THE X-GAMMA IMAGING SPECTROMETER (XGIS) ONBOARD THESEUS

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on behalf of the XGIS team
INAF/IASF-Bologna
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The XGIS instrument

A sensitive broadband X and γ-ray instrument is needed to

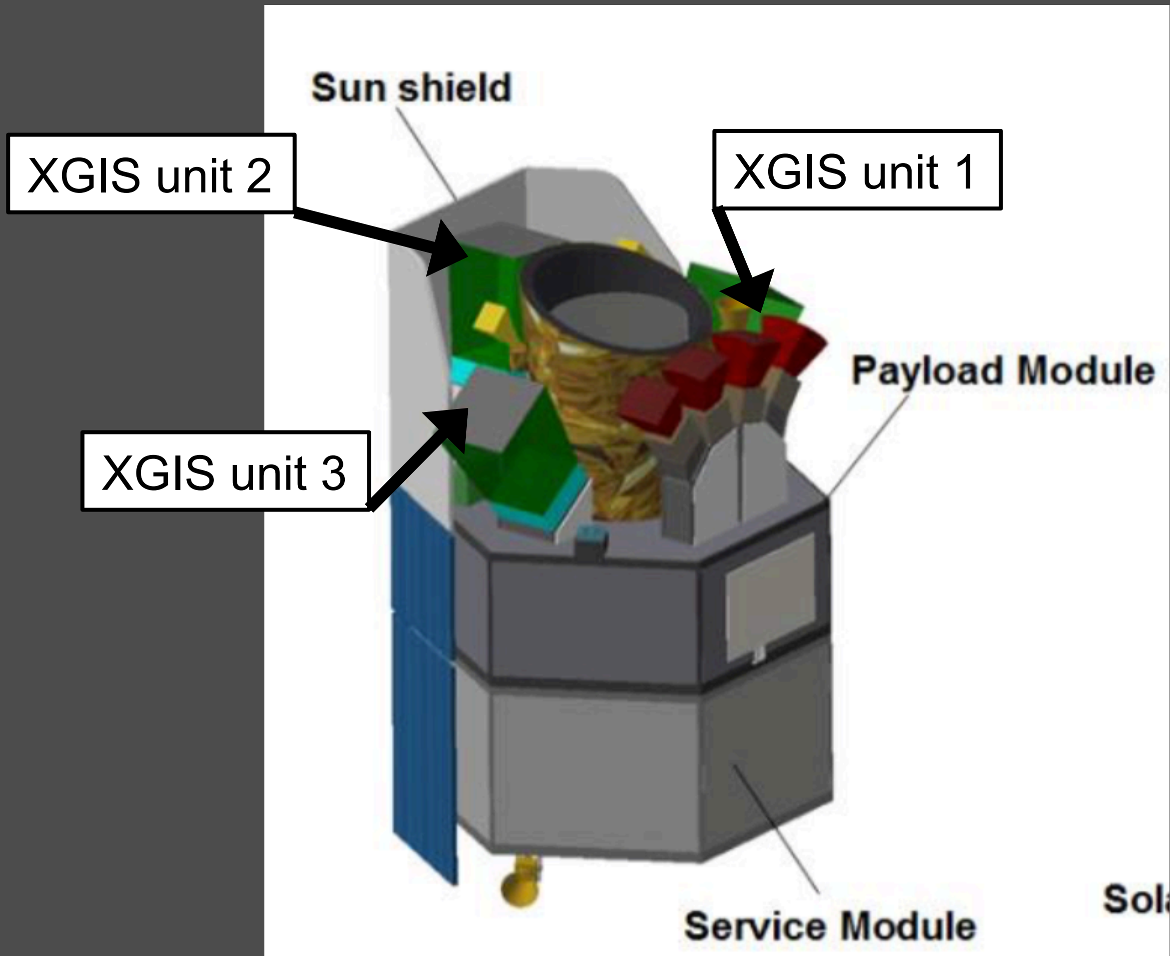
- Reliably **identify** GRBs and other transients
- Measure GRBs and other transients on **short** (μs to ms) time scales, providing high energy **light curves**
- Provide their **spectroscopic** characterisation
- **Extend** the soft X-ray band of SXI up to MeV energies
- Provide a simultaneous and **independent trigger** with ~arcmin localisation capabilities

The XGIS instrument

XGIS baseline

- **3 instruments (units)** pointing in different directions
- Each unit has 4 detection modules based on solid-state detectors and scintillators: **SDD+CsI(Tl)**
- Twice the **FoV** of SXI
- Energy band **2 keV – 20 MeV**
- **Imaging capabilities at low energies** (2–30 keV) using a coded mask
- **Restricted FoV at intermediate energies** (30–150 keV) using a FoV delimiter
- **~Isotropic detection capabilities at high energies** (150 keV – 20 MeV)

