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Combined Ion and Neutron Spectrometer for Space Applications (CINS)

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CINS concept

I. Combine a charged particle telescope and neutron spectrometer into a single unit with common electronics.

II. Charged particle telescope: silicon + plastic scintillators + BGO scintillator.

- Mars Odyssey MARIE instrument design with many improvements.

III. Neutron spectrometer: Low, medium, and high-energy detectors developed under previous NSBRI grants.

Project Goals I

- CINS will monitor the complete particle radiation environment
- After instrument detector procurement, fabrication and calibration are complete, CINS will be used in ground based accelerator experiments using heavy ions, protons and neutrons to determine energy spectra
  - The dose or dose equivalent calculated from the CINS energy spectra will be compared with the measured LET or dose of TEPCs or dosimeters to ascertain the limitations in response of the latter devices.

Project Goals II

Evaluate detector and telescope performance characteristics including noise, resolution and event rate.

Extensive testing at accelerator facilities.

- Emphasis on heavy ion beams and thick target collisions producing charged particle fragments and neutrons.

In second generation instrument reduce size, mass, power.

Technical Approach

1. Create a charged particle telescope system that improves the MARIE instrument flying on the Mars Odyssey mission.

   a) eliminate the gain saturation for heavy ions with LET> 35 keV/micron;

   b) increase the dynamic range of the MARIE instrument by a factor of 10-20 (up to 1000:1) to include protons with energies above 100 MeV;

   c) increase the maximum event rate of MARIE by at least a factor of 10 above the current limit of 3 Hz.

2. Fabricate, evaluate and calibrate the Eljen 454 scintillator detector system for medium energy neutrons from 1-15 MeV.

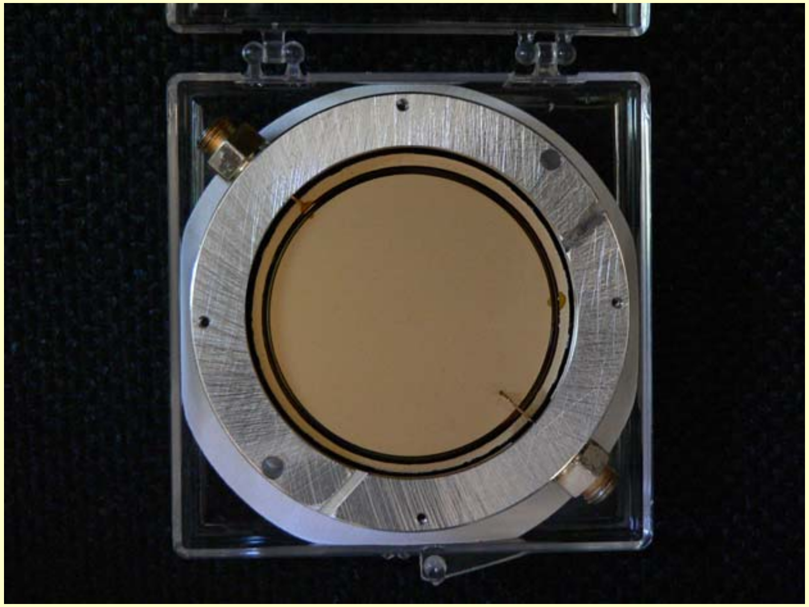
3. Develop the instrument electronics design based on the Gamma Ray Neutron Spectrometer (GRNS) instrument for the MESSENGER mission.

CINS Tasks and Milestones

The main initial tasks to date in 05/06

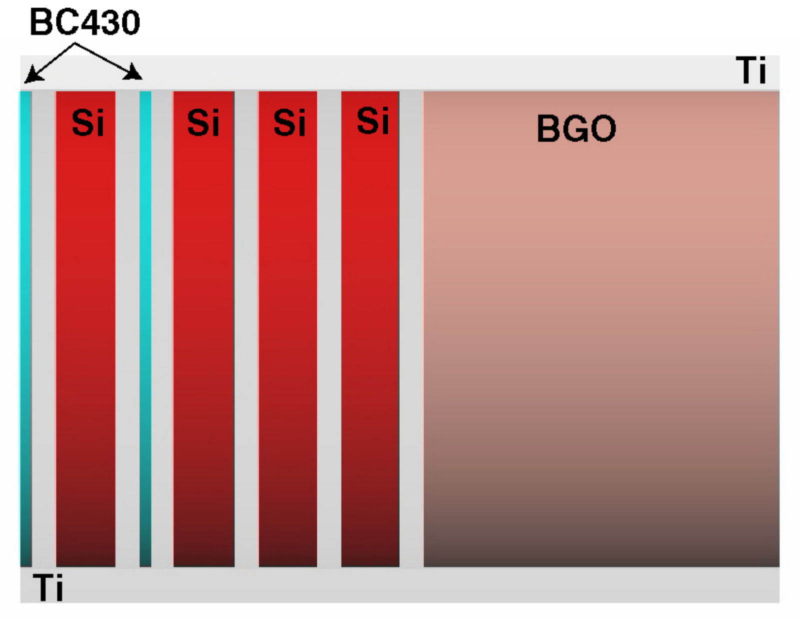
- Refurbished 4cm diameter X 5mm thick silicon detectors by re-drifiting and applying guard rings
- Designed and procured an Eljen boron-loaded scintillator sized to detect up to 15 MeV neutrons producing a cross over region with the higher energy thick silicon neutron detector
- Modeled the charged particle telescope design with GEANT 4
- Executed experiments at NSRL on 3/25.

