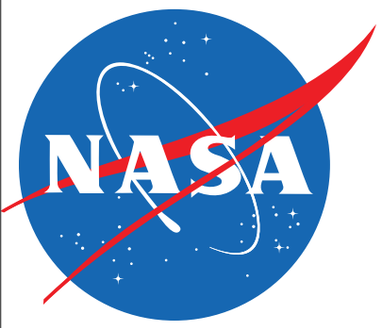
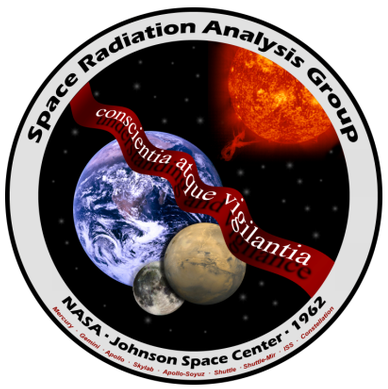
Status of the International Space Station Radiation Assessment Detector

18th Workshop on Radiation Monitoring for the International Space Station
3-5 September, 2013

R. Rios[1], K. B. Beard[1], E. Semones[2]
on behalf of the ISS-RAD Team

[1] Lockheed Martin, [2] NASA - JSC





SRAG-CONF-RAD-2013-013

overview

The International Space Station (ISS) Radiation Assessment Detector (RAD) is an intra-vehicular energetic particle detector designed to measure a broad spectrum of charged particle and neutron radiation unique to the ISS radiation environment.

→ ISS-RAD is being built by Southwest Research Institute (SwRI).

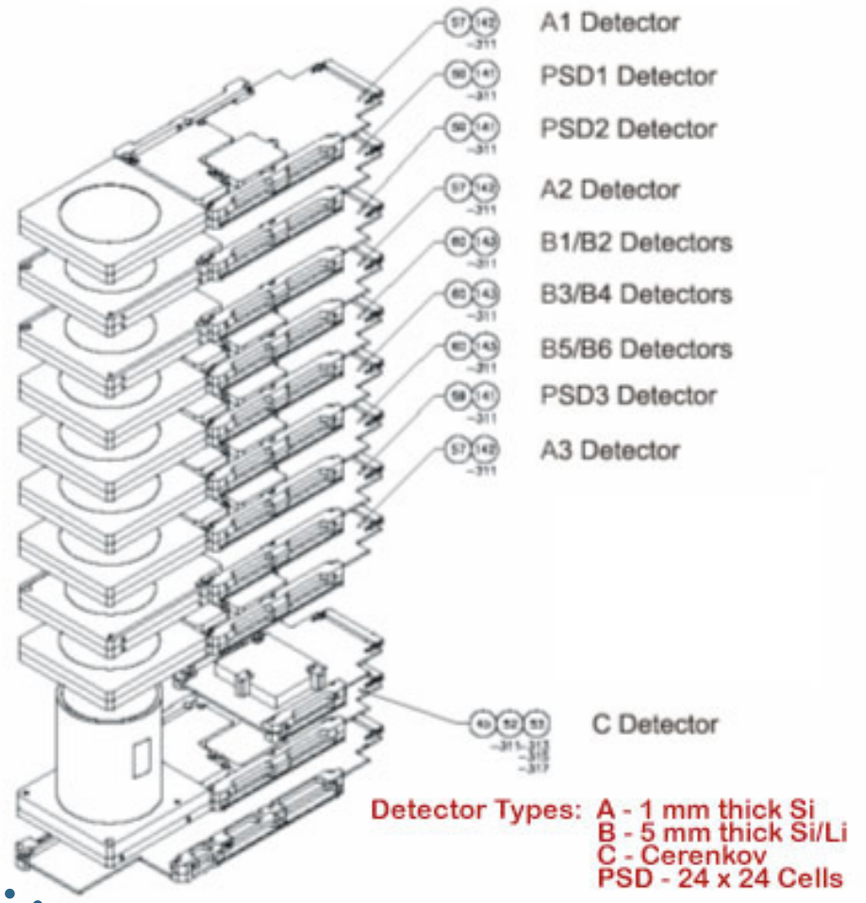
→ NASA JSC's Space Radiation Analysis Group (SRAG) has been overseeing the development of the ISS-RAD.

- This talk will lightly touch on:
    - CPDS → ISS-RAD
    - Engineering Model: from delivery to return
    - Preliminary look at data
    - Data products
    - Current status of ISS-RAD
    - Closing remarks

CPDS → ISS-RAD

- JSC has been operating the CPDS (Charged Particle Directional Spectrometer) family of detectors for ~13 years; this includes:
  - 1 × Intra-Vehicular CPDS (IV-CPDS)
  - 3 × Extra-Vehicular CPDS (EV-CPDS)
    - EV1 - points forward along velocity vector.
    - EV2 - points toward anti-velocity vector.
    - EV3 - points along zenith direction. (Still operational).

- ISS-RAD is poised to replace CPDS.
  - Will offer high-precision measurements.
  - Insight to the neutron component of ISS radiation environment.

