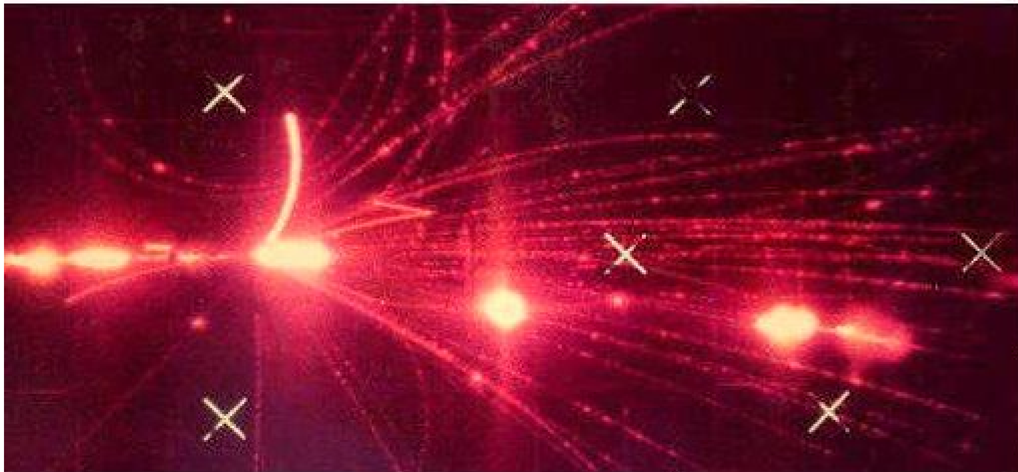
Measurements Consortium
NASA Space Radiation Shielding Program

NASA



Lawrence Berkeley National Laboratory

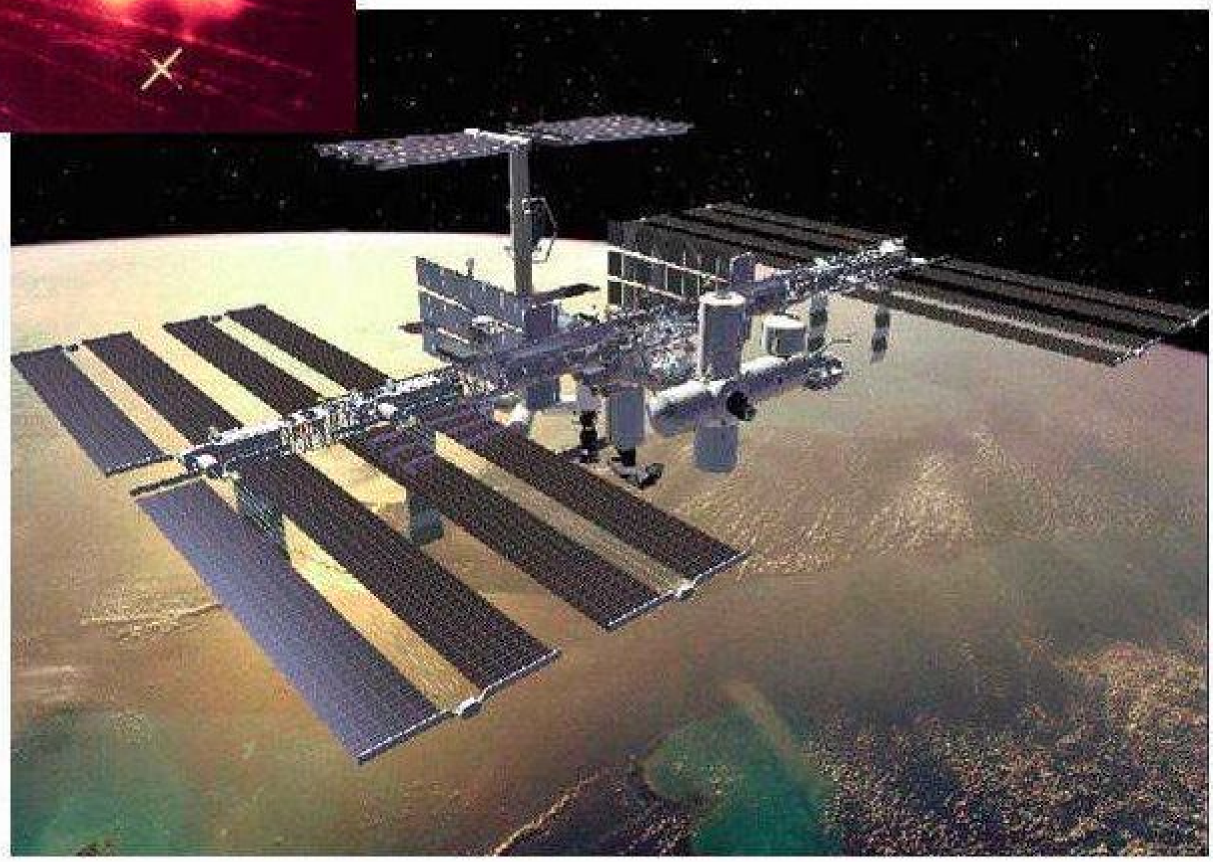
Brookhaven National Laboratory

NSCL

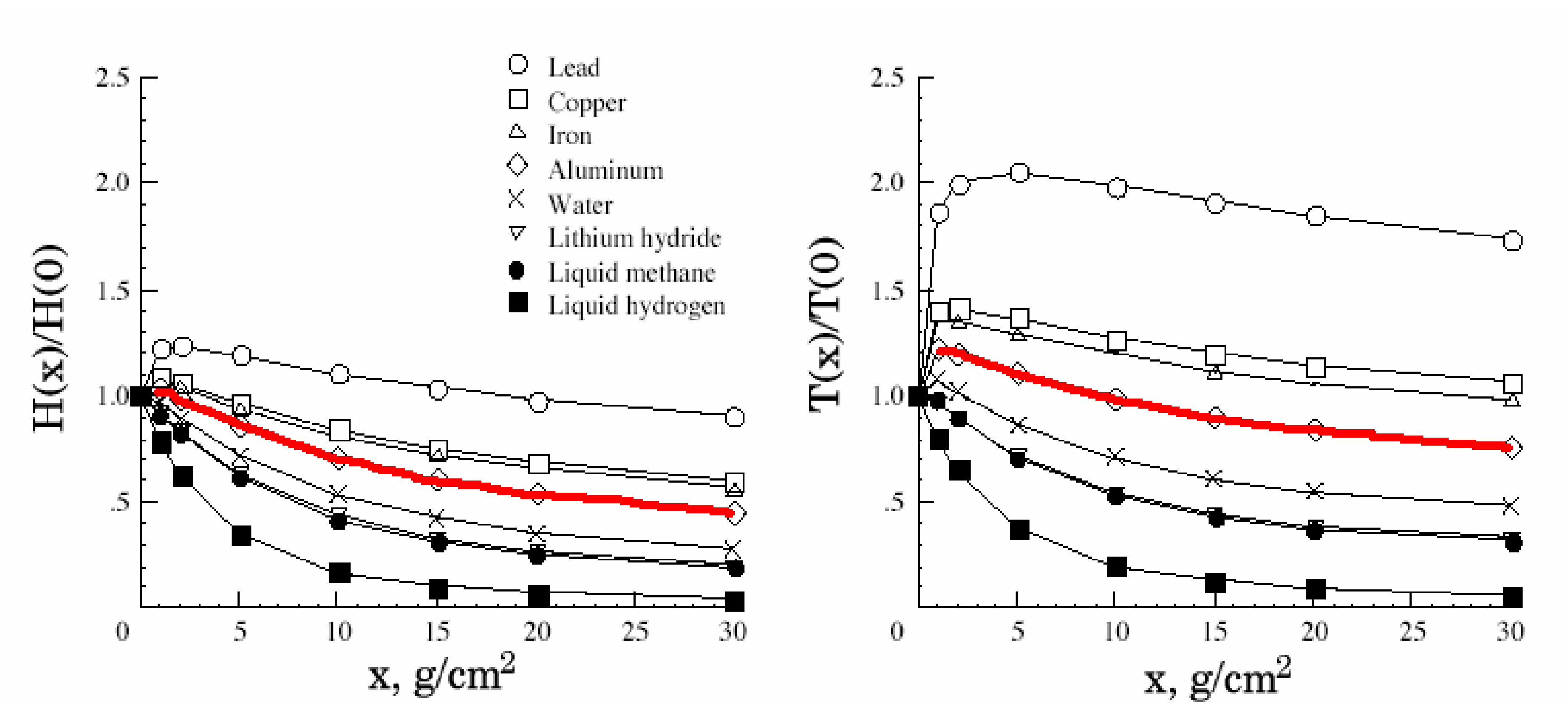
Tohoku University Founded 1907 Sendai Japan

NIRS

UH



CHALMERS



- **For some materials, modest thicknesses (5-10 g-cm^{-2}) may *increase* risk from GCR (Wilson *et al*.)**

NASA-SRSP Objectives:

- Use model calculations and experiments at particle accelerators to evaluate the radiation transport properties of potential spacecraft and habitat materials as a function of composition and thickness.

- From the accelerator measurements, develop a database of nuclear fragmentation data for use as model source terms and benchmarks.

- Ultimately, develop the models into a design tool for use by mission planners, spacecraft and instrument designers, flight surgeons and radiation health specialists.

Berkeley Workshop Recommendations:

1. Use existing cross section data sets to ascertain the accuracy of the present radiation transport models.

2. Measure a recommended list of nuclear cross sections.

3. Use these new measurements and improved cross section calculations to improve radiation transport codes.

4. Incorporate measured cross section data into transport models under development. Establish a feedback mechanism with the model developers.

5. Determine whether models are sufficiently precise, by means of both ground-based measurements and in the natural cosmic ray environment using a suite of instruments to measure the radiation field with and without shielding.

Measurements Consortium Mission:

To provide the data to make the models as accurate and precise as required.

- **Nuclear fragmentation cross sections are needed to ensure that the models get the underlying physics right, and radiation transport measurements with proposed shielding materials are needed to validate the models and to evaluate promising materials.**

- **The Consortium works with the SRSP Transport Consortium (PI, Prof. L Townsend) to assign priorities for the data gathering and analysis, and is pursuing new detector methods to optimize the use of accelerator resources.**

Measurements Program

Fundamental Physics Needed for Code Development

- Cross sections for charged-particle production in HZE reactions using elemental targets (Zeitlin)
- Cross sections for neutron production in HZE reactions (Heilbronn)

Shielding Materials Evaluation

- Heavy charged particle fragmentation and transport in proposed shielding materials (Guetersloh, Zeitlin)

Instrument Responses

- TEPC (with T. Borak *et al.*)
- PNTD (Eril Research)
- ICCHIBAN

Quantities to be measured:

- inclusive single and double differential cross sections as a function of particle charge energy and emission angle
- semi-inclusive cross sections over large solid angle
- particle yields as a function of projectile and target mass, particle charge, energy (or LET) and emission angle
- absorbed dose and dose equivalent per incident ion

Projectiles: Z=1-26

Energies: 100 - 10000 MeV/nucleon

Particles: charged nuclear fragments
neutrons
pions

Facilities

	Z_{proj} (max)	E_{proj} (MeV/u)	E_{proj} (^{56}Fe) (MeV/u)
NSRL (BNL)	79	40-3000	100-1100
AGS (BNL)	79	600-30000	600-10000
HIMAC (NIRS-Chiba)	36	100-800	400-500
LLUPTC (Loma Linda)	1	40-250	—

NSRL – 3-4 beam opportunities/year. Each running period provides several ion-energy combinations decided upon by a scientific program advisory committee in consultation with the user community and NASA program managers.

AGS – (7/05) 3, 5, 10 GeV/u C, Si, Fe

HIMAC – Operates ten months per year; shut down in March and September. Applications for beam time are due 6-8 months in advance.

LLUPTC – Beam time potentially available throughout the year, usually during nights and weekends when patient treatments are not taking place.

Charged Particle Detectors

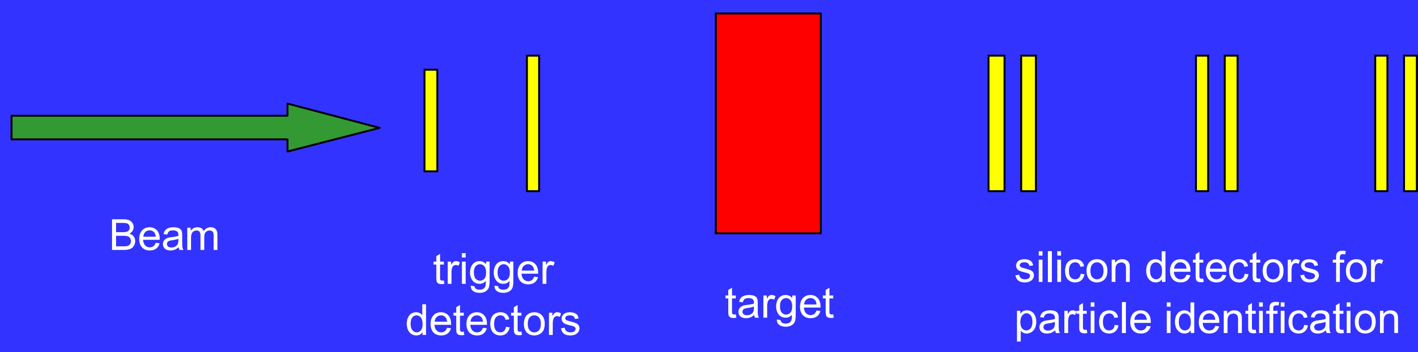
- LBNL SSD stack
  - small acceptance
  - measurements along beam axis
  - off-axis measurements possible
  - limited granularity

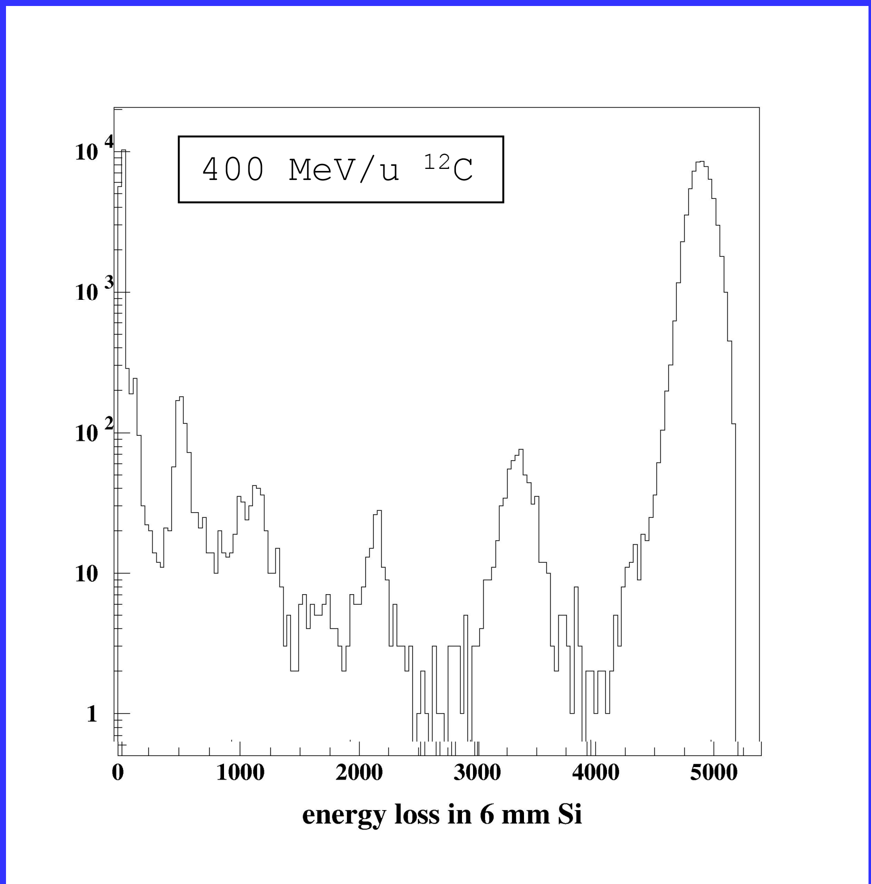
- MSFC ZDDS
  - larger acceptance (w/ hole at 0°)
- - higher granularity (multiple particle resolution)

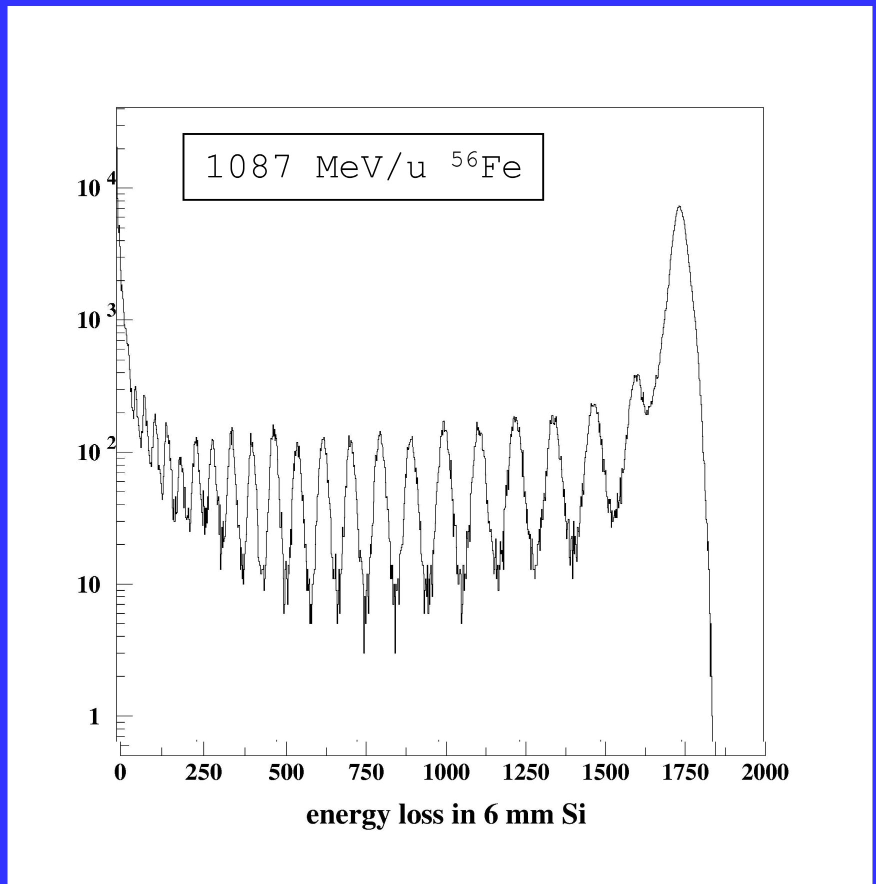
- UH strip detectors
  - largest acceptance
  - singly charged particles only

