Recent developments at HLL,
including new LGAD silicon sensors

Jelena Ninković for MPG HLL Team

MPS Semiconductor Laboratory (in German: MPG Halbleiterlabor - HLL)

Central facility of the Max Planck Society
with 40 employees: scientists, engineers and technicians + guest scientists, engineers and students

At present @ Siemens Campus Neuperlach Munich

- 1000m² of clean room area
- 330m² of ISO3 area
- Full 6 inch silicon process line

From end 2023 @ IPP Campus Garching

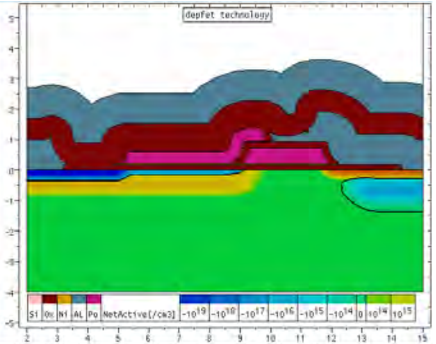
- 1500m² of clean room area
- 600m² of ISO3 & ISO4 area
- 8 inch silicon process line

From 2024 HLL will be part of Munich Quantum Valley

MPG HLL is developing and producing fully depleted silicon radiation sensors with integrated electronics optimized for different scientific projects

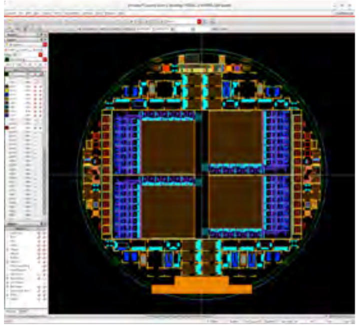
Inside HLL – Sensors and Systems : Design, fabrication & Test

Process simulation

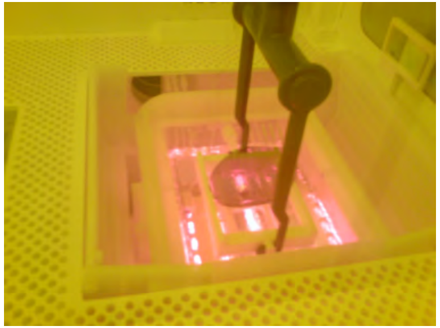


Device simulation, 2D and 3D

State-of-the-art layout tools



In house fabrication



Wire bonding, hybrid assembly

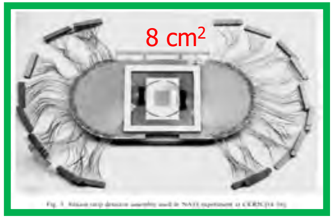
@ HLL:

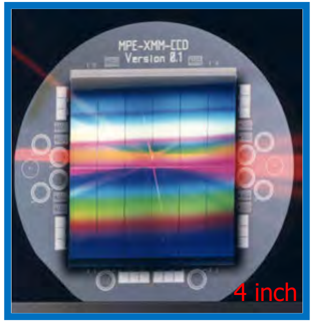
- sensor design and fabrication
- interconnection
- system/camera design and test

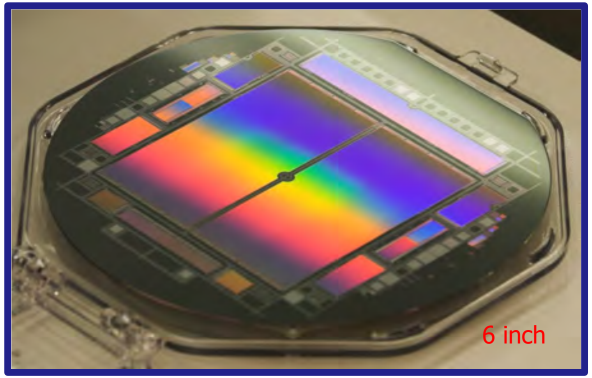
System test facilities

Highlights from the past

- **NA11 - NA32 experiments at CERN (1982 -1988) [MPP]**
  First usage of silicon strip detectors in the high energy physics
- **XMM Newton (launch 1999) [MPE]**
  Large area device with 100% fill factor, and very sensitive entrance window
- **ATLAS (2004) [MPP]**
  development at HLL, fabrication at industry, 3.000 wafers produced
- **LAMP (2011 – 2014) [CFEL]**
  Photon sicence: Large area device with ultra sensitive entrance windows



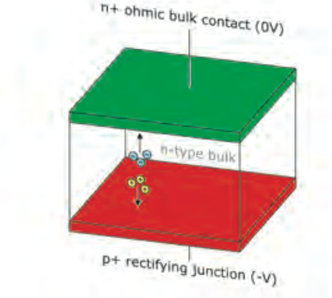




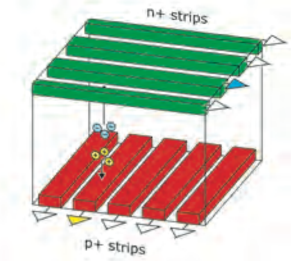
Devices @ HLL

- **Building blocks**

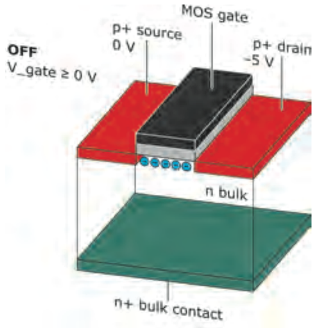
Diodes



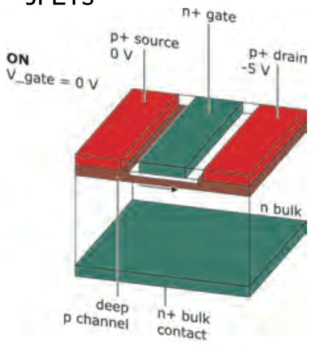
Strip detectors



MOSFETs

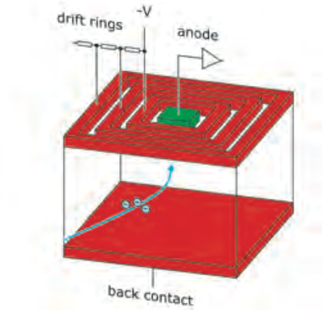


JFETs

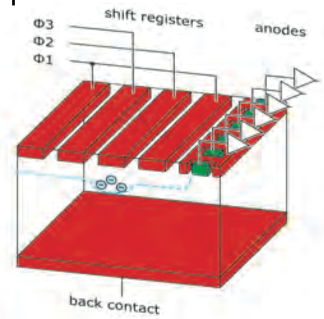


- **Devices**

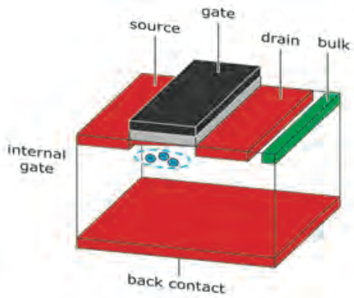
Silicon drift detectors (SDD)



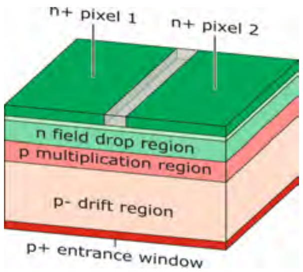
pnCCDs



DEPFETs

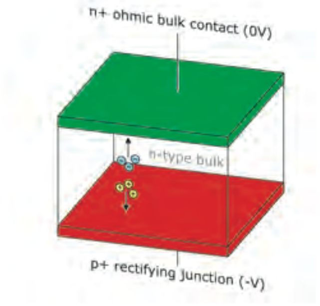


Avalanche devices



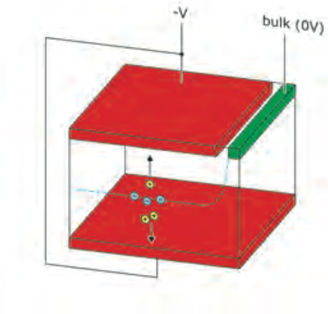
Advanced detector concepts

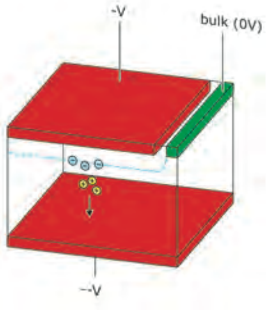
Diode



Sideward depletion structure
Emilio Gatti & Pavel Rehak, 1983

Symmetric bias and Asymmetric bias





- ▷ electronic noise

$$ENC = \sqrt{\frac{2kT}{g_m} C_{tot}^2 A_1 \frac{1}{\tau} + 2\pi a_f C_{tot}^2 A_2 + q I_L A_3 \tau}$$

- ▷ optimum shaping time

$$\tau_{opt} = \sqrt{\frac{2A_3}{A_1} \frac{kT}{q} \frac{C_{tot}^2}{I_L} \frac{2}{3g_m}}$$

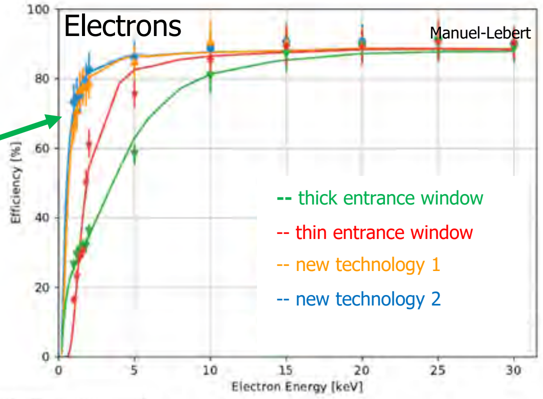
↳ for **good energy resolution and high count rate capability**

the total capacitance must be minimized!!

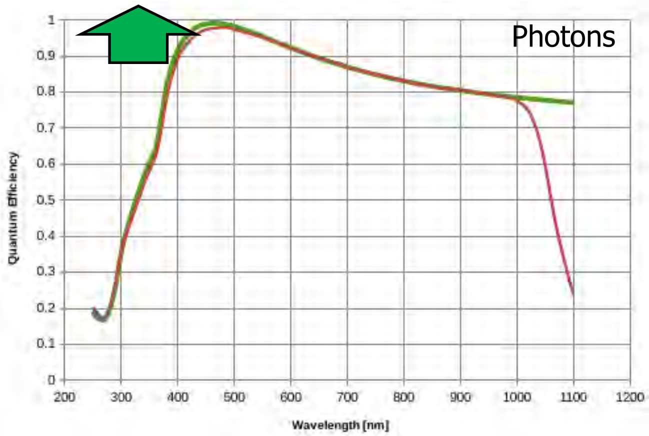
- ▷ volume is fully depleted by reverse biased diodes on both surfaces
- ▷ minimum capacitance of bulk contact, independent of overall area
- ▷ potential minimum for majority carriers (electrons @ n-Si)

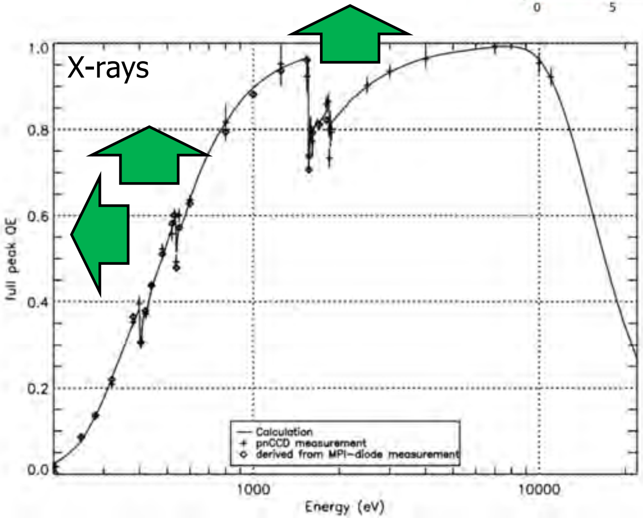
Entrance window engineering – application optimization

- anti-reflective coating (ARC)
  - ▷ sequence of dielectric layers deposited on the entrance window
  - ▷ variation of material and thickness
  - ▷ transmittance tuning to application needs
  - ▷ blocking filters
  - ▷ mechanical protection
  - ▷ optical coupling



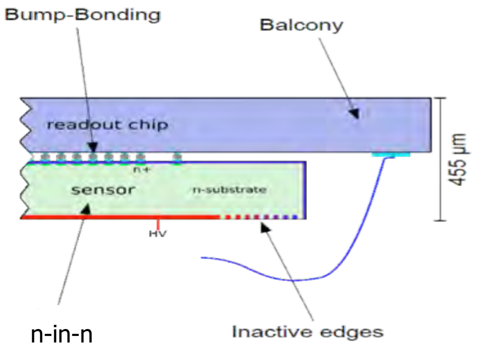
Ongoing developments
Reduction of dead layer to < 20nm



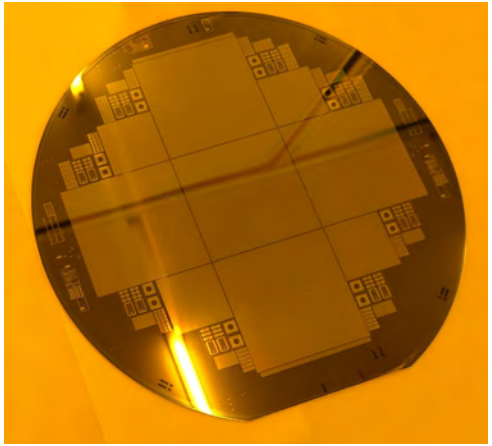


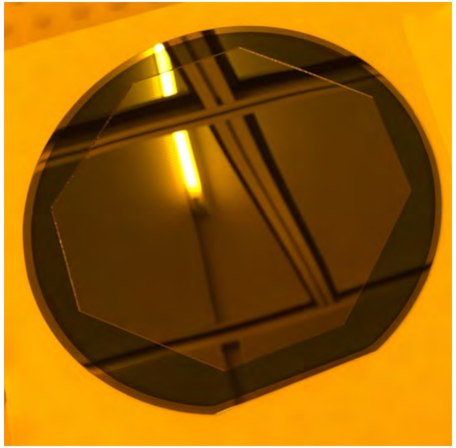
PAD detectors for ATLAS

Thin planar sensors for high luminosity upgrade of ATLAS experiment
→ Collaboration partner Max Planck for Physics



