Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Calibration

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Outline

- Introduction
- Species and Energy Ranges
- Calibration Plan
- Facilities
- Test Flow
- In-Flight Calibration

Introduction

EPI-HI Measurement Requirements:

– Composition, energy spectra, and angular distributions of ions and electrons in flare and CME-related SEP events, and at shocks

– Required Species for EPI-Hi

- H, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, Fe ≤ 1 MeV/nuc (TBR) to ≥ 50 MeV/nuc

– Required Species for Mission

- Electrons with ≤ 0.5 MeV to ≥ 3 MeV

– SEP Directional Distributions

- The combined LET and HET fields of view are required to measure SEP angular distributions over ≥ $\pi/2$ sr in both the sunward and anti-sunward directions

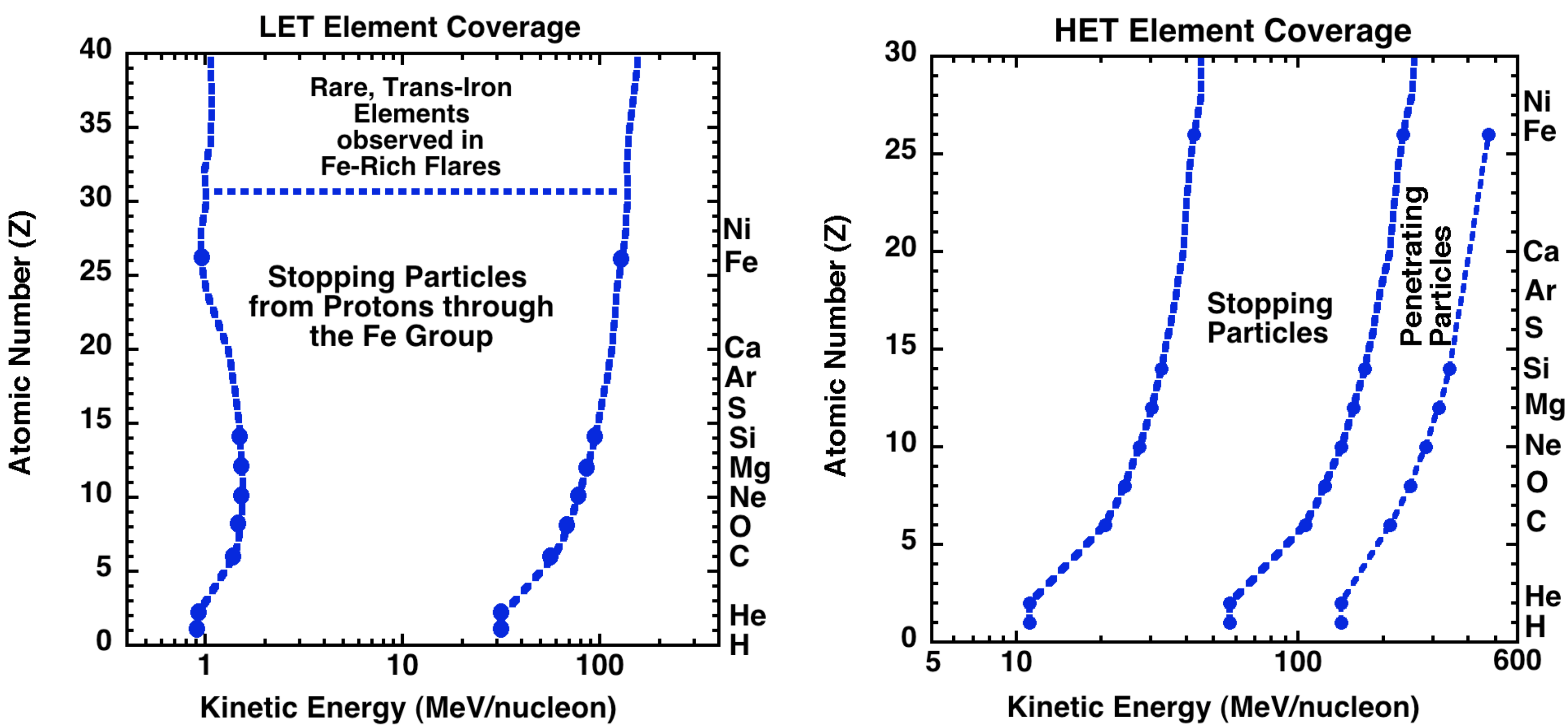
EPI-Hi Measurement Goals:

– SEP Ions: Composition and energy spectra of ~16 species with 1 ≤ Z ≤ 28 and trans-Fe element groups

– SEP Electrons with ≤ 0.05 to 6 MeV

Species and Energy Ranges

LET and HET energy coverage for stopping elements is shown below. Note that LET and HET have considerable energy overlap. Also shown is the energy range over which HET can identify penetrating ions. Required species are indicated by blue dots. LET will also measure rare trans-Fe species often overabundant in ^{3}He-rich flares.



