AHEAD-2020

Detector development for

HERMES Scientific Pathfinder *and* theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

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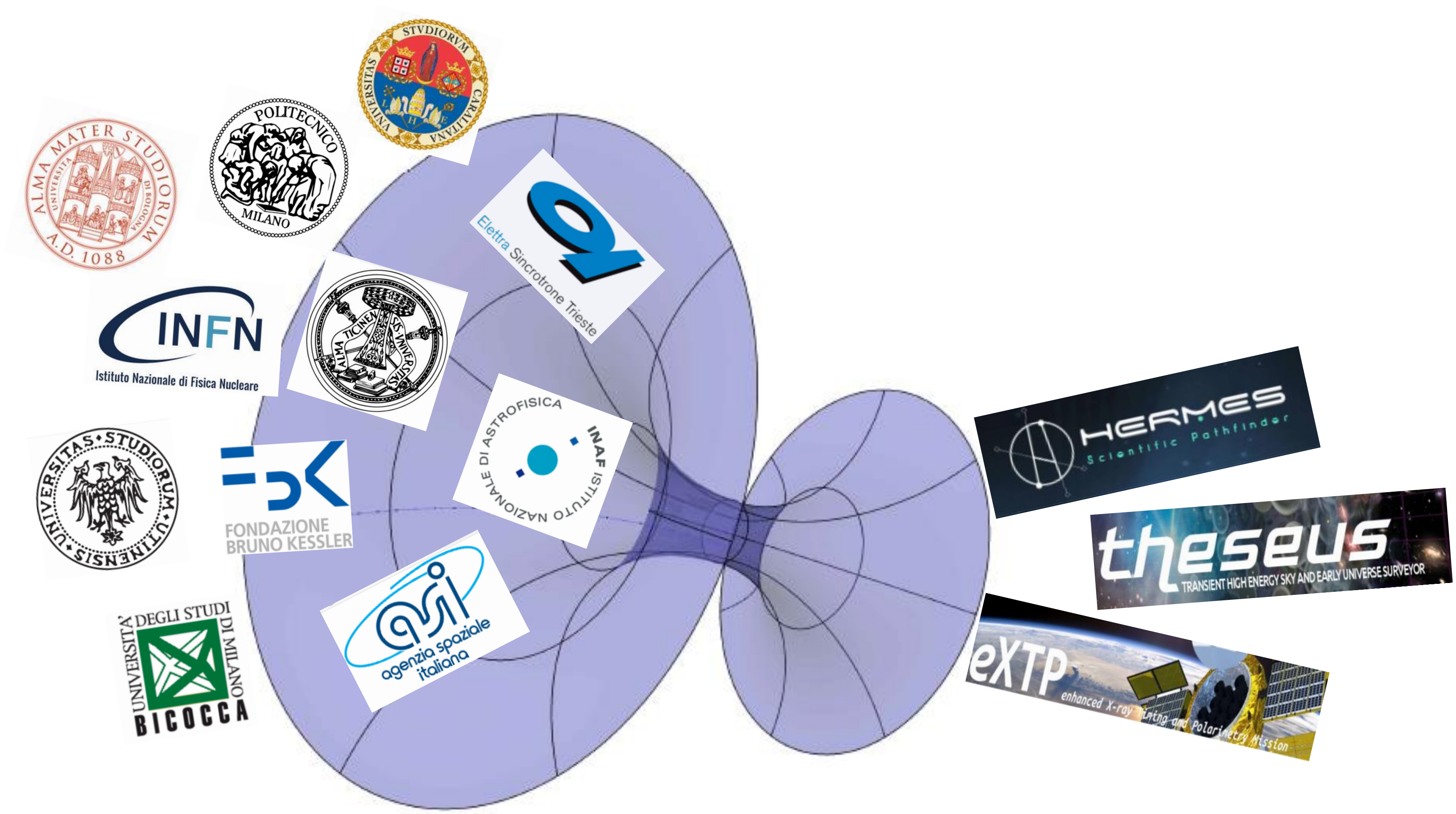
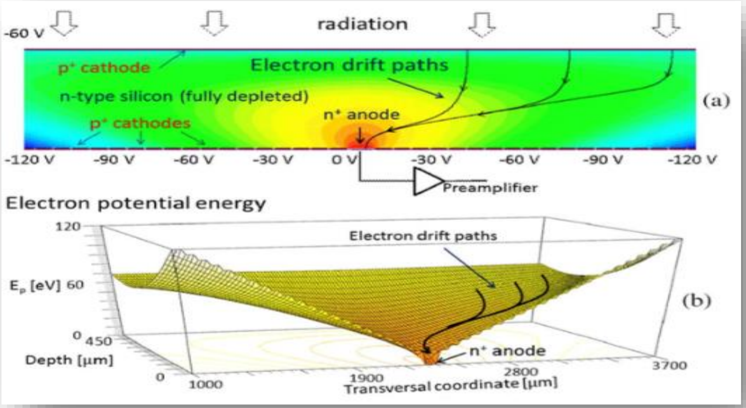
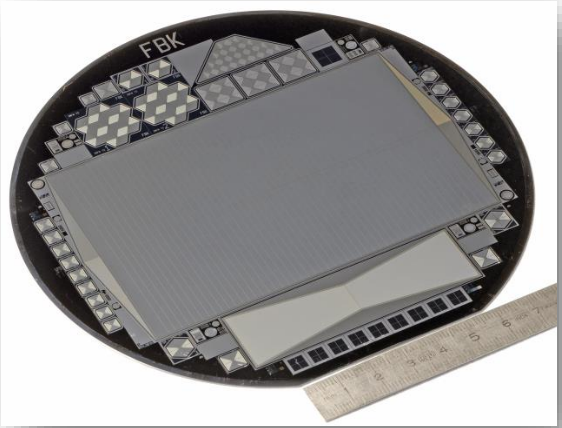
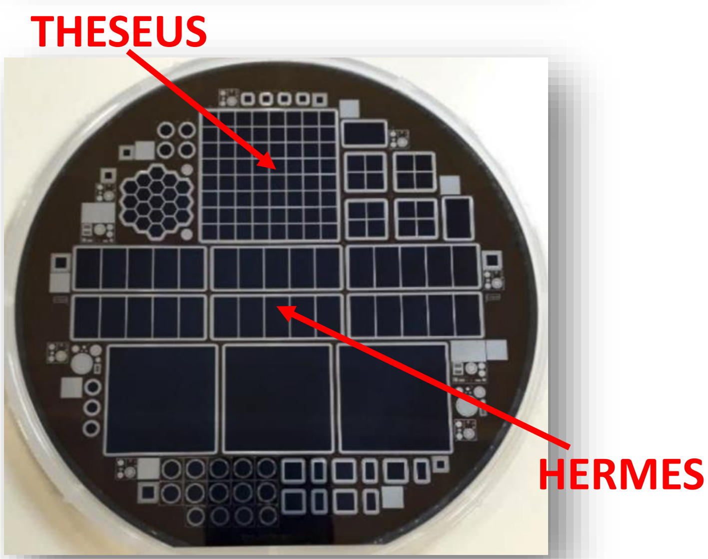
The *'mother'* of this kind of detectors



SDD design & production capability





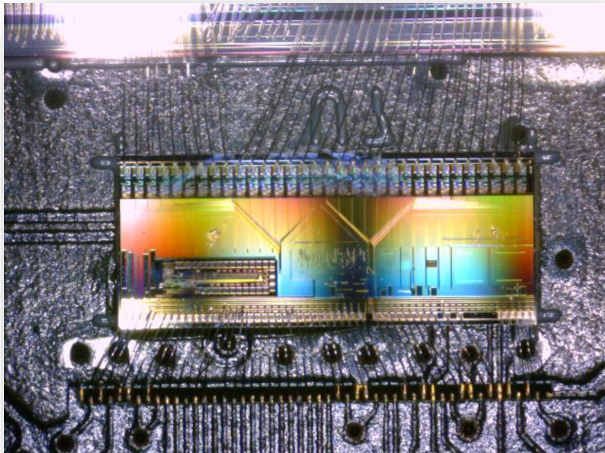


SDD production from REDSOX project (INFN) realized at Fondazione Bruno Kessler (FBK Trento) in 2016 (run 3).

The large central detector is an array of 3x3 SDDs, 1 cm^2 in size each

In Redsox run 3 the technology level reached ensures a leakage current of < 100 nA/cm^2

ASIC design (& production) capability

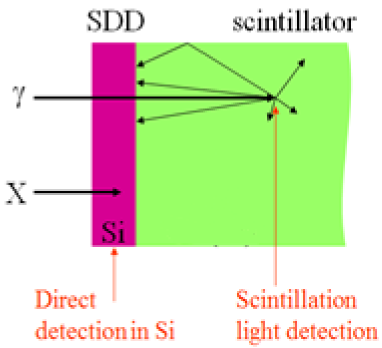


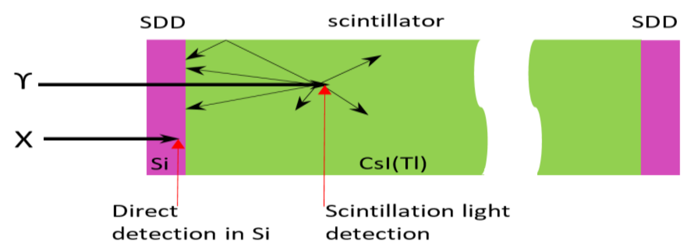
Starting point: the VEGA ASIC

- 32 channels, 200 µm input channel pitch
- Preamplifier: negative charge input, continuous reset, individual enable/disable for preamp and discriminator
- Configurable shaper (8 shaping times selectable, 0.5–10 µs range)
- Discriminator (8 bit global + 3 bit individual threshold) + Peak stretcher
- Triggering logic: single channel trigger, OR trigger, external trigger
- Multiplexed 32 channel single output
- Low power consumption: 0.5 mW/channel
- Noise ~ 20 e^- rms (with a LOFT-like SDD)
- AMS C35B4C3 technology

Detector plane operation principle

- Silicon Drift Detectors (SDD) optically coupled to a scintillator and acting both as **direct** X-ray detector and **photodiode**
- Detecting element (pixel) made of a **scintillator** with **double SDD readout** (top and bottom)
- Detecting elements arranged in an **array** configuration





HERMES

- GAGG(Ce) scintillator
- Size 12×7×15 mm^3
- 2 SDD readout on the same side

THESEUS

- CsI(Tl) scintillator
- Size 4.5×4.5×30 mm^3
- 2 SDD readout on the two sides

HERMES scientific and technical objectives

(see F. Fiore talk)

