Estimates of Cosmic Rays Directional Dose for ISS (part – II)

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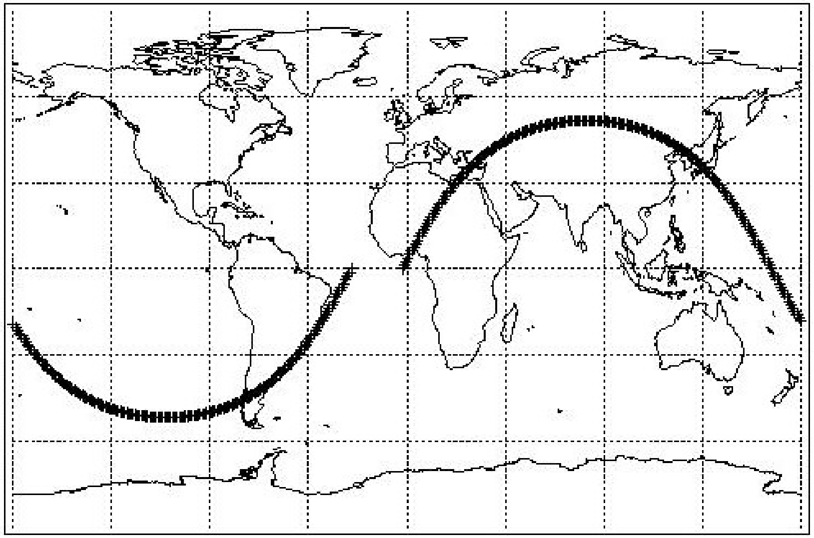
Background

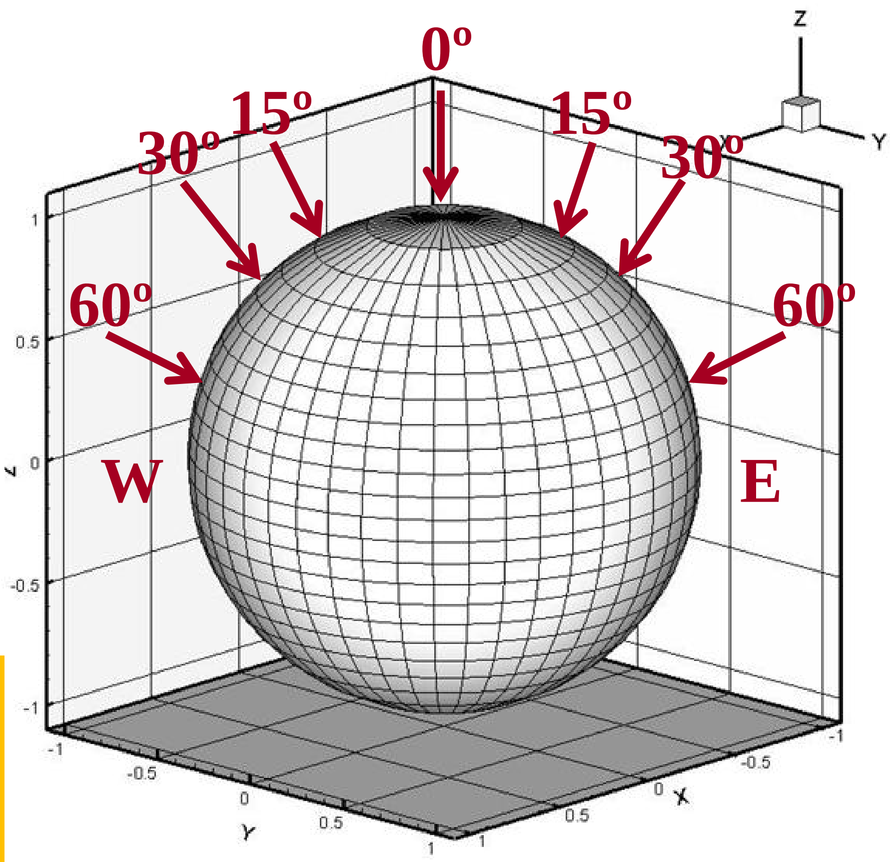
- I – Traditionally, LaRC radiation team has developed fast deterministic-based particle transport codes.
- II – Last year in Austin, for ISS, theory and limited validation of a directional GCR model was presented.
- III – The 20 minutes talk was followed by 30 minutes of Q/A. Experimentalists were reasonably happy with my answers. Questions concerning the validity of the 3D GCR model at high energy (GeV – TeV) were not satisfactorily answered and I will answer them today.

Outline

- I – How deterministic codes validate measurements.
- II – Explain the connection between CAD/mass models of ISS and dosemetric measurements.
- III – Discuss how the directional model handles high energy (GeV – TeV) portion of the GCR spectrum.
- IV – Show what has been done by others folks in the field of simulating directional GCR.
- V – Summary and future work.

Introduction (3D GCR Validation)





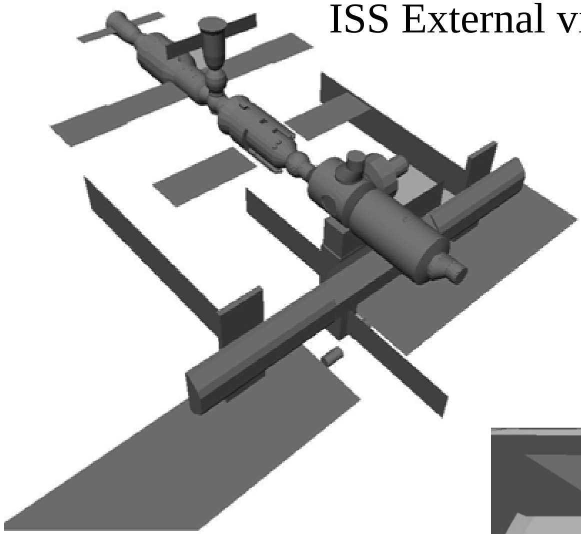
Can we validate the ISS measurements by 3D detectors such as TRITEL, etc… ???

Will need a fast 1D/3D transport code. ✓
Will need a 3D GCR/trap environments. ✓
Will need the appropriate trajectory. ✓
Will need a reliable <u>epoch dependent</u> CAD/mass model of ISS. ✗

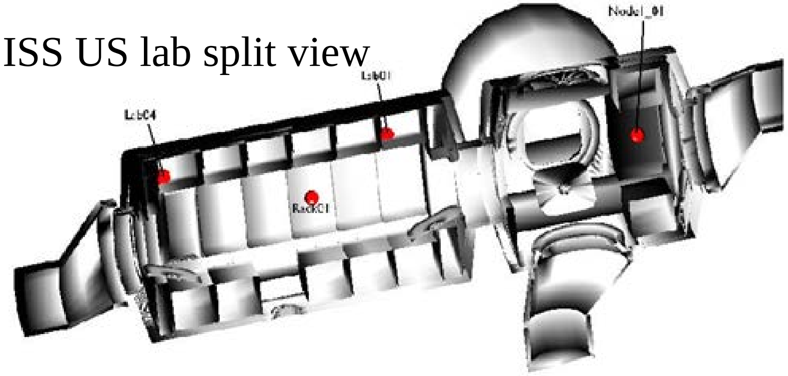
ULF7 (2011)
3R (2014)