Calibration Plan

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Calibration Plan:

- Lab measurements of electronic gains, offsets, linearity, thresholds, noise, and temperature variations
- Alpha-particle and heavy-ion mapping of detector uniformity
- Accelerator measurements of heavy-ion dE/dX-E-Range parameters, combined with modeling
- Monte-Carlo simulations of expected detector performance
- Monte-Carlo determinations of LET and HET geometry factors for directional sectors versus “range” in the telescope
- Accelerator measurements of heavy-ion dE/dX–E’ “tracks” for new flight detectors and end-to-end testing/tuning of on-board particle identification algorithms
- In-flight measurements that optimize/validate on-board particle identification processes

Calibrating Detector Energy Thresholds

Each dual-gain PHA chain contains a precision test pulser that will be used to measure the preflight and in-flight trigger thresholds of the 88 separate detector segments in EPI-HI. The Table below shows a sample of such data for the STEREO LET-B sensor. Typically, in-flight thresholds can be set lower than pre-flight thresholds.

STB - LET Thresholds

LET Detector	FM2 Detector		Thick microns	rms microns	Area (cm2)	Launch High Gain DAC Setting	Launch Thresh (MeV)	Dec, 2006 High Gain DAC Setting	Dec, 2006 High Gain Thresh (MeV)	Proton Max E (MeV)
L1A0	L1-36	a	22.71	0.97	0.8	190	0.188	180	0.153	12.7
		b	21.73	0.22	0.4	223	0.153	216	0.129	15.0
		c	22.66	0.55	0.8	167	0.188	160	0.163	11.7
L1A1	L1-02	a	26.22	0.59	0.8	166	0.218	155	0.178	12.6
		b	26.31	0.47	0.4	165	0.185	157	0.156	14.9
		c	26.12	0.44	0.8	190	0.217	178	0.176	12.7
L1A2	2250-2-3	a	29.85	0.21	0.8	320	0.248	308	0.203	12.5
		b	29.82	0.17	0.4	215	0.210	206	0.177	15.0
		c	29.12	0.51	0.8	273	0.242	261	0.199	12.5
L1A3	L1-08	a	24.47	0.46	0.8	196	0.203	186	0.167	12.5
		b	24.19	0.30	0.4	243	0.171	236	0.144	14.9
		c	24.72	0.41	0.8	192	0.205	182	0.169	12.5
L1A4	L1-24	a	25.68	0.42	0.8	139	0.213	128	0.174	12.6
		b	25.98	0.65	0.4	188	0.183	179	0.153	15.1
		c	25.20	0.65	0.8	179	0.209	168	0.170	12.7

Measuring Gains/Offsets of PHASICS

Onboard particle identification requires accurate calibrations of the flight electronics and their dependence on temperature

Onboard measurements of the nuclear charge (Z) and kinetic energy (E) of energetic particles requires accurate pre-launch and in-flight measurements of the gain and offset of individual PHASIC circuits.

Since the SPP orbit may lead to significant temperature variations, these parameters must be measured, and available for implementation

Although the PHASICs are relatively stable with temperature, it is prudent to be prepared for unexpected temperature excursions.

The LET and HET designs also allow for periodic on-board calibration of the transfer function of each ADC on a grid of logarithmically-spaced points.

Would like a Figure. I have obtained test data for STEREO PHASICs vs. Temperature, but need to figure out how to display it

Monte Carlo Simulations

Monte Carlo simulations were used throughout the LET & HET design process to identify and optimize parameters controlling charge and energy resolution.

Such simulations continue to be important in evaluating accelerator and laboratory measurements of detector and electronic performance.

