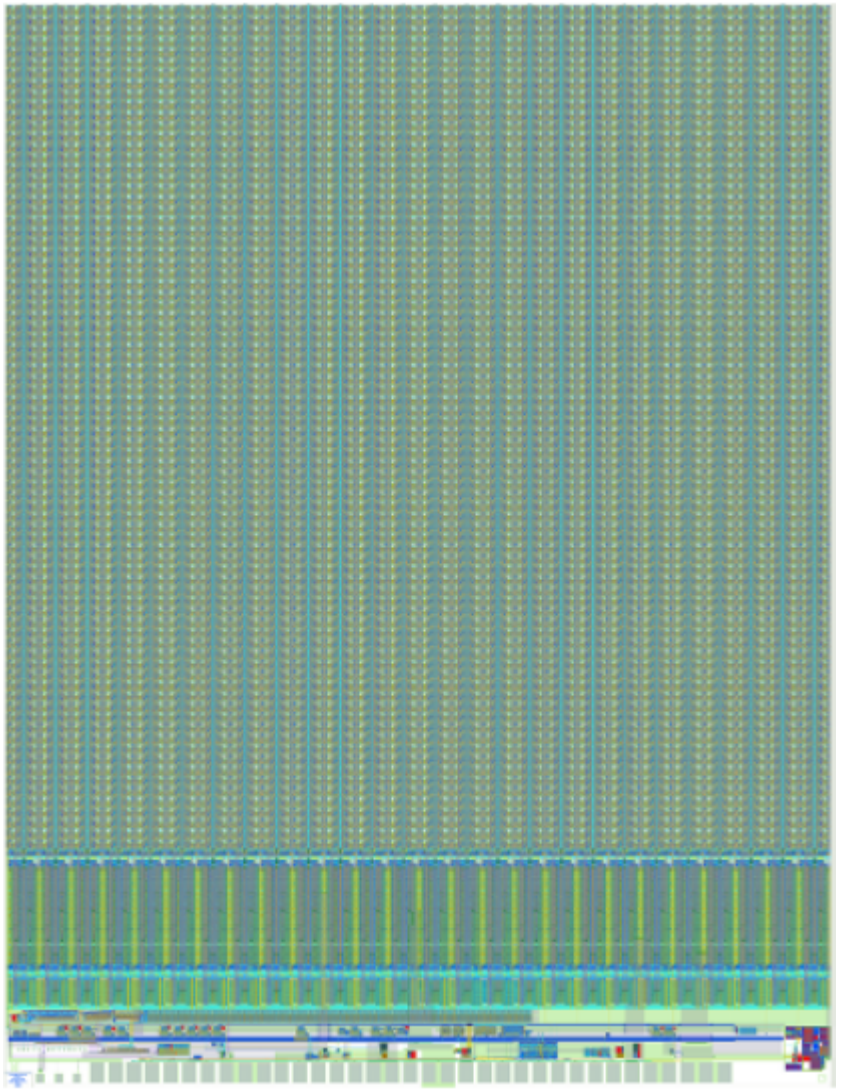
Irradiated digital ROCs 3

Ganna Dolinska, Ievgen Korol, Daniel Pitzl, DESY

PSI visit, 17.4.2013



- LHC dose vs radius
- KIT irradiation: 38 and 113 MRad
- Lab results:
  - analog current
  - gain
  - S-curves
  - time walk

Tracker radiation dose

Layer 1: 1 MGy

Layer 2: 400 kGy

Layer 3: 200 kGy

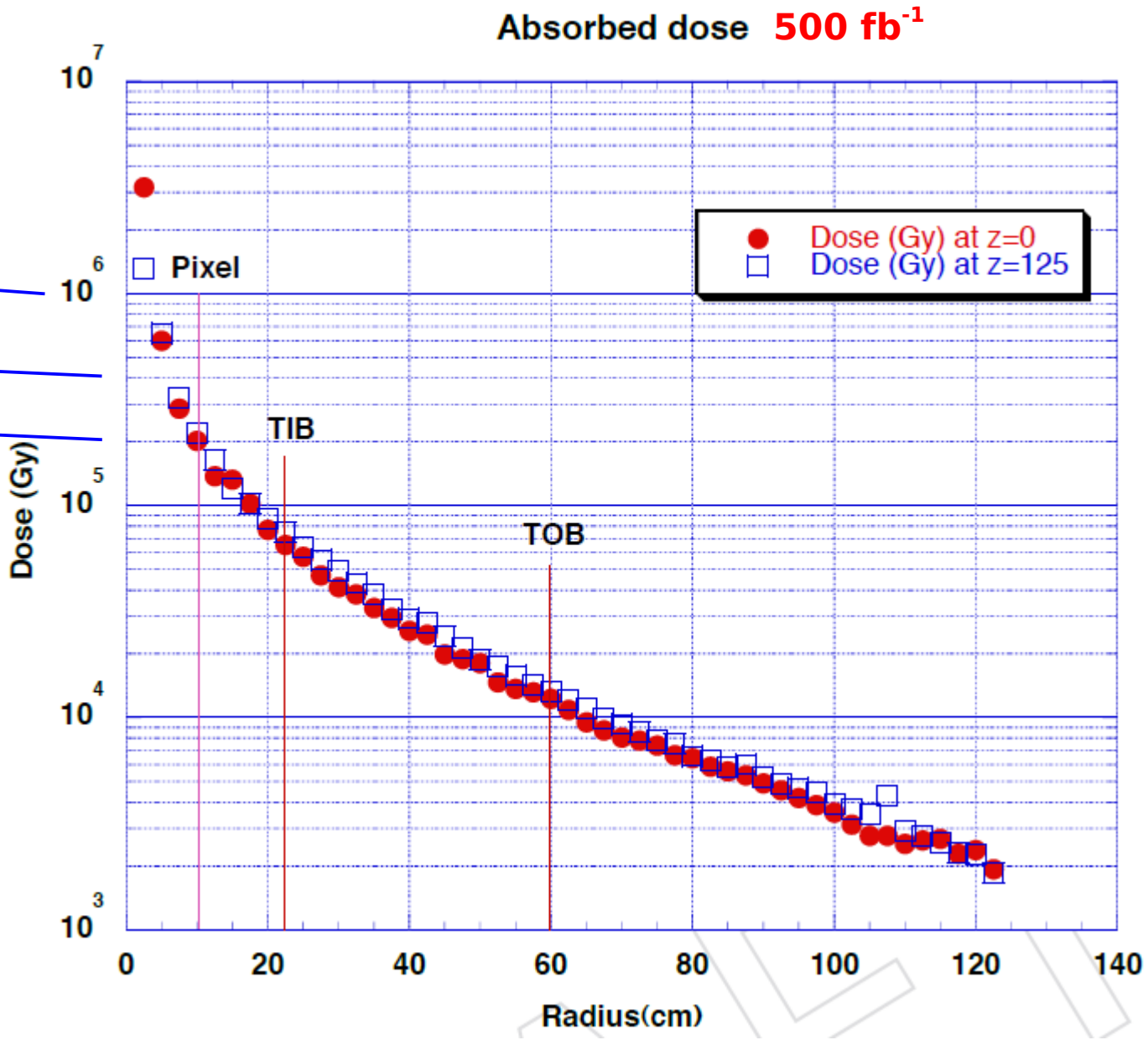
Layer 4: 150 kGy

100 kGy = 10 MRad

Fluence:

