

# 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

Richard Mewaldt

*EPI-Hi Scientist (Caltech)*



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# Outline



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



# Introduction



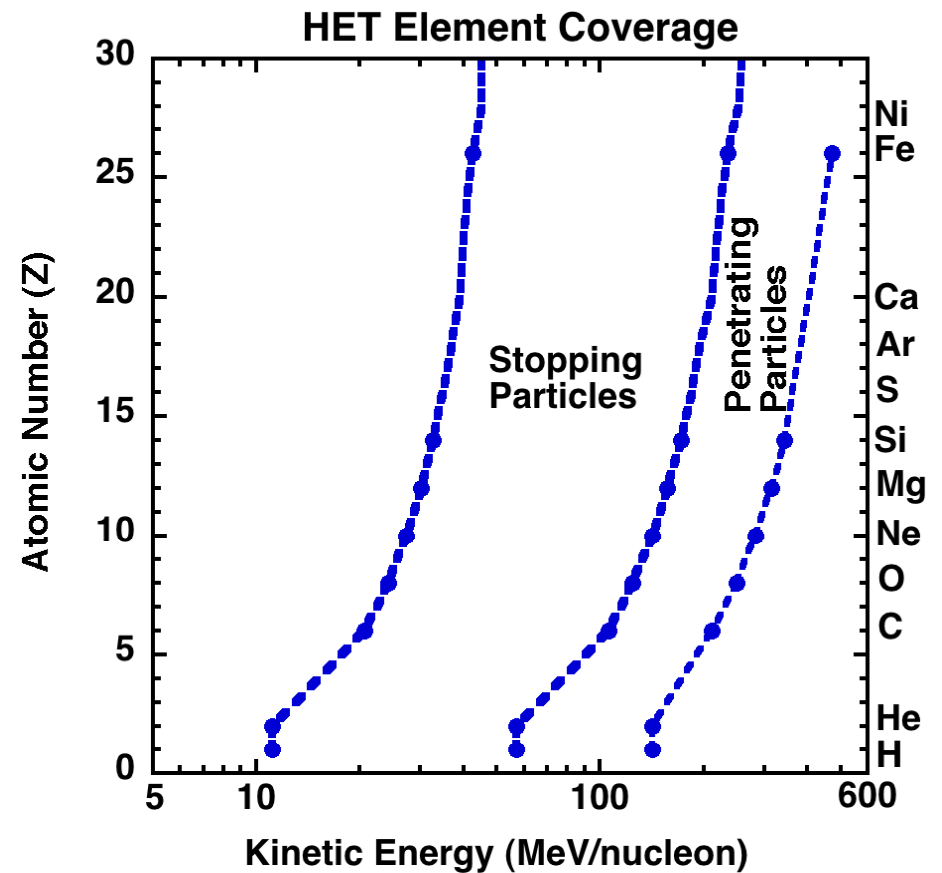
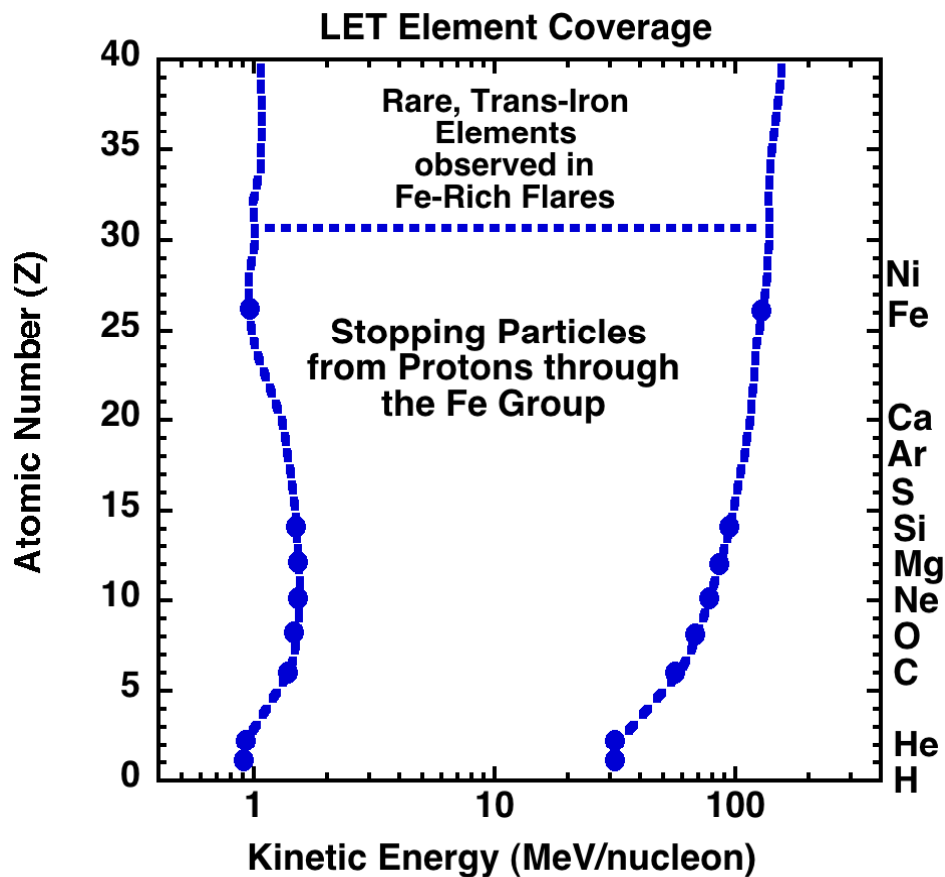
- EPI-HI Measurement Requirements:
  - Composition, energy spectra, and angular distributions of ions and electrons in flare and CME-related SEP events, and at shocks
  - Required Species for EPI-Hi
    - H,  $^3\text{He}$ ,  $^4\text{He}$ , C, O, Ne, Mg, Si, Fe  $\leq 1$  MeV/nuc (TBR) to  $\geq 50$  MeV/nuc
  - Required Species for Mission
    - Electrons with  $\leq 0.5$  MeV to  $\geq 3$  MeV
  - SEP Directional Distributions
  - The combined LET and HET fields of view are required to measure SEP angular distributions over  $\geq \pi/2$  sr in both the sunward and anti-sunward directions
- EPI-Hi Measurement Goals:
  - SEP Ions: Composition and energy spectra of  $\sim 16$  species with  $1 \leq Z \leq 28$  and trans-Fe element groups
  - SEP Electrons with  $\leq 0.5$  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  $^3\text{He}$ -rich flares.







