PAUL SCHERRER INSTITUT

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for the Swiss Light Source Detector Group

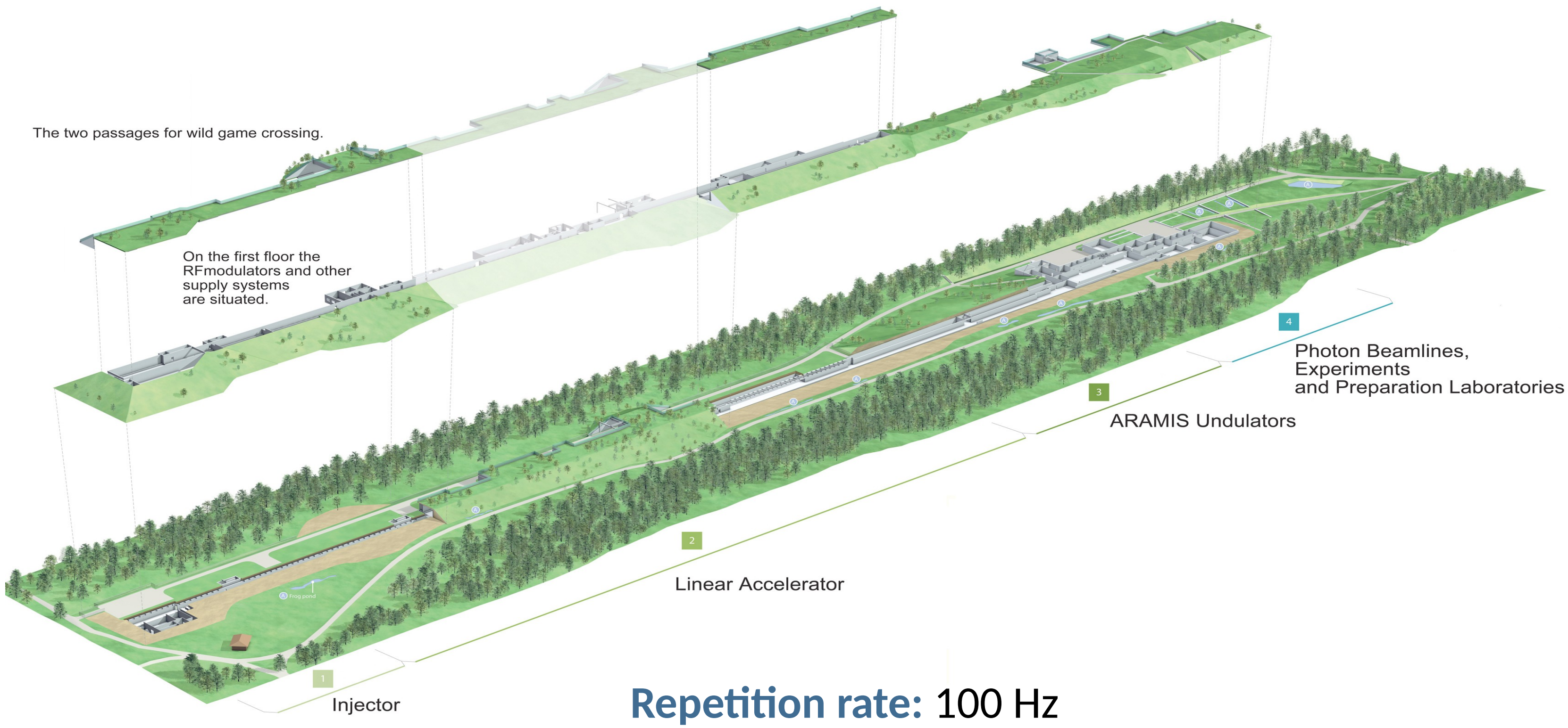
JUNGFRAU: a pixel detector for photon science at free electron laser facilities.

PIXEL 2016

Outline

- Introduction
- The pixel architecture and layout
- The ASIC and Module design
- From modules to systems and cameras
- First modules characterization results:
  - noise and gain maps in G0-HG0
  - noise across dynamic range
  - Intensity scan with visible light laser pulses
- An example of GS at work
- Specification summary
- Conclusions

SwissFEL



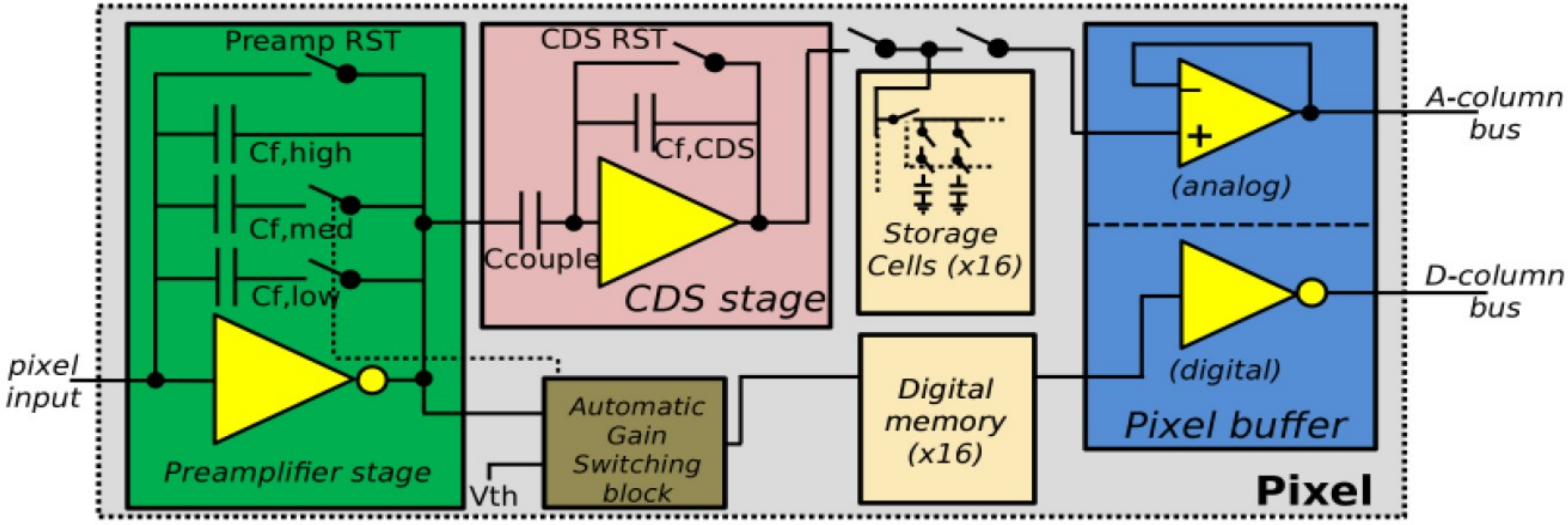
Repetition rate: 100 Hz
Photons per pulse (12keV): 0.7 x 10^{10}
Photon energy: 0.25 - 12 keV
Duration of light pulse: 1 - 60 fs
Brilliance: 1.3 x 10^{33} γ / (s x 0.1% b.w. x mm^2 x mrad^2)

Jungfrau pixel architecture

Some electronic design parameters:

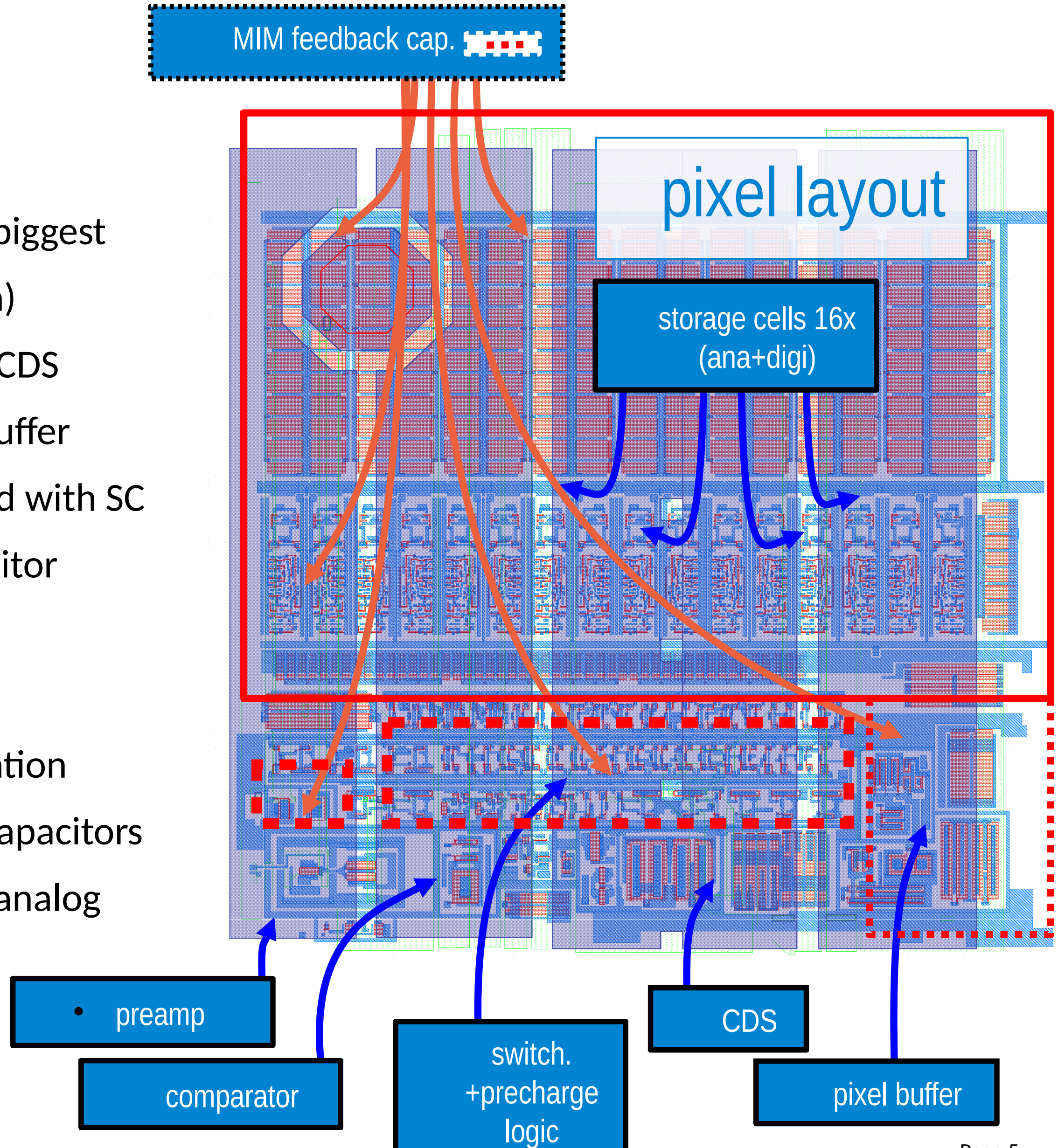
- preamp: 1.2V 8uA
- CDS+comp: 1.4V 14uA
- settling time pre. ~100ns
- Tot. power 30uW/ch, max. 2A/chip