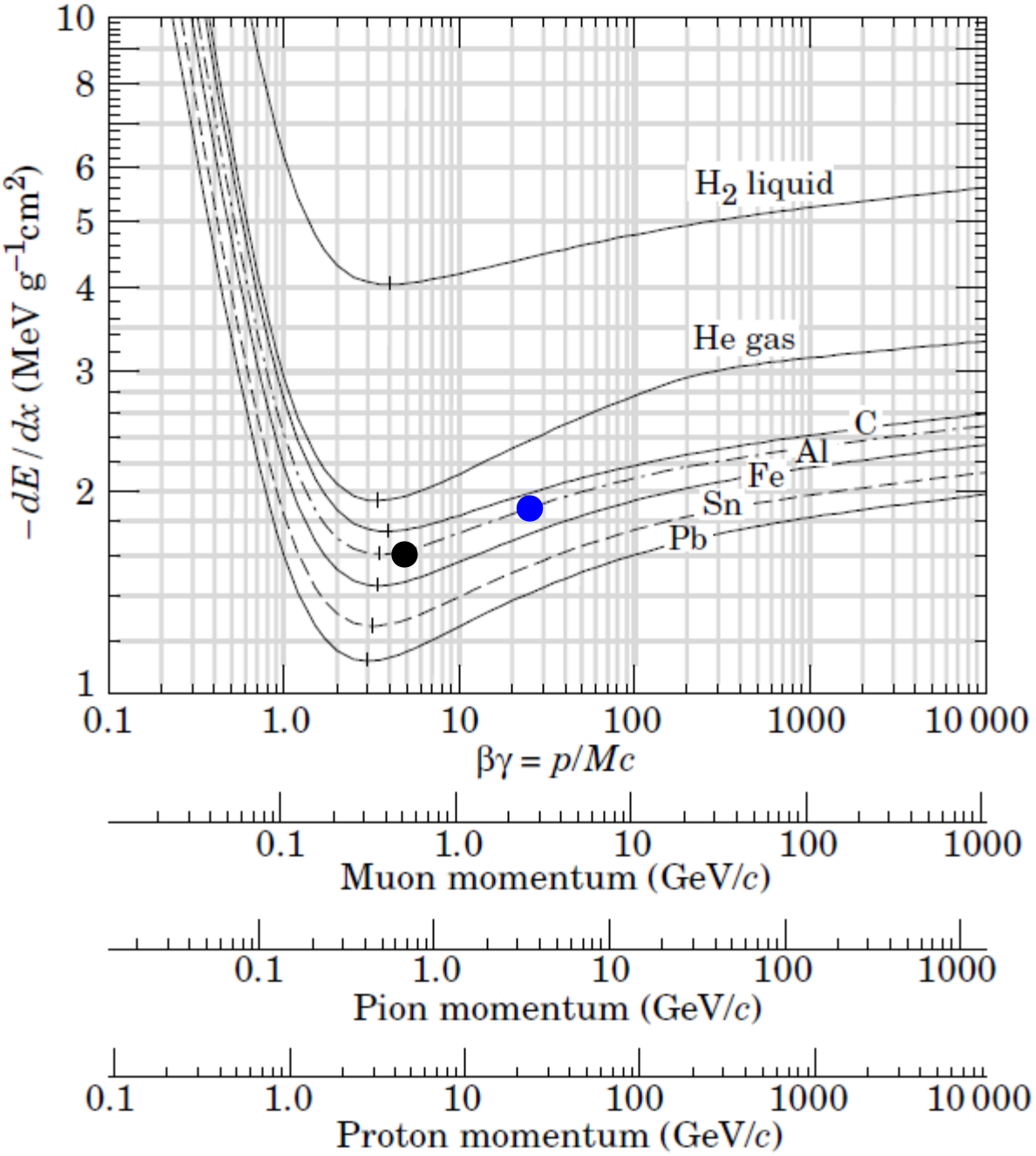
3 10^{13}/cm^2 mips

≃ 1 MRad



Pixel upgrade TDR 2012

ionization



Ka Zyklotron:
0.2 GeV/c protons
factor 20 above LHC

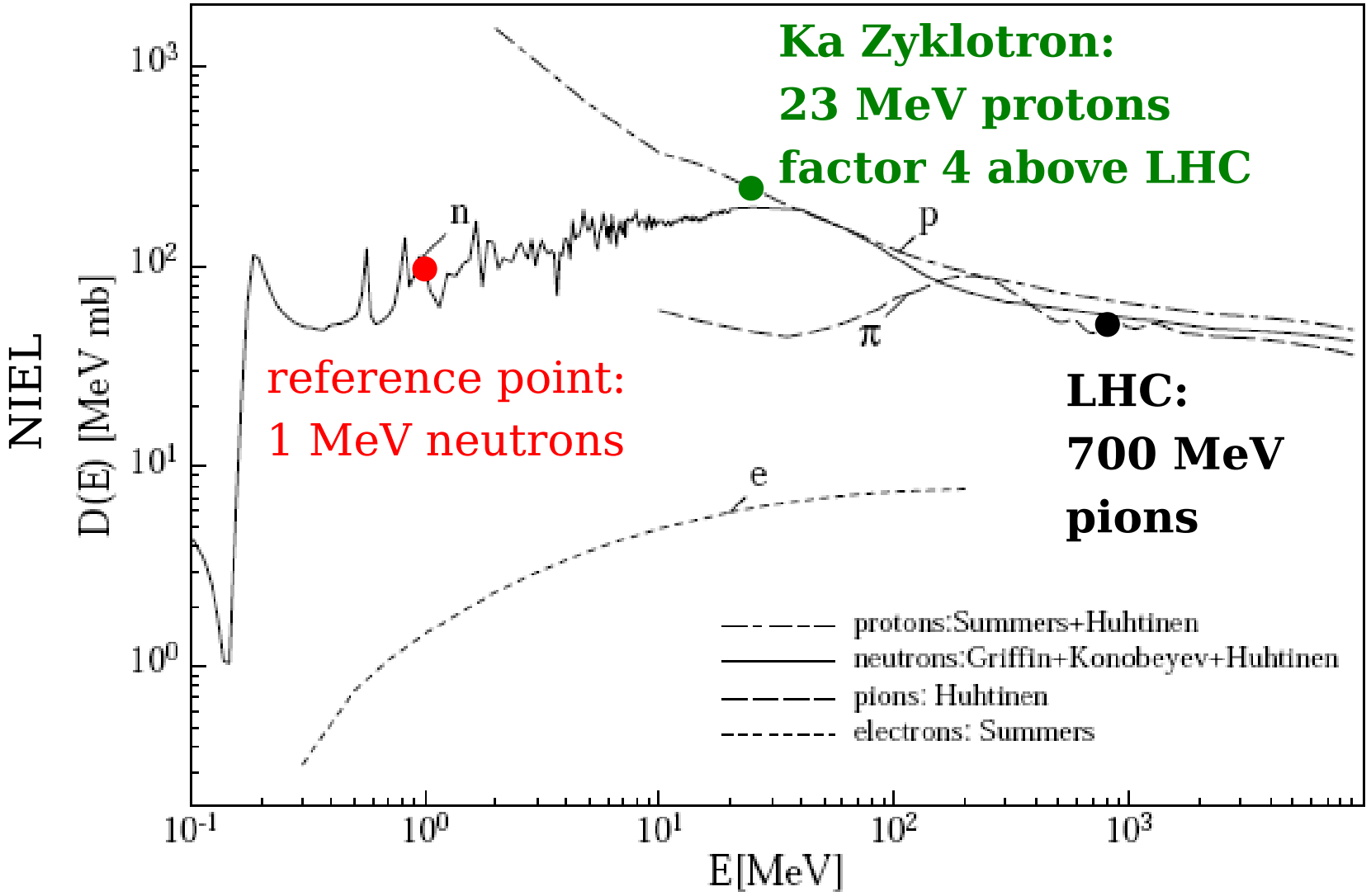
CERN PS:
24 GeV/c protons

LHC:
0.7 GeV/c pions

non-ionizing energy loss in silicon

non-ionizing energy loss (NIEL): displacement of atoms

Leakage current ~ NIEL

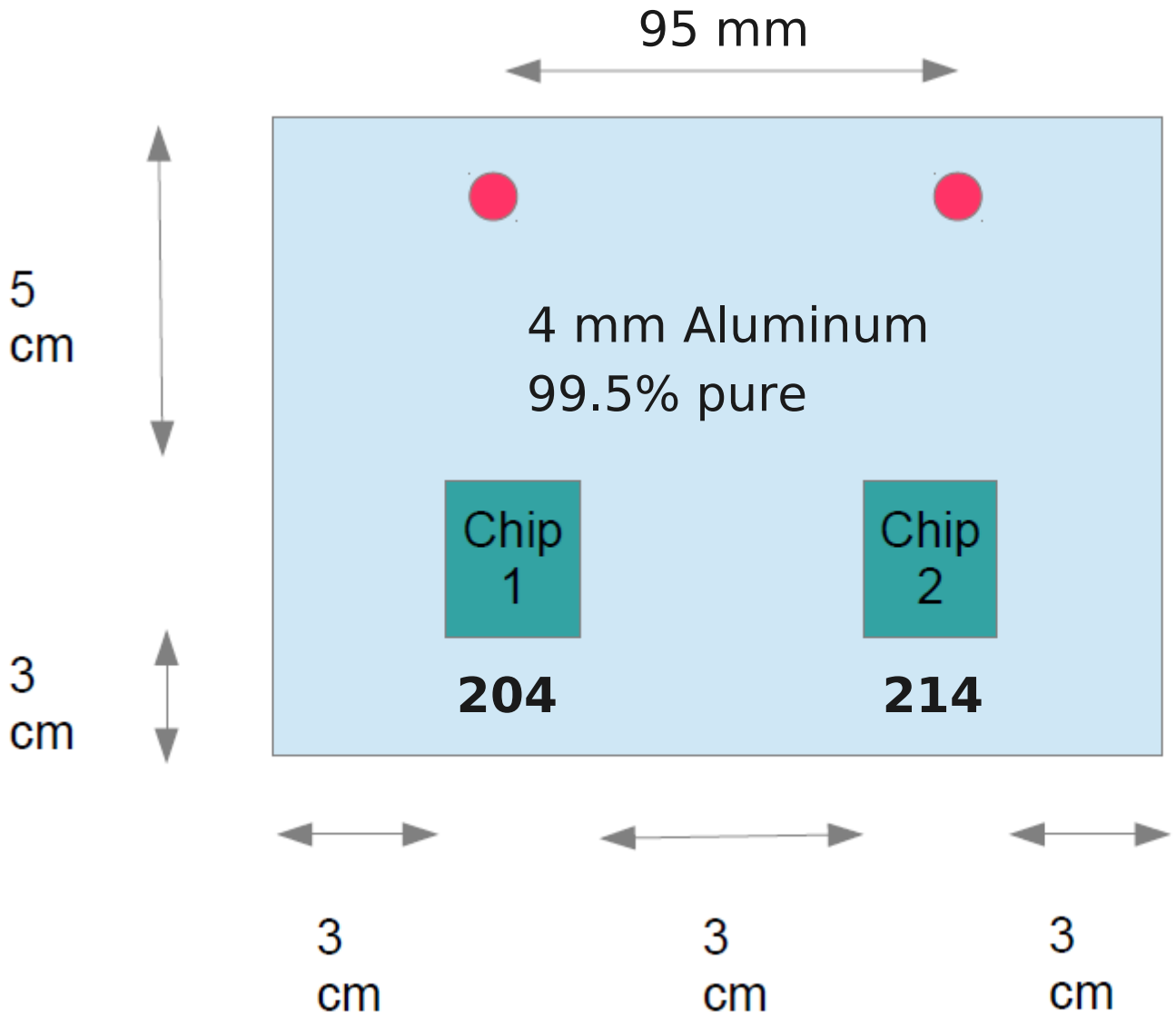


irradiation with slow protons at KIT

- Karlsruhe Zyklotron AG on KIT Campus Nord
  - E_{kin} = 25.3 MeV proton cyclotron, ~23 MeV at the sample
  - p = 208 MeV/c at the sample: non-relativistic, heavily ionizing
  - Minimal dose rate: 0.5 Mrad / s
  - Minimal flux: 1.6 10^{12} p/cm^{2}s
  - beam area is only few mm^2, sample is moved around. Uniformity?
- Dose in SiO_2 from proton fluence:
  - D = 3.17·10^{-9} Gy · F [p/cm^2] (from Alexander Dierlamm)
- Ni foil dosimetry:
  - dig 204: F = 1.185E14 p/cm² = 37.5 MRad in $Si0_2$
  - digtrig 214: F = 3.56E14 p/cm² = 113 MRad in $Si0_2$

`http://www.ekp.kit.edu/english/264.php`

irradiation mask for KIT

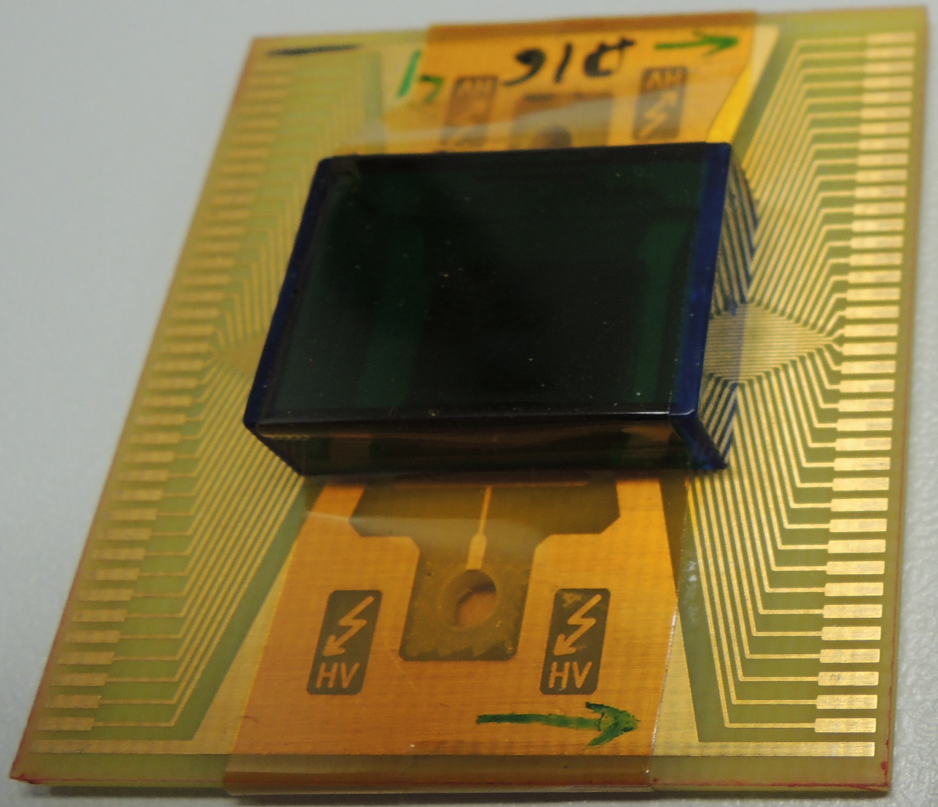


KIT:
irradiation mask required:
4 mm high purity aluminum,
just leaving the chips exposed.
Made at DESY.

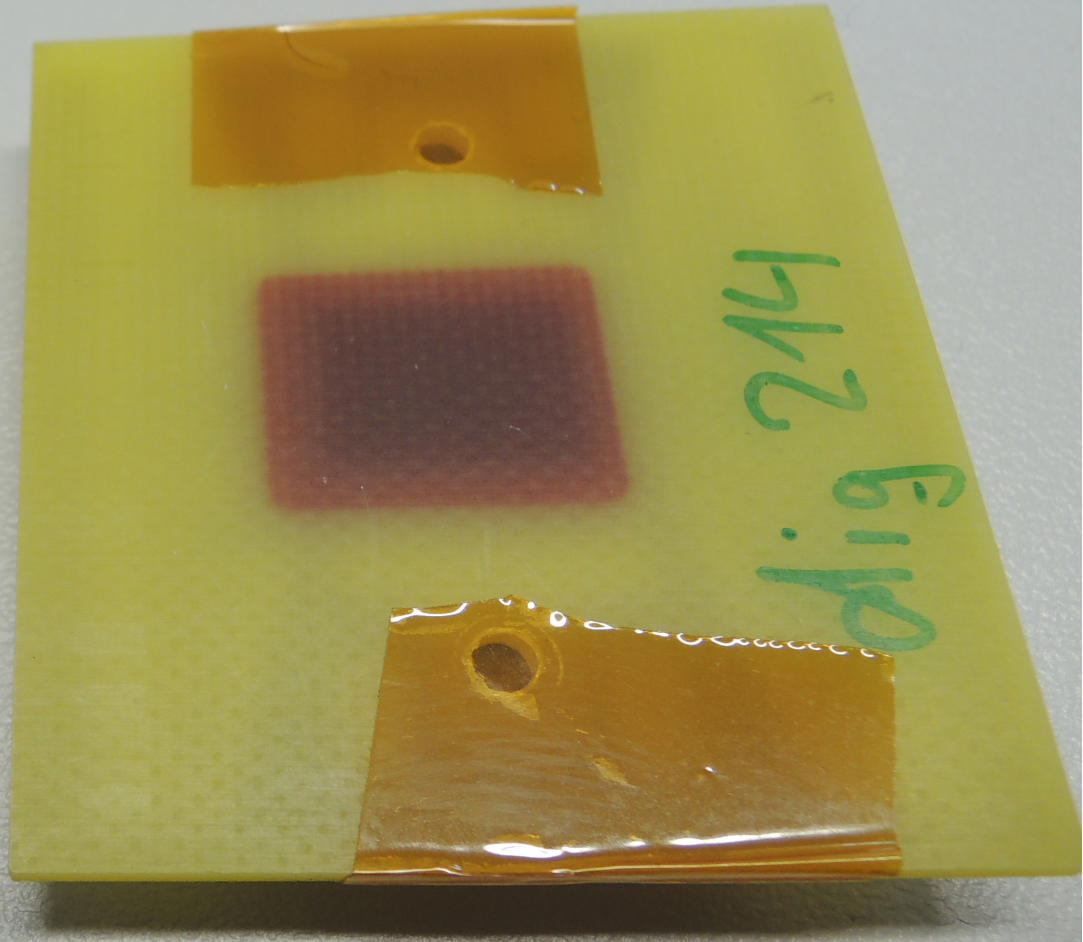
Stefan Heindl, KIT, Sep 2012

irradiated at Karlsruhe p Zyklotron

204 dig: 37.5 MRad



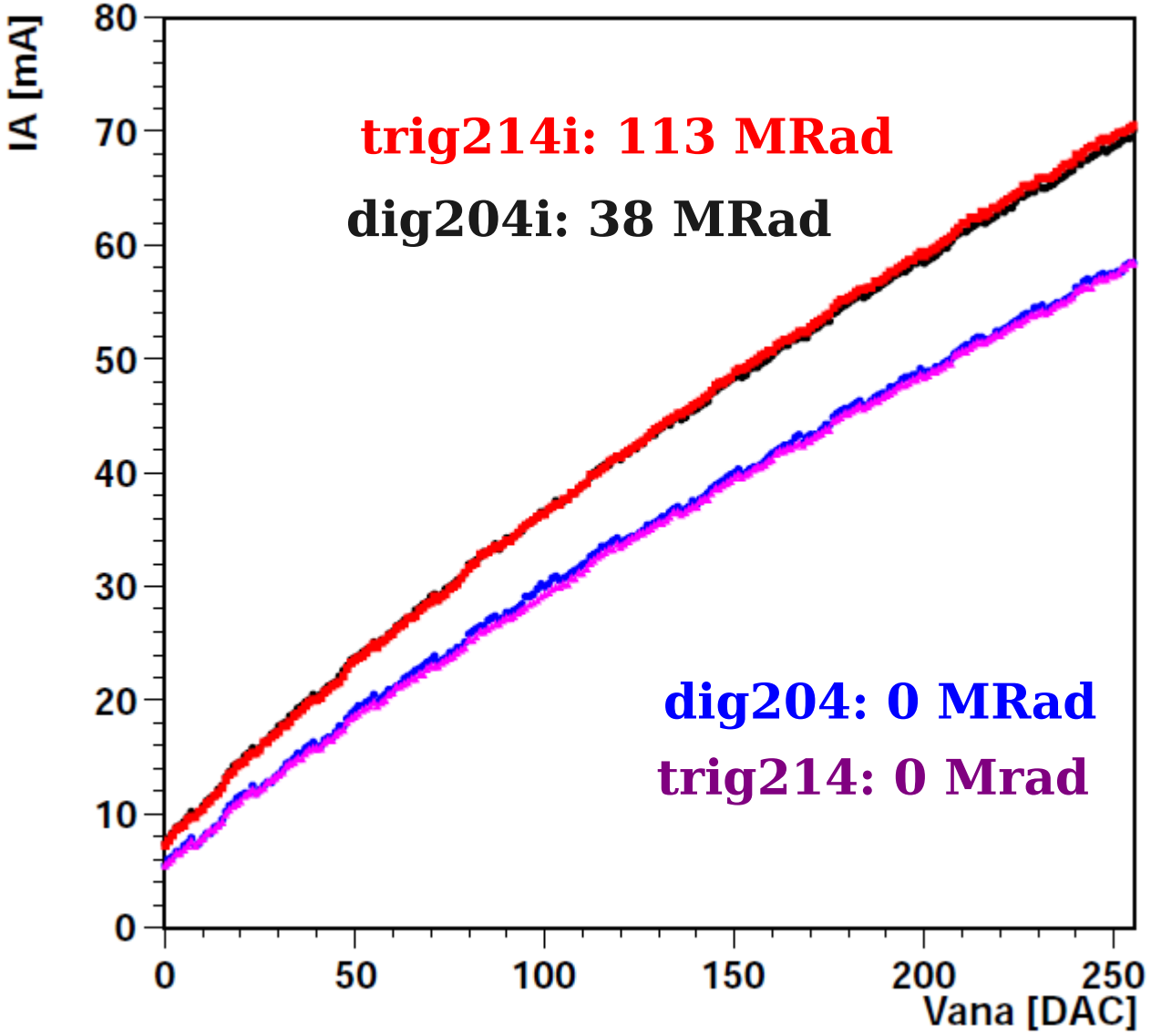
214 digtrig: 113 MRad



Al mask opening visible on PCB

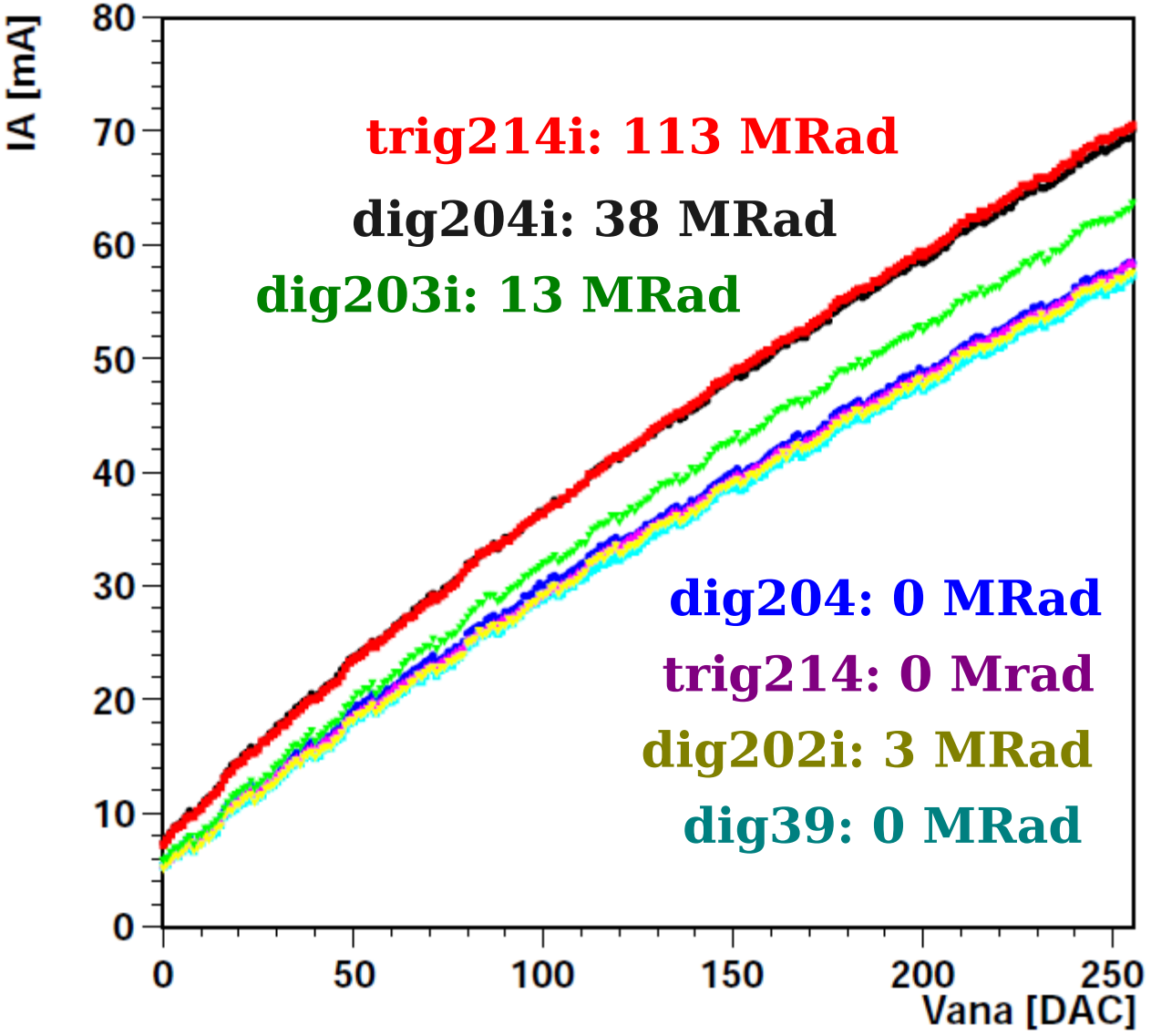
ROC analog current

Analog current vs Vana DAC



- Test board:
  - `va 1900 mV`
- Vana: 8 bit DAC, scanned in steps of one, with 500 ms delay.
- Current measured on the test board: `GetIA`
- unirradiated ROCs are similar
- irradiated ROCs have 20% higher analog current at the same Vana setting.