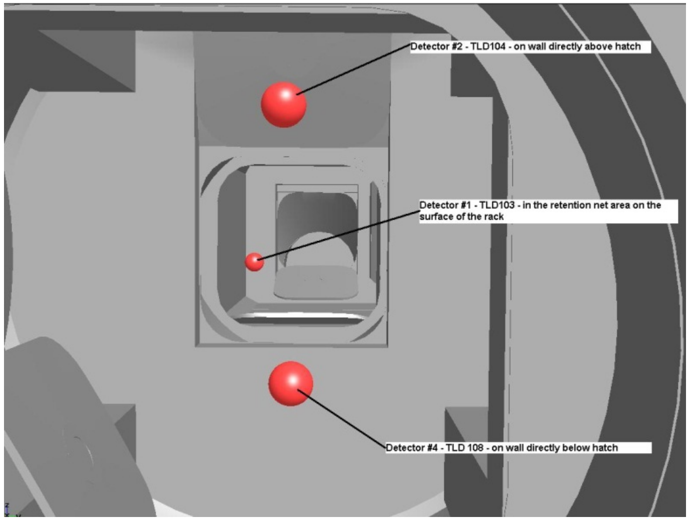
CAD Model of ISS 11A Configuration (2005)

ISS External view



ISS US lab split view

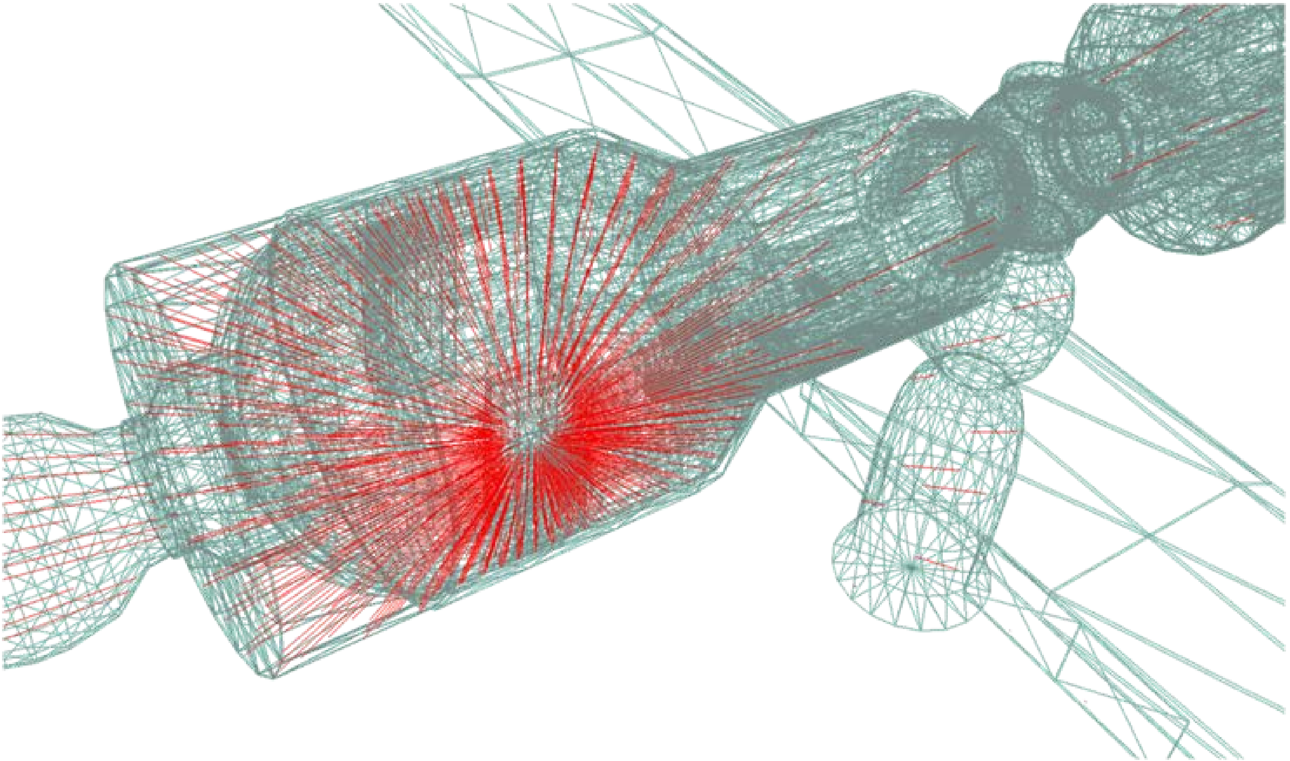




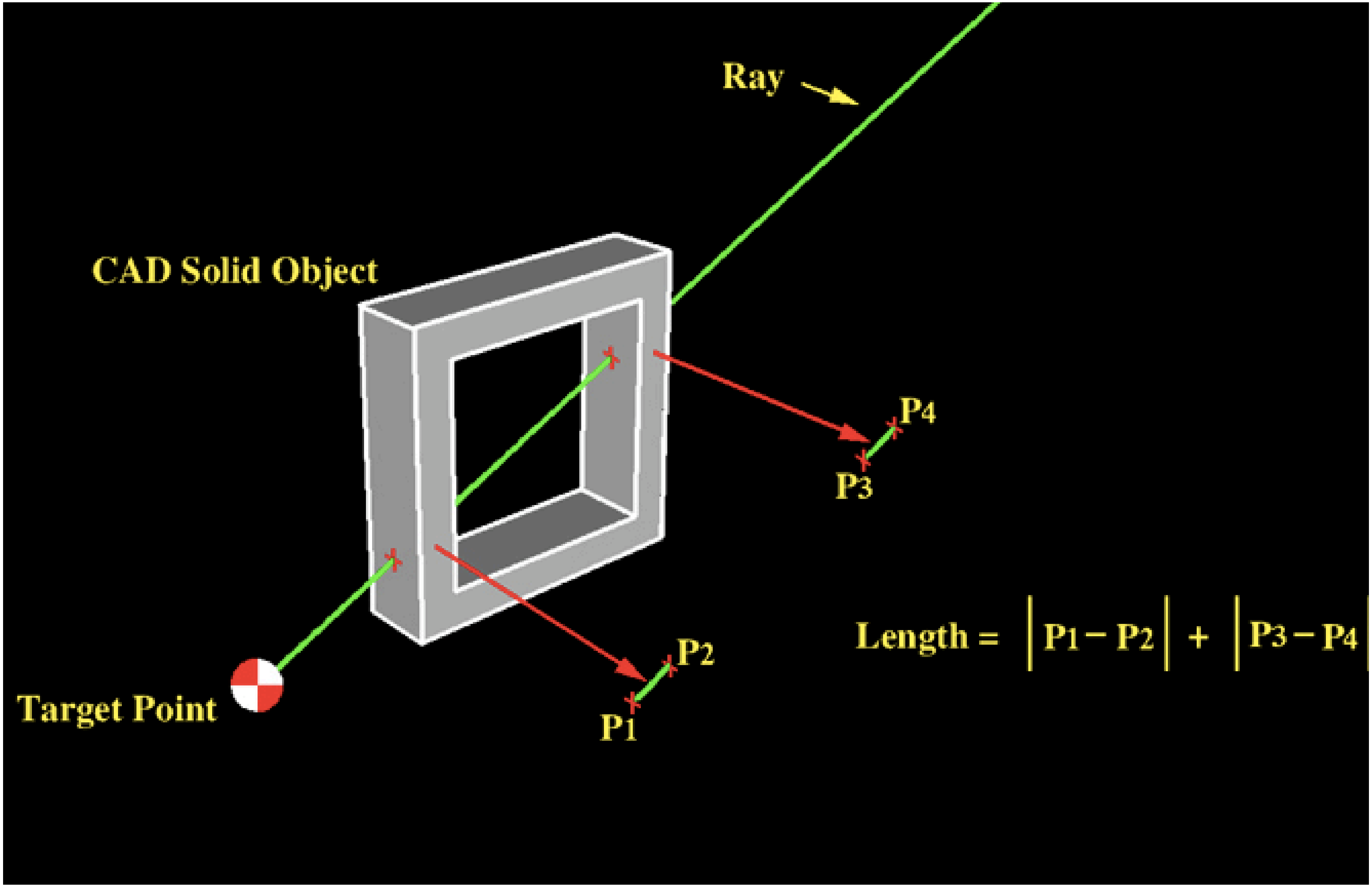
Internal view of Node1 looking Forwards towards US Lab