- 1st gain switch at 25 ph. , 2nd at 600 (12keV)
- Linear up to >1000 12keV ph.
- Linearity err. <1%
- pix. to pix. X-talk <<1%

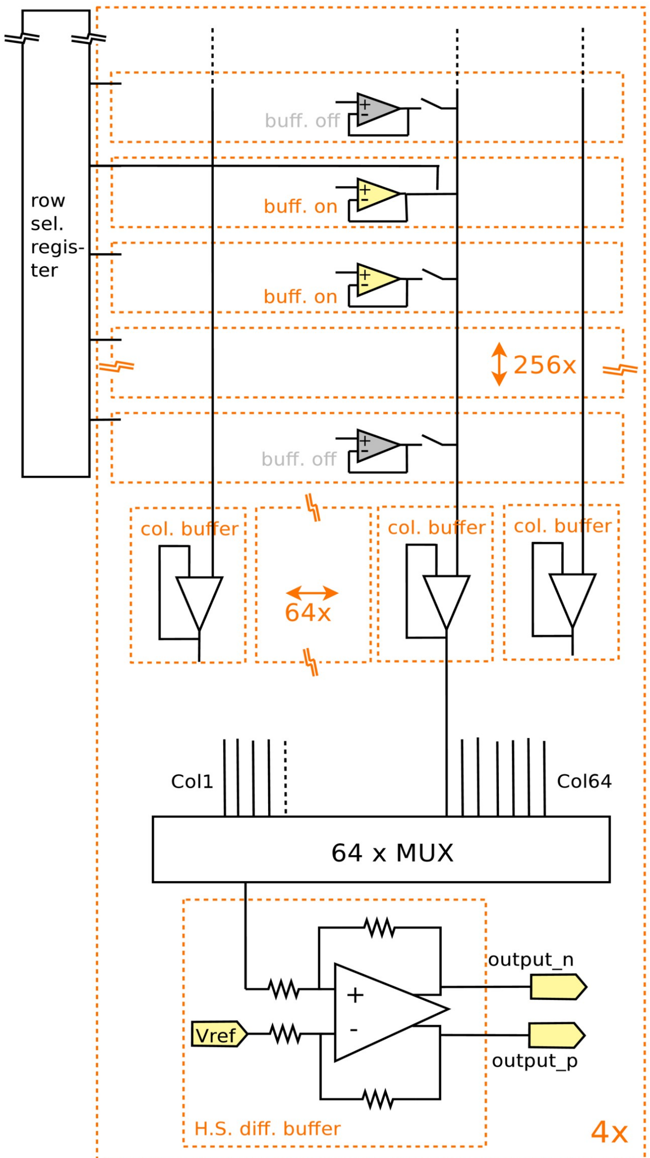


Jungfrau pixel layout

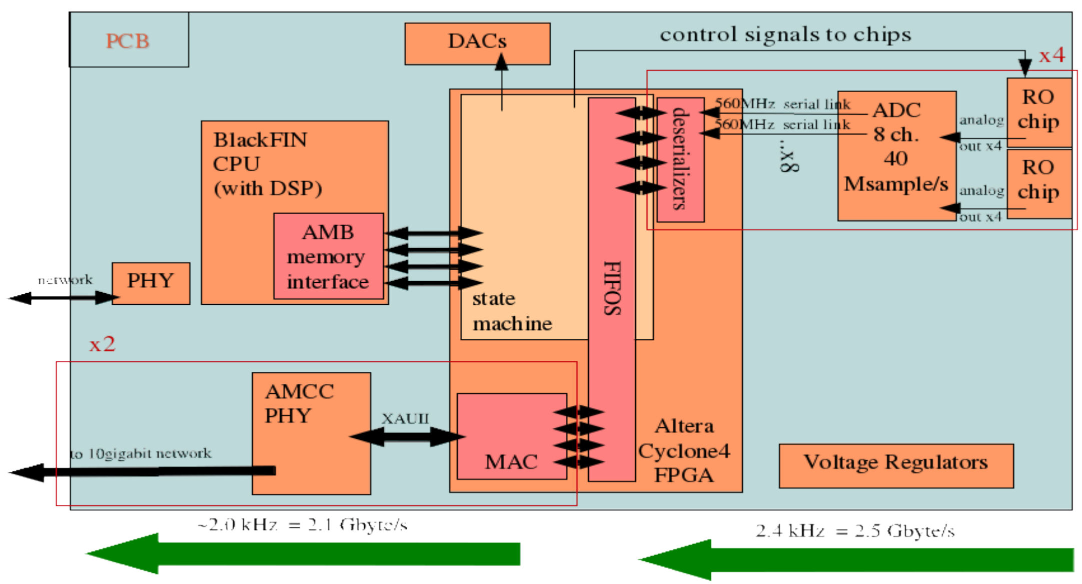
- UMC 110nm technology
- Power consumption probably biggest challenge (budget of ~25uA/ch)
  - low power preamp and CDS
  - power cycled off-pixel buffer
- plenty of space for circuit, filled with SC
- Space for MiM feedback capacitor limited, low gain 13pC (AGIPD,GOTTHARD)->7.5pC
  - amplifier range optimization
  - precharge of feedback capacitors
- Enclosed gate layout for most analog sections



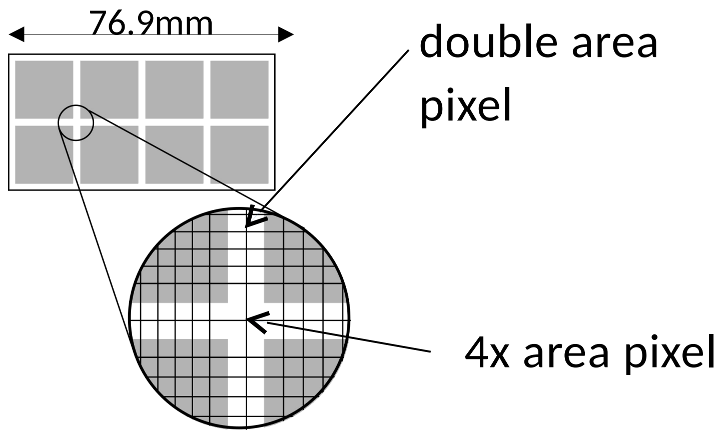
Readout and FE Architecture



- Per row readout with bottom MUX (@ 40MHz max)
- Power cycling: 2 rows of pixel buffers are active
- ASIC output directly connected to a 8 ch. AD9257
- Total readout time = 64x265/40=0.4ms
- 4 diff. analog output per chip (32 per module)
- Max teo. frame rate 2.4 kHz

