ComPair

A Wide-Aperture Discovery Mission for the MeV Band

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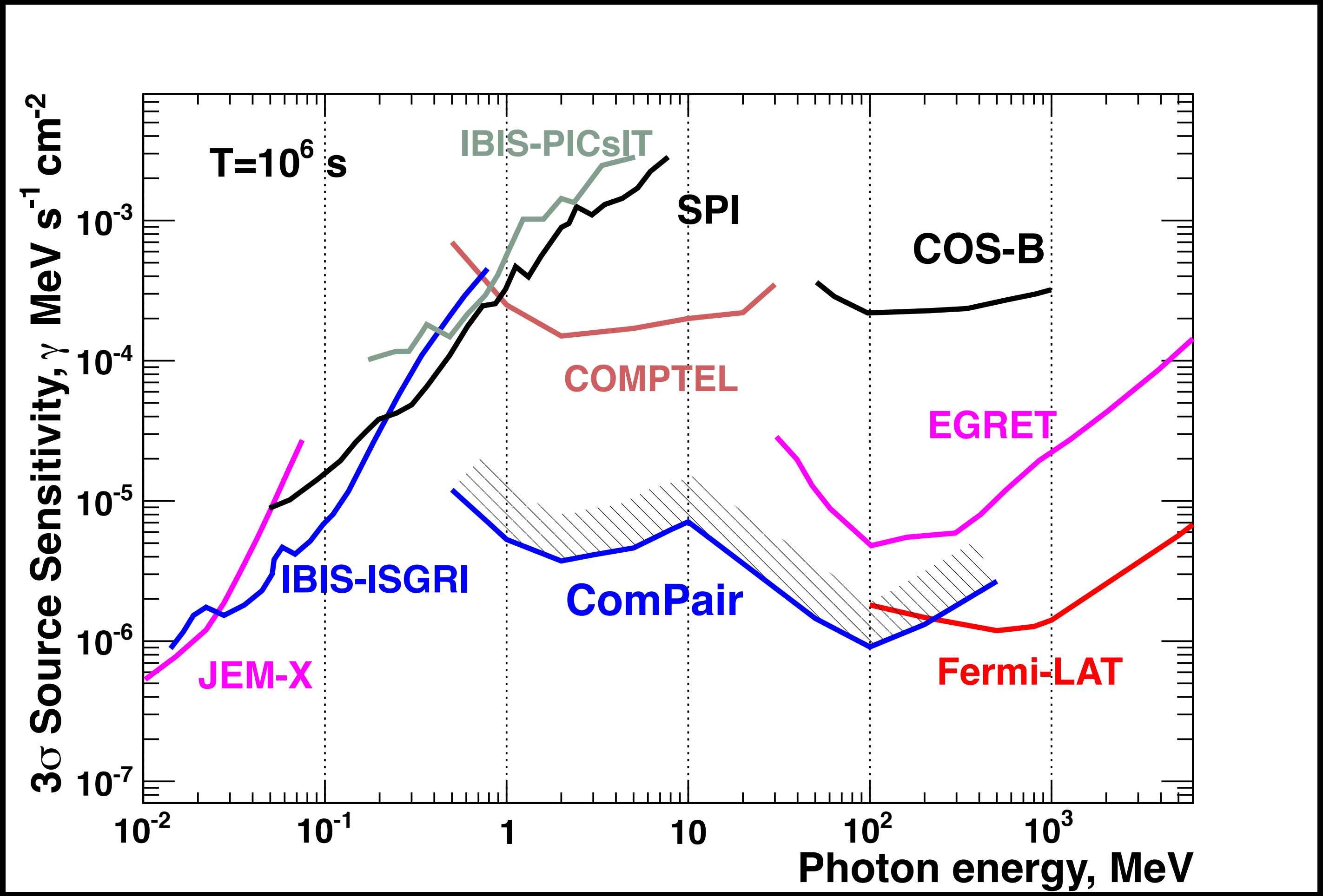
Why do we want to
look in the MeV range?

Science Driver: Guaranteed Discovery Space

- We have not looked deep into the MeV range
- Discovery space
- Key piece to the high-energy view of the Universe



Continuum Sensitivity for instruments in/near the MeV Band

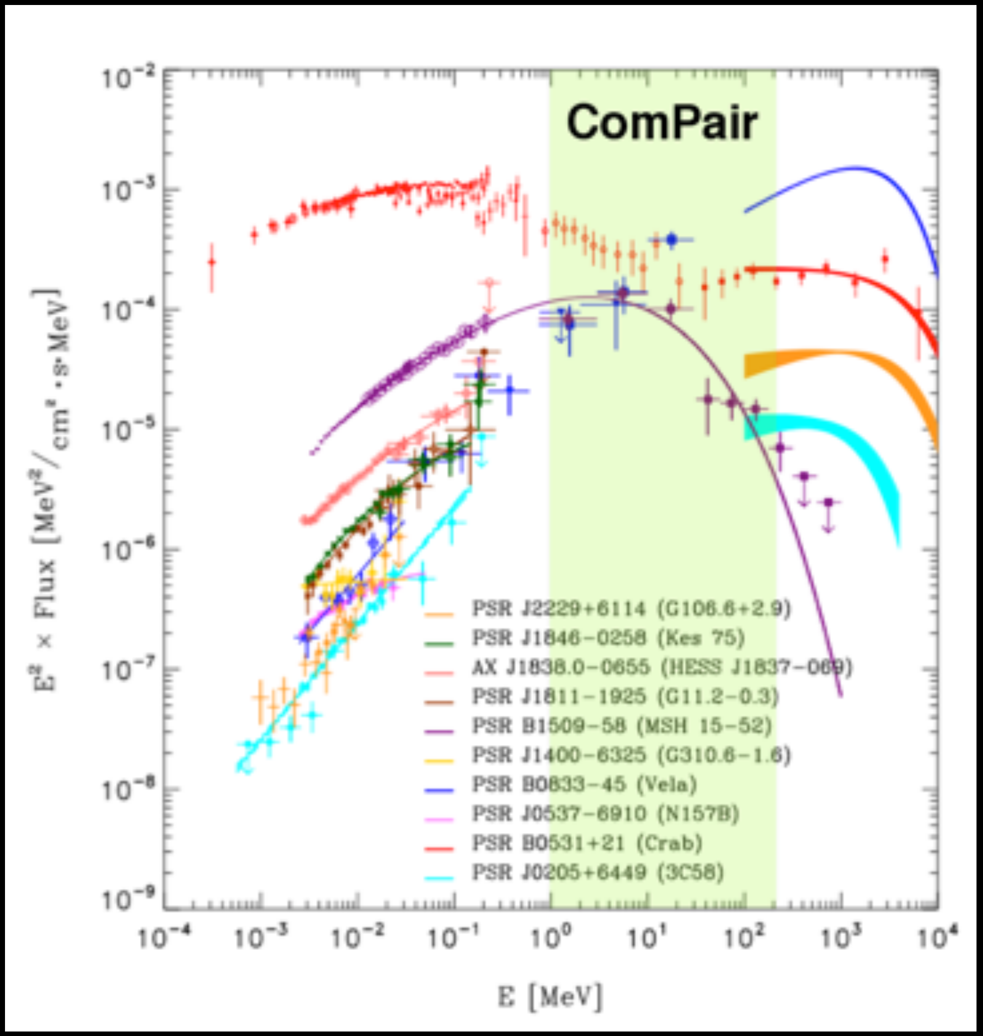
Science Objectives: Extreme Astrophysics

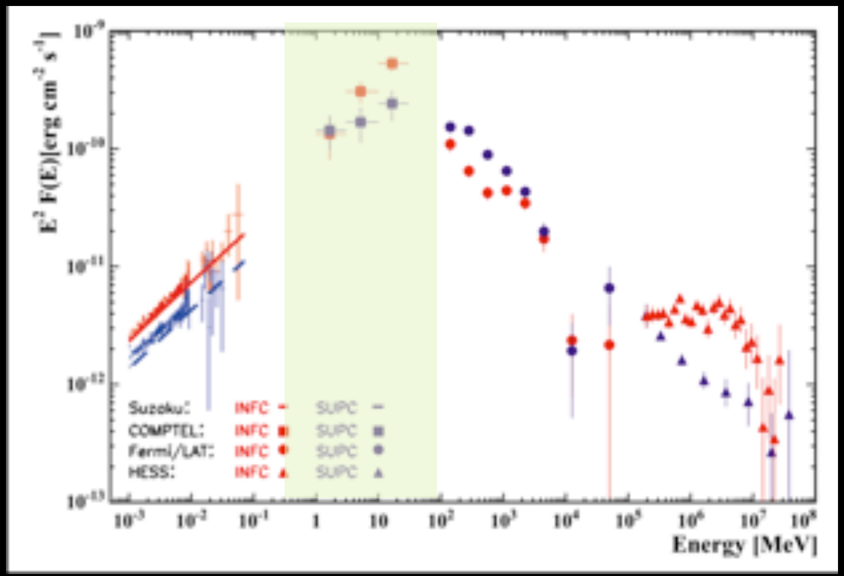
- Understanding how the Universe works requires observing astrophysical sources at the wavelength of **peak power output.**
  - Peak power is crucial for establishing source energetics
  - *Fermi*, NuSTAR, and Swift BAT have uncovered source classes with peak energy output int he poorly explored MeV band
  - ComPair science objectives focus on cases of extreme astrophysics
    - High matter densities
    - Strong magnetic fields
    - Powerful Jets
- Spectral features occurring in this energy range - breaks, turnovers, and cutoffs - and their temporal behavior are crucial to discriminate between competing physical models.