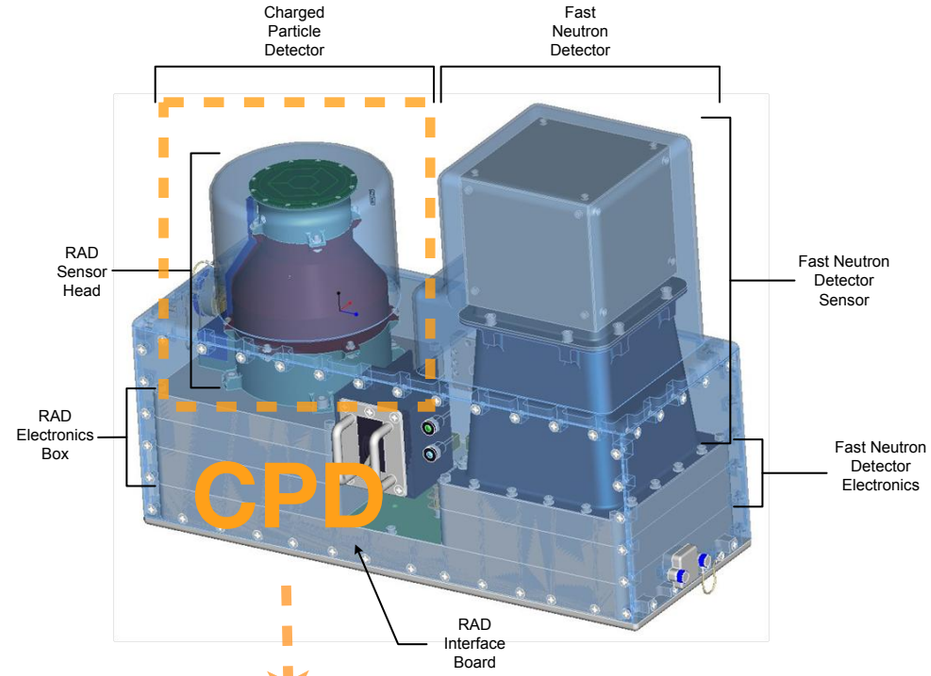


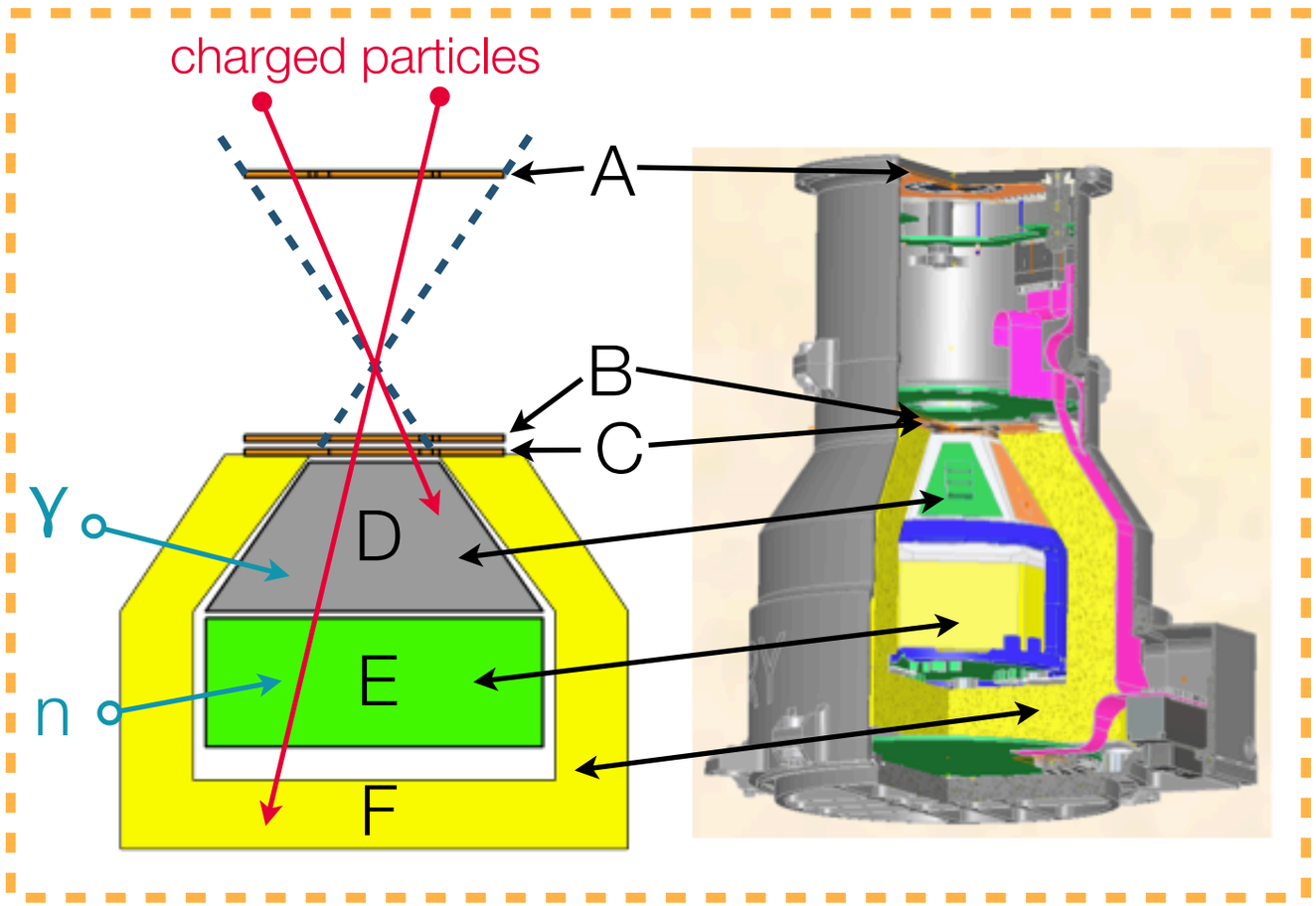
Radiation Assessment Detector (RAD)

- ISS-RAD is based on the Mars Science Laboratory RAD (MSL-RAD), with several exceptions, like:
  - an additional telemetry channel;
  - use of different materials;
  - addition of a fast neutron detector;
  - interface board.
- ISS-RAD contains two main detector-systems.
  - Charged particle detector (**CPD**).
  - Fast neutron detector (**FND**).
- Charged particles:
  - Time-resolved energy spectra for particles with $1 \leq Z < 26$ (proton → Fe).
  - Detect incident protons with $E > 20$ MeV.
  - Proton flux in three bins within $20\ \text{MeV} < E \leq 100\ \text{MeV}$.
- Differential flux of charged particles:
  - $Z < 3$ within 30 to 200 MeV/nucleon.
  - $3 \leq Z \leq 26$ within 100 to 200 MeV/nucleon.
- Neutrons:
  - Time-resolved energy spectra within 0.5 to 80 MeV.

Charged Particle Detector (CPD)

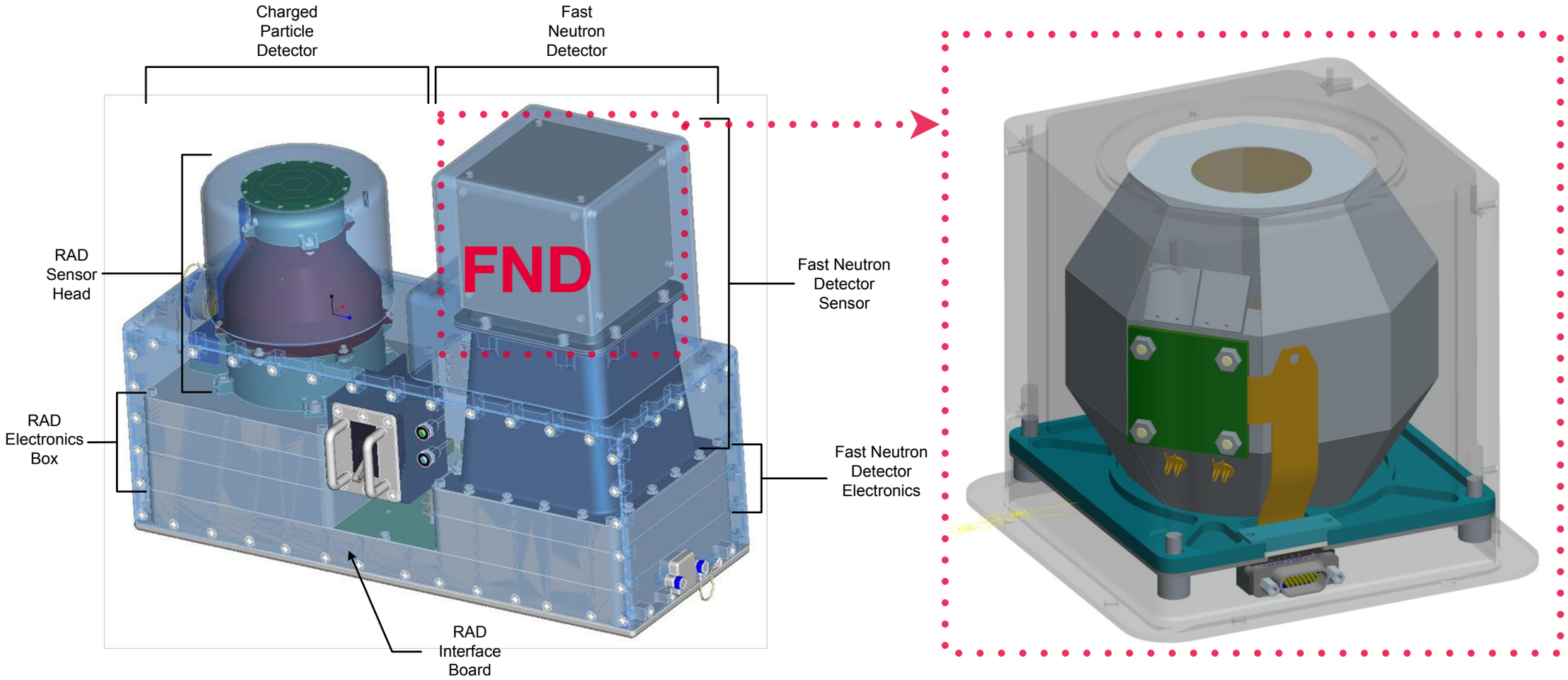
- The CPD consists of four detectors used in measuring the spectroscopy of charged particles – A, B, C, and D.
    - A, B, and C are solid state detectors made from silicon;
        - B provides dosimetry.
    - D is an energy resolving detector made from bismuth germanium oxide (BGO).
- High-energy neutral and charged particles are measured in E, which is made from EJ260XL plastic scintillator.
- F – is an anti-coincidence detector, which is also made from EJ260XL plastic scintillator.





Fast Neutron Detector (FND)

- The FND consists of a natural boron loaded plastic scintillator (EJ254XL).
- Flashes in the scintillator are detected by a 2” ruggedized photomultiplier tube - ET 9272B.
- Gadolinium low energy neutron, X-ray, and γ shield.