XGIS location onboard THESEUS

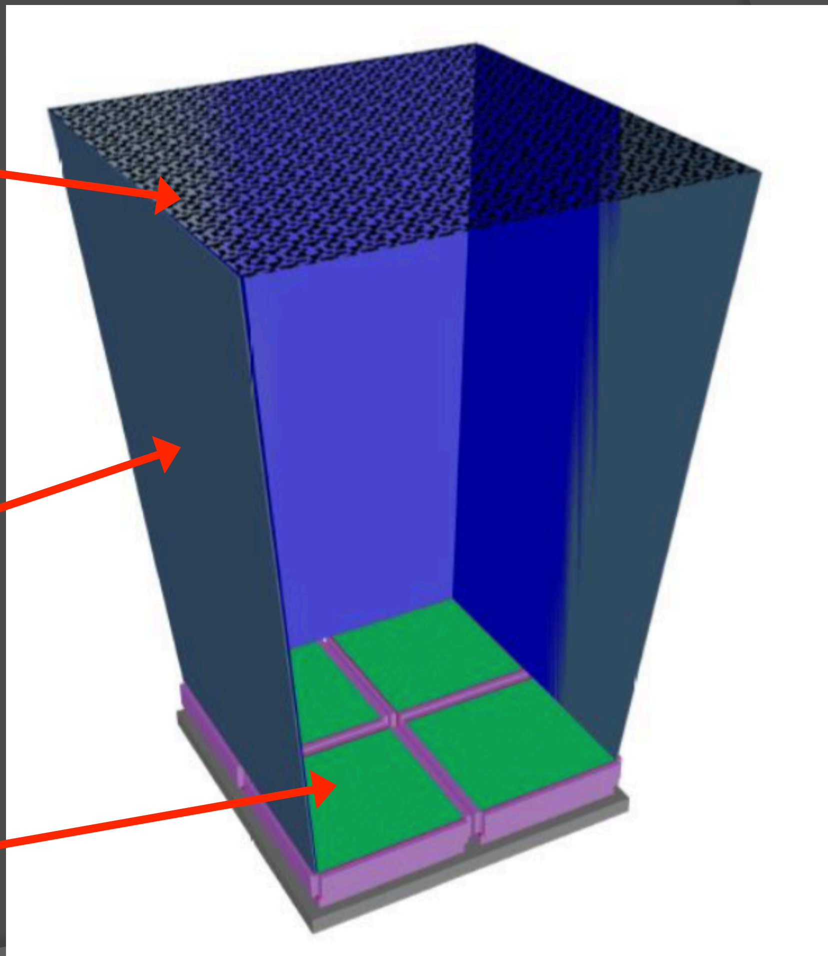


The XGIS instrument: one unit

Coded mask
Provides imaging capabilites below ~30 keV

Collimator
Shields the FoV below ~150 keV

Detection plane
2×2 modules, SDD+CsI



One XGIS unit at a glance - 1

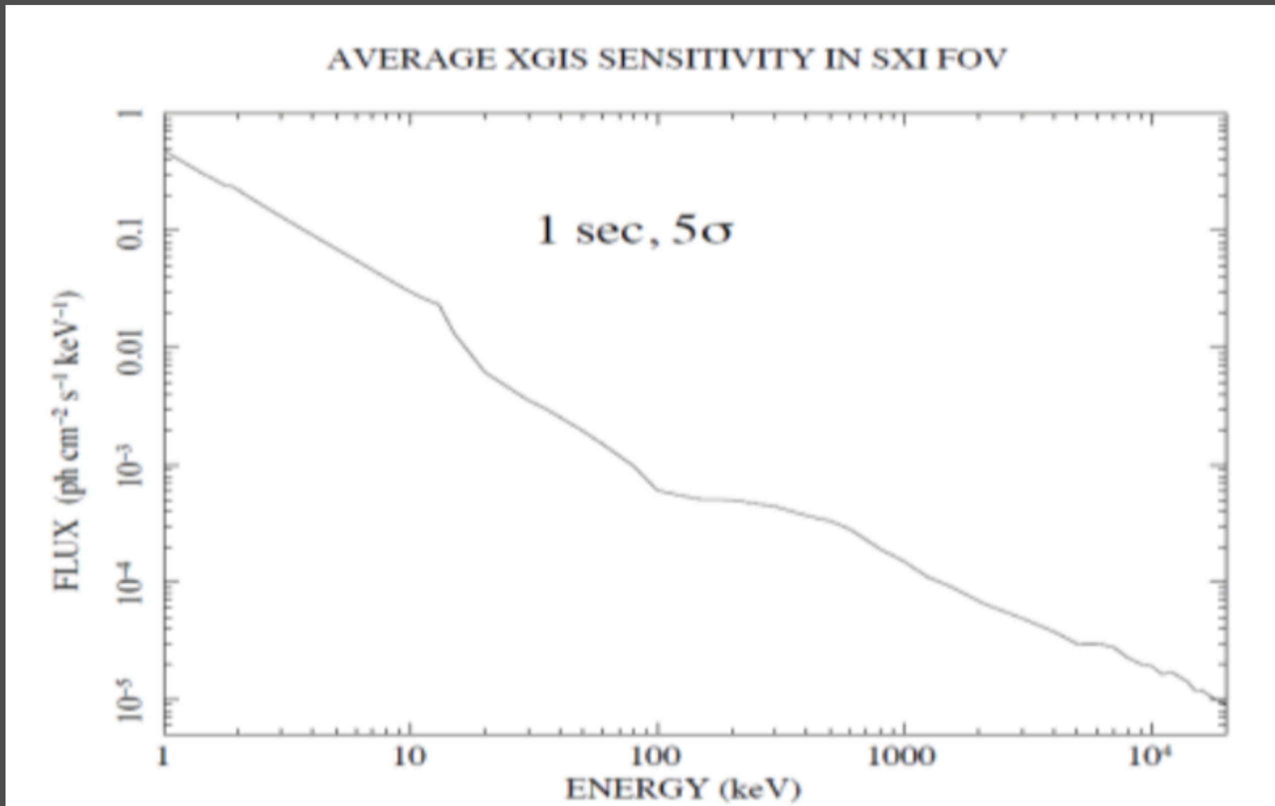
Energy band	2 keV – 20 MeV
# of detection plane modules	4
# of pixels per module	32×32
Pixel size = Mask element size	5 mm × 5 mm
Low Energy detector (2-30 keV)	Silicon Drift Detector (SDD)
High Energy detector (>30 keV)	CsI(Tl) scintillator, readout by SDD
Discrimination of LE/HE events	Pulse shape analysis
Size [cm]	50 × 50 × 85
Power [W]	30
Weight [kg]	37.3
Typical telemetry load	2 Gbit/orbit

One XGIS unit at a glance - 2

	2-30 keV	30-150 keV	>150 keV
Fully coded FoV	9×9 deg^2		
Half sens. FoV	50×50 deg^2	50×50 deg^2 (FWHM)	
Total FoV	64×64 deg^2	85×85 deg^2 (FWZR)	~2π sr
Angular resolution	25 arcmin		
Source loc. accuracy	5 arcmin @>6σ		
Energy resolution	200 eV FWHM @6 keV	18% FWHM @60 keV	6% FWHM @500 keV
Timing resolution	1 μs	1 μs	1 μs
On-axis area	512 cm^2	1024 cm^2	1024 cm^2

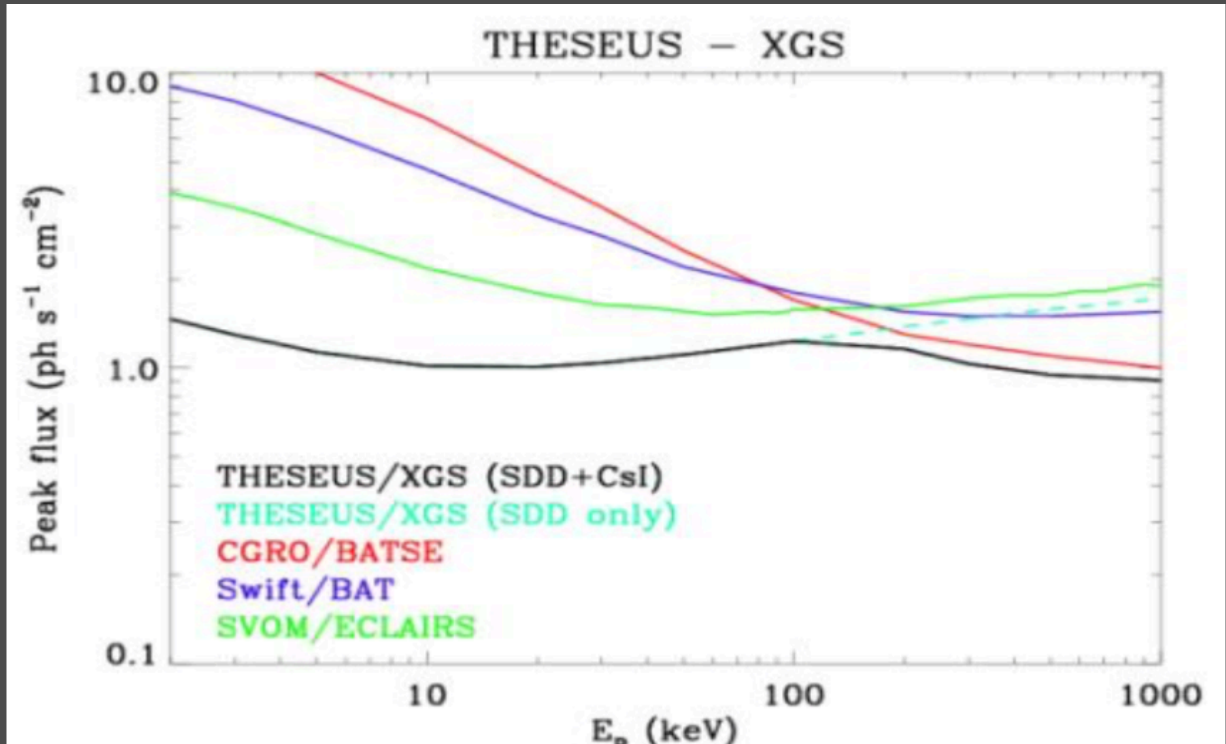
Performance

XGIS sensitivity in 1 second (5σ level)



