Calibration of the Radiation Assessment Detector (RAD) for MSL

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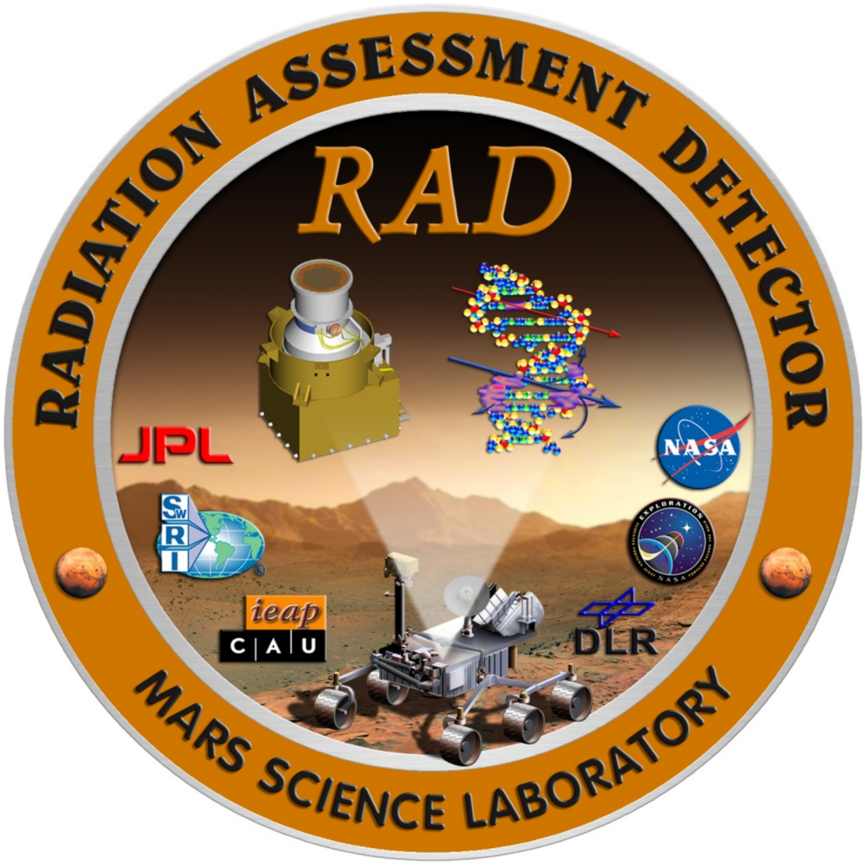
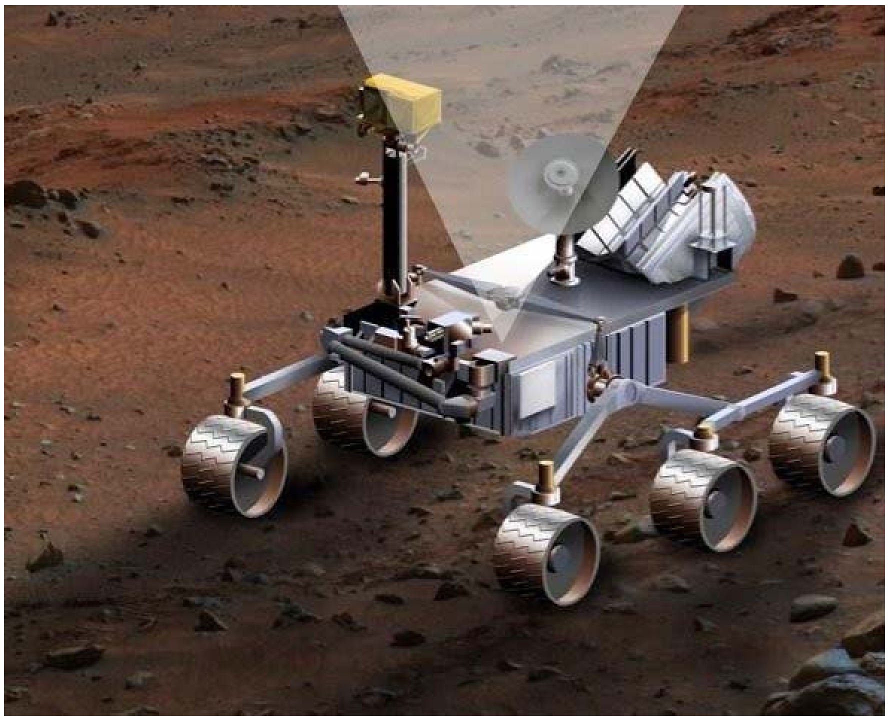


The Mars Science Laboratory (MSL) Mission



- MSL is the largest Mars rover to date
  - 850 kg
  - 10 instruments
- Launch date – Fall '09
- Arrives at Mars between July & September 2010 (just prior to Solar Max).
- Prime mission duration is 1 Mars year (687 days)

