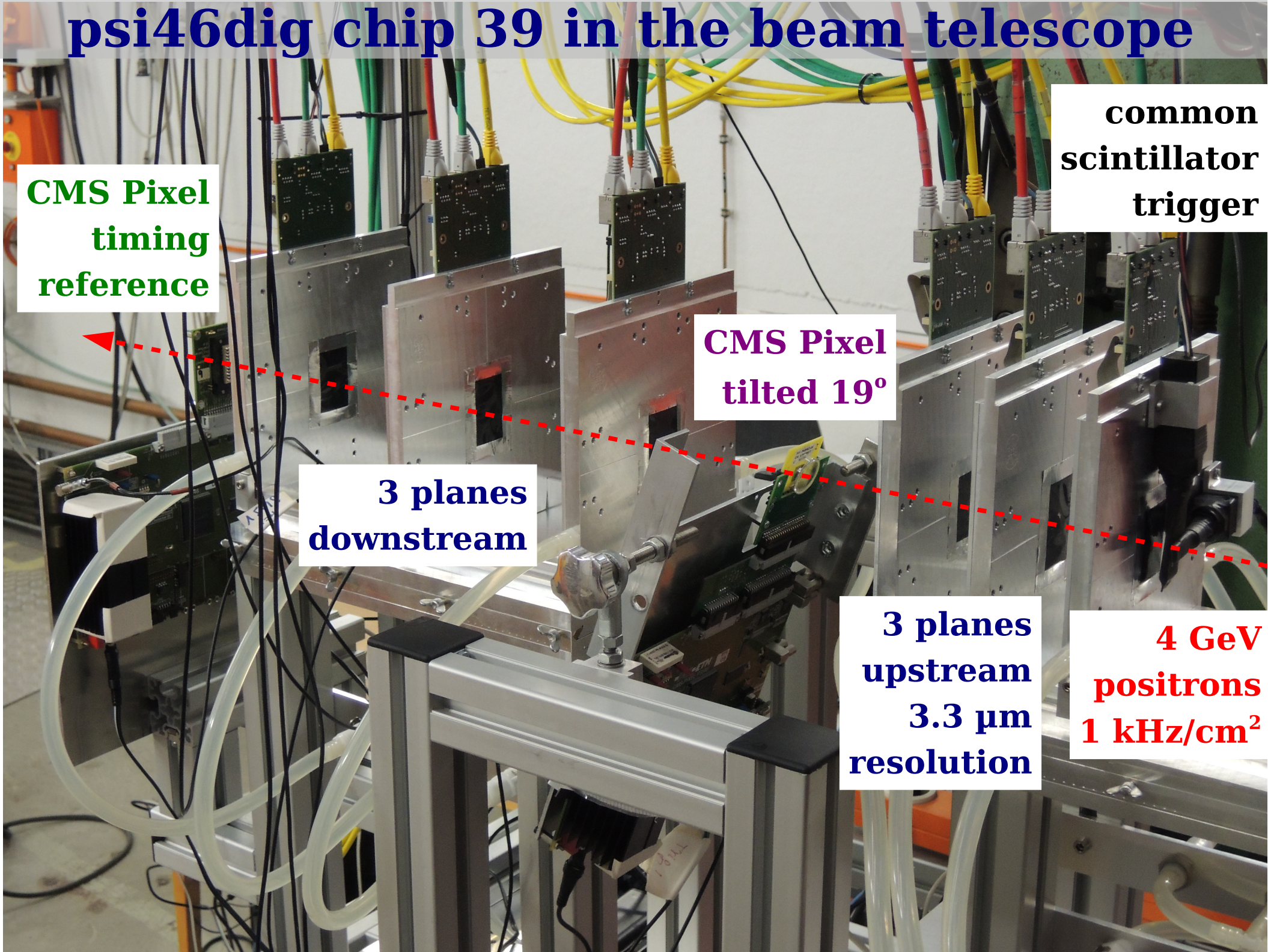
Beam test results at low threshold

Ganna Dolinska, Ievgen Korol, Daniel Pitzl

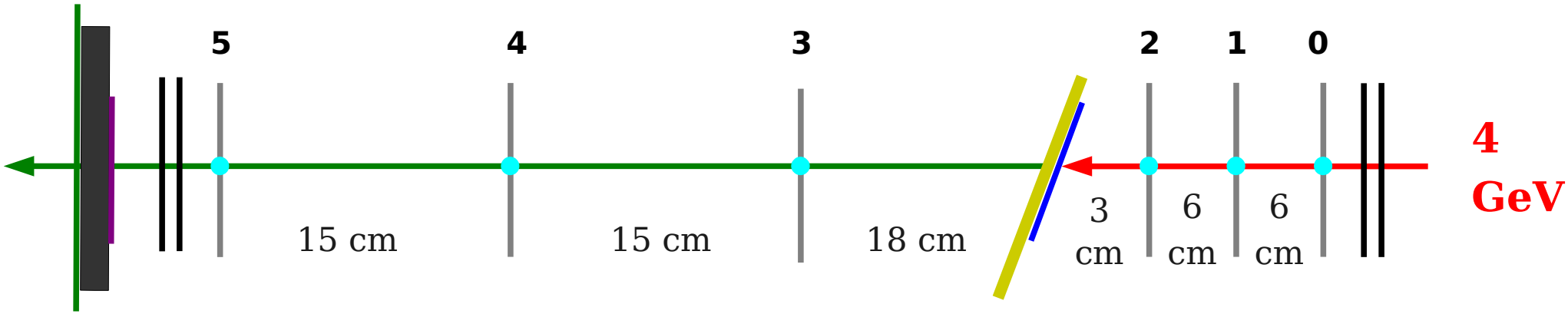
Hamburg CMS Pixel Upgrade meeting, 11.1.2013

- digital ROC beam test in Dec 2012:
  - Ia = 25 mA (PSI design analog current)
  - threshold trimmed down to 1.2 keV
- update from 14.12.2012
- (also compare slides from 5.10.2012 and 24.8.2012)

psi46dig chip 39 in the beam telescope



test beam set up

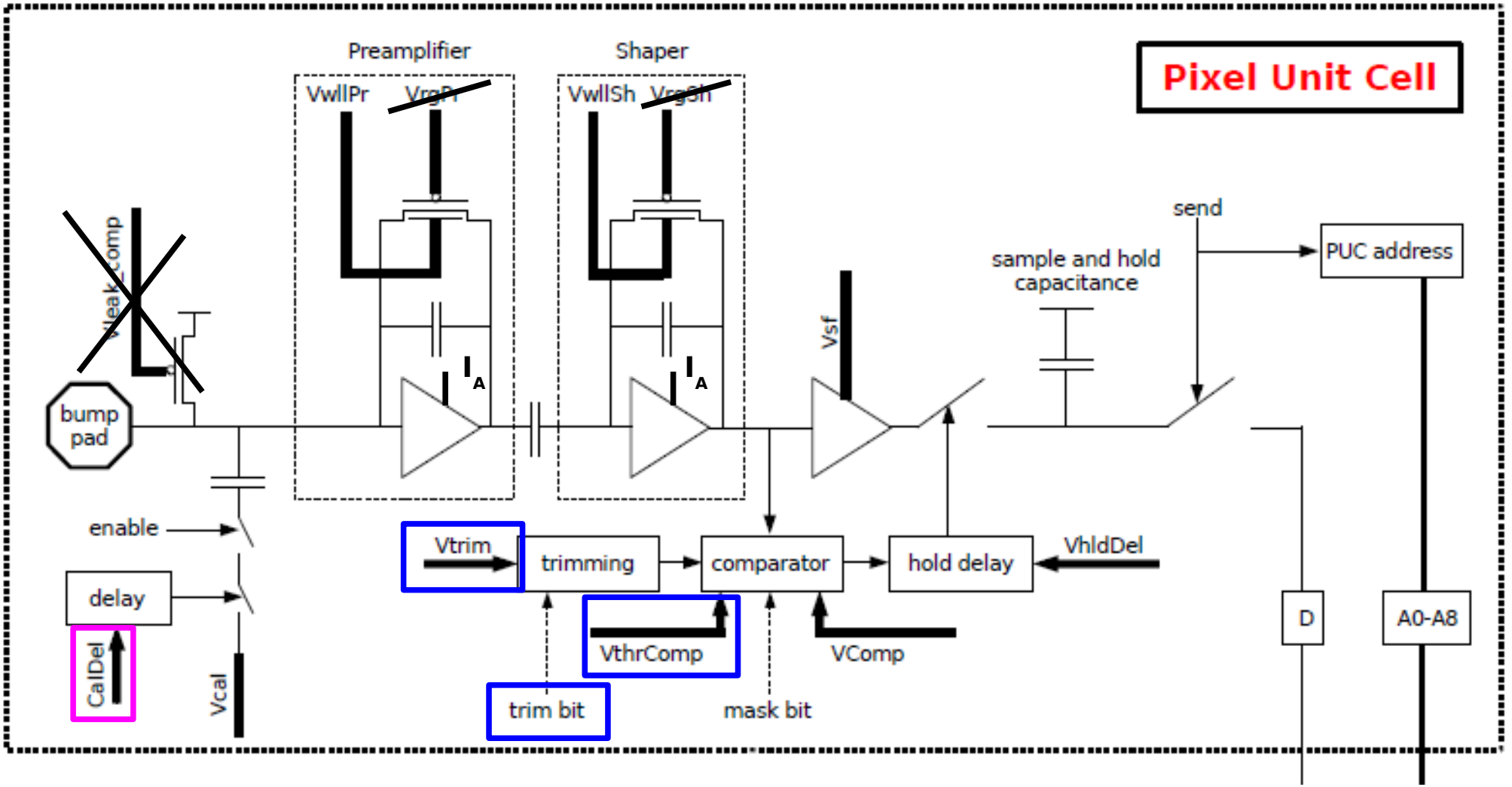


- Upstream arm 0-1-2:
  - as close as possible to DUT: 4.8 µm extrapolation error (at 4 GeV)
- DUT = single chip module, tilted by 19.3° = atan(100 µm / 285 µm)
- Downstream arm 3-4-5:
  - equally spaced between DUT and REF
- REF = single chip module for timing, as close as possible behind scint
- trigger: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

Dec 2012 beam test

- 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
- Use psi46dig chip 39:
  - on loan from Uni HH
- Beam conditions: difficult
  - DORIS ran for Olympus at 2 GeV, topping up every 1.5 min
  - Lower duty cycle for test beam, frequent timing jumps
  - Switch between electrons and positrons every day at 9:30