840 m^3
455,000 kg.
(1,000,000 lbs.)

Raytracing Approach

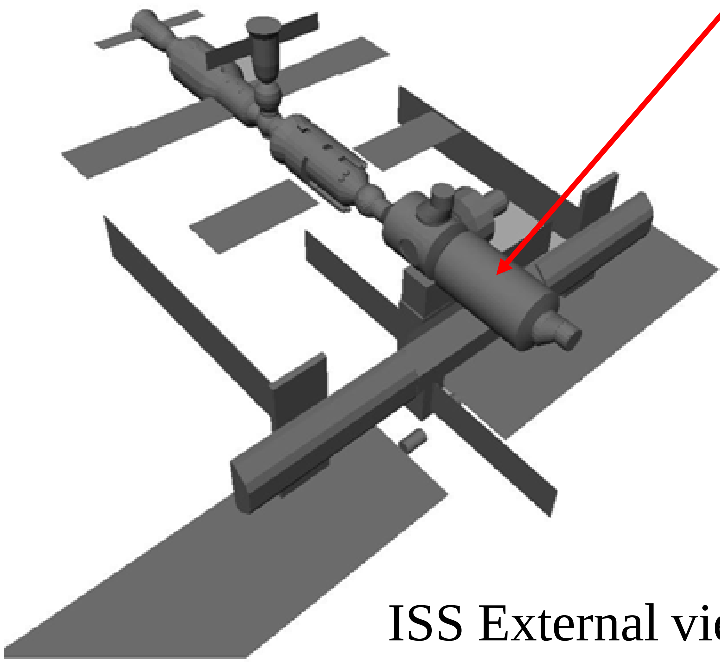


Ray Tracing Approach

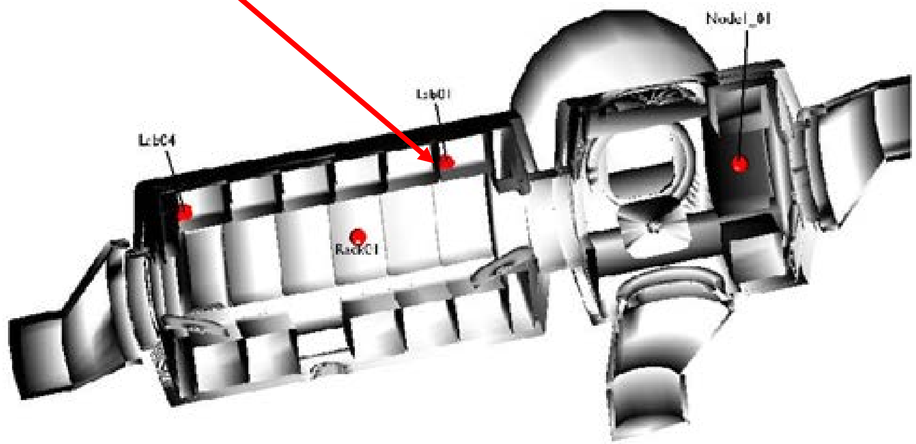


CAD Model of ISS 11A Configuration (2005)

Lab01 target point (US lab-module)



ISS External view



ISS US lab split view

Liulin measurements courtesy of T. Dachev

Validation of 3D Detector Measurements

Can we validate the ISS measurements by 3D detectors such as TRITEL, etc… ???

Will need a fast 1D/3D transport code. ✓
Will need a 3D GCR/trap environment. ✓
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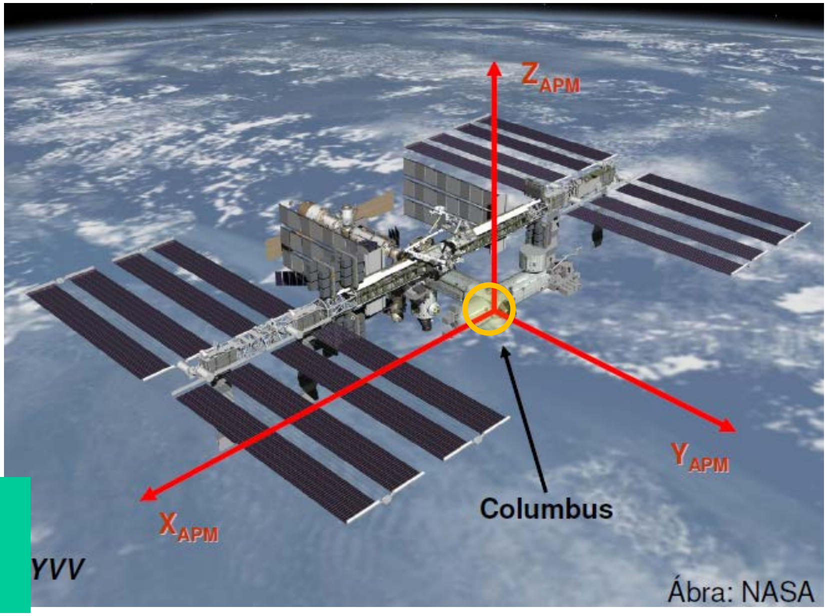
ULF7 (2011)
3R (2014)