0º Charged Particle Cross Sections (6/05)

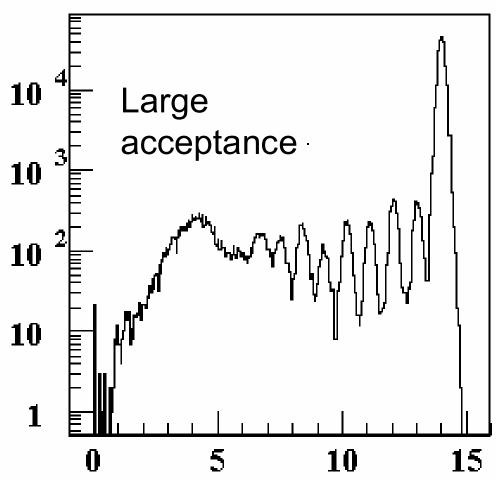
Ion	E (MeV/A)	E (MeV/A)	E (MeV/A)	E (MeV/A)	E (MeV/A)	Large acceptance	Small acceptance
^{56}Fe	400	500	600	800	1000	1000 done	1000 done
^{48}Ti	1000					Done	Done
^{40}Ar	290	400	650			In progress	In progress
^{28}Si	290	400	600	800	1200	All done	Some done
^{20}Ne	290	400	600			All done	600 done
^{16}O	290	400	600	1000		Done	Done
^{14}N	290	400				Done	Done
^{12}C	290	400				Done	Done
^{4}He	230						


Beam
trigger detectors
target
silicon detectors for particle identification

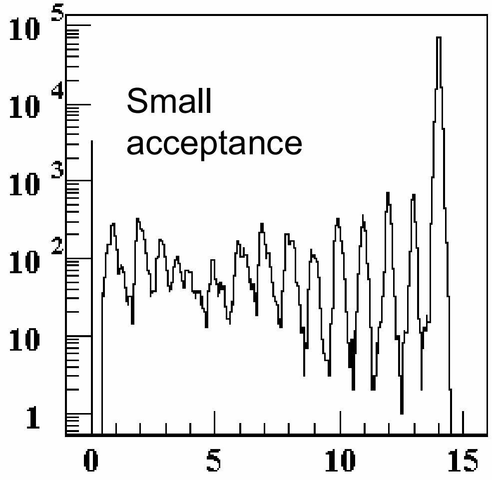

400 MeV/u ^{12}C
10^4
10^3
10^2
10
1
0
1000
2000
3000
4000
5000
energy loss in 6 mm Si


1087 MeV/u ^{56}Fe
10^4
10^3
10^2
10
1
0
250
500
750
1000
1250
1500
1750
2000
energy loss in 6 mm Si

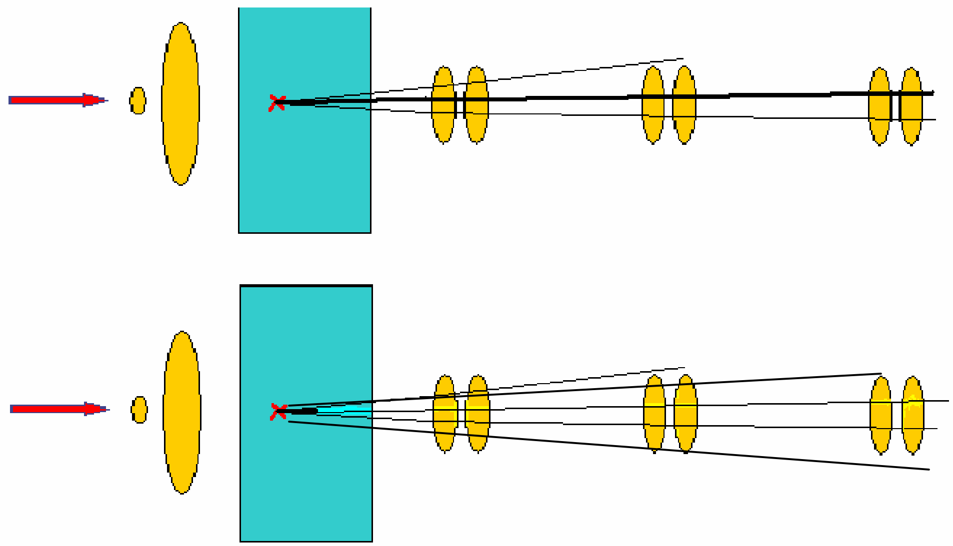
Si+C at 600 MeV/u



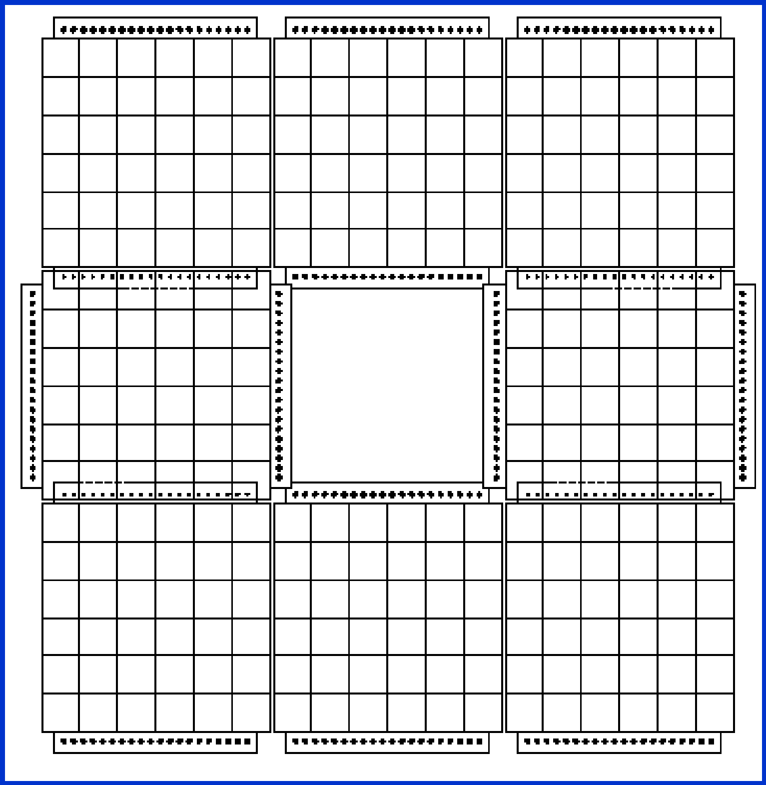
Detected Z



Detected Z

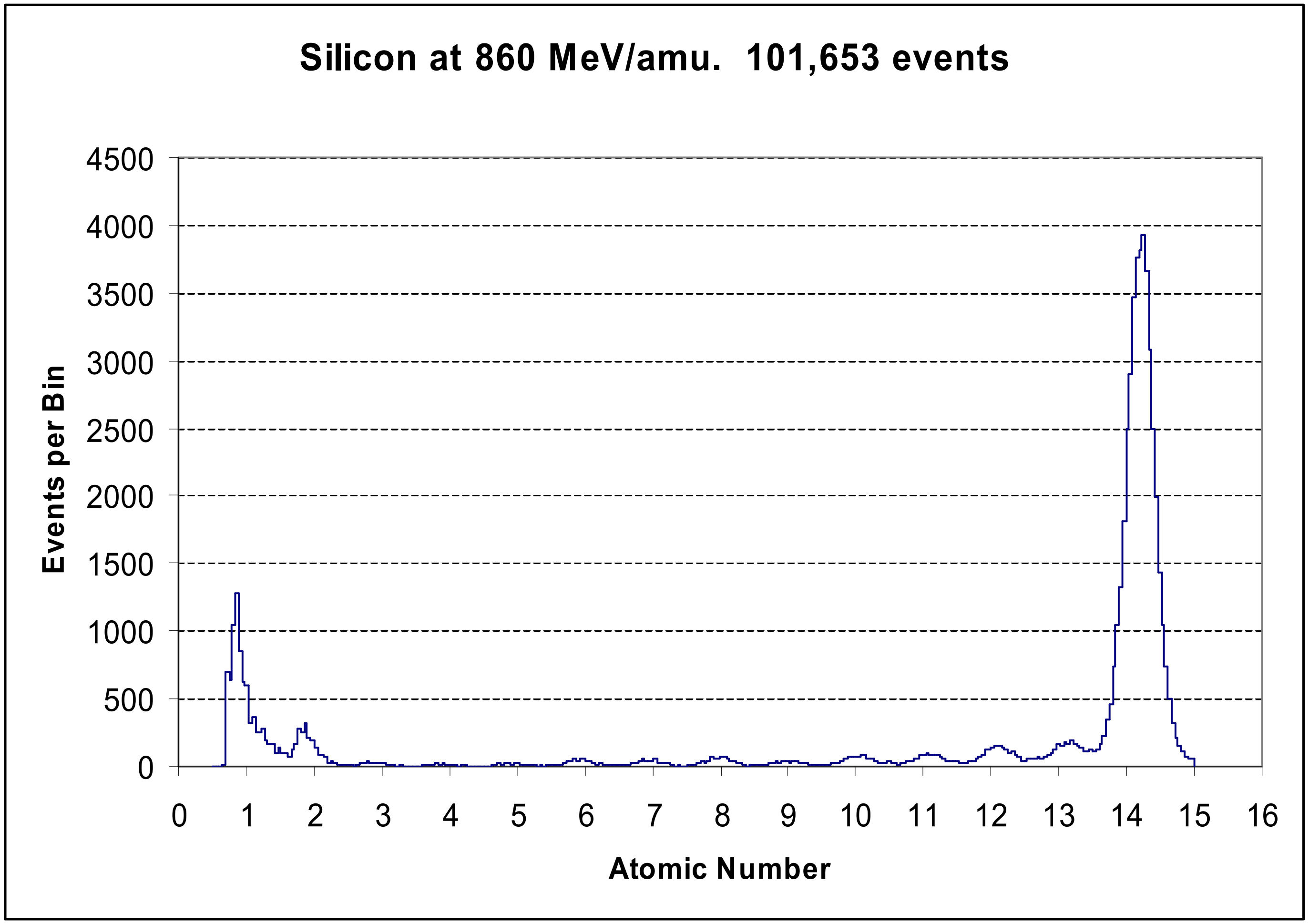


ZDDS (NASA-MSFC)

