The energetic Solar Particle Events (SPEs) measured by ALTEA in the ISS during the ALTEA-shield experiment (2011-2012): first 1.5 years long study of SPE radiation inside a space habitat.

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- Quasi-linear relationship with GOES
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LIDAL

- Rationale
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- Conclusions

Why

• Forecasting SPE is a must, however:

- SPEs not only are sporadic, but also their features may significantly differ event by event
- Forecasting for deep space exploration IS DIFFERENT from forecasting for SEU (think about false negatives)

• Understanding the parameters of the SPE that produce events leading to higher health risks for the astronauts in deep space is a first priority issue

• In principle this can be simulated (several previous talks): from a set of realistic SPE spectra and a transport simulation inside the spacecraft/base we can study the “inside” radiation environment.

• This brings in two issues: the definition (and ‘usefulness’) of ‘a’ realistic spectrum and the understanding of the mass distribution (and its changes) to produce a meaningful transport simulation.

• Measurements of SPE effects with active devices inside the ISS can also be used for this purpose: they are less flexible, limited by detector performances and positions, but for certain they produce valid information for the specific SPEs measured, relative to the specific detector location in the ISS.

• Also, active detectors can select data from specific geo-magnetic regions along the orbits, mimicking deep space radiation

How

In principle the measurement should be performed with a detector able to follow in real time all the radiation dynamics, including ions (Z = 1 to 26) and neutrons (produced by the primary ions), at all energies.

Furthermore the detector should be placed in a position with known shielding, i.e. where we have a quantitative knowledge of the mass distribution around.

The two requirements above are never entirely fulfilled:

- Detectors have windows of acceptance (in particle kinds, kinetic energy, rate, energy transferred, etc.)

- The best we usually have is a *qualitative* knowledge of the mass distribution around and often even less information about daily changes[1,2,3].

1 Narici et al. J. Space Wea. and Space Clim. 5, A37 (2015)
2 Narici et al Radiat. Meas. 47:1030-1034 (2012)
3 Di Fino et al. Radiat Res. 176(3):397-406 (2011)

What ALTEA can offer

ALTEA (developed by ASI) is a detector system with tracing and spectrometric capability. From the point of view of this topic it offers:

- Real time operation
- Ability to select any specific geo-magnetic region
- Telescopes on the 3 directions (X Y Z), with single ion tracing capability
- 3.5 years of data, from 8/2006 to 9/2012 (not continuous)[1]
- Statistical nuclear discrimination for Z>3

But as mentioned before

- Reduced Z, Ek coverage

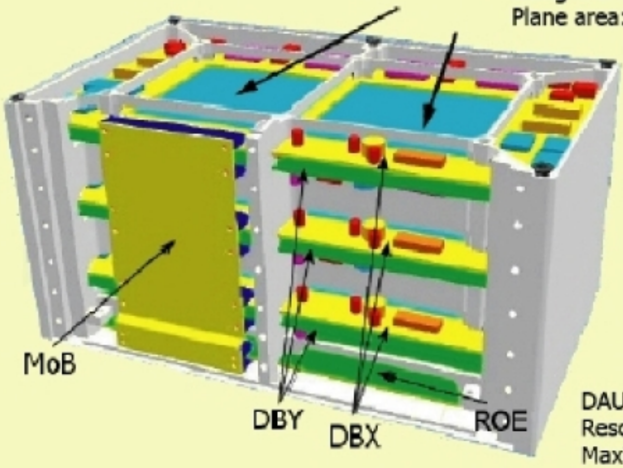
And during the measurements there has been

- Approximate knowledge of shielding (typical for ISS)

1 In this talk only the period 2010 – 2012 will be considered (ALTEA – shield, ESA sponsored program)

ALTEA characteristics

SDU: Silicon Detector Unit



DETECTORS: 6 double strip silicon layers arranged alternately along X and Y directions
Plane area: 2 x (8x8) cm^2
Thickness: 380 μm
Distance X-Y planes: 3.75 cm
Maximum error of angular reconstruction: 1.8°
Geometric Factor (bidirectional): **230** cm^2 sr

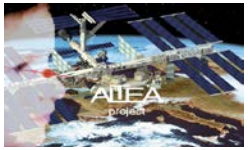
PERFORMANCES:
Threshold: 5 -33 MIP
Saturation: 2400 MIP
(1 MIP=109 KeV/plane)
ADC: 12 bit

DAU SOFTWARE PARAMETERS:
Resolution: 0.64 MIP/ADC ch
Maximum Acquisition Rate: 700 Hz
Autotrigger (logic OR or logic AND of X planes, software switchable)

With the used parameters:

3 keV/μm < **LET(Si)** < 800 keV/μm

ALTEA while set in position in the USLab



ALTEA acceptance

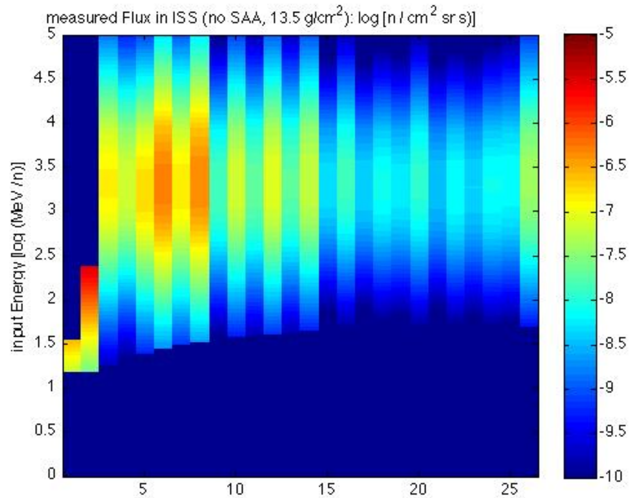
CREME model (GCR) inside the ISS + PHITS model of ALTEA

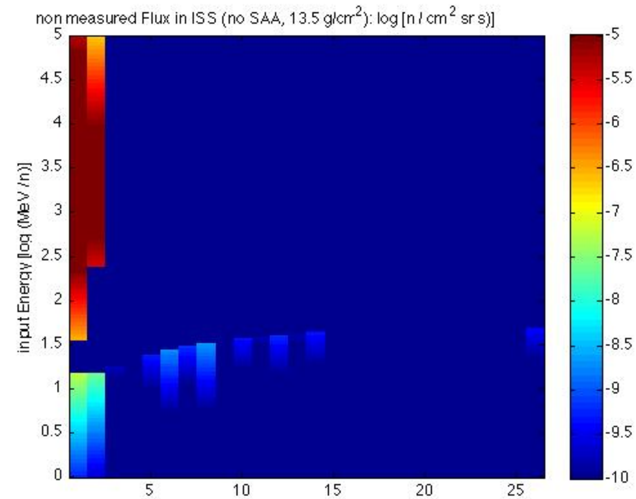
Z	*%measured*
1	0.024 %
2	3.2 %
>2	>99 %
All	1.3 %

Measured by ALTEA

Not measured by ALTEA

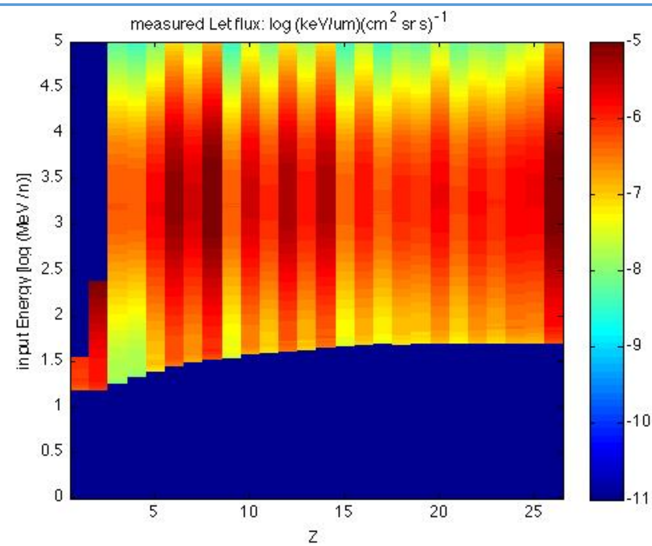
Flux

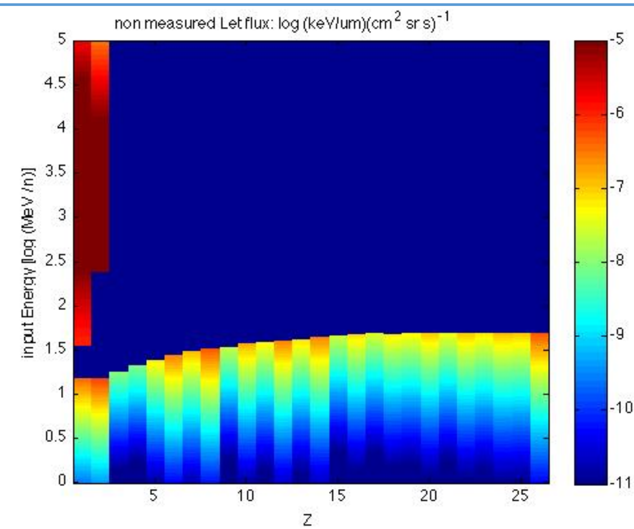




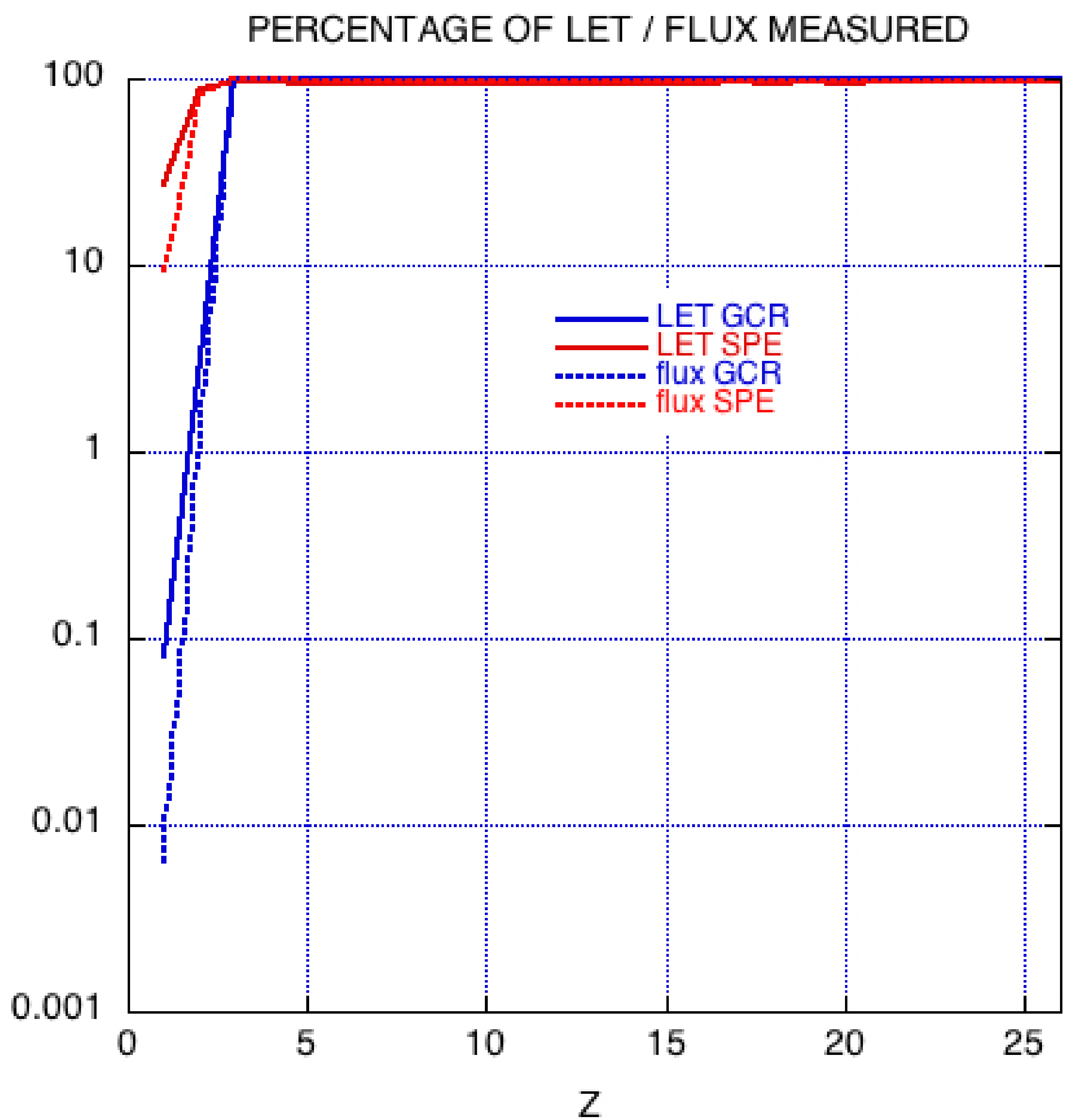
Z	*%measured*
1	0.29 %
2	8.7 %
>2	>99 %
All	41 %

LET





ALTEA acceptance 2



ALTEA location

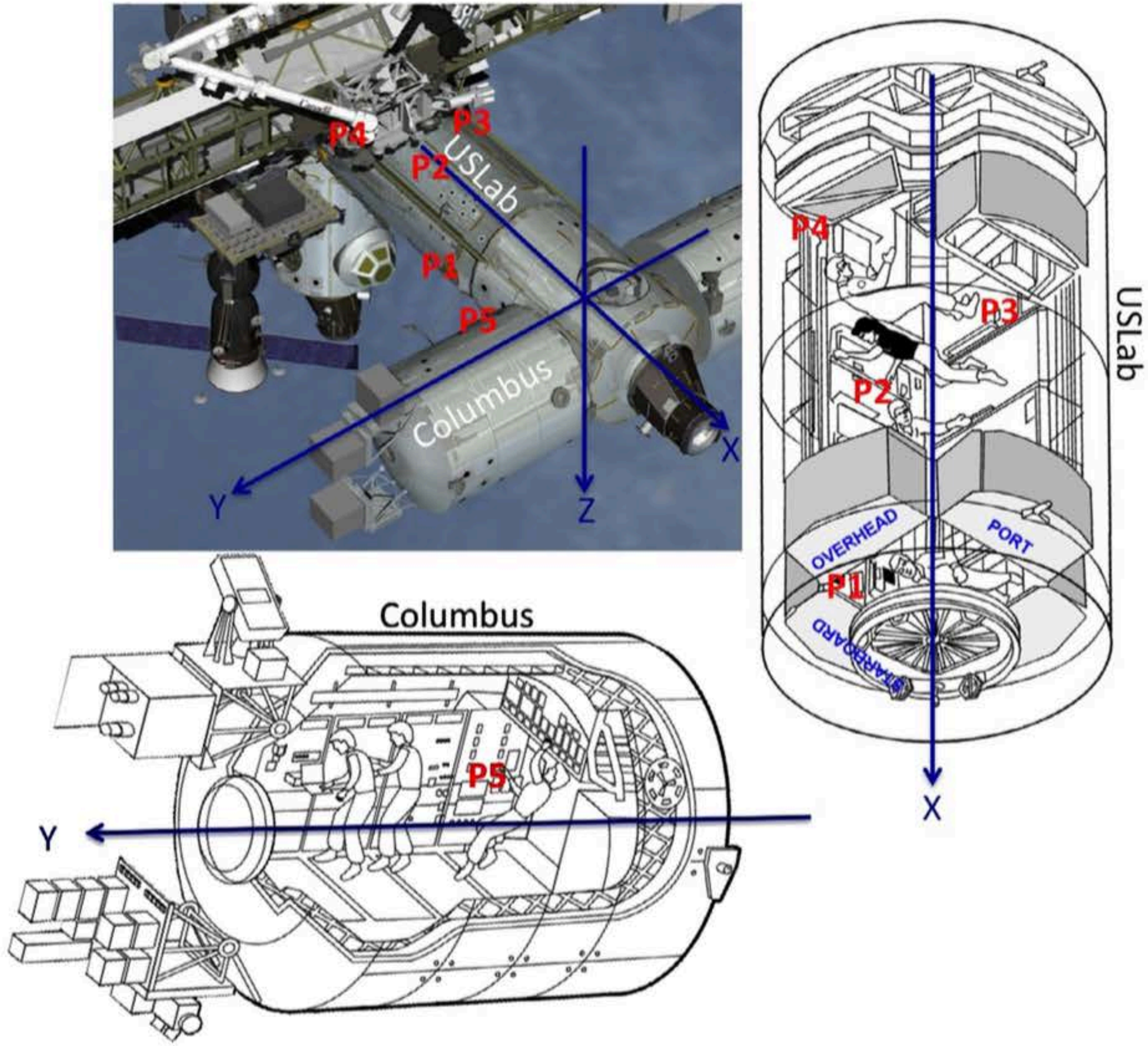


Fig. 1. The four measurement sites (P1–P4) in the USLab and the fifth one (P5) in Columbus. The three ISS orthogonal directions are also shown (see, for example, Di Fino et al. 2011).

