PAUL SCHERRER INSTITUT

PSI

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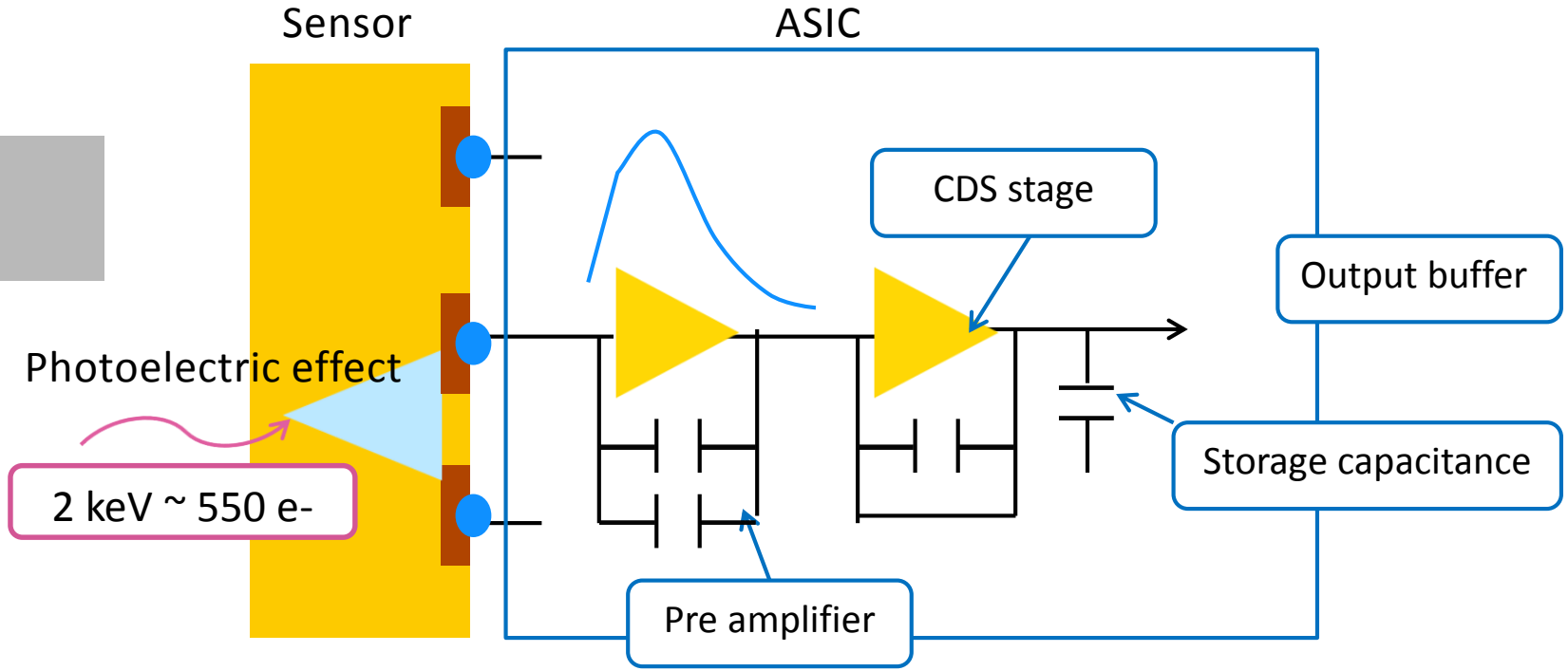
Performance of MÖNCH, a 25 μm pitch hybrid pixel detector for photon science

14th Vienna Conference of Instrumentation – VCI 2016

Overview

- MÖNCH
  - Possible applications
- Detector characterization
  - Bump bonding yield
  - Gain
  - Noise
  - Dynamic range
- Image reconstruction
- Conclusions & Outlook

Charge integrating hybrid pixel detectors

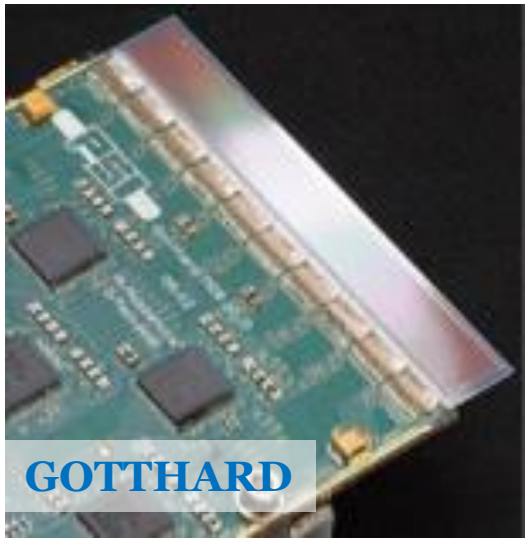


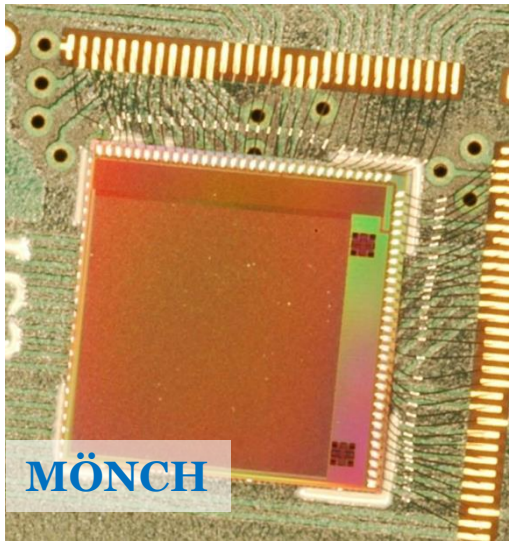
Sensor and ASIC separately developed

Each pixel individually connected (bump bonding) to its readout architecture:

- Electron cloud collected by one or more pixel (**charge sharing**)
- Signal amplified – possible designs:
  a. **Static gain** setting
  b. Switch automatically between different gains – **Dynamic Gain Switching** (DGS)
- Charge stored in capacitance

Charge integrating detectors at PSI





- 50 µm strips
- XFEL application
- Dynamic gain switching

- 75 µm pixels
- SWISSFEL application
- Dynamic gain switching

- 25 µm pixels
- …

Advantages of small pixels

- Higher spatial resolution
- Lower noise (smaller capacitance)

Challenges of small pixels

- Bump bonding yield
- Charge sharing
- Pixel design (small pixel dimensions)
- High data output

Possible applications …

Imaging

~1um spatial resolution

Small pixels +interpolation

High spatial resolution

Phase contrast imaging

access to three complementary contrast:

