MeVCube: a CubeSat for MeV astrophysics

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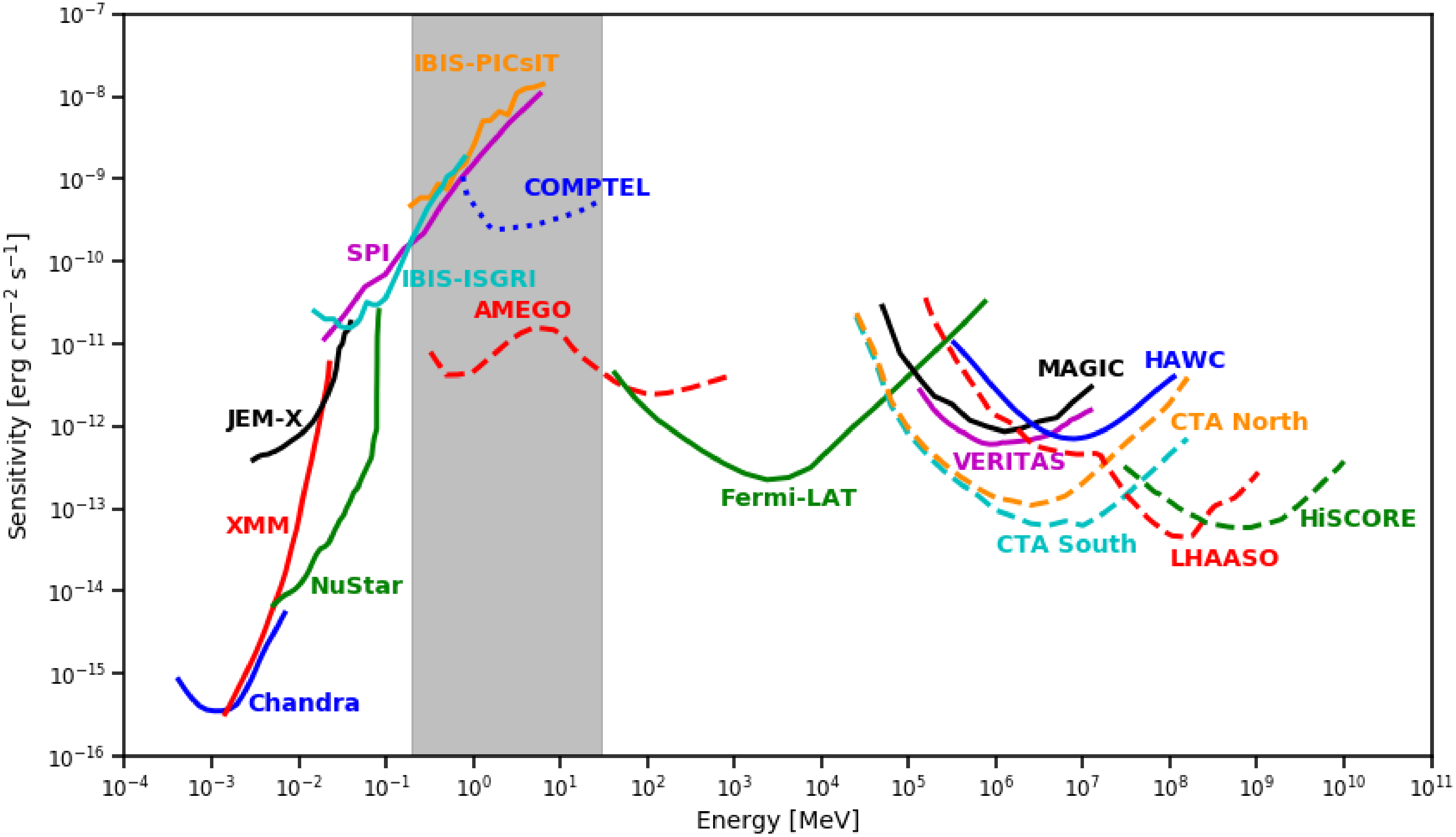
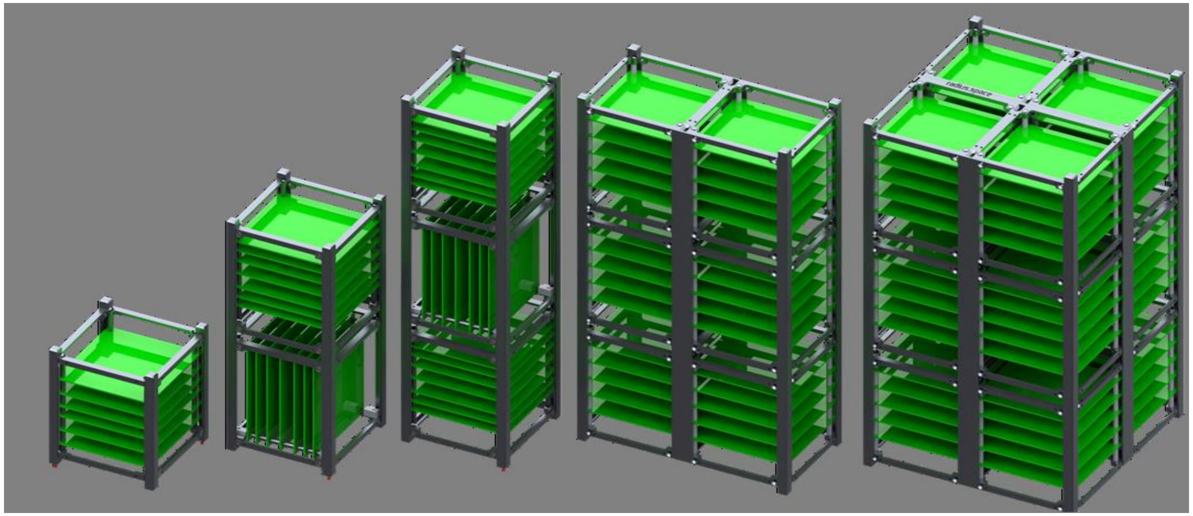
Introduction: the “MeV gap”