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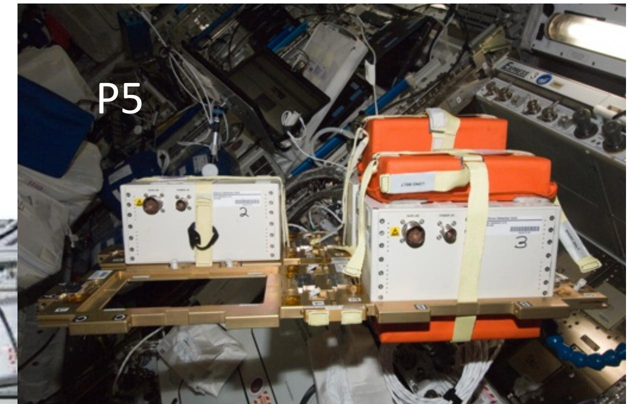
ALTEA configurations



P5 in Columbus (ER3)

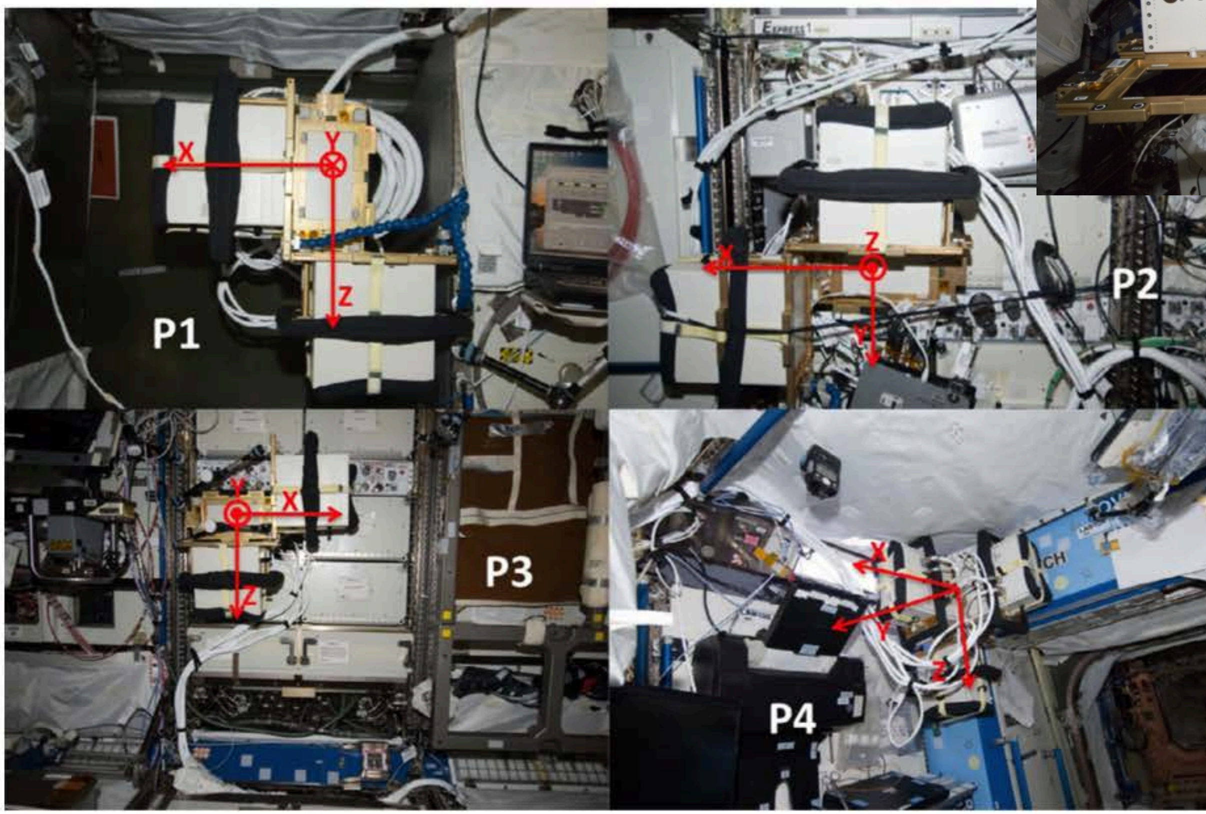
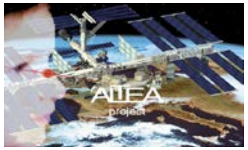


Fig. 3. ALTEA in the four USLab positions (see Table 1). Top left: Position P1 (in this site the rack was temporarily missing and the *Y*-directed detectors were facing the USLab hull); Top right: P2 on the overhead with the *Z*-directed detectors inserted in an empty drawer; Bottom left: P3 on the port side with the *Y*-directed detectors inserted in an empty drawer; Bottom right: P4 on the overhead. *X*, *Y*, *Z*: ISS coordinate system. Photo courtesy of NASA.



ALTEA measurement time

Table 1. Running days in the four ALTEA-shield/survey positions. The last line corresponds to the "shield" section of the experiment. The total duration might be less than the total number of days between start and end because of shut-off periods.

Year	Date	Total duration (days)	Position name	Position
2010	09/20–10/04	14	P1	Lab1S1
2010	10/15–11/30	40	P2	Lab1O2
2011	04/24–07/22	90	P3	Lab1P4
2011/ 2012	07/23/2011– 06/07/2012	263	P4	Lab1S6
2012	06/08–09/30	114	P5	Columbus ER 3

Typical measurement and data selection

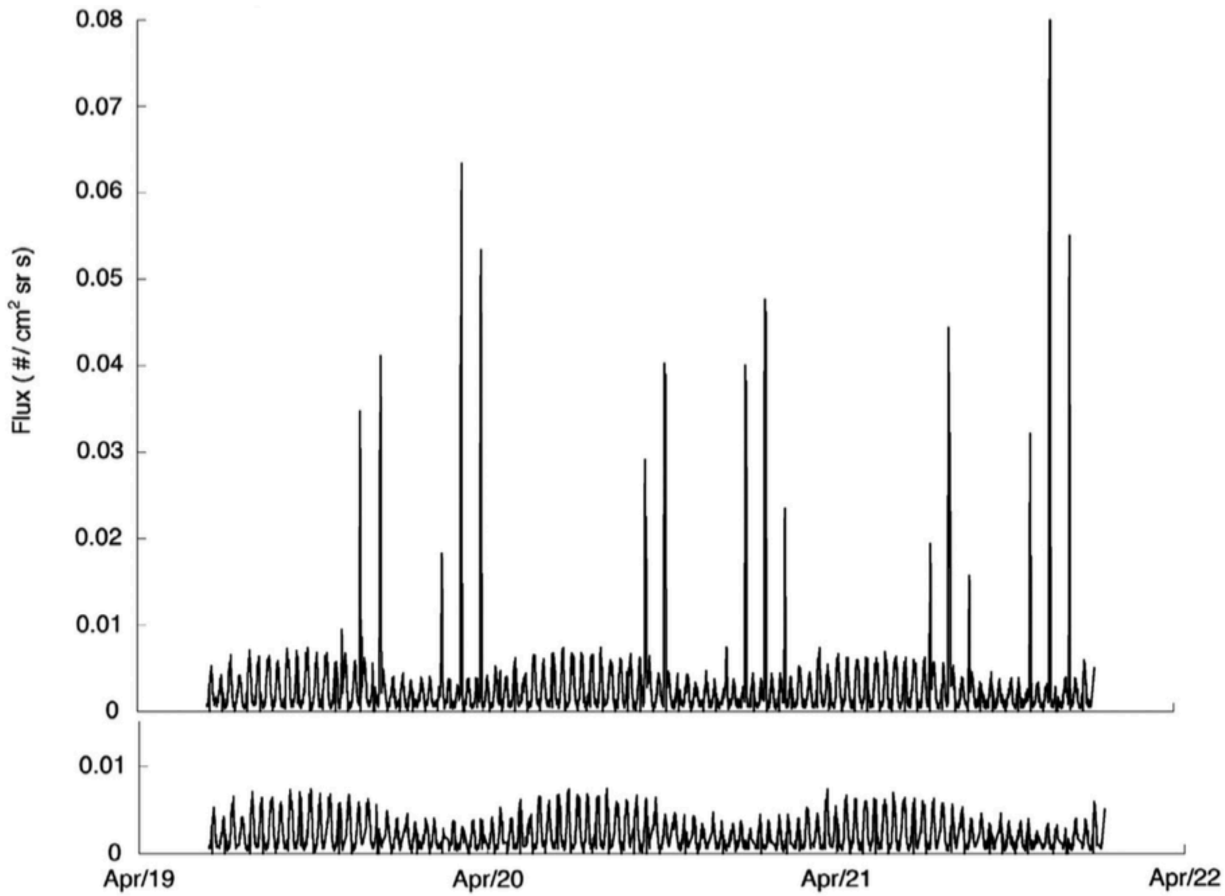


Fig. 4. Radiation flux measured by one SDU (SDU2, *Z* direction) in a quiet Solar Period (April 19–22, 2012). Top: complete data set. Bottom: Same data set, filtering out the passes through the SAA.

ALTEA survey results

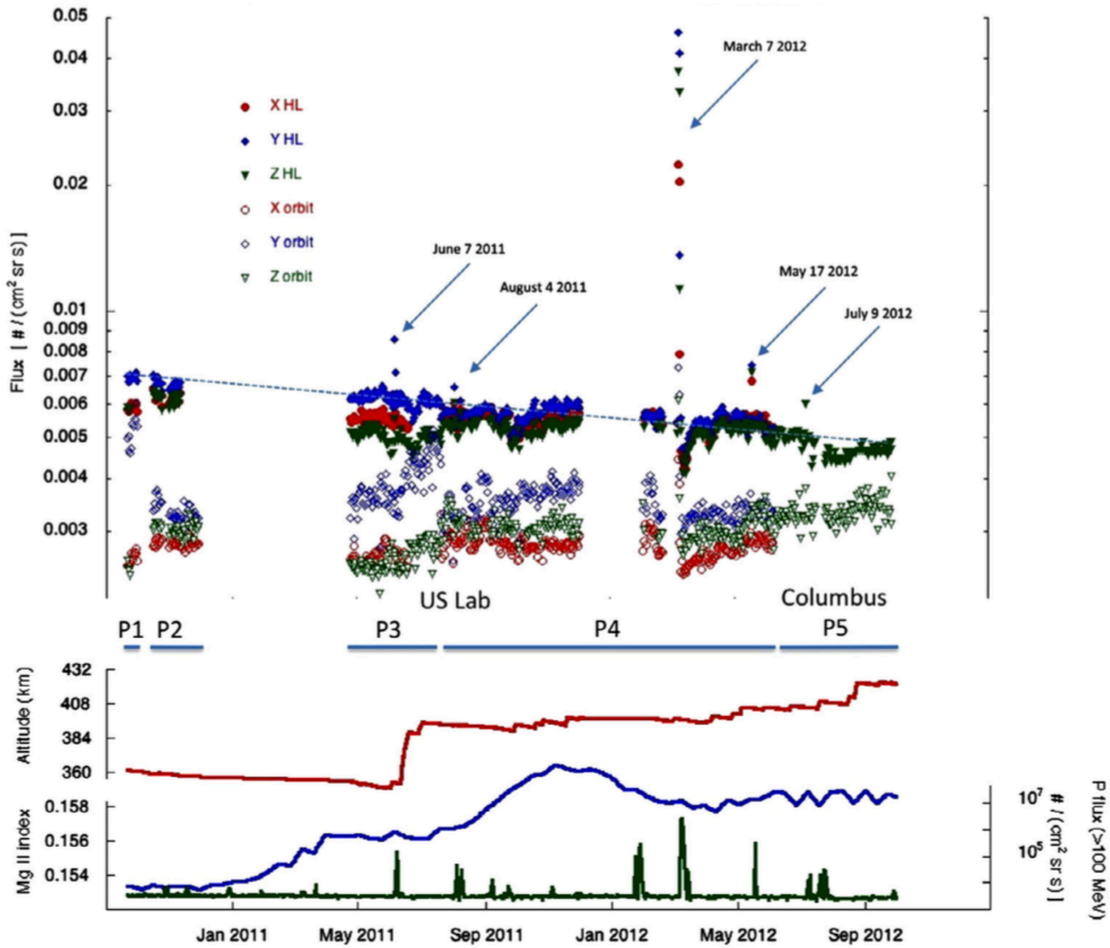


Fig. 5. Top: Flux measured by ALTEA in the three directions both in the whole orbit (empty symbols) and in the high latitude passes (*HL*, full symbols). The five most evident Solar Particle Events (SPEs) are indicated with an arrow. The dotted line serves as a guide for the eyes to follow the mean steady decrease of the flux linked to the solar cycle modulation. Bottom: Altitude of the ISS from the ancillary data acquired concurrently with the ALTEA measurements (above in red); solar cycle as described by the MgII index (middle, in blue); flux of the energetic (>100 MeV) protons, as measured by GOES (lowest, in green); The P1–P5 segments indicate the periods that the detector system ALTEA spent in the five different positions during the experiments ALTEA-shield/survey (P1–P4) and ALTEA-shield/shield (P5).

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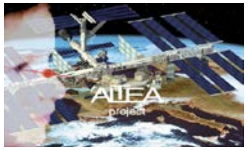


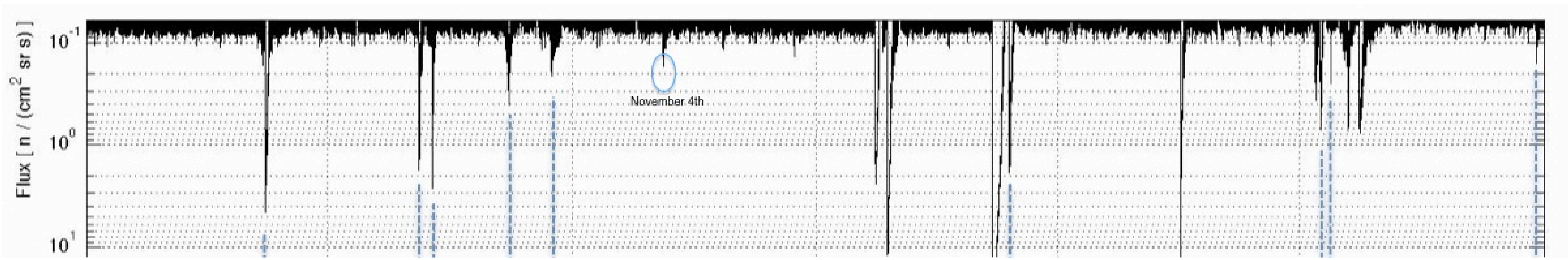
SPEs in 2010 – 2012 *(adapted from NOA)*

	Start	Flux [#/(cm^2 sr s)]			ISS mag low cut	NOA	CME	Flare Max.	Flare Importance	Flare Location	Region (SWO)
		P > 10 MeV	P >100 MeV	ALTEA							
1	May 27			--	Y	N					
2	Jun 07/0820 [1]	72	4.53	0.01462	Y	Y	SW/08 1750	Jun 07/0803	M2/2N	S21W64	1226
3	Aug 04/0635	96	1.8	0.003992	Y	Y	NW/06 0515	Aug 04/0412	M9/2B	N15W49	1261
4	Aug 09/0845	26	2.54	0.006074	Y	Y	NW/09 1710	Aug 09/0805	X6/2B	N17W83	1263
5	Sep 06		0.41	--	Y	N					
6	Sep 23/2255	35	0.211	-- [2]	Y	Y	NE/27 0430	Sep 22/1101	X1/2N	N11E74	1302
7	Nov 04		0.172		N	N					
8	Nov 26/1125	80		[3]	N	Y	NW/28 0145	Nov 26/0710	N/A	N08W49	1353
9	Mar 07/0510	6530	69.3	0.09076	Y	Y	NE/07 0036	Mar 07/0024	X5/3B	N17E15	1429
10	Mar 13/1810	469	1.89	0.004481	Y	Y	NW/13 1736	Mar 13/1741	M7/	N18W62	1429
11	May 17/0210	255	20.4	0.009376	N	Y	NW/17 0148	May 17/0147	M5/1F	N12W89	1476
12	May 27/0535	14			N	Y	/27 2112	N/A	N/A	N/A	1482
13	Jun 16/1955	14			Y	Y	SE/14 1430	Jun 14/1435	M1/1N	S17E14	1504
14	Jul 07/0400 [4]	25	0.706	0.004124	Y	Y	SW/06 2312	Jul 06/2308	X1/	S18W50	1515
15	Jul 12/1835	96	0.251	0.001433	Y	Y	SW/12 1649	Jul 12/1710	X1/2B	S16W09	1520
16	Jul 17/1715 [5]	136	0.731		N	Y	SW/17 1348	Jul 17/1715	M1/	S17W75	1520
17	Sep 01/1335	59			Y	Y	SE/31 2012	Aug 31/2043	C8/2F	S06E20	
18	Sep 28/0300	28	0.159	--	Y	Y	NW/28 0018	Sep 27/2357	C3/1F	N08W41	1577

(1) GOES100 & ALTEA sees a start on the day before (June 6).
(2) Only Forbush, Maybe there is also a small signal for ALTEA
(3) A very small signal for ALTEA
(4) Two events, on the 7th and on the 9th. ALTEA sees well the 9th one (indicated). The 7th has a maximum at high magnetic cut, and ALTEA barely sees it.
(5) On the 17th a small P >100 at high magnetic cut, on the 19 a large burst (indicated), however ALTEA was off.