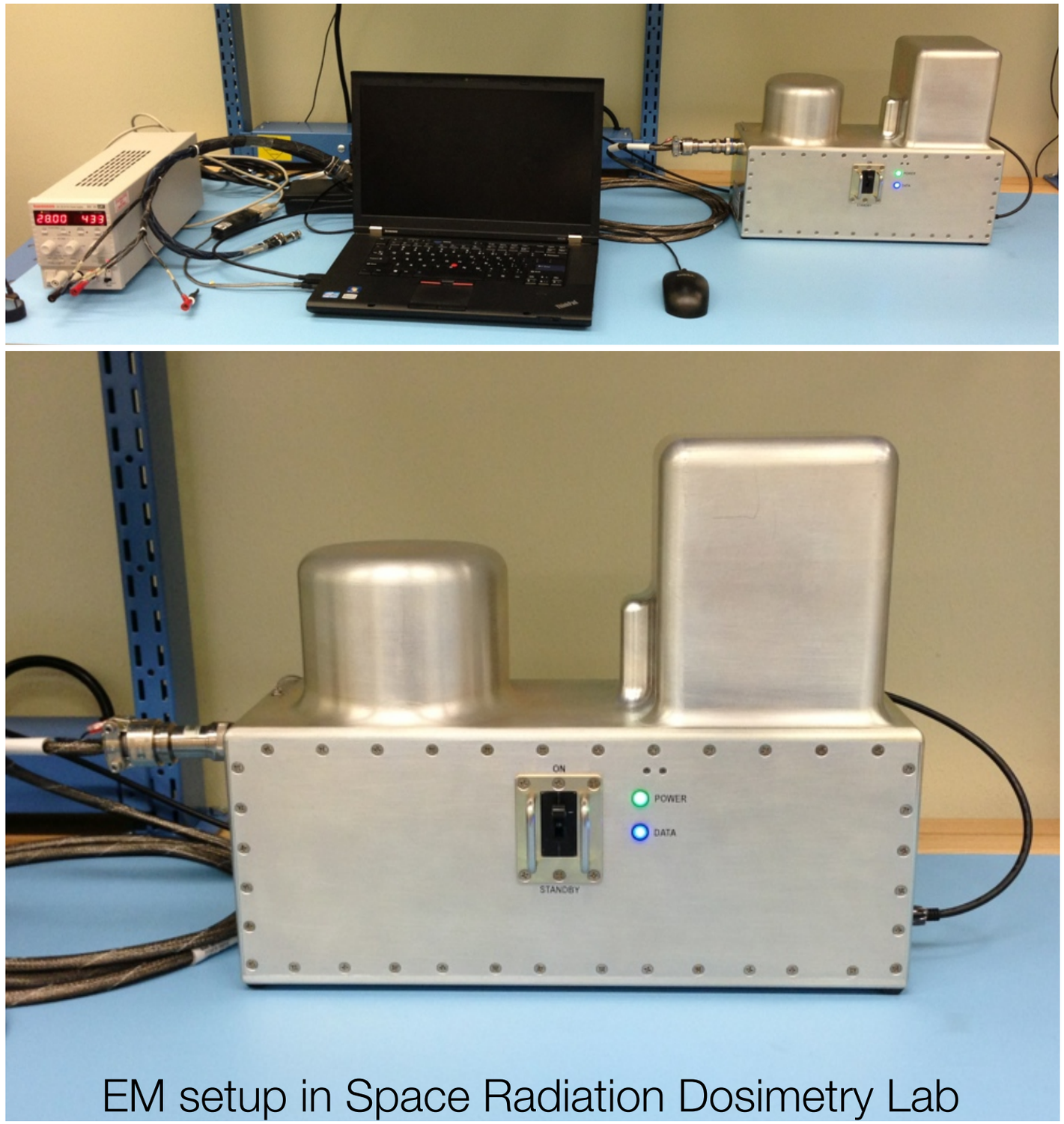


delivery

- The Engineering Model (EM) of ISS-RAD was delivered to JSC around 08:30 - 11 June, 2013.

- Safe to mate & functionality tests were successfully executed by S. Escobedo[1] and Y. Tyler[1].
  →RAD arrived safely.

- By 11:00, SRAG personnel - K. B. Beard[2] and R. Rios[2] began training to operate the EM RAD.



EM setup in Space Radiation Dosimetry Lab

from newbie to experienced user in 14hrs

- Training for the ISS-RAD EM included:
    - Familiarization with the Ground Software Equipment (GSE);
    - Familiarization with RAD's startup and runtime modes;
    - Procedures for data-taking/retrieval (e.g. calibration mode, science mode);
    - Learning about the EM's current features and nuances in firmware and software;
        - Configurations, changing/saving settings, temporary exceptions.
- Practical "exams".
- Mid-level debugging.

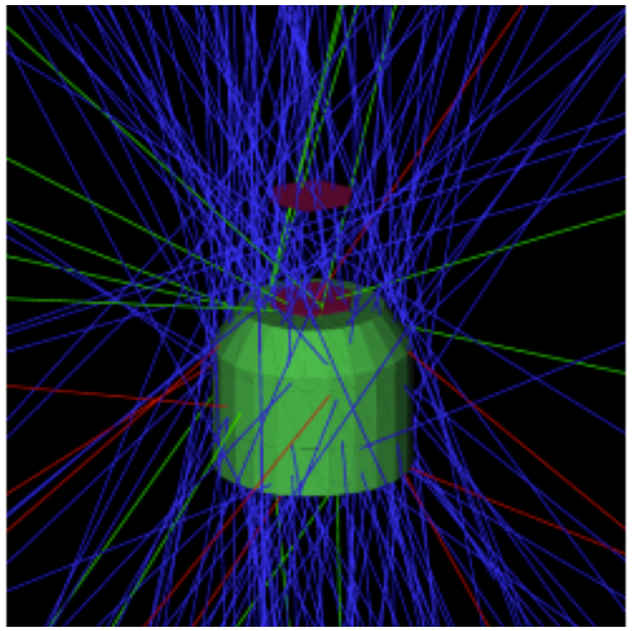
example accomplishments between delivery and return

- SRAG has been providing plenty of feedback ranging from diagnosing issues to asking if ROOT files can be produced by the Ground Analysis Software
- There were many opportunities to acquire data.
    - Cosmic ray muons;
    - Sources: ^{60}Co, ^{137}Cs, & ^{241}AmBe.
- Code acquisition (from SwRI):
    - Pre pre-release Python scripts to unpack CPD data;
    - FORTRAN code to unpack FND data;
    - Python script to set nominal settings for the FND.
- Code development (by SRAG):
    - drab (**D**ecompressor for **RA**D **B**inary) is a C-based unpacker for the types of binary data produced by the EM.
        - Updated as ISS-RAD evolves.
        - ROOT-based C++ & Python scripts to unpack/convert raw data and analyze data.
- Drafts of documentation:
    - Useful for getting specifications, or learning about additional features in software.
- Social Networking:
    - We increased our visibility with the SwRI experts and opened the channels of communications.

