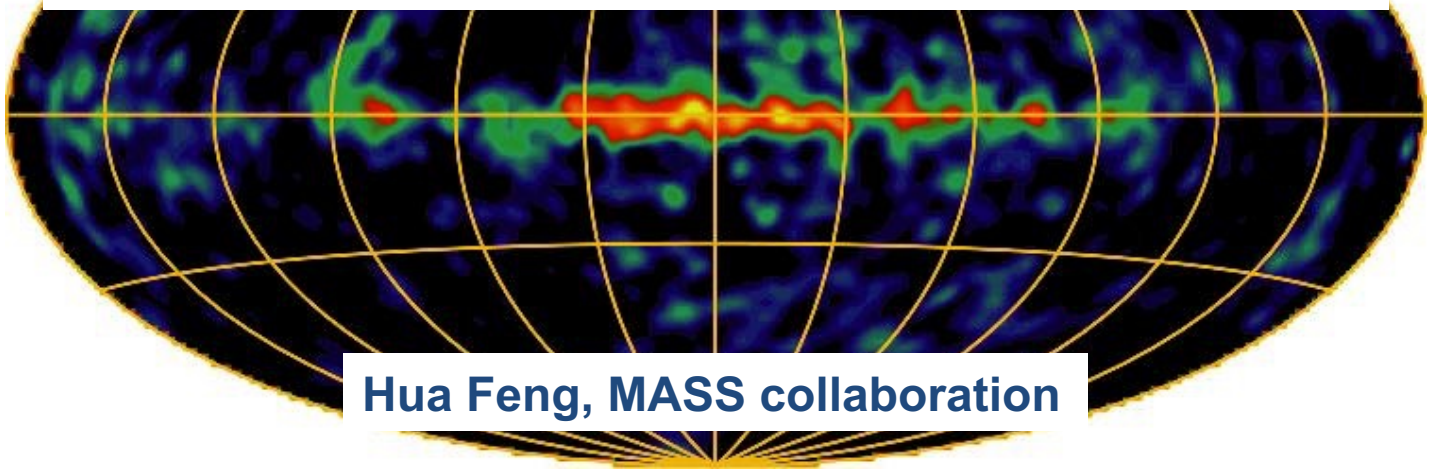
MASS: MeV Emission Line Astrophysics With Fine Resolution CZT Detectors



Hua Feng, MASS collaboration

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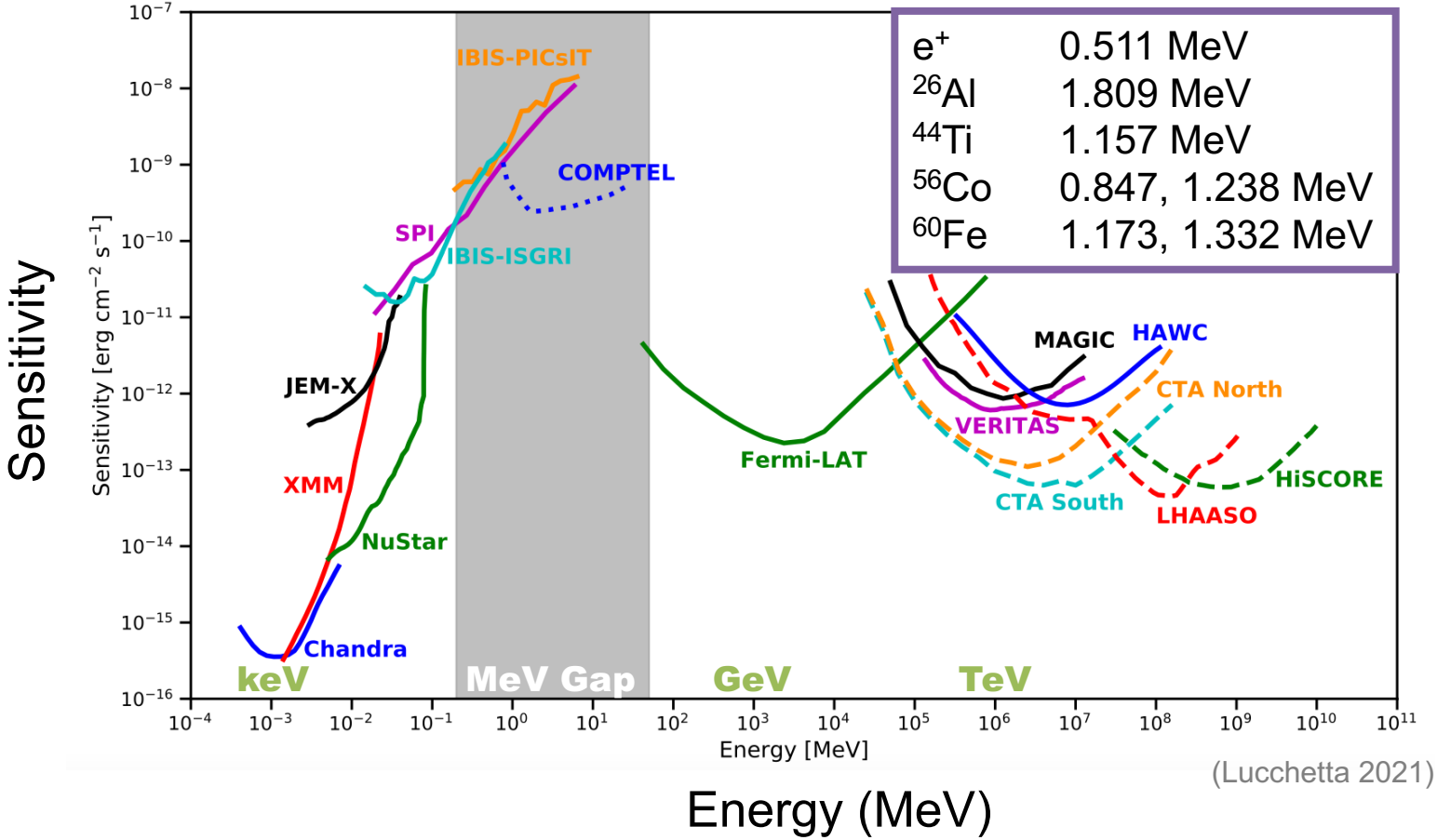
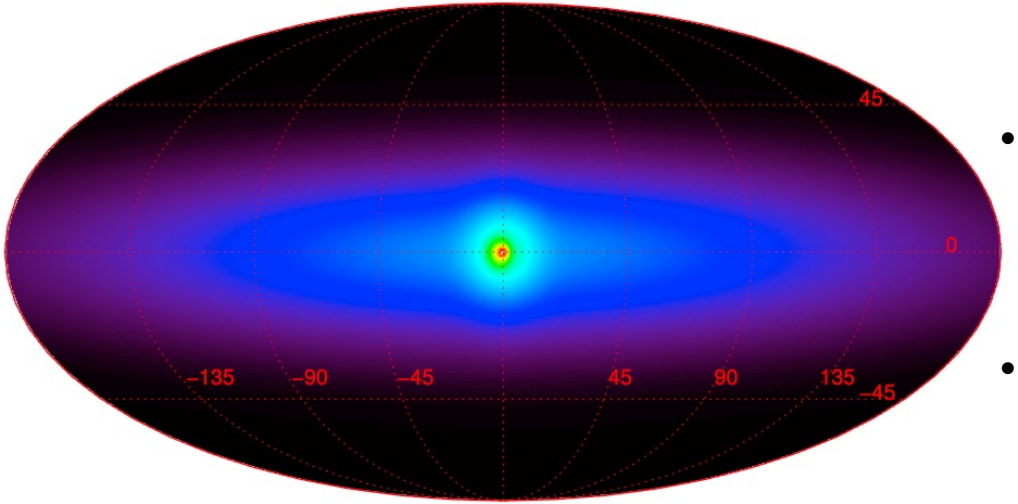
MeV gap in astrophysics