Performance

Sensitivity of the XGIS to GRBs in terms of **minimum detectable photon peak flux in 1s** (5σ) in the **1-1000 keV** energy band as a function of the spectral peak energy



*The combination of **large effective area** and unprecedented **large energy band** provides a **much higher sensitivity** w/r to previous (e.g., CGRO/BATSE), present (e.g., Swift/BAT) and next future (e.g., SVOM/ECLAIRS) in the soft energy range, while keeping a very good sensitivity up to the MeV range.*

Trigger logic

- XGIS will **qualify** SXI triggers
  - Find XGIS unit corresponding to SXI trigger location and look for an excess in count rates
- **Autonomous** trigger capability
  - **Ratemeters** on different time scales (e.g. 10 ms, 100 ms, 1 s, 10 s) and energies
  - **Image deconvolution** in 2-30 keV (accumulates an image in a certain time scale, comparing with previous ones looking for significant excesses)

See also Filippo's talk

The coded mask and FoV delimiter

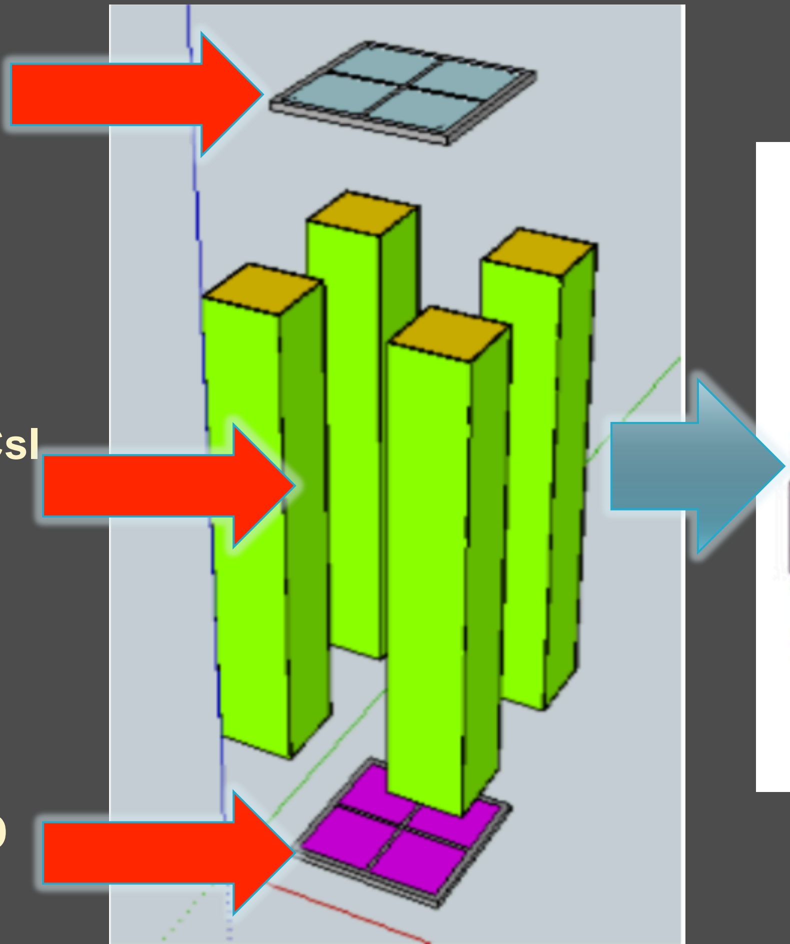
The **coded mask** of each XGIS unit is:

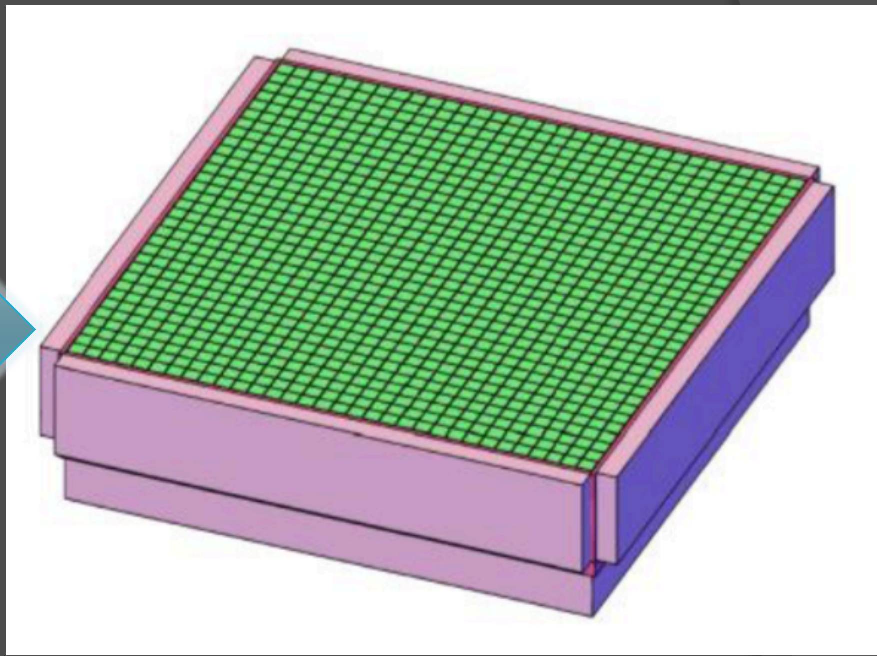
- placed **70 cm** above the detector modules
- made of **stainless steel of 0.5 mm** thickness
- has an overall size of **50×50 cm^2**
- **self supporting pattern** (to guarantee the maximum transparency of the open elements)

The **mechanical structure** connecting the mask with the detector is

- made of **stainless steel** 0.1 mm thick supporting 4 **tungsten** slats 45 cm high with a variable thickness (0.5-0.3 mm).
- will act as a **lateral passive shield** for the **imager** system (2-30 keV) and as a **FOV delimiter** at energies >150 keV.
- By combining the three units, with an **offset of ±35°** for two of them, the FOV delimiter guarantees an **average XGIS effective area of ~1400 cm^2 in the SXI FOV (104×31 deg^2).**

