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PSI

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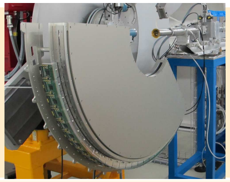
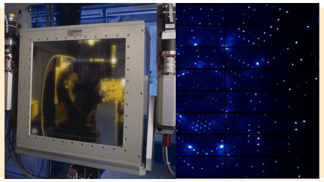
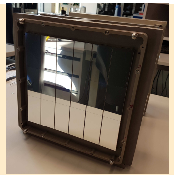
Microstrip detectors with GaAs sensors

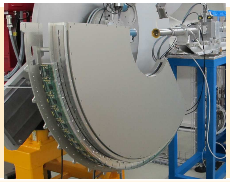
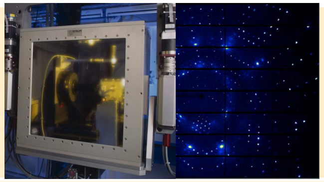
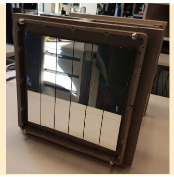
19th International Workshop on Radiation Imaging Detectors
04.07.2017 – Krakow, Poland

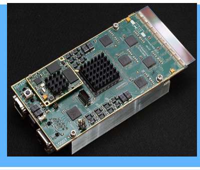
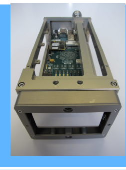
Detectors at PSI: Single Photon Counters

	MYTHEN	PILATUS[1]	EIGER[1]
	 		
Pixel size	**50 µm (Strips)**	172 x 172 μm^2	**75 x 75 μm^2**
Maximum system size	**120º (=48 modules)**	**6M (=42 x 43 cm^2)**	**9M (=23 x 23 cm^2)**
Count rate capability	0.6 MHz/Strip (10% deviation, Standard)	0.5-1.0 MHz/Pixel (10% deviation)	0.2-0.7 MHz/Pixel (10% deviation)
Maximum frame rate	**1 kHz/Module**	300 Hz/Module	**23 kHz (4-bit)**
Applications **(Examples)**	•Powder Diffraction •Energy dispersive Spectrometer •Beam Position Monitors	•Protein Crystallography •Time-resolved experiments •Small and wide-angle X-Ray Scattering (SAXS/WAXS)	•Protein Crystallography • XPCS • Coherent X-Ray Imaging • Photoelectron detection

1)EIGER & PILATUS Detector systems are also commercially available from DECTRIS

Detectors at PSI: Single Photon Counters... And charge integrators

	MYTHEN	PILATUS[1]	EIGER[1]
	 		

	GOTTHARD	AGIPD[1]	JUNGFRAU	MÖNCH
				
Pixel size	50 µm (Strips)	200 x 200 µm^2	**75 x 75 µm^2**	**25 x 25 µm^2**
Noise (r.m.s.)	<300 e$^-$ ENC	<322 e$^-$ ENC <214 e$^-$ ENC (HG)	**<100 e$^-$ ENC <55 e$^-$ ENC (HG)**	**35 e$^-$ ENC**
Dynamic range	**<1·10^4 x 12.4 keV (3 gain stages)**	**<1·10^4 x 12.4 keV (3 gain stages)**	**<1·10^4 x 12.4 keV (3 gain stages)**	<500 x 12.4 keV (2 gain stages)
Maximum frame rate	40 kHz (cont.) 1 MHz (burst)	**< 5 MHz (burst/352 frames)**	**2.4 kHz (continuous)**	**6-8 kHz (continuous)**

For more details: Moench talk Monday 11:20, M. Ramilli, Gotthard poster B07, J. Zhang (Monday), Mythen3 poster B12, M. Andrae (Monday), Jungfrau poster A20, S. Redford (Wednesday), Jungfrau talk Wednesday 10:00, A. Mozzanica

Detectors with High-Z sensors: Context

Detectors originally developed for silicon sensors

In the context of:

- State of the art beamlines wanting to operate at higher X-ray energies, ex. X-ray diffraction for Material science at 40 keV

- Synchrotron facilities upgrades with higher brilliance and higher energies available

→ Evaluate the performance of existing detector readout chips with high-Z sensors

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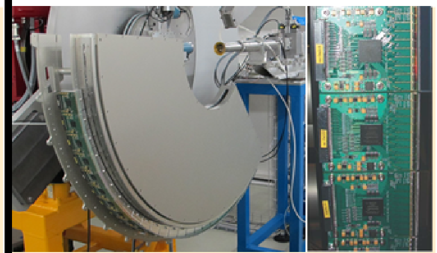
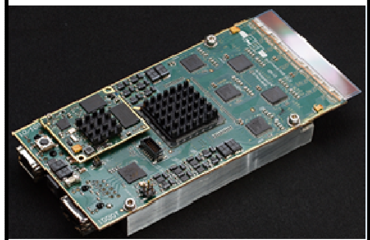
Strip detectors with GaAs sensors

MYTHEN	GOTTHARD
	
UMC 250 nm	IBM 130 nm
Commercially available	Modules available
50 µm (Strips)	50 µm (Strips)
120º (=48 modules)	Modules (=10 ASICs)
< 5 keV	<200 e^- ENC
0.6 MHz/Strip (10% deviation, Standard)	**<1·10^4 x 12.4 keV (3 gain stages)**
1 kHz/Module	40 kHz (cont.) 1 MHz (burst)
•Powder Diffraction •Energy dispersive Spectrometer •Beam Position Monitors	

+

GaAs sensors:

LEC GaAs wafer, Chromium compensated

Ohmic contacts

Thickness: 500 µm, Absorption efficiency: **50% @ 50 keV**

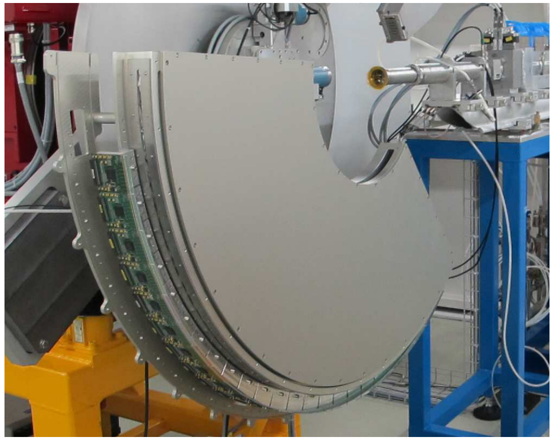
100 µm & 50 µm strips with guard ring

Direct wirebonding on sensor possible

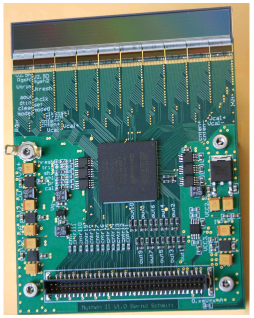
MYTHEN: Microstrip sYstem for Time rEsolved experimeNts

- **Single photon counting microstrip**
  - Standard geometry for silicon sensors: 50 µm pitch, 8 mm long
  - Single modules 1280 channels, 6.4 cm available for different geometries

- **Frame rate up to 20 Hz - 1 kHz**
  - Depending on dynamic and angular range
  - Burst mode up to 10 kHz, 32 frames



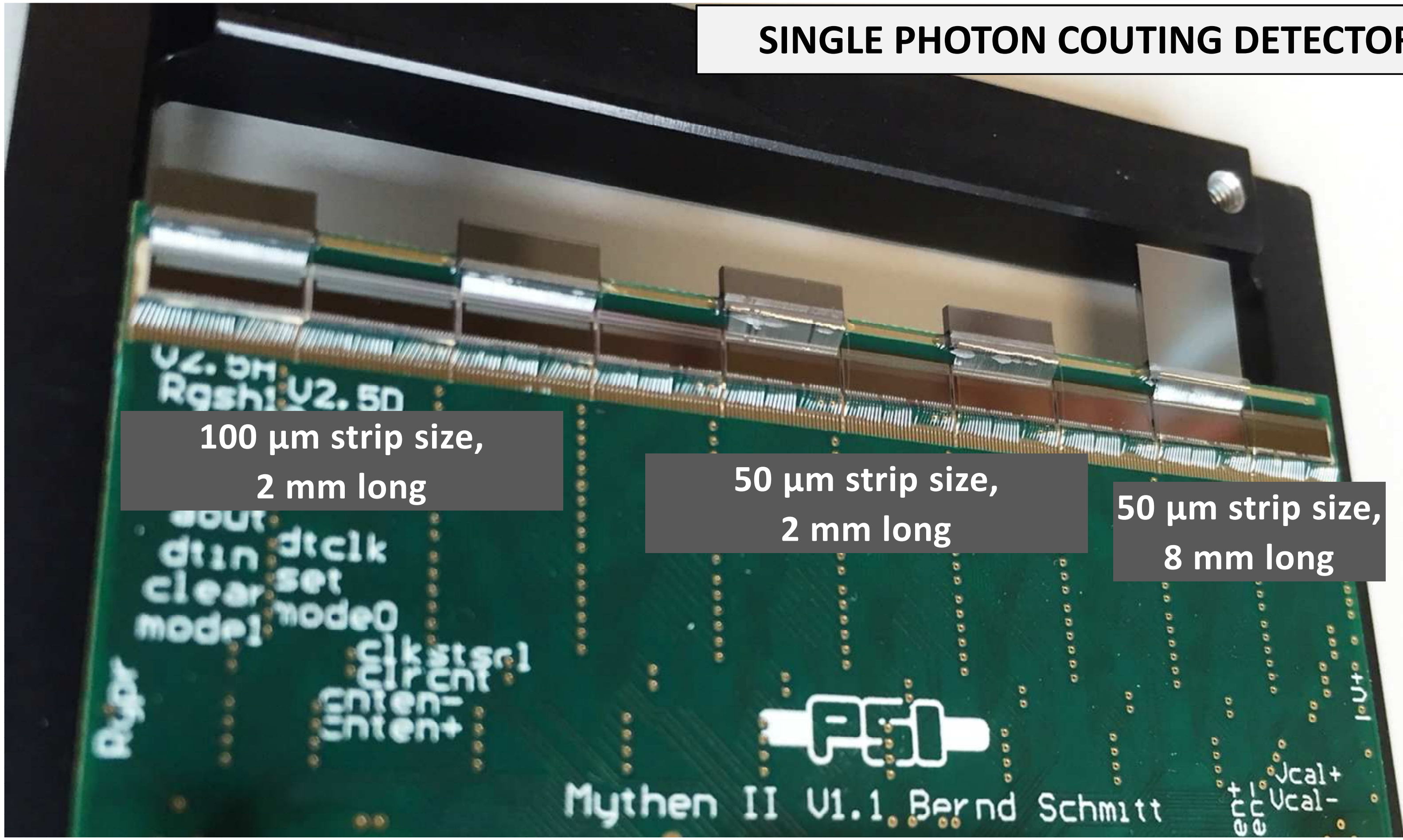
- **Users operation at the SLS since 2007**
  - In-situ measurements
  - Pump-probe experiments
  - Monitoring of radiation damage
  - Systems available also at the
    Australian synchrotron, Diamond (UK),
    Alba (Spain), Spring8 (Japan), ESRF (France),
    DESY (Germany), APS (USA)…
  - Commercialized by DECTRIS



