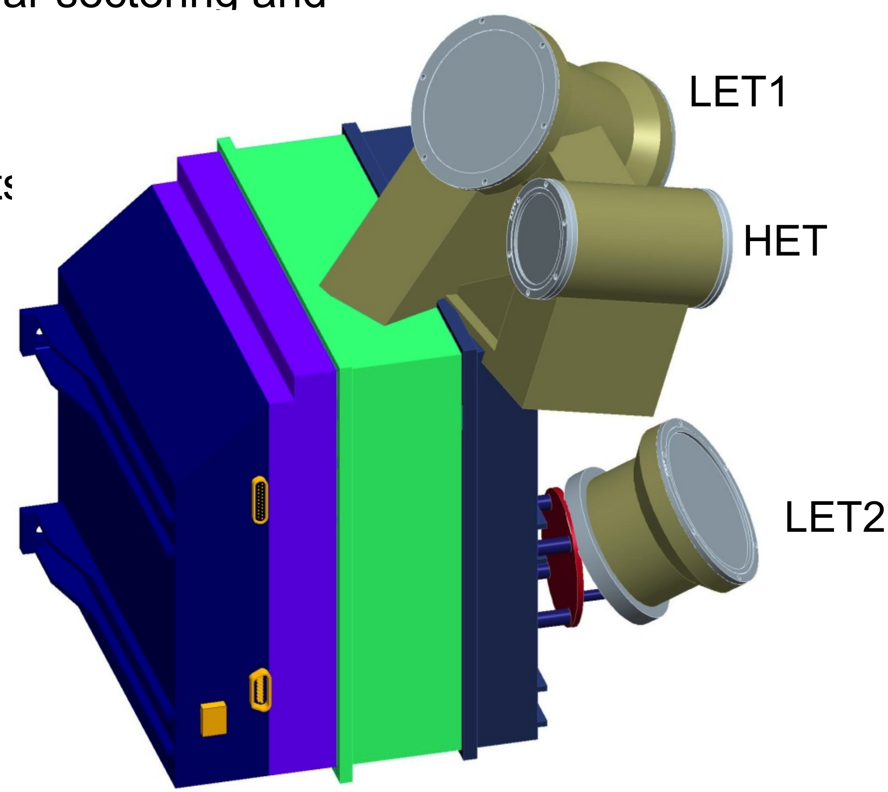
SPP ISIS/EPI-Hi Detector Peer Review

Caltech

29 October 2014

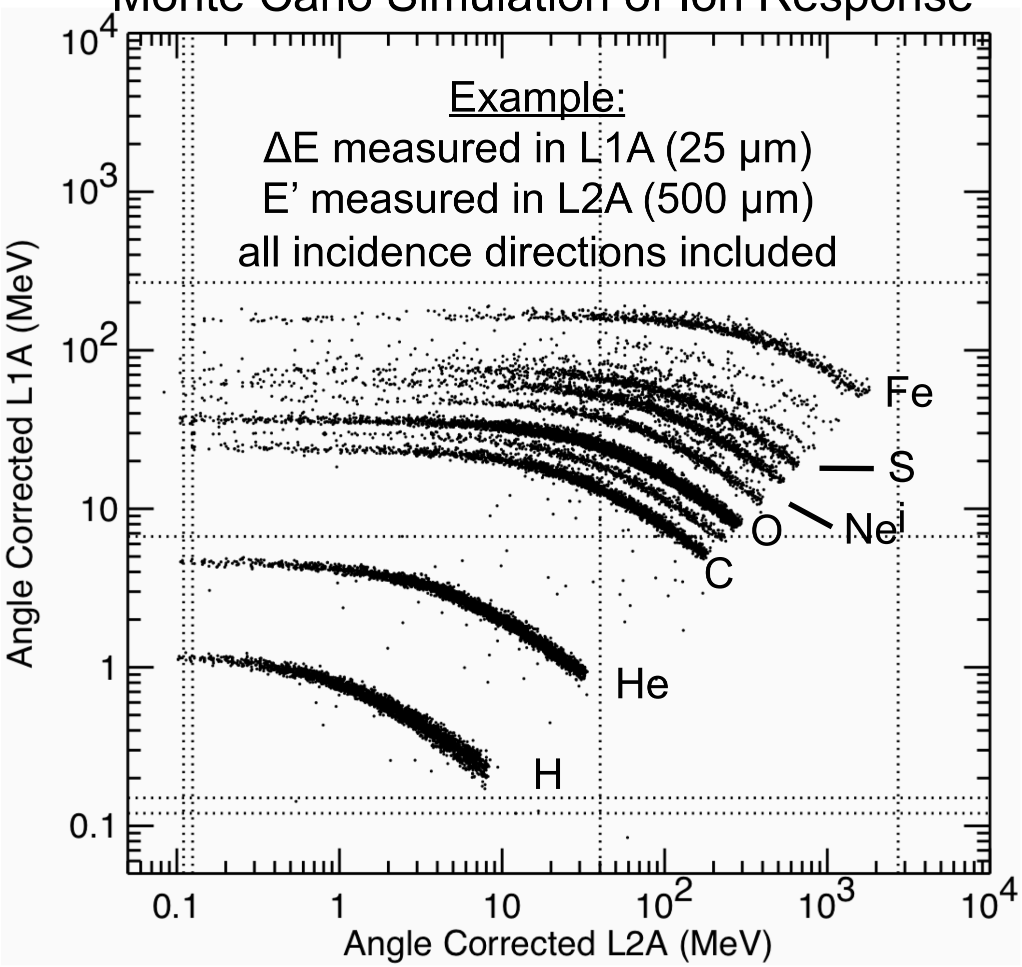
Sensor System Overview

- 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



Principle of Operation

Monte Carlo Simulation of Ion Response

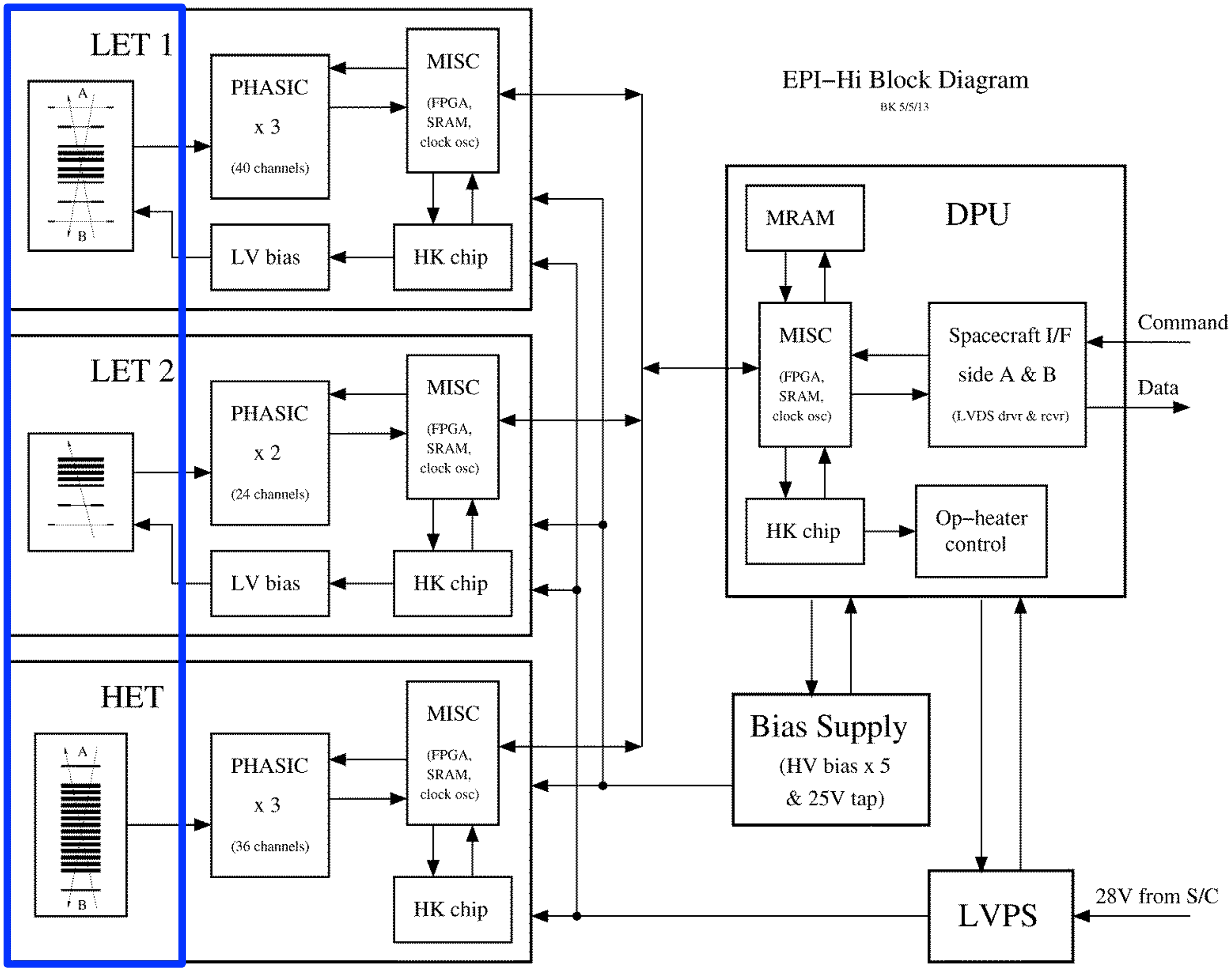


- Energy loss measurements from the detector in which a particle stops (E') and the preceding detector (ΔE) organize the data into distinct tracks for the various elements.
- Sector information is used to obtain mean thickness penetrated in the ΔE detector and make an on-board correction to the measured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

EPI-Hi Block Diagram

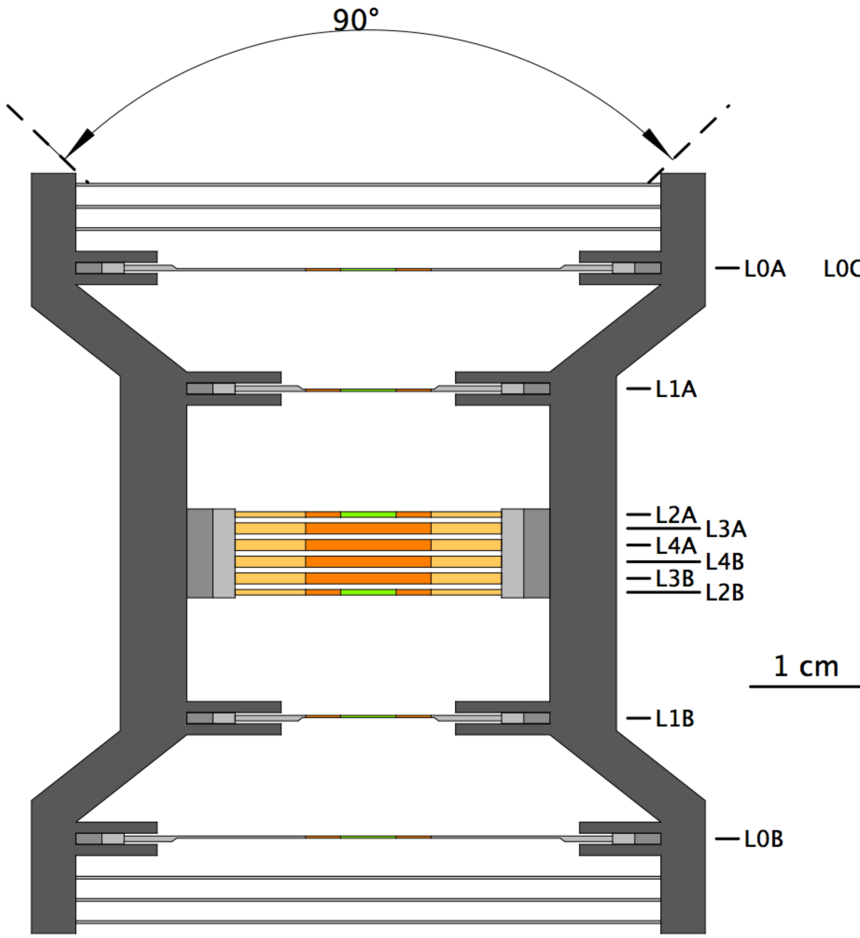
3 detector telescopes:

- 1 double-ended low-energy telescope (LET1)
- 1 single-ended low-energy telescope (LET2)
- 1 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

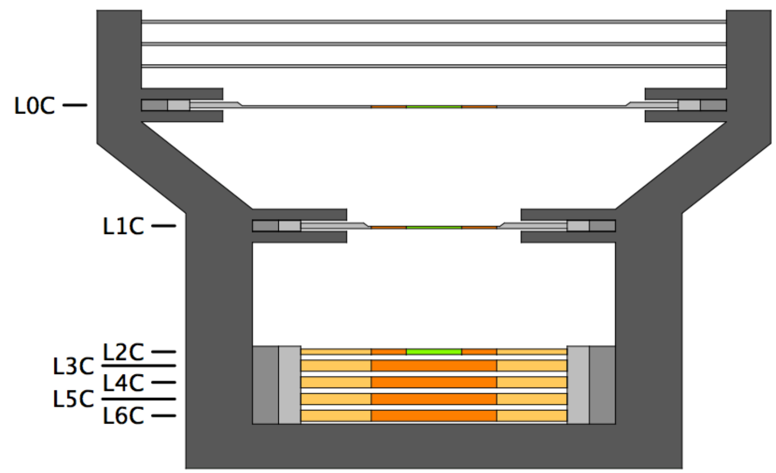


Low Energy Telescopes (LET1 and LET2)

