November 2013 analysis of high energy electrons on the Japan Experimental Module (JEM: Kibo)

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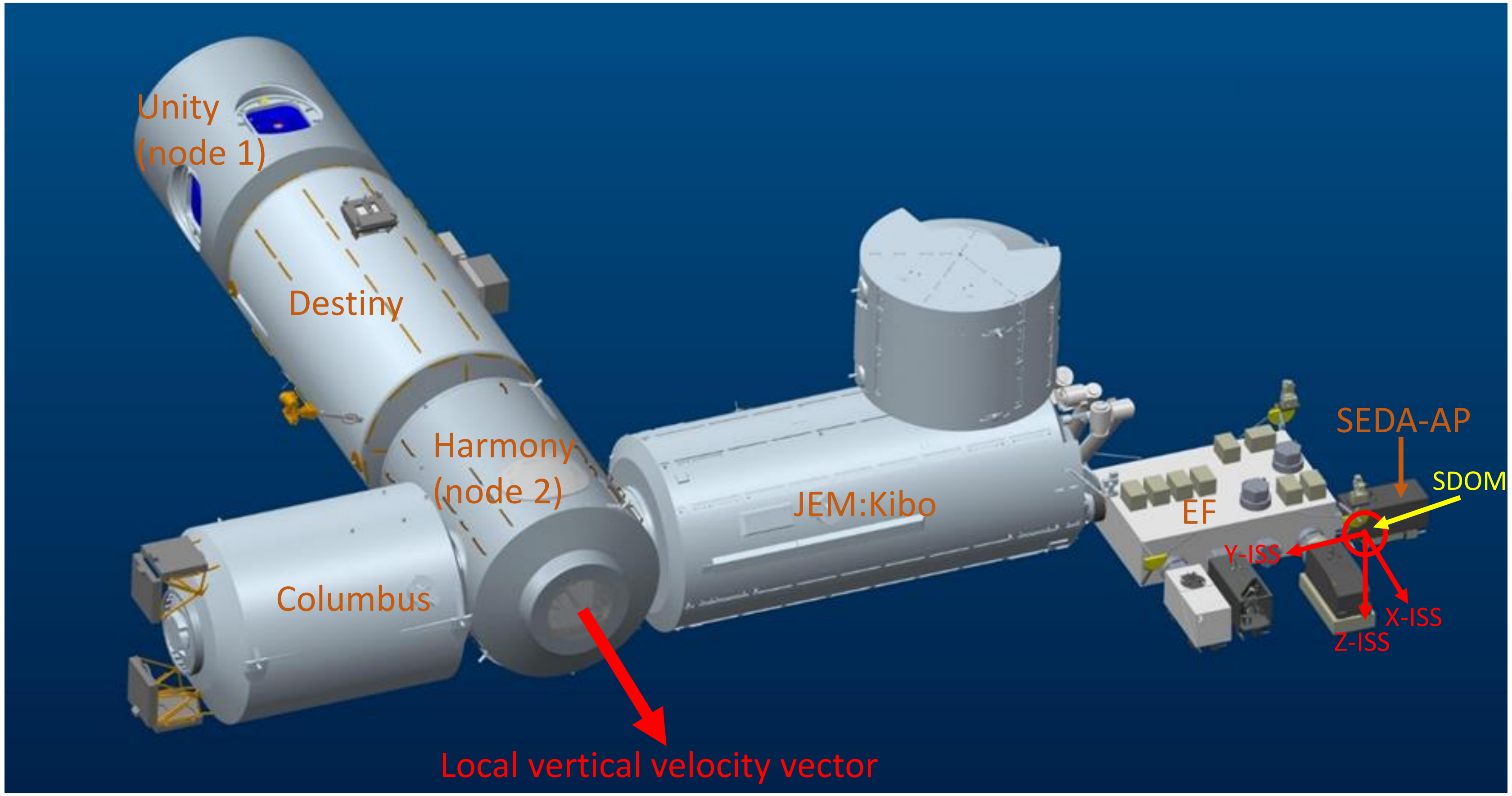
Outline

- Background on the Japan Experimental Module (**JEM**:Kibo), Exposed Facility (**EF**), Space Environment Data Acquisition Equipment - Attached Payload (**SEDA-AP**) and Standard DOse Monitor (**SDOM**)
- November 2013 electrons/protons measurements by SDOM
- Correlation of Geostationary Operational Environment Satellites 13/15 (**GOES 13/15**) measurements with SDOM
- SDOM individual electron channels data and specifically channels 6/7 data analysis
- Mechanisms for albedo electron production inside/outside the South Atlantic Anomaly (SAA) region and dosimetric analysis
- Summary

Location and orientation of JEM (Kibo), EF, SEDA-AP and SDOM on the International Space Station (ISS)

Dimensions (m: meter)

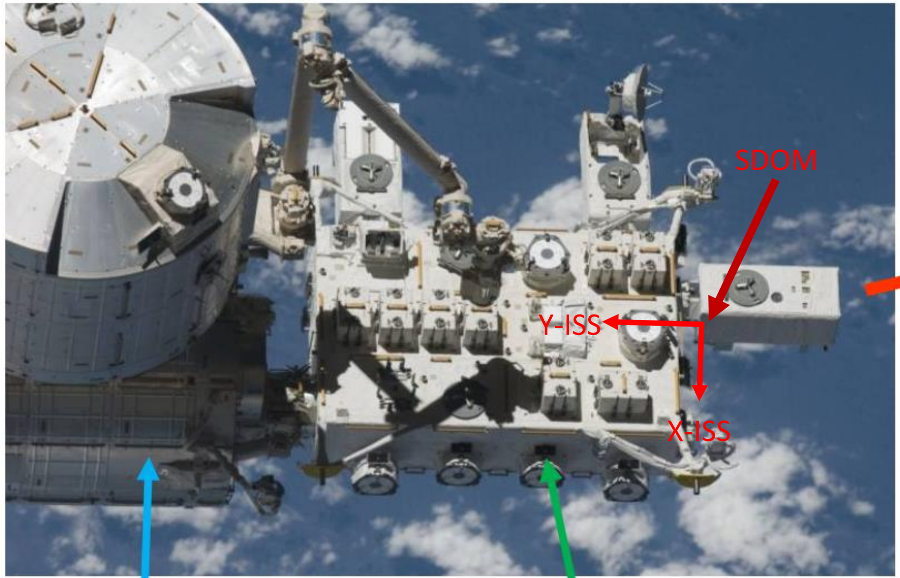
JEM: 11.2L*4.4D (m)
EF: 4.0L*5.6W*5.0H (m)
SEDA-AP: 1.8L*1.0W*0.8H (m)



[Abston 2014]

Picture provided by L. Abston (NASA LaRC). ISS radiation shielding CAD model created under NASA Advanced Exploration Systems (AES), Radiation Sensor and Monitoring project, 2014

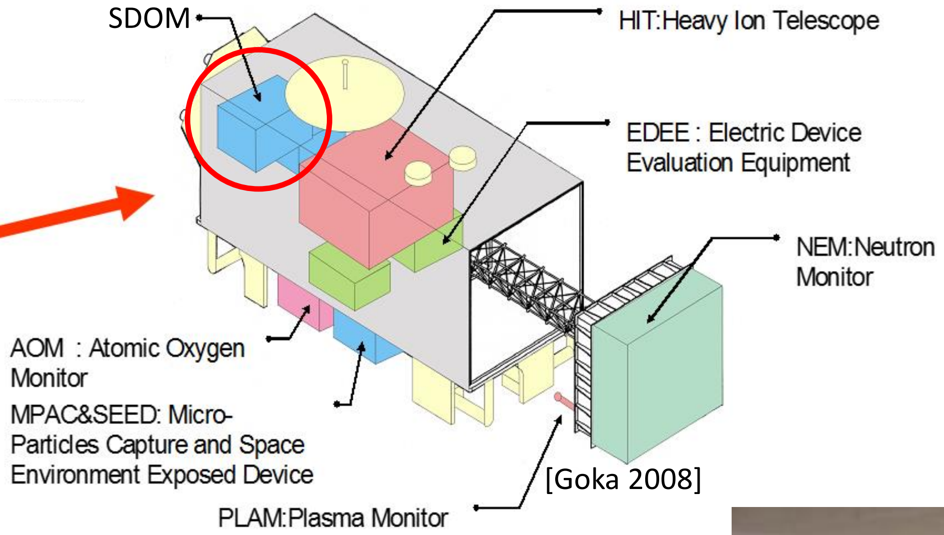
Japan Experimental Module (JEM: Kibo)



[Goka 2008]

Pressurized Module Exposed Facility

Space Environment Data Acquisition Equipment – Attached Payload (SEDA-AP)



[Goka 2008]

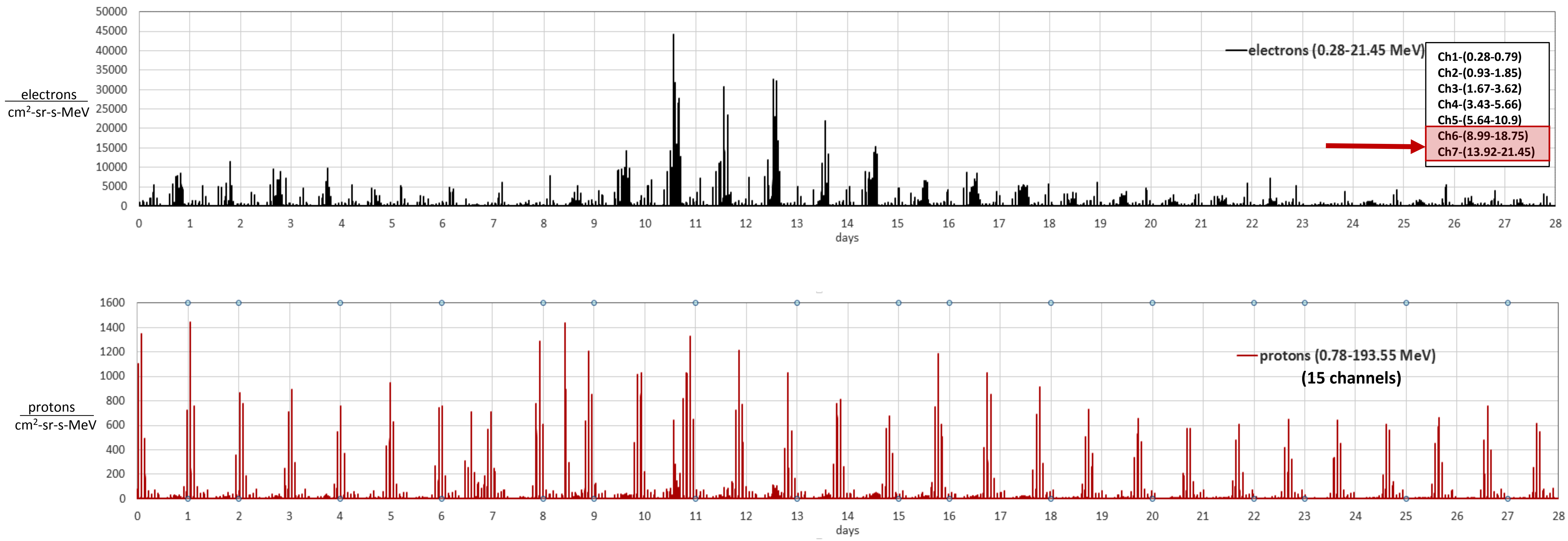
SDOM

[Matsumoto 2001]