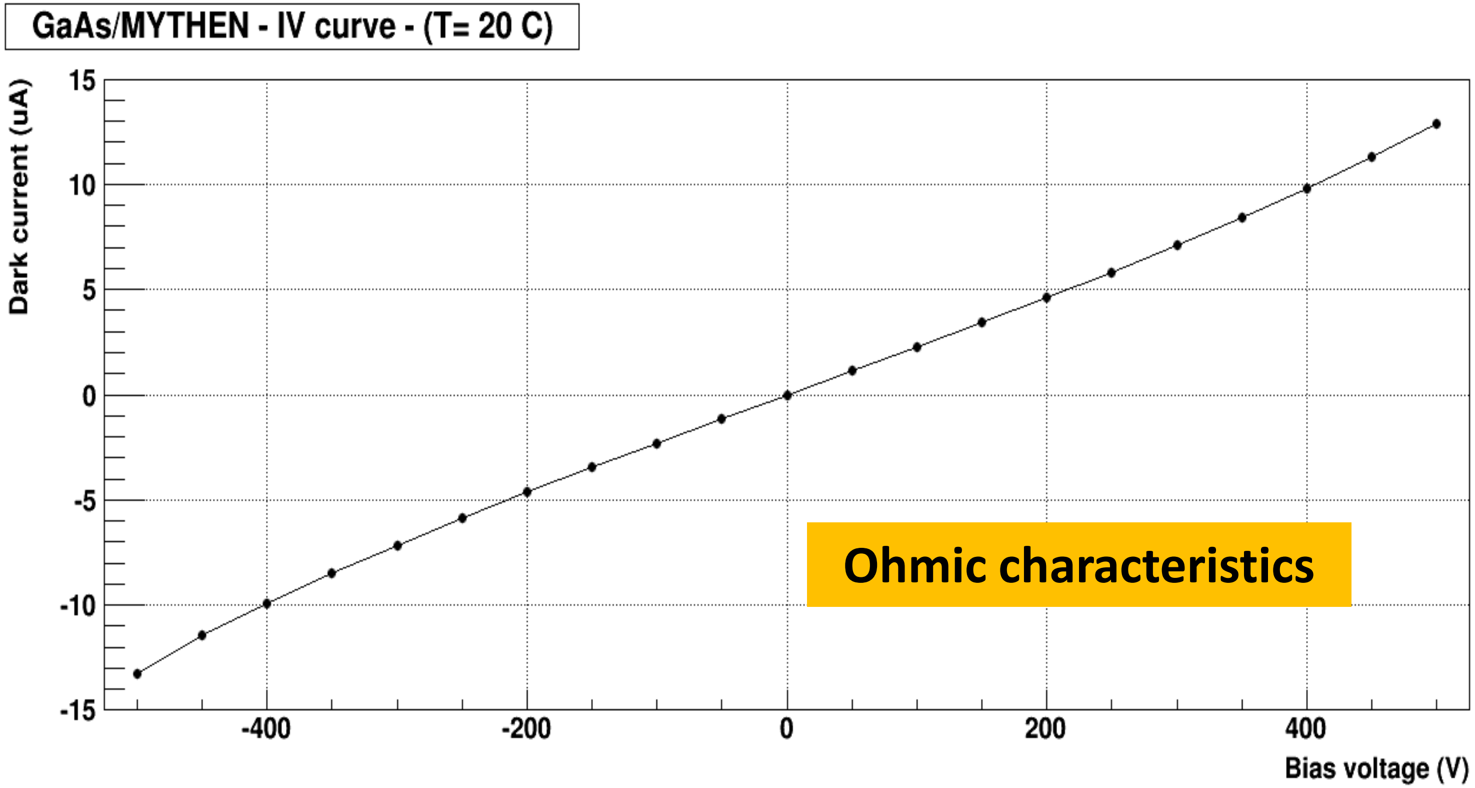
- **Diffraction, von Hamos spectrometers, beam monitoring…**

A. Bergamaschi al., J. Synchrotron Rad. **17**, 653-668 (2010): http://dx.doi.org/10.1107/S0909049510026051

MYTHEN with GaAs sensor



MYTHEN with GaAs sensor: Leakage current

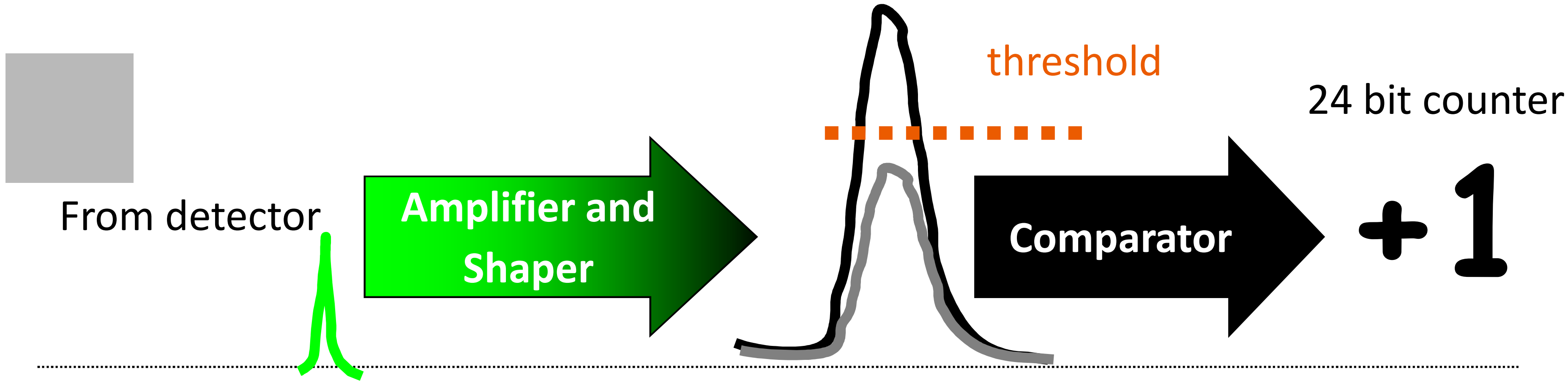


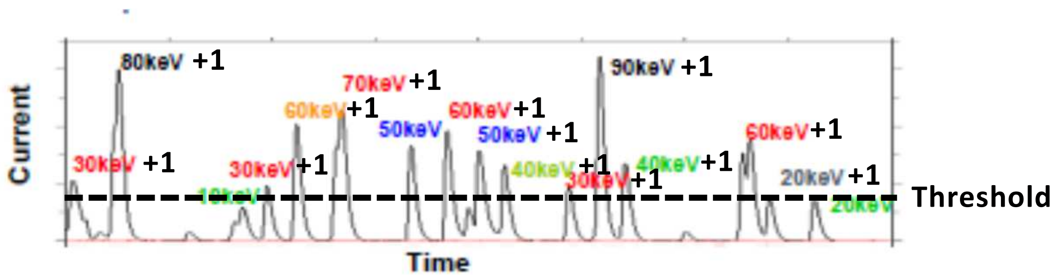
Dark current @ -300 V:

- ~ 40 nA / strip (50 µm / 8 mm long)
- ~ 10 nA / strip (50 µm / 2 mm long)
- ~ 20 nA / strip (100 µm / 2 mm long)

= 100 nA / mm2

Single Photon counting readout





Adds 1 count independently of the photon energy provided it's above threshold

- The threshold is used to suppress
  – the electronic noise
  – the fluorescence background
- High dynamic range
  – Essentially noiseless
  – No saturation
    – Counter depth