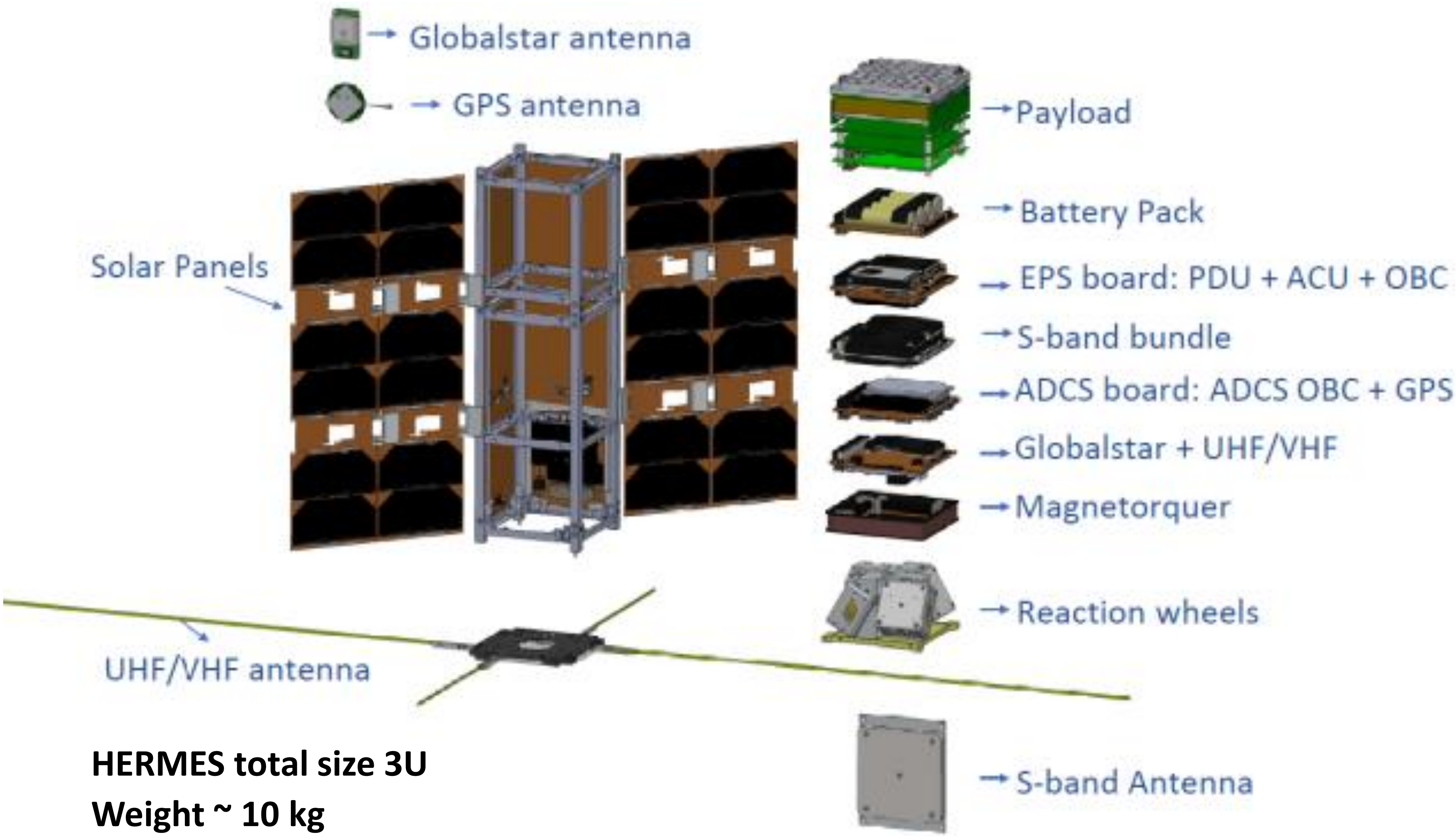
a) **the accurate and prompt localization of bright hard X-ray/soft gamma-ray transients such as Gamma-Ray Bursts (GRBs).** Fast high-energy transients are among the likely electromagnetic counterparts of the gravitational wave events (GWE) recently discovered by Advanced LIGO/Virgo, and of the Fast Radio Burst.

b) Open the window of timing down to a fraction of microseconds at X-ray energies, and thus **investigate for the first time the temporal structure of GRBs down to microseconds, to constrain models for the GRB engine.**

c) **Test quantum space-time scenarios by measuring the delay time between GRB photons of different energy**

1. **To prove the feasibility of GRBs detection with miniaturized payload on miniaturized SMs;**
2. **To compute the cross correlation function between the arrival time of the GRB signal on different detectors to study all relevant statistical and systematic errors.**

