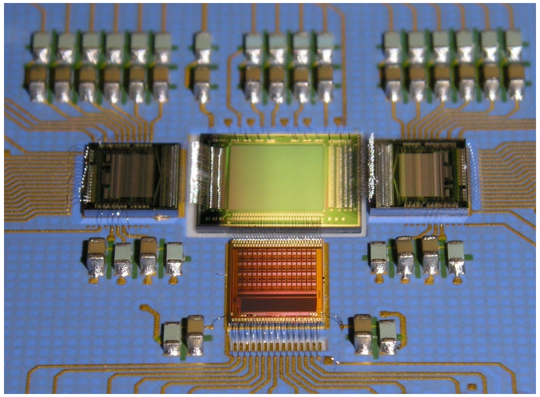
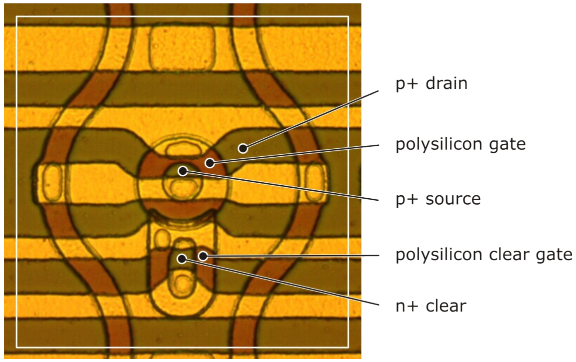
The IXO Wide Field Imager

IXO Science Meeting

MPE Garching, 16.9.2008



- *Content*
  - DEPFET devices
  - Prototypes
  - WFI requirements
  - WFI concept
  - Outlook



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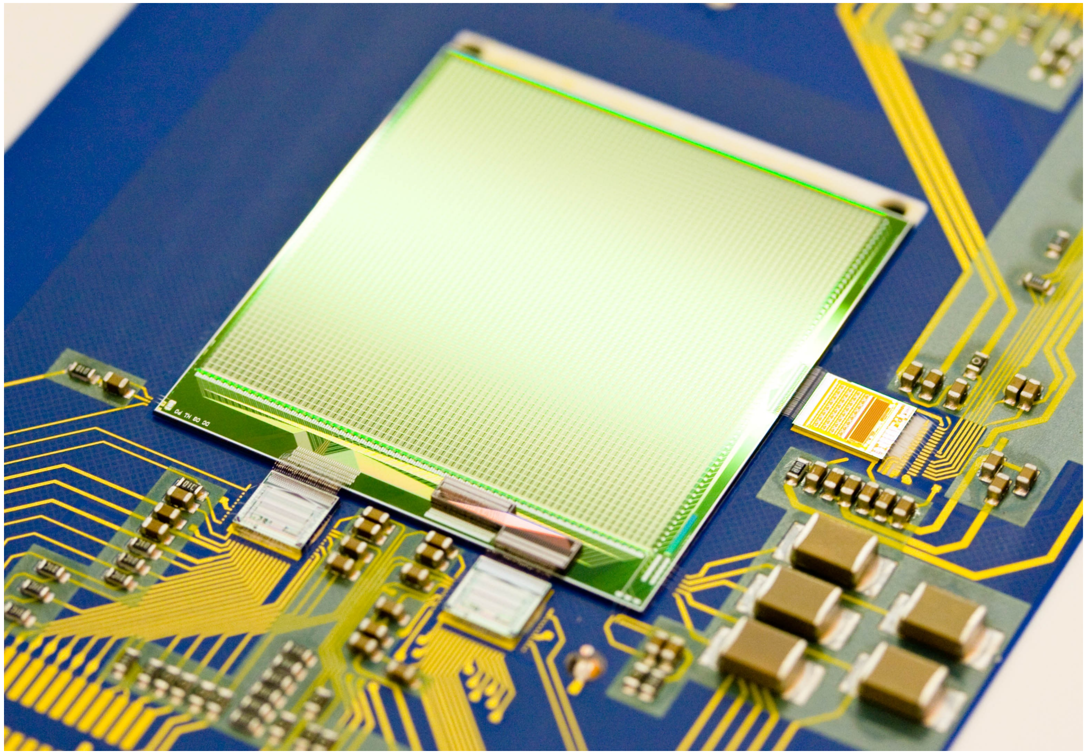
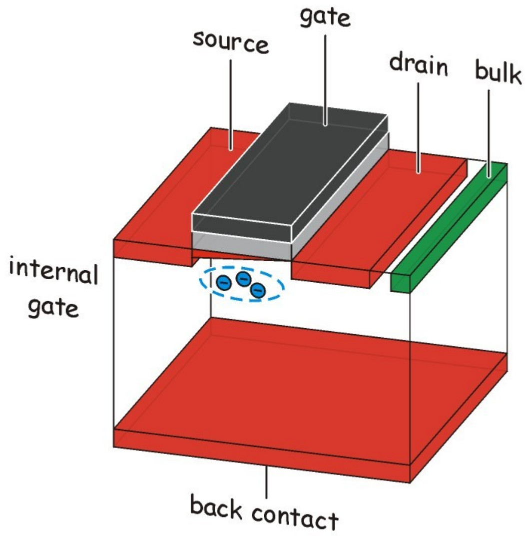
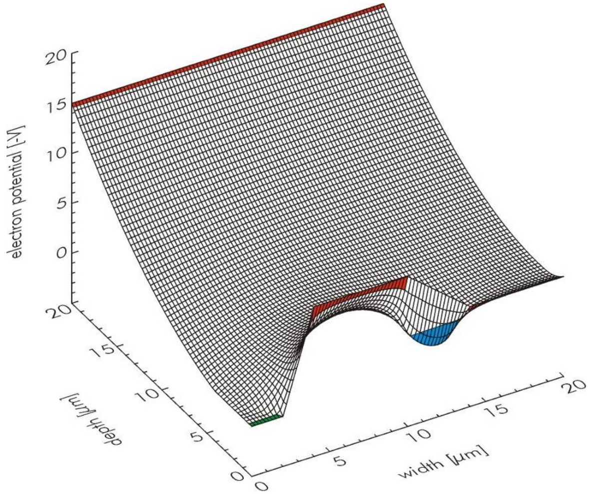
DEPFET devices



The DEPFET concept

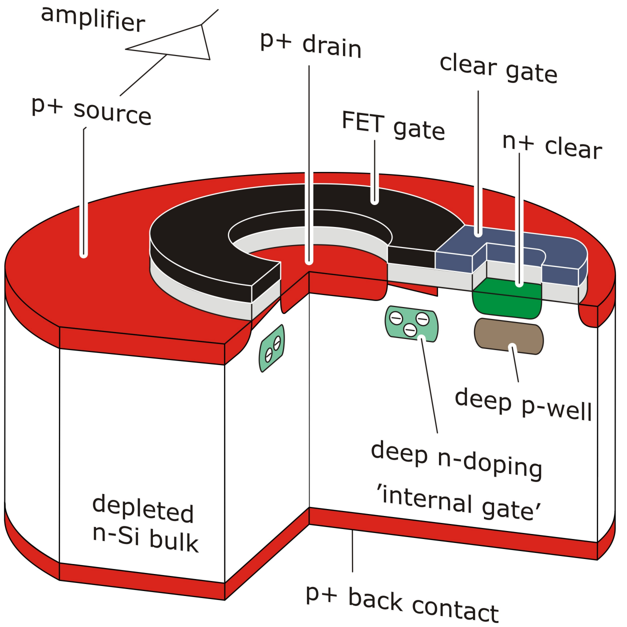
- *DePFET*
  - DEpleted-P-channel FET
  - Sidewards depleted device
  - p-channel MOSFET on depleted n-bulk
  - Additional deep-n implantation underneath Gate
  - Potential minimum for electrons below FET channel (*internal gate*)
  - Bulk generated electrons are collected in internal gate
  - Modify transistor channel conductivity
  - Transistor current modulation 300 pA/el.
  - Internal gate has extremely low capacitance
  - Backside can be used as entrance window
  - 100 % fill factor
  - Taylored QE to respective experiment

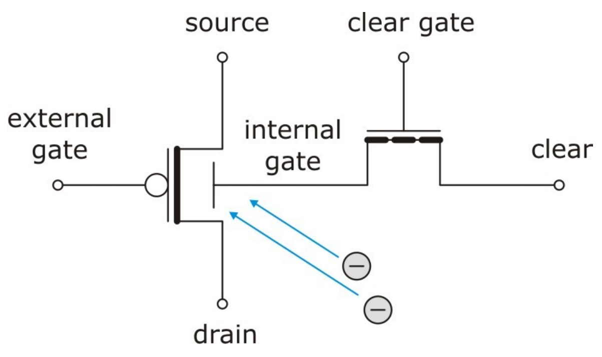




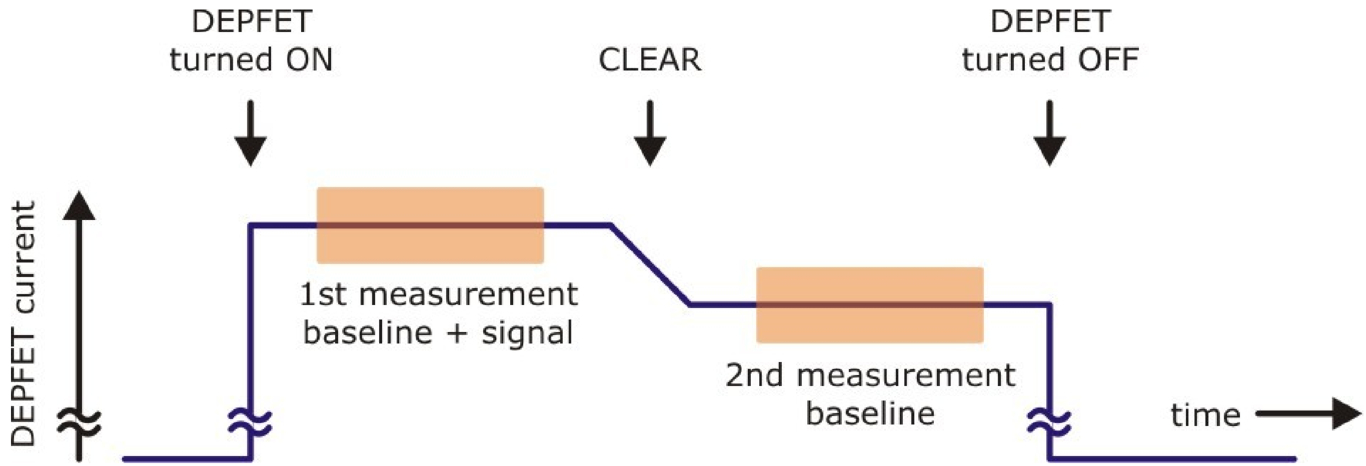
Why use DEPFETs?

- *Combined sensor / amplifier structure*
  - Low capacitance (20 fF) and noise
    - s excellent spectroscopic performance
  - Complete clearing of signal charge
    - no reset/ktC noise
  - Charge storage capability
    - selective readout on demand / windowing
  - Non-destructive readout
    - potential of repetitive readout
  - Backside illuminated, fully depleted
    - quantum efficiency
  - Fast readout
    - low deadtime
    - high framerate
  - Low power
    - Only "read" pixels consume power
  - no charge transfer
    - radiation hard
    - no charge transfer,
    - no out-of-time-events





