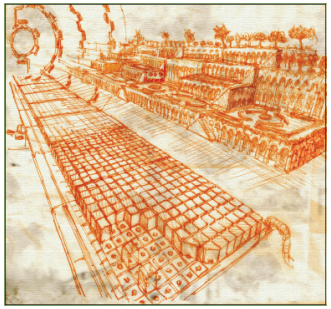


CMS Tracker Week
Phase I Upgrade Plenary
15 May 2013

Update on Test Beam Results with Irradiated PSI46dig

Matteo Centis Vignali, Ganna Dolinska, Erika Garutti, Johannes Haller, Malte Hoffmann, Ievgen Korol, Stefan Mättig, Hanno Perrey, Daniel Pitzl, Valentina Sola, Simon Spannagel, Georg Steinbrück

(DESY and Universität Hamburg)

Universität Hamburg

Chips Under Test

Four psi46dig Read Out Chips (ROCs) irradiated

Two chips irradiated @ CERN PS - 24 GeV protons

- psi46dig chip 202 with sensor
  D = 3 MRad
  F = $0.91 \cdot 10^{14}/cm^2$ (±7.4%) *
- psi46dig chip 203 with sensor
  D = 13 MRad
  F = $3.77 \cdot 10^{14}/cm^2$ (±7.6%) *

Two chips irradiated @ Karlsruhe p Zyklotron

- psi46dig chip 204 without sensor
  D = 37.5 MRad
- psi46digtrig chip 214 without sensor
  D = 113 MRad

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

Tracker Radiation Dose

[CMS-TDR-011]

Layer 1: 1 MGy

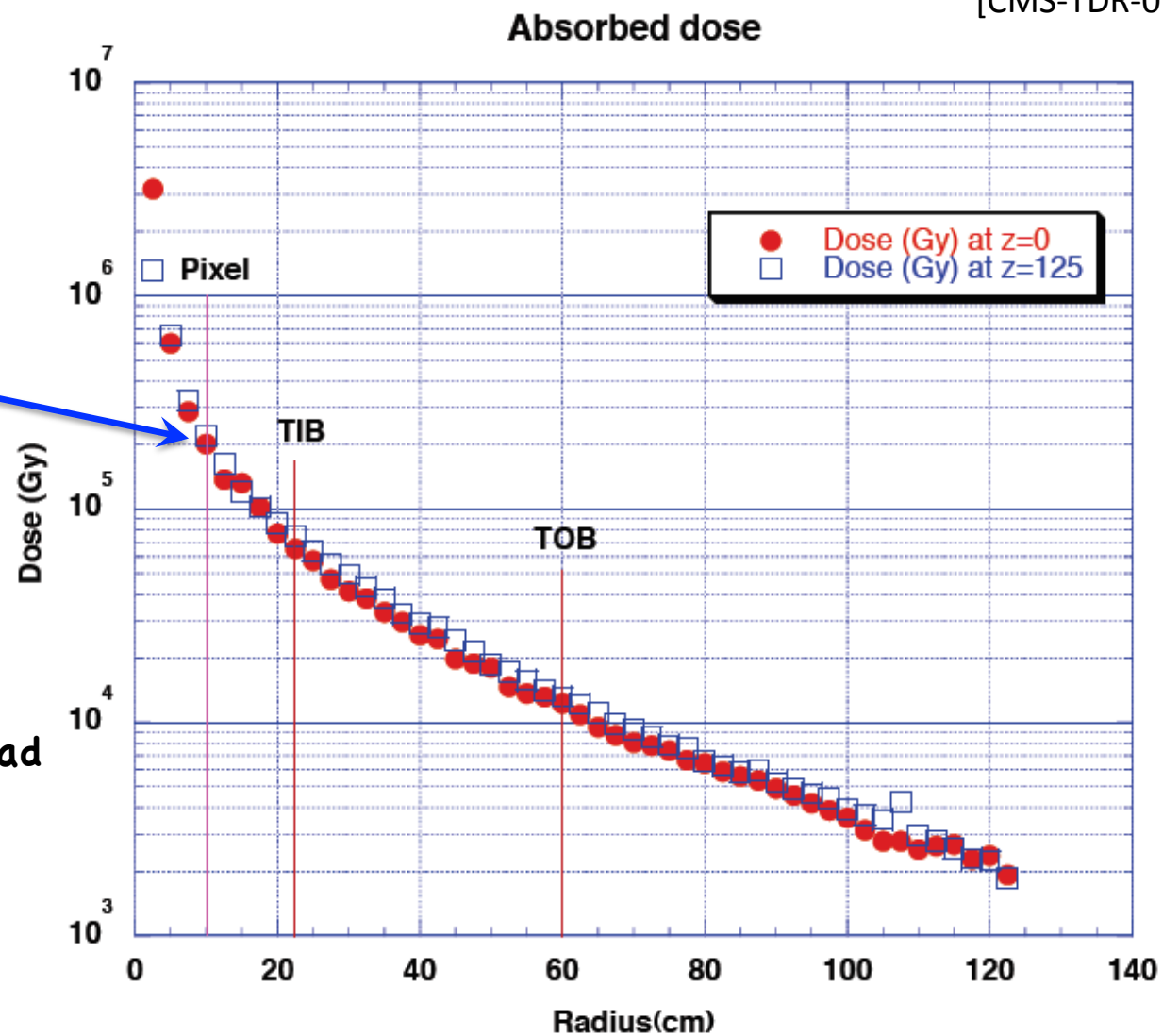
Layer 2: 400 kGy

Layer 3: 200 kGy

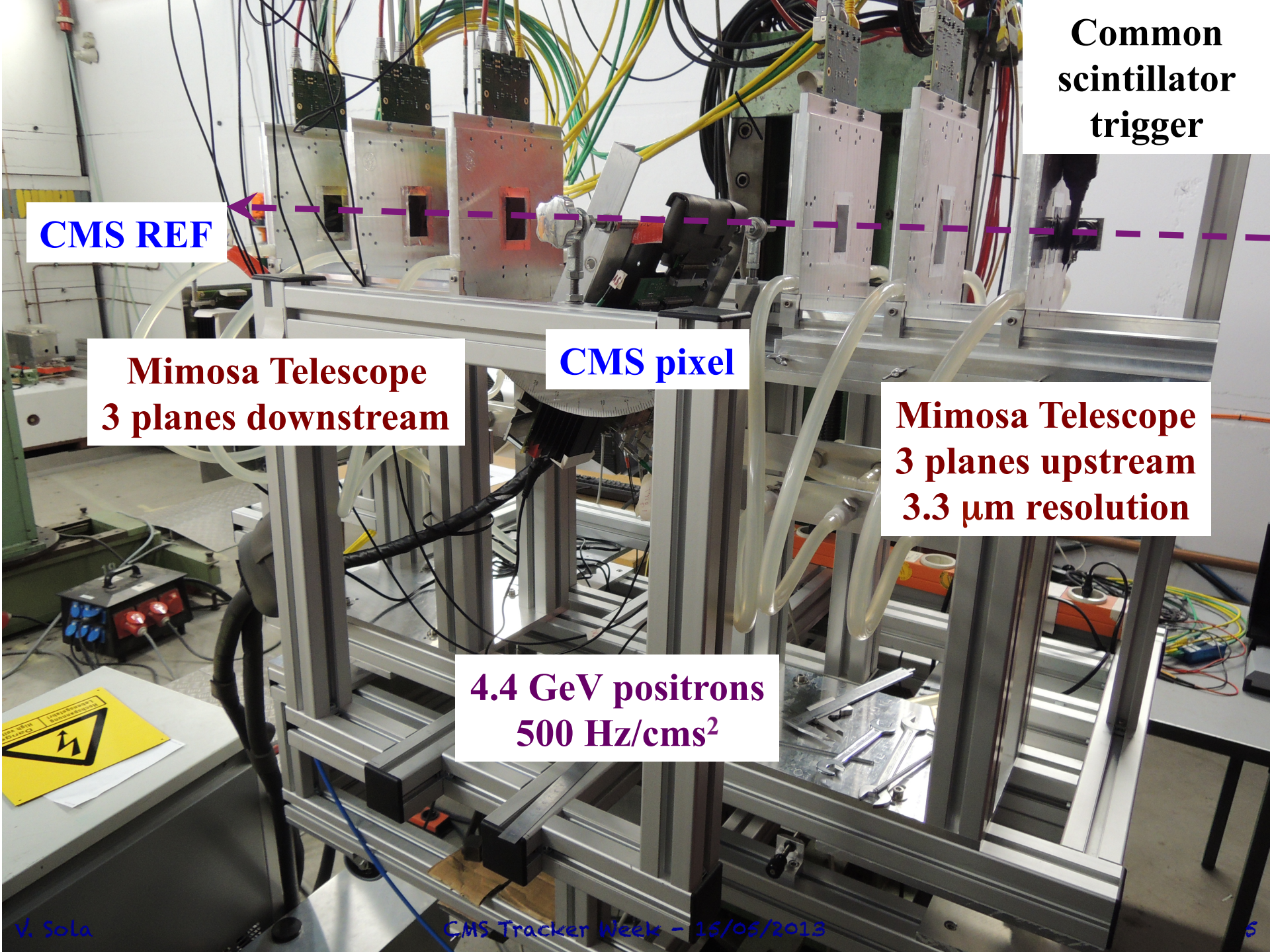
Layer 4: 150 kGy

100 kGy = 10 MRad

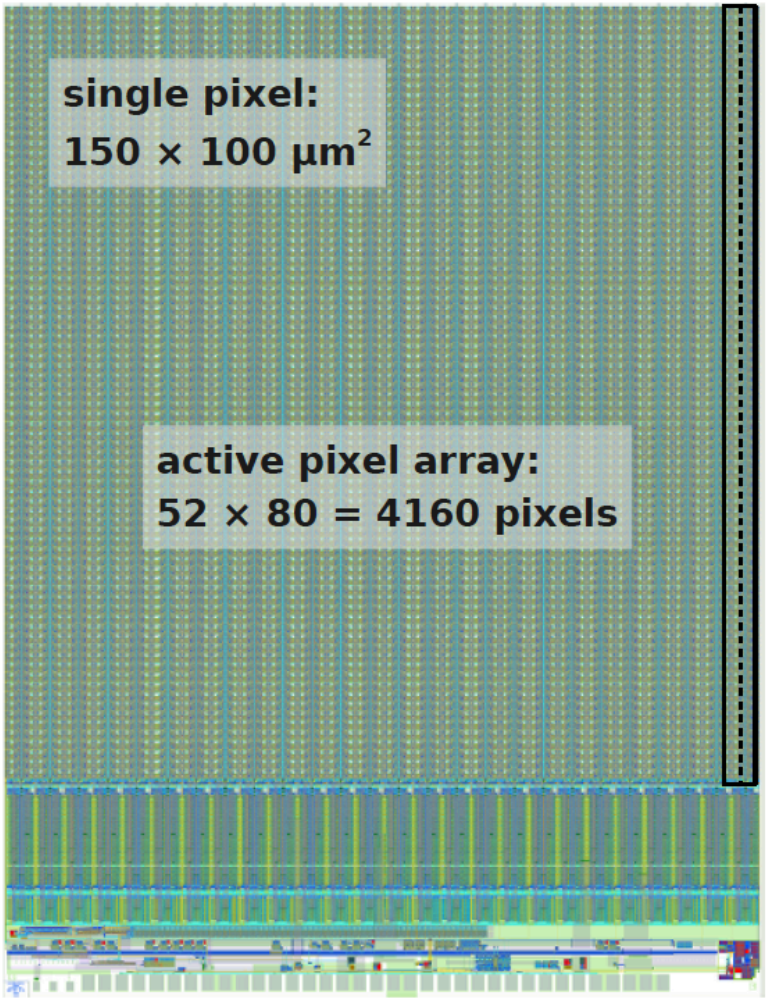
Fluence:
$3 \cdot 10^{13}/cm^2$ mips ~ 1MRad