Introduction: the “MeV gap”

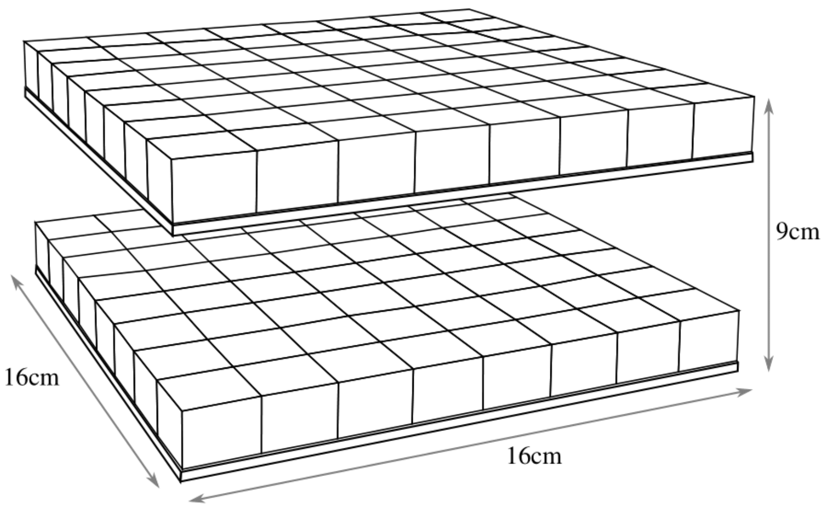
- COMPTEL (1991-2000) was the first satellite to accomplish a complete survey of the MeV sky.
- Missions like AMEGO have been proposed in order to fill this gap in observation (≥2030).
- Different approach may be profitable on a shorter time-scale: Compton telescope based on the CubeSat standard.