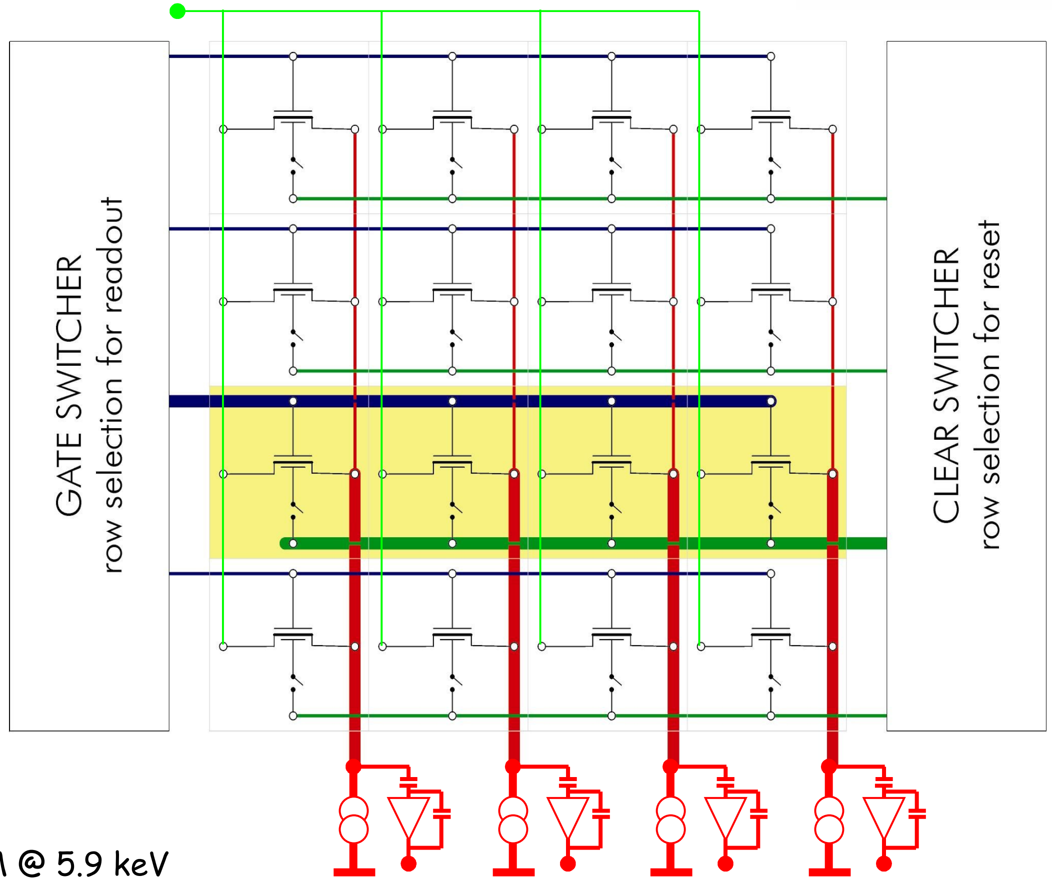
DEPFET readout



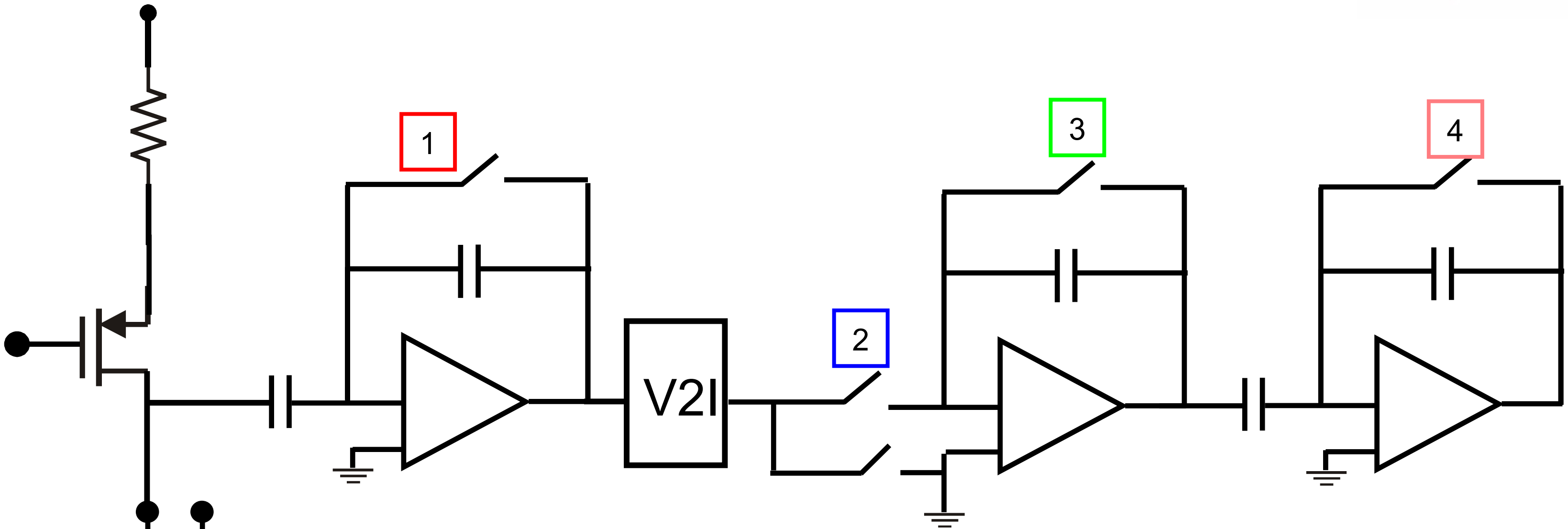
- *Measurement of signal*
  - Measure signal levels
    - source potential / drain current
  - Measure both before and after clear
  - Calculate the difference
    - correlated double sampling (CDS)
- *Level acquisition*
  - N-fold CDS
    - Sample current / voltage level N times
  - Trapezoidal shaping
    - Integration / deintegration

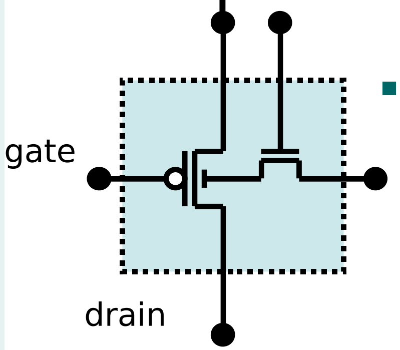
DEPFET matrix devices

- *Readout scheme*
  - Global drain contact
  - Gate,Clear and Cleargate connected row-wise
  - Sources connected column-wise
  - Only one row is turned on and read out
- *Source follower readout*
  - Column bias by current source
  - Alternatively: Conversion of drain current
- *Target:*
  - Framerate 1 kHz
  - Array dimension 1024 x 1024
  - Energy resolution < 125 eV FWHM @ 5.9 keV
- *2 ASICS required:*
  - Analog Amplifier ASIC
  - Switcher ASIC

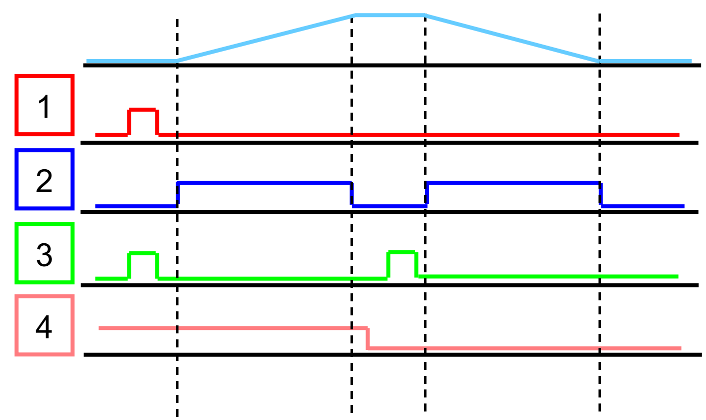


Analog FE concepts



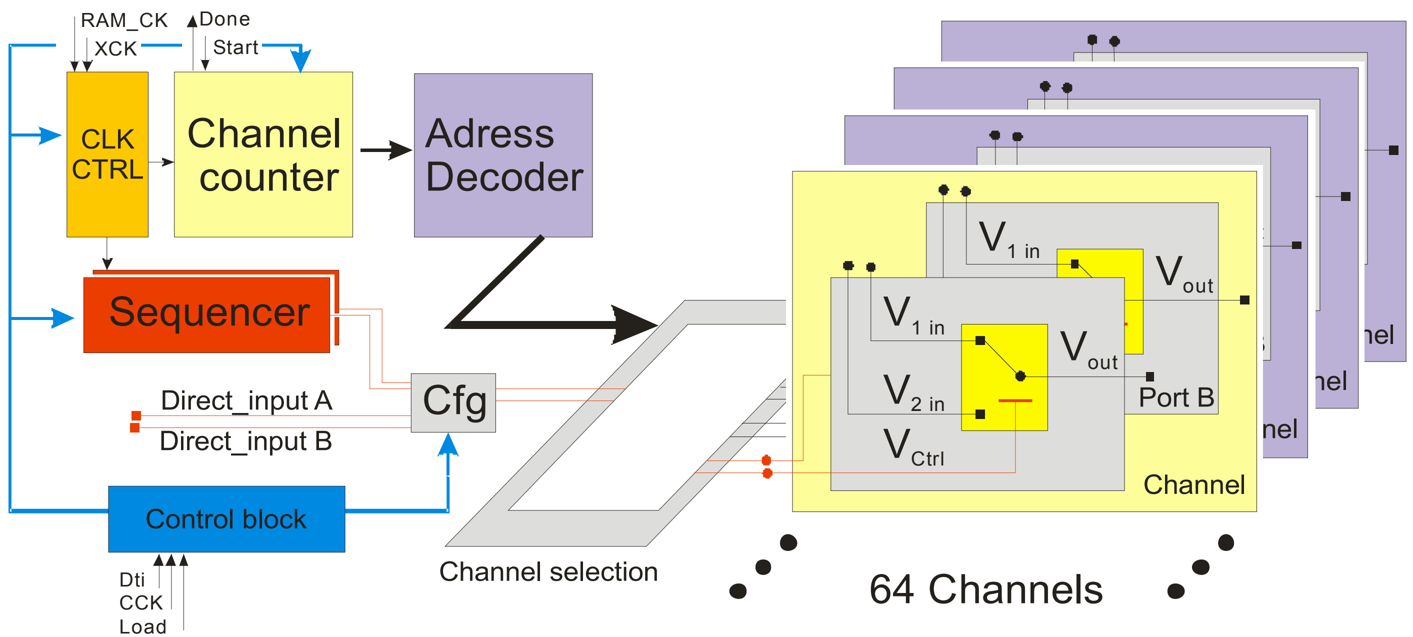


- *ASTEROID /CAMEX*
  - Source follower readout
  - 64 channel parallel trapezoidal (CDS) filter
  - integrated sequencer
  - analog output serializer
  - adjustable gain
  - AMS 0.35μ CMOS technology
  - Current readout option also under development



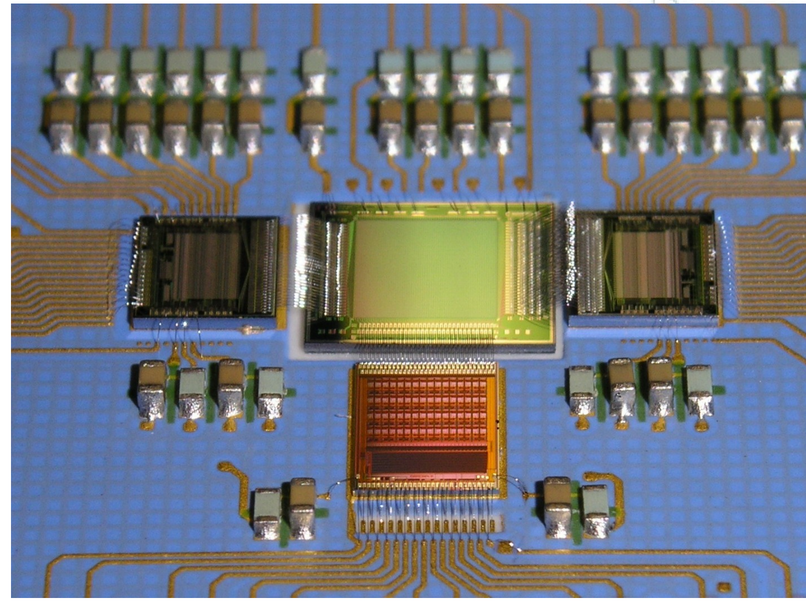
Switcher ASIC

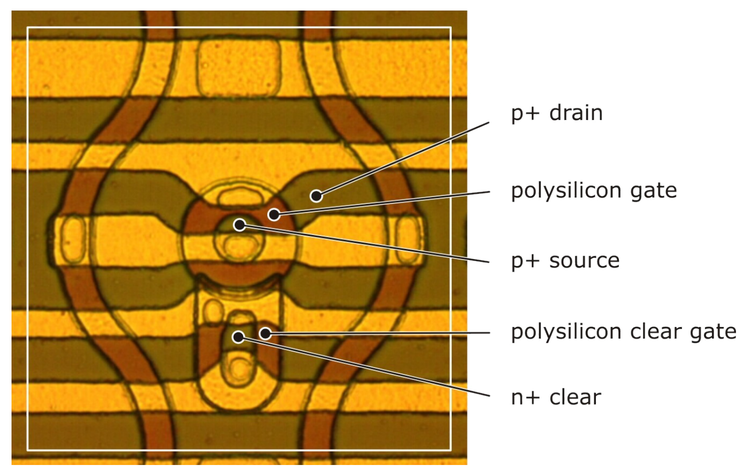
- *Current SWITCHER IIb*:
  - 64 channels
  - Sequential switching row-by-row
  - Only passive (resistive) driving circuitry
  - Low noise (!!)
  - Fast, high voltages (20 V)
  - Not sufficiently radiation hard
- *New SWITCHER VI:*
  - Same as SWITCHER IIb, but
  - Radiation hard (300 krad est.)
  - Channel sequencer
  - Lower power consumption
  - Improved testability & diagnosis



XS devices

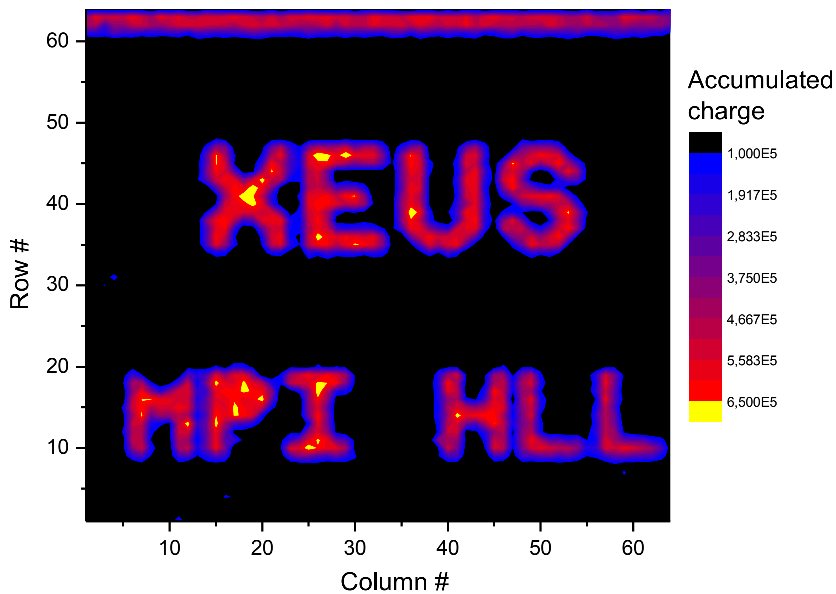
- *Small prototype:*
  - 2 prototyping productions, PXD04 and PXD05 were successfully finished
  - Devices with extremely good properties
  - Formats: XS (XEUS small): 64 x 64 pixels of 75 x 75 μ m² size
  - Geometry: W = 47 μ m, L = 5 μ m
  - Sensitivity g_Q = 300 pA / e-
  - Many devices have been successfully operated
  - Many design variants
  - „Workhorse" for design evaluation & test

