ICME Associated Forbush Decreases in Neutron Monitors and AMS

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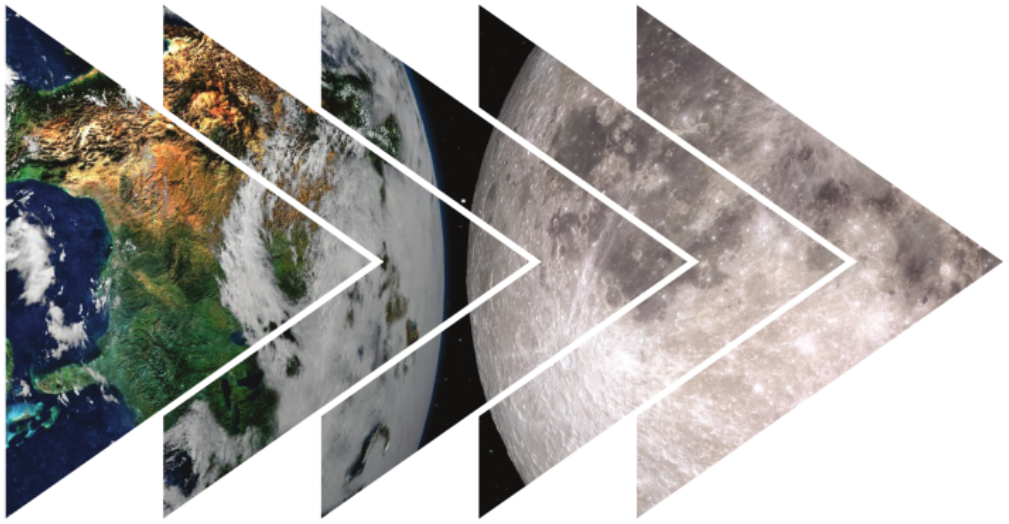
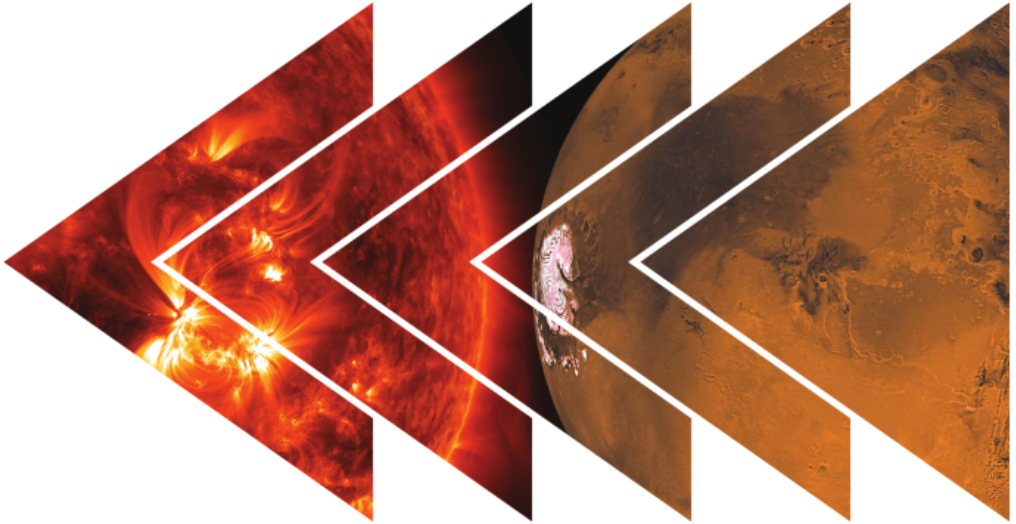
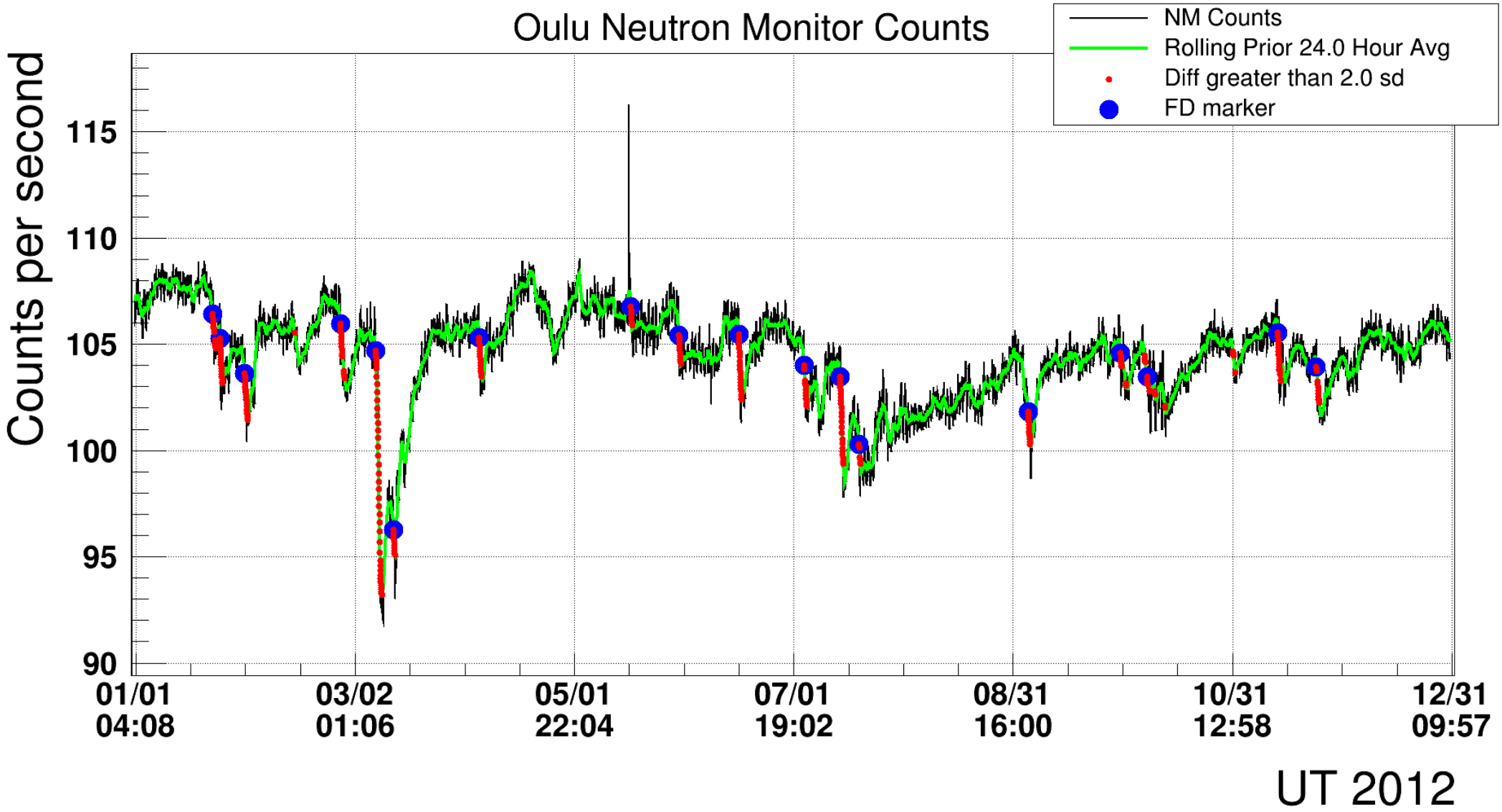
University of Hawai'i at Manoa

Solar Energetic Particles (SEP), Solar Modulation and Space Radiation: New Opportunities in the AMS-02 Era #3



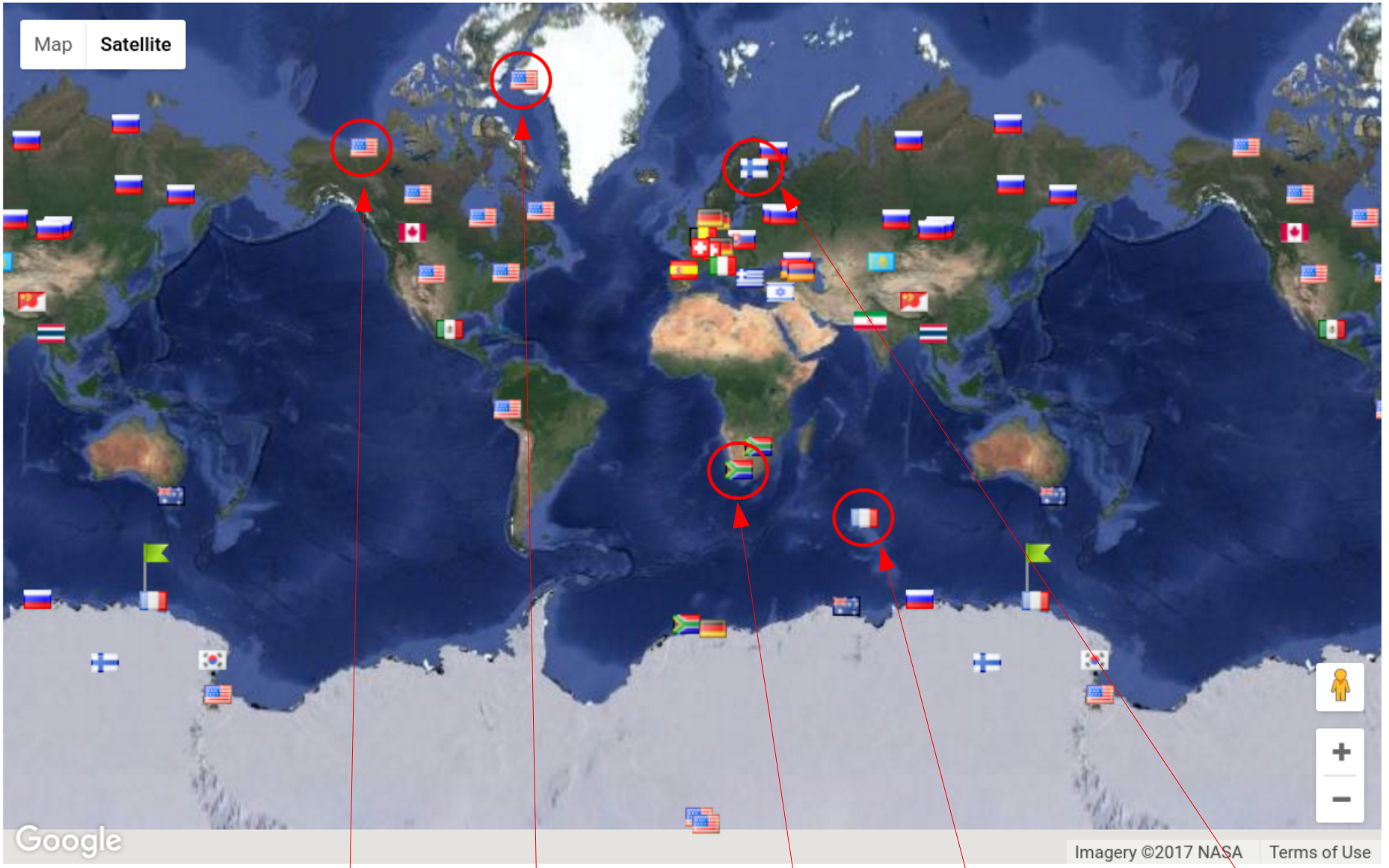


Identifying Forbush Decreases (FDs) in Neutron Monitor Data



My automated program essentially applies a steepness and a magnitude requirement to dips in NM counts/s to identify FDs

Identifying Forbush Decreases (FDs) in Neutron Monitor Data



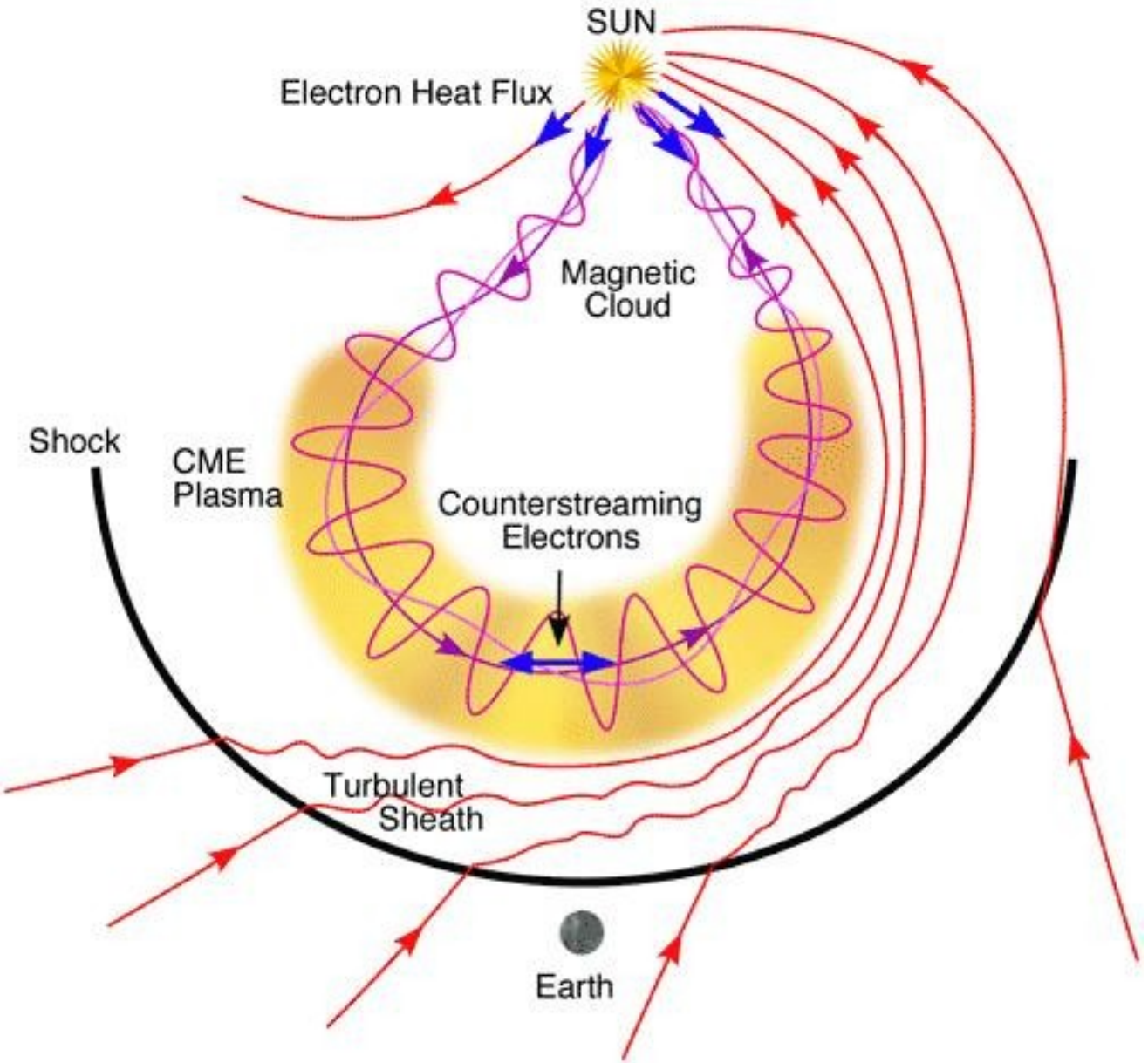
NM (Cutoff Rig)	Inuvik (0.3 GV)	Thule (0.3 GV)	Hermanus (4.58 GV)	Kerguelen (1.14 GV)	Oulu (0.8 GV)

http://www.nmdb.eu/nest/help.php#helpstations

Identifying Forbush Decreases (FDs) in Neutron Monitor Data

- Required events to show up in 3 of these 5 NMs
- Process produced 219 FD events from 2001 through 2016

