Estimates of Cosmic Rays Directional Dose for ISS

Francis F. Badavi*

(NASA Langley Radiation Team)

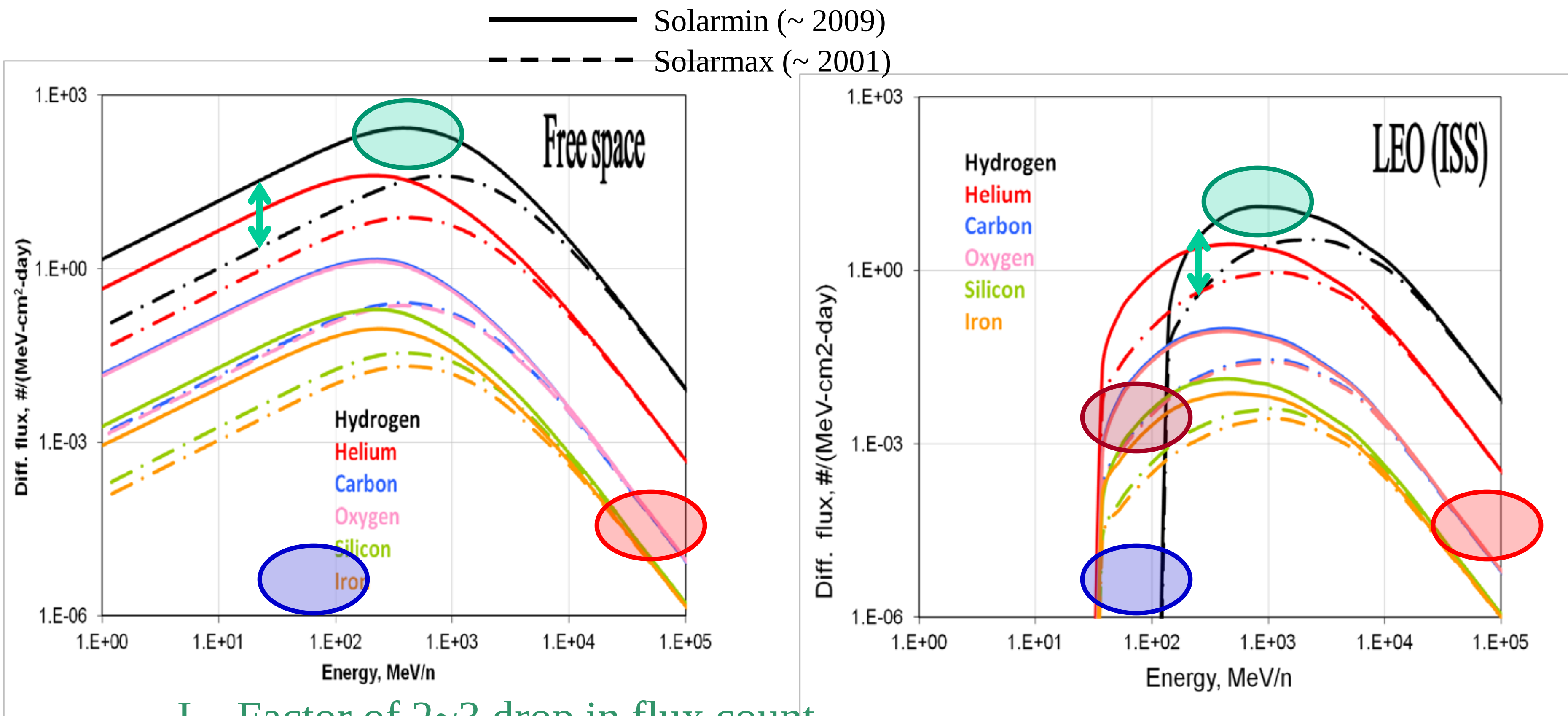
**Old Dominion University, Norfolk, VA 23529 , USA*

WRMISS17, 4-6 September 2012, Austin, Texas

Outline

- I – Why the directionality of cosmic rays (GCR) at ISS altitude is important.
- II – Say a few words about "local vertical / local horizontal (LVLH)" orientation of ISS.
- III – Say a few words about rigidity, vertical cutoff rigidity and directionally averaged cutoff rigidity.
- IV – Computational tools used (very brief). The emphasize of the talk is on the results and not on ion transport methodology.
- V – Simulation results for an ISS point directional flux and dose on Si target.
- VI – Summary and future work.

Intensities of Selected GCR Ions in Free Space and LEO (ISS)



I – Factor of 2~3 drop in flux count

II – 100 % geomagnetic attenuation below 100 MeV

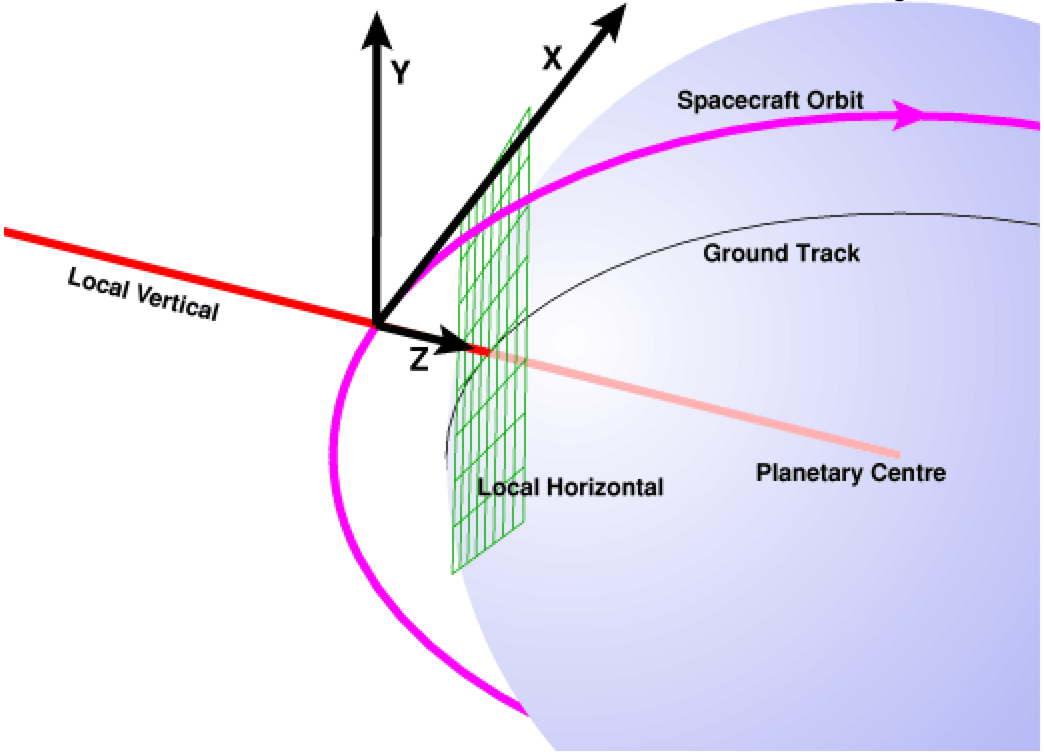
III – Z/A distinguishes proton from all other ions