- 100µm thin sensors
- 50x50µm2 pixels





Advanced detector concepts – Silicon drift detector

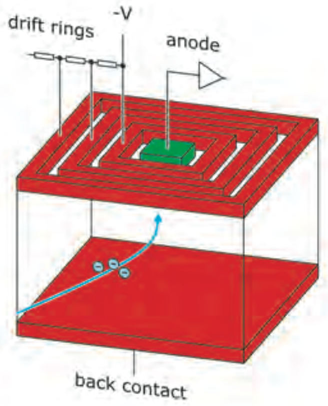
spectroscopy SDD - Josef Kemmer & Gerhard Lutz, 1987

one-sided field strip system

▷ non-structured backside diode

↳ optimized for photon spectroscopy

↳ irradiation through homogeneous thin entrance window



SDD with on-chip FET - Peter Lechner et al., 1994

backside illuminated

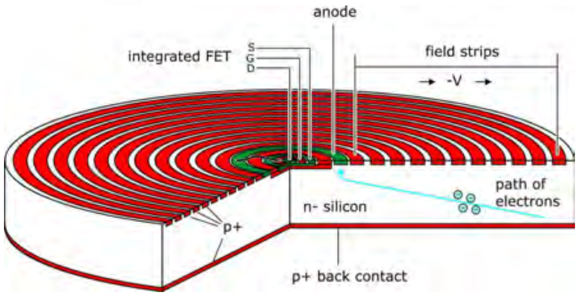
▷ integration of 1st amplifying FET

↳ minimization of total capacitance

↳ good energy resolution

↳ high count rate capability

↳ robust against pickup, microphony



- pin diode 10 mm² x 300 µm **C_{tot} = 3.5 pF**
- SDD with FET 10 mm² **C_{tot} = 150 fF**

▷ Application: X-ray spectroscopy (XRF, EDX)
γ-ray imaging (scintillator readout)

SDD highlights

Mini SDD - DSSC @ EuXFEL
(imaging of X-ray diffraction patterns)

M. Porro et al., *The MiniSDD-based 1-Megapixel Camera of the DSSC Project for the European XFEL*, IEEE TNS 68(6), pp. 1334 - 1350, June 2021

camera	**1024 x 1024 pixels** 21 x 21 cm² 32 sensor chips 4 quadrants central hole for direct beam
sensor	mini-SDD cells 128 x 256 pixels 3.0 x 6.2 cm² (chip)
hex. pixel pitch	204 μm × 236 μm
energy range	**0.25 keV – 6 keV**
noise	60 el. r.m.s.
peak frame rate	**4.5 MHz**
frame storage	800 frames

eXTP (enhanced X-ray Timing and Polarimetry) SFA (spectroscopic focusing array)
(fast time-resolved X-ray spectroscopy)

SDD layout plot

SFA instrument	11 telescopes & sensors sensors out of focus
sensor	**19-cells SDD**
SDD cell	hexagonal 3.2 mm side length **30 mm² area**
energy resolution	< 180 eV (FWHM @ 6 keV)
time resolution	< 10 μsec

TRISTAN (tritium sterile anti-neutrino) @ KIT
sterile neutrino search by electron spectroscopy

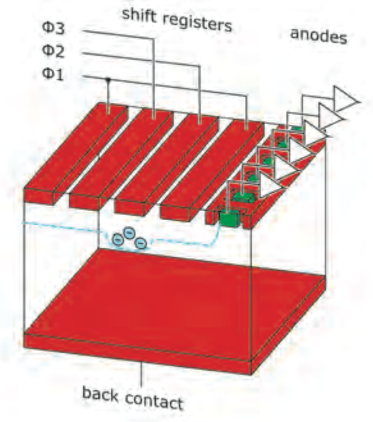
TRISTAN focal plane, 21 modules.

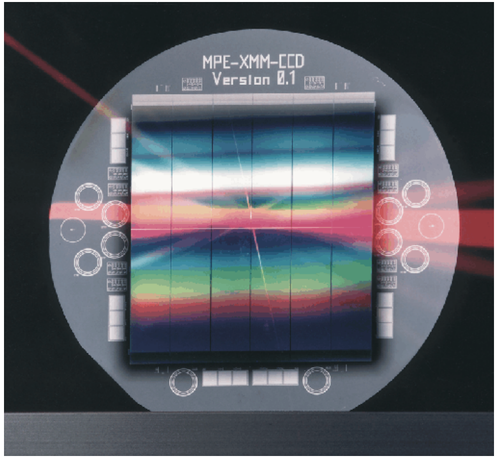
system	21 sensors **20 cm diameter**
sensor	SDD with integrated FET **166 cells (~ 14 x 12 array)** **3.8 x 4.0 cm² (chip)**
SDD cell	hexagonal, 3 mm side length 7 mm² area
energy resolution	< 300 eV FWHM @ 20 keV
count rate	≤ 10^8/sec on focal plane ≤ 10^5/sec on sensor cell
dead layer	**as thin as possible**

Advanced detector concepts - pnCCD

pnCCD - Lothar Strüder et al., 1987

- ▷ definition of potential pockets by differently reverse-biased diodes
- ▷ charge transport by periodic clocking of shift registers
- ▷ column-parallel readout → high frame rate (~4 μs /row)
- ▷ integrated 1st FET (1 / column) → low noise (<2el. ENC)
- ▷ backside illuminated, fully depleted → high quantum efficiency





▷ applications
- X-ray imaging & spectroscopy
- optical light imaging

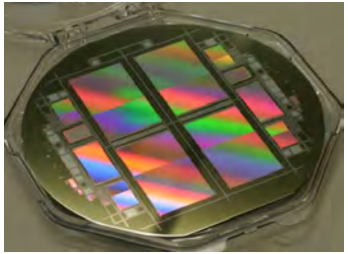
pn-CCD for XMM-Newton (since 1999 in space)
- produced at MPG HLL

- monolithic 6 x 6 cm²
- pixel size 150 x 150 µm²
- format 384 x 400 pixel

World leading soft X-ray large area pnCCD devices @ MPG HLL

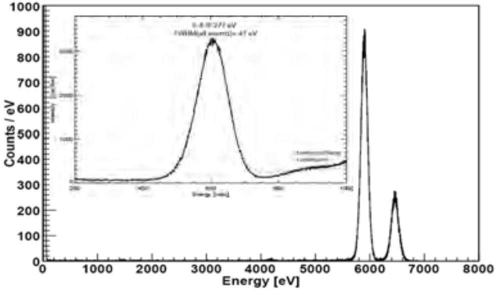
MAX PLANCK SEMICONDUCTOR LABORATORY

eROSITA
X-ray imaging & spectroscopy

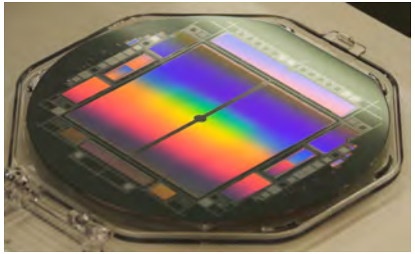


Sensor: 3 x 3 cm^2
384 × 384

Pixel size: 75 x 75 μm^2
Frame time: 50msec (20Hz)

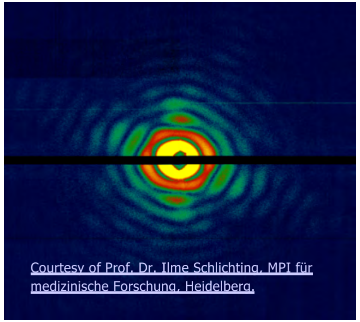


CAMP / LAMP
Soft Xray camera for Photon science

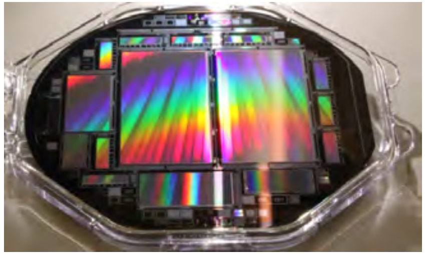


Sensor: 3.7 x 7.8 cm^2
1024 × 512 pixels.

Pixel size: 75 x 75 μm^2
Frame time: 8 msec (up to 120Hz)

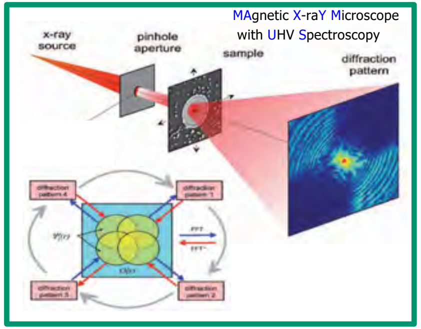


FSP – TNG for MAXIMUS
Fast Small Pixel – The Next Generation



Sensor: 3.7 x 7.4 cm^2
1024×1024 +(2x512) pixels

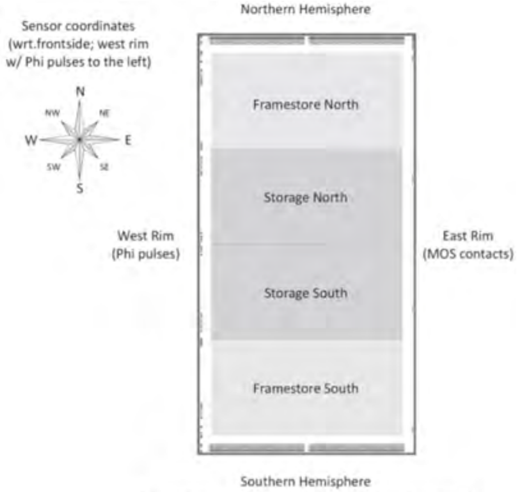
Pixel size: 36 x 36 μm^2
Frame time: 2.5 msec (400Hz)



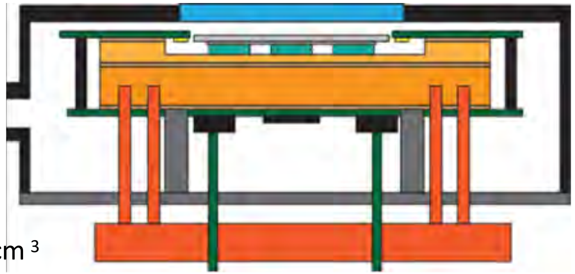
Fast Small Pixel pnCCDs (FSP) @ HLL

Device characteristics:

- pnCCD concept:
  - Backside illuminated,
  - frame store,
  - split frame,
  - column-parallel readout
- Format: **1k x 1k** storage, 2 x 1 k x 0.5 k framestore
- Pixel size: **36 x 36** μm^2
- Total sensitive area: 36.8 x 73.3 mm^2
- Total chip size: 4.2 x 8.1 cm^2
- Operating temperature: -35°C (target)
- Target operating frame rate: **400 Hz** (~4 μs /row)
- Data rate: 840 Mbyte / s (16 bit)

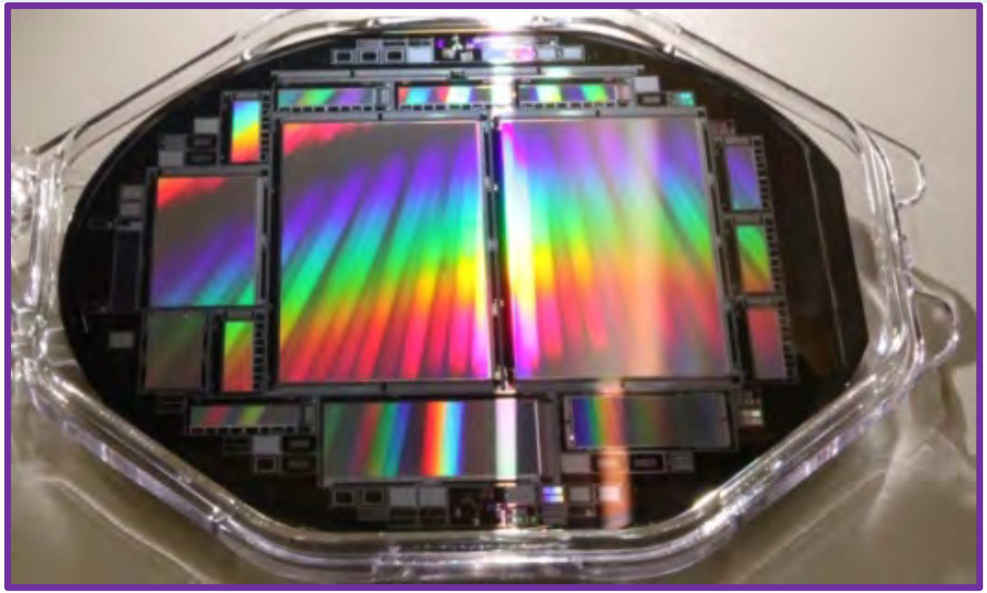


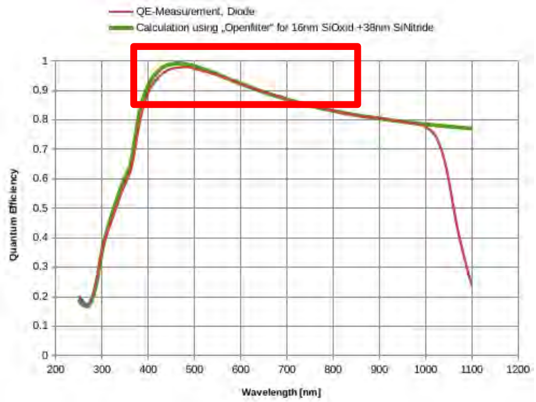
Frame store, split frame, column parallel readout pnCCD



Compact vacuum-tight camera housing ~ 18 x 25 x 10cm ^{3}

FSP production



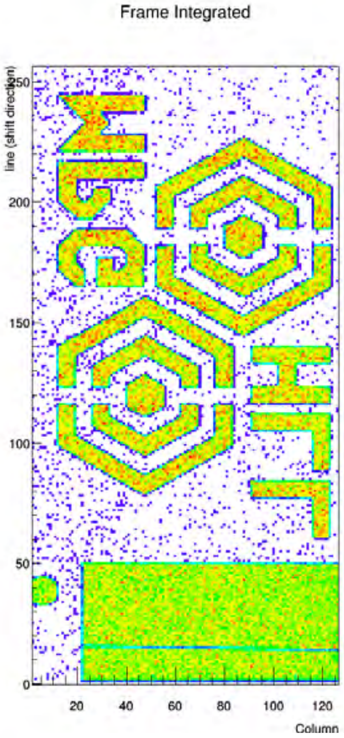


Optimized for two applications:
Soft X-rays and optical application

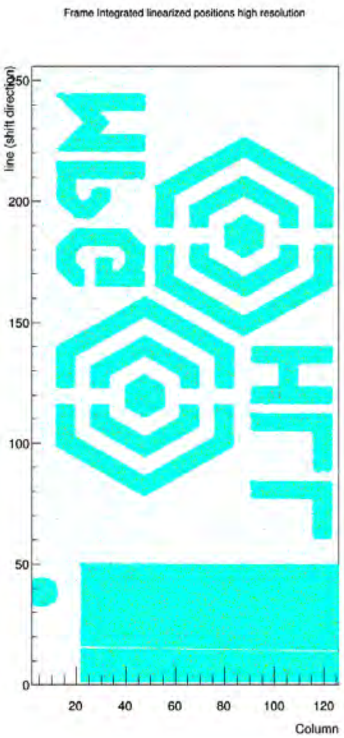
X ray imaging using small pixel pnCCDs

Imaging of a collimated Fe^{55} Source through a mask + goldwire

Mikroscope Image of mask and wire in front of the pnCCD.

