The Max-Planck Advanced Study Group

within the Center of Free Electron Laser Science

High Speed, large format imagers for X-rays from 50 eV up to 30 keV

for experiments in astrophysics at X-ray FELs and in industry

MPE-HLL projects

1. X-ray astronomy
   - XMM since 2000 'til now
   - eROSITA 2012
   - BepiColombo 2014
   - ASTRO-H 2015
   - IXO 2022 + x

2. Center for Free Electron Laser Science
   - FLASH 2008
   - BESSY 2008
   - LCLS/SCSS 2009/2010
   - XFEL 2013

3. X-ray Fluorescence Physics
   - Spirit and Opportunity since 2004 ´til now
   - EXOMars 2013
   - SIDDHARTA 2009
   - HICAM and DRAGO 2010
   - CETRA 2014
   - Plasmadiagnostics 2014
   - X-ray microscopy 2012

4. Optical applications
   - LBT, wave front sensing 2012
   - Avalanche pnCCDs 2011
   - RNDR – DePFETs 2015
   - IBC (BIB) detectors 2013
   - Gatable DePFETs 2015

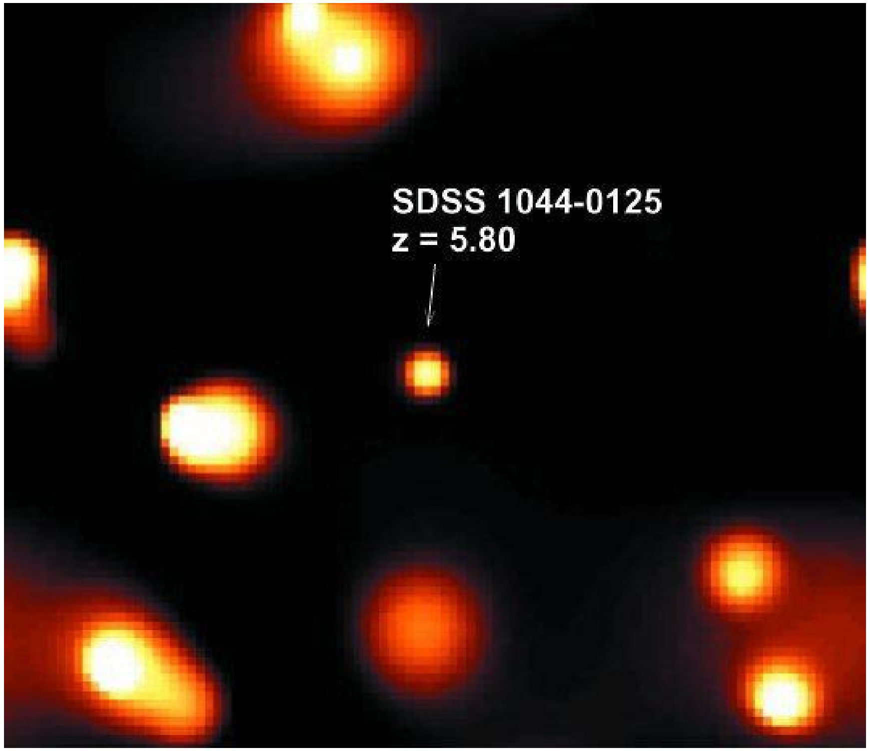
XMM-Newton

Outline

- X-ray CCDs for
  - eROSITA
  - BESSY, FLASH
  - LCLS, SCSS, FERMI
- DePFETs for
  - BepiColombo
  - IXO
  - XFEL
- Future plans

XMM Summary

- Working since launch (10. Dez. 1999) without any problem.
- The energy resolution @ the Al_K line (1.5keV) decreased since launch from 98 eV to 99 eV (FWHM).
- Since launch the operating conditions have never been changed.
- Up to now more than *15.000* observations were made with XMM – Newton. *80 %* with the pnCCD as prime instrument
- Up to now, > *2.600* refereed astrophysics publications have been made



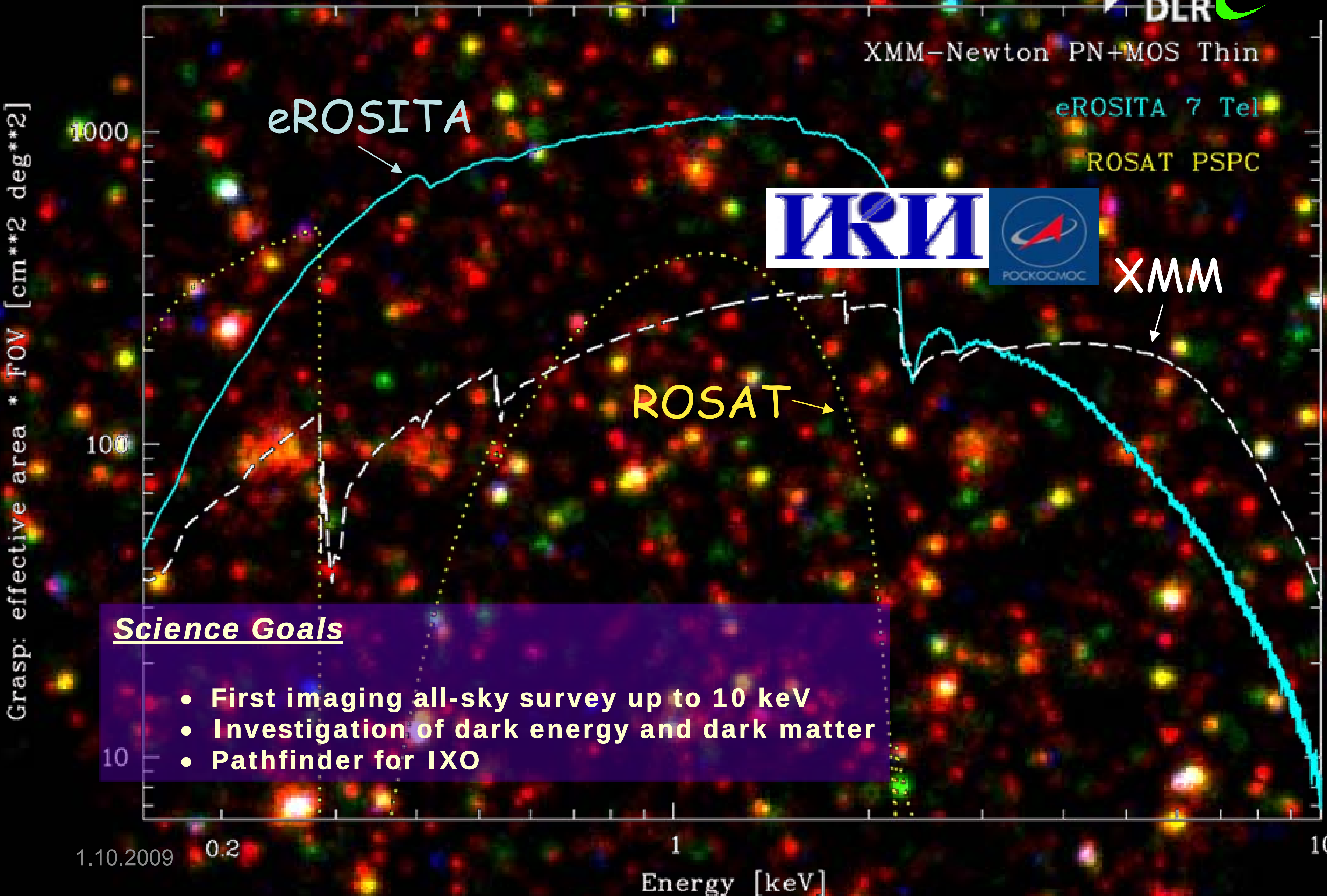
QSO SDSS 1044-0125

European Space Agency

Very high redshift QSO observed by XMM EPIC

- pnCCD paper was cited *1.000* times in refereed journals

eROSITA

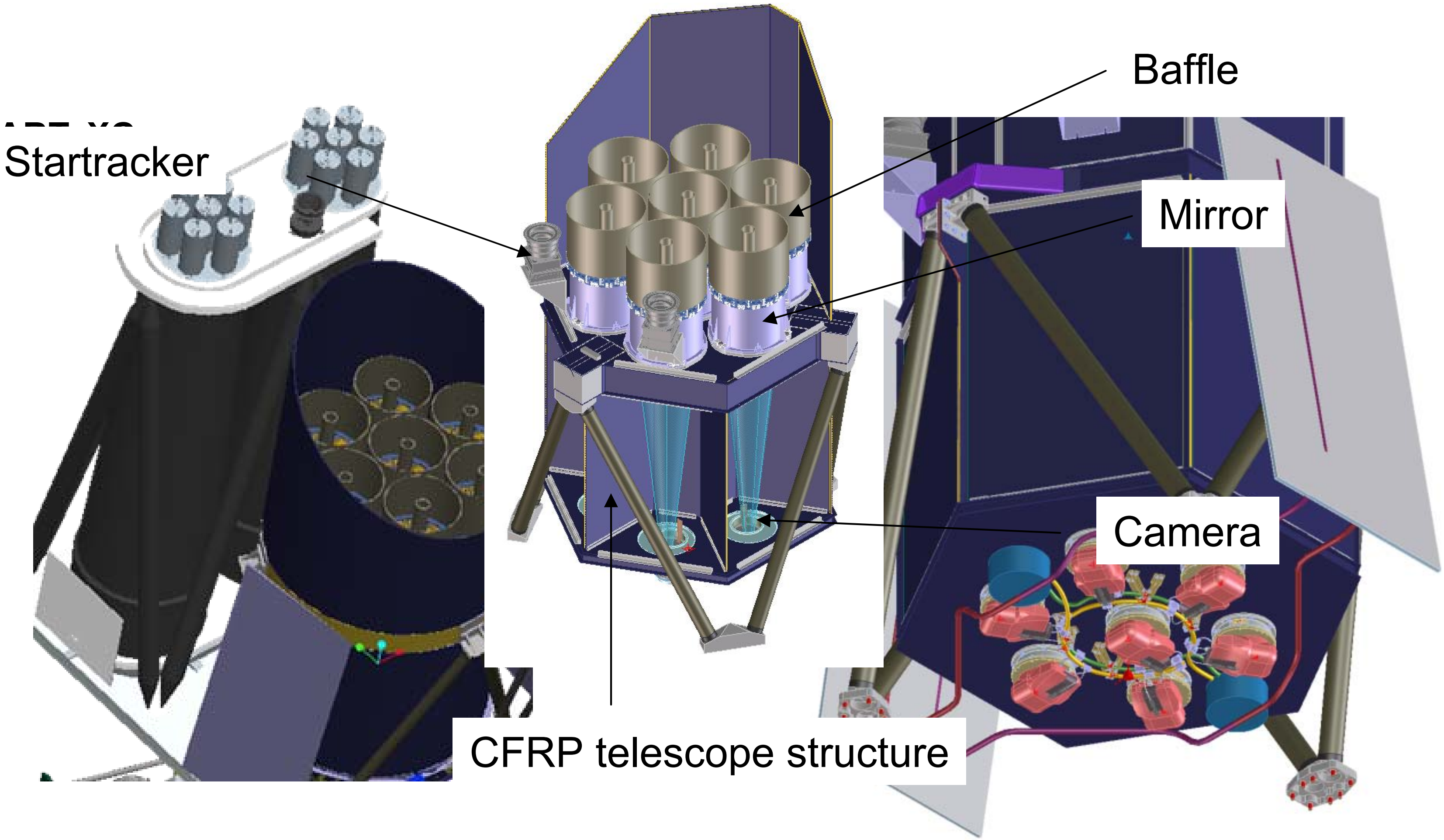


Science Goals

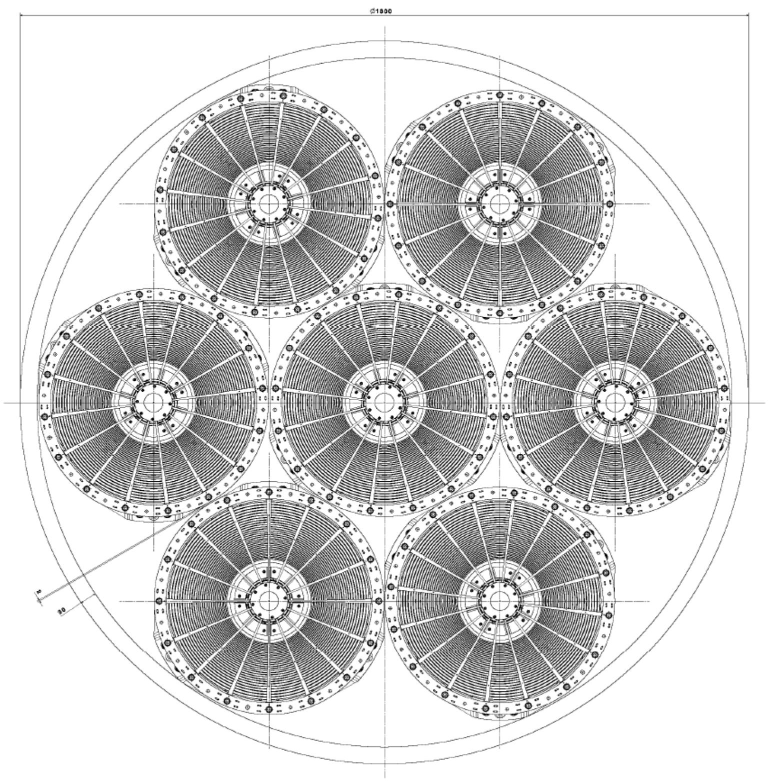
- First imaging all-sky survey up to 10 keV
- Investigation of dark energy and dark matter
- Pathfinder for IXO

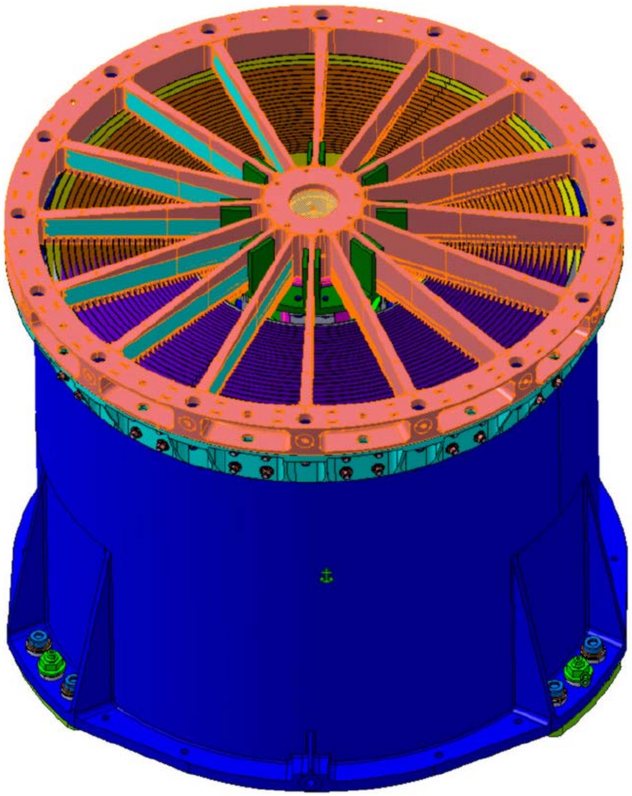
Telescope Elements

- eROSITA: 7 „identical" **mirror systems** and **PNCCD cameras**
- ART XC: 2 X-ray optic Array of 7 telescopes **eras**



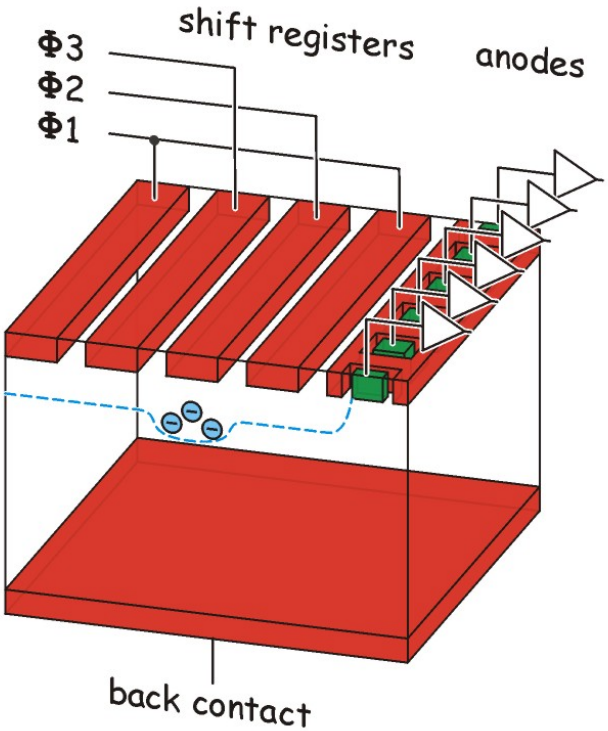
Mirror System

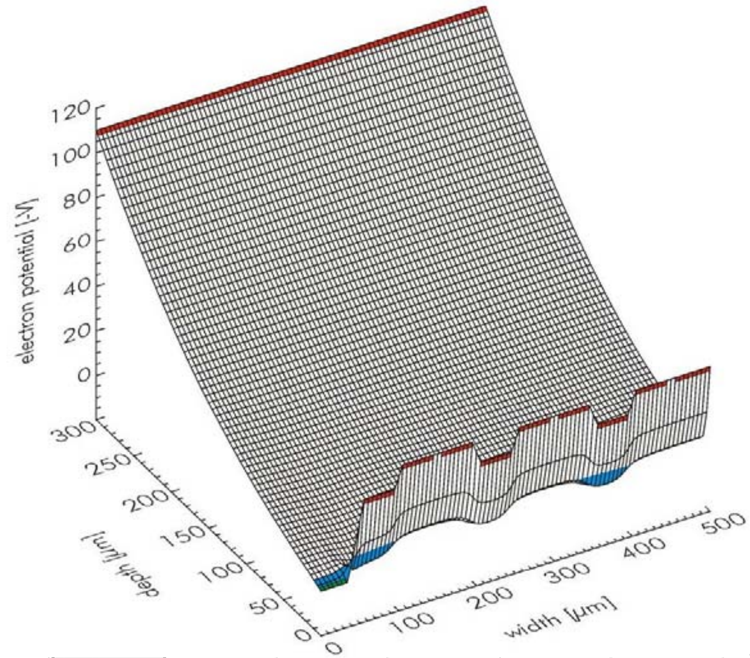


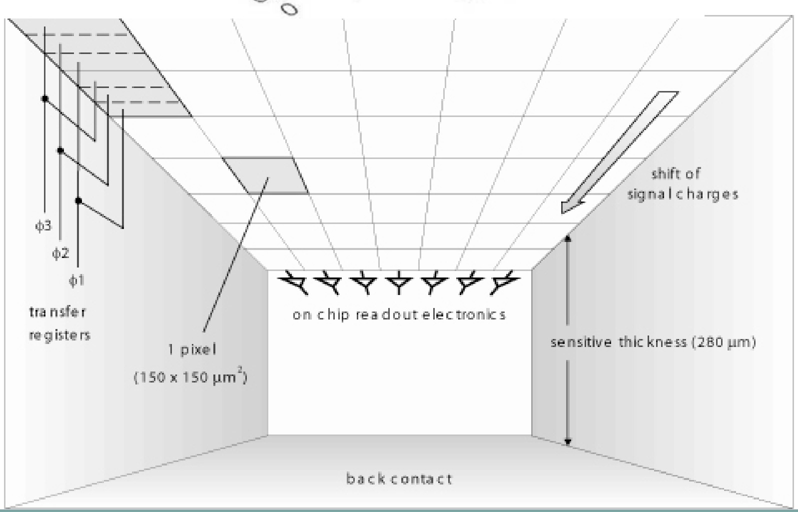


- 7 Mirror Modules, 54 shells each, 360mm Ø, f=1.600mm
- inner 27 shells to be replicated from old ABRIXAS mandrels
- 3 outer mandrels already manufactured (#1, #2, #27)

CCD basics







- full depletion (50 µm to 500 µm)
- back side illumination
- radiation hardness
- high readout speed
- pixel sizes from 36 µm to 650 µm
- charge handling: more than 10^6 e^-/pixel
- high quantum efficiency

How many charges can be stored in one pixel ?

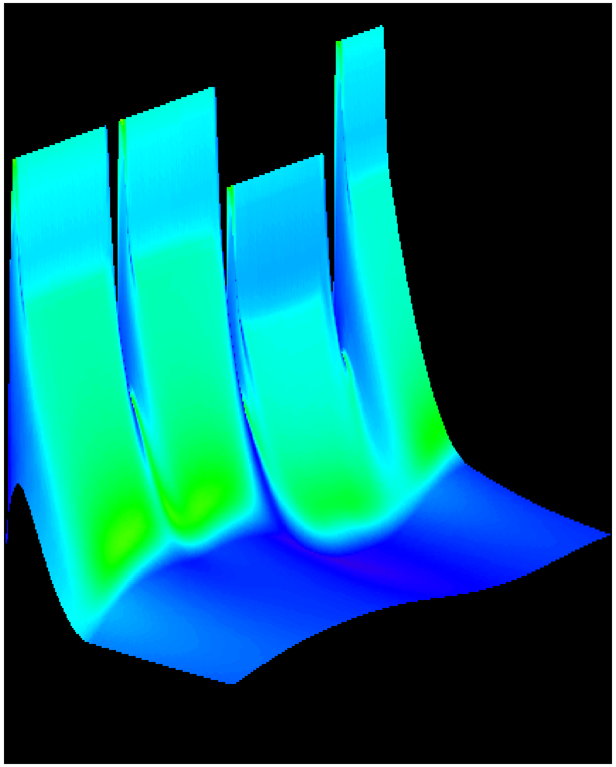
pixel volume:
$20 \times 40 \times 12\ \mu m^3 \approx 1 \times 10^4 \mu m^3$

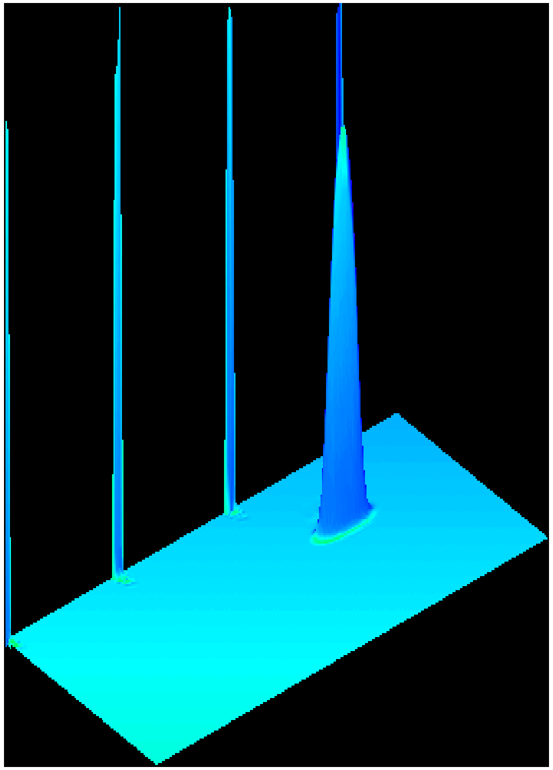
Doping: 10^2 P per μm^3

CHC = $3\text{-}8 \times 10^5$ per pixel

can be increased by
external voltages

can be increased by doping





The charge spread function

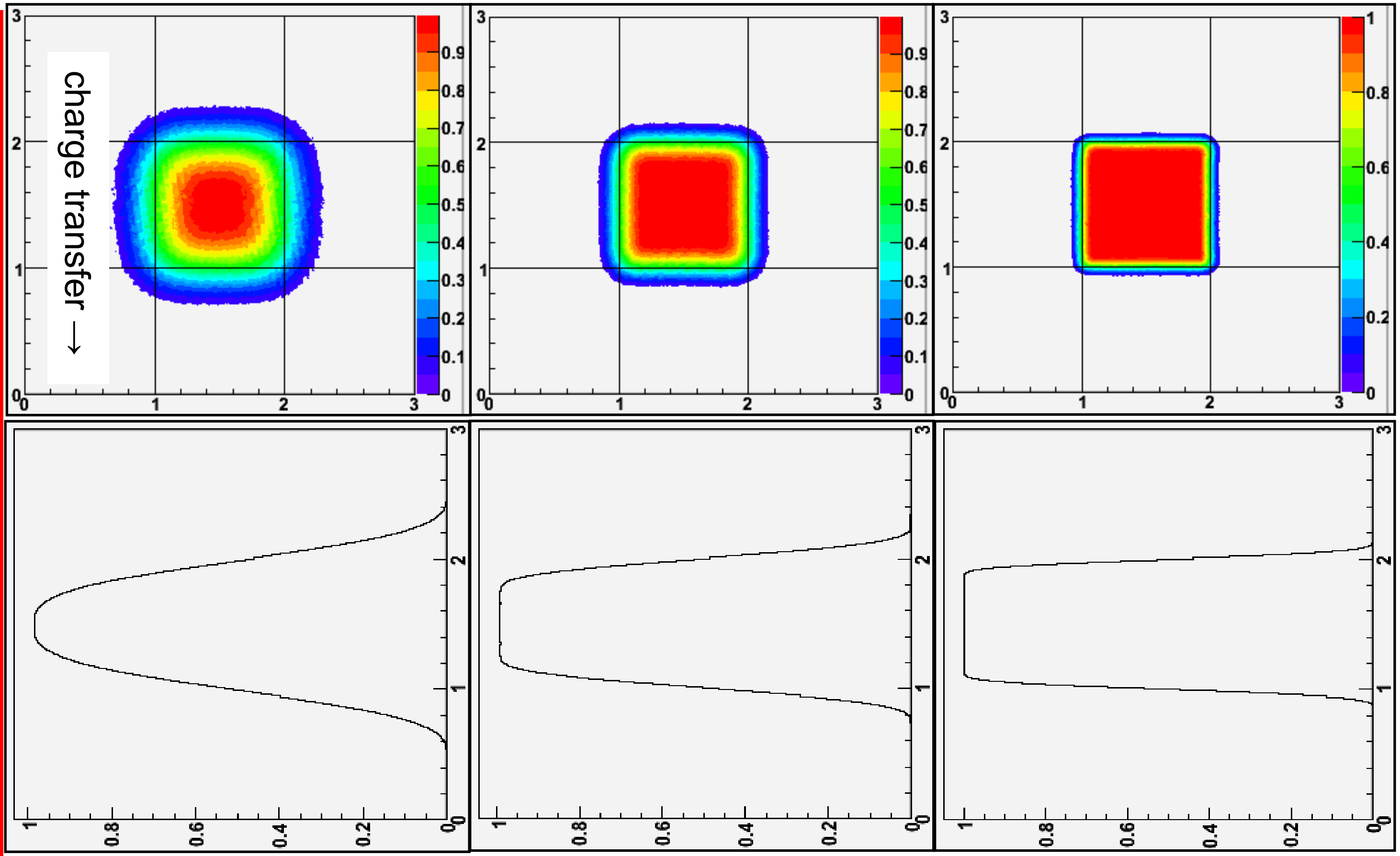
Injected charge:
4.5 keV, i.e.
1.250 electrons

➡

At 1000 X-rays of 12 keV the # of electrons is 3.600.000

The charge spread depends on:

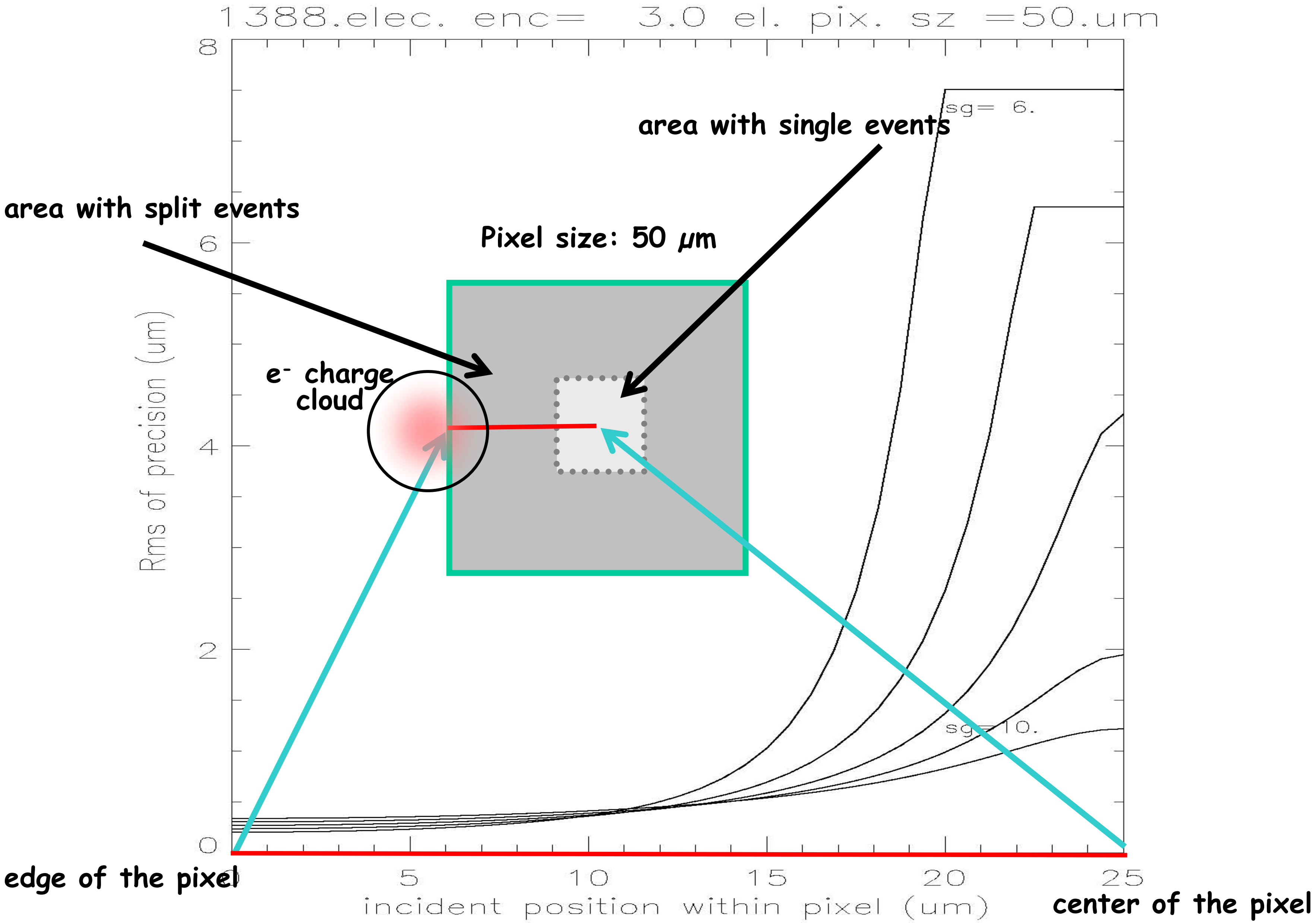
- charge collection time
- pixel size
- number of charges
- operating temp.