(Lucchetta 2021)

Science case: 511 keV emission from GC

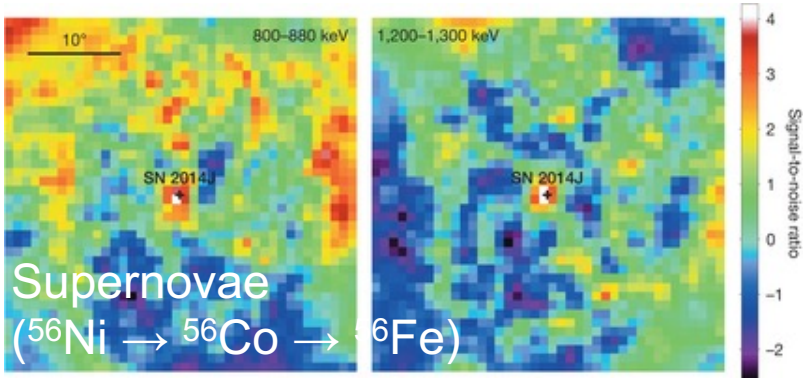
INTEGRAL/SPI 11-year 511 keV map (Siegert et al. 2016)



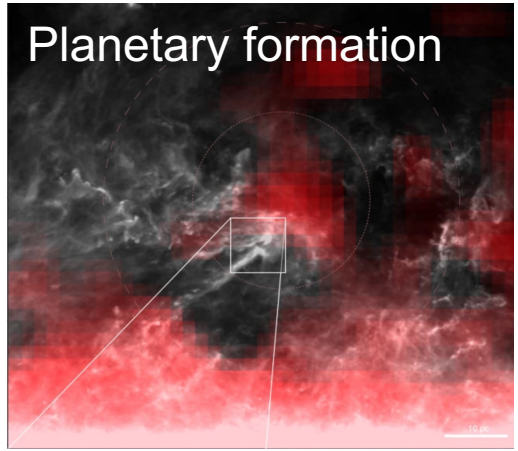
- Astrophysical origins
  - Sgr A* (Totani et al. 2006)
  - Nucleosynthesis from GC molecular clouds (Alexis et al. 2014)
- Dark matter? (Ascasibar et al. 2006)

Bulge-to-disk flux ratio = 0.58 ± 0.13
Consistent results obtained with COSI balloon flights (Siegert et al. 2020)

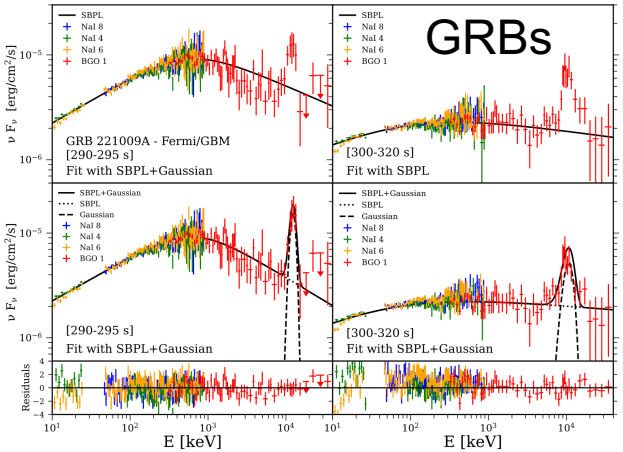
Science cases



(Churazov et al. 2015)