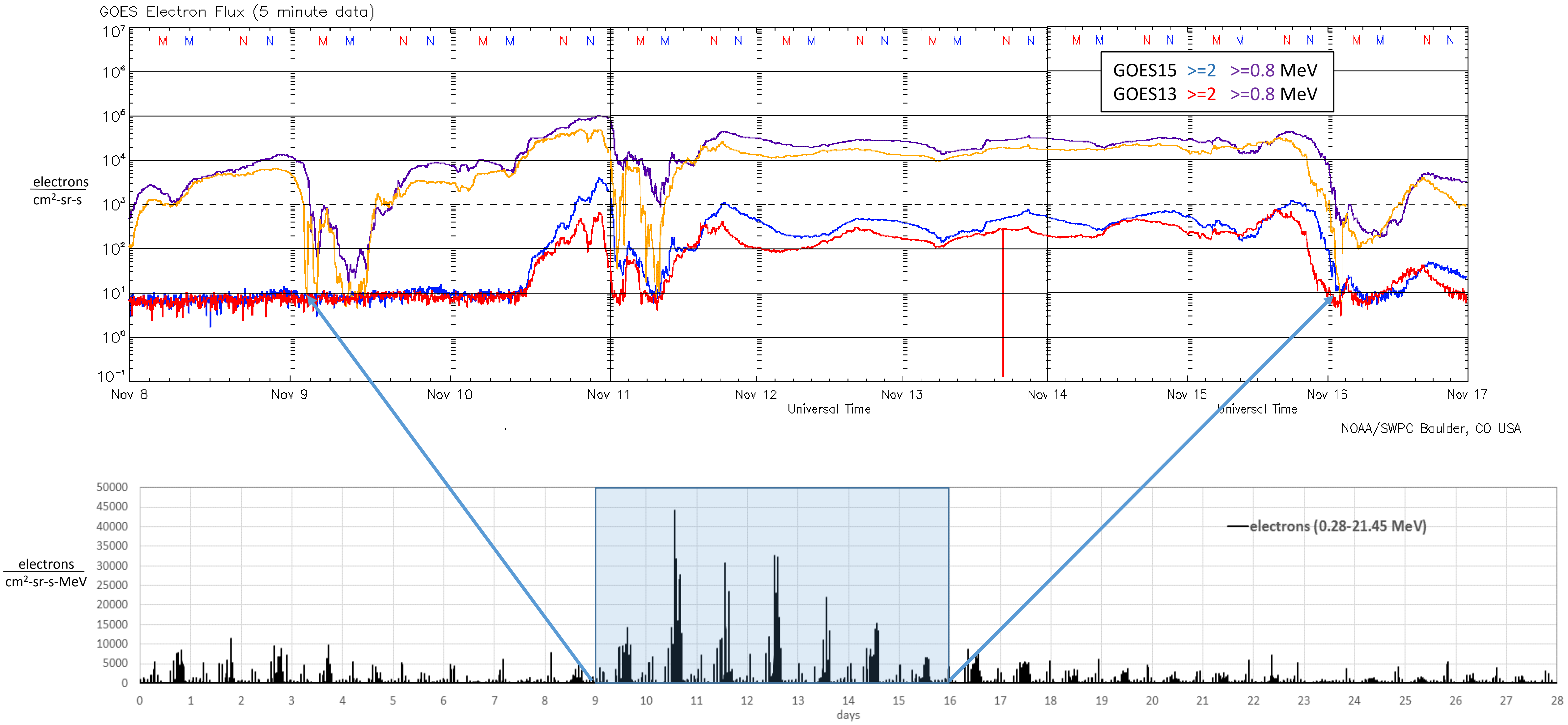
Picture provided K. Goka, Initial results from the space environment data acquisition equipment on board the international space station, RASEDA 12/17, 2008

Picture provide by H. Matsumoto, Compact, lightweight spectrometer for energetic particles, IEEE Trans. on Nuc. Sci., v. 48, 2001

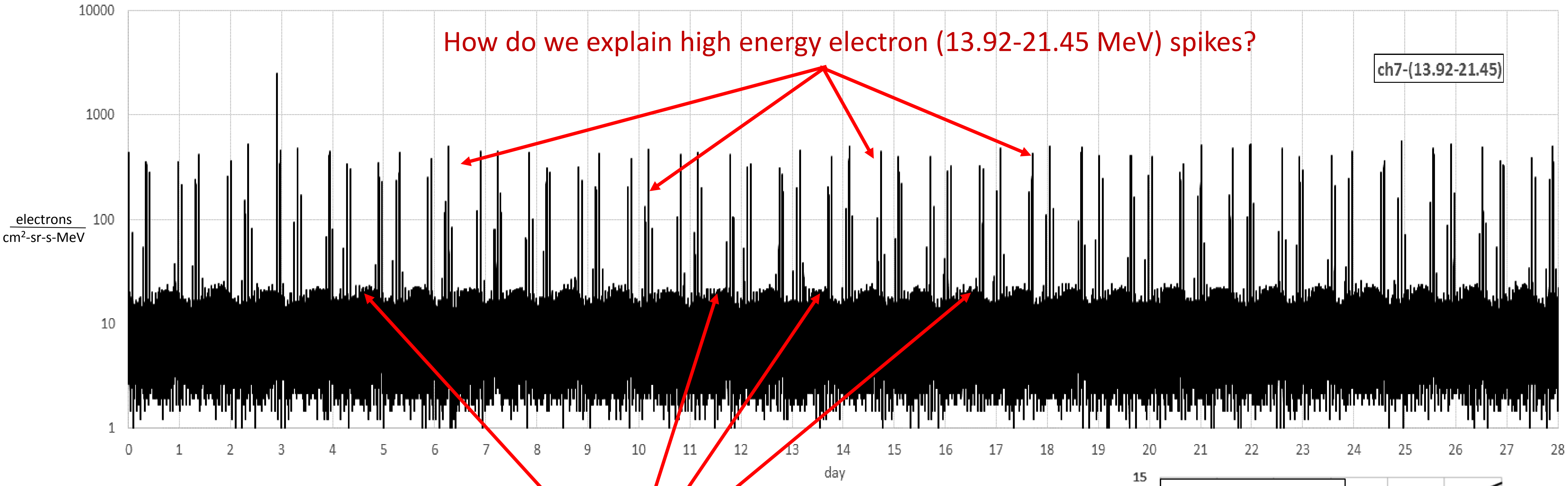
November 1-28, 2013 SDOM measurement of electrons/protons



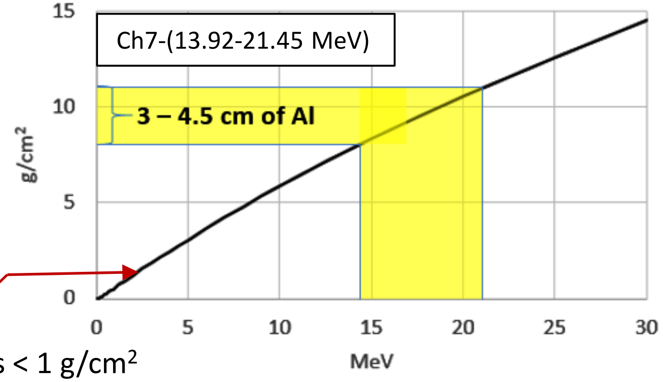
November 8-17, 2013 GOES 13/15 electron measurement



November 1-28, 2013 SDOM electrons from channel 7

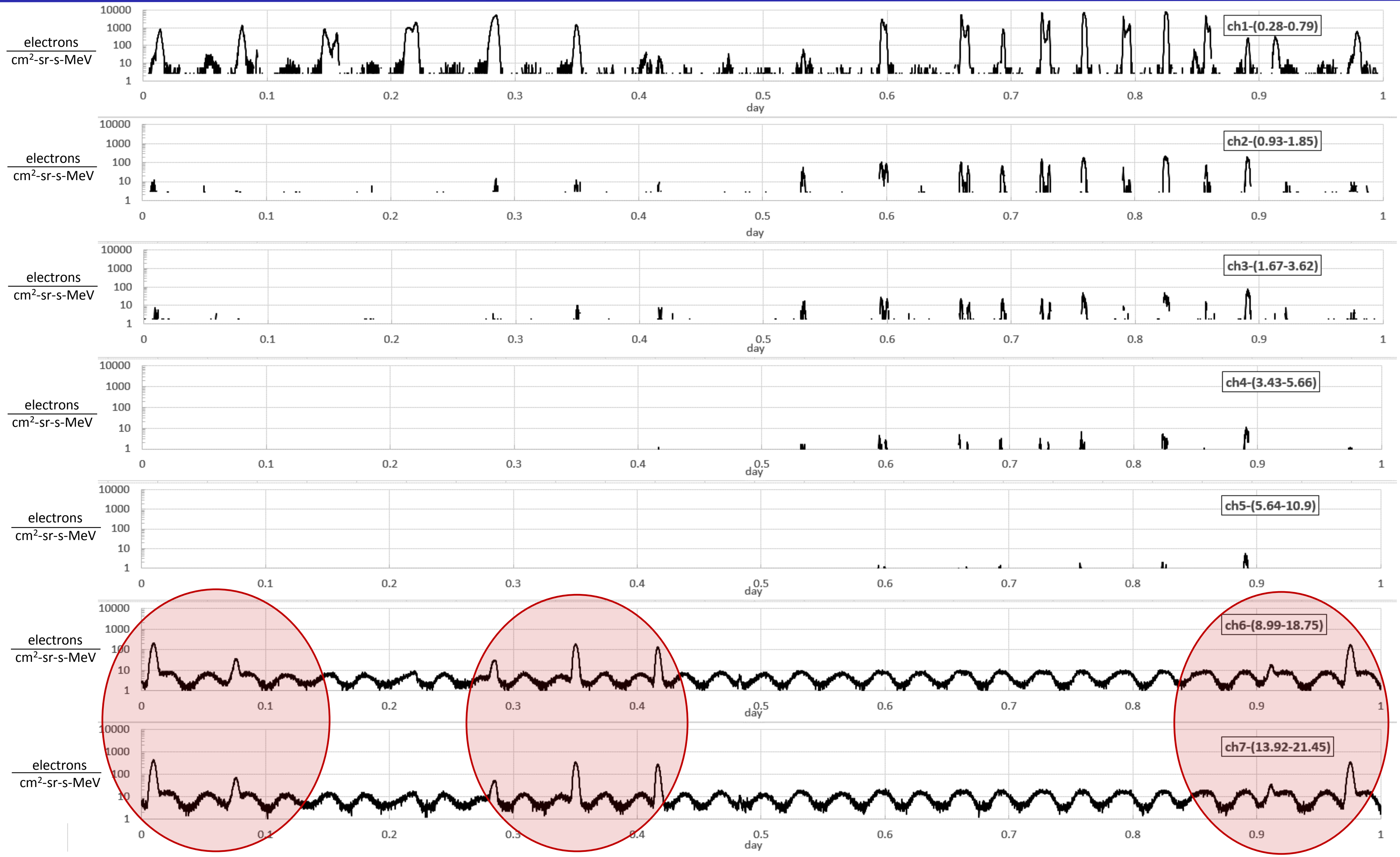


Inside/outside SAA, latitude dependent (-51.6˚ ~ +51.6˚) sinusoidal variation of electron flux is modulated by the cosmic rays cutoff rigidity envelope



