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Optimising the design of small pitch Hybrid Pixel Detectors with MÖNCH04

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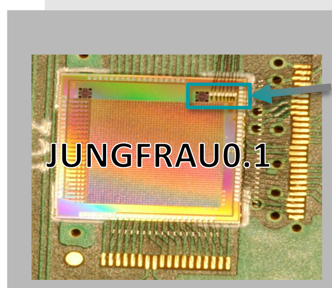
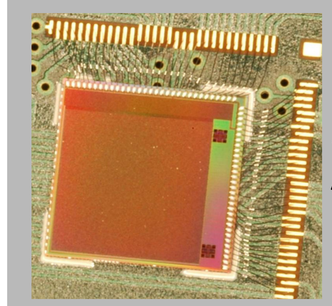
The MÖNCH timeline

WE ARE HERE



MÖNCH01
6 Test structures on JUNGFRAU0.1
→ Technology performance assessment
→ Base design choices [1]



MÖNCH02
Full active chip (160 x 160 pixels)
5 pixel architectures (25 µm pitch) [1]
Area: 4 x 4 mm²

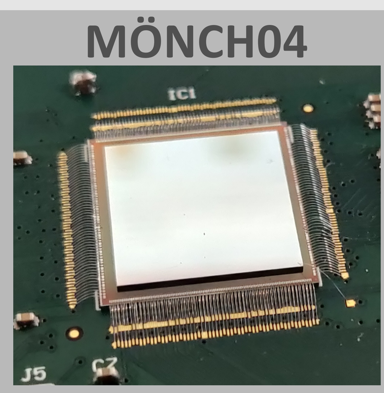
2012

MÖNCH03

400 x 400 pixels, 25 µm pitch → 1 cm²
Best MÖNCH02 pixel design (Noise ≈ 31e⁻ RMS)
Spatial resolution (interpolated): 1–4 µm [2 - 5]
Operated with high-Z sensors [6, 7]

2014 → Today

MÖNCH04



400 x 400 pixels, 25 µm pitch → 1 cm²
19 pixel designs for synchrotron and XFEL applications
High testability of architectures and components

2018 → Today

MÖNCH1.0

Optimized pixel architectures
MÖNCH for synchrotron, for XFEL, or for both?
Maximum single chip area: 2 x 3 cm²
Module: 2 readout chips on a single detector

MÖNCH05 before MÖNCH1.0?

SOON?

MÖNCH at Synchrotrons…

Exploiting the low noise for single photon detection capabilities

Fast frame rates with large duty cycle. Single photon detection capabilities with high DQE and highest spatial resolution

Soft X-ray applications
Detection of single low energy photons (< 1 keV)

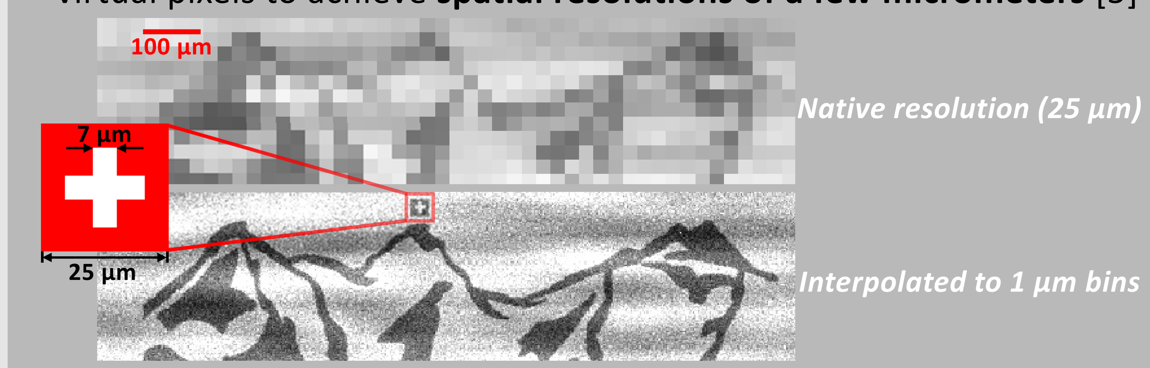
High-resolution imaging
Spatial resolution of a few micrometers with interpolation algorithms
- Spectrometry [2]
- G2-less grating interferometry [3]

