PSI Center for Photon Science

Adaptive Gain Frontends

Outline:

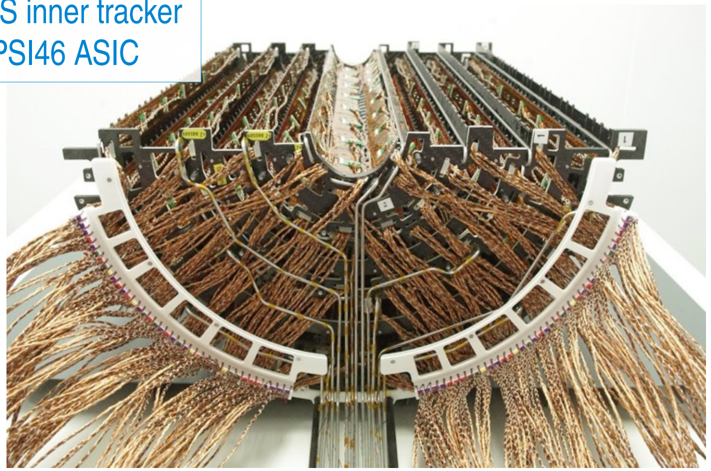
- Why do we need AGFs?
- Theory of operation
- The Jungfrau FE design choices in detail
- Pushing the DR at Synchrotrons
- Pushing the DR at FELs.

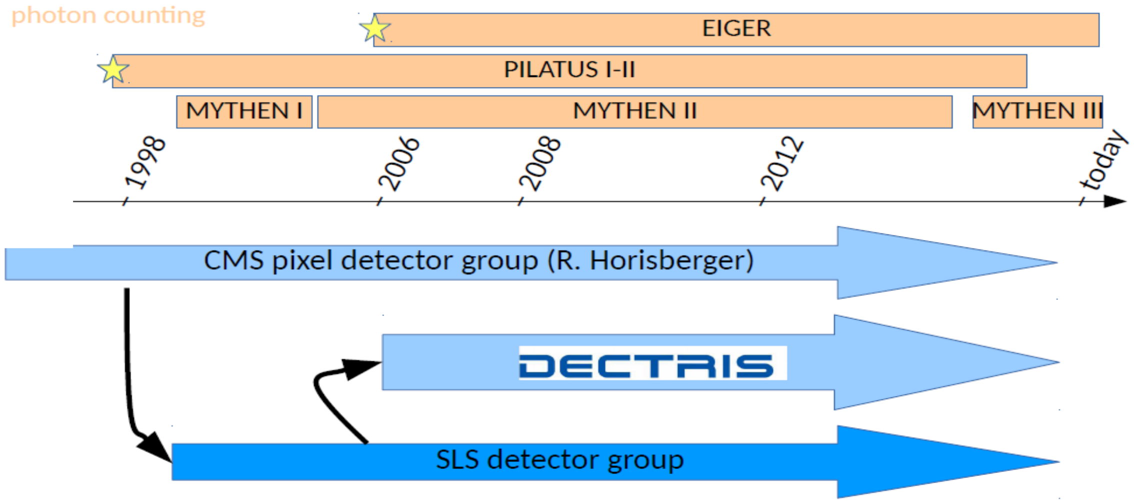
Aldo.Mozzanica@psi.ch

FEE 2026 workshop 05.2026

History of CPS detector group

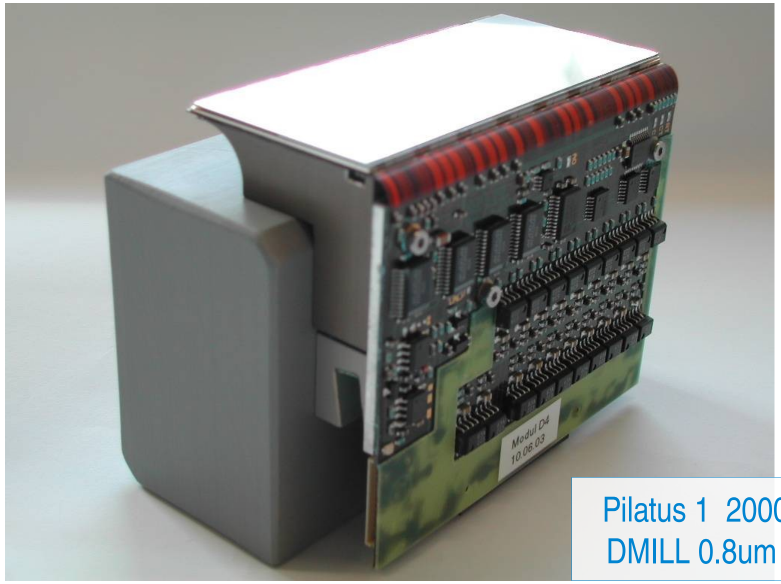
CMS inner tracker
PSI46 ASIC





X-ray detector development:

- Late 90s, X-ray detectors at the time were slow, perceived bottleneck for SLS, then in construction
- Technology transferred from CMS group → our first photon counting detector PILATUS
- Successfully developing photon counters (PCs) for X-ray science sing 1998. PCs were praised for:
  - Speed
  - DR
  - being “noiseless”



Pilatus 1 2000
DMILL 0.8um

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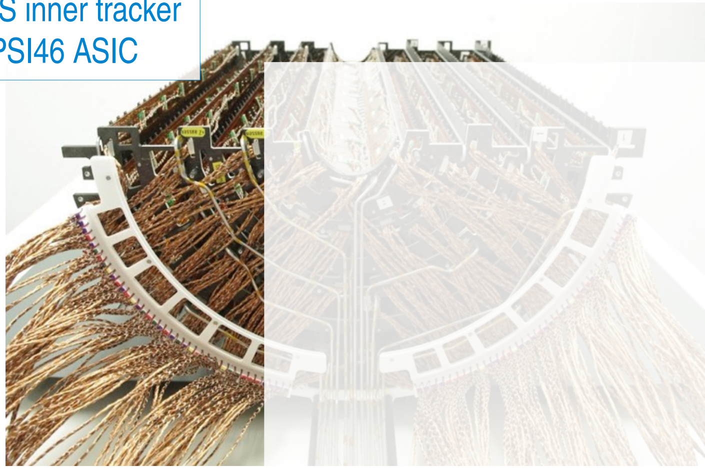

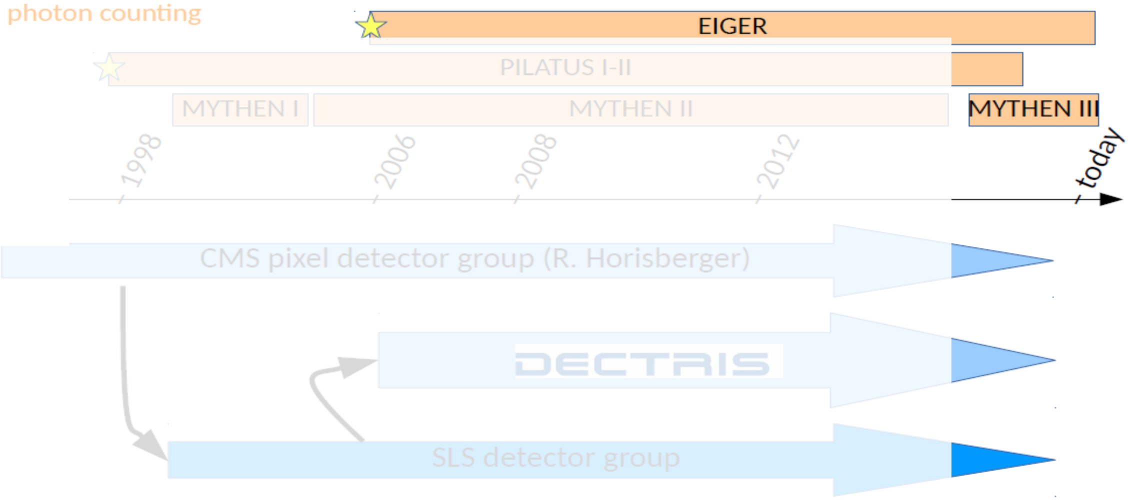

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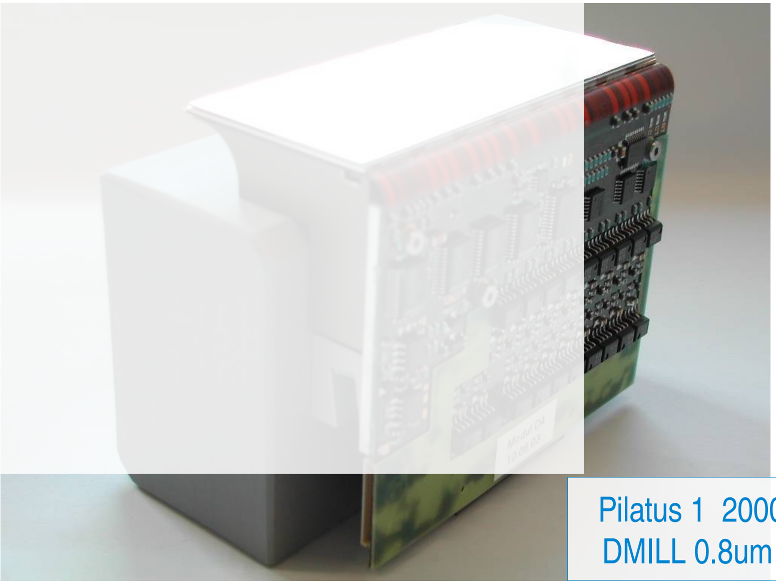
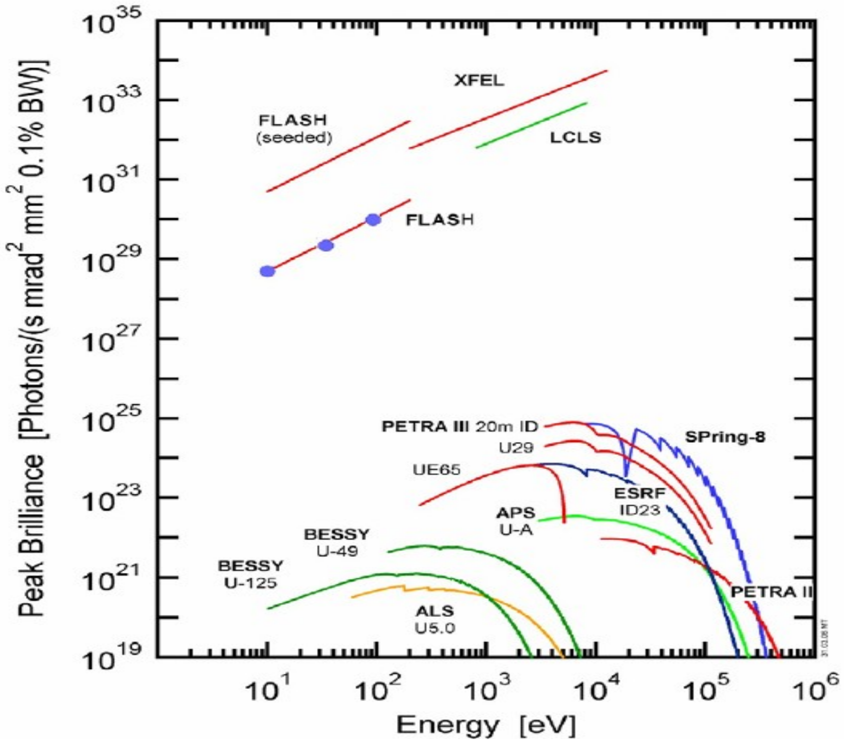
Then came the FEL

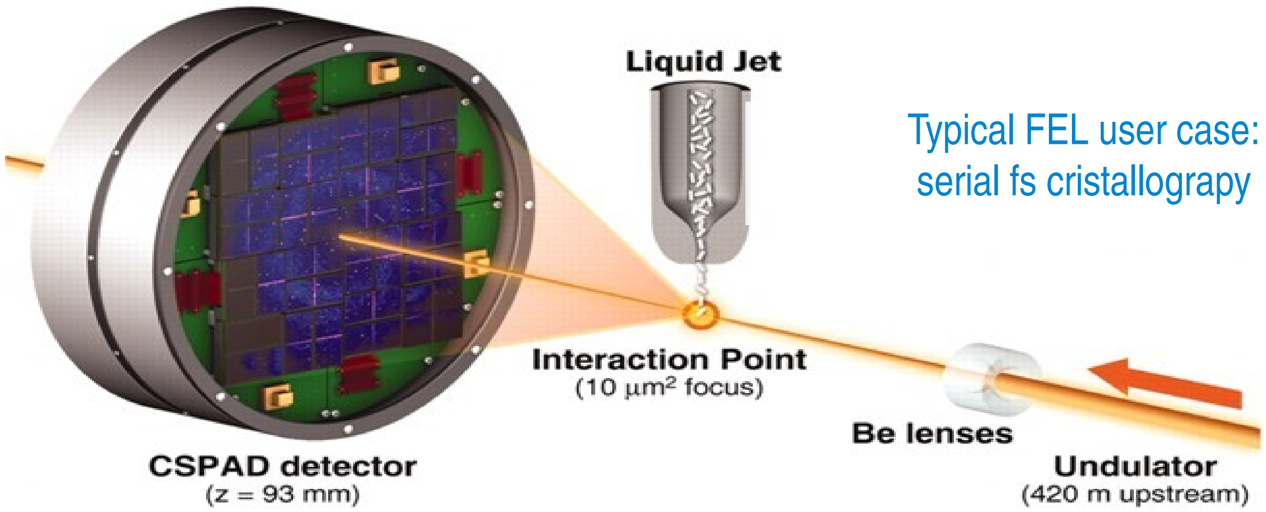


Pilatus 1 2000
DMILL 0.8um

Detectors for Free electron laser

- First hard X-ray lasing at LCSL: 2008
- FELs provide orders of magnitude more brilliance than other light sources: all photons come at once – no counting possible
- **A FEL delivers in a single pulse (~100fs) the same number of photons as 0.1-1s at Synchrotron sources**
- New detectors had to be developed – Cornell-SLAC CSPAD lead the way
- PSI was involved in the AGIPD collaboration since 2008
- GOTTHARD 0.1 was gain switching test chip from 2004
- in 2012 the Jungfrau project started.





Typical FEL user case: serial fs cristallograpy

Charge integrating amplifier, can it meet the requirements ?

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Requirements:

1 single photon resolution at 2keV (SwissFEL)
2 DR? hard to get a fix number from science: 1 FEL pulse~1s at synchrotrons, Bragg reflections @sync have Mcps/pix, but FEL are used for smaller, harder, weaker diffracting crystals
3 A 10^4 saturation level was considered sufficient in 2008.

A standard CSA with a reset switch and a fixed feedback capacitor: could this work?

2keV single photon resolution → 1keV threshold → 4 sigma from noise, → noise < 250eV r.m.s. or 70 ENC

10E4 12keV photons → 120MeV → 33Me- charge

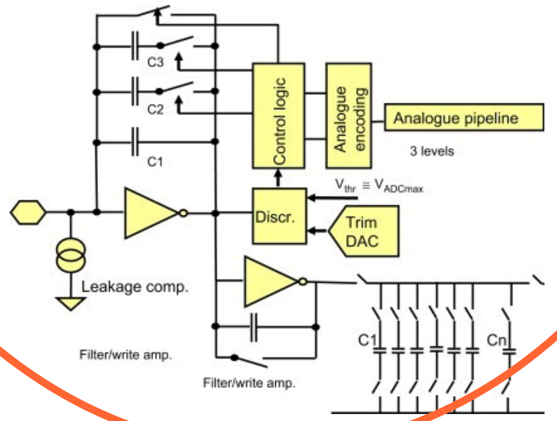
33M/70= 470k = 19bit DR* → No way, not with a single, linear, gain

** here defined as saturation_level/noise_level*

Three classes of solution to the HDR problem

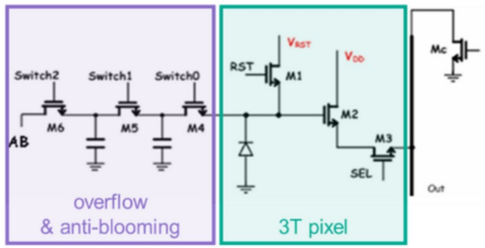
Active pixel gain switching:
Gotthard(1D), AGIPD, Jungfrau, EPix(HUR)10k, STARLIGHT, unnamed* (Tue. Pres. by A.C., Wed pres. By L.G.)

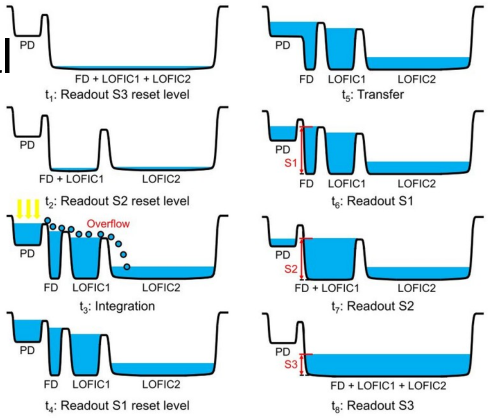
10.1016/j.nima.2010.06.107
10.1109/NSSMIC.2013.6829505
10.1109/TNS.2025.3637403
10.1088/1748-0221/20/02/C02019

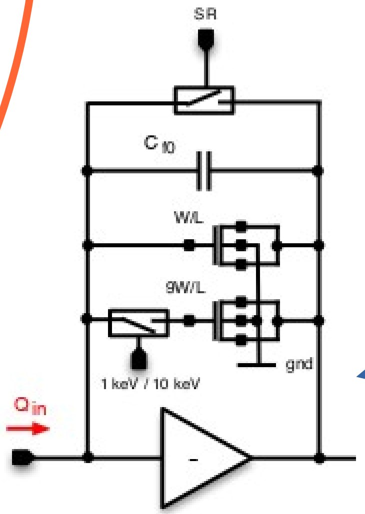


Passive in pixel multi-gain with variations of “lateral overflow”(LOFIC): CITIUS, Percival

10.1107/S1600577523004897
10.1063/1.5084691

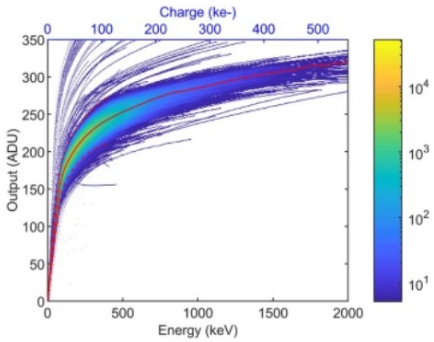






Nonlinear gain/nonlinear capacitors:
in sensor: DSSC
in FE: PixFEL*

10.1038/s41598-023-38508-9
10.1088/1748-0221/10/02/C02024



** prototypes*

Introducing the Adaptive Gain

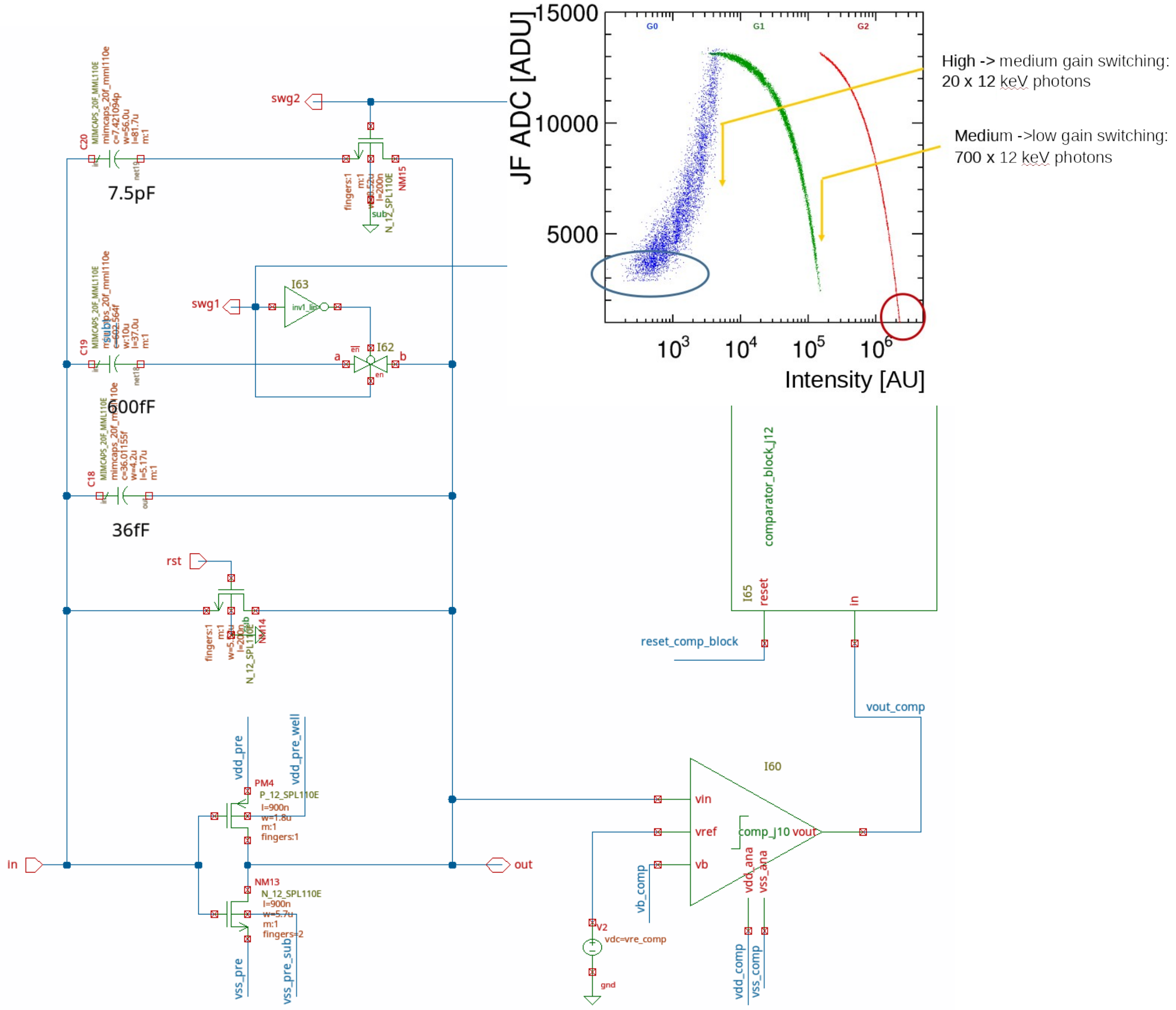
Per pixel and per frame, the circuit automatically adjusts the gain to the input charge:

- starts in high gain
- small input charge: high gain
- medium input charge: medium gain
- high input charge: low gain

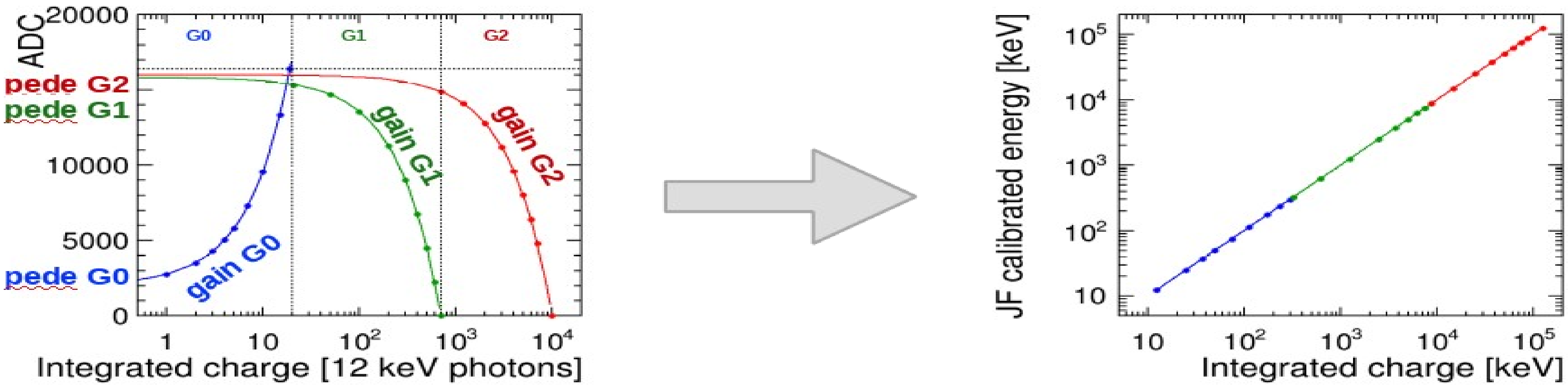
Per pixel and per frame, 16 bits output:

- 2 bits: what gain was used
- 14 bits: what was the amplified charge

This needs correcting to retrieve the number of photons detected



Correcting raw data: 6 constants per pixel:



Per pixel per frame:

Q1: which gain are we in? (which pedestal and gain apply?)

