Compton-Pair Production Space Telescope (ComPair) for MeV Gamma-ray astronomy

Concept

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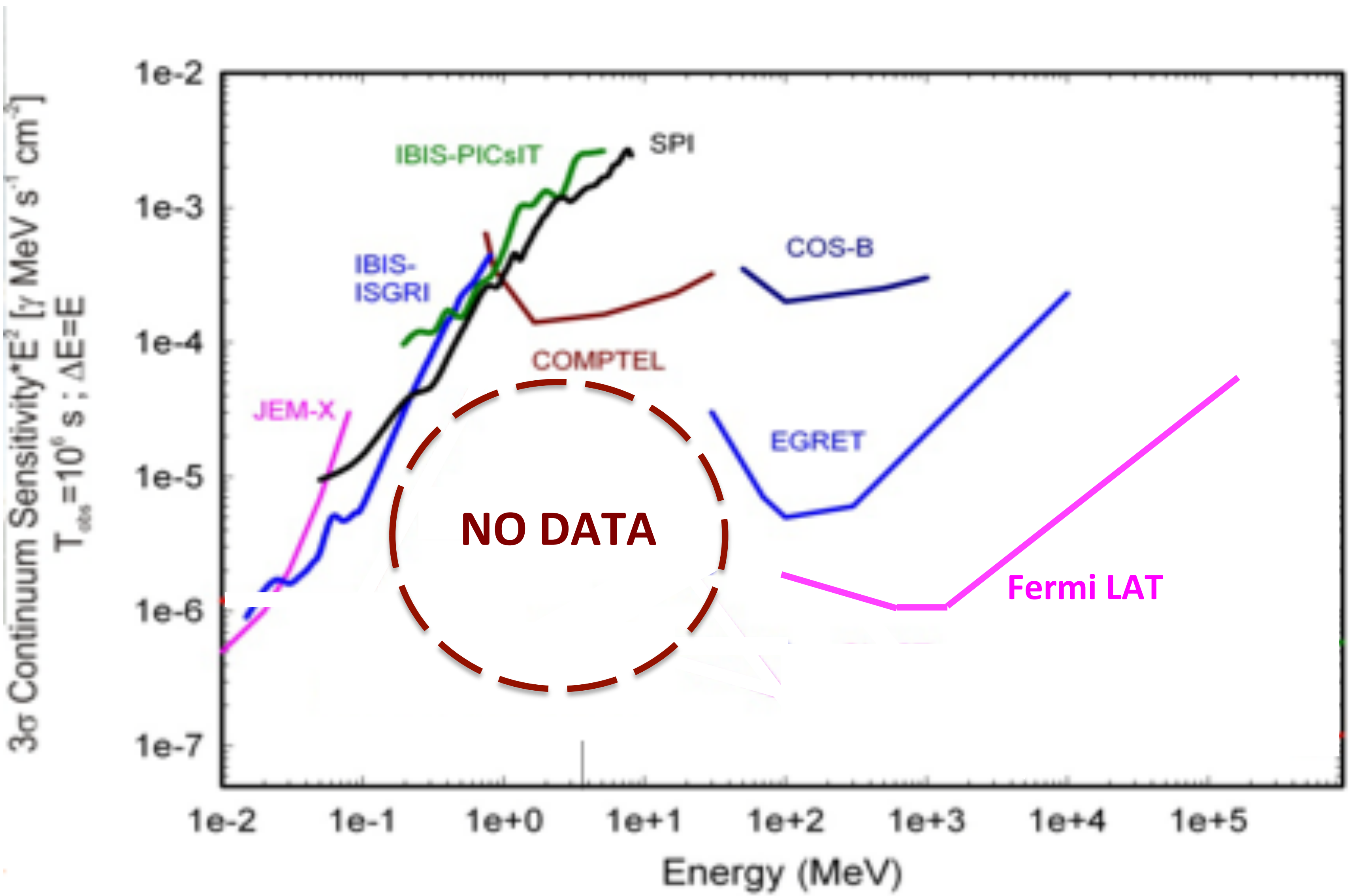
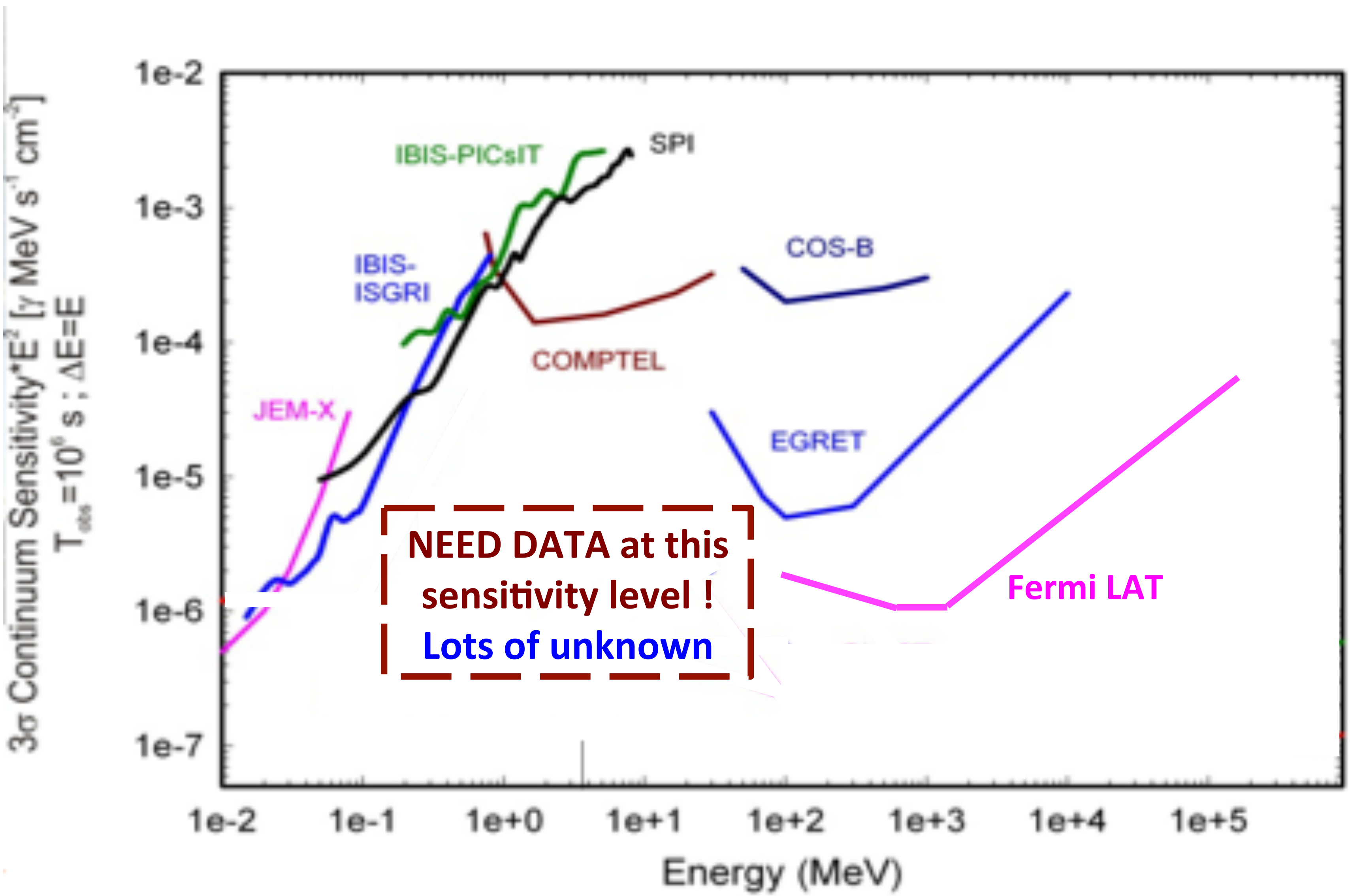
with contributions from Dave Thompson, John Mitchell, Julie McEnery, and other GSFC folks