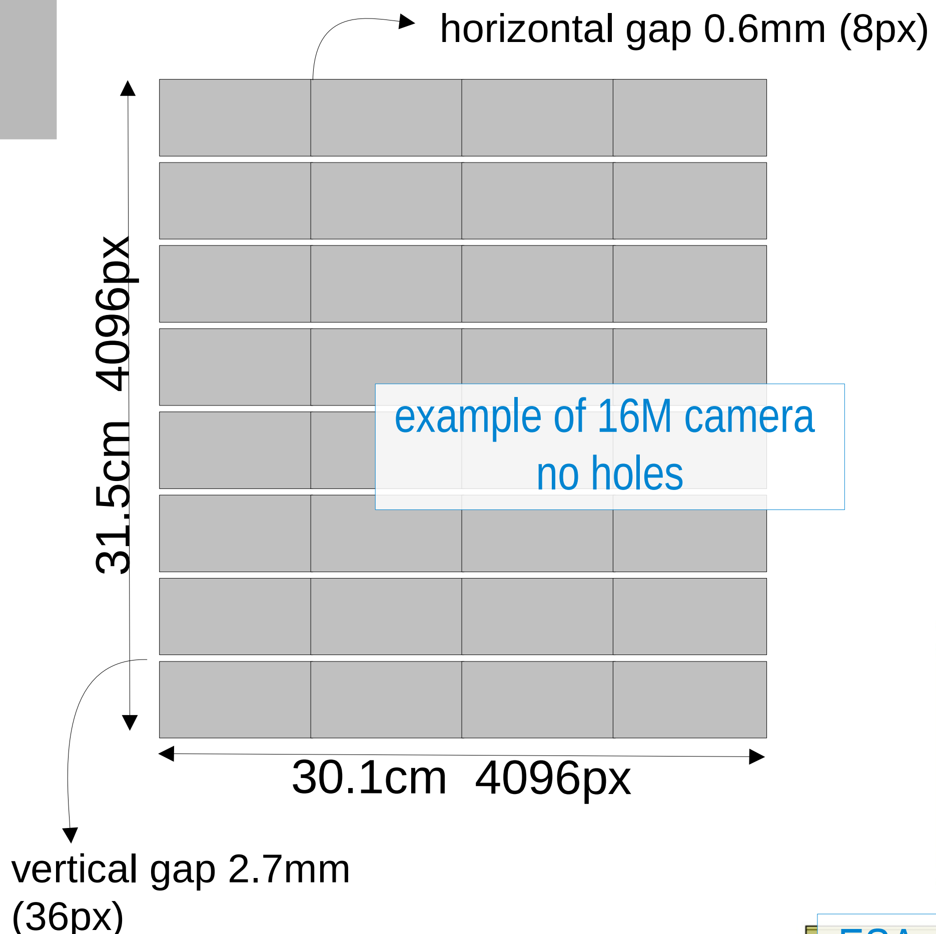


500k pixel module

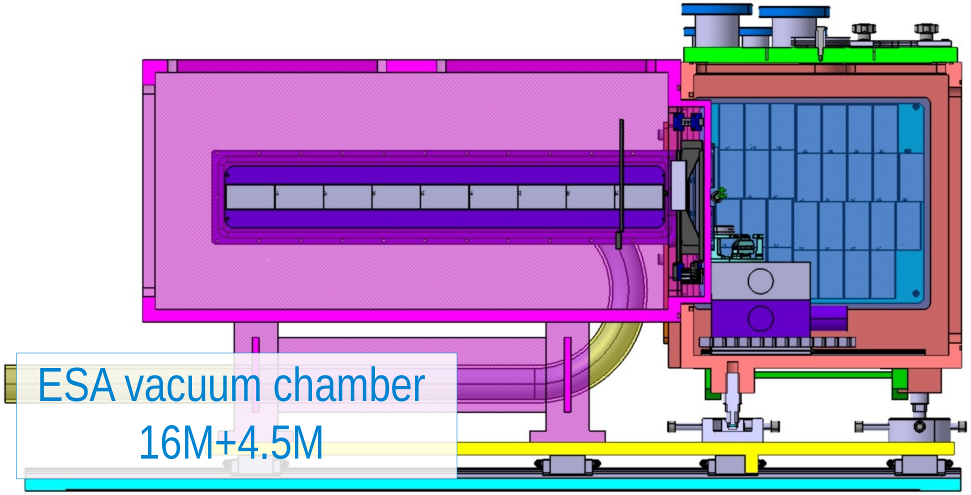


- Same geometry as an EIGER module
- 2x4 chips
- 1024x512 pixels
- 3.8x7.7 cm^2 silicon sensor
- Sensor thickness 320 µm
- Modular readout electronics
- Water cooling, operation at 20 ^{0}C

From modules to systems



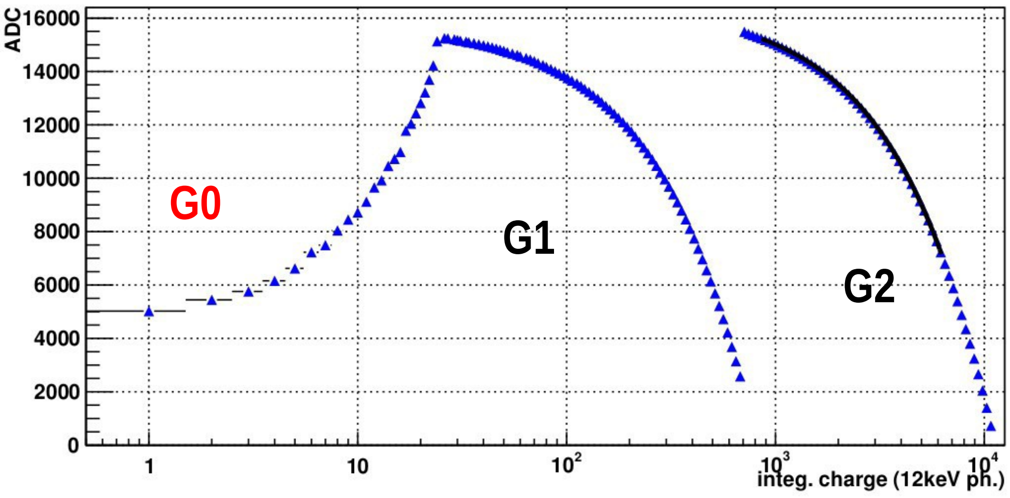
- 500k (one module), 1M (2 modules), 4M and 16M (ESA-ESB main instruments) systems are foreseen
- same geometry as the EIGER systems (gaps,etc..)
- Horizontal gaps VERY small
- compact (20-25cm) in the Z direction
- 16Mpix @ 100Hz will generate ~3GB/s

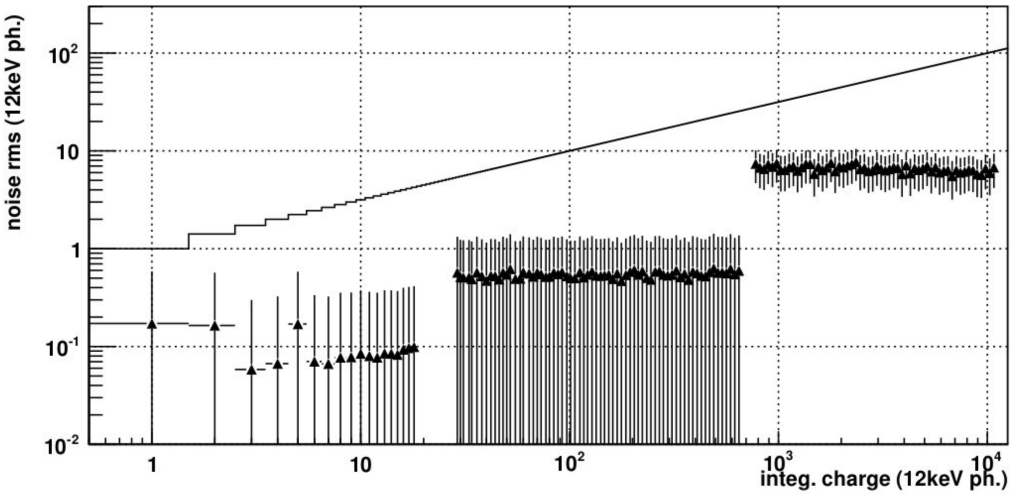


Gain naming convention and gain options

Gain switching is automatic (per pixel) but: two options for the first gain stage:

- **Normal gain G0**
- High gain HG0 for low energies





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- Normal gain **G0**
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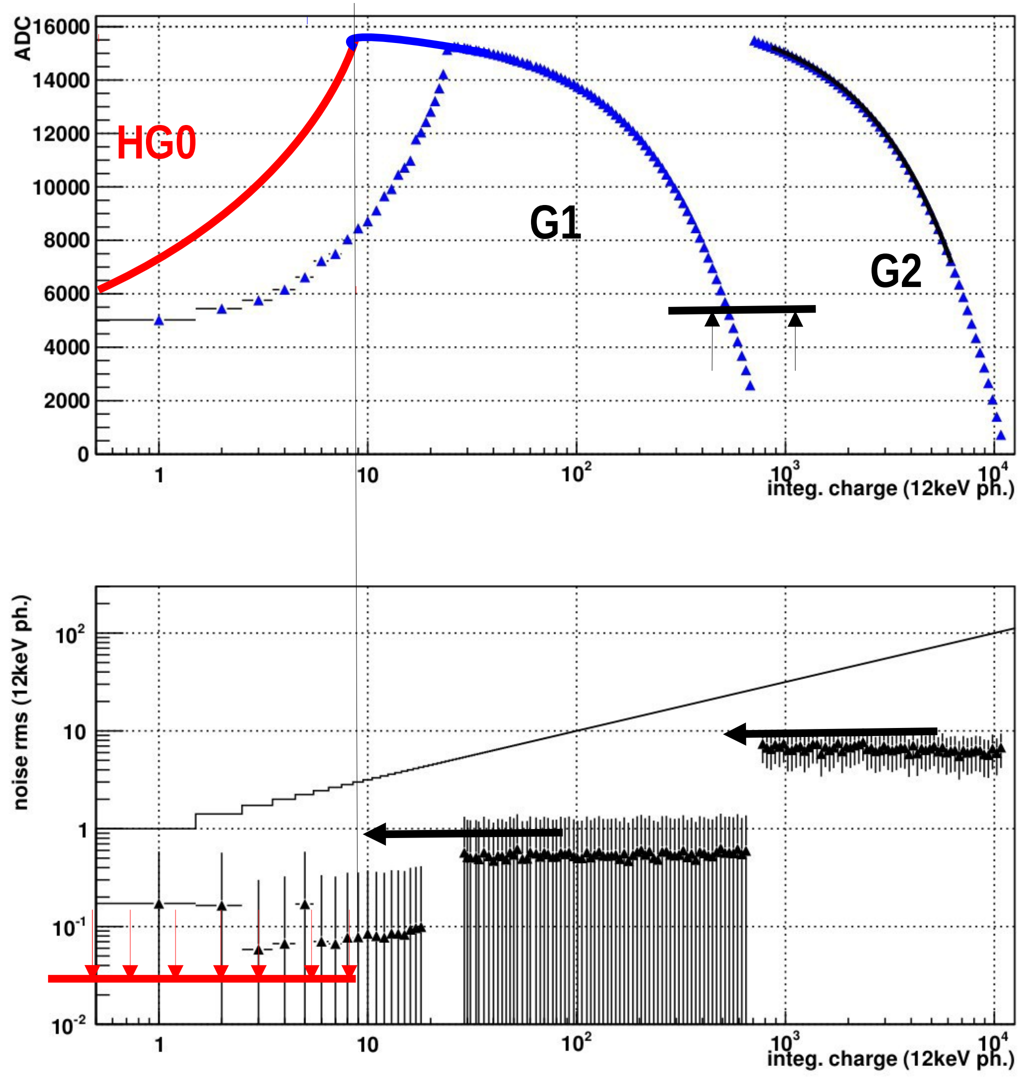
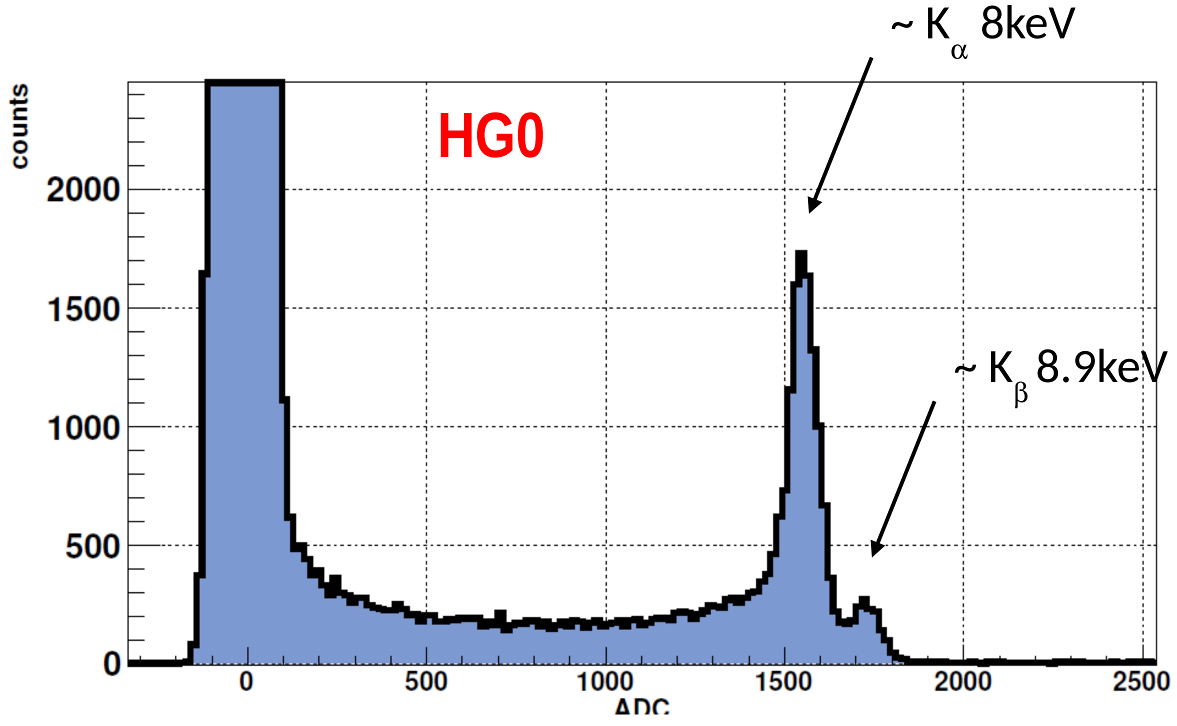
This is a global (module wide) manual selection



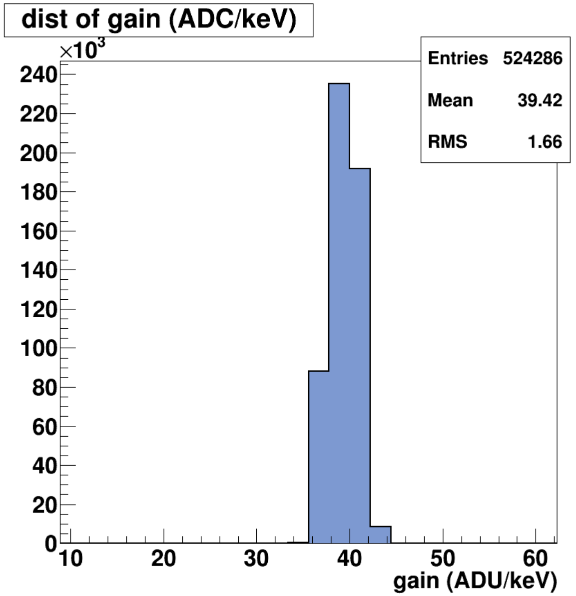
Single photon measurements

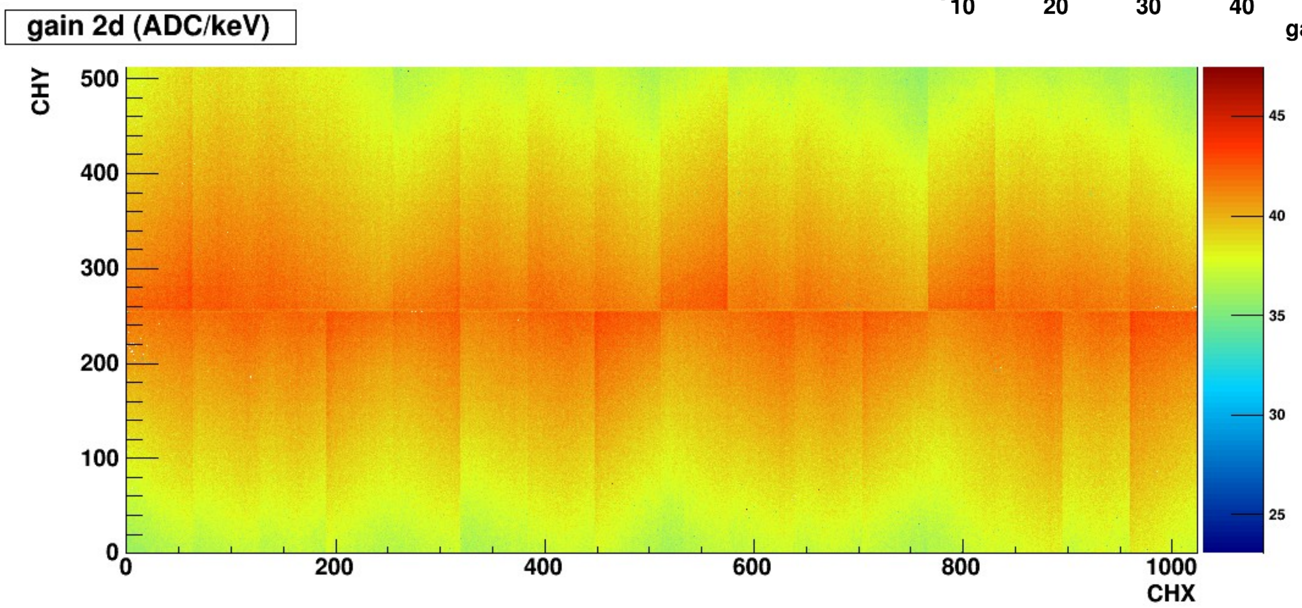
- X-Ray tube, W anode
- Cu Fluorescence target
- 10us integration time
- **HG0**
- HV=200V
- Readout at 500-700Hz
  - limited by prototype firmware
  - 20MHz ASIC readout



Gain map and distribution (G0)

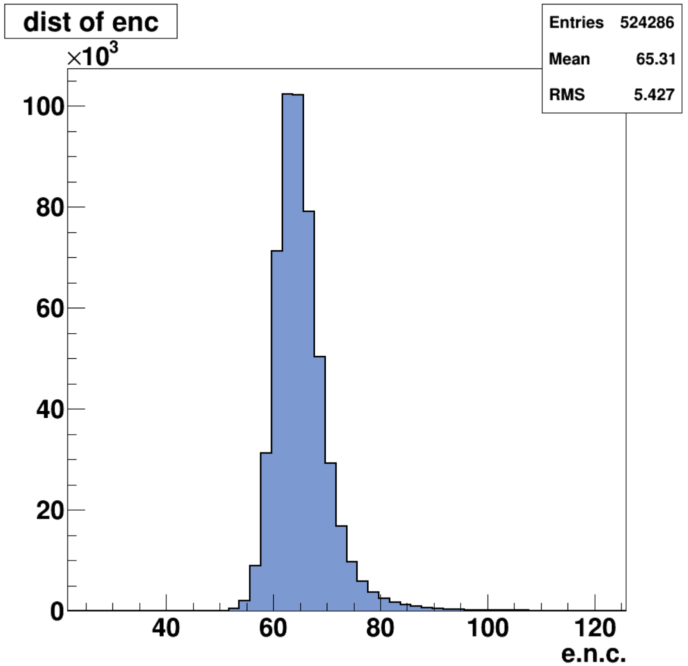
- for every pixel a Gaussian + charge sharing model function is fit to the P.H. data
- Gain is extracted as Gaussian peak position
- gain variation ~3.5% r.m.s.
- gain depends (slightly) on power distibution and on readout (ADC+buffers mismatch)