Refurbished Thick Silicon Detectors



Refurbished thick silicon detector (4 cm X 5 mm) re-drifted with lithium to reduce noise (30 keV) and with guard ring added to define active diameter (3.7cm).

Charged Particle Telescope I



Conceptual design of 7 detector charged particle telescope determined by modeling; BGO detector is 3 cm thick

Charged Particle Telescope II

Similar to MARIE in that the 4 thick Si detectors provide particle identification and LET spectra.

- MARIE dynamic range problem fixed.

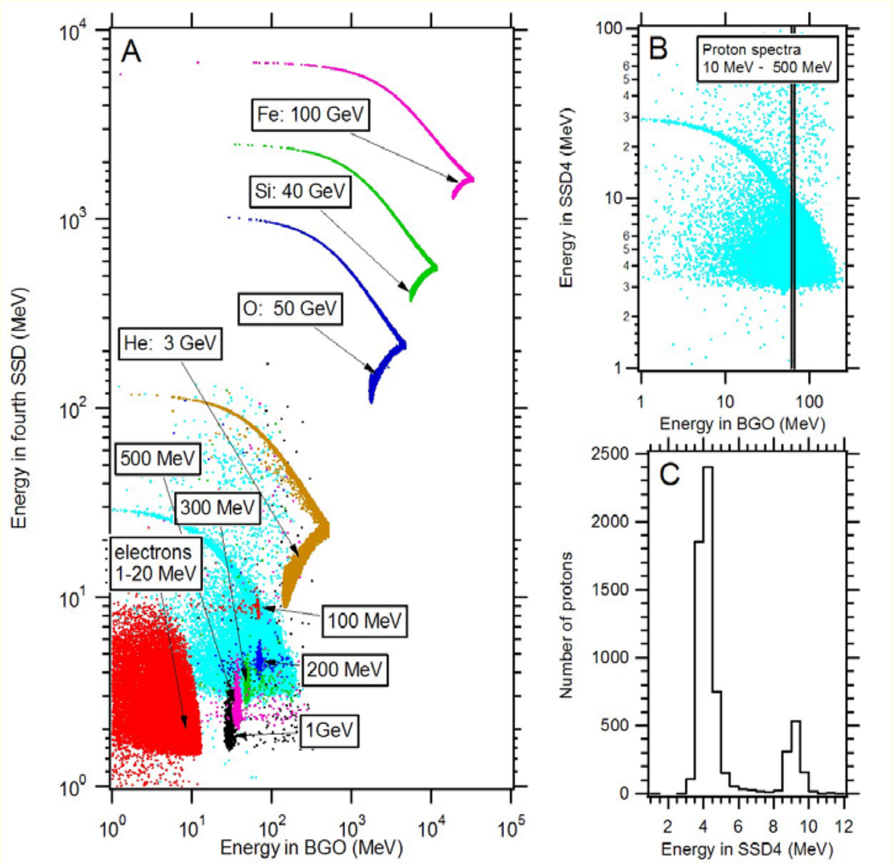
BGO adds mass, stops protons up to energy of 150 MeV; makes the stack asymmetric for directionality.

Plastic scintillators used as triggers & simple counters; helpful in high-rate environments.

Charged Particle Telescope Simulations

A shows the energy deposition in the thick BGO detector on the abscissa with the energy deposition in the last Si SSD on the ordinate. The vast majority of the protons can be separated from the electrons. With the BGO this simulation shows that protons up to ~300 MeV can be uniquely identified.

B and C show that a proton depositing ~80 MeV in the BGO yields primary and penetrating depositions in SSD4 of 1 MeV resolution.