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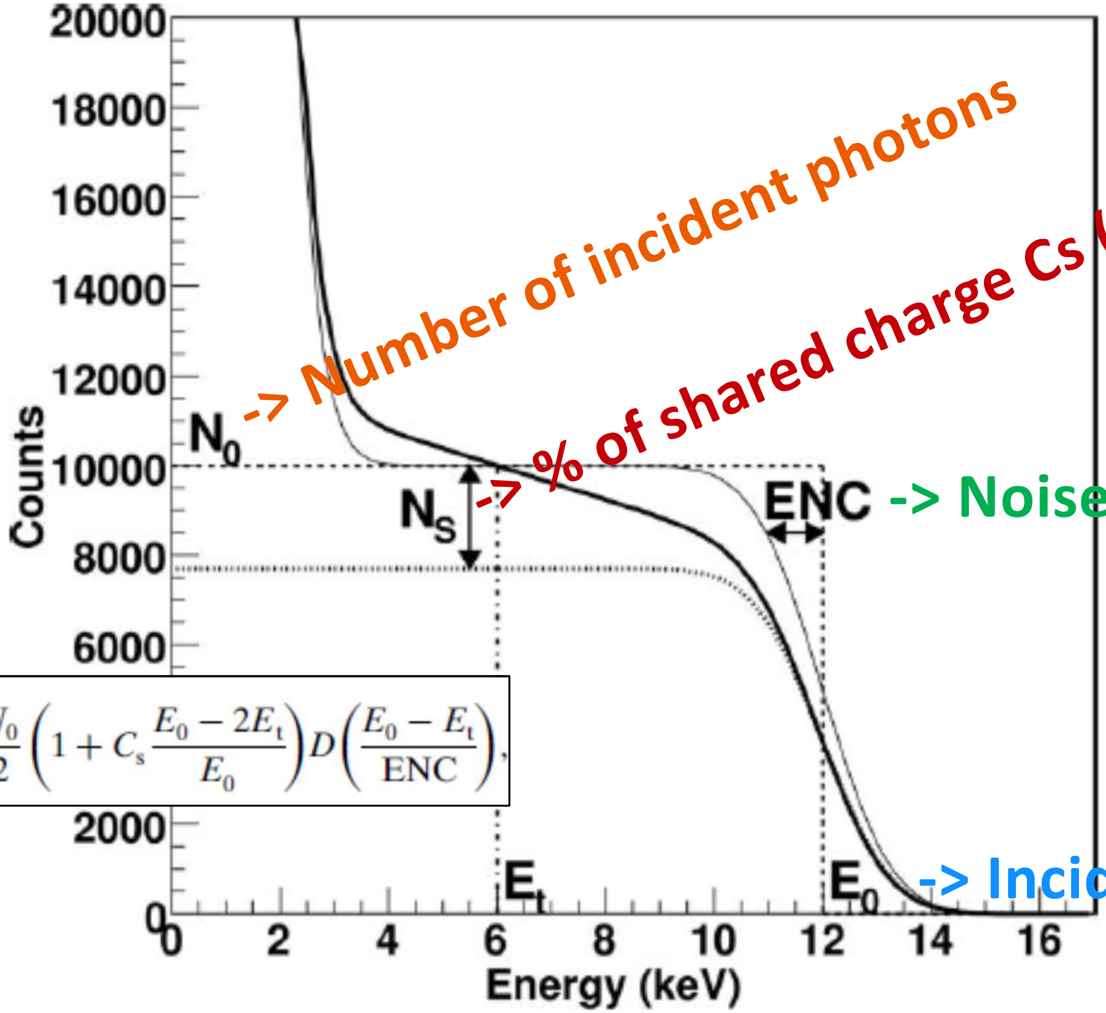
Detector calibration and characterization:

MYTHEN, PHOTON-COUNTING

Expected counts (Energy) for monochromatic beam at 12 keV

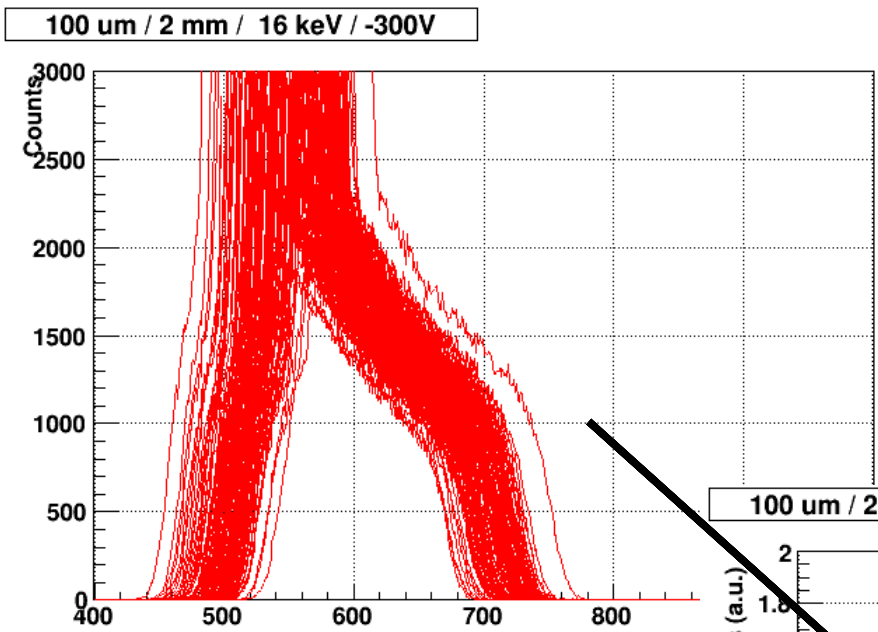


$$N_\gamma(E_t) = \frac{N_0}{2}\left(1 + C_s \frac{E_0 - 2E_t}{E_0}\right) D\left(\frac{E_0 - E_t}{\mathrm{ENC}}\right),$$

A. Bergamaschi al., J. Synchrotron Rad. **17**, 653-668 (2010): http://dx.doi.org/10.1107/S0909049510026051

MYTHEN with GaAs sensor: Energy calibration

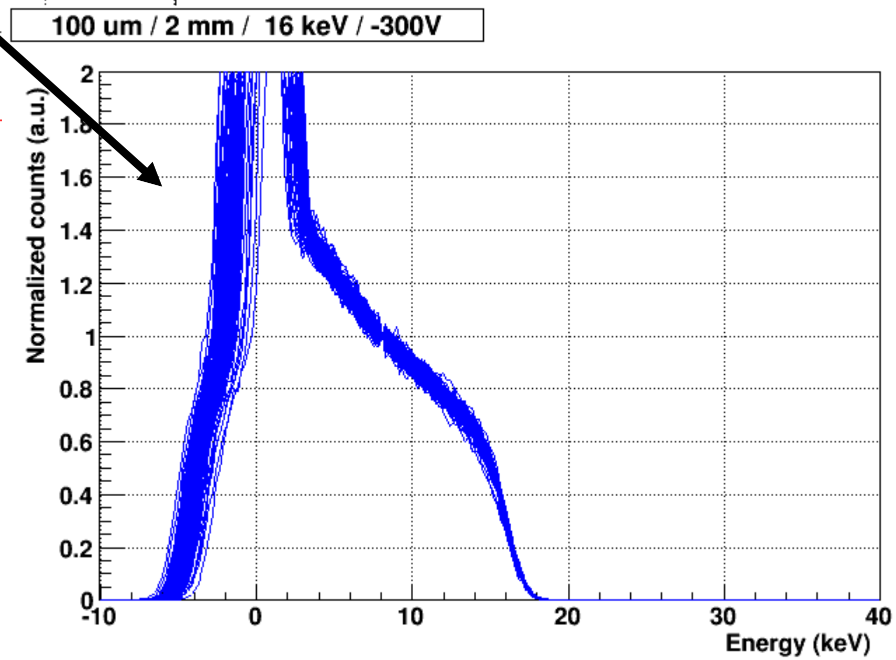
MYTHEN, PHOTON-COUNTING



<u>Trimming or Calibrating</u>

Adjusting the voltage threshold on a channel-by-channel basis &

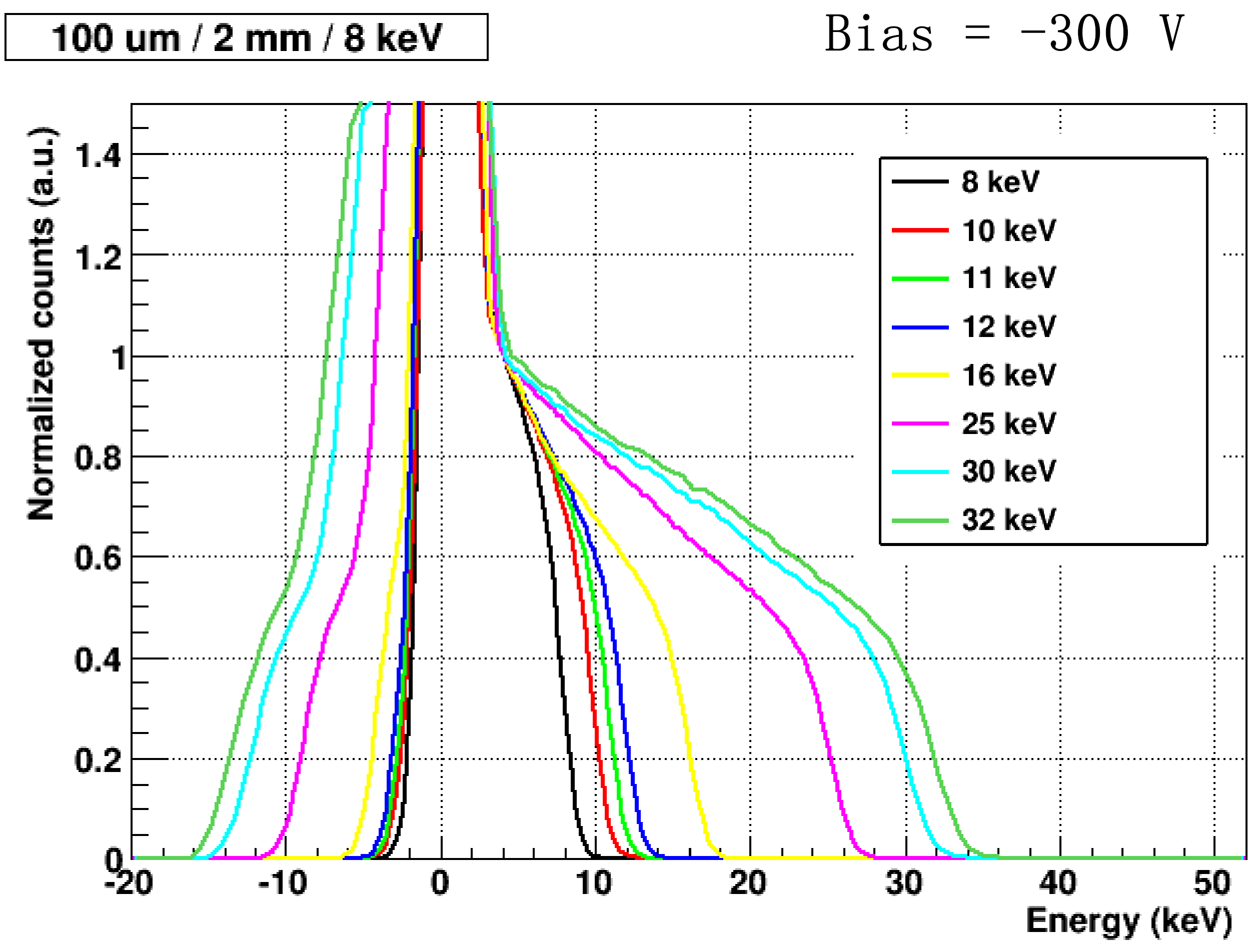
Determine individual channel gains



- **After X-ray calibration**
- **And removal of:**
  - **5 to 20 % of outliers for the 50 um strips**
  - **No 100 µm strips**

