EPI-Hi Sensor System

Outline

- requirements
- system overview (?)
- detector telescopes
- measurement capabilities
    - energy range and resolution
    - fields of view and angular sectoring
    - species coverage / composition
    - cadences
    - dynamic range in particle intensities
- expected performance compared with requirements
- maturity of design
- system testing approach
- summary

need to update outline to reflect slides that follow

EPI-Hi Measurement Requirements

Protons and Heavy Ions

- energy range: 1 MeV/nuc (TBR) to ≥50 MeV/nuc
- energy binning: ≥6 bins per decade
- cadence: at least energy bin with time resolution of 5 s or better
- FoV: ≥π/2 sr in sunward and anti-sunward hemipsheres (incl. 10° from S/C-Sun line)
- angular sectoring: ≤30° sector width
- composition: at least H, He, C, O, Ne, Mg, Si, Fe, ^{3}He
- species resolution: FWHM ≤ 0.5 (TBR) × separation from nearest abundant neighbor
- max intensity: up to 10% (TBR) of upper limit proton spectrum from EDTRD

Electrons

- energy range: 0.5 MeV (TBR) to ≥3 MeV
- energy binning: ≥6 bins per decade
- cadence: at least energy bin with time resolution of 1 s or better
- FoV: ≥π/2 sr in sunward and anti-sunward hemipsheres (incl. 10° from S/C-Sun line)
- angular sectoring: ≤45° sector width
- max intensity: up to 10% (TBR) of upper limit electron spectrum from EDTRD*

*Note: upper limit electron spectrum not yet specified in EDTRD

EPI-Hi Sensor System Overview

Sensor Approach:

- all sensor elements are silicon solid state detectors
- multiple detector telescopes to provide large energy range and sky coverage
- some telescopes double ended to increase sky coverage
- detector segmentation to provide angular sectoring and adjustable geometrical factor

Heritage:

- numerous energetic particle instruments over the past 40 years
- direct predecessor: STEREO/LET & HET

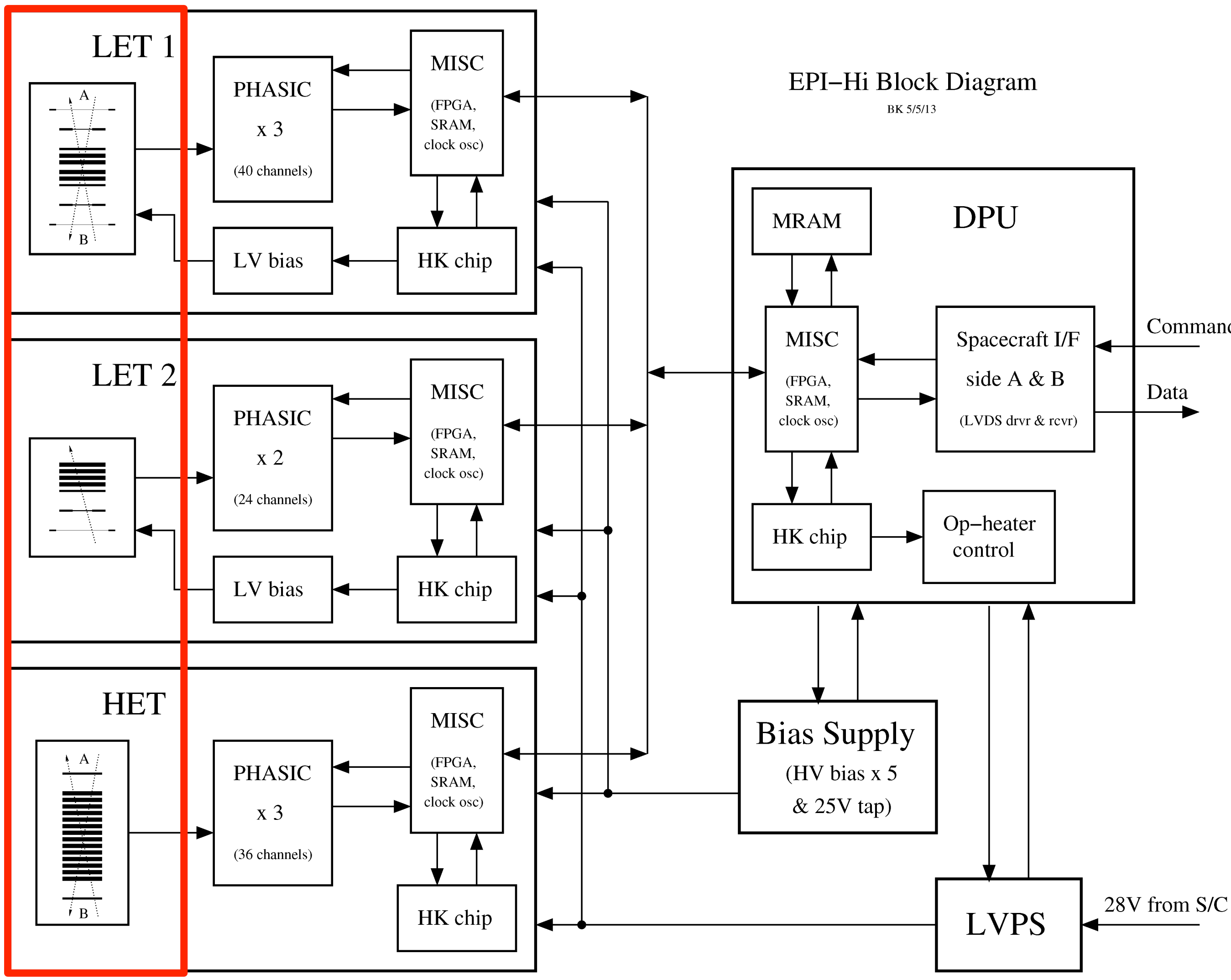
Key Differences:

- thinner detectors and windows to reduce energy threshold
- compact telescope designs to reduce saturation at high particle intensities and backgrounds at low intensities

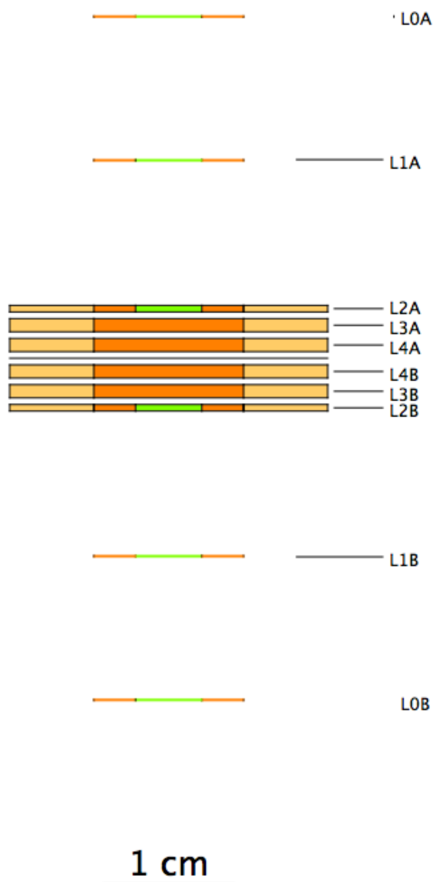
EPI-Hi Block Diagram

3 detector telescopes:

- one double-ended low-energy telescope (LET1)
- one single-ended low-energy telescope (LET2)
- one double-ended high-energy telescope (HET)
- all sensor elements are ion-implanted silicon solid-state detectors
- signals from each telescope processed by an individual electronics board



Low-Energy Telescopes: LET1 and LET2



HET2 is single ended and identical to HET1 down through L3B

Need to replace figure with version that includes inactive elements (windows, housing, etc.)

Energy Range

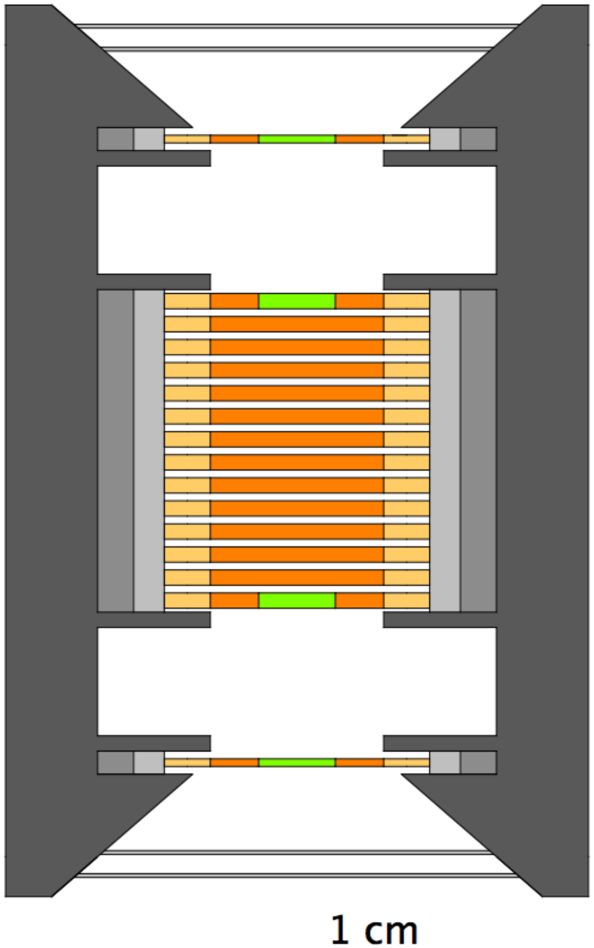
Stack Thickness through L4B: 3.5 mm of Si

highest stopping energies:
- H & He: ~25 MeV/nuc
- C: ~45 MeV/nuc
- Fe: ~100 MeV/nuc
- e: ~1.3 MeV

Front Detector Thickness: 12 µm Si
Combined window thicknesses: 3 µm Si equiv.

energies to penetrate windows + first detector:
- H: ~1.0 MeV
- He: ~0.9 MeV/nuc
- C: ~1.3 MeV/nuc
- Fe: ~1.5 MeV/nuc
- e: ~0.4 MeV (penetration to L3)

High-Energy Telescope: HET



colored regions: active Si
grey colored: inactive material

Energy Range

Stack Thickness: 15 mm of Si

highest stopping energies:
- H & He: ~55 MeV/nuc
- C: ~100 MeV/nuc
- Fe: ~230 MeV/nuc
- e: ~6 MeV

Front Detector Thickness: 0.5 mm Si

energies to penetrate windows + first detector:
- H & He: ~10 MeV/nuc
- C: ~18 MeV/nuc
- Fe: ~36 MeV/nuc
- e: ~0.4 MeV