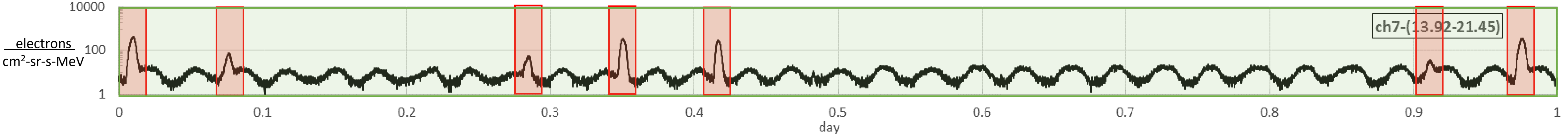
ave. spacesuit thickness < 1 g/cm²

November 1, 2013 SDOM electrons from channels 1-7



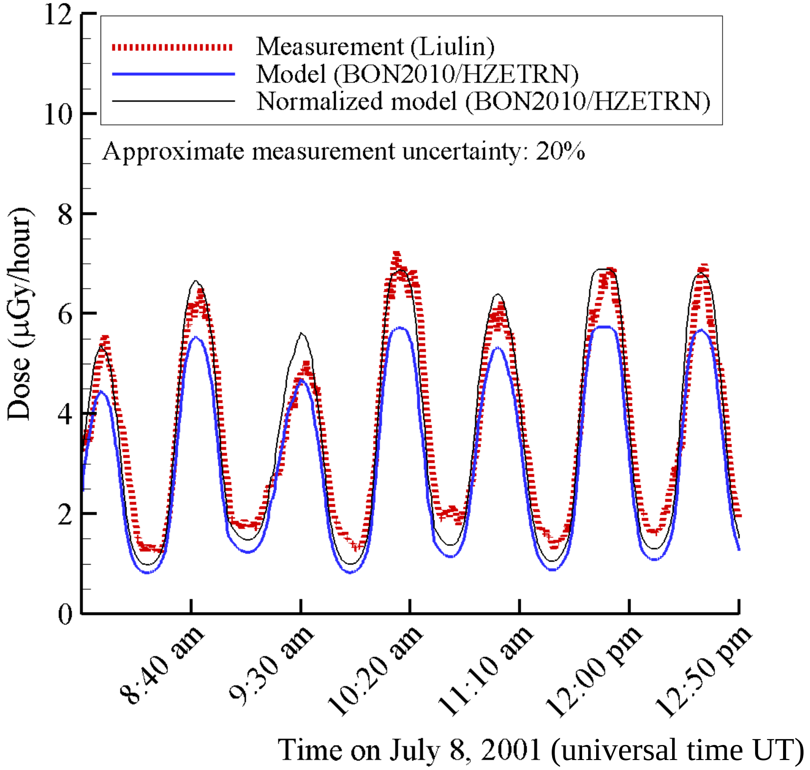
Implication of high energy electron production inside/outside SAA at ISS altitude

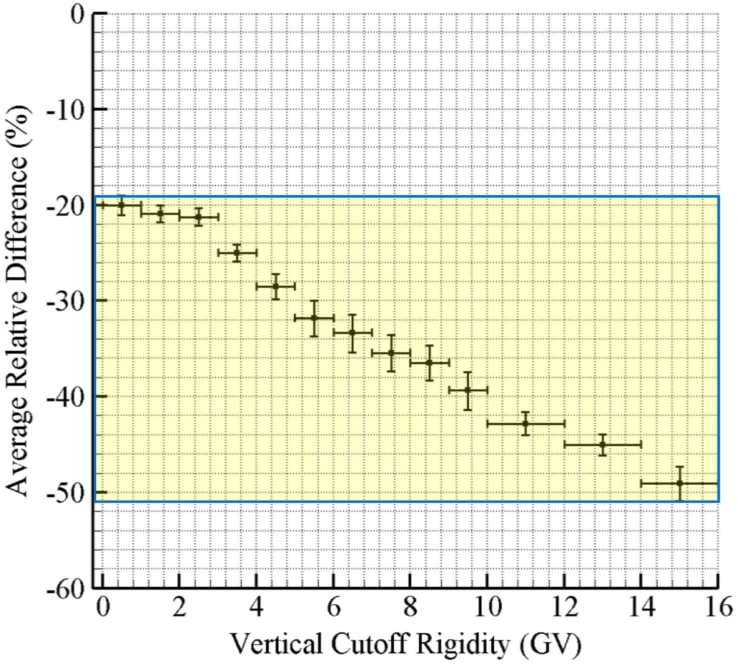
- During SAA passes, due to potential exposure by trapped protons, ISS mission planners **do not allow** Extra Vehicular Activity (EVA) for the crew
- Inside SAA, cosmic rays produced electrons can contribute to the crew exposure during EVA as well. However, since the crew can't perform EVA, the dosimetric contribution of electrons can be ignored
- Outside SAA, EVA is allowed and cosmic rays produced electrons contribute to the crew exposure during EVA. This region must be included in the estimation of exposure for the crew



Prior statistical validation

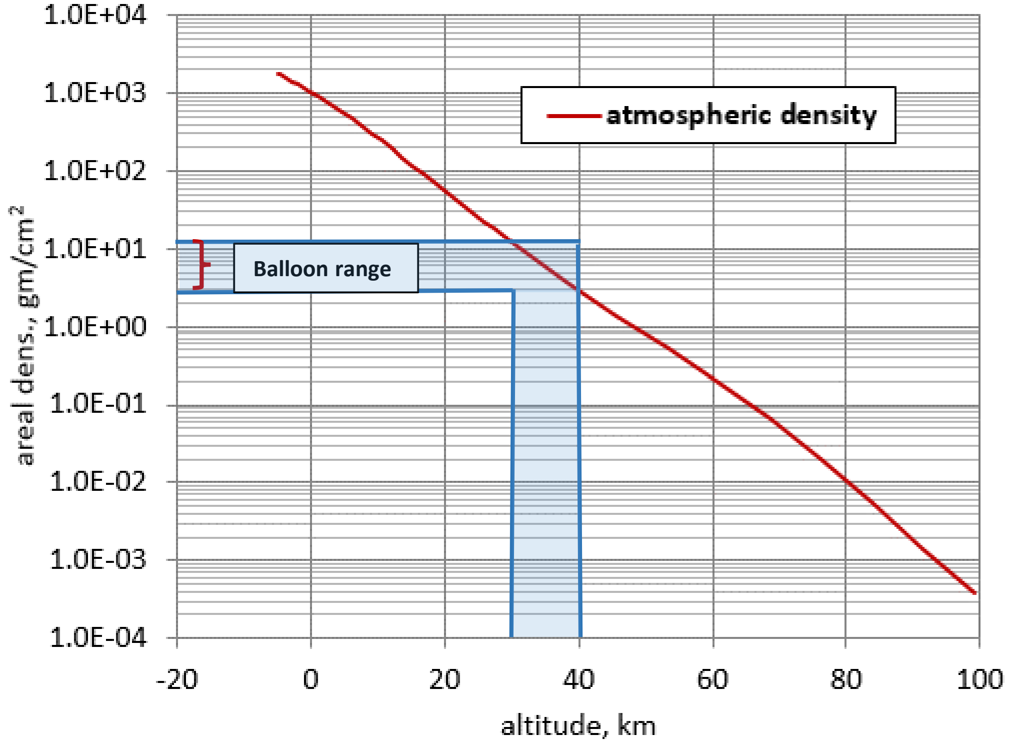
- End-to-end model results show systematic under-prediction at all cutoff rigidities and especially at high cutoff rigidity in the equatorial region
- Under-prediction is associated with environment models, geometry, nuclear physics, etc…

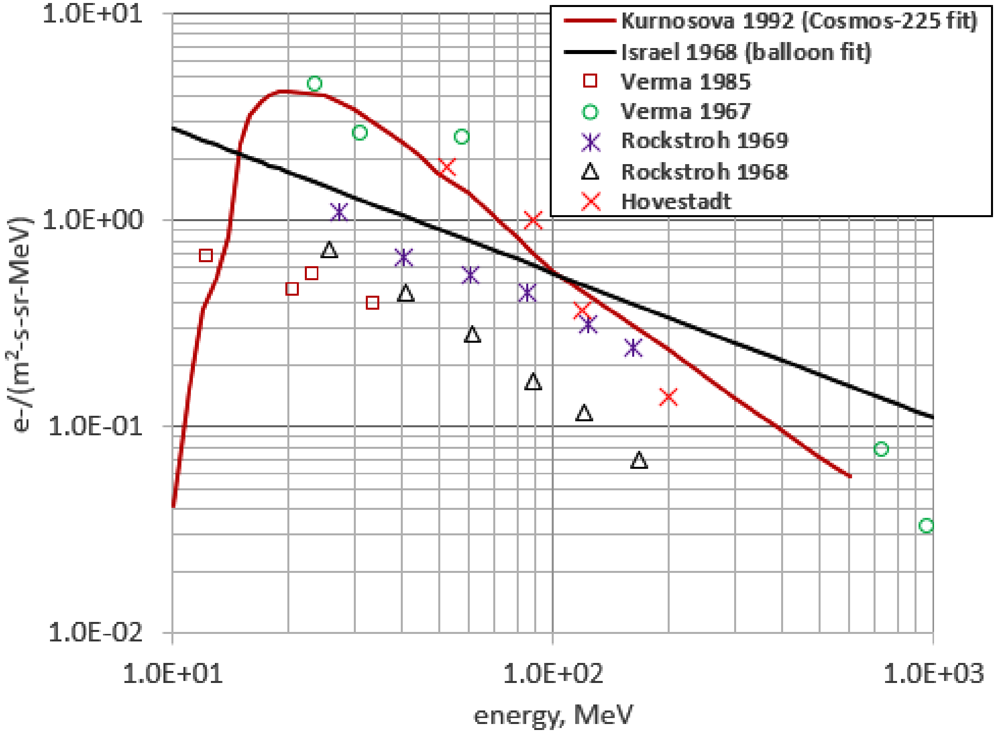




T. C. Slaba et al., Pion and electromagnetic contribution to dose : Comparisons of HZETRN to Monte Carlo results and ISS data. Adv. Space Res., v. 52, 2013