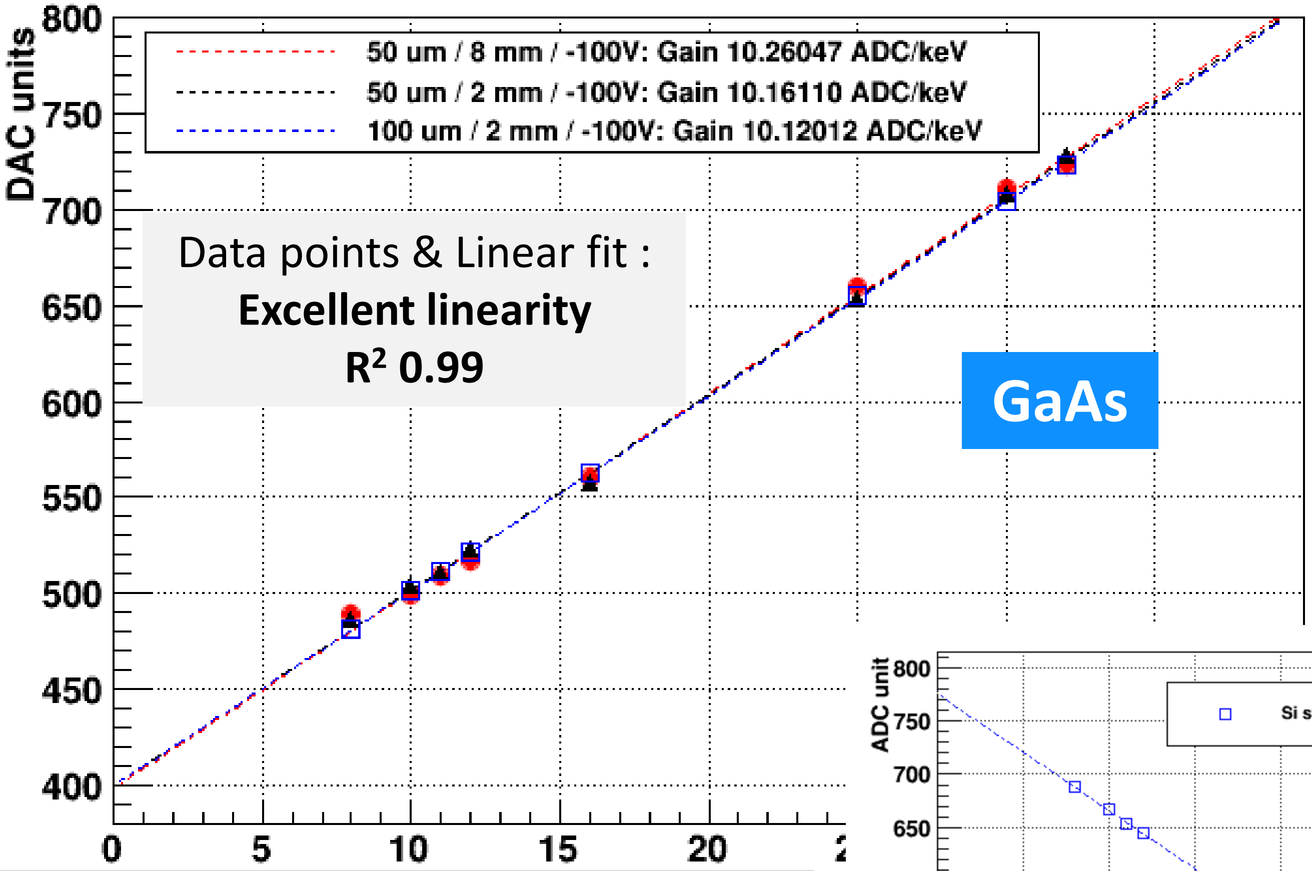
MYTHEN with GaAs sensor: Energy calibration

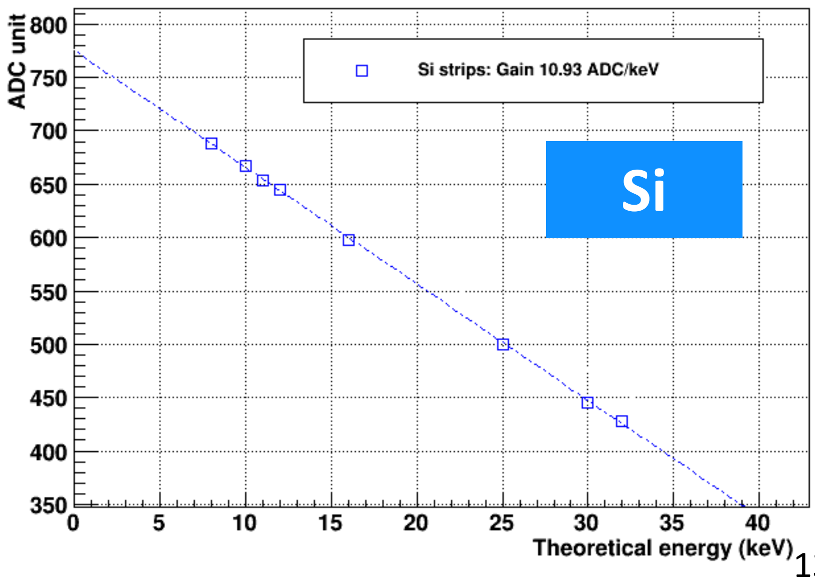
MYTHEN, PHOTON-COUNTING



- **Noise floor ~ 4 keV**
- **Nice inflection points for photon energies >12 keV**
- Extract the linearity

MYTHEN with GaAs sensor: Energy calibration





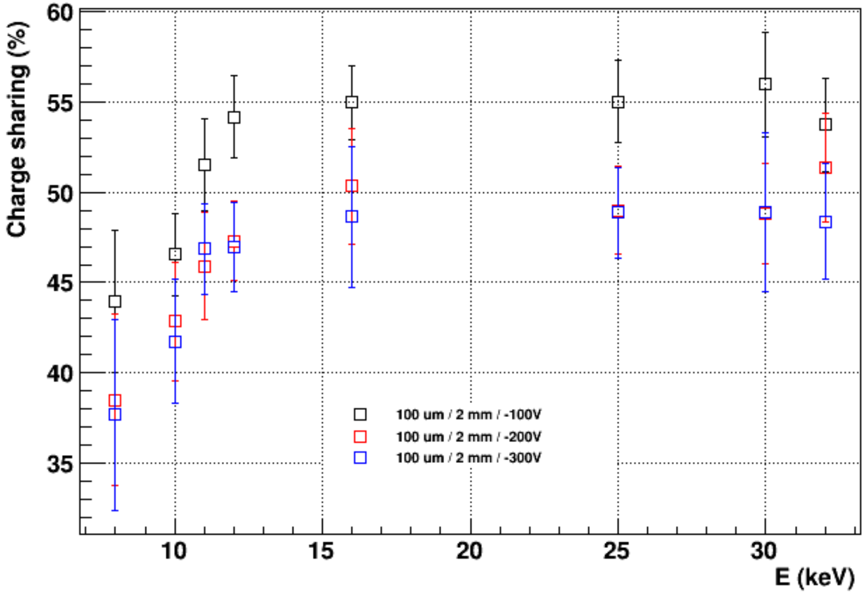
- **Similar gains for different strip pitch / length**
- **Comparison with Si:**
  - Gain GaAs / Gain Si = 94%
  - Pair creation energy Si (3.6 eV)/ Pair creation energy GaAs (4.2 eV) = 86%
  - -> Acceptable agreement

