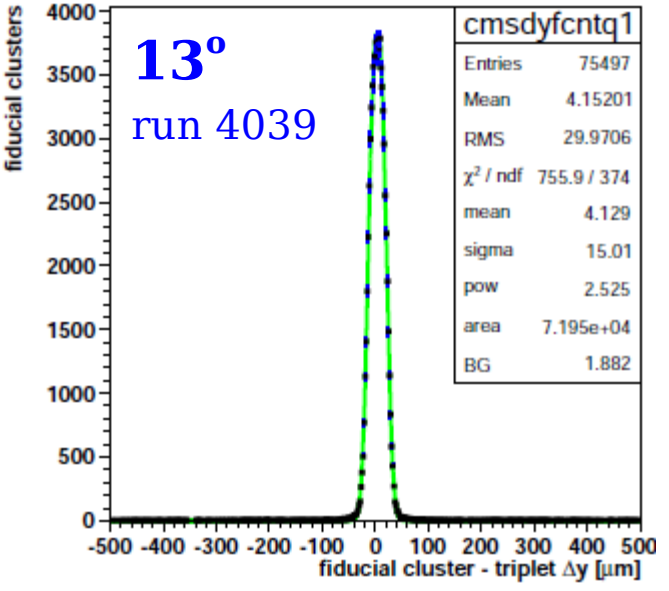


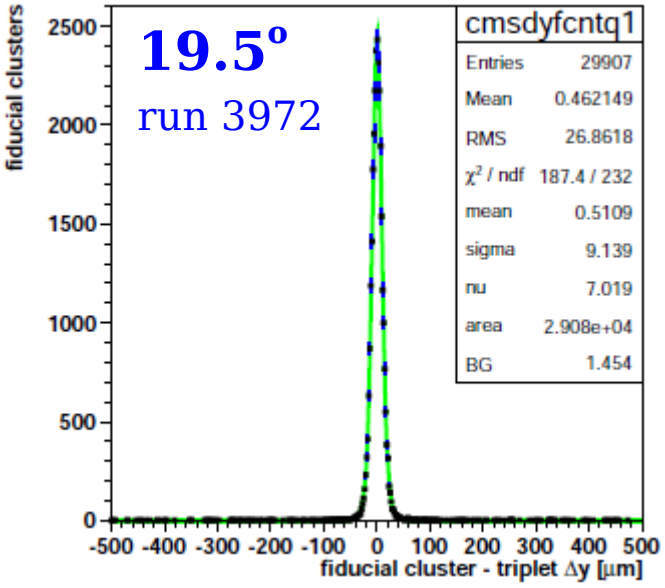
- Chip xdb2, 5.6 GeV, telescope extrapolation uncertainty subtracted.
- row pixels = 100 μm.
- At 0°:
  - σ = 100 / √12 = 29 μm
- Optimal angle 19.5°:
  - σ = 7 μm.
- Similar to psi46

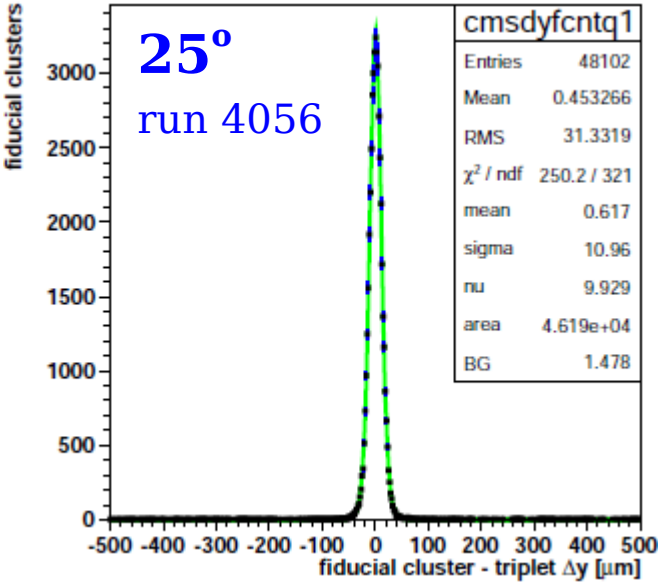
xdb row resolution vs tilt angle

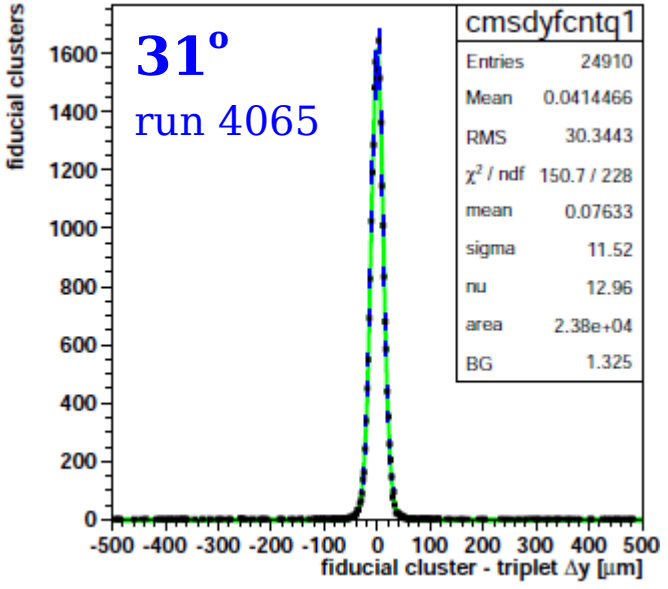




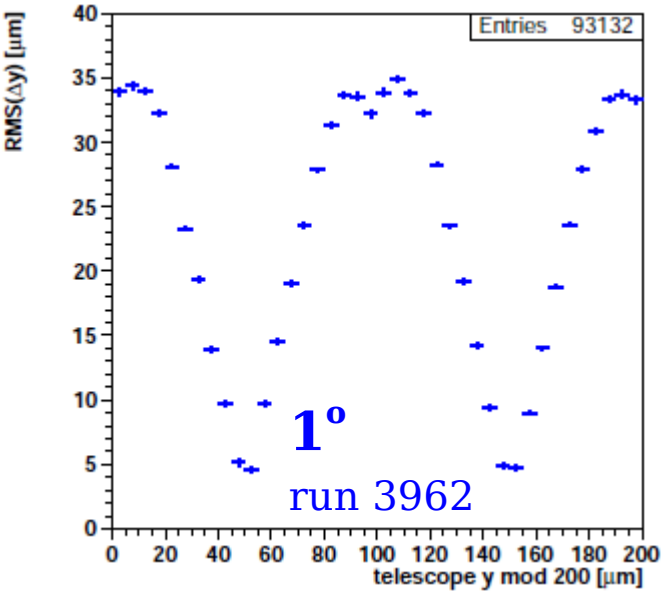


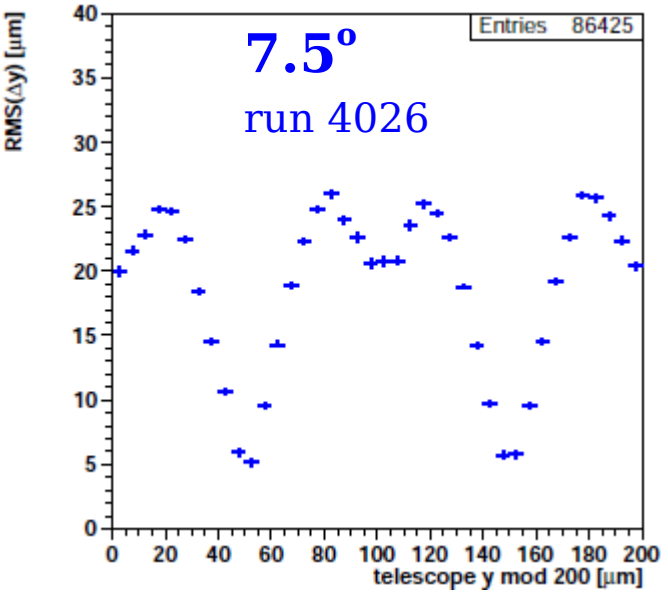


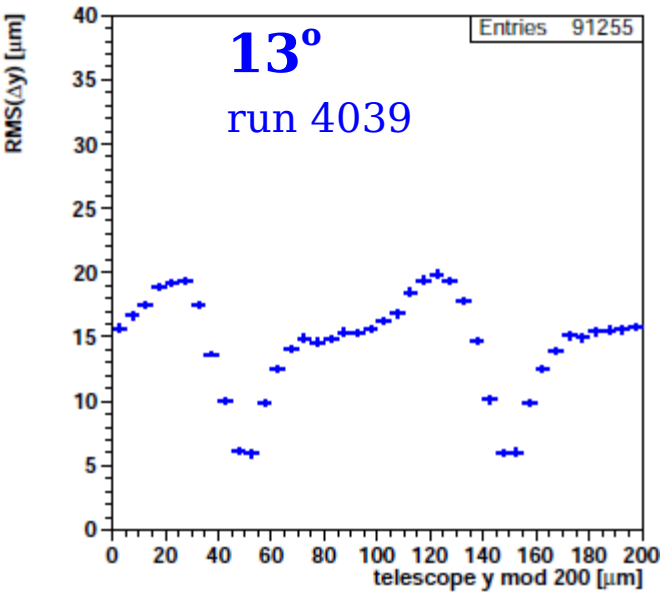




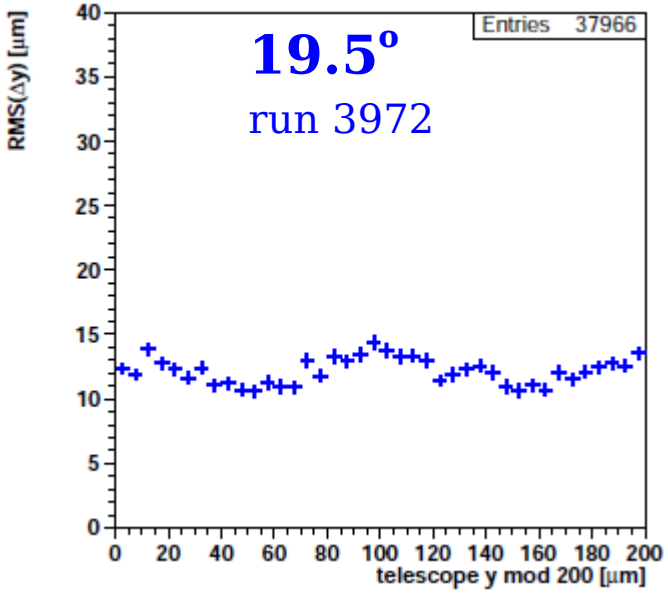
xdb resolution vs impact point & tilt angle