Threshold

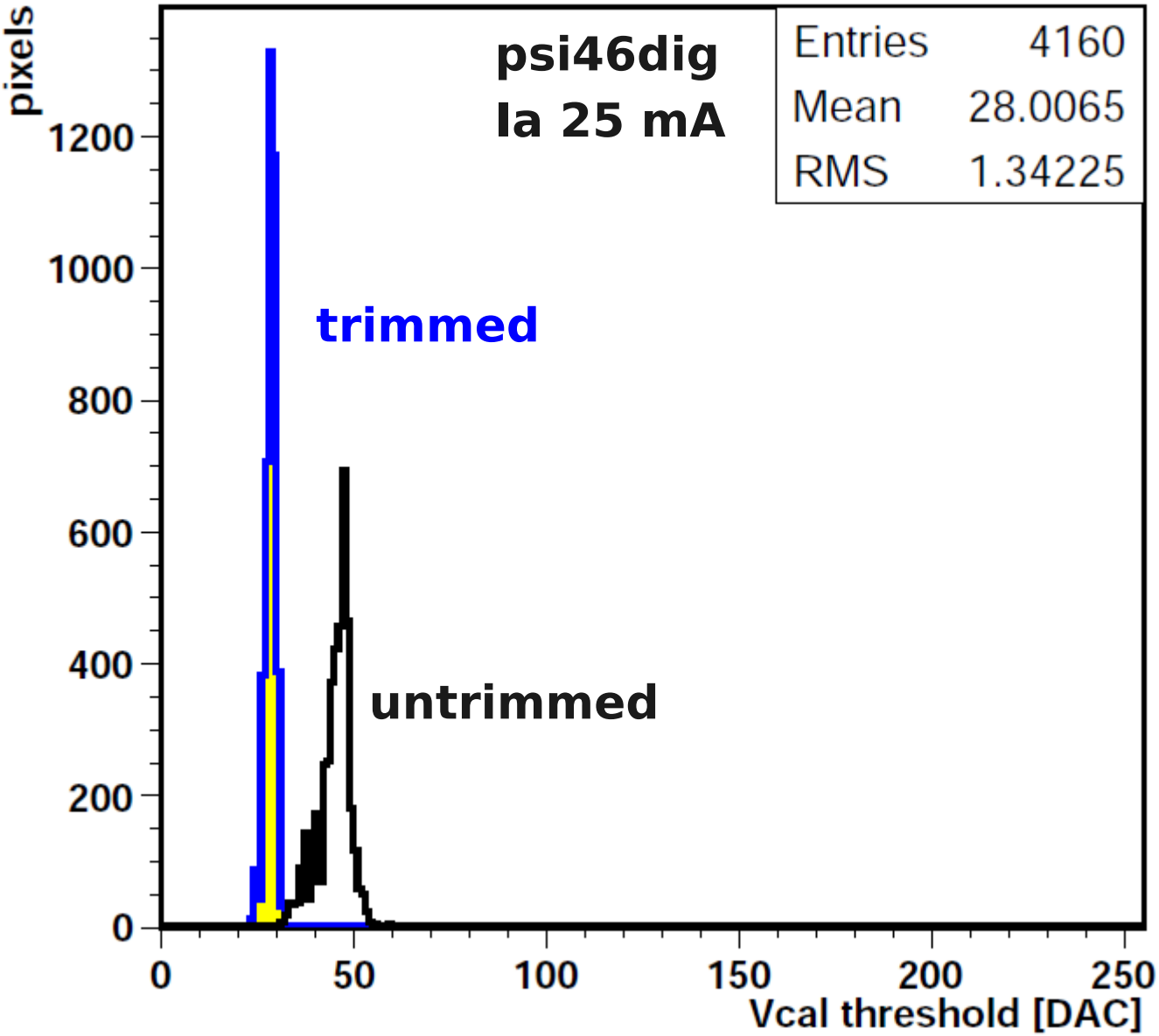


Threshold = VthrComp – Vtrim · (15 – trimbits)

Harder threshold: loose small pulses

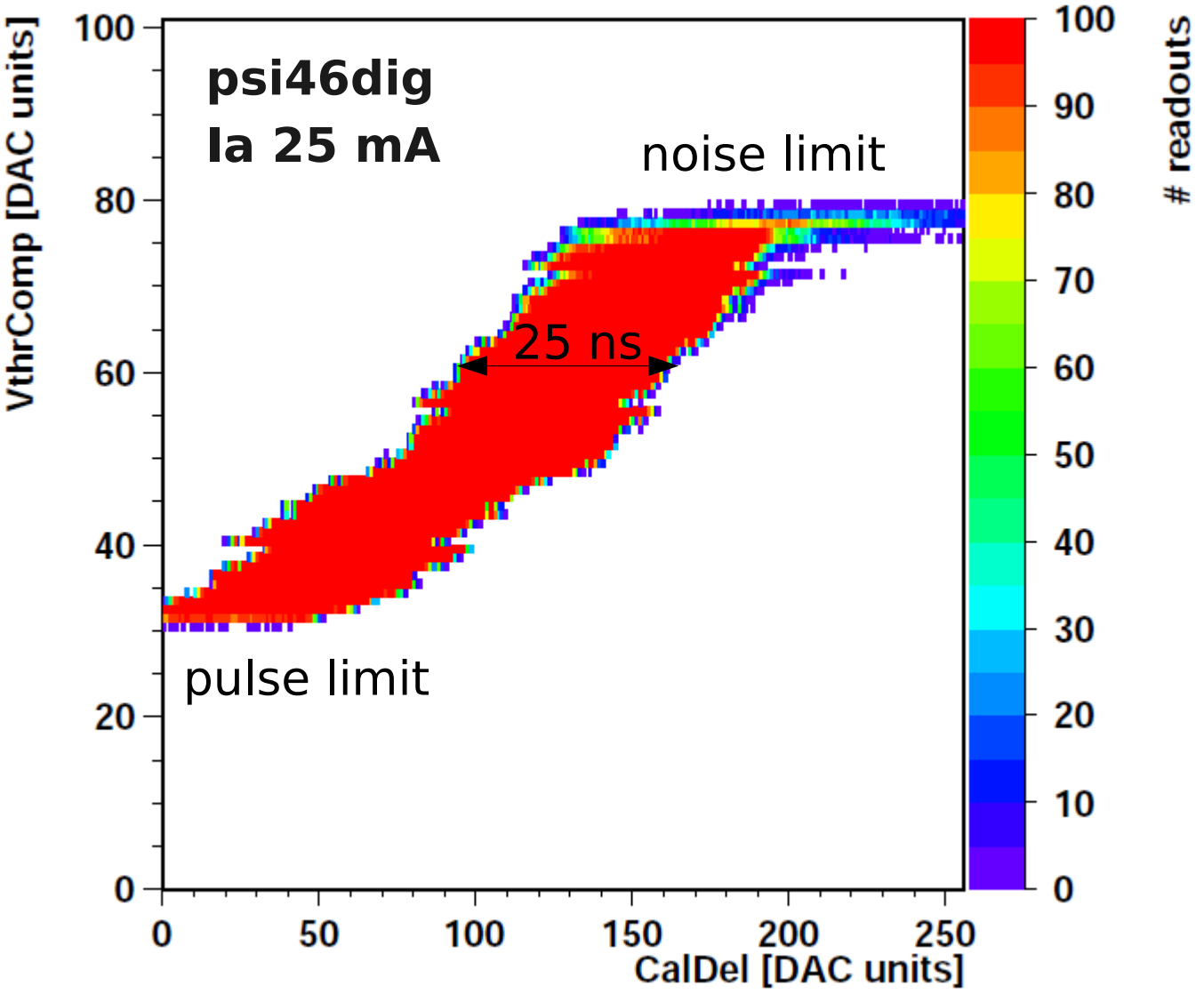
Simulates reduced charge collection (radiation damage)

threshold trimming



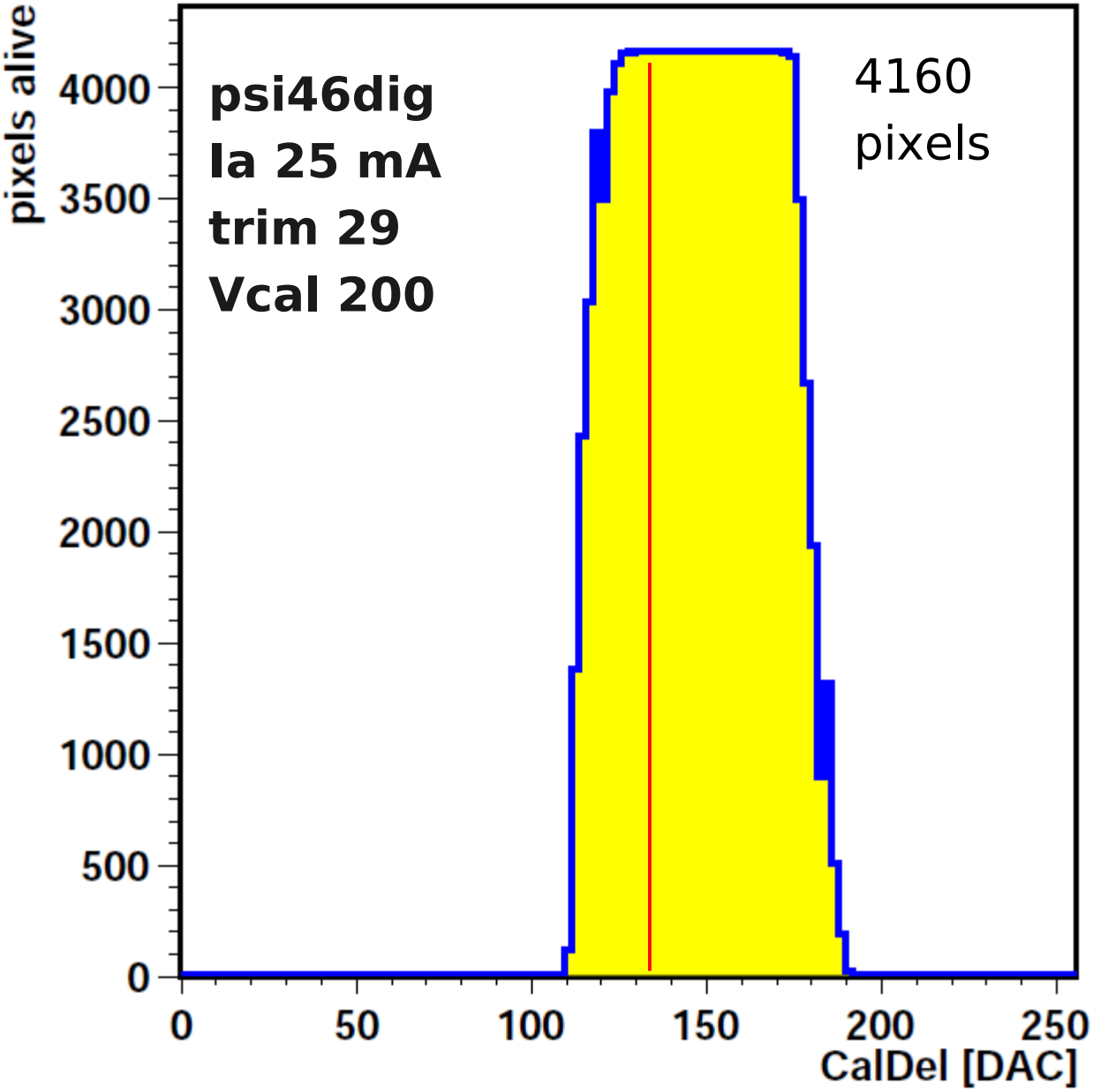
- digital chip 39
- iterated psi46expert procedure:
  - preTest sets Vana, VthrComp, CalDel
  - run effvscaldel to check CalDel
  - Trim sets VthrComp, Vtrim, trim bits
  - check CalDel once more
- works down to target Vcal of 20 (1 ke).

ROC timing changes with threshold setting



- Digital Chip 39:
  - Ia 25 mA
  - pixel 22, 22
  - Vcal 200 (10 ke)
  - 100 triggers per bin
- Changing the comparator threshold affects the timing by up to 3 clock cycles.
- We take this into account during trimming and data taking.

