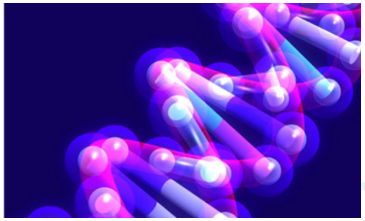
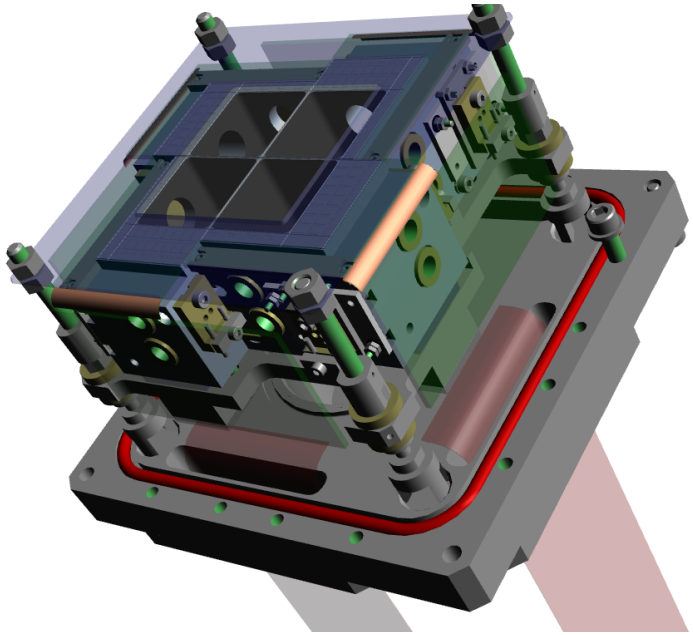



DCDE Measurement Results



OVERVIEW

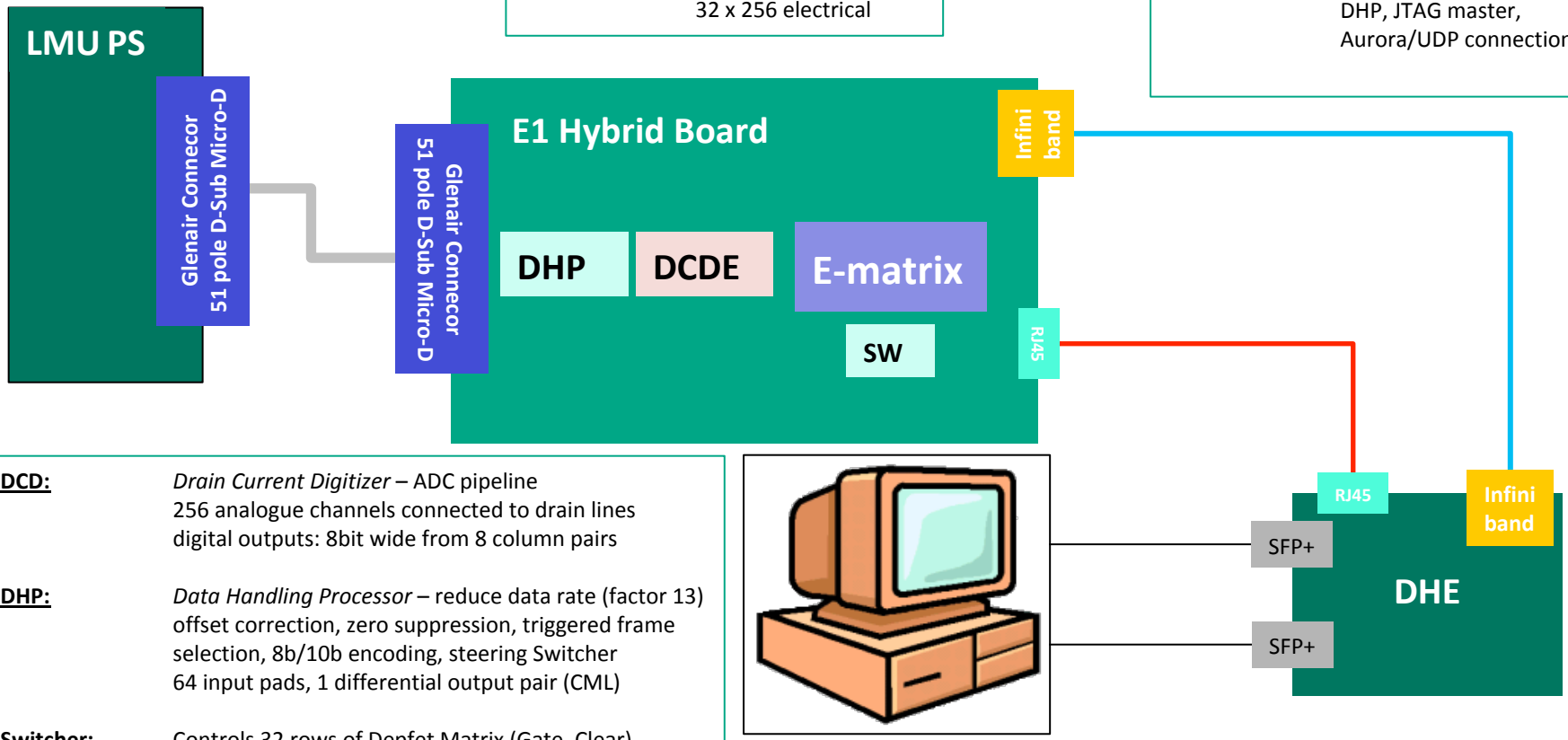
- SMALL MATRIX TEST SYSTEM
- TRANSFER CURVES
  - DCDE Transfer Curves: dynamic ranges
  - Matrix Transfer Curves: shape
- SINGLE PIXEL LASER SCANS
  - Spillover region → dynamic DCDE range
- 2-bit DAC
  - IPDAC current
  - Impact on pixel gain
- COMMON MODE
- SAMPLING POINT CURVE

SMALL MATRIX TEST-SYSTEM – STATUS QUO

Starting with the functional BELLE II chain all components are stepwise replaced and tested

Matrix Size: 12 x 7 mm
128 x 64 physical pixels
32 x 256 electrical

DHE: *Data Handling Engine*
data reader, framing, data buffering, steering DHP, JTAG master, Aurora/UDP connection



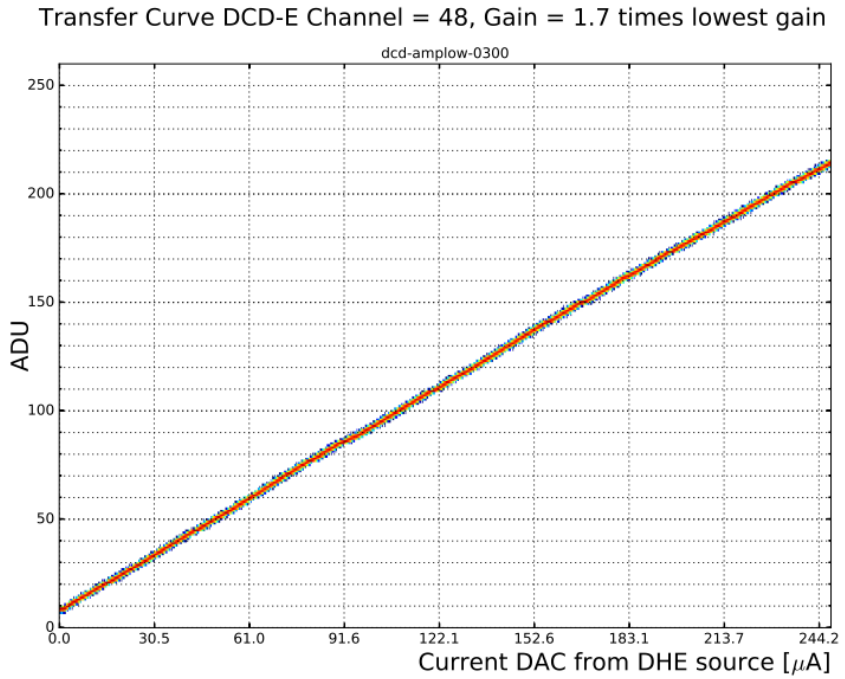
DCD: *Drain Current Digitizer* – ADC pipeline
256 analogue channels connected to drain lines
digital outputs: 8bit wide from 8 column pairs

DHP: *Data Handling Processor* – reduce data rate (factor 13)
offset correction, zero suppression, triggered frame selection, 8b/10b encoding, steering Switcher
64 input pads, 1 differential output pair (CML)

Switcher: Controls 32 rows of Depfet Matrix (Gate, Clear)
high voltage CMOS technology supporting up to 20V

ADC-TRANSFER CURVE for different GAINS

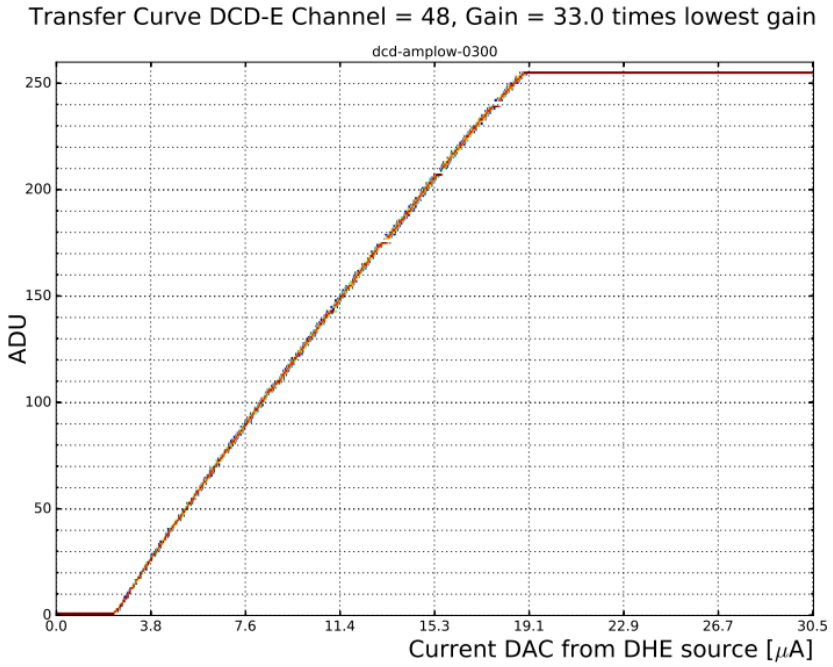
E1_I_04 PPS-Testing (Summer 2018)



DHE current source 248µA, 65k DAC steps

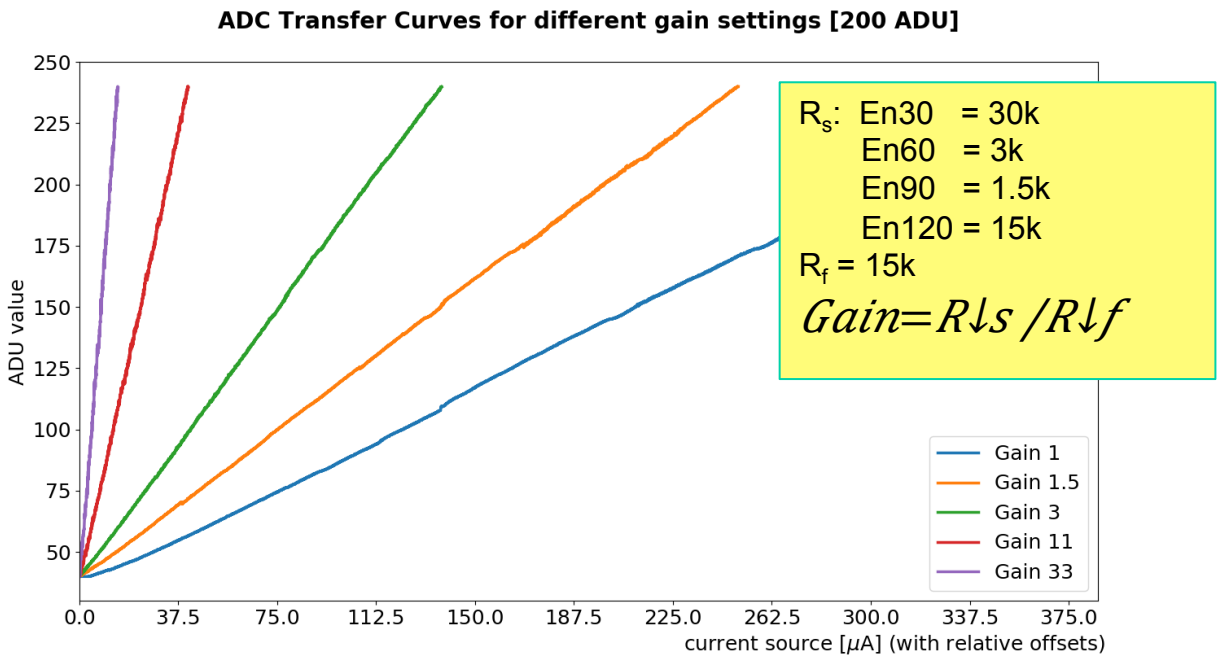
→ strengthen switch for higher currents

Gain	200ADU
33.0	13µA
1.7	240µA



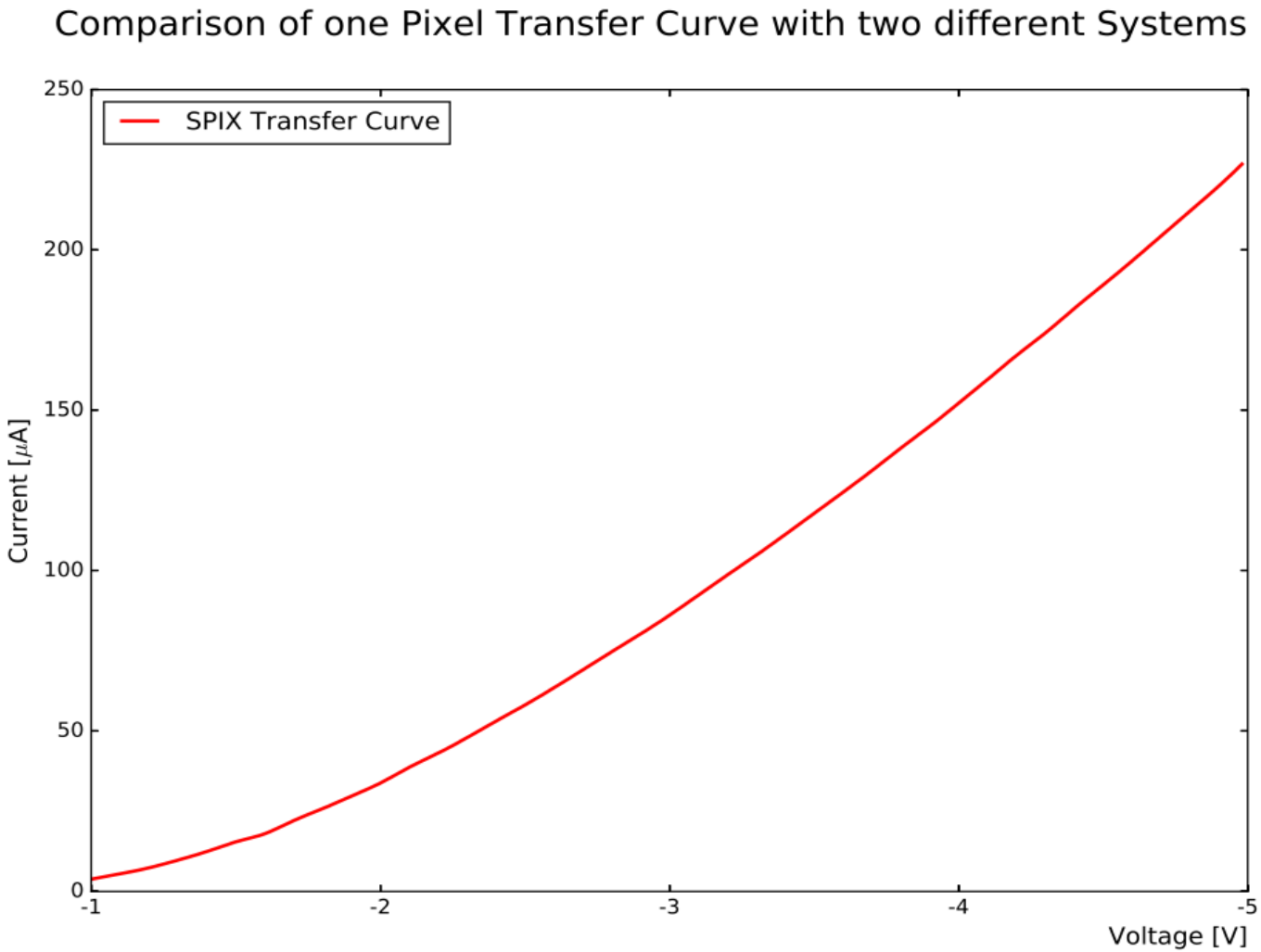
TRANSFER CURVE DCDE GAIN IMPLEMENTATION

En30	En60	En90	En120	Gain	Times lowest Gain
1	1	1	1	0.061	1.0
0	1	1	1	0.063	1.0
1	1	1	0	0.065	1.1
0	1	1	0	0.067	1.1
1	0	1	1	0.087	1.4
0	0	1	1	0.091	1.5
1	0	1	0	0.095	1.6
0	0	1	0	0.100	1.7
1	1	0	1	0.154	2.5
0	1	0	1	0.167	2.8
1	1	0	0	0.182	3.0
0	1	0	0	0.200	3.3
1	0	0	1	0.667	11.0
0	0	0	1	1.000	16.5
1	0	0	0	2	33