With so many excellent science talks in this meeting already, I take for granted that the science objectives for an MeV gamma-ray space mission are fully justified and enjoy the luxury to present one option for a tool: how to reach those objectives



3σ Continuum Sensitivity*E² [γ MeV s⁻¹ cm⁻²]
T_obs=10⁶ s ; ΔE=E
1e-2
1e-3
1e-4
1e-5
1e-6
1e-7
IBIS-PICsIT
SPI
IBIS-
ISGRI
COS-B
COMPTEL
JEM-X
EGRET
NO DATA
Fermi LAT
1e-2
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Energy (MeV)



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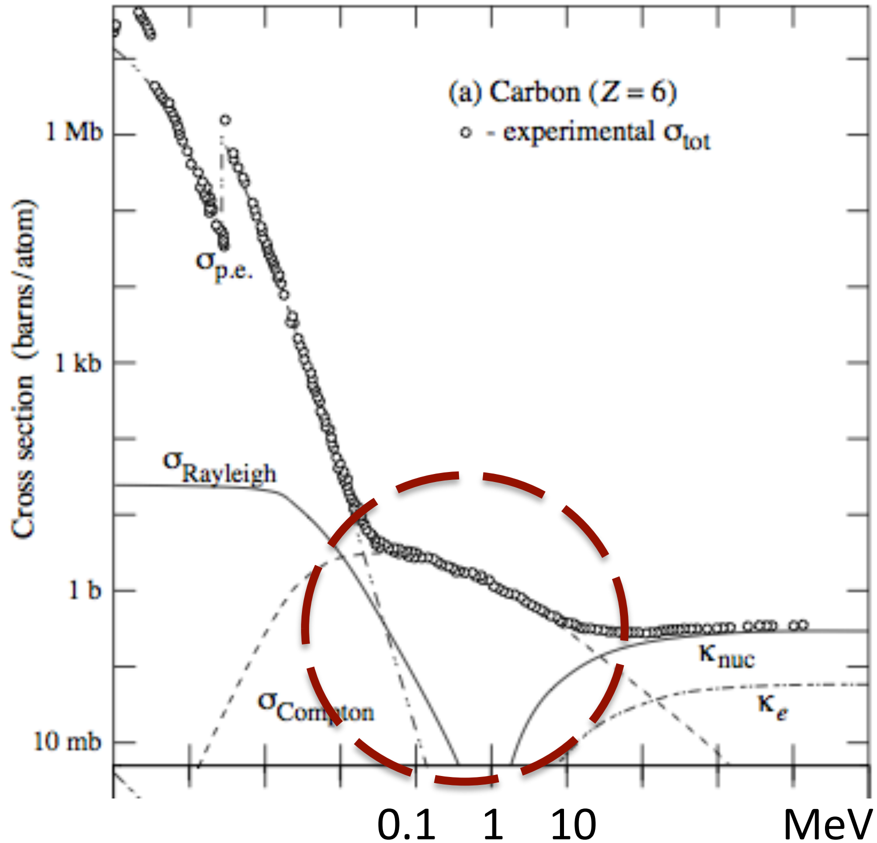
Energy (MeV)
IBIS-PICsIT
SPI
IBIS-
ISGRI
COS-B
COMPTEL
JEM-X
EGRET
Fermi LAT
NEED DATA at this
sensitivity level !
Lots of unknown