IV – No geomagnetic attenuation above ~100 GeV

V – Modulated by solar cycle (2009min – 2001max)

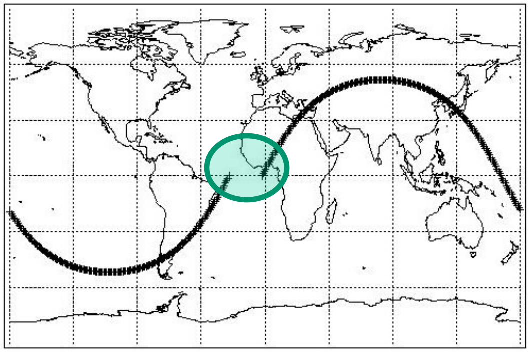
Local Vertical/Local Horizontal Orientation of ISS

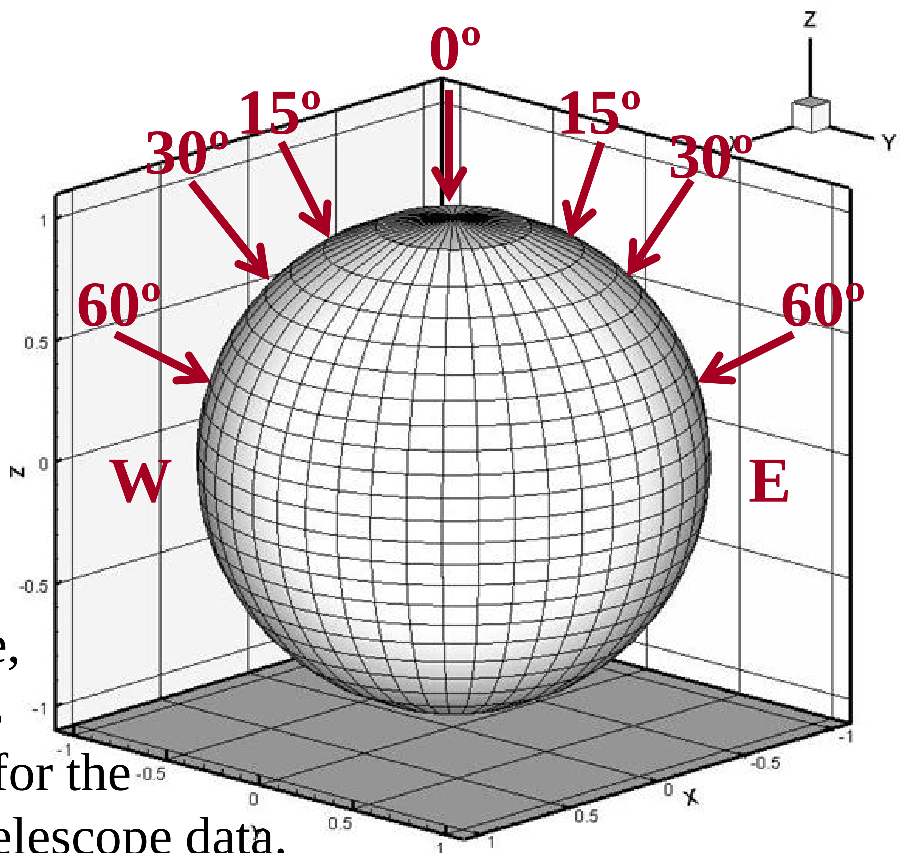
X is velocity vector



ISS flies in LVLH orientation. Not so for STS or Soyuz

Point Orientation Within ISS





- For ISS, the intensity of GCR as a function of latitude changes, while the orientation of ISS remains LV/LH.
- For ISS ephemeris , for a point sphere, we want to track GCR ion intensity as a function of direction. This is useful for the analysis of directional (3D) particle telescope data.
- However, we must first compute the directional rigidity of GCR ions.