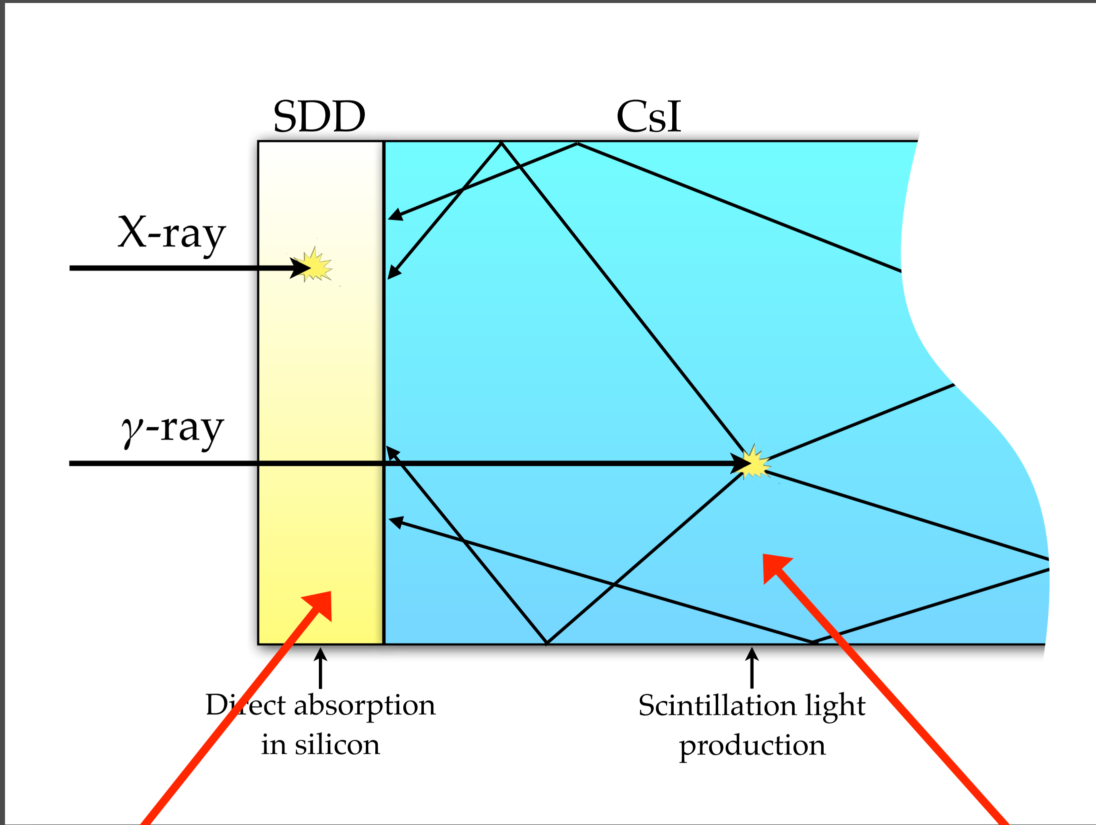
The detection module





32×32 array of single pixels
Surrounded by the FEE
Dimensions 19.5×19.5×5 cm^3

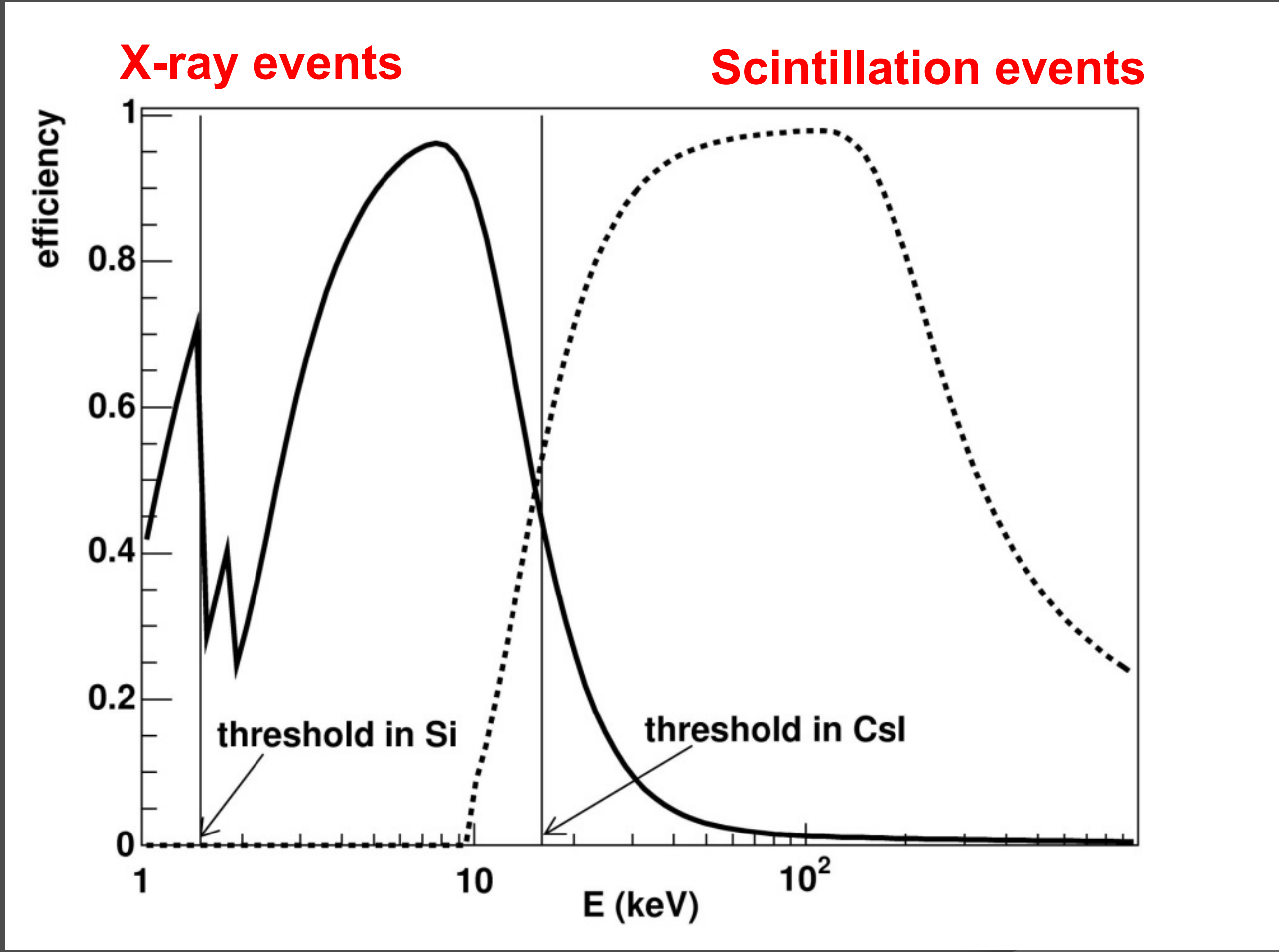
The "siswich" detection principle



- **Low-energy threshold** (~2 keV)
- **Extended energy range** (up to ~20 MeV, depending on crystal thickness)
- Excellent **energy resolution** at low energies
- Using two SDDs for readout, **position-sensitive** in γ-rays