Challenging for detection: it is a range where two processes of photon interaction, Compton scattering and pair production, compete, with crossover at around 10 MeV

Goals and Approach

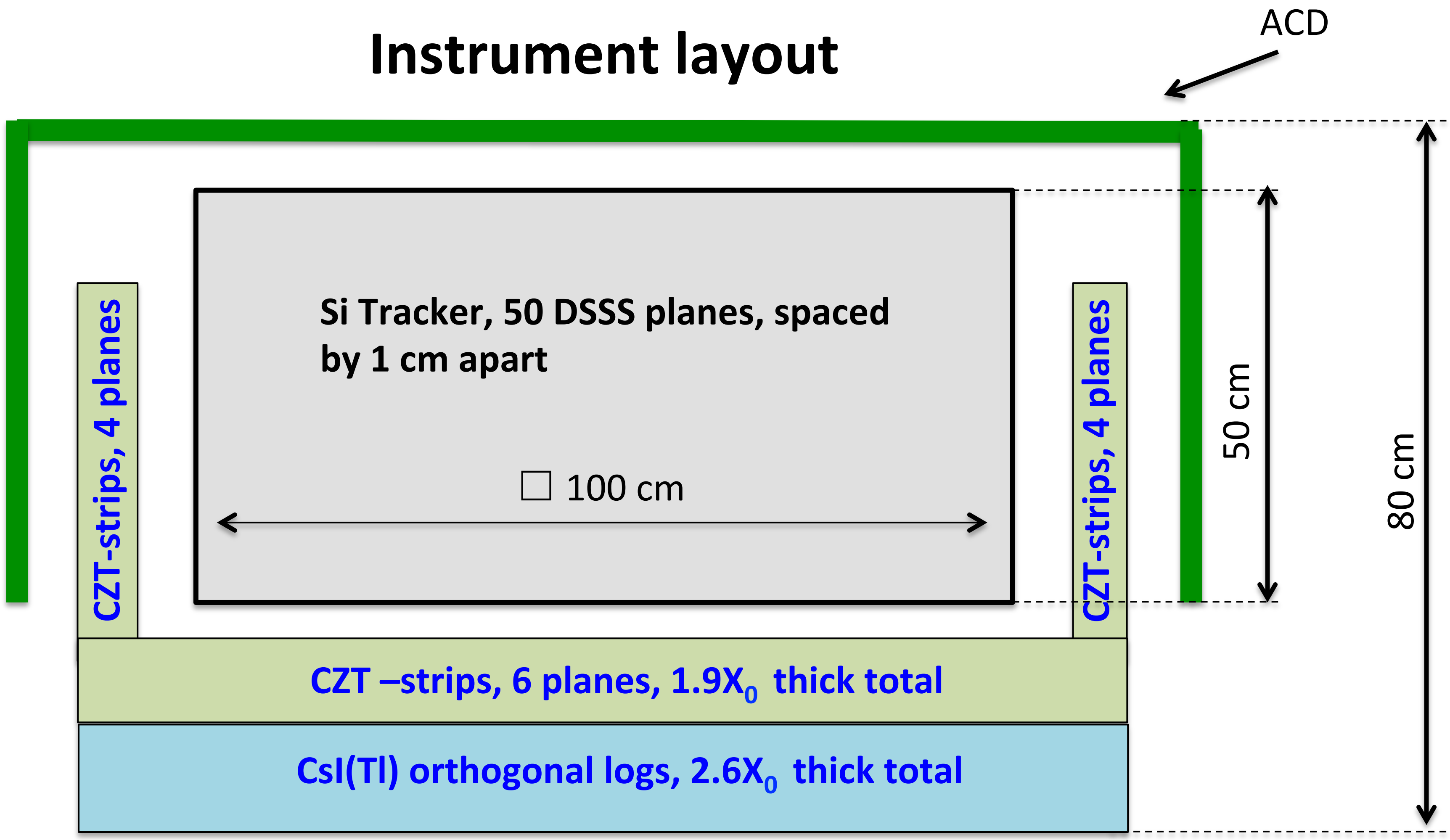
- **Wide-aperture discovery mission** to monitor the whole gamma-ray sky in the energy range 200 keV – > 500 MeV with sensitivity ~100 times better than COMPTEL at ~ 1 MeV and improved PSF over Fermi LAT at 20-100 MeV by a factor 3-5
- Design a **cost-saving single instrument**, capable to detect both Compton-scattering and pair-production events, optimizing its performance in the 1 – 100 MeV span
- Capability to measure **polarization**
- Aim to extend Fermi LAT measurements to below the useful LAT low-energy limit, which is currently 50-100 MeV