Energy resolved imaging
Combination of spectroscopy and imaging for X-ray applications with polychromatic beams [2]
- Laue diffraction
- Color imaging (K-edge subtraction, material discrimination)

High-resolution imaging

Charge sharing over several pixels can increase resolution (cluster size depends on photon energy; sensor material, bias, and thickness)

Position interpolation algorithm based on η algorithm: sub-division into virtual pixels to achieve **spatial resolutions of a few micrometers** [5]



X-ray image of a gold on silicon sample depicting the Eiger, Mönch, and Jungfrau mountains acquired with MÖNCH03 at 10 keV [7]

But limited pixel area for resources, very large amount of data, and challenging bump bonding

…and for XFELs

Exploiting the charge integrating architectures

Very short exposure times with time for readout

Charge integration of multiple soft X-ray photons (up to 200 x 12 keV ph/pix/frame)

Spatial resolution will be limited to the pixel pitch which is an improvement from the other available XFEL detectors:
- **ePix100: 50 µm** [8] (*LCLS, Eu-XFEL*)
- **Jungfrau: 75 µm** [9] (*SwissFEL, Eu-XFEL, LCLS, PAL-XFEL*)
- **AGIPD: 200 µm** [10] (*Eu-XFEL*)
- **DSSC: 204 x 236 µm²** [11] (*Eu-XFEL*)
- **Large Pixel Detector: 500 µm** [12] (*Eu-XFEL*)

Dynamic Gain Switching (DGS) (dynamic range increase), and **overvoltage protection** required

Implemented MÖNCH04 pixel features

19 pixel designs

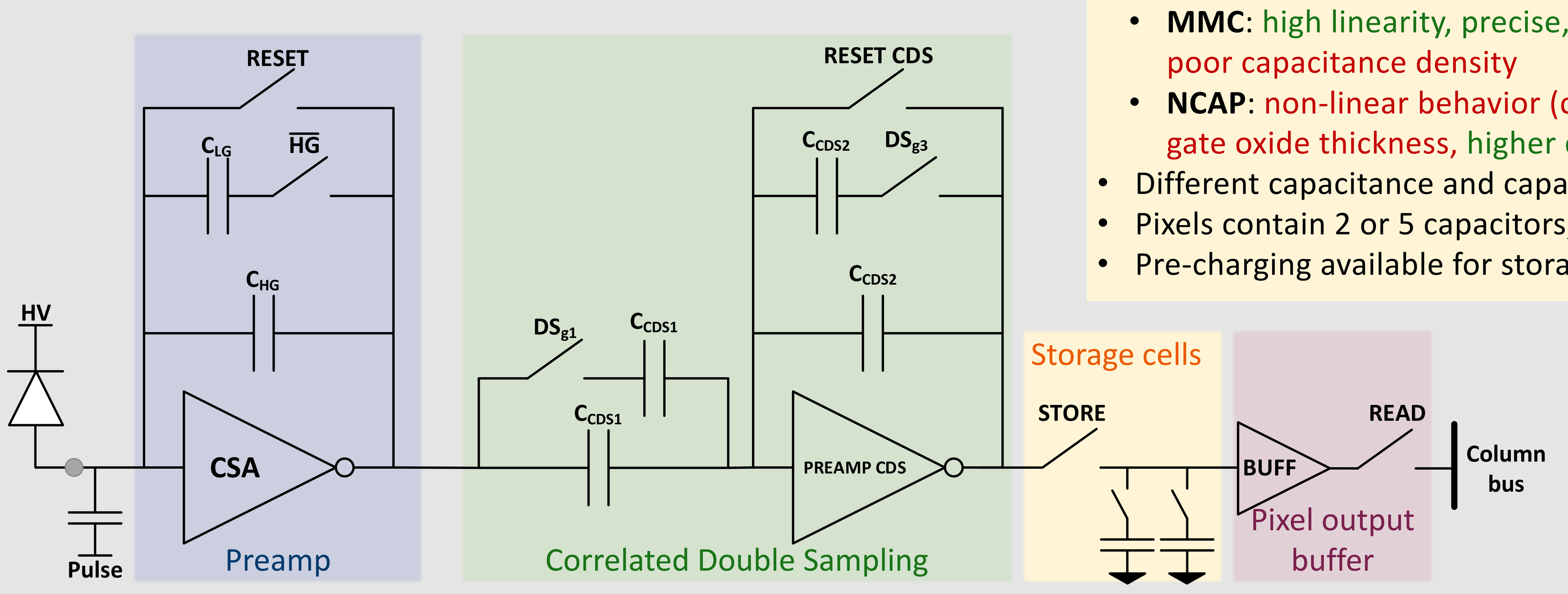
13 designs with 200 x 50 pixels
6 designs with 200 x 25 pixels