For example, the simulation shown here illustrates the expected resolution of ^{3}He and ^{4}He in the LET telescope

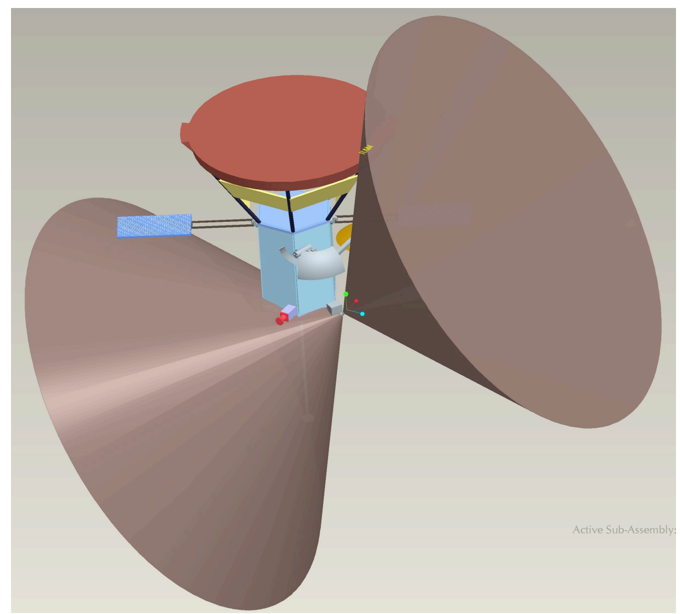
(insert example simulation of ^{3}He/^{4}He mass distribution [or heavy-ion ΔE vs E' tracks], or charge histogram, from Mark)

Calibrating LET/HET Fields of View

The combined LET and HET fields of view are to cover ≥ $\pi/2$ sr in both the sunward and anti-sunward directions (see LET-1 example below)

- **The geometry factor and directional coverage of each of the 25 sectors within each cone will be determined with a Monte Carlo calculation taking into account the pointing directions of the three telescopes relative to the spacecraft and Sun and any obstructions.**

- **The relative geometry factor of each sector can be validated in-flight during the decay phase of SEP events when solar energetic particles become nearly isotropic in the solar wind rest frame.**



LET-1 Field of View

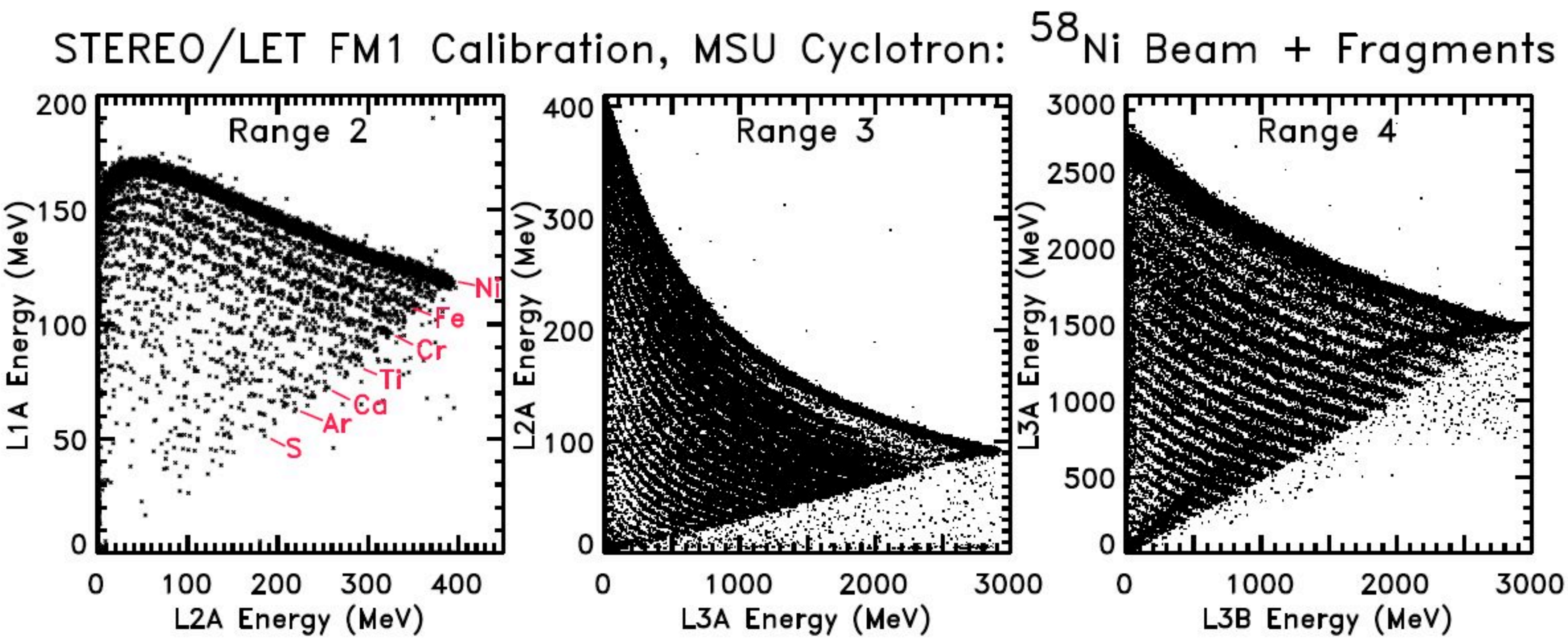
Facilities – Accelerator Calibration Data

