Short-term Solar Activity Measured by AMS-02

K. Whitman, V. Bindi, C. Consolandi,
C. Corti, J. Hoffman, B. Yamashiro

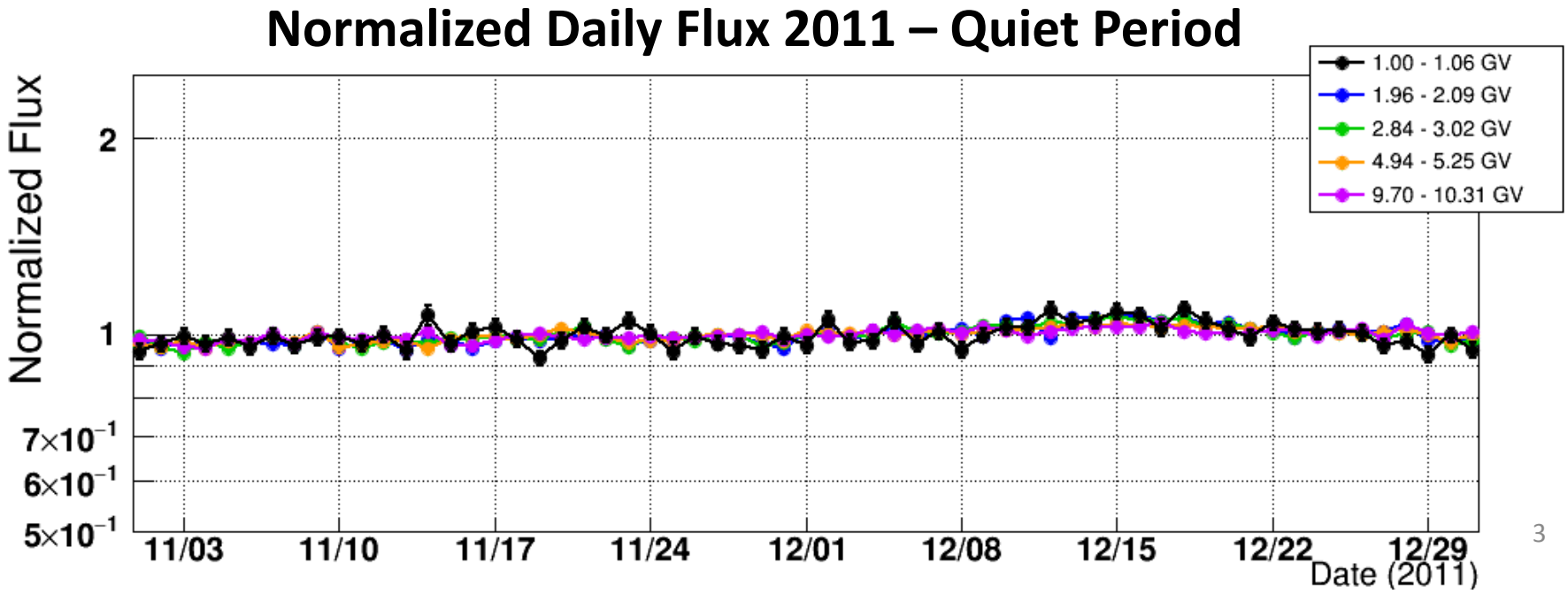
University of Hawaii at Manoa

Short-term Phenomena Observed in AMS-02 Proton Flux

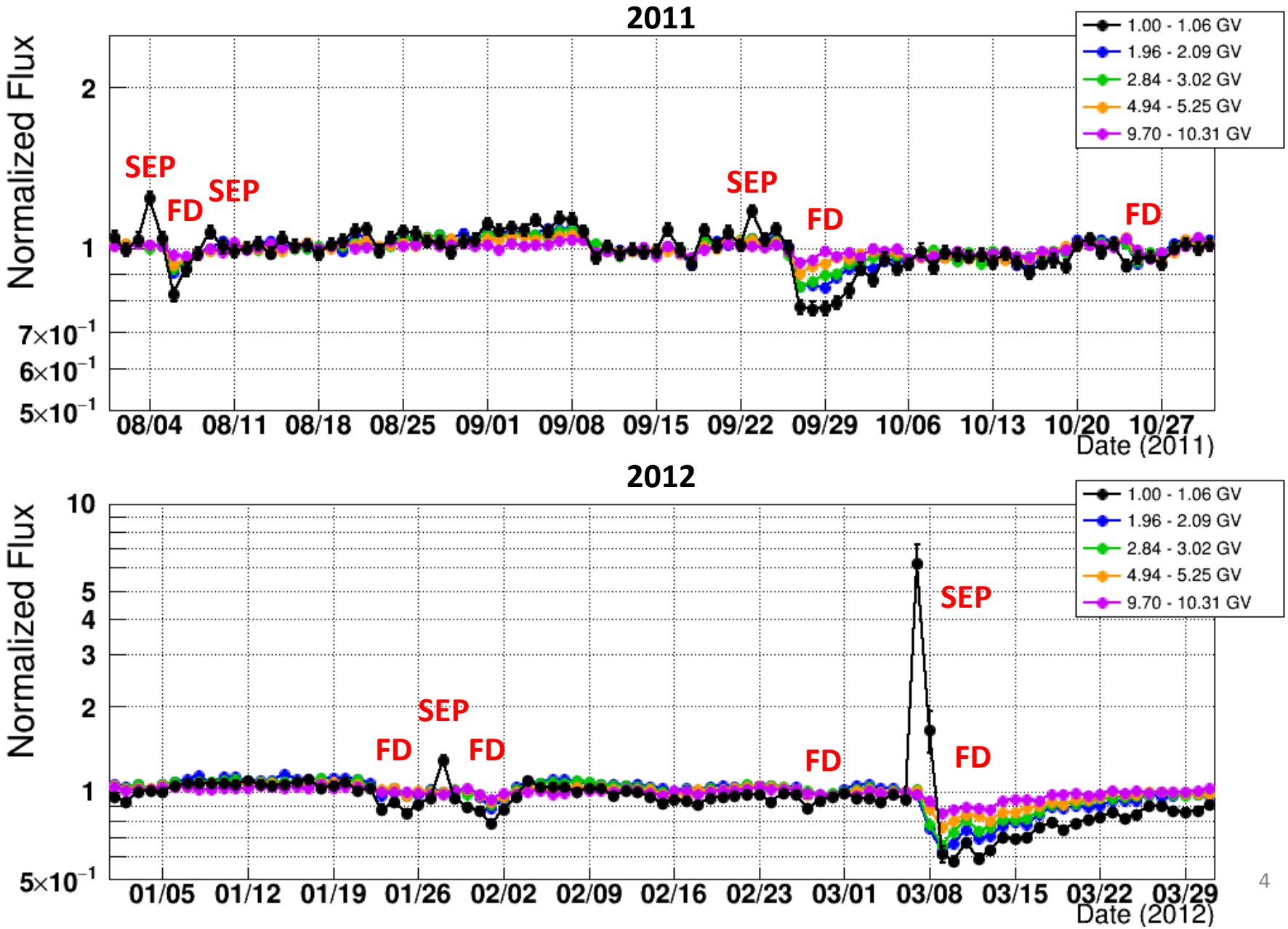
- Forbush Decreases (FD)
  - Temporary decrease in the galactic cosmic ray flux
  - Caused by a passing ICME
  - FDs observed both by satellites inside and outside the Earth's geomagnetic field
- Solar Energetic Particles (SEP)
  - Temporary increase in particle flux typically < 1 – 2 GV
  - M- and X-class flares and high speed coronal mass ejections (CME) generate SEP events measured by AMS-02

Normalized Daily Flux

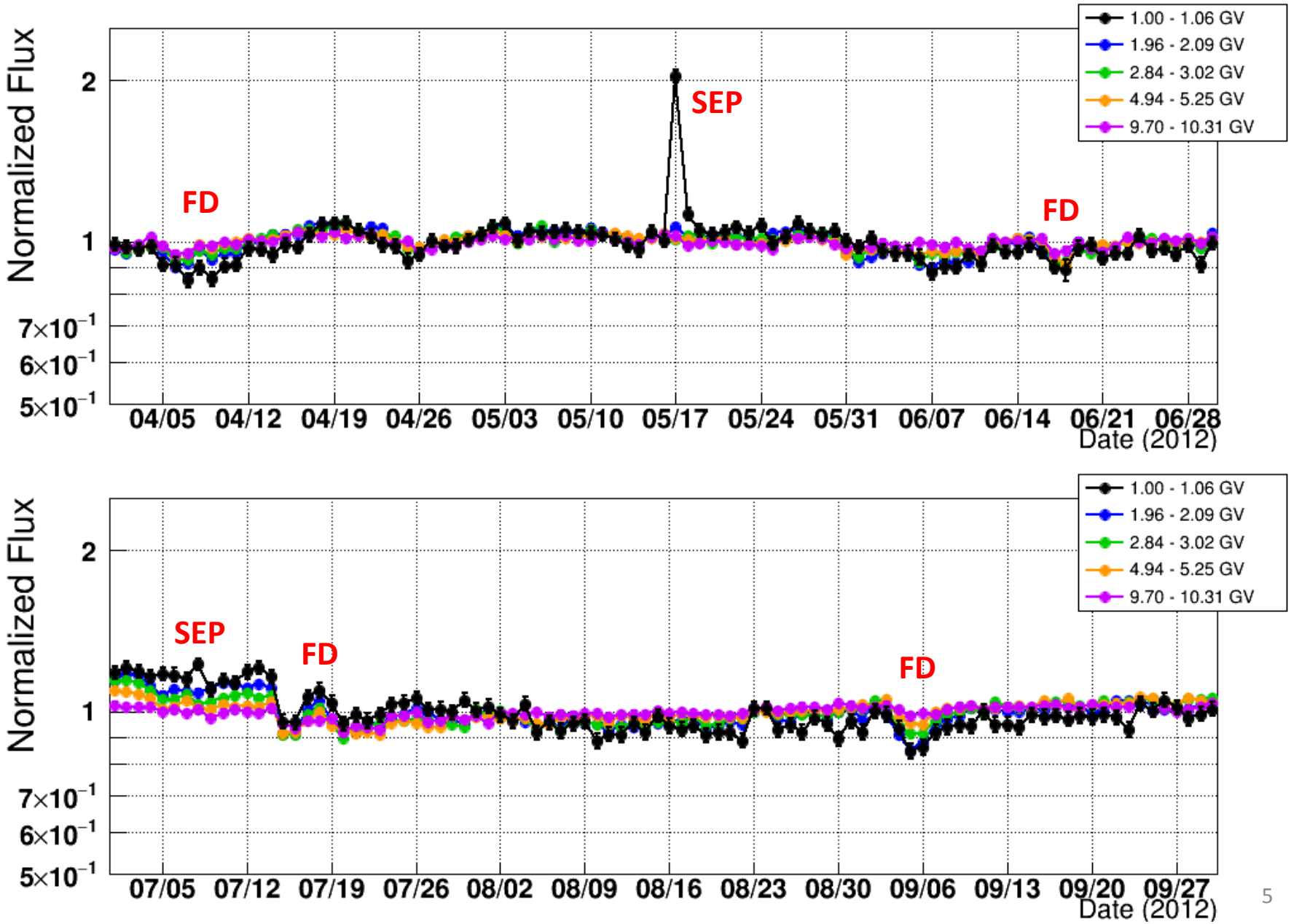
- Time periods of ~3 months
- Flux is normalized by the average of each time period
- Selected rigidities from 1 – 10 GV
- Labels indicate confirmed FD and confirmed SEP events



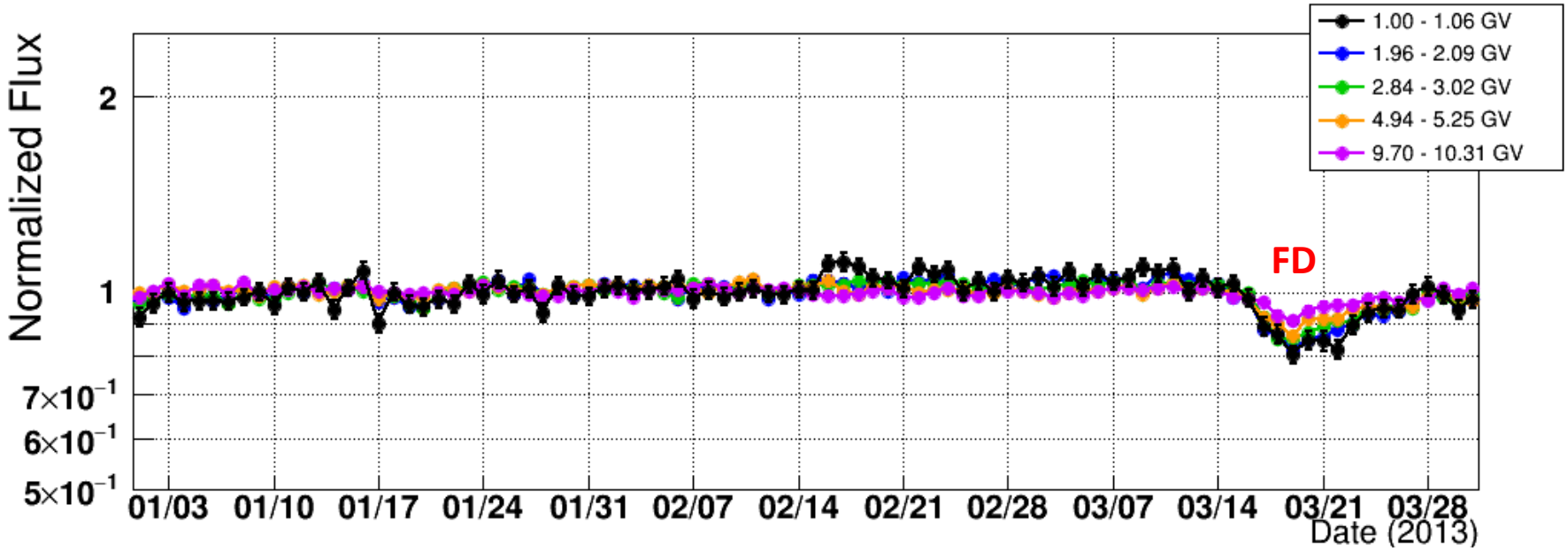
Normalized Daily Flux

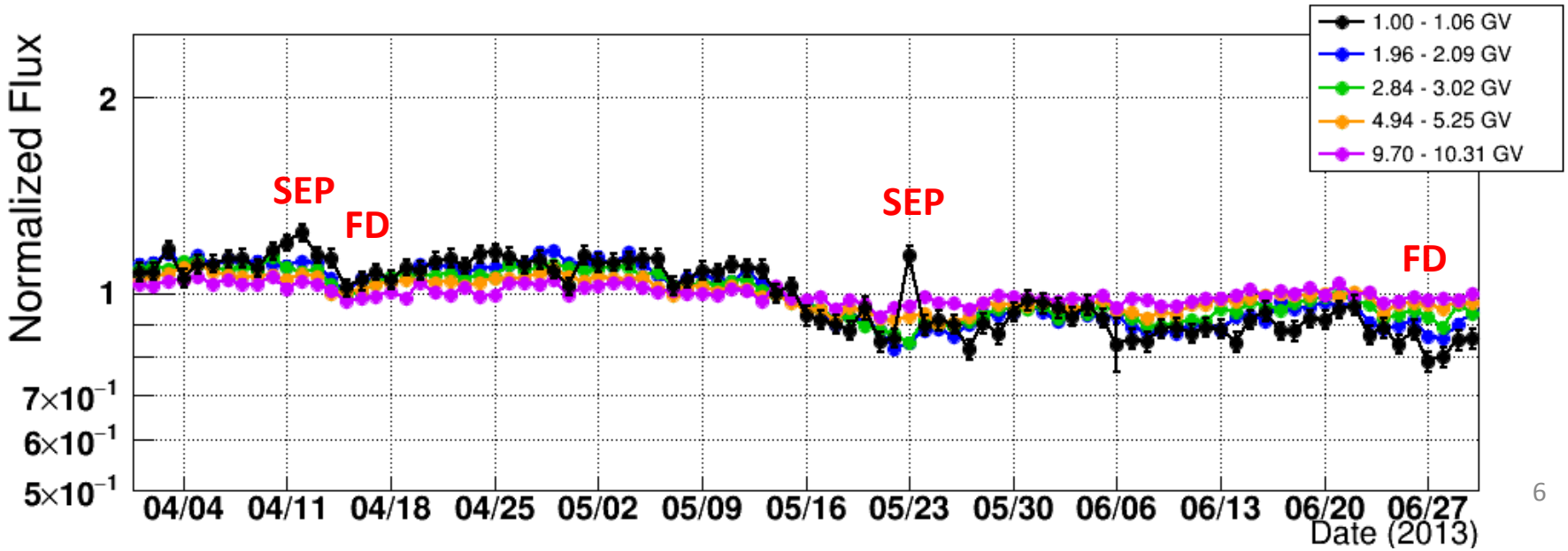


Normalized Daily Flux 2012



Normalized Daily Flux 2013





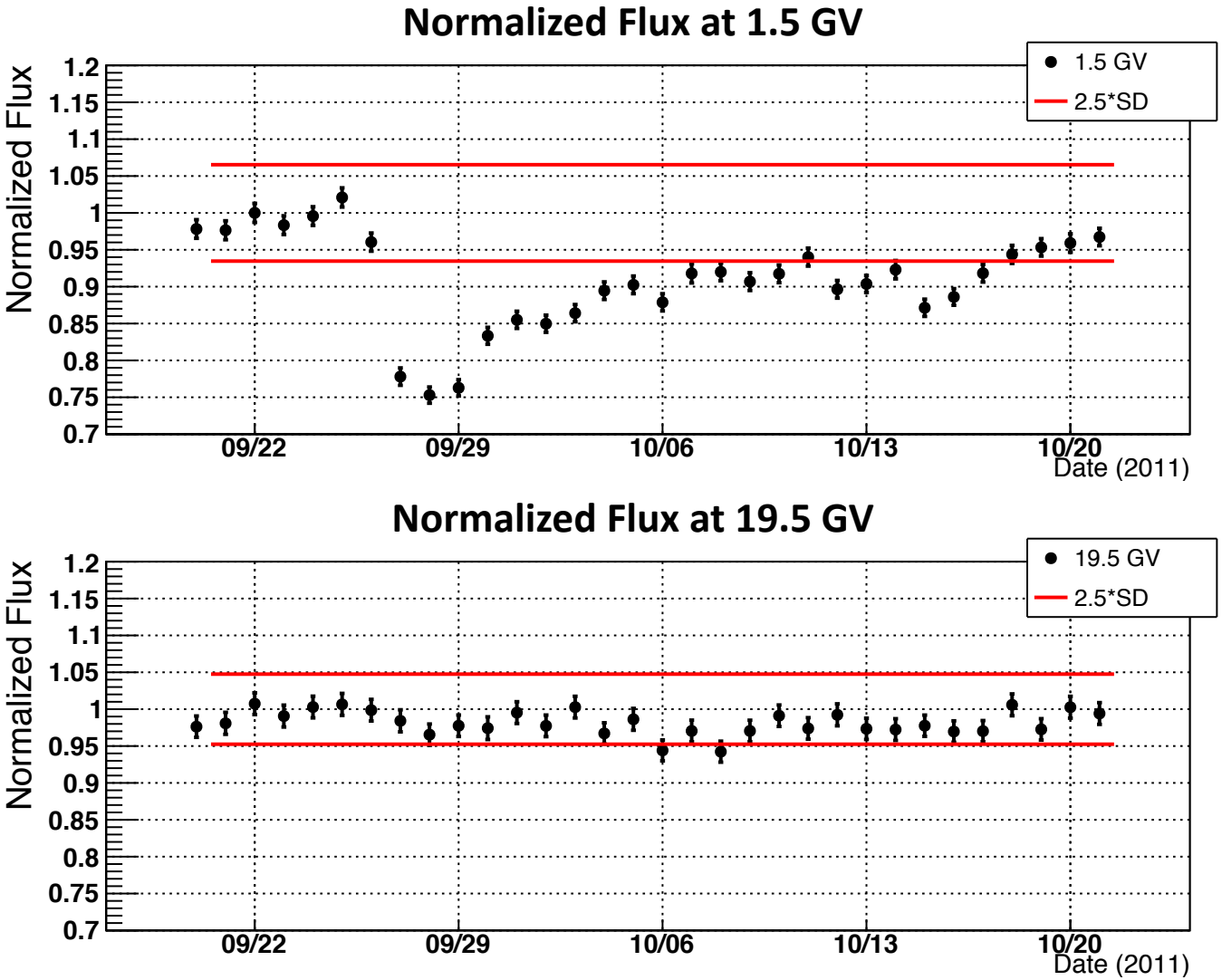
FORBUSH DECREASES

Characterize Day-to-Day Variability

- Select “quiet” periods of time similar in duration to FDs (~ 1 month x 6)
- Normalize flux to first 72 hours of time period, as done for FDs
- For each time period, generate a flux distribution at each rigidity
- Calculate the mean and standard deviation σ(R) for each distribution
- Find the average σ(R)