LET1 (double ended)



LET2 (single ended)



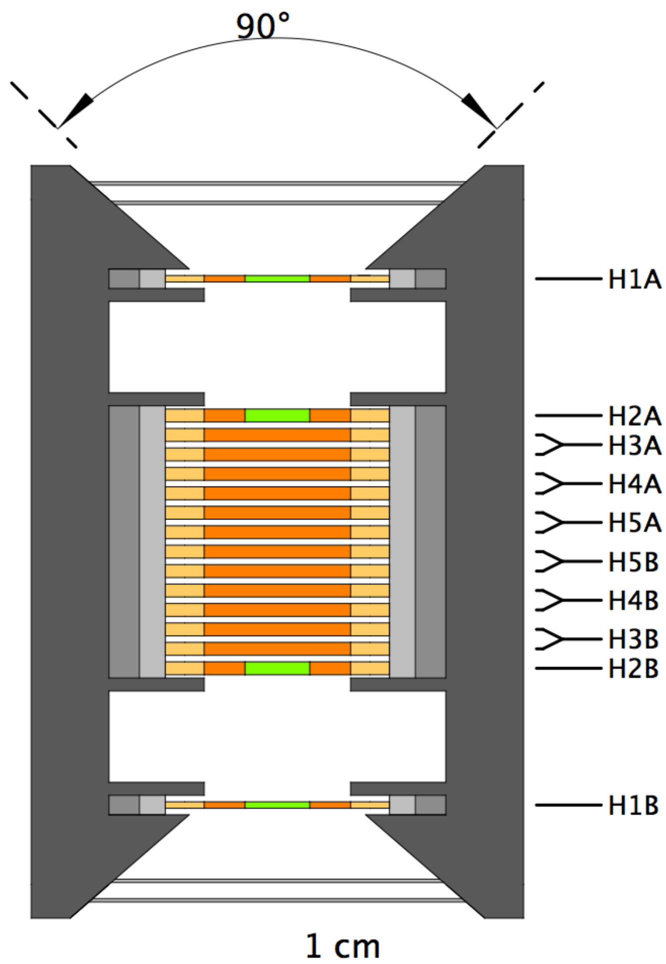
windows (each end):
2 µm, 1 µm, 1 µm Kapton

color: active silicon
grey: inactive material

High Energy Telescope (HET)

Conceptual Cross Section

HET (double ended)



windows (each end):
2 × 127 μm Kapton

color: active silicon
grey: inactive material

Two Types of Detectors

“Thin Detectors”

- L0 (12 μm)
- L1 (25 μm)
- made from silicon-on-insulator (SOI) wafers
- thin membrane supported by surrounding thick frame
- diodes made by ion implantation on thin membrane
- new technology brought to TRL6 during Phase B
- technology development carried out in parallel by two sources: Micron Semiconductor and LBNL (with Caltech participation)

“Thick Detectors”

- L2 (500 μm *)
- L3 through L6 [identical] (1000 μm)
- H1 (500 μm *)
- H2 (1000 μm)
- H3 through H5 [identical] (2 x 1000 μm)
- made by implantation of conventional silicon wafers

* 700 μm versions of L2 and H1 being procured as a backup

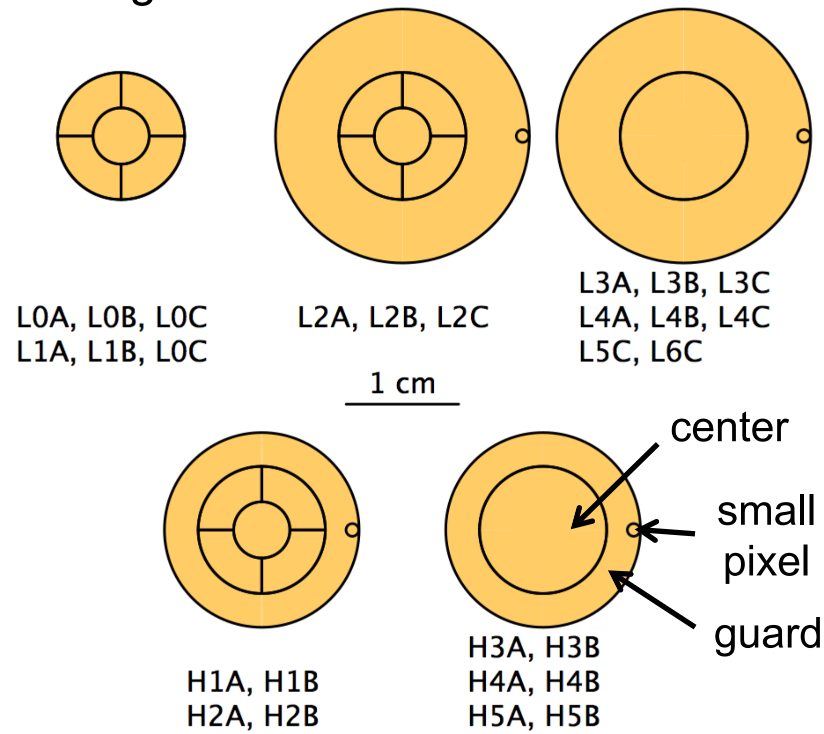
Detector Geometry Details

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:



Detector Geometry Details

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LET2	L0C	12 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
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	L4C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
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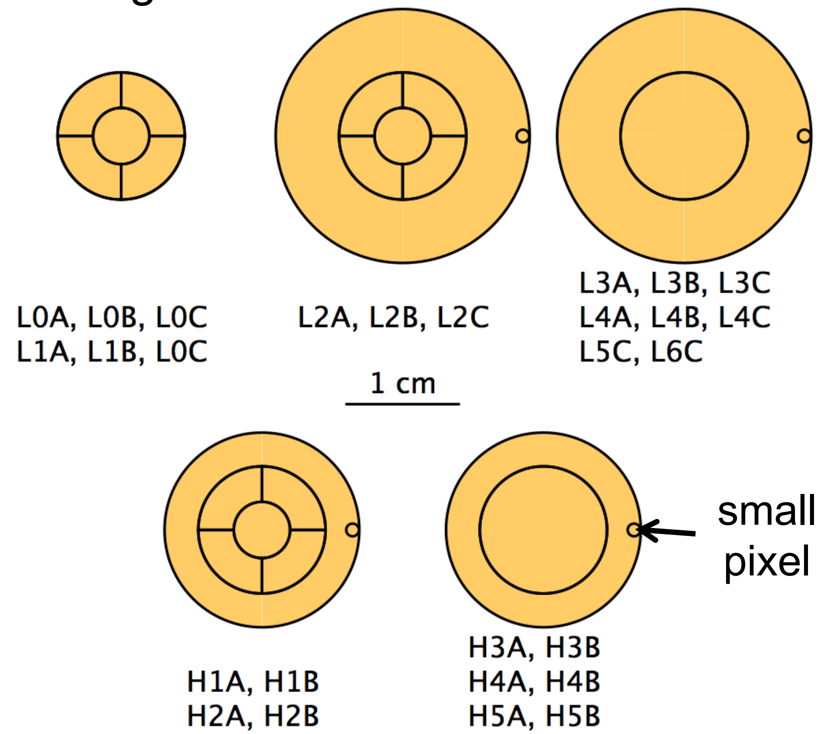
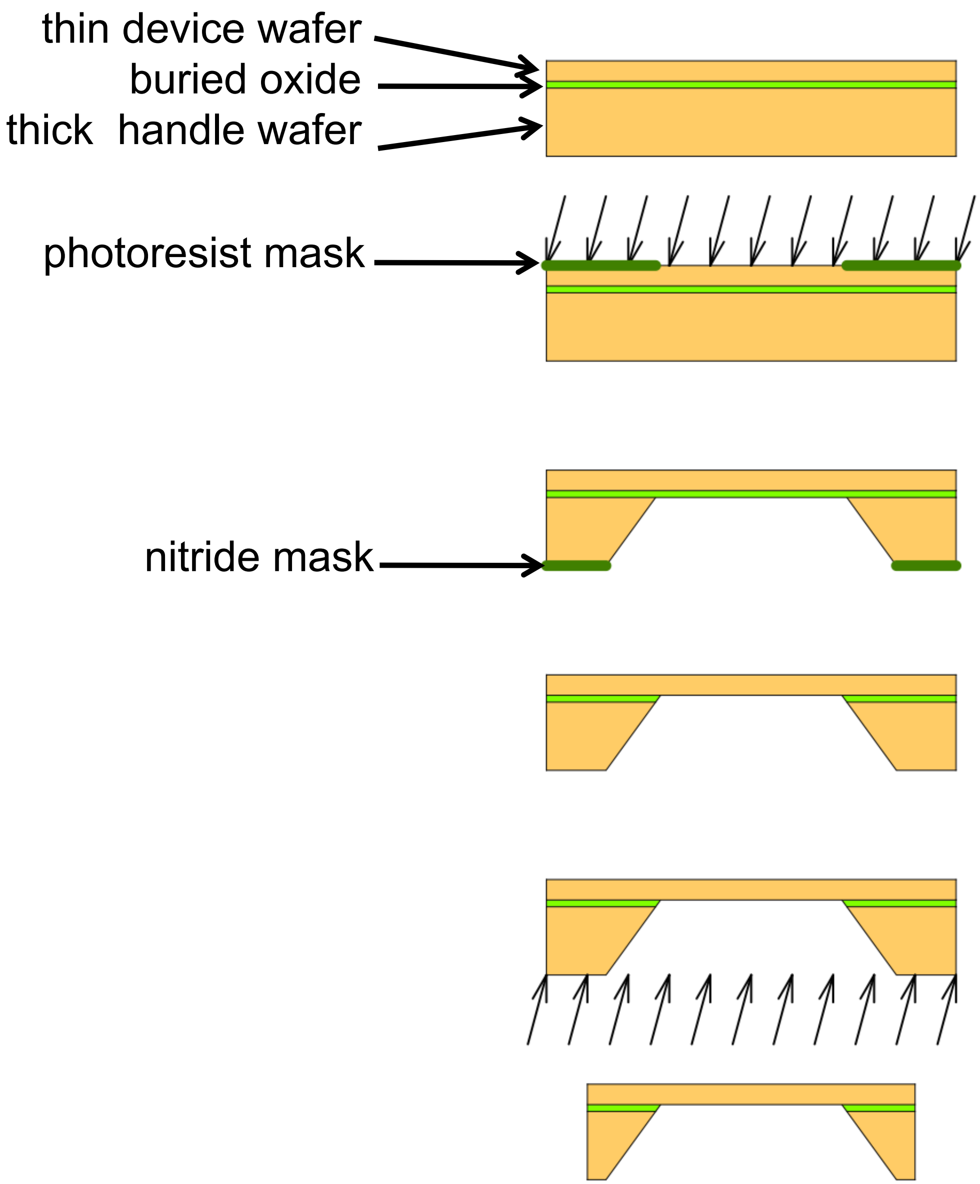


Thin Detector Fabrication Process



silicon-on-insulator (SOI) wafer is a commercial product with excellent device layer uniformity and control

ion implant to produce diode pn junctions on device layer

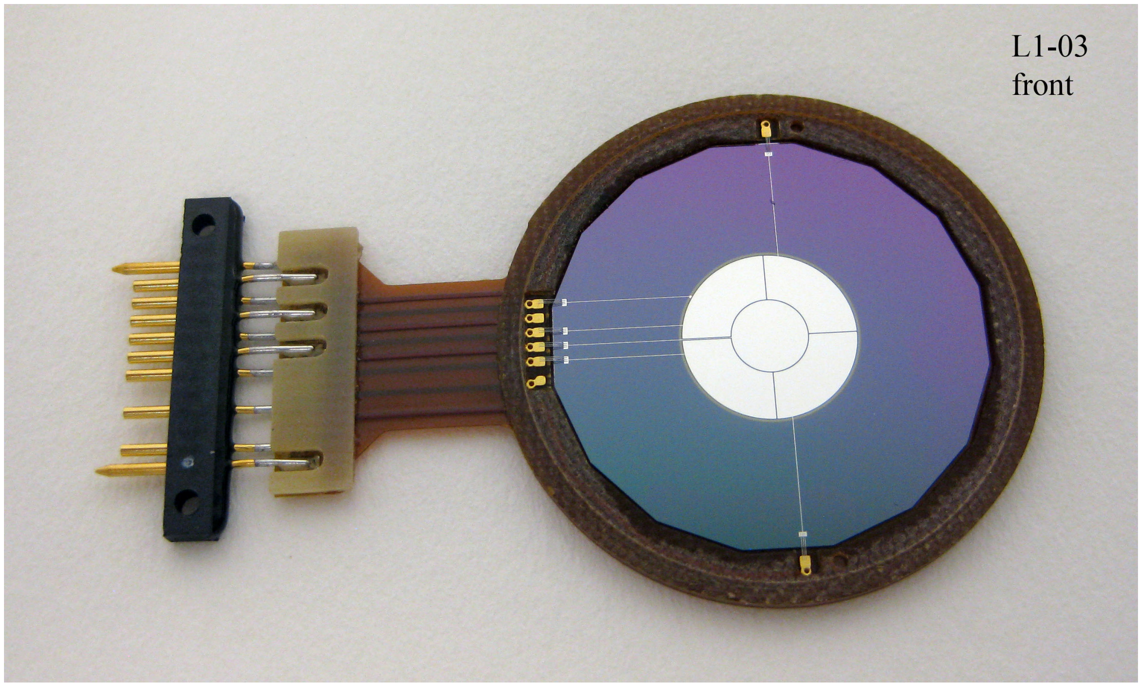
wet etch to remove handle layer under active area—oxide acts as etch stop and preserves the thickness uniformity of the device layer