The HERMES nanosatellite

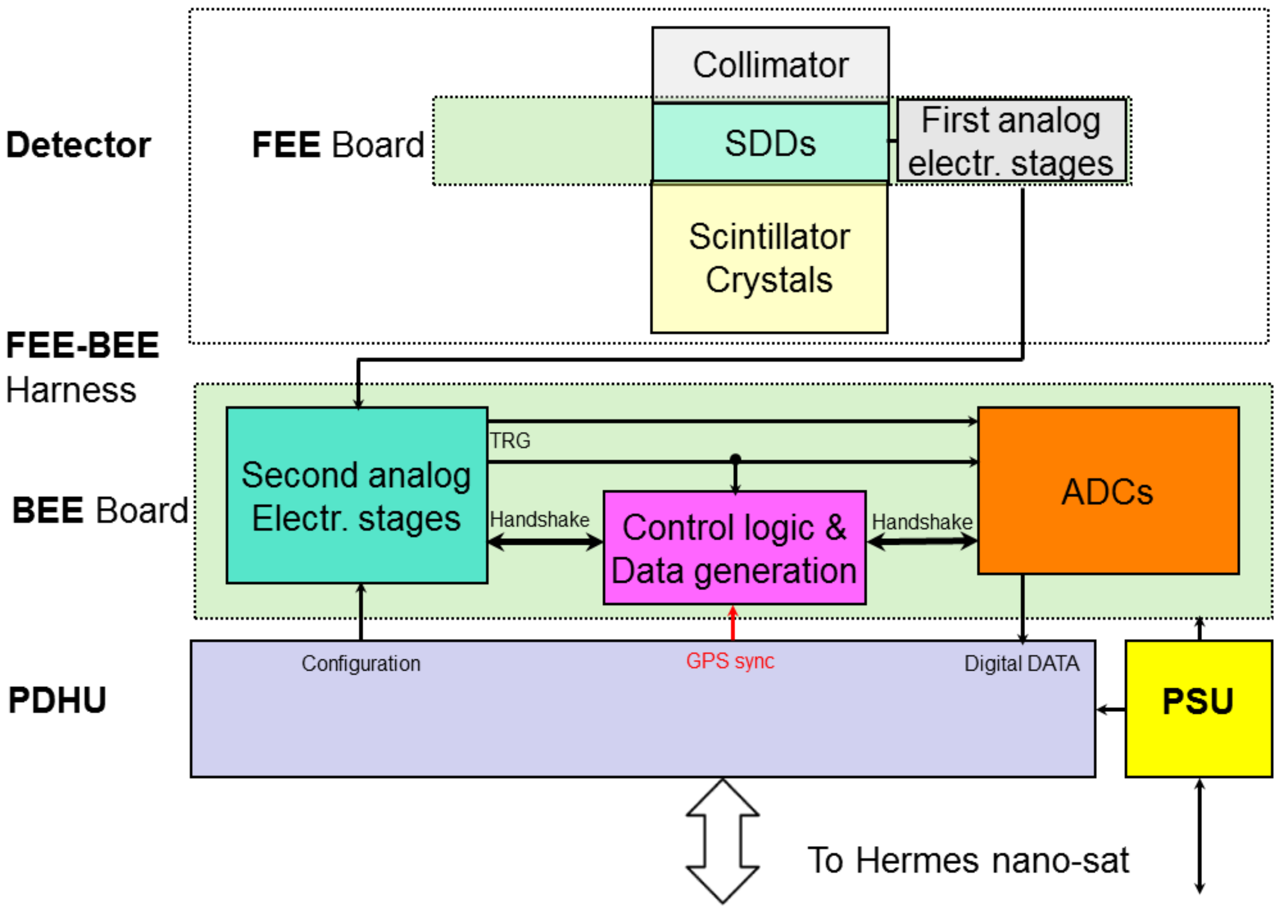


HERMES total size 3U
Weight ~ 10 kg

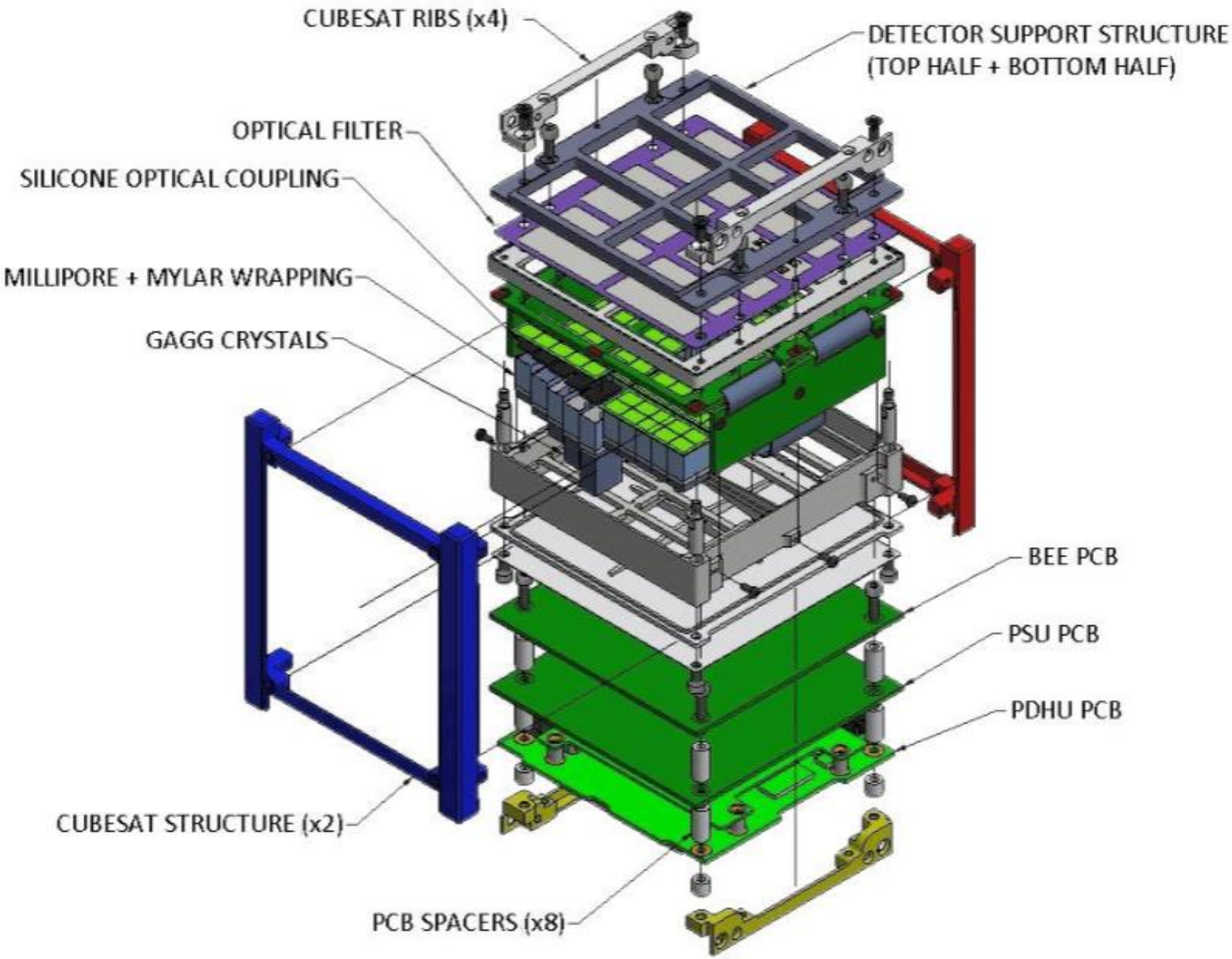
HERMES payload: some numbers

Requirement	Condition	Value
Sensitivity	3–20 keV (GRB short/long)	≤ 1–2 ph/s/cm^2
	50–300 keV (GRB short/long)	≤ 0.4–1 ph/s/cm^2
Peak effective area	X-mode	≥ 50 cm^2
	S-mode	≥ 50 cm^2
Lower energy threshold		≤ 5 keV
Energy resolution EOL	between 5.0 and 6.0 keV	≤ 1 keV FWHM
	between 50.0 and 60.0 keV	≤ 5 keV FWHM
Time resolution (1σ)	X-mode	≤ 400 ns
	S-mode	≤ 250 ns
Time accuracy (1σ)	GPS locked	≤ 100 ns
	GPS unlocked (up to 1500 s)	≤ 200 ns
Field of view		≥ 3 sr FWHM
Background rate 50–300 keV		≤ 1.5 counts/s/cm^2
Background rate 20–300 keV		≤ 12 counts/s/cm^2
Background knowledge		≤ 5%
Maximum sustainable GRB flux		40000 counts/s
On-board memory		≥ 16 Gbit
Mass allocation		< 1.8 kg
Volume allocation		≤ 1.25 U
Power allocation		≤ 5W
Detector operative temperature range		−30° C — +10° C
P/L non operative temperature range		−40° C — +80° C