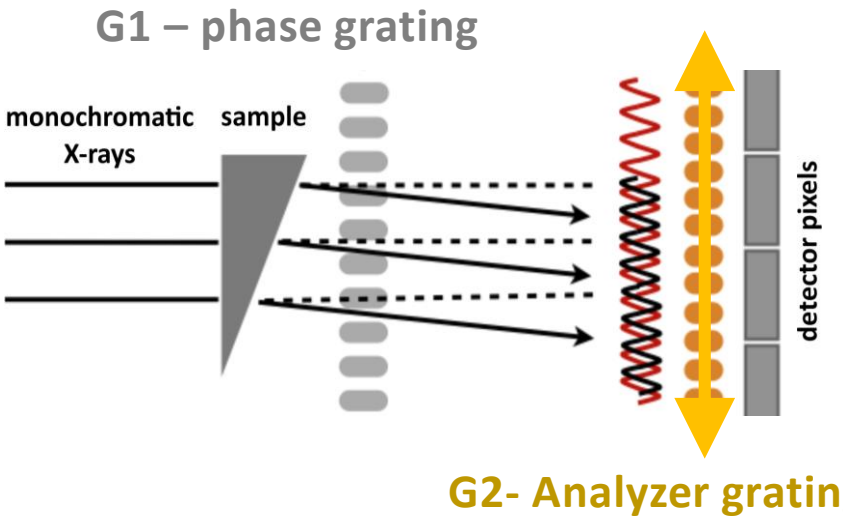
- Absorption
- Differential phase
- Dark field

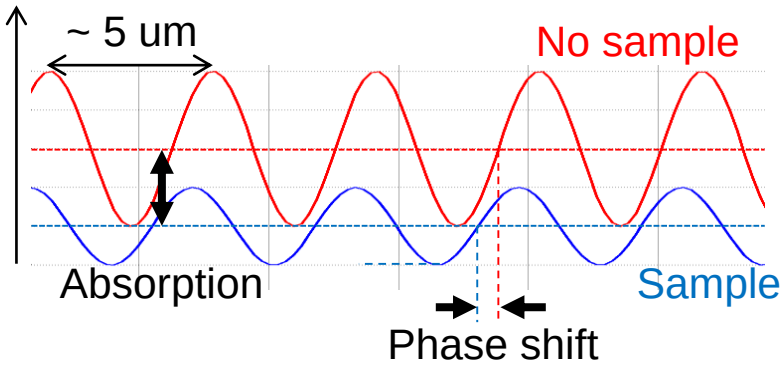
Standard technique needs analyzer grid G2:

- Difficult manufacturing
- Mechanical movement for acquisition
- Increases dose

capable to detect fringes shifts

analyzer grating is no longer needed





… more possible applications …

- **Energy dispersive**
  - Single photon resolution
  - <150 eV energy resolution

Charge integrating

spectroscopic information

Small pixels

high intrinsic spatial resolution

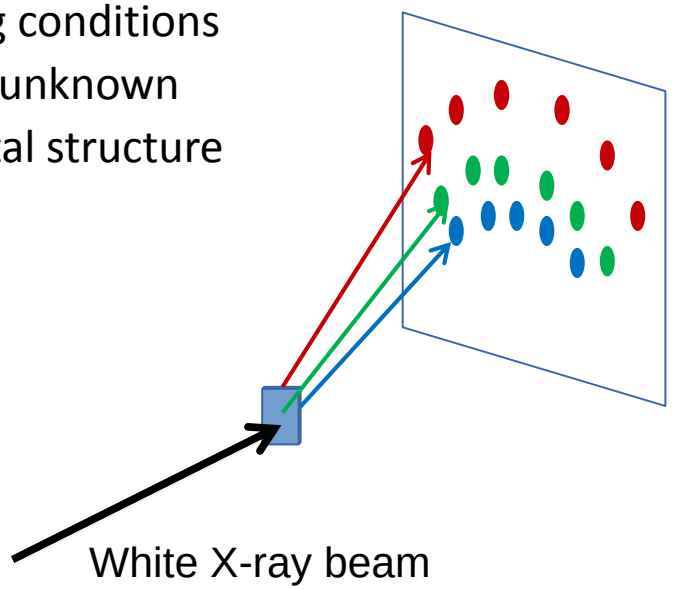
Laue diffraction

- "White" X-ray beam on crystal
- Each plane diffracts a wavelength satisfying Bragg conditions
- Typically only position is measured and energy is unknown
  – Complex procedures necessary to retrieve crystal structure

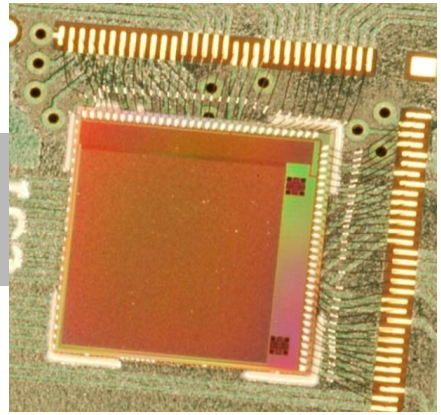
Spectroscopic information

combined with

position resolution



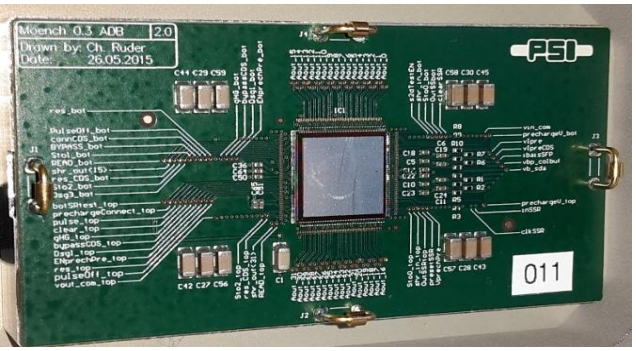
MÖNCH prototypes



MÖNCH 02

- 160 x 160 pixels
- Divided into 4 supercolumns 40 x 160 pixels
- Five different pixel architectures implemented

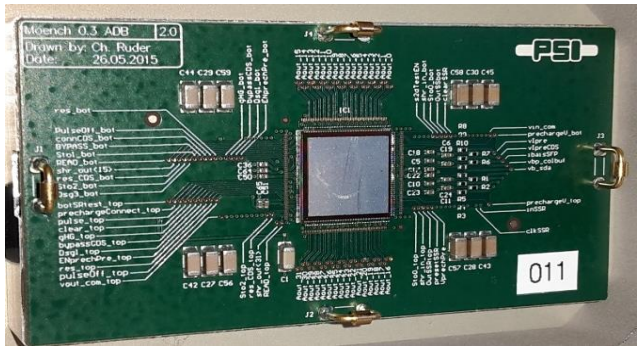
Characterize different pixel architectures



MÖNCH 03

- Pixel architecture optimized for single photons
  - Less than one photon/frame per 3x3 pixel cluster
- Area 1x1 cm^2
- 400x400 pixels
  - Divided in 32 supercolumns 25x200 pixels
- 1 kHz frame rate (10 Gb port)
  - Up to 6 kHz by design