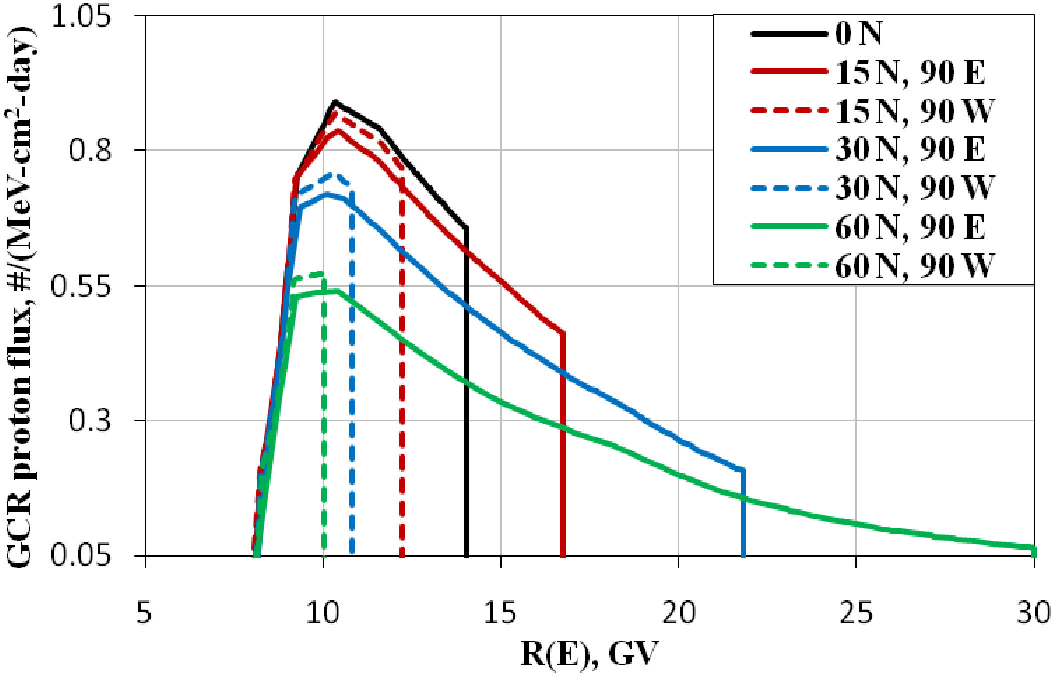
Courtesy of Attila Hirn (2013)

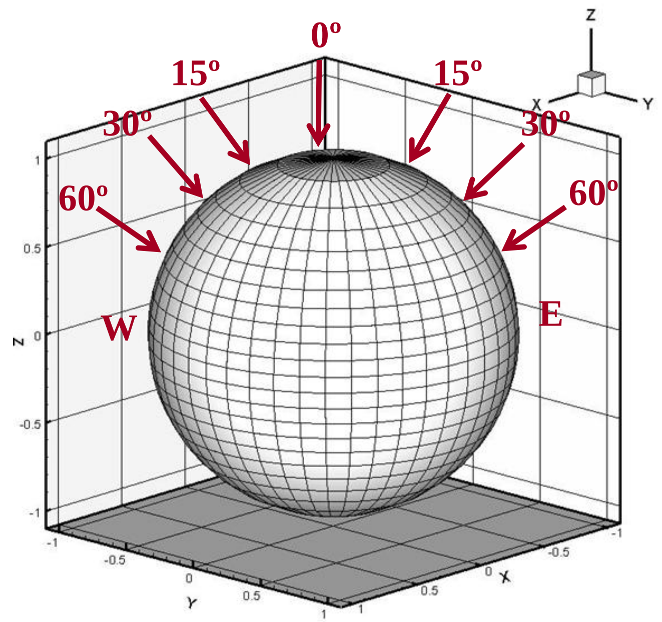
What is needed from instrument people:

1 - CAD/mass model of the detector (location, orientation, what ISS CS…)

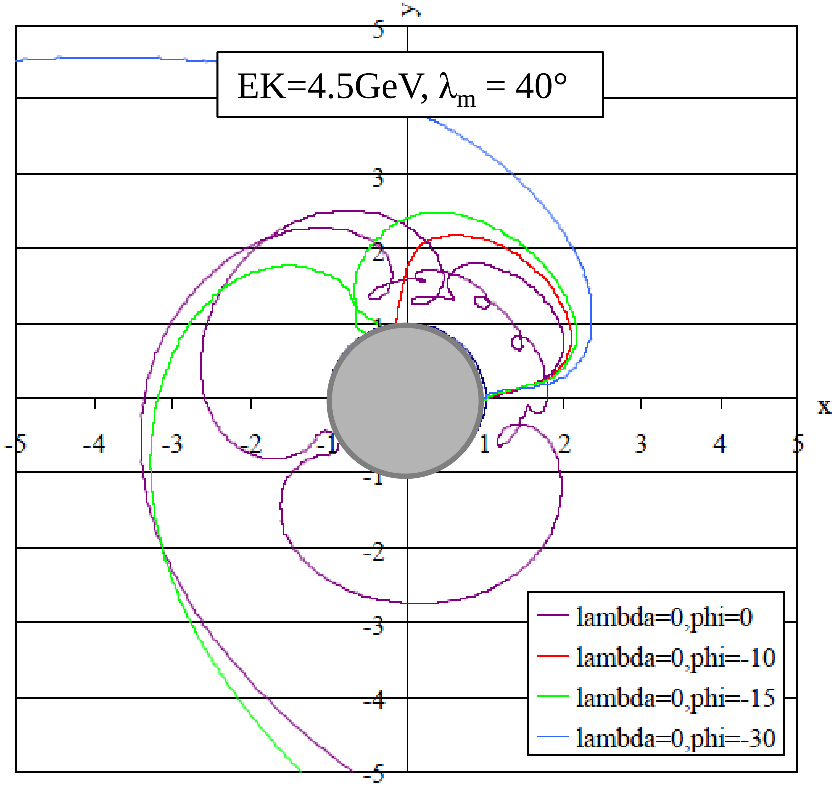
2 - $\boldsymbol{counts} = \iiiint eff\,(E, \Omega)\, \boldsymbol{J\,(E, \Omega, A, t)}\,dE\,d\Omega\,dA\,dt$

ISS GCR Proton Directional Flux Distribution for 7 Angles of Incidence (400 km, 2005 epoch)

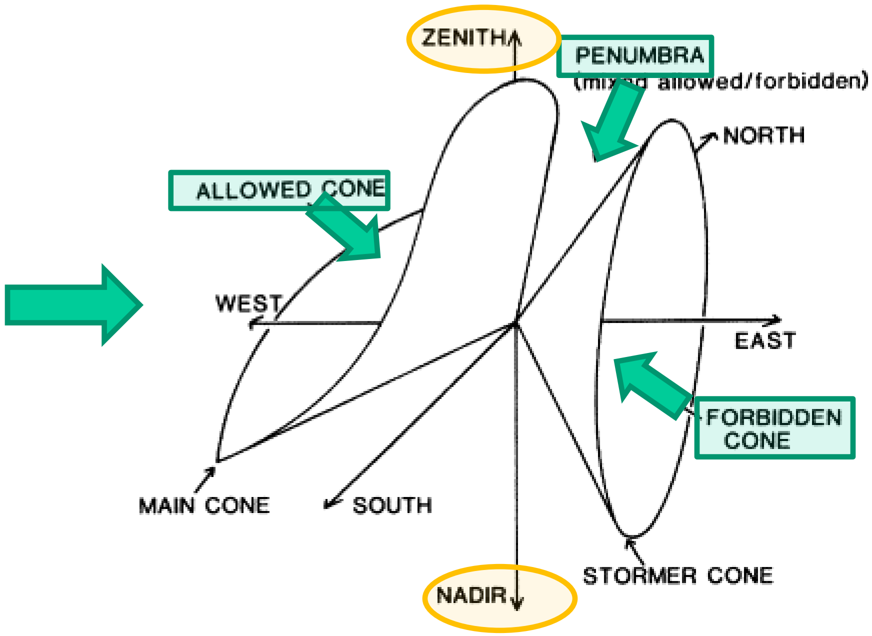




Directional Stormer Theory (Dipole approximation)