LET & HET use ΔE vs. Residual Energy (E') to measure SEP composition

The ΔE vs. E' tracks for lighter species are obtained by fragmenting a heavy-ion beam on a polyethylene target

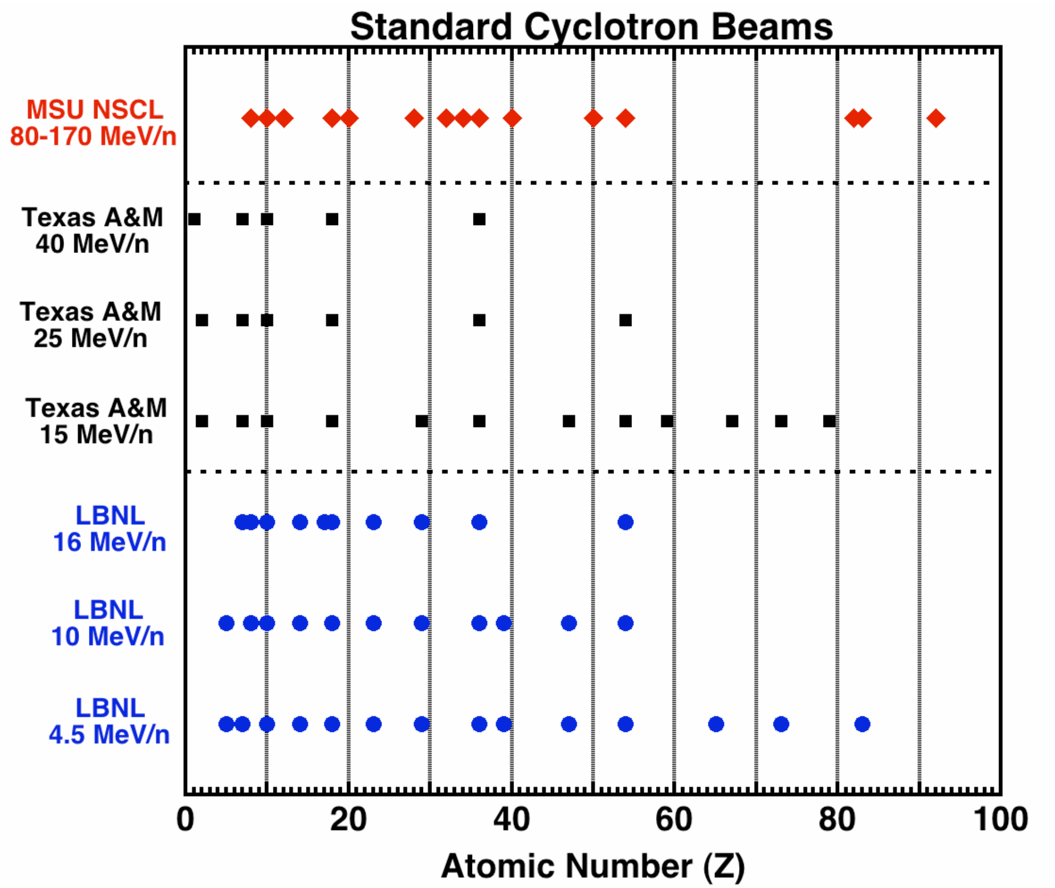
The example below from STEREO/LET uses a ^{58}Ni beam at the MSU NSCL

This also provides an end-to-end test of the onboard identification system



Facilities – Accelerator Calibrations

There are three appropriate heavy-ion accelerators in the U.S.



