The Nuclear Compton Telescope: Goals and Performance on Mapping the Galactic Positron Emission

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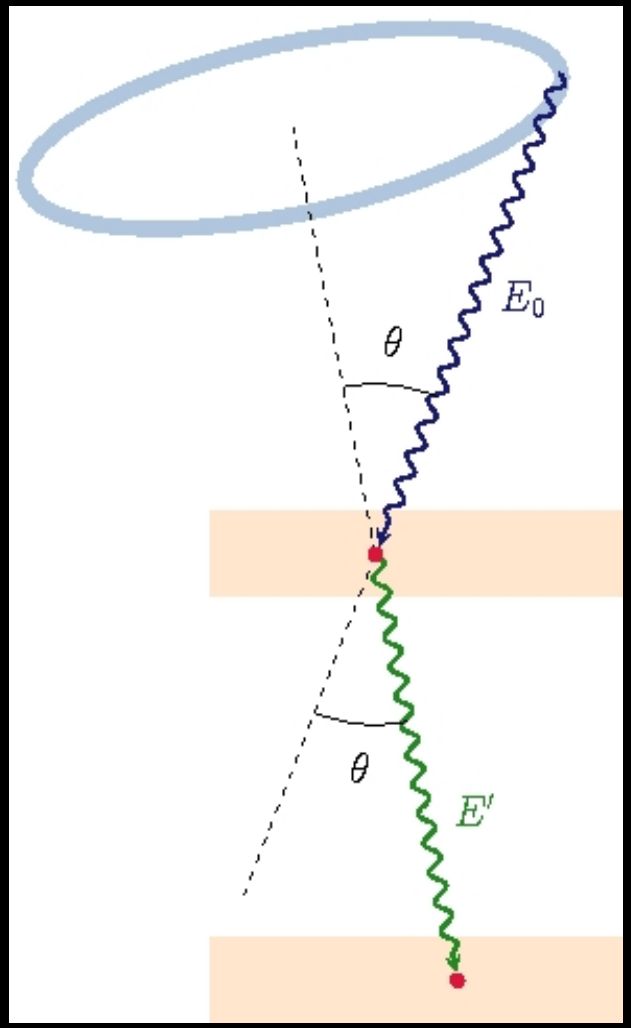
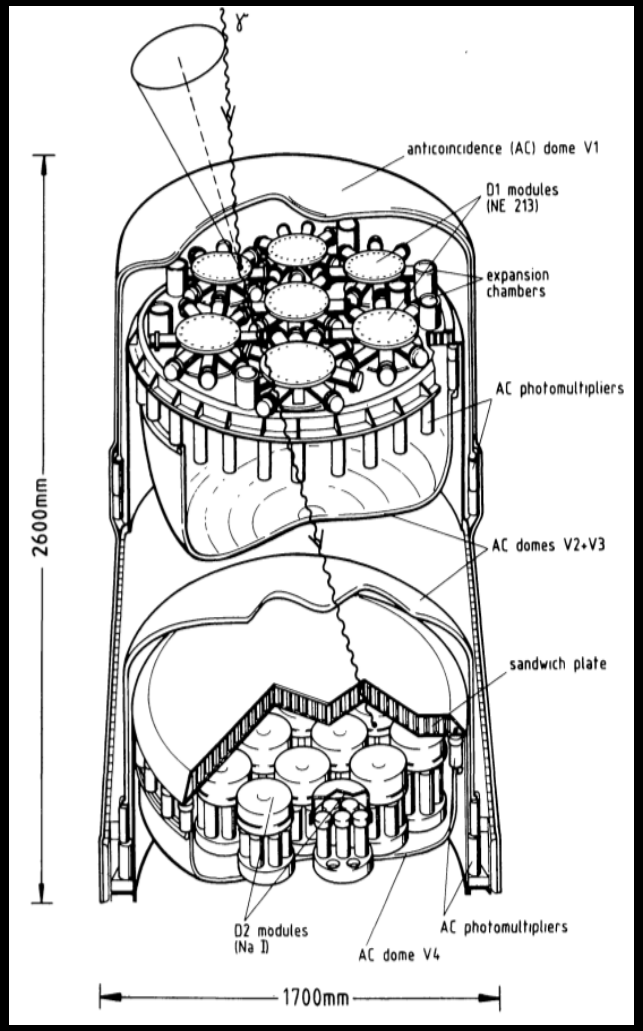
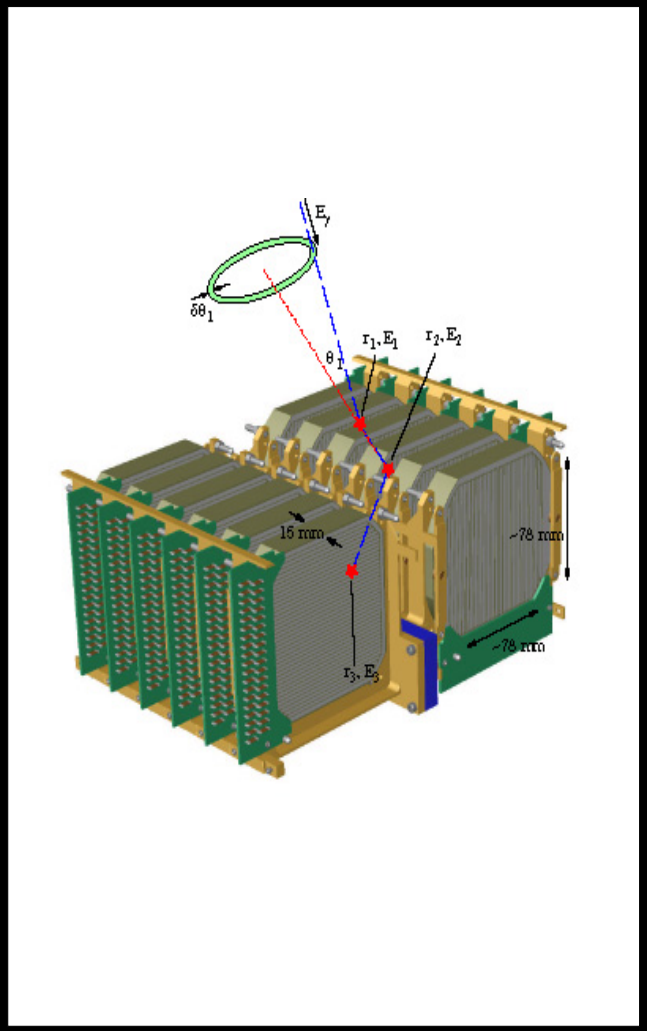
Compton Telescope Principle:







$$E' = \frac{E_0}{1 + \frac{E_0}{m_e c^2}(1 - \cos\theta)}$$

Scatterer/Absorber; COMPTEL

Compact Geometry; NCT

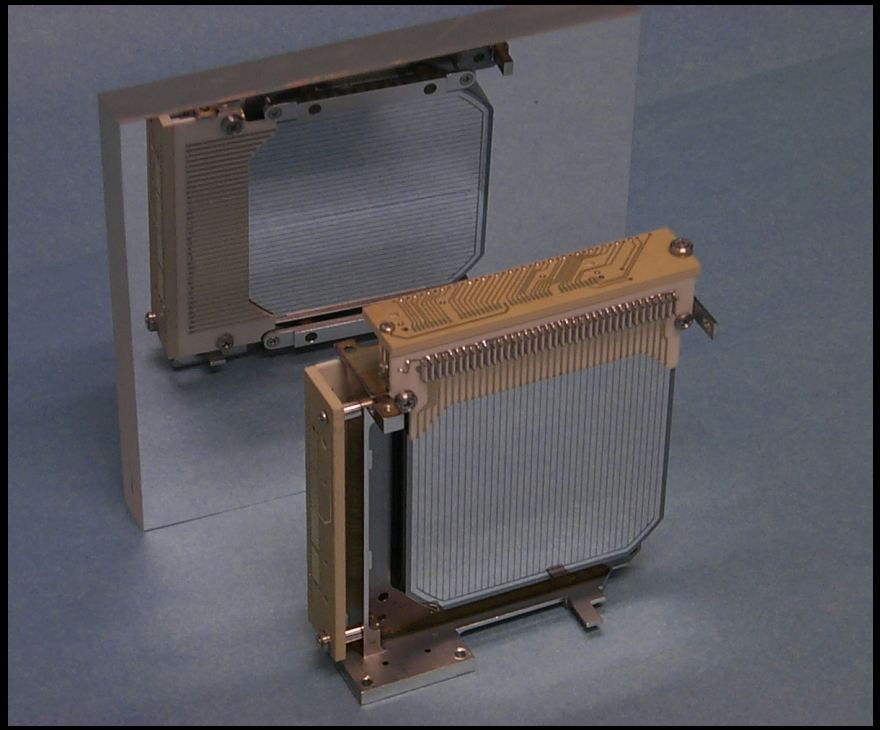
The NCT Instrument:

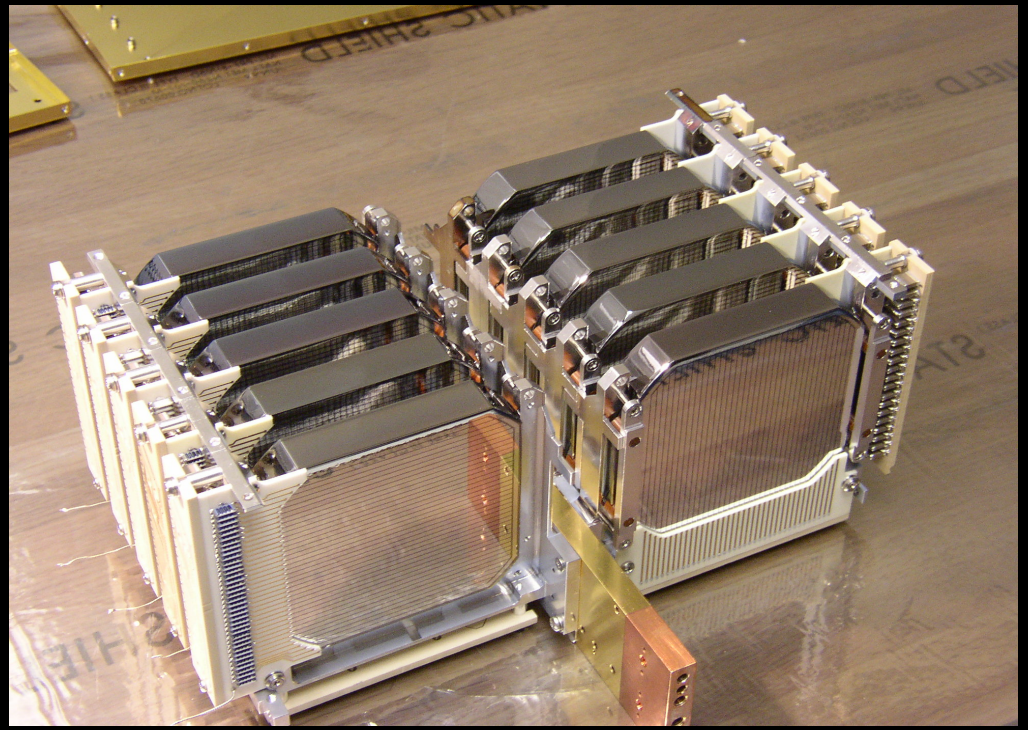
~ Array of Cross-Strip High Purity Germanium (HPGe) Detectors