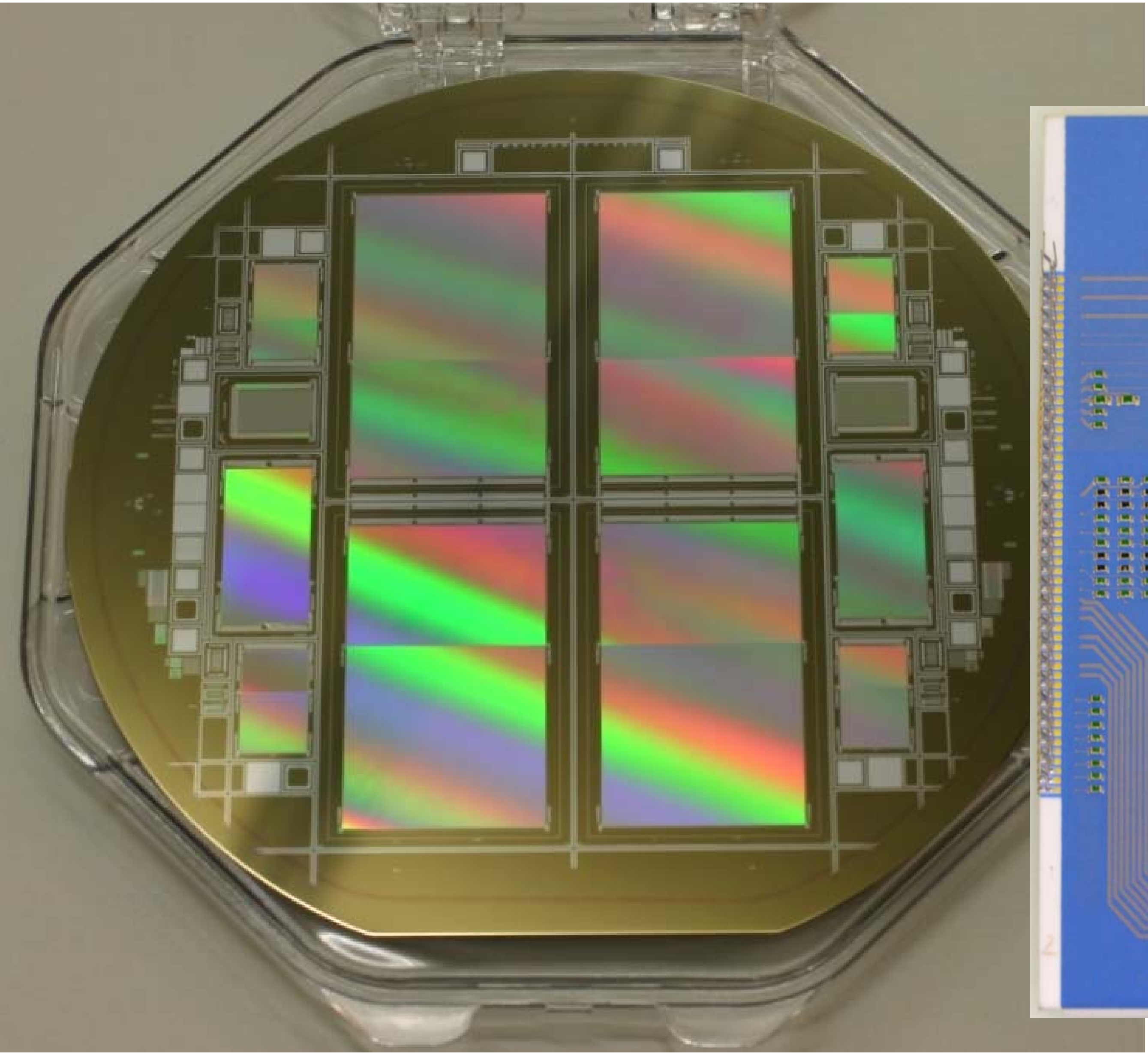
51µm pixel $\sigma_{transfer}$ = 8.5µm **75µm pixel** $\sigma_{transfer}$ = 7.0µm **150µm pixel** $\sigma_{transfer}$ = 6.4µm

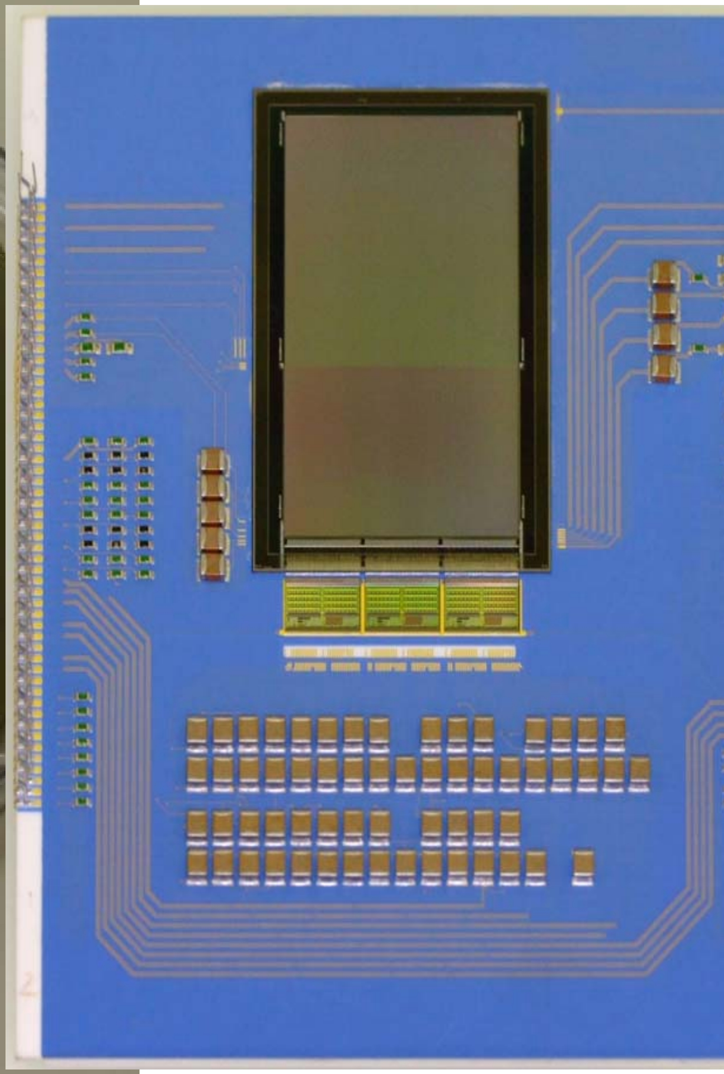
For more than 1.500.000 signal charges a pixel size of less than 150 µm is not adequate

Single photon counting position precision



II. eROSITA detector design





eROSITA camera concept

eROSITA (extended ROentgen Survey with an Imaging Telescope Array) **X-ray telescope** aboard **Spectrum-RG** satellite
(launch: 2012, L2 orbit)

7 identical eROSITA cameras: imaging + spectroscopy
0.3 - 10 keV

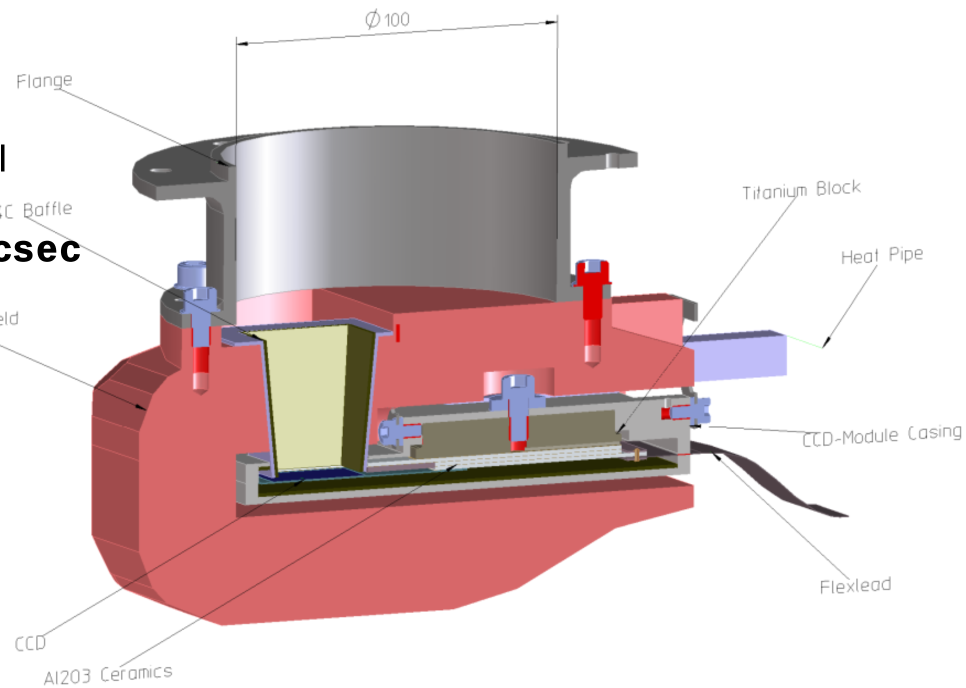
(identical cameras for ART-XC: 2-11 keV

FoV: 1.0 degree = 28.8 mm x 28.8 mm
= 75 x 75 µm² size → 384 x 384 pixel

expected angular resolution: 25 arcsec

one pixel of 75 x 75 µm² : 9 arcsec

position resolution of the camera for 1 – 10 keV: 4 arcsec



First measurements with eROSITA CCDs: Intensity image

- **Performance measurement**:

eROSITA CCD C12-03-42

(384 x 384)

frame transfer mode

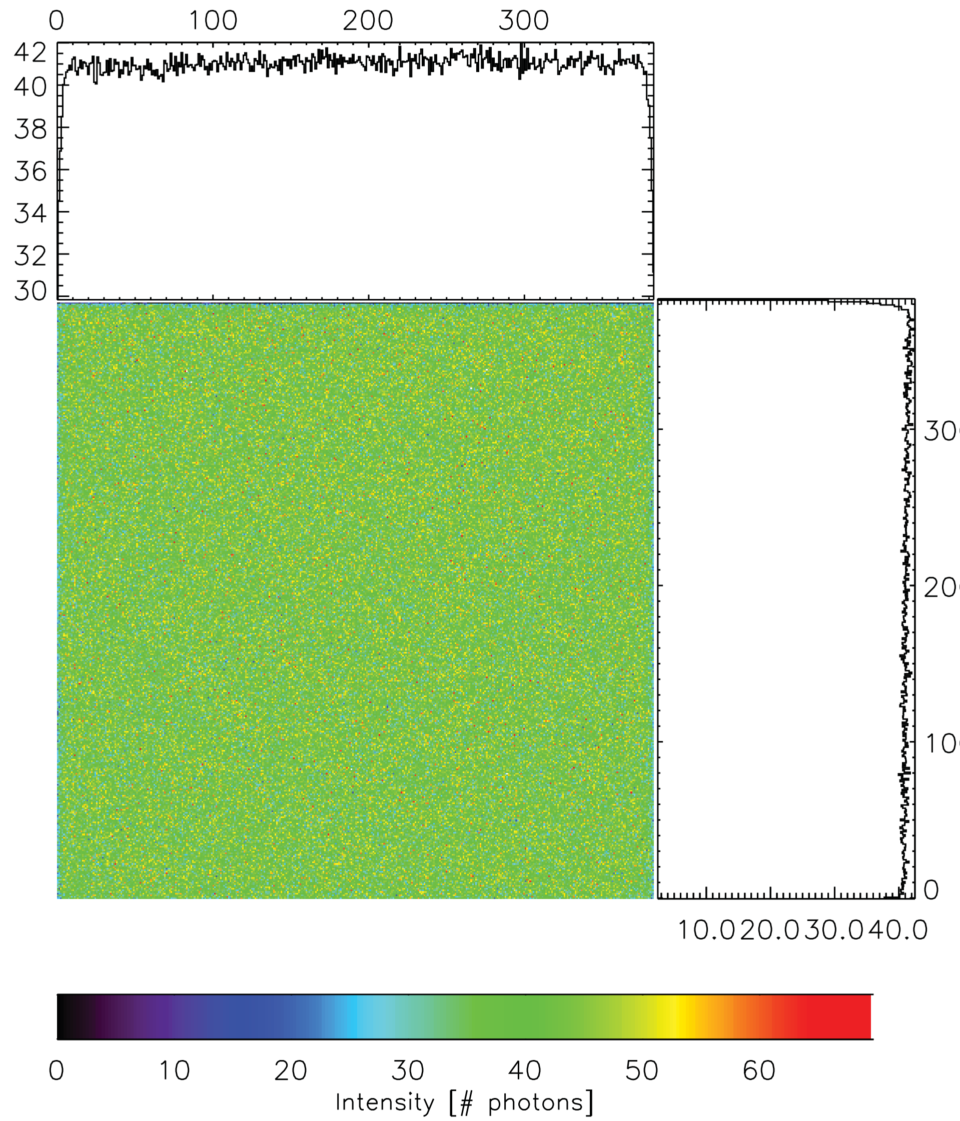
T = -80°C

20 images / s

Results:

No pixel defects / **14 cm²**

Noise: **2.4 e⁻** ENC

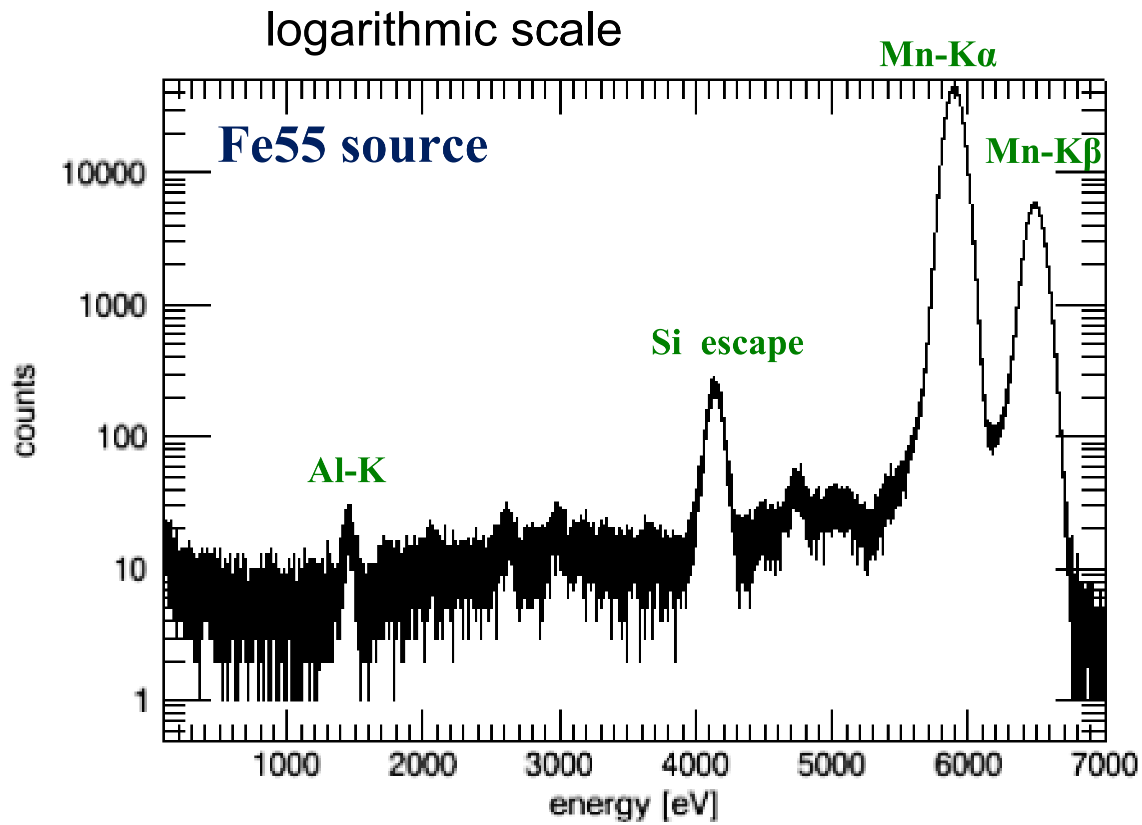


First measurements with eROSITA CCDs: Spectroscopic images

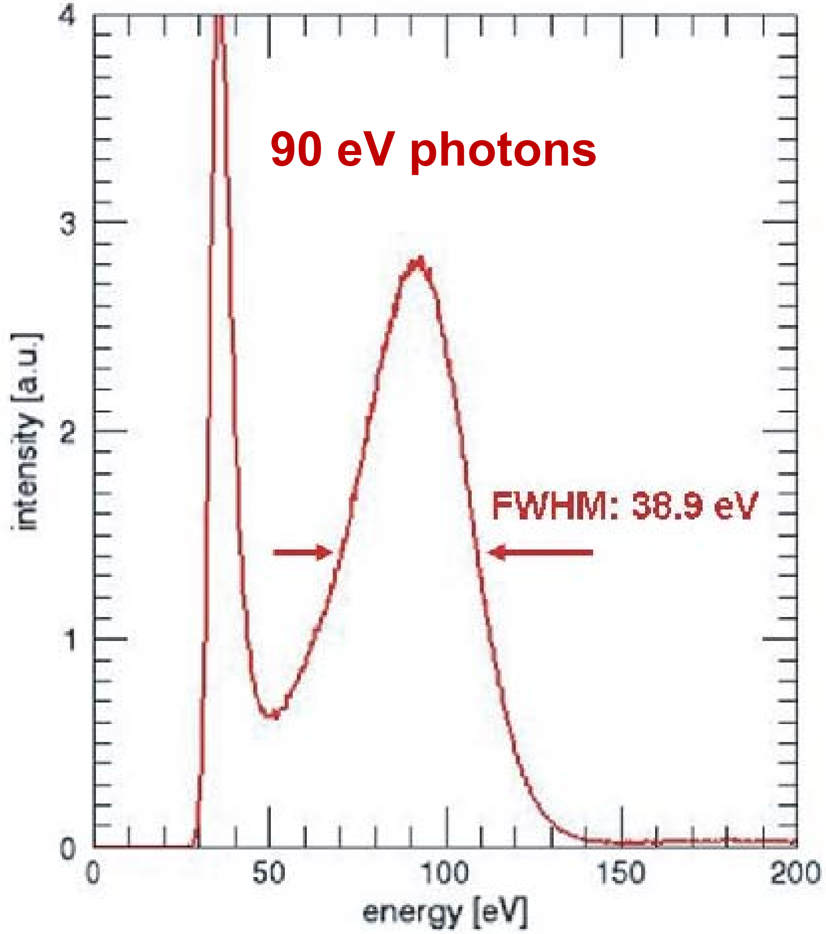
- **Performance measurement**:

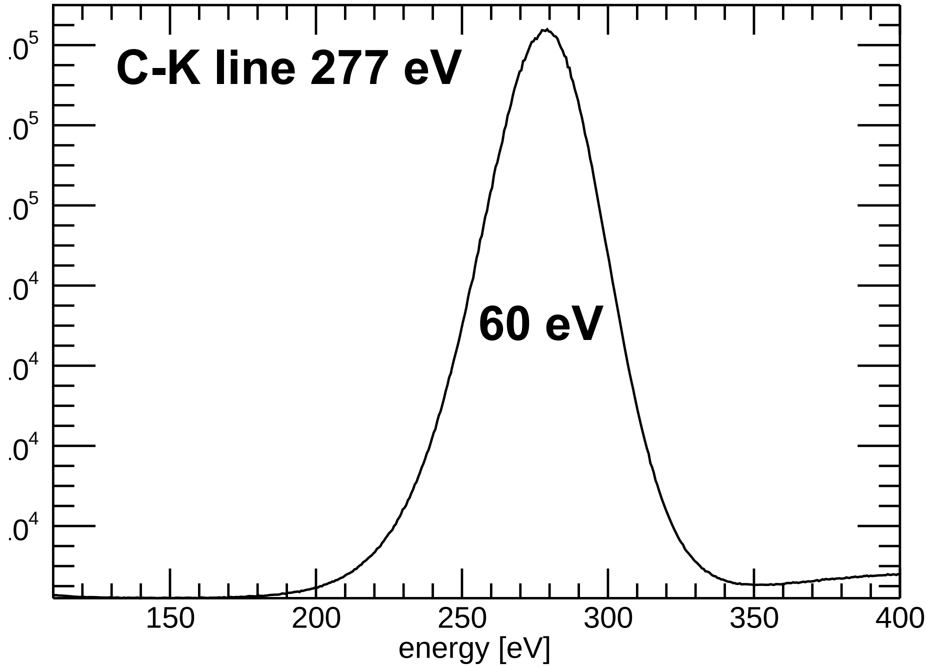
Peak to valley: 7700 : 1

(photon entrance window equipped with light filter)



First measurements with eROSITA CCDs: Low energy performance





fluorescence line of X-ray tube

eROSITA is on track for launch in 2012

Status of camera components is according to schedule

→ detailed design + testing of prototype

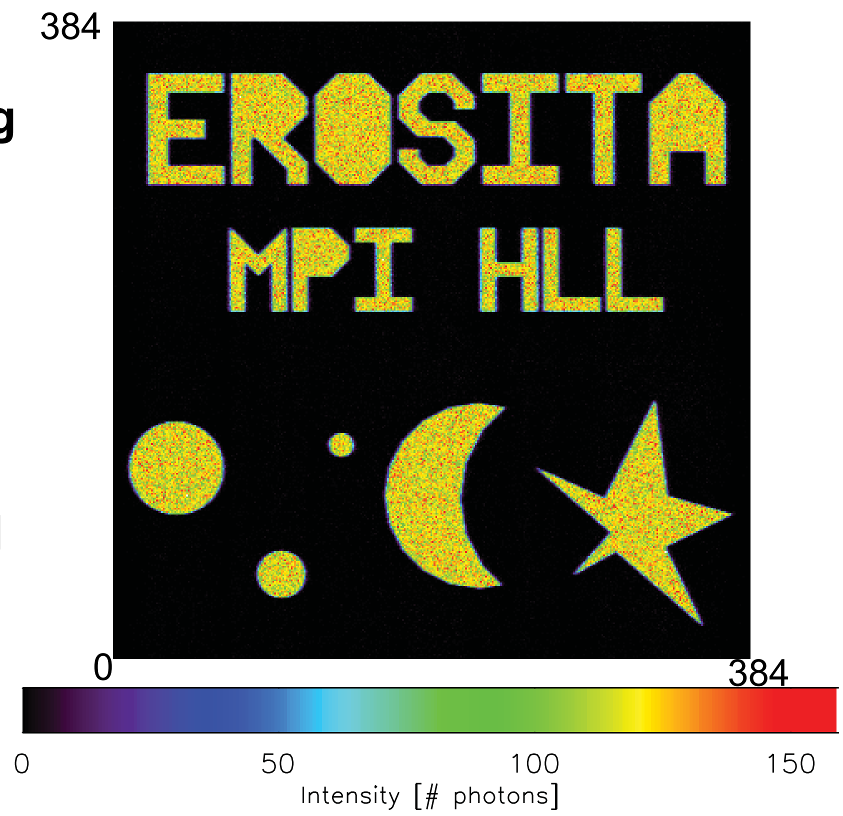
→ PDR on Oct. 21/22 2009

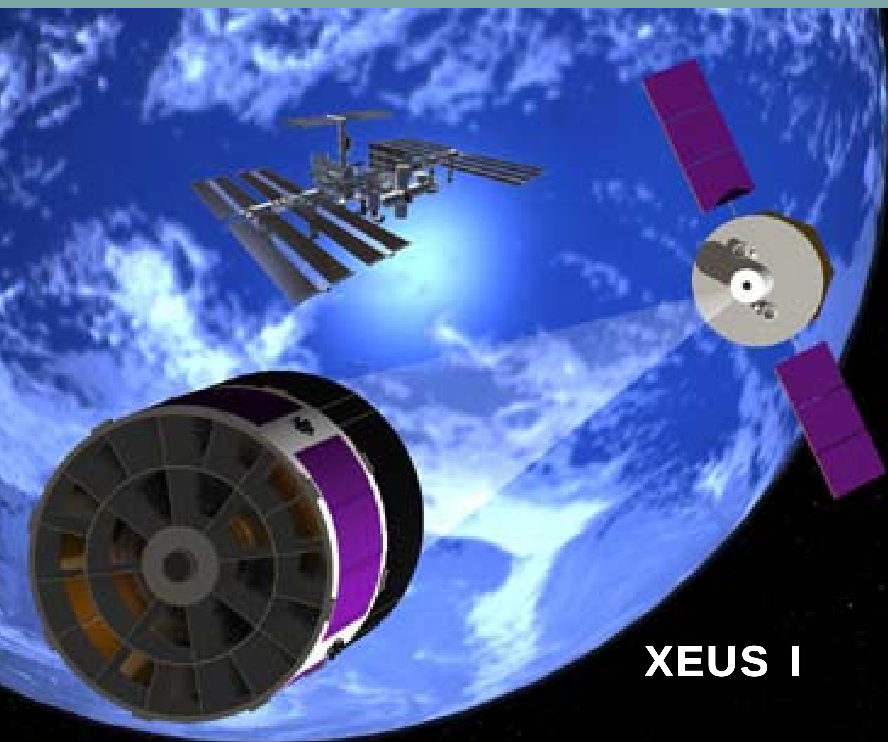
eROSITA flight CCDs produced and tested

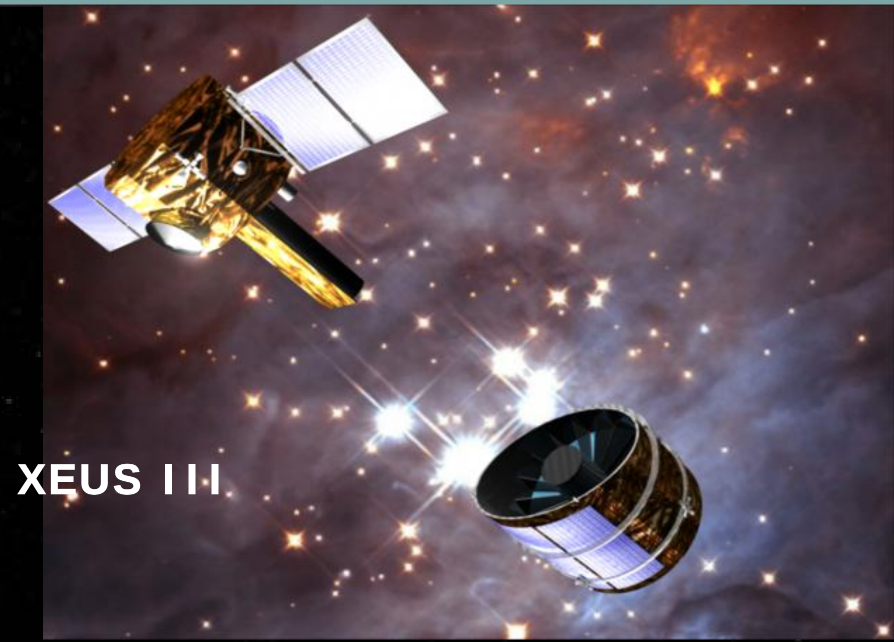
→ design + production process verified

→ performance excellent

→ more tests needed

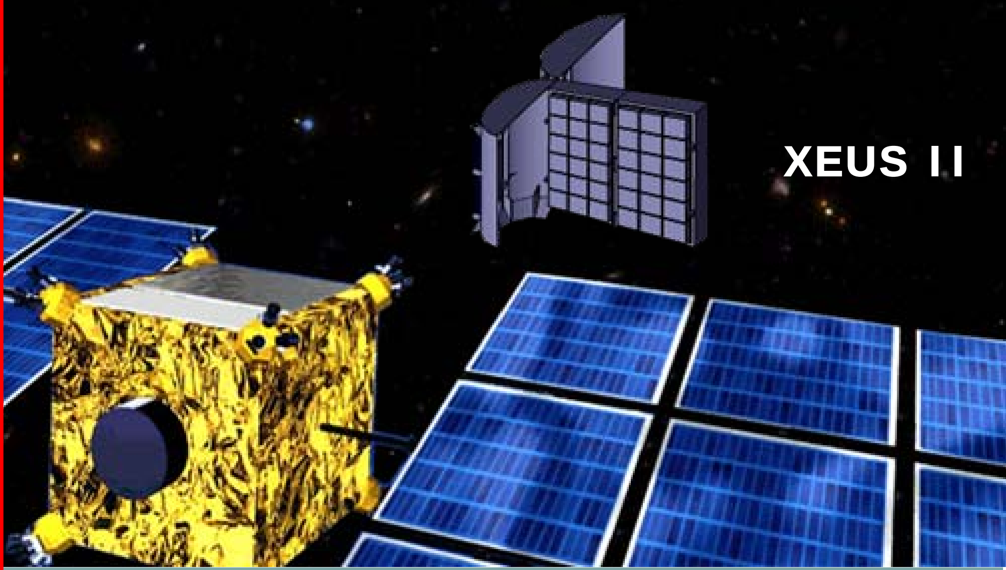




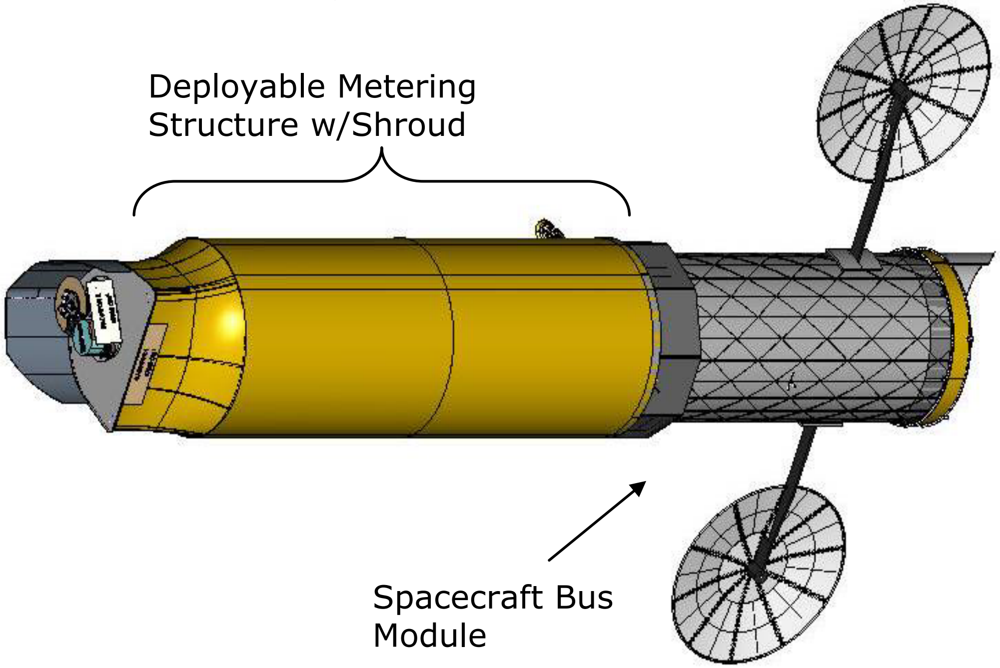


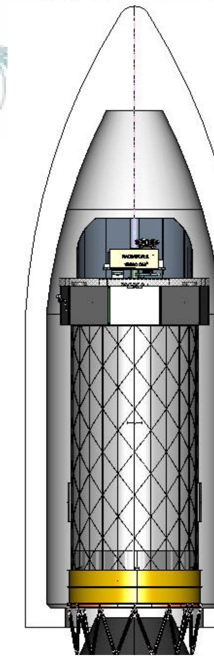
- **History of XEUS (IXO)**
- **"constitutional meeting @ LU in ´96**
- **ESA mission under study 2002**
- **ESA cosmic vision process 2007**
- **ESA, JAXA, NASA study 2008**

- **assessment study, Phase A study: end 2009**
- **definition phase study, Phase B1: end 2011**



IXO – baseline concept

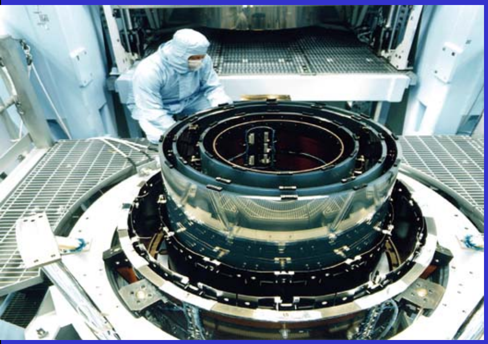


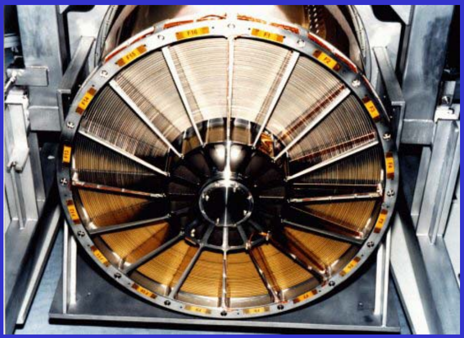


Atlas V 551 Medium Composite Fairing

- Focal length of 20-25m with extendible optical bench
- Concept compatible with Ariane 5 and Atlas V 551
- Core instruments to include:
  - Wide Field Imager including Hard X-ray Imager
  - X-ray Micro-calorimeter / Narrow Field Imager
  - X-ray Grating Spectrometer
  - high-time resolution instrument, a polarimeter and a hard X-ray imager are under study

XEUS – Optics Development



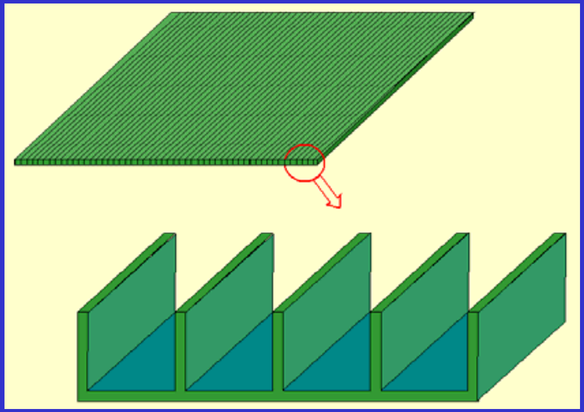


Chandra
0.5"
18500 kg m^{-2}
A_{eff} @ 1 keV

XMM-Newton
15"
2300 kg m^{-2}
A_{eff} @ 1 keV

Si-HPO
5"
200 kg m^{-2}
A_{eff} @ 1 keV

Glass-MPO
30"
25 kg m^{-2}
A_{eff} @ 1 keV



XEUS Requirement

Instrument Module

MPI Halbleiterlabor

The IM consists of the FIP, MIP, Sunshade, Instruments, Electronics boxes

XGS CCD Camera

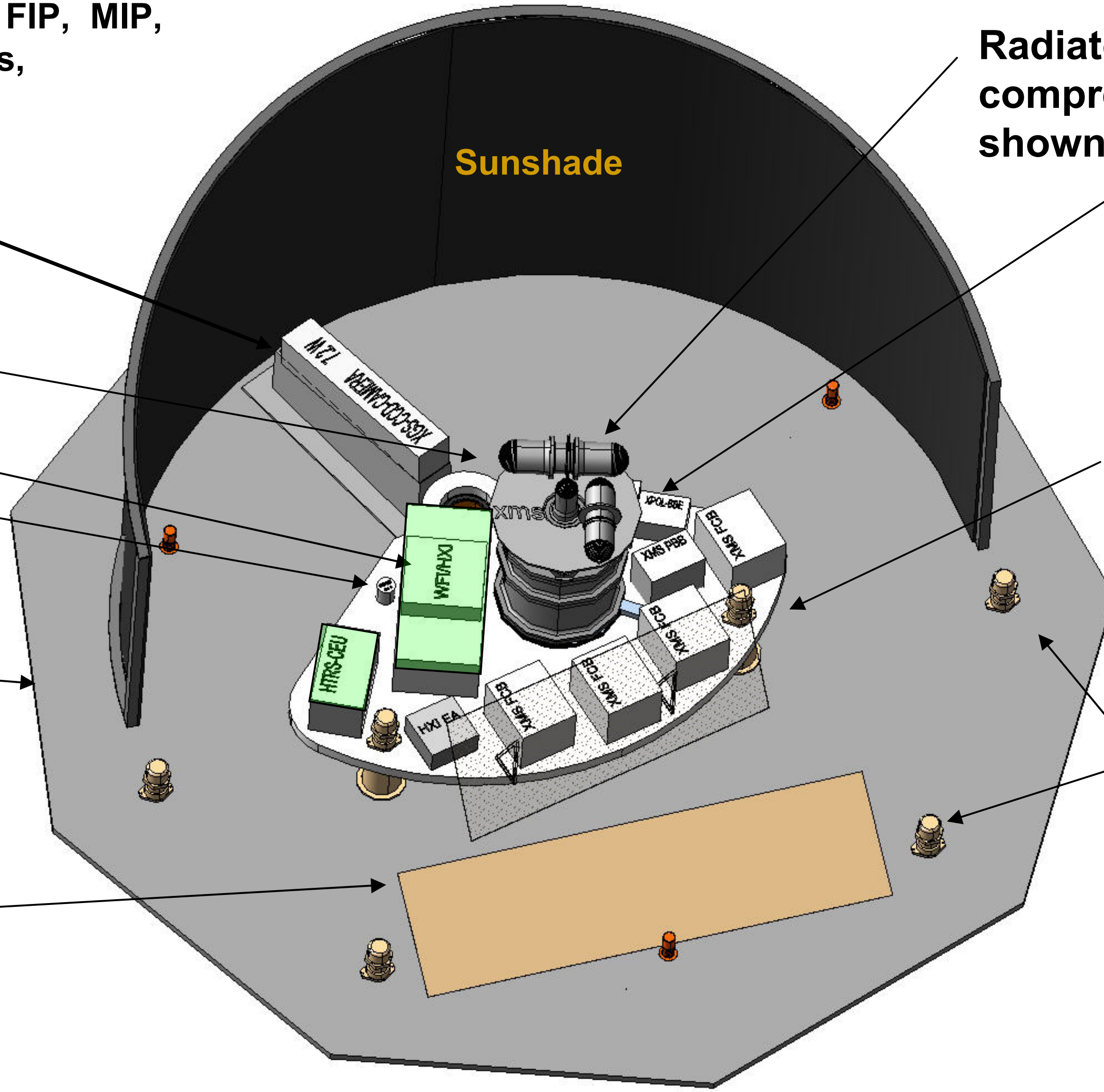
XMS

WFI/HXI

HTRS Instrument

Fixed Instrument Platform (FIP)

Radiator for electronics boxes underneath FIP



Radiator for XMS compressor not shown

XPOL

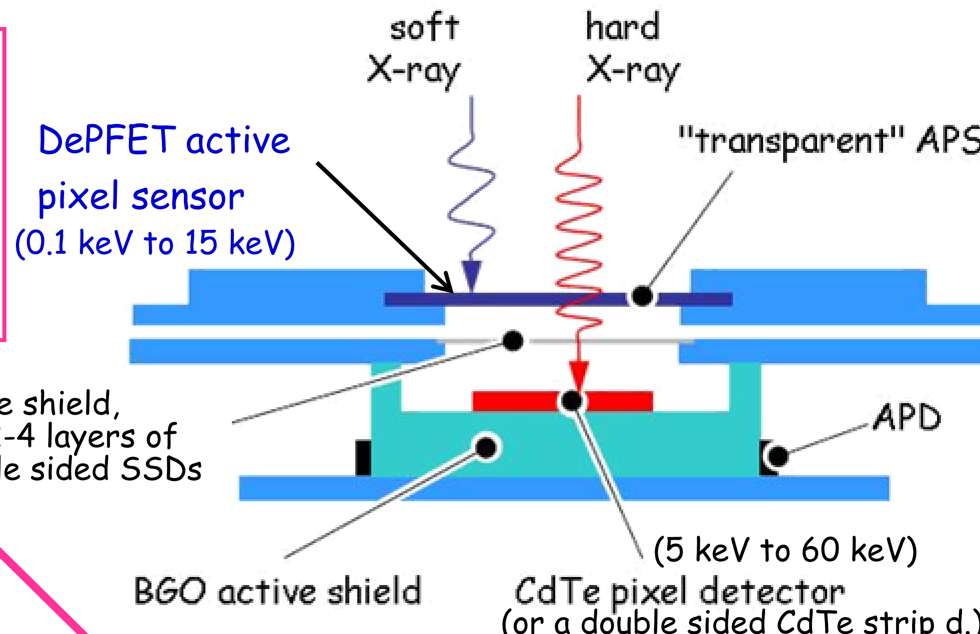
Radiator for boxes on Moving Instrument Platform (MIP)

Launch Lock Mechanisms (6)

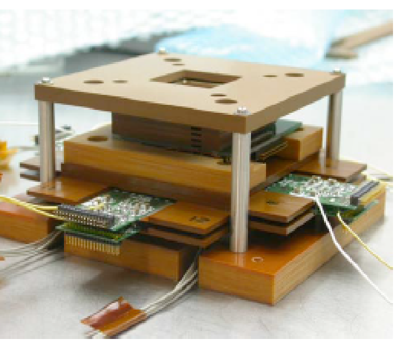
WFI and HXI on XEUS

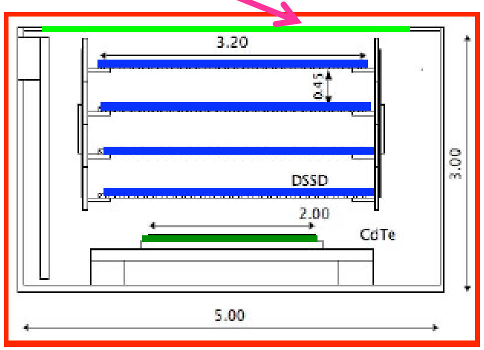
one possibility of accomodation the DePFET WFI and the HXI within a single camera housing:

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)



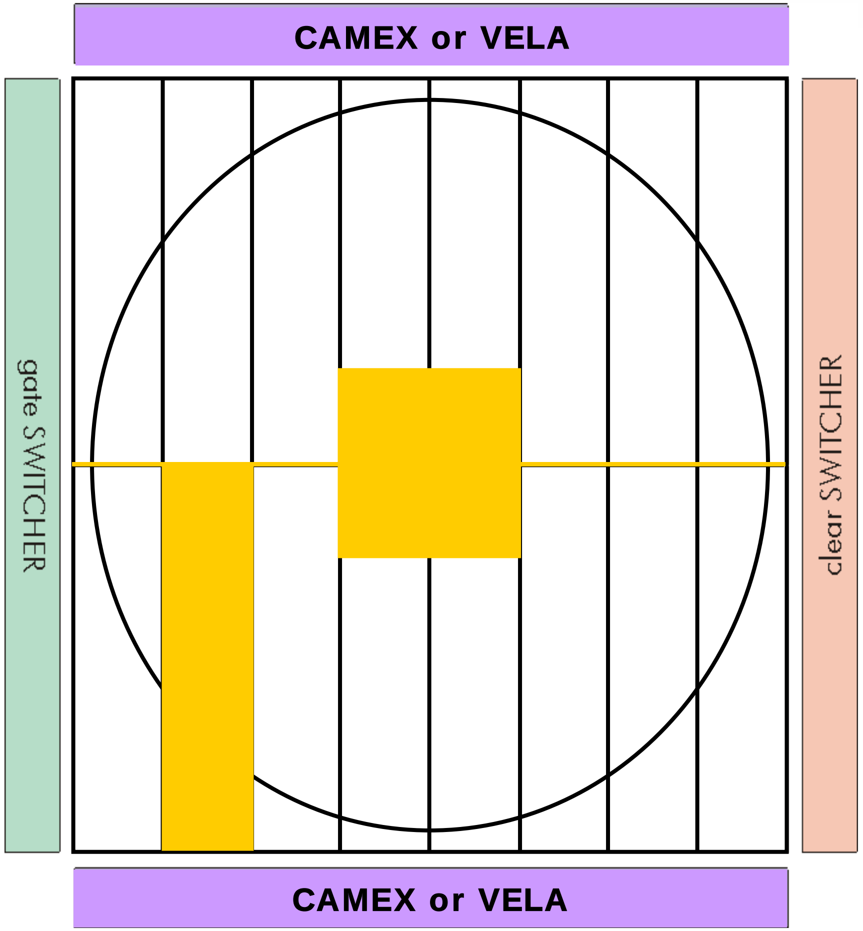


Test set-up for the combined double sided SSD and the CdTe detector. The distance between the WFI and the CdTe detector of the HXI is approximately 2 cm.