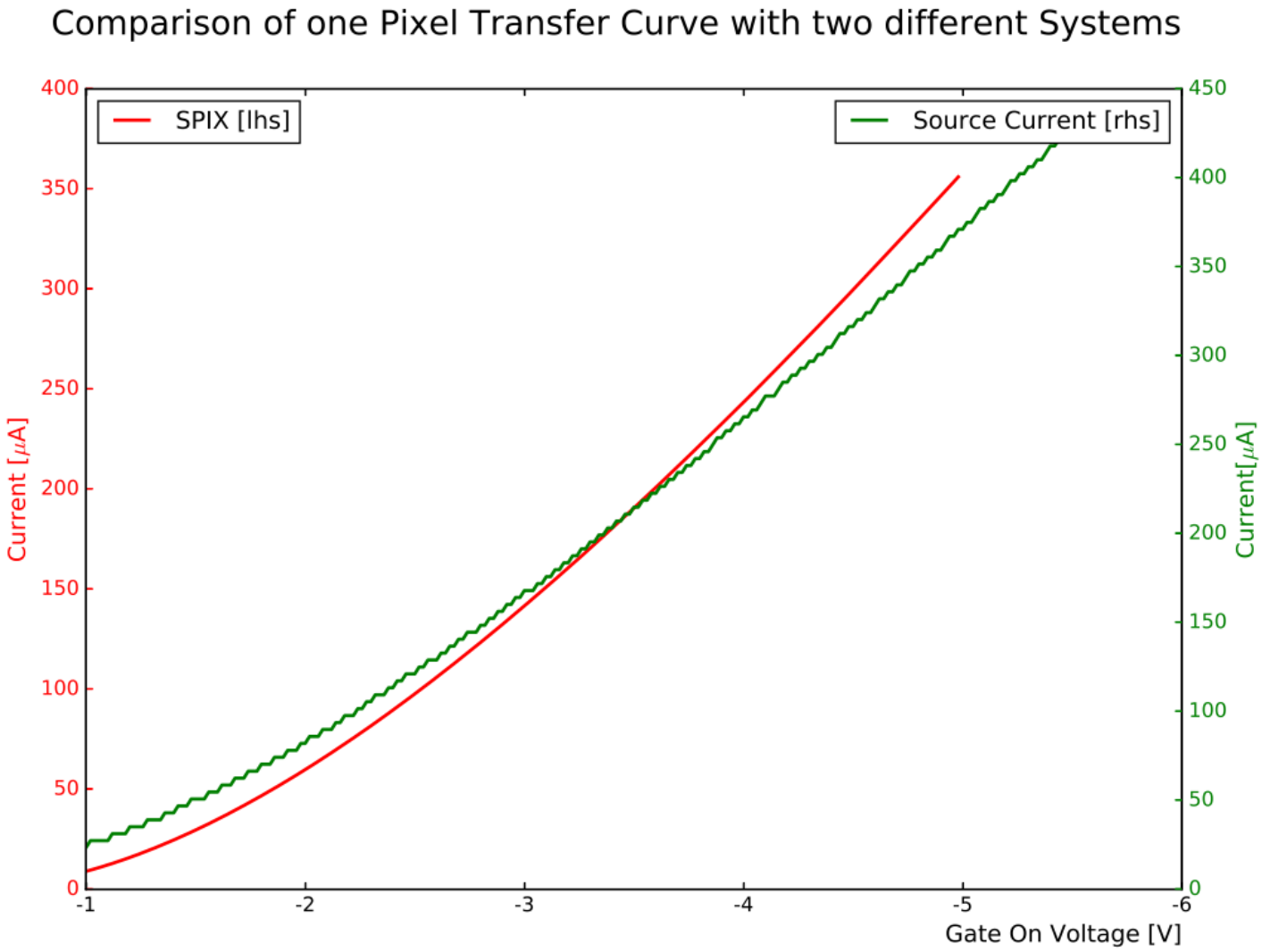


Gain	200ADUs	current/ADU	ADU/current	to lowest Gain	from Resistor
EnAll	410 (est.)	2.05	0.49	1.0	1.0
En90	240	1.2	0.83	1.71	1.7
En30,60,120	165	0.825	1.21	2.48	2.5
En30,120	126	0.63	1.59	3.25	3.3
En30,120	39	0.195	5.13	10.5	11.0
En30	13	0.065	15.4	31.5	33.0

Pixel Transfer Curve – Expectation vs Measurement

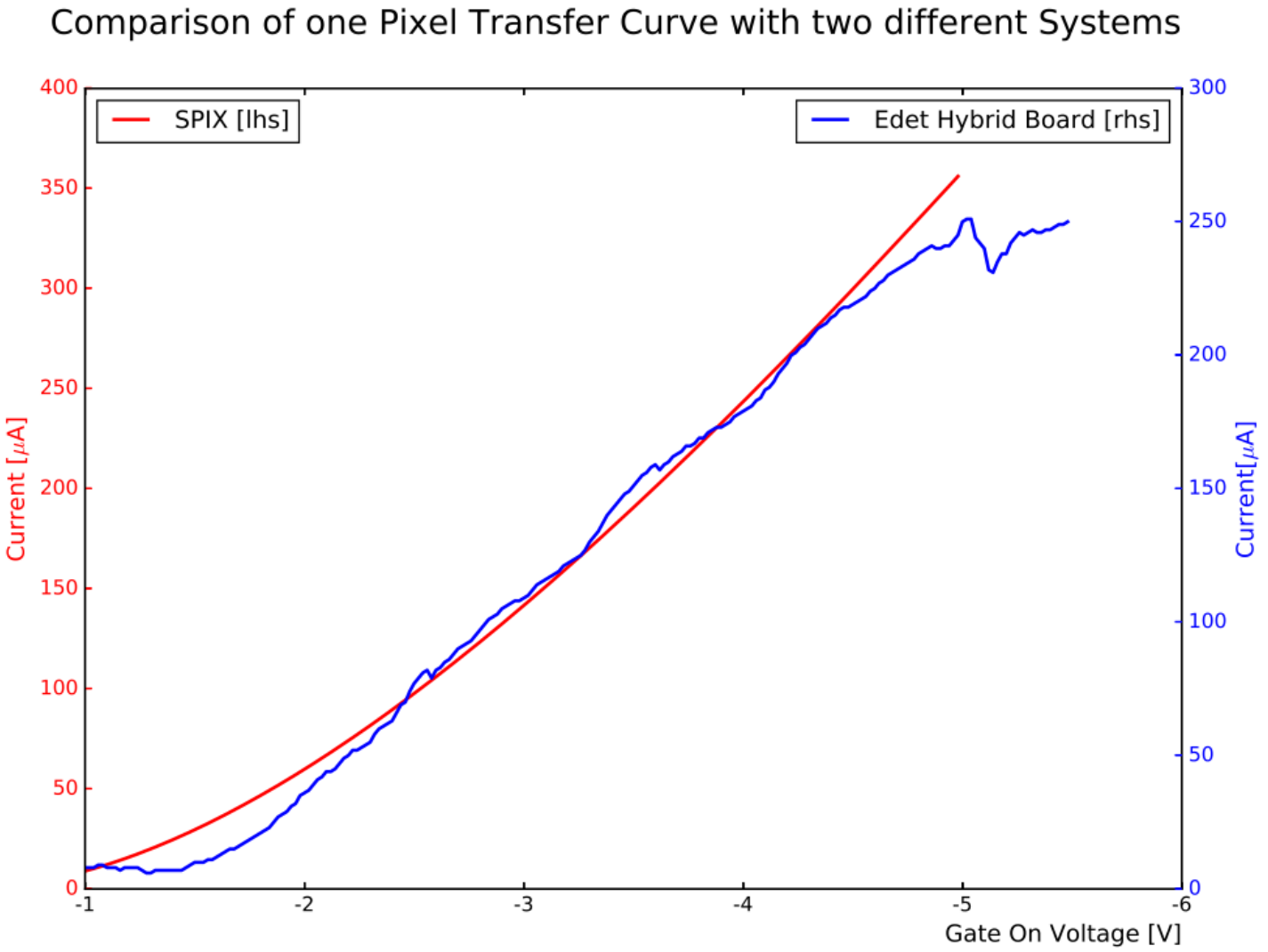


Pixel Transfer Curve – Expectation vs Measurement (I)



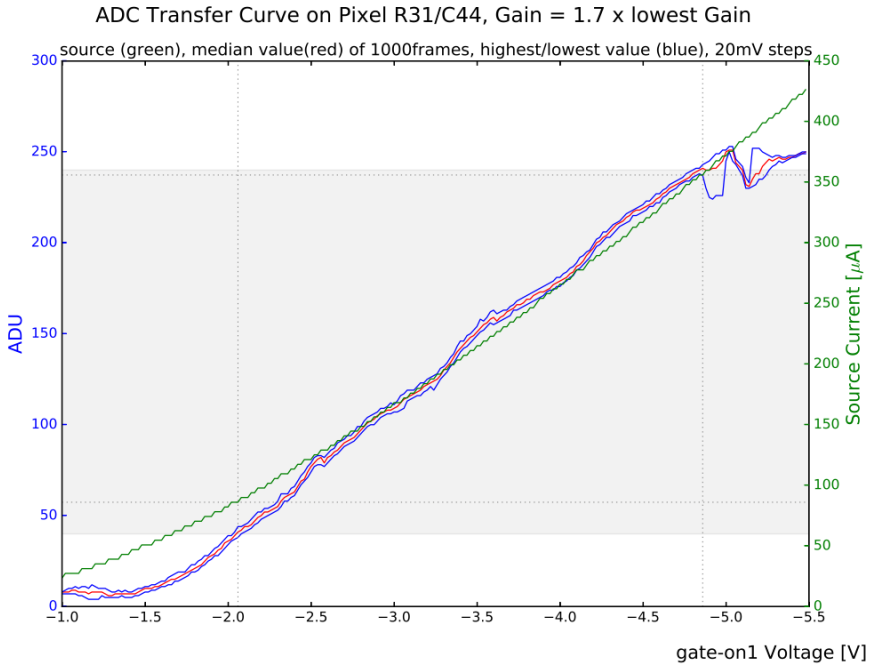
© Mitja Predikaka

Pixel Transfer Curve – Expectation vs Measurement (II)

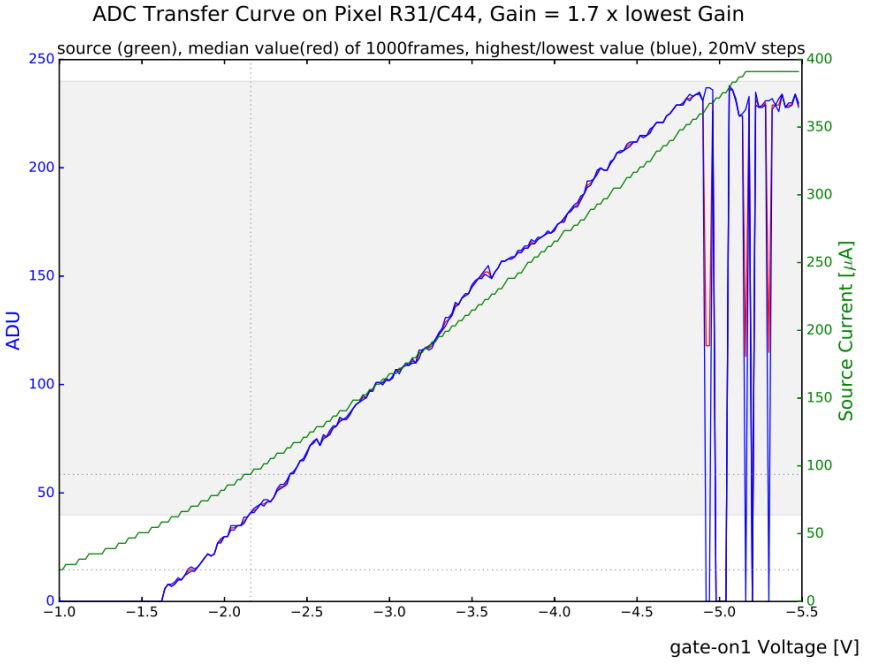


© Mitja Predikaka

TRANSFER CURVE 1.7 x lowest Gain



expect same curve shape as with source current



Potential Problem Areas:

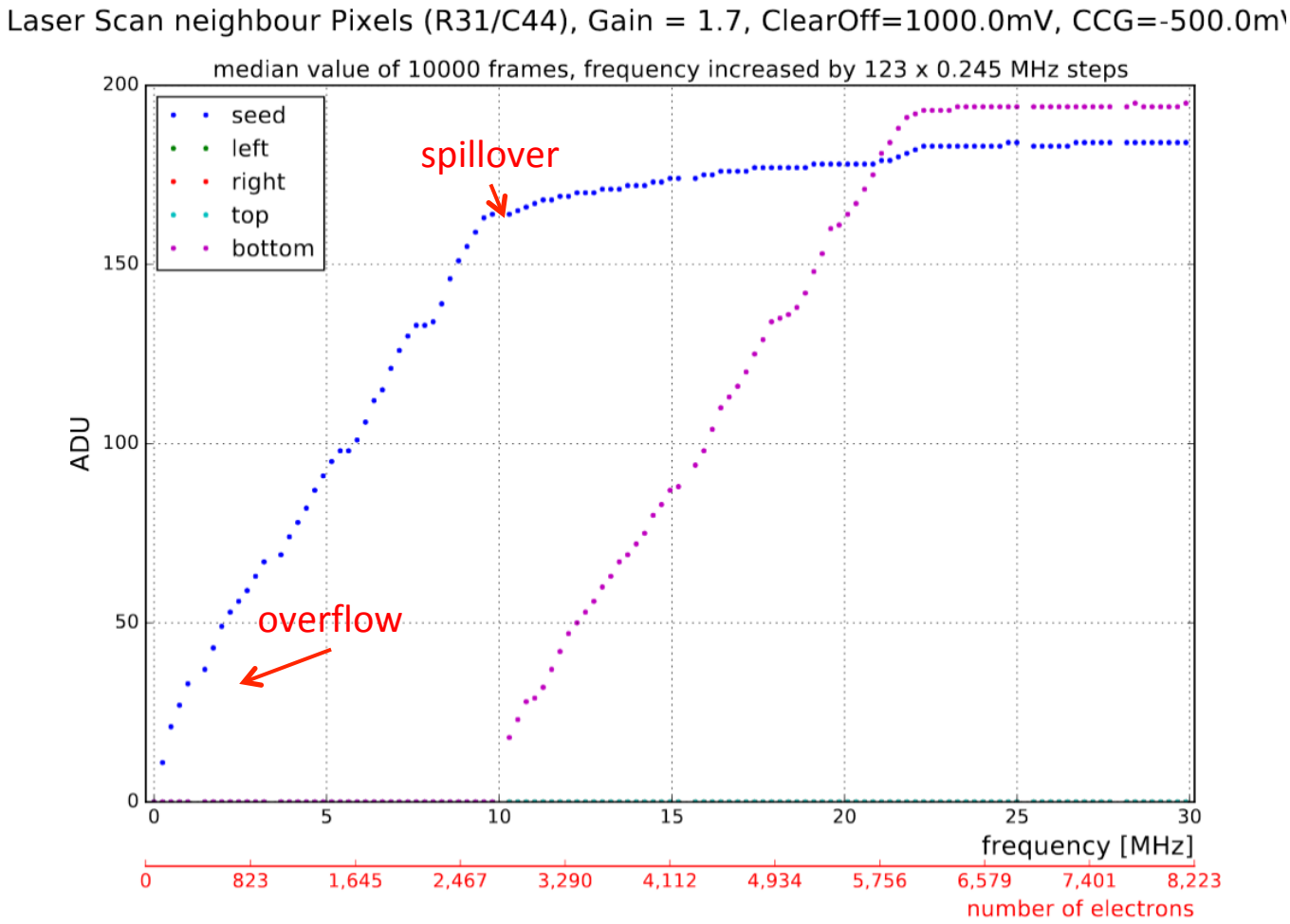
- High currents at once
- Edet Hybrid Board
- DCDE settings
- pixel position
- readout speed
- …

