

Beam test with irradiated digital ROCs first results

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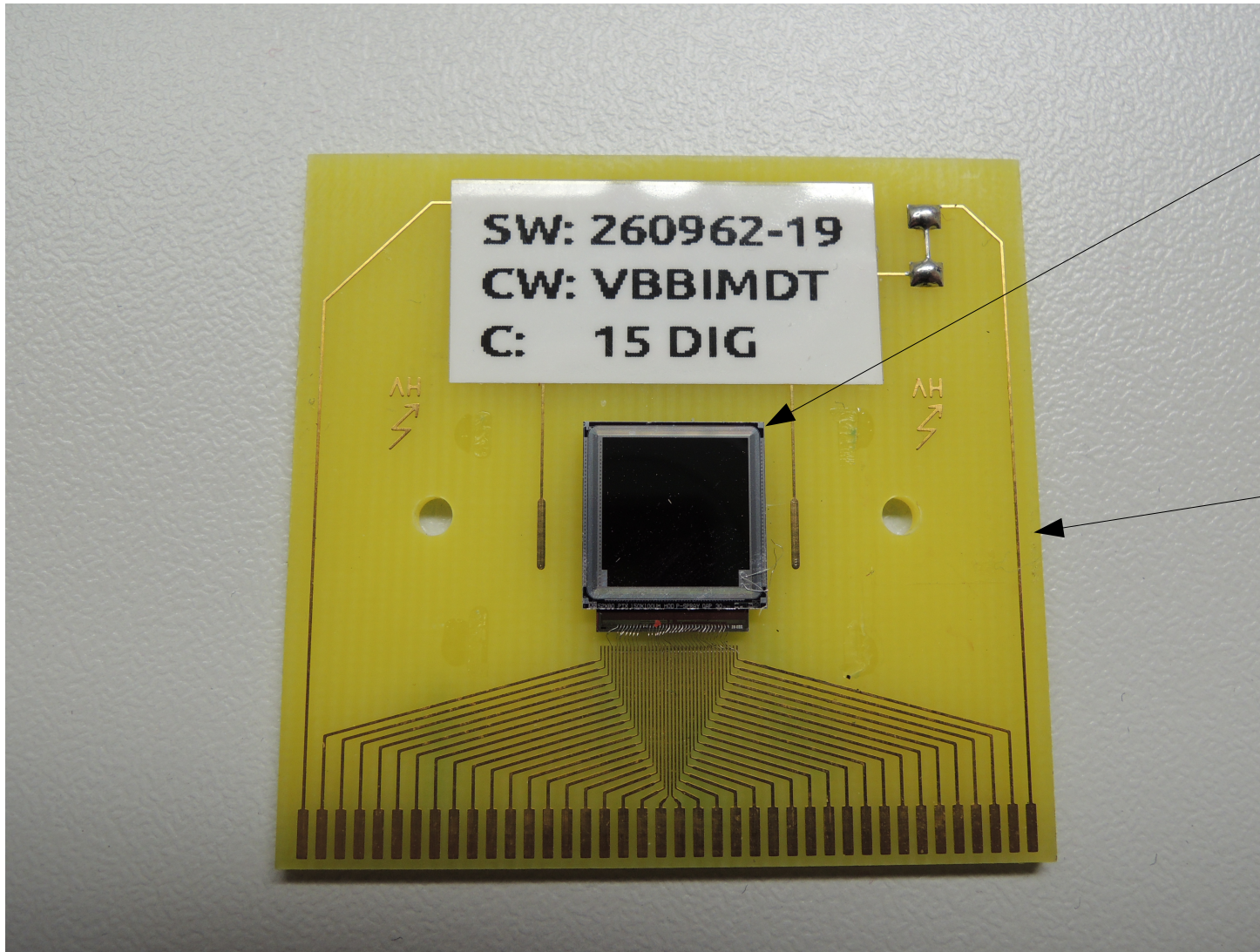
DESY and Uni HH

Hamburg CMS Tracker Upgrade meeting, 12.4.2013



- irradiation at CERN PS:
Oct 28-30, 2012
- beam test at DESY T21:
April 1-7, 2013
 - cooling
 - first results

CMS pixel single chip module



- **Single chip module:**
 - **Si: $10 \times 10 \text{ mm}^2$**
 - **Indium bump bonded at PSI**
 - **Glued and wire bonded to carrier printed circuit board**
 - **PCB: $40 \times 40 \text{ mm}^2$**

PCB with minimal metal (activation)

CERN PS irradiation

- CERN PS IRRAD 1: 24 GeV protons
- **psi46dig chip 202 with sensor = sample 1785**
 - 29.10.2012, 9:26 – 16:00, **$F = 0.91 \cdot 10^{14}/\text{cm}^2$** ($\pm 7.4\%$)
 - **$D = 3 \text{ Mrad}$**
- **psi46dig chip 203 with sensor = sample 1786**
 - 28./29.10.2012, 17:05 – 8:45, $F = 2.27 \cdot 10^{14}/\text{cm}^2$
 - 29.10.2012, 9:26 – 16:00, $F = 0.91 \cdot 10^{14}/\text{cm}^2$
 - 30.10.2012, 9:27 – 12:52, $F = 0.60 \cdot 10^{14}/\text{cm}^2$
 - total **$F = 3.77 \cdot 10^{14}/\text{cm}^2$** ($\pm 7.6\%$)
 - **$D = 13 \text{ Mrad}$**
- stored at -20°C

<https://irradiation.web.cern.ch/irradiation/Dosimeter/Sets-2012.htm>

Tracker radiation dose

Layer 1: 1 MGy

Layer 2: 400 kGy

Layer 3: 200 kGy

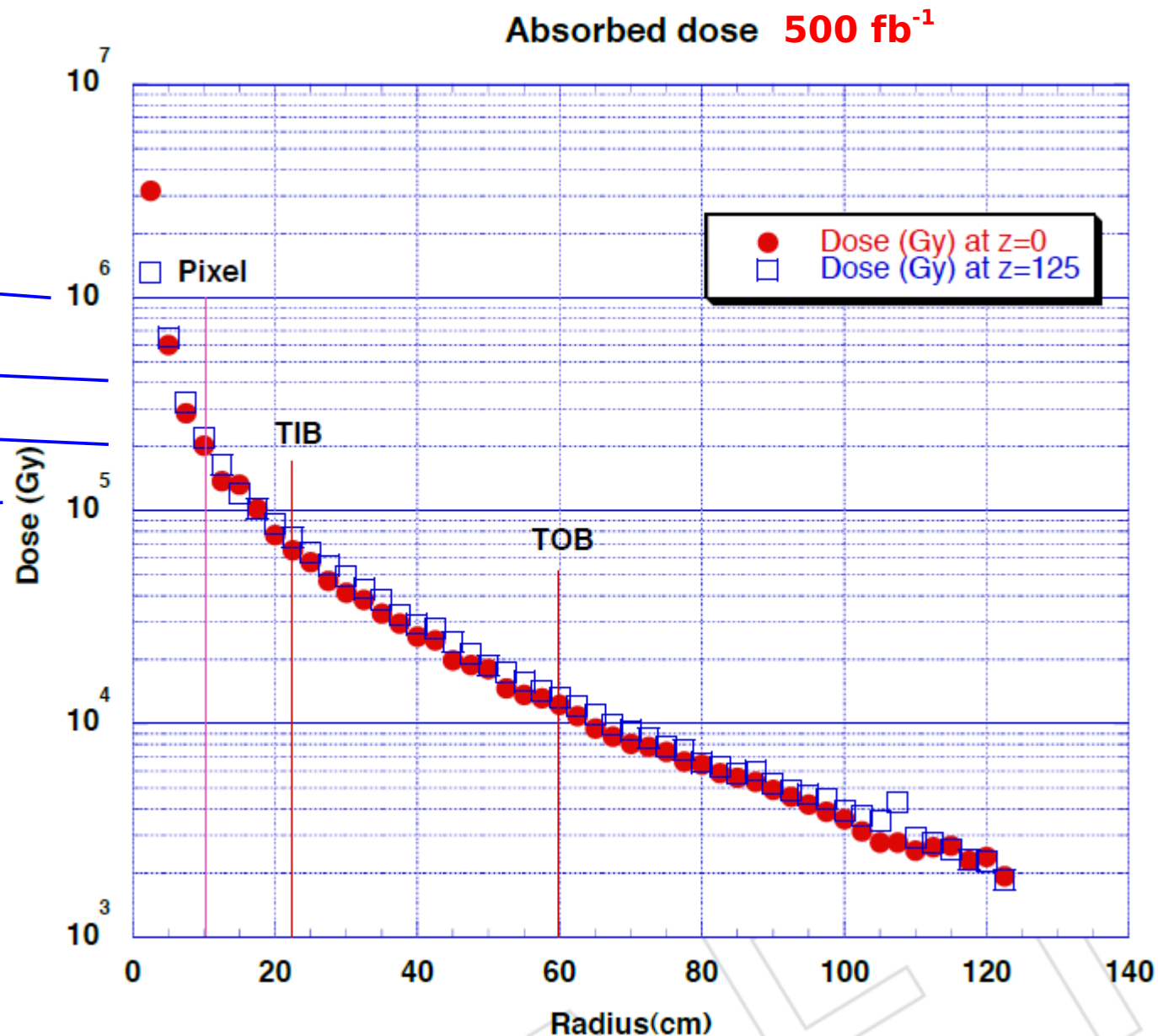
Layer 4: 150 kGy

100 kGy = 10 MRad

Fluence:

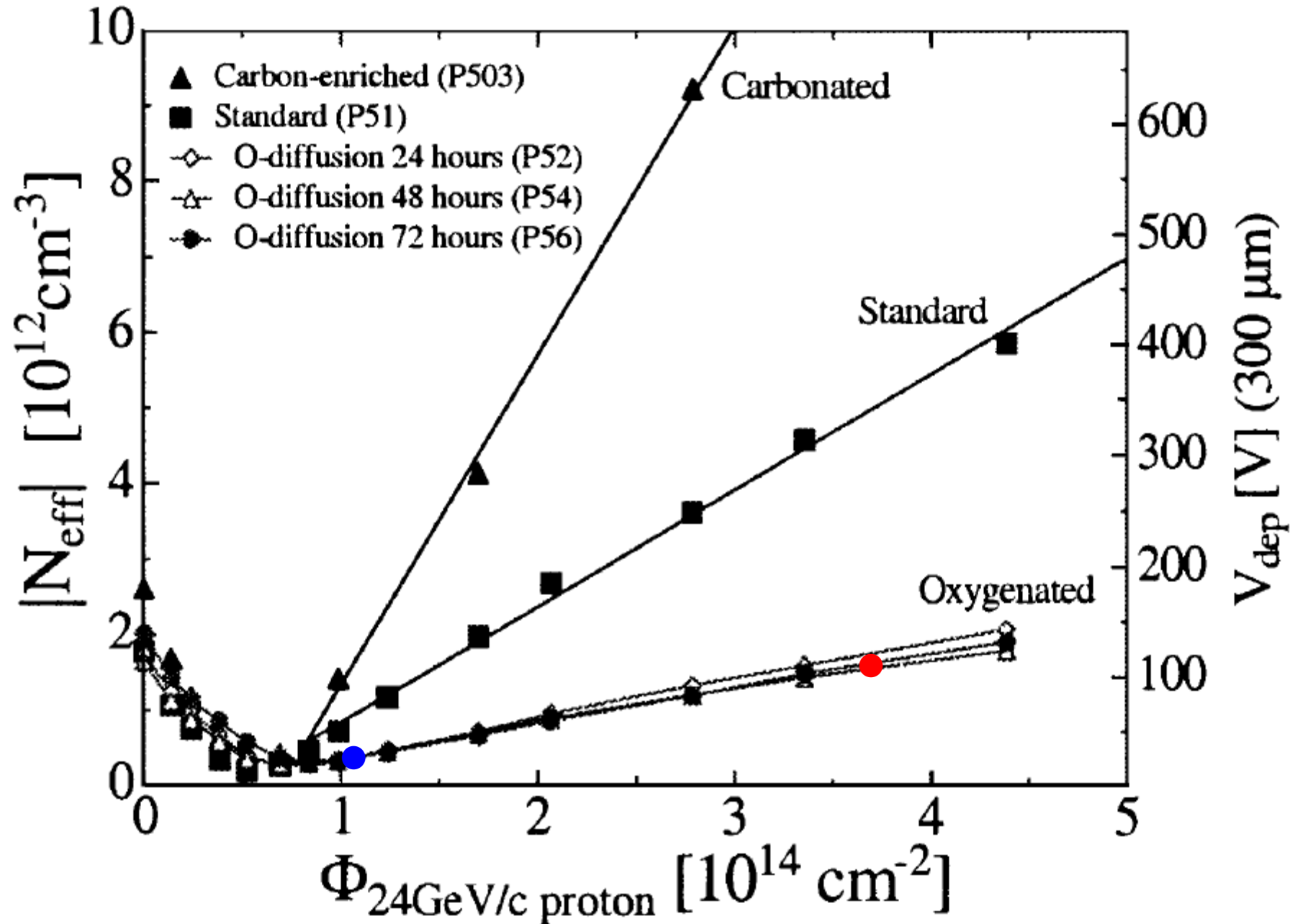
$3 \cdot 10^{13}/\text{cm}^2$ mips

≈ 1 MRad



Pixel upgrade TDR 2012

silicon depletion voltage vs p fluence



G. Lindstroem NIM A 512 (2003) 30

CMS pixel test beam team April 2013

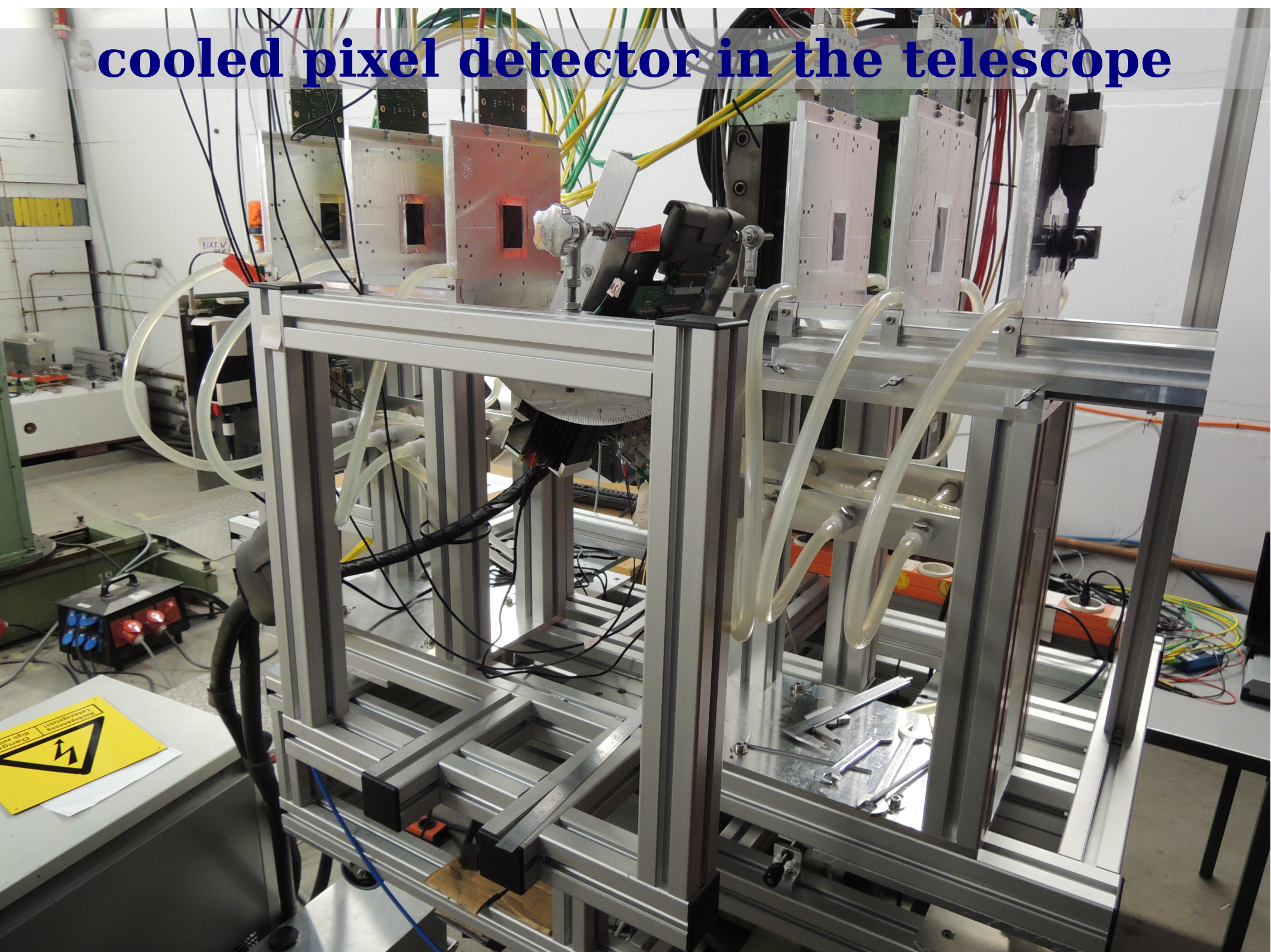


**chiller
with
ethanol
from
Hermes**

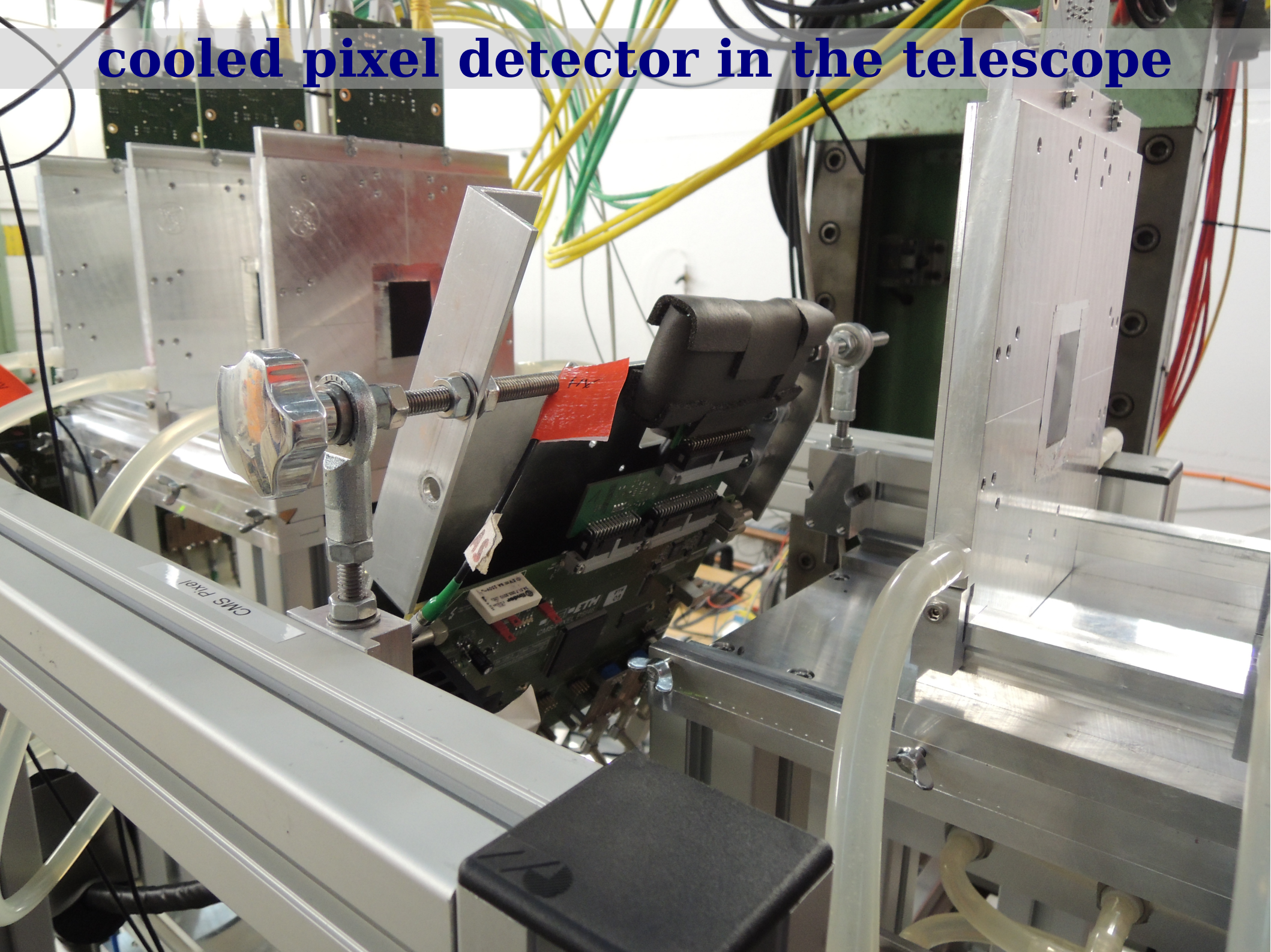
**thanks to
Volker
Prah**



cooled pixel detector in the telescope



cooled pixel detector in the telescope



cooled single chip pixel detector

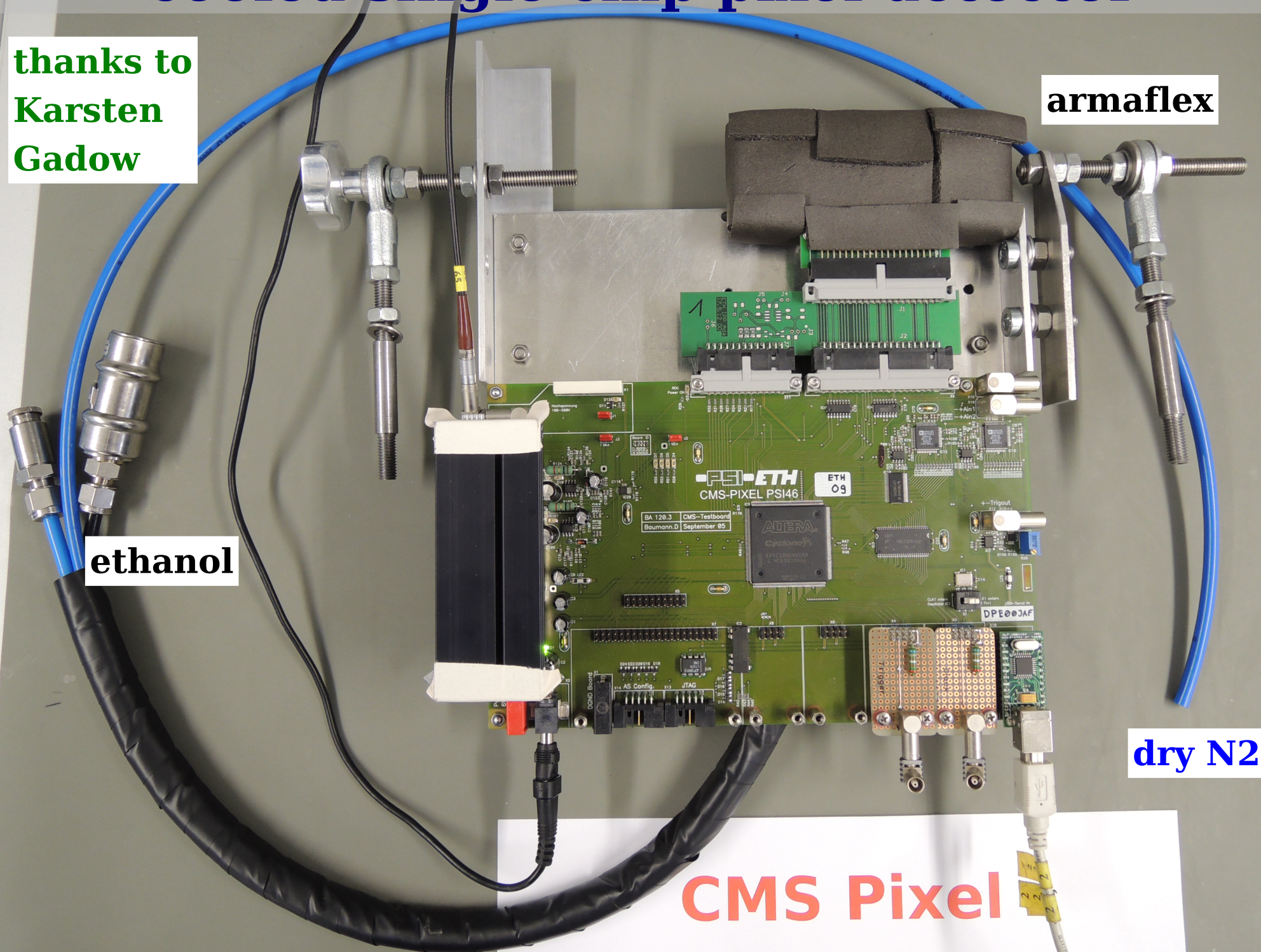
thanks to
Karsten
Gadow

armaflex

ethanol

dry N2

CMS Pixel



Beam test program

- fixed: 4.4 GeV, ~ 600 Hz, Mimosa threshold 6