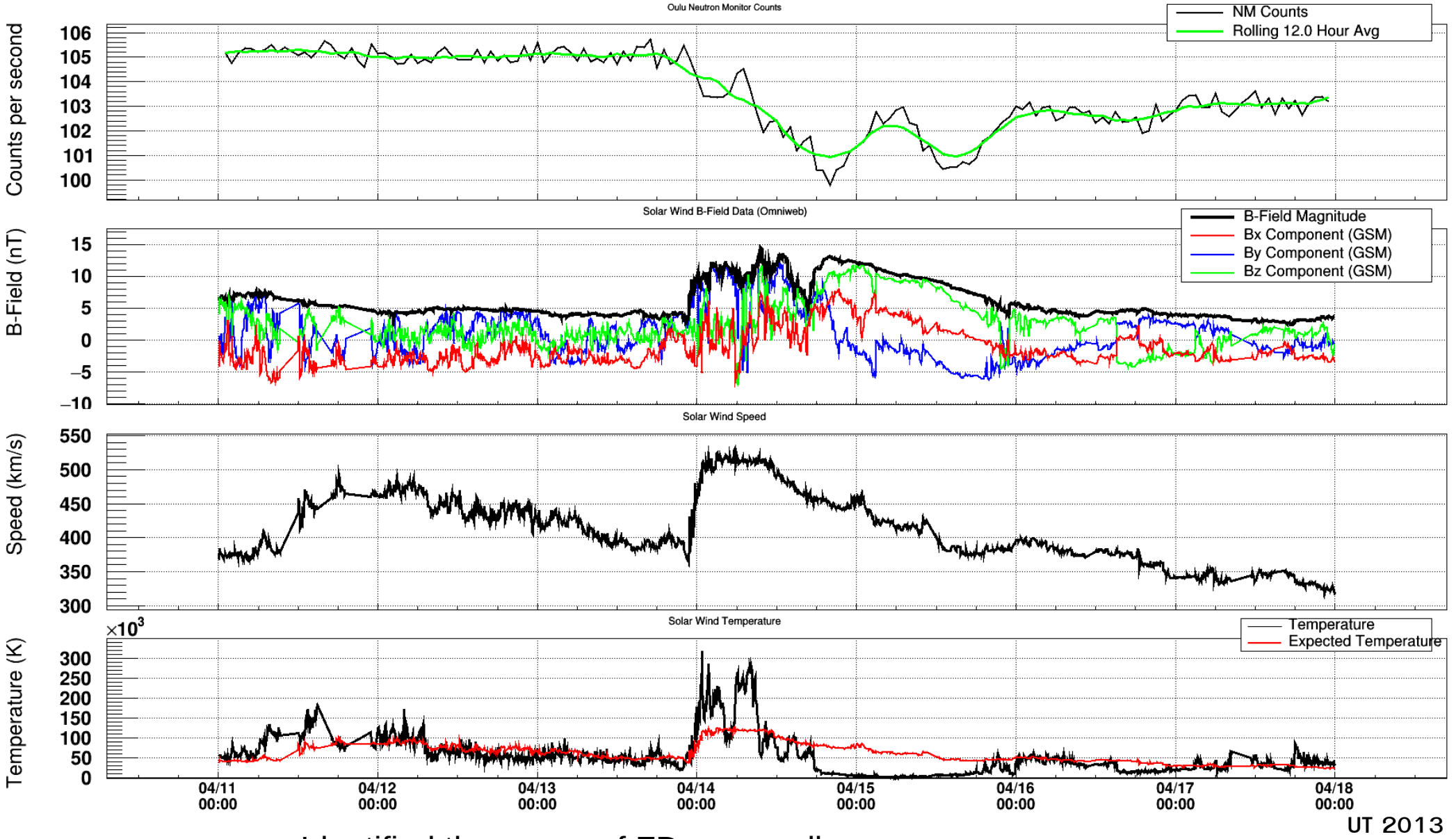
Interplanetary Coronal Mass Ejection (ICME)



ICMEs have a few notable structures that affect local galactic cosmic ray flux and allow for the identification of ICMEs using in situ solar wind data.

Richardson & Cane 2011

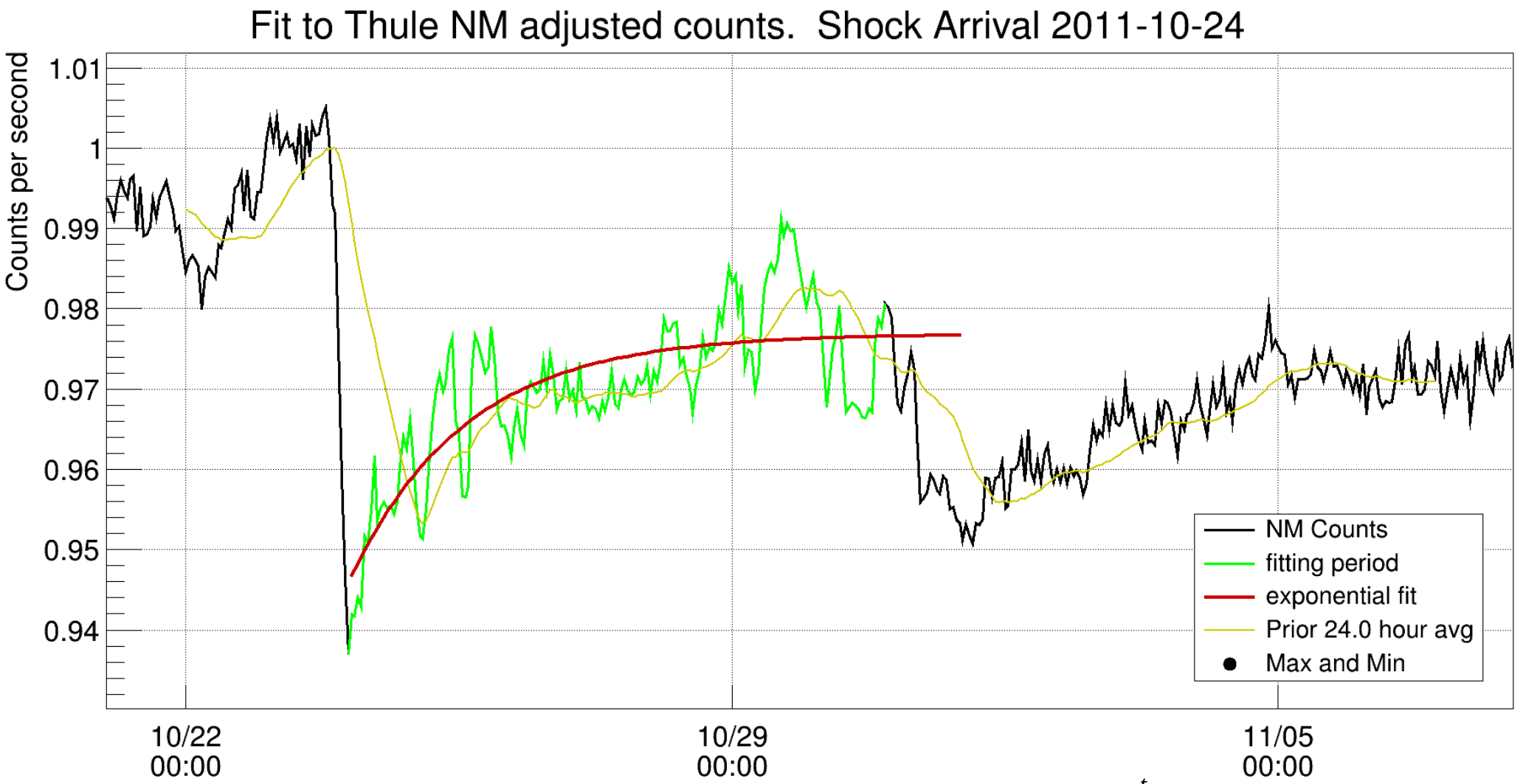
Identifying FD Causes in Neutron Monitor Data



- Identified the cause of FDs manually
- Created a group of 28 “Golden” Events
  - ICME associated FDs with clear shock, sheath, and magnetic cloud
  - Relatively quiet solar wind immediately before and after the event

Richardson & Cane 1995

Fitting FD Recovery in NM Data

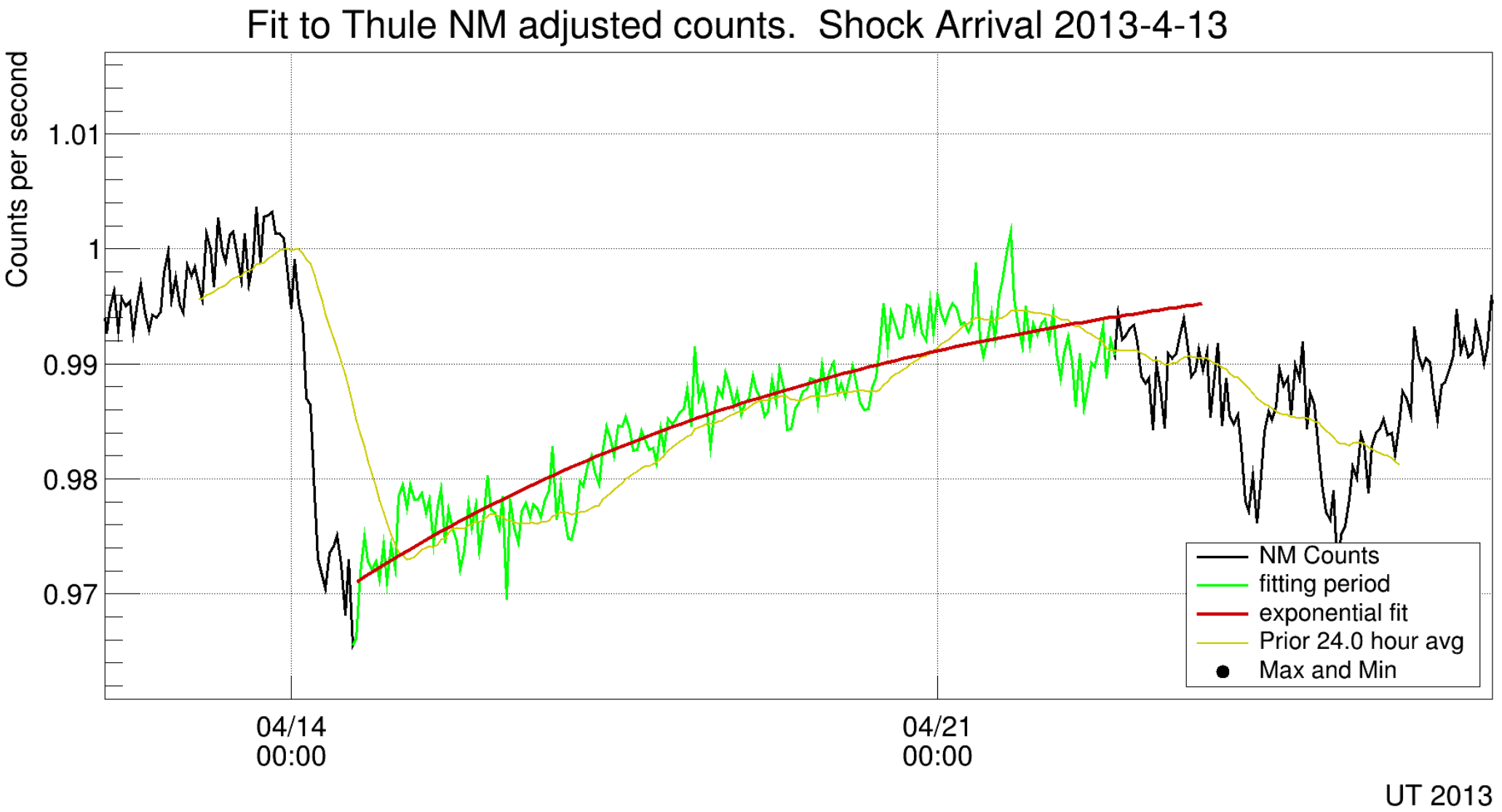


Exponential Recovery: $[\text{Norm Flux}] = A - Be^{-\frac{t}{\tau}}$

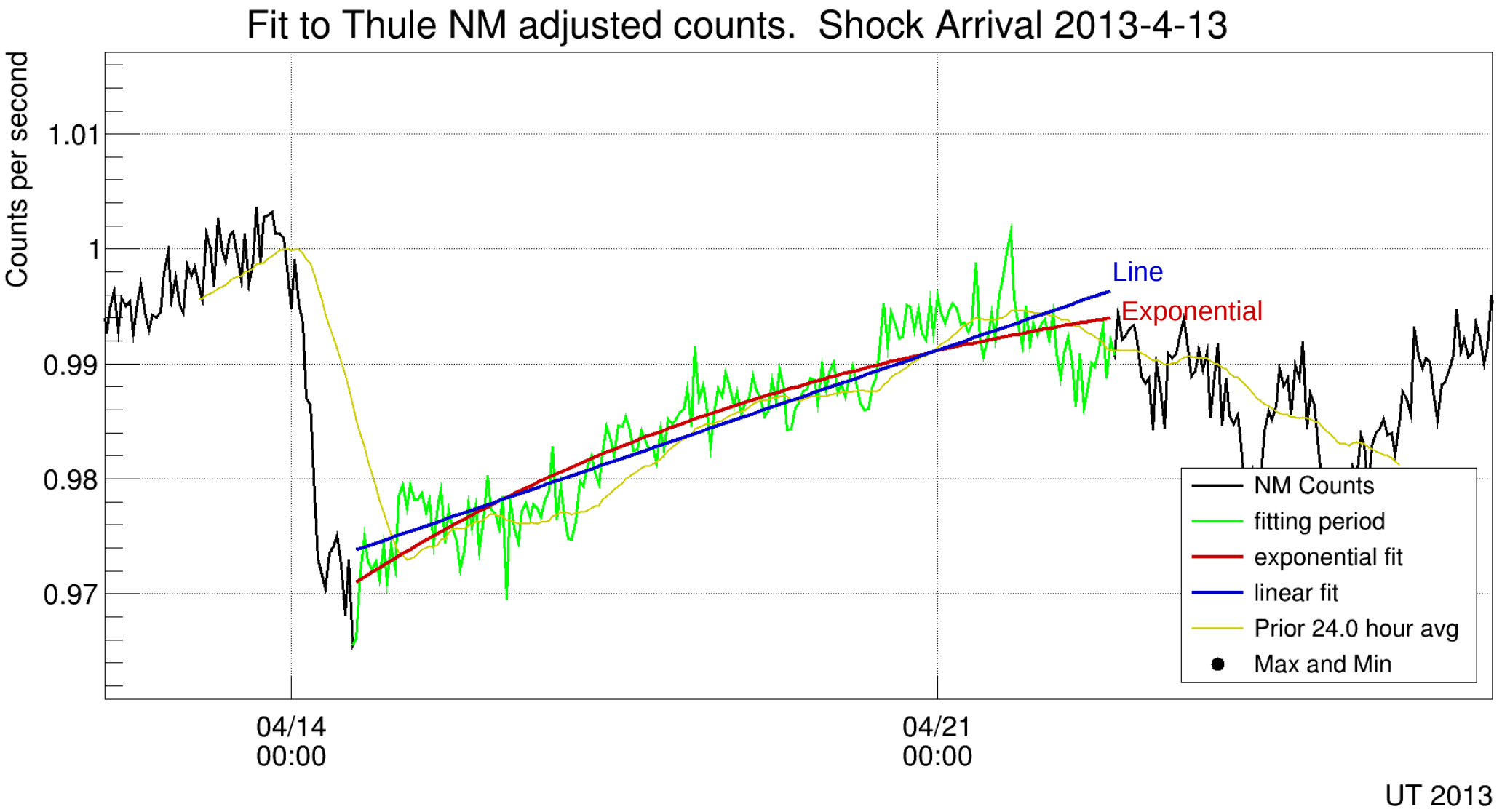
Where A, B, and τ are fit parameters.