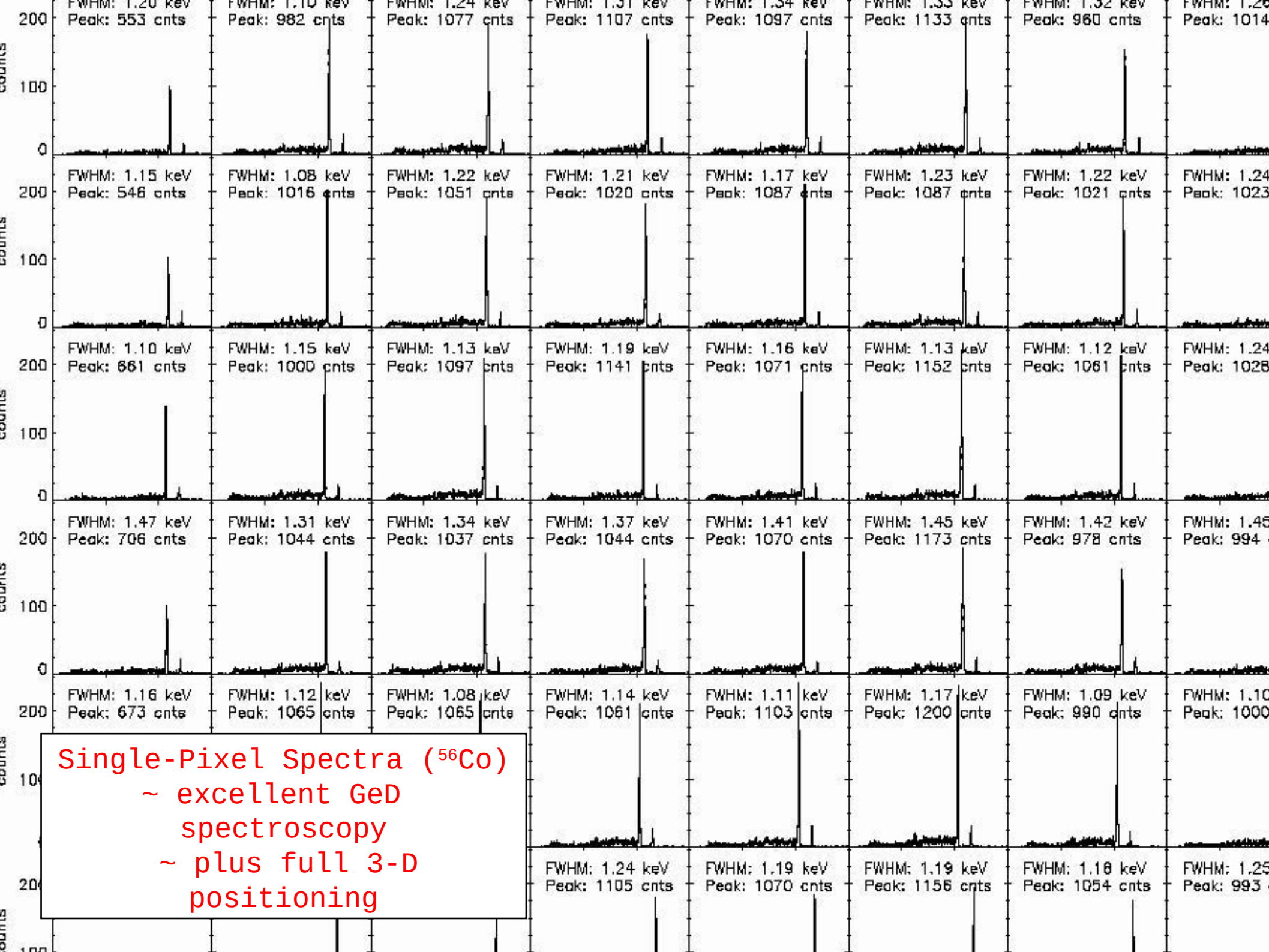
~ HPGe - > Unprecedented energy resolution in the 0.2 - 10 MeV range

~ 37x37 channels per detector

~ 2 mm strip pitch, 0.25 mm between strips



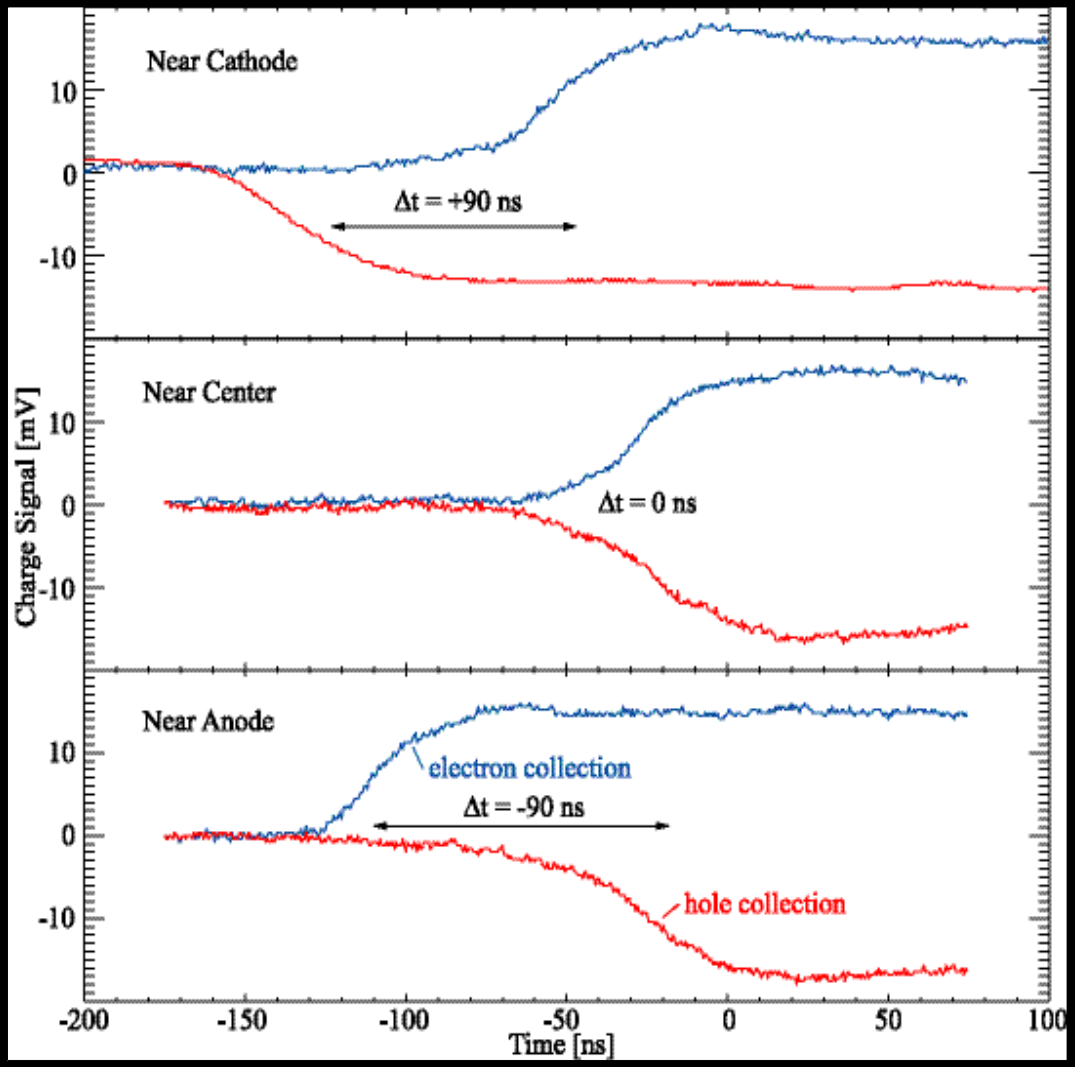


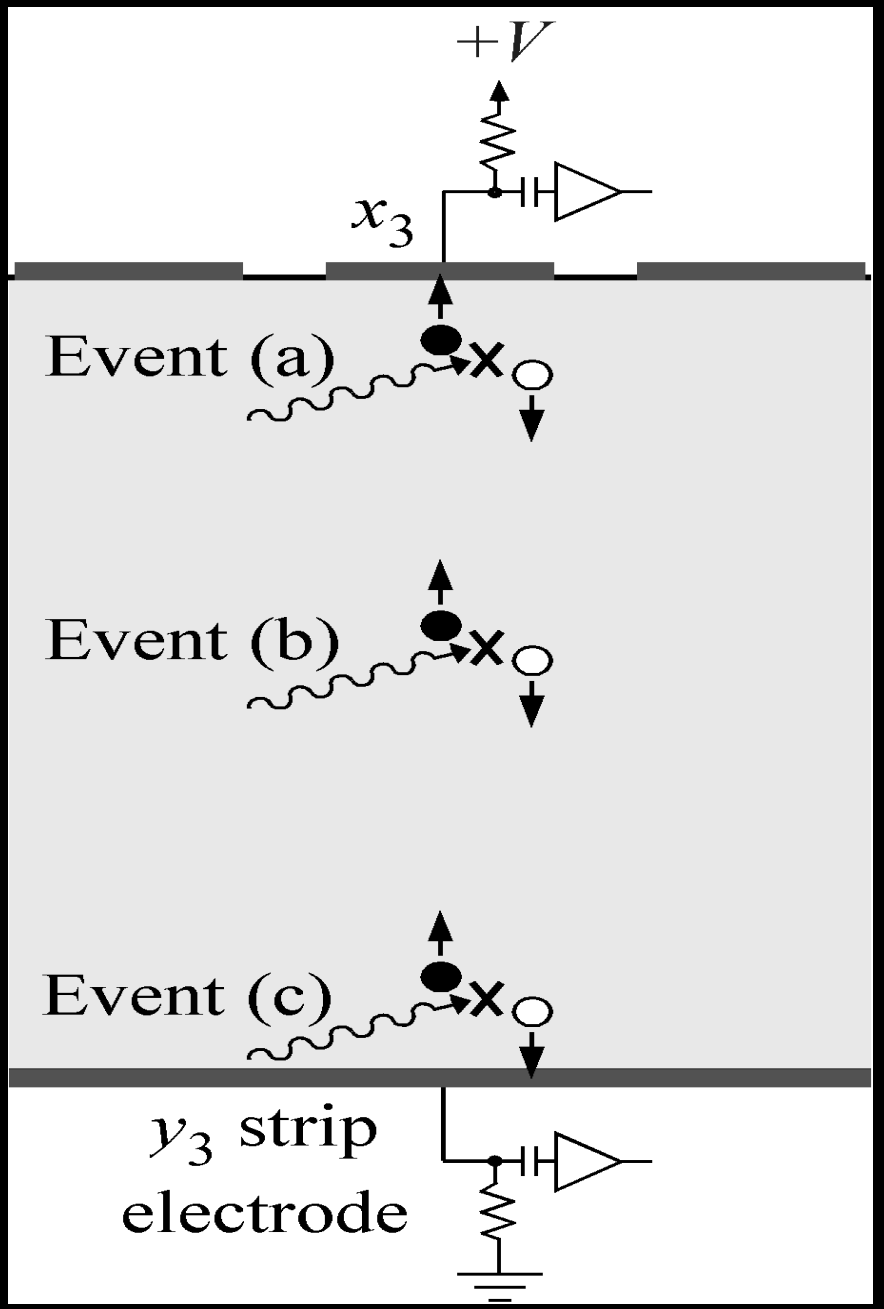


Single-Pixel Spectra (^{56}Co)
~ excellent GeD spectroscopy
~ plus full 3-D positioning