Science Objectives: Extreme Physics of Compact Objects

- Compact objects with key energy features in the MeV range include
  - **Magnetars** - strongest magnetic fields in the Universe
  - **Pulsars** - neutron stars represent the highest matter densities possible before collapse to a black hole

Selected pulsars
(N.B. ~170 gamma-ray puslars known)



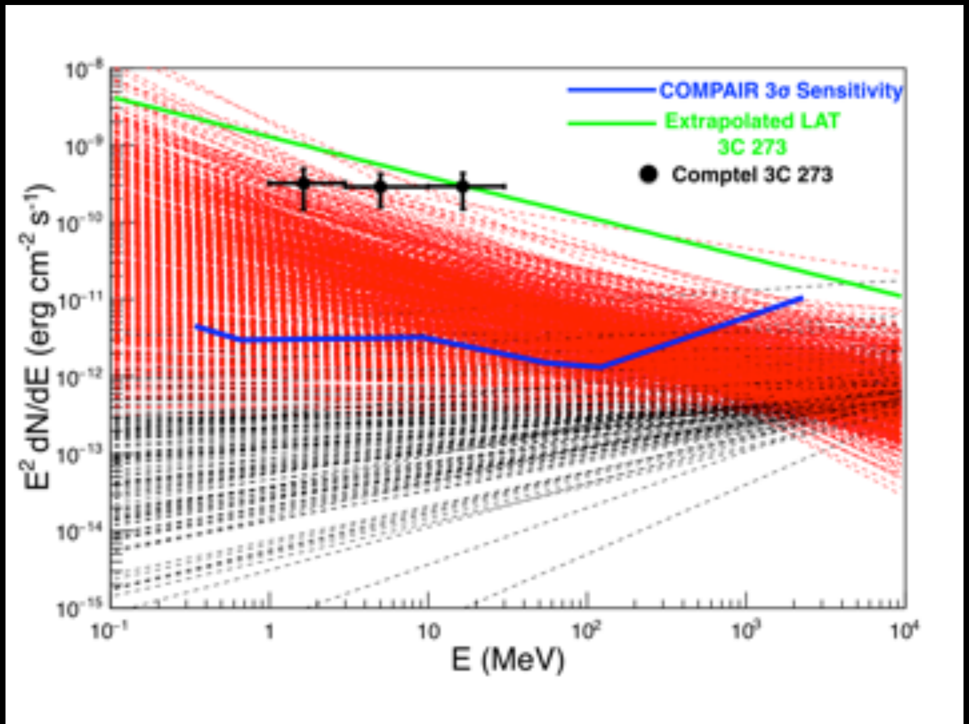


High mass x-ray binary LS 5039 at inferior and superior conjunction.

Science Objectives: Discovery Space

- Instruments covering the 1-100 MeV range have been limited in sensitivity, e.g. COMPTEL/OSSE on CGRO, Integral SPI
  - N.B. Fermi-GBM occultation studies are primarily < 1 MeV
- About 1/3 of Fermi-LAT sources remain unidentified.
- ComPair will provide the missing view between high-energy gamma-ray and X-ray regimes, helping to identify and study those objects.

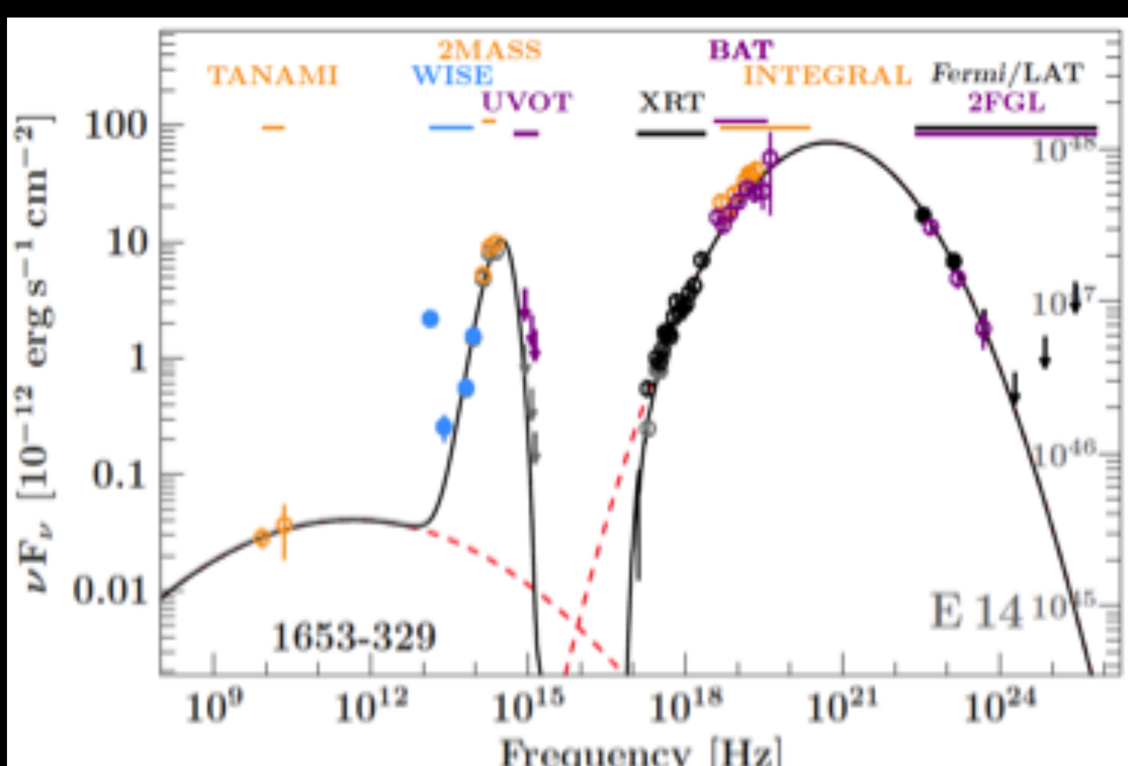
More than 1/3 of Fermi-LAT catalog sources peak below the Fermi-LAT band.



Below 200 MeV ComPair will dramatically improve sensitivity and will open a new window in the spectrum leading to the discovery of new sources and new source classes.