Motivated by the shape of recovery in a diffusive barrier model. Luo et al. 2017

Fitting FD Recovery in NM Data



Fitting FD Recovery in NM Data



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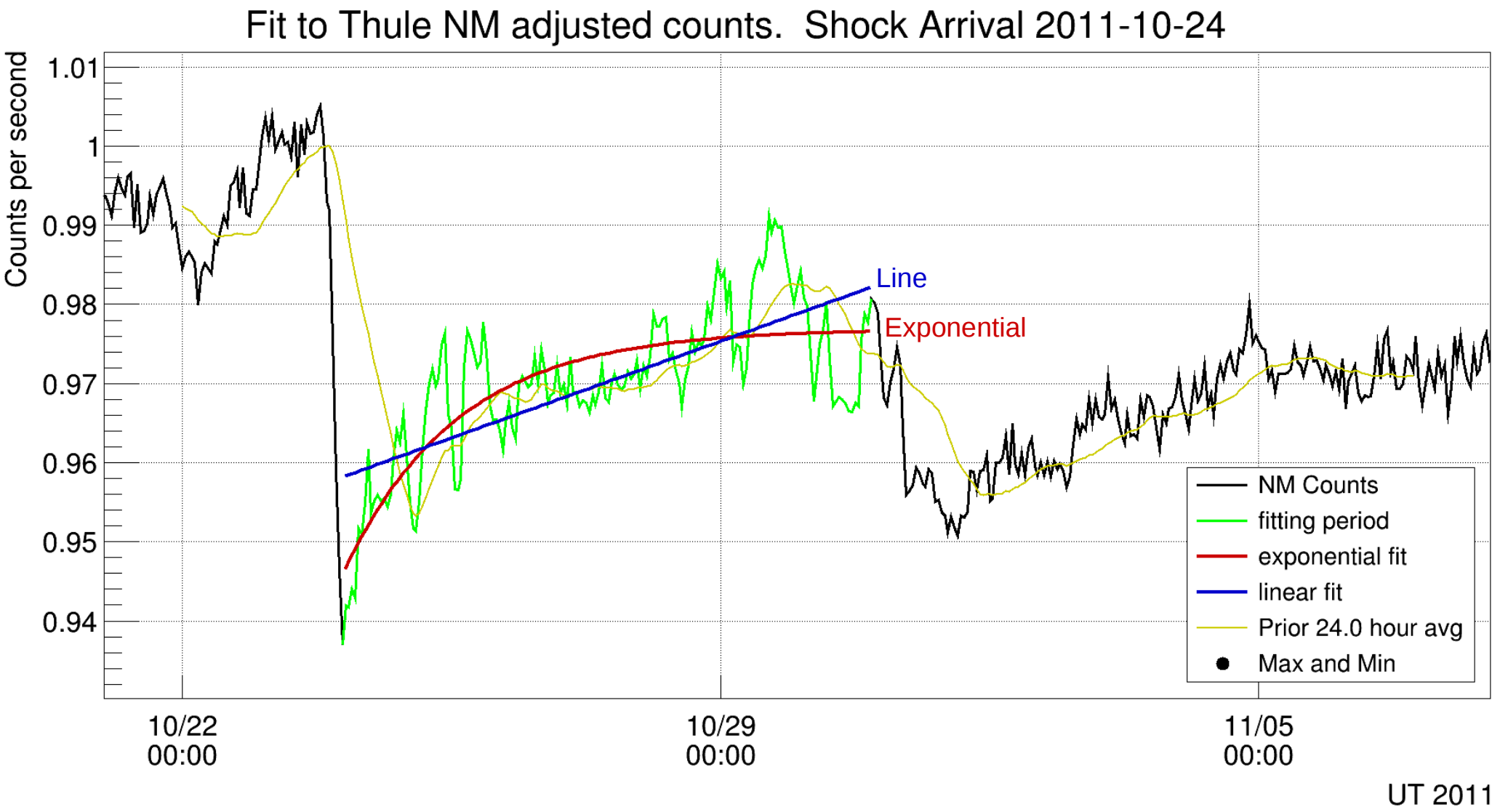
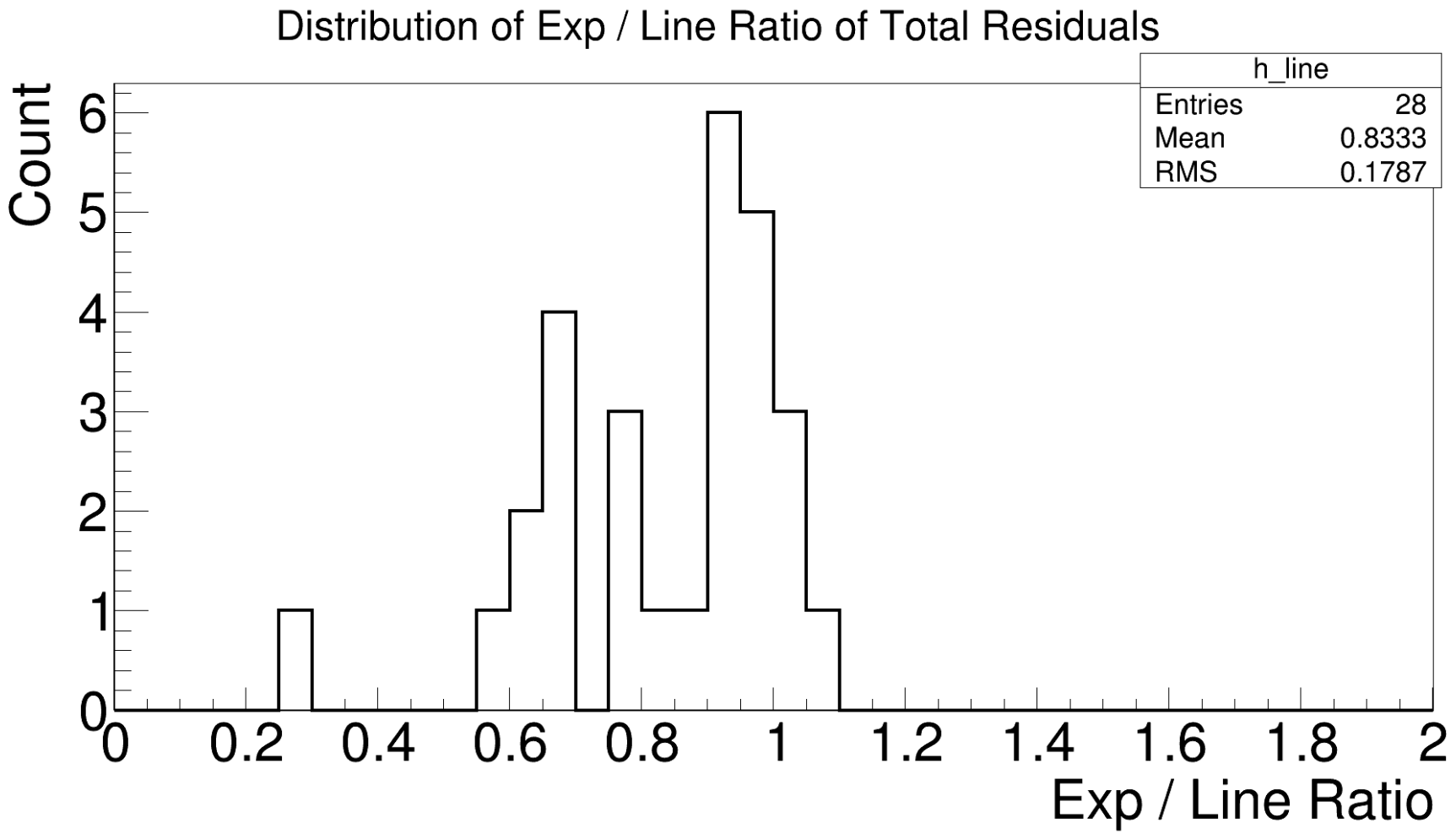


Fits for Golden Events



Used the total residual over all points in the fitting period as a measure of the fit quality, and compared it to a linear fit.

Fits for Golden Events

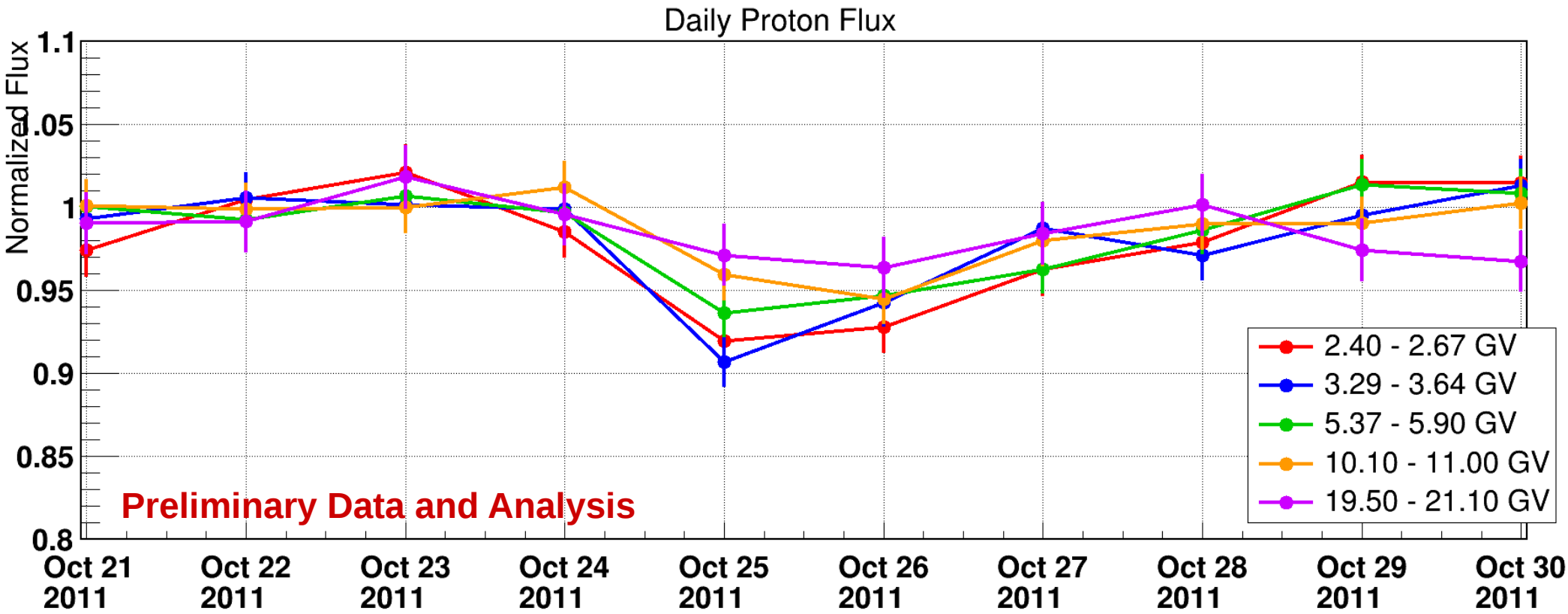
Number	FD Day	Recovery Time Parameter
1	2001/3/19	1.63212 +/- 0.116969
2	2001/04/28	6.21467 +/- 0.0952219
3	2001/8/17	0.724846 +/- 0.0751258
4	2001/10/11	9.91971 +/- 0.0940956
5	2001/10/21	2.79701 +/- 0.126677
6	2001/11/24	0.463208 +/- 0.0972734
7	2004/7/27	7.38059 +/- 0.172619
8	2004/11/9	5.92285 +/- 0.0799339
9	2005/5/15	0.703905 +/- 0.0871275
10	2006/12/14	3.16189 +/- 0.0653105
11	2010/4/5	1.12868 +/- 0.130125
12	2010/8/3	6.16613 +/- 0.0604355
13	2011/6/4	0.770372 +/- 0.0584472
14	2011/6/16	2.70251 +/- 0.0788699
15	2011/10/24	5.92904 +/- 0.0501638
16	2012/7/14	5.58859 +/- 0.0843184
17	2012/11/13	3.54178 +/- 0.113261
18	2013/4/13	3.2795 +/- 0.0880901
19	2013/6/27	17.3234 +/- 0.0882637
20	2013/7/12	10.8166 +/- 0.0654389
21	2014/9/11	29.9955 +/- 0.178859
22	2015/3/16	12.9968 +/- 0.161447
23	2015/5/5	1.18915 +/- 0.0483625
24	2015/9/7	2.37212 +/- 0.121683
25	2015/11/6	4.30787 +/- 0.0658424
26	2015/12/19	1.31167 +/- 0.0715716
27	2015/12/30	10.2527 +/- 0.102401
28	2016/7/19	1.48213 +/- 0.11642

- Recovery time parameter τ for fitting exponential recovery to Thule neutron monitor data.

$$Y = A - B\,e^{-\frac{x}{\tau}}$$

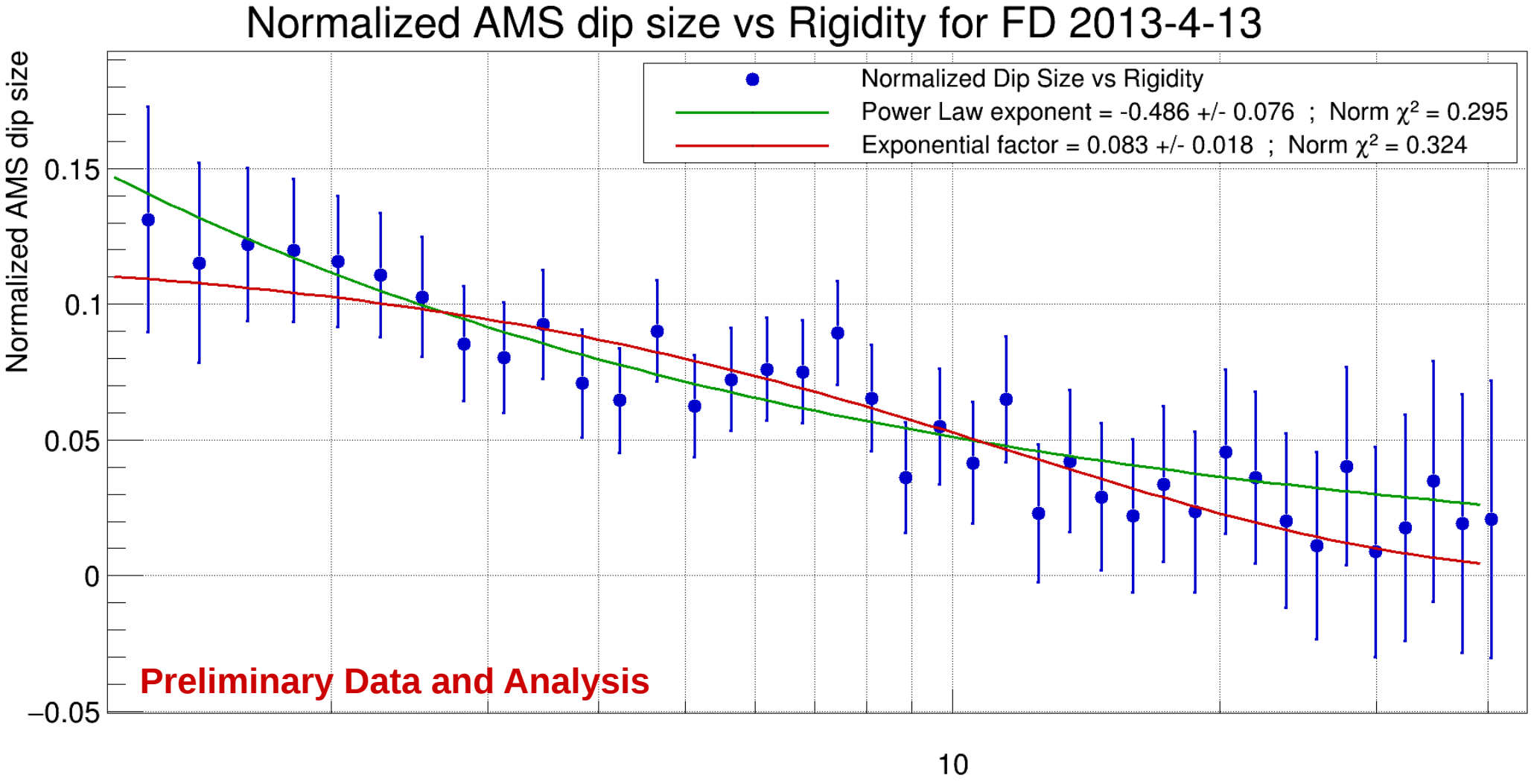
- τ is constrained to be between 10 hours and 30 days
- This list is 28 events from 2001-2016 selected to have a clear associated ICME signature and limited interferance from other transient solar events.