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

DEPFETs for the XEUS WFI

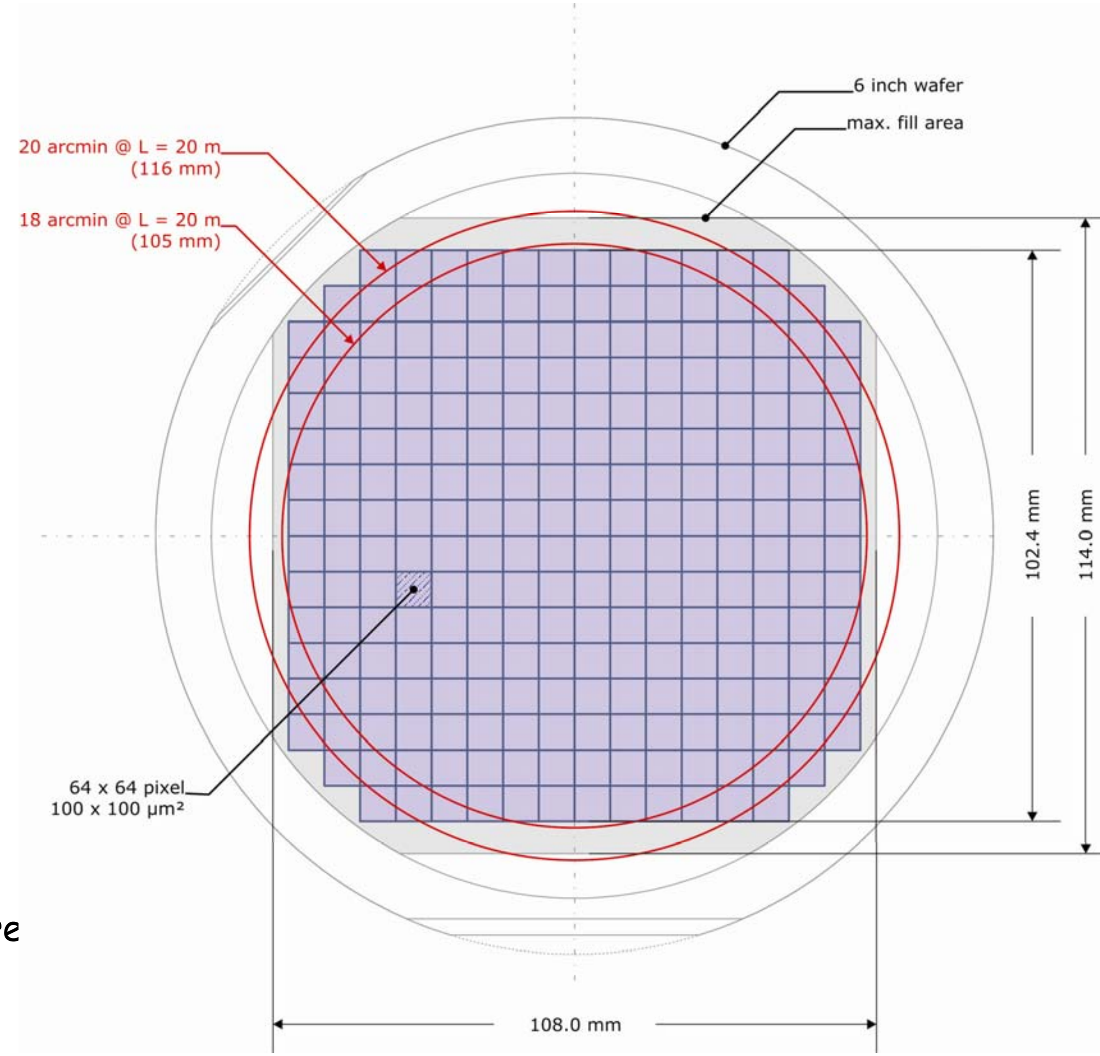
1. Flexible operating modes
2. low power dissipation (less than 2 W in 100 cm^2, DePFETs only)
3. Fano limited energy resolution from 0.5 keV to 30 keV
4. Spatial resolution better than 20 µm @ 100 µm pixel size
5. Homogeneous radiation entrance window
6. Intrinsic radiation hardness, no charge transfer 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



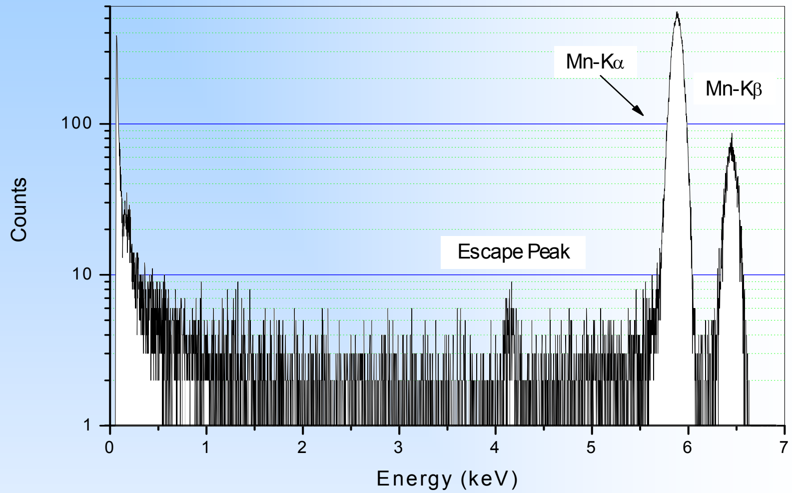
Wide Field Imager

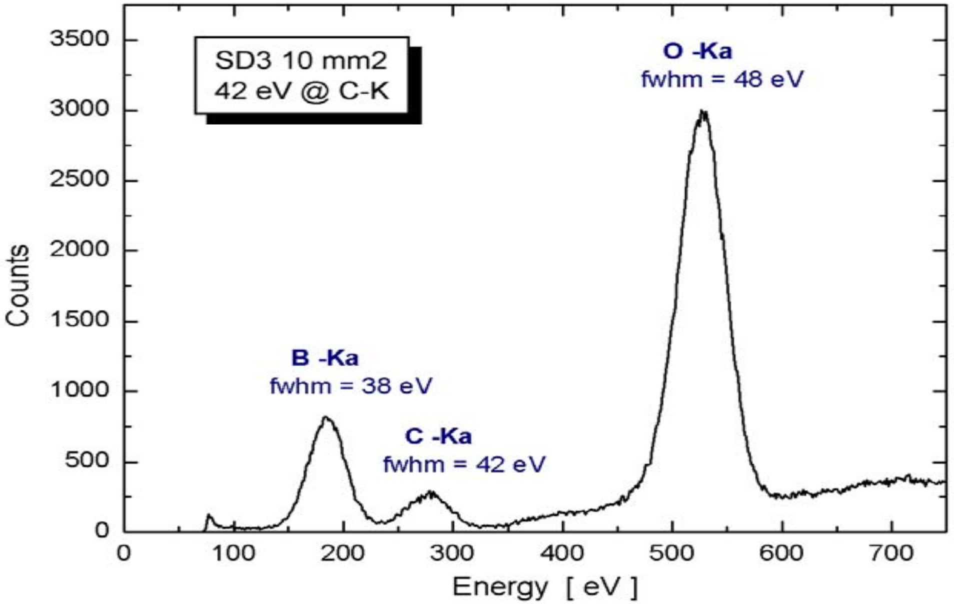
♦ tentative wafer layout

- **pixel size** 100 µm □
  1 arcsec ≈ 97 µm @ 20 m
  ≈ 1/5 of PSF (5 arcmin)
- **format**
  102.4 x 102.4 mm²
  1024 x 1024 pixels
  with ´rounded´ corners
- **field of view**
  18 arcmin ≈ 105 mm @ 20 m
  20 arcmin ≈ 116 mm @ 20 m
- no. of pixels 999.414
- FOV fraction outside sensor are
  1.6 ‰ @ 18 arcmin
  9 % @ 20 arcmin



"Backside" illumination: Source on top of entrance window





- timing

  2 µsec/row <-> 32 µsec/32x512 sensor

- room temperature

  220 eV FWHM @ 5.9 keV (singles)

- moderate cooling -40 °C

  127 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)

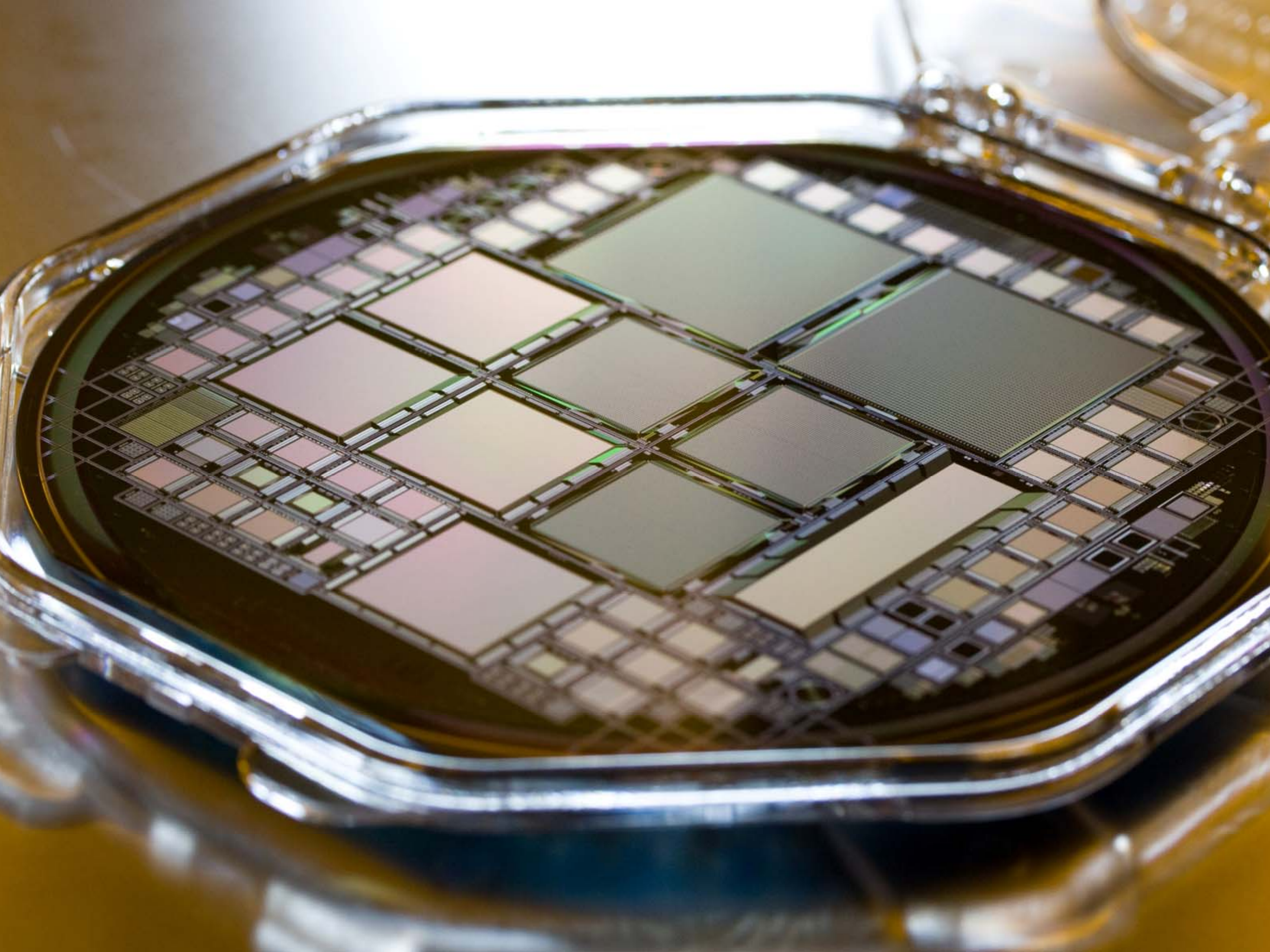
  pixel yield > 0.99999

- dispersions

  offset < 2 % (of Mn-Ka)

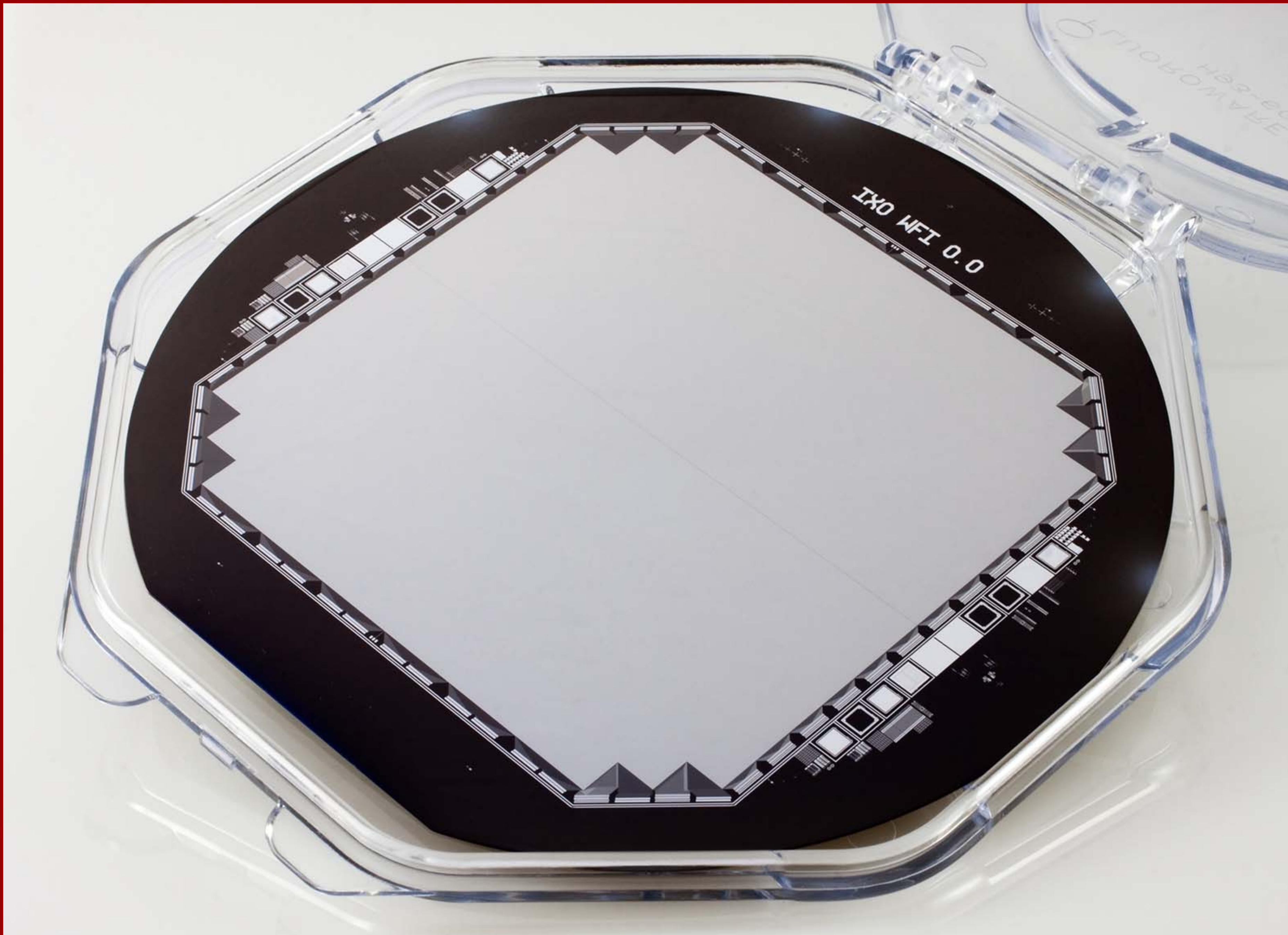
  gain < 5 %

  noise < 10 %



``Collaborating´´ Institutions for the WFI:

1. *Max-Planck-Institut für extraterrestrische Physik*
   - *Institut für Astronomie + Astrophysik, Tübingen*
   - *Universität Erlangen*
   - *Universität Darmstadt*
2. *University of Leicester, UK*
3. *Politecnico di Milano, Italy*
4. *University of Osaka, Japan*
5. *Center for Astrophysics, Cambridge, MA, Penn State University and MIT*
6. *PNSensor , Germany*


IXO WFI 0.0

Large-Format, High-Speed, X-ray pnCCDs Combined with Electron and Ion Imaging Spectrometers in a Multipurpose Chamber for Experiments at 4th Generation Light Sources

Lothar Strüder [a,c,e,h], Sascha Epp [a], Daniel Rolles [a], Robert Hartmann [b,e], Peter Holl [b,e], Gerhard Lutz [b,e], Heike Soltau [b,e], Rouven Eckart [b,e], Christian Reich [b,e], Klaus Heinzinger [b,e], Christian Thamm [b,e], Artem Rudenko [a], Faton Krasniqi [a], Kai-Uwe Kühnel [i], Christian Bauer [i], Claus-Dieter Schröter [i], Danilo Miessner [c,e], Matteo Porro [c,e], Olaf Hälker [c,e], Norbert Meidinger [c,e], Nils Kimmel [c,e], Robert Andritschke [c,e], Florian Schopper [c,e], Georg Weidenspointner [c,e], Alexander Ziegler [c,e], Sven Herrmann [c,e], Ullrich Pietsch [h], Albert Walenta [h], Wolfram Leitenberger [h], Christoph Bostedt [f], Thomas Möller [f], Daniela Rupp [f], Marcus Adolph [f], Heinz Graafsma [g], Helmut Hirsemann [g], Klaus Gärtner [k], Rainer Richter [d,e], Daniel Pietschner [c,e], Lutz Foucar [a], Robert L. Shoeman [l], Ilme Schlichting [a,l], Joachim Ullrich [a,i]

[a] *Max Planck Advanced Study Group, Center for Free Electron Laser Science (CFEL) at DESY, Notkestr. 85, D-22607 Hamburg, Germany*
[b] *PNSensor GmbH, Römerstraße 28, D-80803 München, Germany*
[c] *Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße, D-85741 Garching, Germany*
[d] *Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany*
[e] *MPI Halbleiterlabor, Otto-Hahn-Ring 6, D-81739 München, Germany*
[f] *Technische Universität Berlin, Institut für Optik und Atomare Physik, Hardenbergstraße 36, D-10623 Berlin, Germany*
[g] *DESY, Notkestr.85, D-22607 Hamburg, Germany*
[h] *University of Siegen, Emmy-Noether Campus, Walter Flex Str. 3, D-57068 Siegen, Germany*
[i] *Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany*
[k] *Weierstrass Institut, Berlin, Mohrenstr. 39, D-10117 Berlin, Germany*
[l] *Max-Planck-Institut für medizinische Forschung, Jahnstr. 29, D-69120 Heidelberg, Germany*

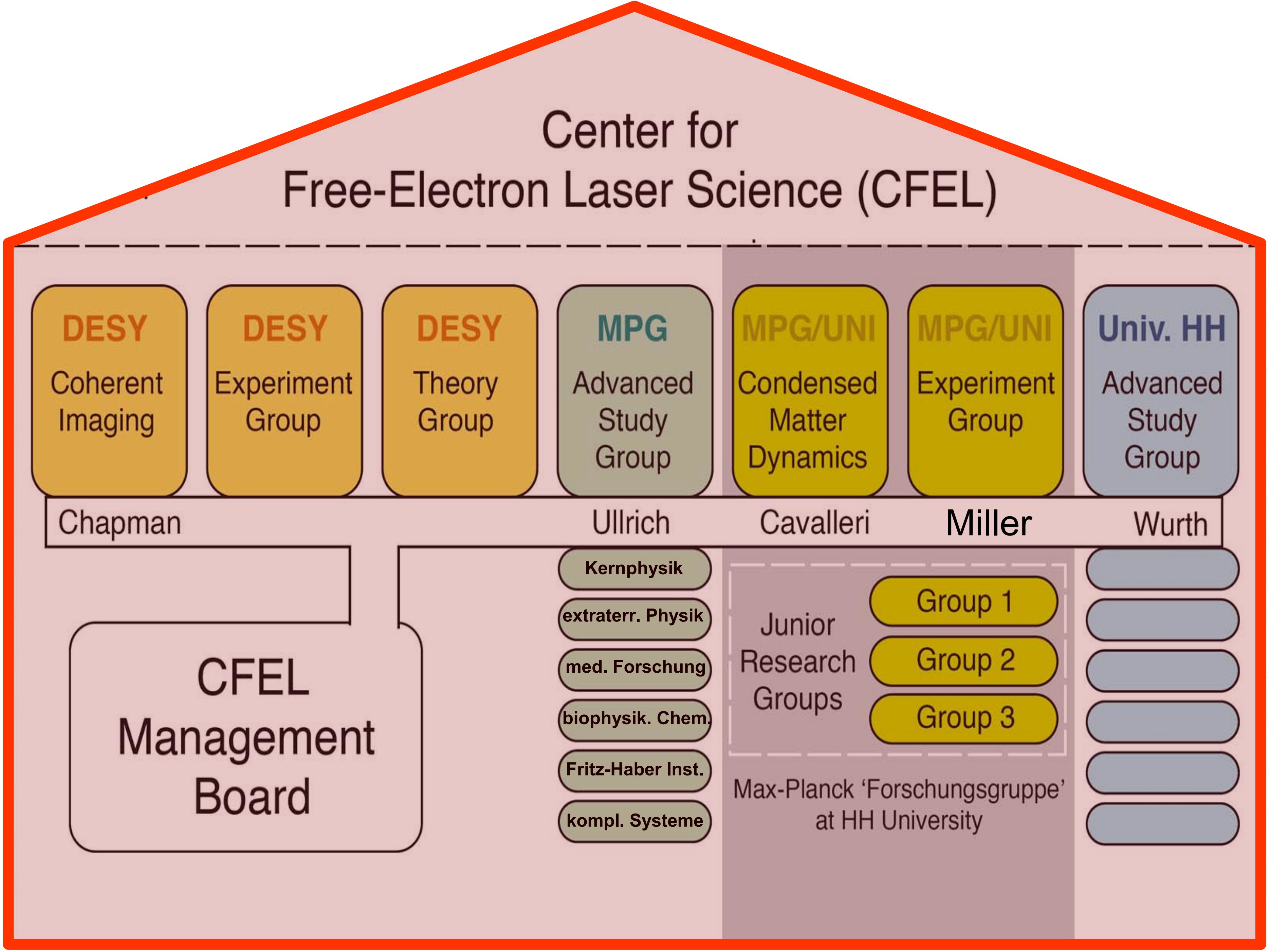
Free Electron Lasers

...across the classical disciplines

...across institutions

CFEL: 350 people

UHH + DESY + MPG


Center for
Free-Electron Laser Science (CFEL)
DESY
Coherent Imaging
DESY
Experiment Group
DESY
Theory Group
MPG
Advanced Study Group
MPG/UNI
Condensed Matter Dynamics
MPG/UNI
Experiment Group
Univ. HH
Advanced Study Group
Chapman
Ullrich
Cavalleri
Miller
Wurth
Kernphysik
extraterr. Physik
med. Forschung
biophysik. Chem.
Fritz-Haber Inst.
kompl. Systeme
Junior Research Groups
Group 1
Group 2
Group 3
Max-Planck 'Forschungsgruppe' at HH University
CFEL Management Board

The Max-Planck Advanced Study Group

Topic 1:
FLASH Experiments
(Ullrich, Moshammer)

Topic 2:
LCLS/XFEL Exp.
across the sections
(Schlichting, Techert)

Topic 3
Detectors
(Strüder)

Topic 4
Theory
(Rost)

Core ASG based at the CFEL site

Scientist 1 | Scientists 2 & 3 | Scientist 4 **& 5** | SWNG*

supported by 2 technicians and ~ 4 PhD students

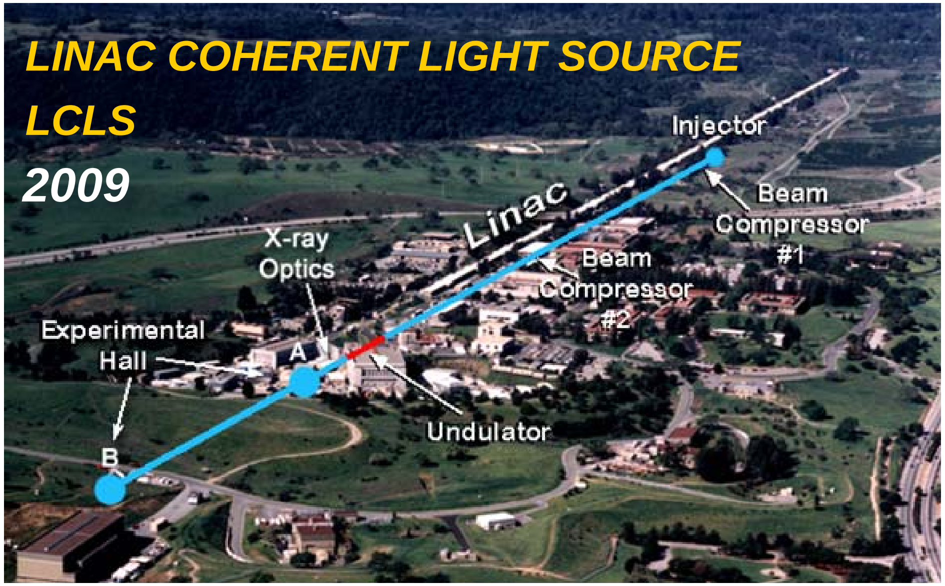
- Atoms & molecules
- Molecular Ions
- Cluster physics
- Ultra-cold plasmas
- Pump-Probe exp.
- Ion Spectroscopy (EBIT)

- Structure investigation of larger molecules and soft matter
- Alignment of molecules in the gas phase
- Fragment-imaging
- Ultra-cold gases
- Ion Spectroscopy (EBIT)

- **Pixel detectors**
  - **pnCCDs**
  - **DePFETS**
  - **SDDs**
- **large formats**
  up to 4 Mpix
- **MHz readout for XFEL**
- **low noise**
- **high dynamic range**
- **radiation hardness**

- Basics of light-matter interactions
- Cluster dynamics & bio-molecules
- Imaging, dynamics of fragmentation

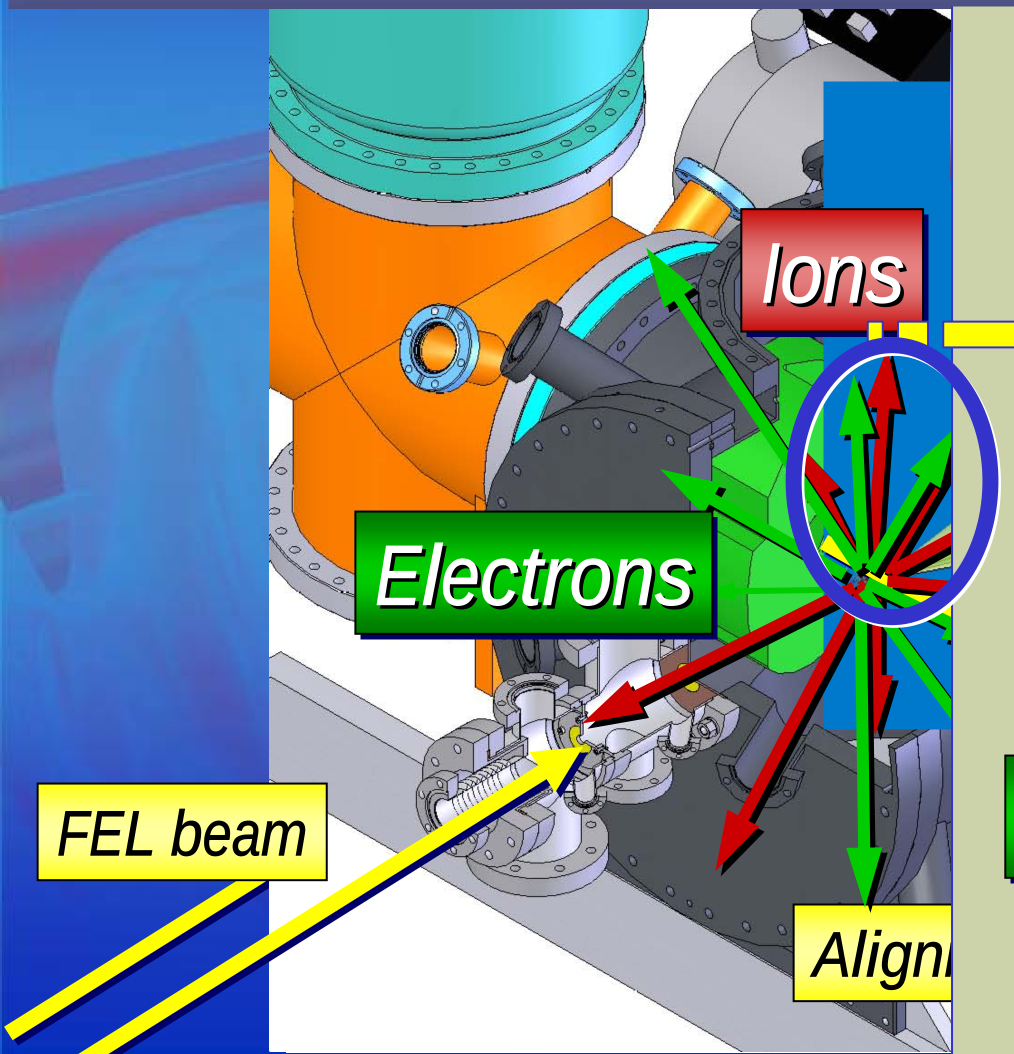
Hard X-ray SASE Free Electron Lasers

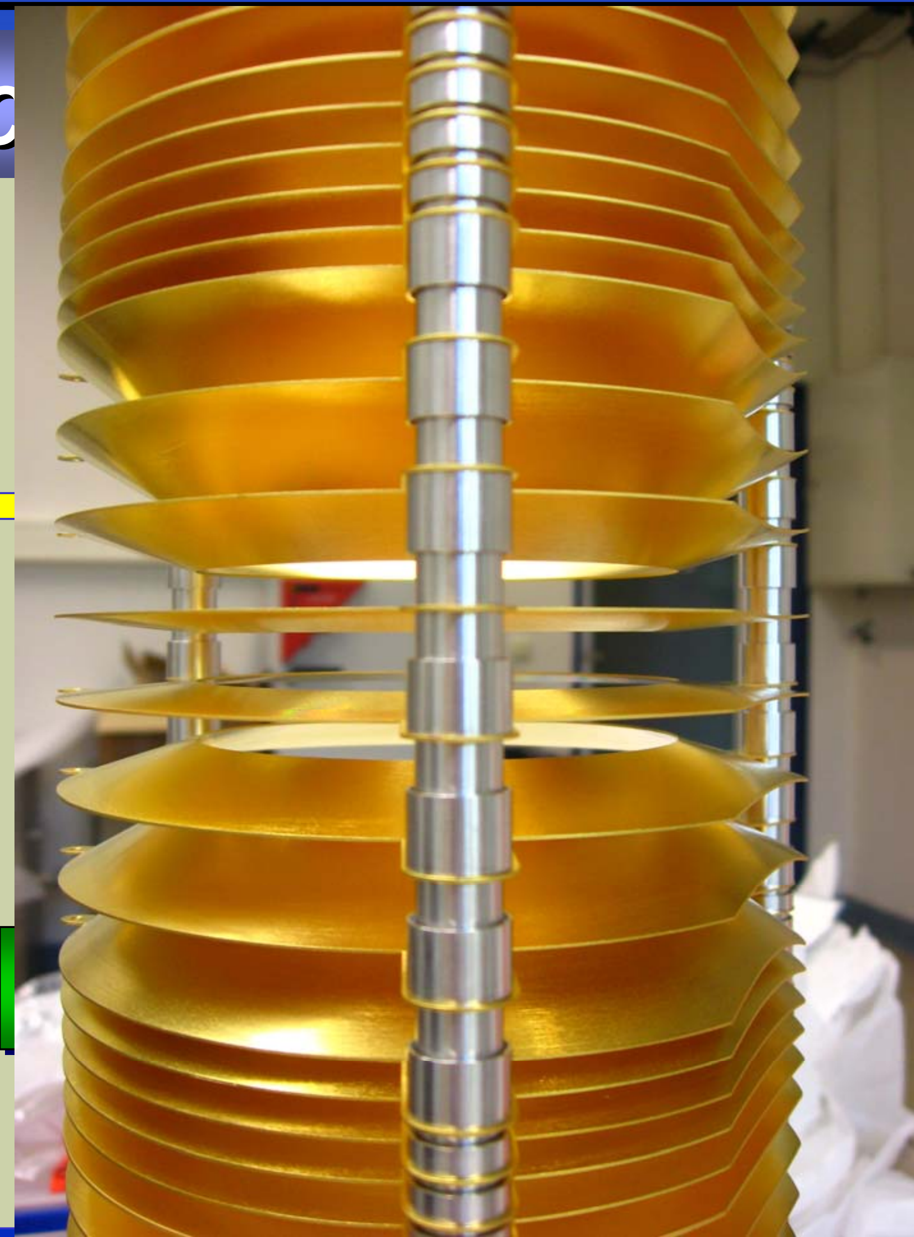


FLASH:	5 Hz, 10 Hz and 5 MHz
LCLS:	120 Hz
SCSS:	60 Hz
XFEL:	5 Hz, 10 Hz and 5 MHz