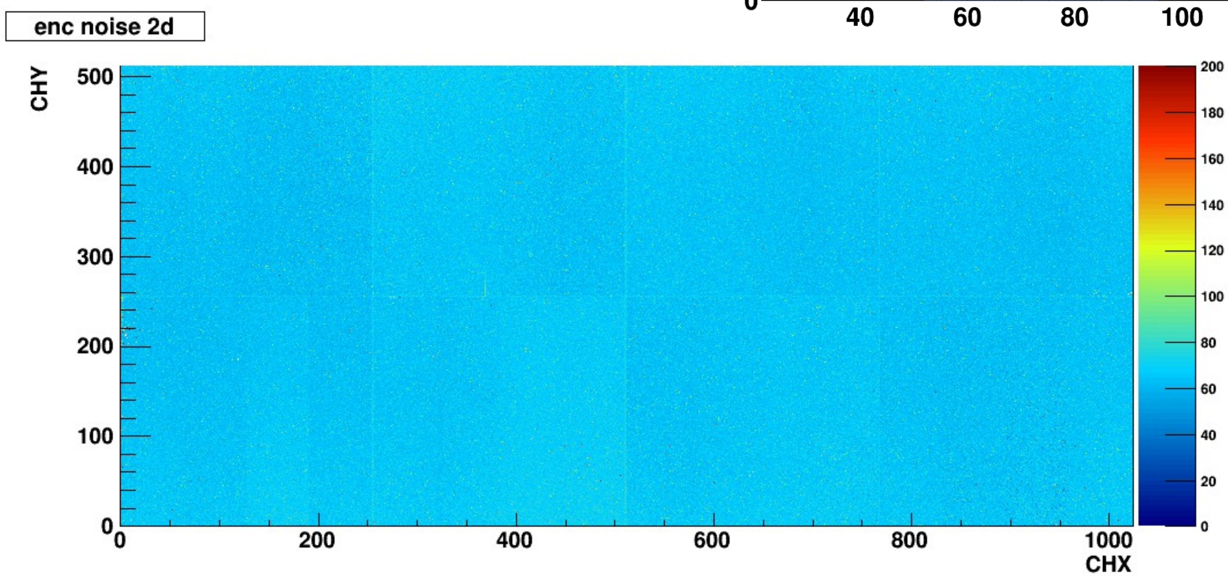




Noise map and distribution (G0)

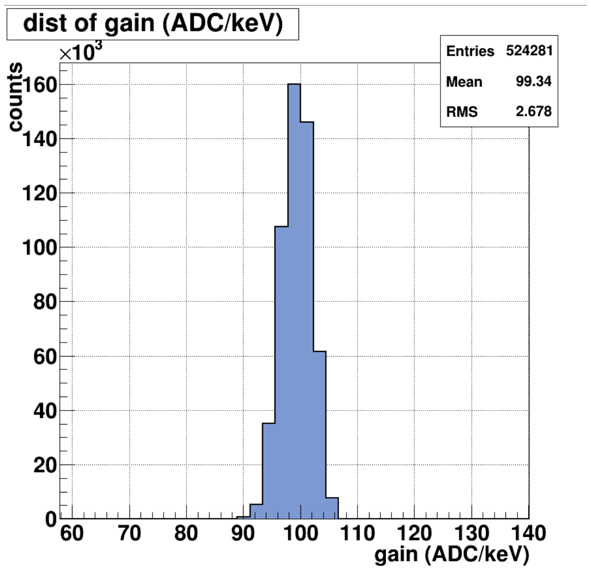
- Average noise of 65 electrons r.m.s.
- Noise map quite uniform
- Some tails in the noise distribution:
  - 1% pixels above 85e-
  - 0.1% pixels above 100e-

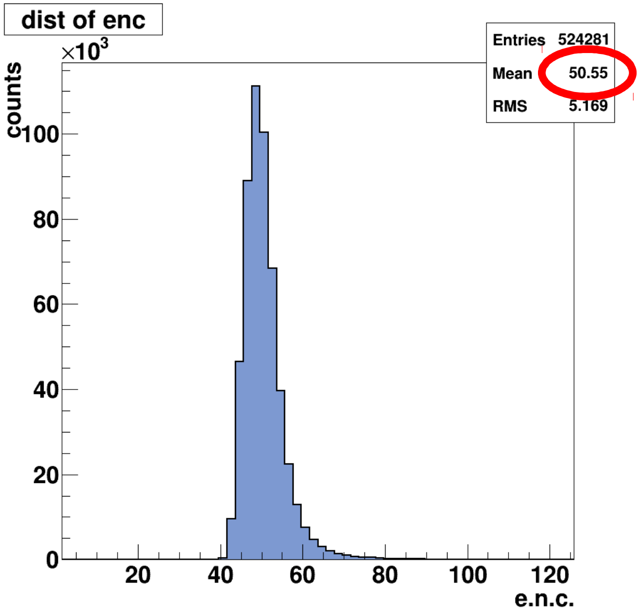


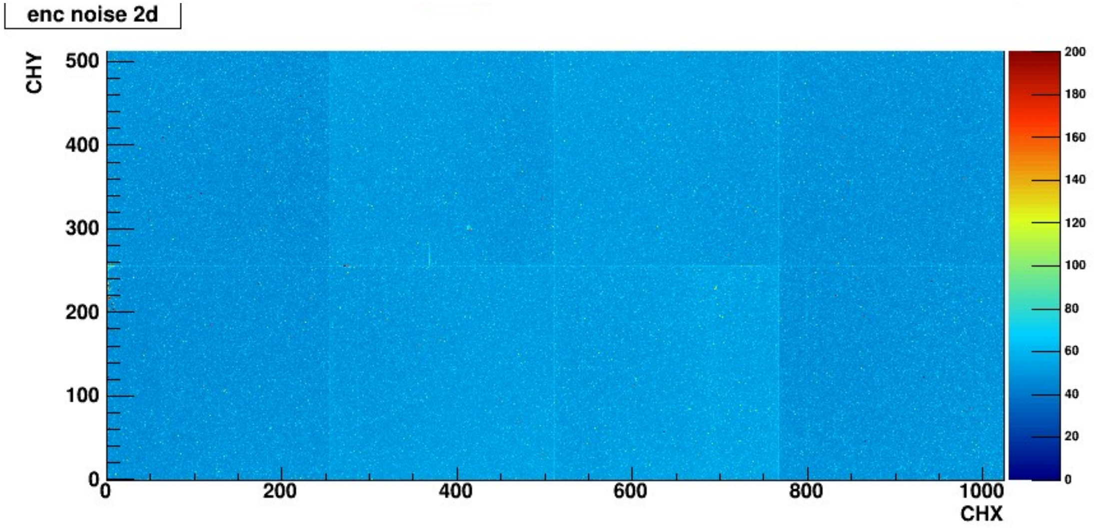


Noise map and distribution (HG0)

- In HG0 the gain is ~2x WRT G0
- Gain uniformity 2.7%
- Noise is 30% less
- Noise map uniform
- MPV < 50 e.n.c.
- Single photon resolution at 1.5keV demonstrated



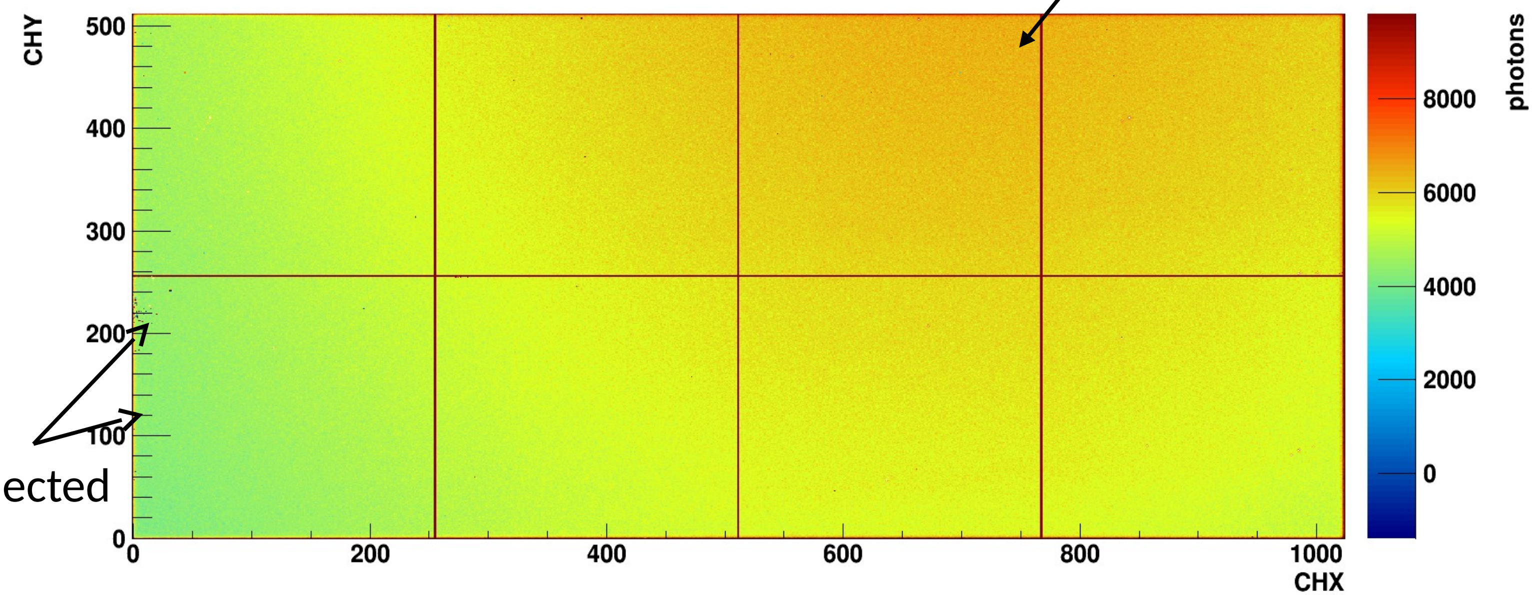




Flood image (G0)