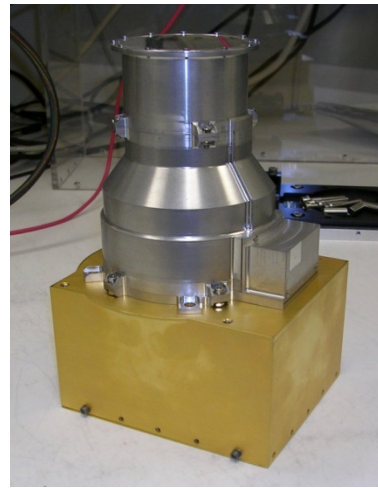
RAD Instrument Overview

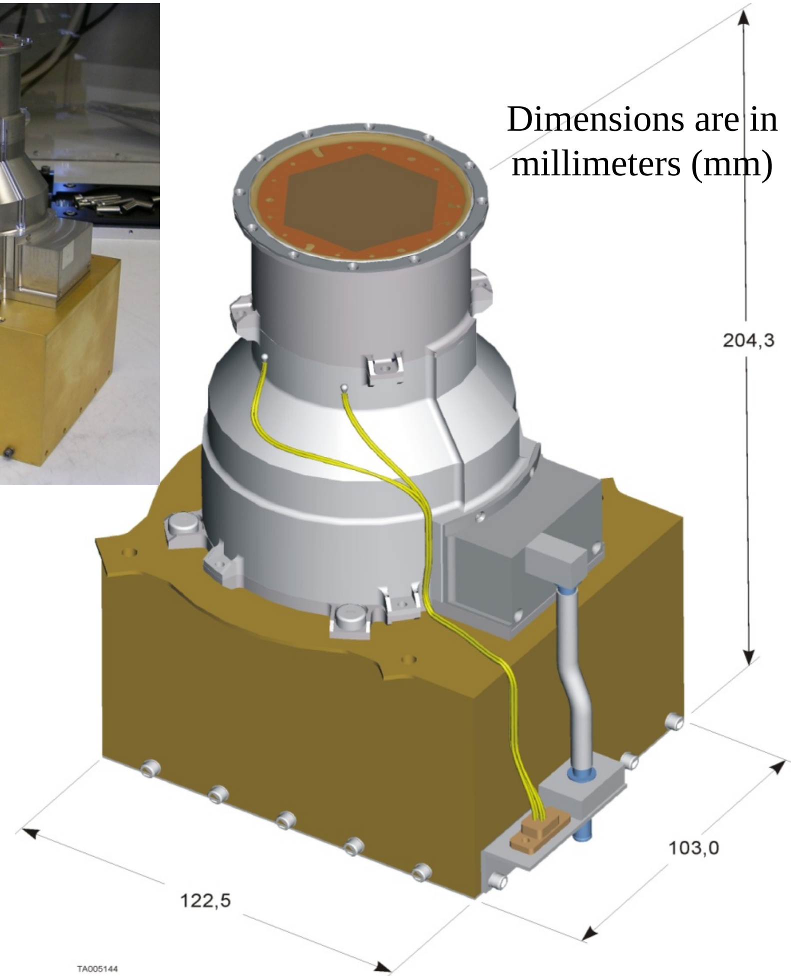
RAD – The Radiation Assessment Detector for MSL

• Solid state detector telescope and CsI calorimeter with active coincidence logic to identify charged particles.

•Separate scintillators w/ anti-coincidence logic to detect neutrons and γ-rays.

- Mass = 1.5 kg
- Power = 4.2 W
- Volume = 10.3 x 12.2 x 20.4 cm^3
- Field-of-View = 65 deg. (view cone)
- Geometric Factor = 1 cm^2*sr





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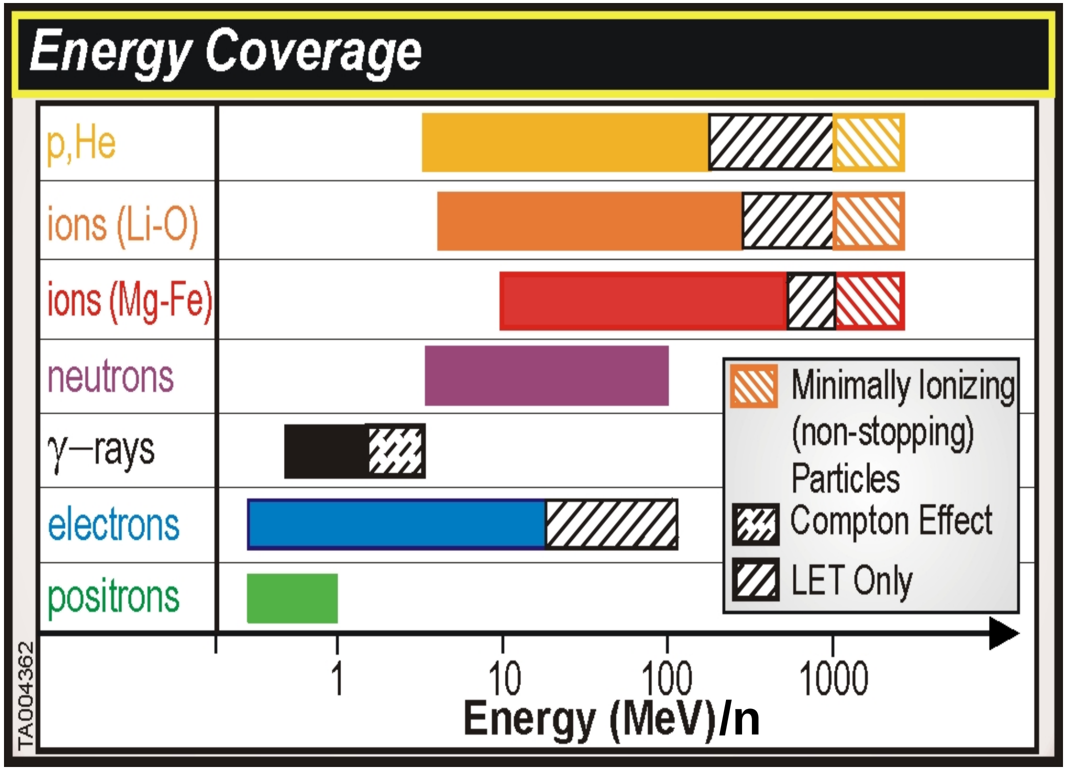
RAD Measurement Capability