- irradiated psi46dig chip 202:
 - no cooling
 - tilt 19° , later add turn 28°
 - bias scan at low threshold
 - threshold scan at high bias
- irradiated psi46dig chip 203:
 - cooling with chiller at -15°C
 - bias scan and threshold with tilt and turn
 - bias and tilt scan at low threshold, no turn

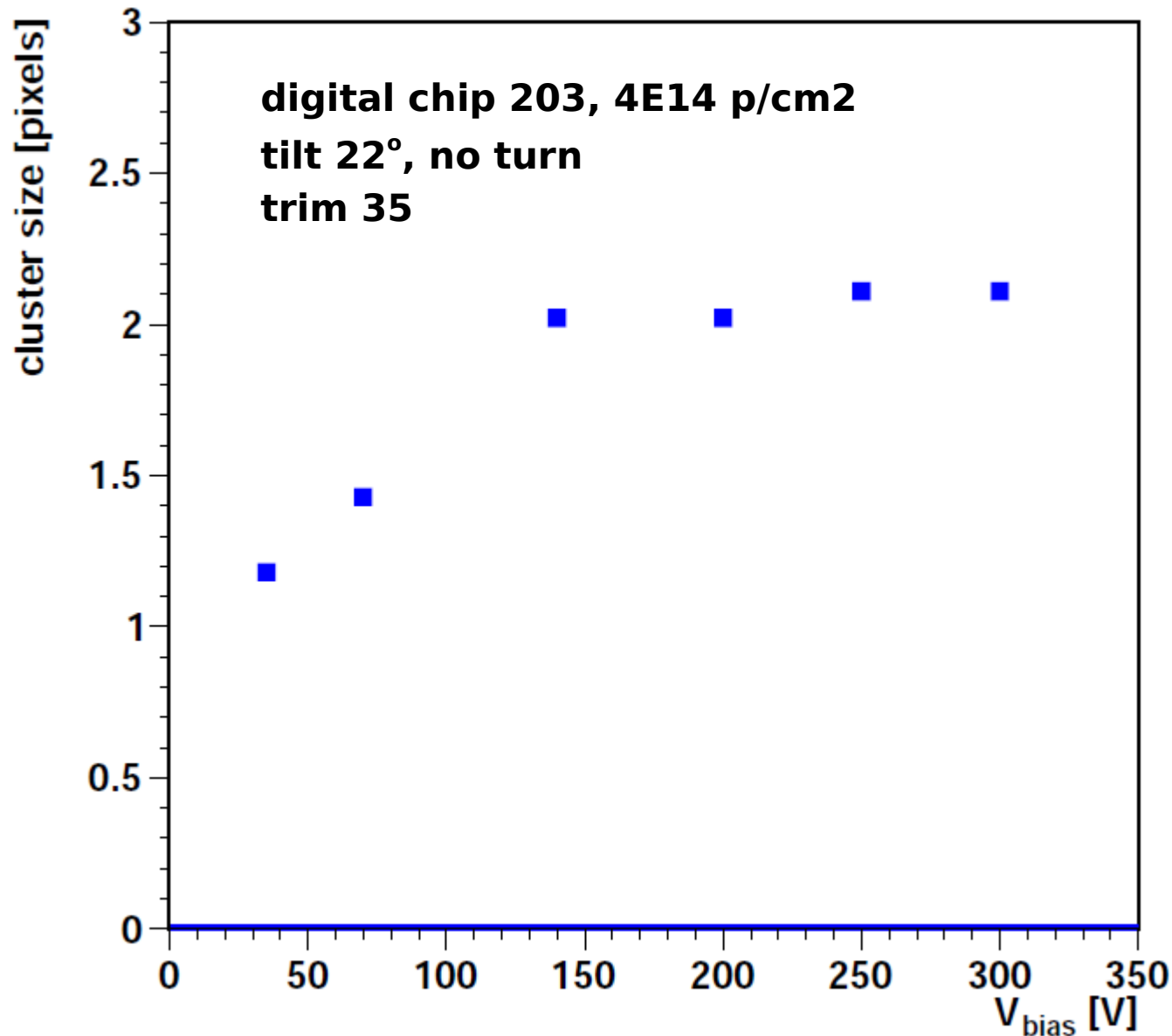
<https://docs.google.com/spreadsheet/ccc?>

[key=0AsHfEWLQILQVdDRodWt1dTVWRXkyd25NWlNNX25haUE#gid=0](https://docs.google.com/spreadsheet/ccc?key=0AsHfEWLQILQVdDRodWt1dTVWRXkyd25NWlNNX25haUE#gid=0)

Results from chip 203: $4E14$ p/cm²

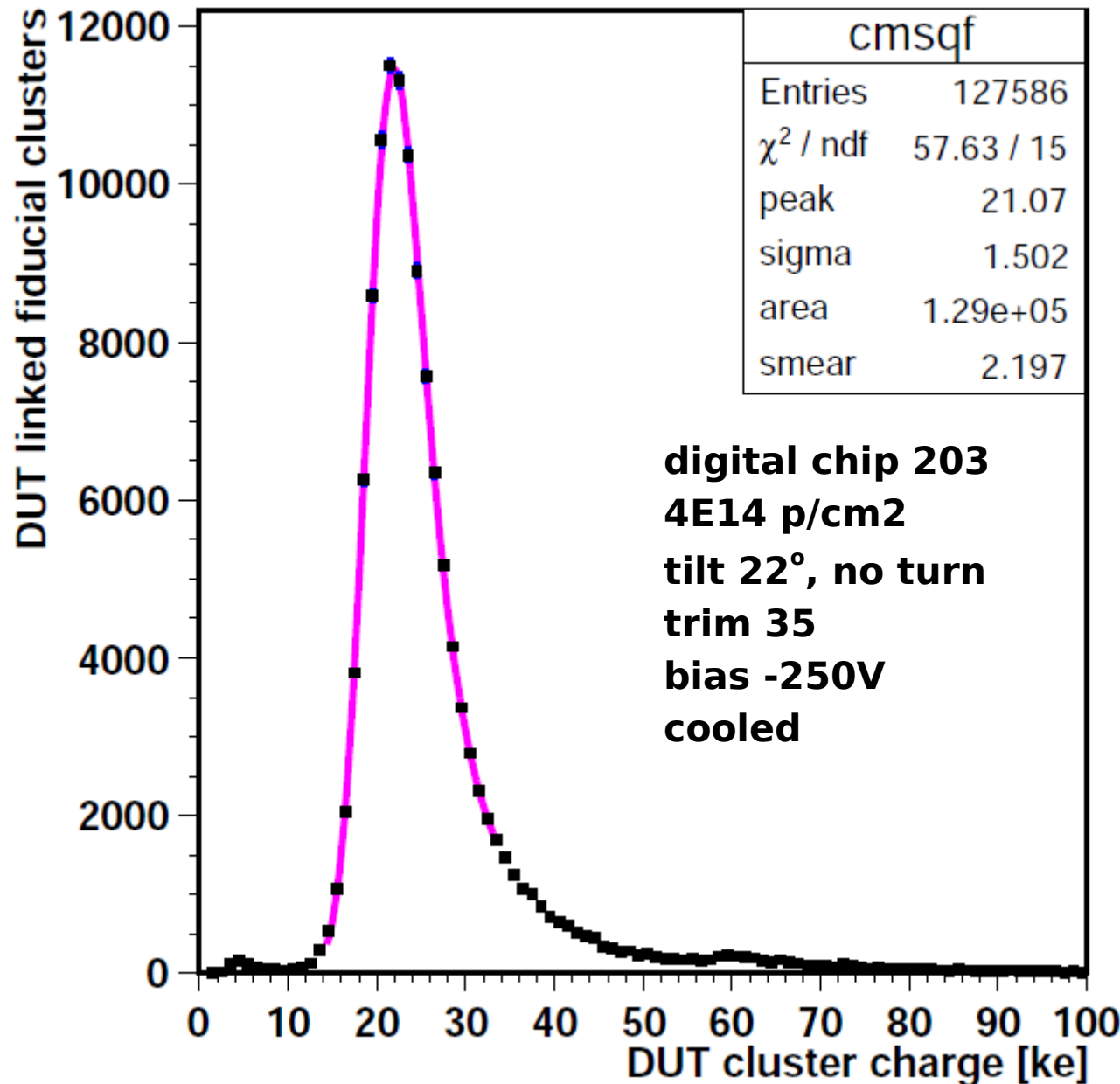
- depletion voltage
- resolution
- efficiency