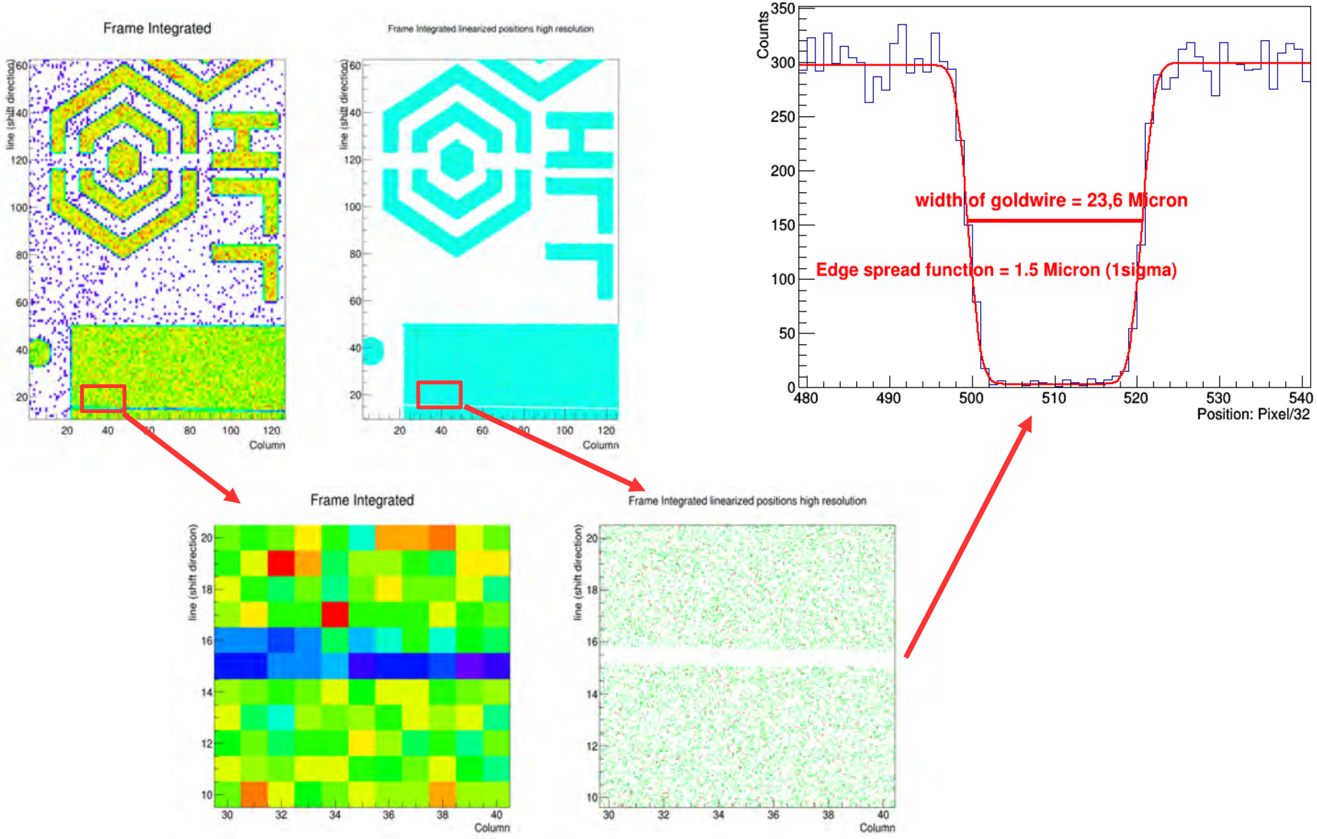


Frame as obtained by integrating Photons per pixel



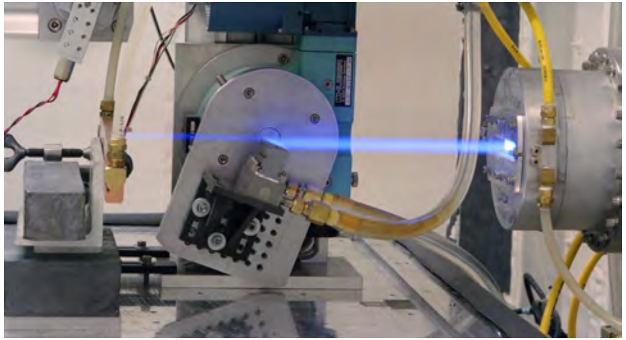
Frame as obtained by cluster reconstruction and integration per subpixel (32x32 subgrid)

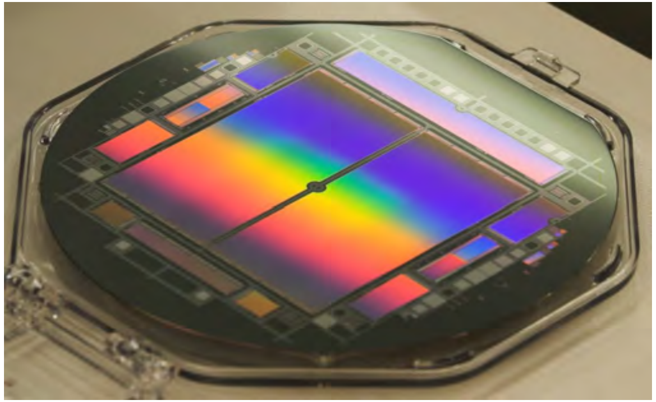
Image Resolution for Cluster Imaging @ 5.9 keV



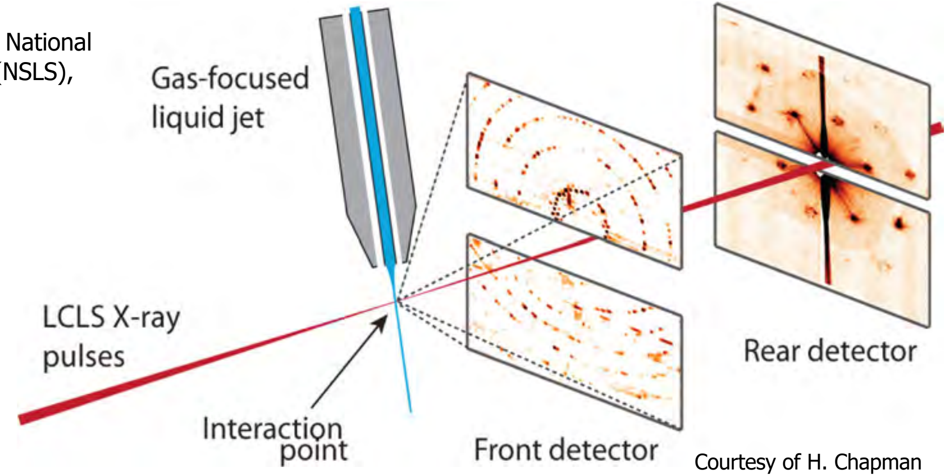
FEL radiation detection

- Sensors for LCLS (collaboration partner MP Extraterrestrial Physics)





Synchrotron light from the National Synchrotron Light Source (NSLS), Brookhaven

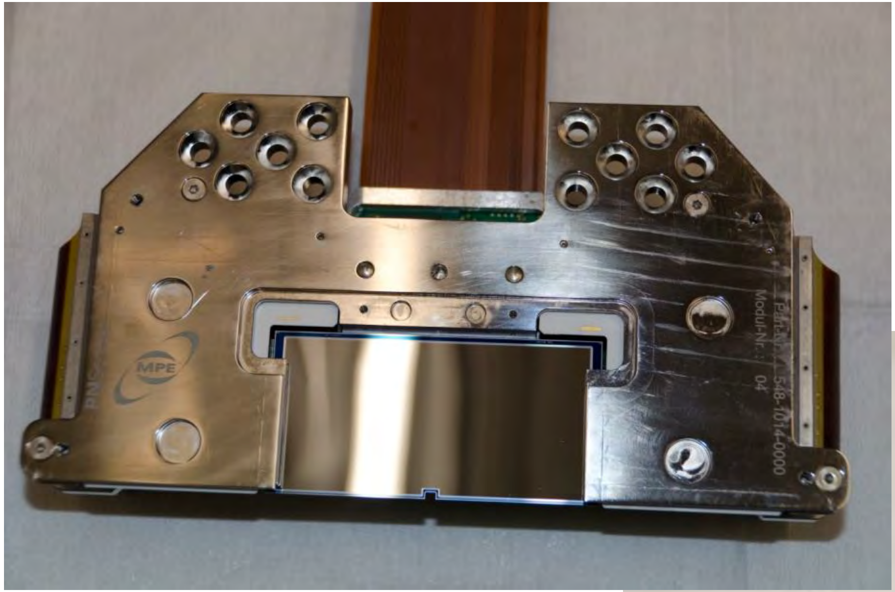


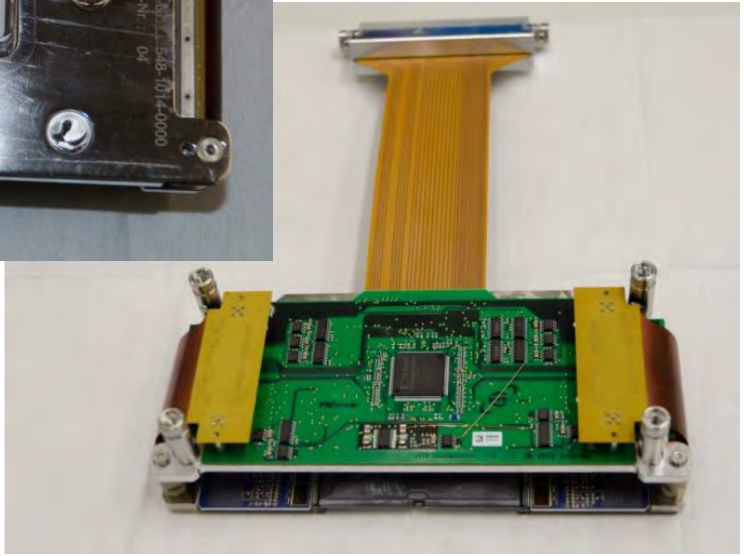
Courtesy of H. Chapman

- Large area pnCCDs: 30 cm^2
- 1024 x 512 pixel of 75 x 75 μm^2
- 3.7 x 7.8 cm^2

LAMP module

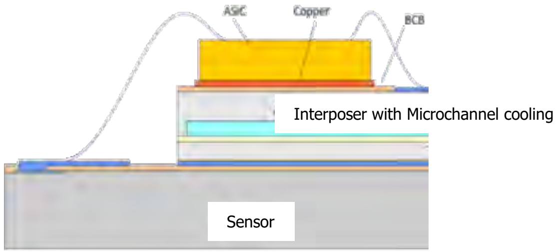
MAX PLANCK
SEMICONDUCTOR
LABORATORY

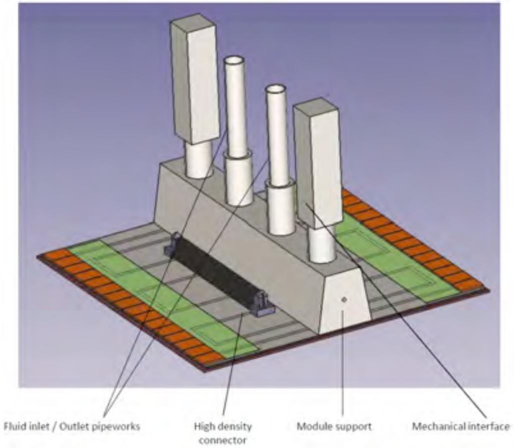


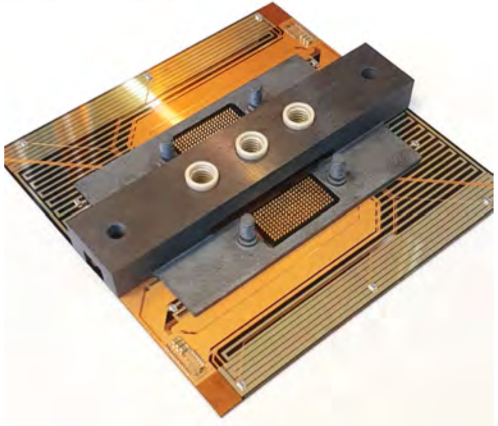


In development - four side buttable pnCCDs

- no frame store
- Split frame, column parallel readout for optimized framerate
- 75 x 75 μm^2 pixels
- 1 MPixel array
- Sensitive area 76.8 x 76.8 mm^2
- Narrow guard ring structure
- Chip size 77.65 x 78.05 mm^2
- 2 times 1024 JFETs read simultaneously
- Readout with 2 x 16 VERITAS II ICs with 64 channels each