Identifying a Decrease in Flux

Example: September 26, 2011



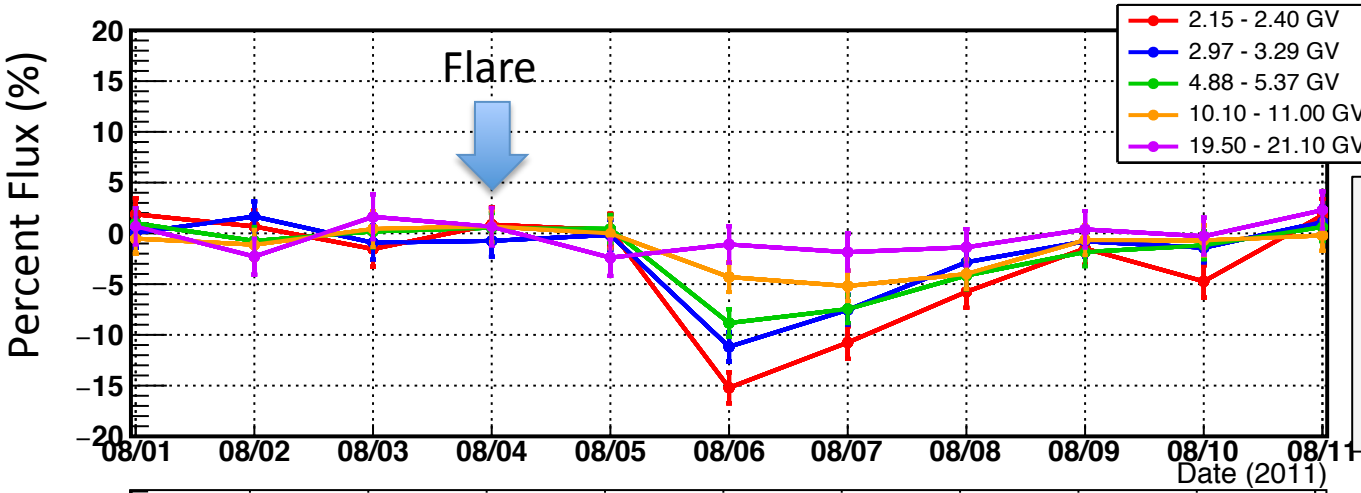
1) Normalize flux by average flux 72 hours prior to decrease

2) For each rigidity, identify decreases that exceed 2.5σ(R)

3) Estimate date of recovery when flux no longer exceeds 2.5σ(R)

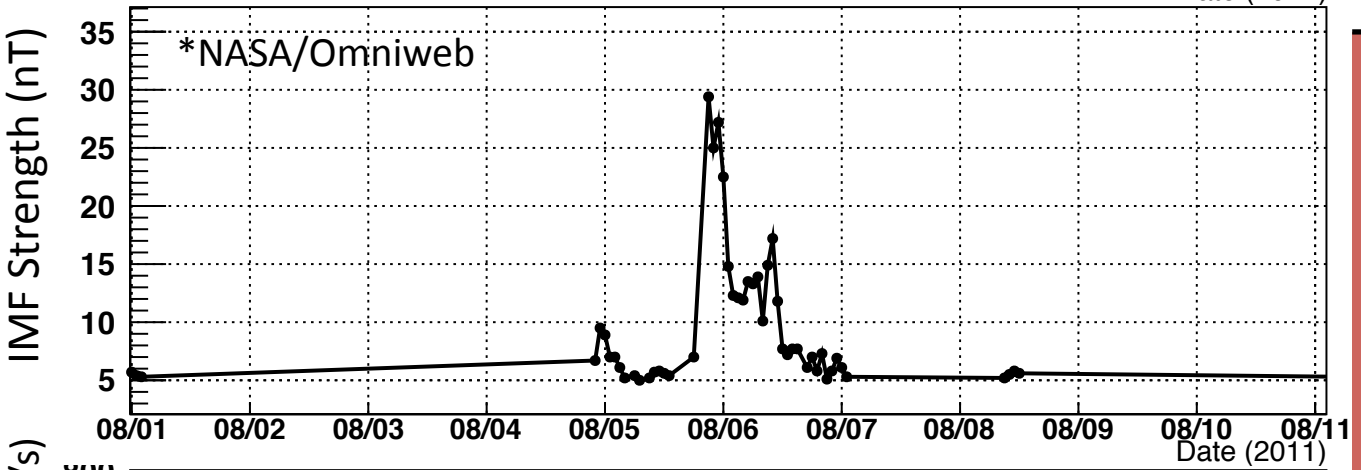
Forbush Decrease Characteristics

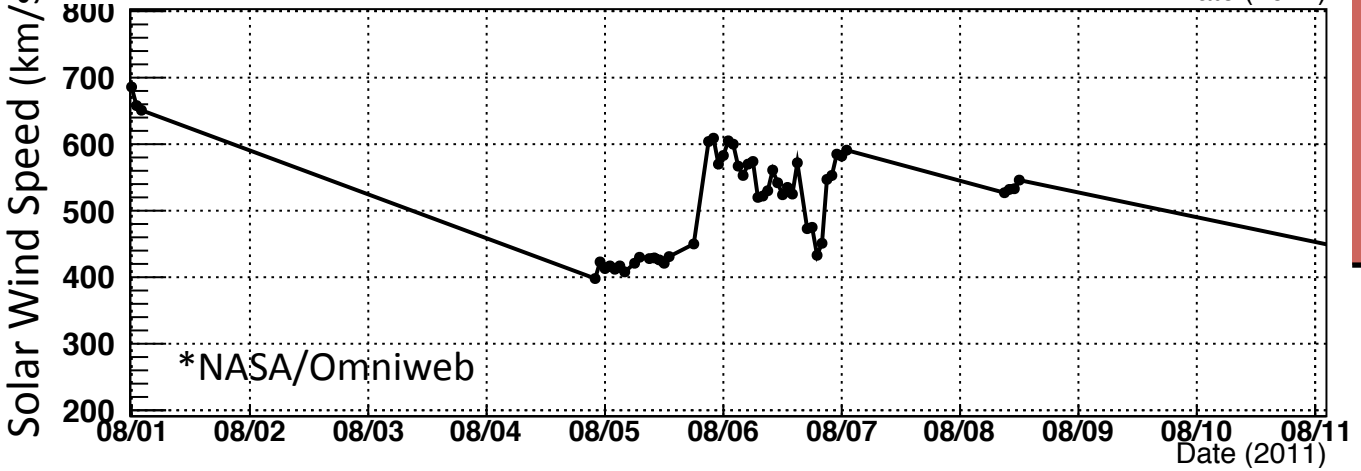
- **Start Date:** date that decrease is first observed at low rigidities
- **Date of Minimum:** date that majority of rigidities reach a minimum value
- **Recovery Date:** date when normalized flux at middle rigidity for each event > 1. - 2.5σ
- **Duration:** number of days a decrease is observed at a middle rigidity
- **Maximum Rigidity:** highest rigidity that shows a real decrease, *i.e.* normalized flux < 1. - 2.5σ
- **Maximum Decrease:** Percent decrease of the flux at 2 GV on the date of the minimum
  Percent Decrease = (1. – normalized flux) * 100%



Forbush Decrease Aug 6, 2011

*Errors include systematic and statistical errors.

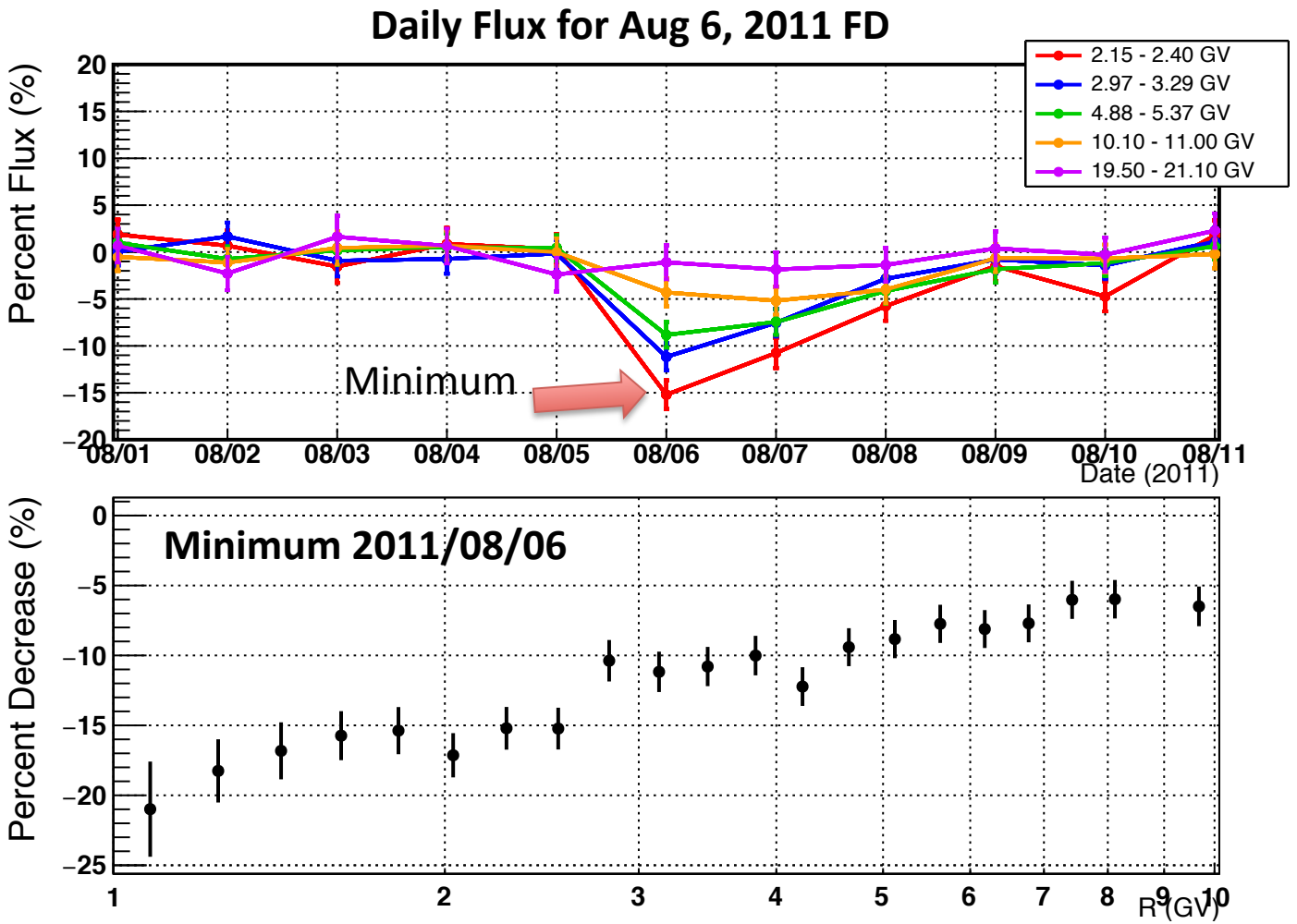


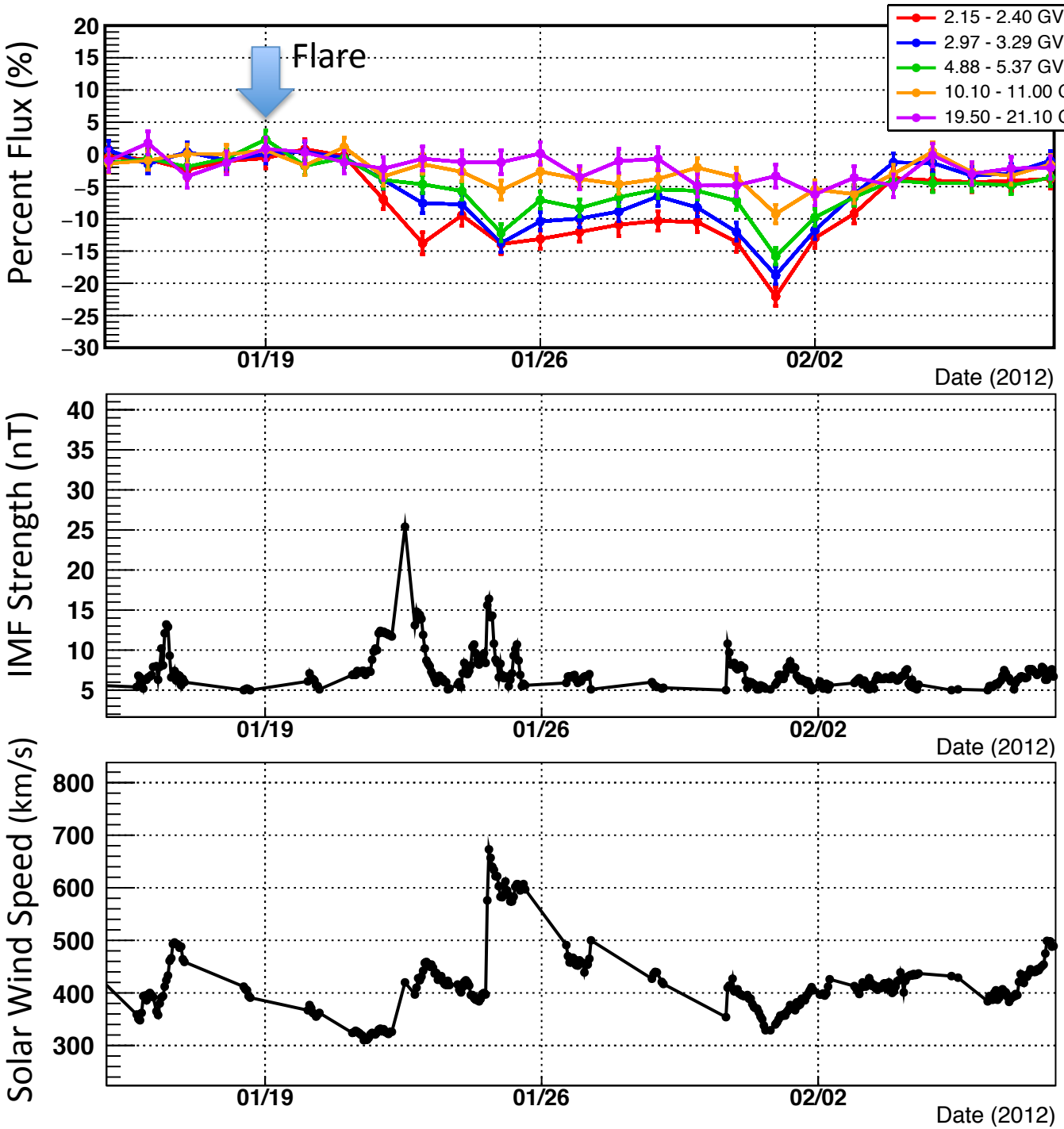


Flare Date	2011/08/04
Flare Class	M9.3
CME	1315 km/s
Location	N19W36
Max IMF	29 nT
Addl CMEs	None

Forbush Decrease August 6, 2011

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2011/08/06	2011/08/06	2011/08/08	2 days	9 GV	17%