Analog current vs Vana DAC



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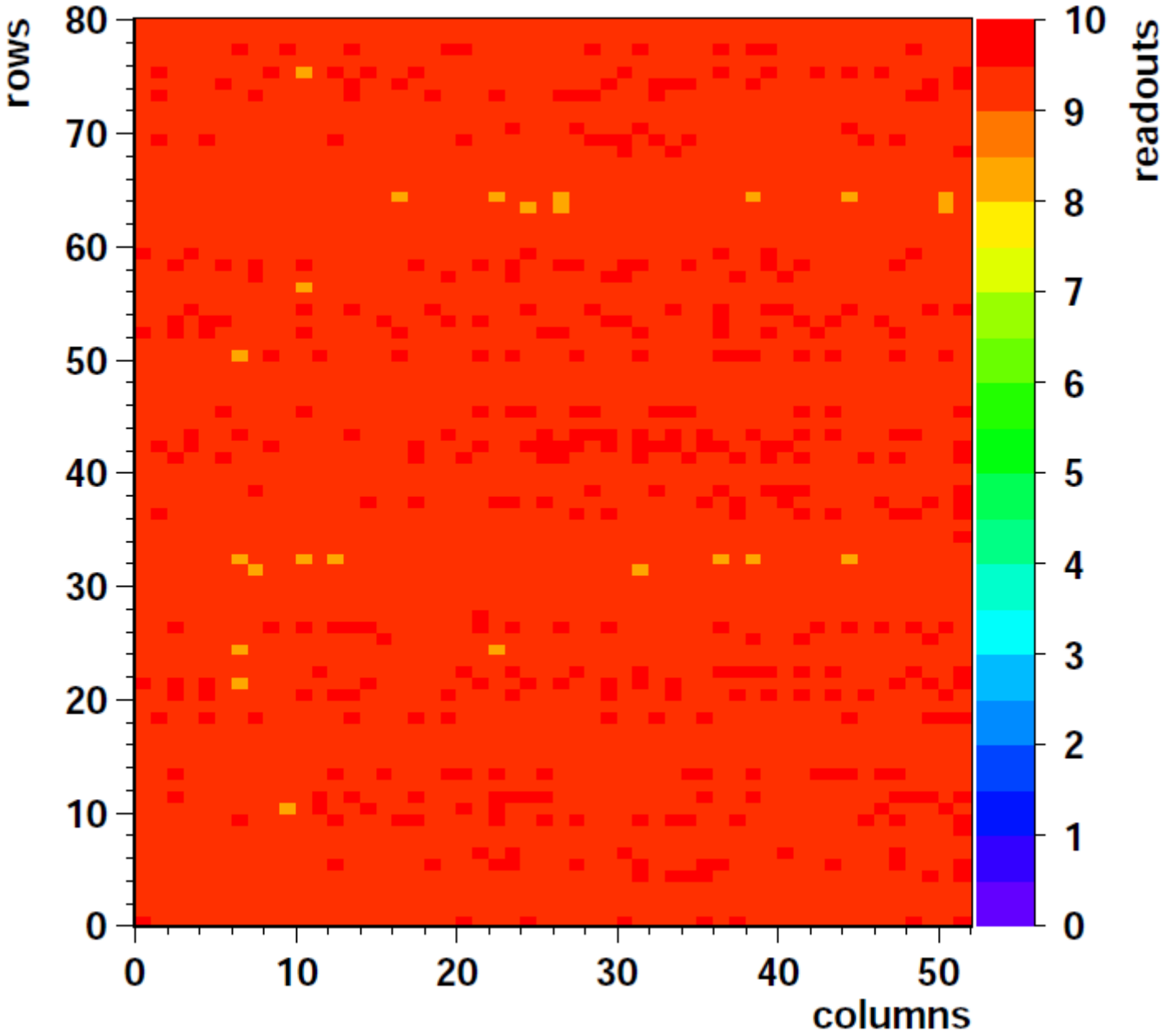
Alive test

Pixel alive test



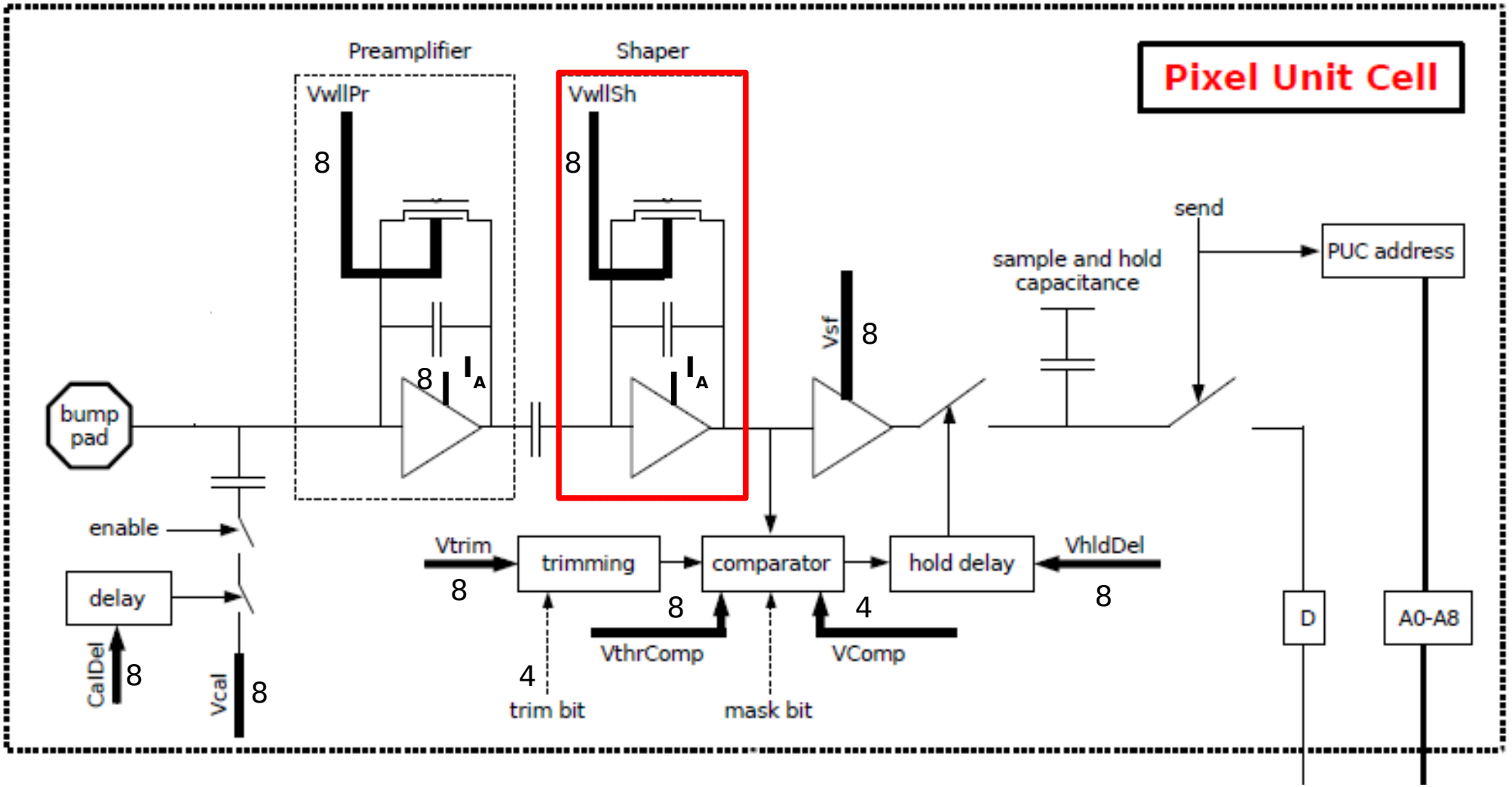
- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
  - **default DACs**
- PixelAlive test runs ChipEfficiency with 10 triggers per pixel
- **Not all pixels respond 10 times**

default DAC parameters

1	Vdig	6
2	Vana	58
3	Vsf	30
4	Vcomp	12
7	VwllPr	60
9	VwllSh	60
10	VhldDel	252
11	Vtrim	45
12	VthrComp	36
13	VIBias_Bus	20
14	Vbias_sf	10
15	VoffsetOp	30
17	VOffsetRO	110
18	VIon	115
19	Vcomp_ADC	120
20	VIref_ADC	70
22	VIColOr	100
25	Vcal	199
26	CalDel	86
253	CtrlReg	0
254	WBC	100

- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25

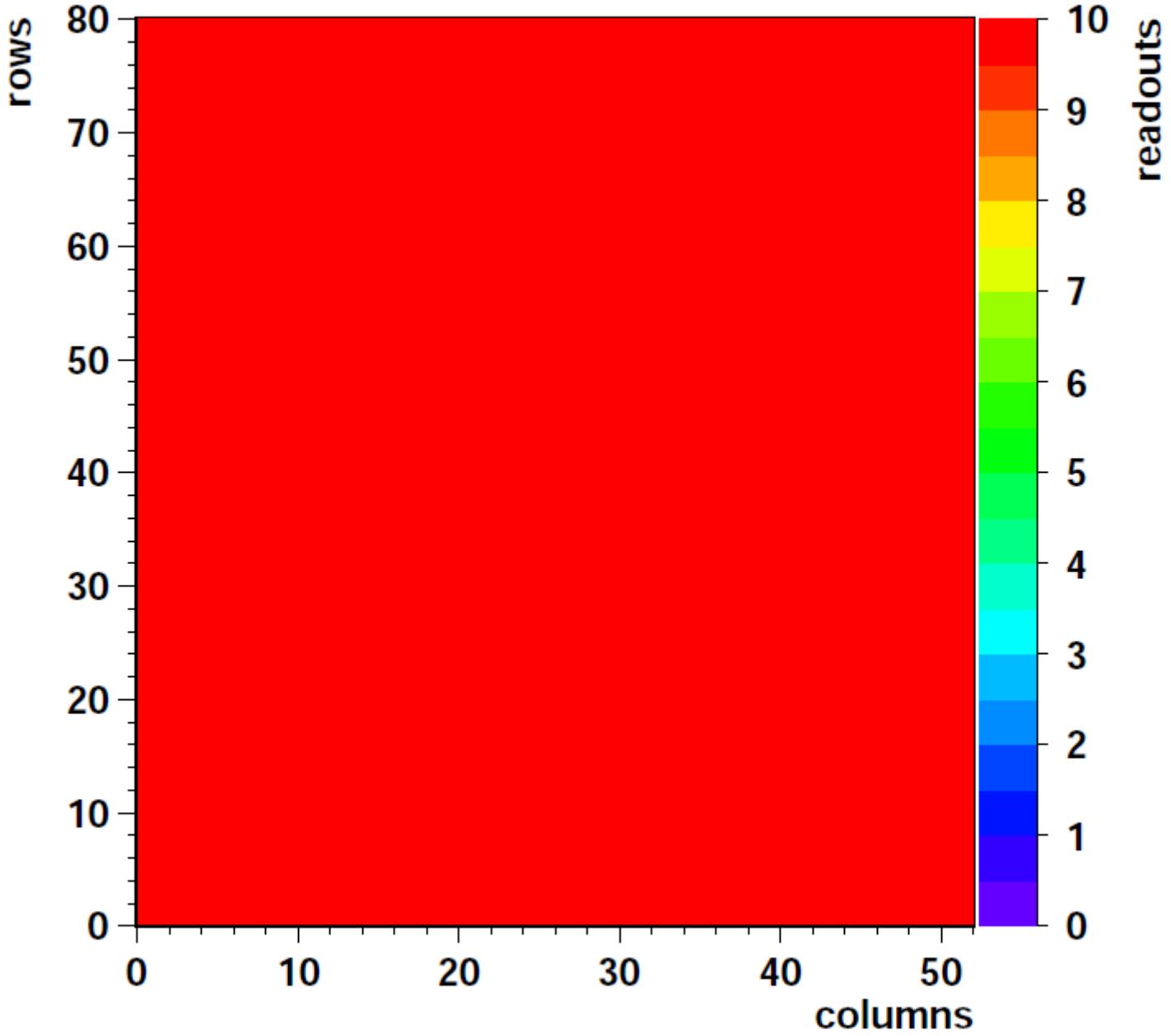
psi46dig pixel unit cell



name / bits **adjustable by programmable DAC**

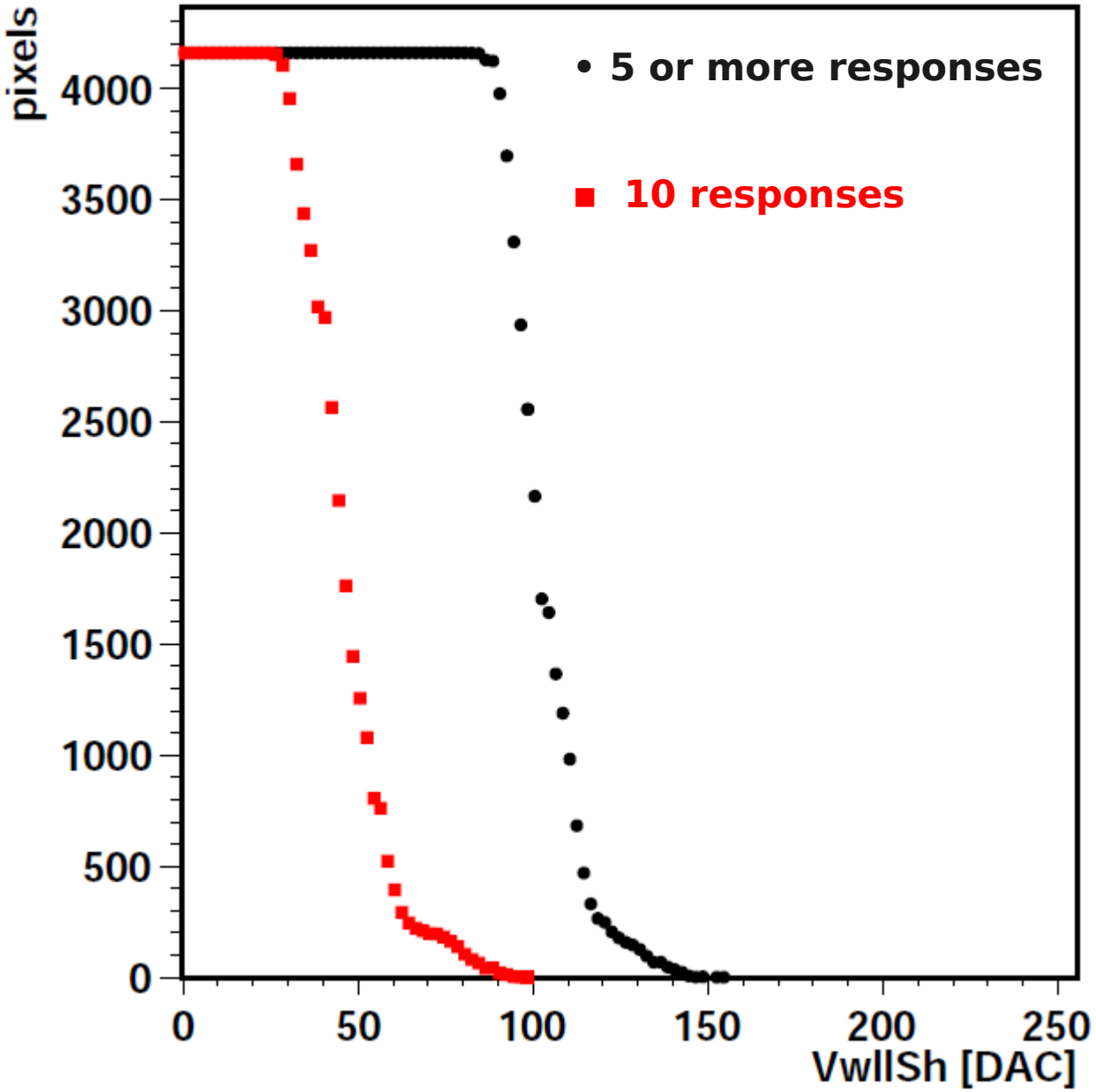
tried CalDel, VwllPr, VwllSh, Vana

Pixel alive test VwllSh 0



- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
  - **VwllSh 0**
- PixelAlive test runs ChipEfficiency with 10 triggers per pixel
- **Now all pixels respond 10 times**