Q2: how far above pedestal are we? (pedestal correction)

Q3: what energy caused that? (gain correction)

Q4: how many photons does that mean? (divide by beam energy)

$$N_\gamma = \frac{|\mathrm{ADC} - \mathrm{pede}|\,[\mathrm{ADU}] \times \mathrm{gain}\,[\mathrm{keV/ADU}]}{E_{\mathrm{beam}}\,[\mathrm{keV}]}$$

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Example:

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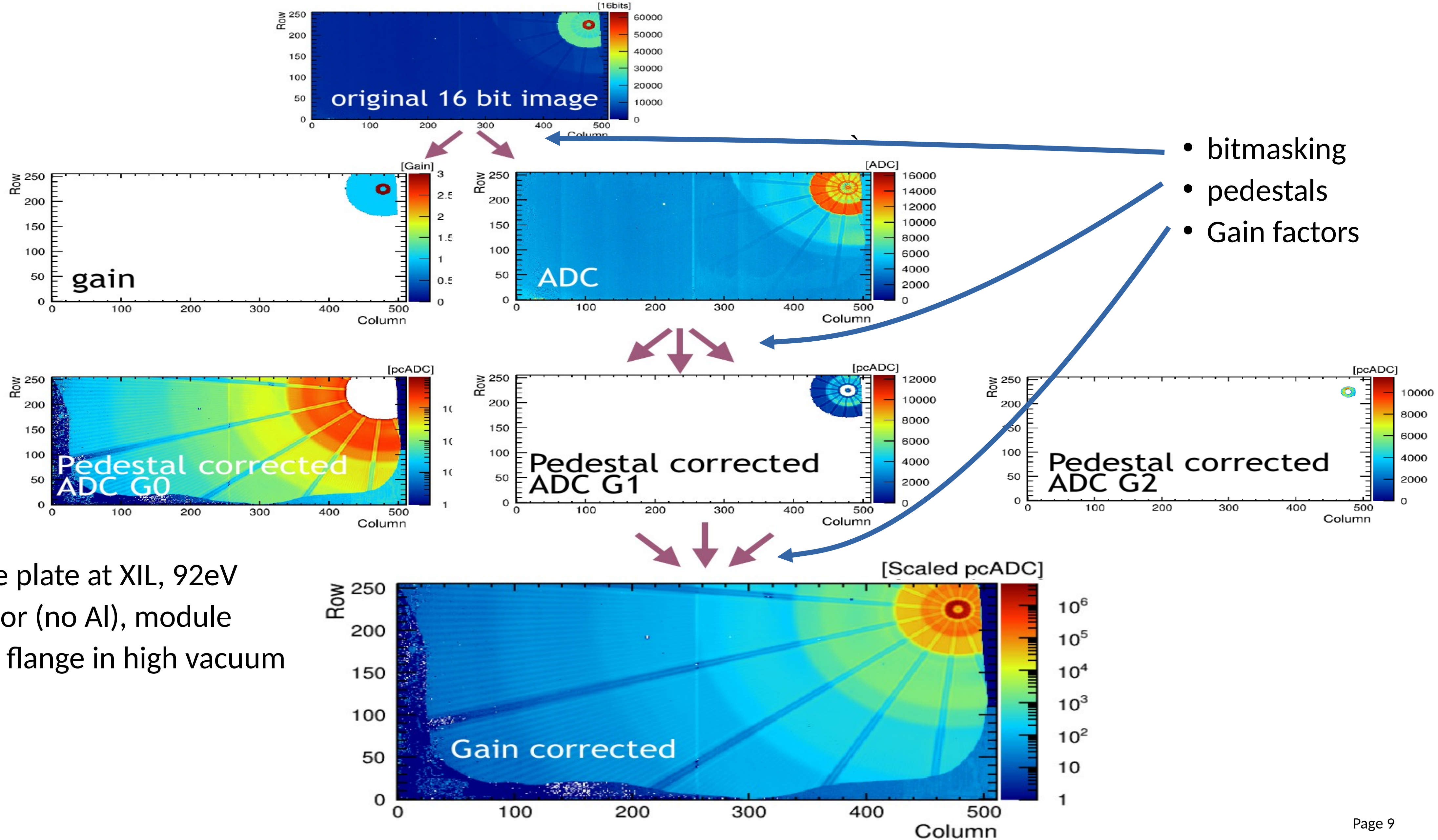
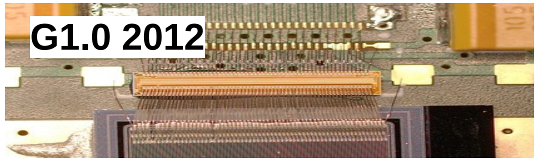
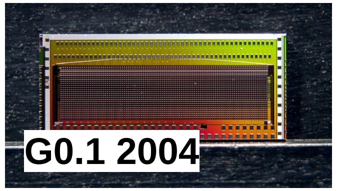
- bitmasking
- pedestals
- Gain factors

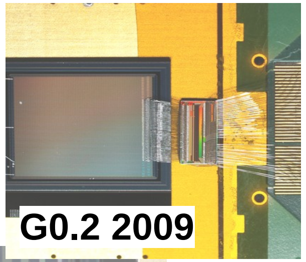


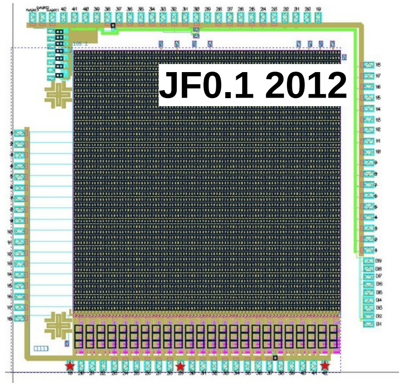
- Fresnel zone plate at XIL, 92eV
- etched sensor (no Al), module mounted to flange in high vacuum

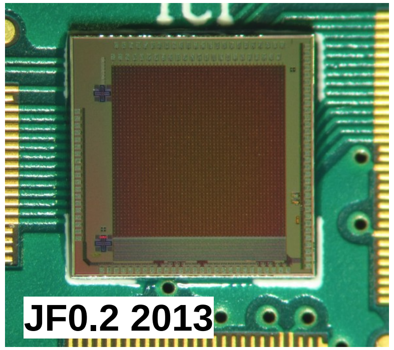
Adaptive Gain @ PSI

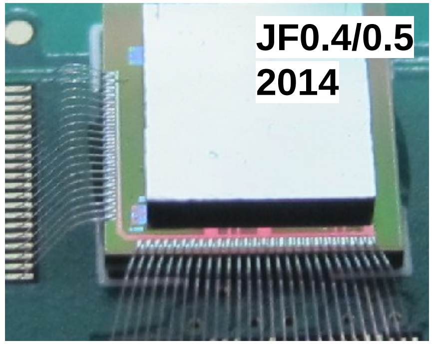


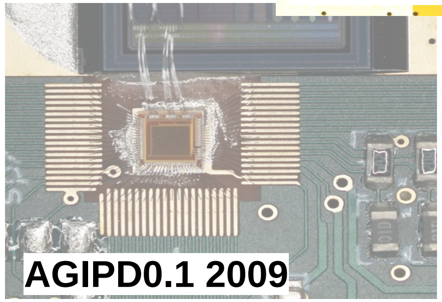


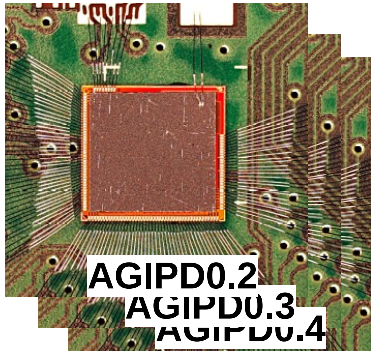




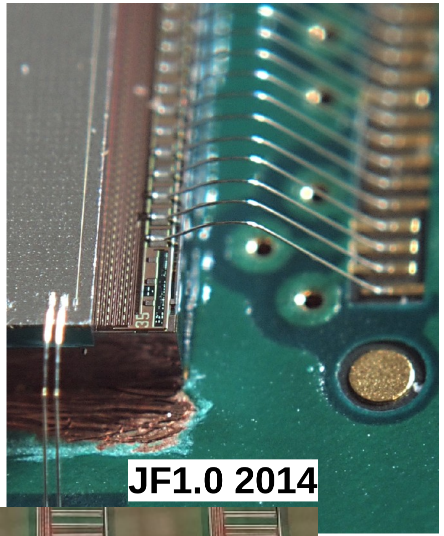


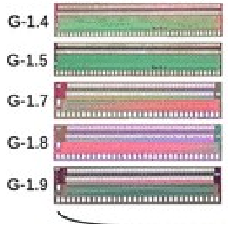




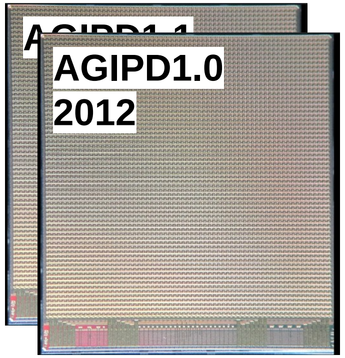


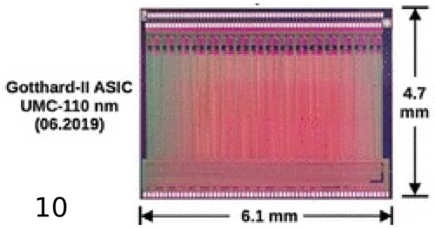
- More than 30 ASICs submissions in 20y

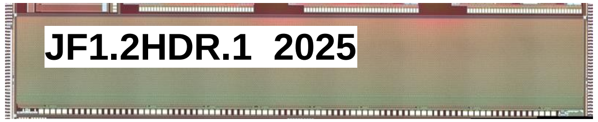


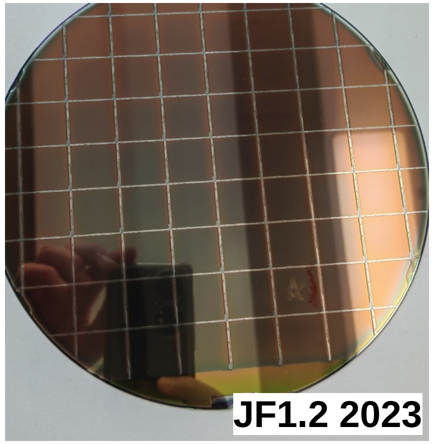


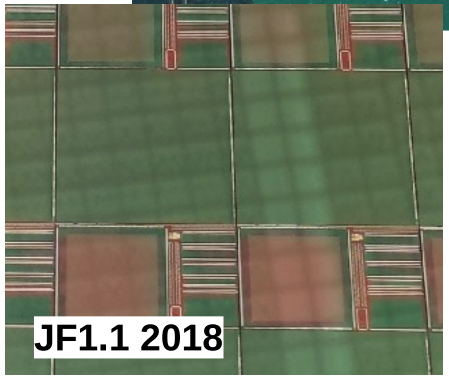
2014-2019









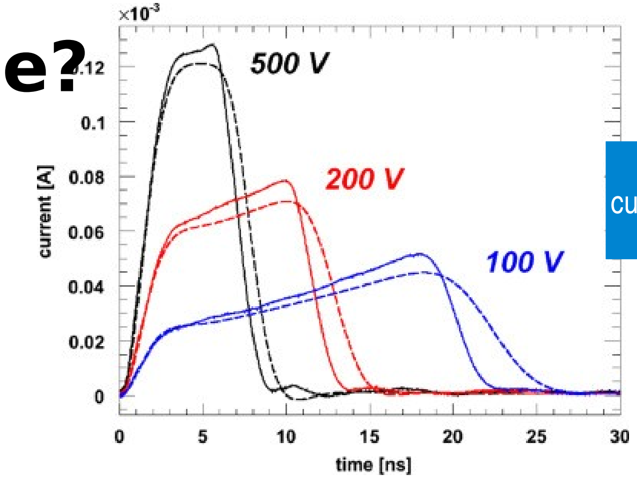


How fast should the preamplifier be?

Signal (holes) arrive at input in O(10ns).

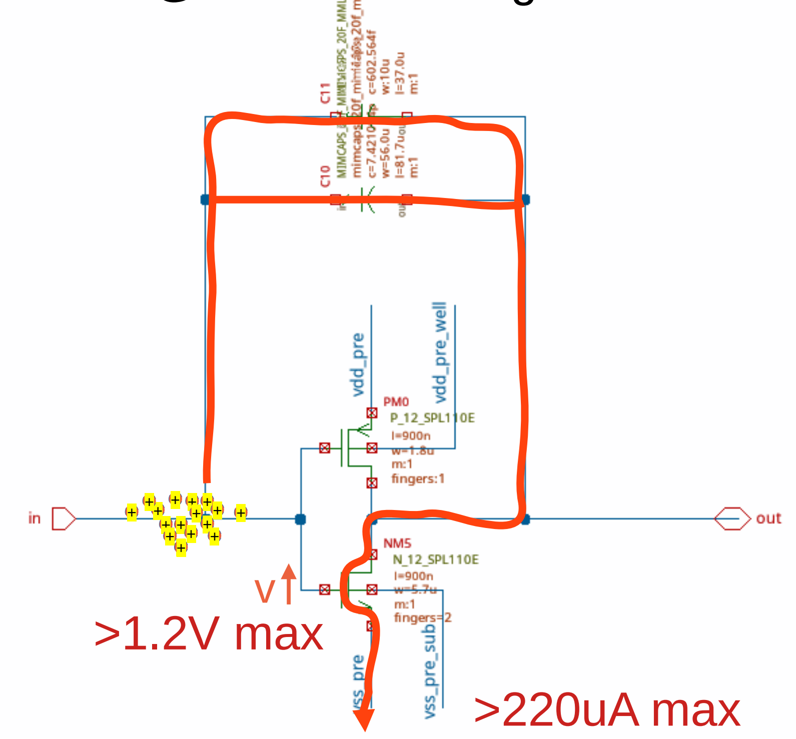
Our power budget is 10uA static for the preamplifier.
If only (100% of) the static current would be used to discharge: 33Me- = 5pC → 600us of discharge time.

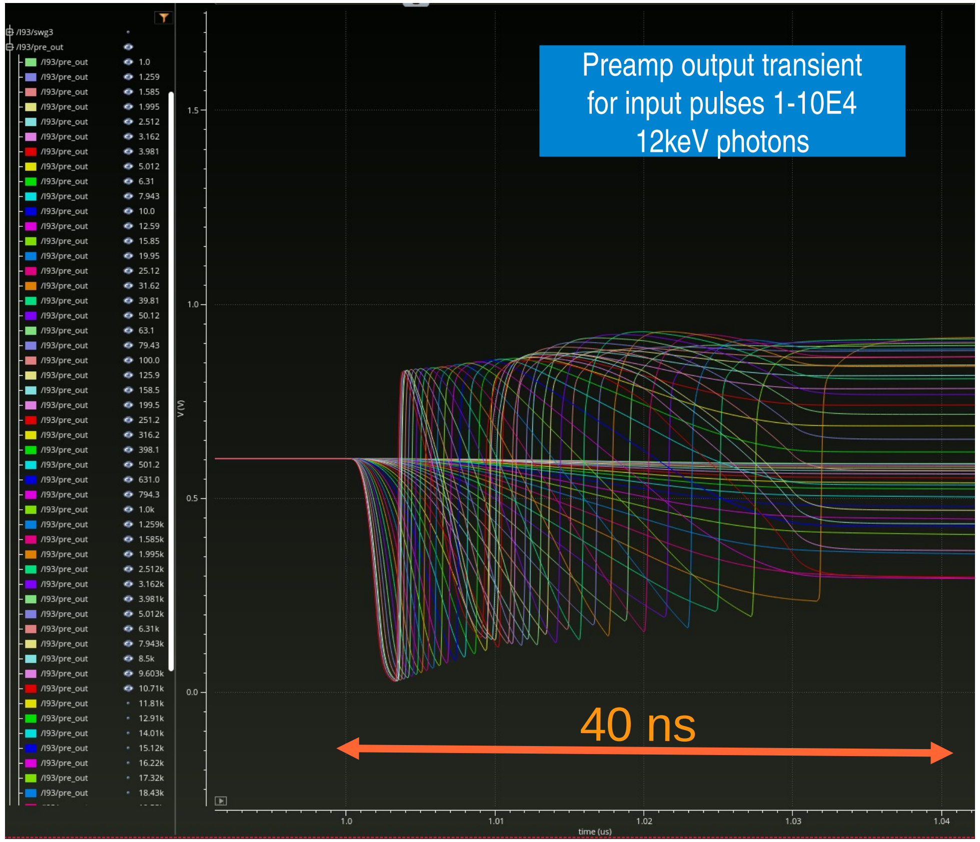
We need more current during transient: an inverter based amplifier offers a simple and efficient way out. 33Me- in 40ns @ >155uA average.



Measured and simulated currents for 10Me- input charge 500um sensor

10.1016/j.nima.2010.10.010





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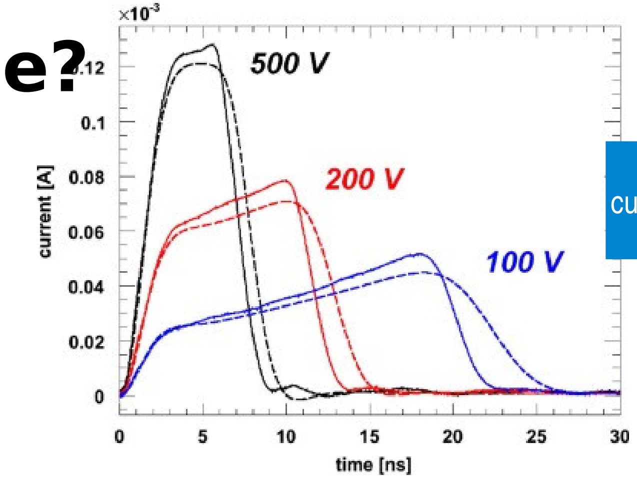

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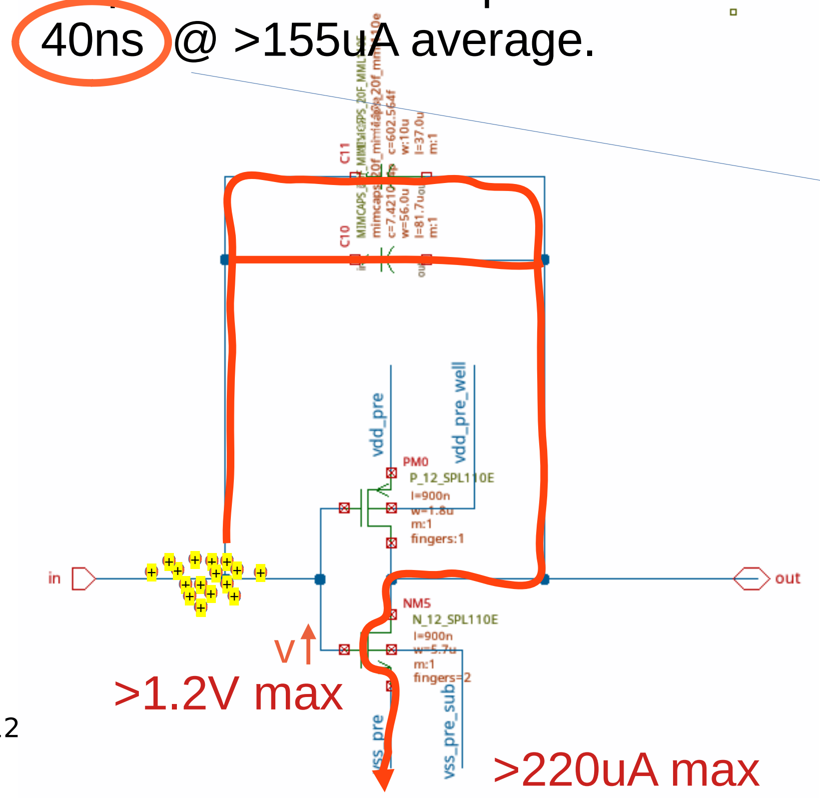
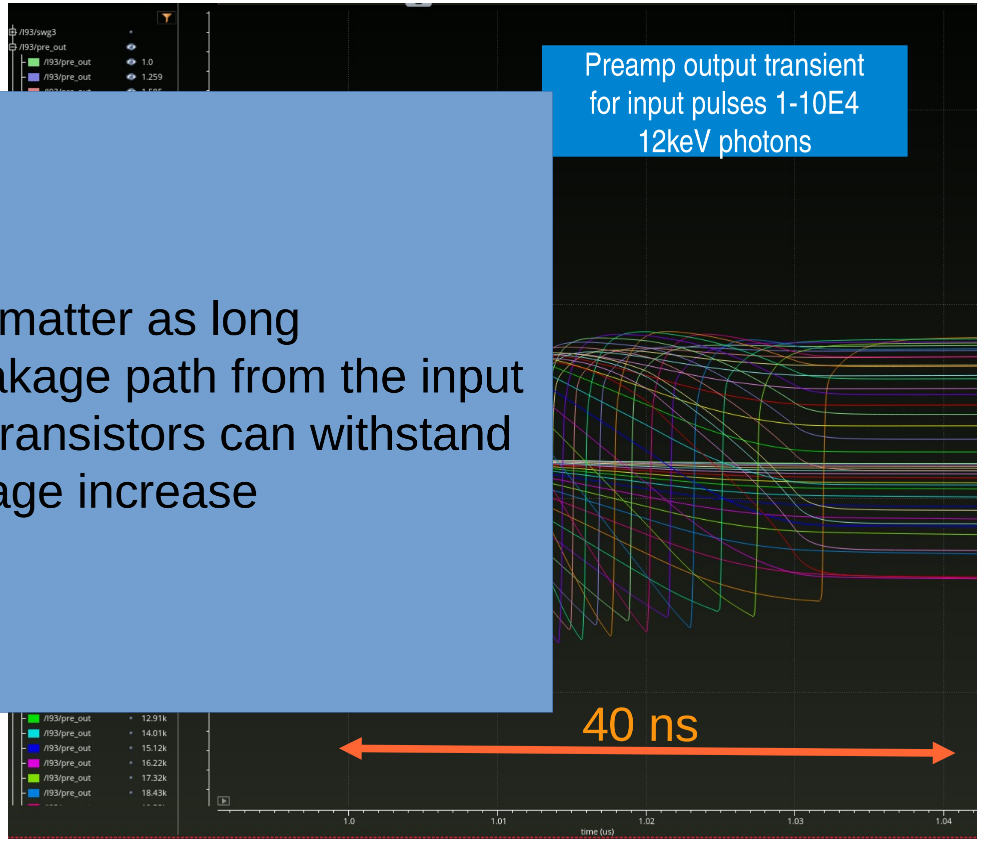




Preamp output transient for input pulses 1-10E4 12keV photons

does not matter as long as the there is no leakage path from the input node and the input transistors can withstand the voltage increase

Does not matter but:

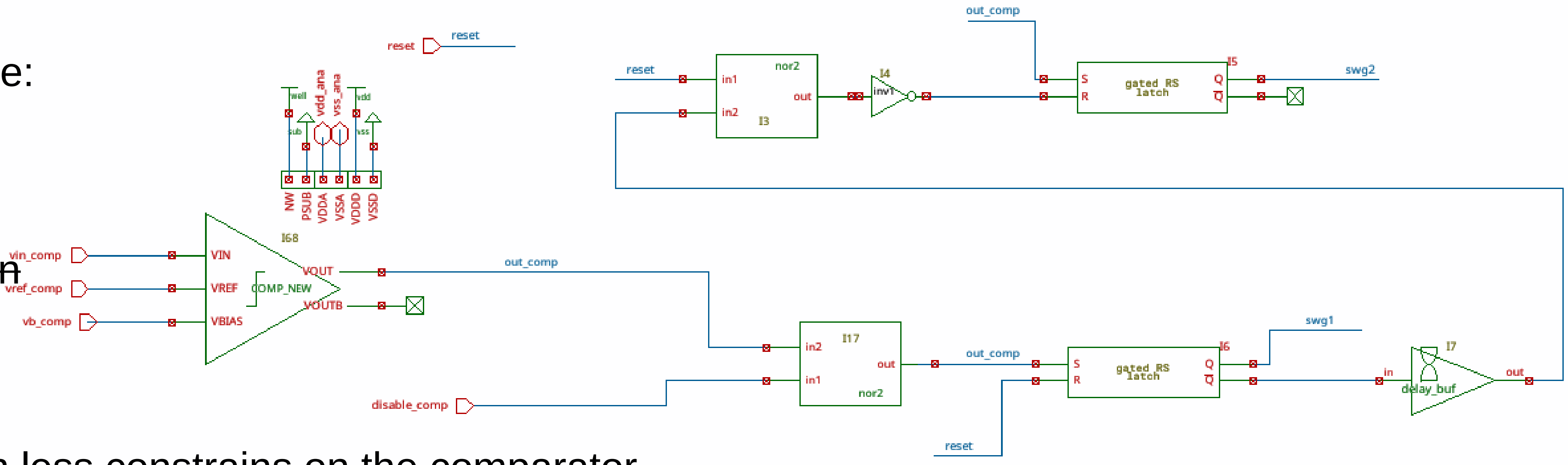
For a three gain adaptive gain circuit, for signals covered by the middle gain:

if the preamplifier (or the comparator) is too slow, the system will always/at times re-trigger into low gain.

a delay (hold-off) as long as the convoluted time response of preamplifier + comparator, worst corner, has to be inserted in the digital logic.

The comparator should be:

- fast
- ~~low noise~~
- ~~low threshold dispersion~~
- low power



A 2 gains circuit has even less constrains on the comparator

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Moreover, the comparator should be disabled some time (>5x filtering RC) before the end to avoid late switching.

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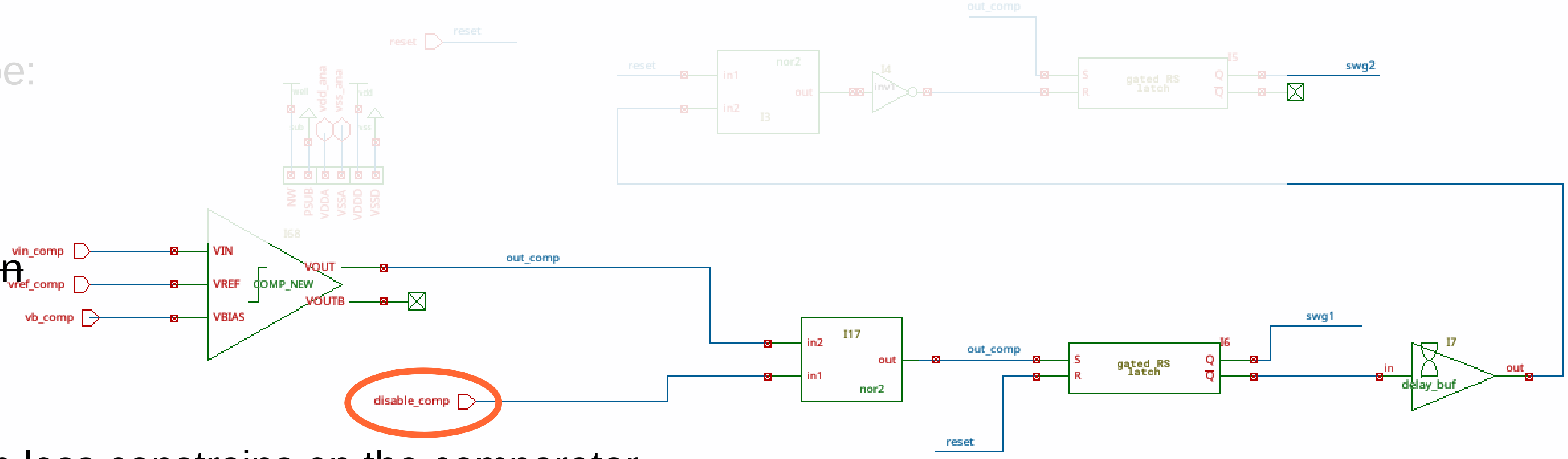
- ~~low threshold dispersion~~
- low power



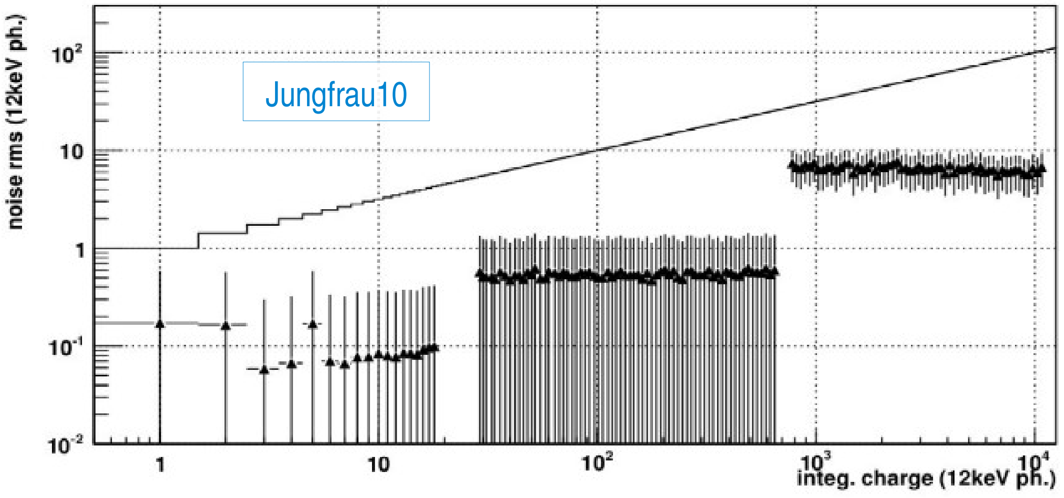
A 2 gains circuit has even less constrains on the comparator

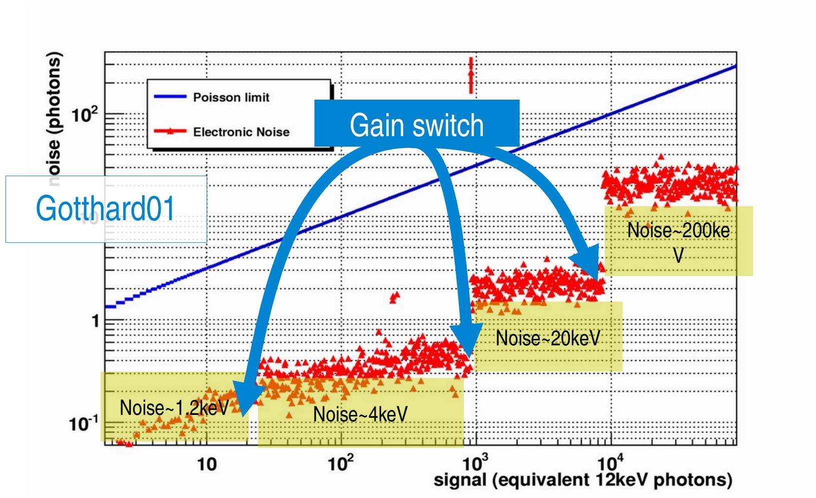
How many gains?

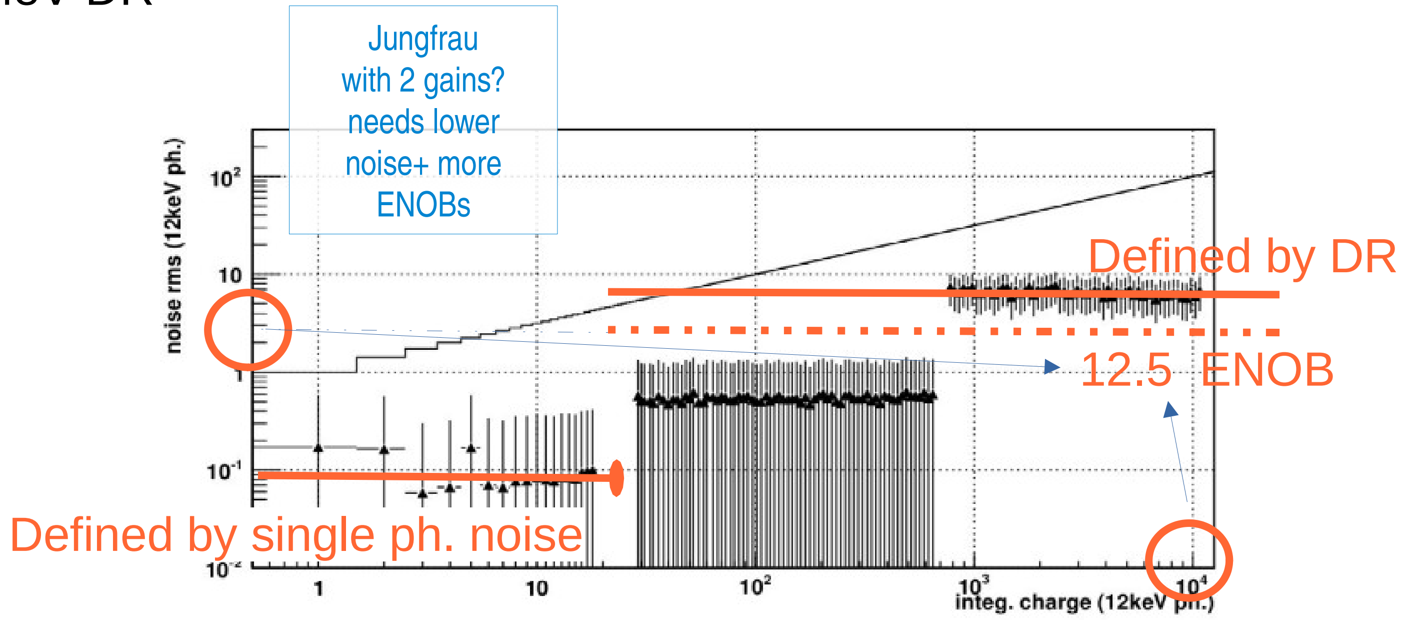
Difficult choice: not a definitive answer.
More gains: lower noise after all switching point
Less gains: simpler circuit, simpler calibration

We started with 4, we settled to 3.