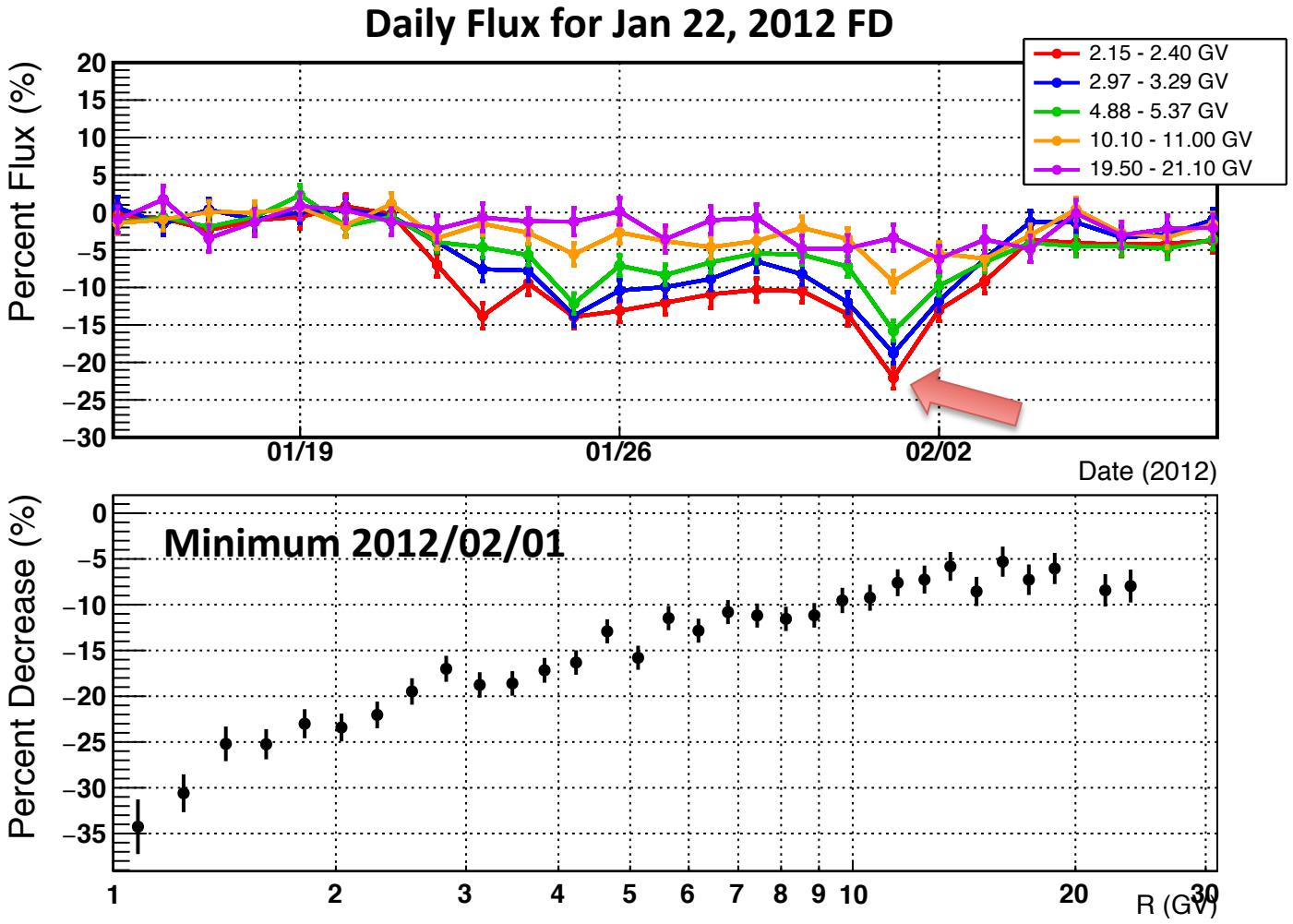


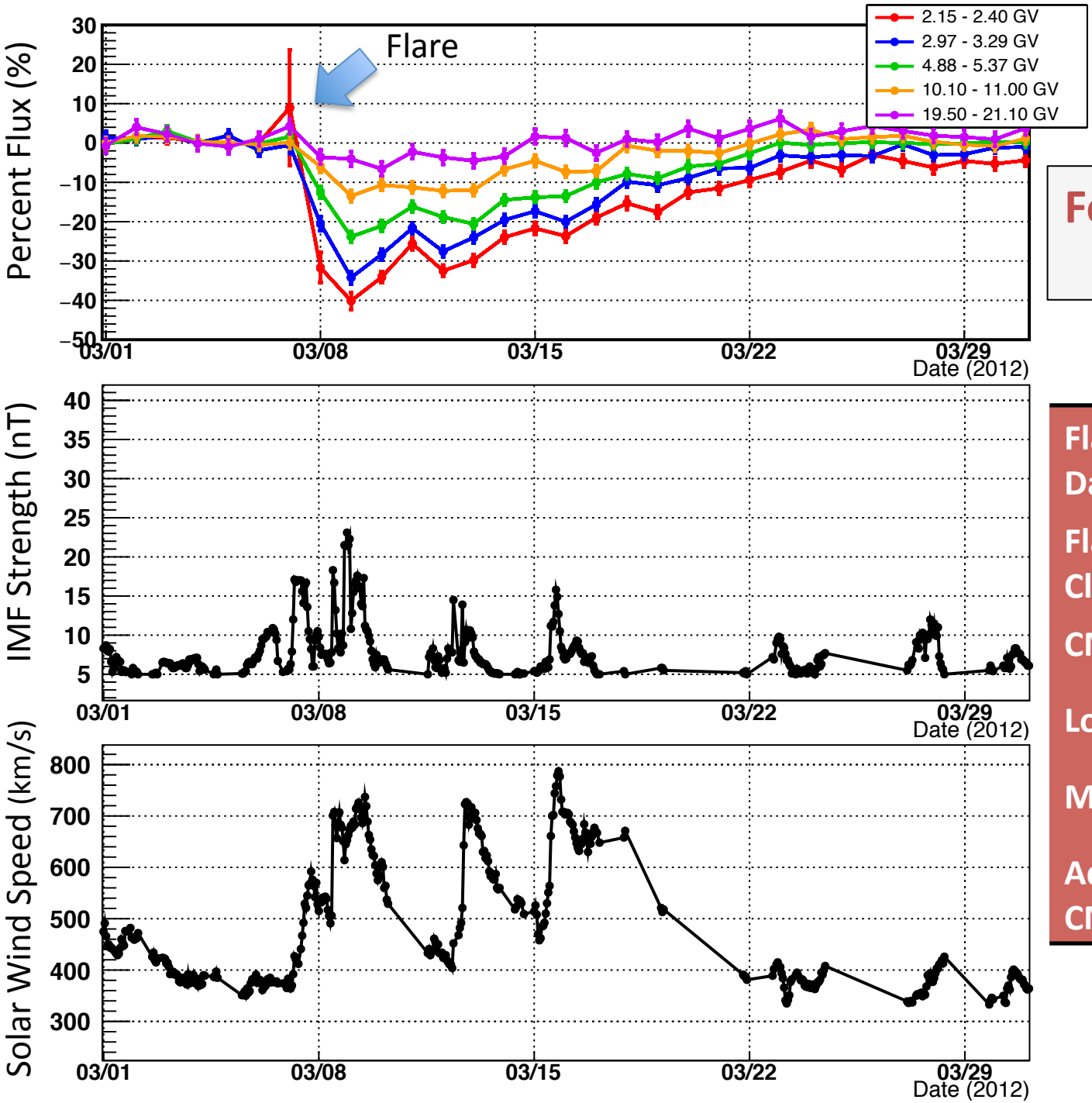
Forbush Decrease Jan 22, 2012

Flare Date	2012/01/19
Flare Class	M3.2
CME	1120 km/s
Location	N32E22
Max IMF	27 nT
Addl CMEs	1/23, 1/26, and 1/27

Forbush Decrease January 22, 2012

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2012/01/22	2012/02/01	2012/02/04	12 days	23 GV	23%



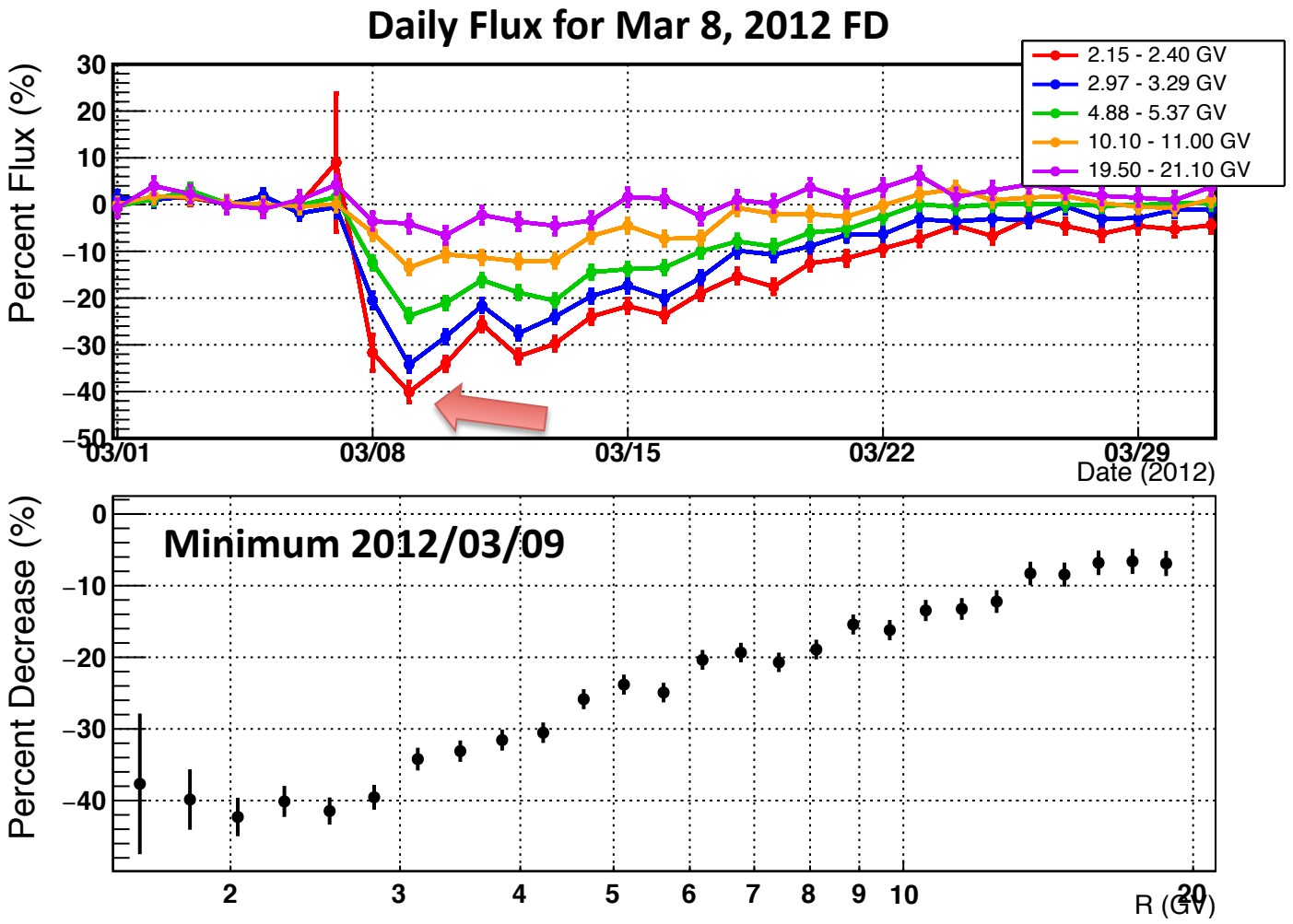


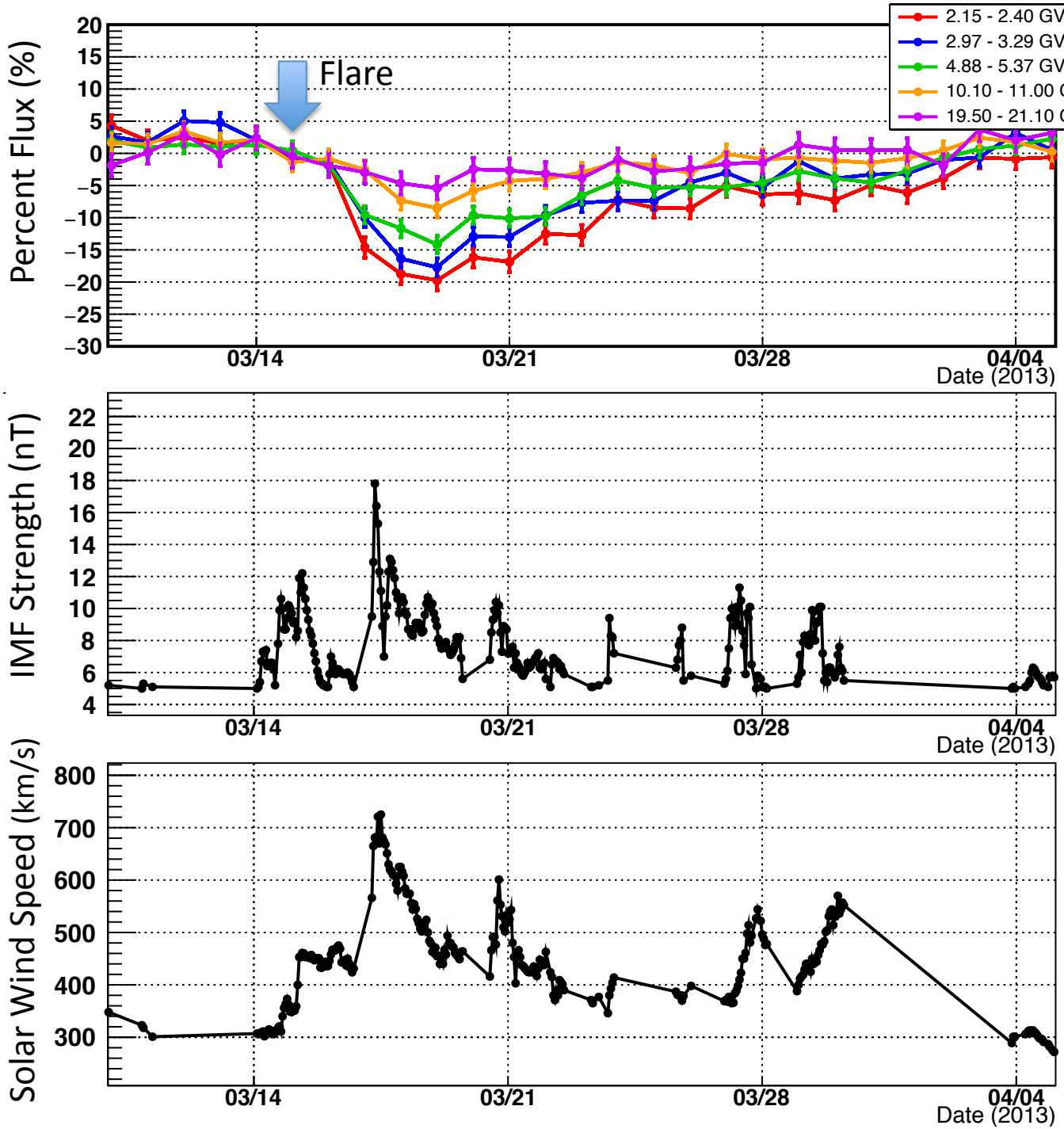
Forbush Decrease
Mar 8, 2012

Flare Date	2012/03/07
Flare Class	X5.4, X1.3
CME	2684, 1825
Location	N22E12
Max IMF	23 nT
Addl CMEs	3/9, 3/10, and 3/13

Forbush Decrease March 8, 2012

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2012/03/08	2012/03/09	2012/03/22	14 days	18 GV	**42%**



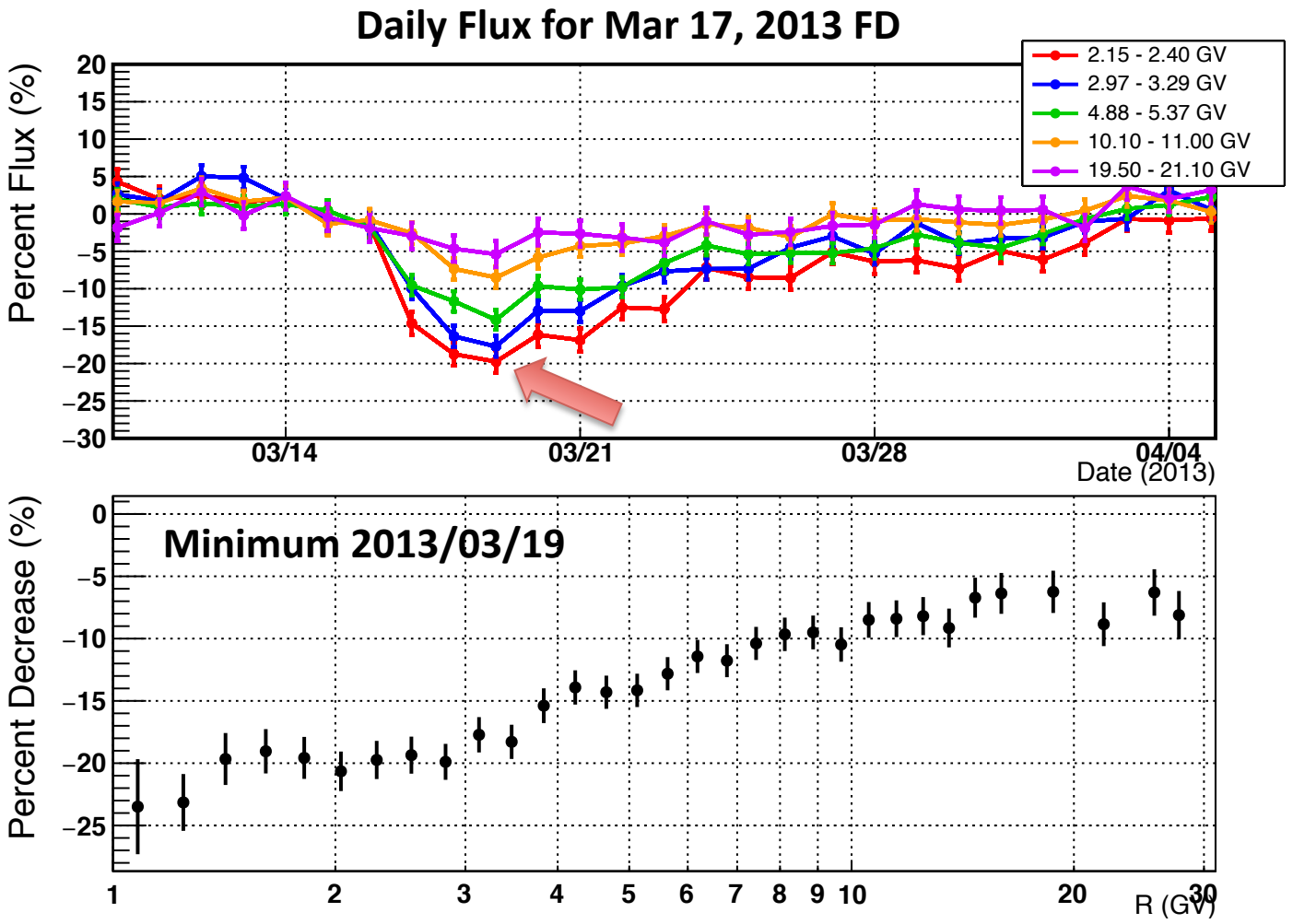


Forbush Decrease
Mar 17, 2013

Flare Date	2013/03/15
Flare Class	M1.1
CME	1063 km/s
Location	N11E12
Max IMF	18 nT
Addl CMEs	none

Forbush Decrease March 17, 2013

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2013/03/17	2013/03/19	2013/03/28	11 days	**26 GV**	20%



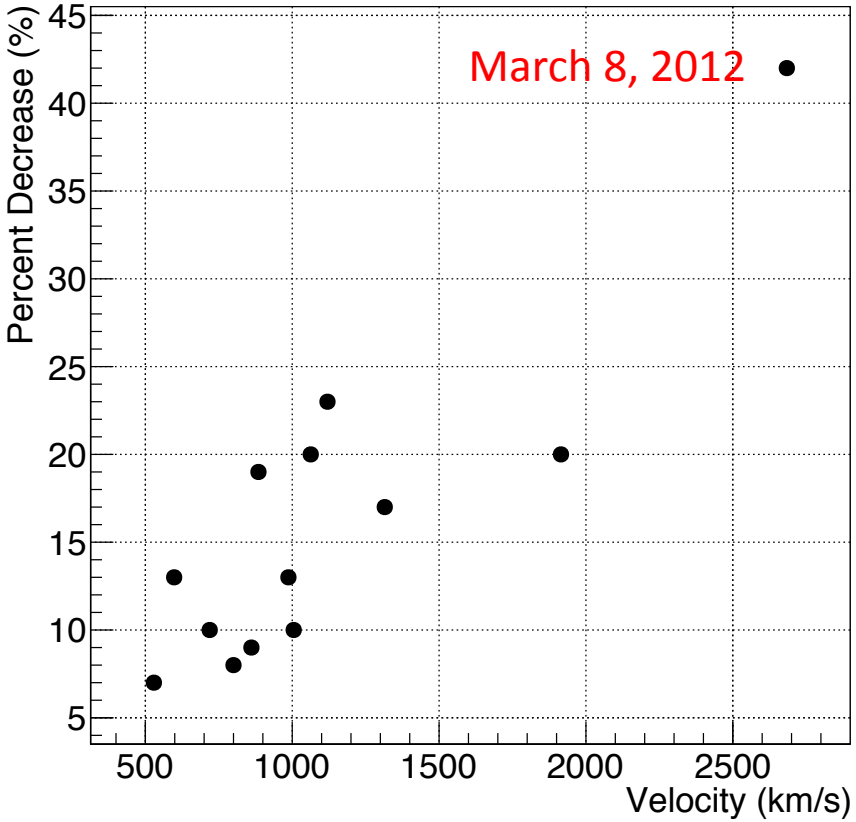
Confirmed FD Observed by AMS-02

May 5, 2011 – Nov 26, 2013

Start Date	Minimum	Recovery	Duration	Max Rigidity	Max Decrease - 2GV
2011/06/24	2011/06/24	2011/06/26	2 days	7 GV	10% ± 1.5%
2011/08/06	2011/08/06	2011/08/08	2 days	9 GV	17% ± 1.5%
2011/09/26	2011/09/27	2011/10/18	**22 days**	14 GV	20% ± 1.5%
2011/10/25	2011/10/25	2011/10/28	3 days	12 GV	10% ± 1.5%
2012/01/22	2012/02/01	2012/02/04	12 days	23 GV	23% ± 1.5%
2012/02/27	2012/02/27	2012/03/01	3 days	10 GV	8% ± 1.5%
2012/03/08	2012/03/09	2012/03/22	14 days	18 GV	**42% ± 3%**
2012/04/06	2012/04/06	2012/04/08	2 days	3 GV	8% ± 1.5%
2012/06/17	2012/06/18	2012/06/19	2 days	9 GV	13% ± 2%
2012/07/15	2012/07/16	2012/07/26	11 days	11 GV	19% ± 1.5%
2012/09/04	2012/09/05	2012/09/07	3 days	11 GV	13% ± 1.5%
2012/11/24	2012/11/25	2012/11/26	2 days	8 GV	7% ± 1.5%
2013/03/17	2013/03/19	2013/03/28	11 days	**26 GV**	20% ± 1.5%
2013/04/15	2013/04/15	2013/04/17	2 days	11 GV	9% ± 1.5%
2013/06/23	2013/06/28	2013/06/30	7 days	8 GV	12% ± 1.5%