Chip efficiency vs VwllSh

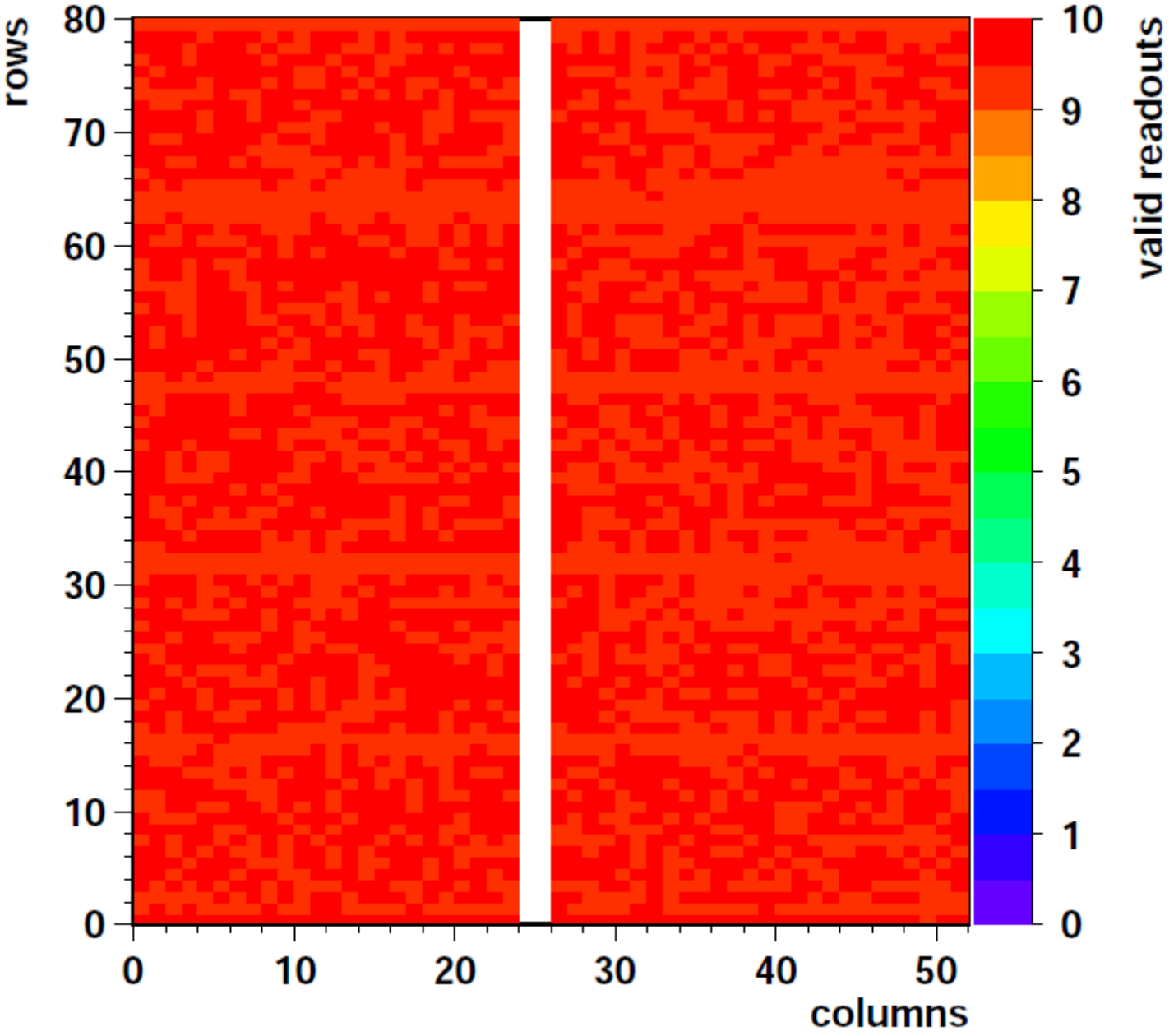


- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
- PixelAlive test runs ChipEfficiency with 10 triggers per pixel
- **Need VwllSh < 30 DACs to have all pixels respond 10 times**

Alive test chip 214

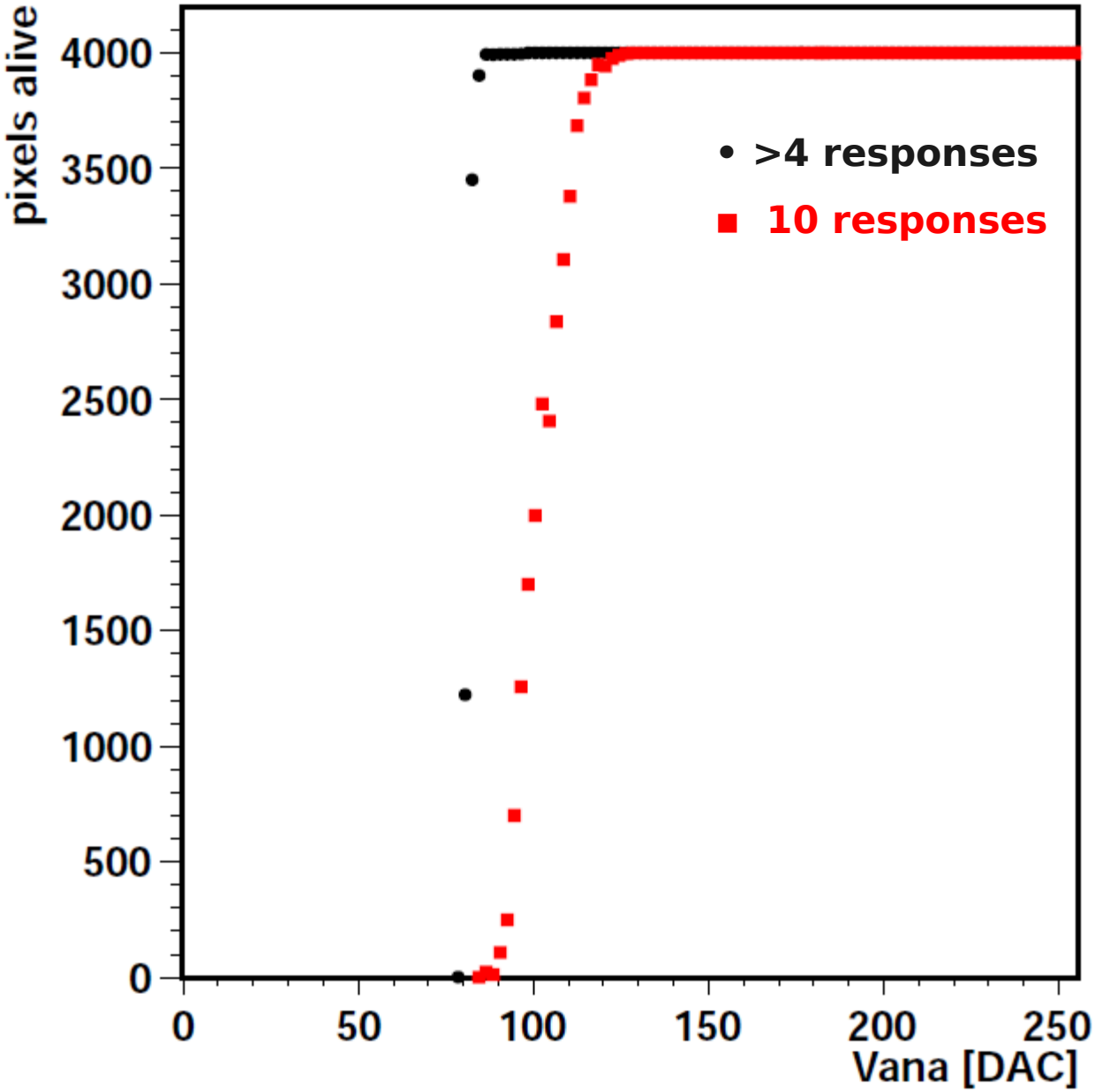
chip 214 is a psi46digtrig

Pixel alive test



- Digital Chip 214
  - 113 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 31
  - **VwllSh 0**
  - **CtrlReg 4, Vcal 200**
- PixelAlive test runs ChipEfficiency with 10 triggers per pixel
- **Not all pixels respond 10 times**

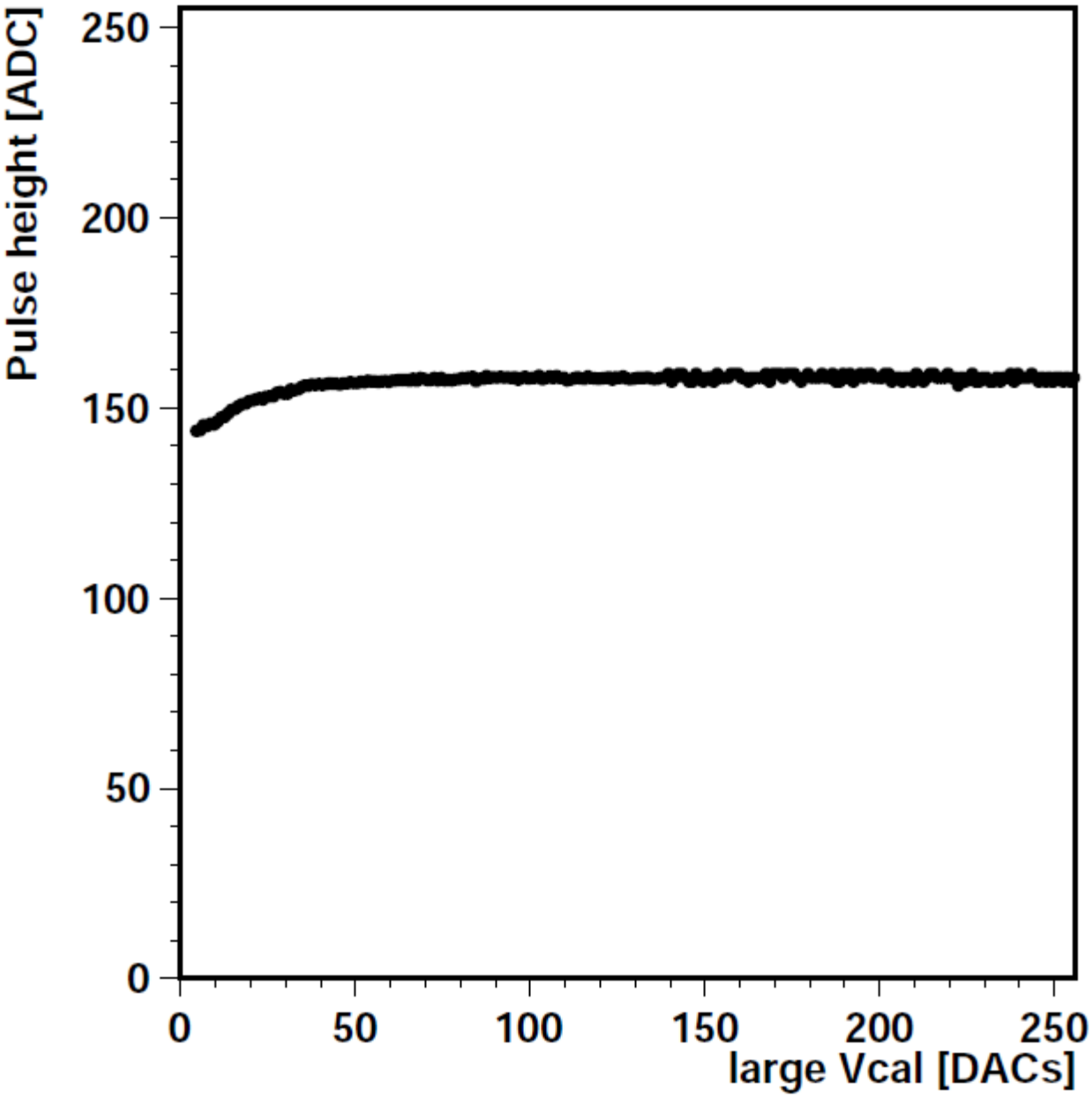
Chip efficiency vs Vana



- Digital Chip 214
  - 113 MRad
  - trimmed to Vcal threshold 31
  - CtrlReg 4, Vcal 200
- PixelAlive test runs ChipEfficiency with 10 triggers per pixel
- **Need Vana > 110 DACs to have all pixels respond 10 times**
  - **Ia = 40 mA**