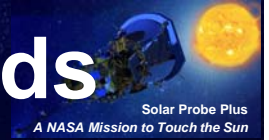
# Calibration Plan



- Lab measurements of electronic gains, offsets, linearity, thresholds, noise, and temperature variations
- Alpha-particle and heavy-ion measurements of detector uniformity
- Accelerator measurements of heavy-ion  $dE/dX$ -E-Range parameters, combined with modeling
- Monte-Carlo simulations of detector performance
- Monte-Carlo determinations of LET and HET geometry factors for directional sectors
- GEANT-4 calibrations of the HET and LET electron response
- 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
- Validate high-rate performance
- In-flight measurements that optimize/validate on-board particle identification processes



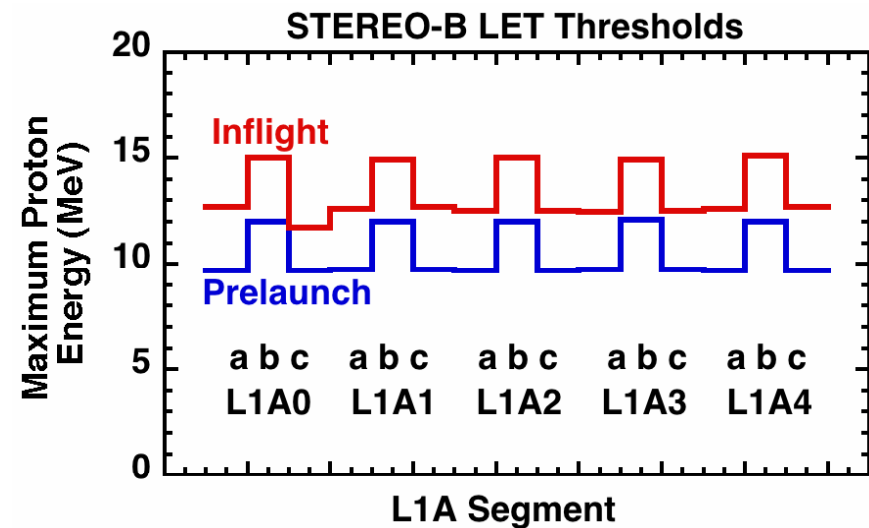
# Calibrating Detector Energy Thresholds



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

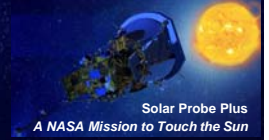
STEREO-B Prelaunch and Inflight Discriminator Settings

Detector	Segment	Thick (microns)	Area (cm <sup>2</sup> )	Launch Thresh (MeV)	Flight Thresh MeV
L1A0	a	22.7	0.8	0.188	0.153
	b	21.7	0.4	0.153	0.129
	c	22.7	0.8	0.188	0.163
L1A1	a	26.2	0.8	0.218	0.178
	b	26.3	0.4	0.185	0.156
	c	26.1	0.8	0.217	0.176
L1A2	a	29.9	0.8	0.248	0.203
	b	29.8	0.4	0.210	0.177
	c	29.1	0.8	0.242	0.199
L1A3	a	24.5	0.8	0.203	0.167
	b	24.2	0.4	0.171	0.144
	c	24.7	0.8	0.205	0.169
L1A4	a	25.7	0.8	0.213	0.174
	b	26.0	0.4	0.183	0.153
	c	25.2	0.8	0.209	0.170





# 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 each PHASIC dual-gain PHA
- Since the SPP orbit may lead to temperature variations, need to also measure the temperature coefficients of each PHASIC
- The LET and HET designs also provide for periodic in-flight calibration of each ADC on a grid of logarithmically-spaced points.
- Fortunately, the PHASICs are relatively stable with temperature.