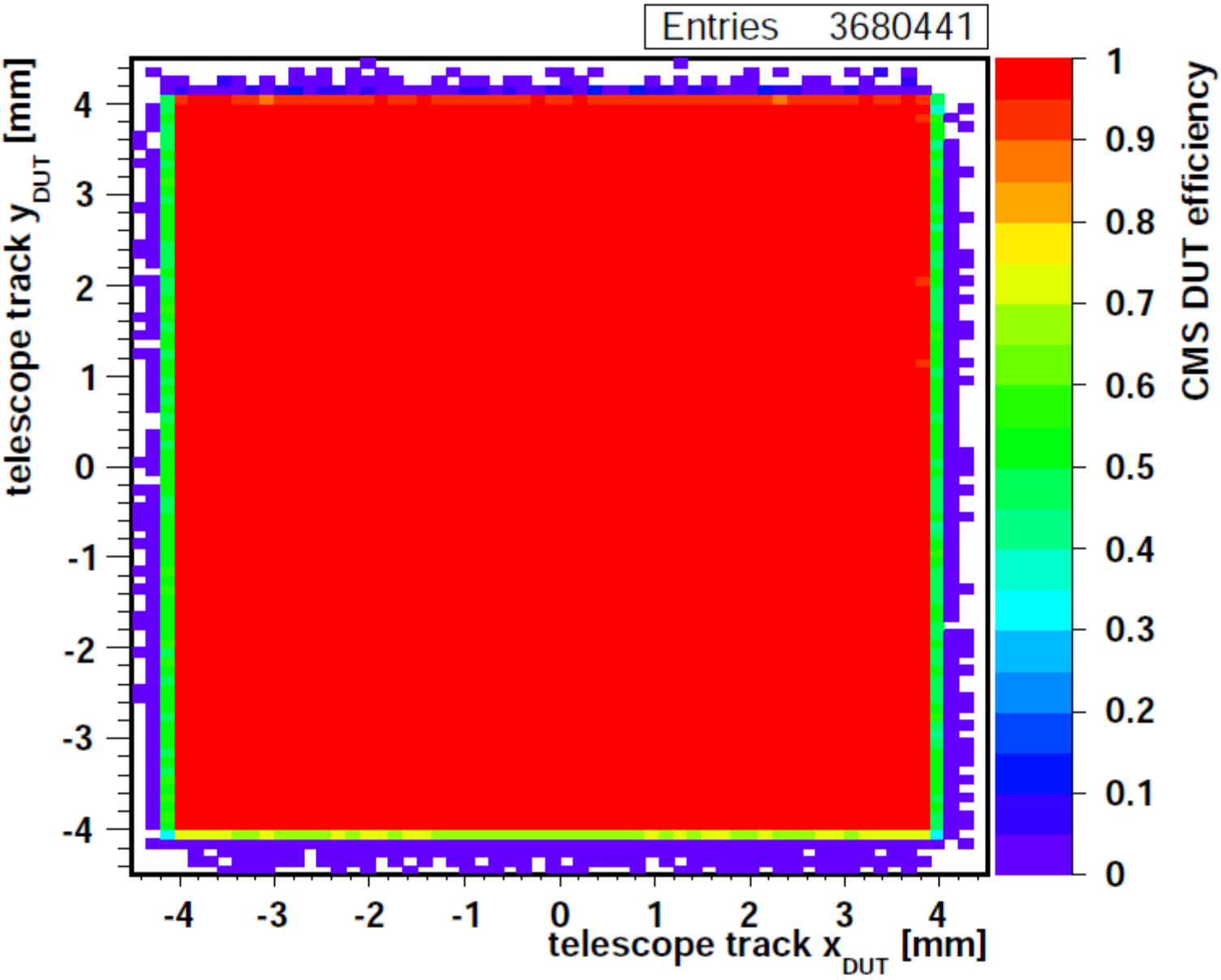
Efficiency vs timing



- Digital Chip 39:
  - Ia 25 mA
  - Vcal 200 (4 ke)
  - scan ChipEfficiency: effvscaldel
- Choose operating point towards the left edge of the efficiency plateau.
- Repeat this for every threshold setting...

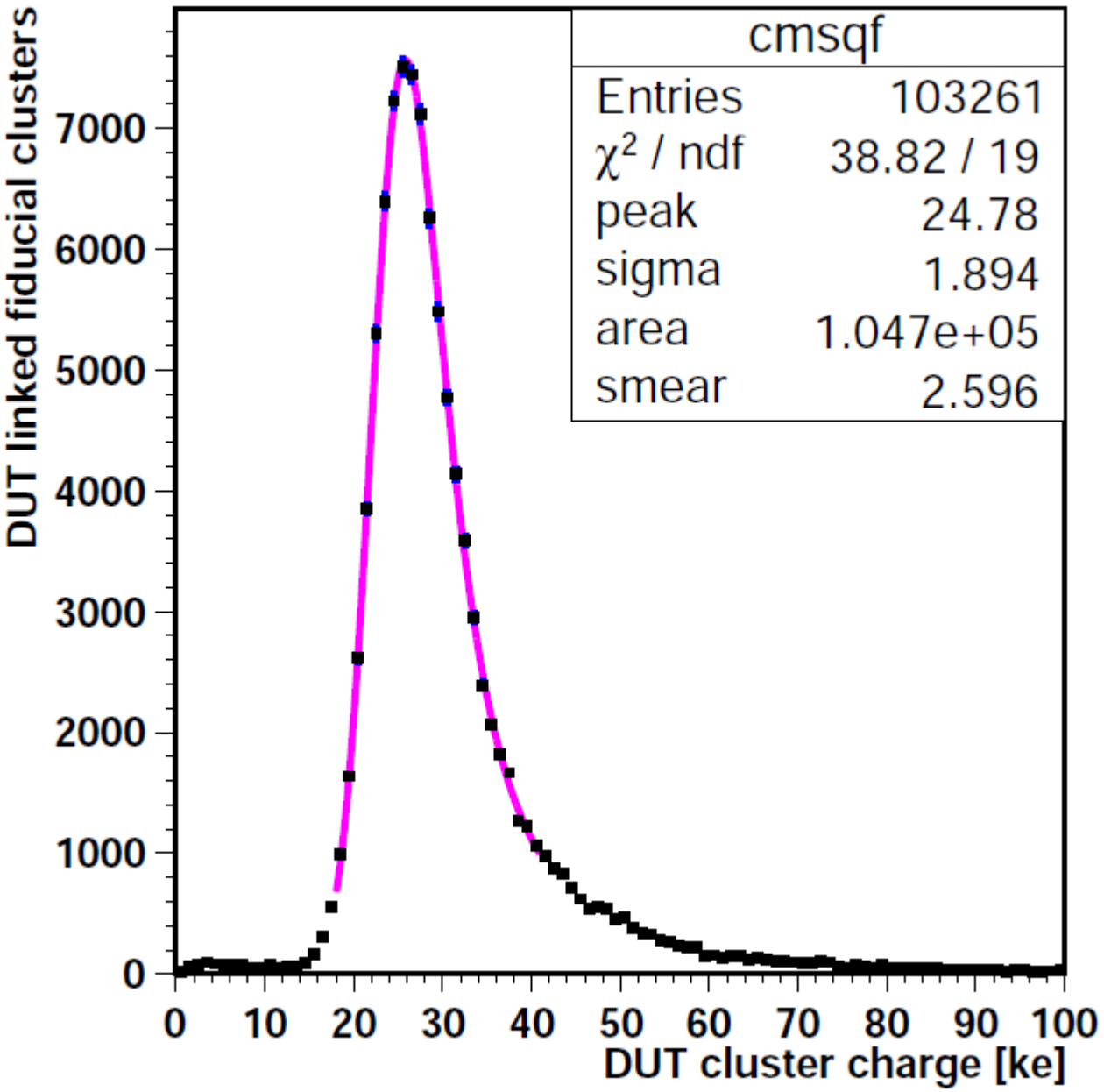
digital ROC efficiency map

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



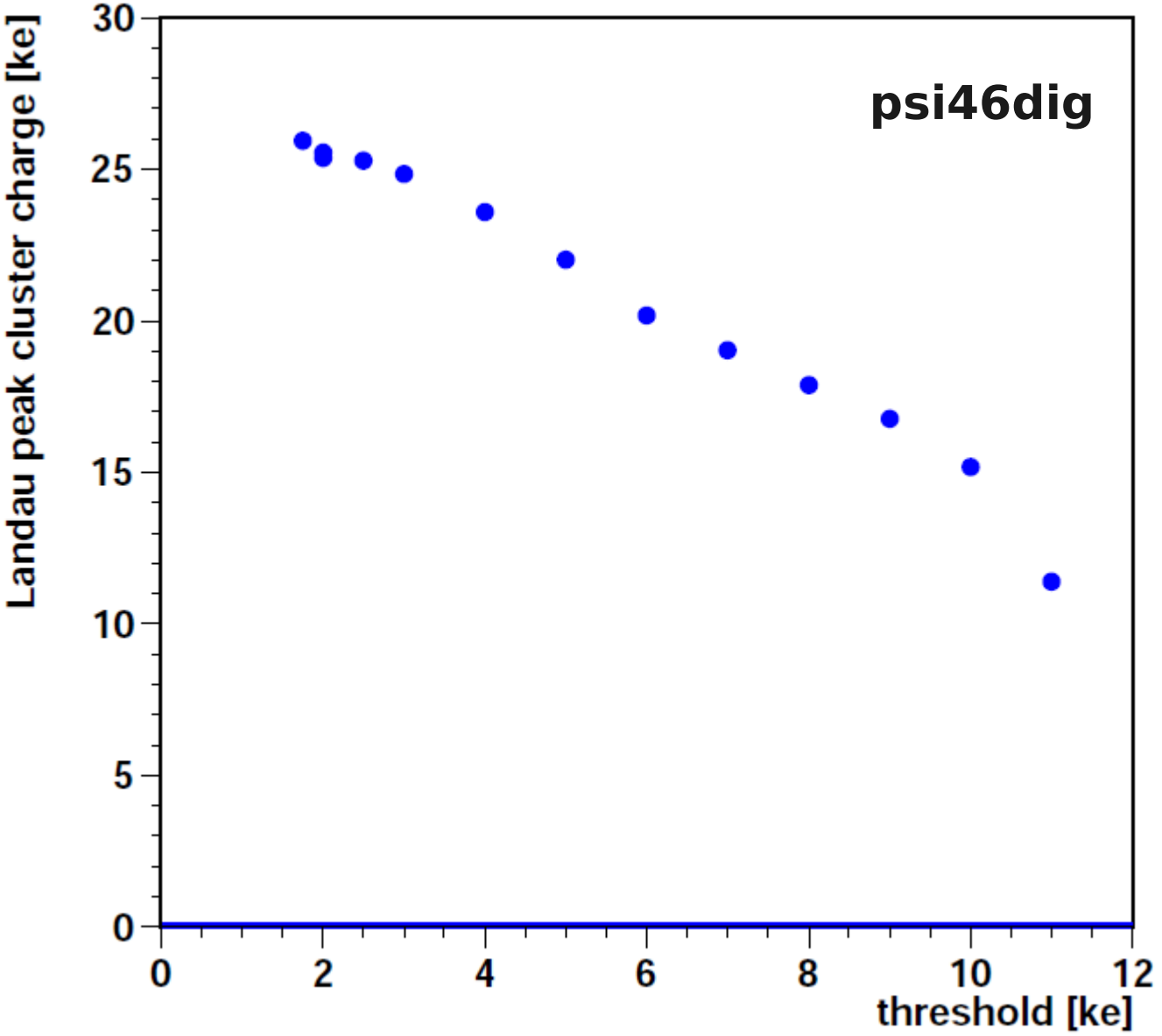
- chip 39
  - I_A 25 mA
  - trim 24
- runs 5223-5520
- tilt 19°
- **99% in fiducial region**
  - losses due to timing jumps

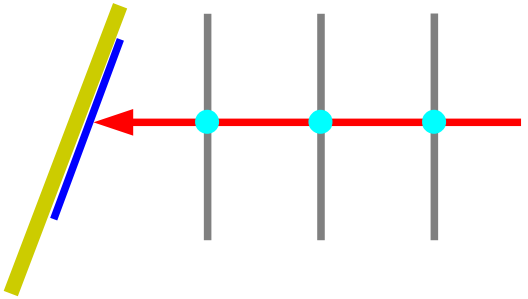
Landau distribution from digital ROC



- digital chip 39
- Telescope run 5359:
  - bias -150V
  - threshold 1.2 ke
  - tilt 19°
- Gain calibration: Weibull fit, nominal gain 50e/DAC used.
- Cluster charge distribution fit by Landau ⊗ Gauss
  - peak at 24.8 ke as expected: gain 50 confirmed.