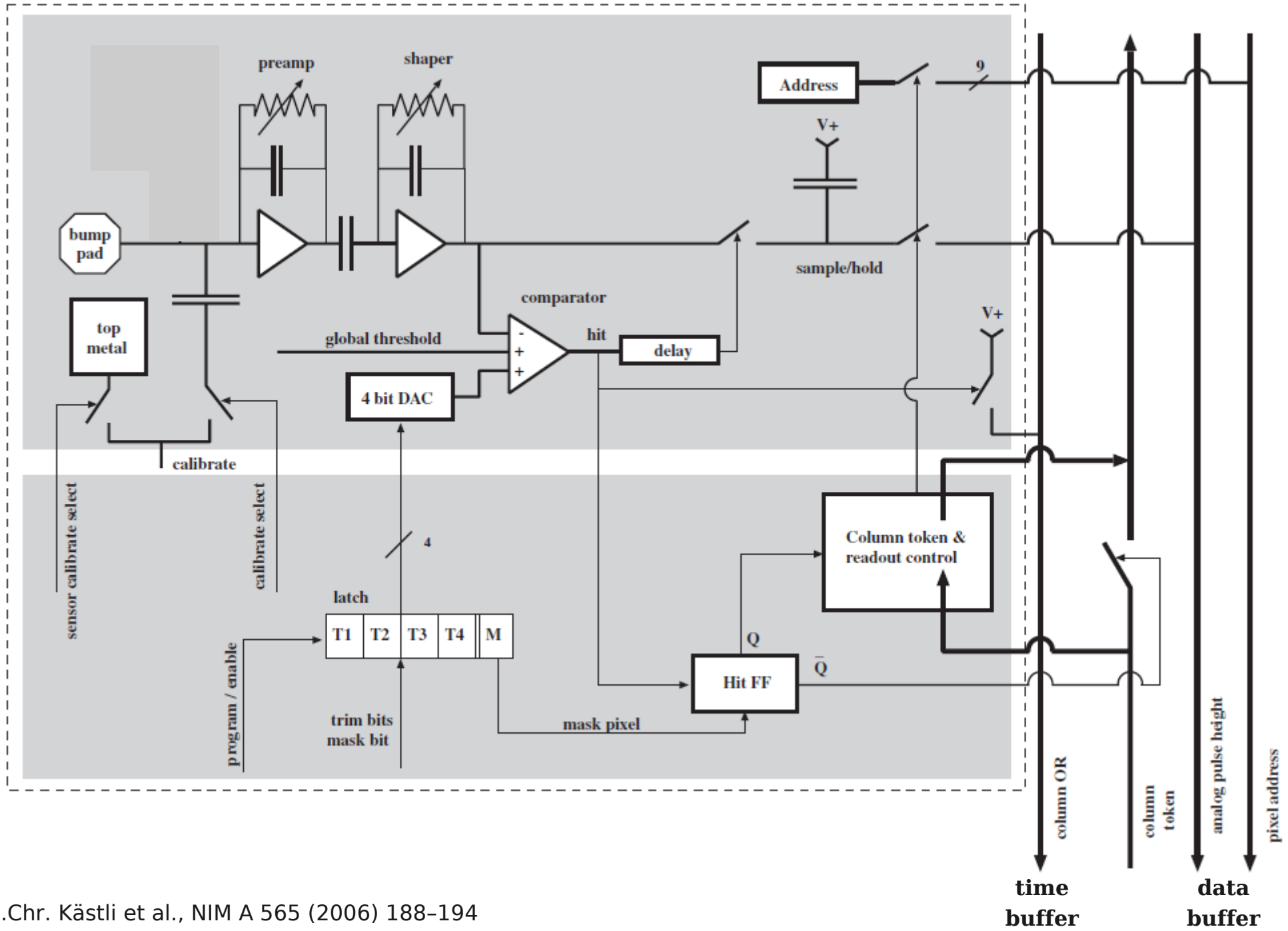
gain

PH vs Vcal



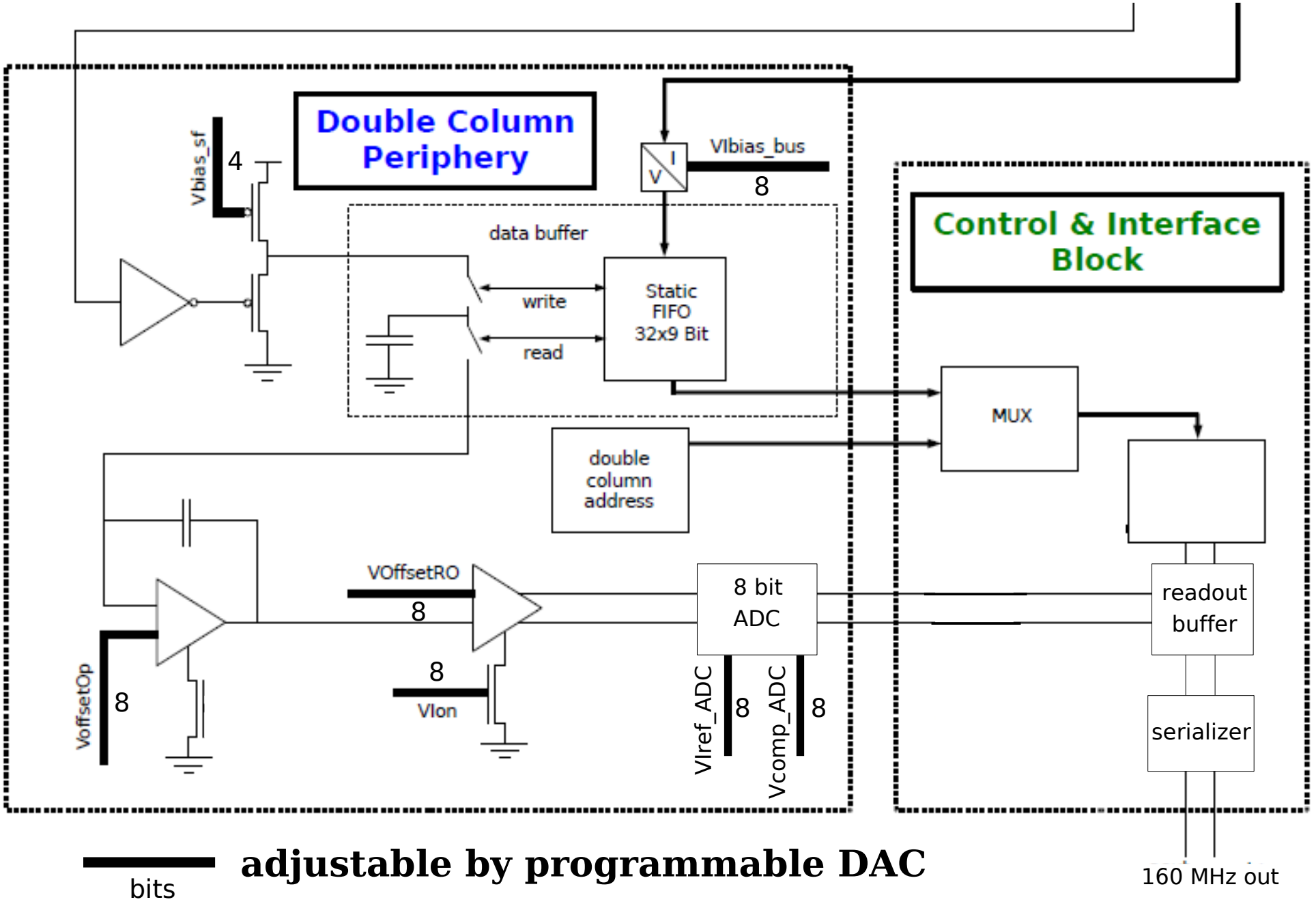
- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
  - **default DACs**
- PH vs large Vcal:
  - CtrlReg 4
- **Large offset and saturation?**