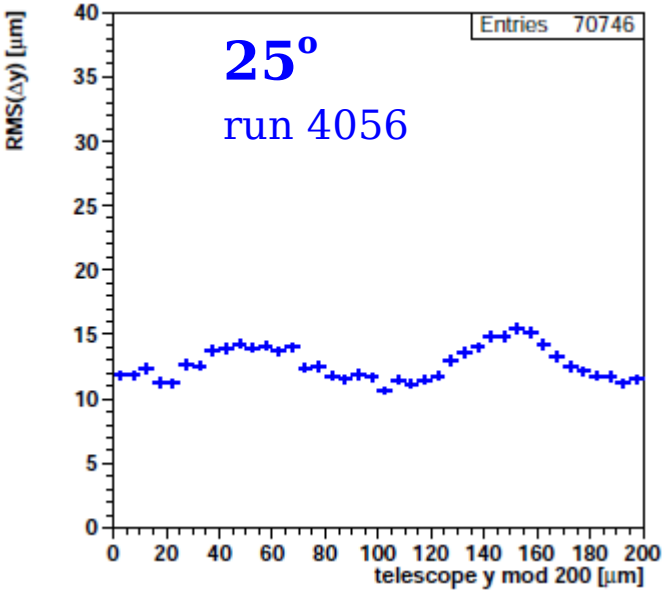


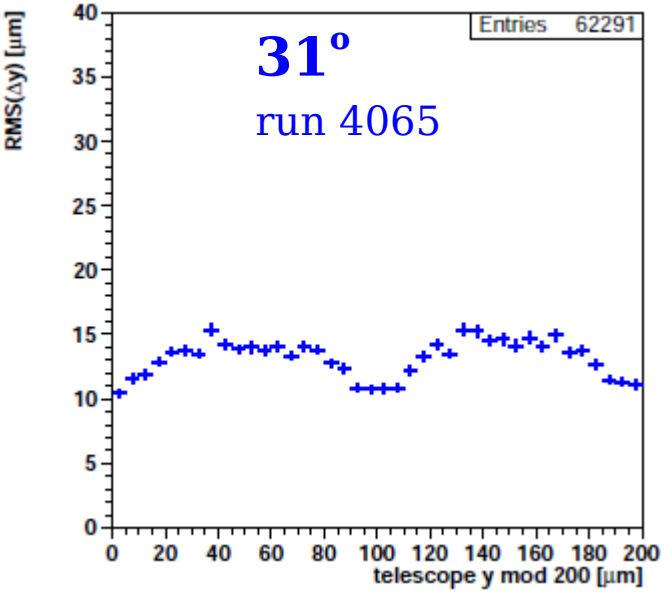




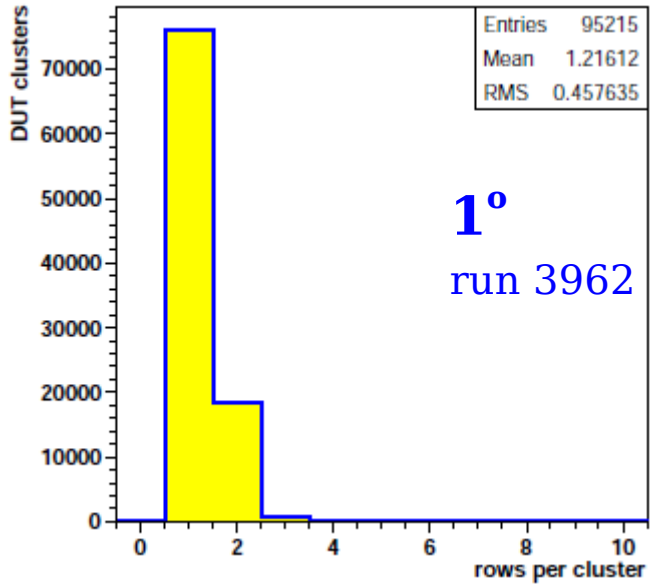
y_{impact} mod 200 μm: 2 pixels wide

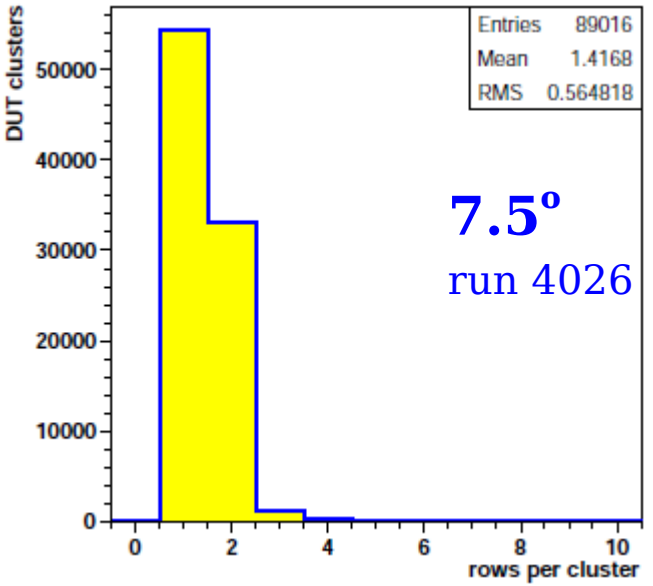


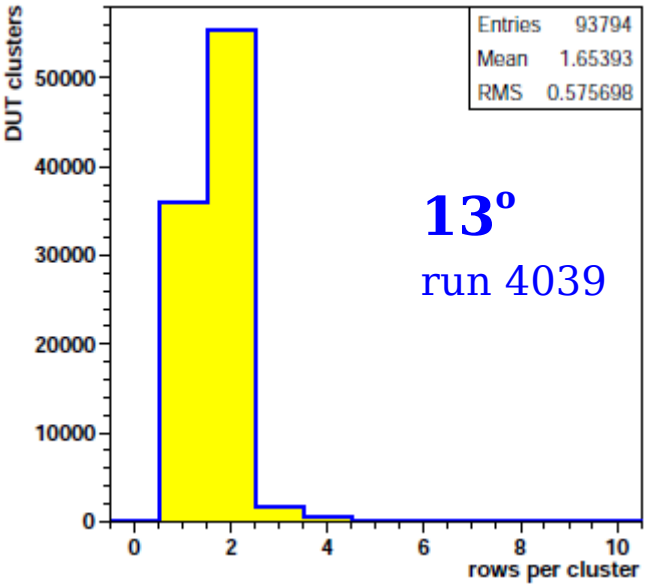


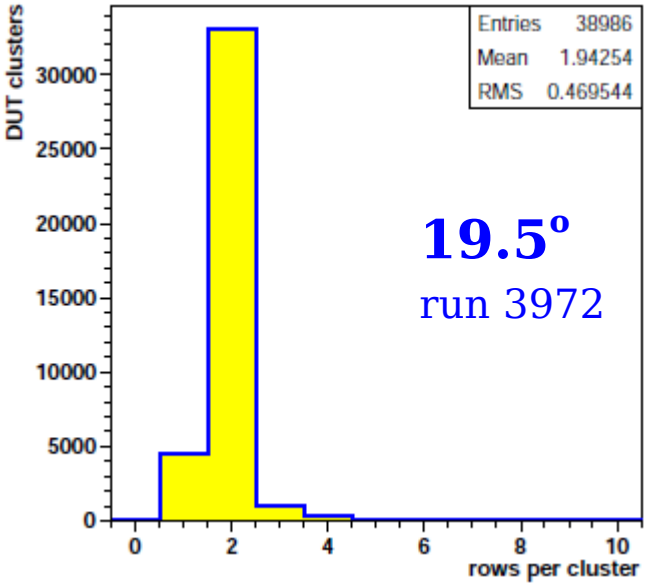


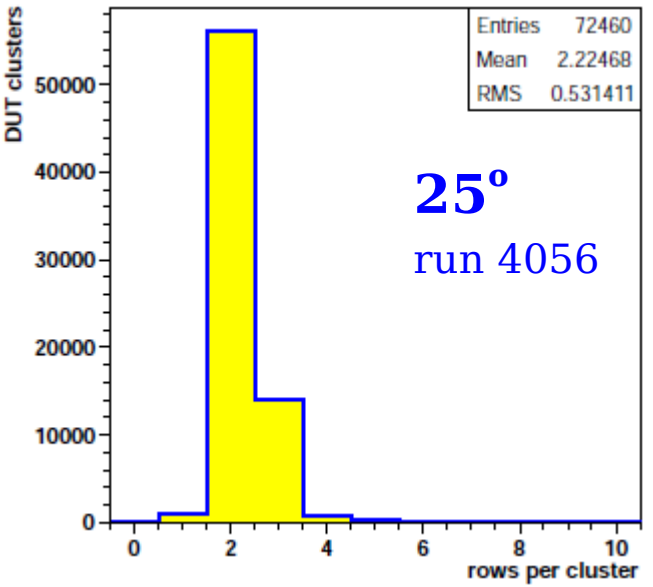
xdb rows per cluster vs tilt angle

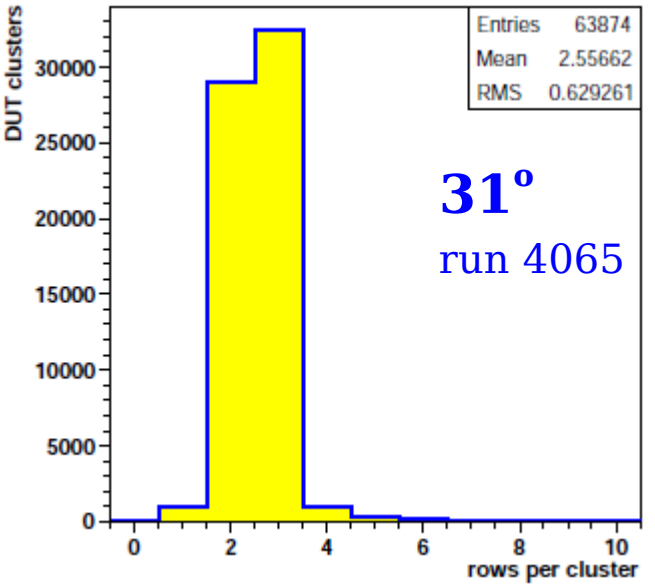




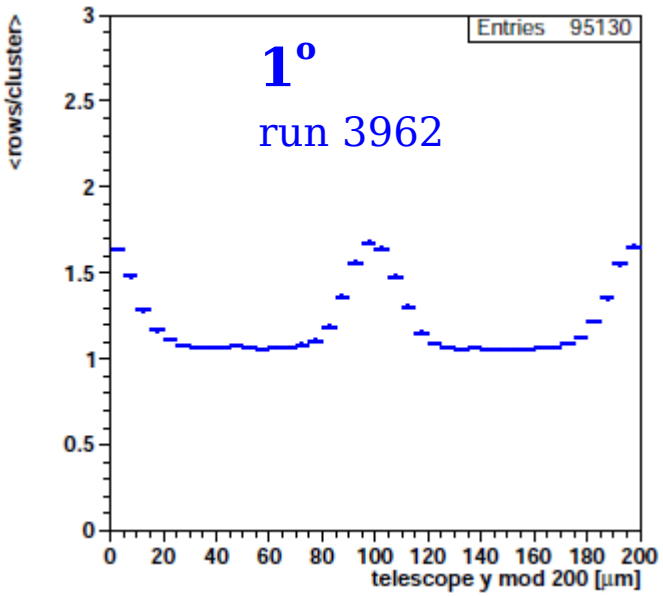


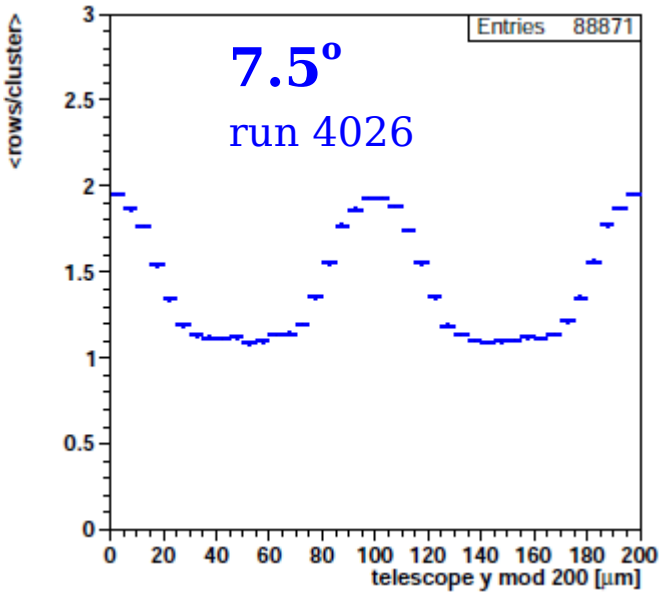


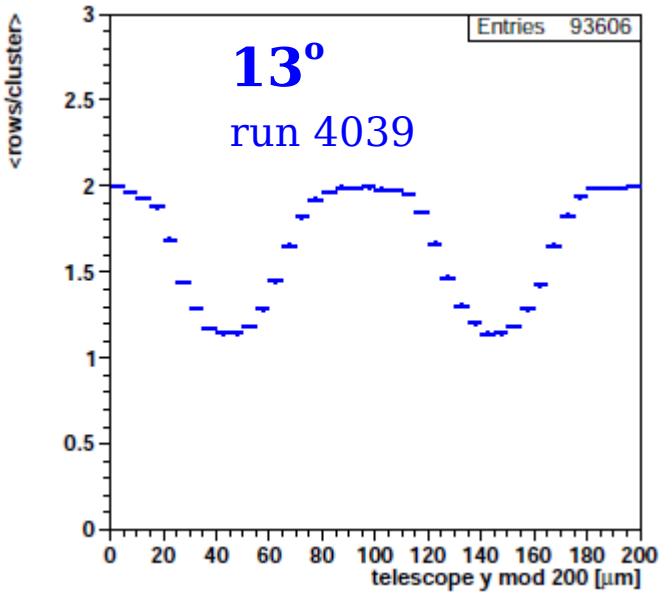




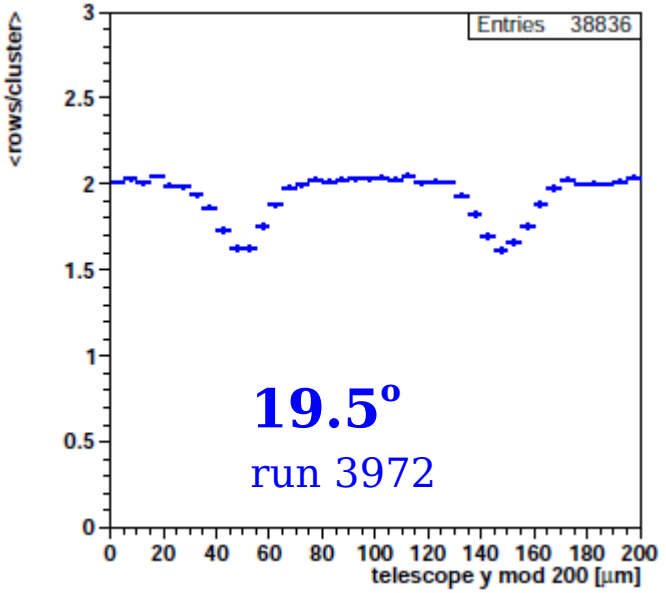
cluster size vs impact point and tilt angle

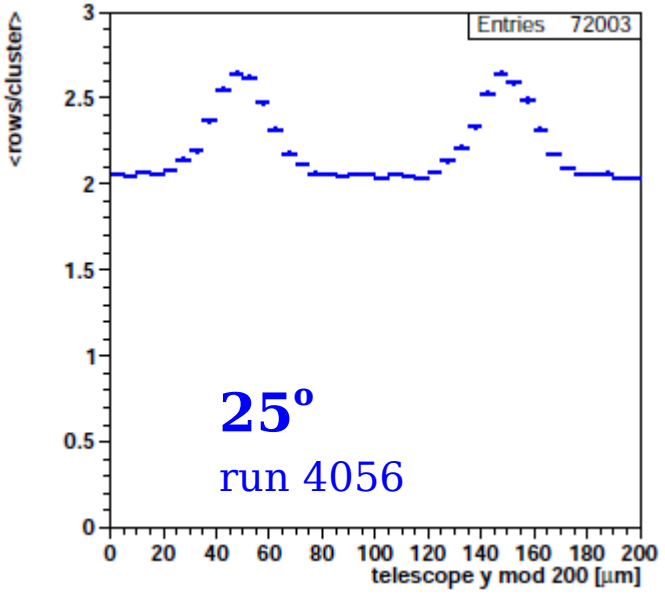


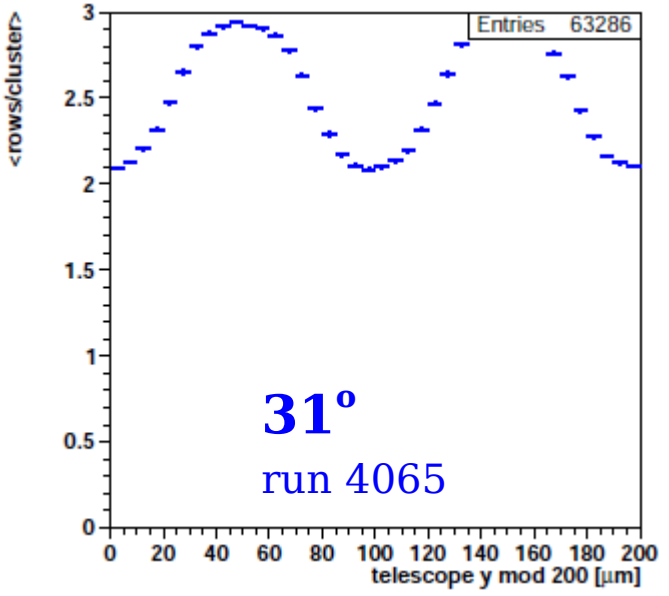




y_{impact} mod 200 µm: 2 pixels wide

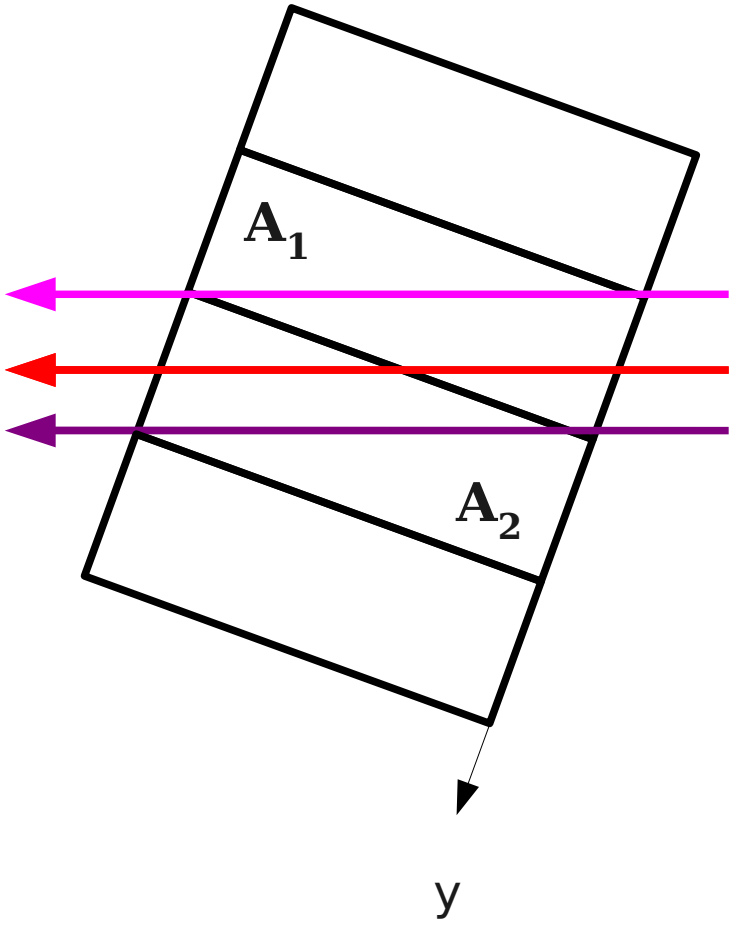






charge sharing: η

at 20°:



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

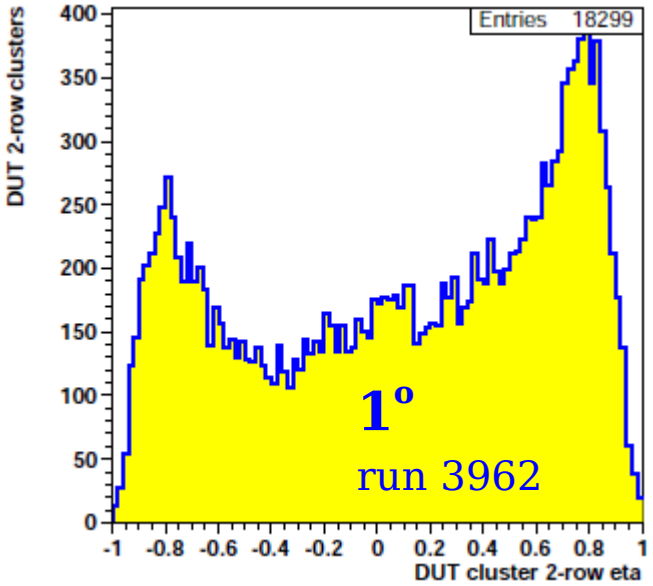
1.0
0.0
(-1.0)

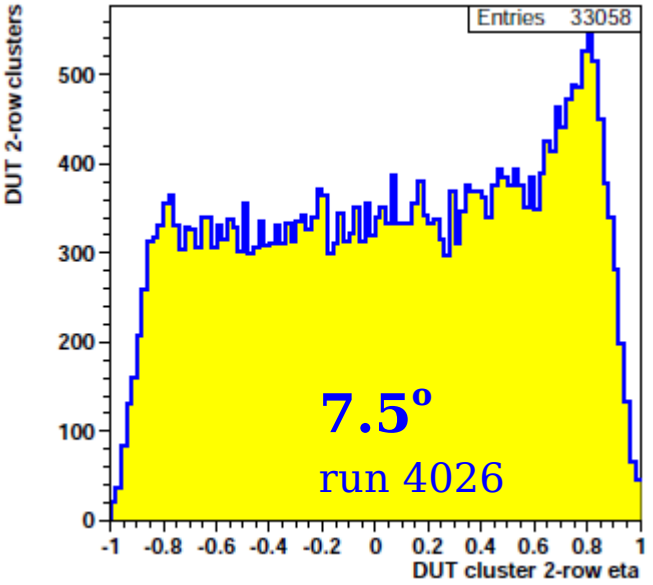
1-row clusters have η = 1.