1U = 10cm x 10cm x 11.35cm cube, maximum weight of 1.33 kg



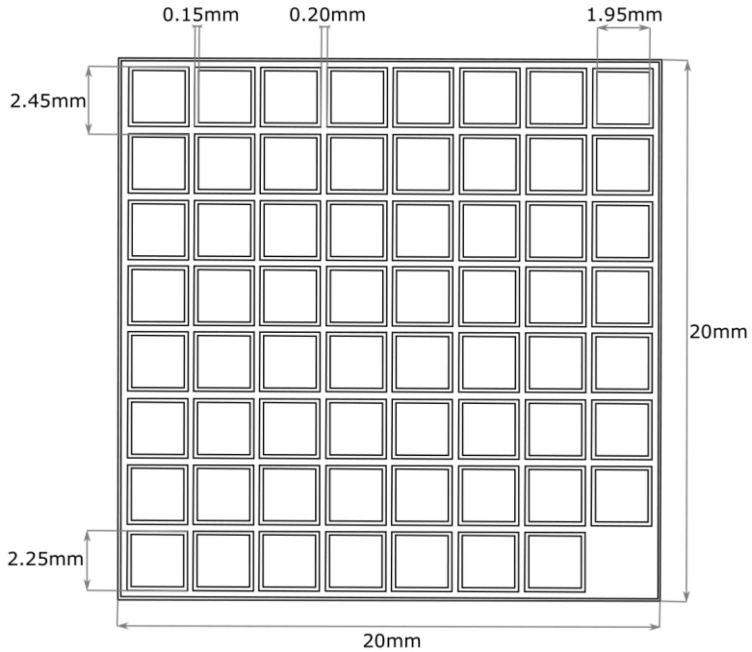
Credits: *Radius Space*

MeVCube design

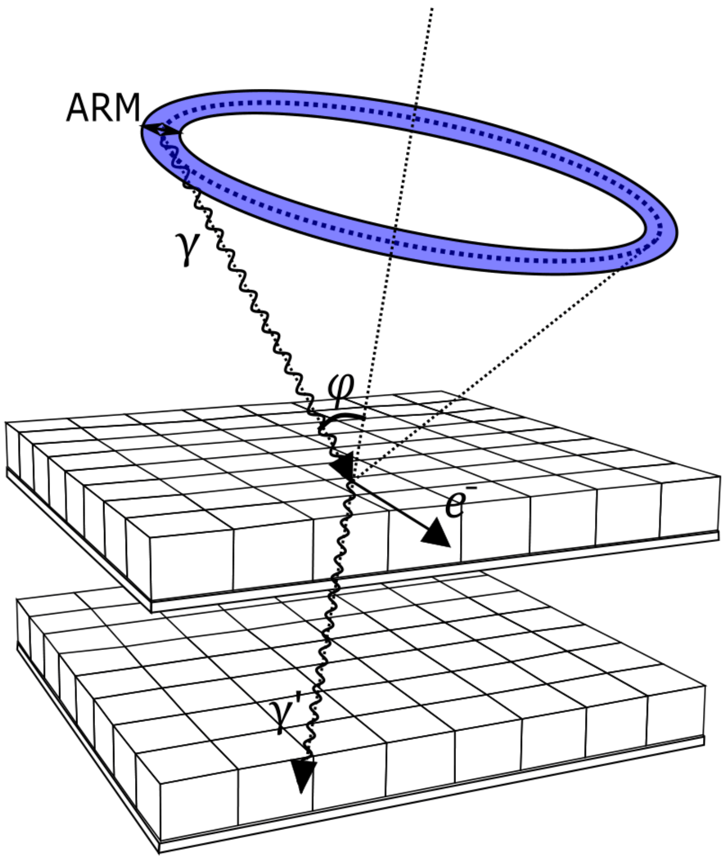


- Cadmium-Zinc-Telluride (CdZnTe or CZT) semiconductor detectors, arranged on two layers.
- High atomic number, density and stopping power.
- Good spectral and imaging performance.

Parameter	Value
CubeSat model	4U scientific payload, 6U complete satellite
Orbit	Low Earth Orbit (LEO), ~ 550 km
Energy range	200 keV – 4 MeV
Number of CdZnTe detectors	128
CdZnTe detector size	2.0 cm $\times$ 2.0 cm $\times$ 1.5 cm
Pixel pitch	2.45 mm
Depth resolution	$\lesssim 2.0$ mm (FWHM)
Energy resolution	$\lesssim 3.0\%$ at 662 keV (FWHM)
Read-out electronics	VATA450.3
Total power consumption	< 5 W



MeVCube: principle of operation



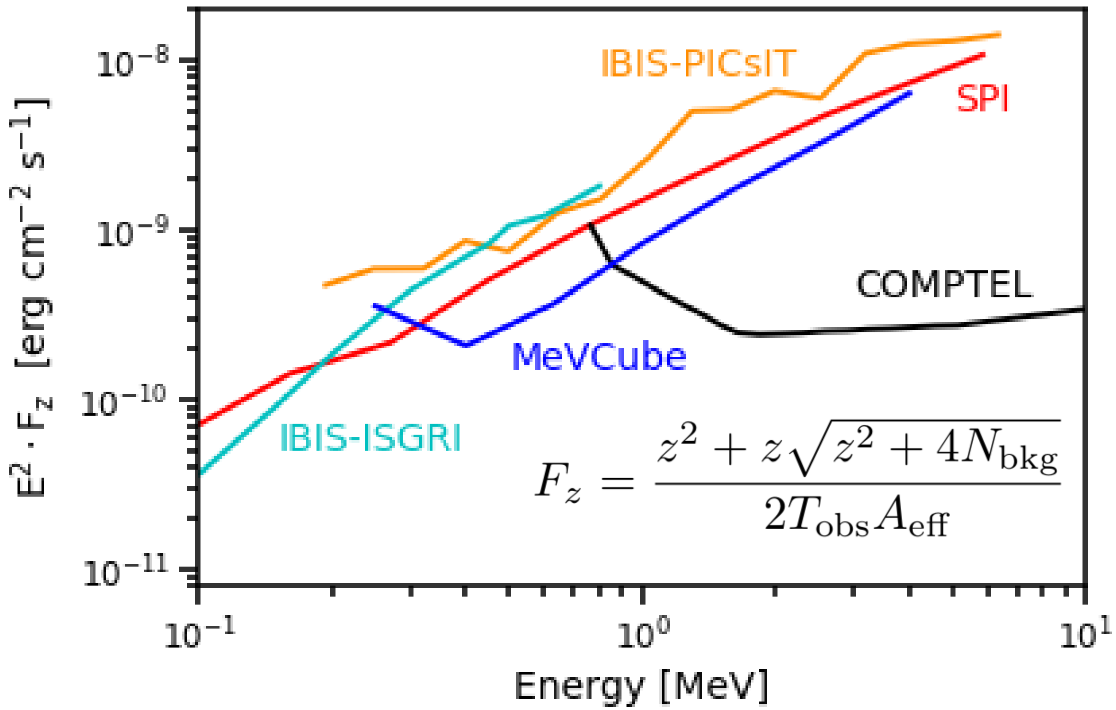
- MeV gamma-rays: undergo Compton scattering in the first layer; scattered photon absorbed in the second layer.
- Direction of the incoming gamma-ray confined within an *annulus* on the sky.

$$\vec{e}'_\gamma \cdot \vec{e}_\gamma = \cos\varphi = 1 - \frac{m_e c^2}{E'_\gamma} + \frac{m_e c^2}{E_\gamma}$$

- Required both good spatial and energy resolution.