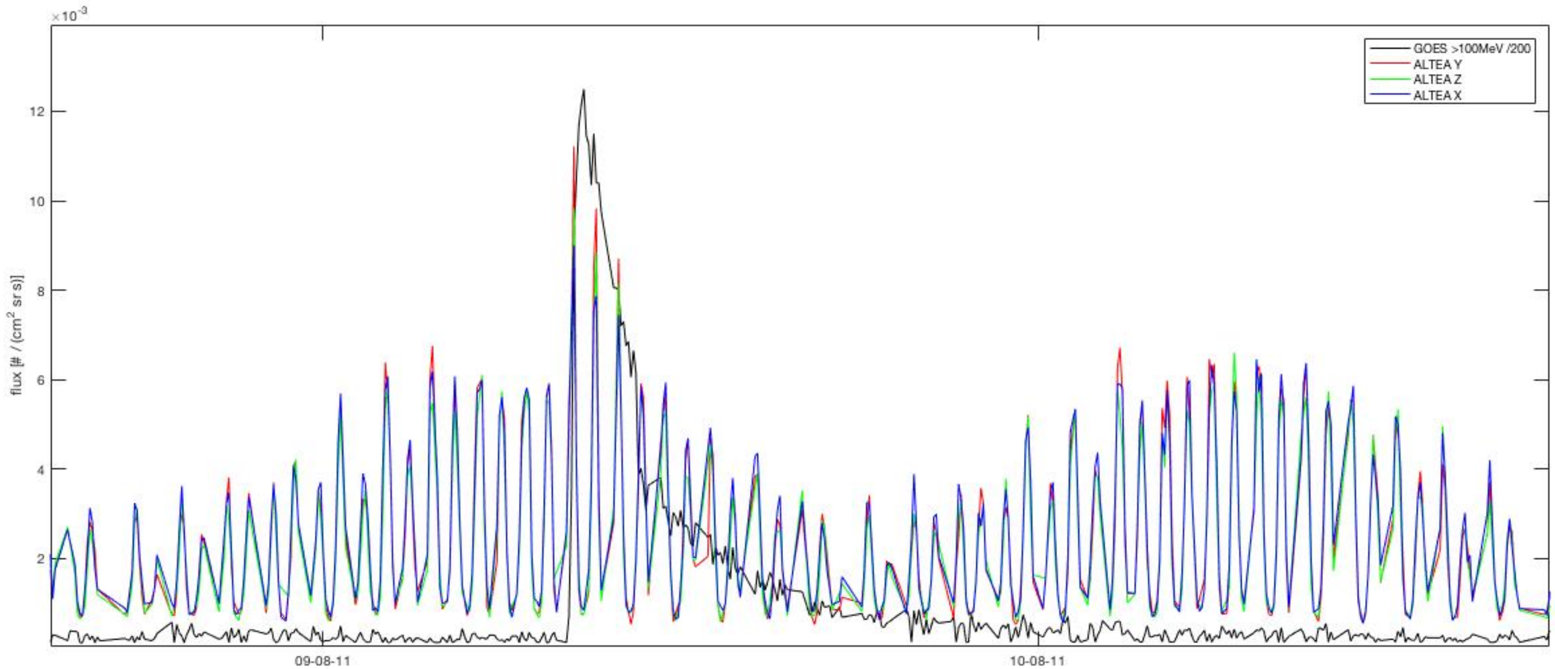
SPEs in 2010 – 2012: GOES and ALTEA results

GOES



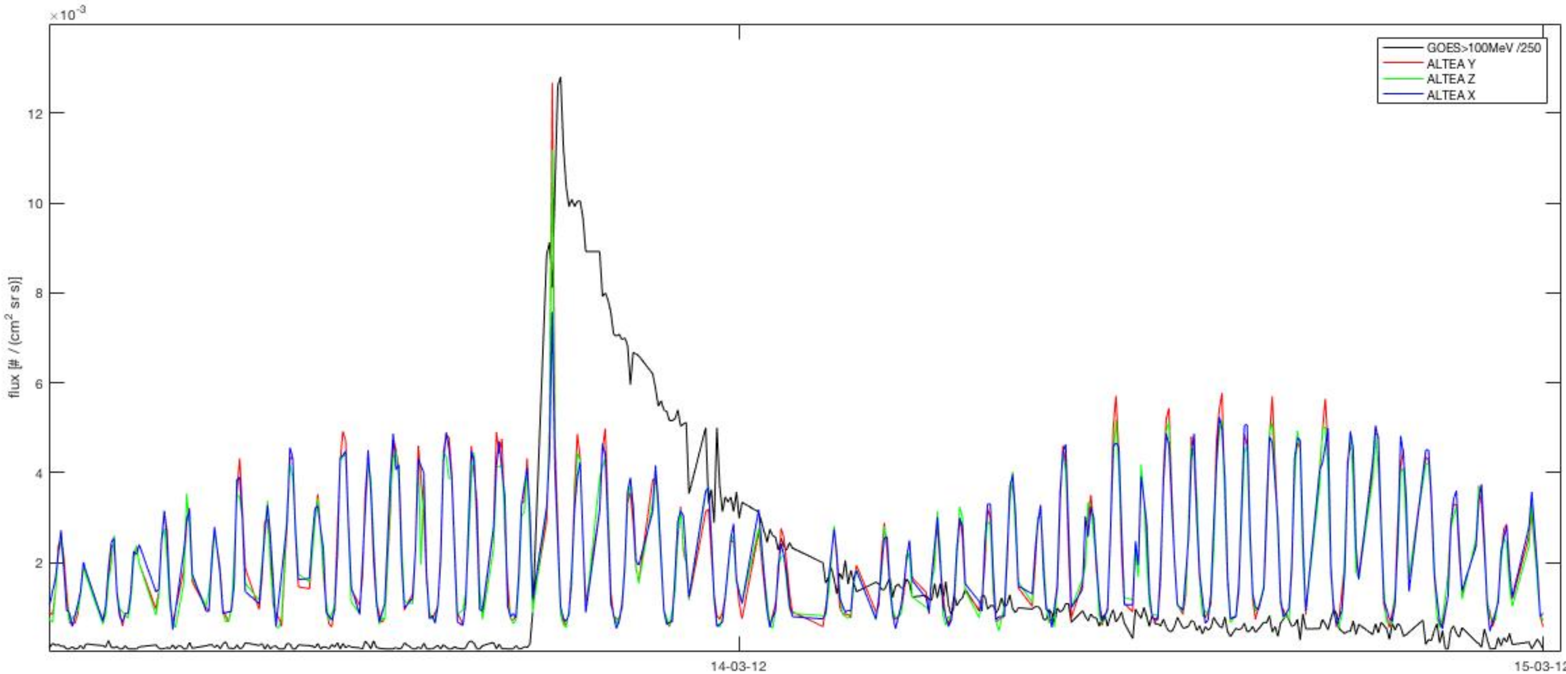
SPEs in 2010 – 2012: example 1

SPE 4: Aug 9th, 2011



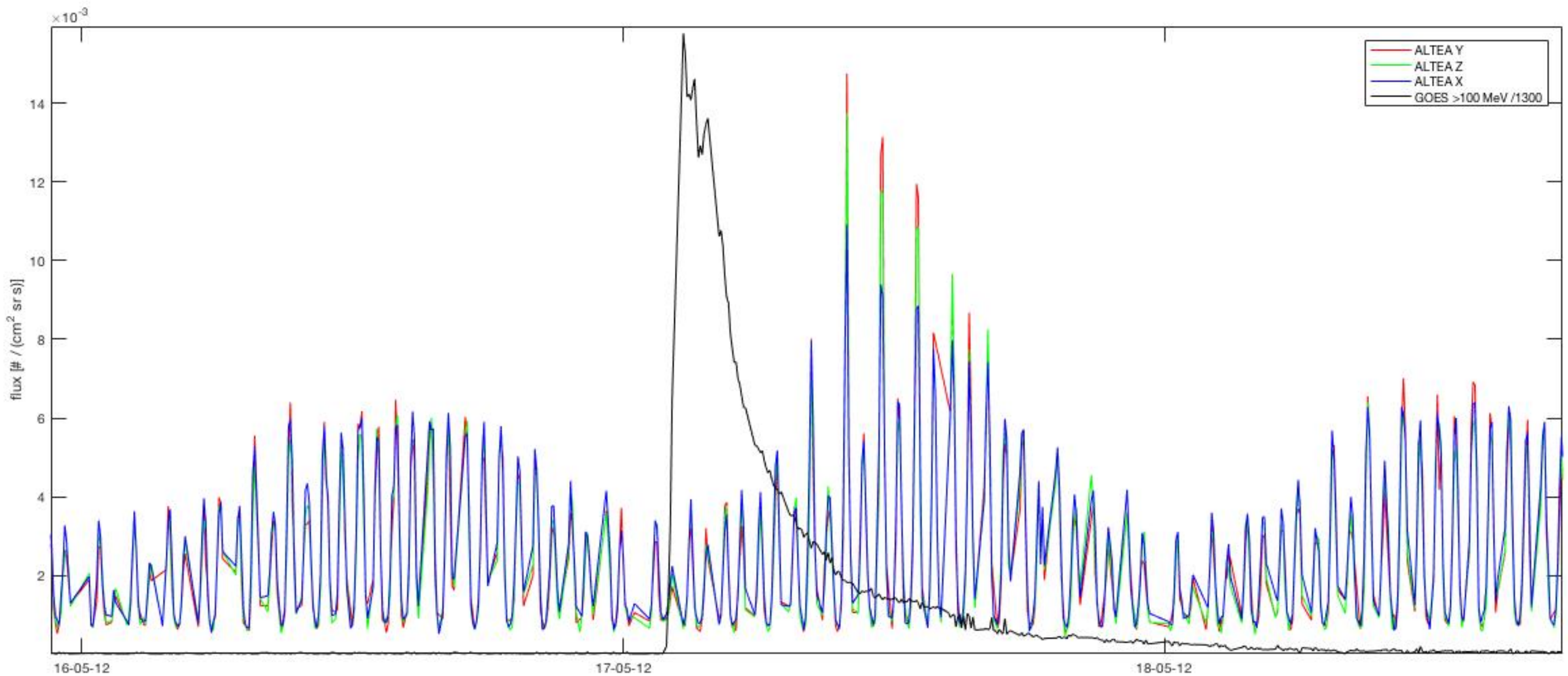
SPEs in 2010 – 2012: example 2

SPE 9: March 13th, 2012



SPEs in 2010 – 2012: example 3

SPE 11: May 17th, 2012



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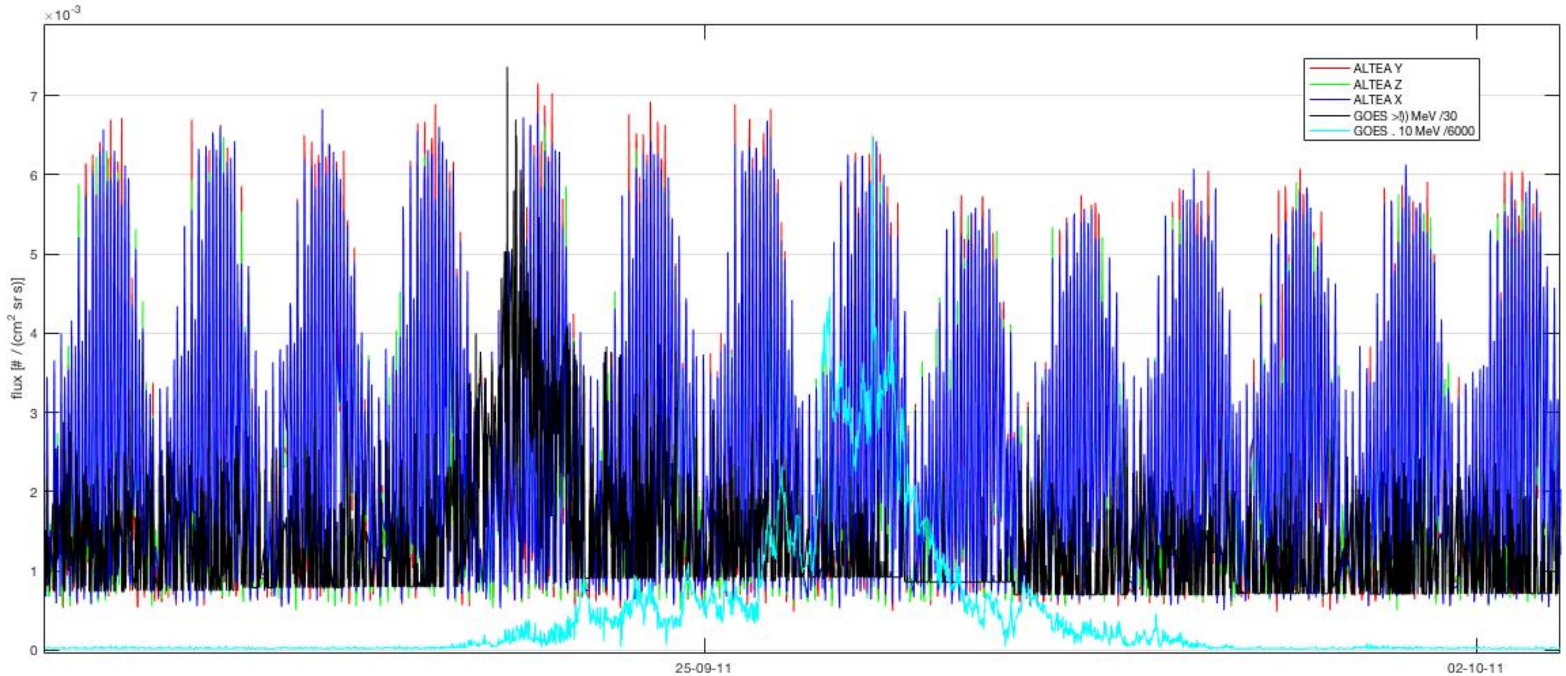
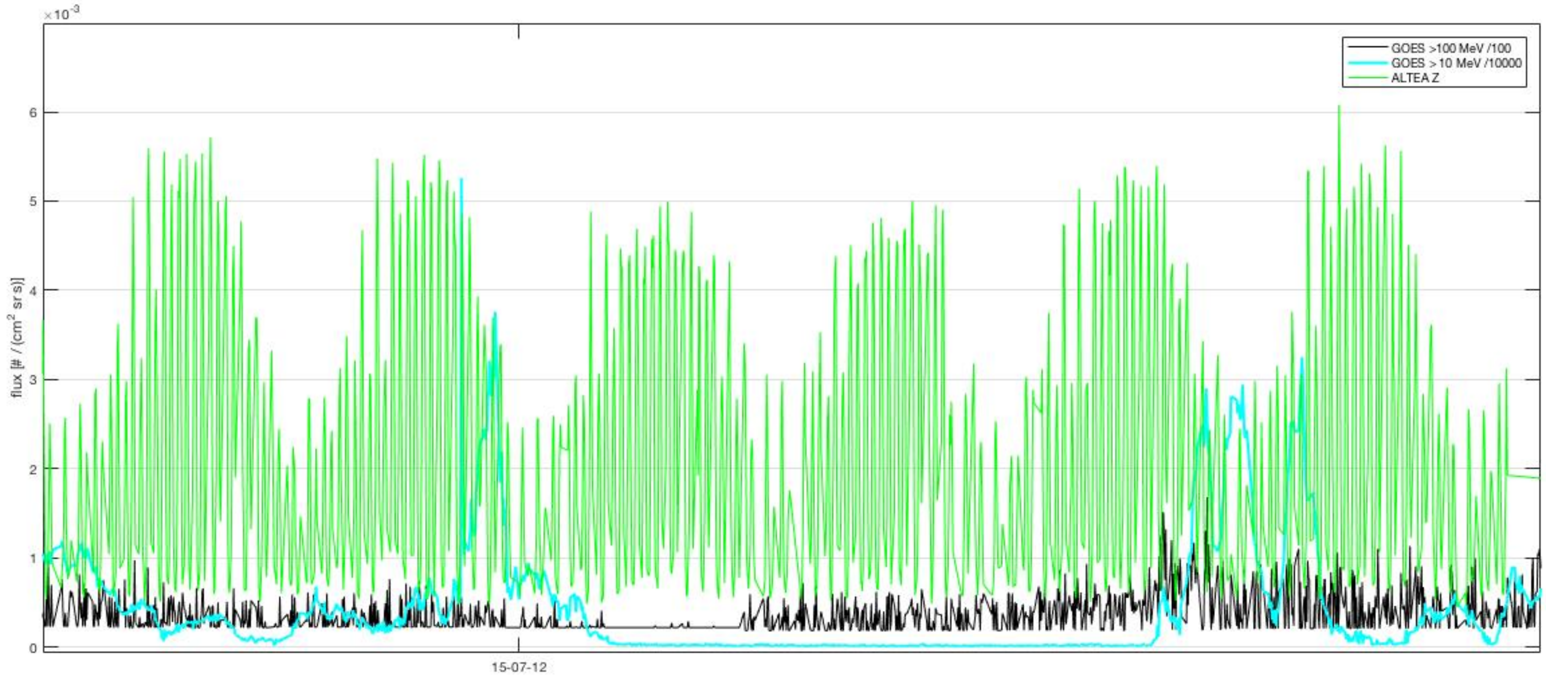
SPEs in 2010 – 2012: example 4