Solid State Detectors

EPI-Hi Silicon Solid-State Detector Designs

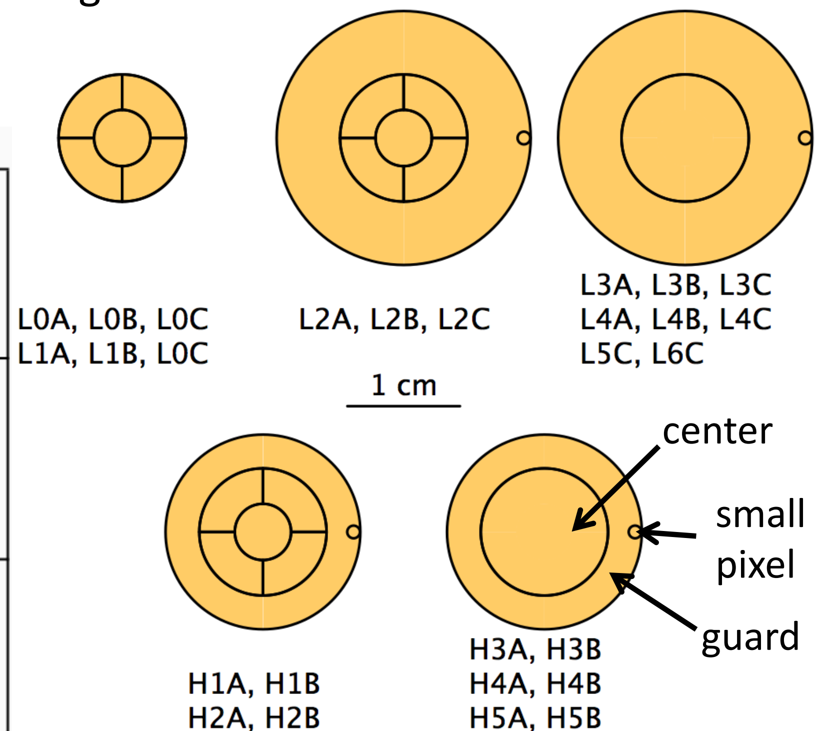
Detector Telescope	Detector Designations	Thickness	Number of Central / Guard / Small Pixel Segments	Central Active Area	Guard Active Area	Notes
LET1	L0A, L0B	12 µm	5 / 0 /0	1.0 cm^2	N/A	[1]
	L1A, L1B	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2A, L2B	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3A, L3B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4A, L4B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
LET2	L0C	12 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L1C	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2C	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L5C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L6C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
HET	H1A, H1B	500 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H2A, H2B	1000 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H3A, H3B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H4A, H4B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H5A, H5B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]

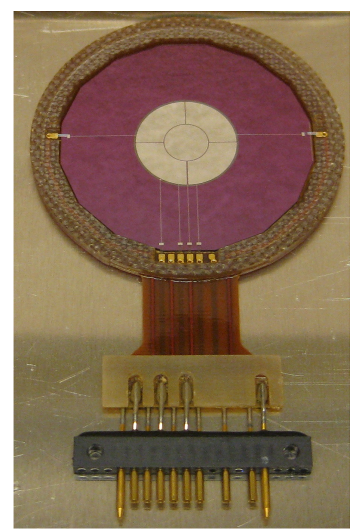
Notes:

[1] new technology development

[2] small pixel at edge for rate monitoring on some detectors; area: 1 mm^2

Segmentation of Active Areas:

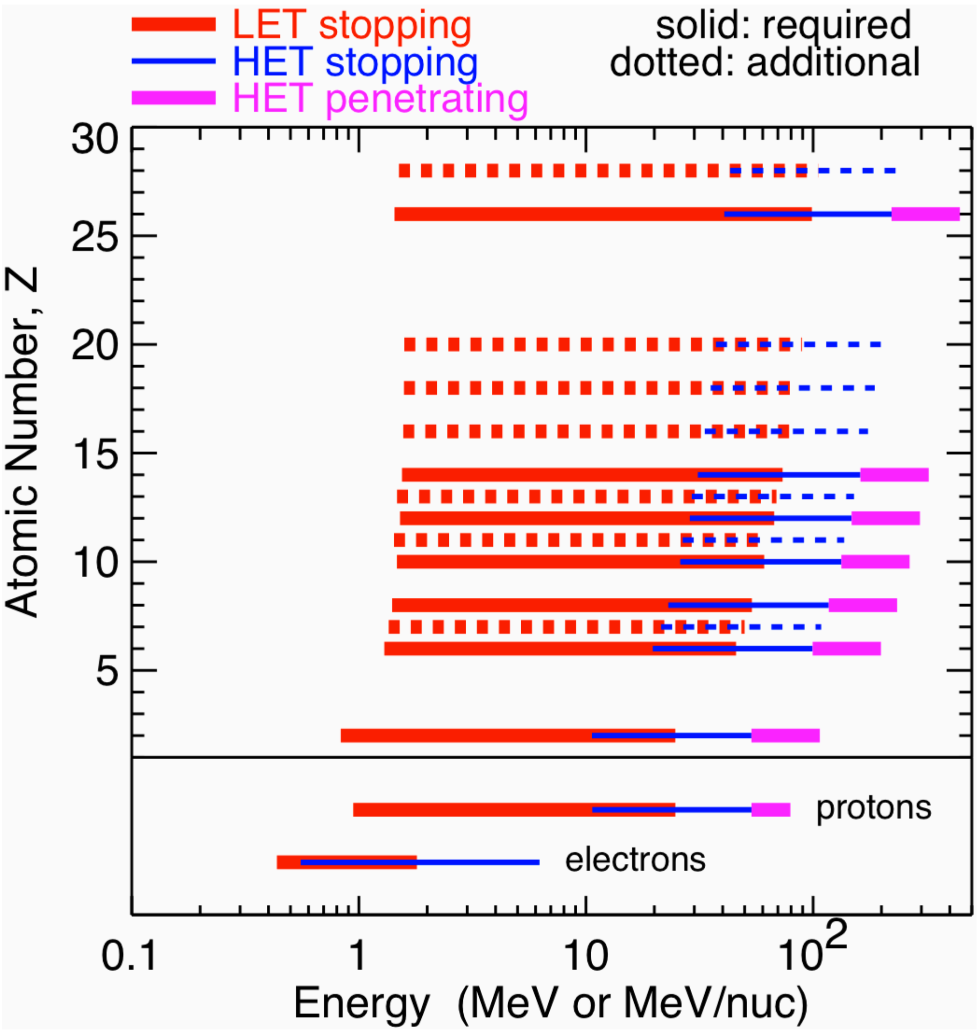




prototype L1 detector

Measurement Capabilities:

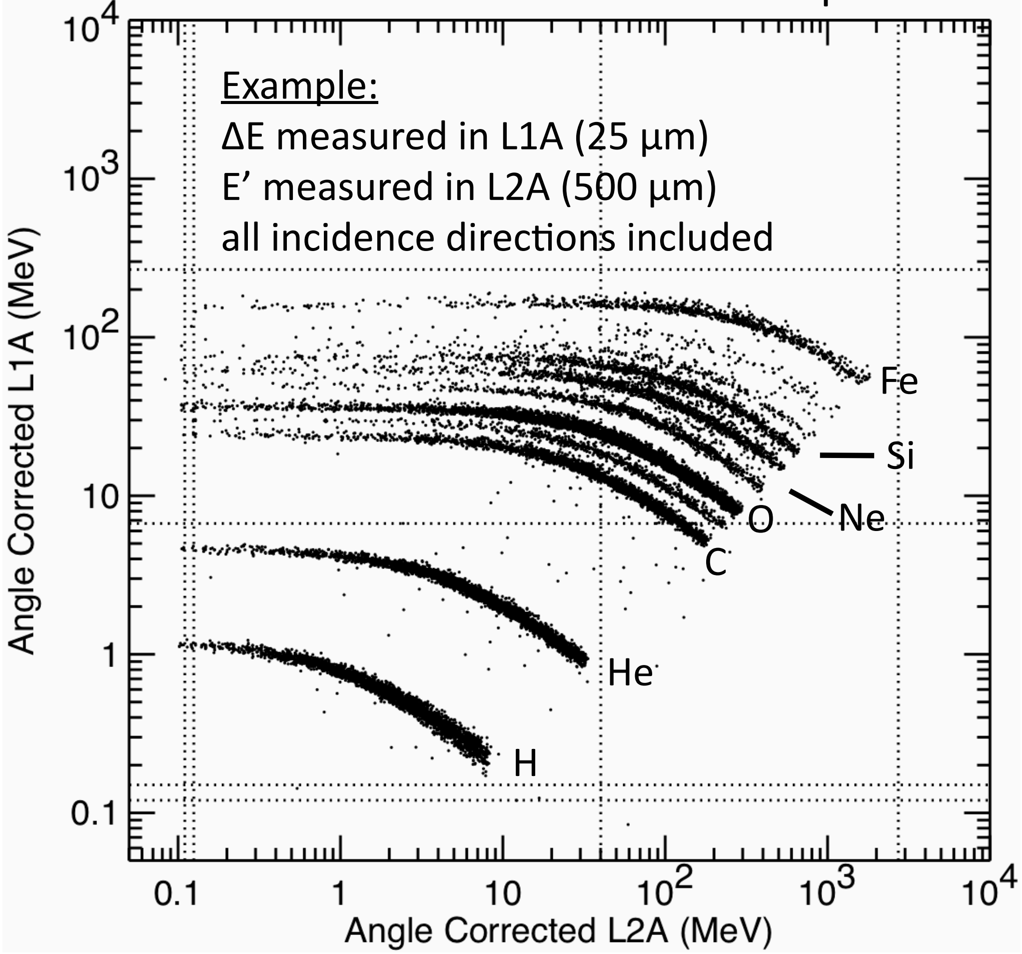
Species and Energy Coverage and Energy Binning



- Rates are accumulated on board in logarithmically spaced energy bins of width of a factor of 2^½ or 2^¼
- Bin width of 2^½ corresponds to ~6.6 bins per decade
- Larger bins are used for some rates accumulated at the highest cadence (1 second) in order to increase statistically accuracy.

Measurement Capabilities:
Species Coverage / Elemental Composition

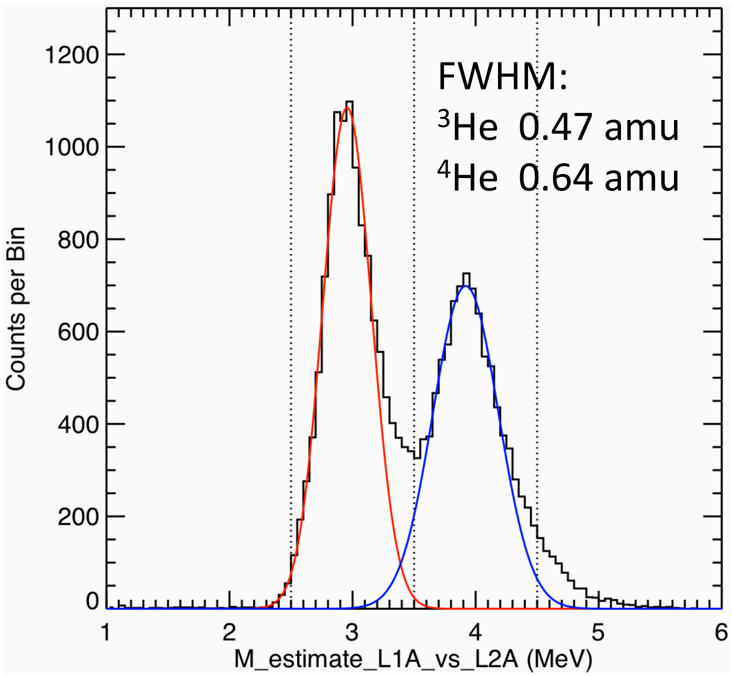
Monte Carlo simulation of ion response.