etch away oxide from underneath the active area using HF, which has negligible effect on the silicon

ion implant from back to produce detector's ohmic contact

dice wafer into individual thin detectors with thick supporting frames

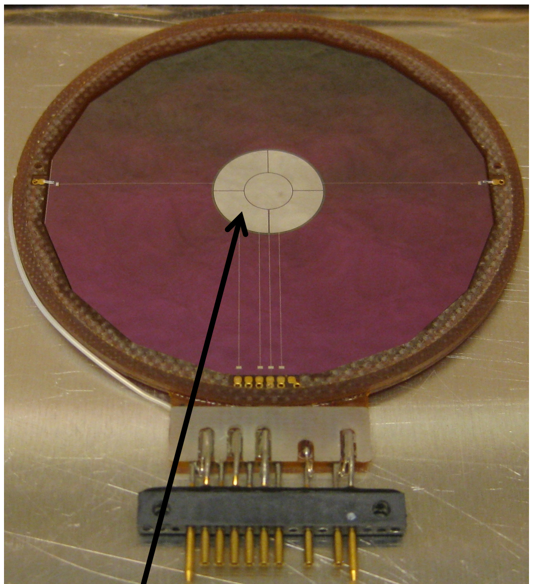
Prototype Thin Detectors



"L1" Detector

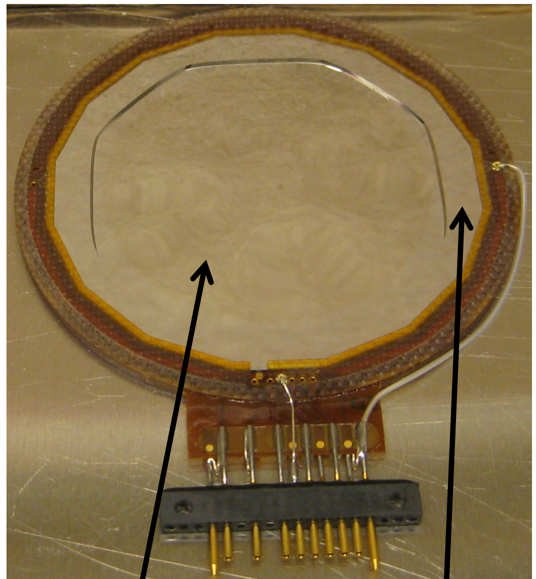
- 25 μm membrane thickness
- 1 cm^2 active area segmented into a central bull's eye surrounded by four quadrants
- membrane area just slightly larger than active area
- wide thick area outside membrane to make overall size identical to other following (thick) detectors in stack

Prototype Thin Detectors



front (junction)

active area (1 cm^2)



back (ohmic)

12 µm membrane

thick frame

"L0" Detector

- 12 µm membrane thickness
- 3.4 cm membrane diameter
- 1 cm^2 active area segmented into a central bull's eye surrounded by four quadrants

Detector Development Status

- prototypes of thin detectors have been obtained from both sources and samples have been extensively tested
    - from Micron: 6 L0 detectors, 7 L1 detectors
    - from LBNL: 3 L0 detectors, 5 L1 detectors
- Micron has been selected to fabricate flight L0 and L1 detectors
- engineering model detectors, which should also be suitable for use as flight detectors, ordered from Micron and currently in production
- some work with LBNL has continued so that LBNL detectors can serve as a backup should a problem come up with the Micron detectors
- prototypes and EM units of all designs of the thick detectors have been ordered from Micron and are currently in production

Thin Detector Testing Status

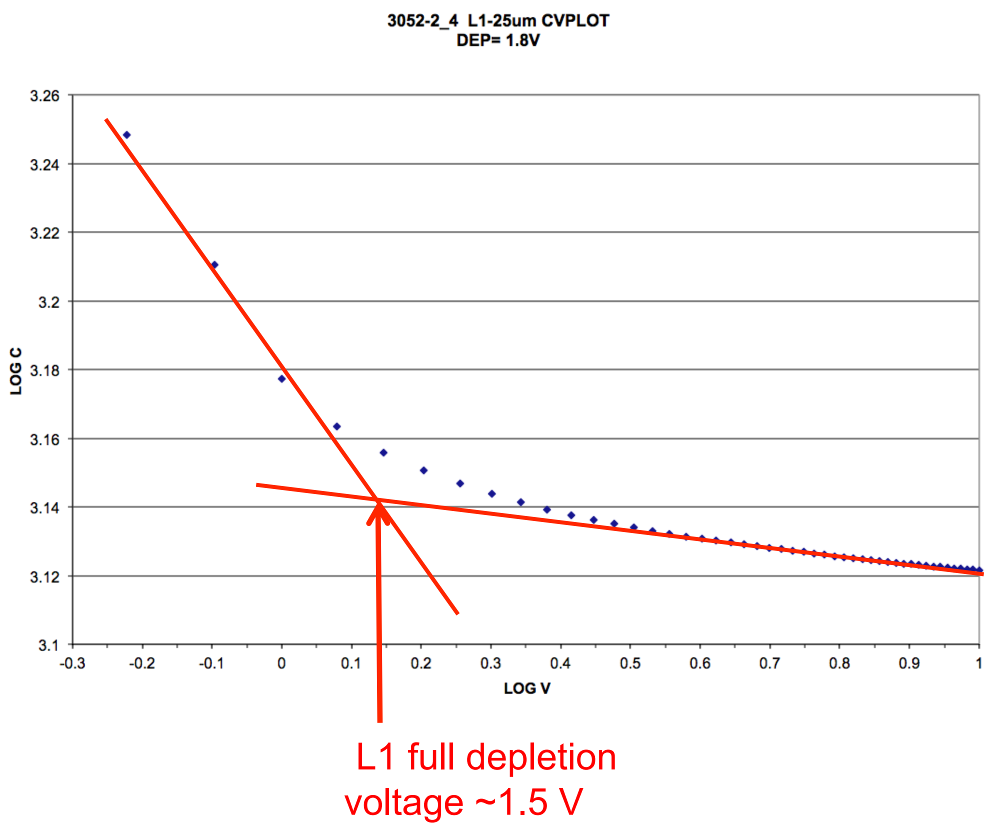
<u>Tests carried out to date:</u>

- capacitance versus bias
- leakage current (overall and individual segments) versus bias
- long-term thermal-vacuum stability
- thermal cycling
- response to alpha particles
- response to accelerator beams of heavy ions
- thickness uniformity mapping
- radiation testing: total dose (^{60}Co) and displacement damage (protons)
- effect of high-speed dust impacts
- ability to survive acoustic environment
- ability to survive vibration environment

<u>Additional tests anticipated:</u>

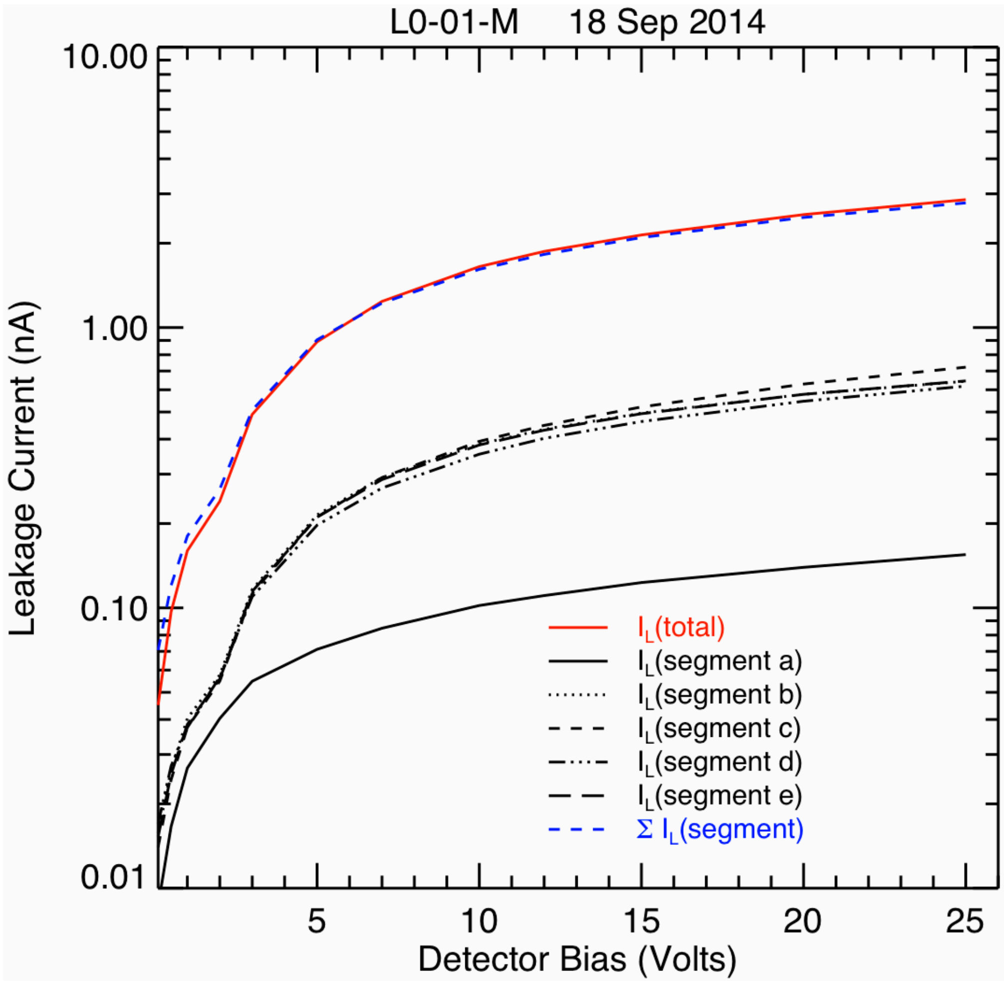
- extension of displacement damage test to higher proton fluences
- further dust tests to characterize dust impact response and risks

Capacitance versus Bias



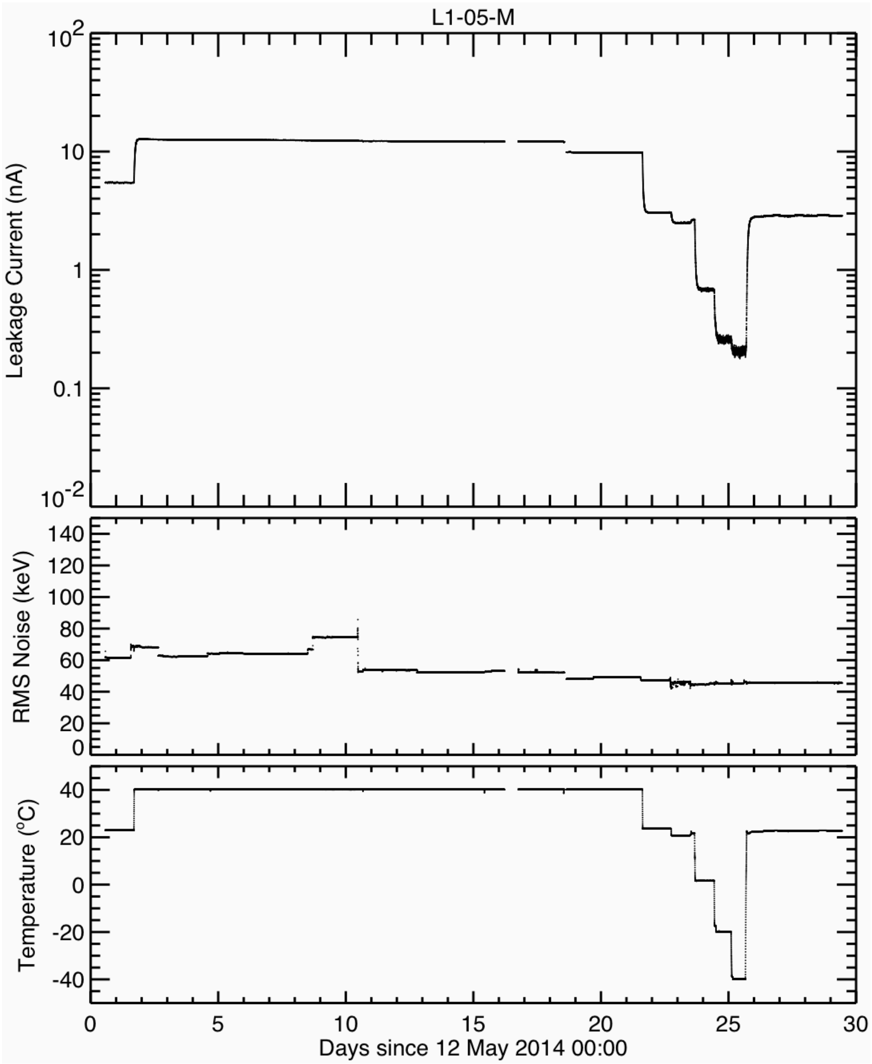
- detector capacitance versus applied bias measured by Micron Semiconductor
- can also measure CV curves at GSFC and check the values reported by Micron
- ankle in the curve indicates minimum bias required to deplete fully deplete the detector
- select applied bias for flight to be significantly greater than this value

Leakage Current versus Bias



- detector leakage currents measured at room temperature for individual segments and for all segments combined
- measurements done up to 25 V bias (maximum flight bias is 20 V) with no breakdown observed in detectors tested to date