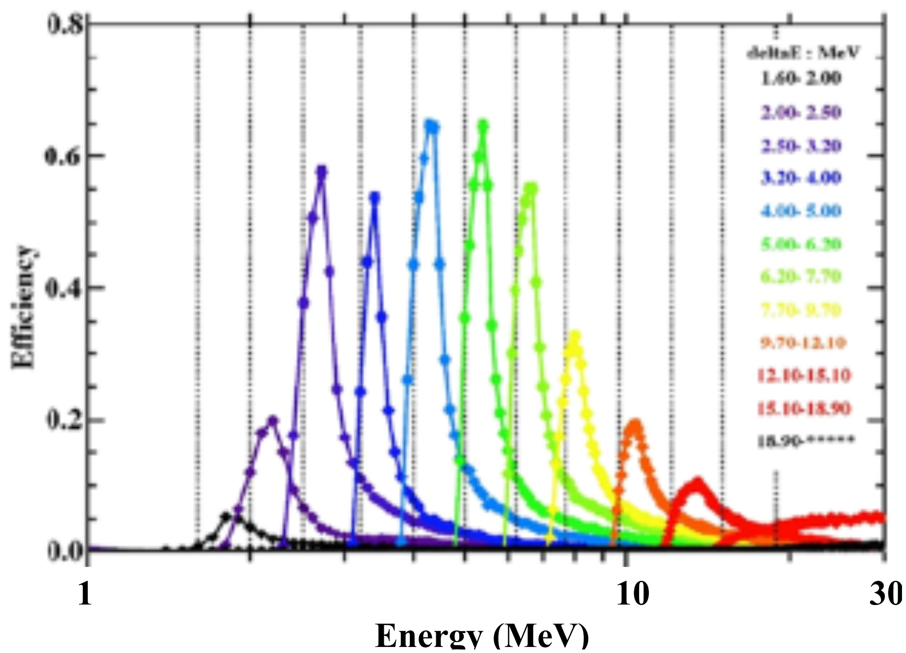
- All 3 cover the key heavy-ion charge range (6≤Z≤28) and also provide for trans-iron (Z>30) calibrations
- However, only MSU covers the full energy range of EPI-Hi.
- The MSU accelerator also reaches high enough energy to produce a much greater yield of lower-Z fragments
- In the past we have also used the heavy-ion accelerator in Darmstadt, Germany

Propose an accelerator calibration of EPI-Hi (or the engineering unit) for 2016

Electron Calibrations

HET will measure energetic electrons with 0.5 – 6 MeV

- The electron response will be simulated using GEANT-4, which was used to calibrate the REPT sensors on the Van Allen Probes (Baker et al. 2012)
- HET is 13.5 mm of Si deep with a (2-ended) geometry factor of G ≈ 0.5 cm^2sr compared to 23 mm deep and 0.2 cm^2sr for REPT. The HET threshold is 0.5 MeV because of a thinner front end
- Based on the calibrations of REPT and SAMPEX/PET, the HET energy range of 0.5 – 6 MeV is achievable
- Routine testing of the HET electron response will use β−decay sources like ^{106}Ru and ^{90}Sr.
- LET will also provide electron measurements over a more limited energy range



REPT electron calibration using GEANT-4

Calibration Test Flow

Overview of Key Steps

Determine how the Science Requirements drive detector, electronics, and software requirements (noise, resolution, dynamic range, near-Sun environment)
  (requirements on detector thickness, uniformity, noise)
  (requirements on PHASIC noise, dynamic range, radiation hardness)

Evaluate expected instrument performance with calculations and simulations

Develop new detector/electronic hardware; new flight software

Test new detectors, hardware, software with real/simulated particles to determine if they meet requirements? (Accelerator and lab tests; simulations)