Two is also possible (ePIX10k) but hard with our requirements - 2keV single ph. and 120MeV DR

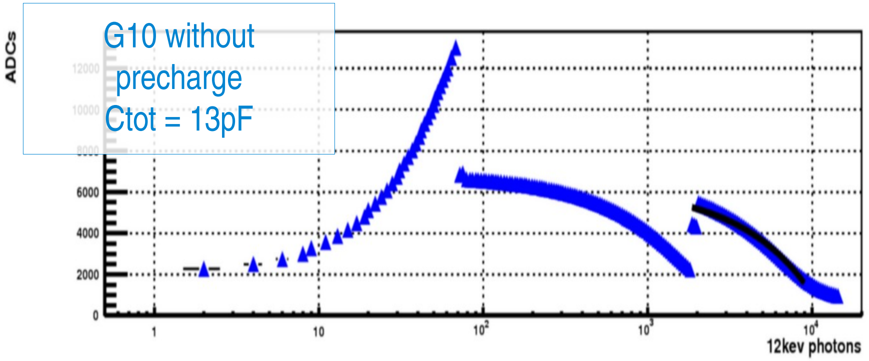


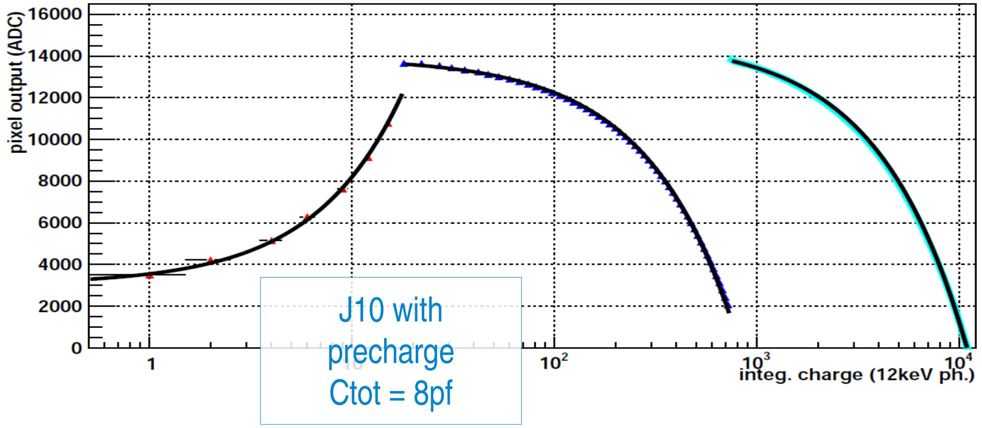


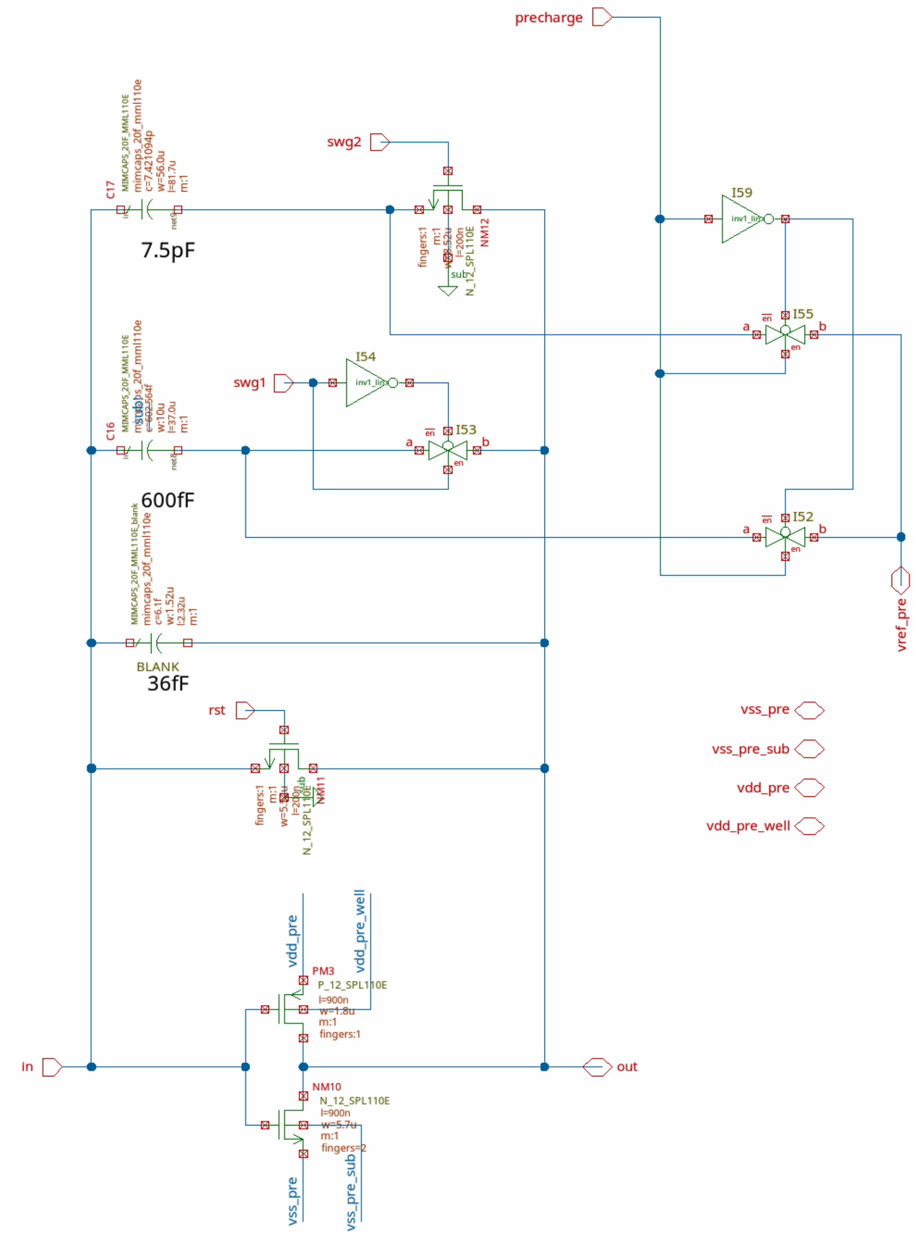


How to use more of the amplifier output range?

- If the big capacitor is simply reset, i.e. the terminals are shorted, only the range below the preamplifier WP can be used
- A precharge circuit is introduced: while in reset, we charge the output plate of the mid and low capacitors to (e.g. 950mV).







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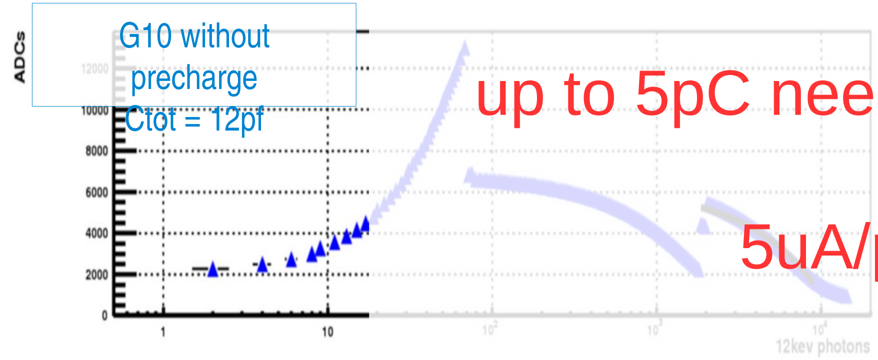
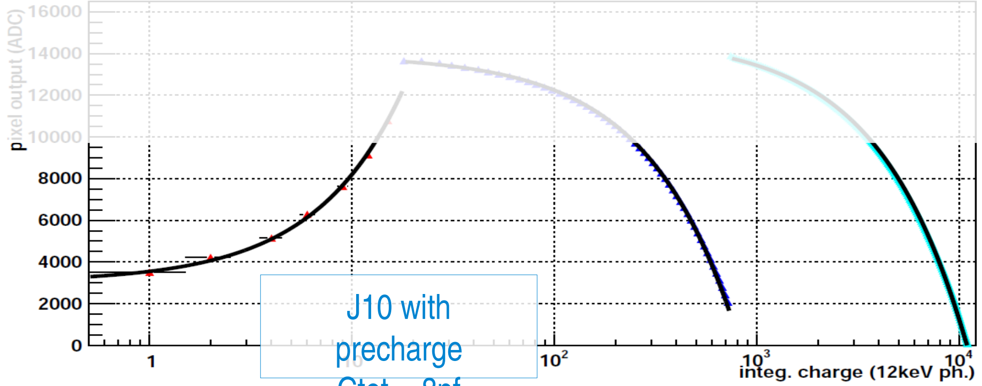
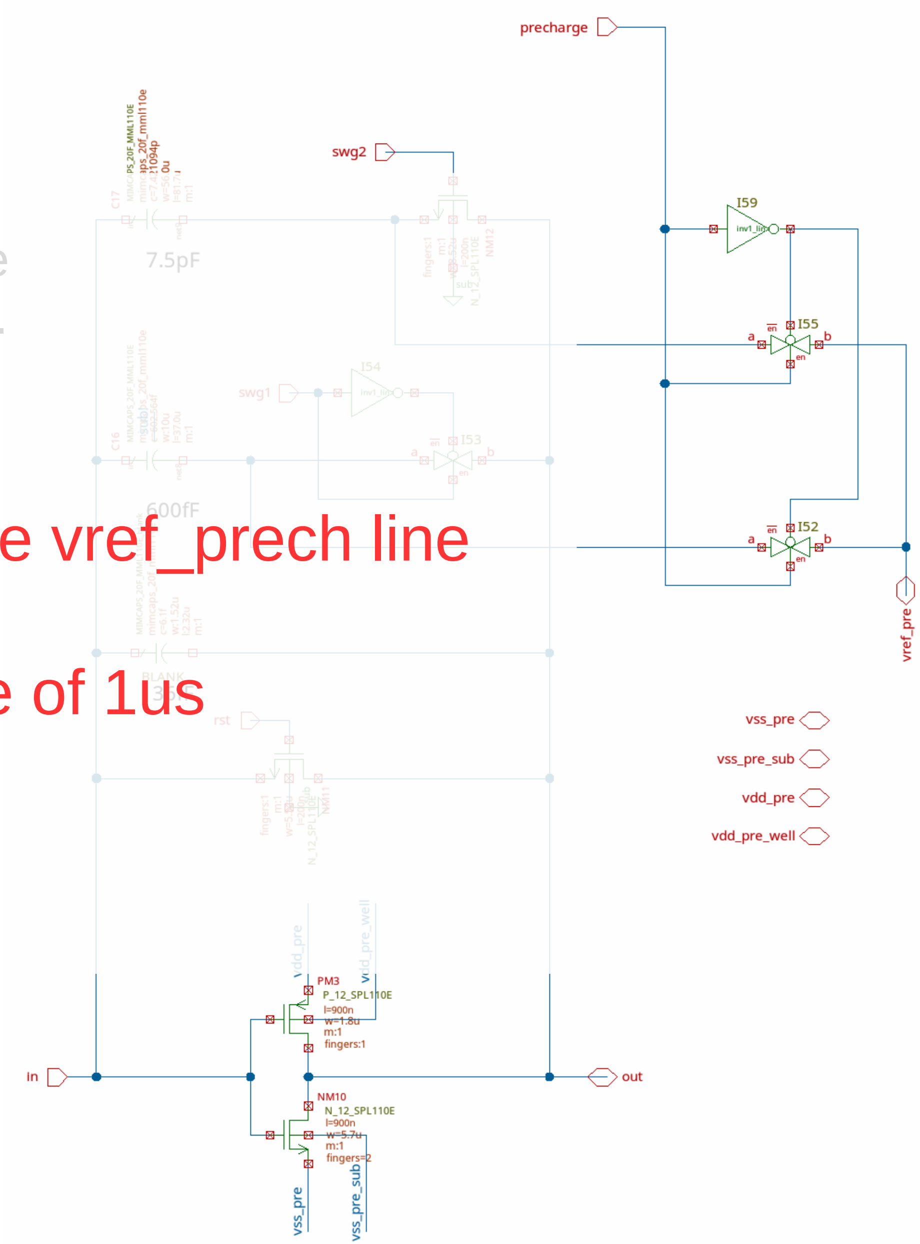


G10 without precharge
Ctot = 12pf

Note:
up to 5pC need to be sourced by the vref_prech line after every pulse.
5uA/pix for precharge time of 1us

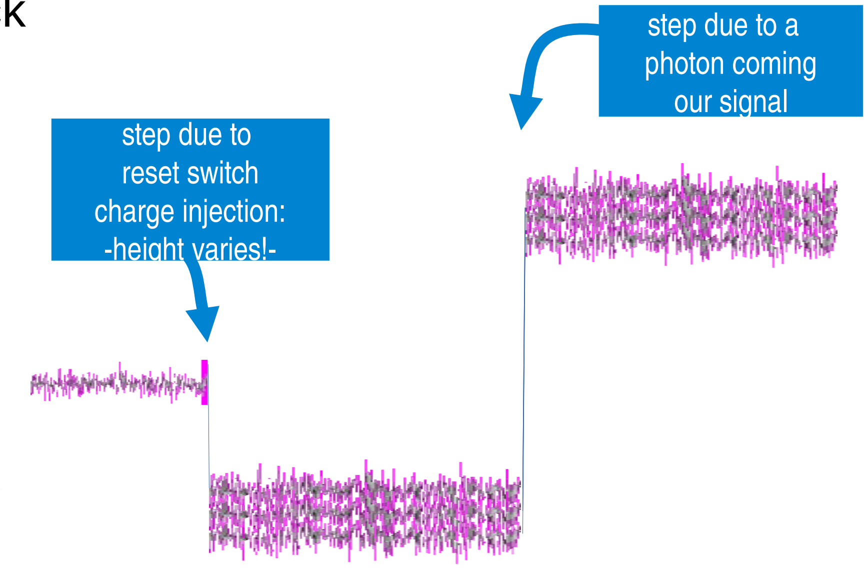


J10 with precharge
Ctot = 8pf

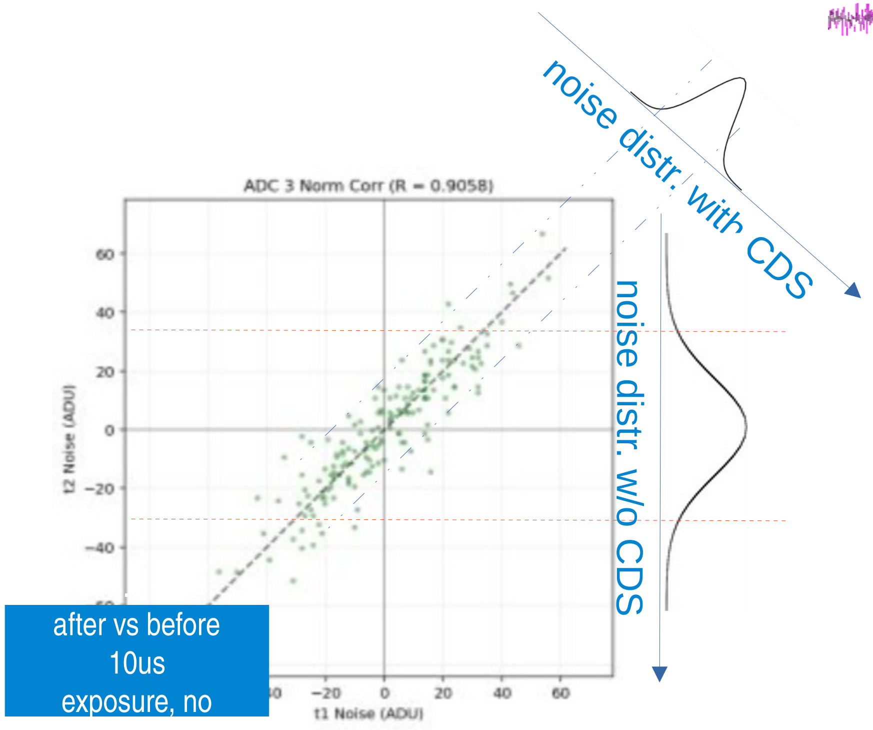


How to control the noise in high gain?

A standard CSA with a reset switch and a fixed, 30fF small feedback capacitor.
first problem, reset noise is high.
How much noise from the reset switch?
For JF about a 20ADU rms, ~800uV
- for a 35fF Cap this corresponds to ~200 ENC
- by far biggest noise source

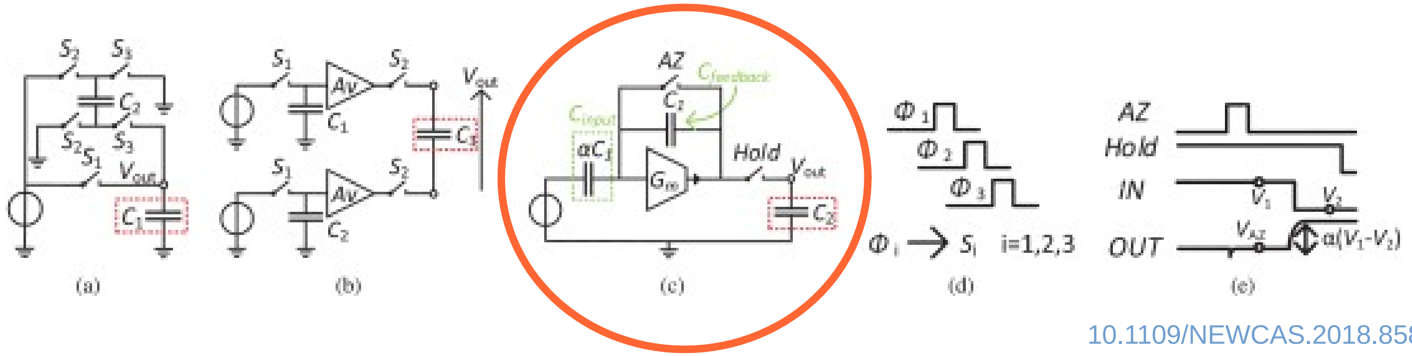


We need a CDS stage.
Or pay x4 factor in noise.

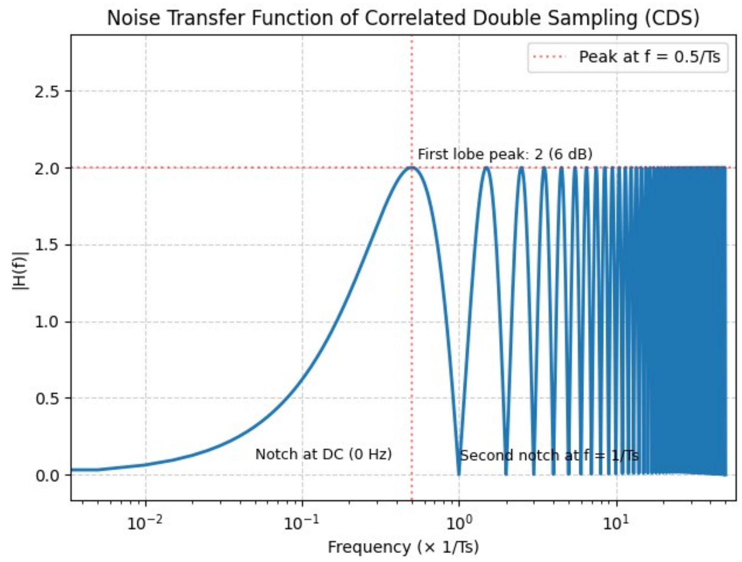


CDS stage

We add a CDS stage. We choose an active implementation



10.1109/NEWCAS.2018.8585674.

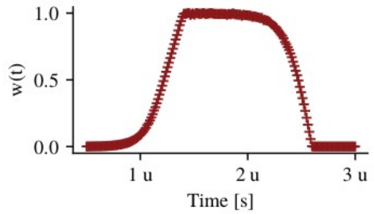


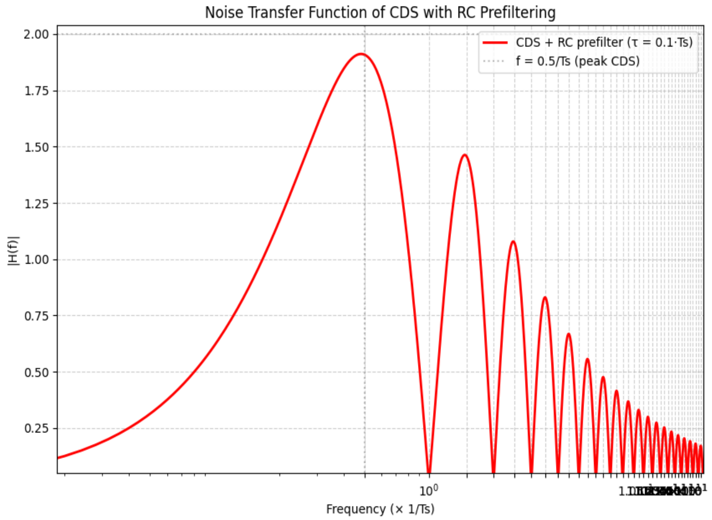
The C1/C2 ratio adds some gain. Since JF1.1, a resistor+capacitance to ground adds pre-filtering; the finite bandwidth of the CDS amplifier also contributes to the low pass filter.

CDS weighting func. for CDS with filtering

Trapeizoidal filter would reduce the noise further, but:

- requires V-to-i converter
- only really works for pulsed sources
- not gain invariant

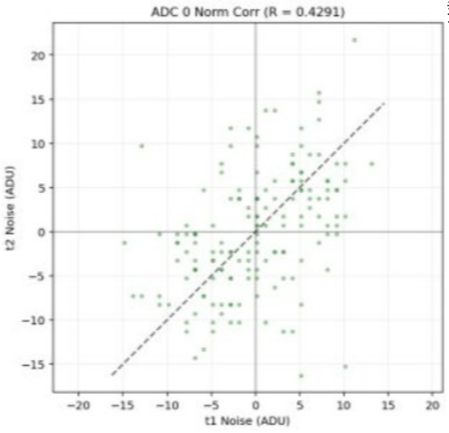




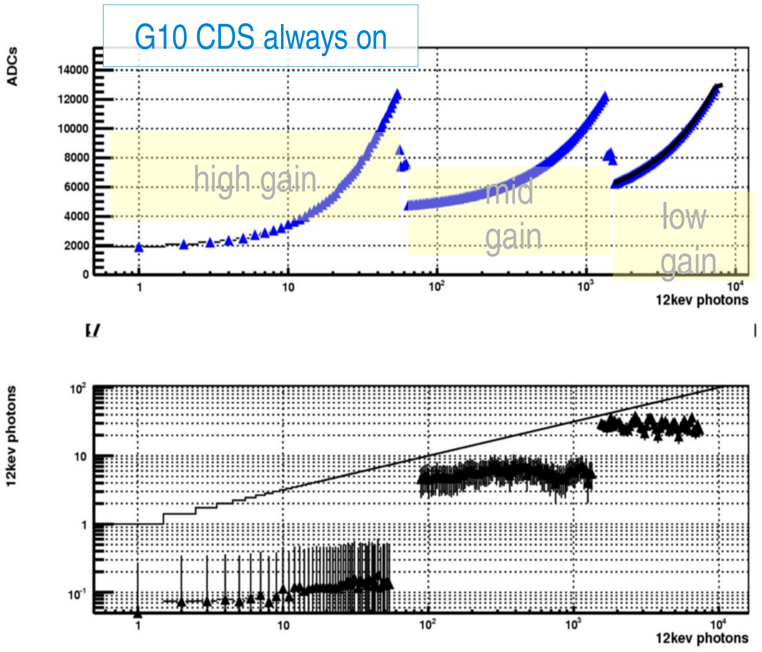
V. Radeka, IEEE-TNS v19/1, pp. 412-428, (1972).

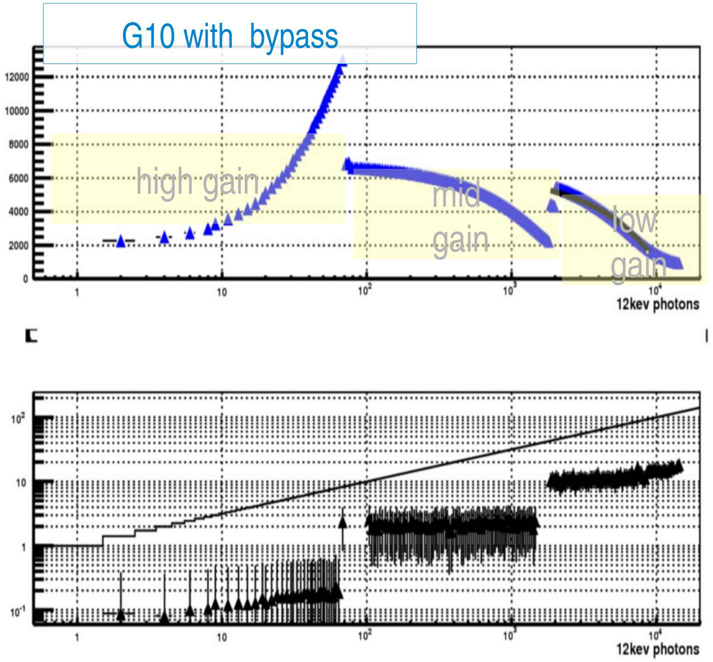
10.1088/1748-0221/14/12/C12014

CDS stage bypassed after switching!



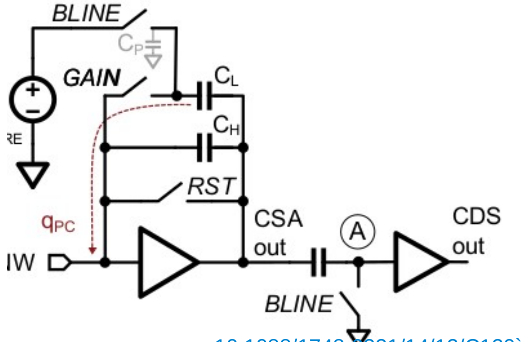
CDS stage is detrimental after Gain switching: if the charge injected by the rst switch is dQ, CDS samples and subtracts $dV=dQ/Cf_{high}$
and not the $dV=dQ/Cf_{mid}$ required after switching
CDS stage has to be bypassed or reconfigured as buffer after switching
Do we lose something neglecting $dV=dQ/Cf_{mid}$? → no, reset switch contribution in G1 is negligible





- These noise plots are best obtained with constant, low noise i source (visible light), increasing integration time – X-rays are to quantized

alternative: correlated precharging (EPix)



10.1088/1748-0221/14/12/C120`14

“for free” if the switches are at the input side

What drives the noise in high gain?