Long-Term Thermal-Vacuum Stability



- based on extensive experience with previous space missions, we require silicon detectors to perform stably while biased in vacuum at the maximum planned operating temperature for a period of several weeks
- detector problems can manifest themselves as leakage currents that gradually grow or as intermittent bursts of elevated noise
- have not observed these behaviors in any of the L0 and L1 detectors tested to date
- variation seen in the plotted noise level was associated with external interference or electronics problems
- have also done a brief test down to -40°C and demonstrated that the detectors don't break

Thermal Cycling

TEMPERATURE CYCLING TESTS

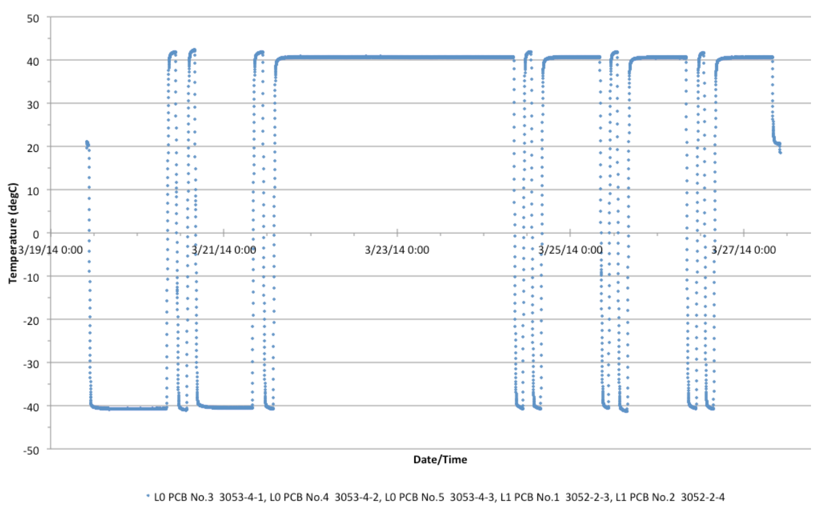
Customer	Caltech Solar Probe Plus				OPERATOR	Craig Hawkins	
Specification	Thick/thin detector spec V1.02 + email 18th March 2014					P.O. No.	44A-S151610
Equipment Used						Serial No.	Cal due Date
Climatic Chamber =	VLK07/90					25070909B	3-Feb-15
Ammeter =	Keithley 6485					1012631	2-Dec-14
Power supply =	Keithley 237					0705183	11-Apr-14
Thermocouple =	Tinytag PT100					566783	22-Jan-15
Start Date	19-Mar-14	Time	10:35	Finish Date	27-Mar-14	Time	10:00
Un-Biased Cycles at -60°C to +60°C	No. Of Cycles	1	Pass (P) / Fail (F)	P			
Biased Cycles at -40°C to +40°C	No. Of Cycles	10	Pass (P) / Fail (F)	P			
Cycle information:	Change Rate = 2° per minute	Dwell time =	1 HOUR				

Device I.D.	PCB	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5		Cycle 6		Cycle 7		Cycle 8		Cycle 9		Cycle 10		
		-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	-40°	+40°	
3053-4-1	L0 No.3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Active area
		<1	11	<1	11	<1	11	<1	10	<1	10	<1	10	<1	9	<1	9	<1	10	<1	10	G.R.
3053-4-2	L0 No.4	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Active area
		<1	11	<1	11	<1	11	<1	10	<1	10	<1	10	<1	10	<1	9	<1	10	<1	9	G.R.
3053-4-3	L0 No.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Active area
		<1	11	<1	11	<1	11	<1	10	<1	11	<1	10	<1	11	<1	10	<1	11	<1	10	G.R.
3052-2-3	L1 No.1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Active area
		<1	7	<1	7	<1	7	<1	7	<1	7	<1	6	<1	7	<1	6	<1	7	<1	6	G.R.
3052-2-4	L1 No.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Active area
		<1	7	<1	7	<1	7	<1	6	<1	7	<1	6	<1	7	<1	6	<1	7	<1	6	G.R.

ALL SENSORS BIASED AT 10V, ALL CURRENTS IN nA

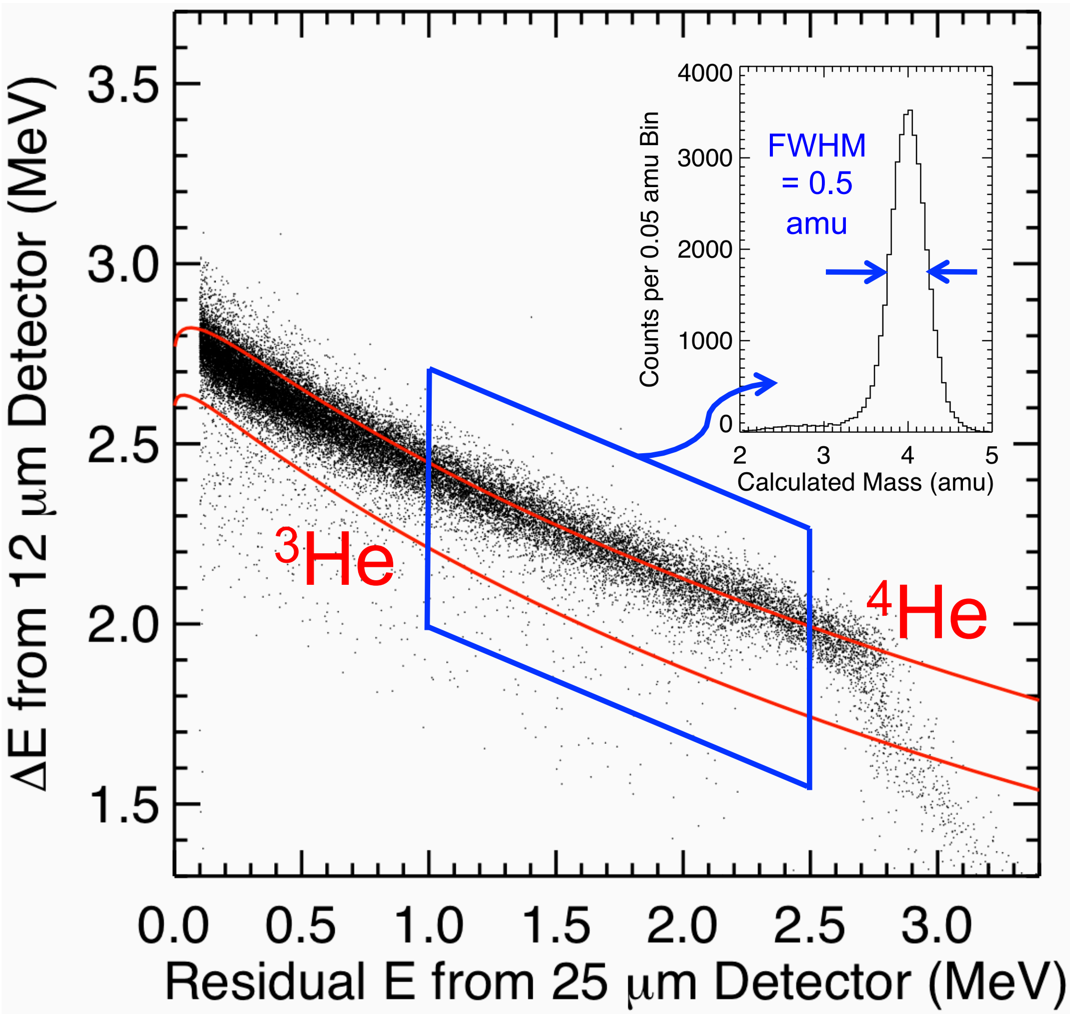
Active area = individual sectors measured, each has value shown

Solar Probe Plus
thermal cycle - end 27th Mar 2014

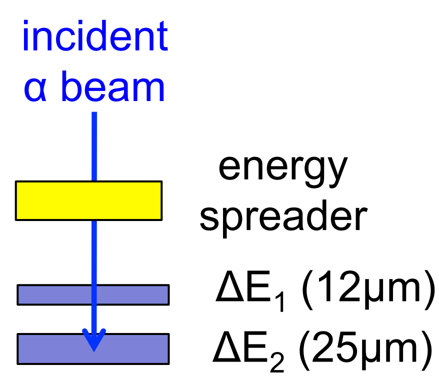


- thermal cycling test performed by Micron Semiconductor
- leakage currents checked after each cycle
- no problems identified

Response to Alpha Particles

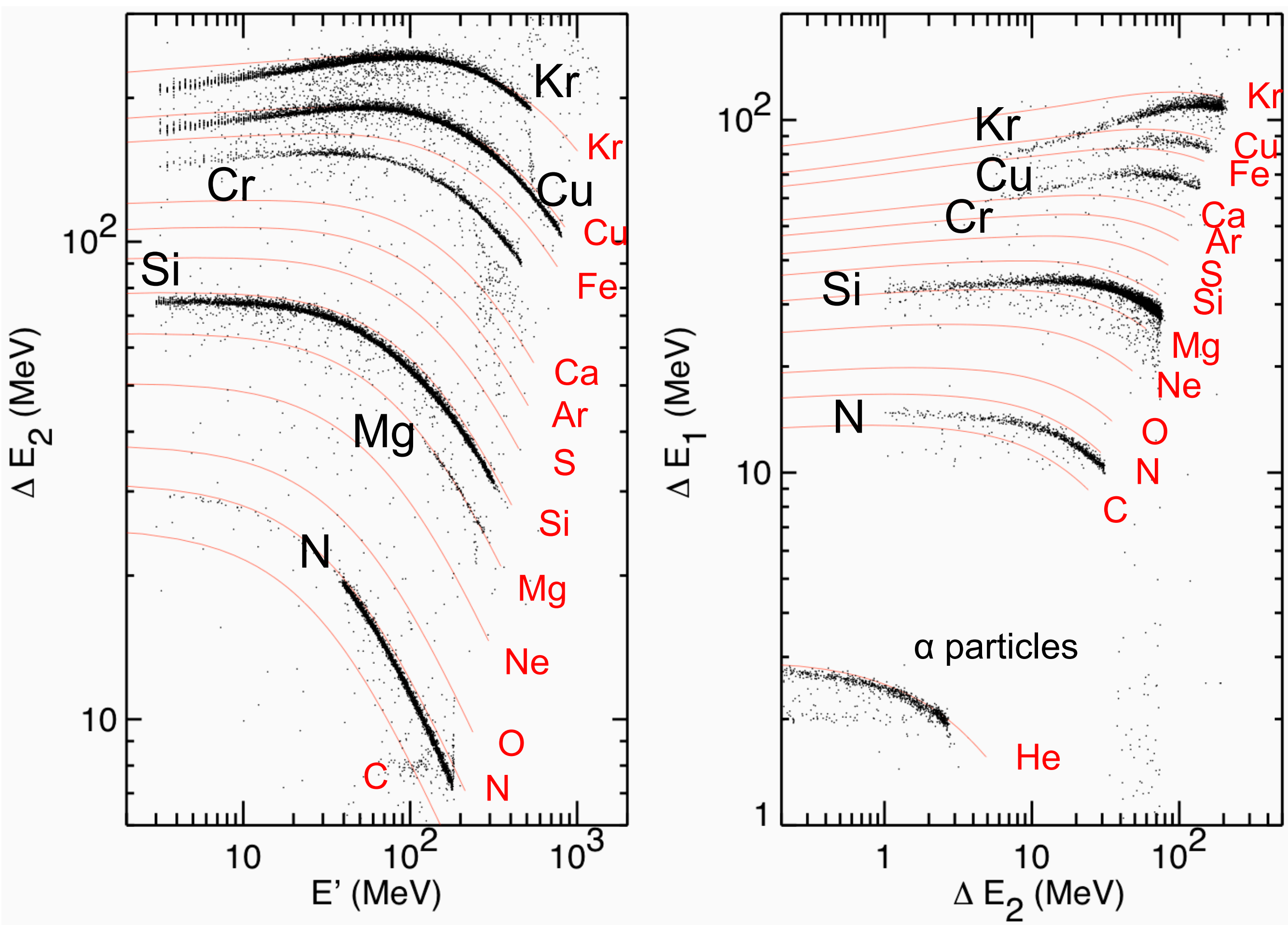


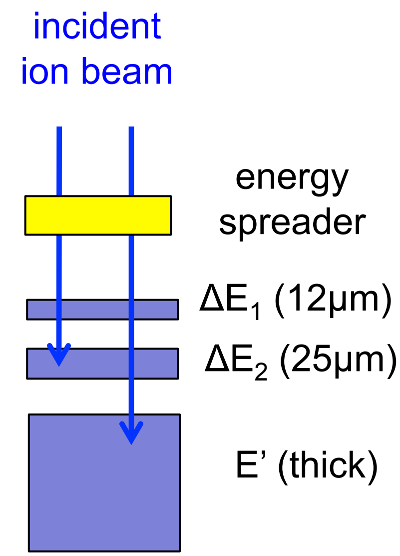
- alphas from a ^{244}Cm source passed through an "energy spreader" (layer of thin fabric) to obtain a distribution of energies
- ^{4}He response track compared with track calculated from range-energy relation adjusting ΔE thickness to 11.8 μm and dead layer to 0.1 μm to improve agreement