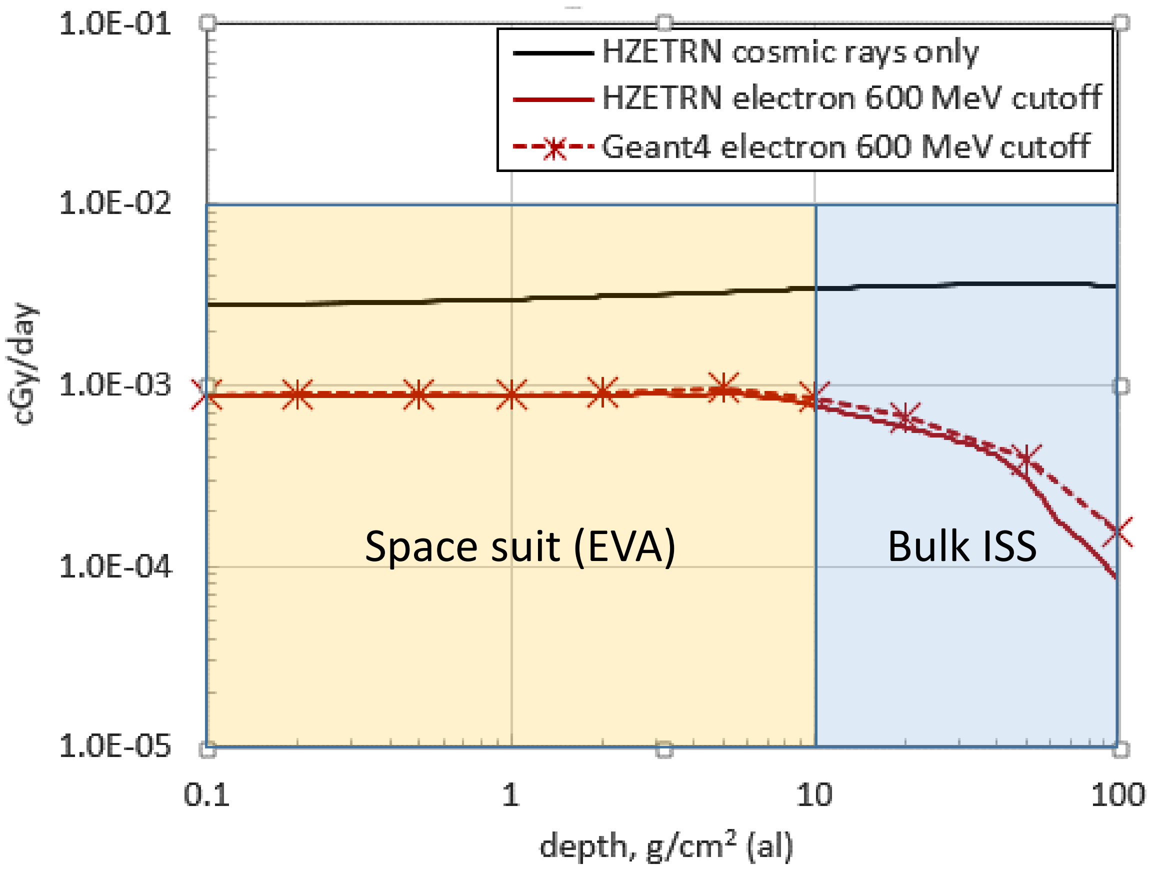
Albedo electrons dosimetric consideration

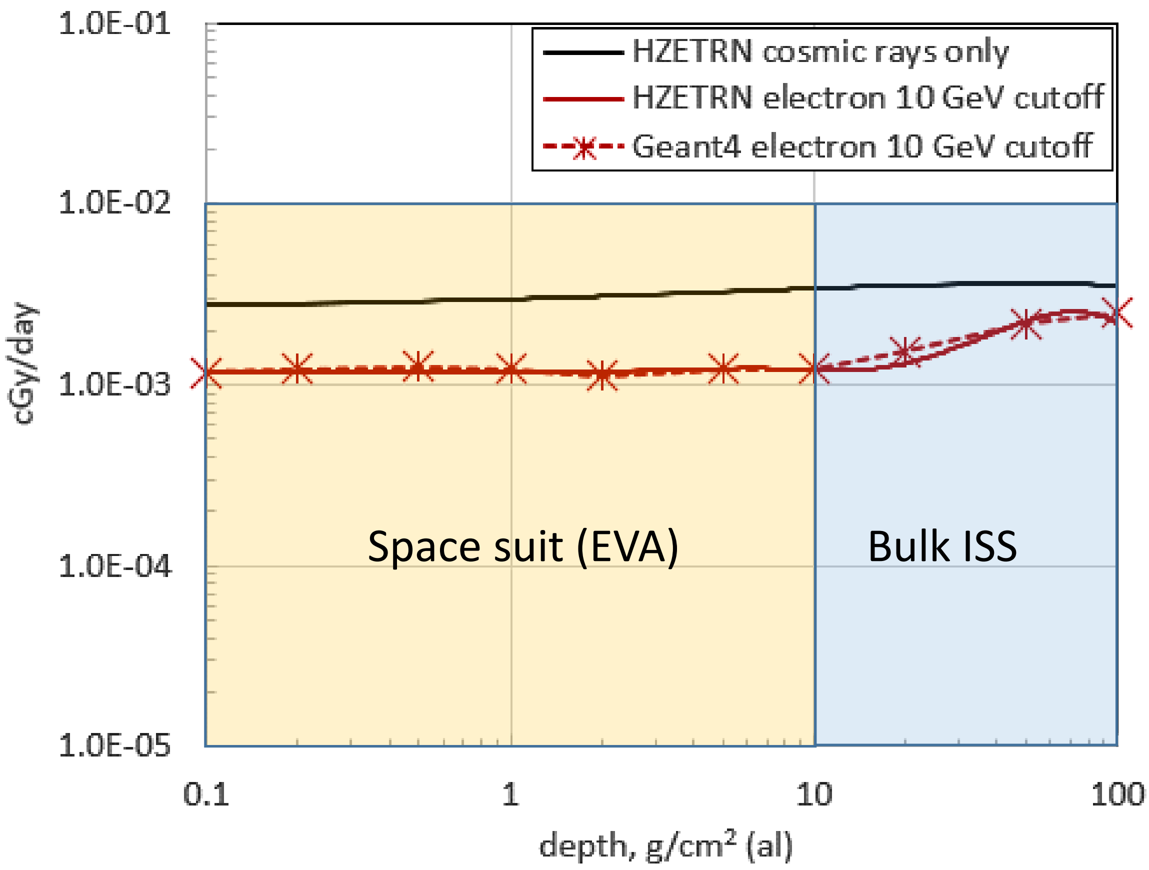




L.V. Kurnosova et al., Flux of electrons with energies above 100 MeV in the Earth's inner radiation belt, Cosmic Res., v. 29, 1992
M.H. Israel, Primary cosmic ray electrons and albedo electrons in 1967 at energies between 12 and 1000 MeV, PhD thesis, 1968
S.D. Verma et al., Observation of energy spectrum of electron albedo in low-latitude region at Hyderabad, India, Proc. 19th Int. Cosmic Ray Conf., 1985
S.D. Verma et al., Measurement of the charged splash and reentrant albedo of the cosmic radiation, J. Geophys. Res., v. 72, 1967
J. Rockstroh et al., A measurement of the spectrum of cosmic-ray electrons between 20 MeV and 3 BeV in 1968-Further evidence for extensive time variations of this component, J . Geophys Res., v. 74, 1969
D. Hovestadt et al., The energy spectrum of primary cosmic ray electrons from 20 MeV to 20 GeV in 1968 and 1969, Astrophys. Lett., v. 9, 1971

Albedo electrons dosimetric consideration





HZETRN:
J.W. Wilson et al., Transport methods and interactions for space radiations, NASA RP 1257, 1991
T.C. Slaba et al., Faster and more Accurate Transport Procedures for HZETRN. Journal of Computational Physics, v. 229, 2010a
T.C. Slaba et al., Coupled Neutron Transport for HZETRN. Radiation Measurements, v. 45, 2010b
R.B. Norman et al., An Extension of HZETRN for Cosmic Ray Initiated Electromagnetic Cascades. Advances in Space Research, v. 51, 2013

Geant4:
S. Agostinelli et al., Geant4--a simulation toolkit. Nucl. Instrum. & Methods A 506: 250-303, 2003

Scenarios for high energy electron production

Where do the SDOM high energy electrons (channels 6/7) inside/outside SAA come from?

Physics that we know since 1950s [Fazzini]:

- Target nuclei are available in the upper atmosphere
- Pion production is through strong force. The subsequent pion/muon decays are through electro-weak force

286.52 MeV $\rightarrow$ $p + n \rightarrow \pi^- + X$ (inclusive reaction)

$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu$$

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$$

- Above reactions apply to both inside/outside SAA
- We must still figure out the mechanism for production of high energy electron spikes inside SAA

T. Fazzini et al., Electron decay of the pion, Physical Rev. Lett., v. 1, 1958

Scenarios for high energy electron production

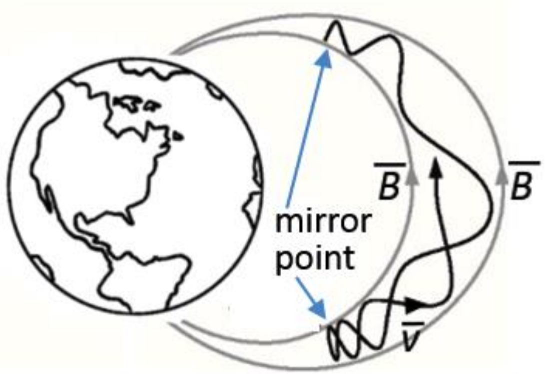
Inside/outside SAA

- Cosmic rays collision with upper atmosphere creates albedo electrons (previous slide)