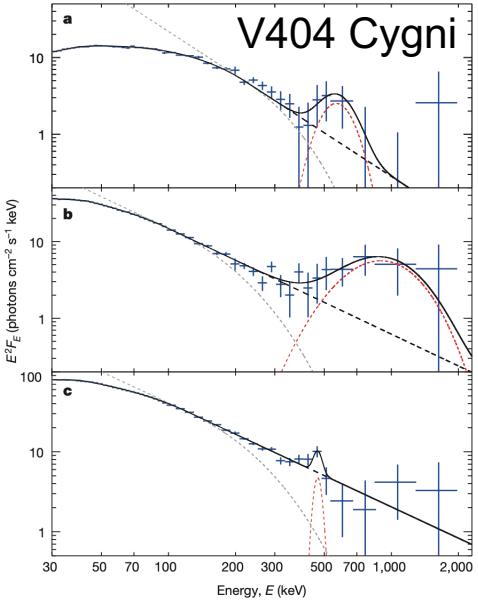
(Forbes et al. 2021)



(Edvige Ravasio et al. 2023)

(Aharonian & Sunyaev 1984)

Microquasars



(Siegert et al. 2016)

Requirements for Compton telescopes

- High energy resolution
  - FWHM < 1% @ MeV
- 3D position-sensitive & high spatial resolution
  - Compton imaging
- Large area
  - S/N and sensitivity
- COSI
  - Germanium detector
  - Cryogenic (T < −193℃)
  - 0.8% FWHM @ 662 keV

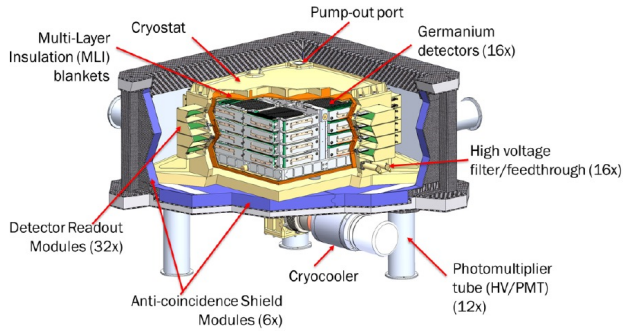
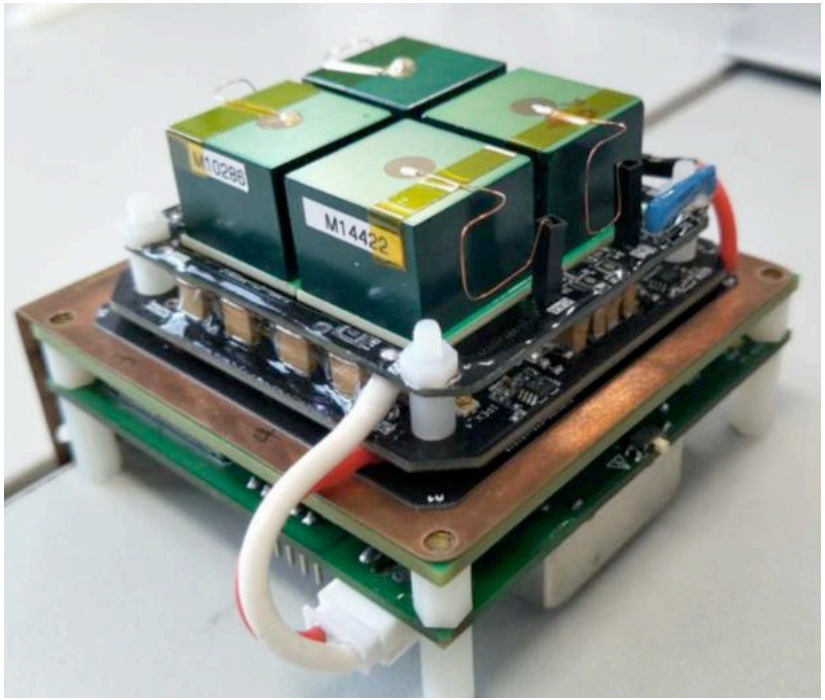


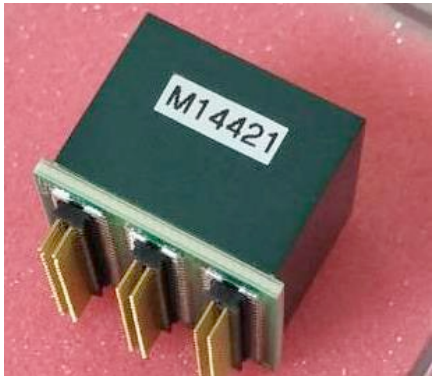
Figure 4: Cutaway view of the COSI instrument. Each germanium detector is $8 \times 8 \times 1.5\,\mathrm{cm}^3$. The BGO shield box is $42 \times 46 \times 20\,\mathrm{cm}^3$.