Response to Accelerator Beams of Heavy Ions

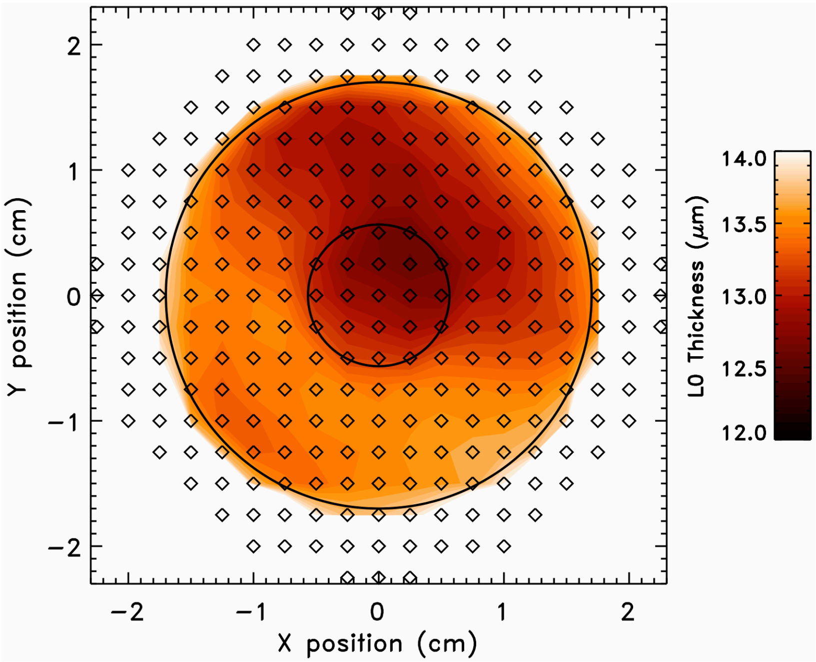
red curves: calculated response; black points: measured events
LBNL 88-inch Cyclotron, 16 MeV/nuc Cocktail Beam, 3 Oct 2013

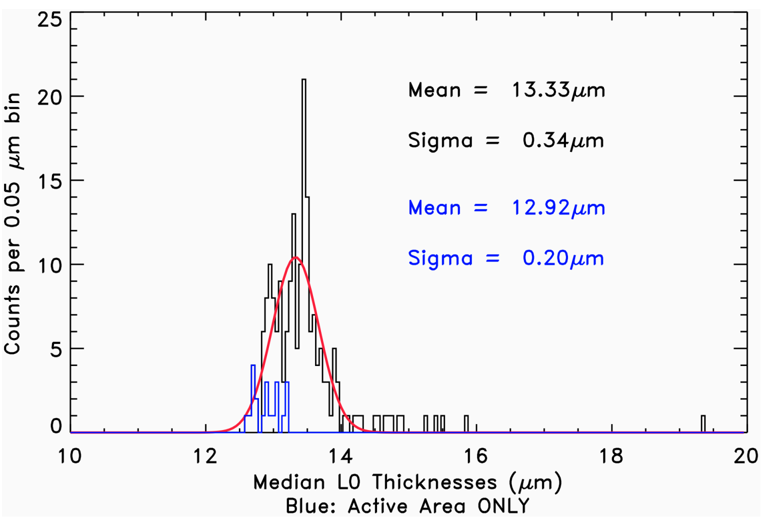




Obtained similar performance using two 12 μm detectors from Micron and two 25 μm detectors from both Micron and LBNL

Thickness Uniformity Mapping





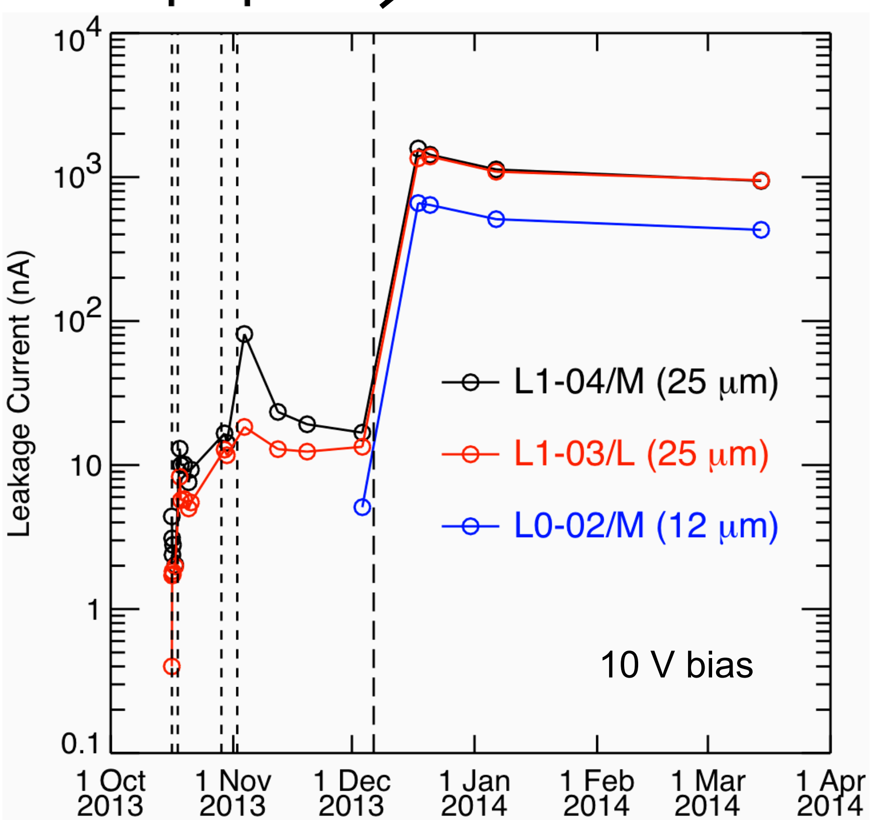
- measure thickness of L0 detectors using a beam of 5.8 MeV alpha particle that penetrate the ~12 μm membrane
- residual energy in backing detector used to infer energy lost in membrane
- range—energy relation to convert energy loss to silicon thickness
- sensitive to total silicon thickness (active + dead)
- compare with energy loss in aluminum foils to calibrate absolute thickness
- details of absolute thickness calibration still being worked out—could change absolute thickness shown here
- need to map additional L0 detectors
- plan to map L1 (25 μm) detectors using 8.78 MeV alphas from a ^{228}Th source

Radiation Testing: Total Dose and Displacement Damage

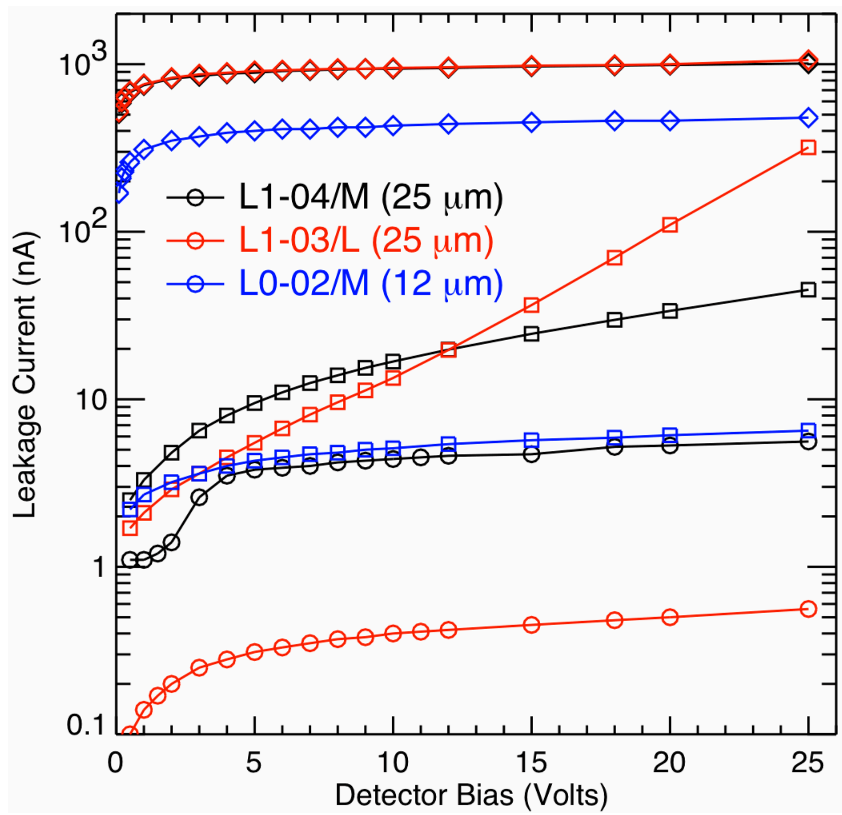
- total dose tested to 10 Mrad (10^5 Gy) using JPL ^{60}Co facility
- displacement damage tested to 10^{13}/cm^2 proton fluence at UC Davis Crocker Cyclotron Laboratory
- acceptable performance after irradiations

four successive ^{60}Co exposures for a total of 10 Mrad

irradiation with 67 MeV protons, 10^{13}/cm^2



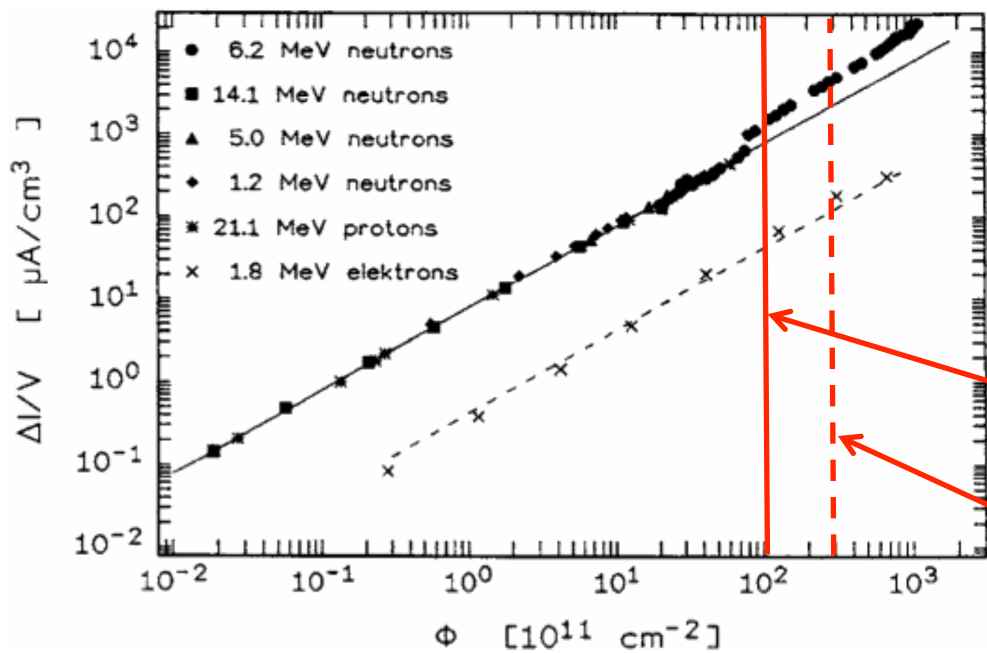
circles: before irradiation
squares: after 10 Mrad dose from ^{60}Co
diamonds: after 10^{13}/cm^2 proton fluence



Radiation Testing Comments

- L0 detector has minimum radiation shielding (4 μm of polyimide in the three windows)
- David Roth estimated (7 Nov 2013 e-mail):
  - mission total doses of 10 Mrad for L0 and “significantly lower than” 2 Mrad for L1
  - proton fluences of $3.0\times10^{13}/\mathrm{cm}^2$ for L0 and $4.5\times10^{12}/\mathrm{cm}^2$ for L1 (rounding the numbers up “just a bit”)
- to date one L0 detector from Micron, one L1 detector from Micron, and one L1 detector from LBNL have each been given 10 Mrad total dose and $1\times10^{13}/\mathrm{cm}^2$ proton fluence

current increase per unit active volume



fluence

- leakage current increases caused by displacement damage agreed well with expectations from linear parameterization of Wunstorf (1992) [see Lutz “Semiconductor Radiation Detectors”, Springer, 1999]