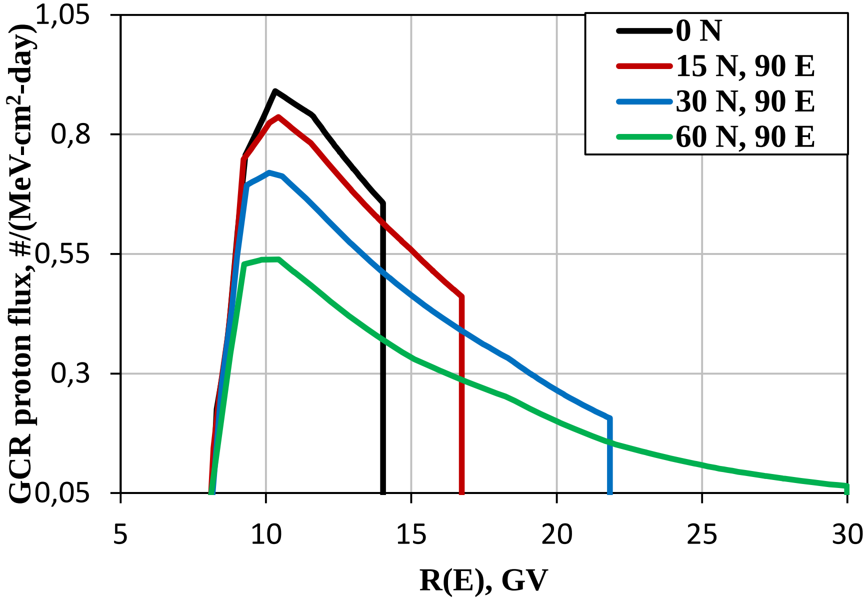
Courtesy of R. Mugford (2003)



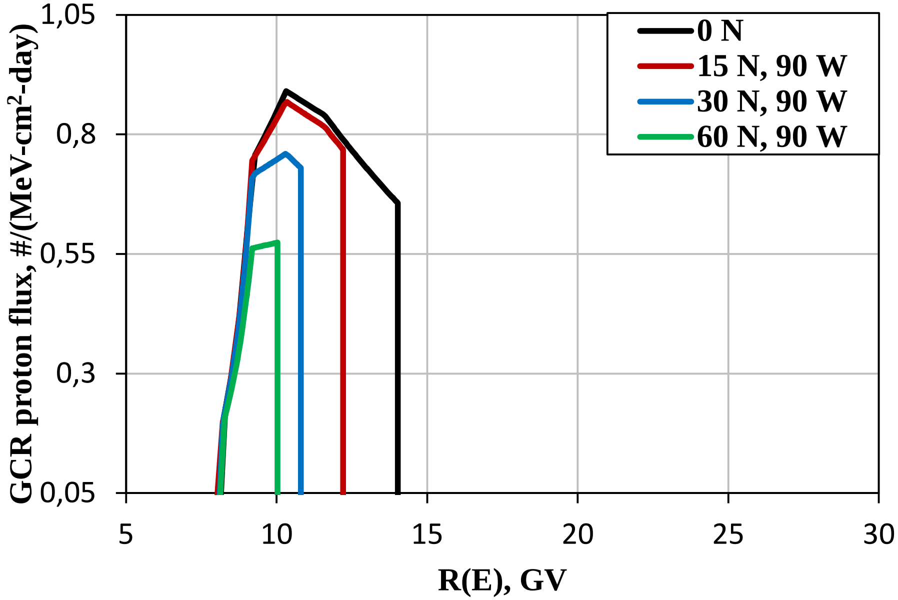
$$R(\lambda_m,\xi,\psi) = (c_D\cos^4\lambda_m)/(r_D^2[1+(1-\cos^3\lambda_m\sin\xi\sin\psi)^{1/2}]^2)$$

ISS GCR Proton Directional Flux Distribution for 4 Angles of Incidence (400 km, 2005 epoch)

Protons in partially allowed cone



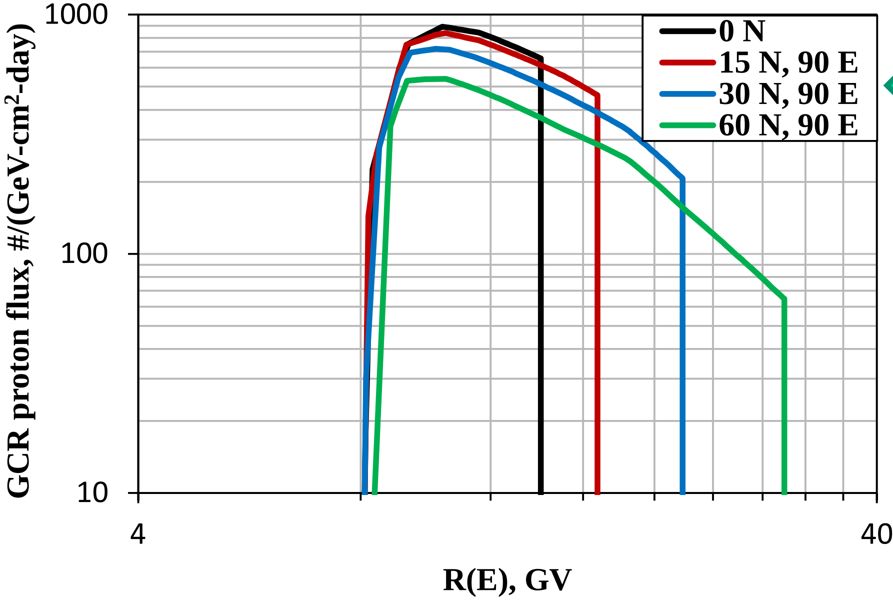
Protons in partially forbidden cone



GCR Proton Directional Flux Distribution for 4 Angles of Incidence (Badavi and Hirn)

Table 1
Parameters of the coordinate transformation.

Parameter	Value	Reference field model
θ_N	79.54°	IGRF 2000
φ_N	288.43°	IGRF 2000
η	$-0.06308\ R_{\text{Earth}}$	IGRF 2000
ζ	$0.04713\ R_{\text{Earth}}$	IGRF 2000
ξ	$0.03149\ R_{\text{Earth}}$	IGRF 2000



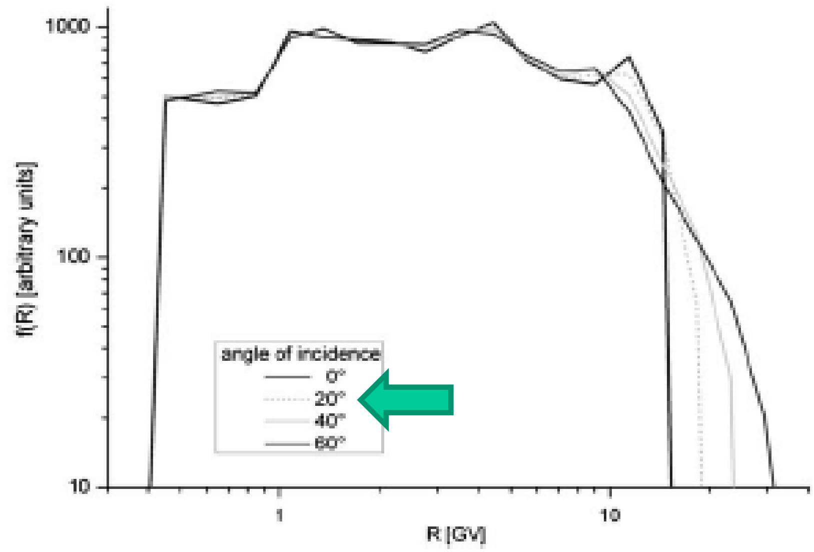


Fig. 2. Cut-off distribution for different angles of incidence for a telescope pointing towards the geographical zenith direction.