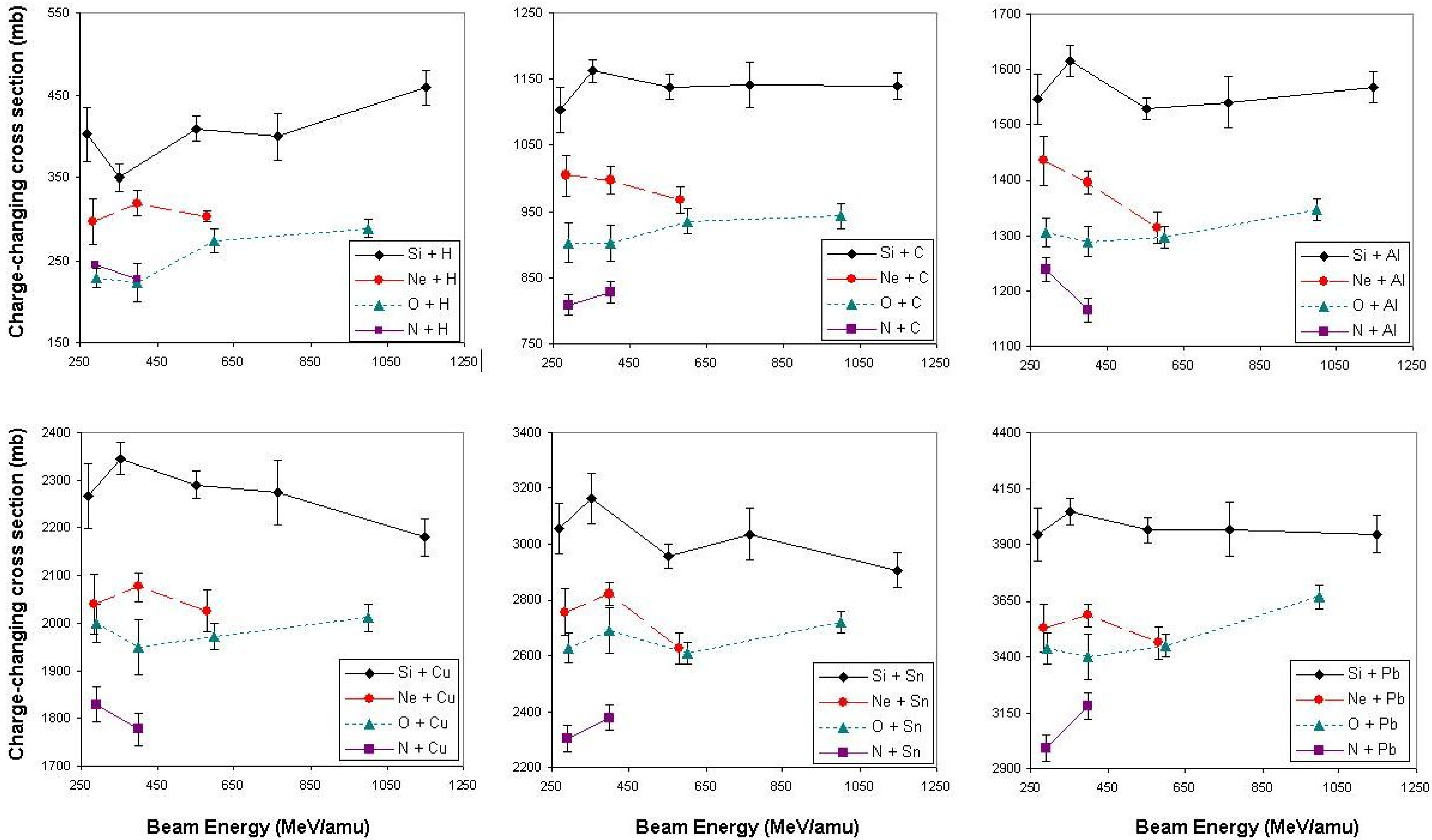


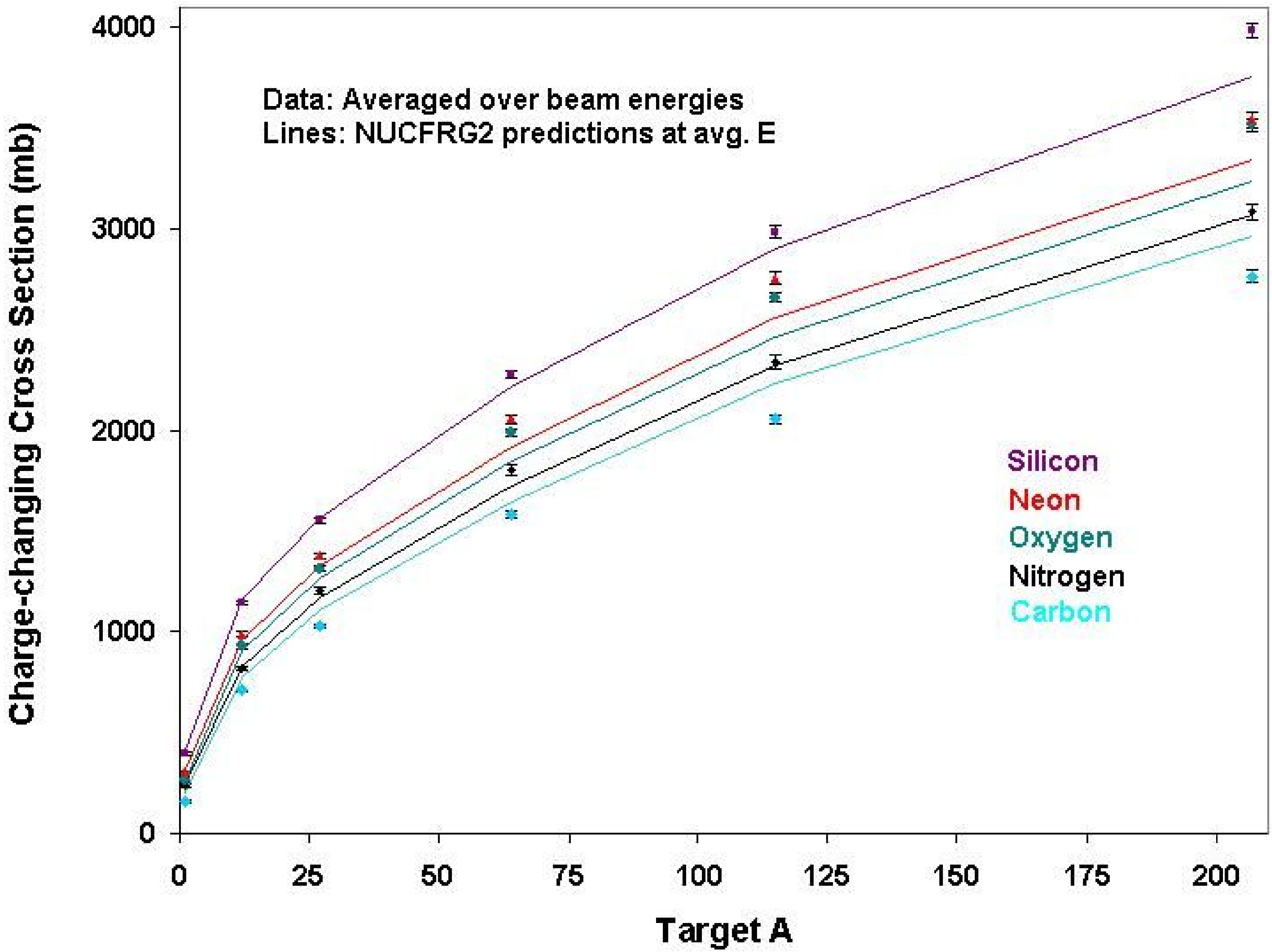
18 cm

ZDDS Charge Resolution



Charge-changing cross section systematics – beam energy dependence

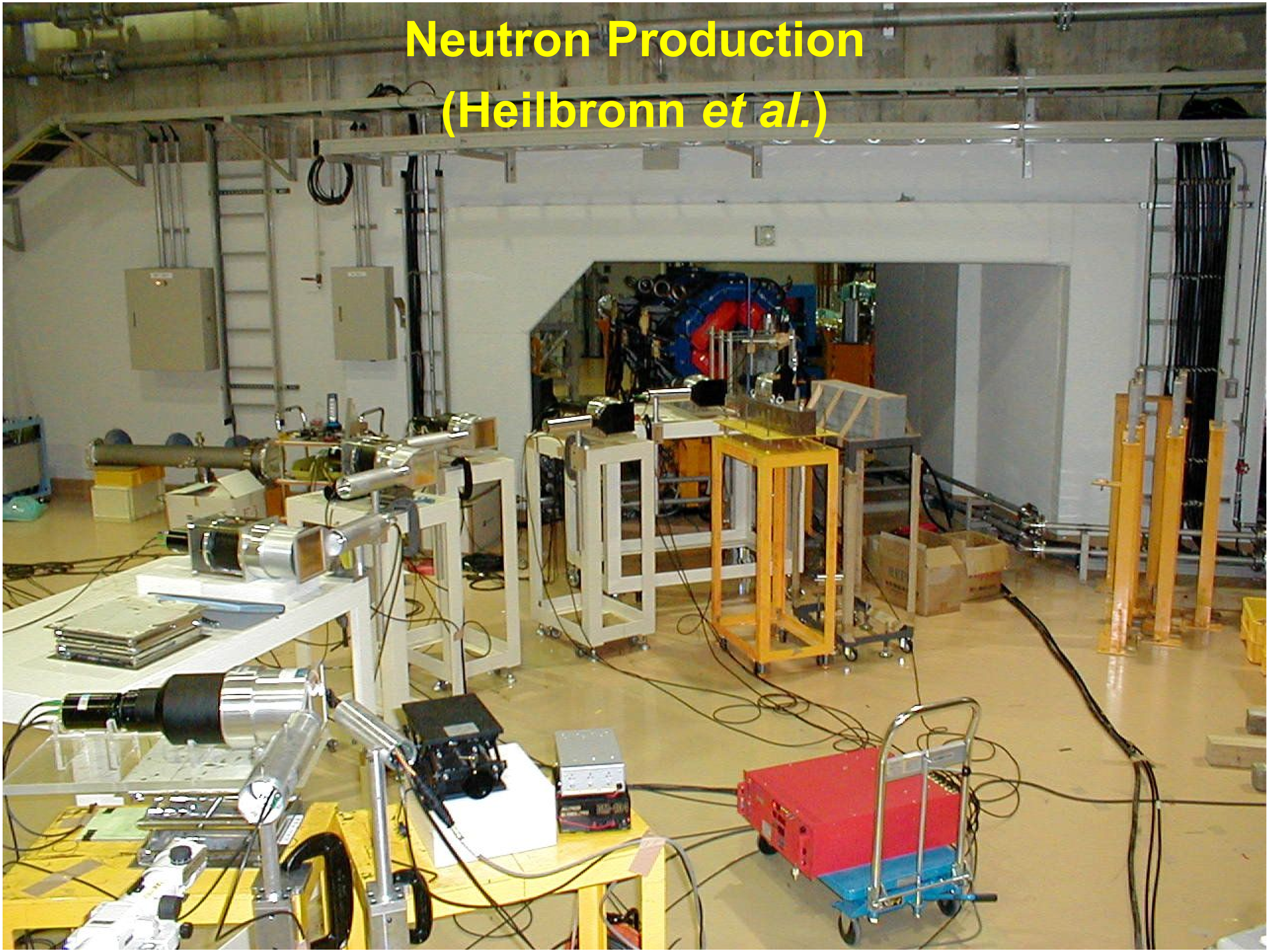



Data: Averaged over beam energies
Lines: NUCFRG2 predictions at avg. E
Silicon
Neon
Oxygen
Nitrogen
Carbon
Charge-changing Cross Section (mb)
Target A
0
1000
2000
3000
4000
0
25
50
75
100
125
150
175
200

The “Berkeley Matrix”

Proj. / E (GeV)	H	He	C	N	O	Ne	Si	Ar	Ca	Mn	Fe
0.1											
0.2		●									
0.4			●	●	●	●	●	●			●
0.6				●		●	●	●			●
0.8							●				●
1.0	●			●			●				●
1.5											
2.0											

Neutron Production
(Heilbronn *et al.*)



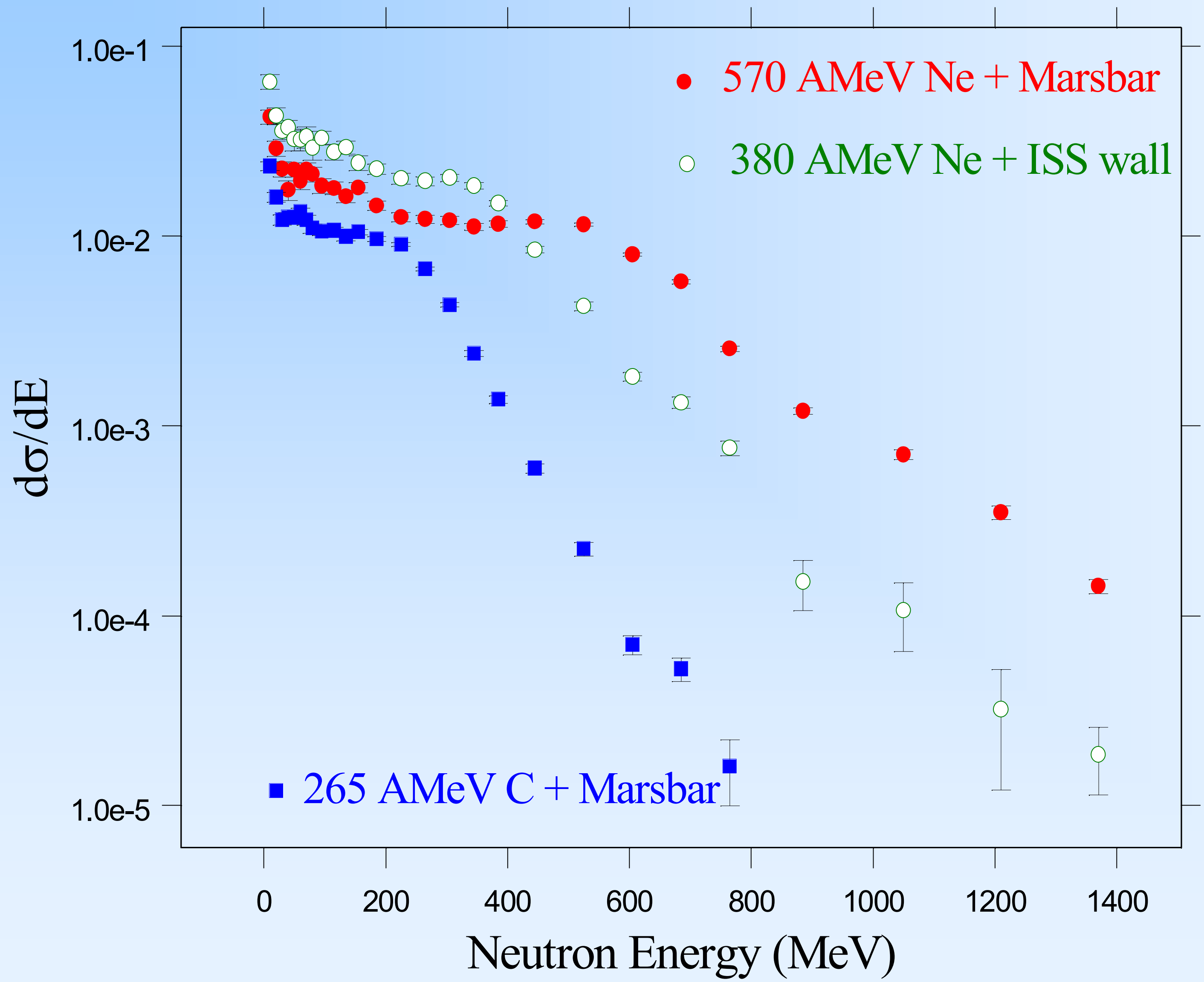
Neutron Yields and Production Cross Sections

- a comprehensive set of 3-dimensional data available for the development of HZE transport models

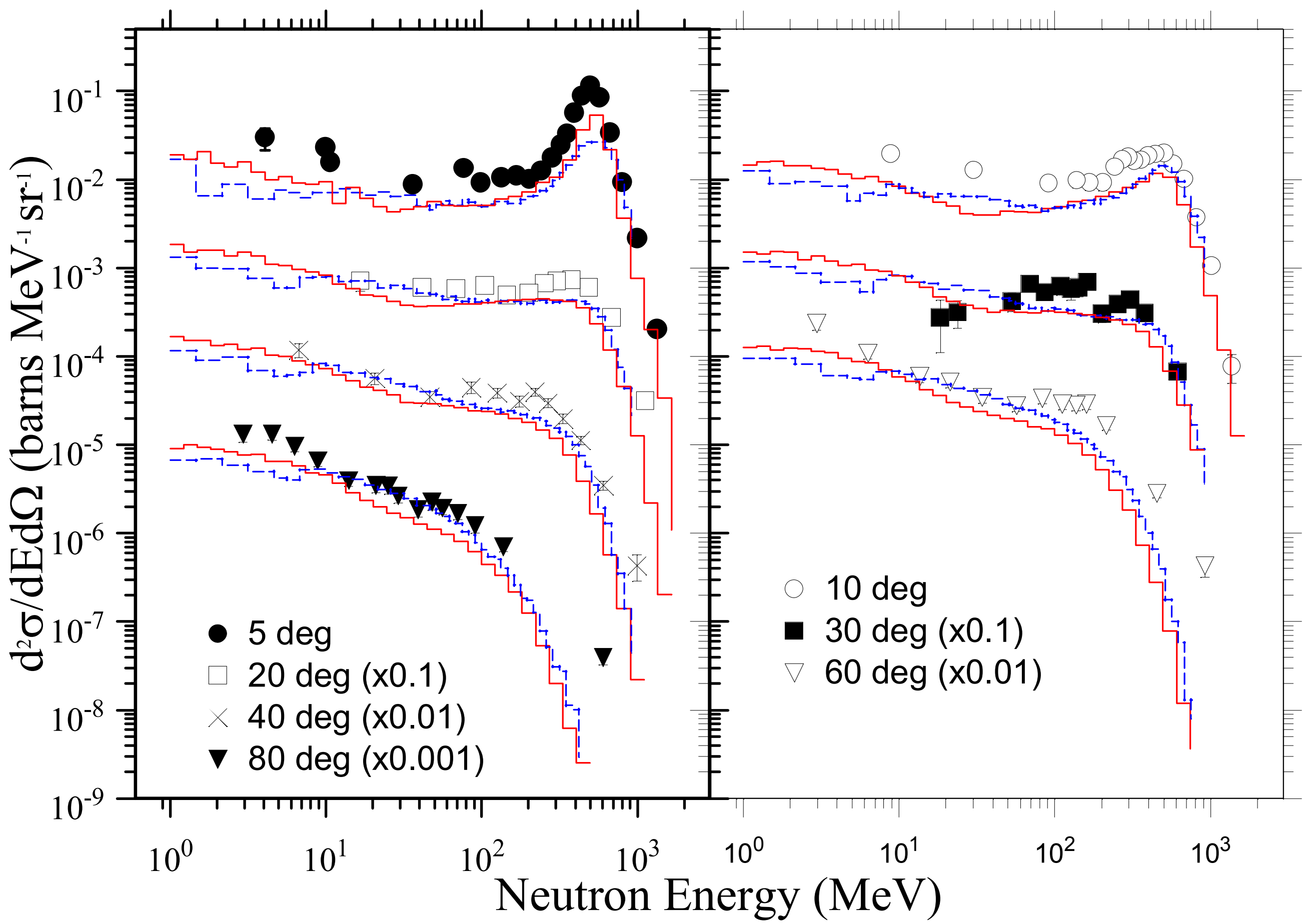
- low energy (< 20 MeV) neutrons at back angles provide information on target fragmentation

- data will be available in a handbook on secondary particle production from heavy-ion interactions

Energy Distributions



600 MeV/nucleon Ne + "Mars bar"



- PHITS and SHIELD-HIT both reproduce the spectra shapes very well
- Both models slightly underestimate the yield

Neutron Yields and Cross Sections

Ion	E (MeV/A)	E (MeV/A)	E (MeV/A)	Targets	Type	Pub.
^{131}Xe	400			Li, C, CH_2, Al, Cu, Pb	σ	draft
^{93}Nb	272	435		Nb, Al (272 only)	y	Y
^{84}Kr	400			Li, C, Al, Cu, Pb	σ	draft
^{56}Fe	400	500		Li,C,Cu,Pb Li,CH_2,Al	σ,y	draft
^{40}Ar	400	560		C, Cu, Pb	σ	Y
^{28}Si	600			C, Cu, Pb	σ	draft
^{20}Ne	400	600		C, Cu, Pb, ISS, Mars Reg.	σ	Y
^{14}N	400			C, Cu	σ	draft
^{12}C	155	290	400	Al (155), C, Cu, Pb Mars Reg (290)	y (Al), σ	Y
^{4}He	155	230		Al, Cu (290)	σ,y	Y

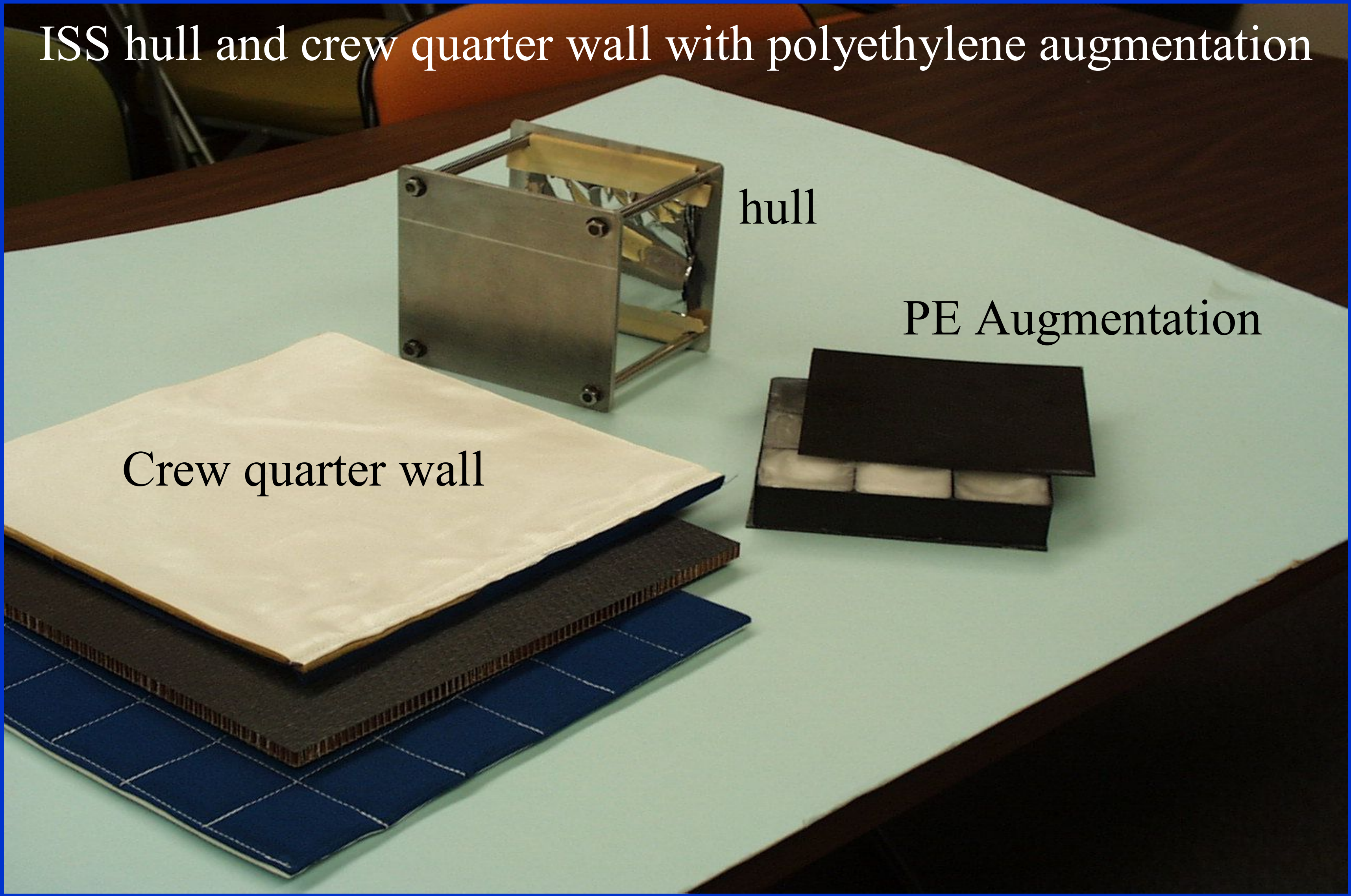
“Handbook on Secondary Particle Production and Transport by High Energy Heavy Ions”

T. Nakamura and L. Heilbronn, Eds.

(World Scientific, Singapore, to be published late 2005)

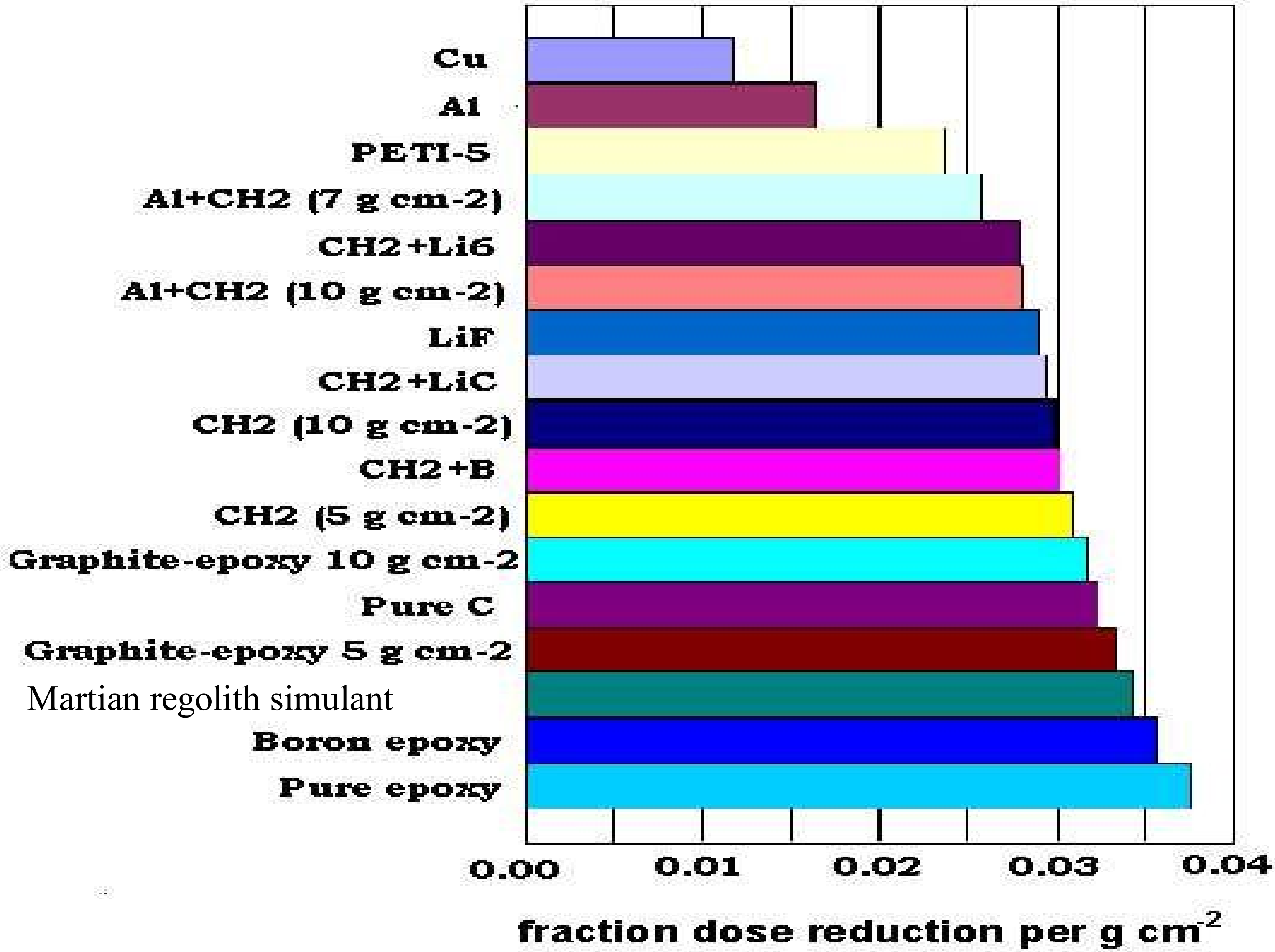
- neutron production cross section data
- thick-target neutron yields
- neutron production behind shielding
- spallation production cross sections
- moving-source parameterizations of the neutron-production cross sections and thick-target yields
- detailed descriptions of the experiments and analysis