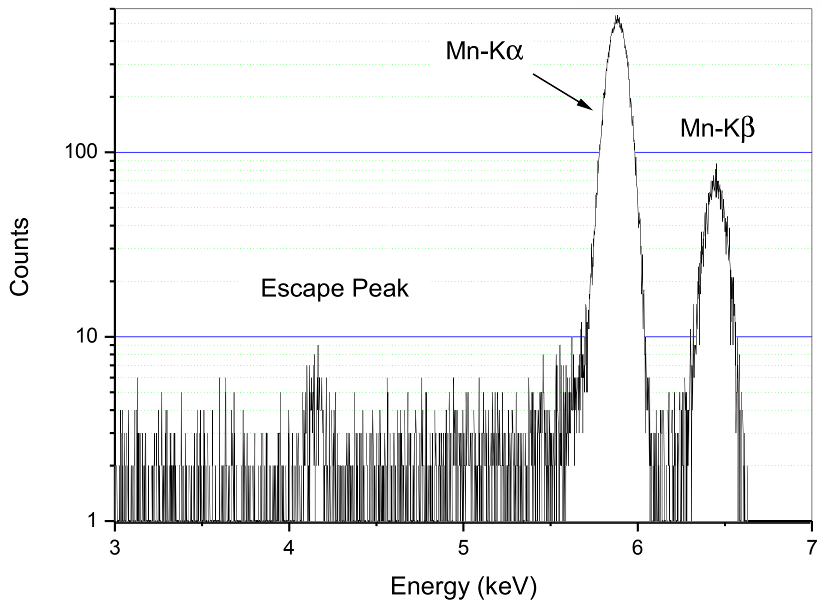




Microphotography of DEPFET pixel within matrix environment

XS performance



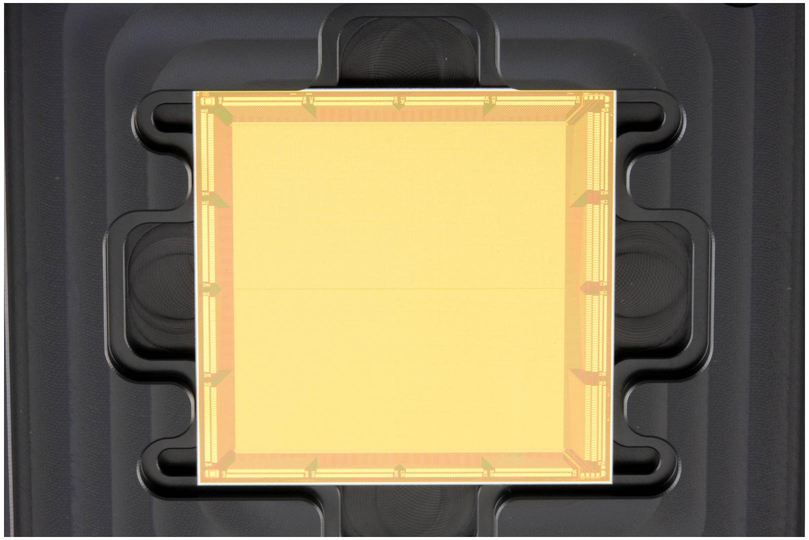


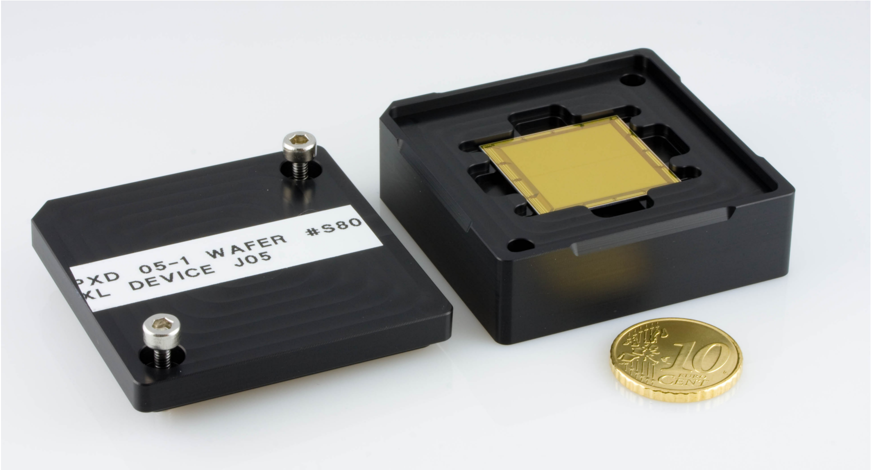
- 132 eV FWHM energy resolution @ 5.9 keV
- Readout noise ~ 3.5 e- ENC
- Very good Offset and Gain homogeneity (< 5%)
- Very good device yield: > 90 %
- Defective devices mostly due to cosmetic defects in single pixels (i.e. pixel yield even higher)

- Performance limitations due to peripheral constraints (old CAMEX device)
- Temperature ~ -40 °C
- Framerate ~ 500 Hz
- Line processing time ~ 25 μ s
- Linearity correction required

XL devices

- *Larger prototypes:*
  - Larger prototypes on PXD05
  - XL (XEUS Large) format
  - 256 x 256 pixels of 75 x 75 μ m^2
  - 1.9 x 1.9 cm^2 sensitive area
  - Uni- and bidirectional readout
  - Factor of 16 in area an pixel count compared to XS

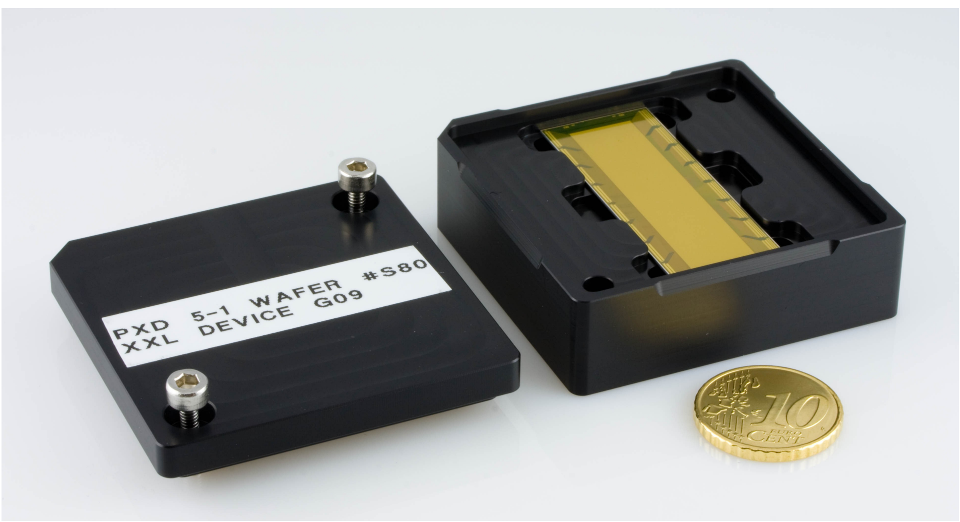




- Study yield and homogeneity of large area matrix devices
- Bidirectional readout: Data acquisition and fame building
- Commissioning in progress

XXL devices

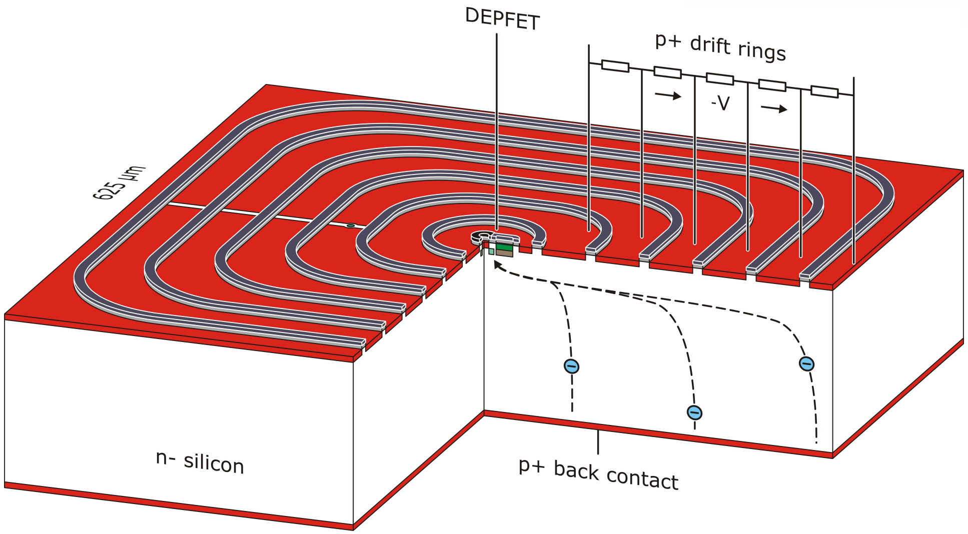
- *Column prototypes:*
  - Also on PXD05: Sector prototypes for WFI
  - XXL (XEUS X-Large) format
  - 128 x 512 pixels of 75 x 75 μ m^2
  - Unidirectional readout
  - Same area & pixel count as XL
  - Same setup as XEUS sector (capacitance etc.)

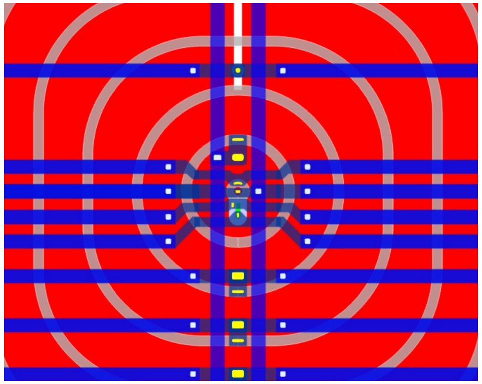


- Study timing behaviour of WFI on device with realistic device
- Commissioning in progress

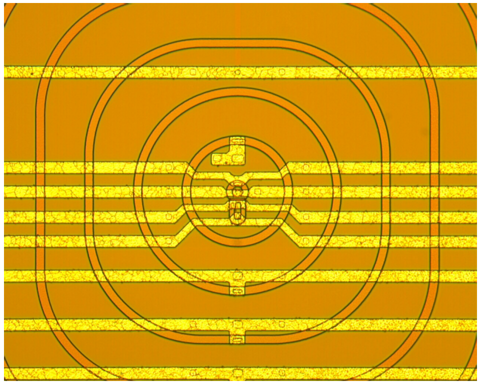
DEPFET Macropixel devices

- *Macro Pixel Detector (MPD)*
  - Combined heritage of SDD & DePFET
    - large area & low noise
  - Common backside diode & bulk
    - thin entrance window
    - fill factor 1
  - Arbitrary scalable pixel size
    - Adjust geometry & number of driftrings
    - Pixel sizes up to ~ mm possible
  - Readout scheme & specs
    - same as for “normal” DEPFETs





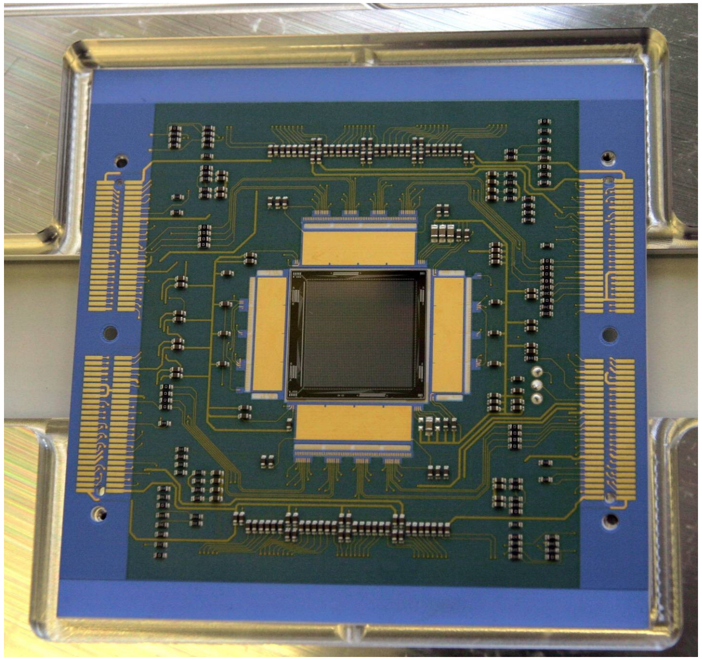
Demonstrator pixel
layout screenshot

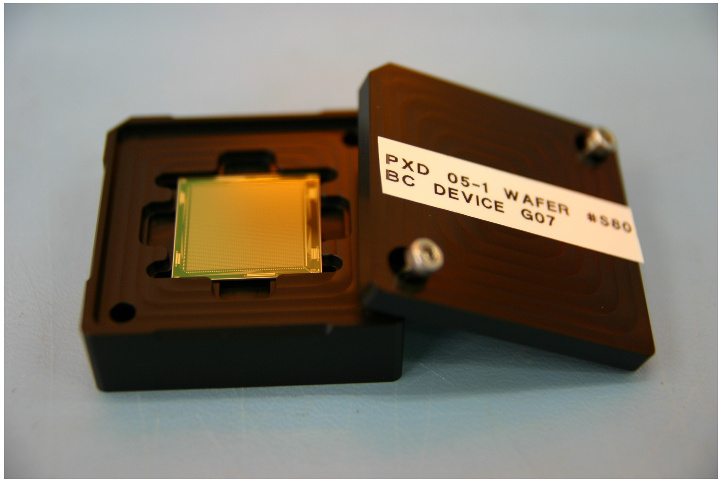


Demonstrator pixel
status 18.06.07

MIXS devices

- *Flight detectors:*
  - FPA flight sensors for MIXS on BC
  - Same area as XL (XEUS X-Large)
  - 64 x 64 pixels of 300 x 300 μ m^2
  - Macropixel device
  - Bidirectional readout
  - **First DEPFET based sensor to undergo space qualification program**