SPE 6: Sept 23rd, 2011



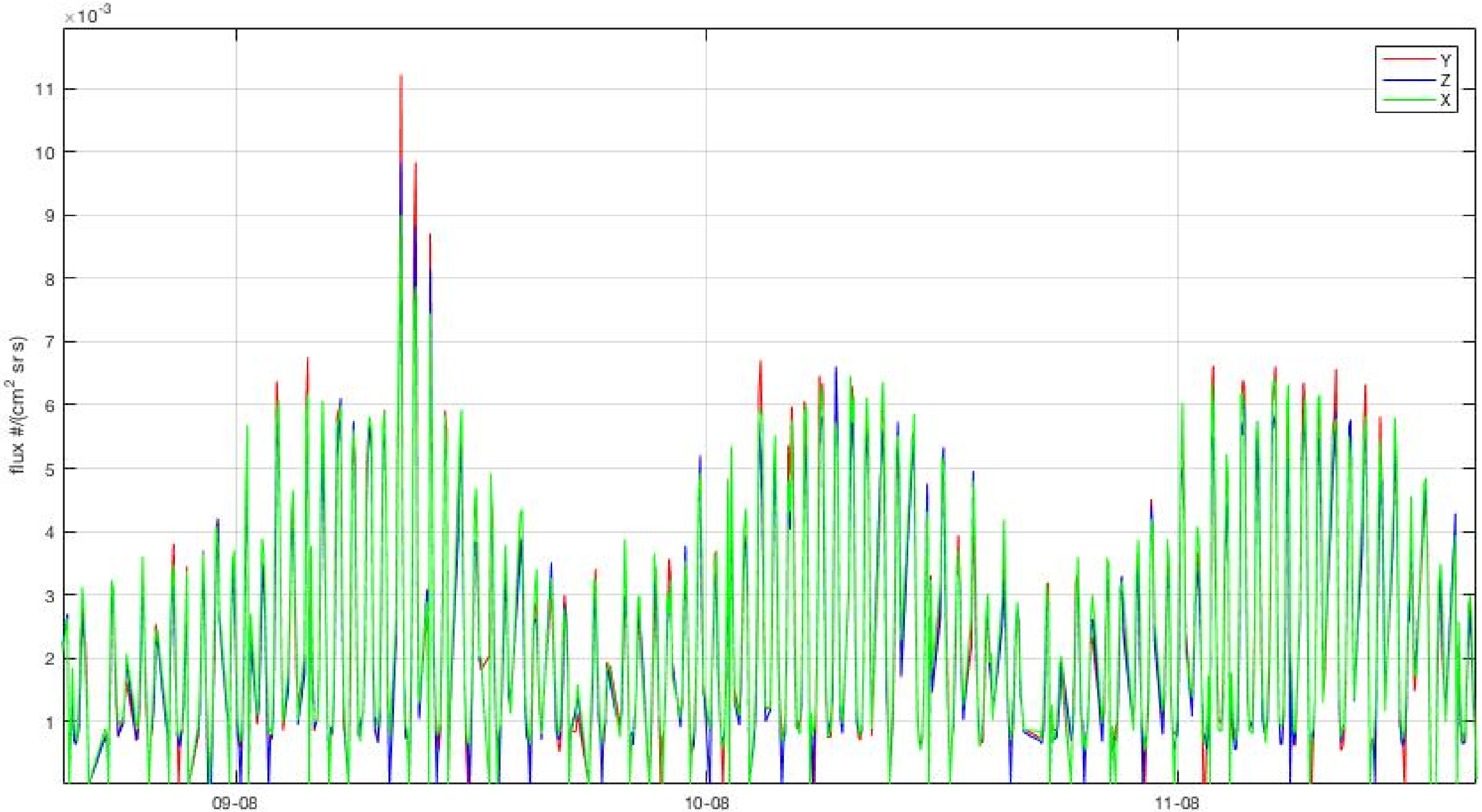
SPEs in 2010 – 2012: example 5

SPE 16: July 17th, 2012



A ‘value’ for the SPE: the data reduction model

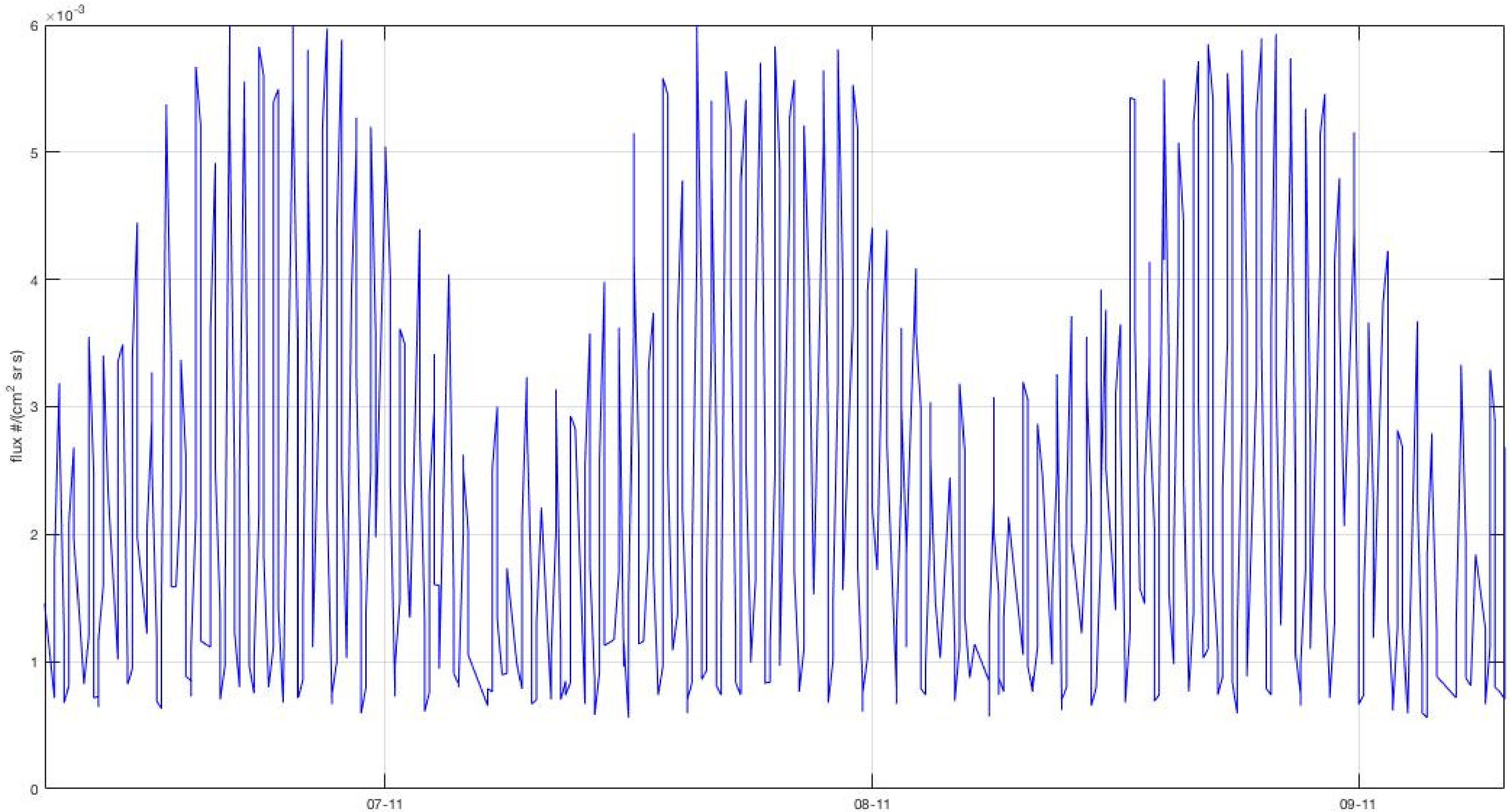
Question: how do we provide a first ‘measure’ the SPE effects?



SPE 4: Aug 9, 2011

A ‘value’ for the SPE: the data reduction model

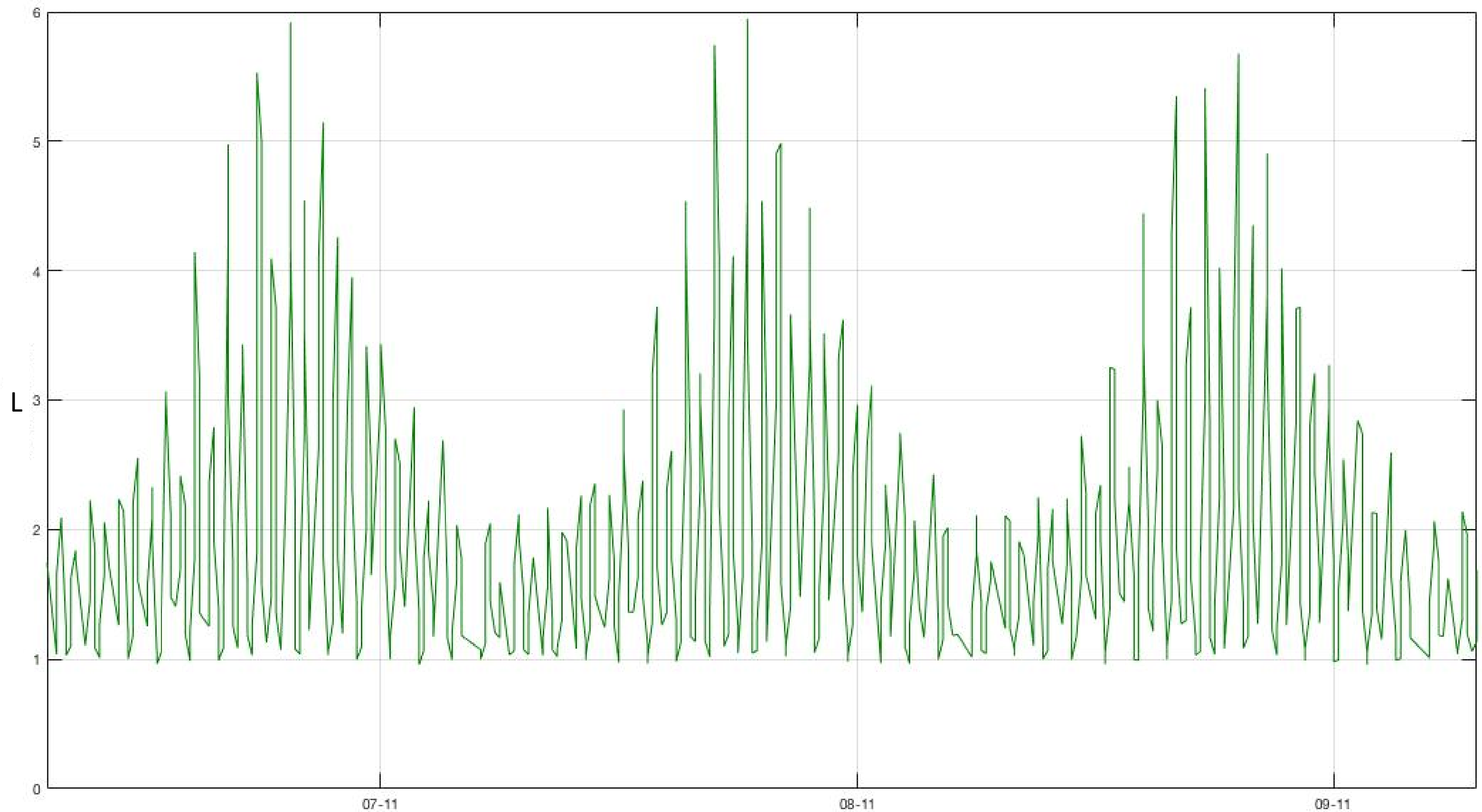
This quite period



Correspond to

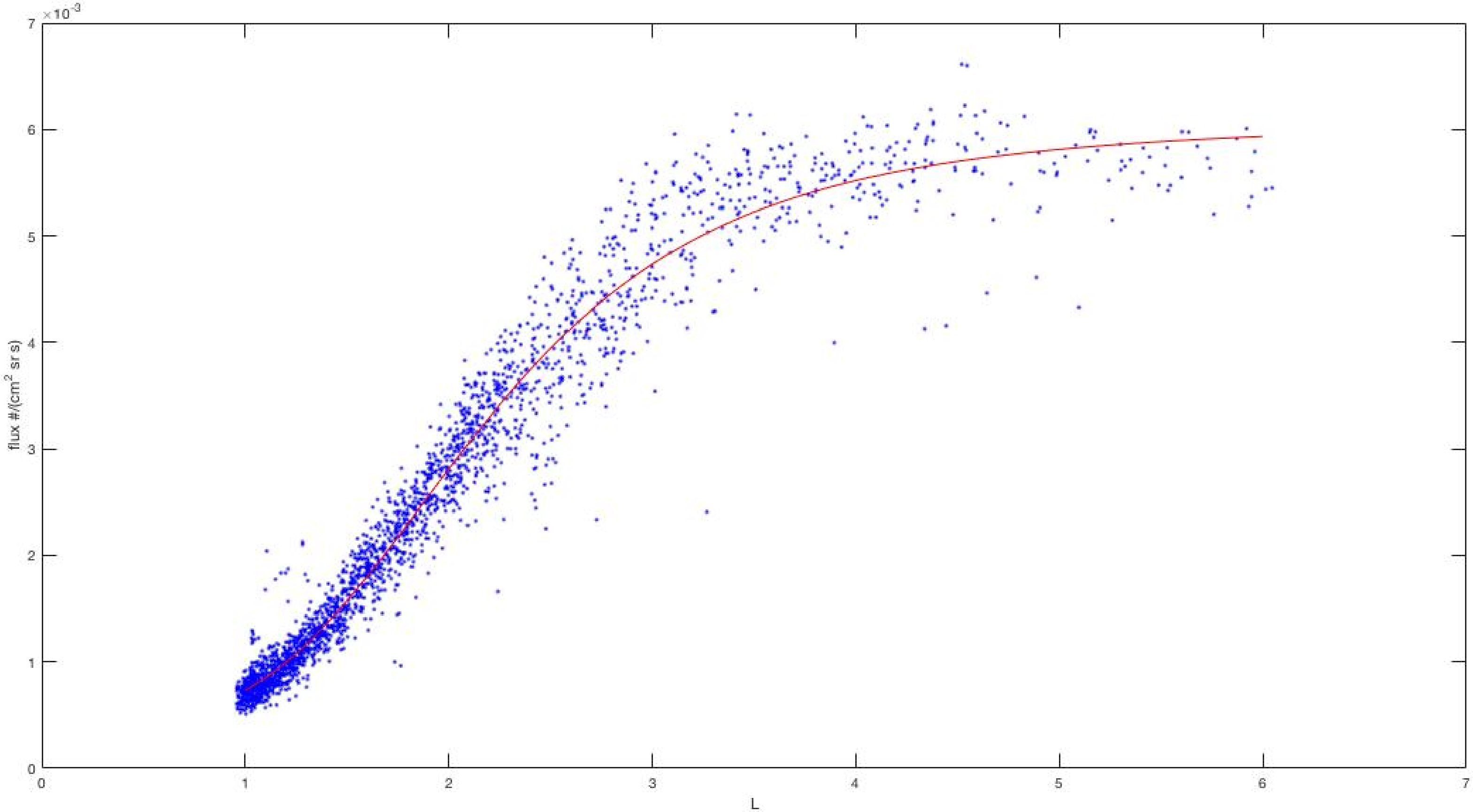
A ‘value’ for the SPE: the data reduction model