Design Approach

- Use well-developed technologies with flight heritage (**TRL 4-5** for most components): **high confidence in mission realization.**
- Maximal use of **Fermi LAT heritage** and lessons learned, as well as the proposed but not flown instruments MEGA and GRIPS : **confidence and savings**
- Si-strip and CdZnTe technology in combination with scintillating detectors represent the most straightforward, reliable, already space-qualified, well-tested and highly-performing approach for the future Explorer-scale mission for measurement of keV-MeV cosmic ray photons
- Cross-check the results obtained from Compton-scattered events with that from pair-production events in energy span 5 – 30 MeV to **increase confidence in the results and to improve background rejection**
- Science payload mass under 1,000 kg, power under 1 kW

Critical design driver: fit the budget, mass and power constraints of MIDEX

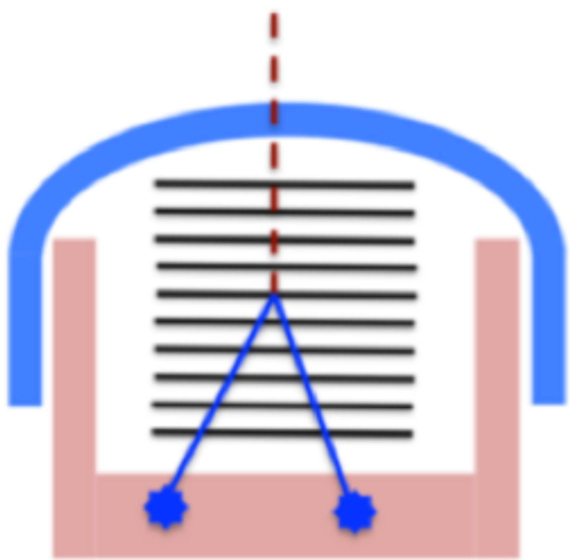
Instrument layout



Ω ~ 3.5 sr (larger than for LAT)

Detection of Pair-production events

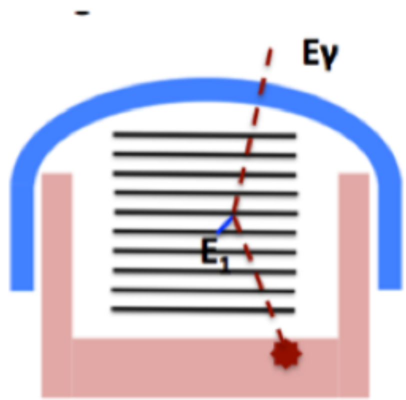
- **Photon conversion** occurs in multi-plane Si-strip tracker (no additional conversion material). Arrival direction is determined by measuring tracks of pair components
- **Trigger:** presence of the hits in 2 consecutive Si-strip layers + signal in Calorimeter
- **Photon energy** is determined in the Si-strips and in the Calorimeter.



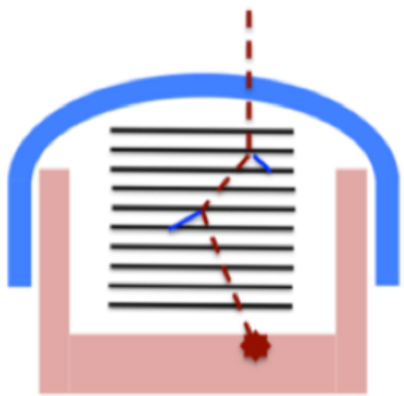
a) Pair production event

Detection of Compton-scattered events

- **First Compton scattering** occurs in one of the Si tracker planes, creating low-energy electron and scattered photon
- **The scattered photon** can be absorbed in the calorimeter. Photon arrival direction (arc on the event circle) is determined by measuring the points of Compton scattering and photon absorption in the calorimeter and measuring energy and direction of electron and absorbed photon.
- **Scattered photon can undergo second Compton scattering** in the Si planes and further be absorbed in the calorimeter. Such events are easier to recognize and subject to smaller background, but the probability of such events is significantly smaller
- **Triggering:** Hits in two consecutive Si layers (Compton scattering and track of Compton electron) + signal in Calorimeter