Test Beam Results


Common scintillator trigger
CMS REF
Mimosa Telescope
3 planes downstream
CMS pixel
Mimosa Telescope
3 planes upstream
3.3 μm resolution
4.4 GeV positrons
500 Hz/cms^2

psi46dig Pixel Read Out Chip

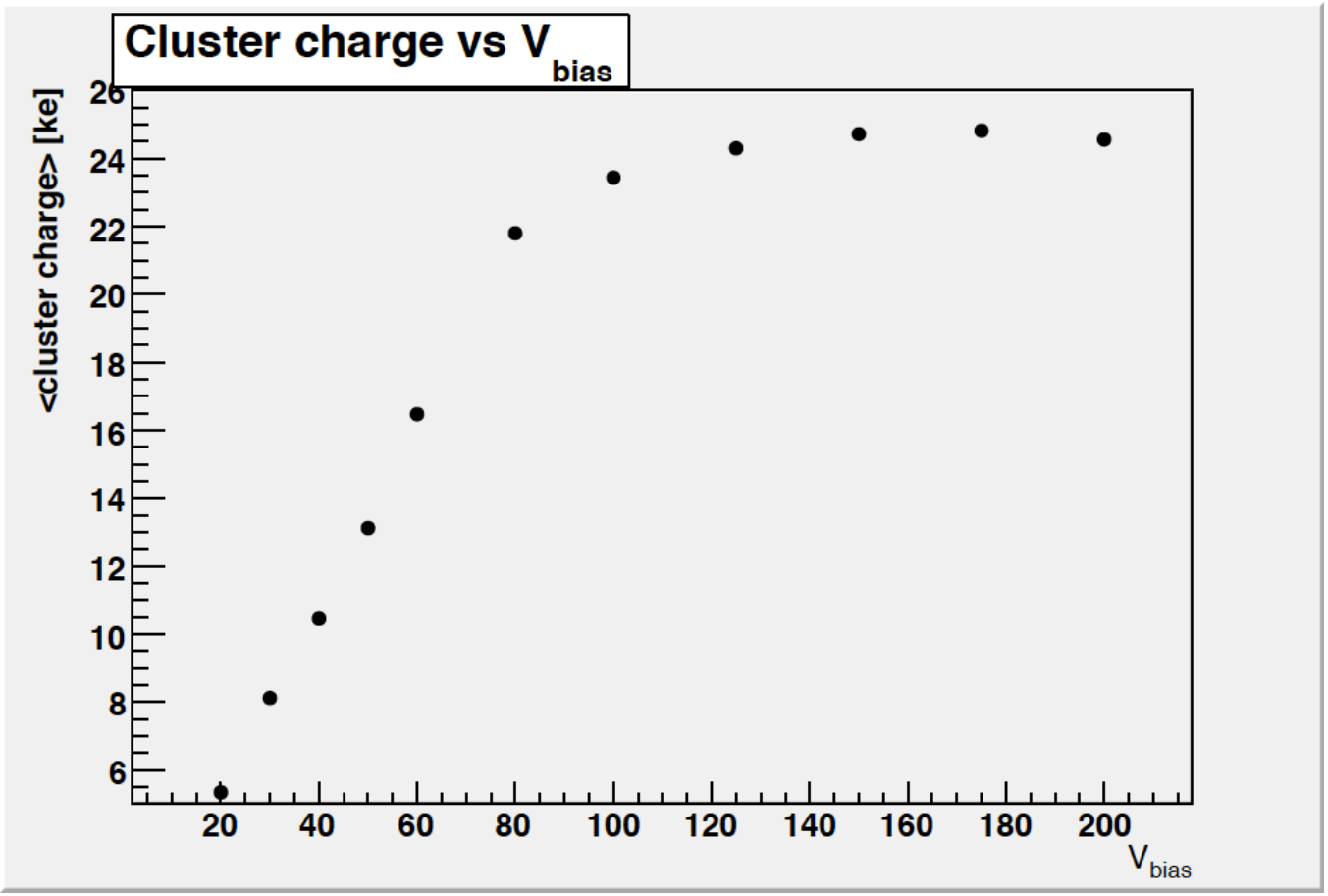


Test Beam Program

Beam Energy set to 4.4 GeV (e^-)

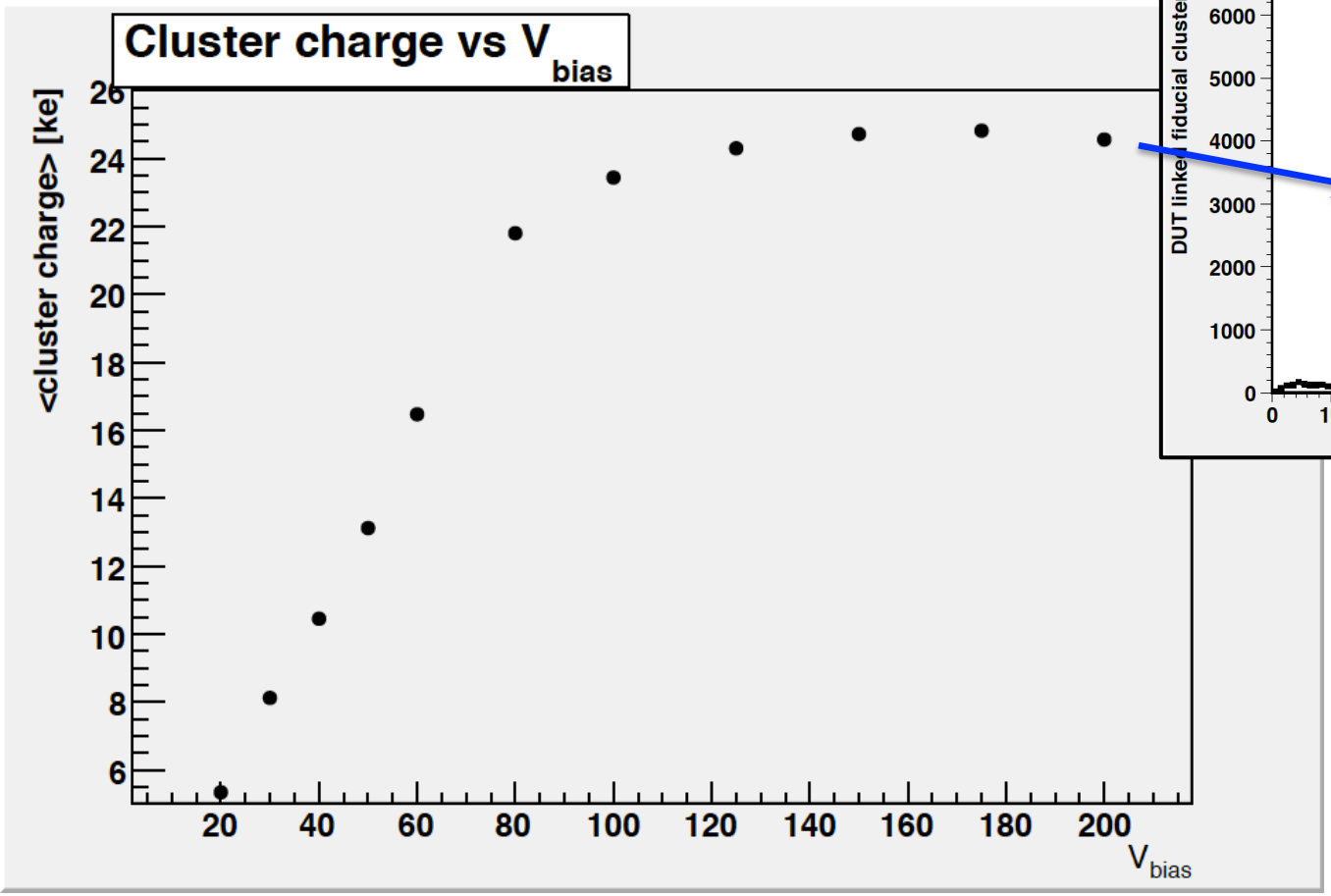
- psi46dig chip 202
  - no cooling
  - tilt 19, later add turn 28
  - bias voltage scan at low threshold
  - threshold scan at high bias voltage
- psi46dig chip 203
  - cooling with chiller at -15°C (expected -5°C at the sensor)
  - bias voltage scan and threshold with tilt and turn
  - bias voltage and tilt scan at low threshold, no turn

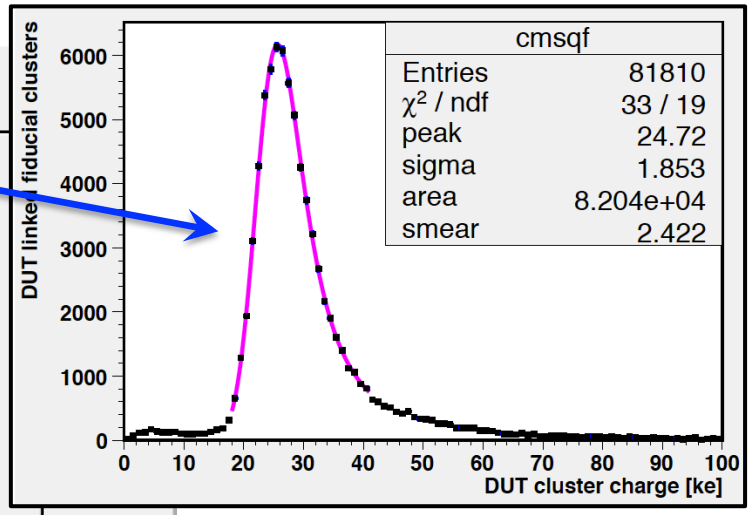
Cluster Charge - Chip 202



- psi46dig chip 202
  - D = 3 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 19.2°
  - no turn
- Full depletion around -100 V