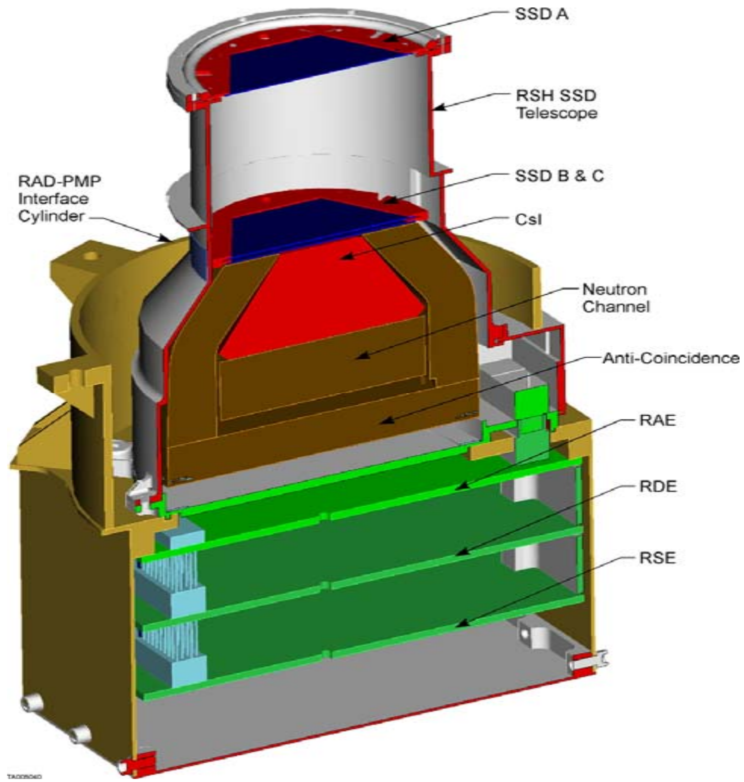
RAD – The Radiation Assessment Detector for MSL

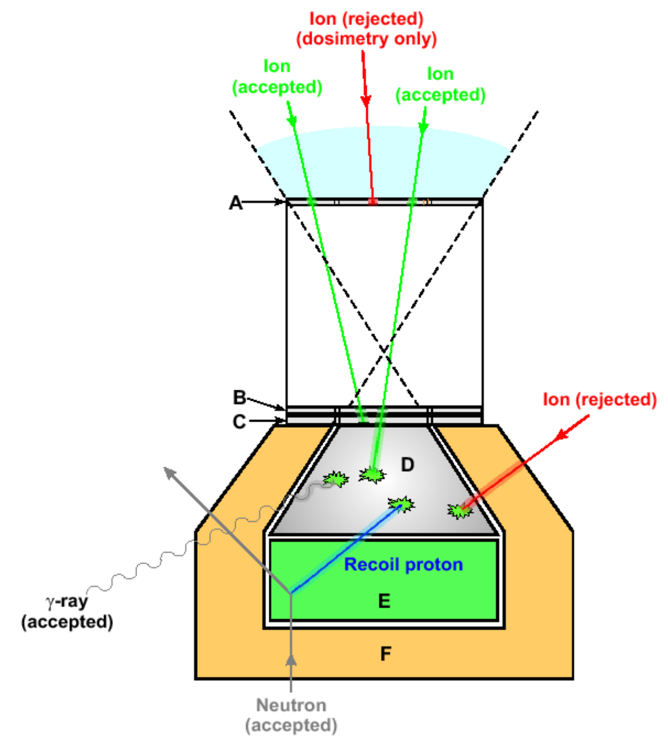
- ***Charge particles*** (protons and heavy ions up to Fe) ($1 \leq Z \leq 26$) vs energy and time
- ***Neutral particles*** (neutrons and γ-rays) (1-100 MeV neutrons) vs energy and time
- ***Absorbed Dose** and **Dose rate*** (LET of 0.3 to 1000 keV/μm) as a function of time
- ***Dose Equivalent*** (time-resolved Si LET spectra to determine LET-based Quality Factors)



RAD Cut-away View and Principle of Operation

RAD – The Radiation Assessment Detector for MSL





- Thin silicon detectors for dE/dx, CsI for stopping lower-energy protons & ions.
- BC-432 plastic for neutron detection (stops some charged particles).
- Recoil protons from upward-going neutrons stop in CsI.
- Hermetic anticoincidence also made of BC-432.

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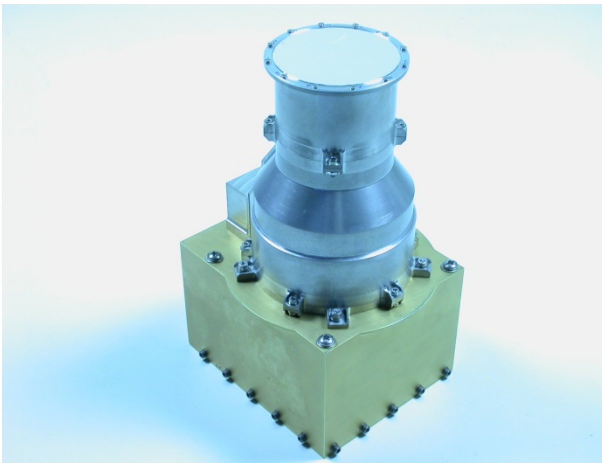
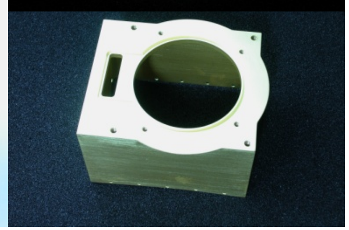
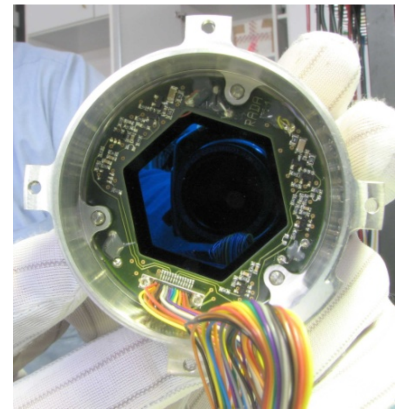
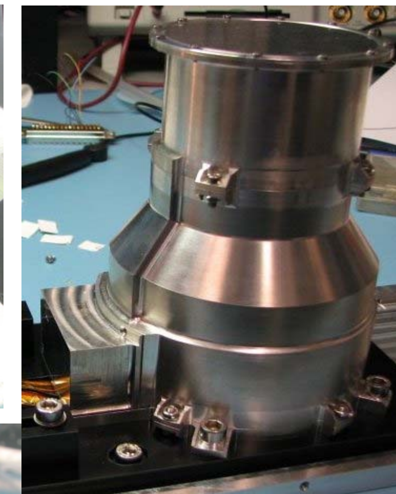
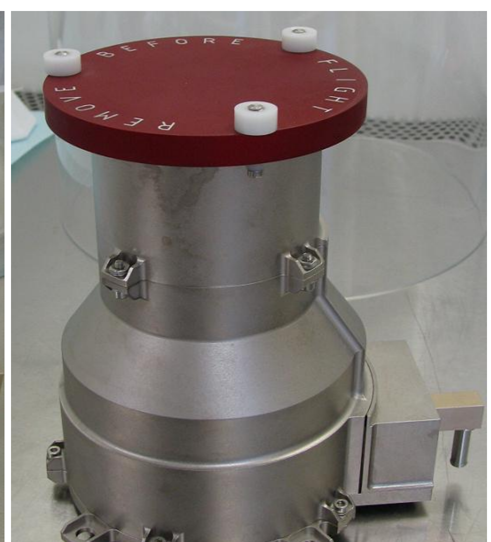
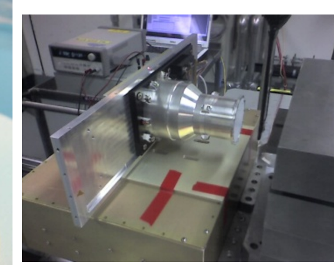
RAD Flight Hardware