Charged Particle Telescope Directionality

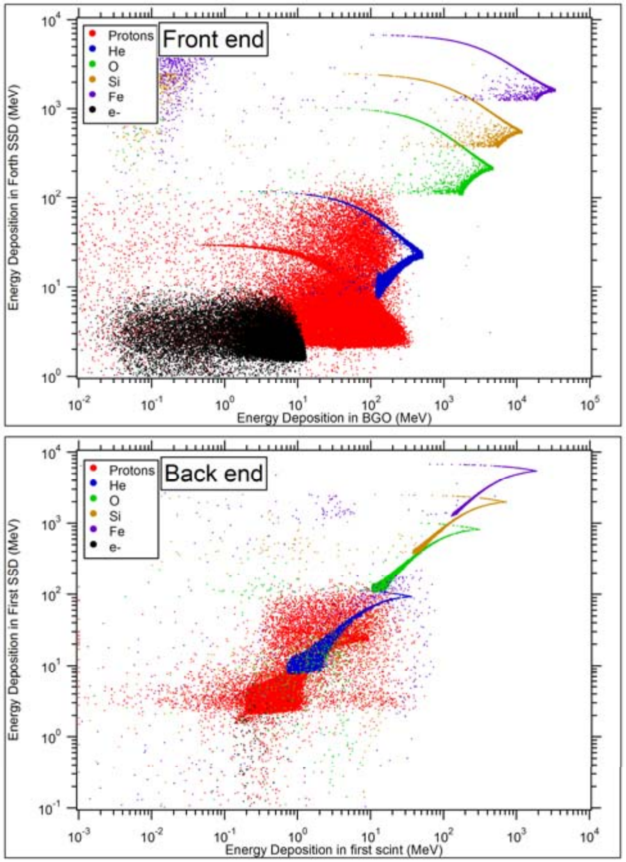


Figure shows asymmetry of the telescope yields directionality

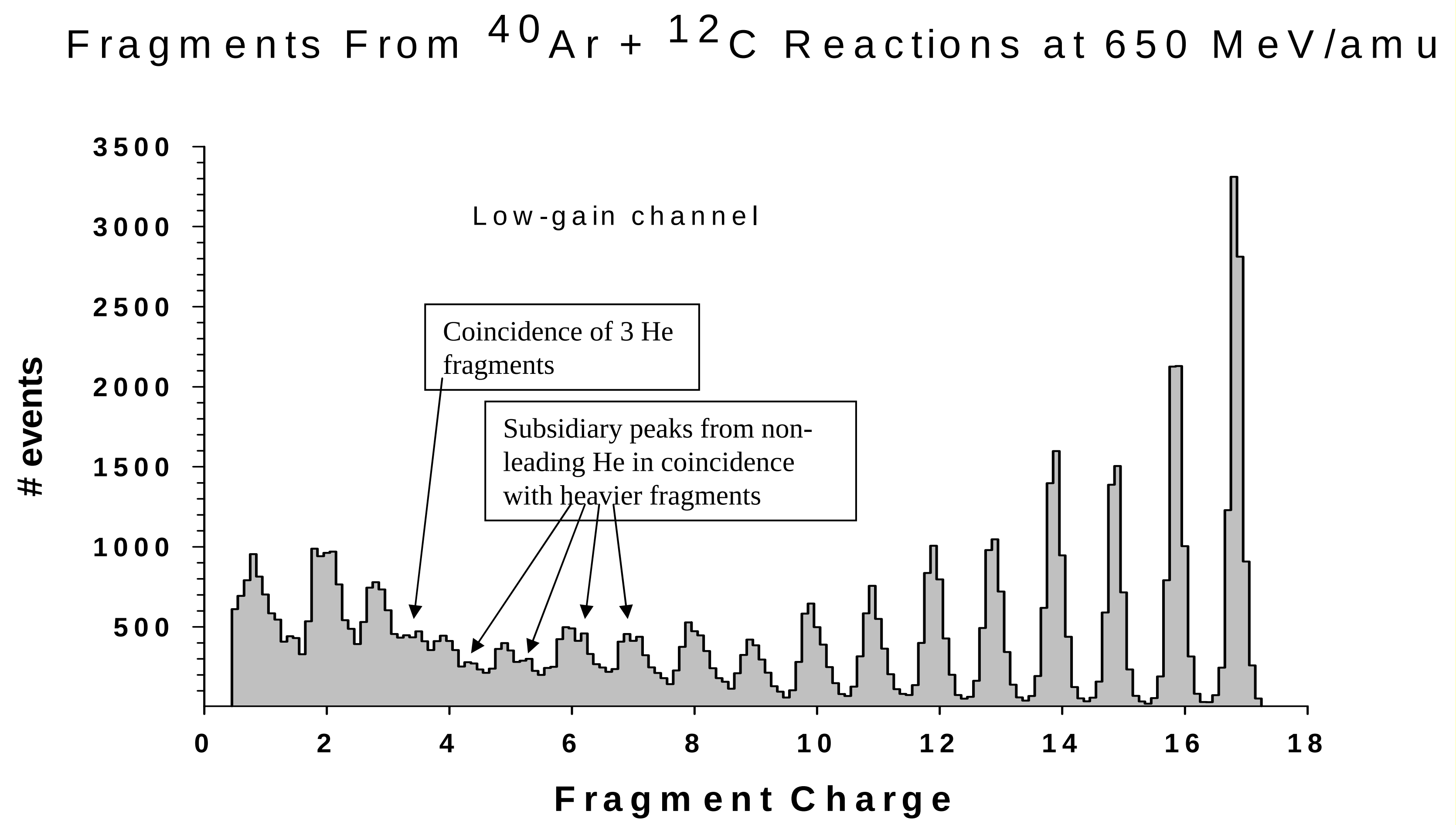
a) Particles from the front end deposit larger ranges of energy in SSD4 and the BGO.

b) Particles from the back end deposit smaller ranges of energy in SSD1 and Scint1. Electrons incident on the back end are absorbed by the BGO.

