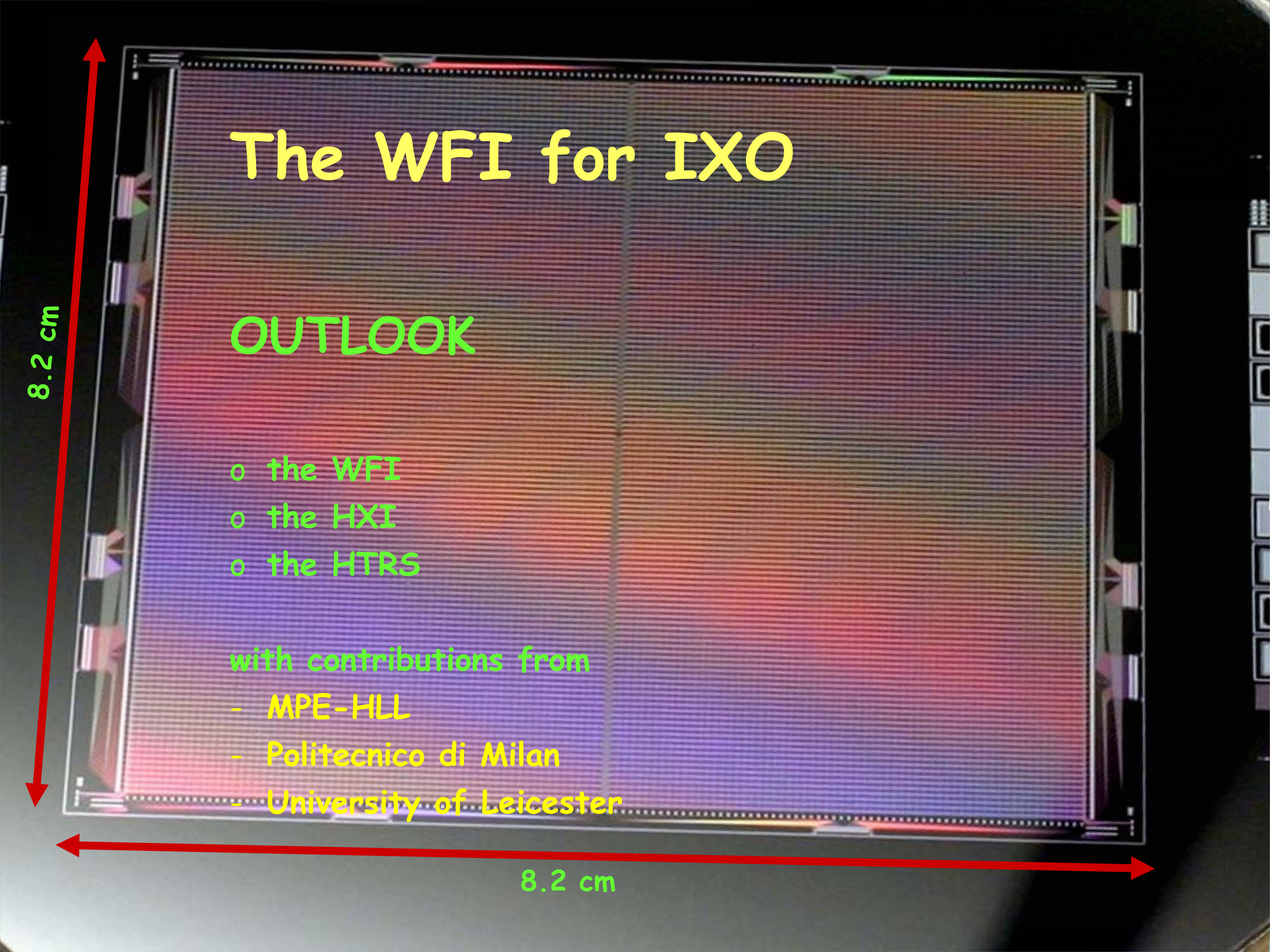
The WFI for IXO

OUTLOOK

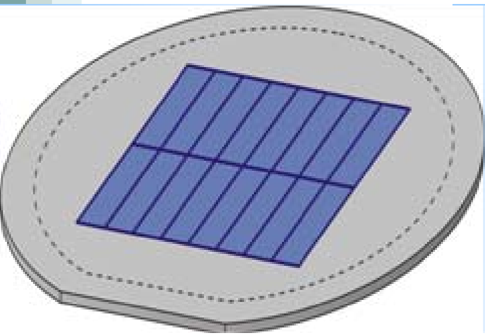
- the WFI
- the HXI
- the HTRS

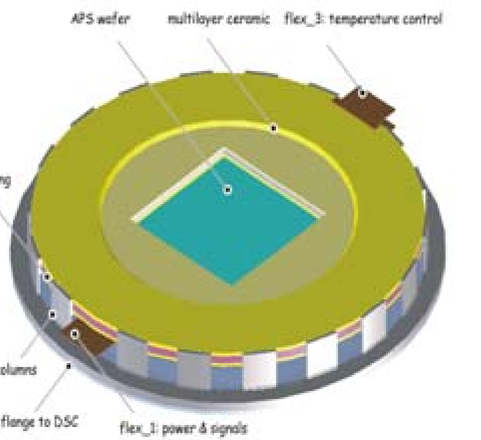
with contributions from

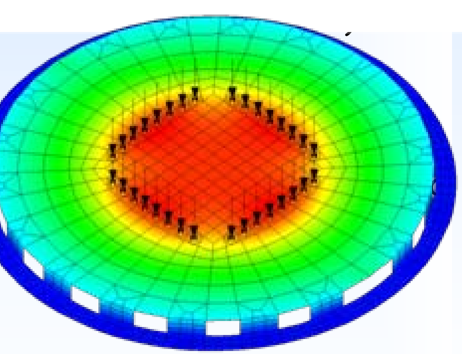
- MPE-HLL
- Politecnico di Milan
- University of Leicester



The Wide Field Imager







specifications

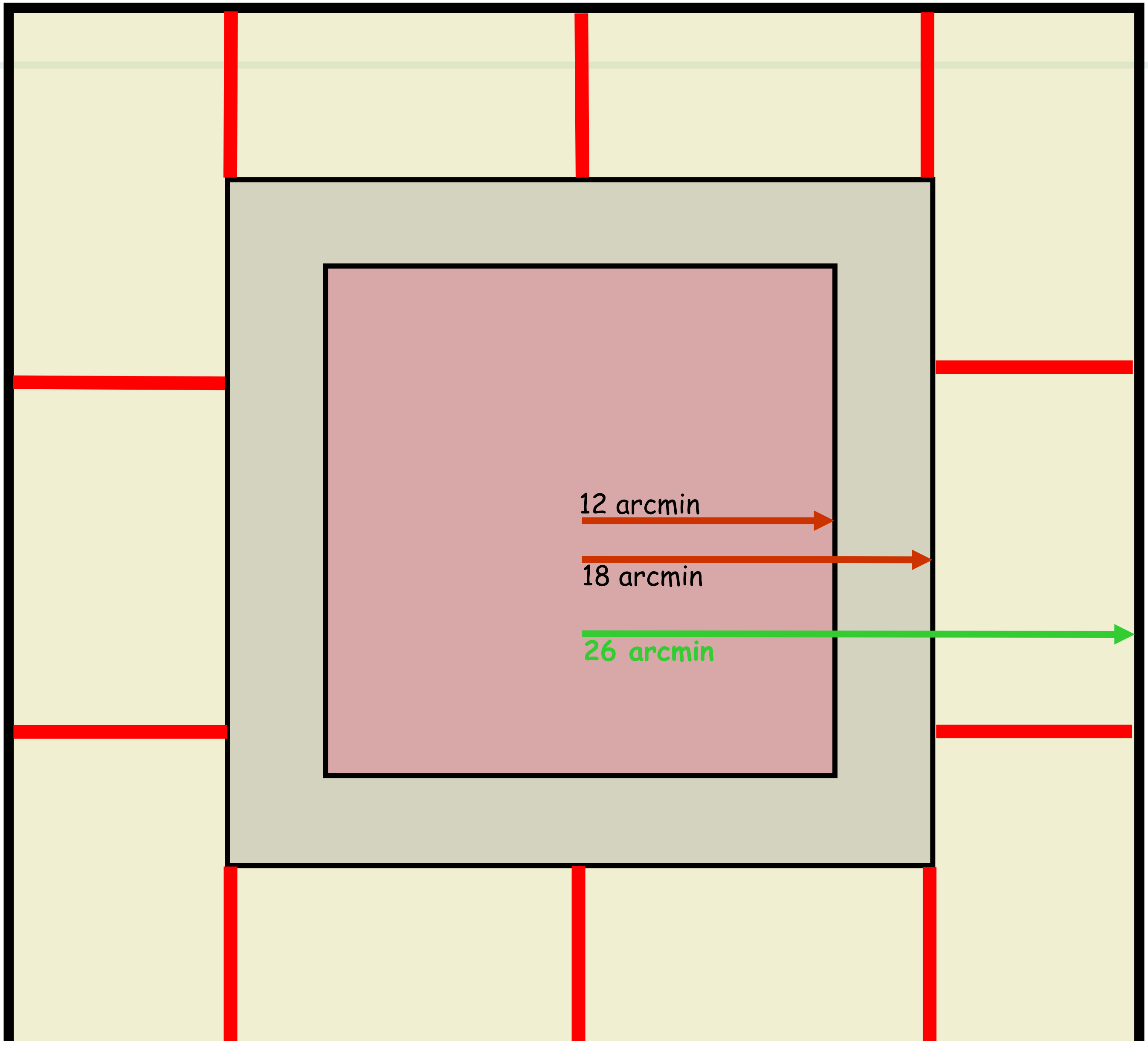
- field of view (min.)
  - > 12 arcmin Ø
  - > 7.2 cm Ø
- angular resolution
  - ≤ 5 arcsec @ 20 m
  - point spread function
  - 500 µm
- energy range
  - 0.1 … 15 keV
- energy resolution
  - < 130 eV @ 6 keV
- count rate capability
  - 10 kcps
  - < 1% pileup
- hard X-ray camera option
- spacecraft constraints

WFI parameters

- 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
- low power
  - < 10 W
- high temperature
  - ≥ -60 °C

- min. - max. pixel size
  - 24 x 24 µm²
  - 500 x 500 µm²
- thin entrance window
  - for E > 50 eV
- integrated optical blocking filter
  - for E > 50 eV
- detector thickness
  - 150 - 450 µm
- low electronic noise
  - « 3.5 el. ENC
  - ⇨ Δ E = 130 eV (FWHM)
- fast readout
  - 2 µsec / row
  - @ 1000 frames per sec
- window mode
  - 32 x 1024 pixel, i.e. 32 µs per frame
- monolithic device
- low power
  - < 8 W
- high temperature
  - ≥ -40 °C

Potential WFI layouts (FL 20 m)



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

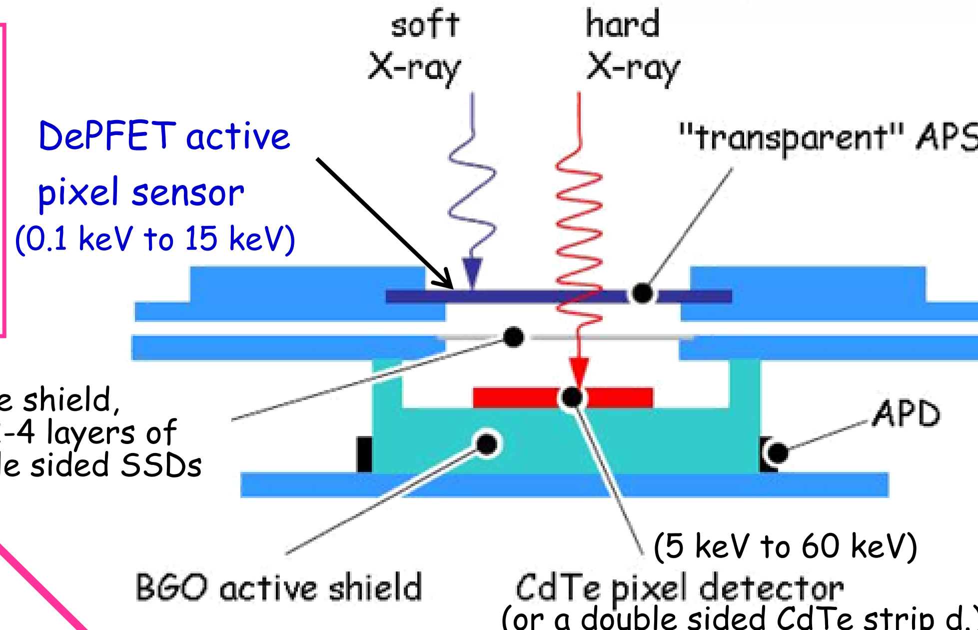
„actual“ WFI monolithic DePFET APS, BI,
sensitive thickness: 450 μm,
format: 1024 x 1024 pixel,
FOV: 18 arcmin @ 20 m FL,
pixel size: 100 x 100 μm^2

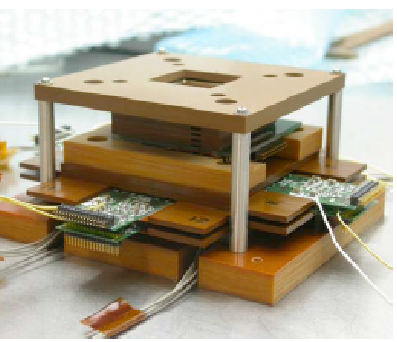
„original“ WFI: monolithic DePFET APS, BI,
sensitive thickness: 450 μm
format: 712 x 712 pixel
FOV: 12 arcmin @ 20 m FL,
pixel size: 100 x 100 μm^2