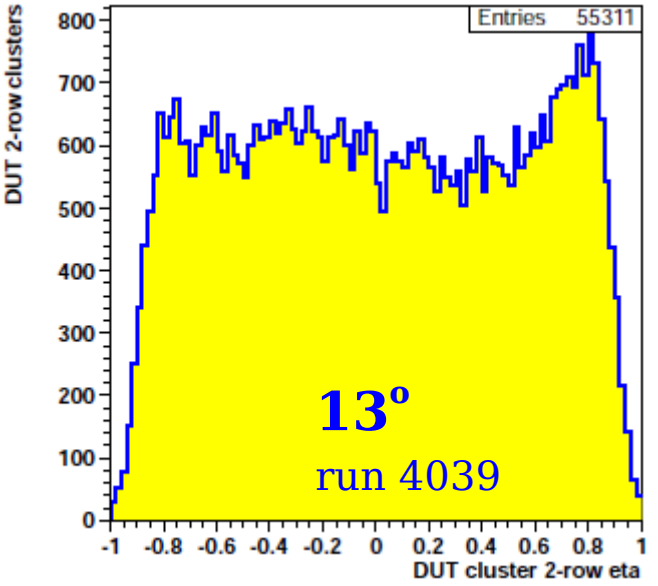
ideal:
linear η vs y
(saw tooth)

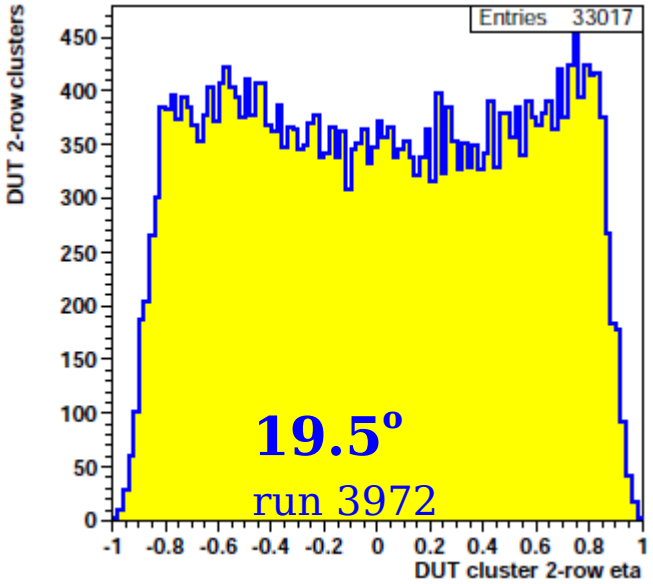
deviations:
- **diffusion**
- **thresholds**
- **trapping**
- **delta-rays**