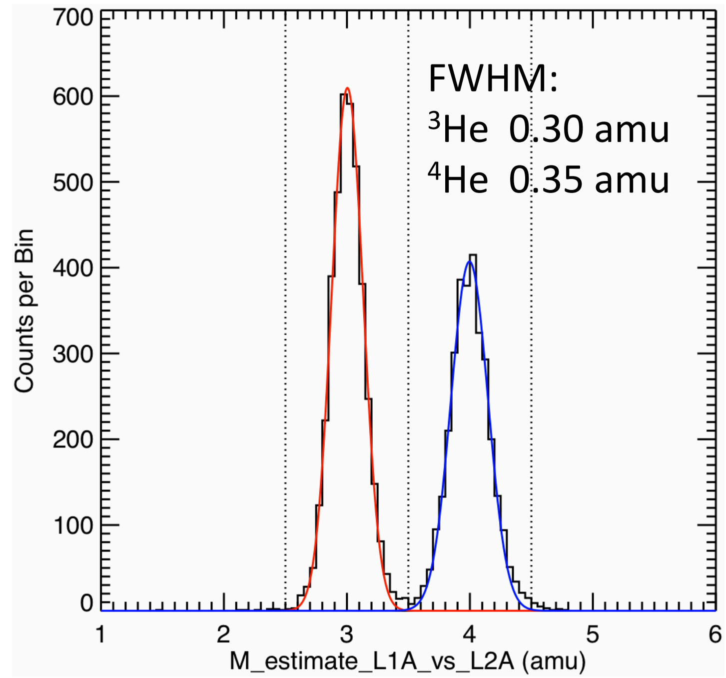
- Energy loss measurements from the detector in which a particle stops (E') and the preceding detector (ΔE) organize the data into distinct tracks for the various elements.
- Sector information is used to obtain mean thickness penetrated in the ΔE detector and make an on-board correction to the measured energies to optimize species resolution.
- Energy assigned on board includes energies measured in overlying detectors and calculated energy loss in windows.

Measurement Capabilities:
Helium Isotope Identification

full geometry defined by
L1•L2 coincidence



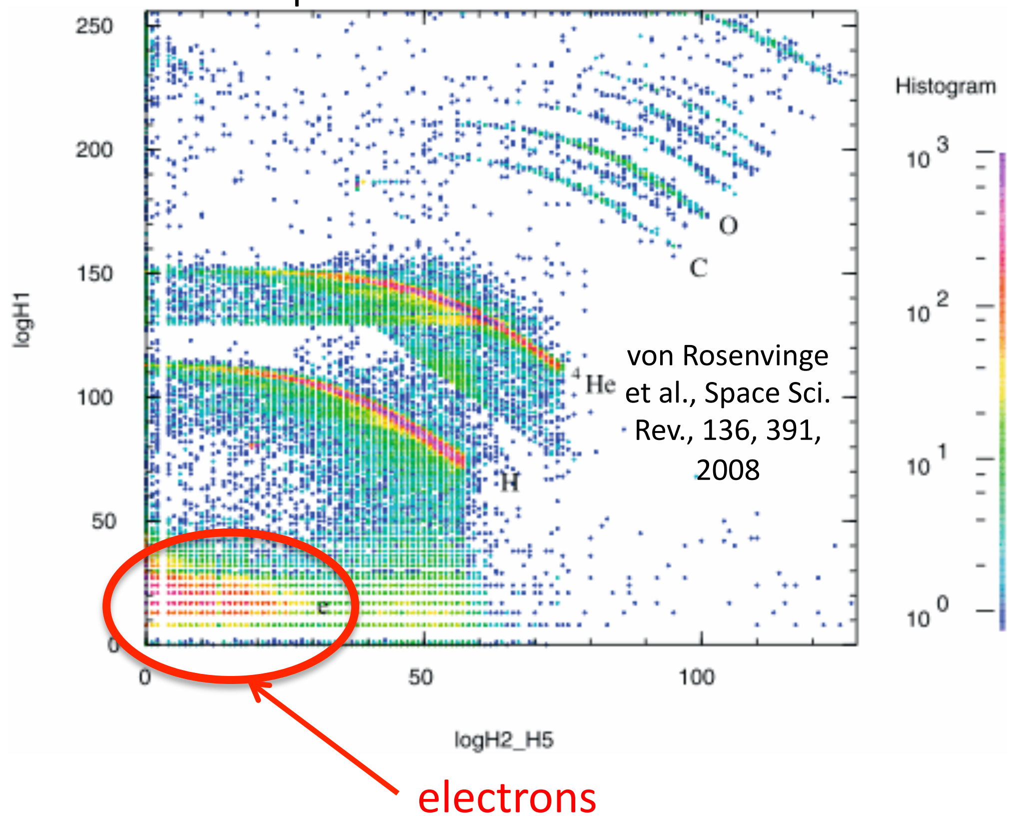
geometry defined by
L0•L1•L2 coincidence
(~1/4 of L1•L2 geometry)