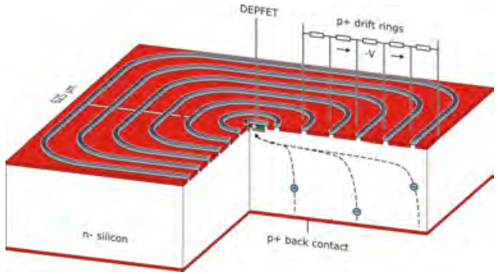


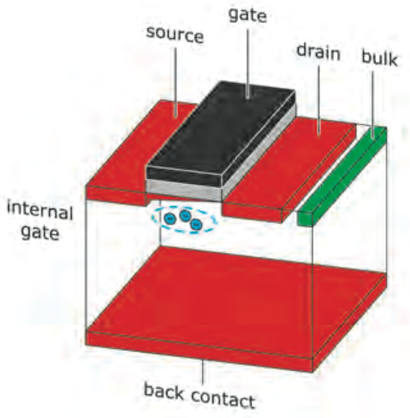
Goal:
More compact system design by improving the electronics integration density.
Lightweight mechanical design to reduce both thermal and inert mass.
Device independent platform.
Versatile use cases. - sensors to be 4-side buttable with minimum sensitivity gap
More compact sensor design minimal guard ring structure
Standardized data I/O interfaces - high-performance FPGA based hardware as smart backend in the system.
Integrated housekeeping and diagnosis functions

DEPFET - Josef Kemmer & Gerhard Lutz, 1987

▷ p-MOSFET on fully depleted n-substrate

- fully depleted sensitive volume
  - fast signal rise time (~ns), small cluster size
- Fabrication at MPG HLL
  - Wafer scale devices possible
  - no stitching, 100% fill factor
- Charge collection in "off" state, read out on demand
  - potentially low power device
  - Non destructive readout
- internal amplification
  - charge-to-current conversion (500 pA/el.)
  - large signal, even for thin devices
  - r/o cap. independent of sensor thickness (20 fF)





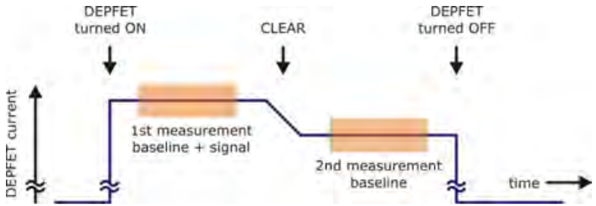
▷ applications
- unit cell of active pixel sensor
  - ↳ X-ray imaging & spectroscopy
  - ↳ particle tracking
- integrated readout device of SDD, CCD, …

▷ format	~ cm² … wafer scale
▷ thickness	25… 450 µm
▷ pixel size (DEPFET & SDD)	20 … 150 µm … 1 cm²
▷ readout time	90ns …4 µsec / row
▷ low noise	down to <2 el. ENC

Advanced detector concepts

DEPFET readout

▷ readout sequence

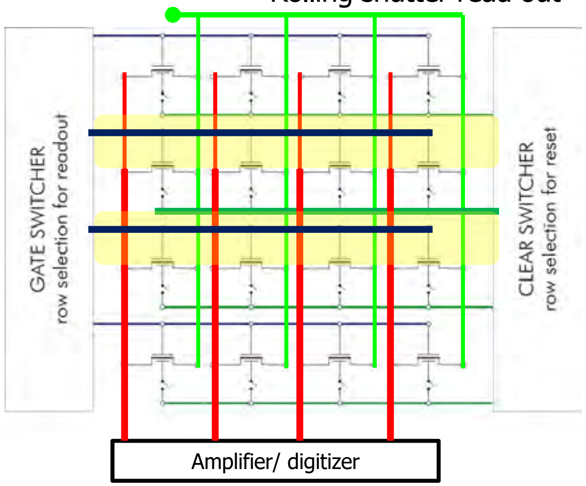


- Double sampling
  - 1st measurement: signal + baseline
  - clear: removal of signal charges
  - 2nd measurement: baseline
  - difference = signal
- Single sampling
  - Measure pedestals and store
  - Read once and clear

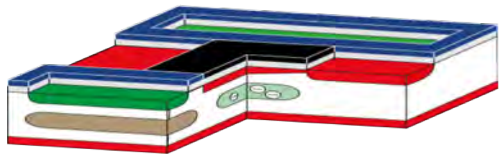
▷ active pixel sensor operation

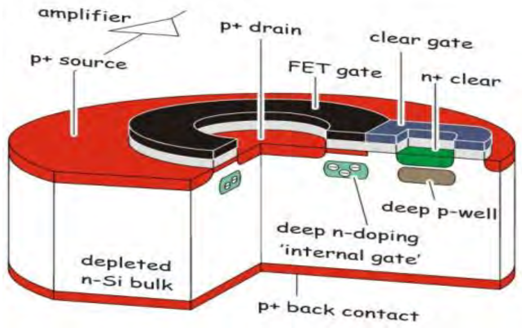
- horizontal supply lines, row selection
- vertical signal lines
- 1 active row, other pixels integrating

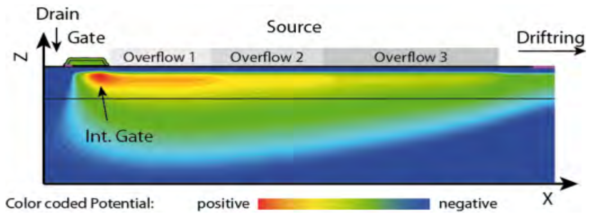
Rolling shutter read out



DEPFET classes







Thin & small pixel: vertex, low E electron detectors (TEM)

pixel size: 20µm…75µm
read out time per row: 25ns-100ns
Noise: ≈100 el ENC
thin detectors: 50µm…75µm → still large signal: 40nA/µm for MIP

Low noise: Spectroscopic X-Ray imaging

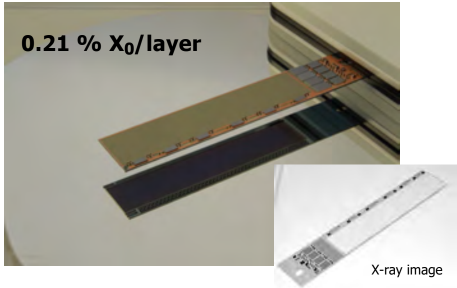
pixel size: 100µm, with drift rings several 100s of µm
read out time per row: few µs
Noise: ≈4 el ENC
fully depleted, the thicker the better → large QE for higher E

High Dynamic range

DEPFET **S**ensor with **S**ignal **C**ompression
Sensitivity to single photons and high dynamic range
pixel size: 60 -200 µm

Highlights from DEPFET projects

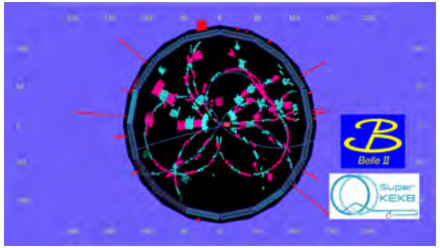
BELLE II pixel detector
High energy particle vertexing



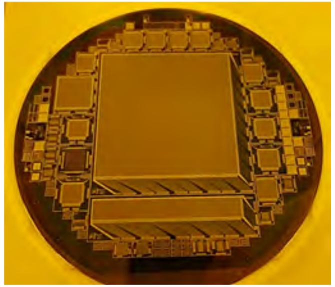
Active area	12.5 x 44.8(61.44)mm^2
	250 x 800 pixels
	Thickness: **75 µm**

rolling shutter mode

Pixel size:	50 x 55(85) μm^2
Frame time:	20ms (50kHz) (10MHz -row)



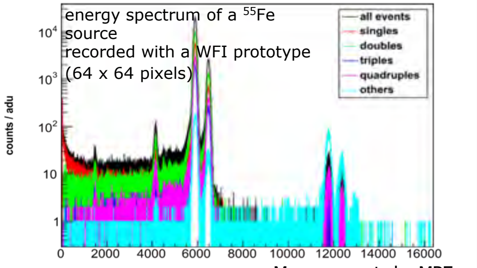
ATHENA Wide Field Imager
the **A**dvanced **T**elescope for **H**igh-**En**ergy **A**strophysics
as ESA's next-generation X-ray astronomy observatory



Sensor:	512 x 512 pixels
	78.00 x 76.15 mm²

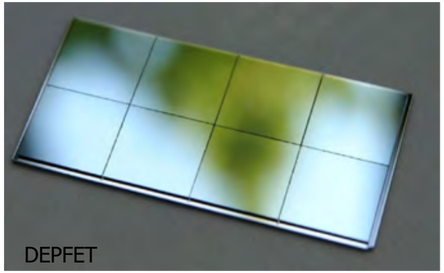
rolling shutter mode

Pixel size:	130x 130 μm^2
Frame time:	**1.28 msec, i.e. 2.5 µsec / row**
	with 128 eV (singles) & 136 eV (all)



Measurements by MPE

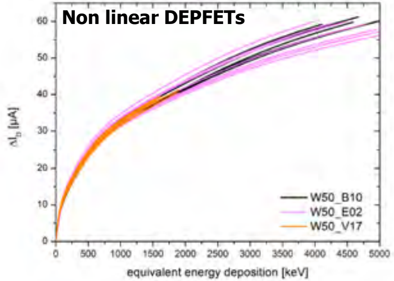
DSSC @ EuXFEL
DEPFET **S**ensor with **S**ignal **C**ompression
(imaging of X-ray diffraction patterns)



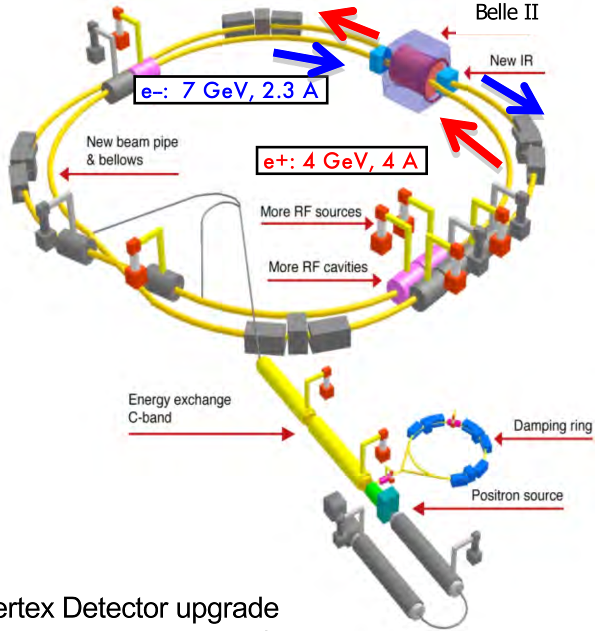
Sensor	**2.56 x 10.24 cm²**
	512 × 128 pixels

Hybrid detector
with 8 readout ASICs (64x64)

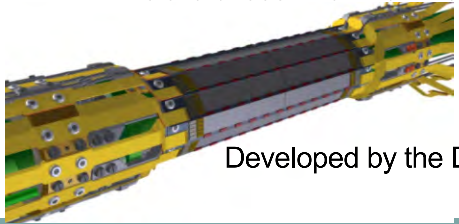
Pixel size:	204 x 236 μm^2
Frame time:	**220ns (4.5MHz)**



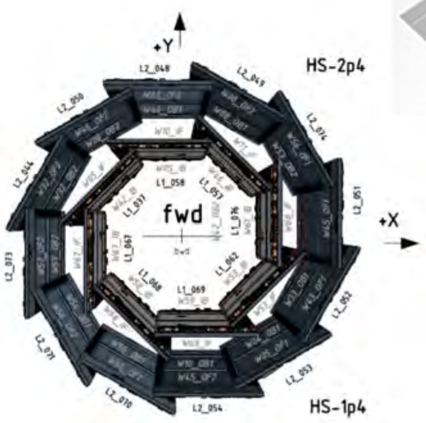
BELLE II @ SuperKEKB

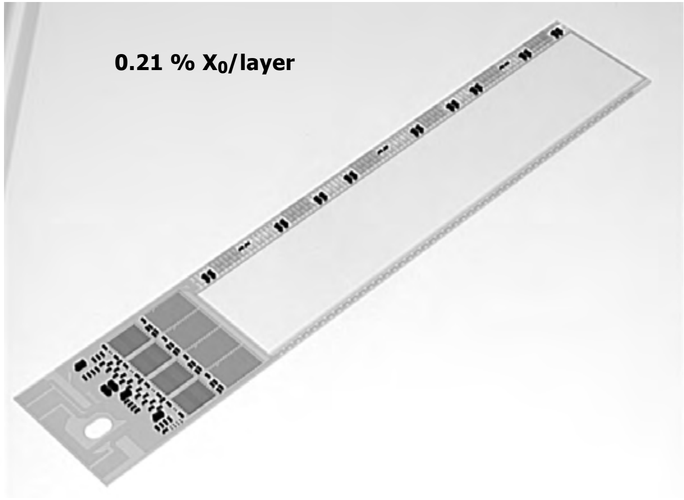


Vertex Detector upgrade
DEPFETs are chosen for the inner layers



Developed by the DEPFET collaboration





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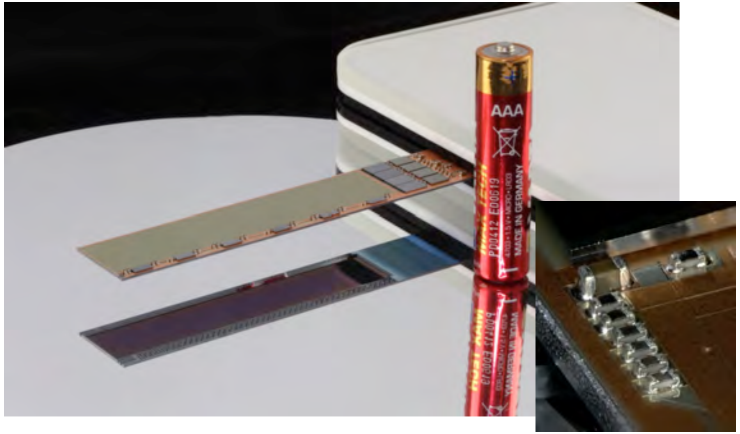
250 x 800 pixels
Thickness: **75 μm**

rolling shutter mode

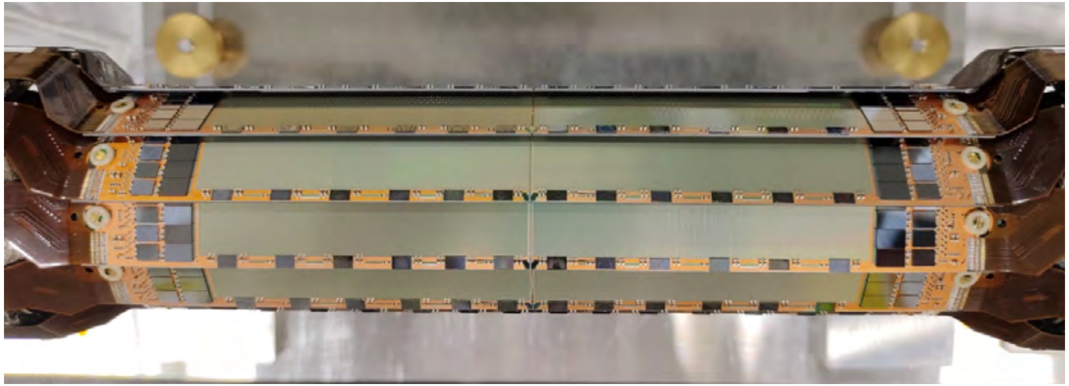
Pixel size: 50 x 55(85) μm^2

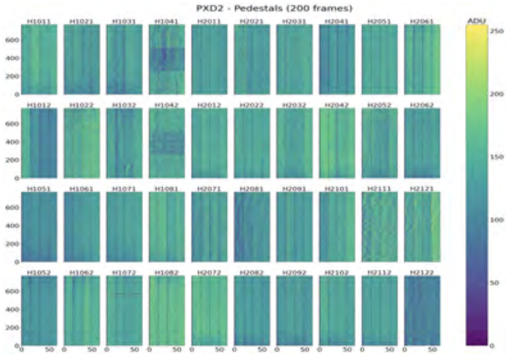
Frame time: 20ms (50kHz) (10MHz -row)