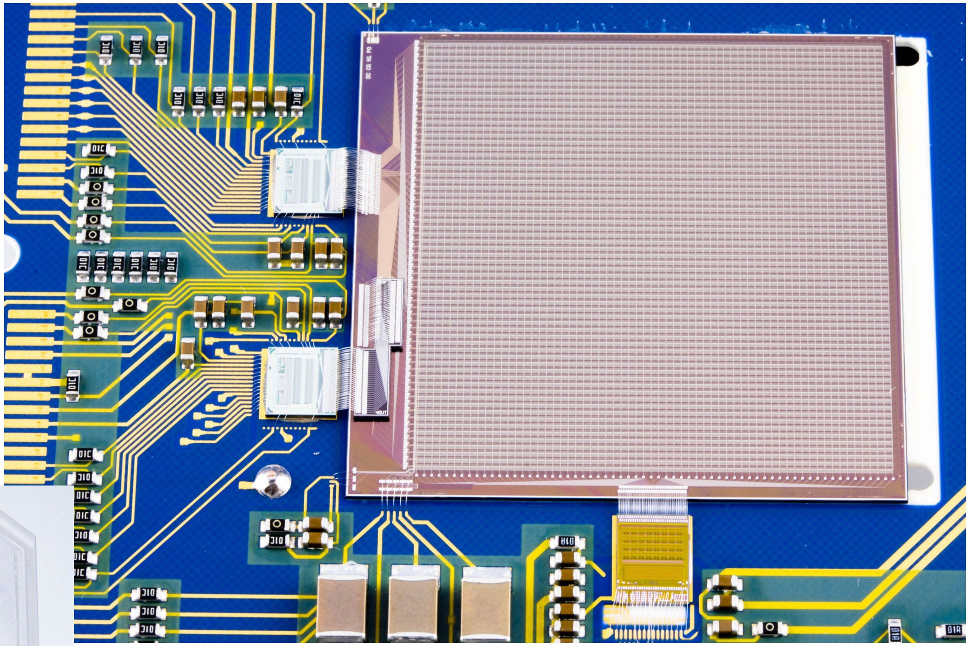


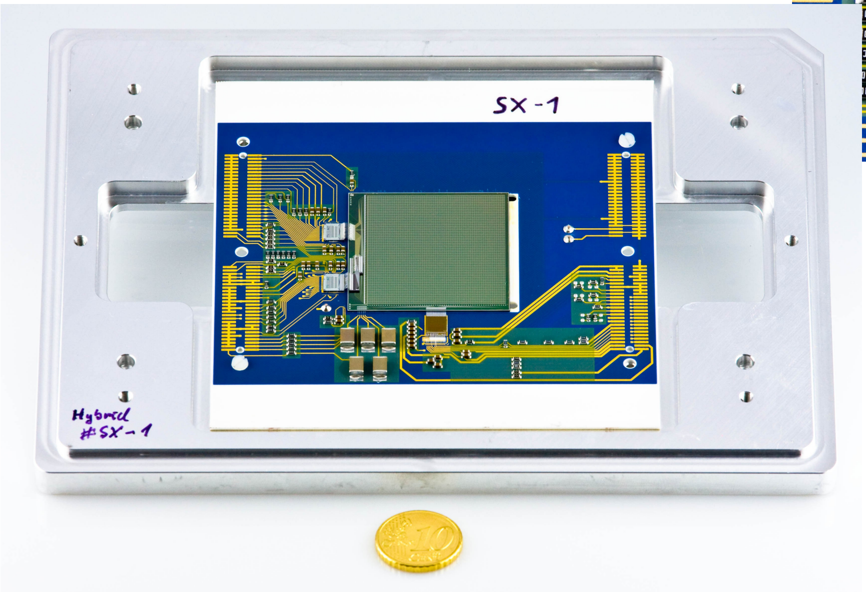


- Commissioning in progress

SX devices

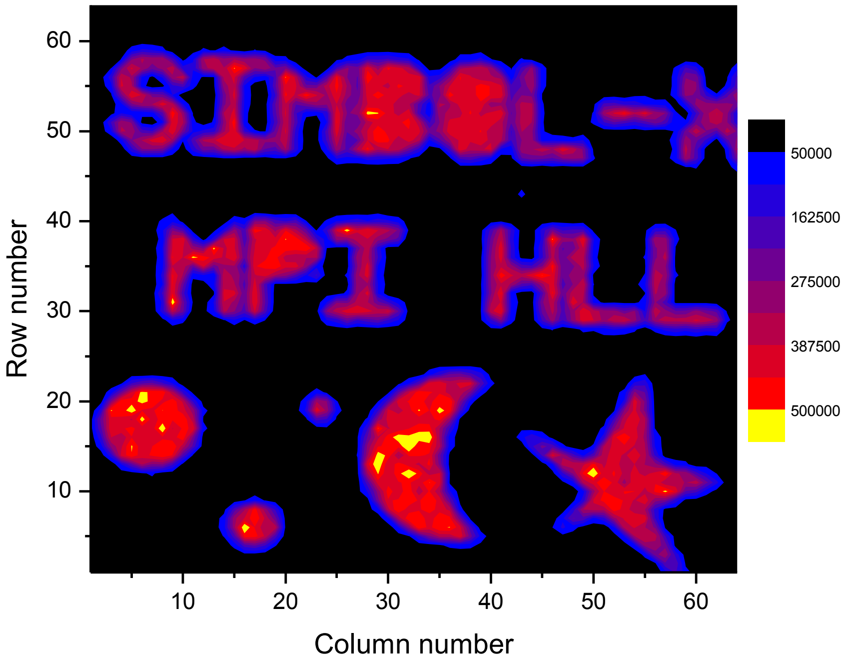
- *SX quadrant prototypes:*
  - Also on PXD05: SX sensor quadrant prototypes
  - 3.2 x 3.2 cm² sensitive area
  - 64 x 64 pixels of 500 x 500 μ m²
  - Macropixel device
  - Unidirectional readout
  - Parallel readout prototypes

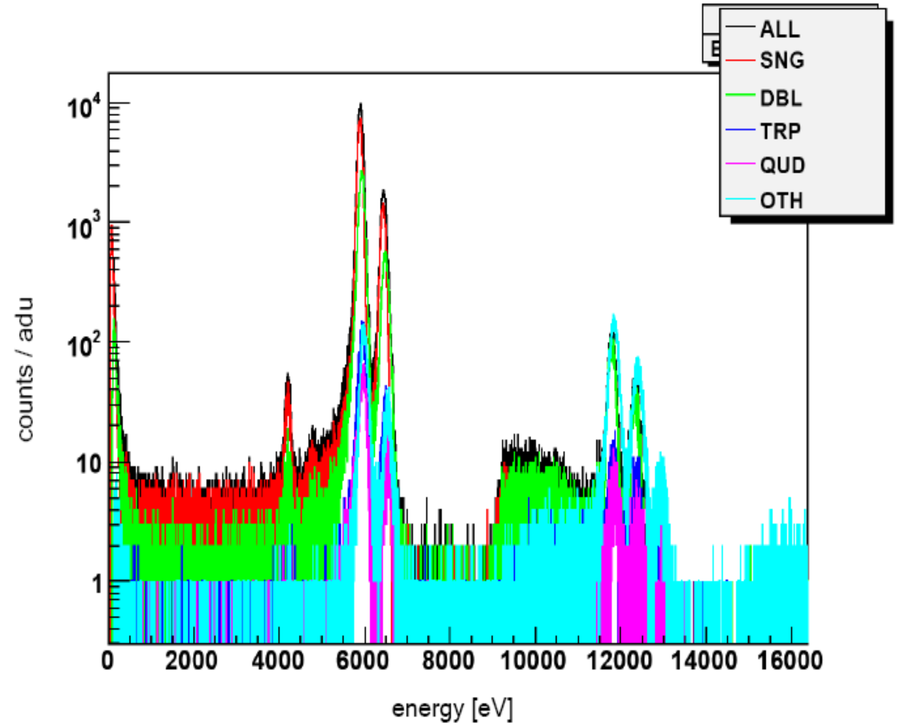




- Operational devices have been tested
- Excellent properties
- SX FPA will be wafer scale device!

Sensor roadmap: SX devices



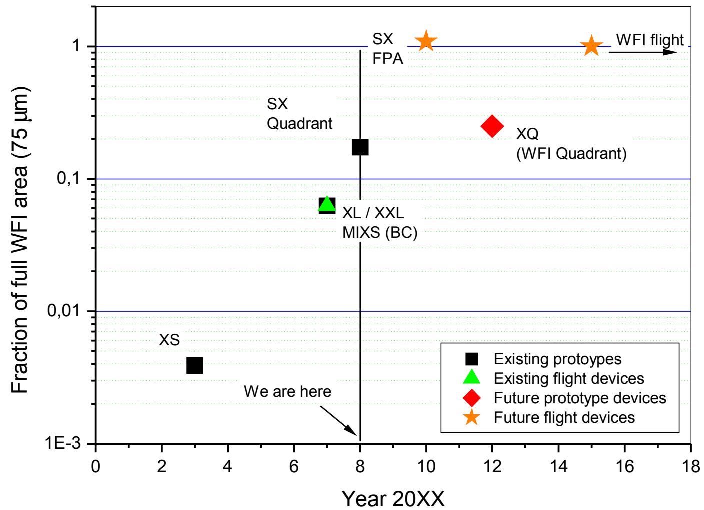


- 127 eV FWHM energy resolution @ 5.9 keV (single events)
- Excellent peak / background
- Readout noise ~ 3.5 e- ENC

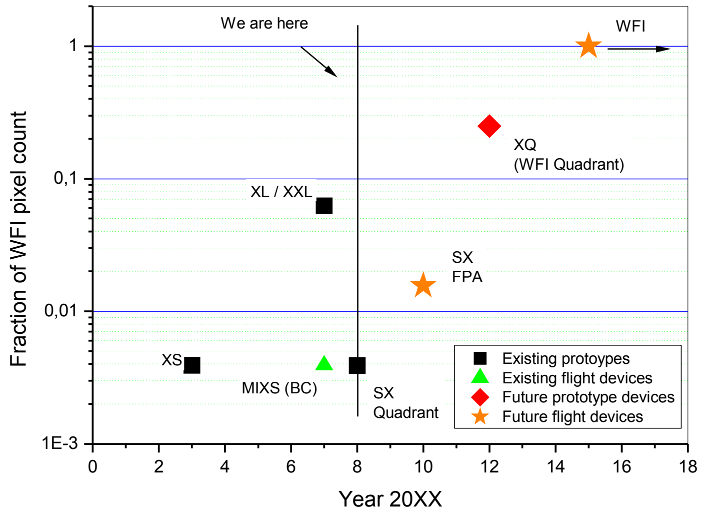
- Few samples built so far
- Homogeneity comparable to XS devices
- No cosmetic defects

Sensor development roadmap

- *Current status:*
  - Factor of 16 to go to final WFI area
  - Next prototyping run yields another factor of 8 in area
  - WFI Quadrant prototypes
- *Challenges:*
  - Large area...
  - ...**and (!!)** large pixel count!
  - BC / MIXS: Qualification process
  - SX / LEDA: Large area
  - IXO WFI: Full array dimension!