3D Positioning:

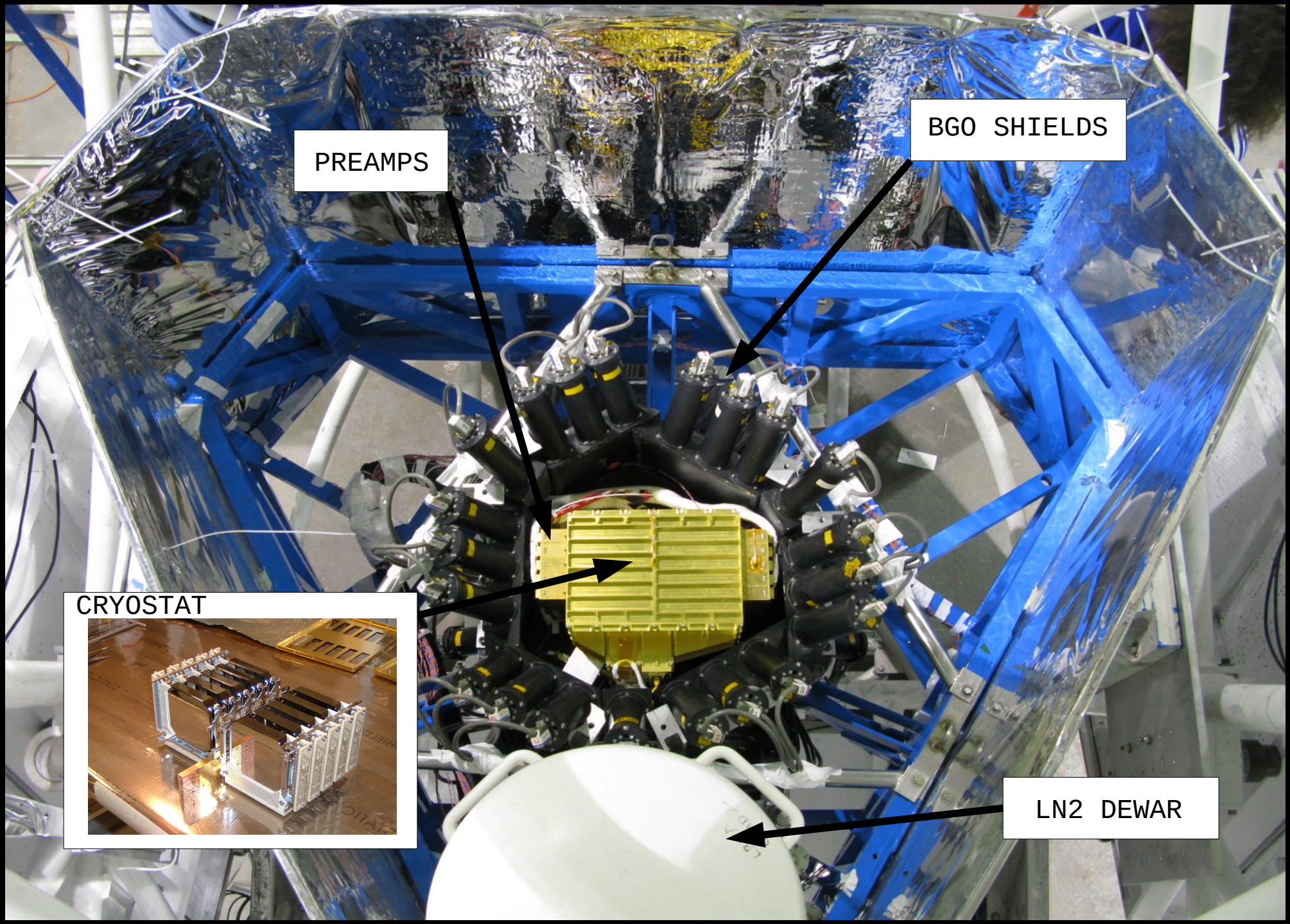
~XY position determined by triggered strips
~Z position determined by collection time difference
~Depth (Z) resolution of 0.5 mm
~Effective voxel size of 2 mm^3



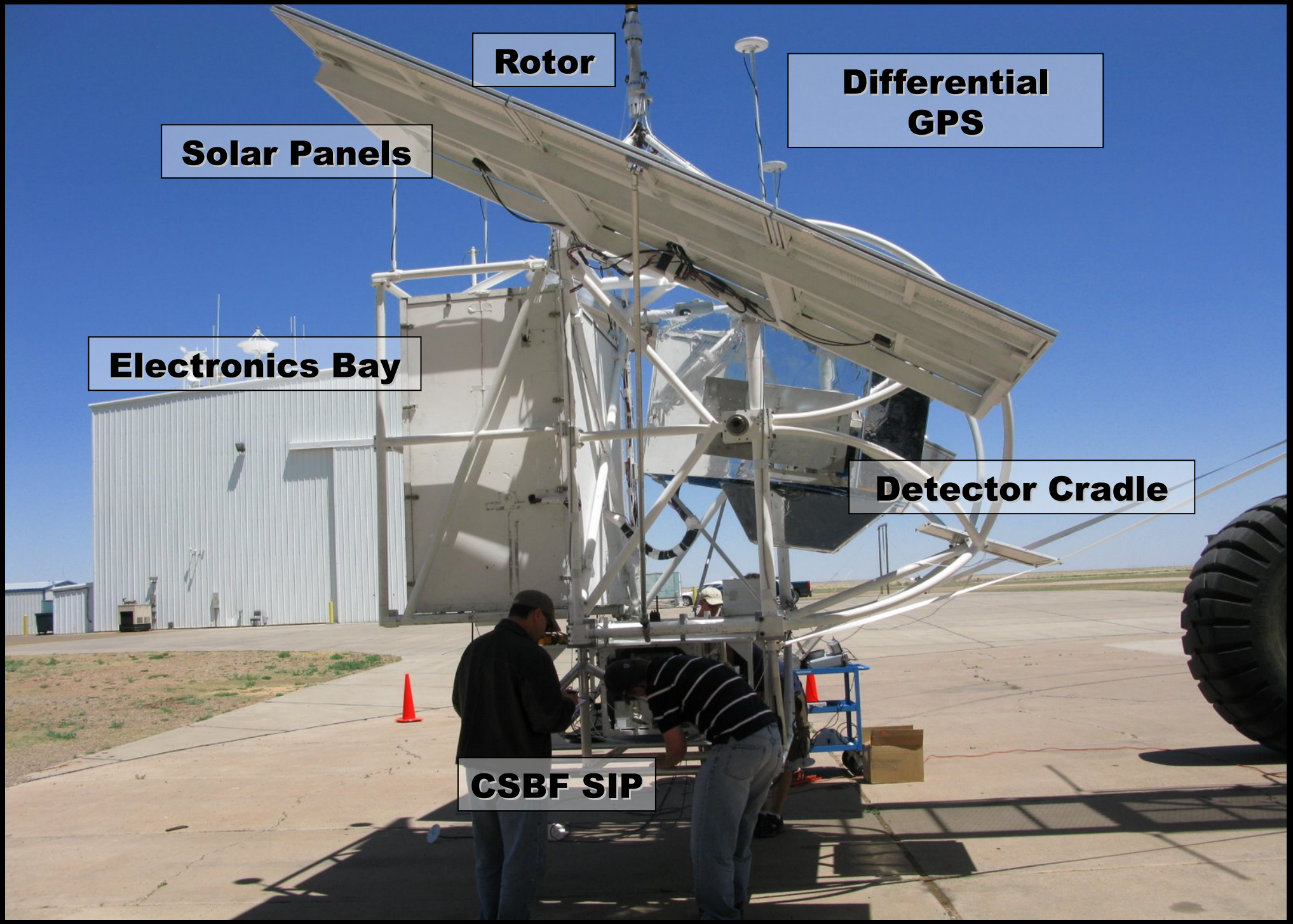


(Amman & Luke, NIM A452, 2000)
(Amrose et. al., IEEE, 2001)