Cluster Charge - Chip 202

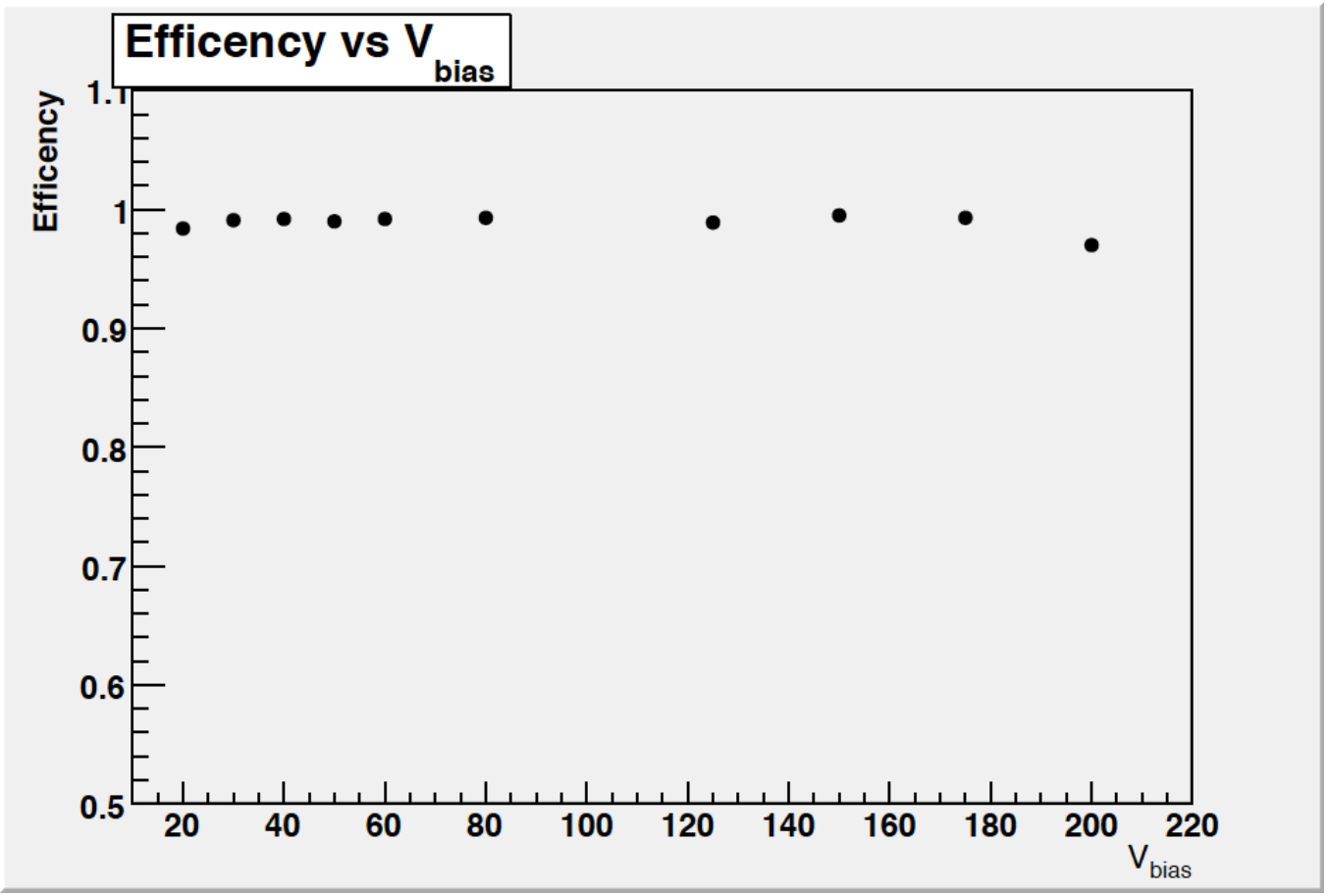




- Cluster charge distribution fit by Landau ⊗ Gauss

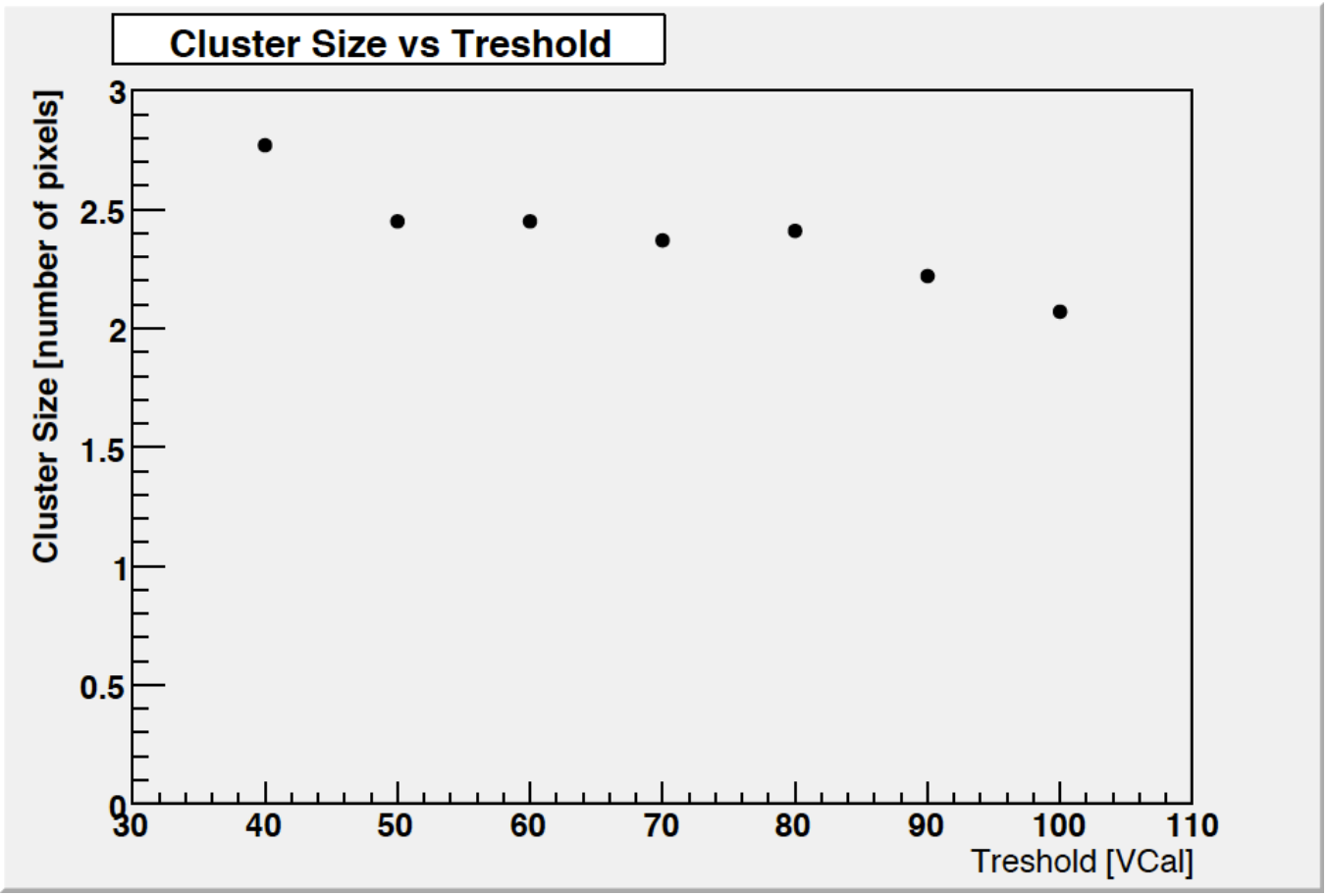
Gain calibration: Weibull fit, assume 50e/DAC

Efficiency - Chip 202



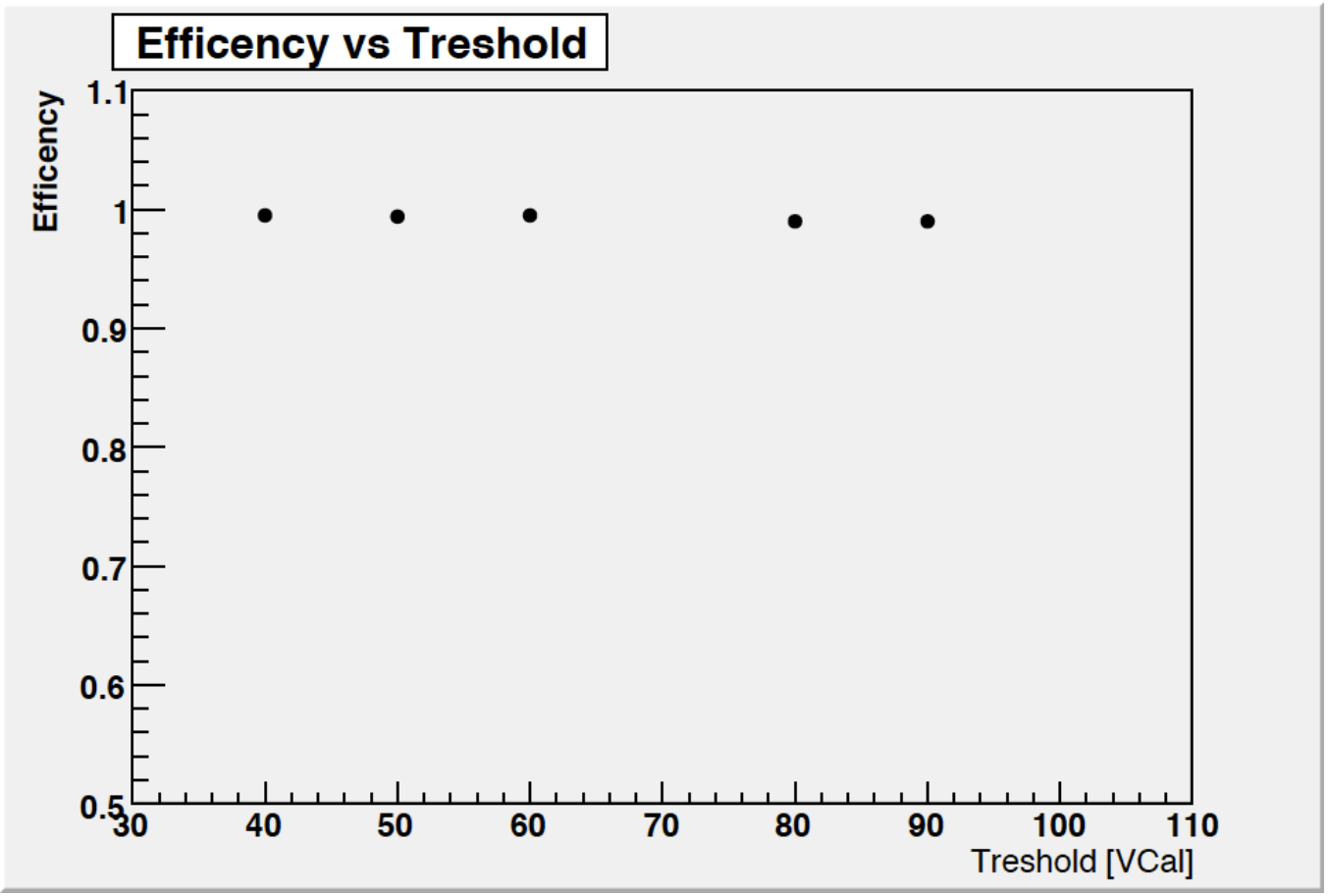
- psi46dig chip 202
  - D = 3 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 19.2°
  - no turn

Cluster Size - Chip 202



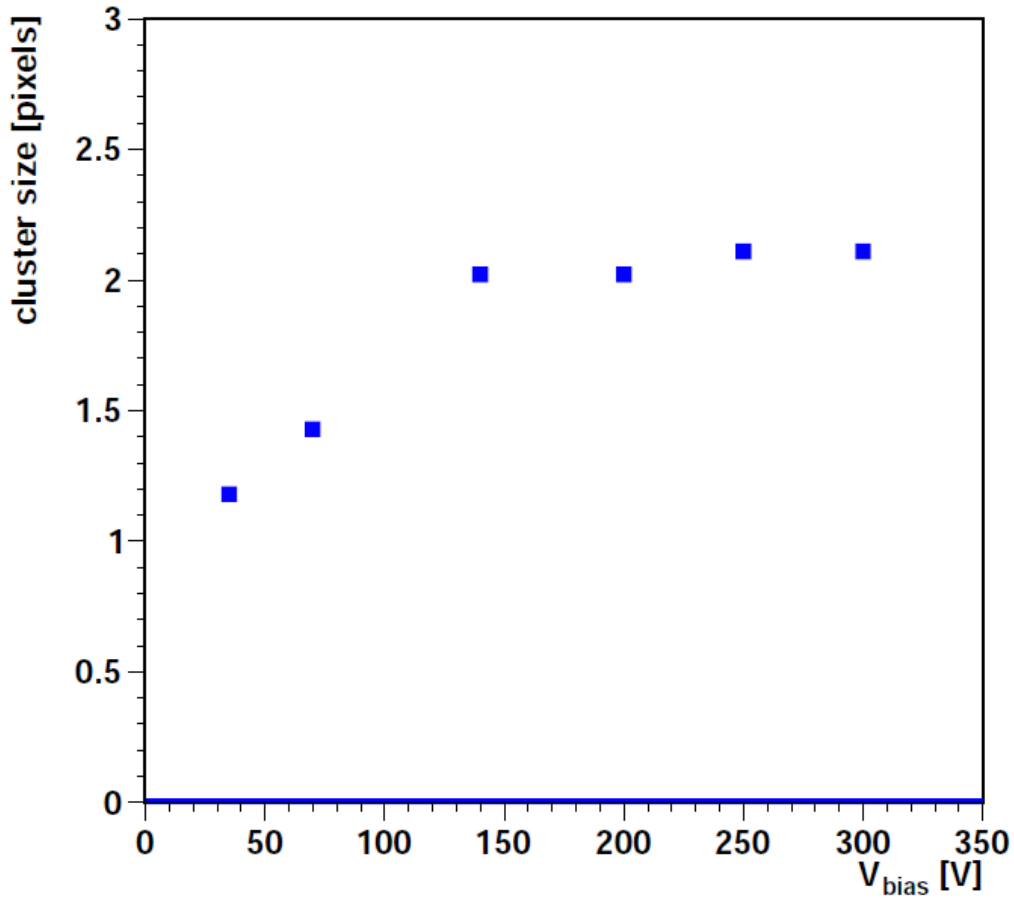
- psi46dig chip 202
  - > D = 3 Mrad
  - > I_A = 25 mA
  - > threshold = 35
  - > tilt = 20.3°
  - > turn = 28.5°