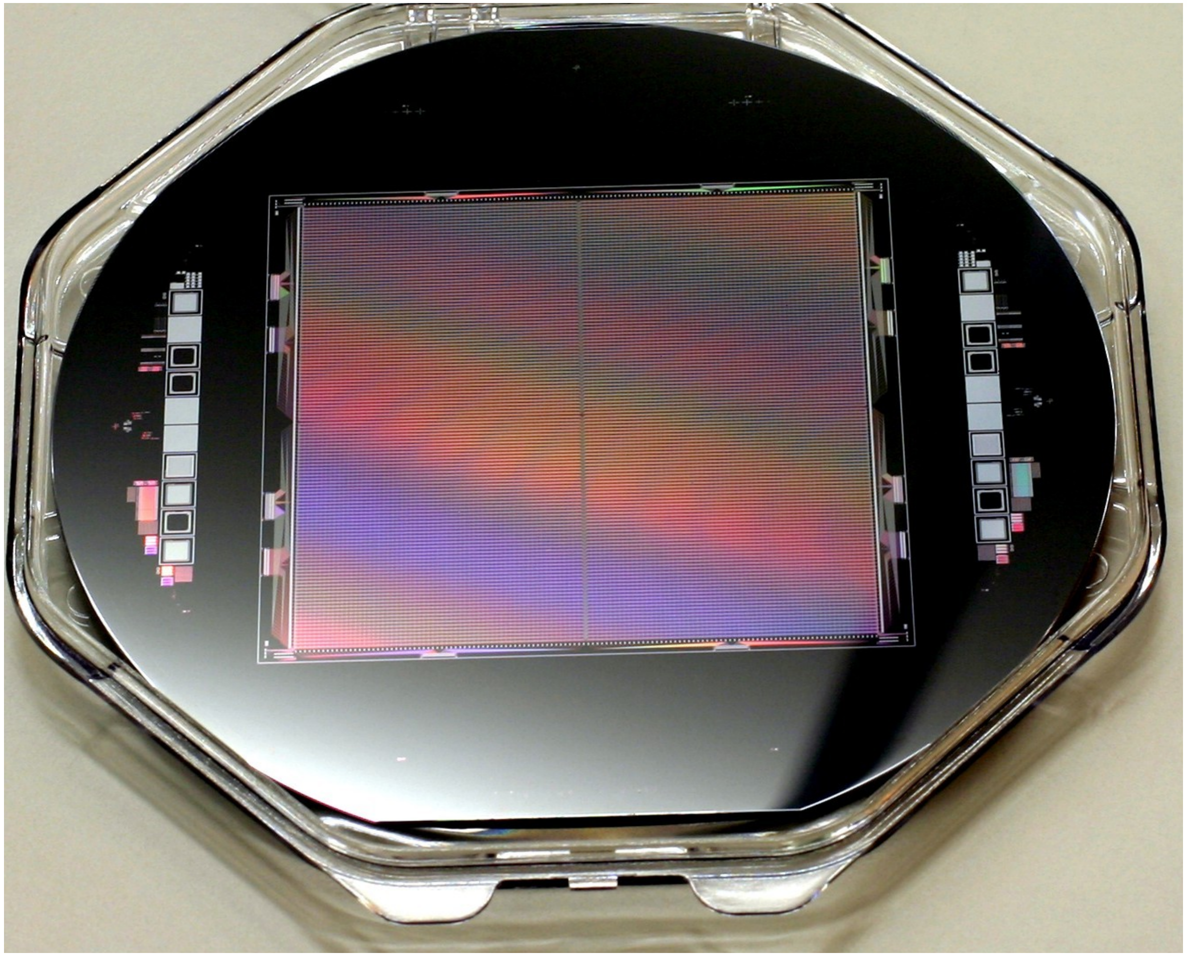


Sensor area roadmap



Pixel count roadmap

The DEPFET based WFI

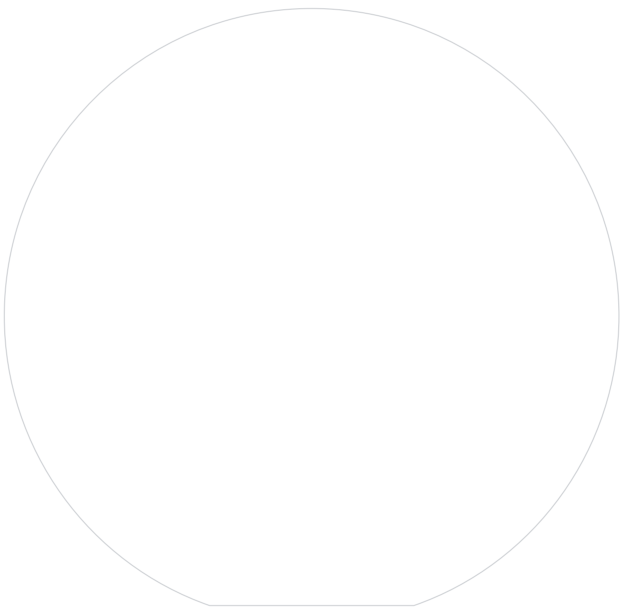


WFI requirements

- *Specifications*
  - Field of view (min.)
    > 12 arcmin Ø
    > 7.2 cm Ø
  - Angular resolution
    ≤ 5 arcsec @ 20 m
  - Point spread function
    500 µm
  - Good QE
  - Energy range
    0.1 … 15 keV
  - Energy resolution
    < 130 eV @ 6 keV
  - Count rate capability
    10 kcps
    < 1% pileup
  - Hard X-ray camera option
- Compliance with

- *WFI requirements*
- Detector format
  1024 x 1024 pix
  14 arcmin @ 25m
  18 arcmin @ 20m
  - Pixel size
    100 x 100 µm²
    75 x 75 µm²
  - Thin entrance window
  - Detector thickness
    450 µm
  - Low electronic noise
    « 4 el. ENC
  - Fast readout
    2 µsec / pixel-row
  - Window mode
    32 x 1024 pixel
  - Monolithic device

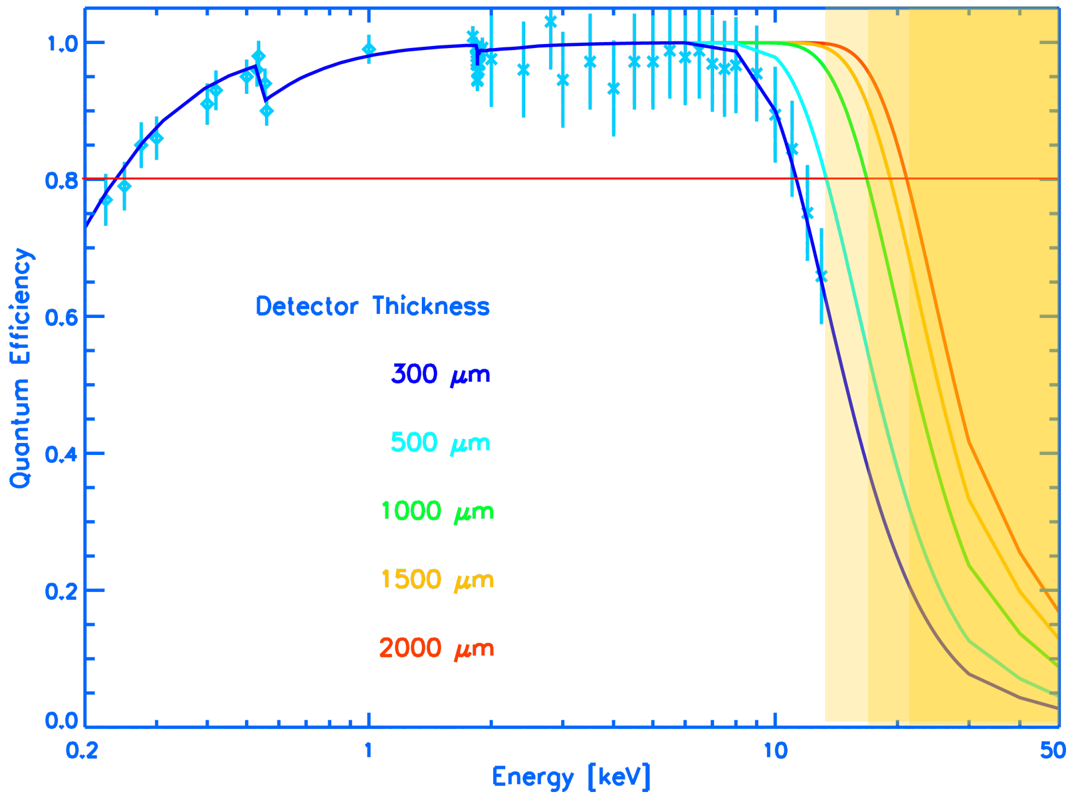
WFI concept



- *Current baseline:*
  - WFI will consist of monolithic device integrated on 6“ wafer
  - Wafer thickness of 450 μ m is proposed

Impact of device thickness

- *Device thickness*
  - Lower absorption cross section for higher eneries
  - ~12 keV for 0.5 mm thickness
  - ~17 keV for 1 mm thickness
  - ~21 keV for 2 mm thickness
  - Improvement small



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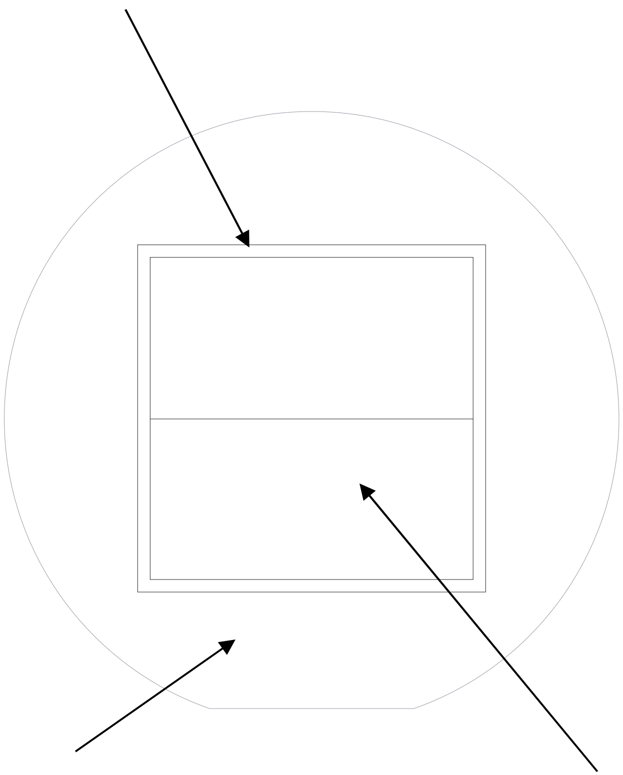
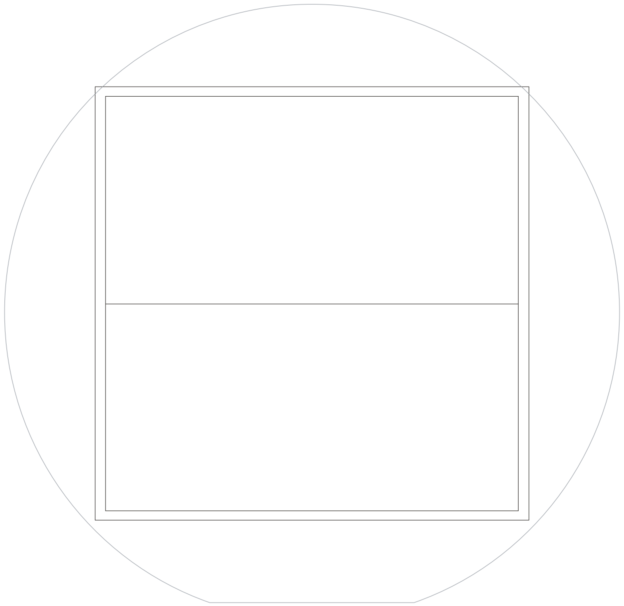


- *Current baseline:*
  - WFI will consist of monolithic device integrated on 6“ wafer
  - Array dimension: 1024 x 1024 pixels
  - Pixel size of ~75 x 75 μ m²
  - Device will occupy an area of about ~ 86 x 86 mm² (including service areas)

WFI concept

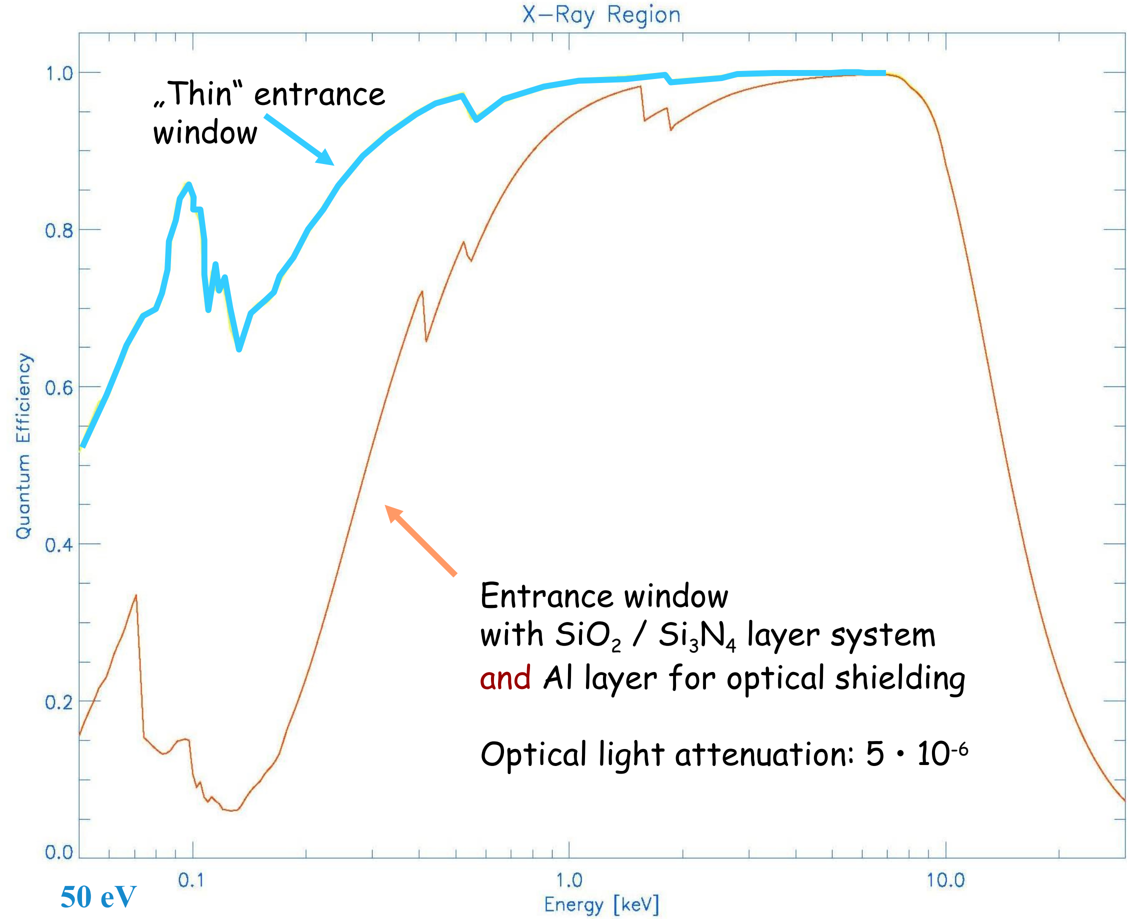


- *Current baseline:*
  - WFI will consist of monolithic device integrated on 6" wafer
  - Array dimension: 1024 x 1024 pixels
  - Pixel size of ~75 x 75 μ m^2
  - Device will occupy an area of about ~ 86 x 86 mm^2 (including service areas)
  - Pixel size of up to 100 x 100 μ m^2 could be accommodated on a monolithic device on a 6" wafer for given array dimension
  - Edge regions require special care!