Perform an end-to-end test of all systems at a heavy ion accelerator

In-flight tuning and validation of onboard analysis routines

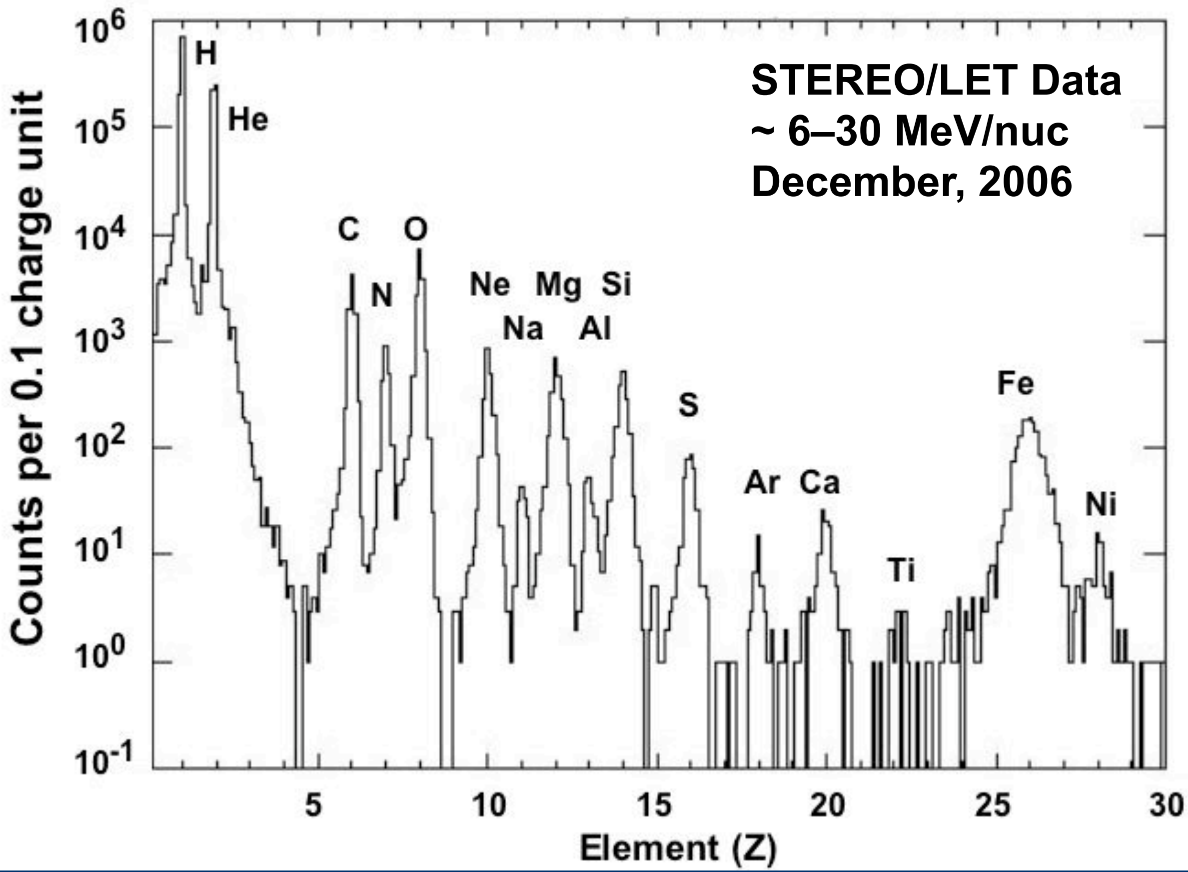
Calibration Test Flow

Calibrate New Detectors, PHASICS, and Software			
Task	**Complete**	**In Progress**	**Scheduled For**
New, thin SSDs meet uniformity and response requirements		√	
New PHASIC meets dynamic range, noise, requirements		√	
Test linearity, temperature-stability performance of new PHASIC		√	
Calibrate transfer function of flight PHASICS vs. temperature			2014?
Propose for beam time at MSU Superconducting Cyclotron Lab			2014
On-board He-mass algorithm meets requirements		√	2014
Simulate HET and LET SEP electron response using GEANT-4			2014-2015
Test SEP electron detection and γ-ray background with lab sources			2014-2015
Validate on-board analysis routines at accelerator			2016
Determine location of element tracks at MSU accelerator			2016
Inflight tuning and validation of on-board analysis routines			≥2018