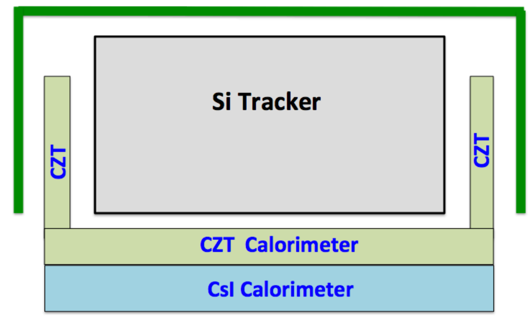
b) Compton event, 1 hit in Tracker



c) Compton event, 2 hits in Tracker

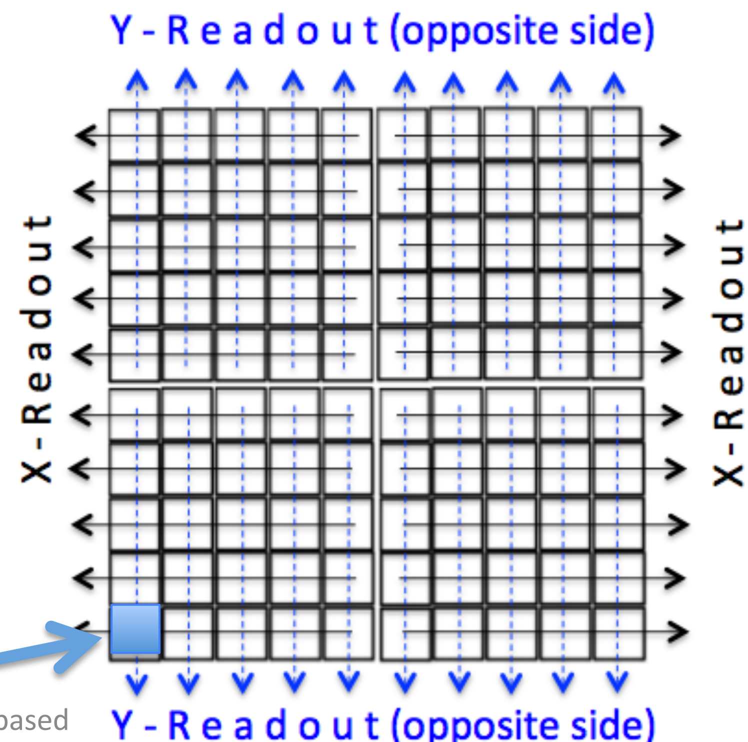
TRACKER

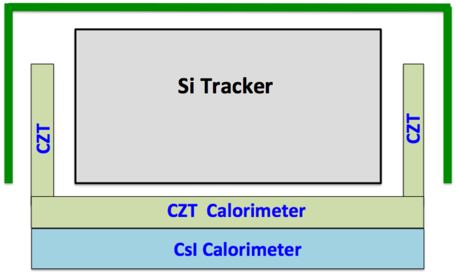
- **Stack of 50 double-side Si-strip planes** without passive converters, spaced by 1cm (Al honeycomb-Carbon face sheets supporting structure). Analog readout from each strip
- **Each plane** is made of 4 sections, with 5 x 5 daisy-chained array of 9.5cm x 9.5 cm DSSD, with thickness of 0.5mm and strip pitch 0.25 mm
- **X- and Y- strips** are on opposite sides of DSSD
- Number of FEE channels: 4×10^5
- **Power:** 40 W at 100 μW per channel.



One-plane array of 50x50 daisy-chained Si-strip detectors

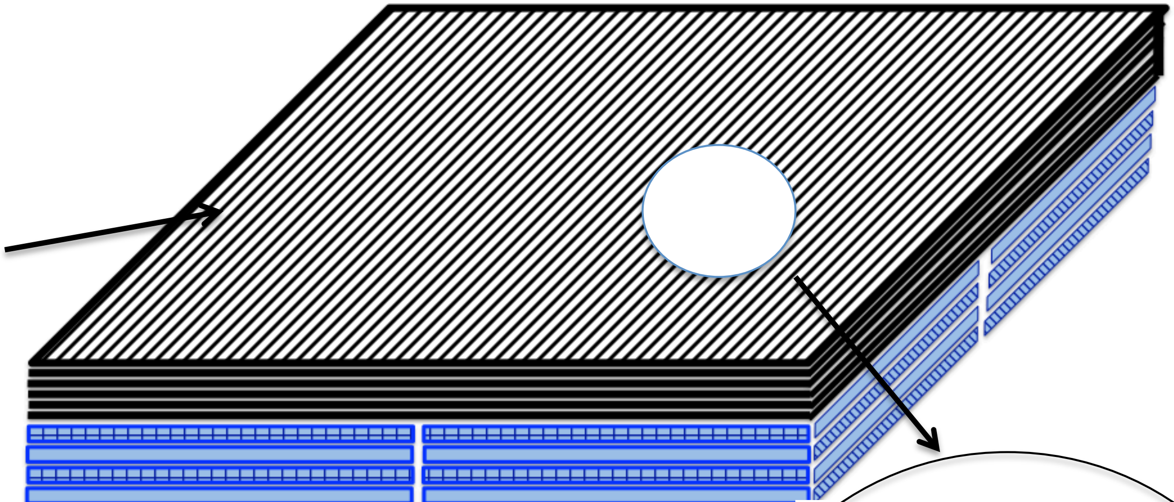
Single double-side Si-strip chip, 9.5cm x 9.5 cm





CALORIMETER (bottom section)

