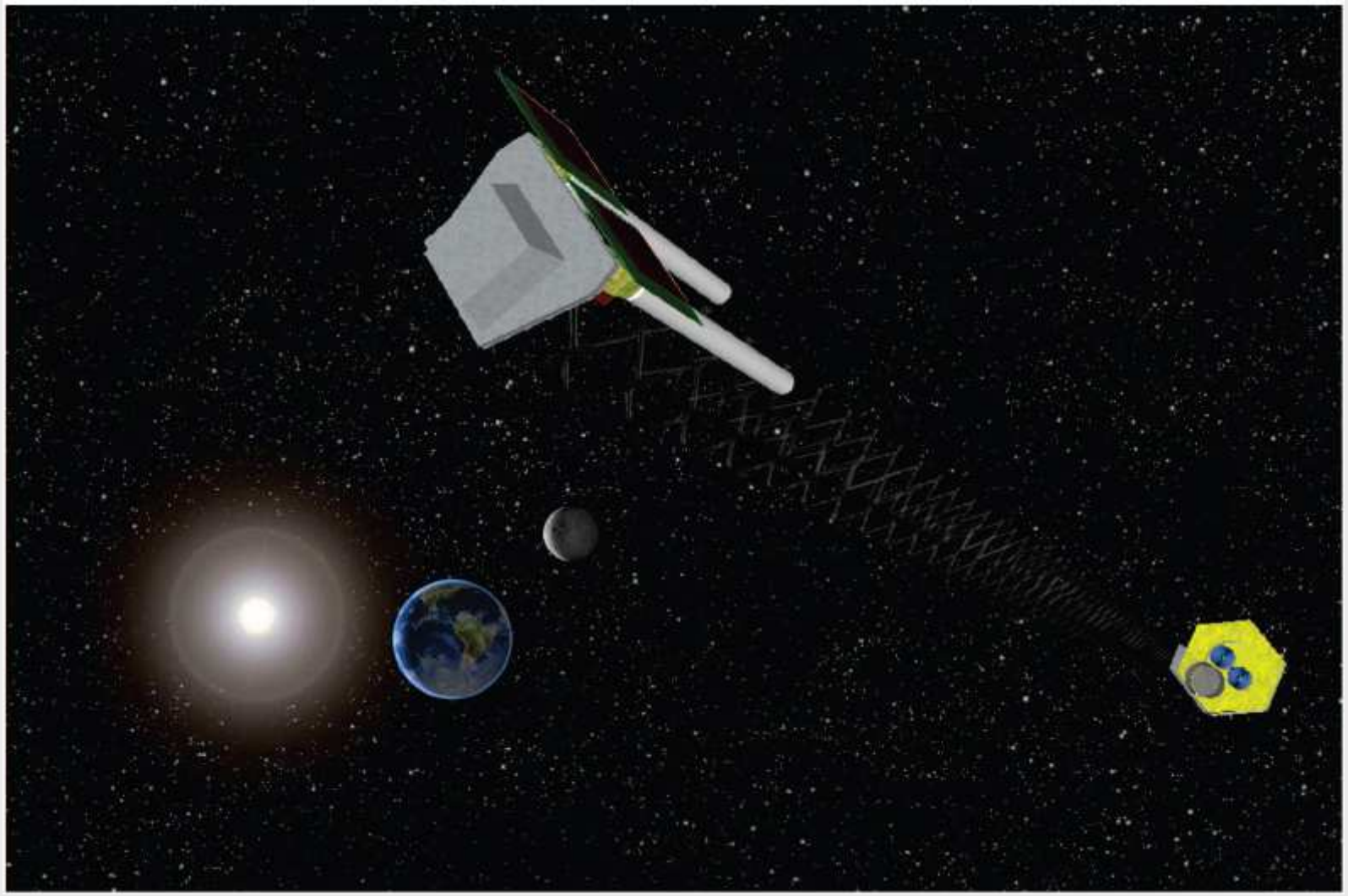
PheniX

A NEW VISION OF THE HARD X-RAY SKY



J.P. ROQUES

PheniX: M3

Proposed by:

J.P. Roques, E. Jourdain, L. Bassani, A. Bazzano, R. Belmont, A.J. Bird, E. Caroli, M. Chauvin, D. Clark, N. Gehrels, U. Goerlach, F. Harrisson, P. Laurent, J. Malzac,P. Medina, A. Merloni, S. Paltani, J. Stephen, P. Ubertini, J. Wilms.

CESR Toulouse - IASF Roma - IASFC Bologna - Southampton Univ. - NASA/GSFC - APC Paris - CEA Saclay - MPE Garching - ISDC Geneva - Erlangen-Nurember Univ – IPHC, Strasbourg - SRL, Caltech, Pasadena-

We thanks:
F. Cordero Vega Space
Emmanuel Hinglais CNES
Astrium France

PheniX: The context

After coded mask – large detection area era :

- Major steps in hard X-ray astronomy will come from focusing optics instruments.
- An attempt was Simbol-X (formation flying) CNES-ASI
- Next step is NuStar 6-79 keV (USA, 2012)
- Beyond that:
  - Better detector
  - Better sensitivity
  - Energy coverage increase

PheniX: Science objectives

Solving the black hole engine emission

- Unique laboratory to study matter and radiation under extreme temperature, density and strong gravitational field
- Various processes: thermal emission – iron line – Comptonization- reflection – non thermal emission – Jet
- Full energy coverage 1-200 keV to disentangle processes
- Ultra high sensitivity 20 – 200 keV will open a new window:
  - Precise spectral shape and cutoff
  - Spectral variability at short time scale (minute)
  - High energy non-poissonian noise will be revealed
- Polarization will give access to jet nature and physical properties of the corona.

PheniX: Science objectives

AGN

- Detailed spectral properties studies
- Connection between accretion and jet emission
- Role of reflection
- Determination of the high energy cutoff on a large sample
- Role of the AGN energy release in the surrounding ISM
- Detection of high redshift o AGN’s:
  - evolution
  - Direct probe of the CXB at E>20 keV
- Study of absorption : tests of unified theory

PheniX: Science objectives

Elements formation

- Ti 44 lines (68 and 78 keV) in SNR:
  - Velocity turbulence and spatial distributions

- Co 57 (122 keV) from supernovae : Dynamics of the core bounce mechanism
  - Co57 mass → infos on pre-supernova object
  - Ratio line/continuum → thickness of the ejecta
- Need high sensitivity and good energy resolution

PheniX: Science objectives

Neutron stars

- Matter properties in most extreme environments with B up to 10^{15} G
- Measure of the magnetic field and probing accretion geometry
  - Detailed measurement of cyclotron lines and harmonics up to E>100 keV
  - Polarization measurements.
- Investigation of acceleration in pulsar magnetosphere
  - Timing and phase resolved spectroscopy
  - Polarization

PheniX: Science objectives

Others topics

- Acceleration in SNR
- Galactic Center
- Emission from giant planets: Jupiter..
- Magnetic cataclysmic variables
- Non thermal emission from cluster of galaxies
- ……..