psi46 pixel unit cell



H.Chr. Kästli et al., NIM A 565 (2006) 188–194

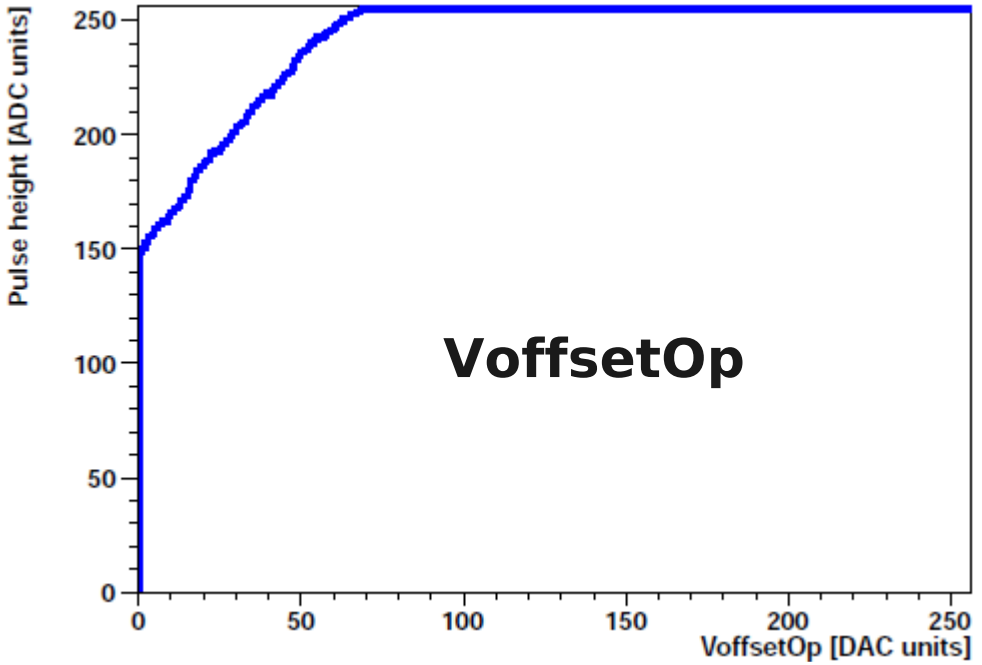
psi46dig periphery

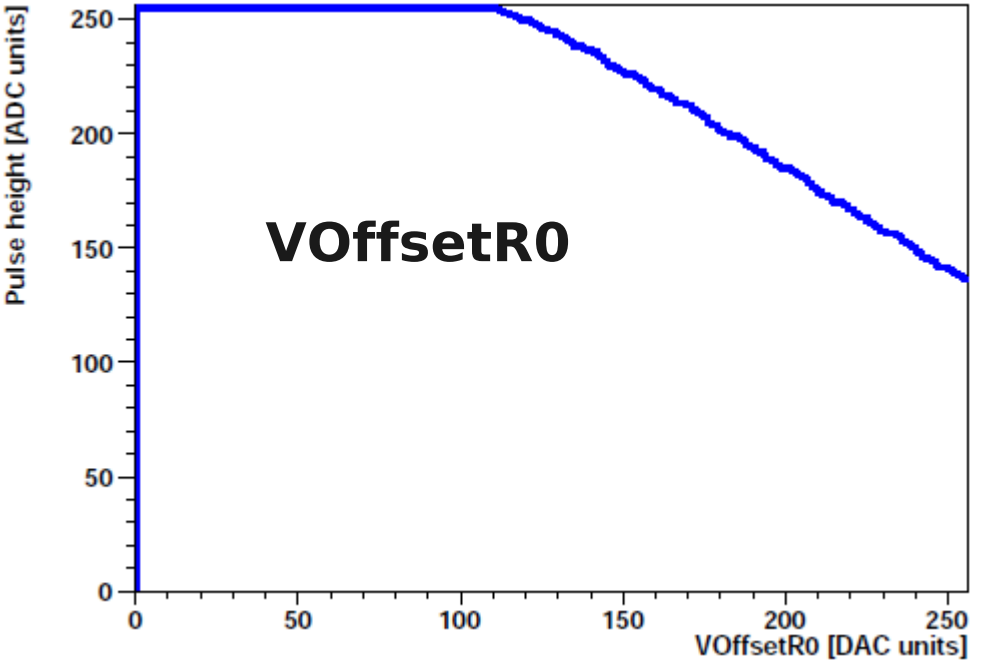


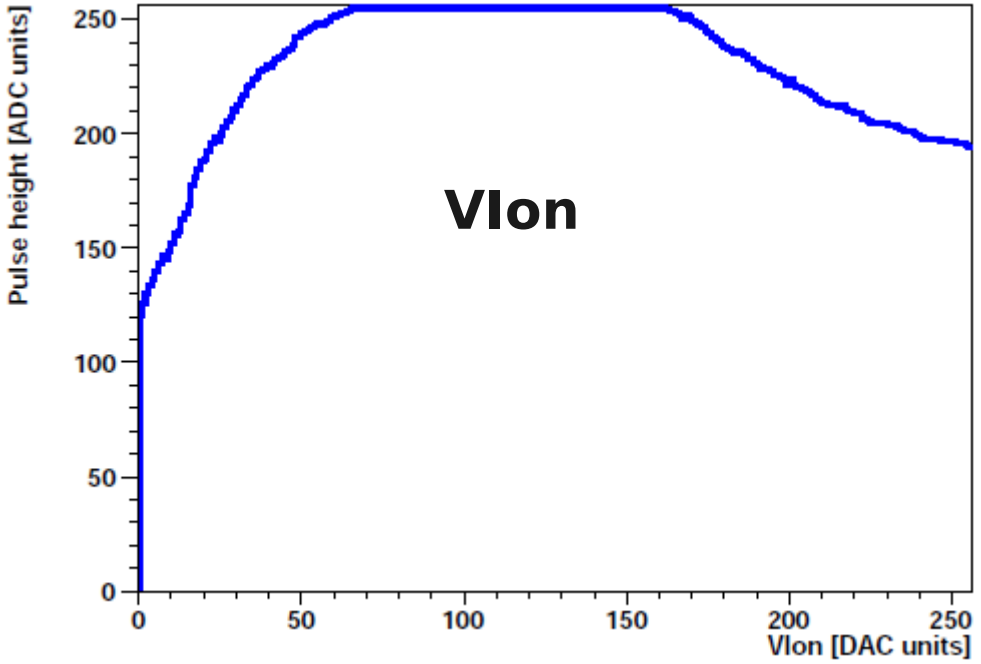
pix 3-3

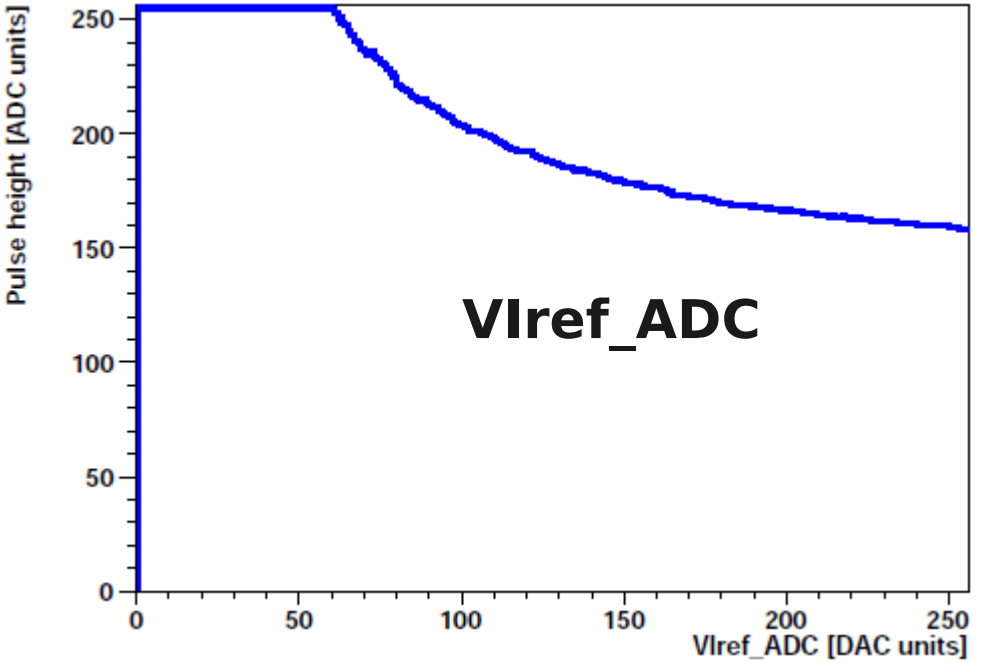
DAC dependencies

large pulse:
CtrlReg 4, Vcal 255





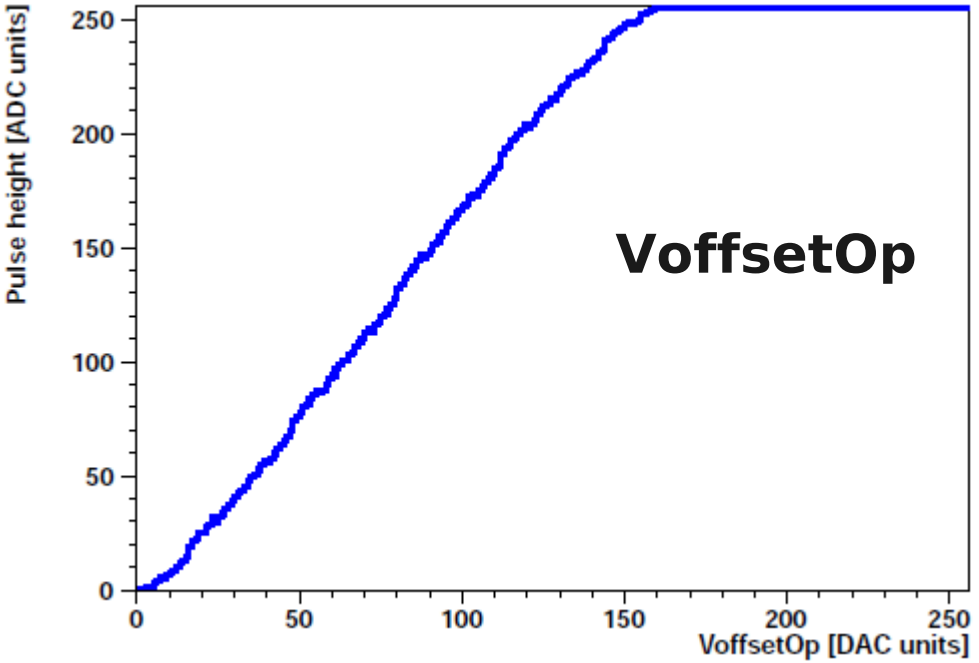


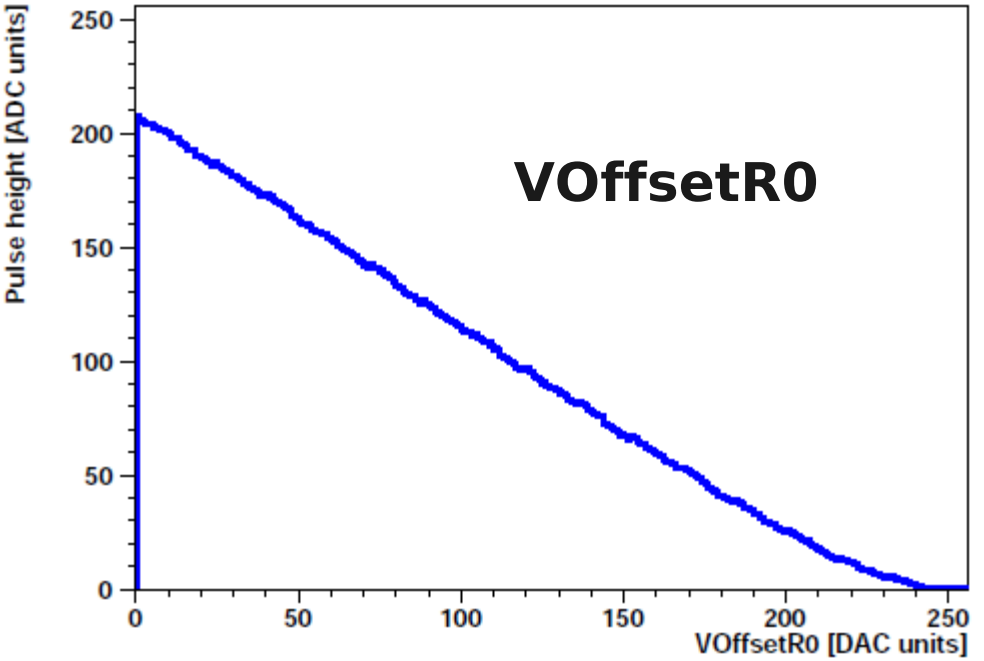


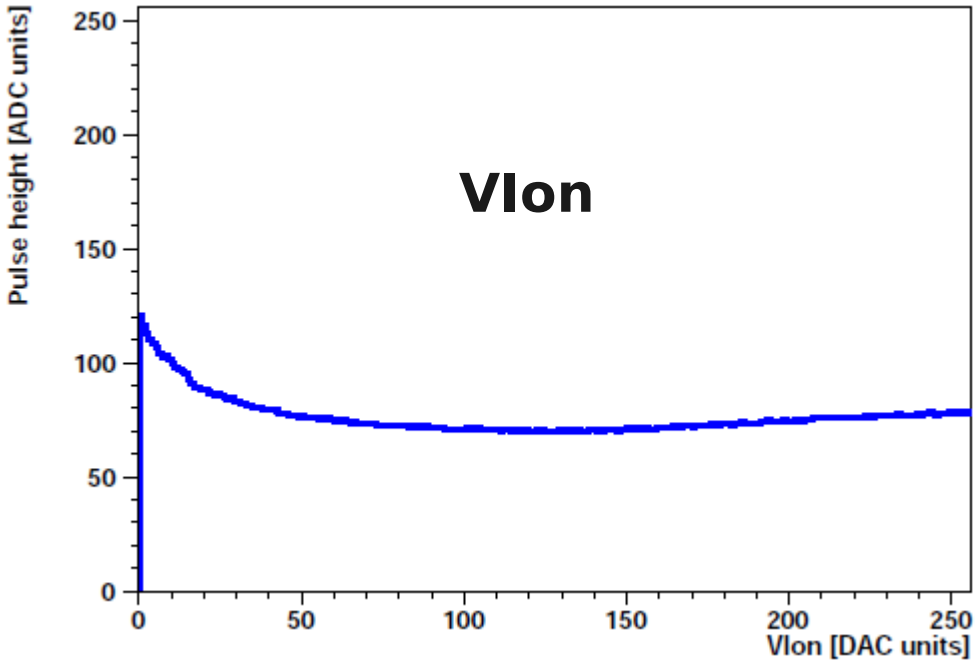
pix 3-3

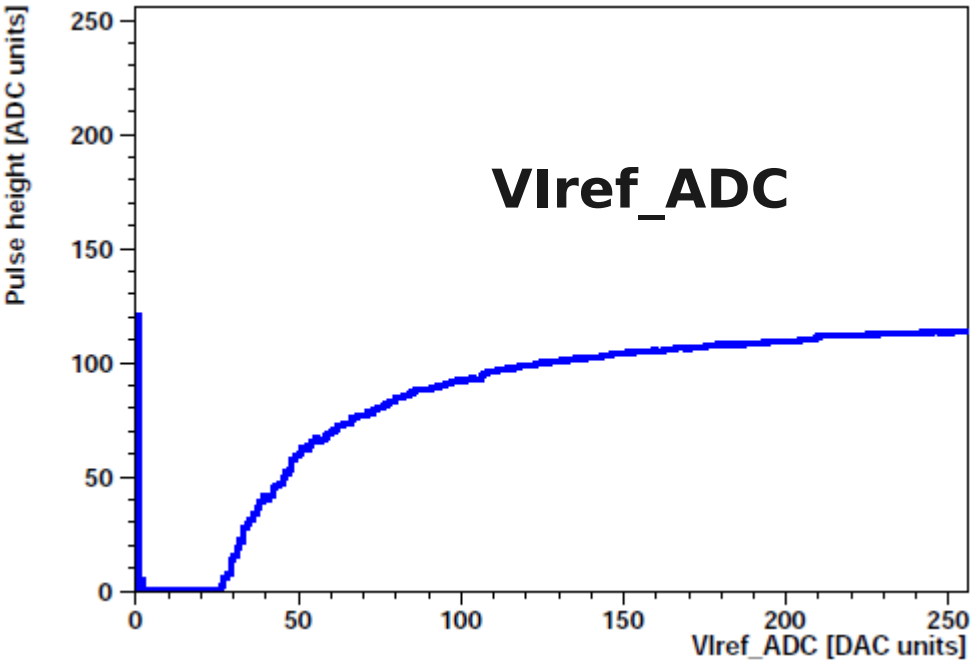
DAC dependencies

small pulse:
CtrlReg 0, Vcal 40

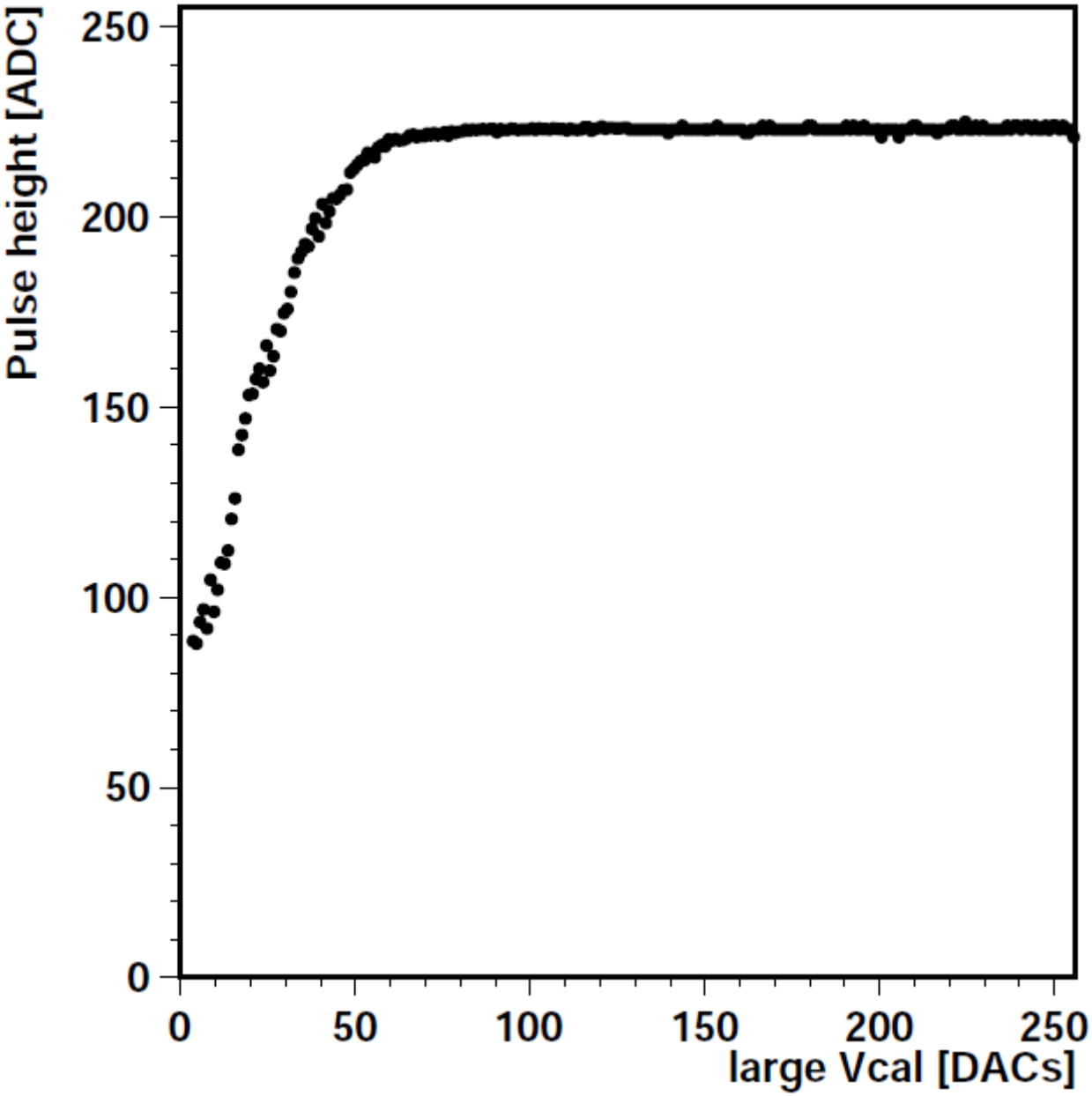








PH vs Vcal



- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
  - **Vdig 11**
  - 5 gain and offset DACs tuned
- PH vs large Vcal:
  - CtrlReg 4
- **analog response recovered**

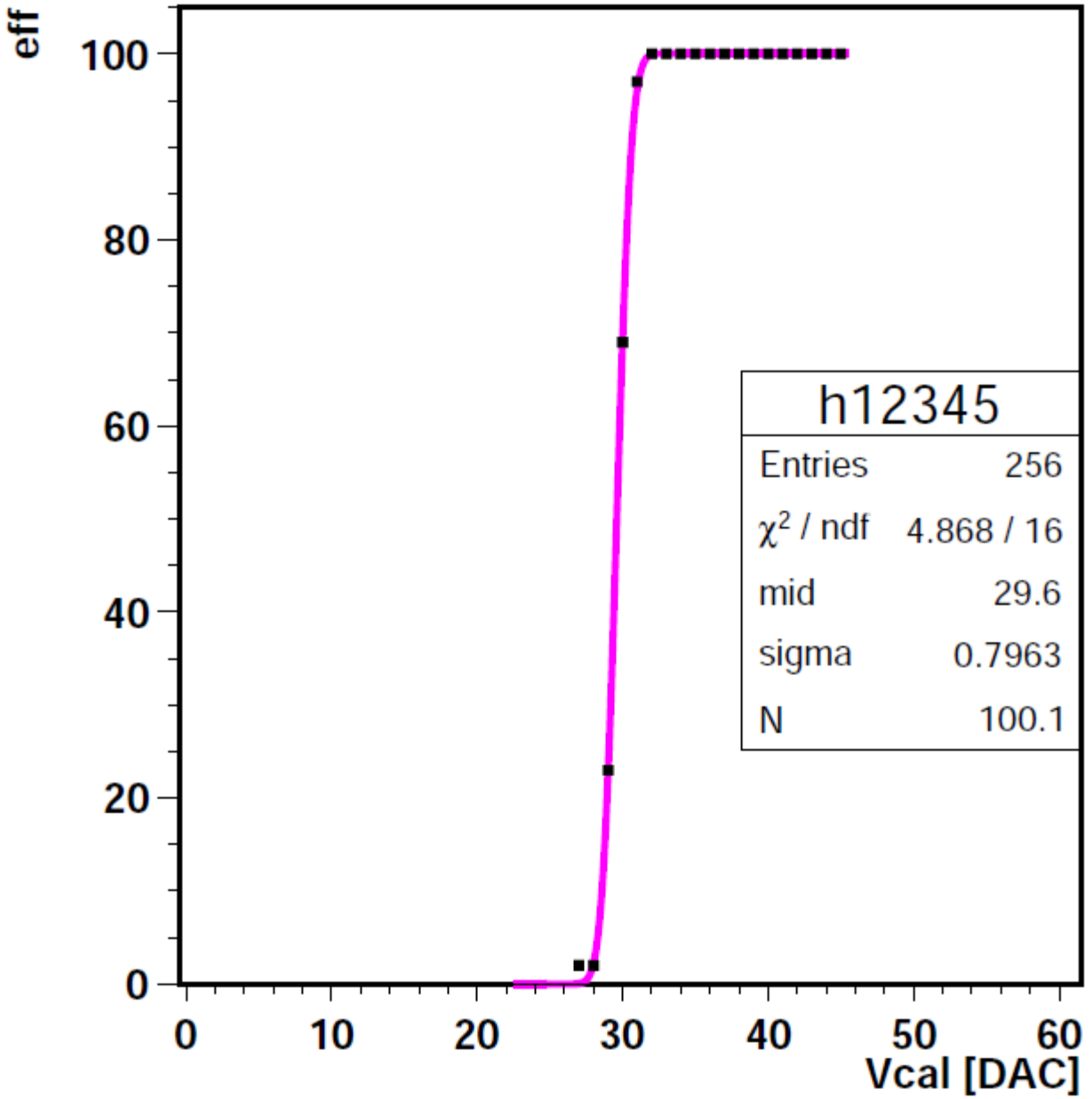
tuned DAC parameters

1	Vdig	11
2	Vana	58
3	Vsf	30
4	Vcomp	12
7	VwllPr	60
9	VwllSh	0
10	VhldDel	252
11	Vtrim	45
12	VthrComp	36
13	VIBias_Bus	20
14	Vbias_sf	14
15	VoffsetOp	33
17	VOffsetR0	170
18	VIon	40
19	Vcomp_ADC	120
20	VIref_ADC	34
22	VIColOr	100
25	Vcal	200
26	CalDel	86
253	CtrlReg	0
254	WBC	100

- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 25
  - analog readout tuned