(Tomsick et al. 2022)

Room-temperature 3D position-sensitive CdZnTe detectors



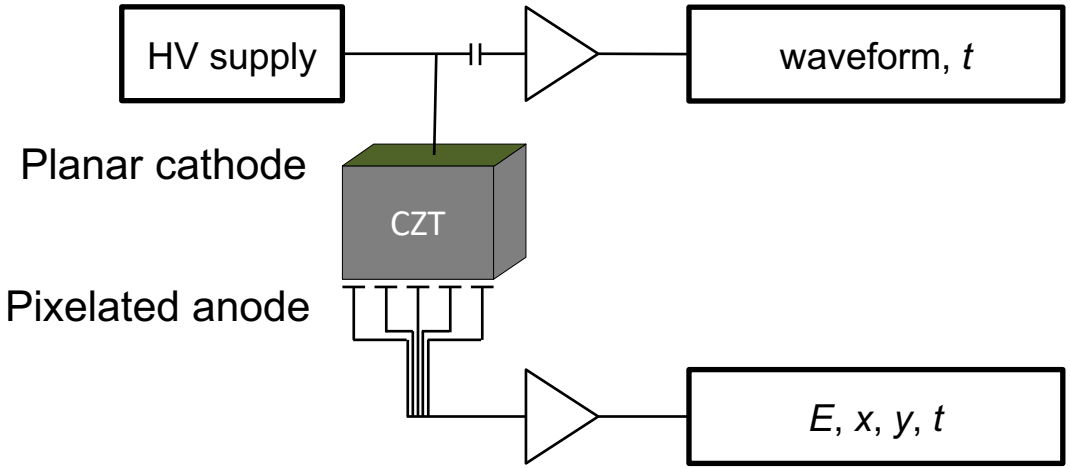
Energy resolution: 0.6% @ 662 keV (FWHM)



CZT
$2 \times 2 \times 1.5$ cm^3
$\Delta x = \Delta y = 1.72$ mm
$\Delta z = 0.6$ mm

IDEAS ASIC

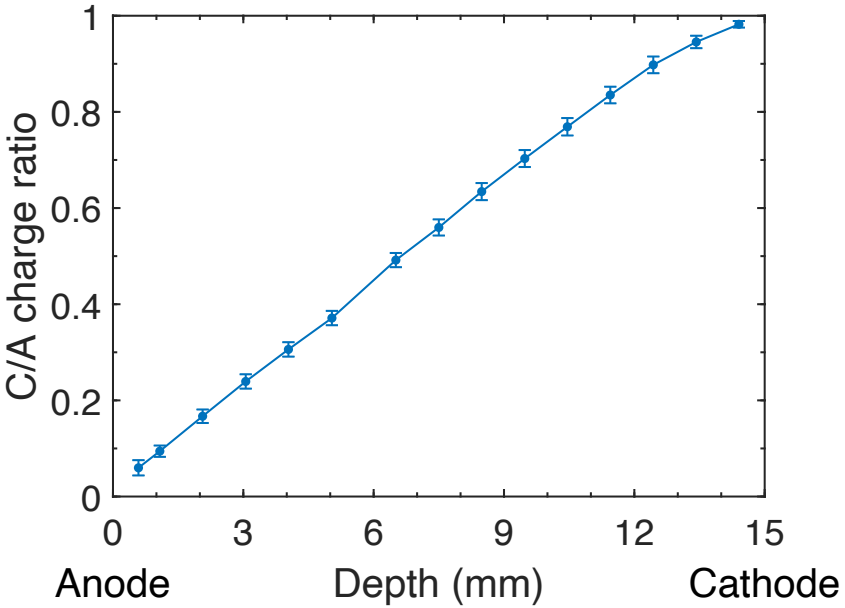
Readout & event reconstruction

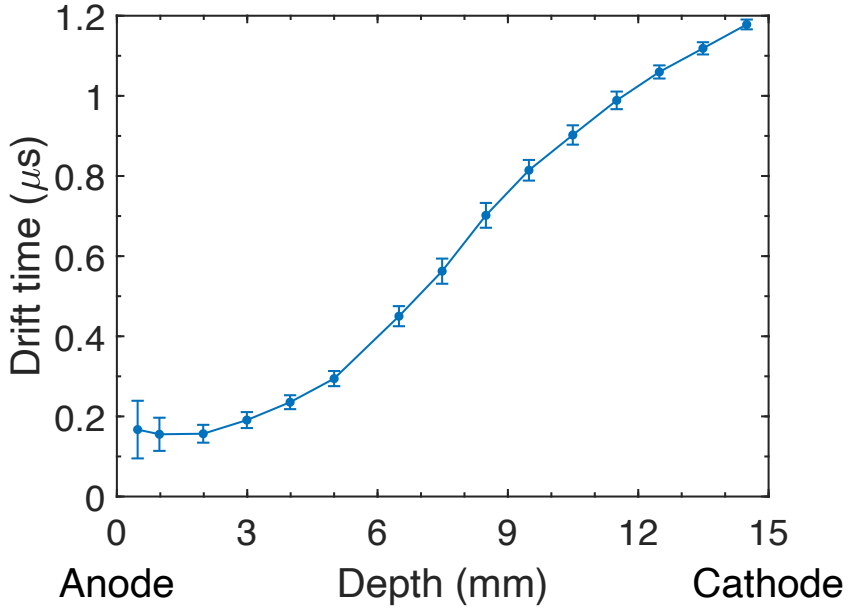


- ✓ The anode pixel provides the *x* and *y* positions
- ✓ The *z* position is derived the cathode/anode charge ratio and/or the drift time