PheniX: Science objectives

From scientific requirements to instrument performance

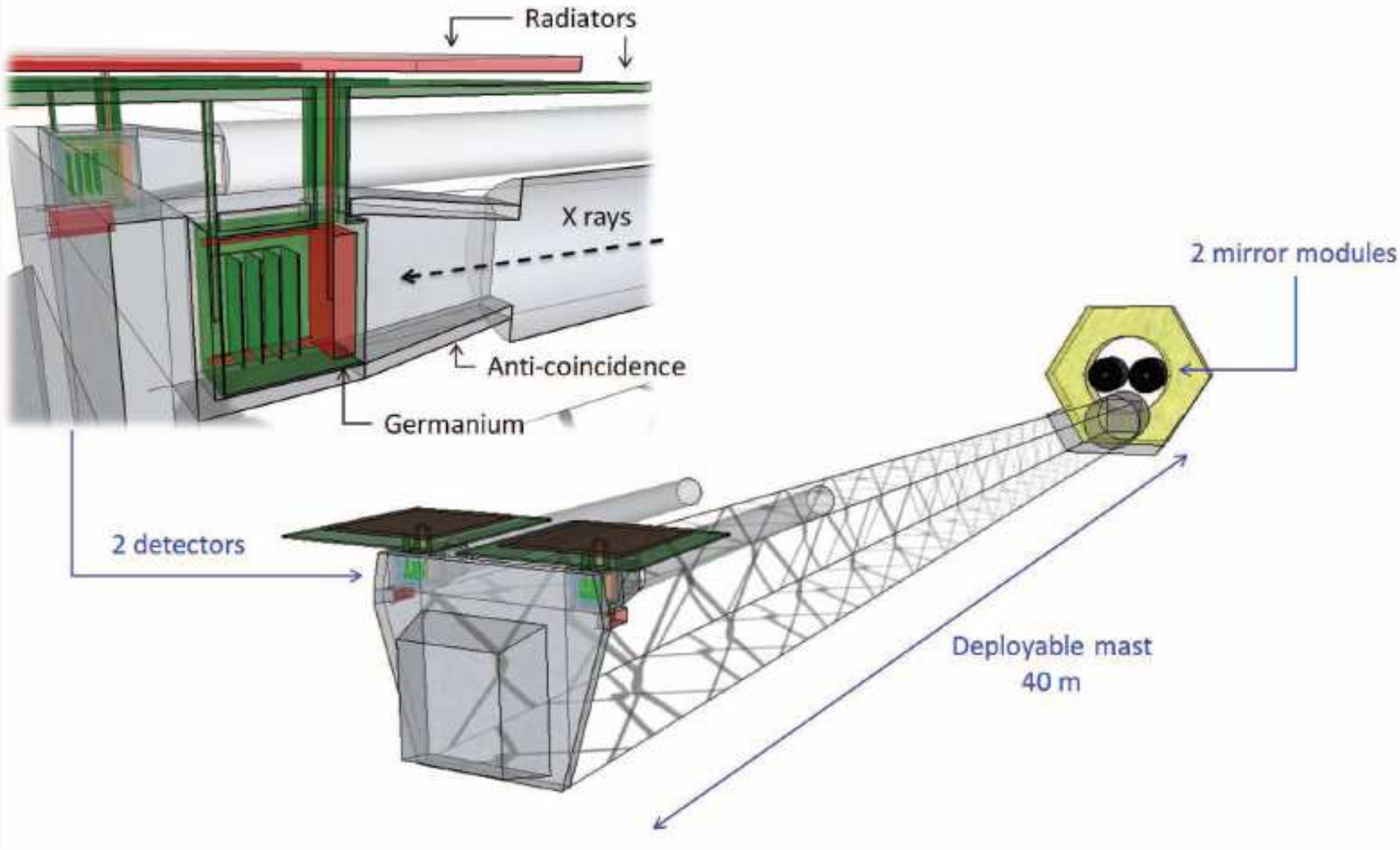
- Unique instrument covering the 1-200 keV range
- High sensitivity: > x5 Nustar and >x50 Integral
- High energy resolution and high counting rate
- Polarimetry capability

Parameters		Requirement	Drivers
Energy range		1-200 keV	All
Spectral resolution ($\Delta E/E$ FWHM)	@ 7 keV @ 100 keV	150 eV 0.5 keV	X-Rays Binaries , AGNs (Fe line) Explosive Nucleosynthesis (^{44}Ti lines)
Angular resolution		Better than 30''	SNR , Galactic Centre region
Sensitivity 3σ, 10^5ks For $\Delta E/E$ =0.5	@ 7 keV @ 100 keV @ 200 keV	4 10^{-8} photons /cm. s. keV 2 10^{-8} photons /cm. s. keV 15 10^{-8} photons /cm. s. keV	All
Polarimetry MDP		1-a few % (0.1 Crab)	Pulsars, X-Rays Binaries , AGNs
Time accuracy		Better than 100 µs	Pulsars
Minmal count rate without pile-up		A few Crab / 2.10^5 c/s	Bright sources

PheniX: Proposed model payload

- Two co-aligned telescopes working in parallel
- Focal length of 40m by extensible mast
- Two grazing incidence mirror modules “inside” the spacecraft
- Two focal plane assemblies on top of the mast
- Focal plane:
  - HPGe DSSD cooled at 90K
  - Passive cooling
  - Active and passive shield
- All sky monitor

PheniX: Instrumental concept



PheniX: Optical design

- Two co-aligned mirror modules in Wolter I configuration
- Slumped glass technology (e.g. Nustar)
- Increase of reflectivity at high energy:
  - Adapted depth graded multilayer (DGML)
- Two coatings options:
  - Pt/C bilayers (Nustar) but Pt 78 keV K-edge absorption
  - Co/C bilayers (Bellotti and Windt,SPIE,2009)

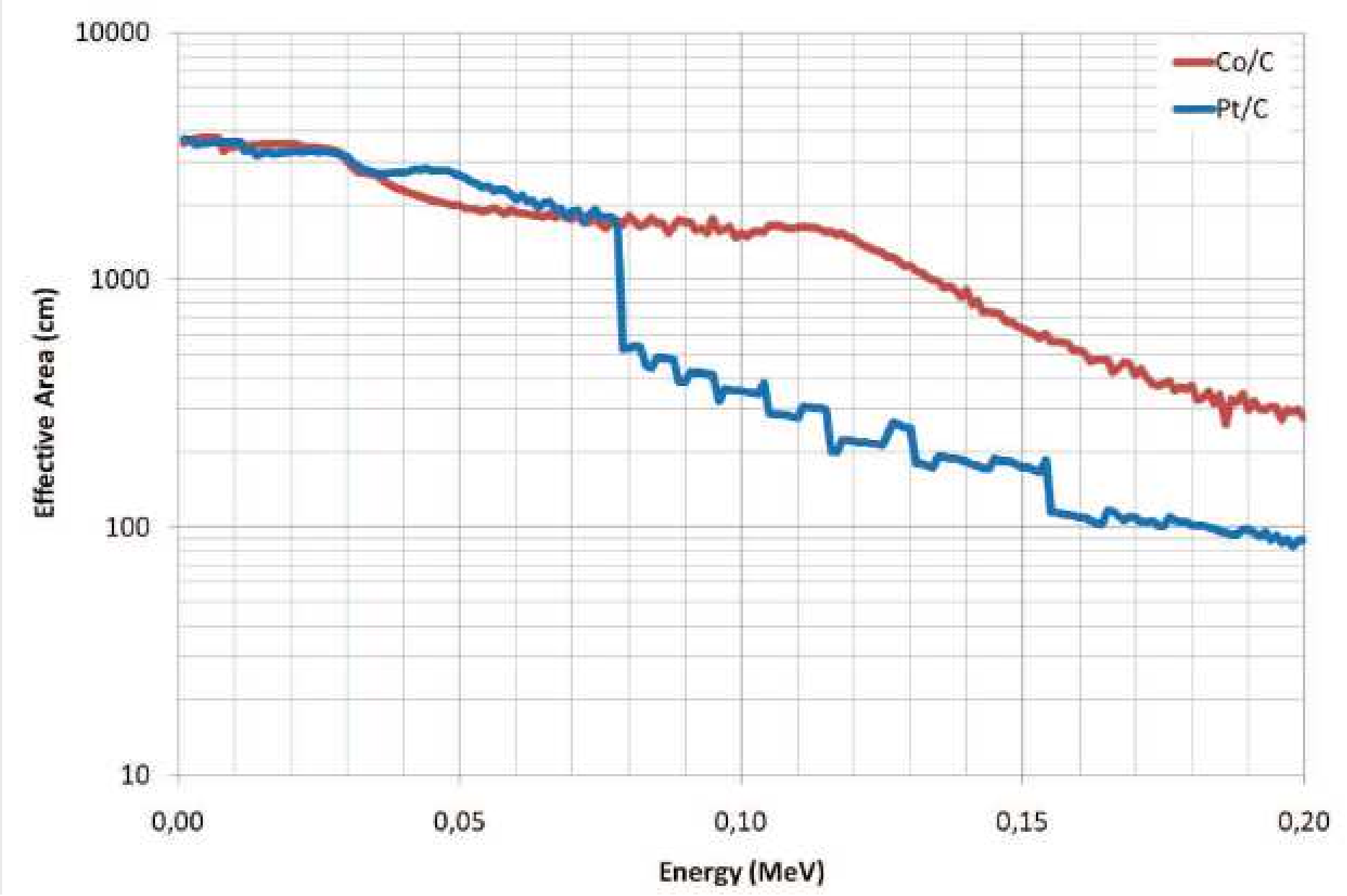
PheniX: Optical design

Focal Length	**40 m**
Mirrors	**260**
Radius Min	**0.05 m**
Radius Max	**0.31 m**
Shell Length	**0.5 m**
Total Mirror Length	**1 m**
Field Of View (Aeff >50% on axis)	**6 arcmin**
Coating A (Depth Graded Multilayer)	**100 Pt/C bilayers**
Coating B (Depth Graded Multilayer)	**1100 Co/C bilayers**
Mass (slumped glass hypothesis)	**175 kg**