9 designs for synchrotron
10 designs for FEL

Preamp

Synchrotron applications
- Charge Sensitive Amplifiers (CSA) with static gain selection (+1 source follower design)
- Different feedback capacitor values tested
- "Stripped" variants with super high gain (and additional filtering)

XFEL applications
- CSA optimized for Dynamic Gain Switching (two variants)
- Overvoltage protection circuit (not showed)
- Pixels with preamp pre-charging capabilities for testing



Storage cells

- Different capacitor technologies tested
  - **MMC**: high linearity, precise, low sensitivity to temperature, no leakage, poor capacitance density
  - **NCAP**: non-linear behavior (capacitance ∝ voltage), leakage depends on gate oxide thickness, higher capacitance density
- Different capacitance and capacity density tested
- Pixels contain 2 or 5 capacitors, each individually addressable
- Pre-charging available for storage cells and output buffer testing

Correlated Double Sampling (CDS)

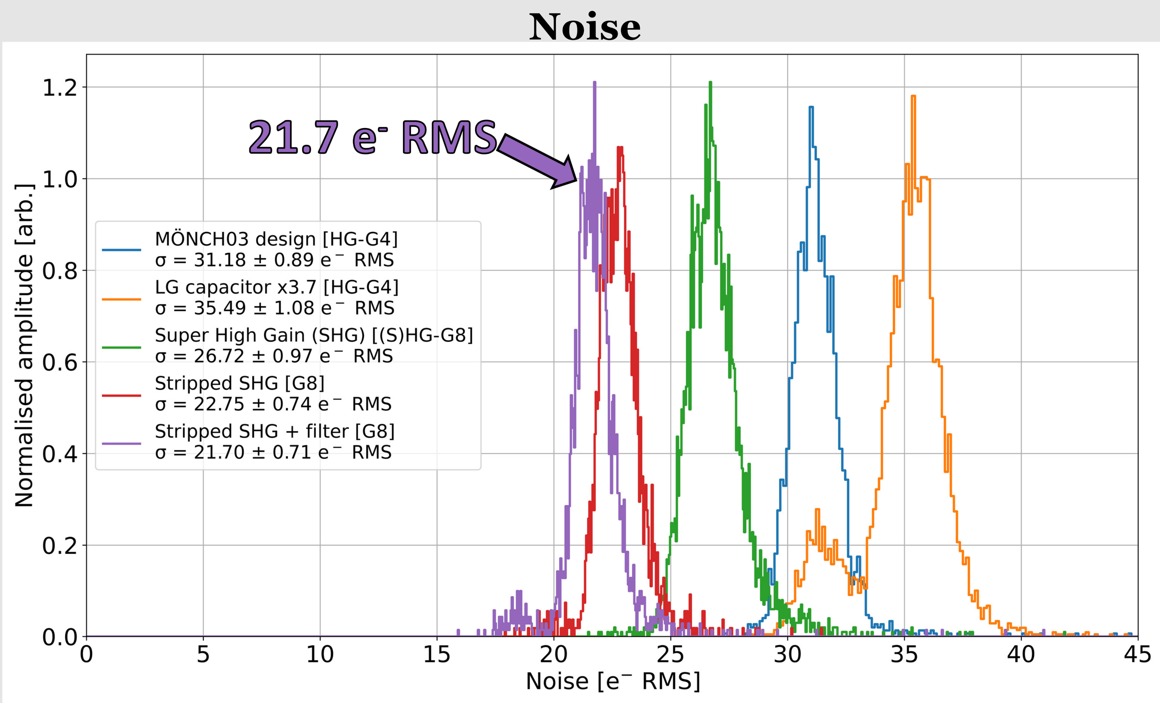
- Static gain selection (x1, x2, x4); doubled for super high gain pixels
- 2 pixel designs with passive CDS, and 2 designs without CDS stage
- CDS stage bypass available on most designs for testing