Inside SAA (a possible scenario)

$$\boxed{r_g \propto \frac{E_{albedo}}{B}}$$

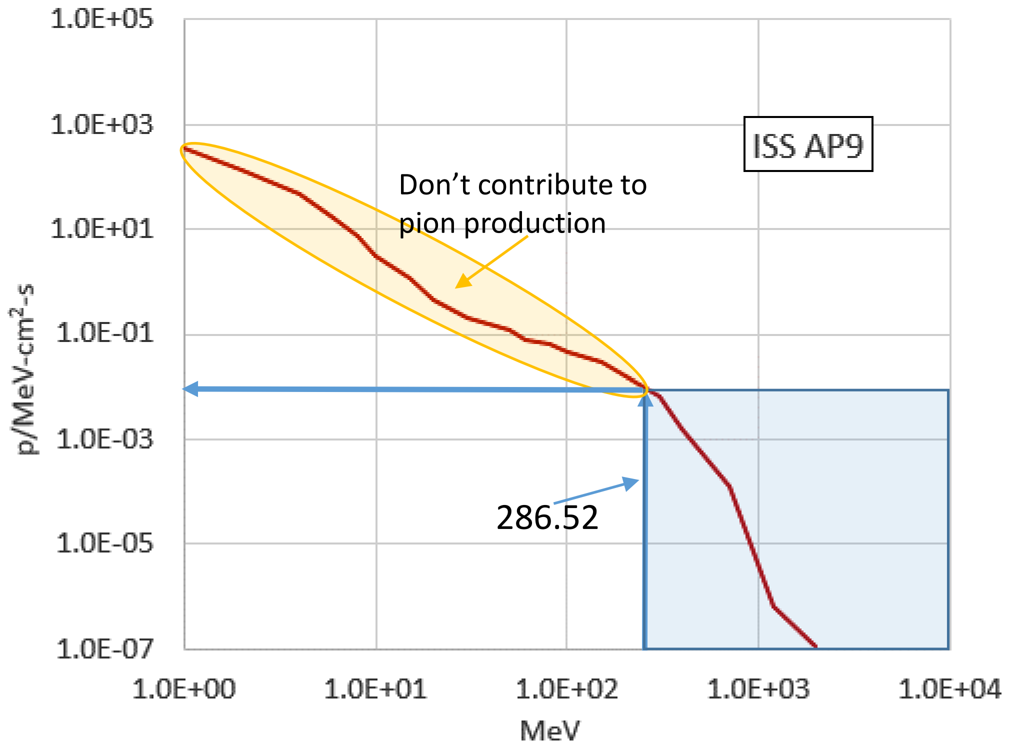
$$\boxed{\frac{r_{g,e}}{r_{g,p}} \approx \sqrt{\frac{m_e}{m_p}} = \frac{1}{43} \Rightarrow r_{g,e} << r_{g,p}}$$



- Within SAA, due to a very large r_g, albedo electrons have a much wider envelop of gyration. This wider envelope allows SDOM channels 6/7 to spend a much longer time being exposed to albedo electrons

What about the contribution of trapped protons to high energy electron production in SDOM channels 6/7?

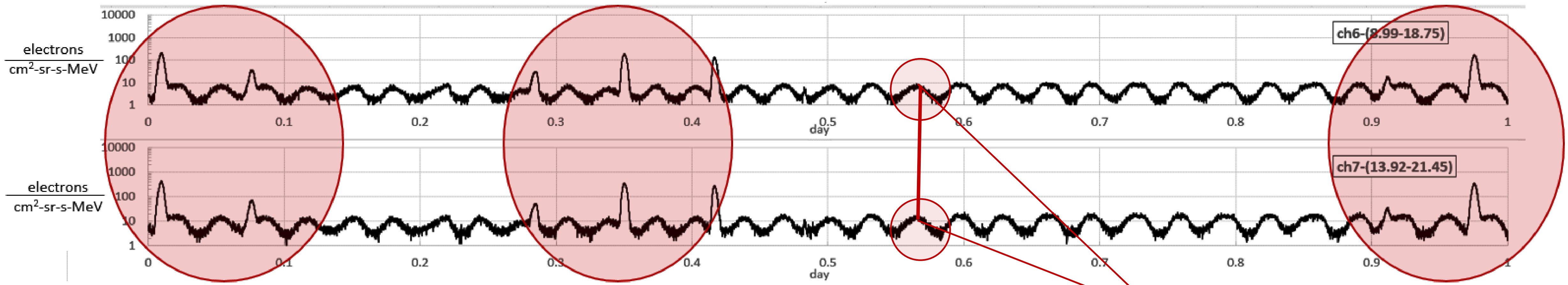
About trapped proton contribution to electron production

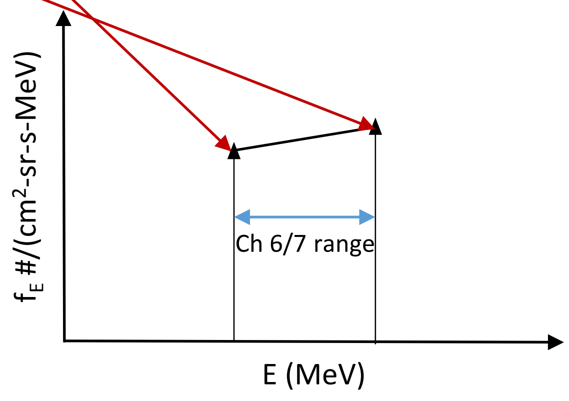


Reaction	$KE_{threshold}$ (MeV)
$p + n \rightarrow \pi^- + X$ ←	286.52 MeV
$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$	
$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$	

In SAA, the probability of high energy electron production using trapped protons as source is very low because a minimum trapped proton threshold energy of 286.52 MeV is required

How can we improve the validation work?





- For electron transport, we need to extract a detailed electron spectrum from SDOM electron measurements. Currently SDOM provides us with two points only (a flat spectrum)
- SDOM ch7 is limited to E < 21.45 MeV. We have to combine SDOM spectrum with other electron detector spectra to build a spectrum up to at least 1 GeV
- To construct a 1 GeV spectrum, we have to consider the possibility of combining balloon measurements with very limited satellite measurements

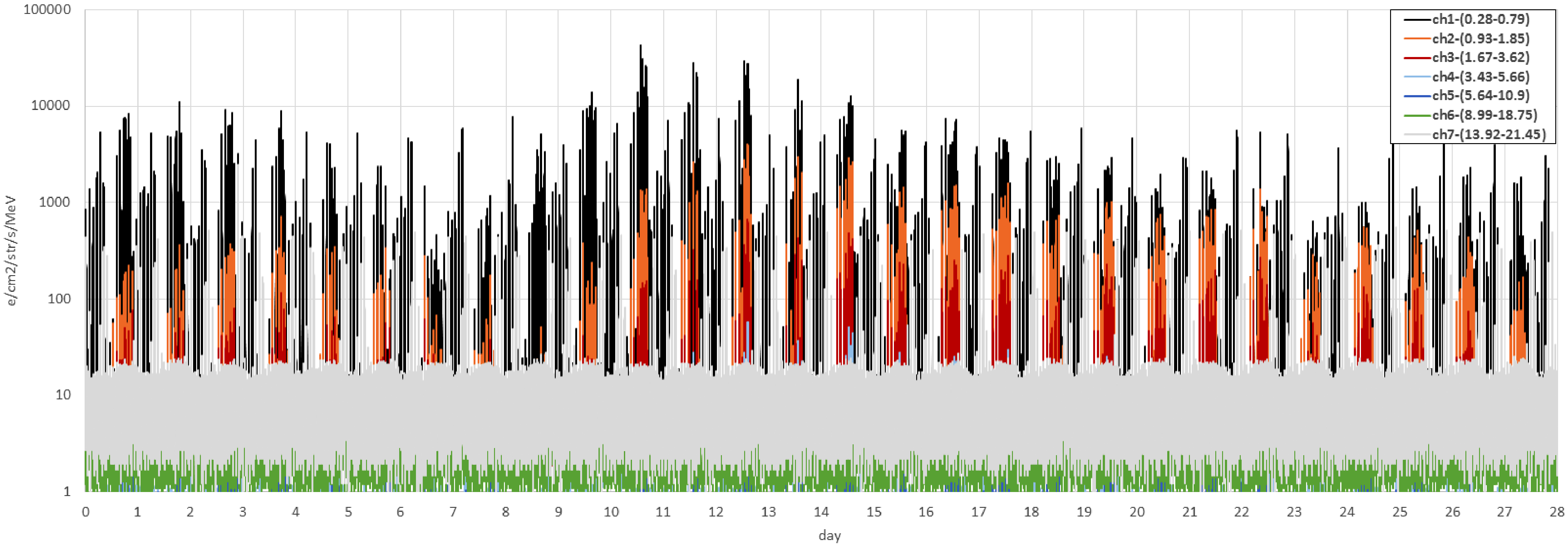
- Must explore the possibility of proton contamination of electrons

Summary

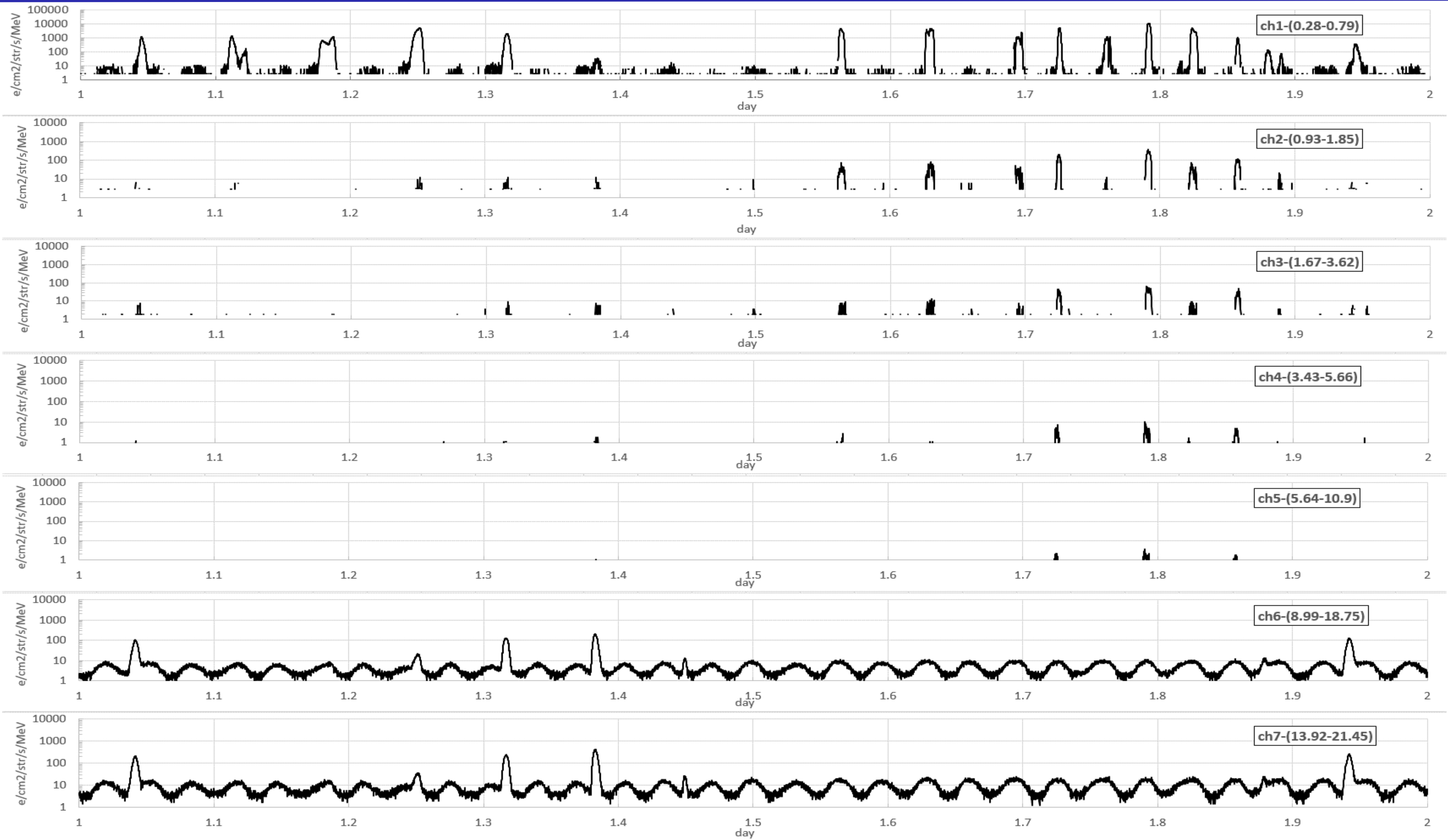
- Provided background on JEM, EF, SEDA-AP and SDOM
- Reviewed November 2013 electron measurements by SDOM and electron correlation with GOES 13/15 satellites measurements
- Discussed SDOM individual electron channels data and specifically high energy electron channels 6/7
- For ISS inside/outside SAA, discussed the scenarios for cosmic rays electrons production and their implications during crew EVA activity
- Provided potential justification for underestimation of prior validation work and the recommendation that albedo particles (p/e^-) must be accounted for in future validation work
- Reviewed what addition measurements are needed
- Discussed possible future direction for this activity