Radiation Transport in Materials



Dose reduction (1 GeV/u ^{56}Fe)

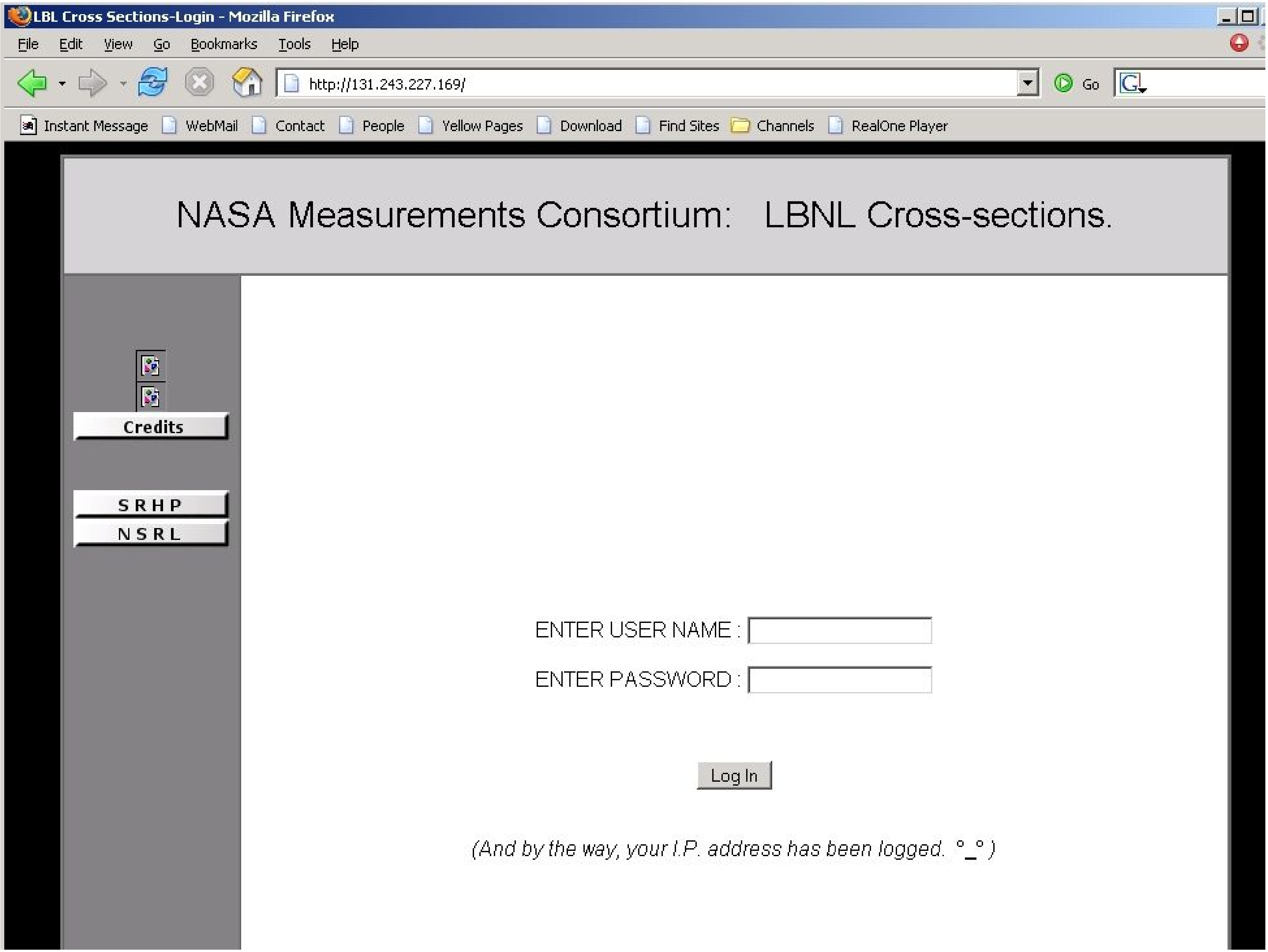
(Zeitlin, *et al.*)



Testing and Data Analysis of Composite Radiation Shielding Materials

To date, 127 samples tested and data analysed:

NASA-MSFC	C (290)	2
	N (290)	6
	Ne (290)	6
	Si (290)	6
	Si (800)	6
	Ti (1000)	2
	Fe (800)	2
	Fe (1000)	6
NASA-LaRC	O (600)	15
	O (1000)	2
	Fe (1000)	17
ORNL	O (600)	3
	O (1000)	15
U. Of Utah	O (600)	9
	H (40)	30


LBL Cross Sections-Login - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://131.243.227.169/
Go
Instant Message WebMail Contact People Yellow Pages Download Find Sites Channels RealOne Player
NASA Measurements Consortium: LBNL Cross-sections.
Credits
S R H P
N S R L
ENTER USER NAME :
ENTER PASSWORD :
Log In
(And by the way, your I.P. address has been logged. °_°)

NASA Measurements Consortium: LBNL Cross-sections.

Green cells are active links.

Ion	Energy (MeV/nucleon)					
^{56}Fe	400	500	600	800	1000	5000
^{48}Ti					1000	
^{40}Ar	290	400	650			
^{28}Si	290	400	600	800	1200	
^{20}Ne	290	400	600			
^{16}O	290	400	600		1000	
^{14}N	290	400				
^{12}C	290	400				
^{4}H	230					

NASA Measurements Consortium : LBNL Cross-sections

Click here for the entire silicon data set in .pdf format

Main Page

S R H P

N S R L

Credits

Silicon at 290 MeV/nucleon

(Cross sections listed by target. All values are in mBarn)

	H	C	Al	Cu	Sn	Pb
σ_{cc}	402 ± 33	1103 ± 34	1546 ± 46	2276 ± 68	3056 ± 91	3943 ± 120
Z = 13	90 ± 9	144 ± 8	175 ± 10	219 ± 14	259 ± 18	380 ± 28
Z = 12	105 ± 11	161 ± 9	190 ± 11	226 ± 13	268 ± 17	338 ± 24
Z = 11	53 ± 6	89 ± 5	111 ± 7	141 ± 9	166 ± 11	200 ± 15
Z = 10	49 ± 6	91 ± 5	106 ± 7	143 ± 9	151 ± 11	199 ± 15
Z = 9	18 ± 3	49 ± 3	67 ± 5	69 ± 5	90 ± 7	97 ± 10
Z = 8	31 ± 5	91 ± 5	112 ± 7	157 ± 9	185 ± 12	185 ± 15

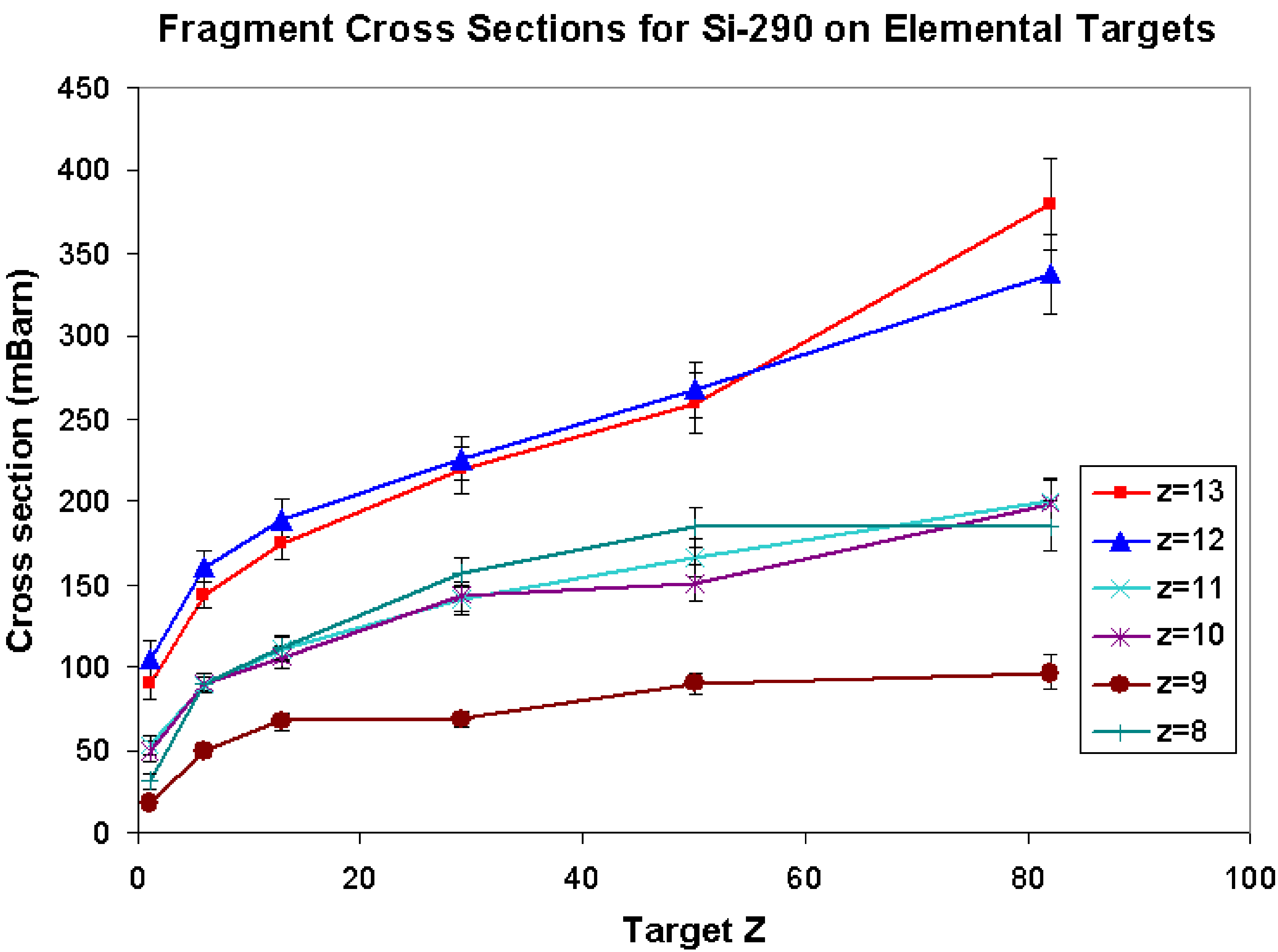
Charge-Changing Cross Sections of Si Beams

(E_{beam}, MeV/amu)	σ_{cc}(Si+H)	σ_{cc}(Si+C)	σ_{cc}(Si+Al)	σ_{cc}(Si+Cu)	σ_{cc}(Si+Sn)	σ_{cc}(Si+Pb)
270 ± 8	402 ± 33	1103 ± 34	1546 ± 46	2276 ± 68	3056 ± 91	3943 ± 120
352 ± 12	350 ± 16	1162 ± 17	1615 ± 29	2345 ± 34	3163 ± 91	4047 ± 59
552 ± 16	409 ± 15	1138 ± 19	1528 ± 19	2289 ± 29	2955 ± 44	3962 ± 57
765 ± 5	399 ± 28	1141 ± 34	1540 ± 46	2273 ± 68	3035 ± 91	3967 ± 120
1147 ± 11	459 ± 21	1139 ± 20	1567 ± 28	2179 ± 39	2905 ± 62	3945 ± 84

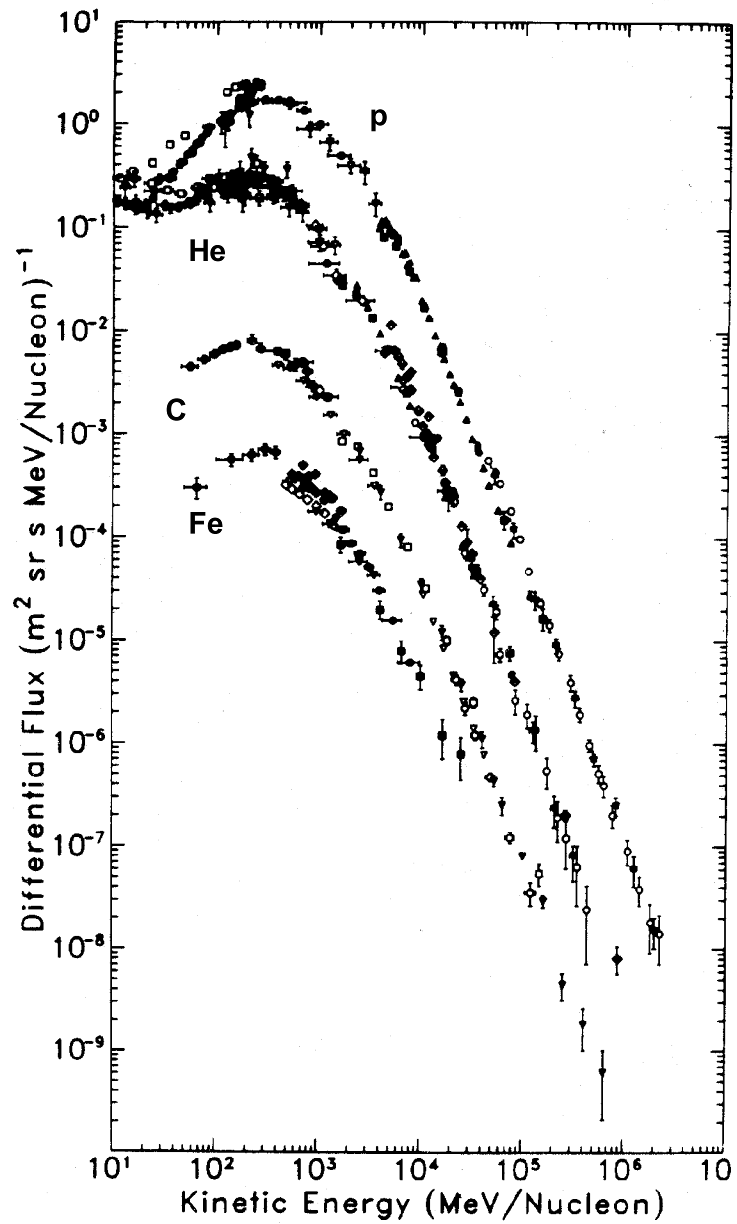
Fragment Production Cross Sections at Large Acceptance

Si + H

E_{beam}	263	350	560	765	1160
σ(Z=13)	90 ± 9	76 ± 4	75 ± 3	74 ± 7	61 ± 4
σ(Z=12)	105±11	93 ± 5	88 ± 3	83 ± 8	74 ± 5
σ(Z=11)	53 ± 6	48 ± 3	46 ± 2	43 ± 4	43 ± 3
σ(Z=10)	49 ± 6	43 ± 3	49 ± 2	45 ± 5	44 ± 3
σ(Z=9)	18 ± 3	16 ± 3	21 ± 1	22 ± 2	23 ± 3
σ(Z=8)	31 ± 5	31 ± 7	41 ± 2	41 ± 5	44 ± 5
σ(Z=7)		15 ± 5	26 ± 2	22 ± 3	36 ± 5
σ(Z=6)		17 ± 6	21 ± 2	30 ± 4	28 ± 5
σ(≤ 5)		26± 14	46 ± 7	51± 19	92± 20



Fragment Cross Sections for Si-290 on Elemental Targets
Cross section (mBarn)
Target Z
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
z=13
z=12
z=11
z=10
z=9
z=8



p
He
C
Fe
Differential Flux (m² sr s MeV/Nucleon)⁻¹
Kinetic Energy (MeV/Nucleon)

High Energy Fragmentation Measurements at the AGS (7/05)

C, Si, Fe at 3, 5 and 10 GeV/A.

