Development of a Telescope for Medium-Energy Gamma-Ray Astronomy

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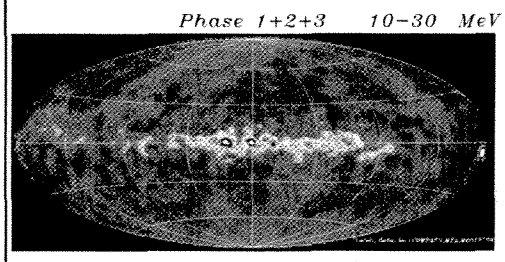
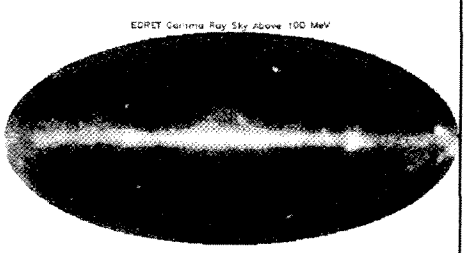
Medium-Energy Gamma-Ray Astronomy

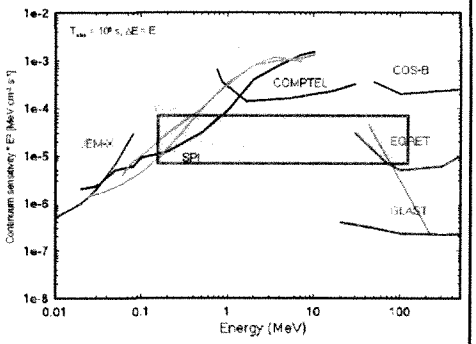
- ~0.3 to ~300 MeV
  - Compton Scattering, $E\gamma \lesssim 10$ MeV
    Pair Production , $E\gamma \gtrsim 5$ MeV
- COMPTEL and EGRET provided first all-sky maps
  - Angular resolution 10's of degrees





Current Missions

- AGILE & FERMI launched in 2009
  - Dramatic progress in high-energy (> ~200 MeV) gamma-ray science
- Neither instrument optimized for observations below ~200 MeV
  - Transition from electron to hadron processes and nuclear emission to exotic processes
  - Many astrophysical objects exhibit unique, transitory behavior, such as spectral breaks, bursts, and flares
- Large gap in sensitivity
- Medium-energy mission is needed



Mission Motivation: Diverse Science

- Potential contributions to long-standing problems
  - G-rays from dark matter annihilation
  - Extragalactic background radiation
    magnetic field strength
  - Process leading to growth of black holes
  - Early epoch of star formation
  - Extreme particle accelerators in the universe
- Specific subjects
  - Galactic & extragalactic diffuse emission
  - Pulsars, super nova remnants
  - AGN & Blazars
  - Testing relativity with polarization
  - Solar flares

Mission Instrument Drivers

- Large field of view, ~2π sr
- Uniform sensitivity (homogenous detector)
- Low instrument background
- High angular resolution & polarization sensitivity
- Highest effective area possible

Our approach: optimize sensitivity with two telescopes

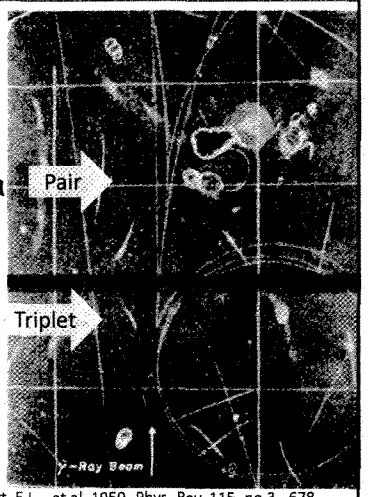
- Compton scattering, $E\gamma \lesssim 20$ MeV (Bloser, et al.)
- Pair production , $E\gamma \gtrsim 5$ MeV (this presentation)

Pair Production Telescope

- Mission instrument drivers have motivated the **3-Dimensional Track Imager (3-DTI)**
  - Gas time projection chamber with 2-D micro-well readout
  - Provides 3-D electron tracking and *momenta*
    - **Homogenous detector:** 2π sr fov & uniform sensitivity
    - **Electron tracking with high granularity:** Low instrument background, high angular resolution & polarization sensitivity
    - **Challenge:** Sensitivity is trade-off between effective area and detector density
      - Low density countered by large volume
- *Satisfies all of the mission drivers!*