Correlation with CME Velocity

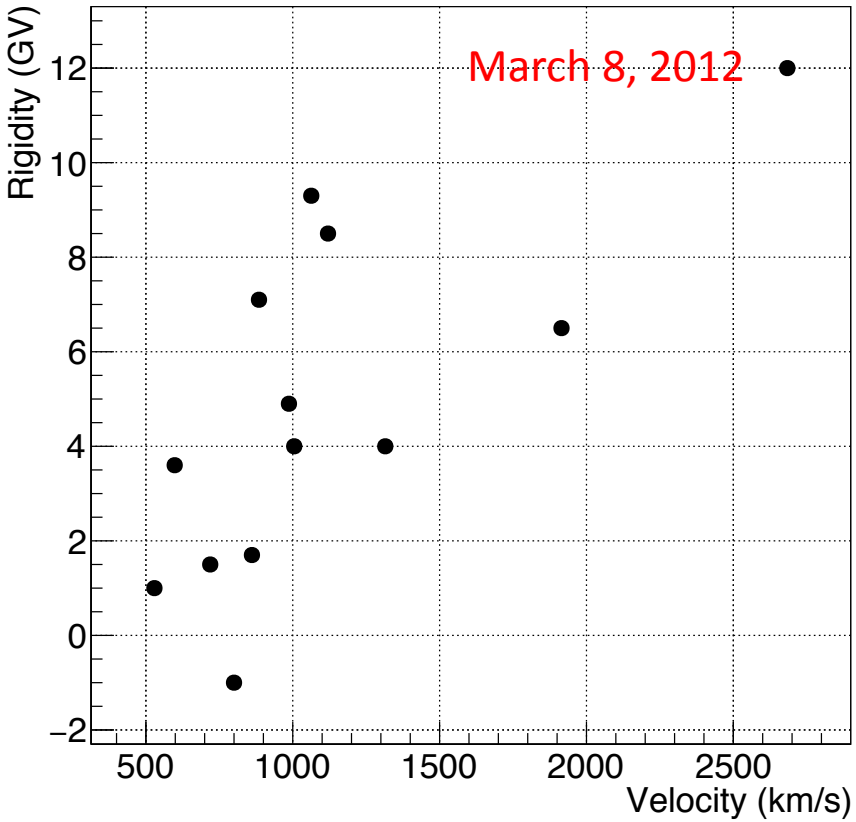
CME Velocity vs. Max % Decrease (2 GV)



Correlation Factor = 0.86

Greater CME velocity implies deeper FD

CME Velocity vs. Max Rigidity (> 10% Decrease)



Correlation Factor = 0.71

Greater CME velocity implies higher maximum rigidity

Force Field Parameterization Applied to FD

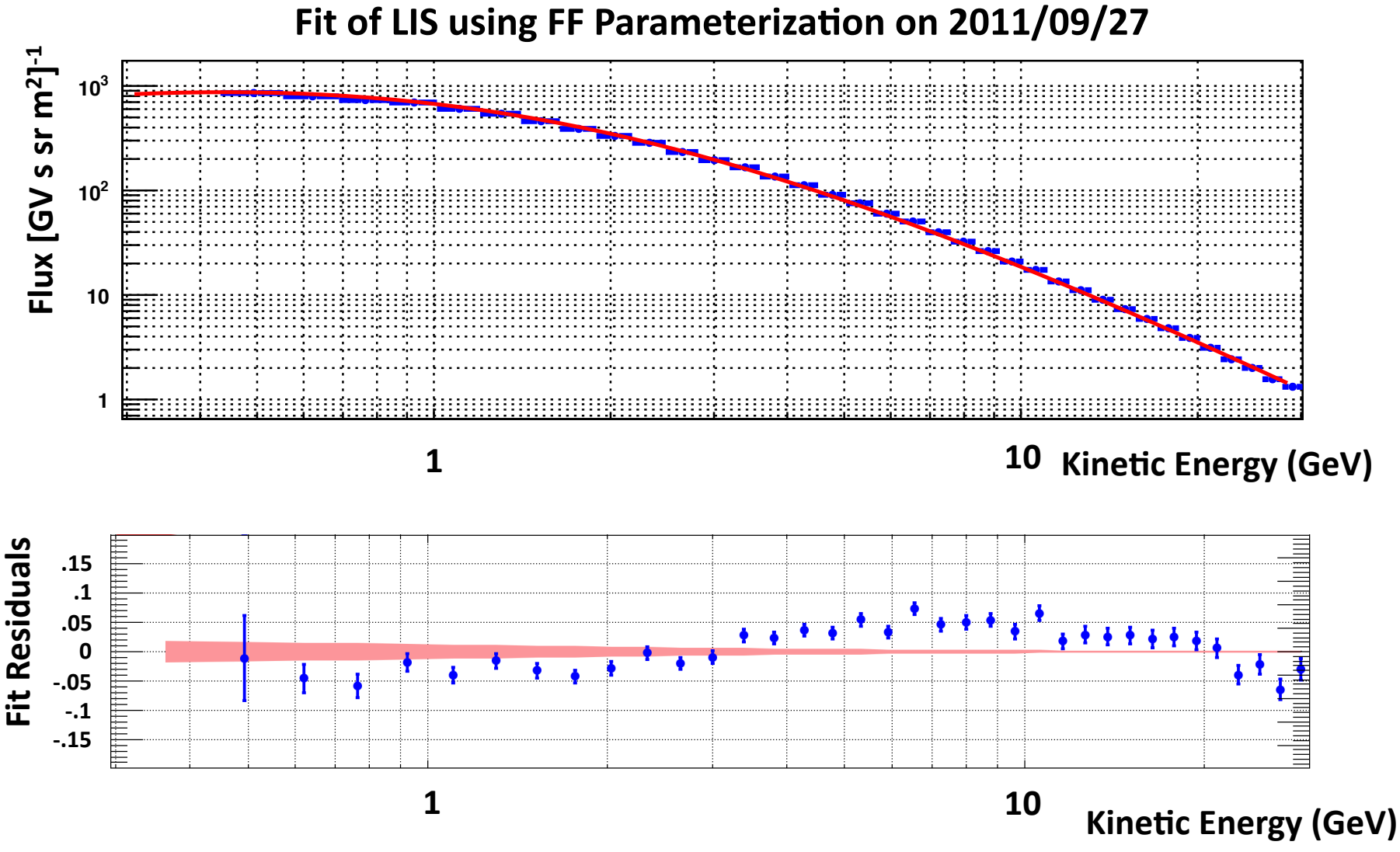
- PAMELA collaboration analyzed a FD in Dec 2006 and found that the force-field parameterization could be applied
- Fit to AMS-02 observed FD
  - Local interstellar spectrum (LIS) defined in Usoskin et al. 2005
  - Fit LIS to daily proton spectrum in kinetic energy with:

$$\mathrm{F}_{\mathrm{Earth}}(T,t) = \frac{T(T+2M)}{(T+\Phi(t))(T+\Phi(t)+2M)} F_{LIS}(T+\Phi(t))$$

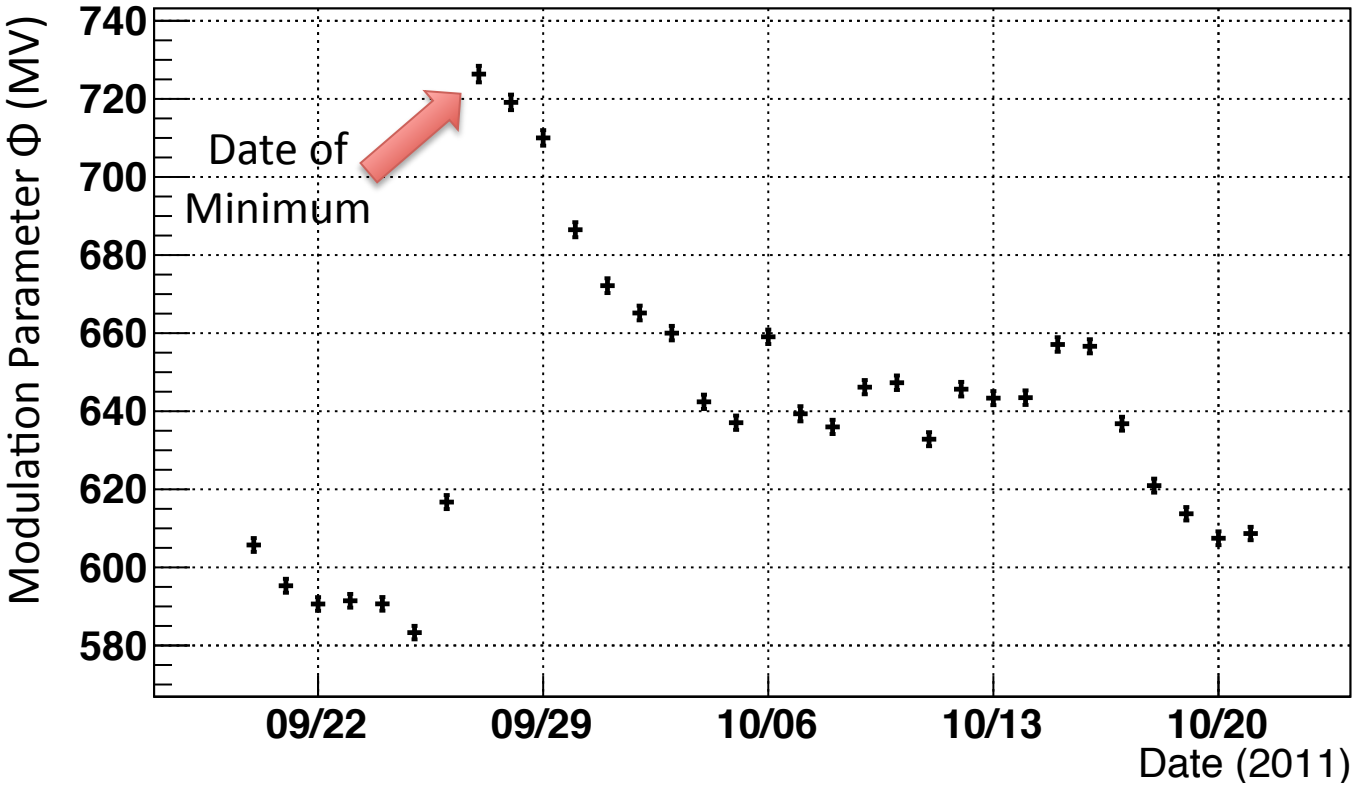
Where T = kinetic energy, M = proton mass, Φ solar modulation parameter or potential, and F_{LIS} is the LIS

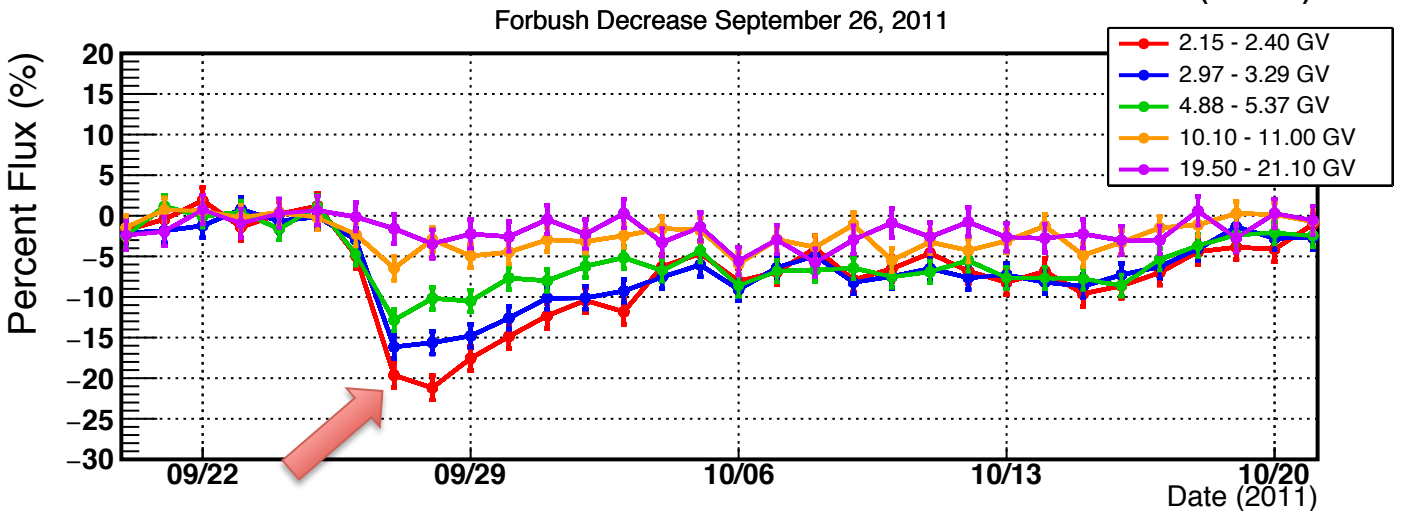
  - Φ, the potential, is the only free parameter in the fit

Fit of Force Field Parameterization to FD Minimum

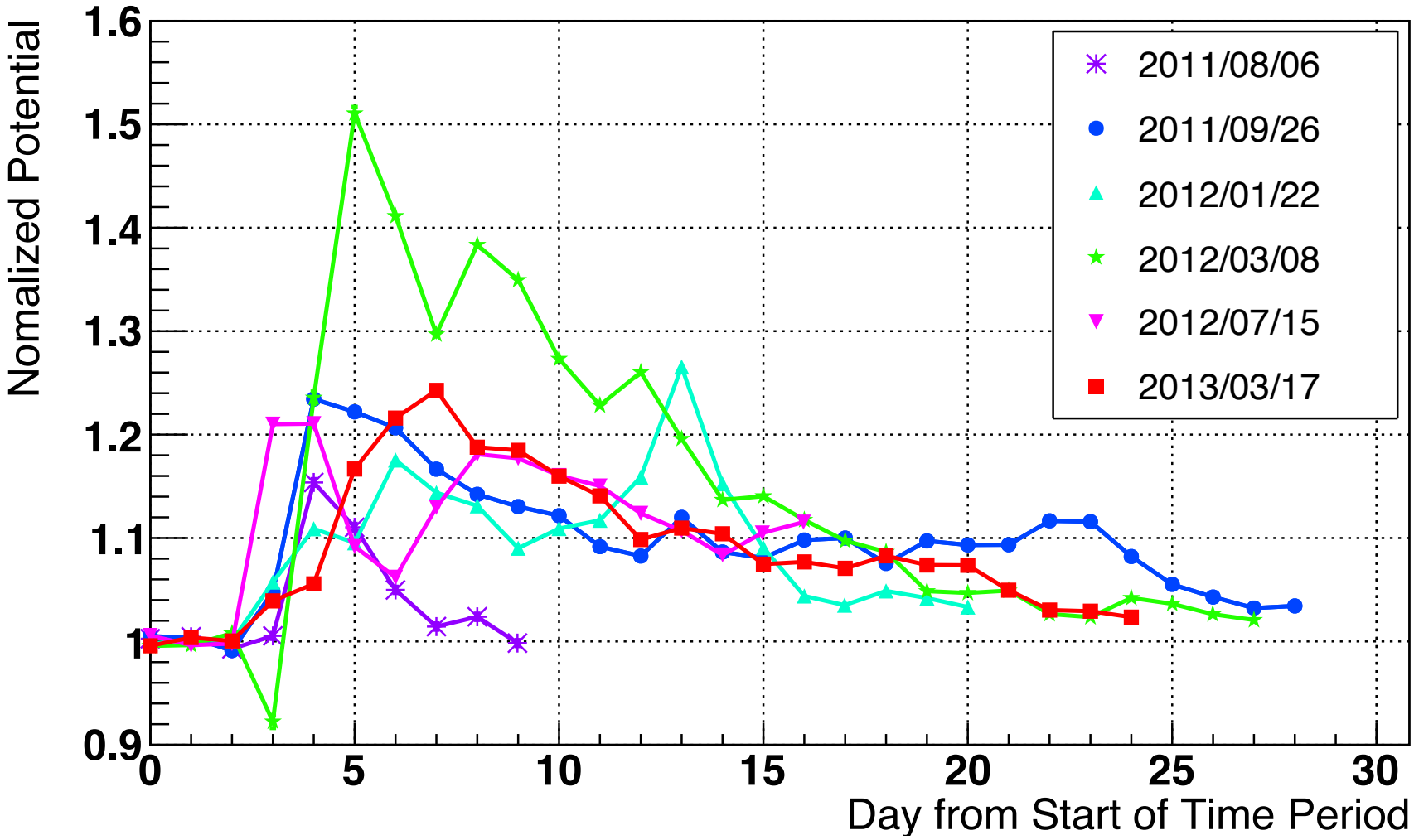


Force Field Potential September 26, 2011





Comparison of FDs with the Normalized Potential



Application of the Force Field approximation may be useful to 1) identify the date of the FD minimum & 2) identify when the FD recovers.

SOLAR ENERGETIC PARTICLES

SEP Events Observed by AMS-02

May 20, 2011 – September 30, 2014

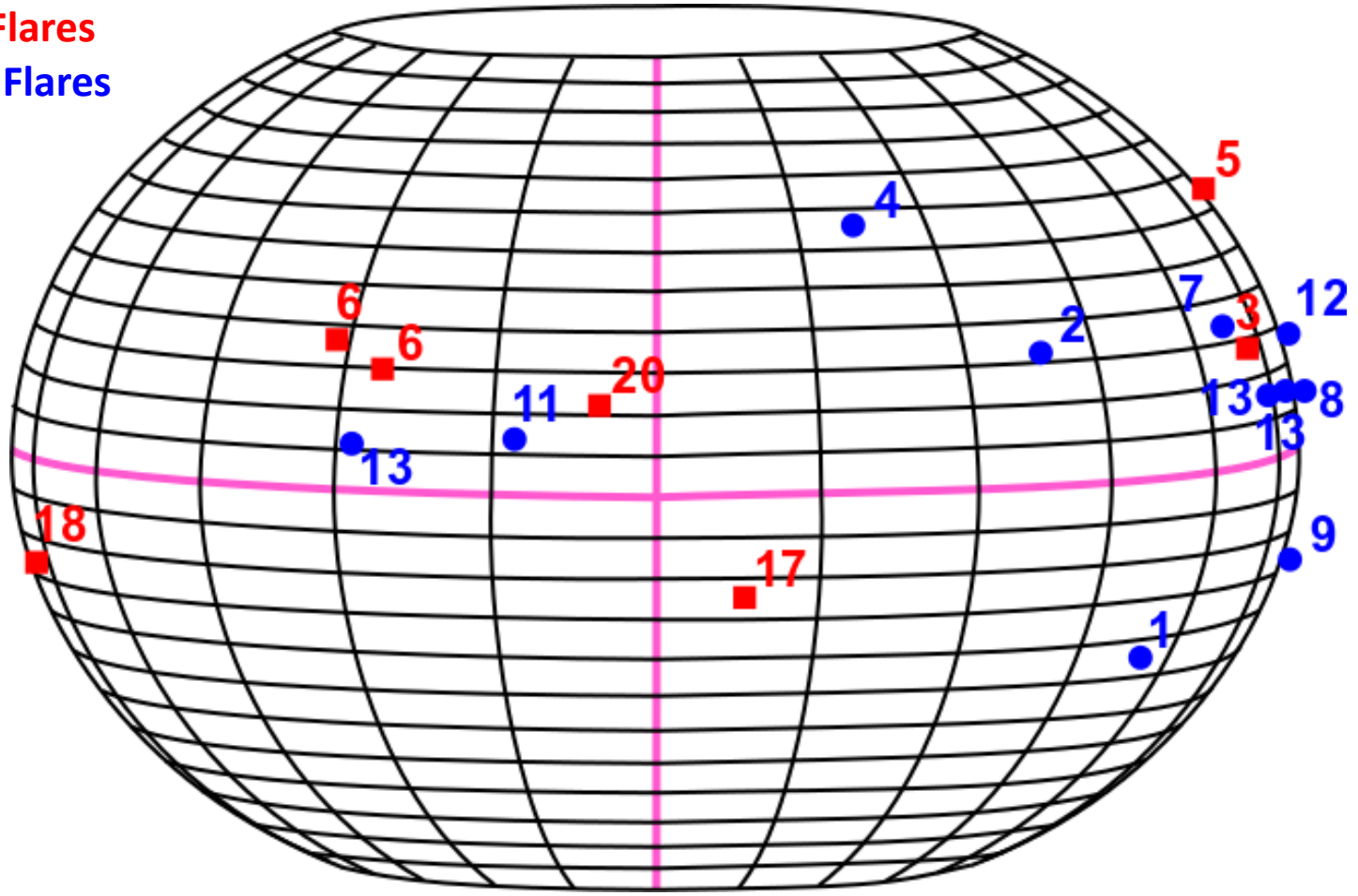
AMS-02 Event	Event Date	Flare Class	CME Vel. (km/s)
1	06/07/11	M2.5	1255
2	08/04/11	M9.3	1315
3	08/09/11	X6.9	1610
4	01/23/12	M8.7	2175
5	01/27/12	X1.7	2508
6	03/07/12	X5.4, X1.3	2684, 1825
7	03/13/12	M-class	1884
8	05/17/12	M5.1	1582
9	07/19/12	M7.7	1631
10	07/23/12	backside	2003
11	04/11/13	M6.5	861
12	05/22/13	M5.0	1466
13	10/28/13	M5.1, M2.8, M4.4	1201, 1073, 812
14	11/02/13	backside	828
15	12/28/13	backside	1118
16	01/06/14	backside	1118
17	01/07/14	X1.2	1830
18	02/25/14	X4.9	2147
19	09/01/14	backside	1404
20	09/10/14	X1.6	1267

AMS-02 is the largest high energy SEP detector ever flown in Space that can measure **P** and **He** from solar events with high statistics at energies not always accessible from current satellites.