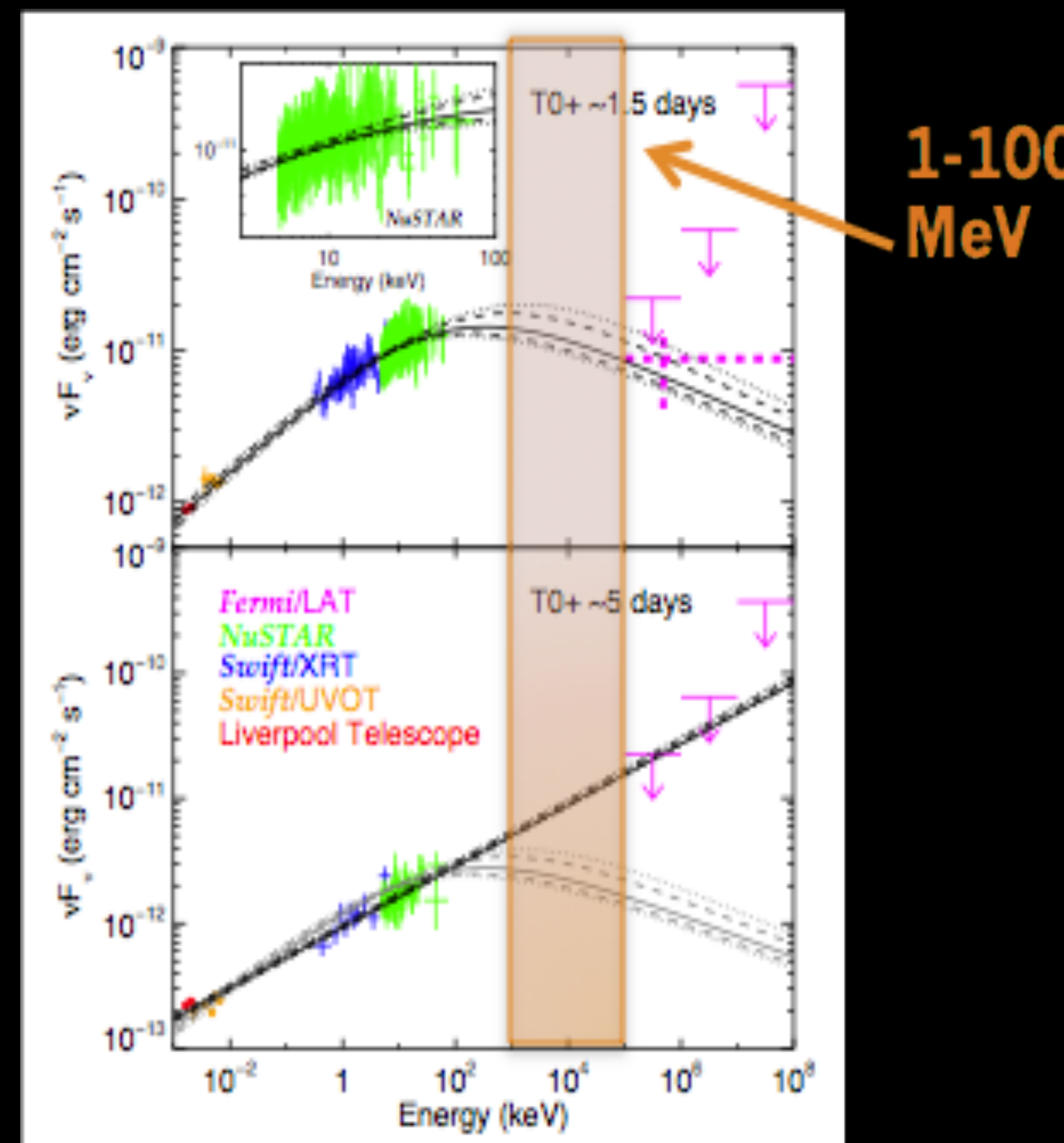
Science Objectives: Ubiquity of Jets

- Jets are powerful accelerators, but we do not yet understand their emission mechanisms
- Measurement of SEDs at interesting times with sufficient sensitivity is vital for physical models of their radiation processes



J1653-329, a candidate PeV neutrino emitter
Krauss et al. 2014

GRB 130427A



Kouveliotou et al. 2013

Science Requirements

Goal	Energy Range	Spatial Resolution	Time Resolution	Sensitivity	FoV
Jets	~ 0.5-100 MeV	~ 1 deg	< msec	10-10 erg/cm2/s	Large
Compact Objects	~ 0.1-100 MeV	~ 1 deg	< msec	10-10 erg/cm2/s	Large
New Sources	~ 1-100 MeV	~ 1 deg	< msec	10-10 erg/cm2/s	Large

Hence, we focus on a large field-of-view instrument with modest angular and energy resolution, optimized for continuum sensitivity and time domain science.

- Not really a new idea. Which is a good thing…

Focus on Continuum Flux Sensitivity

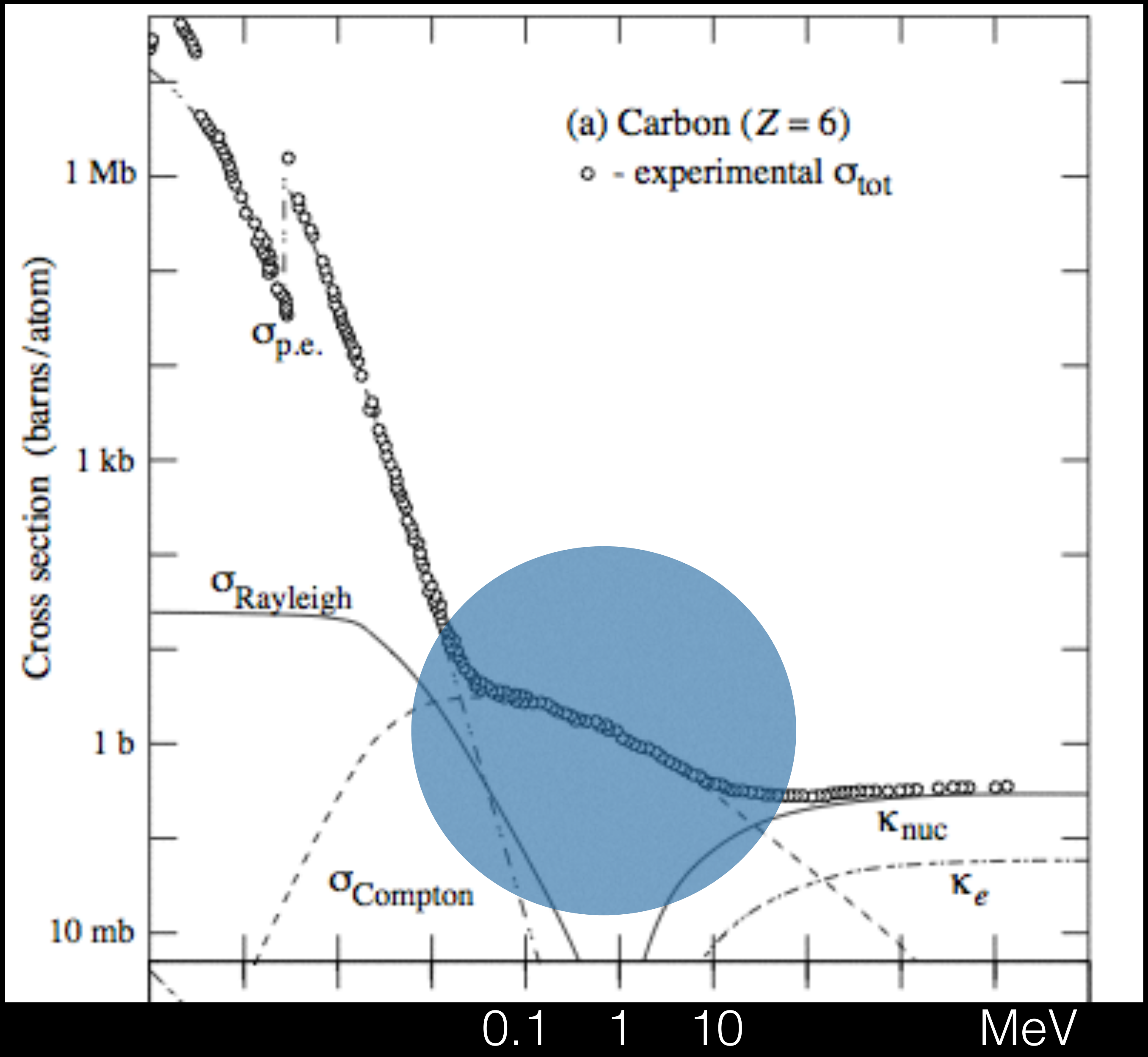
- ComPair is a new instrument in name but not in heritage. Concept is built on on mature technology and extensive prior instrument development and optimization
  - Maximal use of Fermi LAT hardware heritage and lessons learned
  - Modification of a mature, well studied mission concept (MEGA)
  - Most technically straightforward approach for this energy range
- Addresses compelling science questions and allows a broad science discovery capability

Goals

- Wide-field - monitor the whole gamma-ray sky
- Energy range 200 keV –> 500 MeV
- Sensitivity ~10-50 times better than COMPTEL at ~ 1 MeV
- Angular resolution 3-5 times better than Fermi LAT at 20-100 MeV

What are the challenges?