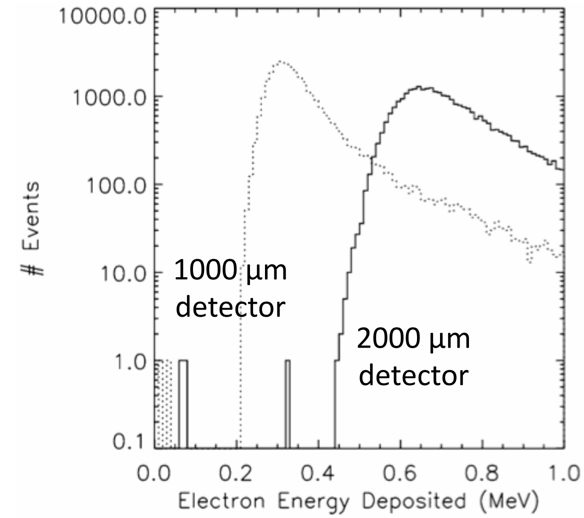
- Monte Carlo simulation of He isotope resolution: example based on L1A vs L2A
- resolution dominated by effect of incidence angle uncertainty on ΔE thickness penetrated
- restricting analysis to narrow-angle sectors gives higher resolution dataset
- other effects (e.g., channeling) limit measurable ^{3}He/^{4}He ratio at energies of a few MeV/nuc to >~5%

Measurement Capabilities:
Electron Identification

Example: measurements from the STEREO/HET telescope in the 13 Dec 2013 SEP event



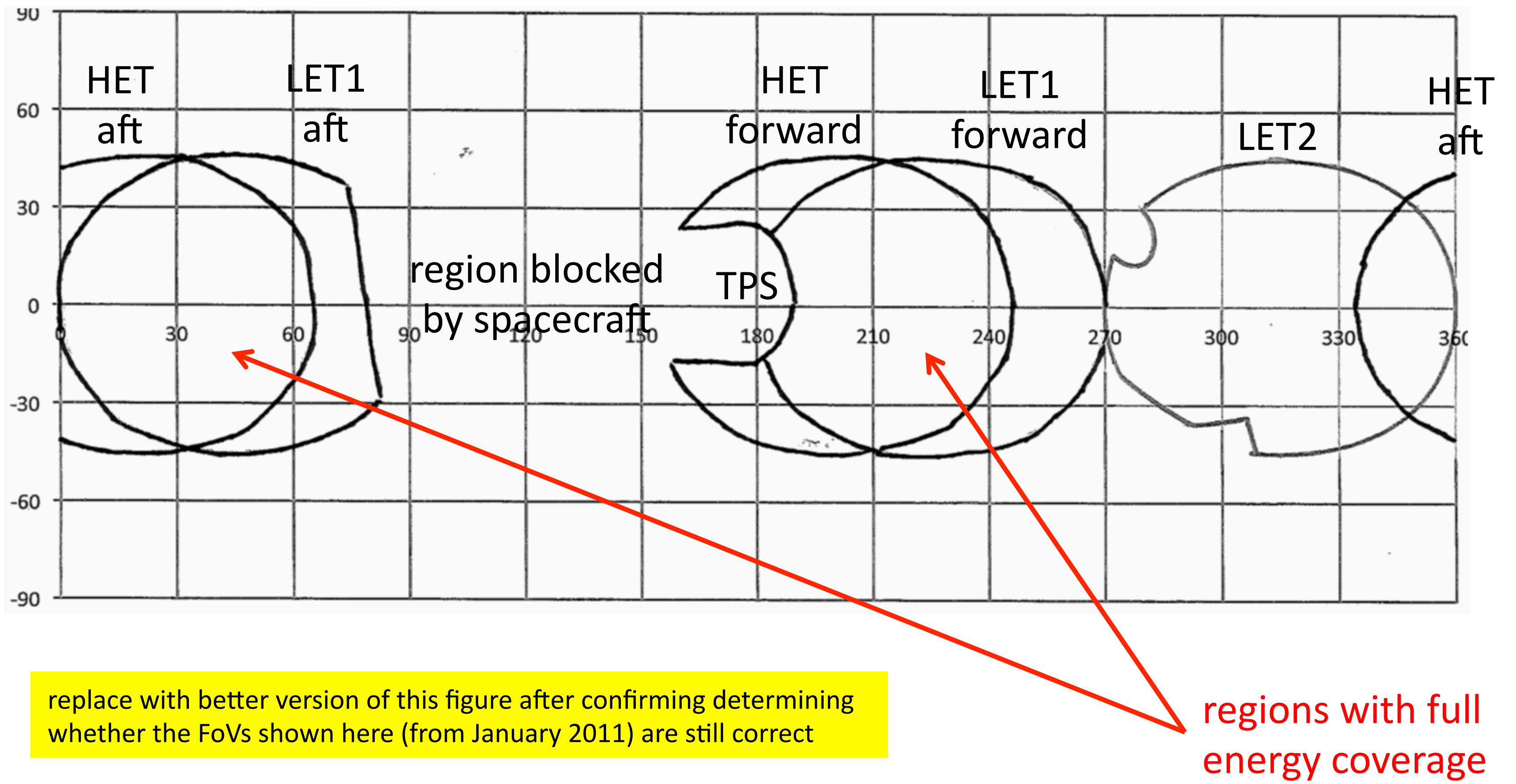
STEREO/HET Electron Threshold: GEANT4 simulation



- EPI-Hi HET uses a 500µm front, detector vs 1000µm in STEREO/HET
- high-energy electrons should deposit ~0.17 MeV in H1 and be detectable using the modeled 0.11 MeV threshold
- once electronic noise level has been measured in a realistic setup, we will assess whether a modest increase in the H1 thickness is desirable