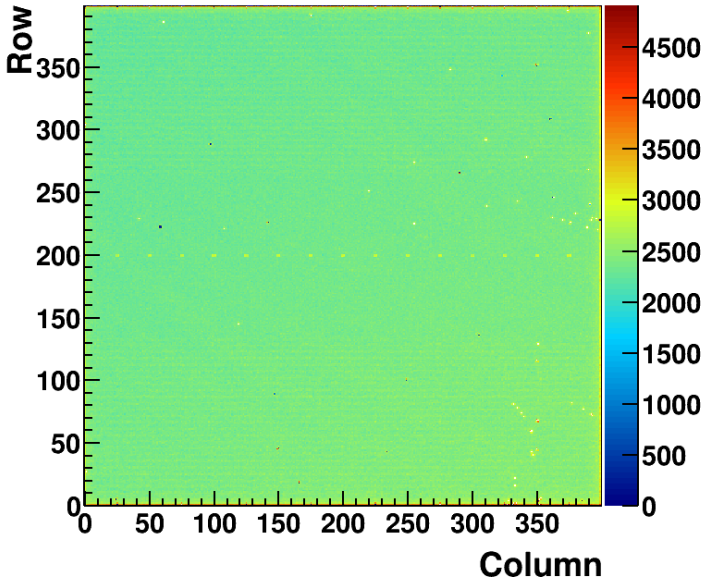
Bump bonding



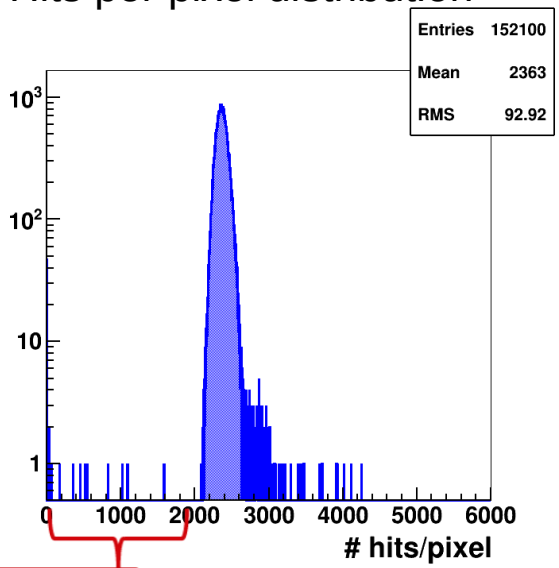
- Standard process
- Performed in-house at PSI
- Indium balls of diameter ~ 15 µm

Yield better than 99.95%

Hit map from Ge Kα fluorescence



Hits per pixel distribution



Bad bump bonds

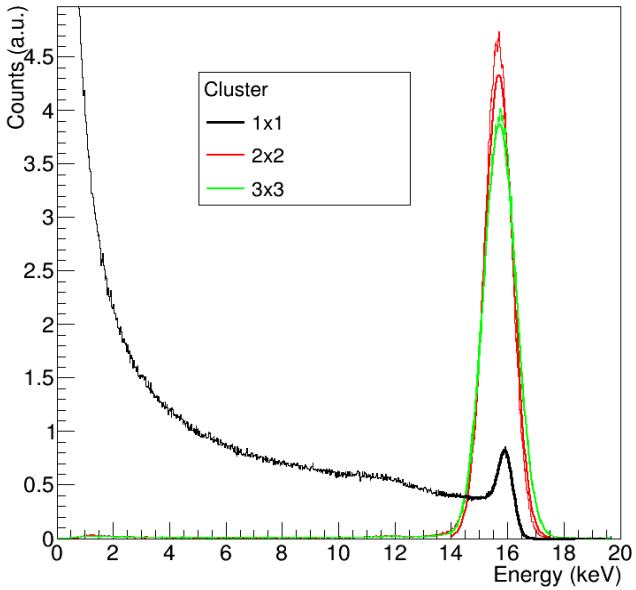
Neighbour pixels

Clustering

Clustering algorithm:

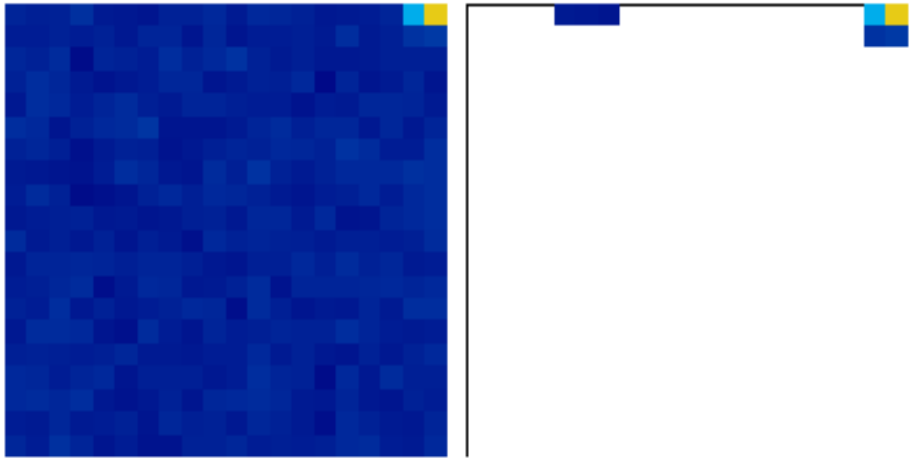
- Identify photon hits
- Create cluster of neighbours around a maximum

Total photon energy retrieved from cluster sum



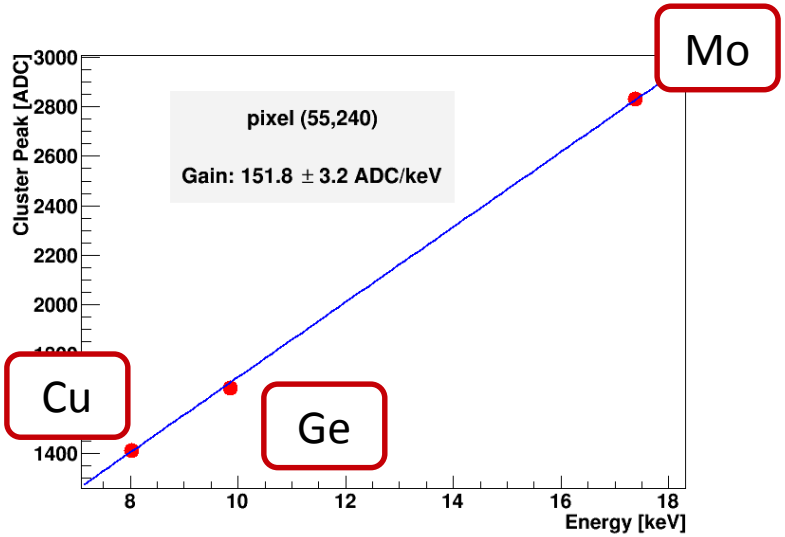
Pedestal subtracted ADC output

ADC output after clustering



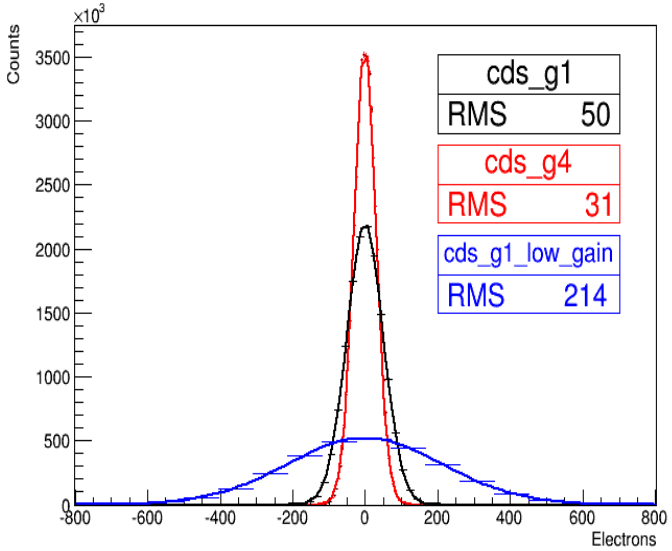
- Clustering performed offline
- Online clustering (software):
  - Reduce data volume
  - Lower frame rate capability