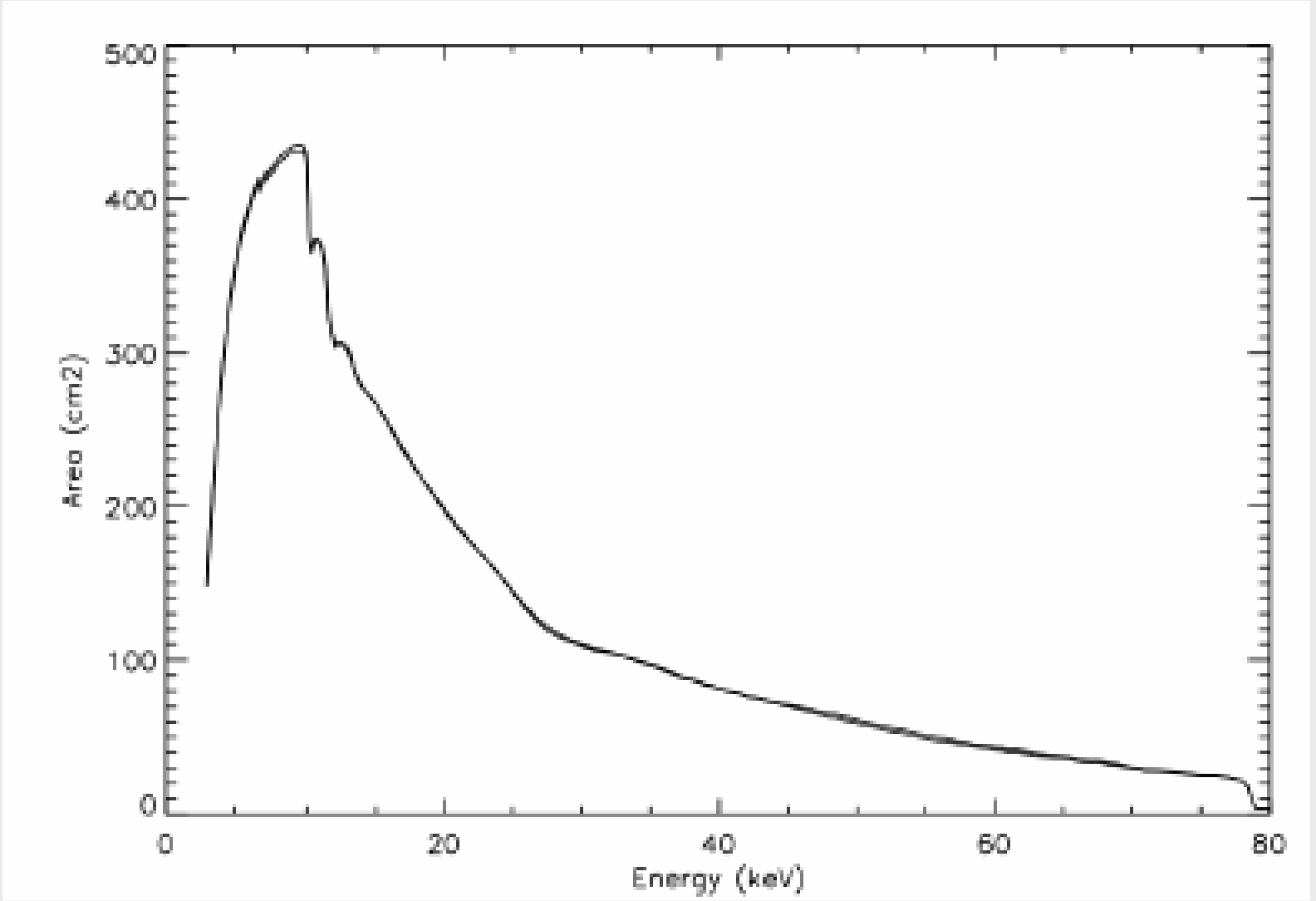
PheniX: Angular resolution

- Nustar is 60’’ HEW
- Improving assembly/alignments accuracy we aim 20’’
- @high energy 80’’ was expected
- Better possible (to be studied)

PheniX: Optical design



Nustar: ARF



PheniX: Focal plane design

New generation detector for the focal plane of Hard X-ray telescope

- Good spatial resolution: 0.2 x 0.2 mm
- Size: around 8x8 cm
- Energy resolution: 0.13 keV @ 5 keV - 0.5 keV @ 100keV
- Energy range 1 – 200 keV
- Aim for a single detector
- Polarimetry capabilities
- Background reduction technique
- A single detector.
- No pile-up
- Annealing capabilities

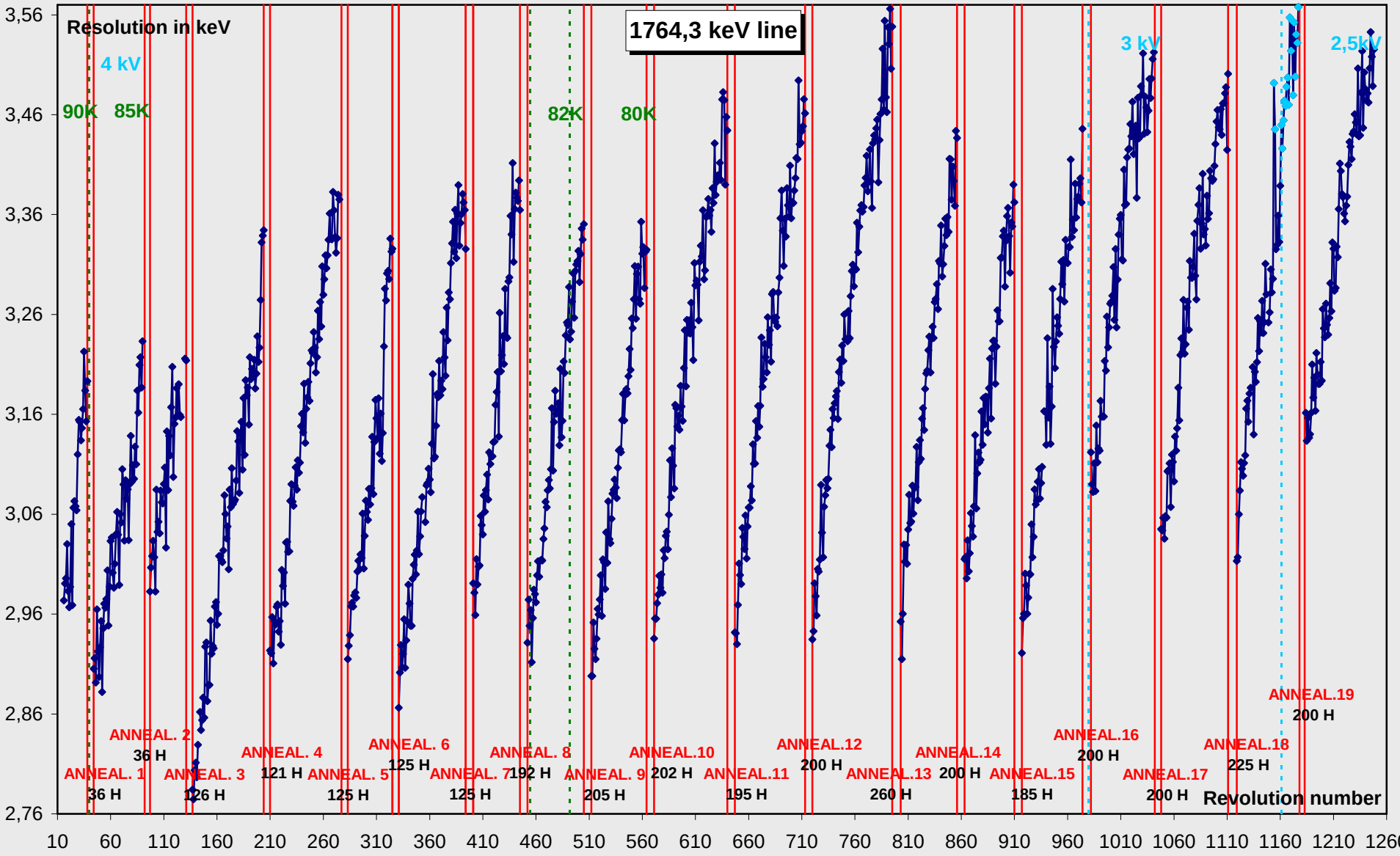
Detector choice: why Germanium ?