Silicon Detector Performance in Fragmentation Experiment

1) Argon-beam experiment at CHIBA, Japan: fragments and surviving primaries detected with re-drifted 5mm thick Si(Li) detectors.
2) Deposited energy $\propto (Z^2/v^2)$, with $v^2 \sim$ const.
3) Even with old electronics, easily cover the 400:1 dynamic range in a single channel.
   - CINS will have 2 different gains per Si detector.
4) Resolution sufficient to resolve peaks from detection of multiple fragments in coincidence.
   - E.g., effective $Z = (6^2+2^2)^{1/2} = 6.3$ from coincidence of C and He.

Charged Fragment Spectra from Heavy Ion Experiments



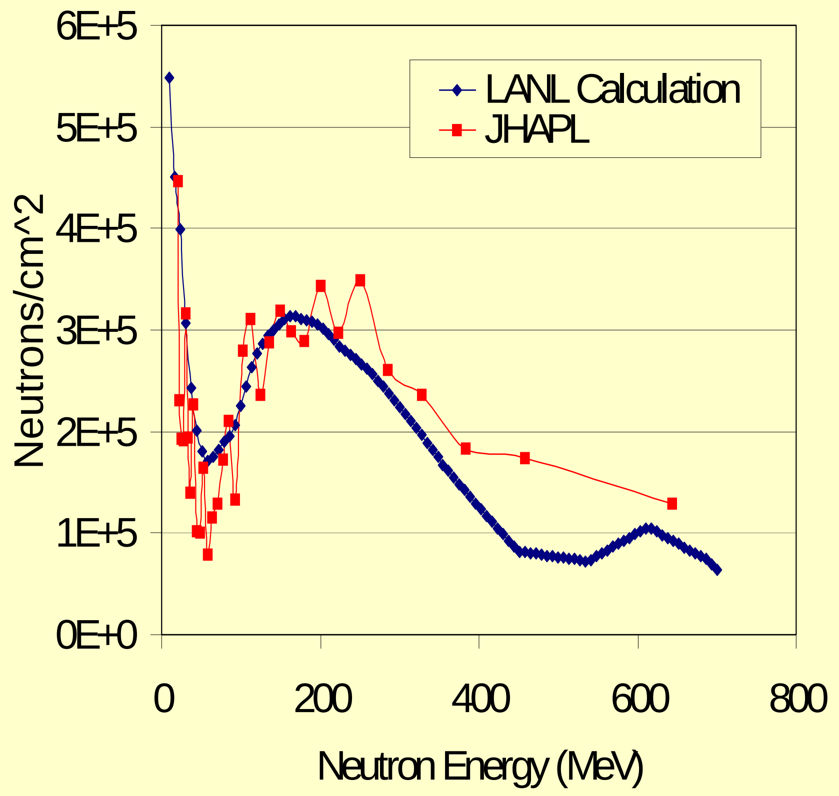
Neutron Spectrometer
(originally aimed at ISS)

Three components to monitor interior environment:

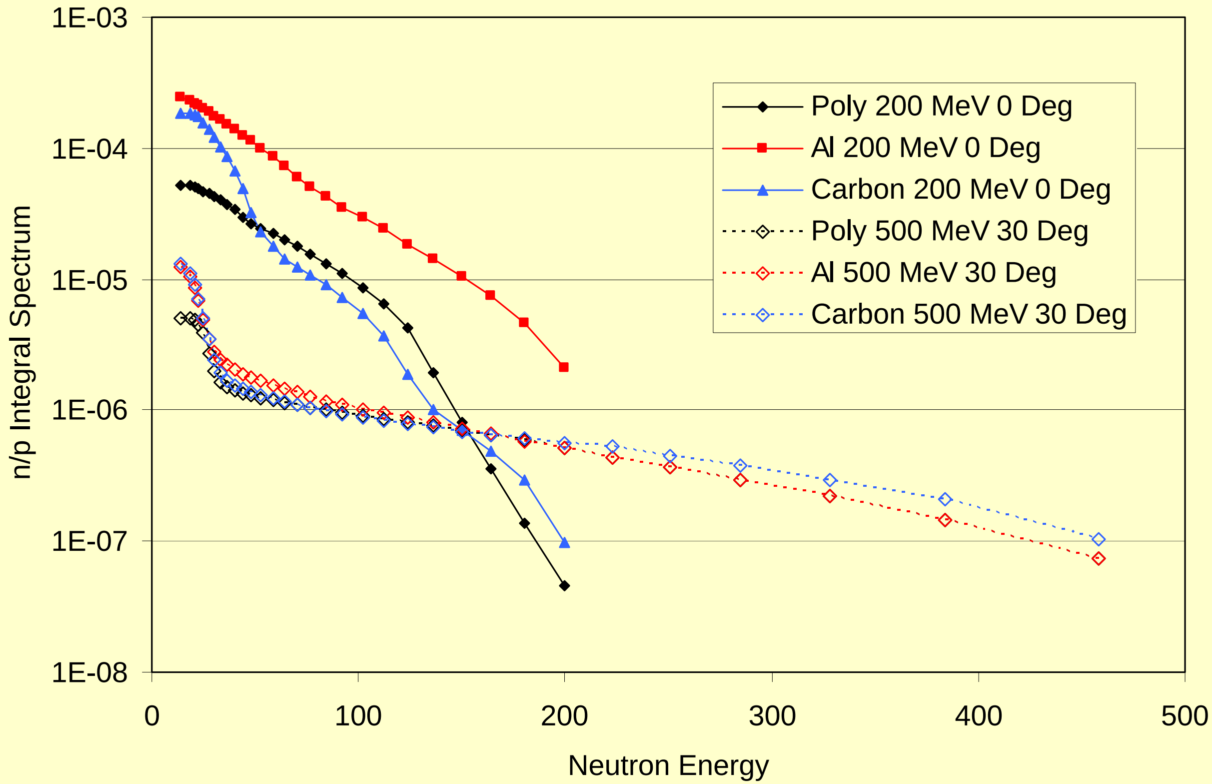
- ^{3}He tube for low energy (thermal to 1 MeV)
- Boron-loaded plastic scintillator (Eljen) for medium energy (1-15 MeV)
- Thick Si(Li) detector with anti-coincidence shield for high energy (12-600 MeV)
    - Unfolding to get incident neutron energy spectrum from deposited energy spectrum is maximum likelihood method.