- 0-3 deg. - plastic scintillators and silicon SSD (LBNL)
- 3-9 deg. - segmented silicon detectors (NASA-MSFC)
- 3-45 deg. - silicon strip detectors to cover single charged particles (**UH**)
- 15-115 deg – neutron counters (LBNL)
- FLUKA Simulations of the entire setup including all detector systems. (UH)

AGS Detector Layout - 7/05

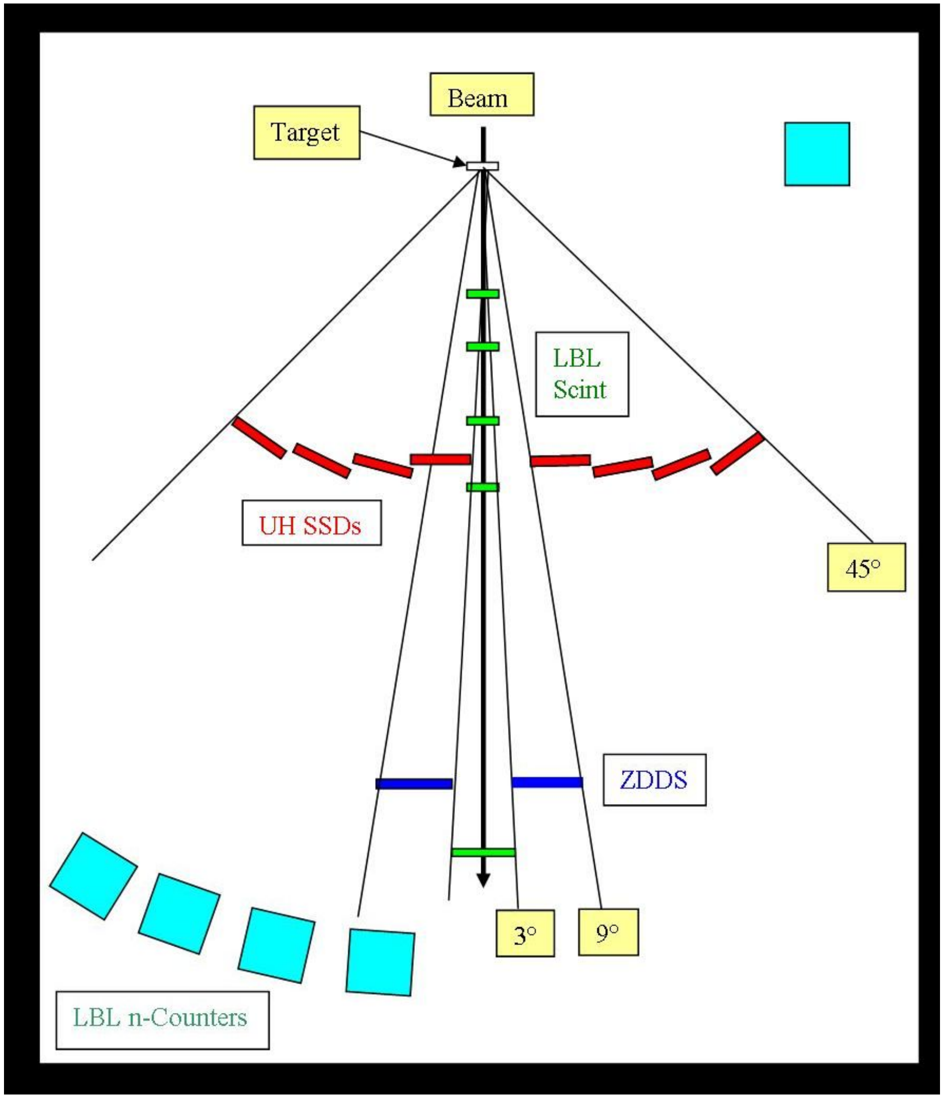
UH-MSFC-LBNL

HIMAC

Test Run

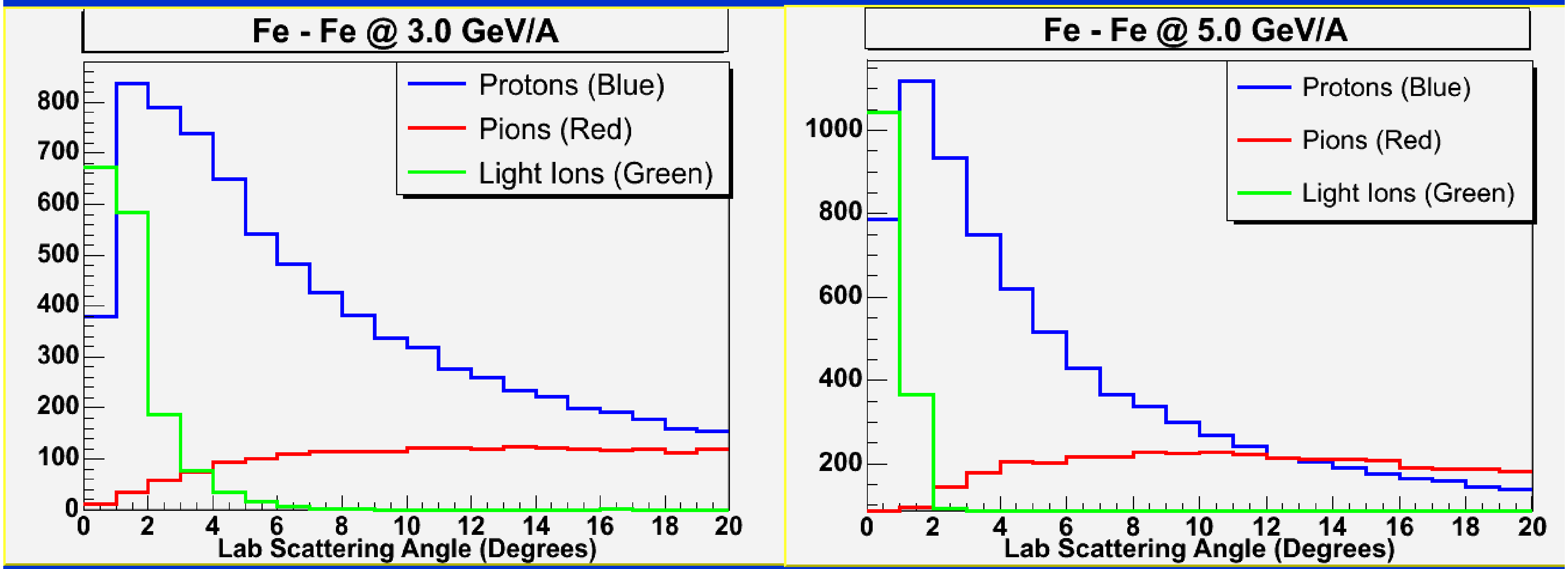
Setup

Feb. ‘05



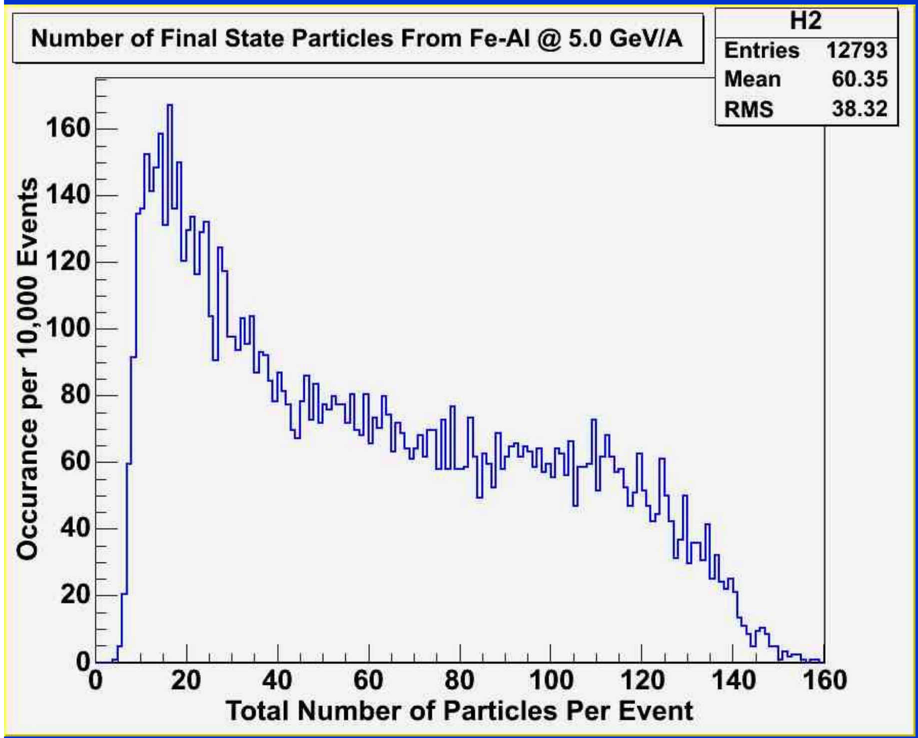
Planned AGS Layout

FLUKA RQMD AGS Predictions (UH)

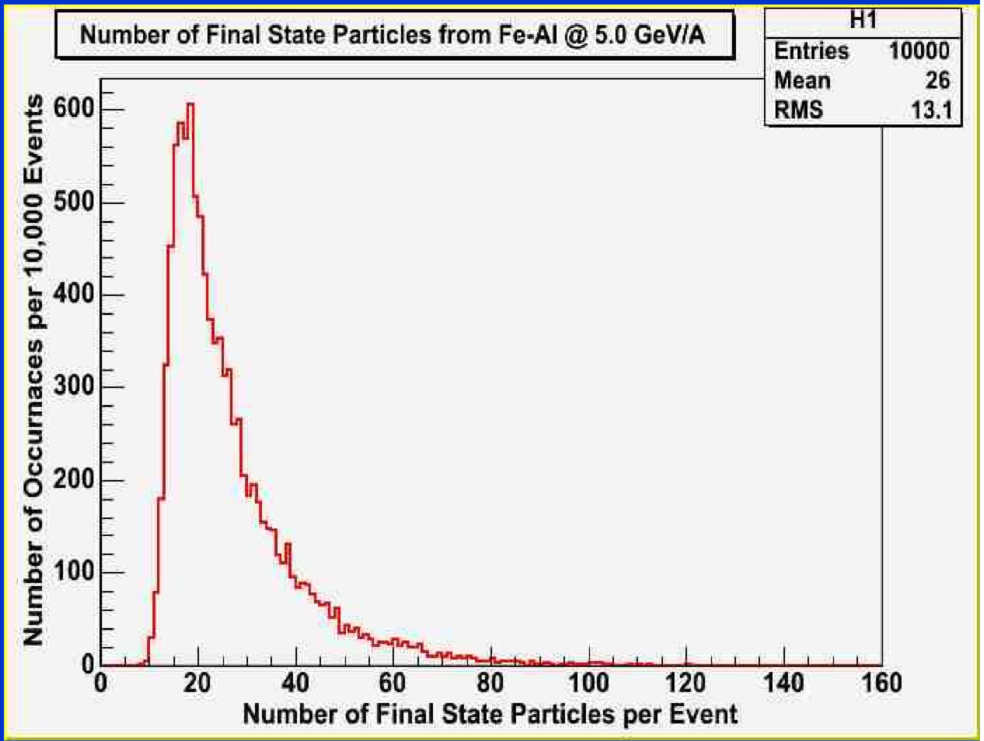


- RQMD Generator Predictions of Scattering Angle Distributions at 3 & 5 GeV/A Fe-Fe Collisions

One of the Primary Motivations for the AGS Measurements…
Predicted Number of Particles Per Event
RQMD v DPMJET for Fe-Al @ 5 GeV/A



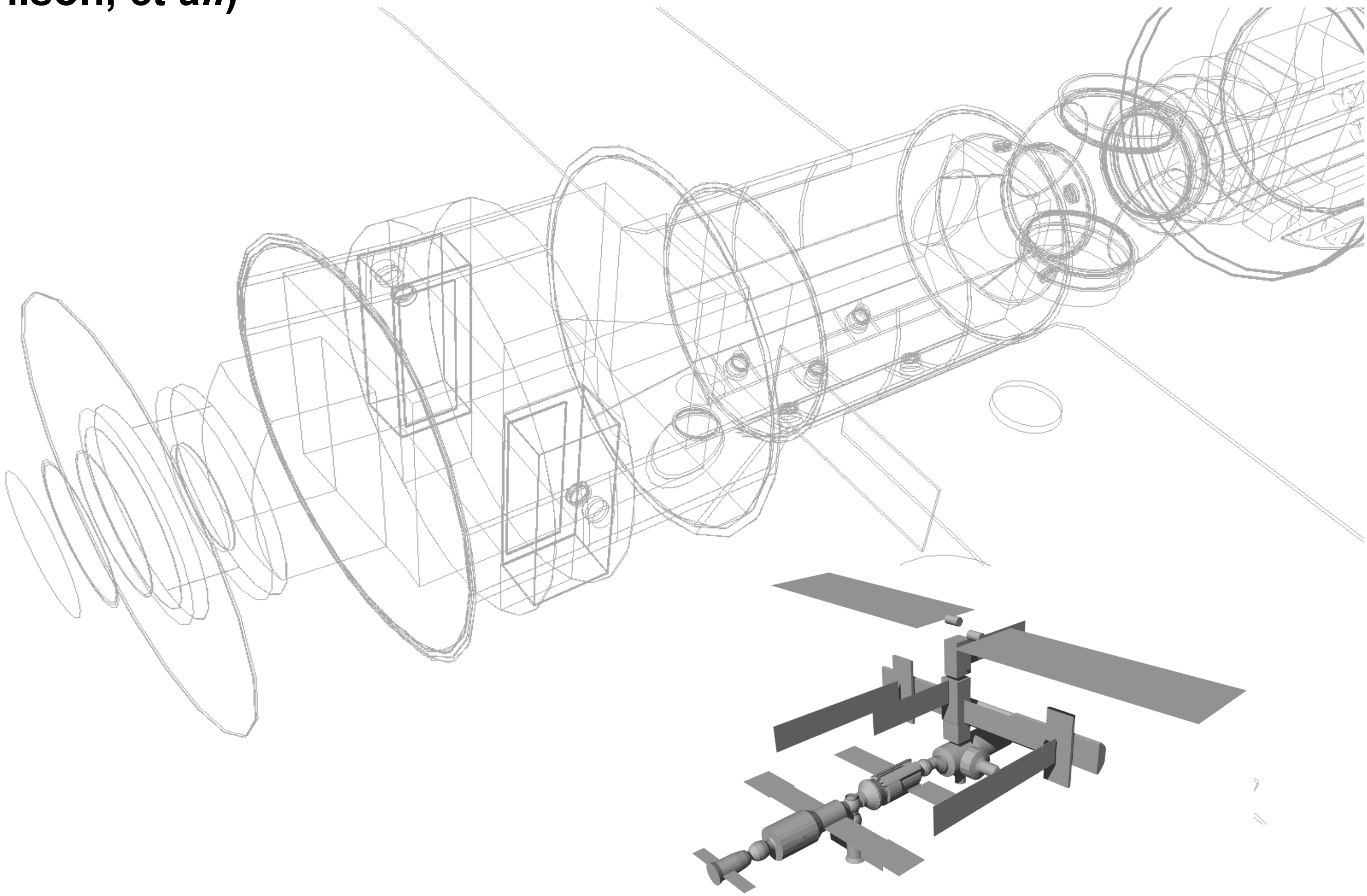
RQMD



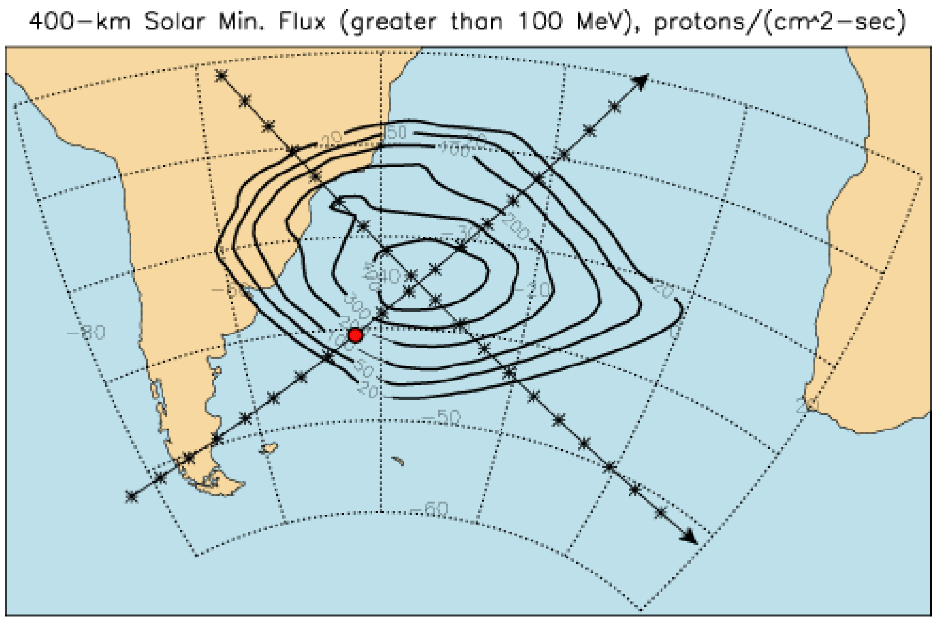
DPMJET

Radiation Shielding Model: Service Module Crew Quarters

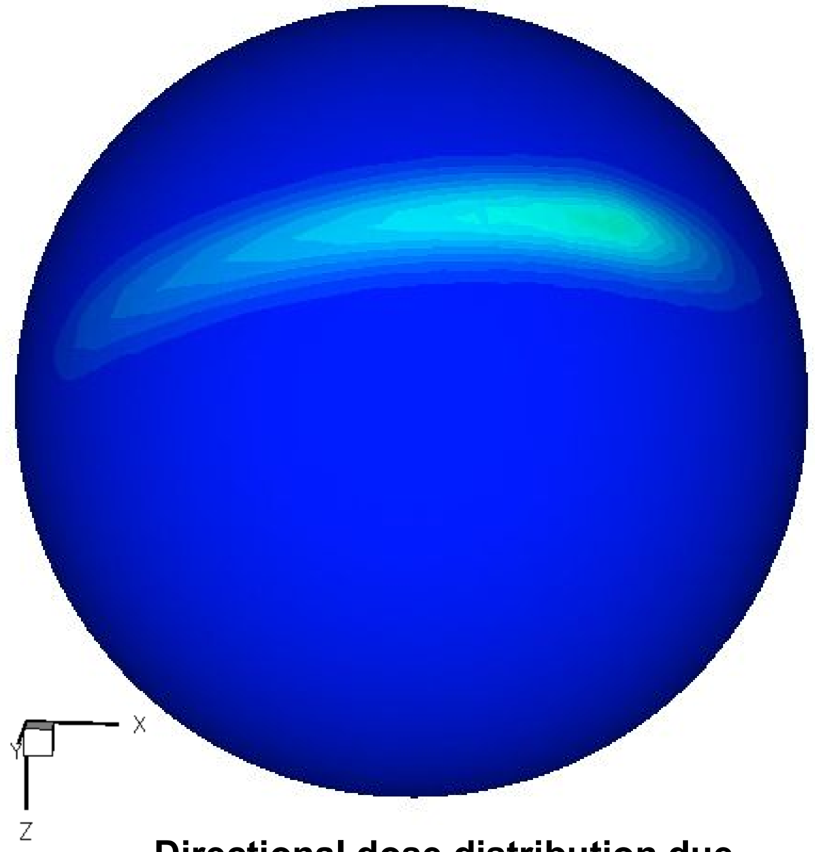
(Wilson, *et al.*)