Backups

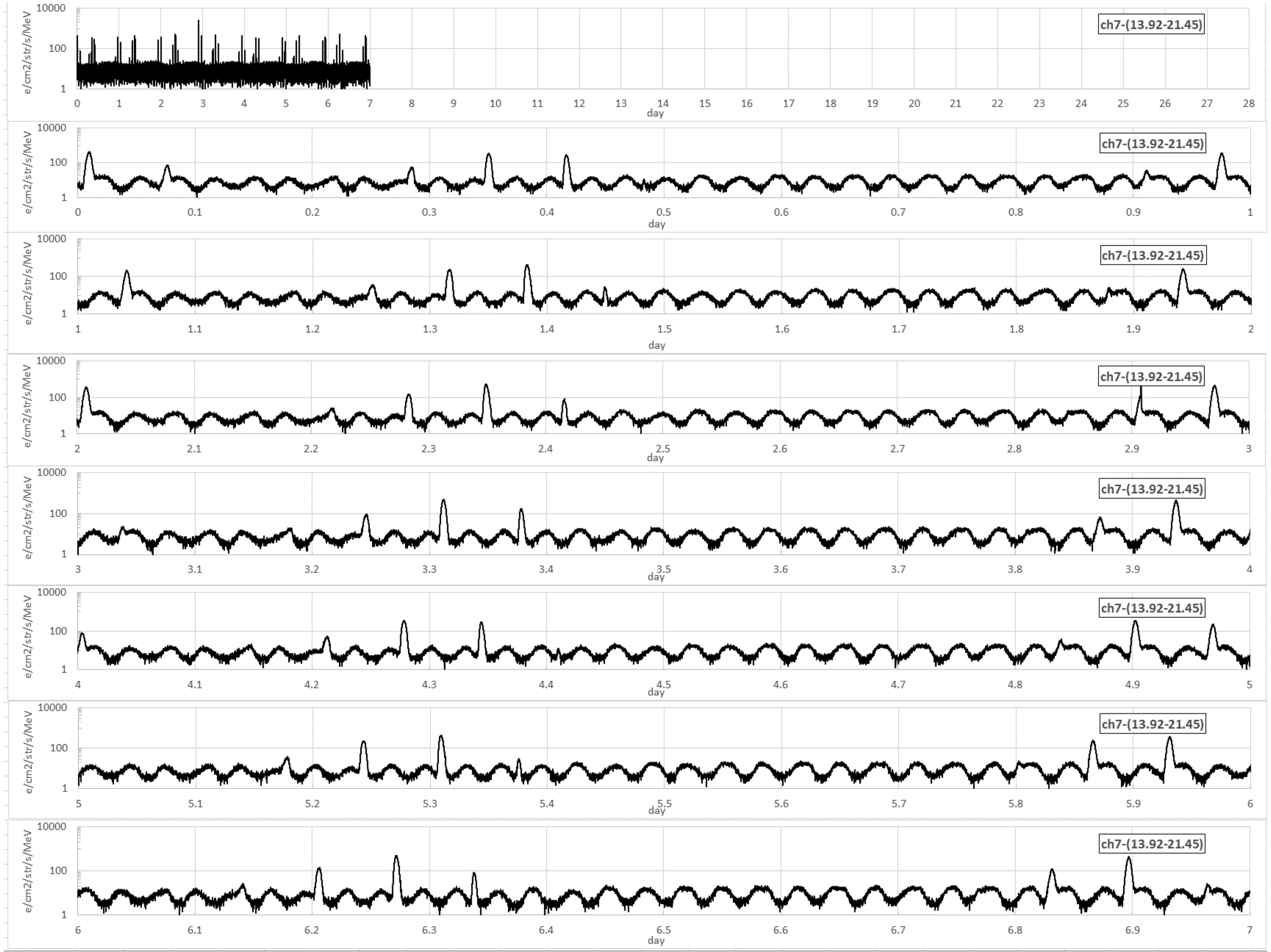
November 2013 SDOM individual electron channels



November 2, 2013 SDOM electrons from channels 1-7

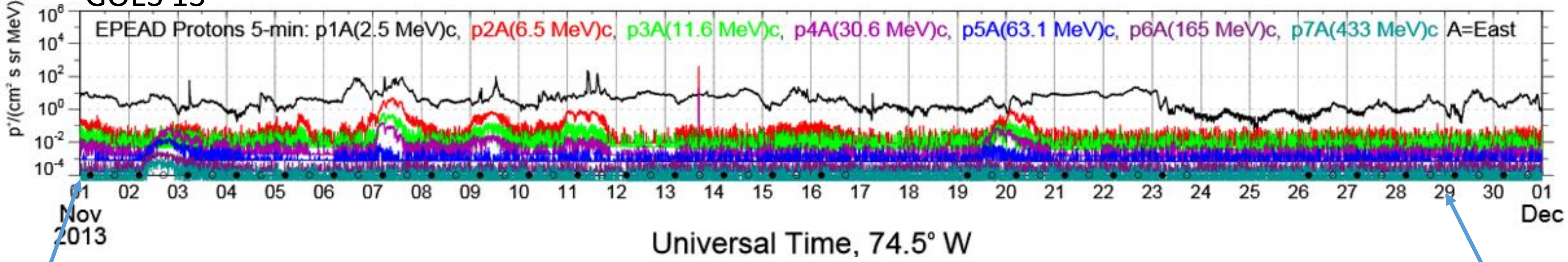


November 1-7, 2013 SDOM electrons from channel 7

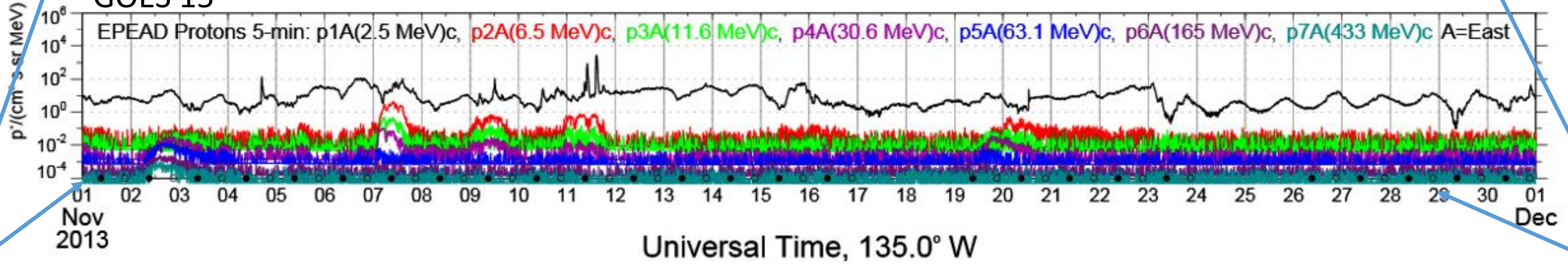


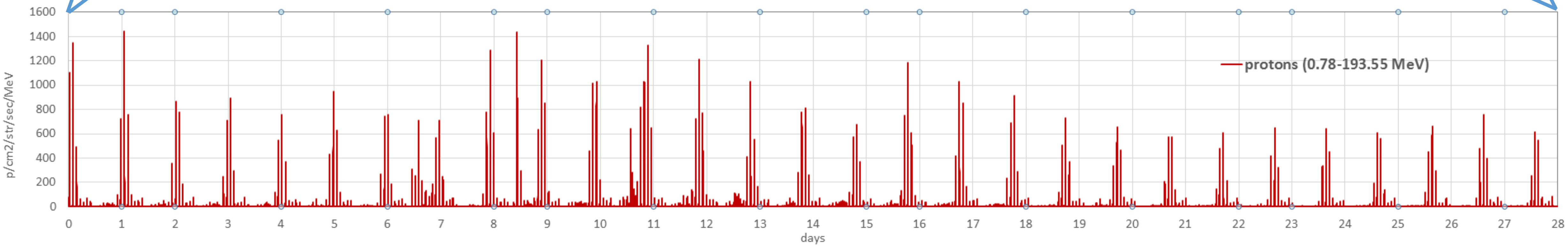
November 1-30, 2013 NOAA GOES 13/15 protons