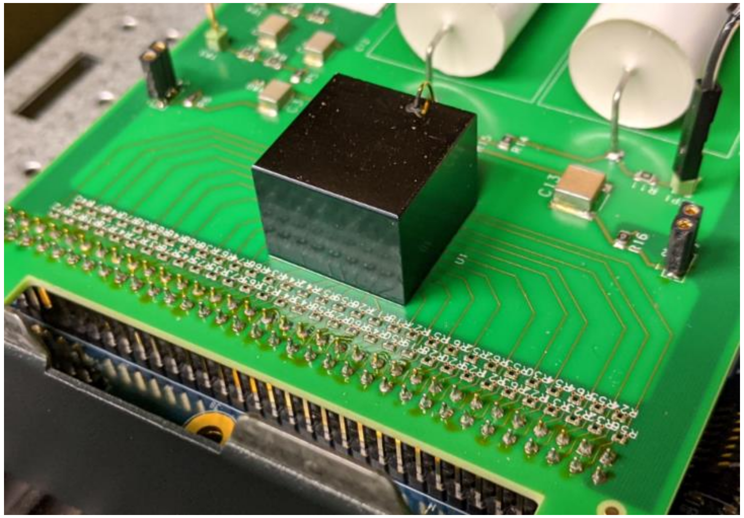
MeVCube sensitivity

- MeVCube response evaluated with the simulation toolkit *MegaLib*: Zoglauer et al., *New Astron. Rev*., 50 (2006) .
- Background from Cumani et al., *Exp. Astron*., 47 (2019).
- MeVCube sensitivity evaluated for z=3 and 100ks observation time.

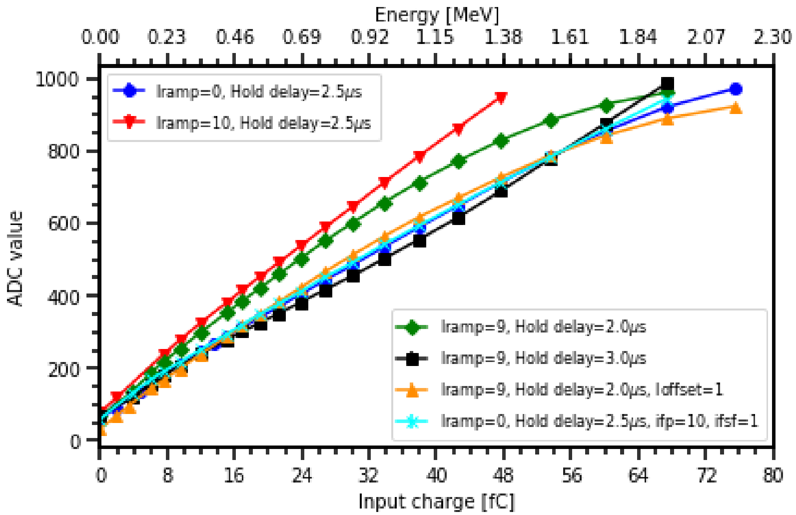


COMPTEL data from Schönfelder, *New Astron. Rev.,* 48 (2004).
INTEGRAL-SPI from Roques et al., *A & A*, 411 (2003).
INTEGRAL-IBIS from Ubertini et al., *A & A*, 411 (2003).

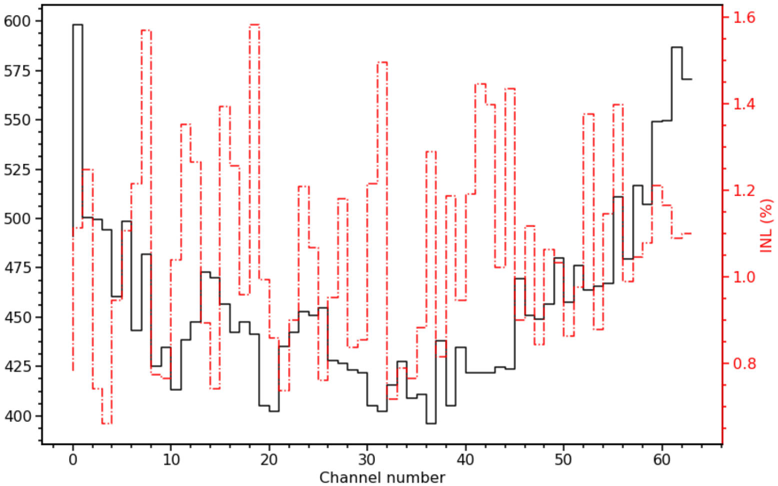
Experimental results



- Performance of pixelated CdZnTe detector tested with radioactive sources.
- Anode read-out: VATA450.3 ASIC by *Ideas* (adequate dynamic range and noise, low-power design).
- Preliminary cathode read-out: discrete *Amptek A250* pre-amplifier and DRS4 evaluation board.