400 km

IGRF 2005

340 km

IGRF 2000

Summary and Future Work

- I – Hirn and Badavi, have essentially produced the same GCR directional cutoff distributions.

- II – The vertical drop of directional flux at high rigidity is due to the limitation of Stormer formalism in the allowed, forbidden and penumbra cones.

- III – The success of 3D GCR formalism depends on an accurate epoch dependent CAD/mass model. Once the CAD/mass model of current version of ISS (ULF7) become available, it will be desirable to validate the 3D ISS measurements (tissue/SSD) with the corresponding simulations.

Backups

$$\boxed{\textbf{counts} = \iiiint eff\,(E, \Omega)\, \boldsymbol{J(E, \Omega, A, t)}\, dE\, d\Omega\, dA\, dt}$$

$$\textbf{counts} = \Delta t \iiint eff\,(E, \Omega)\, \boldsymbol{J(E, \Omega, A)}\, dE\, d\Omega\, dA$$

$$\textbf{1 -}\quad \textbf{counts}/\, \Delta t = \iiint eff\,(E, \Omega)\, \boldsymbol{J(E, \Omega, A)}\, dE\, d\Omega\, dA$$

$$\textbf{counts}/\, \Delta t = A \iint eff\,(E, \Omega)\, \boldsymbol{J(E, \Omega)}\, dE\, d\Omega$$

$$\textbf{2 -}\quad \textbf{counts}/\, \Delta t\, A = \iint eff\,(E, \Omega)\, \boldsymbol{J(E, \Omega)}\, dE\, d\Omega$$

$$\textbf{counts}/\, \Delta t\, A = \Delta\Omega \int eff\,(E)\, \boldsymbol{J(E)}\, dE$$

$$\textbf{3 -}\ \textbf{counts}/\, \Delta t\, A\, \Delta\Omega = \int eff\,(E)\, \boldsymbol{J(E)}\, dE$$

$$\textbf{counts}/\, \Delta t\, A\, \Delta\Omega \approx \boldsymbol{J\,(E)}\, \Delta E$$

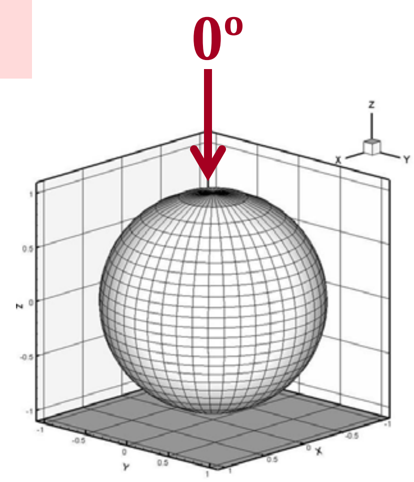
$$\boxed{\textbf{4 -}\quad \textbf{counts}/\, \Delta t\, A\, \Delta\Omega\, \Delta E = \boldsymbol{J(E)}}$$

Directional and Omni GCR Dose Rates in Si for ISS Lab01 Target Point (2005 epoch)

incident GCR ions direction (ions: n-Ni)	anisotropic GCR TID (Si) µGy/(sr-min)	isotropic GCR TID (Si) µGy/min	measurement µGy/min	long/lat	altitude
0 N	1.13E-02	1.41E-01	1.56E-01	95.72/-6.33	380.55
15 N, 90 E	1.07E-02	1.34E-01			
15 N, 90 W	1.10E-02	1.39E-01			
30 N, 90 E	9.17E-03	1.15E-01			
30 N, 90 W	9.58E-03	1.20E-01			
60 N, 90 E	6.88E-03	8.64E-02			
60 N, 90 W	7.29E-03	9.16E-02			

X   X*4π

up to factor of 2 error due to normal vs. omni



****Note: Si dose is due to all GCR ions (P-Ni) ****

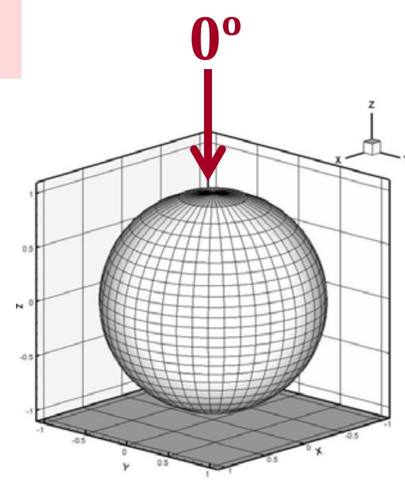
Liulin measurements courtesy of T. Dachev

Directional and Omni GCR Dose Rates in Si for ISS Lab01 Target Point (2005 epoch)

incident GCR ions direction (ions: n-Ni)	anisotropic GCR TID (Si) µGy/(sr-min)	isotropic GCR TID (Si) µGy/min	measurement µGy/min	long/lat	altitude
0 N	3.44E-02	4.32E-01	4.68E-01	175.68/-51.74	391.16
15 N, 90 E	3.35E-02	4.21E-01			
15 N, 90 W	3.37E-02	4.24E-01			
30 N, 90 E	3.22E-02	4.04E-01			
30 N, 90 W	3.25E-02	4.08E-01			
60 N, 90 E	3.03E-02	3.81E-01			
60 N, 90 W	3.07E-02	3.85E-01			

X   X*4π

up to factor of 2 error due to normal vs. omni



****Note: Si dose is due to all GCR ions (P-Ni) ****

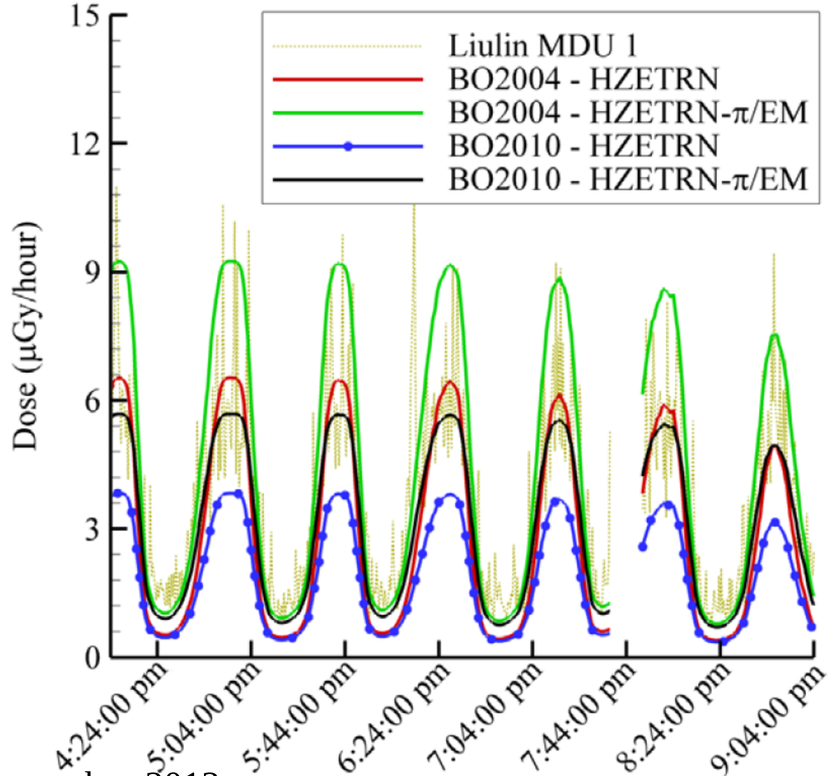
Liulin measurements courtesy of T. Dachev

Computational Loop

- I – For every ISS trajectory point provided from telemetry downlinks, define the GCR and the trapped environments (i.e. environment is epoch dependent).
- II – For each trajectory point environment(s), we perform a full transport run.
- III – We follow the transport runs with computing the dosemetric quantities of interest (tissue/SSD) using the appropriate ray traced ISS mass model.
- IV – We validate versus available measurement.
- V – We repeat steps I – IV above for all trajectory points .