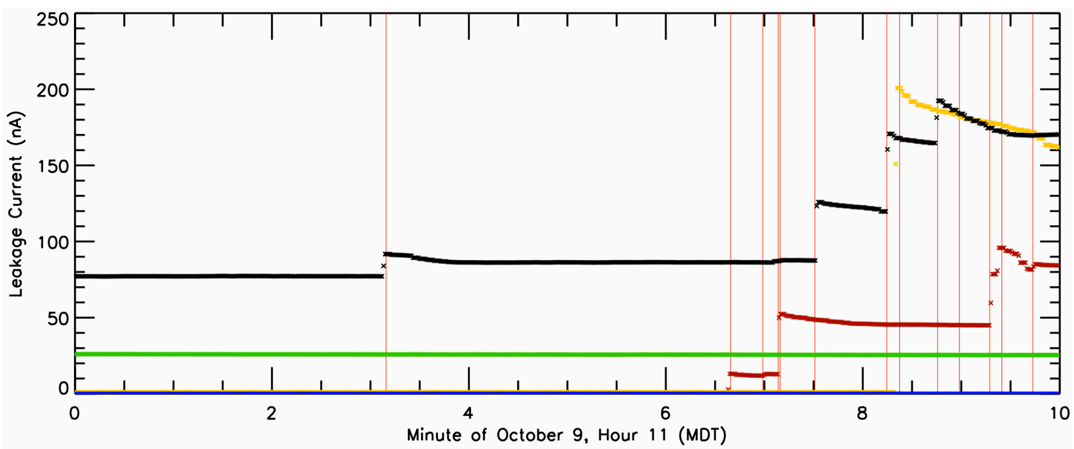
displacement damage testing to date

David Roth’s estimate for full mission fluence for L0 detector

Effects of High-Speed Dust Impacts

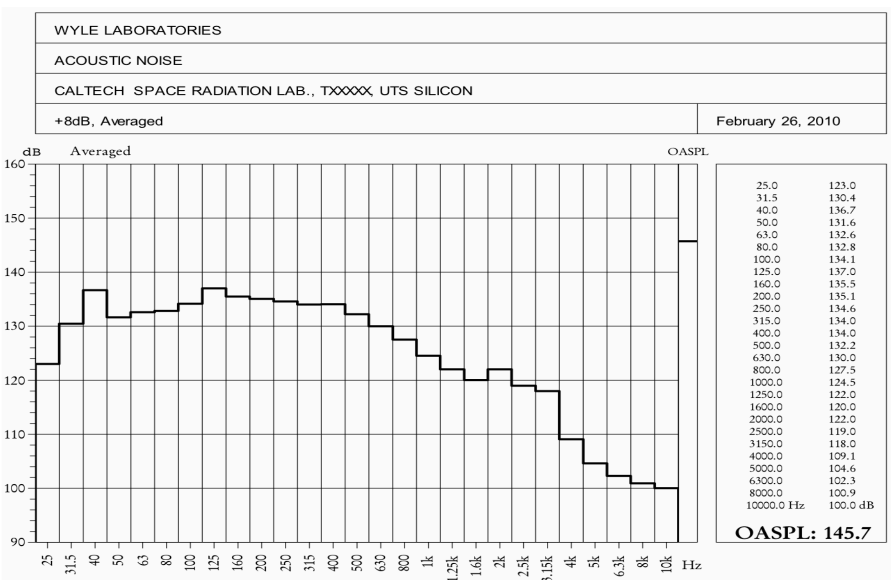
- preliminary tests at U. of Colorado and Heidelberg dust accelerators showed that high speed dust can penetrate LET windows but damage is confined to hole with size comparable to the diameter of the impacting particle
- test of L0 and L1 detectors at U. of Colorado (8-9 Oct 2014) showed that dust impacts cause leakage current increases in the detectors but detector segments that were not hit appear to be unaffected
- analysis of data from the recent run are under way
- if the L0 detector is disabled due to dust impacts but is still intact it will serve as an additional window (12 µm of Si) in front of the remaining detectors and LET will continue to perform as designed except for an increased energy threshold

colored traces: leakage currents from 5 segments of an L0 detector
vertical lines: times of incident dust particles reported by accelerator



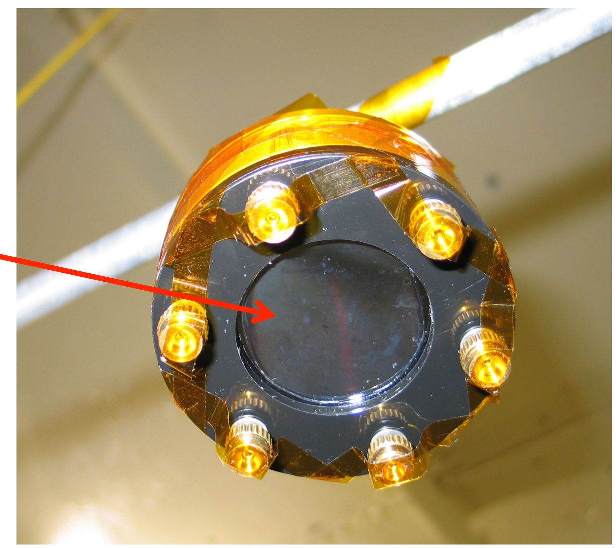
Ability to Survive Acoustic Environment

- silicon membrane (not an actual detector) with the diameter of the L0 detector was fabricated from an SOI wafer with 10 μm device layer (i.e., thinner than the L0 detector) and subjected to an Atlas V acoustic spectrum
- the sample survived without any problems
- plan to do an acoustic test of LET front end (windows plus actual L0 and L1 detectors) with appropriate Delta 4 levels before CDR



highest test level: 145 dB = Atlas V level + 7 dB

silicon membrane
10 μm thick
~3.4 cm diameter



TESAT-SPACECOM UK TEST LABORATORIES

TESAT SPACECOM UK
PIONEERING WITH PASSION

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TEST CERTIFICATE

Issued under UKAS registration number 0093

To	**Certificate Serial No**
Micron Semiconductor Ltd, 1 Royal Buildings, Marlborough Road, Lancing, West Sussex, BN15 8SJ.	**EL14415-2** Customer Order No 19162 Test Dates
F.A.O. Mr. C. Hawkins. Tel. 01903 755252	29/04/14

Title
Random Vibration of 6 off Solar Probe Detectors.

Description / Identification of Test Item(s)
Solar Probe Detectors.

Serial Number(s)
See table on page 2.

Specification / Method / Procedure (& Issue)
Vibration to customer requirements and listed in results/observations below.

Deviations from the above
None.

Results / Observations

All the test records are held in Astrium Test Laboratories logbook EL14415.

Vibration control plots are included on pages 3 to 5 of this Test House Certificate.

The random profile applied in each axis was: 20 Hz @ 0.01 g^2/Hz
60 to 200 Hz @ 1.25 g^2/Hz
350 to 500 Hz @ 0.04 g^2/Hz
2000 Hz @ 0.01 g^2/Hz
Overall 16.39 g_{rms}, 2 minute per axis.

The tests detailed above are certified to have been carried out to the requirements of the contract/order unless otherwise stated above. This certificate is issued in accordance with the quality control arrangements granted by our **UKAS TESTING** accreditation.

Author (Sign & Print Name)		Approved by (Sign & Print Name)		For and on behalf of the Laboratory Manager
Brian Wearn		G.M. Stancombe		
Position: Senior Engineer	Date: 30/4/14	Position: Snr Engineer	Date: 30/4/14	

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Ability to Survive Random Vibration Environment

- Micron Semiconductor has 3-axis random vibration test carried out on each detector by a commercial test laboratory prior to delivery

Additional Tests Anticipated

- plan to expose the same three detectors that were used in the December 2013 displacement damage test to an additional 2×10^{13} protons/cm^2 in order to reach the full-mission fluence estimated by David Roth

- plan additional measurements on detectors that were used in October 2014 dust test to address some outstanding questions:
    - do increased leakage currents recover over time?
    - what is time scale for recovery?
    - is recovery time affected by temperature?

- plan to carry out an additional dust impact test after the analysis of the results from the October test has been been completed
- some questions being considered for further investigation:
    - dependence on dust composition (iron particles used in October test
    - dependence on which surface of detector is hit
    - dependence on dust direction of incidence
    - dependence on detector bias
    - possibility of transients that could affect front end electronics

Detector Design Changes Since PDR

- The design of the thick detector mounts was modified to incorporate a capacitor in parallel with each detector segment and a resistor in series with each segment's connection to the front-end electronics. This is to prevent excessive signal transients at the detector where they could lead to cross talk between segments.

Detector Design Changes between EM and FM

- No changes are currently planned
- However, on-going investigations (dust impact effects, acoustics, electronic noise, accelerator test of EM unit) could still provide insights that would dictate minor changes

How EPI-Hi Meets Level 4 Requirements

EPI-Hi Level 4 Requirements

Protons and Heavy Ions

- Energy range: 1 MeV/nuc (TBR) to ≥50 MeV/nuc
- Energy binning: ≥6 bins per decade
- Cadence: at least one energy bin with time resolution of 5 s or better
- FoV: ≥π/2 sr in sunward and anti-sunward hemispheres (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 × 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 one energy bin with time resolution of 1 s or better
- FoV: ≥π/2 sr in sunward and anti-sunward hemispheres (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*

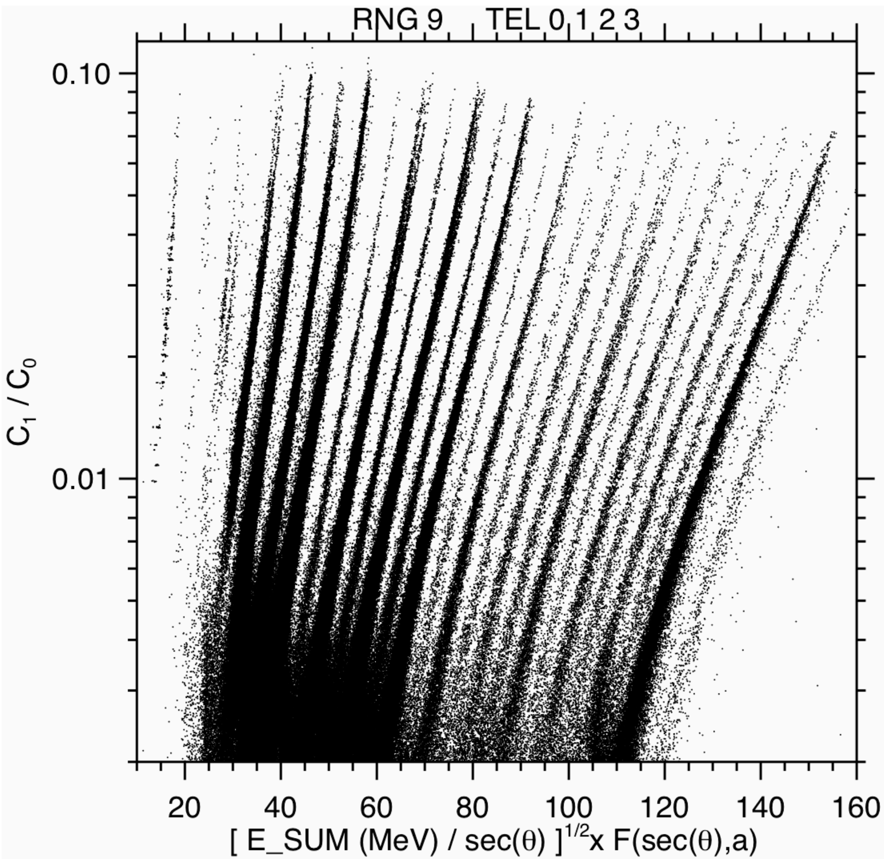
Ion Energy Range Requirements (1/3)

- energy coverage determined primarily by detector thicknesses
- minimum energy for protons and heavy ions determined by energy required to penetrate LET windows (3 μm Si equivalent of polyimide) plus L0 detector (12 μm)
- maximum energy for stopping protons in LET set by when ΔE signal in L1 detector falls below electronic threshold (L0 not required for high energy proton measurements)
- if windows or L0 detector need to be made thicker in order to survive effects of dust or acoustics, that increase will translate directly into an increase in the EPI-Hi energy threshold (approximately linear dependence)
- maximum energy for stopping $Z \geq 2$ nuclei in LET determined by the thickness of the LET detector stack and the mean angle of incidence
- minimum energy for protons stopping in HET set by the thickness of the HET windows plus the H1 detector—there is significant overlap between the maximum LET energy and the minimum HET energy

Ion Energy Range Requirements (2/3)

- for protons and He the thickness of the HET stack is sufficient to cover all energies up to the 50 MeV/nuc specified in the level 4 requirements
- higher energy protons and H penetrating the entire HET stack can be identified based on the change in dE/dx from the front to the back of the stack
- penetrating particle analysis should allow proton and He measurements up to at least 100 MeV/nuc—the upper limit remains to be investigated more precisely using Monte Carlo simulations
- for carbon and heavier nuclei stopping analysis will cover energies up to at least 100 MeV/nuc
- higher energies for heavy nuclei will be measured in penetrating particle mode

Ion Energy Range Requirements (3/3)