WFI and HXI on XEUS

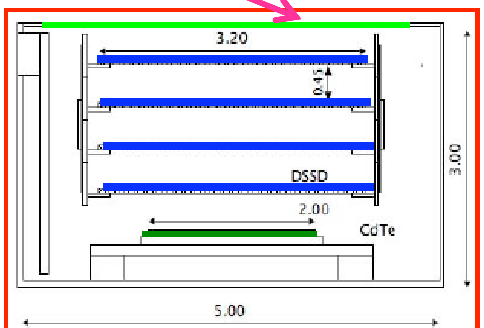
one possibility of accomodation the DePFET WFI and the HXI within a single camera housing:

For X-rays above typ. 20 keV the DePFET becomes transparent and the X-rays will eventually interact with the double sided SSD or the CdTe detector





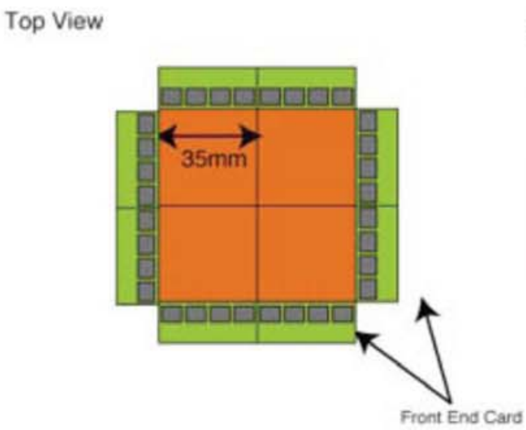
wide field imager (DePFET)

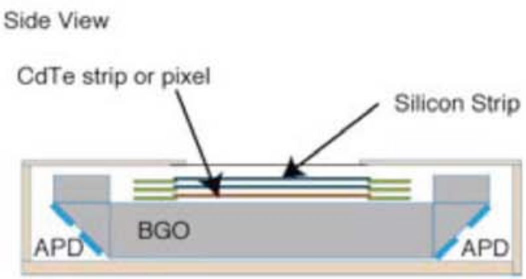


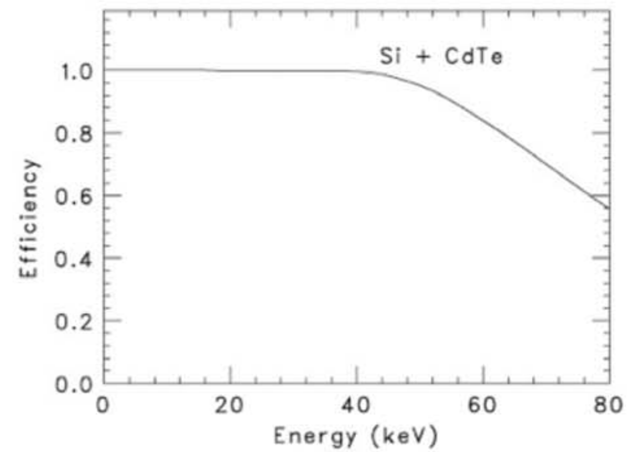
Test set-up for the combined double sided SSD and the CdTe detector. The distance between the WFI and the CdTe detector of the HXI is approximately 2 cm.

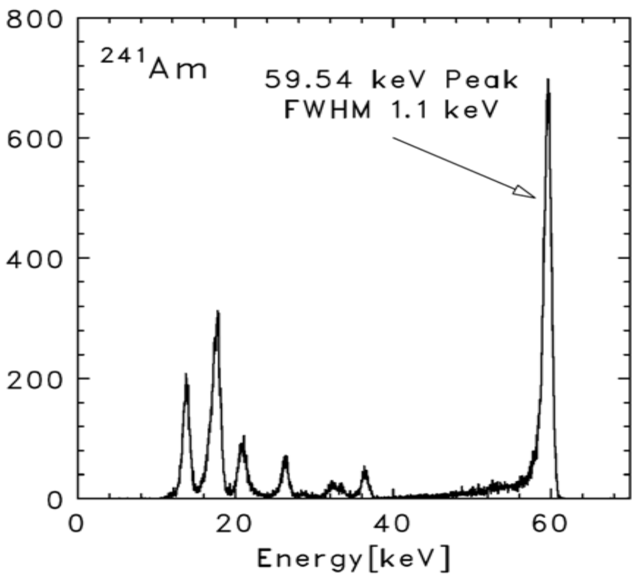
- Double Side Silicon Strip (4 layers)
- Double Side CdTe Strip (1 layer)

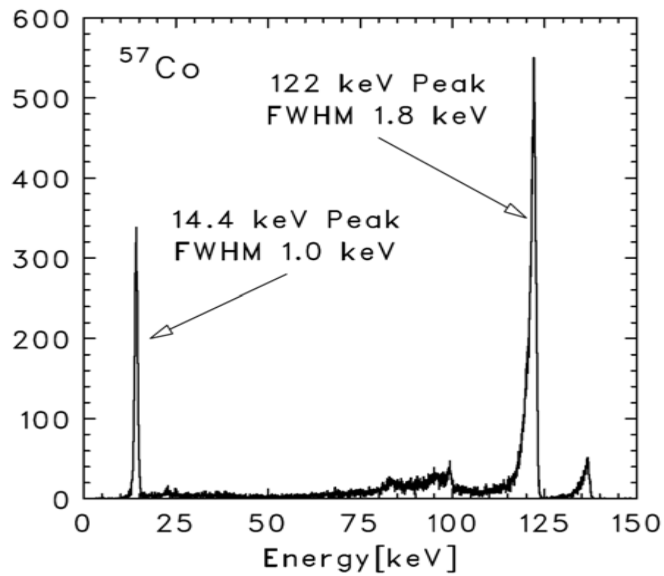
HXI layout and performance





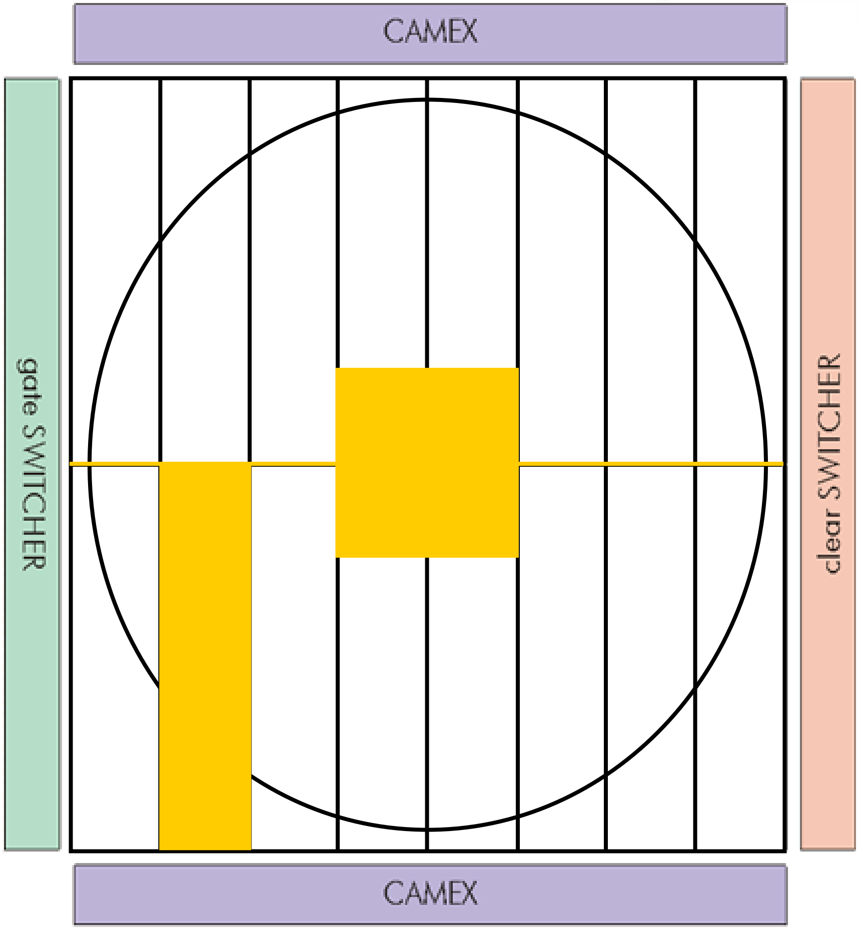






DEPFETs for the XEUS WFI

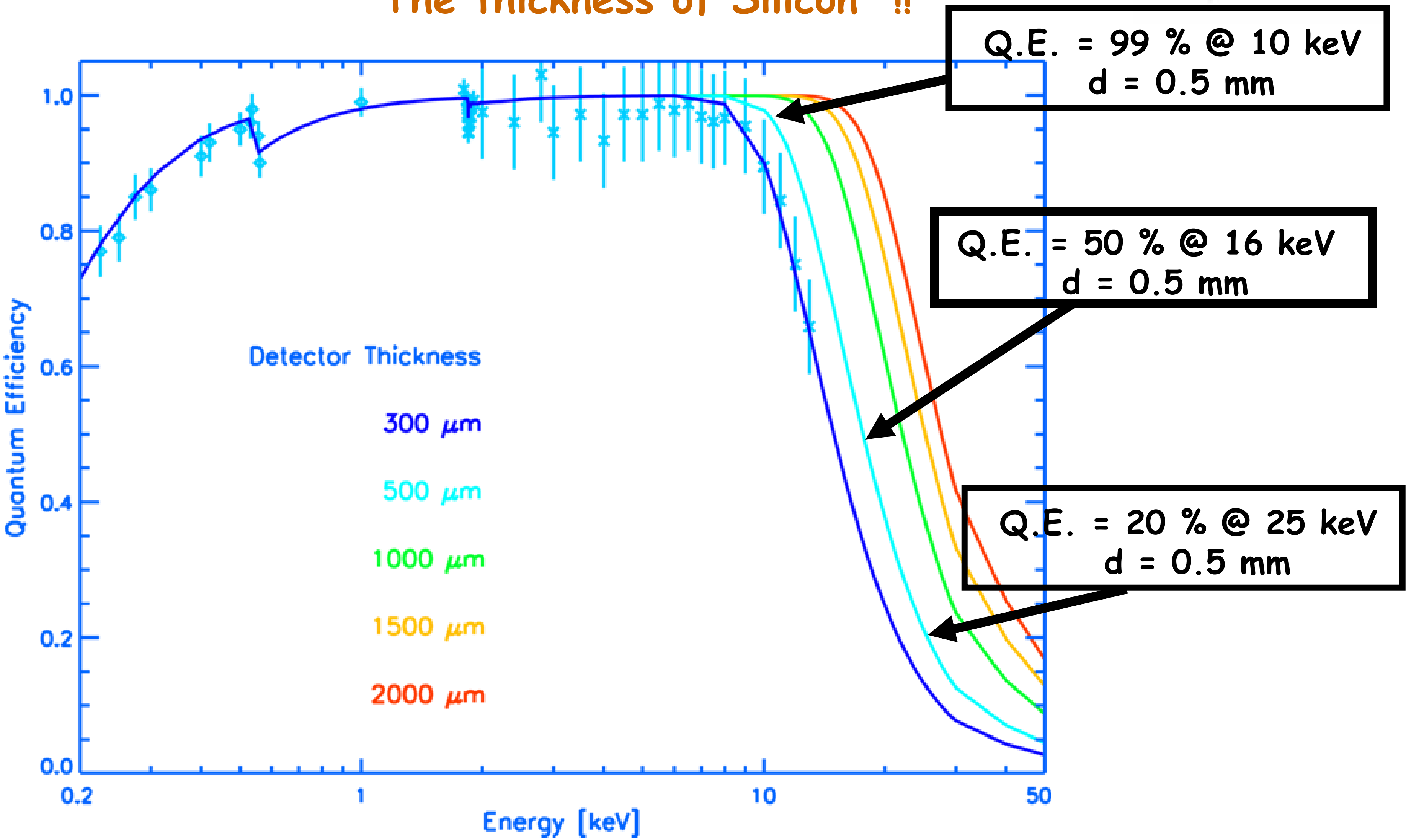
1. Flexible operating modes
2. low power dissipation (less than 2 W in 100 cm^2, DePFETs only)
3. Fano limited energy resolution from 0.5 keV to 30 keV
4. Spatial resolution better than 20 µm @ 100 µm pixel size
5. Homogeneous radiation entrance window
6. Intrinsic radiation hardness, no charge transfer needed
7. ENC was lowered to 0.2 e^- rms with RNDR
8. Thin optical ``Blocking Filter´´ can be directly integrated
9. Operation at ``warm temperatures´´, e.g. – 40 °C