LANSCE High Energy Neutron Blind Experiment

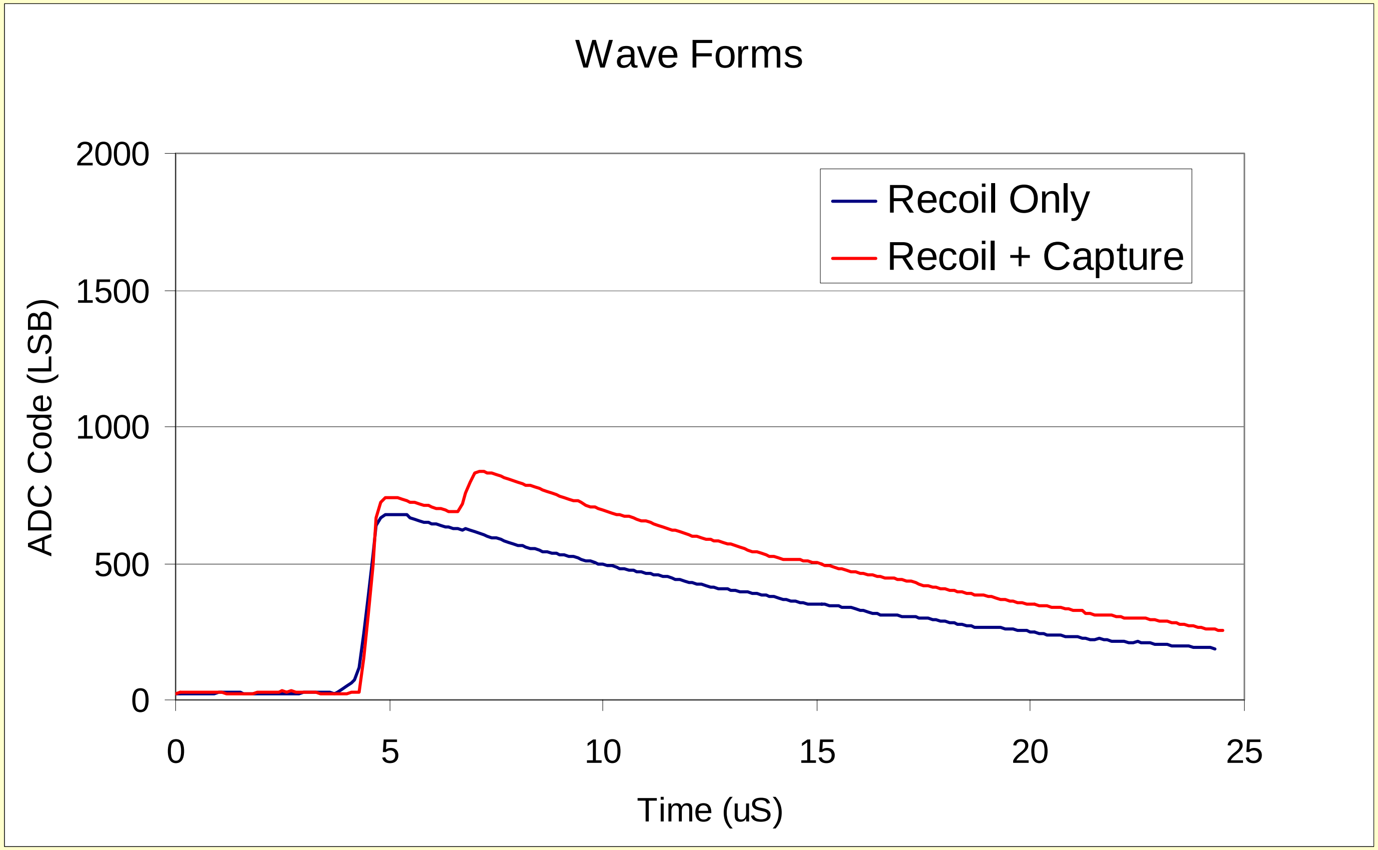
Comparison of the measured high energy neutron spectrum >20 MeV (red) from the 5mm thick silicon detector with the Los Alamos calculation for the beam-target configuration