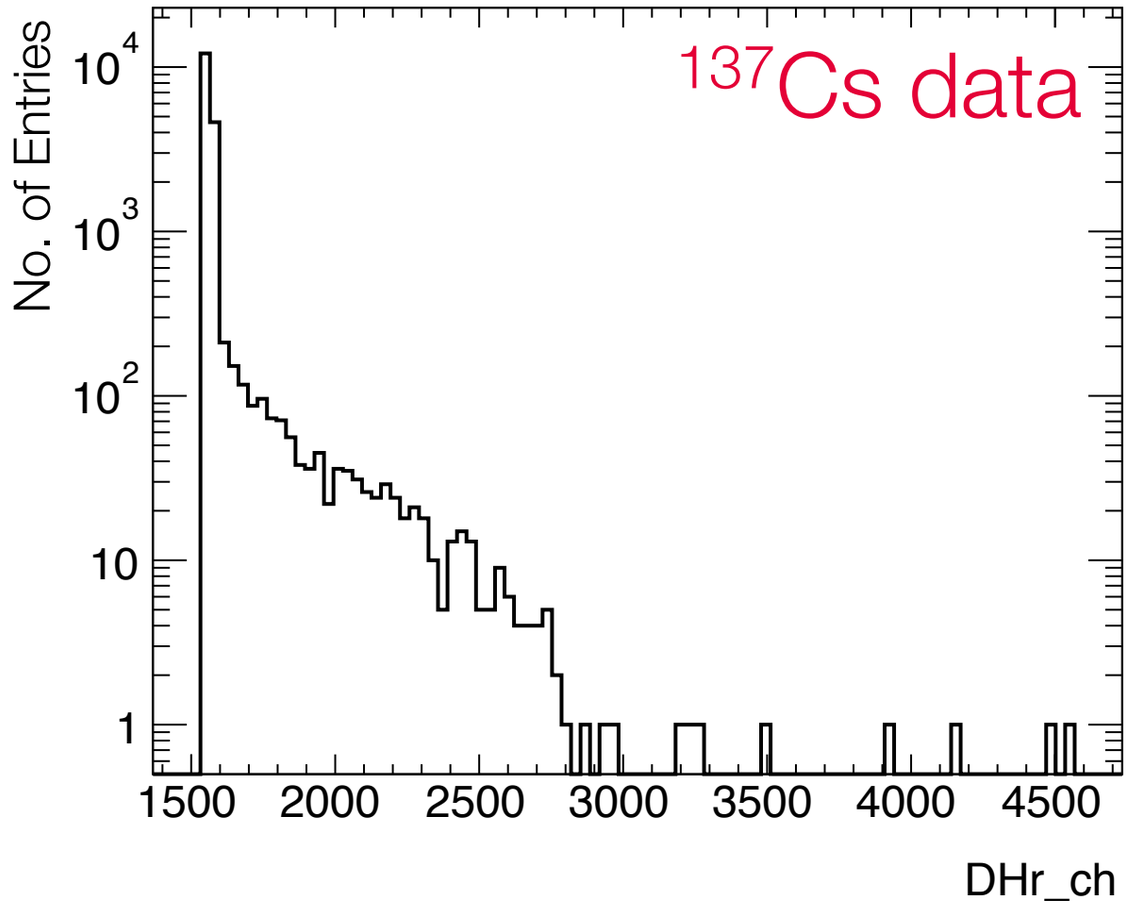
- The ISS-RAD EM was returned to SwRI 9 August, 2013 for upgrades to firmware, hardware, and software.
- Between delivery and return, SRAG was able to accomplish many things.

