Development of the Battery-operated Independent Radiation Detector (BIRD)

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9-11 September 2014

19th Workshop on Radiation Monitoring for the International Space Station (WRMISS)

UNIVERSITY of HOUSTON

NASA

Acknowledgements

- Advanced Exploration Systems RadWorks
  - Program integration
  - Resources
- Medipix Collaboration
  - Technology
  - Facilities

Outline

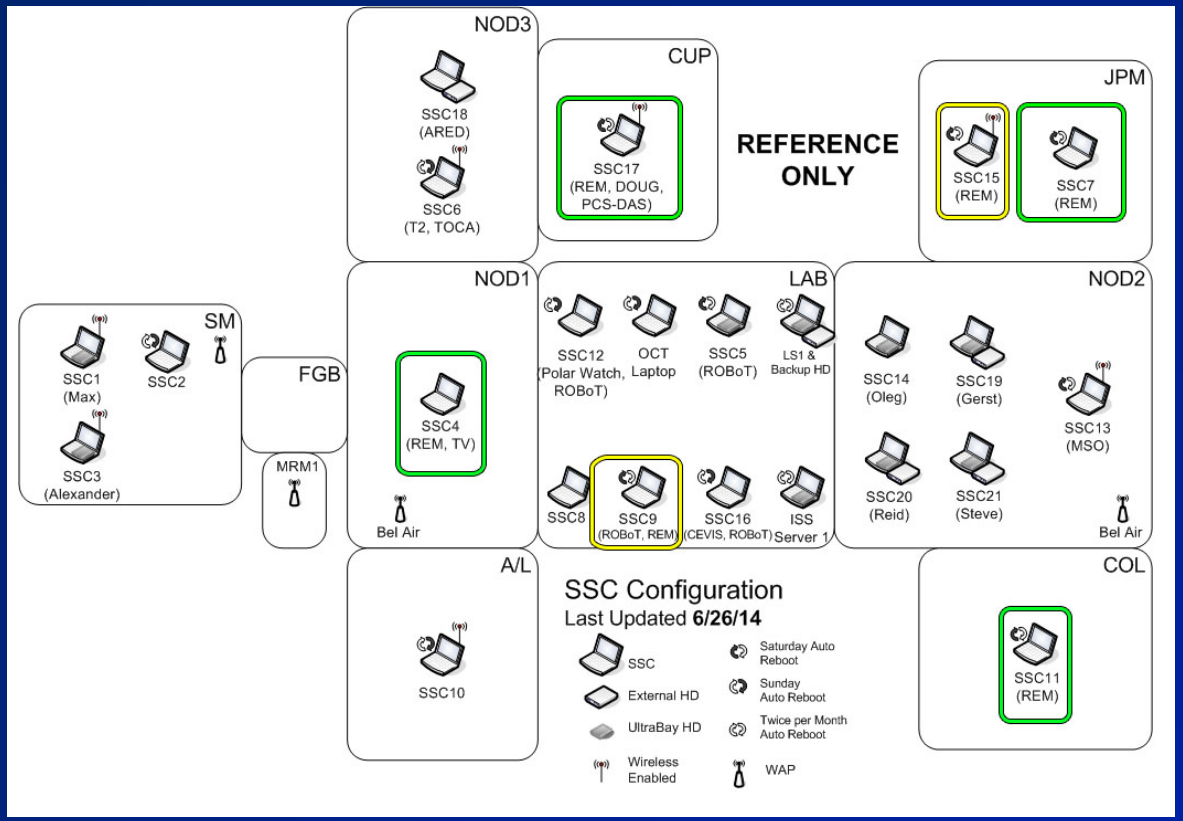
- Introduction
- BIRD Aims
  - Design
  - Data Acquisition
  - Flight Hardware Experience
- Concept of Operations
- Conclusion

Introduction

- Timepix detection at NASA
  - ISS Radiation Environment Monitor (REM)
    - Technology demonstration
    - USB communication with laptop
  - BIRD
    - Will fly on Orion MPCV in December 2014
    - Independent of vehicle systems
  - Hybrid Electronic Radiation Assessor (HERA)
    - Integrated system
    - Distributed monitoring

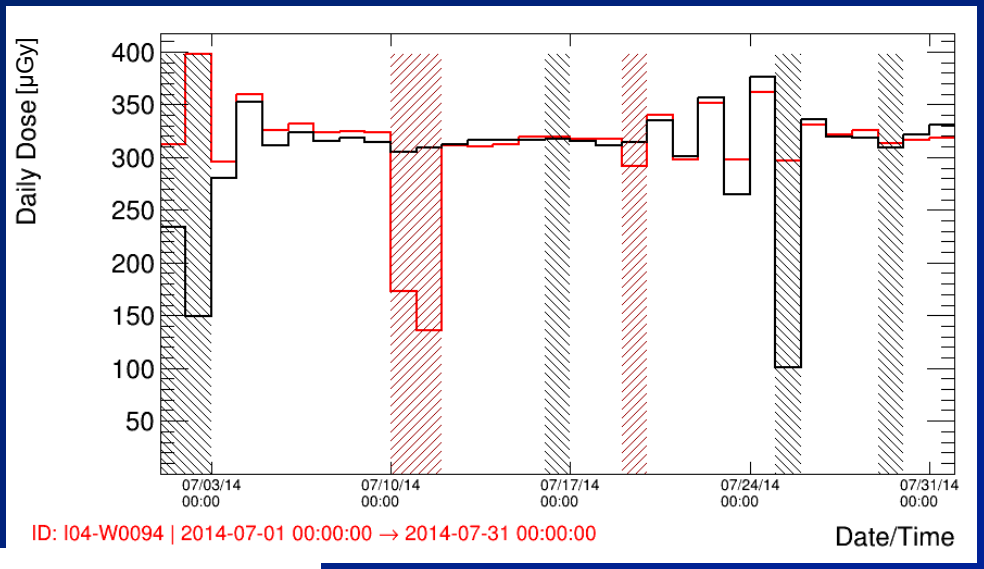
Introduction

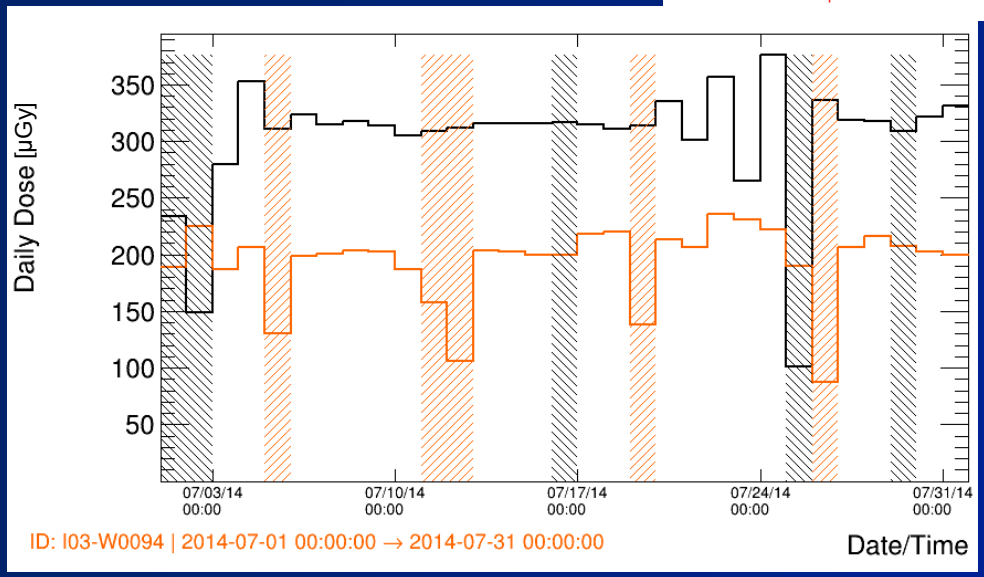
- ISS REM



Introduction

- ISS REM

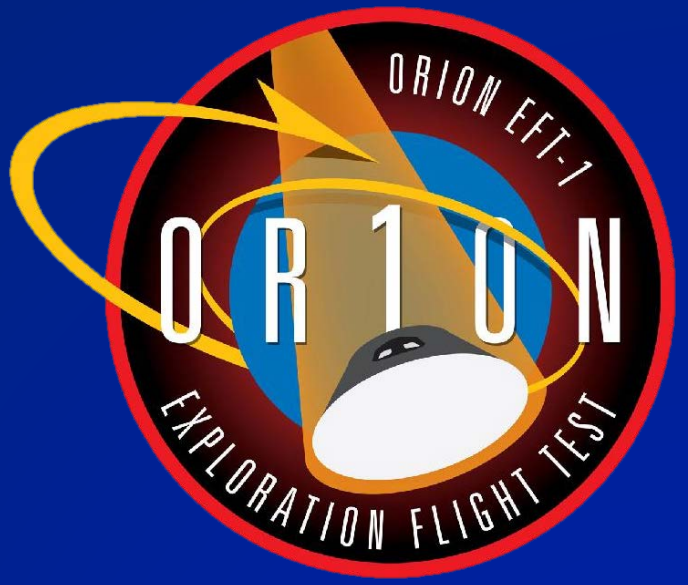




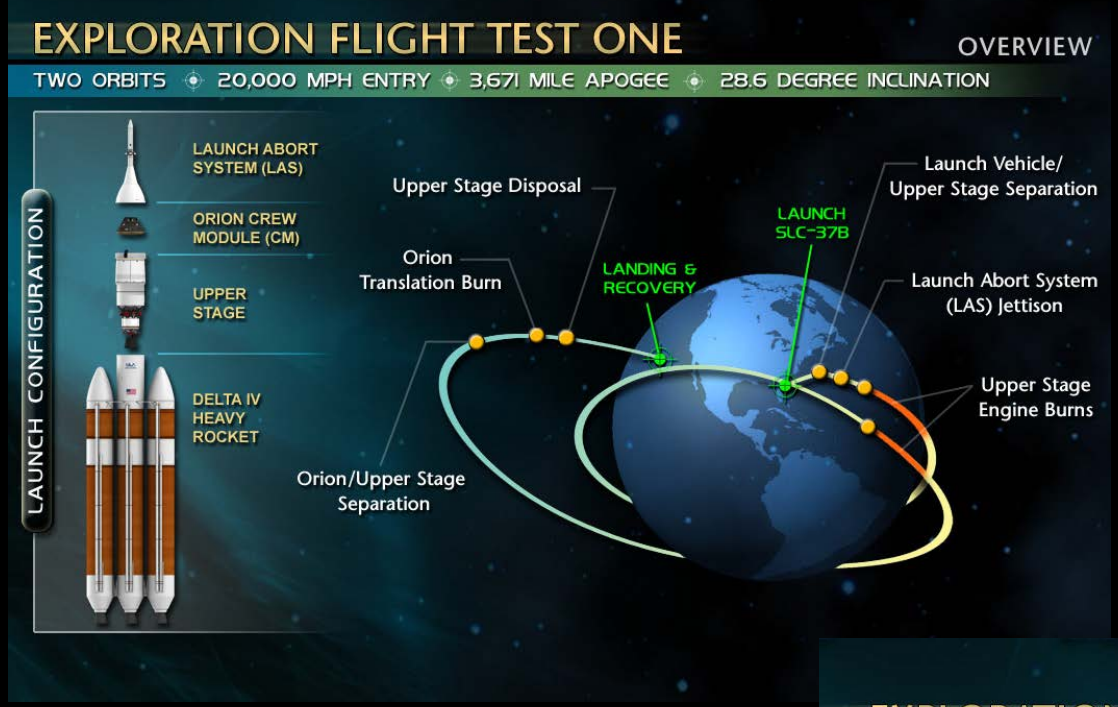
Generated using WebREM (D. Turecek)

Introduction

- BIRD
  - Exploration Flight Test 1
  - Payload
  - No data or power
  - Develop in < 2 y



Credit: NASA

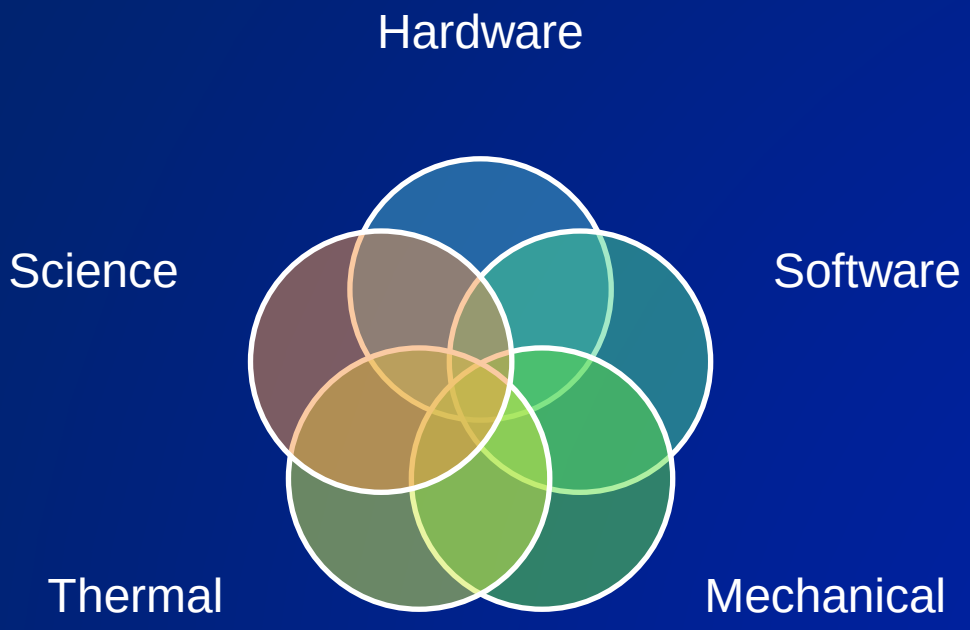

EXPLORATION FLIGHT TEST ONE
OVERVIEW
TWO ORBITS
20,000 MPH ENTRY
3,671 MILE APOGEE
28.6 DEGREE INCLINATION
LAUNCH CONFIGURATION
LAUNCH ABORT SYSTEM (LAS)
ORION CREW MODULE (CM)
UPPER STAGE
DELTA IV HEAVY ROCKET
Upper Stage Disposal
Orion Translation Burn
LANDING & RECOVERY
LAUNCH SLC-37B
Launch Vehicle/ Upper Stage Separation
Launch Abort System (LAS) Jettison
Upper Stage Engine Burns
Orion/Upper Stage Separation