Readout & event reconstruction

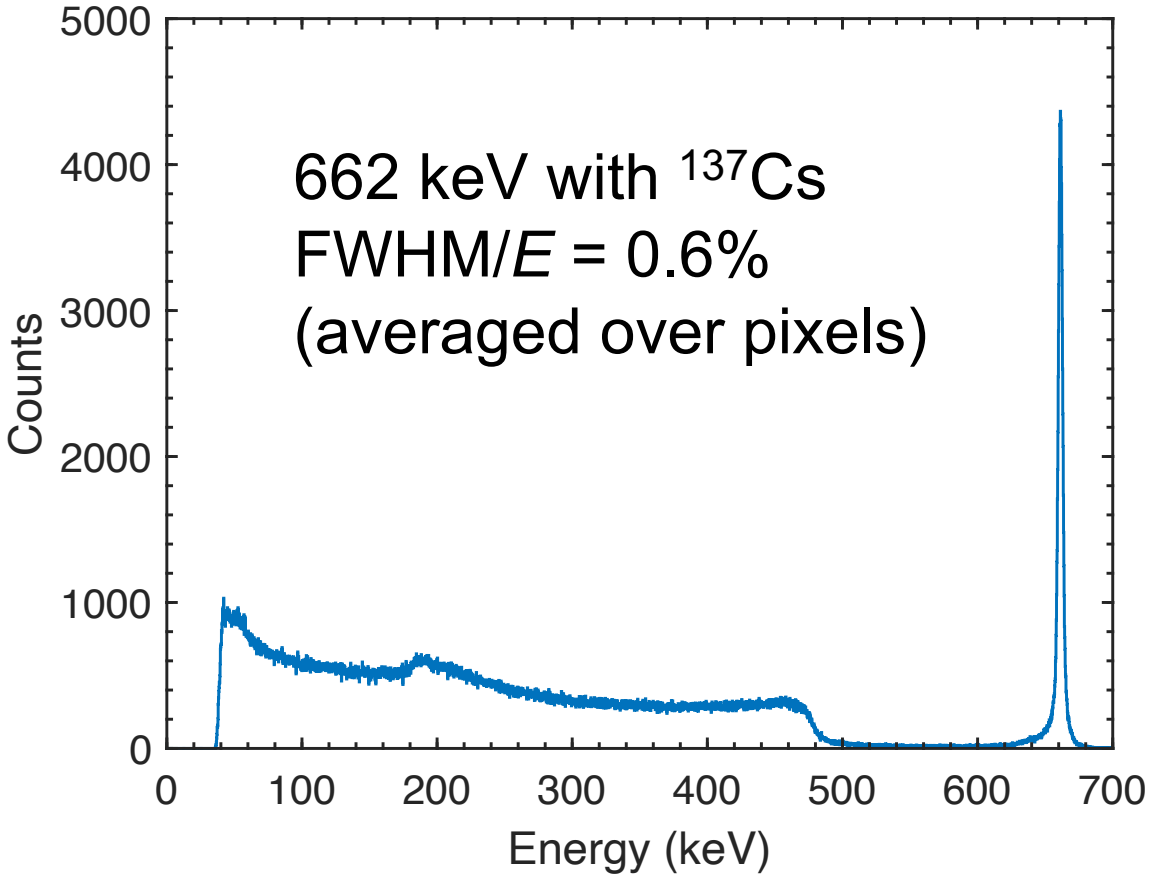
Position accuracy Δz = 0.6 mm





Above relations can also help correct the charge loss

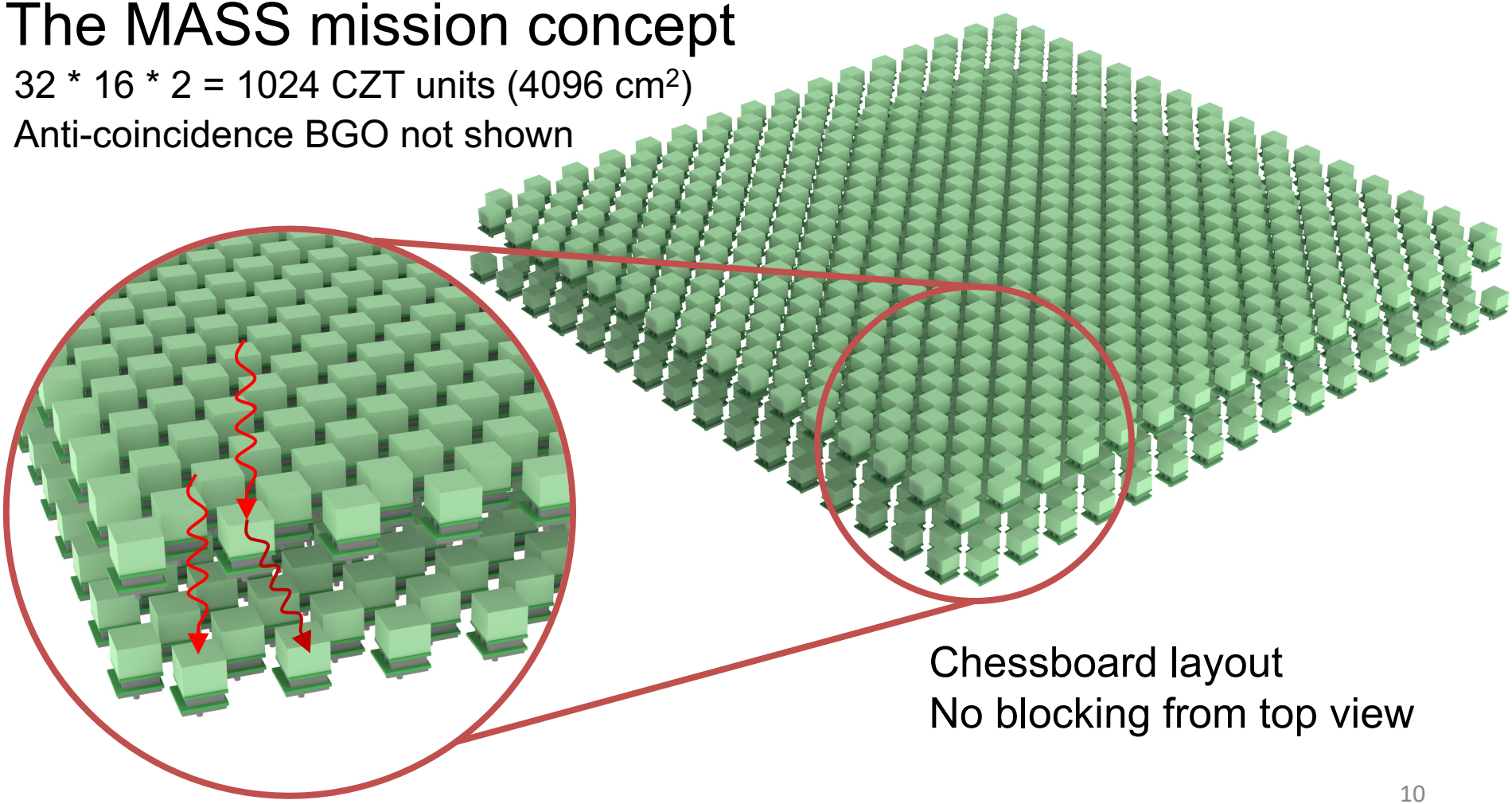
Measured energy spectrum



The MASS mission concept

32 * 16 * 2 = 1024 CZT units (4096 cm^2)