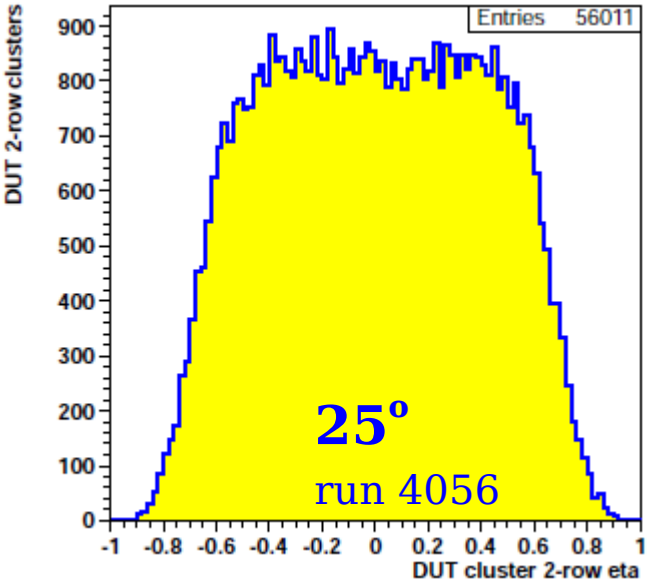
xdb charge sharing vs tilt angle

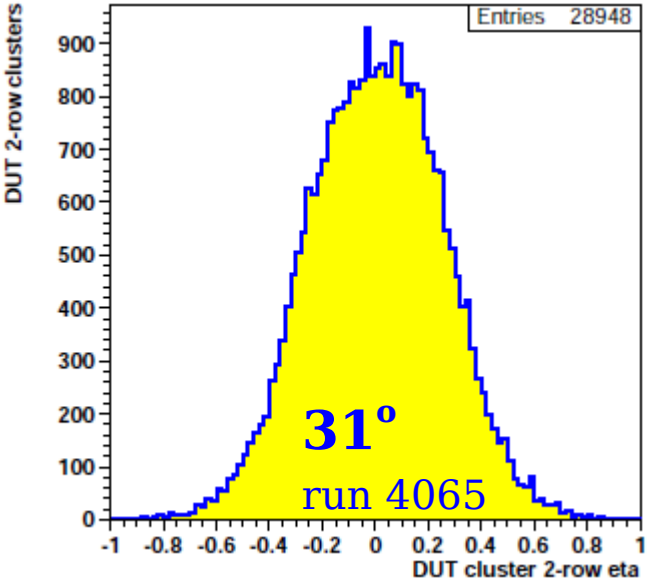




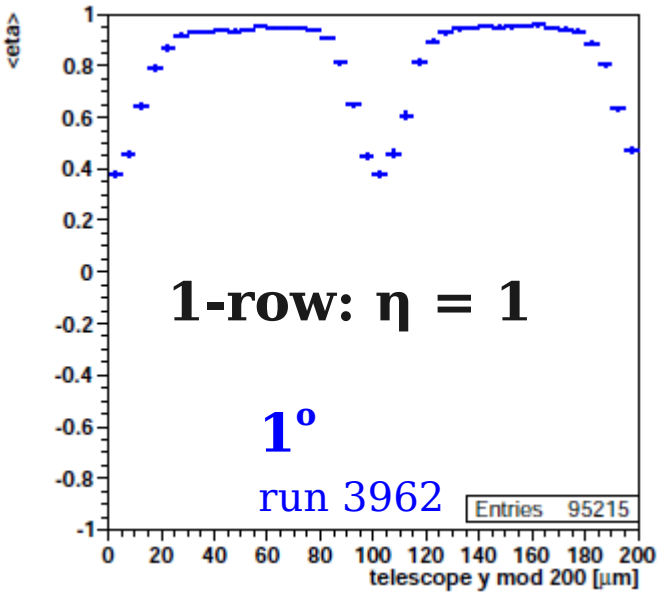


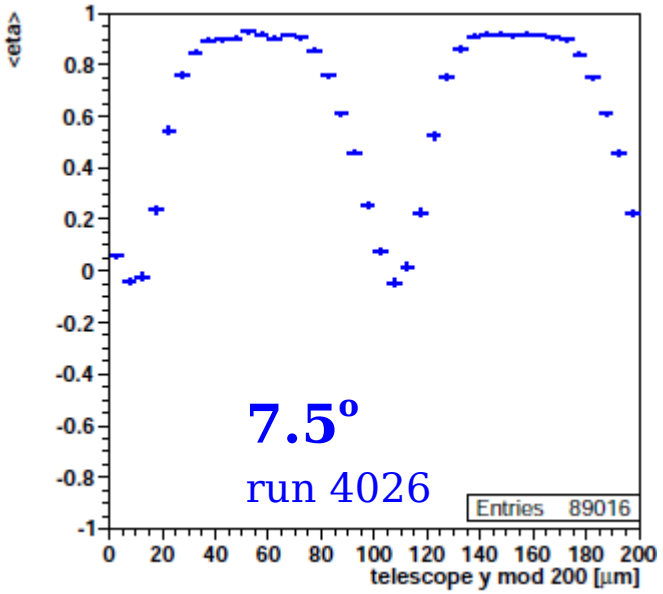


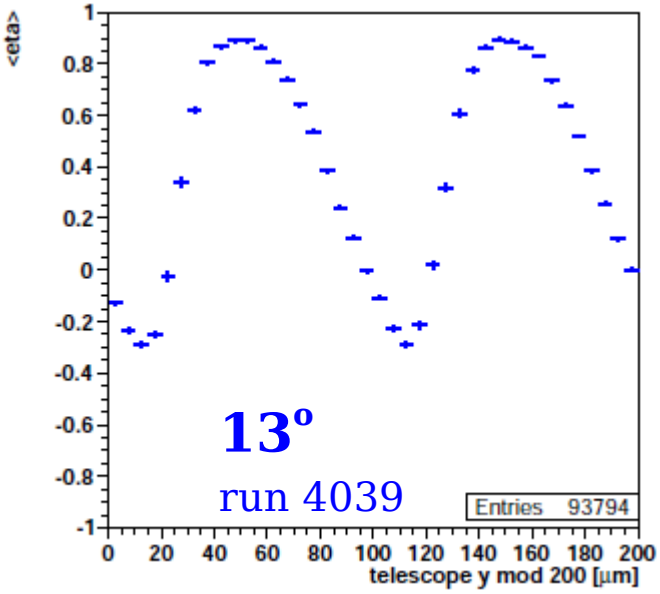




xdb charge sharing vs impact point

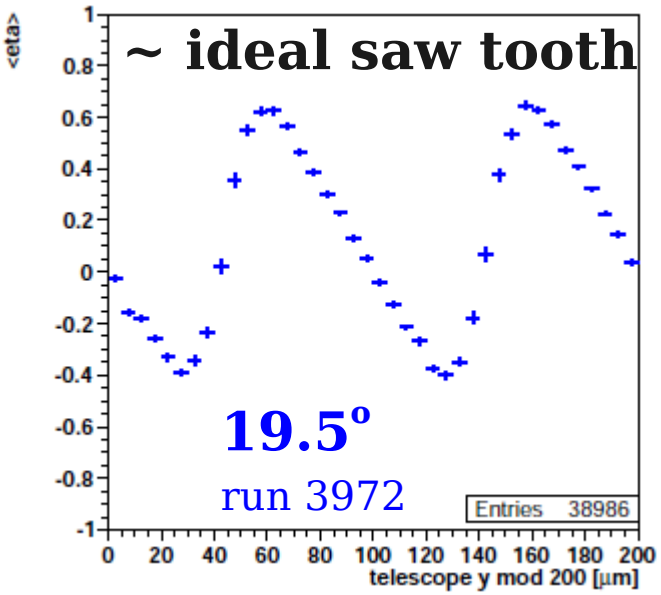


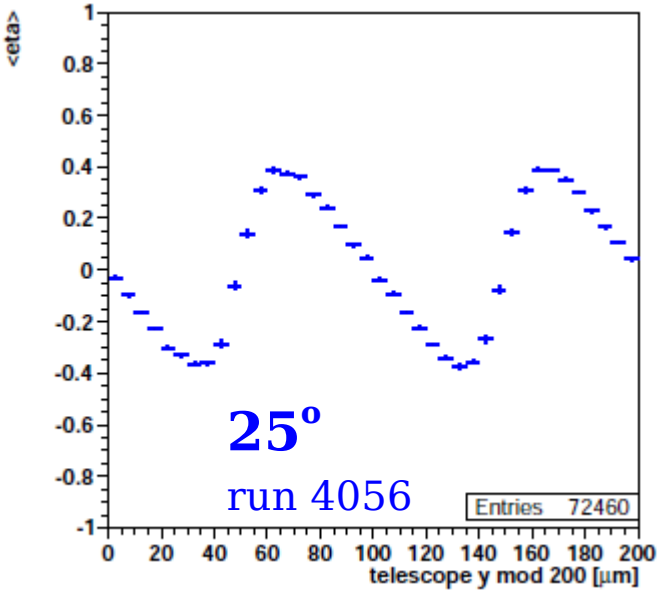


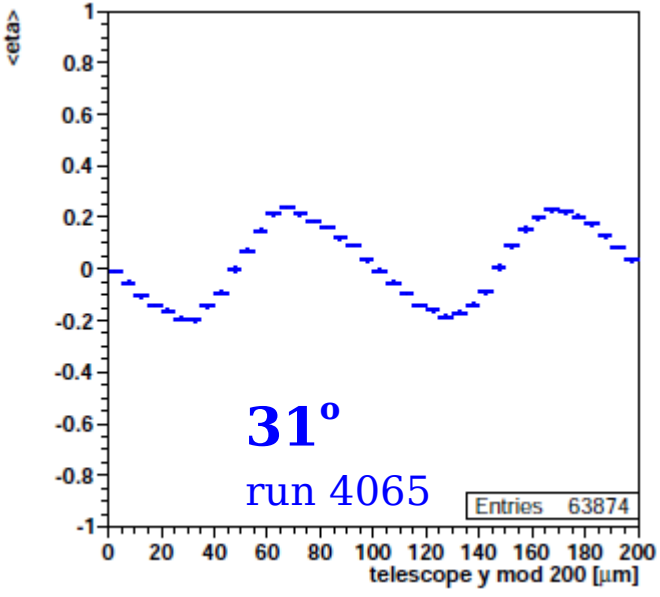


1- and 2-row clusters

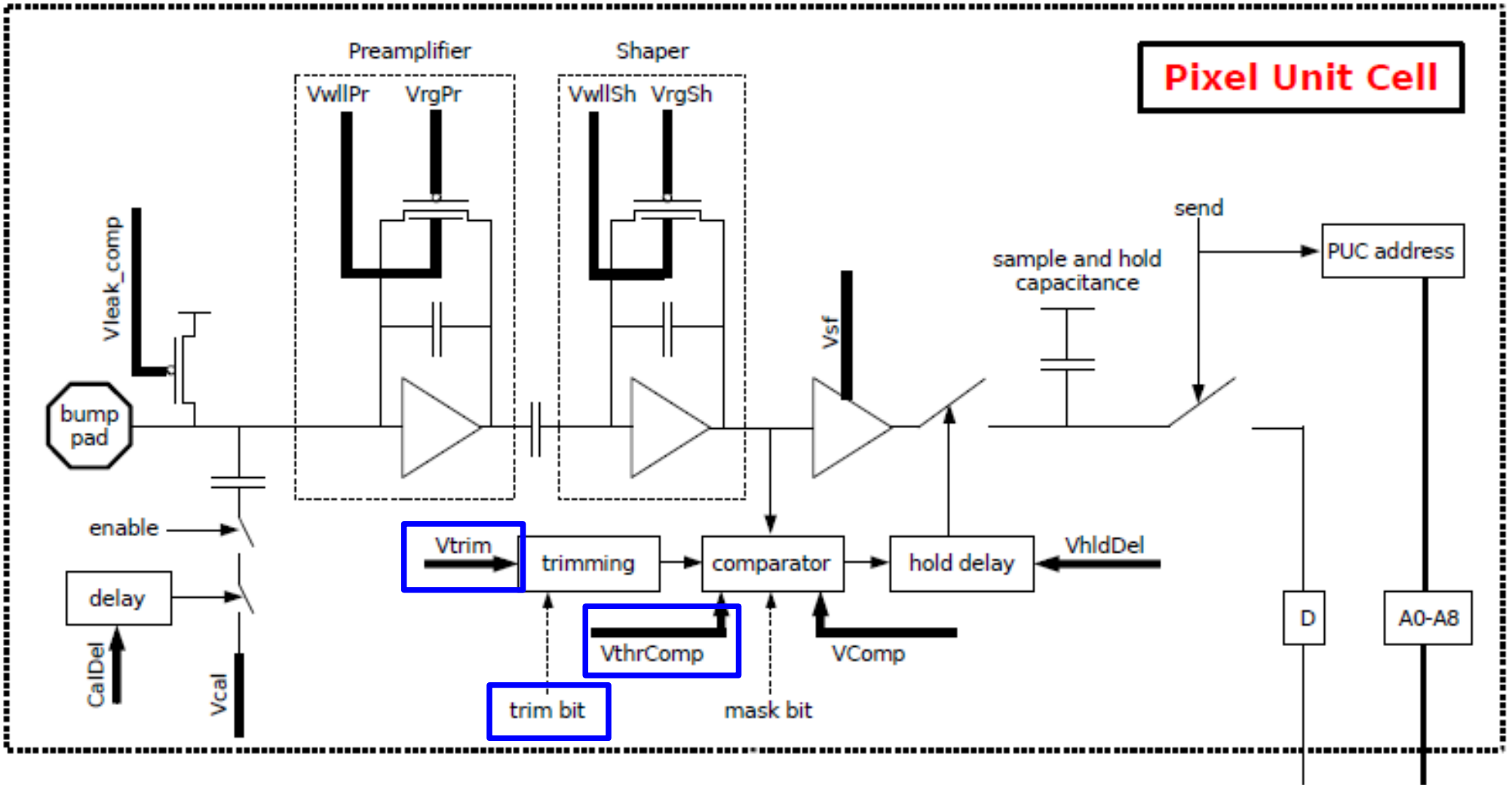
y_{impact} mod 200 μm: 2 pixels wide







Threshold scan

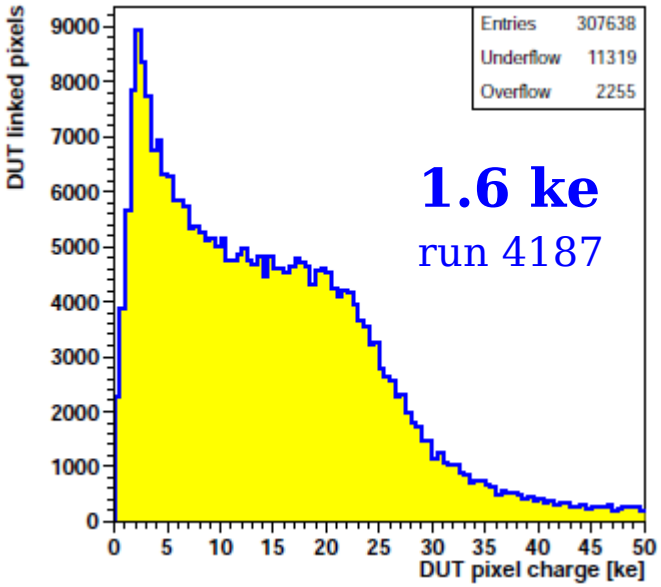


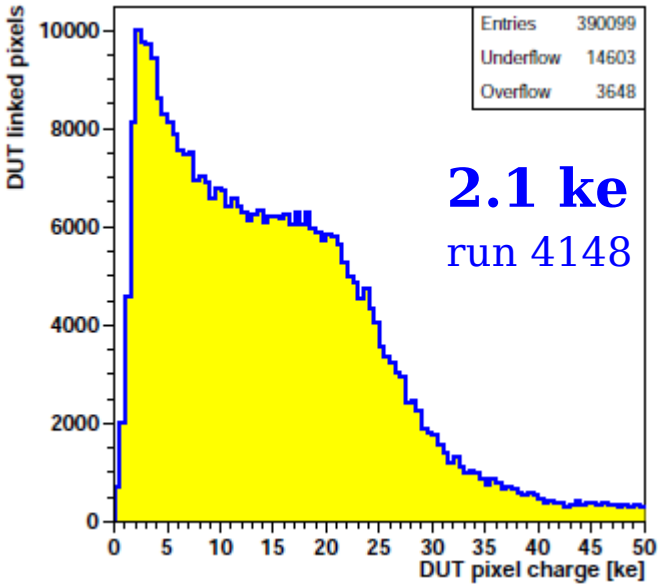
Threshold = VthrComp – Vtrim · trimbits

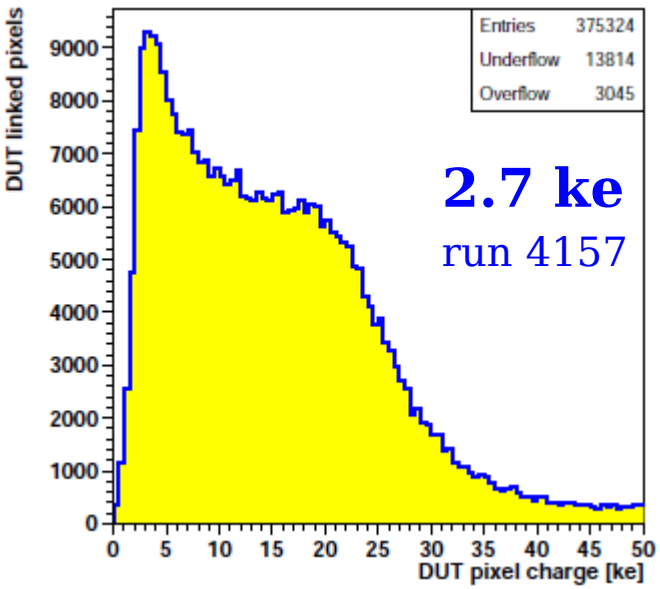
Harder threshold: loose small pulses

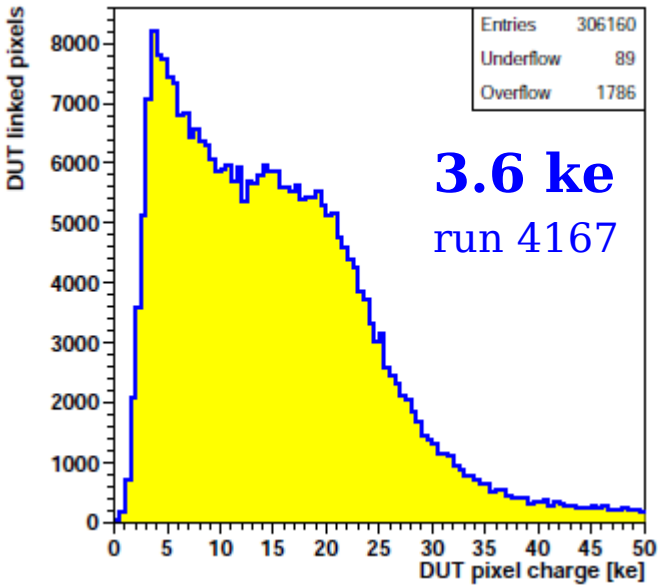
Simulates reduced charge collection (radiation damage)

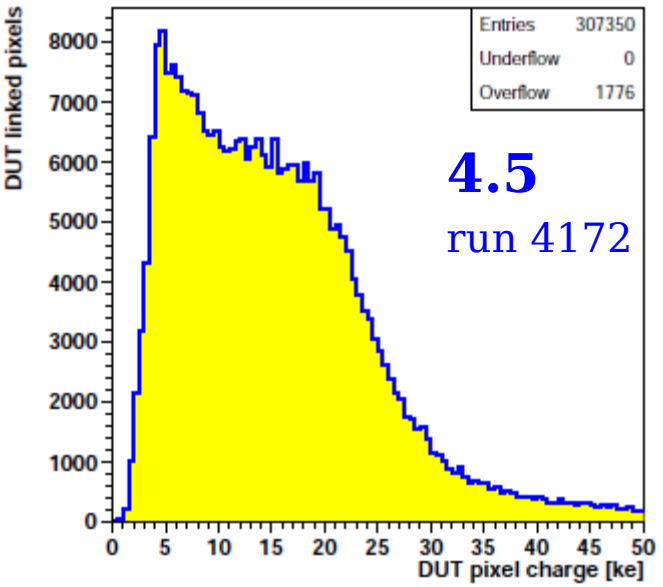
xdb pixel charge vs threshold

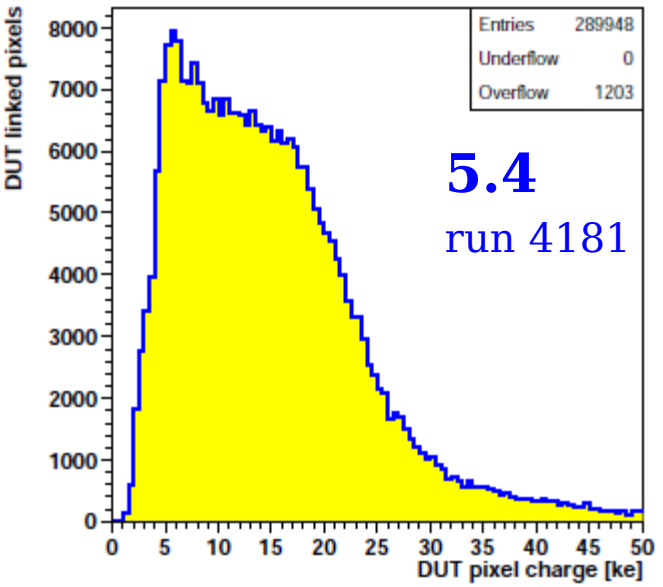




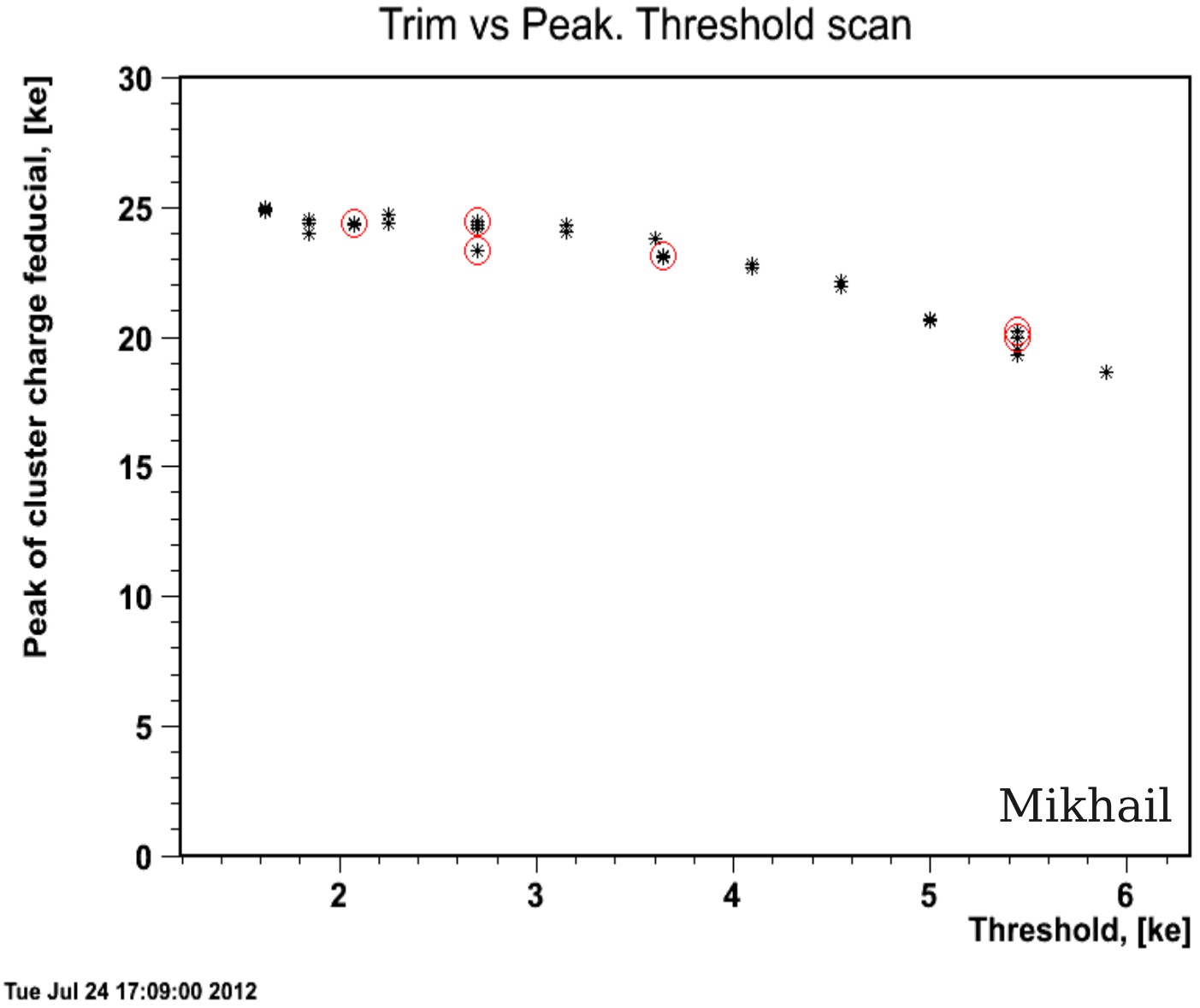






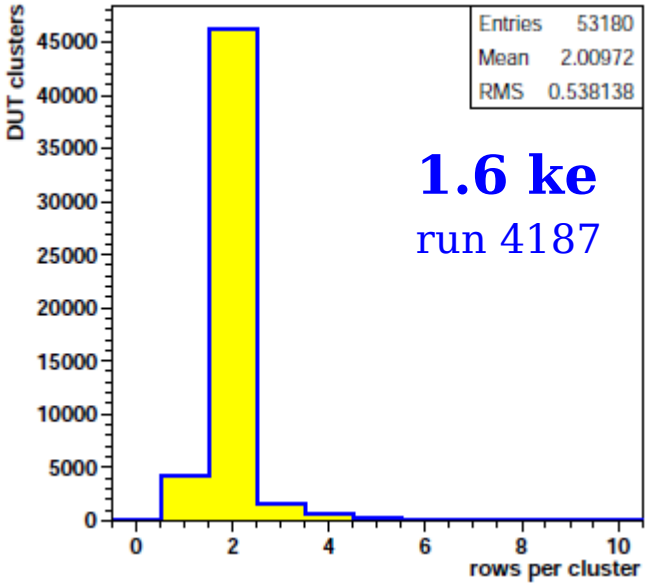


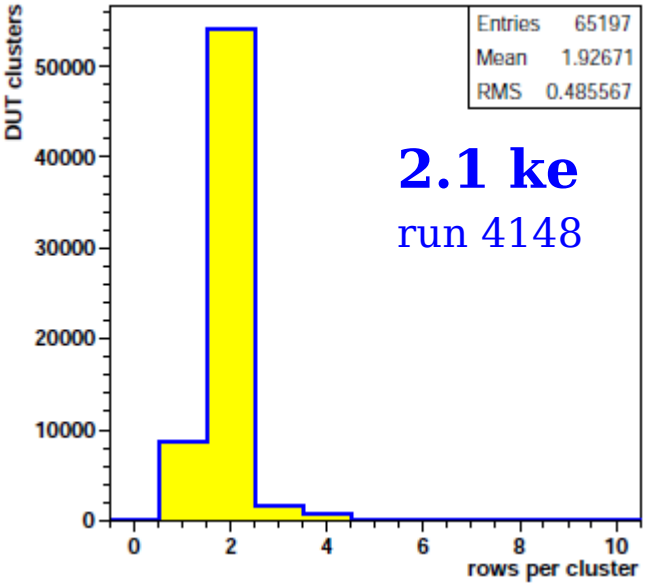
xdb cluster charge vs threshold

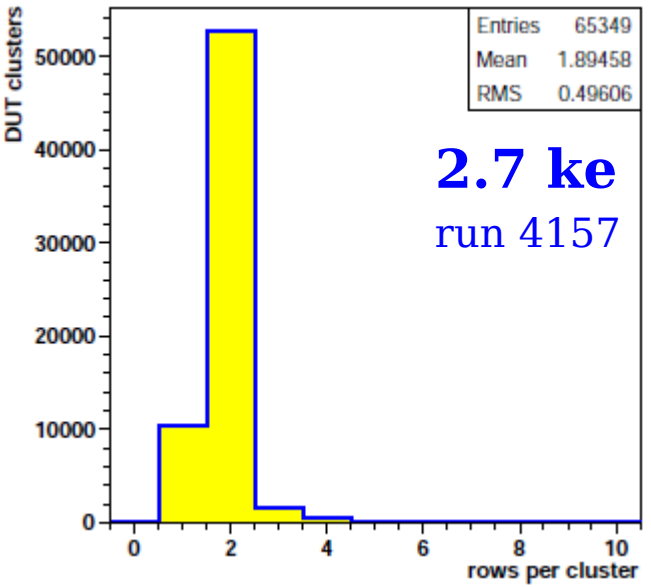


- Chip xdb2, -150V, 19° tilt
- Position of Landau peak
  - decreases with harder threshold