I invite suggestions/corrections

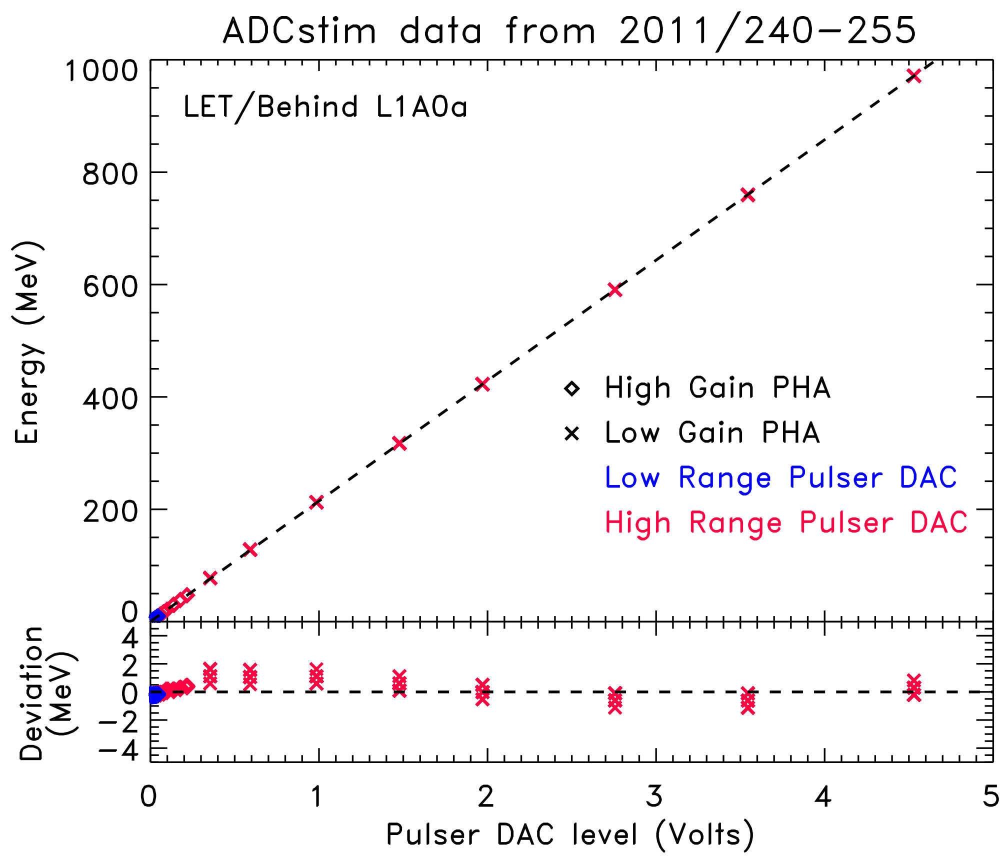
In-Flight Calibration

Pulse-height data from the EPI-Hi LET and HET sensors will provide the final calibration of the on-board particle identification system. Shown are STEREO LET data from the Dec. 2006 SEP events. Sixteen elements are resolved. EPI-Hi should provide similar resolution extending to ~100 MeV/nuc.