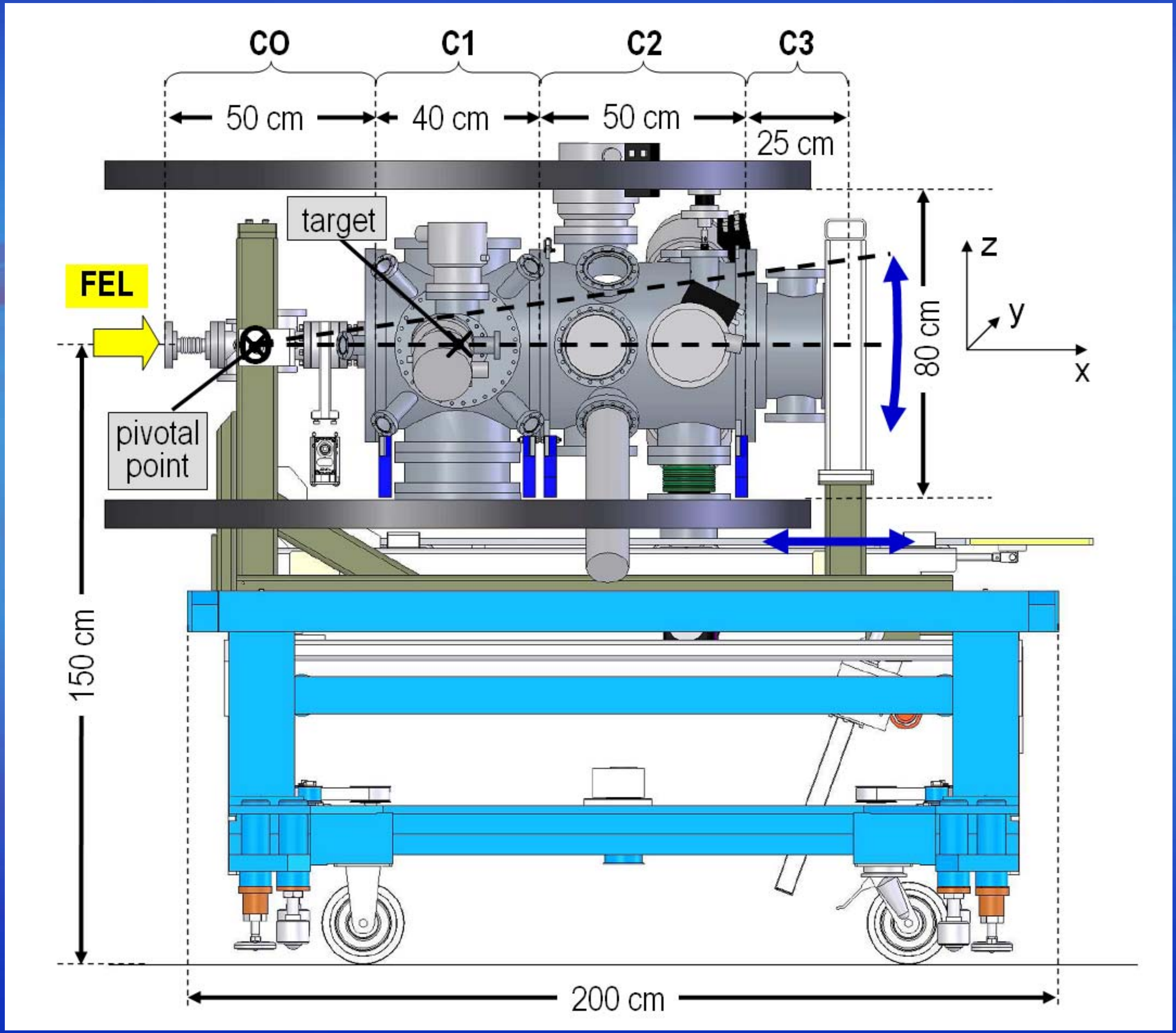
CFEL-ASG MultiPurpose Chamber

Integrated Reaction Mic

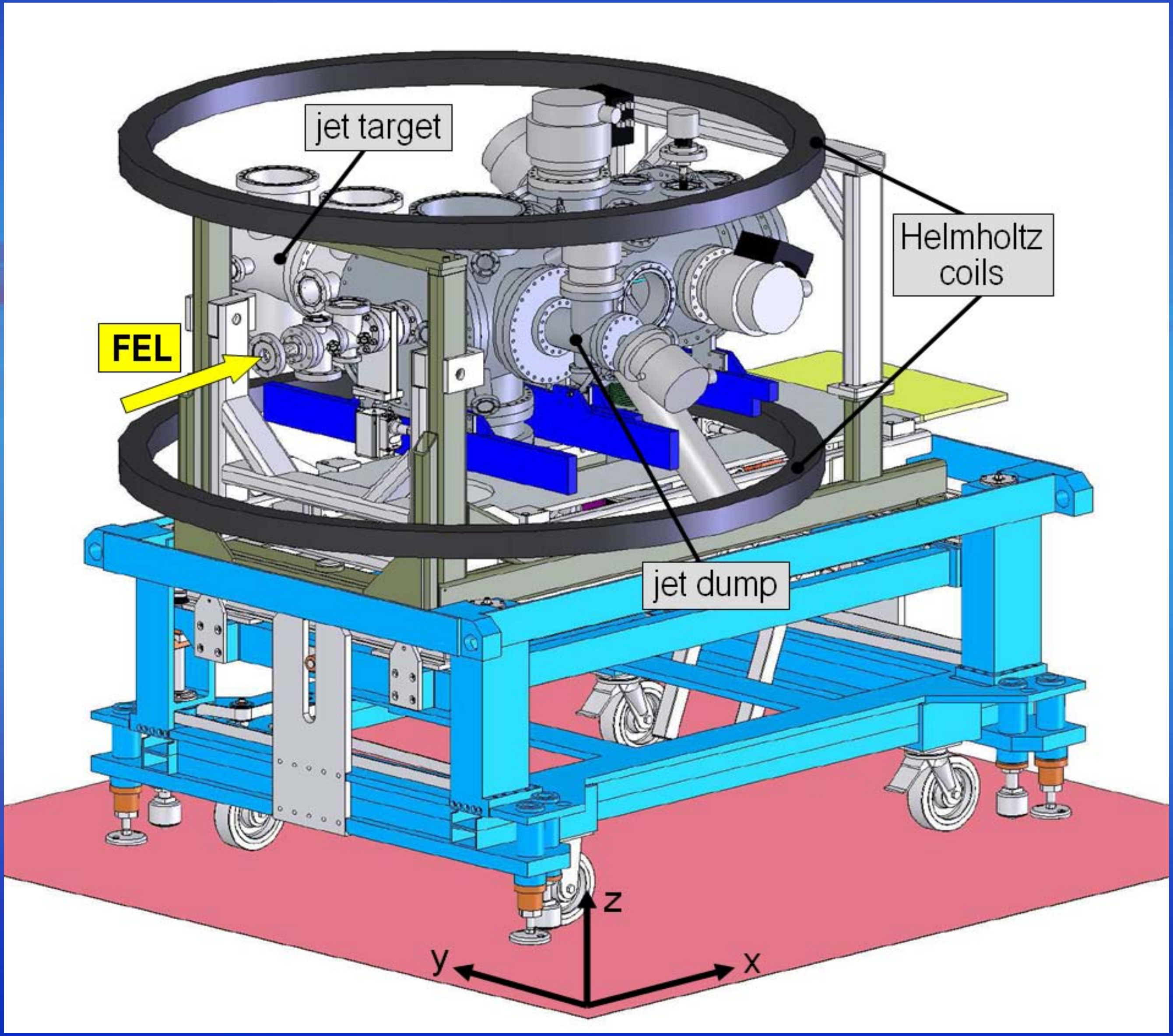




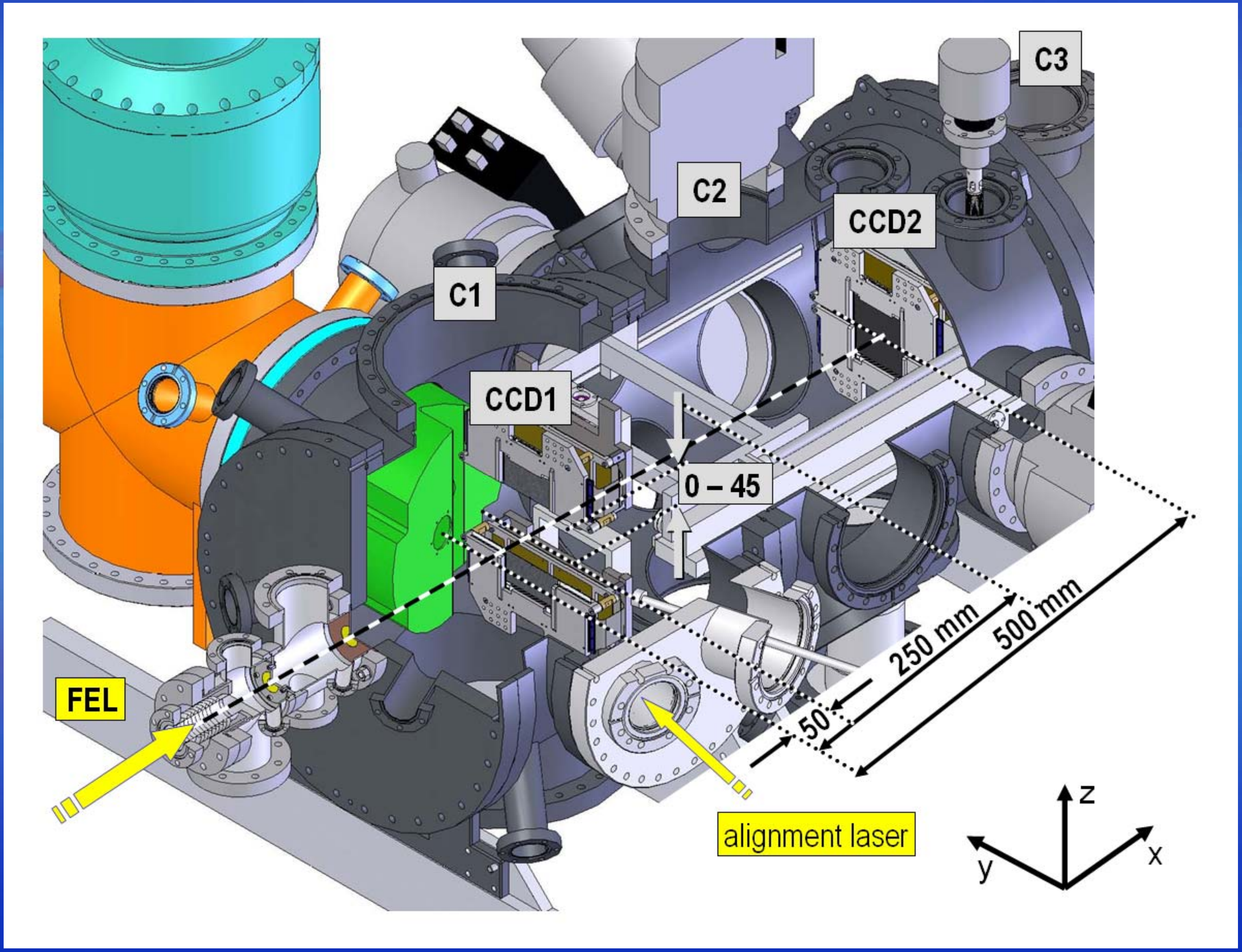
CFEL-ASG MultiPurpose Chamber



CFEL-ASG MultiPurpose Chamber



CFEL-ASG MultiPurpose Chamber



Requirements of the FLASH, LCLS and XFEL

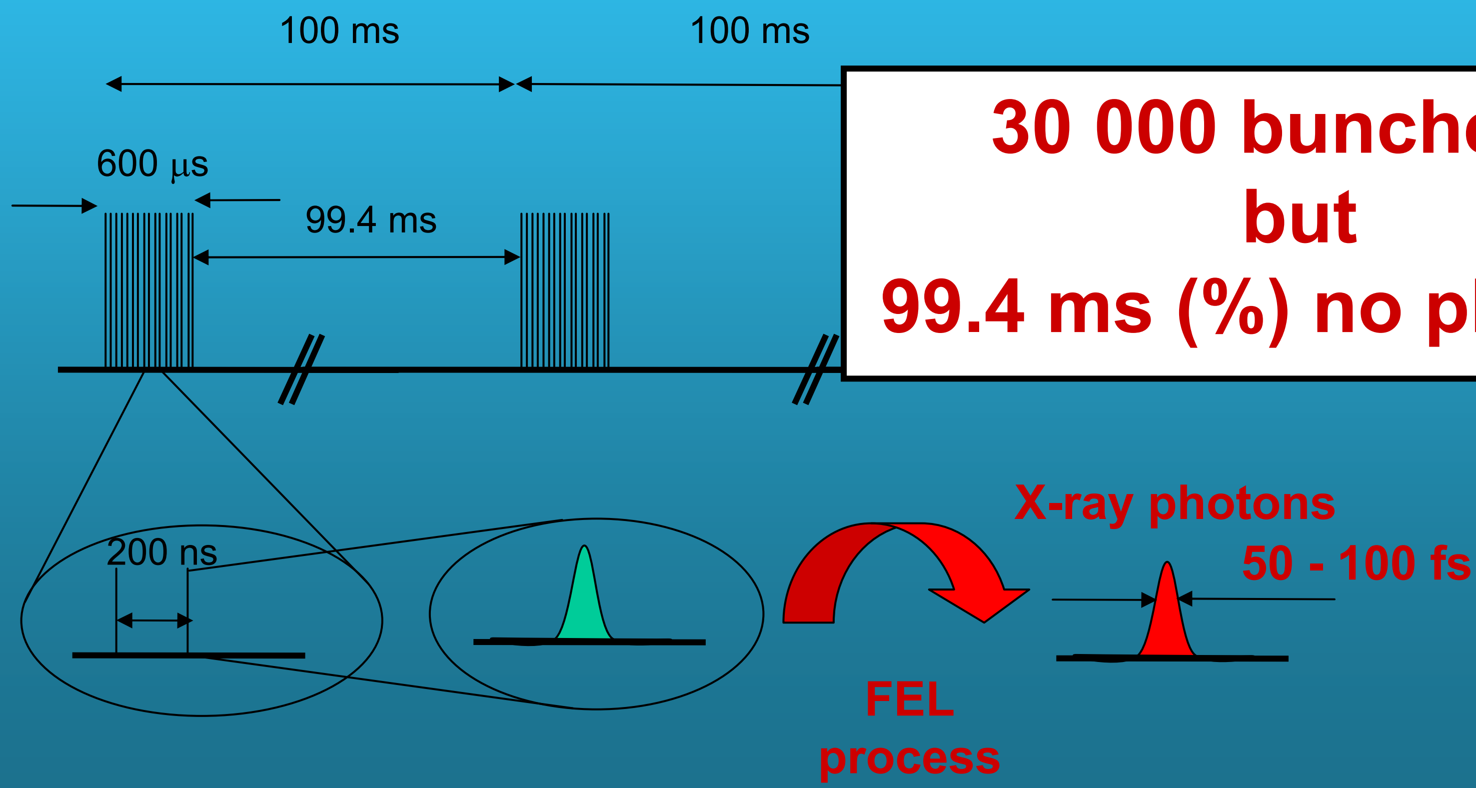
Integrating Area Detectors

	FLASH, LCLS + XFEL	pnCCD and DePFET system
single photon resolution	yes	yes
energy range	0.05 < E < 24 (keV)	0.05 < E < 25 [keV]
pixel size (µm)	100	75 (200)
sig.rate/pixel/bunch	10^3 (10^5)	10^3 - 10^4
quantum efficiency	> 0.8	> 0.8 from 0.3 to 12 keV
number of pixels	512 x 512 (min.)	1024 x 1024 and 2048 x 2048
frame rate/repetition rate	10 Hz - 120 Hz	up to 250 Hz with pnCCD
XFEL burst mode	5 MHz (3.000 bunches)	> 5 MHz (3.000 bunches) with DePFET system
Readout noise	< 150 e^- (rms)	< 10 e^- (rms) (2 e^- possible)
cooling	possible	- 20° C optimum room temperature possible
vacuum compatibility	yes	yes
preprocessing	no (yes) ?	possible upon request

What is the challenge for Detectors @ XFEL

Time structure: difference with "others"

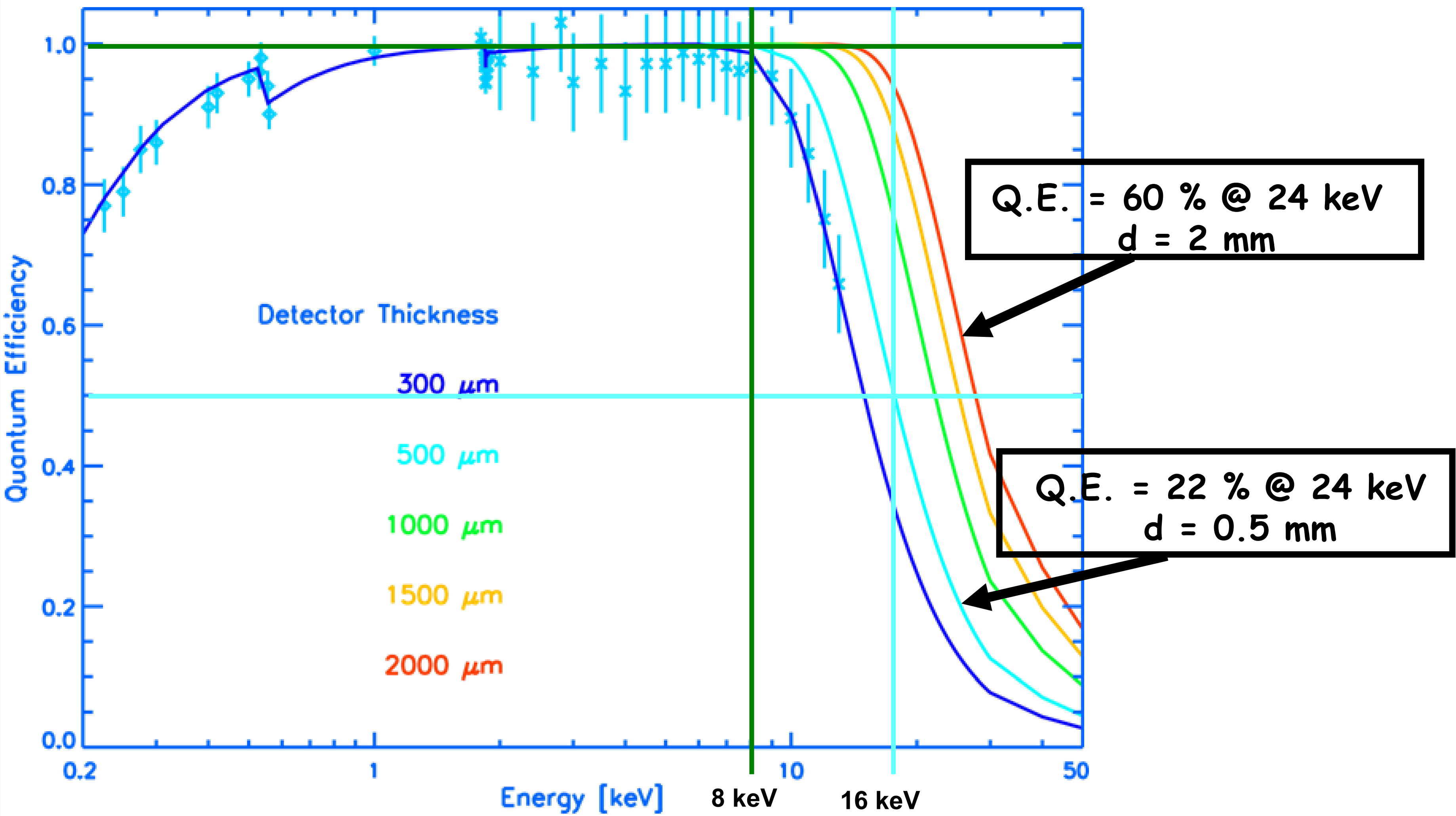
Electron bunch trains; up to 3000 bunches in 600 μsec, repeated 10 times per second.
Producing 100 fsec X-ray pulses (up to 30 000 bunches per second).



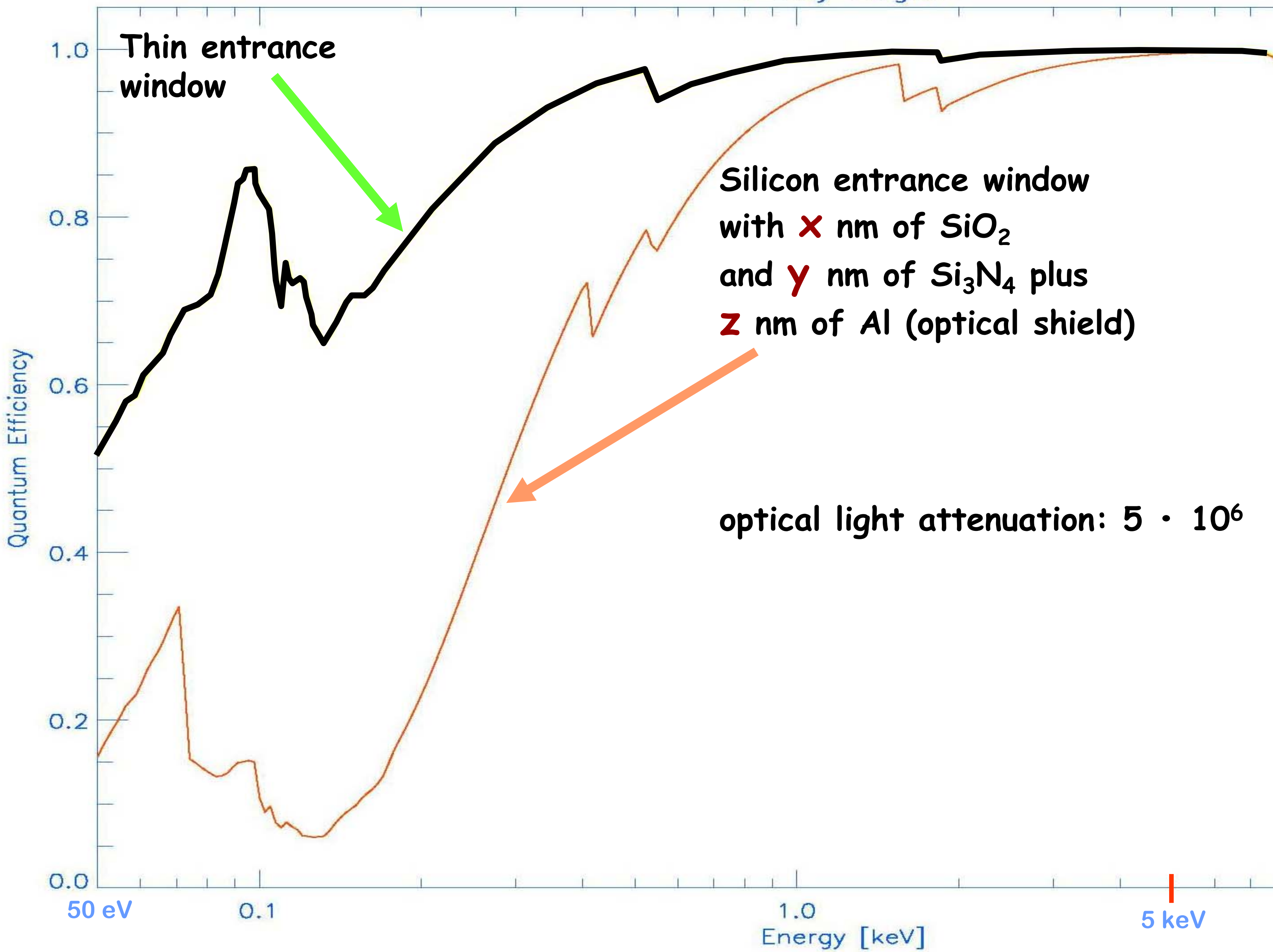
30 000 bunches/s
but
99.4 ms (%) no photons

What is limiting the quantum efficiency ?

The thickness of Silicon !!

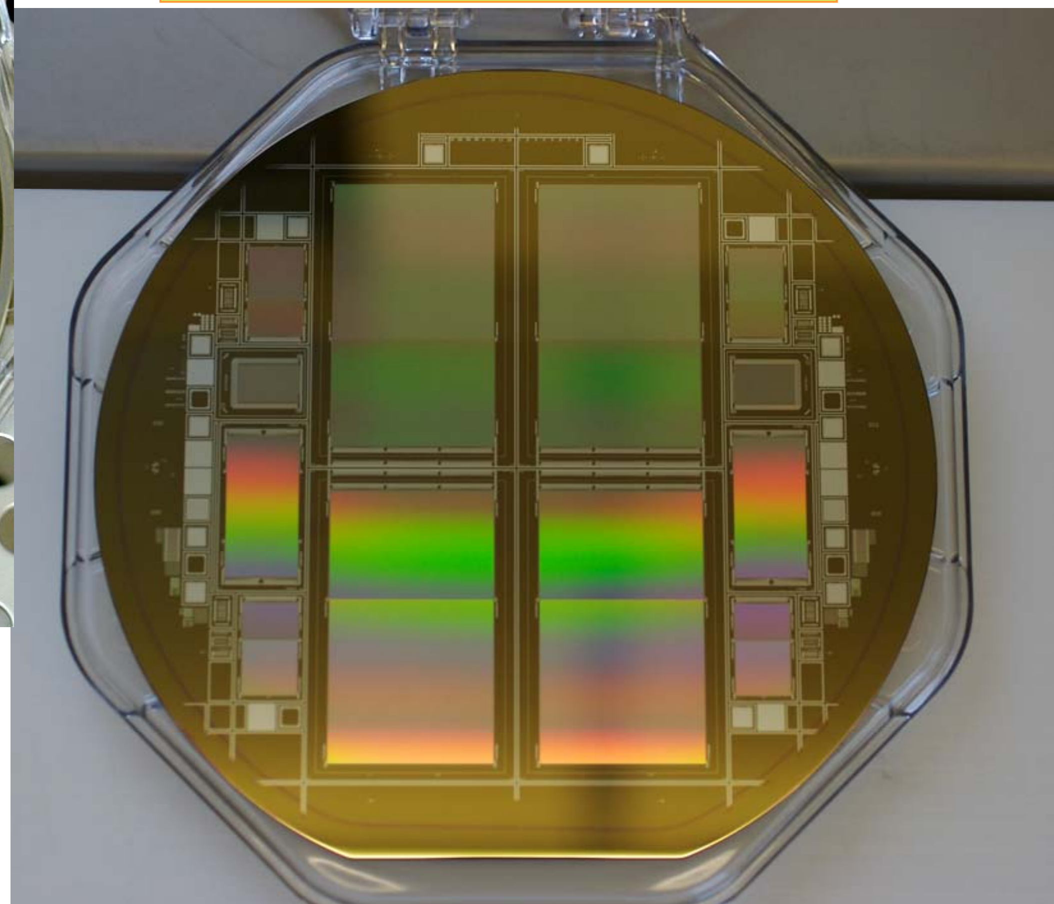


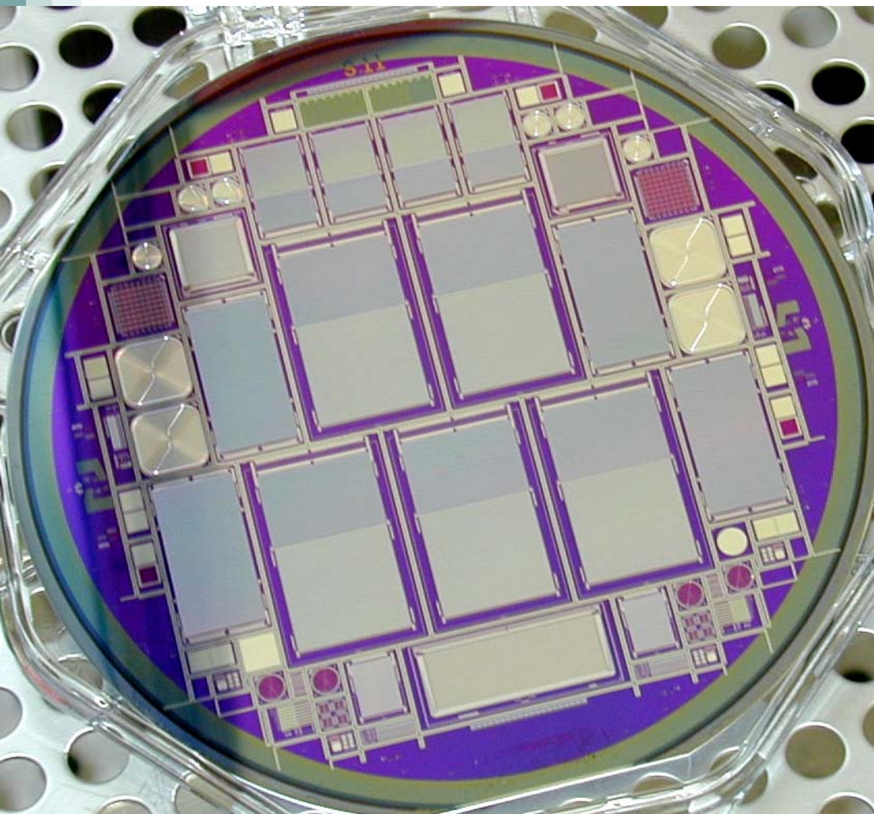
Monolithic Integration of optical blocking filters



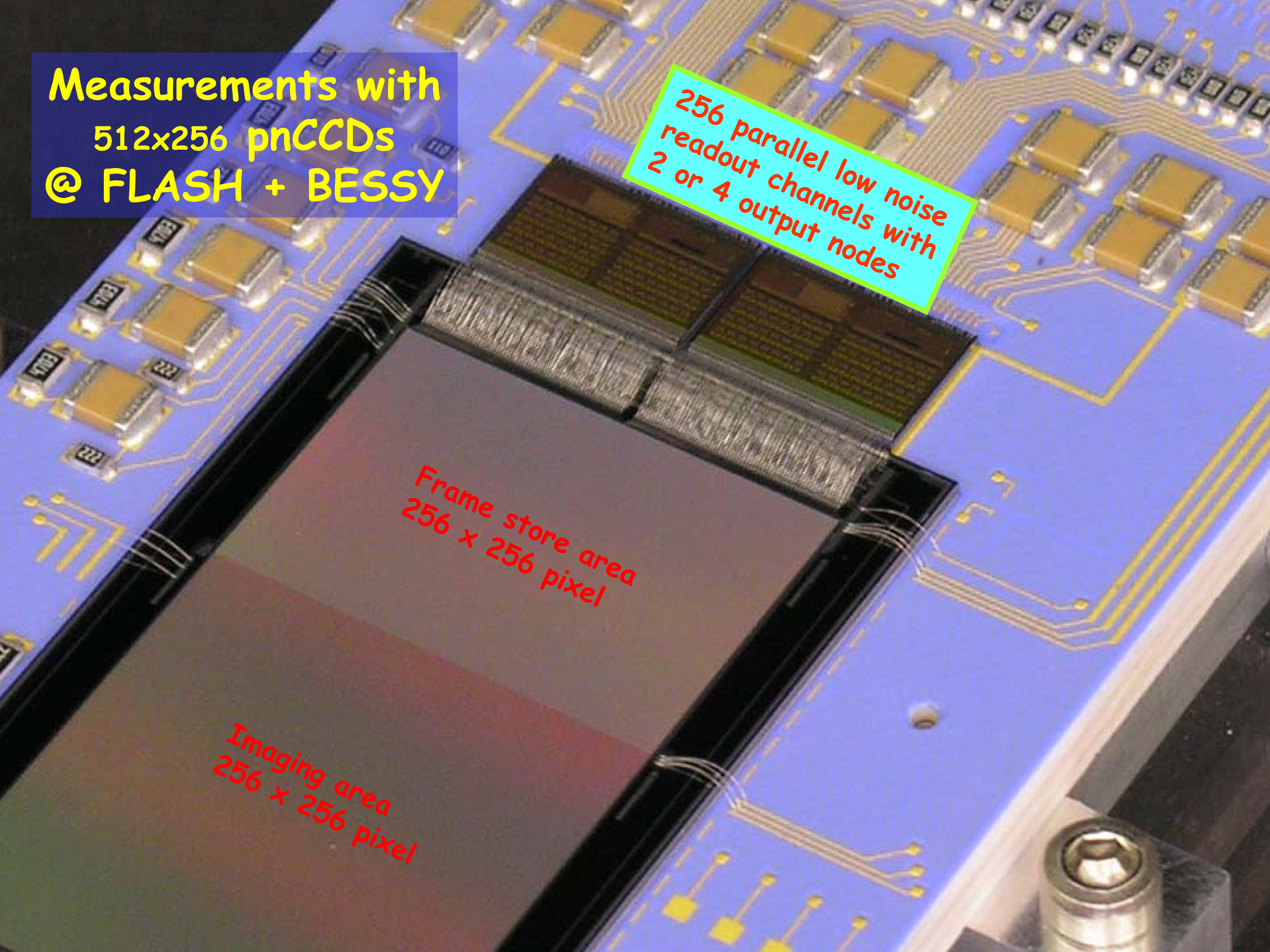
Recent pnCCDs fabrications

flight type eROSITA version
format: 384 x 384 x 2 pixel
area: 8.4 cm^2 + 5.6 cm^2
pixel size: 75 x 75 μm^2