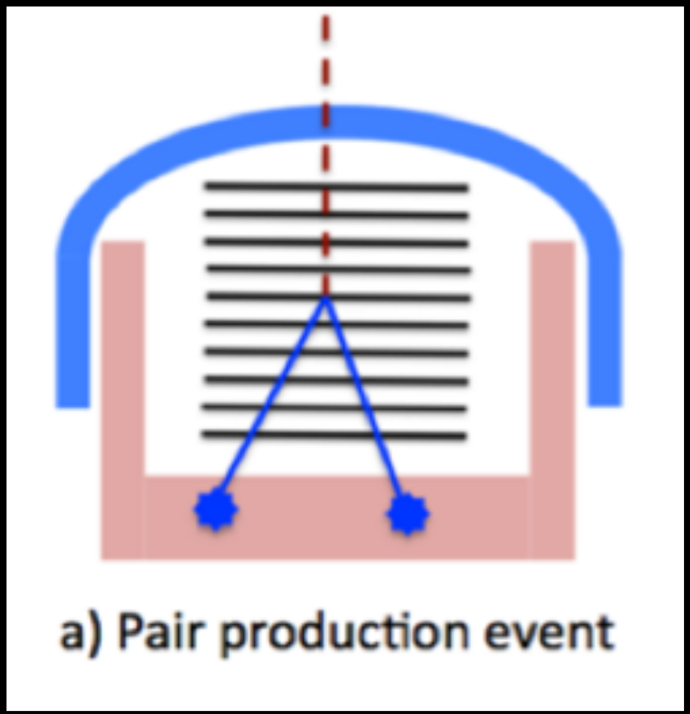
Challenges for MeV Energy Regime



From ~0.1 - 100 MeV two photon interaction processes compete. Compton scattering and pair production cross sections intersect at ~10 MeV.

How are we going to do this?

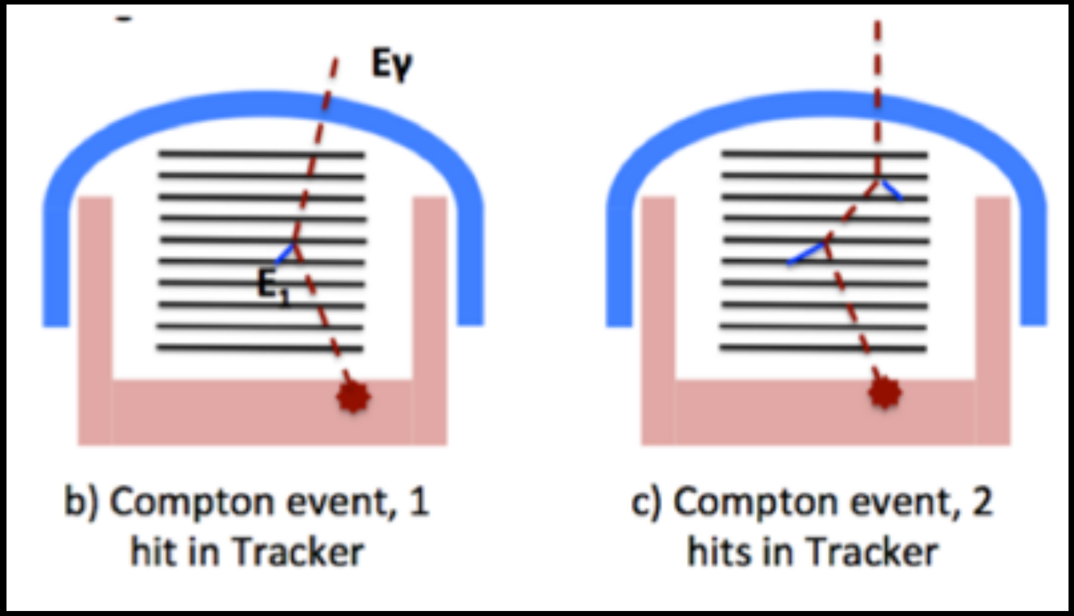
Detection of Pair-production Events



Photon converts to pair (e-/e+) in multi-layer Si-strip tracker (no additional conversion material).

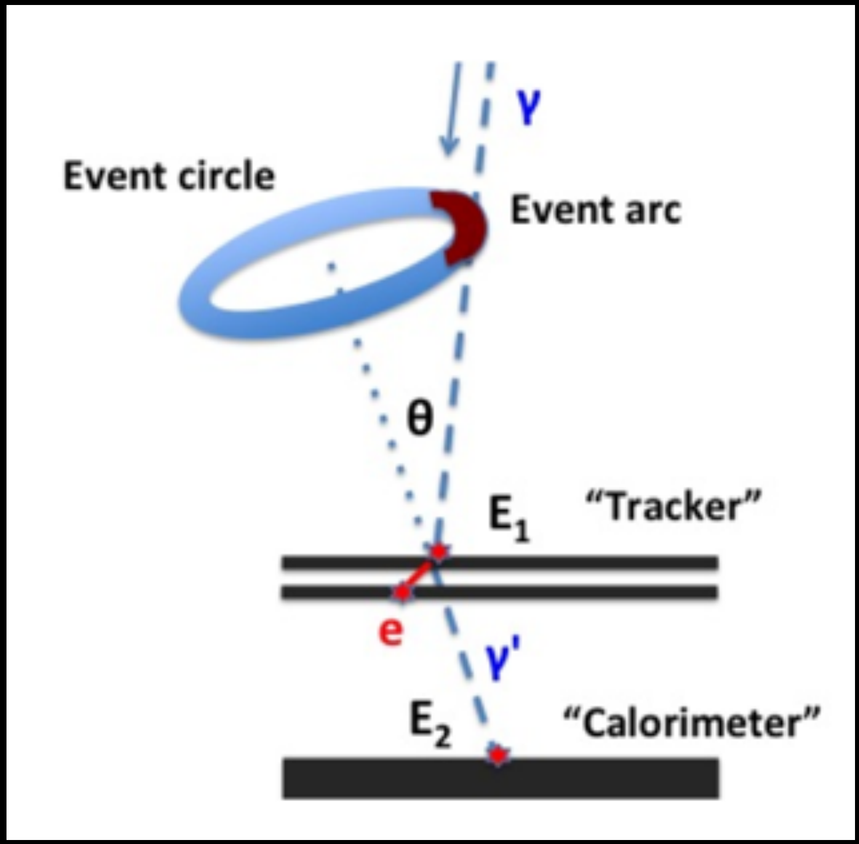
- **Trigger** on signals in 2 consecutive Si-strip layers in coincidence with energy deposit in the calorimeter
- **Photon direction** is determined by measuring the position of the pair components as they pass through the Si-strip layers and calorimeter.
- **Photon energy** is determined by evaluating energy deposited in the Si-strips and in the calorimeter.