FDs in AMS



- AMS allows us to look at FD properties as a function of rigidity
- Due to AMS launching in 2011, 12 of the 28 Golden Events were studied using AMS data
- The AMS data shown in this presentation is not yet optimized for daily statistics

FD Magnitude as a function of rigidity



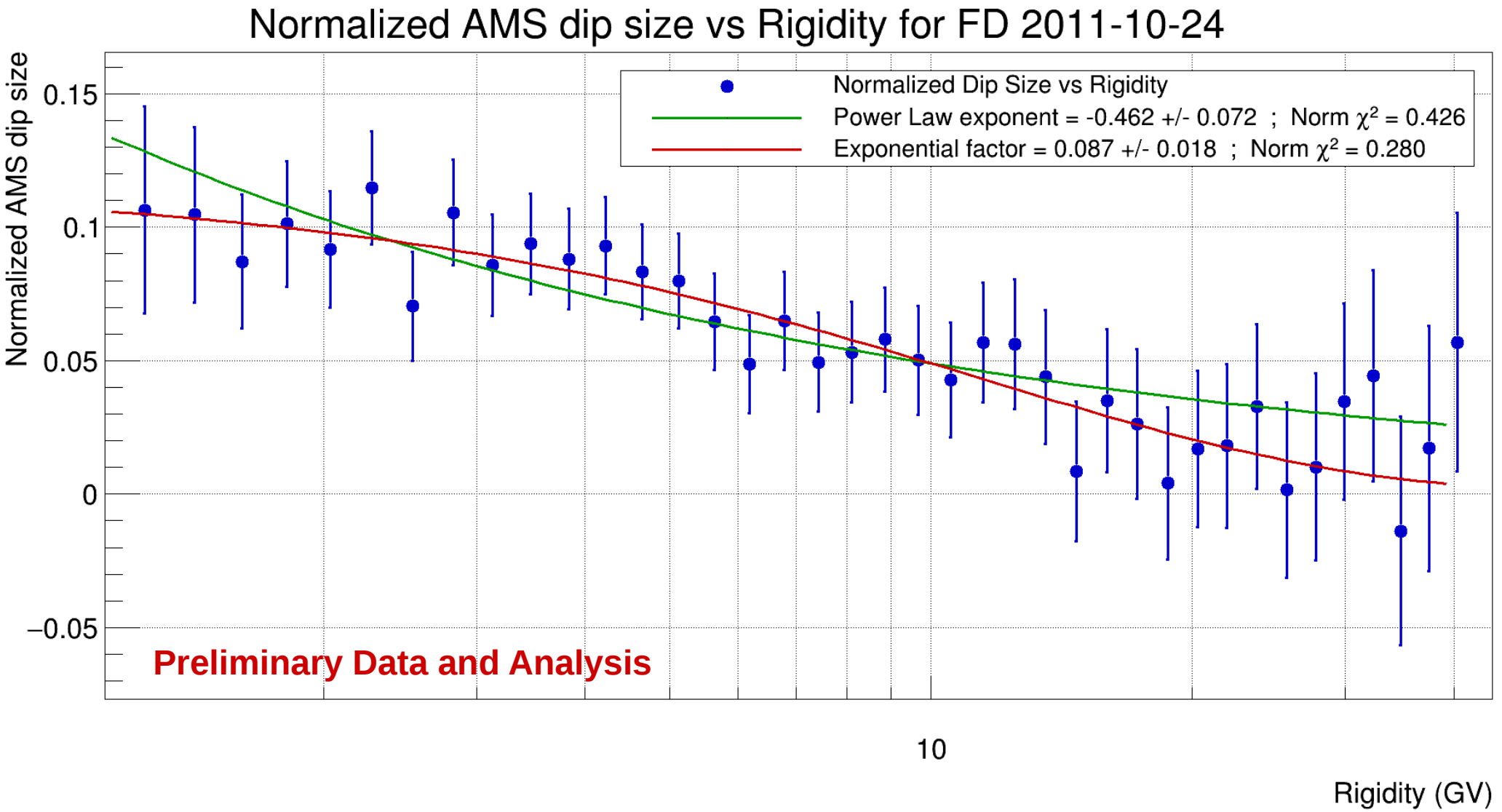
- This fit is for the daily flux on the day that the 2.15-2.4 GV Rigidity Bin was at its minimum.

Power Law: $[\text{Dip Size}] = AR^{\alpha}$

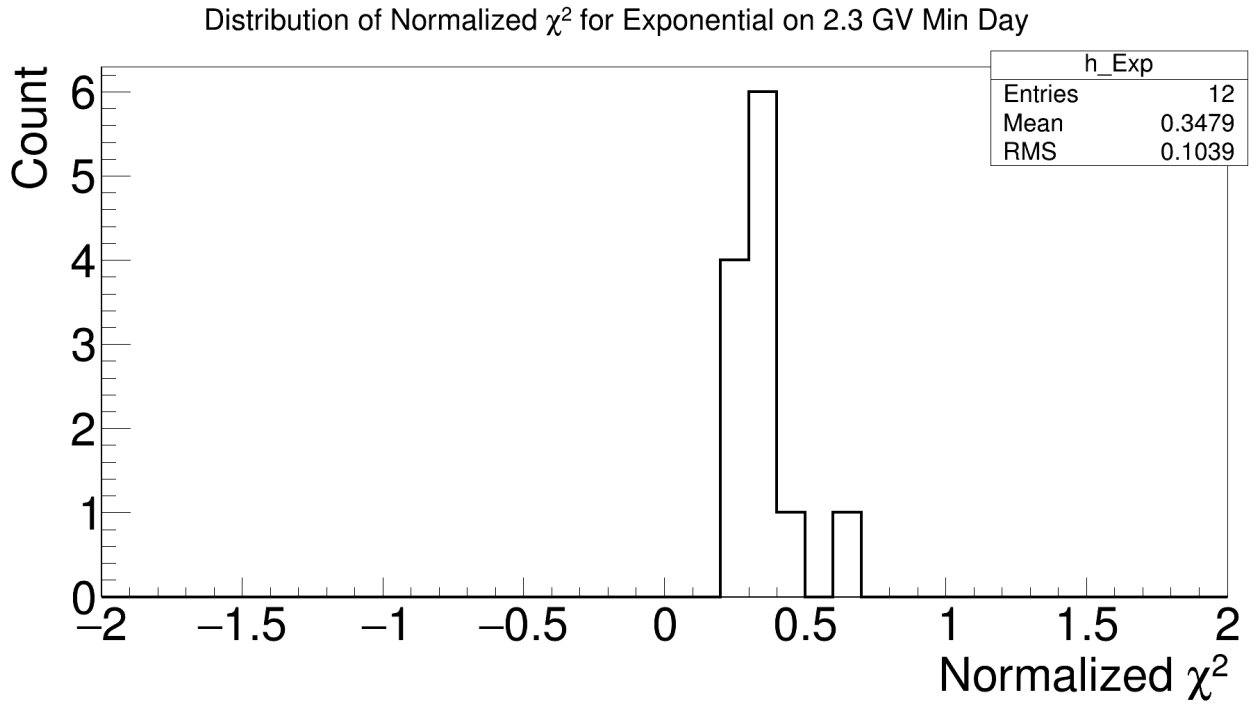
Exponential: $[\text{Dip Size}] = Be^{-\gamma R}$

Where A, B, α, and γ are fitting parameters.

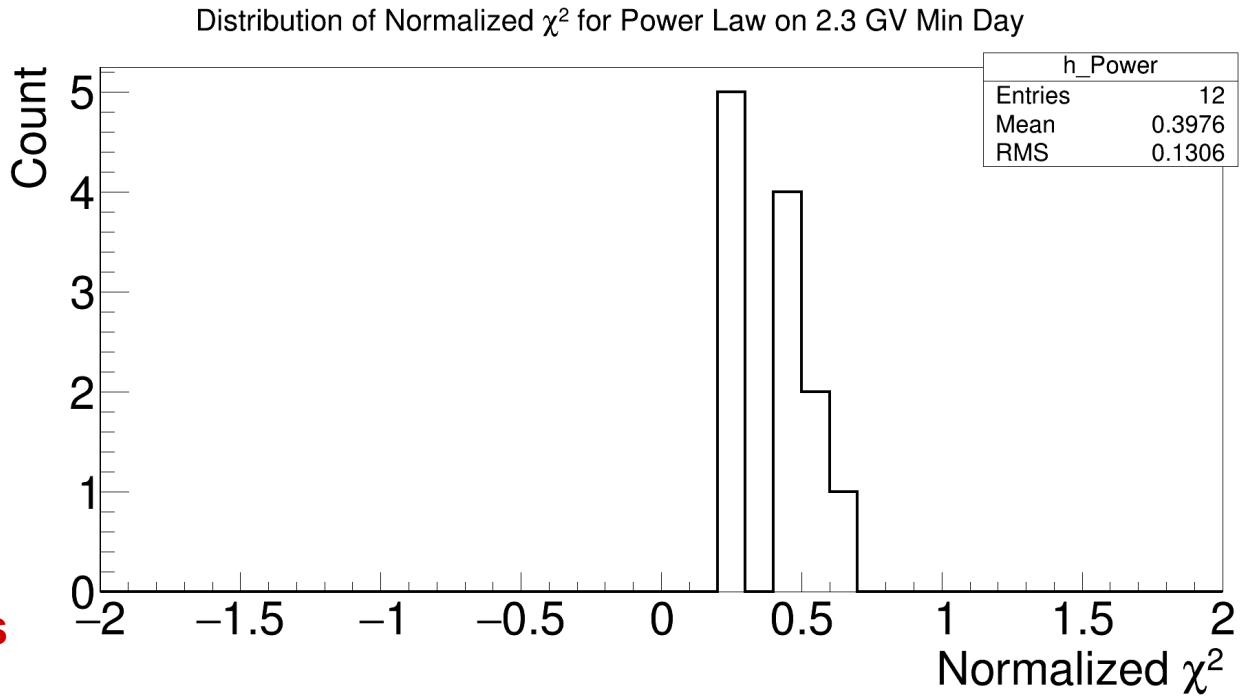
FD Magnitude as a function of rigidity



Fit Quality for All AMS Events



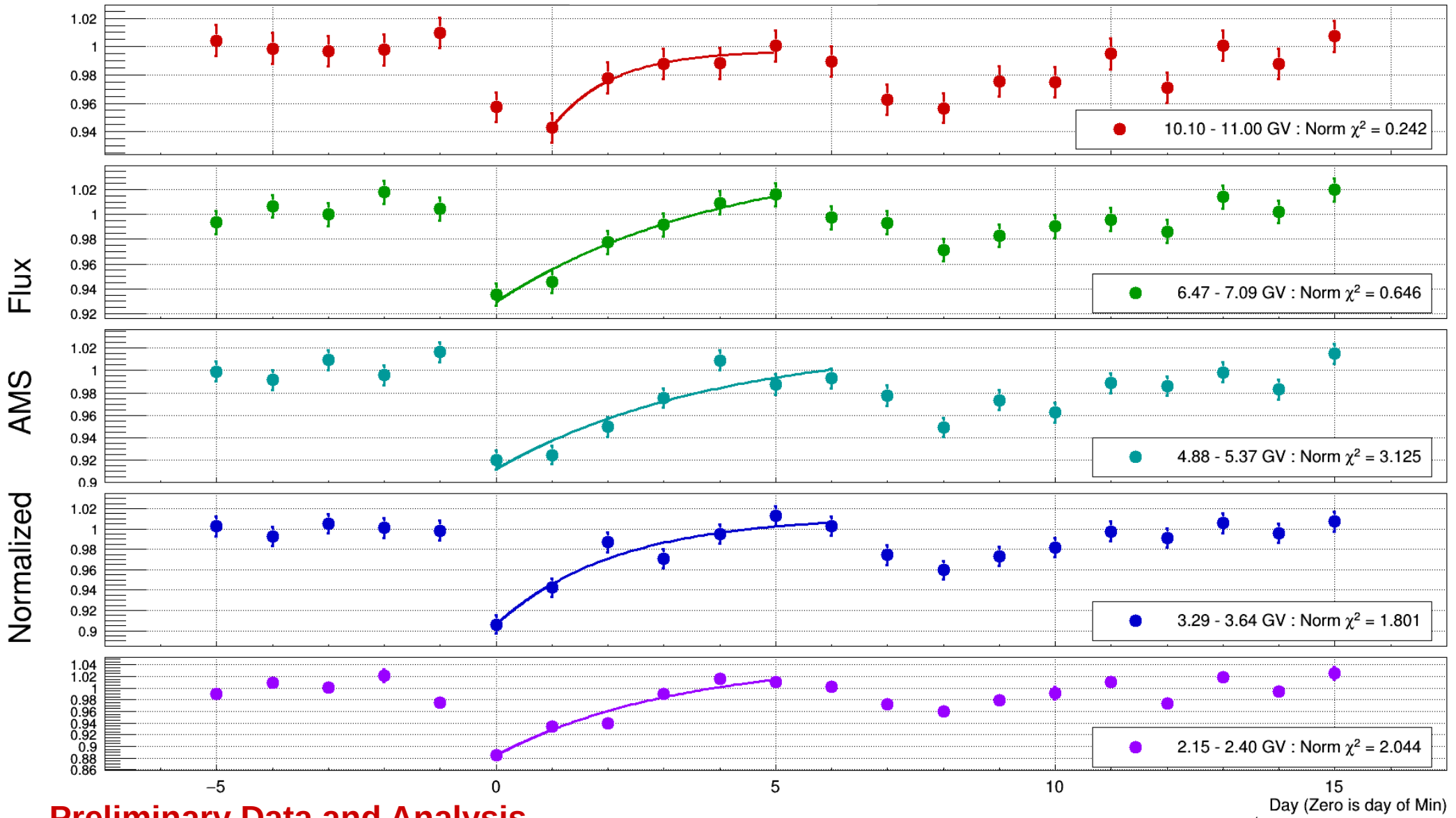
- Over the 12 events considered, the fits are of similar quality, but the exponential fit is slightly better.



- For any given event, either function may be a better fit.