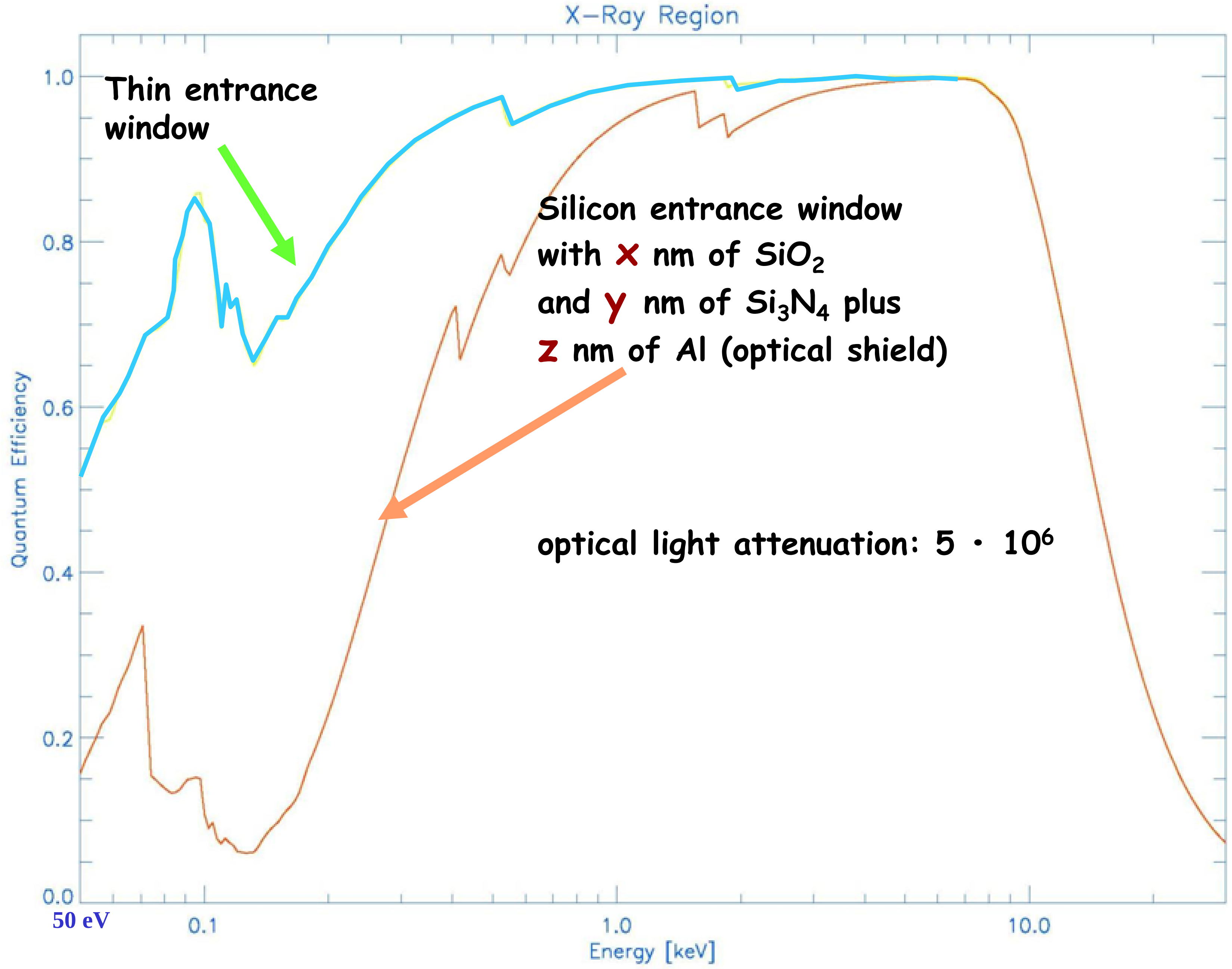
focal length of 35 m

What is limiting the quantum efficiency for photons ?

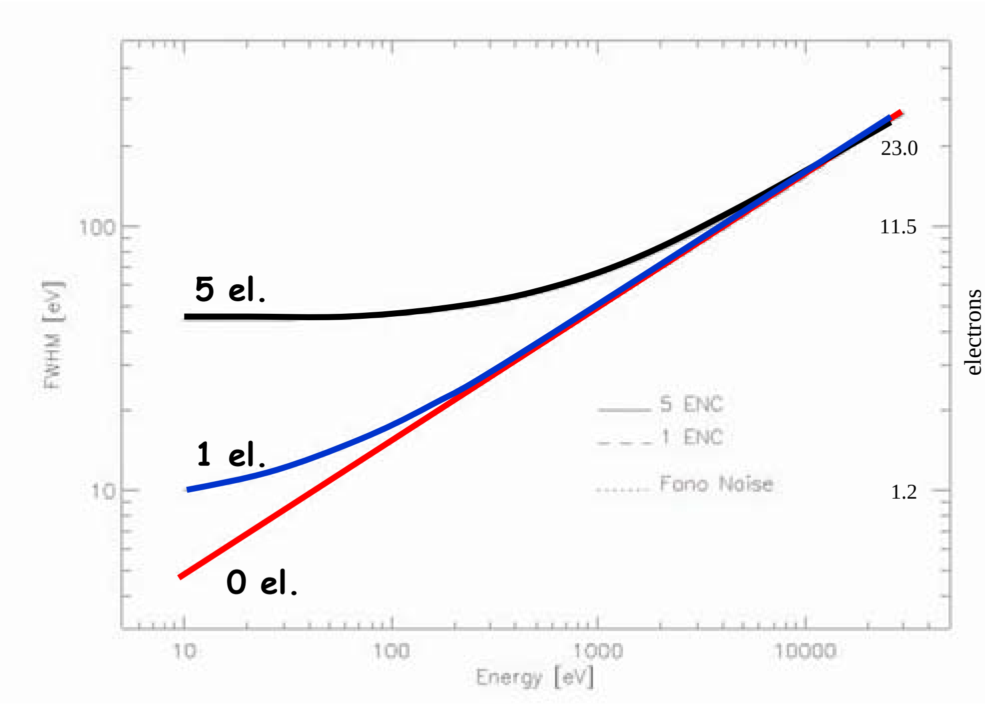
The thickness of Silicon !!



Monolithic Implementation of optical blocking filters



Limits of energy resolution of e.g. X-rays



$$\mathrm{ENC}^2_{\mathrm{fano}} = \frac{F \cdot E}{w}$$

$$\mathrm{ENC}^2 = A_1\left(\alpha \frac{2kT}{g_m} C^2{}_{tot}\right)\frac{1}{\tau} + \left[A_2\left(2\pi a_f C^2{}_{tot} + \frac{b_f}{2\pi}\right)\right] + A_3\left(qI_l + \frac{2kT}{R_f}\right)\tau$$

$$ENC^2{}_{tot} = ENC^2{}_{el} + ENC^2{}_{fano} + \ldots = (0.2\ e^- - 5\ e^-)^2$$

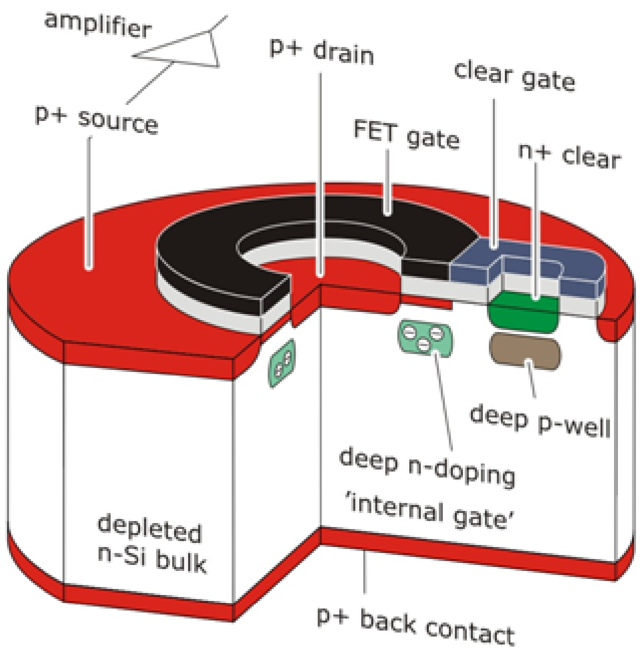
DePFET Active Pixel Sensors

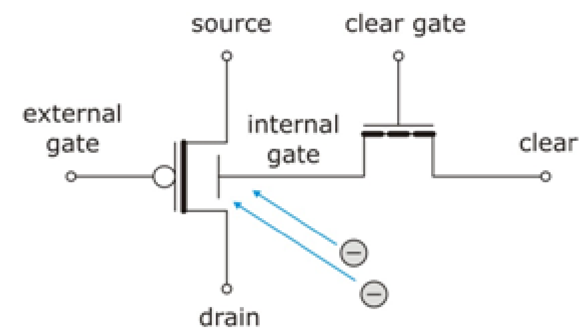
p-FET on depleted n-bulk

- signal charge collected in potential minimum below FET channel
- steers transistor current (1 el. ~ 300 pA)

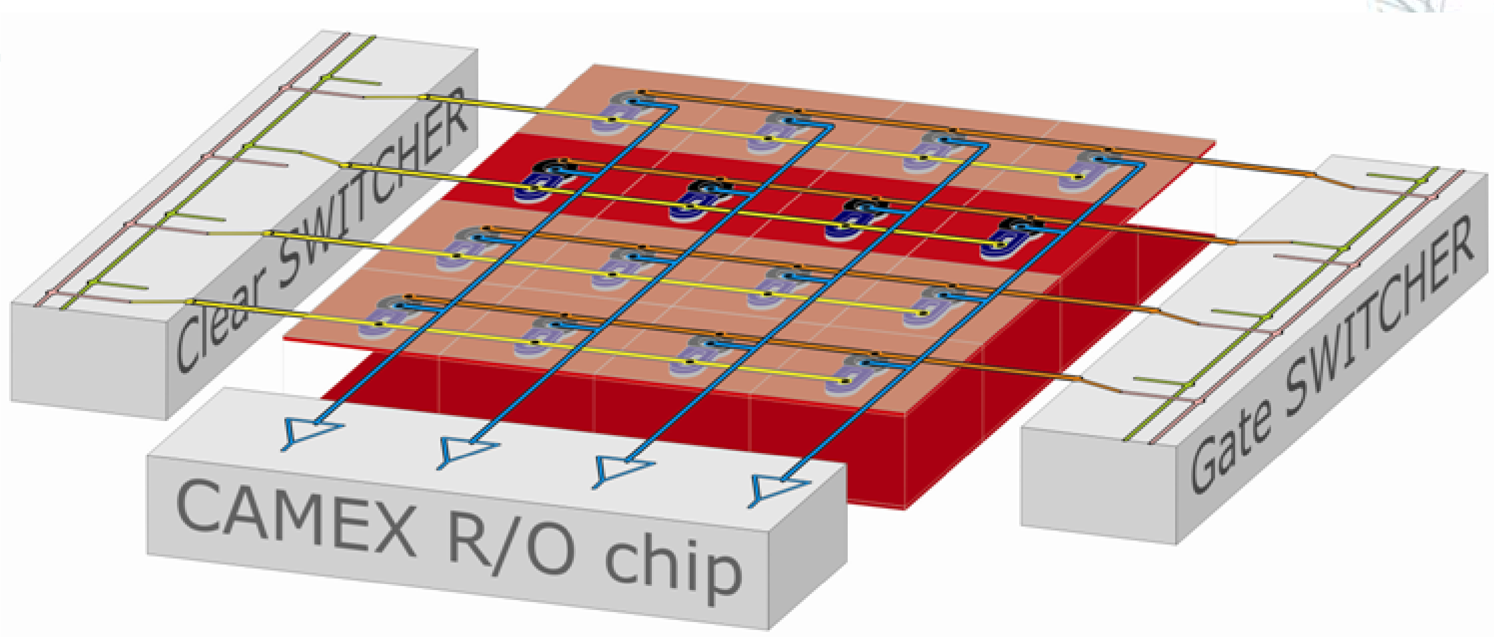
combined sensor & amplifier

- low capacitance and noise
  » **excellent spectroscopic performance**
- complete clearing of signal charge
  » **no reset noise**
- non-destructive readout
  » **potential of repetitive readout**
- charge storage capability
  » **readout on demand**
- full depletion
  » **backside illumination**
  » **thin entrance window**





DEPFET Active Pixel Sensor

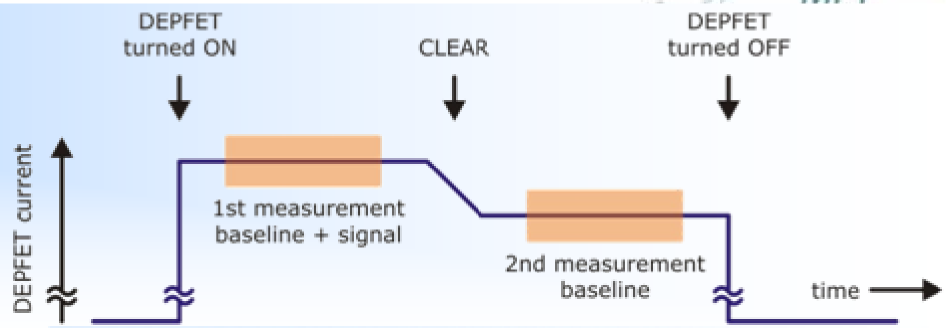


- **matrix organisation**
  - common back contact
    - » **thin, homogeneous entrance window**
    - » **fill factor 100 %**
  - row-wise connection of gate, clear, clear gate
  - column-wise connection of source / drain
    - » **individually addressable pixels**
    - » **windowing option**

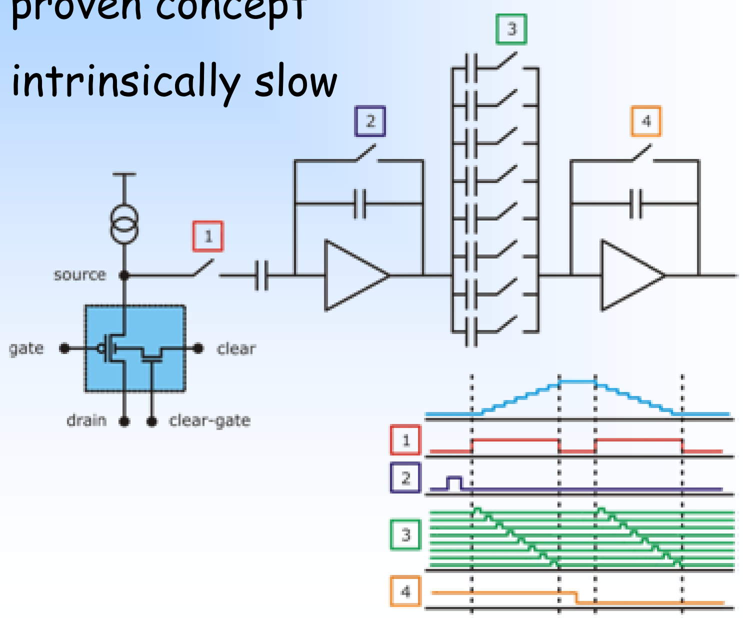
- **operation philosophy**
  - one active row
  - all other pixels turned off
    - » **low power consumption**
  - all operations in a row in parallel
    - » **fast processing**