Detection of Compton-scattered events

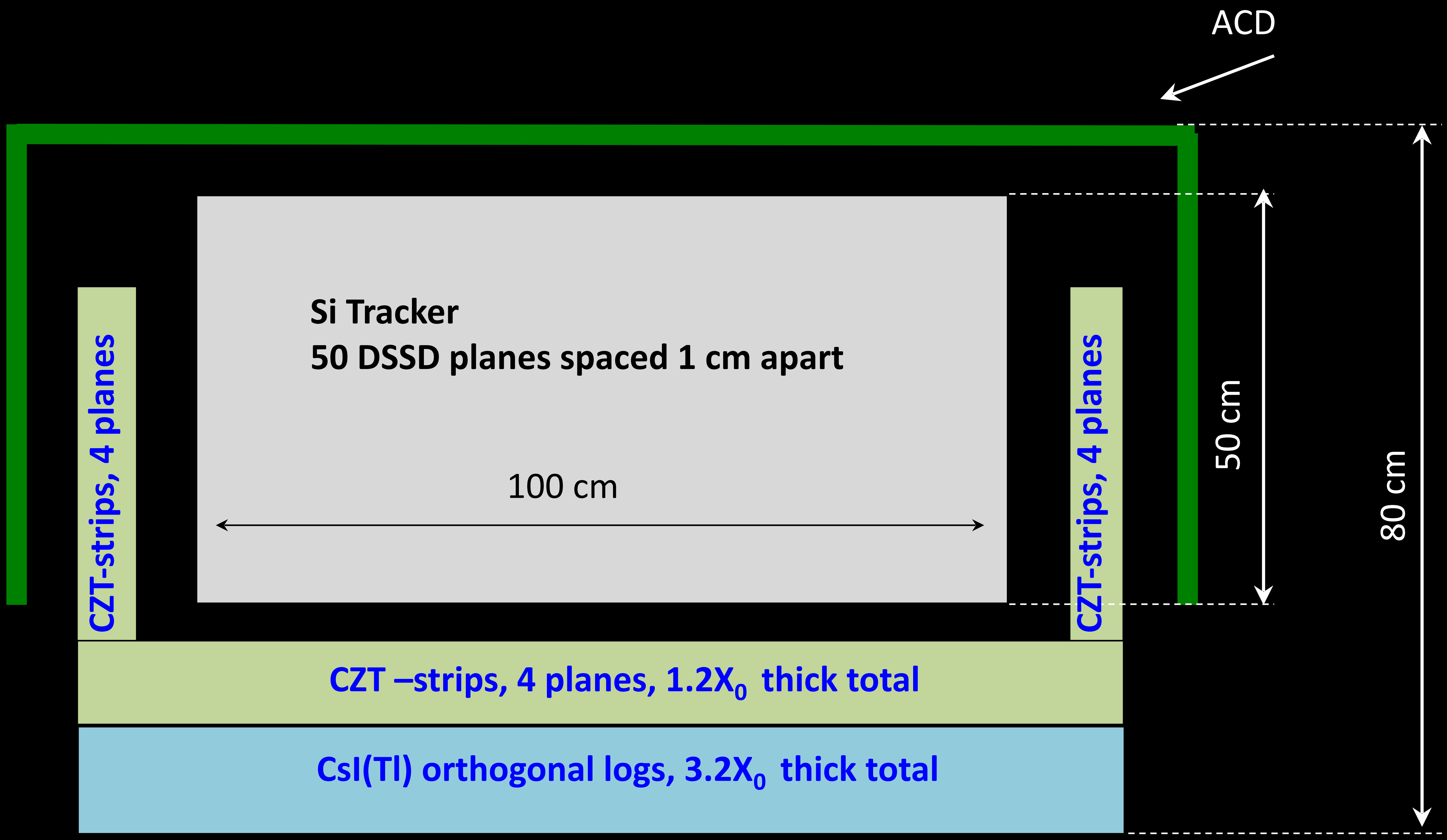


Photon scatters in Si-strip detector, creating low-energy electron. Scattered photon can be absorbed in the calorimeter.

- **Trigger** on signal in Si-strip detector in coincidence with energy deposit in the calorimeter.
- **Photon direction**, constrained to a circle or arc on the sky, is determined by position and energy measurements of electron and absorbed photon.
- **Photon energy** is determined by evaluating energy deposited in the Si-strips and in the calorimeter.
- Measurement of additional scattering enhances reconstruction and background rejection, but occurs less frequently.



Instrument Layout

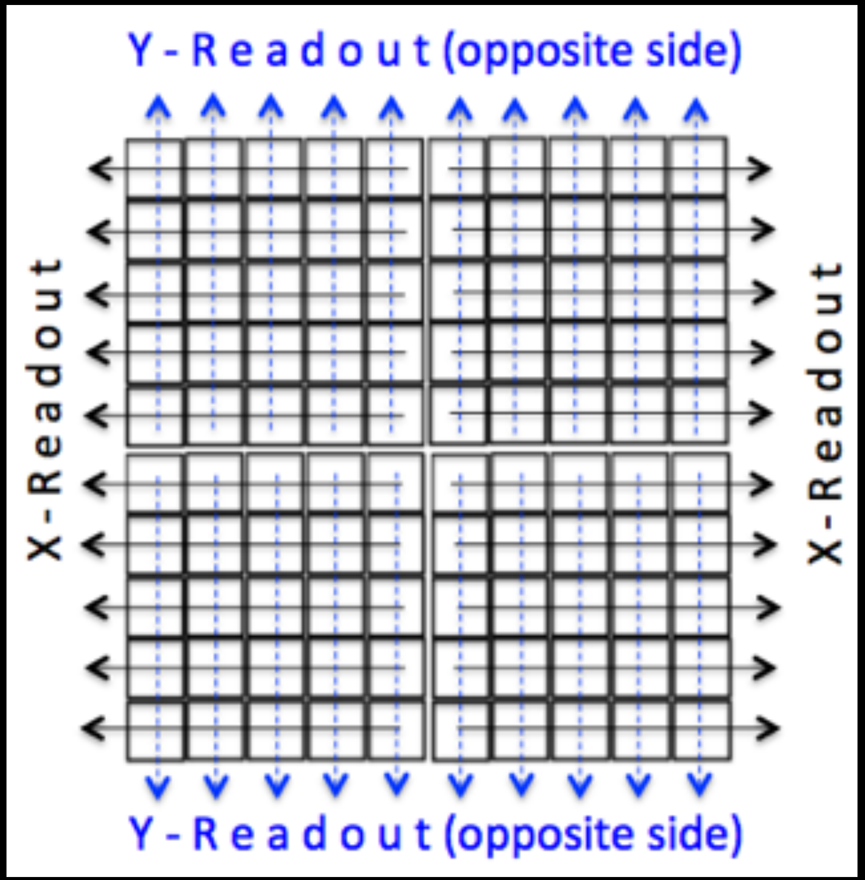


Ω ~ 3 sr (*Fermi*-LAT ~ 2.5 sr)

ComPair Tracker

Provides incident photon interaction position (Compton or pair production) and tracking for secondary charged particles

Tracker Layer Top View



- Stack of 50 double-sided Si-strip planes
  - 1 cm spacing
  - Analog readout from each strip
- Each plane divided into 4 sections
  - 5 x 5 daisy-chained array of 9.5 cm x 9.5 cm DSSD with thickness of 0.5 mm and strip pitch of 0.25 mm
  - X- and Y-strips on opposite sides of DSSD
- Number of FEE channels: 3×10^5

Tracker Heritage

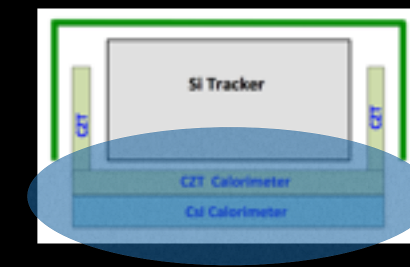
- Si-strip detectors are widely used in particle physics. Practically all complex detectors on accelerators use Si-strip detectors: CERN, FermiLab, SLAC, etc.
- Extensive space flight heritage: Fermi-LAT, AGILE, PAMELA, AMS
- Options available for electronic components with space flight certification: IdEAS, products used in Swift, CREAM, AMS, PAMELA, Astro-H, etc.
- Scale of the detector: 50 m2 of double-sided Si (Fermi-LAT has ~80 m2 of single-sided Si)
- ComPair team includes UCSC, Si-tracker subsystem lead for Fermi-LAT