Efficiency - Chip 202



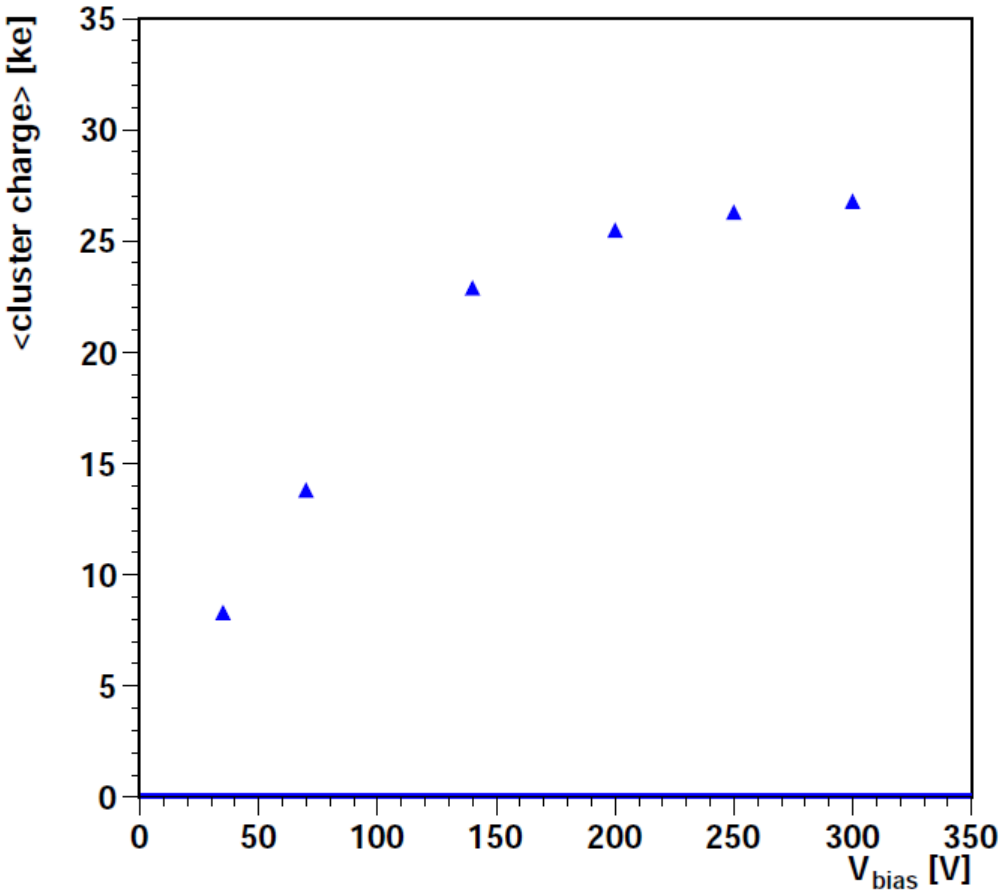
- psi46dig chip 202
  - D = 3 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 20.3°
  - turn = 28.5°

Cluster Size - Chip 203



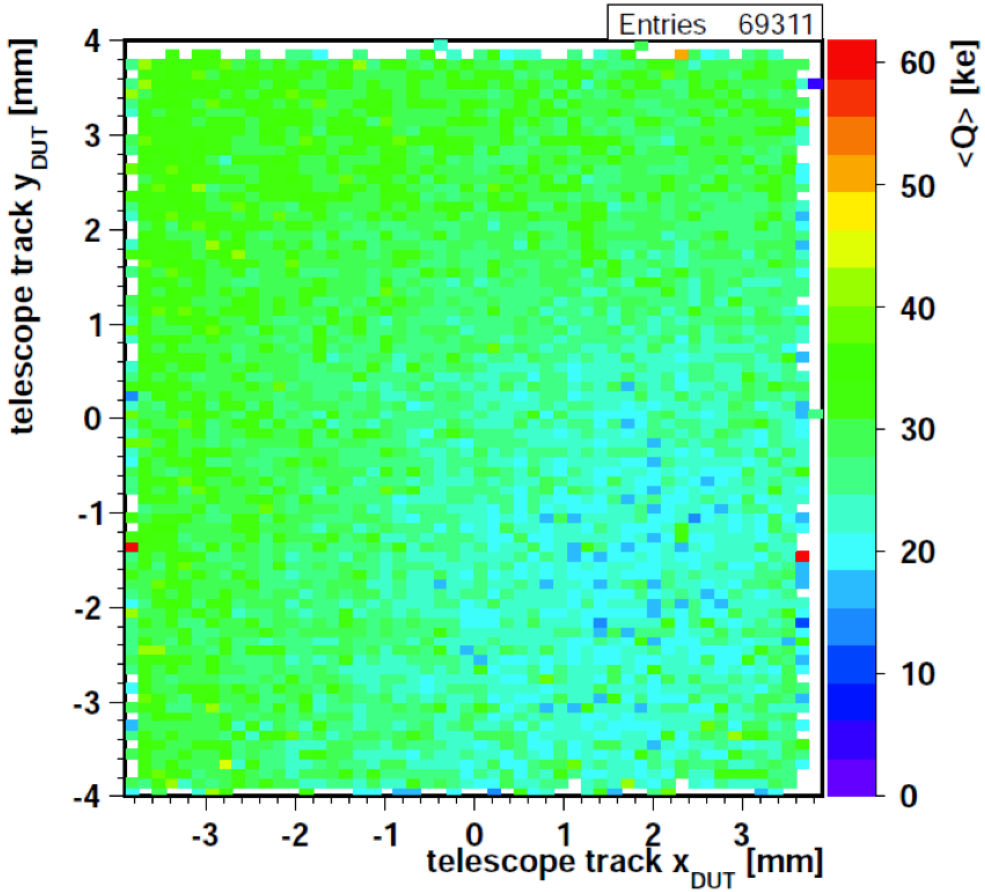
- psi46dig chip 203
  - D = 13 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 22°
  - no turn
  - cooled
- Full depletion around -150 V

Cluster Charge - Chip 203



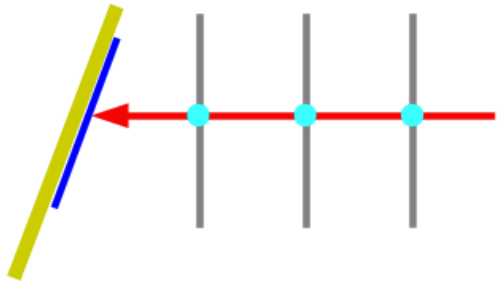
- psi46dig chip 203
  - D = 13 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 22°
  - no turn
  - cooled
- Full depletion around -150 V ?

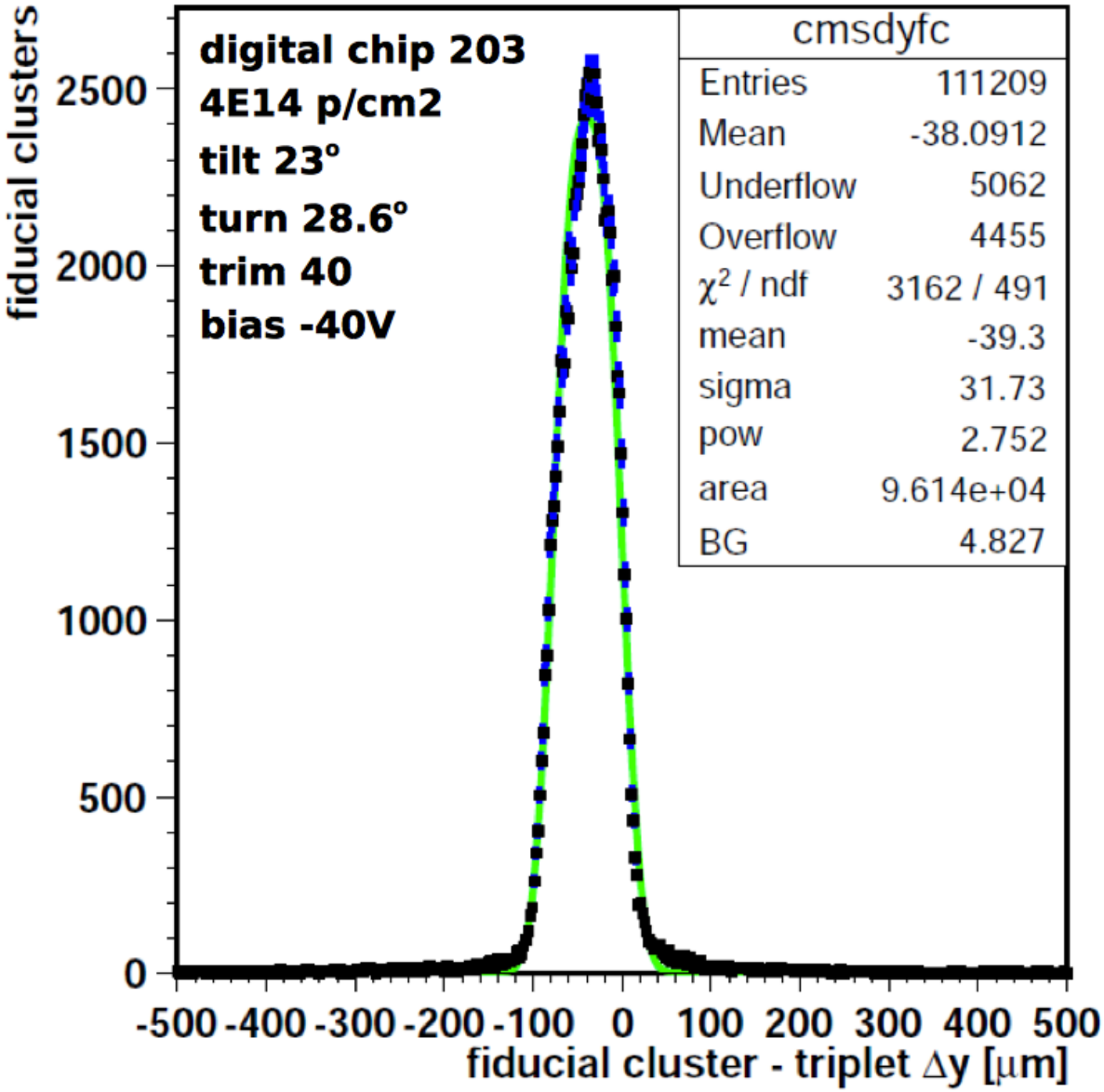
Charge Map - Chip 203



- psi46dig chip 203
  - D = 13 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 23°
  - turn = 29°
  - cooled
- Valley in lower left quadrant

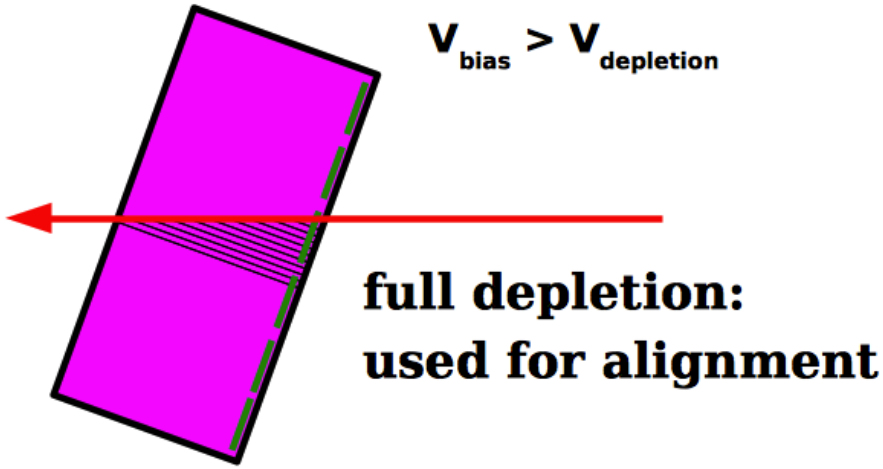
track-cluster residuals

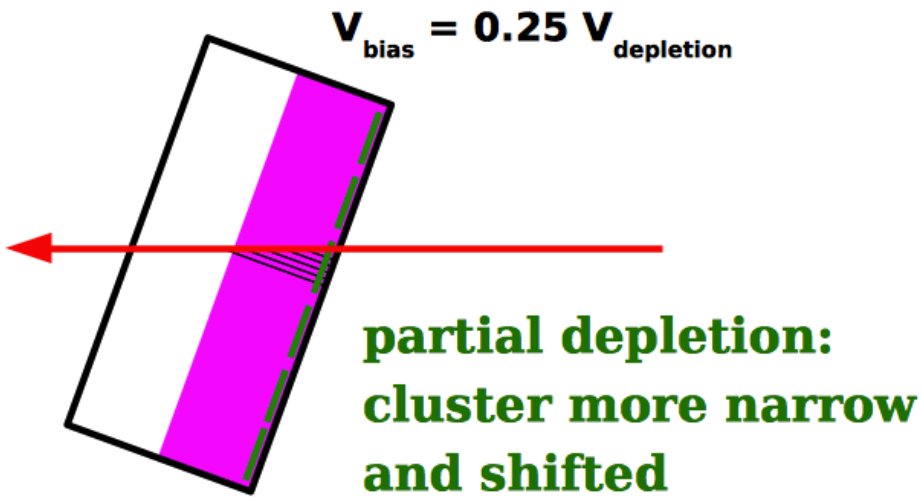




- digital chip 203:
  - 13 MRad
  - Ia 25 mA, trim 40
  - **bias -40V**
  - tilt 23°, turn 29°
- partial depletion and tilt:
  - cluster shifted