DEPFET readout

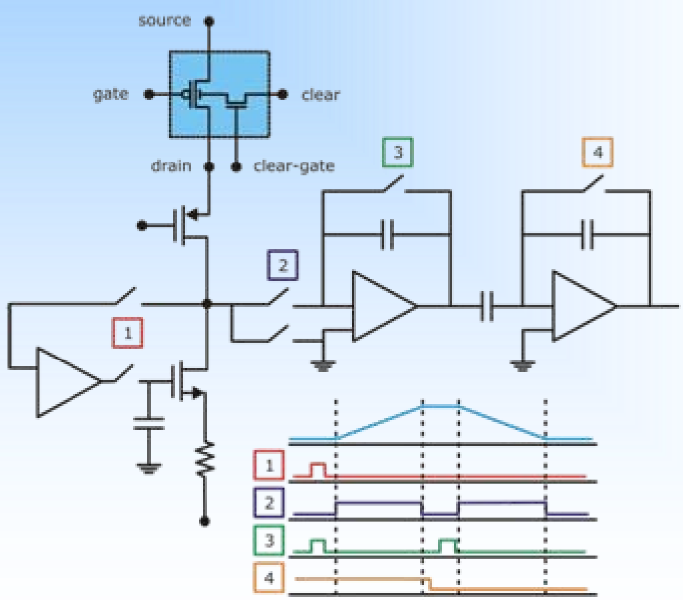
- **principle**
  - measure signal + baseline current
  - 'clear' = remove signal electrons
  - measure baseline current



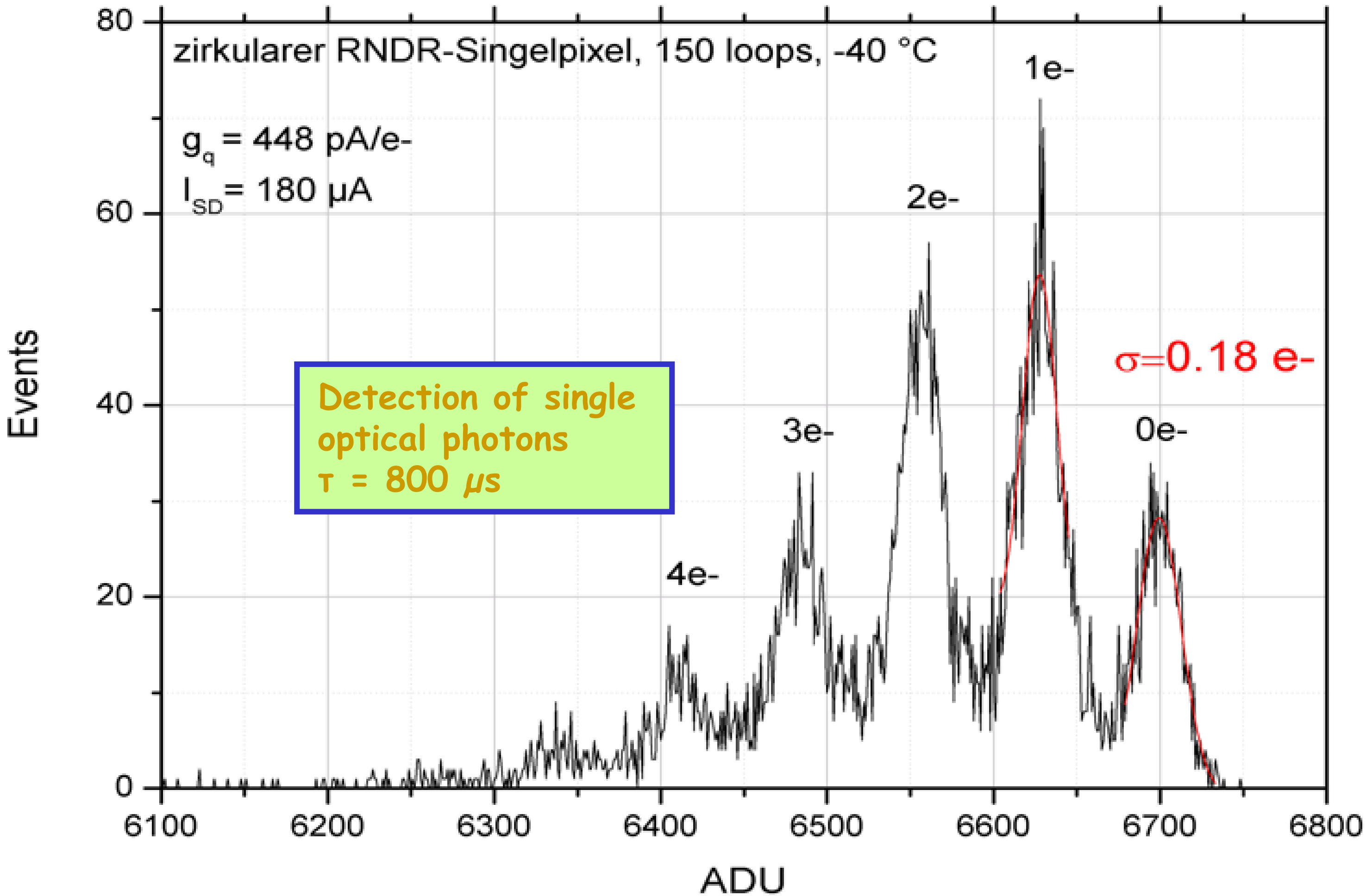
- **CAMEX**
  - source follower, 8-fold CDS
  - CMX64 in operation, CMX128 in design
  - ☑ proven concept
  - ☒ intrinsically slow



- **VELA** (in collaboration with Politecnico di Milano)
  - drain current integration/deintegration
  - 64-channel prototype under test
  - ☑ high readout speed
  - ☒ more sensitive to flatband shifts



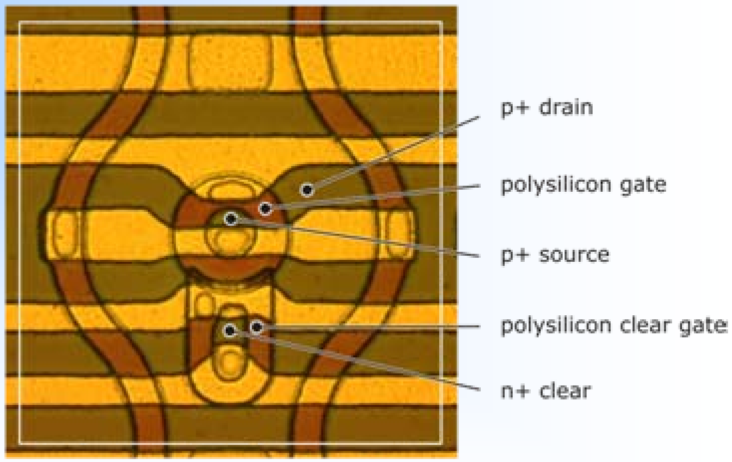
First Results with 64-channel Vela ASIC



DEPFET APS - prototypes

DEPFET pixel 75 µm □

- geometry
  W = 47 µm
  L = 5 µm
- current
  I = 30 µA
- sensitivity
  g_Q = 300 pA/el



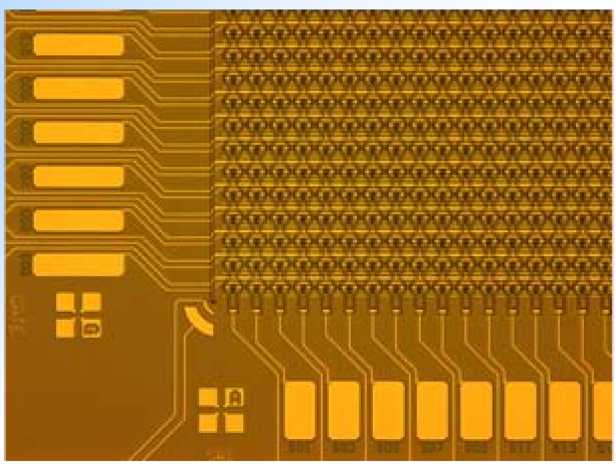
256 x 256 APS

dedicated technology

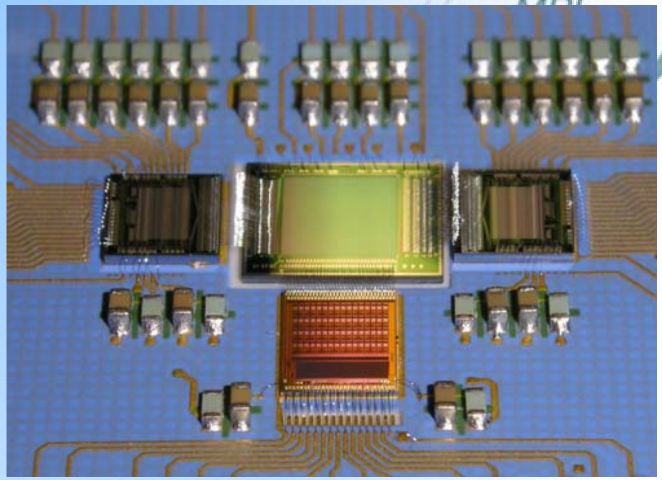
- 2 polysilicon layers
- 2 metal layers

leakage current level

- 100 pA/cm^2
- 16 fA/pixel



APS hybrid



CAMEX64 readout ASIC

- 64 channel low noise voltage amplifier
- 64 channel 8-fold CDS filter
- 64/1 analog multiplexer
- source follower gain 3.7 µV/el.

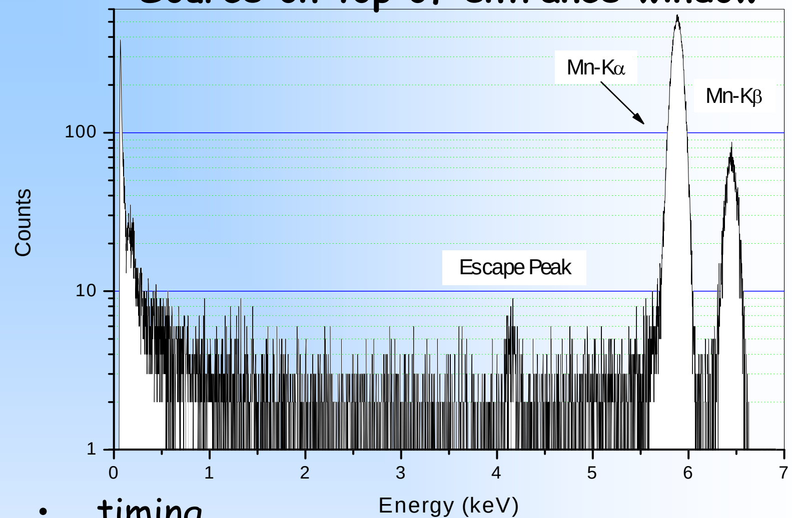
2 x Switcher II control ASIC

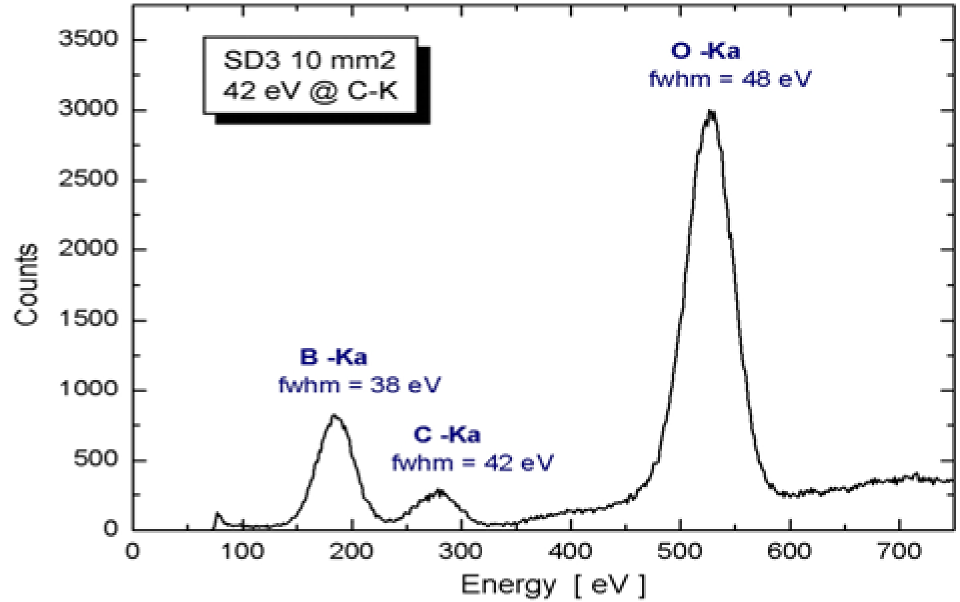
- 64 channel control chip
- 2 ports / channel
- integrated sequencer
- high voltage CMOS process
  > 20 V p-p
- 50 MHz clock