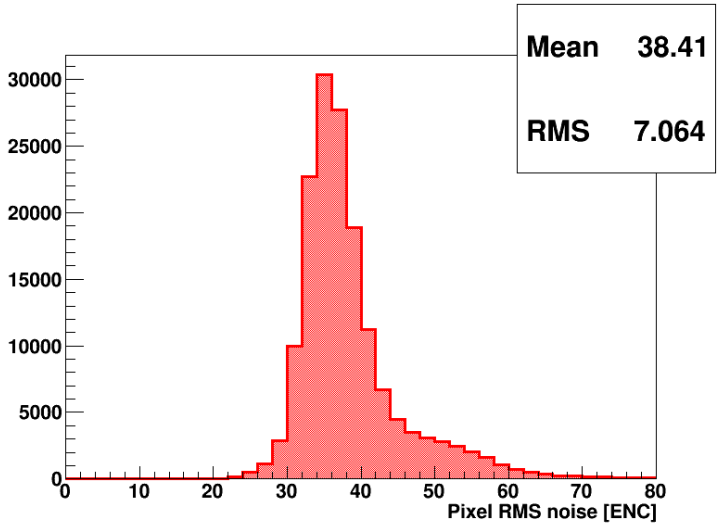
Gain and noise



- Acquisition at different energies
  - (e.g. K_α fluorescence)
- Gain from linear fit
- Noise from pedestal RMS

31 ENC for MÖNCH 02
38 ENC for MÖNCH 03



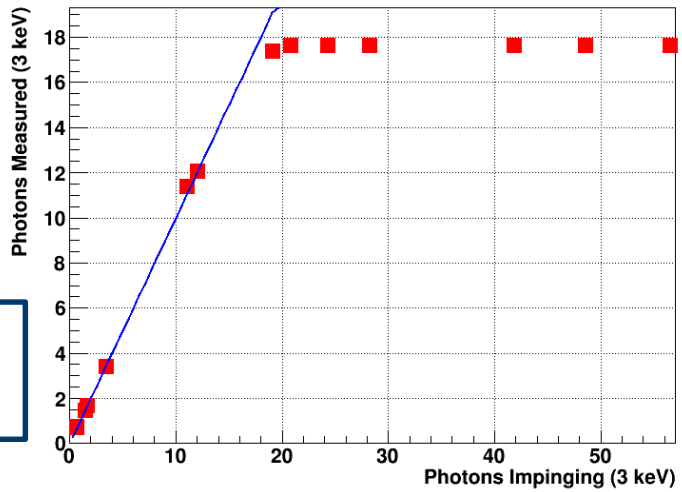


Dynamic range for MÖNCH 03

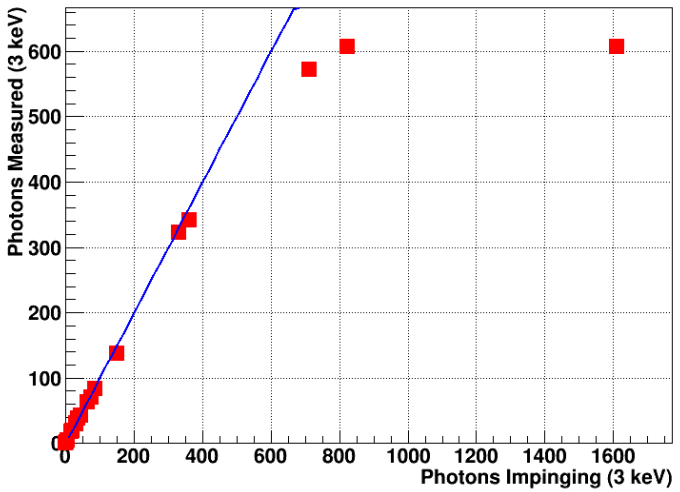
- IR laser
- ND filters

- 3 keV photons
- Kapton thickness

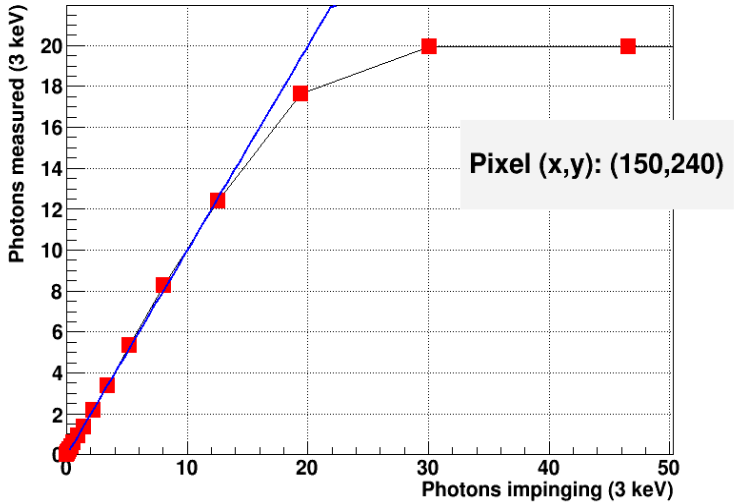
Highest Gain Setting



Lowest Gain Setting



Highest Gain Setting



- Dynamic range:
- 600 3 keV photons at lowest gain setting
- 18 3 keV photons at highest gain setting
  - non-linearity due output buffer saturation
  - optimize chip settings

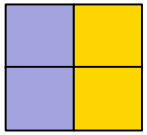
Position interpolation

1) Flat Field illumination acquired

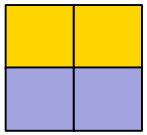
2-dimensional η distribution

Clustering of flat field illumination

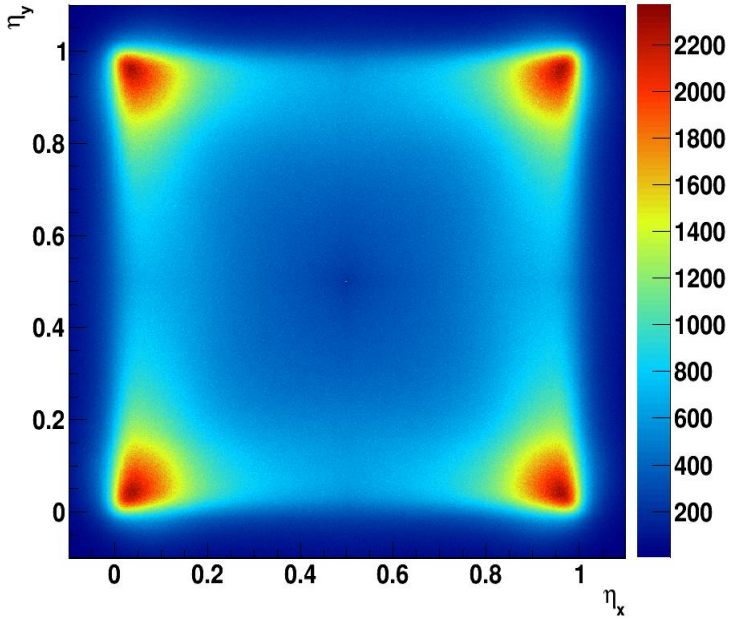
2 x 2 cluster:



$\eta_y = T/(T+B)$



$\eta_x = R/(R+L)$



2) Iterative algorithm applied to η

calculate 2D correction map

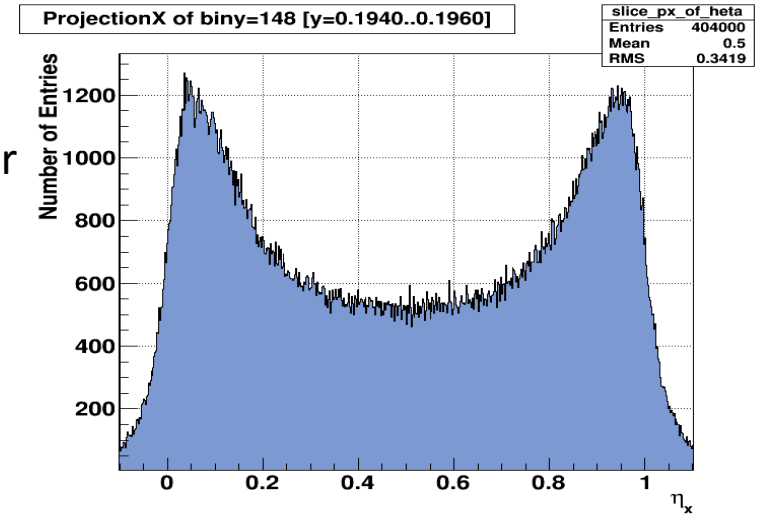
3) Sample data acquired

Clustering: hit position in cluster center

Cluster hit position corrected

$X_{hit} = X_{clus} + X_{corr}$

$Y_{hit} = Y_{clus} + Y_{corr}$



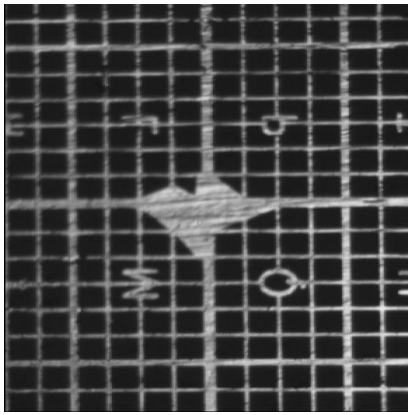
Imaging with MÖNCH 03

- **Absorption image of metal grid**
- PHOENIX beamline at PSI
- 2 keV energy photon beam