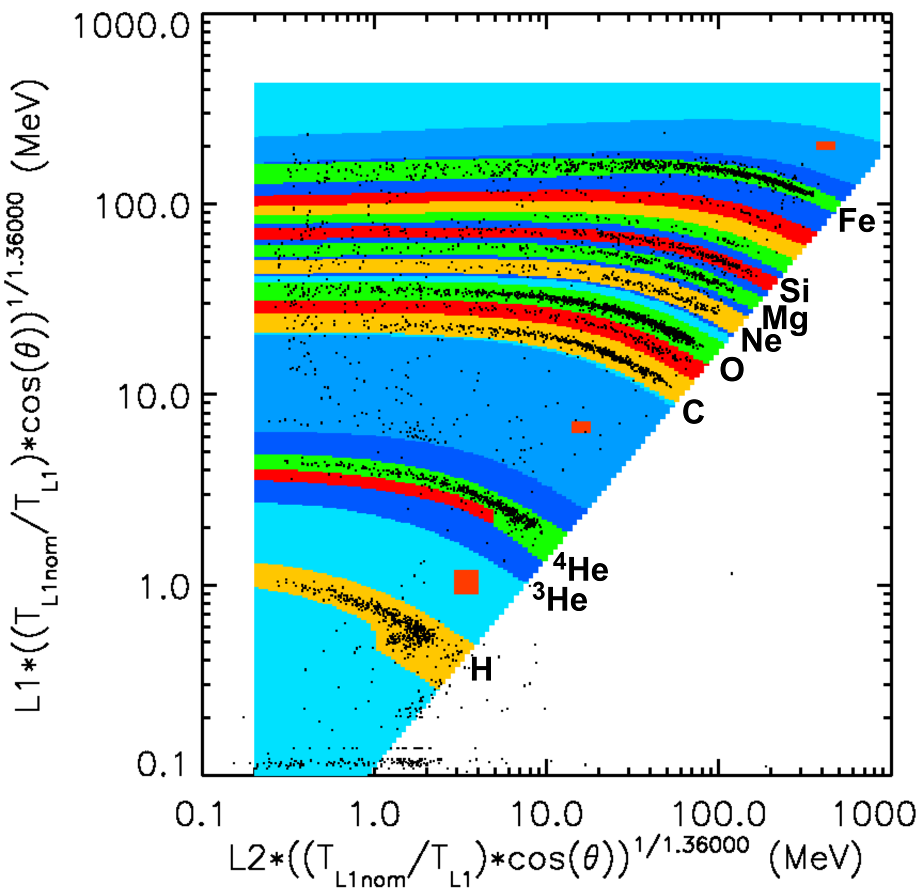
In-Flight Electronics Calibration

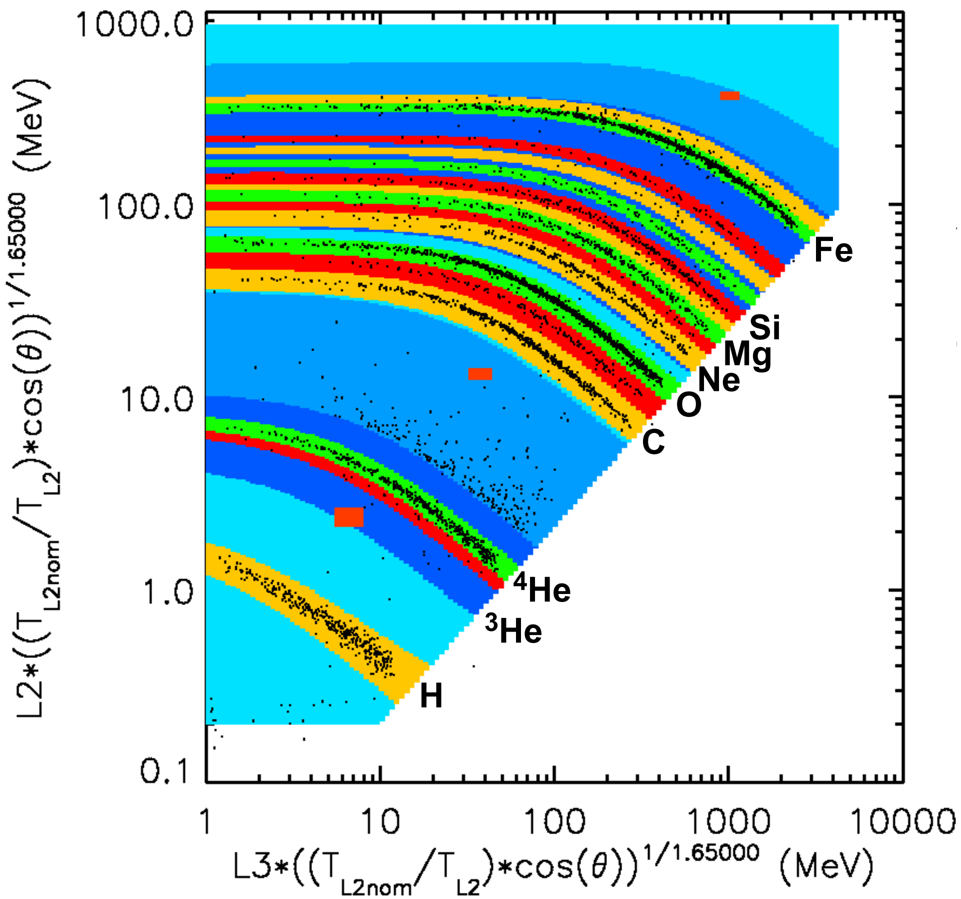
The gain, offset, and threshold of each PHASIC channel will be periodically calibrated onboard using built-in DACs that stimulate multiple detectors. The Figure shows an example of in-flight calibration data from STEREO/LET. Such calibrations are especially important if the temperatures of the LET and HET electronics vary significantly over the course of the SPP orbit.



In-Flight Calibration

STEREO/LET event data from the Dec. 2006 SEP events are plotted on the L1vsL2 and L2vsL3 matrices after correction for incidence angle and individual L1 and L2 segment thicknesses (~25 and ~50 μm thick). Colored bands show regions used for on-board particle identification. EPI-Hi detectors range from 10 μm to 2000 μm thick.





In-flight Energy Spectra

To achieve EPI-Hi science requirements the nuclear charge (Z) and kinetic energy of SEP ions must be measured to construct energy spectra.

Shown at right are energy spectra that combine ACE, GOES & STEREO data measured while the STEREOs were still near Earth. They cover the same energy range as EPI-Lo & Hi (~0.05 to >100 MeV/nuc). Measured intensities are plotted with no correction factors.

The approaches outlined here will enable EPI-Lo and EPI-Hi to produce similar energy spectra.