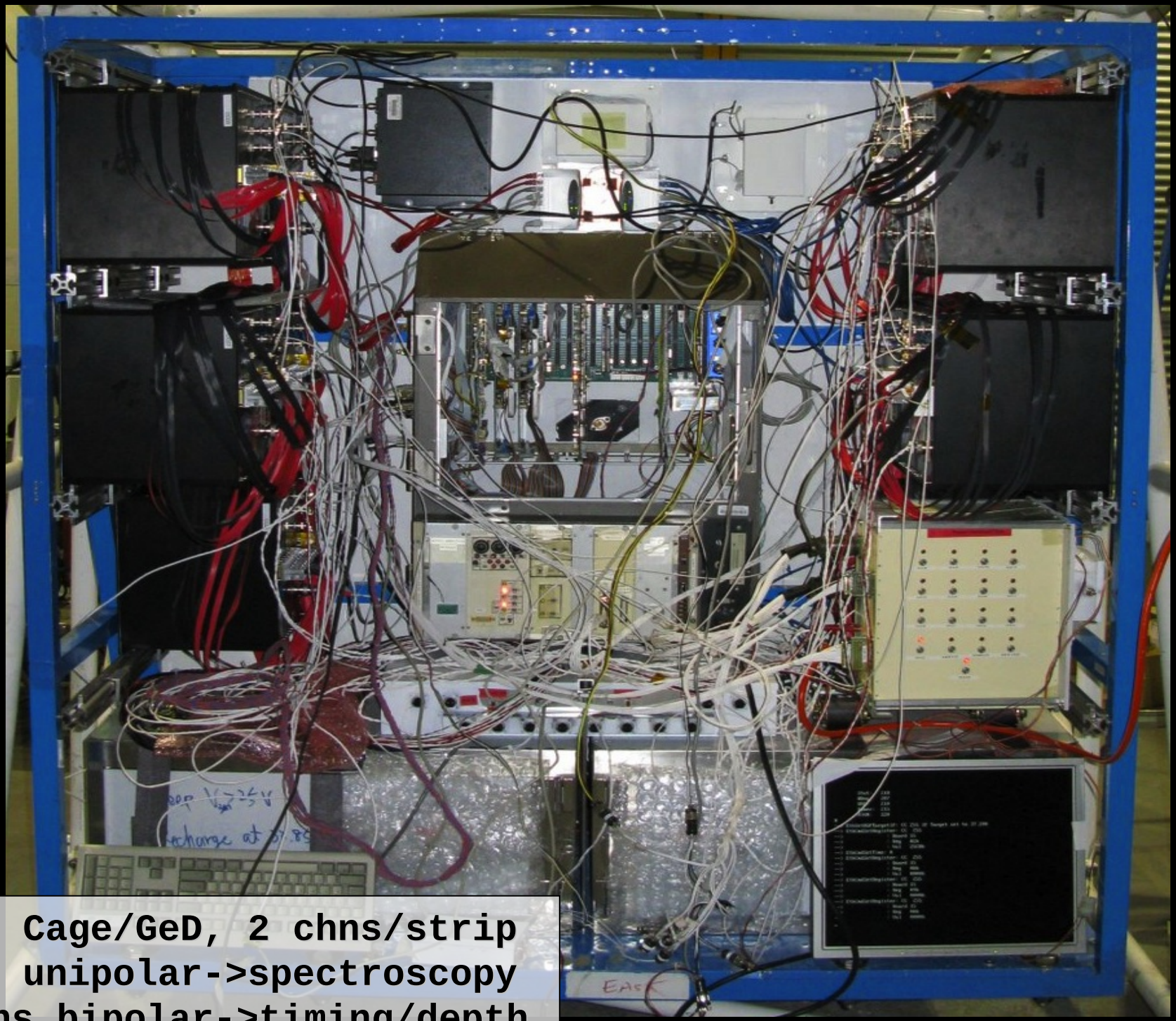
NCT09 Cradle:



NCT09 Gondola:

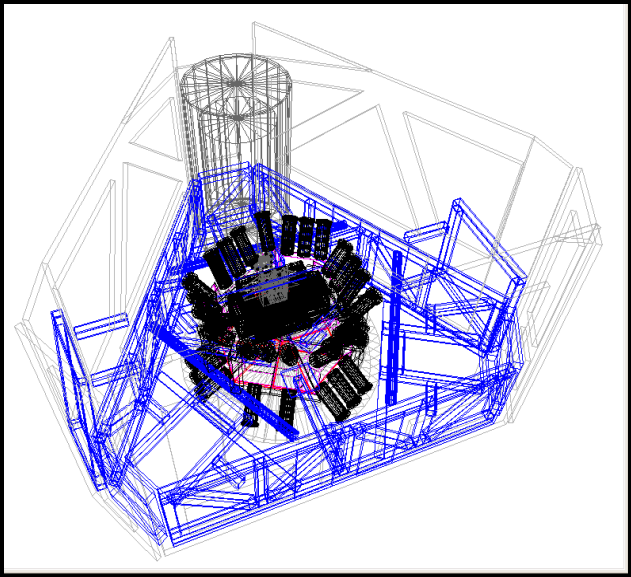


NCT Electronics Bay:



1 Card Cage/GeD, 2 chns/strip
~3 us unipolar->spectroscopy
~170 ns bipolar->timing/depth

Data Analysis; MEGAlib:

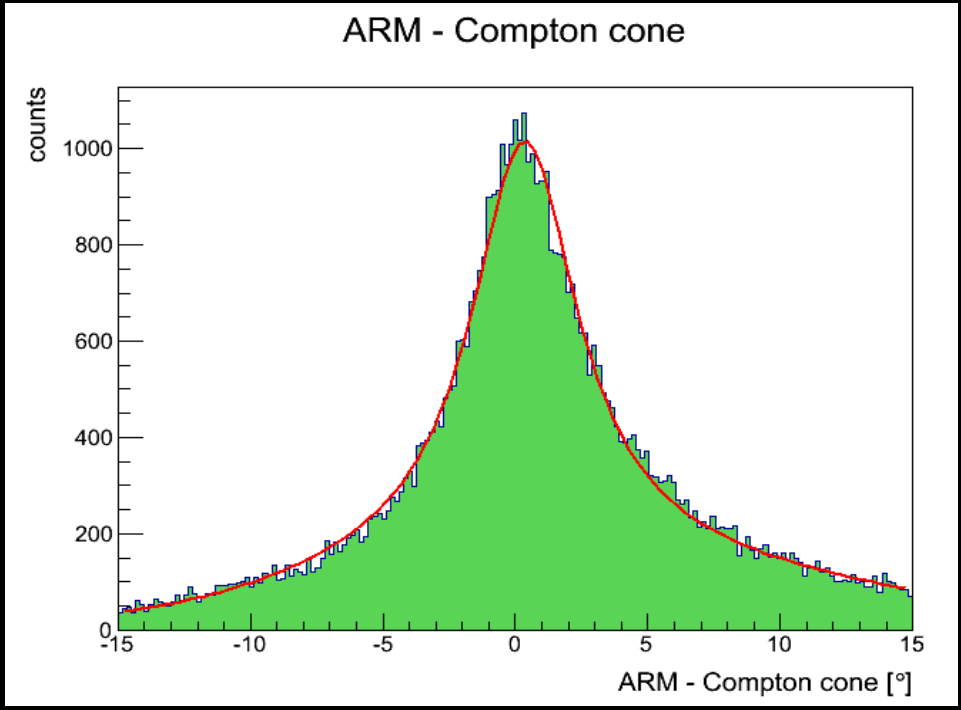


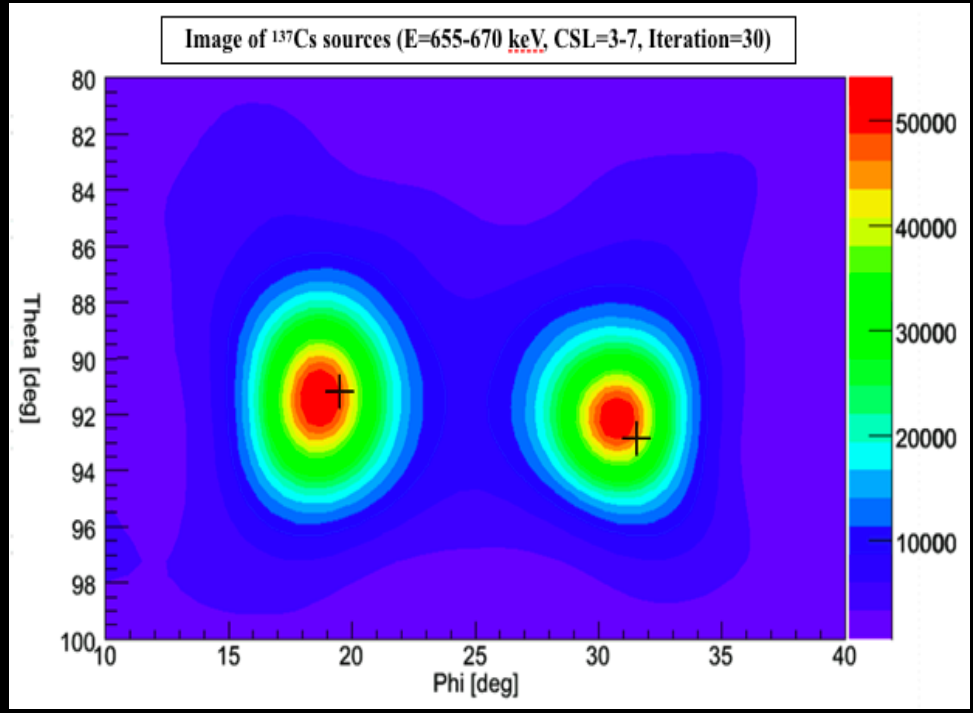
~ MEGAlib -- Medium Energy Gamma-ray Astronomy library

~ Simulation and data analysis tools for hard X-ray to medium energy Gamma-ray instruments

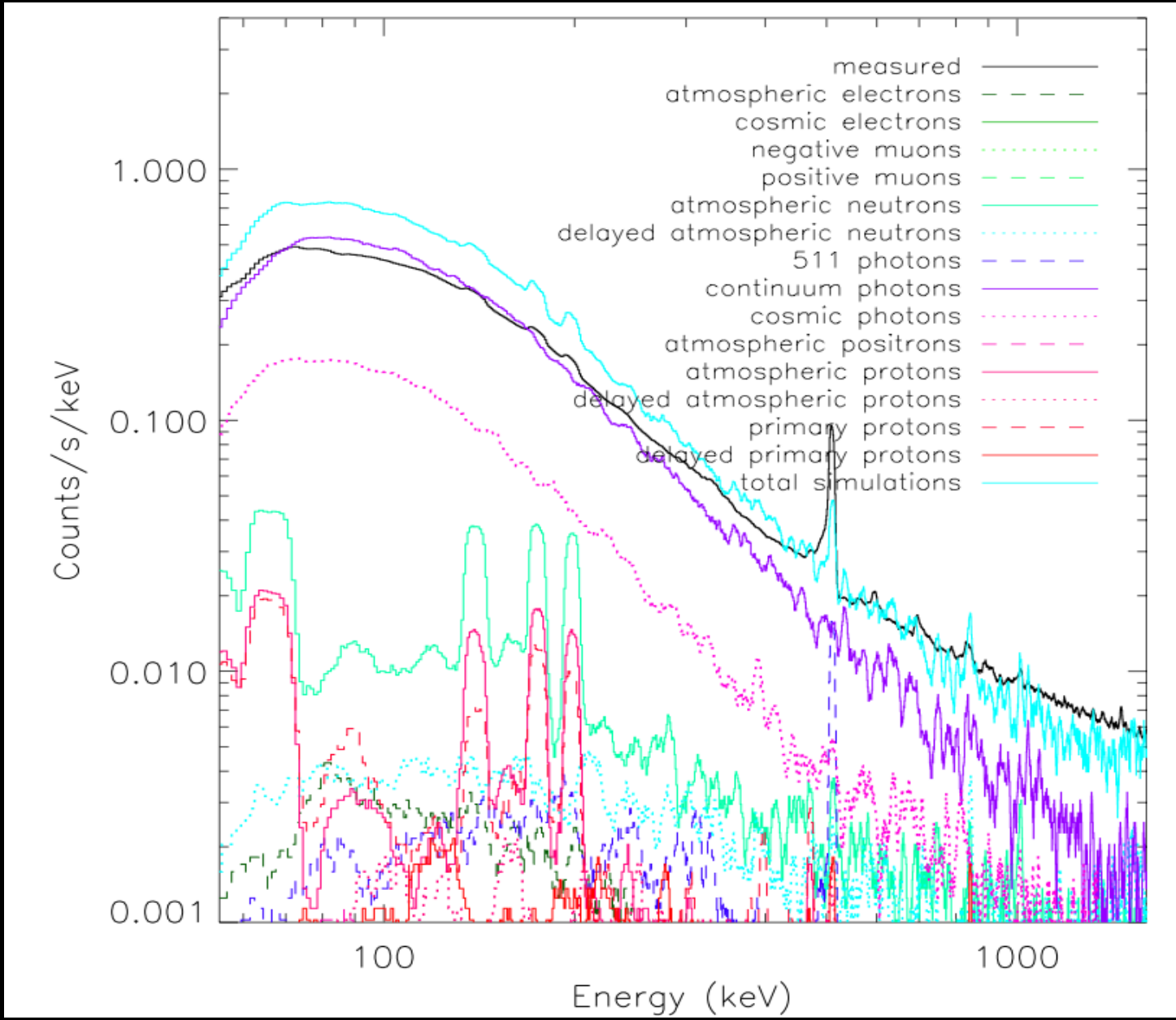
~ Easily adaptable to other telescopes (are you using MEGAlib?)