RAD – The Radiation Assessment Detector for MSL



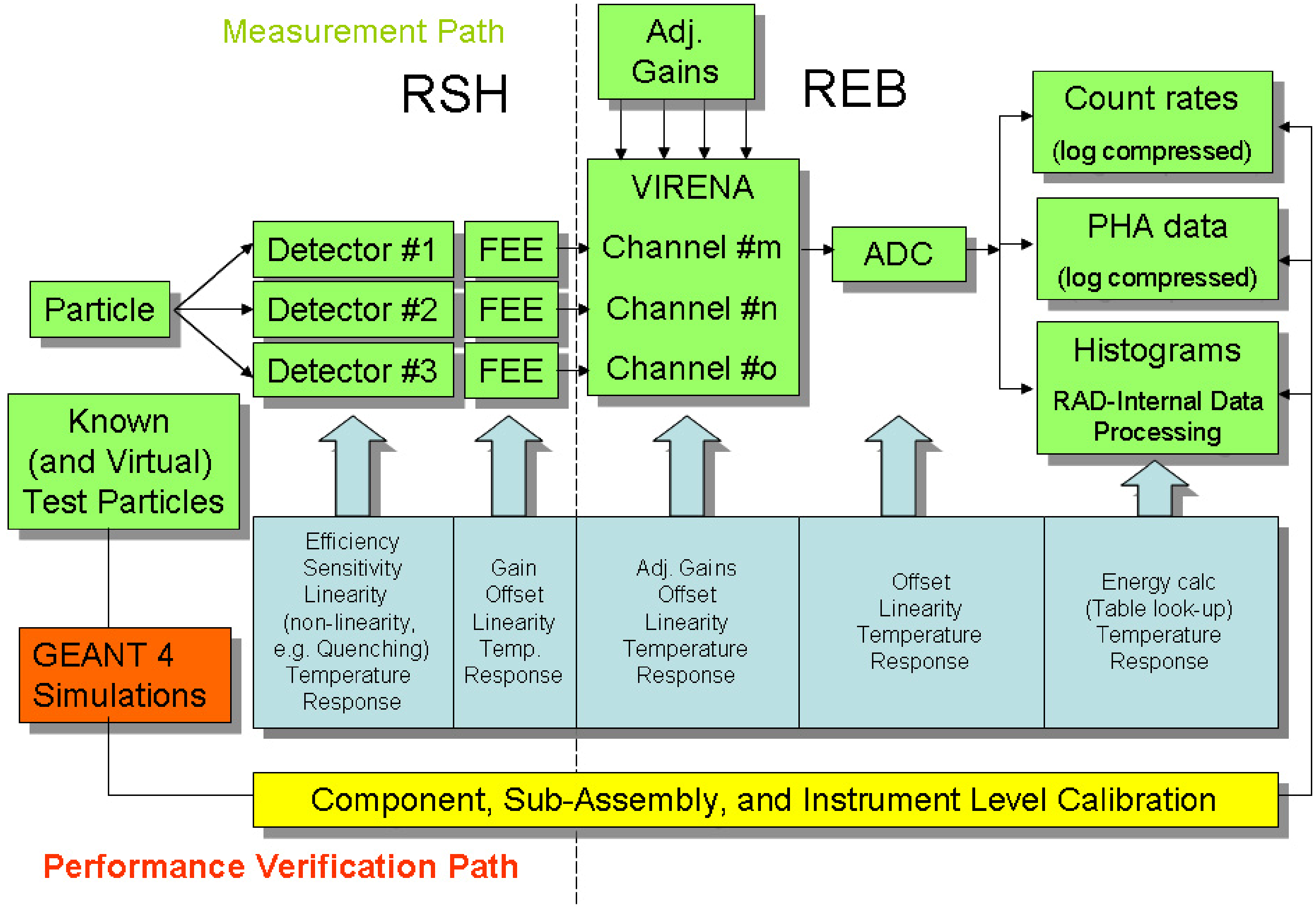







RAD Measurement Flow

RAD – The Radiation Assessment Detector for MSL

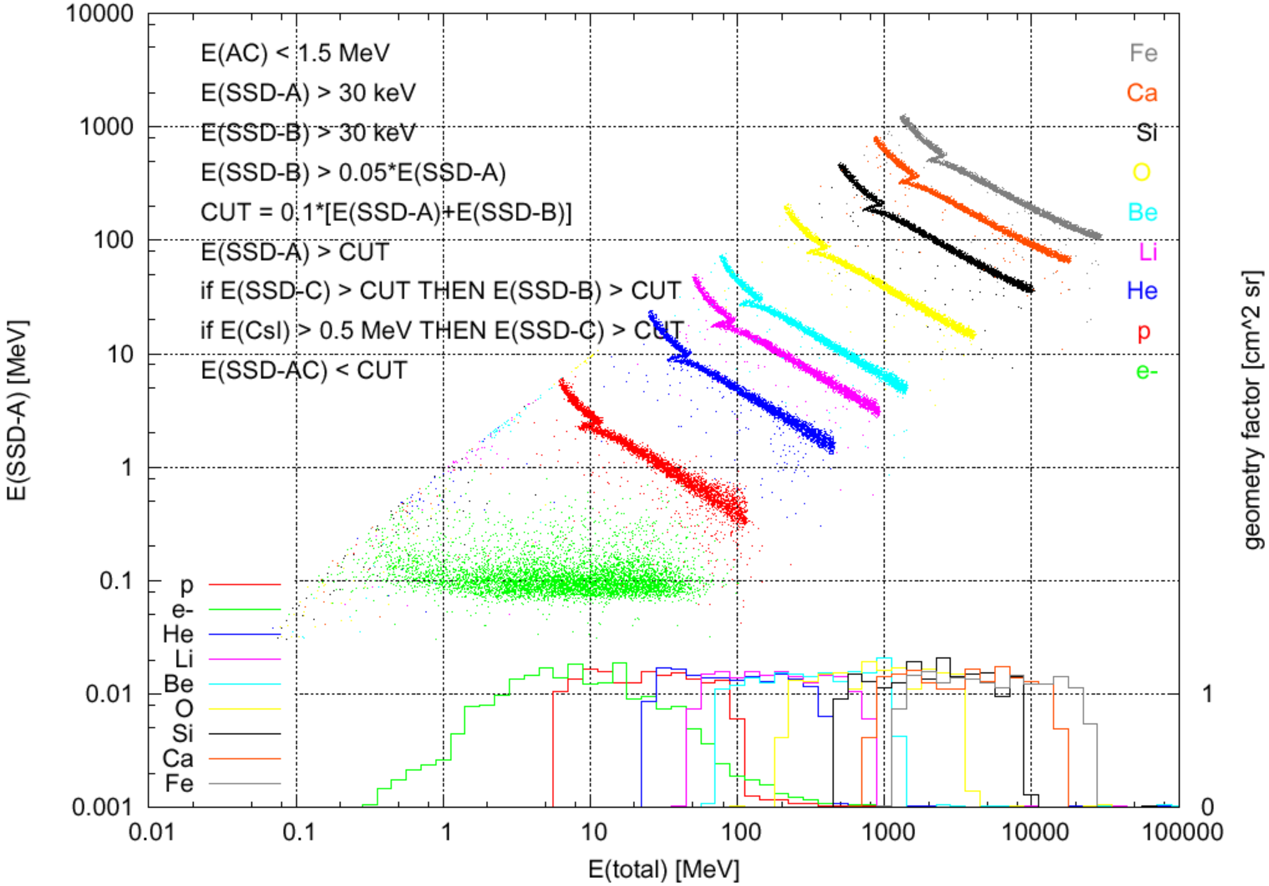


RAD Species Identification uses dE/dx vs E Method

RAD – The Radiation Assessment Detector for MSL