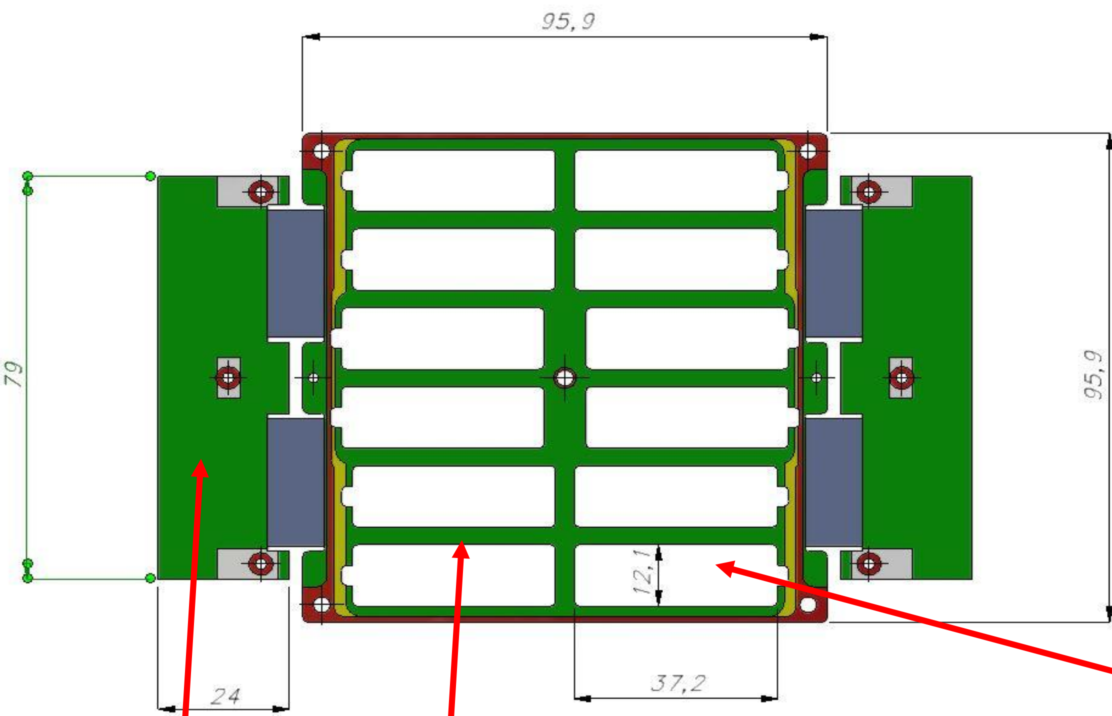
Payload Concept



HERMES payload

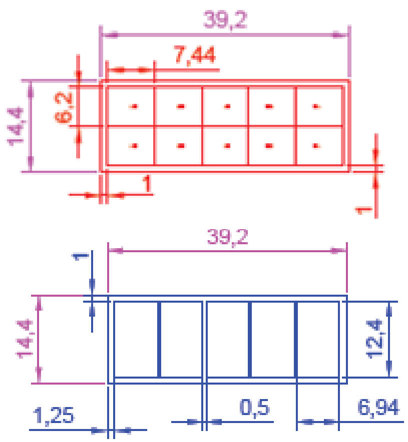


Top PCB details



SDD: 5x2 cells (x-ray)
5x1 Photodiode

n-side radiation input window



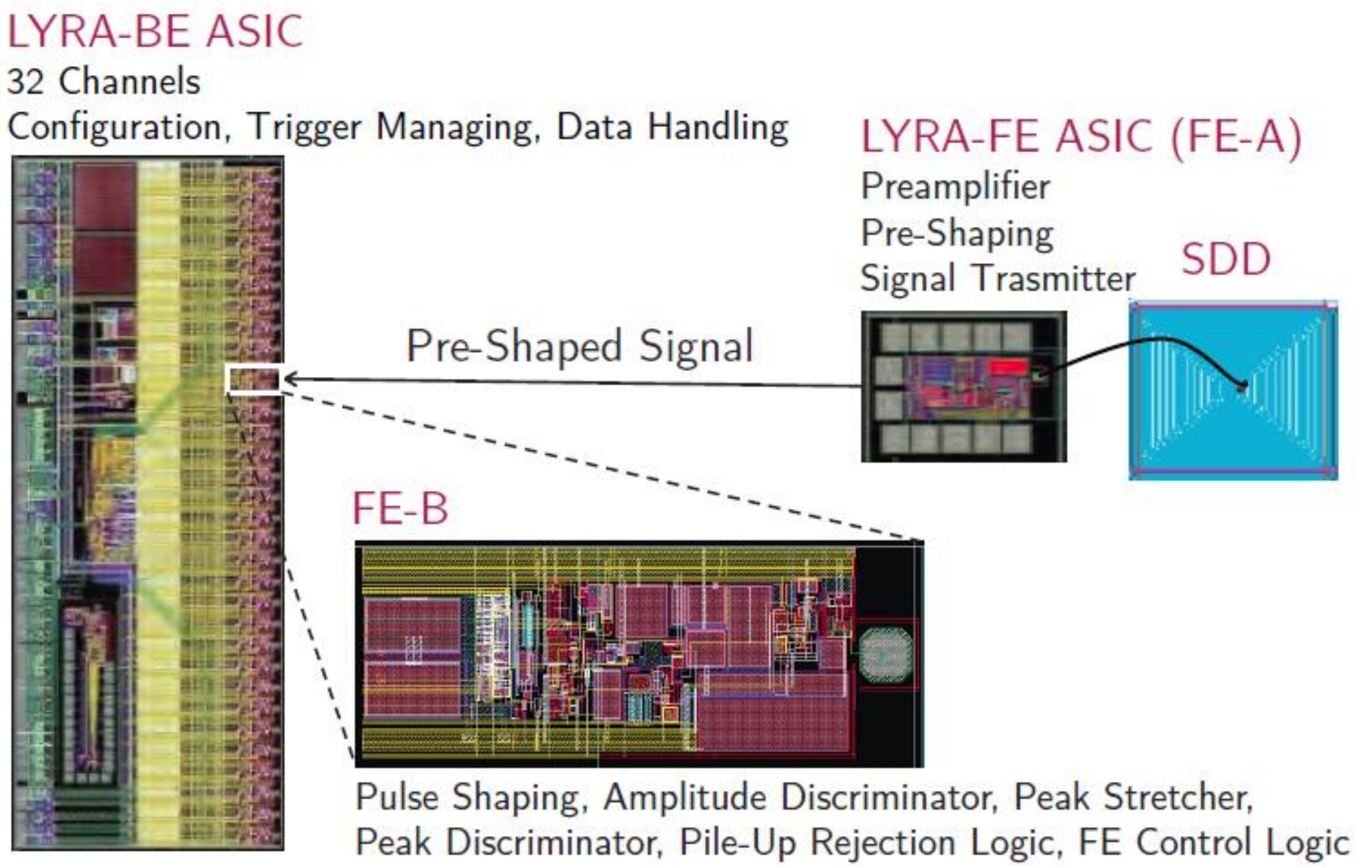
p-side coupled to scintillator

Pre-amp ASICs area

FEE ASICs area

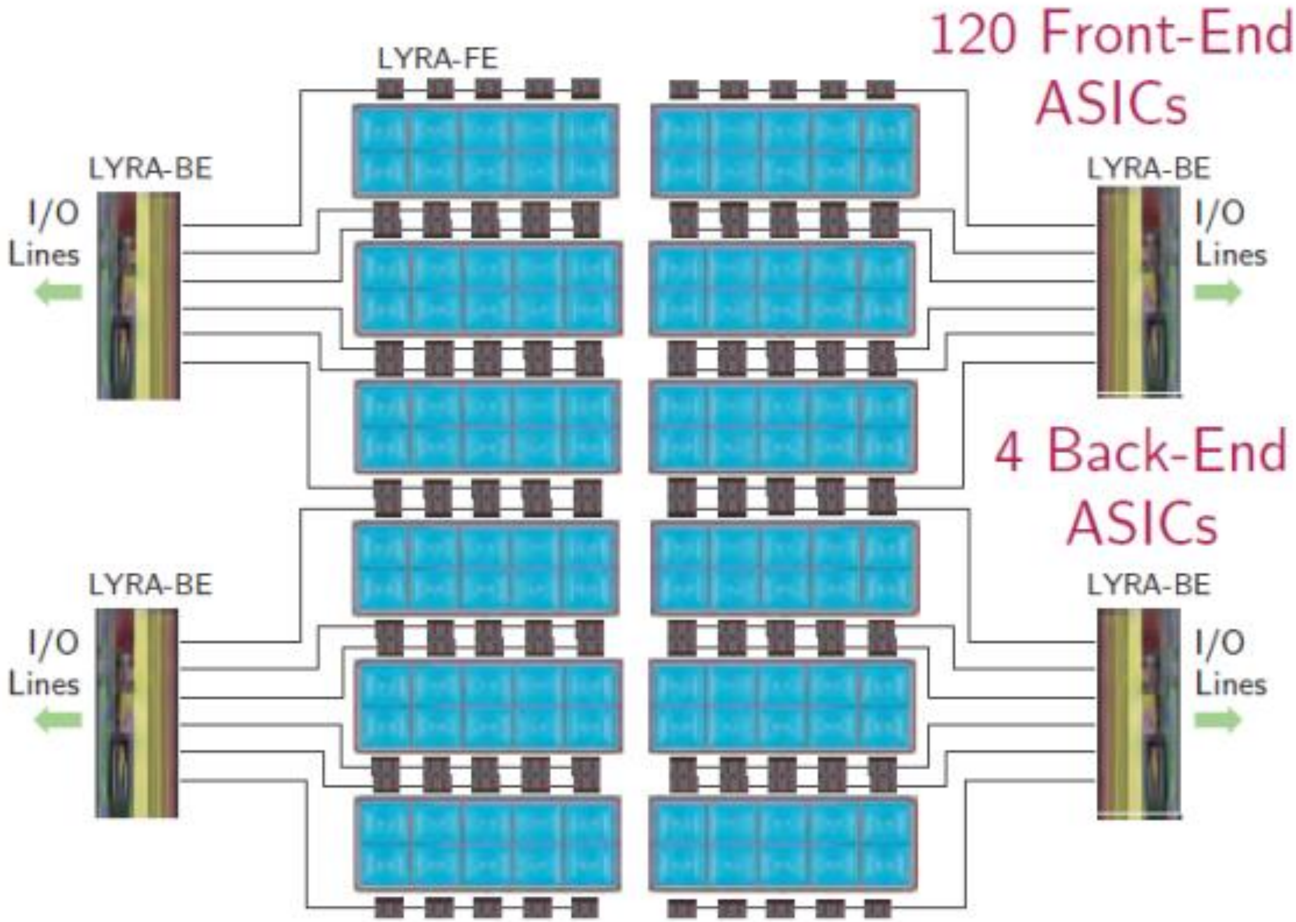
SDD and LYRA ASIC

LYRA ASICs — Block Diagram

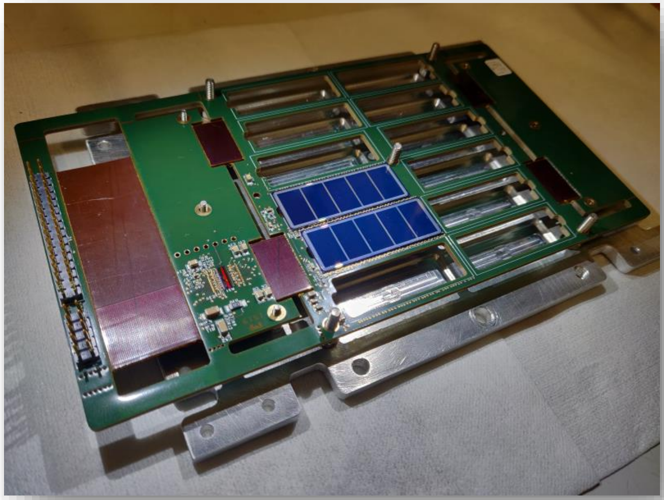


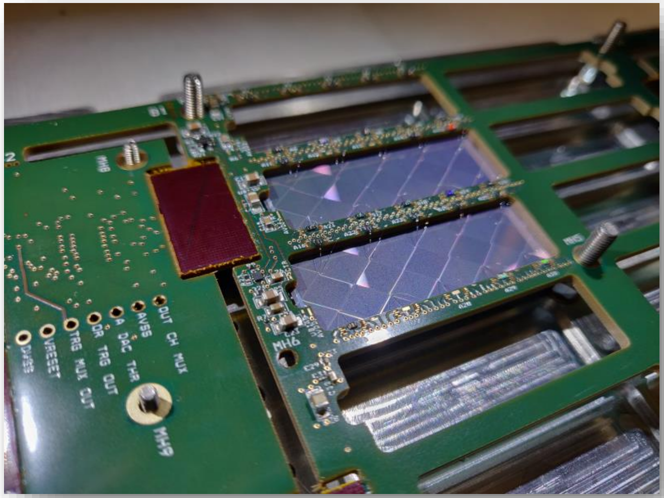
HERMES front-end electronics

LYRA ASICs — System Architecture

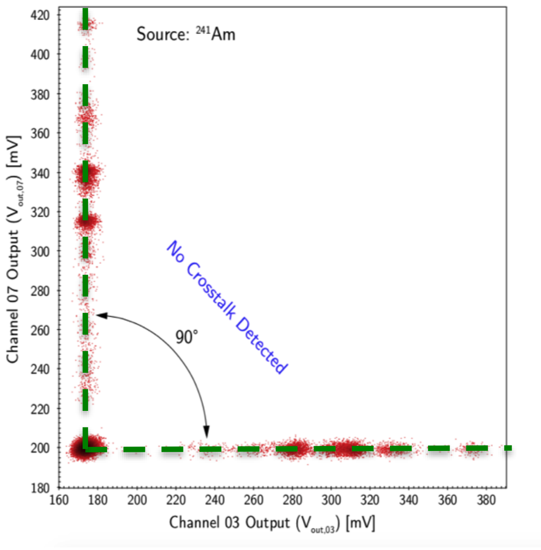


Bread-Board PCB (EM model)

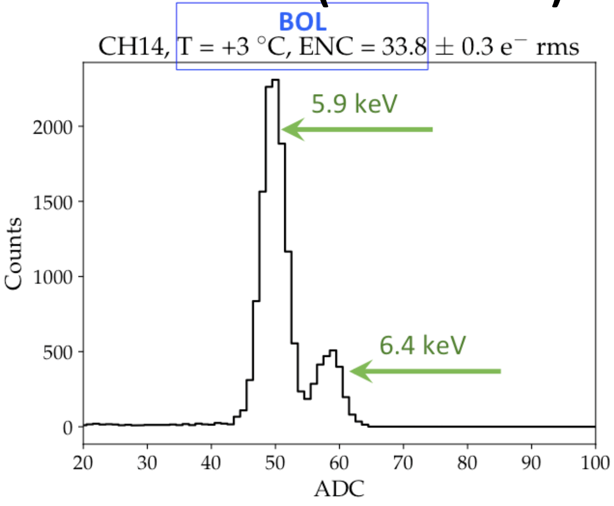




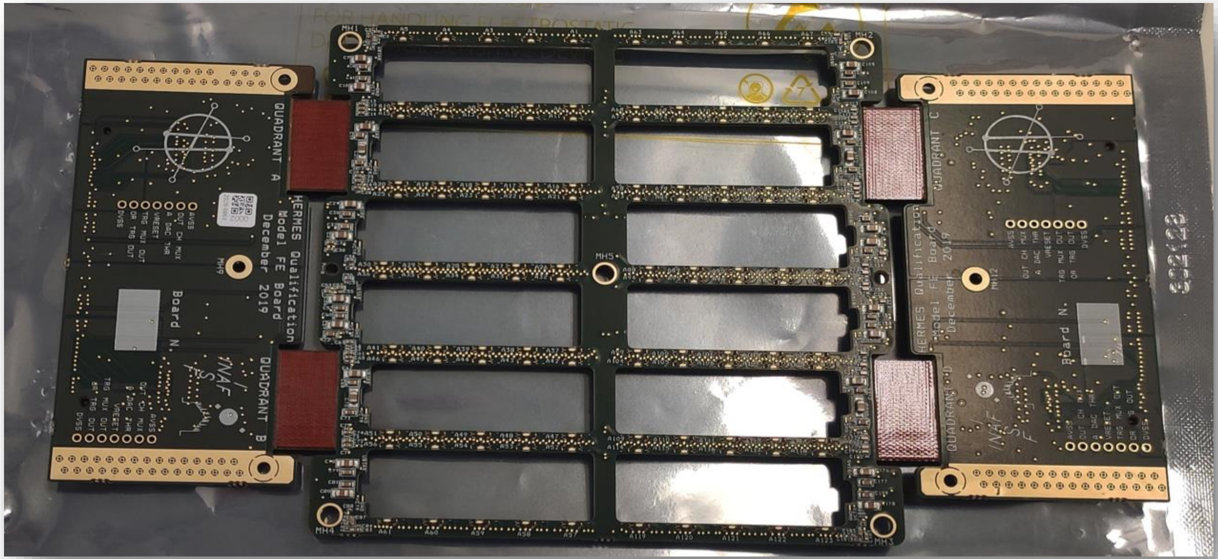
No Cross-Talk (PCB)



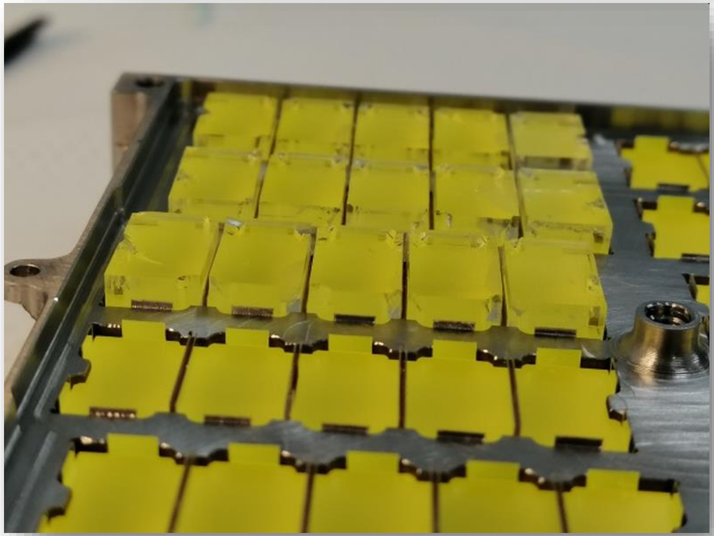
Performance verification (ASIC + SDD)