Rigidity and Vertical / Directional Cutoffs

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

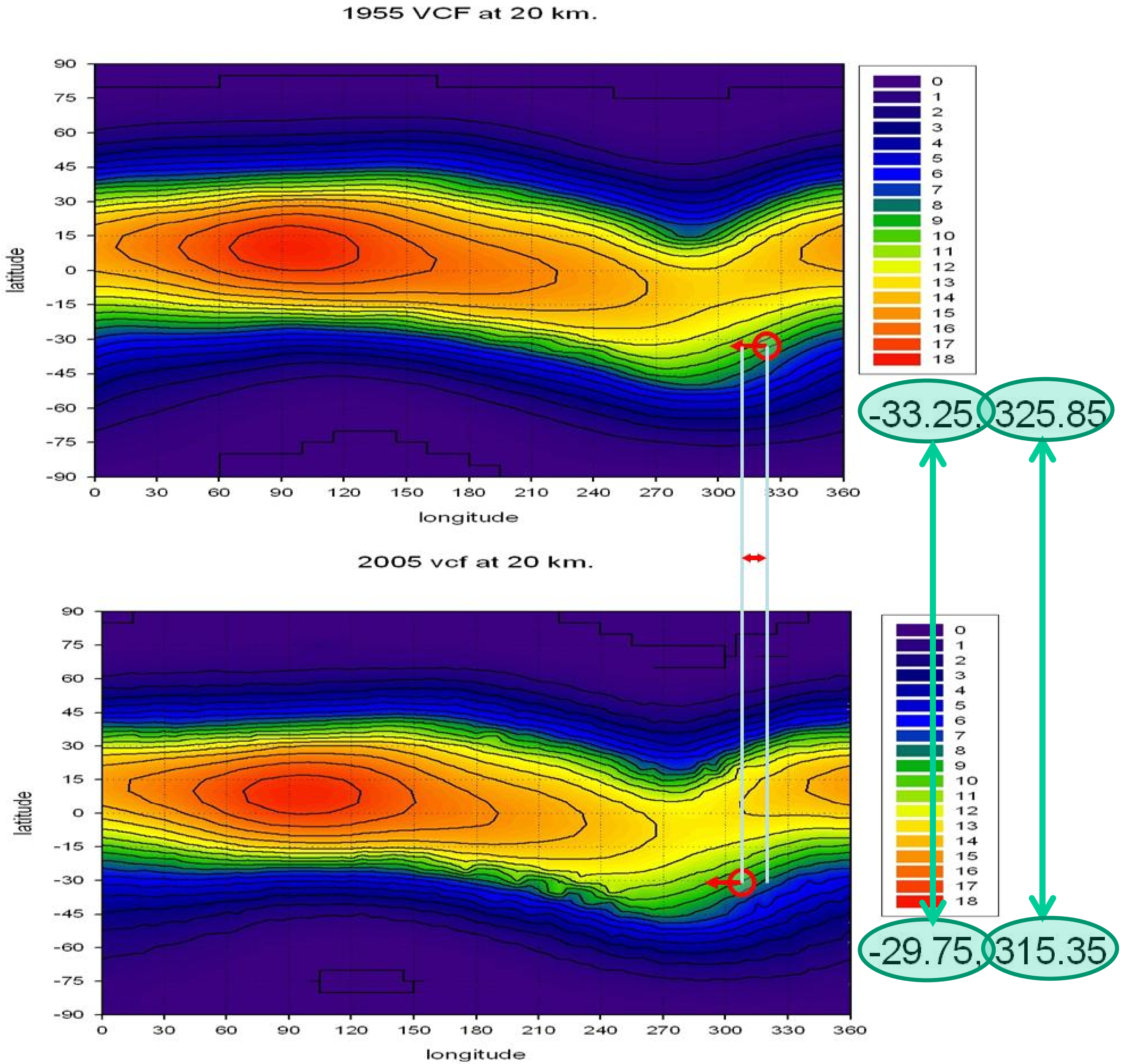
At low energy: $R(E) \sim\sqrt{E}$

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

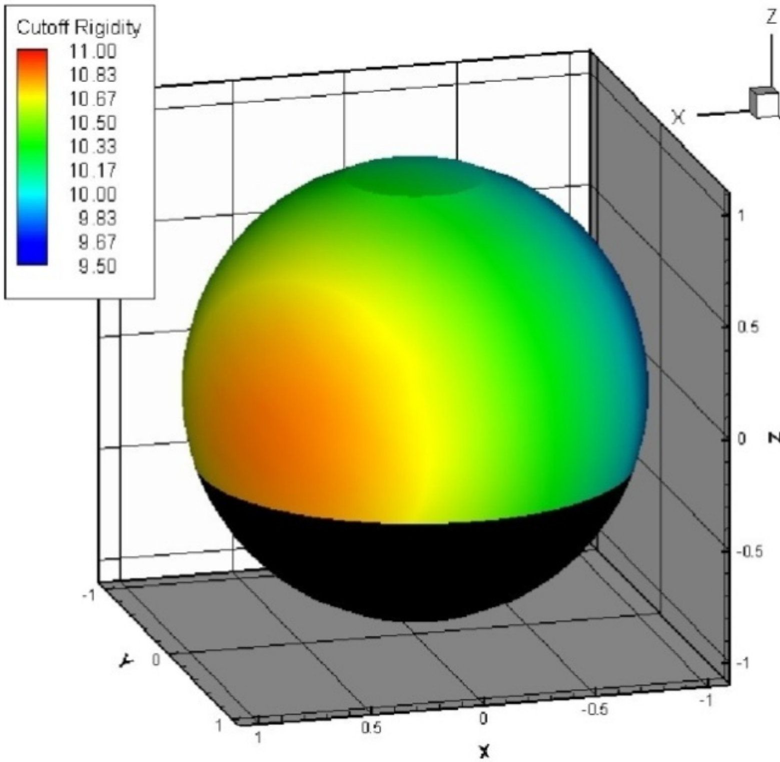
Cutoff (vertical): $C_V(r_d, \lambda_m) = (a_d\cos^4\lambda_m)/4r_d^2$

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.

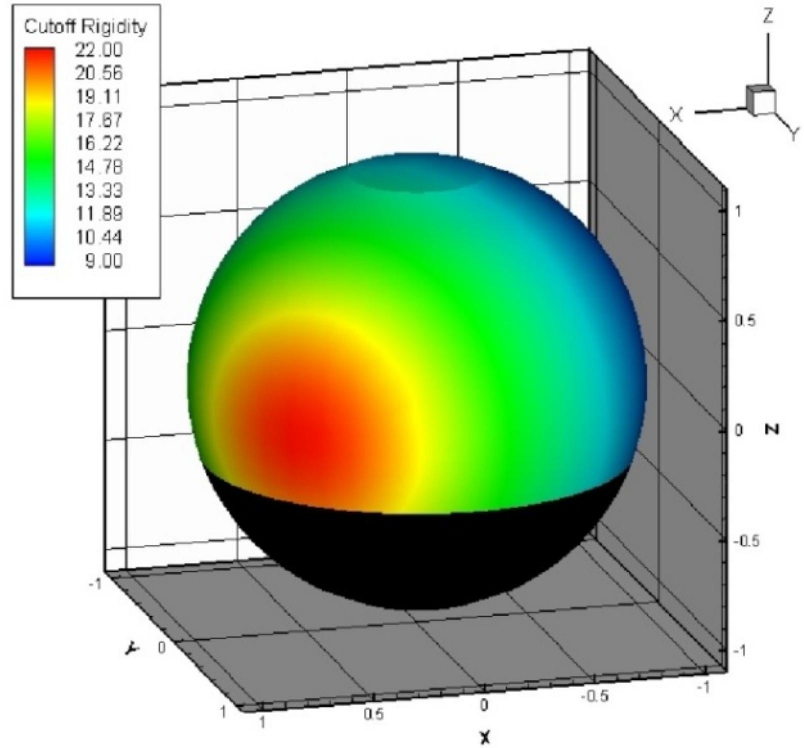

1955 VCF at 20 km.
latitude
longitude
2005 vcf at 20 km.
latitude
longitude
-33.25, 325.85
-29.75, 315.35

Proton Directional Rigidity for ISS Orbit (400 km, 2005 Epoch)