Output buffer

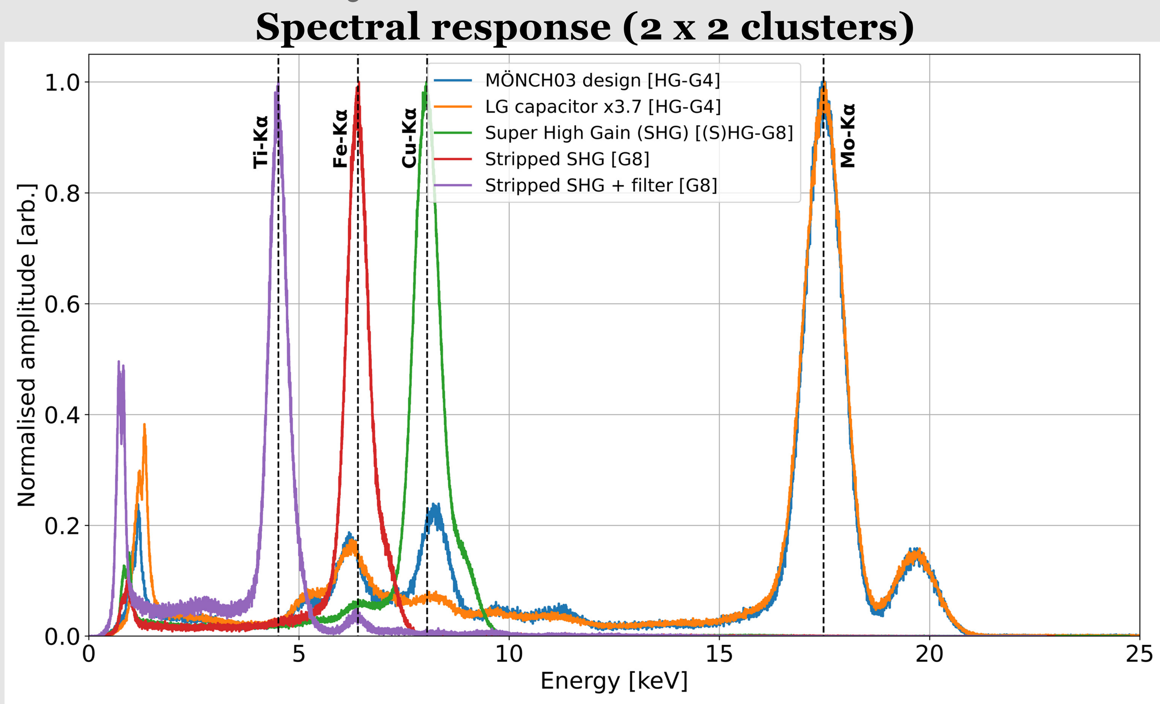
- Source follower output buffer
- Testing possible through storage cell pre-charging feature
- One pixel architecture without SF for charge readout