Cluster charge vs threshold with psi46dig

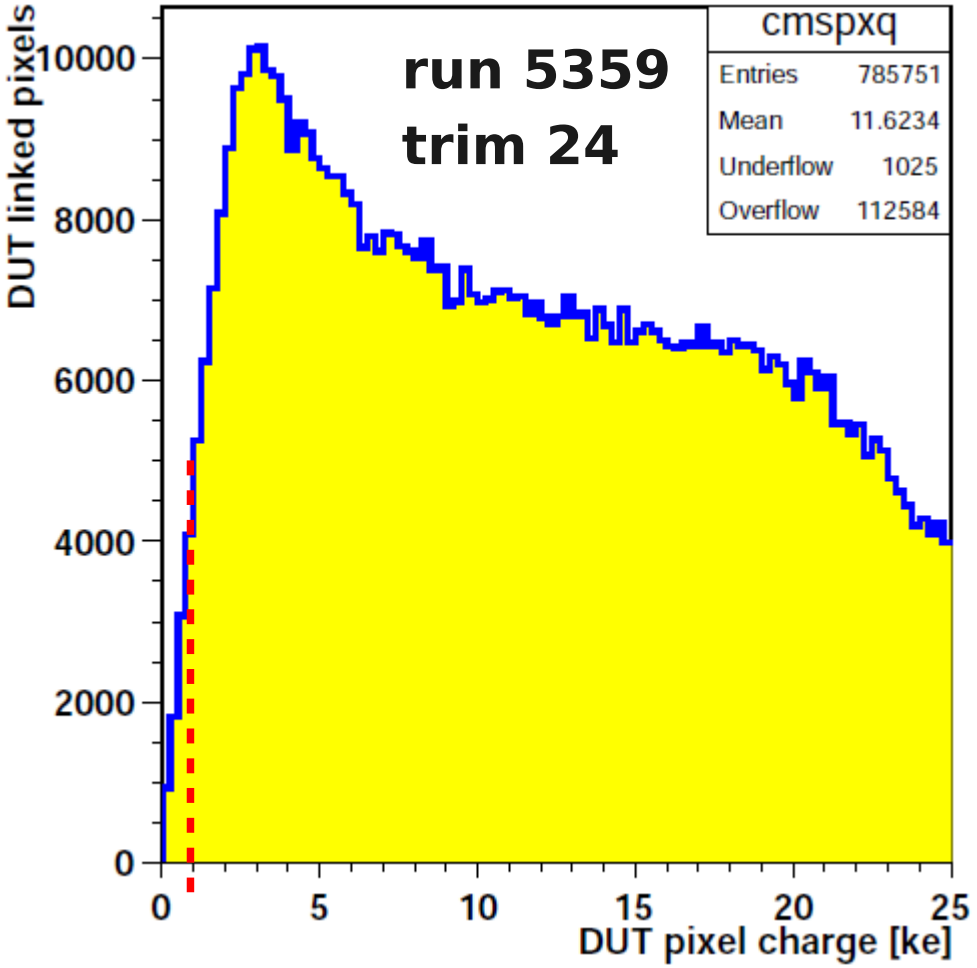


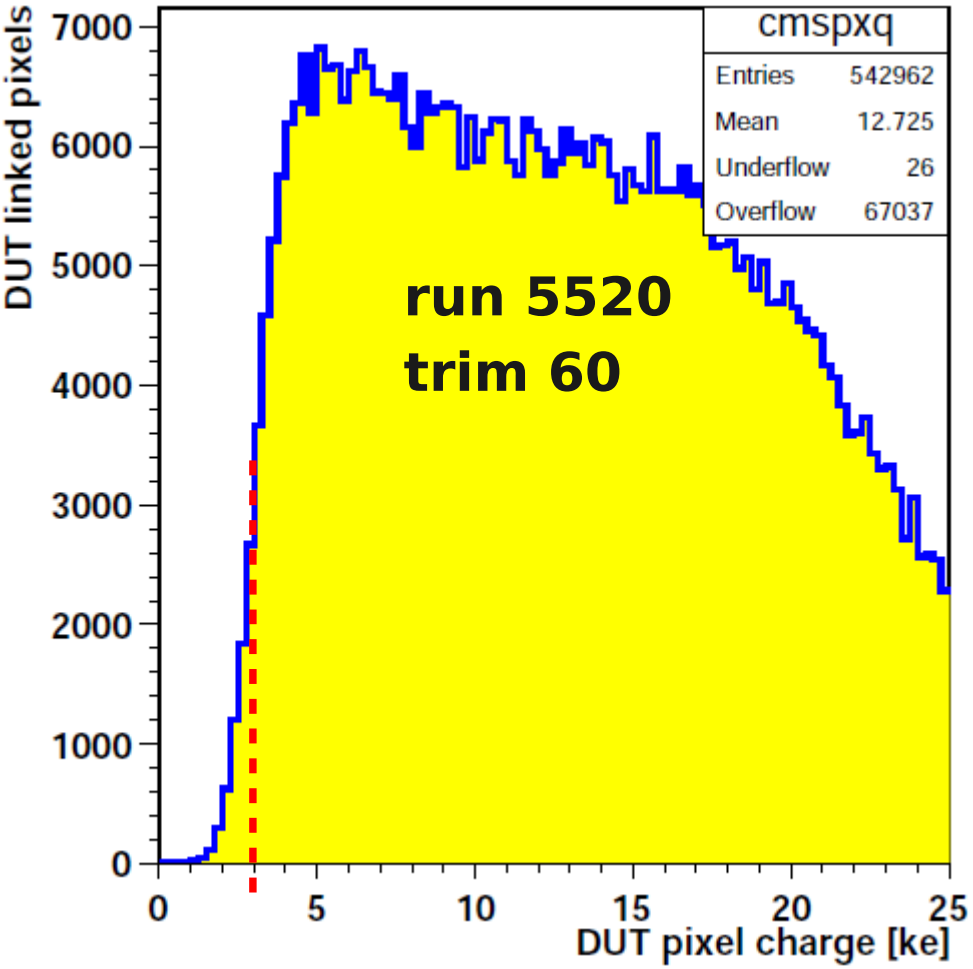


- Digital Chip 202, -150V, 20° tilt, Ia 30 mA
  - runs 5310-5384
- Threshold and delay adjusted together
- Position of Landau peak
  - decreases with harder threshold