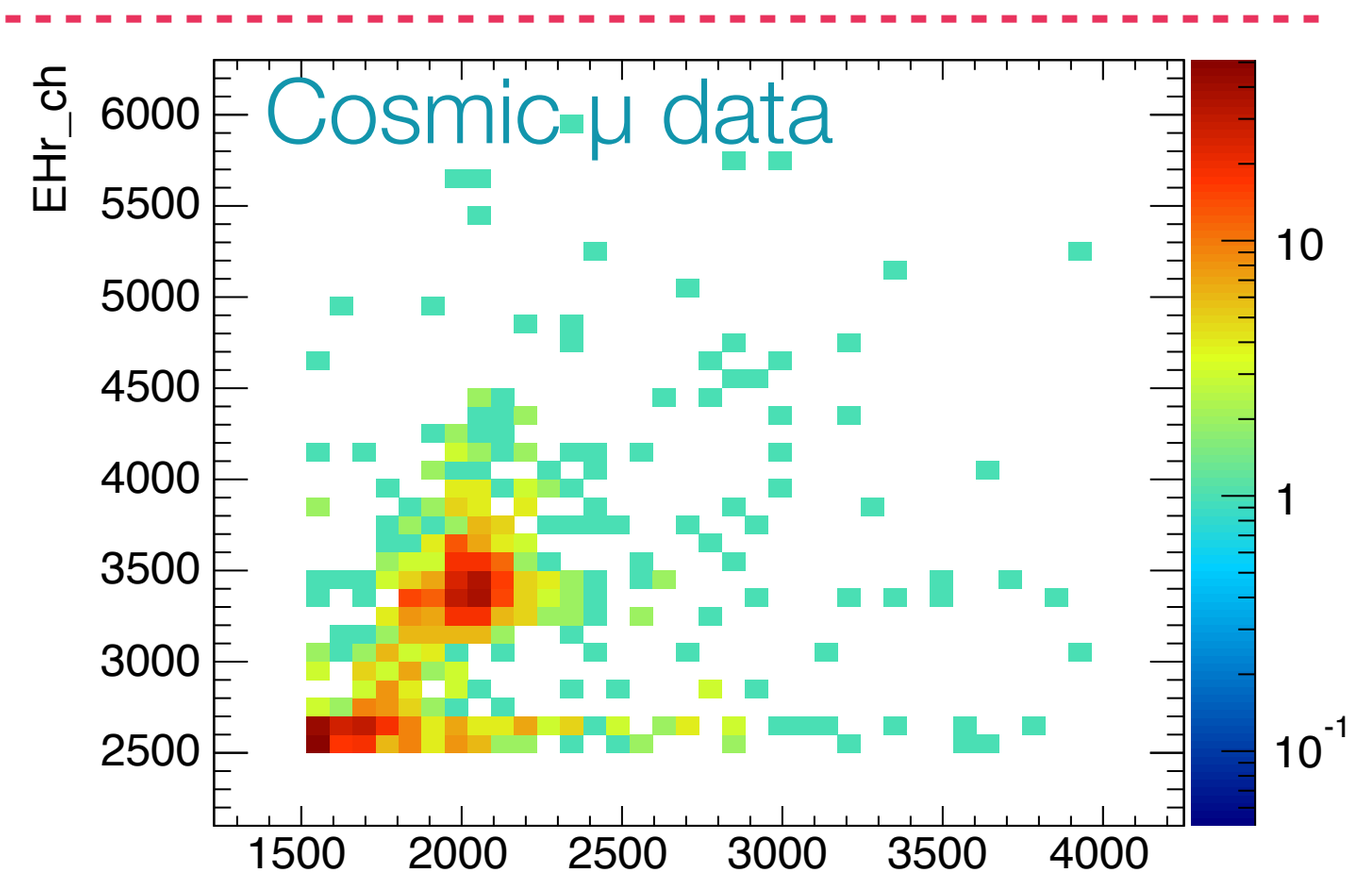
preliminary peek at raw CPD data

SRAG-COM-RAD-2013-003



Cosmic ray μ^+
G4Beamline/GEANT4 simulation

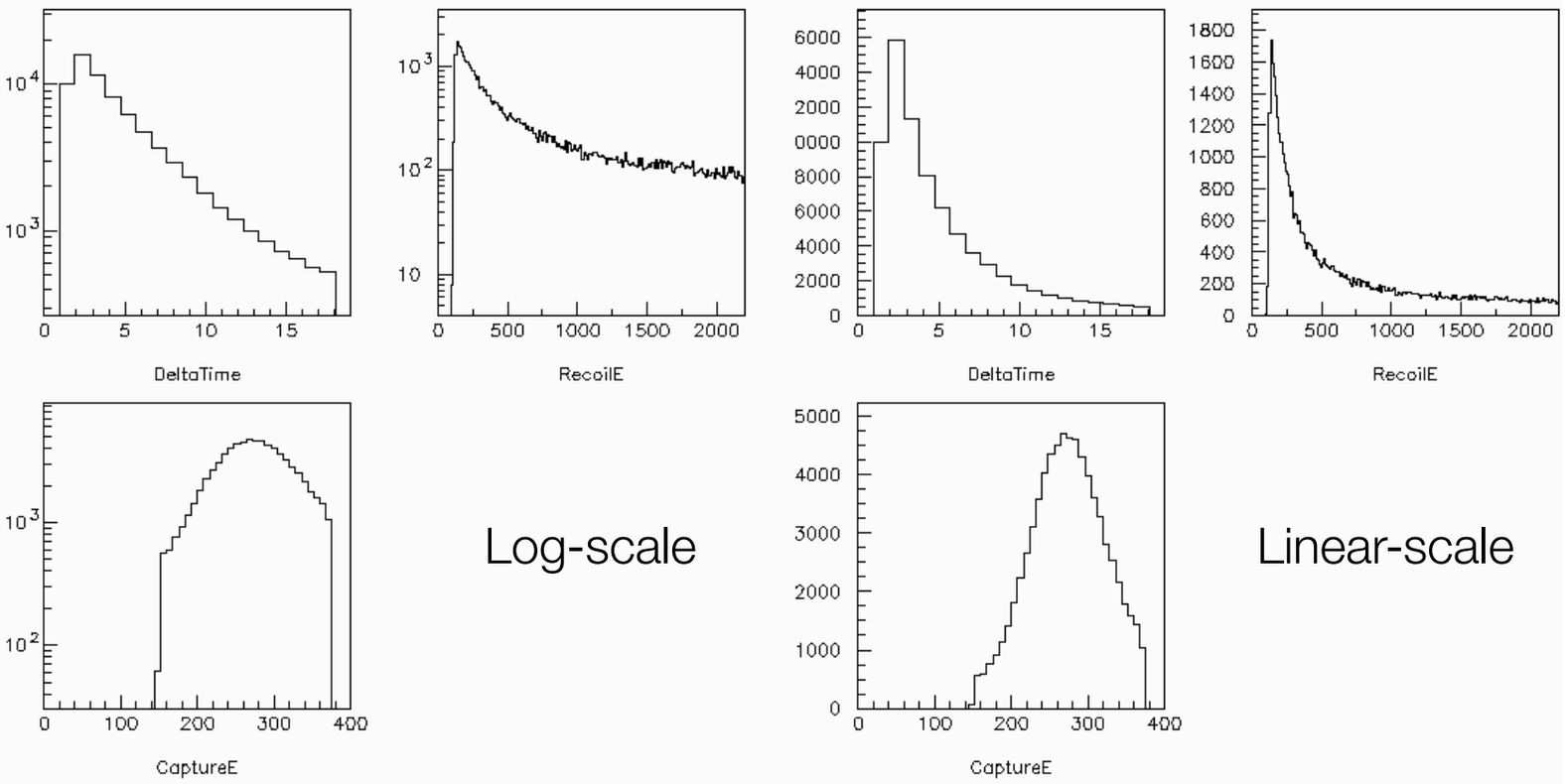




20130614_16_04_34_weekend_cosmic; cpd_data->Draw("EHr_ch:DHr_ch","A2Hr_ch>2000 && DHr_ch<4000 && EHr_ch<6000 && F1r_ch<2000","colz")

preliminary peek at raw FND data

^{241}AmBe data (Doubles mode)

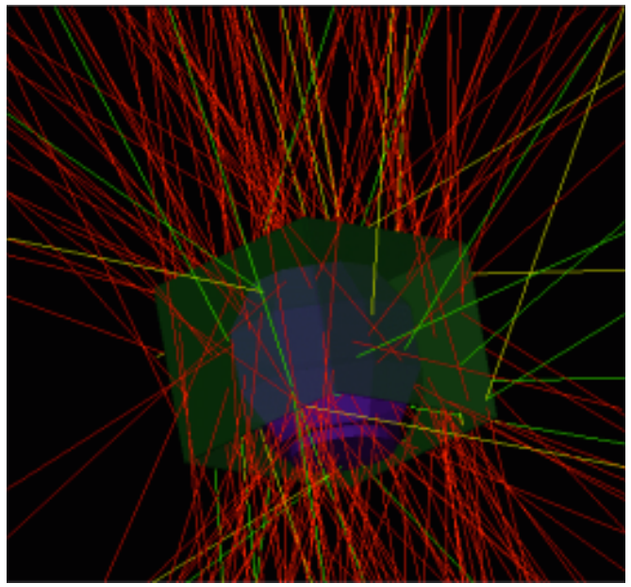


Log-scale

Linear-scale

Capture window is a bit skewed, but it can be corrected in flight software.

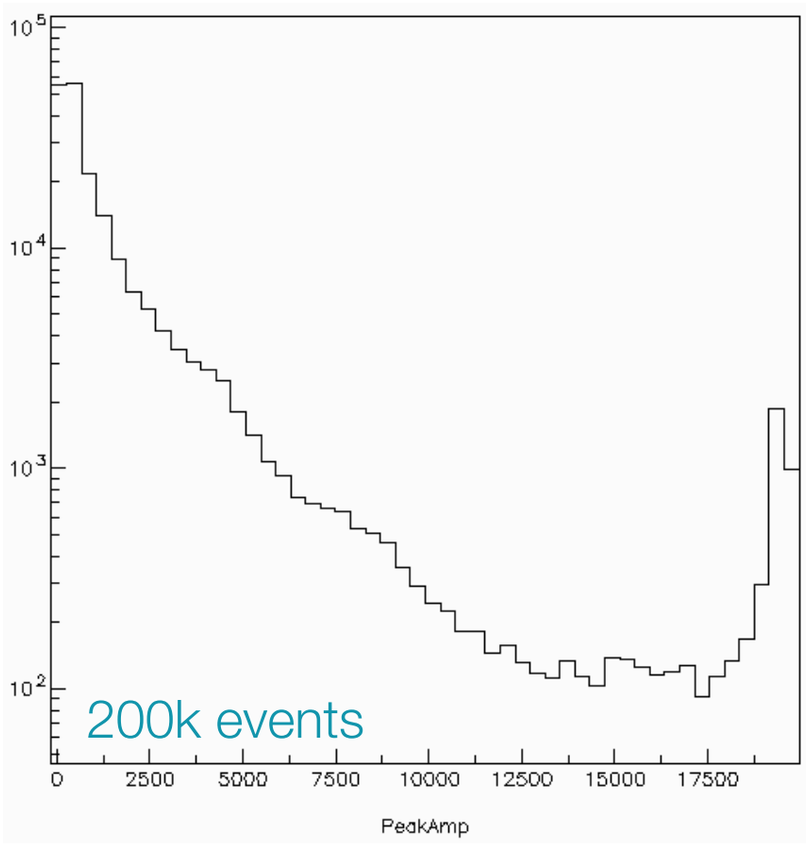
SRAG-COM-RAD-2013-001



Cosmic ray μ^-

G4Beamline/GEANT4 simulation

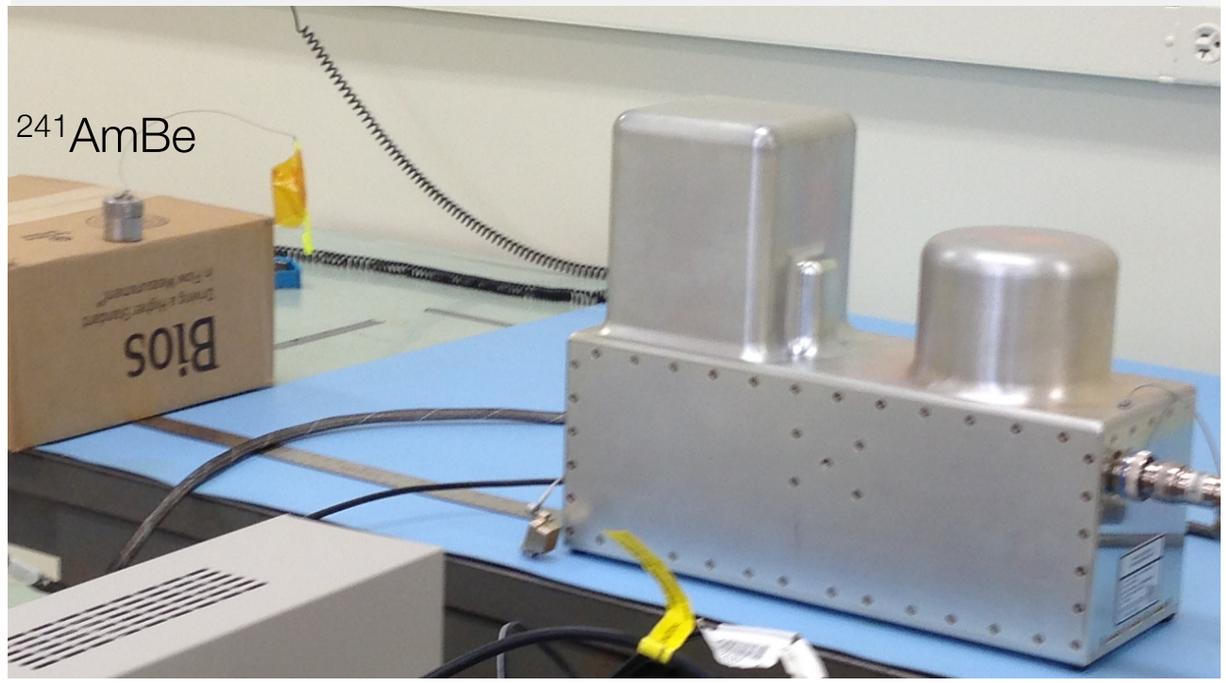
Cosmic μ data (Singles mode)