- High volume monolithic crystals (up to 2-3 kg)
- Low leakage current
- Small band-gap
- High speed of charge carriers (very low trapping)
- Holes current can be used: holes speed~= electron speed
- Irradiation damage recovery (Annealing)

S-C	Z	Densité ($g.cm^{-3}$)	Absorption (à 140 keV) (cm^{-1})	Résistivité (Ohm.cm)	Bande interdite (eV)	Epaire (eV)	Mobilité ($cm^2/V.s$)		Durée de vie (µs)	
							électron	trou	électron	trou
Ge	32	5,32	1,35	50	0,74	2,98	3600	4200	20	20
Si	14	2,33	0,35	10^6	1,16	3,76	2100	1100	20	20
CdTe	48,52	6,06	4	$>10^9$	1,47	4.43	1100	100	1	1
CdZnTe	48/30/52	6	3,84	$>10^{10}$	1.5	4,64	1050	50 à 80	3	0.1
HgI2	80/53	6,4	8,96	10^{13}	2,13	4,2	100	4	1	25

ENERGY RESOLUTION HISTORY: 1764.3 keV

- Regular annealing (GeD at 105C) restore GeD energy resolution.

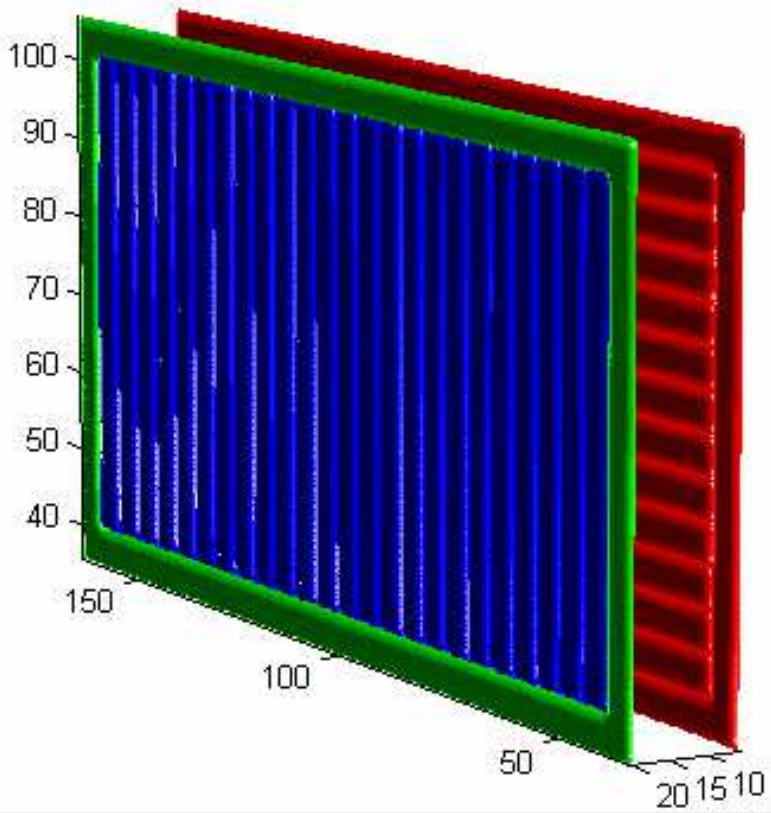


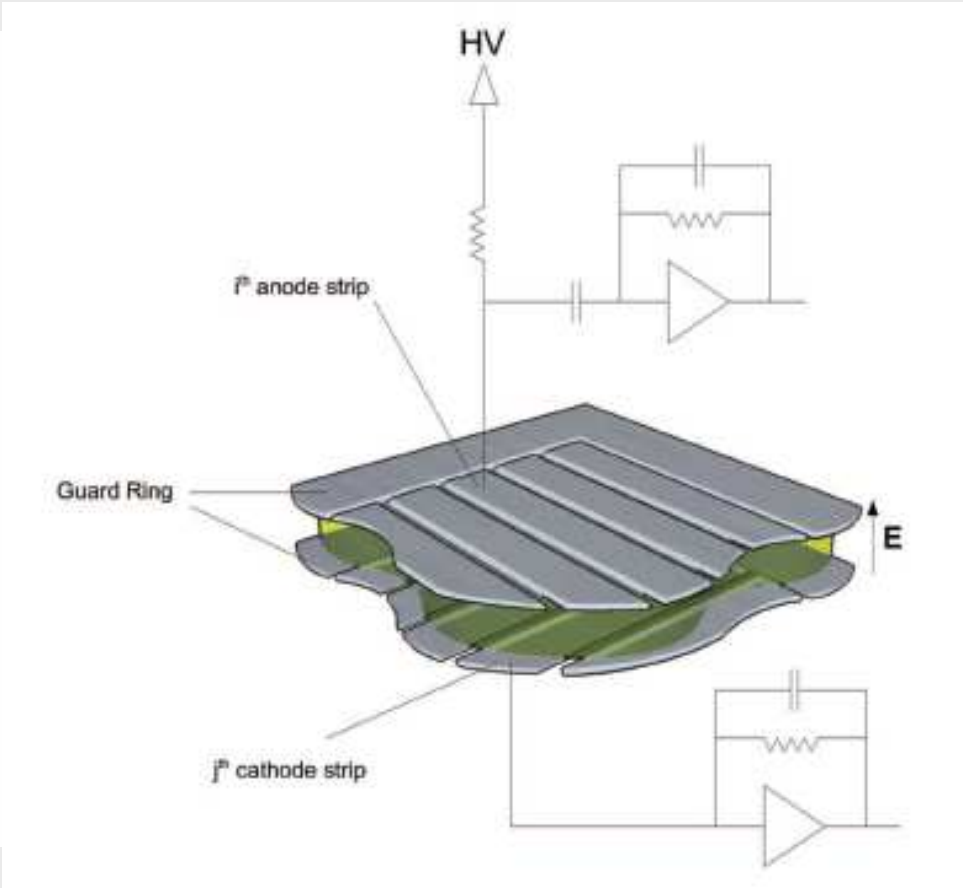
PheniX: 3 DIMENSIONS Ge DETECTOR

New generation detector for the focal plane of Hard X-ray telescope

- Double sided stripped Germanium detector:
  - Size: around 8 x 8 x 1.5 cm cooled at 80 K
  - Strip pitch 0.5 mm
  - Depth of interaction (1-2 mm) : Background reduction
    Energy resolution 0.13 keV @ 5 kev, <0.5 kev @100 keV
  - Energy range : 1 -200 keV
  - Low number of electronic chains: 2x SQRT(Npix)
  - Possible use of “charges splitting” to refine the position
- Intensive use of digital electronics for position and energy reconstruction.
- Multiple events reconstruction capability
- Polarization measurements

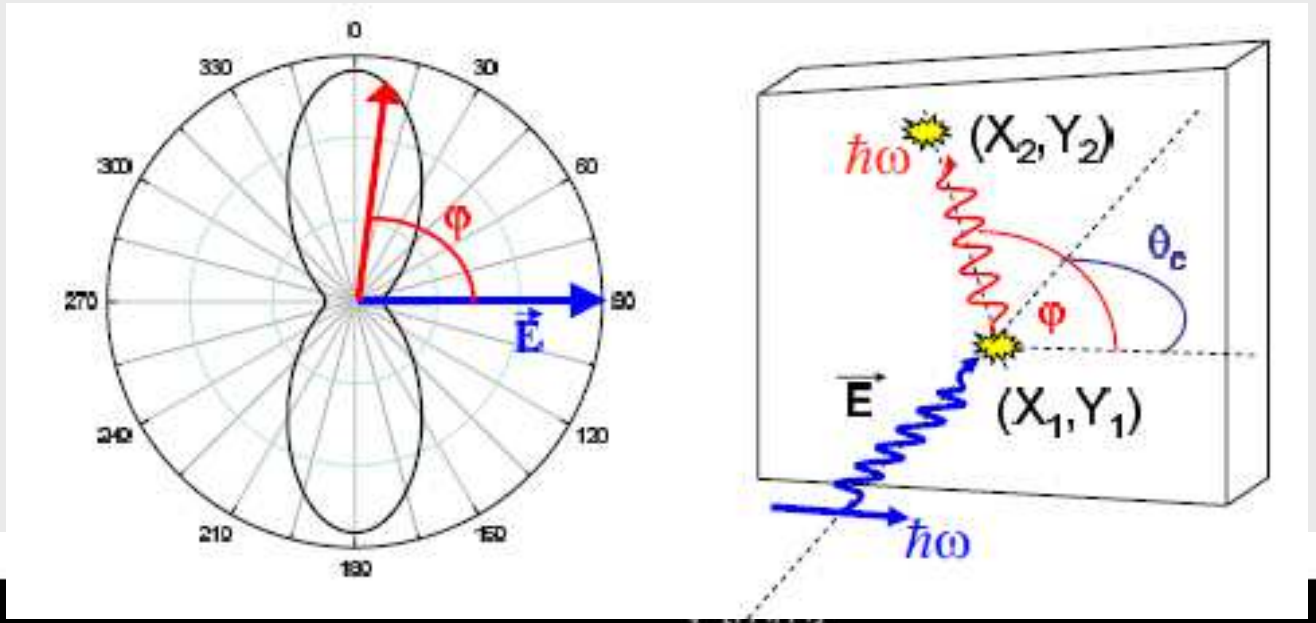
3 DIMENSIONS Ge DETECTOR
DOUBLE SIDED GERMANIUM STRIP DETECTOR