Preliminary Data and Analysis

FD Recovery for AMS Events

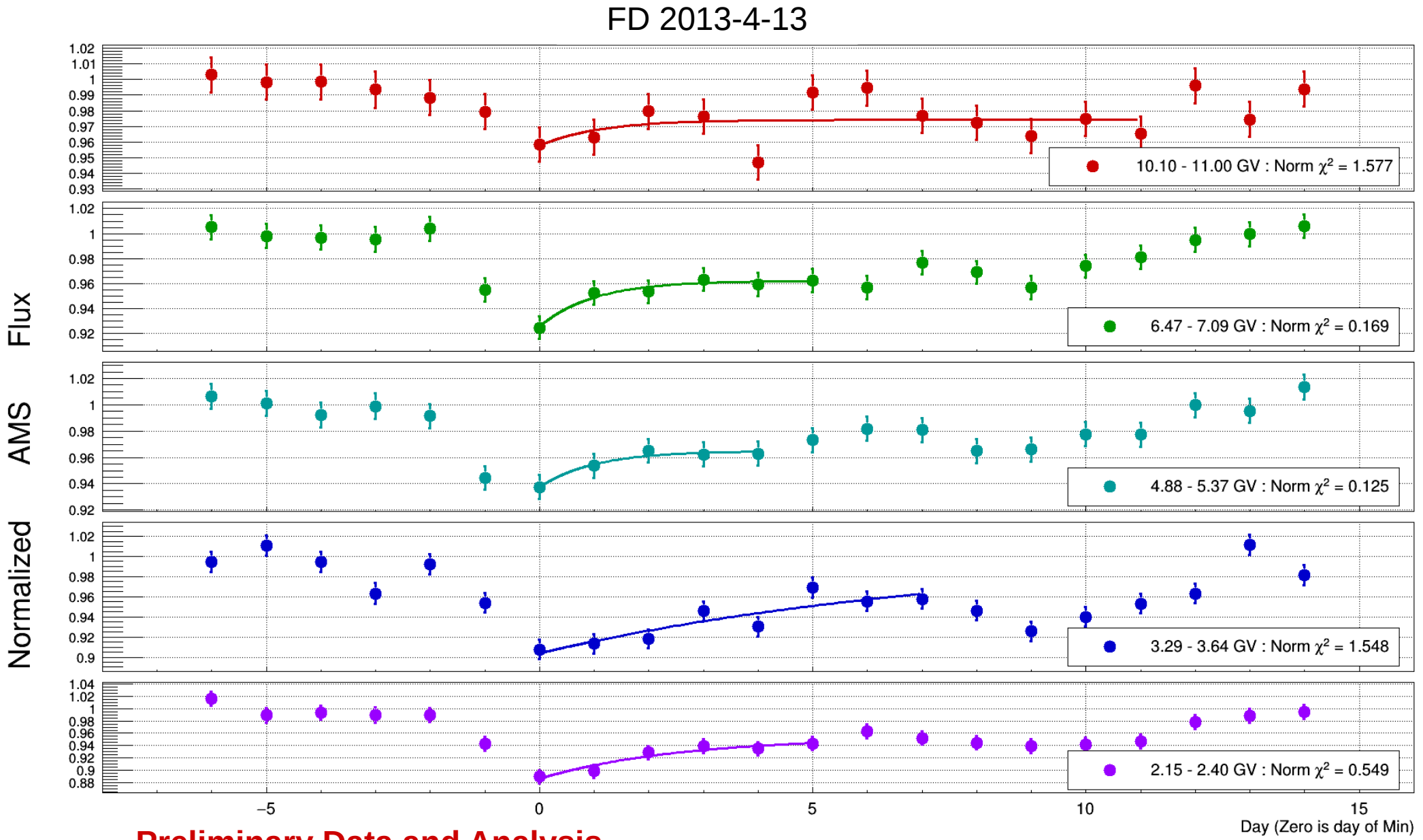


Preliminary Data and Analysis

Exponential Recovery: $[\text{Norm Flux}] = A - Be^{-\frac{t}{\tau}}$

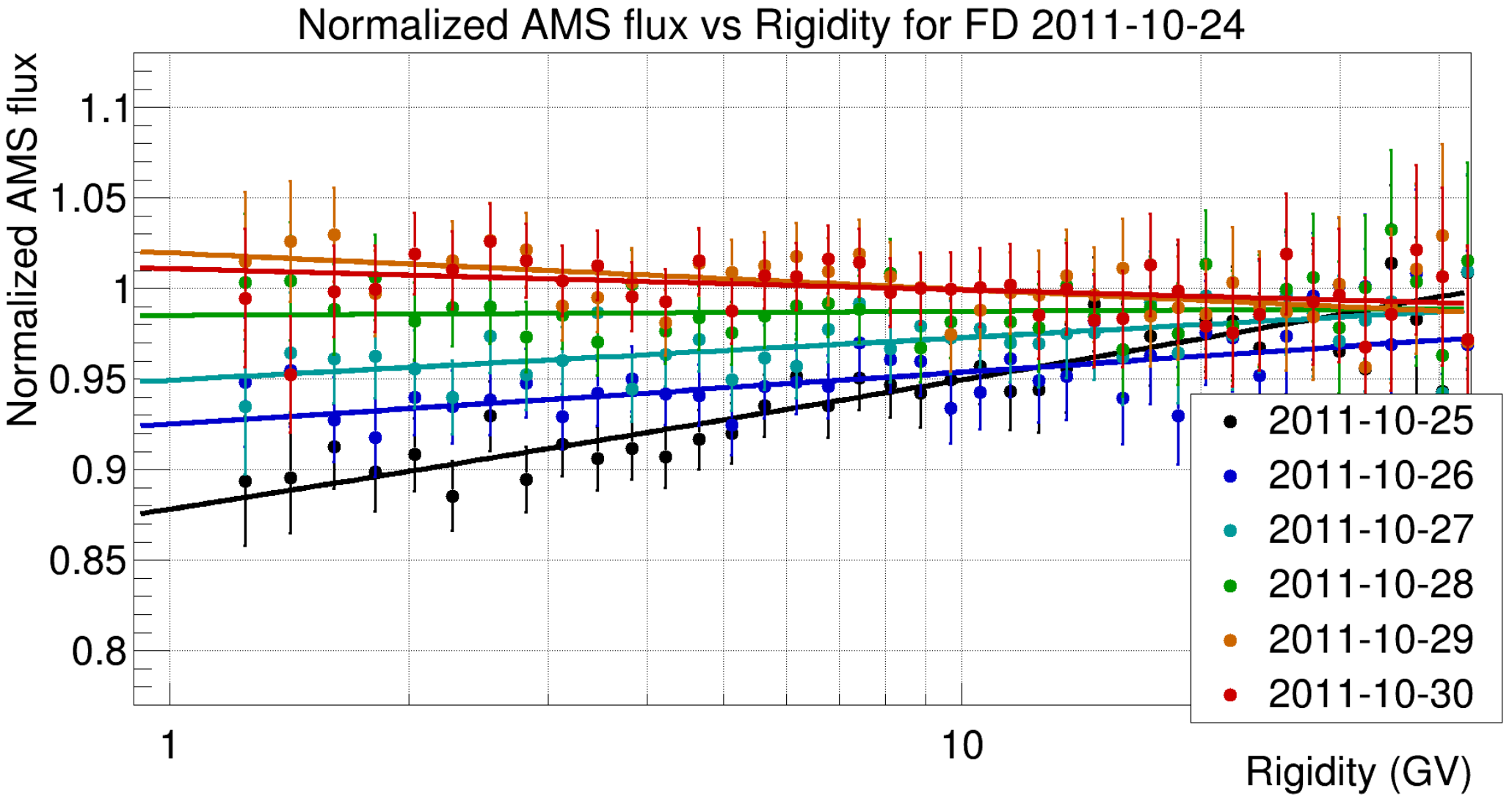
Where A, B, and τ are fit parameters.

FD Recovery for AMS Events



Preliminary Data and Analysis

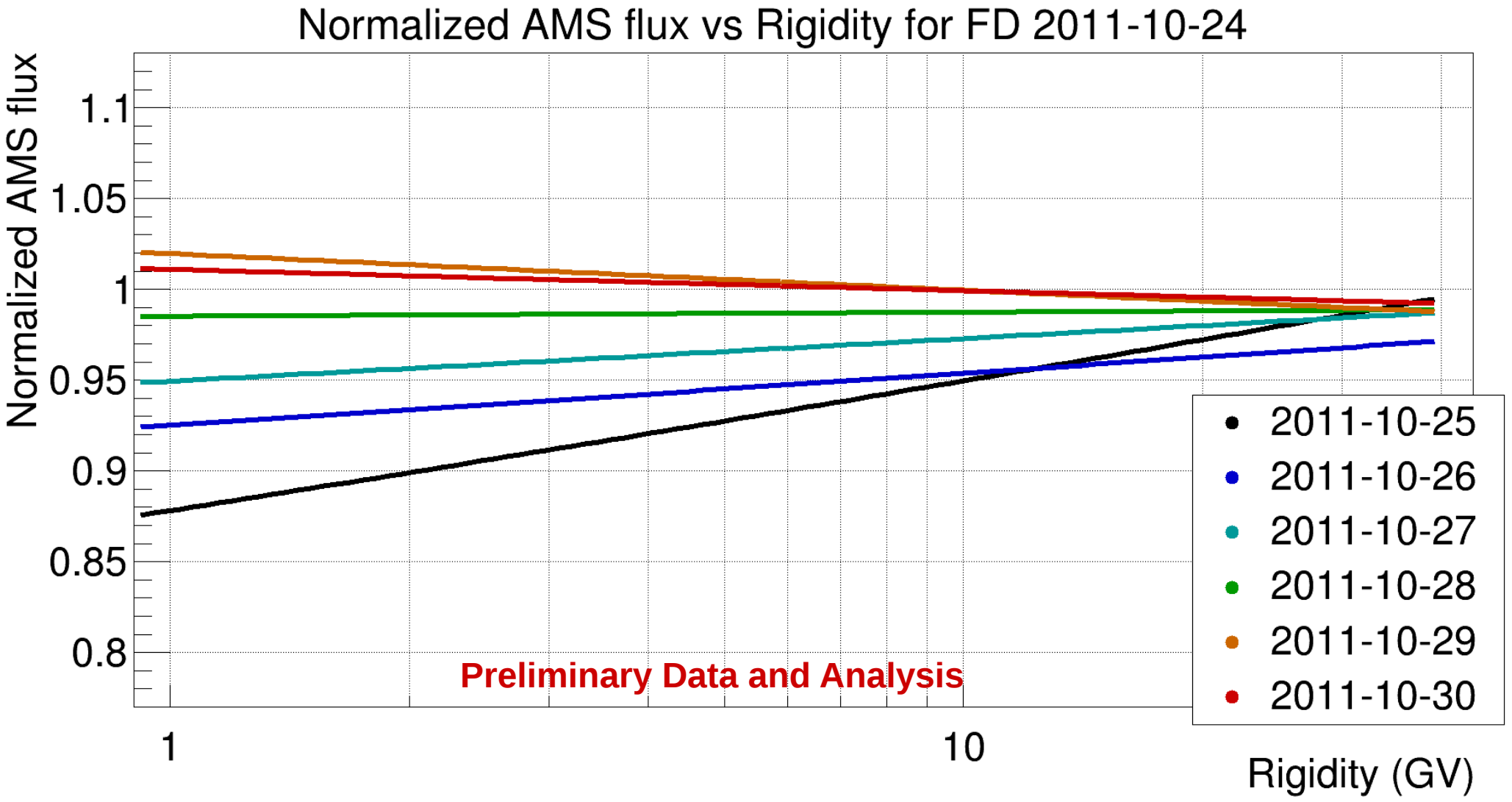
FD Recovery in AMS: Fitting the daily rigidity spectrum



Power Law: $[\text{Norm Flux}] = AR^{\alpha}$

Where A and α are fitting parameters.

FD Recovery in AMS: Fitting the daily rigidity spectrum



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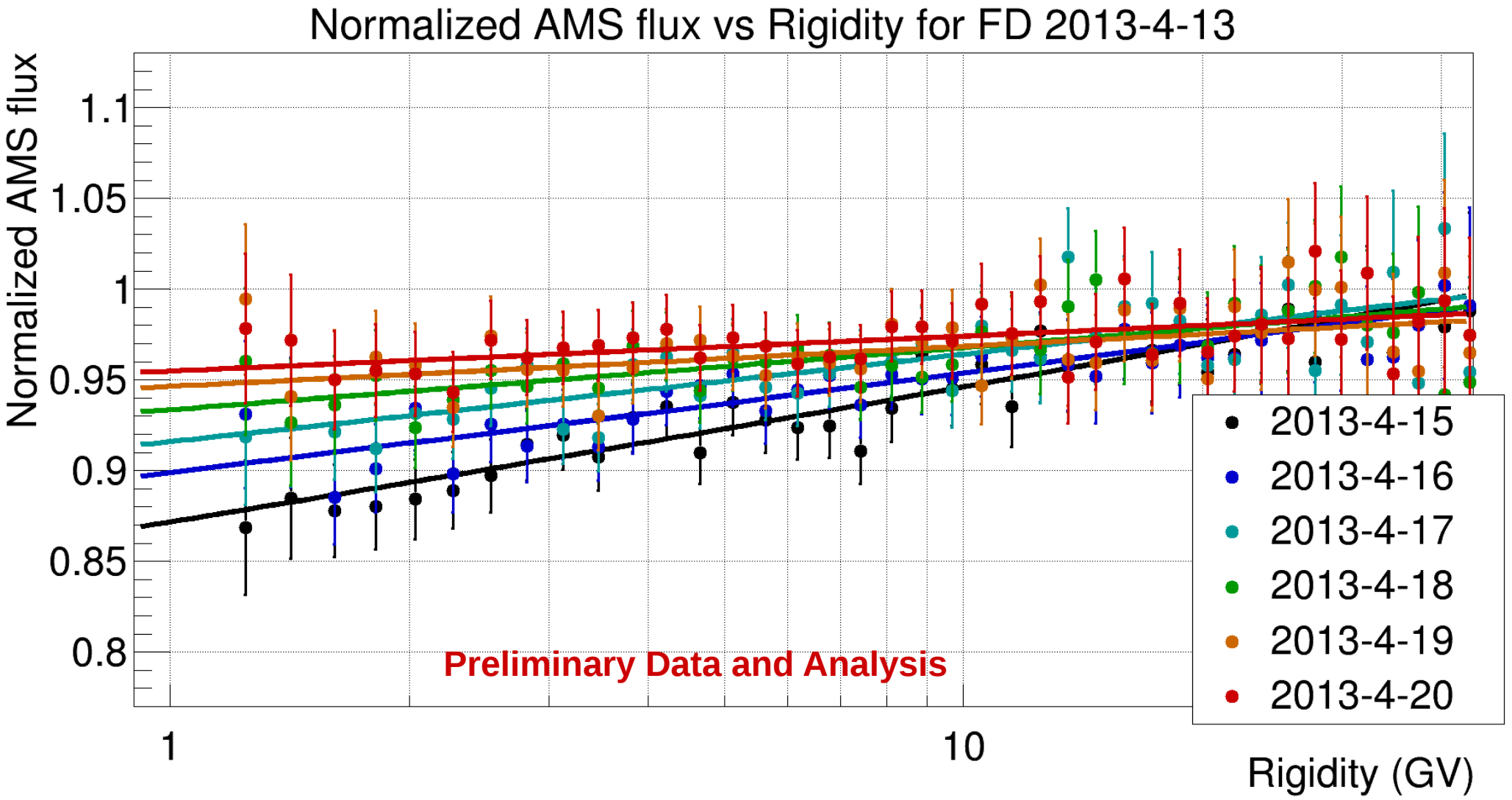