GOES 13

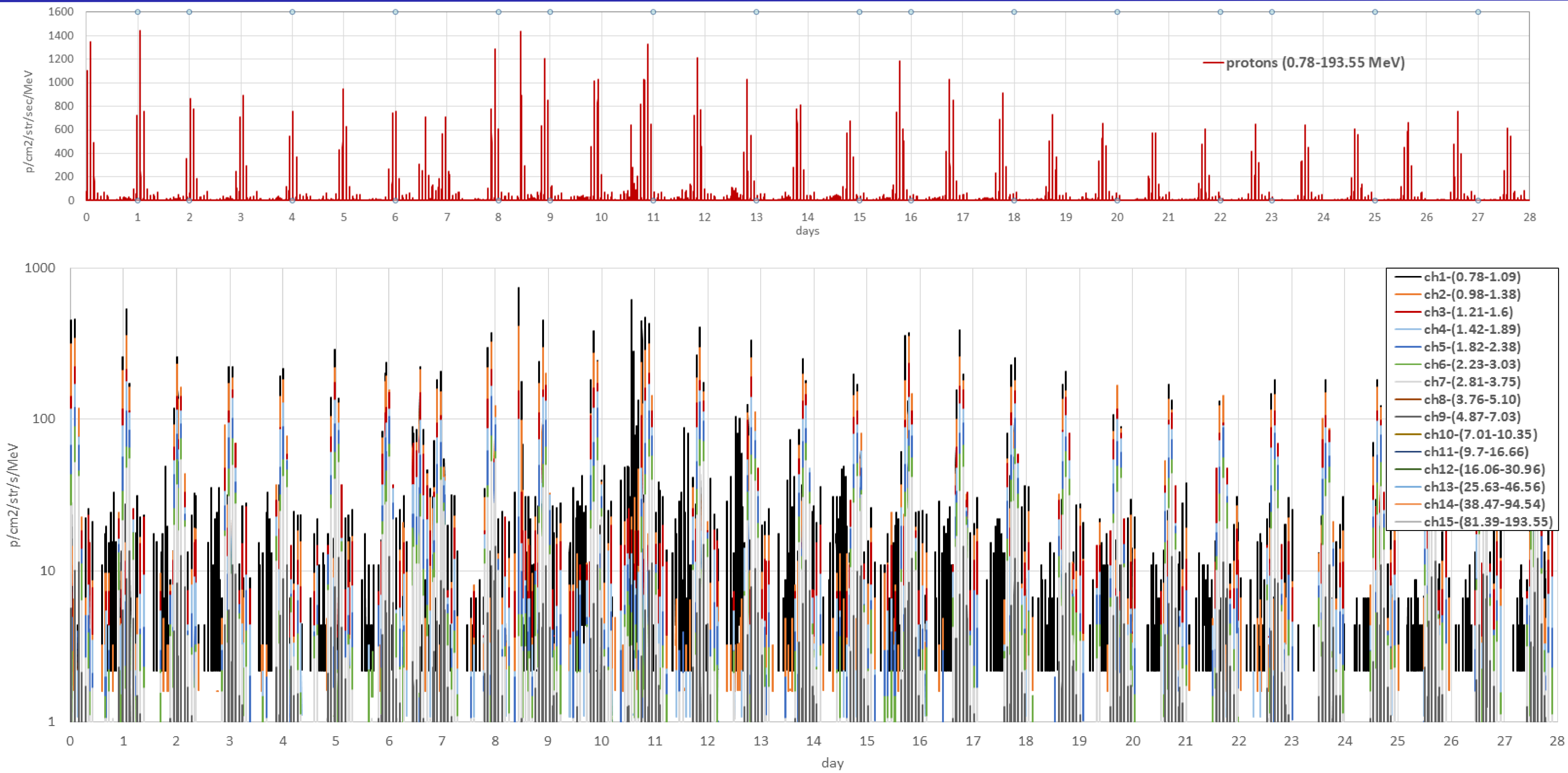


GOES 15

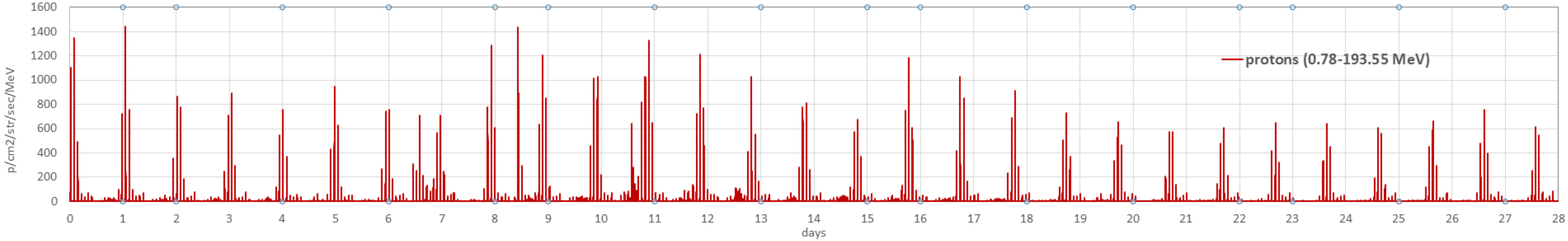


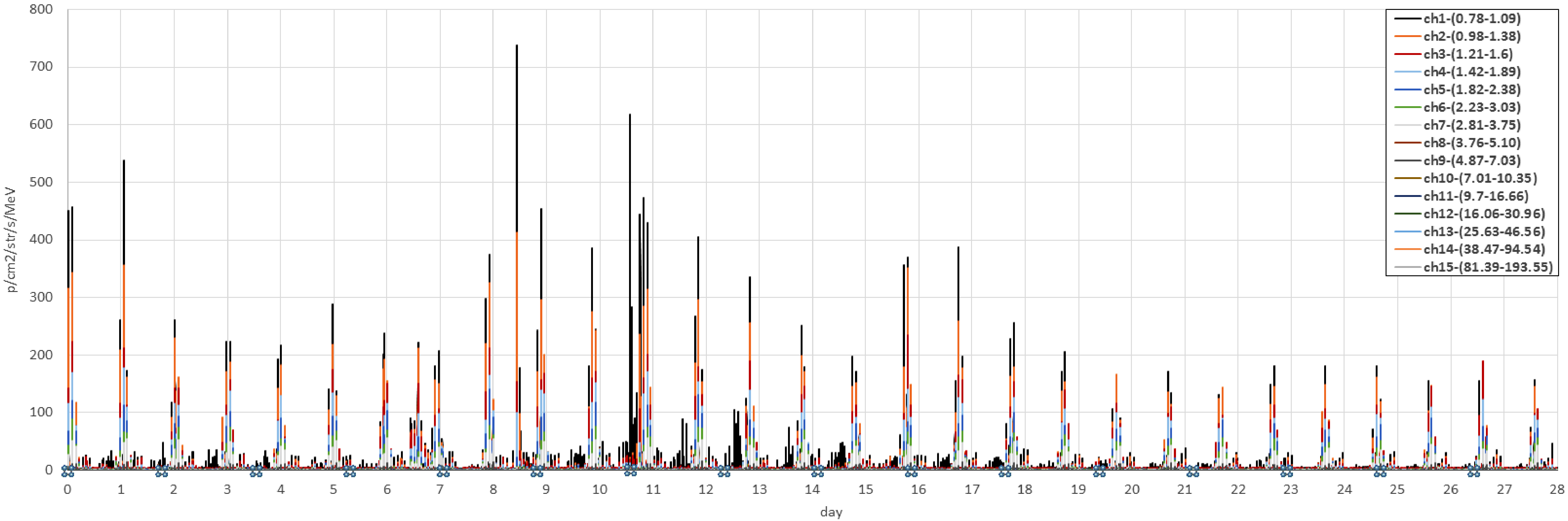


November 1-28, 2013 SDOM protons from channels 1-15

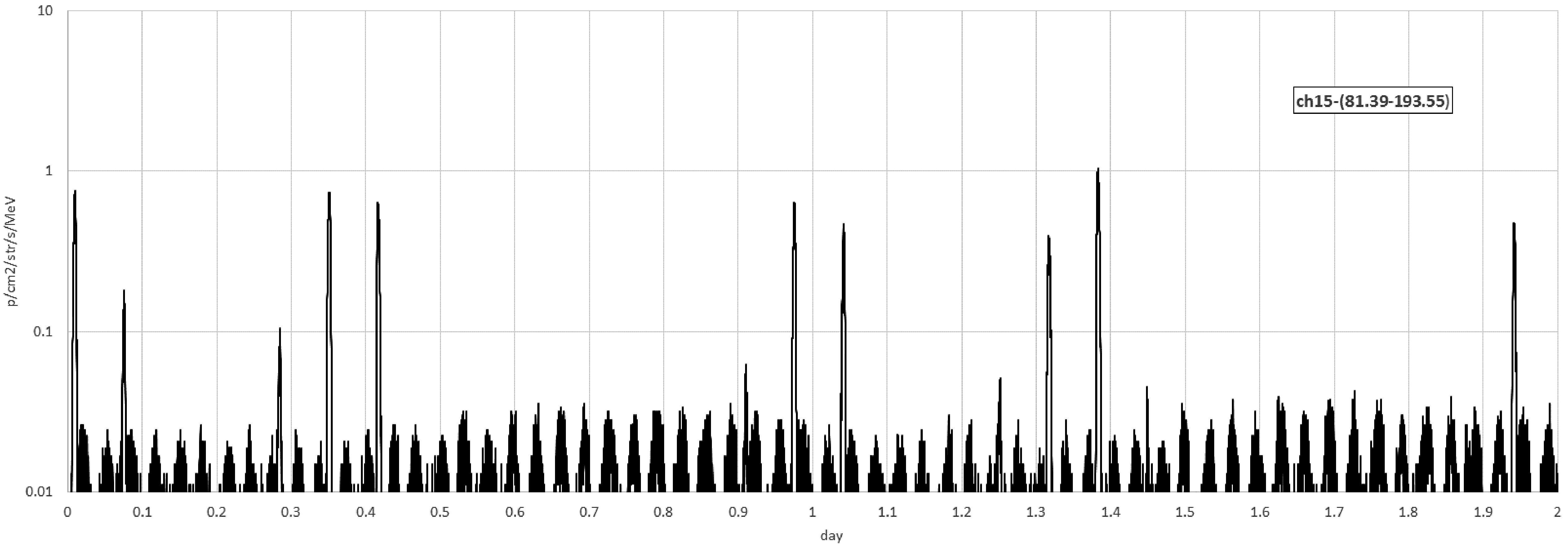


November 1-28, 2013 SDOM protons from channels 1-15





November 1-2, 2013 SDOM protons from channel 15



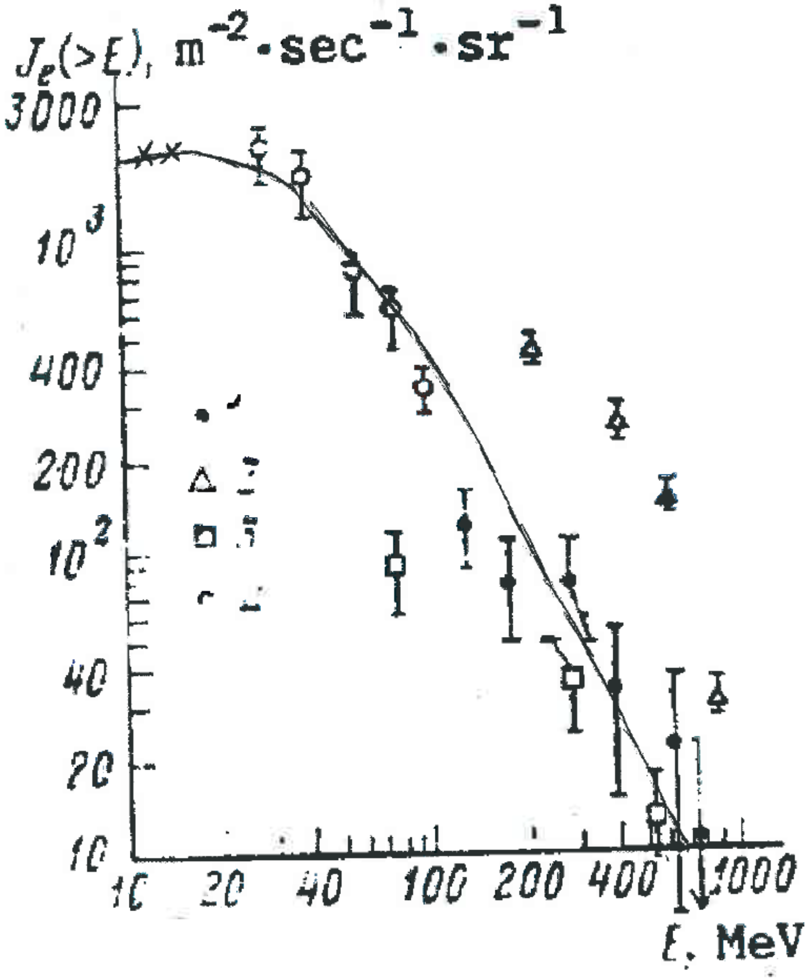
Cosmos 225 measurement

FLUX OF ELECTRONS WITH ENERGIES ABOVE
100 MeV IN THE EARTH'S INNER RADIATION BELTS

L. V. Kurnosova, L. A. Razorenov, and
M. I. Fradkin

UDC 523.037:525.7

Results are presented from measurements of the flux of electrons with E_e > 100 MeV in the Brazilian anomaly region for 15 satellite passes. Results are compared to measurements carried out outside the anomaly at similar magnetic rigidities. No significant differences are found between the fluxes of albedo and captured (quasi-captured) electrons in the two regions. The measured fluxes are then compared to the state of the magnetosphere: A tendency is noted toward increase in electron flux during a period of magnetospheric disturbance. This may explain the divergence in results published by various authors.