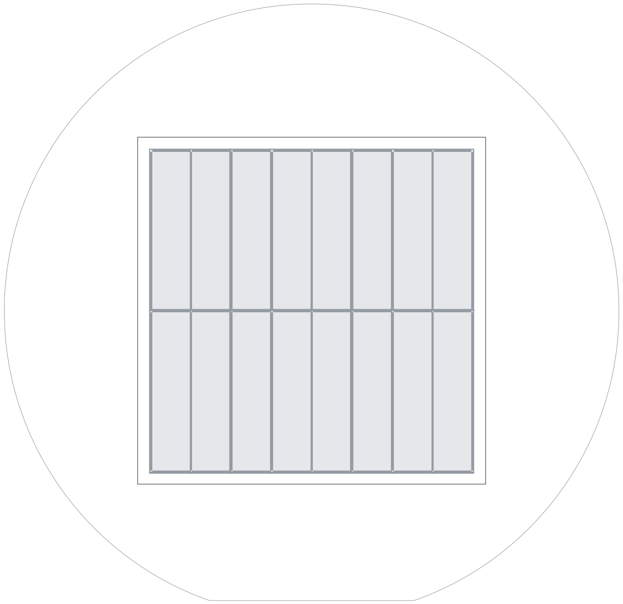
  - Even larger pixels possible, **but:**
  - monolithic approach has to be abandoned
  - Complete revision of entire FPA concept

Entrance window configuration

- *Entrance window*
  - Compromise between:
  - (Visible) light shielding
  - UV shielding
  - Shielding is required:
    - Straylight
    - Visible stars
  - Quantum efficiency in the energy range E > 0.05 keV
  - QE loss also due to (external) filters
  - Monolithic implementation has mechanical advantages

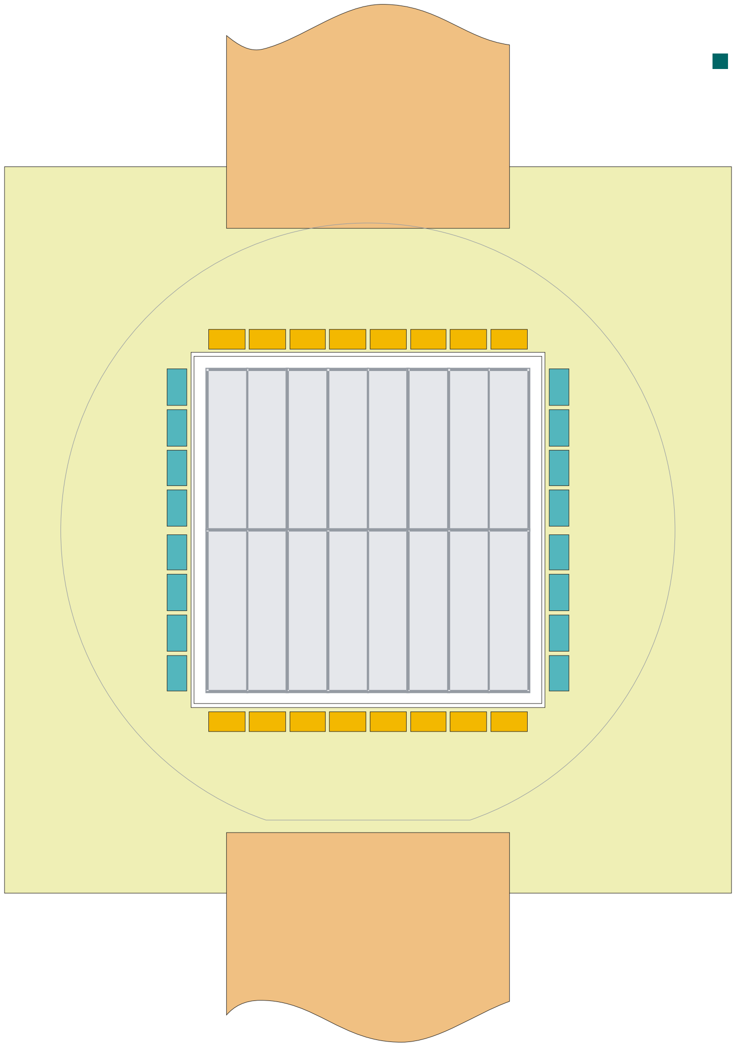


WFI concept



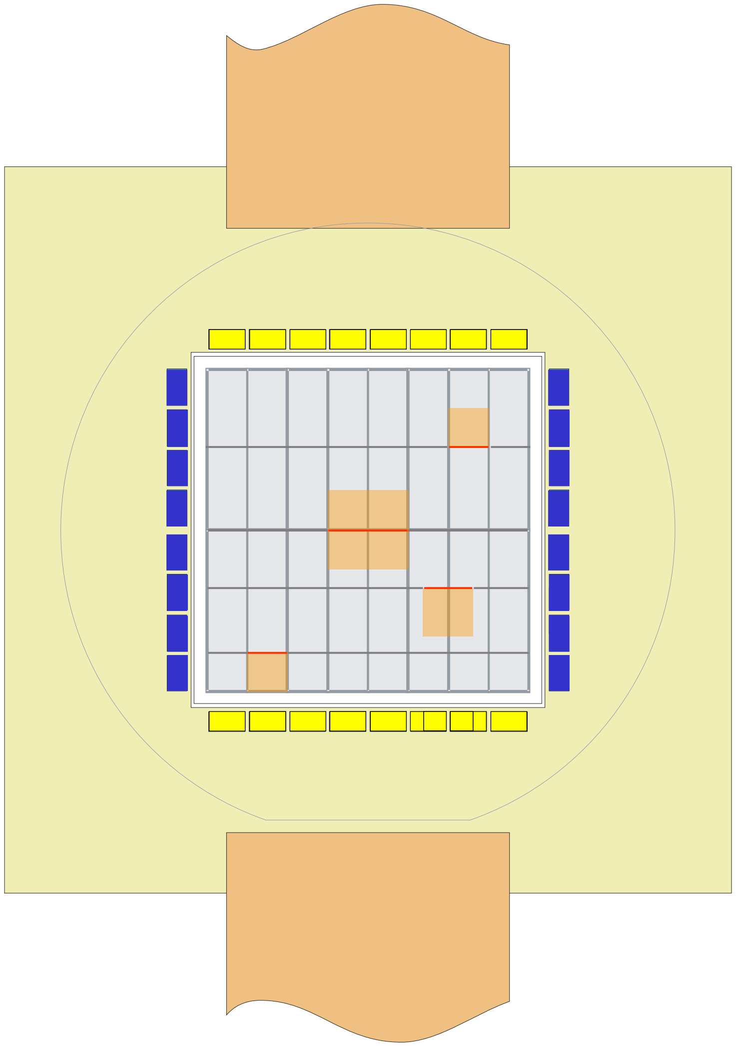
- *Current baseline:*
  - Sensor will be electrically divided into two hemispheres and 16 sectors
  - Division is purely electrical, affects only r/o modularities and (possibly) supply redundancies
  - Common entrance window homogeneous & without dead regions
  - Hemispheres are read out in parallel (factor 2 in parallelization)
  - Processing time ~ 2 μ s / row

WFI concept



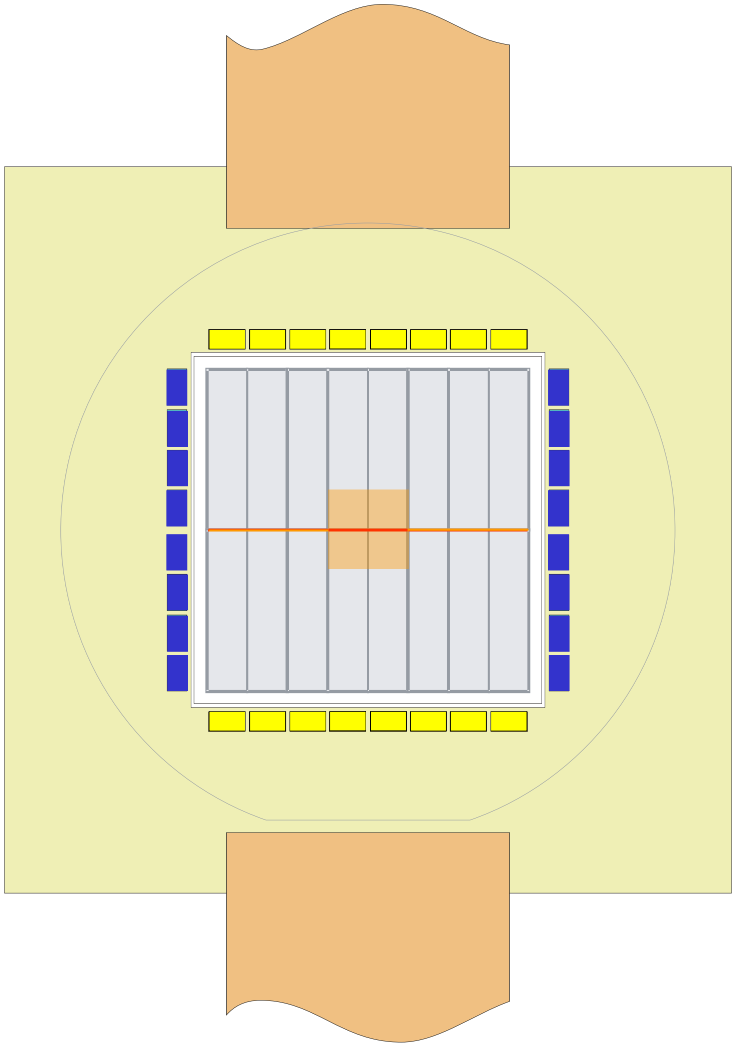
- *Current baseline:*
  - Readout ICs are mounted on multilayer readout ceramics
  - 1 CAMEX IC per sector
  - All sectors of a hemisphere share same switcher ICs
  - Total of 16 CAMEX ICs with 128 channels per IC
  - Total of 16 SWITCHER ICs with 128 channels per IC (optional 32 x 64 channels as fallback solution)
  - Control & configuration can be made redundant
  - Multilayer ceramics is contacted with 2 Flexleads carrying the (optionally redundant) control & config signals as well as the supply voltages and analog output signals

WFI readout concept



- *Readout modes:*
  - **Full frame mode**: Parallel readout of both hemispheres on full width
  - **ROI mode**: Define ROI, read out repetitively with high framelet rate
  - Information of entire row is acquired, but information from outside ROI is discarded in preprocessing
  - Arbitrary position anywhere on the sensor
  - Simultaneous readout of disjunkt ROIs on different hemispheres
  - With next generation of ICs:
  - On-the-fly selection of ROIs / switch between ROIs
  - ROIs exceeding sector borders

WFI readout concept



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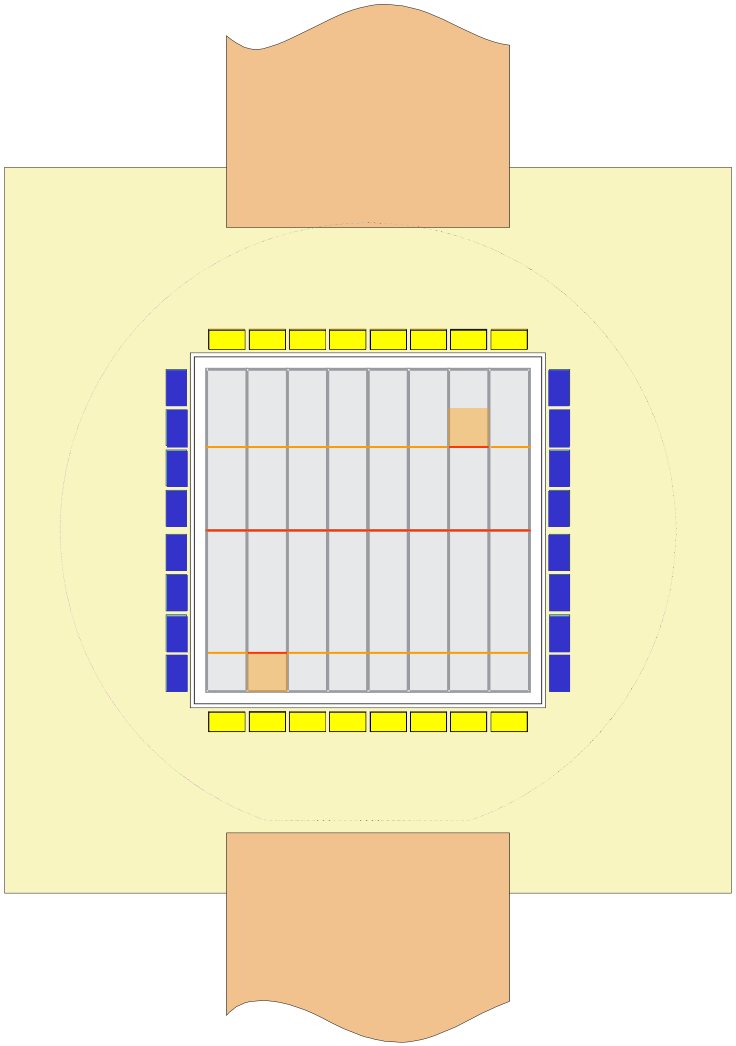
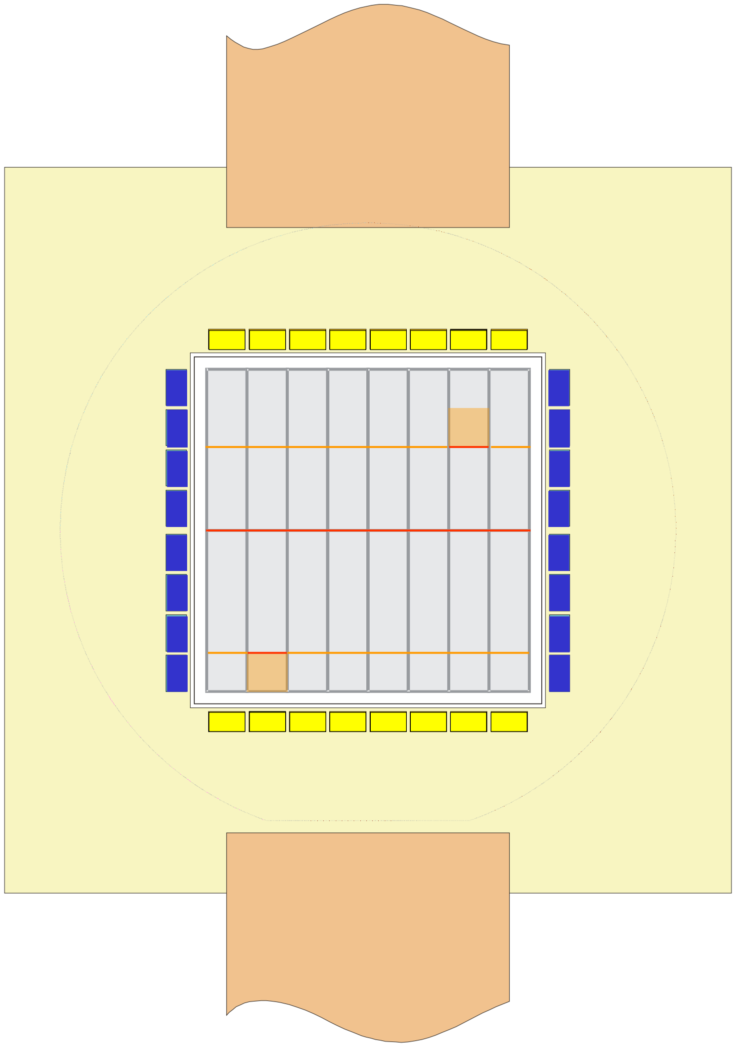
  - With next generation of ICs:
  - On-the-fly selection of ROIs / switch between ROIs
  - ROIs exceeding sector borders
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate

WFI readout concept



- *Readout modes:*
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA

WFI readout concept



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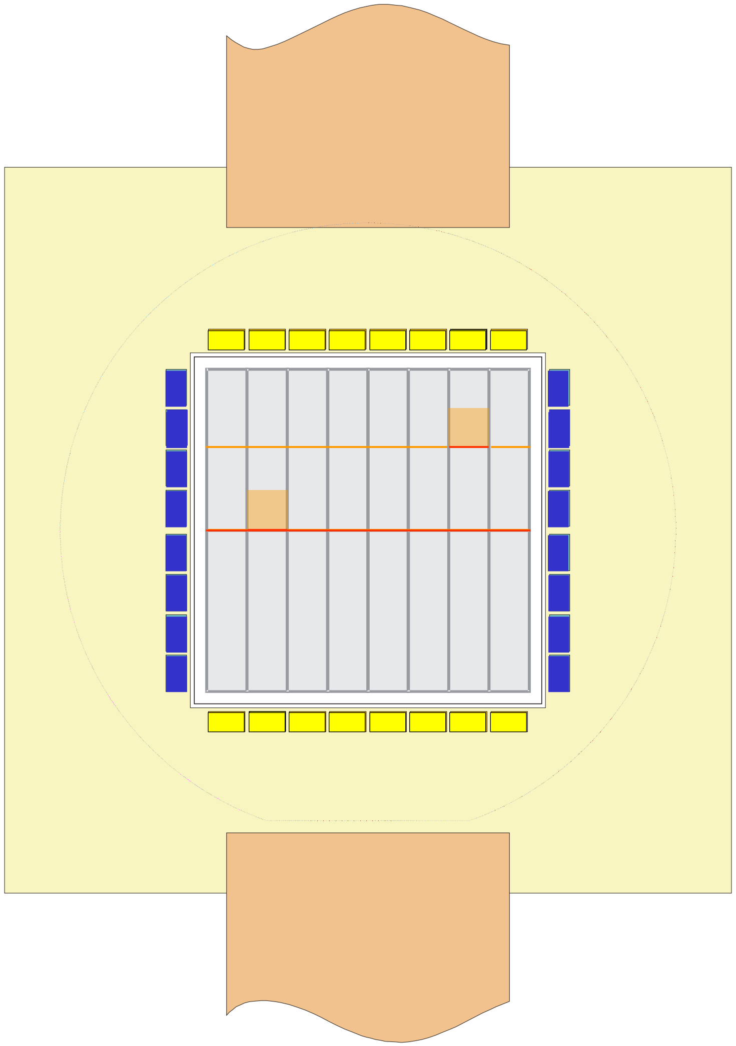
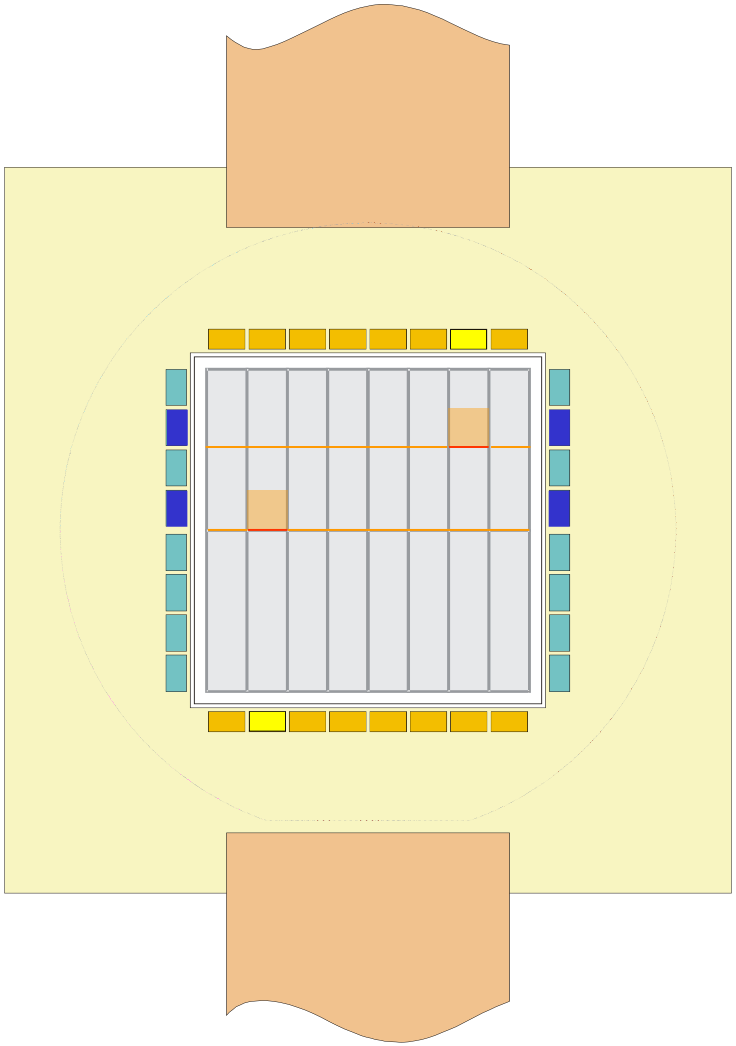
WFI readout concept



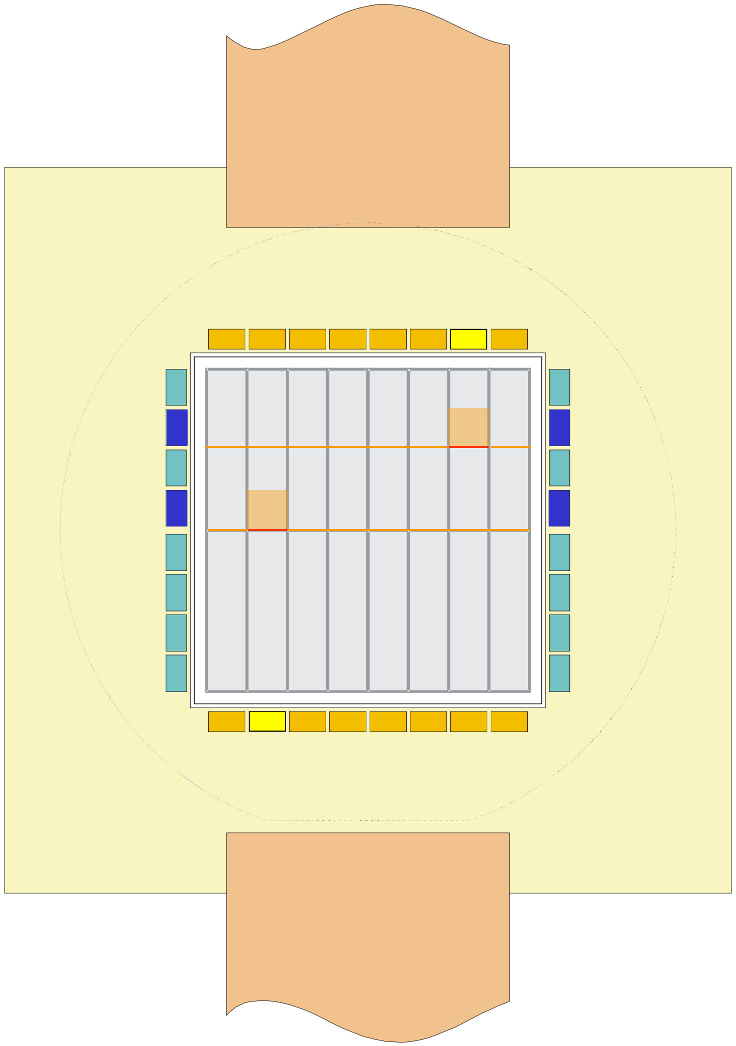
- *Readout modes:*
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

WFI readout concept



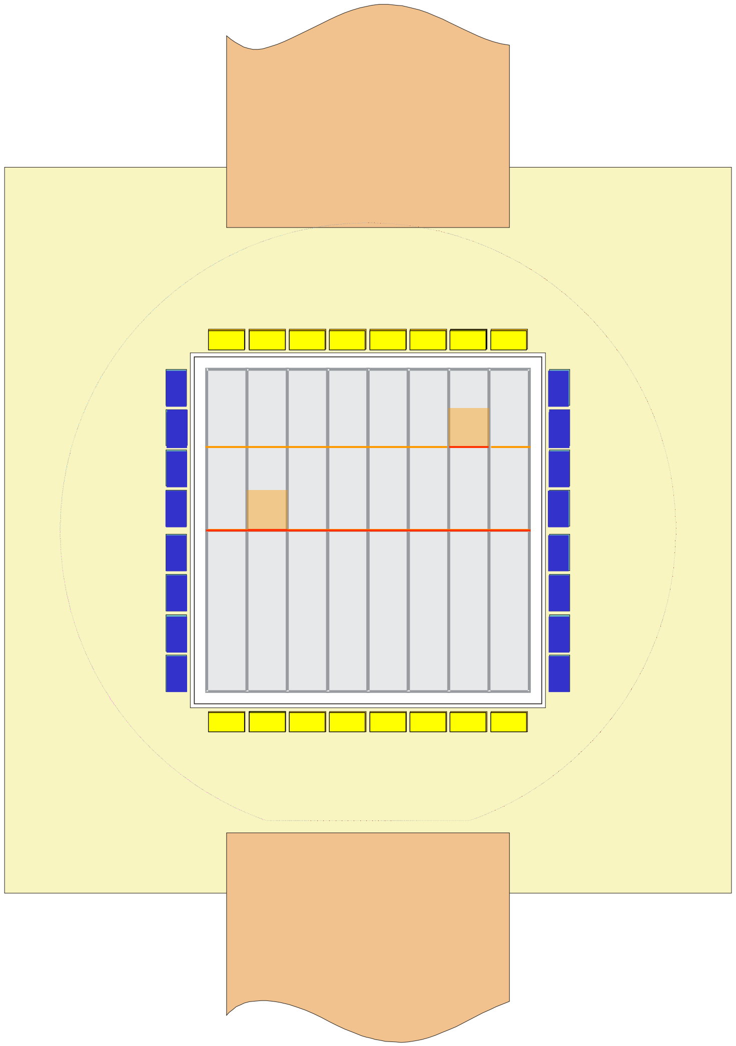
- *Readout modes:*
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