Stopping Charged Particles

dE/dx (SSD-A) and geometry factor versus total energy deposit



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RAD Species Identification uses dE/dx vs E Method

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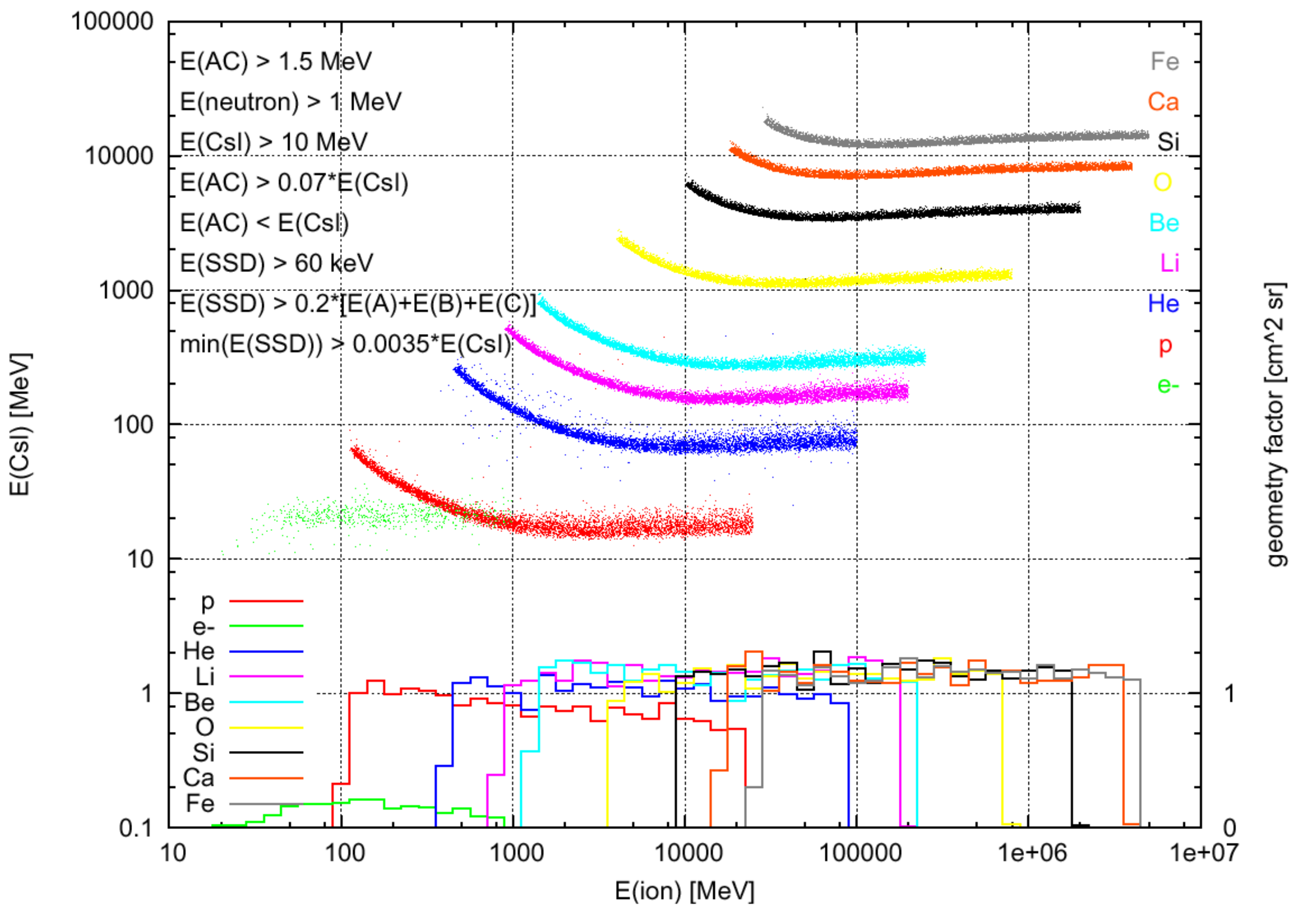
Penetrating Charged Particles