Diode Ge 100X-100Y

POLARIMETRY



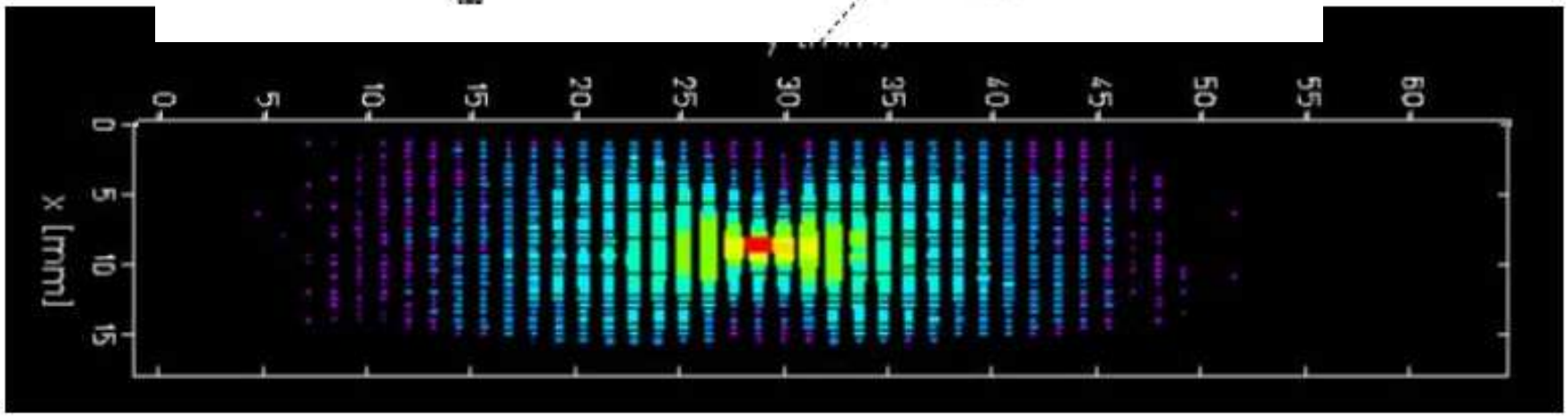
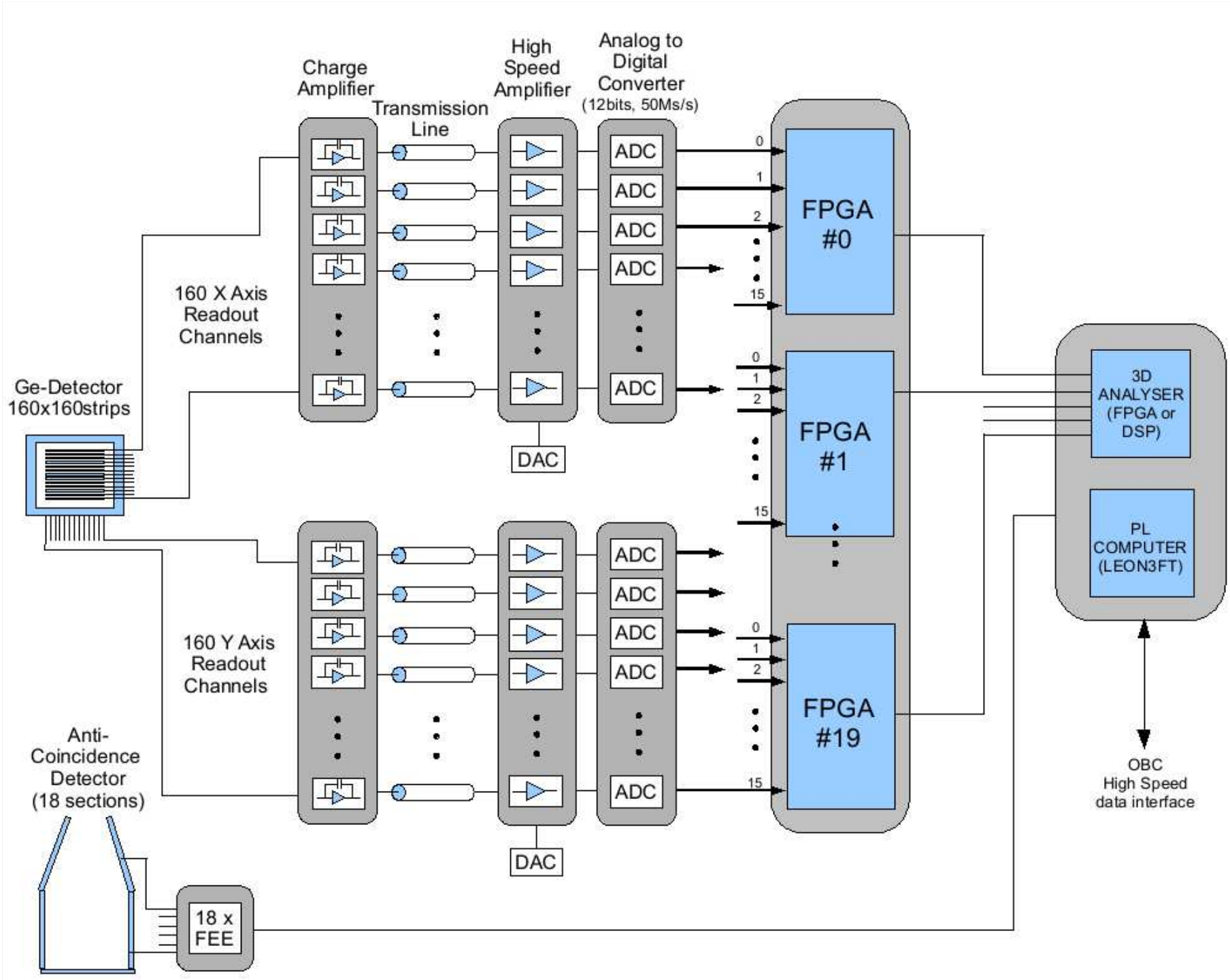


Figure 2. 2D image for Compton scattering of almost 98% linearly polarized x-rays (210 keV) (preliminary result). The image displays the spatial distribution of Compton scattered photons which exhibit an energy of 149 keV corresponding to a scattering angle of $\theta = 90°$. The image was recorded during a detector performance test at the ESRF synchrotron facility