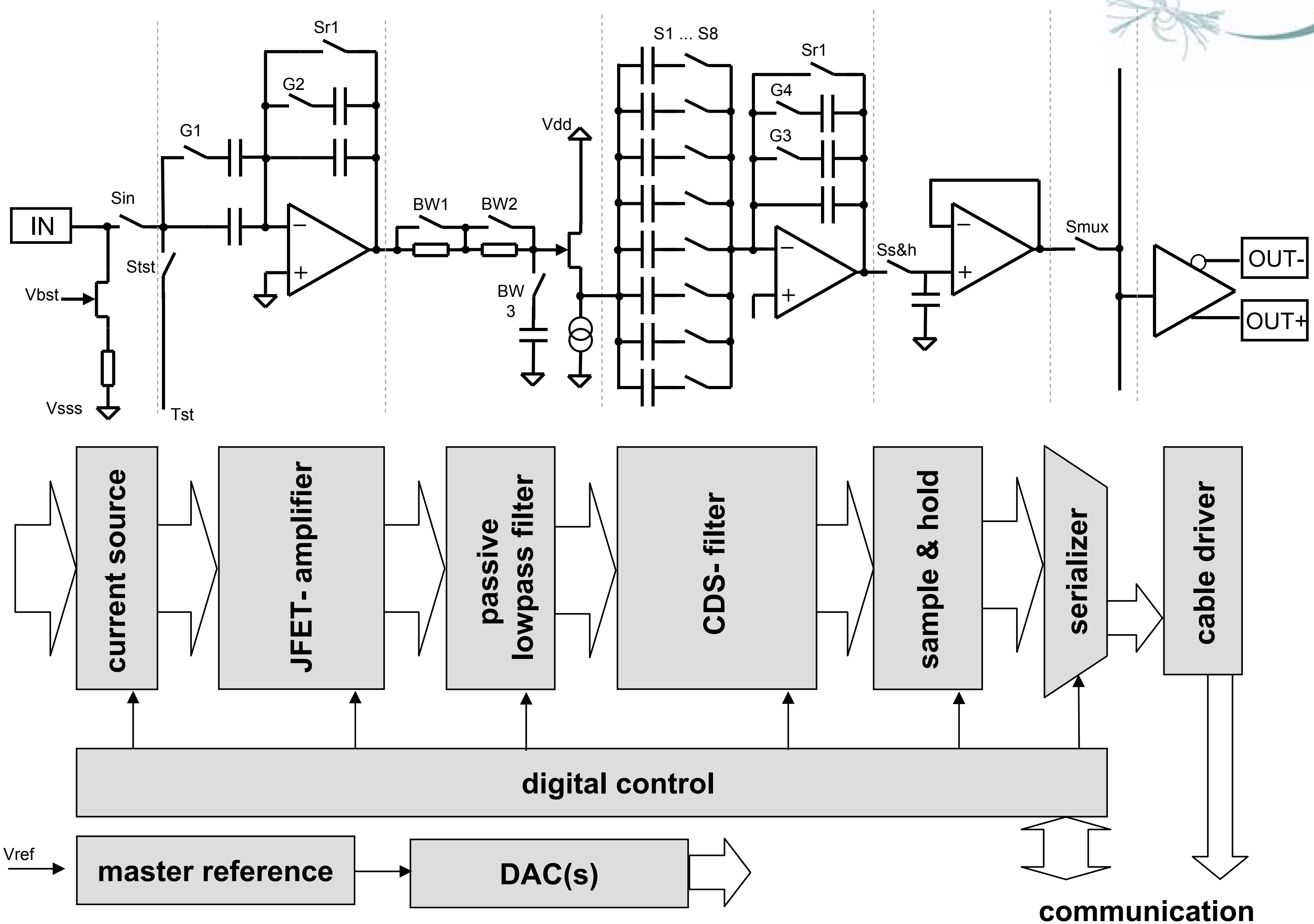




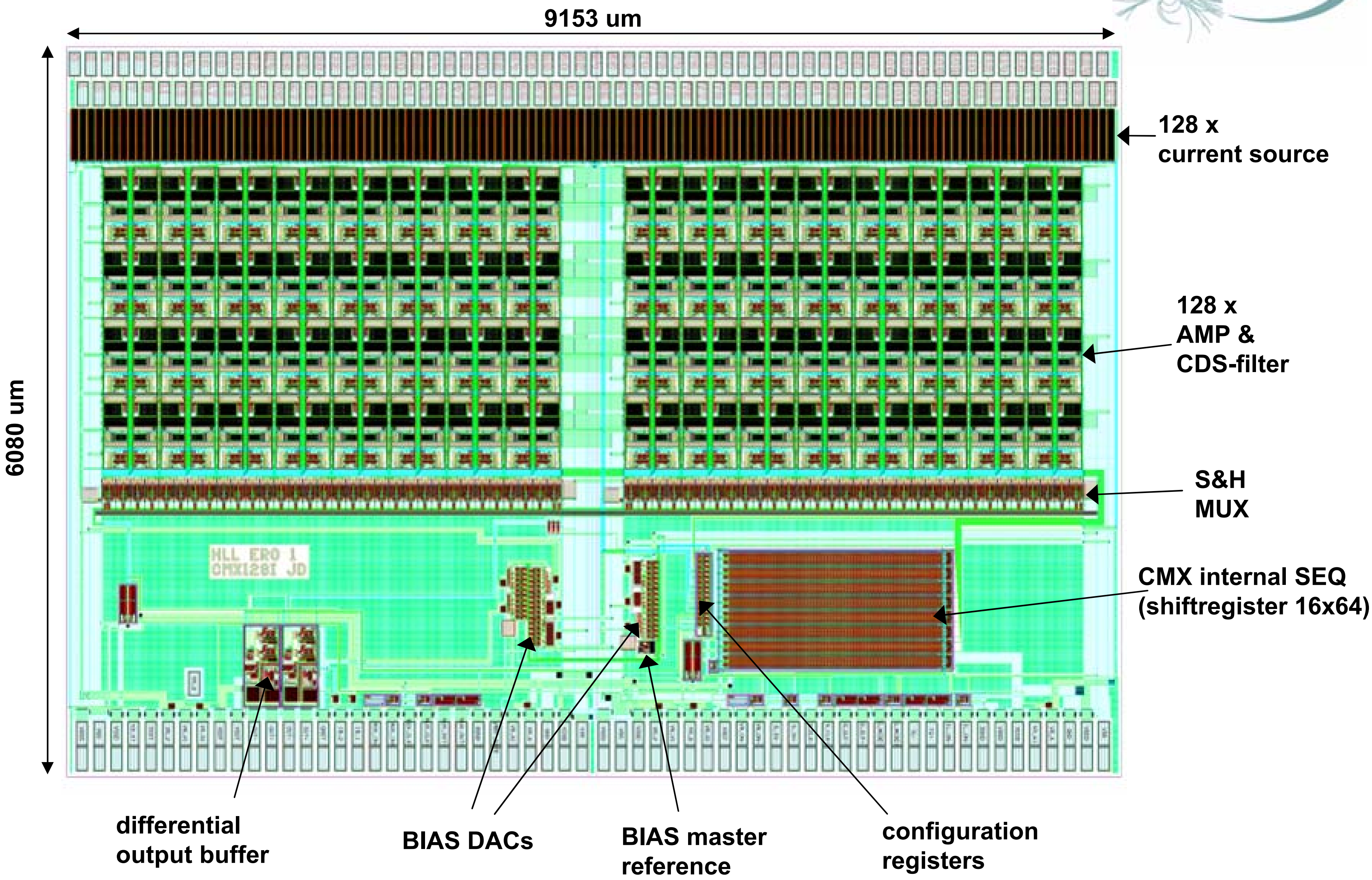
prototype eROSITA version
format: 256 x 256 x 2 pixel
area: 3.7 cm^2 + 2.5 cm^2
pixel size: 75 x 75 μm^2

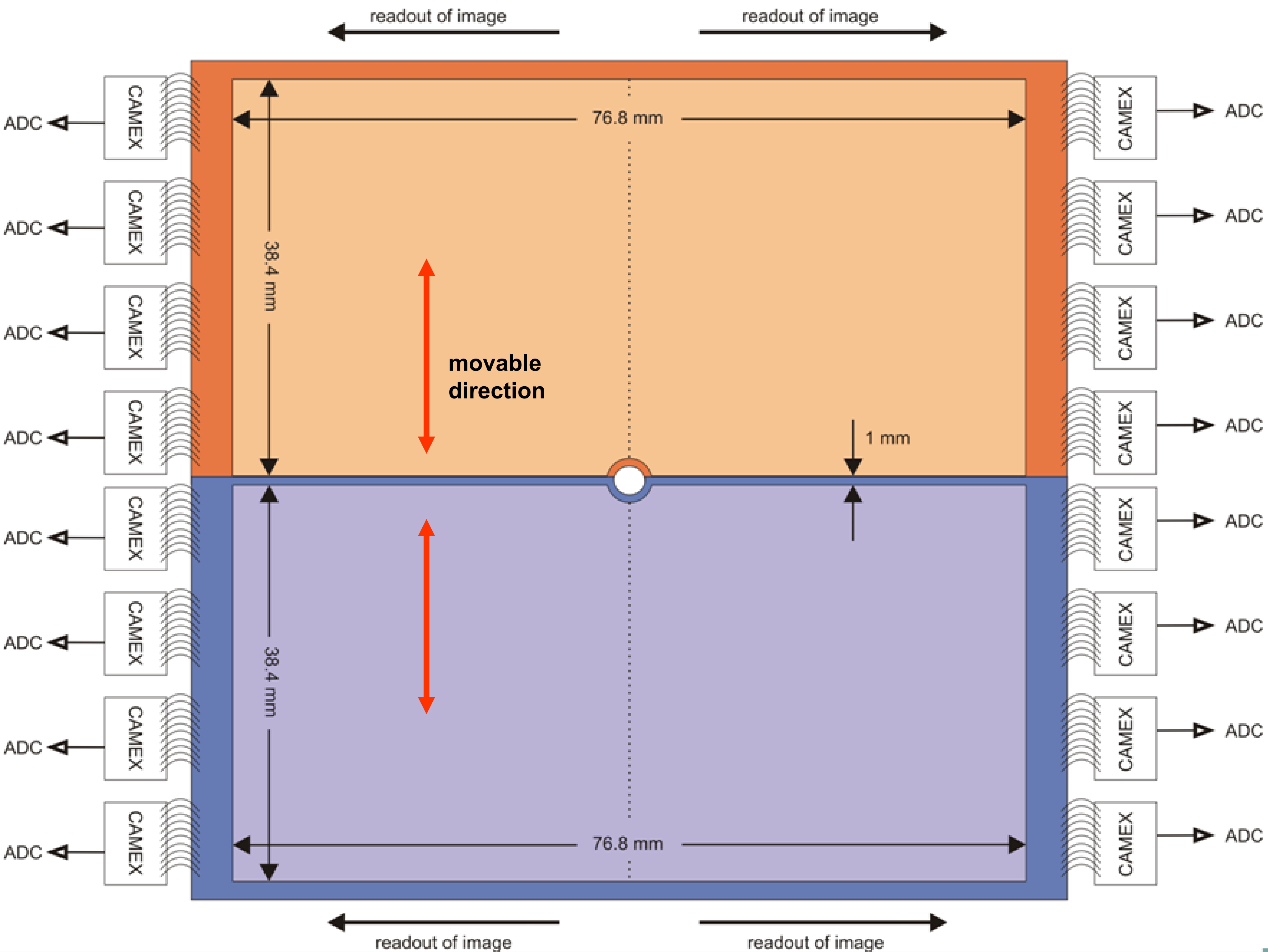

Measurements with
512x256 pnCCDs
@ FLASH + BESSY
256 parallel low noise
readout channels with
2 or 4 output nodes
Frame store area
256 x 256 pixel
Imaging area
256 x 256 pixel

CAMEX block diagram



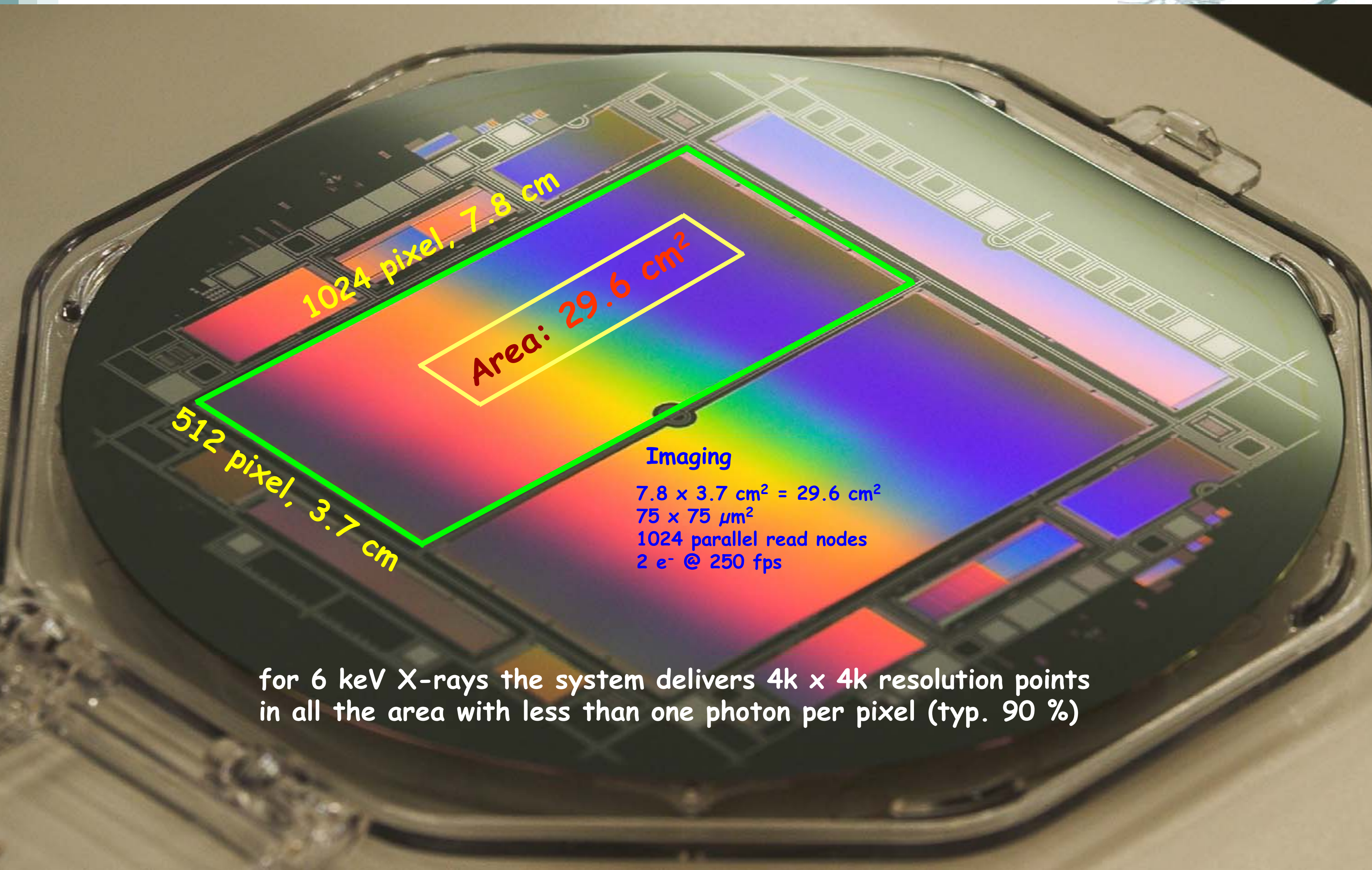
CAMEX eROSITA 128I-JD



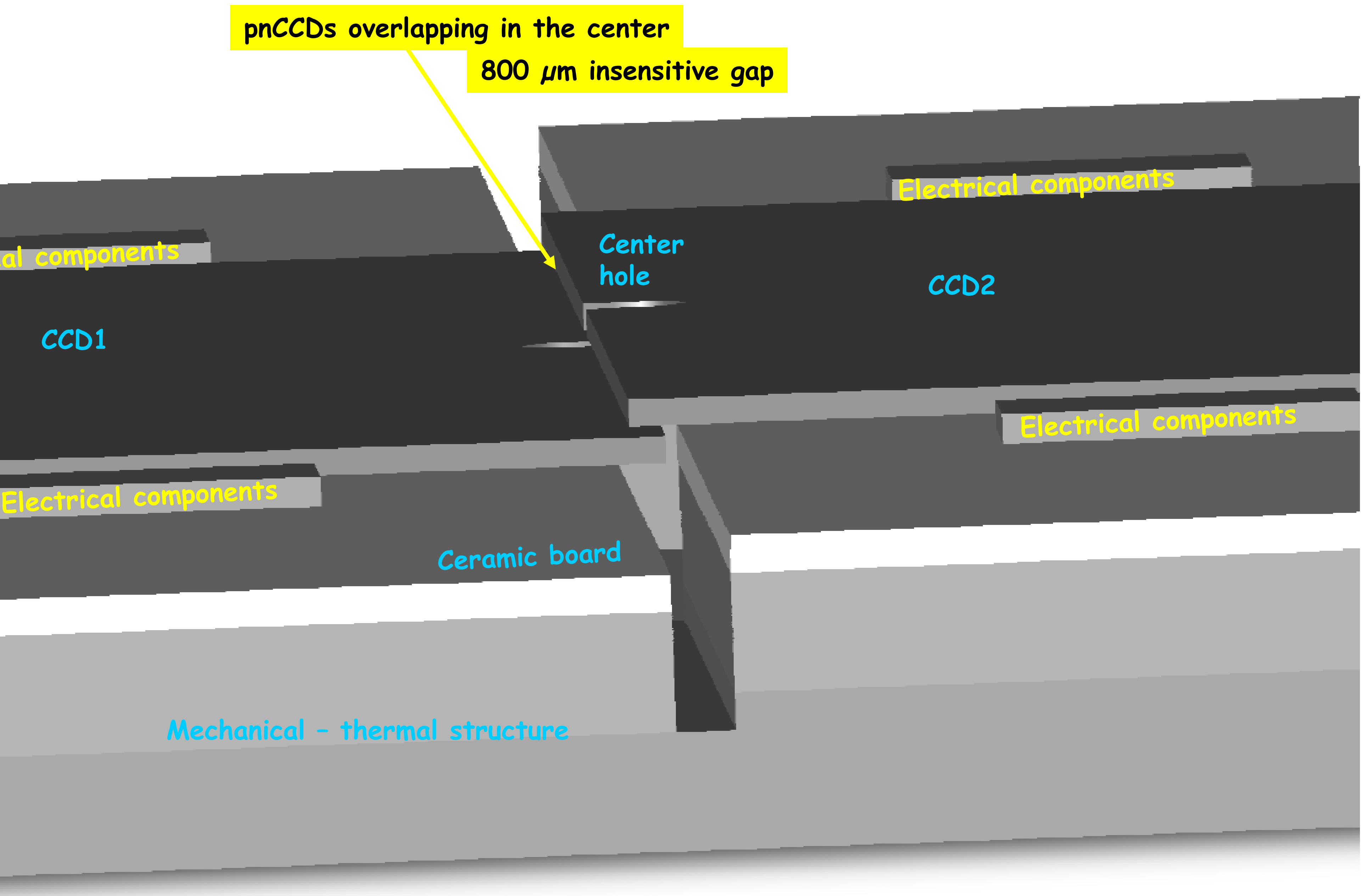

readout of image
readout of image
76.8 mm
38.4 mm
movable direction
1 mm
38.4 mm
76.8 mm
readout of image
readout of image
CAMEX
ADC

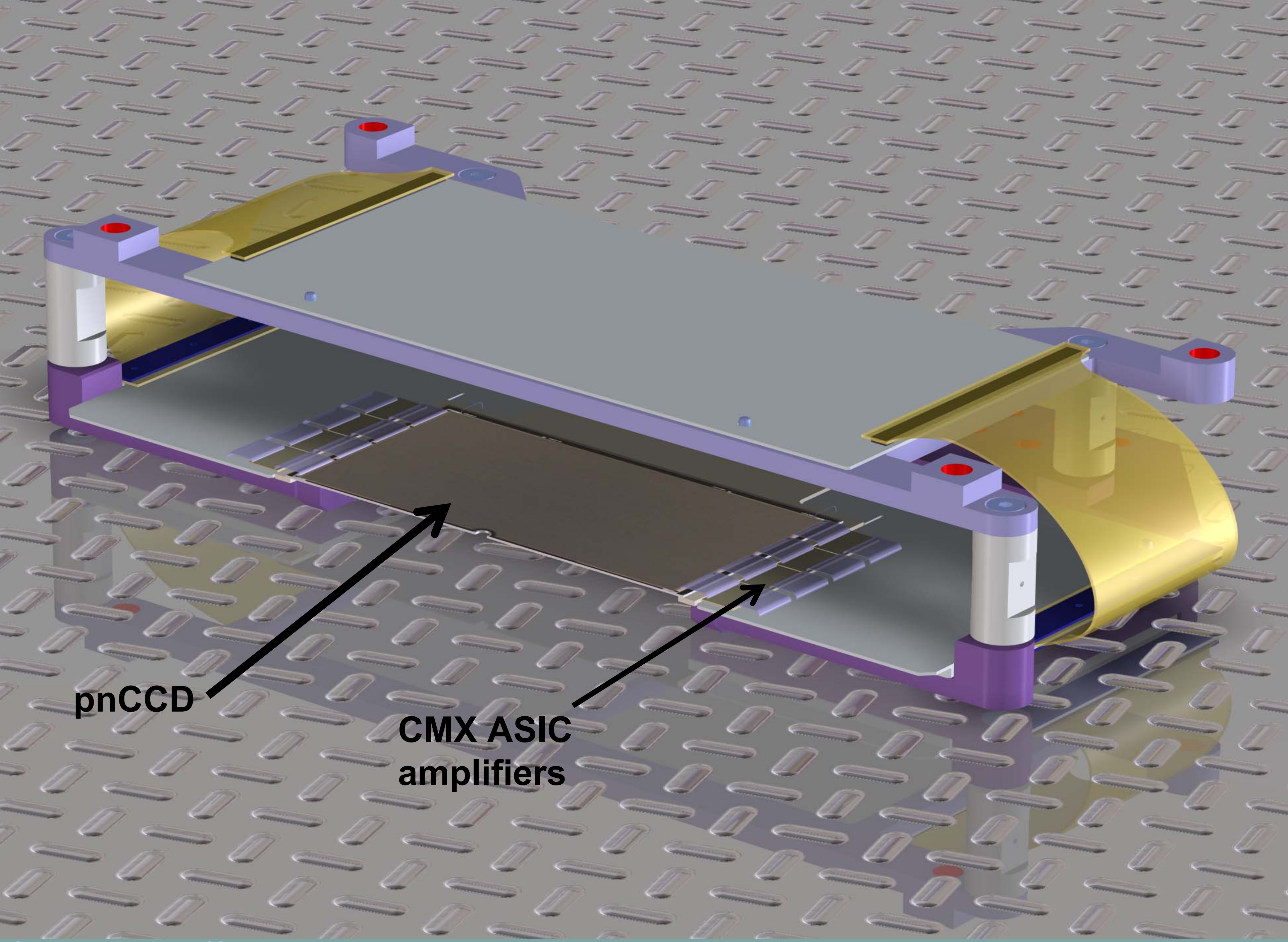
pnCCD: 1024 x 512, 30 cm²

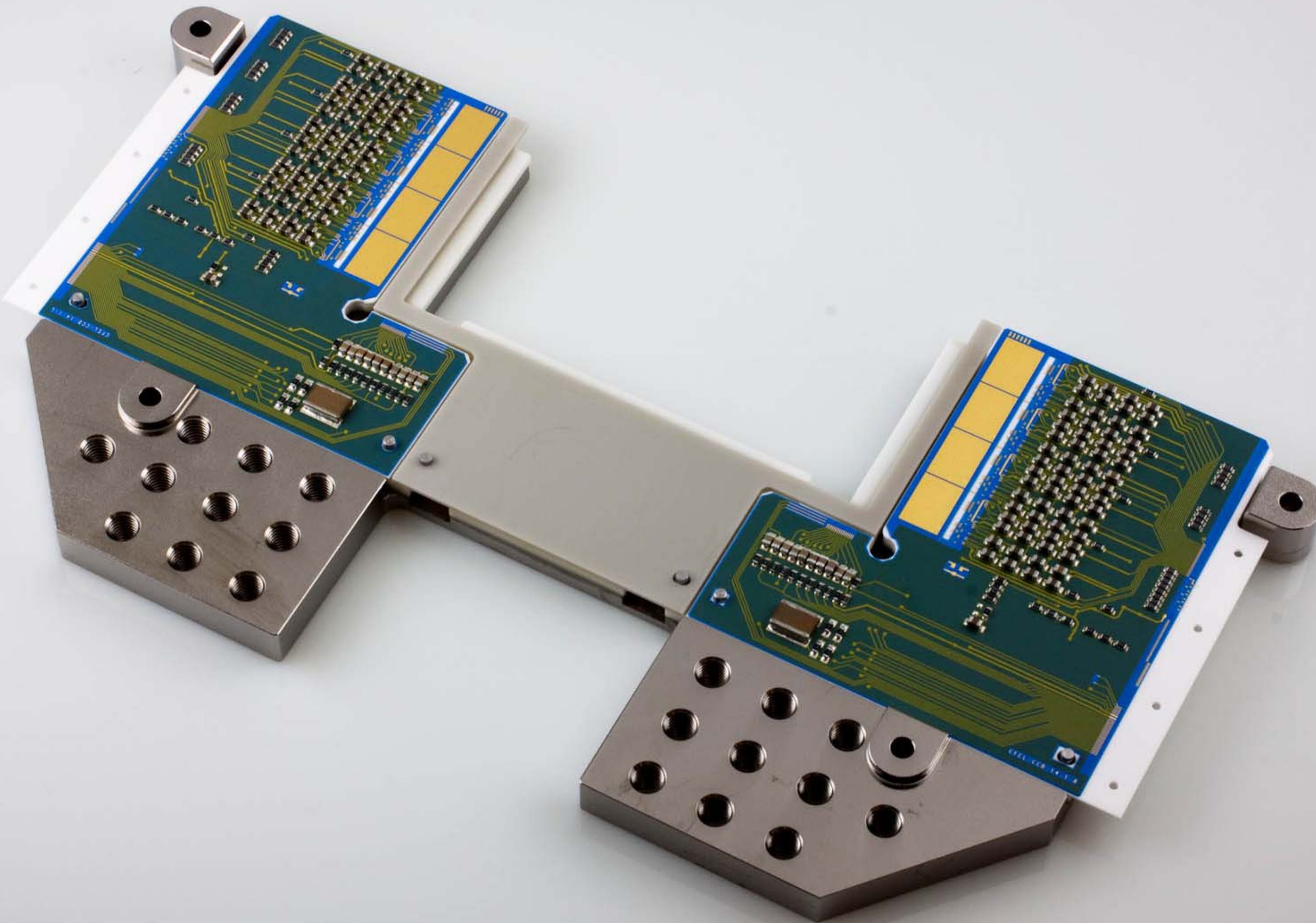
MPI Halbleiterlabor

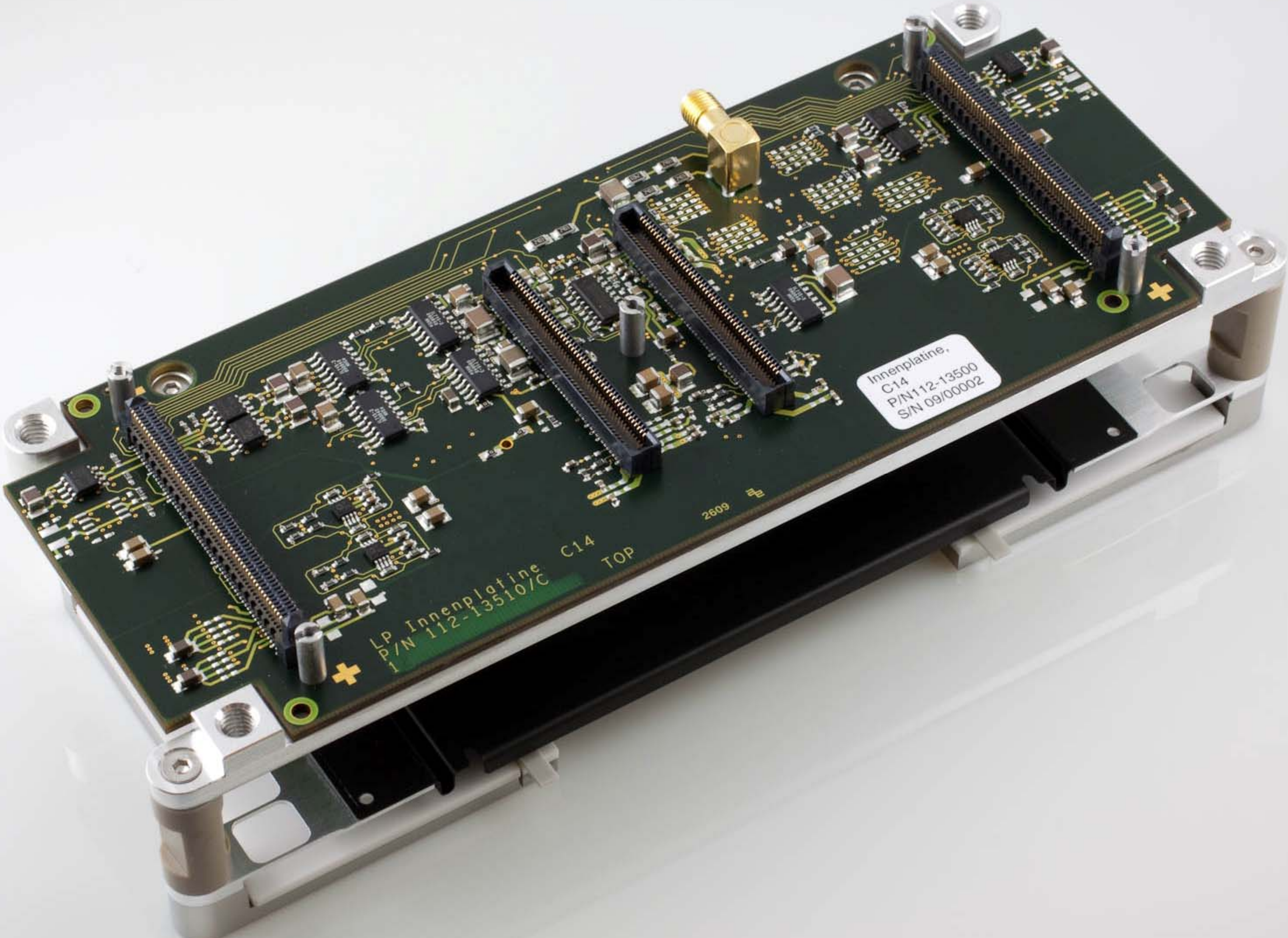


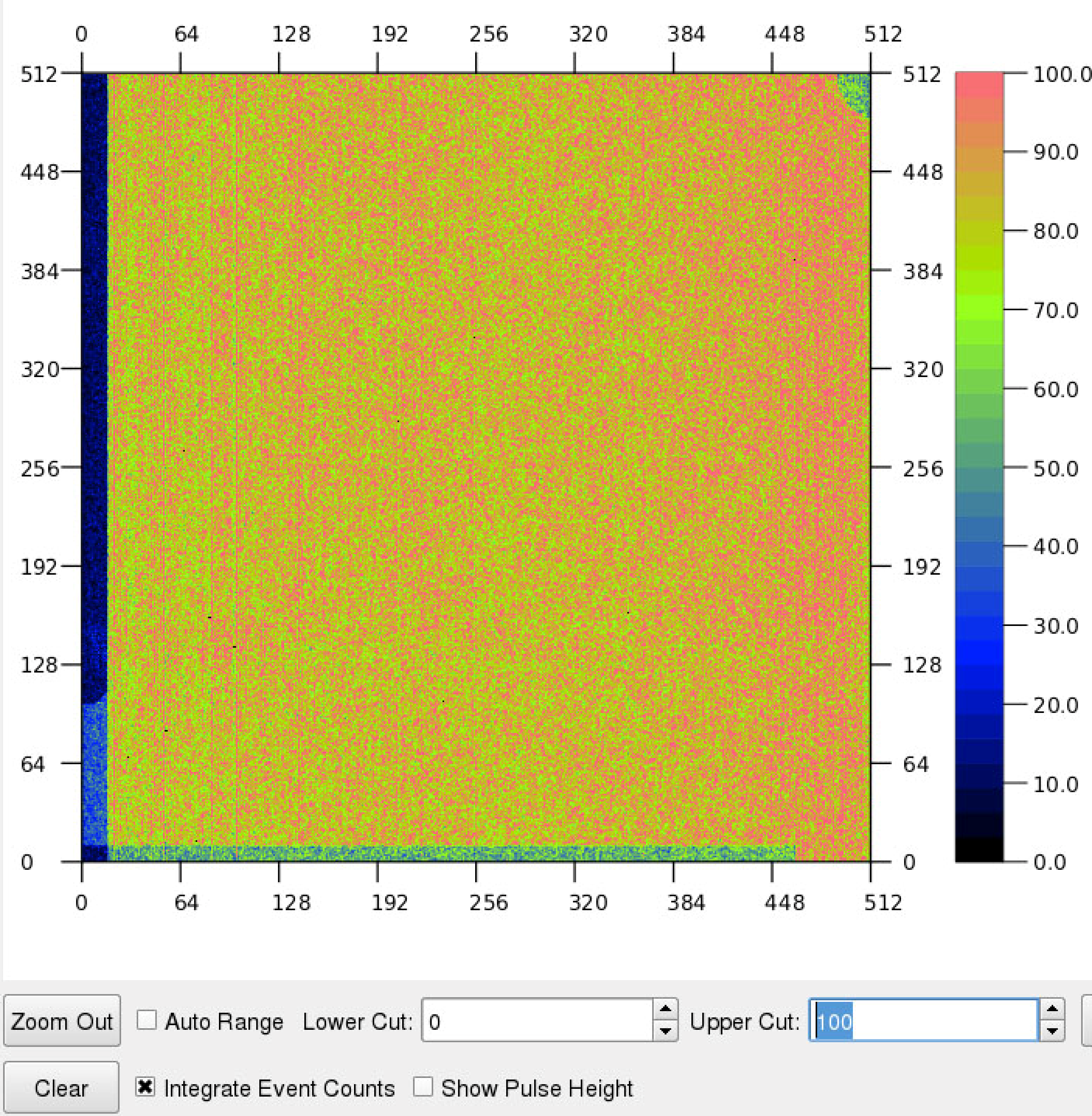
for 6 keV X-rays the system delivers 4k x 4k resolution points in all the area with less than one photon per pixel (typ. 90 %)


pnCCDs overlapping in the center
800 μm insensitive gap
Electrical components
al components
Center
hole
CCD2
CCD1
Electrical components
Electrical components
Ceramic board
Mechanical - thermal structure


pnCCD
CMX ASIC
amplifiers




Innenplatine,
C14
P/N112-13500
S/N 09/00002
LP Innenplatine
P/N 112-13510/C
C14
TOP
2609



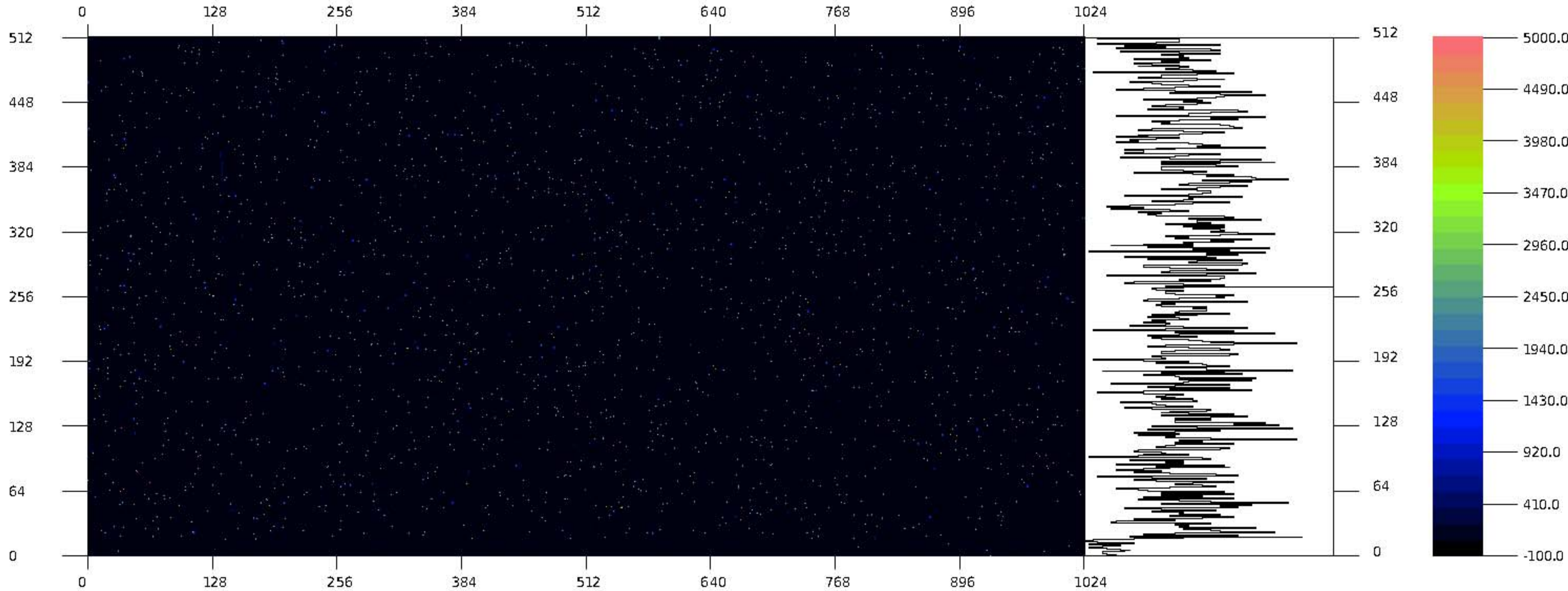
4 "halves" (1024x1024) were sucessfully tested

operation in the coherence experiments starts on August – 5, 7 am (CET)