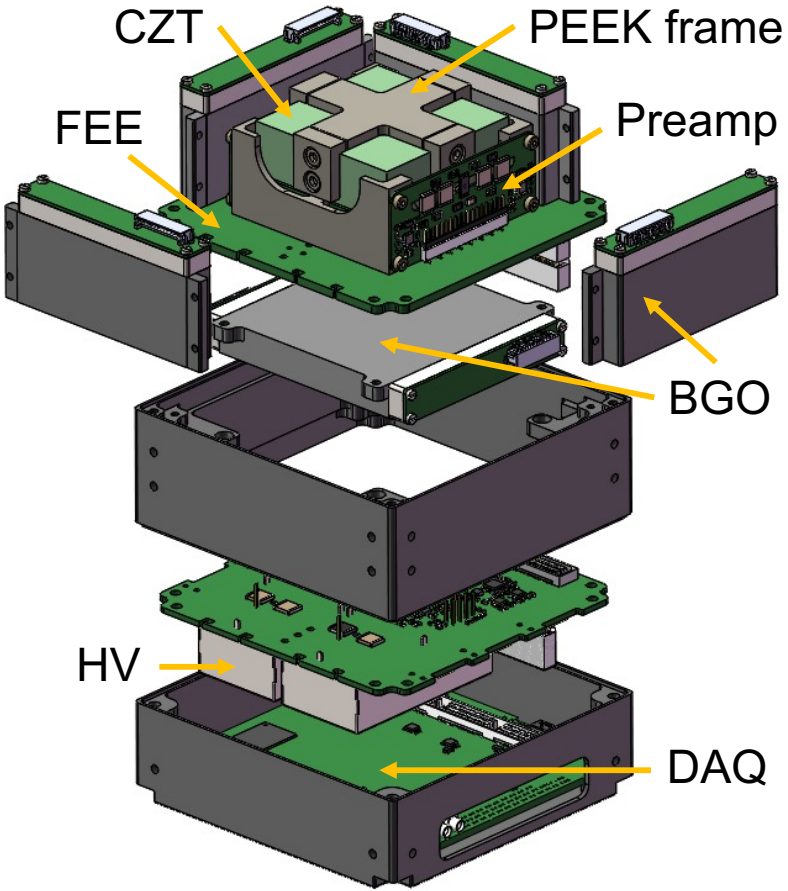
Anti-coincidence BGO not shown

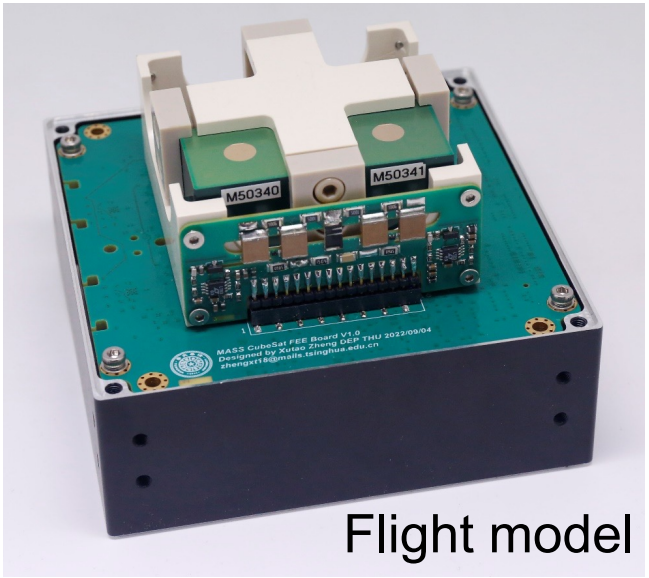


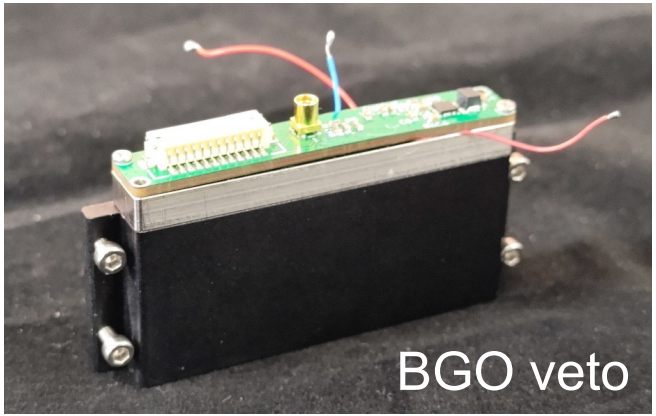
Chessboard layout

No blocking from top view

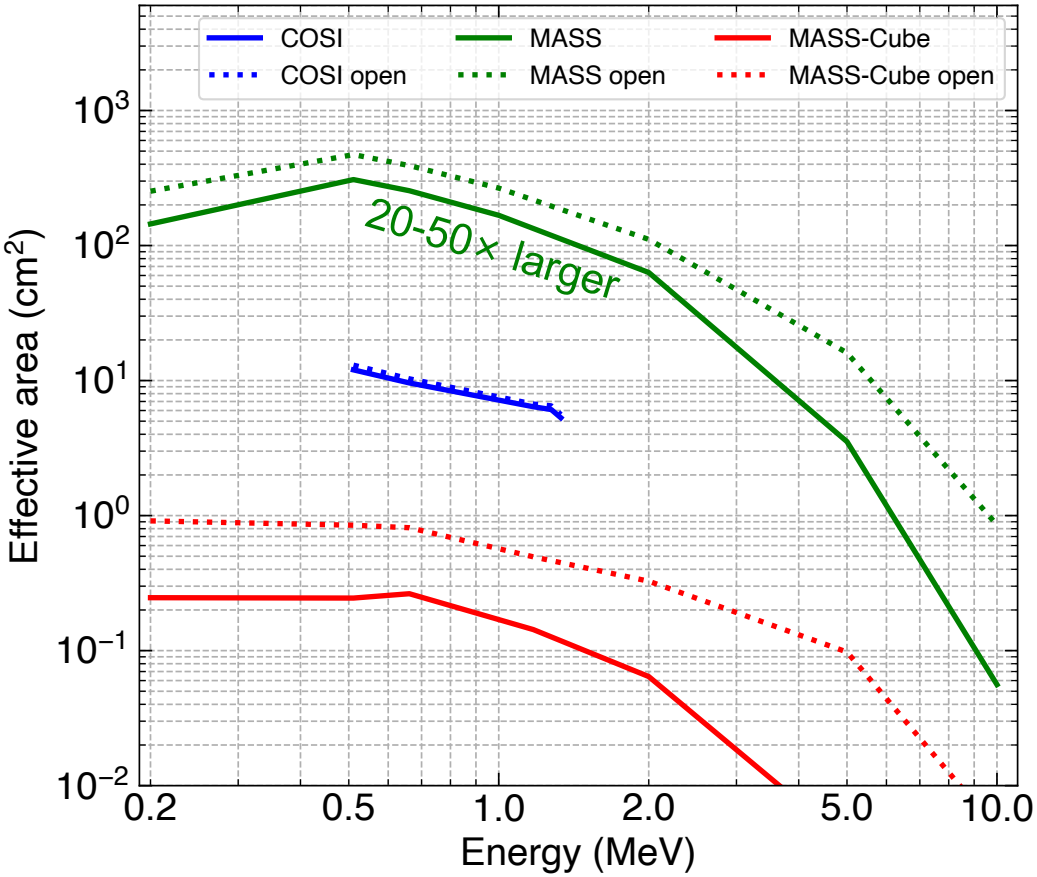