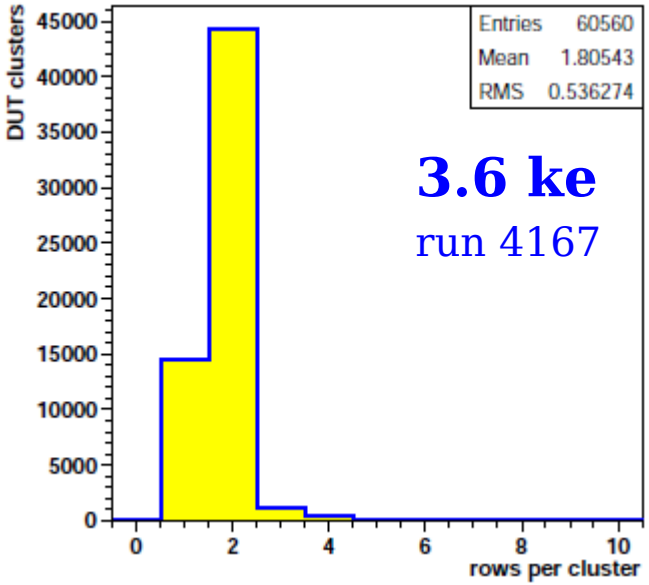
xdb cluster size vs threshold

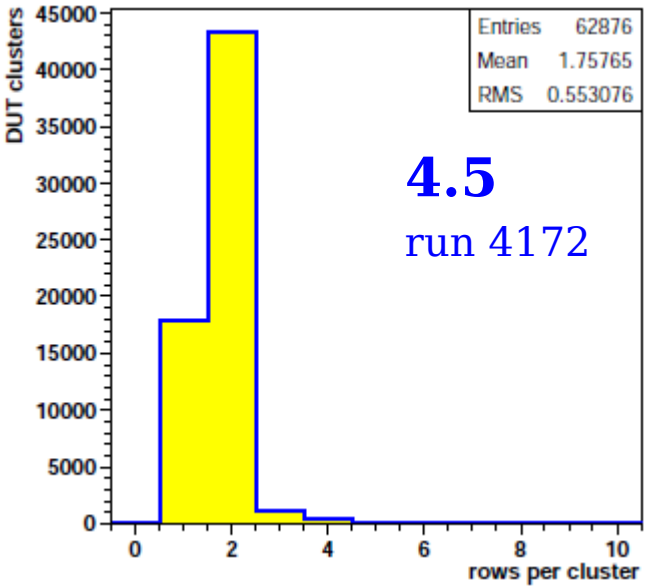


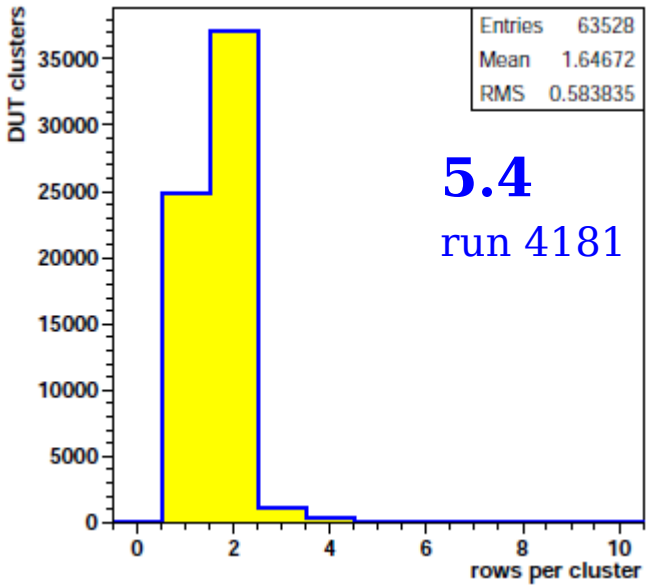




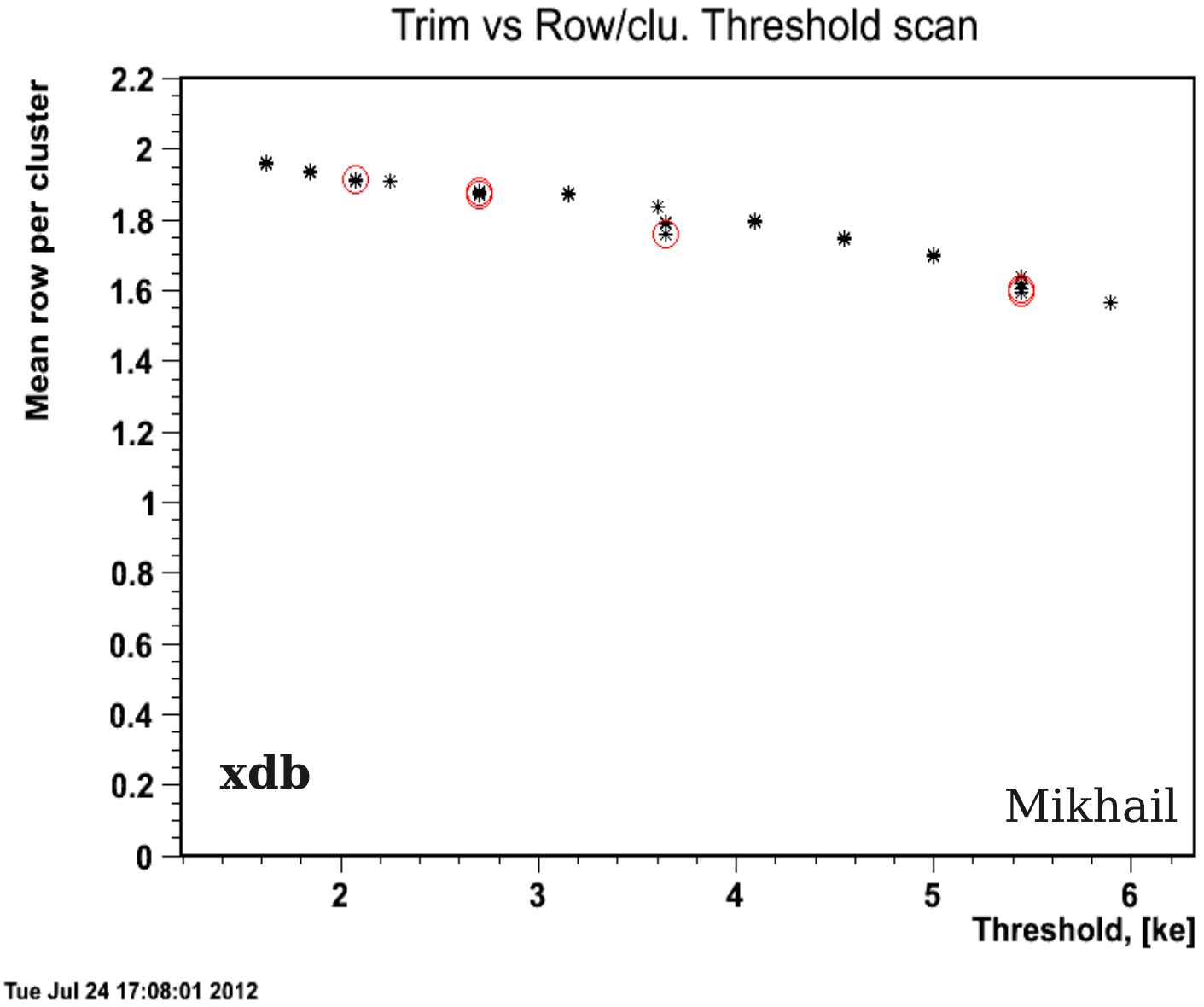
tilt 19.5°





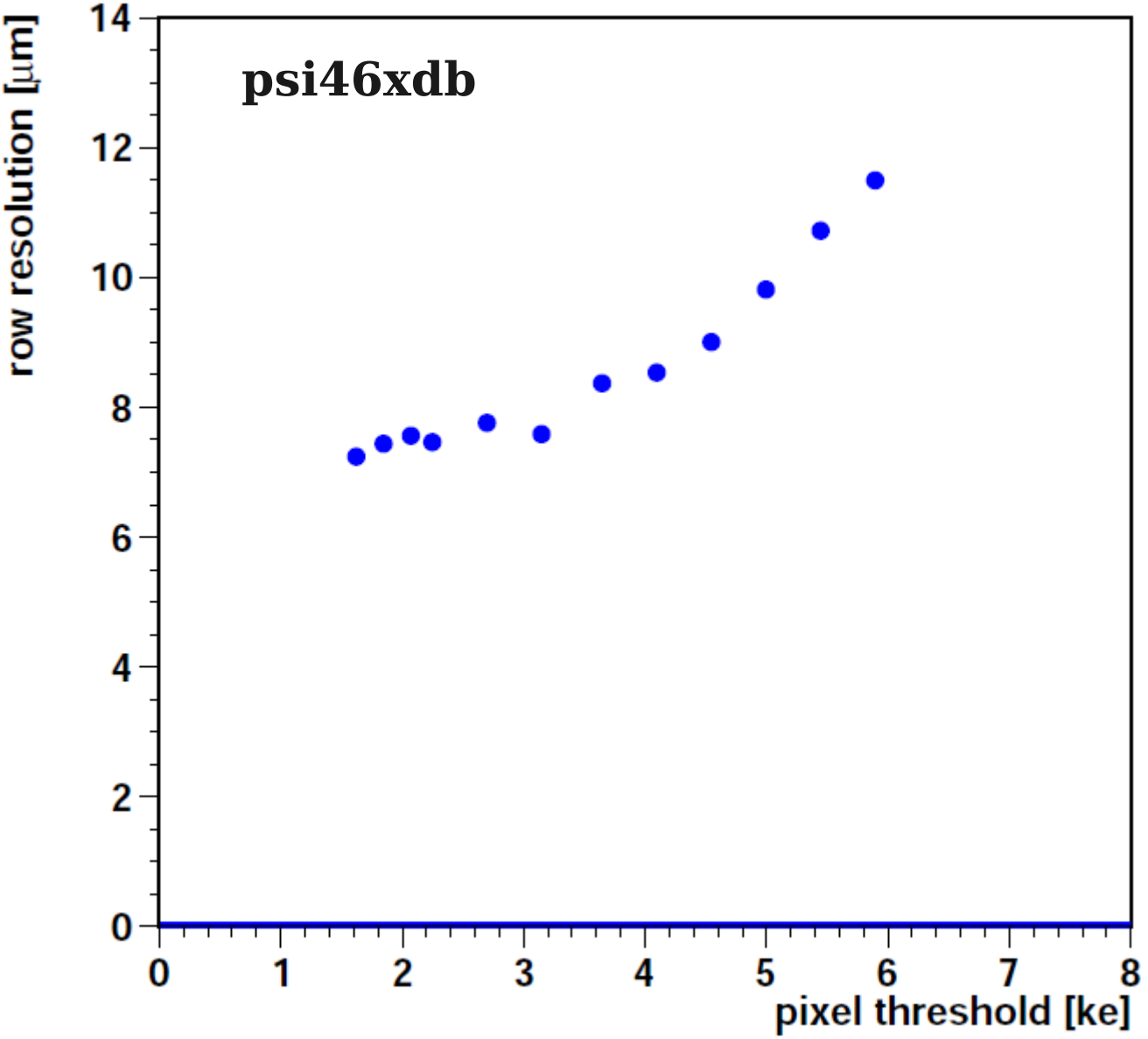


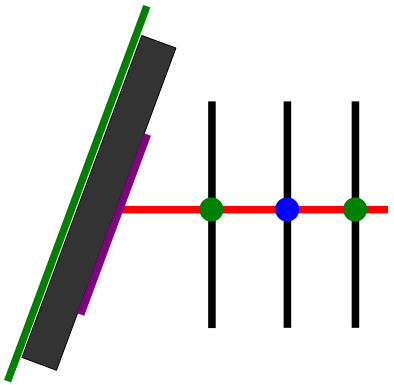
xdb cluster size vs threshold



- Chip xdb2, -150V, 19° tilt
- rows per cluster:
  - decreases with harder threshold

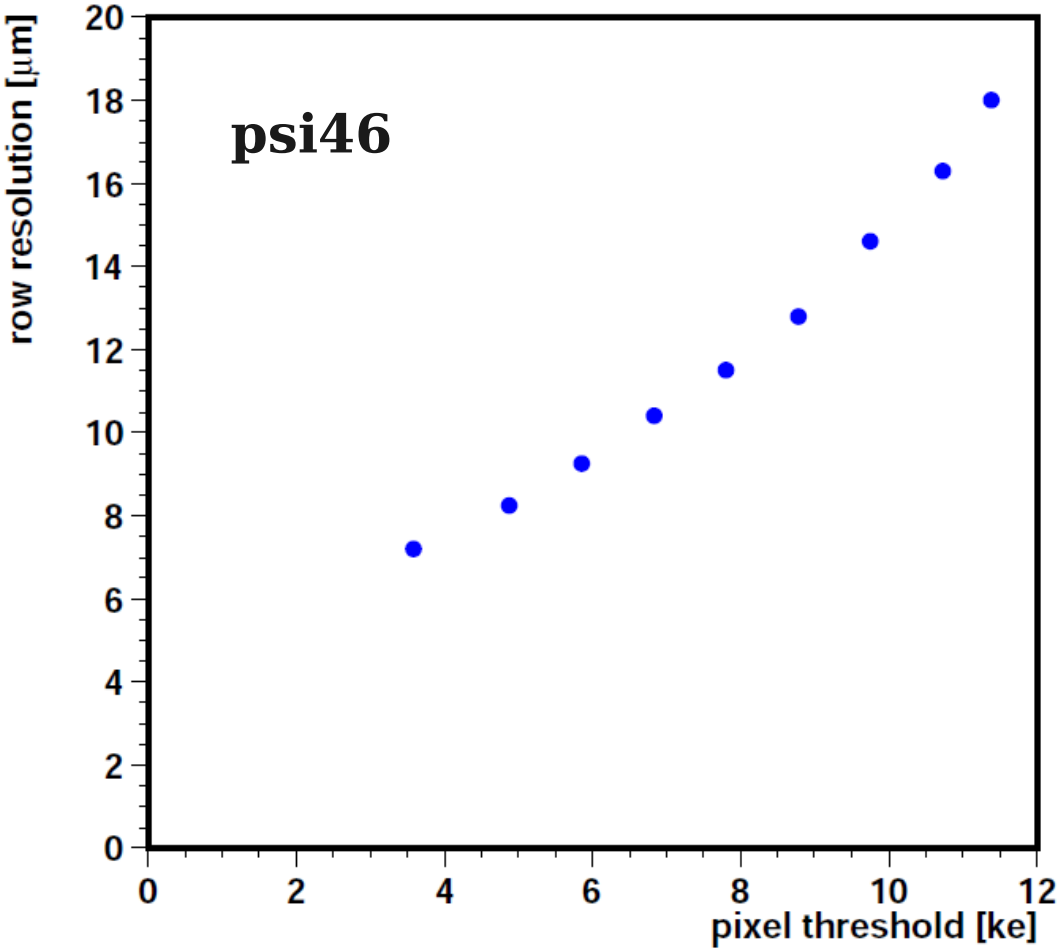
xdb row resolution vs threshold

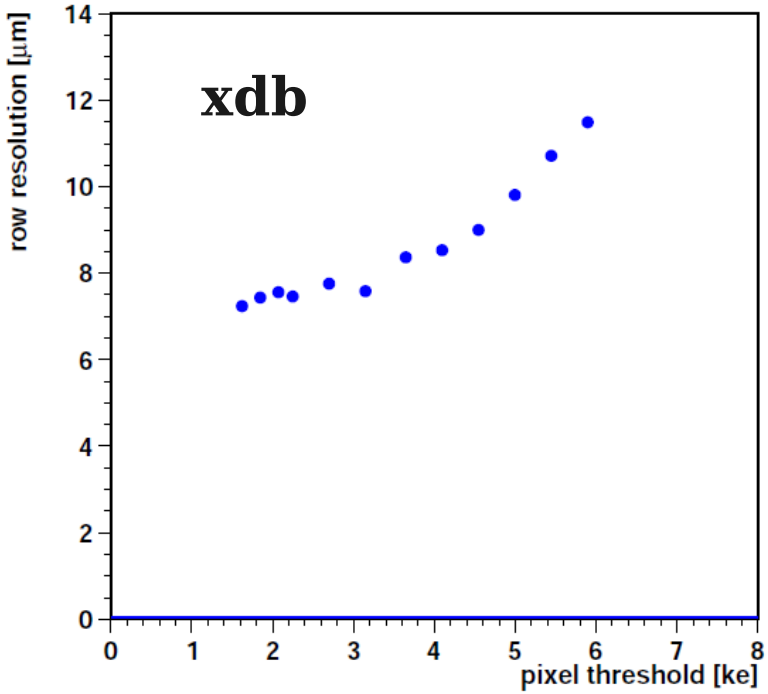




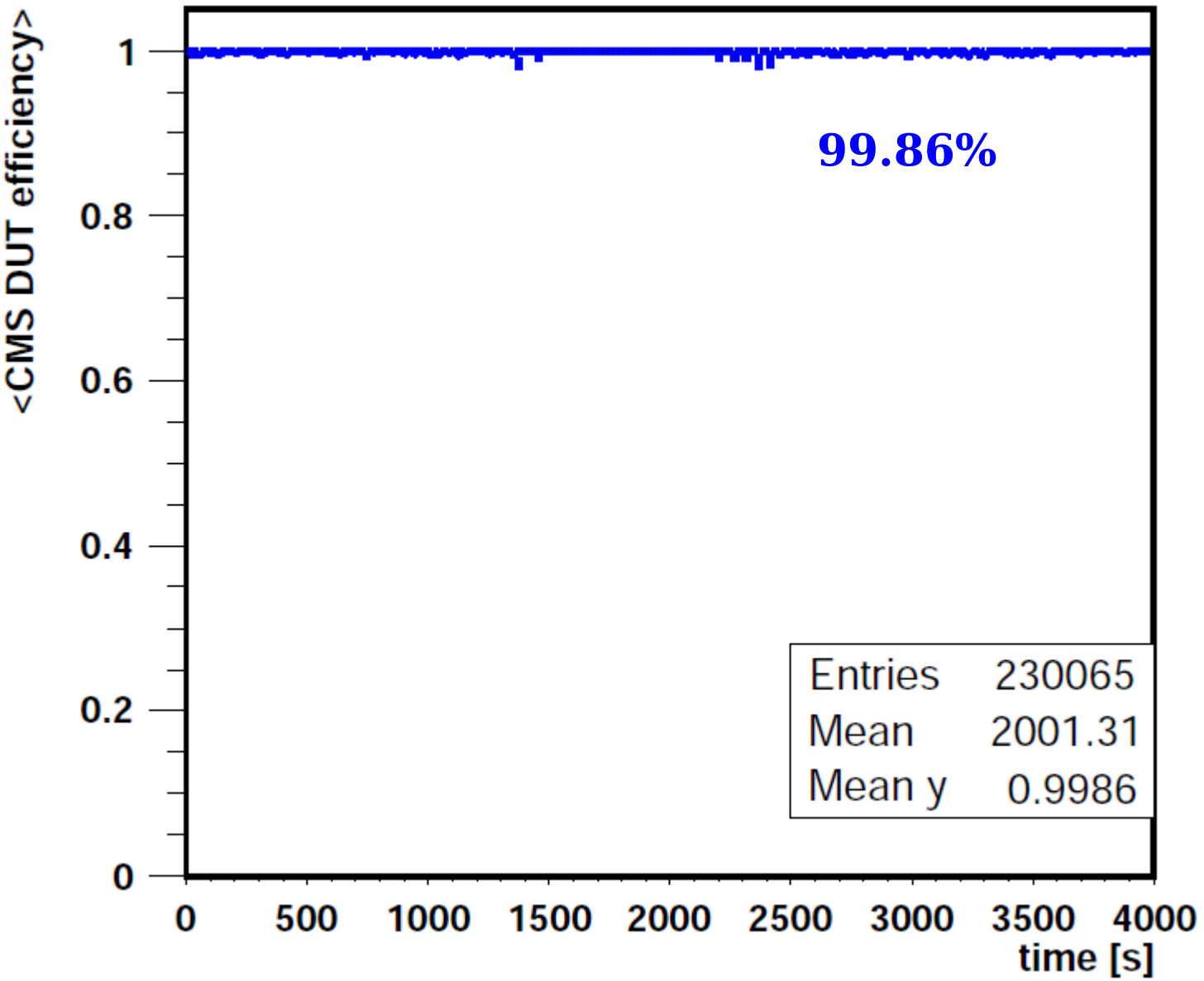
- Chip xdb2, 19.5° tilt
- 5.6 GeV, telescope extrapolation uncertainty subtracted.
- lower threshold:
  - resolution seems to saturate at 7 µm below 3 ke.