BELLE II @ SuperKEKB



In Japan

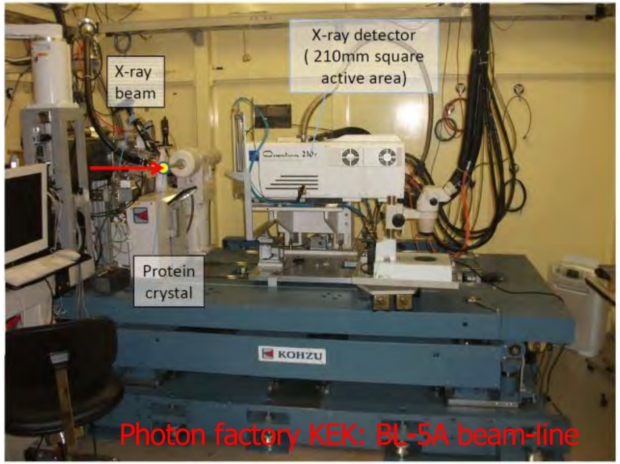


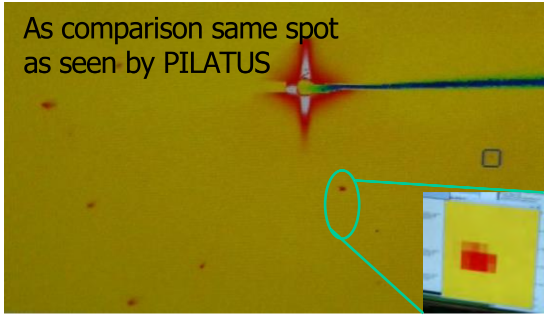


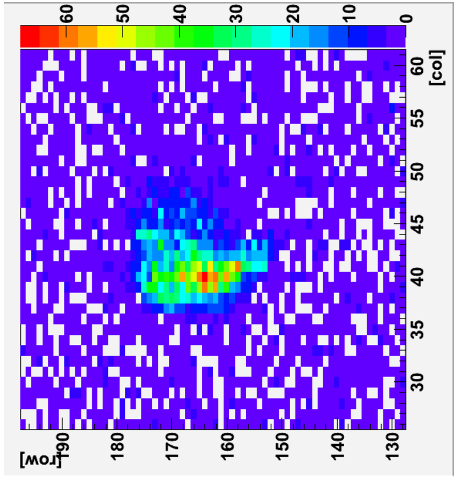
BELLE & ILC DEPFETs for Photon Science

First tests: slow readout system 2.3ms frame readout time (signal integration time) with about 150Hz DAQ readout rate (one frame is read out every 6ms)

Matrix – ILC type $24 \times 32 \mu m^2$ pixel $450 \mu m$ thick
$5120 \mu m \times 1280 \mu m$ (256 x 64 pixels)



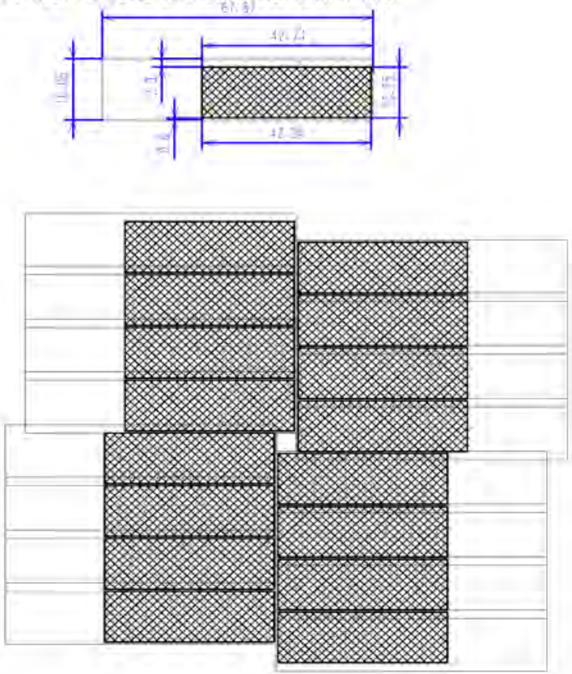


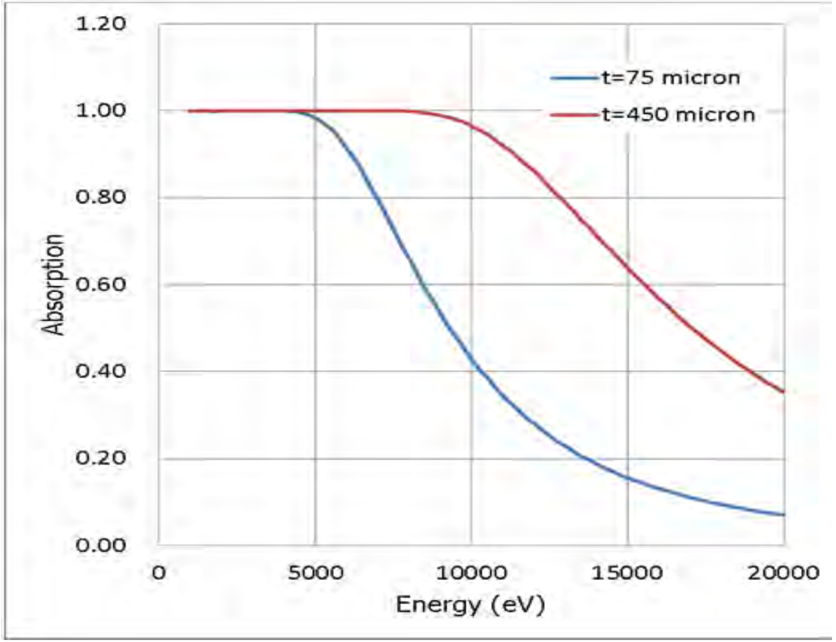


Lysozyme crystal – position of diffraction spots defined by PILATUS and then DEPFET matrix driven to that point

BELLE like sensors (20μs) for PF KEK

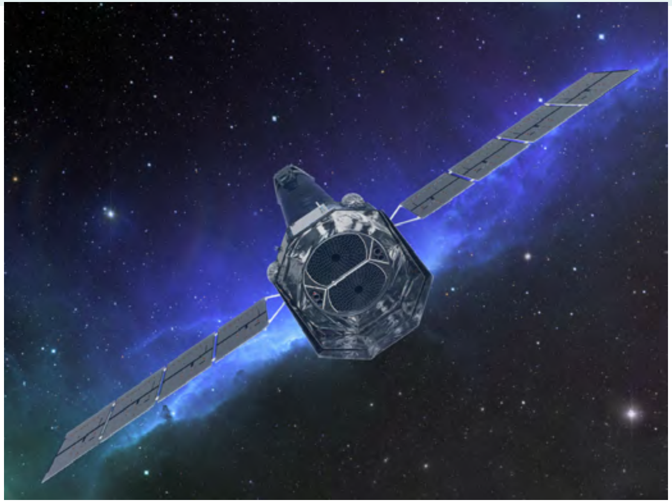
pixel size: 55 um x 55 um
number of rows and columns: 250 x 768



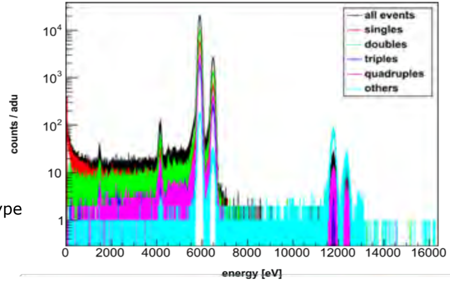


ATHENA mission

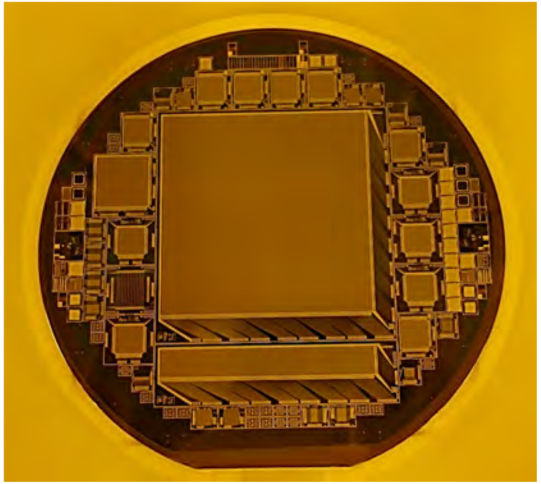
- ESA mission
  - large X-ray observatory
- science targets
  - theme 'The Hot & Energetic Universe'
    - formation of large scale structures
    - evolution of black holes
- scenario
  - launch > 2035
  - Ariane 5 carrier
  - halo orbit around Lagrange point L2
  - design life time 5 y (+5 y)
  - 300 observations per year



Sensor: 512 x 512 pixels
78.00 x 76.15 mm²
rolling shutter mode
Pixel size: 130x 130 μm^2
Frame time**:** **1.28 msec, i.e. 2.5 μsec / row**
with 128 eV (singles) & 136 eV (all)



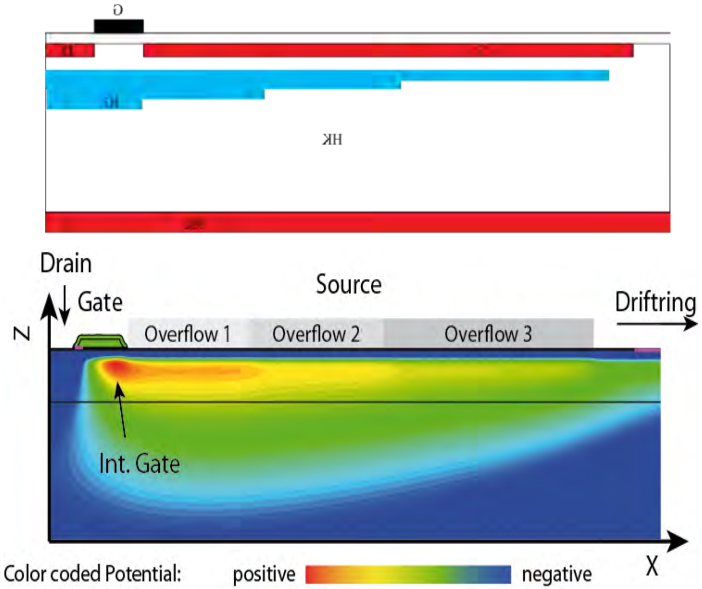
energy spectrum of a ^{55}Fe source
recorded with a WFI prototype
(64 x 64 pixels)



Detector Concept – DEPFET with signal compression

Motivation: develop detector with high dynamic range and preserve other advantages of DEPFETs

DSSC - **D**EPFET **S**ensor with **S**ignal **C**ompression



- The internal gate extends into the region below the source
- Small signals assemble below the channel, being fully effective in steering the transistor current
- Large signals spill over into the region below the source. They are less effective in steering the transistor current.
- 200 x 200 µm pixel has been designed and produced
- 60 x60 µm pixel has been designed and is being produced now

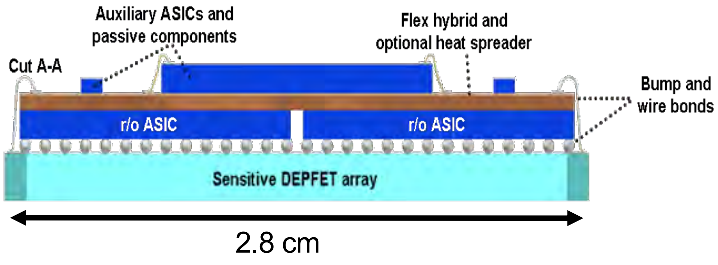
Requirements for the XFEL detectors

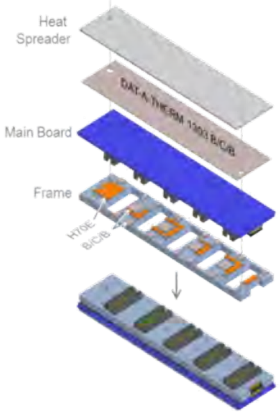
Integrating Area Detector

	XFEL (e.g. XPCS)	DEPFET array system
single photon resolution	yes	yes
energy range	0.5< E < 24 (keV)	0.5 < E < 25 [keV]
ang. resolution or pixel size	4 µrad	200 µm
sig.rate/pixel/bunch	10^3	10^3@10KeV
quantum efficiency	> 0.8	> 0.8 from 0.3 to 12 keV
number of pixels	512 x 512 (min.)	1024 x 1024
frame rate/repetition rate	10 Hz	yes, triggerable
XFEL burst mode	5 MHz (3.000 bunches)	4.5 MHz
Readout noise	< 150 e^- (rms)	< 50 e^- (rms)
cooling	possible	- 20° C optimum, room temperature possible
vacuum compatibility	yes	yes
preprocessing	no (yes) ?	possible upon request
4-side buttability	yes	yes