Two additional SEP events have been identified and are in the process of verification:
September 23, 2011
July 8, 2012

Distribution of AMS-02 SEP Events on the Sun

X-class Flares
M-class Flares



1. Jun 7, 2011
5. Jan 27, 2012
6. Mar 7, 2012
8. May 17, 2012
17. Jan 7, 2014
18. Feb 25, 2014

Event #s correspond to table on previous slide.

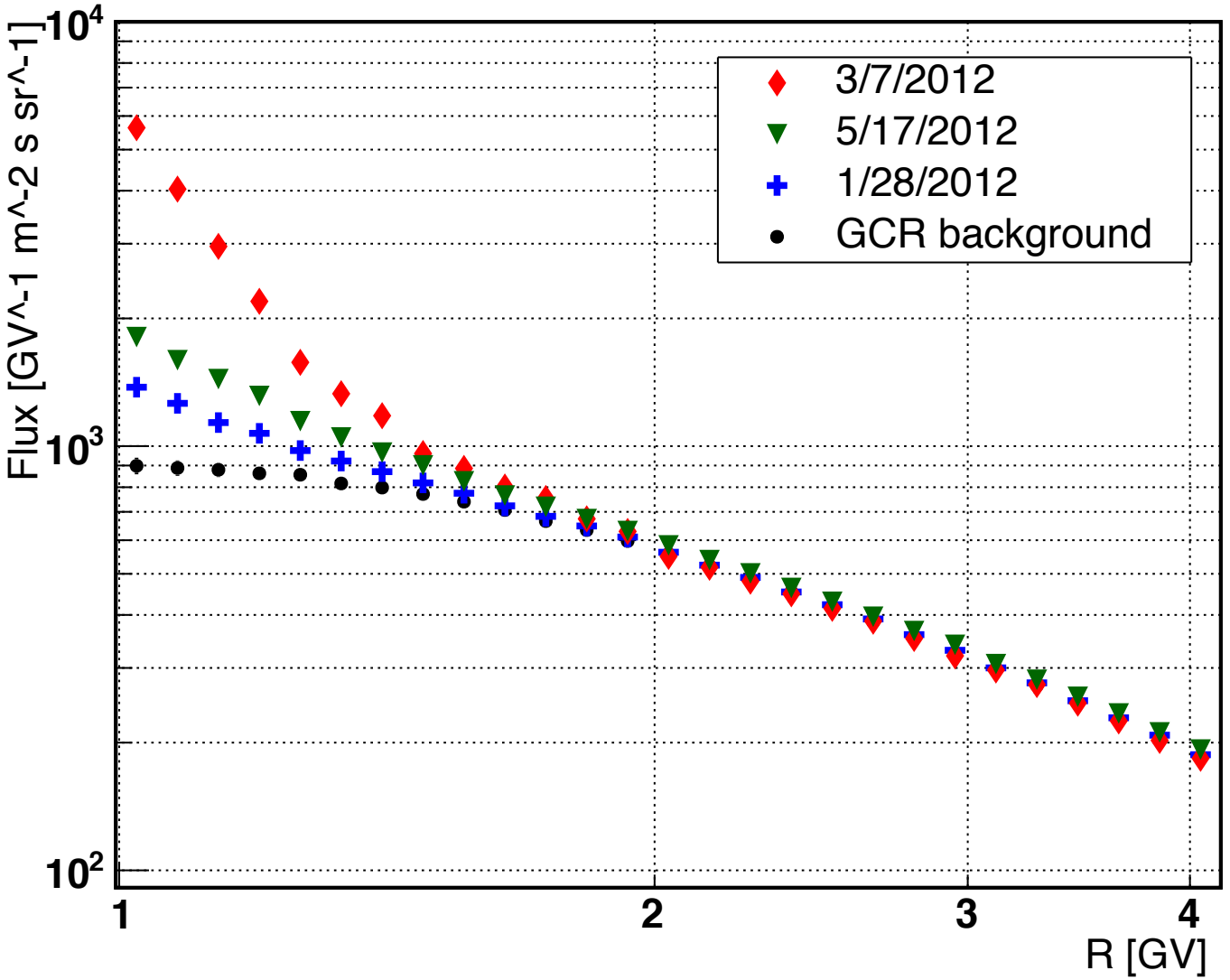
Excess Measured in AMS-02 Proton Flux

Mar 7, 2012

May 17, 2012

Jan 27, 2012

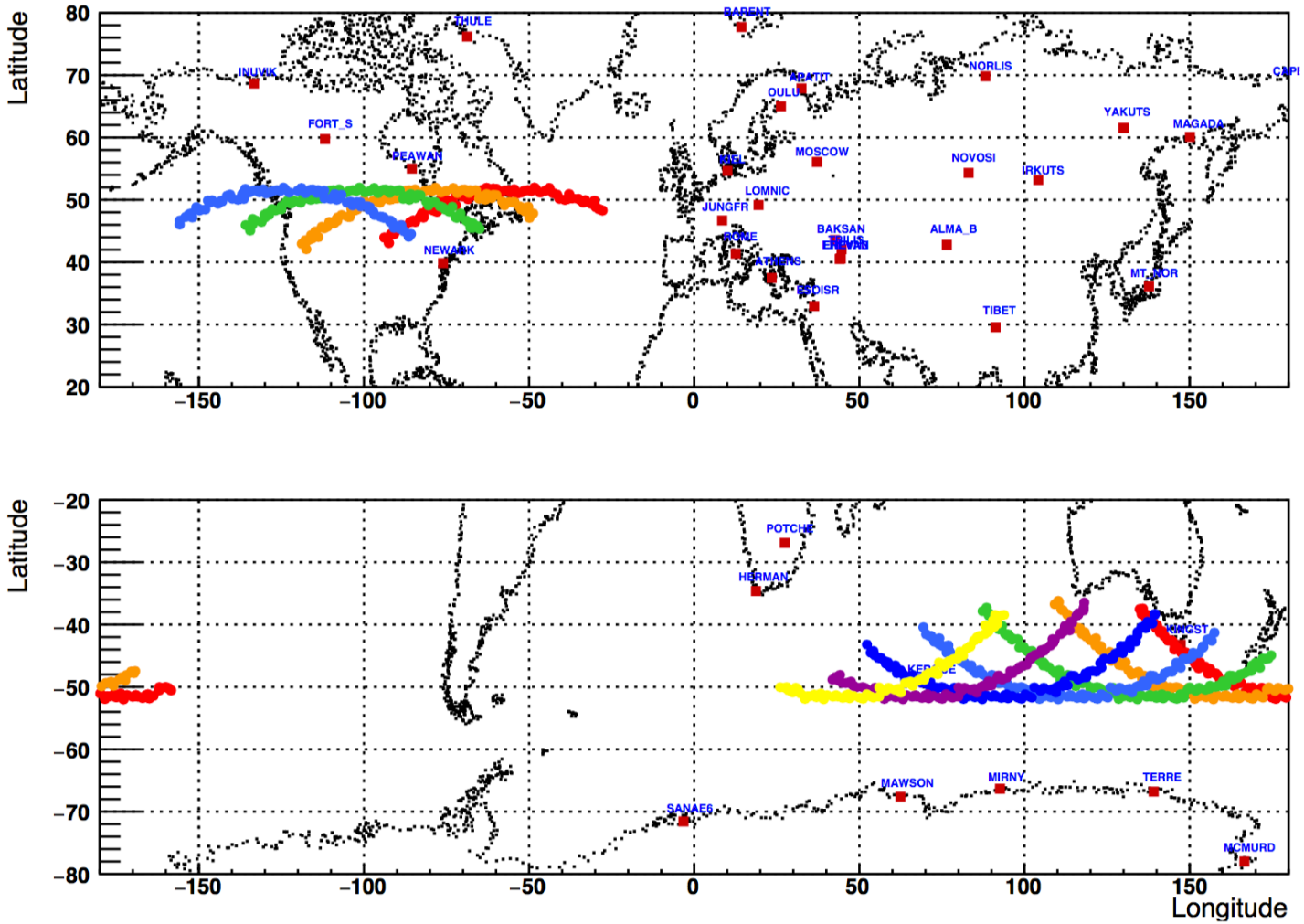
Quiet Sun



Flux integrated over 24 hours.

Location when AMS-02 is sensitive to SEPs

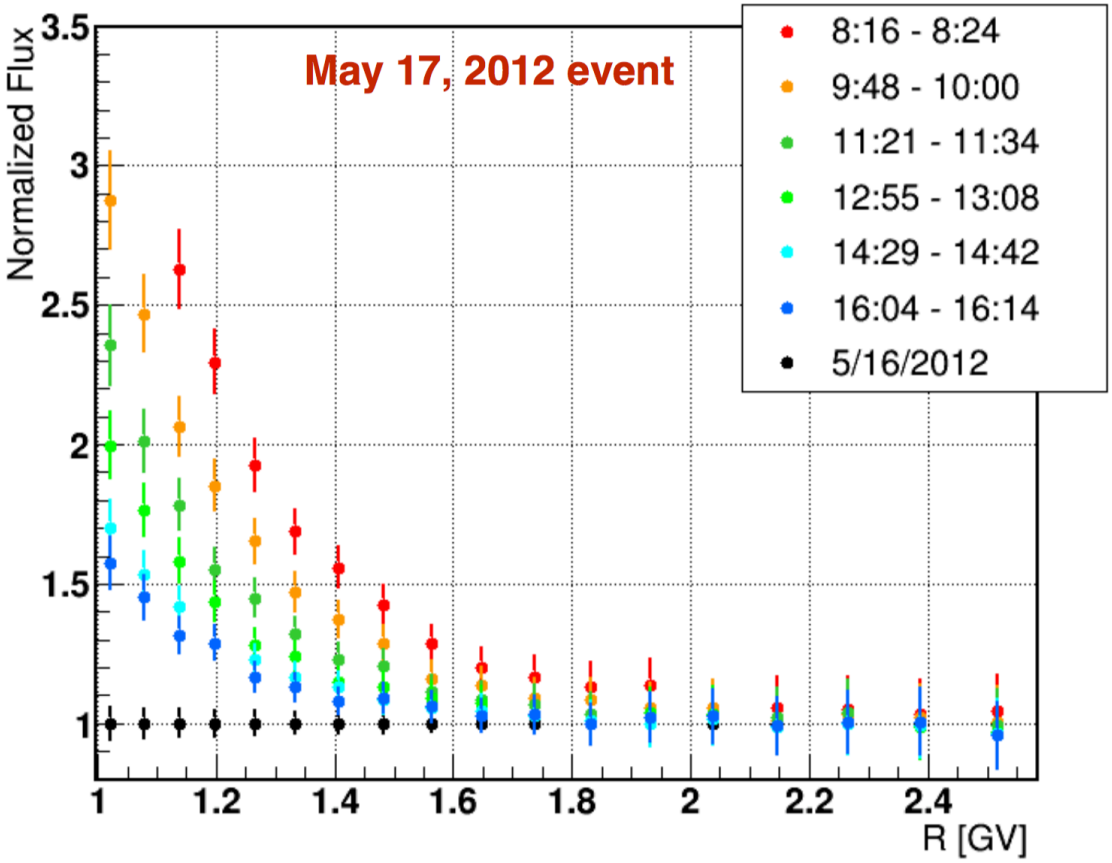
May 17, 2012 event



Part of the ISS orbits where AMS-02 measured an increase of protons during May 17, 2012 event.

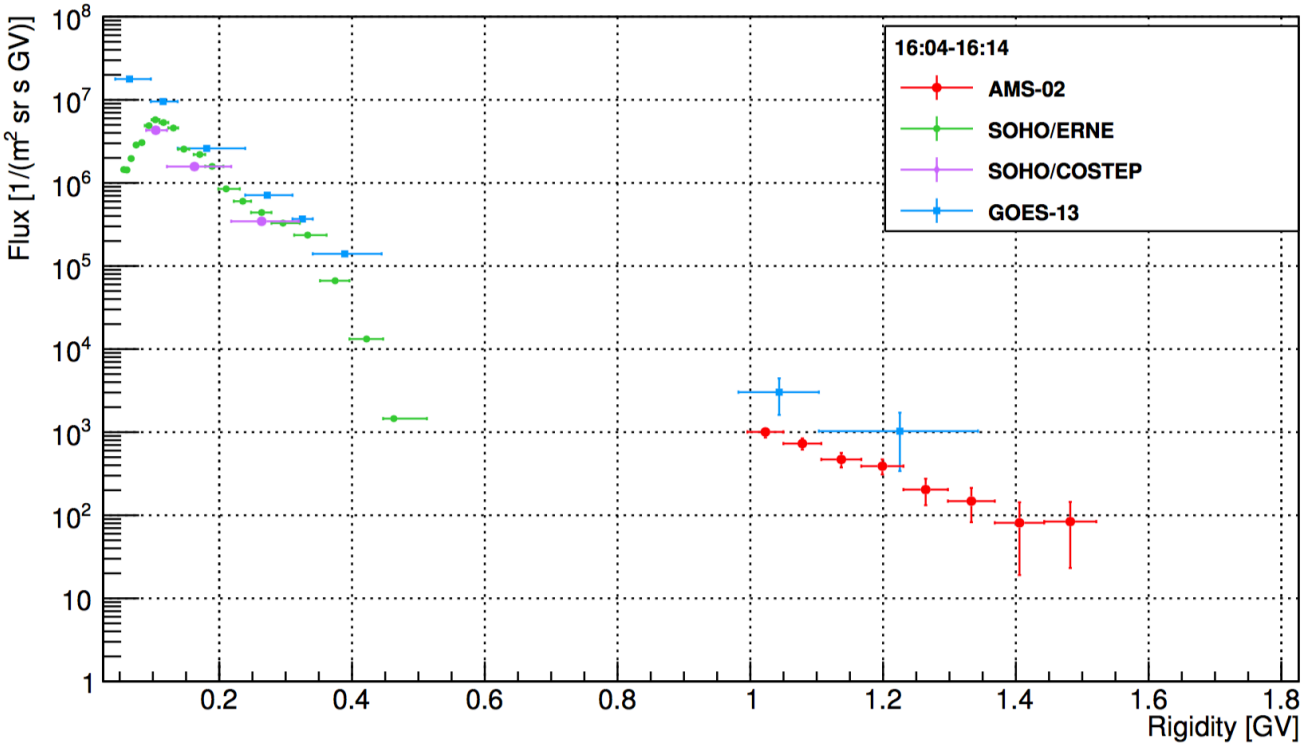
SEP Proton Spectra and Time Evolution

AMS-02 is able **to perform precise measurements in a short period of time** and to collect enough statistics to **measure the time evolution and the energy distribution of SEPs.**



Protons in a short time interval after background subtraction

May 17, 2012 event: Proton measured over a few minutes after background subtraction



AMS data combined with other instruments at lower energy, will provide a baseline for the modeling of SEP production.

Summary

- AMS-02 observed 15 confirmed Forbush Decreases between May 20, 2011 and November 26, 2013
  - Multiple rigidities with one instrument
- AMS-02 observed 22 SEP events
  - Highest energy SEPs (> 0.5 GV, 125 MeV for protons)
  - Precision measurements with high rigidity resolution

Future Work

- Study FD characteristics with rigidity (rigidity dependent?)
- Compare FD characteristics with physical parameters
- Compare AMS-02 observations with NM observations
- Study FD with shorter integration times!!!
- Continue work with SEP analysis

BACKUP SLIDES

Proton Selection

https://twiki.cern.ch/twiki/bin/view/AMS/PHeFluxStandardSelection

RTI :

-AMS Zenith < 25 deg.
-Livetime > 0.5
-Exclude SAA
-|PG-MD| < 35e-4 (L1), 45e-4 (L9)
- Excluded bad runs for Trigger Studies

Preselection:

- have particleR
- have betaR with pattern < 5 and beta> 0.3
- have betaH rebuild with tracker track (TOF track track match)
- number of in-time TOF clusters < 4
- TOF charge from betaH 0.5 <Q_TOFLo< 3

Selection:

- must have good inn charge 0.7 <Q_inn< 1.5
- must have XY hits on L1 and L9
- must have full span track
- Mass cut on Rfs & above 1.2 IGRF cutoff (FoV 25 deg)
- must have good FS chi2 (<10)
- DATA: 0.6<QL1<1.9 & 0.6<QL9<1.9 (for MC + 0.05)

Sample Selection for Efficiency Study

Physical Triggers

Preselection:

- have particleR
- have betaR with pattern < 5 and beta> 0.3
- have **betaH rebuild with TRD**
- TOF must be in time (cuts on number of in-time TOF clusters)
- TOF charge from betaH **0.5 < Q_TofUp < 1.8** & **0.5 < Q_TofLo < 1.8**

Selection:

0 Have inner track
1 R inn above 1.2 IGRF cutoff (FoV 25 deg)
2 mass cut
3 inner track must point to L1 &L9
4 must have good inner chi2 (<10)
5 must have good inn charge 0.7 <Q_inn< 1.5
6 must have XY hits on L1
7 must have XY hits on L9
8 Must have full span track
9 must have good FS chi2 (<10)
10 DATA: 0.6<QL1<1.9 & 0.6<QL9<1.9 (for MC + 0.05)