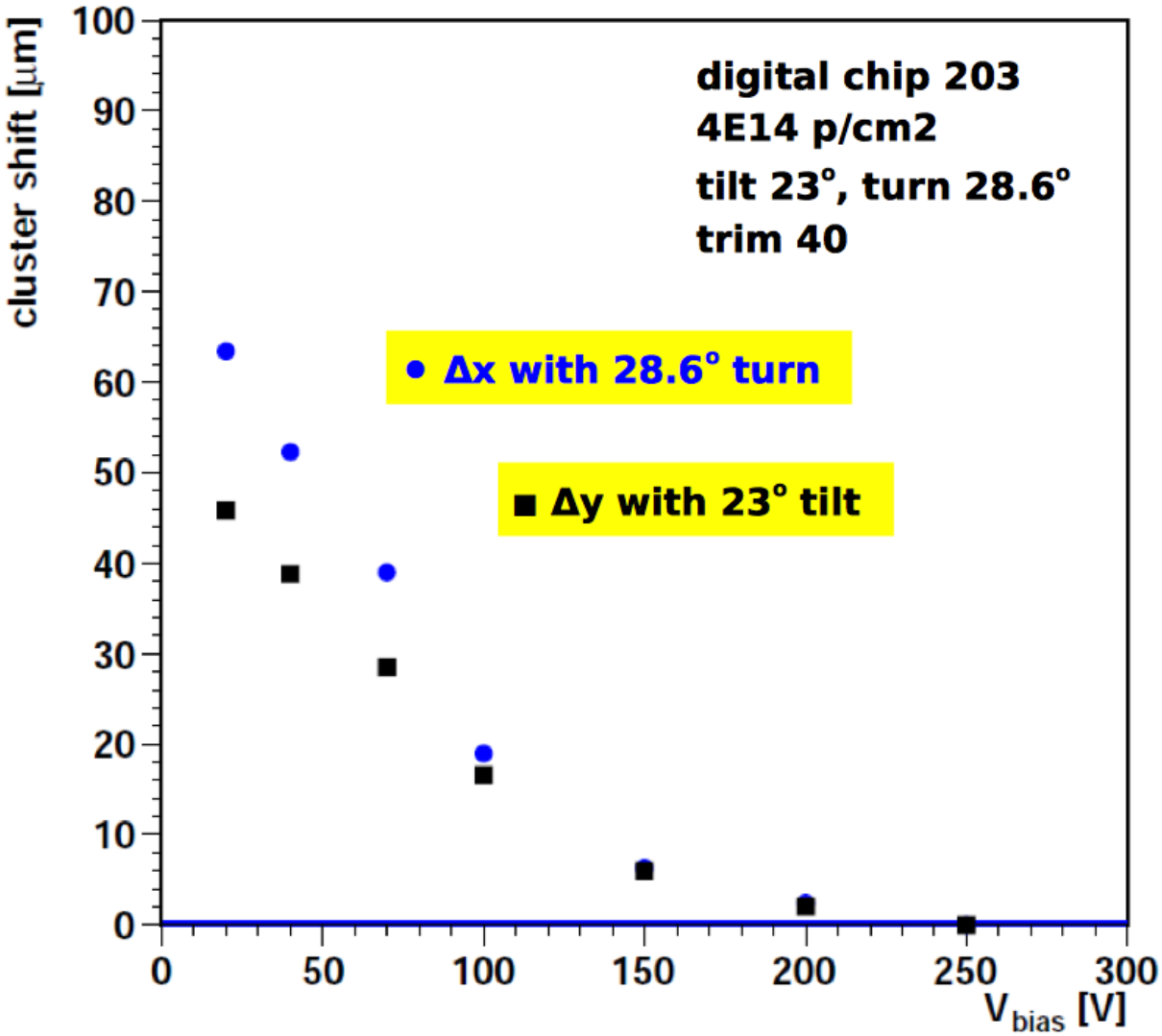
depletion depth





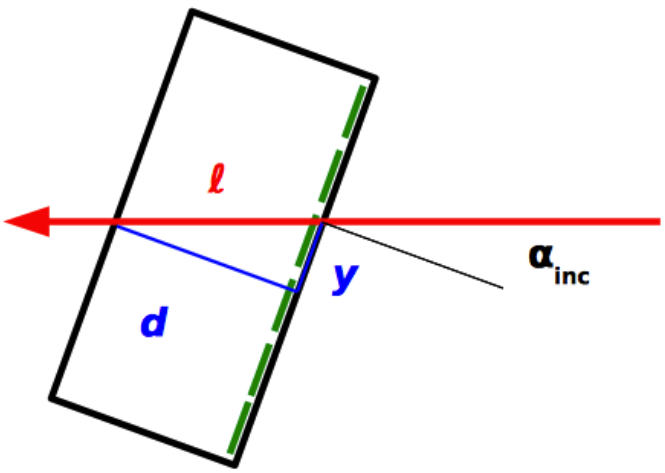
irradiated:
type inversion,
depletion starts
from pixel side

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

angles

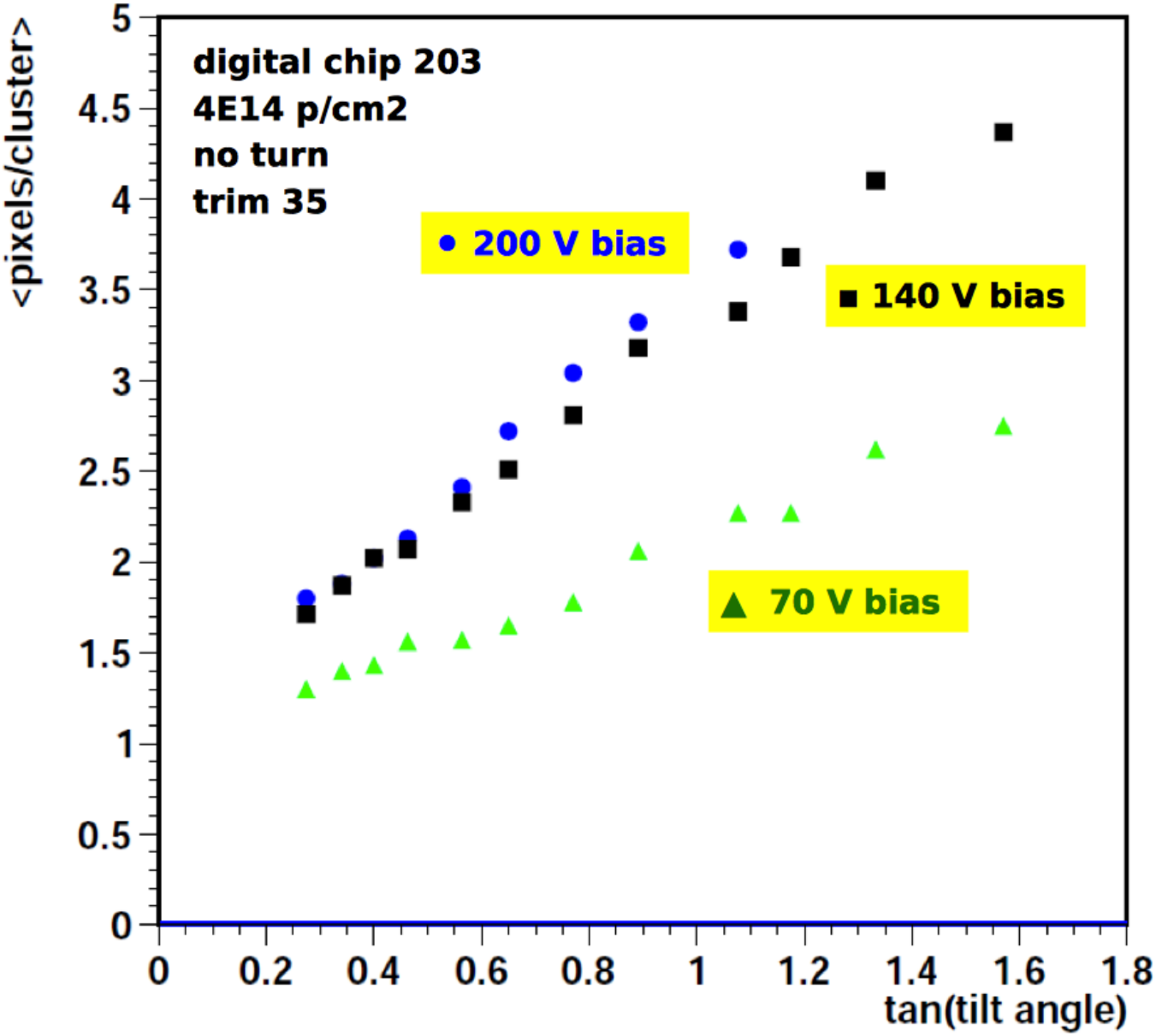


sensor thickness d = 285 μm

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

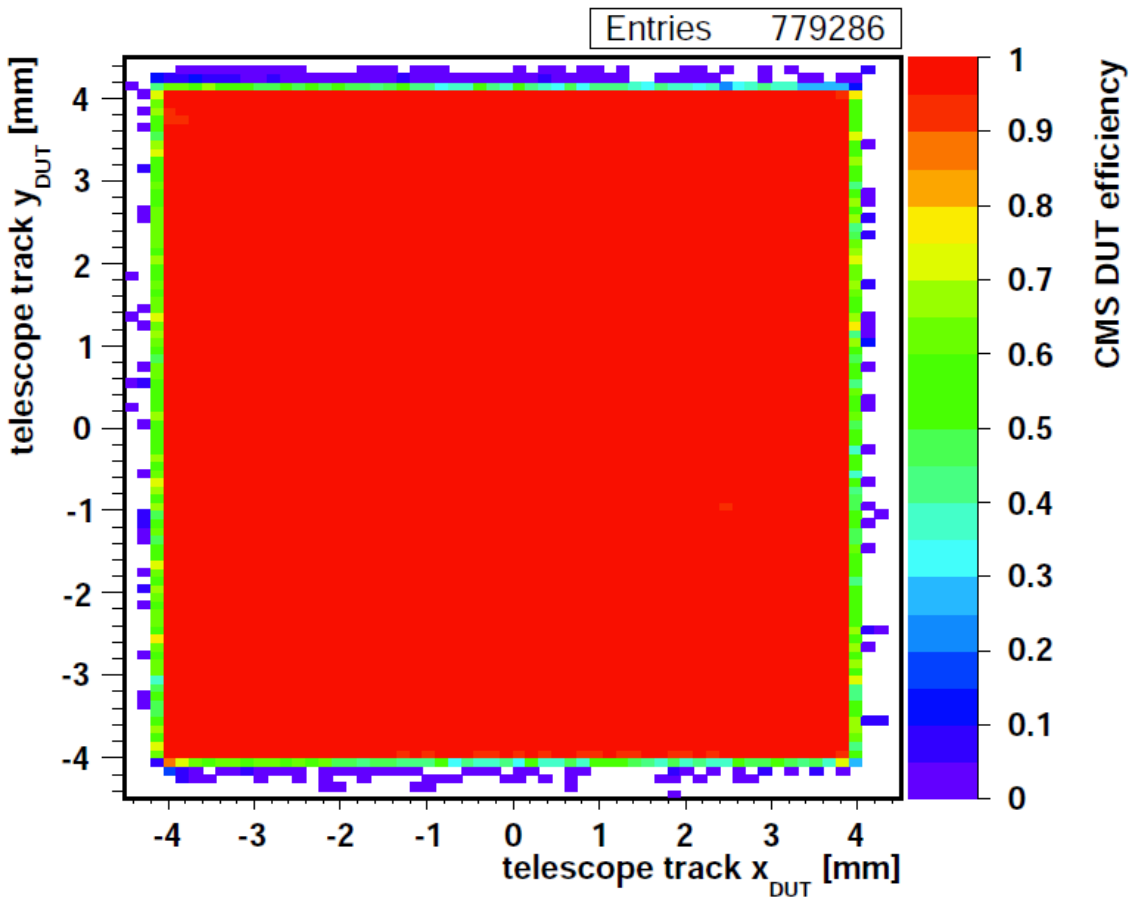
cluster width: $y = d \tan\alpha$

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:
  - $\sim\tan(\alpha_{tilt})$
- cluster size saturated at 140 V
  - full depletion