(A. Zoglauer et al., NewAR, 2006)





NCT Timeline:



Multi-component background spectrum at float altitude

~ 6 hour prototype flight (2 detectors) from Ft. Sumner, New Mexico on June 1st, 2005.

~ Measurement of gamma-ray background at balloon float altitudes

(J.D Bowen et. al., IEEE, 2007)

NCT Timeline (cont.):

~ 37 hour flight with 10 detectors from Ft. Sumner, New Mexico on May 17-18, 2009.

~ Sufficient data to produce an image of the Crab Nebula, first image of an astrophysical source with a compact Compton Telescope! (Bandstra et al., ApJ, 2011)

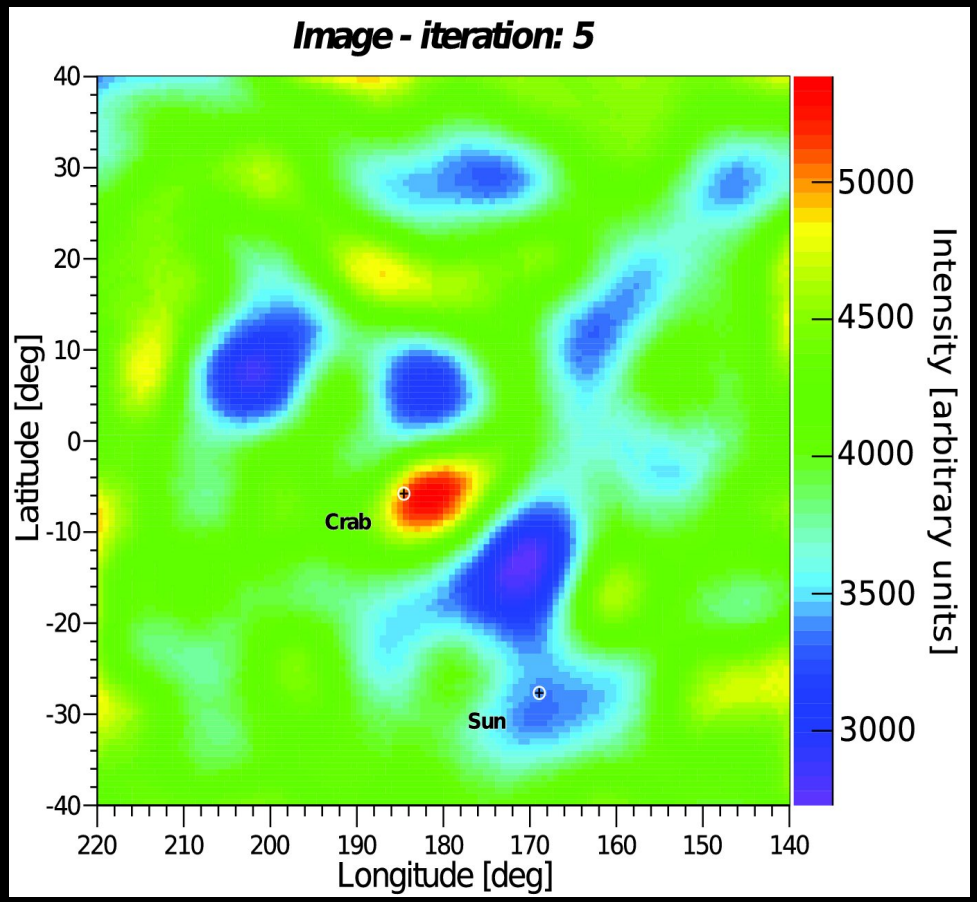


Image processed using List Mode Expectation Maximization technique (Wilderman et al., IEEE NSS 1998)

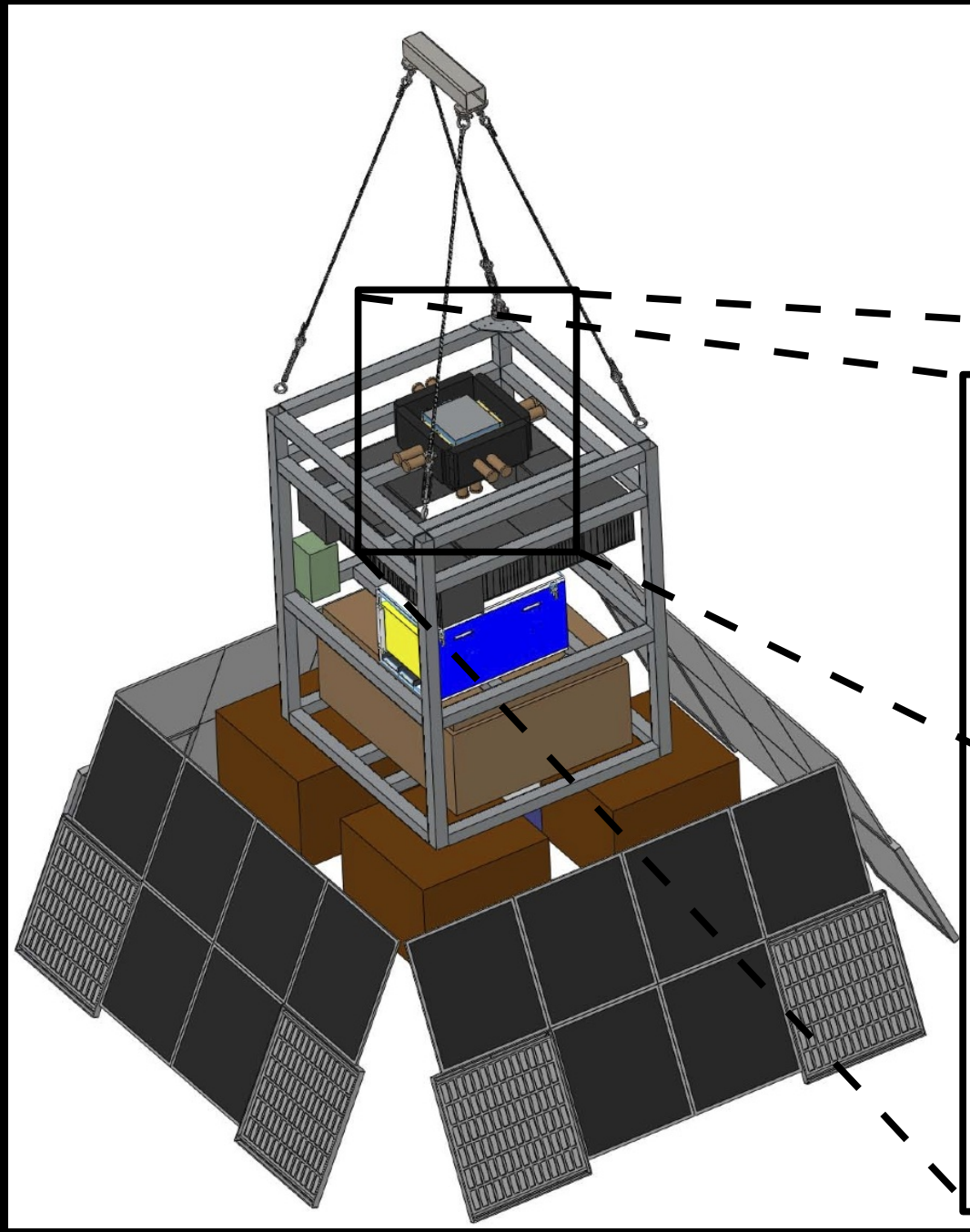
NCT Timeline (cont.):

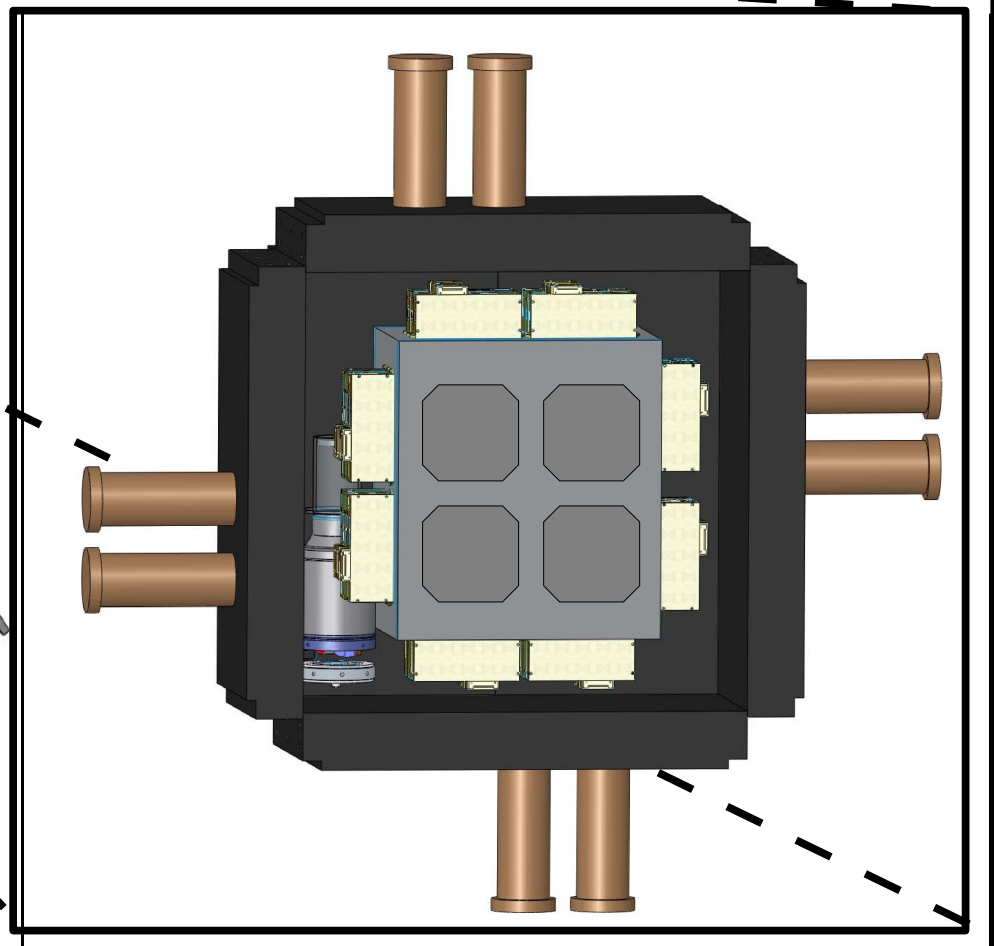
~ 3rd NCT launch attempted from Alice Springs, Australia on April 29th, 2010... Primary science goal was to image the galactic 511 keV emission.