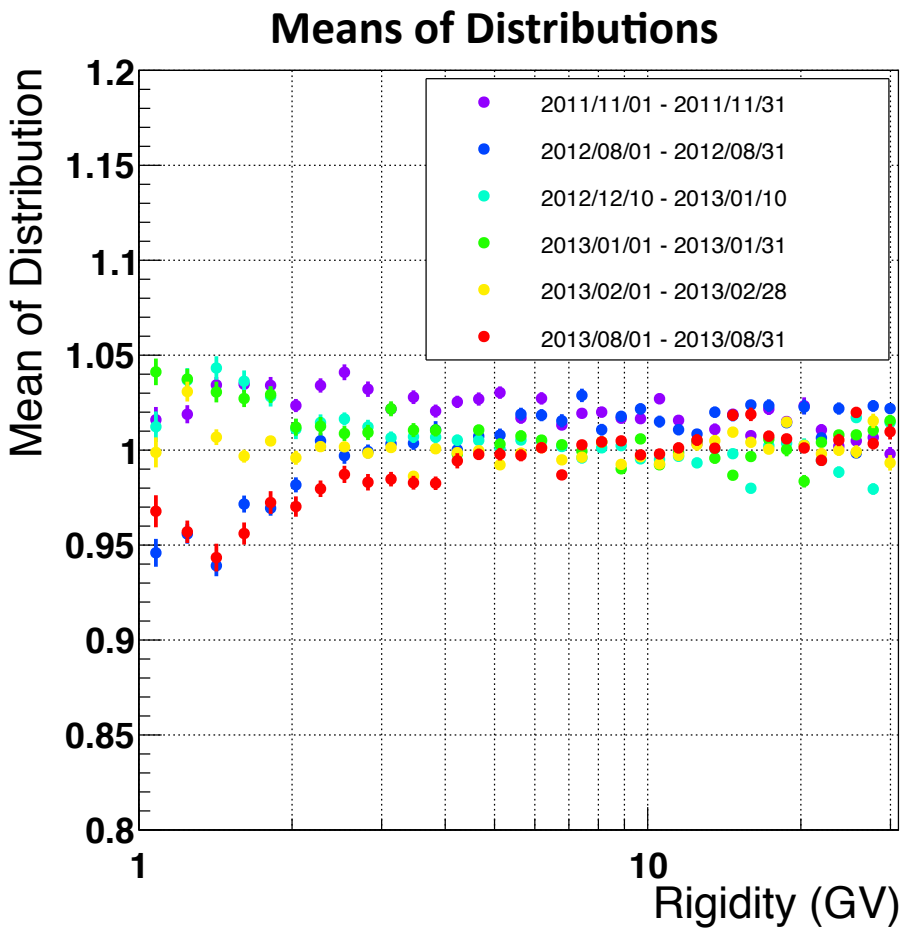
Daily Proton Flux Calculation

- The majority of the analysis is the same used to generate the monthly flux (C. Consolandi)
- Additional steps:
  1. For each efficiency (Trigger, Tracker, and Full Span), the shape of the fit is defined by the monthly data
  2. The efficiencies are calculated using the daily data
  3. The monthly shape is fit with a scaling factor to the daily values

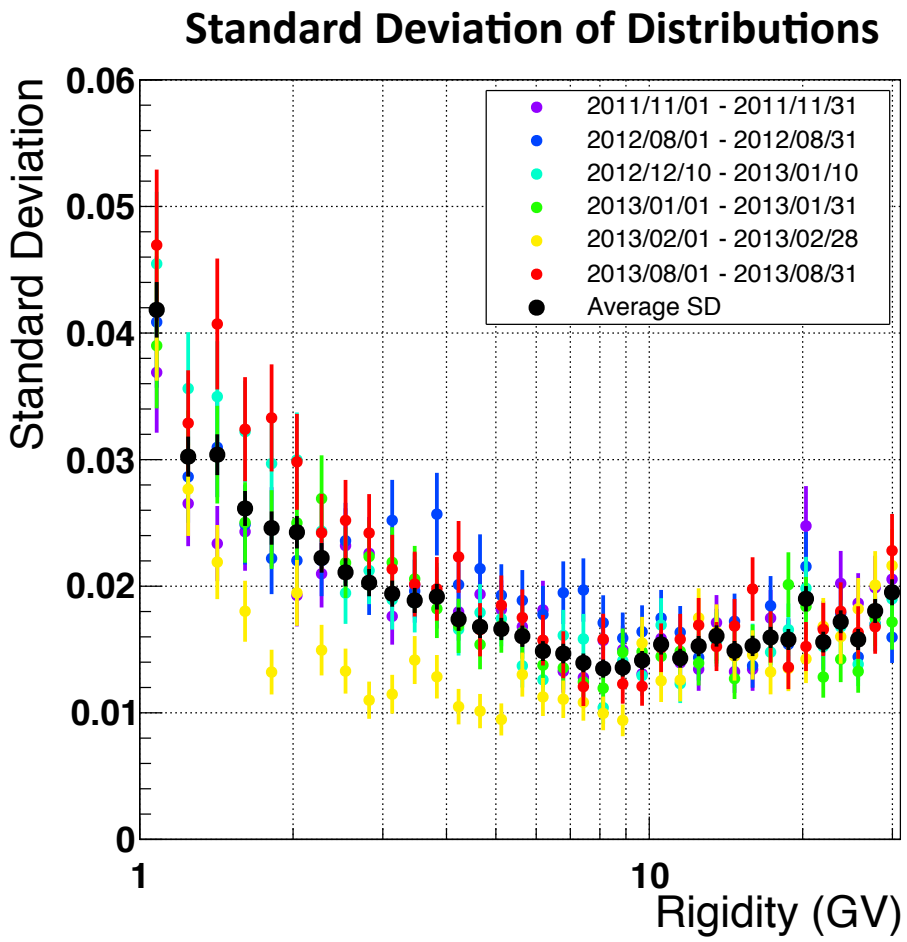
Daily Proton Flux Calculation

- The majority of the analysis is the same used to generate the monthly flux (C. Consolandi)
- Selections to include both GCRs and SEPs
  - 1.0*Stoermer max cutoff in FOV
  - No cut on detector LiveTime
- Selections to cut SEPs and include only GCRs
  - 1.2*IGRF max cutoff in FOV
  - Cut SEP events when LiveTime < 0.5
  - Temporary increases in particle flux, such as during an SEP event, are excluded
  - Only signal due to GCRs

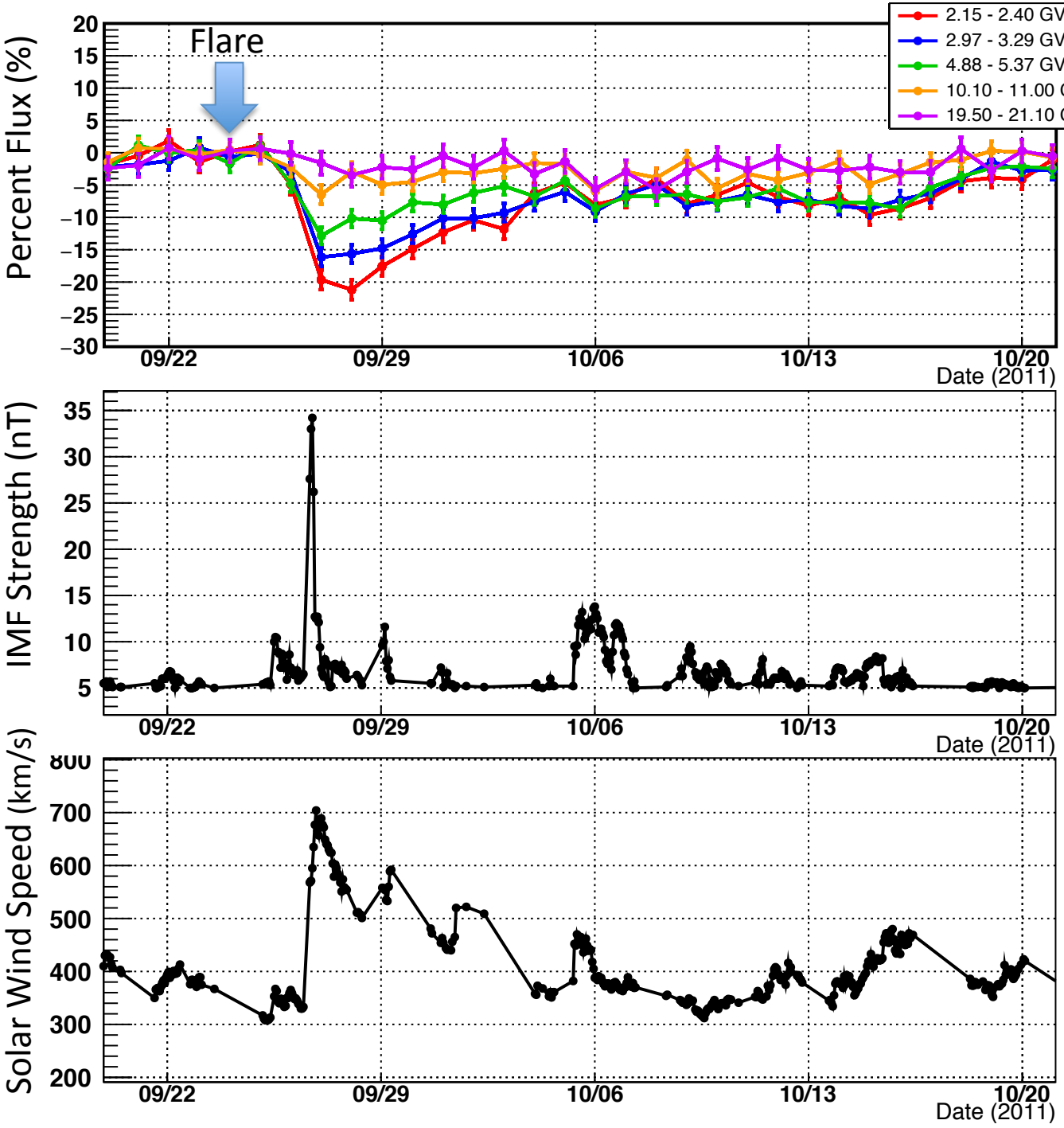
Characterize Day-to-Day Variability



Mean ~ 1 indicates good normalization.



σ(R) varies from ~4% at the lowest rigidities to ~1.5% up to 30 GV.

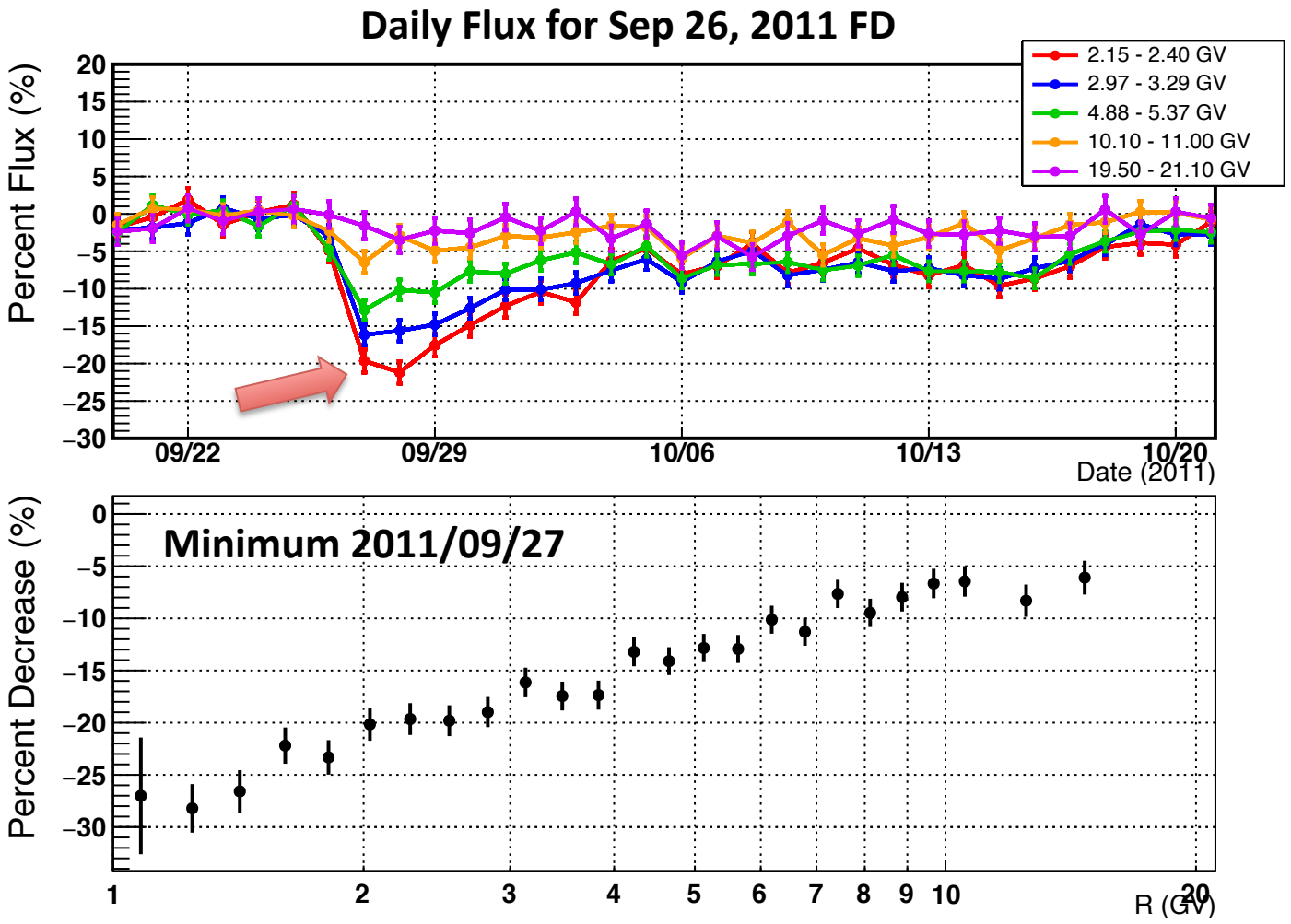


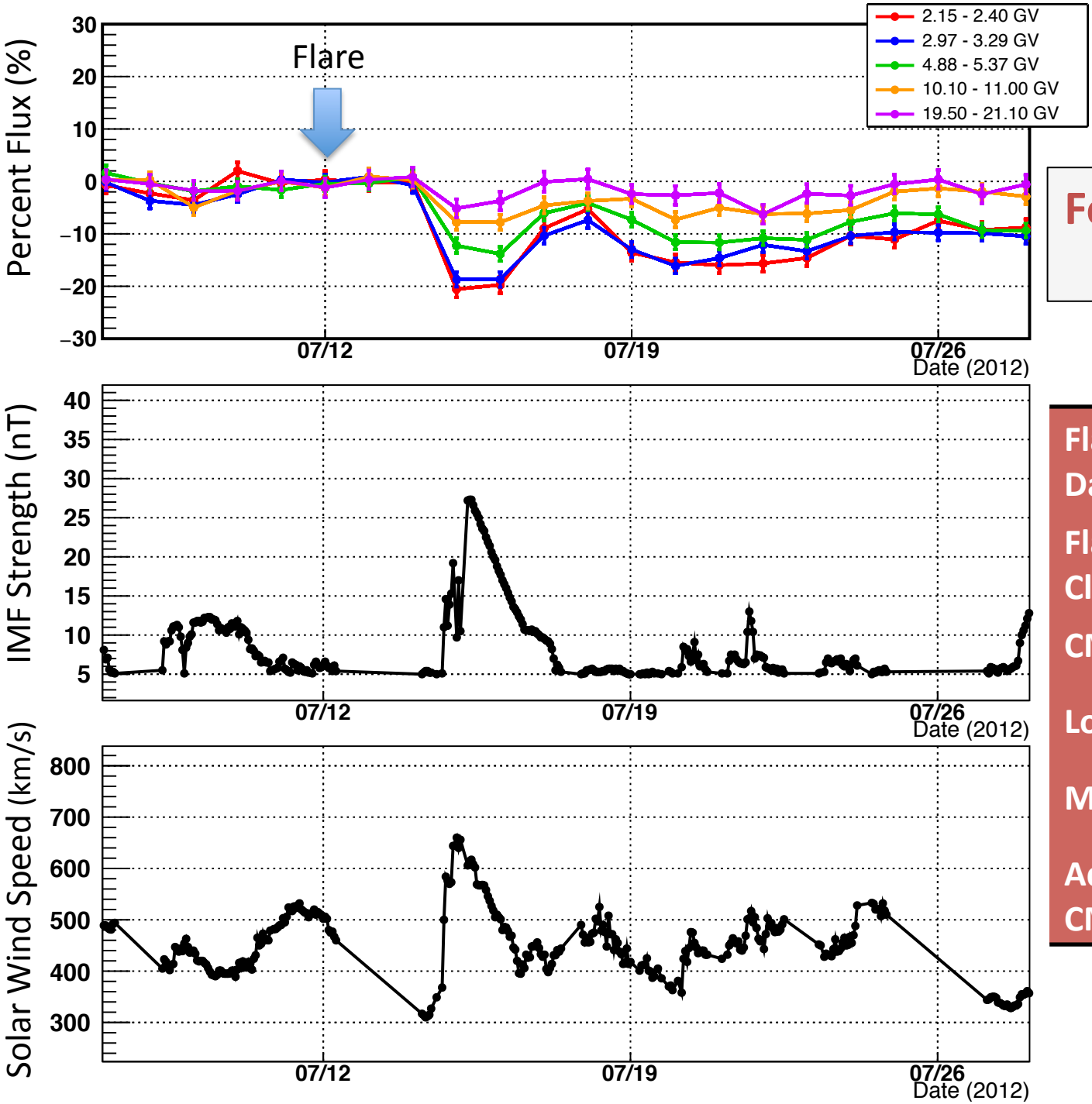
Forbush Decrease Sep 26, 2011

Flare Date	2011/09/24
Flare Class	M7.1
CME	1915 km/s
Location	N13E58
Max IMF	34 nT
Addl CMEs	10/1

Forbush Decrease September 26, 2011

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2011/09/26	2011/09/27	2011/10/18	22 days	14 GV	20%



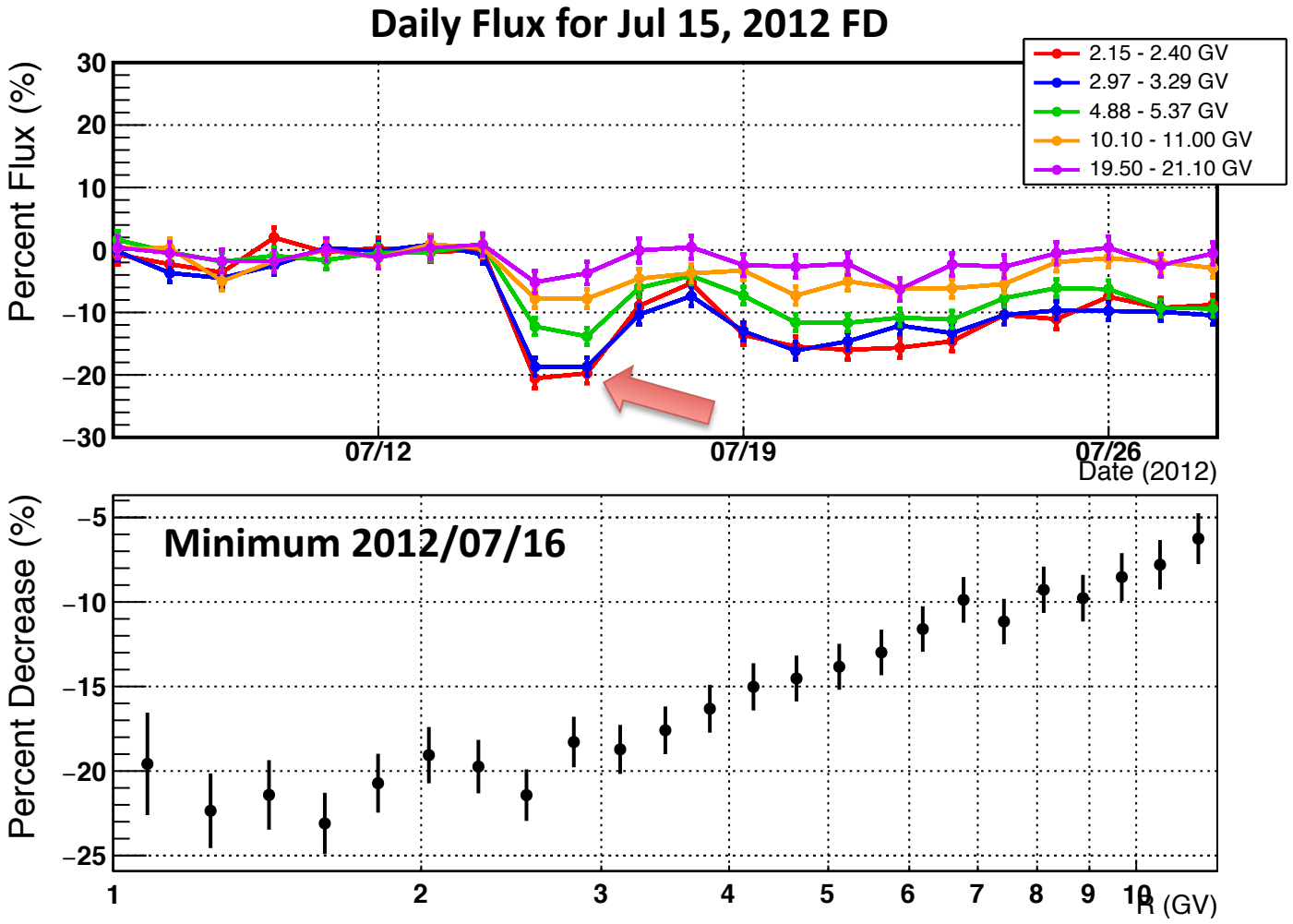


Forbush Decrease
Jul 15, 2012

Flare Date	2012/07/12
Flare Class	X1.4
CME	885 km/s
Location	S15W01
Max IMF	27 nT
Addl CMEs	7/18, 7/19