MATRIX CALIBRATION - APPROACH

- High gain mode: determine pixel specific gain factor using Cd^{109} source – **Statistics**!
- Measure laser pulse ADU in high gain mode
- $$\#electrons\ per\ pulse = 6000 * Pulse\ ADU / Gain\ Factor$$
- Step-increase of pulse count within one readout period in order to measure:
  - "kink"-position & secondary g_q
  - discrete gain curve
  - explore complete dynamic range of the pixel

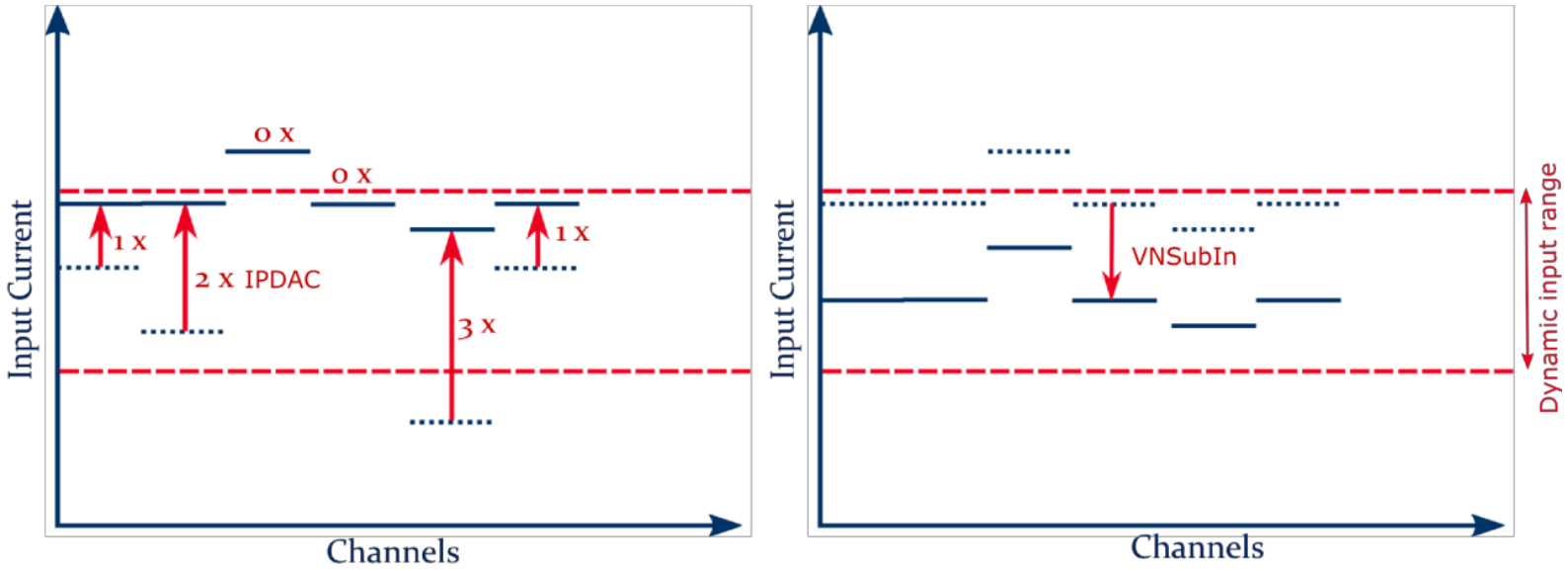
Pixel Capacity

Increasing frequency of laser pulses explores full dynamic range of device



- **bottom pixel (gain 20) shows higher plateau current than central pixel (gain 19)**
- **Overflow ~ 100k electrons**
- **Spillover ~ 2.3mio electrons or 160 ADUs (70 ADUs for 1mio electrons)→3 times higher gain 5.1 (assumption: 50ADU offset width)**

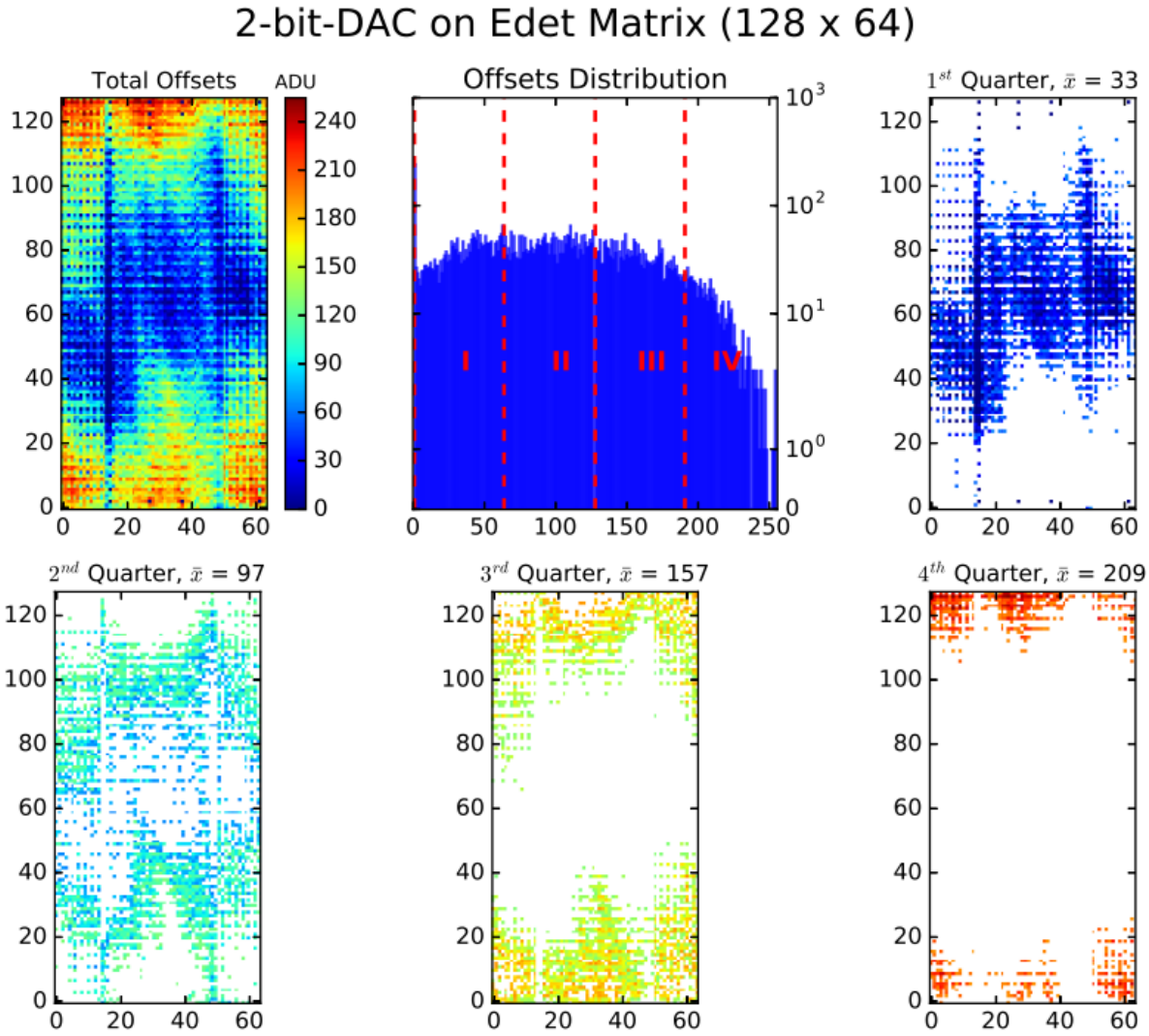
DCDE Offset Compensation Principle



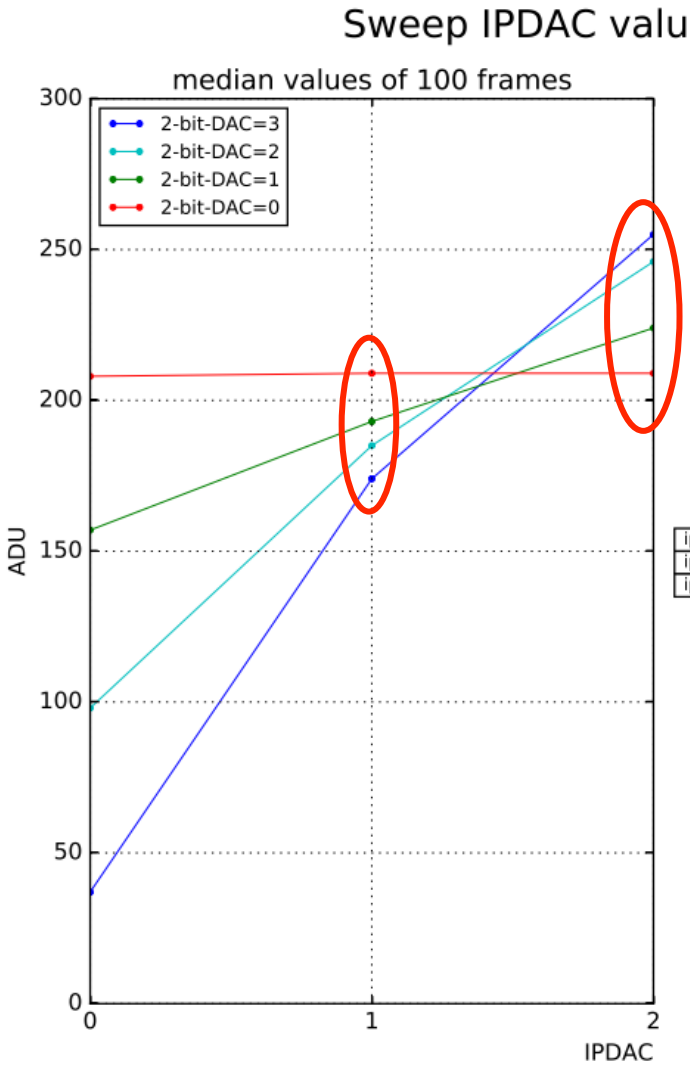
2 step process:

1. different channel spreads are corrected by individual additions of *IPDAC*
2. channels are collectively pulled into the dynamic range by *VNSubIn* + *IPAddIn*

2-bit DAC principle (I)



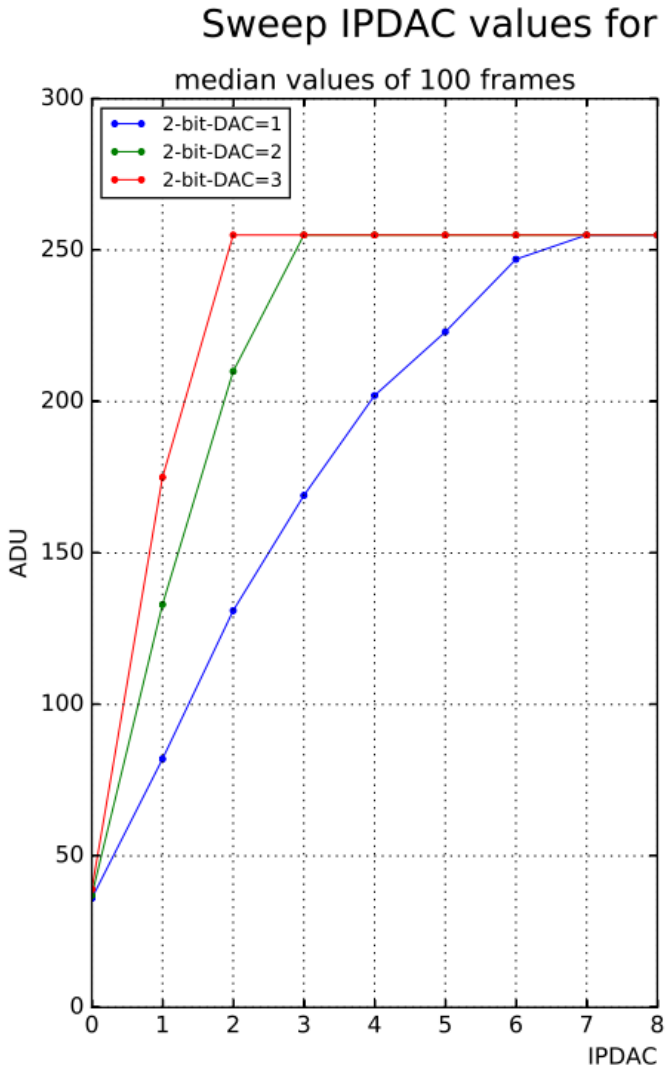
2-bit DAC principle (II)



	2-bit-DAC=3	2-bit-DAC=2	2-bit-DAC=1	2-bit-DAC=0
ipdac0	37	98	157	208
ipdac1	174	185	193	209
ipdac2	255	246	224	209

High Gain: can only use 1 out of 127 IPDAC values for offset adjustment

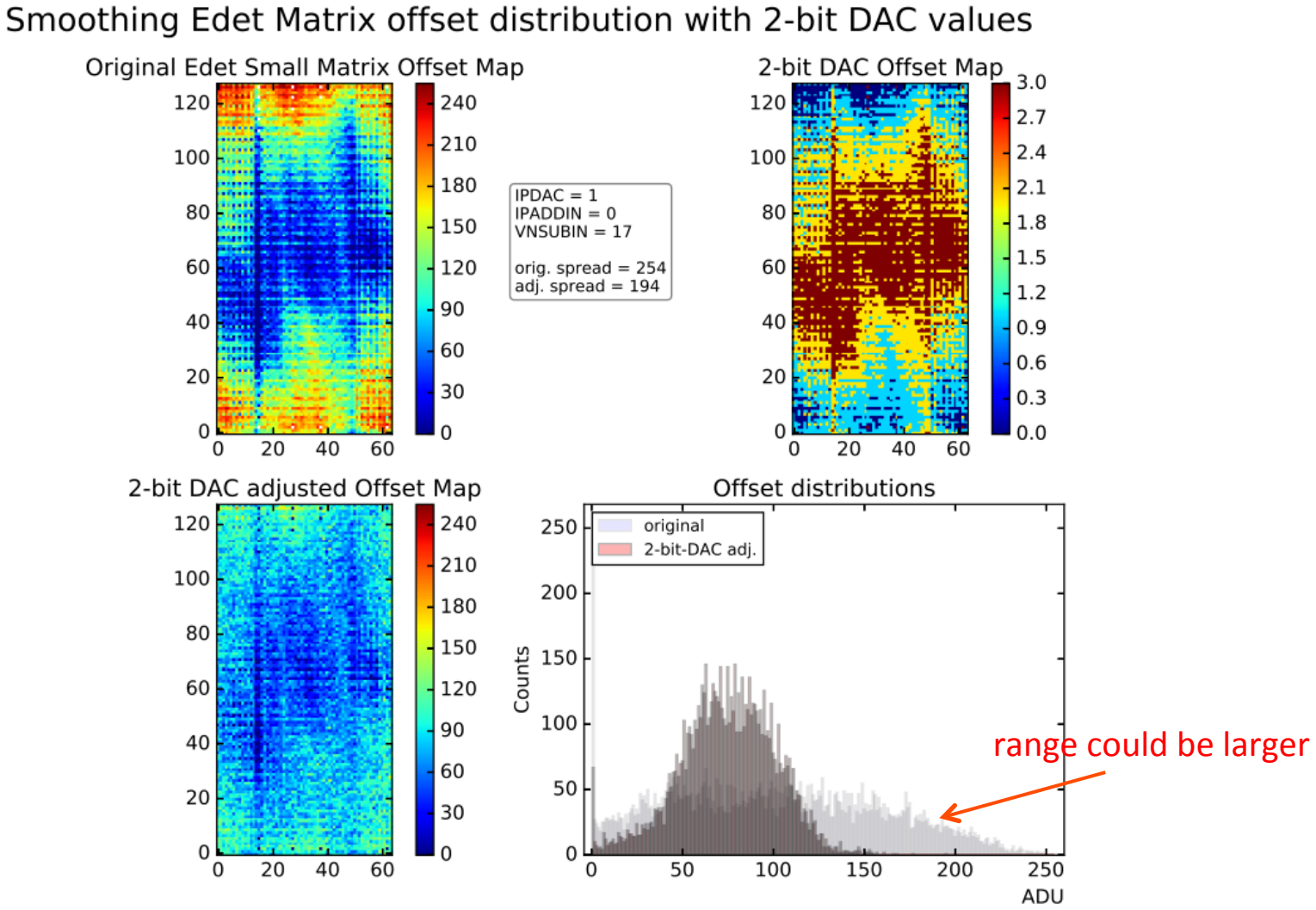
2-bit DAC principle (III)