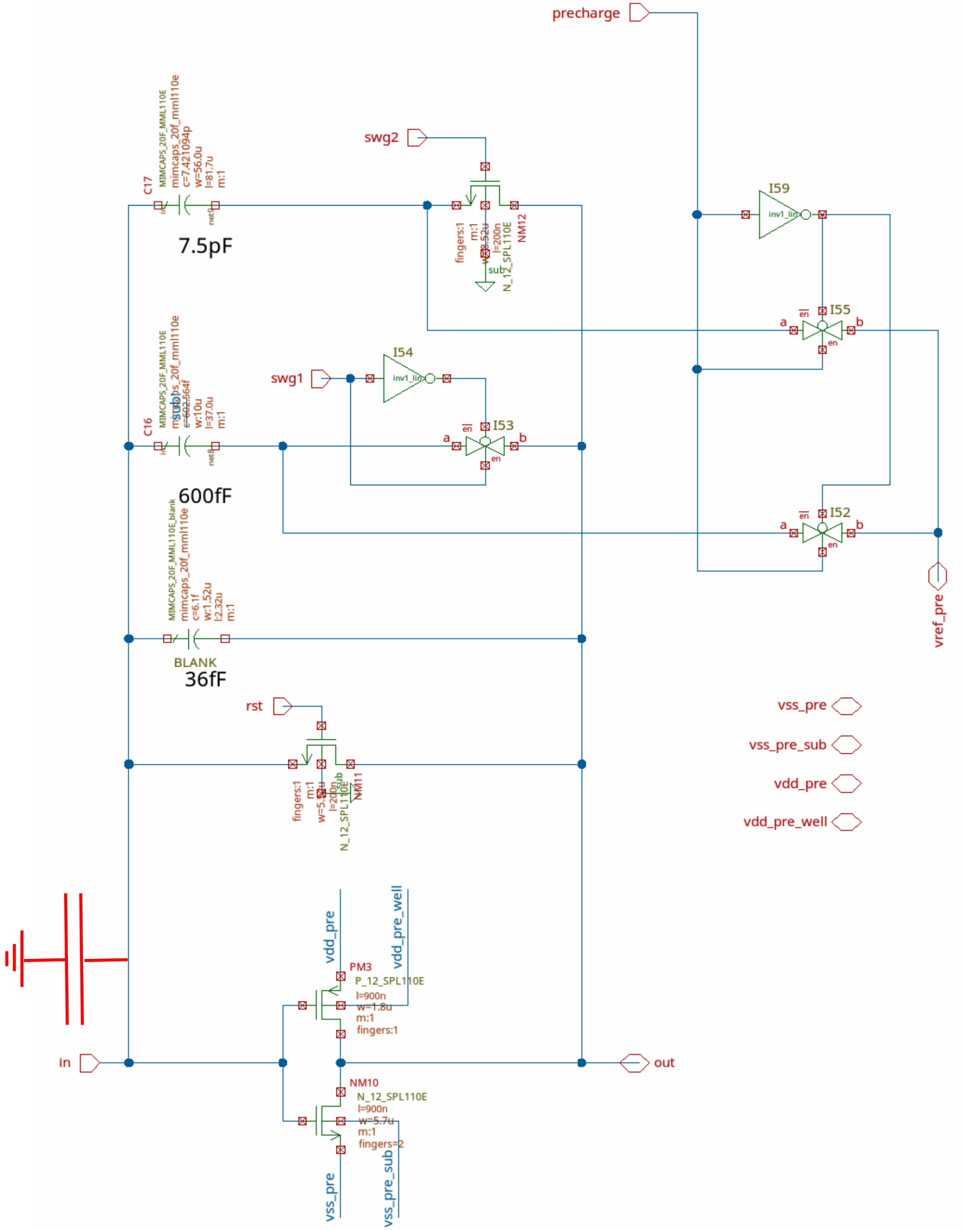
Besides the amplifiers, obviously the parasitic input capacitance:
Layout and PEX should be used to reduce it.

Note: also the output plate of the big mimcap counts!

Jungfrau 0.1 prototype 50fF parasitic:
120 ENC @ 40fF C_feed

Jungfrau 0.2 prototype, 50fF parasitic:
160 ENC @46fF C_feed

better power distribution



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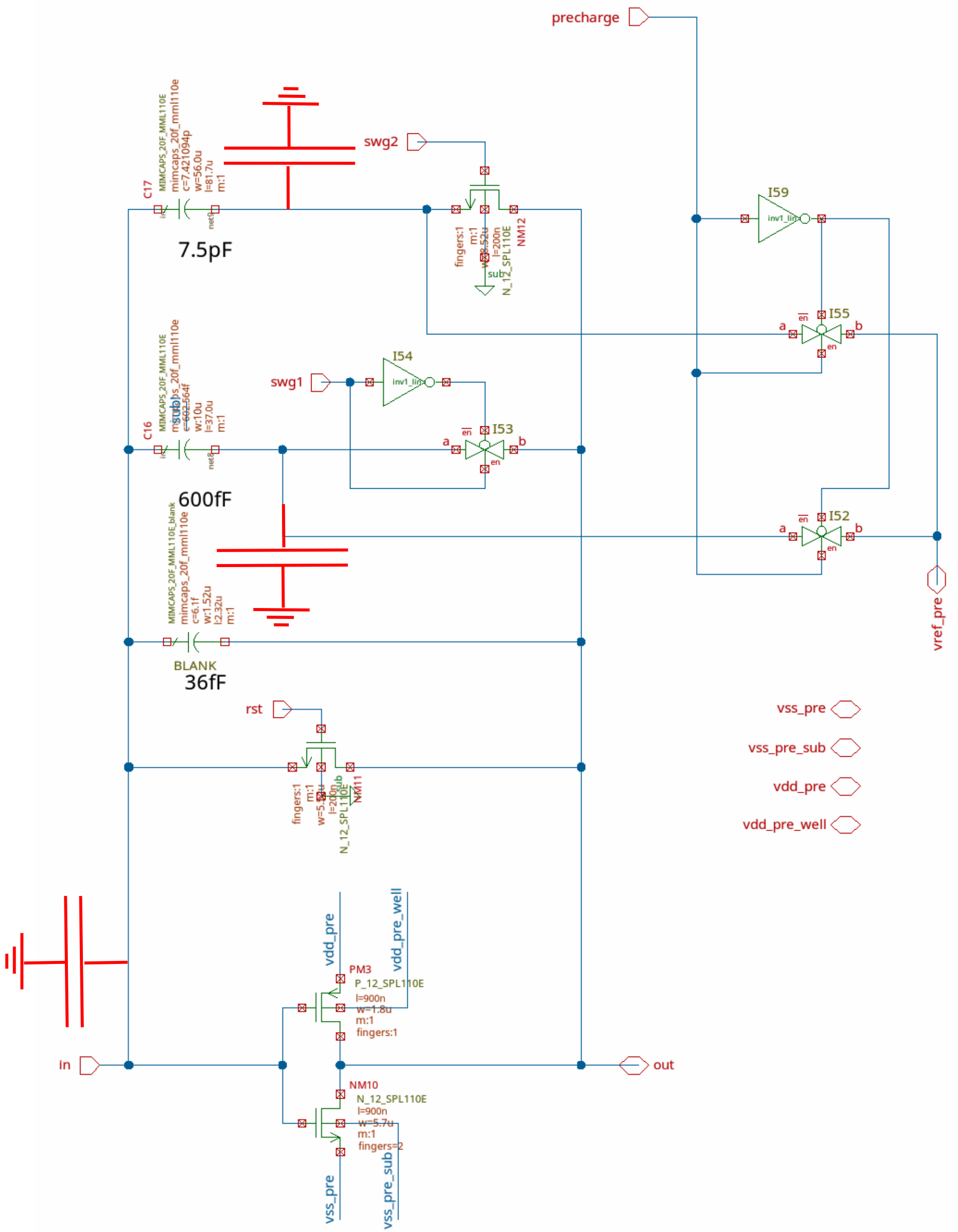
Jungfrau 0.1 prototype 450fF parasitic:
120 ENC @ 40fF C_feed

Jungfrau 0.2 prototype, 670fF parasitic:
160 ENC @46fF C_feed

better power distribution



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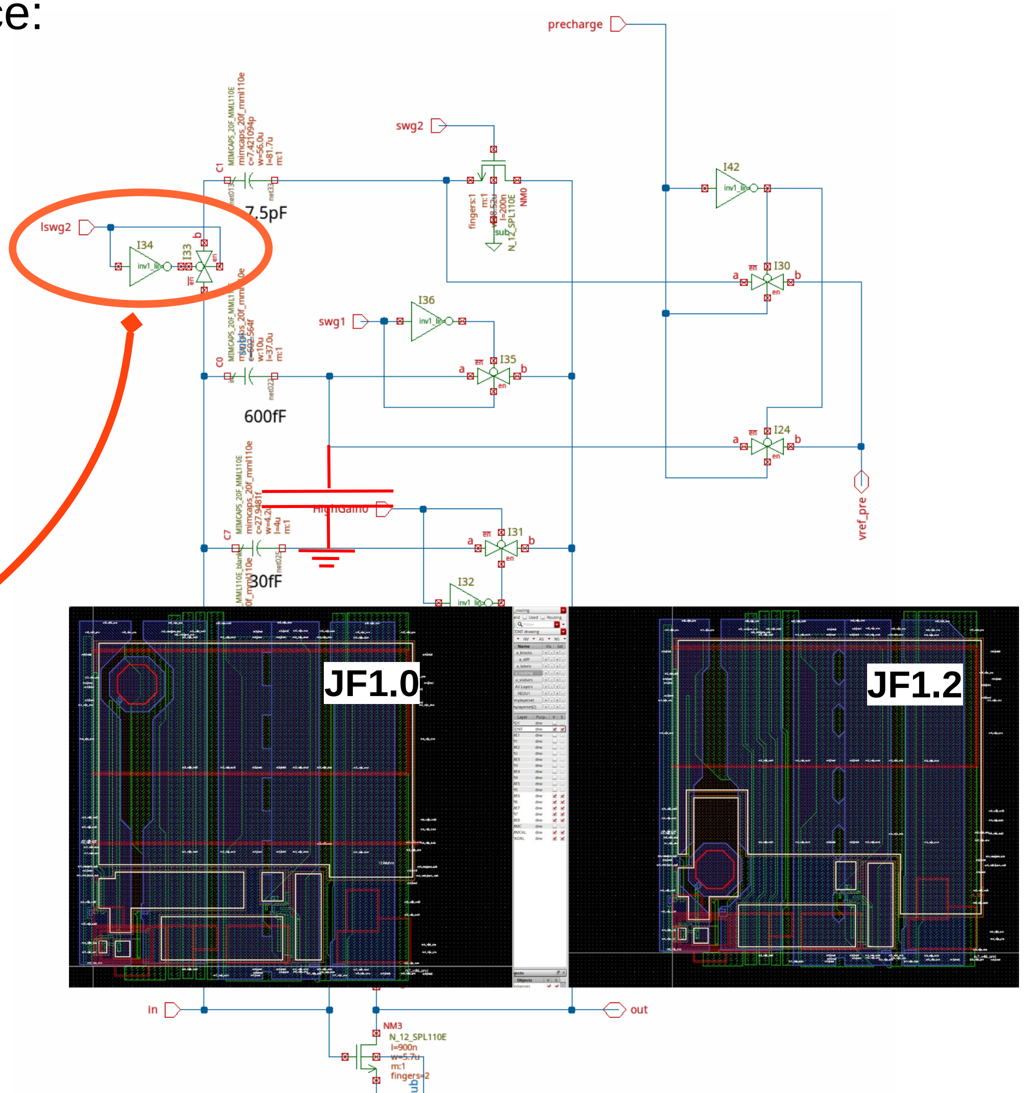
Jungfrau 0.1 prototype 450fF parasitic:
120 ENC @ 40fF C_feed*

Jungfrau 0.2 prototype, 670fF parasitic:
160 ENC @46fF C_feed*

better power distribution

Jungfrau1.0, 52fF parasitic
80 ENC @34fF C_feed*
55 ENC @10fF C_feed*
Jungfrau1.2, 24fF parasitic
64 ENC @ 36fF C_feed*
31 ENC @ 6fF C_feed*

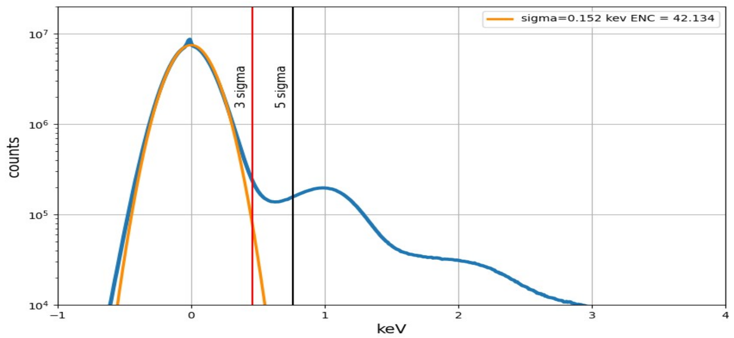
layout for C_para



the TG can be safely closed after the first gain switch
Possible source of leakage!

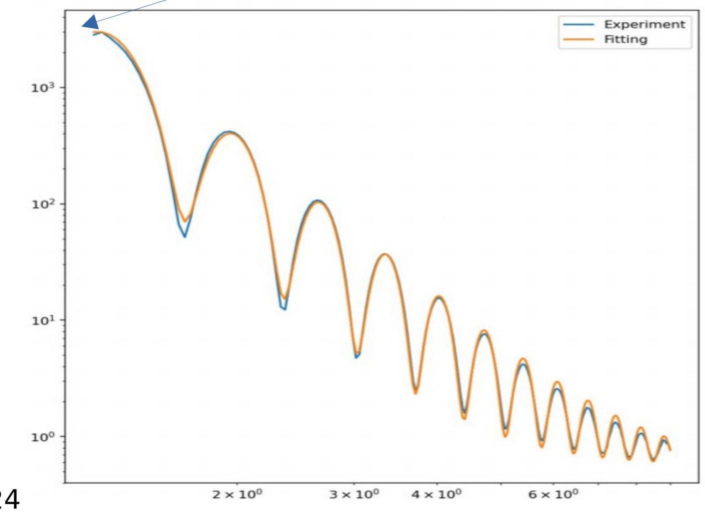
*nominal. Plus some 5fF parasitic

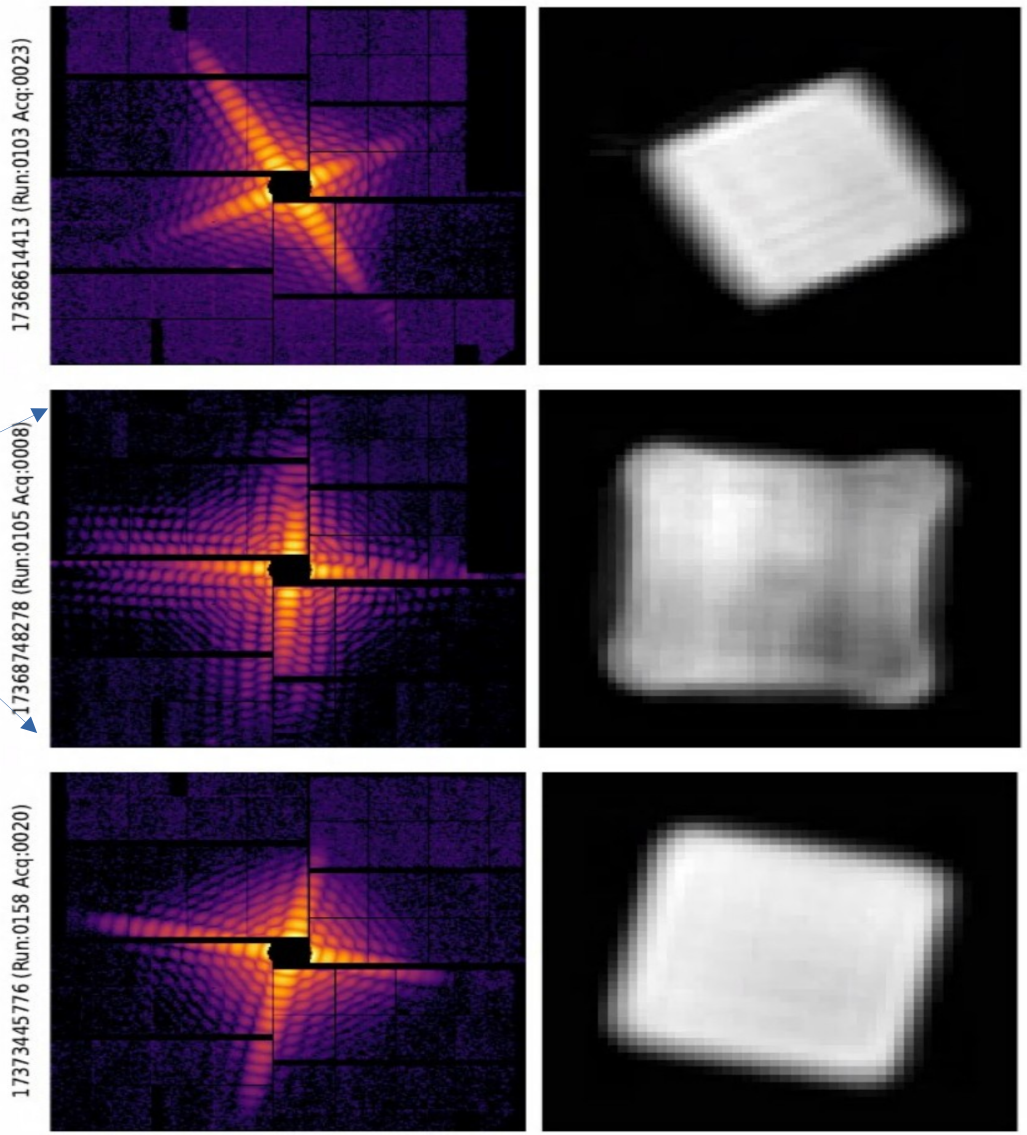
Single particle CDI at 1keV at Maloja (SwissFEL)



Measurements profit from detector:

High DR – Large Area





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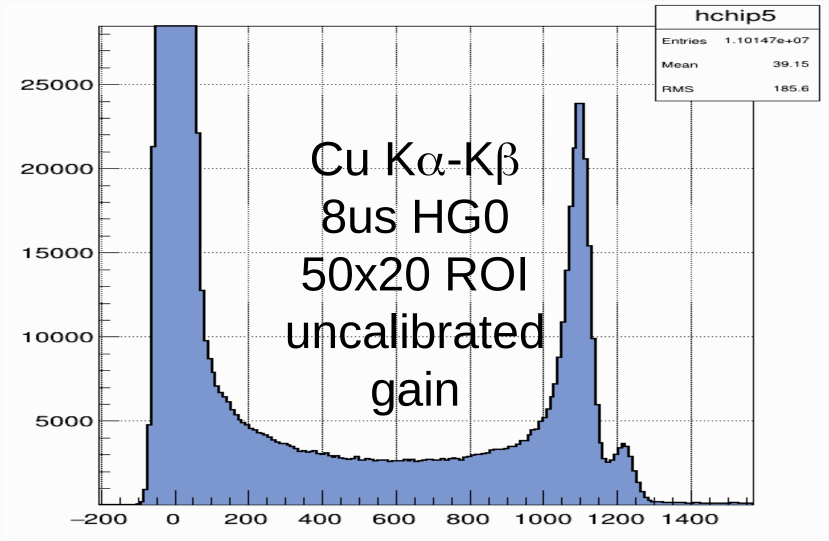
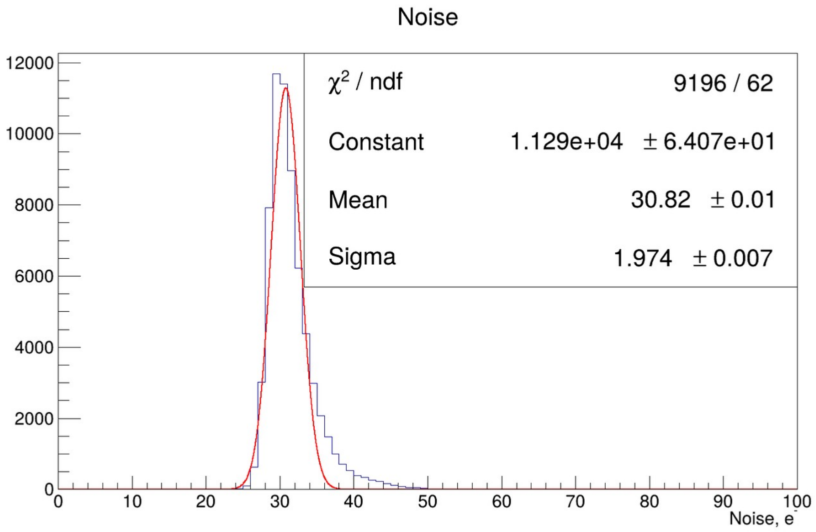
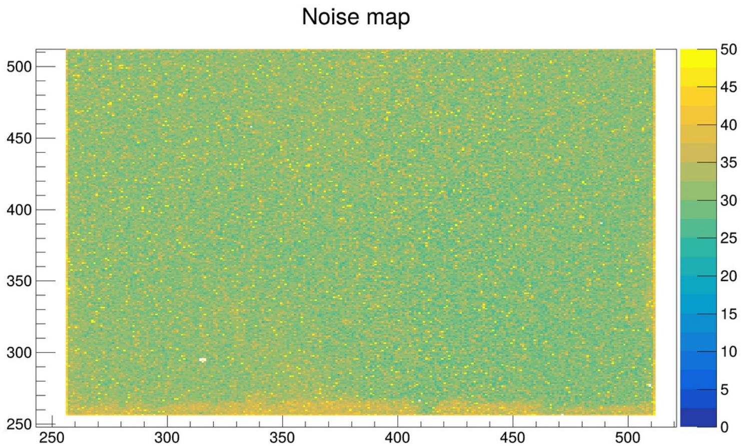
courtesy A.Colombo

Where are we with the noise: Jungfrau 1.2 (HG0)





- @ 5us
- 31e$^-$ E.N.C.
- JF1.0 was ~51e$^-$
- JF1.1 was ~34e$^-$
- gain dispersion 2.1%
- depends on exposure time

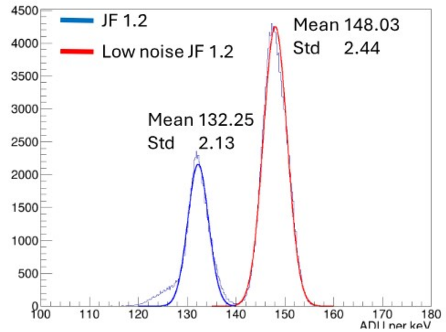


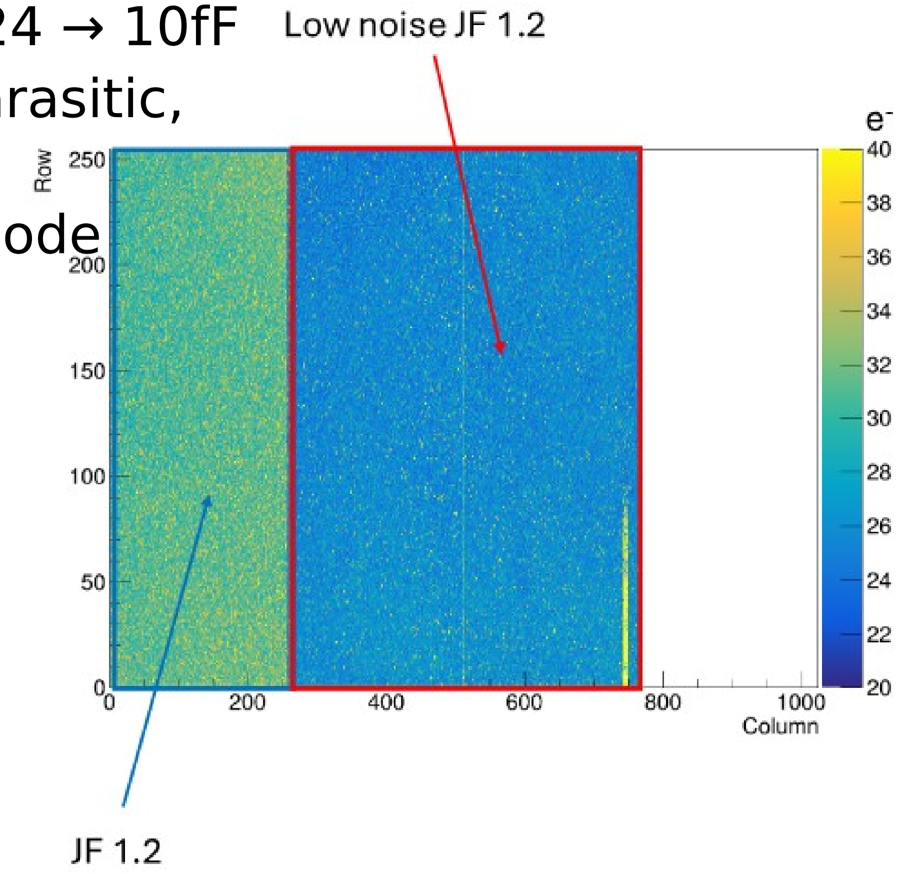
Curiosity, how much ENC we pay for the gain switching?

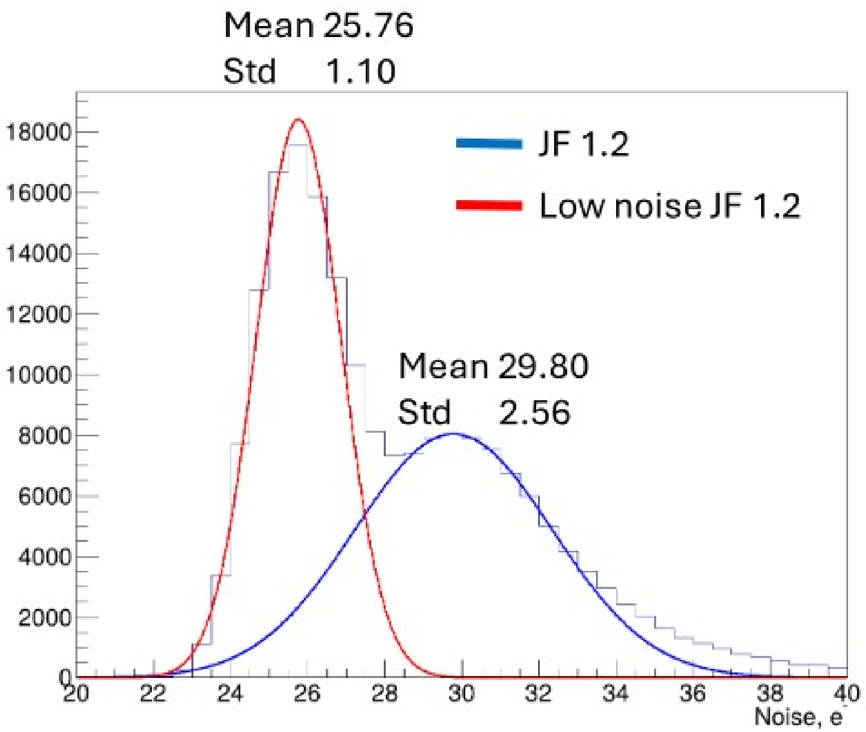
With a mask change, for RIXS applications, a JF1.2 has been stripped out from all the gain switching circuits:

- lower parasitic C_in 24 → 10fF
- lower total C_feed parasitic, gain increased
- no TGs at the input node

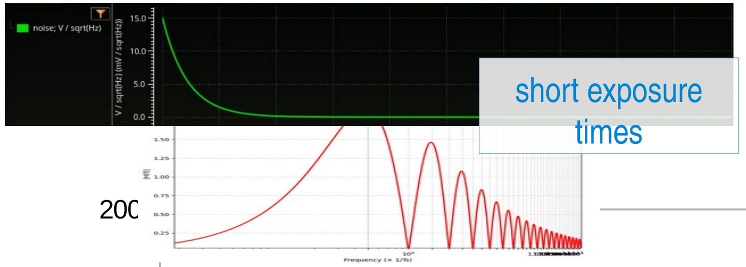
15% less noise.