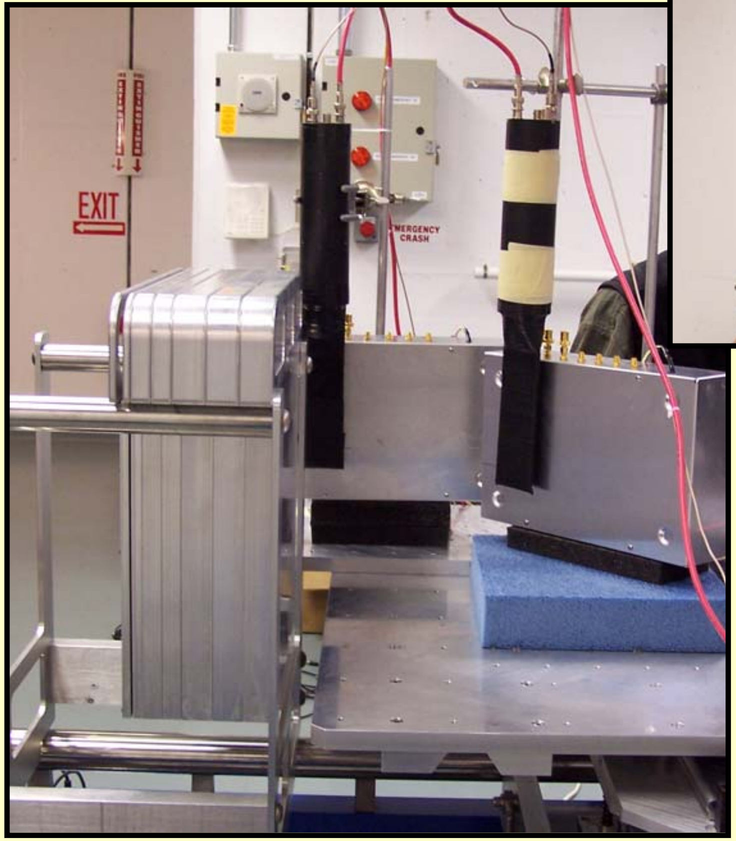
Effect of Shielding Materials 200 & 500 MeV Proton Collisions

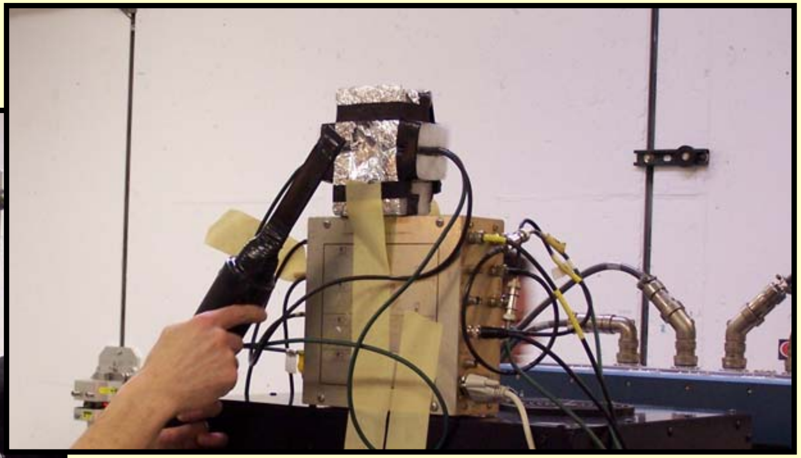


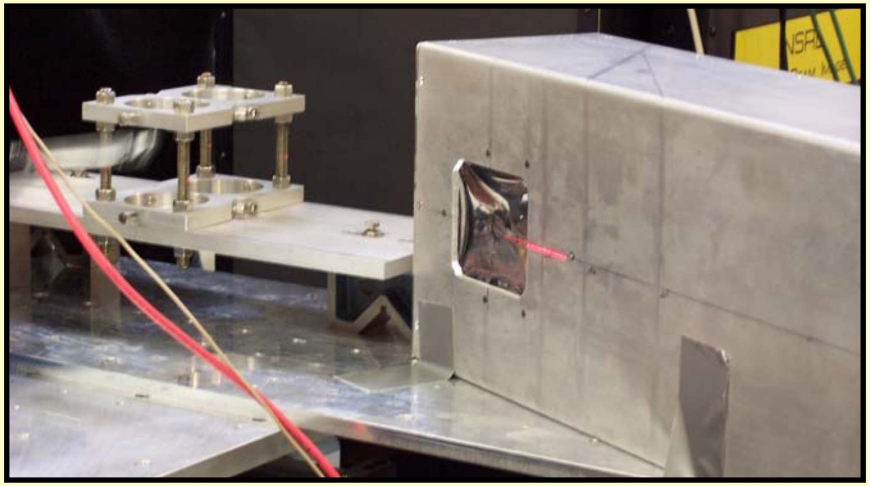
Typical 6 MeV Neutron Waveforms from Bicron 454 Scintillator