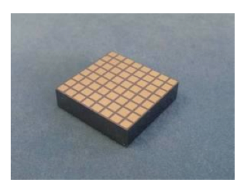
☐ 110cm x 110cm

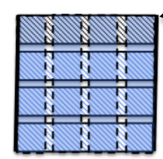


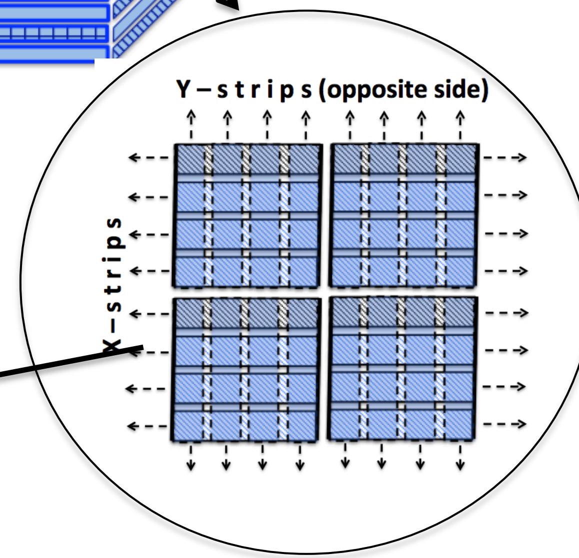
6 planes of 55x55 double-side daisy-chained CZT detectors

4 planes of 1.2cm x 1.2cm cross section CsI(Tl) logs
- X and Y orthogonal layout
- Light collection from both ends of each log by SiPM

A. 20 x 20 x 5 mm³ (8*8 pixels) - Example







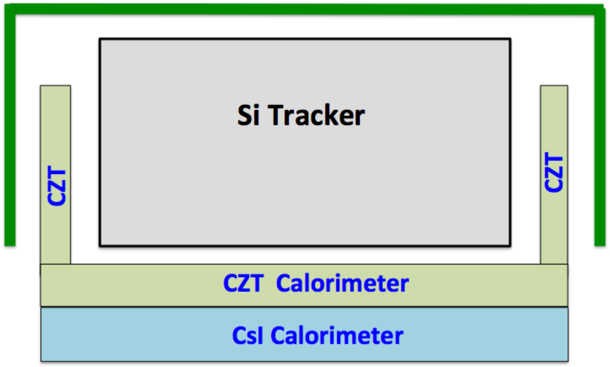
TOTAL
- CZT: 3cm, or 1.9 X_0
- CsI(Tl): 4.8 cm, or 2.6 X_0
- 4.5 X_0 total
- Mass ~ 400 kg (only dets)

Double-side 20mm x 20mm, 5mm thick CZT detector, with 5mm-pitched orthogonal strips on both sides

Daisy-chained CZT-detectors (2x2 array is shown)

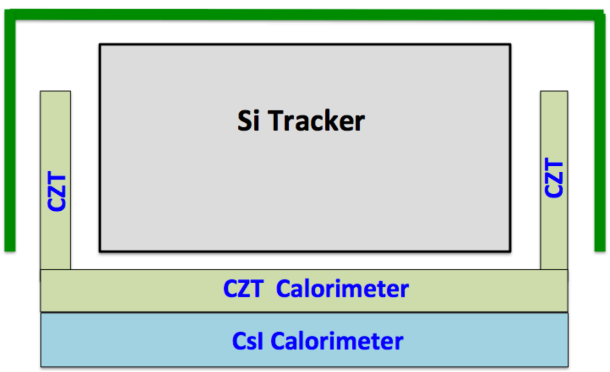
CALORIMETER (side section)

- **Conceptual design** is practically the same as for the CZT part of the bottom section
- **Each side** section consists of 4 planes of CZT detectors, 108cm x 30cm each
- **Each plane** is made of 54 x 15 CZT detectors
- **Thickness of CZT** is 2cm, or 1.25 X_0
- **Mass** of 4 side sections: 150 kg (CZT only)