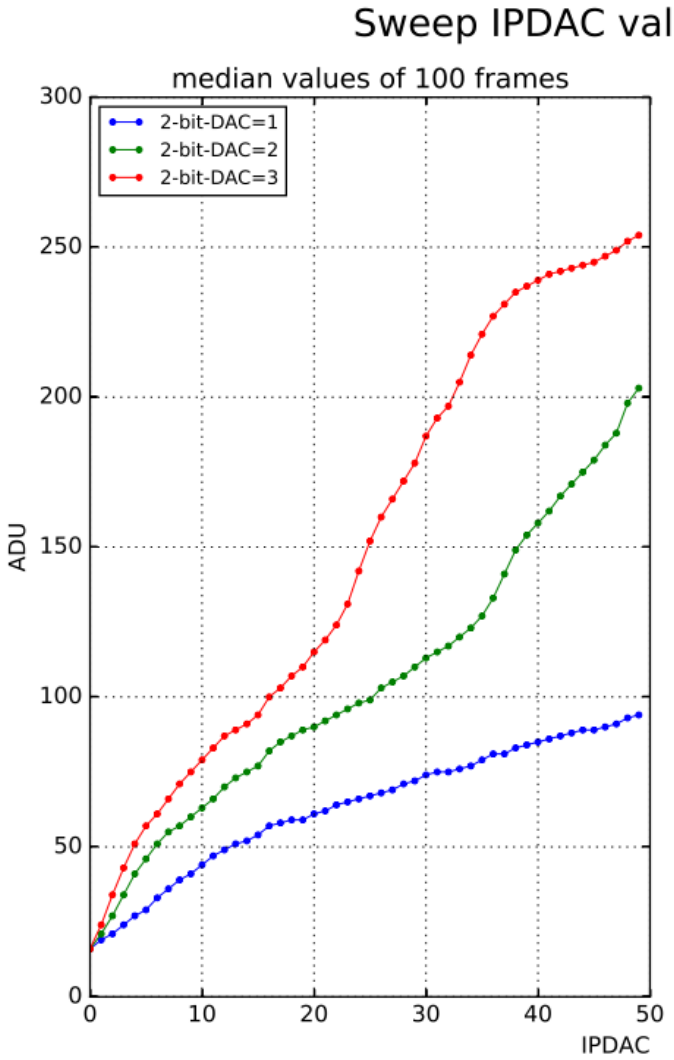
$Ipdac=1 \approx \phi\downarrow 3$
$44ADU \approx 44 \times 13\mu A / 200 \approx 2.9\mu A$

	2-bit-DAC=1	2-bit-DAC=2	2-bit-DAC=3
ipdac0	36.0	37.0	39.0
ipdac1	82.0	133.0	175.0
ipdac2	131.0	210.0	255.0
ipdac3	169.0	255.0	255.0
ipdac4	202.0	255.0	255.0
ipdac5	223.0	255.0	255.0
ipdac6	247.0	255.0	255.0
ipdac7	255.0	255.0	255.0
ipdac8	255.0	255.0	255.0

2-bit DAC principle (IV)



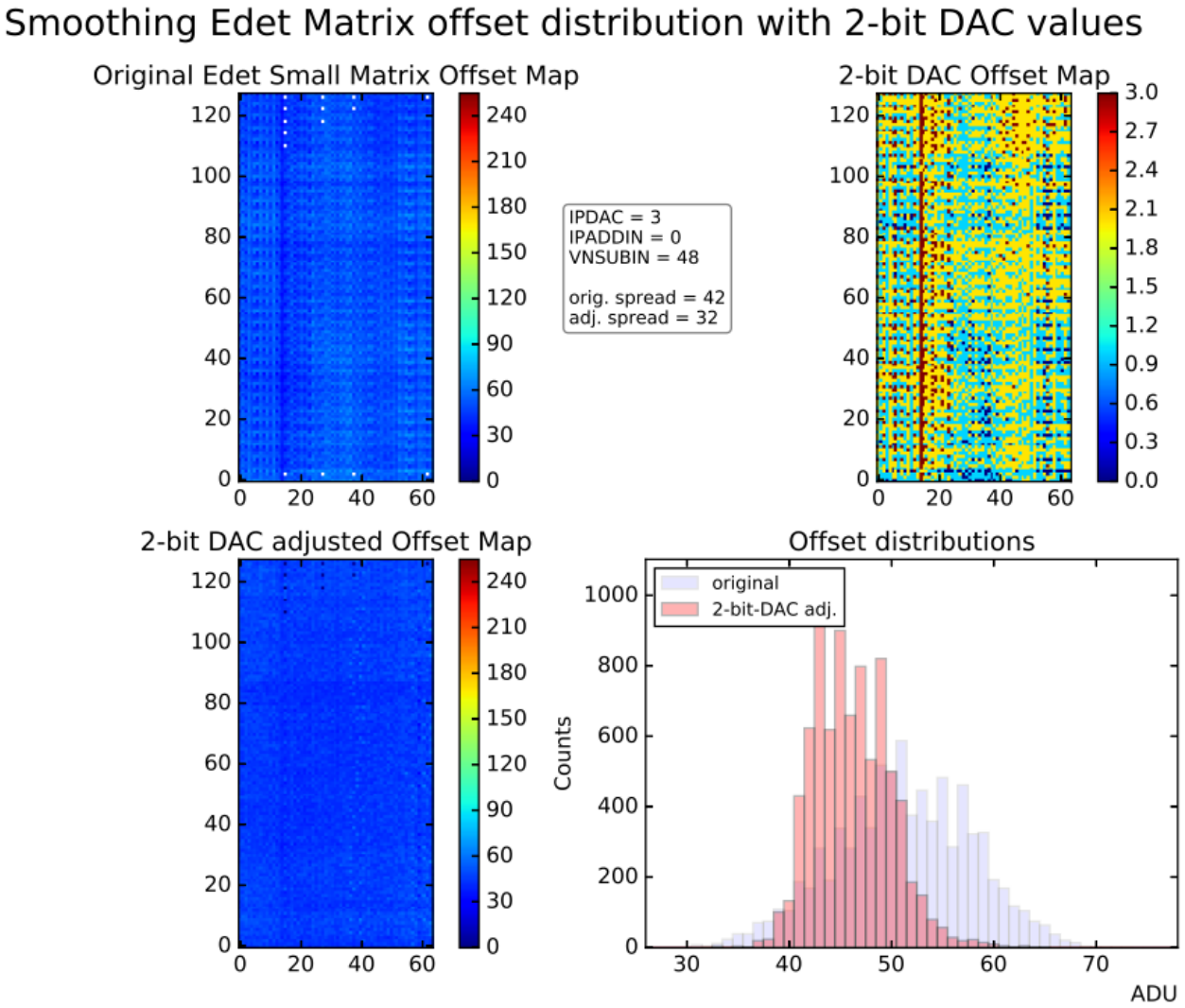
2-bit DAC principle 1.7 gain (I)



	2-bit-DAC=1	2-bit-DAC=2	2-bit-DAC=3
ipdac0	16.0	16.0	16.0
ipdac1	19.0	21.0	24.0
ipdac2	21.0	27.0	34.0
ipdac3	24.0	34.0	43.0
ipdac4	27.0	41.0	51.0
ipdac5	29.0	46.0	57.0
ipdac6	33.0	51.0	61.0
ipdac7	36.0	55.0	66.0
ipdac8	39.0	57.0	71.0
ipdac9	41.0	60.0	75.0
ipdac10	44.0	63.0	79.0
ipdac11	47.0	66.0	83.0
ipdac12	49.0	70.0	87.0
ipdac13	51.0	73.0	89.0
ipdac14	52.0	75.0	91.0
ipdac15	54.0	77.0	94.0
ipdac16	57.0	82.0	100.0
ipdac17	58.0	85.0	103.0
ipdac18	59.0	87.0	107.0
ipdac19	59.0	89.0	110.0
ipdac20	61.0	90.0	115.0
ipdac21	62.0	92.0	119.0
ipdac22	64.0	94.0	124.0
ipdac23	65.0	96.0	131.0
ipdac24	66.0	98.0	142.0
ipdac25	67.0	99.0	152.0
ipdac26	68.0	103.0	160.0
ipdac27	69.0	105.0	166.0
ipdac28	71.0	107.0	172.0
ipdac29	72.0	110.0	178.0
ipdac30	74.0	113.0	187.0
ipdac31	75.0	115.0	193.0
ipdac32	75.0	117.0	197.0
ipdac33	76.0	120.0	205.0
ipdac34	77.0	123.0	214.0
ipdac35	79.0	127.0	221.0
ipdac36	81.0	133.0	227.0
ipdac37	81.0	141.0	231.0
ipdac38	83.0	149.0	235.0
ipdac39	84.0	154.0	237.0
ipdac40	85.0	158.0	239.0
ipdac41	86.0	162.0	241.0
ipdac42	87.0	167.0	242.0
ipdac43	88.0	171.0	243.0
ipdac44	89.0	175.0	244.0
ipdac45	89.0	179.0	245.0
ipdac46	90.0	184.0	247.0
ipdac47	91.0	188.0	249.0
ipdac48	93.0	198.0	252.0
ipdac49	94.0	203.0	254.0

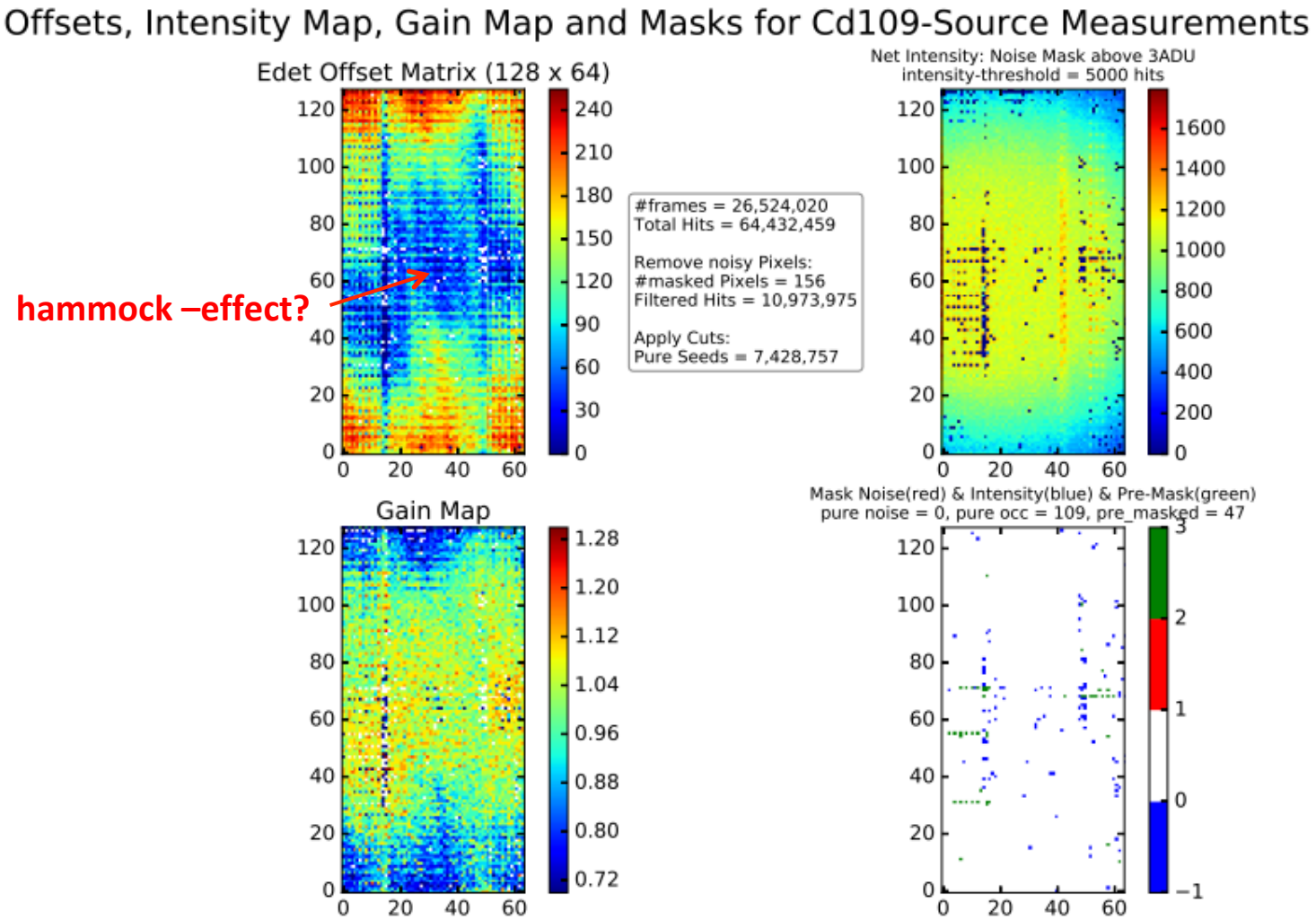
$$Ipdac{=}1{\approx}\phi{\downarrow}10$$
$$2.8ADU{\approx}2.8$$
$$\times 240\mu A/200$$
$$\approx 3.4\mu A$$

2-bit DAC principle 1.7 gain (II)



Cd109 SOURCE high gain

30 mio frames

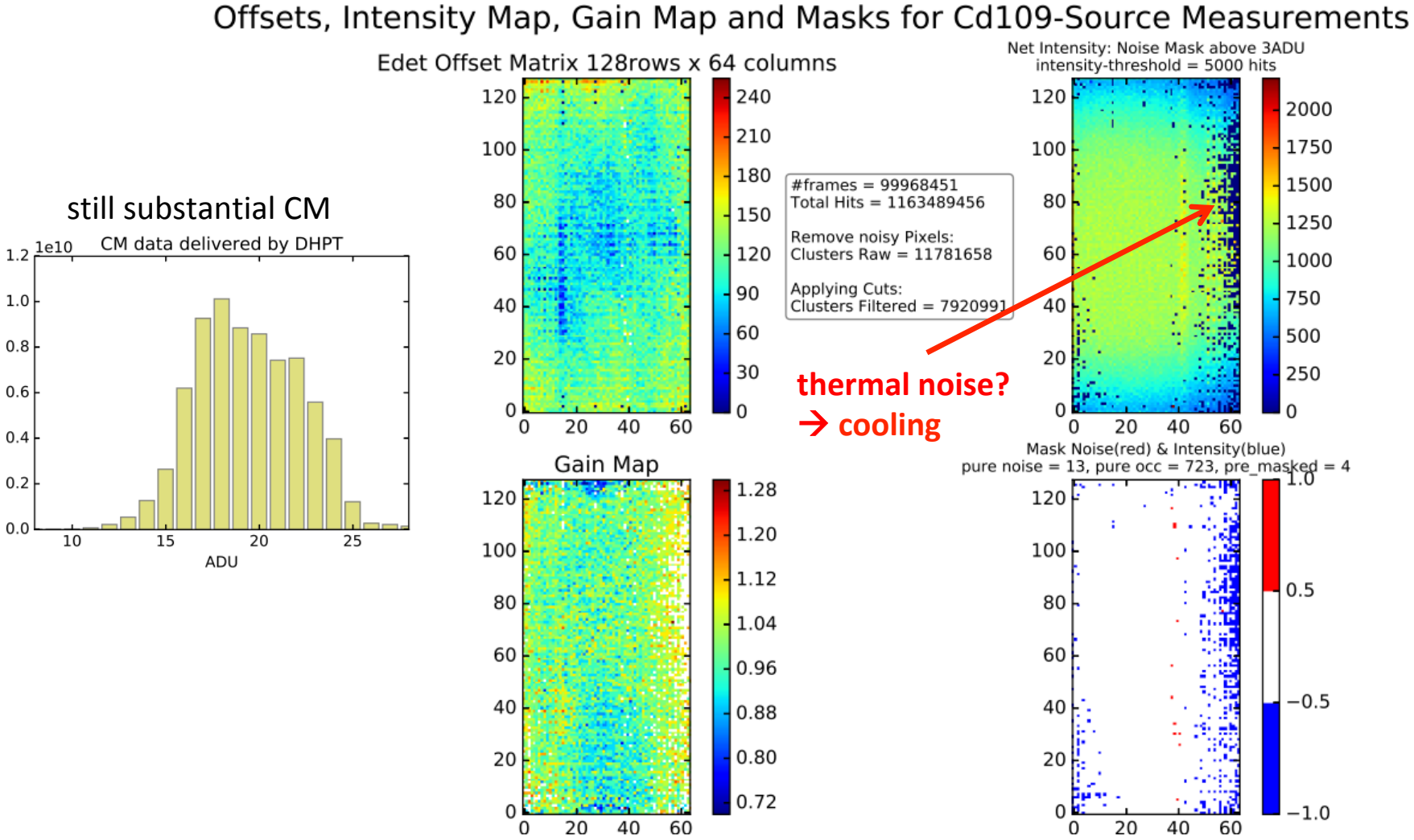


ISSUES:

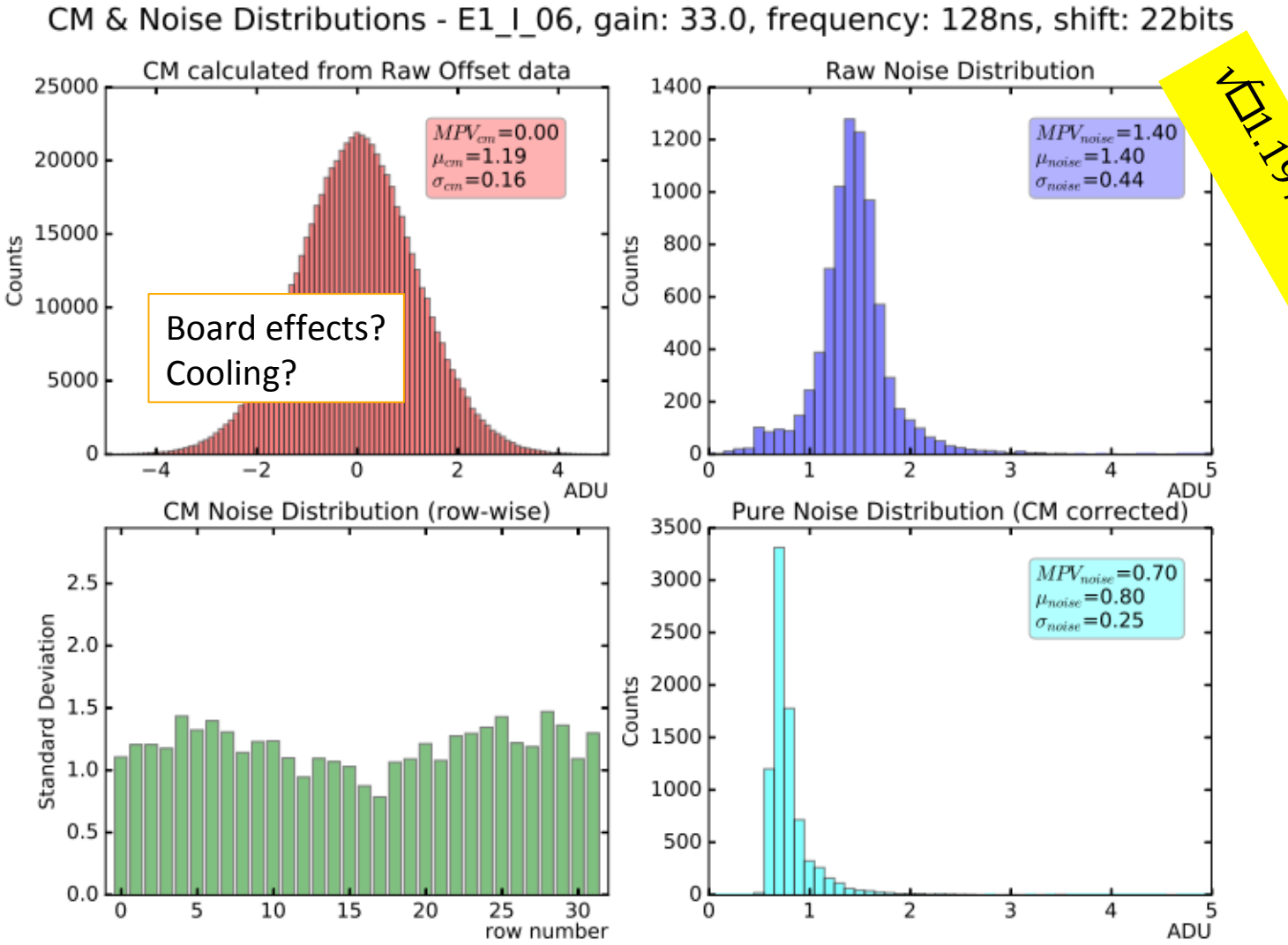
- **offset dispersion consumes full dynamic range due to high gain mode**
- **gain map & offset map anti-correlation**