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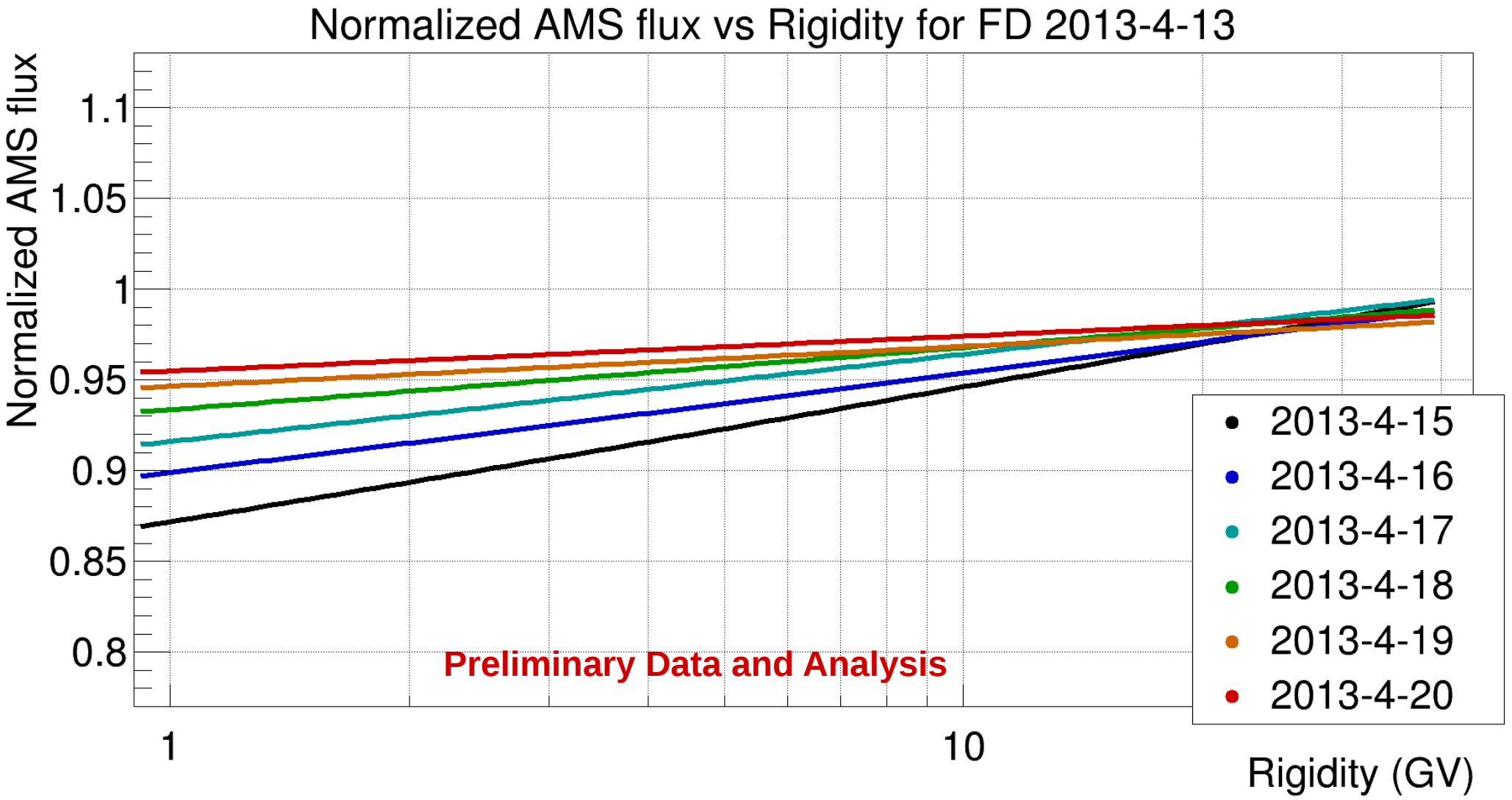
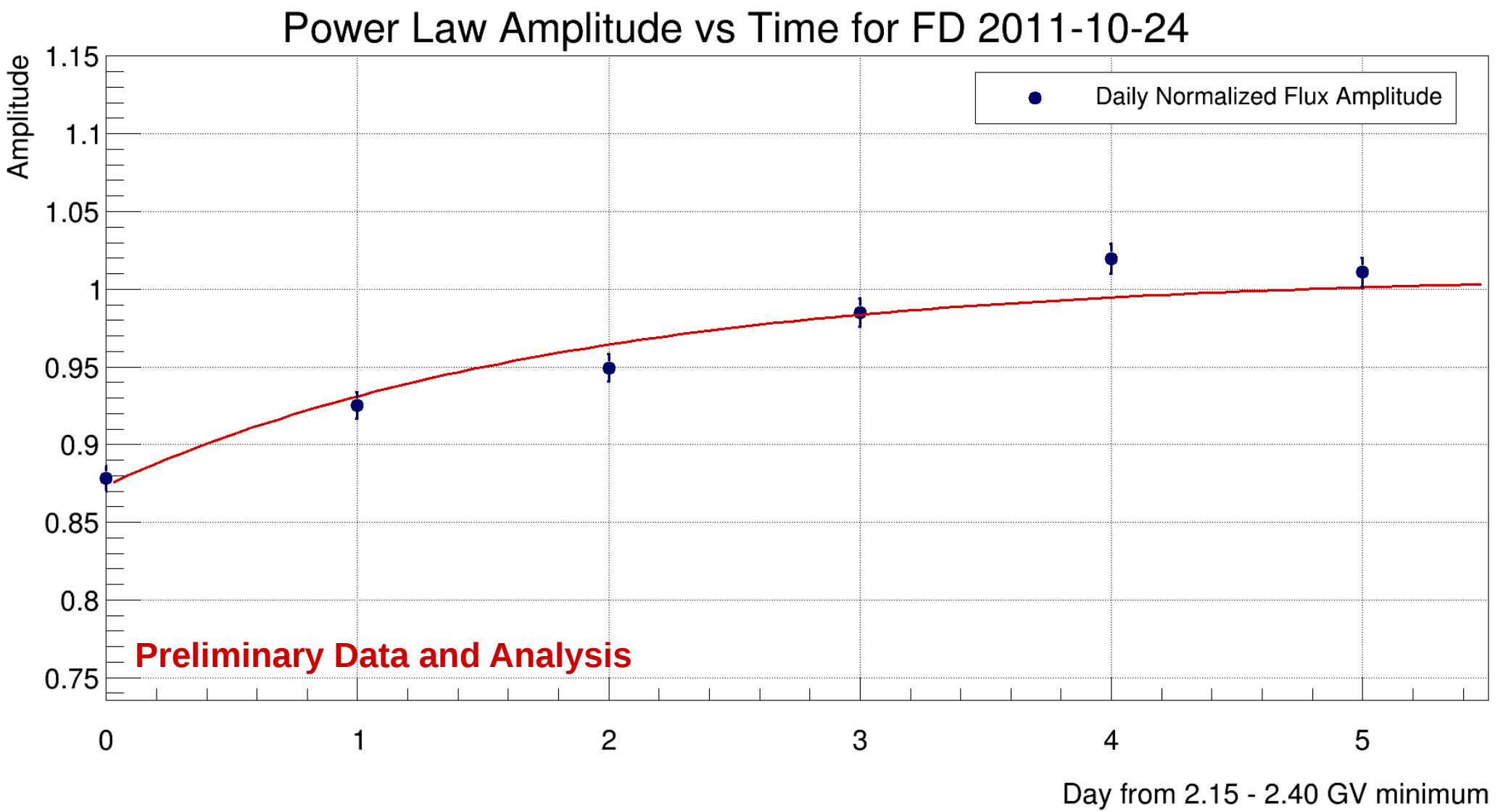


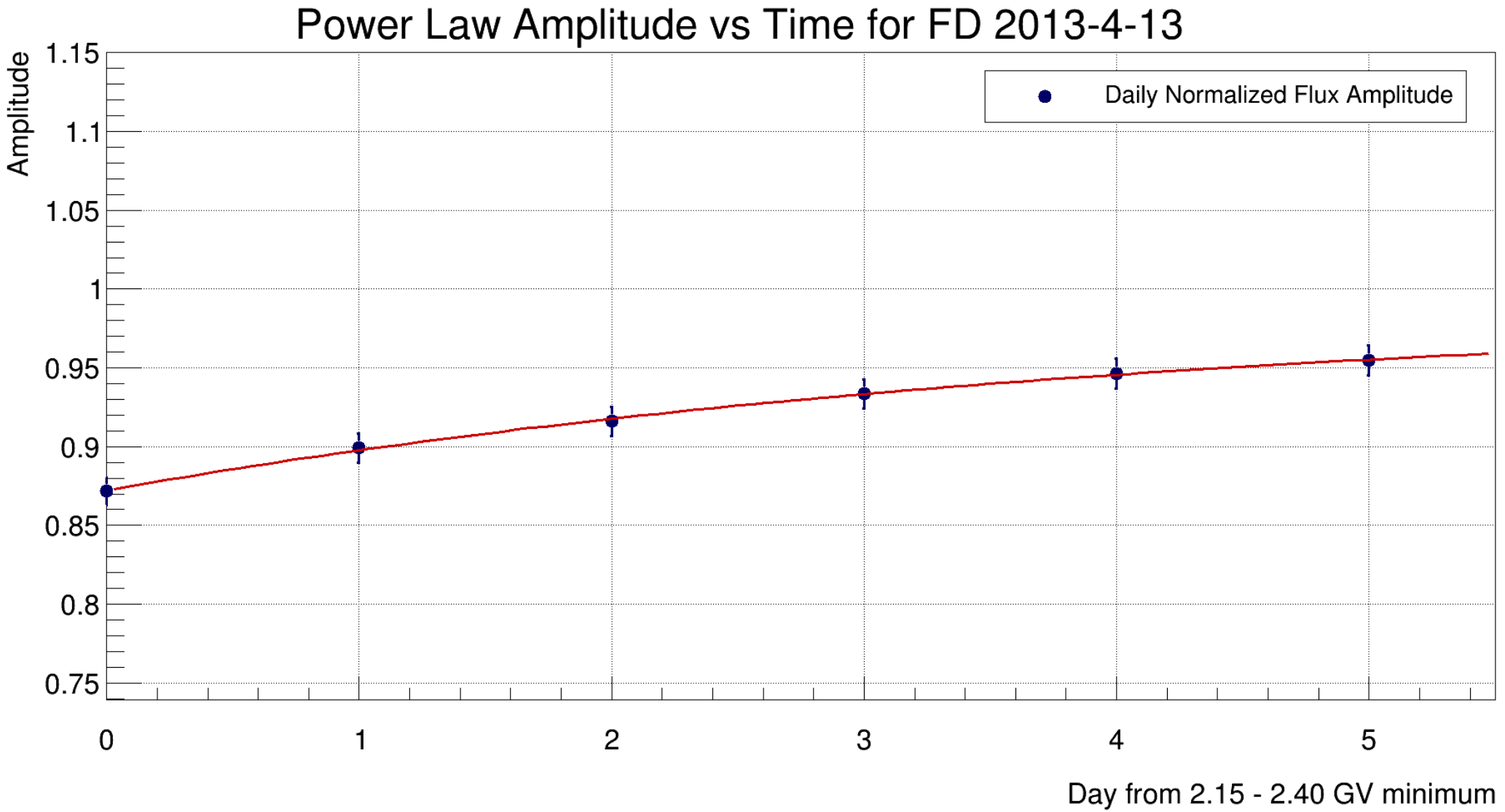
FD Recovery in AMS: Trends in daily spectra



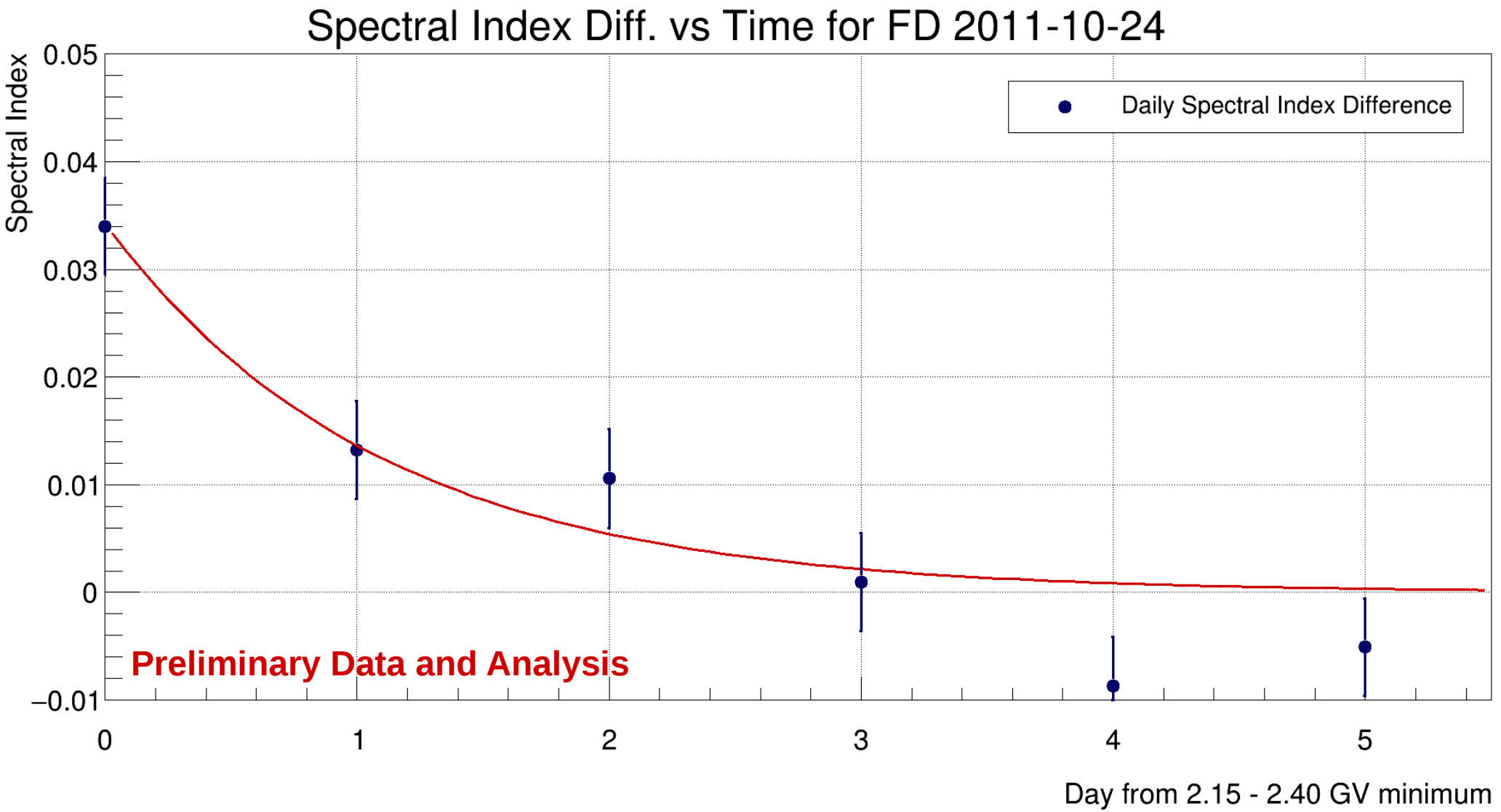
Exponential Recovery: $[\text{Norm Flux}] = A - Be^{-\frac{t}{\tau}}$

Where A, B, and τ are fit parameters.