Fermi LAT

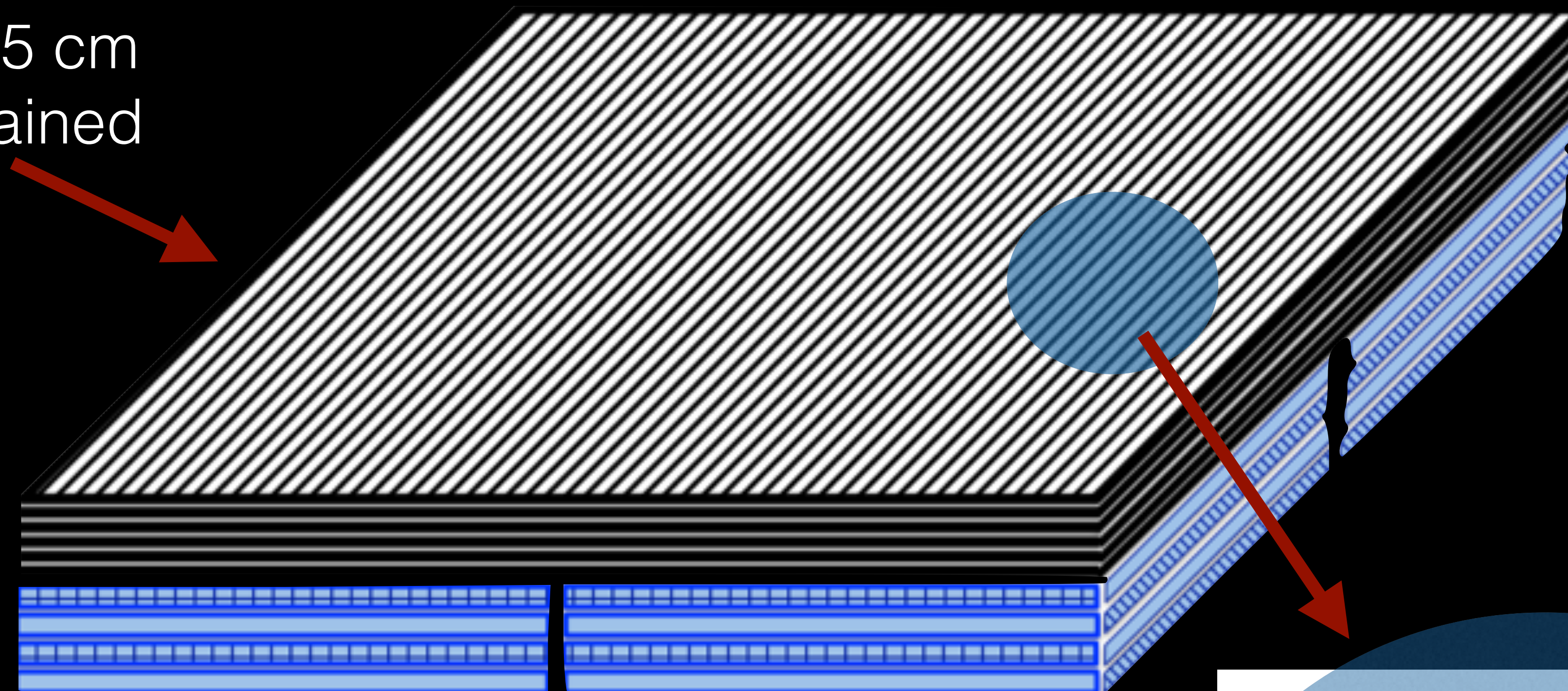
PAMELA

AMS-02

ComPair Calorimeter

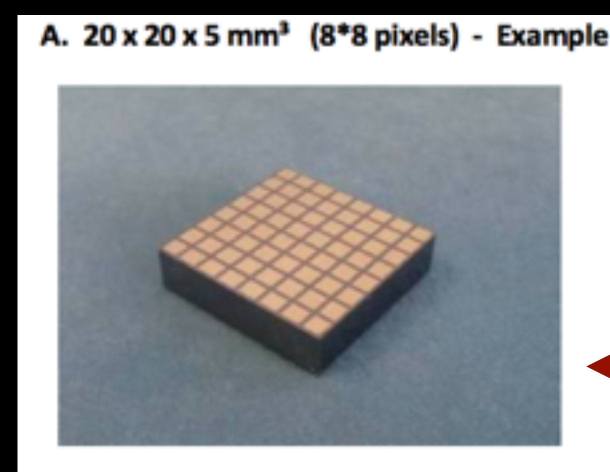


Upper Calorimeter
4 planes of 5.5 cm x 5.5 cm
double-sided daisy-chained
CZT detectors

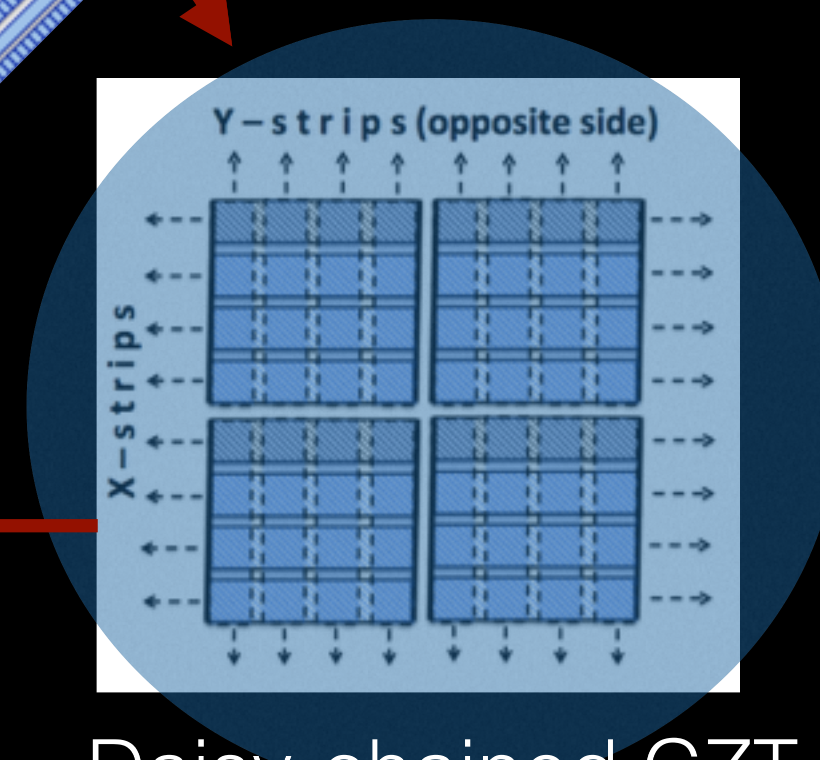


Lower Calorimeter
5 planes of 1.2 cm x 1.2 cm
cross section CsI(Tl) logs
X and Y orthogonal layout
Light collection from both
ends of each log by SiPM

- Calorimeter Depth
  - CZT: 2 cm (1.2 X_0)
  - CsI(Tl): 6 cm (3.2 X_0)
  - Total depth: 4.4 X_0



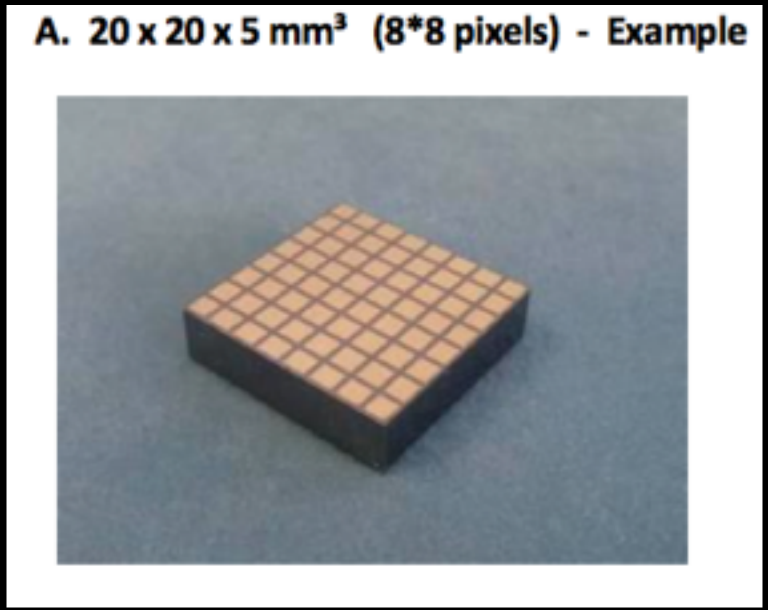
Double-sided 20 mm x 20 mm x 5 mm CZT detector with 5 mm-pitched orthogonal strips on both sides



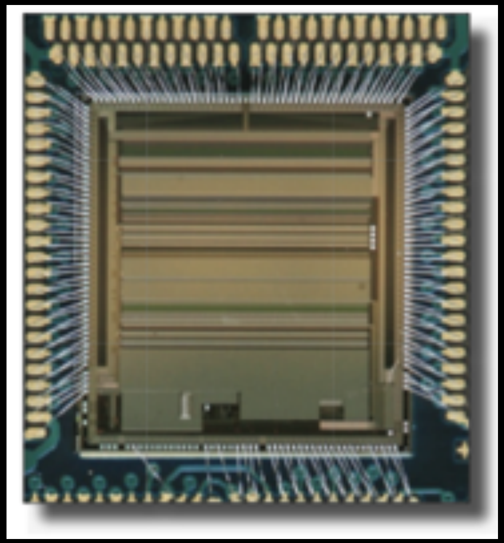
Daisy-chained CZT-strip detectors (2x2 array shown)

Calorimeter Heritage

- CsI calorimeter: widely used in particle physics and astrophysics. Successfully used in Fermi LAT with very similar design. ComPair team includes NRL, Calorimeter subsystem lead for Fermi-LAT
  - Mechanical design uses LAT heritage
  - Lowest TRL item is readout electronics for SiPMs
- CZT calorimeter: rapid development from significant investment from homeland security community in last decade; increasing usage in science instruments.
  - Instruments: Polaris (Univ. Michigan), Swift