WFI readout concept



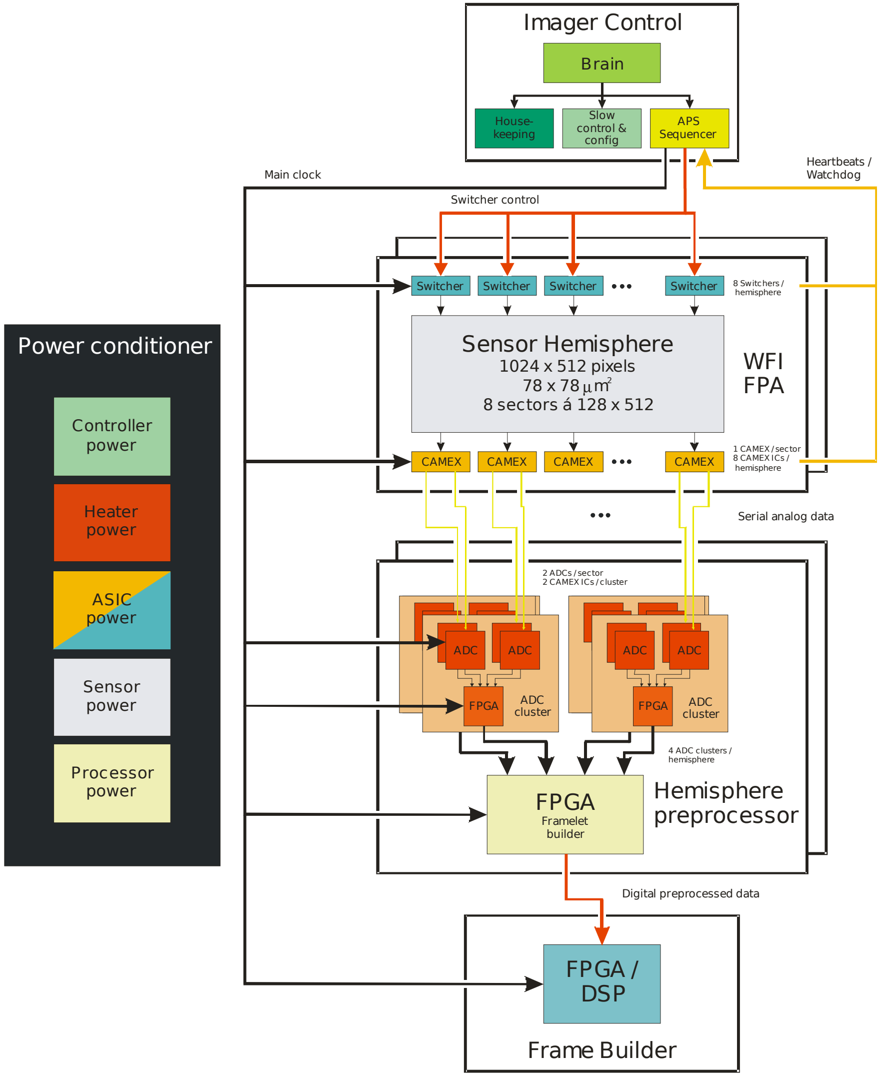
- *Readout modes:*
  - **Window mode:** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

WFI readout concept



- *Readout modes:*
  - **Window mode (cont.):** Acquire fully sized window strip (anywhere on FPA) repetitively
  - Read rest of frame with reduced framerate
  - Different ROIs on arbitrary positions on FPA
  - Even different non-overlapping ROIs on same Hemisphere possible (subsequent readout)

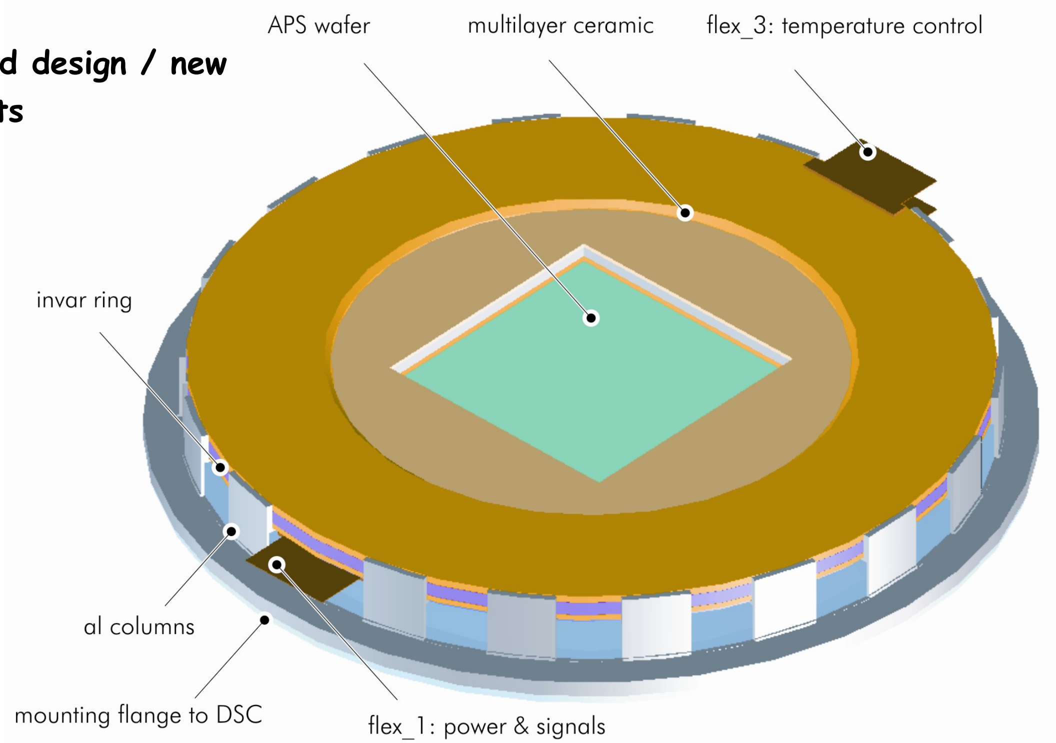
System



- *System components:*
  - WFI APS (2 redundant hemispheres)
  - Hemisphere preprocessor, consisting of 4 ADC clusters containing 4 ADCs each and one framelet builder FPGA
  - Frame builder FPGA
  - Imager control unit with housekeeper microcontroller, sequencer FPGA and slow control and configuration unit
  - Power supply units for the various subcomponents
  - Only sensor hemispheres are at „cold“ temperatures. Required cooling power ~ 22 W (est.)

Mechanics & services

- *Mechanical design*
  - Current concept based on SX & XEUS heritage
  - Preliminary design exists
  - Including thermal simulations
  - **Needs to be adapted to revised design / new spacecraft & mission constraints**



WFI performance

Specifications

- Field of view (min.)
  > 12 arcmin Ø
  > 7.2 cm Ø
- Angular resolution
  ≤ 5 arcsec @ 20 m
- Point spread function
  500 µm
- Good QE
- Energy range
  0.1 … 15 keV
- Energy resolution
  < 130 eV @ 6 keV
- Count rate capability
  10 kcps
  < 1% pileup
- Hard X-ray camera option
- Compliance with

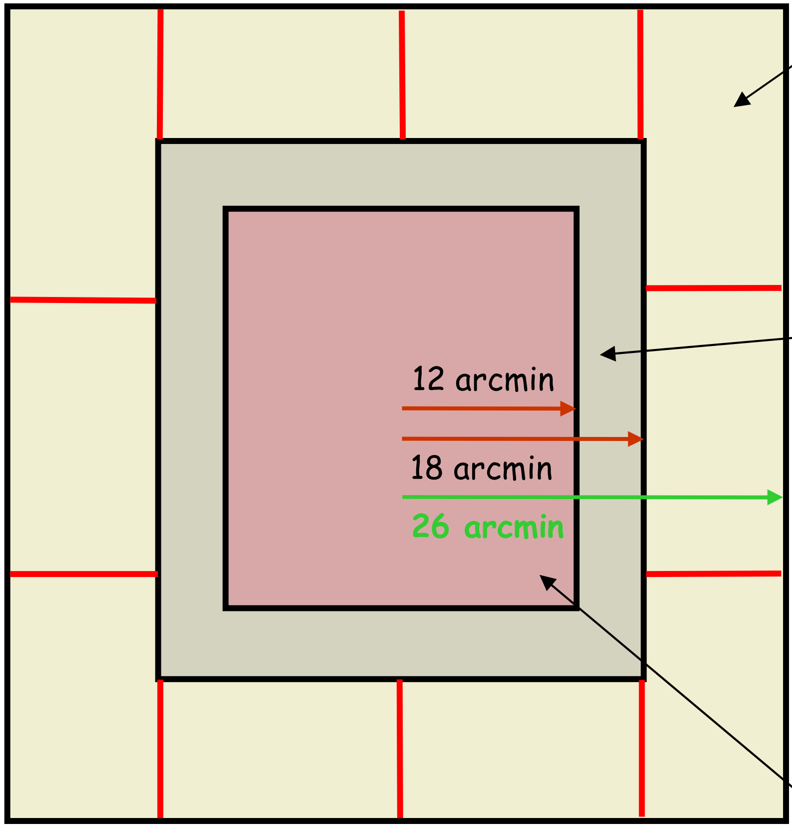
WFI requirements

- Detector format
  1024 x 1024 pix
  14 arcmin @ 25m
  18 arcmin @ 20m
- Pixel size
  100 x 100 μm^2
  75 x 75 μm^2
- Thin entrance window
- Detector thickness
  450 µm
- Low electronic noise
  « 4 el. ENC
- Fast readout
  2 µsec / pixel-row
- Window mode
  32 x 1024 pixel
- Monolithic device

WFI properties

- Min. - max. pixel size
  24 x 24 μm^2
  500 x 500 μm^2
- Thin entrance window
  for E > 50 eV
- Integrated optical blocking filter
  for E < 50 eV
- Detector thickness
  450 µm
- Low electronic noise
  « 3.5 el. ENC
  Δ E < 130 eV (FWHM)
- Fast readout
  2 µsec / row ~ 1000 frames/s
- Window mode
  32 x 1024 pixel ~ 32 µs/„framelet"
- Monolithic device
- Low power
  ~ 16 W
- High temperature
  ≥ -40 °C

WFI options

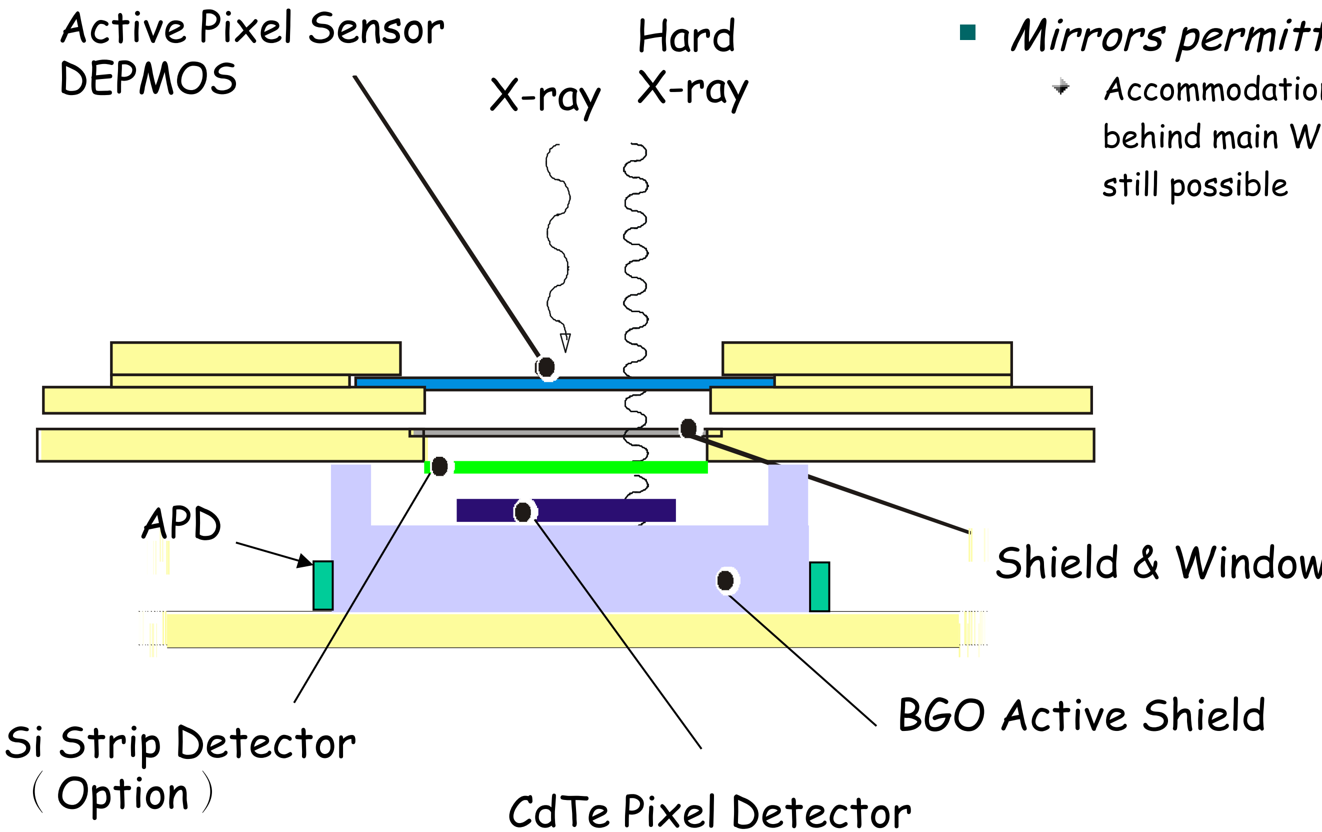


Optional: WFI expansion with e.g. MOS-type CCDs:
pixel size: 100 x 100 μm^2,
format: 1024 x 512 pixel
sensitive thickness: 200 μm

„actual“ WFI monolithic DePFET APS, BI,
sensitive thickness: 450 μm,
format: 1024 x 1024 pixel,
FOV: 18 arcmin @ 20 m FL,
pixel size: 100 x 100 μm^2

„original“ WFI: monolithic DePFET APS, BI,
sensitive thickness: 450 μm
format: 712 x 712 pixel
FOV: 12 arcmin @ 20 m FL,
pixel size: 100 x 100 μm^2

WFI options



- *Mirrors permitting:*
  - Accommodation of HXD behind main WFI FPA is still possible

IXO WFI Collaboration

Potential WFI Team:

MPE, Garching, IAAT	Germany
LU, Leicester	UK
Politecnico di Milano,	Italy
CAS, Tsinghua University	China
PNSensor GmbH	Germany
University of Osaka	Japan

US teams are welcome