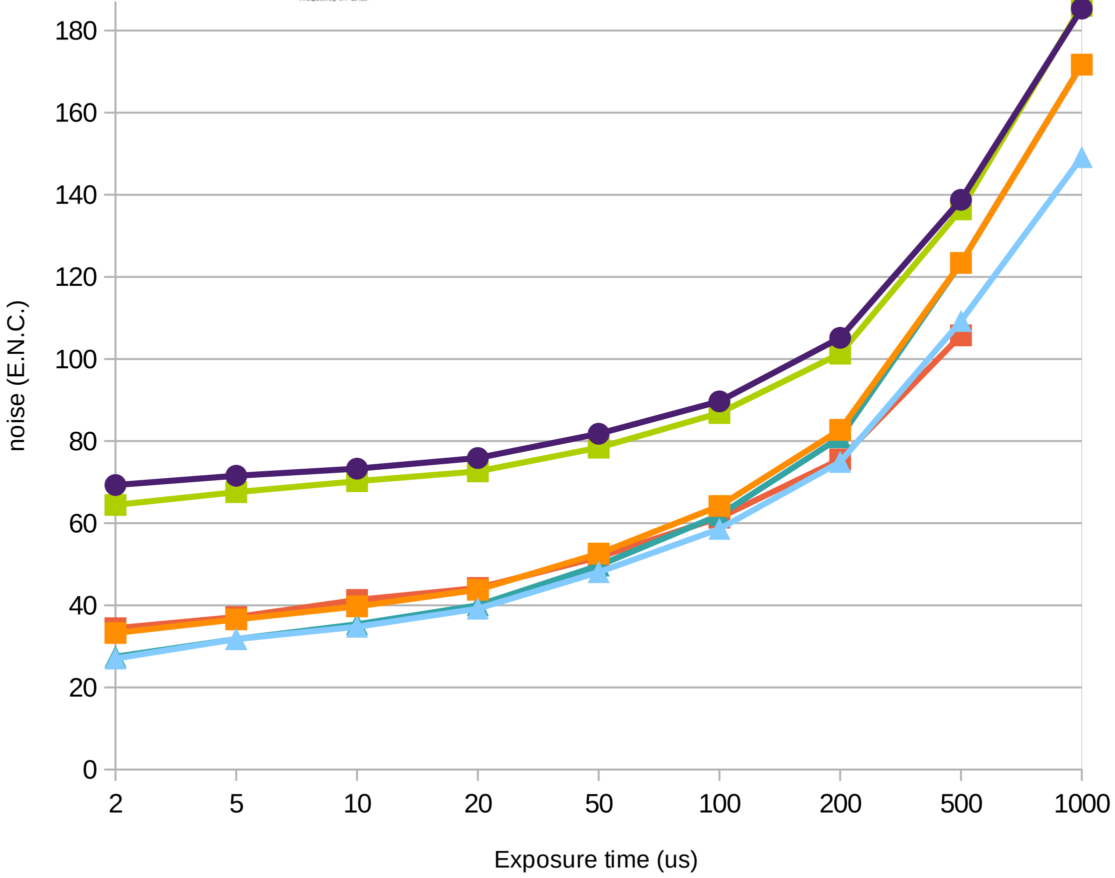






Jungfrau 1.2 noise vs exposure time

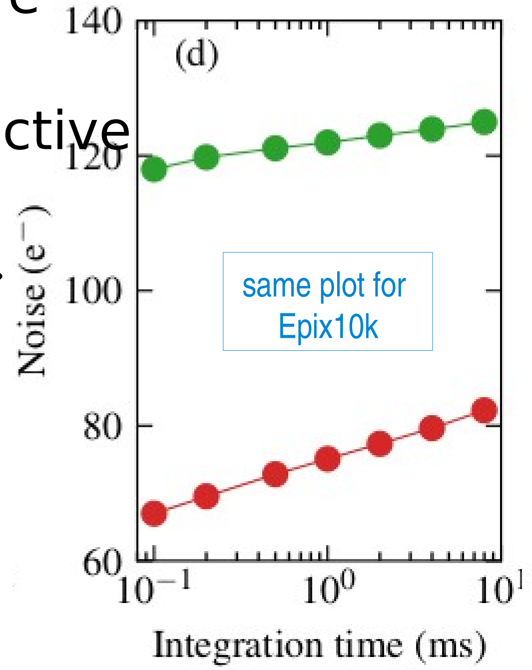




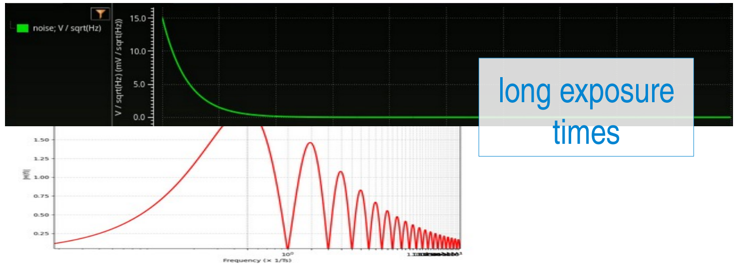
1/f noise of the N-input transistor dominates at longer exposure time

CDS filtering becomes ineffective

Epix10k does much better →

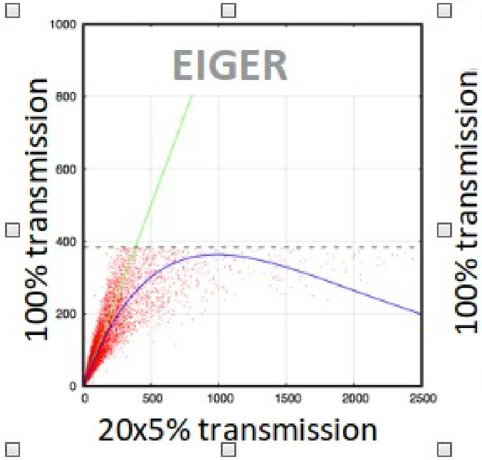


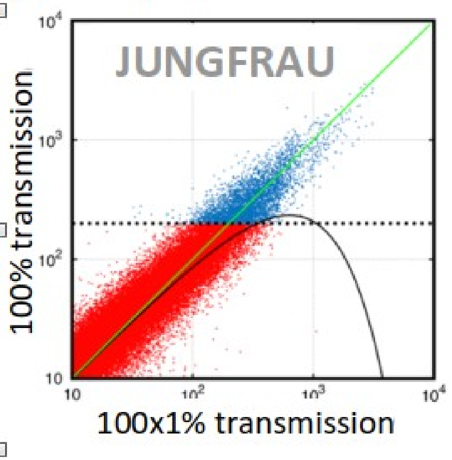
/doi.org/10.1063/1.5084693



The good: Better than a PC detector (sometimes)

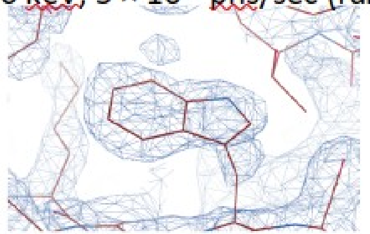
EIGER rate limited by pile-up → JUNGFRAU enables faster data collection

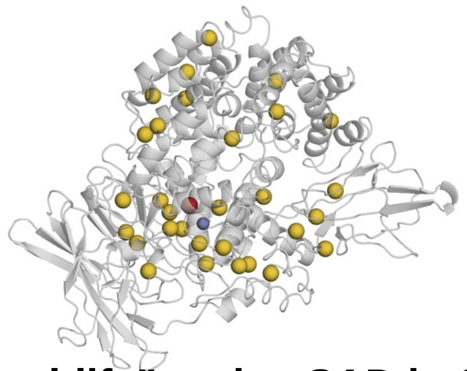




"Easy" native-SAD in 600 ms

- Thaumatin
- 100°/sec, 60°
- 6 keV, 5 × 10^{11} phs/sec (full beam)

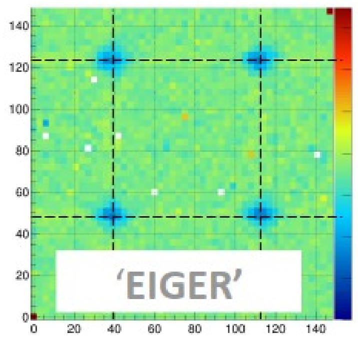


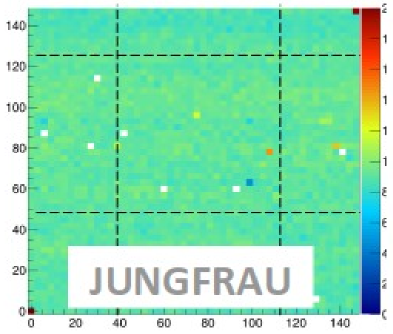


"Real-life" native-SAD in 60 s

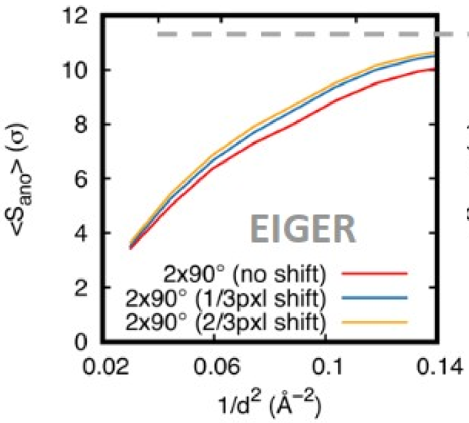
- Aminopeptidase, 101 kDa
- 10°/sec, 600°
- 6 keV, 5 × 10^{11} phs/sec (full beam)

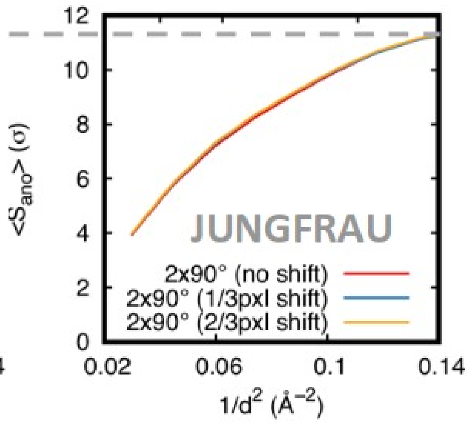
EIGER loses efficiency in the corner of pixels → JUNGFRAU provides better data quality





20 keV pencil beam scans



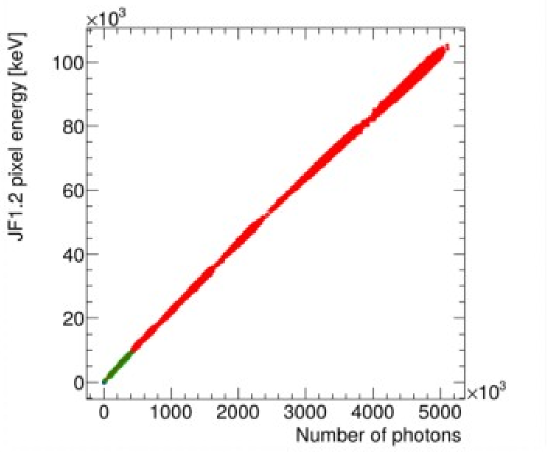


The bad: switching point artifacts

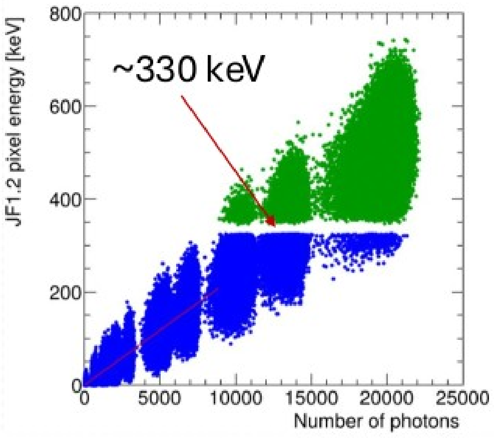
PSI

Is just an offset, but:

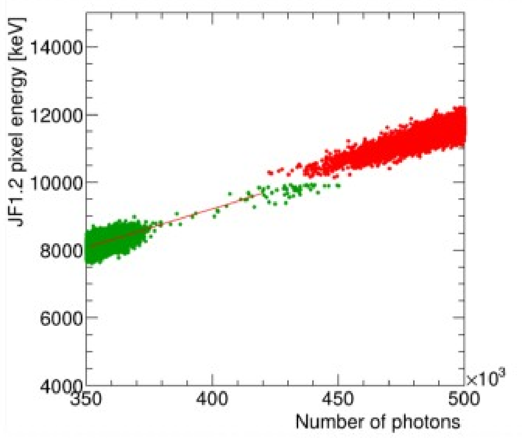
- How to measure it
- Depends on illumination
- Depends on position in module



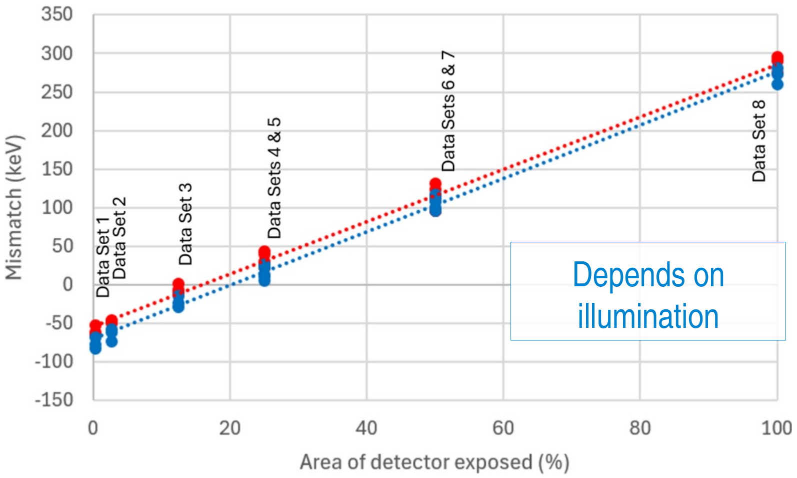
(Almost) Full dynamic range

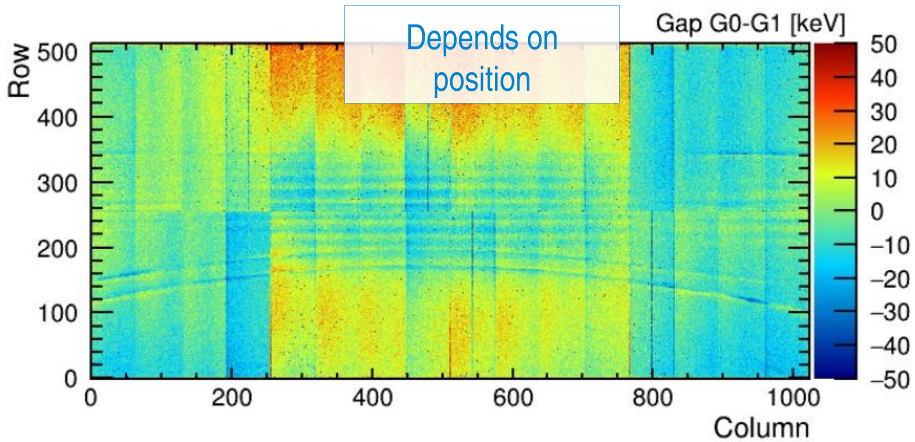


G0 to G1 switch region



G1 to G2 switch region





The bad: switching point artifacts

Is just an offset, but:

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- Depends on illumination
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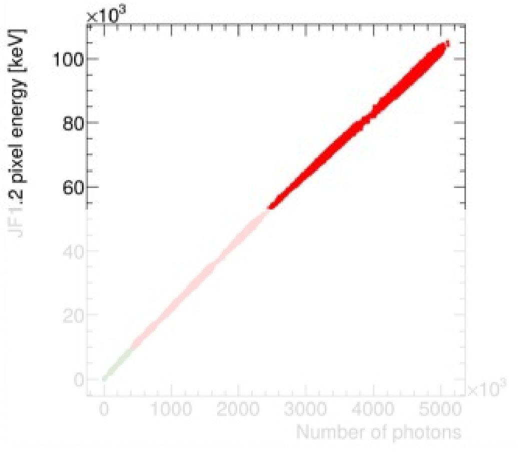
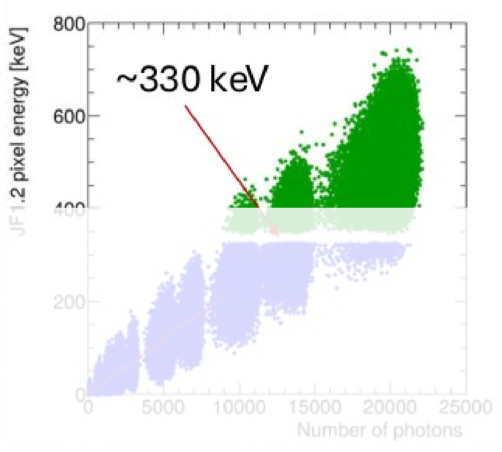
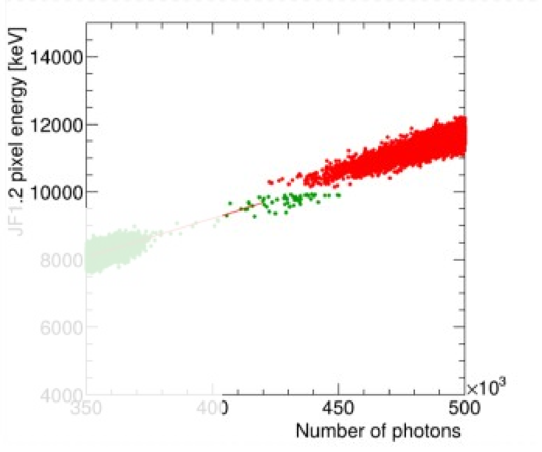


(Almost) Full dynamic range

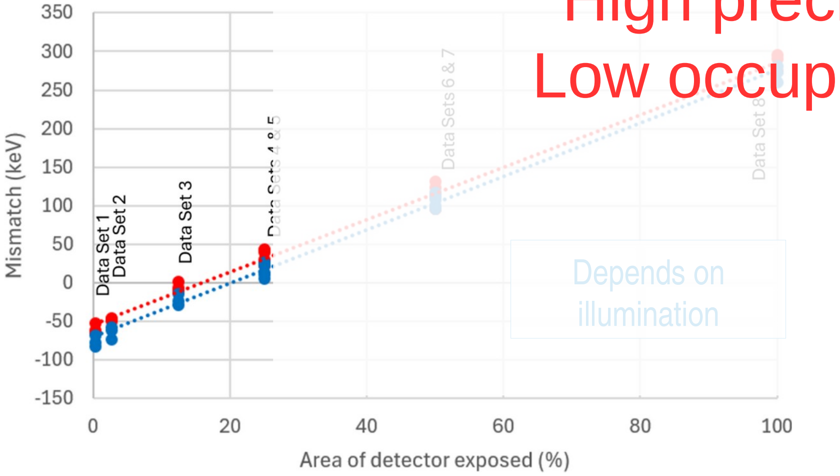


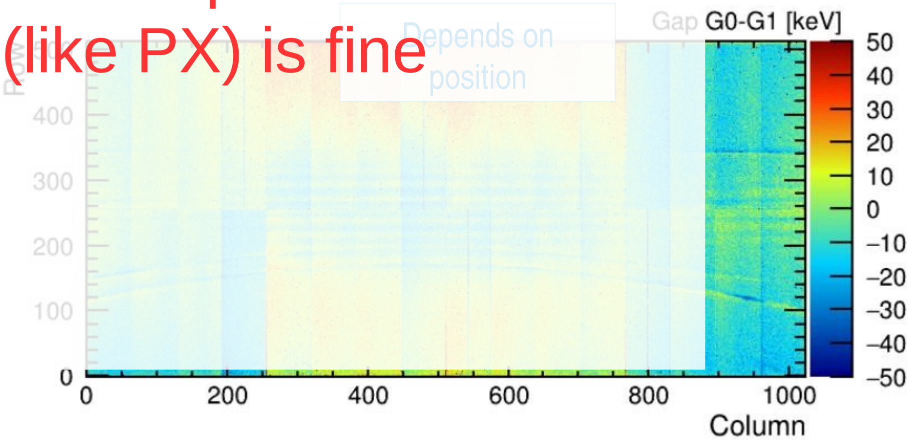
G0 to G1 switch region



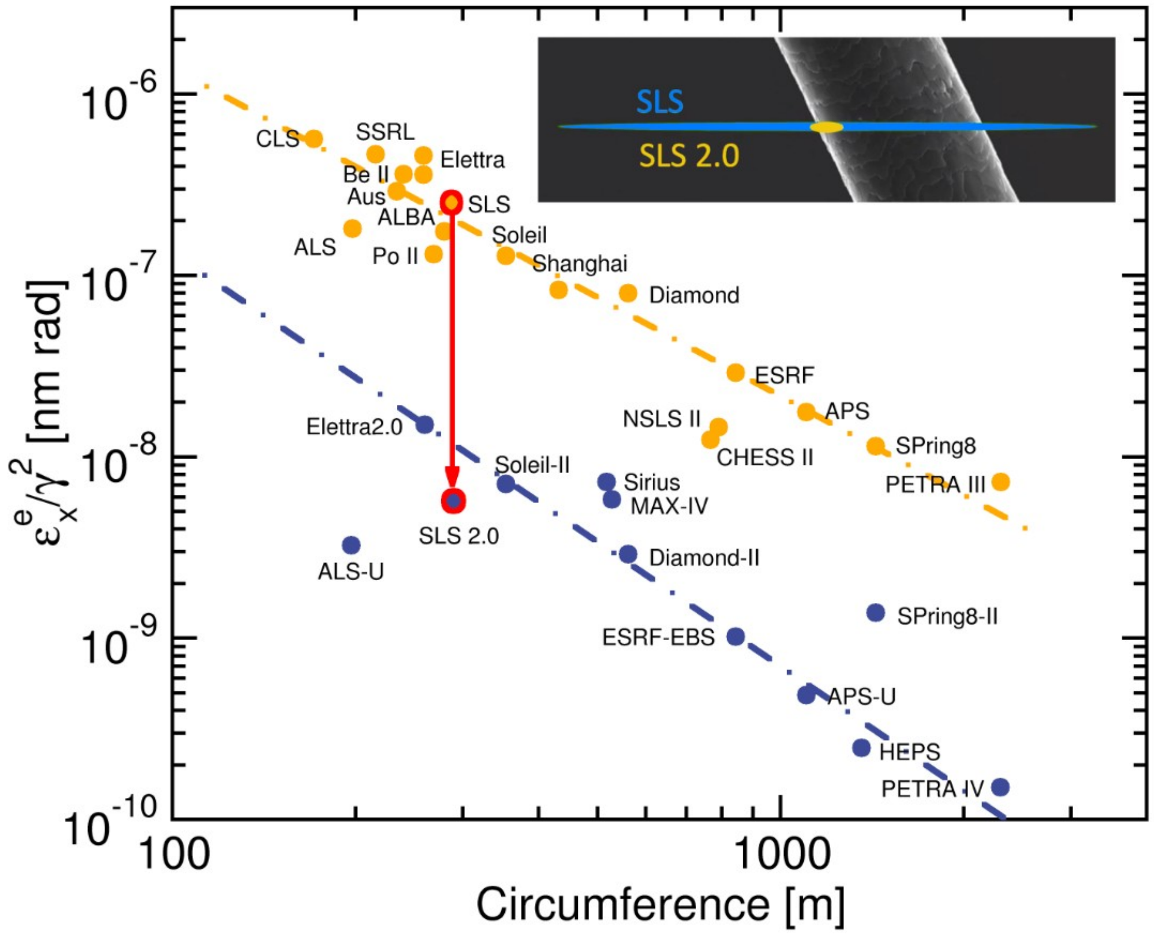
G1 to G2 switch region

Smaller than Poisson, but systematics,
High precision measuremnts impacted.
Low occupancy-High DR (like PX) is fine





SLS 2.0 – a 4th generation synchrotron



Improved emittance, increased brightness
First photons to the beamlines Q2/2025
Pilot users on some beamlines Q3/2025
Full user operation Q3/2026

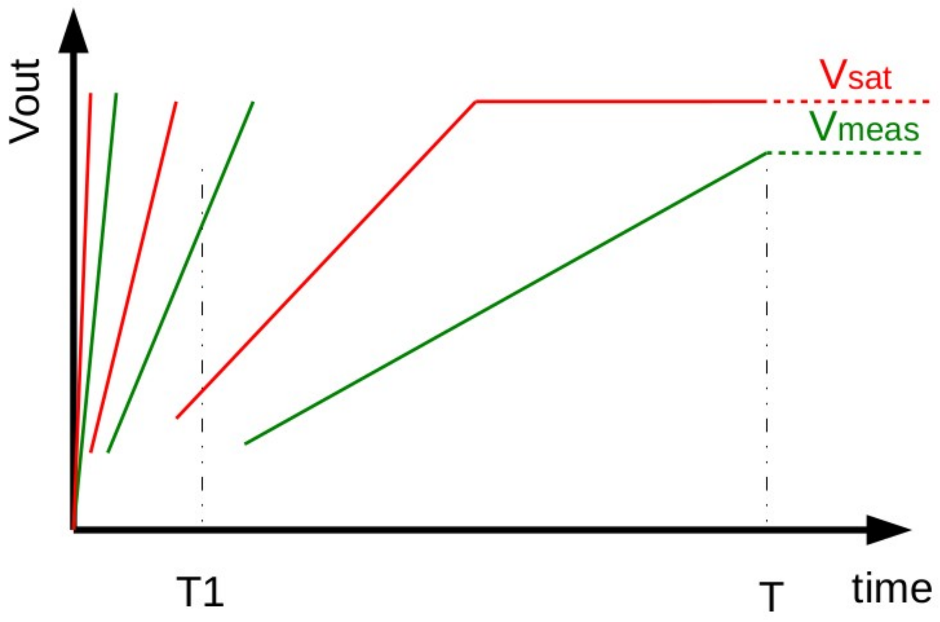
After commissioning, Coherent flux increase by up to 100x !

Dynamic range extension for Continuous sources.

- A CI front-end has an almost infinite cps limit: with 1us exposure time we can accept 10E10 12keV ph/s/pix
- But at full duty cycle: cps = Frame rate x single image DR
- So just go faster: yes, but the price to pay is complexity, costs, storage

- Observation:
- often beam on sensor is quasi-continous, i.e. beam time fluctuation frequencies << 2kHz*.
- Looking at the gain bits at specific time(s) in the exposure can reliably predict saturation
- If I know that the pixel will saturate, can I do something better than just let it saturate?

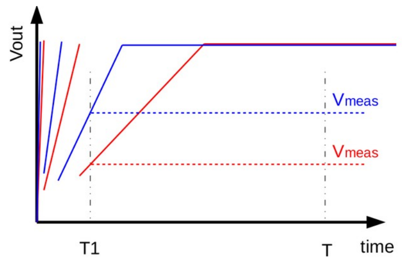
The red pixel is already in g2 at T1: it will saturate



the frame rate, in this case of Jungfrau

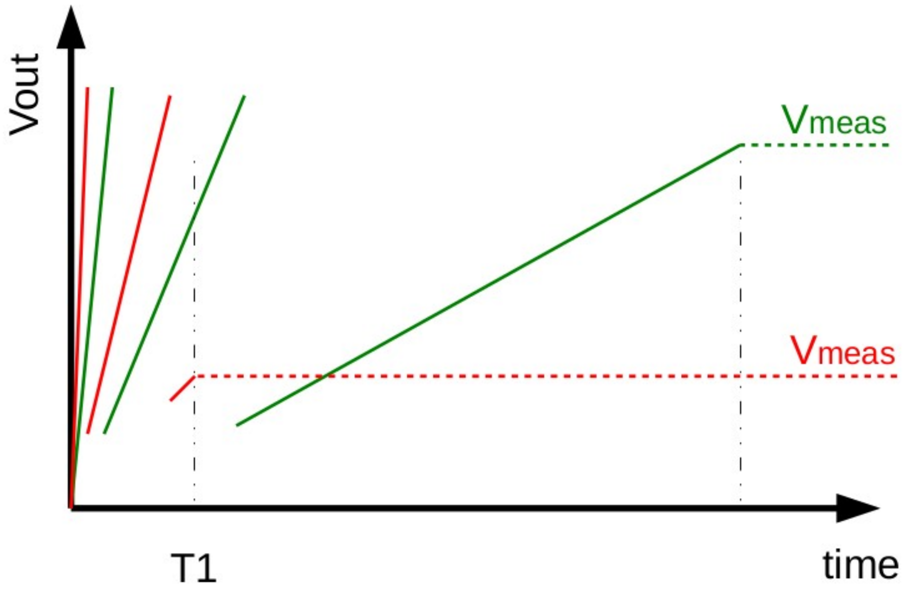
Dynamic range extension for Continuous sources.

- We evaluate the gain state at a time T1
- if in g0 or g1, NOOP
- if in g2:
  - open the store switch, voltage is stored for ro
  - reset preamplifier, for safety/stability
  - encode the state (g3) in the gain bits for later readout
- in post processing the values for pixels in g3 are decoded as g2, then multiplied by T/T1 ratio: no additional pedestal, no additional gain calibration



Two pixels with DR extension

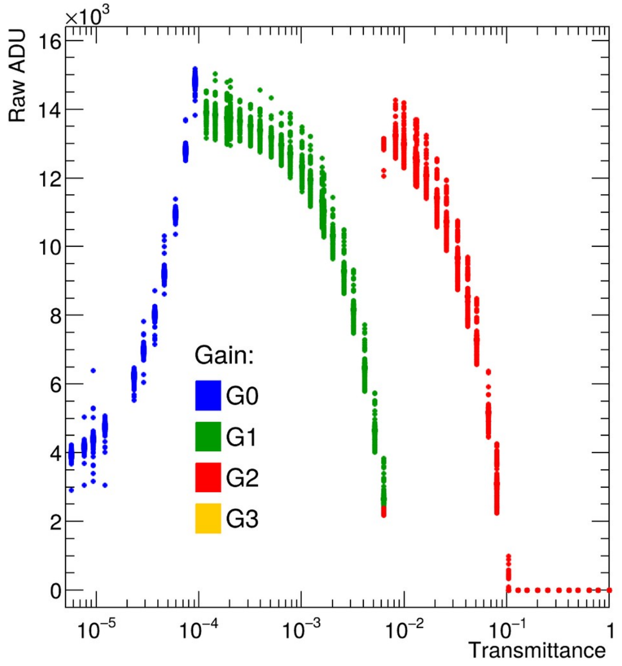
Same two pixels but with the DR extension enabled



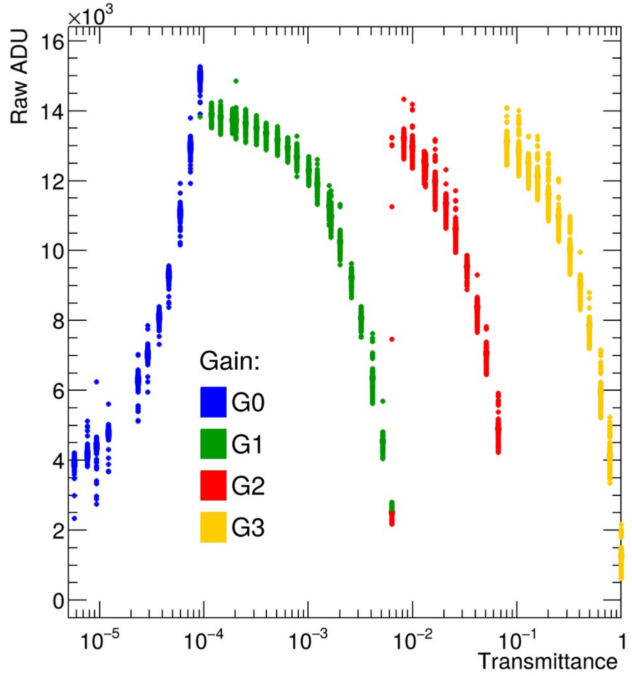
Dynamic range increase for Continuous sources.