DEPFET APS – performance

low energy response

"Backside" illumination:
Source on top of entrance window





- timing
  - 4 µsec/row <-> 64 µsec/32x512 sensor
- room temperature
  - 220 eV FWHM @ 5.9 keV (singles)
- moderate cooling -40 °C
  - 126 eV FWHM @ 5.9 keV (singles)
  - 132 eV FWHM @ 5.9 keV (all events)
- extrinsic speed & resolution limitations

yield & homogeneity

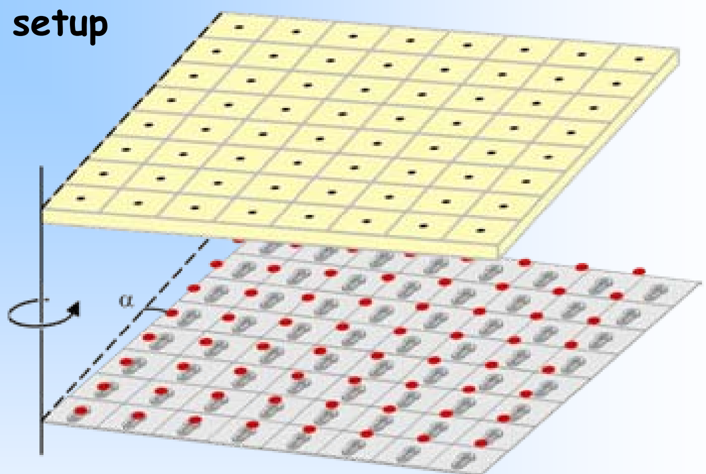
- defect pixels
  - 2 in 45 devices (> 10^6 pixels)
  - pixel yield > 0.99999
- dispersions
  - offset < 2 % (of Mn-Ka)
  - gain < 5 %
  - noise < 10 %

DEPFET APS – mesh experiment

method

- irradiation through tilted periodic mesh
- Moire pattern
- X-ray interaction position with subpixel resolution

setup

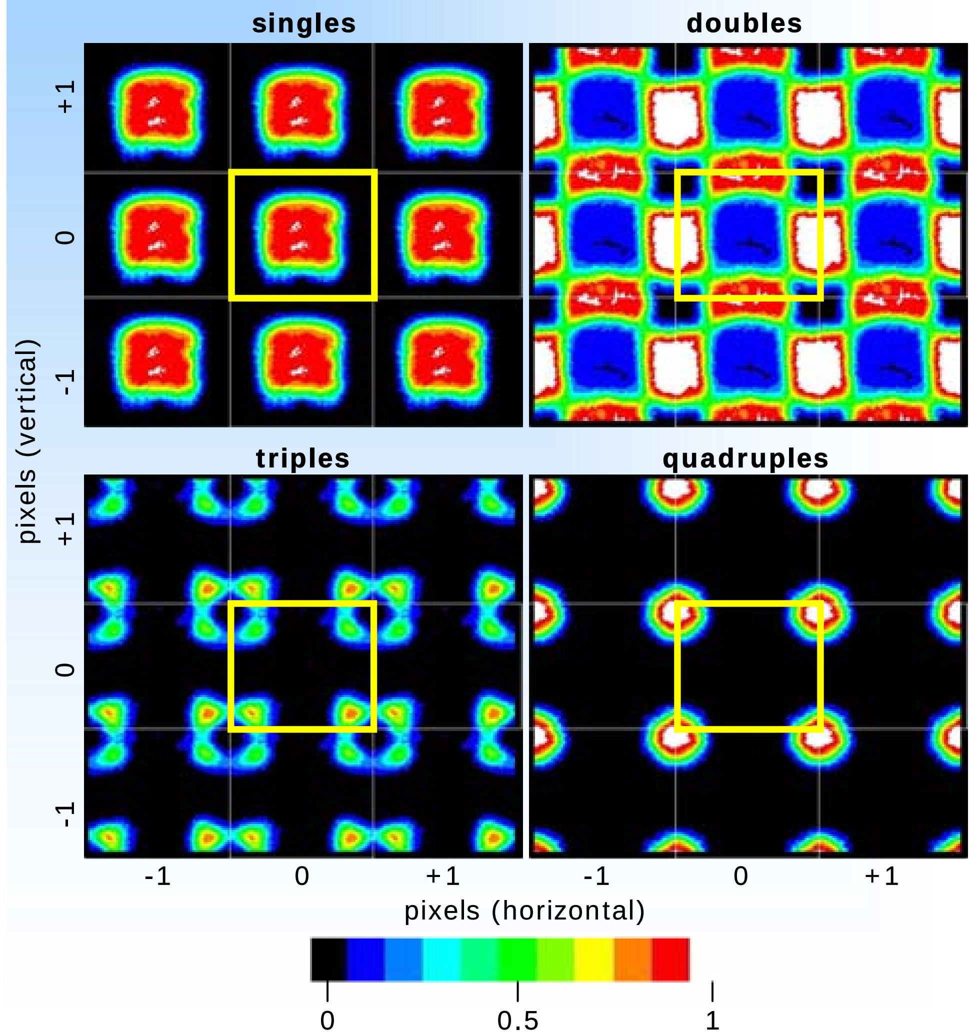


- mesh 10 μm gold
  5 μm holes
  150 μm pitch
- X-rays Cr-K_α (5.4 keV)

example

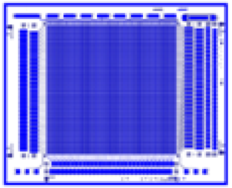
- variation of multiple pixel hit patterns with back contact voltage
- V_back =

-400 V

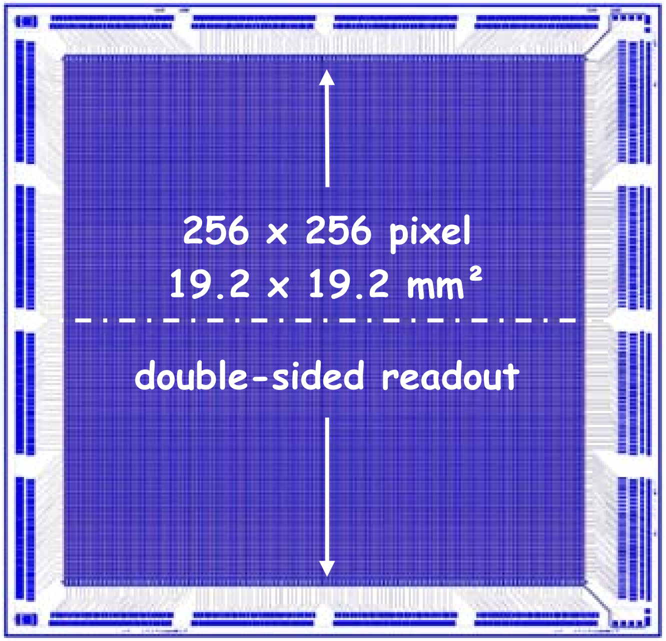


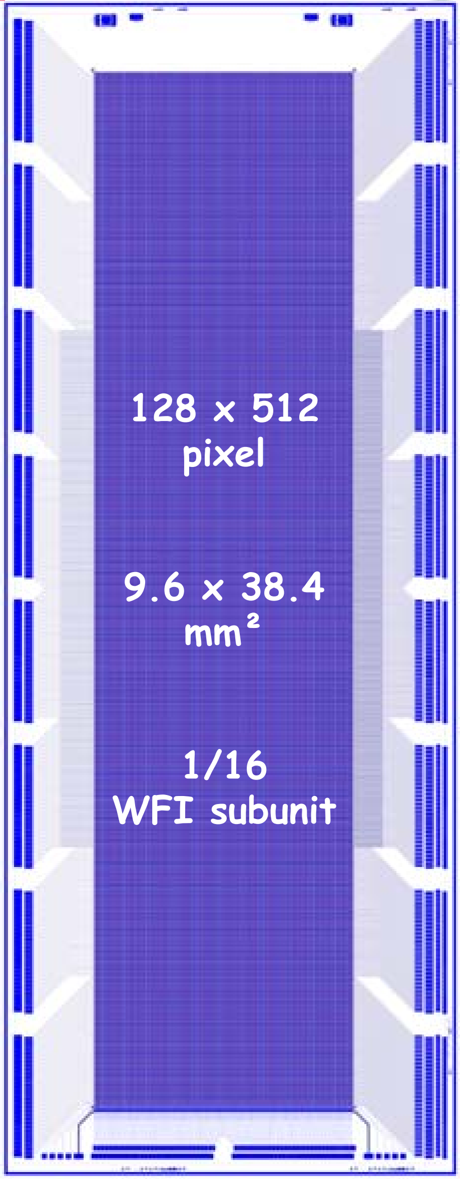
DEPFET APS – next generation

- **new production**
  - first results scheduled summer 2008
- **minor pixel modifications**
  - faster charge collection
  - low-voltage clear process
- **large formats**
  - yield & homogeneity studies
  - readout & control system adaptation
  - effect of long signal lines