Forbush Decrease July 15, 2012

Start Date	Date of Min	Recovery Date	Duration	Max Rigidity	Max Decrease (2GV)
2012/07/15	2012/07/16	2012/07/26	11 days	11 GV	19%



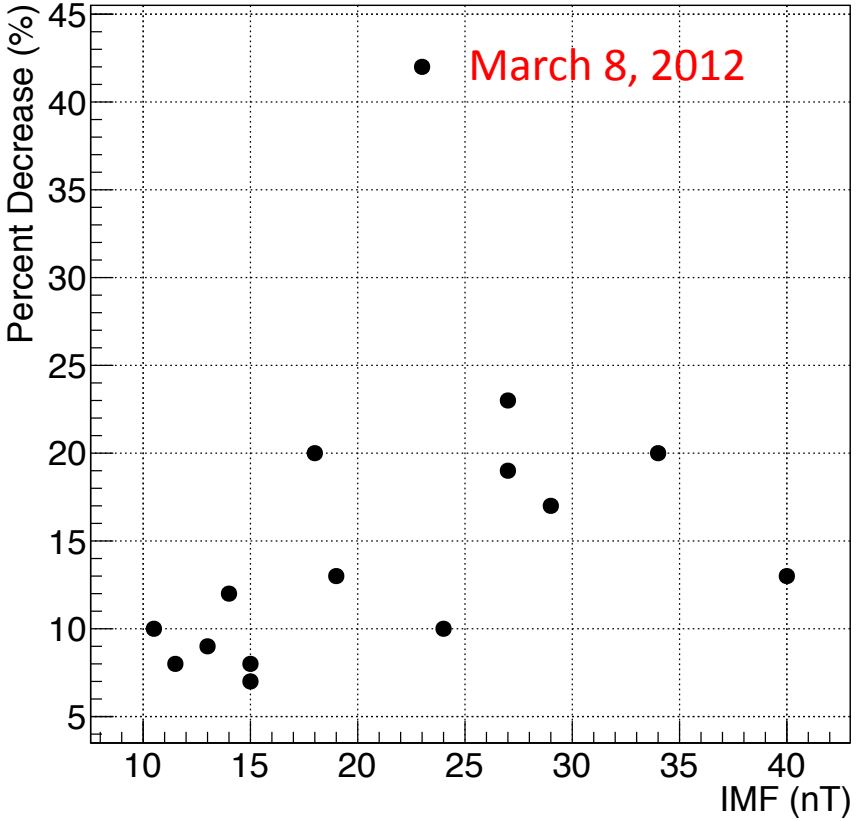
Physical Characteristics Related to FD

May 5, 2011 – Nov 26, 2013

FD Start Date	1st CME Velocity	Max Kp	Max Kp Date	Max IMF	Max IMF Date
2011/06/24	719 km/s	4	2011/06/22 & 23	10.5	2011/06/23
2011/08/06	1315 km/s	8	2011/08/05	29	2011/08/05
2011/09/26	1915 km/s*	8	2011/09/26	34	2011/09/26
2011/10/25	1005 km/s	7	2011/10/24	24	2011/10/25
2012/01/22	1120 km/s*	5	2012/01/22 & 24	27	2012/01/22
2012/02/27	800 km/s	5	2012/02/27	15	2012/02/28
2012/03/08	2684, 1825*	7	2012/03/09	23	2012/03/08 &12
2012/04/06	Unclear	4	2012/04/05	11.5	2012/04/06
2012/06/17	987 km/s	6	2012/06/17 & 18	40	2012/06/17
2012/07/15	885 km/s*	6	2012/07/15 & 16	27	2012/07/15
2012/09/04	598 km/s	6	2012/09/05	19	2012/09/05
2012/11/24	529 km/s*	4	2012/11/23 & 24	15	2012/11/24
2013/03/17	1063 km/s	6	2013/03/17	18	2013/03/17
2013/04/15	861 km/s	3	2013/04/14 & 15	13	2013/04/14
2013/06/23	Unclear*	7	2013/06/29	14 & 13	2013/06/21 &30

Correlation with Interplanetary Magnetic Field (IMF) Strength

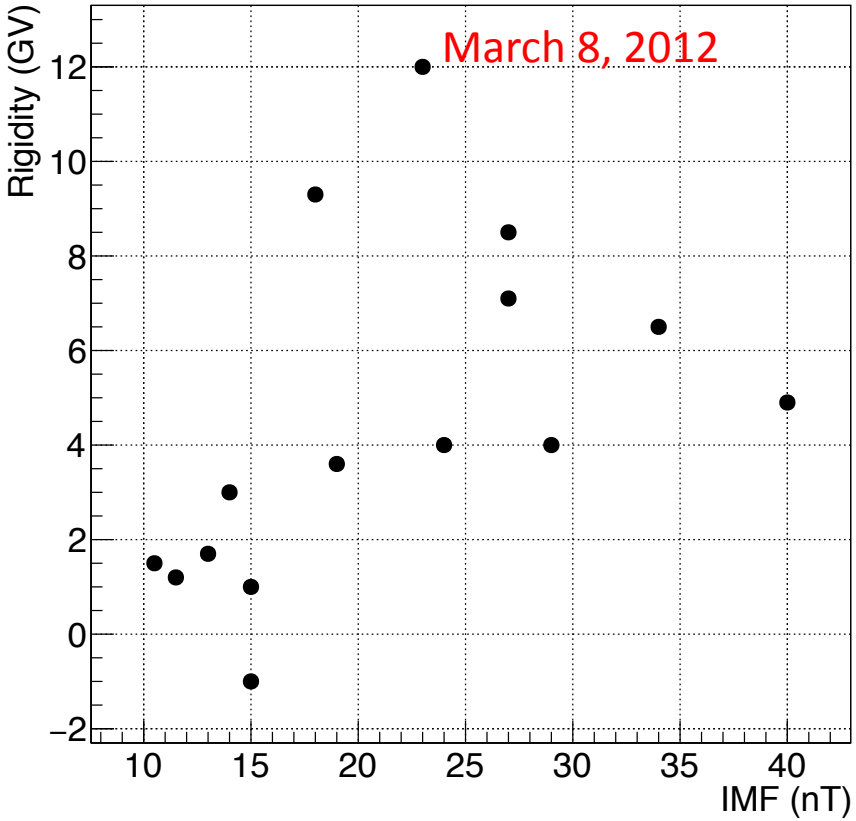
Max IMF vs. Max % Decrease (2 GV)



Correlation Factor = 0.38

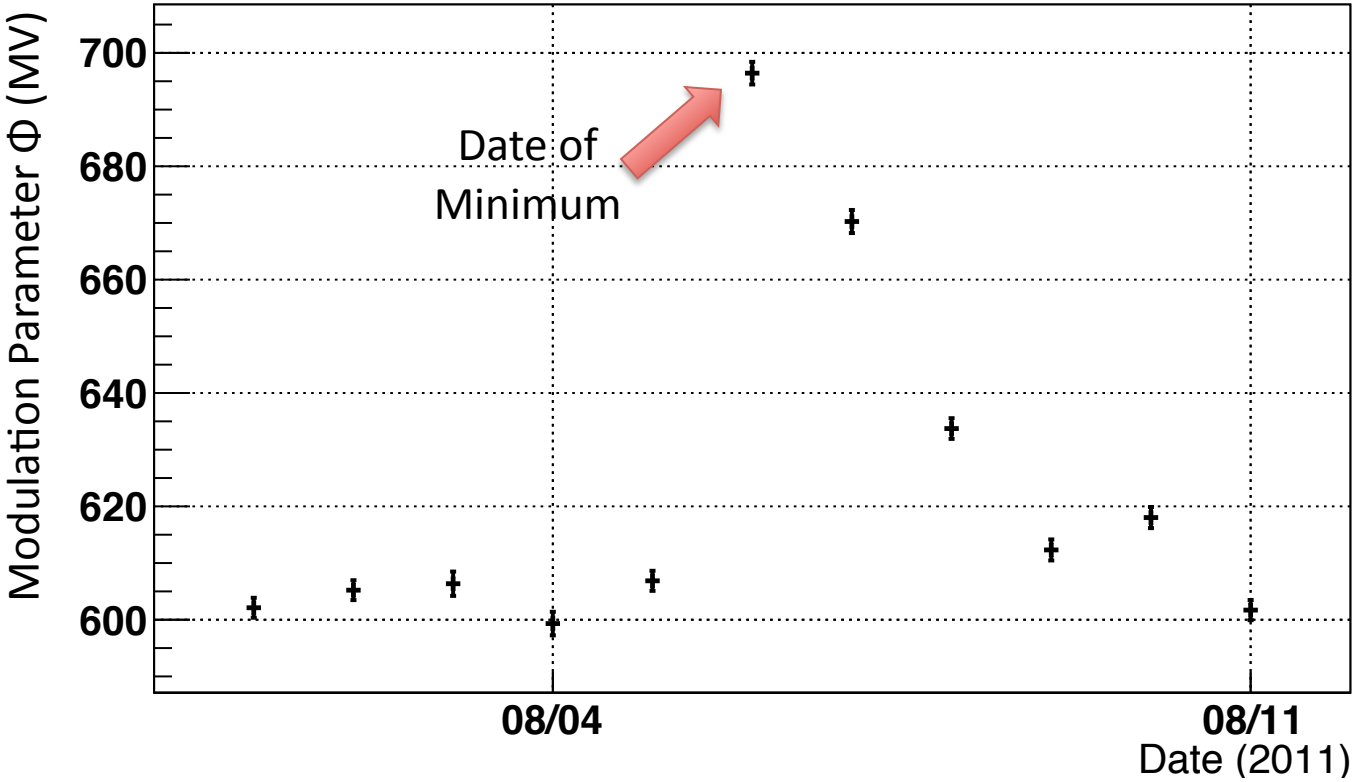
Correlation Factor = 0.59 excluding March 8th, 2012 event

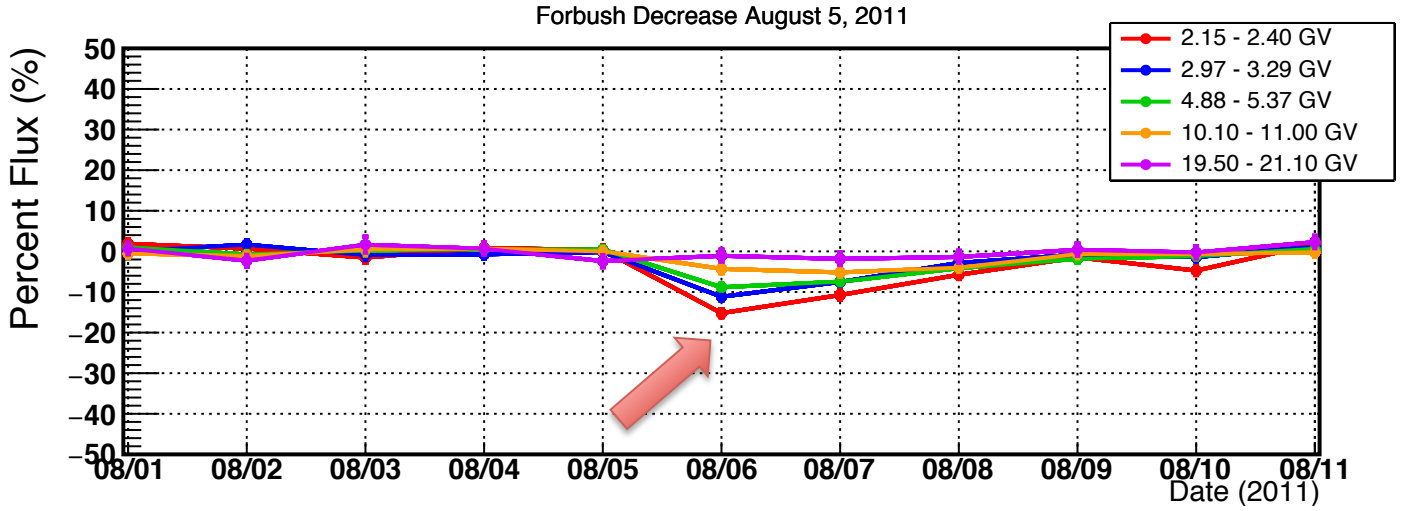
Max IMF vs. Max Rigidity (> 10% Decrease)