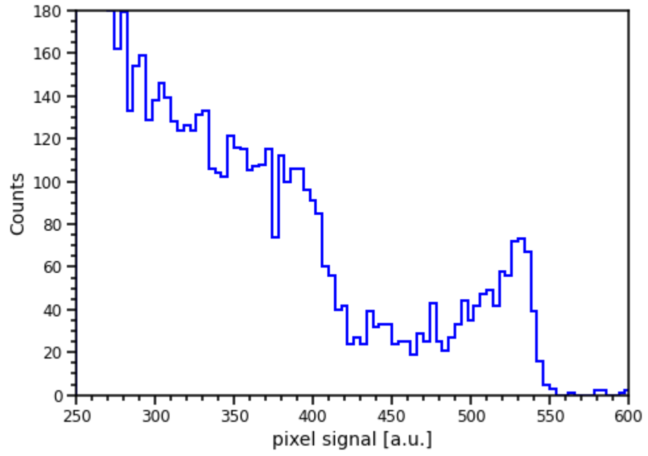


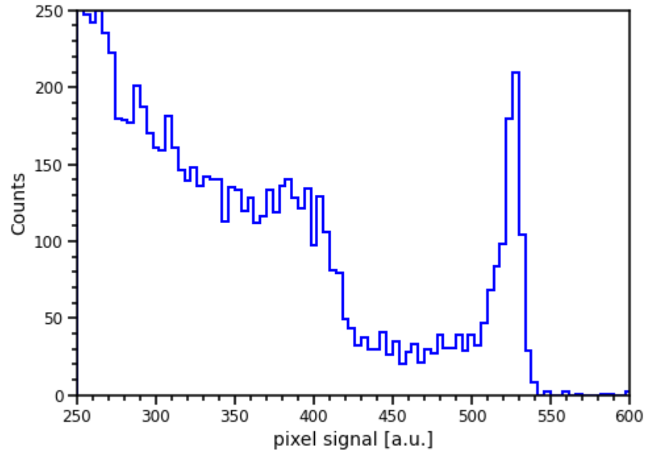
dynamic range for different VATA450 settings