psi46 row resolution vs threshold





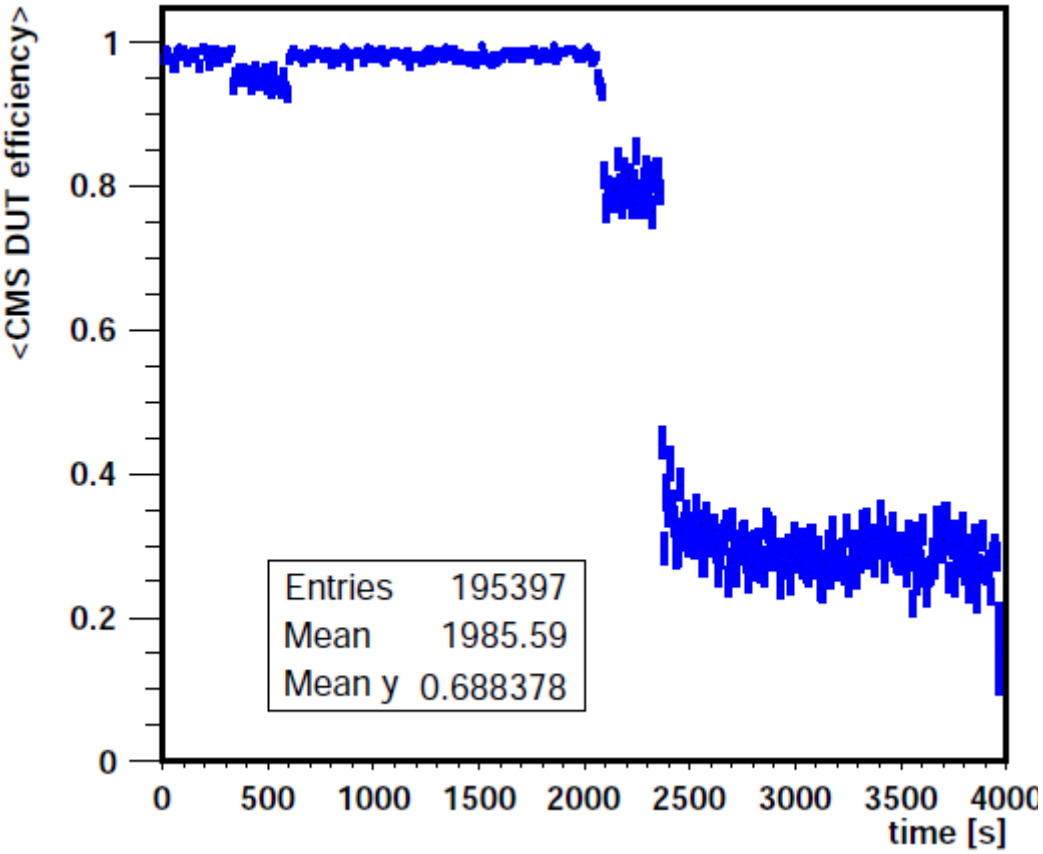
xdb efficiency stability



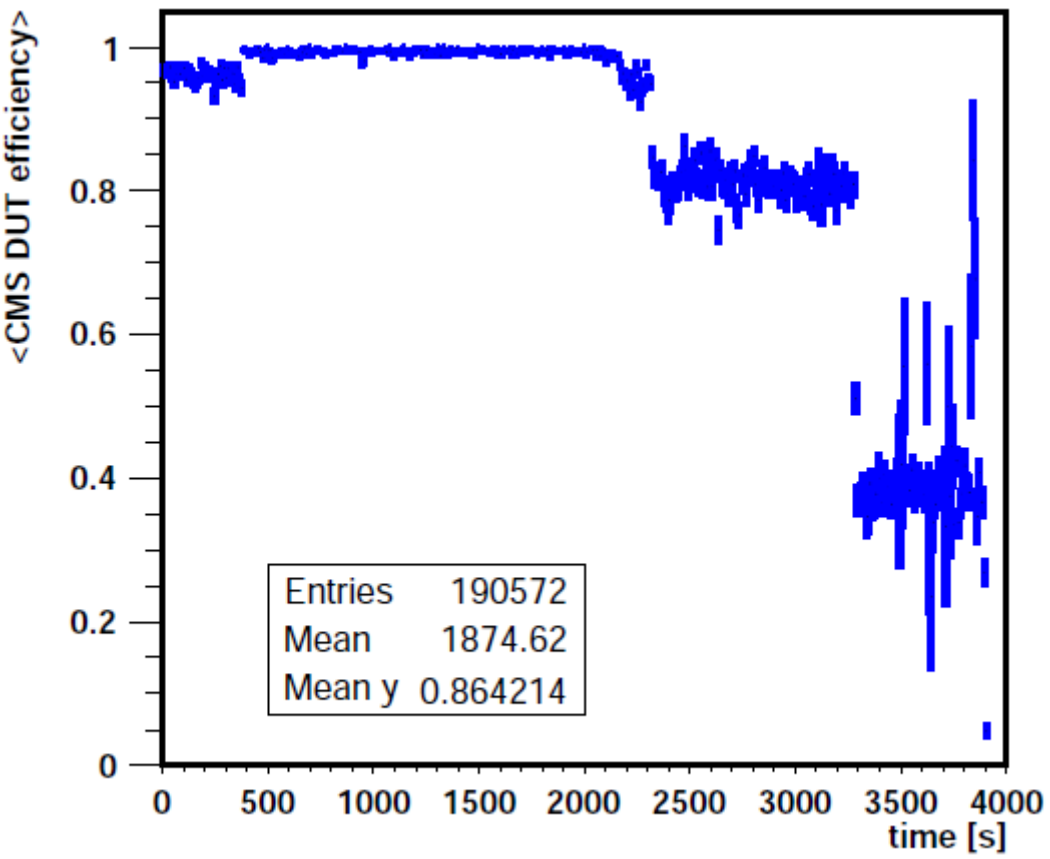
- Chip xdb2
  - 19.5° tilt
  - trim 80
  - run 3899
- fiducial region:
  - track 0.1 mm from edge
- 99.86% stable over 1 hour.

xdb efficiency instability

xdb 2, run 3958



xdb 2, run 3960

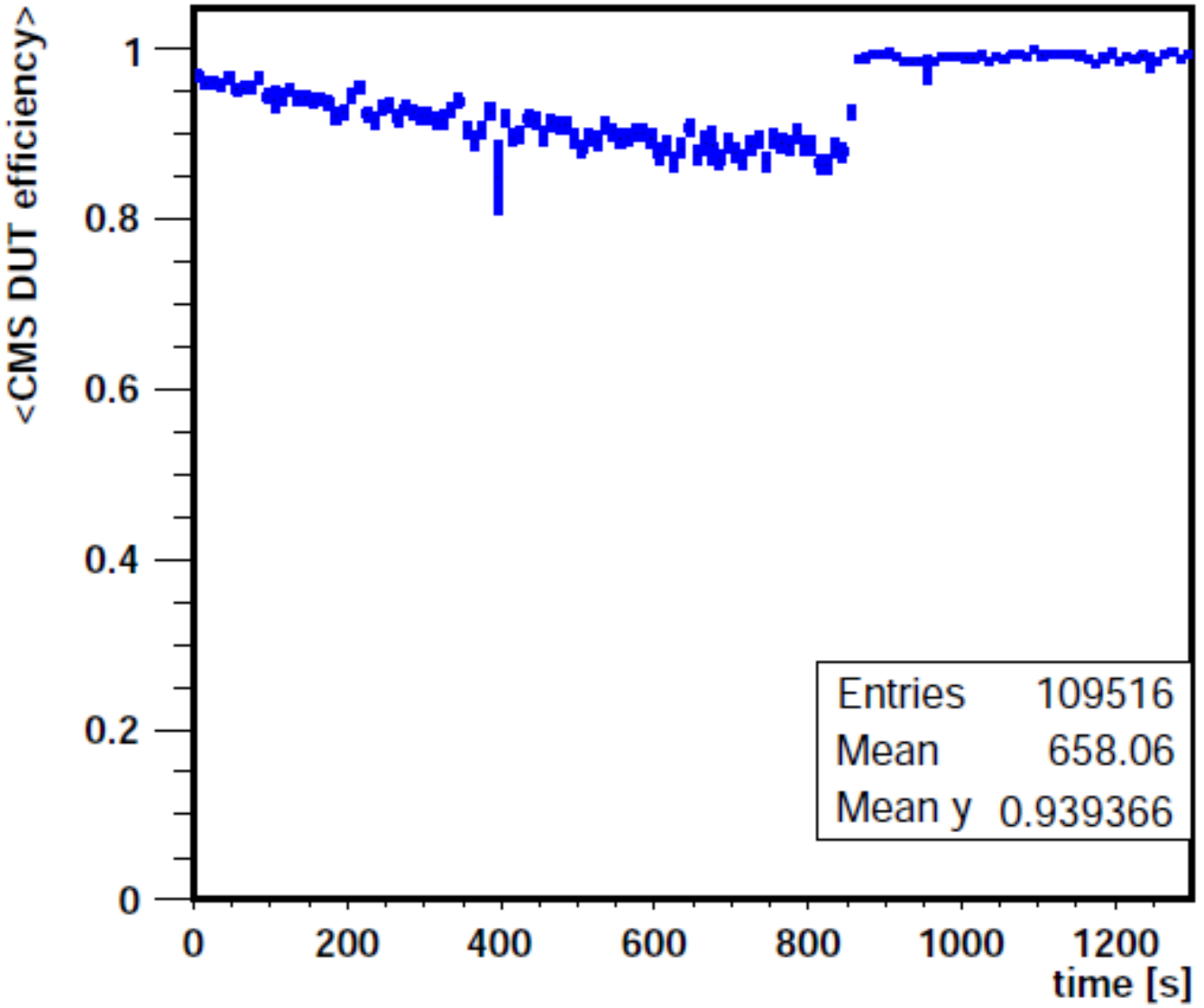


such runs are not used for analysis

most analysis runs are only 600 s long

xdb efficiency recovery

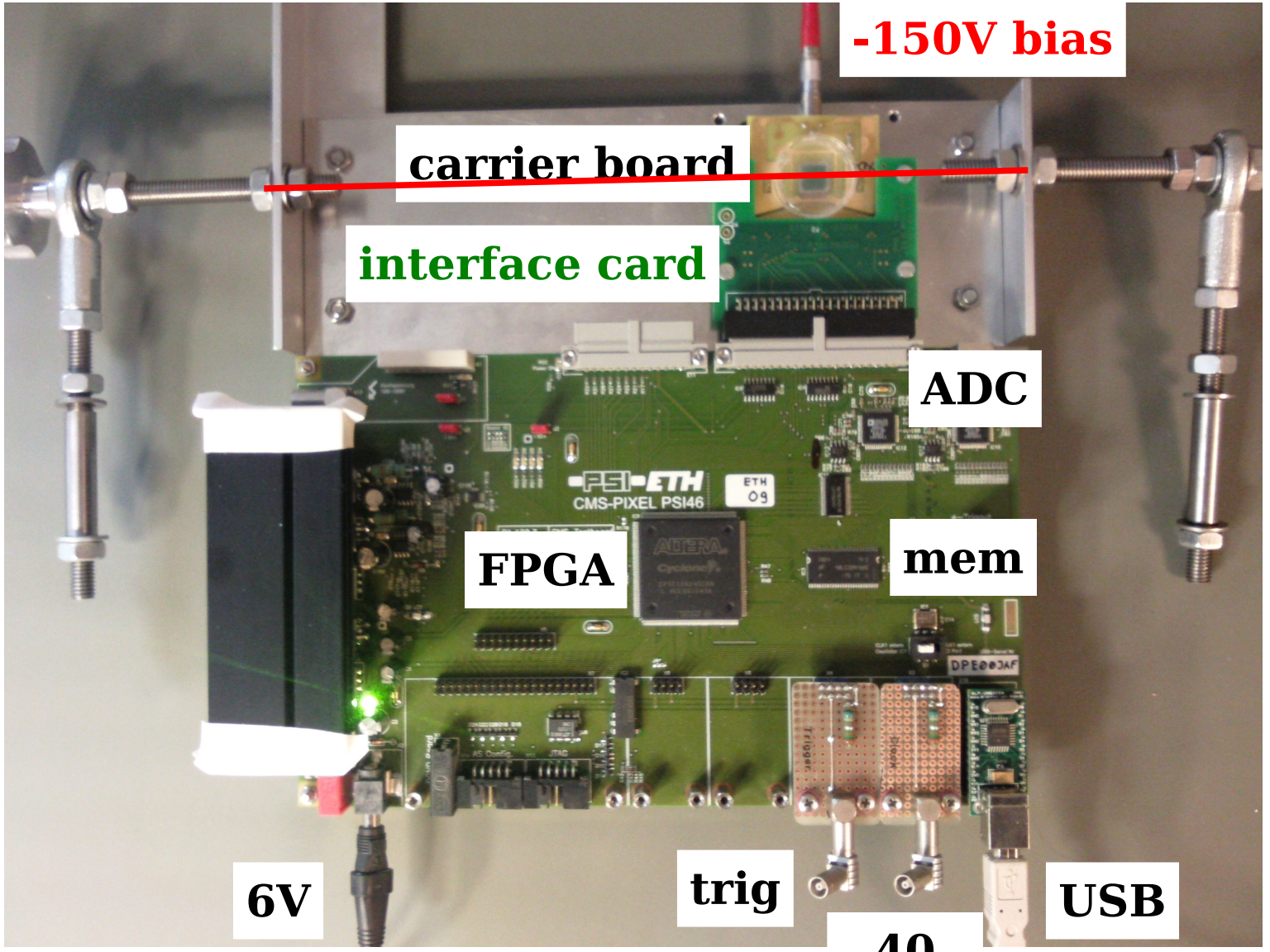
xdb 2, run 3898



Summary and outlook

- PSI46xdb single chip pixel sensor operated at the DESY test beam:
  - simultaneous threshold trimming of both halves possible
  - lower thresholds reached (1.8 ke), less time walk than psi46
  - better gain uniformity than psi46
  - efficiency up to 99.8%
  - resolution 7 µm at 19°, similar to psi46, despite lower thresholds
- Improve in beam test:
  - Timing stability (Hanno)
- During August:
  - test PSI46dig

psi46xdb and test board at DESY



- Single chip module:
  - Indium bump bonded at PSI
  - Glued and wire bonded to carrier printed circuit board
  - Interface card to test board
  - xdb 2 arrived 25.6.
- Use the same board, firmware, software as for psi46

PSI46xdb

Data Rate, Efficiency:

- Extended data buffer 32 → 80 cells
- Extended time stamp buffer 16 → 24

Crosstalk, threshold uniformity:

- 6 metal layer (process option)
- Thick top metal (LM instead of MZ process option, +37%)
  → better power and ground distribution (lower resistance)
  → better threshold uniformity
- New routing for calibrate signal → less crosstalk of calibrate signal
- Better decoupling of comparator and digital voltage → less crosstalk
- Different other minor layout changes to reduce crosstalk

PSI46xdb

DAC:

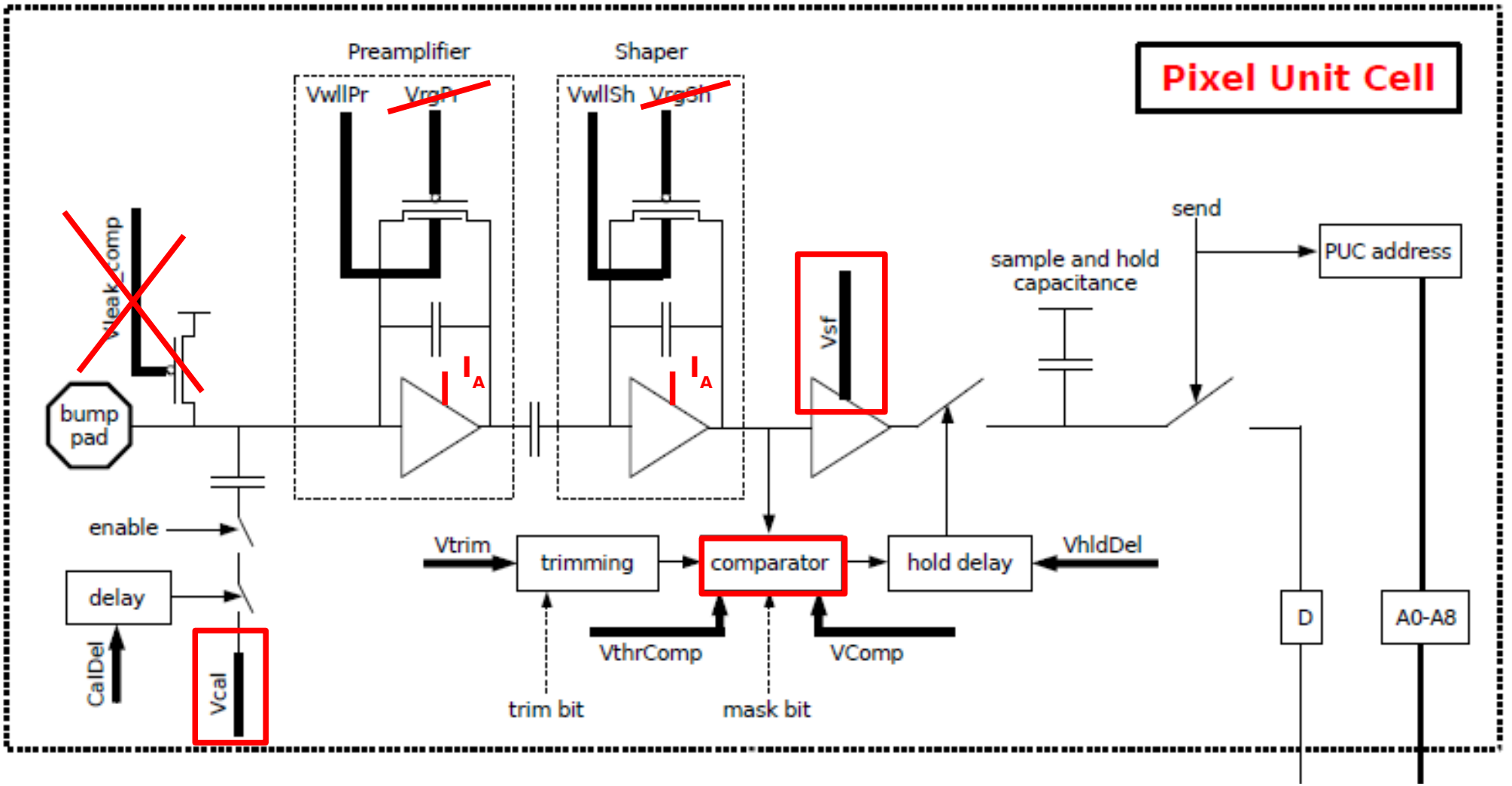
- 3 DACs removed: VRGPR, VRGSH and Vleakage
- All DAC's with power on reset for low power ROC configuration
- Current control instead of voltage control for S&H and analog power supply → easier and independent setup