EXPLORATION FLIGHT TEST ONE GROUND TRACK
STAGE 1 BURN
STAGE 2 BURN
COAST
Entry Interface
Orion Separation
ORION ENTRY INTERFACE TARGET
ORION LANDING TARGET
LATITUDE
60
45
30
15
0
-15
-30
-45
-60
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
DEGREES
LONGITUDE

Credit: NASA

BIRD Aim 1

- Design
  - Timepix communication and control



Architecture

Hardware

- Carrier board
  - Connection for Timepix assembly
  - Allows interchangeability
- Processor board
  - Low level voltage conversion
  - Timepix operations
    - Configure
    - Read data
    - Save data
- Power supply board
  - Dynamic battery voltage input
  - Constant 3.3 VDC output
- External interface/testing board

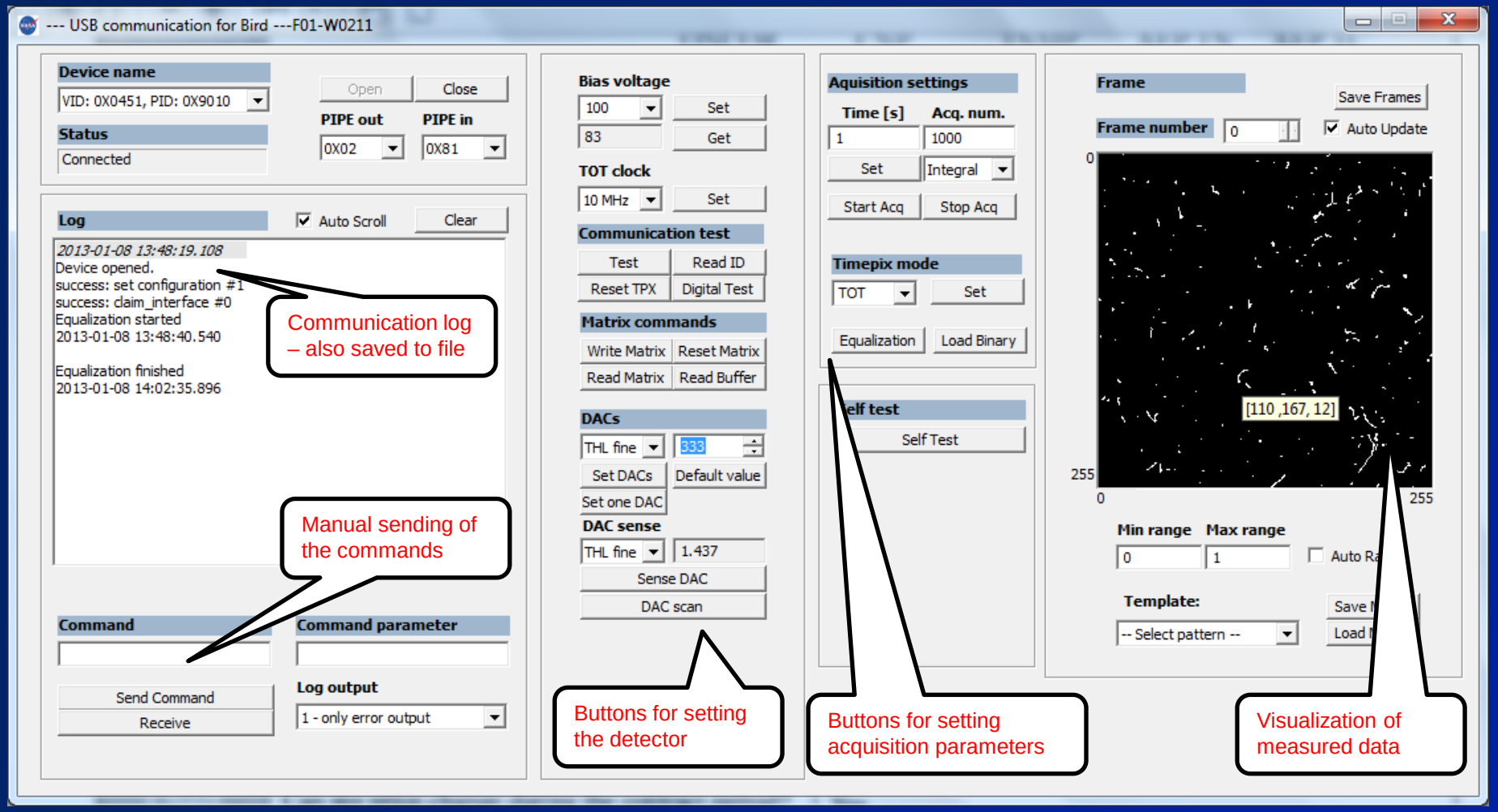
Flight SW Functions

- USB interface to the GSE SW
  - Calibration
  - Pre-flight functions
- Check for a launch
  - Wake from sleep
  - Return to sleep if no launch
- Launch detection
  - Acquire Timepix frames
  - Write to memory

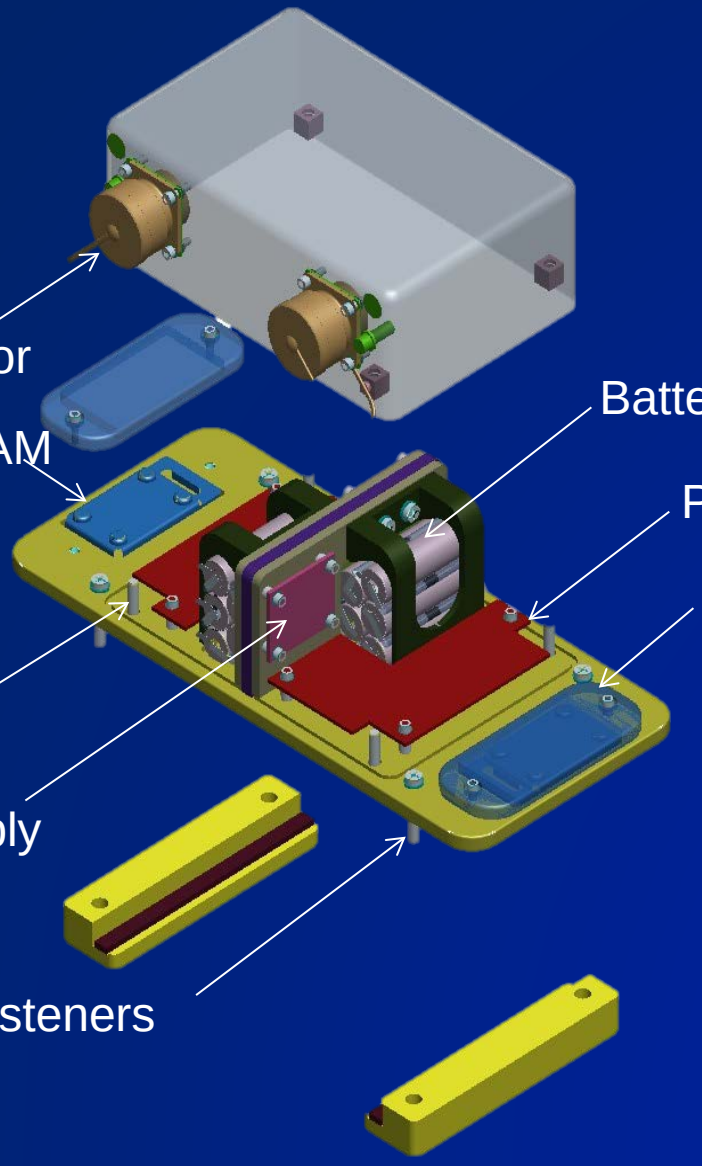
Ground SW Functions

- Initialize flash memory on the BIRD
  - BIRD FSW
  - Timepix initialization matrix
  - Timepix DAC settings
- Memory functions
  - Initialize the uSD file
  - Read/store the uSD format
- Correct card format in case of errors

GSE SW

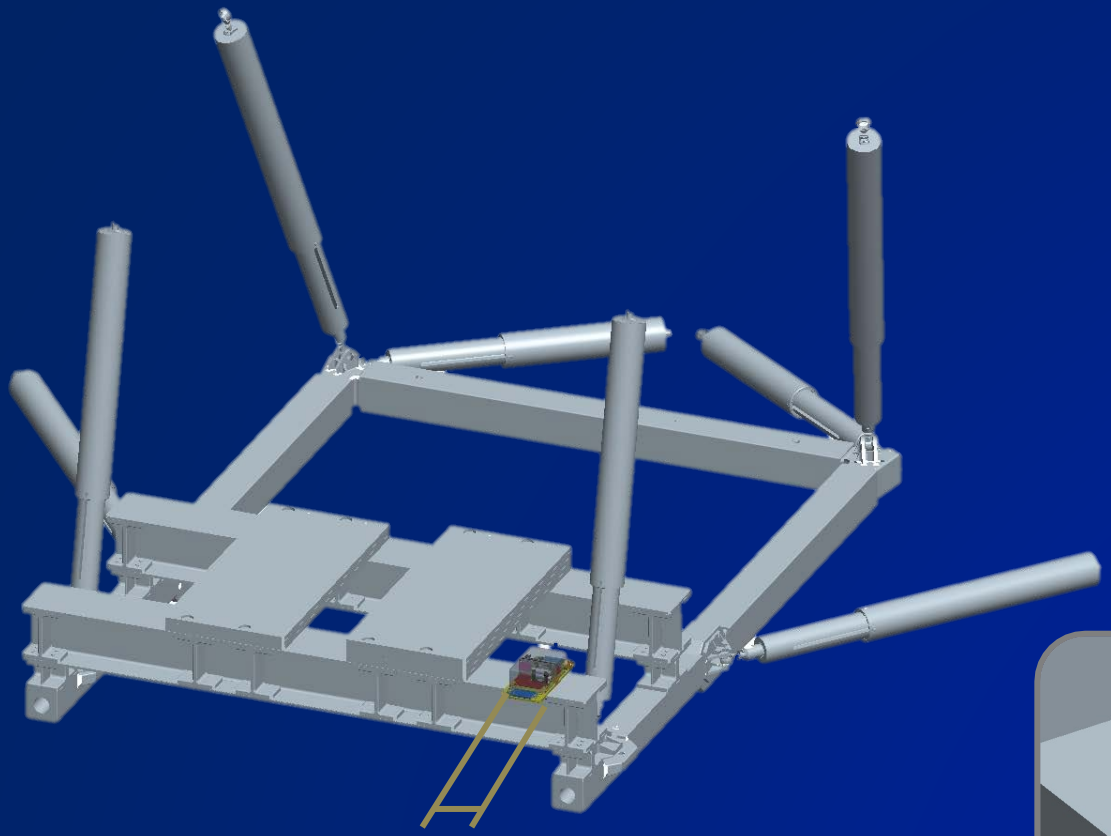

--- USB communication for Bird ---F01-W0211
Device name
VID: 0X0451, PID: 0X9010
Open
Close
PIPE out
PIPE in
0X02
0X81
Status
Connected
Log
Auto Scroll
Clear
2013-01-08 13:48:19.108
Device opened.
success: set configuration #1
success: claim_interface #0
Equalization started
2013-01-08 13:48:40.540
Equalization finished
2013-01-08 14:02:35.896
Communication log – also saved to file
Manual sending of the commands
Command
Command parameter
Send Command
Receive
Log output
1 - only error output
Bias voltage
100
Set
83
Get
TOT clock
10 MHz
Set
Communication test
Test
Read ID
Reset TPX
Digital Test
Matrix commands
Write Matrix
Reset Matrix
Read Matrix
Read Buffer
DACs
THL fine
333
Set DACs
Default value
Set one DAC
DAC sense
THL fine
1.437
Sense DAC
DAC scan
Buttons for setting the detector
Aquisition settings
Time [s]
Acq. num.
1
1000
Set
Integral
Start Acq
Stop Acq
Timepix mode
TOT
Set
Equalization
Load Binary
elf test
Self Test
Buttons for setting acquisition parameters
Frame
Save Frames
Frame number
0
Auto Update
0
255
[110 ,167, 12]
0
255
Min range
Max range
0
1
Template:
-- Select pattern --
Visualization of measured data