30^{o}N, 60^{o}E

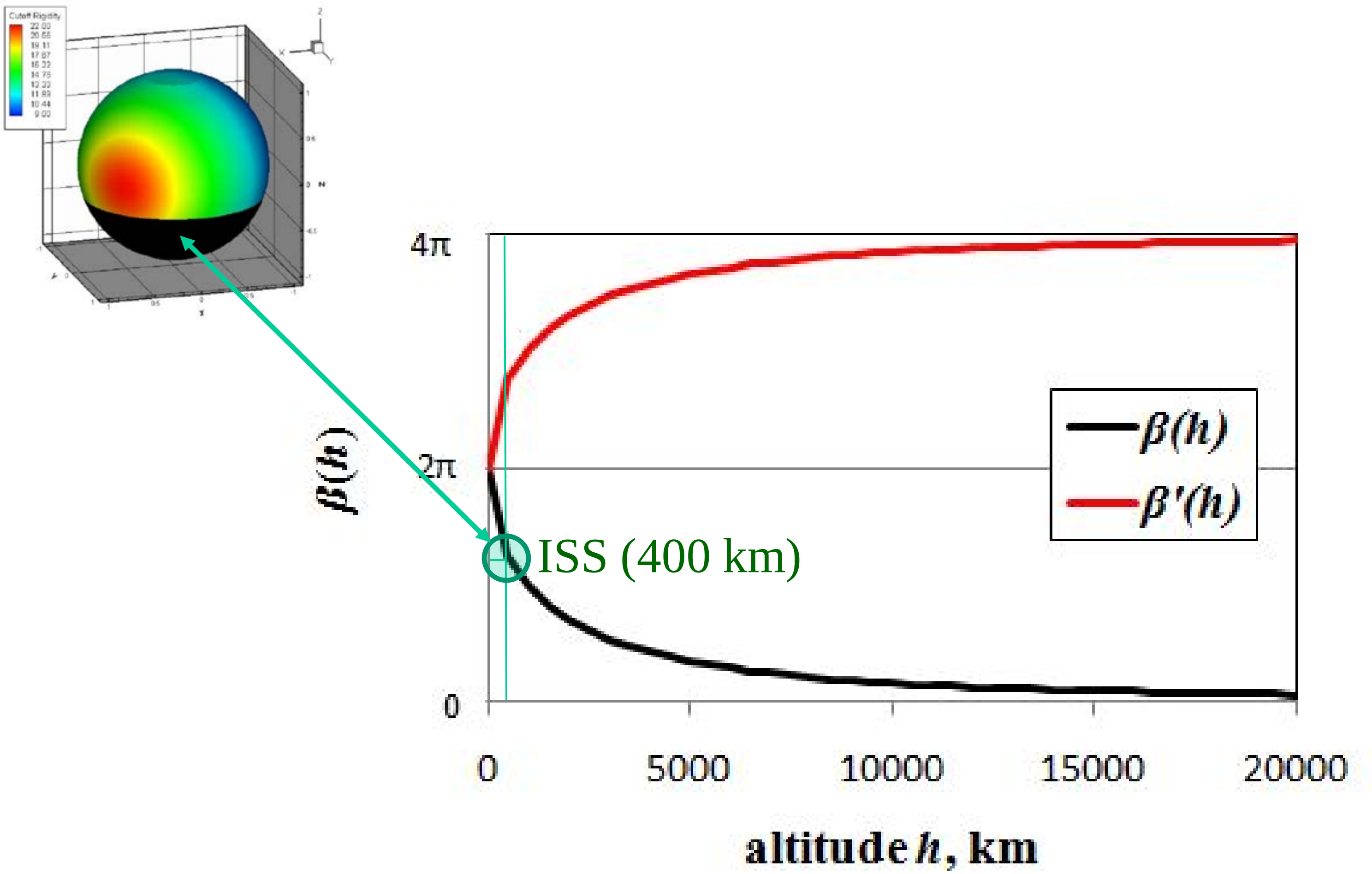
(9<*R(E)*<11 GV)



0^{o}N, 60^{o}E

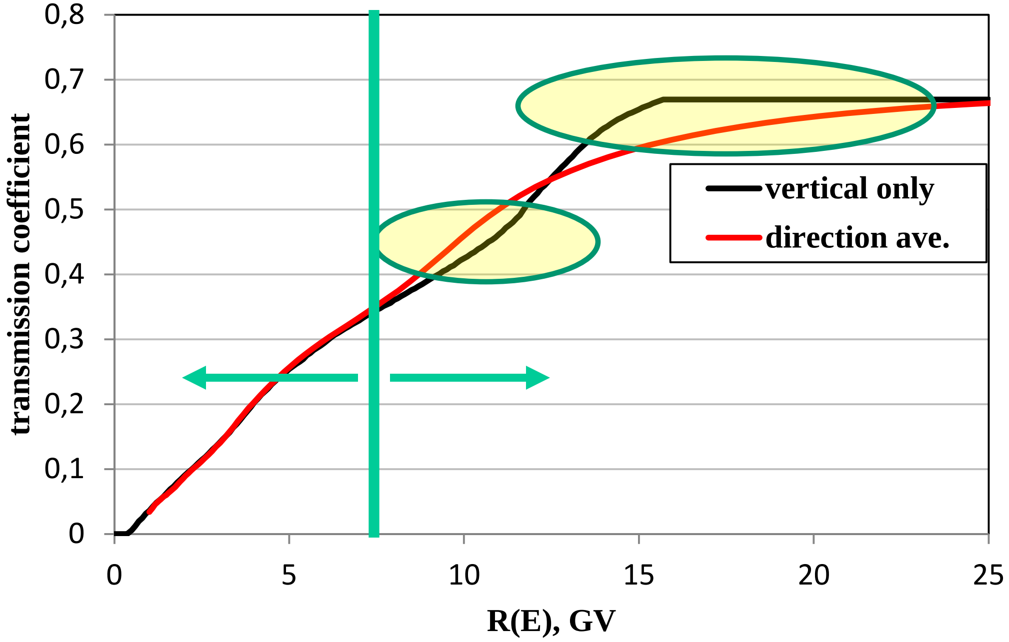
(9<*R(E)*<22 GV)