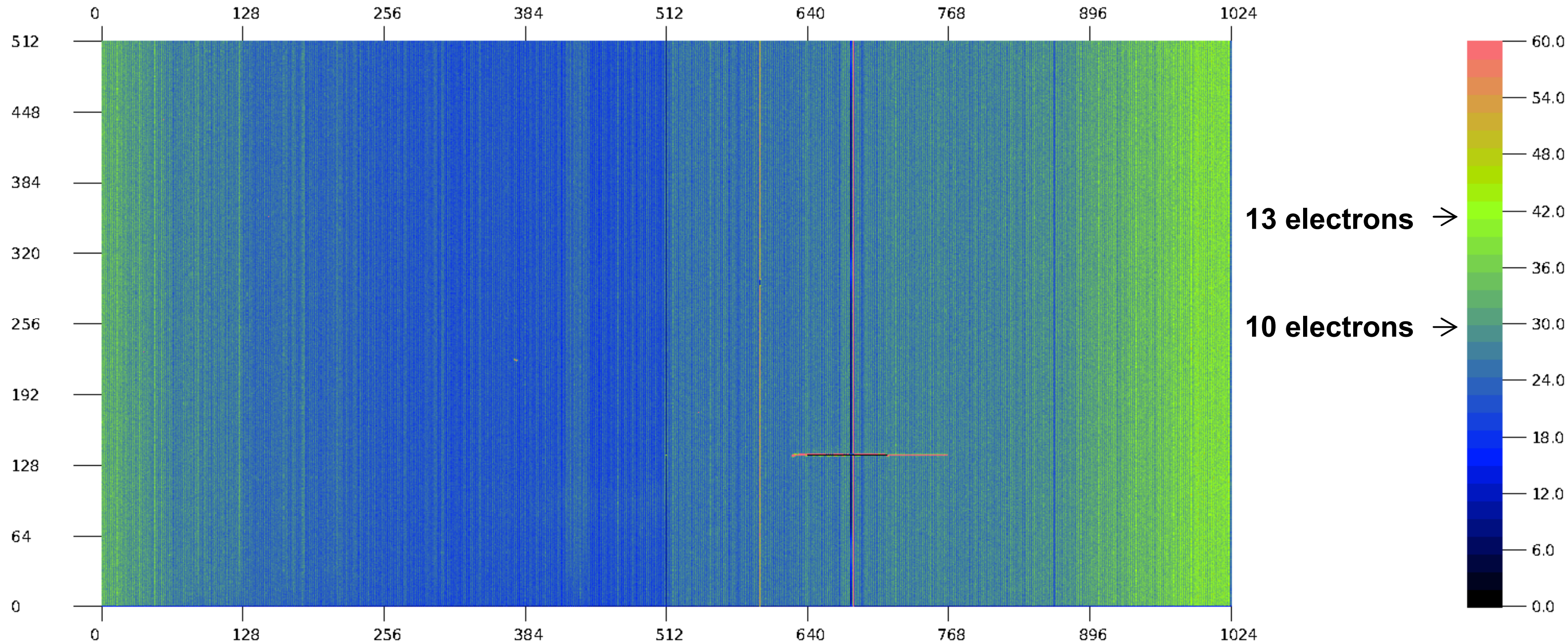
noise floor at – 40 ° C
ENC = 6 el. (rms)

QE @ 2 keV = 98 %

Frame rate: up to 150 Hz


0
128
256
384
512
640
768
896
1024
512
448
384
320
256
192
128
64
0
5000.0
4490.0
3980.0
3470.0
2960.0
2450.0
1940.0
1430.0
920.0
410.0
-100.0

CAMP pnCCD module performance
(typical module)

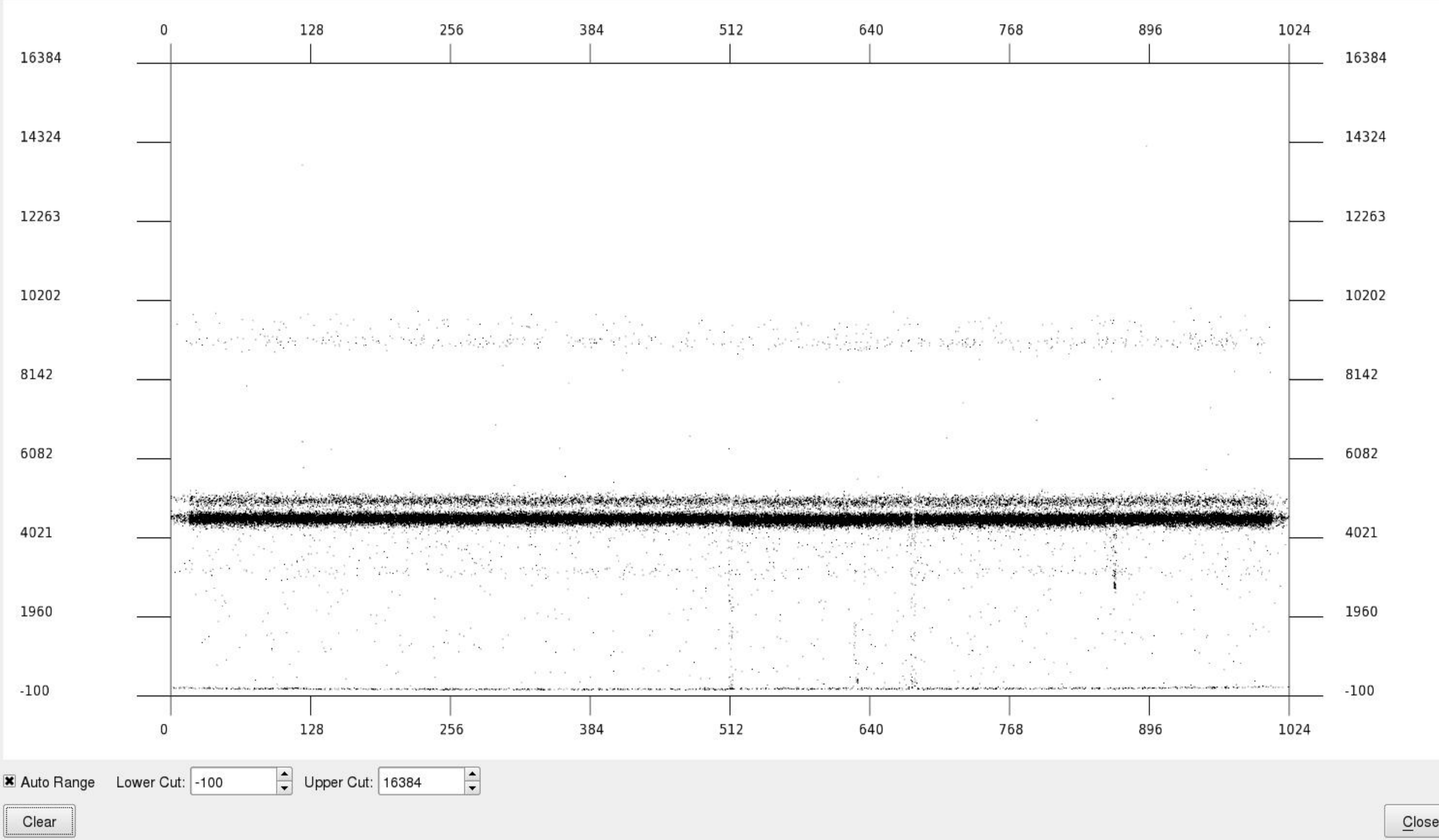


→ **588 noisy or bad pixel out of 524.288 pixel**

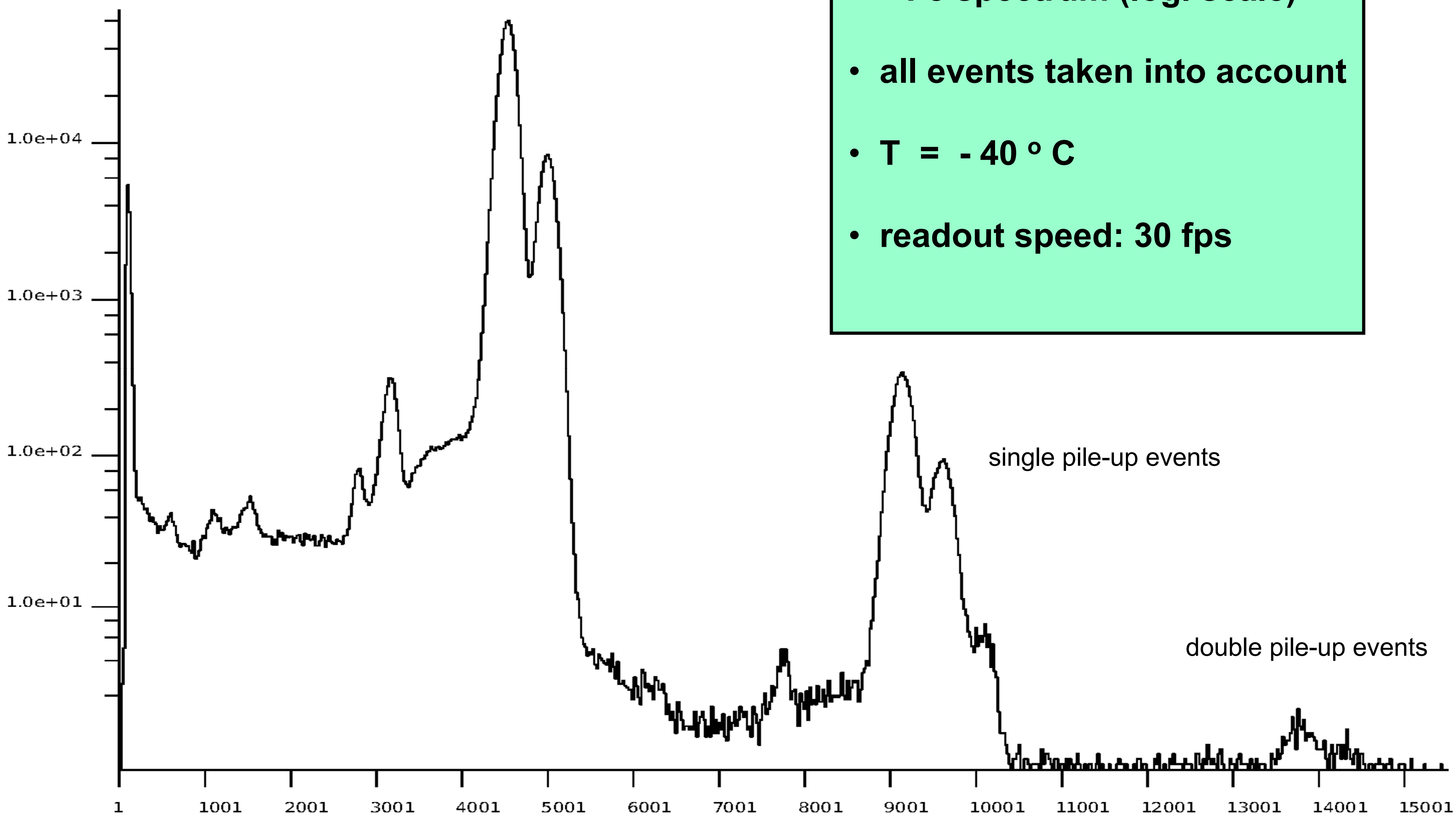
→ **average noise is 9 electrons (rms) at – 40 ° C**

→ **min. X-ray energy: 850 eV, i.e. 240 electrons. S/N = 27/1**

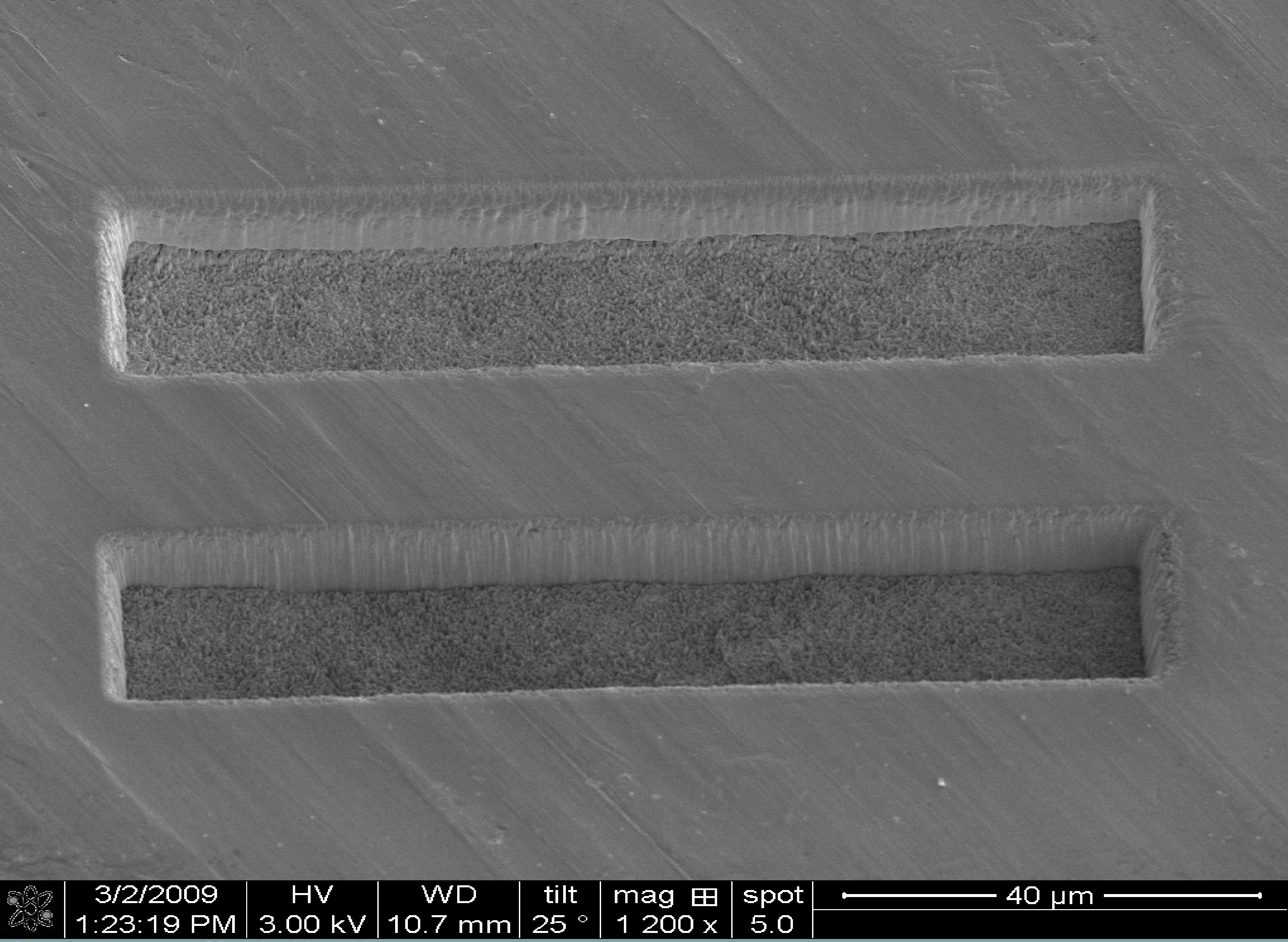
CAMP pnCCD module performance
(typical module)



CAMP pnCCD module performance
(typical module)



- ^{55}Fe spectrum (log. scale)
- all events taken into account
- T = - 40 ° C
- readout speed: 30 fps


3/2/2009
1:23:19 PM
HV
3.00 kV
WD
10.7 mm
tilt
25 °
mag
1 200 x
spot
5.0
40 µm

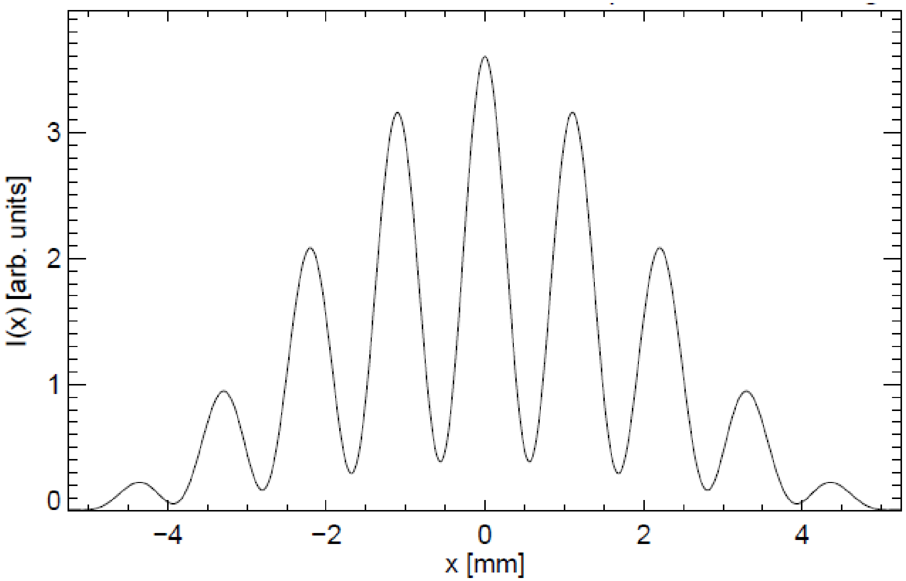
GEANT4 simulations

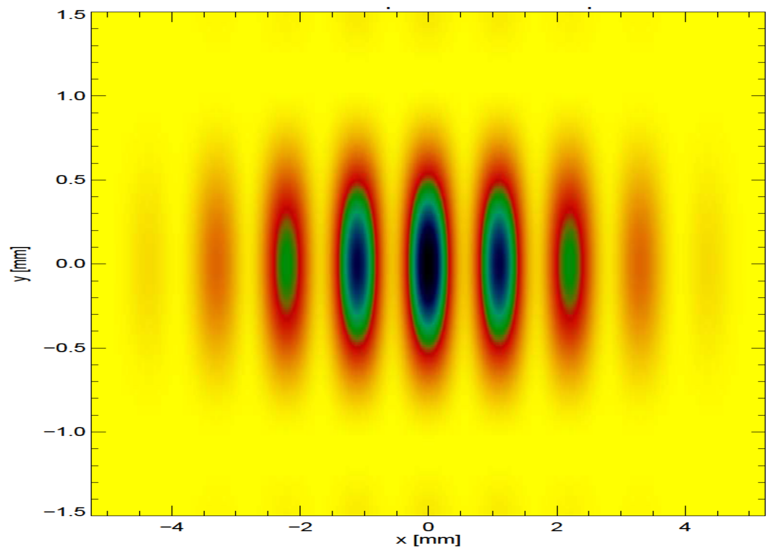
Upcoming FLASH Experiments: Double Slit Beam Geometries

Implemented according to Singer et al., 2008:

$$I(P) = I_1(P) + I_2(P) + 2\sqrt{I_1(P)I_2(P)}|\gamma_{12}(\tau)| \times \cos[\omega\tau - \alpha_{12}(\tau)],$$

Slit size 10 µm × 50 µm, d = 8 m, γ = 0.8, λ = 7 nm



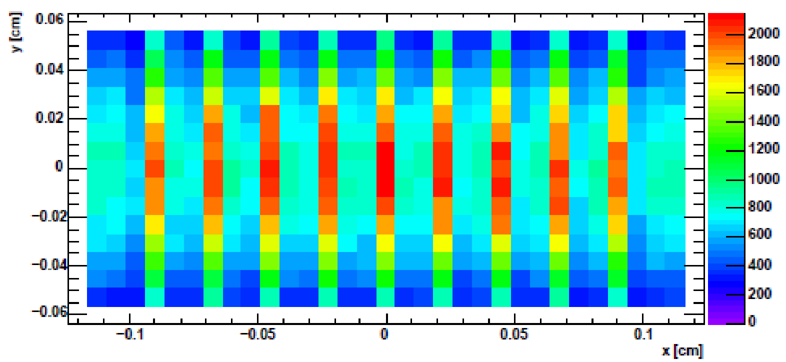


Slit distance 50 µm

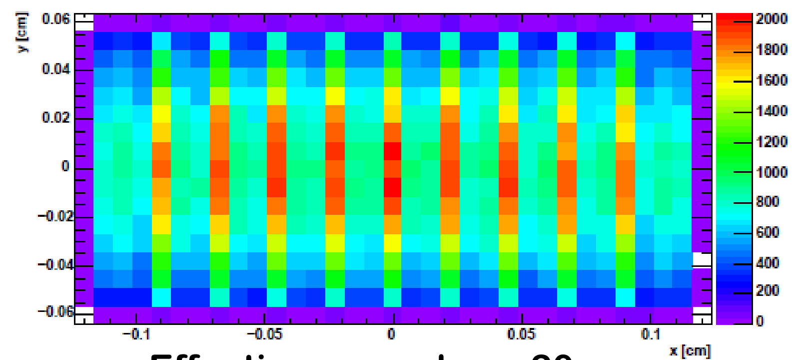
Upcoming FLASH Experiments:
Pixel Distribution of Measured Photons

Spread of signal electrons depends on:

- initial electron number and density
- number of electrons collected per pixel
  (overflow if charge handling capacity exceeded)



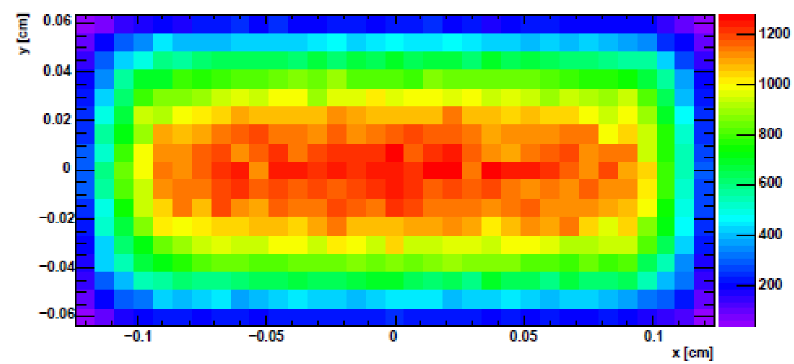
No spread, ideal detector



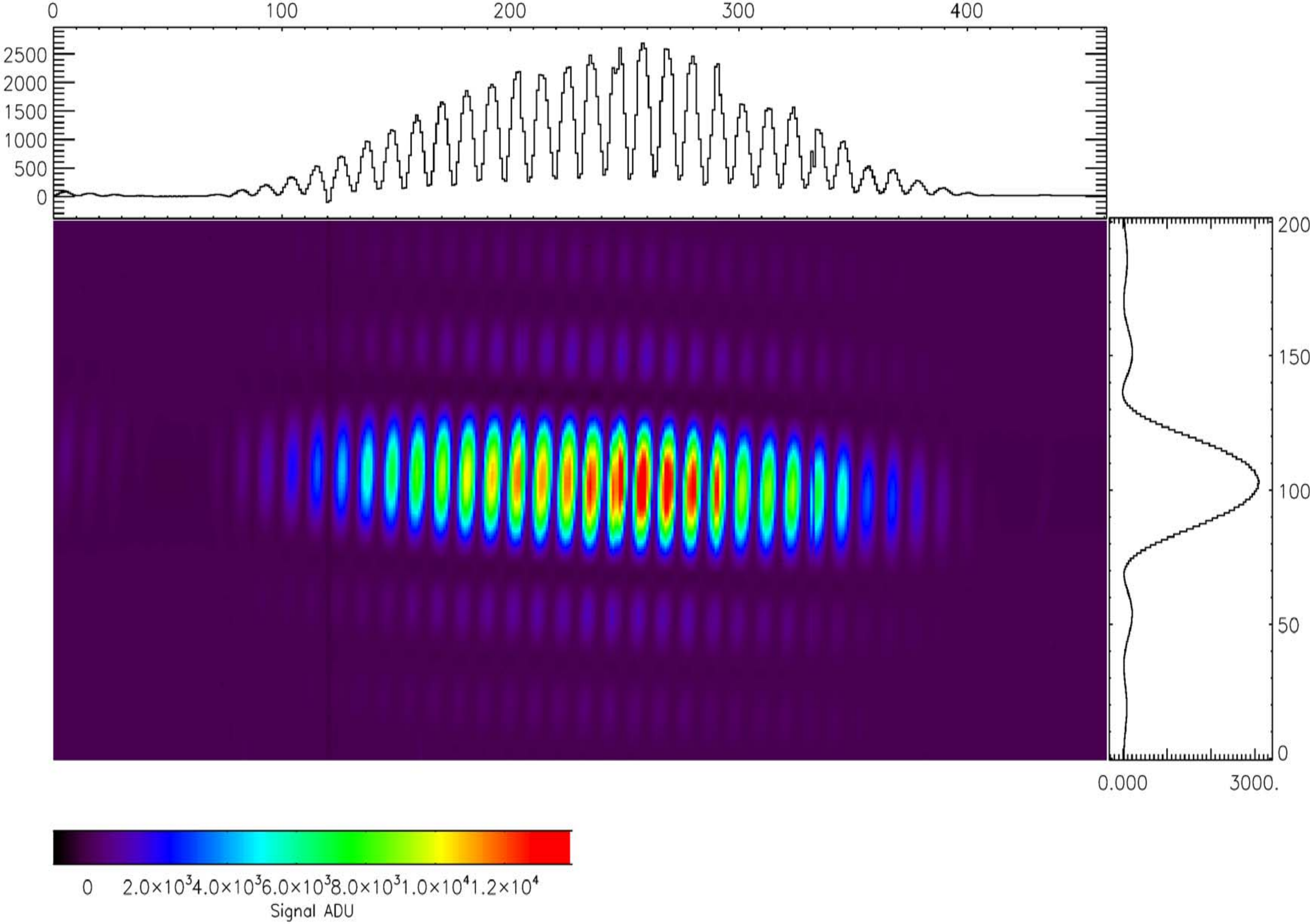
Effective spread: σ = 20 µm

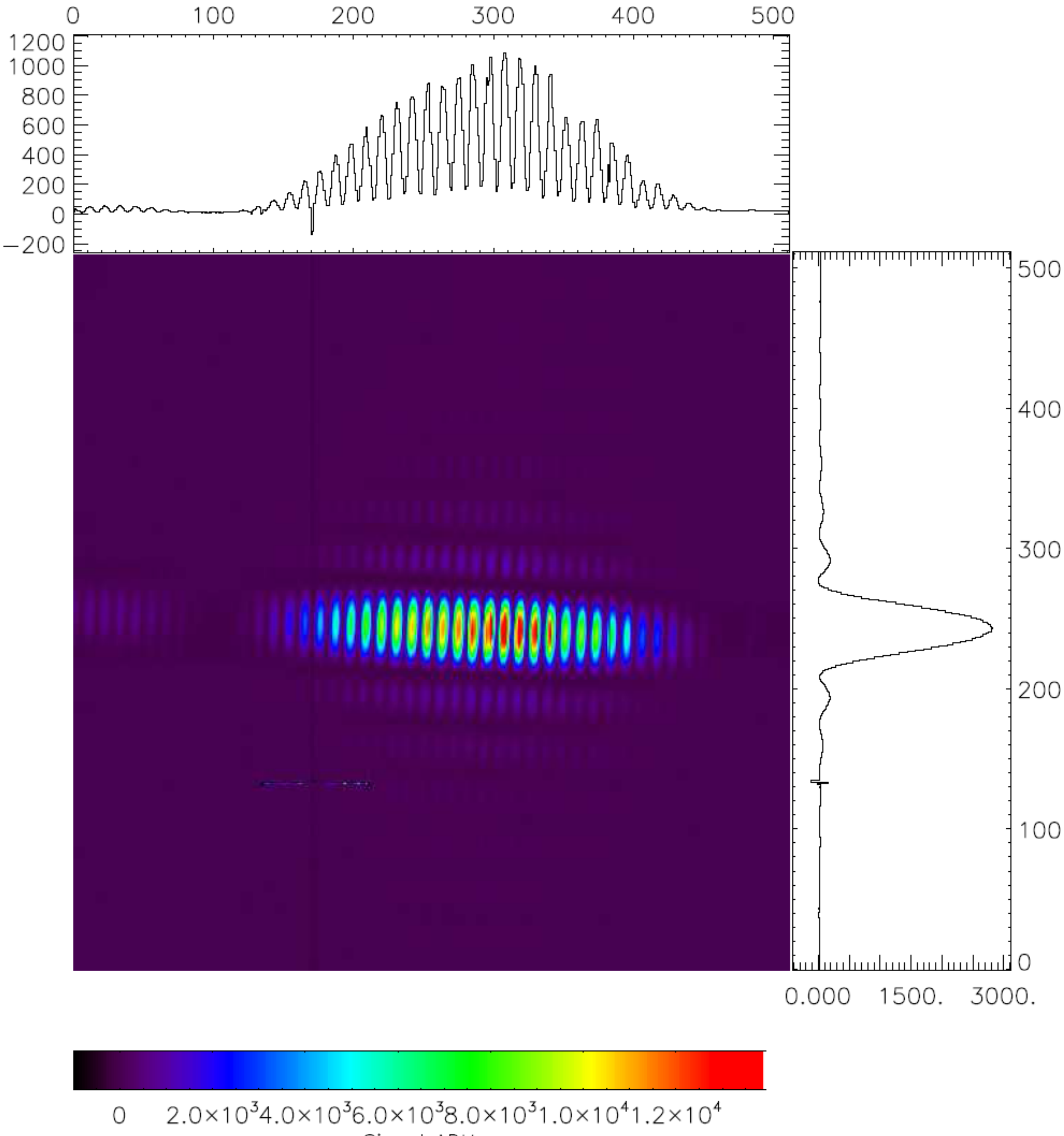
Slit size 10 µm × 50 µm,
d = 8 m, γ = 0.8, λ = 7 nm

Pattern for 10^{12} photon pulse, unfocused beam



Effective spread: σ = 100 µm (“overflow”)


0
100
200
300
400
2500
2000
1500
1000
500
0
200
150
100
50
0
0.000
3000.
0
2.0×10³4.0×10³6.0×10³8.0×10³1.0×10⁴1.2×10⁴
Signal ADU



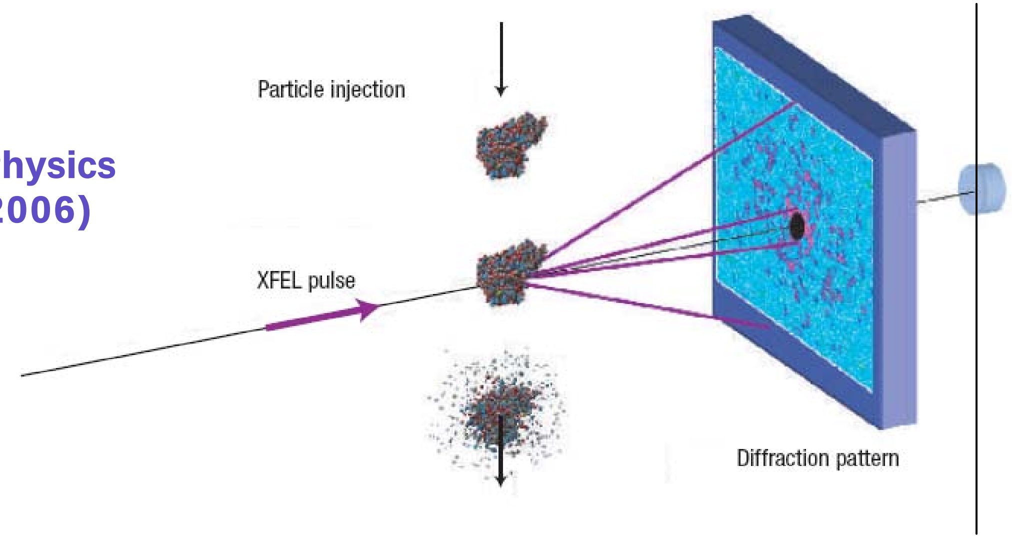
beam energy: 90 eV

double slit: 10 x 50 μm^2

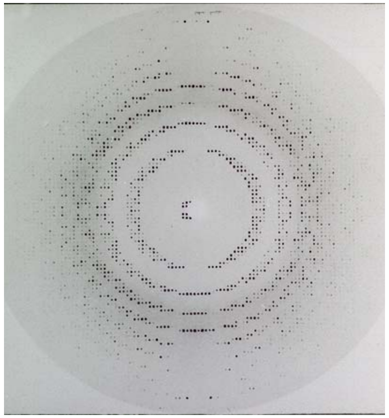
Time resolved structure determination with X-ray FELs