This L dynamics



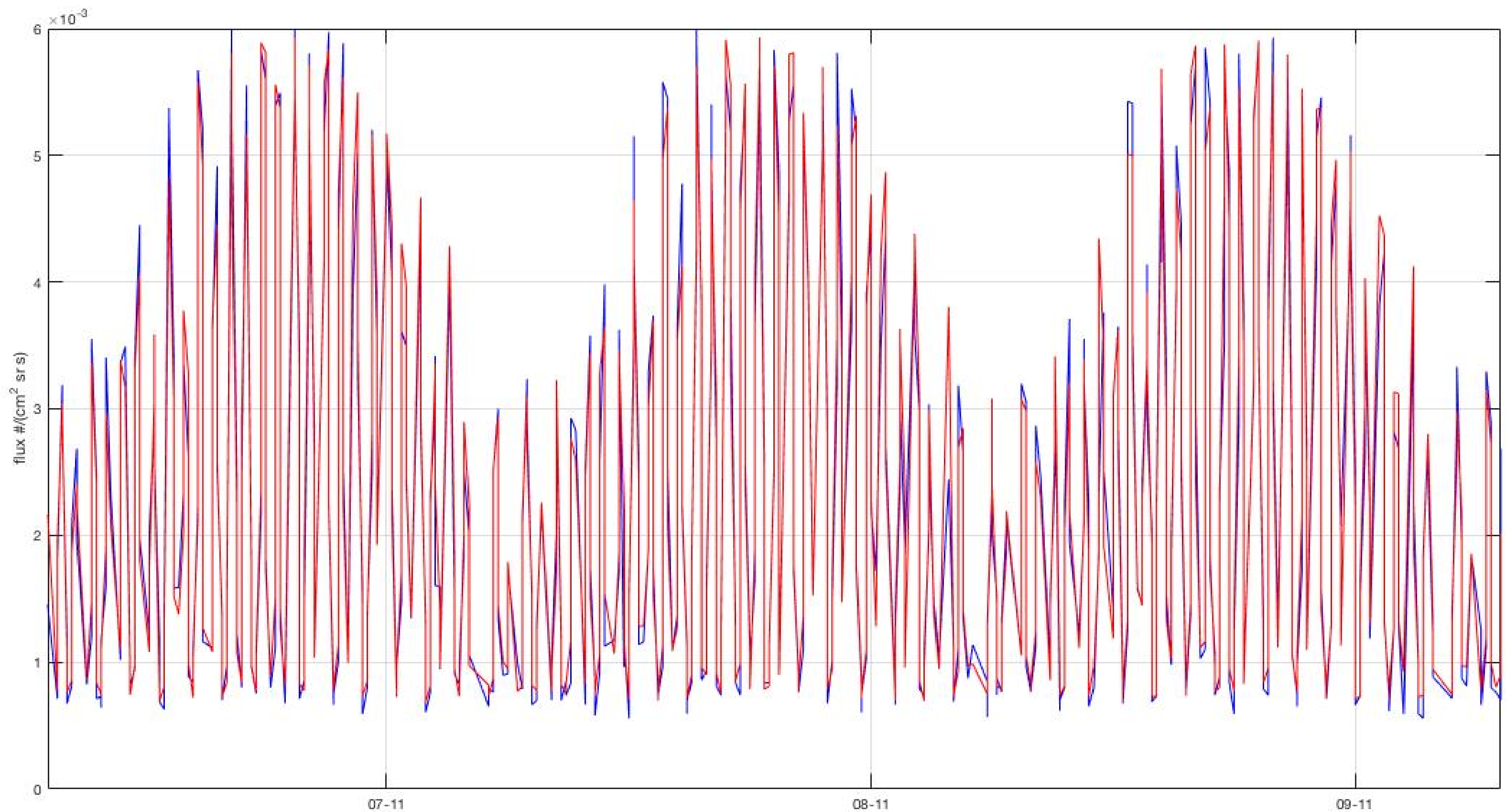
A ‘value’ for the SPE: the data reduction model

L and the ion flux are linked through a sigmoid function

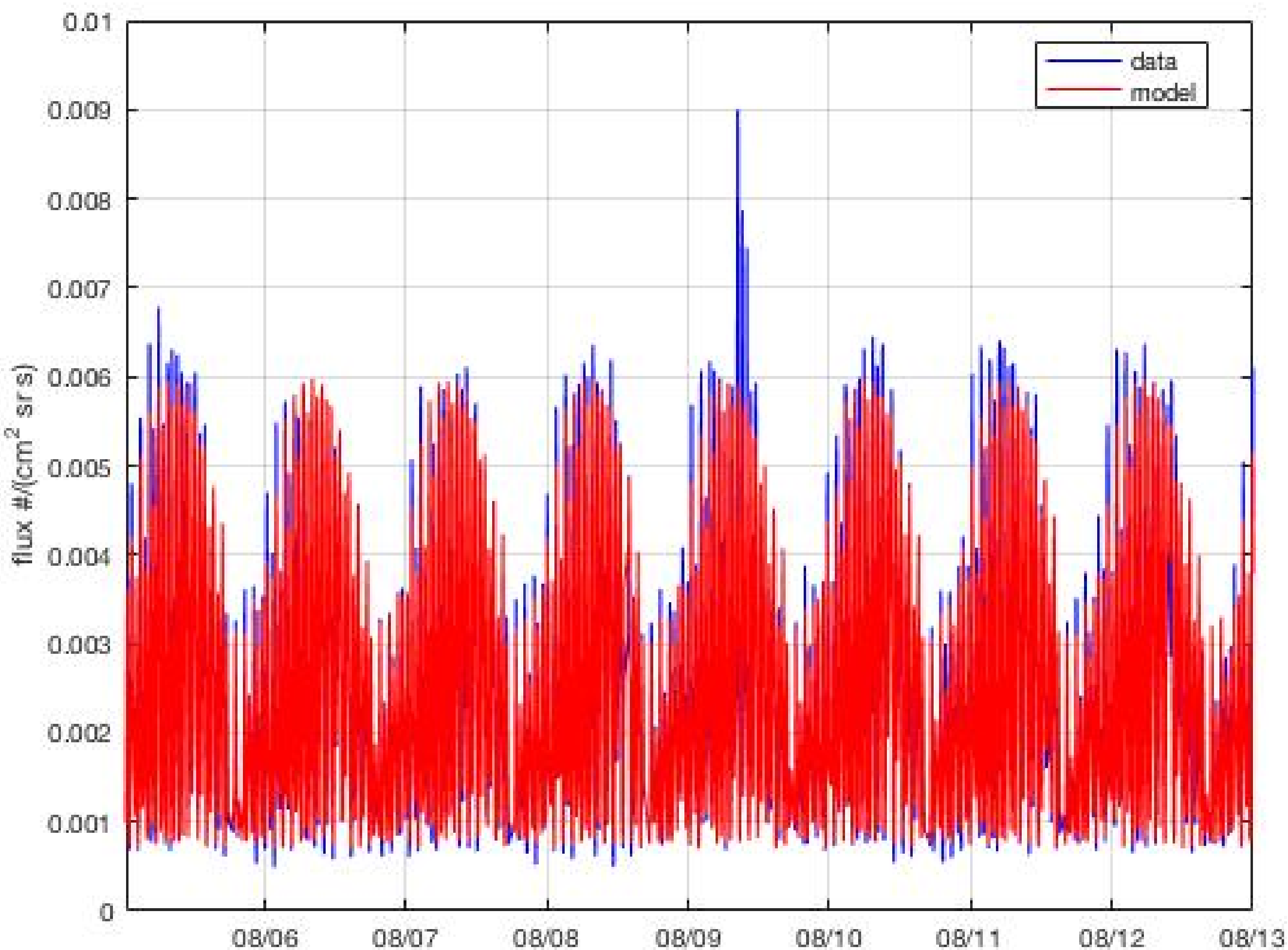


A ‘value’ for the SPE: the data reduction model

… not a bad fit (red = model)

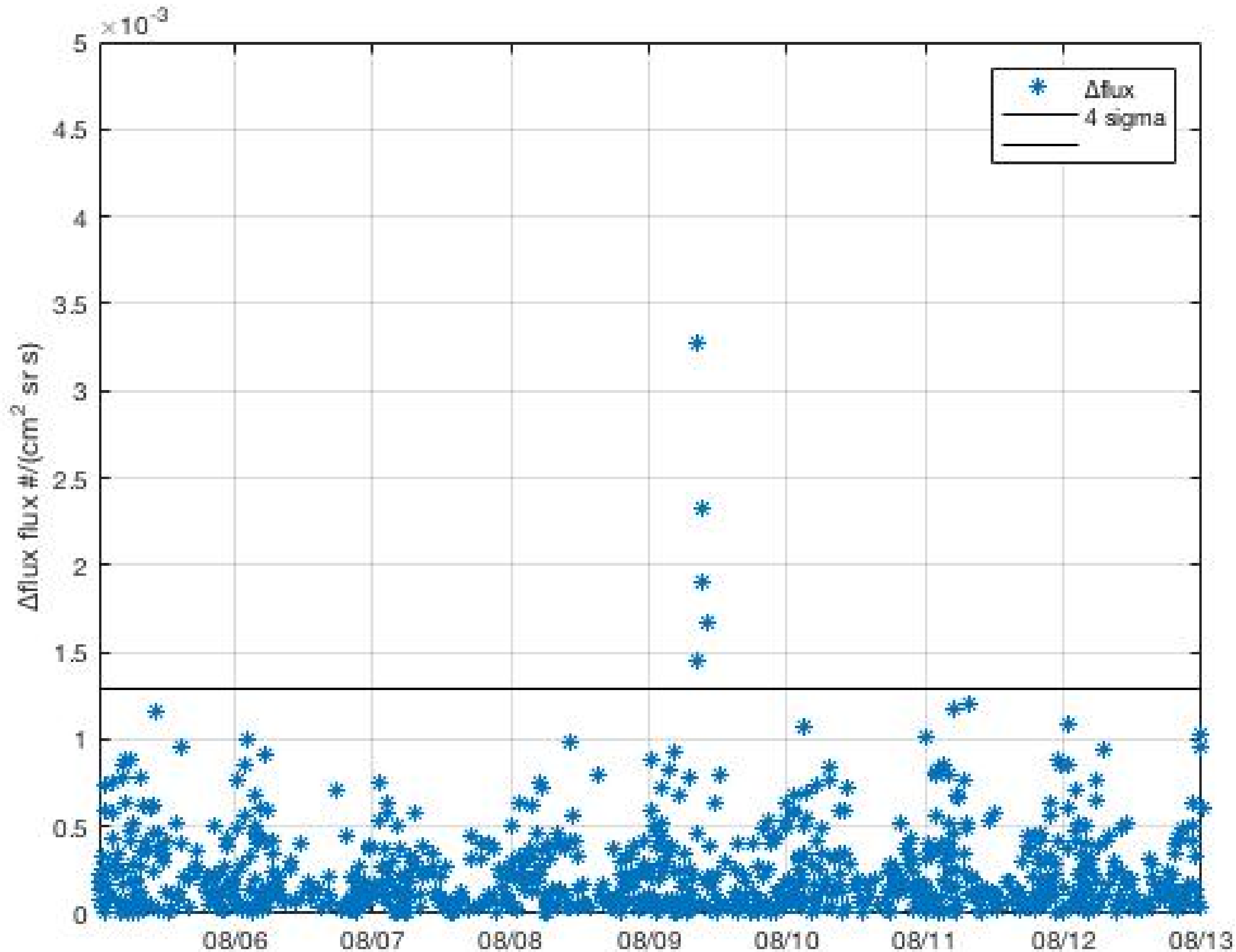


A ‘value’ for the SPE: the data reduction model



SPE 4: Aug 9, 2011

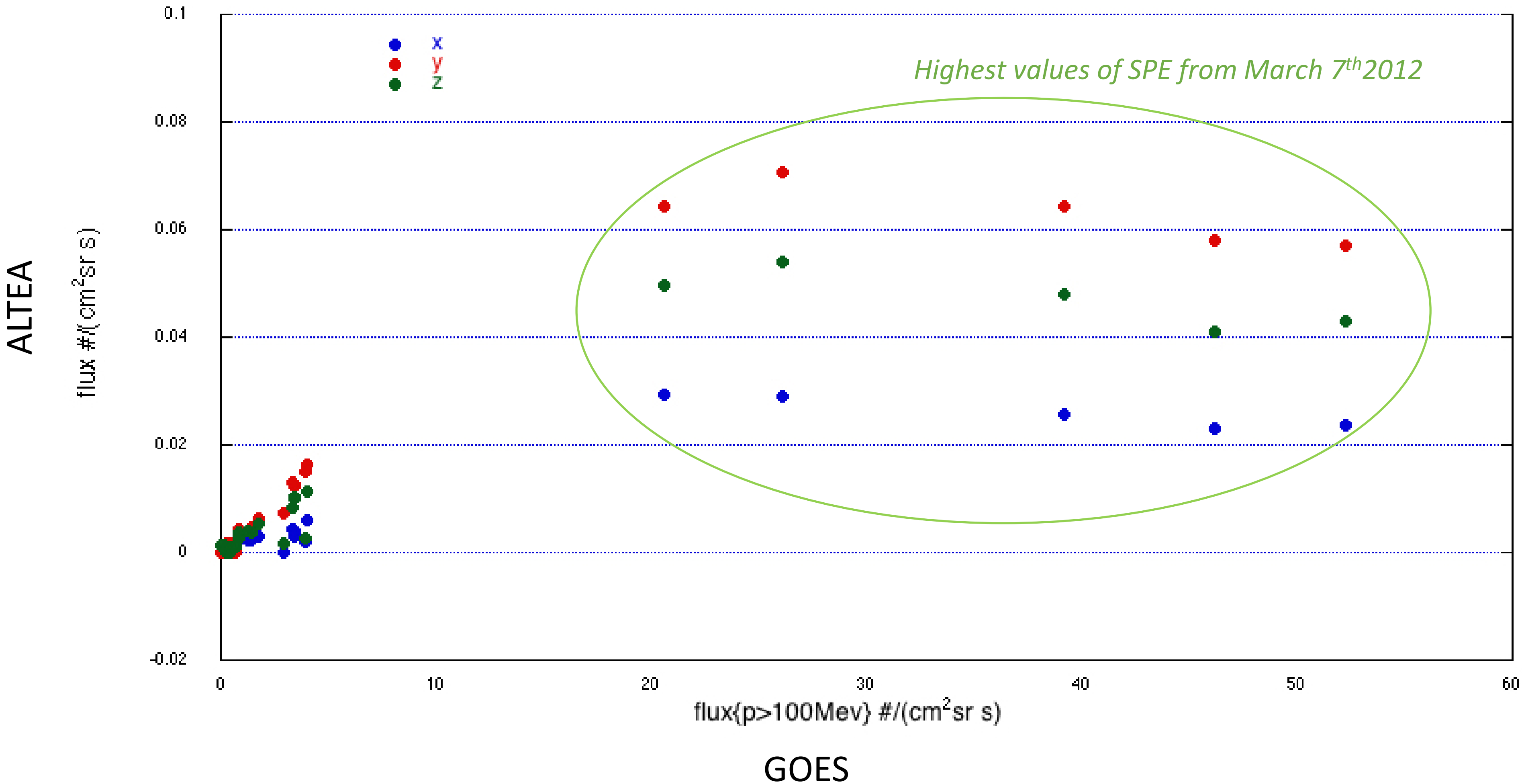
A ‘value’ for the SPE: the data reduction model