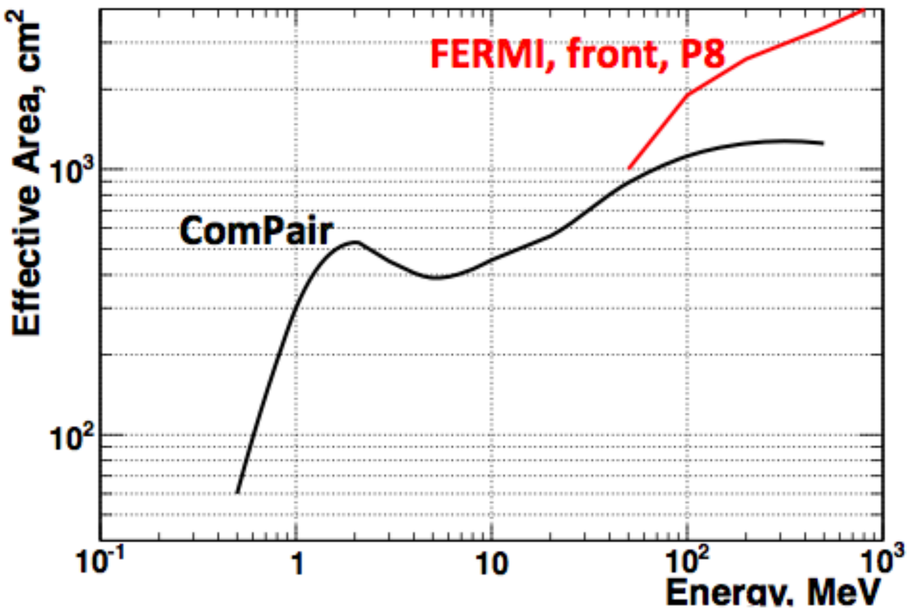
Instrument Summary

Energy Range	1 – 200 MeV (200 keV - > 500 MeV)
Effective Area	600 – 1200 cm^2 for 10 MeV – 500 MeV
PSF	~7° at 10 MeV, ~1° at 100 MeV
Energy Resolution	~2% (1 MeV), ~4% (10 MeV), ~12% (100 MeV)
Dimensions	1m x 1m x 0.7m (only detecting part)
Solid angle	~3.2 sr
Total mass	1000 kg (only science payload)
Detector thickness	tracker 0.3 X_0 , bottom calorimeter 4.5 X_0