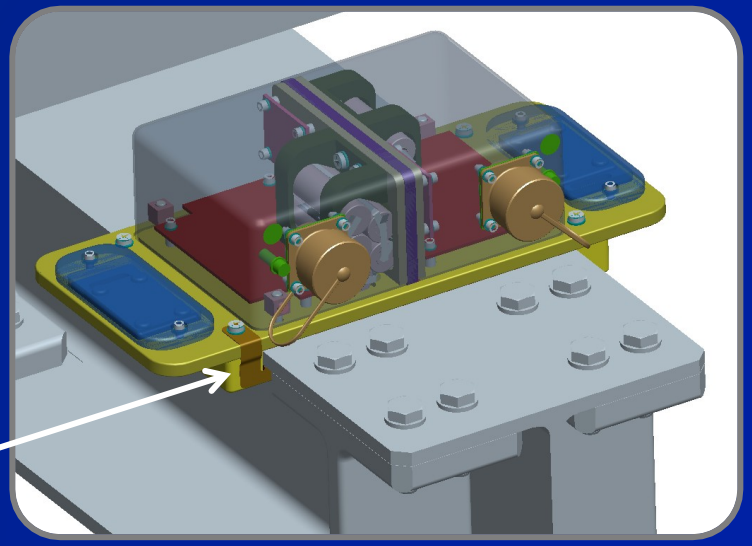
Mechanical Design



9.8” long x 5.1” wide x 3.0” tall
~3.1 lbs

Vehicle Attachment

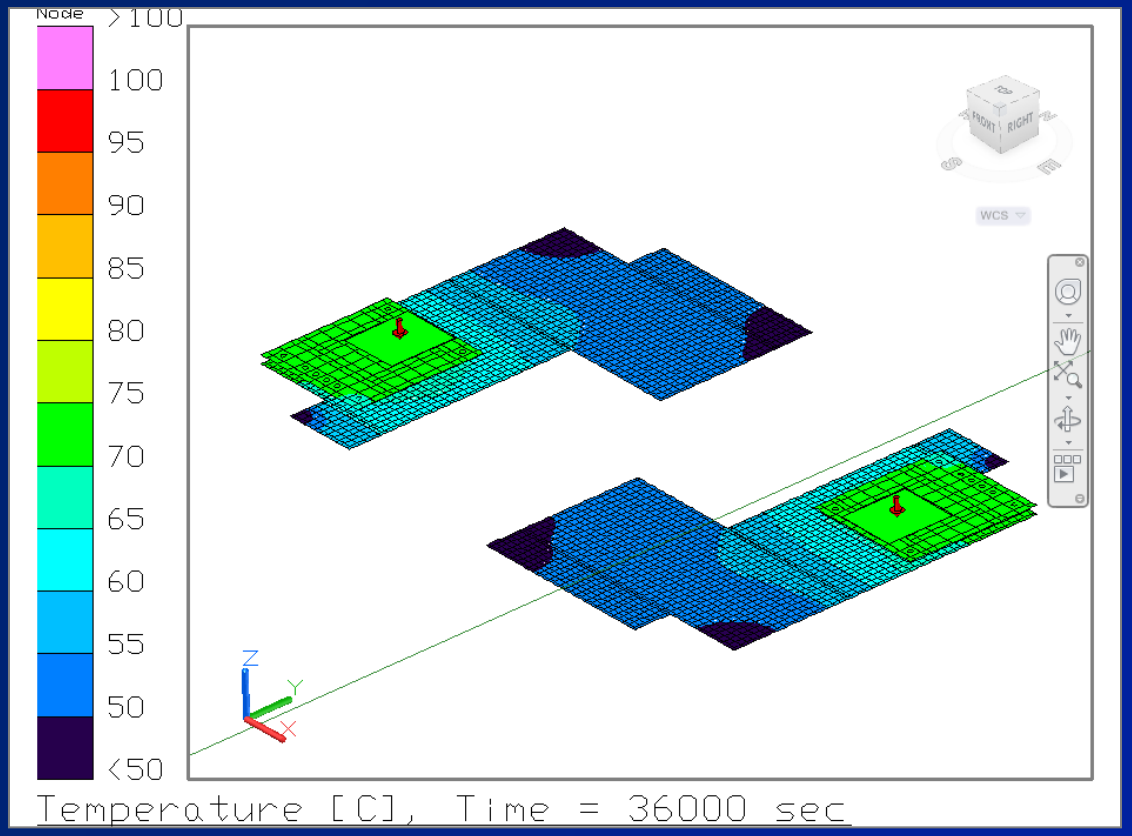




Copper bonding strip positioned to contact an alodined surface

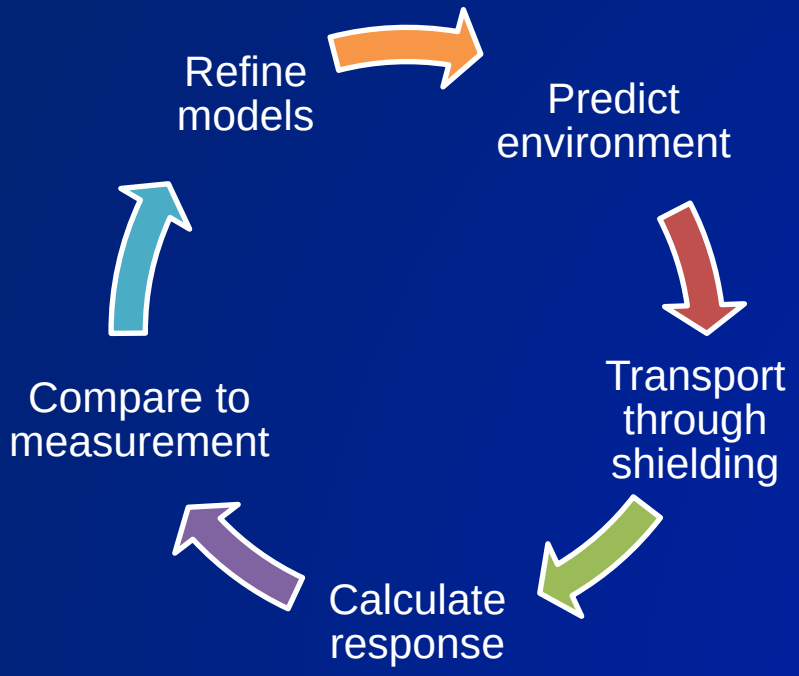
Thermal Math Model

- 37 ºC for air and CIAS
- 74 ºC Timepix (steady-state)

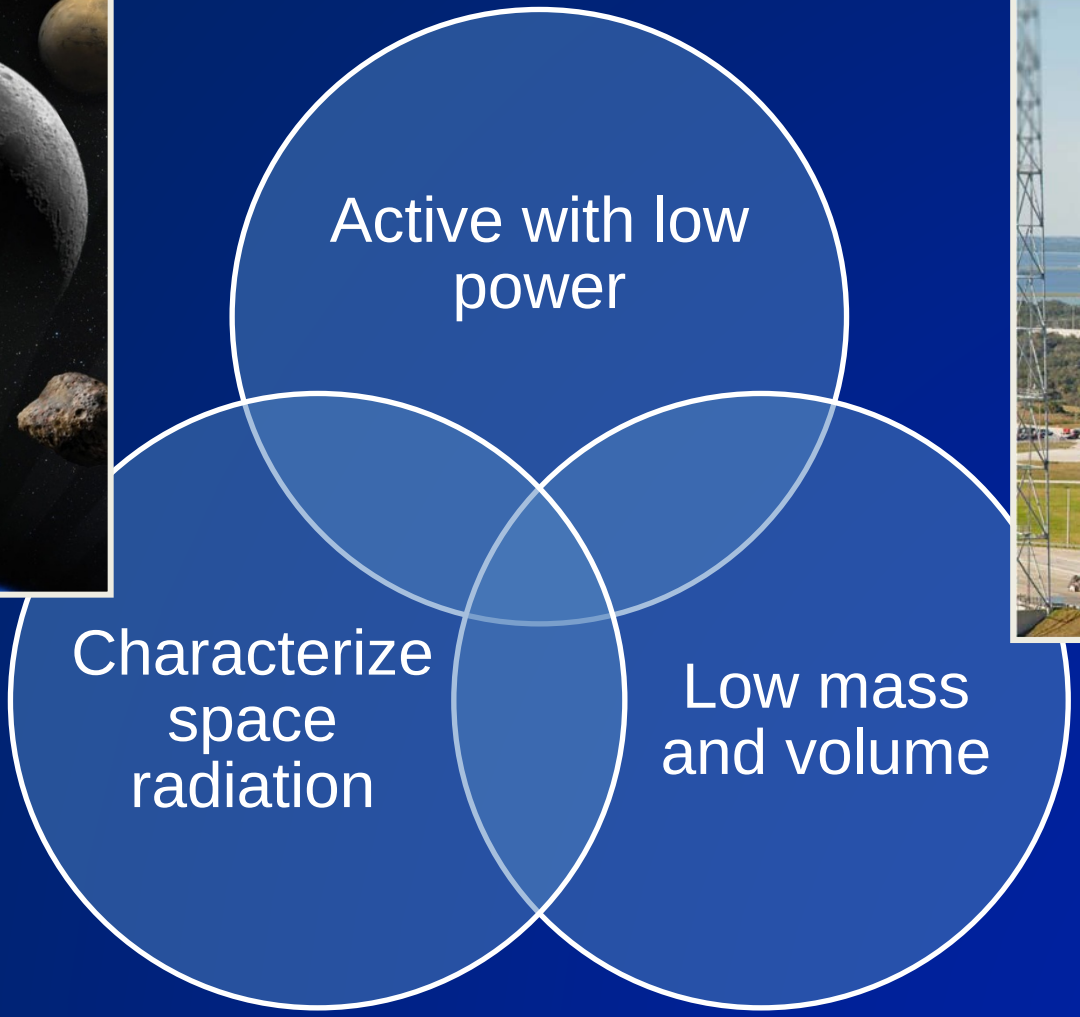


BIRD Aim 2

- Data Acquisition
  - EFT-1 data from launch to landing
  - High-altitude Van Allen belt passes

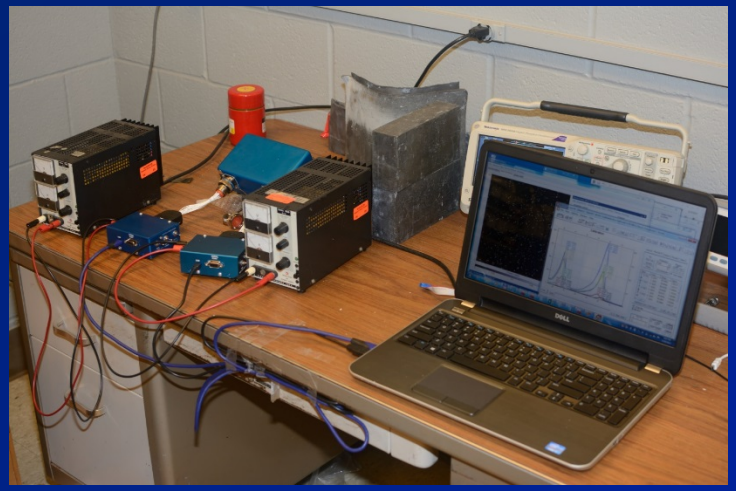


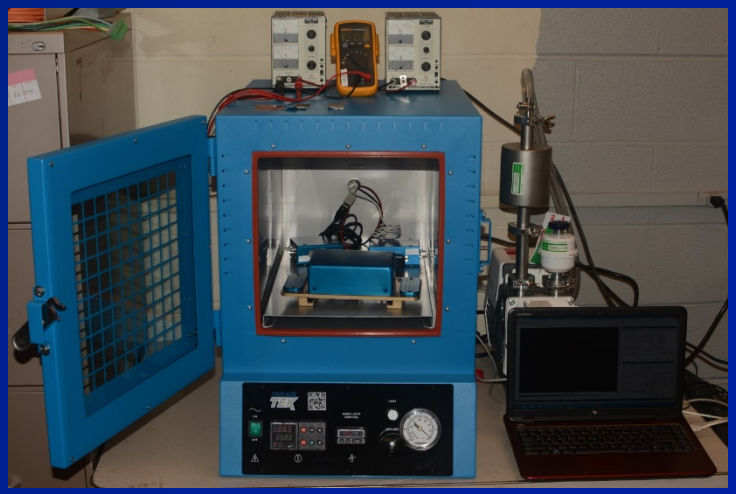
Exploration Mission Monitoring



Data Products

- BIRD Data Stored
  - ToT counts
  - Date-time
  - Duration
  - Acceleration
  - Temperature
- Ground Software Products
  - Absorbed dose
  - Angle and dE/dx
  - Dose equivalent
- Z & E identification/binning





Radiation Testing Opportunities

- April 2013
  - 500 AMeV and 1 AGeV ^{56}Fe
  - 300 and 600 AMeV ^{12}C
- May 2013
  - 300 and 400 AMeV ^{4}He
  - 50 and 300 AMeV ^{1}H
- June 2014
  - Flight unit testing
  - Rates matched to AP9 predictions