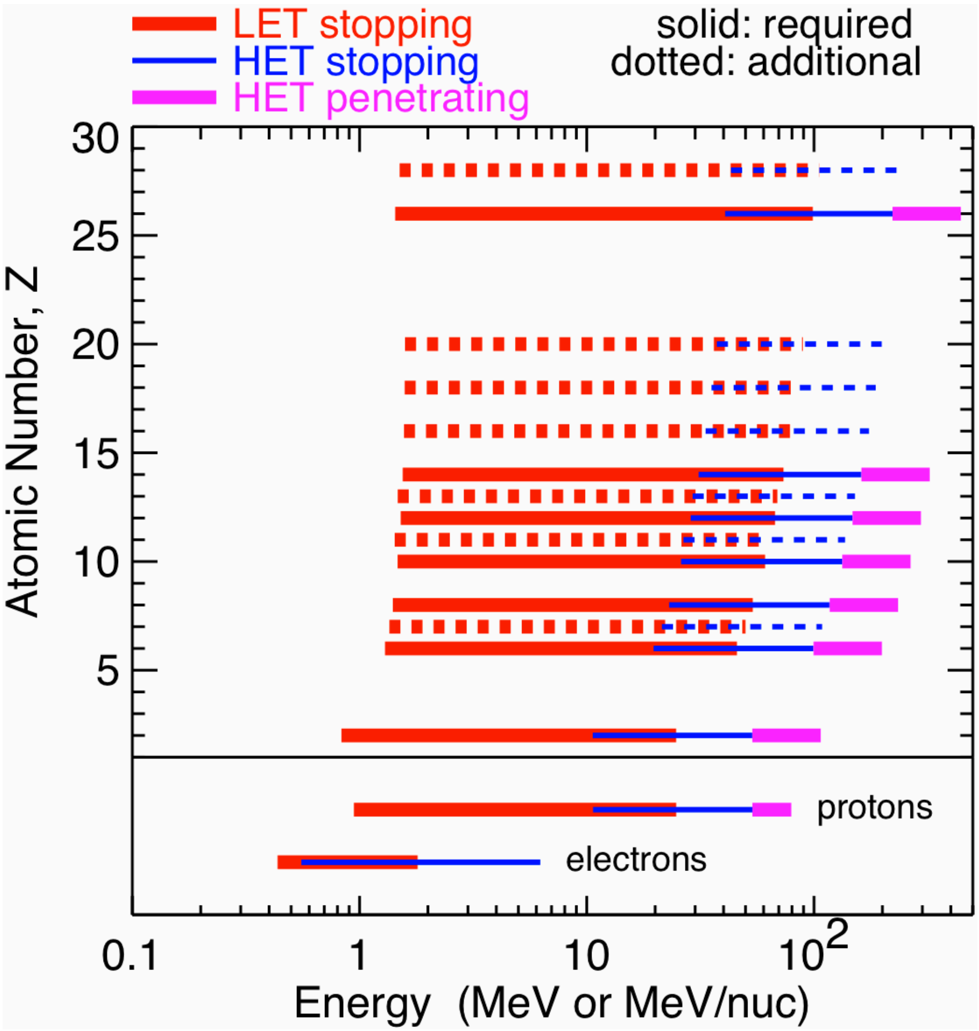


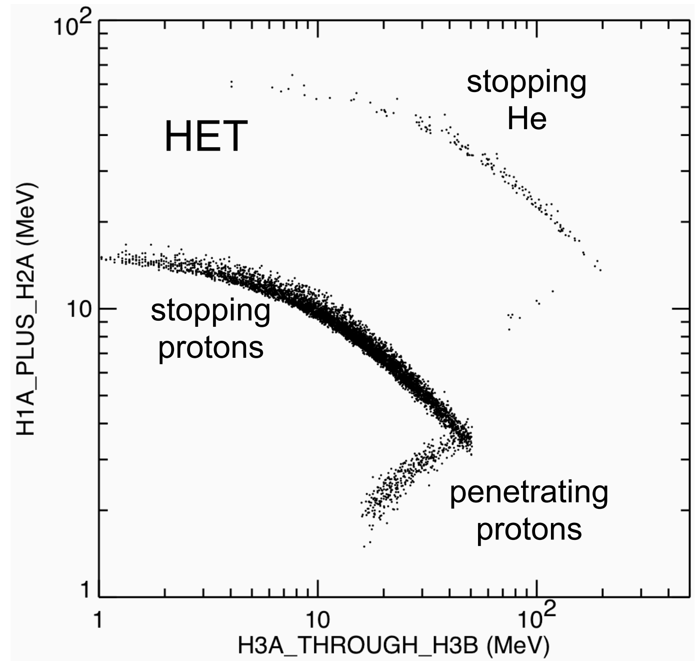
- recent work with ACE/CRIS penetrating particles led to the development of an approach to the penetrating particle analysis that should be simple enough to implement on board for HET and LET
- compares the fractional increase in dE/dx per unit thickness penetrated in the stack (called C_1/C_0) with the sum of the energies deposited in all the stack detectors (E_SUM), with a correction for incidence angle
- particle energy calculated calculated from E_SUM once the species has been identified

Electron Energy Range Requirements

- energy coverage determined primarily by detector thicknesses
- thin detectors (L0 and L1) are insensitive to electrons
- the minimum energy for electrons is set by the energy required to penetrate the windows plus thin detectors plus the first thick (500 μm) detector: ~540 μm Si equivalent for LET, ~655 μm Si equivalent for HET
- maximum energy for electrons corresponds to the energy at which the signal deposited in the 500 μm detector (L2 or H1) falls below the electronic threshold
- a relativistic, singly-charged particle deposits ~200 keV in penetrating 500 μm of Si, so planned thresholds for these detectors (~100 keV) should easily allow detection of these electrons
- if measured electronic noise turns out to be higher than anticipated and requires a higher threshold, the thickness of H1 and/or L2 could be increased at the expense of increasing the electron energy threshold
- some 720 μm H1 and L2 detectors have been ordered to cover this contingency
- the maximum electron energy, which corresponds approximately to a relativistic, singly-charged particle penetrating the entire HET stack, is ~5.3 MeV for normal incidence and gets up to ~6 MeV at the larger angles

Anticipated Energy Ranges





Energy Binning Requirements (Ions and Electrons)

- energies are measured particle by particle on board and then rates are accumulated in selected energy bins that are typically significantly broader than the energy-measurement resolution
- thus the energy binning is largely determined by the software, which is covered in a separate software peer review
- the basic energy binning has been selected to be logarithmic with a bin width of $2^{1/4}$ yielding ~13 bins per decade, which is approximately twice as many as the required 6 per decade
- broader bins are used to provide statistically significant measurements at time cadences shorter than the basic 1 minute
- for ions stopping in the telescopes, incident energies can be derived from measured energy losses by simply adding a small correction for energy deposited in the windows
- for penetrating ions, bins of deposited energies can be pre-calculated and tabulated to correspond to desired bins of incident energy
- because electrons undergo significant scattering in the telescopes a model will be used to derive the energy spectrum of incident electrons from the measured spectrum of electron energy deposits

Cadence Requirements (Ions and Electrons)

Highest cadence: 1 second

- Used for one electron bin below and one above 1 MeV
- Used for 4 proton bins above 1 MeV

Intermediate cadence: 10 sec

- Used for narrow energy bins for e, H, He, ^{3}He
- Used for intermediate-width energy bins for element groups CNO, NeMgSi, Fe

Normal cadence: 60 sec

- 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

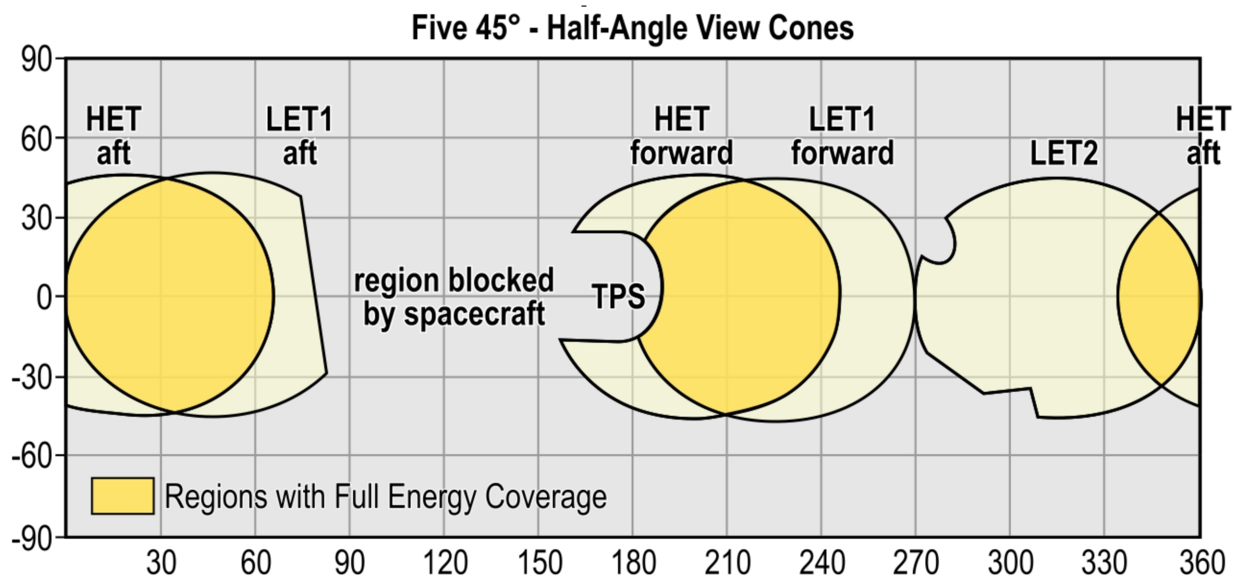
Low cadence: 300 sec

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

Very low cadence: 1 hr

- All rates accumulated at cadences of 60 sec and 300 sec are also accumulated over 1 hr

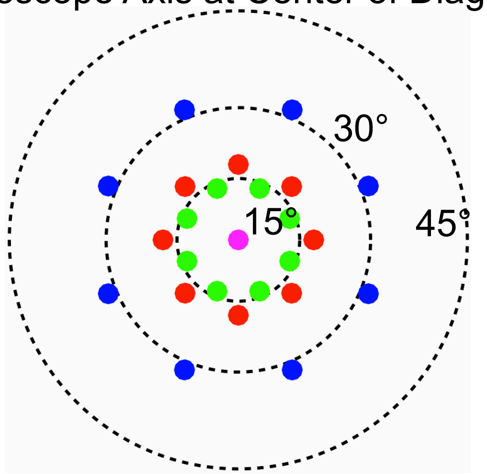
Field-of-View Requirements (Ions and Electrons)

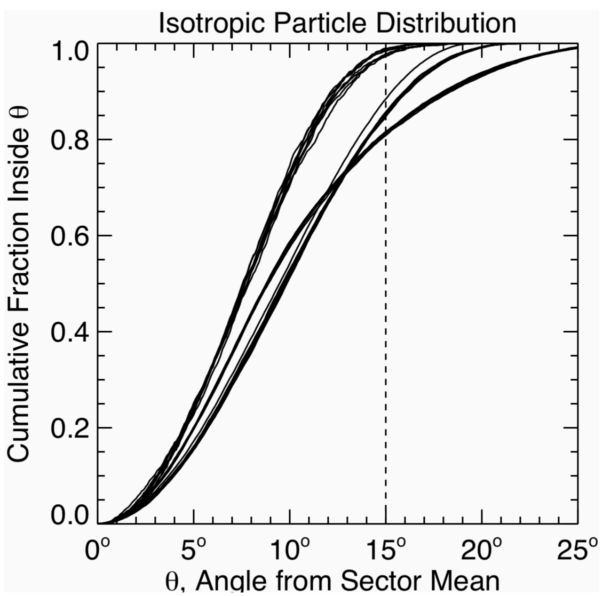


- each telescope has a view cone with a half-angle of ~45°
- this cone subtends a solid angle of ~0.58π (although with the geometrical factor falling off toward the edges)
- the combination of the 5 telescope apertures provides significantly more than the required π/2 field of view in the sunward and anti-sunward hemispheres, even after taking account of blockages by the TPS and other obstructions

Angular Sectoring Requirements (Ions and Electrons)

Locations of Centers of Angular Sectors,
Telescope Axis at Center of Diagram





- Particle directions of incidence are determined based on active elements 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 L1 (H1) are rotated 45° about the telescope axis relative to L2 (H2)
- 25 combinations of hit elements in the two detectors are used to assign event to a viewing sector
- For an isotropic distribution of particles, ≥80% of the particles detected in a sector have directions of incidence within 15° of the mean viewing direction of the sector
- Significant overlap among sectors allows measurements of particle distributions with angular resolution smaller than the size of a sector
- HET provides sectored electron data, LET1 provides only front-back direction information for electrons

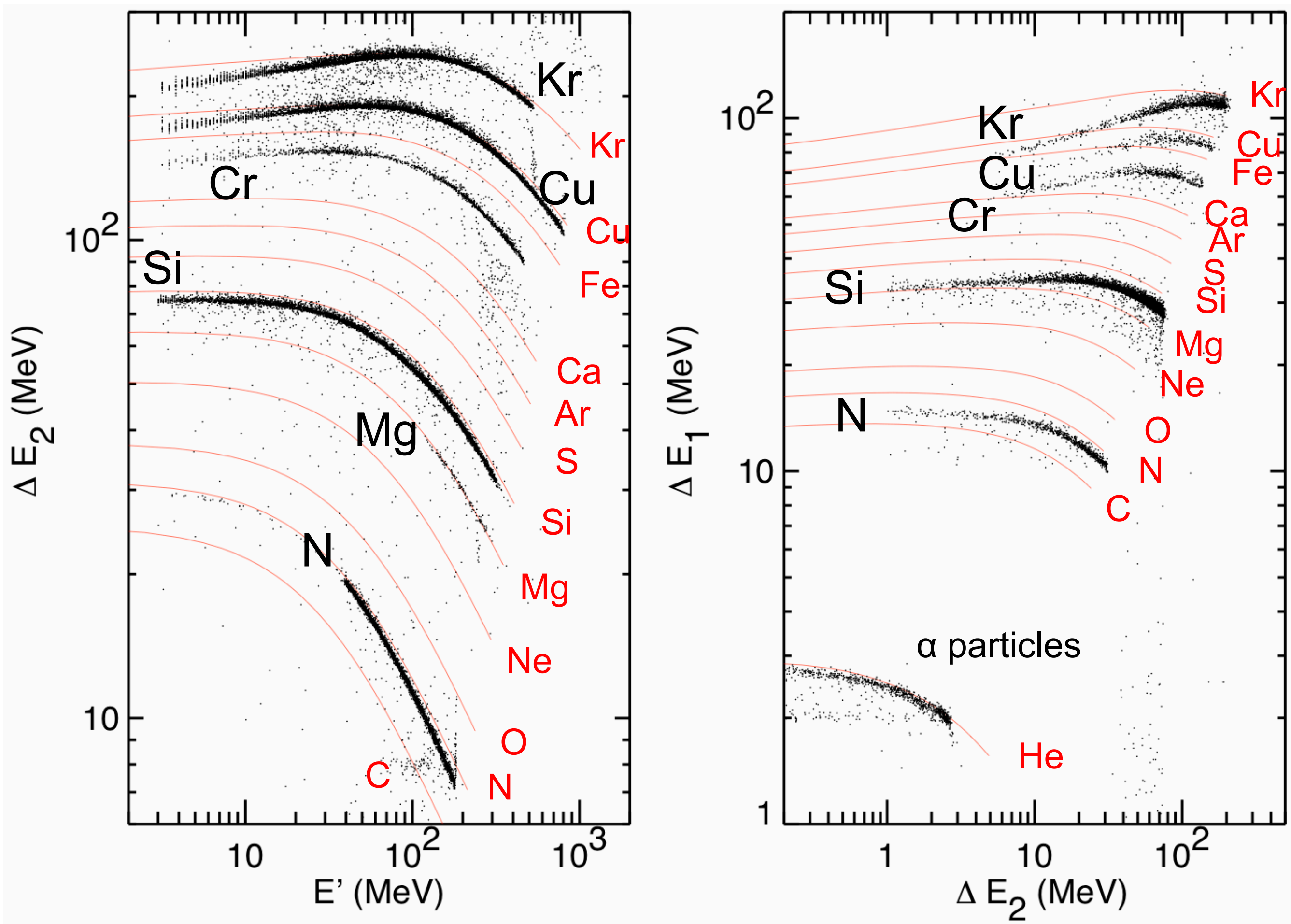
Species Resolution Requirements: Elements (1/2)