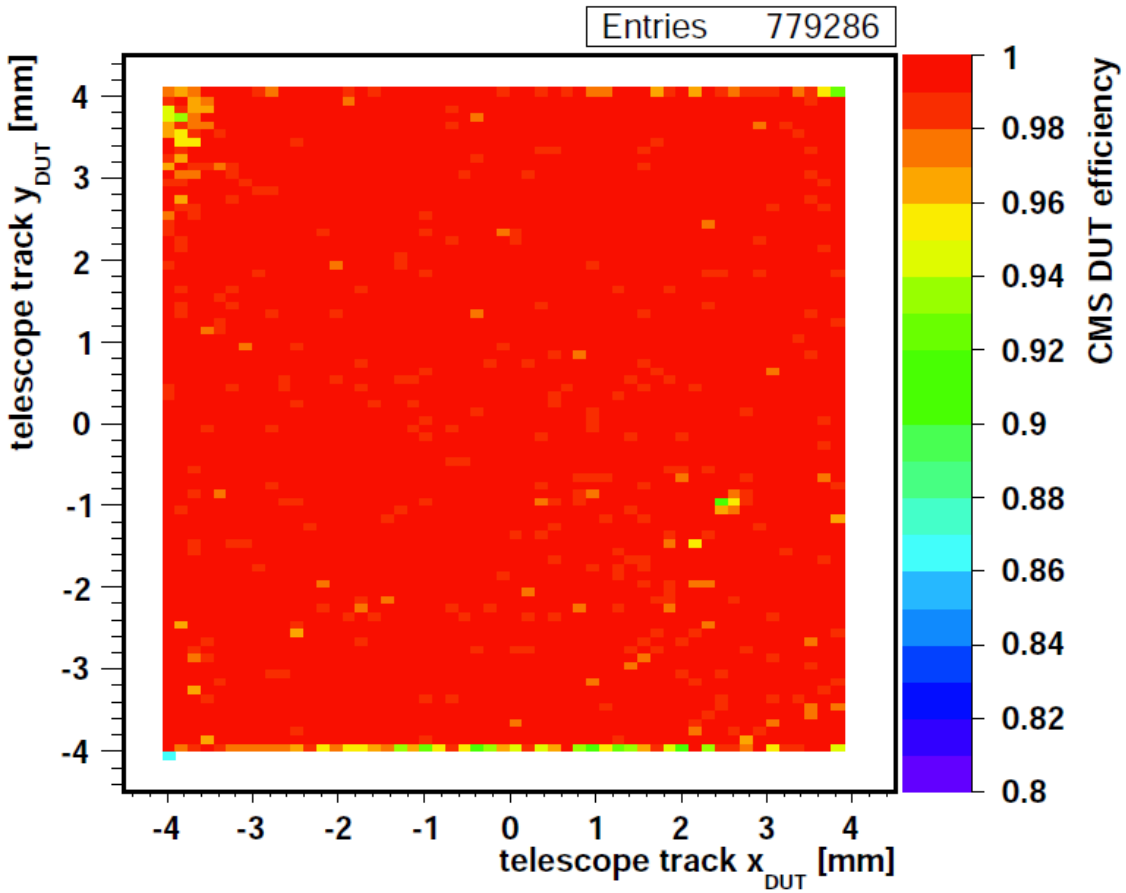
Efficiency Map - Chip 203



- psi46dig chip 203
  - D = 13 Mrad
  - I_A = 25 mA
  - threshold = 35
  - tilt = 22°
  - no turn
  - cooled
- 99.8 % in fiducial volume

Efficiency = (DUT linked cluster) / (telescope track with REF cluster)

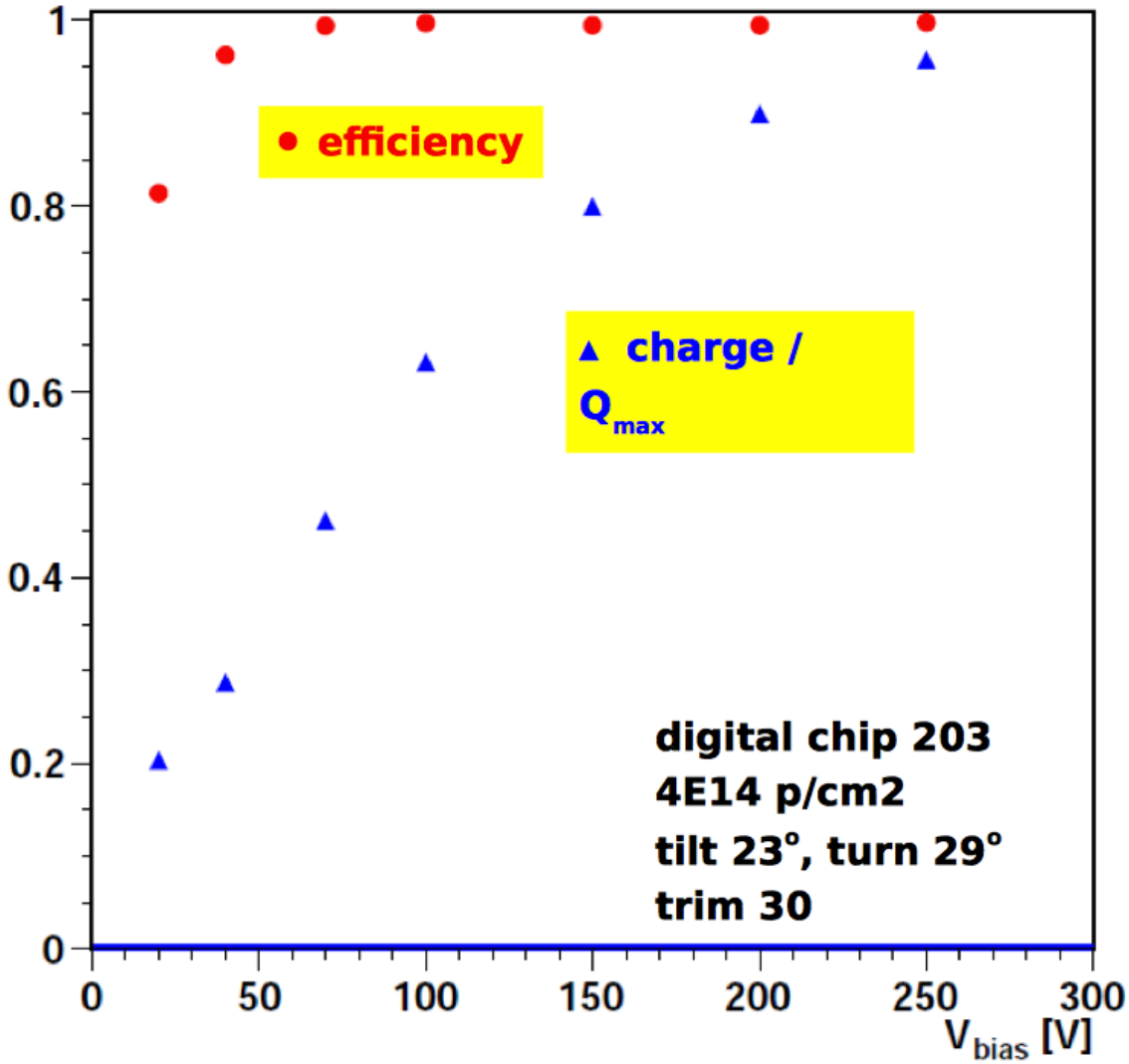
Efficiency Map - Chip 203



- psi46dig chip 203
  - > D = 13 Mrad
  - > I_A = 25 mA
  - > threshold = 35
  - > tilt = 22°
  - > no turn
  - > cooled
- 99.8 % in fiducial volume

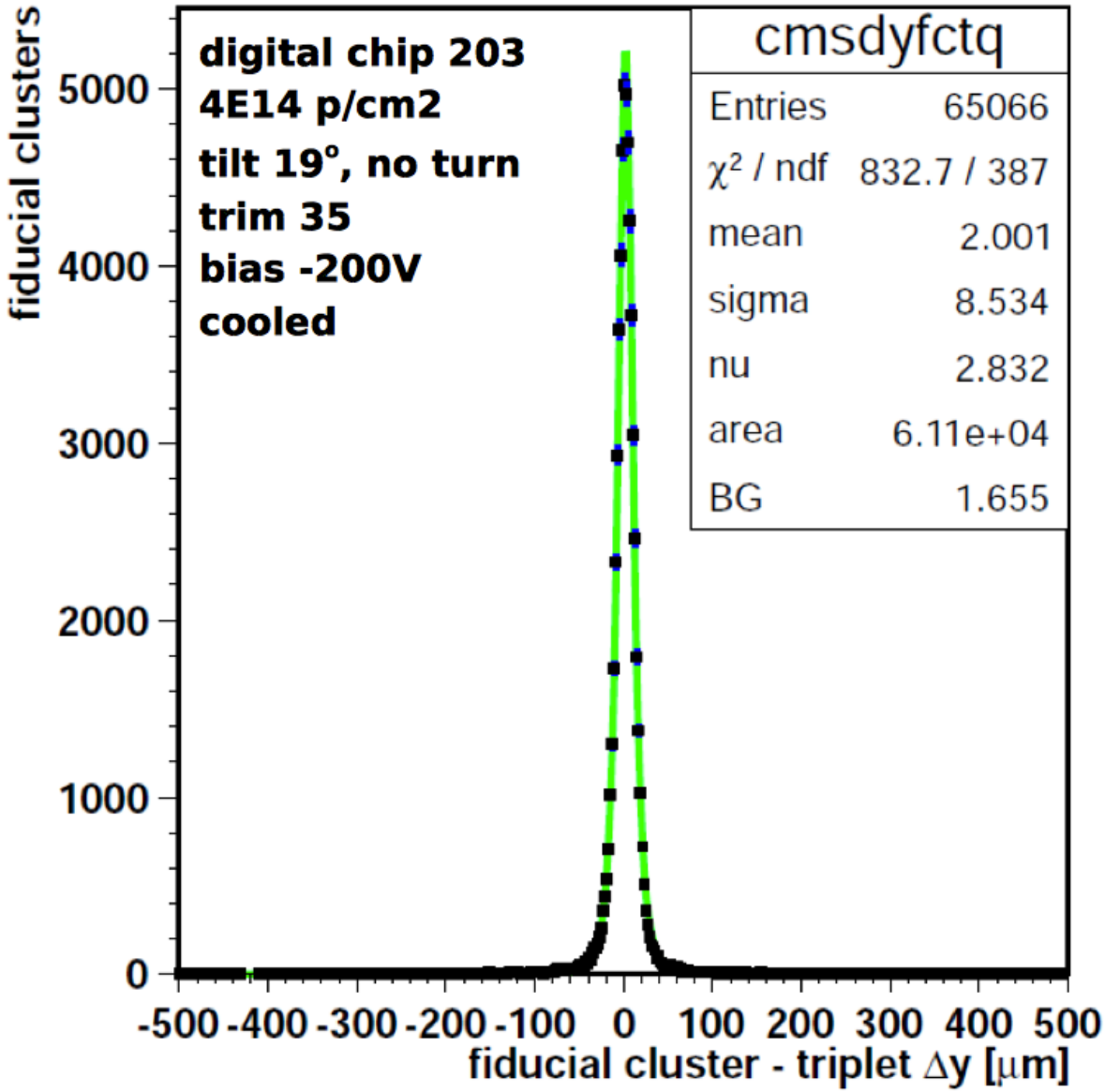
Efficiency = (DUT linked cluster) / (telescope track with REF cluster)