FAST signal → **PULSE SHAPE ANALYSIS** ← **SLOW signal**

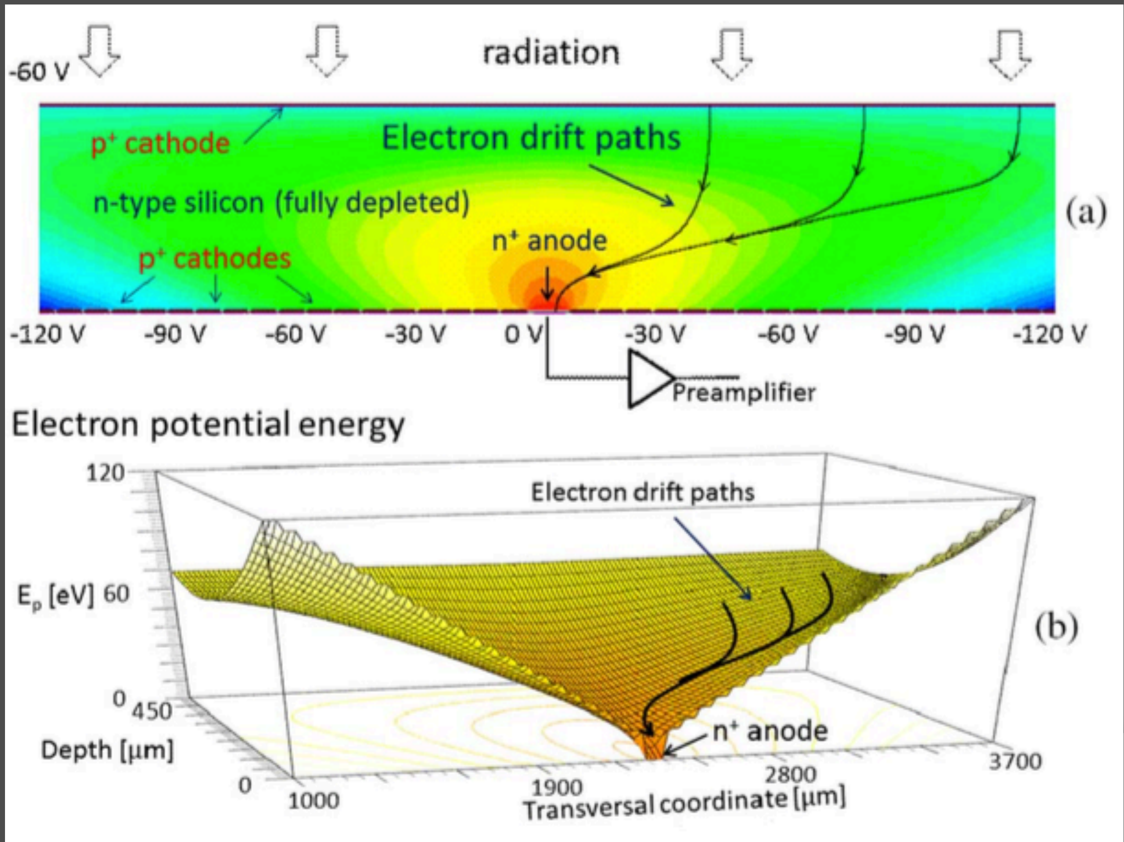
The “siswich” detection principle



Excellent overlap of sensitivity between the two operating modes thanks to the SDDs low noise

SDD & FEE

Operating principle of a Silicon Drift Detector



Credits: Bertuccio+16

SDD & FEE

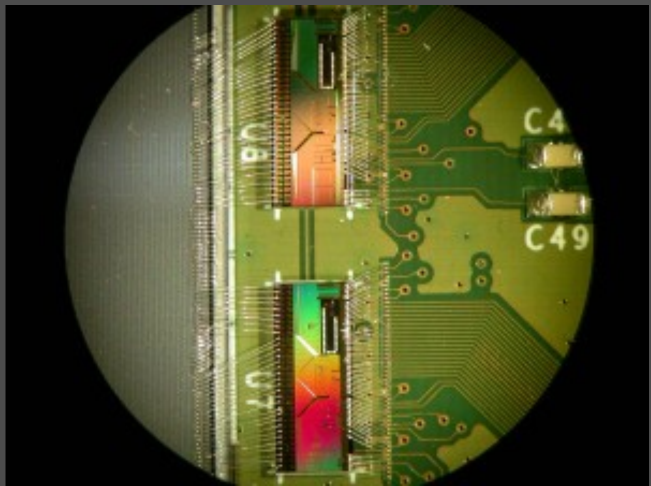
R&D activity in the framework of the **ReDSoX** collaboration led by **INFN** and **FBK** involving several institutions (INAF/IASF-Bo & IAPS, PoliMi, UniUD, UniPV, ELETTRA)
http://redsox.iasfbo.inaf.it

ReDSoX **2×2 SDD matrix** with four 25 mm^2 cells
(left: anode side; right: entrance window)

RESEARCH DRIFT FOR SOFT X-RAYS redsox

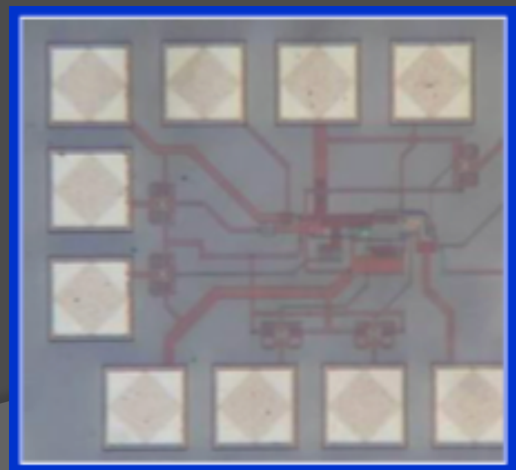
SDD & FEE

The R&D activity in the framework of the **ReDSoX** collaboration involves also the front-end electronics



VEGA: A low-noise and low-power Application Specific Integrated Circuit (ASIC) designed to read out large area monolithic linear SDDs.