noise and integral non linearity of VATA450

CdZnTe spectral performance

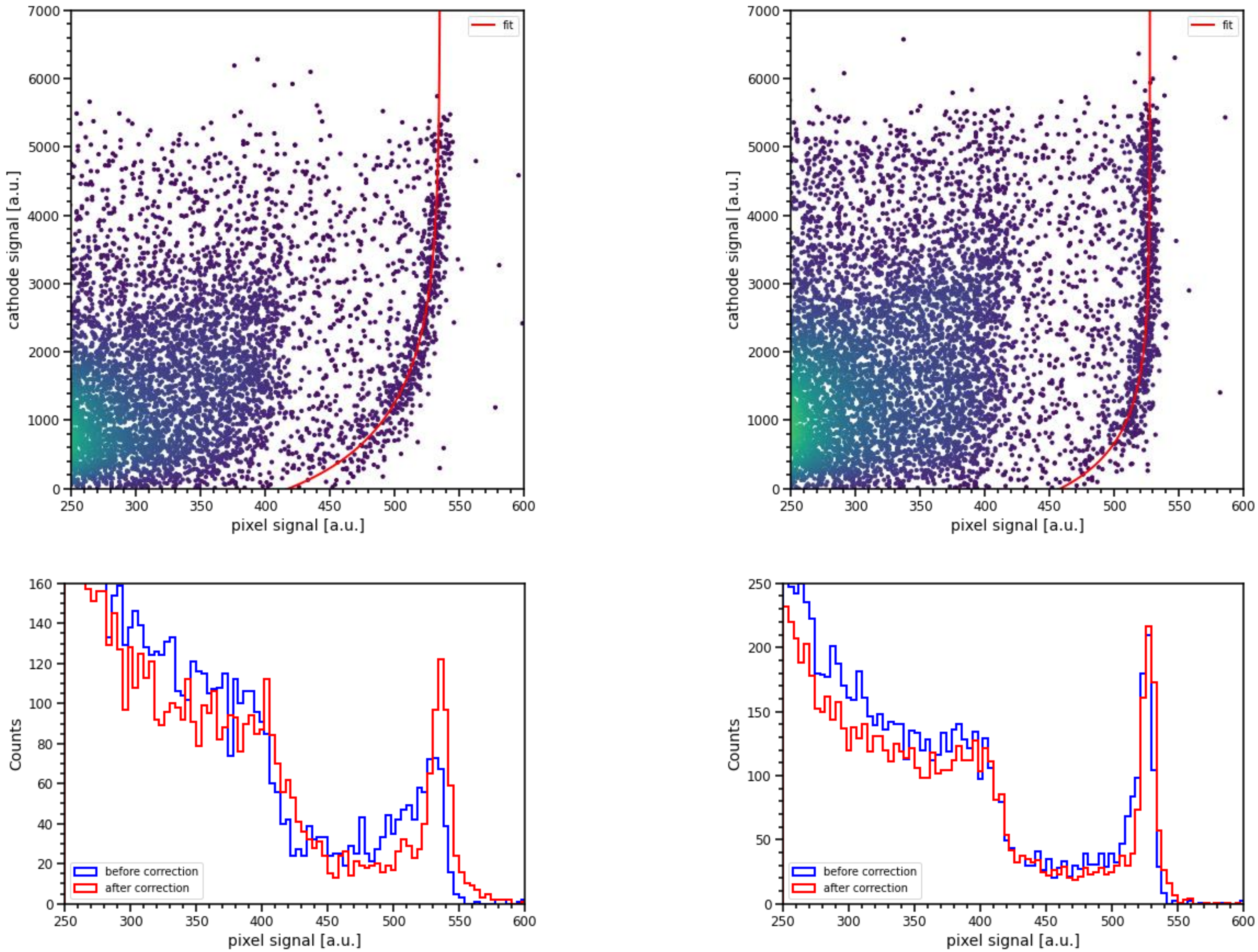




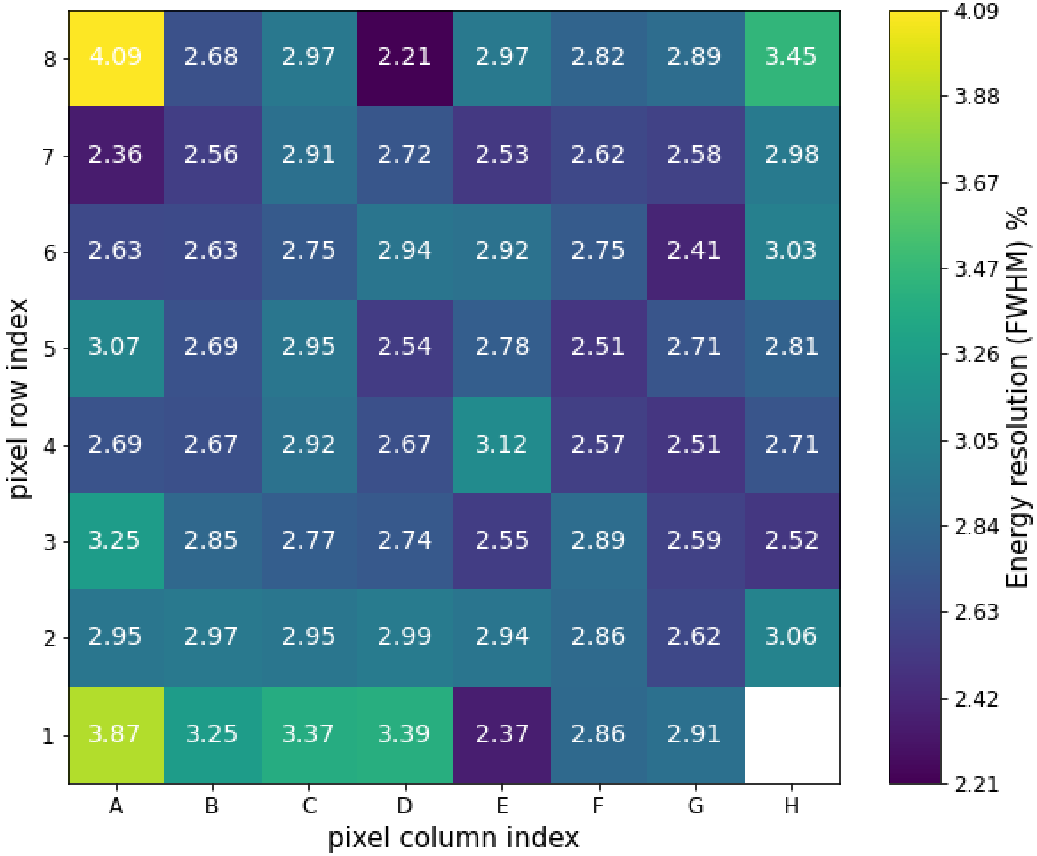
- In thick CdZnTe detectors pixel spectra might exhibit pronounced left tails due to incomplete charge collection and electron trapping.

- Signals from the cathode, taken in coincidence with those of the anode electrodes, provide a correction for electron trapping.