63 µm pitch

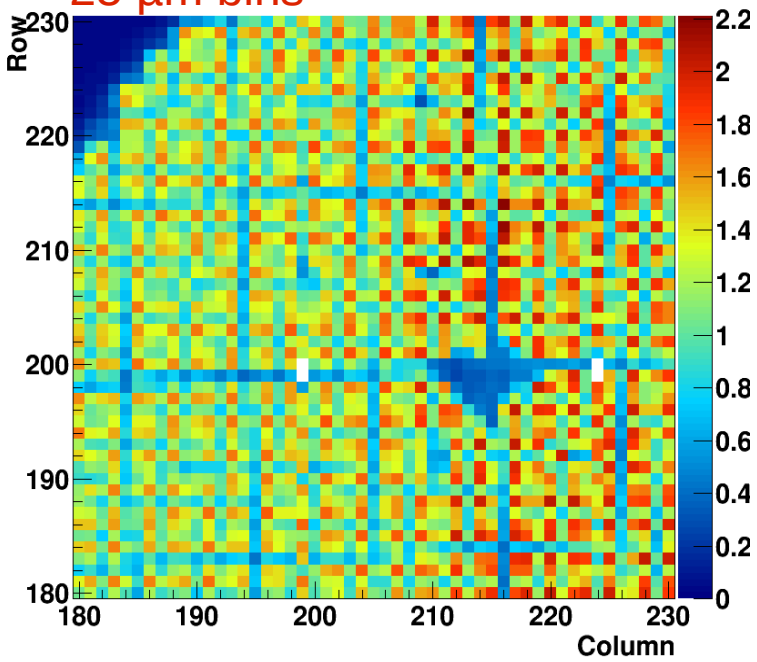
12 µm bar width

51 µm hole width



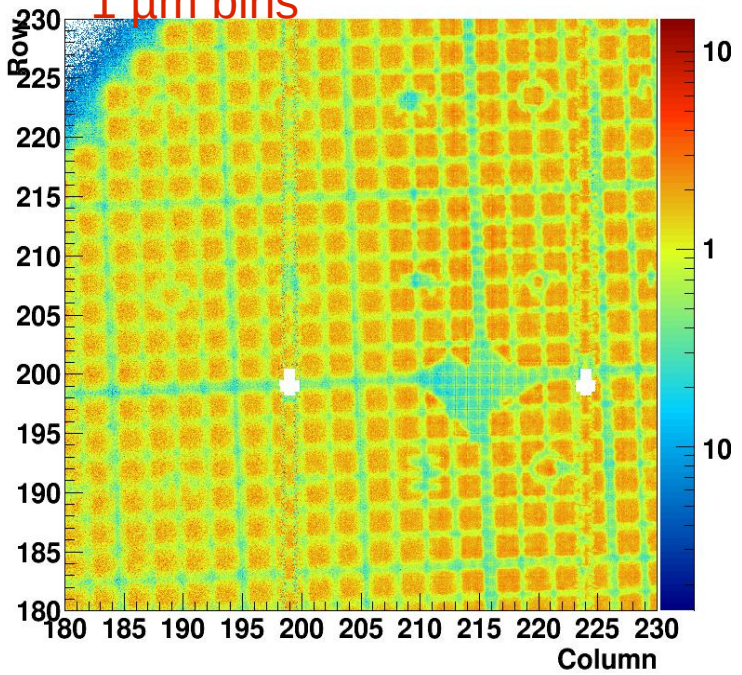
No position interpolation

25 µm bins



With position interpolation

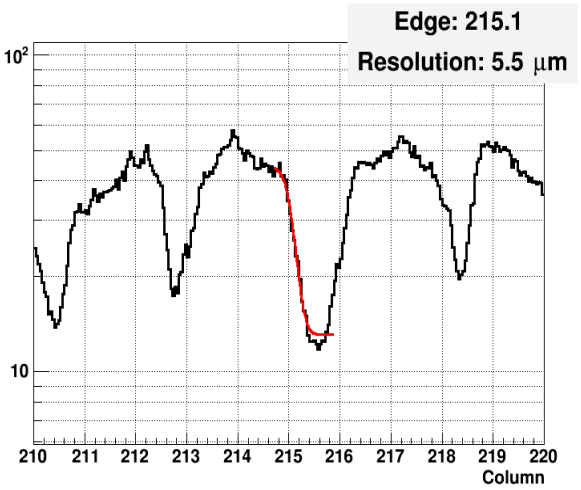
1 µm bins

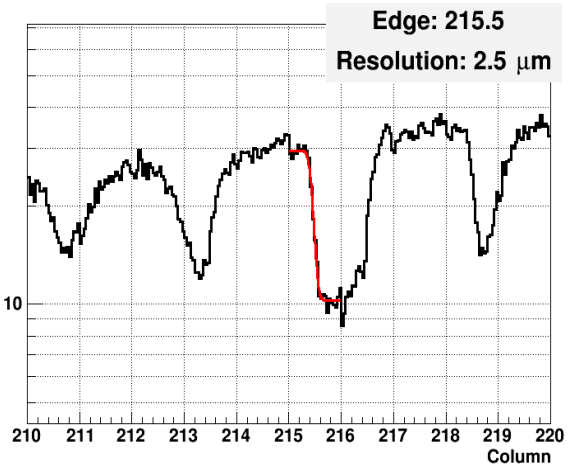


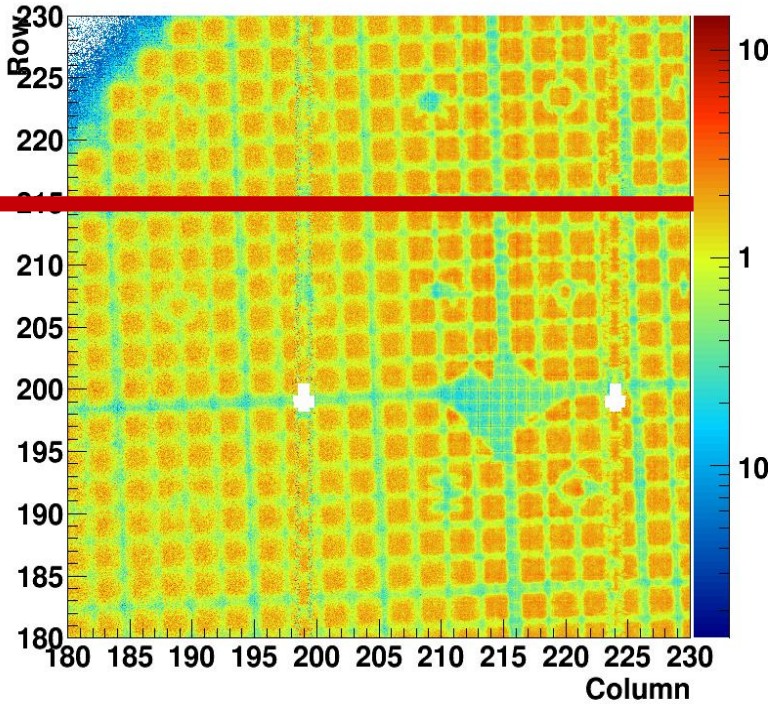
Interpolation position resolution

Average pixel resolution

Integrating along y





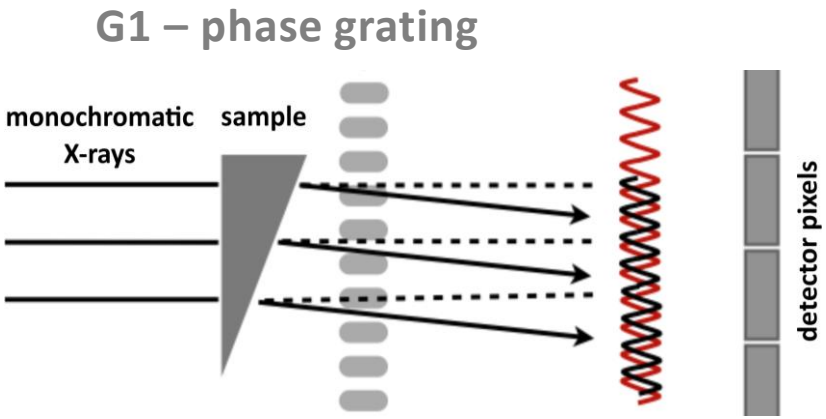


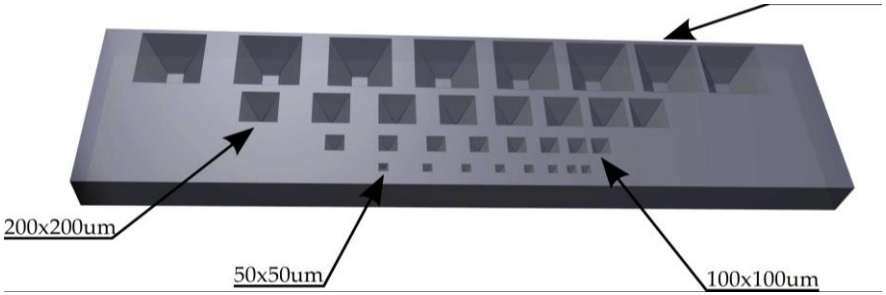
Position dependent resolution

- Average pixel resolution (2 keV):
- ~ 2.5 µm near the pixel edges
- ~ 5.5 µm near the pixel center

Imaging with MÖNCH 02

- **G2-less Phase contrast imaging**
- Performed at TOMCAT beamline at PSI
- 16 keV beam

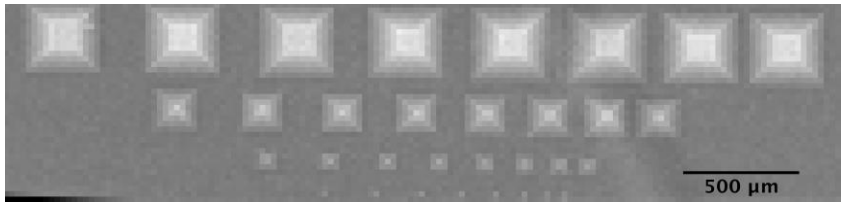




Si wafer target

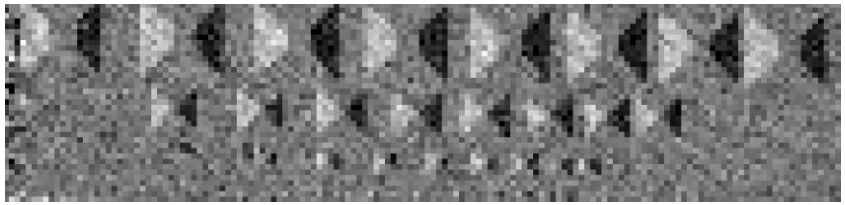
Pyramids of different size

without G2!