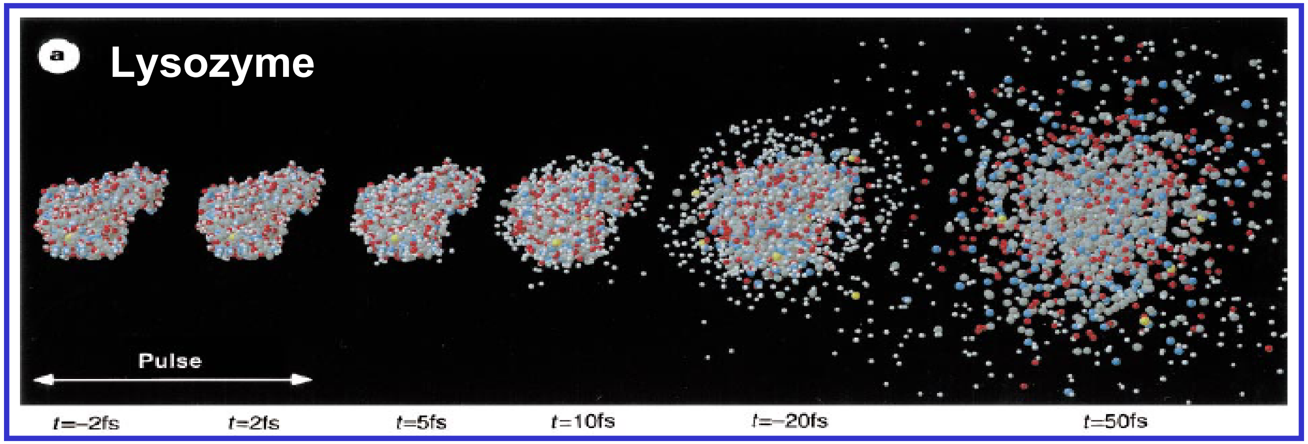
Molecules atomic resolution

J. Kirz, Nature Physics 2, 799 (2006)



Crystal

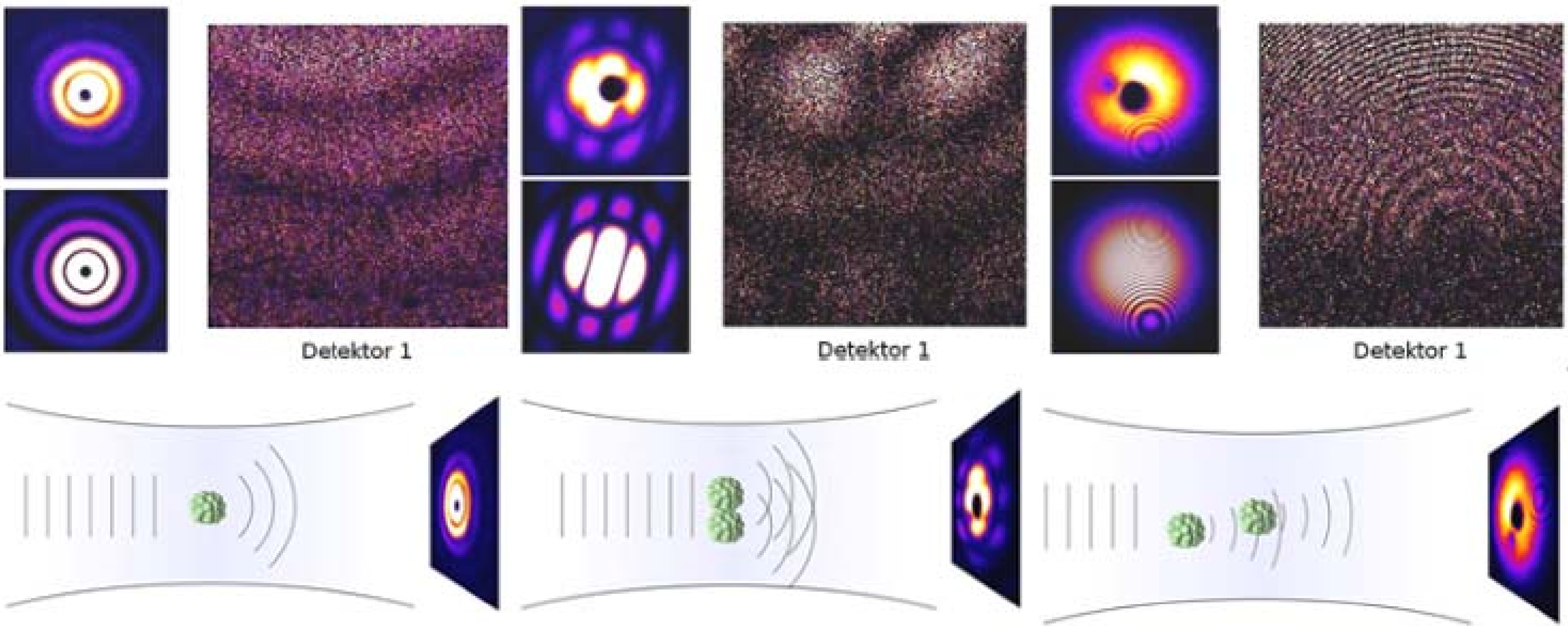




R. Neutze, J. Haidu et al., Nature 406, 752 (2000)

Radiation damage and Coulomb explosion

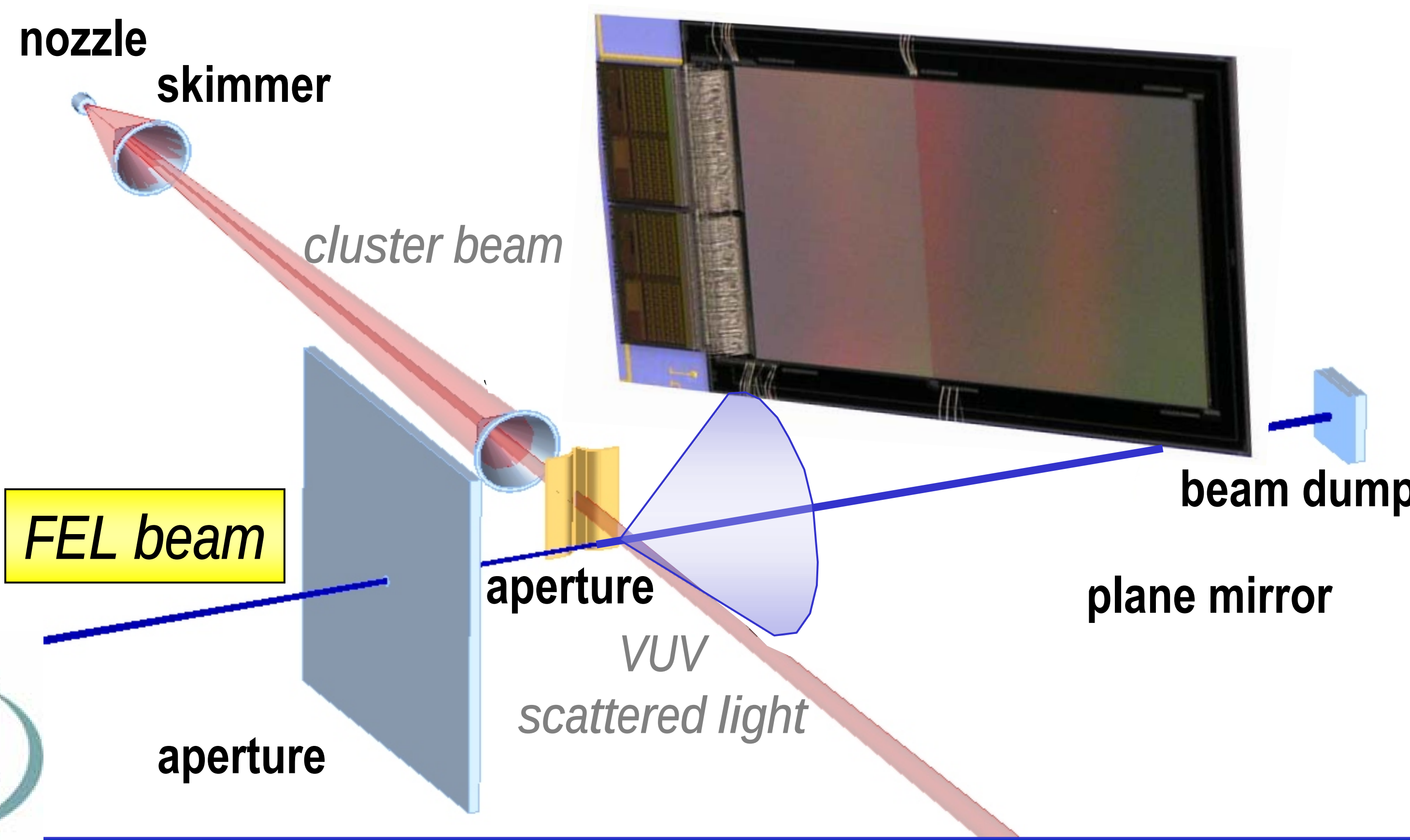
X-ray scattering: 30 nm Xe - Cluster

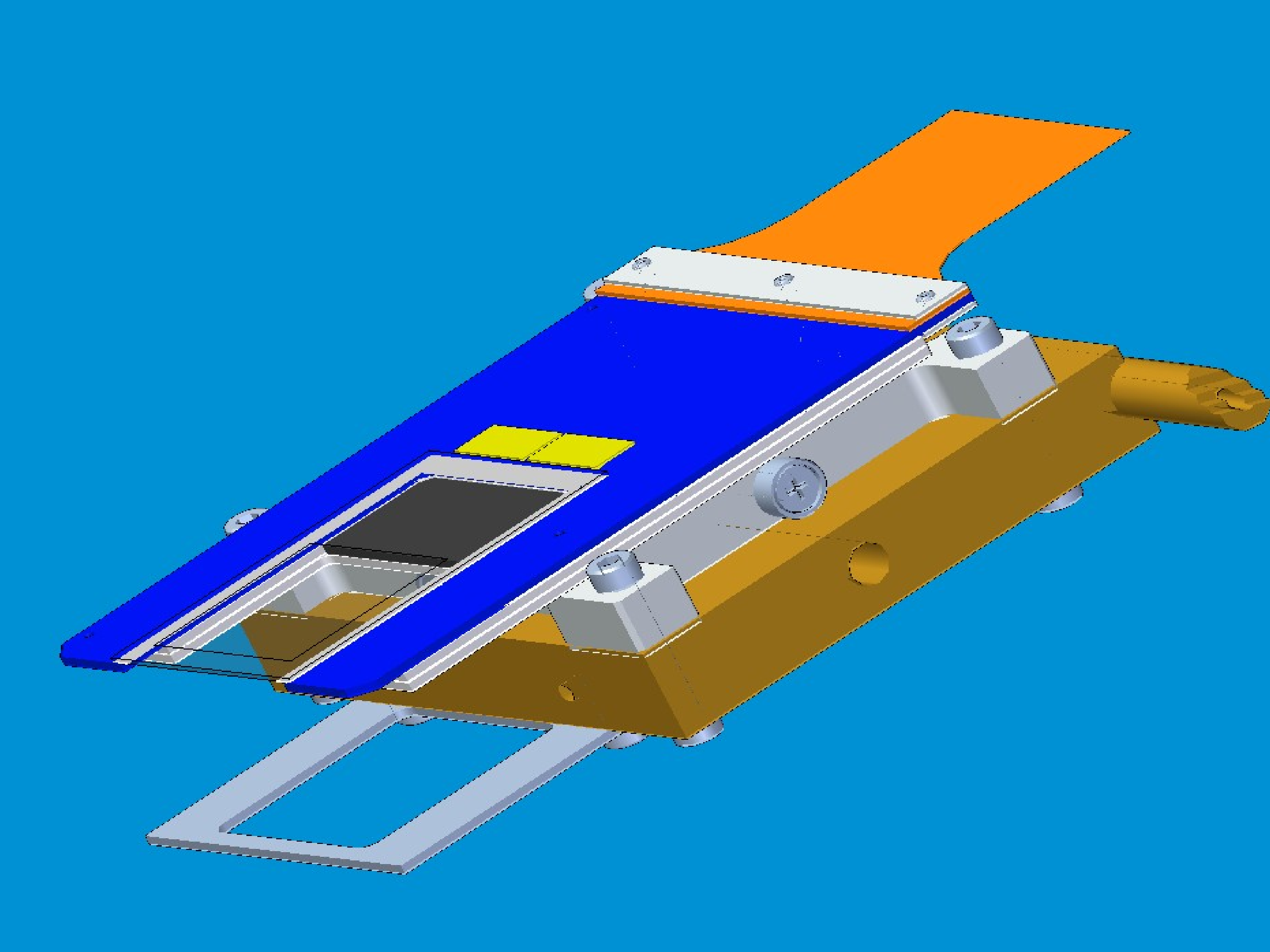


Clusters “in the Flight”

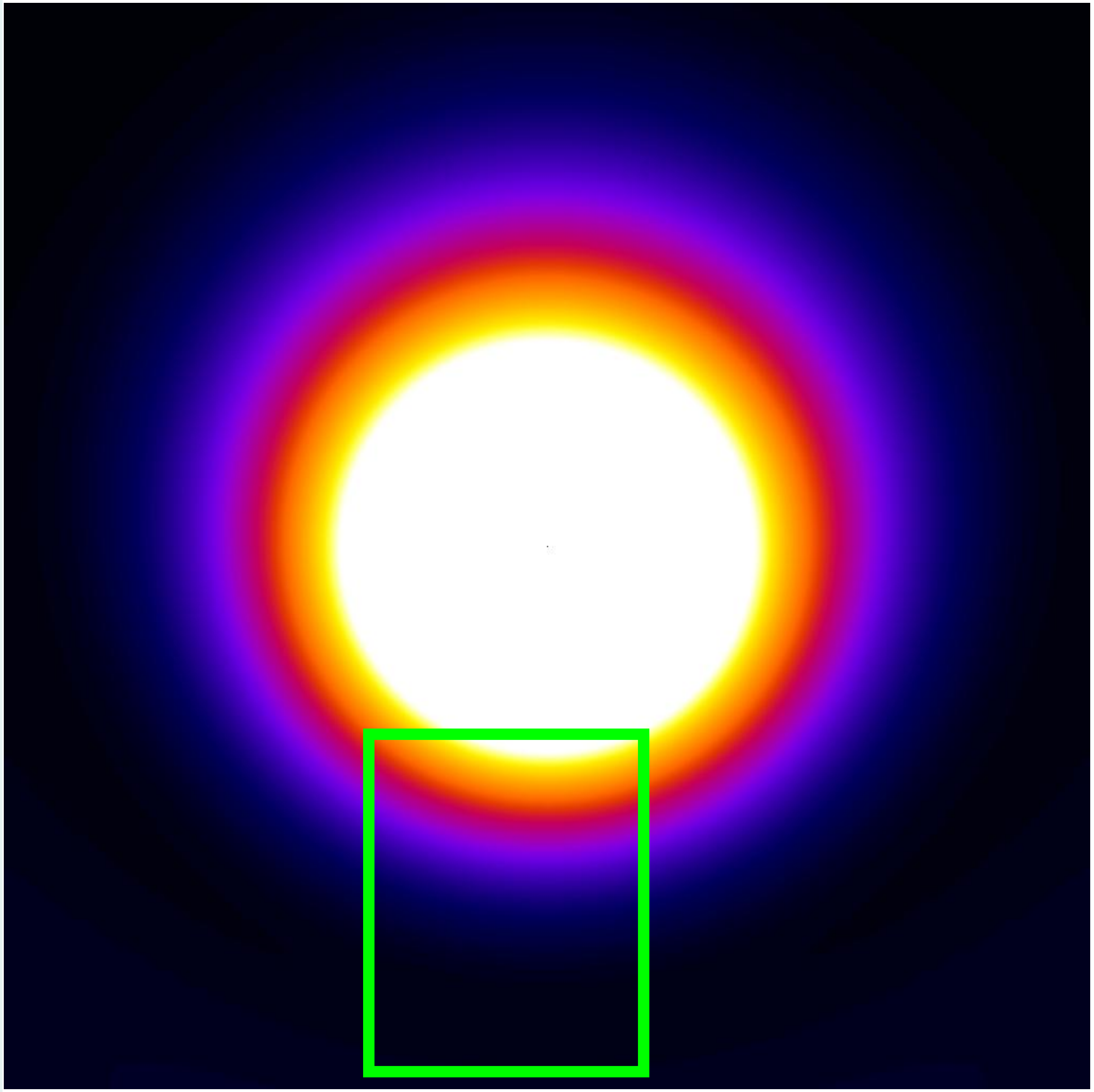
Xe clusters

CFEL Detectors





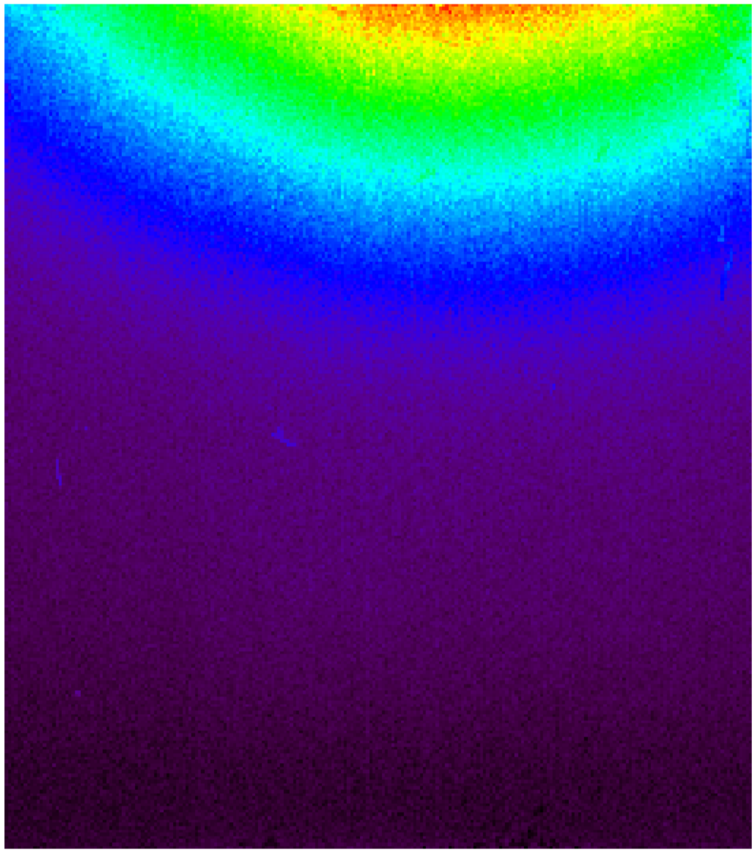
First observation of 32 nm Xe – nanocluster in direct detection mode



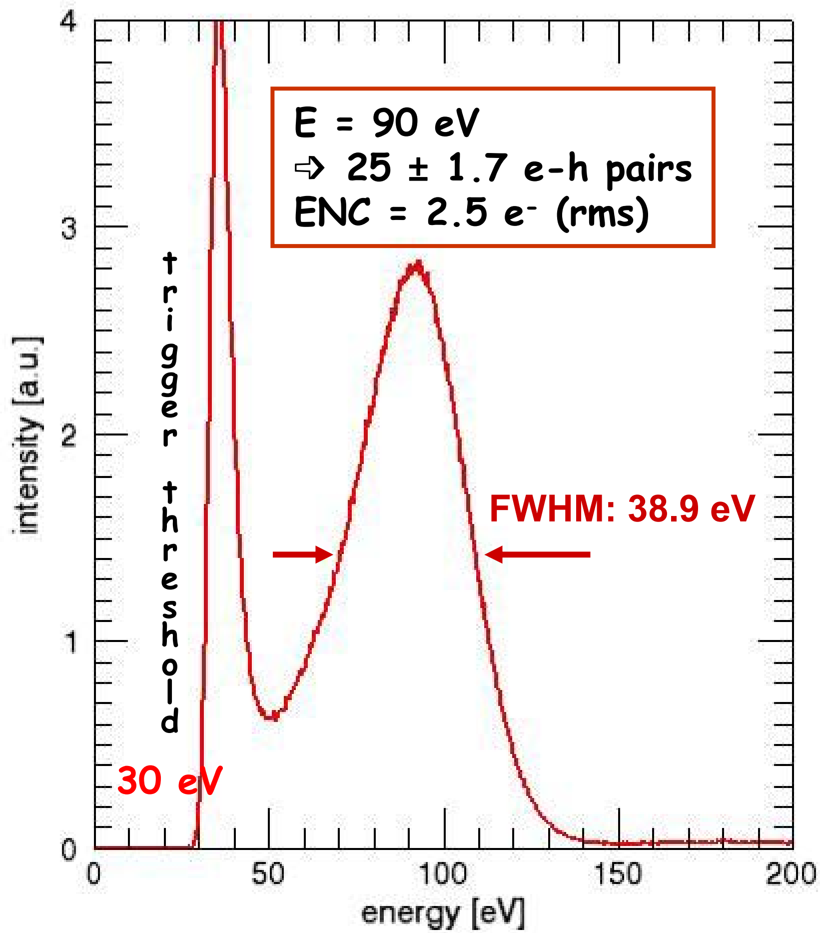
simulation of 90 eV X-rays scattering at single Xe nanoclusters with 32 nm size (C. Bostedt et al.)

field of view of the pnCCD during the experiment at the FLASH X-ray free electron laser facility at DESY, Hamburg

90 eV X-rays in single photon counting mode !!!

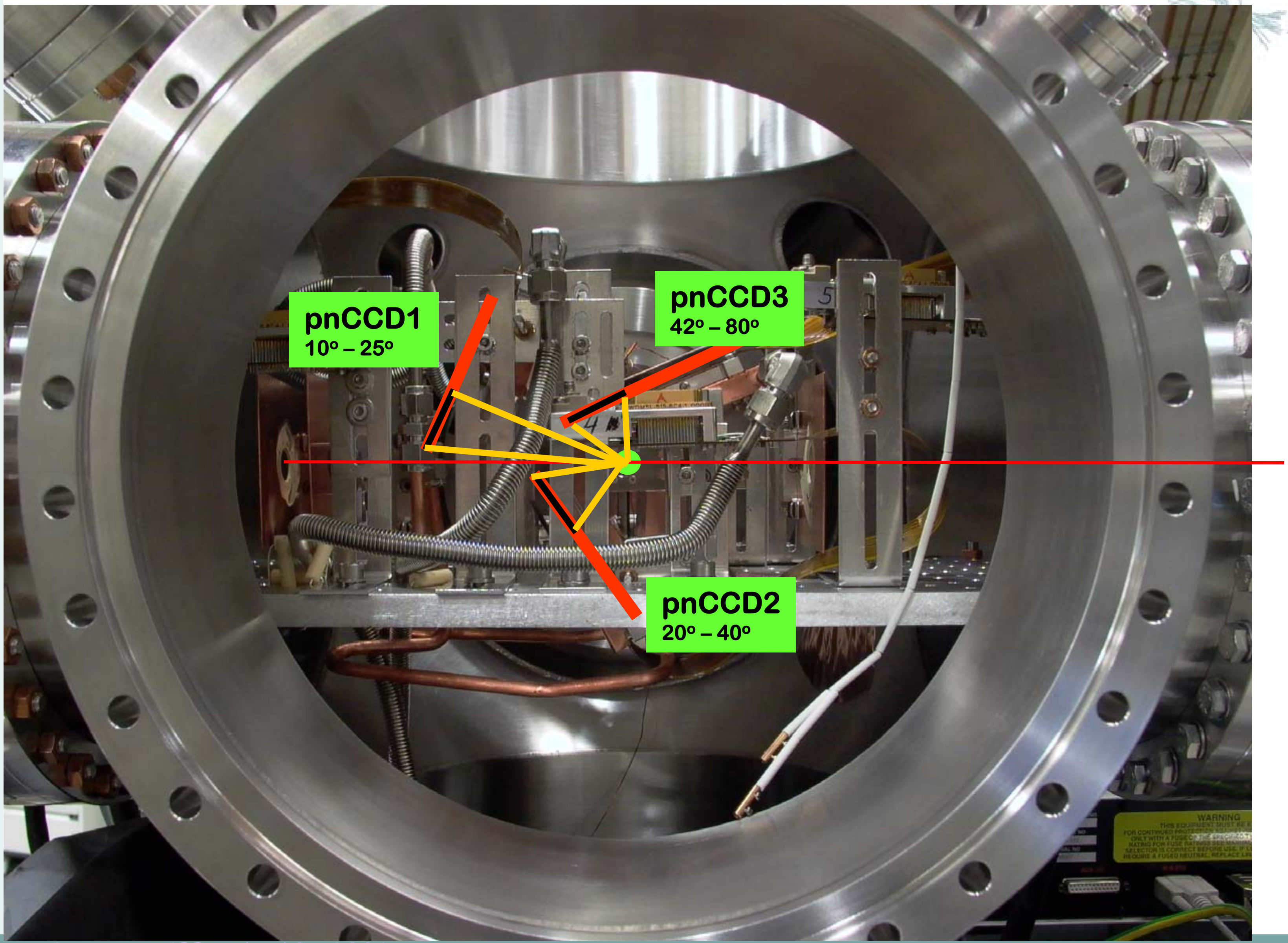


T = -50° C

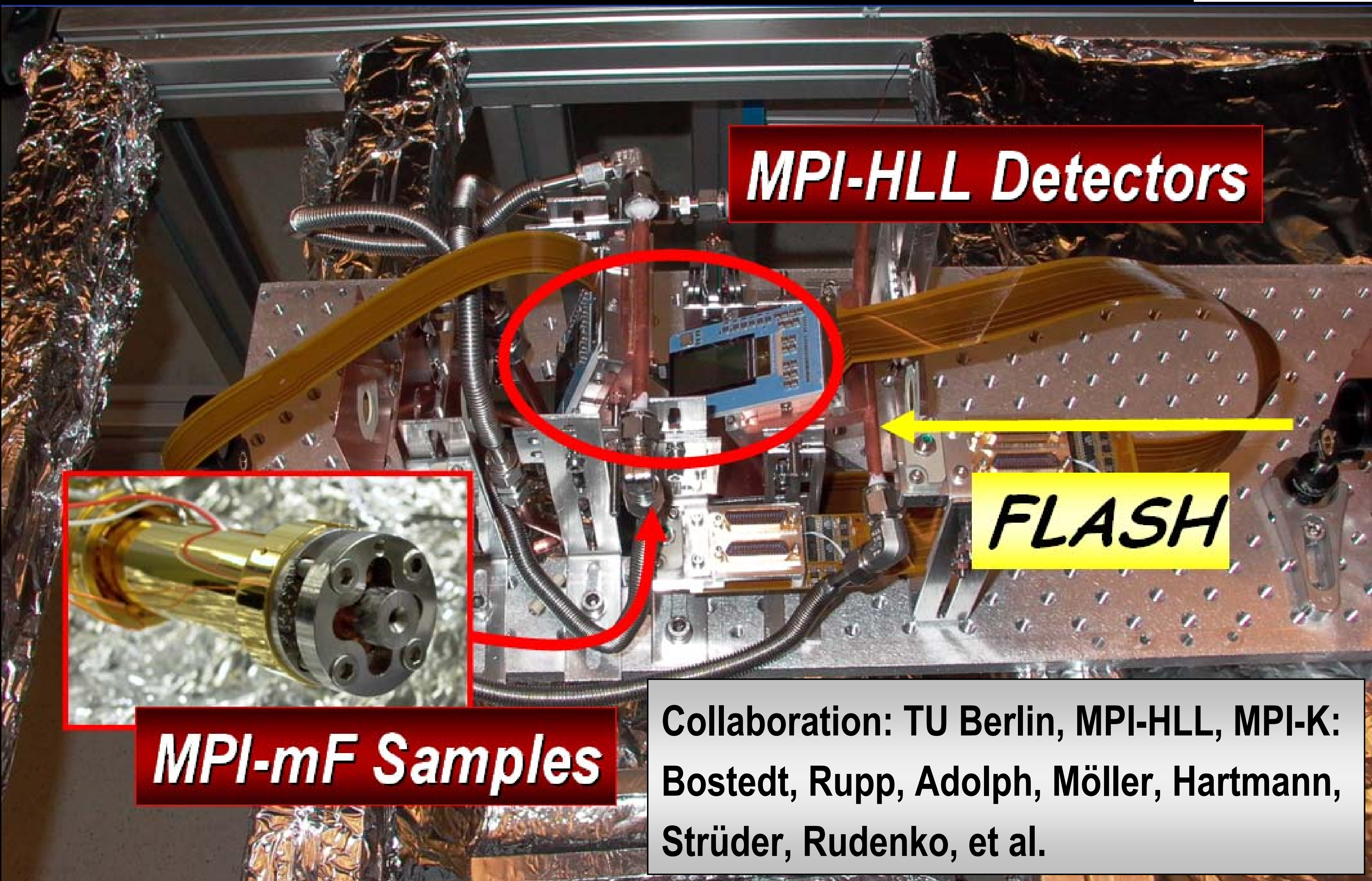


Spectrum from 4.000 frames with 0.01 photons/pixel/frame

Set-up in T.M. Beamline @ FLASH

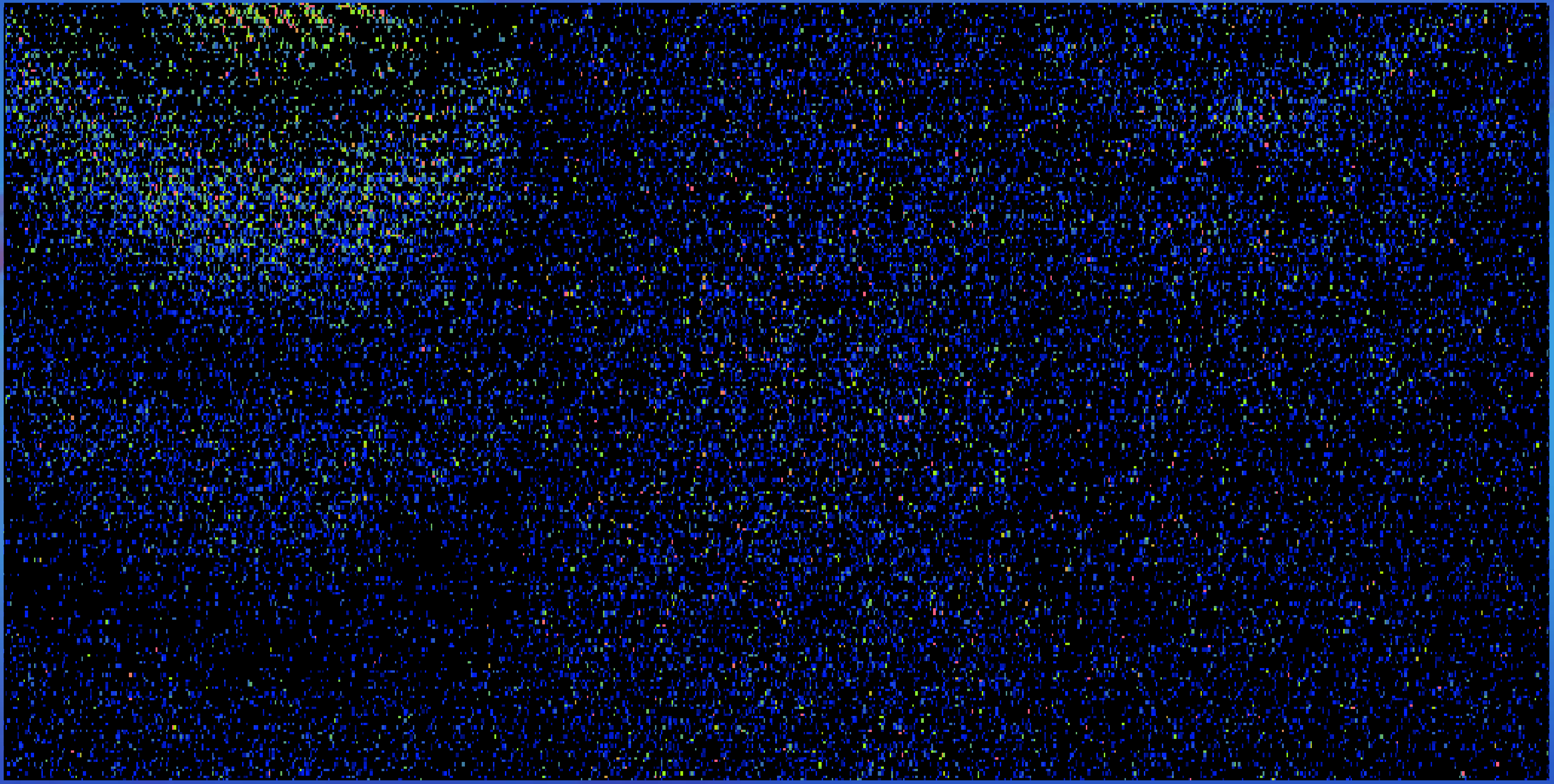


Clusters “in the Flight”



Collaboration: TU Berlin, MPI-HLL, MPI-K:
Bostedt, Rupp, Adolph, Möller, Hartmann,
Strüder, Rudenko, et al.

Free Electron Lasers



Screen-Shots: To be evaluated!

typ. 5.000 X-rays
per shot per detector,
i.e. ≈ 0.1 photon per pix.

Measurement @ FLASH
λ ≈ 40 nm
on Xe clusters

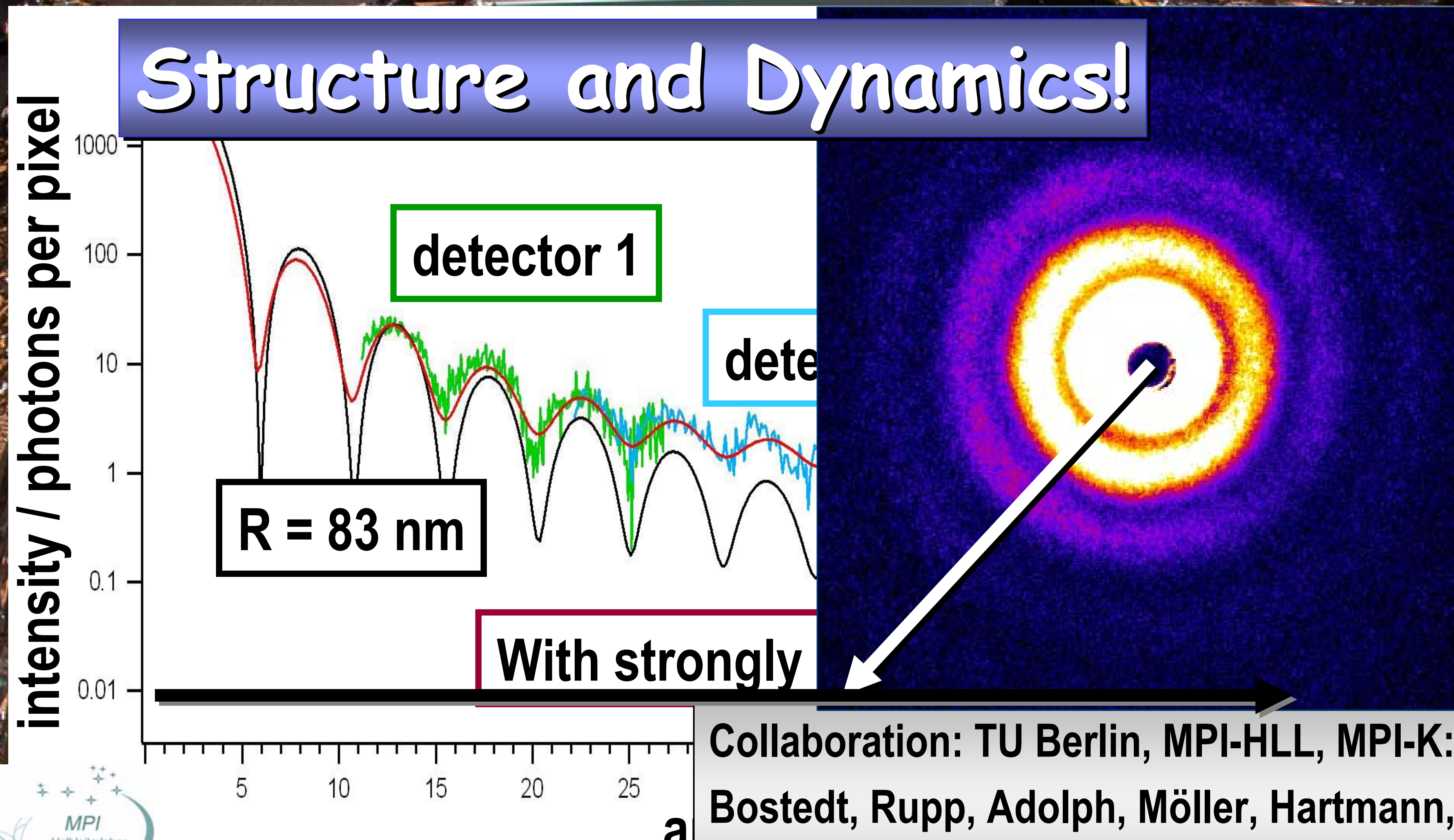
E = 30 eV

i.e. 8.1 e/h pairs

ENC = 2.7 el. (rms)

Clusters “in the Flight”

Structure and Dynamics!