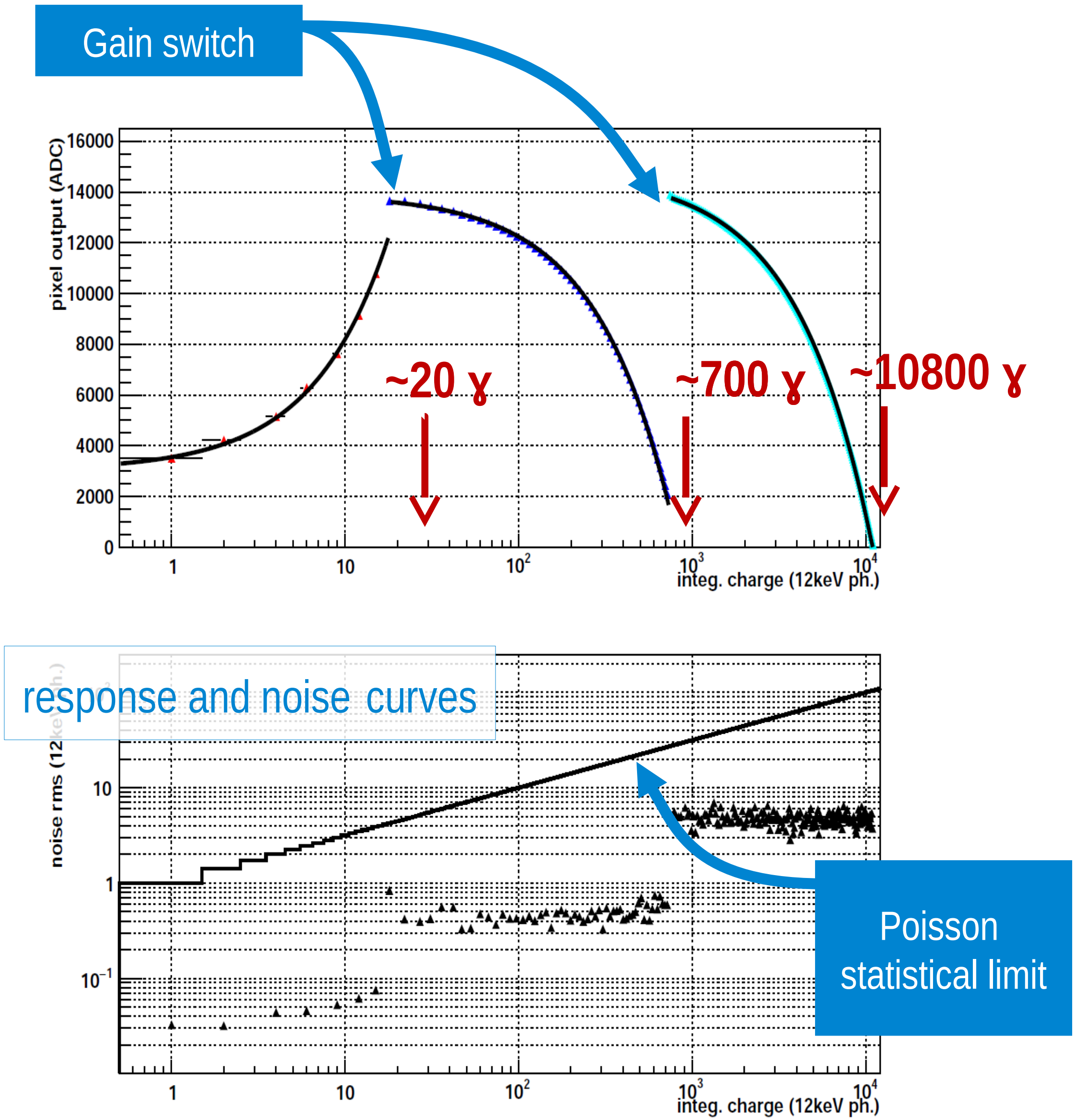
- In single photon mode (over 100kFrames)
- FF with flourescence sample
- Offline photon counting with per pixel threshold (gain correction)
- Compatible with photon statistics
- >99.99 bump yield - can still be improved

~ center of the fluo. sample



unconnected pixels

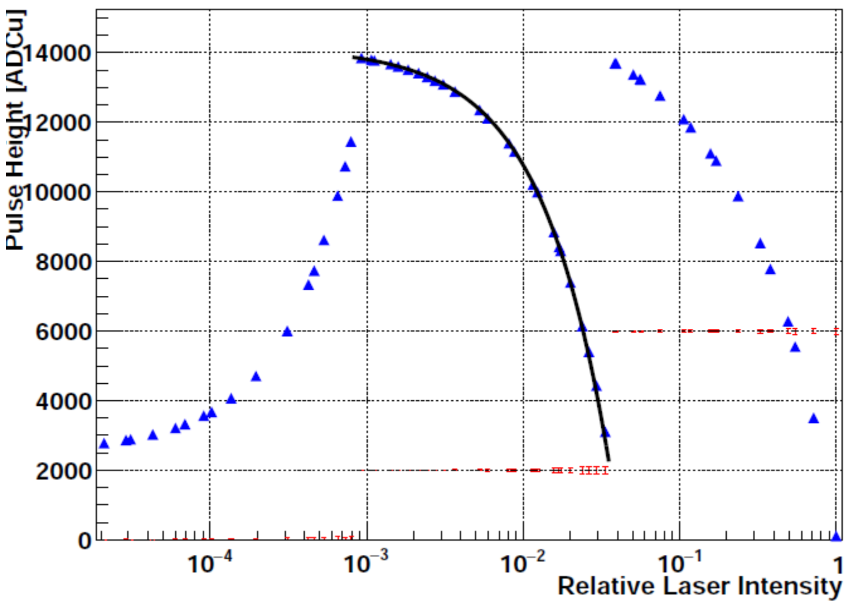
Noise across dynamic range

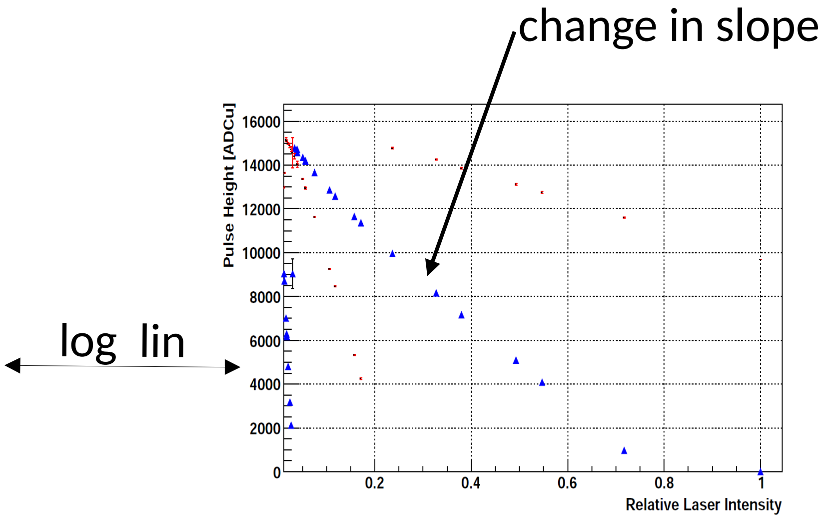


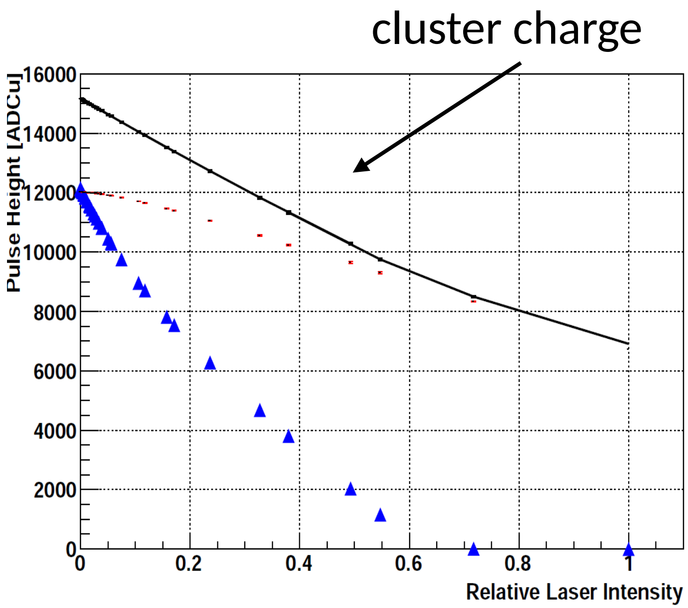
Automatic gain switching scan:

- White visible light illumination
- Requires etching of Al entrance window
- Increasing integration time
- plots in unit of 12keV photons
- charge injection is continuous and not pulsed