Absorption image

25 µm binning



Differential phase contrast image

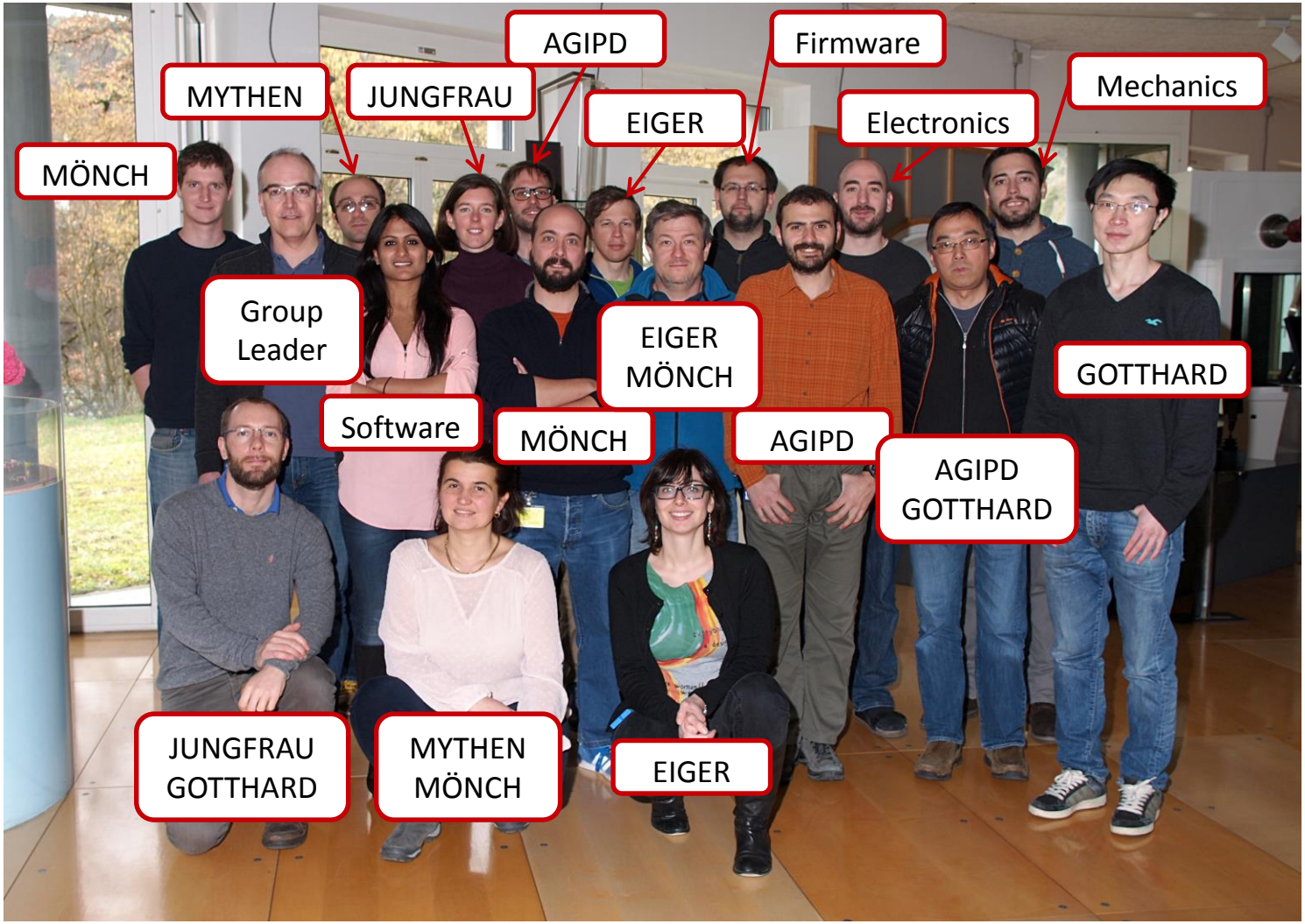
Conclusions and outlook

- MÖNCH is a 25 µm pitch hybrid pixel detector, based on charge integration
- MÖNCH 02: Five different pixel architectures implemented
- MÖNCH 03: Optimized for single photon

- Bump bonding yield > 99.9%
- Low noise (~ 30 ENC rms minimum)
- Clustering allows energy measurement
- Static gain selection of MÖNCH 03:
  - dynamic range ~ 600 3 keV photons (lowest gain setting)
  - dynamic range ~ 18 3 keV photons (highest gain setting)
  - output buffer saturation
- 2D interpolation algorithm MÖNCH:
  - position dependent spatial resolution ~ 1 - 5 µm

- Characterize Dynamic Gain Switching (DGS) achitectures
- Proceed towards a design for low energies (>400 eV)
  - Dynamic range ~ 20000 400 eV photons
  - ASIC of 2 x 3 cm^2, modules up to 4 x 3 cm^2 (~ 2M pixels)

The SLS detector group at PSI



S. Cartier, D. Mayilyan, S. Redford, D. Greiffenberg, E. Fröjdh, M. Brückner, C. Ruder, L. Schädler

B. Schmitt, D. Thattil, M. Ramilli, R. Dinapoli, D. Mezza, X. Shi, J. Zhang

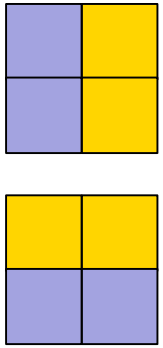
A. Mozzanica, A. Bergamaschi, G. Tinti

Wir schaffen Wissen – heute für morgen

Position Finding Algorithm for MÖNCH

- For pixel detectors 2d-algorithm necessary since eta distribution for x depends on linearized position in y
- Iterative method to determine optimal correction map
- Determination of correction map converges if output is flat

Cluster: 2x2 pixels with signal

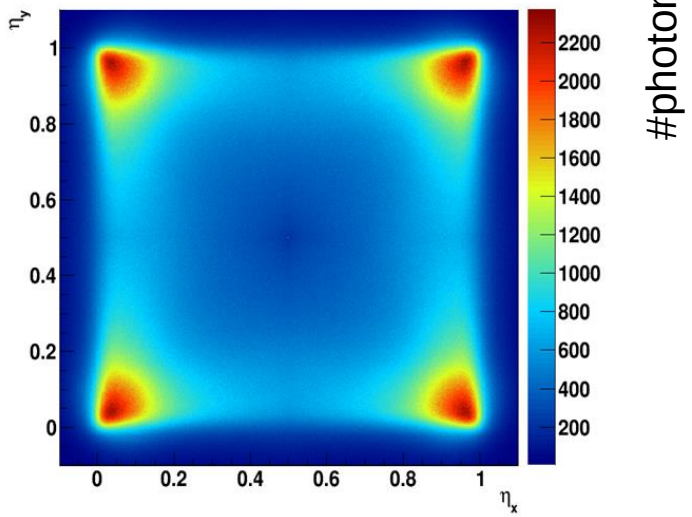


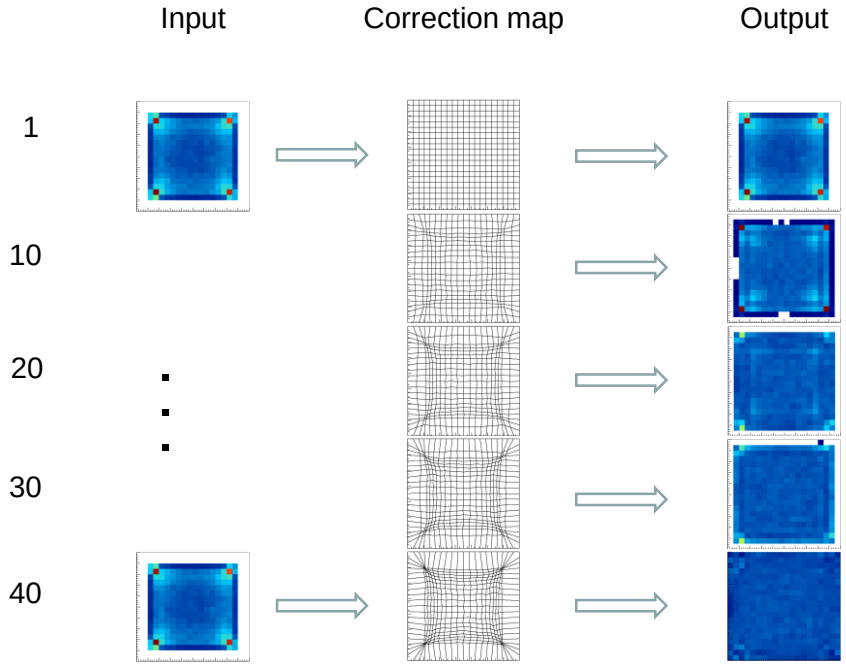
$\eta_x = R/(L+R)$ $\quad X_{int} = X_{clus} + X_{sub}$