Pixel charge distribution

- digital chip 39, Ia 25 mA, tilt 19°

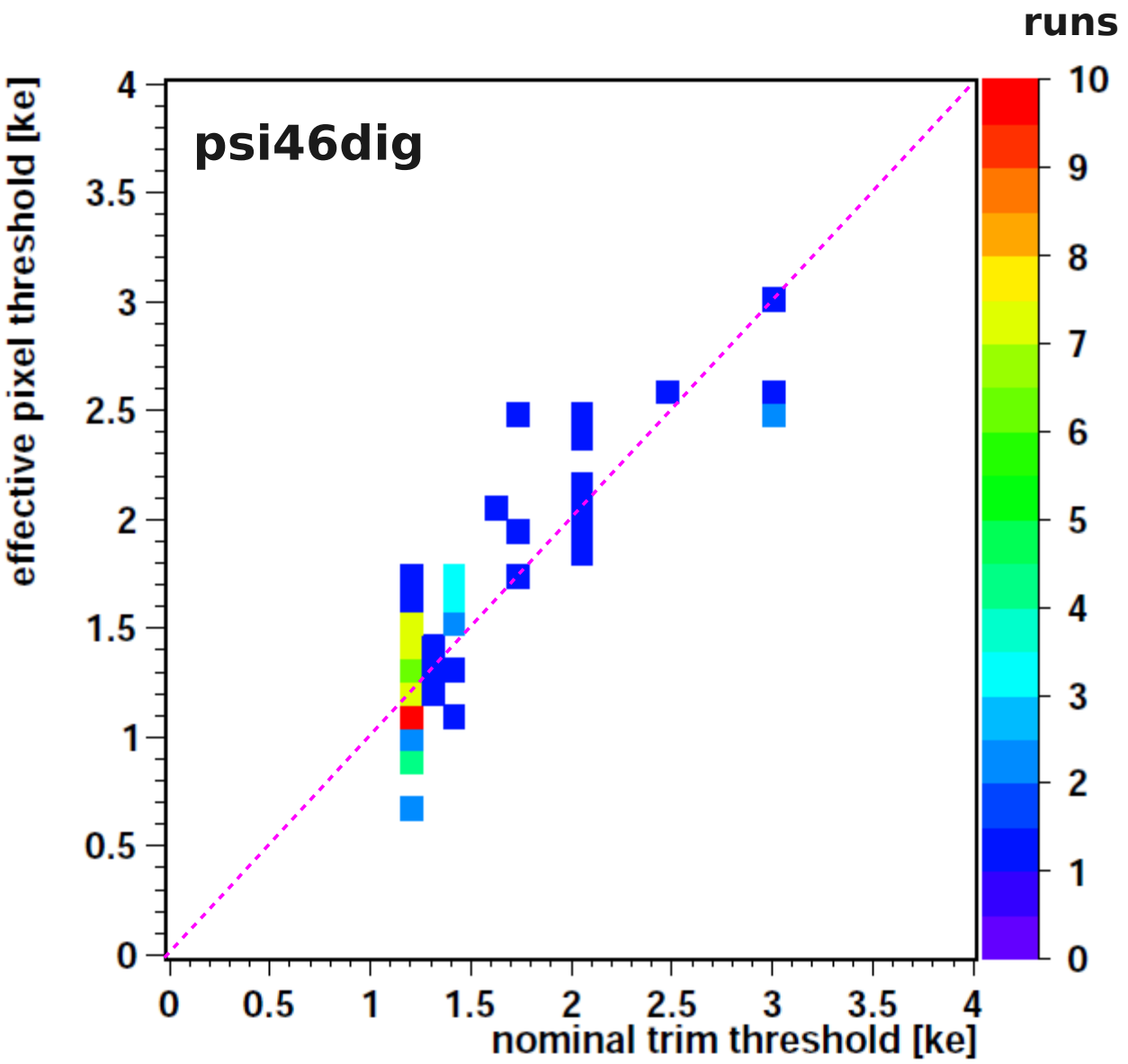


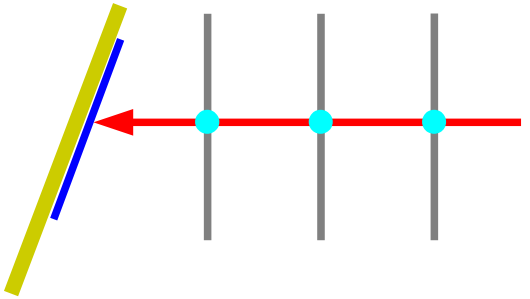


1.2 ke **3 ke**

mid of rising edge = effective threshold

Threshold calibration

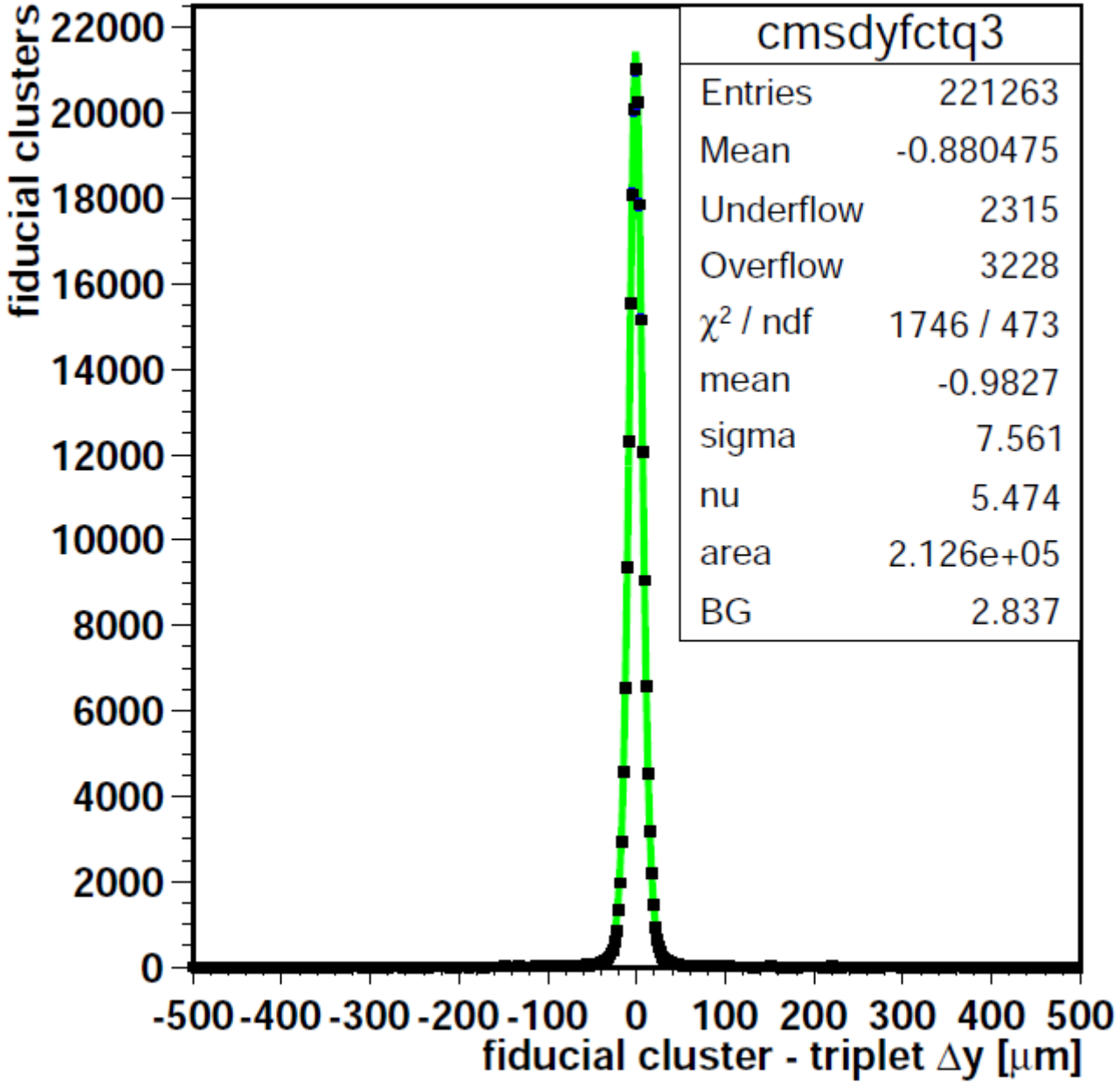


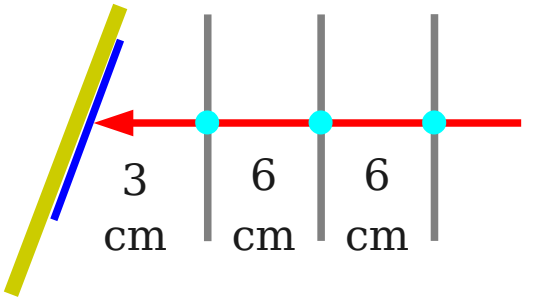


- Digital Chip 39:
  - 19° tilt, Ia 25 mA
  - runs 5223-5520
- Effective threshold from pixel charge distribution
- Line with slope 1 through origin:
  - nominal threshold confirmed.

row resolution with digital ROC

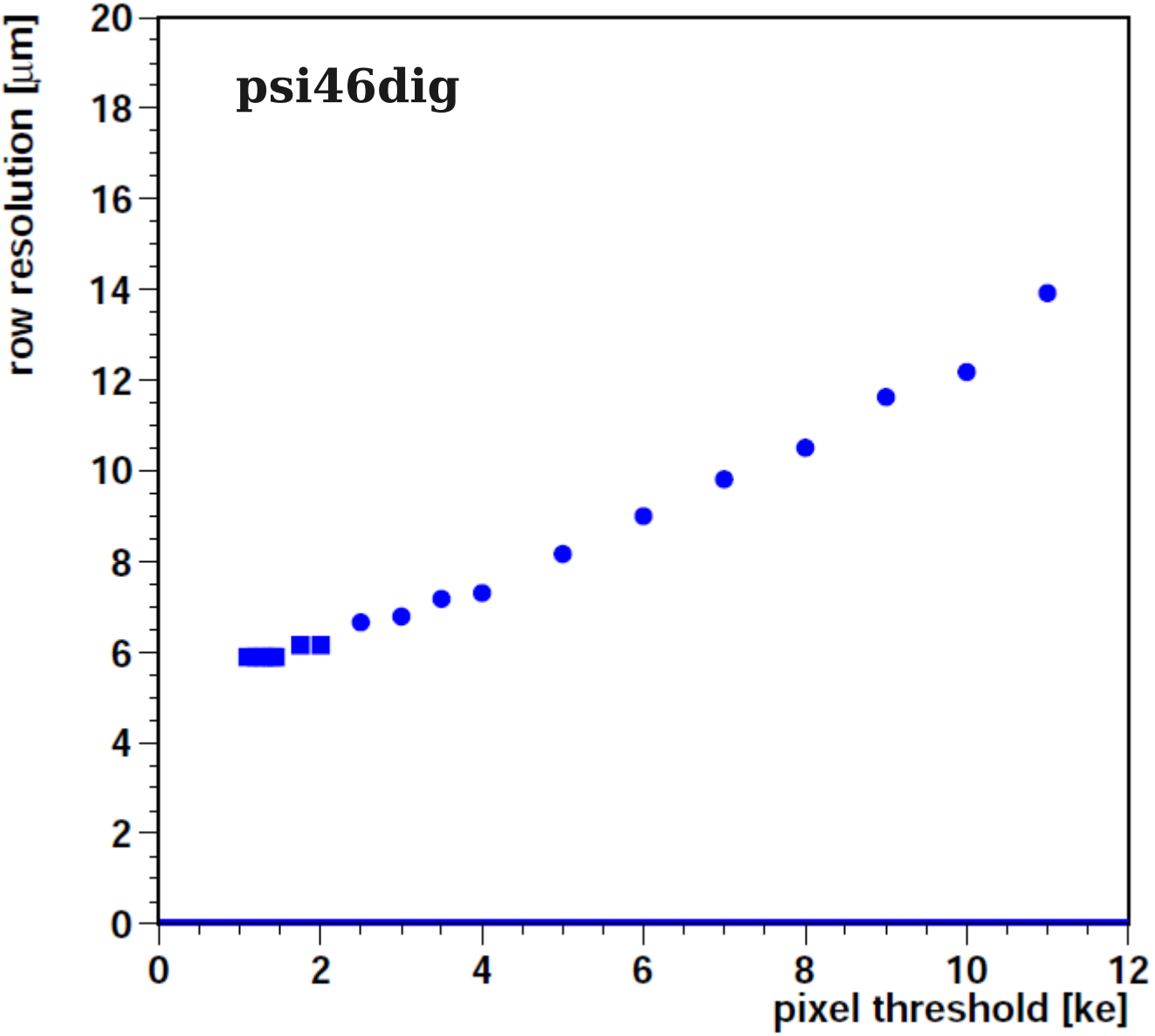
dig chip39, trim 24, run 5500, 4 GeV, 19° tilt

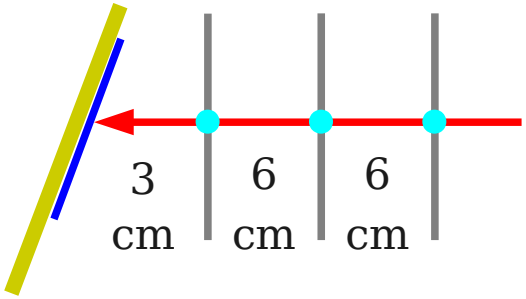




- Vertical = rows
  - pixel height 100 µm
- Residual:
  - σ = 7.6 µm,
  - telescope extrapolation: 4.8 µm,
  - **CMS pixel intrinsic resolution: 6 µm**
  - **Our best so far!**

Resolution vs psi46dig threshold





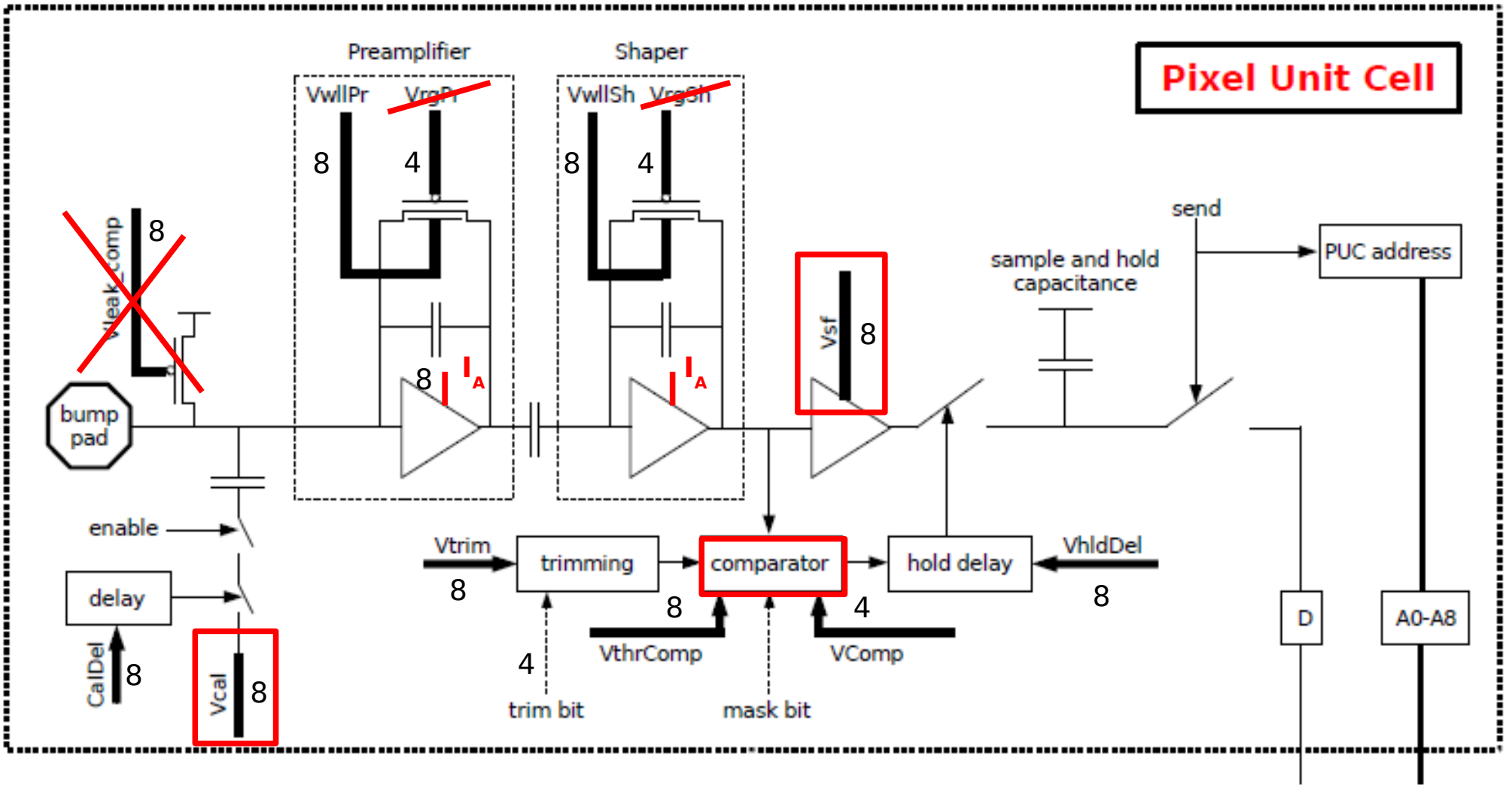
- Digital ROC 203 and 239, 20° tilt
- 4.4 GeV, telescope extrapolation uncertainty subtracted.
- lower threshold:
  - resolution seems to saturate at 6 μm below 2 ke.