STEREO PHASIC	Gain Temperature Coeff.:	<50 ppm/deg. C
Performance:	Offset Temperature Coeff.:	<0.1 Channel/°C

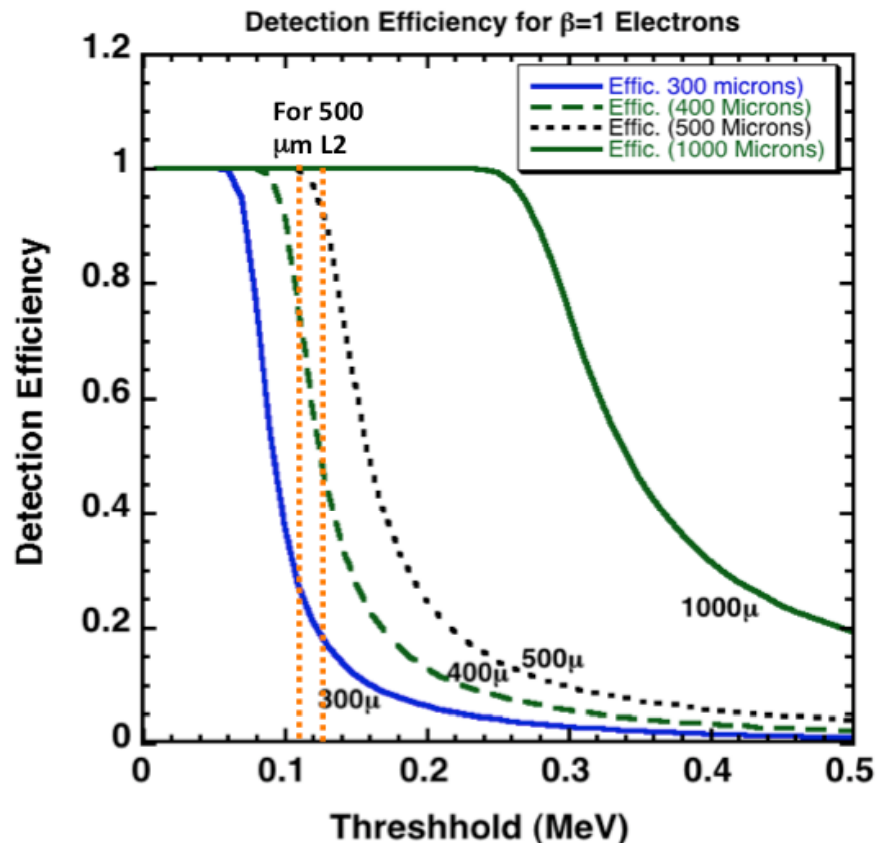


# Monte Carlo Simulations



- 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, this GEANT-4 simulation illustrates the L2 threshold requirements for measuring electrons with LET. For an L2 thickness of 500  $\mu\text{m}$  a trigger threshold of 0.110 - 0.125 MeV gives 95% - 100% detection efficiency for all electrons of interest (0.5 – 6 MeV)

Simulation by A. Labrador





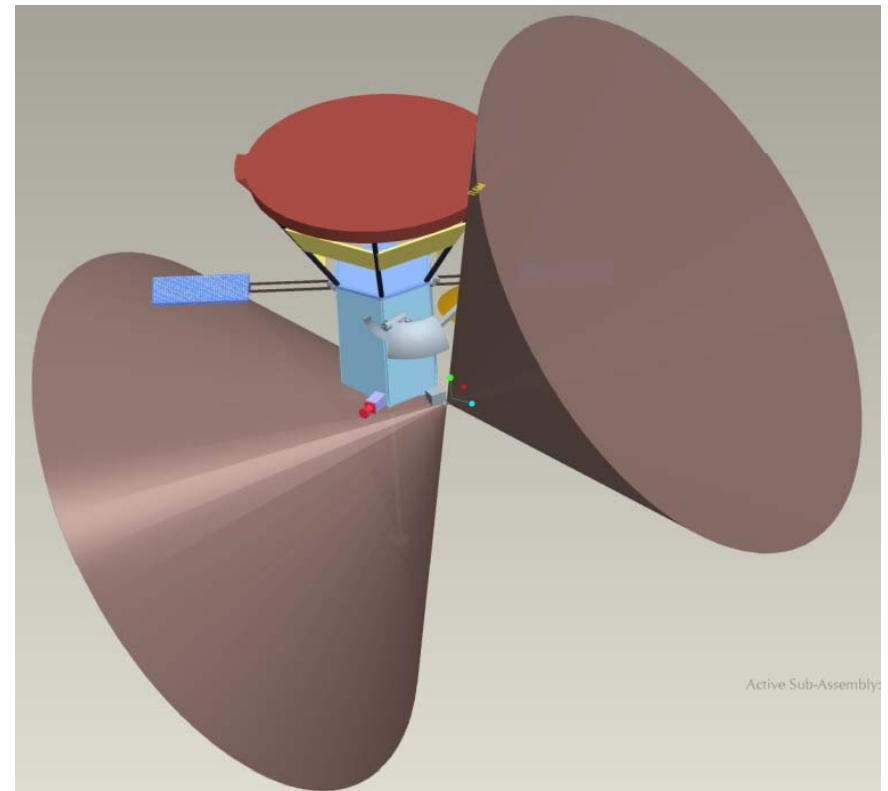


# Calibrating LET/HET Fields of View



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

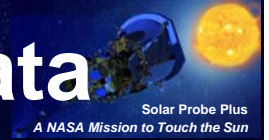
- The geometry factor and directional coverage of each of the 25 sectors within each cone will be determined with a Monte Carlo calculation taking into account the pointing directions of the three telescopes relative to the spacecraft and Sun and any obstructions.
- The relative geometry factor of each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