CdZnTe spectral performance



CdZnTe spectral performance



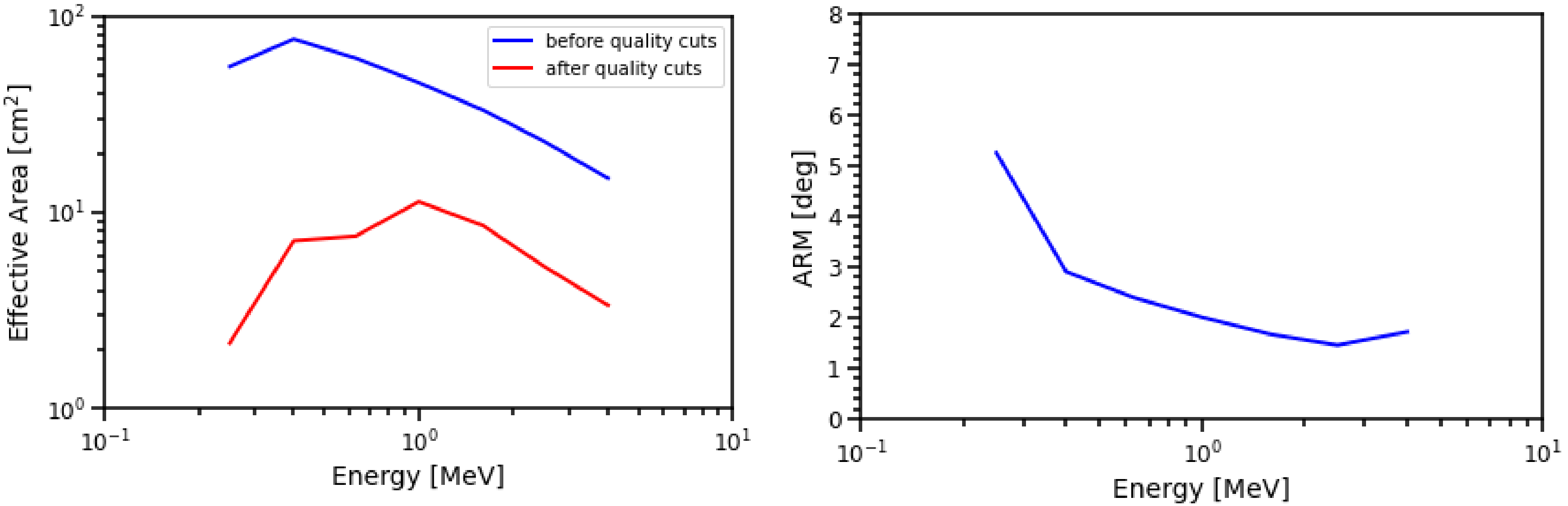
Majority of pixels show an energy resolution < 3.0% (FWHM) for the 662 keV line of Cs-137.

Conclusions

- Evaluation of the viability of a Compton telescope based on the CubeSat standard: expected sensitivity comparable to the one achieved by COMPTEL and INTEGRAL.
- First proof of concept: evaluation of the read-out electronics and spectral performance of custom design CdZnTe detector.
- Energy resolution <3.0% FWHM at 662 keV: validation of the requirement put in the simulation.
- Test of the depth resolution is going to start soon.