Laser dynamic range scan





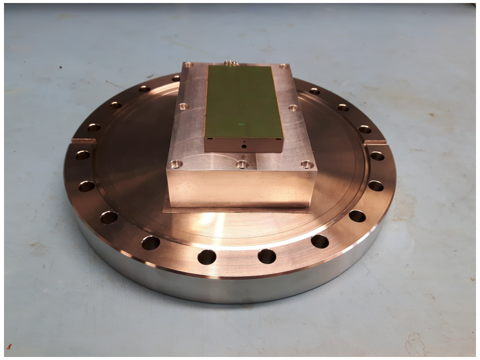


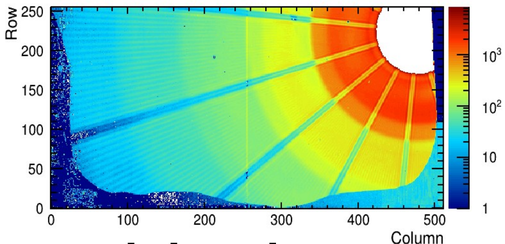
- A single µm-focused laser pulse
- Intensity modulated via ND filters
- At high intensity (>5000 12keV) central pixel deviates from linearity
- is a sensor effect, charge cloud gets bigger
- cluster charge is linear (until central pixel saturates)
- Sensor bias 200V

Gain switching at work

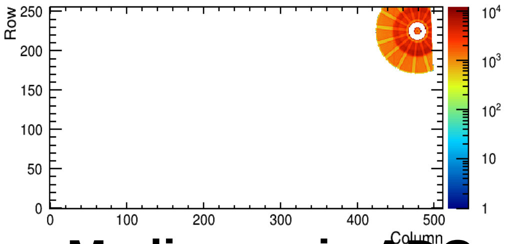
Image of Fresnel Zone Plate diffraction orders at XIL beamline, SLS:

- extreme ultraviolet 92 eV photons
- vacuum 10^{-7} mbar
- etched sensor (no Al), module mounted to flange

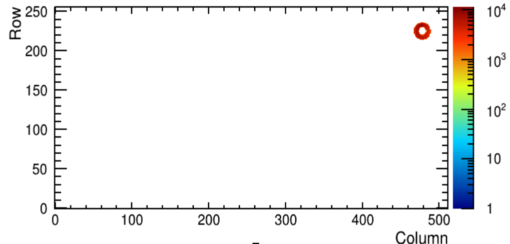




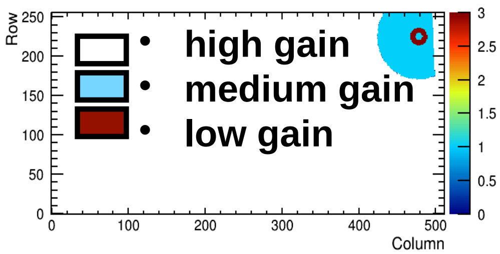
- High gain ADC



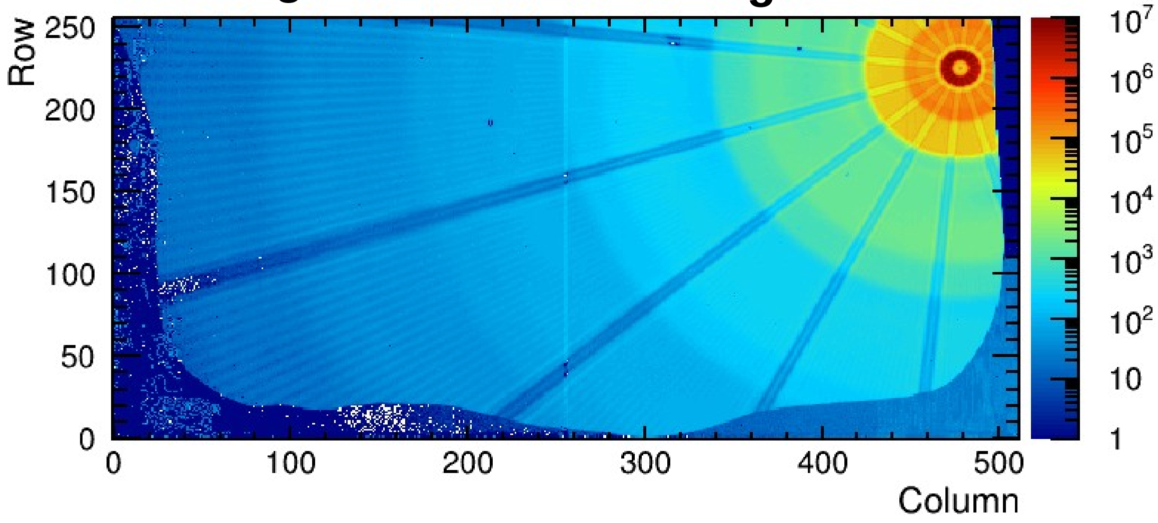
- Medium gain ADC



- Low gain ADC



- Gain

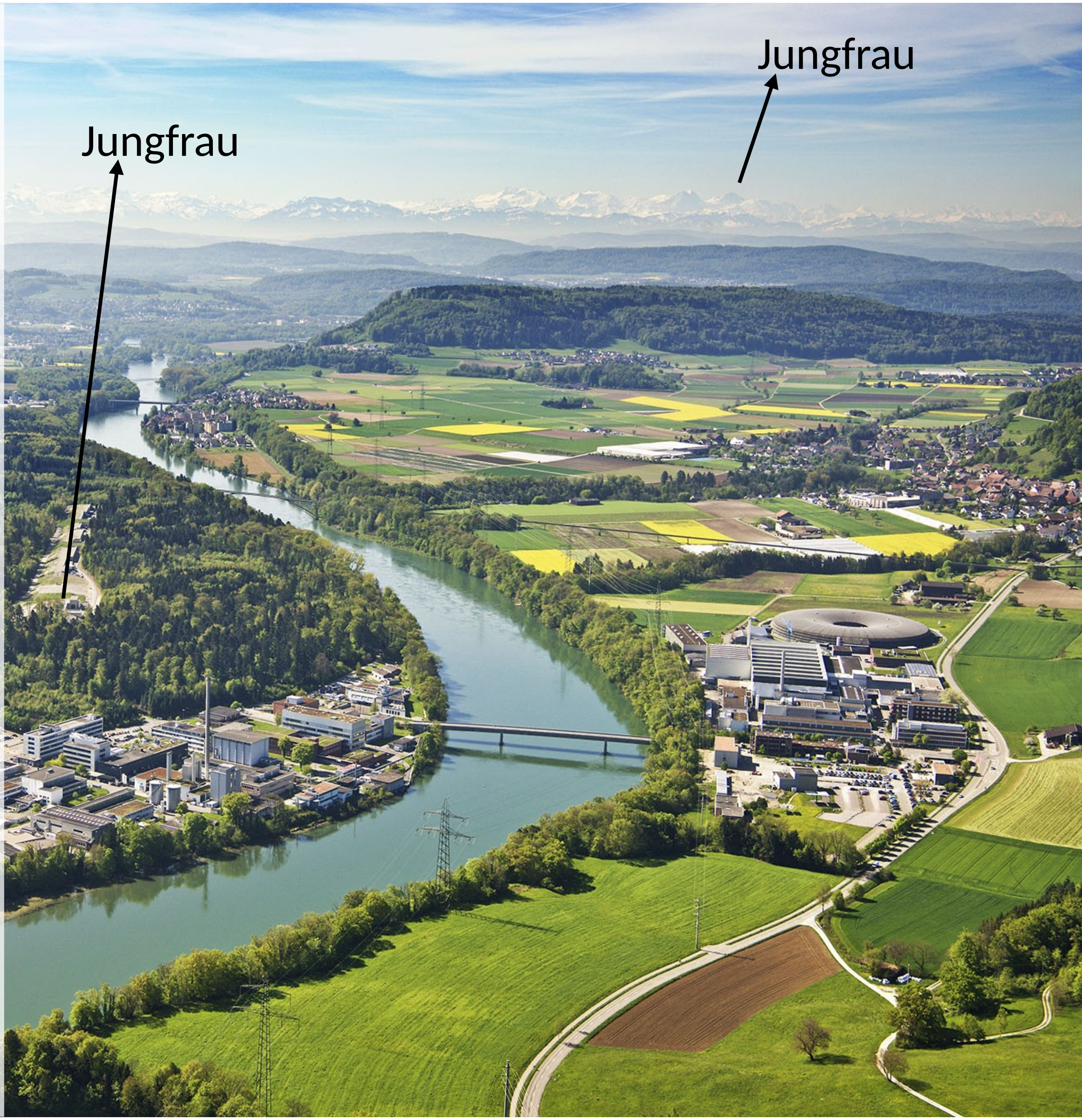


Specification summary

ASIC technology	UMC110nm
mudule pixel count	525k
mudule size	80x40 mm^2
sensor thickness	320 μm
pixel size	75x75 mm^2
dynamic range	up to 10^4 12keV photons
noise r.m.s.	~50 e.n.c.
min. energy	<1.5 keV
linearity	better than 1%
point spread function	1 pixel
dead time	~200ns
ext. power consumption	30 W /module
cooling	liquid (water 20 ^oC)
readout time = 1/frame rate	2.4kHz with 10GbE
rate capability @ syncrotron (with 10GbE)	10^4 x 2.4 10^3 = $2.4 x 10^7$ photons/ch/s