ISS Umbral Shadow

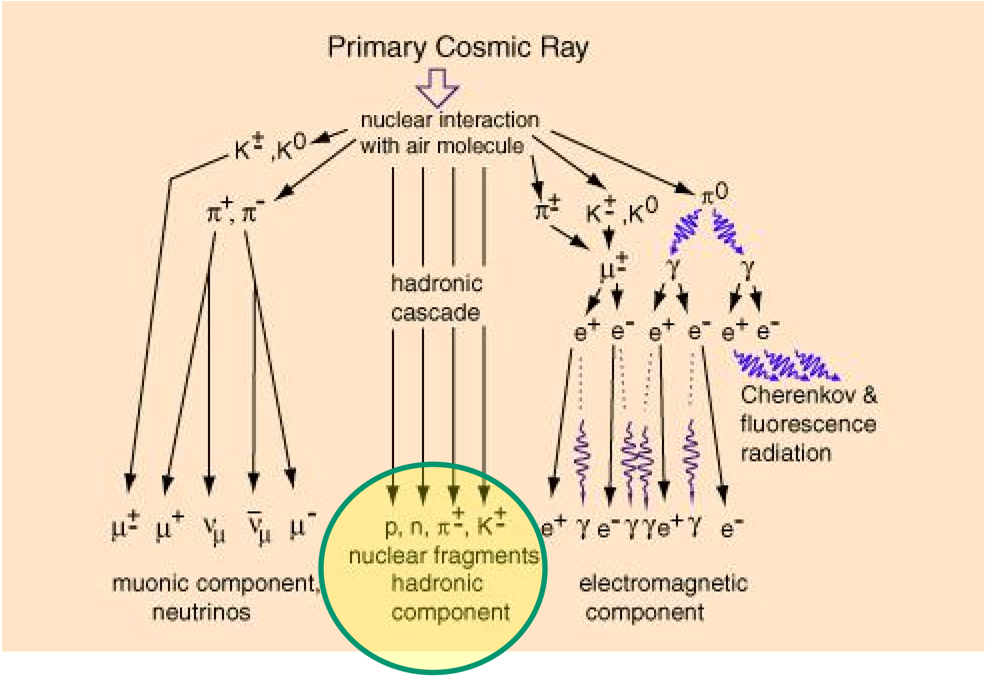


Earth umbral Shadow is independent of spacecraft latitude

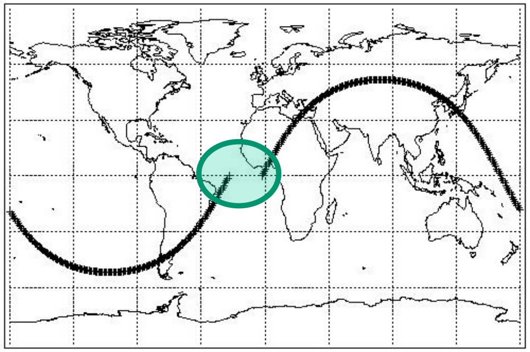
ISS Transmission Coefficient for Vertical Cutoff Rigidity and Directionally Averaged Cutoff Rigidity (2005)