Summary and outlook

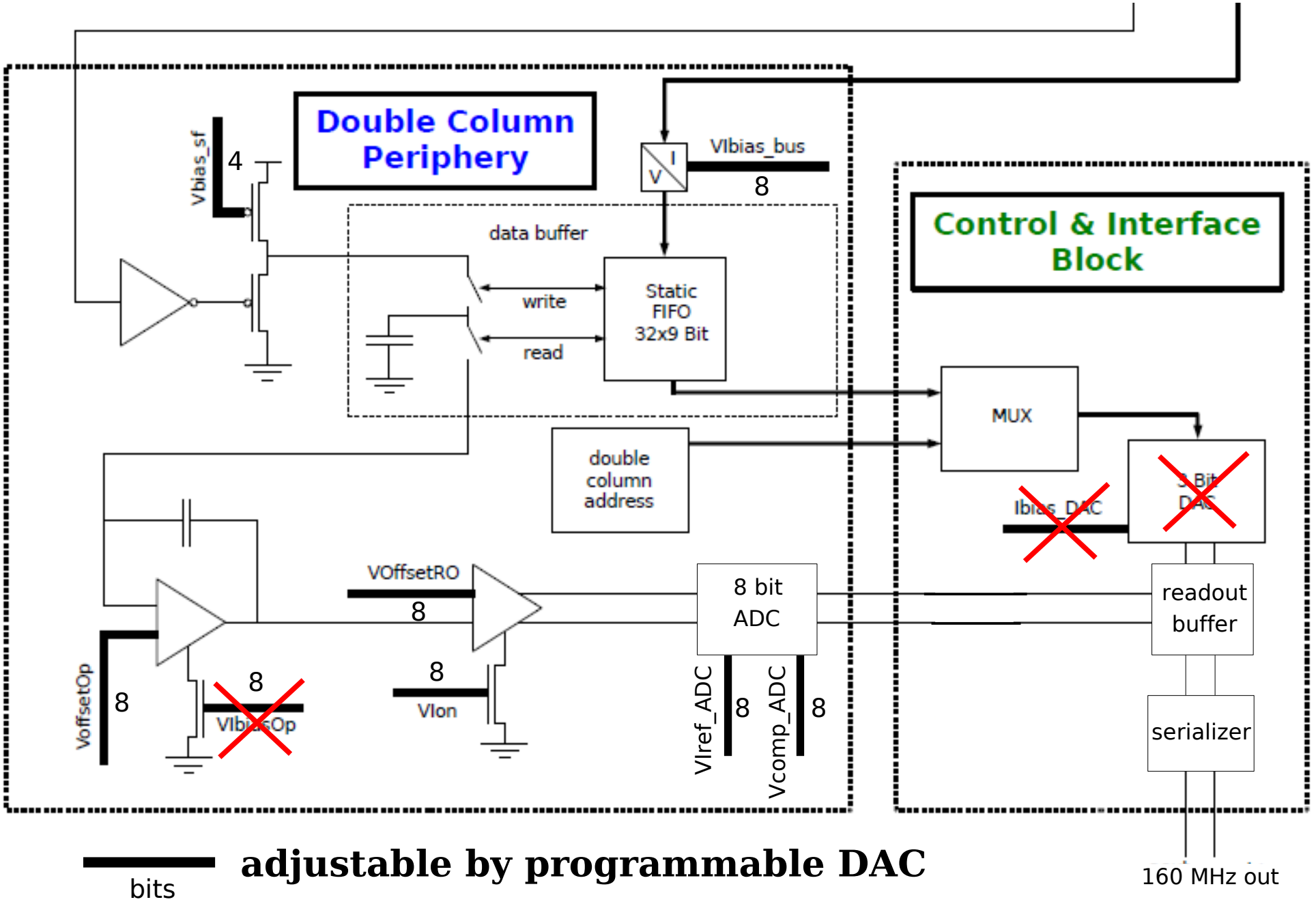
- Digital ROC 39 with sensor measured in the test beam:
  - tuned and trimmed for 25 mA analog current
  - thresholds down to 1.2 ke work without noise
  - resolution at 19^{o} tilt reaches 6 µm at lowest thresholds
- Next beam test: 1st week of Feb
  - irradiated digital ROCs 202 and 203 (with sensors, cooled)
- Publish results
- For the X-ray tests:
  - Fluorescence lines from Cu (8.0 keV) and Fe (6.4 keV) should be measurable with a threshold of 1.2 ke (4.3 keV).

Back up

psi46dig pixel unit cell



psi46dig periphery

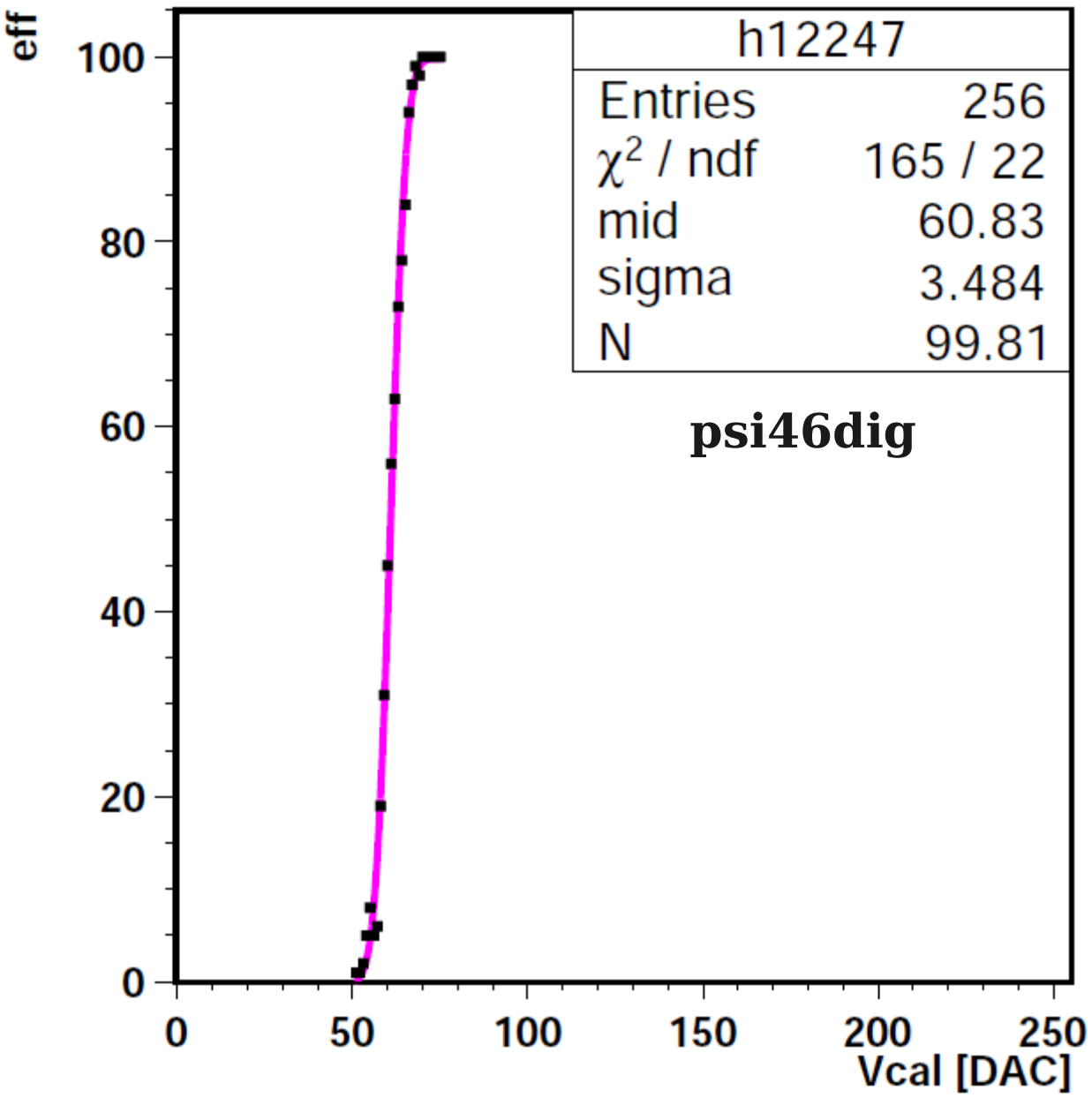


psi46dig DACs (Vcal threshold 24)

1	Vdig	12
2	Vana	83
3	Vsf	30
4	Vcomp	12
7	VwllPr	60
9	VwllSh	60
10	VhldDel	252
11	Vtrim	55
12	VthrComp	69

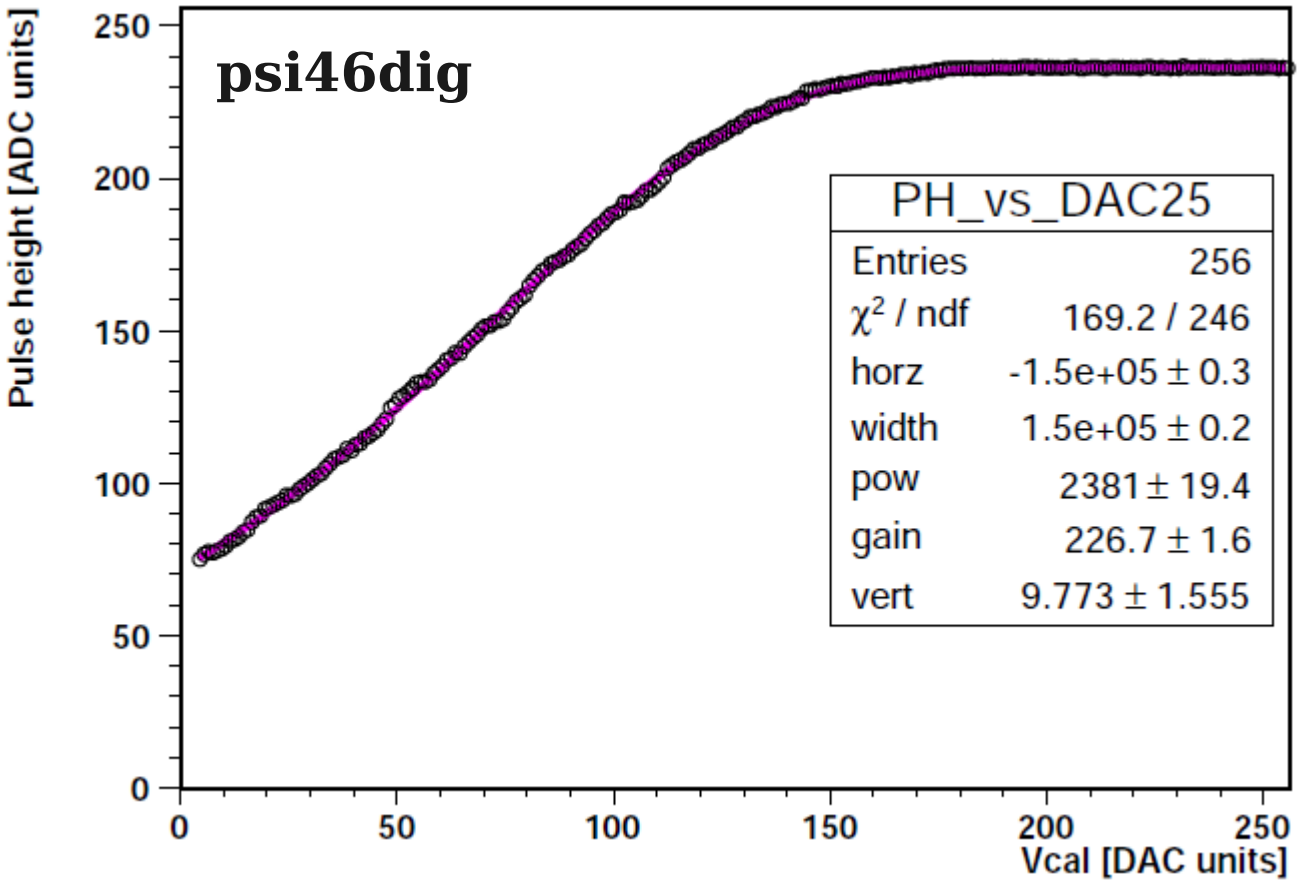
13	VIBias_Bus	20
14	Vbias_sf	14
15	VoffsetOp	50
17	VOffsetR0	140
18	VIon	45
19	Vcomp_ADC	100
20	VIref_ADC	70
22	VIColOr	100
25	Vcal	200
26	CalDel	125
253	CtrlReg	0
254	WBC	160