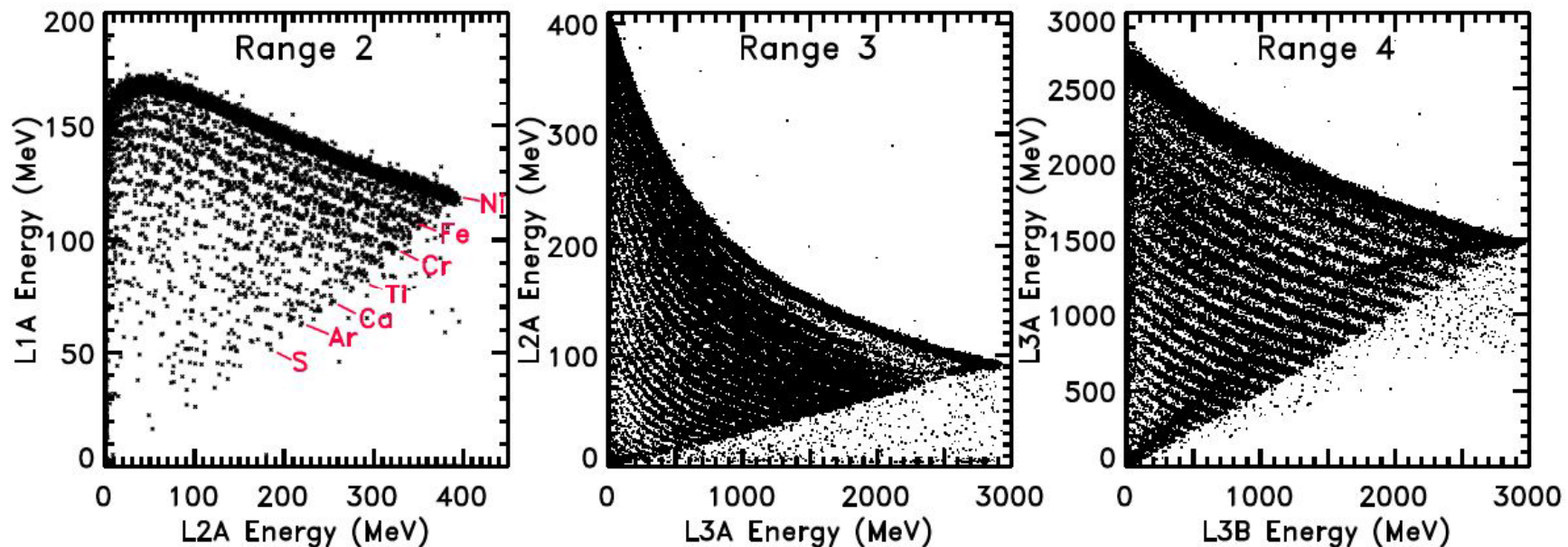


# Facilities – Accelerator Calibration Data



- LET & HET use  $\Delta E$  vs. Residual Energy ( $E'$ ) to measure SEP composition
- The  $\Delta E$  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  $^{58}\text{Ni}$  beam at the MSU NSCL
- This also provides an end-to-end test of the onboard identification system