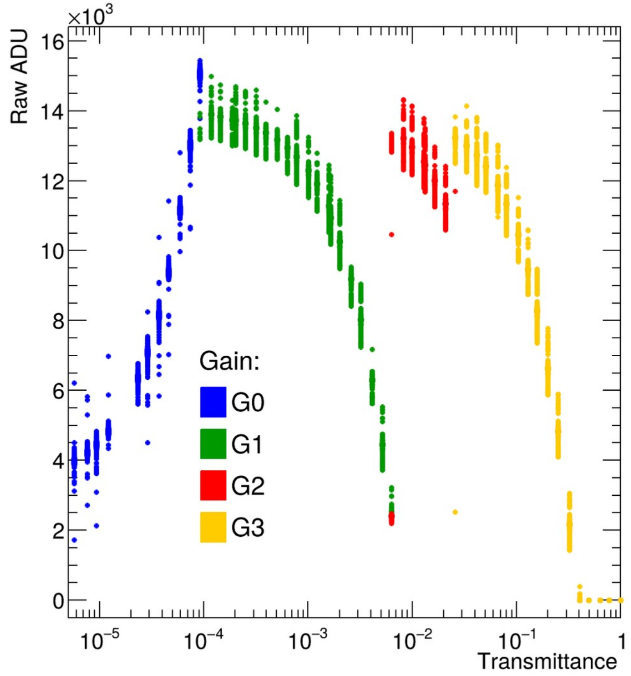
- Test with visible light continuous laser, modulating intensity with ND filters
- 0 (DR extension disabled), 8% and 25% T1/T ratios
- Proper T1/T is critical to obtain maximum DR
- Factor ~10x increase in DR with T1/T at 8%

500Mcps/pix @6keV



no decision/ too early





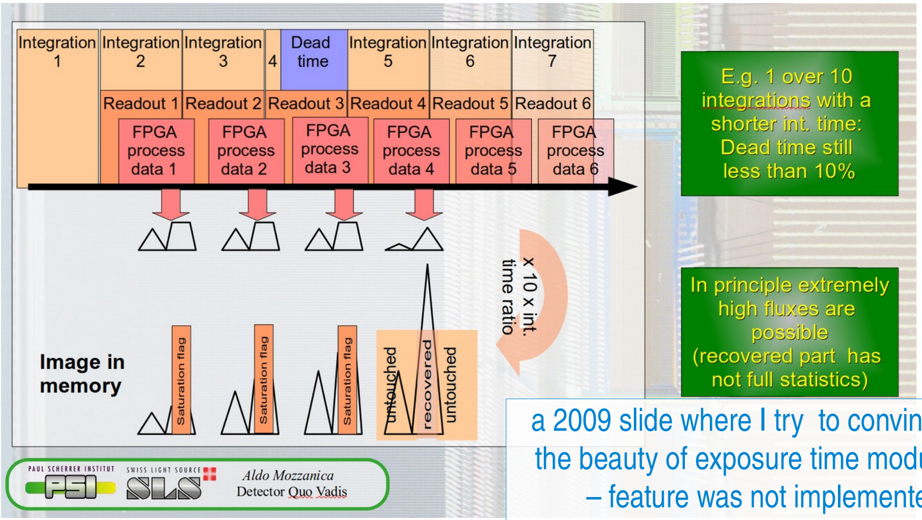
decision too late

Dynamic range extension for Continuous sources.

- There are alternatives!
- exposure time modulation: long and short exposures interleaved
  - with dead time: always possible
  - w/o dead time: logic to store 1 frame in pixel
- Time to saturation (requires in pixel counter+clock or distribution of ramp voltage)
- Two/more samples per frames, in periphery selection
- What CITIUS does

Dead time AND lower effective frame rate

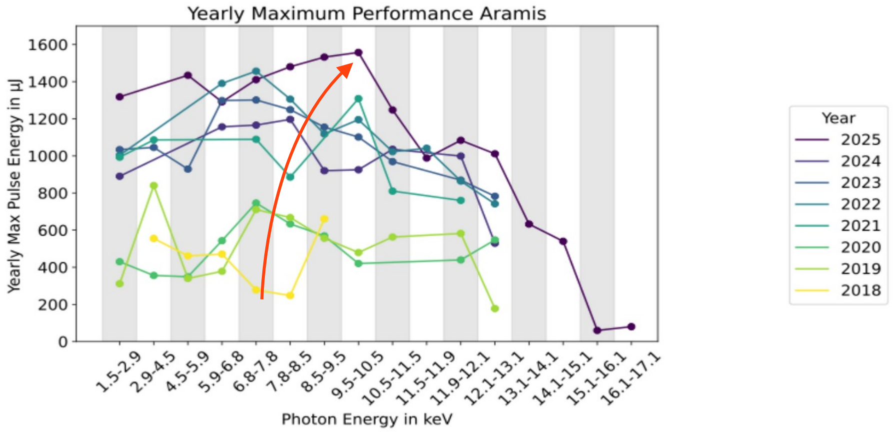
Lower effective frame rate

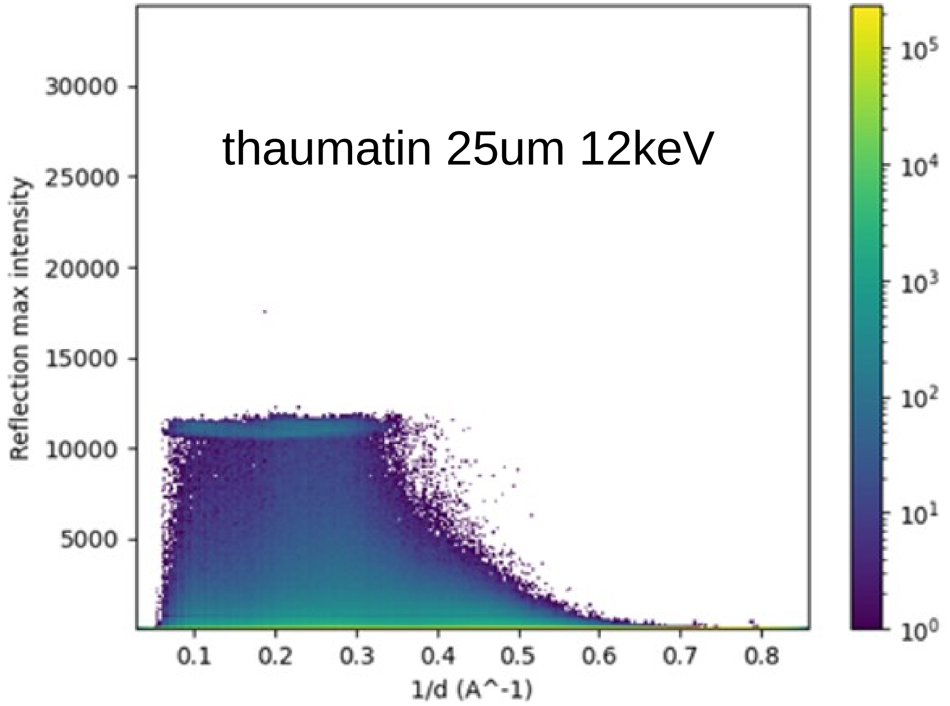


a 2009 slide where I try to convince the audience about the beauty of exposure time modulation with dead time – feature was not implemented nor requested

Dynamic range increase for FELS

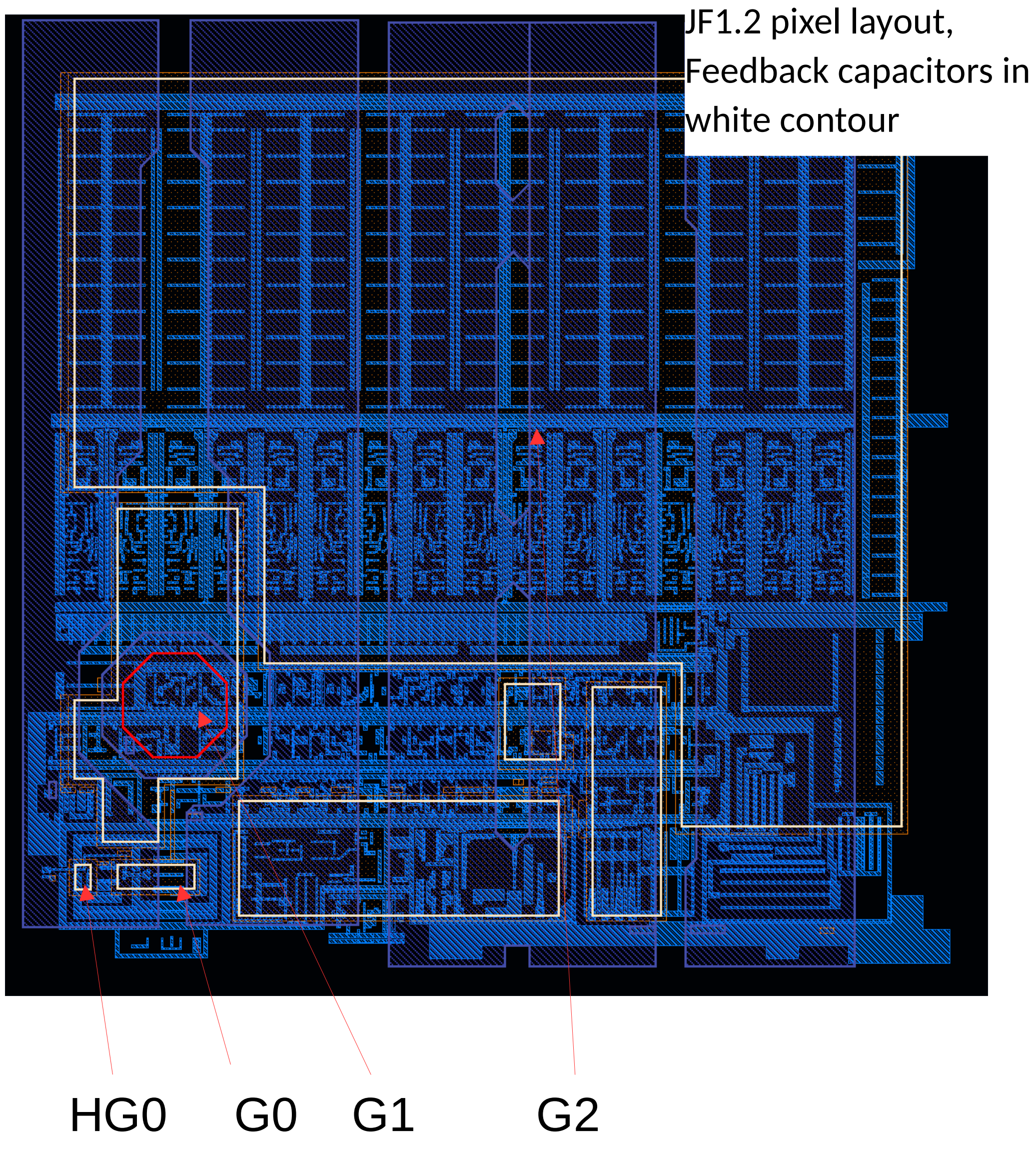
- Machine is constantly improving
- SFX experiments at e.g. Cristallina routinely run into detector saturation issues
  - beam has to be attenuated
  - outer, high-q information is lost
  - longer measurement time
- a detector with higher DR is needed!





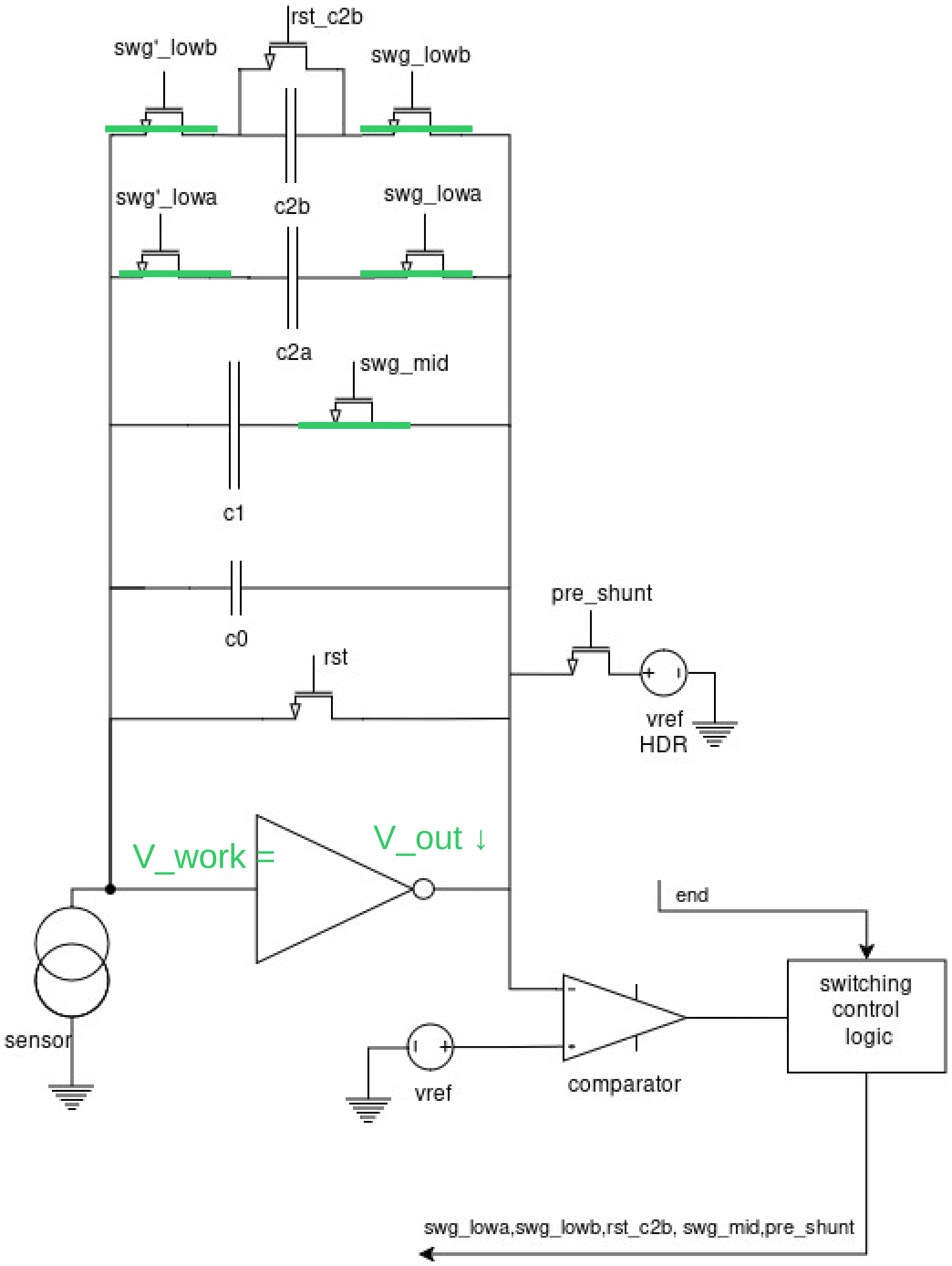
Jungfrau HDR for Free Electron Laser

- With a pulsed beam, we cannot play with exposure time, frame rates, etc.
- No space for bigger feedback capacitors
- What can we do? Increase C(mos)? Increase V (thick gate transistors)? External capacitor (Monday talk Mujin Li)
- We increase V, but at the input node!
  - Observation 1: a normal JF pixel dies at 30-80x saturation levels (with protection diode)
  - Observation 2: in simulator, a saturated pixel preamplifier has Vout ~0, Vin up to ~3V (before protection diode trigger)
  - Observation 3: ~3V >> 0.9V the preamp output range.



Jungfrau HDR for Free Electron L

- Until the end of G2 everything works as normal
- But for higher intensity pulses:
  - Comparator triggers again
  - Amplifier (which is in saturation) is shunt to a voltage close to GND
  - charge is collected on the input plate of the big feedback capacitor
  - Voltage at the input raises, while charge is stored in the feedback cap
  -



Jungfrau HDR for Free Electron L

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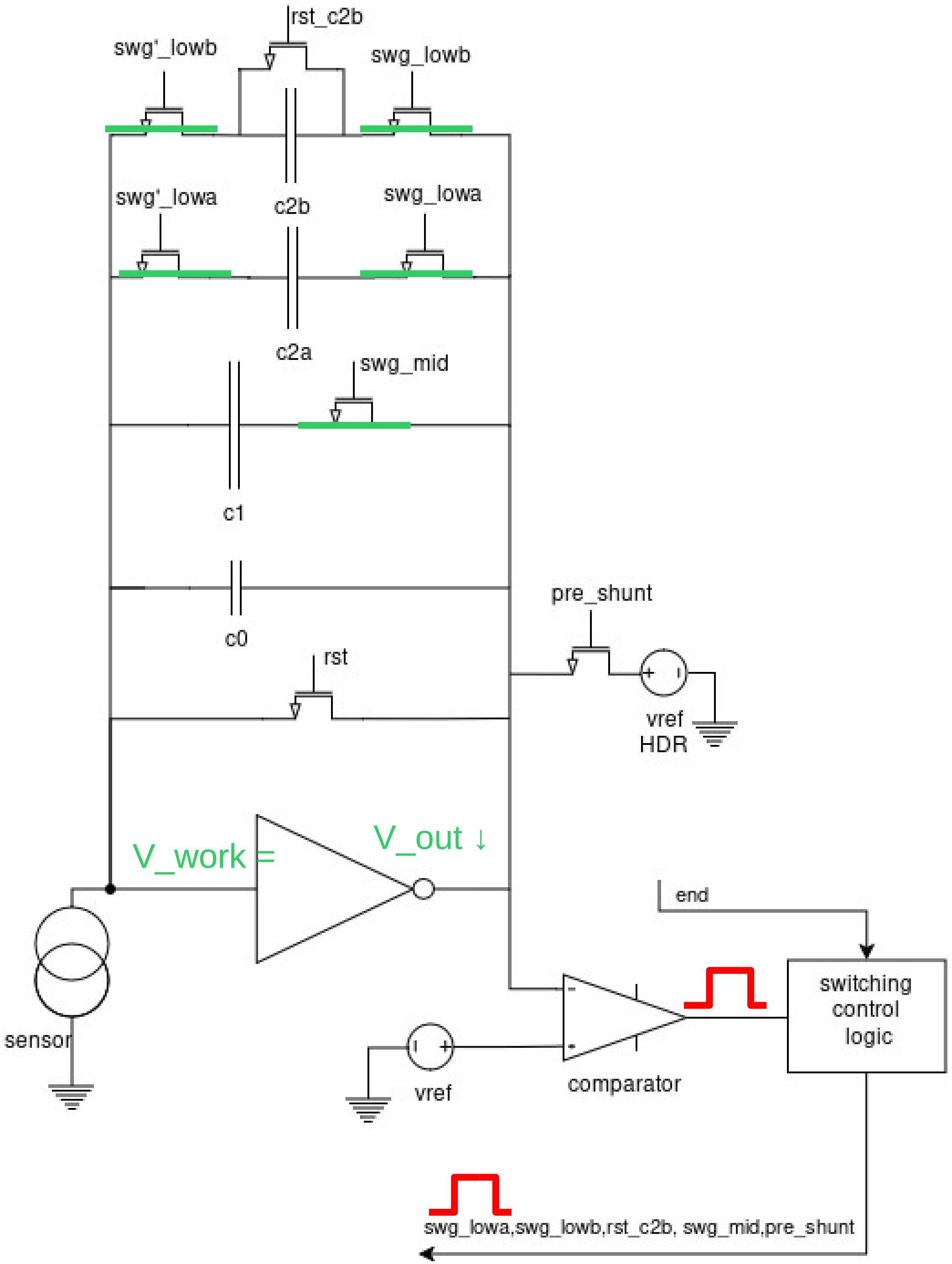
  -



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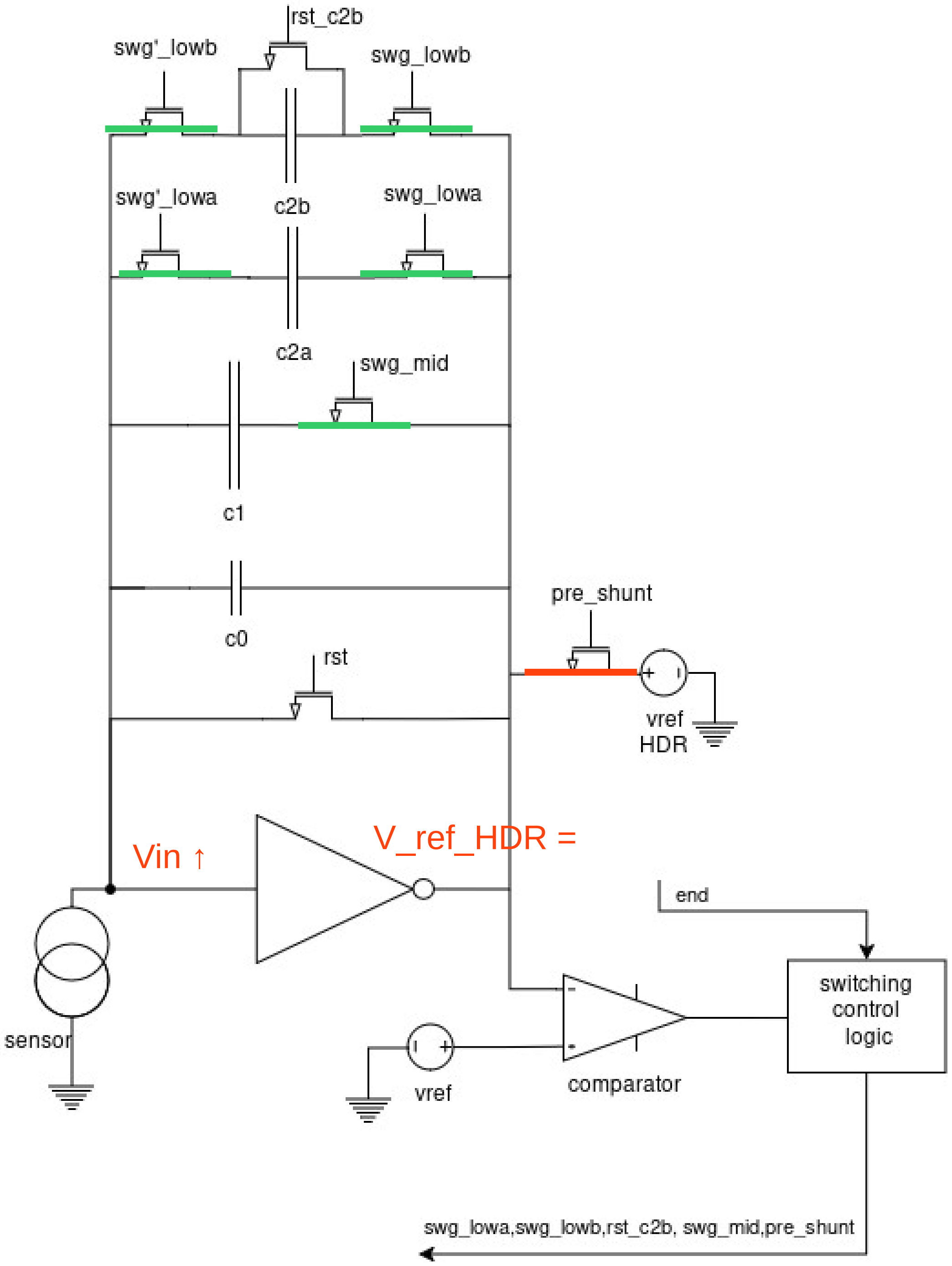
  - charge is collected on the input plate of the big feedback capacitor
  - Voltage at the input raises, while charge is stored in the feedback cap
  - Voltage at the input can exceed the supplies
    - How to read it out?
  -



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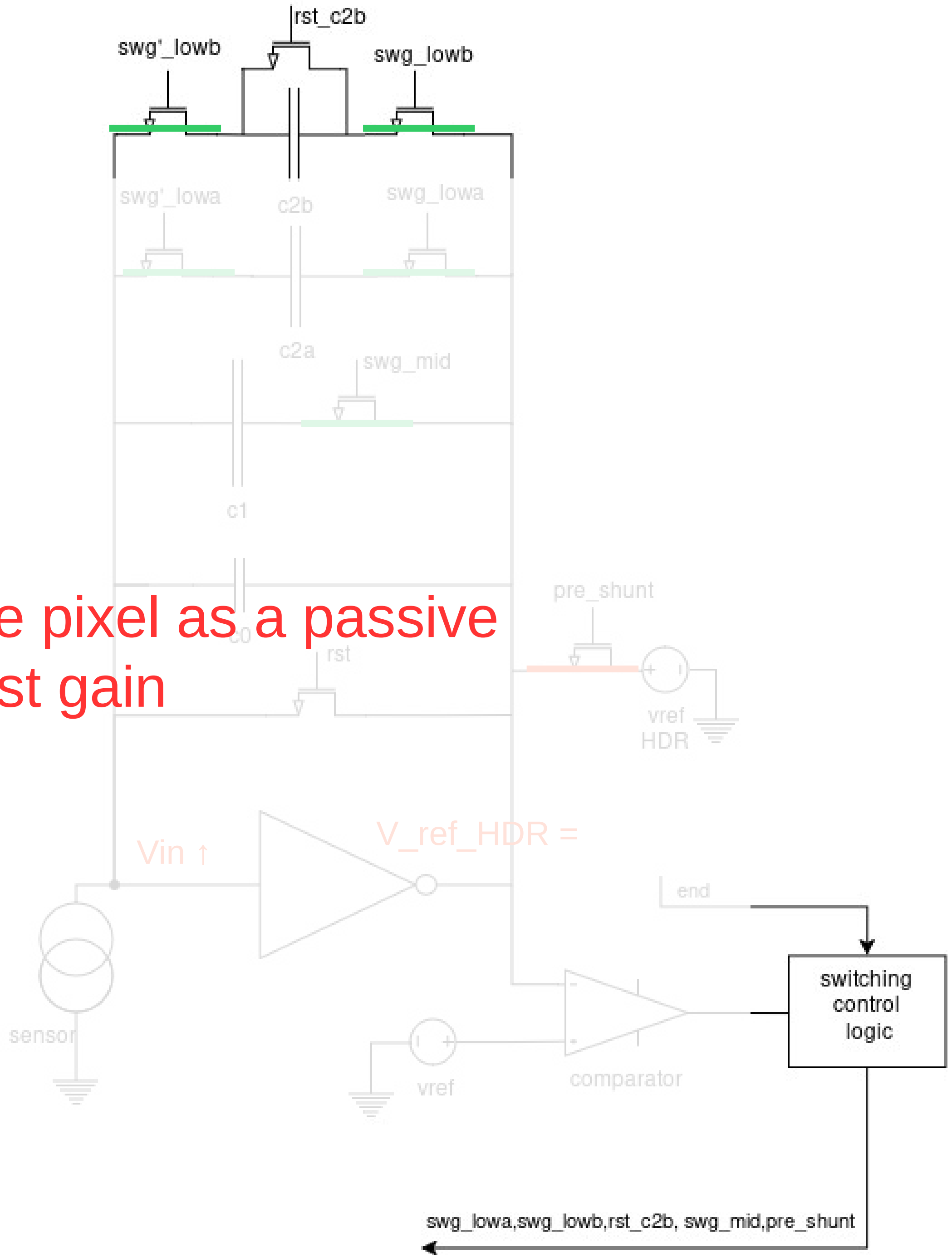
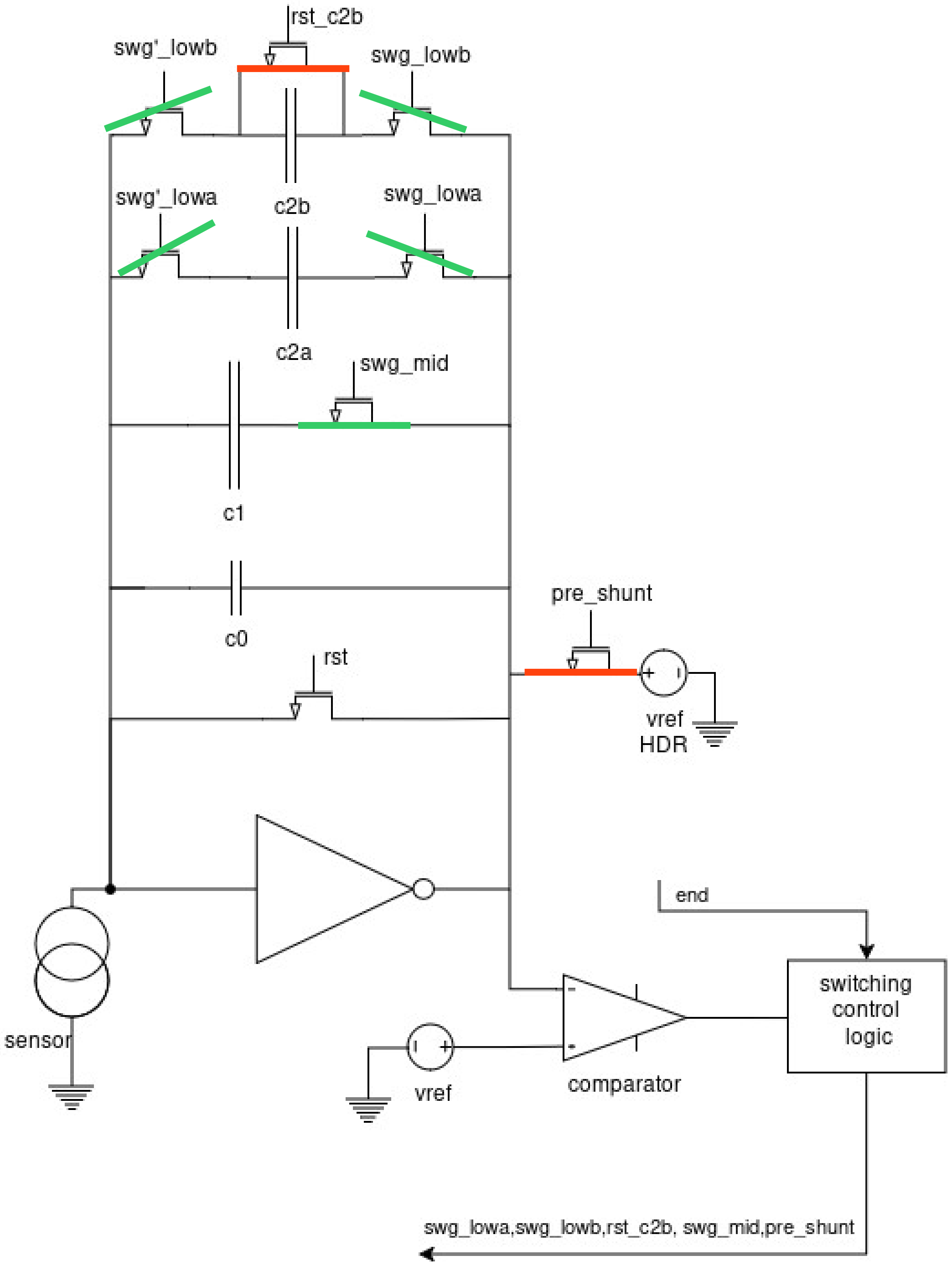
    - How to read it out?
  -