cluster size vs bias voltage



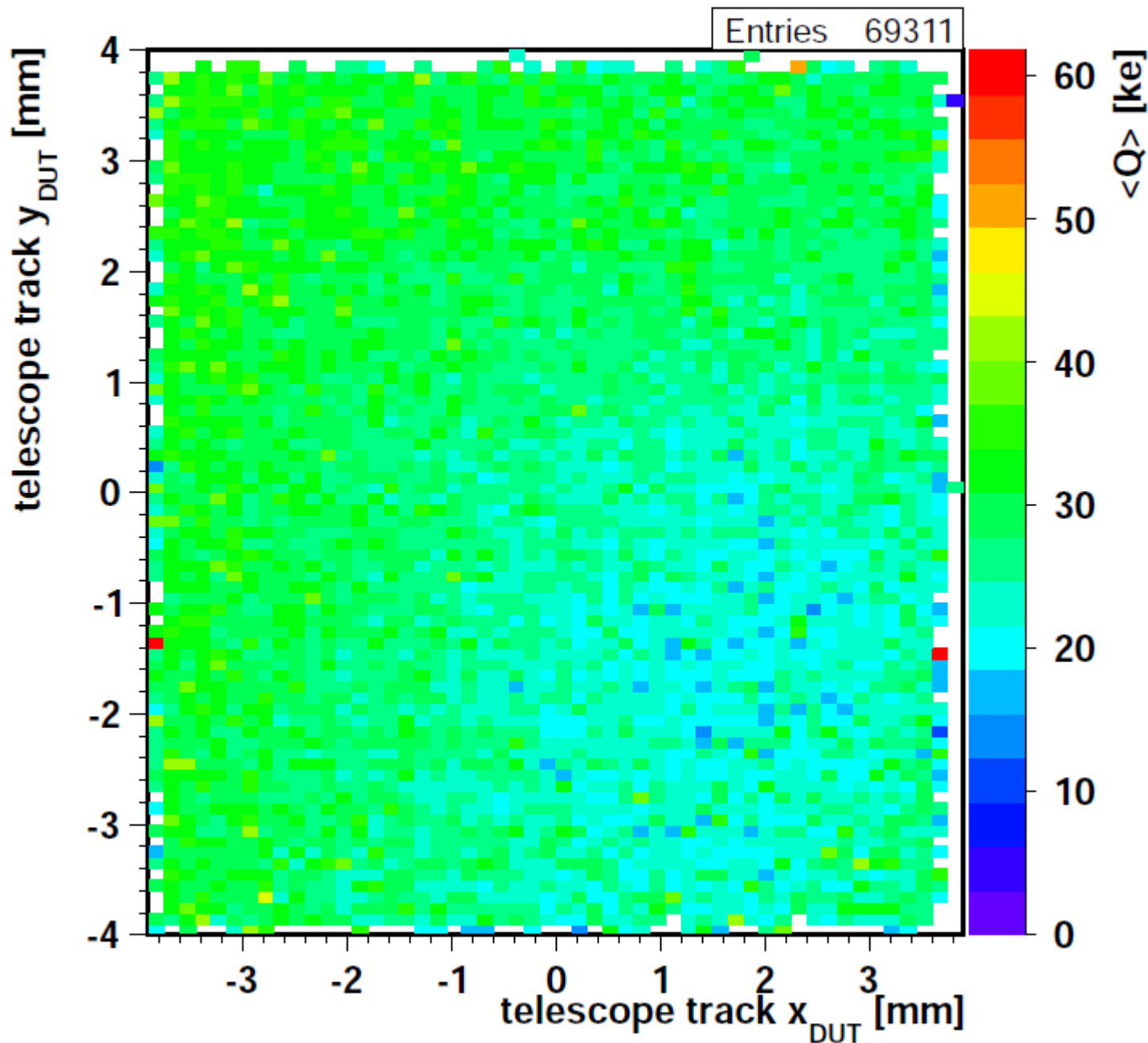
- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 35
 - 22° tilt, no turn
- full depletion
around 150 V

cluster charge distribution



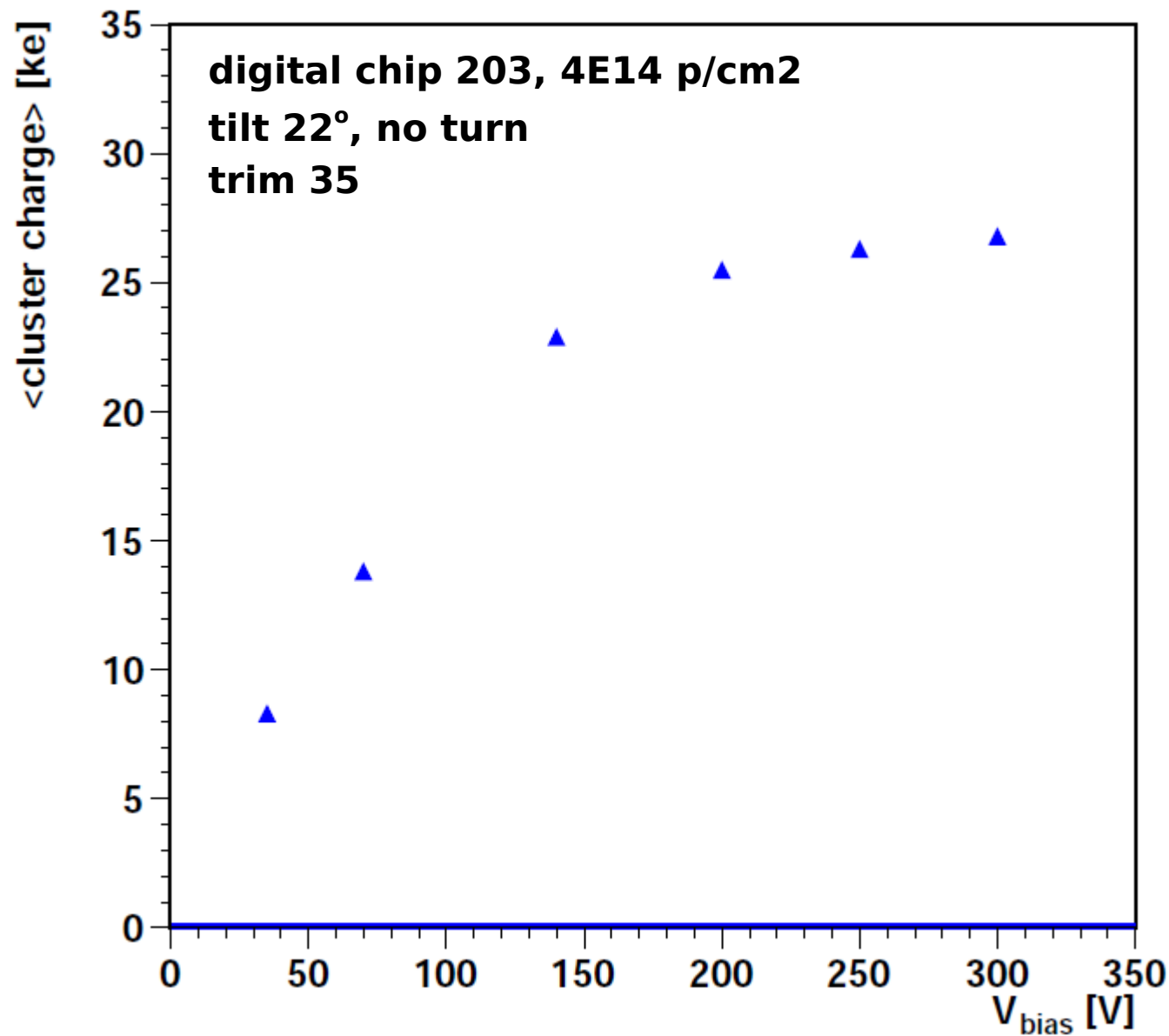
- digital chip 203:
 - 13 MRad
 - Ia 25 mA, trim 35
 - bias -250V, cooled
 - tilt 22°, no turn
- Gain calibration:
cooled, Weibull fit,
assume 50e/DAC
- Cluster charge
distribution fit by
Landau \otimes Gauss:
 - peak at 21.1 ke a
little low
 - width as before

charge map



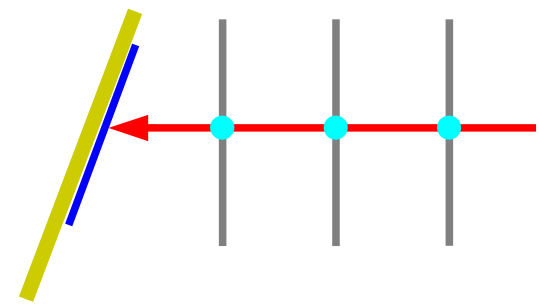
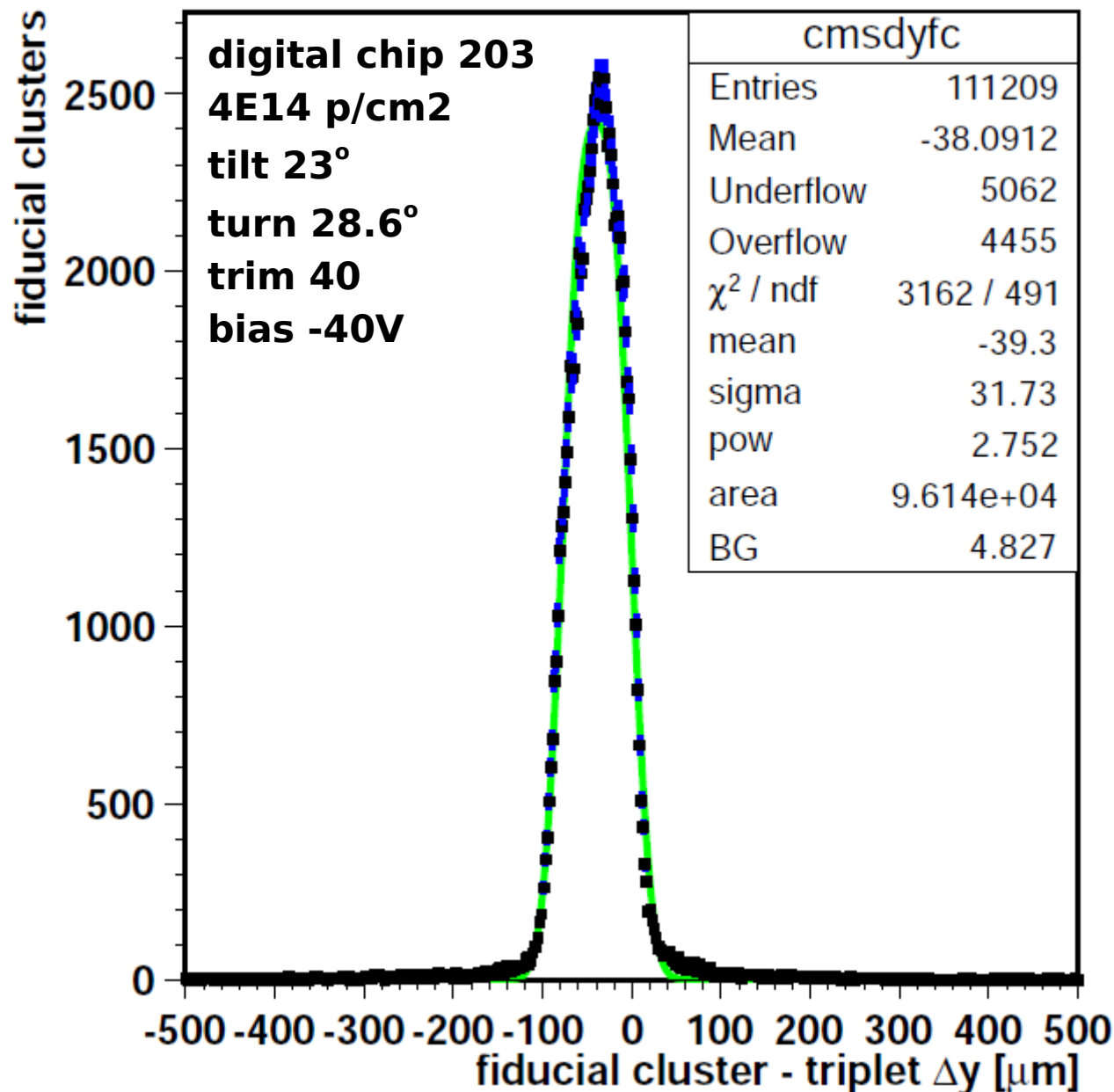
- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 40
 - 23° tilt, turn 29°
 - Weibull gain calibration
- valley in lower left quadrant:
 - sensor or ROC feature?