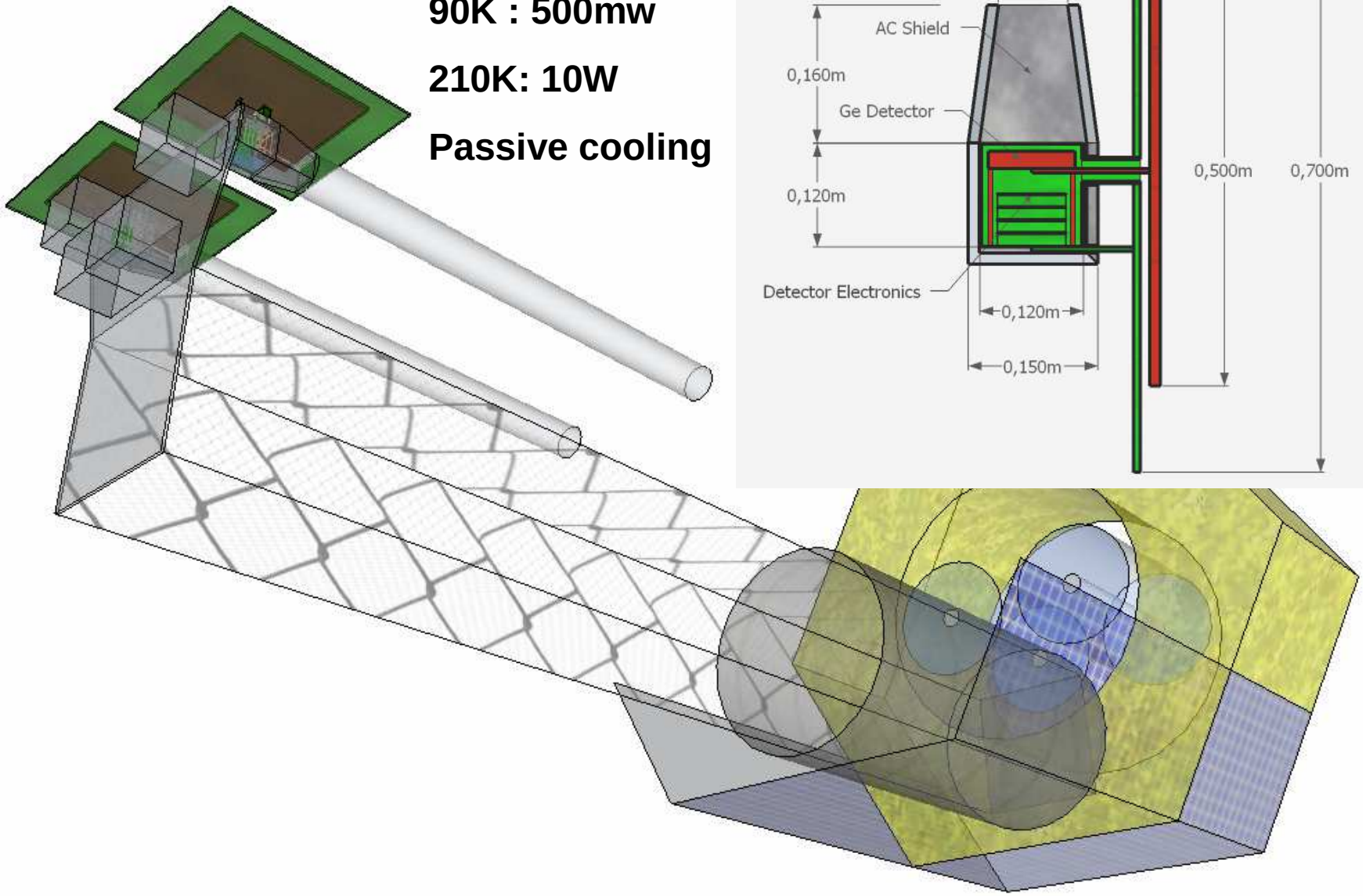

Charge Amplifier
Transmission Line
High Speed Amplifier
Analog to Digital Converter
(12bits, 50Ms/s)
160 X Axis Readout Channels
Ge-Detector 160x160strips
ADC
DAC
FPGA #0
FPGA #1
FPGA #19
0
1
2
15
3D ANALYSER (FPGA or DSP)
PL COMPUTER (LEON3FT)
OBC High Speed data interface
160 Y Axis Readout Channels
Anti-Coincidence Detector (18 sections)
18 x FEE