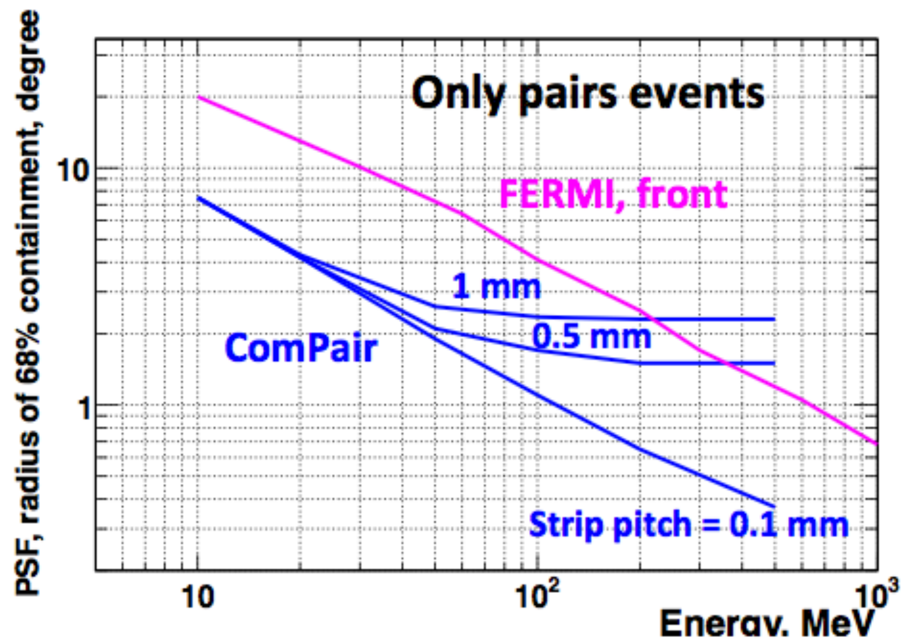


Instrument Response Functions

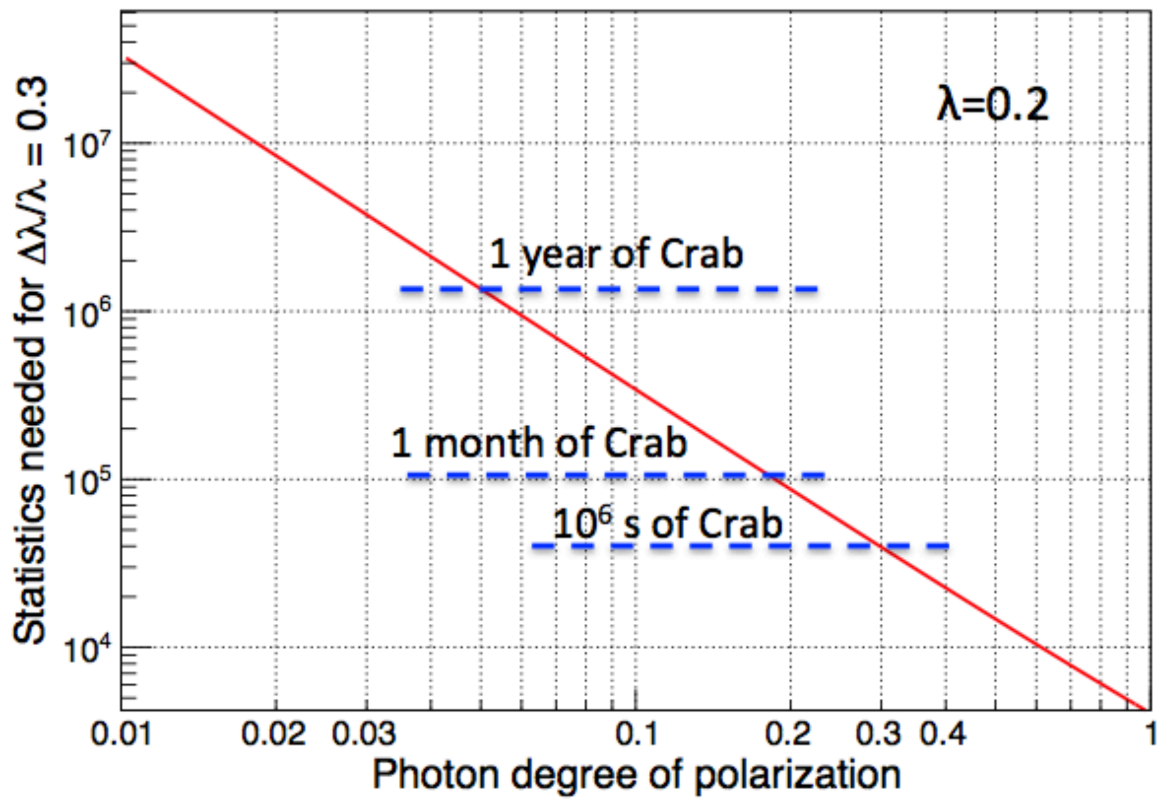
Effective Area



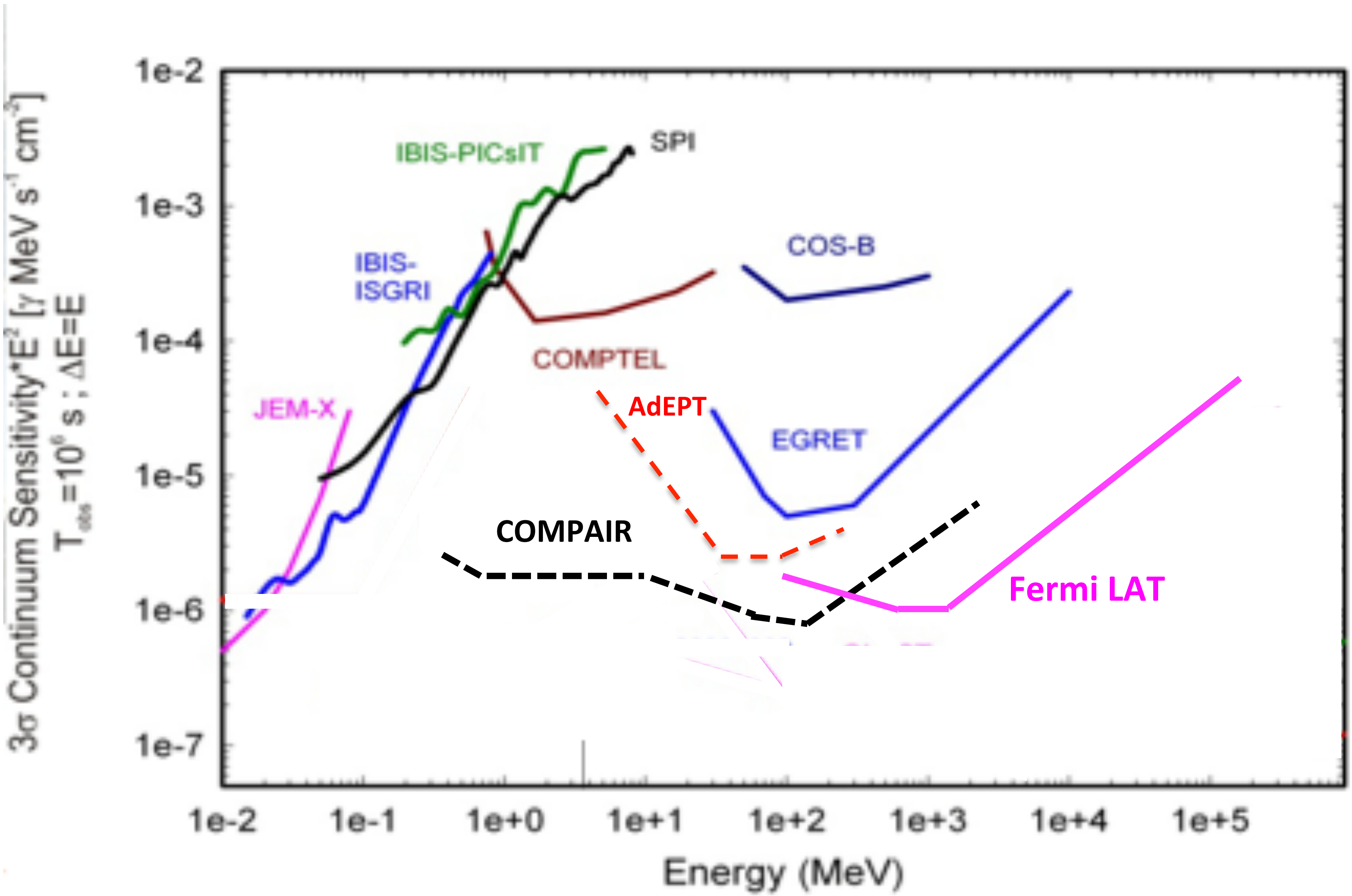
PSF



What degree of polarization we can detect?



Statistics needed to measure photon degree of polarization with 30% accuracy, assuming measured asymmetry parameter λ=0.2. This is a rather conservative assumption, corresponding to Eγ = 10 MeV. We will be detecting pair production events starting from 5 MeV at least.



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1e-2
1e-1
1e+0
1e+1
1e+2
1e+3
1e+4
1e+5
Energy (MeV)

SUMMARY

- The team is working hard on the APRA proposal
- Aim is to close “Impossible” Window