FD Recovery in AMS: Trends in daily spectra

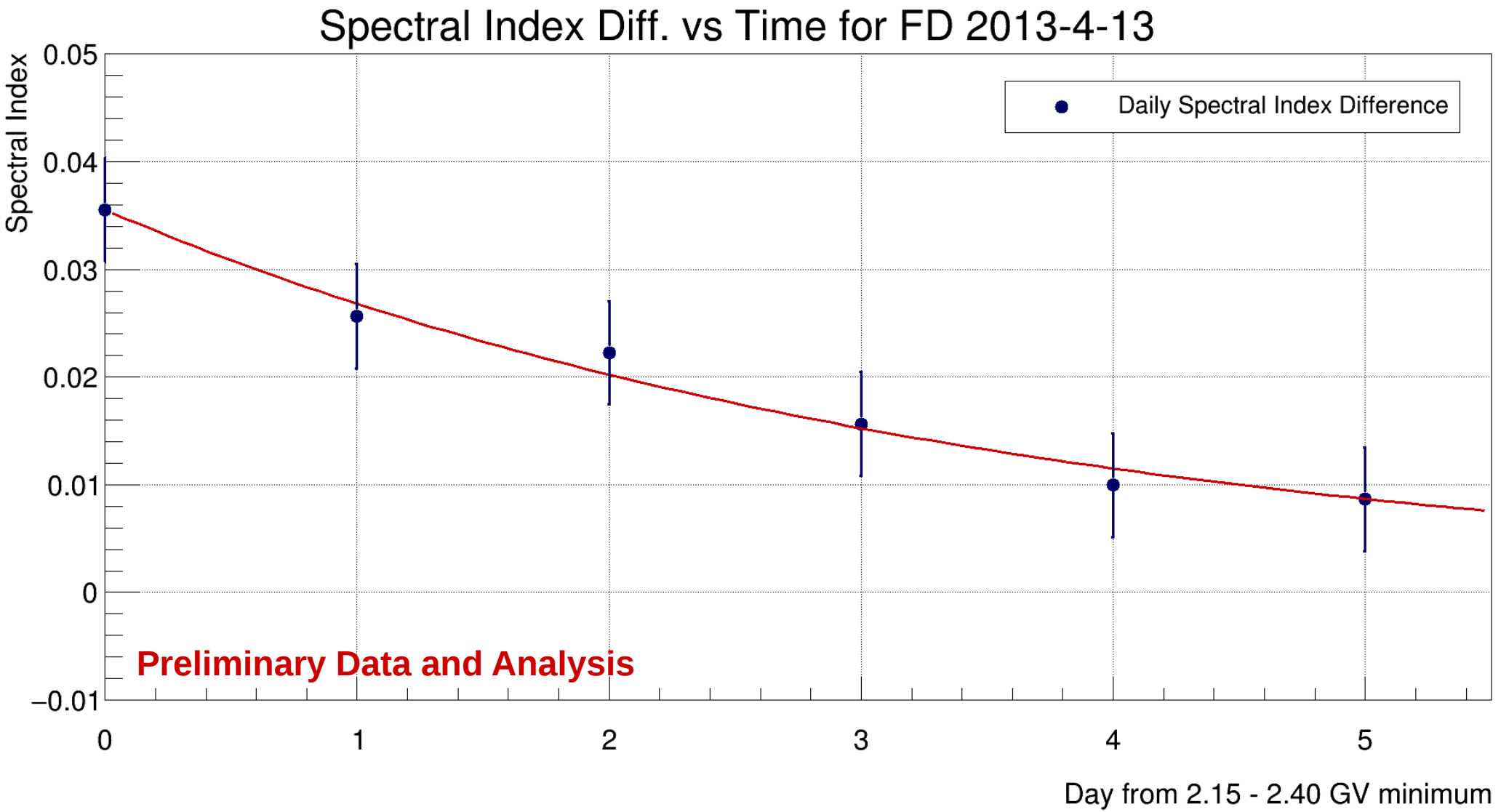


FD Recovery in AMS: Trends in daily spectra

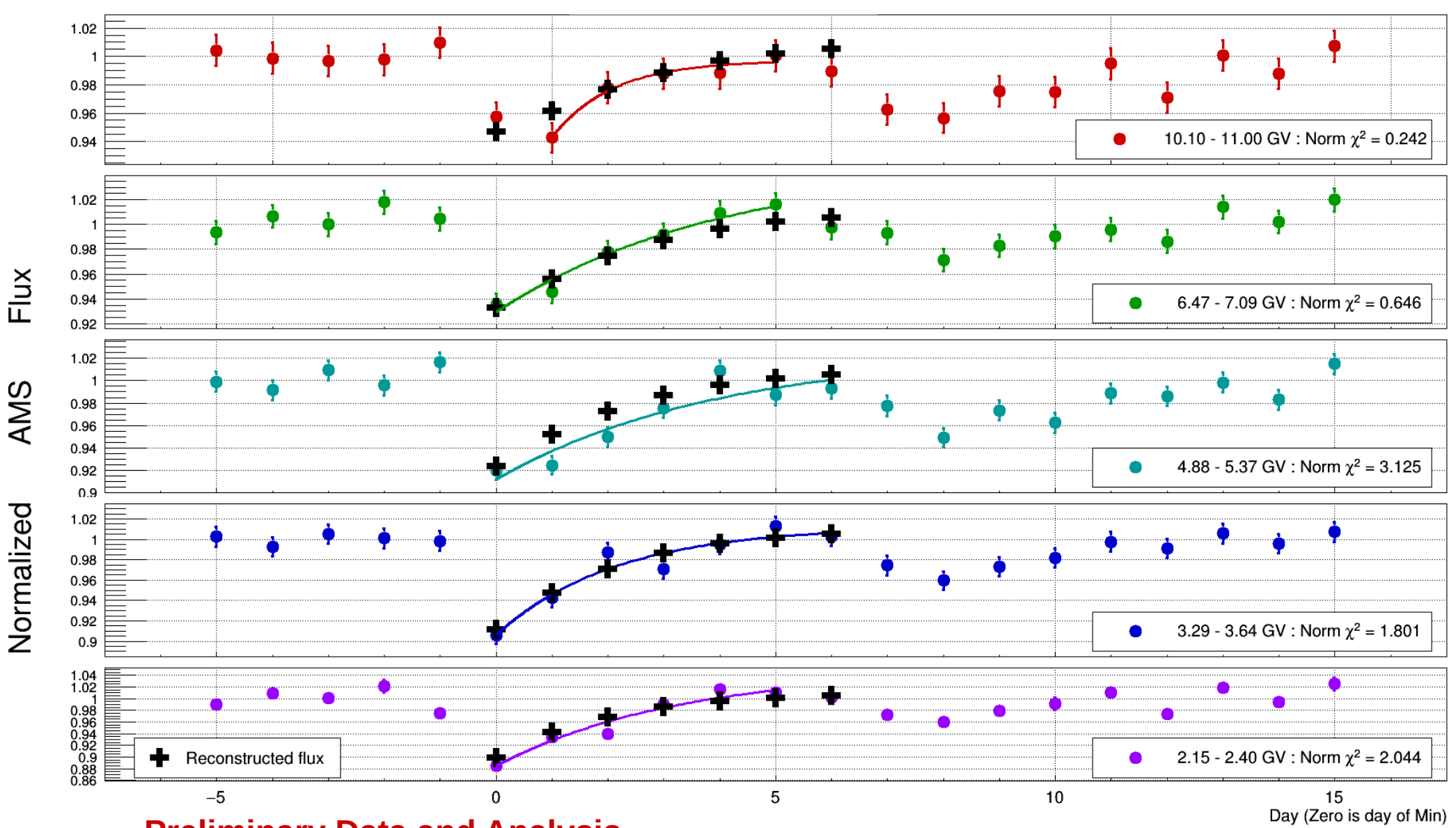


Exponential decay fit: $\alpha = Ce^{-\beta t}$

FD Recovery in AMS: Trends in daily spectra

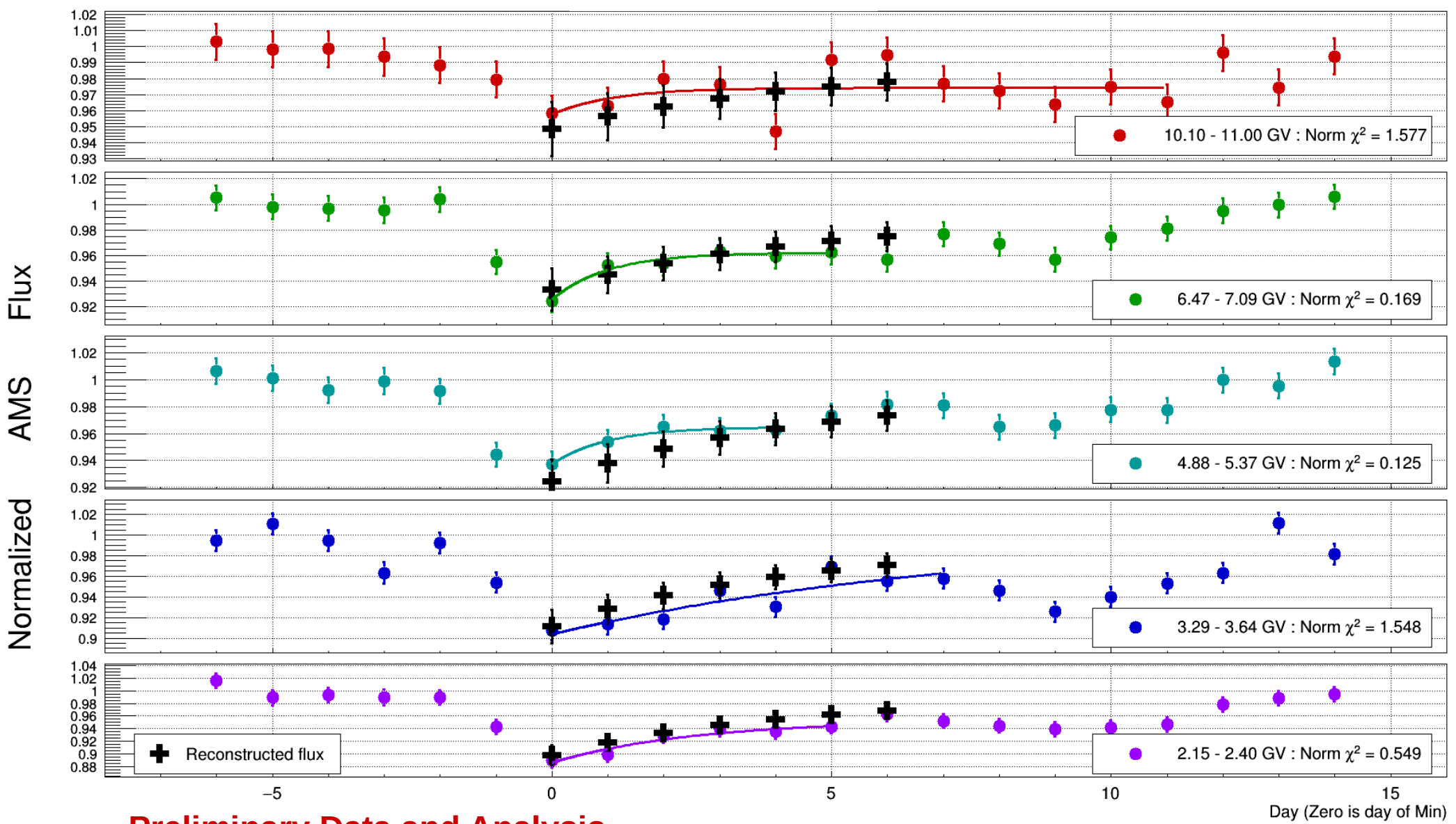


FD Recovery in AMS: Reconstructing a smoothed AMS Flux



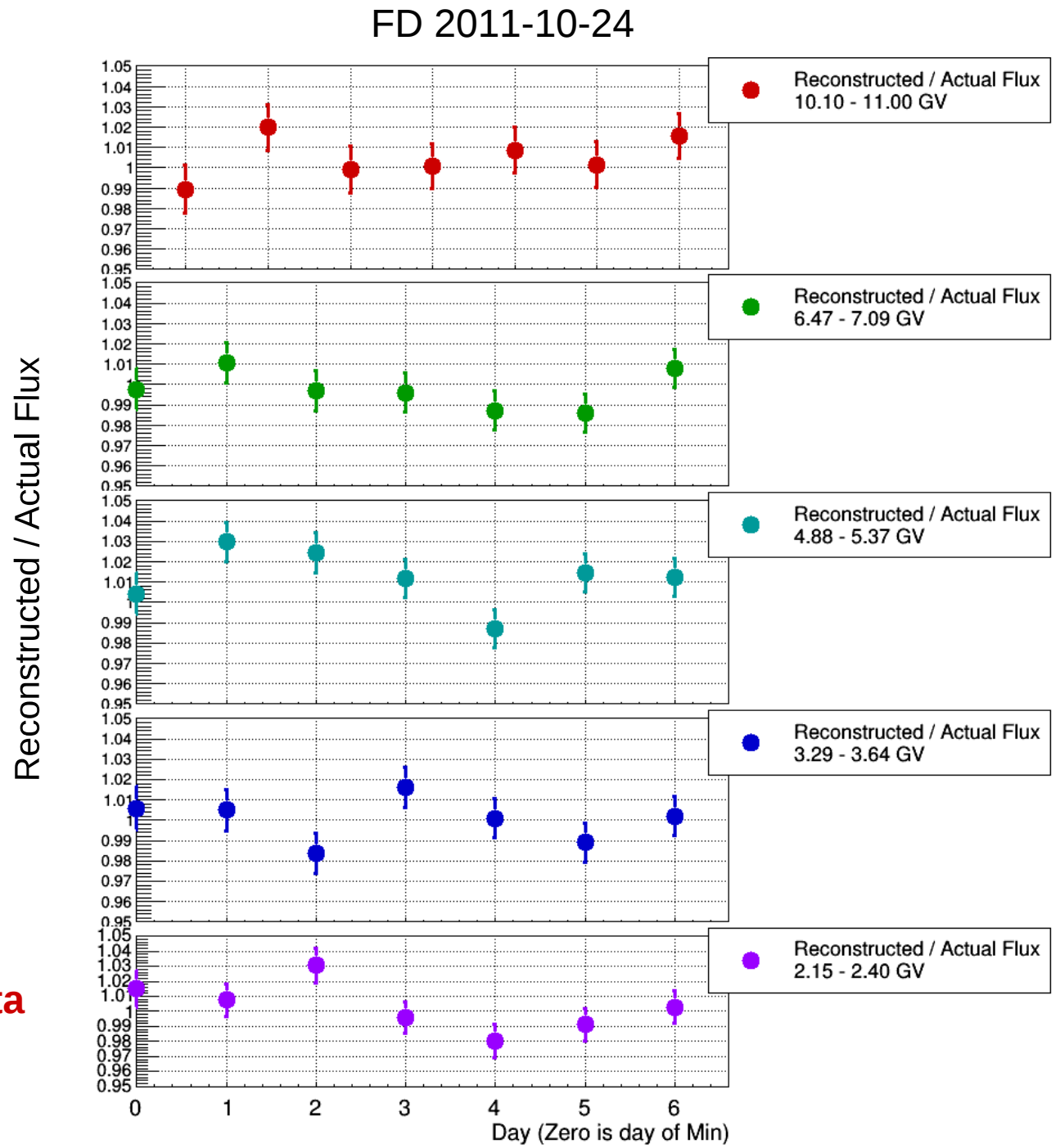
Preliminary Data and Analysis

FD Recovery in AMS: Reconstructing a smoothed AMS Flux



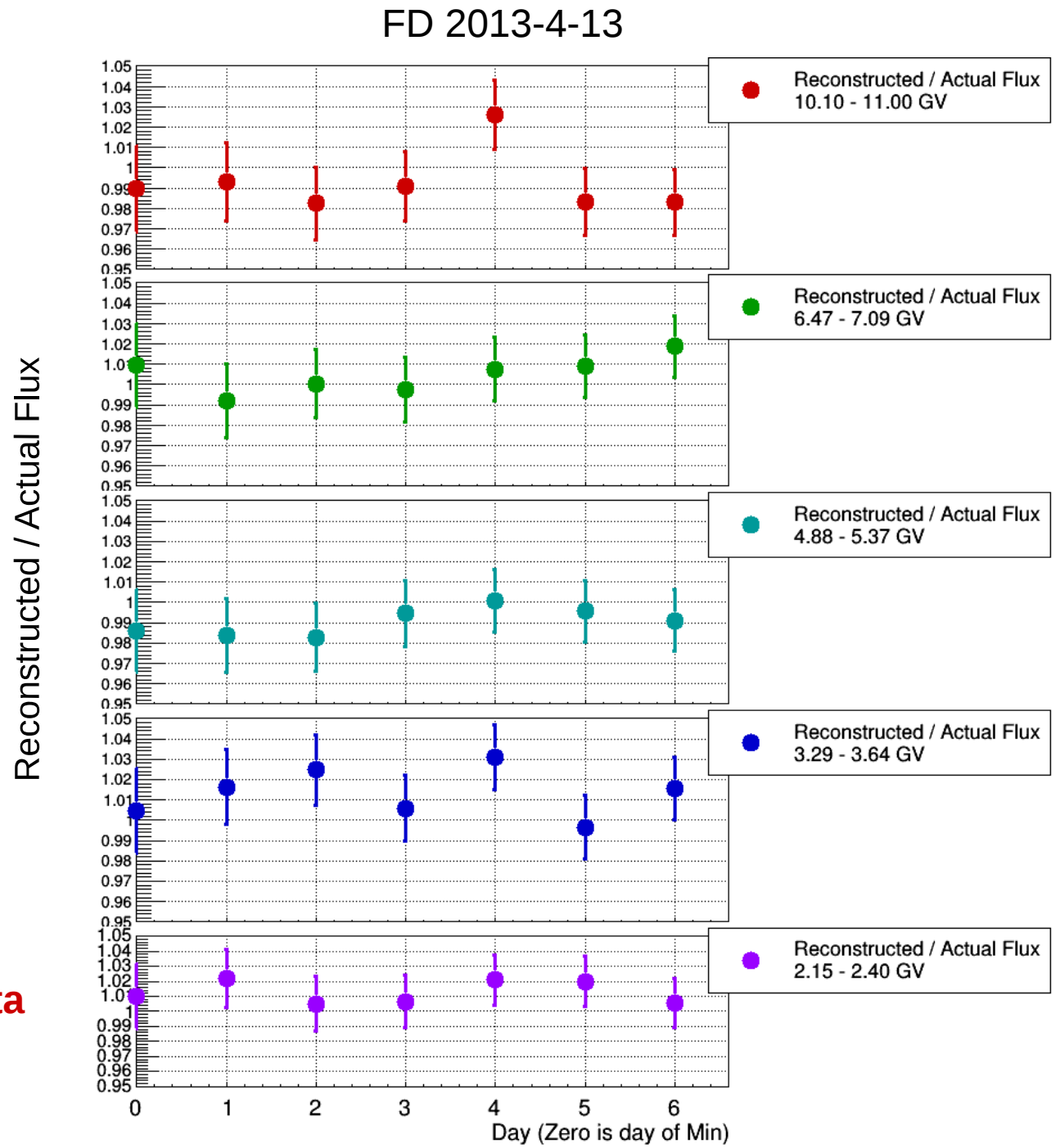
Preliminary Data and Analysis

FD Recovery in AMS: Reconstructed / Actual Flux



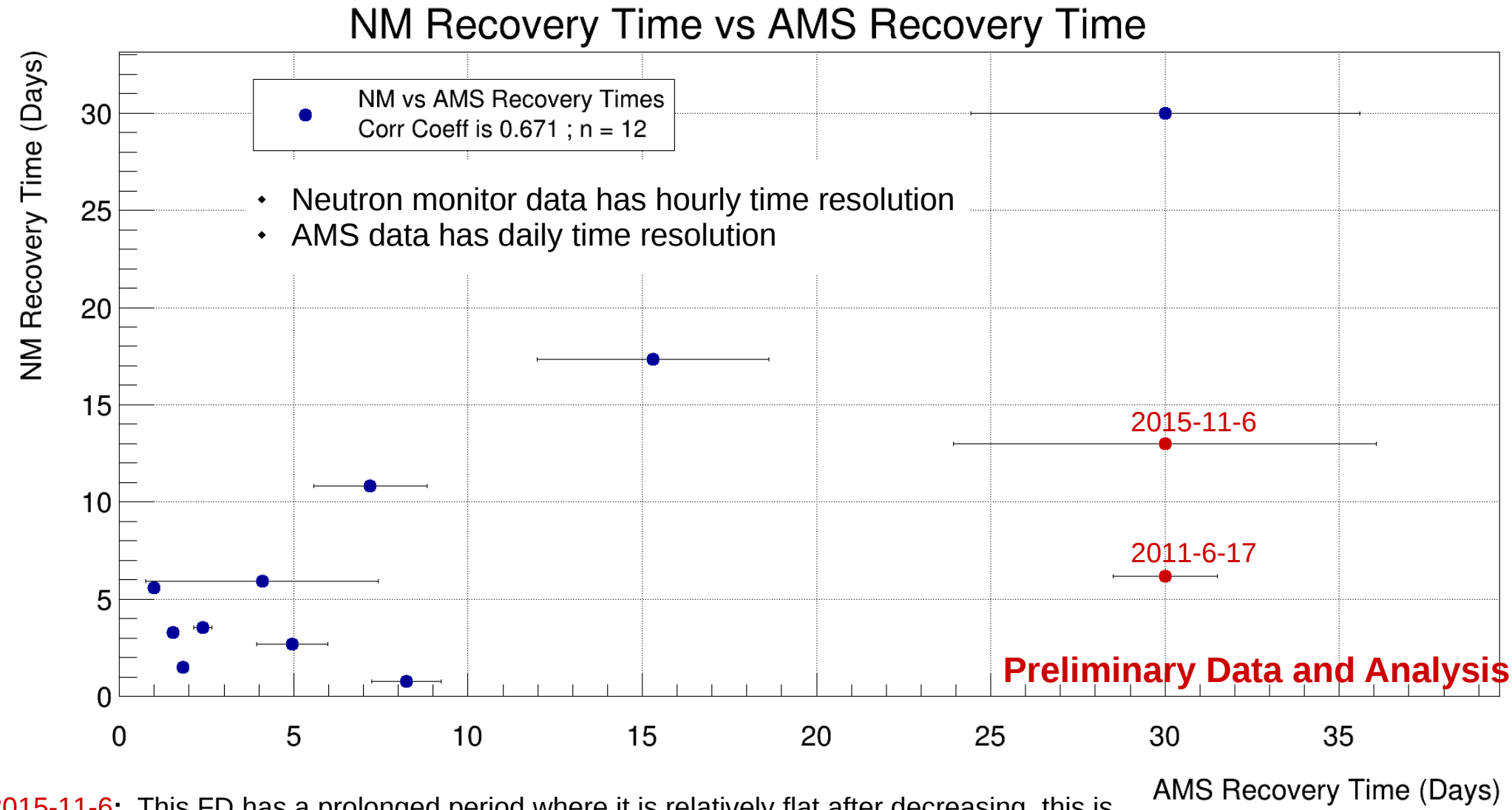
Preliminary Data and Analysis

FD Recovery in AMS: Reconstructed / Actual Flux



Preliminary Data and Analysis

AMS Recovery Time τ



2015-11-6**:** This FD has a prolonged period where it is relatively flat after decreasing, this is currently adversely affecting my ability to fit this event in AMS data because I only used 6 days of AMS data to find the recovery time.

2011-6-17**:** This FD recovers to 1 on the third day. Because I have 3 fitting parameters in the current process, I cannont effectively fit to three days. On the fourth day, the normalized flux dips again. Fitting to six days with the function used and the second dip causes the recovery time to become exceptionally long.

Summary

- For this sample of events, FD Recoveries are generally well described by an exponential recovery, consistent with a diffusive barrier model.