Reaction channels

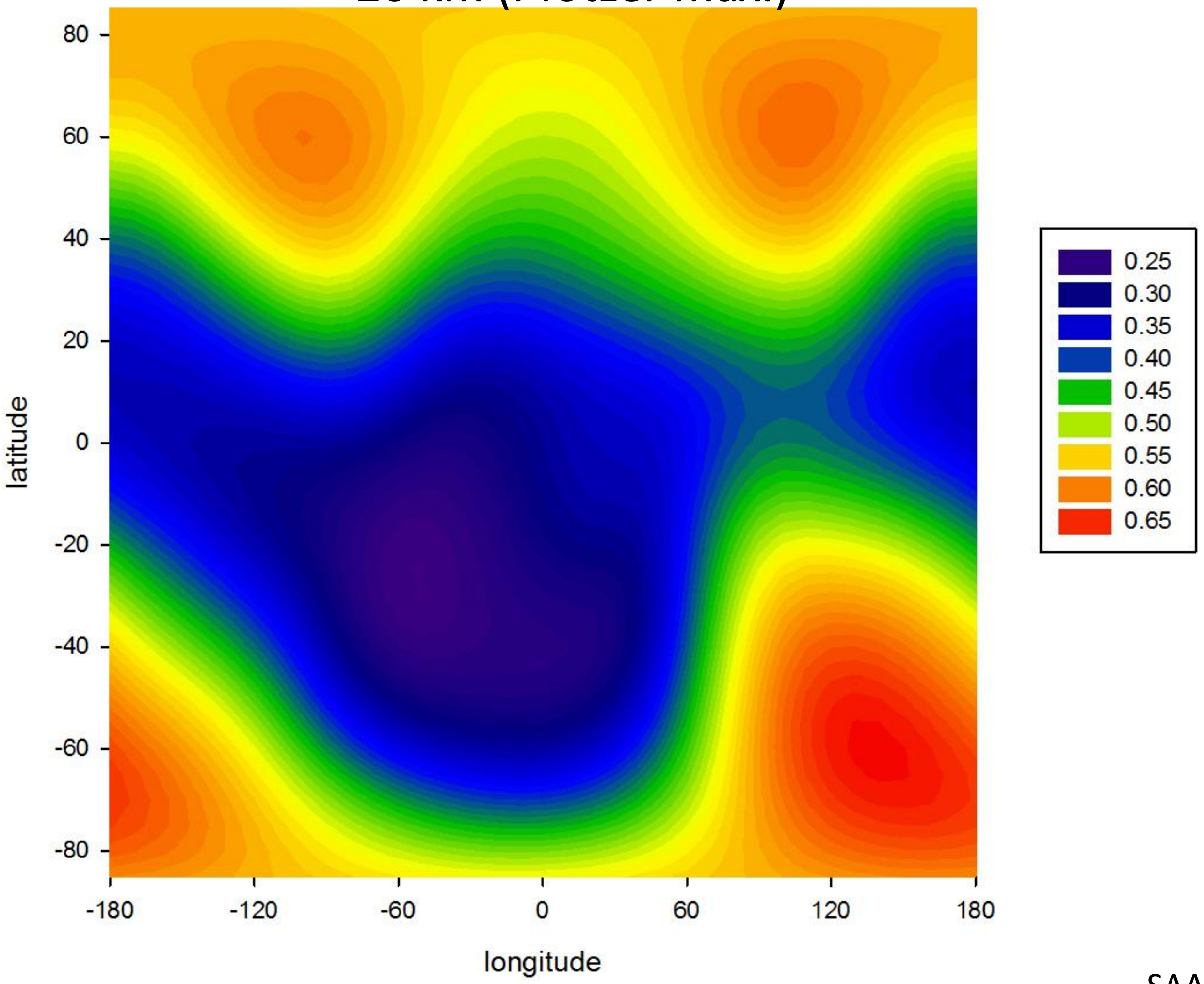
Table 5. The m_X for Minimum Threshold Particle Reactions† Occurring via the Strong Interaction

Reaction $A + B \rightarrow C + X$		$KE_{1\ lab}$	$p_{1\ lab}$	$\sqrt{s}$	m_X
$\boxed{p + p} \rightarrow$	$p + p$	0	0	1876.5	938.27
	$n + p + \pi^+$	292.31	796.23	2017.4	1077.8
	$\pi^0 + p + p$	279.67	776.55	2011.5	1876.5
	$\pi^+ + p + n$	292.31	796.23	2017.4	1877.8
	$\pi^- + d$	288.63	790.53	2015.7	1876.1
	$\pi^- + p + p + \pi^+$	599.8	1218.7	2155.7	2016.1
$n + n \rightarrow$	$p + n + \pi^-$	286.71	788.02	2017.4	1079.1
	$n + n$	0	0	1879.1	939.57
	$\pi^0 + n + n$	279.66	776.99	2014.1	1879.1
	$\pi^+ + \pi^- + n + n$	599.75	1219.3	2158.3	2018.7
	$\pi^- + p + n$	286.71	788.02	2017.4	1877.8
	$\pi^- + d$	283.03	782.28	2015.7	1876.1
$\boxed{p + n} \rightarrow$	$p + n$	0	0	1877.8	939.57
	$n + p$	0	0	1877.8	938.27
	$\pi^0 + p + n$	279.47	776.23	2012.8	1877.8
	$\pi^0 + d$	275.8	770.46	2011.1	1876.1
	$\pi^+ + n + n$	292.11	795.91	2018.7	1879.1
	$\pi^- + p + p$	286.52	787.25	2016.1	1876.5

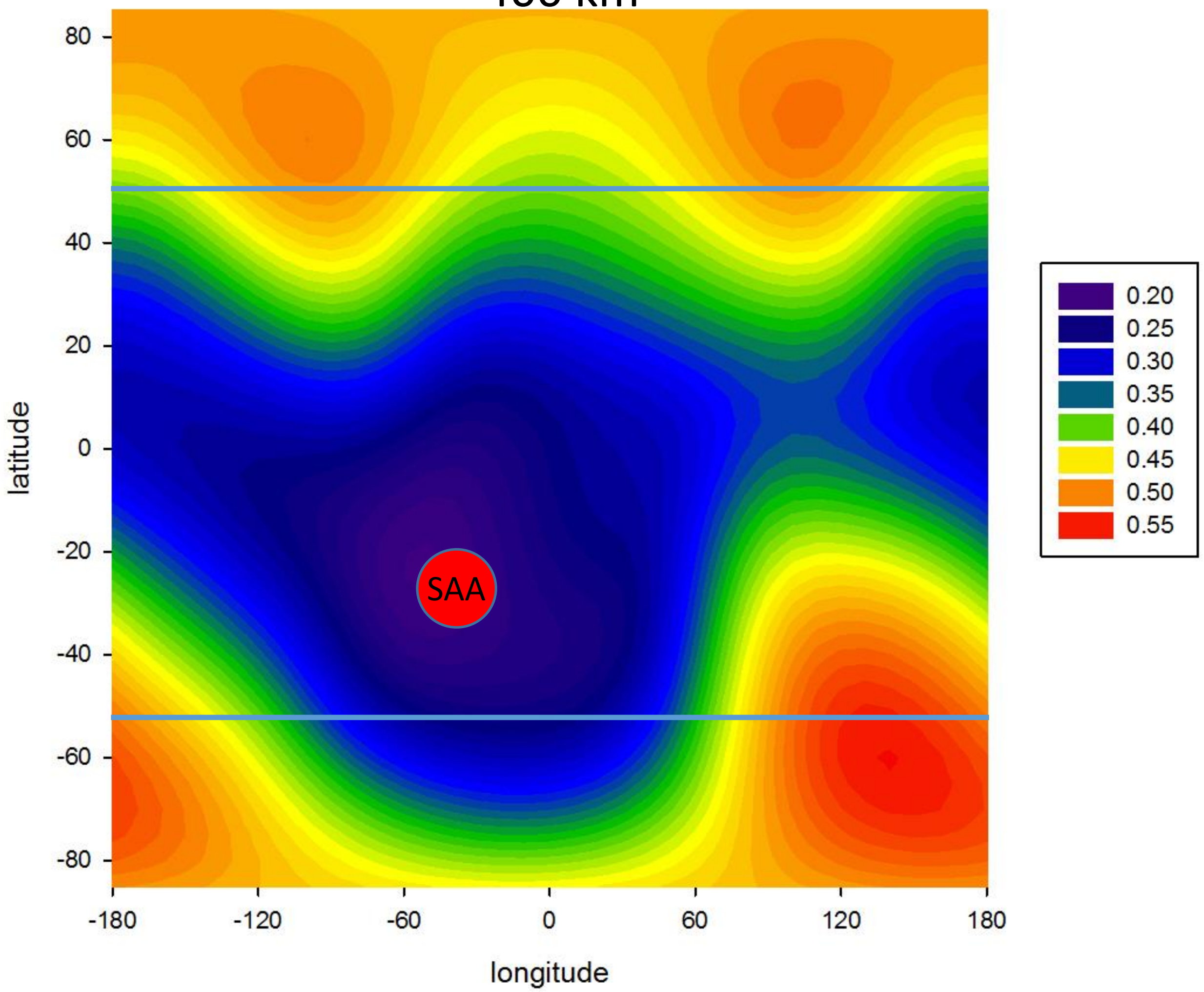
†Particle C is the produced particle of interest and is the first particle listed on the right-hand side of each reaction. Particles X are all the remaining particles; m_X is the sum of the masses of these remaining particles.

2013 global magnetic field (B) for IGRF 2010-2015

20 km (Pfotzer max.)



400 km



SAA

Standard DOse Monitor (SDOM) field of view

SDOM (Standard DOse Monitor) measures the energy Distribution of high-energy electrons, protons and Alpha particles