Radiation Environment: South Atlantic Anomaly, Protons

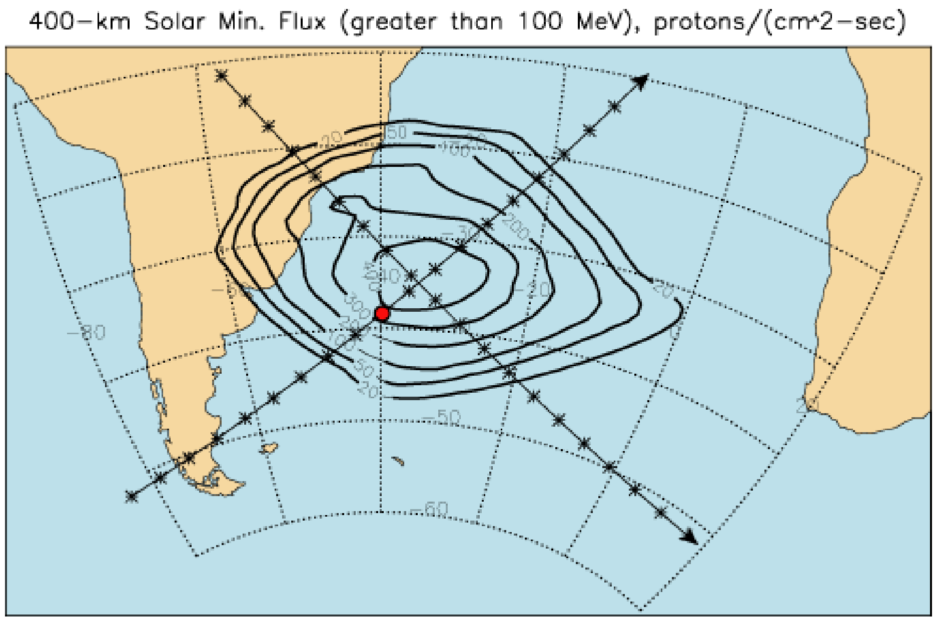


ISS ascending pass through center of SAA

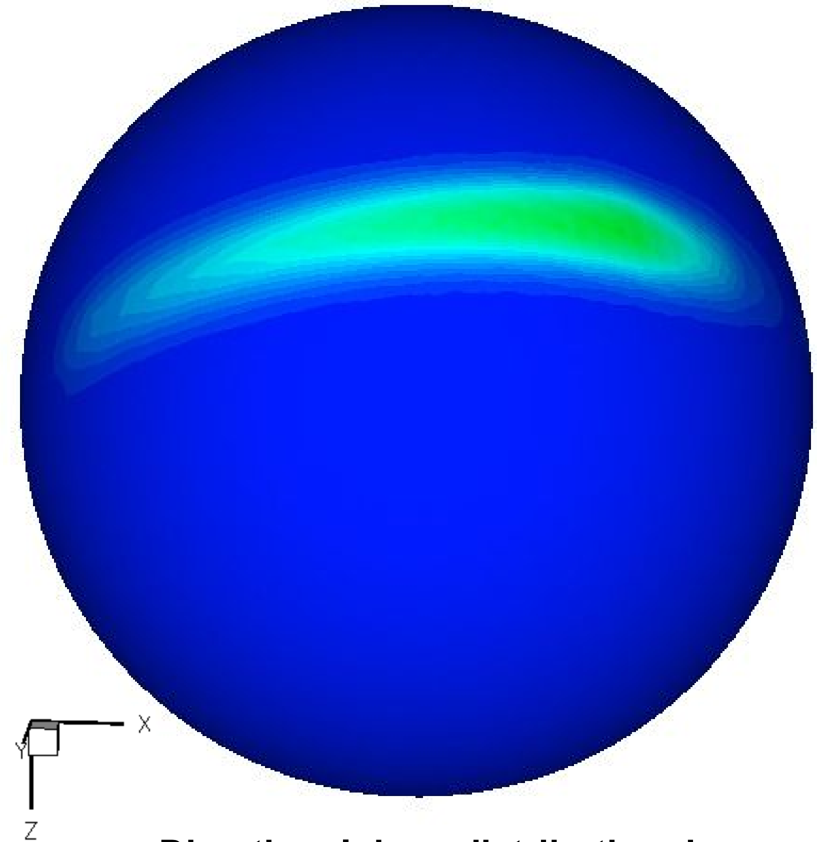


Directional dose distribution due to protons within the SM starboard Crew Quarters

Radiation Environment: South Atlantic Anomaly, Protons



ISS ascending pass through center of SAA



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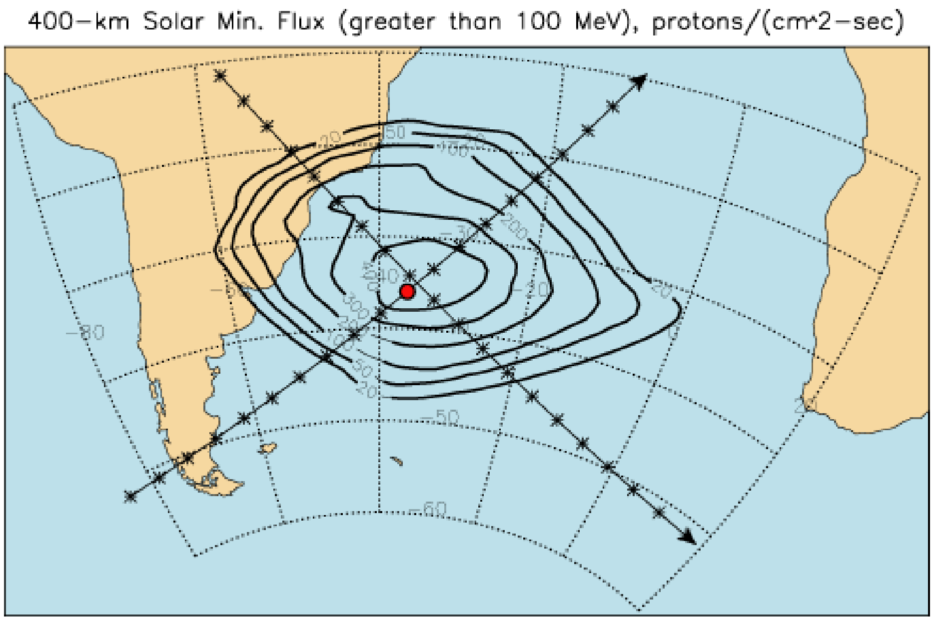
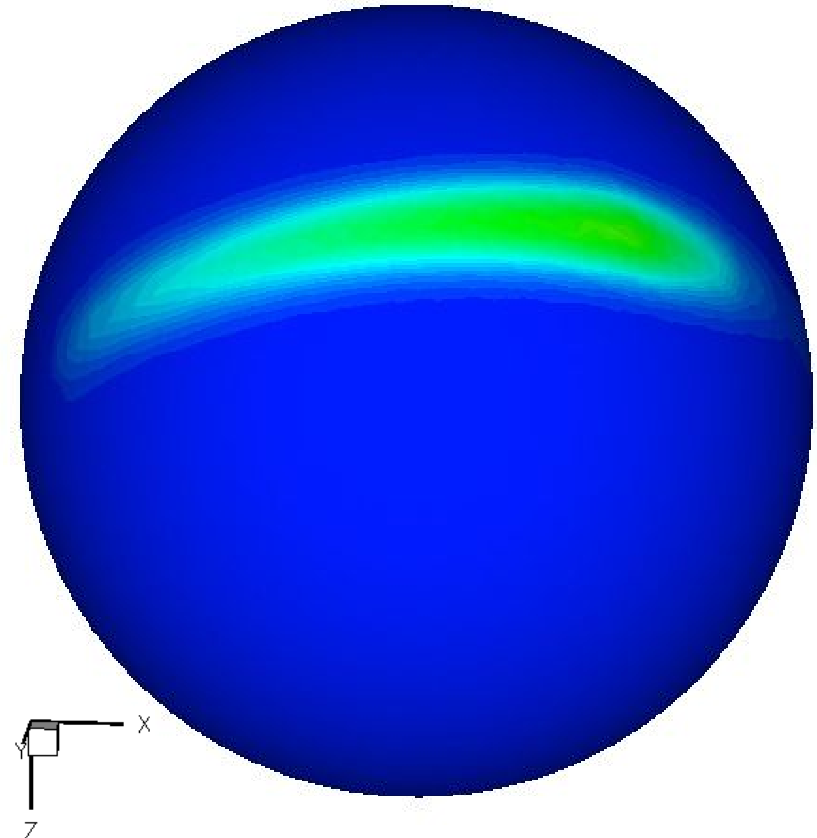
Radiation Environment: South Atlantic Anomaly, Protons



ISS ascending pass through center of SAA



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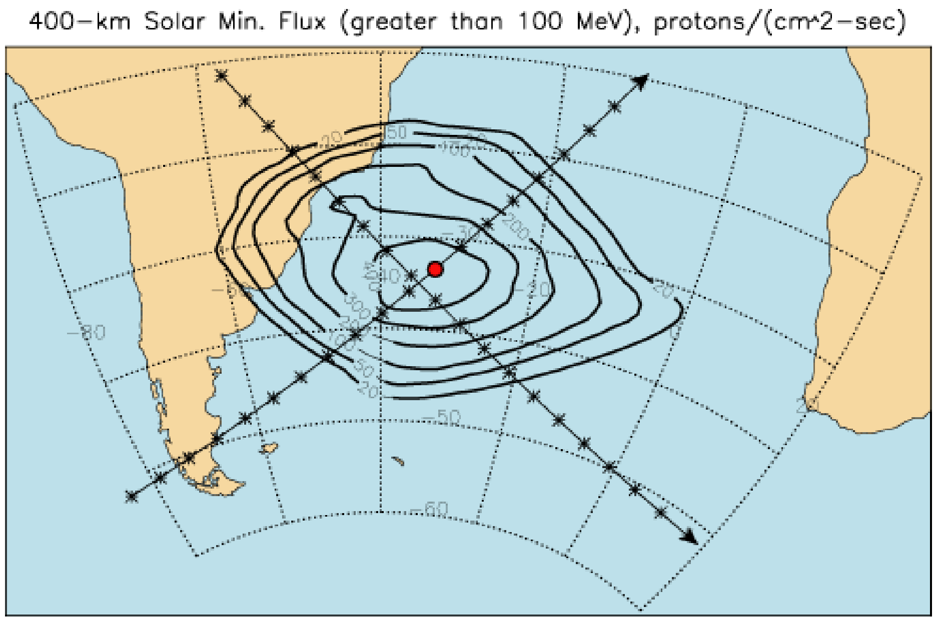

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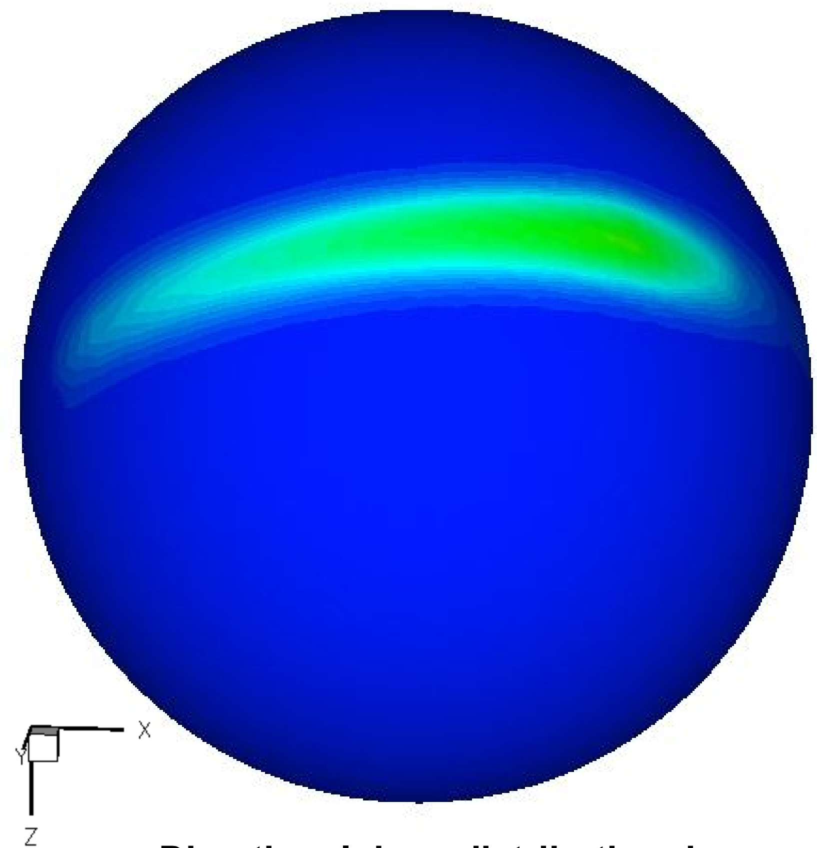

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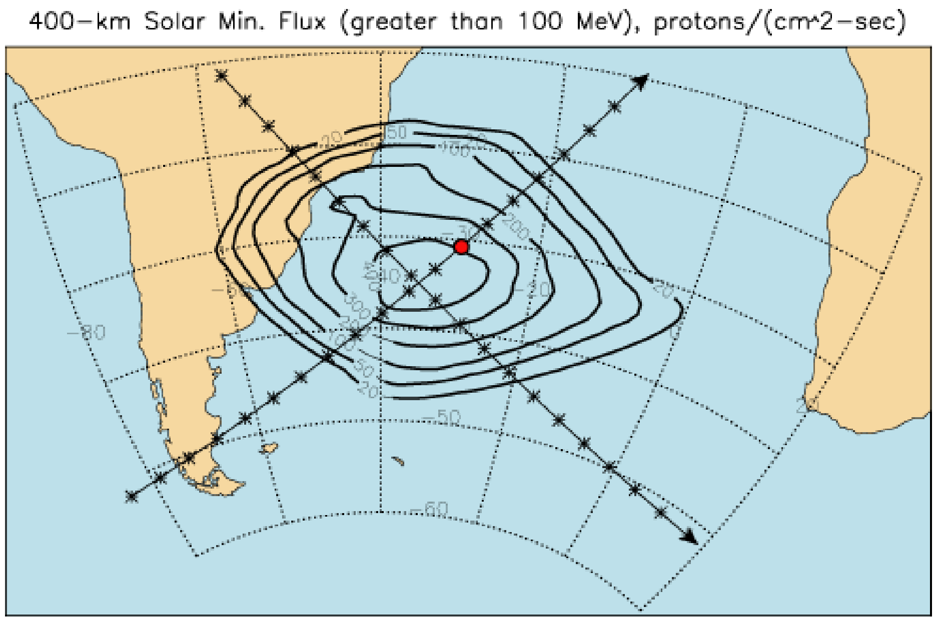

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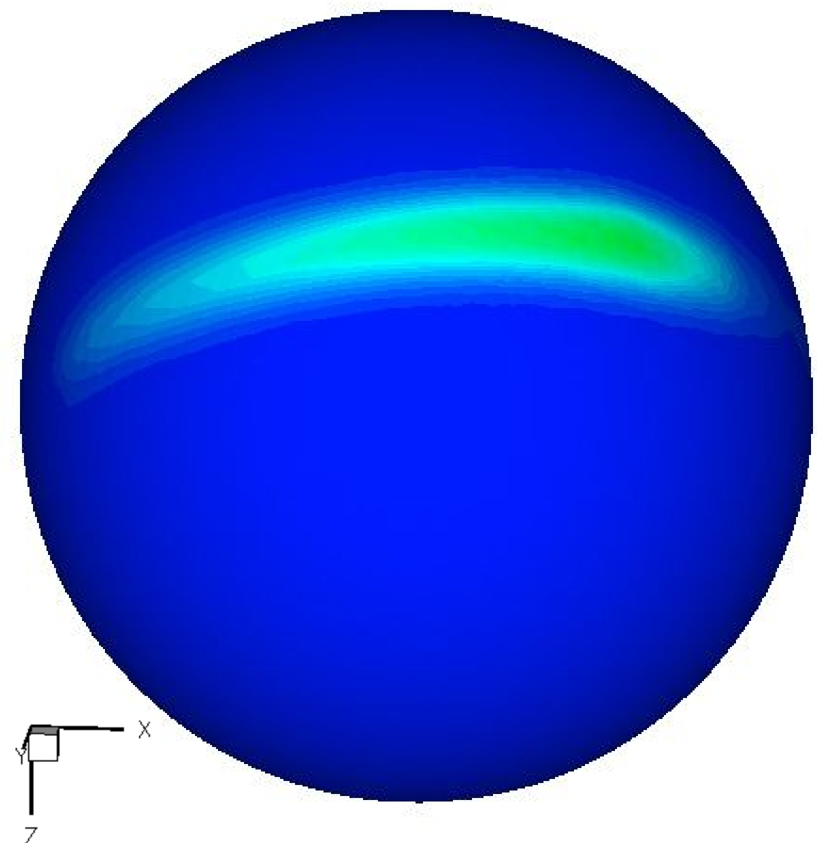

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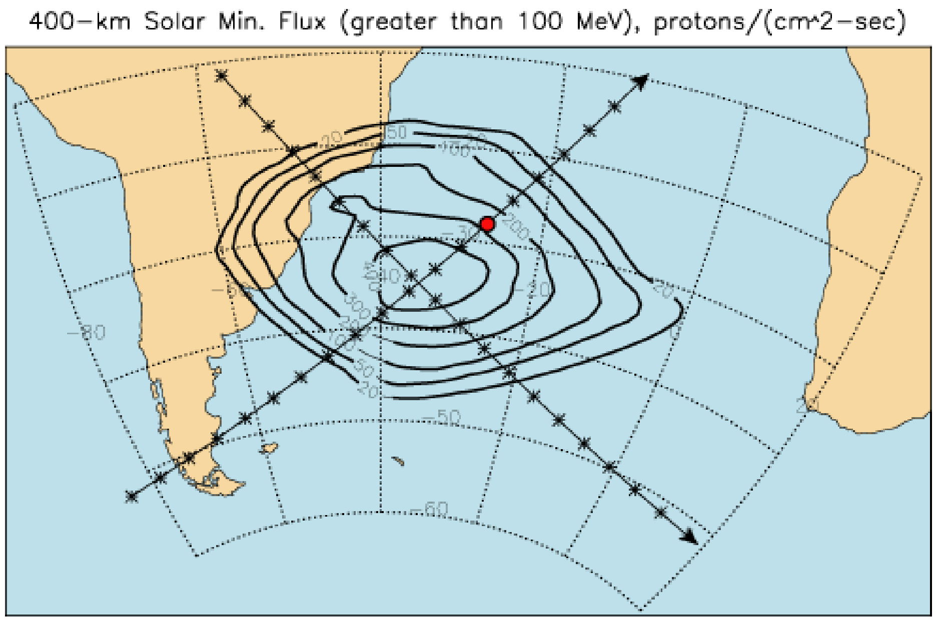