Timing:

- Small performance optimization in column drain mechanism (timing)
- Modified comparator with reduced timewalk

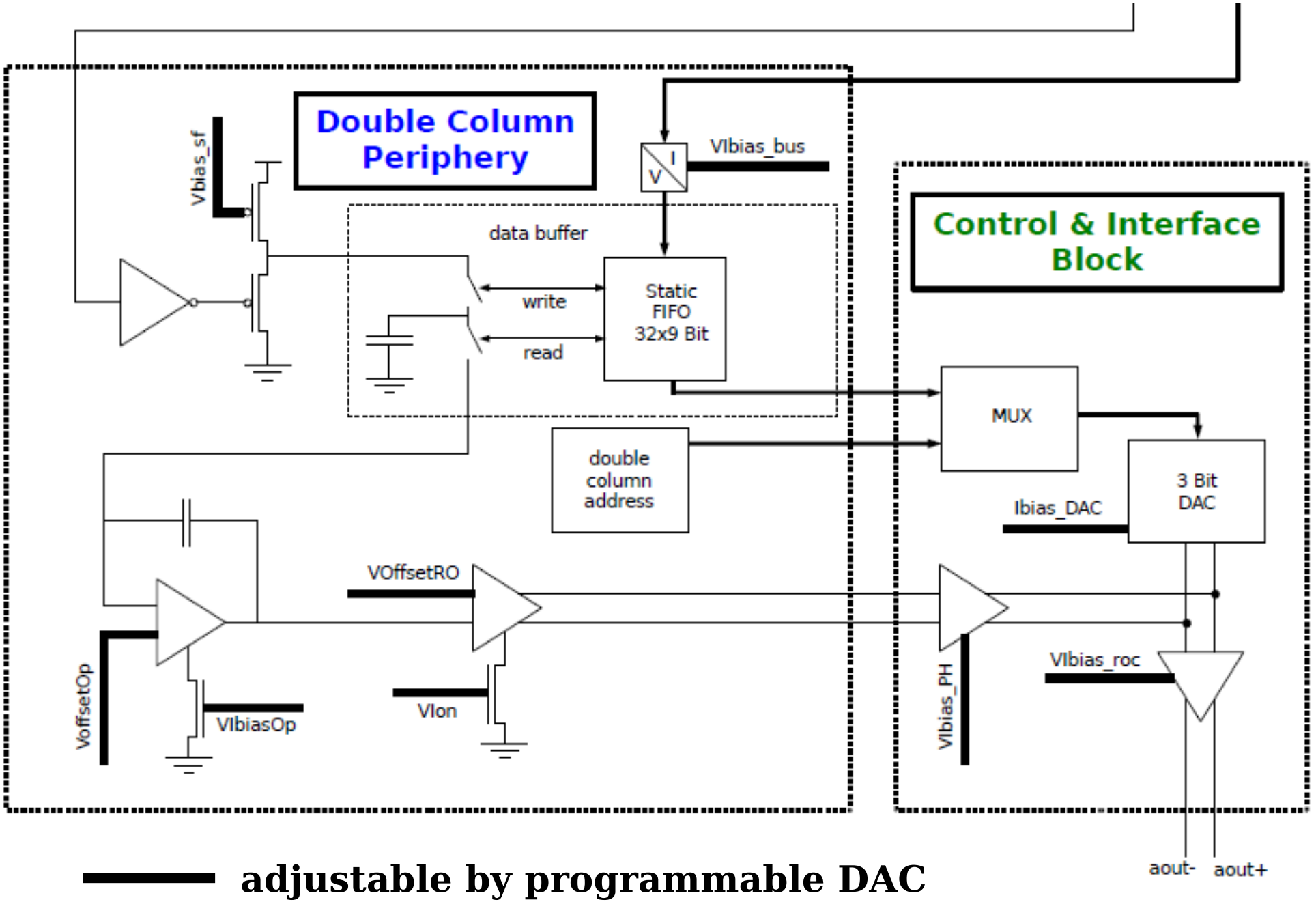
- Same analog read out as PSI46 → same test board
- Comparison possible between PSI46 and PSI46xdb

PSI46xdb pixel unit cell



modified in PSI46xdb

psi46 pixel readout chip



adjustable by programmable DAC

psi46xdb DACs

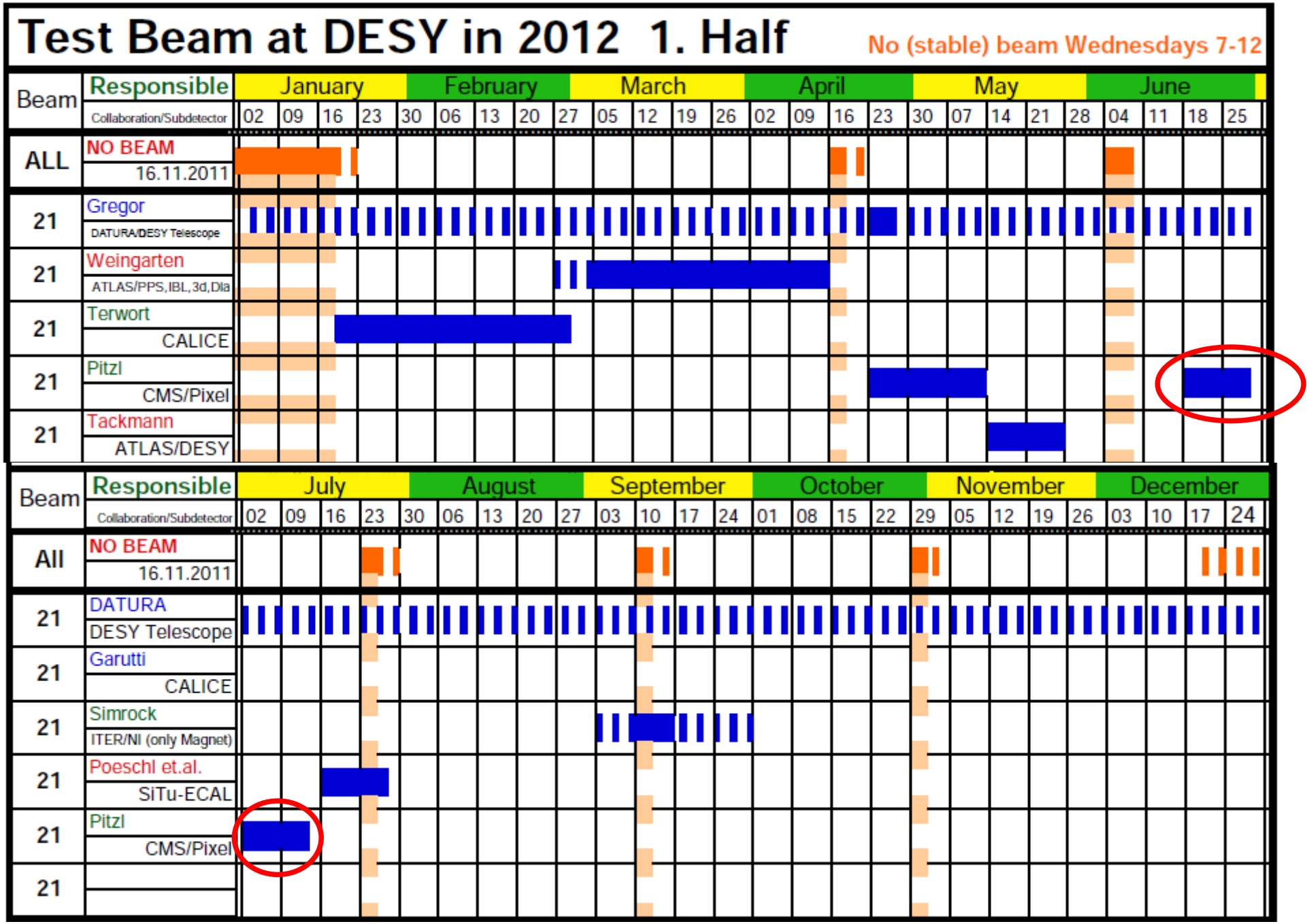
1	Vdig	6
2	Vana	166
3	Vsf	30
4	Vcomp	10
7	VwllPr	60
9	VwllSh	60
10	VhldDel	250
11	Vtrim	130
12	VthrComp	74
253	CtrlReg	0
254	WBC	20

13	VIBias_Bus	30
14	Vbias_sf	10
15	VoffsetOp	57
16	VIbiasOp	115
17	VOffsetR0	120
18	VIon	115
19	VIbias_PH	130
20	Ibias_DAC	83
21	VIbias_roc	190
25	Vcal	200
26	CalDel	155
27	RangeTemp	0

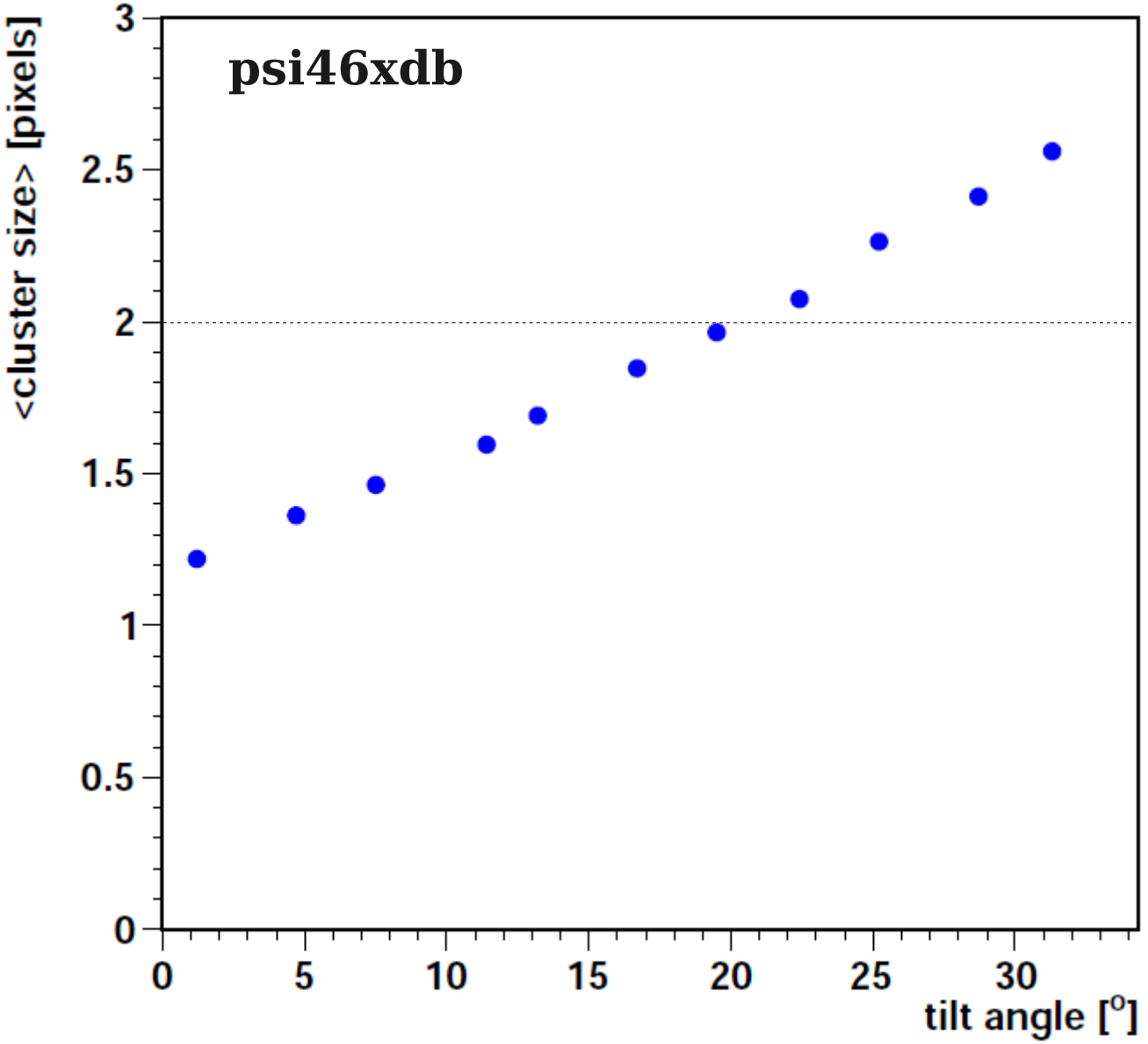
CMS Pixel in the DESY test beam

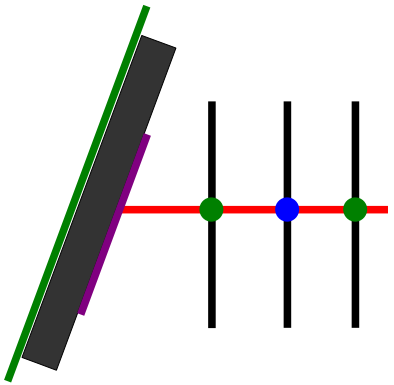
http://adweb.desy.de/~testbeam/

29.05.2012



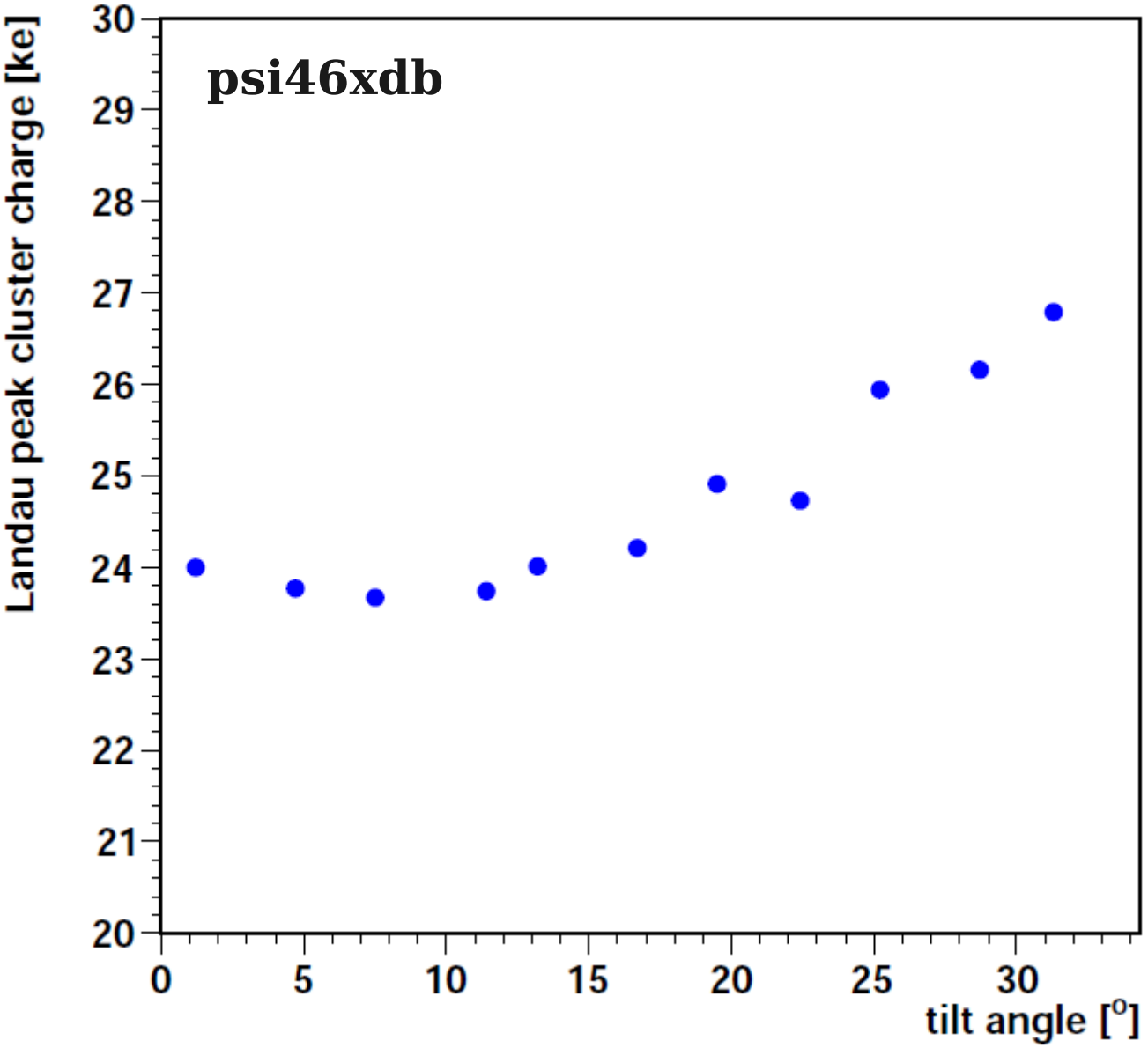
CMS pixel cluster size vs tilt angle

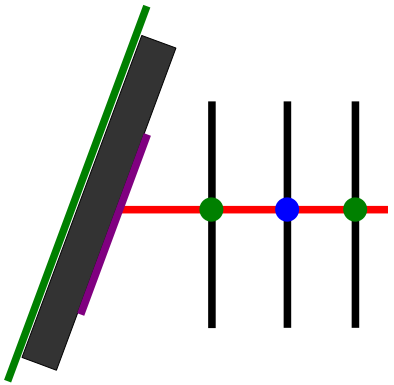




- Chip xdb2, -150V
- row pixels = 100 µm.
- sensor thickness 285 µm
- optimal:
  - size 2 at 20°.