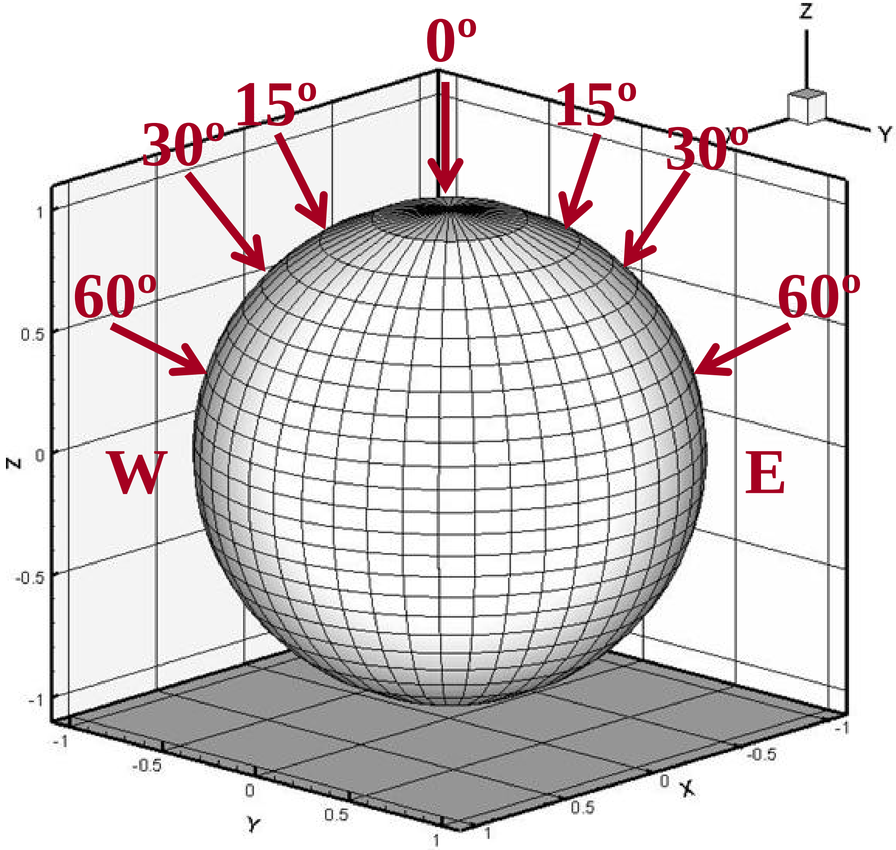


A Caveat, What Particles are Included



Implemented Directional Point Sphere with 970 Rays





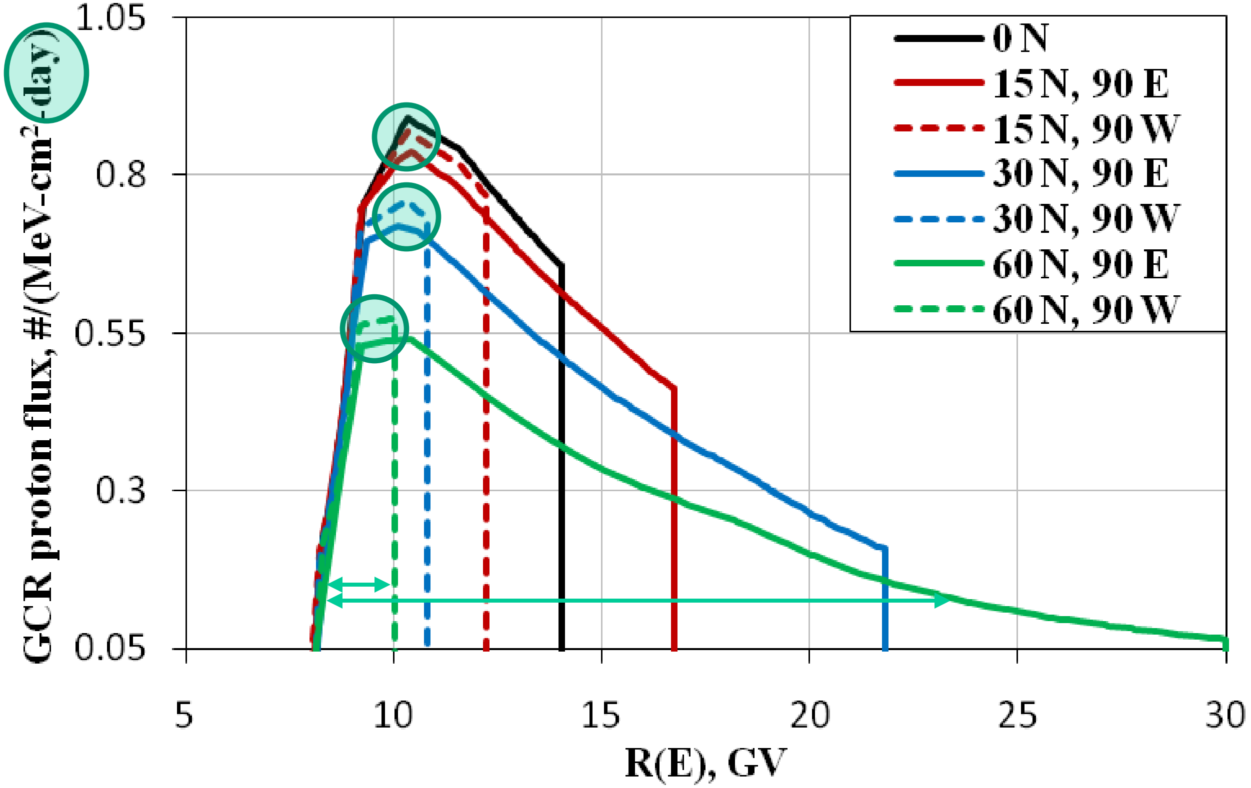
We will look at only 90°E and 90°W at different Zenith angles

But first we have to say something about how we are going to do the number crunching

Implemented Computational Approach (very brief)

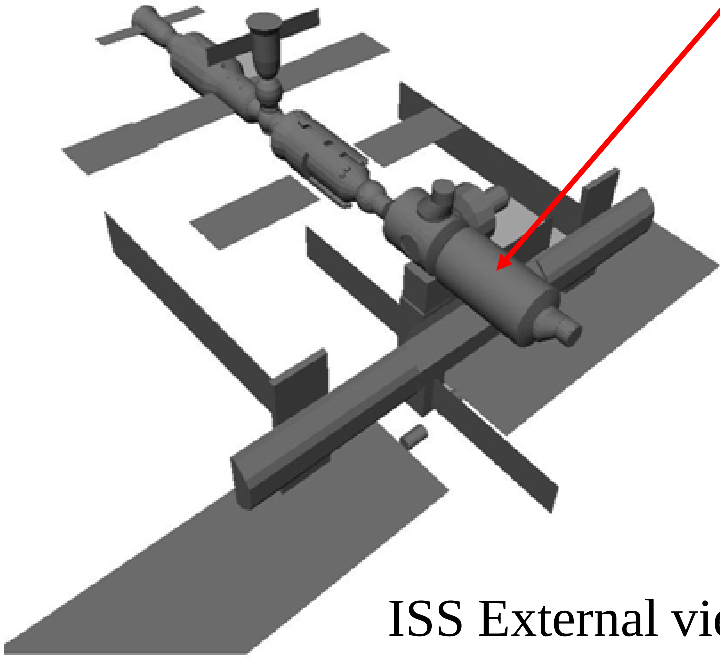
- For free space GCR, O'Neill 2010 model (JSC).
- For geomagnetic cutoffs, GEORAD code package (LaRC).
- For particle transport, HZETRN2010 (LaRC).
- For shield model, ISS-11A (2005) configuration (JSC).