Campana et al. 2014
Ahanganariabhari et al. 2014
Rachevski et al. 2015

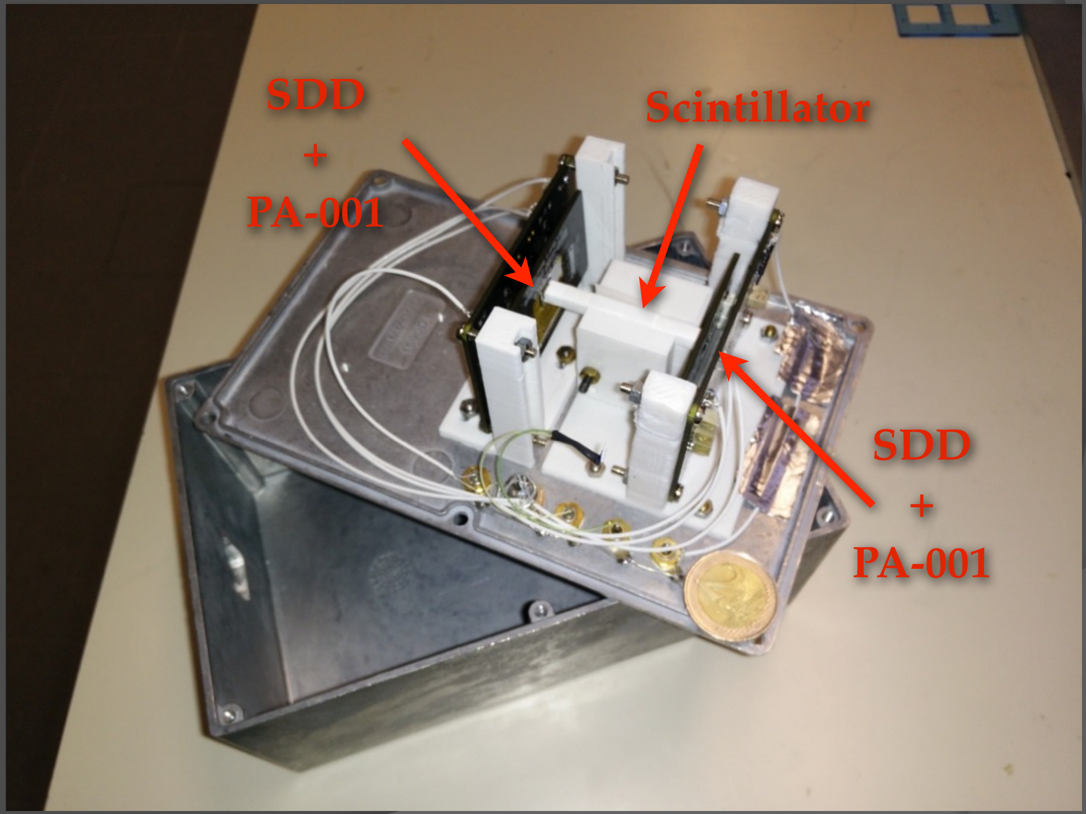


SIRIO: A ultra low-noise charge-sensitive preamplifier for SDDs.

Bertuccio et al. 2016

Laboratory prototypes

R&D activity at INAF/IASF-Bologna
Various **prototypes** and **architecture demonstrators** have been developed and tested



First prototype with one CsI bar coupled with two 25 mm² SDDs
Discrete elements charge-sensitive preamplifier

Laboratory prototypes

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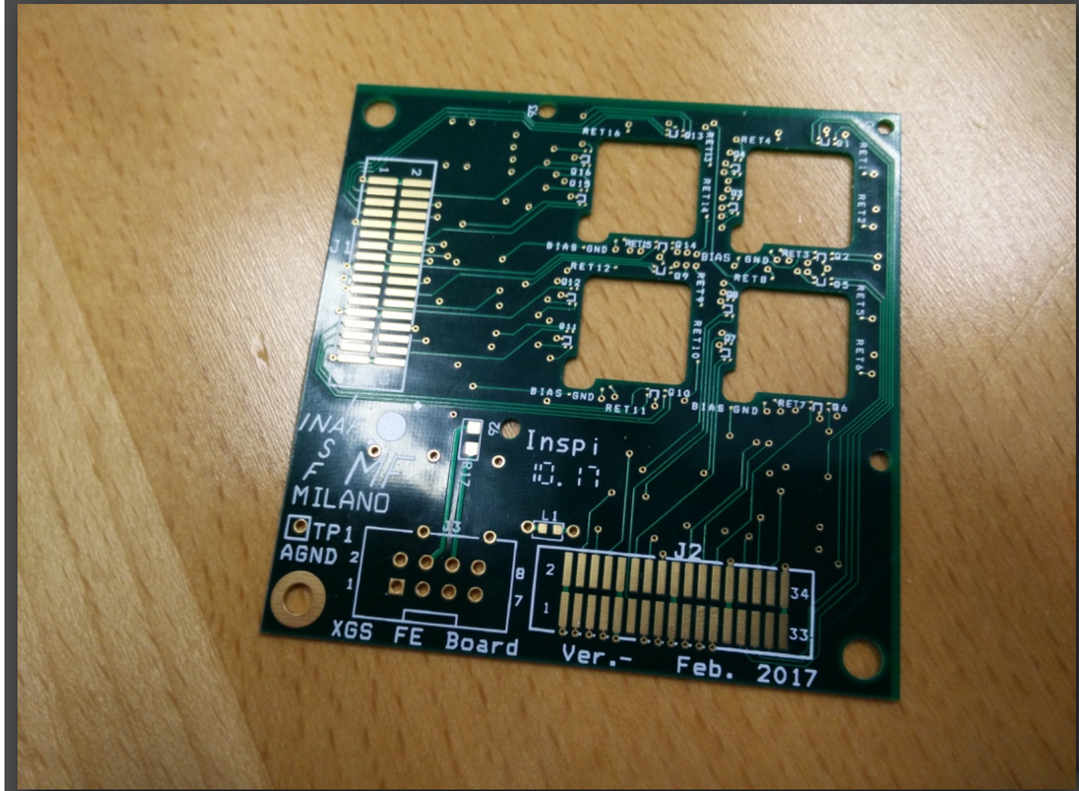
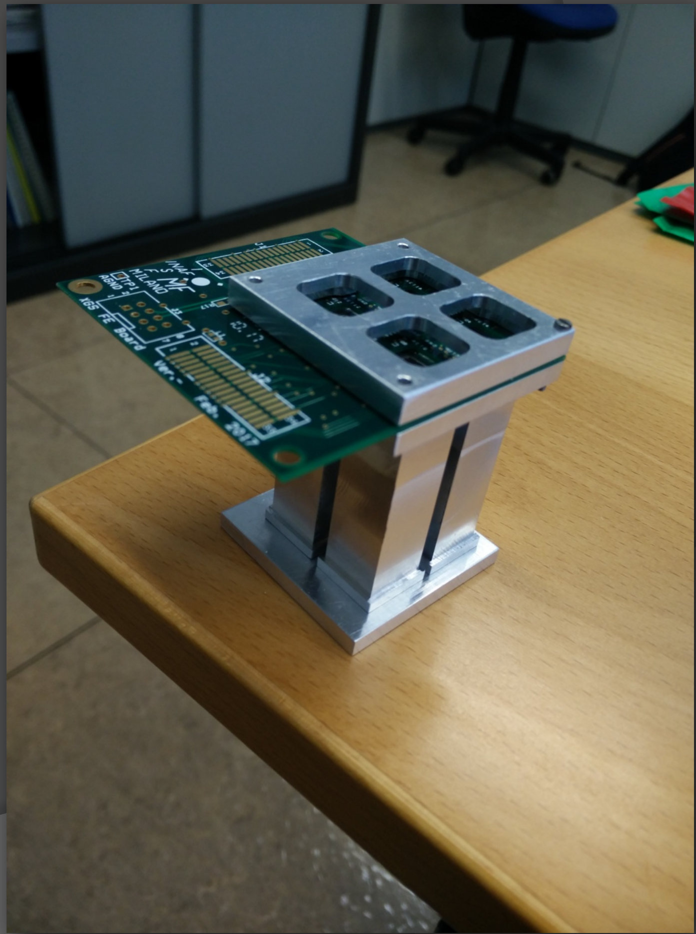