Measurement Capabilities:
Fields of View

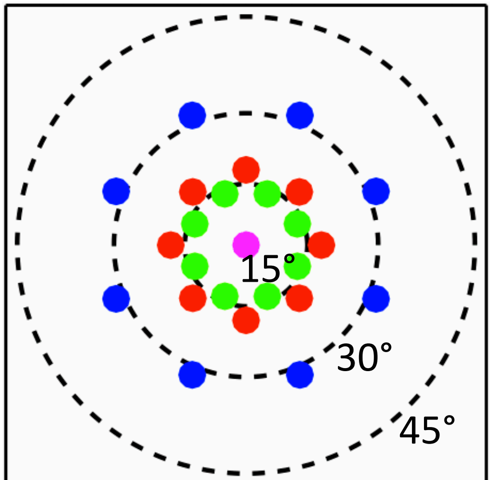
five 45°-degree half-angle view cones



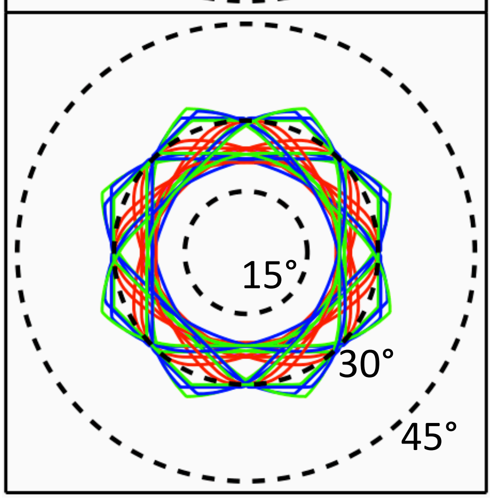
replace with better version of this figure after confirming determining whether the FoVs shown here (from January 2011) are still correct

Measurement Capabilities: Angular Sectoring

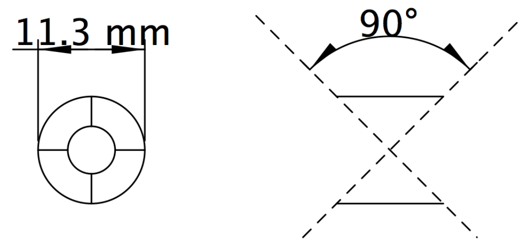
quote value(s) for rms spreads of angles encompassed by individual sectors



Locations of Centers of Angular Sectors



Shapes and Orientations of Angular Sectors (plotted relative to sector center location)



Particle direction of incidence determined based on active element hit in two position-sensitive Si detectors (L0 and L1, L1 and L2, or H1 and H2)

- each of these detectors has central bull's eye surrounded by 4 quadrants
- area of each active element is 0.2 cm^2
- quadrants in the second detector rotated 45° relative to those in the first first
- 25 combinations of hit elements in the two detectors used to assign event to a viewing sector
- significant overlaps among sectors allows measurements of particle distribution with angular resolution smaller than the size of a sector
- HET provides sectored electron data, LET1 provides only front-back direction information for electrons

Measurement Capabilities: Cadences

<u>highest cadence: 1 second</u>

• used for one electron bin below and one above 1 MeV

• used for 4 proton bins above 1 MeV

<u>intermediate cadence: 10 sec</u>

• used for narrow energy bins for e, H, He, ^{3}He

• used for intermediate energy resolution bins for element groups CNO, NeMgSi, Fe

<u>normal cadence: 60 sec</u>

• used for narrow energy bins for ^{3}He, and major elements from C through Ni

• used for wide energy bins for groups of ultraheavy elements

<u>low cadence: 300 sec</u>

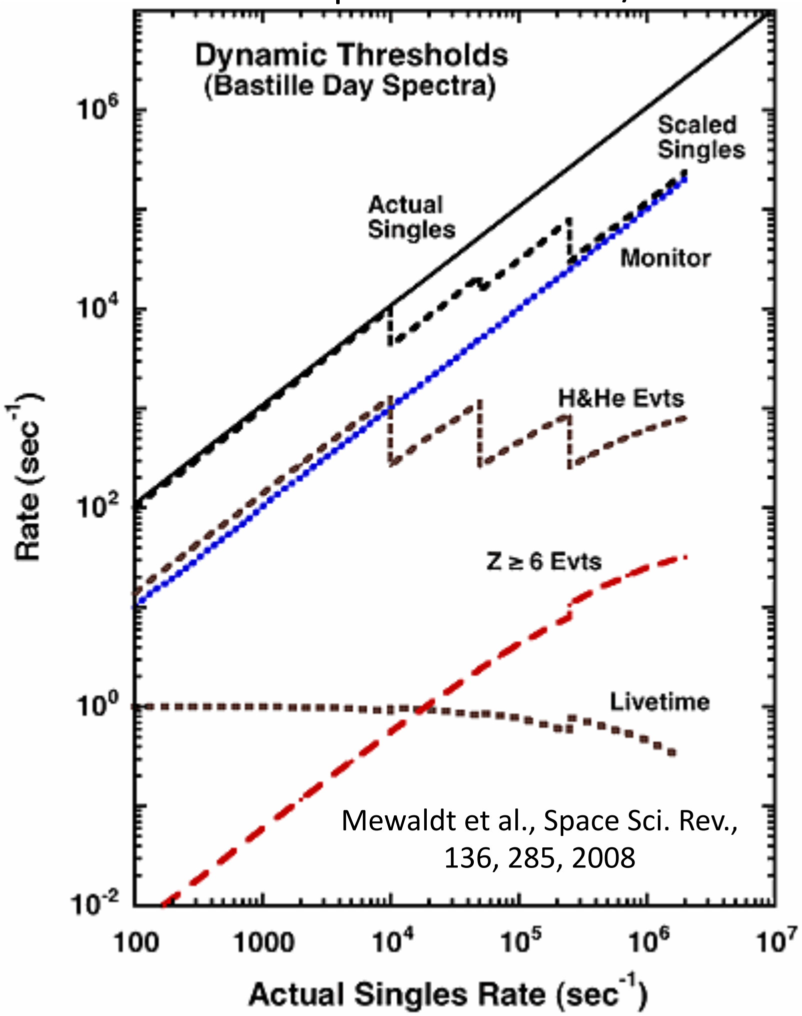
• used for angular distribution of e, p, He, ^{3}He, CNO, NeMgSi, and Fe in intermediate energy bins