MASS-Cube: a path-finder







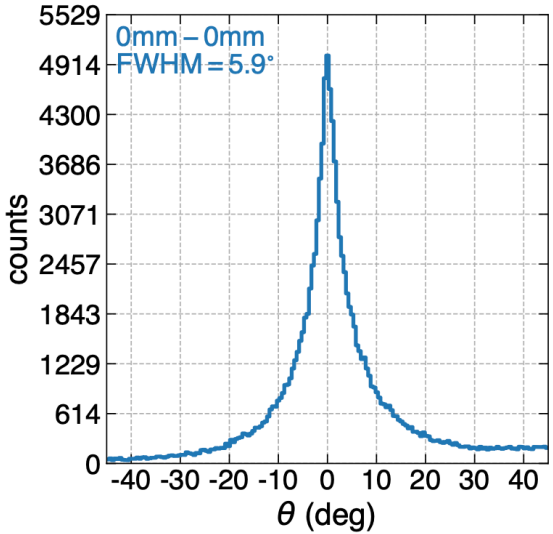
Effective area for line detection in comparison with COSI



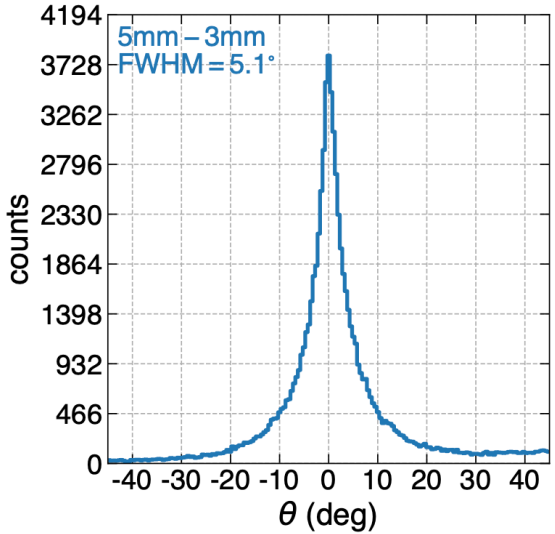
dashed: ≥ 2 hits, ±2σ
solid: ≥ 2 hits, ±2σ, 5mm, 3mm