PheniX: Thermal concept

90K : 500mw

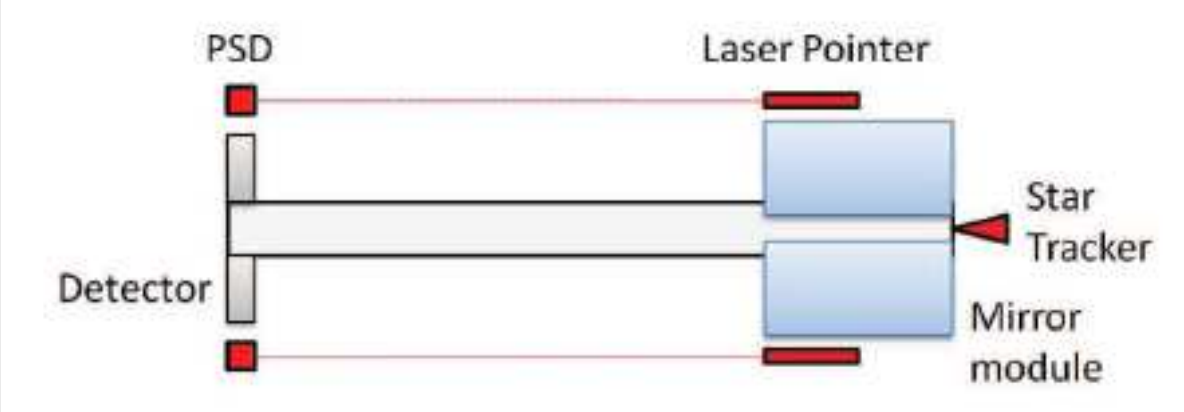
210K: 10W

Passive cooling

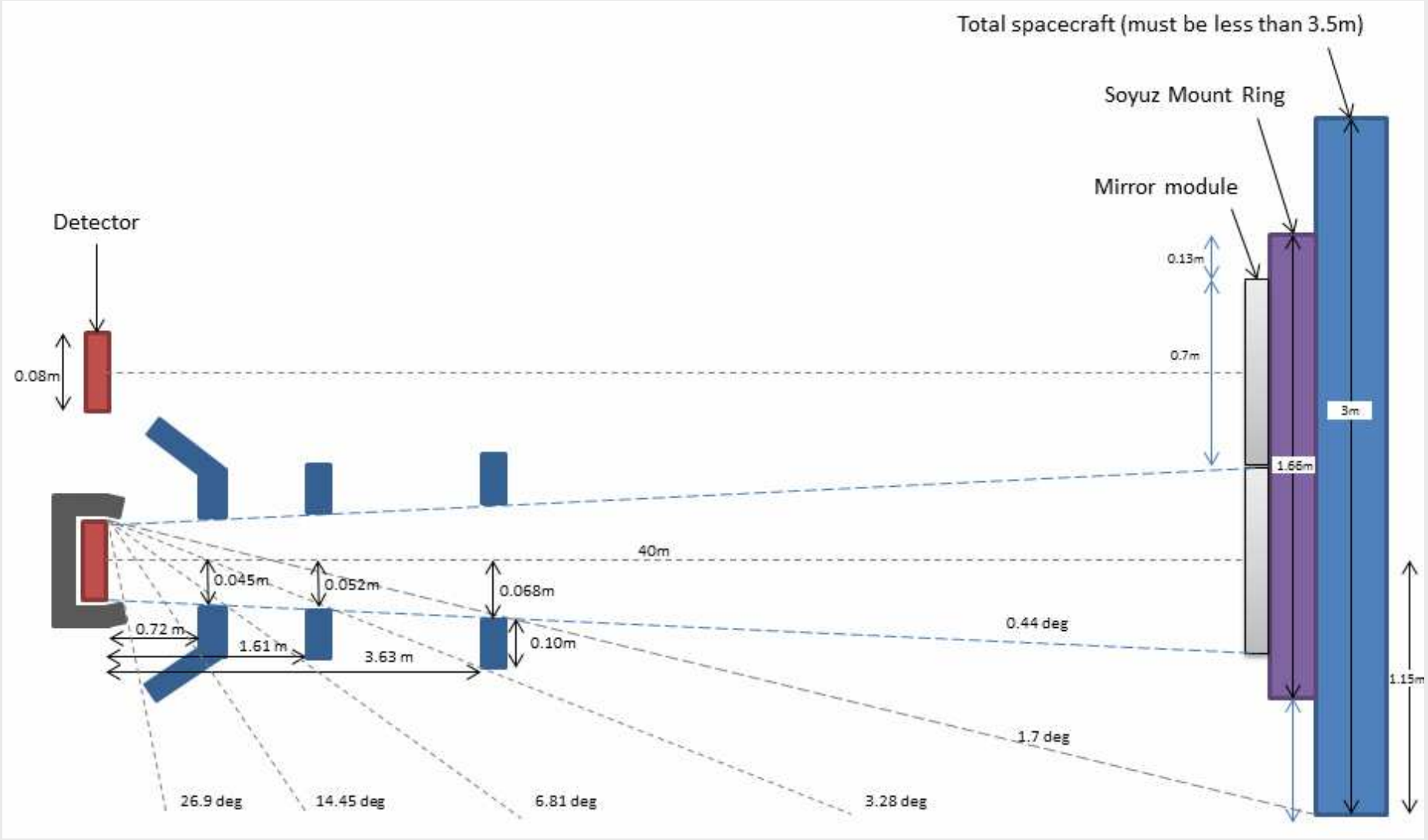


PheniX: Mast and metrology

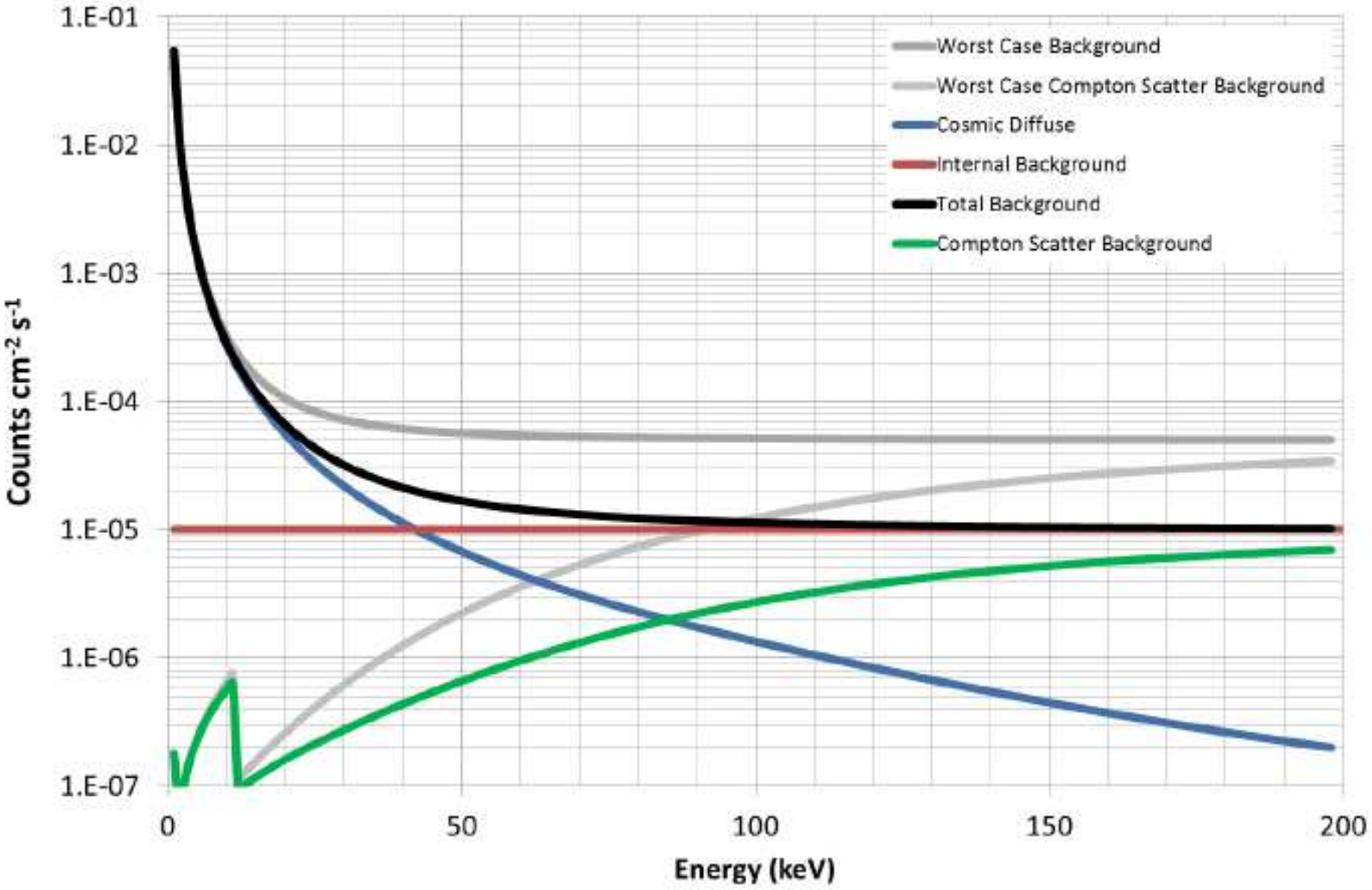
- Able technology: among a huge experience
  - SRTM: shuttle radar interferometry 60m
  - Nustar: 10m.
- Stability: +/- 1 cm
- Metrology:



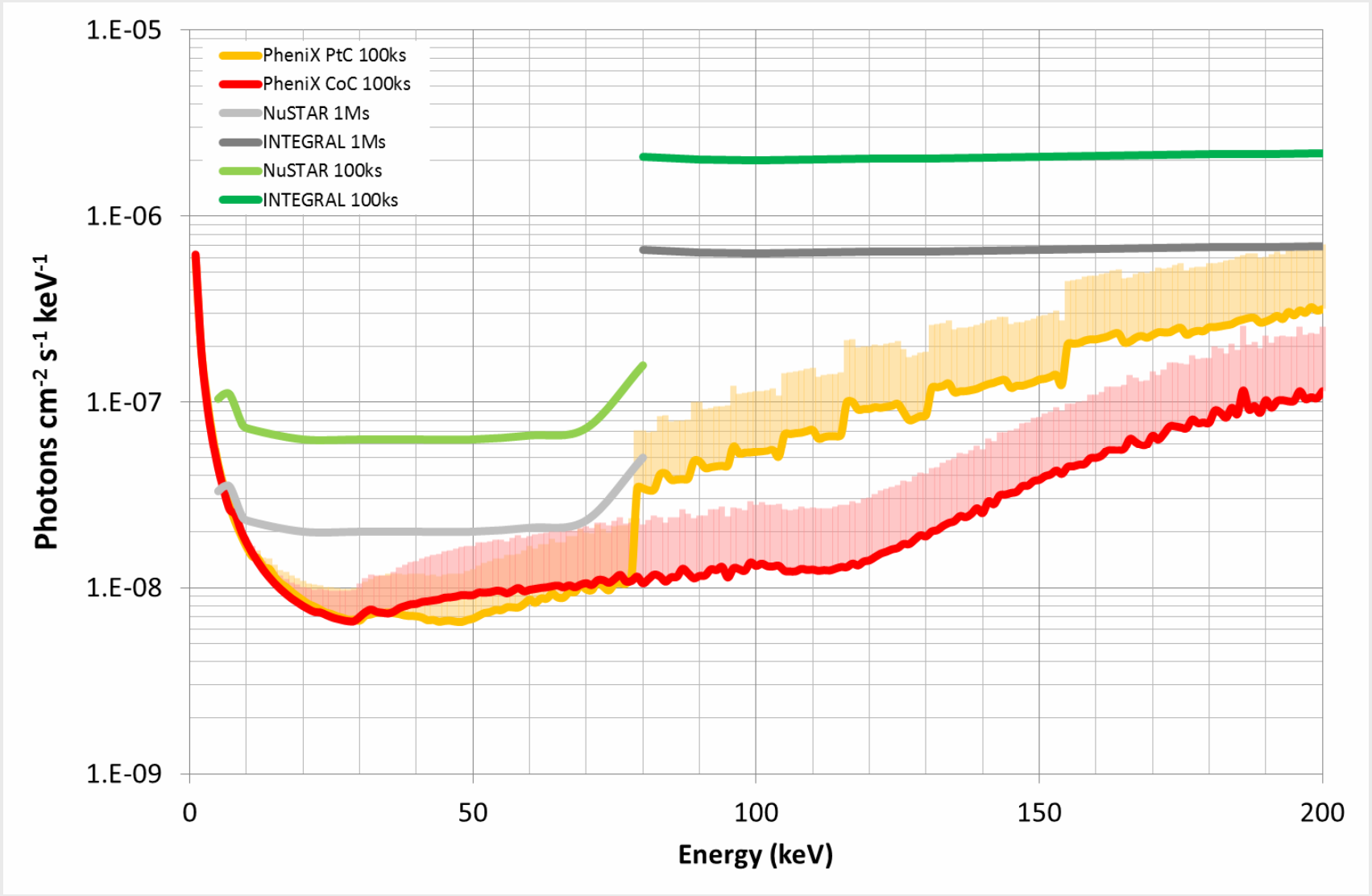
PheniX: Shielding concept



PheniX: Background



PheniX: Sensitivity



Does not include background reduction due to interaction depth measurement

PHENIX-M3 POLARIZATION

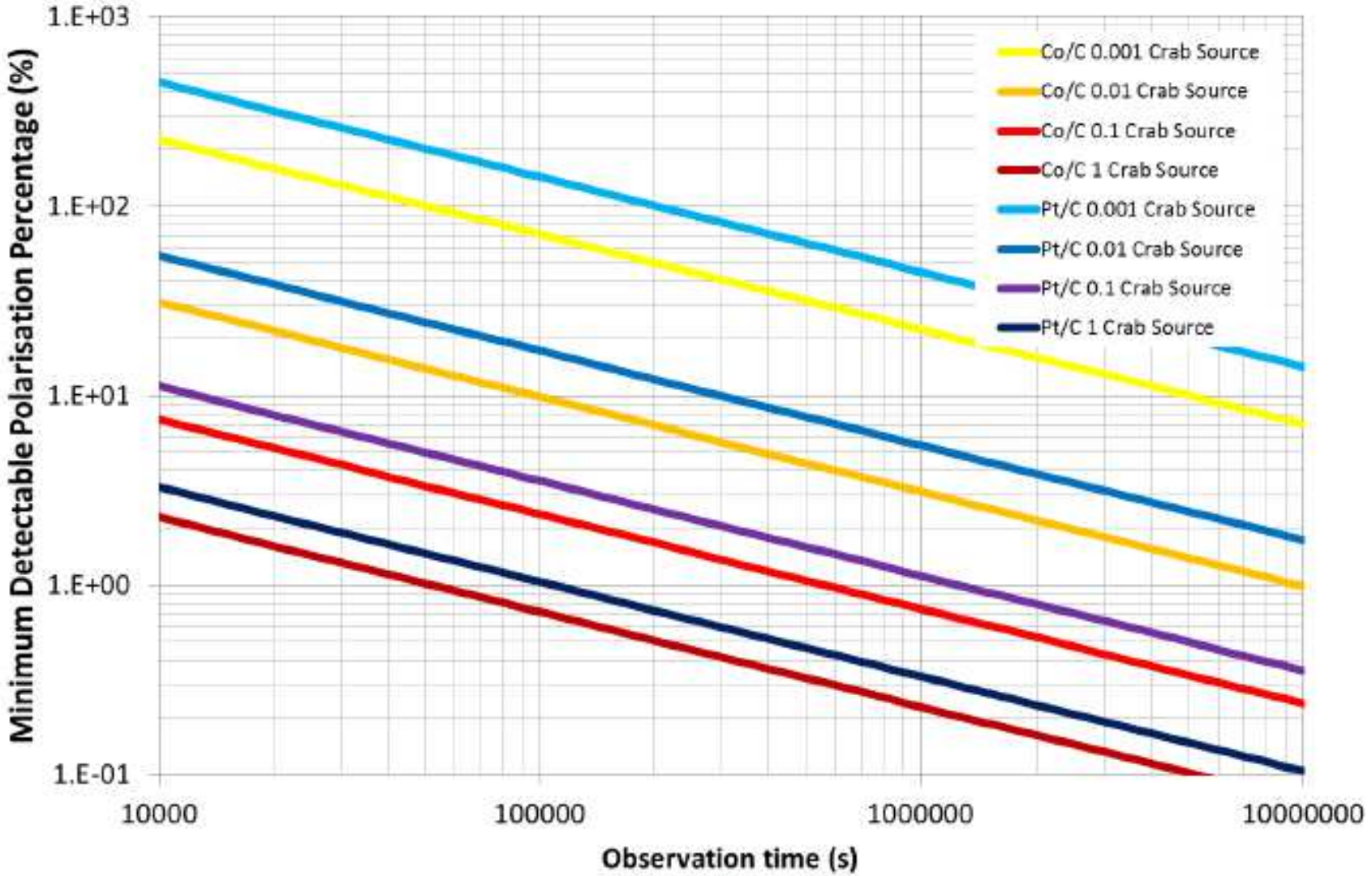


Figure 5: The minimum detectable polarisation (50-200 keV) for PheniX vs observation duration for different source strengths and mirror coatings.

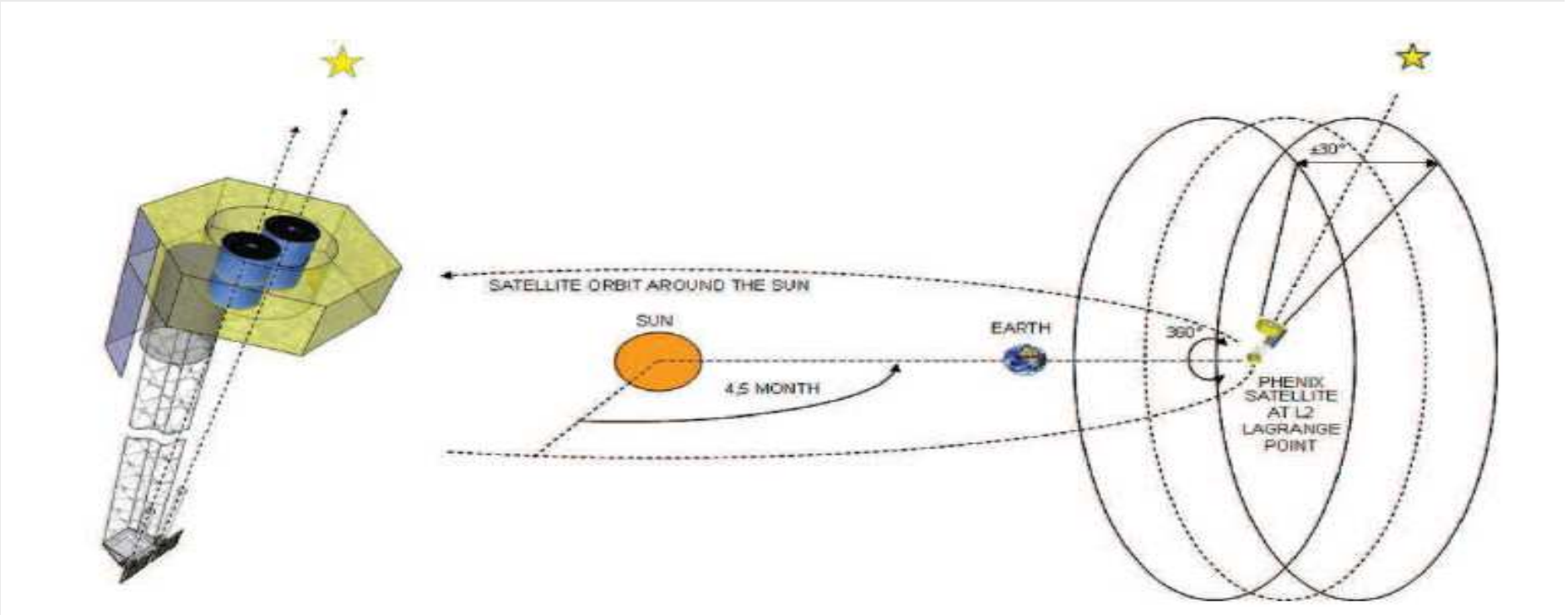
PheniX: Mission profile

- Libration orbit at L2:
  - No gravity gradient – No earth albedo – No eclipses
  - Good thermal stability – very low thrust consumption
- Spacecraft: Gaia – Plato concept
- Soyouz launcher:
  - 2.1 t at L2 from Kourou 75 Meuros
- Mission lifetime: 5 yr with possible extensions

PheniX: Mass - power - communication

- Total mass (including margins) : 2088kg
- Soyouz capability at L2: 2100kg
- Total power: 1000W
- Data transfert rate 30GB/week
- Ranging and tracking +/- 5km
- UTC synchro +/- 50microsec

PheniX: Attitude and orbit control



- Attitude control by standard reaction wheels
- LOS reorientation 10 deg./hr
- Higher speed possible if nedeed
- Pointing accuracy < 20 arcsec, knowledge: a few arcsec
- Mast motion reconstruction .5mm accuracy

PheniX: TRL

- SVM: standard requirement, GAIA example. TRL 9
- MAST: SRTM/Nustar … TRL 9
- Optics: Slumped glass … TRL 5 - coating ?
- Ge DSSD : TRL 4-5
- ACS : TRL 4-5

PheniX: Towards an M4 proposal

- High energy extension?
  - Mirrors limitation: X-ray scattering ?
  - Focal length increase 50 -60 m ?
  - Detector: thickness increase or two layers?
  - Low energy threshold ?
- Do we keep the same mission profile ?
  - L2
  - High eccentric orbit ?
  - Mass / telemetry budget /cost