Basically we reconfigure the pixel as a passive pixel for the last gain



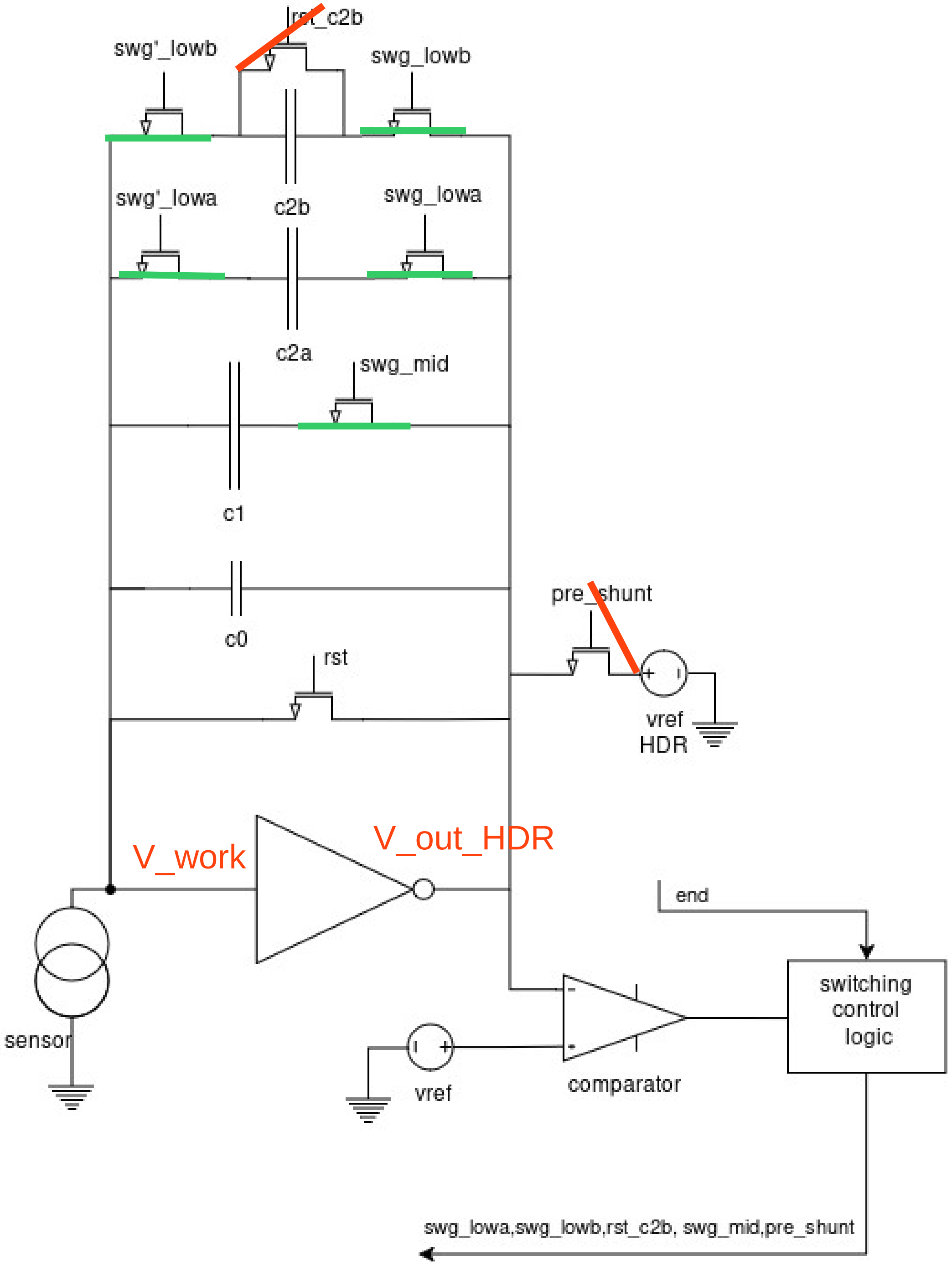
Jungfrau HDR for Free Electron L

- Until the end of G2 everything works as normal
- But for higher intensity pulses:
  - Comparator triggers again
  - Amplifier (which is in saturation) is shunt to a voltage close to GND
  - charge is collected on the input plate of the big feedback capacitor
  - Voltage at the input raises, while charge is stored in the feedback cap
  - Voltage at the input can exceed the supplies
    - How to read it out?
    - switches of the big capacitors are opened, the bigger of the two is reset (2.5V transistor)

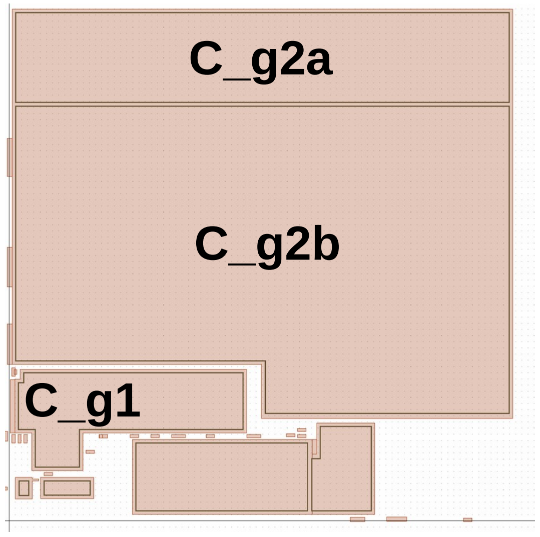


Jungfrau HDR for Free Electron L

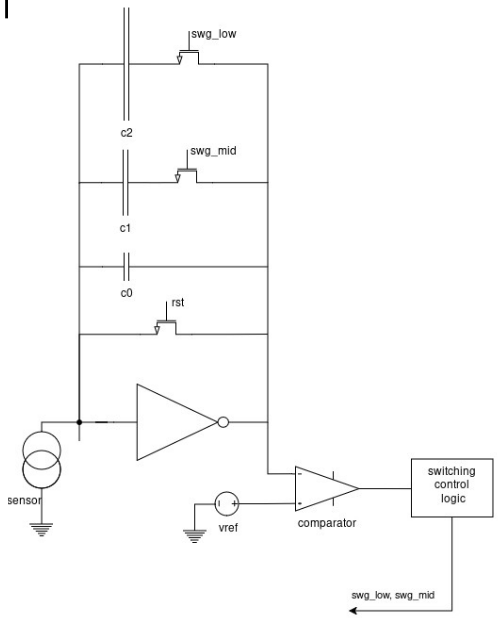
- Voltage at the input can exceed the supplies
  - How to read it out?
  - switches of the big capacitors are opened, the bigger of the two is reset (2.5V transistor)
  - reset is released, shunt is opened, switches close the loop again
  - Preamplifier restarts - > after some time we can sample.
-

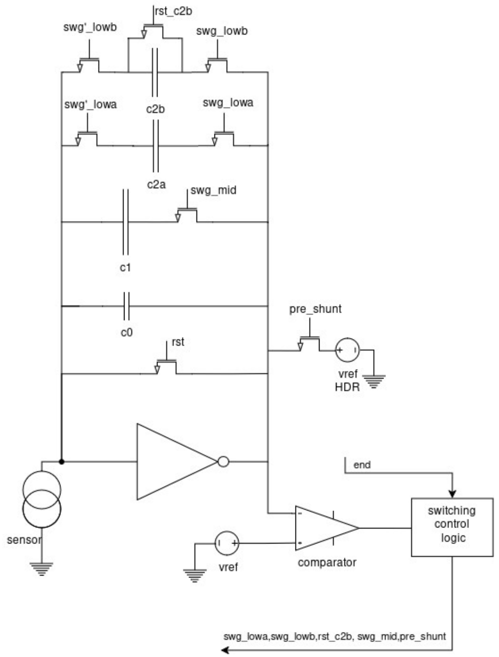


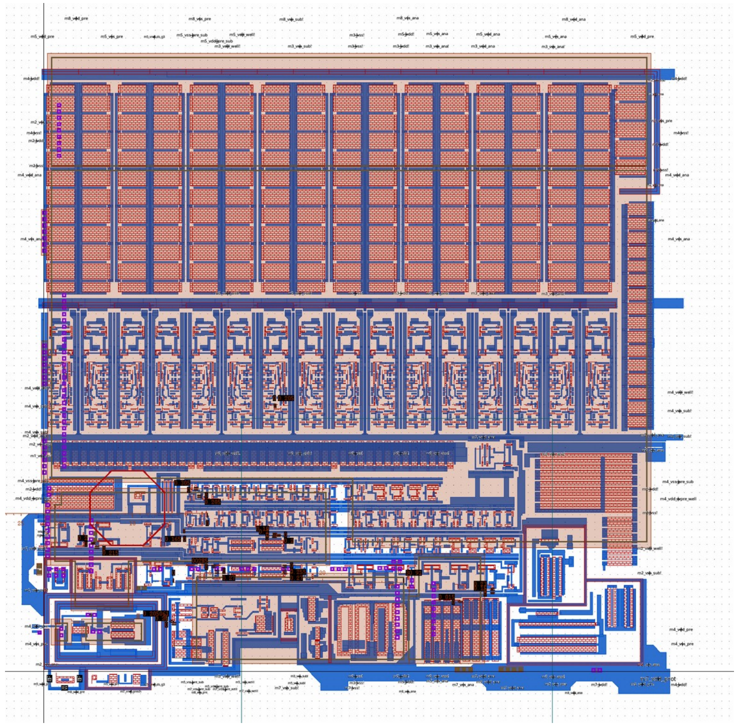
Jungfrau HDR – implementation



- Only 5 more switches
- The big cap reset switch is in thick gate (2.5V), driven by bootstrap drivers
- Cap ratio 1.89/(1.89+6.0)=0.25
- Digital logic block a bit more complex
- A global signal has to reach the pixel son pulse.

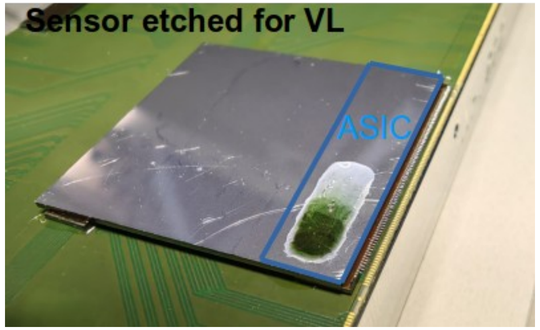


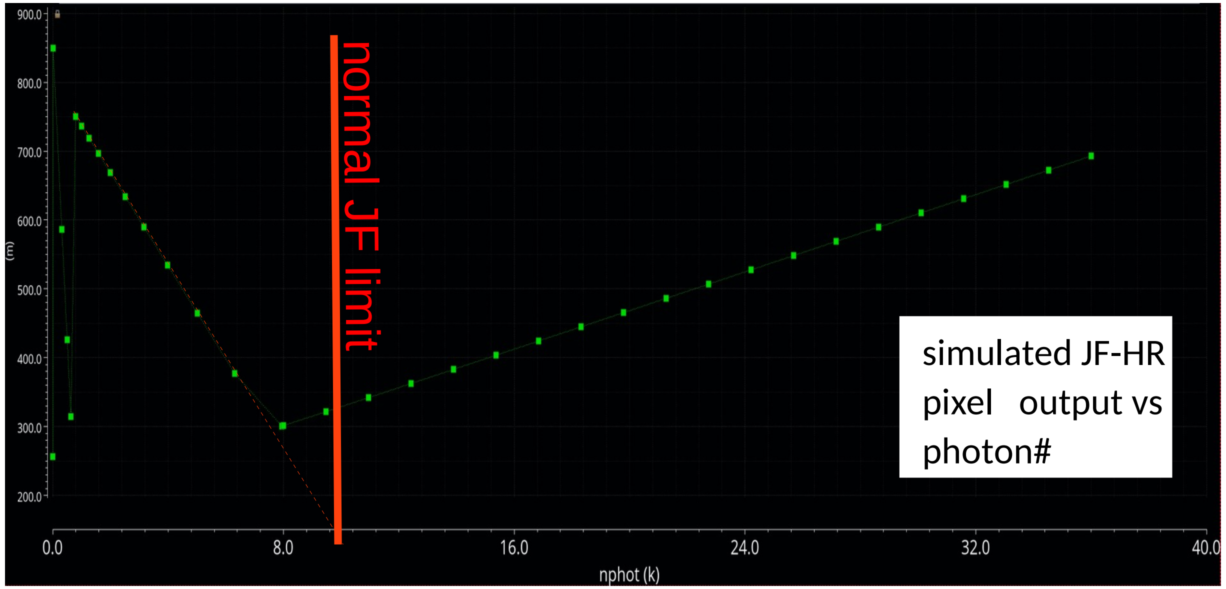


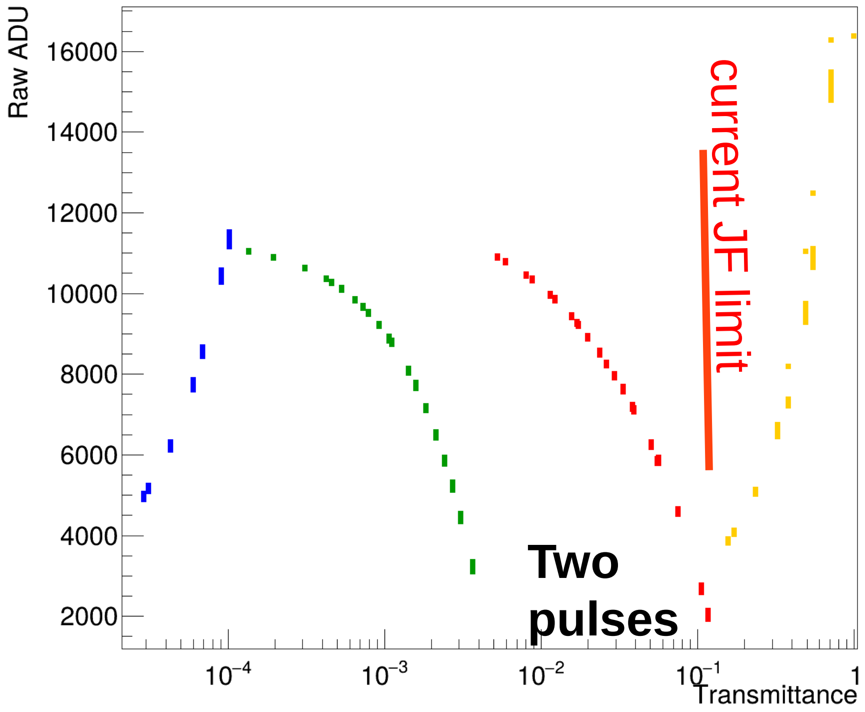


Jungfrau HDR – Simulation and Laser Scan

- 256x48 prototype taped out on the M1.0 ER
- Laser Scan with transmission filters
- IR laser focused in one pixel
- exp_time 10us, pulse @3us, recombination signal at 7us
- HV 200V
- Need 2 laser pulses to cover full range







Jungfrau HDR – Simulation and Laser Scan

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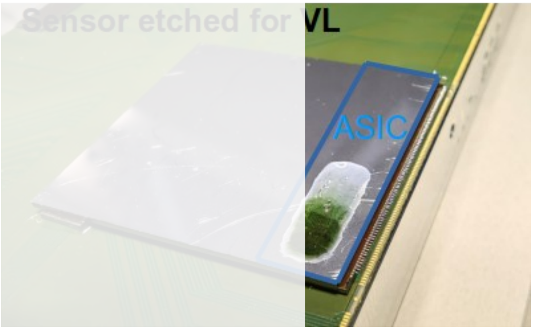
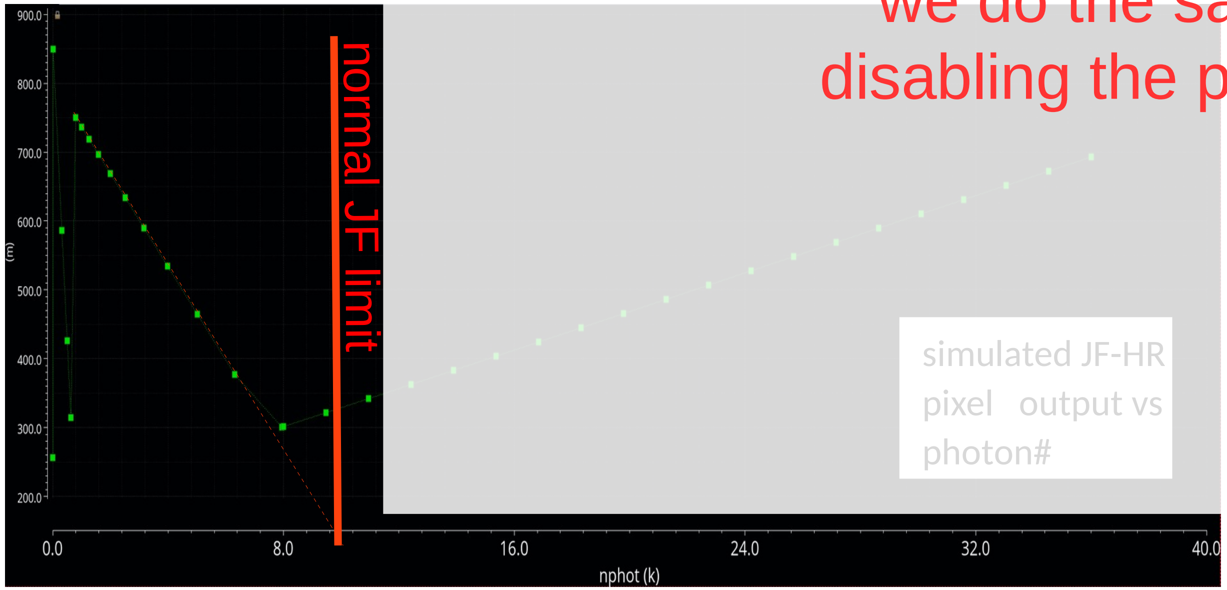
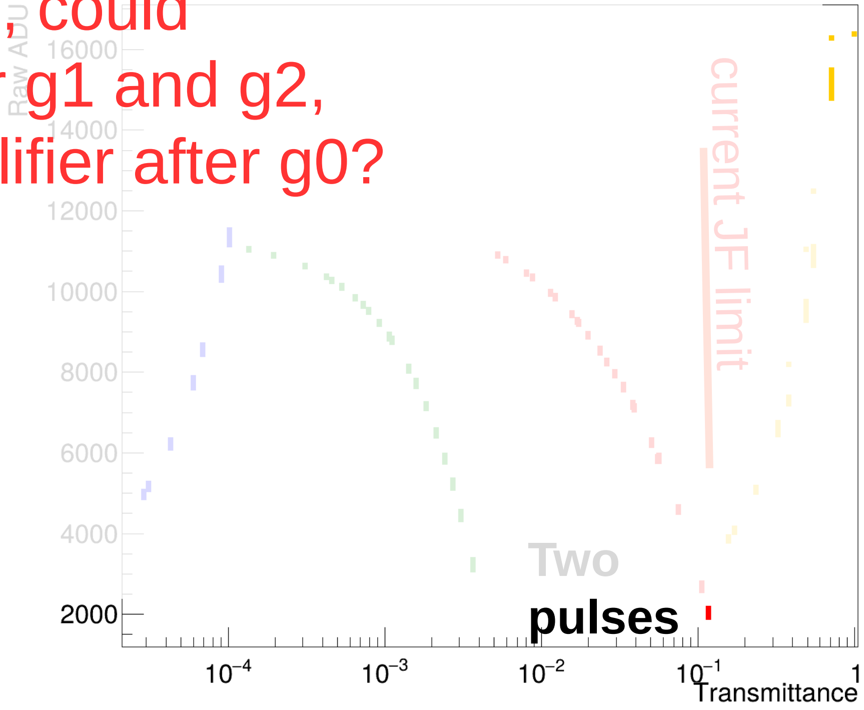


Idea:
if g3 is passive, could
we do the same for g1 and g2,
disabling the preamplifier after g0?





summary table active gain switching + CITIUS

	node	Noise ENC low noise mode	Noise ENC normal mode	Pitch	gains	Saturation level	Max Frame rate (CW)	Count rate at Synchr. with DR extension	SC	Deployment year
unit		ENC r.m.s.	ENC r.m.s	um	#	# 12keV ph.	Hz	cps	#	a.D.
JF1.0	UMC 110	55	80	75	3	10K	2.2k	22M/265M	16	2016
JF1.2	UMC 110	31	60	75	3	10K	2.2k	22M/265M	16	2024
JF1.2_EUXFEL	UMC 110	50	80	75	3	10K	2.2k	-	32	2027
JF1.2_EUXFEL Binned mode	UMC 110	-	200	150	3	40K	2.2k	-	128	2027
AGIPD	IBM 130	150	250	200	3	10K	20k	200M	352	2017
EPiX10k	250	67	115	100	2	7K	480	3.4M	2	2016
EPixUHR	130	150	150	100	2	7K	100k	700M	2	2026
STARLIGHT (HYLITE200F)	130	-	450	200	3	10K	1k	10M		-
STARLIGHT (HYLITE100S)	130	-	380	100	3	10K	10k	100M		2027
CITIUS (FEL)	SONY 65	25 (multi sample)	60	72.6	3	8.5k	5k	42M		2024
CITIUS (SR)	SONY 65	25 (multi sample)	60	72.6	2	1.8k	17.5k	30M/600M		2024

Acknowledgements

Photon Science Detector Group

Back: B. Braham, K. Moustakas, C. Ruder, D. Greiffenberg, J. Heymes, K. Ferjaoui, C. Lopez-Cuenca, K. Kozlowski, M. Brückner, K. A. Paton, F. Baruffaldi, T. King, and P. Sieberer

Front: J. Zhang, V. Hinger, S. Hasanaj, A. Bergamaschi, X. Xie, R. Dinapoli, and B. Schmitt

not in picture: R. Barten, S. Ebner, E. Fröjdh, D. Mezza, **A. Mozzanica** and D. Thattil, V. Kedych

Backup Slides

JF publications list

- "Prototype characterization of the JUNGFRAU pixel detector.." Mozzanica A, 2014. https://doi.org/10.1088/1748-0221/9/05/C05010
- "JUNGFRAU 0.2: prototype characterization of a gain-switching.." Jungmann-Smith JH, 2014. https://doi.org/10.1088/1748-0221/9/12/P12013
- "Looking at single photons using hybrid detectors." Bergamaschi A, 2015. https://doi.org/10.1088/1748-0221/10/01/C01033
- "Radiation hardness assessment of the charge-integrating.." Jungmann-Smith JH, 2015. https://doi.org/10.1063/1.4938166
- "Towards hybrid pixel detectors for energy-dispersive or.." Jungmann-Smith JH, 2016. https://doi.org/10.1107/S1600577515023541
- "Characterization results of the JUNGFRAU full scale.." Mozzanica A, 2016. https://doi.org/10.1088/1748-0221/11/02/C02047
- "Calibration status and plans for the charge integrating.." Redford S, 2016. https://doi.org/10.1088/1748-0221/11/11/C11013
- "SwissFEL: the Swiss X-ray free electron laser." Milne CJ, 2017. https://doi.org/10.3390/app7070720
- "Towards a stand-alone high-throughput EUV actinic.." Rajendran R, 2017. https://doi.org/10.1117/12.2258379
- "Fast and accurate data collection for macromolecular.." Leonarski F, 2018. https://doi.org/10.1038/s41592-018-0143-7
- "The JUNGFRAU detector for applications at synchrotron.." Mozzanica A, 2018. https://doi.org/10.1080/08940886.2018.1528429
- "First full dynamic range calibration of the JUNGFRAU.." Redford S, 2018. https://doi.org/10.1088/1748-0221/13/01/C01027
- "Operation and performance of the JUNGFRAU photon detector.." Redford S, 2018. https://doi.org/10.1088/1748-0221/13/11/C11006
- "Characterization of GaAs:Cr sensors using the charge.." Greiffenberg D, 2019. https://doi.org/10.1088/1748-0221/14/05/P05020
- "1 kHz fixed-target serial crystallography using a multilayer.." Tolstikova A, 2019. https://doi.org/10.1107/S205225251900914X
- "Discrimination of aluminum from silicon by electron.." Fröjdh E, 2020. https://doi.org/10.3390/cryst10121148
- "Measurement of charge deposition from heavy ions with.." Fröjdh E, 2020. https://doi.org/10.1088/1748-0221/15/05/C05044
- "JUNGFRAU detector for brighter x-ray sources: solutions.." Leonarski F, 2020. https://doi.org/10.1063/1.5143480
- "X-ray fluorescence detection for serial macromolecular.." Martiel I, 2020. https://doi.org/10.1107/S1600577519016758
- "First full dynamic range scan of the JUNGFRAU detector.." Redford S, 2020. https://doi.org/10.1088/1748-0221/15/02/C02025
- "Characterization of chromium compensated GaAs sensors.." Greiffenberg D, 2021. https://doi.org/10.3390/s21041550
- "Strain wave pathway to semiconductor-to-metal transition.." Mariette C, 2021. https://doi.org/10.1038/s41467-021-21316-y
- "Detection of MeV electrons using a charge integrating.." Fröjdh E, 2022. https://doi.org/10.1088/1748-0221/17/12/C12004
- "Electron detection with CdTe and GaAs sensors using.." Fröjdh E, 2022. https://doi.org/10.1088/1748-0221/17/01/C01020
- "Advancing the JUNGFRAU detector toward low-energy.." Hinger V, 2022. https://doi.org/10.1088/1748-0221/17/09/C09027
- "Observation of radiation damage in CdTe Schottky.." Meyer M, 2022. https://doi.org/10.1088/1748-0221/17/06/P06035
- "Jungfraujoch: hardware-accelerated data-acquisition.." Leonarski F, 2023. https://doi.org/10.1107/S1600577522010268
- "Kilohertz serial crystallography with the JUNGFRAU.." Leonarski F, 2023. https://doi.org/10.1107/S2052252523008618
- "Electromagnetic pulse protective shielding for digital.." Schreiner S, 2023. https://doi.org/10.1063/5.0160120
- "First operation of the JUNGFRAU detector in 16-memory.." Sikorski M, 2023. https://doi.org/10.3389/fphy.2023.1303247
- "Resolving soft X-ray photons with a high-rate.." Hinger V, 2024. https://doi.org/10.3389/fphy.2024.1352134
- "First results of the ADC-SAR-05 prototype.." Sieberer P, 2025. https://doi.org/10.1016/j.nima.2025.170697
- "Experience with the Jungfrau-1M detector at Diamond Light Source" Matheson J. 2026 https://doi.org/10.1107/S1600577526000342
- + (AGIPD based)
- "Calibration methods for charge integrating detectors" Mezza D. 2022 https://doi.org/10.1016/j.nima.2021.166078

Can we trust the noise simulation?