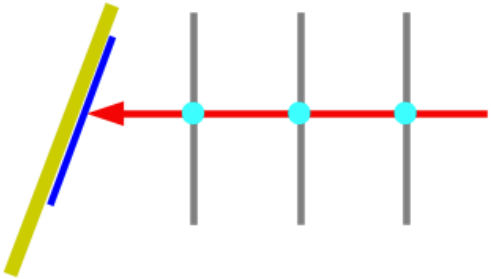
efficiency vs bias voltage



- 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

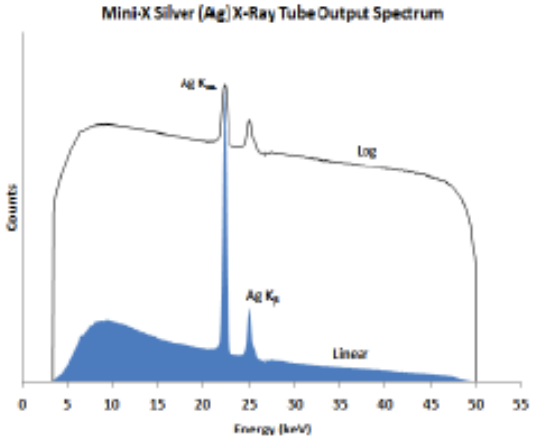




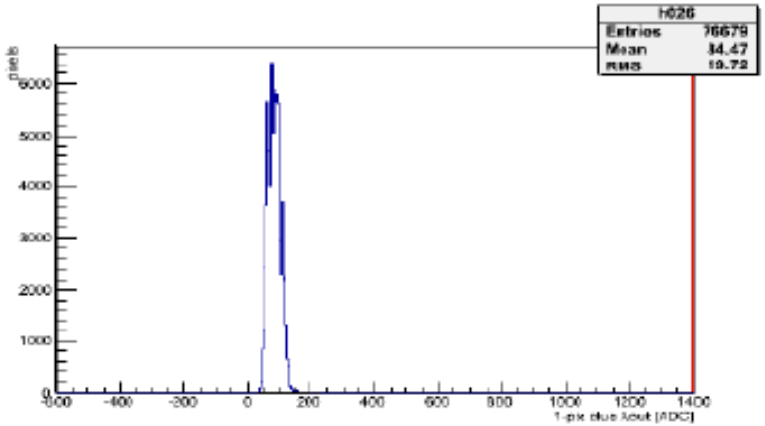
- digital chip 203:
  - 13 MRad
  - Ia 25 mA, trim 35
  - bias -200V, cooled
  - tilt 19°, no turn
- residual to track:
  - sigma 8.5 μm
  - subtract telescope resolution 4.6 μm
  - CMS pixel row resolution 7 μm
  - like before

x-ray Results

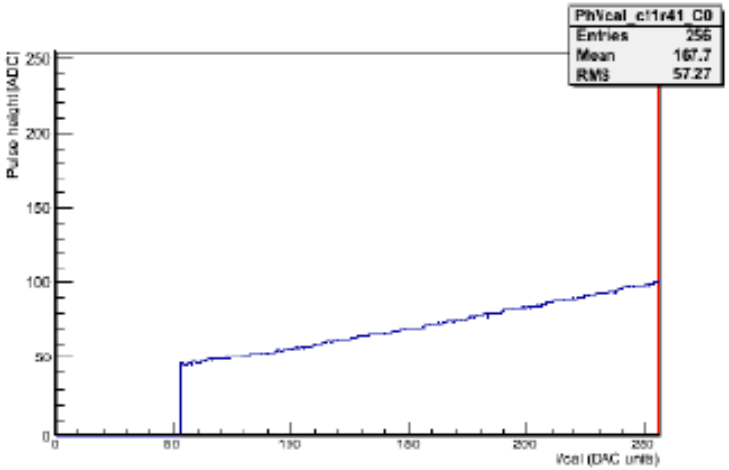
The Spectrum Method



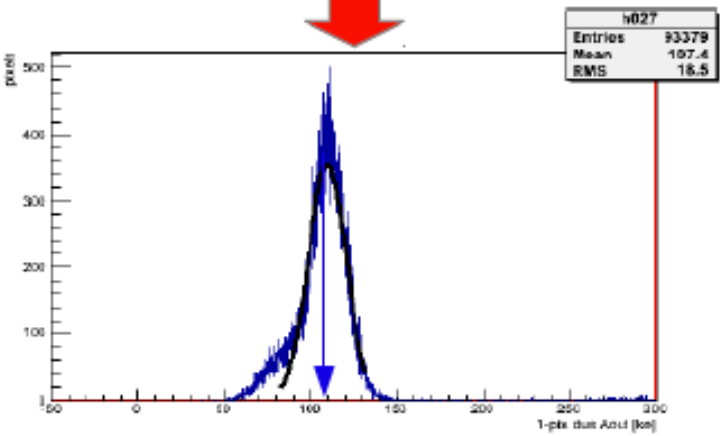
Choose specific energy with different targets



Measure ph-spectrum in adc units

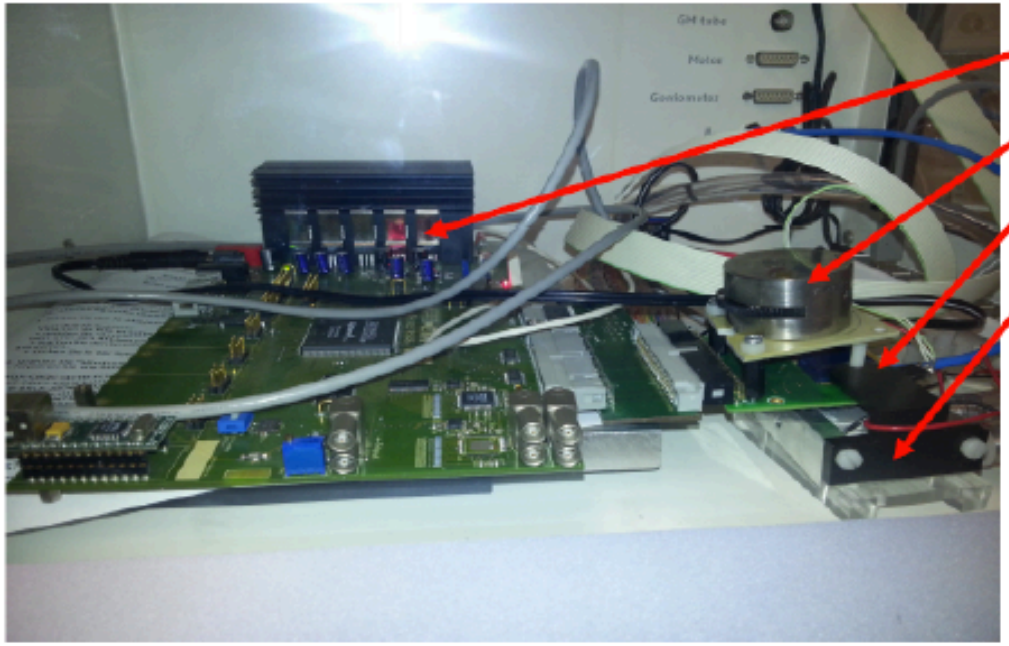


Do ph-calibration

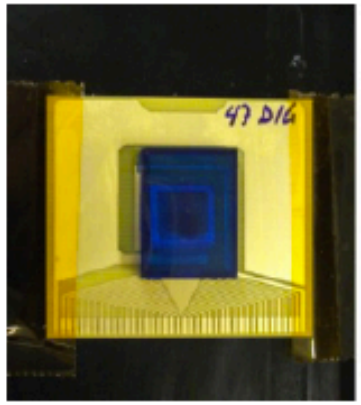


Get ph-distribution in vcal units

Measurement Setup



Testboard
Variable X-ray source
Digital single chip
Cold block with peltiers



- Bias-voltage = 200V

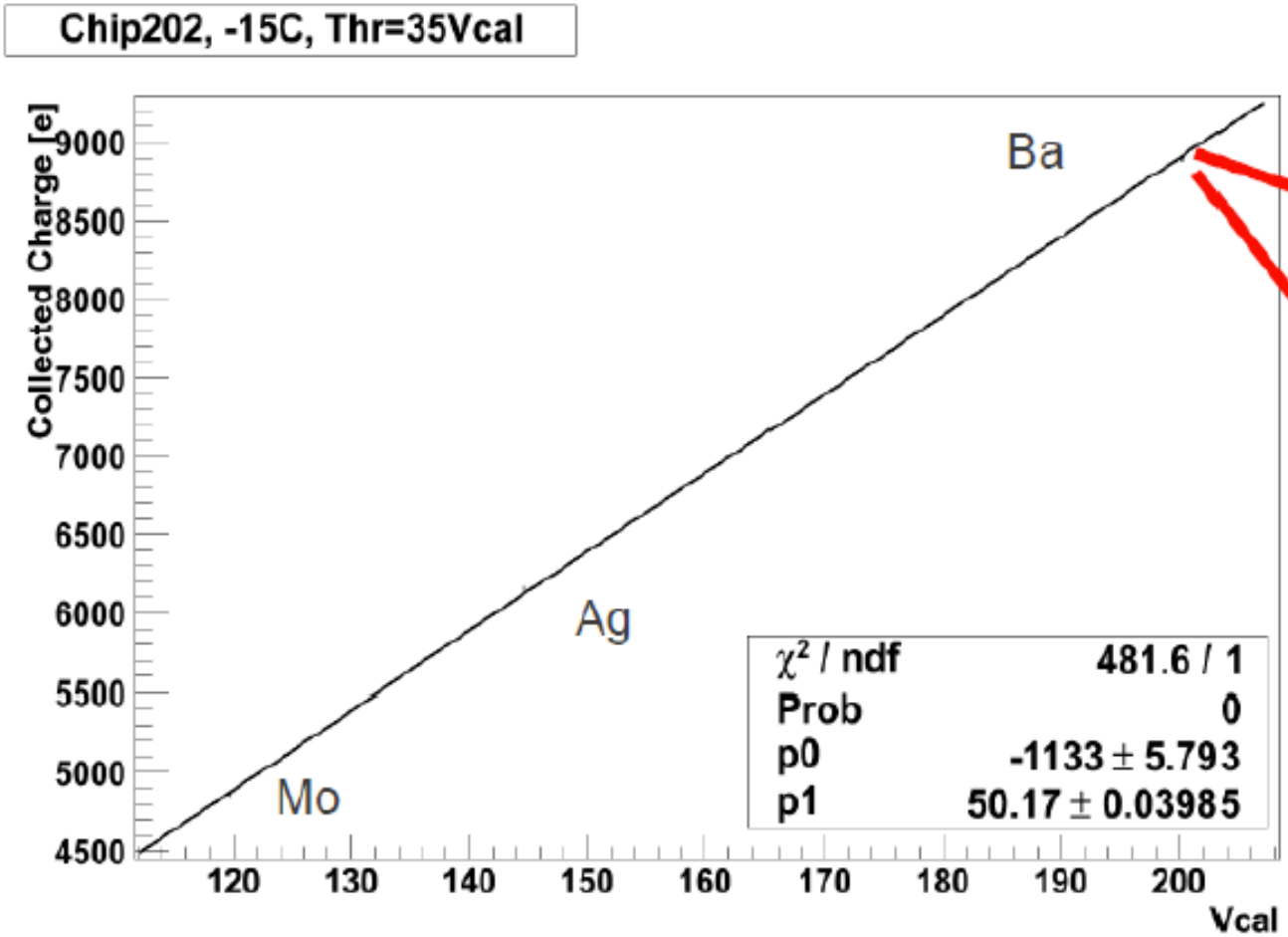
- 3 targets were used:

Mo: 17.48 keV (4.9 ke in Si)
Ag: 22.16 keV (6.2 ke in Si)
Ba: 32.19 keV (8.9 ke in Si)

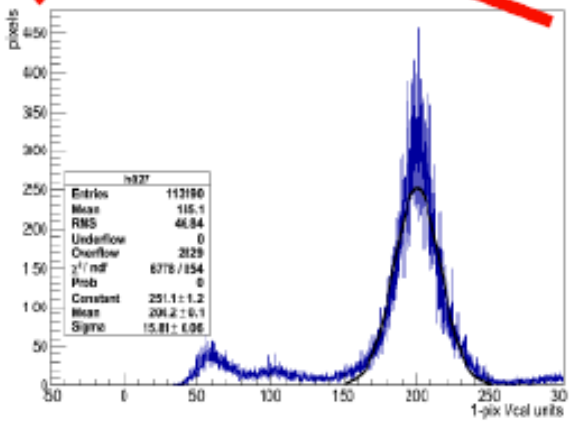
Chip 202 (0.9x10^14 p/cm^2; 3Mrad)
Calibrated at: -15° (Thr1= 35VCAL, Thr2= 50VCAL)
+15° (Thr1= 35VCAL)

Chip 203 (4x10^14 p/cm^2; 13Mrad)
Calibrated at: -15° (Thr1= 35VCAL)

Chip 202: T=-15°, Thr = 35VCAL



- Calibration done with a threshold of 35Vcal
- Leakage current: 25uA



Lab Results

S-curves

time walk

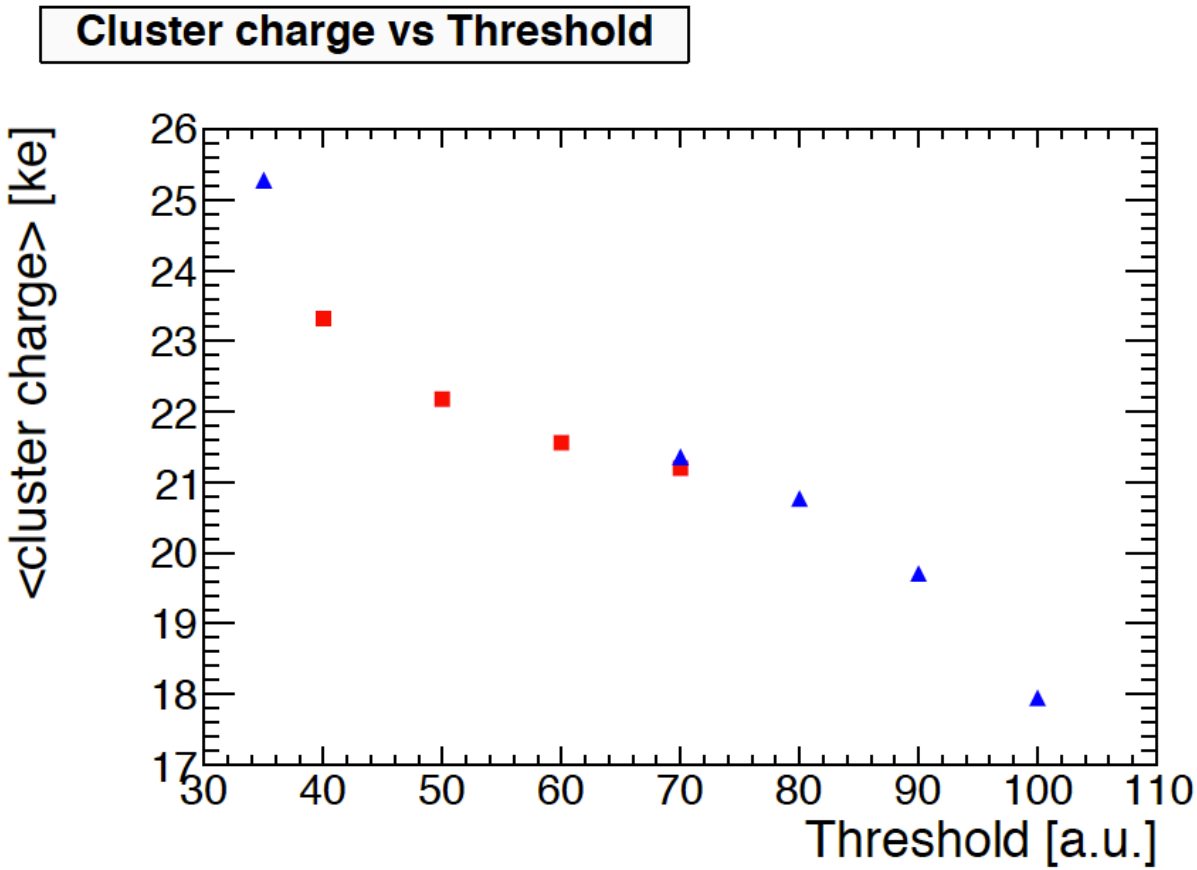
gain

Summary & Outlook

- Test beam with irradiated digital ROCs done
- First analysis on data collected on April 2013
  - = depletion voltage about 150V
  - = similar resolution as un-irradiated ~ 7 μm
- Many features still to be investigated

Backup

Cluster Charge - Chip 202

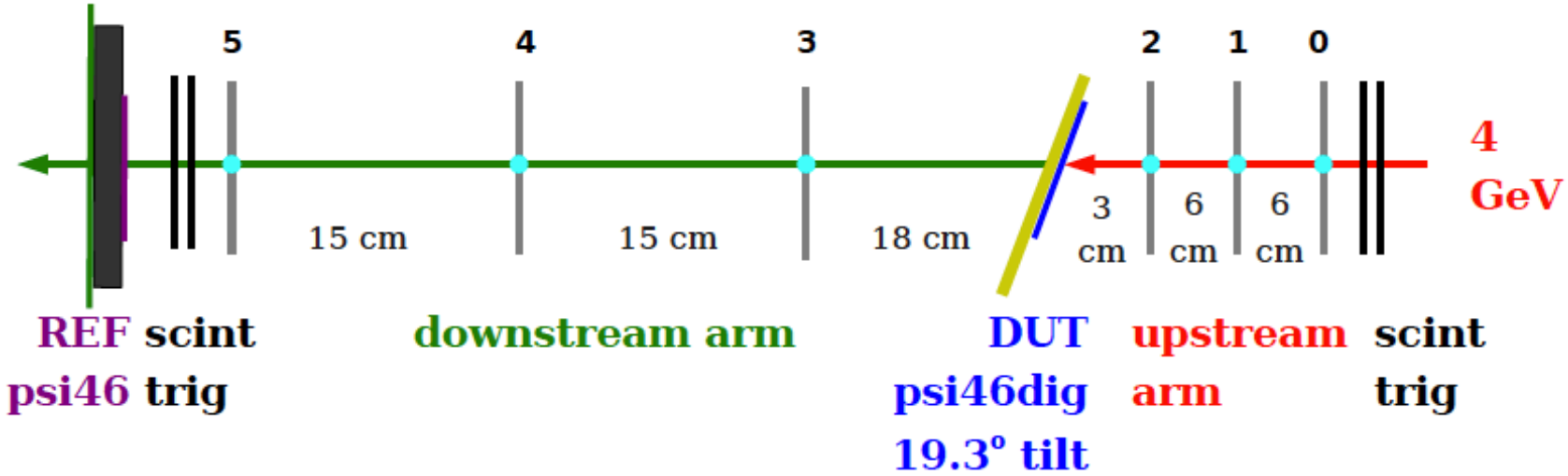


- psi46dig chip 202
  - D = 3 Mrad
  - I_A = 25 mA
  - no turn

▲ V_{bias} = -200 V
tilt = 21°

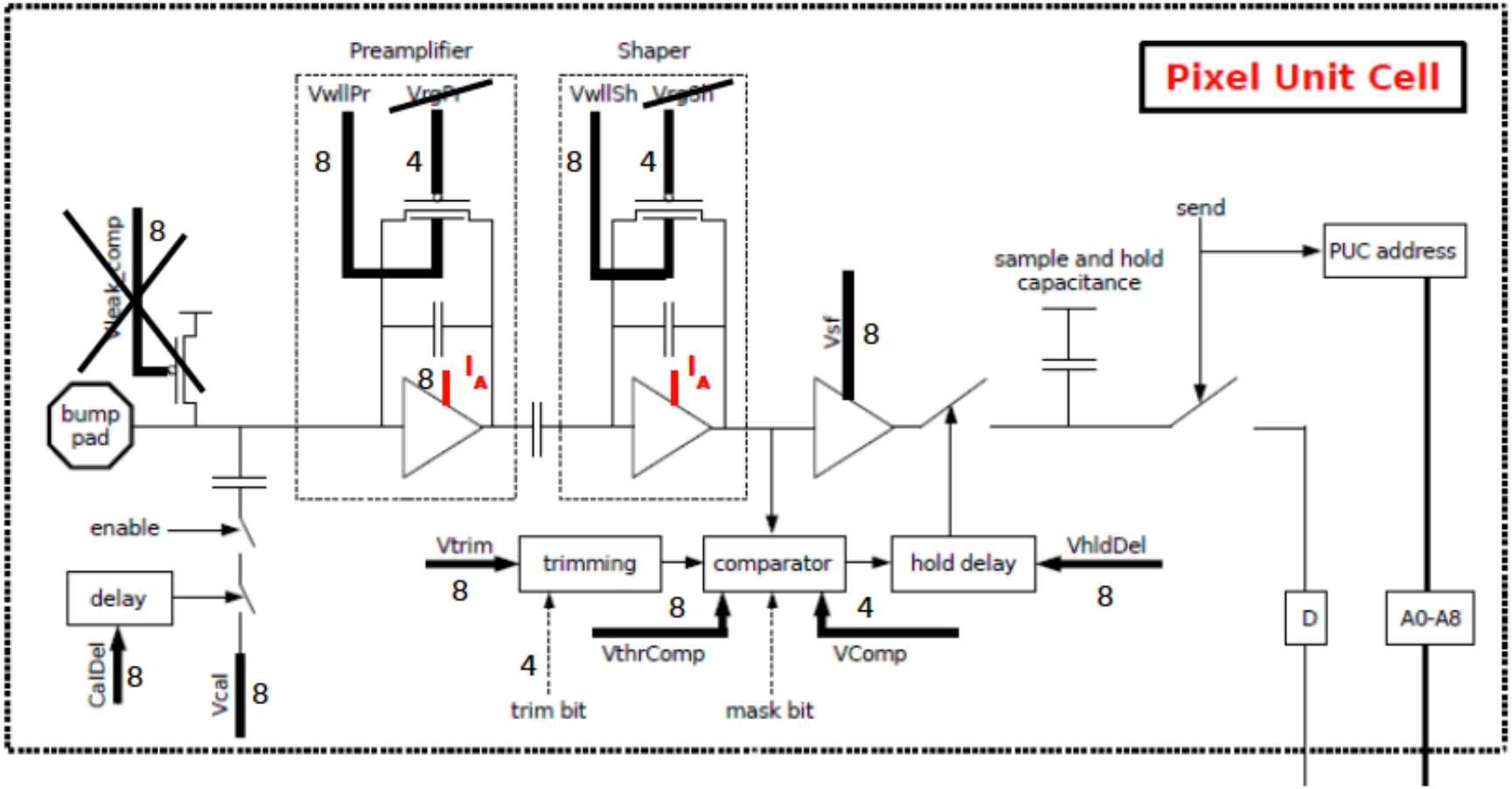
■ V_{bias} = -150 V
tilt = 17°

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 Unit Cell



bits — adjustable by programmable DAC

supplied by analog current