MYTHEN with GaAs sensor: Charge sharing

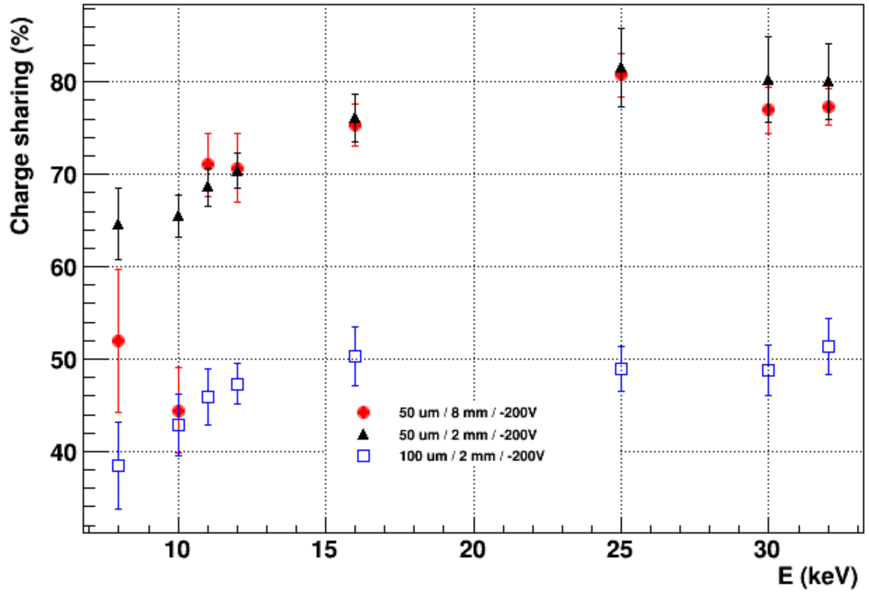
MYTHEN, PHOTON-COUNTING

% of charge sharing as a function of the energy

For 100 um strips, varying the sensor bias



-200V sensor bias, comparing all strip types

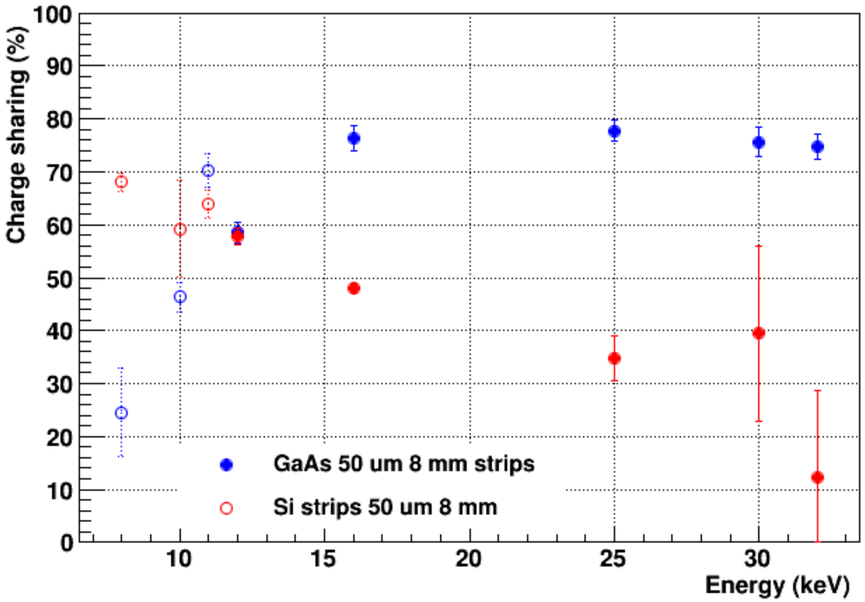


- CS lower at higher bias
- **40% less CS for 100 µm w.r.t 50 µm strips, compares to the expected 50%**
- Charge sharing increasing for energies lower than 12 keV, then stable -> difficult fitting of the S-Curve at low energies

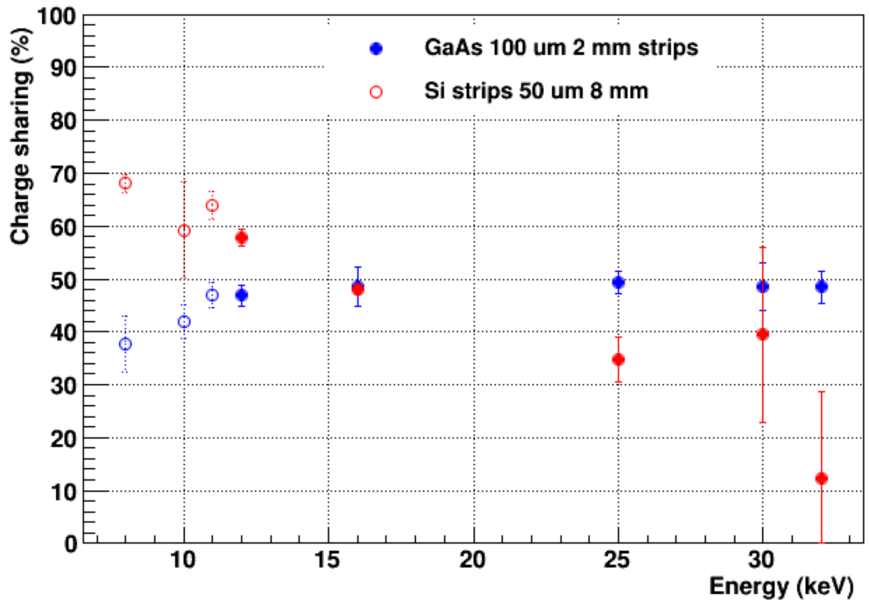
MYTHEN with GaAs sensor: Charge sharing

% of charge sharing as a function of the energy, comparison with Si sensor (450 µm thick, +120V)

For 50 strip pitch, as in Si



For 100 um strip pitch

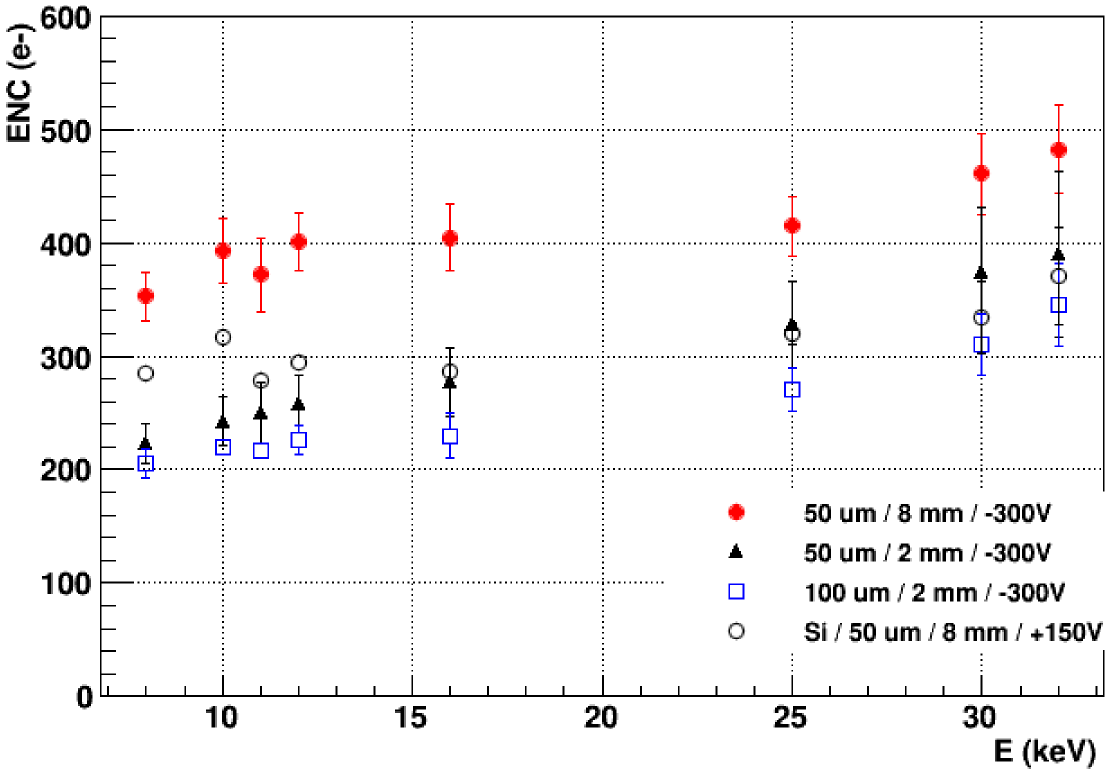


- Charge sharing in GaAs strips / charge sharing in Si strips = 2

MYTHEN with GaAs sensor: Noise

MYTHEN, PHOTON-COUNTING

RMS noise in electrons as a function of the energy, comparison with Si sensor (450 um thick, +120V)



- 30% higher noise for long 50 µm GaAs strips (increased input capacitance)
- Noise 15% lower for 100 µm GaAs strips as compared to Si
- **Values for 50 µm / 8 mm Si strips compare with 50 µm / 2 mm GaAs strips**

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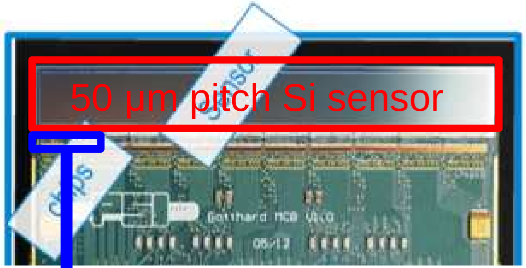
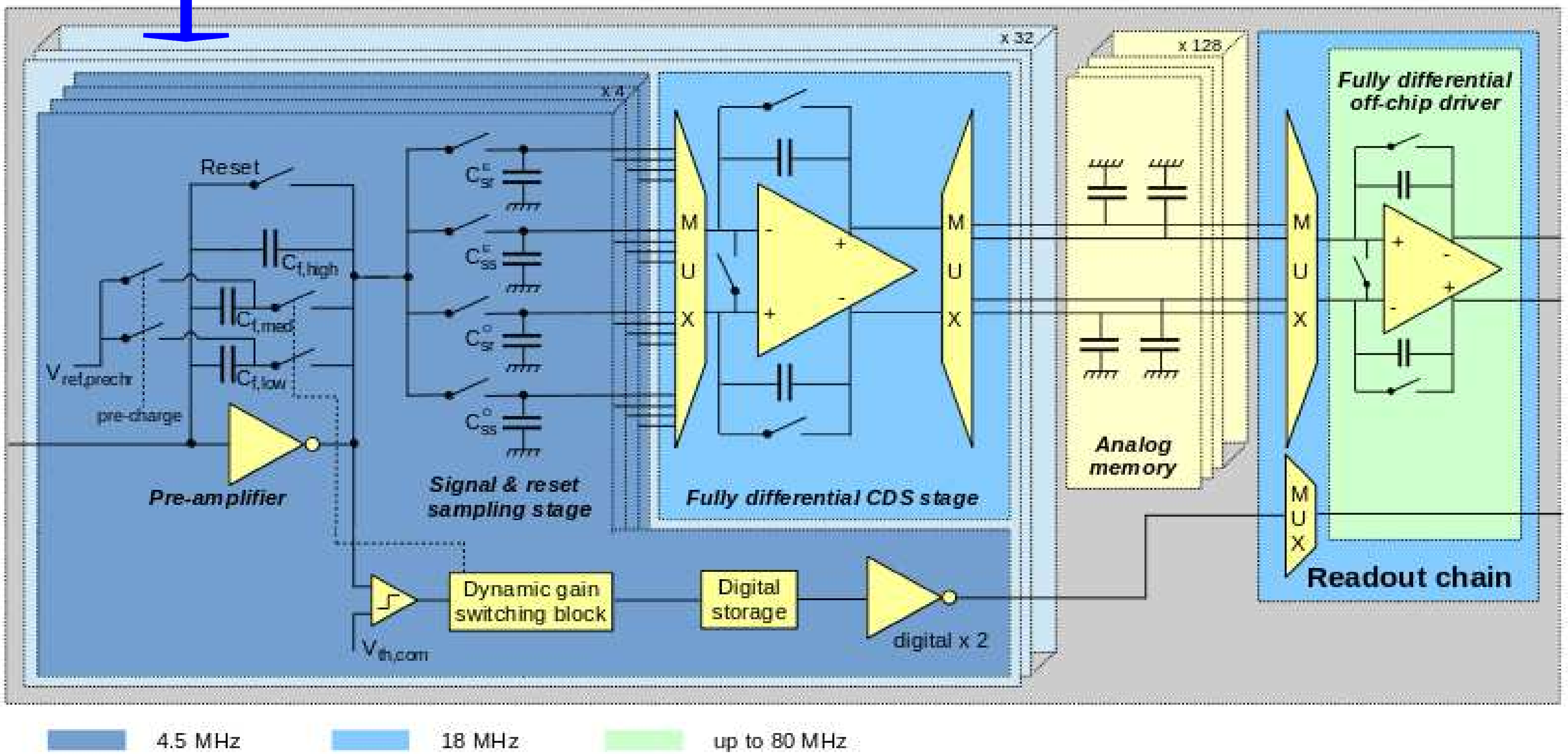
GOTTHARD 1.7 prototype architecture