cluster charge vs bias voltage



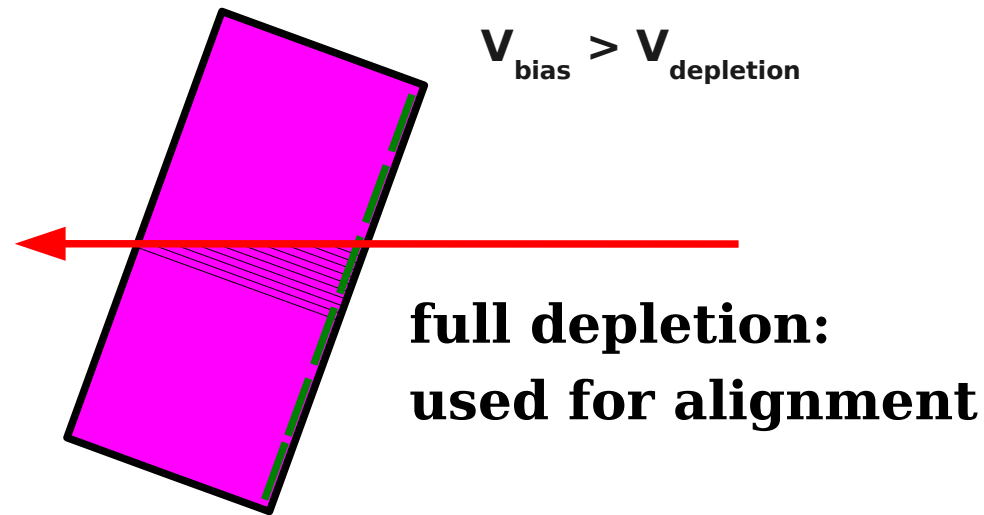
- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 35
 - 22° tilt, no turn
- full depletion?

track-cluster residuals

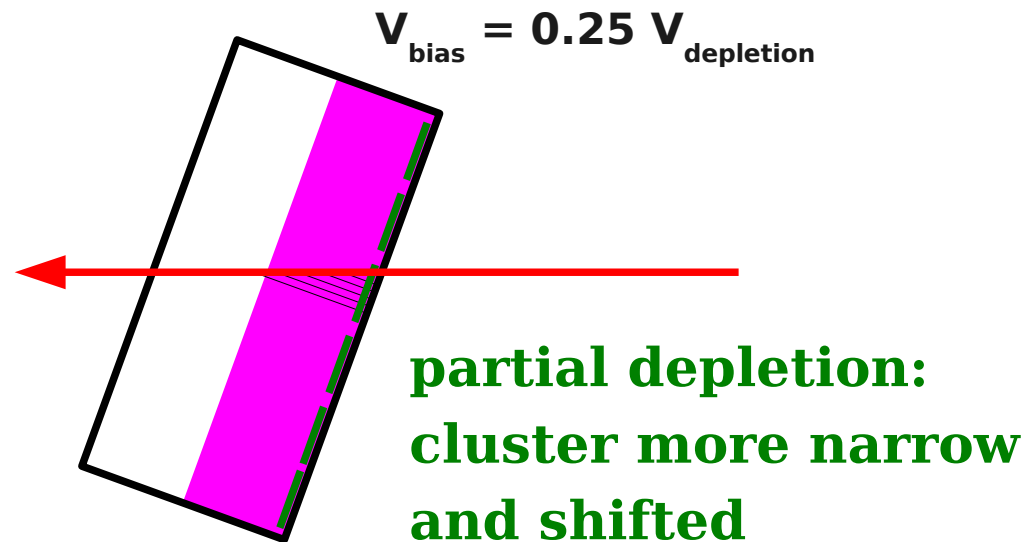


- digital chip 203:
 - 13 MRad
 - Ia 25 mA, trim 40
 - **bias -40V**
 - tilt 23°, turn 29°
- partial depletion and tilt:
 - cluster shifted

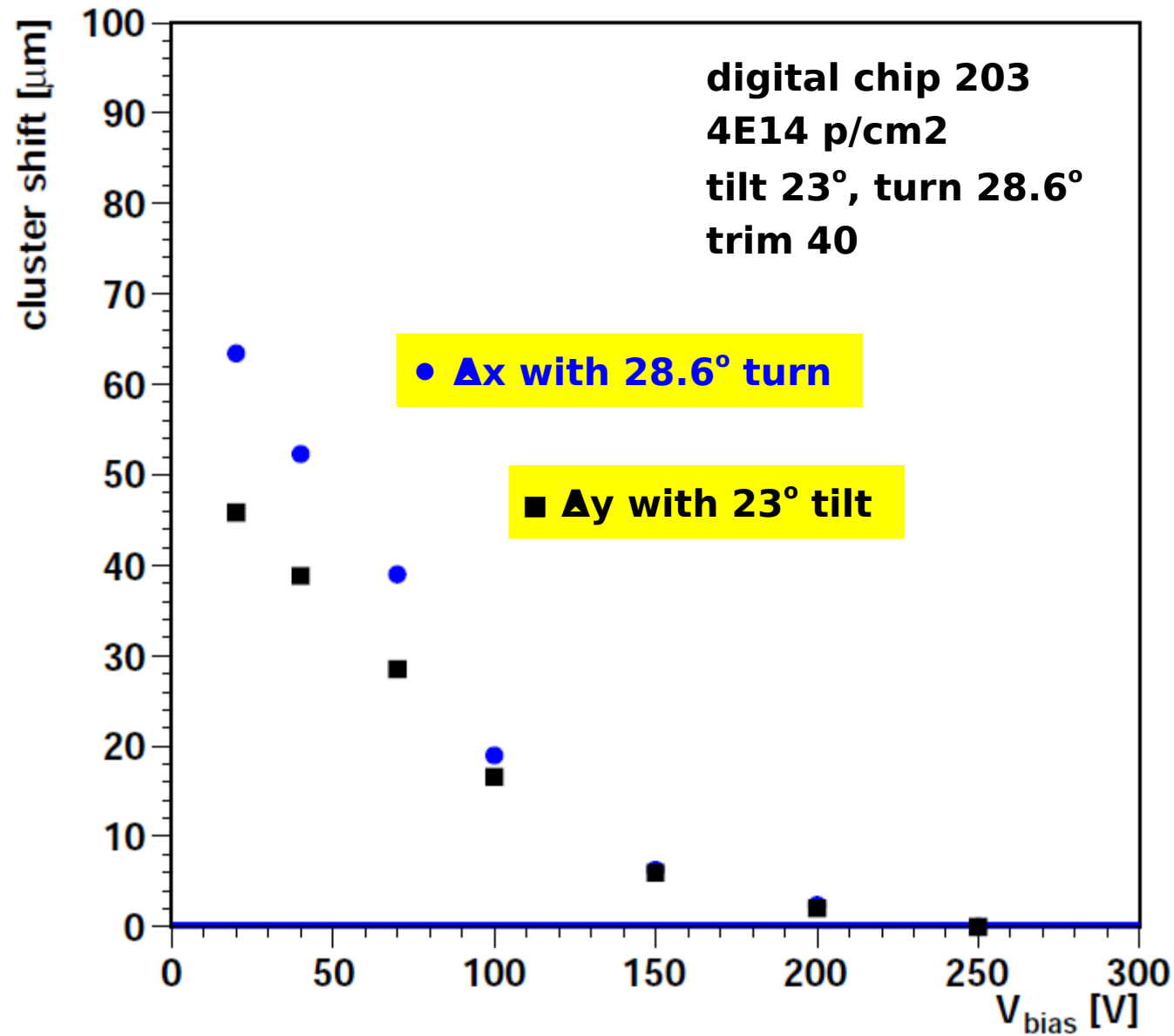
depletion depth



**irradiated:
type inversion,
depletion starts
from pixel side**



cluster shift vs bias voltage

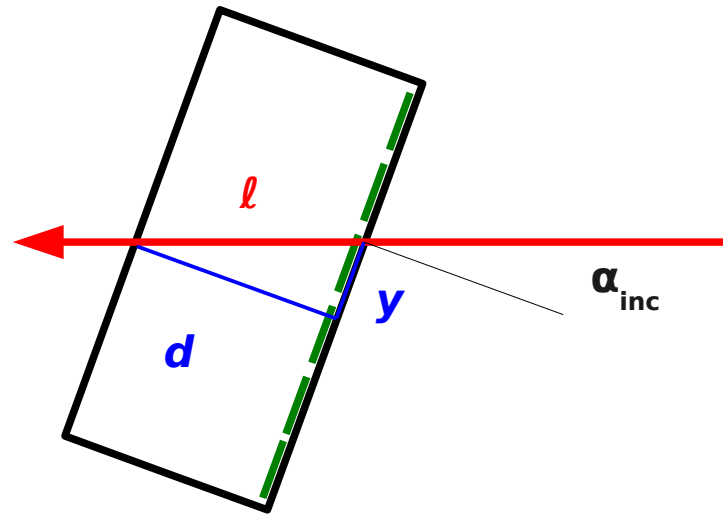


- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 40
 - 23° tilt, turn 29°
- partial depletion
 - effective depth changes
- and tilt:
 - cluster position gets shifted

to do

- use cluster shift as function of bias and angle
 - to map out the depletion depth
- check:
 - uniformity across the sensor
 - $d \sim \sqrt{V_{\text{bias}}}$