linearization

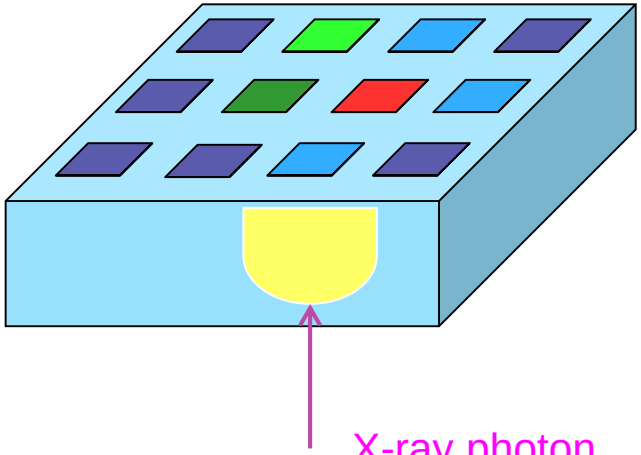
$\eta_y = T/(B+T)$ $\quad Y_{int} = Y_{clus} + Y_{sub}$

Eta distribution for a flat illumination

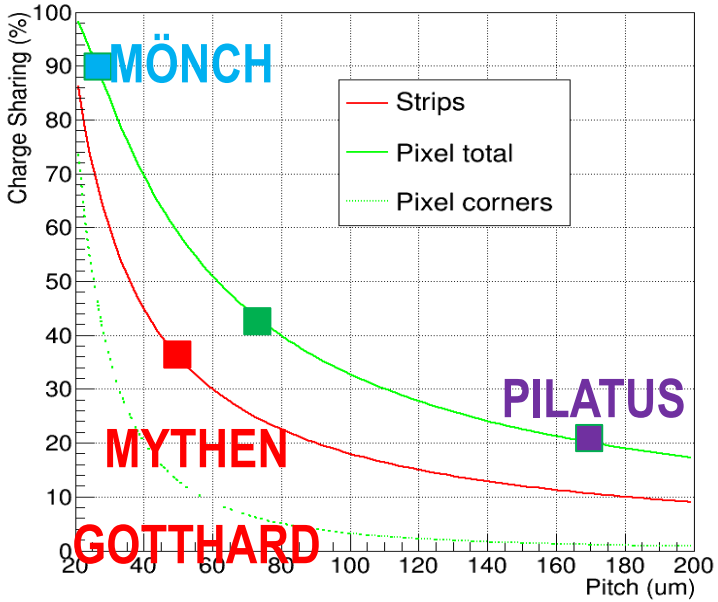




Charge sharing



- The charge diffuses while drifting to the electrodes
- The diffusion length depends on the drift time:
  - Charge mobility
  - Applied bias voltage
  - Absorption depth
    - Sensor thickness
    - X-ray energy
- The charge can be collected by several strips/pixels
- For 320 µm thick sensors, 120V bias voltage we have measured a charge sharing region of 15-2(µm
- Can reduce or increase the spatial resolution

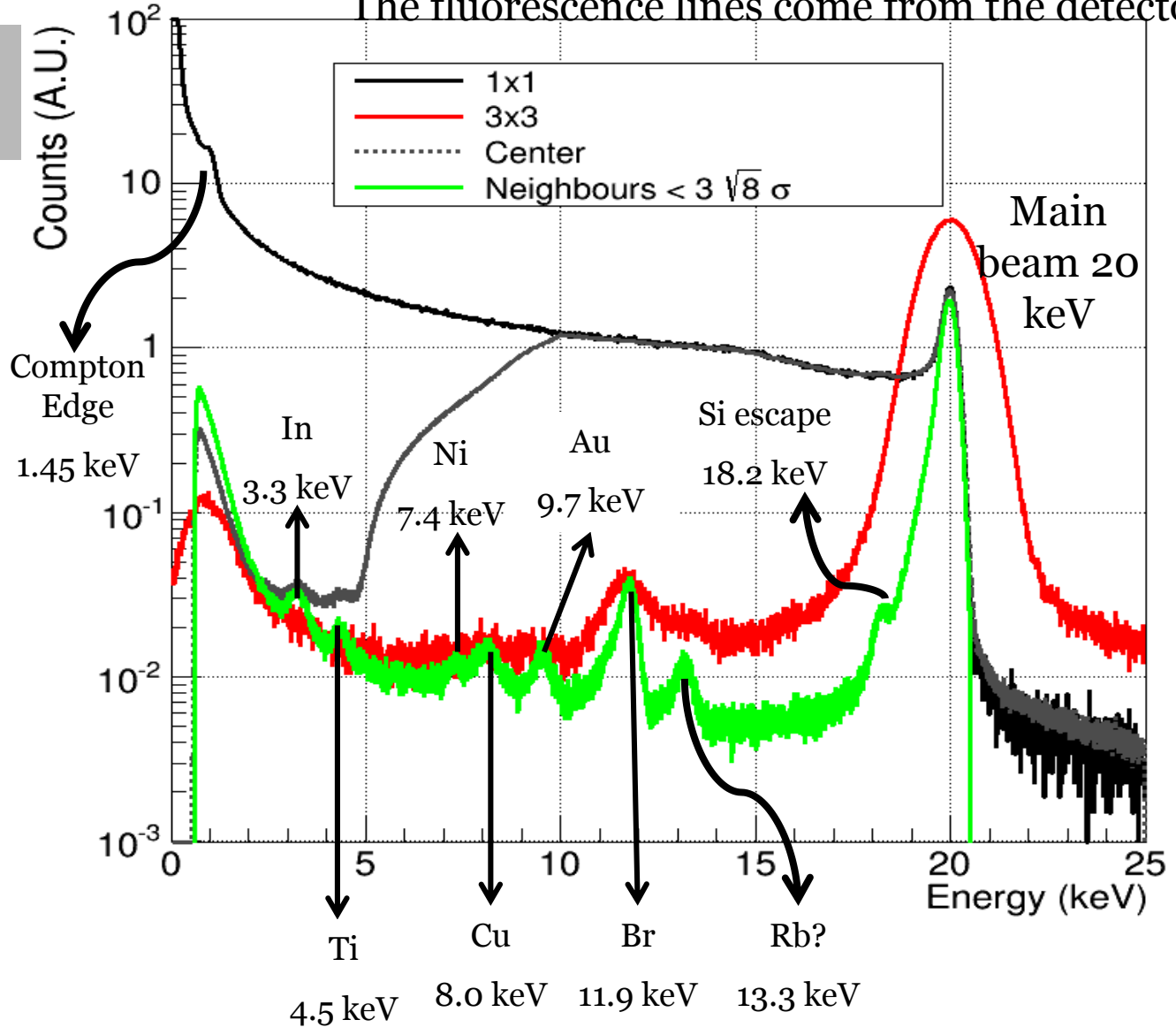


MÖNCH is charge integrating

Energy resolution

MÖNCH 20keV monochromatic data (300 eV FWHM energy resolution).

The fluorescence lines come from the detector itself.



An offline collimator filter can be applied to the data instead of clustering

to suppress charge sharing

- No noise increase
- 99% of photons rejected in 25um pixels
- Larger pixels could be better…
- …but double counts should be avoided