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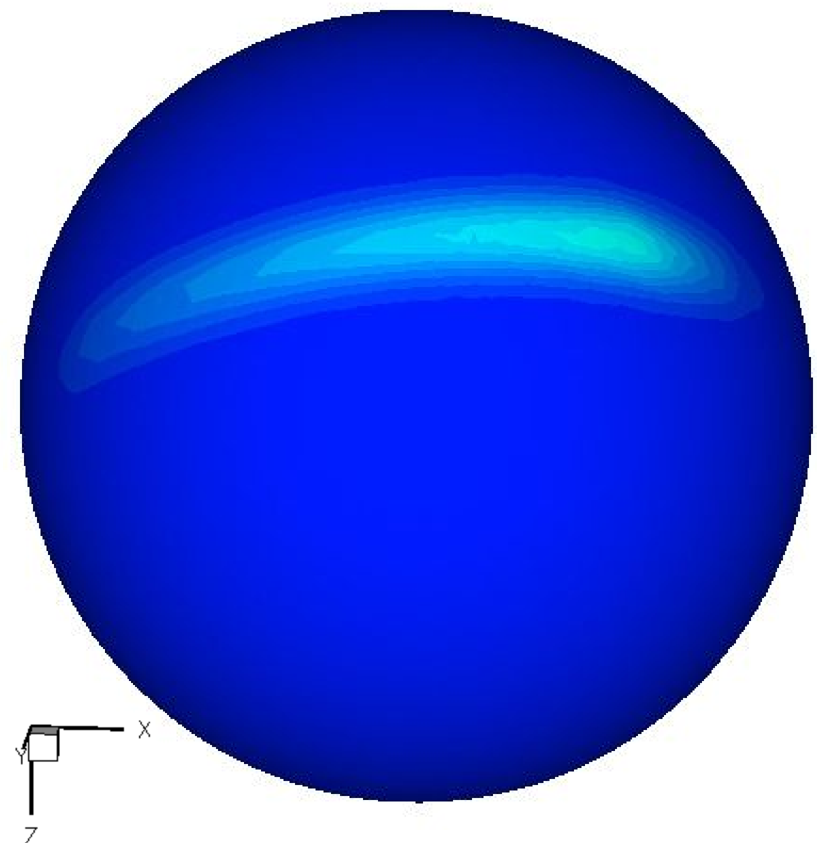
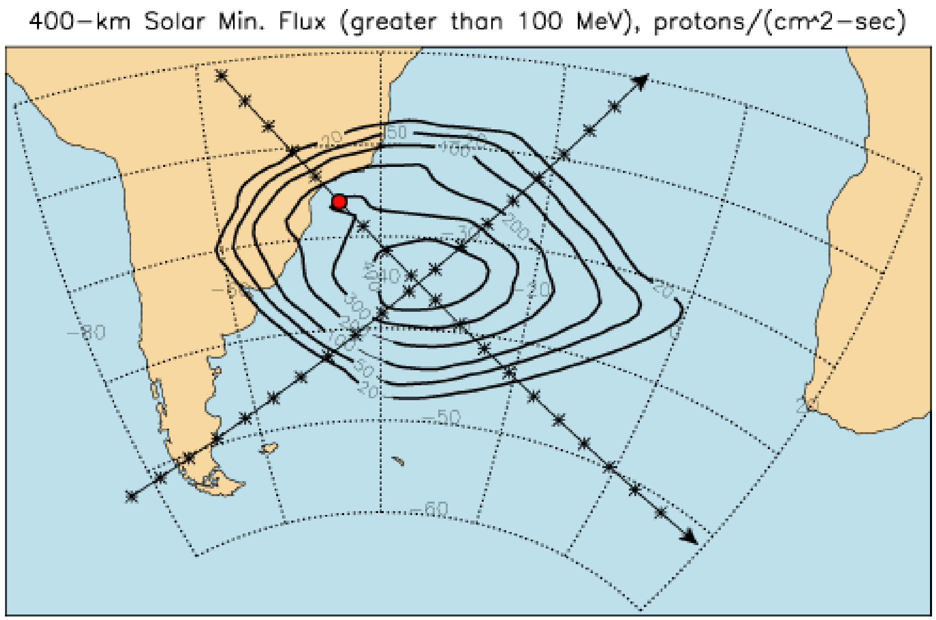
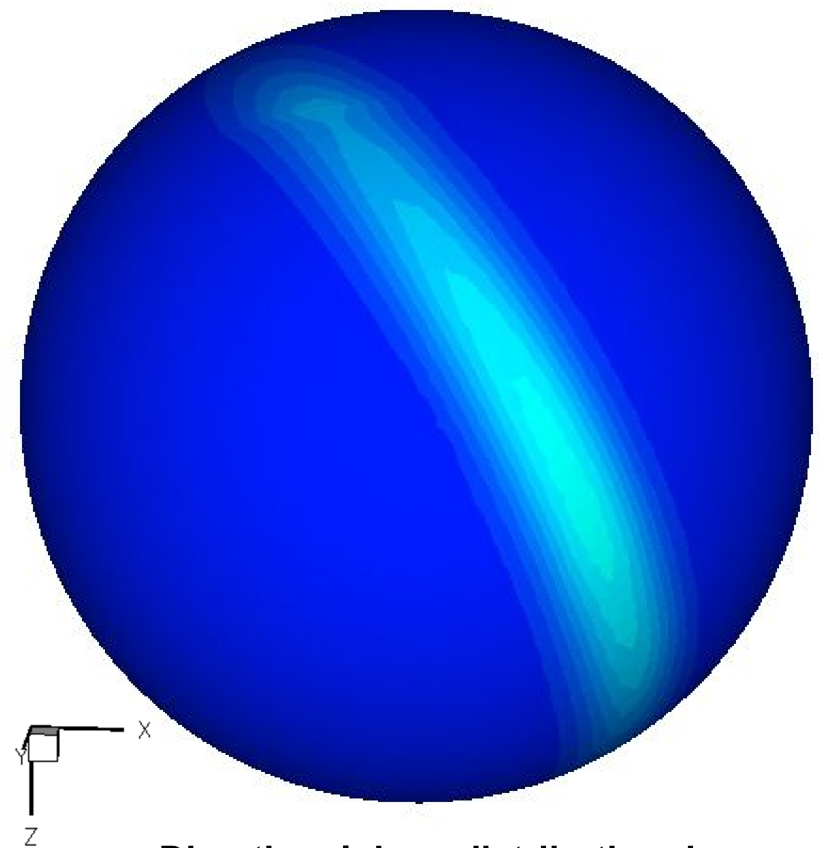


Directional dose distribution due to protons within the SM starboard Crew Quarters

Radiation Environment: South Atlantic Anomaly, Protons



ISS descending pass through center of SAA



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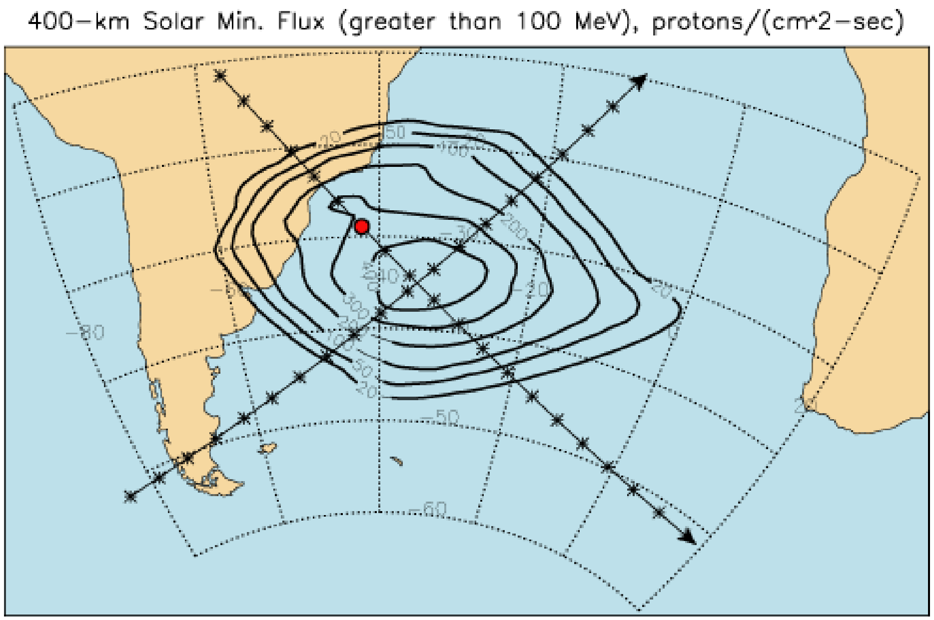
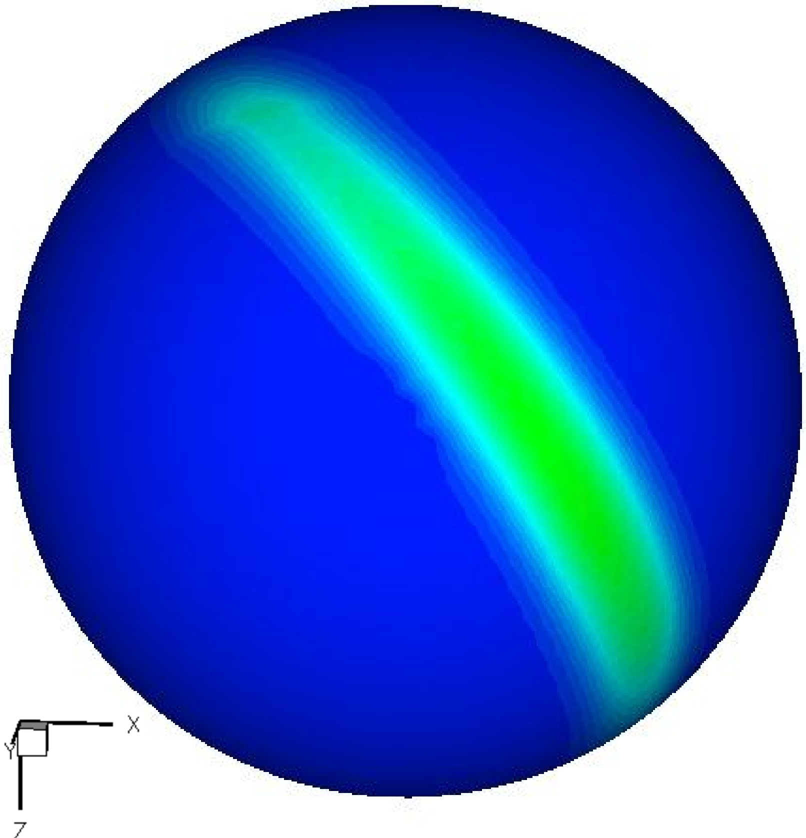


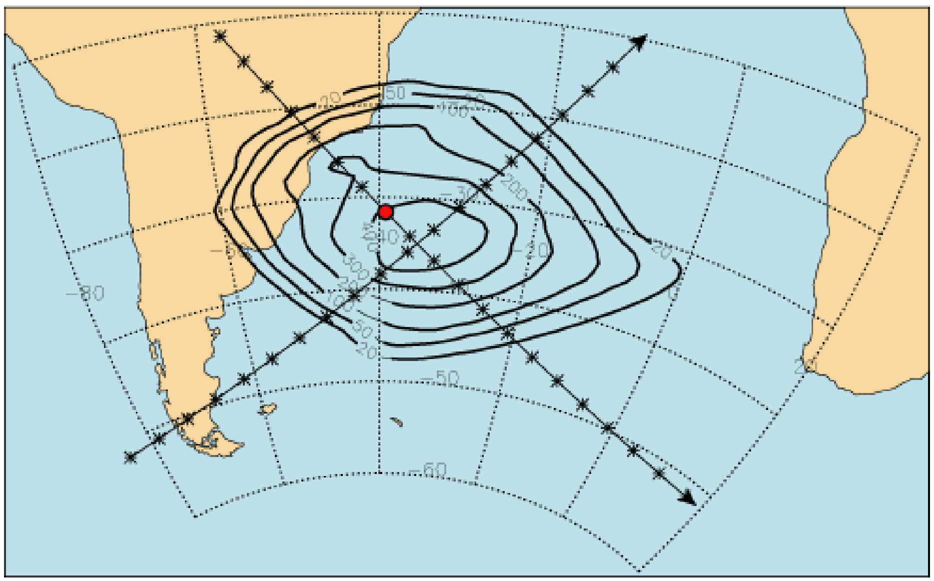
ISS descending pass through center of SAA



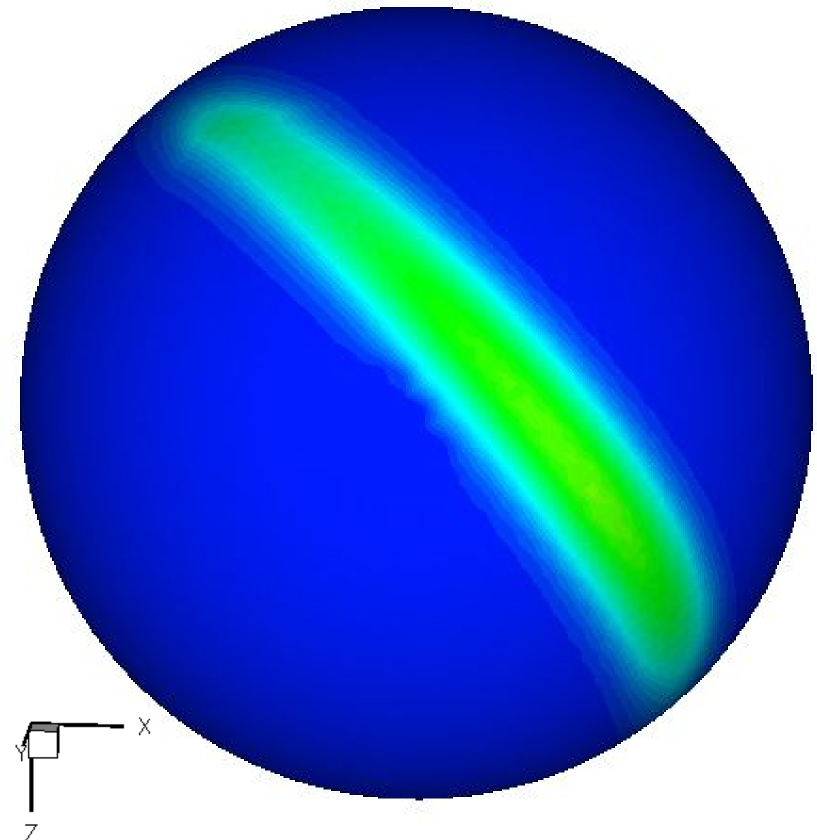
Directional dose distribution due to protons within the SM starboard Crew Quarters

Radiation Environment: South Atlantic Anomaly, Protons

400-km Solar Min. Flux (greater than 100 MeV), protons/(cm^2-sec)



ISS descending pass through center of SAA



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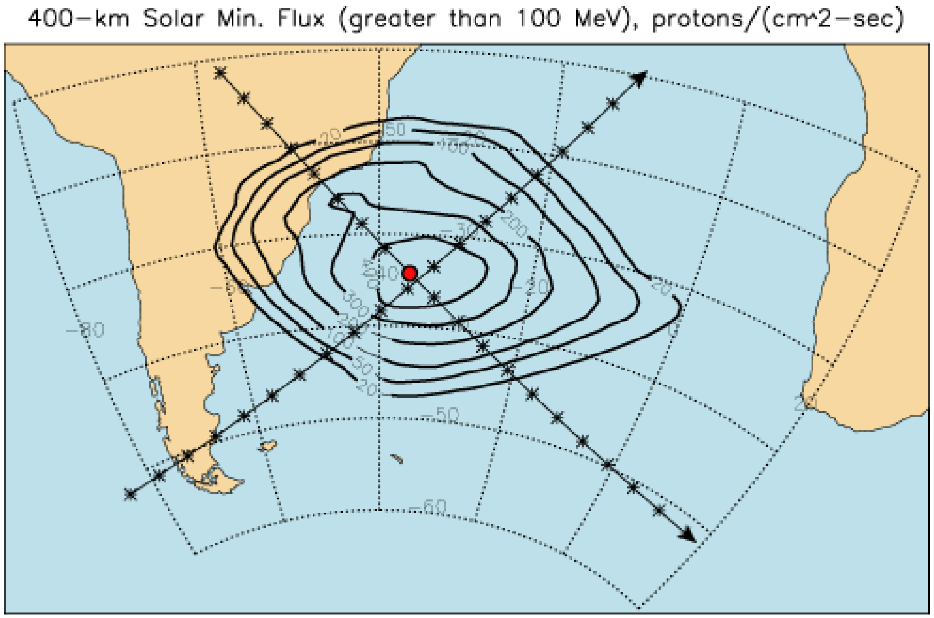
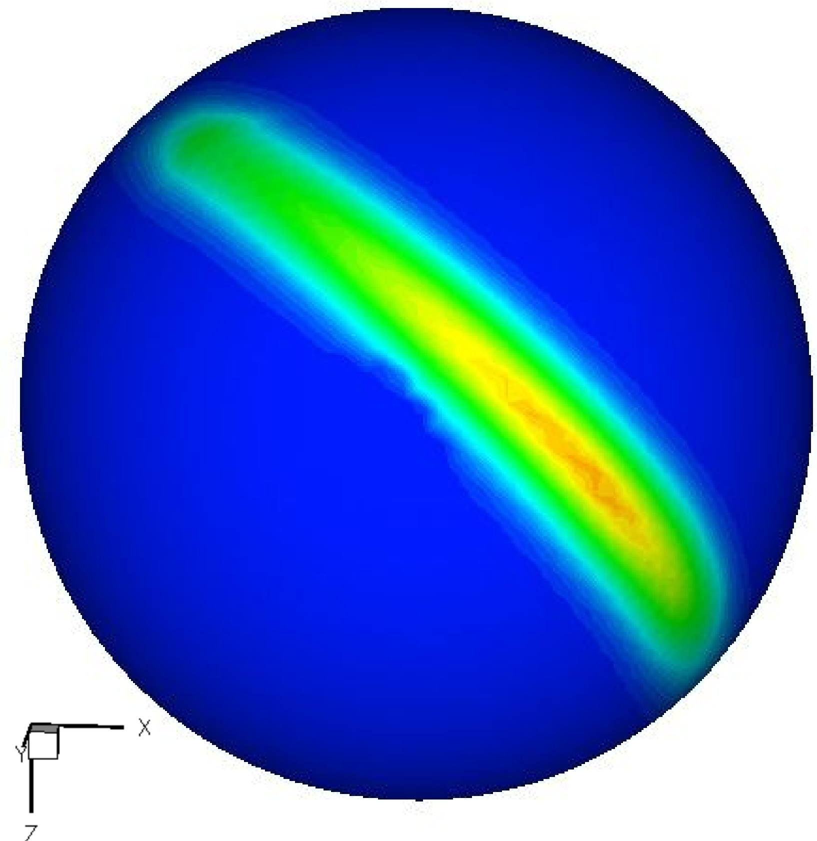