STEREO/LET FM1 Calibration, MSU Cyclotron:  $^{58}\text{Ni}$  Beam + Fragments



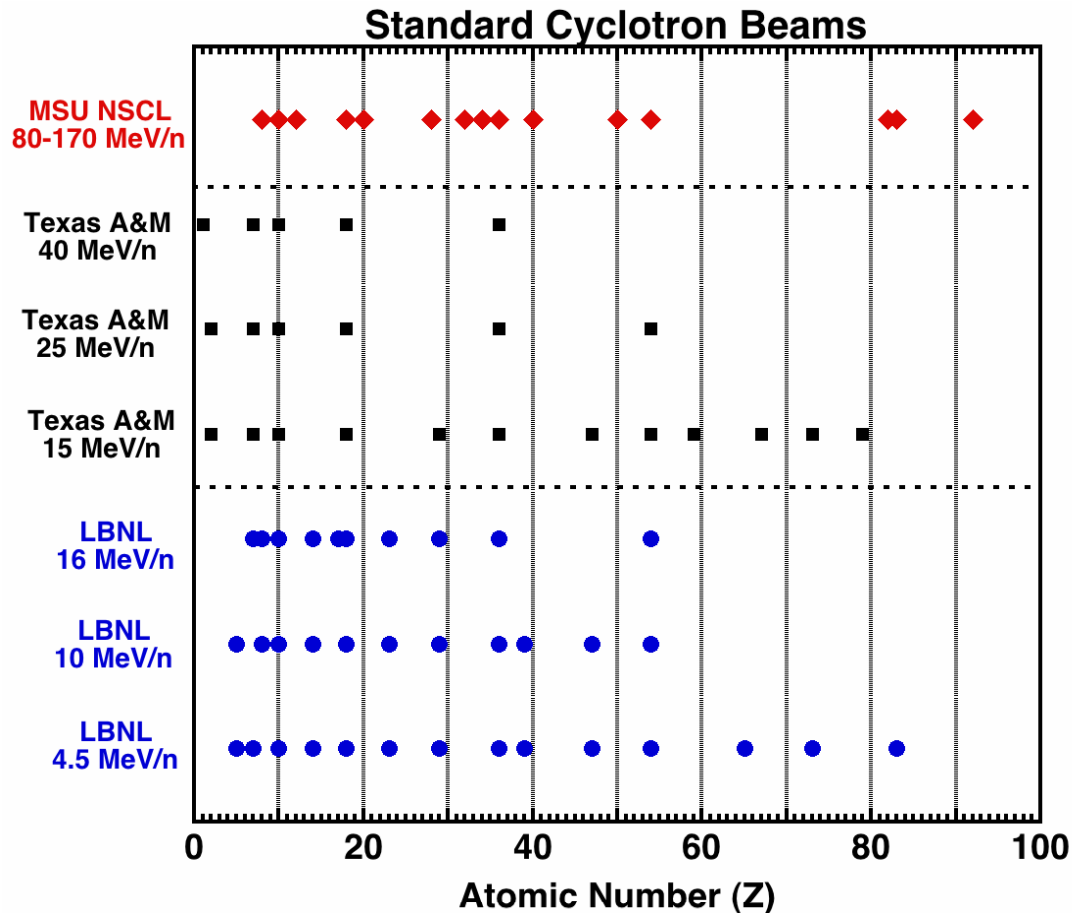
Mewaldt et al. 2008



# Facilities – Accelerator Calibrations



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



- All 3 cover the key heavy-ion charge range ( $6 \leq Z \leq 28$ ) 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**

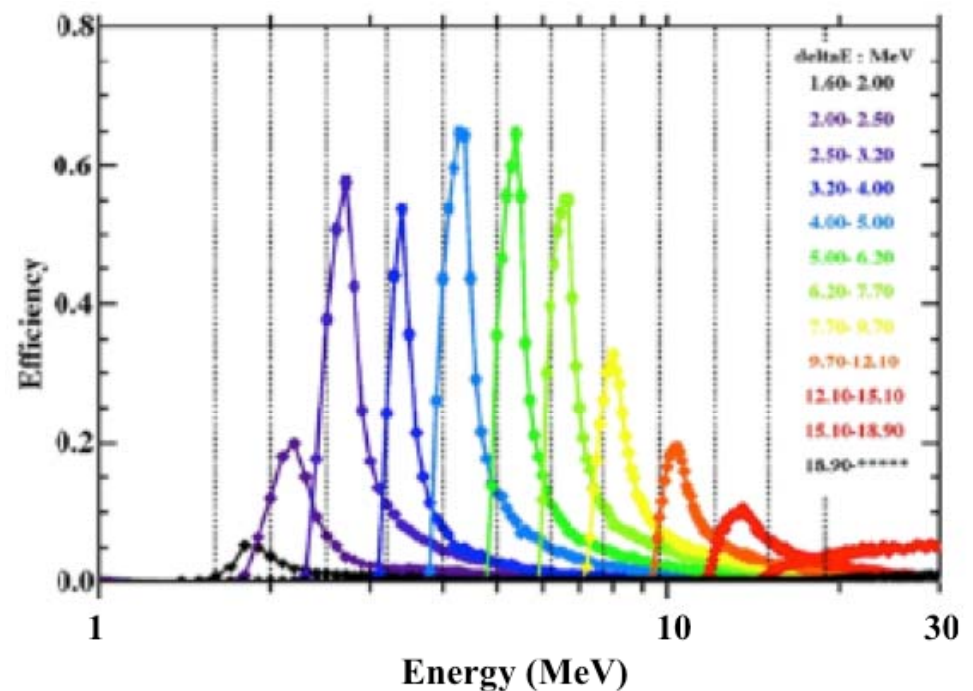


# Electron Calibrations



HET and LET will measure energetic electrons with 0.5-6 MeV

- The HET and LET electron response will be calibrated with GEANT-4, used to calibrate the REPT sensors on the Van Allen Probes (Baker et al. 2012)
- HET is 13.5 mm of Si deep compared to a 23-mm depth for REPT
- Based on REPT and SAMPEX/PET calibrations, a HET/LET energy range covering 0.5 – 6 MeV is achievable
- The LETs will provide electron measurements over a more limited energy range (~0.5 – ~4 MeV)
- Routine testing of the HET/LET electron response will use  $\beta$ -decay sources like  $^{106}\text{Ru}$  and  $^{90}\text{Sr}$ .