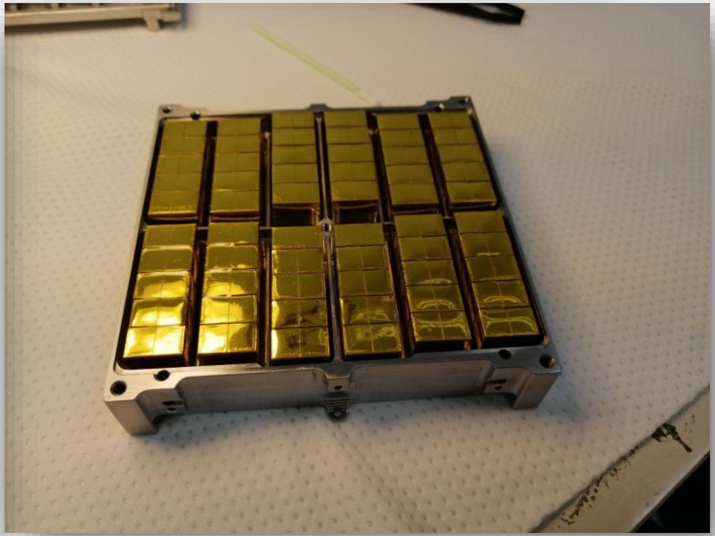


QM model



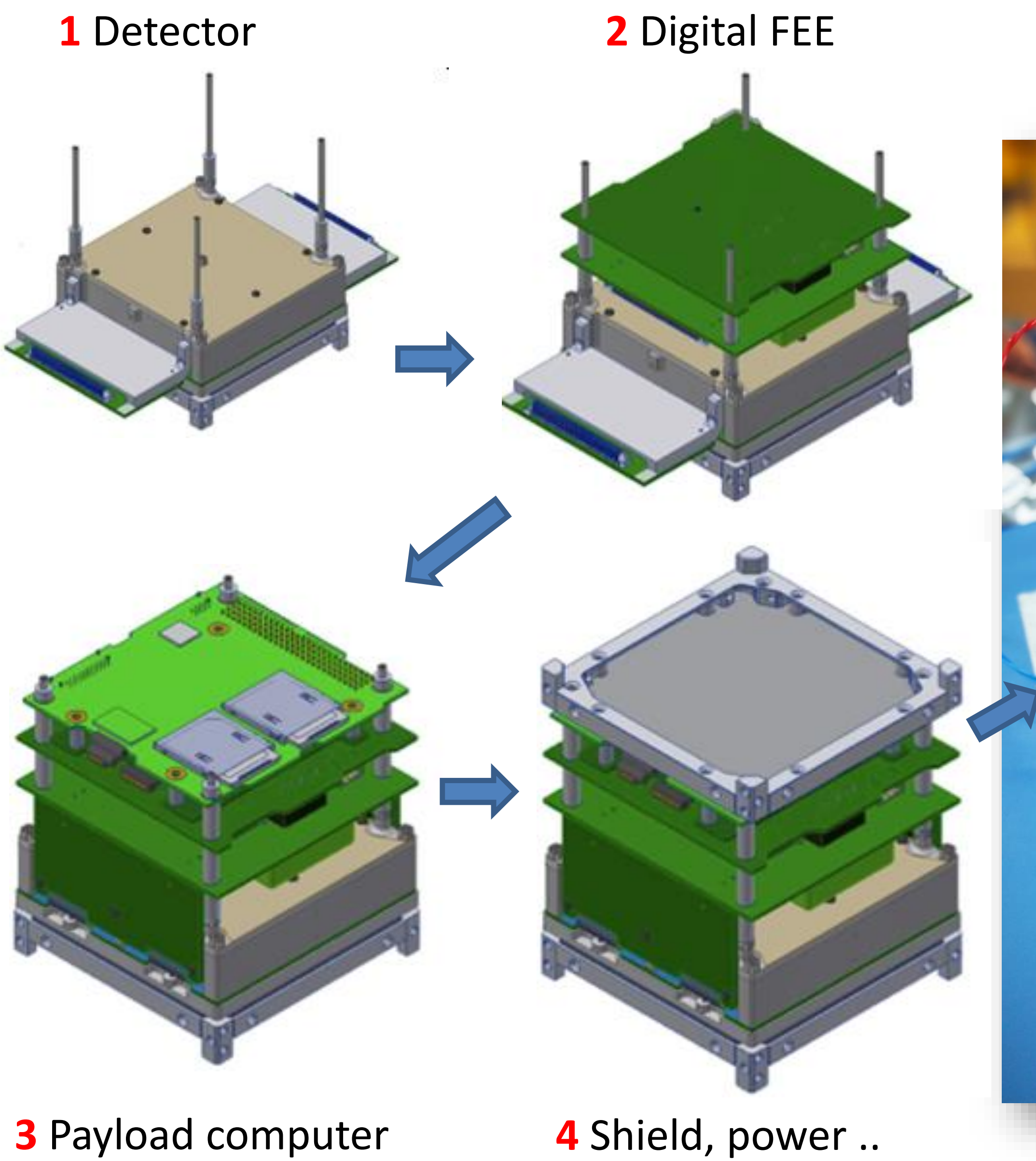
FEE-PCB
Top view





Crystal box

QM model


1 Detector
2 Digital FEE
3 Payload computer
4 Shield, power ..


Sept 2020
HERMES
SP

THESEUS scientific objectives
(see L. Amati talk)

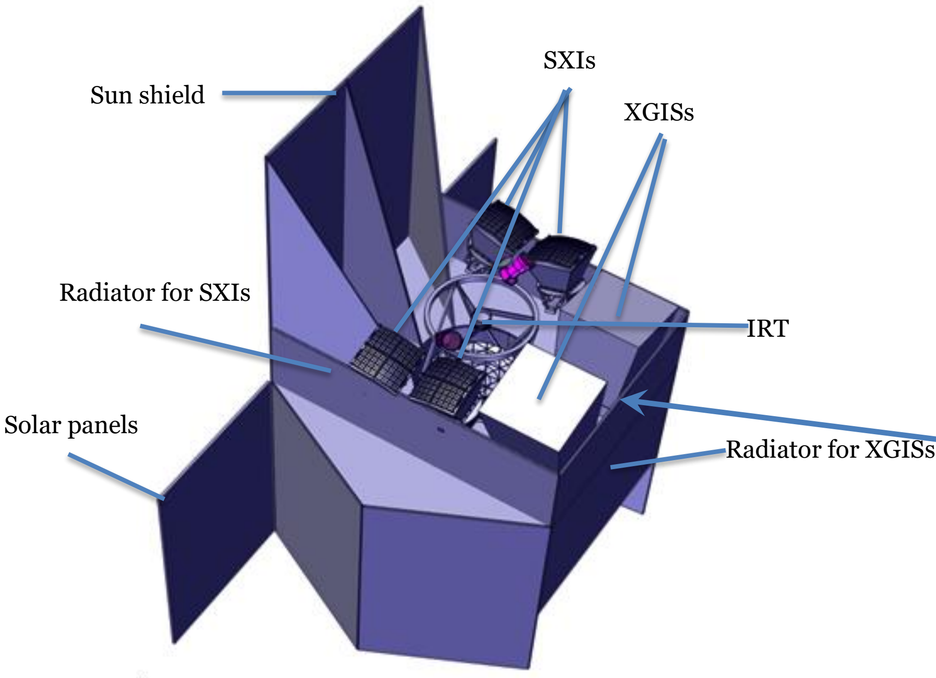
a) Explore the Early Universe (cosmic dawn and reionization era) by unveiling a complete census of the Gamma-Ray Burst (GRB) population in the first billion years. Specifically:

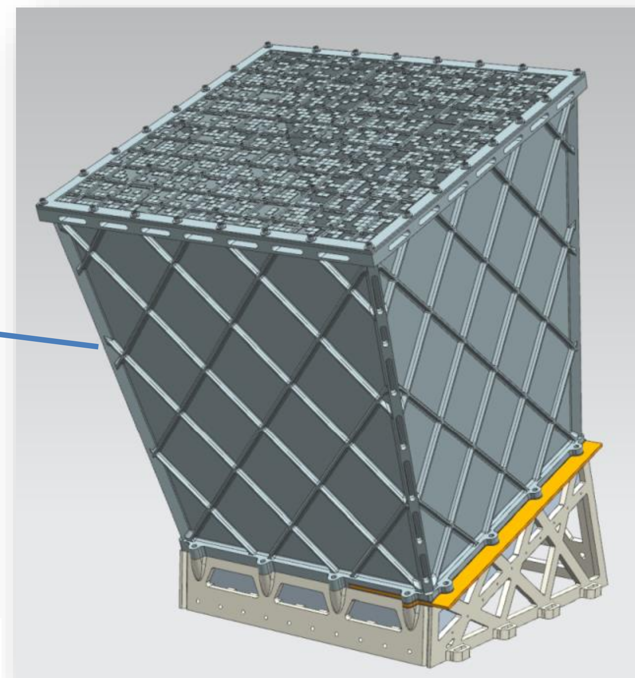
- Perform unprecedented studies of the global star formation history of the Universe up to z~10
- Detect and study the primordial (pop III) star population
- Investigate the re-ionization epoch, the interstellar medium (ISM) and the intergalactic medium (IGM) up to z~8-10
- Investigate the properties of the early galaxies and determine their star formation properties in the re-ionization era.

b) Perform an unprecedented deep monitoring of the X-ray transient Universe in order to:

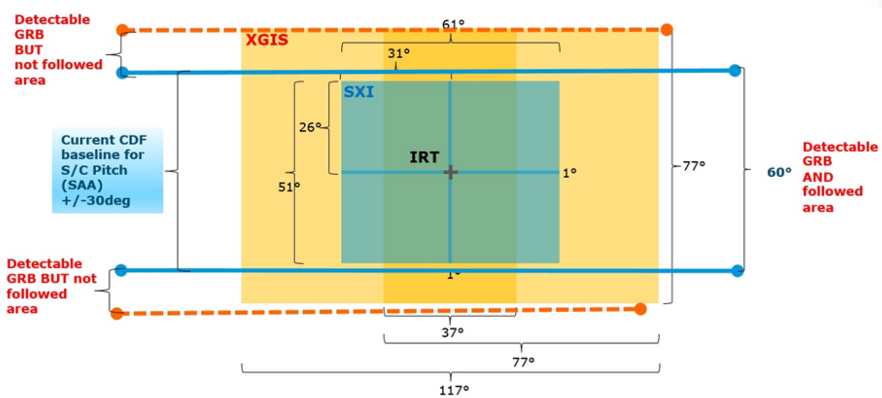
- Locate and identify the electromagnetic counterparts to sources of GW and high-energy neutrinos
- Provide real-time triggers and accurate locations of (long/short) GRB and high-energy transients for follow-up with next-generation optical-NIR (E-ELT, JWST if still operating), radio (ALMA, SKA), X-rays (ATHENA), TeV (CTA) telescopes;
- Provide a fundamental step forward in the comprehension of the physics of various classes of Galactic and extra-Galactic transients,
- Provide unprecedented insights into the physics and progenitors of GRB and their connection with peculiar core-collapse SNe and substantially increase the detection rate and characterization of sub-energetic GRB and X-Ray Flashes;
- Fill the present gap in the discovery space of new classes of high-energy transient events, thus providing unexpected phenomena and discoveries.