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

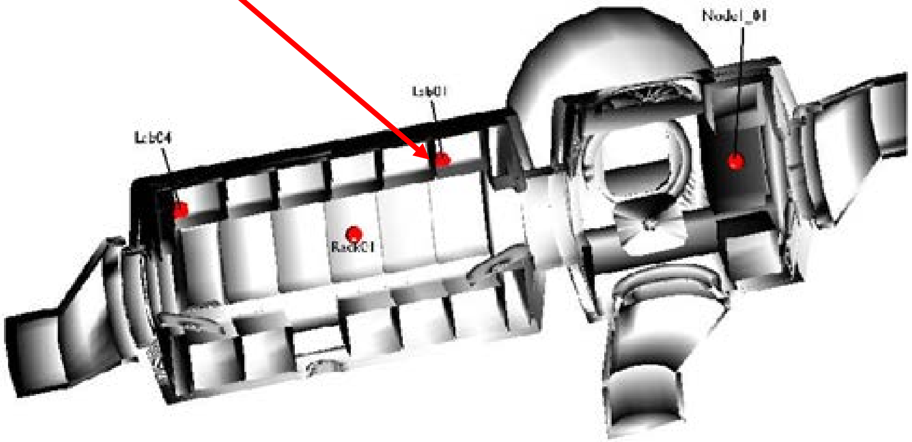


CAD Model of ISS 11A Configuration

Lab01 target point (US lab-module)