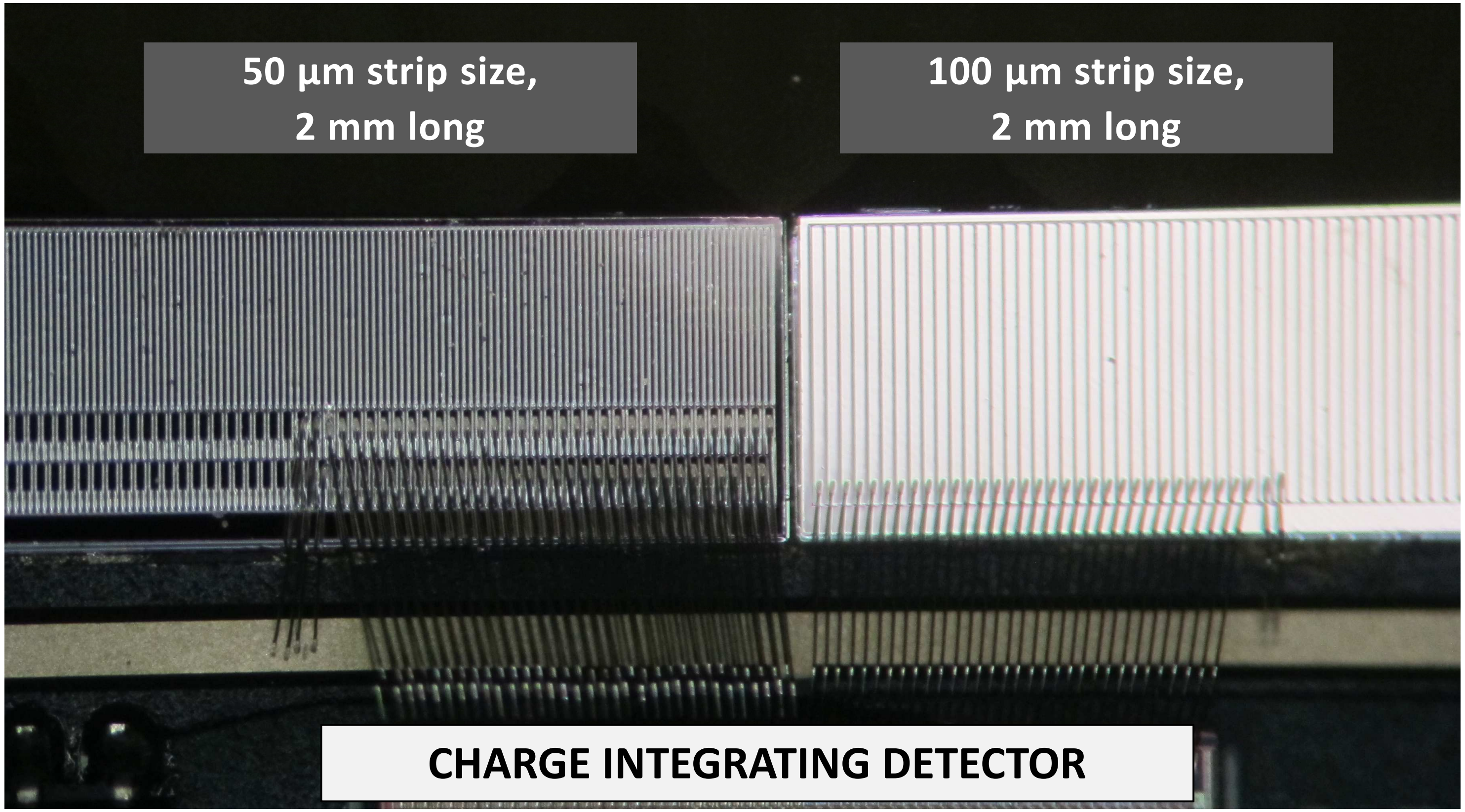
- Dynamic gain switching: Not working in e collection mode
- high DC gain, fully differential front-end
- High DC gain pre-amplifier (700-950)
- Continuous CDS sampling at > 18 MHz
- Fully differential output
- Available for plugging in ADC