Cd109 SOURCE high gain

2-bit DAC adjustment, 100 mio frames

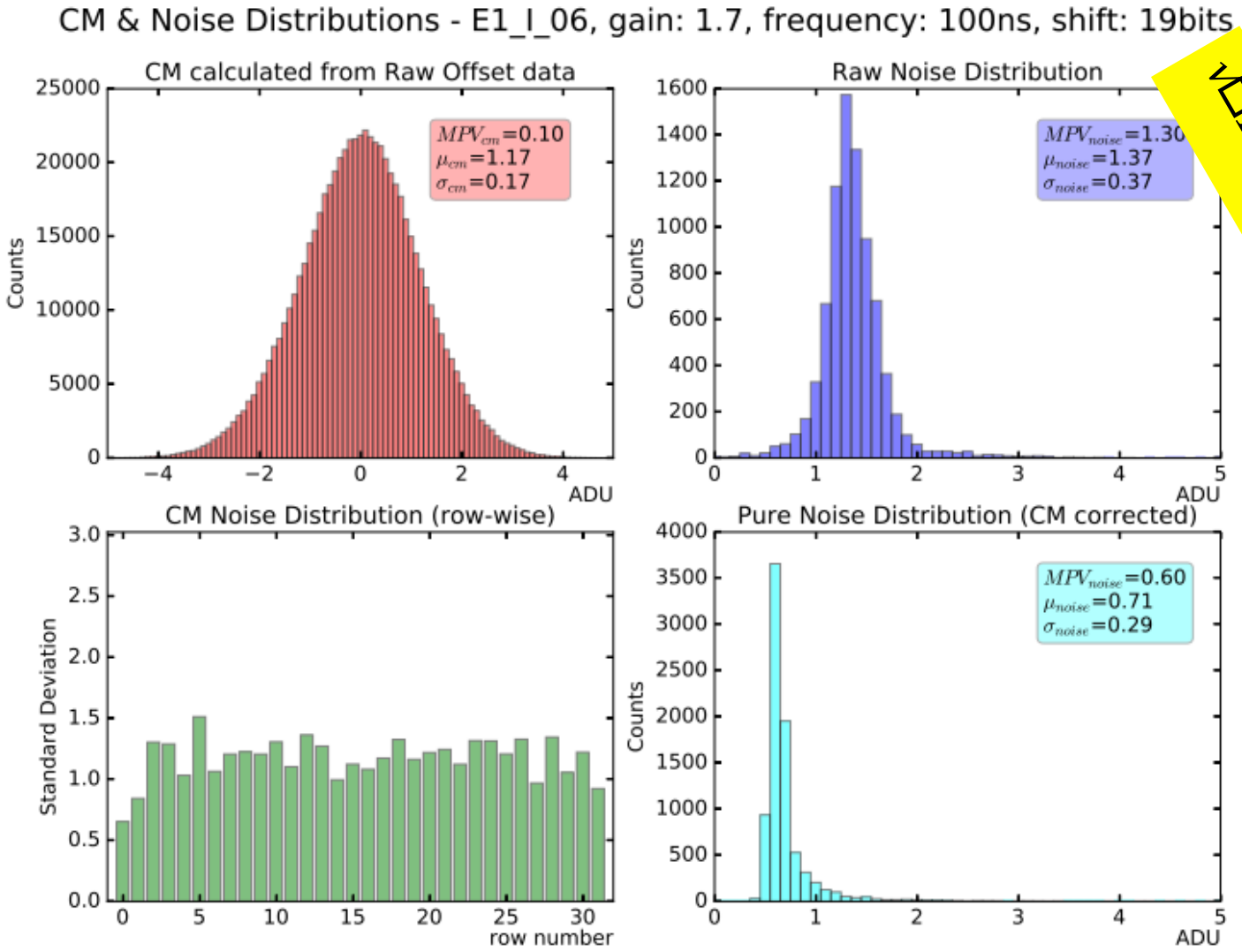


COMMON MODE – high gain



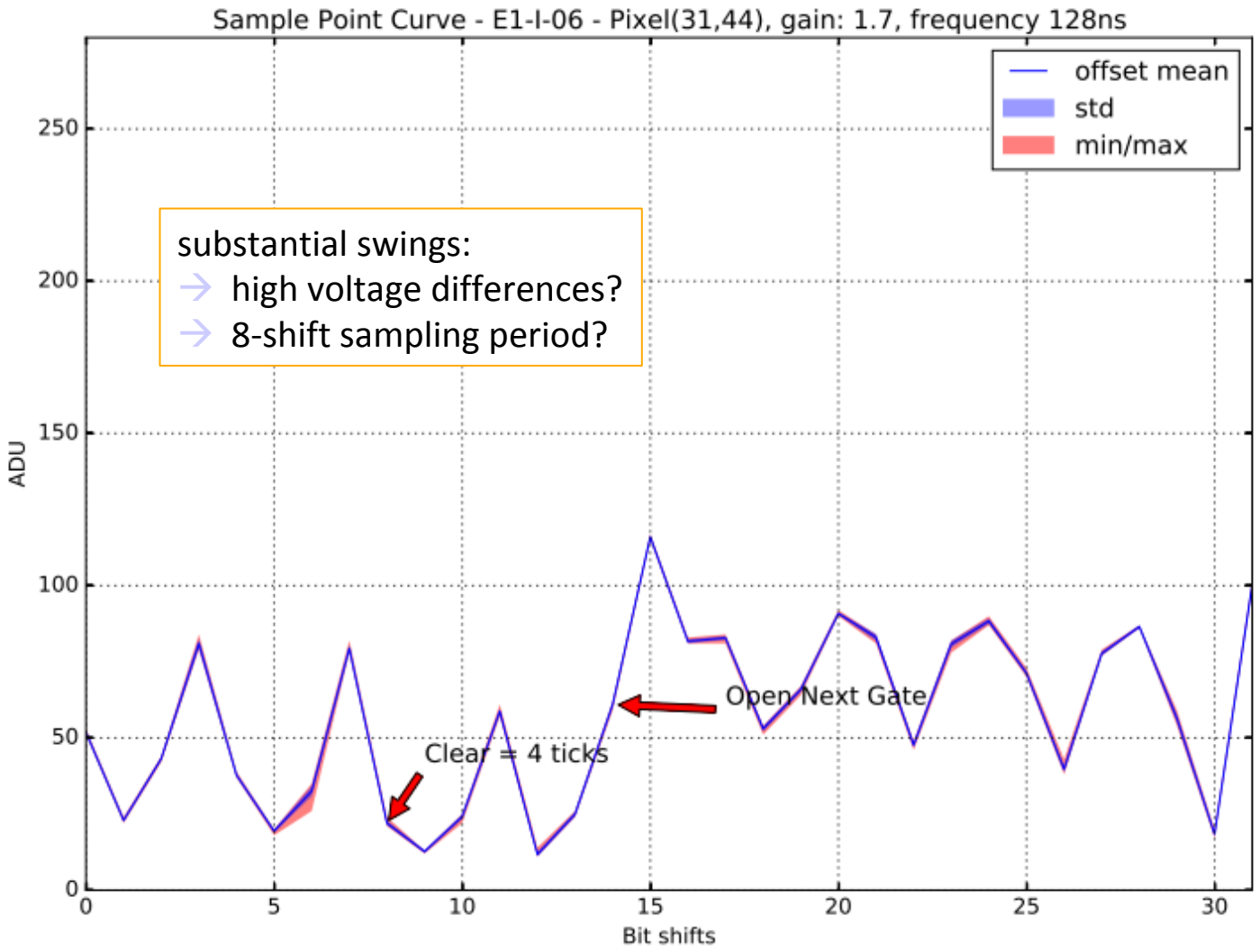
√(1.19^2 + 0.80^2) = 1.43

COMMON MODE – 1.7 gain



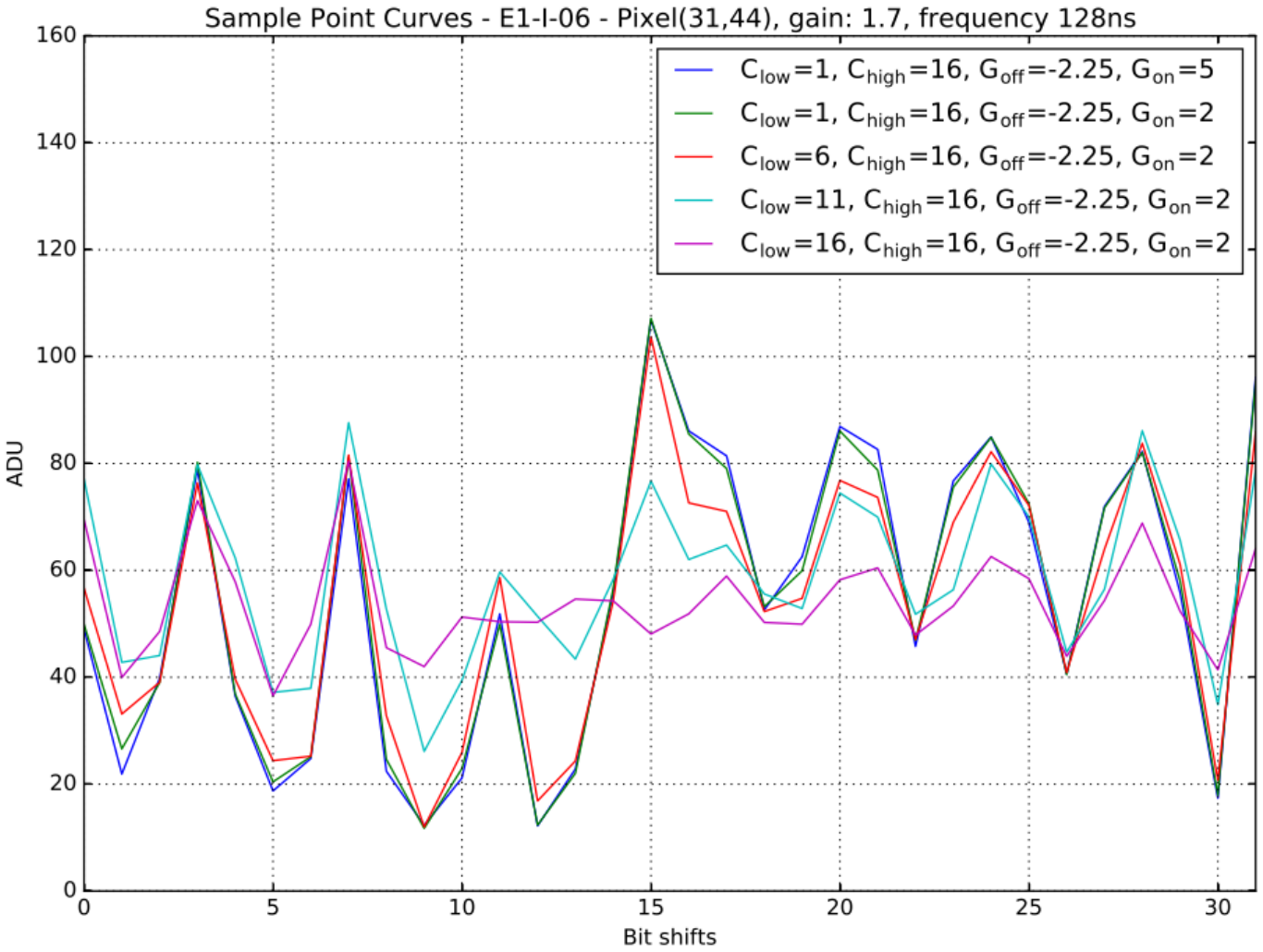
$\sqrt{1.17^2 + 0.71^2} = 1.37$

Sampling Point Curve P(31,44), gain 1.7, 128ns

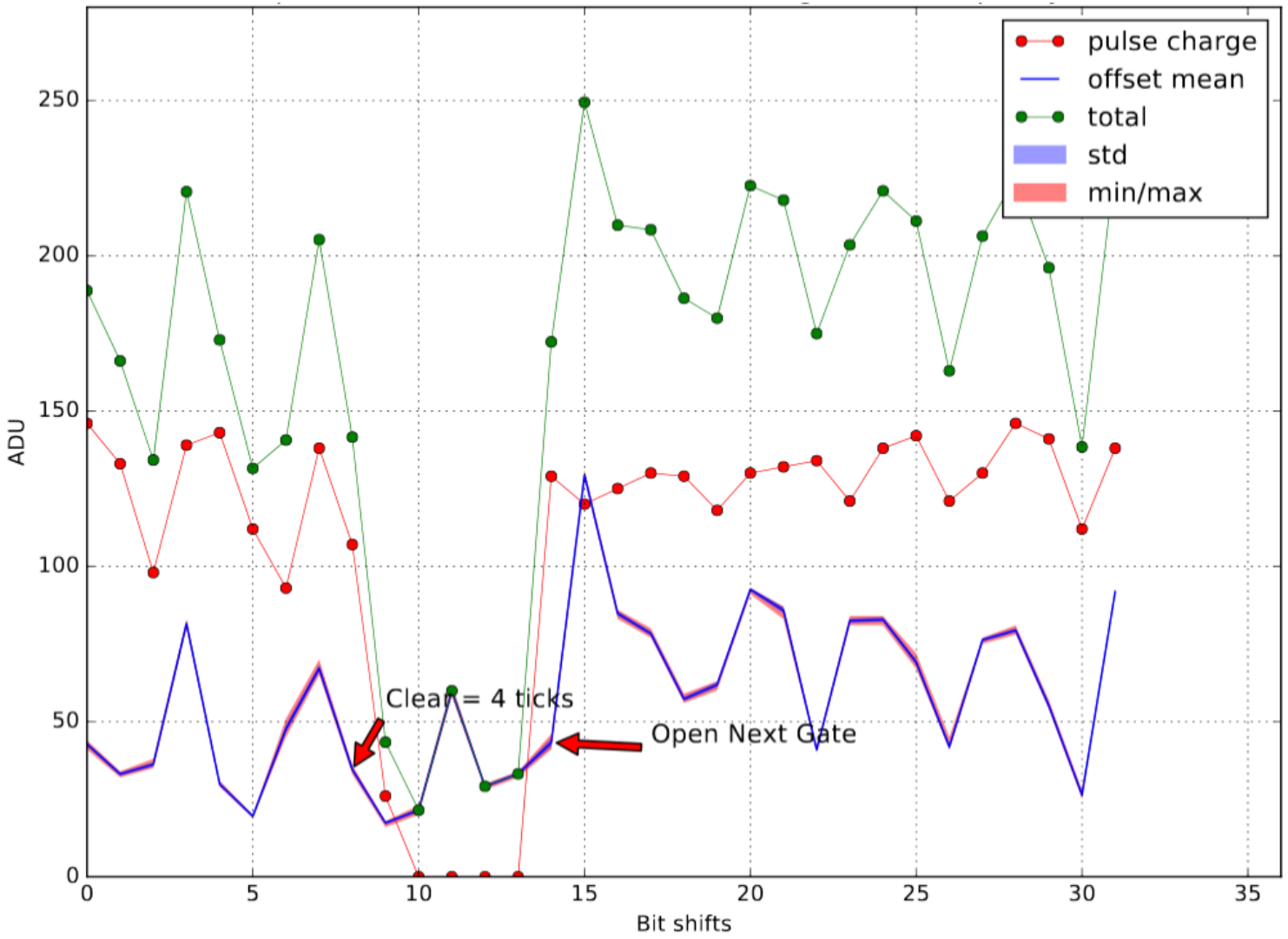


substantial swings:
- high voltage differences?
- 8-shift sampling period?

Sampling Point Curves w different matrix settings



Laser on Pixel(31,44), gain 1.7, 128ns



Summary

- Gain, IPDAC
  - Gap between 3.3 and 11.0 times lowest gain
  - IPDAC = 1 corresponds to $\approx 3\mu A$
  - 100 prim. electrons = 56 ADU (800k sec. e-) at gain 1.7
  - Precision vs Radiation Hardness
    - abandonment of 150 ADU (50 ADU offset assumption)
    - Poisson Noise no issue
    - IPDAC potential unused
    - 4-bit DAC possible?
    - rad. damage: sustain pixel spread> 400µA

Gain	current 200ADUs [µA]
1.0	410 (est.)
1.7	240
2.5	165
3.3	126
11.0	39
33.0	13

- No explanation for odd shape of matrix transfer curve, high sampling point curve shifts & high Common Mode

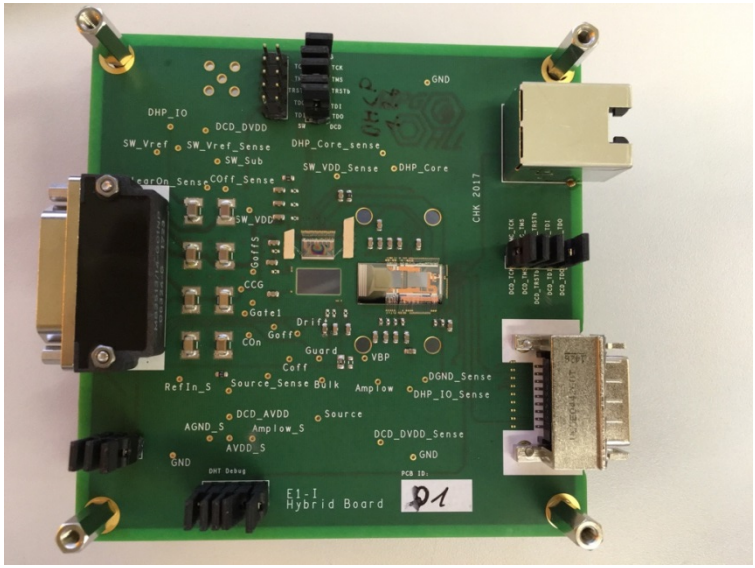
Poisson Noise

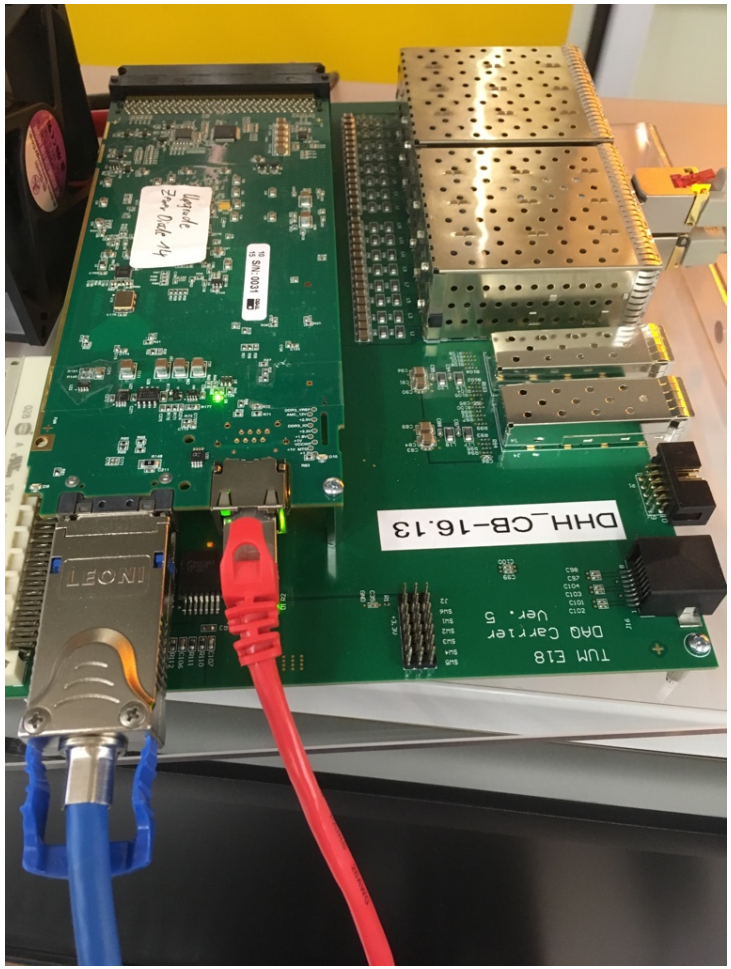
$$\sigma_{primary\ e^-} = \sqrt{primary\ e^-} \quad (mean)$$

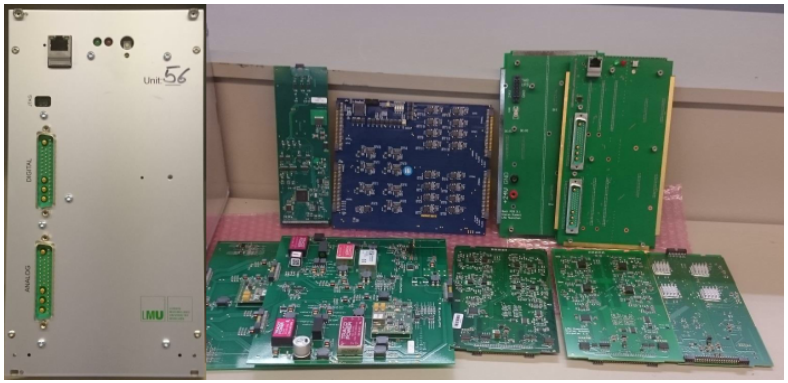
$$\sigma_{100\ =10\ e^-} \approx 80{,}000\ secondary\ e^-$$

THANK YOU FOR YOUR ATTENTION

TEST SYSTEM – MAIN COMPONENTS



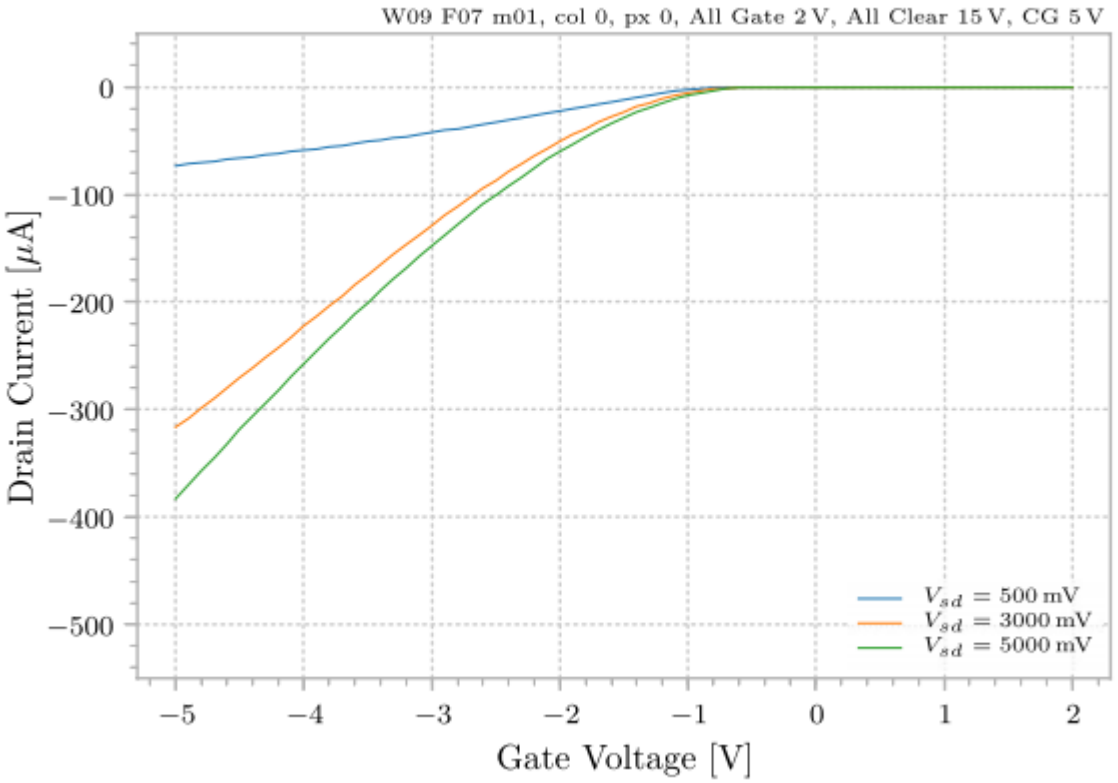




LMU PS: 9 different boards for each unit

ADC-TRANSFER CURVE 1.7 x lowest Gain

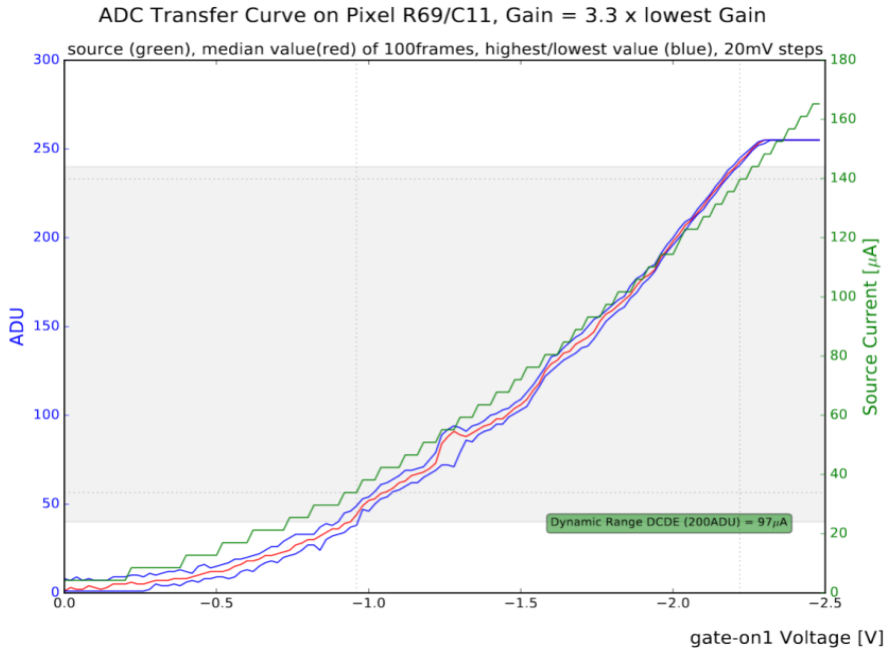
E1_I_04 PSP-Testing (Aug 2018)



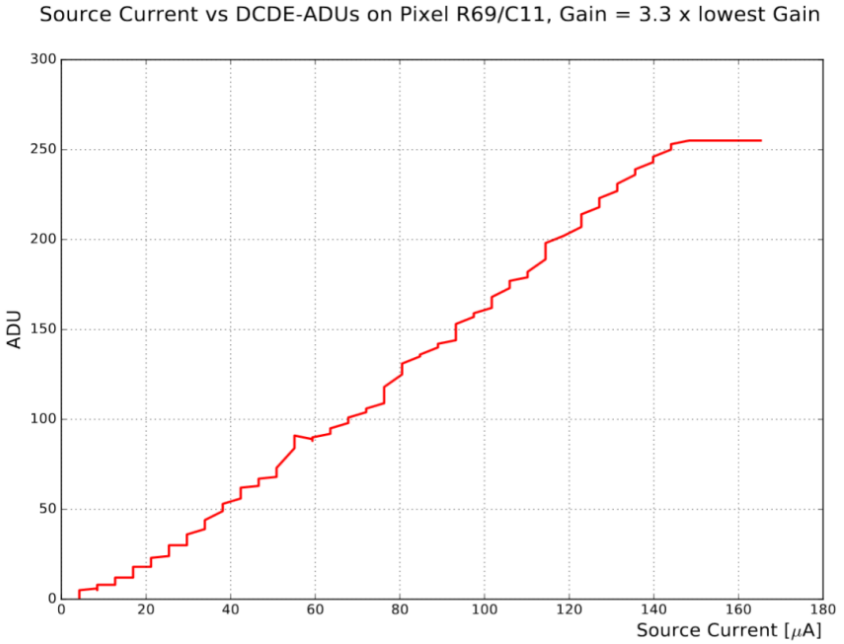
Gain Calculation Sheet

	En30	En60	En90	En120	Gain	Times lowest Gain	Rank
Rs	30	3	1.5	15	Rf=15		
	1	1	1	1	0.061	1.0	1
	0	1	1	1	0.063	1.0	2
	1	1	1	0	0.065	1.1	3
	0	1	1	0	0.067	1.1	4
	1	0	1	1	0.087	1.4	5
	0	0	1	1	0.091	1.5	6
	1	0	1	0	0.095	1.6	7
	0	0	1	0	0.100	1.7	8
	1	1	0	1	0.154	2.5	9
	0	1	0	1	0.167	2.8	10
	1	1	0	0	0.182	3.0	11
	0	1	0	0	0.200	3.3	12
	1	0	0	1	0.667	11.0	13
	0	0	0	1	1.000	16.5	14
	1	0	0	0	2.000	33.0	15