REPT electron calibration using GEANT-4





# Calibration Test Flow (1/2)



## 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 (2/2)

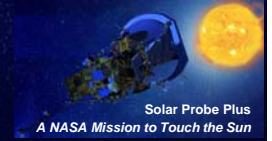


## Calibrate New Detectors, PHASICS, and Software

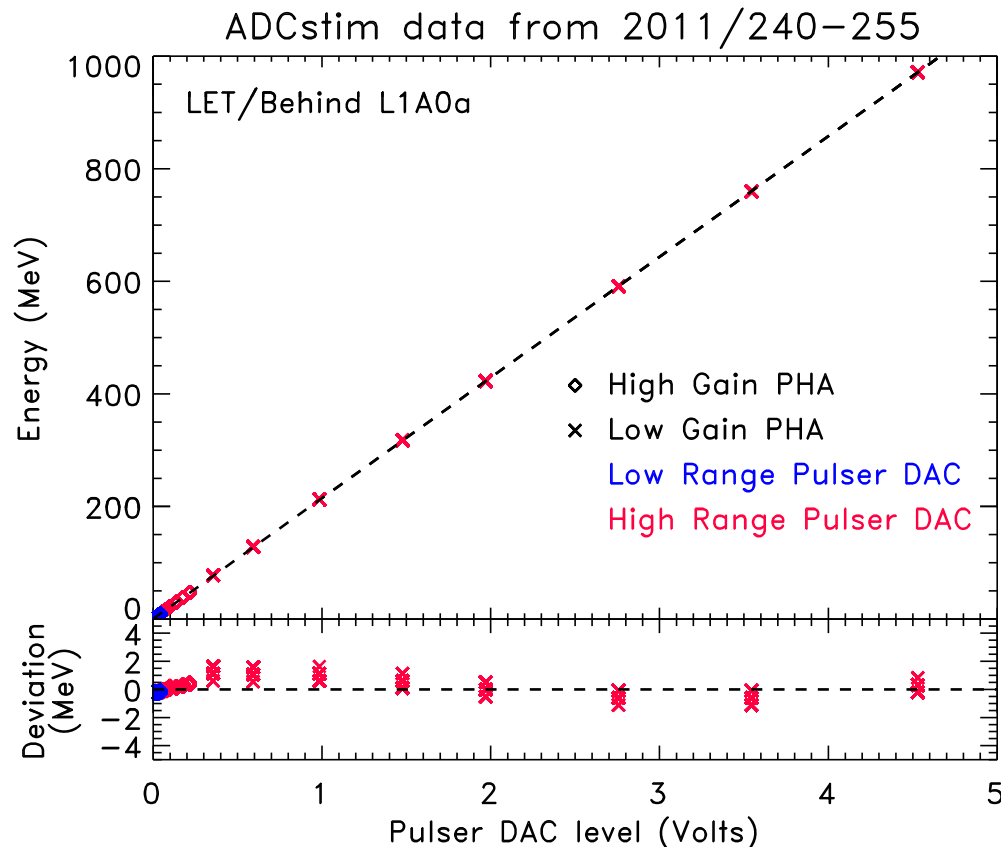
Task	In Progress	Scheduled For
New, thin SSDs meet uniformity and response requirements	√	
Calibrate transfer function of flight PHASICS vs. temperature		End of 2014
Propose for beam time at MSU Superconducting Cyclotron Lab		2014
Calibrate HET and LET SEP electron response using GEANT-4		mid-2016
Test SEP electron detection and $\gamma$ -ray background with lab sources		mid 2016
Validate on-board analysis routines at accelerator		mid-2016
Determine location of element tracks at MSU accelerator		mid-2016
Inflight tuning and validation of on-board analysis routines		≥2018