DSSC - Focal Plane

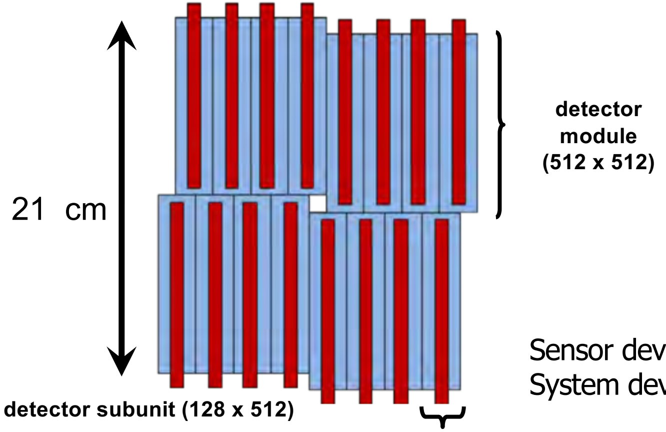
Submodule 128x512



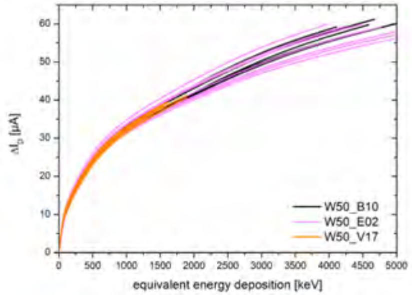


Multi Chip Modules

- DEPFET Sensor bump bonded to Readout ASICs
- Optional Heat spreader
- Flex Hybrid with passive components and auxiliary ASICs (e.g. voltage regulators)
- Sensor (512x128 pixels) 2.56x10.24 cm^2
- 16 readout ASICs (64x64)
- Dead area: 10-15%



Fully functional devices delivered in early 2015

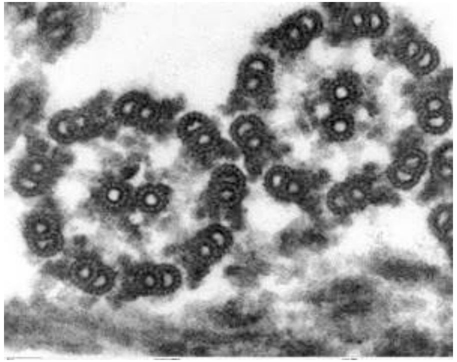


Sensor development by MPG HLL
System development by DSSC collaboration

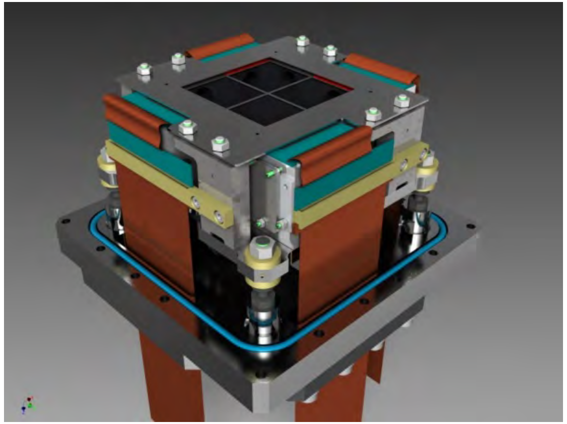
DEPFETs for low E electron detectors

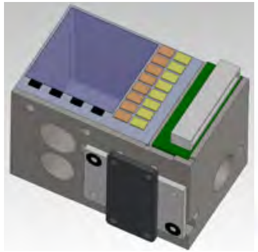
Goal: develop high speed direct hit low energy electron detector
Solution: thin, nonlinear DEPFETs with 80kHz frame rate

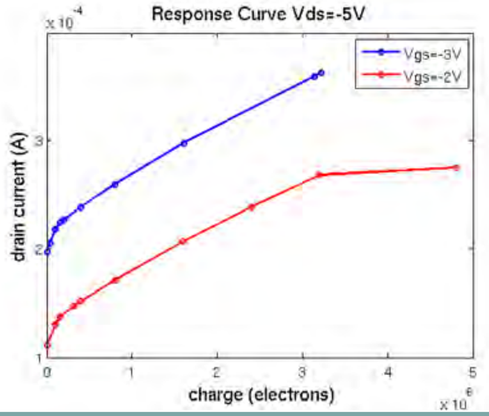
- 1Mpix, 60µm DEPFET pixel, 4 quadrants, 6x6 cm^2 sensitive
- 1-3 M electrons to store into internal gate
- 30-50µm thin sensitive area
- Bidirectional 4-fold read out, frame rate: 80kHz
- memory to store ~ 60 frames



(collaboration partner MP Structural Dynamics)

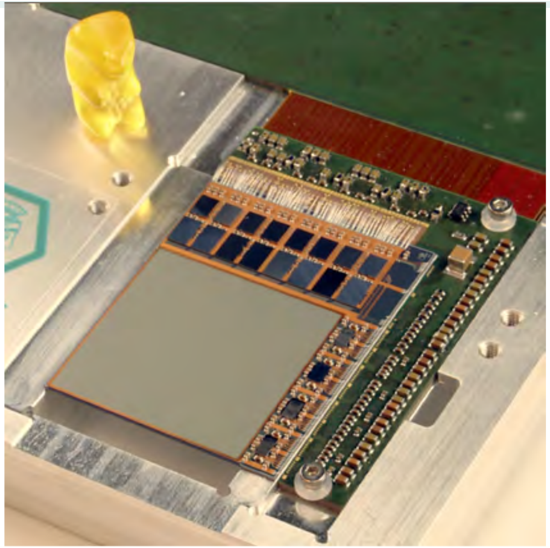






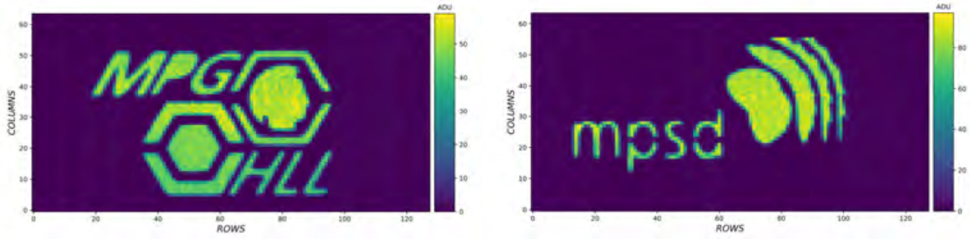
DEPFETs for low E electron detectors

MAX PLANCK SEMICONDUCTOR LABORATORY

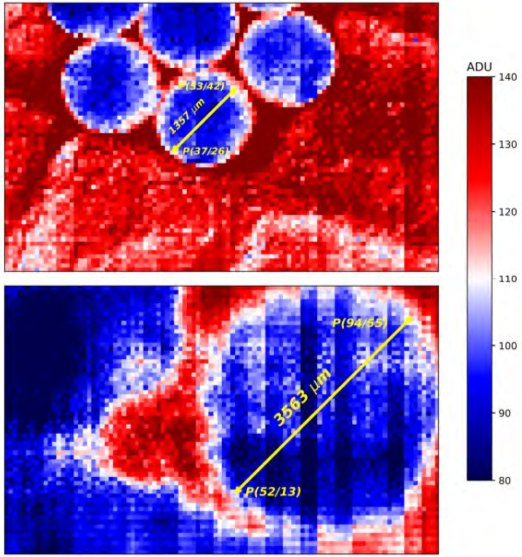


Edet 80k assemblies (30-50μm thin sensors)

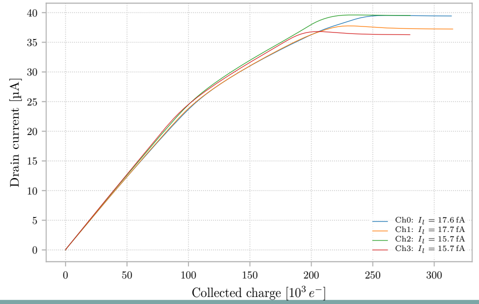
Tests with small format prototype devices



Images of 261 nm latex spheres for calibration purposes



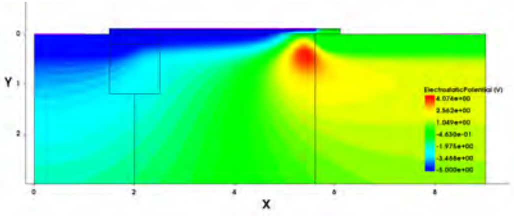
First measurements on the non linear characteristics



DEPFETs – advanced concepts

Super g_q DEPFETs – Super high S/N

- New DEPFET technology allows **improved S/N** of a factor of 3
- better S/N -> better spectroscopic applications (**ENC>1e-**)
- **High speed** readout devices
- **High precision** devices
- **High dynamic range** DEPFETs
- thinner detectors
- Smaller bias current - **less power** in pixel area
- Thinner gate isolator - **higher radiation** tolerance

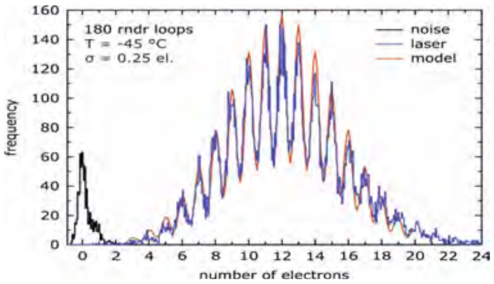


Combine different conceptual features

Create devices with multiple capabilities

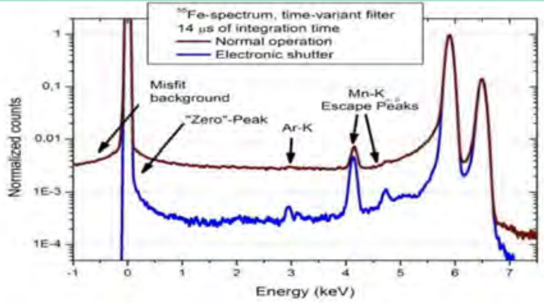
Repetitive readout – sub e⁻ resolution RNDR DEPFETs

- an equivalent noise of 0.2 e- is achieved in ~6ms with 180 transfers
- **Extremely low noise** and background suppression
- Experiments w/ single electron sensitivity (e.g. low light level astronomy)
- Extremely low background applications (e.g. dark matter detection)



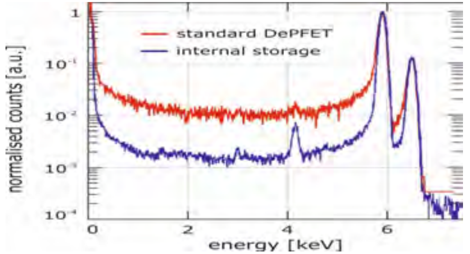
Gated DEPFETs - precise timing

- allows replacement of external shutters → better timing properties
- Sensors for experiments requiring **selective sensitivity**, e.g. light curve measurements, LIDAR, AO etc.



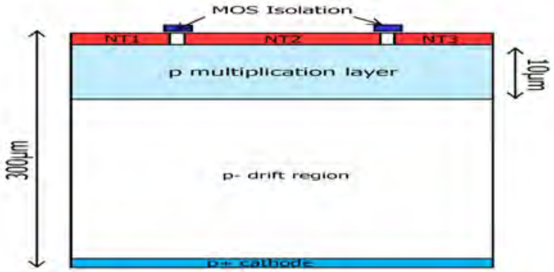
Multiple DEPFET structure – NO deadtime

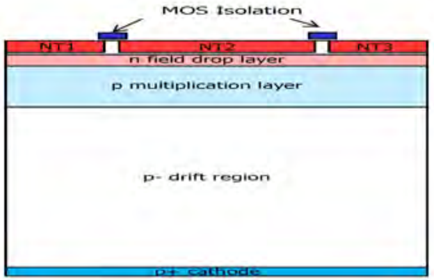
- superpixel is composed of two or more standard or advanced DEPFET subpixels, which are alternately used for the detection of charge.
- one subpixel is read out, while the other one is collecting new charge



MARTHA - **M**onolytic **A**rray of **R**each **T**hrough **APD**s

Initial motivation – develop low gain avalanche device with high fill factor for photon science applications



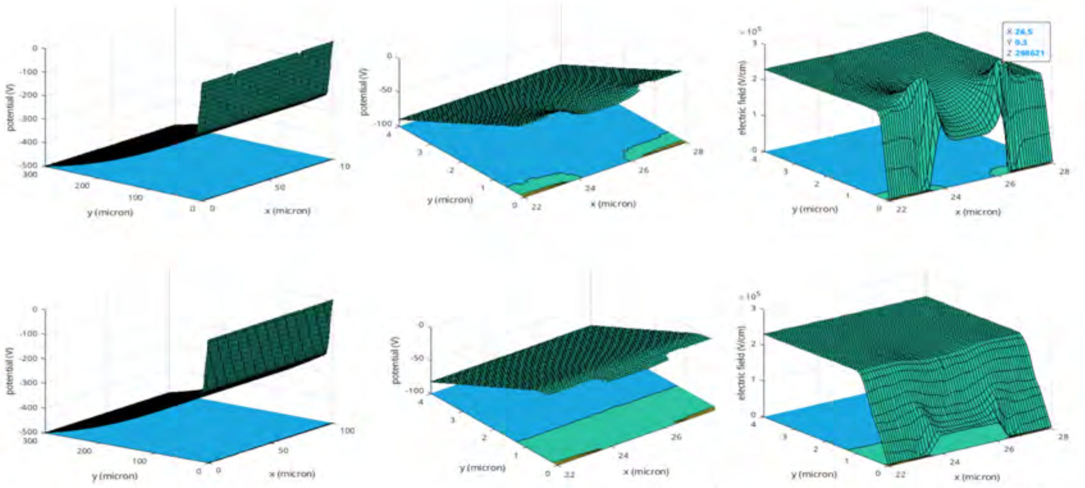


Potentials

E Field

HF region extends over pixel gaps

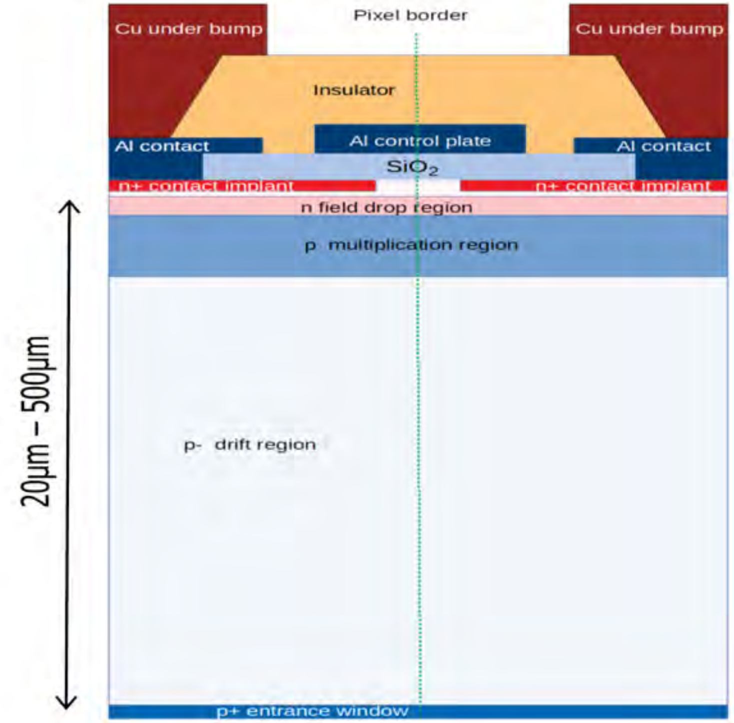
HF region and field drop layer extend over pixel gaps