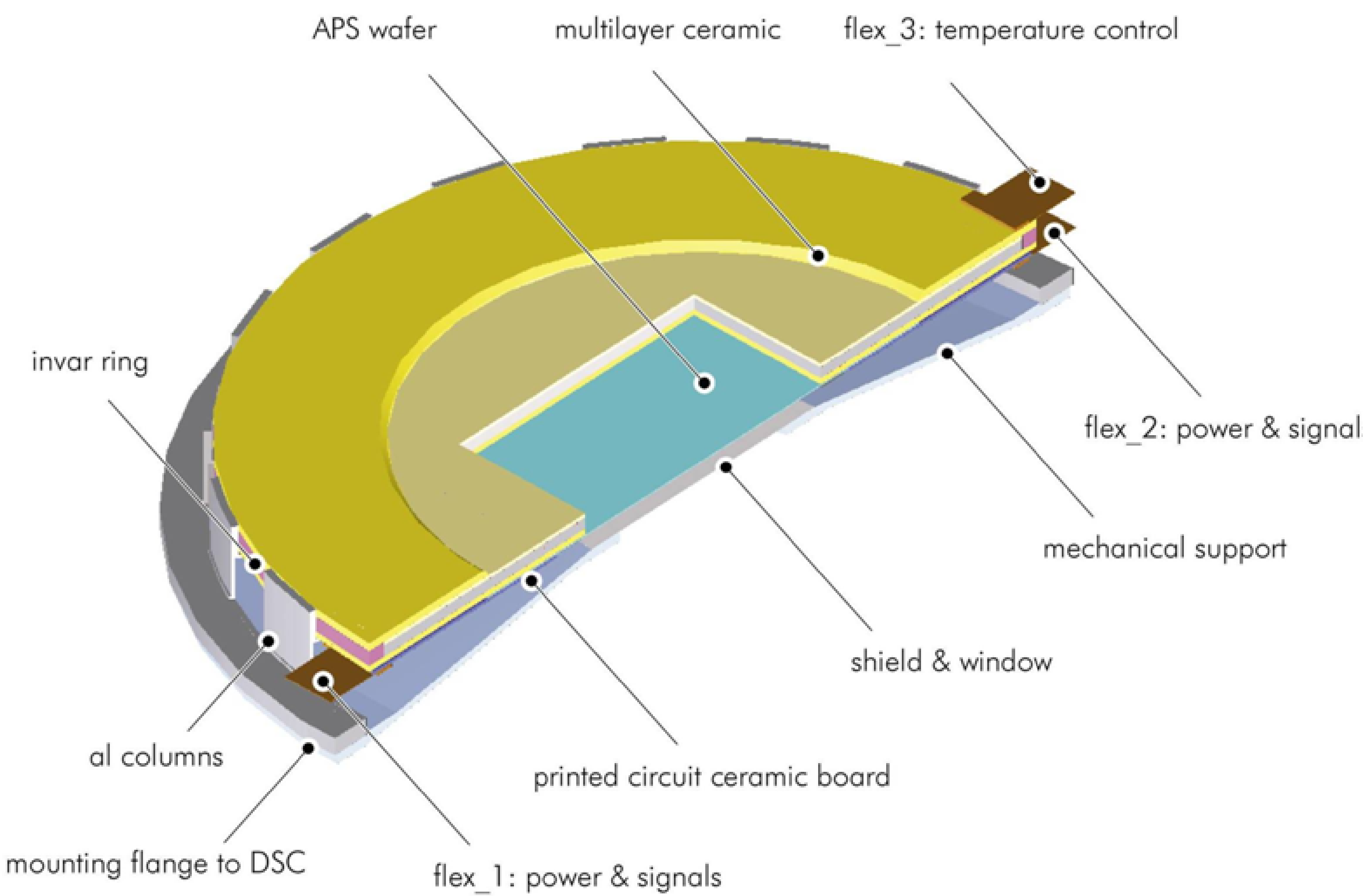


64 x 64 pixel
4.8 x 4.8 mm²

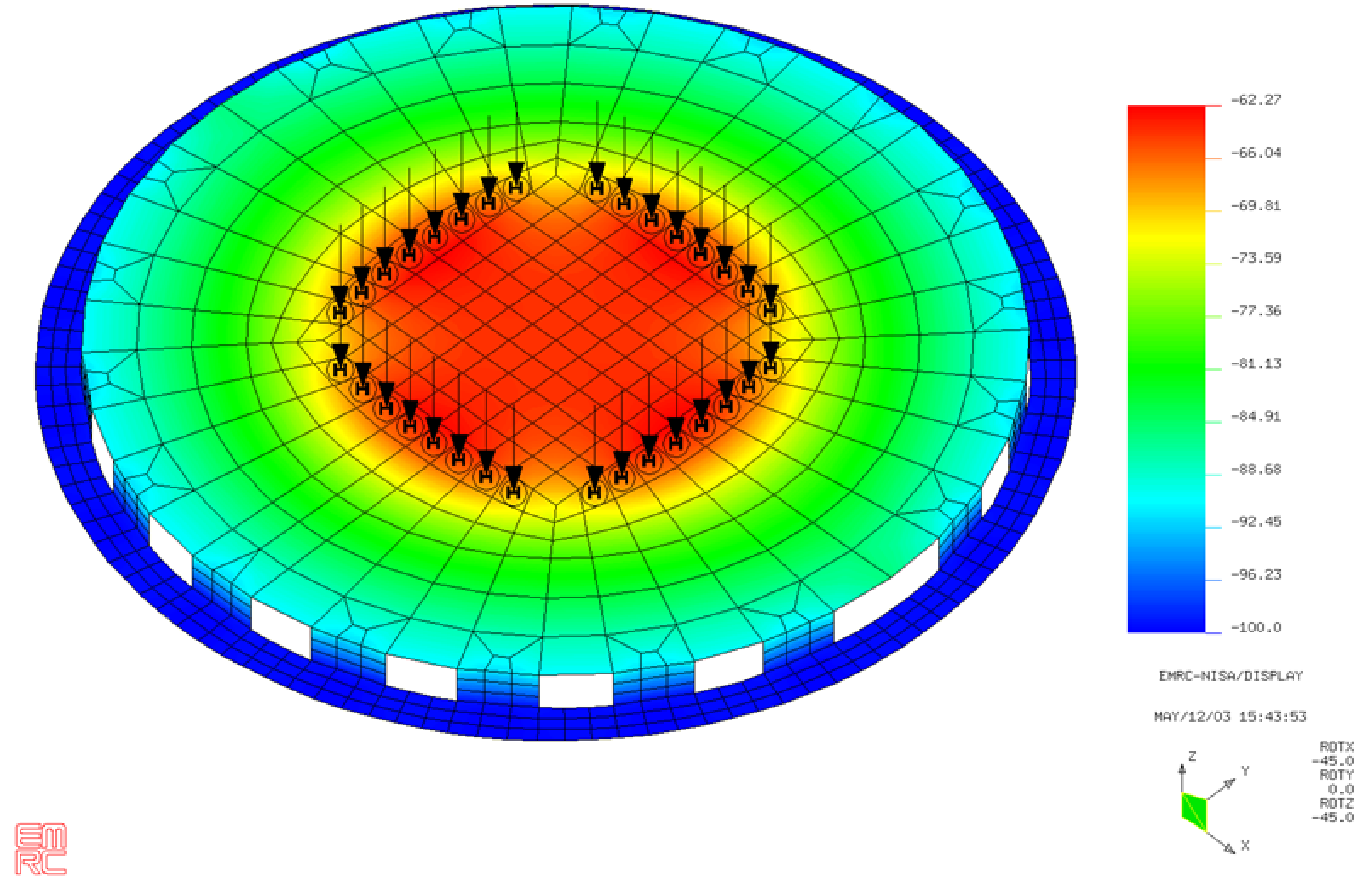




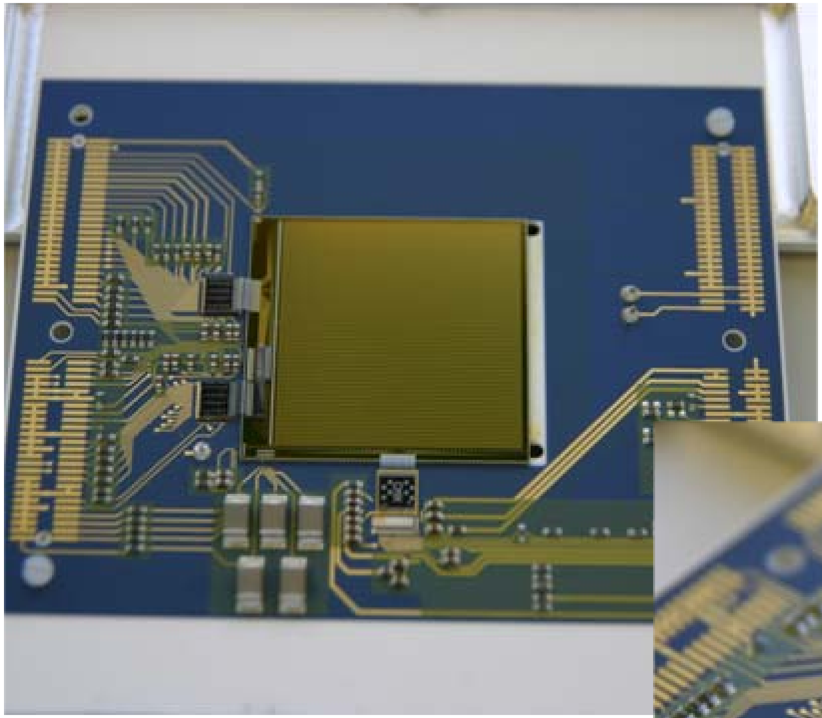
Mechanical structure of APS

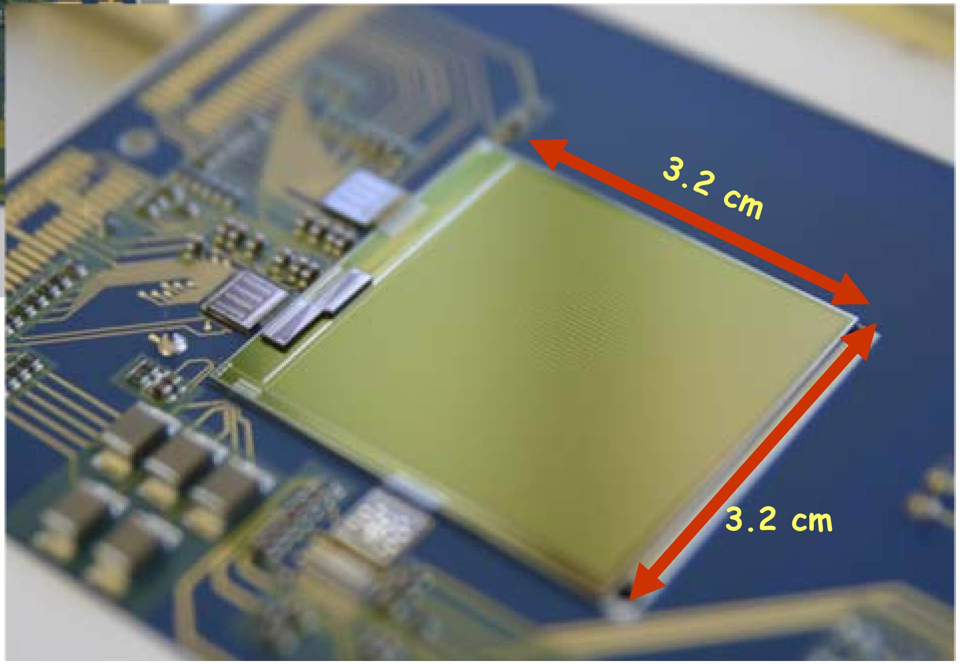


Thermal Analysis of the APS System

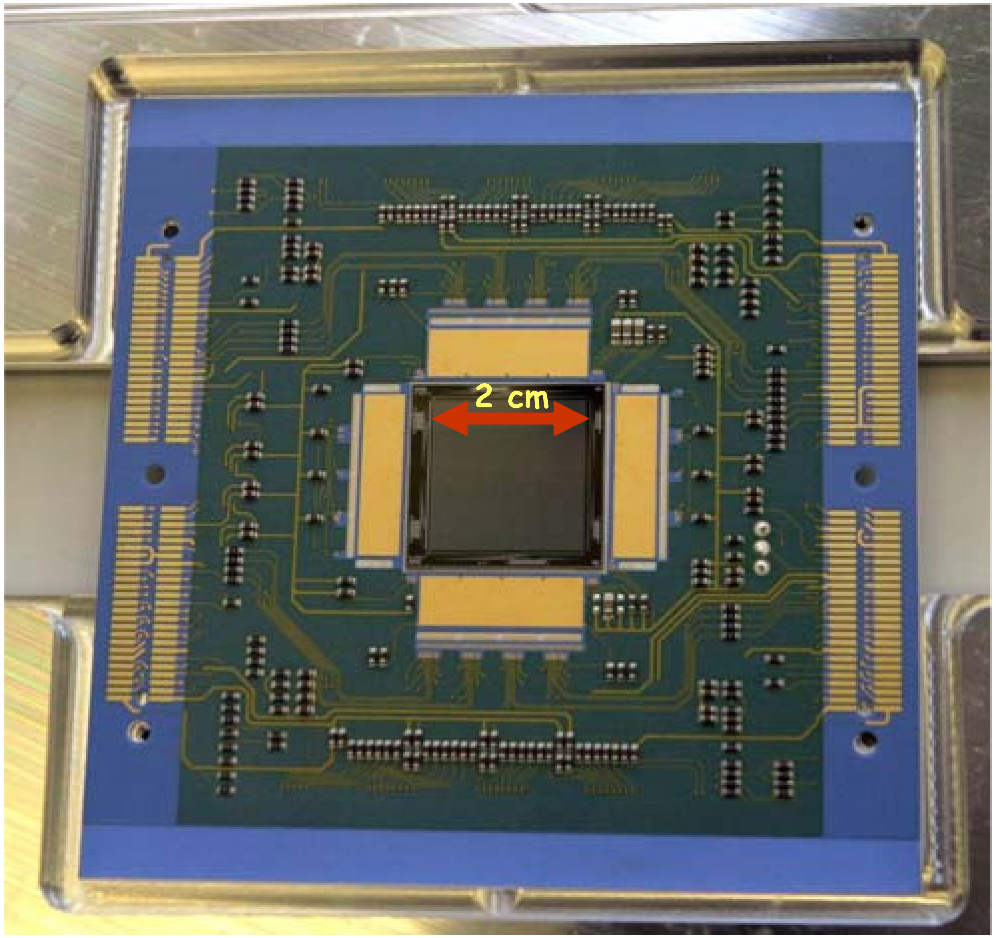


SIMBOL-X-Hybrid





BepiColombo Chip and Hybrid



Breadboard module test assembly of the BepiColombo system

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

8.2 cm

8.2 cm

HTRS requirements (CESR, Didier Barret)

PARAMETER	REQUIREMENT (GOAL)	SCIENCE DRIVER
Effective area (m^2)	1 (1.5) @ 0.2 keV 5 @ 1 keV	WHIM, early BHs, clusters Clusters, WHIM, early BHs
	2 @ 7 keV 1 @ 10 keV (0.1) @ 30 keV	EOS, gravity in strong fields EOS, acceleration, early BHs Acceleration, early BHs, EOS
Energy range (keV)	0.1–40	BHs, acceleration, clusters
Angular resolution (arc-sec)	5 (2)@ < 10 keV 10 @ 40 keV	Clusters, early BHs, WHIM Early BHs
Field of view (arc-min)	7 (10) diameter: WFI, HXI 1.7 diameter: NFI	Clusters, early BHs, acceleration Clusters, enrichment, galaxy evolution
Spectral resolution (eV)(FWHM)	2 (1) @ 0.5 keV: NFI 2 @ <2 keV: NFI 6 (3) (@ 6 keV: NFI 150 @ 6 keV: WFI 1000 @ 40 keV: HXI	WHIM Clusters Clusters, enrichment, galaxy evolution Early BHs Early BHs
Point source detection sensitivity, erg cm^{-2} s^{-1}	(3×10^{-18}) @ 0.2–8 keV; 4σ	Early BHs
Time Resolution (s)	10^{-5} : HTRS	EOS studies
Count rate capability (s^{-1})	$2\ 10^6$: HTRS	EOS studies
Polarimetry (MDP, 3σ-confidence in 10 ks)	2% at 10^{-2} Crab: XPOL	EOS studies
Observing constraints	>2 weeks visibility each 6m ToO response in (<1 day) 10^3 (5.10^4) s cont. observ. $\pm 5^o$ ($\pm 15^o$)range Sun angle	EOS studies EOS studies EOS studies, strong gravity EOS studies