ASIC



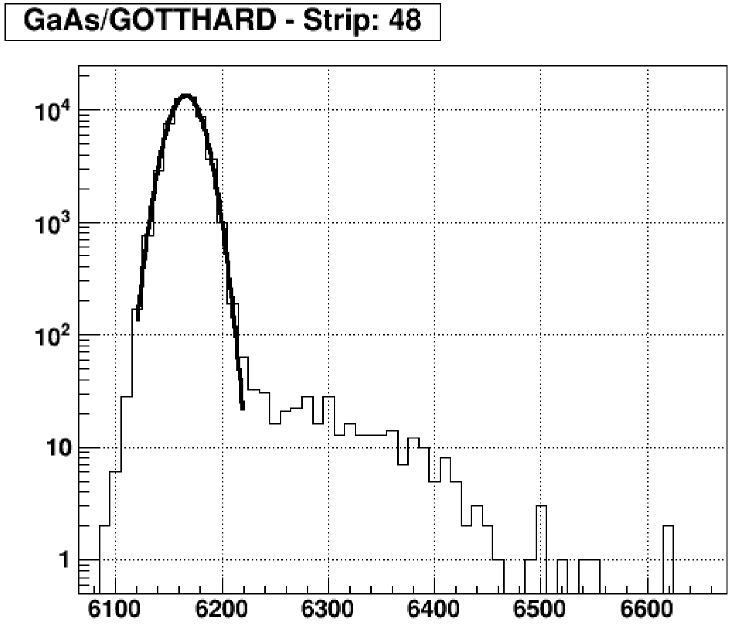
GOTTHARD 1.7 with GaAs sensor

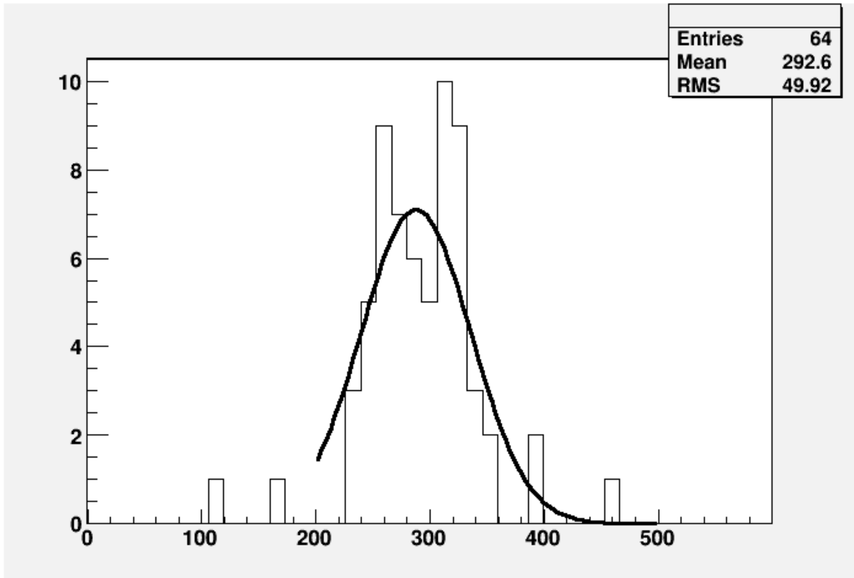


GOTTHARD 1.5 with GaAs sensor: noise

GOTTHARD, CHARGE INTEGRATING

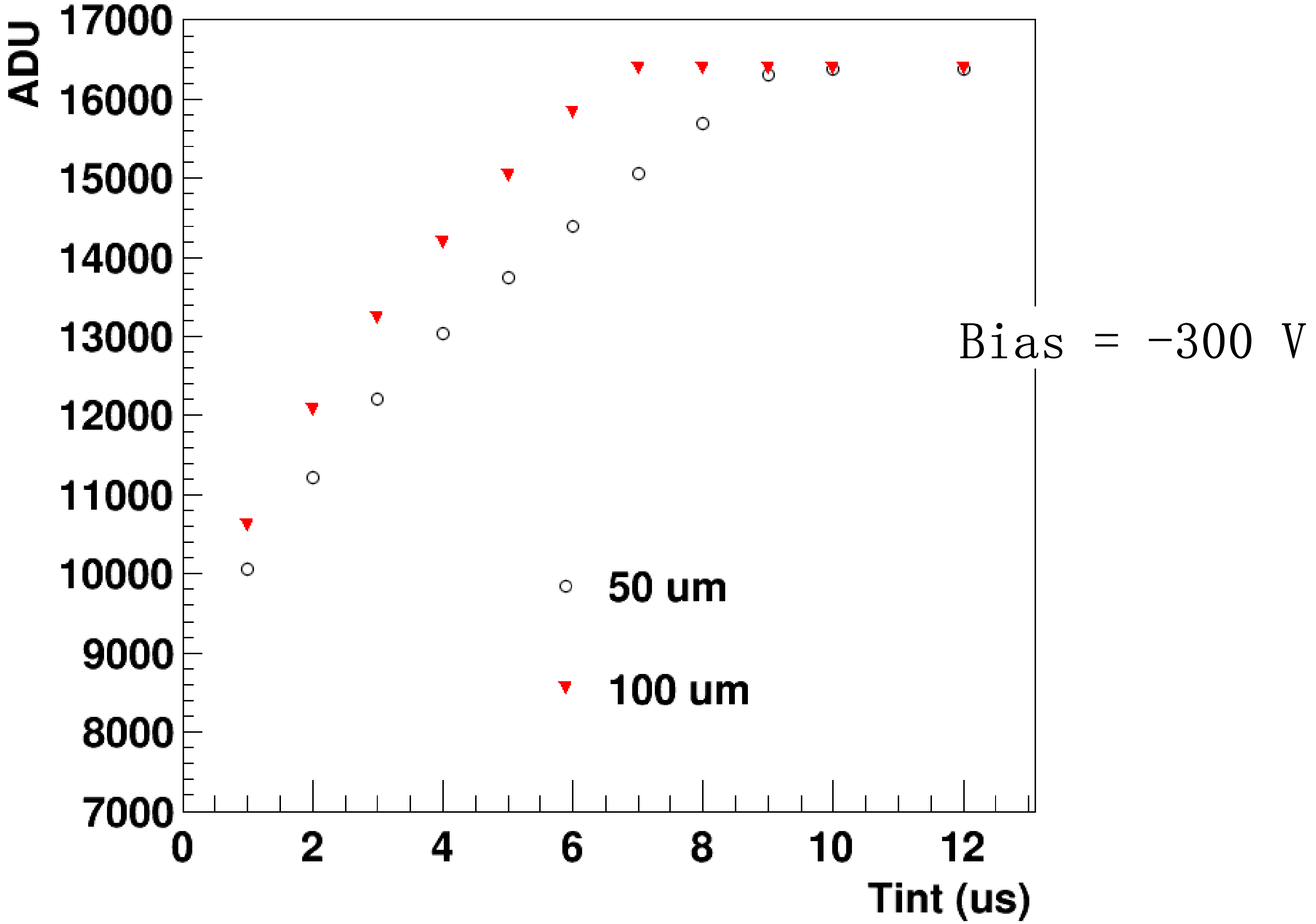
G0





Mean noise in G0: 292 e- RMS, comparable to Si sensors

Leakage current and dynamic range

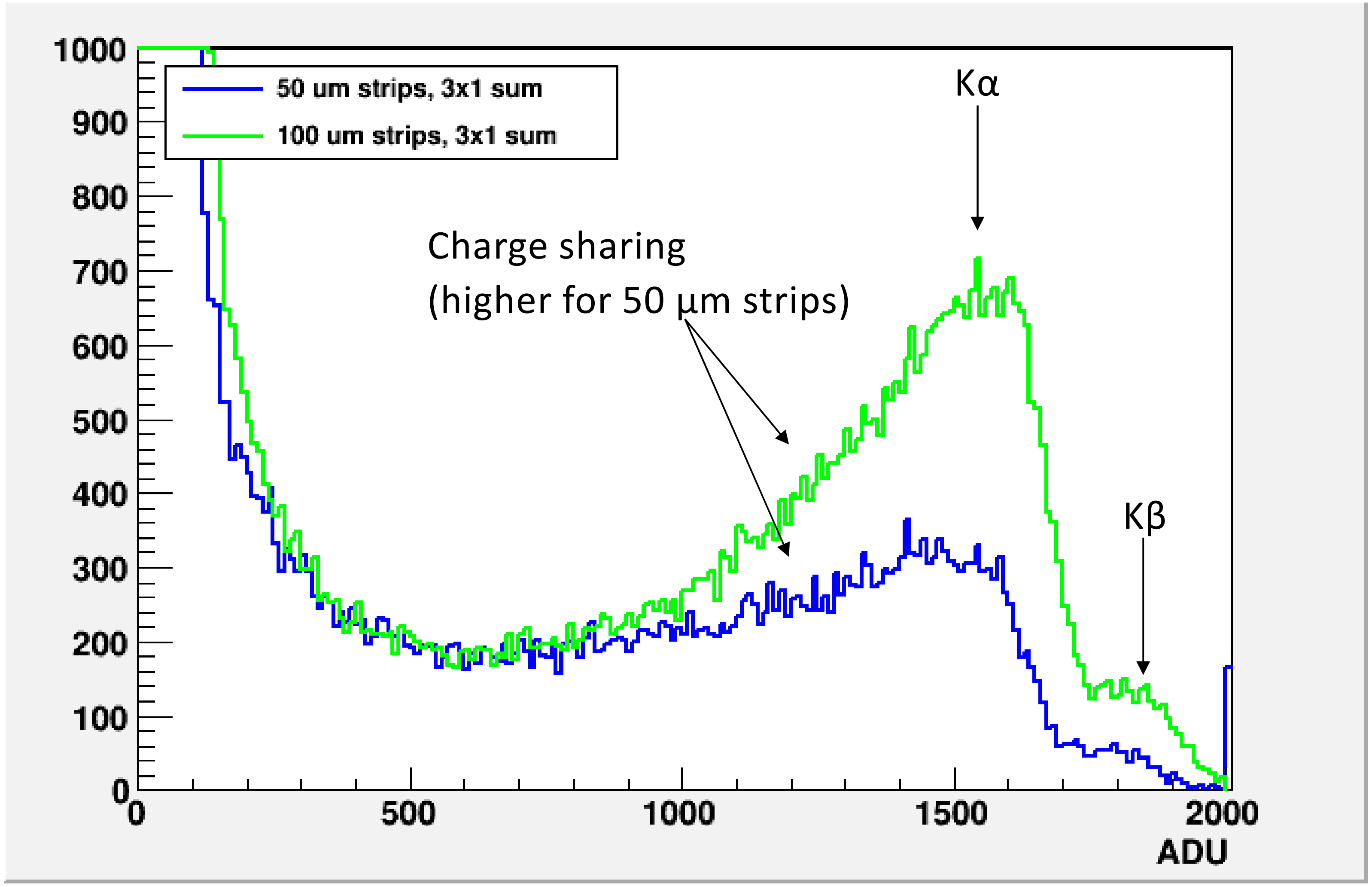


The dynamic range is reduced by 43 keV / µs for 100 µm strips and 31 keV / µs for 50 µm strips by the leakage current

Spectra from fluorescence irradiation

GOTTHARD, CHARGE INTEGRATING

Fluorescence from Mo (17.5 keV), W (59.3 keV), **Pb (74.9 keV)**



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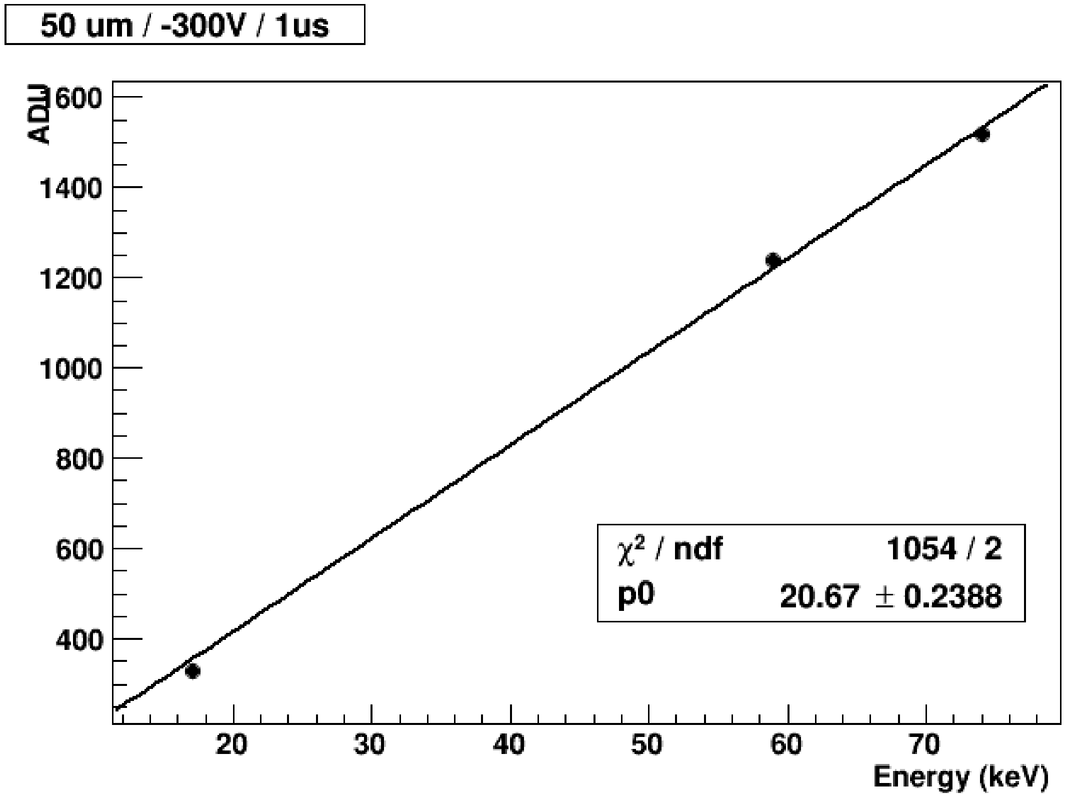
Energy Calibration