~ CSBF Gondola release mechanism failed resulting in a crash. The detectors and electronics chains were relatively unharmed.

NCT 2.0:

~ New detector geometry
~ All new gondola
~ No pointing system
~ LN2 replaced by cryocooler
~ BGO shields CsI shields





2014/2015 Flight Campaign:

~ Rebuilding of instrument has begun

~ Designing for Super Pressure Balloon

~ Southern Hemisphere launch, possible Ultra Long Duration Balloon Flight

Primary Science Goal:

~ Use Compton Imaging to map the 511 keV positron annihilation line from the galactic center

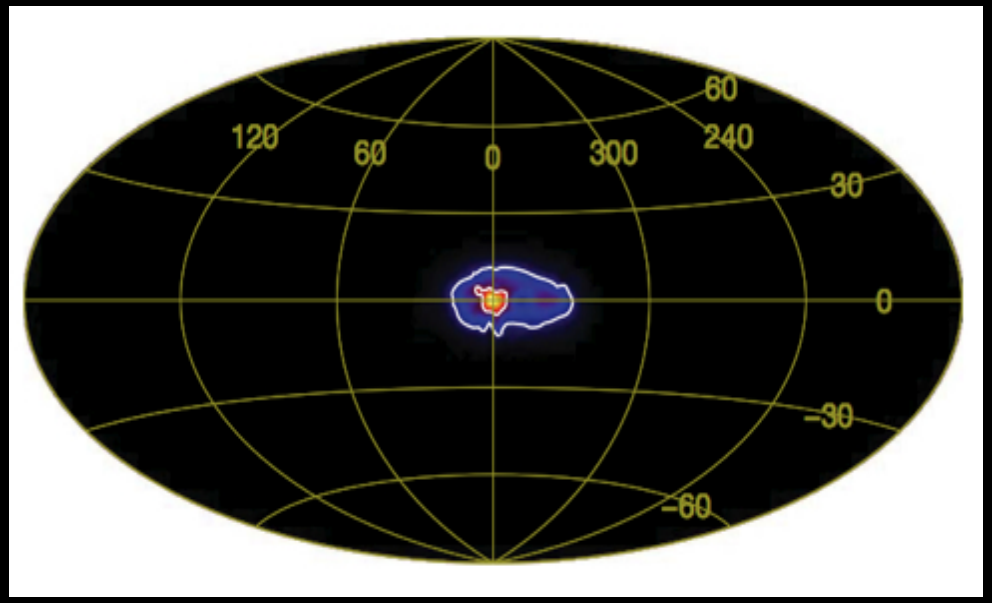
Secondary Science Goals:

~ SNe gamma-ray lines (^{26}Al at 1809 keV, ^{60}Fe at 1173 keV and 1333 keV, ^{44}Ti at 1157 keV)

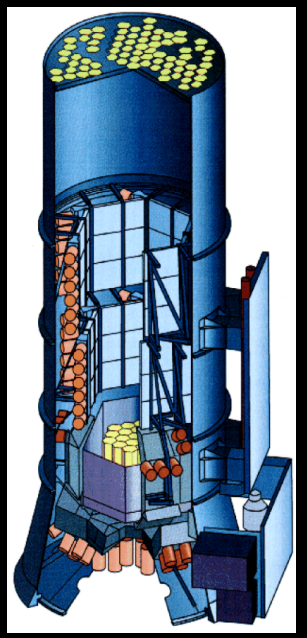
~ Compact Objects (AGN, black holes, neutron stars)

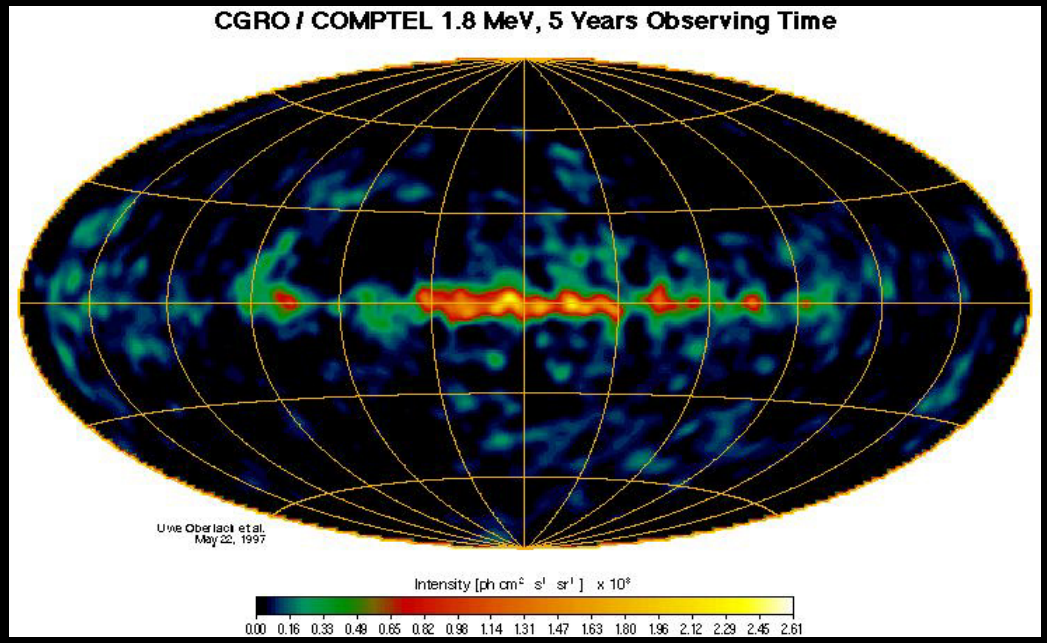
~ Gamma-ray polarization

Galactic positron and ^{26}Al emission:



INTEGRAL/SPI Map of 511 keV Emission (Weidenspointner et al., Nature, 2008)





COMPTEL ^{26}Al all-sky map (Diehl et al., A&A, 1995)

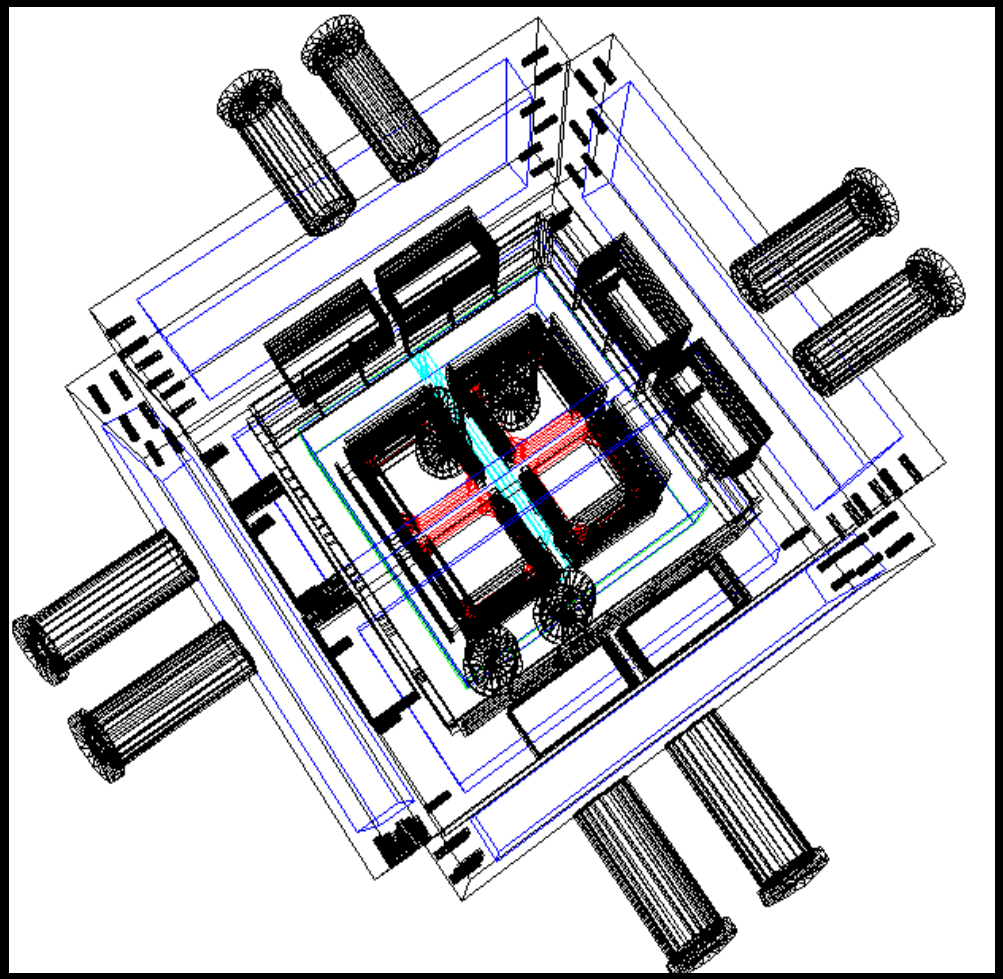
Key Parameters for 511 keV Mapping:

~ High effective area at 511 keV

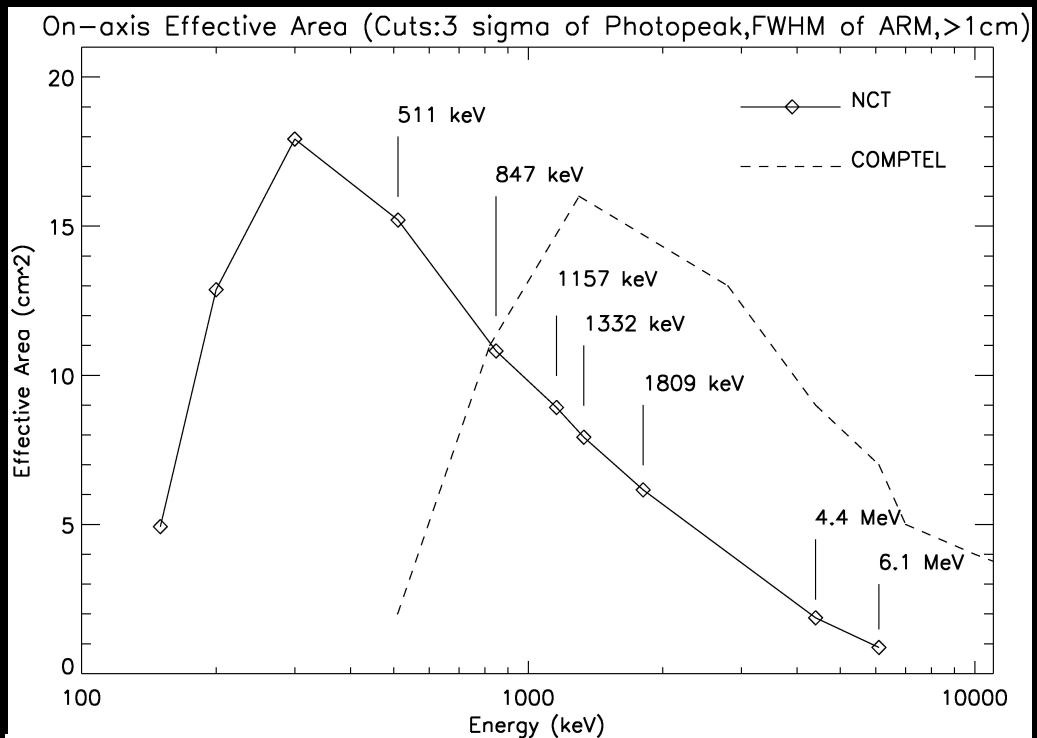
~ Large field of view

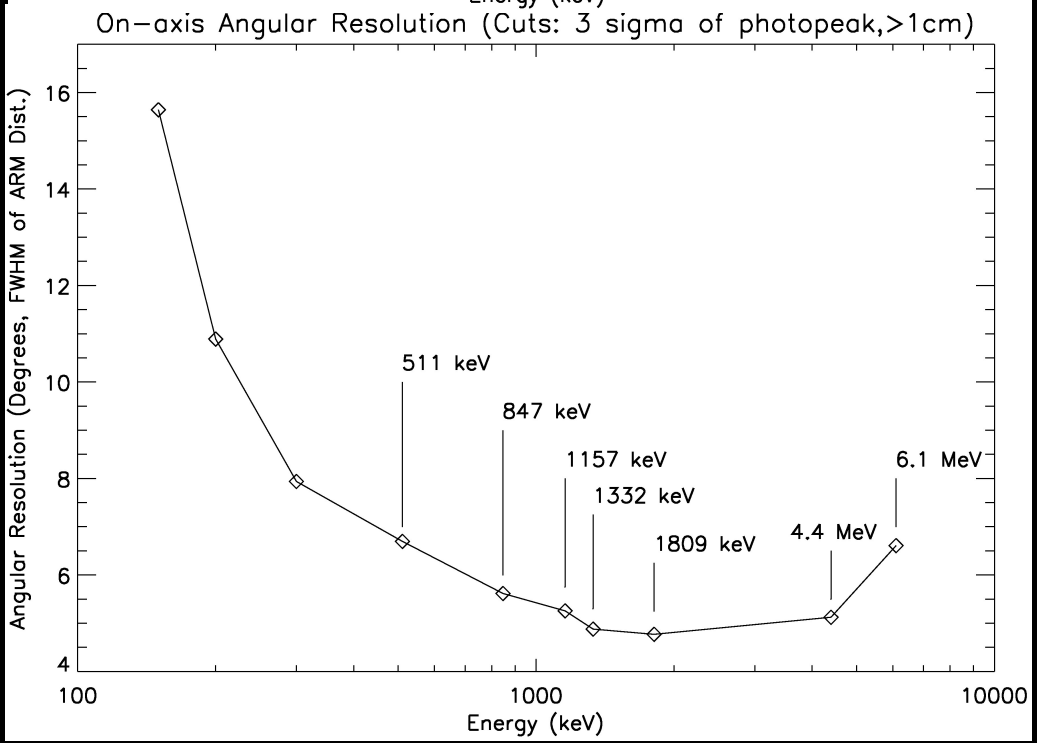
~ Sensitivity to diffuse emission
While maintaining a moderate
angular resolution

511 keV Performance of NCT:



- ~ New mass model in development
- ~ High effective area at 511 keV (15 cm^2)
- ~ Angular resolution of 6.5 deg FWHM at 511 keV. Dominated by strip pitch!





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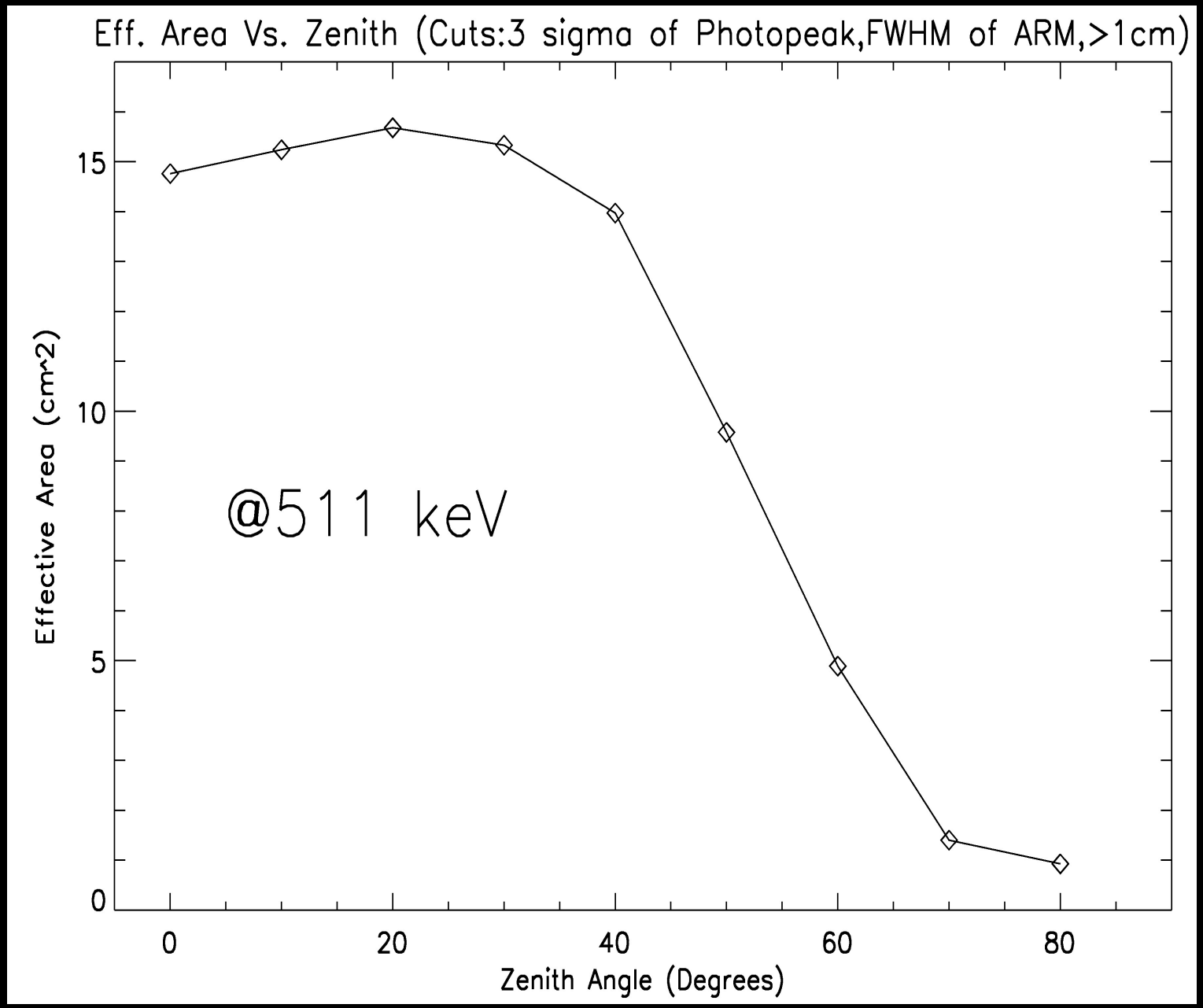
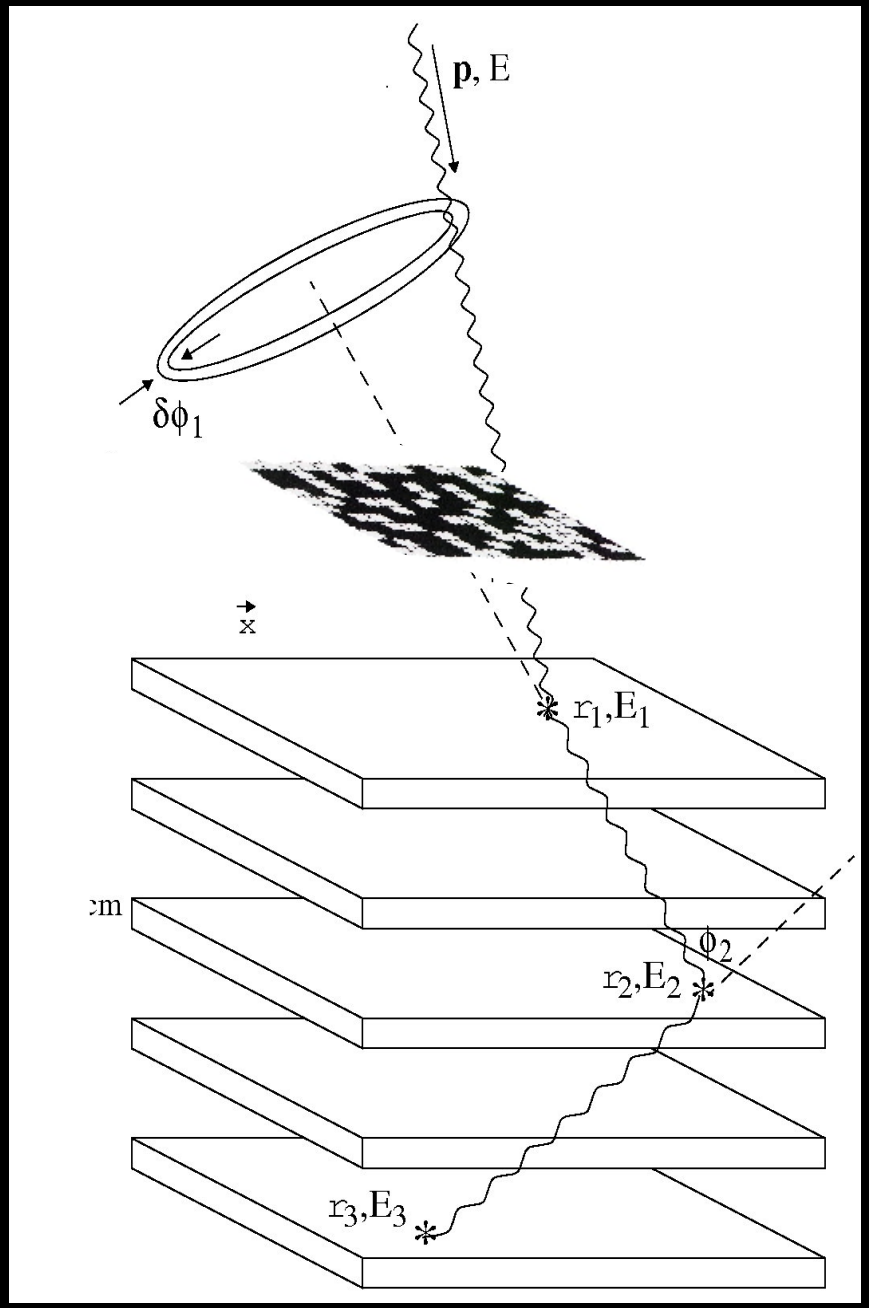