V_{MOS}=3V

MARTHA - **M**onolytic **A**rray of **R**each **T**hrough **A**PDs

Initial motivation – develop low gain avalanche device with high fill factor for photon science applications



Expected features:

Gain up to 20

Collection efficiencies: > 99%

Pixel pitch: given by bump bond technology and read out electronics space consumption (ATLAS 50µm)

Position resolution: $<< \frac{pitch}{\sqrt{12}}$ ($<< 10\mu m$)

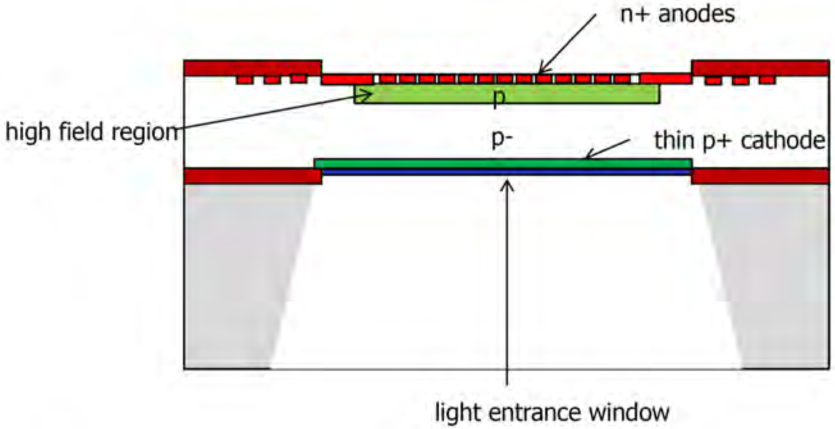
Time resolution:

Application dependent

- Leading edge trigger: <50ps
- Full signal formation 50ns (for thickness 500µm)

MARTHA - **M**onolytic **A**rray of **R**each **T**hrough **A**PDs

Faster device for particle tracking ? → Thinned Reach Through APD based on HLL SOI Technology



$t_{APD} \gtrsim 20\mu m$

$t\_handle\_wafer \approx 400\mu m$

t_{APD} = 20µm: drift times (triggering electrons + amplified holes) ≈ 0.5ns

Full signal formation 0.5ns (50ns for thickness 500µm)

MARTHA - **M**onolytic **A**rray of **R**each **T**hrough **A**PDs

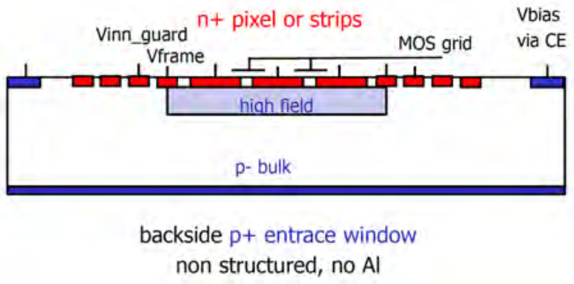
Proof of principle production ongoing on standard thick material

Aims

-proof of concept

-Efficiency, gain, cross talk and noise studies (vs T)

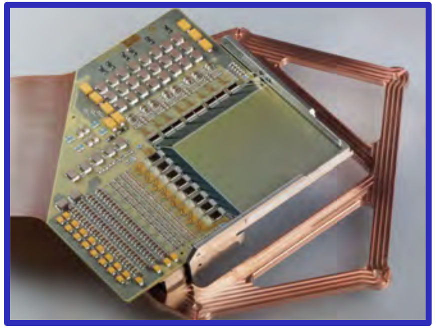
-find a reliable narrow guard ring structure (in view of high voltage operation, buttable arrays)



Designed structures:
Pixel arrays
Strip sensors
Diodes
Multi Guard Ring Test diodes

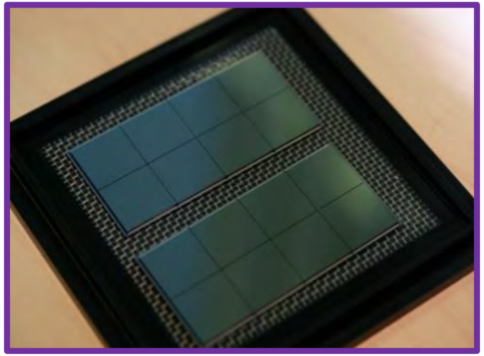
Interconnection technologies

Standard wire bonding (Al and Au)
Frame time: 1.28 msec,
i.e. 2.5 µsec / row

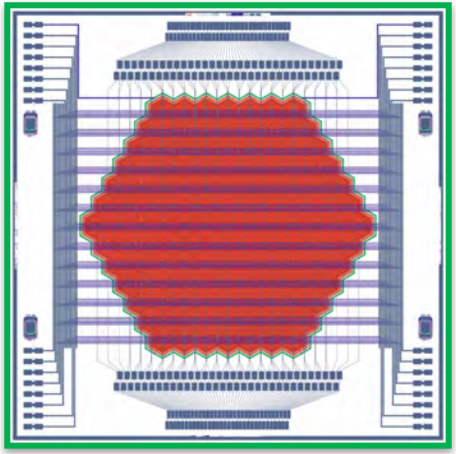


Athena WFI module
Courtesy MPE

Full parallel readout
dedicated wire routing
flip chip technology – hybrid detectors



DSSC module
With 8 CMOS chips
Frame rate: 4.5MHz



Full frame read-out DEPFET detector

application **ultra-fast X-ray timing & imaging**
frame rate **> 100 kHz**

sensor 127 hexagonal hexagonal pixels
cell diameter 800 µm

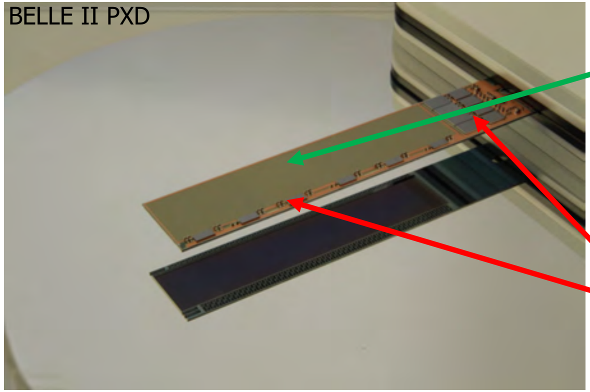
DePFET with internal storage

Interconnection technologies – All Silicon Module (ASM)

Sensor and Hybrid in one silicon piece

- Belle II Pixel detector – tracking of high energy particles
- EDET80k project – development of ultra fast direct electron detectors for TEM

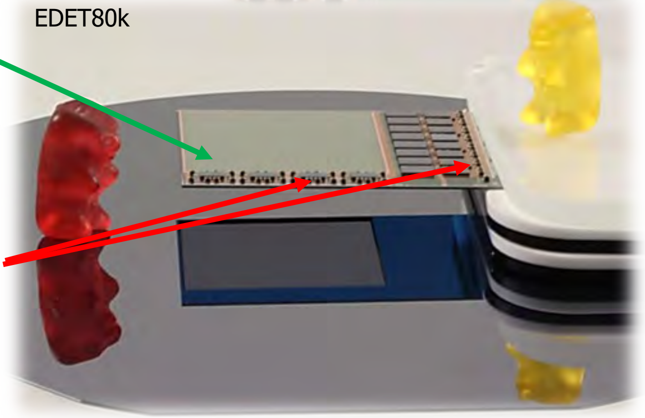
BELLE II PXD



Thin sensitive area with nonlinear DEPFETs

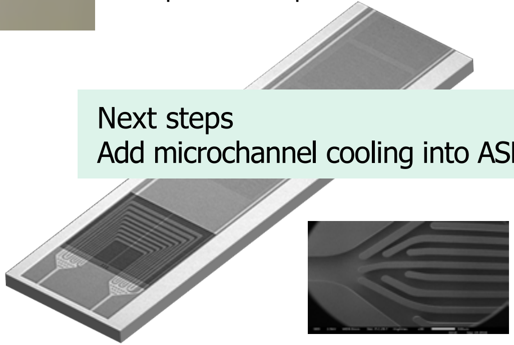
Thick silicon area for cooling and landing pads and interconnection for the read out and steering electronics and all passive components.

EDET80k



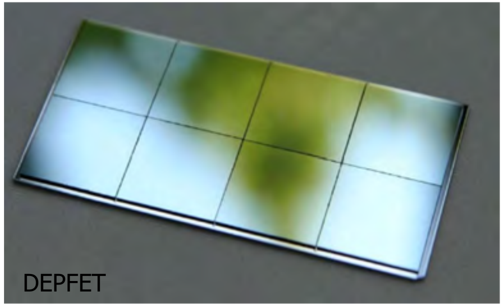
~50µm pixel size
8M pixel detector
50kHz frame time
75 µm thin detectors
Linear DEPFETs

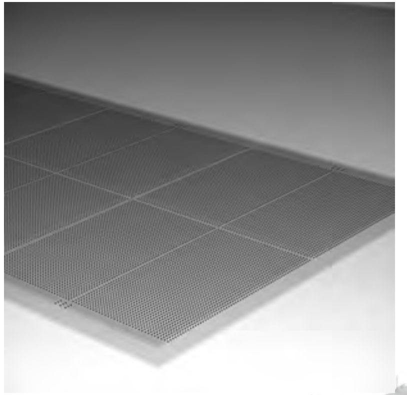
Next steps
Add microchannel cooling into ASM

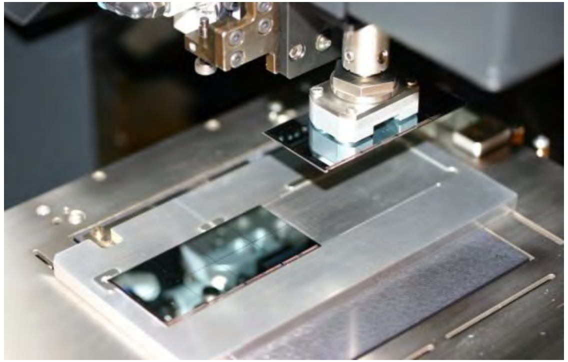


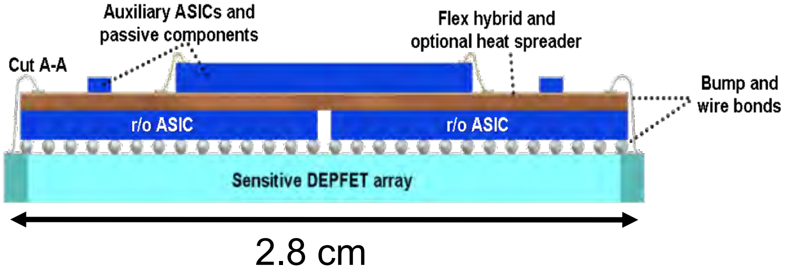
60µm pixel size
1M pixel camera
80kHz frame time
30 and 50 µm thin detectors
Nonlinear DEPFETs

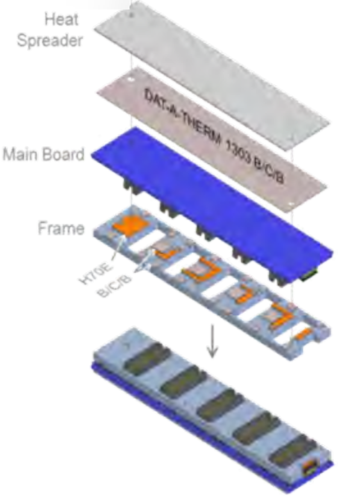
Macro/Micro assemblies

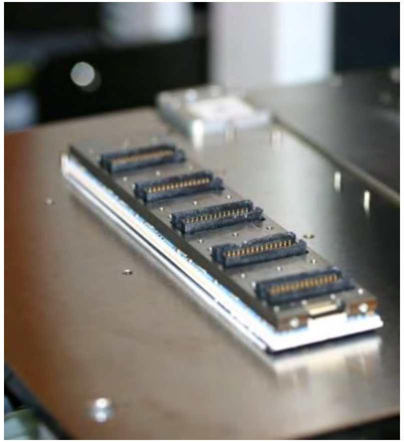




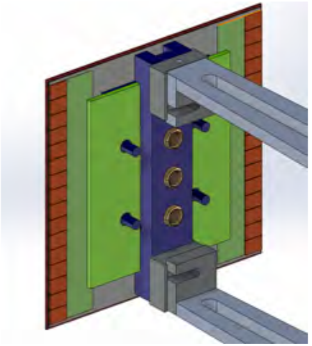


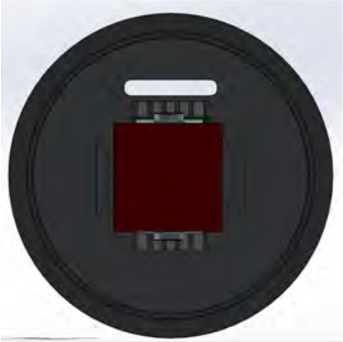


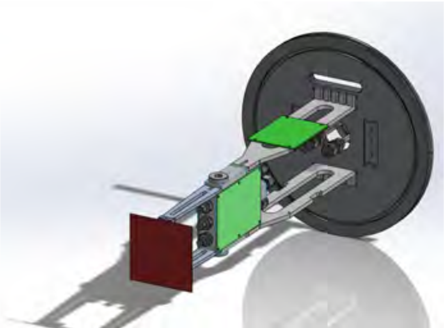




4 side buttable module development @ HLL







Design of the demonstrator module

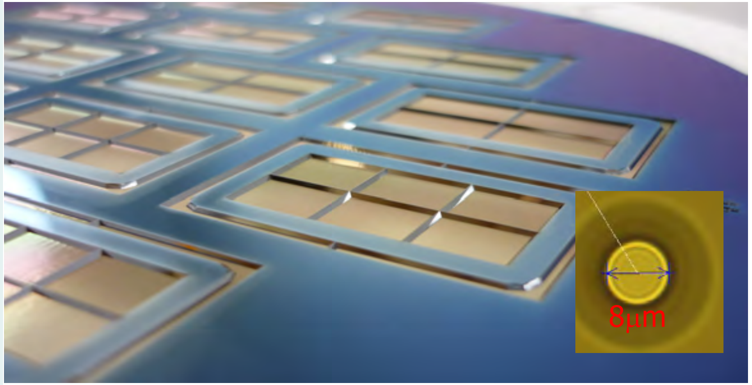
TrueTile:

- **Novel concept** for sensor integration
- **Compact and modular** for high-density sensor integration
- **4-side buttable** devices - large sensor areas with extremely low sensitivity gaps
- Core element: **Active cooling interposer** (AI) for frontend supply integration and cooling
- Multi-level development project

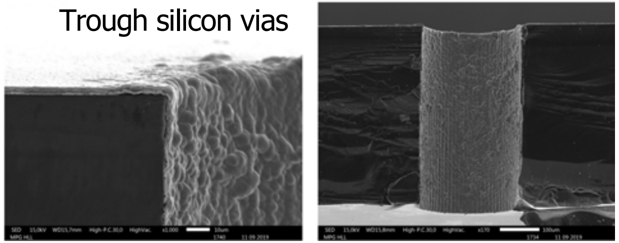
- Large area pnCCD as demonstrator device
    - 1 MPixel with 75 x 75 mm^2 pixels, 76.8 x 76.8 mm^2
- Interposer with microchannel cooling structures
- Compact camera interior for standalone operation

Non active components

Production of perforated thin membranes as sample holders

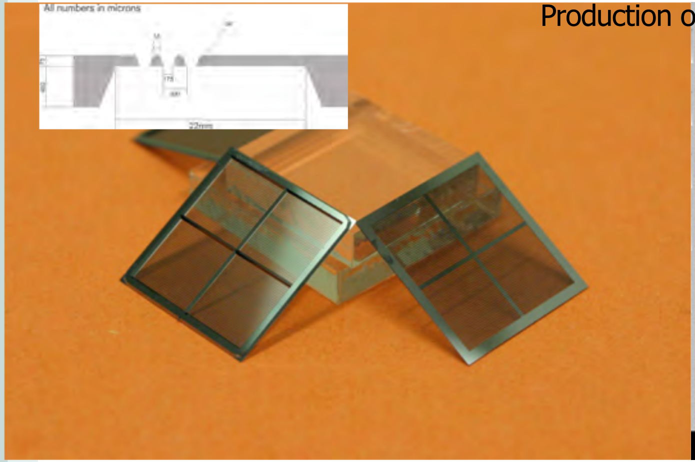


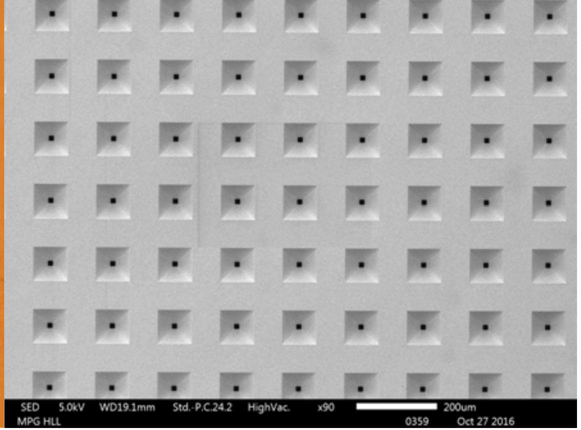
Trough silicon vias

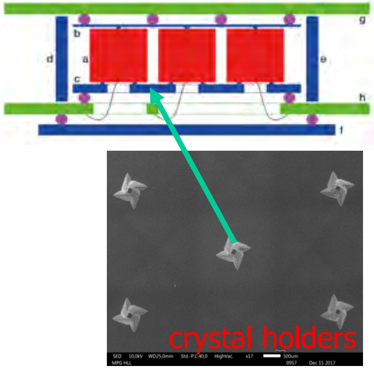


Metallization over extreme topography

Production of sample holders







Inside HLL

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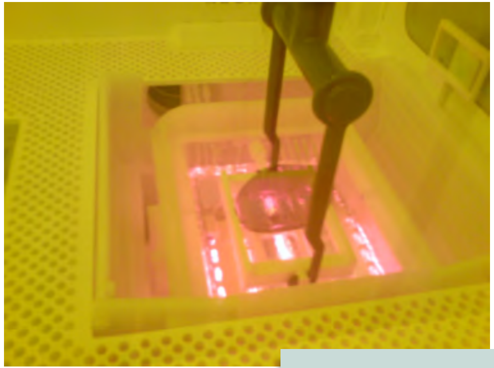
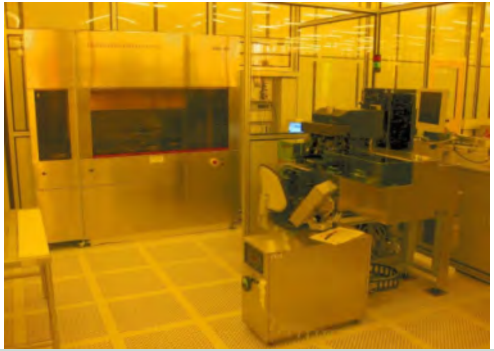
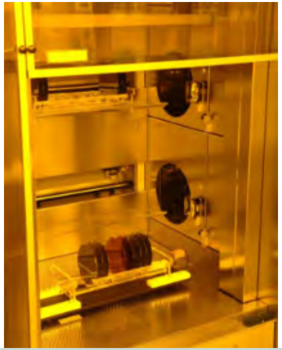
cleaning



lithography



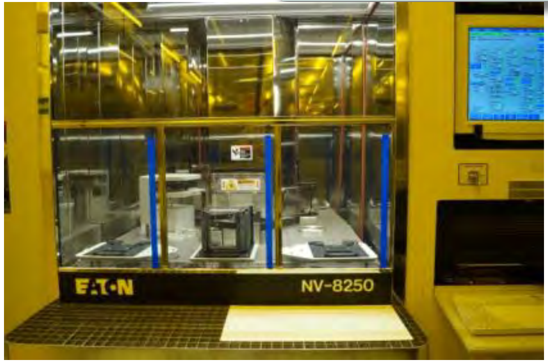
thermal

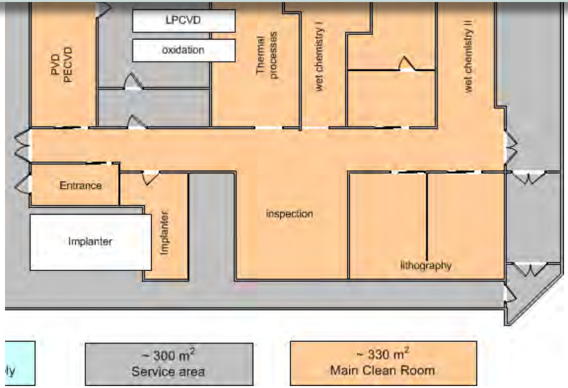


inspection

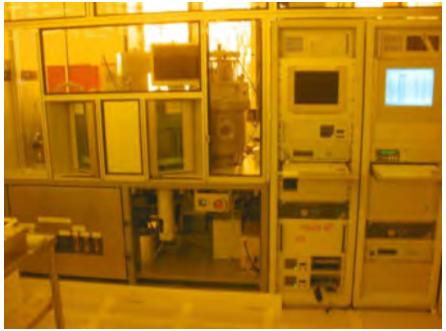
6″ Si full processing line
class 1000 (ISO5) to class 1 (ISO3) in certain areas

implantation





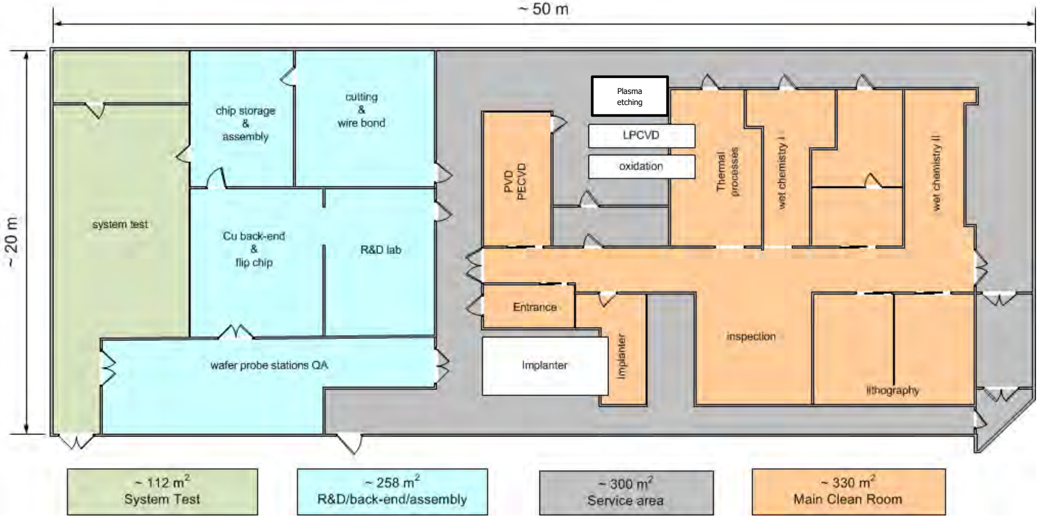
plasma and sputter



Cu line

flip chip

assembly and test



New MPG HLL building

MAX PLANCK
SEMICONDUCTOR
LABORATORY

Building description

- New HLL building on IPP campus Garching
- Building divided into two parts: laboratory with technical areas / academic offices
- Arrangement of the two structures creates entrance area in the west

Front view

Rear view

Impressions from the site 12/2022

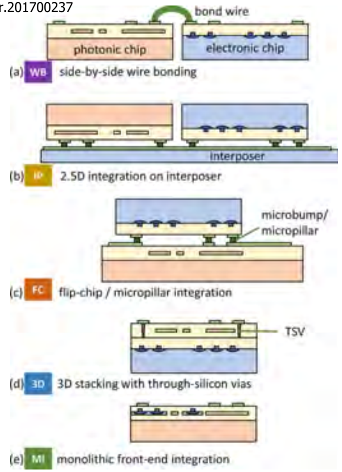




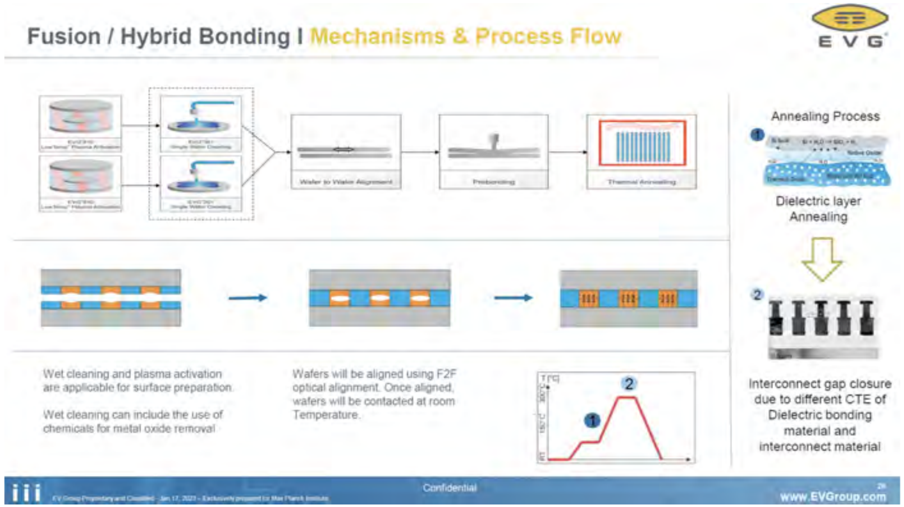

● Munich Quantum Valley @ MPG HLL

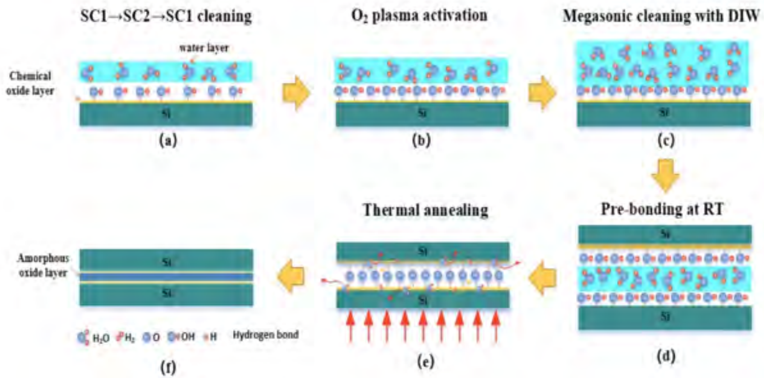
MAX PLANCK SEMICONDUCTOR LABORATORY

https://doi.org/10.1002/lpor.201700237



- Post processing of CMOS and PIC wafers
- Wafer-wafer and wafer-chip bonding
- Interconnection and assembly





https://doi.org/10.3390/pr9091599

Thank you for your attention …

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