<u>ultra-low cadence: 1 hr</u>

• all rates accumulated at cadences of 60 sec and 300 sec are also accumulated over 1 hr

Measurement Capabilities:
Dynamic Range in Particle Intensities (1/3)

Example from STEREO/LET



Mewaldt et al., Space Sci. Rev., 136, 285, 2008

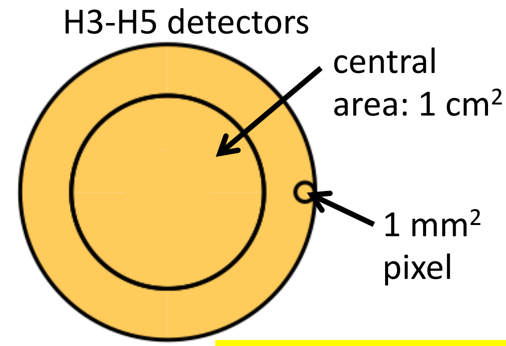
- protons and He dominate the EPI-Hi count rates and the associated deadtime
- a "dynamic threshold" system, successfully used in the LET and HET instruments on STEREO, allows the adjustment of the geometrical factor for protons and He while maintaining the full geometrical factor for Z≥6 elements
- in several stages, thresholds are raised on all but one active element in detectors progressively deeper in the stack to suppress protons and He over a portion of the instrument geometrical factor
- a detector element that remains sensitive to protons and He is used to monitor the actual rate and so that thresholds can be returned to the lower values (with some hysteresis) when particle intensities have decreased
- count rates at which thresholds are dynamically raised and lowered are controlled by entries in the command table

Measurement Capabilities:
Dynamic Range in Particle Intensities (2/3)

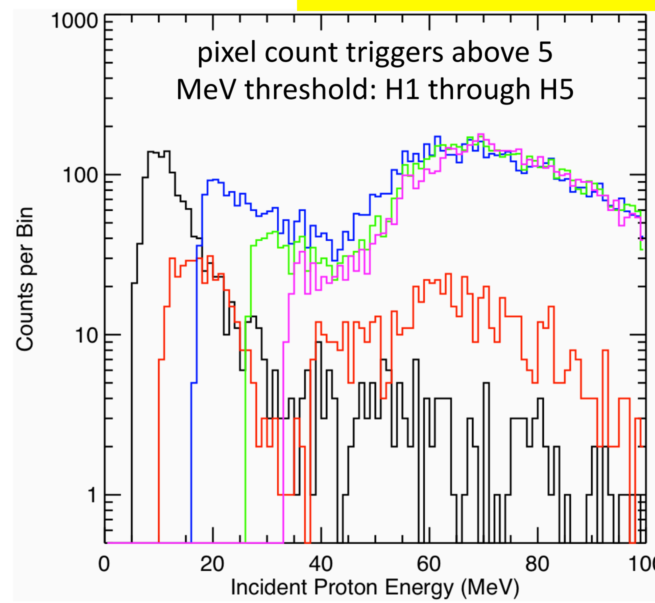
- the EPI-Hi front-end electronics can process slightly more than 10^5 events/s from all detector elements combined
- dynamic threshold approach:
  - stage 1: raise the threshold on 4 of the 5 segments of the L1 detectors to exclude protons and He decreases the count LET count rate by a factor ~5
  - stage 2: raise the threshold on 4 of the 5 segments of the L2 detectors for an overall count rate reduction by a factor ~25
  - stage 3: raise the threshold on the outer segments of the L3 and L4 detectors for a modest additional reduction of the count rates for high-energy particles entering through the telescope apertures and to reduce count rate from out-of-geometry particles entering through the sides of the telescope
  - stage 4: raise the thresholds on all detector elements to eliminate protons and He from the normal analysis and obtain some information about the proton and He spectra from singles rates measured in "small pixels" that are instrumented on several of the detectors
- based on the STEREO example, when stage 4 is reached the actual singles rate (without raised thresholds) would be ~2×10^6/s and the livetime fraction would be ~30%

Measurement Capabilities:
Dynamic Range in Particle Intensities (3/3)

- in large SEP events the intensity ratio (protons+He)/(Z≥6)≈300 so when count rate due to protons plus He would be 2×10^6/s without dynamic thresholds raised, the count rate of Z≥6 still be below 10^4/s, about an order of magnitude below the maximum rate capability of the front end electronics, so useful measurements of heavy nuclei are still possible
- in order to provide some information about protons and He at the highest intensities, singles rates in small (1 mm^2) instrumented on selected detectors will be used
- small pixel rates can be calibrated against rates in other detector segments until dynamic threshold level 4 is enabled
- by setting the thresholds on the small pixels set slightly below value expected from stopping protons, some information about the incident energy spectrum is obtained from the dependence of pixel count rate on depth in the telescope



omit histogram—too complicated to explain in a short amount of time?



Bonus Science

The design of EPI-Hi lends itself to several measurements without requiring modifications of the hardware design:

- ultraheavy elements
- 22Ne/20Ne isotope ratio measurements
- neutral particles including gamma-rays, neutrons, and energetic neutral atoms

Summary