Advantages of Gaseous Detector

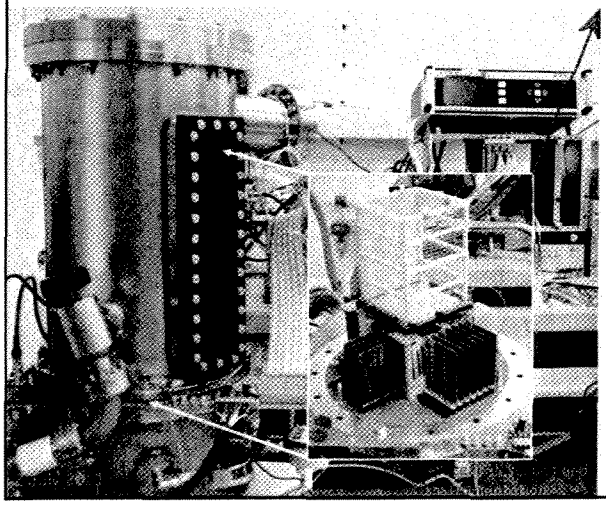
- High granularity: Low density, homogenous conversion medium
  - Minimizes scattering
  - Determine momenta with high accura
    ⇒ improved angular resolution
  - Polarization sensitivity
  - Triplet production ($\gamma + e^- \rightarrow e^- + e^- +$
    - Golden Events! –
      Essentially no misidentification
      Near total momentum reconstruction
      Highest angular resolution and polarization sensitivity

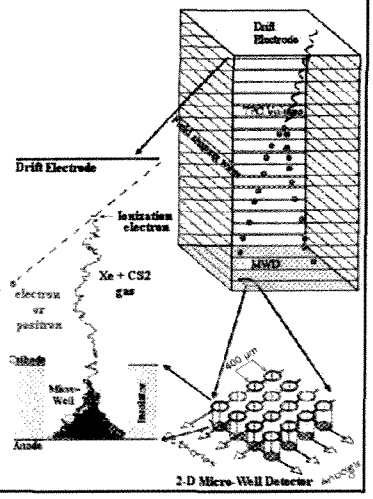


Hart, E.L., et al. 1959, Phys. Rev. 115, no 3, 678

3-DTI Prototype

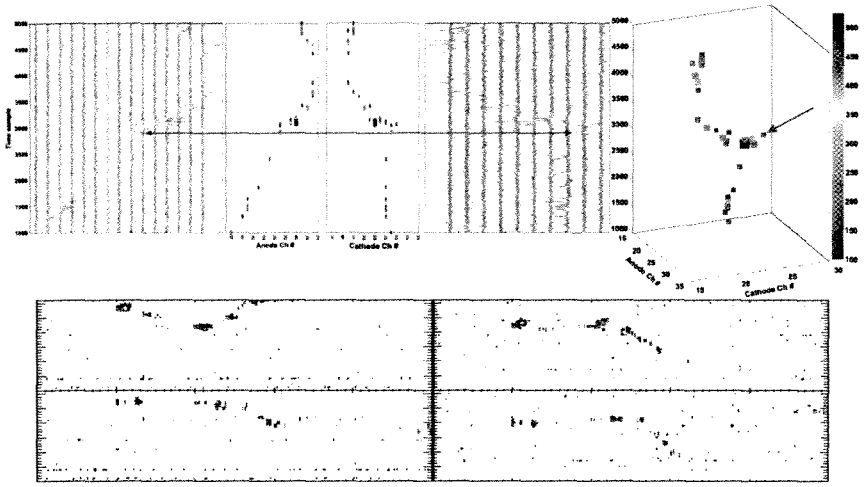
- **Ionization chamber**: Large-volume time projection chamber (TPC)
- **Proportional counter**: 2-D gas micro-well detector (MWD) readout
  - Low density, homogenous medium (low energy particle tracking)
  - 100 % active detector volume (no scattering in passive material)





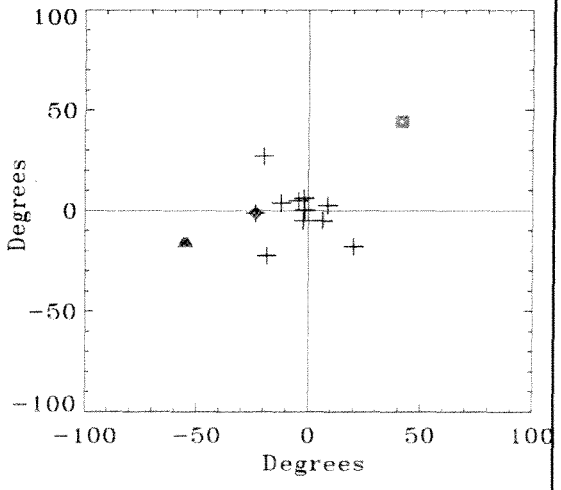
3-DTI Gamma Ray Performance

- Raw 3-DTI data from the anodes (red) and cathodes (blue), 2-D voxelized data, and 3-D projection
- Alpha capture reaction, $C^{12}(\alpha,\gamma)O^{16}$ in P-10 + CS_2 at 1 atm