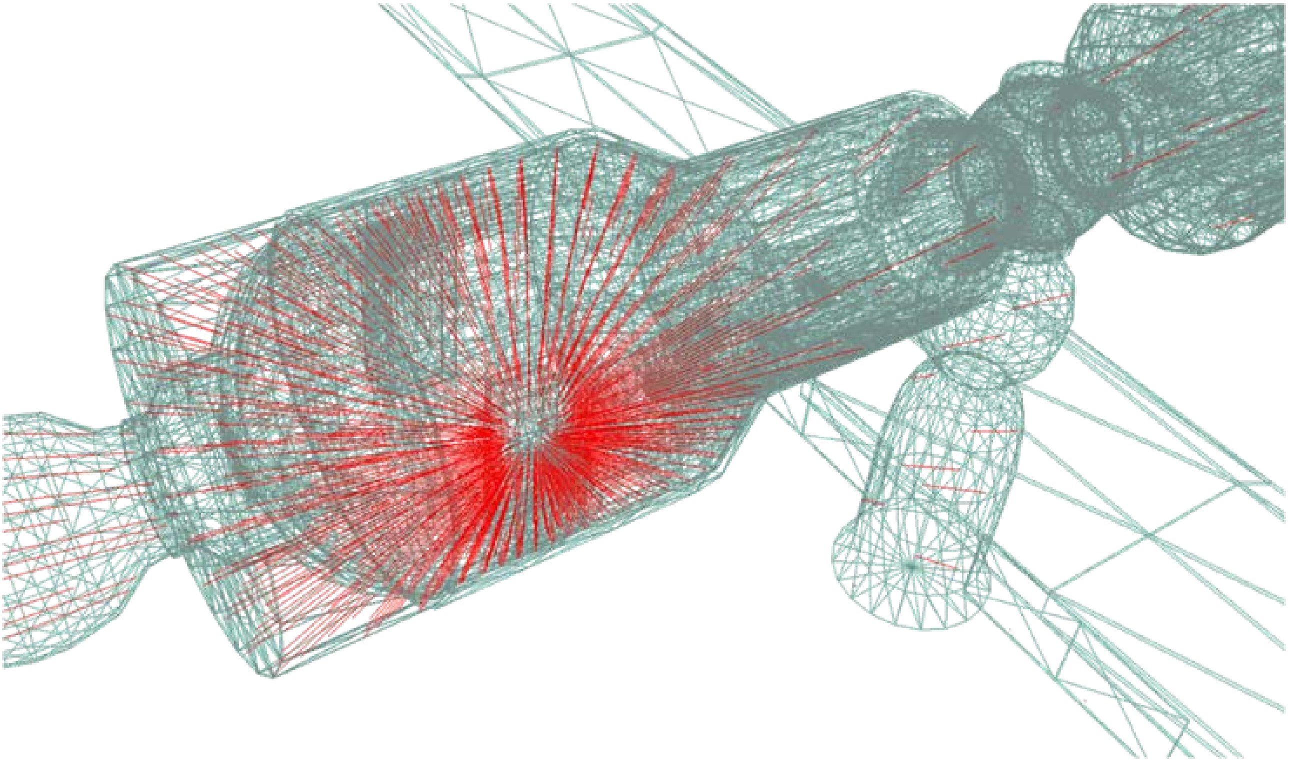


ISS External view



ISS US lab split view

CAD Model of ISS 11A Configuration



CAD Model of ISS 11A Configuration

lab01_970_thickness.dat - Notepad

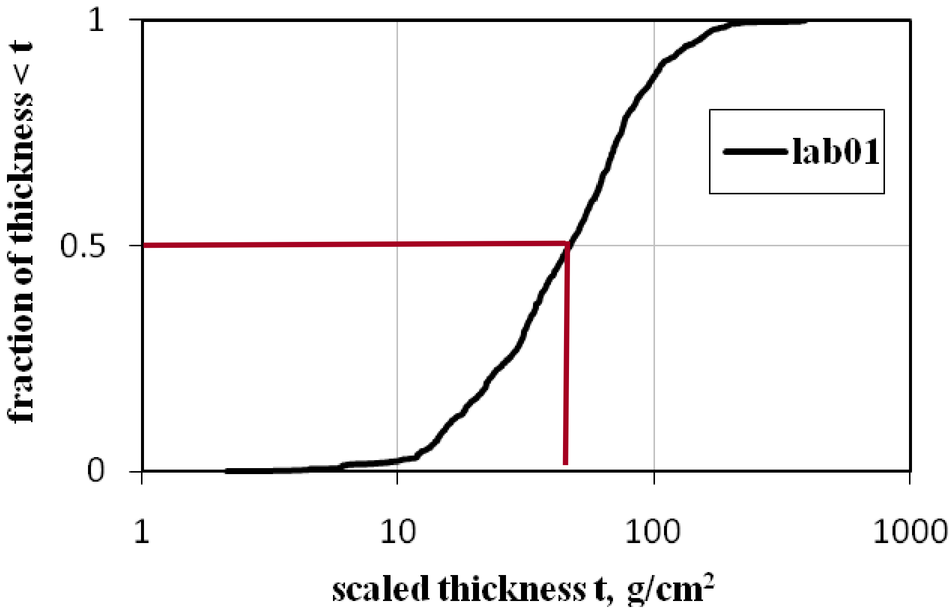
File Edit Format View Help

ISS-11A, lab01_970_thickness

970

33.62315	35.82686	34.90266	33.93249	33.08489
32.29924	31.46067	30.71562	30.09453	29.72910
29.37106	29.17449	29.04861	29.04861	29.17449
29.37127	29.72919	30.21096	30.83209	31.57710
32.41563	33.08480	33.93181	139.2848	151.8487
149.1778	143.5264	54.58679	27.97095	25.78386
24.34196	23.49846	22.94281	22.62079	22.45082
22.45082	22.62079	22.94285	23.49851	24.22558
25.66739	27.97095	31.55295	37.91531	40.02189
40.08867	38.10356	36.30617	34.42016	32.69615
31.32080	30.12077	29.13940	28.37867	27.80902
27.51583	27.31324	27.31324	27.51583	27.93770
28.50740	29.26808	30.24949	31.44948	32.69603
35.97437	37.79490	122.8788	124.8633	126.9720
120.0752	95.37025	48.02364	21.70106	20.81677
20.37012	20.02794	19.86859	19.79258	19.79258
19.86859	19.89935	18.73409	18.25264	18.90986
21.13854	23.06446	28.36745	40.49883	45.28836
42.15365	39.28688	36.41385	34.10328	32.12326
30.43885	29.02499	27.94109	27.17145	26.66386
26.55453	26.55458	26.80707	27.31458	28.08498
29.16965	32.07927	33.57073	35.42360	37.65023
40.47337	143.9054	147.0400	136.8949	127.3030
98.52609	47.97455	21.99628	21.20150	20.80078
20.47564	20.05943	19.95479	19.95566	19.91563
17.67814	17.30670	17.51485	18.17729	19.02246
20.73245	26.00441	35.10620	51.89677	47.26217
42.90008	39.13295	35.96495	33.21699	31.00209
29.29454	28.02512	27.12075	26.53404	26.40899
26.40899	26.69703	27.28310	28.02444	30.97610
32.42641	34.47483	35.96495	39.13303	42.89996
175.3160	179.9506	162.8813	157.2944	131.0014
54.72758	23.12977	22.09355	21.17806	20.93526
21.06292	21.12955	21.12946	20.89985	16.88296
16.66376	17.25932	18.18767	19.23786	20.85989
25.89408	33.45598	60.68458	53.88329	47.46824
42.42238	38.05272	34.60791	31.94399	29.95694
28.49275	27.44479	26.72029	26.56162	26.56162
26.90820	27.63271	30.40057	31.48282	31.94403
34.60796	38.05264	42.42151	47.46820	190.3061
201.9977	195.1958	198.1633	154.4783	78.01070
37.08343	24.19471	24.14728	23.83267	23.92678
23.80272	23.80272	20.13792	18.81537	18.50529
18.19119	17.99692	19.72472	21.71543	25.16658
33.75794	70.68797	62.73131	53.58985	46.34462
40.64267	36.40737	33.28625	30.80741	28.99944
27.73571	26.94320	26.78393	26.78393	27.16541
30.17185	30.77867	30.80741	33.28629	36.40732
40.64267	46.34466	62.81015	198.5751	219.1039
192.0745	193.5948	155.2783	93.03509	69.56323
48.31889	26.98783	26.55348	26.46254	27.09126
27.09134	21.52040	20.43118	20.20216	20.53034
20.91949	20.19723	22.38269	26.65672	35.15393
70.65536	75.11590	61.40370	51.09578	43.82661
38.58986	34.56757	31.71940	29.69314	28.31145
27.43651	27.02360	27.02360	27.43651	30.62418
29.69322	31.71944	34.56757	38.58990	43.82657
59.18365	77.34965	161.5552	162.4308	151.5628
158.3301	132.1740	90.36662	74.47546	77.70247
43.66725	30.33382	29.57110	29.07412	29.07404
23.79779	23.13683	23.31624	22.79559	23.03738
24.27302	24.70212	29.17068	36.03066	75.31640
92.86037	71.54426	57.09377	47.53219	40.79291
36.18142	32.94045	30.68178	29.15469	28.20106
27.73874	27.73874	28.20106	29.15469	30.68182
32.94049	36.18151	40.79295	49.53193	72.99130
79.08171	102.8822	103.7758	99.74635	103.7725
77.81854	68.84650	75.71479	83.56918	68.65559
31.78189	30.43575	29.79143	29.79151	23.96220
23.72891	23.58631	25.37558	27.50679	29.85899
32.02129	34.18904	43.58479	85.03460	122.1538
85.53343	64.54142	51.60229	43.59051	38.24582
34.54170	31.86634	30.02340	28.94391	28.42114

Thickness Distribution (CDF) of ISS 11A Lab01 Module



Aluminum equivalent CDF

50% ~ 50 g/cm^2 of shield

Directional and Omni GCR Dose Rates in Si for ISS Lab01 Target Point (V&V)

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 $\quad$ $X*4\pi$

- For any look angle (15º, 30º, 60º) $Dose_W$ and $Dose_E$ are different
- $Dose_W$ and $Dose_E$ increase toward zenith

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

Directional and Omni GCR Dose Rates in Si for ISS Lab01 Target Point (V&V)

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

- For any look angle (15º, 30º, 60º) $Dose_W$ and $Dose_E$ are different
- $Dose_W$ and $Dose_E$ increase toward zenith

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

Summary and Future Work

- The talk presented a methodology to study the directionality of GCR ions at LEO (ISS) as a tool to analyze the measurements by a 3D particle detector.
- For ISS, calculated dose in a Si detector showed that for a given look angle, $Dose_W$ and $Dose_E$ are slightly different.
- Near term future work, V&V of presented methodology vs. Liulin (Si) , TEPC (tissue) and hopefully ISS-RAD are needed (start with Mars RAD).
- Long term future work, V&V of presented methodology vs. a 3D detector. This will be done with the RBR (ray-by-ray) version of HZETRN. From biological POV this is very important.