Energy loss and geometry factor of penetrating charged particles



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Calibration Data vs. Flight

- Flight data will consist of histograms and compressed PHA's for high-LET events.
- For calibration analysis, need much more.
- “High-speed” data stream created to fill this gap.
- Output via GSE USB interface.
  - UDP streamer lets networked clients receive data.
  - All calibration data to date have been obtained through this interface.
- High speed puts out full data records, with RAD in most cases configured to do a complete 32-channel readout.
- Unfortunately we cannot send this much data from Mars!

RAD Calibration (to date)

RAD – The Radiation Assessment Detector for MSL

Particle Type	Beam Energy (MeV/nucleon)	Targets	RSH + REB Used
^{1}H (protons)	85, 95, 105, 110, 1,000		FM1 + PFM1 FM2 + EM
^{12}C	290	CH 7, 9, 12 g cm^{-2}	FM1 + EM FM2 + PFM2
^{56}Fe	1,000	CH: 3, 20, 22 g cm^{-2}	FM1 + PFM1 FM2 + EM
neutrons	5, 15, 19	none	FM1 + EM
neutrons	100	none	PF + EM

Beam ions and energies obtained to date for MSL RAD calibration

Charged Particle Calibration

- Runs at NSRL in May and June 2008:
  - Protons at 85, 95, 105, 110, and 1000 MeV.
  - Carbon at 290 MeV/nuc.
  - Iron at 1000 MeV/nuc.
- Polyethylene targets used with carbon and iron beams to create fragments, slow ions to stop in D, E.
- Low energy protons also stop in D, E.
- Beam data crucial for understanding scintillator quenching.
- Calibration Approach:
  - calculate energy depositions
  - use data to get ΔE vs. PHA calibration
  - The more data points the better!

NSRL Data May 2008

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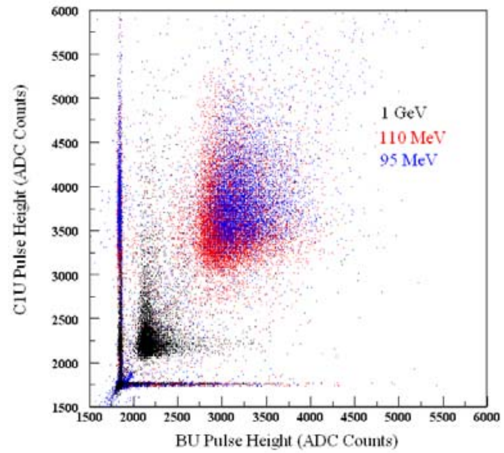
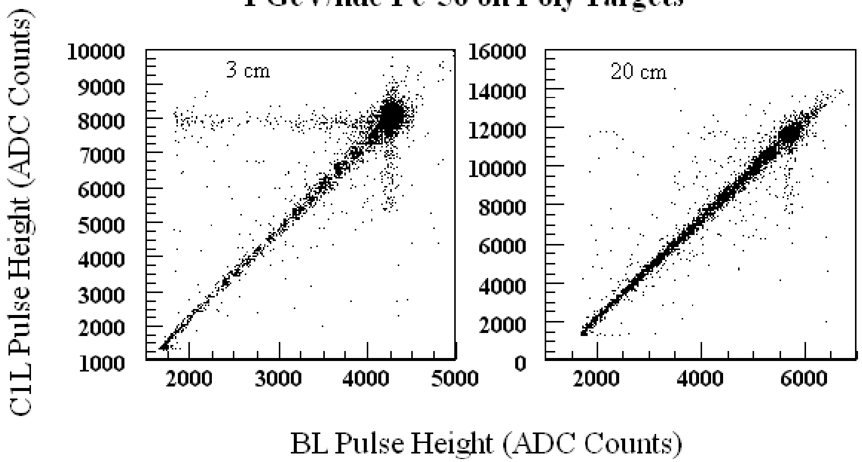


1 GeV/nuc Fe-56 on Poly Targets



- Upper: C vs. B, protons, ultra-high gain channels.
- Lower: C vs. B, iron on polyethylene, low gain channels.
- Proton energies varied:
  - 1 GeV = fully penetrating
  - 110 MeV stops in E
  - 95 and 80 MeV stop in D
- Analysis ongoing in Kiel and Boulder.