Threshold curve



- Digital Chip 202
  - Ia 30 mA
  - pixel (28, 7)
- Standard S-curve:
  - pixel efficiency vs small Vcal
- Fit by error function:
  - mid = threshold
  - sigma = noise

gain calibration

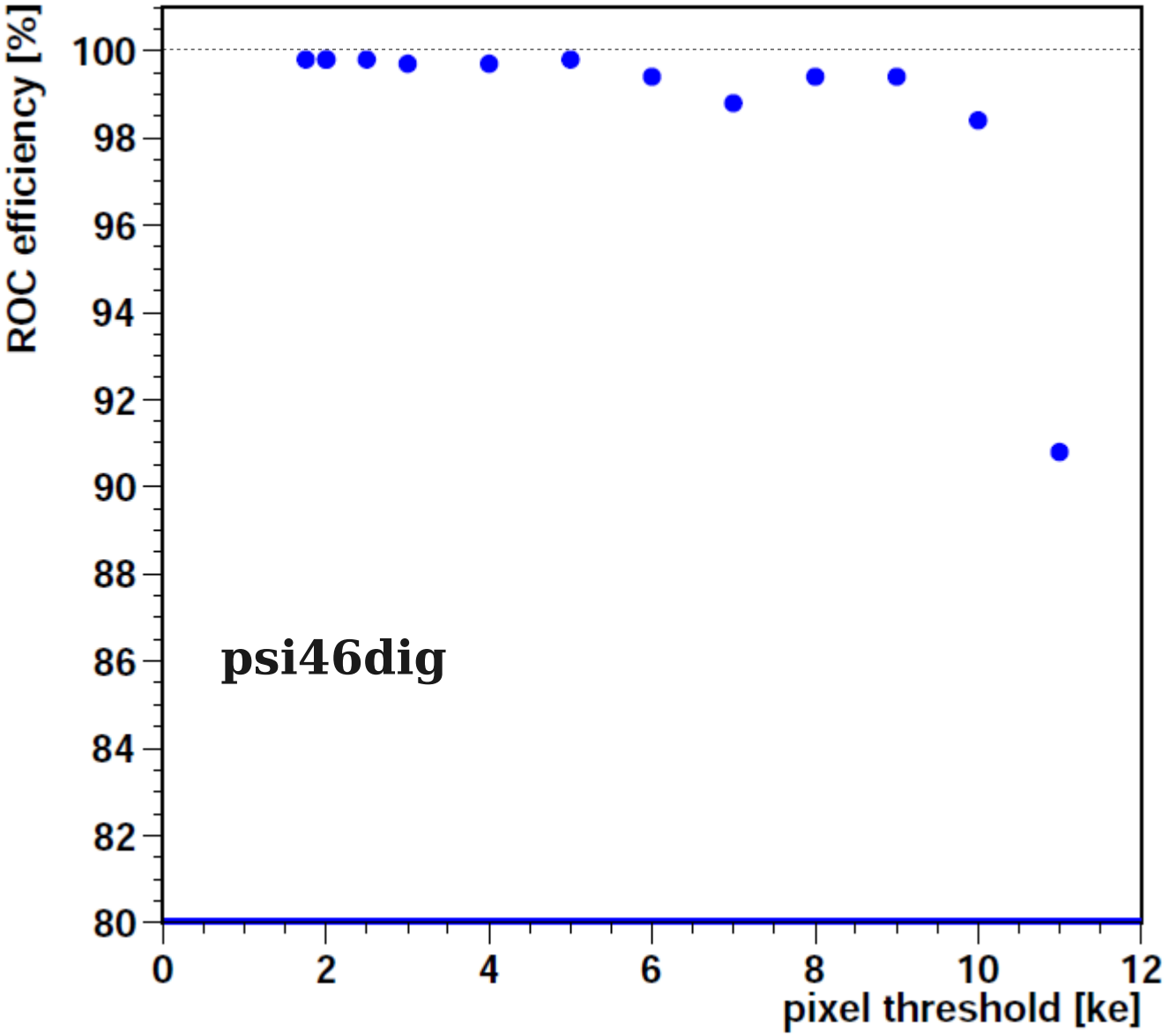


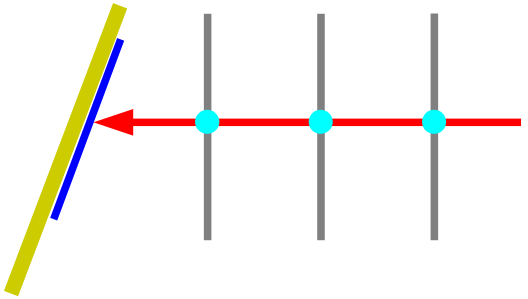
- Pulse height vs large Vcal
- Fit by Weibull function:
  - good fit from threshold to saturation
  - 5 parameters

Weibull: $PH = p_4 + p_3 \left(1 - \exp\left(-((V - p_0) / p_1)^{p_2}\right)\right)$

inverse: $V = p_1 \left(-\ln\left(1 - (PH - p_4)/p_3\right)\right)^{1/p_2} + p_0$

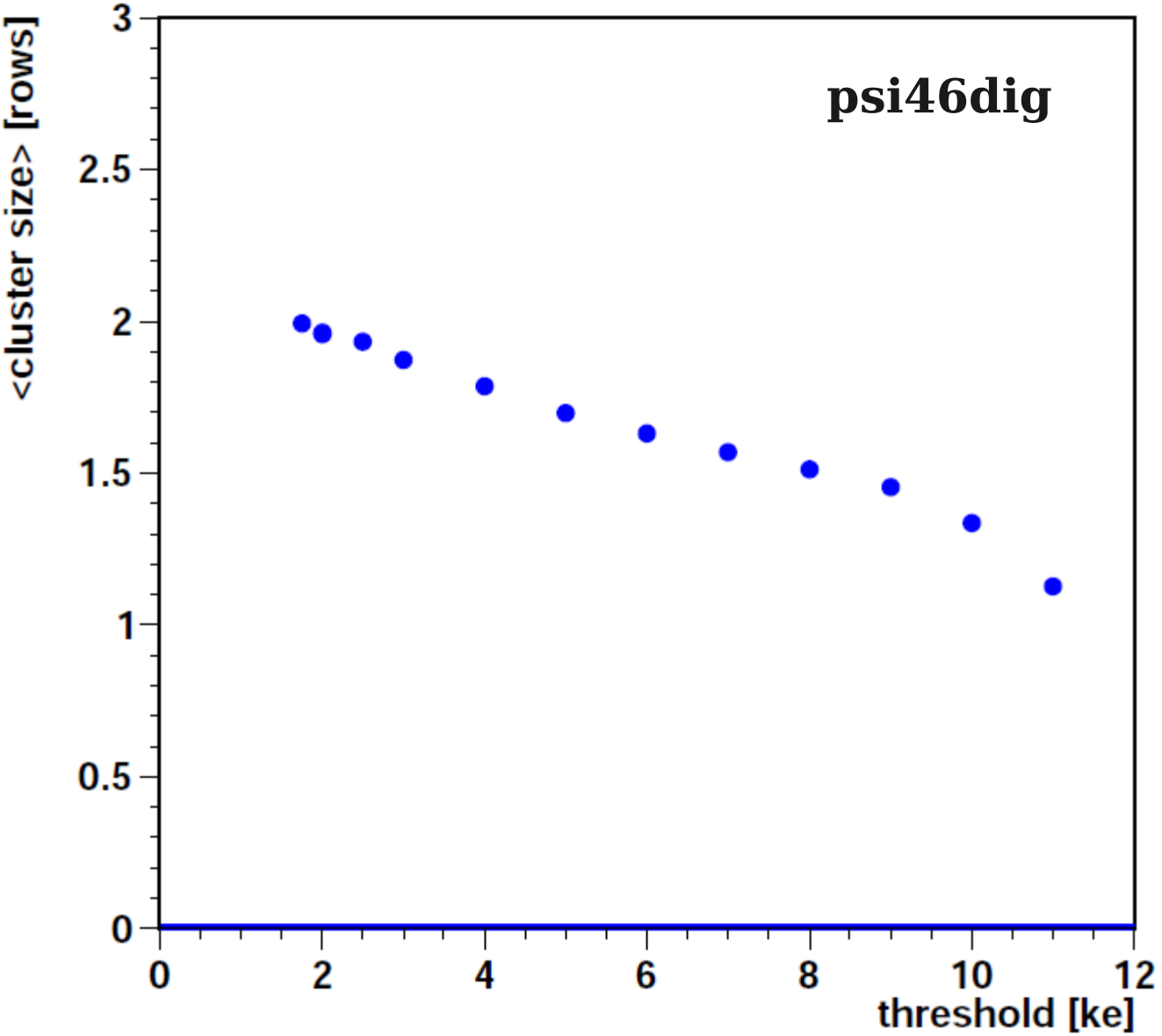
Efficiency vs threshold with psi46dig

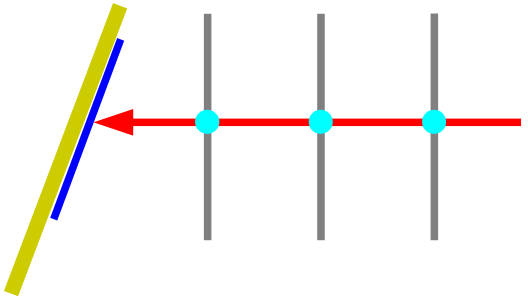




- Digital Chip 202, -150V, 20° tilt, Ia 30 mA
  - runs 5310-5384
- Threshold and delay adjusted together
- Efficiency:
  - 99.8% at low threshold
  - remains above 98% up to 10 ke