CZT detector from RedLen



VATA460 ASIC from IdEAS

ComPair
Instrument Summary

Energy Range	1 – 200 MeV (200 keV – 500 MeV)
Effective Area	100 – 200 cm2 <10 MeV, 200-1200 cm2 >10 MeV
Angular Resolution	~7o at 10 MeV, ~1o at 100 MeV
Energy Resolution	2-5% <20 MeV, ~12% at 100 MeV
Solid Angle	~3 sr
Dimensions	1 m x 1 m x 0.7 m (sensitive volume)
Mass	<1000 kg (science payload)
Power	<1000 W
Detector Depth	4.7 X0 (Tracker: 0.3 X0, CSI Calorimeter: 4.4 X0)

IDL run just completed, MDL run still needed

Summary

ComPair is a moderate and readily doable concept for a observatory that addresses extreme astrophysics and has a broad science reach in a poorly explored part of the spectrum

ComPair provides key capabilities for time domain astrophysics

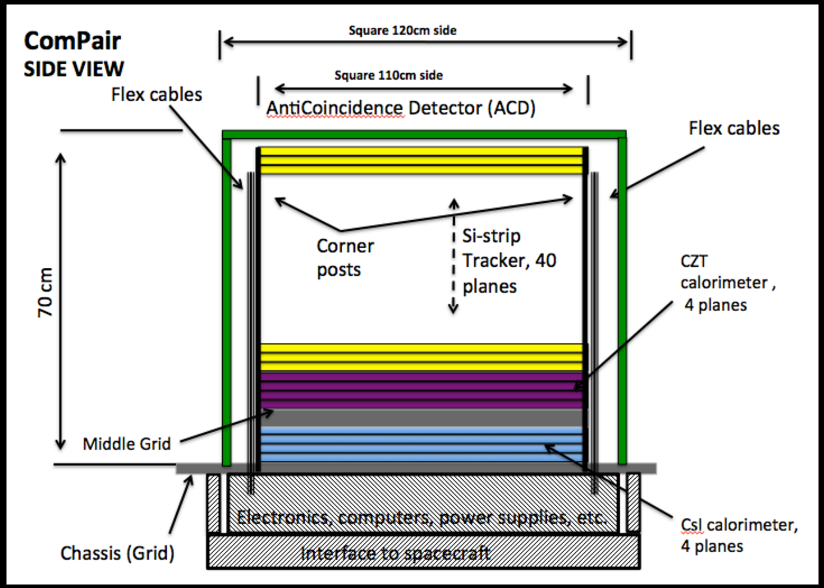
For more information: arXiv:1508.07349

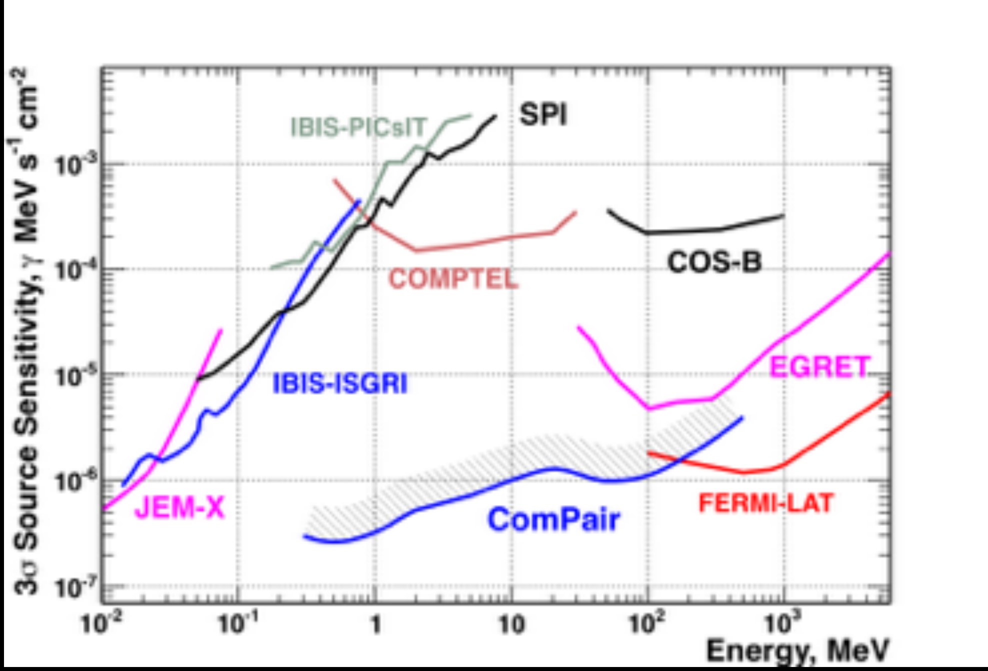
Back-up

ComPair

A Wide-Aperture Discovery Mission for the MeV Band

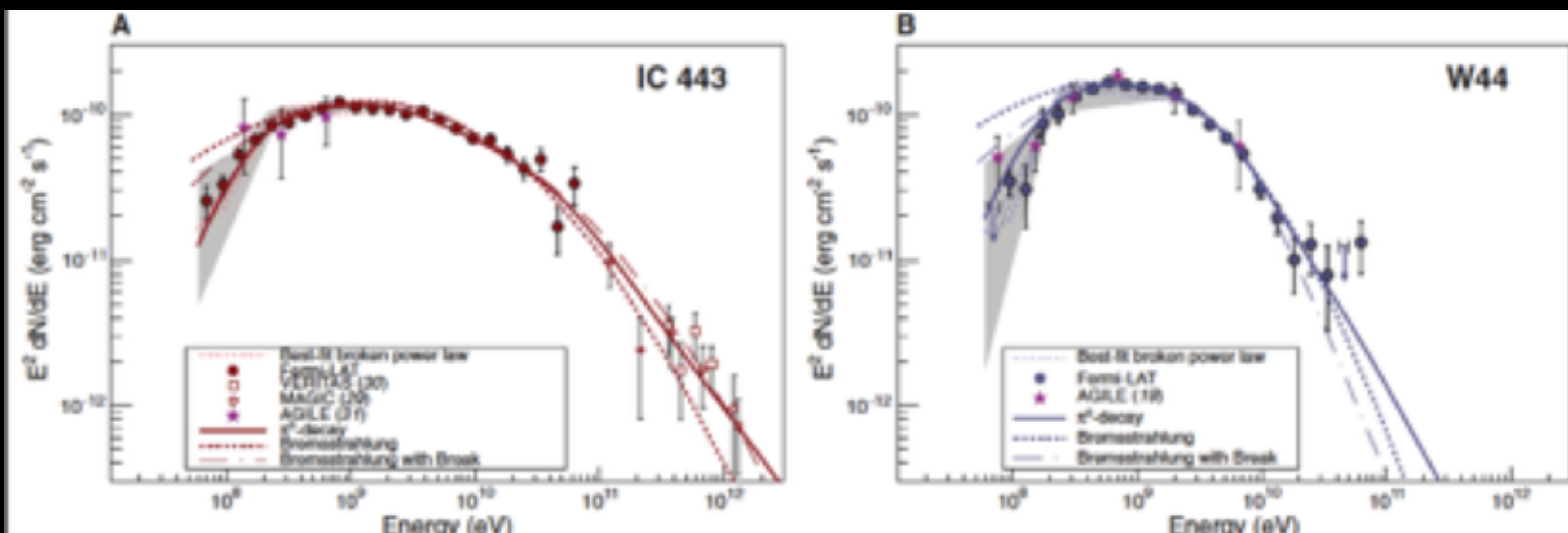
- Science focus: extreme astrophysics - high matter densities, strong magnetic fields, powerful jets
- Monitor the whole gamma-ray sky in the energy range 200 keV – > 500 MeV with sensitivity ~10 -50 times better than COMPTEL at ~1 MeV and improved angular resolution over Fermi LAT
- Optimized for continuum sensitivity and field of view but also will provide other ground-breaking capabilities, e.g. polarization, spectroscopy