^{241}AmBe test results, excerpt from RAD System Design Review Status and FND Flight Design on 30 July, 2013

- From E. Semones[1] before the test:
  - The flux at 50 cm will be on the order of 8.4 n $cm^{-2}s^{-1}$.
  - Using ICRP 74 conversion factors, the predicted neutron dose rate is 11.3 μSv/h at 50 cm.
  - Using the rem meter, we measured a neutron dose rate of 8.16 μSv/h. We will get more detailed calibration data (NIST) in the future, but the actual dose rate will most likely be 8-12 μSv/h at 50 cm.
  - The gamma ray dose rate from this source is 1.2 μSv/h.
- Factor of 3.64 reduction in rate at 100 cm distance (source to front face) compared to 50 cm distance.

Test	Measured Dose Equivalent	Expected Dose Equivalent
50 cm 2.55 hr	24.1 μSv	28.9 μSv ICRP 74 calculated value 25.6 ± 5 μSv rem meter estimate
100 cm 18.37 hr	58.6 μSv	57.0 μSv ICRP 74 calculated value 50.5 ± 10 μSv rem meter estimate



[1] NASA - JSC

current status of ISS-RAD

- Both the engineering and flight models of ISS-RAD are being built and debugged at SwRI.
    - ISS-RAD EM and accompanying ground test equipment and undergoing various changes to software (e.g. GSE), firmware, and hardware (e.g. FPGA upgrade).
        - 20 - 22 August, 2013 - Many fruitful discussions took place at SwRI in San Antonio; topics included:
            - a review of feedback given to SwRI (by SRAG);
            - plans for the EM;
            - Ground Analysis Software (GAS).

- Tentative delivery date for flight models is early January 2014; after delivery, the flight models will go through a series of environmental and stability tests.
    - Other tests include beam-time at NSRL and PTB (for calibration and unfolding); ^{241}AmBe runs (neutron unfolding).

- Anticipate ISS-RAD to fly on ISS in late 2014.

cyclic data products

- Cyclic data (telemetered once per minute) includes:
  - dose, dose equivalent (cumulative & rate);
  - proton flux;
  - event rates (CPD & FND);
  - some housekeeping (temperature, statuses);
  - bit to drive the Caution & Warning alarm (backup to TEPC).

- Cyclic data is fairly straight forward, all of the values are calculated on-orbit.

science mode data products

- Science mode data (50 MB per week):
  - some event data;
  - particle fluxes (proton, He, Z ≥ 3);
  - LET spectra;
  - timestamps;
  - dosimetry information;
  - logical 2D histograms, which essentially provide Z, E from CPD & neutron energy spectra.

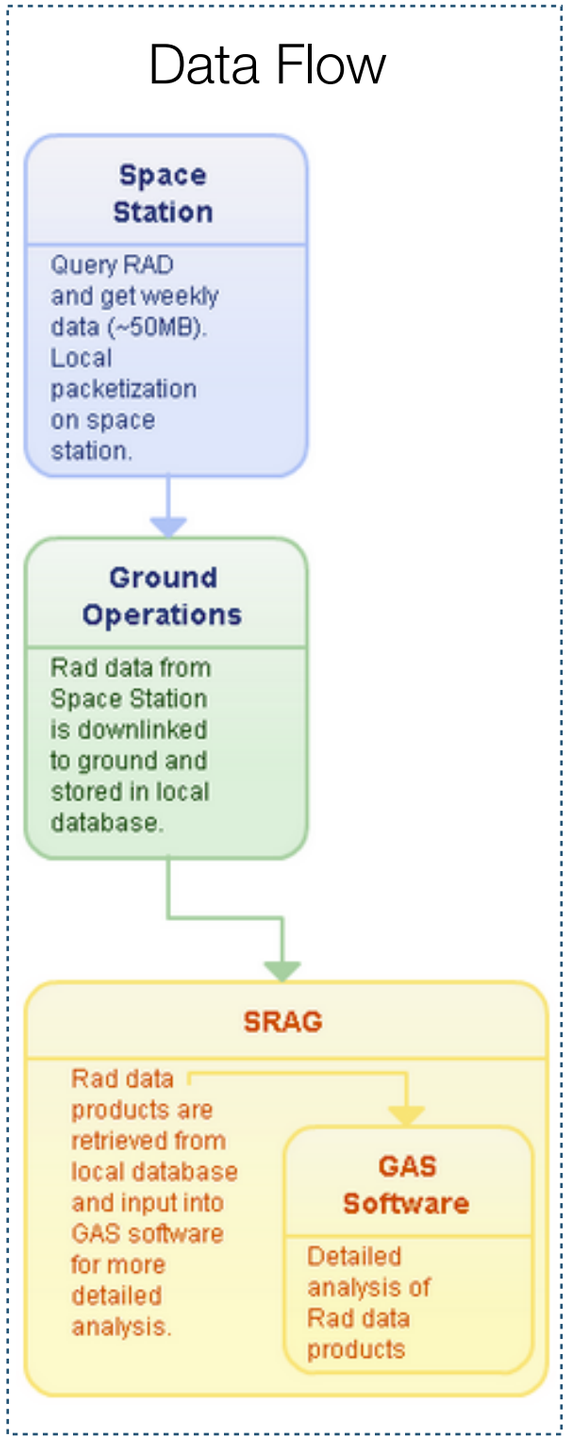
- Getting all these data products involves more processing, but this where the Ground Analysis Software (GAS) comes in.