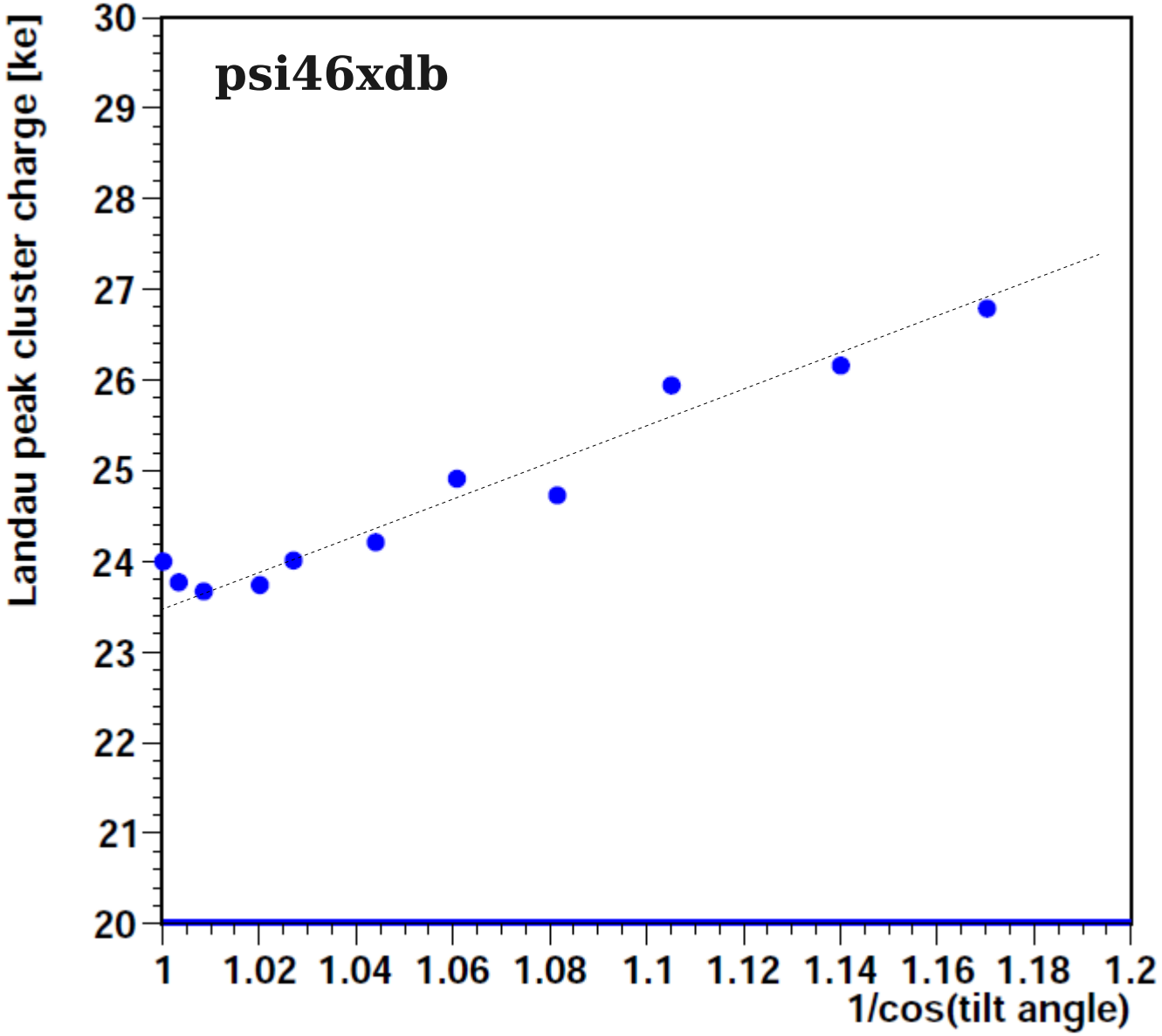
Cluster charge vs tilt angle

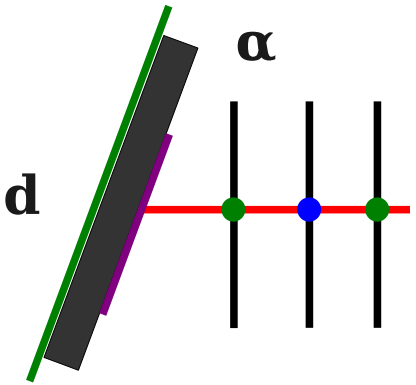




- Chip xdb2, -150V
- sensor thickness 285 µm
- position of the Landau peak
  - should increase with path length in silicon

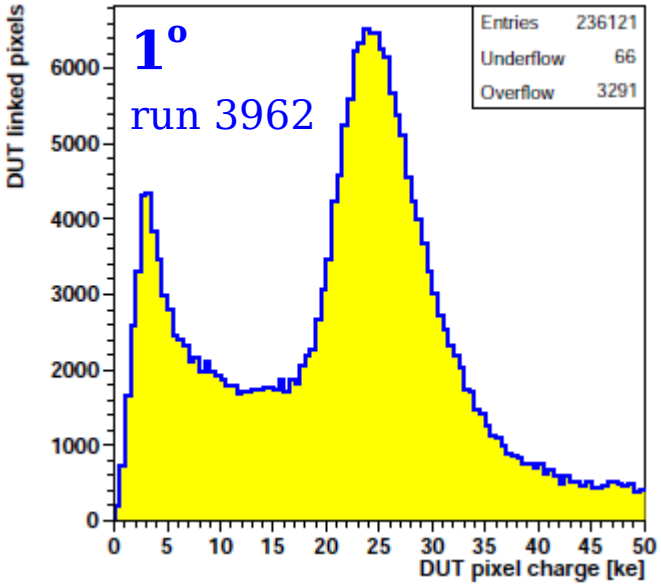
Cluster charge vs tilt angle

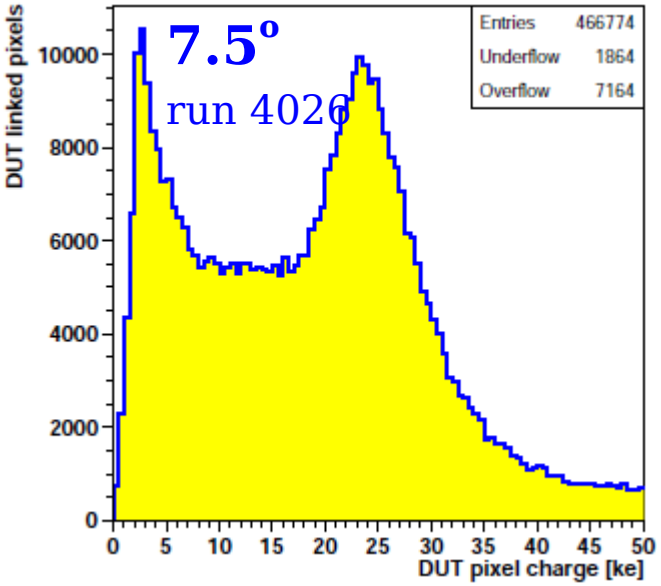


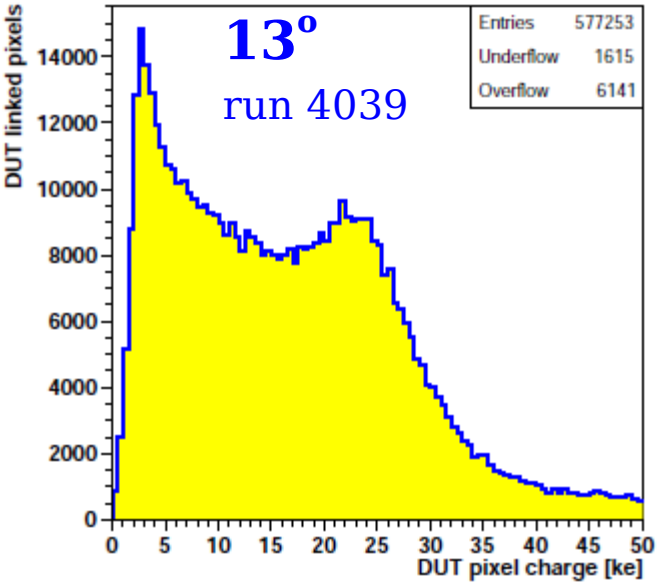


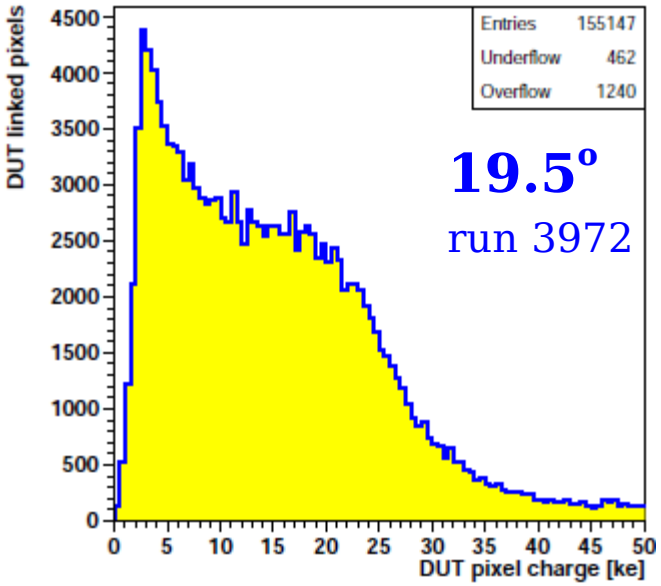
- Chip xdb2, 150V
- effective sensor thickness:
  - d = 285 µm / cos α
- position of the Landau peak should be linear in d
  - timing problems?
  - threshold effects?

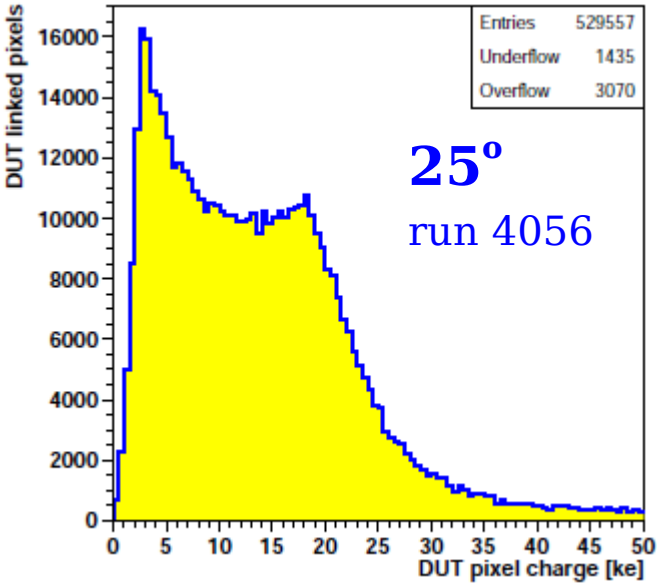
xdb pixel charge vs tilt angle

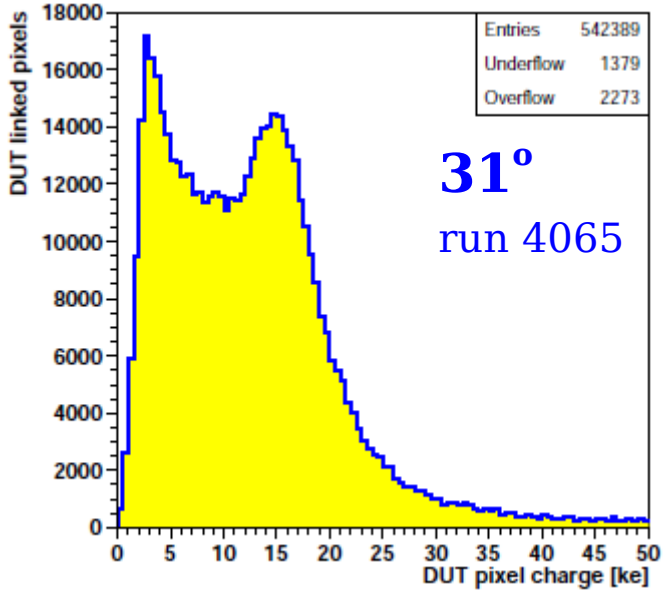








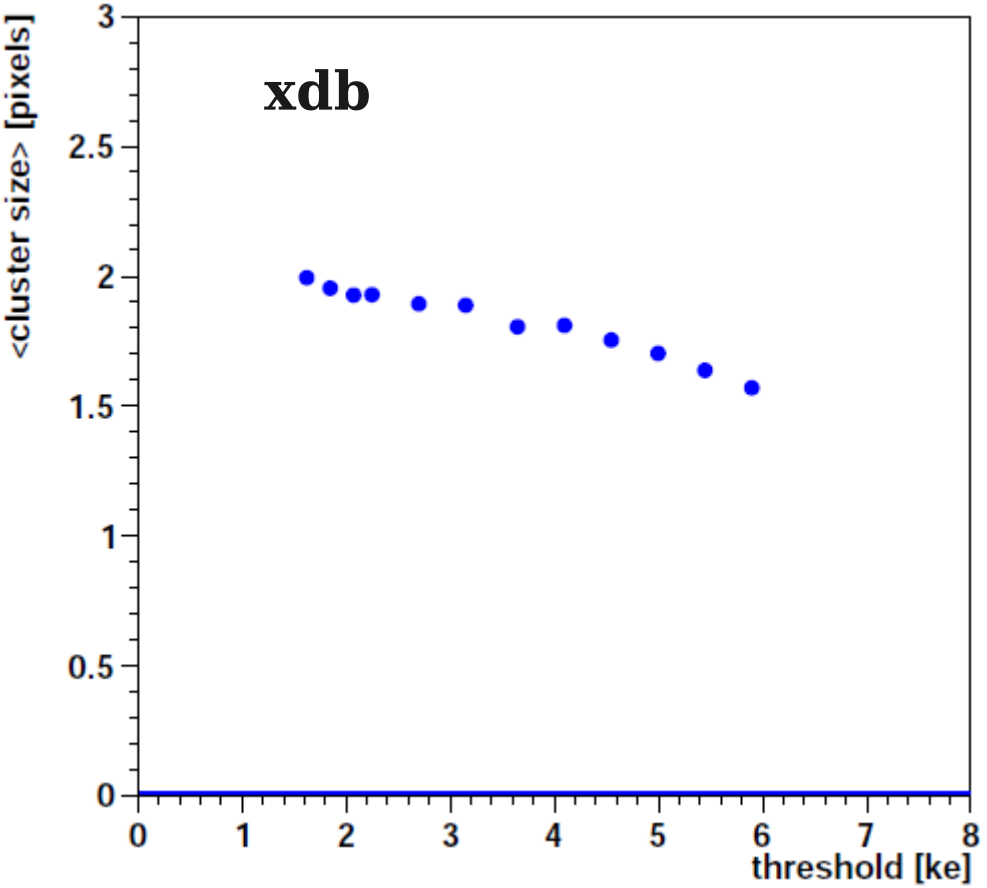




xdb cluster size and charge vs threshold

Chip xdb2, 19° tilt

pixel / cluster



position of Landau peak