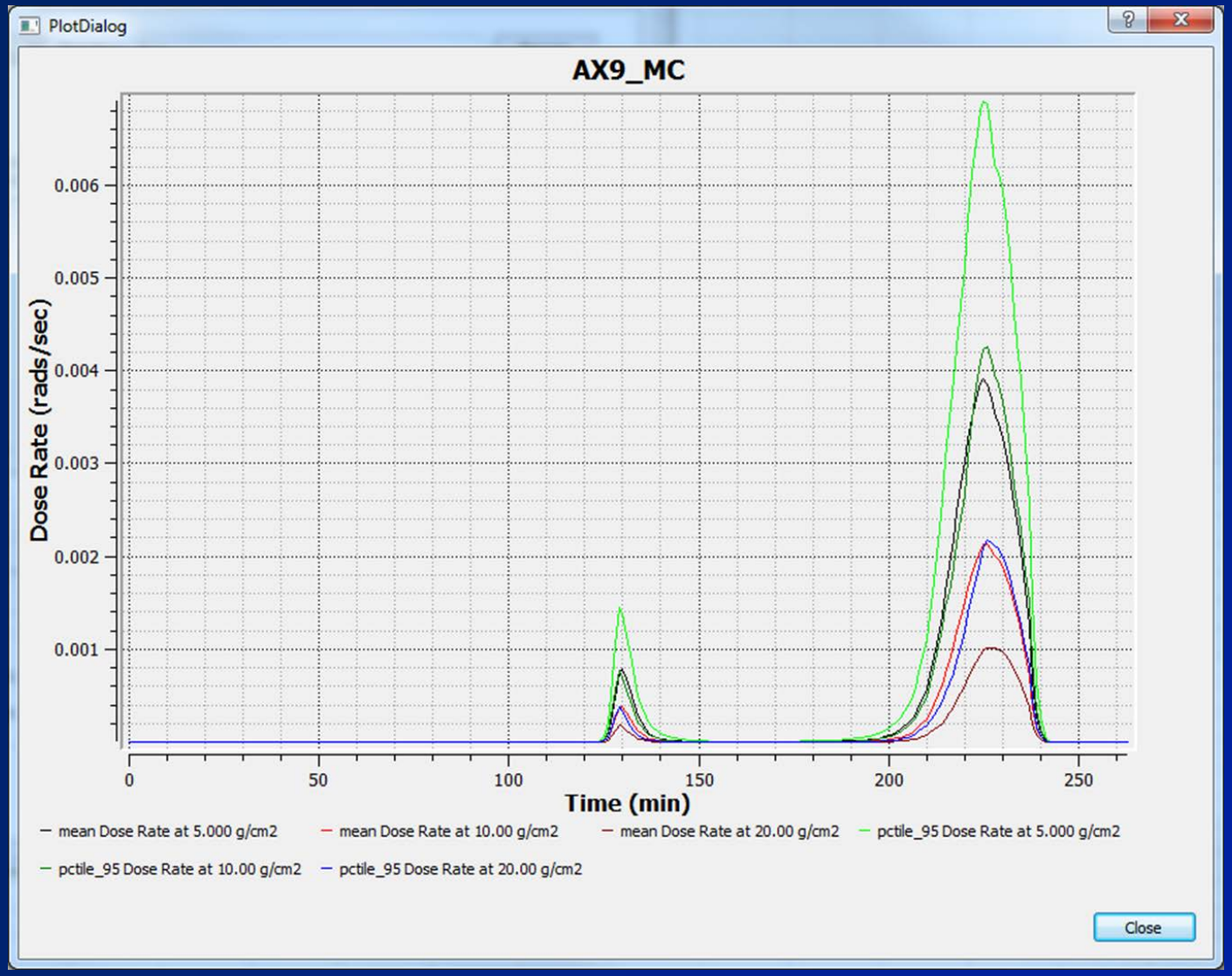
April 2013 NSRL Summary

- Single event upsets
  - Iron and Carbon
  - Very high fluence rates
- Upsets from 1 AGeV ^{56}Fe
  - Required power cycling
  - Large local energy depositions
- Upsets from 600 AMeV ^{12}C
  - Watchdog timer recovered
- LET estimates improved by data processing algorithms

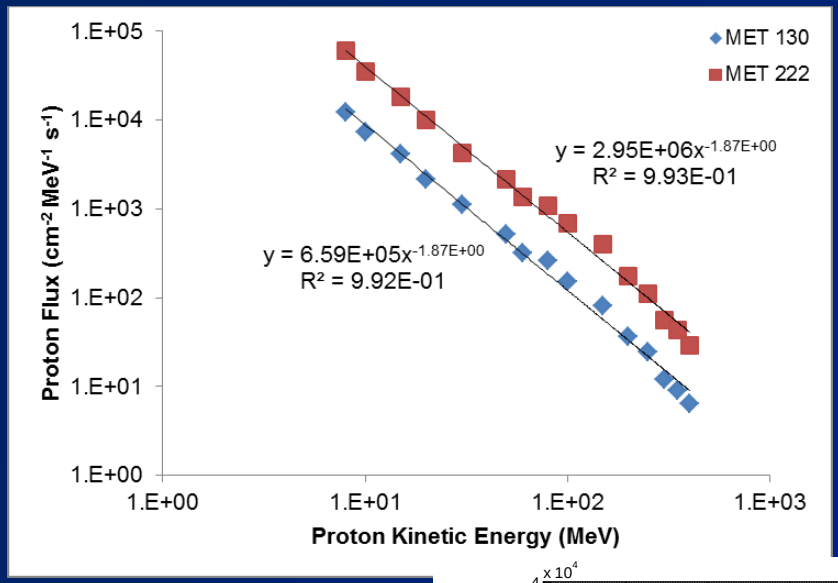
May 2013 NSRL Summary

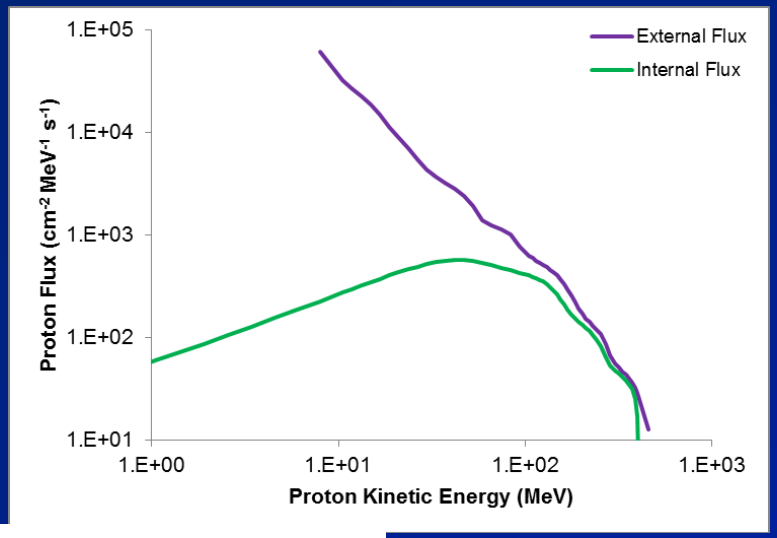
- BIRD EU2 in GSE mode
  - Energetic alpha particle data for algorithm development
- BIRD EU2 operation tested
  - Low- and moderate-energy
  - Rates far exceeding the AP9-predicted max integral flux (>20 MeV)
- No SEUs were observed
- Tests indicate BIRD will operate in the predicted environment

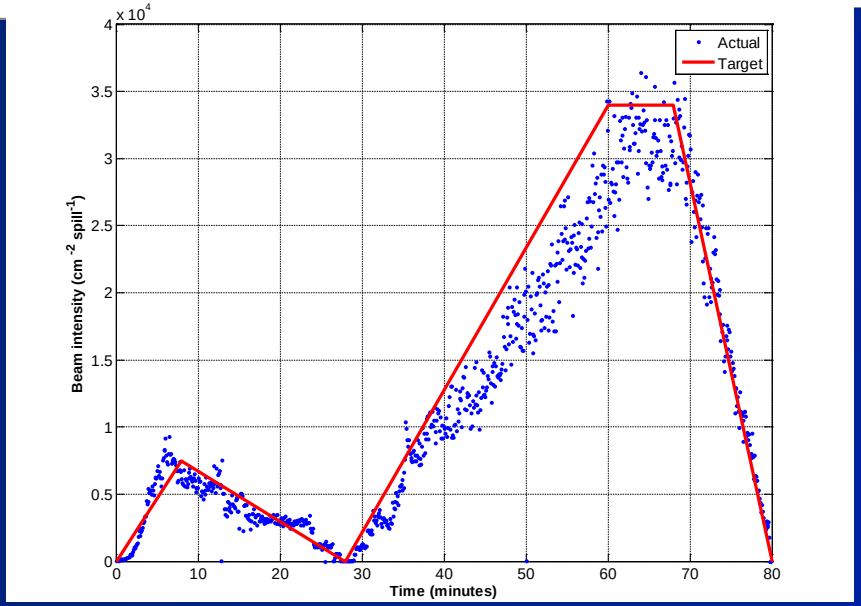
June 2014 NSRL Testing



June 2014 NSRL Testing





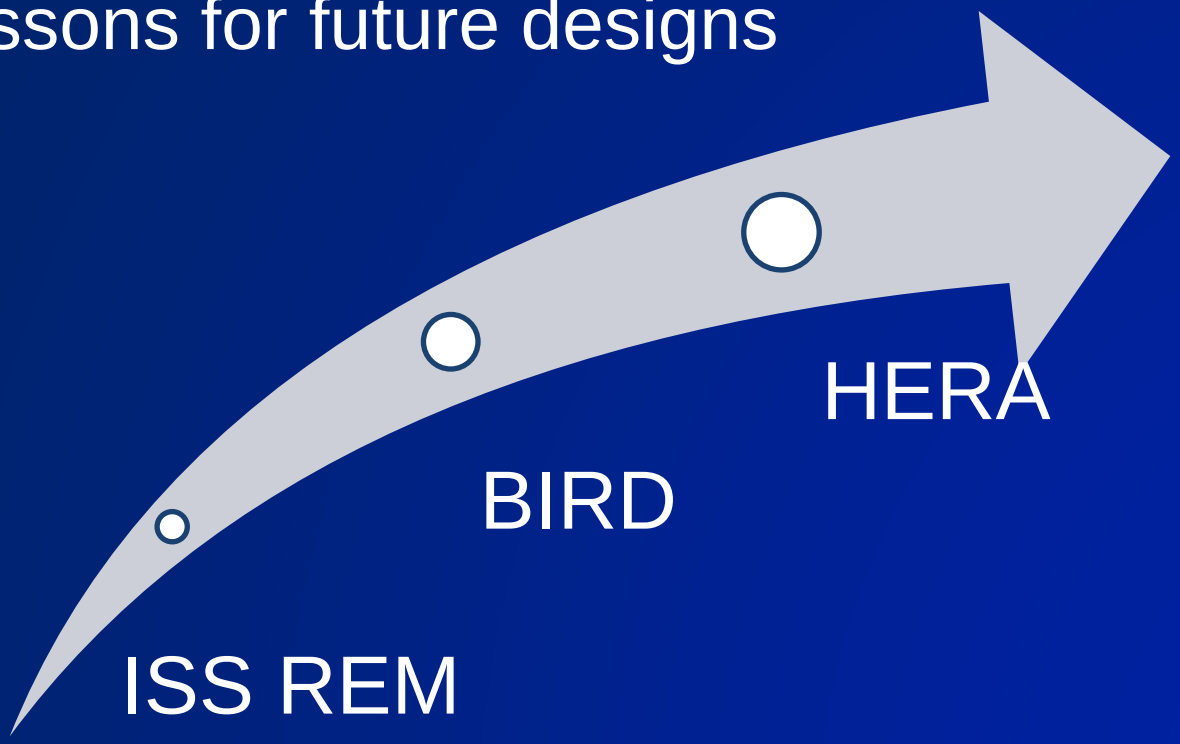


June 2014 NSRL Summary

- No SEU in primary beam
- High occupancy for frames near local maxima
- Usable dosimetry data will still be acquired

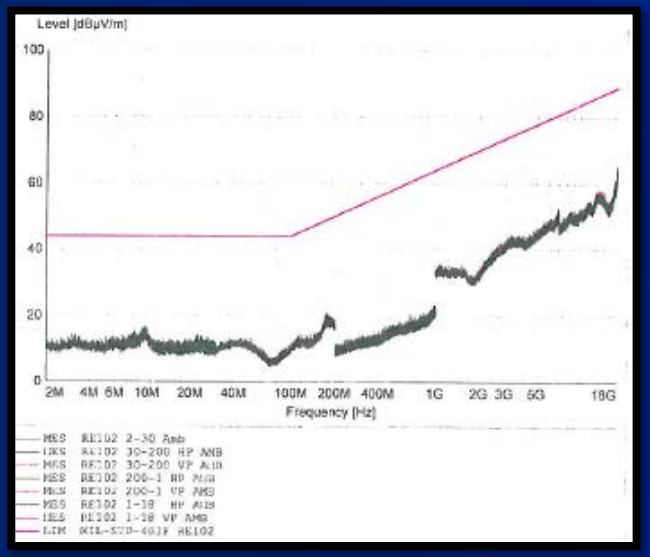
BIRD Aim 3

- Flight Hardware Experience
  - NASA processes
  - Lessons for future designs

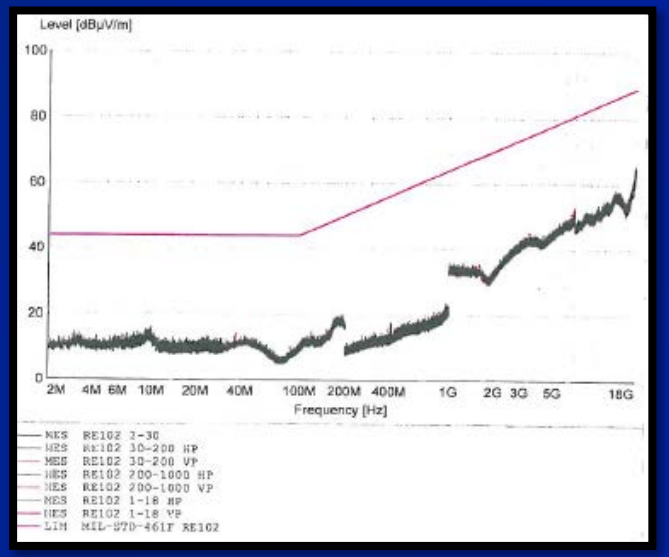


EMI Testing

- Radiated Emissions (RE102) was performed on flight unit 2 (SN 1002)
  - 2 MHz – 18 GHz electrical field
- Installed on vibration test fixture
  - Mimic same clamping mechanism and bonding as the vehicle
  - Bond measured to be < 2.5 mohms
- Passed, no exceedances noted