Proton Calibration Data at NSRL (May 2008)

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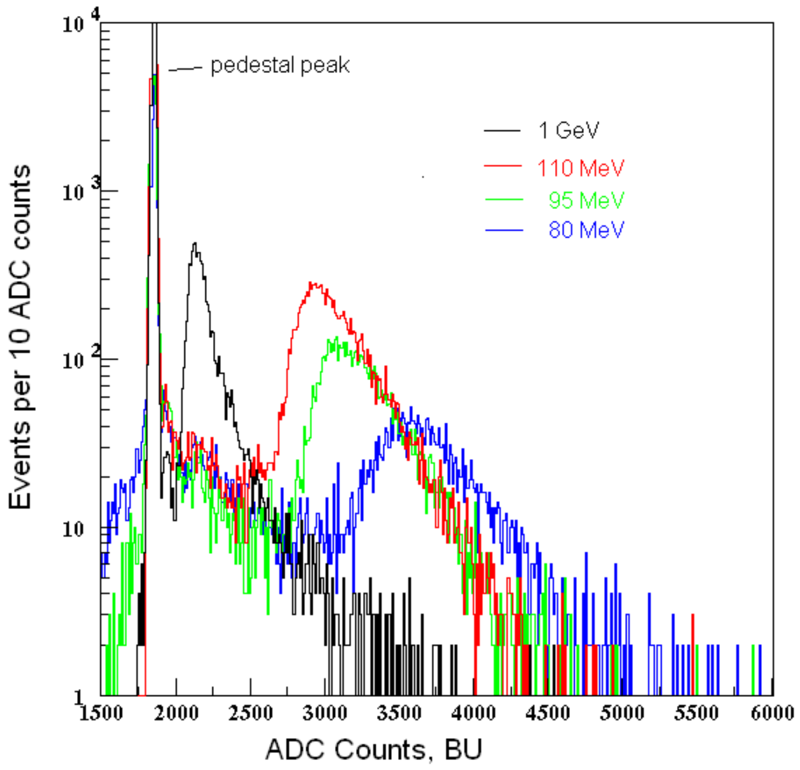

- Proton data from NSRL at Brookhaven, May 2008, using FM2 with EM REB.
- Proton energies varied:
  - 1 GeV = fully penetrating
  - 110 MeV stops in E
  - 95 and 80 MeV stop in D.
- Energy depositions (ΔE's) can be calculated so the calibration constants can be determined for all channels,
  - ADC = ΔE * slope + pedestal.

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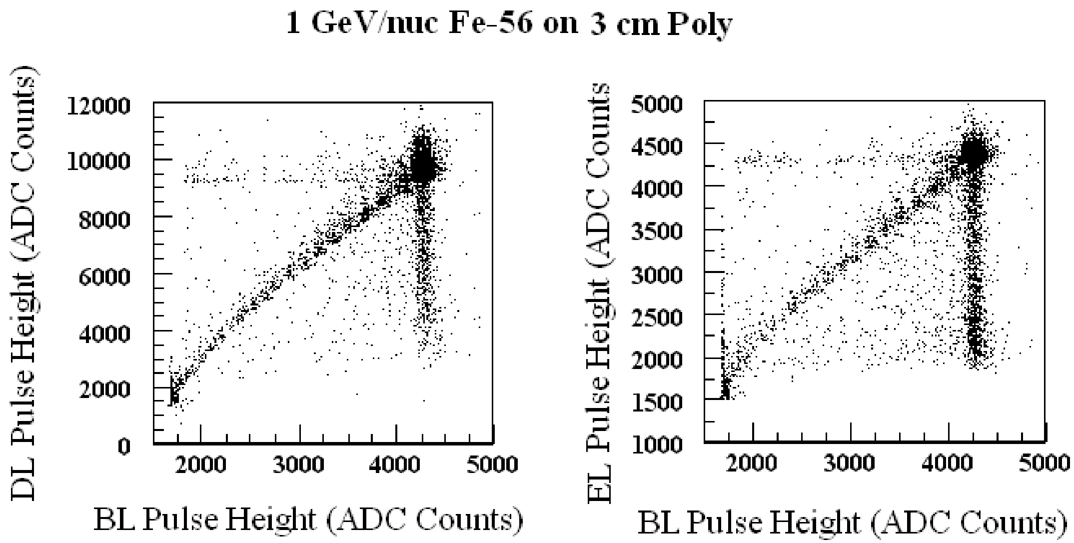
Scintillator Quenching

RAD – The Radiation Assessment Detector for MSL



- Signals in CsI(Tl) (D detector) and BC432 (E detector) suppressed by quenching according to Birk's formula:

  $dL/dx = [\eta(dE/dx)]/(1 + k\, dE/dx)$

- Looks simple but k is a function of charge & energy so we need a lot of data to map responses!
- Good news: NSRL data show that CsI in FM1 = CsI in FM2
  - Additional calibration data to be taken with FM1 will be applicable.

Neutron Calibration Runs

- Run at PTB in Braunschweig April 2008 with 5, 15, and 19 MeV quasi-monoenergetic n^0 beams.
- Run at iThemba, October 2007, 100 MeV.
- Maximum proton recoil energy = full neutron energy.
- Neutrons from below (from Martian surface) make energetic recoil protons that may not stop in E.
  - These penetrate into D and maybe beyond, but if they leave D they fire the anticoincidence.
- Compton electrons from γ's in D (most likely source) can deposit energy in E, so γ's and neutrons may have similar signatures, i.e., energy in only D and E.