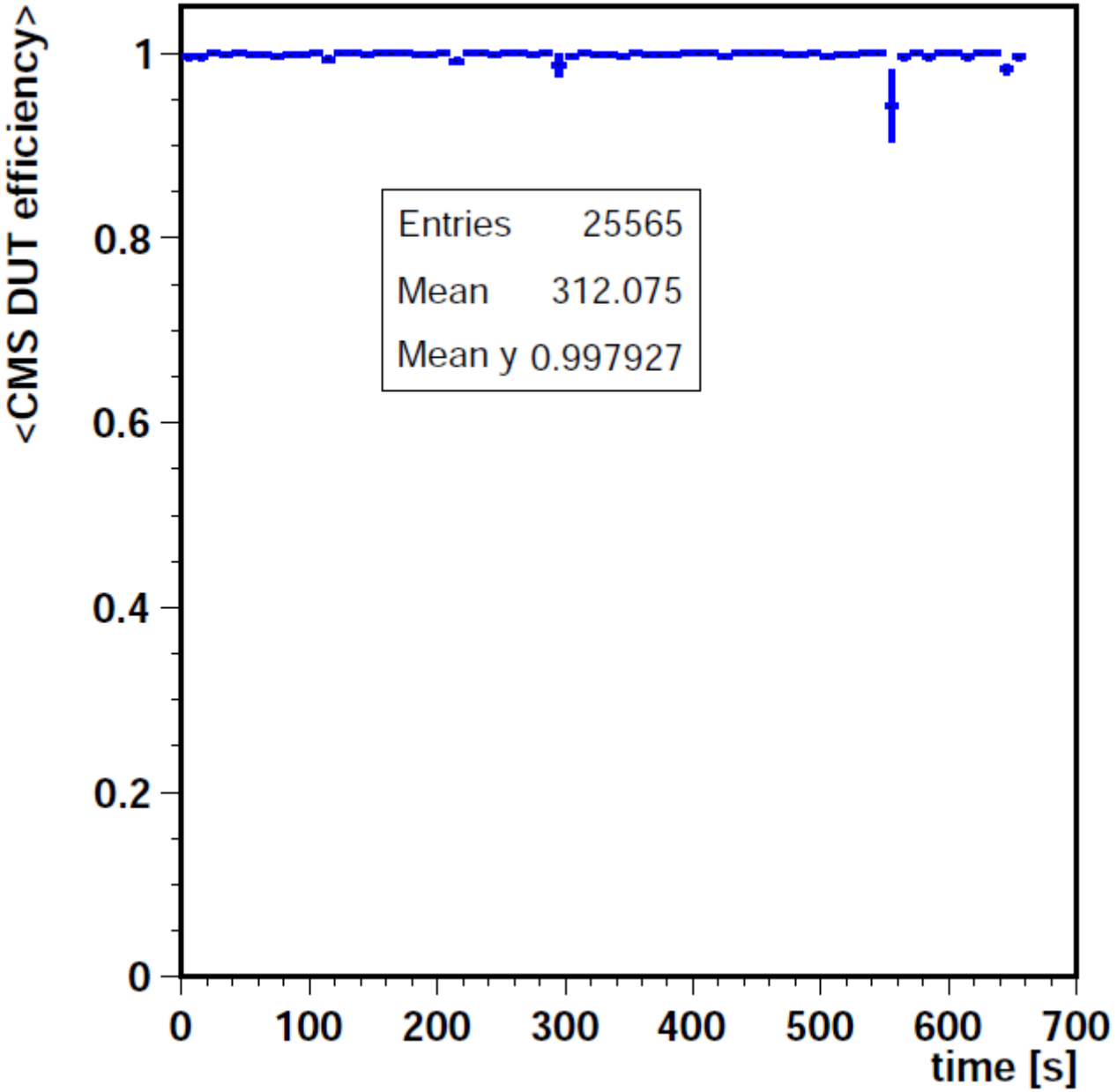
Cluster size vs threshold with psi46dig





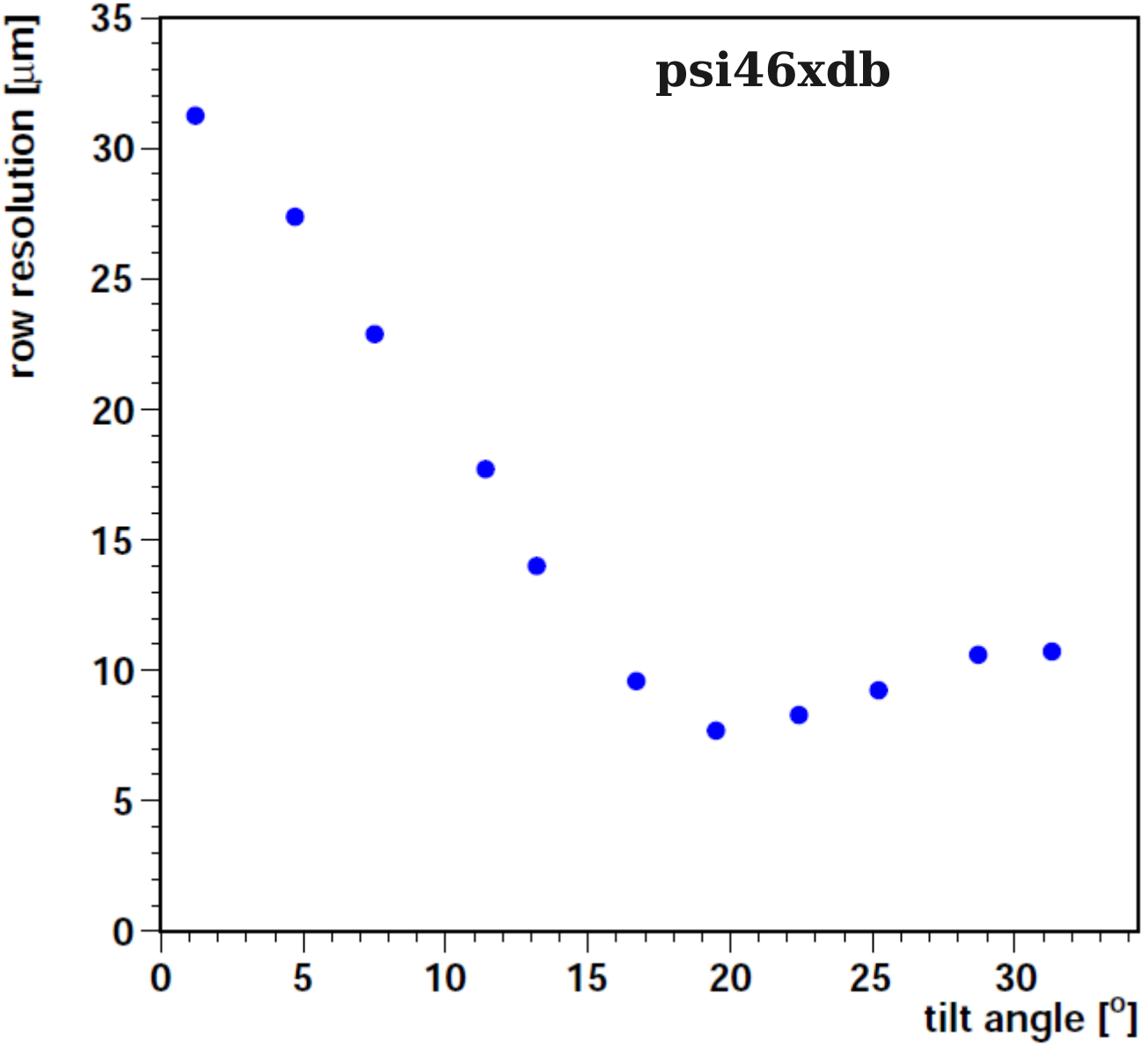
- Digital Chip 202, -150V, 20° tilt, Ia 30 mA
  - runs 5310-5384
- Threshold and delay adjusted together
- rows per cluster:
  - decreases with harder threshold

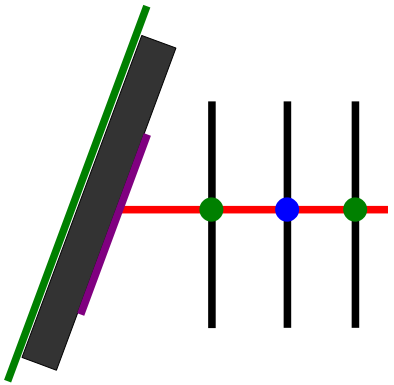
efficiency with 1.45 ke threshold



- digital chip 39
  - 19° tilt
  - **trim 29 (1.45 ke)**
  - run 5238
- fiducial region:
  - track 0.1 mm from edge
- <eff> = 99.8% over 10 minutes.

Row resolution vs tilt angle

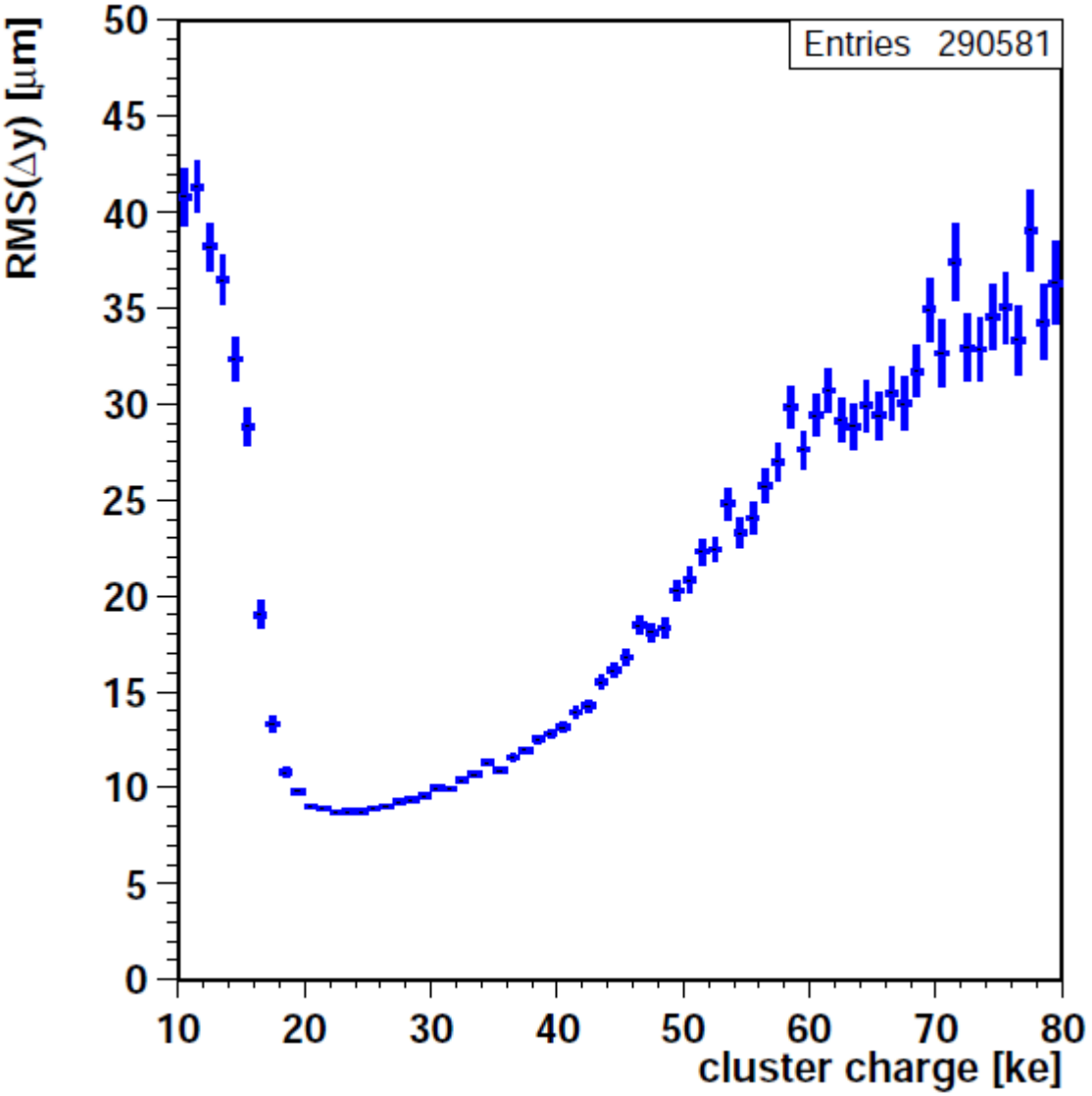


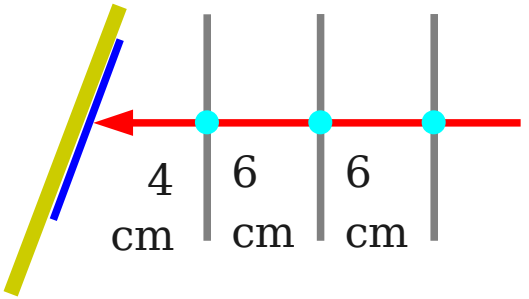


- Chip xdb2, 5.6 GeV, telescope extrapolation uncertainty subtracted.
- row pixels = 100 μm.
- At 0°:
  - σ = 100 / √12 = 29 μm
- Optimal angle 19.5°:
  - σ = 7 μm.
- Similar to psi46

row resolution vs cluster charge

dig202, runs 4732-4740, 5.6 GeV, 20° tilt





- 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