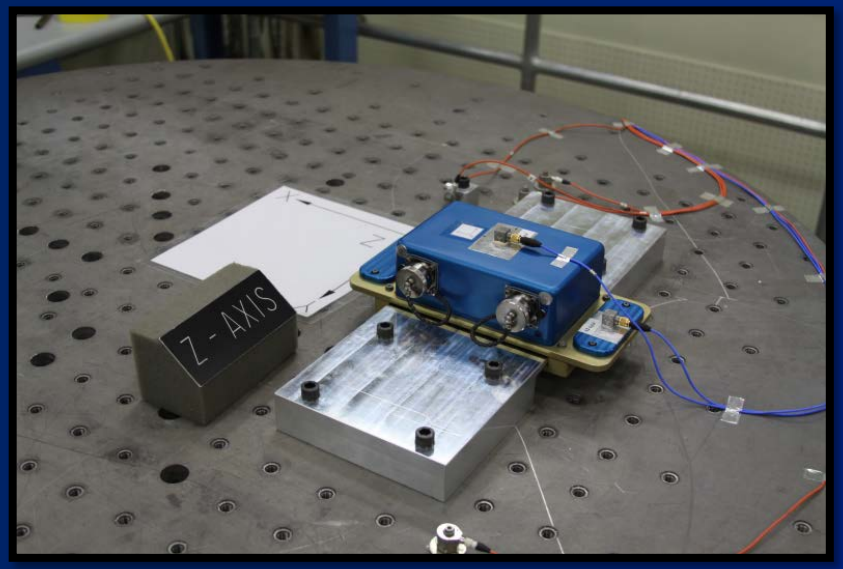


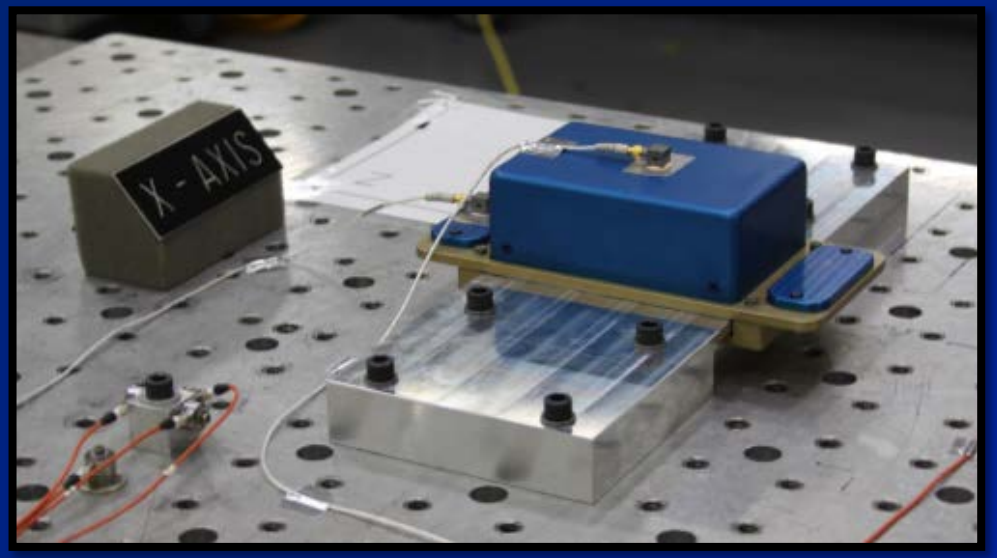
Background (baseline)

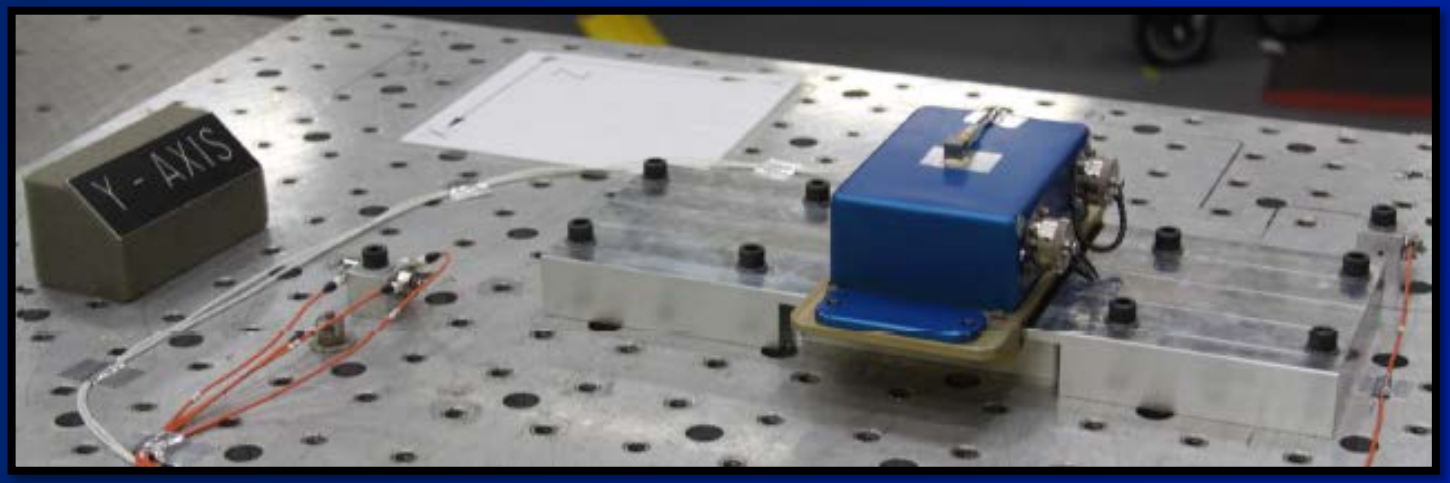


BIRD radiated

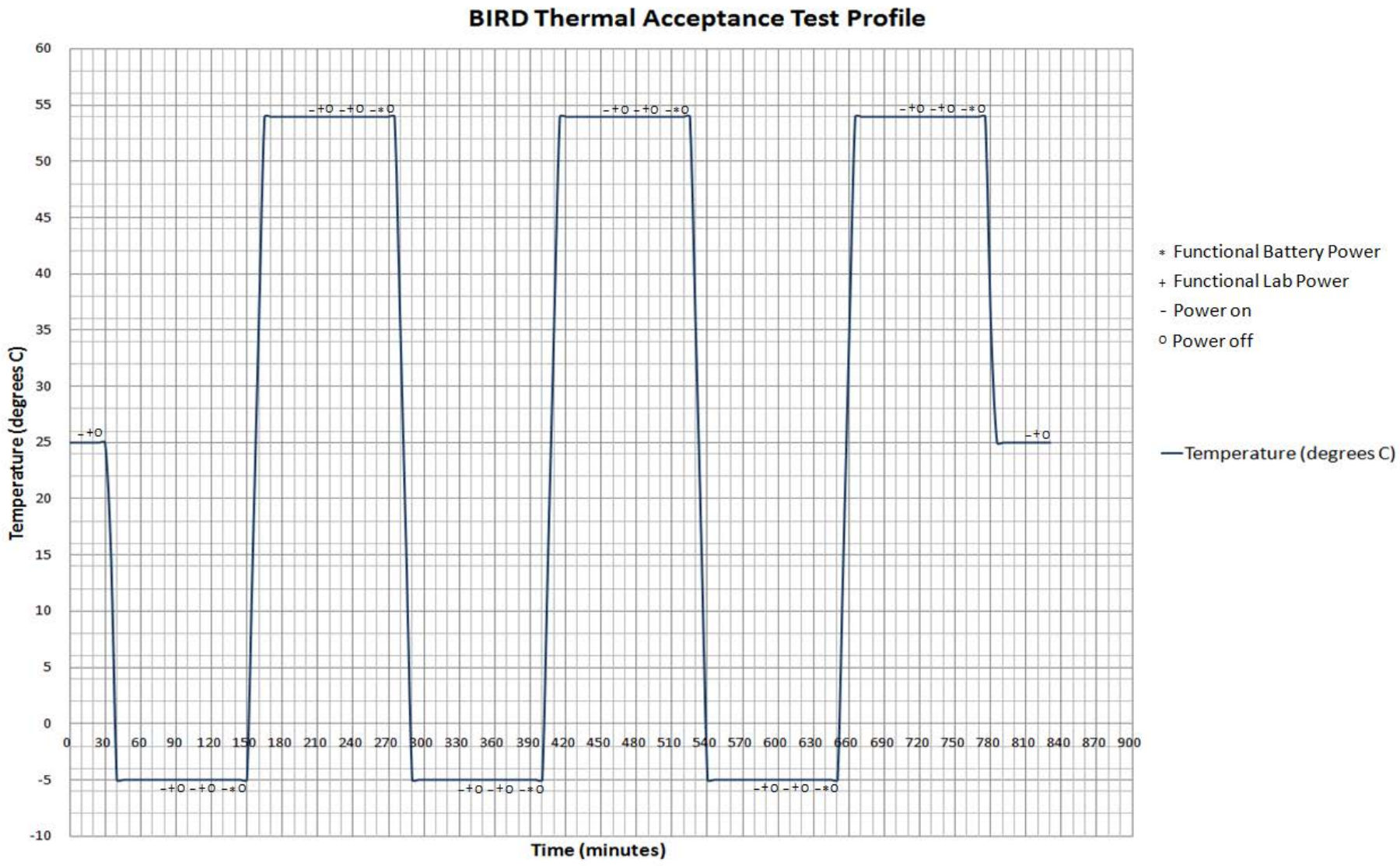
Vibration Testing



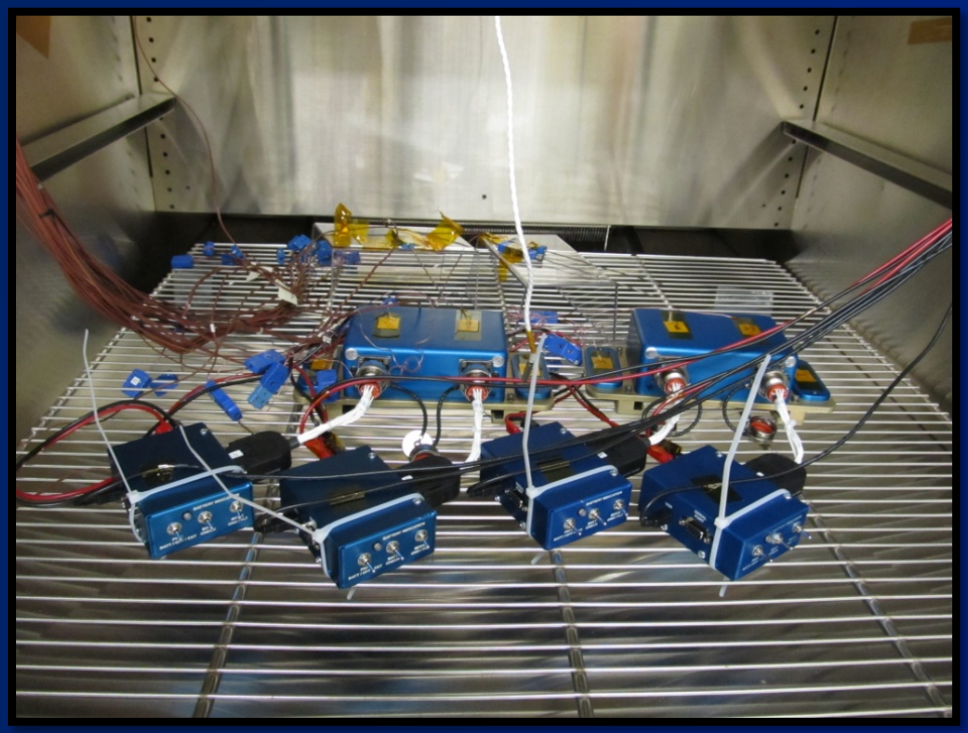




Thermal Testing

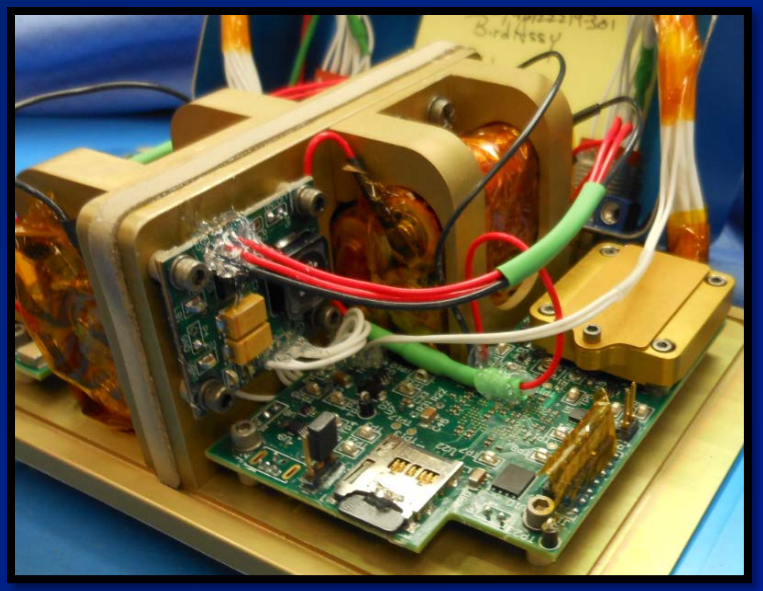


Thermal Testing



Lessons Learned

- Main fuse
  - Short from mate/de-mate
  - Replaced with slow blow fuse



- Battery wires
  - Pinched between connector and cover
  - Replaced battery assembly
  - Staked wires

Concept of Operations

Pre-flight

- Functional check
- Enter sleep mode
- Install in Orion MPCV

Flight

- Begin data acquisition upon launch
- Terminate once voltage drops below threshold
- Graceful shutdown

Post-flight

- De-install from Orion MPCV
- Transfer data from BIRD
- Analyze and distribute data

Conclusion

- BIRD development completed
- Experience gained
  - Timepix communication and control
  - Data acquisition
  - Flight hardware
- Final test is December 2014 (EFT-1)
  - Anticipate a successful flight
  - Excited to analyze unique data