SPE 4: Aug 9, 2011

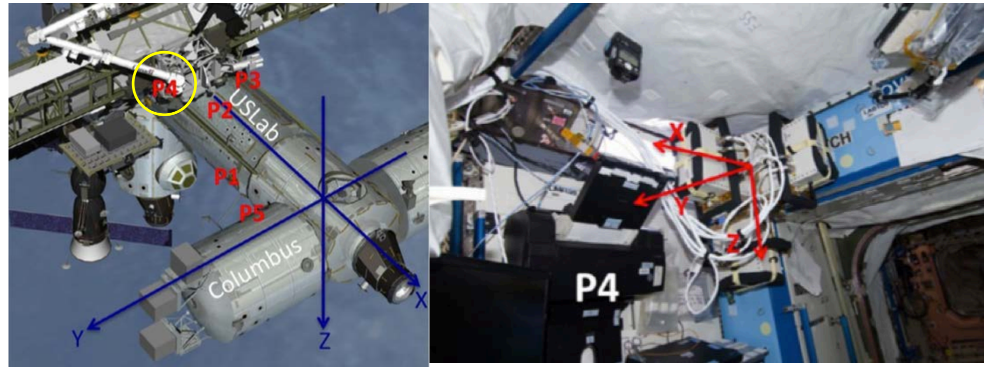
ALTEA vs GOES

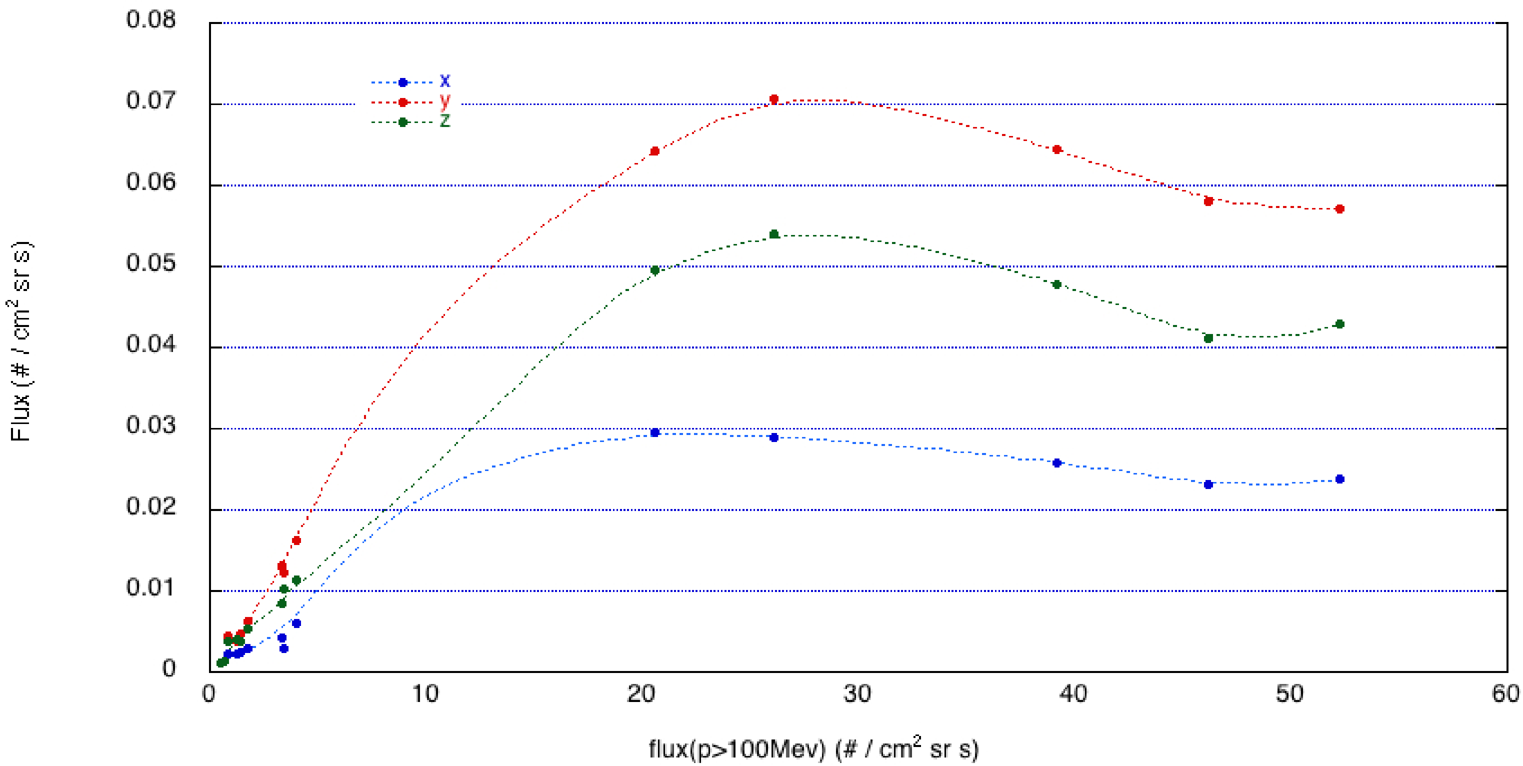
All values of the measured SPEs



ALTEA vs GOES

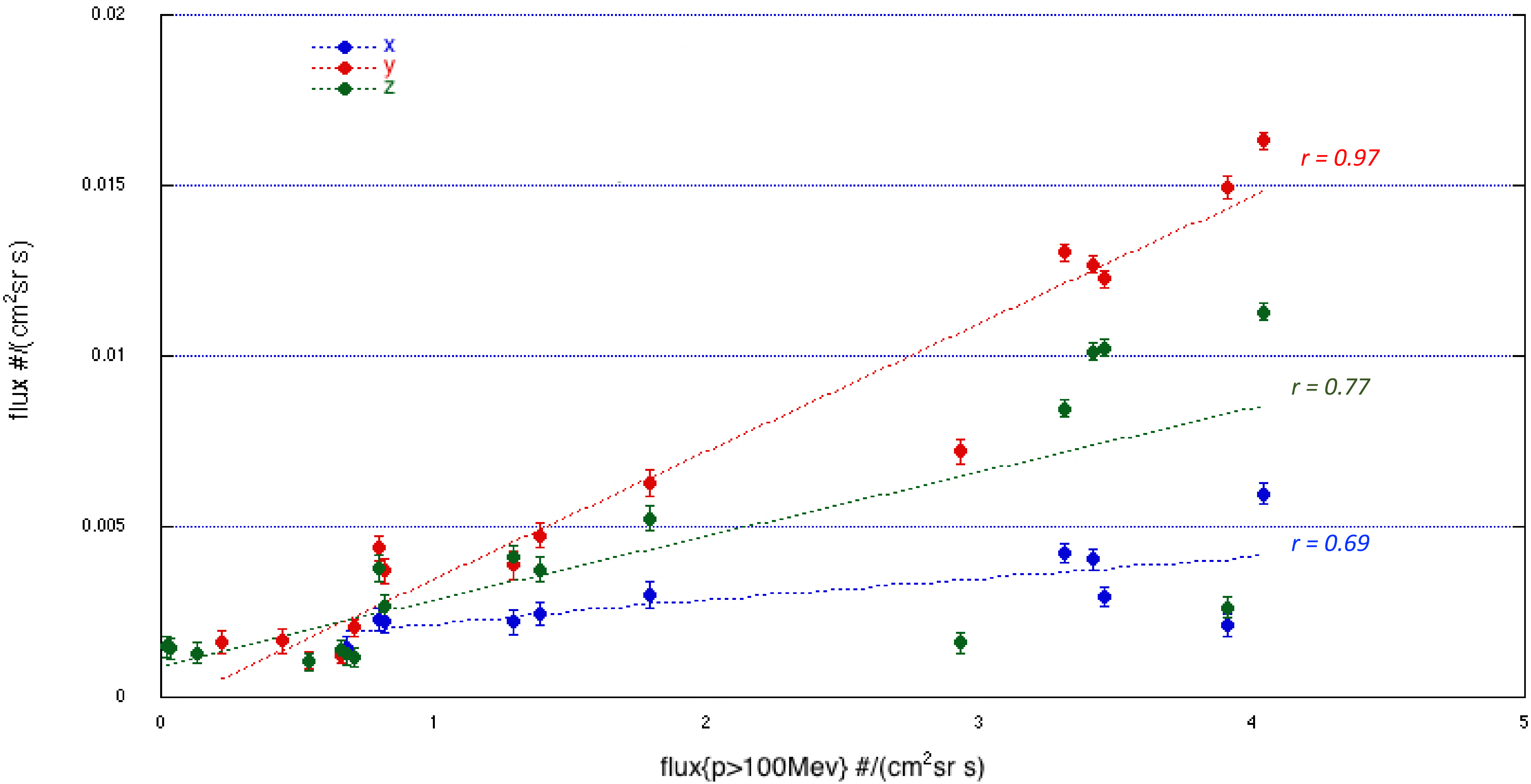
Only Position 4





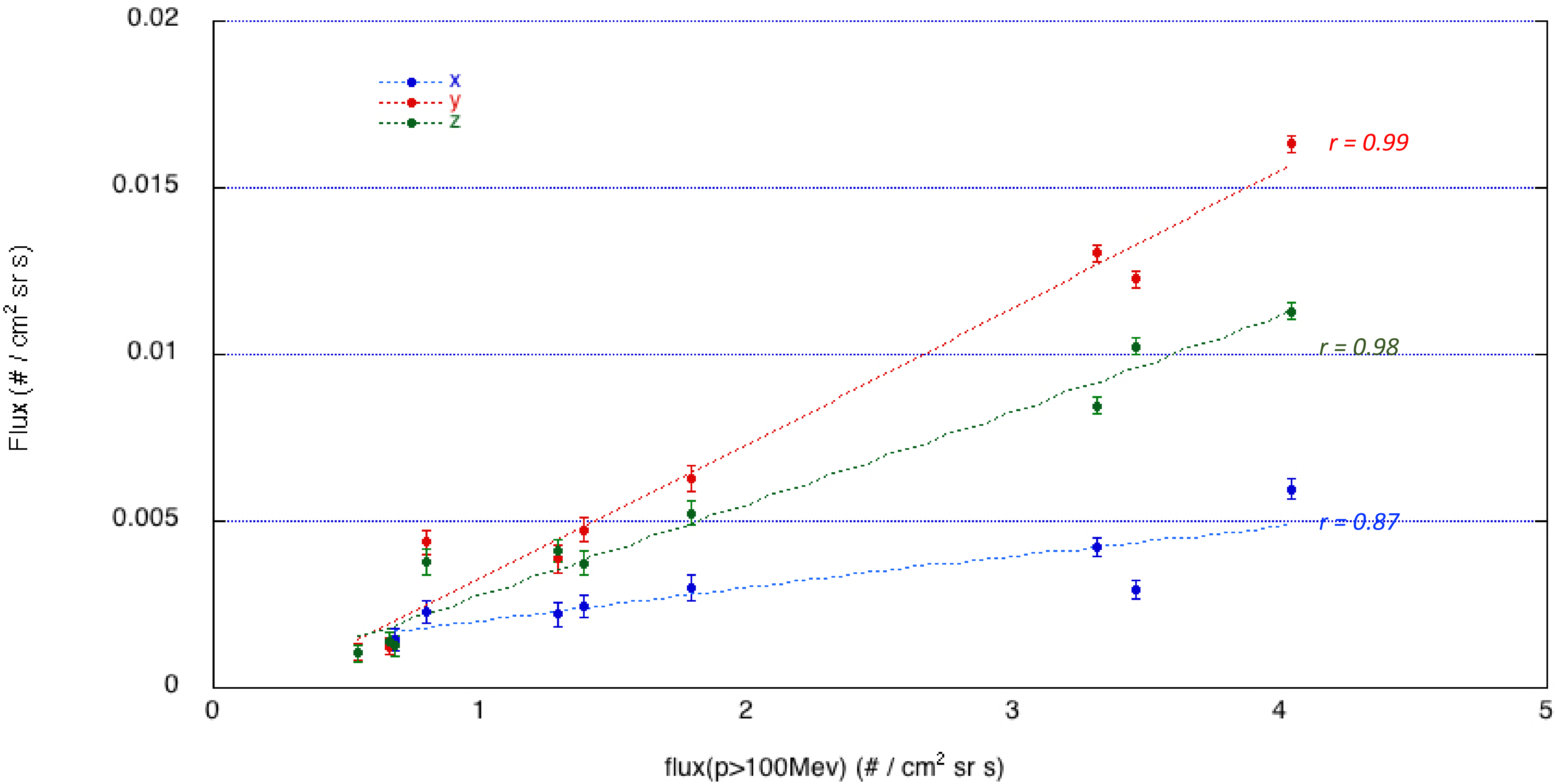
ALTEA vs GOES

All values (low flux)