GAIN 21 ADU / KeV

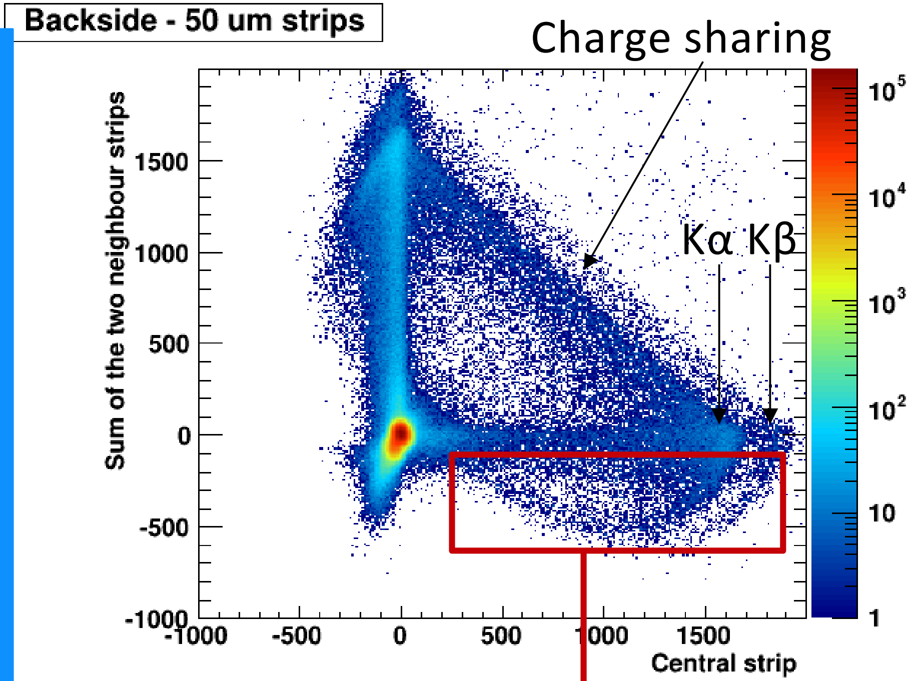
- **Similar gains for different strip pitch / length**
- **Comparison with Si:**
  - Gain GaAs / Gain Si = 21/25 = 84 %
  - Pair creation energy Si / Pair creation energy GaAs = 86%
  - -> Good agreement

Fluorescence irradiation: Correlation plots

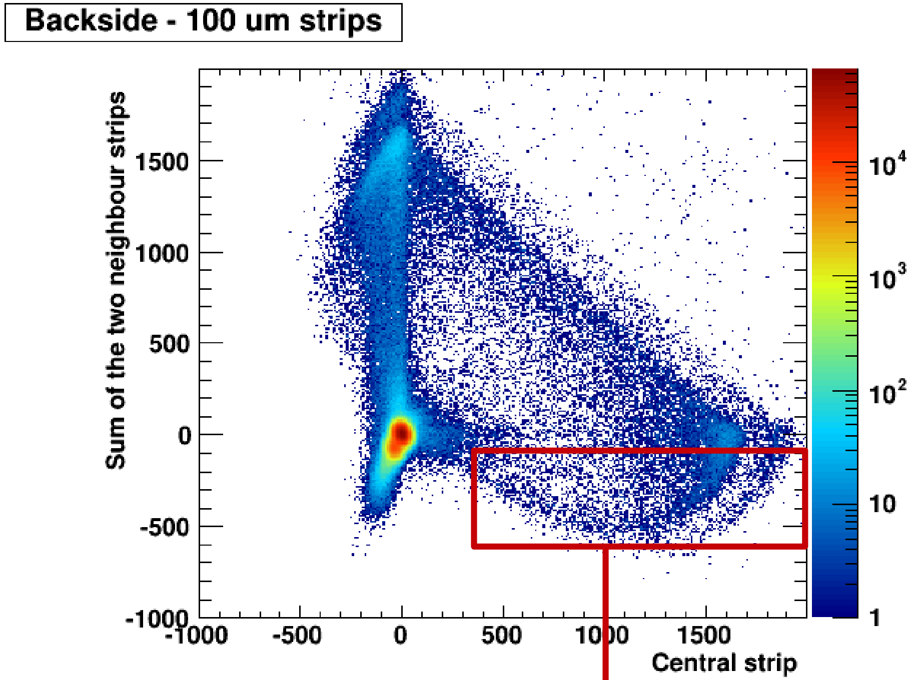
GOTTHARD, CHARGE INTEGRATING

Central pixel vs the sum of its neighbours

50 µm strip



100 µm strip

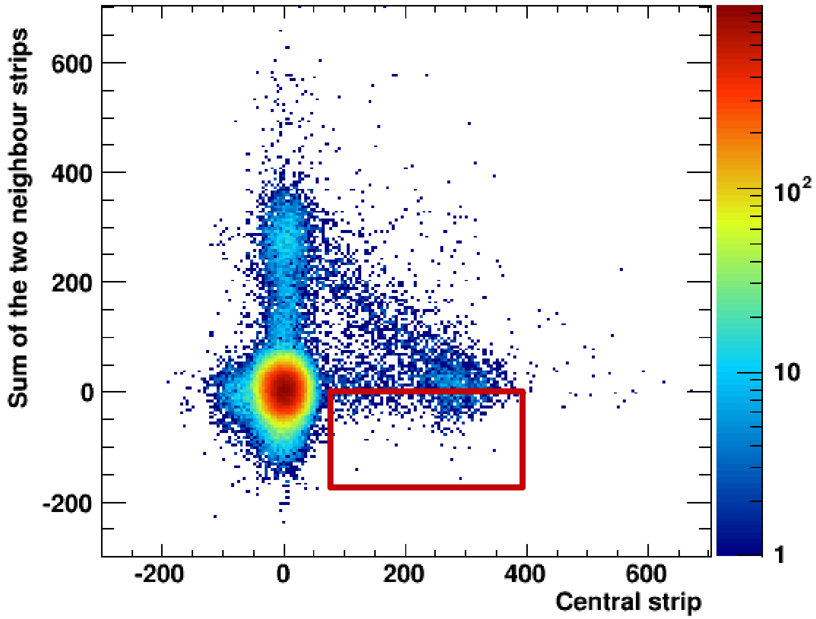


Negative signal visible on all charge integrating readouts

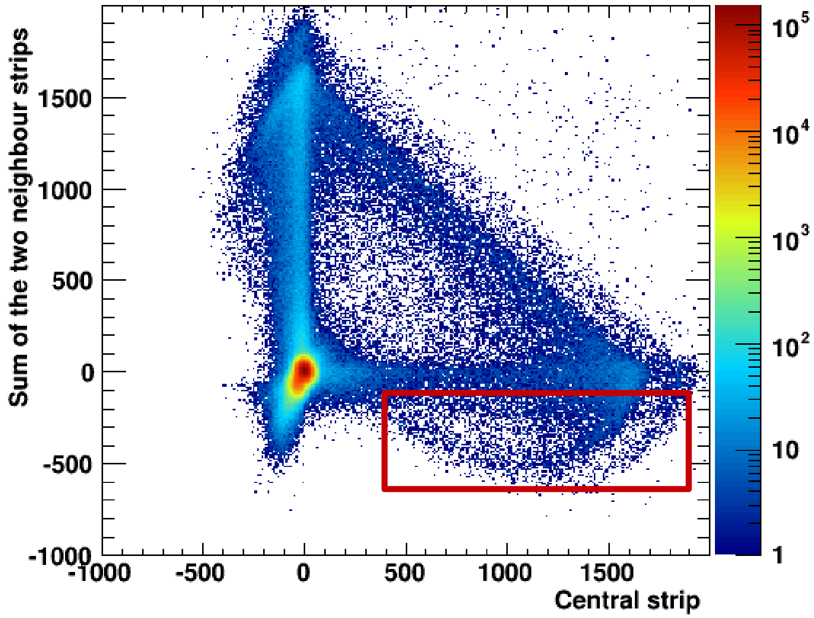
Fluorescence irradiation: Correlation plots

Central pixel vs the sum of its neighbours
50 µm strips at different X-ray energies

17 keV (Mo)



75 keV (Pb)



Negative signal depends on the incoming photon energy
-> Currently working on clarifying this effect

Summary

Characterization of high-Z sensors with various readout chips shows good results, with no specific evaluation of the chips implemented so far

MYTHEN with GaAs

is showing reliable operation especially for the 100 µm strips:

- Leakage current OK & full collection efficiency at -200V
- Excellent linearity of energy calibration
- Noise 30 % higher than with silicon
- Charge sharing 50 % higher as compared to silicon

- Improve the yield of 50 µm strips
- **Improve threshold dispersion**
- High charge sharing

GOTTHARD with GaAs

is showing acceptable operation especially for the 100 µm strips

- Spectral peaks are visible
- Noise is similar to silicon sensors
- The energy calibration gives a 21 ADU/keV gain as expected
- Stable sensor response with time

- **Dynamic range very limited by the leakage current**
- Negative signal effect to be clarified

Further characterization of both sensors and chips foreseen

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The SLS Detector Group

Back: M. Ruat, B. Schmitt, S. Redford, A. Mozzanica, E. Fröjdh
Middle: J. Zhang, C. Lopez-Cuenca, M. Andrä, R. Barten, M. Brückner, C. Ruder, D. Greiffenberg, S. Vetter
Front: X. Shi, D. Thattil, G. Tinti, A. Bergamaschi, M. Ramilli, R. Dinapoli, D. Mezza

Thank you