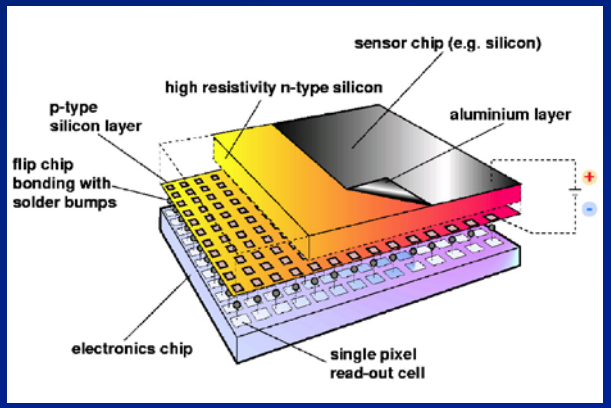
References

- Medipix Collaboration, http://medipix.web.cern.ch/medipix
- Pinsky L. S. and Chancellor J. (2007)
- Pinsky L. S. et al. (2012) *2012 IEEE Aerospace Conference*
- Turecek D. et al. (2011) *JINST*, 6, C12037
- Vykydal Z. and Jakubek J. (2010) *Nucl. Instr. Meth. A* **633** S48
- Hoang S. et al. (2012) *CHEP 2012*
- NASA Orion MPCV EFT-1, http://www.nasa.gov/exploration/systems/mpcv/test_flight_2014.html

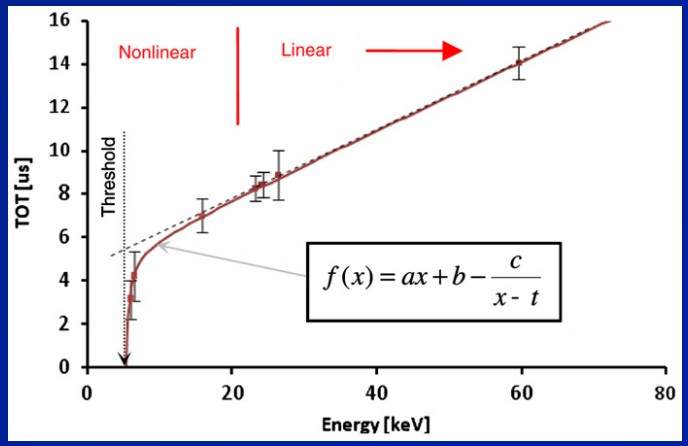
Backup Slides

Introduction

- Timepix chip
  - Single energy threshold
  - 55 µm pixels
  - 256 x 256 pixels
  - Active area ~2 cm^2
  - Silicon detection element



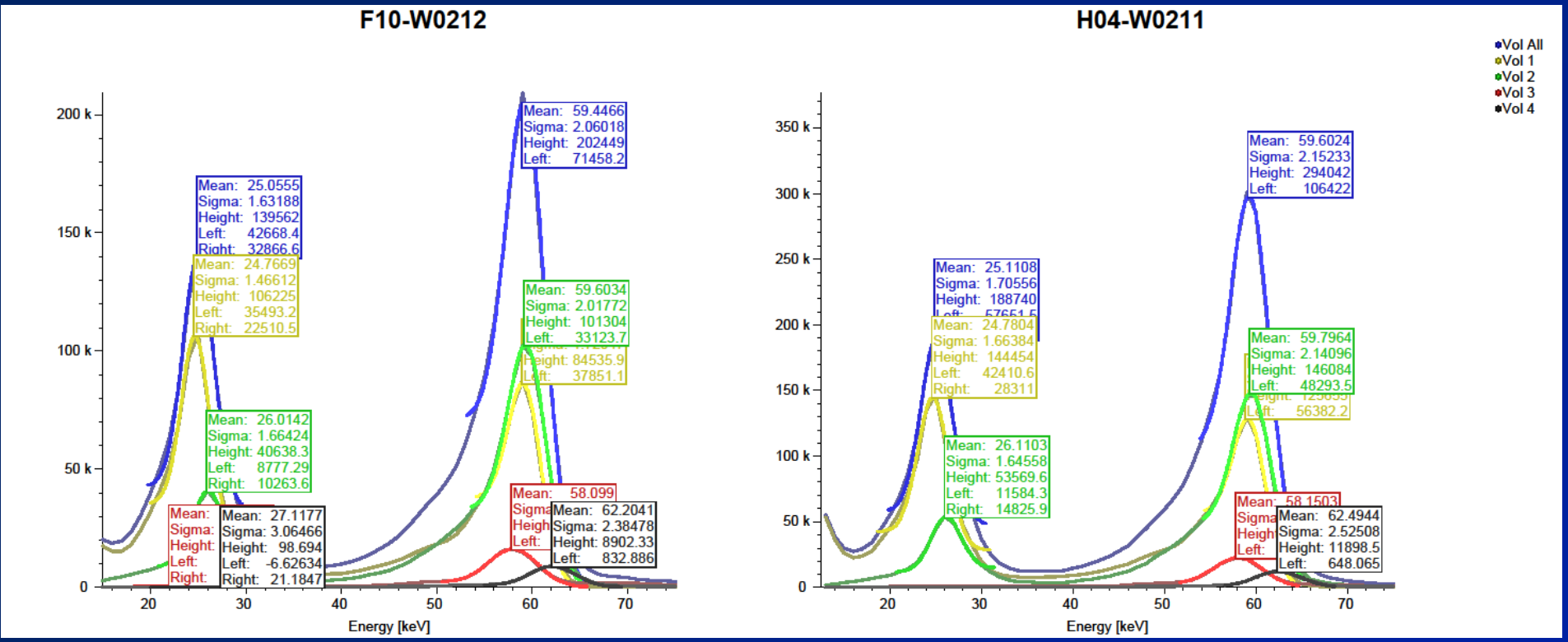
L. Pinsky and J. Chancellor *IEEE* (2007)



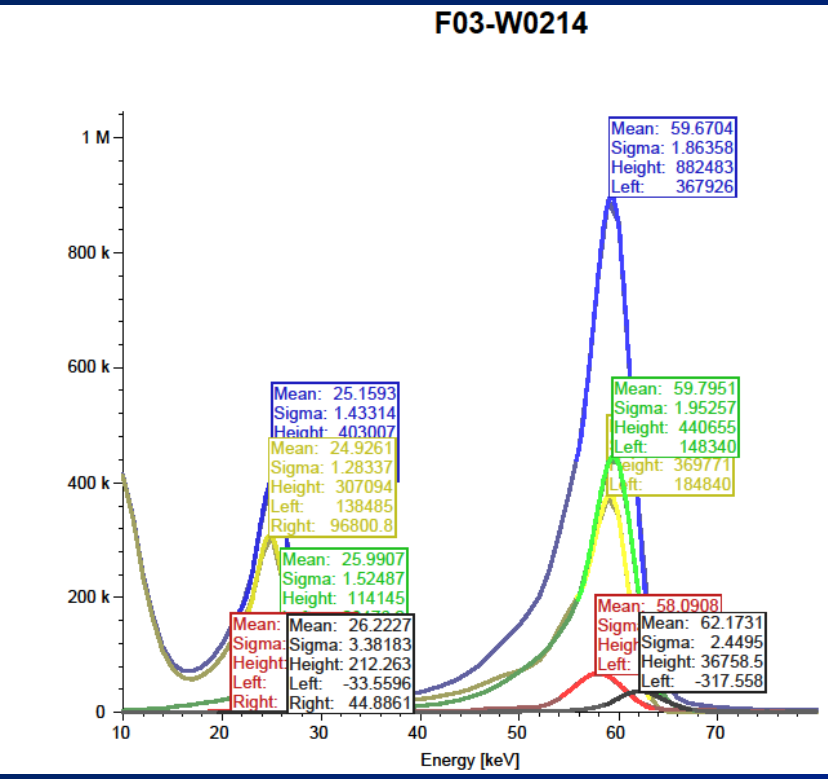
J. Jakubek *Nucl. Inst. Meth. A* **633** (2011)

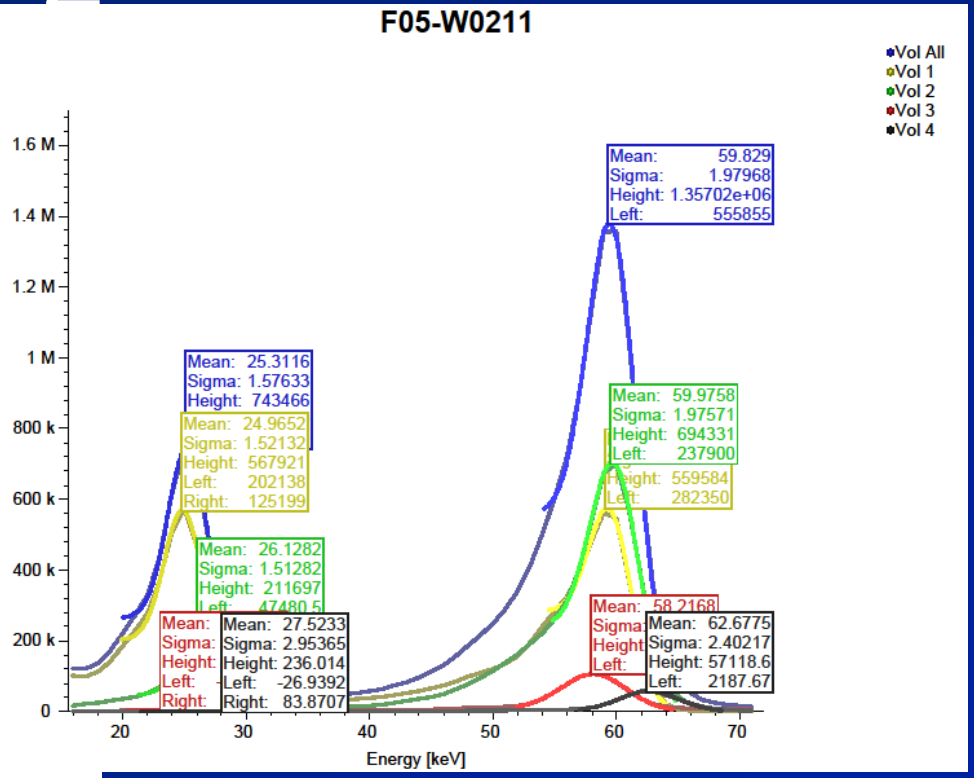
Verification

Flight Unit 1



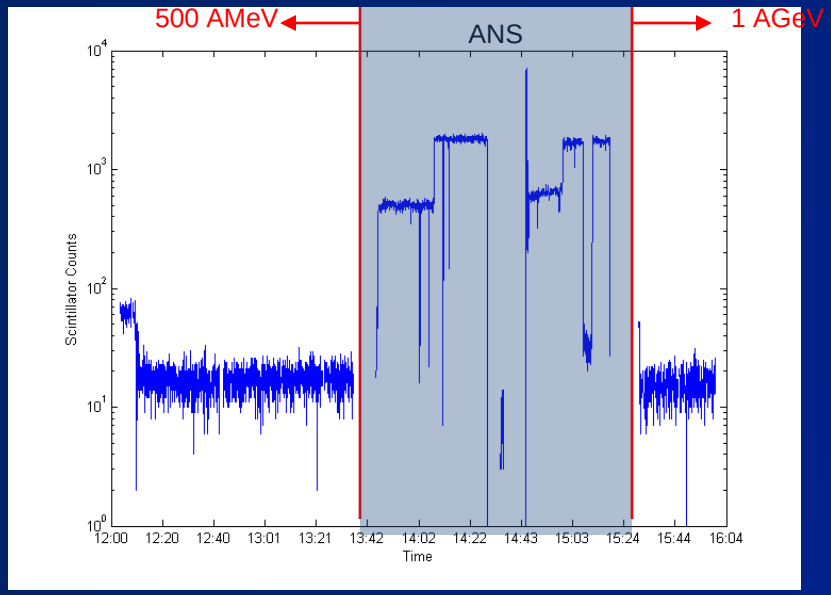
Flight Unit 2



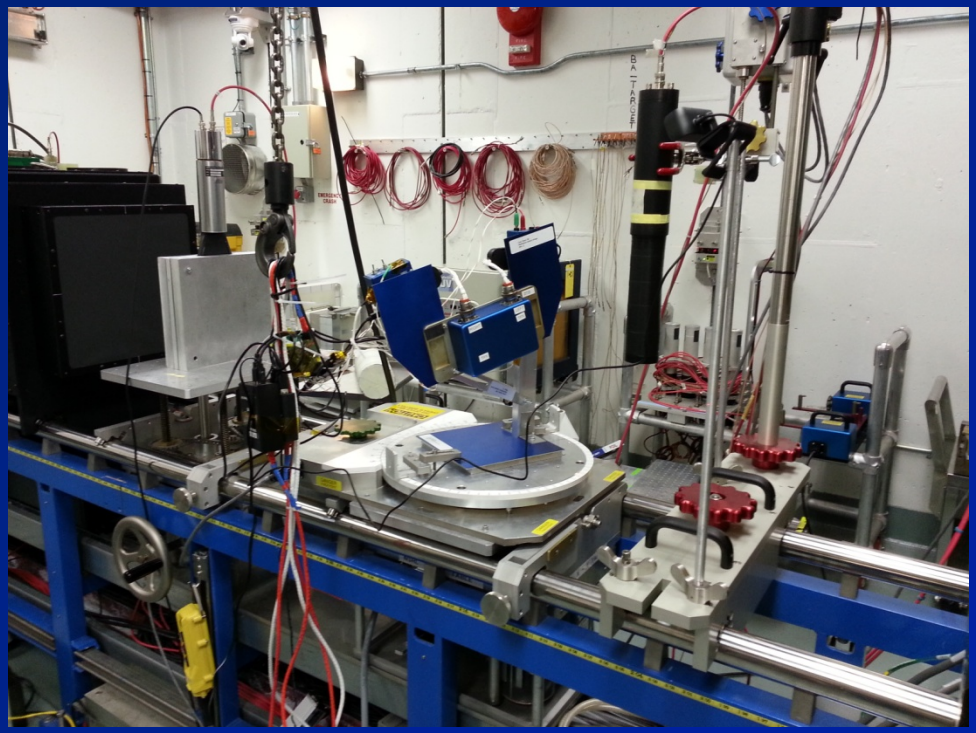


April 2013 NSRL - Iron

- 500 AMeV and 1 AGeV ^{56}Fe
- Incidence angles of 30º and 60º
- Both GSE and Flight Modes
- Utilized External Power