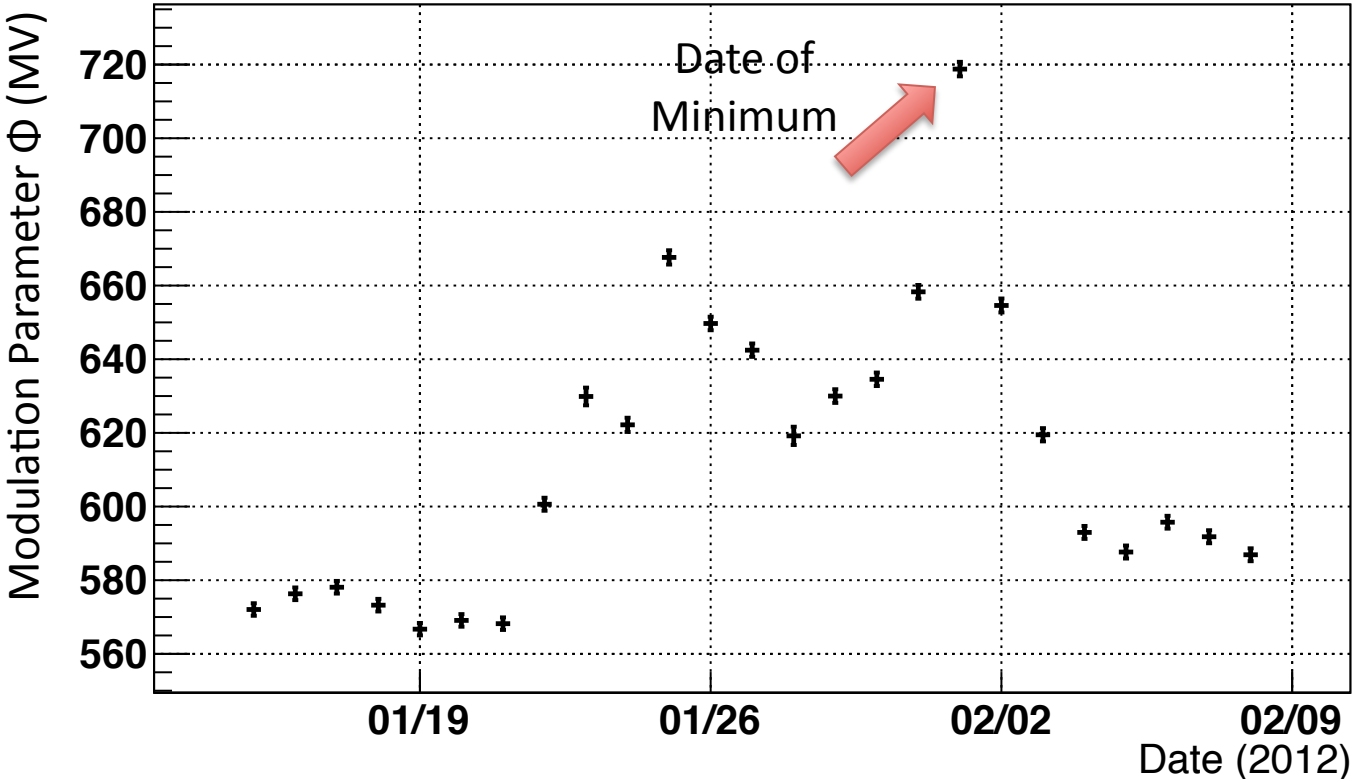
Correlation Factor = 0.50

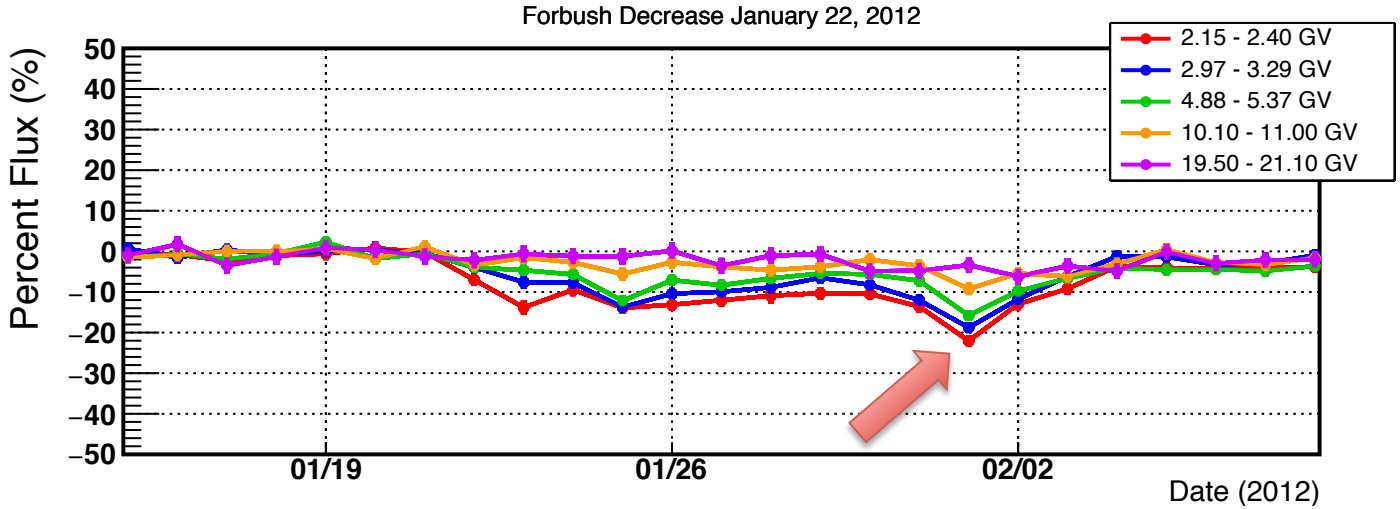
Force Field Potential August 6, 2011



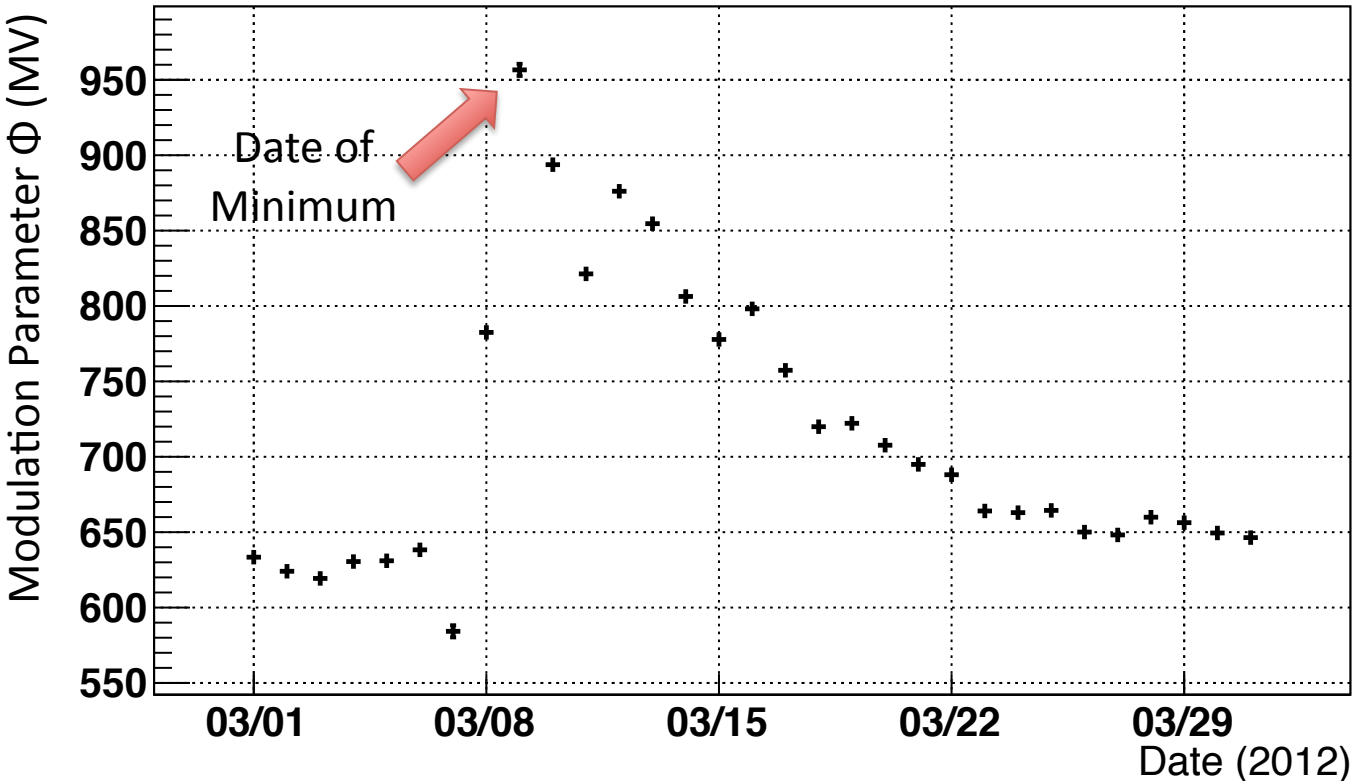


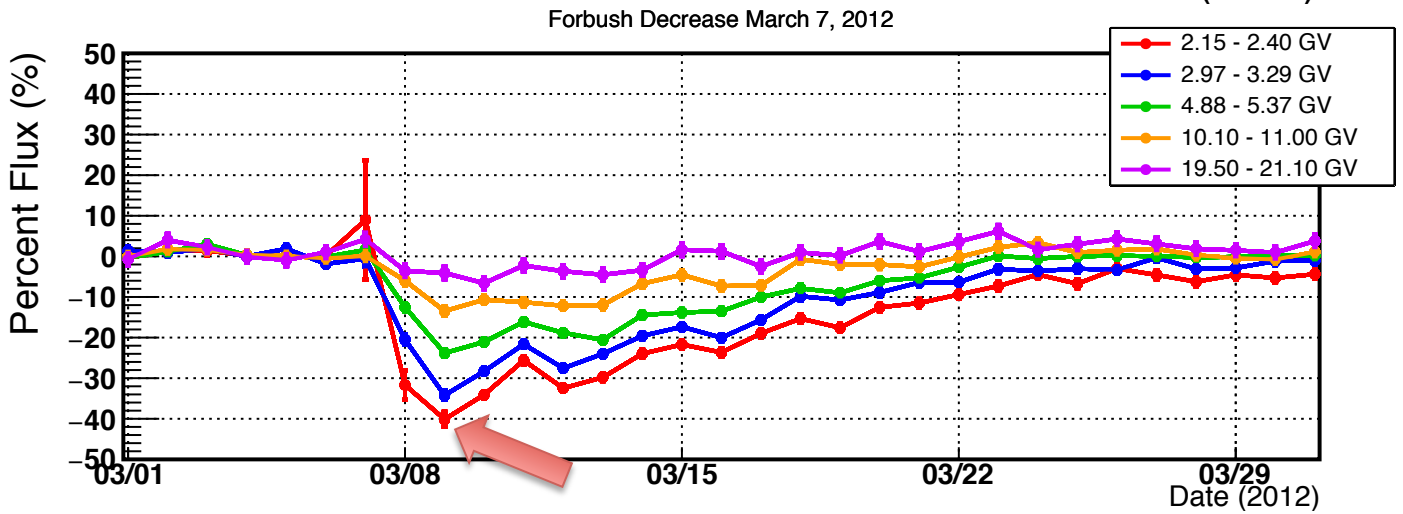
Force Field Potential January 22, 2012



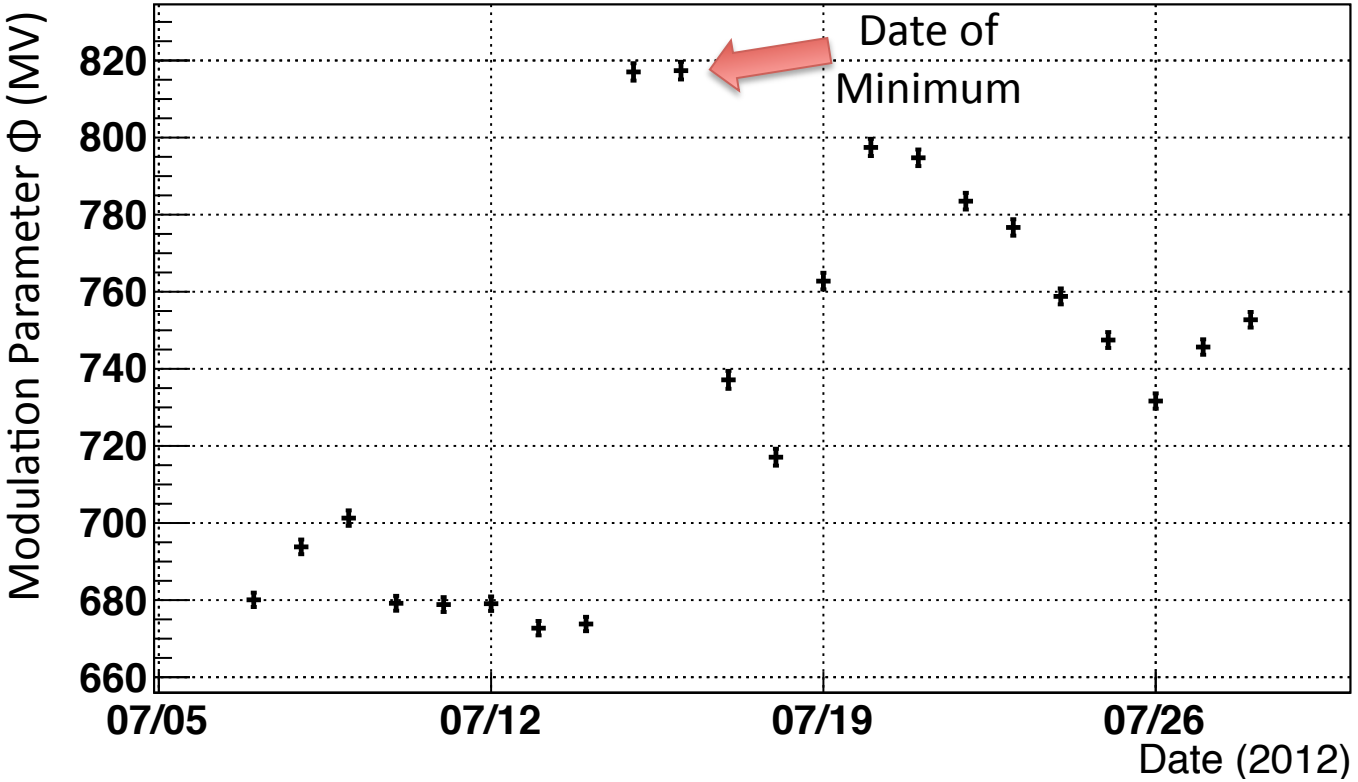


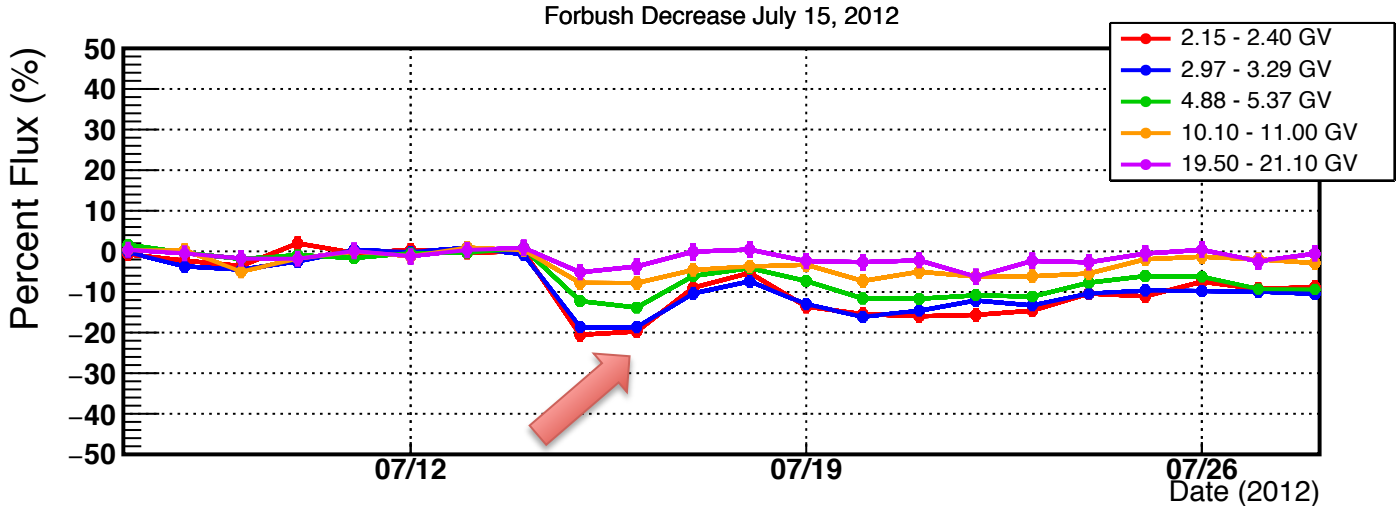
Force Field Potential March 8, 2012



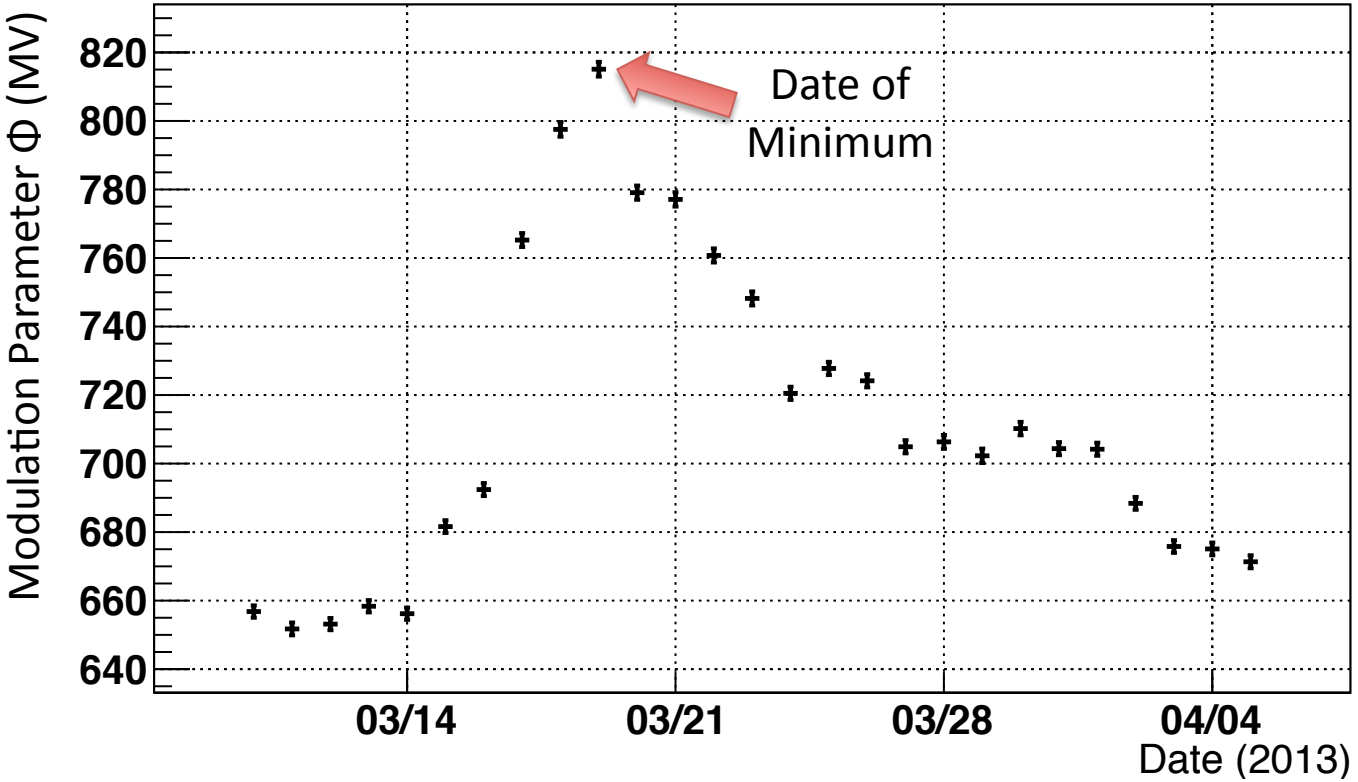


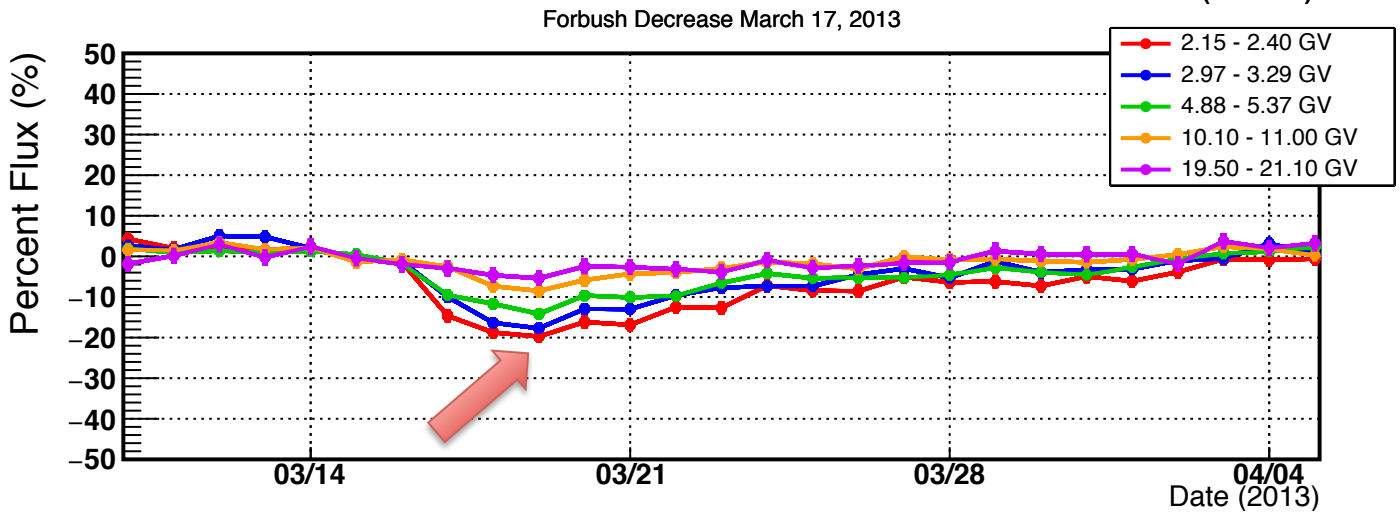
Force Field Potential July 15, 2012



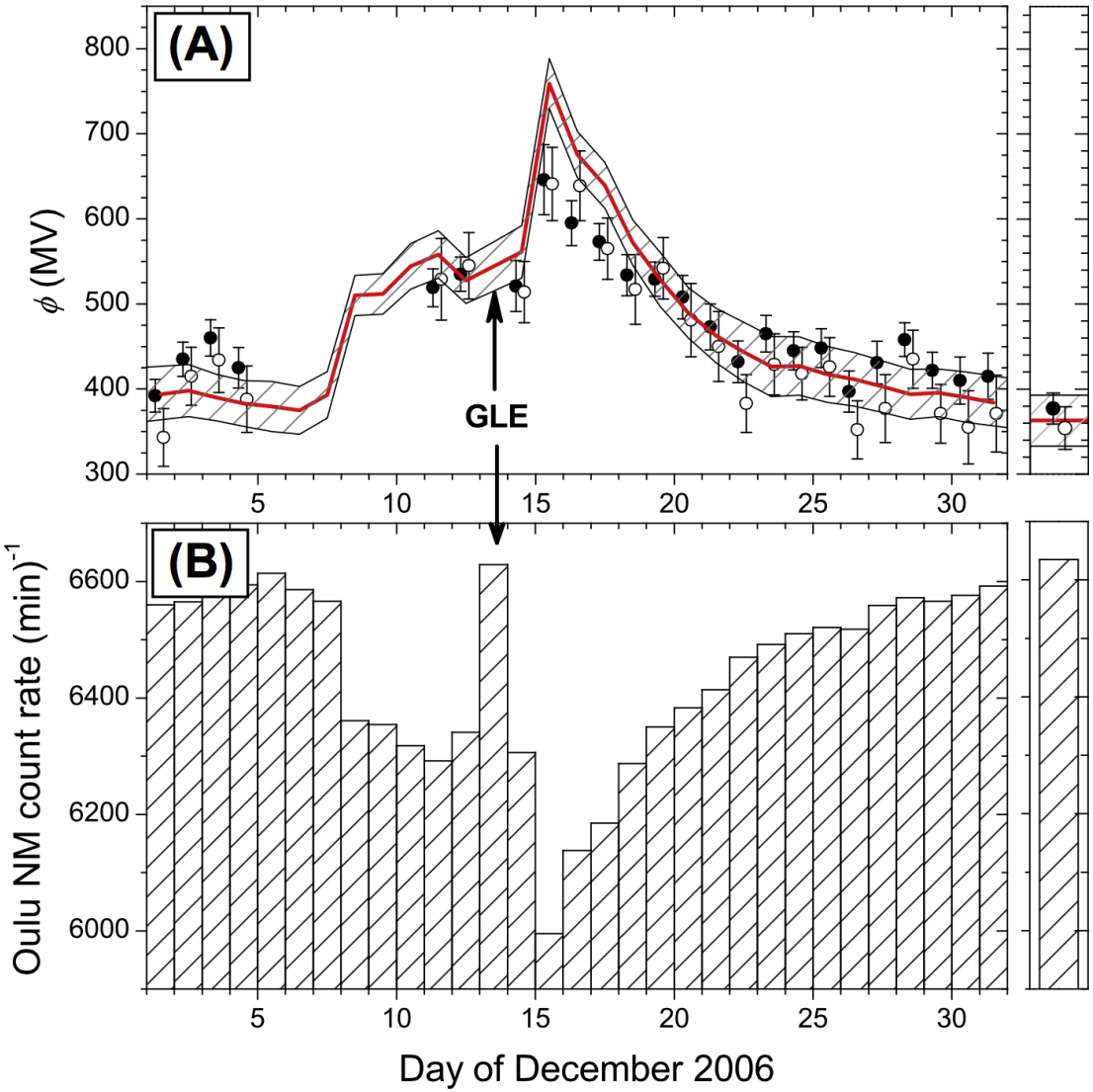


Force Field Potential March 17, 2013





PAMELA FD in December 2006



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Comparison with PAMELA

Event	Max Increase in Φ (%)
PAMELA December 2006	52%
August 6, 2011	15%
September 27, 2011	24%
January 22, 2012	26%
March 8, 2012	52%
July 15, 2012	20%
March 17, 2013	24%

The PAMELA December 2006 event appears to be a very strong Forbush decrease that is similar in strength to the March 8, 2012 event observed by AMS-02.

The March 8, 2012 event shows an 11% decrease in corrected Oulu NM counts while the PAMELA event measures a 9% decrease.
For comparison, the Sep 27, 2011 event shows only a 4.5% decrease in corrected counts.