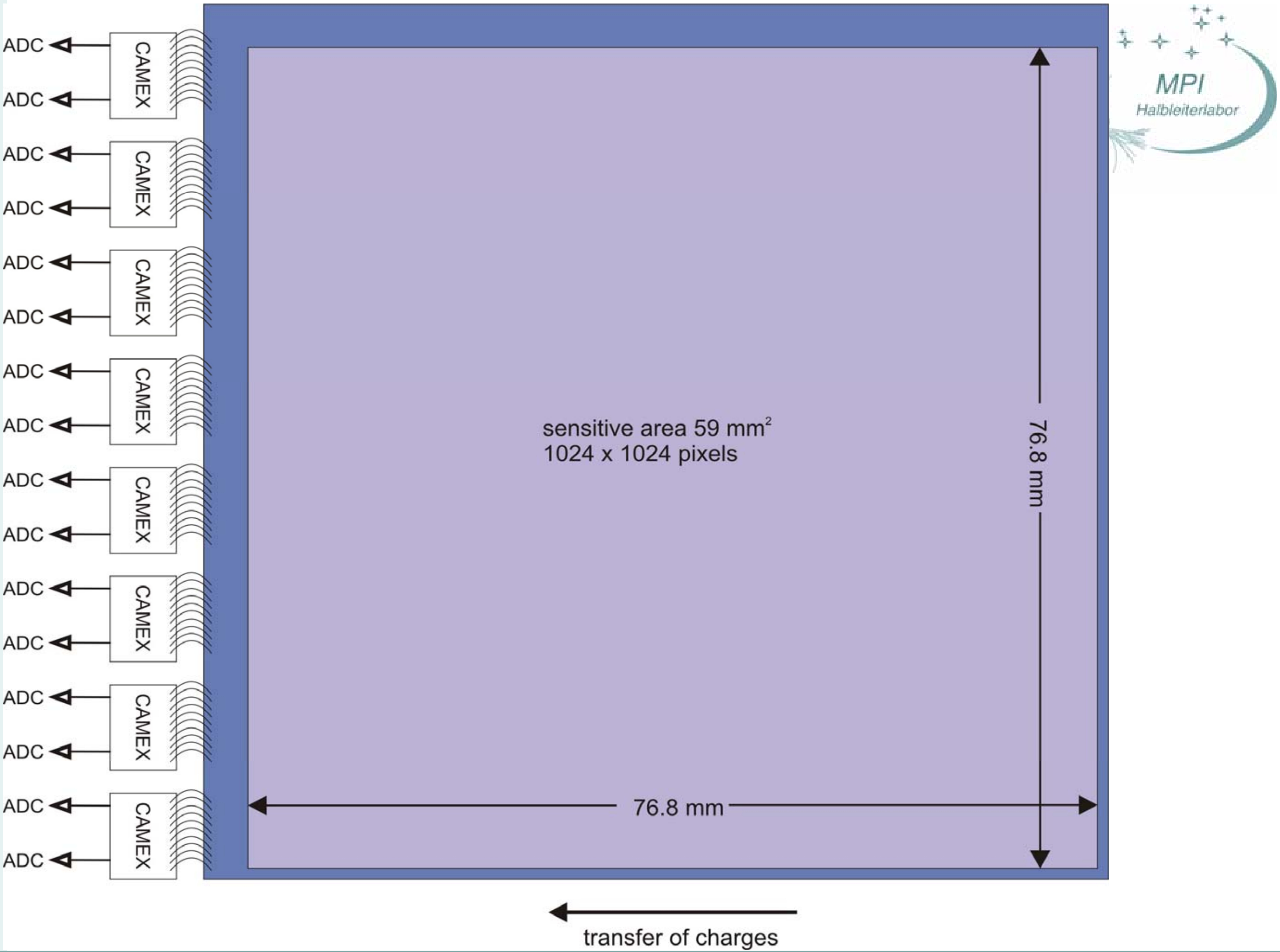


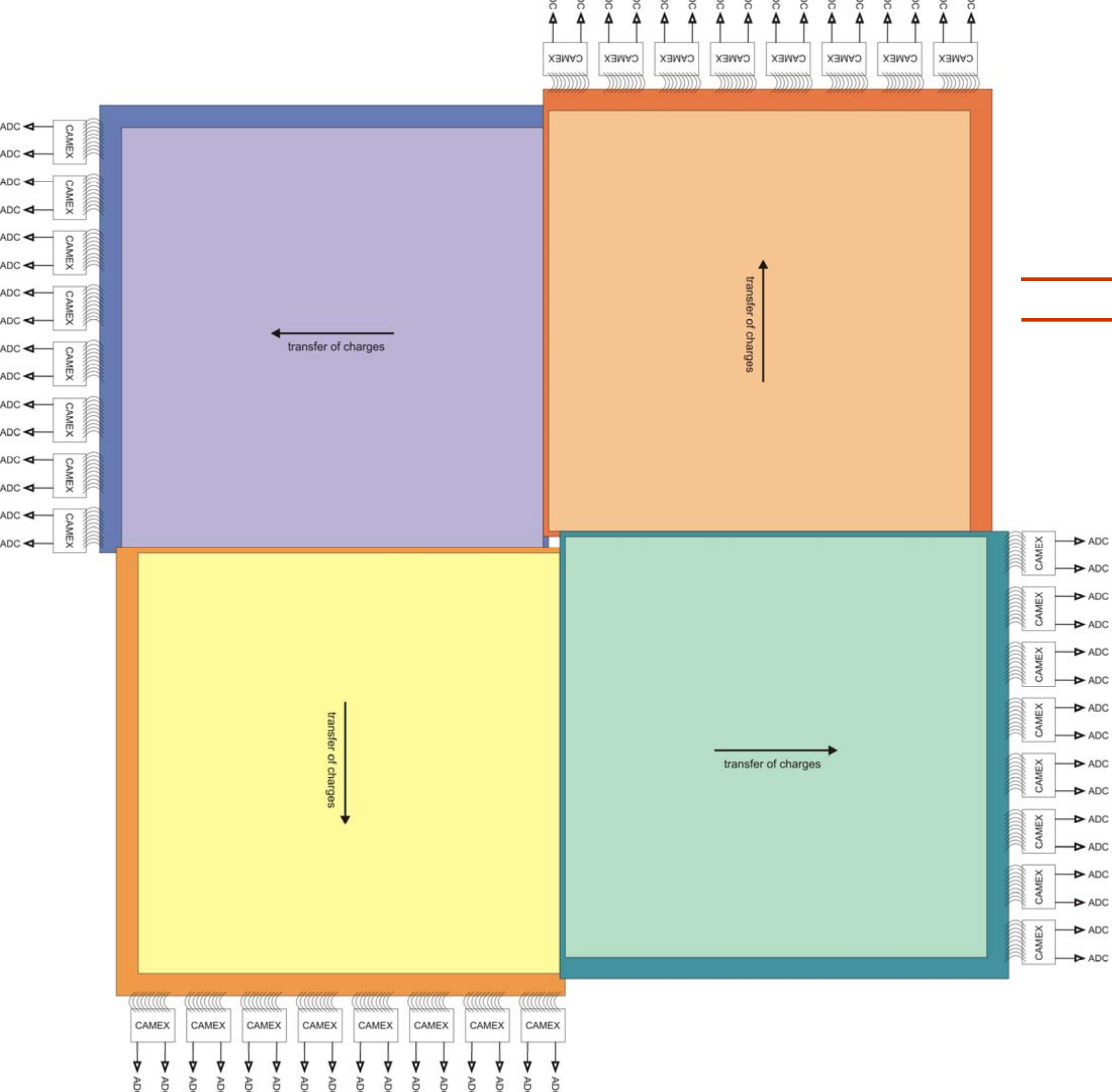
Collaboration: TU Berlin, MPI-HLL, MPI-K:
Bostedt, Rupp, Adolph, Möller, Hartmann, Strüder, Rudenko, et al.

Achievements of the FLASH, LCLS and XFEL

Photon Counting and Integrating X-ray Imaging Detectors

	FLASH, LCLS + XFEL	pnCCD system
single photon resolution	yes	yes
energy range	0.05 < E < 24 (keV)	0.05 < E < 25 [keV]
pixel size (μm)	100	75
sig.rate/pixel/bunch	10^3 (10^5)	10^3 - 10^4
quantum efficiency	> 0.8	> 0.8 from 0.6 to 12 keV
number of pixels	512 x 512 (min.)	1024 x 1024 and 2048 x 2048
frame rate/repetition rate	10 Hz - 120 Hz	up to 250 Hz
Readout noise	< 50 e^- (rms)	< 5 e^- (rms) (2 e^- possible)
cooling	possible	around - 40° C room temperature possible
vacuum compatibility	yes	yes
preprocessing	no (yes) ?	possible upon request


ADC
CAMEX
MPI
Halbleiterlabor
sensitive area 59 mm²
1024 x 1024 pixels
76.8 mm
76.8 mm
transfer of charges



Expected system properties

pixel size: 50 x 50 μm^2
or 75 x 75 μm^2
resolution: $\sigma_{x,y} \leq 10\ \mu m$
frame rate: 150 Hz
noise: 5 el. (rms)
CHC: 500.000 el.
PSF: typ. 3x3
EDpP: 20 MeV
thickness: 450 µm

DSSC - Expected Performance

Parameter	Expected DSSC performance
Energy range	0.5 … 25 keV (optimized for 0.5 … 4 keV)
Number of pixels	1024 x 1024
Sensor Pixel Shape	Hexagonal
Sensor Pixel pitch	~ 204 x 236 μm^2
Dynamic range / pixel / pulse	> 10.000 photons @1 keV
Resolution (S/N >5:1)	Single photon @ 1 keV (5 MHz) Single photon @ 0.5 keV (≤ 2.5 MHz)
Electronics noise	< 40 (25) electrons r.m.s.
Frame rate	1-5 MHz
Stored frames per Macro bunch	≥ 512
Operating temperature	-30˚C optimum, RT possible

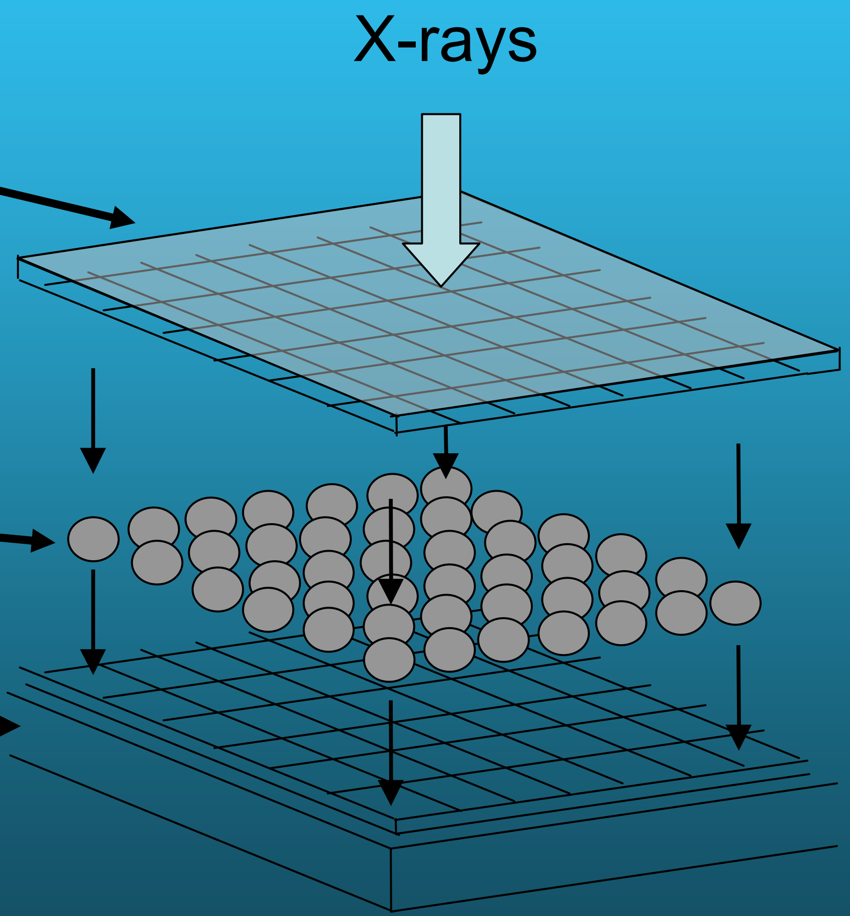
DePMOS Active Pixel Sensor

Connecting Bumps

- 1 per pixel

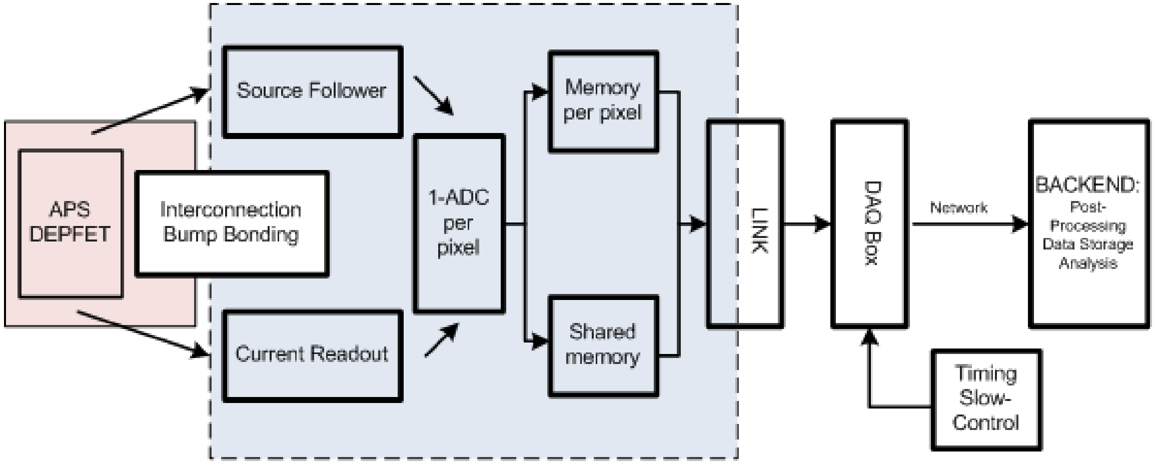
CMOS Layer

- Signal processing
- Signal storage & output



DSSC - Concept

- DEPFET Active Pixel Sensor
- Every DEPFET pixel provides detection and amplification with:
  - **Low noise**
  - **Signal compression at the sensor level**
  - **High speed** (fully parallel readout at 1-5 MHz)



- Readout Concept
  - Immediate 8 Bit digitization
  - In-Pixel digital memory
  - Readout durring macro bunch gaps

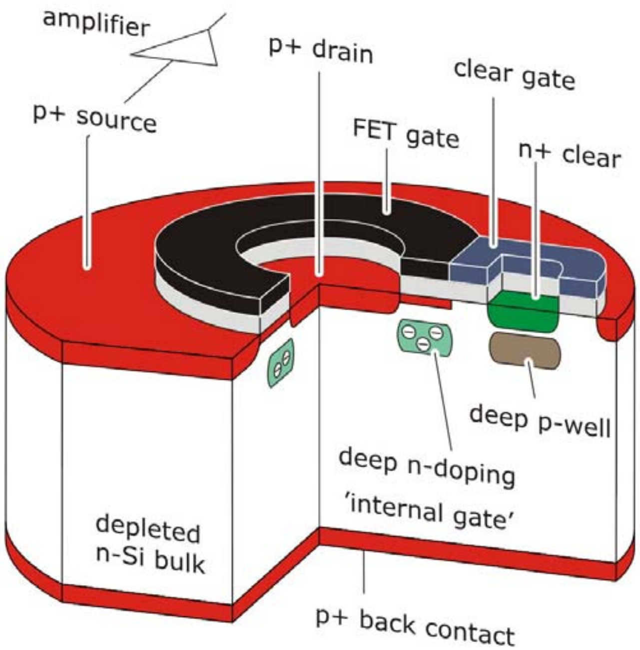
DePFET Active Pixel Sensors

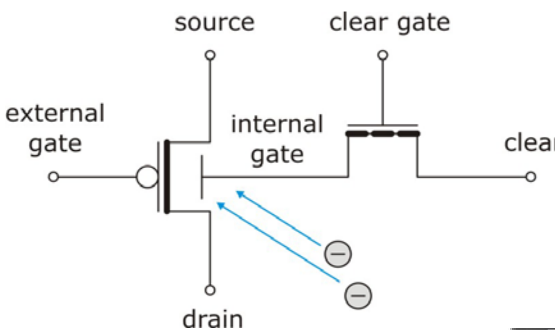
p-FET on depleted n-bulk

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

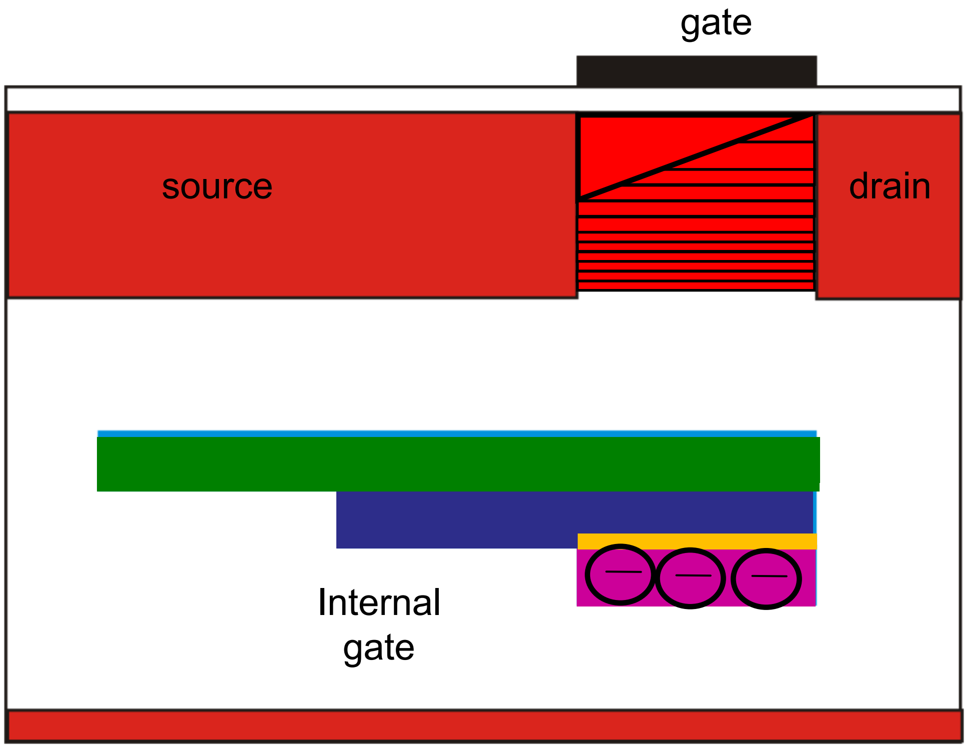
combined sensor & amplifier

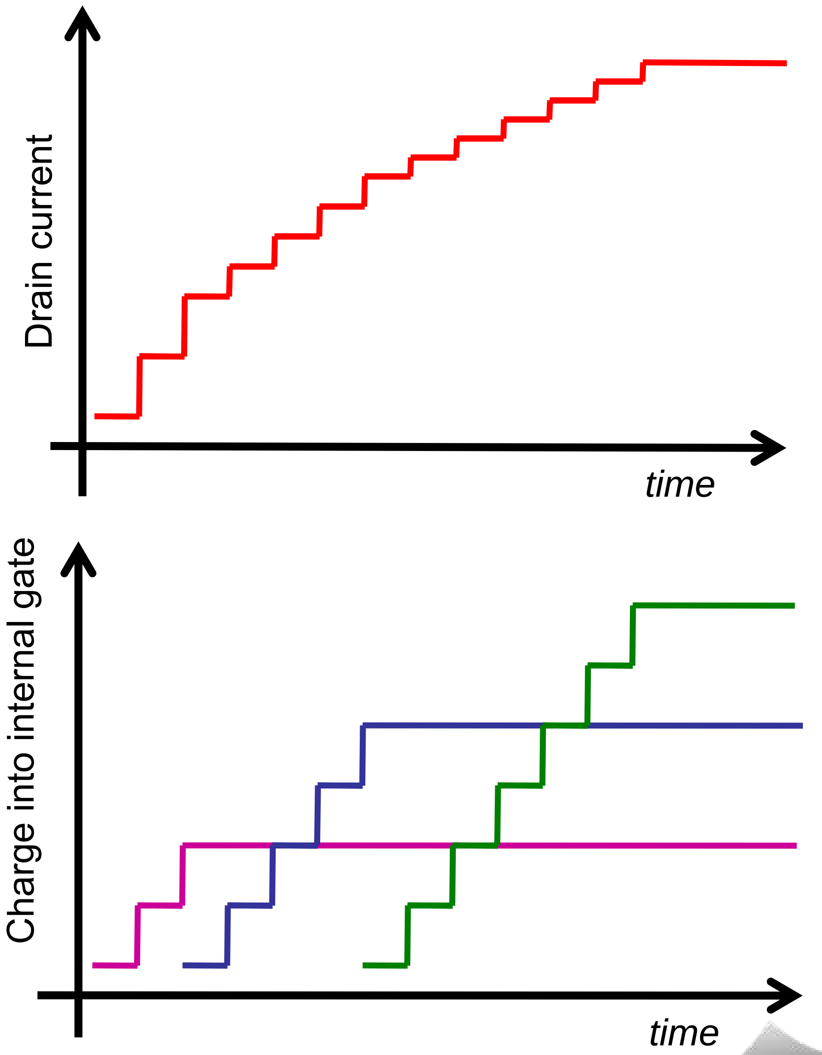
- low capacitance and noise
  - » **excellent spectroscopic performance**
- complete clearing of signal charge
  - » **no reset noise**
- non-destructive readout
  - » **potential of repetitive readout**
- charge storage capability
  - » **readout on demand**
- full depletion
  - » **backside illumination**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





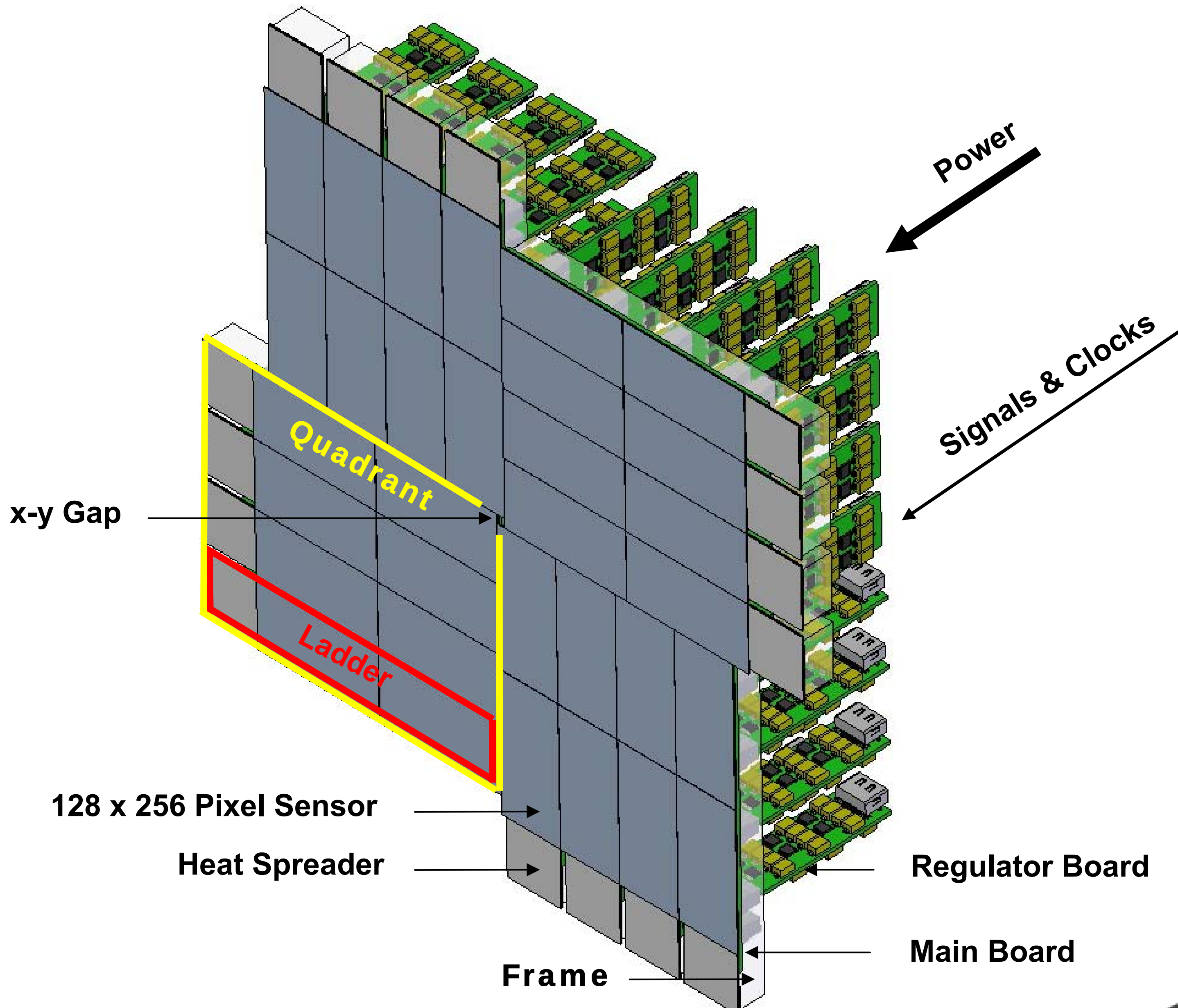
Non-Linear DEPFET Working Principle



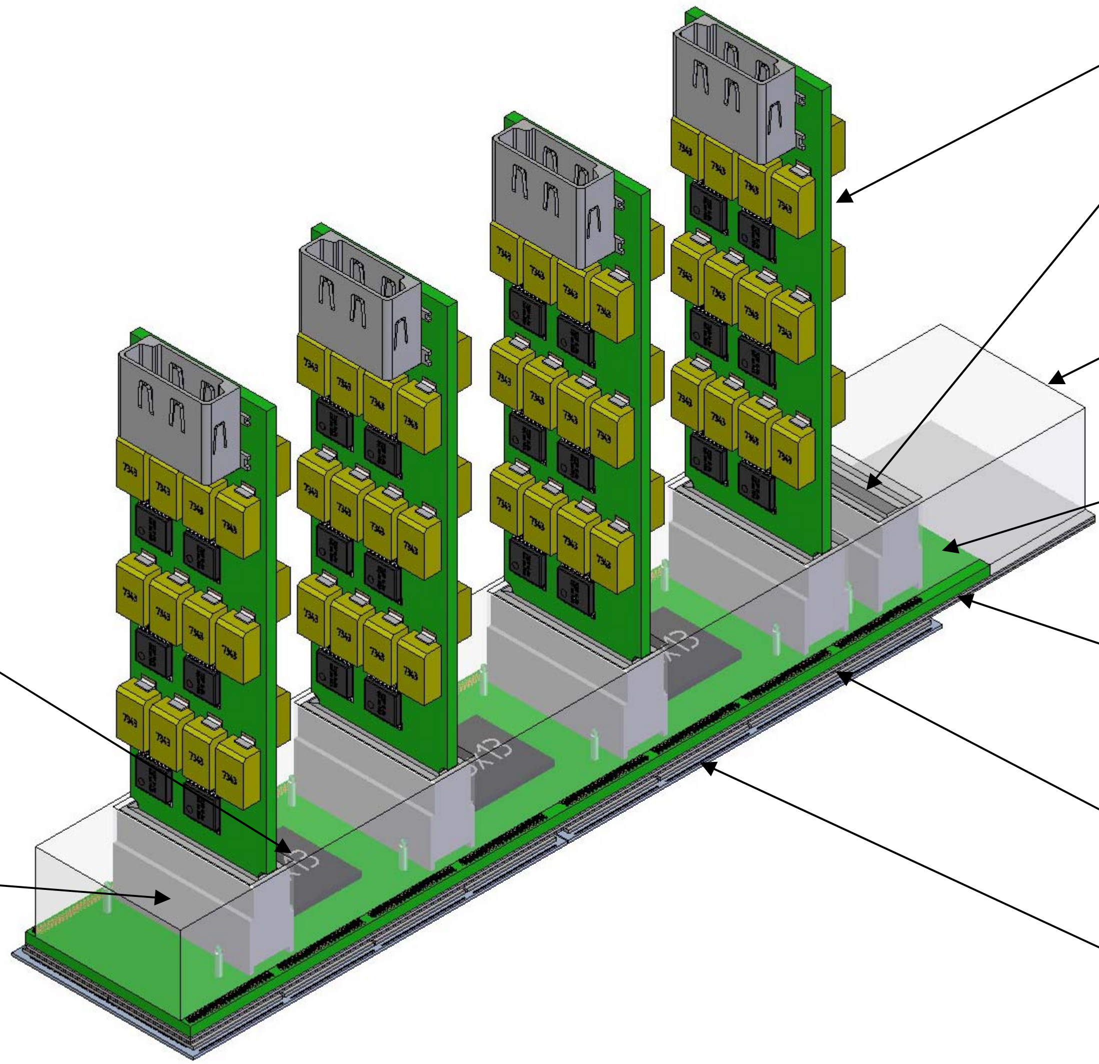


- The internal gate extends into the region below the source
- Small signals assemble below the channel, being fully effective in steering the transistor current
- Large signals spill over into the region below the source. They are less effective in steering the transistor current.

Mechanics - Focal Plane Overview



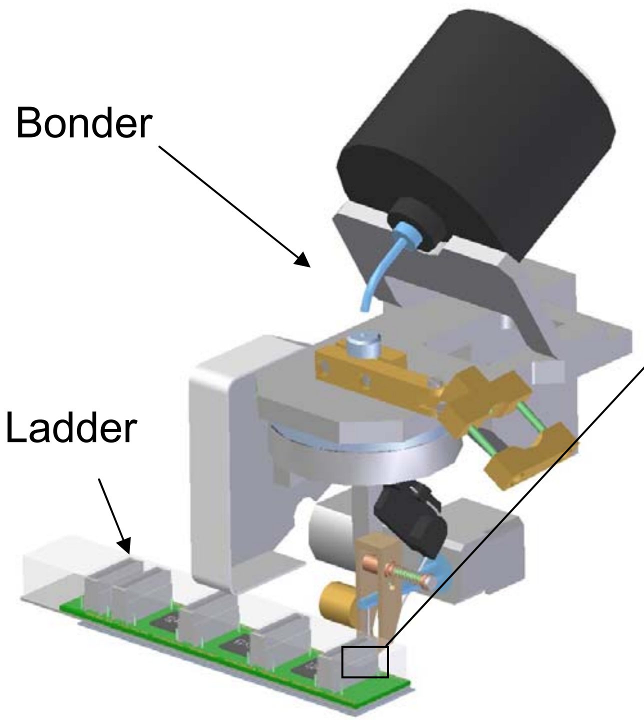
Mechanics - Ladder

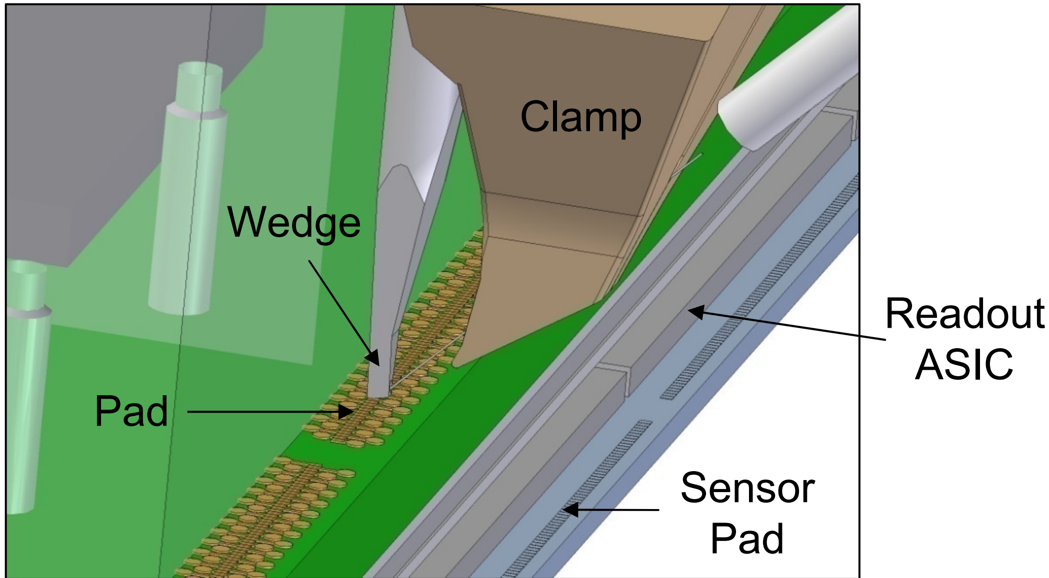


Interconnection Details

Feasibility Check of

- geometry
- process Steps





Wire Bonding

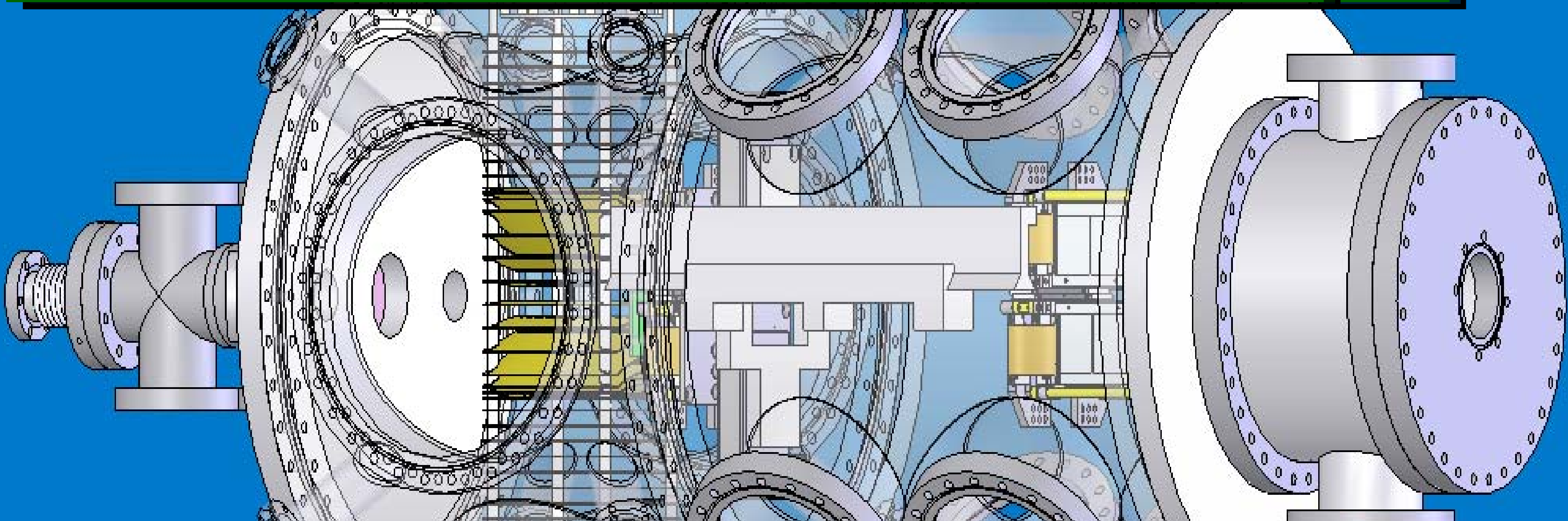
• Pitch	150 µm
• Step Height	3.3 mm
• Distance	2 mm
• Total number	~24.000 for 1MPix

Pads on Hybrid

• Area	100 x 200 µm^2
• min. Gap	50 µm
• out. Via Diam.	300 µm
• Cut. Edge Dist.	300 µm

CFEL-ASG Chamber

Plus 20 proposals for 2010! S!



- Flourescence from atoms: Rolles,..+ ASG
- Clusters: Bostedt, Möller,.. +ASG
- Aligned molecules: Küpper, Chapman,.. + ASG
- Bio-samples: Chapman, .. + ASG

Future Focus:

- High speed, low noise X-ray pnCCD imagers
- X-ray pnCCDs with large formats
- New high speed analog signal processors

- DePFETs for X-ray imaging and vis./NIR imaging
- DePFETs with
  - analog signal compression
  - repetitive non-destructive readout
  - "gatable" internal gate

- SDDs in various shapes and electronic configurations

This provides a scientific horizon of 30 years for innovative detector developments at the MPI HLL!

End