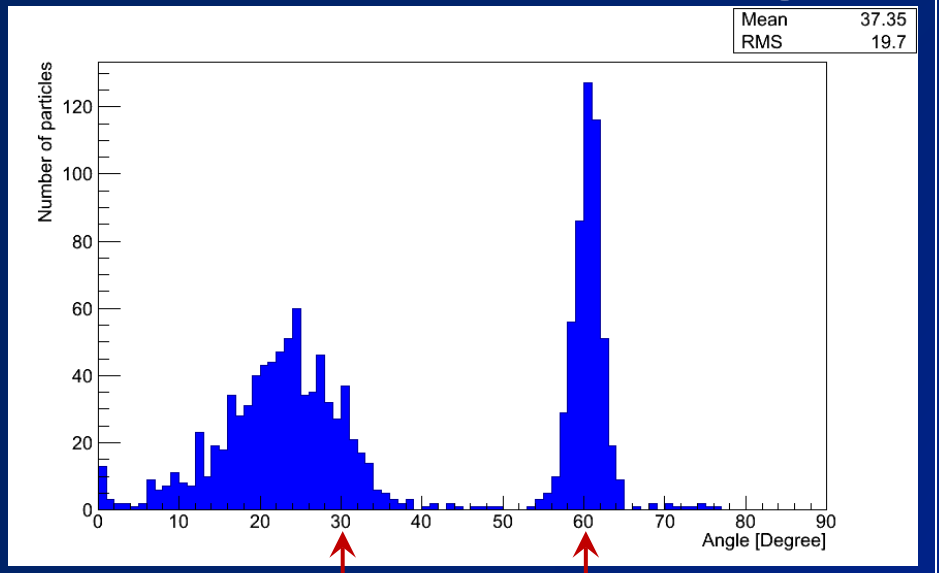
Irradiation Profile



Hardware Setup

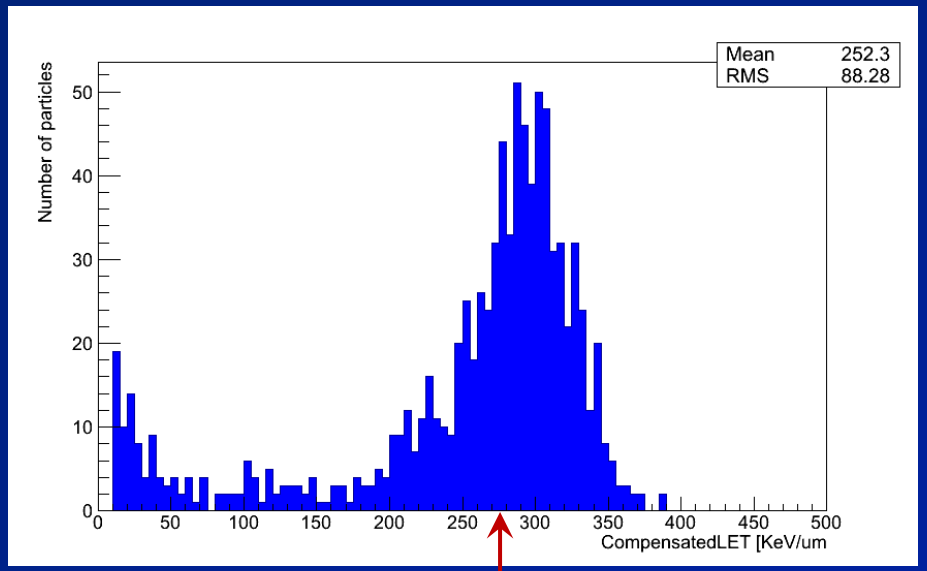
April 2013 NSRL Run
Iron Beam

Corrected Angle Histogram



30 and 60 degree angles of incidence

Corrected LET Histogram



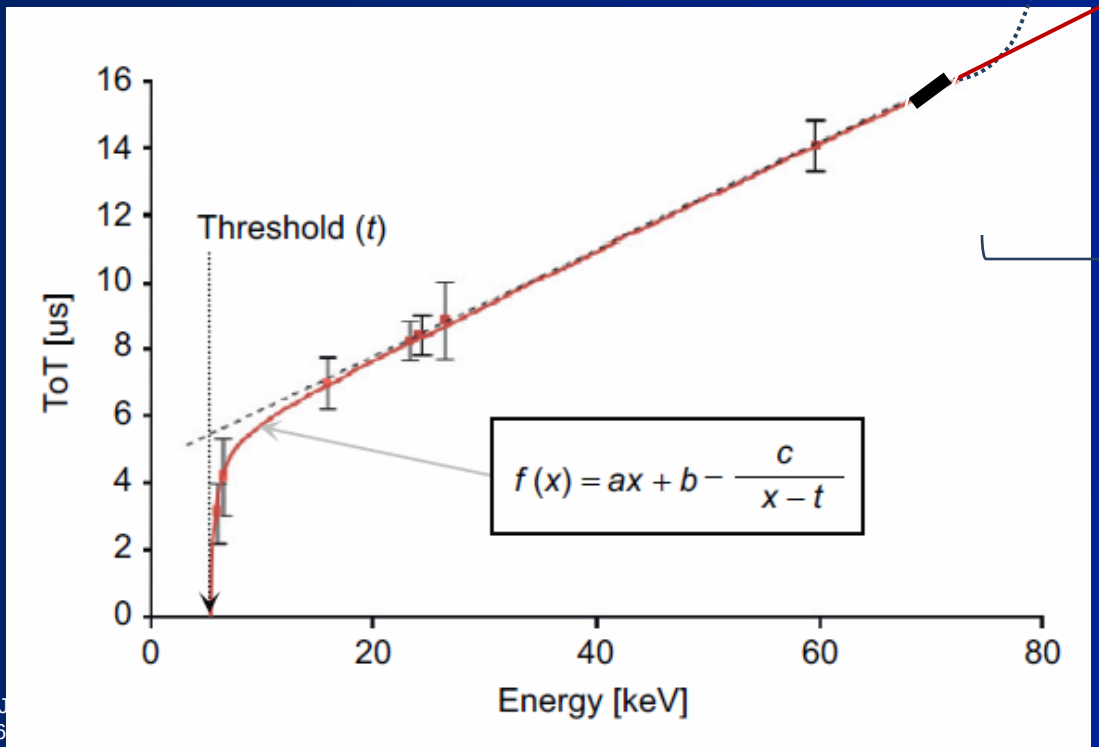
276 KeV/µm expected LET for 1 AGeV ^{56}Fe

Correction applied to account for saturation and ‘volcano’ effects inherent to the Timepix hardware. Such corrections are applied as a post-processing step and enhancements to these algorithms are in development

Saturation Effects

Saturation Effects

- Non-linear region in the calibration curve for ToT value to Energy above around 800 KeV in a single pixel
- Results in an overestimation of energy relative to actual deposition



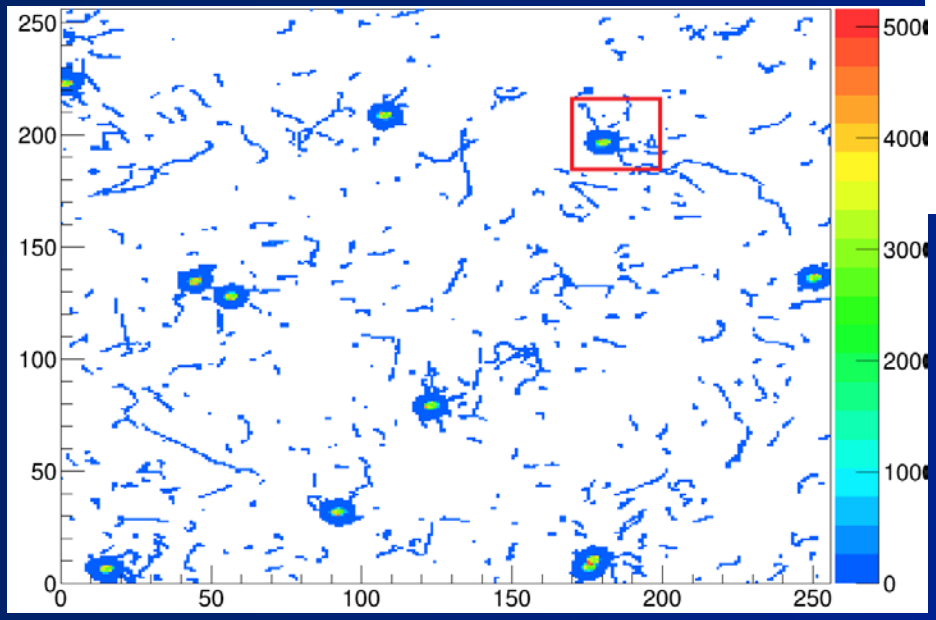
Higher energy depositions (near 800 KeV/pixel) depart from the linear ToT-Energy calibration fit

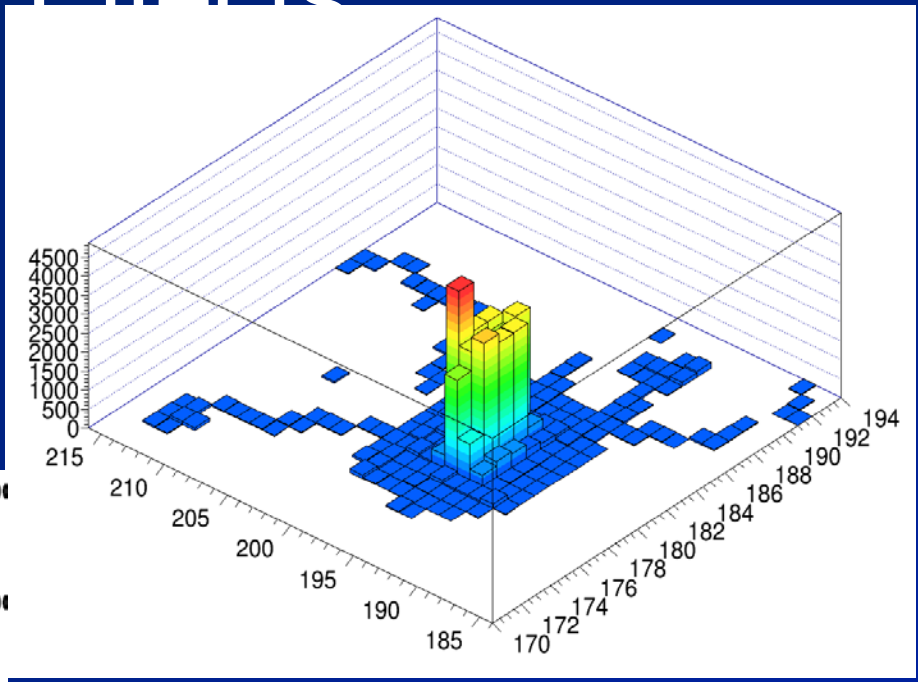
Credit: J
10.1016

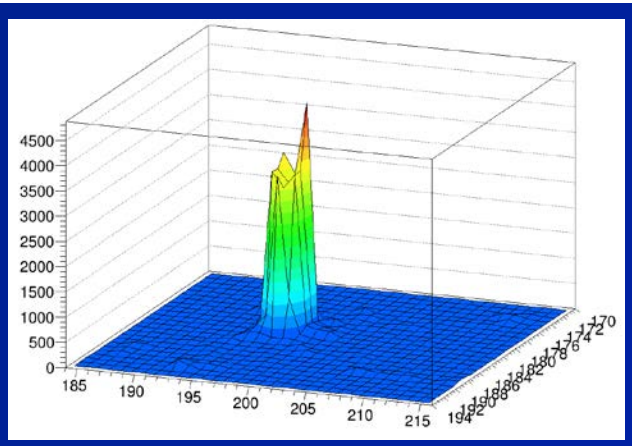
Volcano Effects

Volcano Effects

- Charge collection in cluster center is much lower than the physically expected value
- Result of carrier recombination and pixel-electronics protection circuits