Validation against ISS Data

- Comparison of models to ~77,000 measurements
  - Data from five detectors at ~30 second intervals from July 6-13, 2001
  - Includes Liulin MDU (1-4) and TEPC (ISS 6A configuration)
  - Allows errors to be mapped as a function of meaningful physical quantities
  - Enables extrapolation of LEO errors to free-space conditions

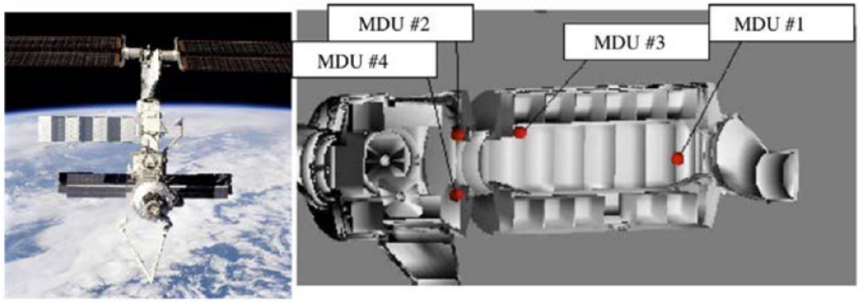


Comparison of models to measured data taken aboard ISS on July 6, 2001

Spikes in measurements are statistical errors due to low count rates

Gap in data near 7:44 is SAA (data removed)

Liulin detectors located in US lab and Node 1 and TEPC was near FRED phantom in US lab



Rigidity and Vertical / Directional Cutoffs

Rigidity: $R(E) = (A/Z)\sqrt{(E^2+2m_oE)}$

At low energy: $R(E) \sim\sqrt{E}$

At high energy: $R(E) \sim E$

Cutoff (vertical): $C_V(r_d, \lambda_m) = (a_d\cos^4\lambda_m)/4r_d^2$

Cutoff (directional): $C_D(r_d, \lambda_m, \xi, \psi) = (a_d\cos^4\lambda_m)/(r_d^2[1+(1-\cos^3\lambda_m \sin\xi\sin\psi)^{1/2}]^2)$

For ISS flying in LVLH, we take advantage of angles ξ and ψ (zenith and azimuth angles) to study the directional intensity of GCR as ISS geographical latitude changes. That is how a directional particle telescope (3D) sees incoming ions.

Cosmic Ray Directional Transmission in the Magnetosphere

- Rigitidy (R) Definition: $R = (A/Z)\sqrt{(E^2+2m_oE)}$

  A and Z are mass and charge numbers, m_o is ion mass in MeV, E is MeV/n

  GCR Directional Rigidity:

  $$R = (c_D\cos^4\lambda_m)/(r_D^2[1+(1-\cos^3\lambda_m\sin\xi\sin\psi)^{1/2}]^2)$$

  ξ: zenith angle

  ψ: azimuth measured clockwise from magnetic north

  λ_m: magnetic latitude

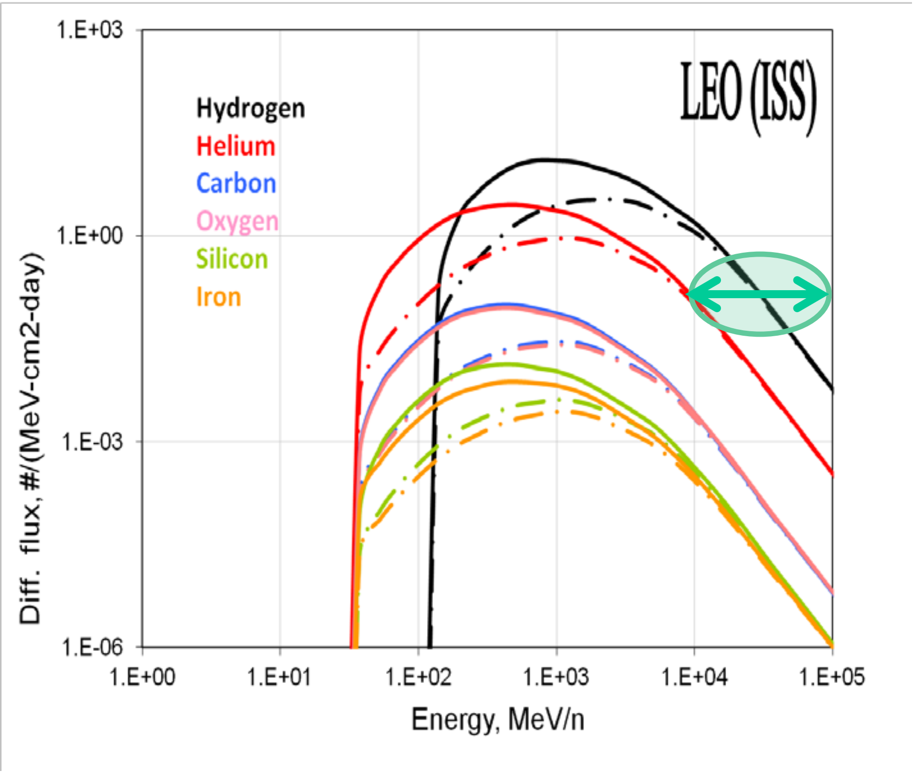
  r_D: distance from effective central dipole