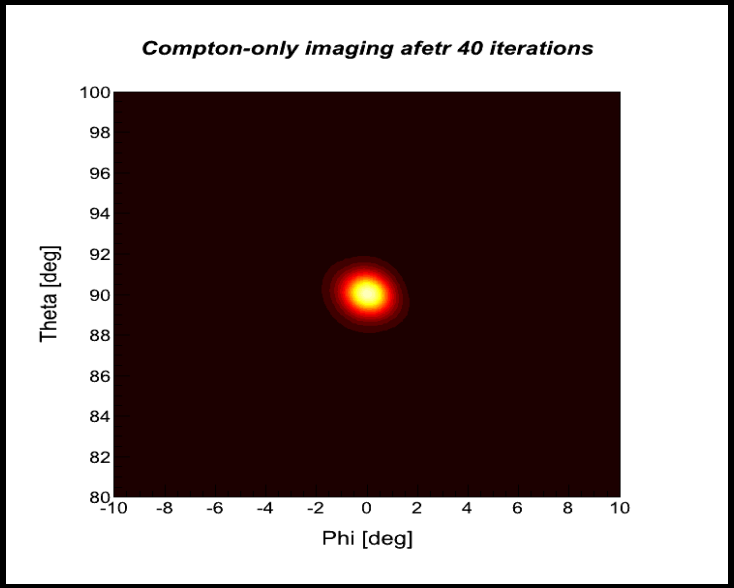
~ FOV of 40-50 Deg, limited by CsI shields

~ Exposure time uncertain, but 6 hrs/day with galactic center < 50 Deg zenith

Addition of Coded Mask:

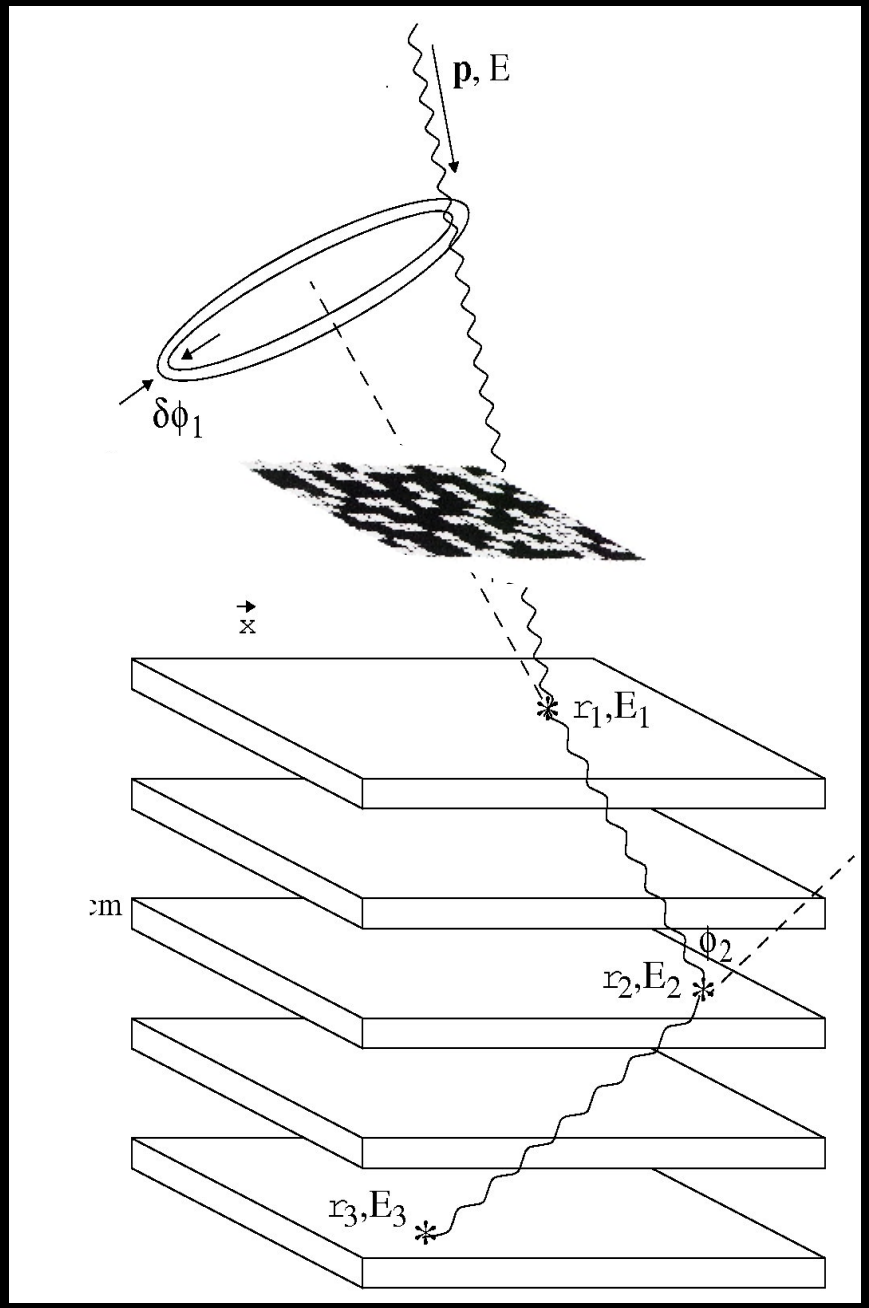


A small coded mask in the FOV increases the angular resolution of a Compton Imager



No mask

Addition of Coded Mask:



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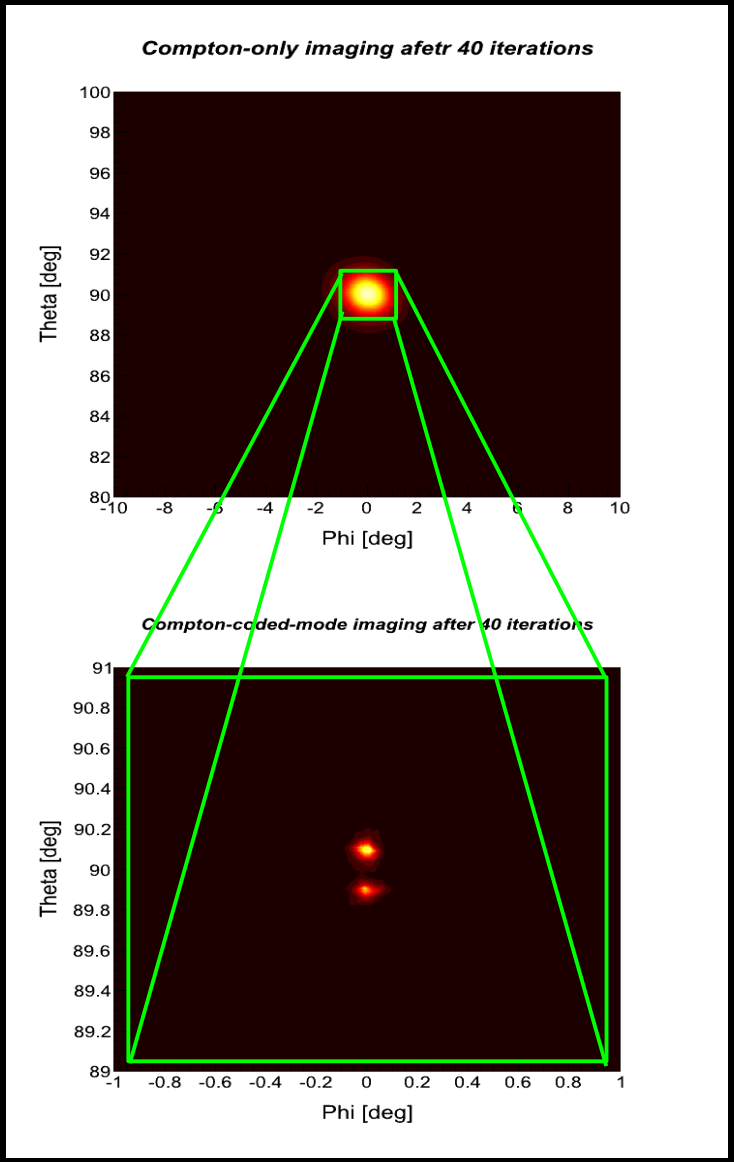

No mask

With mask

(See poster by M. Galloway)

Way Forward for Ge Compton Telescopes:

~ Development of next generation HPGe strip detectors has begun at UCB/LBNL

~ 148x148 channels - > ASIC readouts

~ Strip pitch of 0.45 mm - > Better position resolution - > Better angular resolution!

Simulations of NCT in space:

~ Intrinsic angular resolution of 2 deg FWHM at 511 keV

~ 3 sigma sensitivity of 9×10^{-6} $ph/cm^2/s$ at 511 keV (2 yr observation time)

~ Possibility of 180x360 deg FOV in low background environment

THANKS