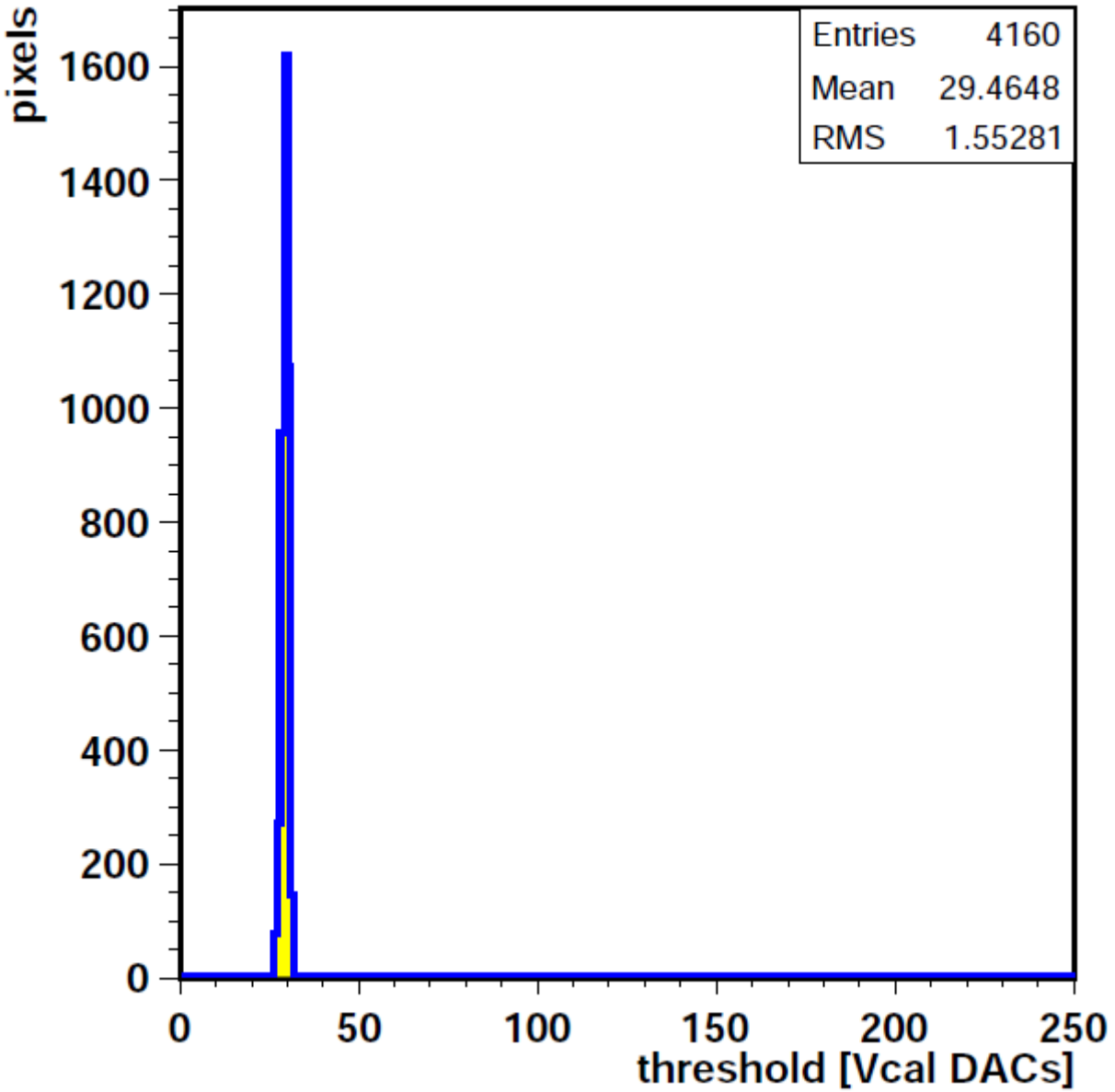
S-curve studies

Threshold curve



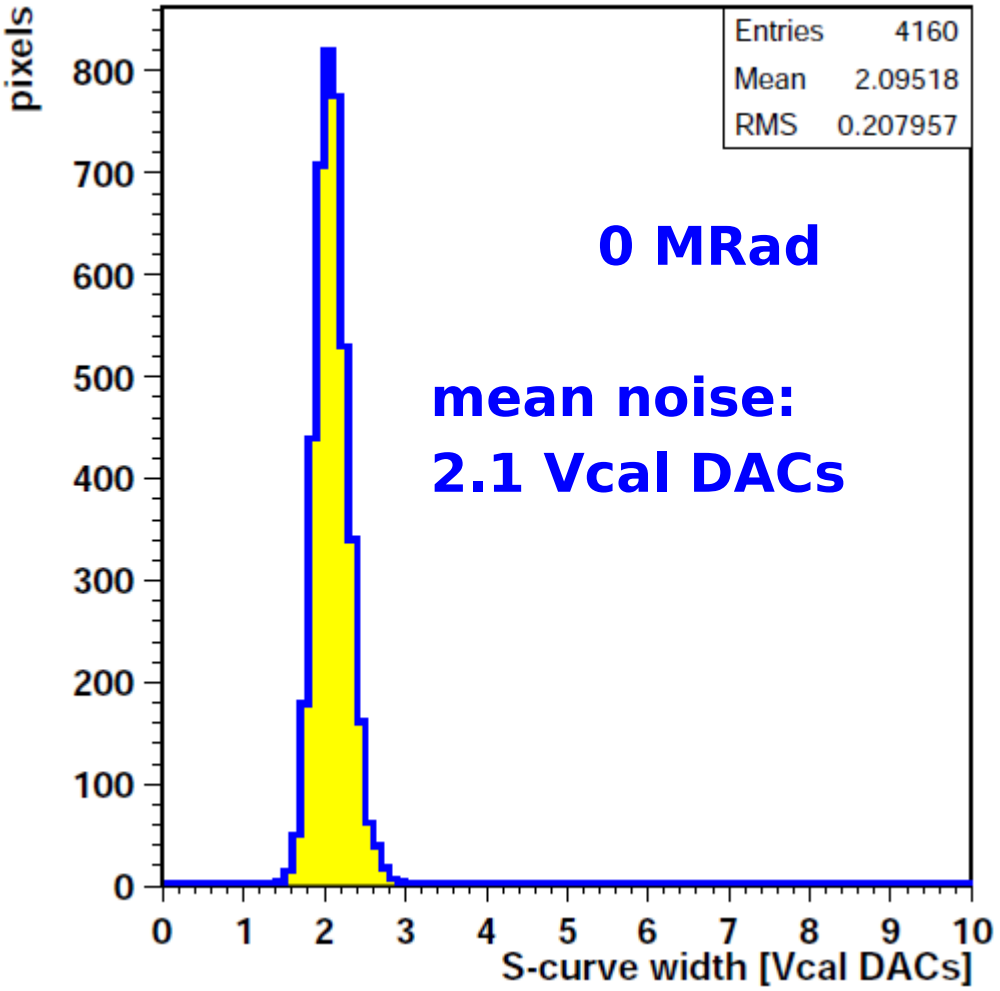
- Digital Chip 204
  - no sensor
  - 38 MRad
  - Ia 25 mA
  - trim 30
  - pixel (29, 25)
- Standard S-curve:
  - pixel efficiency vs small Vcal
- Fit by error function:
  - mid = threshold
  - sigma = noise

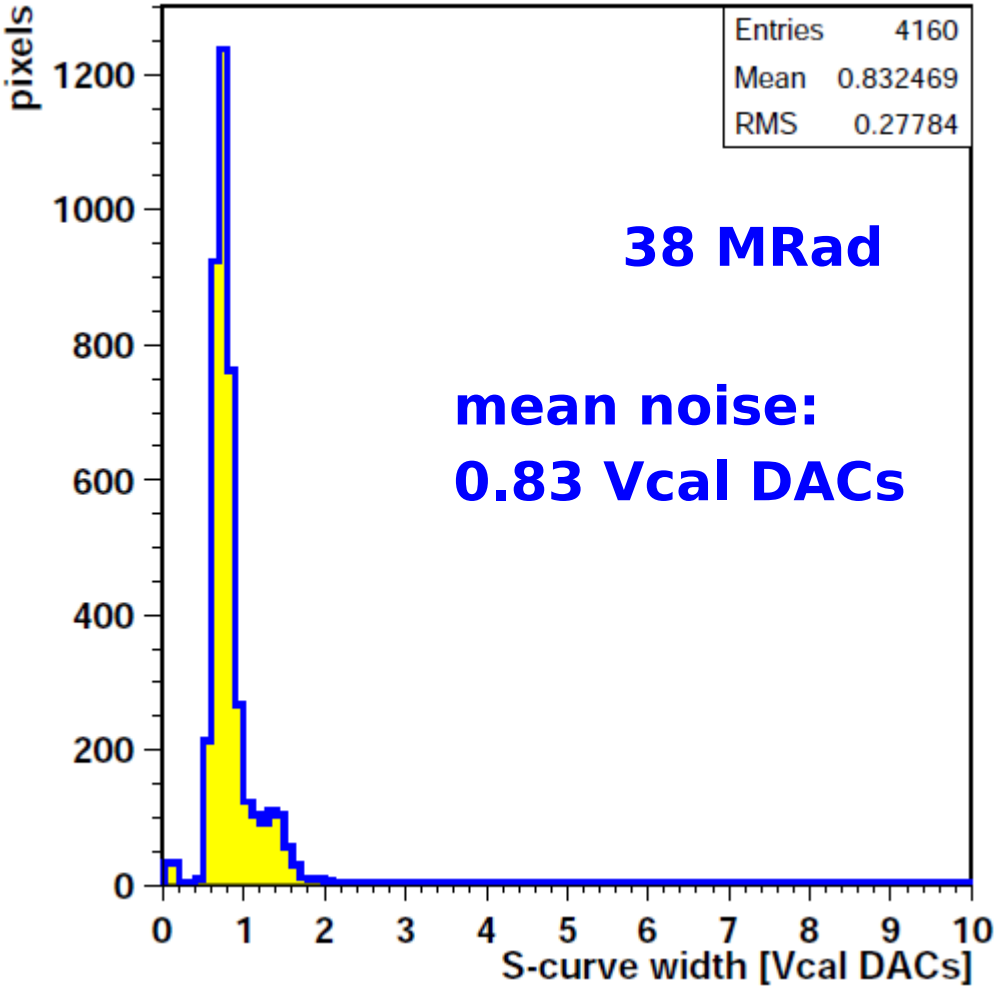
Thresholds, chip204i



- Digital Chip 204
  - 38 MRad
  - Ia 25 mA
  - trimmed to Vcal threshold 30
- **Narrow threshold distribution**

Noise, chip204 (no sensor)

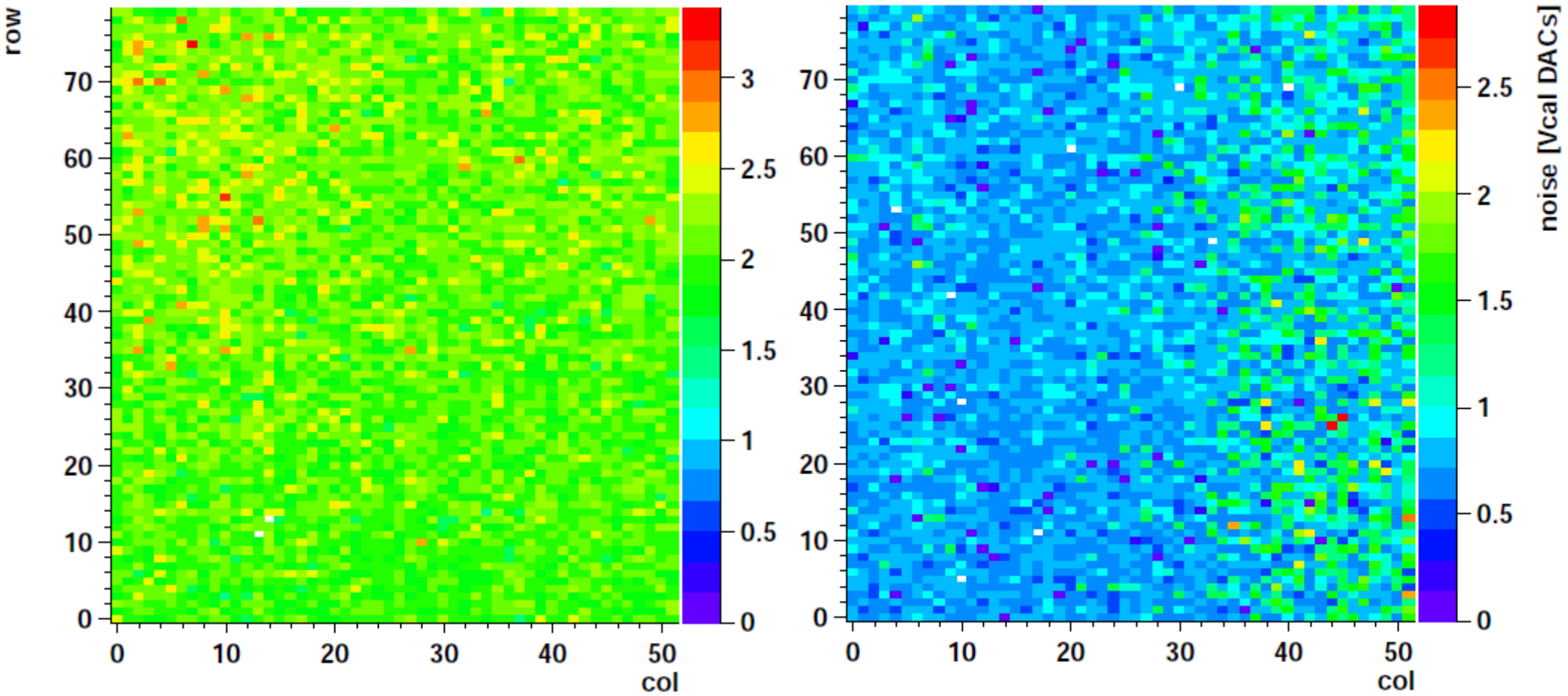




sharper threshold
less noise? lower gain?

Noise map, chip204

0 MRad **38 MRad**



'noise' from width of threshold curves

summary

- high dose irradiation of bare 2012 digital ROCs:
  - 38 and 113 MRad at Karlsruhe
    ~ phase I lifetime dose for layers 2 and 1
- lab tests:
  - chips are operational
  - ...