- separation of major elements (H, He, C, O, Ne, Mg, Si, Fe) with FWHM resolution in atomic number $\leq 0.5 \times$ separation from nearest abundant neighbor is demonstrated using accelerator calibrations similar to the detector test carried out at the LBNL 88-inch cyclotron in October 2013 and Monte Carlo simulations
- an example of the accelerator data is shown on the next page
- results of Monte Carlo simulations are shown in the material from the peer review of EPI-Hi PHASIC parameters that was held on 1 Mar 2013
- both measurements and simulations show that the element resolution is significantly better than required
- in most angular sectors the mass resolution for separating He isotopes is dominated by the large variation in $\sec(\theta)$
- good He isotope resolution is restricted specific sectors:
- in LET the L0 and L1 detectors have quadrants aligned (rather than being offset by 45° as is done between L1 and L2 and between H1 and H2)

Species Resolution Requirements: Elements (2/2)

red curves: calculated response; black points: measured events

LBNL 88-inch Cyclotron, 16 MeV/nuc Cocktail Beam, 3 Oct 2013

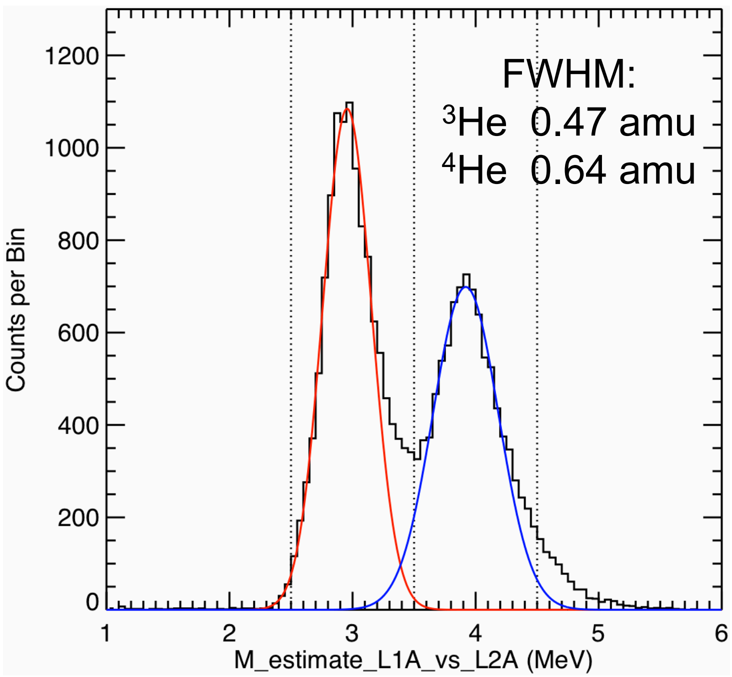


Species Resolution Requirements: He Isotopes (1/2)

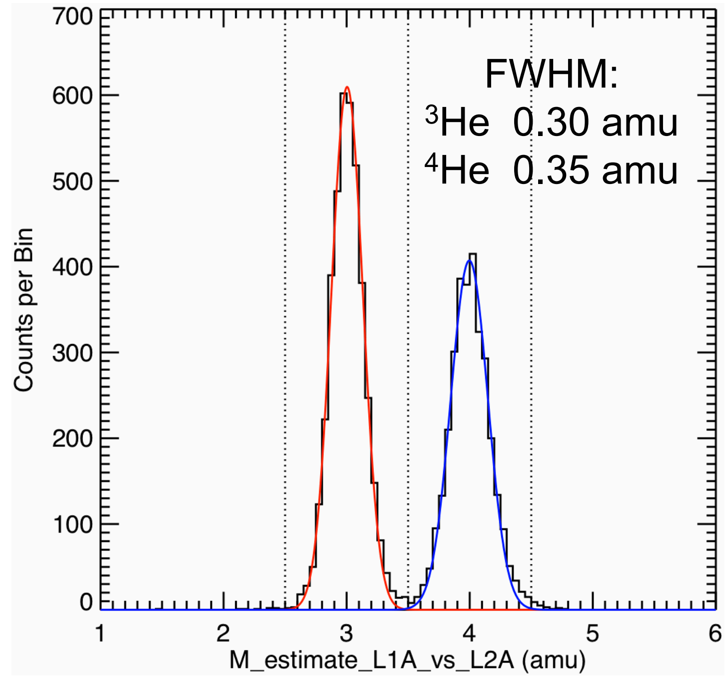
- in most angular sectors the mass resolution for separating He isotopes is dominated by the large variation in sec(θ)
- good He isotope resolution is restricted to specific sectors
- in LET, the L0 and L1 detectors have quadrants aligned (rather than being offset by 45° as is done between L1 and L2 and between H1 and H2) in order to provide five L0-L1 quadrant pairs that have minimal sec(θ) variation and thus good He isotope separation
- in HET only the combination of the central bull's eye in H1 and H2 has small sec(θ) variation, but He-rich SEP events typically have energy spectra so soft that they would not be measured in HET
- in LET any events that satisfy a L0•L1•L2 coincidence will have a small spread in sec(θ) and be useful for He isotope measurements, thus allowing He isotope separation over the full energy range covered by LET
- for sectors with small sec(θ) variation, thickness non-uniformities in the ΔE detector could be a significant contribution to the He mass resolution, however it is expected that the SOI-process used for making the L0 and L1 detectors should yield excellent thickness uniformity, which is borne out by the one L0 detector that has been extensively studied to date

Species Resolution Requirements: He Isotopes (2/2)

Full Geometry Defined by
L1•L2 Coincidence



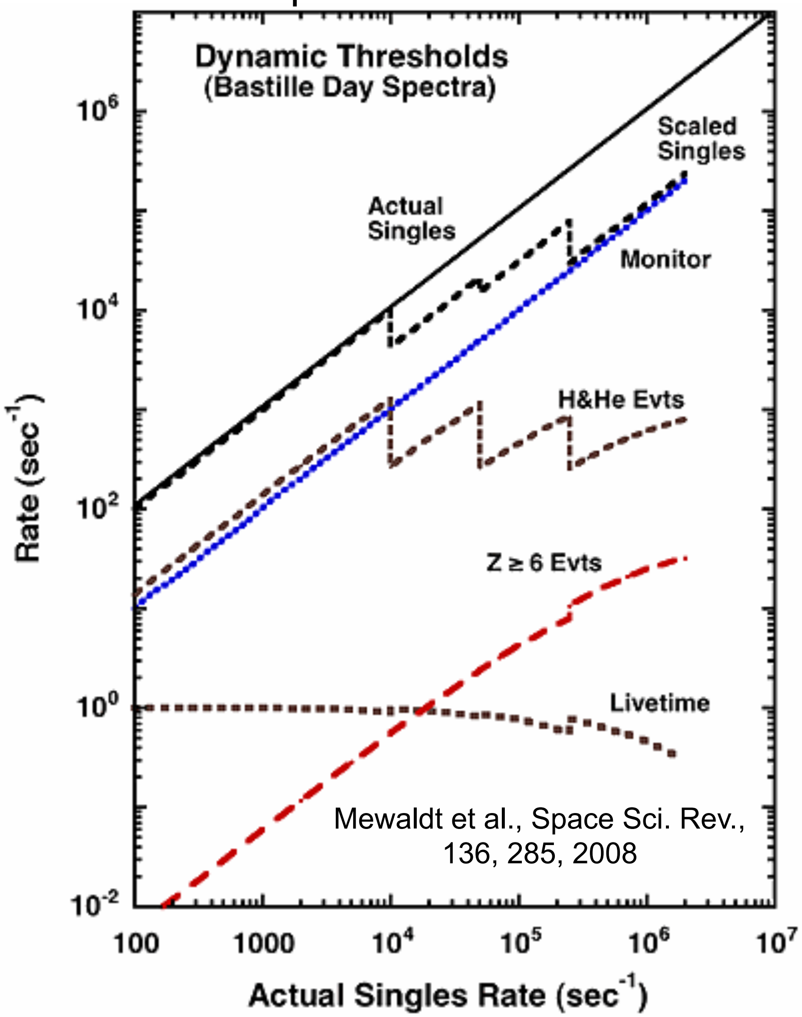
Geometry Defined by
L0•L1•L2 Coincidence
(~1/4 of L1•L2 geometry)



- 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 $^3He/^4He$ ratio at a few MeV/nuc to >~5%

Maximum Intensity Requirements (1/3)

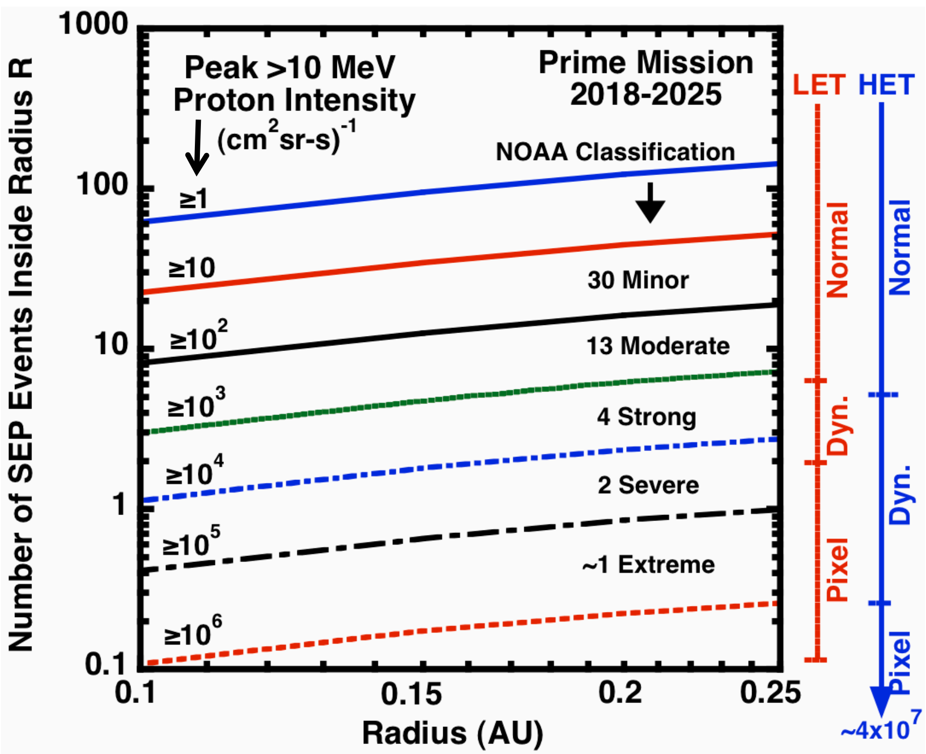
Example from STEREO/LET



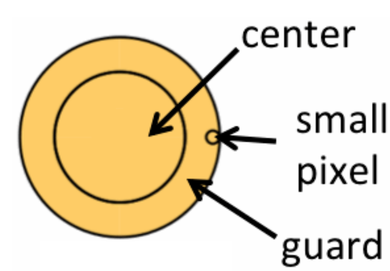
- Protons and He dominate the EPI-Hi count rates and the associated dead-time
- A "dynamic threshold" system, successfully used in the LET and HET instruments on STEREO, allows the adjustment of the geometrical factor for protons and He while maintaining the full geometrical factor for Z≥6 elements
- 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 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

Maximum Intensity Requirements (2/3)

- An estimate of the distribution of SEP event sizes was obtained by combining: 1) an extensive database of SEP observations at 1 AU, 2) the radial dependence of peak intensities derived from Lario et al. (2007), and 3) the SPP orbit
- ~50 events are expected inside 0.25 AU over the 7-year mission, including ~2 “severe” events and possibly an “extreme” event
- Both HET and LET use dynamic thresholds when intensities exceed ~2000 /cm^{2}sr-s



- There is significant uncertainty in the radial dependence of SEP intensities close to the Sun
- The EDTRD includes a worst-case spectrum having a >10 MeV intensity of 3×10^7/cm^{2}sr-s (95% confidence)
- In order to measure proton intensities in extreme events up to this level, singles count rates from several small (1 mm^2) pixels are used with thresholds raised on all other detector elements



Maximum Intensity Requirements (3/3)

- maximum intensities of protons and electrons to which EPI-Hi will be able to make useful measurements continue to be studied in order to resolve the "TBD" in the maximum intensity requirement
- Dick Mewaldt's presentation in HET_DynoThresh_1,28,14-1.pdf summarizes the current status