# 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.

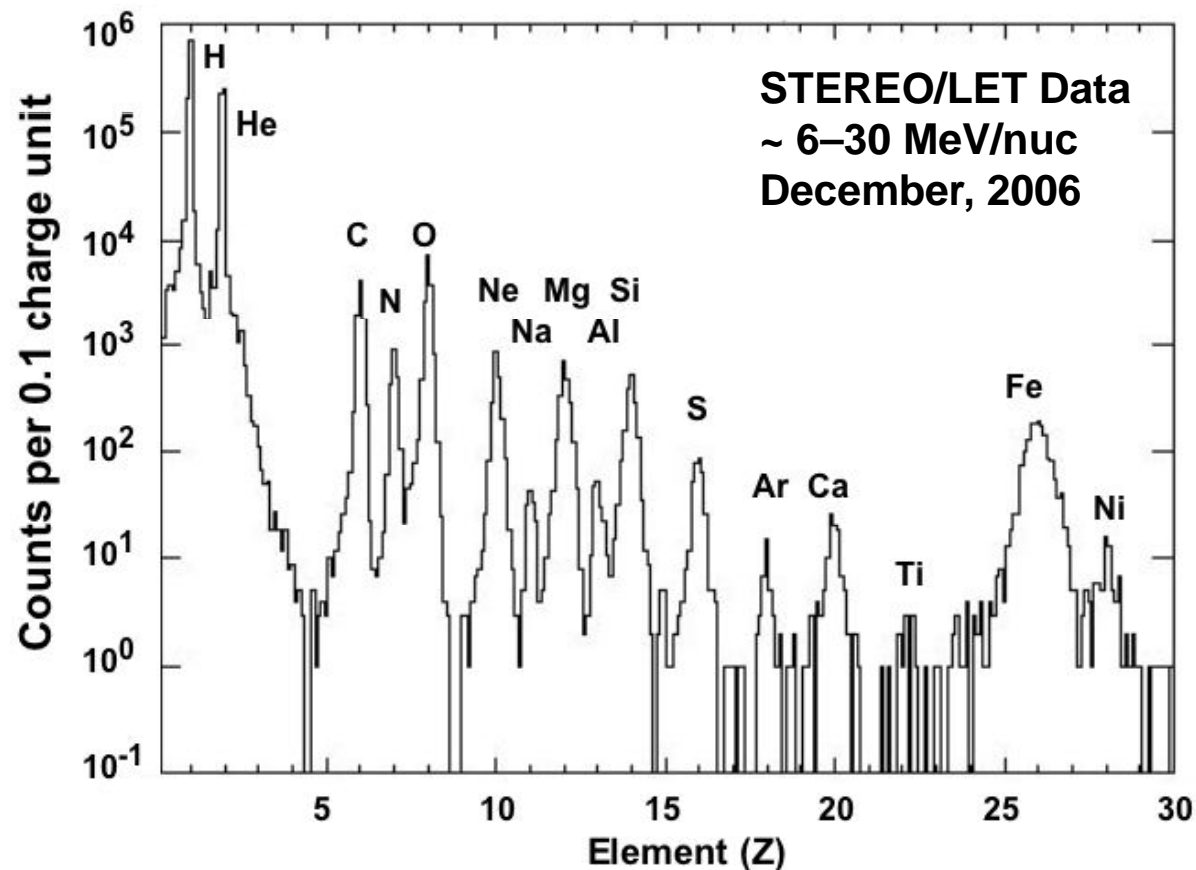




# In-Flight Calibration



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  $\sim 100$  MeV/nuc.



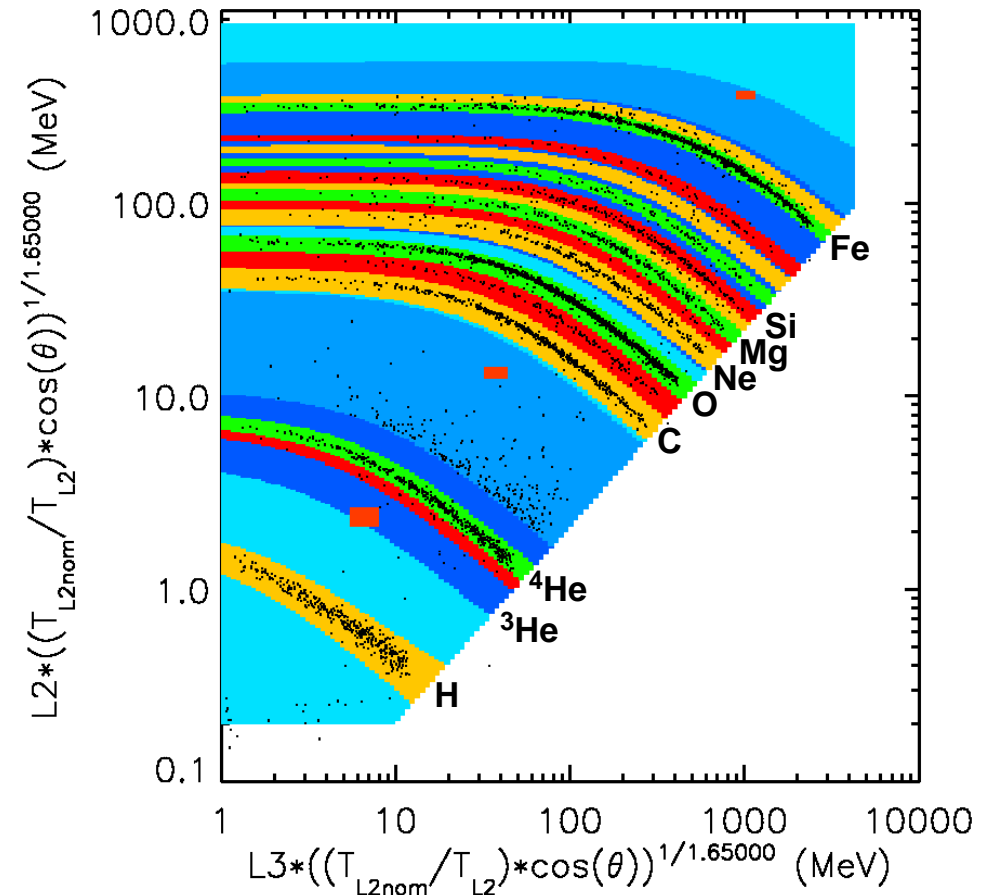
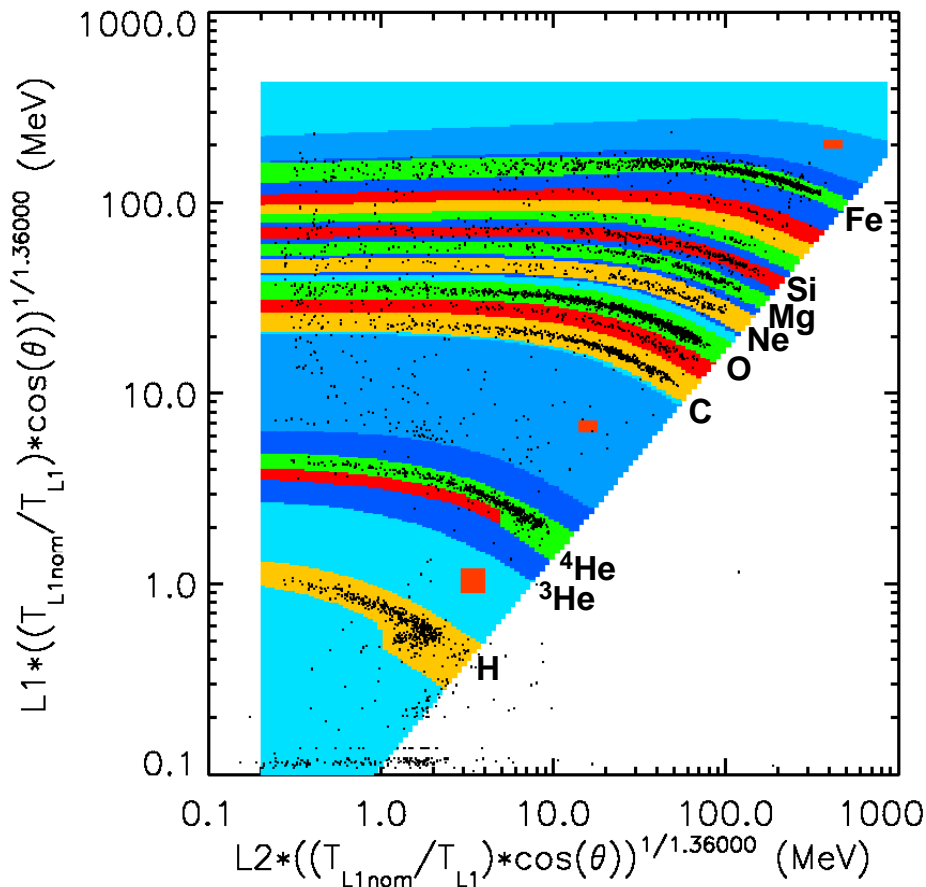