XGIS in THESEUS

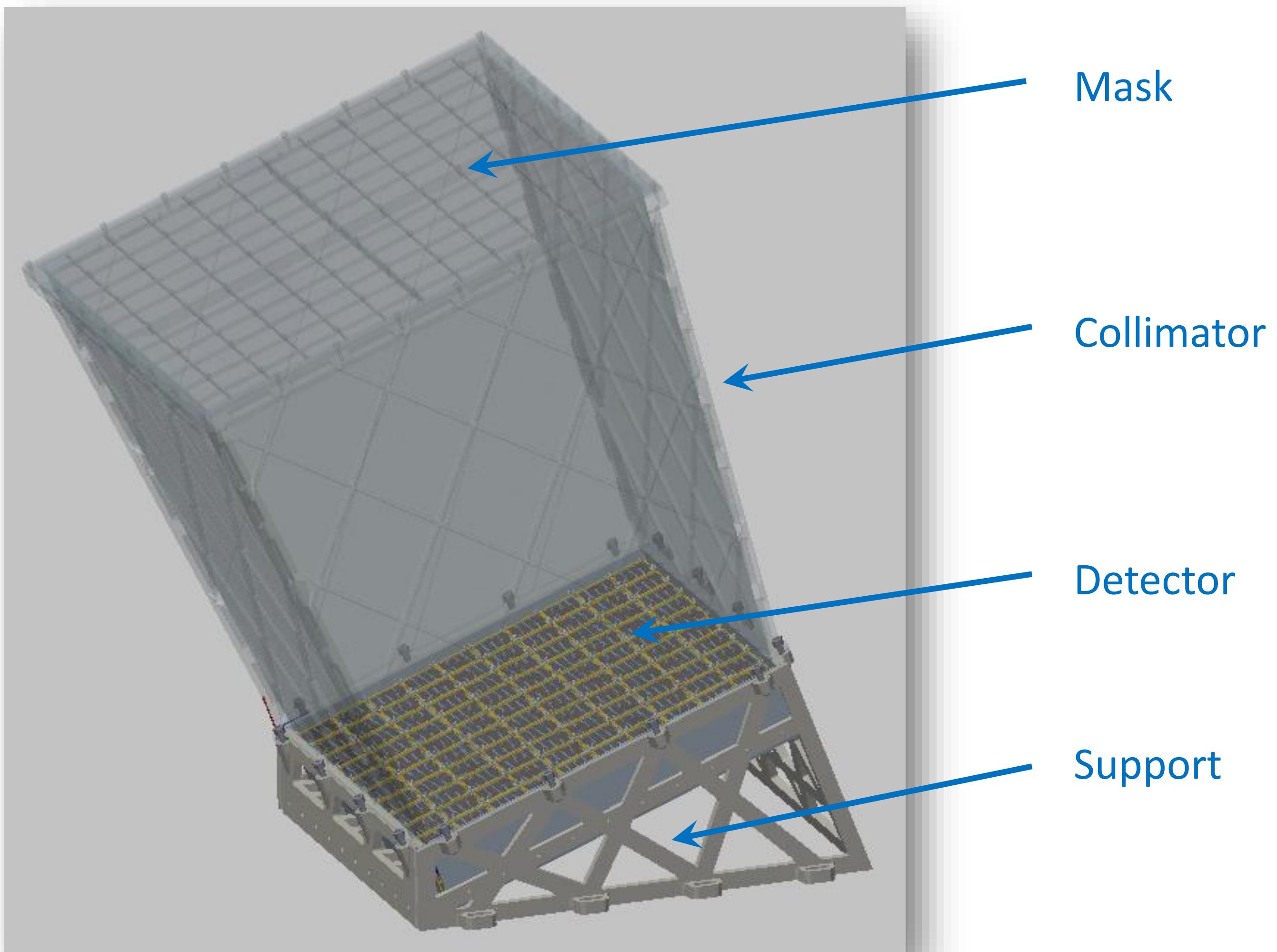




2 XGIS Camera



XGIS-camera mech. elements



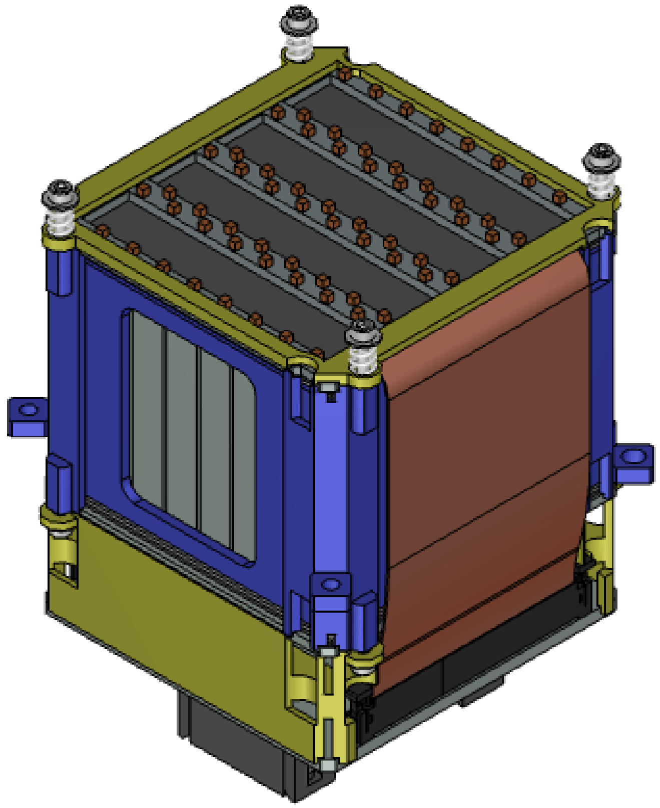
XGIS: some numbers

Energy range	$2 \div 150$ keV	> 150 keV (up to 10 MeV)
Fully coded FOV (FCFOV)	10.5 x 10.5 deg^2	
Partially coded FOV (PCFOV)	77 x 77 deg^2	
FOV		2π sr
XGIS sensitivity (two combined camera)	At EOL at least 10^{-8} cgs over the 2–30 keV E range in 1 s for 99.73% of the observations and at least 3×10^{-8} cgs over the 30–150 keV E range in 1 s for 99.73% of the observations	at least 3×10^{-7} cgs over the 150 keV–1 MeV energy range in 1 s for 99.73% of the observations
Angular resolution	60 arcmin	
Source location accuracy	≤ 7 arcmin 90% confidence level in the 2-150 keV energy band for a source with SNR > 7	
Energy res	≤ 1200 eV FWHM @ 6 keV	6 % FWHM @ 500 keV
Relative timing accuracy	1 μs	

Transient search with images and rate variation

Transient search with rate variation

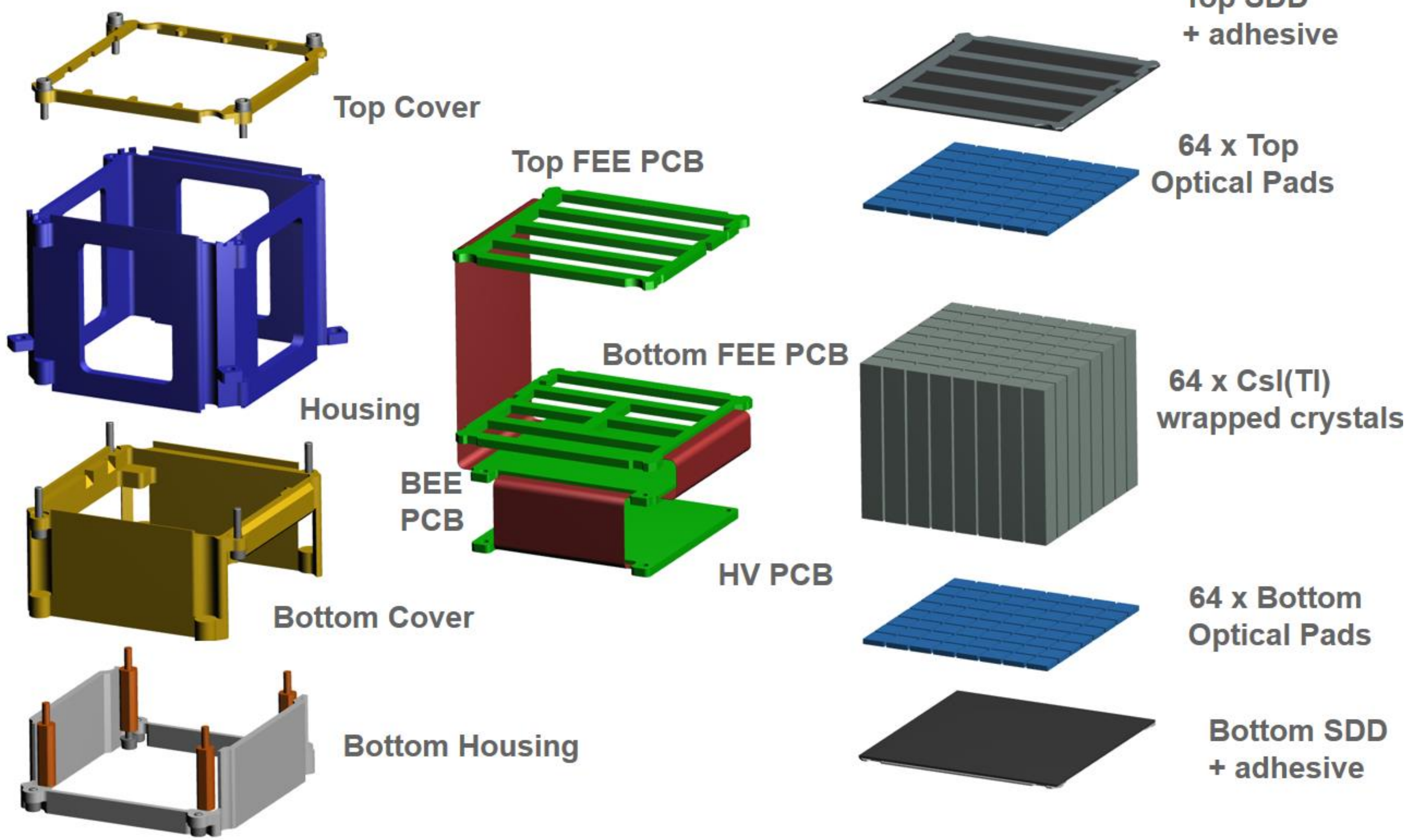
Basic detector element: the XGIS module



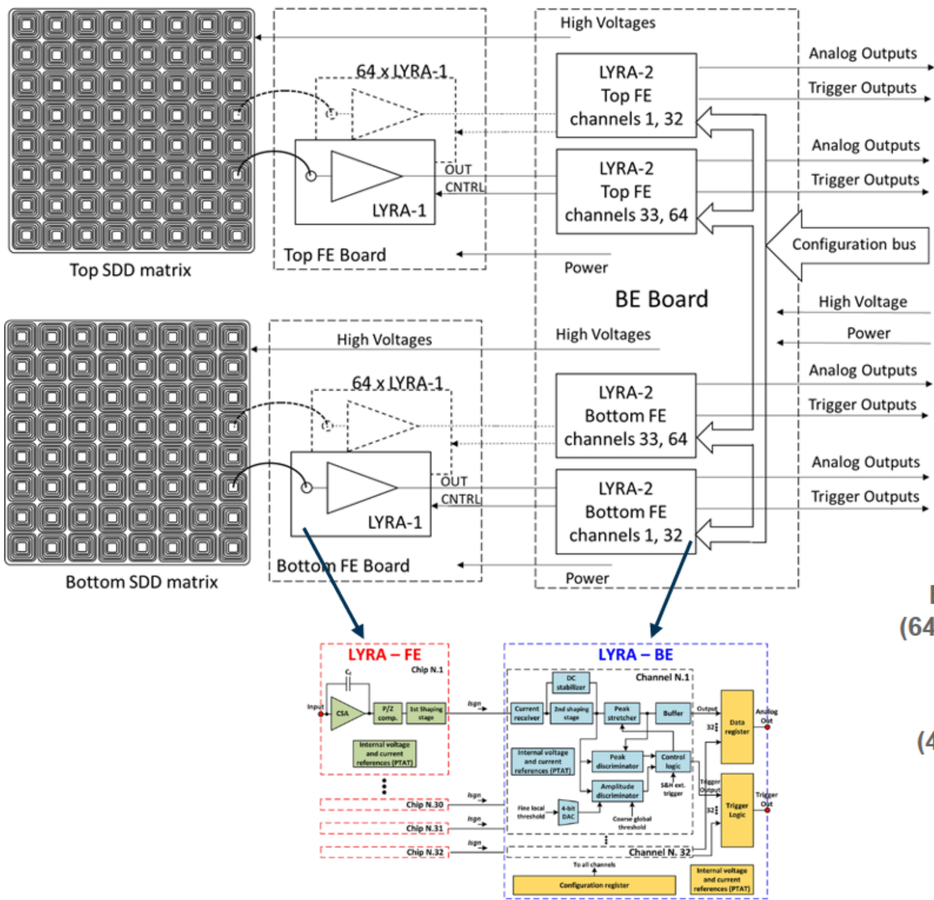
8×8 array of SDDs, CsI(Tl) scintillator and read-out ASICs