JFET front-end discrete electronics board

Full scale prototype
One 4×4 pixel module



Laboratory prototypes

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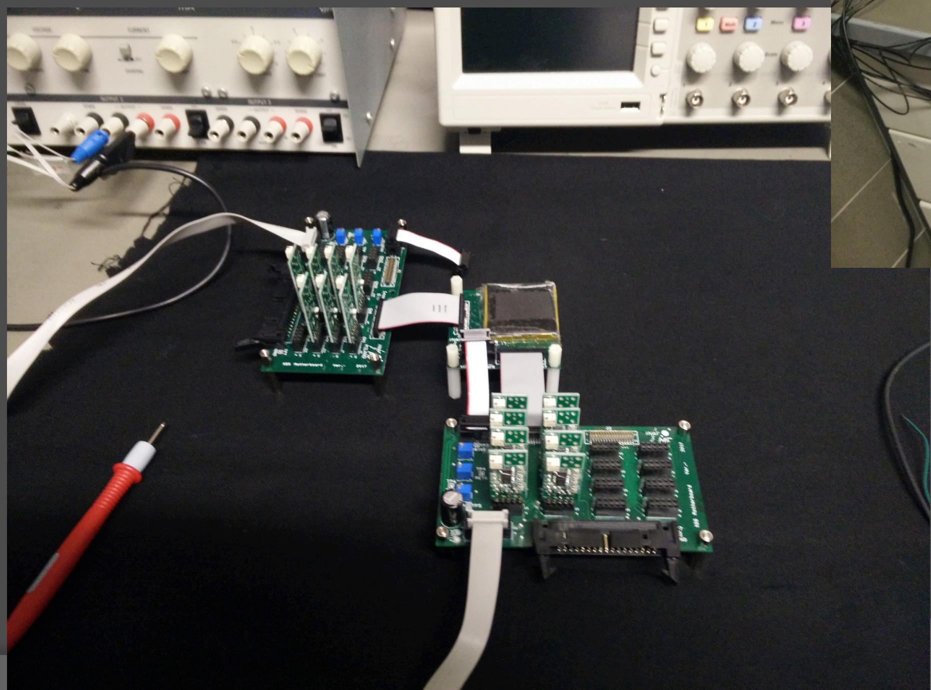
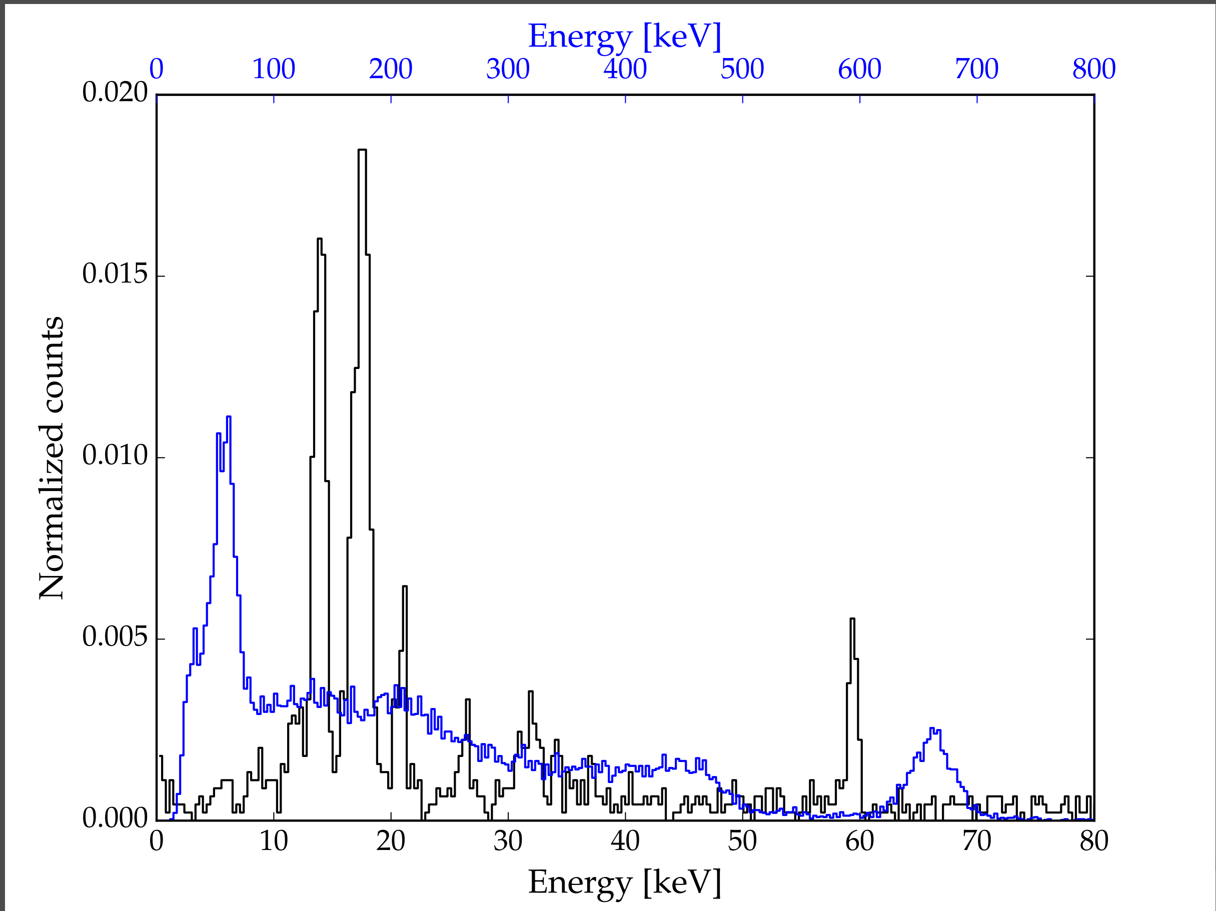