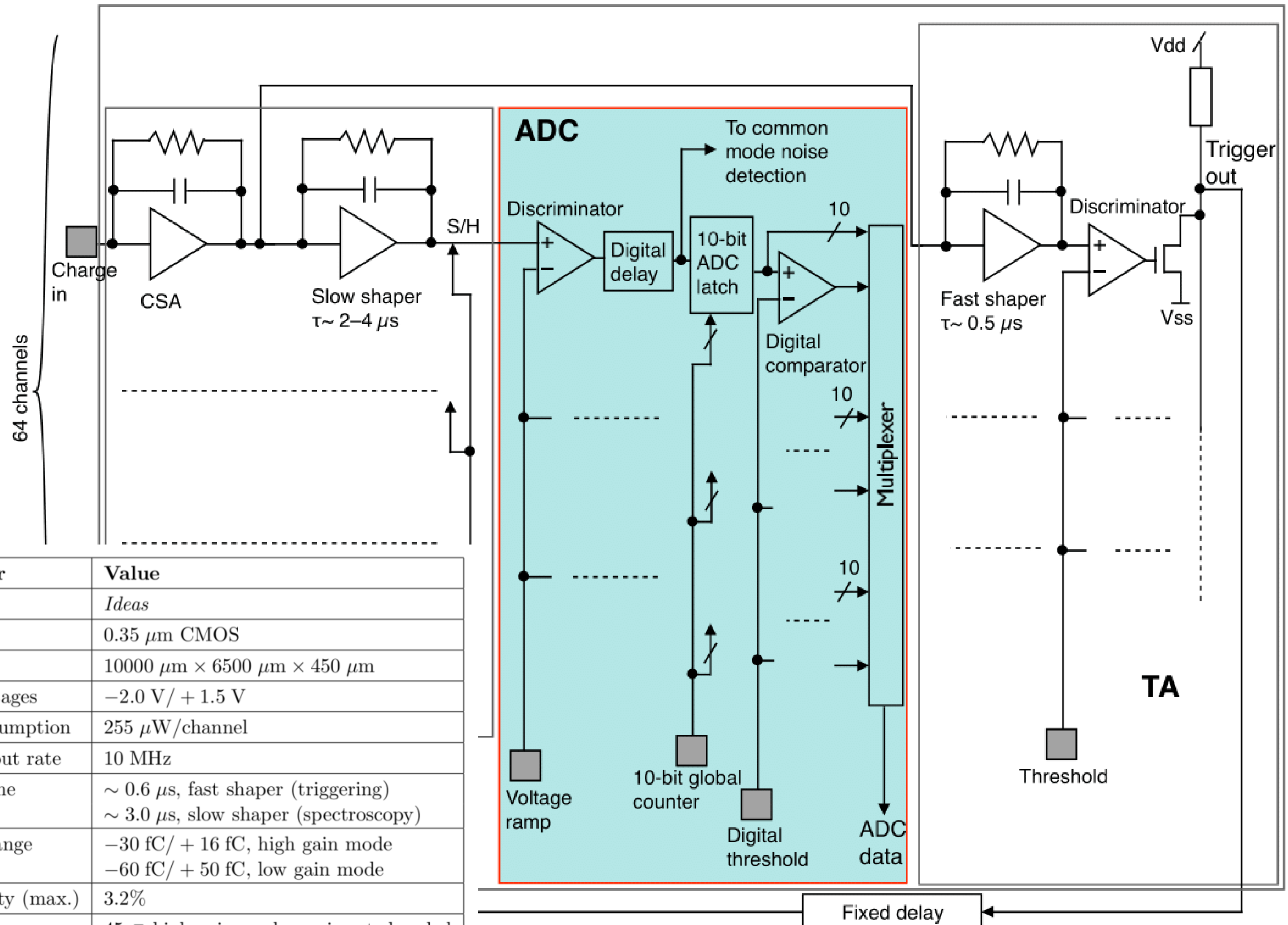
Backup slides

MeVCube performance



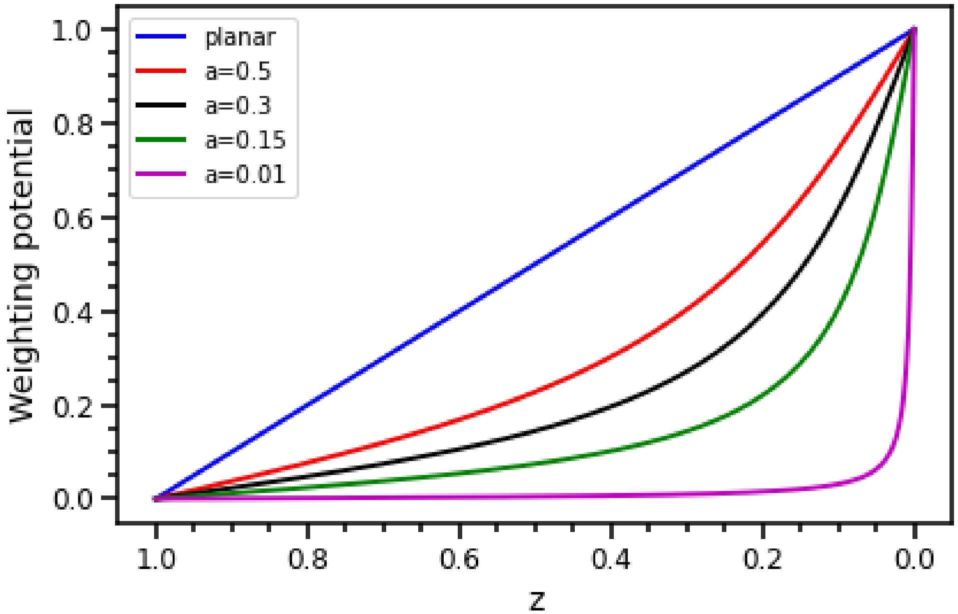
Effective area and angular resolution as a function of energy

VATA450.3 overview



Parameter	Value
Supplier	*Ideas*
Technology	0.35 μm CMOS
Chip size	10000 μm × 6500 μm × 450 μm
Supply voltages	-2.0 V/ $+1.5$ V
Power consumption	255 μW/channel
Max. readout rate	10 MHz
Shaping time	$\sim$ 0.6 μs, fast shaper (triggering) $\sim$ 3.0 μs, slow shaper (spectroscopy)
Dynamic range	-30 fC/ $+16$ fC, high gain mode -60 fC/ $+50$ fC, low gain mode
Non linearity (max.)	3.2%
ENC	45e$^-$ high gain mode, no inputs bonded 65e$^-$ low gain mode, no inputs bonded

CdZnTe signal formation



$$Q_i(t) = q_0[\phi_{w,i}(\vec{r}(t)) - \phi_{w,i}(\vec{r}(t_0))]$$

- Induced signal on a electrode can be estimated from the weighting potential.
- *Small pixel effect*: electrode would feel induced charge of carriers drifting in the proximity of the electrode itself.