Conclusions

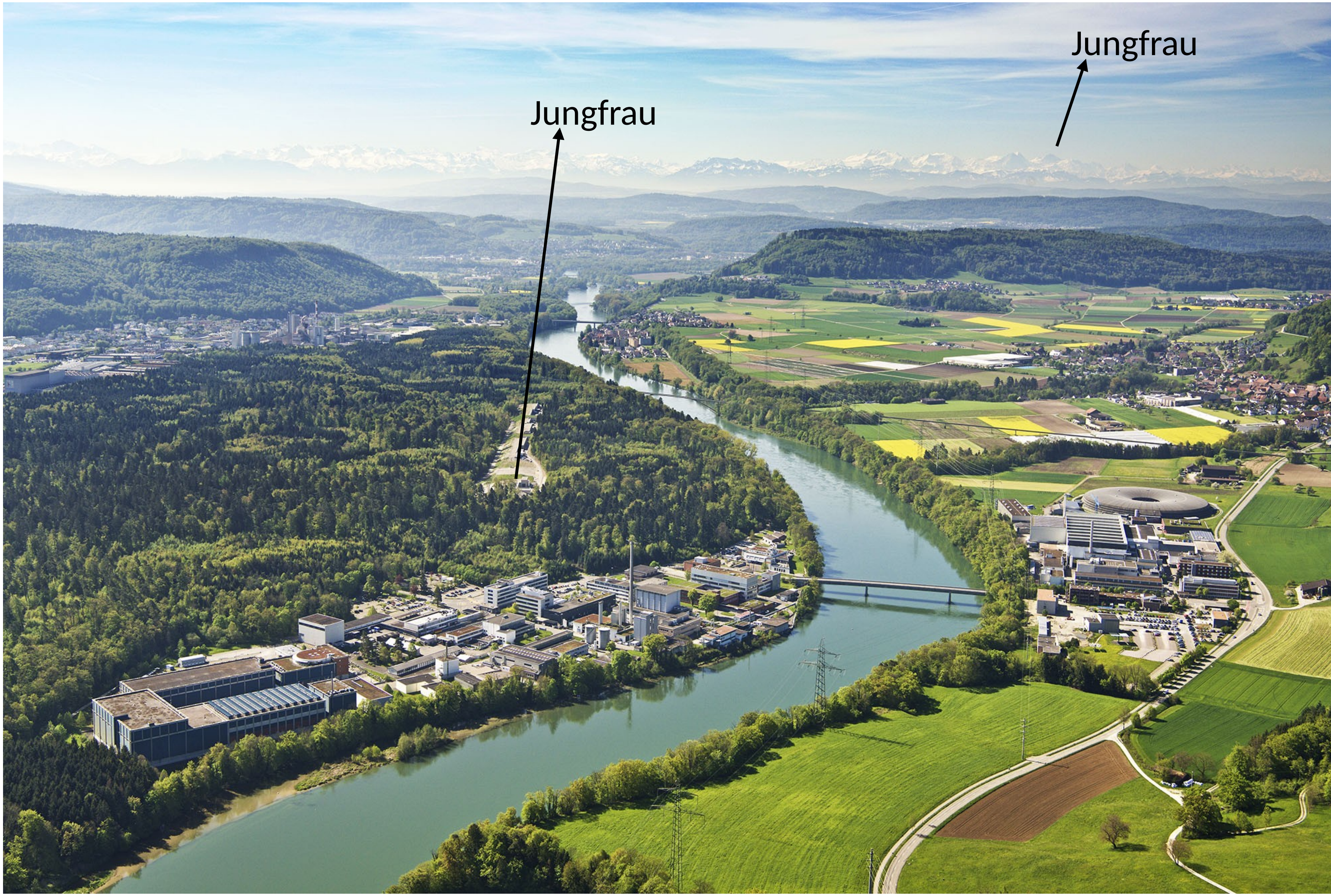
- 75um pixel detector for pulsed X-ray sources, with automatic gain switching
- Tilable design, 500k 8x4 cm^2 modules
- noise in high gain 50e.n.c.
- low noise on the full DR
- We are gaining experience on real world gain switching datasets
- Jungfrau module production is ongoing, ready for swissFEL operation Q4.17



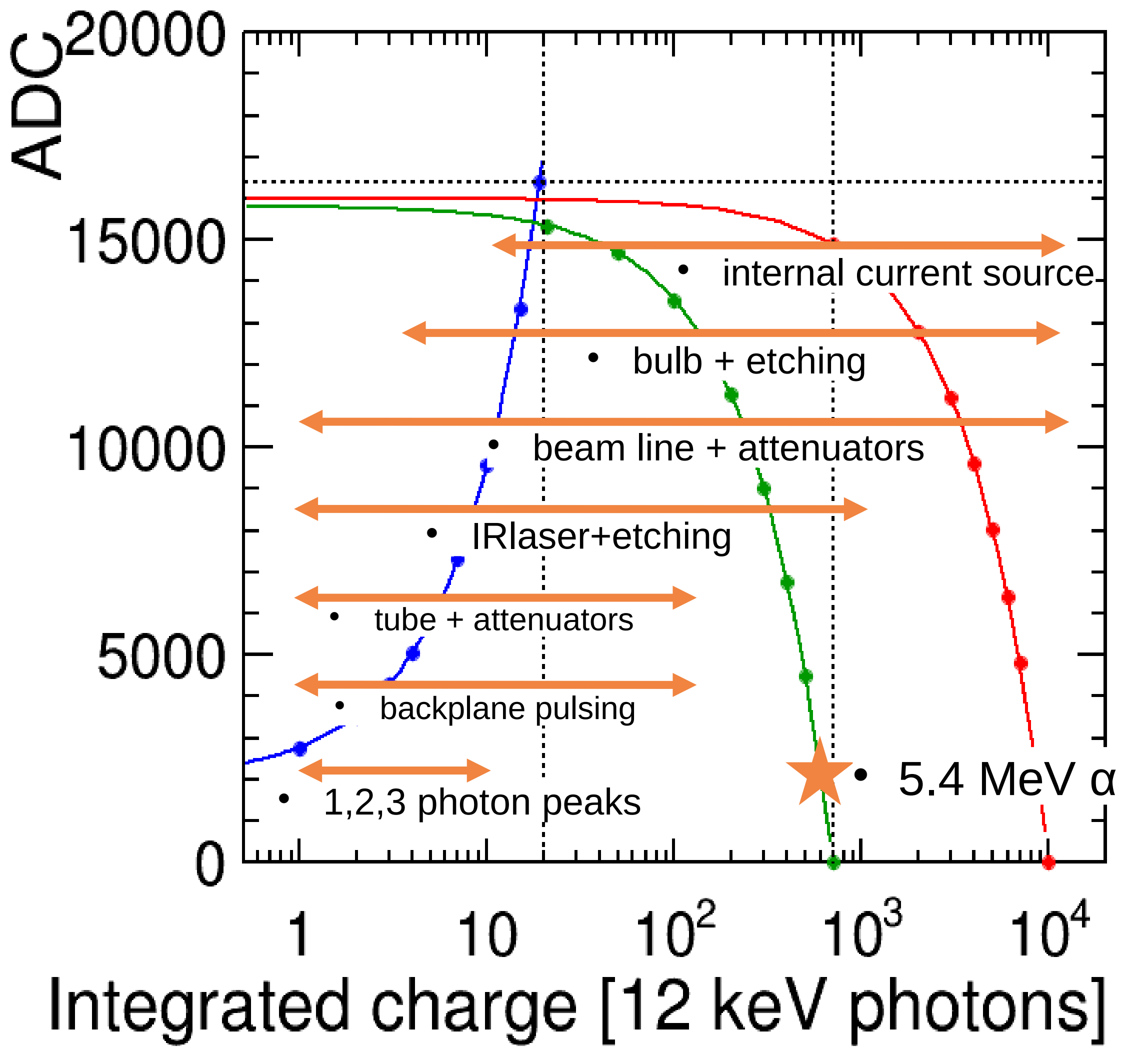
Acknowledgements

Back: Sebastian Cartier, Davit Mayilyan, Sophie Redford, Dominic Greiffenberg, Erik Fröjdh, Martin Brückner, Christian Ruder, Lukas Schädler
Middle: Bernd Schmitt, Dhanya Thattil, Marco Ramilli, Roberto Dinapoli, Davide Mezza, Xintian Shi, Jiaguo Zhang
Front: Aldo Mozzanica, Anna Bergamaschi, Gemma Tinti

Backup Slides



Why? Uniformity, and user
want 'number of photons'
How to calibrate three gai
stages, covering four order
magnitude in energy?
Use a multitude of photon
charge sources
No single best solution
These four discussed here,
more ideas in the backup..



FEL pixel det. comparison

Detector system	Pixel size [µm×µm]	Electronic noise [e-]	Single photon sensitivity	Dynamic range:Photons per pulse per pixel	Repetition rate [kHz]
CSPAD	110×110	~330	Yes†	>$2.5\cdot10^3$ (@ 8 keV)††	0.12
epix100	50x50	<60	Yes	100 (@ 8 keV)	~1
epix100k	100x100	~120	yes	10000 (@ 8 keV)	~1
AGIPD	200×200	~265	Yes†	>10^4 (@ 12 keV)	4500 burst
LPD	500×500	~1000	No	10^5	4500 burst
DSSC	Pitch 200‡	<50	Yes	>$6\cdot10^3$ (@ 1 keV)	1000 burst
SOPHIAS	30×30	~150	Yes	TBD	0.06
JUNGFRAU	75×75	~65 G0 or 50 HG0	Yes	>10^4 (@ 12 keV)	~2.4

‡hexagonal pixels
† at >5keV, for CSPAD in high gain
††in low gain
MPCCD and Parceval not in the table