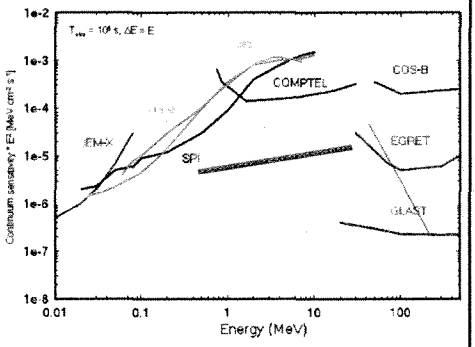
Angular Resolution at 6.13 MeV

- First *pair production* imaging at these energies!
- Angular resolution: θ_{68} < ~20 deg
- Near-field image, not corrected for parallax



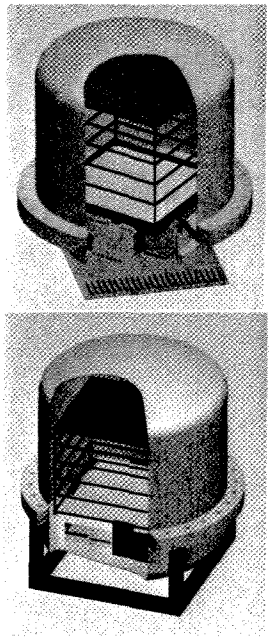
Advance Energetic Pair Telescope (AdEPT)

- Optimize for 5 MeV $\lesssim E\gamma \lesssim$ 300 MeV
  - Electron energies from dE/dx, range, and Coulomb scattering; Eliminate need for calorimeter
- Sensitivity goal: 10^{-5} or better
  - Large effective area
- Straw-man Design
  - 1 m3, argon at 2-3 atm



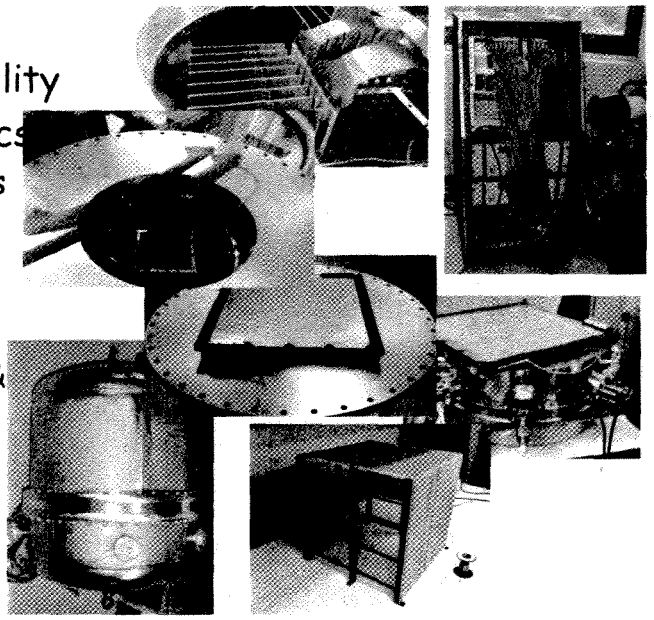
AdEPT Prototype Development

- 30 cm MWD with 10 cm electronics
  - 1/3 resolution readout (512 channels)
    - Gang 3 electrodes to one FEE channel
  - Snapshot and semi-streaming data mode
- 30 cm MWD with 30 cm electronics
  - 1/2 resolution readout (768 channels)
    - Every other electrode read out, limited by number of ASICs
  - Streaming data mode, mid-2011
    - Essentially zero dead-time
- Full resolution readout (1536 channels)
  - Additional ASICs, late-2011



Prototype Hardware Status

- In-house MWD fabrication facility
- 10 cm electronics
  - TD, FEE Boards
- 30 cm MWD
- Mechanical
  - Pressure vessel, MWD support, & Drift grid



Performance Challenges

- Gas pressure, Composition, Z of gas
- Optimize drift velocity & diffusion
  - Test setups
- Ionization energy, Ecrit
- Stopping power

- Add Mike's plots
- Dion et al. in preparation

Testing Plans & Schedule

- Continue with $C^{12}(\alpha,\gamma)O^{16}$
  - Testing this summer
- Higher energies, NSWC/PIAF
- Duke University, FEL
  - Fall 2011
- Parallel program for neutron imaging with same 3-DTI technology
  - Field testing 30 cm prototype this summer
- Simulations
  - Geant4, Garfield, Maxwell, MCNPX
- Proposal for sub-orbital program in 2013
  - 50 cm AdEPT prototype