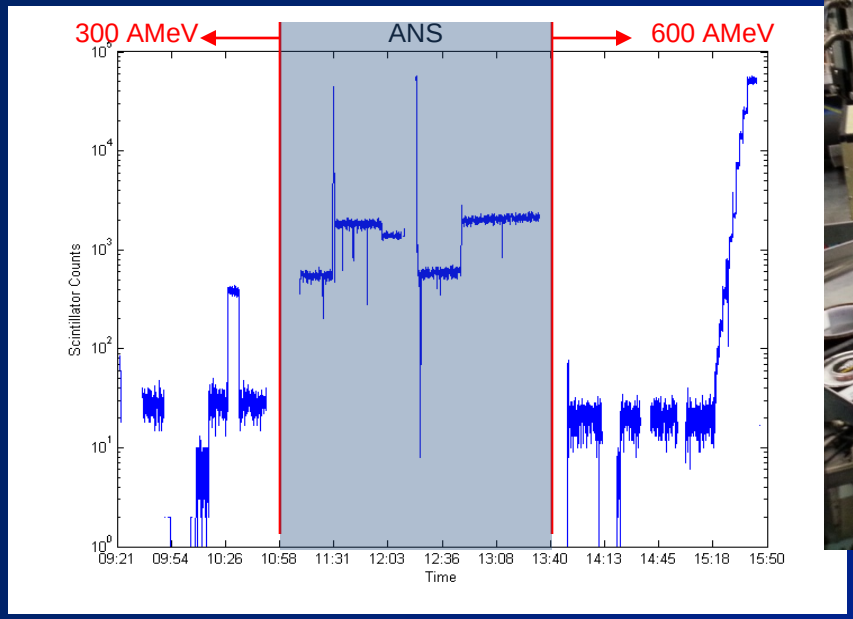




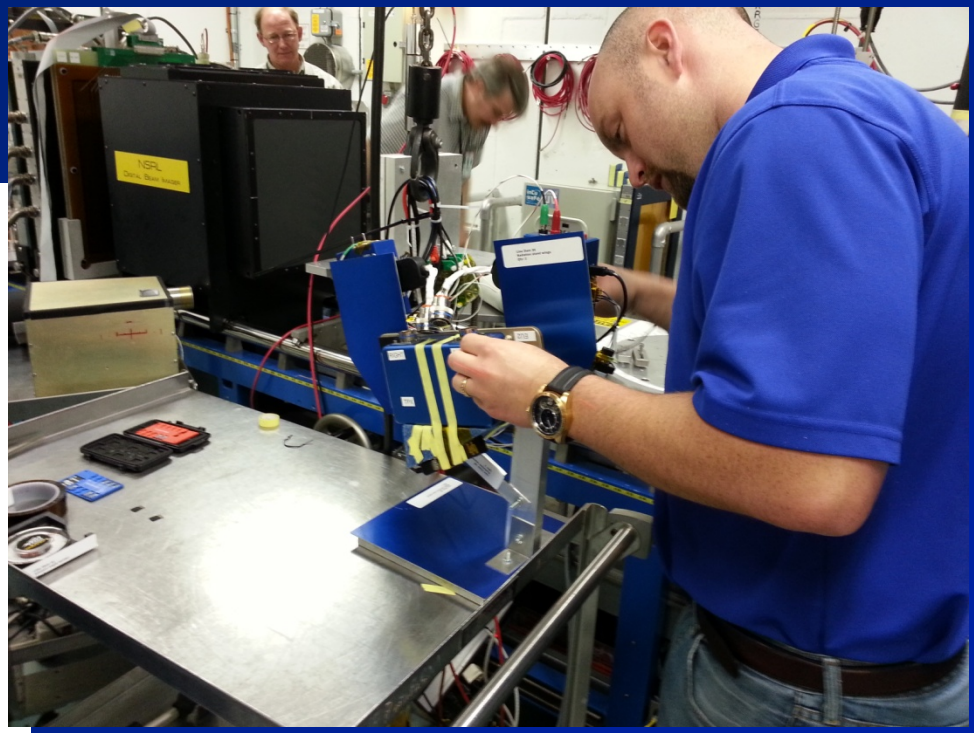


April 2013 NSRL - Carbon

- 300 and 600 AMeV ^{12}C
- Incidence angles of 30º and 60º
- Both GSE and Flight Modes
- Utilized External Power



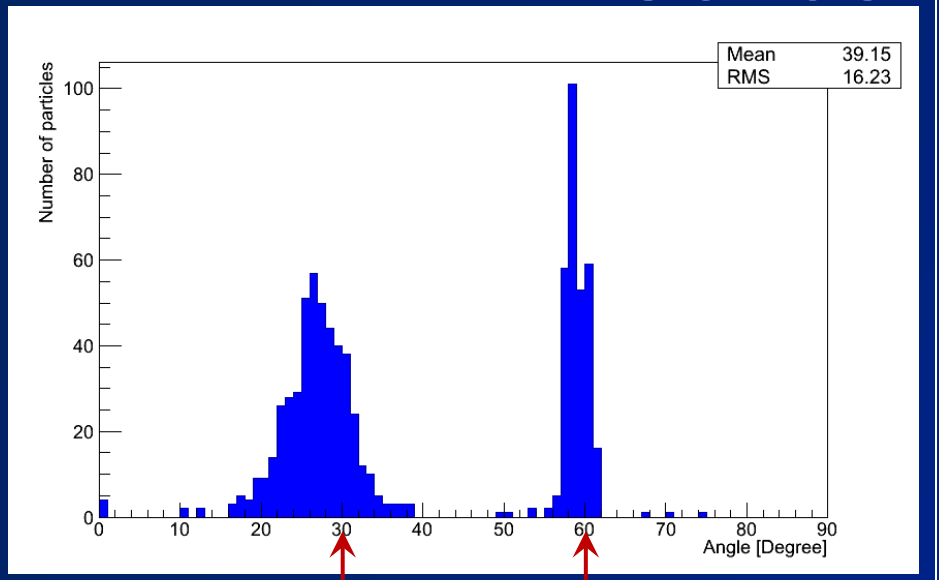
Irradiation Profile



Hardware Setup

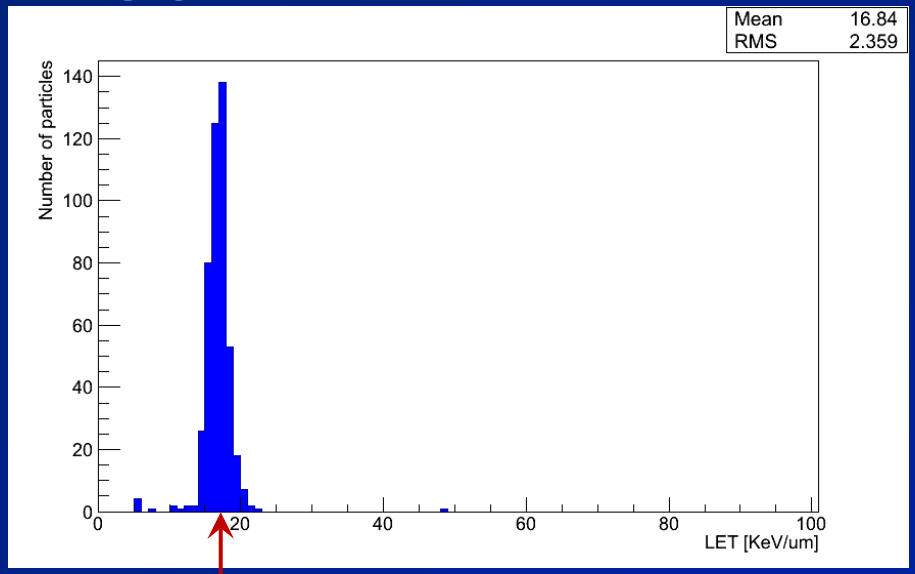
April 2013 NSRL Run
Carbon Beam

Corrected Angle Histogram



30 and 60 degree angles of incidence

Corrected LET Histogram

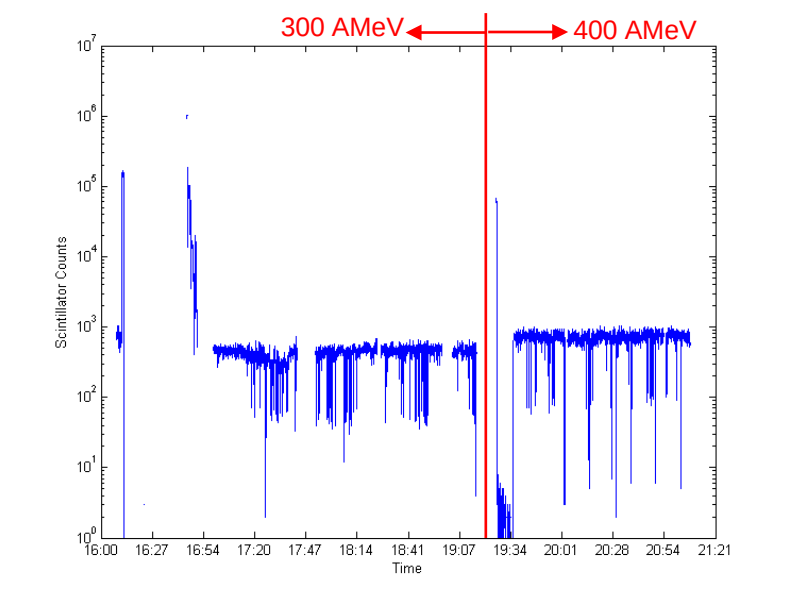


16.9 KeV/µm expected LET for 600 AMeV ^{12}C

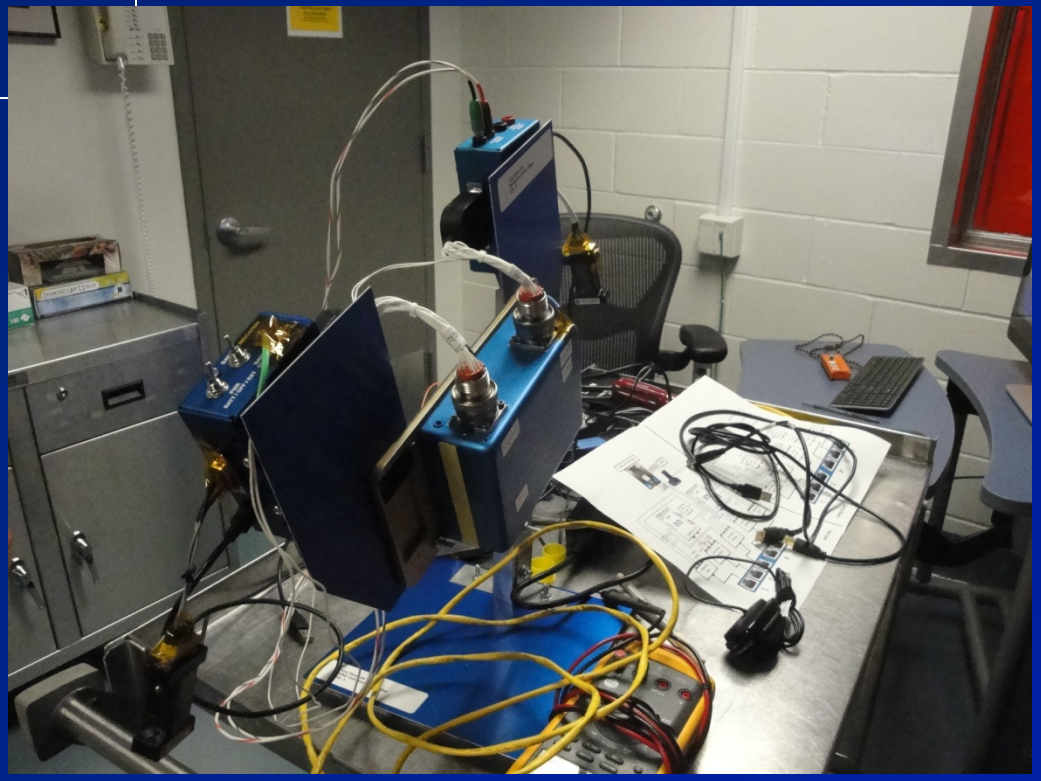
Correction applied to account for saturation and ‘volcano’ effects inherent to the Timepix hardware. Such corrections are applied as a post-processing step and enhancements to these algorithms are in development

May 2013 NSRL - Helium

- 300 and 400 AMeV ^{4}He
- Incidence angles of 0º, 30º, 60º, and 85º
- Both GSE and Flight Modes
- Utilized External Power



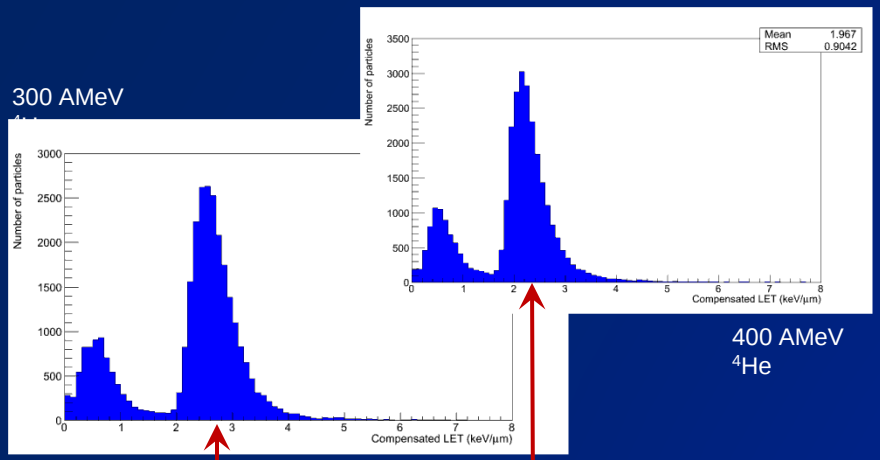
Irradiation Profile



Hardware Setup

May 2013 NSRL Run
Helium Beam

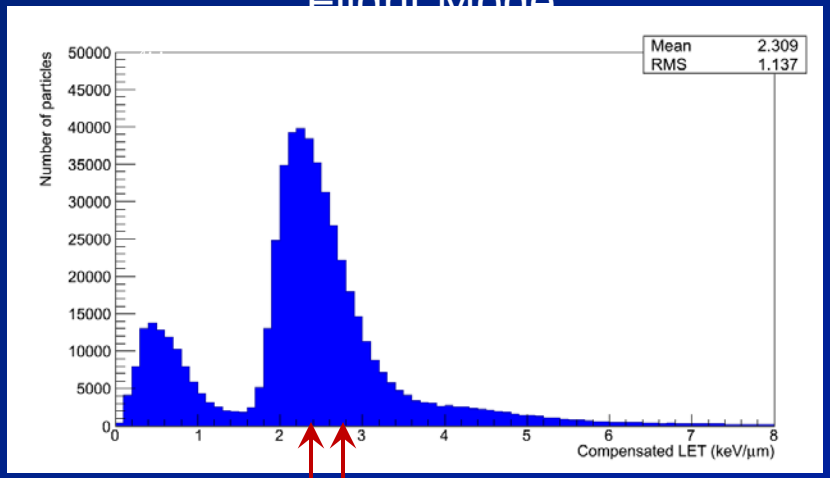
Corrected LET Histogram (Left)
GSE Mode



2.65 KeV/µm

2.29 KeV/µm

Corrected LET Histogram
(Right)
Flight Mode



2.29 KeV/µm
400 AMeV 4He

2.65 KeV/µm
300 AMeV 4He

Correction applied to account for saturation and ‘volcano’ effects inherent to the Timepix hardware. Such corrections are applied as a post-processing step and enhancements to these algorithms are in development

May 2013 NSRL - Proton

- 50 and 300 AMeV ^{1}H
- Normal Incidence
- Both GSE and Flight Modes
- Utilized External Power
- Proton energy similar to that expected on EFT1