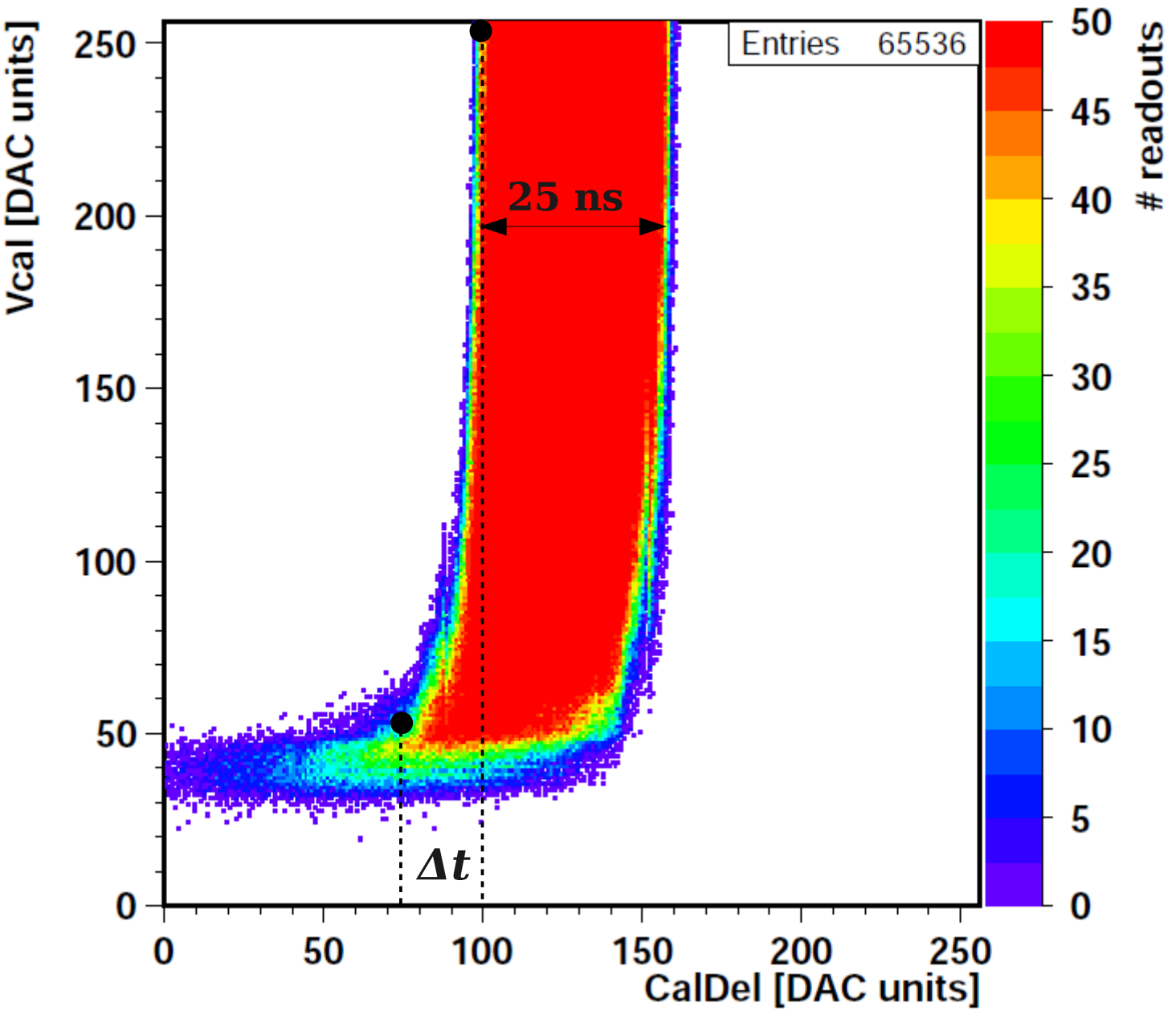
Back up

Time walk

chip 204 is a psi46dig with faster comparator

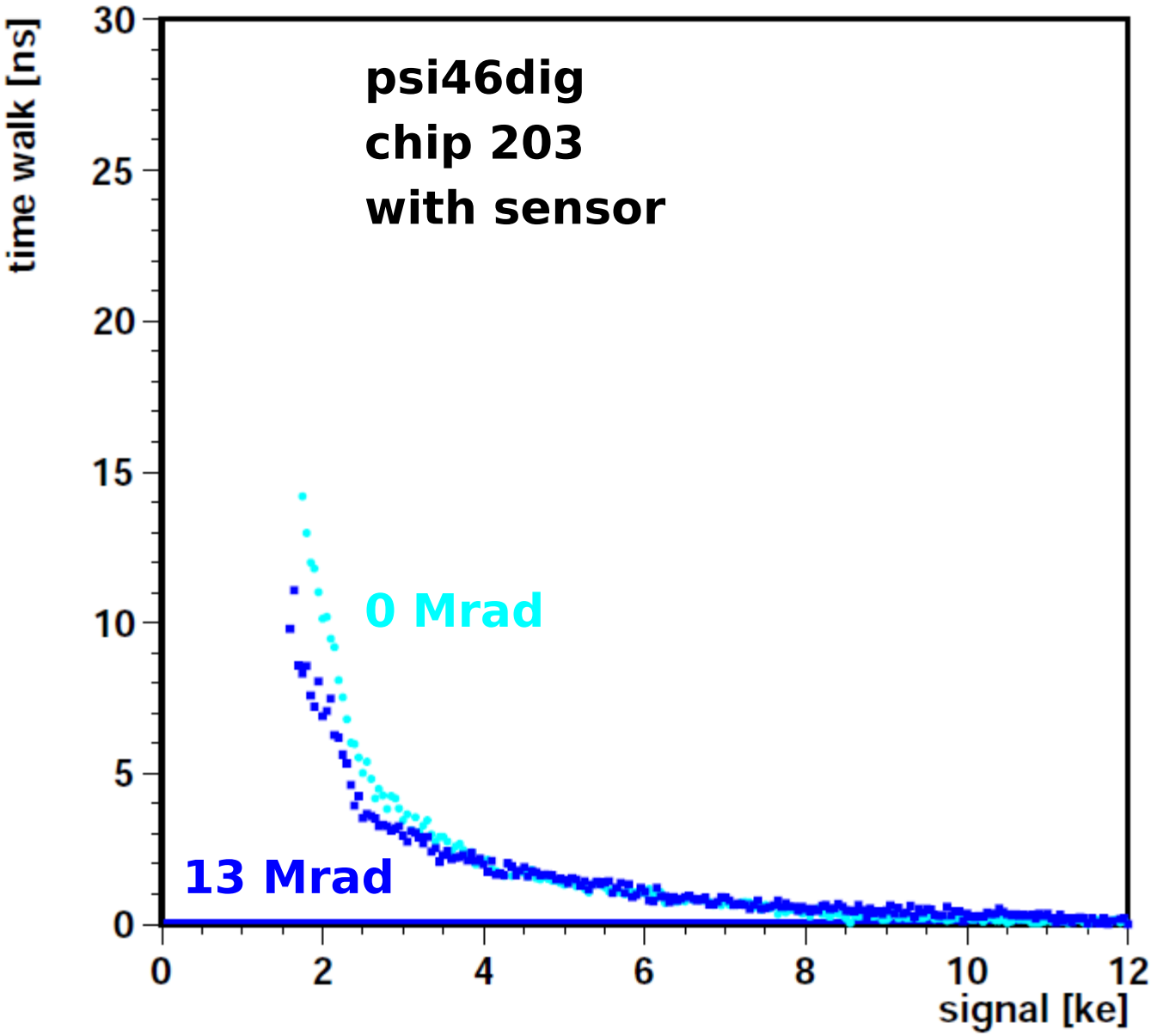
chip 214 is a psi46digtrig with the old comparator

Time walk from tornado plot



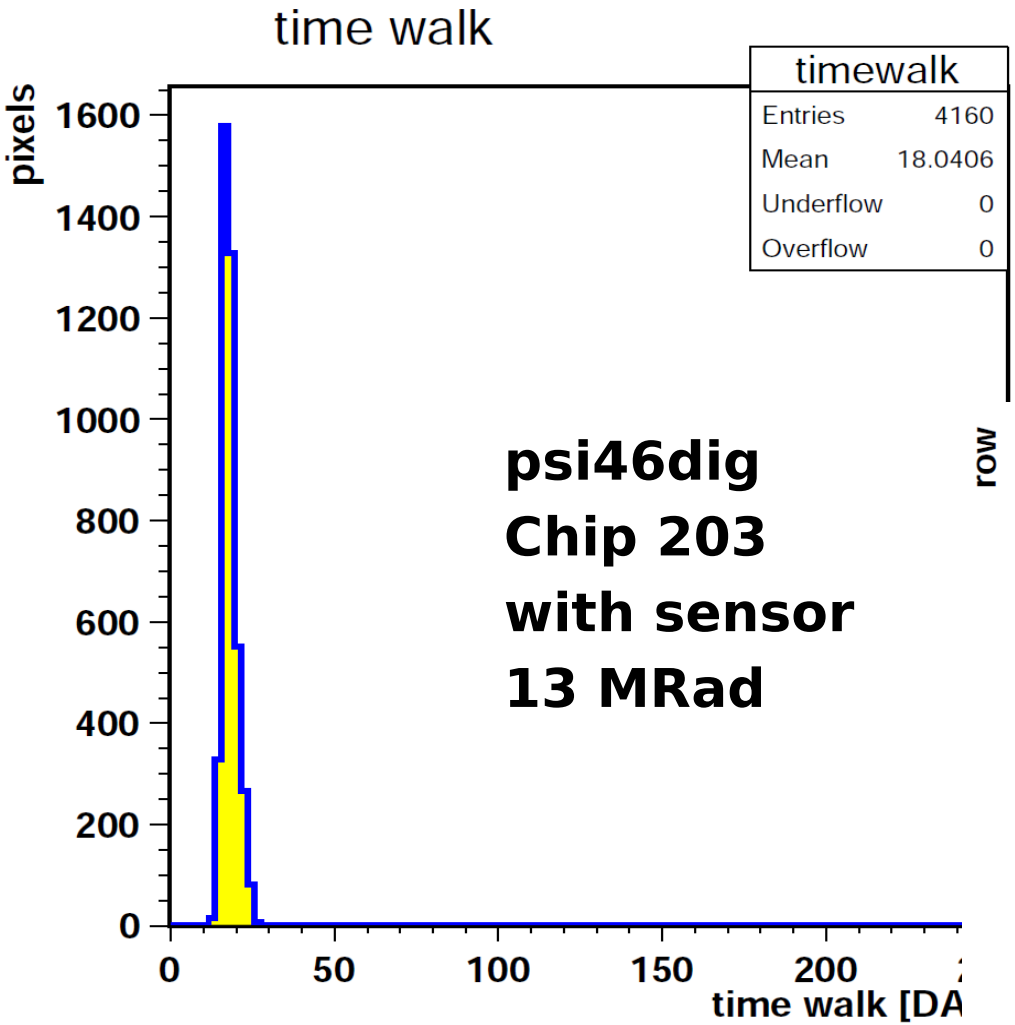
- Chip 203 irrad
- pixel 22-22
- fit S-curve to left edge of tornado plot
  - Vcal 255 as reference
- Translate:
  - 1 Vcal DAC = 50 e
  - 1 CalDel DAC ≈ 0.5 ns

Time walk chip 203



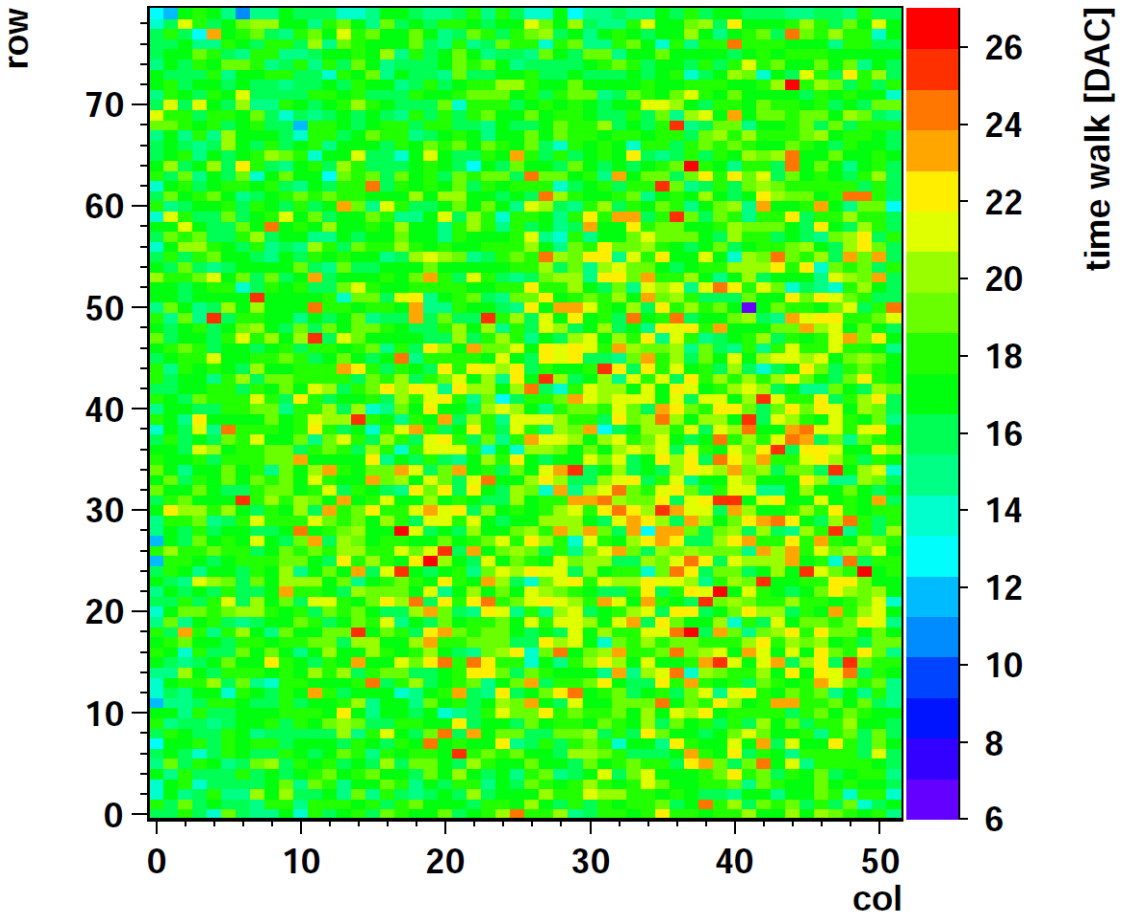
- Chip 203:
  - with sensor
  - Ia 35 mA
  - trimmed to 1.5 ke threshold (Vcal 30)
  - pixel 22 22
  - before and after 13 MRad
  - **slightly less time walk below 3 ke?**

Time walk 200-40 chip 203



psi46dig
Chip 203
with sensor
13 MRad

t(Vcal 200) – t(Vcal 40)



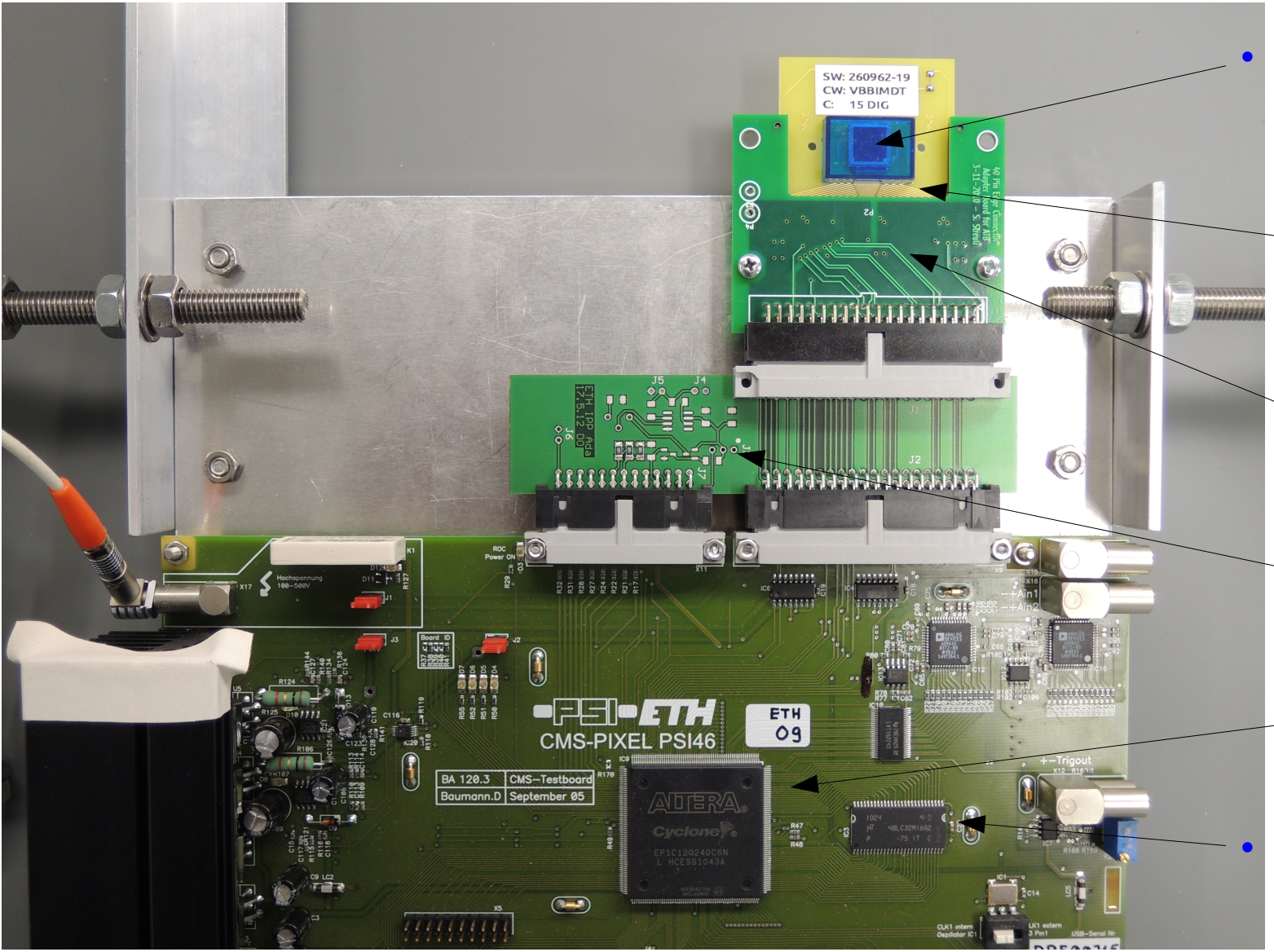
1 DAC ≈ 0.5 ns

all within one clock cycle

Radiation effects

- Total ionizing dose:
  - relevant for surface effects, CMOS and sensors
  - oxide charge trapping
  - transistor threshold voltage shifts
  - transistor leakage current
- Integrated particle flux = fluence:
  - relevant for bulk displacement damage
  - leakage current
  - transistor resistance
  - sensor depletion voltage
  - sensor charge collection efficiency

psi46 test board



- Single chip module:
  - Indium bump bonded at PSI
  - Glued and wire bonded to carrier printed circuit board
  - Interface card to psi46 TB with edge connector
  - ETH adapter card for digital 160 MHz differential signal directly into FPGA (LCDS into LVDS)
- 64 MB memory