TRANSFER CURVE 3.3 x lowest Gain



Readout speed: 104ns
Dynamic range 97µA

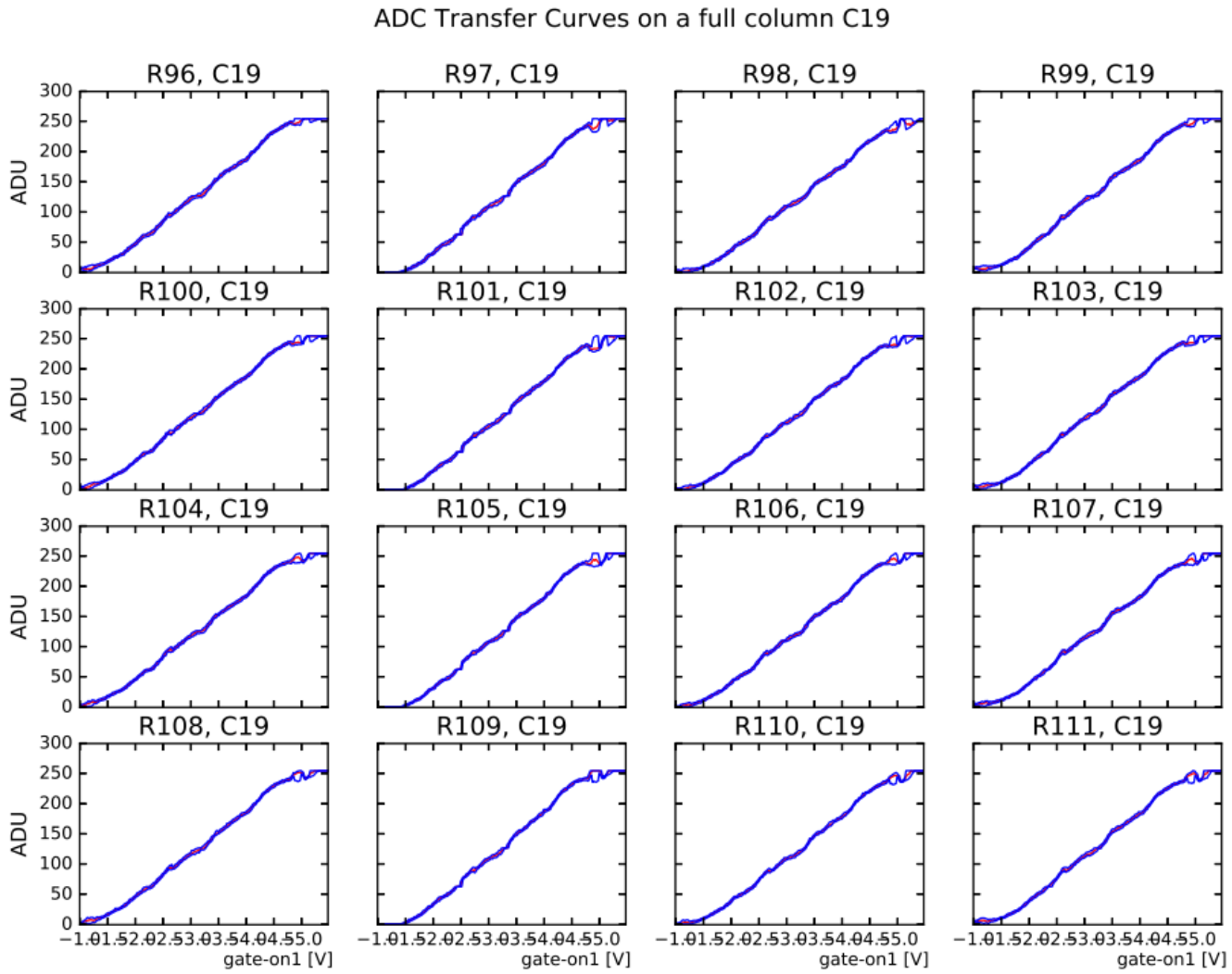


Problem:

different shapes due to:

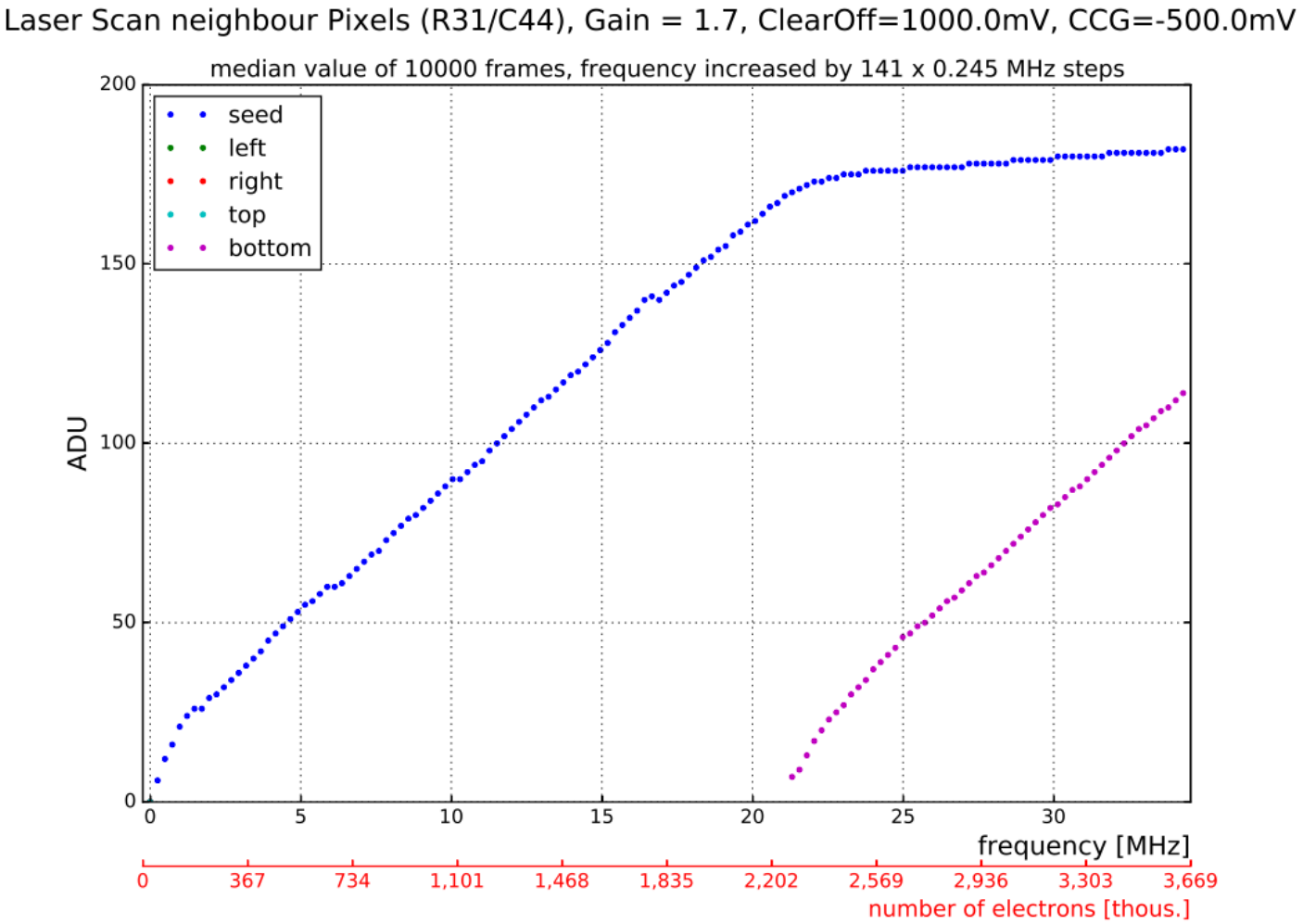
- sampling point shift
- DCDE settings (AmpLow)
- pixel position
- readout speed
- …

TRANSFER CURVE 1.7 x lowest Gain various Pixels

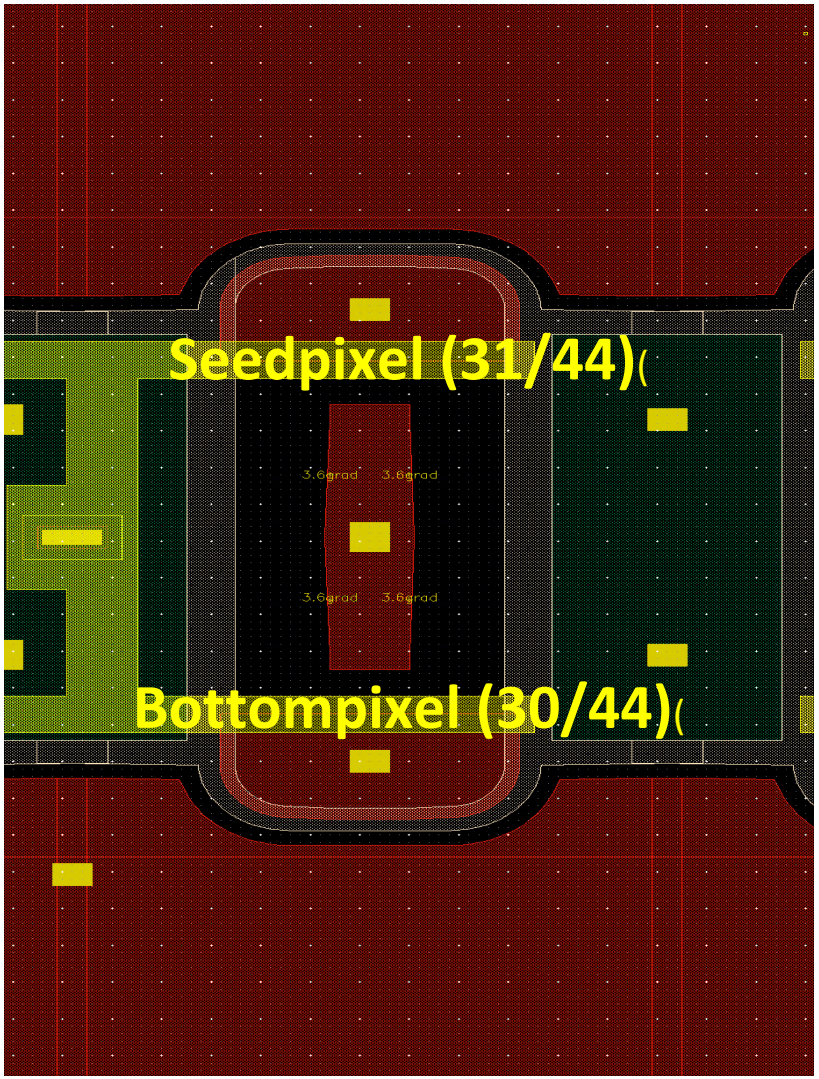


Pixel Capacity

Increasing frequency of laser pulses explores full dynamic range of device



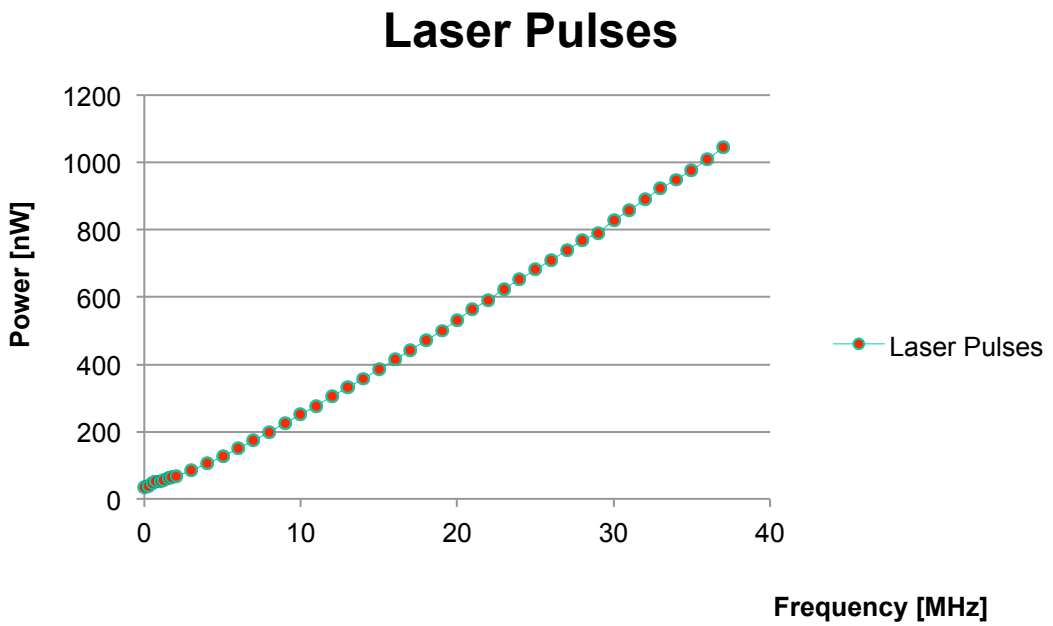
Edet Matrix W09 – A07 Pixel (R31/C44)



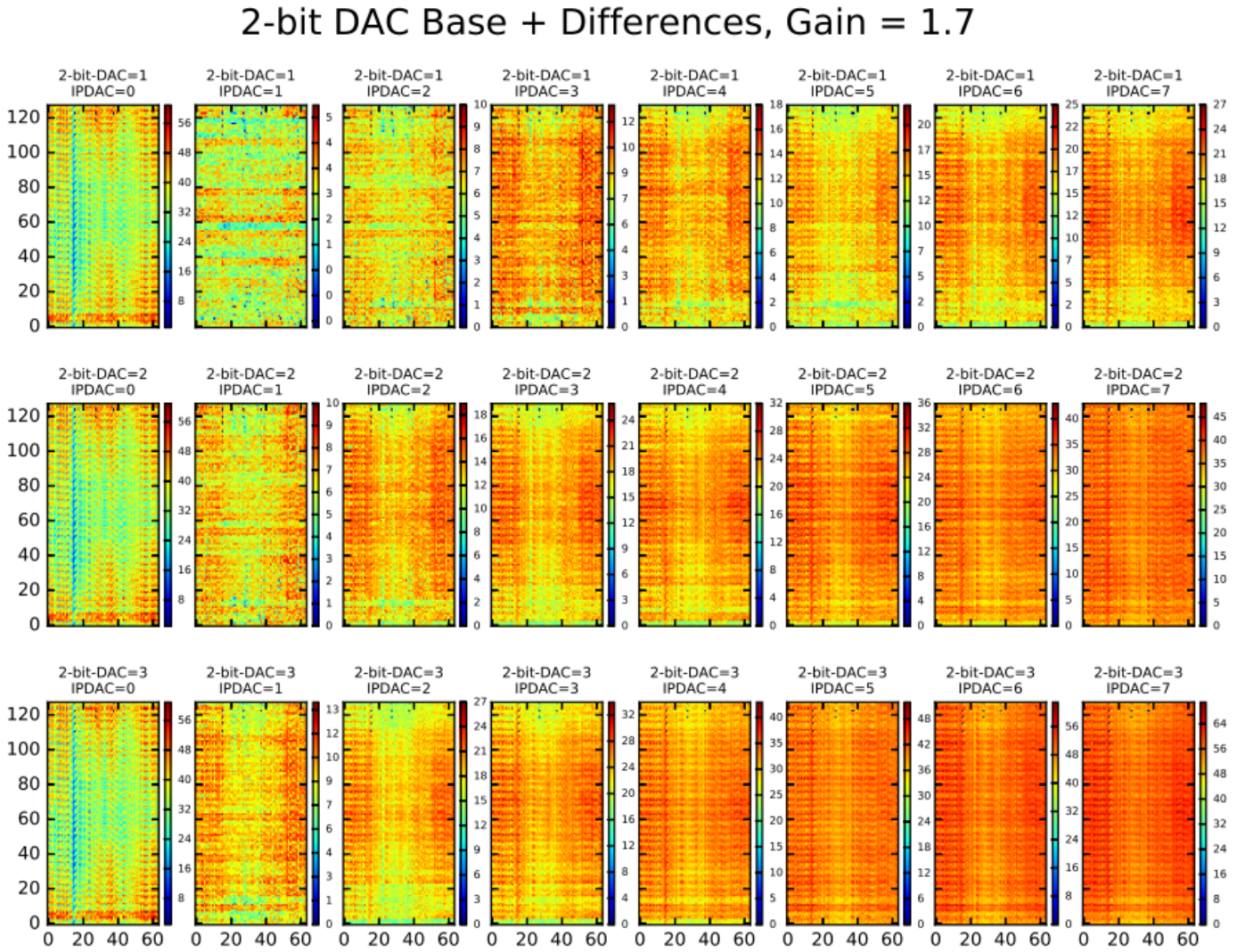
Optical Power Meter Measurements

Sensor Rows	32	
sensor thickness	50	µm
wavelength	635	nm
Frequency	62.5	MHz
time per frame	4.096	µs
E_{photon}	1.952506975	eV
absorption coefficient	3270.00	a/cm
$P_{average}$	1.000	µW
Pulse length	4.096	µs
Pulse energy (eV)	25,565,224	eV
# photons	13,093,538	
p+ layer thickness	3.00	µm
Reflectivity free Silicon	0%	
Coupling Losses (FC/PC)	0%	
Silicon density	2.329	g/cm^3
Absorption	100.0000%	
p+ Implant survival factor	0.37	
# electrons gen.	4,909,238	