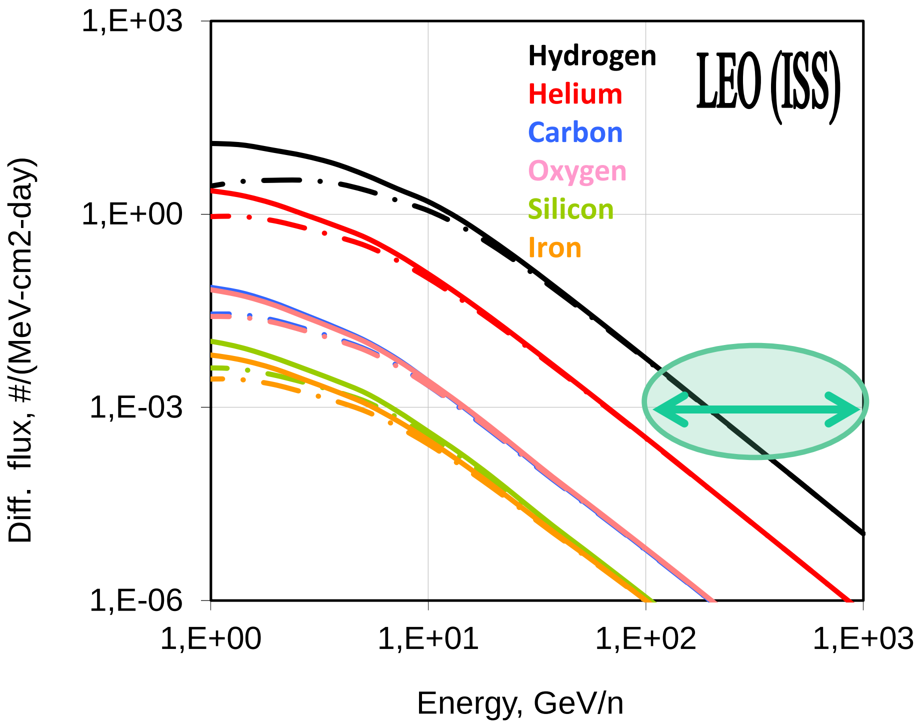
  c_D: normalized rigidity parameter for appropriate vertical cutoff at some geographic location at 20 km.

- Vertical cutoff maps at 20 km. cover the time period 1945-2020

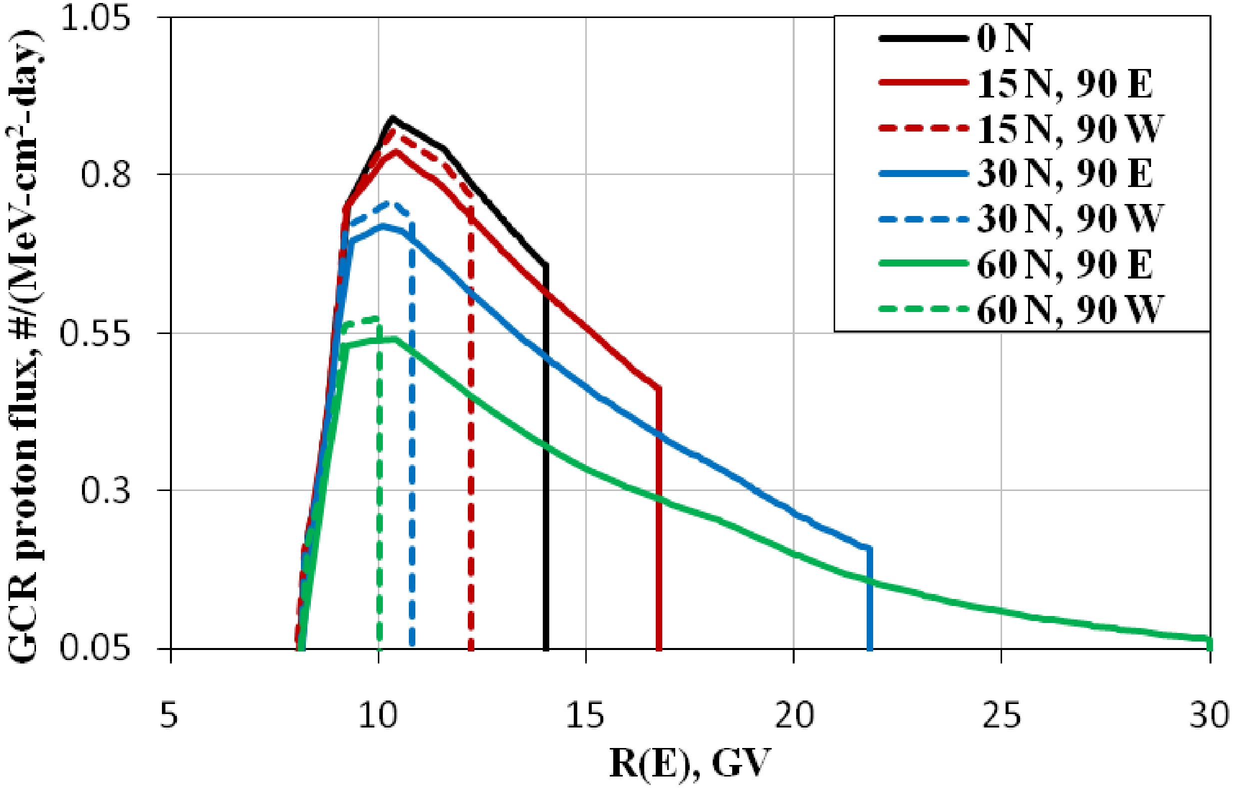
Intensities of Selected GCR Ions in LEO (ISS)

Solarmin (~ 2009)
Solarmax (~ 2001)





ISS GCR Proton Directional Flux Distribution for 4 Angles of Incidence (400 km, 2005 epoch)



GCR Proton Directional Flux Distribution (Attila Hirn)

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Models of performances of dosimetric telescopes in the anisotropic radiation field in low earth orbit

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A R T I C L E I N F O

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A B S T R A C T

In the case of the International Space Station (ISS), the attitude of which is usually stabilized in the local vertical reference frame (airplane-like attitude), the anisotropies in the radiation field, such as the effect of the Earth's shadow, the angular dependence of the geomagnetic transmission factors and the East–West asymmetry in the South Atlantic Anomaly (SAA), cannot be ignored. One-dimensional telescopes used for dosimetry have strong directional sensitivity and therefore they might either under- or overestimate the dose equivalent. The application of 3D telescopes with three, mutually orthogonal axes improves significantly the measuring precision of the instrument. The present paper addresses the expected responses of 1D and 3D telescopes for anisotropic radiation in low Earth orbit on board the ISS. Calculations were performed to estimate the differences between the obtained LET-spectra of the untrapped particles as well as the absorbed dose values. The directionality of trapped protons in the SAA was addressed as well.

1. Introduction

Exposure of crew to space radiation poses one of the most significant hazards to long term space habitations. The cosmic radiation field is quite complex, it varies considerably with time and may even differ from one point to the other. Several different dosemeters and a set of complex calculations are needed to determine the dose to the astronauts.

Albeit the efficiency of TEPCs to low-LET particles has considerably improved, the use of 1D silicon detector telescopes for determining the LET spectrum of the cosmic radiation is still meaningful due to their stability and good signal to noise ratio. However, in an anisotropic radiation field their strongly anisotropic sensitivity might cause the under- or overestimation of the doses. Most of the time ISS is oriented in the local horizontal plane along the velocity vector (XVV mode) [1]. This implies that anisotropies in the cosmic radiation might not be ignored in dosimetric measurements on board the space station unlike for Space Shuttle flights where, due to the changing orientation of the spacecraft, anisotropies usually tend to be averaged out [2].

The main objective of the calculations presented in this paper is to compare the expected responses of 1D and 3D telescopes to the anisotropic radiation field on board ISS. It is assumed that the 3D telescope is installed outside the wall and shielded by the space station from the nadir direction (Fig. 1). The *x*-axis of the telescope points along the orbital velocity vector, the *z*-axis toward the nadir direction, and the *y*-axis completes the right-handed coordinate system. Calculations are performed for ISS orientation with zero pitch, roll and yaw angles.

2. Anisotropy of the cosmic radiation in low Earth orbit

The galactic cosmic radiation (GCR) in the near-Earth free space is approximately isotropic. However, because of

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