# In-Flight Calibration



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  $\mu\text{m}$  thick). Colored bands show regions used for on-board particle identification. EPI-Hi detectors range from 10  $\mu\text{m}$  to 2000  $\mu\text{m}$  thick.

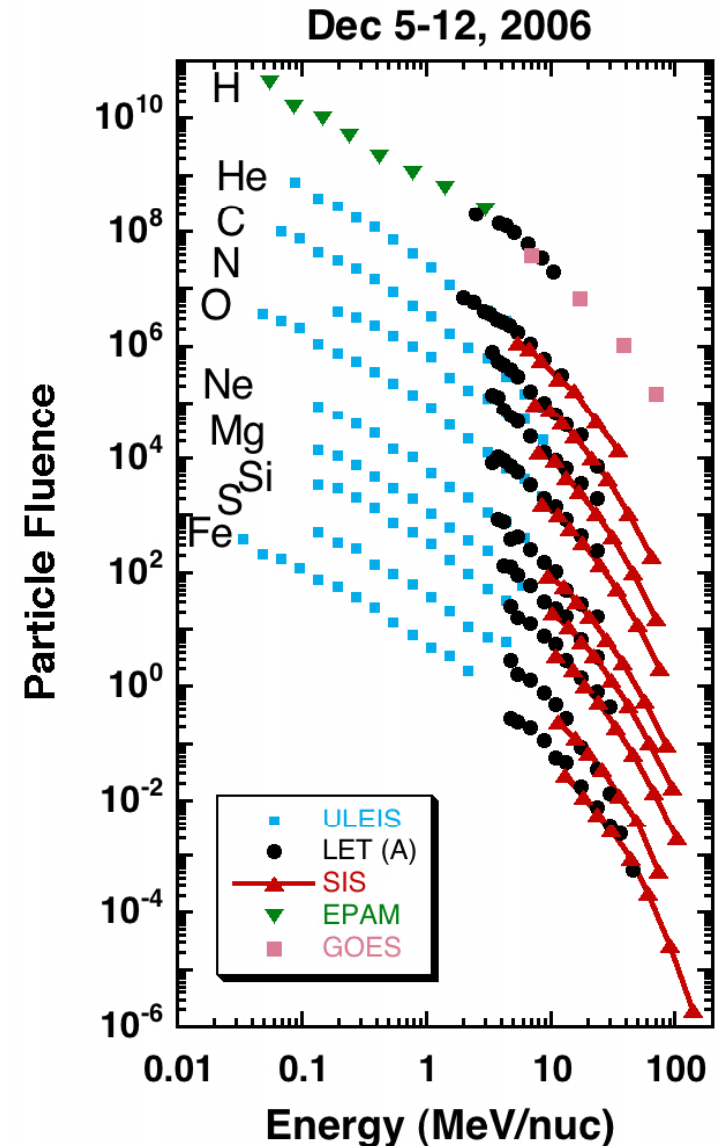




# In-flight Energy Spectra



- 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 ( $\sim 0.05$  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.





# Summary



- Both pre-flight and in-flight calibrations of sensors, electronics and software are essential for meeting the science and measurement requirements of EPI-Hi.
- The plan for calibrating on-board analysis of SEP ions requires both accelerator and in-flight calibrations
- EPI-Hi measurements of SEP electrons will rely on GEANT-4 calibrations, using tests with radioactive sources as a cross check