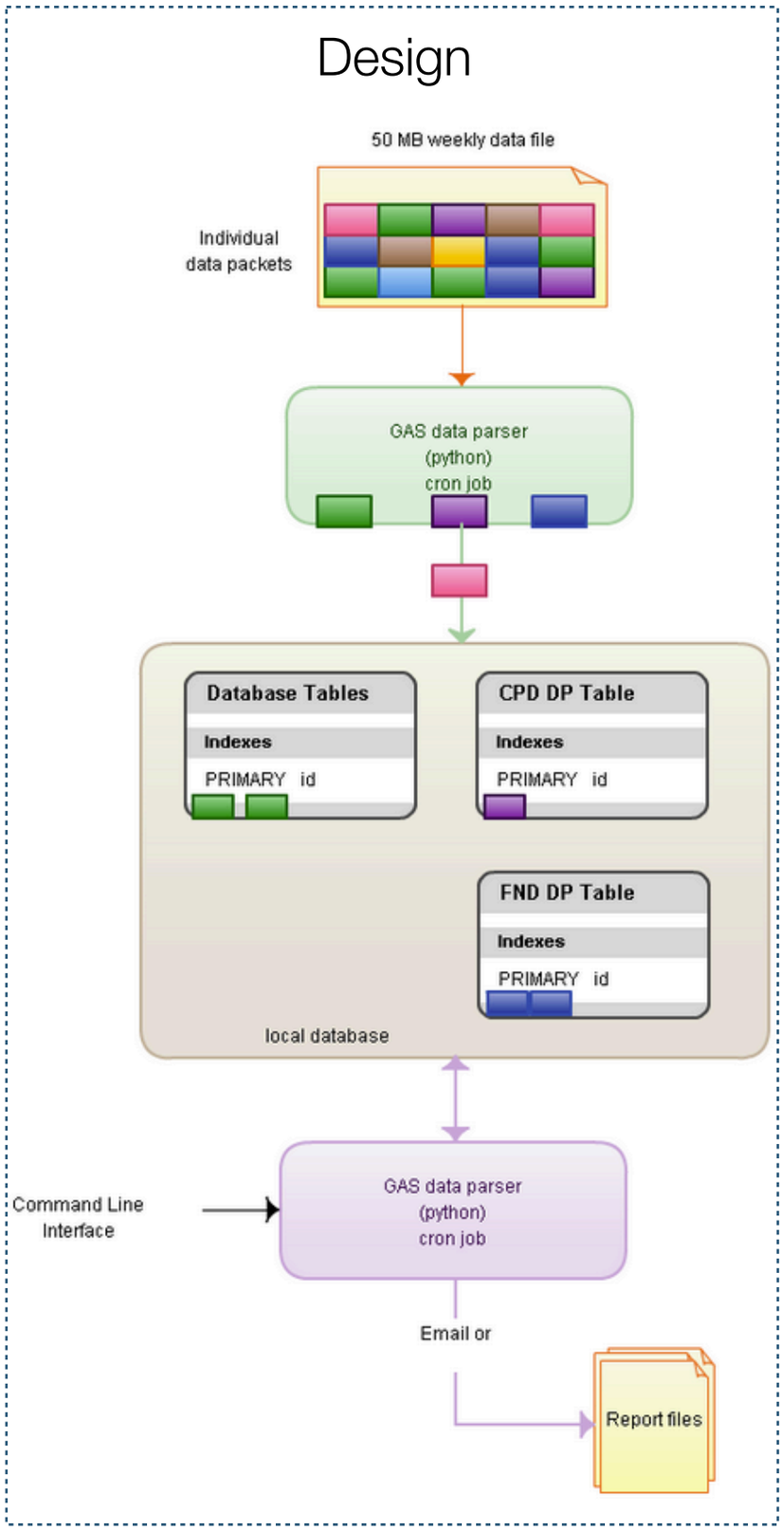
Data products from GAS

Item	Energy Range	Description
Neutron absorbed dose	0.5 MeV - 7 MeV	from FND
	5 MeV - 80 MeV	from CPD
Neutron dose equivalent	0.5 Mev - 7 MeV	from FND
	5 MeV - 80 MeV	from CPD
Heavy ion flux	100 MeV/n - 200 MeV/n	Z ≥ 3
Energy Spectrum	0.5 Mev - 7 MeV	from FND
	5 MeV - 80 MeV	from CPD

Ground Analysis Software (GAS)

- GAS will be designed as a robust tool to:
  - decompress raw binary data;
  - incorporate other ISS data (e.g. ISS state vectors);
  - analyze the decompressed data;
  - populate a MySQL database with all of the data products (raw and derived);
  - produce processed data files.
    - SRAG requested ROOT files.
- Everyone at the discussion at SwRI agreed that the GAS should be:
  - based on open-source tools (e.g. Python & ROOT);
  - have a simple and scriptable command-line interface;
  - autonomous (i.e. cron job) with the ability to run manually.





Diagrams courtesy of E. Weigle, Big Head Endian

closing remarks

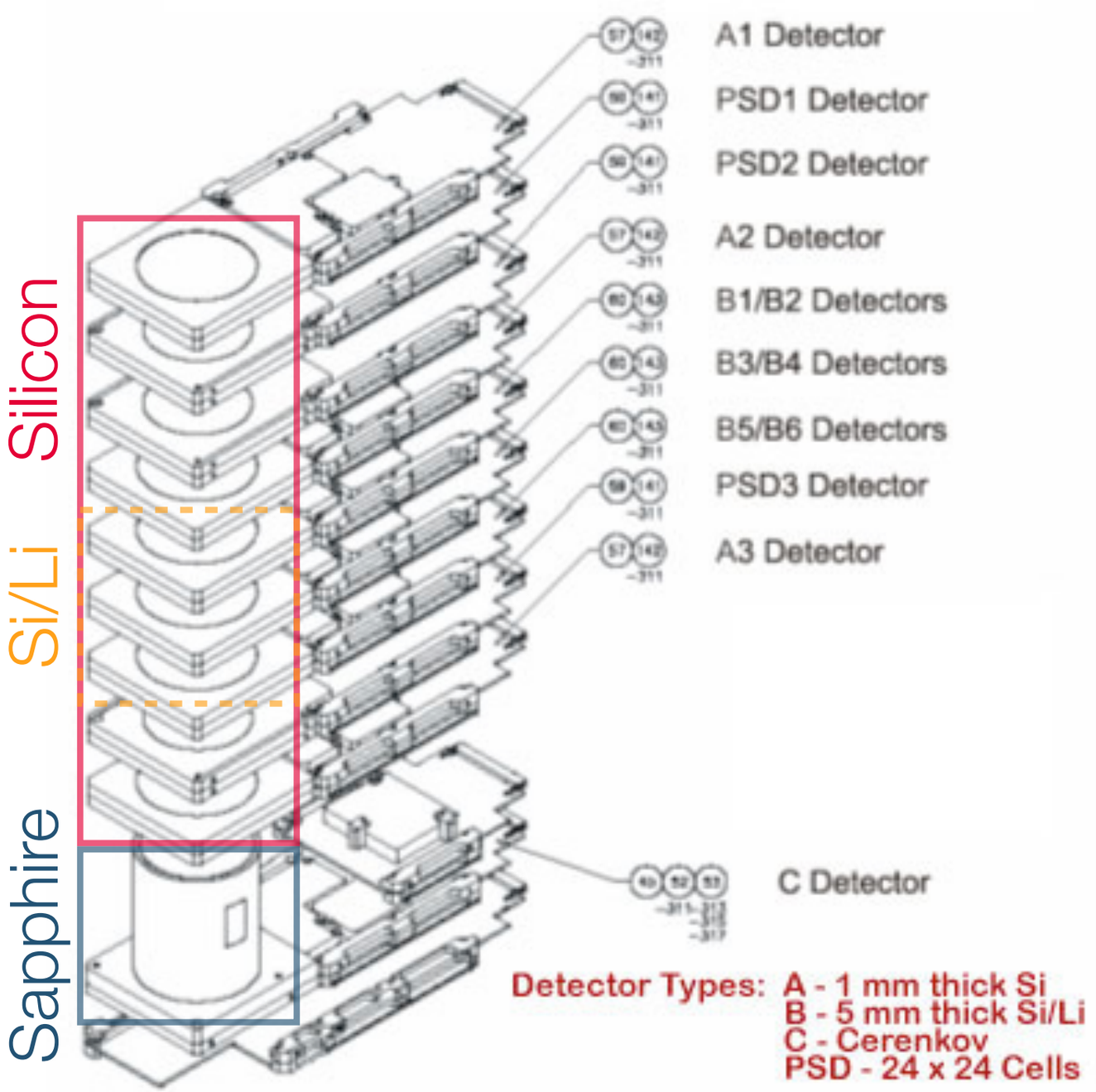
- There is still much work to do in terms of development and debugging.
- SRAG, SwRI, Big Head Endian have been actively communicating to address and resolve issues as they arrive.
- ISS-RAD will improve the current level of radiation monitoring on ISS and even provide insight to neutron component of the radiation environment.
    - To say the least, SRAG is excited.
- Many thanks to:
    - R. Gaza[1] for prepping the Space Radiation Dosimetry Lab at JSC for ISS-RAD and helping K. B. Beard[1] and R. Rios[1] get ESD certified.
    - J. Flores-McLaughlin[2] for coordinating some of the radiation source testing, in particular ^{60}Co, at JSC.
    - S. Escebedo[3], Y. Tyler[3], T. Taylor[3], M. Vincent[3], E. Weigle[4], C. Zeitlin[3], and other experts/developers working on the ISS-RAD project.