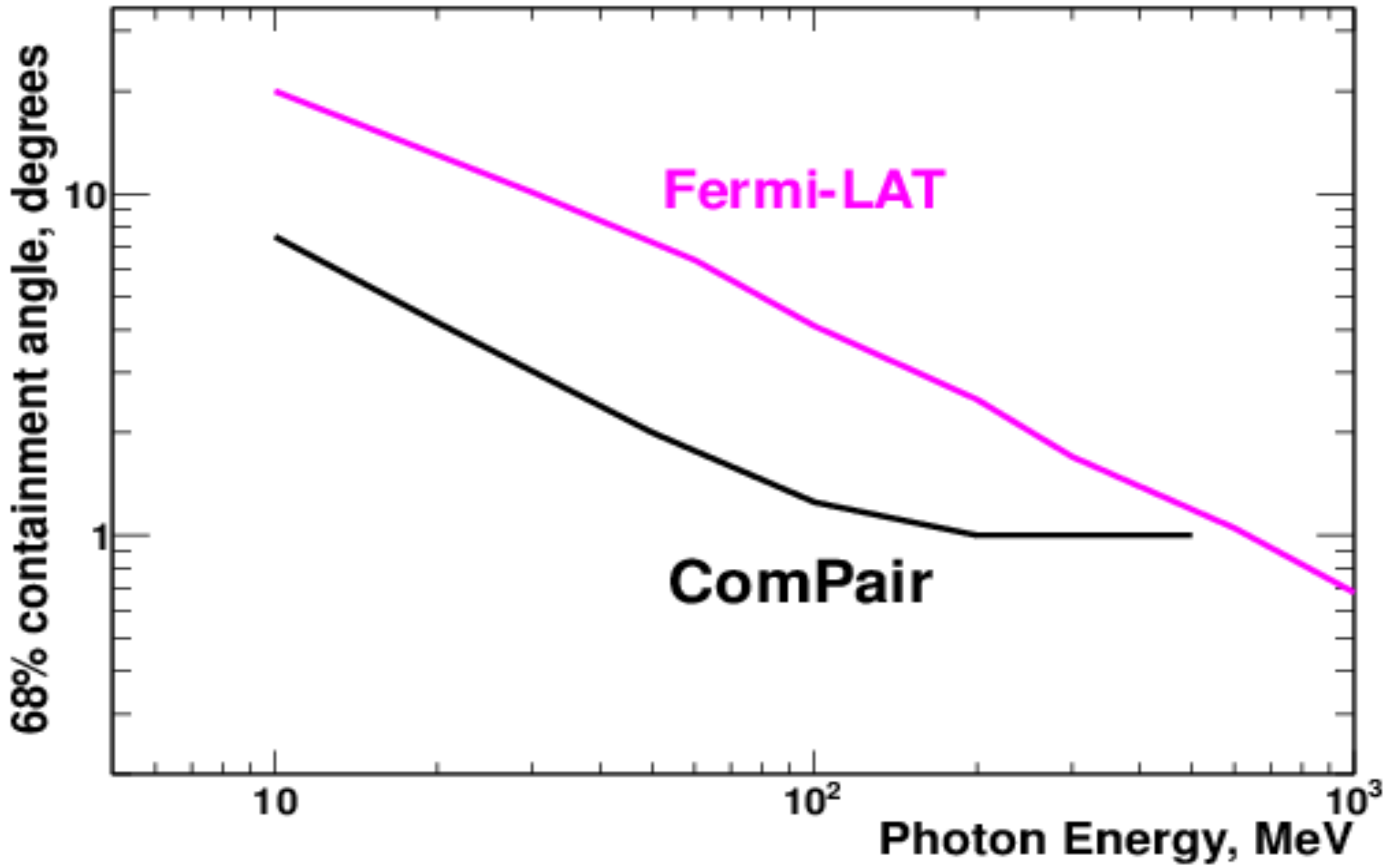
Examples of additional science with continuum instruments

- Galactic Accelerators - Fermi has measured the pion bump in 2 SNRs and detected dozens
    - Detecting pion bump in all GeV SNR key to understanding particle acceleration in the Galaxy
- Dark Matter - new ideas on WIMP dark matter annihilation (dark photon mediators) lead to predictions of continuum gamma-ray signals in the 10-50 MeV band



Angular Resolution

Comparison for pairs with Fermi-LAT front



ComPair as a Probe

Design adapts to explorer class but is well-suited to the probe scale. What is gained?

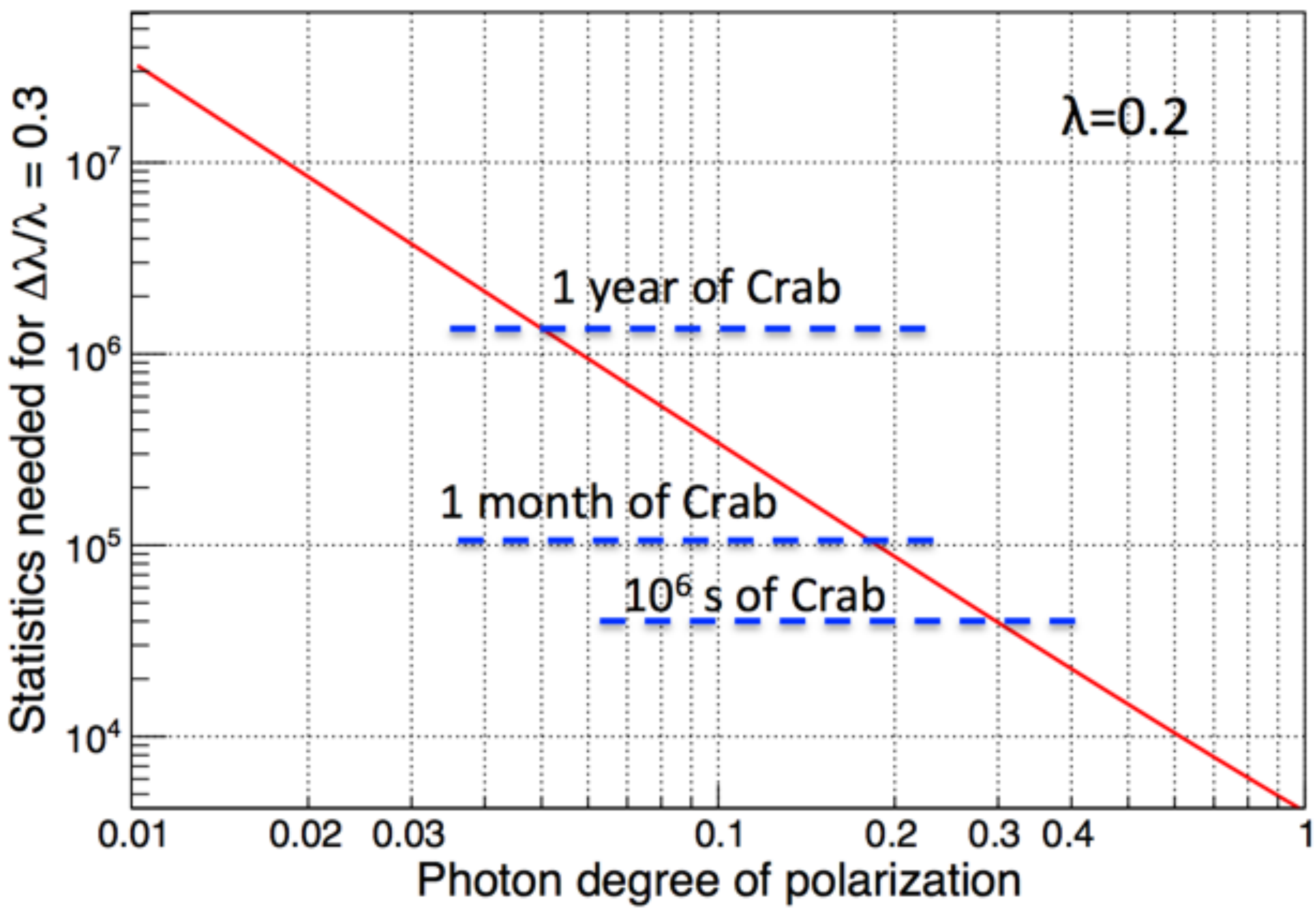
- Energy range – Ideally extend as close to ~1 GeV as possible.
- Overlap with *Fermi* LAT range for calibration and science studies
- Bonus of reducing gamma background from Earth
- Improve angular resolution
- Efficiency enhancement/Background reduction
- Choice of materials and arrangement important for reducing passive material in field of view and controlling internal background

Additional Science Capabilities

ComPair is optimized for **continuum sensitivity** and **field of view** but will also provide other ground-breaking new capabilities

- **Spectroscopy**: nuclear lines explore Galactic chemical evolution and sites of explosive element synthesis (SNe)
- **Polarization**: probe magnetic fields and to constrain emission processes/models - especially relevant for GRBs

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

Mission 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