Statistical Neutron-Gamma Inversion Technique

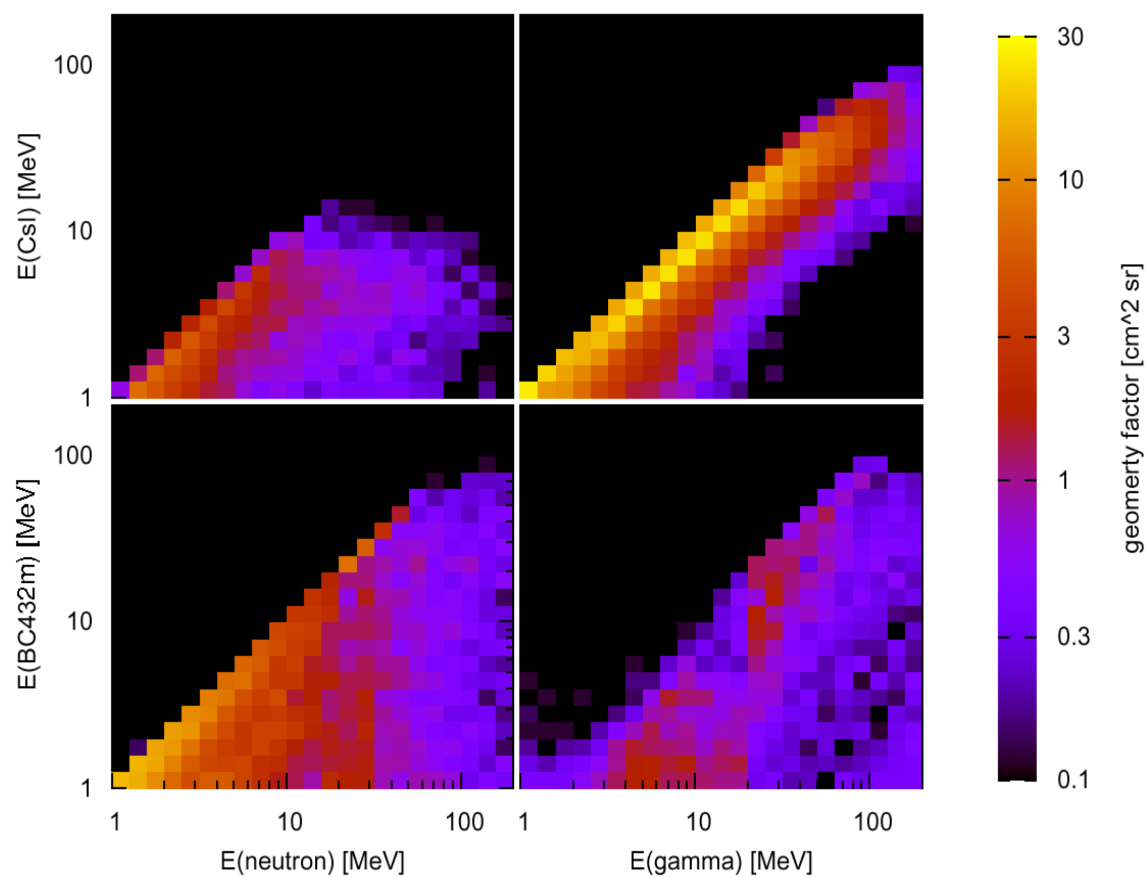
RAD – The Radiation Assessment Detector for MSL

Statistical inversion method described at PDR with SOHO/EPHIN data.

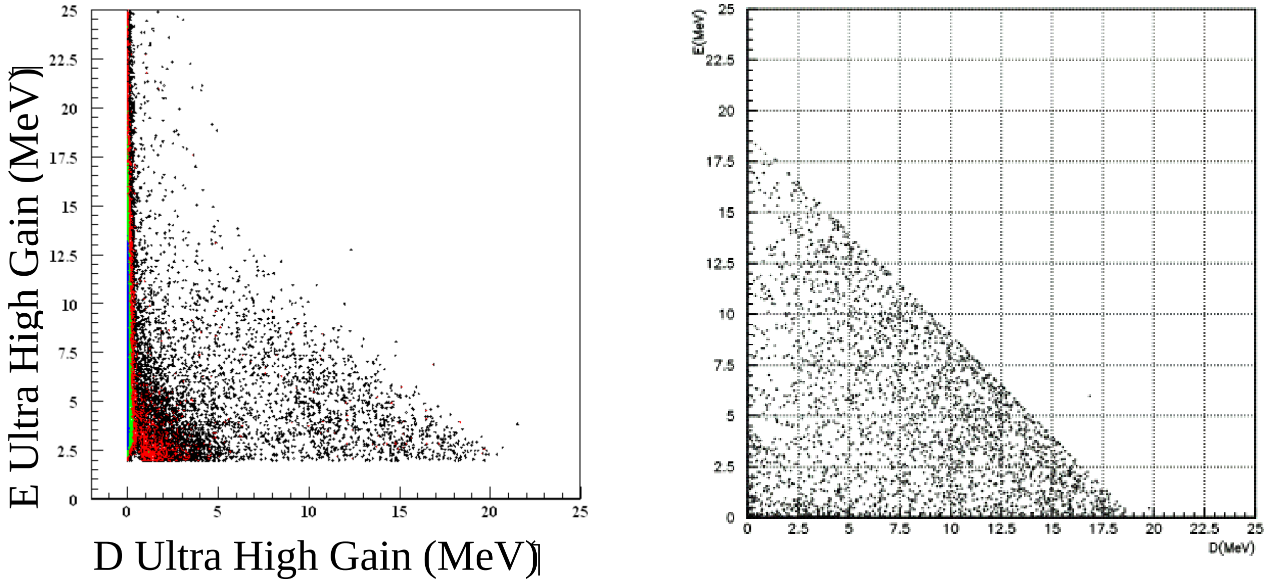
The method is demonstrated to be stable and internally consistent in Böhm et al. (2007).

The figure on the right shows the RAD inversion for neutrons and gamma particles.

Detected energy vs particle energy matrix



Neutrons at PTB



- 19 MeV neutron data from PTB with RAD rotated 180°.
- Cuts in data to require no energy in A, B, C, F.
- Left: data, EU vs DU. Right: GEANT, E vs D
  - Energy calibration of data is very approximate – done using only 1 GeV proton data, without quenching corrections.

EM - FM Cross-Calibration

- To date only engineering model (EM) electronics have been available.
- Two flight RSH's exist (FM1, FM2) as well as an earlier version (Pathfinder).
- Data have been taken with all 3 RSH's and various EM electronics.
- **Data verify that RSH and REB meet requirements for LET range, charge resolution, neutron sensitivity**
- Using these data for calibration requires the extra step of normalizing for (small) differences in gains and offsets in FM electronics vs. EM.
- Pulser data to be taken in the lab will help.

Summary

- A large set of charged particle and neutron data has been obtained, analysis is ongoing.
  - Will get more data for D & E quenching analysis in Feb. 2009 using EM RAD at HIMAC.
  - 500 MeV/nuc Fe and 400 MeV/nuc Si.
- Additional data to be taken with FM RAD include pulser, γ sources, and protons at Loma Linda.
- We are on the way to having a very thorough characterization and calibration of RAD.