(the same LYRA-ASIC of the HERMES project, for time schedule reasons)

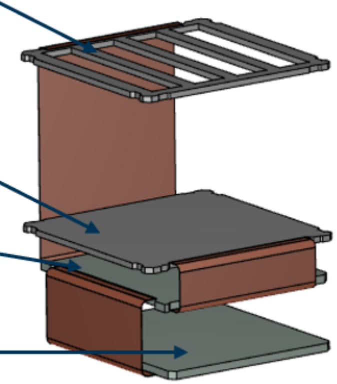
XGIS DM overview



DM Readout Electronics



Built around LYRA ASICs developed for HERMES mission



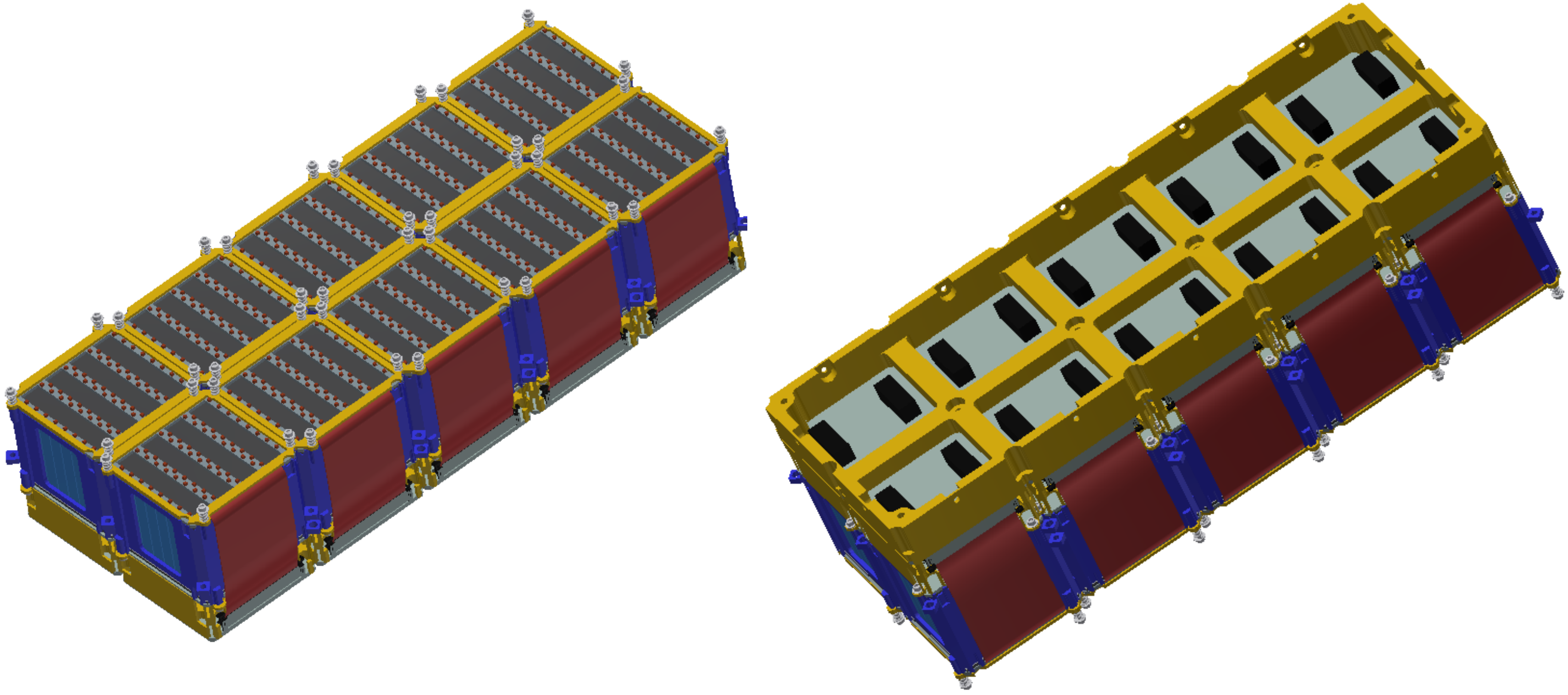
Top FE board
(64 x LYRA FE ASICs)

Bottom FE board
(64 x LYRA FE ASICs)

BE board
(4 x LYRA BE ASICs)

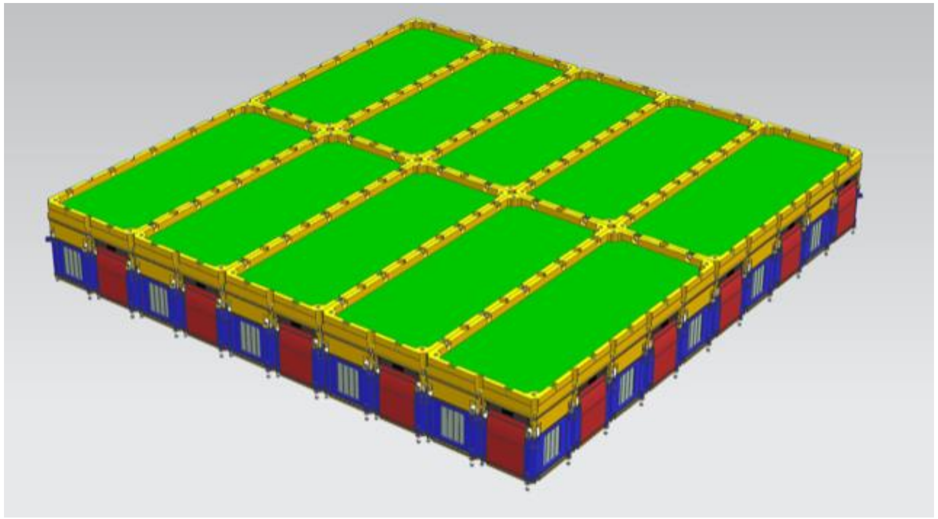
HV board

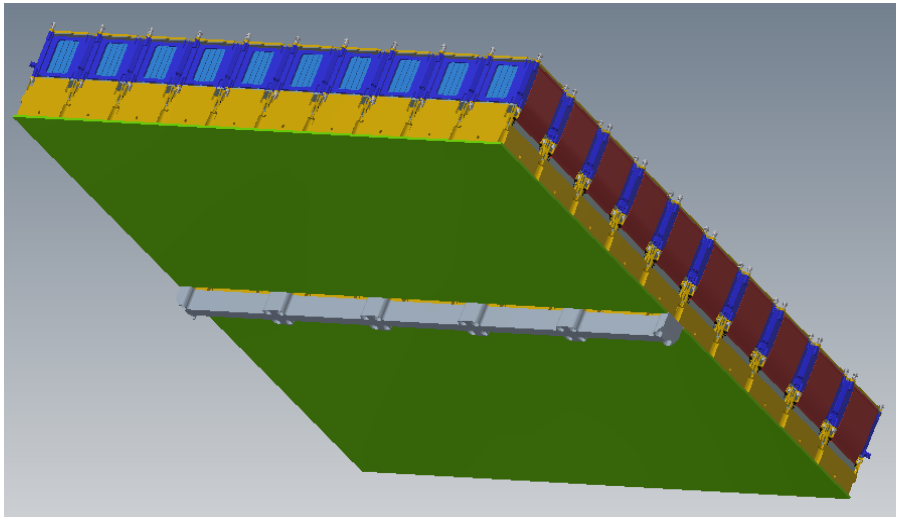
The Super-Module concept



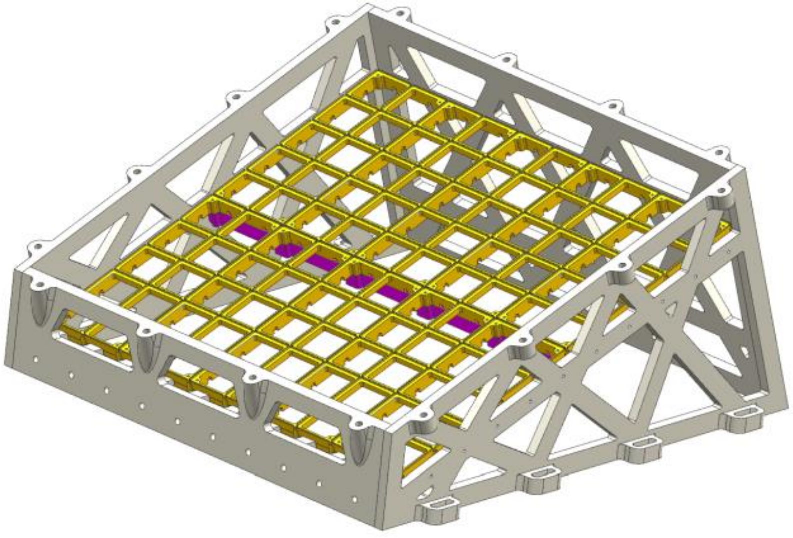
10 modules are assembled in 1 Super-Module with a common service electronics (Power-Supply and FPGA) hosted in a board below the Super-Module (not shown)
A Super.Module mechanical grid support and position the modules