[1] Lockheed Martin, [2] University of Houston, [3] Southwest Research Institute, [4] Big Head Endian

additional material

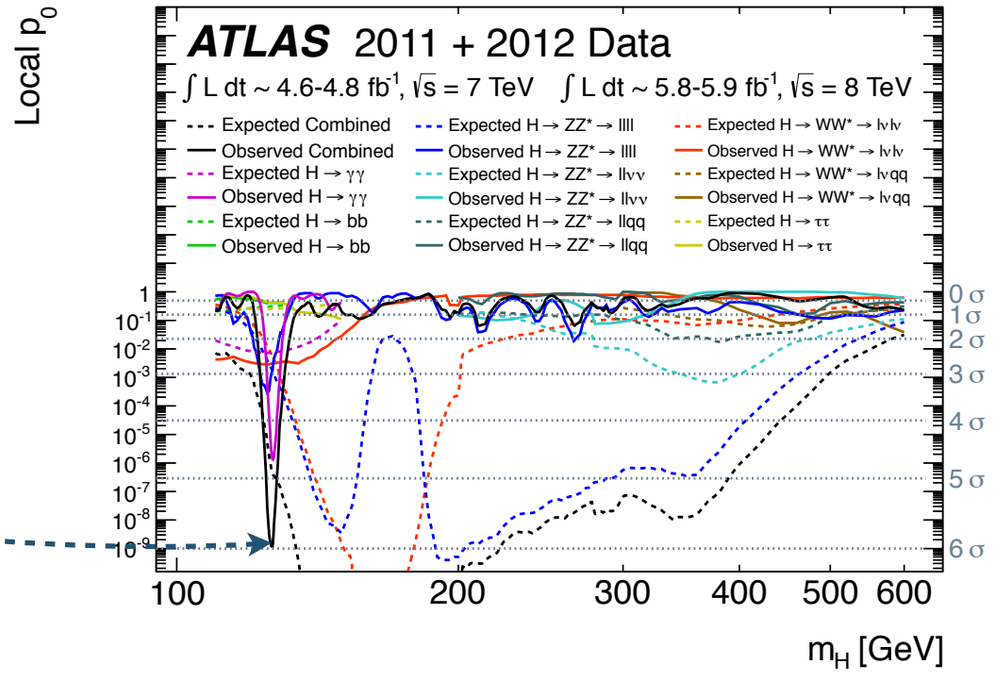
Charged Particle Directional Spectrometer (CPDS)

- Designed to measure the charge, energy, and direction of a particle that passes through the instrument.
- 3 A-detectors: 1 mm thick silicon dE/dx detectors.
- 3 Position Sensitive Detectors (PSD): 0.3 mm thick silicon, with an active area of the detector arranged in a series of 24 horizontal and 24 vertical 1 mm wide strips.
- 3 B-detector stacks: 5 mm thick lithium-drifted silicon dE/dx detectors.
- Čerenkov detector: 1 cm thick single crystal sapphire radiator combined with a PMT.



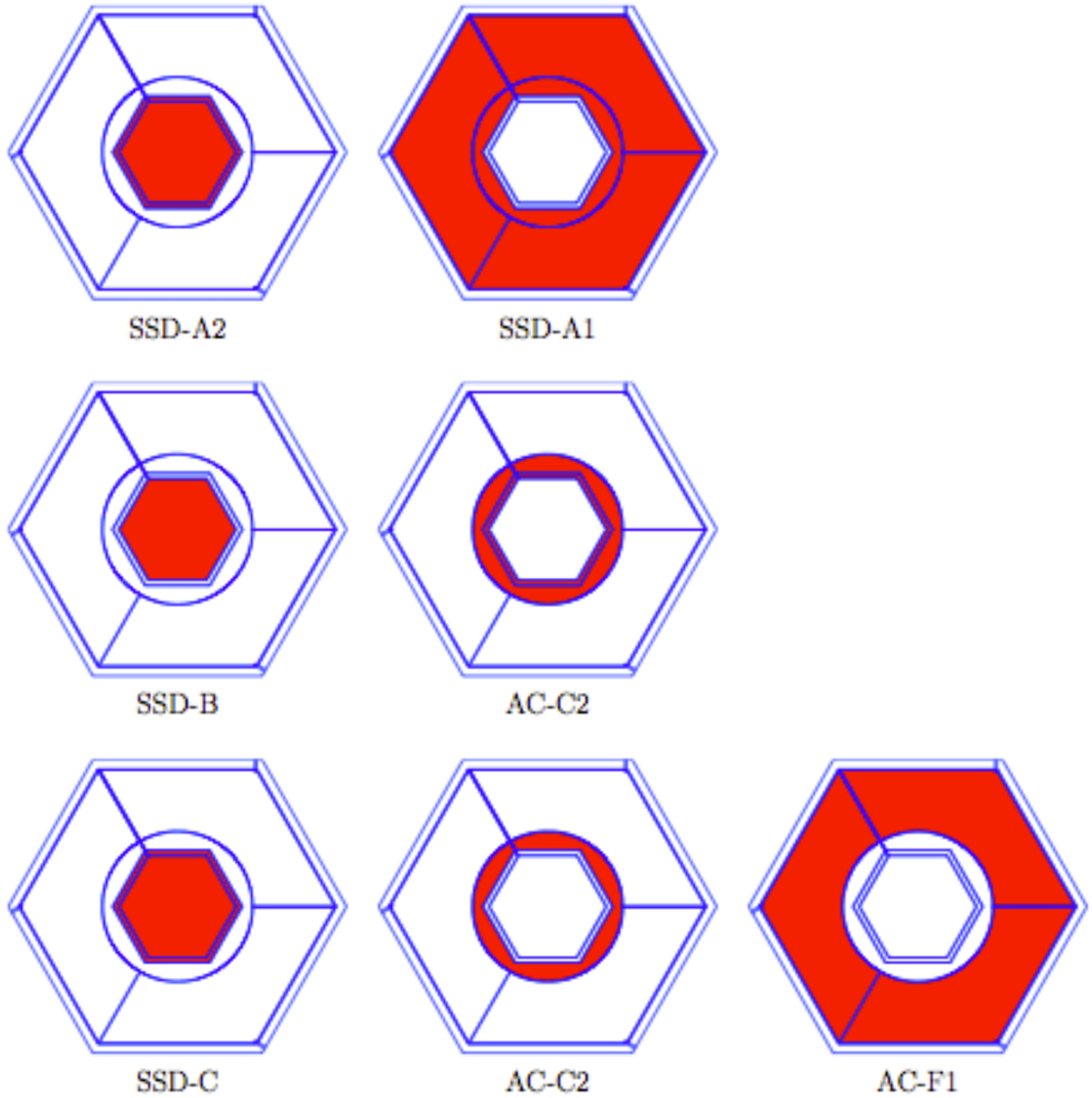
ROOTs Object Oriented Technologies (ROOT)

- ROOT is a data processing and analysis framework that has been widely used in high energy and nuclear physics for more than two decades.
  - Most notably, **all** of the research towards the recently announced Higgs boson discovery used ROOT.
  - AMS (Alpha Magnetic Spectrometer) uses ROOT to process and analyze data.



- ROOT is available in different flavors - C++ or Python and bi-directionally programable (write code *for* ROOT or write code *in* ROOT).
  - ROOT - standard C++ interface
  - PyROOT - Python wrappers around ROOT (C++-like)
  - rootpy - Pythonic ROOT (Python-like)
- Programs like HistoRoot and web-interfaces like JSRootIO and WebOOT lessen the curve for interacting with ROOT files.

Position sensitivity of A, B, C, & F detectors



Signal Processing in the Radiation Assessment Detector for MSL - Stephan Böttcher