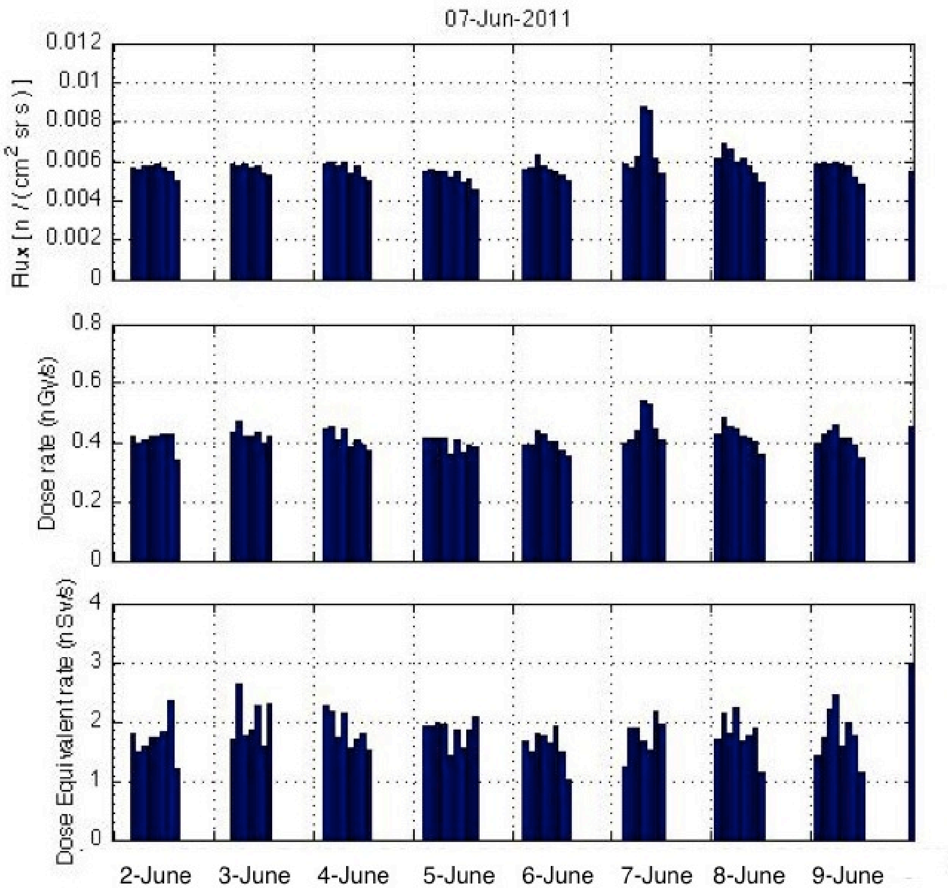
ALTEA vs GOES

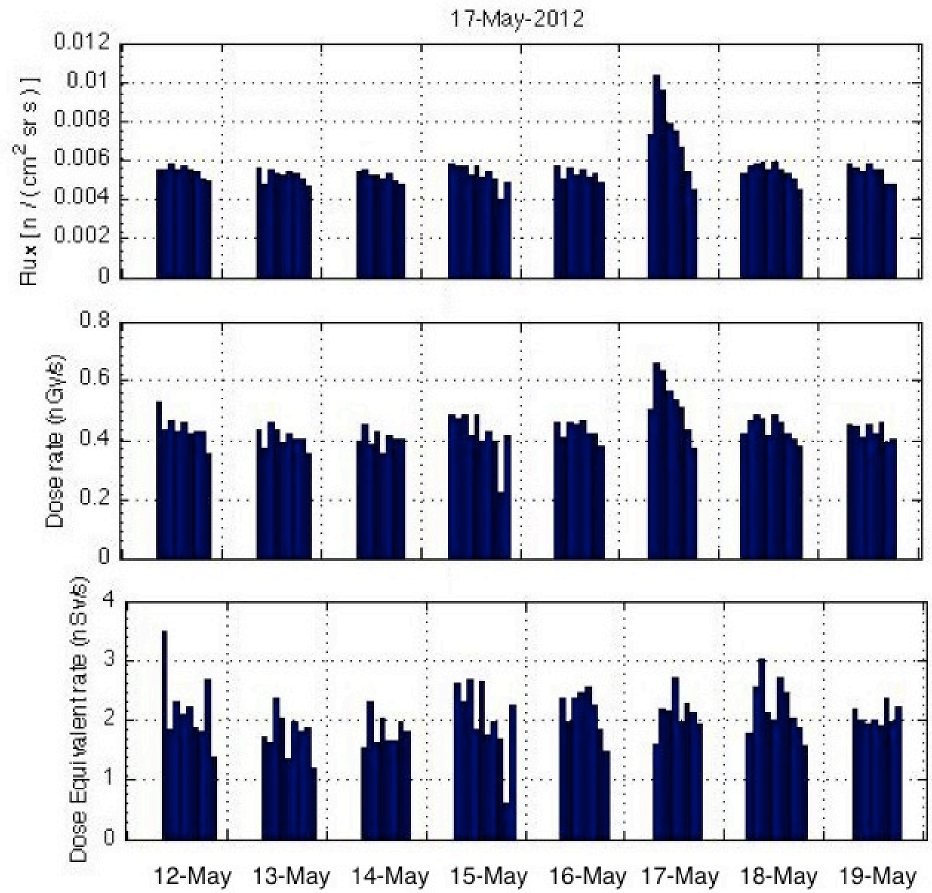
Only Pos 4 Low flux



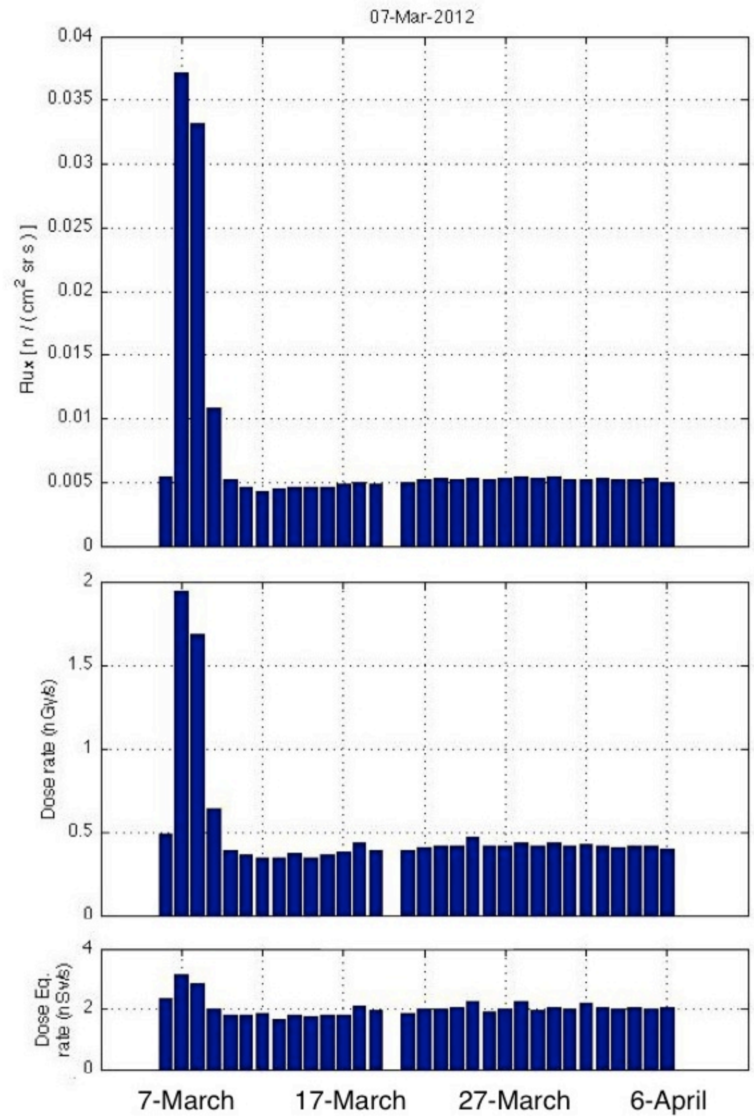
Dose and Dose Equivalent behavior

The two SPE (beside March 2012) with a non negligible dose behavior





Dose and Dose Equivalent behavior



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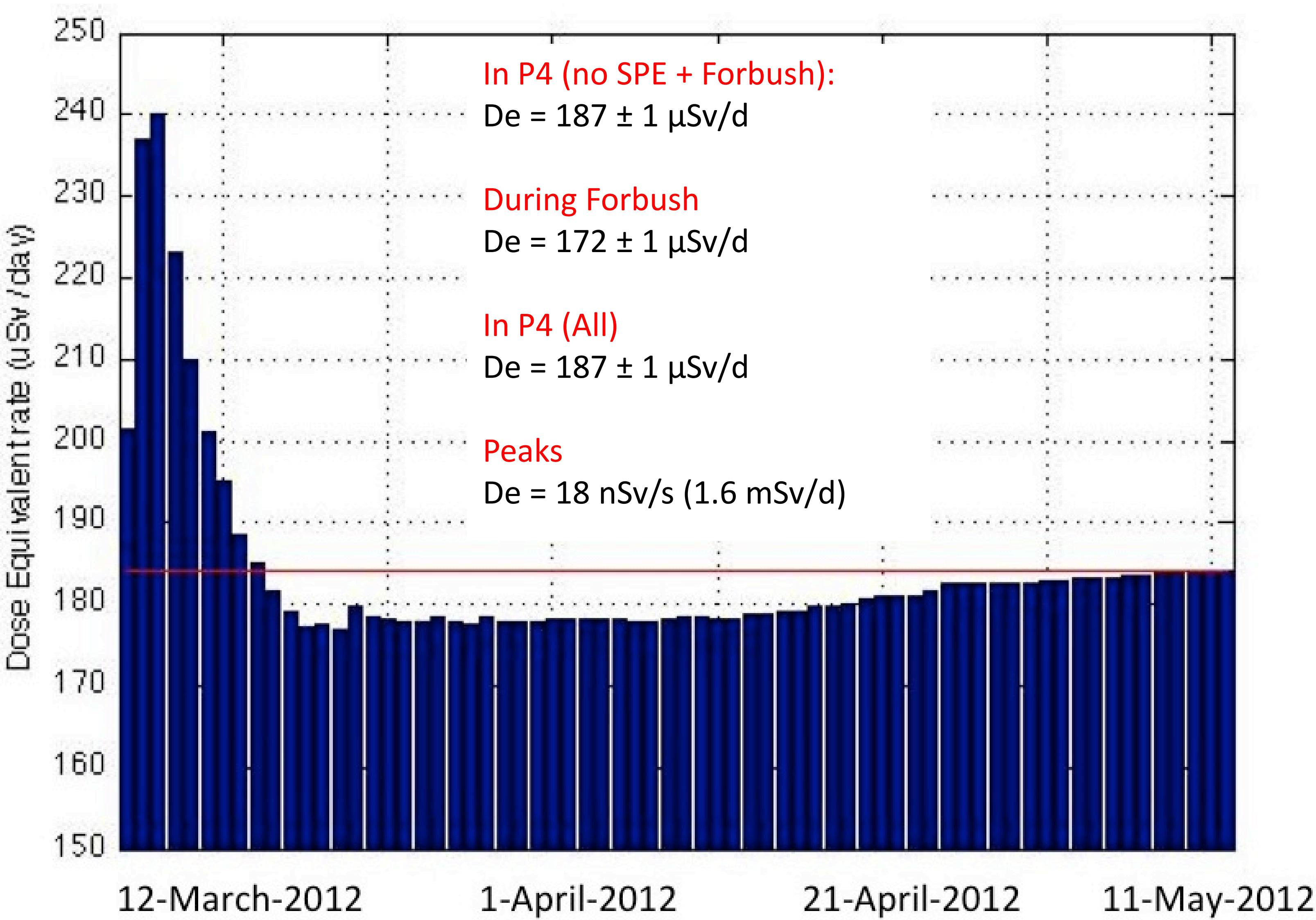
Forbush effect



Some 'conclusion'

- Influence of SPEs in the ISS shows clear and understandable general features such as the
  - monotonic - ≈ linear dependence with GOES (p>100 MeV)

- Influence of SPEs in the ISS shows *to be understood* detailed features
  - single – multi orbit responses with similar SPE (from GOES standpoint)
  - 'saturation' during March 7^{th} SPE *(first analysis: no detector rate problem)*

    important parameters may have still to be determined

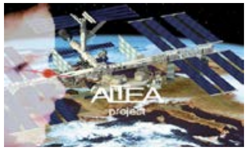
- Directions play important roles

- Simple modeling to 'select out' the GCR behavior is a good tool to search for impulsive events from active detectors data

- Forbush effects, in the reduced ALTEA proton acceptance, may balance the impulsive dose

- Several times Forbush are visible even without impulsive part

- Importance of shielding and its dynamic



The LIDAL rationale

Light Ion Detector for ALTEA: LIDAL

Rationale:
1) expand ALTEA energy acceptance window to include all H and He
2) provide if possible a direct measure of ions kinetic energy through a time of flight

The LIDAL project:
Build a system based on fast scintillator detectors to be used as ToF and as trigger for ALTEA

- Two Detector Units (**DUs**) to be positioned at the end of a Silicon Telescope (**ST: three SDUs**).
- Each DU made of thin plastic scintillators (full ST field of view covered)
- Scintillators will be segmented in the two orthogonal directions (provide first position/tracking)
- Time resolution aimed to be better then 100 ps

Back to the ALTEA acceptance

Z	%measured
1	0.024 %
2	3.2 %
>2	>99 %
All	1.3 %

Z	%measured
1	0.29 %
2	8.7 %
>2	>99 %
All	41 %

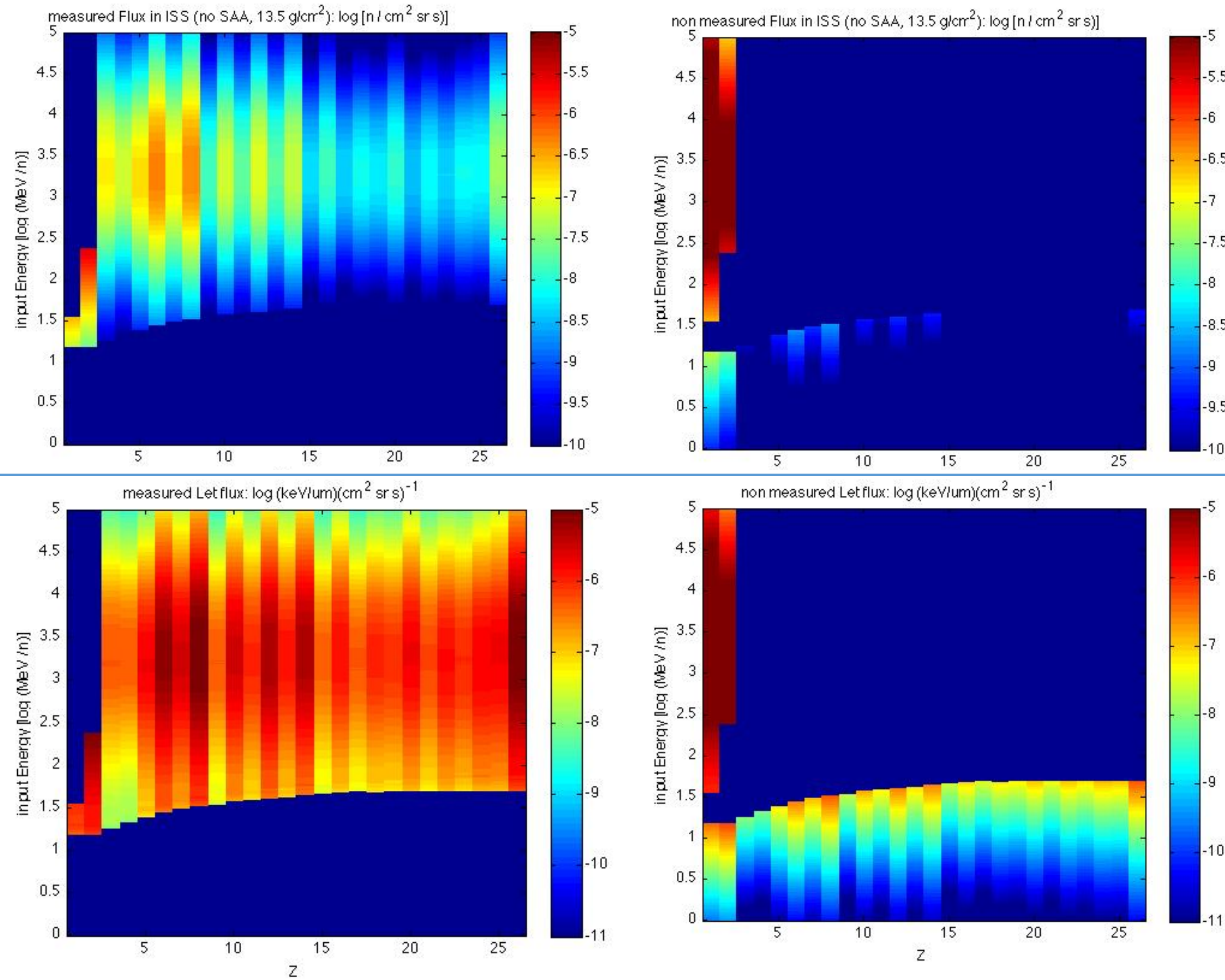
CREME model (GCR) inside the ISS + PHITS model of ALTEA