$$[\text{Norm Flux}] = A - Be^{-\frac{t}{\tau}}$$

  - τ varies widely from event to event
- The Hawai'i AMS group is in the preliminary stages of studying FDs using AMS data
  - Magnitude of FDs has a clear dependence upon rigidity, which is fit very well with either a power law or an exponential fit

$$[\text{Dip Size}] = AR^{\alpha} \qquad [\text{Dip Size}] = Be^{-\gamma R}$$

  - The normalized daily rigidity spectrum from AMS shows a clear exponential recovery in amplitude for most FD events studied thus far.
  - The normalized daily rigidity spectrum from AMS shows an exponential decay back to zero for the spectral index difference after FD minimum.

References

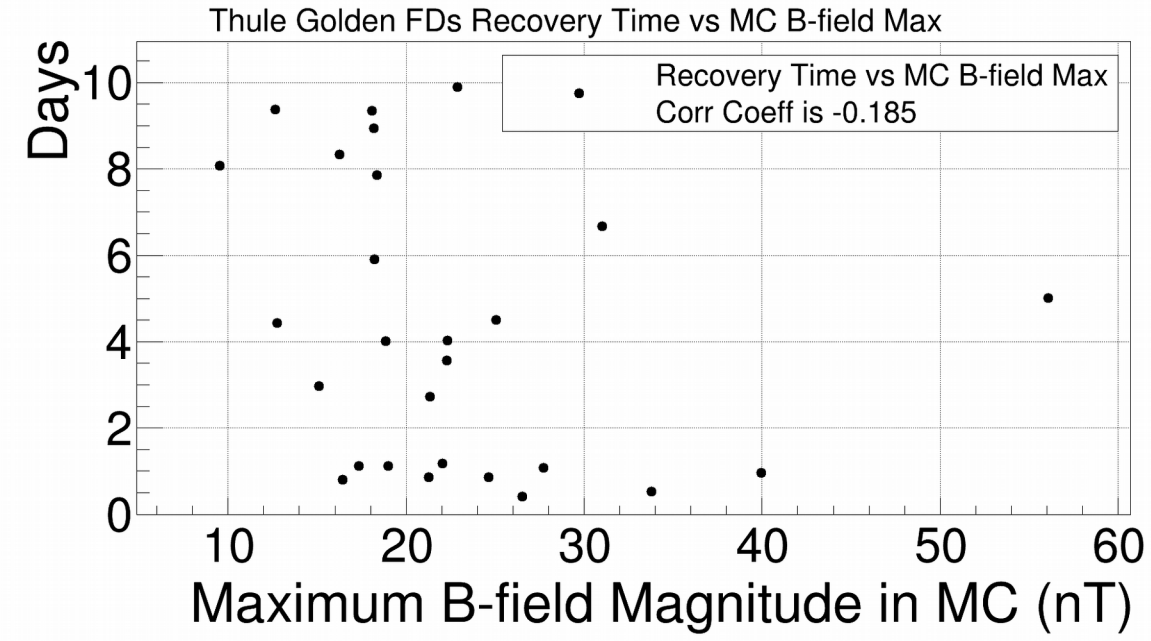
- Richardson & Cane, *Galactic Cosmic Ray Intensity Response to Interplanetary Coronal Mass Ejections / Magnetic Clouds in 1995-2009*, Solar Phys 2011, 270: 609-627. DOI 10.1007/s11207-011-9774-x

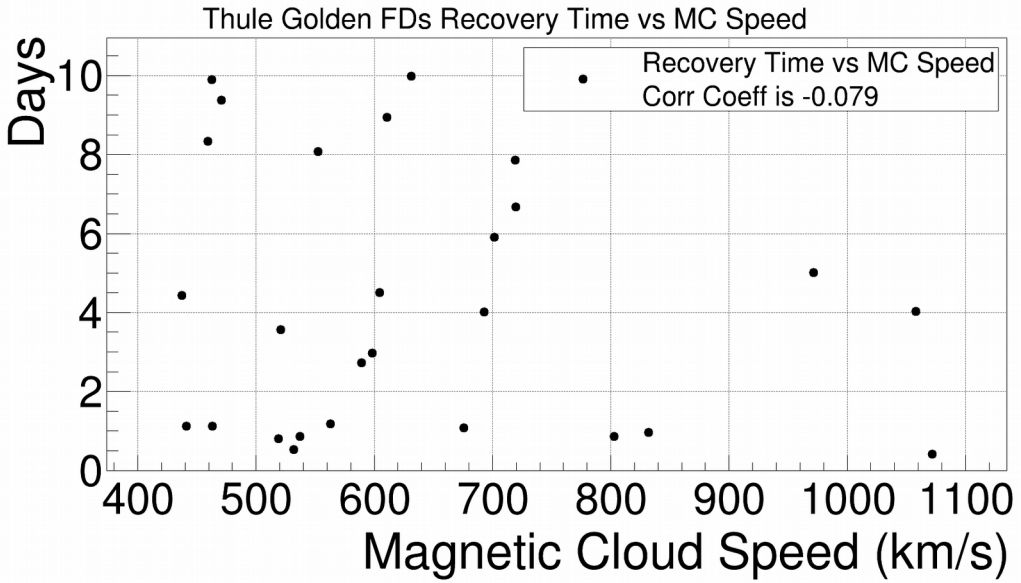
- Richardson & Cane, *Regions of abnormally low proton temperature in the solar wind (1965-1991) and their association with ejecta,* Journal of Geophysical Research, December 1, 1995. 100: 23,397-23,412

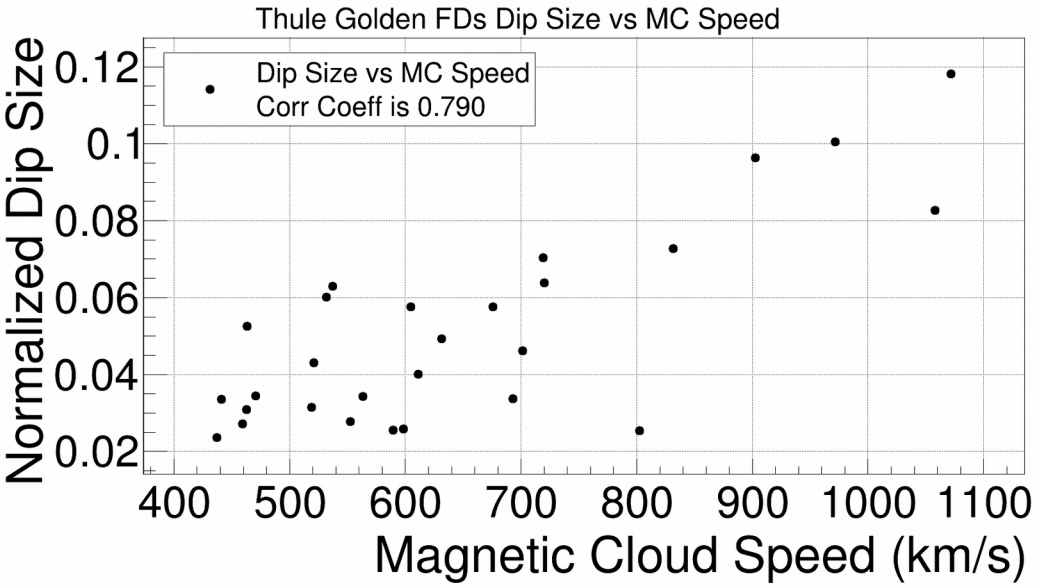
- Luo, Potgieter, Zhang, & Feng, *A Numerical Study of Forbush Decreases with a 3D Cosmic-Ray Modulation Model Based on an SDE Approach*, The Astrophysical Journal, April 10, 2017. 839: 53-63

Backup

Correlations with Recovery







Correlated Recovery time τ with a number of ICME properties, but did not find strong correlations with any of them.