SDDs for astrophysics
the HTRS on XEUS

HTRS (High Time Resolution Spectrometer)

possible choice: 19-cell SDD array

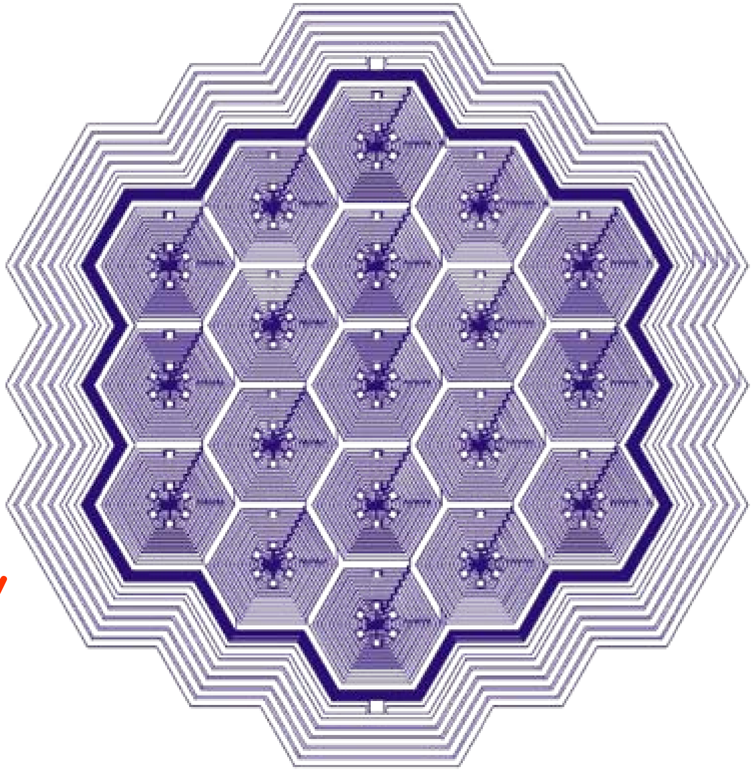
timing and spectroscopy

1- 10 μsec / 150 eV / 20 Mcps

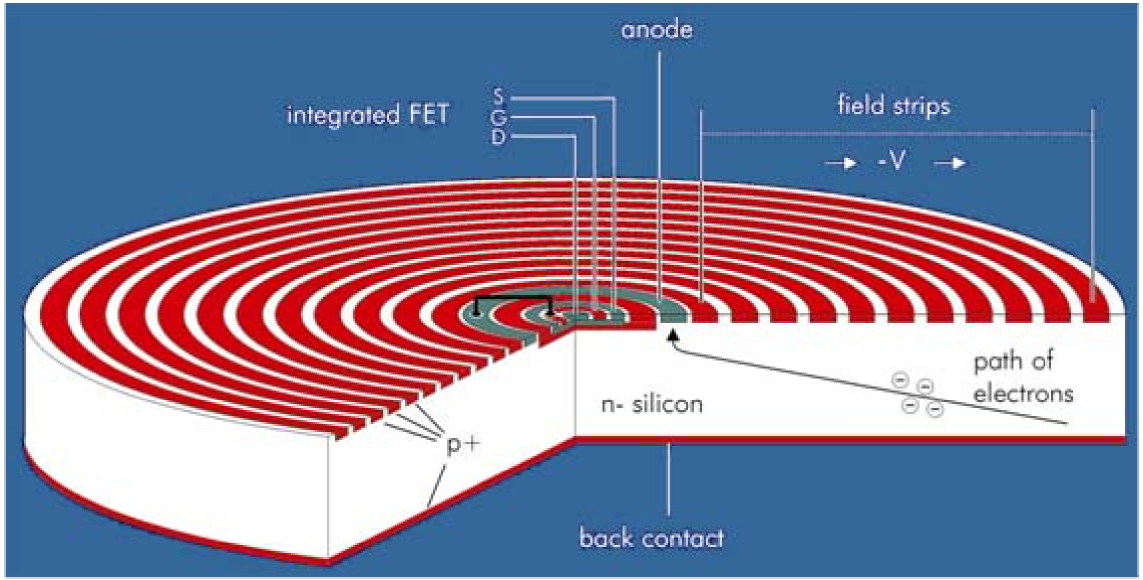
operation out of focus typ. 10 cm to 20 cm

every SDD cell has a count rate capability of typically 1.000.000 cps

19x5 mm^2 = 95 mm^2



SDDs in astrophysics:
the HTRS on XEUS



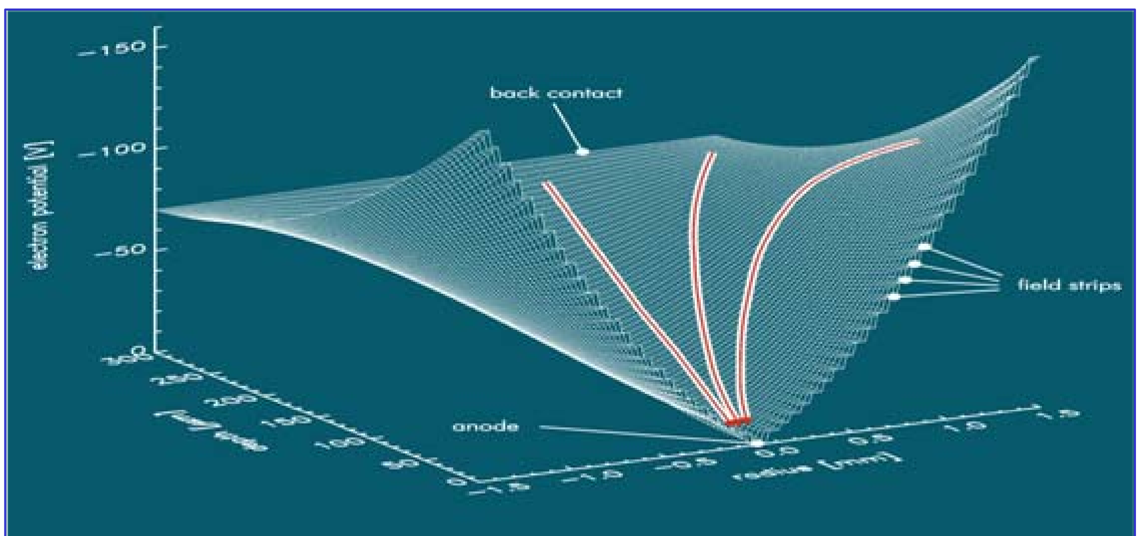
SDD with integrated SSJFET or DePFET

time to drift from device edge to readout node:

$\Delta t = \Delta x / v$
$= \Delta x / \mu E$
$= 100$ ns

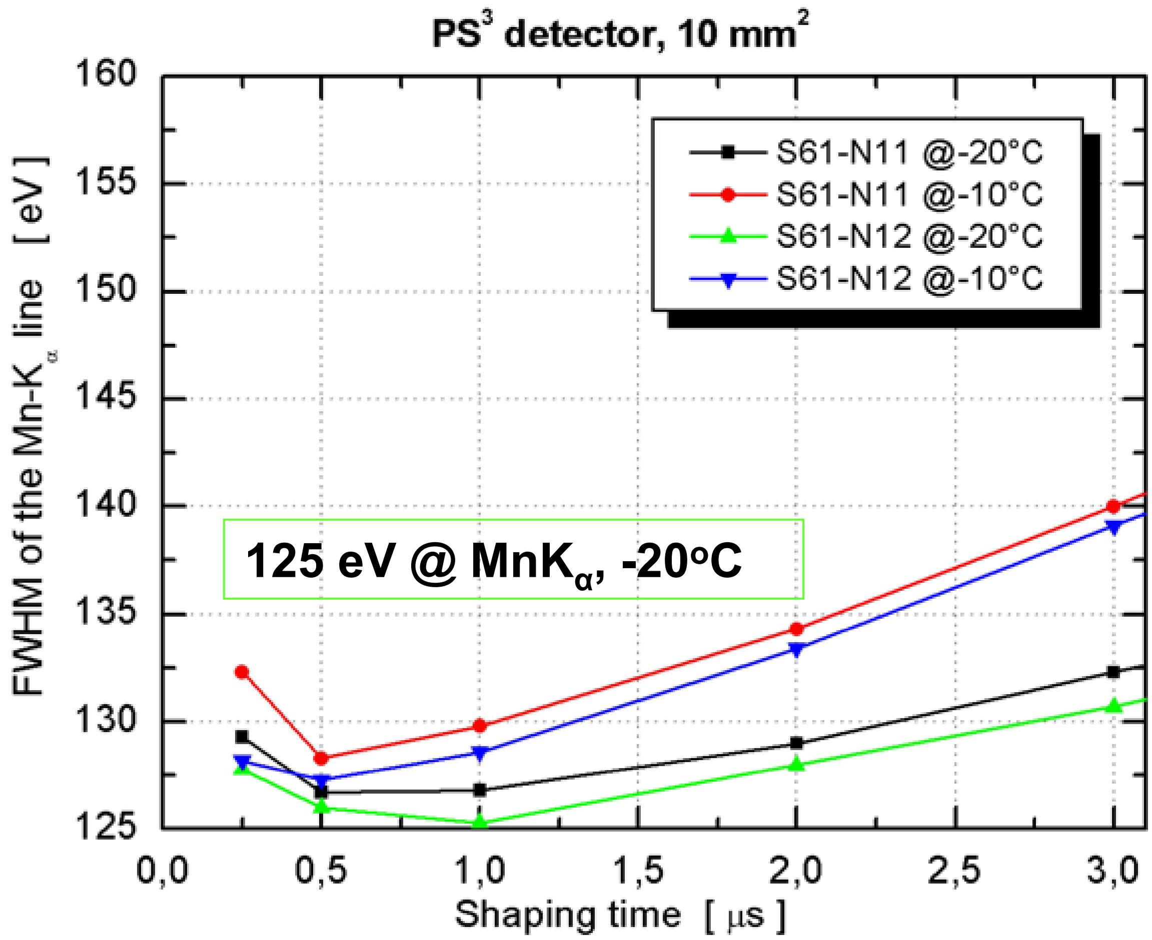
$\sigma_{\Delta t} \leq 8$ ns

for $\Delta r = 1.3$ mm
i.e. $A = 6$ mm^2
and $E = 600$ V /cm



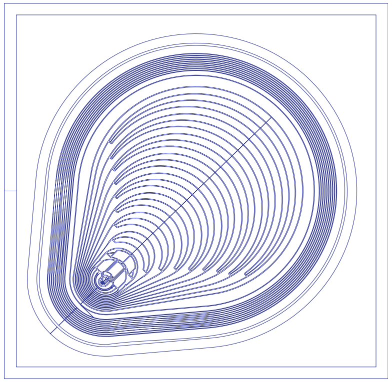
Electrical Potential in a circular SDD

Energy resolution as a function of τ_s



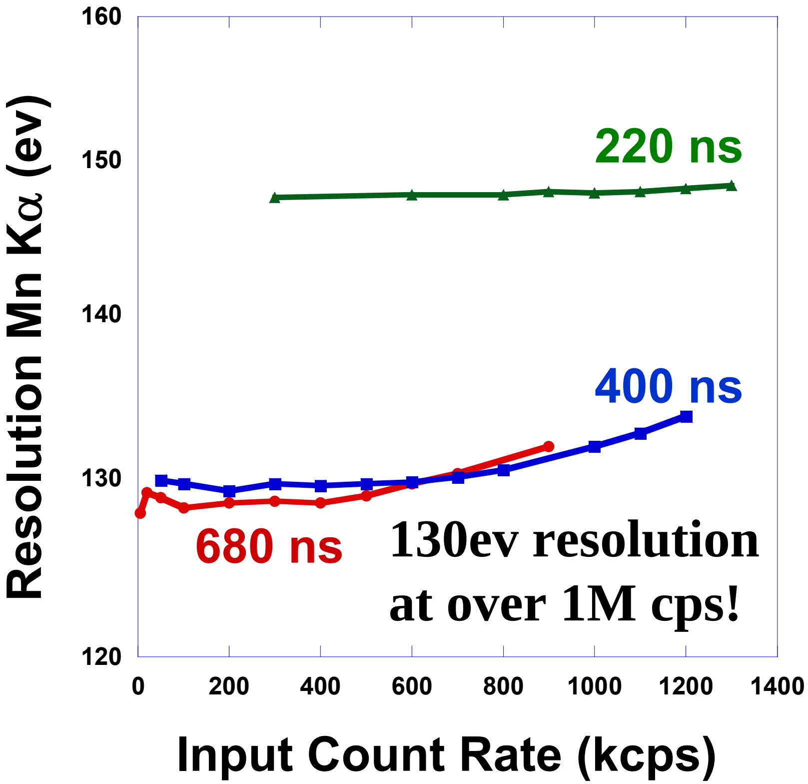
SD³

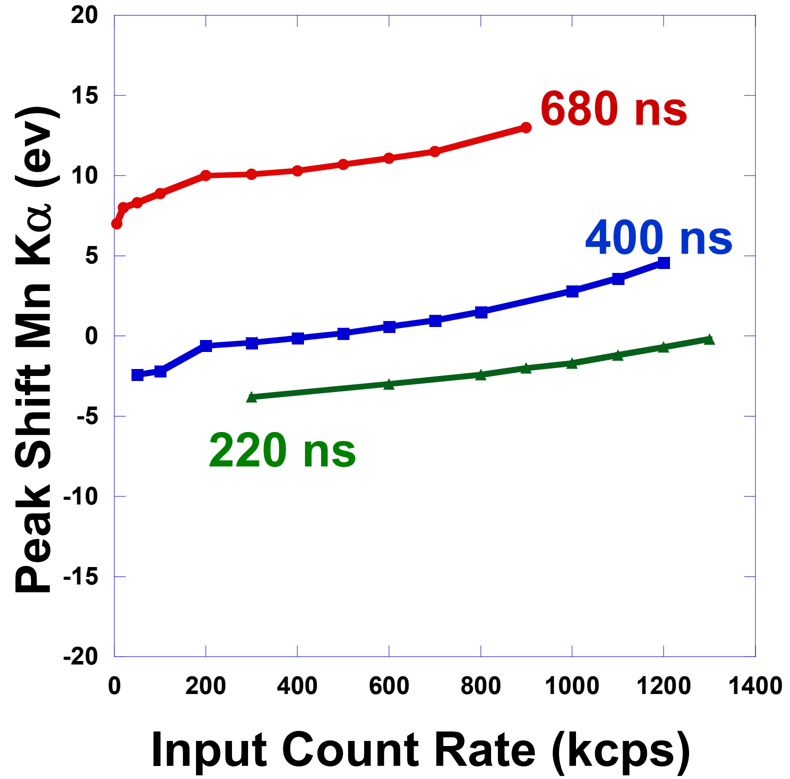
in polysilicon technology



C_{tot} = 40 fF

Pulsed-reset circuitry: Spectacular Performance

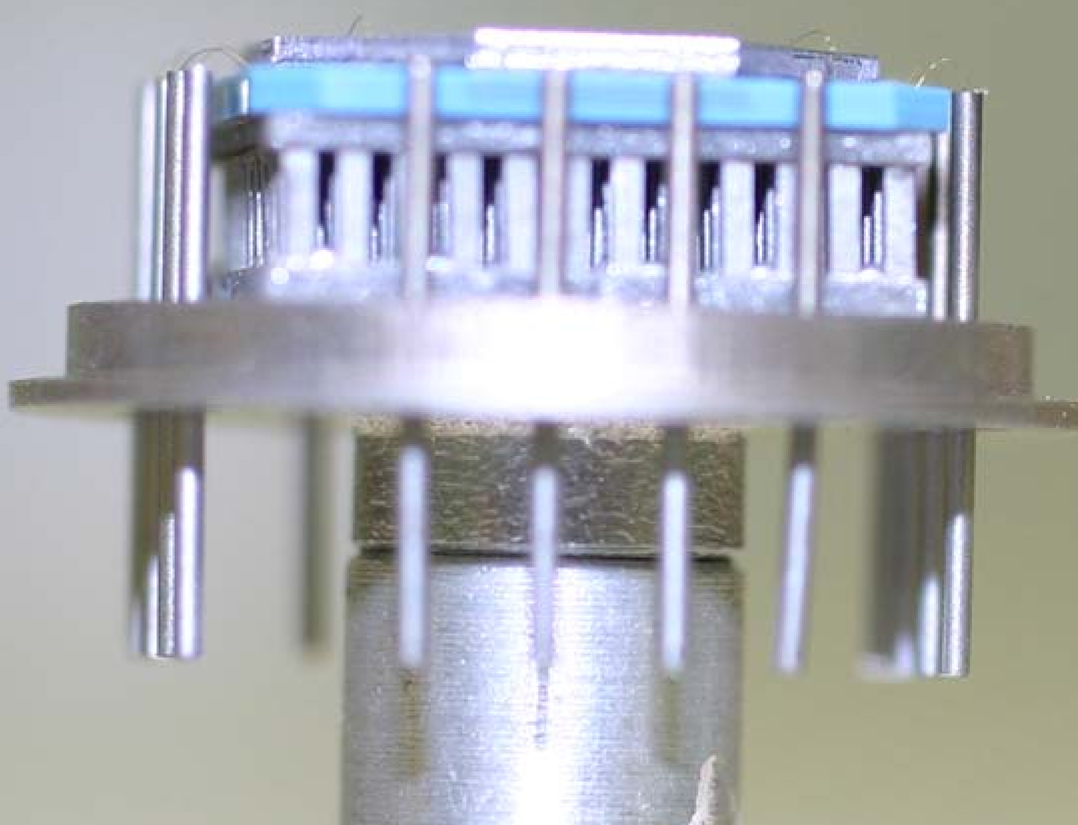




Nearly flat response of resolution and peak position with count-rate for all pulse-processors up to over 1M counts/sec

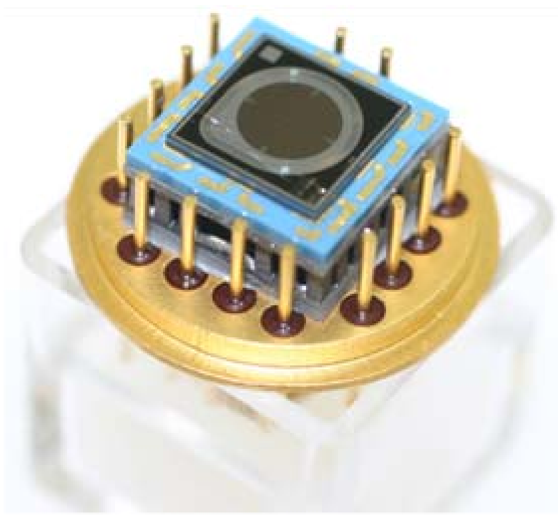
Sandia National Laboratories

flying on - MER (SPIRIT, OPPORTUNITY)
- ROSETTA
- EXOMARS (soon)



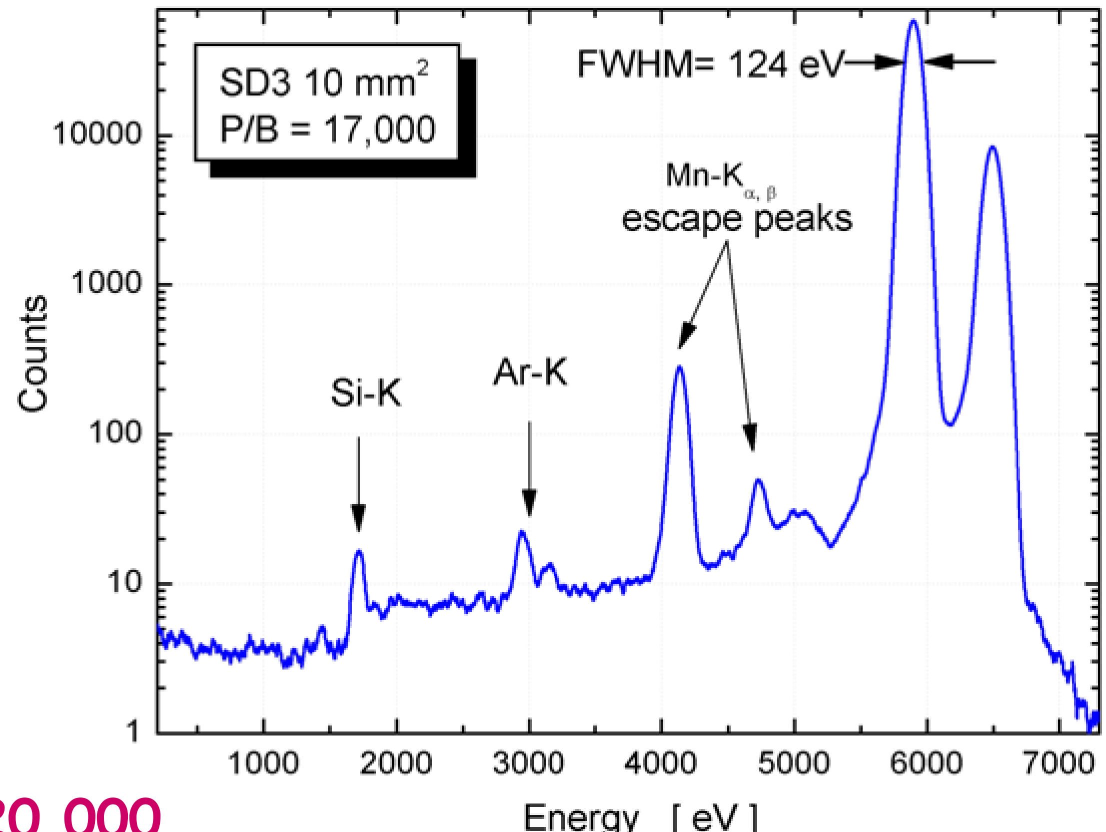
Spectroscopic performance of 5 and 10 mm² SD3 detectors

- operation temperature -20°C
- 1-stage Peltier cooler
- optimum shaping time 0.5 µs
- pulsed reset operation



- Light element detection
  FWHM @ B-K = 38 eV
- P/B = 13,000 ÷ 20,000

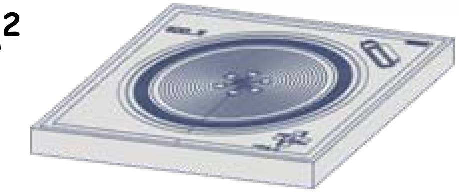
Optimized detector entrance window for light element detection - pnWindow



A single SDD can process up to 1 M counts per sec below 170 eV

Small and Large Area SDDs

Classic Round SDDs with sensitive area of 5, 10 and 20 and 30 mm² up to 1cm²



SDD 5 mm²

chip 5 x 5 x 0.45 mm³

SDD 100 mm²

chip 14 x 14 x 0.45 mm³

SDD 10 mm²

chip 6 x 6 x 0.45 mm³

SDD 30 mm²

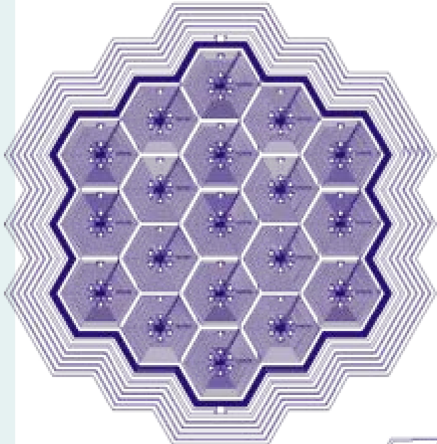
chip 9 x 9 x 0.45 mm³

SDD 20 mm²

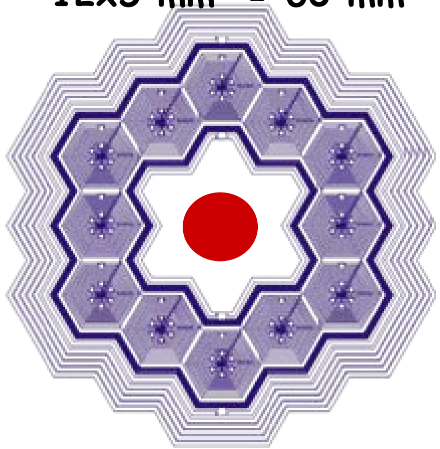
chip 8 x 8 x 0.45 mm³

Multichannel SDDs

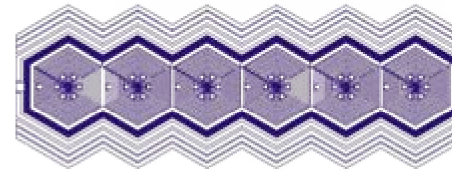
19x5 mm² = 95 mm²



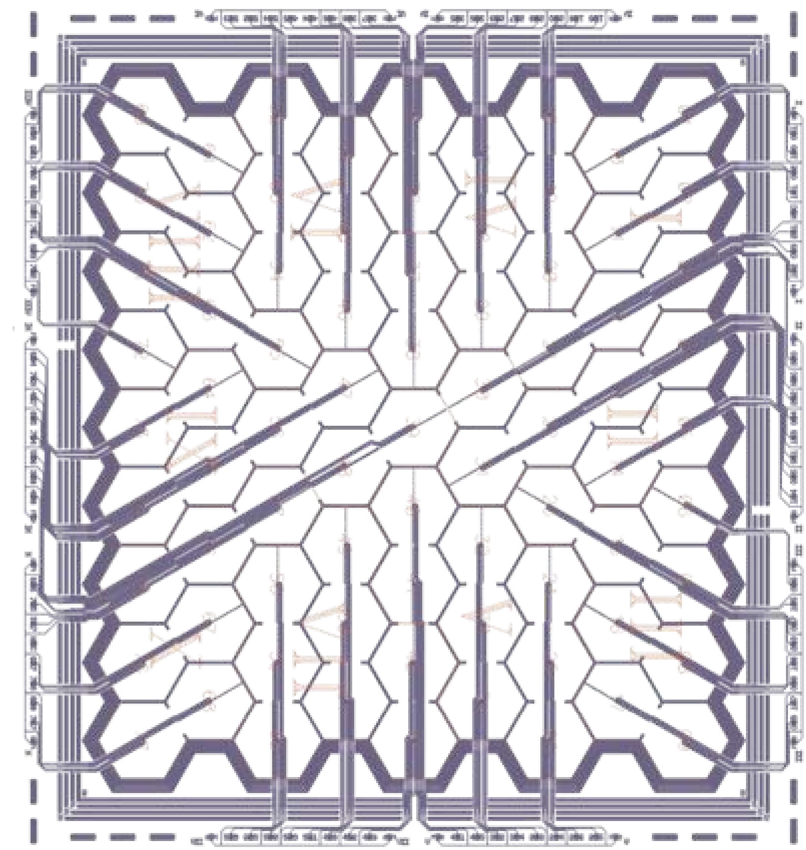
12x5 mm² = 60 mm²

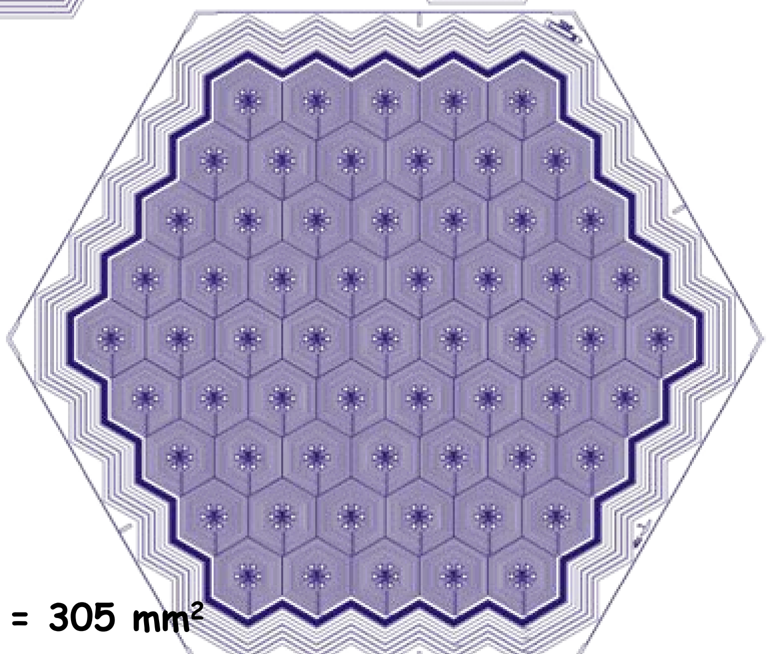


6x5 mm² = 30 mm²



77x7 mm² = 539 mm²





61x5 mm² = 305 mm²

Conclusions

DePFET is ready for

- ❒ fast and slow readout
- ❒ thick and thin depletion layers
- ❒ for large and small pixels
- ❒ for small and large monolithic fields of view

radiation hard and defect free