Test equipment

Laboratory prototypes

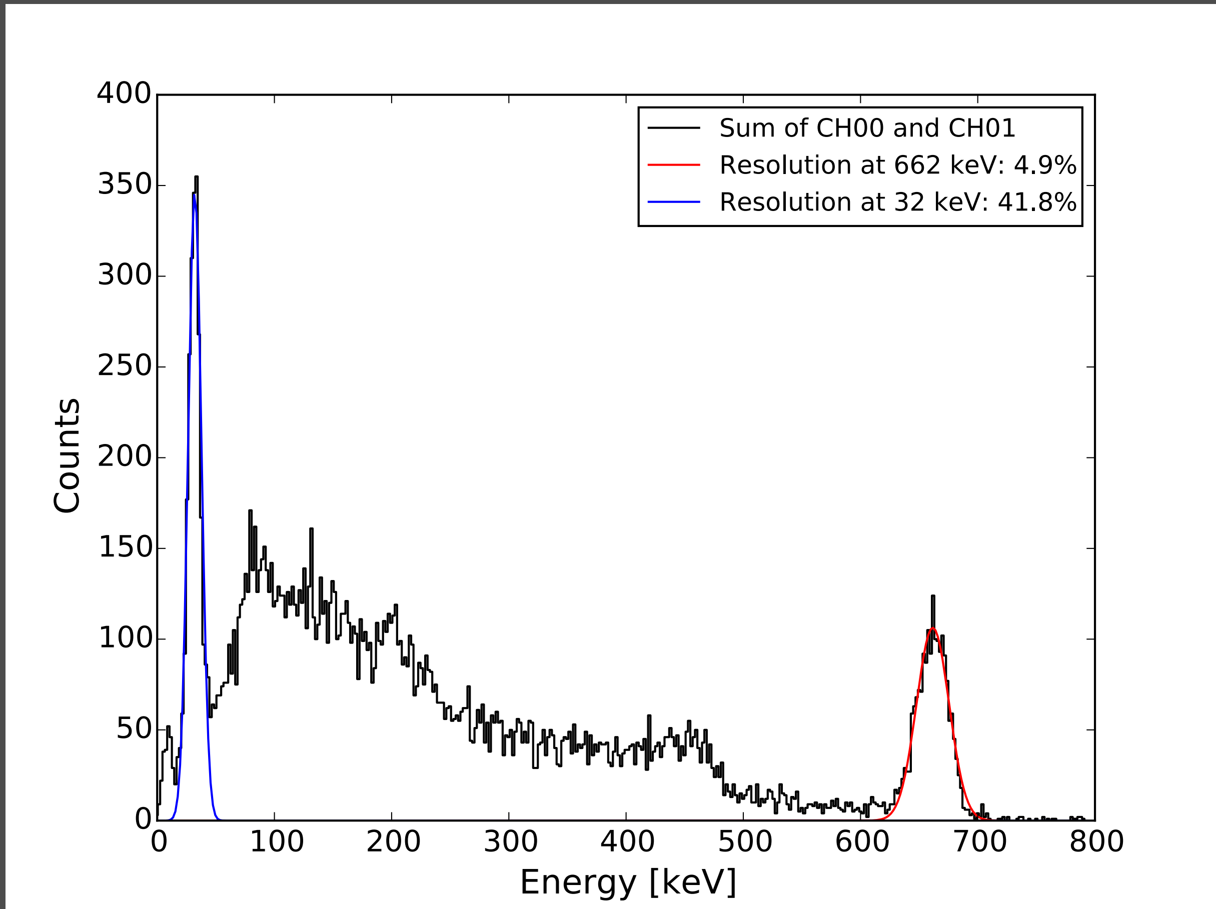


Simultaneous ^{241}Am + ^{137}Cs spectrum, demonstrating PSA capabilities in **separating X and γ-ray events**

X-ray low energy threshold below 1 keV

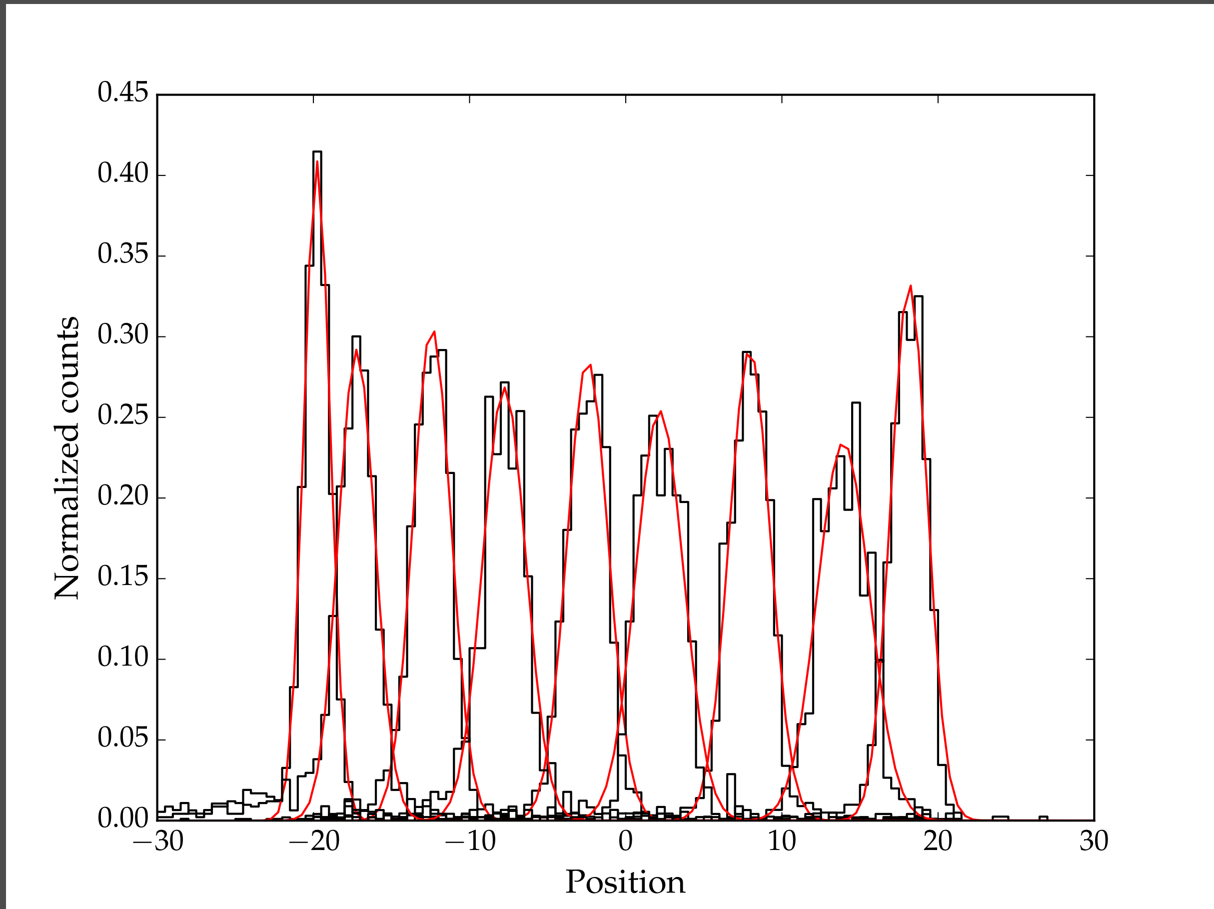
(ENC ~20 e- rms with discrete-elements front-end electronics)

Laboratory prototypes



Low noise SDDs allow a **~20 keV threshold** also for scintillation events besides an excellent resolution at high energies

Laboratory prototypes



Spatial resolution of ~2.2 mm in gamma-rays

Using a 5 cm long CsI(Tl) bar and comparing the readout of the SDDs at the two bar ends

Trade-offs and improvements

- FoV of a single unit
- Optimization of the mask open fraction (impacts on efficiency and sensitivity)
- FEE optimization (number of shapers/ADCs per channel)
- Efficiency at high energies (scintillator type and thickness)
- Triggering logic(s)