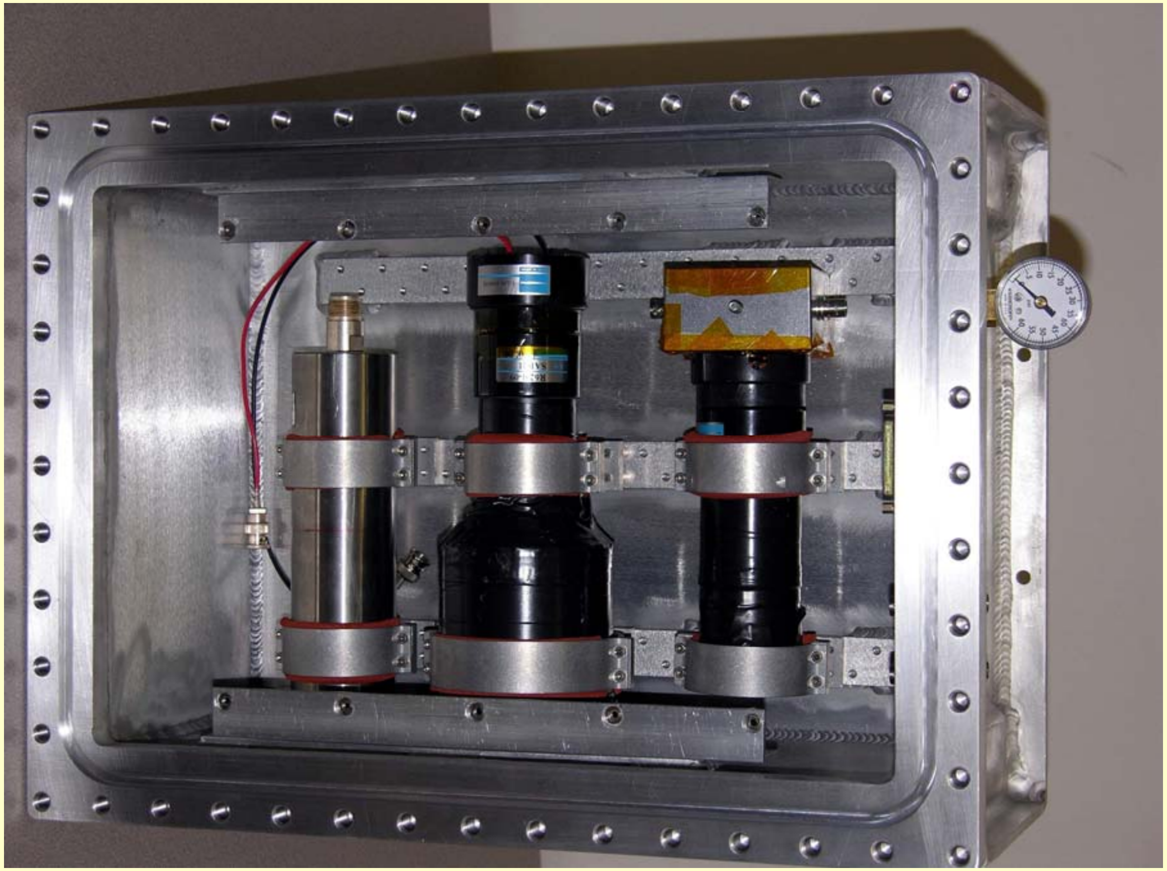
NSRL Detector Configuration March 25,2006