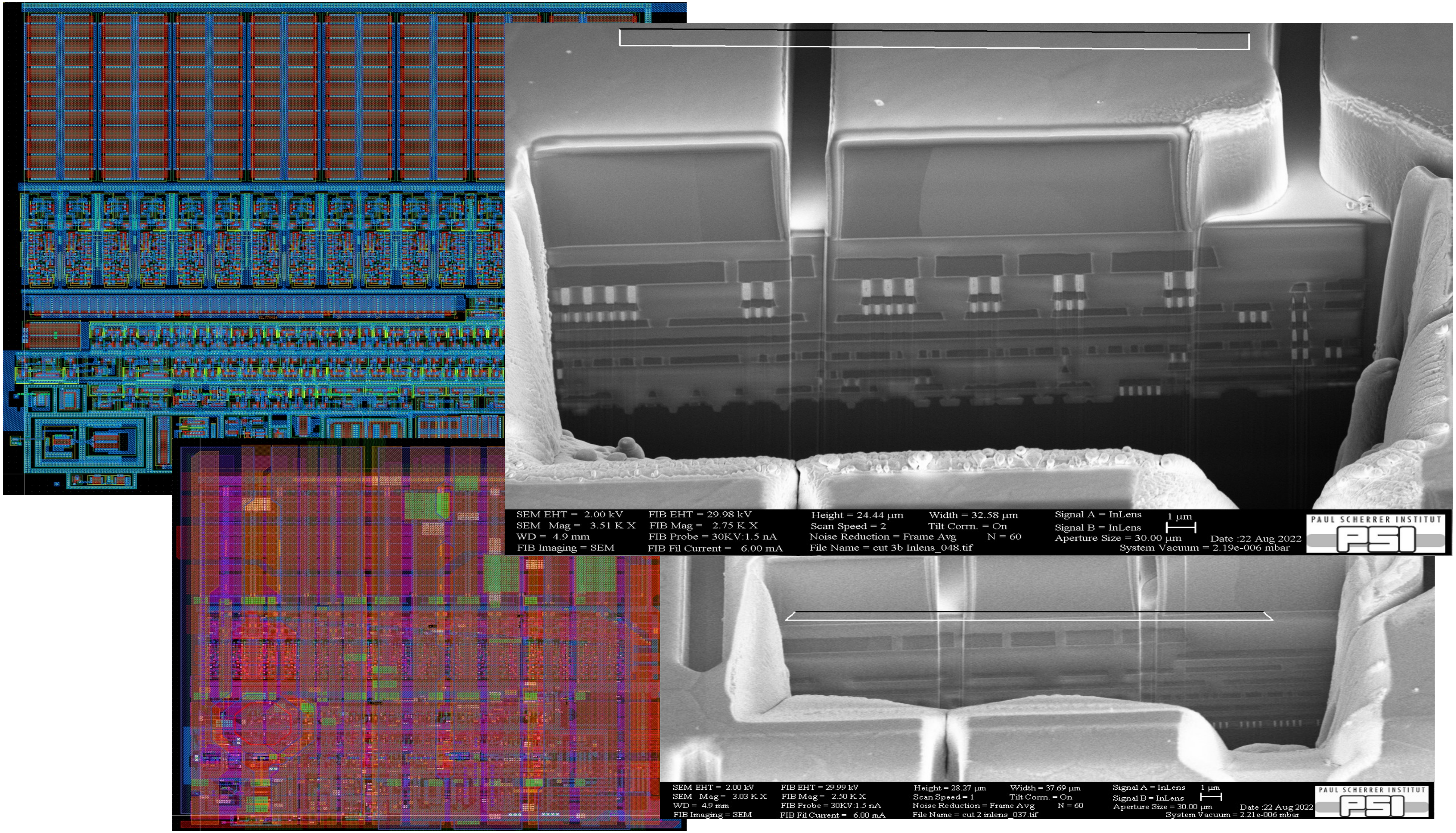
PSI

Method	Vn rms @CDS output
Noise * CDS TF , integrated (Ts=5us, Fmax=1GHz)	536uV
Pss/pnoise (Ts=5us, Fmax=1GHz, 50 harmonics)	642uV
Trans noise (Ts=5us, Fmin=100Hz, Fmax=1GHz)	468uV

Measured 570uV

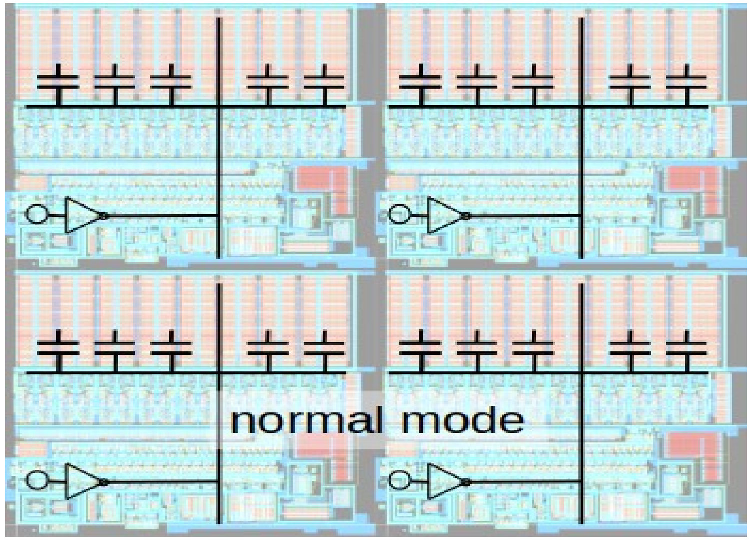
Courtesy S. Emiliani

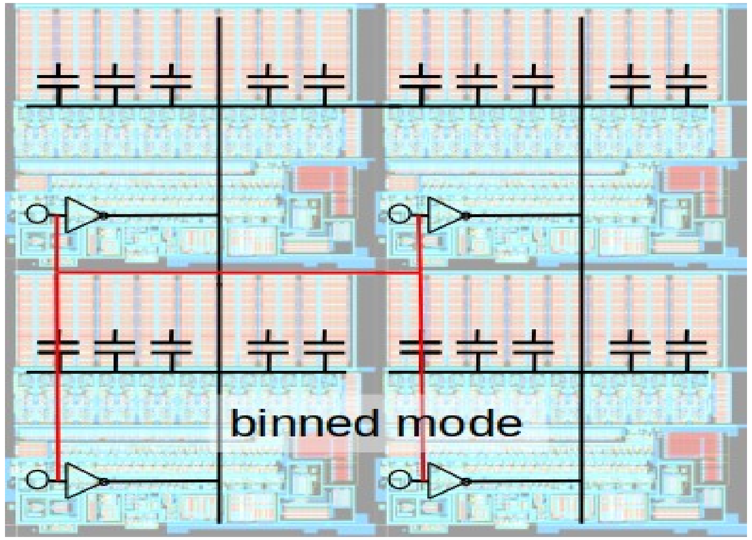
Drawings vs real life.



JF for EU-XFEL: binning + Storage

- increase SC to 32 per pixel
- pixels are part of a 2x2 pixel cluster.
- when configured in binning mode, the SC bus are connected together to the same pixel output
- amplifiers inputs also connected →4x dynamic range in all gains
- only one comparator/digital block enabled
- readout unaffected (bus split)
- readout time only 2x as now.



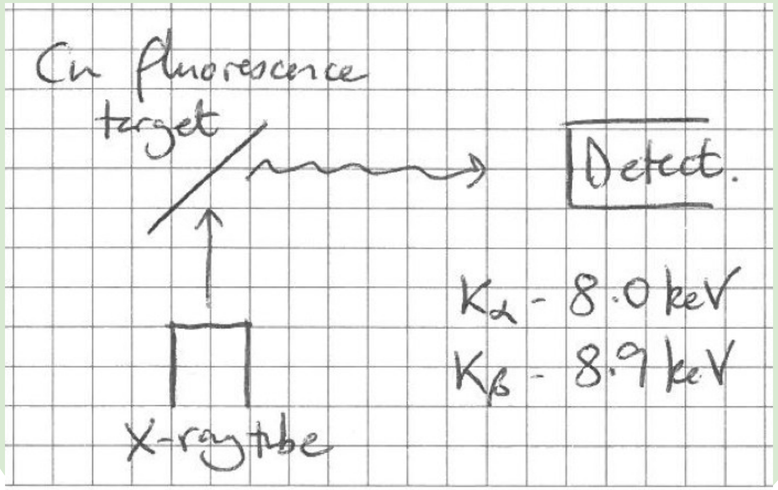


normal	binned
pitch 75μm	pitch 150μm
noise 0.3keV (with CDS)	noise 1.2keV
DR 10000 γ	DR 40000 γ
SC# 32	SC# 128

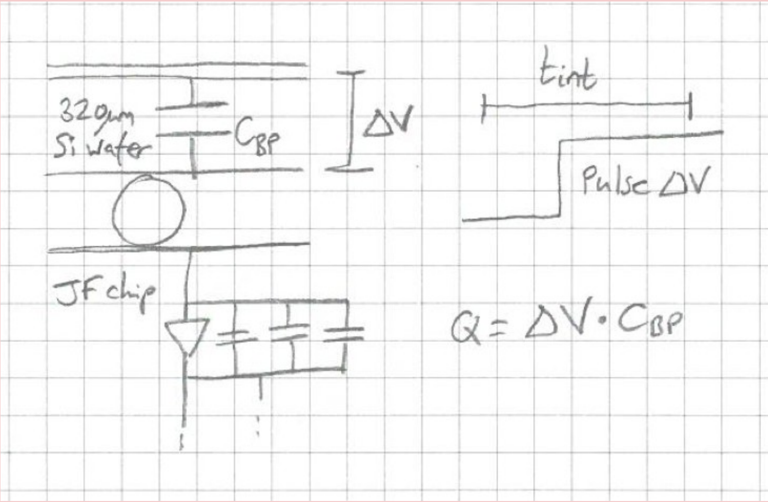
Calibration

- Cu Fluorescence ---> absolute G0
- Backplane Pulsing ---> Xcalibration G0/G1
- Internal Current source ---> Xcalibration G1/G2

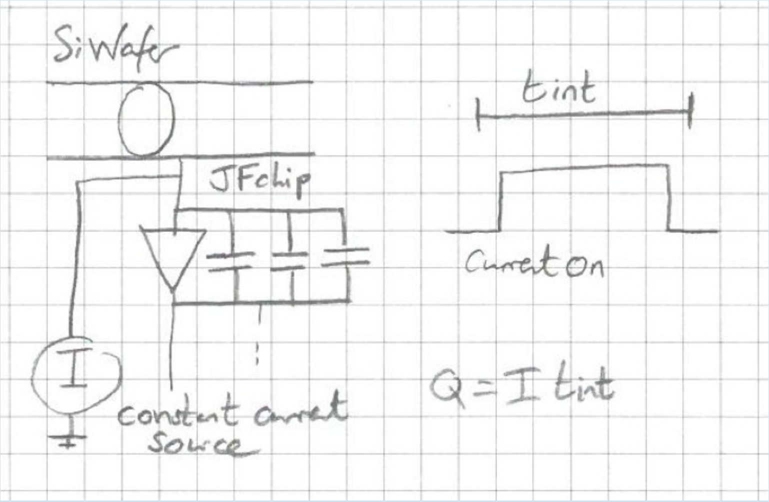
Fluorescence



Backplane pulse



Current source



Data: M236 p58000

Calibration procedure

Three step process:

1. Cu fluorescence for absolute calibration of HG0, G0
2. Backplane pulsing scan for relative calibration of G0/G1
3. Current source scan for relative calibration of G1/G2

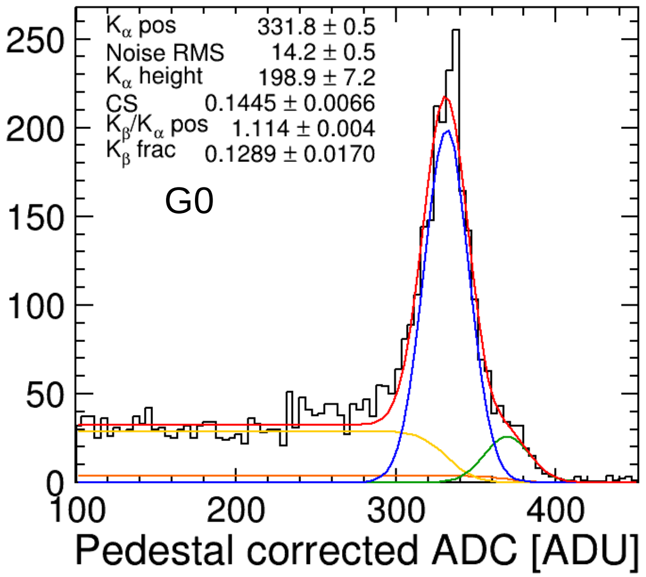
Combine steps for absolute calibration of full dynamic range

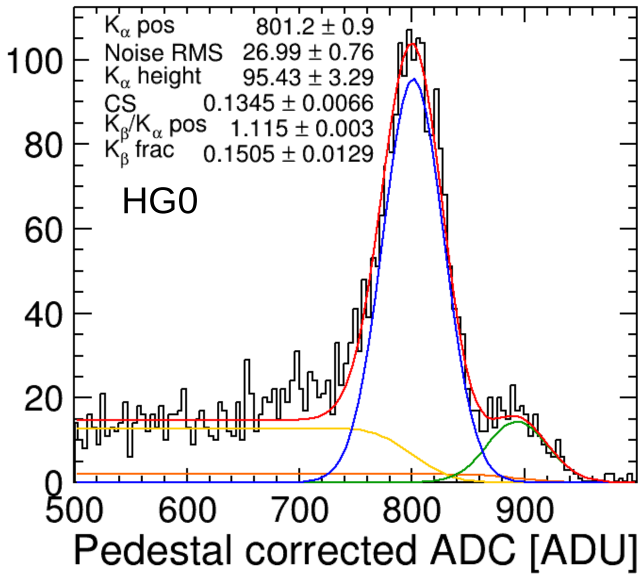
$$G0\,[\mathrm{ADU/keV}] = \frac{\mu_{K_\alpha} - \mu_{\mathrm{noise}}\,[\mathrm{ADU}]}{8.0\,[\mathrm{keV}]},$$

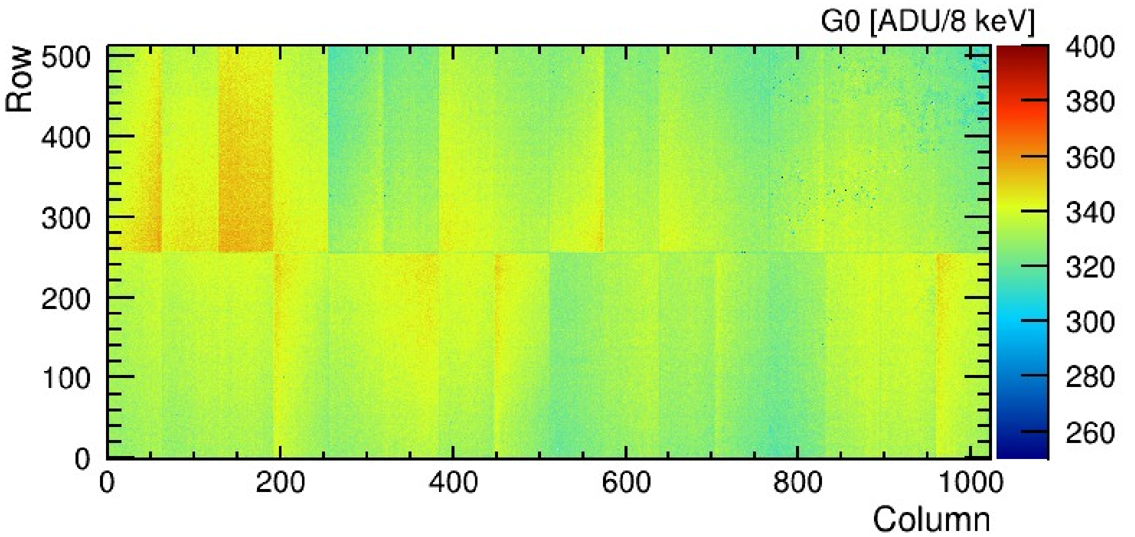
$$G1\,[\mathrm{ADU/keV}] = \frac{G1}{G0} \times G0\,[\mathrm{ADU/keV}],$$

$$G2\,[\mathrm{ADU/keV}] = \frac{G2}{G1} \times \frac{G1}{G0} \times G0\,[\mathrm{ADU/keV}].$$

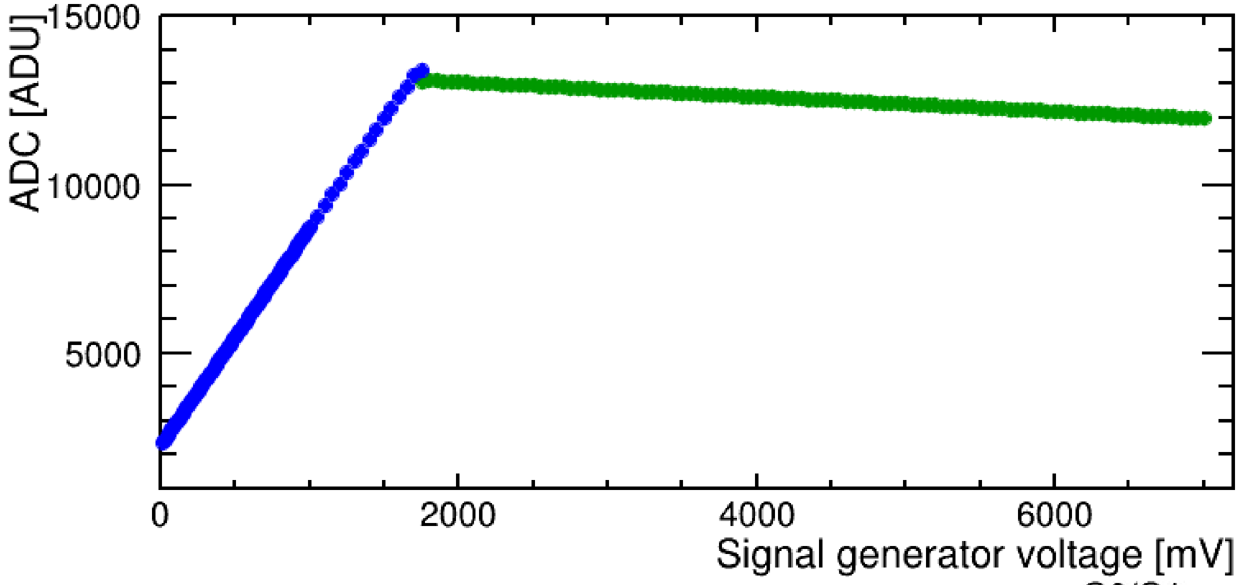
- 200k frames for G0 and HG0 (~0.5TB)
- G0: ~40 ADU/keV, HG0: ~100 ADU/keV
- Variation over module: σ/μ ~ 2%

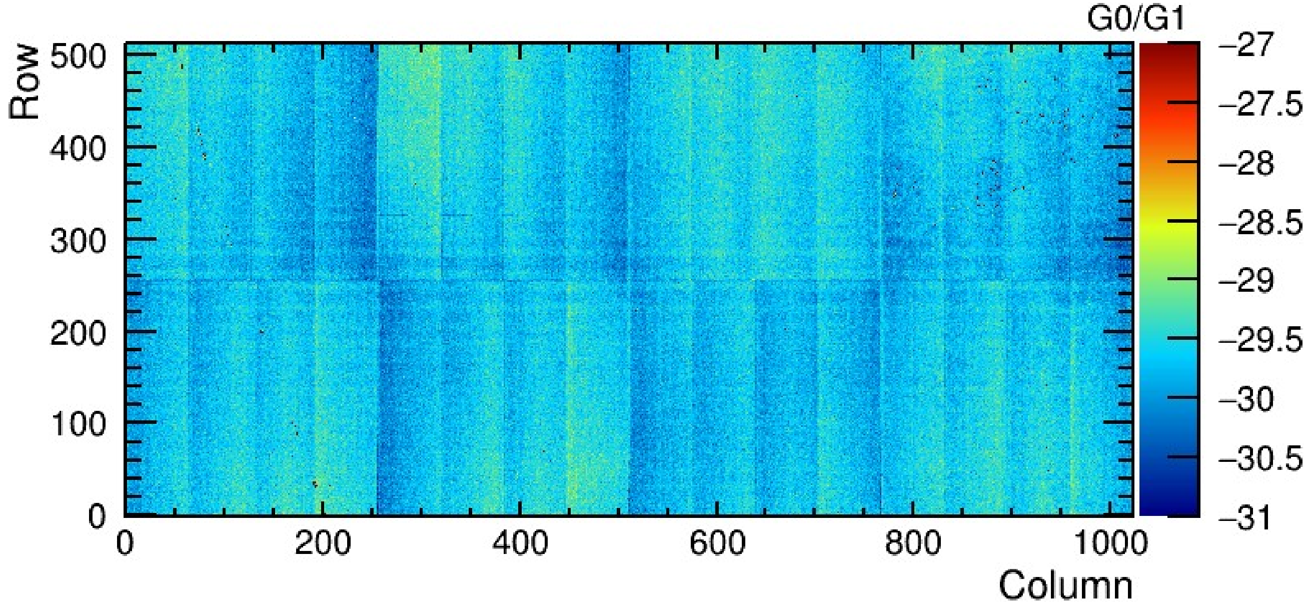




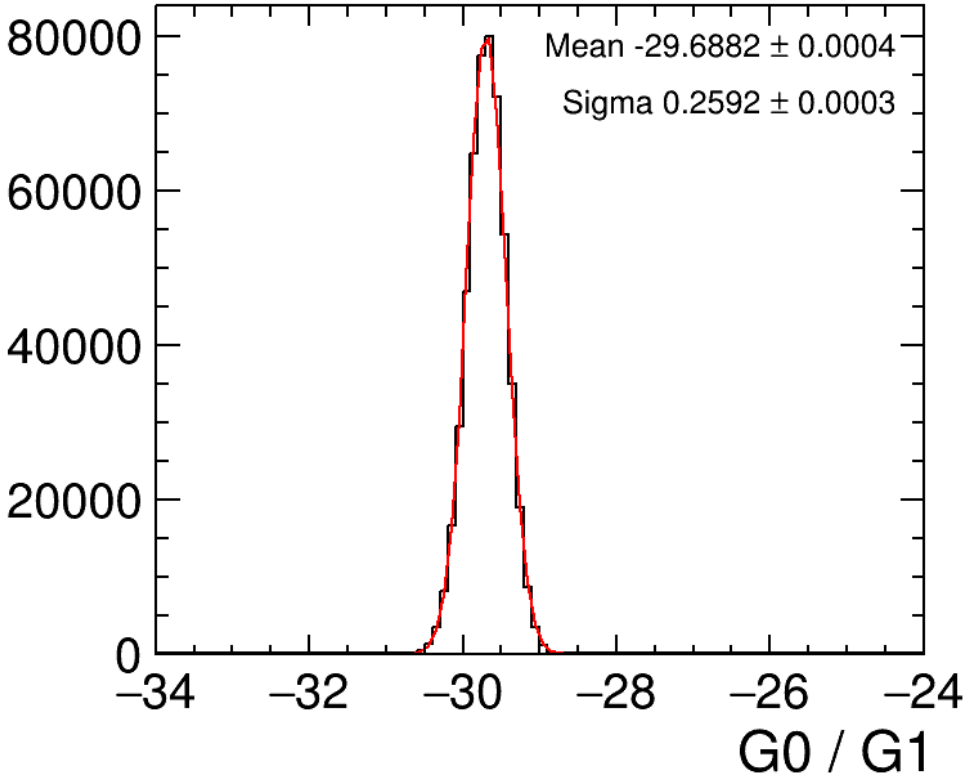


G0/G1 ratio from backplane pulsing scan



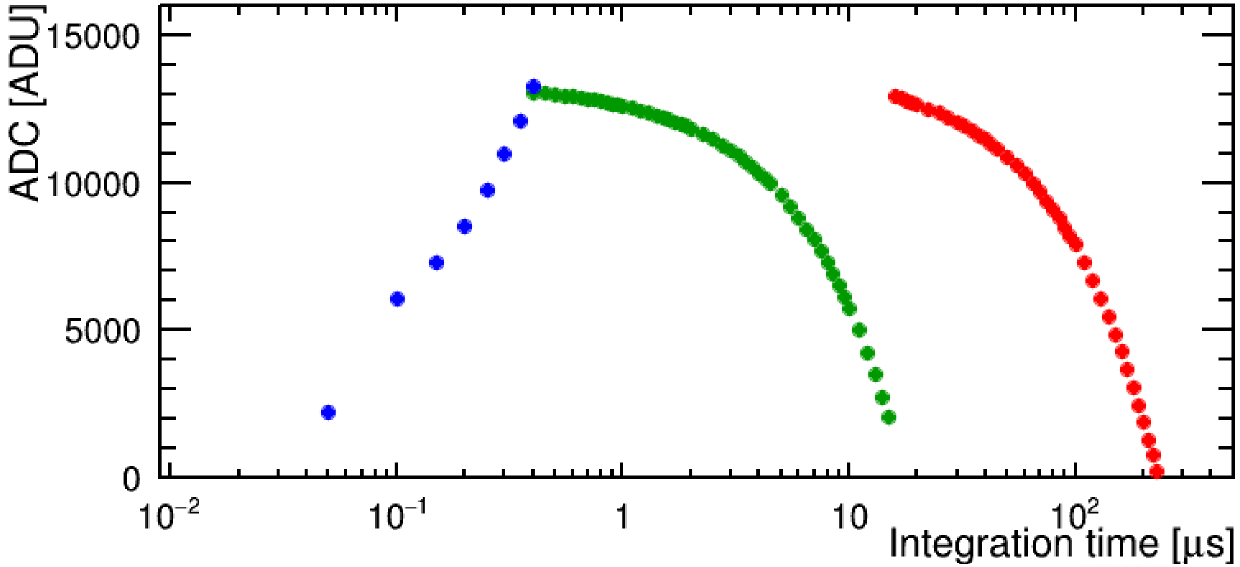


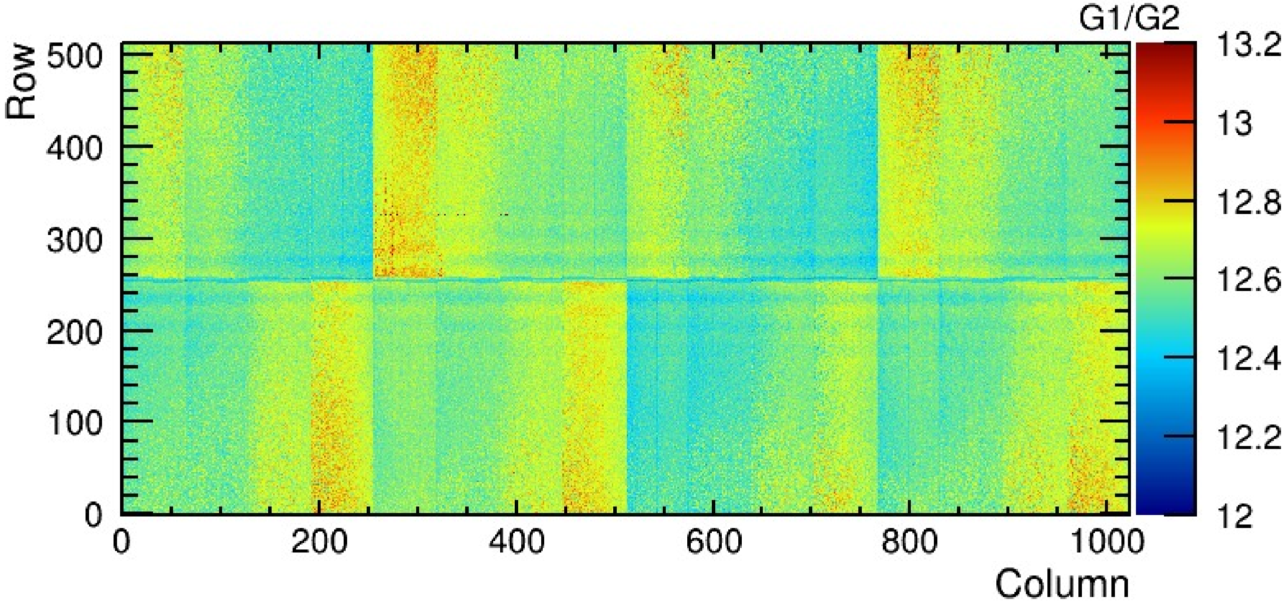
- 200 steps, 100 frames per step
- G0/G1: -30
- Variation over module: σ/μ < 1%



Data: M236 p58000

G1/G2 ratio from current source scan





- 100 integration time point 640 frames per point
- G1/G2: 12.5
- Variation over module: σ/μ < 1%