angles

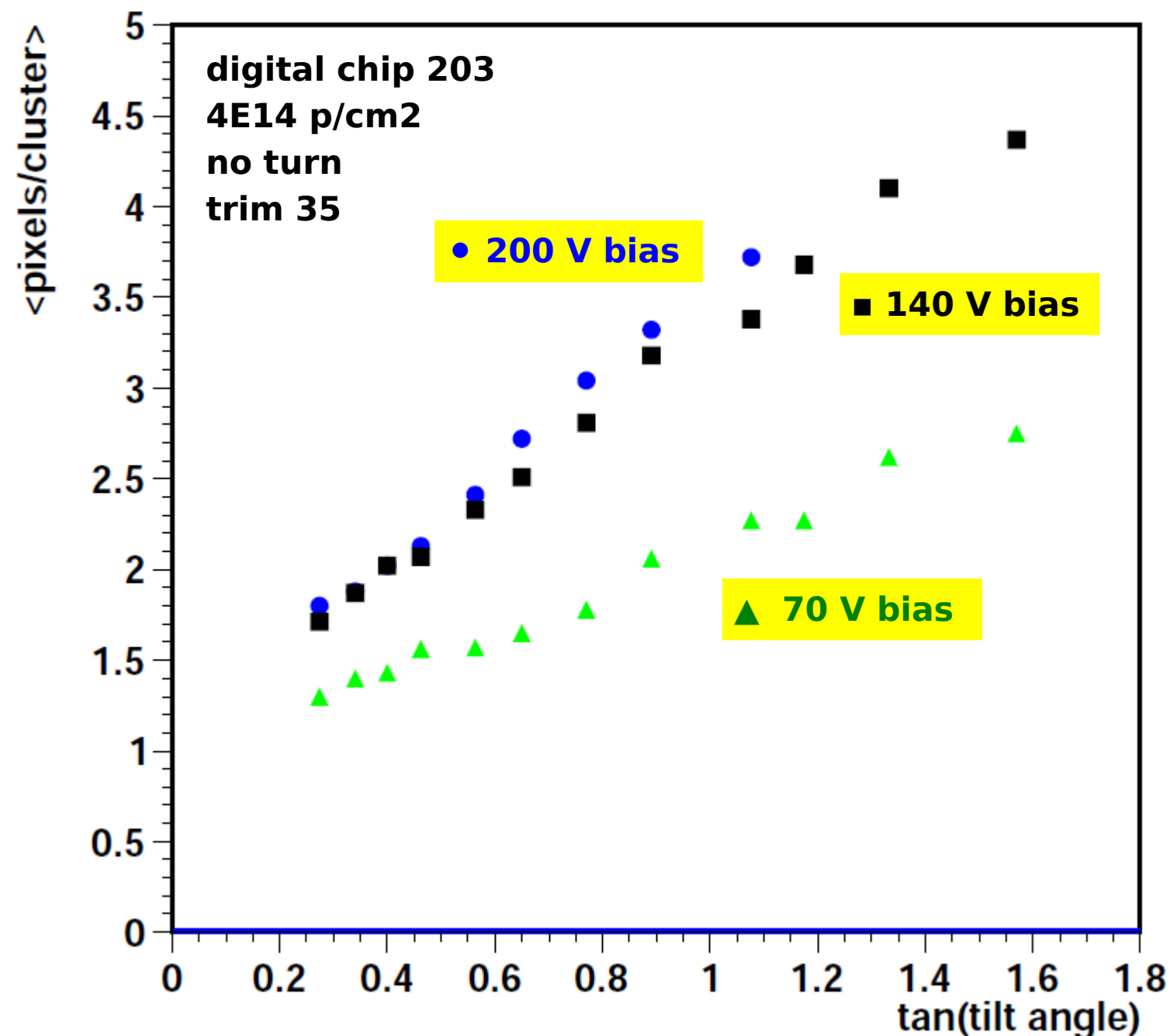


sensor thickness $d = 285 \mu\text{m}$

path length: $\ell = d / \cos\alpha$

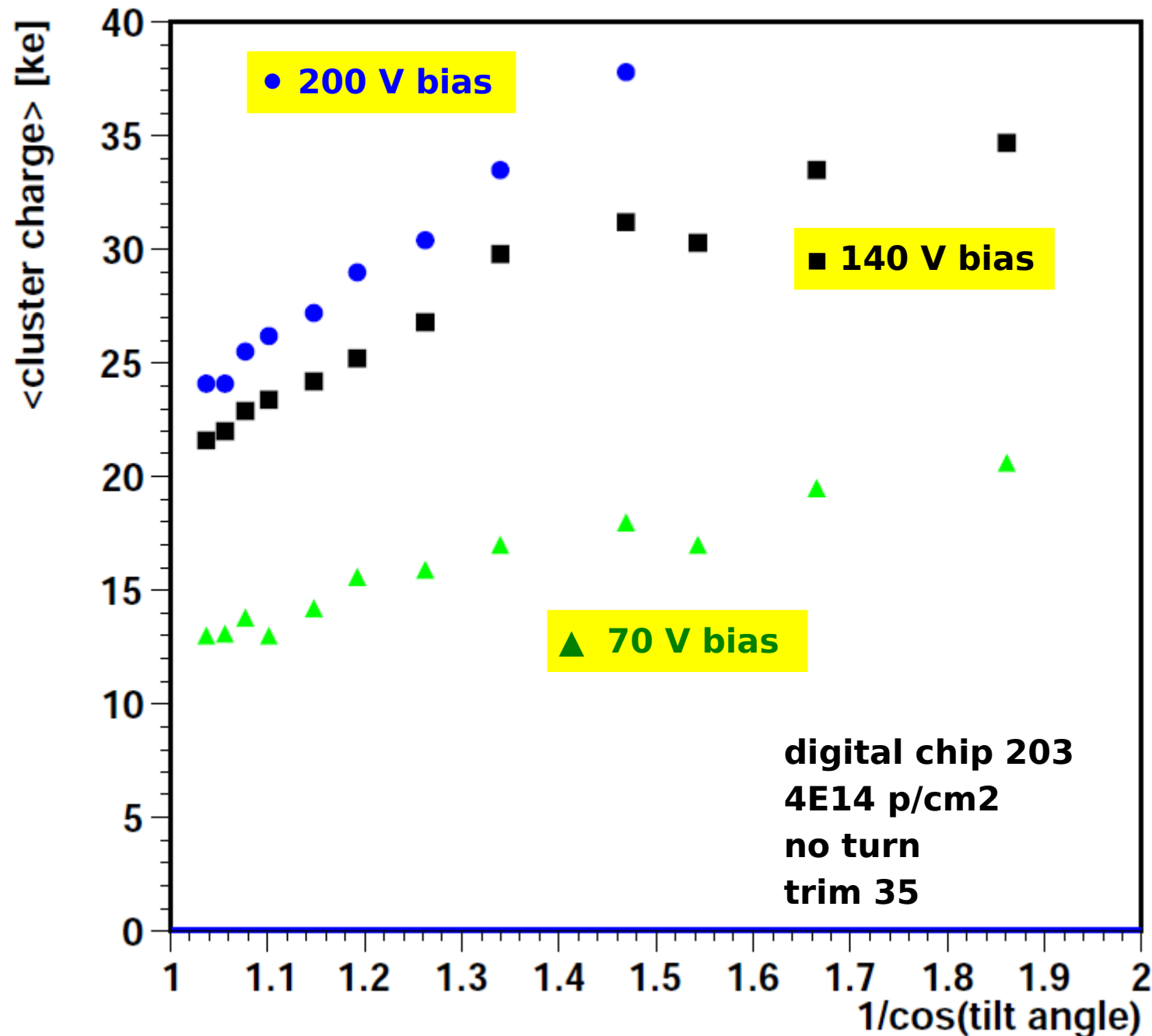
cluster width: $y = d \tan\alpha$

cluster size vs tilt angle and bias



- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 35
 - vary tilt, no turn
- cluster size scales with geometry:
 - $\sim \tan(\alpha_{\text{tilt}})$
- cluster size saturated at 140 V
 - full depletion

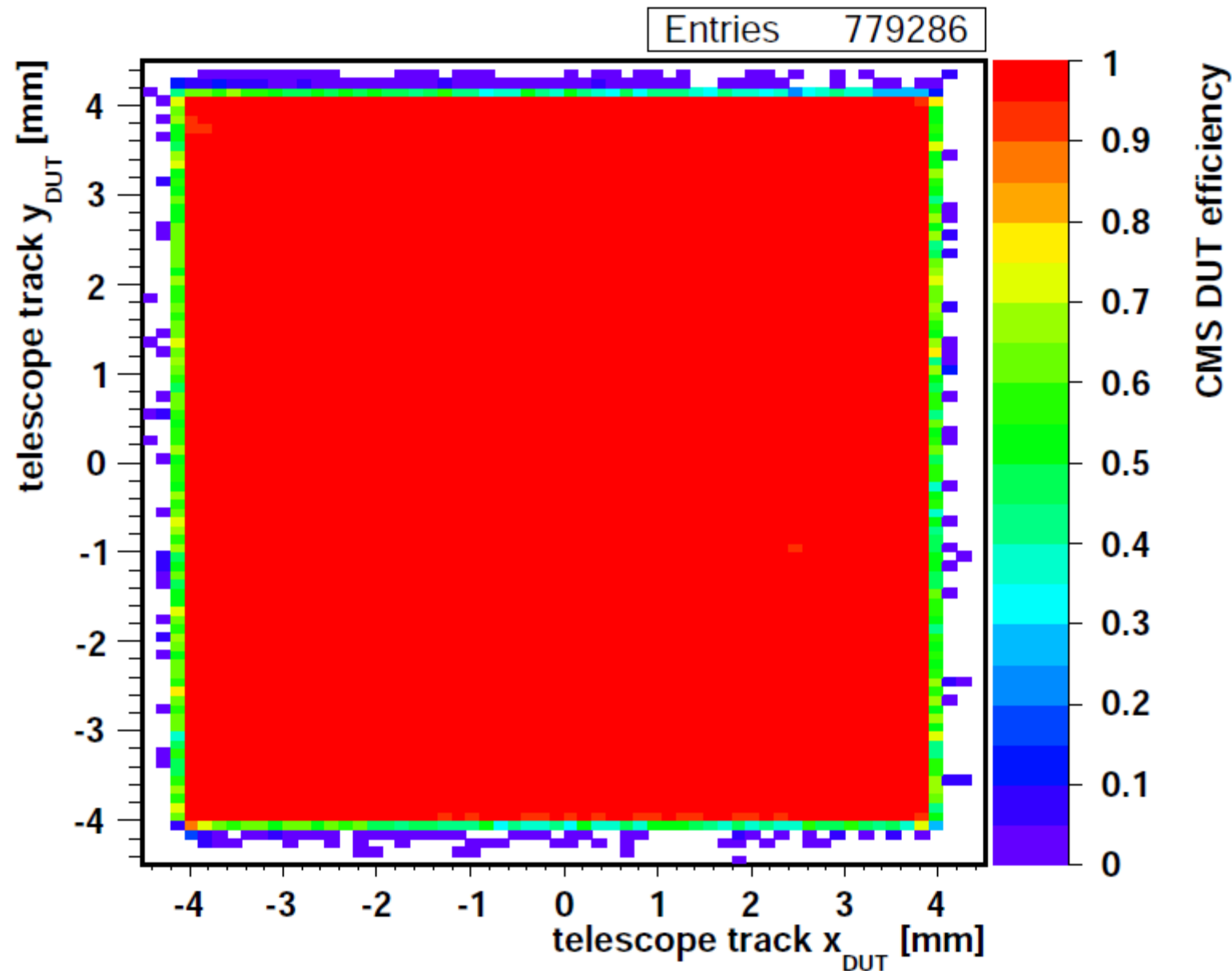
cluster charge vs tilt angle and bias



- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 35
 - vary tilt, no turn
- cluster charge scales with path length in silicon:
 - $\sim 1/\cos(\alpha_{\text{tilt}})$

efficiency map

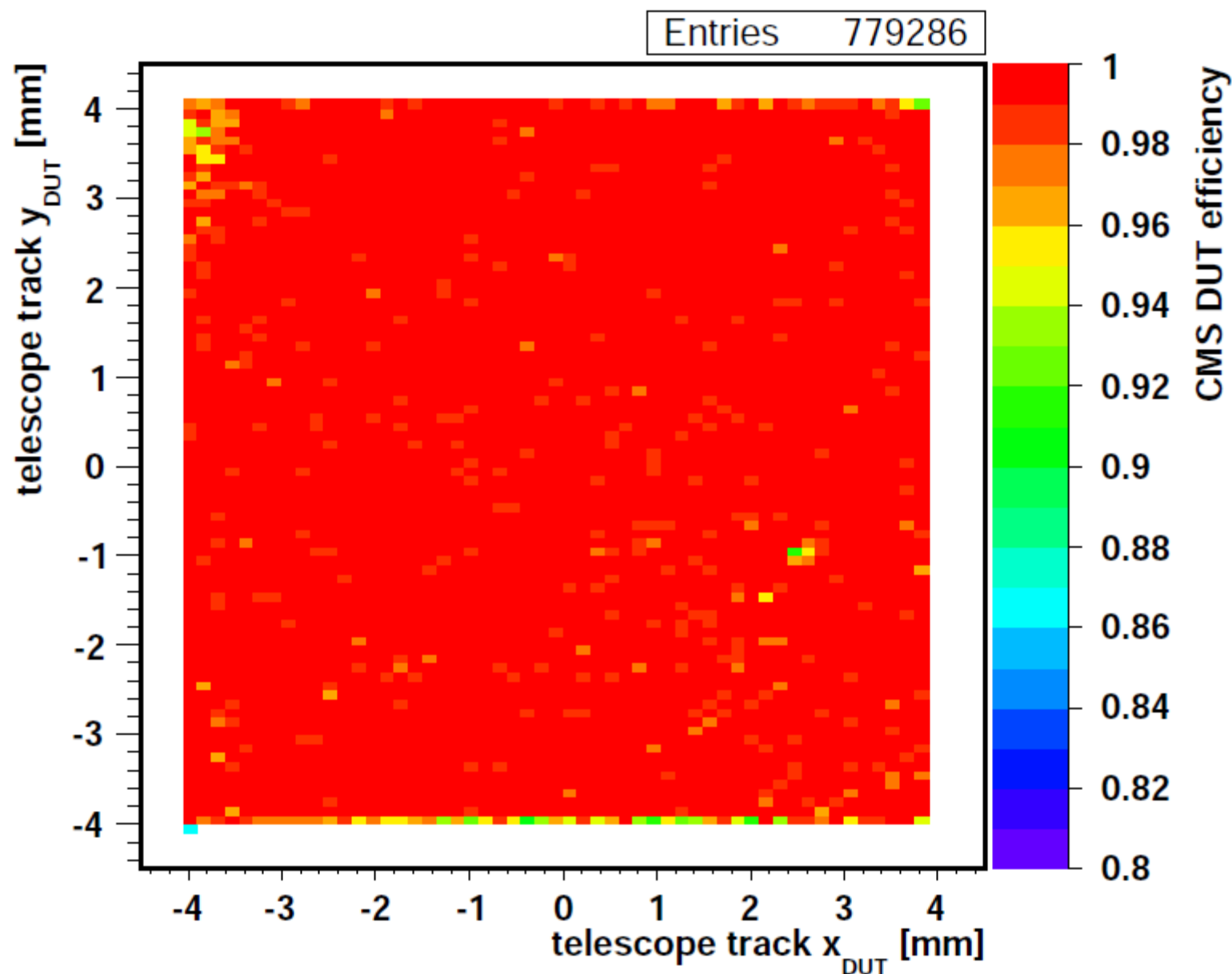
$\text{eff} = (\text{DUT linked clusters}) / (\text{telescope tracks with REF cluster})$