Angular Resolution Measure (ARM) @ 1 MeV

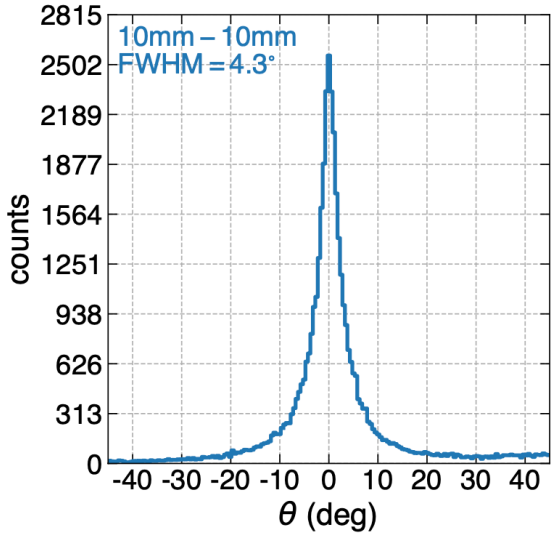
0 mm, 0 mm



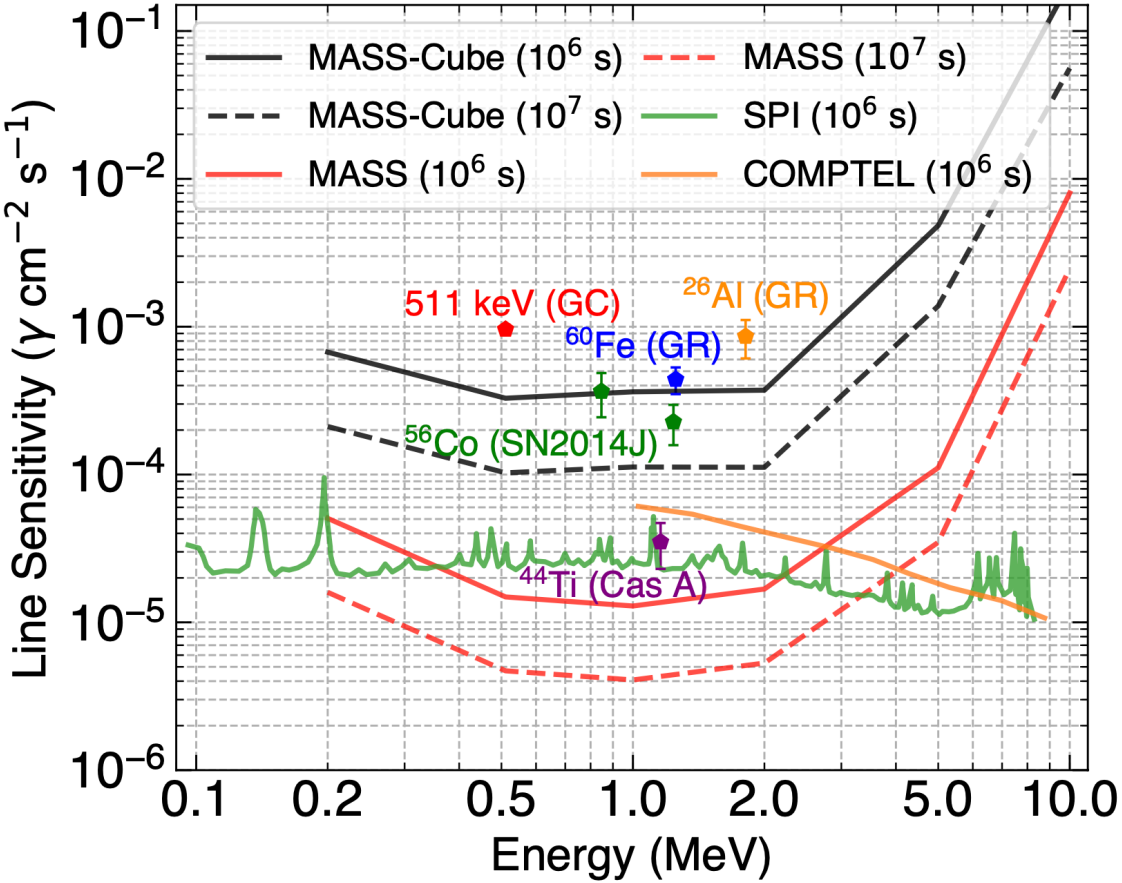
5mm, 3mm



10 mm, 10 mm



Sensitivity for emission line detection



Line (≥ 2 hits; ±2σ)

Summary

- **CZT detectors**
  - Fine energy resolution (0.6% @ 662 keV)
  - 3D position sensitive (1.72 × 1.72 × 0.6 mm^3)
  - Room-temperature
- **On-going work**
  - Developing readout ASICs
  - Radiation damage experiments just done
  - MASS-Cube are being tested and will be launched soon
- **Future**
  - MASS: a small satellite
  - Calorimeters for other MeV missions (MASS + MeVGRO)

THANK YOU!