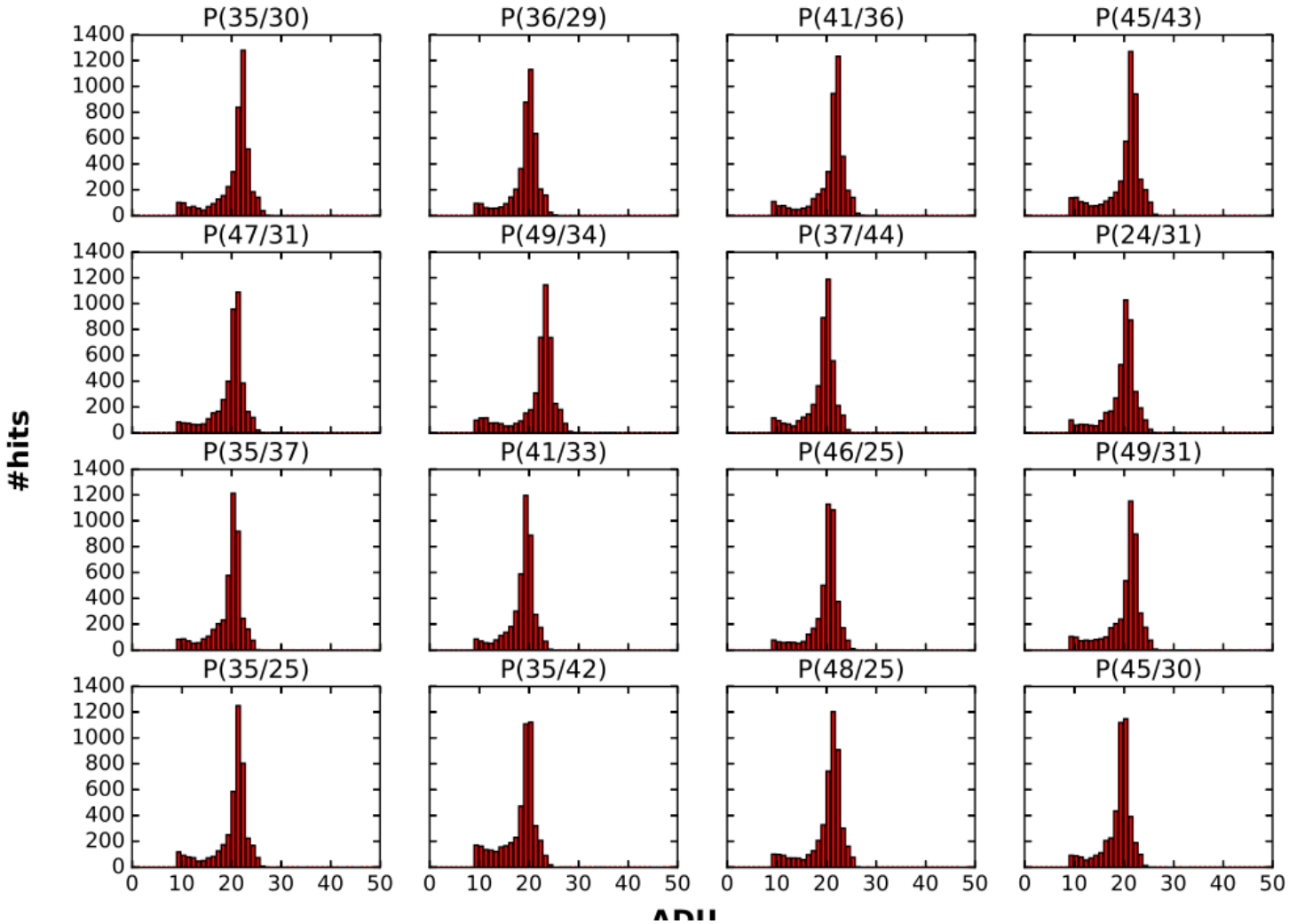
- **Calculation: Pulse Energy divided by photon energy & survival factor**
- **Reflectivity & Coupling losses assumed similar**
- **→ in accordance with measurements**



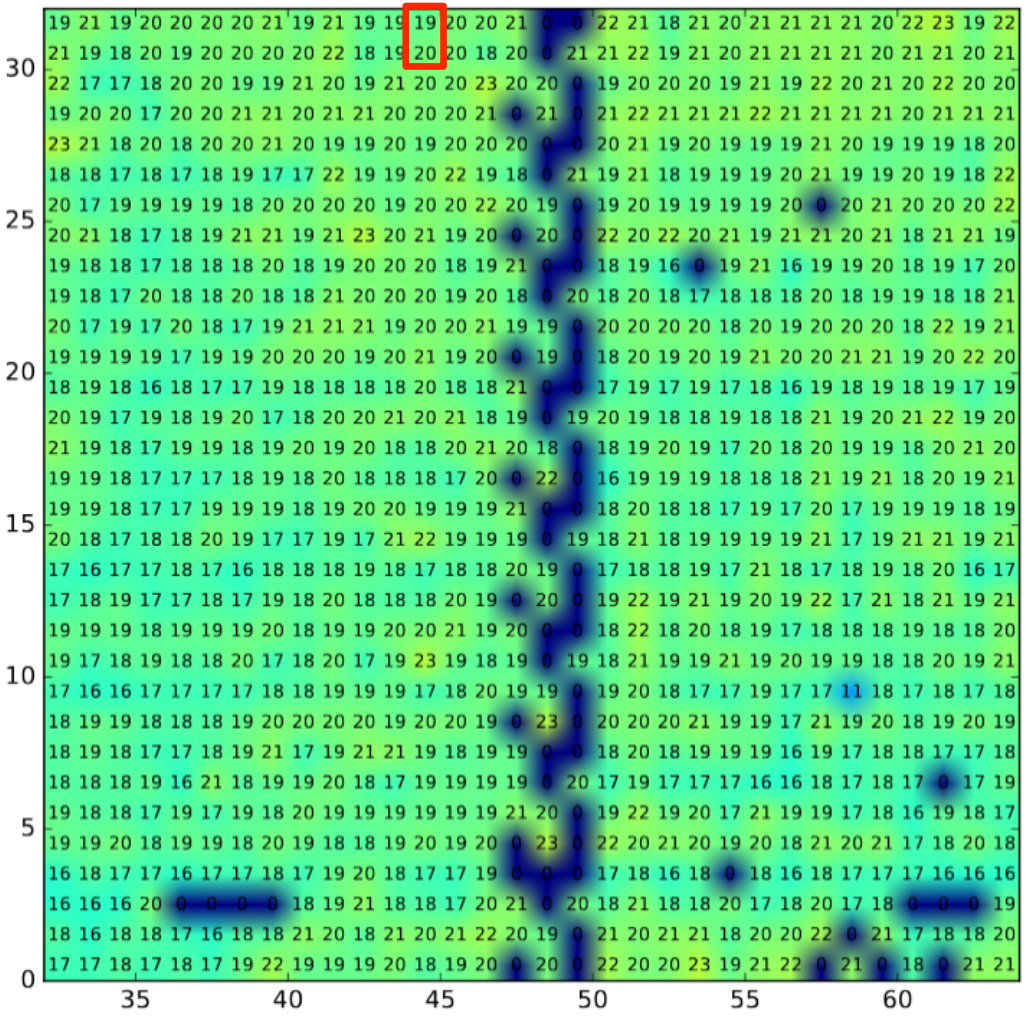
2-bit DAC principle 1.7 gain (III)



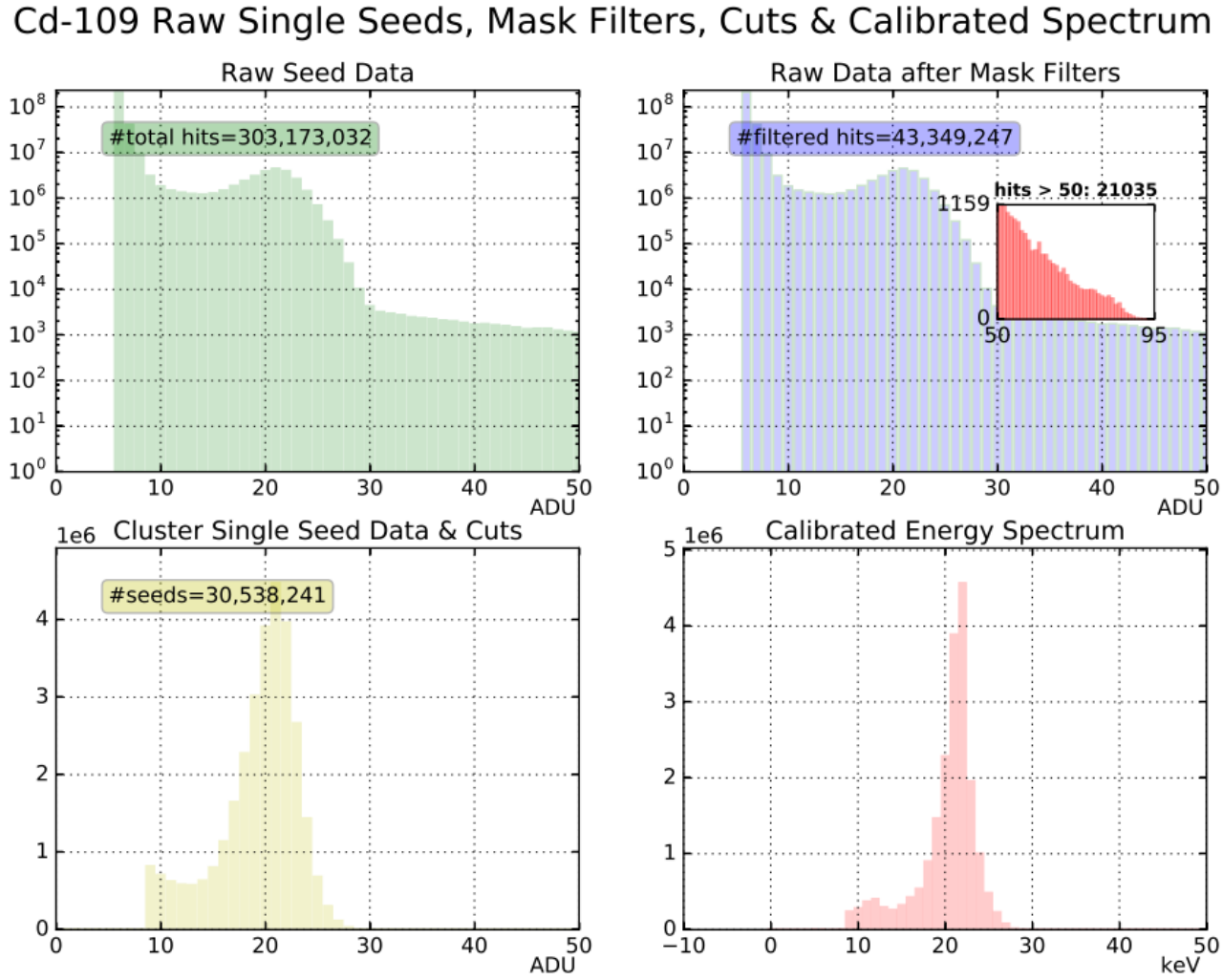
Cd109 SOURCE on 300 Mio Frames



Individual Pixel Gain R(0-31)/C(32-63)

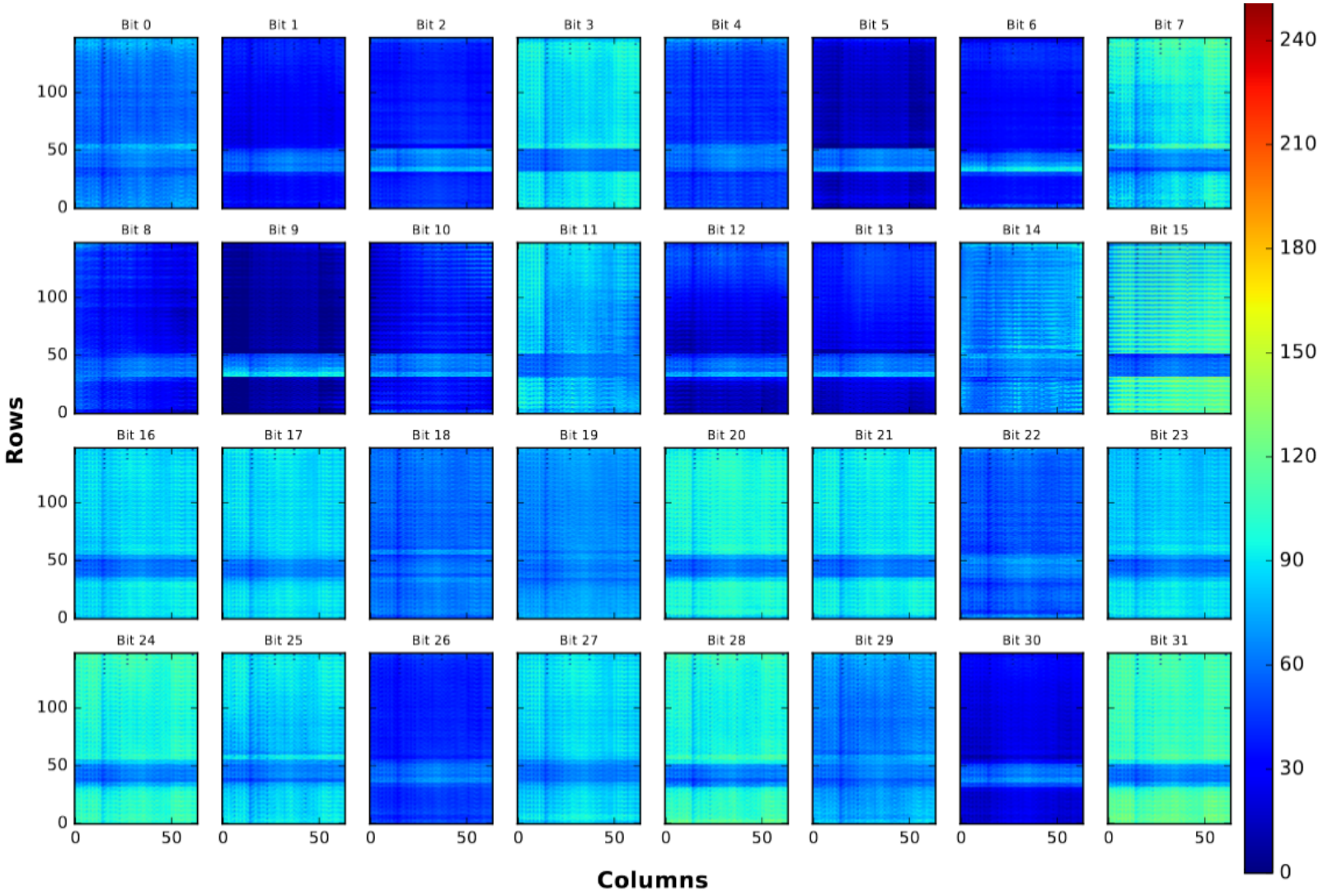


Cd109 SOURCE on 300 Mio Frames (3)



Peak FWHM ~ 3keV

Switcher Bit Shifts, Gain 1.7, 128ns OFFSET VALUES



Laser keeping P(31/44) open add. 5 row cycles