The whole XGIS: the detector plane





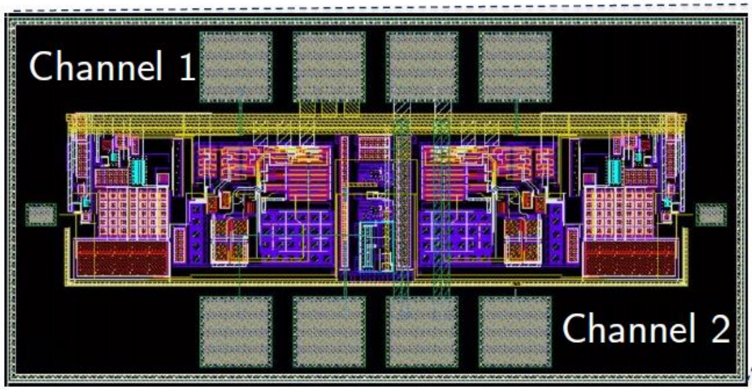
- The Super-Module grids are bolted together in the detector plane
- At the bottom is the I/F board between Super-Modules and the rest of the system
- The assembled Super-Module grids are fixed to the camera support



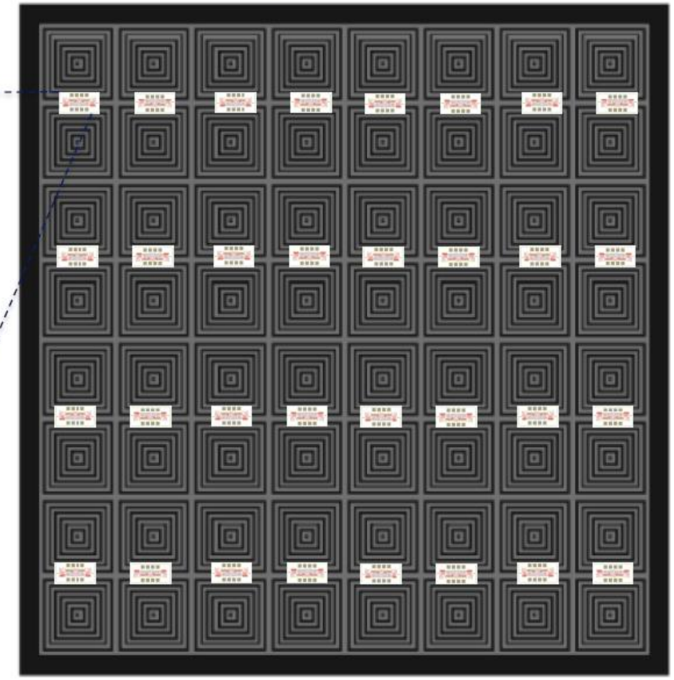
XGIS Instrument — Detector-ORION ASICs Interconnection

ORION- FE ASIC (Front-End)

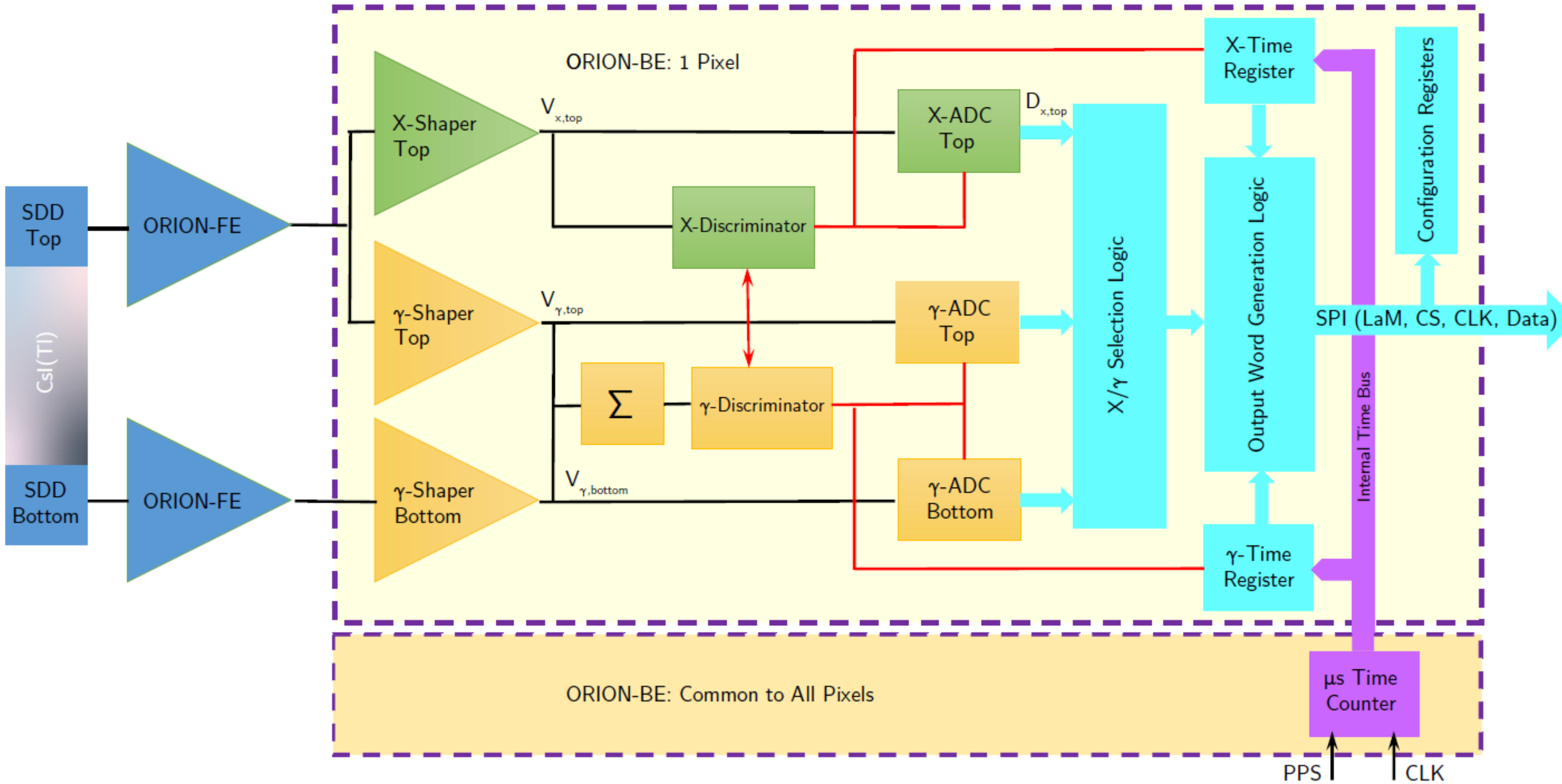
0.49 mm x 0.99 mm



XGIS Module
Detector Array + ORION-FE ASIC



ORION ASIC — Architecture



ORION ASIC — Architecture

- Output data format → 64 bits (62 bits used)

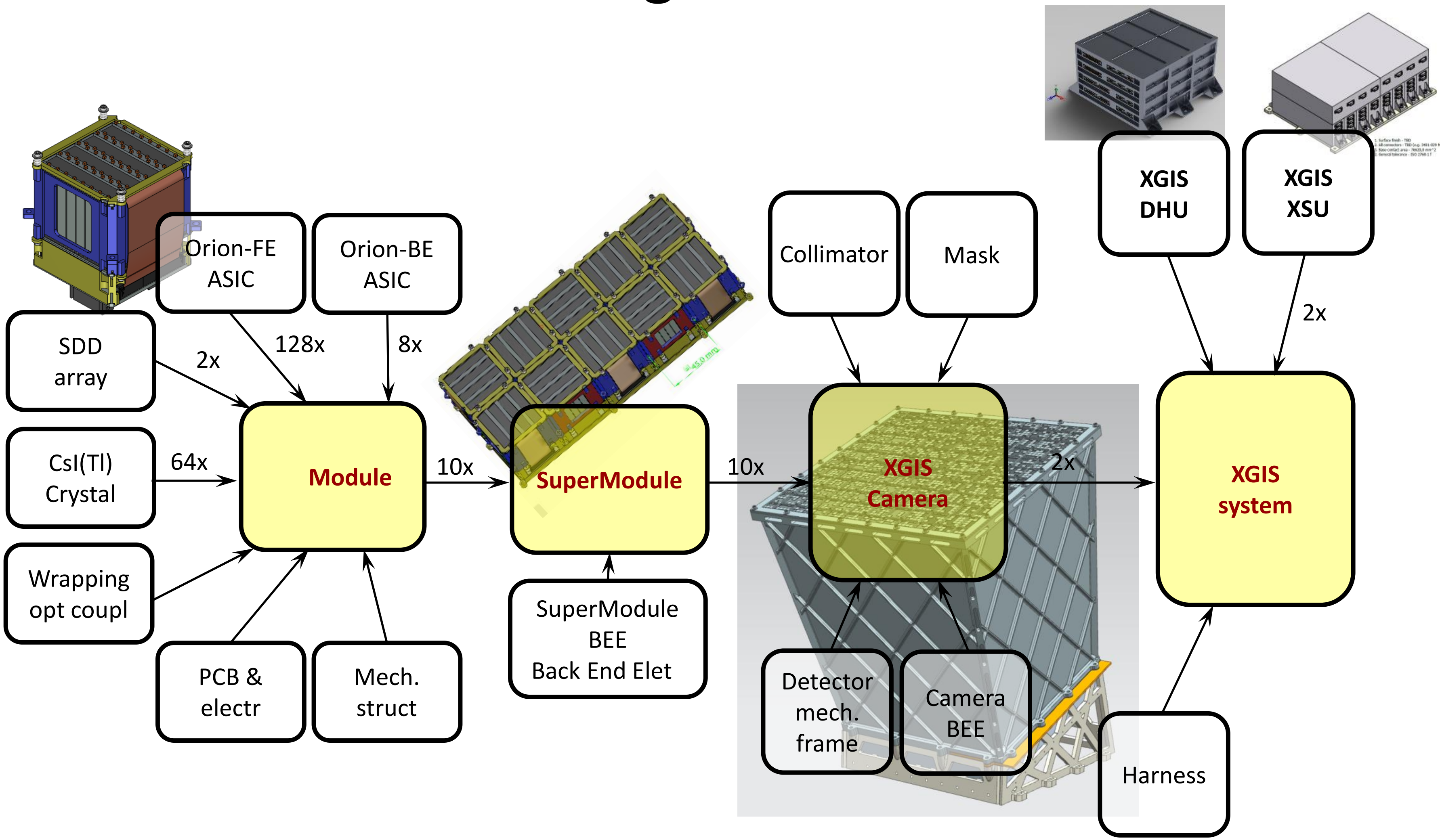
D_{bottom} (16)	D_{top} (16)	X-γ (1)	T_{γ} (1)	T_{X} (1)	Address (3)	Time (24)

- X-/γ-ray discrimination

Event Type	Time	X-γ	D_{bottom}	D_{top}
X	X-Time	1	0	$D_{X,top}$
γ	γ-Time	0	$D_{\gamma,bottom}$	$D_{\gamma,top}$

- Output interface (bidirectional SPI) → Four wires
  - LaM (Look at Me) → Valid data available
  - CS → Chip select
  - CLK (Clock) → Synchronization signal
  - Data → Bidirectional data transmission

XGIS design elements



XGIS product tree