- digital chip 203
 - 13 MRad
 - I_A 25 mA
 - trim 35
 - tilted, cooled
- **99.8% in fiducial volume**

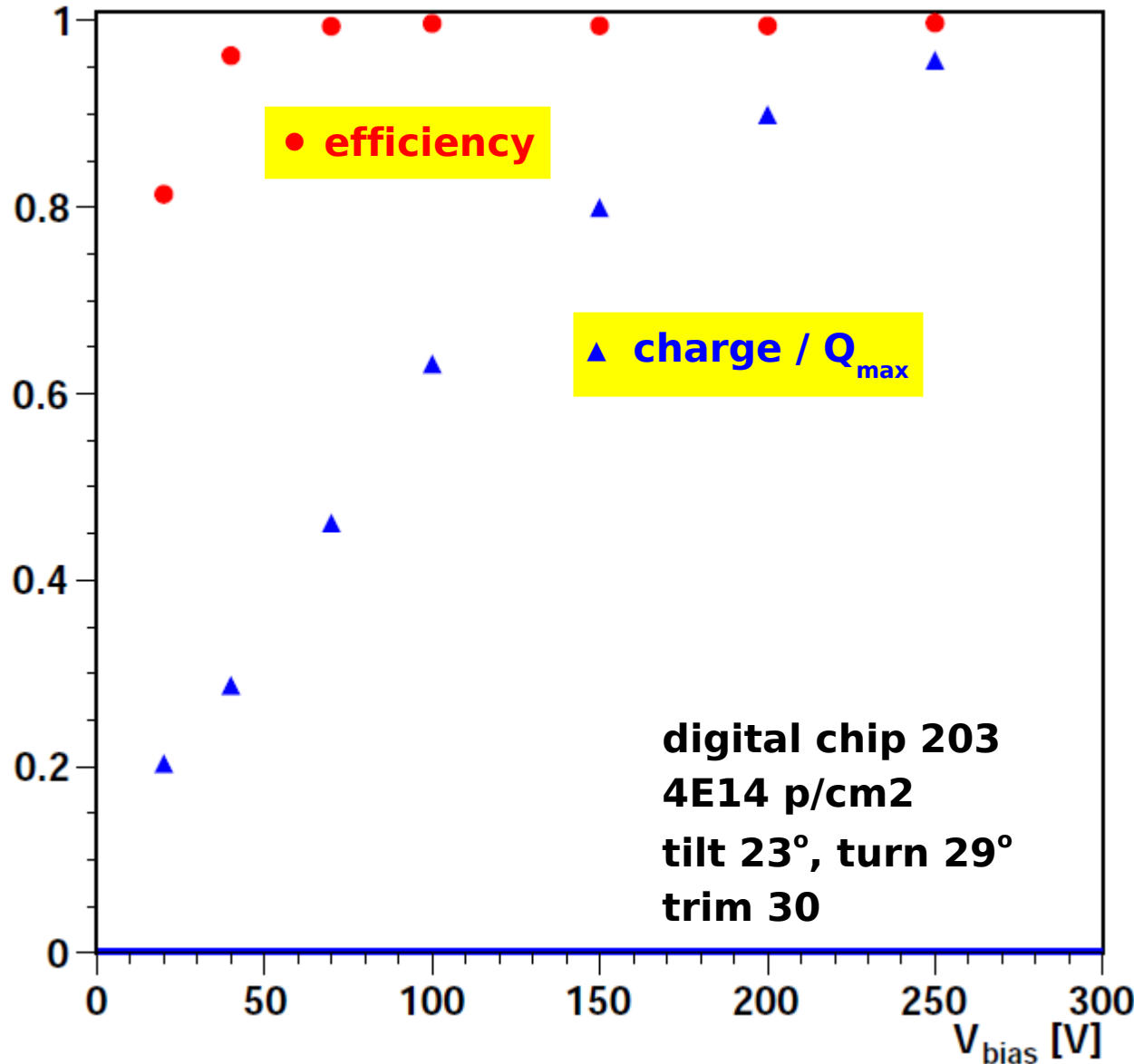
efficiency map (zoomed)

$\text{eff} = (\text{DUT linked clusters}) / (\text{telescope tracks with REF cluster})$



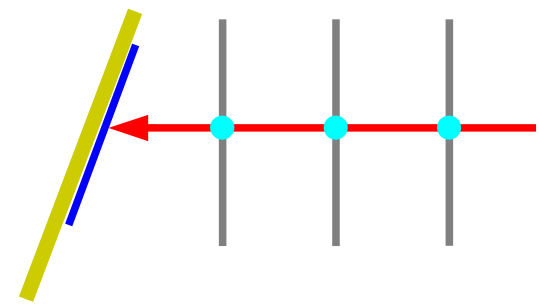
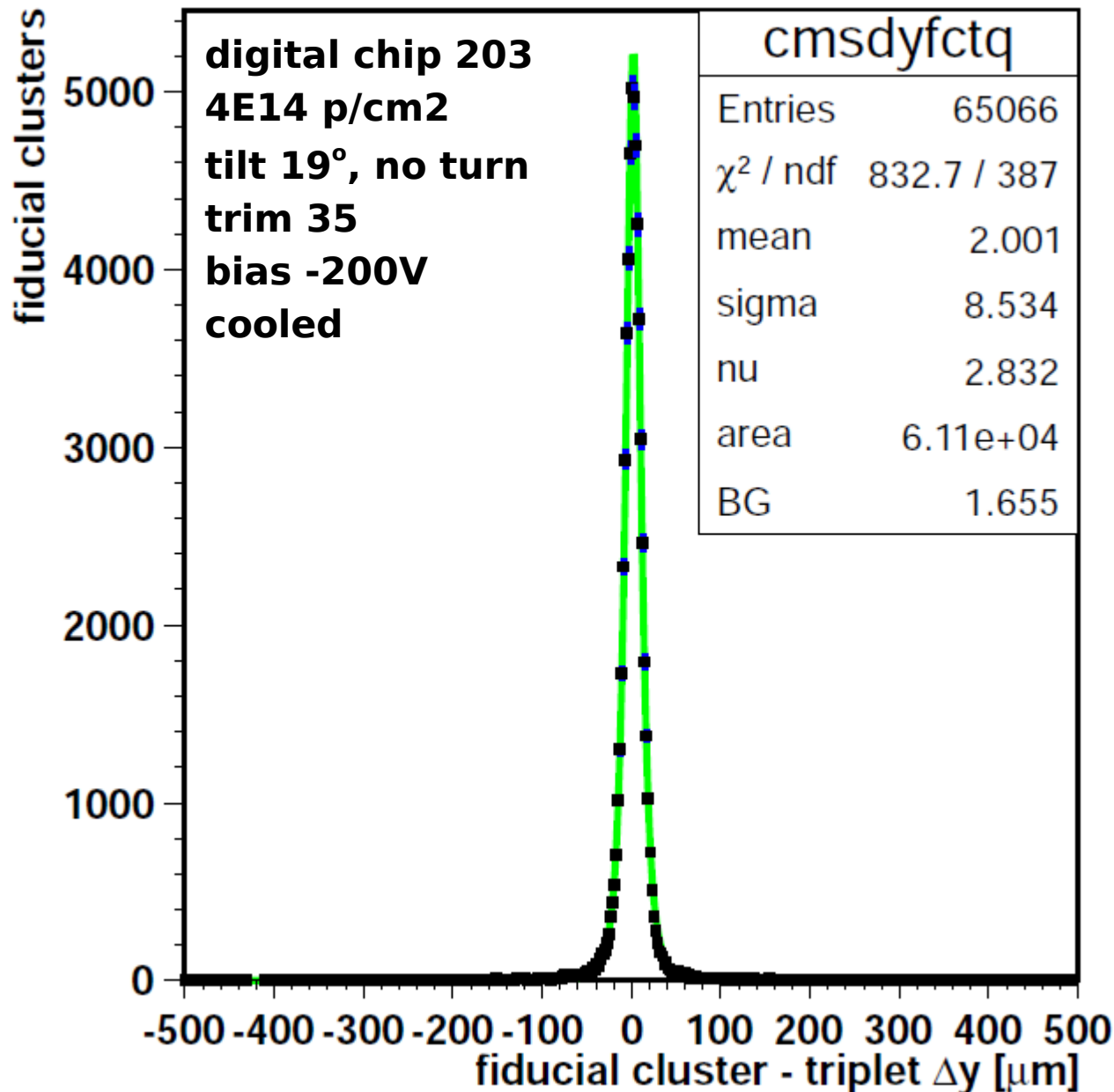
- digital chip 203
 - 13 MRad
 - I_A 25 mA
 - trim 35
 - tilted, cooled
- **99.8% in fiducial volume**