Measured by ALTEA

Not measured by ALTEA

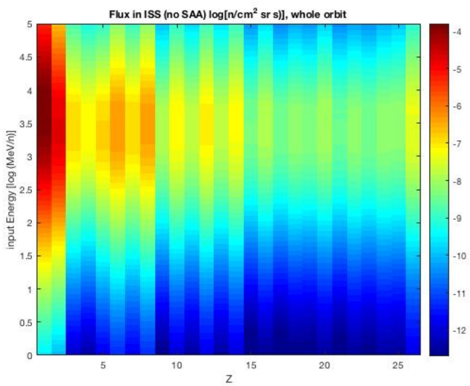
Flux

LET

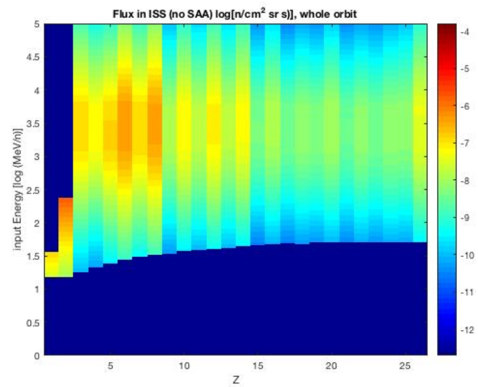


LIDAL improvements

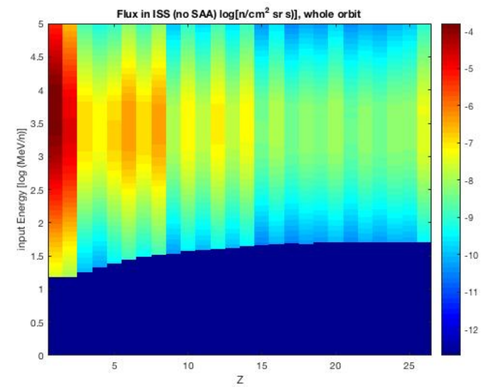
Simulated GCR flux in ISS



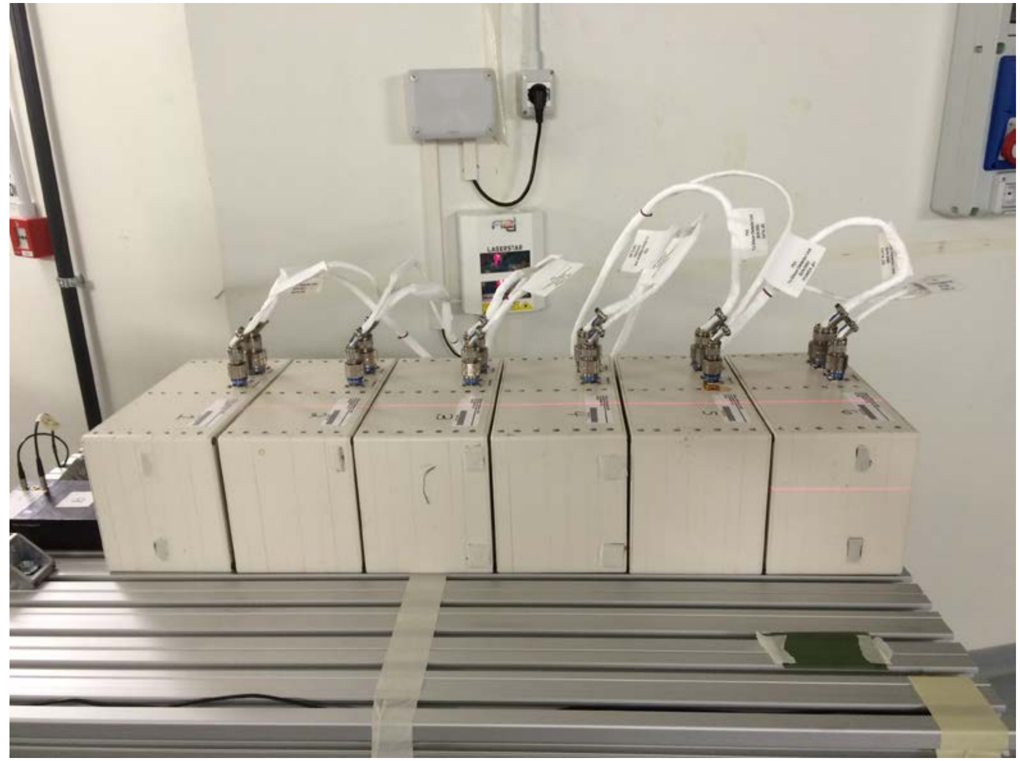
ALTEA
1 % of the flux and 41 % of the Dose.



ALTEA – LIDAL
≈100 % of the flux and ≈100 % of the Dose.



Test on proton beam



The statistical identification and the LIDAL improvement

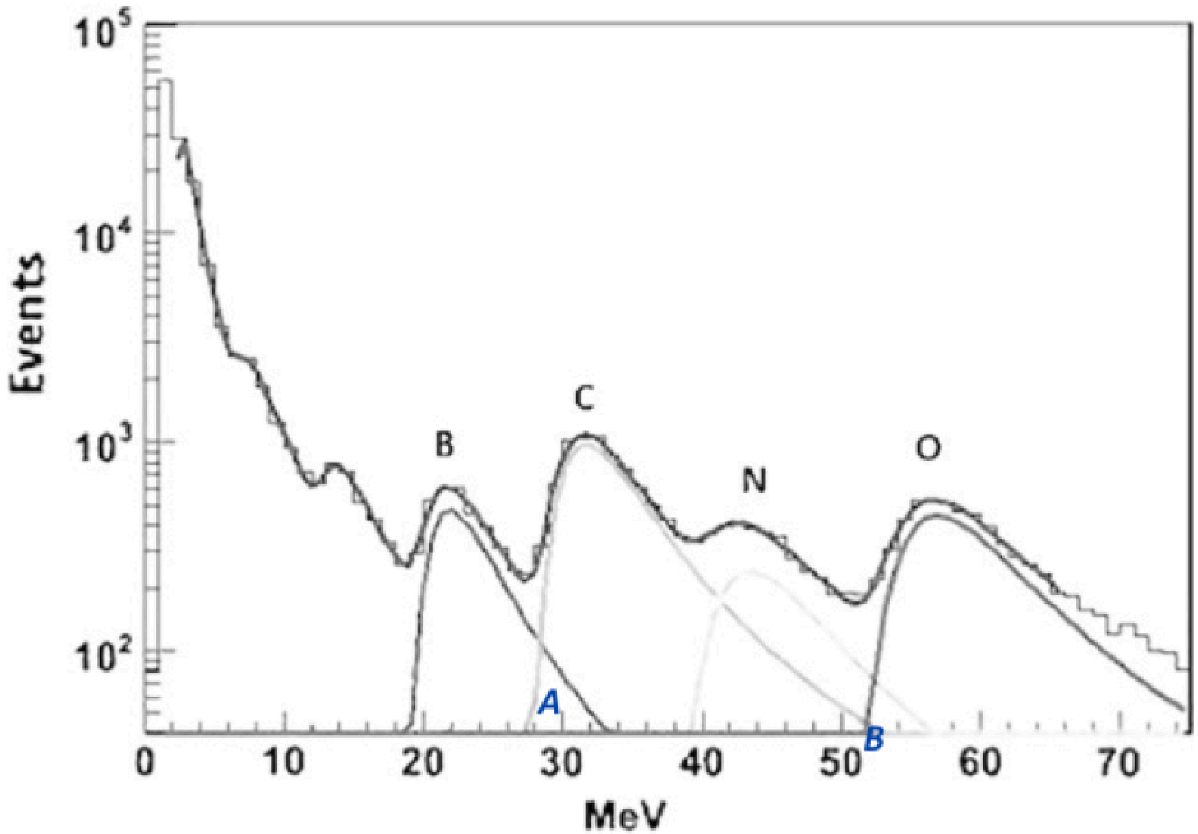


Figure 5A portion of the energy loss spectrum, simulated over the whole Silicon length (≈ 2 mm), fitted with a sum of Landau curves. Without even considering Z ≤ 4 tails in region A can be found Boron or Carbon ions, while, for example, in B, Carbon, Nitrogen or Oxygen ions. The relative population amount can be used to provide a probability for each ion (see Di Fino et al 2012).

The independent measurements of the ion velocity gives information to resolve ions in A and B

Di Fino et al Adv. Space Res. 50:408-414 (2012)

LIDAL hardware

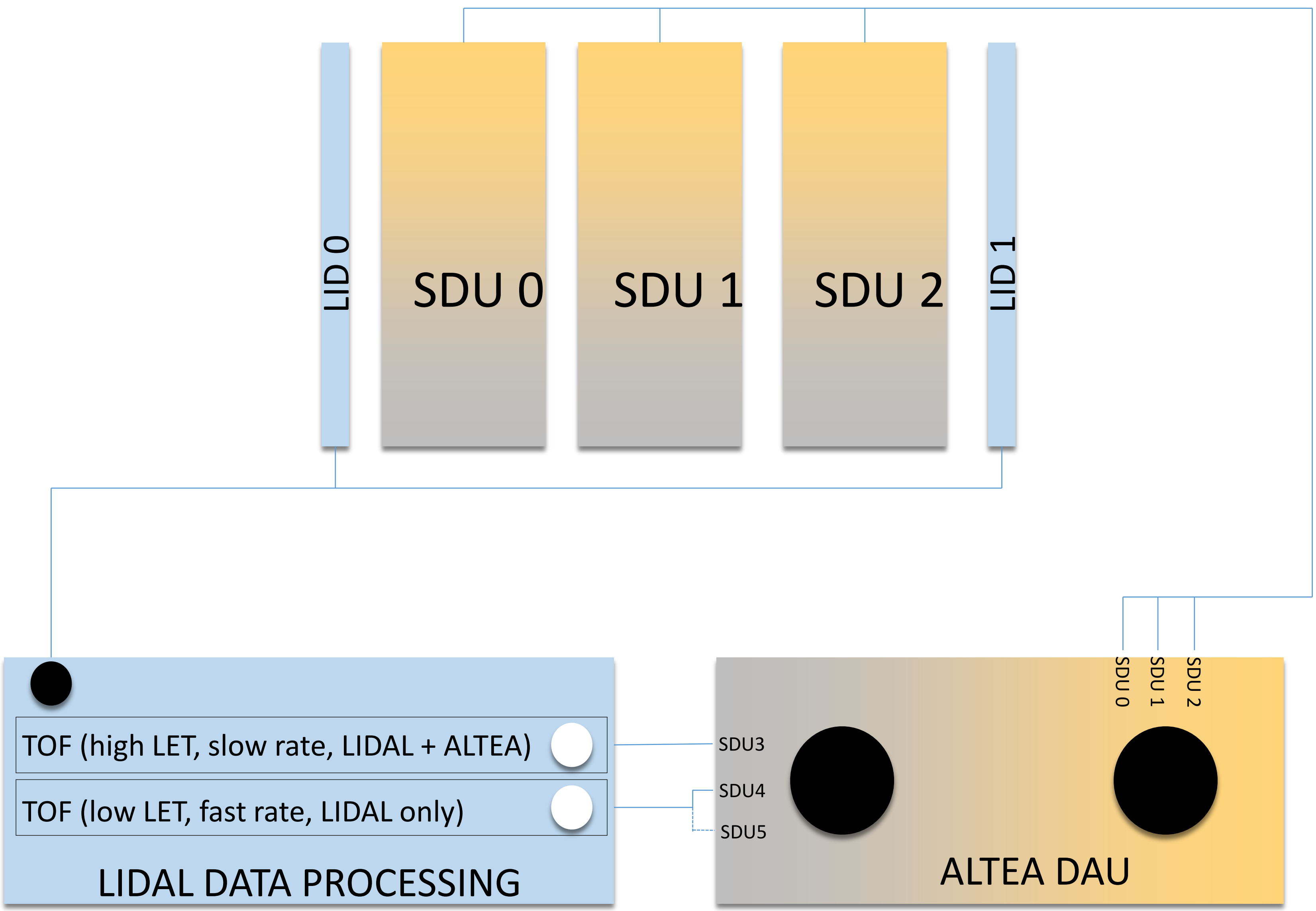
+ 2 sets of scintillators
On the two sides of the SDU stack

LIDAL are two sets of scintillators to be coupled to ALTEA to provide sensitivity to protons and Time of Flight capability

Flight hardware:

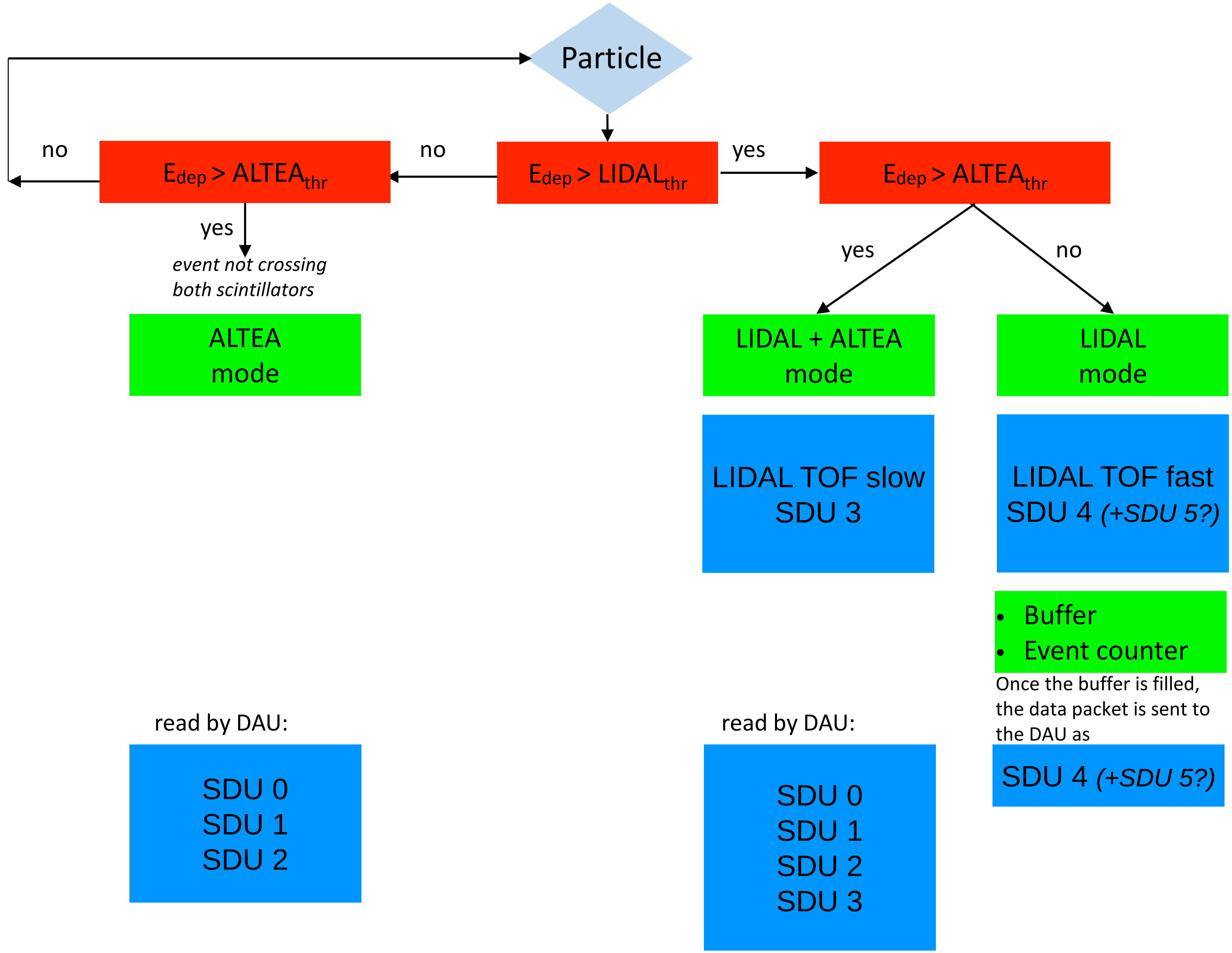
• Two detector units (approx. 240 mm x 120 mm x 60 TBC) + one control unit.
• Each detector unit includes segmented scintillators coupled to photomultipliers (compact and low powered).
• The two units will be mounted at the two sides of 3 of the ALTEA Silicon Detector Unit(s).
• The TOF system high performances guarantees a time resolution ≈ 10^2 ps.

LIDAL logic



LID 0
SDU 0
SDU 1
SDU 2
LID 1
TOF (high LET, slow rate, LIDAL + ALTEA)
TOF (low LET, fast rate, LIDAL only)
LIDAL DATA PROCESSING
SDU 0
SDU 1
SDU 2
SDU3
SDU4
SDU5
ALTEA DAU

LIDAL logic


Particle
no
E_{dep} > $ALTEA_{thr}$
no
E_{dep} > $LIDAL_{thr}$
yes
E_{dep} > $ALTEA_{thr}$
yes
event not crossing both scintillators
ALTEA mode
yes
no
LIDAL + ALTEA mode
LIDAL mode
LIDAL TOF slow SDU 3
LIDAL TOF fast SDU 4 *(+SDU 5?)*
• Buffer
• Event counter
Once the buffer is filled, the data packet is sent to the DAU as
SDU 4 *(+SDU 5?)*
read by DAU:
SDU 0
SDU 1
SDU 2
read by DAU:
SDU 0
SDU 1
SDU 2
SDU 3

Conclusion

LIDAL will provide the sensitivity to most (≈ 100%) of the relevant ions

Time of Flight will allow for a direct and independent measurement of velocity and therefore will strongly improve nuclear identification

LIDAL contract has been just signed.

Thank you for your attention!