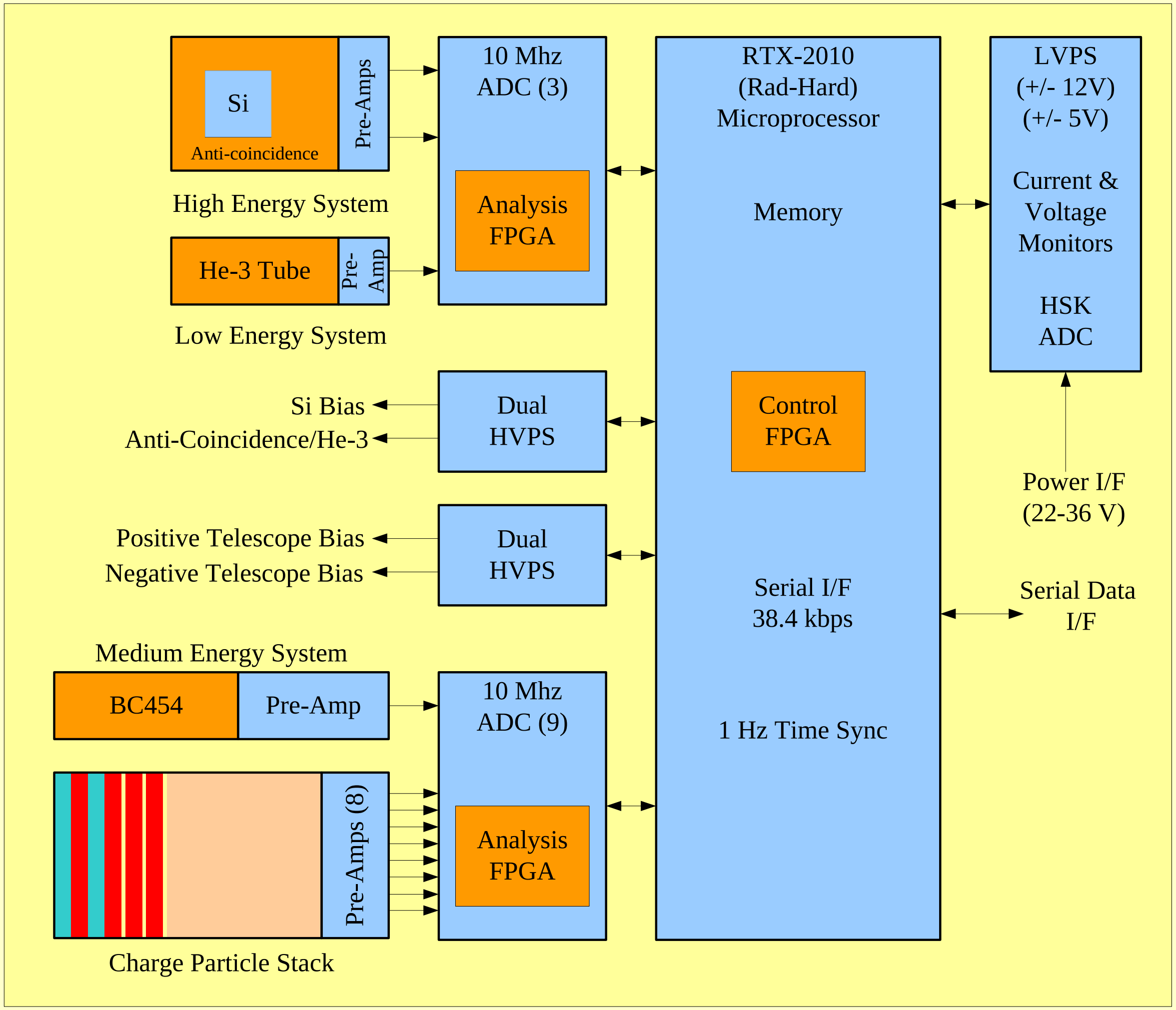




Balloon Flight Detectors



CINS Block Diagram



Heritage

- Low- and medium-energy neutron sensors used on Mars Odyssey, Mercury MESSENGER.
- JHU-APL built electronics for MESSENGER Gamma Ray/Neutron Spectrometer (GRNS).
- High-energy sensor used on balloon flights and thick target accelerator experiments.
- Charged-particle detectors from LBNL SSDL which built detectors for Voyager, ACE/CRIS, MARIE, etc.

Related Projects/Next Steps

- We delivered a version of the NSBRI Neutron Spectrometer for the Deep Space Test Bed (DSTB) balloon flight in December 05. The contract was funded for $272,000 by MSFC. Completion of integration with gondola is scheduled for April 06.
- 3/25/06 NSRL run made for individual Si(Li) detector evaluations and thick Al target collisions
- In 2006 procure BGO scintillator for telescope, complete mechanical design and begin assembly.
- Summer 06: calibrate Eljen 454 scintillator at RARAF.
- Spring 07 NSRL run for scintillator evaluations and first test of telescope.
- Continue GEANT4 modeling (D. Haggerty).

Publications

- R.H. Maurer, J. D. Kinnison and D. R. Roth, “Neutron Production from 200-500 MeV Proton Interaction with Spacecraft Materials,” Radiation Protection Dosimetry 2005, **116**, No. 1-4, 125-130.

- R. H. Maurer, D. R. Roth, J. D. Kinnison, D. K. Haggerty and J. O. Goldsten, “The NSBRI/APL Neutron Energy Spectrometer,” accepted for publication in Johns Hopkins APL Technical Digest 2005.

- R.H. Maurer, C. J. Zeitlin, D. K. Haggerty, D. R. Roth, J. O. Goldsten, “Compact Ion and Neutron Spectrometer (CINS) for Space Application,” 2005 IEEE Nuclear Science Symposium Conference Record, N14-48, pp 428-432, Puerto Rico, 24-27 October 2005.

- C. J. Zeitlin et al., "Overview of the Martian Radiation Environment Experiment", Adv. Space Res. 33, No. 12, 2204-2210, 2004.