efficiency vs bias voltage



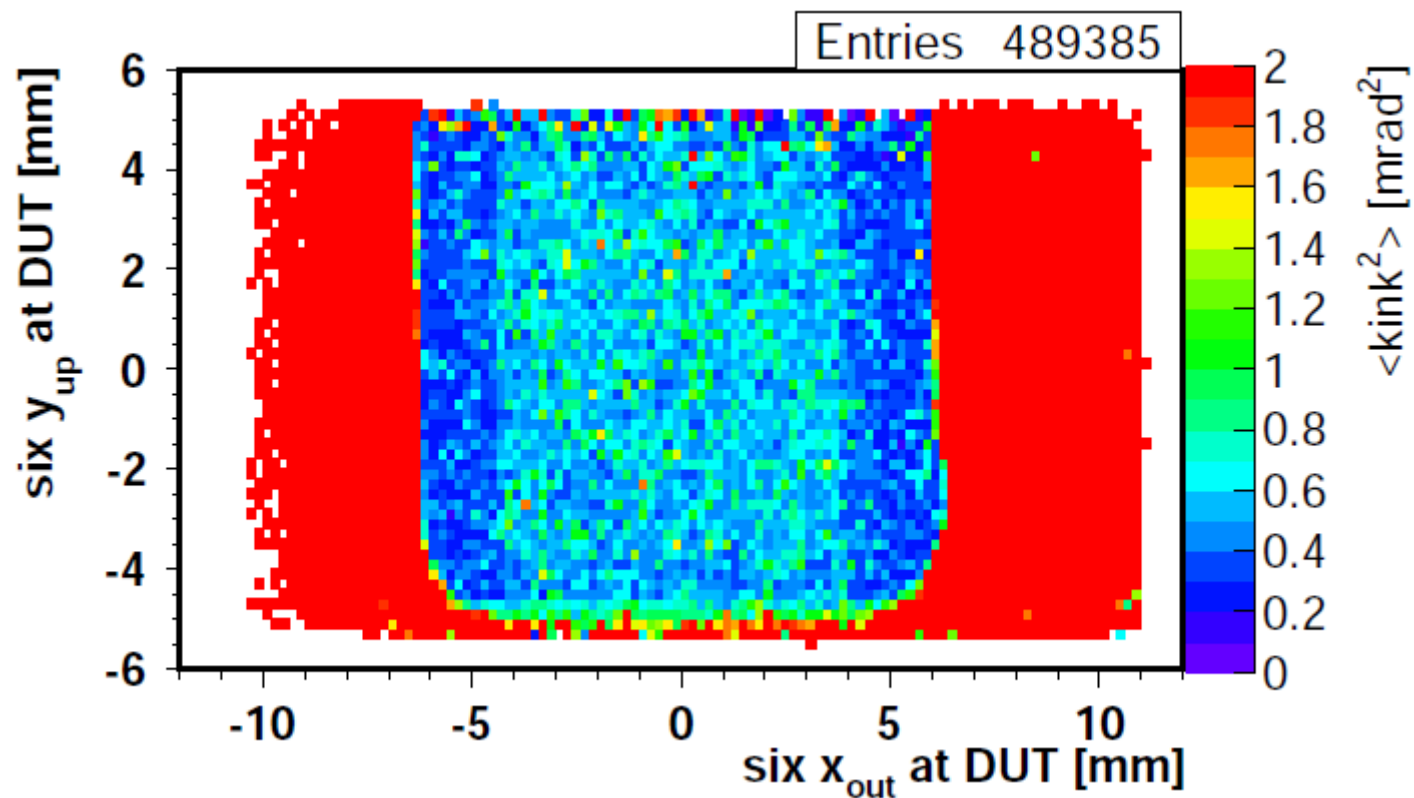
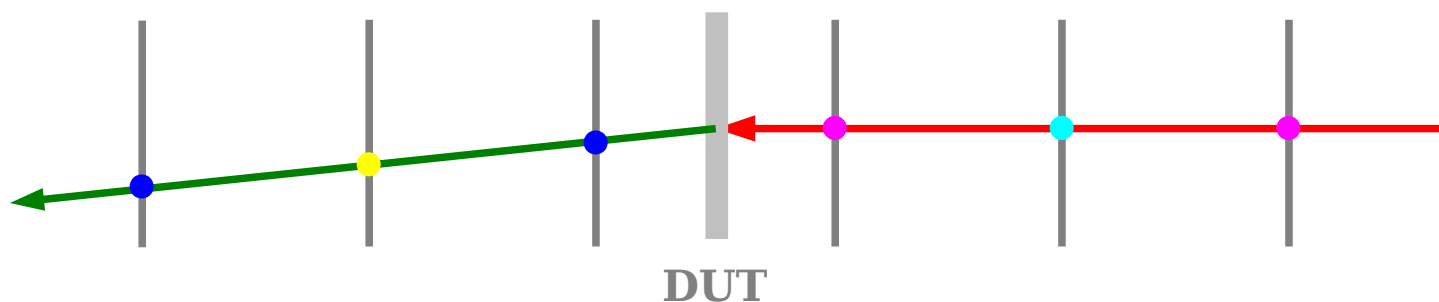
- psi46dig chip 203:
 - 13 MRad
 - Ia 25 mA
 - trim 40
 - tilt 23°, turn 29°
- fully efficient down to 70 V bias
 - half the charge is enough!

resolution



- digital chip 203:
 - 13 MRad
 - Ia 25 mA, trim 35
 - bias -200V, cooled
 - tilt 19°, no turn
- residual to track:
 - sigma 8.5 μm
 - subtract telescope resolution 4.6 μm
 - CMS pixel row resolution 7 μm
 - like before

DUT cooling material map



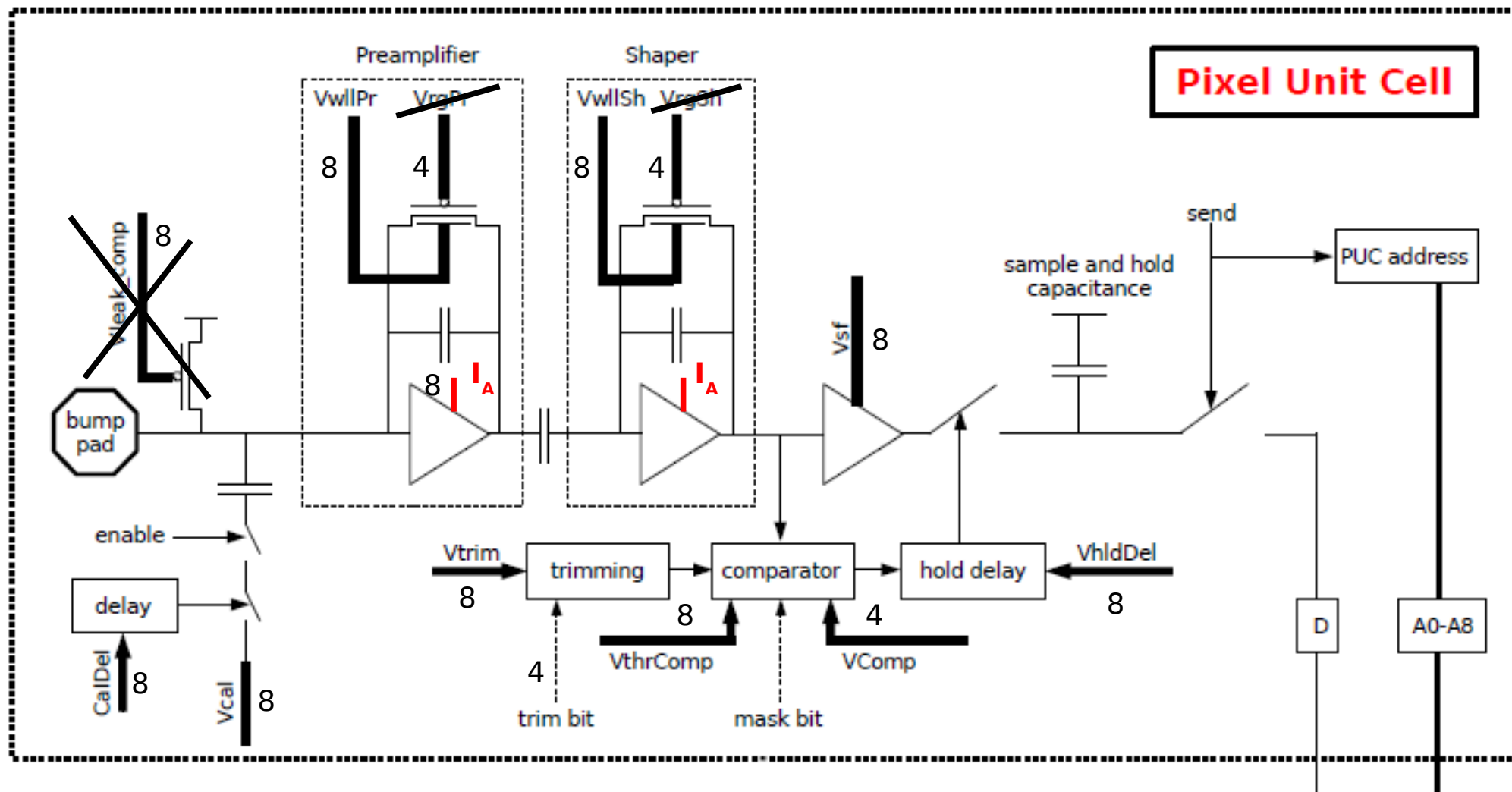
- scattering angle at the DUT
 - from upstream and downstream tracks
- Copper cooling block has ± 6 mm opening
- DUT on PCB visible

summary

- beam test with irradiated digital ROCs done
 - with cooling
- digital ROC after 13 Mrad ($4E14$ p/cm² = lifetime dose for layer 4):
 - depletion voltage about 140 V
 - fully efficient above 70 V (with low threshold)
 - similar resolution as unirradiated: 7 μ m
- next:
 - more analysis: chip202, resolution for partially depleted detectors
 - compare to pre-irradiation beam test (Aug and Sep 2012)
 - simulation
 - publish

Back up

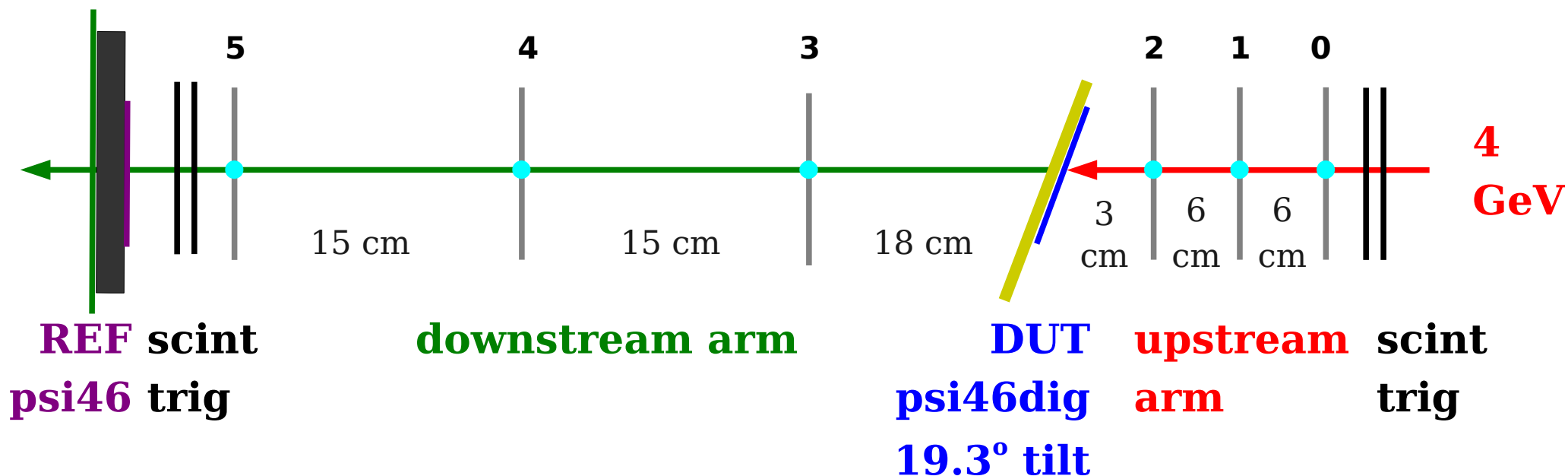
psi46dig pixel unit cell



adjustable by programmable DAC

supplied by analog current

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 $19.3^\circ = \text{atan}(100 \mu\text{m} / 285 \mu\text{m})$
- 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, $2 \times 1 \text{ cm}^2$ area

psi46dig pixel readout chip