ISS descending pass through center of SAA



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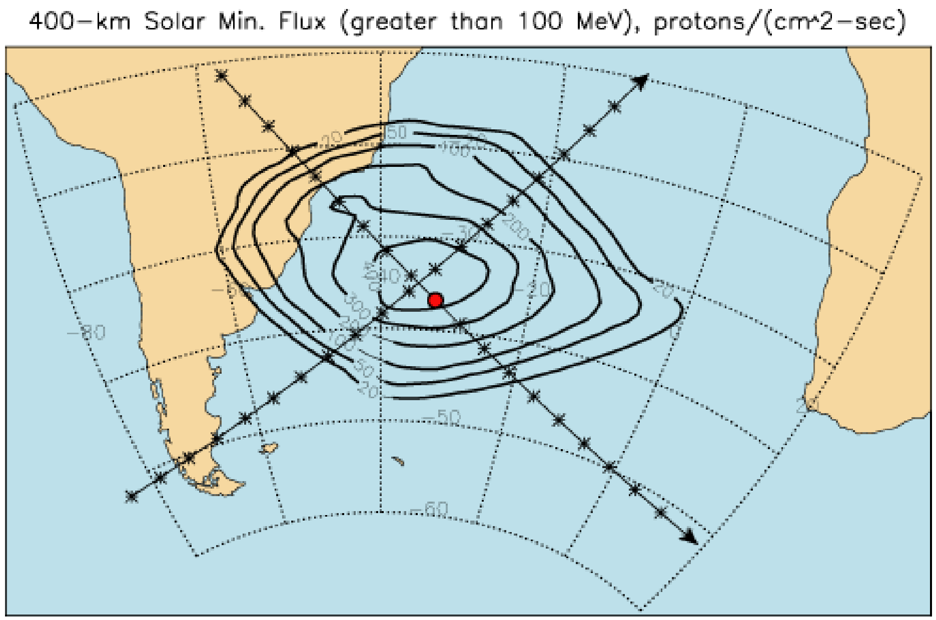
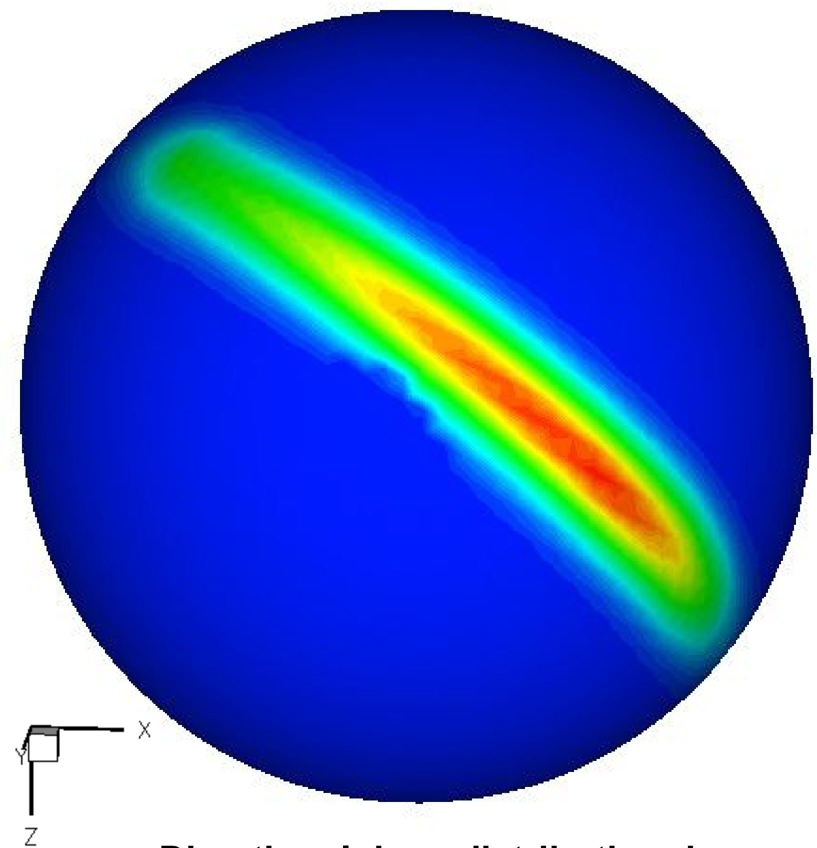
Radiation Environment: South Atlantic Anomaly, Protons



ISS descending pass through center of SAA



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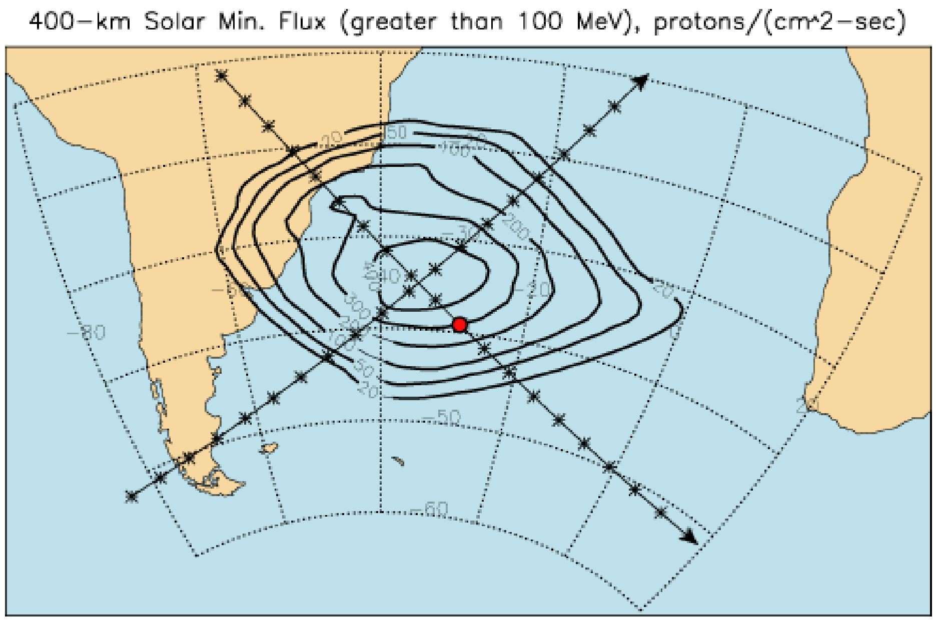

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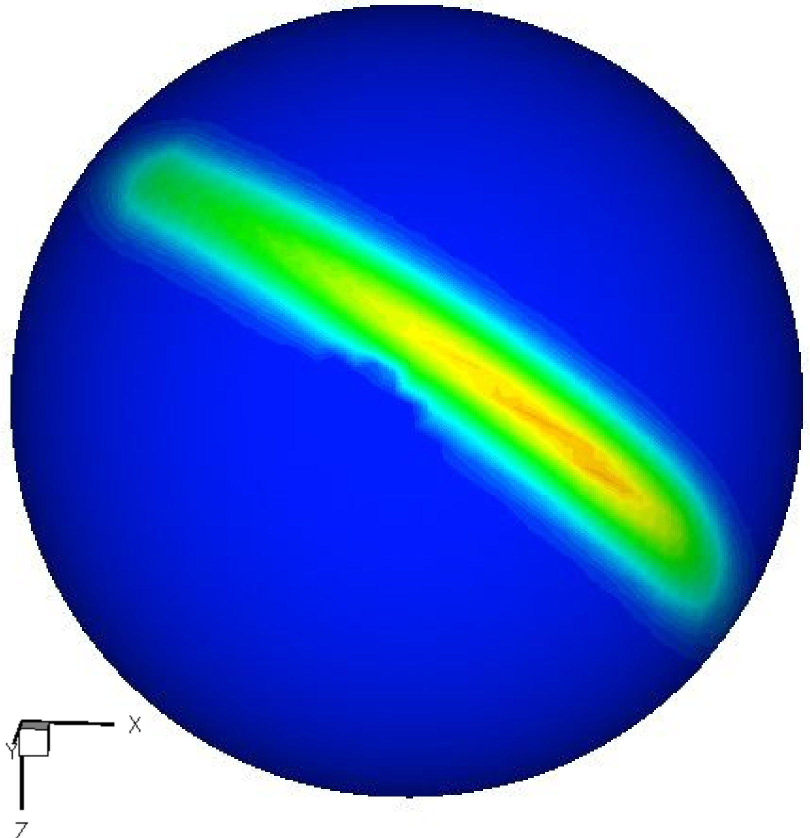

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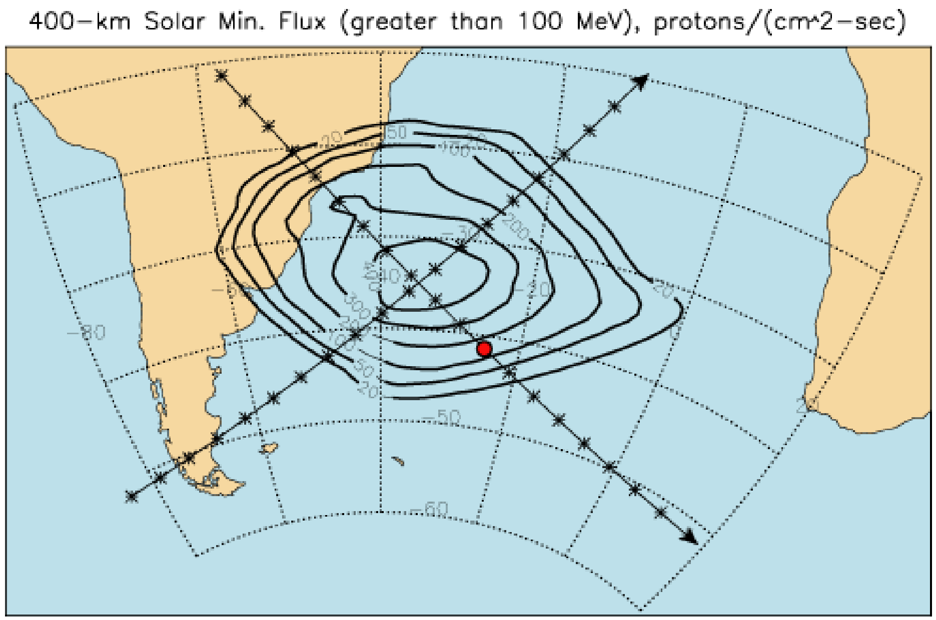
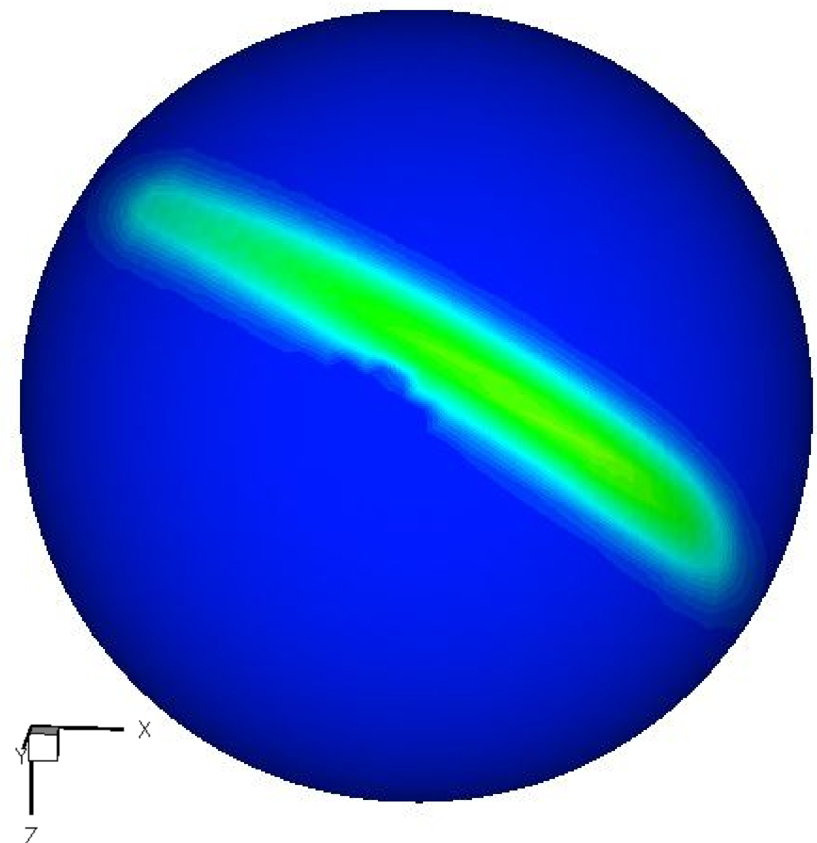
Radiation Environment: South Atlantic Anomaly, Protons



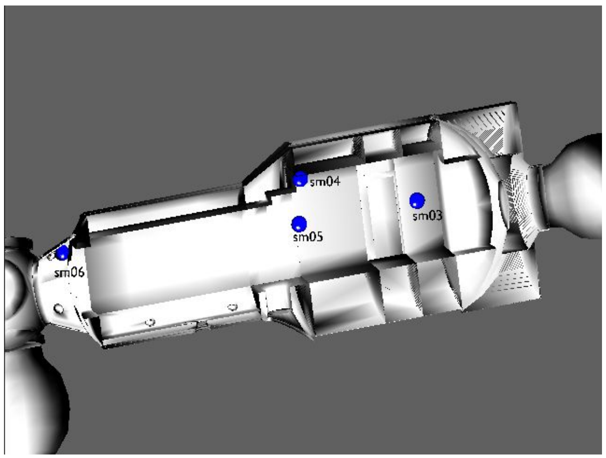
ISS descending pass through center of SAA

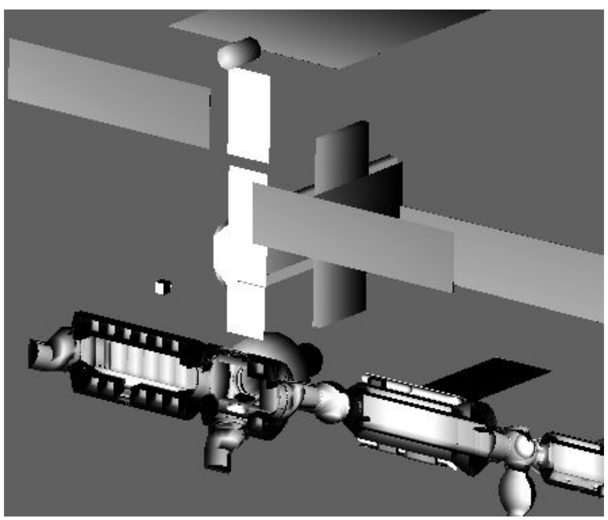


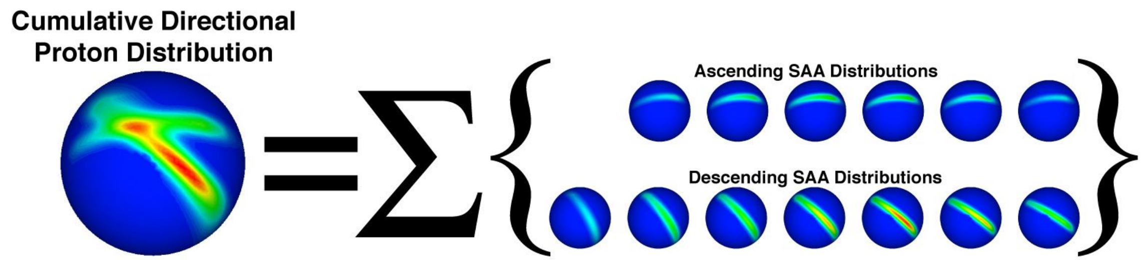
Directional dose distribution due to protons within the SM starboard Crew Quarters

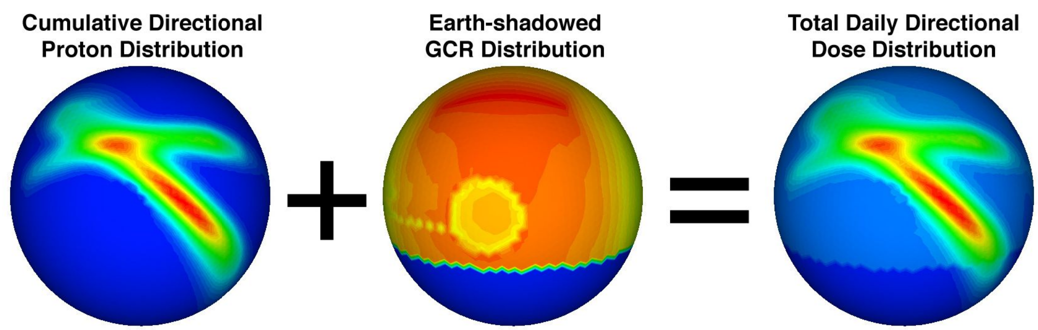
Flight Validation in LEO

ISS 11A

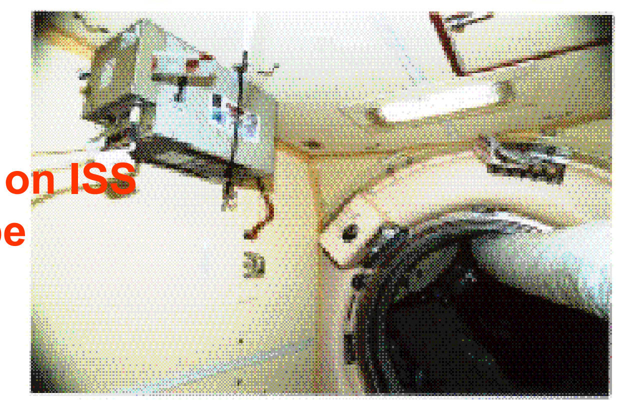








Sileye-3 detector on ISS (particle telescope spectrometer



Summary

- **Accelerator-based measurements produce detailed data on the radiation transport properties of materials for significant components of the GCR HZE flux.**

- **These data are being used to quantify the radiation shielding effectiveness of the candidate materials and to improve the accuracy of the models.**

- **Ultimately the models, in combination with data from radiobiological experiments now in progress, will comprise a tool for use by spacecraft and instrument designers, mission planners, flight surgeons and radiation health specialists.**

Collaborations

- NASA SRSP Transport Consortium
- Flight instruments and detectors
  - ISS partners (ICCHIBAN)
  - Eril Research/OSU (passive)
- DSTB (NASA-MSFC)
- Robotic missions (MARIE)
- Physics support for radiation biology and bioastronautics (NSRL, LBNL NSCOR, LLUPTC, NASA-JSC)

The Measurements Consortium

- **LBNL**
  Charged particle and neutron measurements and data analysis
- **NASA-MSFC**
  ZDDS detector development and operation
- **NIRS**
  Charged particle and neutron measurements and data analysis
- **NSCL**
  Neutron measurements
- **BNL**
  NSRL experiment support
- **Tohoku University**
  Neutron measurements, modeling and data analysis
- **Chalmers University of Technology**
  Modeling and data analysis
- **The University of Houston**
  Charged particle measurements, modeling and data analysis