Preliminary characterisation results

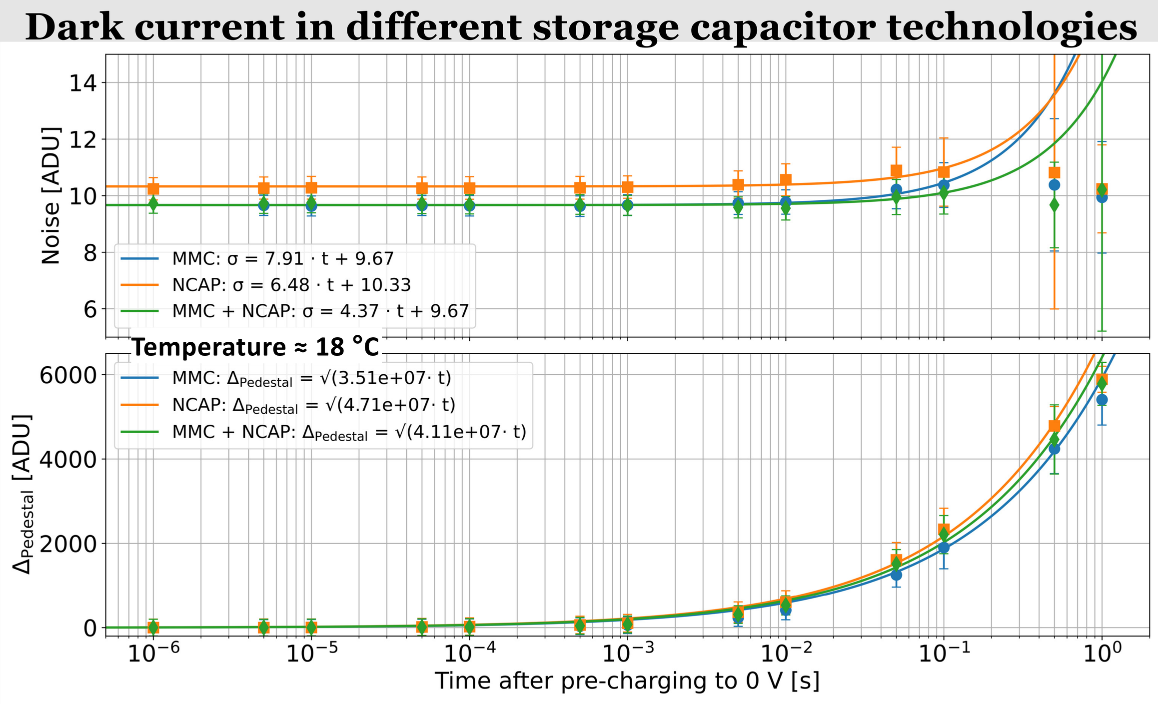
Noise



Spectral response (2 x 2 clusters)



Dark current in different storage capacitor technologies



The journey ahead of us

MÖNCH04 Testing
- Architectures characterisation
  - Additional testing of the presented synchrotron designs (incl. CSA, CDS)
  - XFEL designs to be tested
    - Biasing optimisation and timing implementation
    - Full characterisation with soft X-ray and laser
    - DGS architectures comparison
- Noise sources investigation and optimisation (on-chip and on-board)
- Alternative storage cell usage investigation (e.g. multi-sampling, noise mitigation)

Chip design
- Selection of the optimal design and components to implement
- Design of MÖNCH05 to validate/refine the pixel architectures?
  - One architecture for synchrotron and one for XFEL?
- Design of MÖNCH1.0
  - Up to 2 x 3 cm², at least 1 side-buttable
  - Implementation of the optimised pixel
  - Improved periphery for better performance and on-chip additions to reduce number of wirebonds

Detector technology development
- **Soft X-ray**
  - Use and testing of sensors with thin entrance window
    - ➢ *Poster by M. Carulla, 27/06*
  - Detection of softer X-rays with LGADs/iLGADs
    - ➢ *Talk by J. Zhang, 29/06 @14:00, and poster by M. Carulla, 27/06*
- **Hard X-ray**
  - High-Z sensors characterisation and spatial resolution investigation

References

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