The Dynamic GLE Proton Spectrum of 2001 April 15 and 2005 January 20

J.M. Ryan, T. Morgan and the Milagro Collaboration

Ground Level Enhancement Spectra

- Difficult to measure during the impulsive phase.
- Impulsive phase is typically anisotropic. (Spectrum function of pitch angle?)
- For **nearby** neutron monitors, need multiple stations with **P_c< atmospheric cutoff**, then use the different rates at two different altitudes to compute power law index.
- Durham and Mt. Washington make such a pair.

Measurement Problems

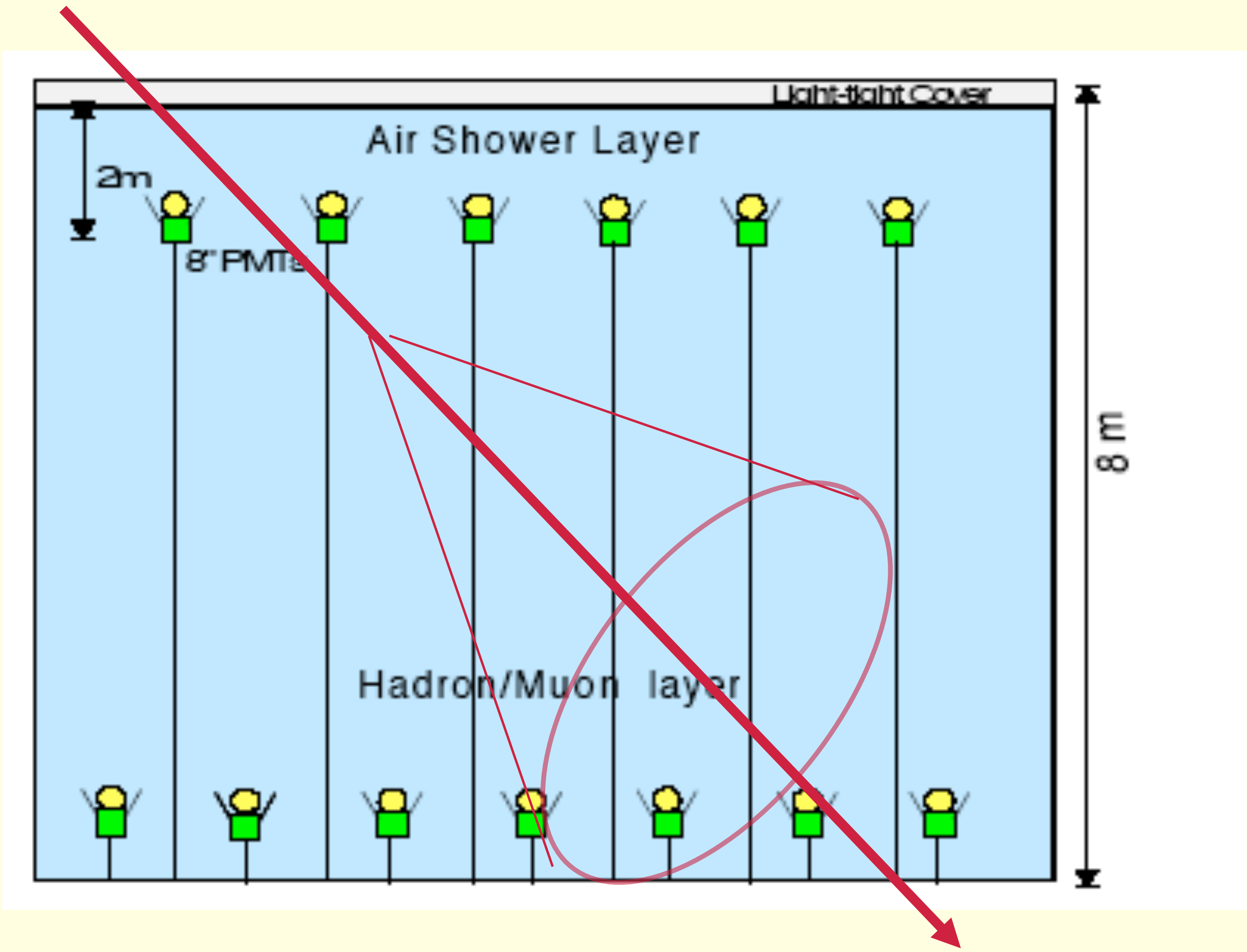
- Neutron monitors provide only an integral measure of the particle intensity.
- Two stations can yield a two-point power law.
- A third independent station is needed to see curvature in the spectrum.
- Must all be in the particle beam.
- Alternatively, use instruments with different thresholds produced by other means, e.g., Polar Bare and South Pole.

Milagro Instrument

TeV ground-level γ-ray telescope. Detects electromagnetic (or hadronic) showers in a 1-acre pond of water outfitted with PMTs.

Differential timing provides the incident direction, identifying TeV sources.

Milagro Cross-sectional schematic



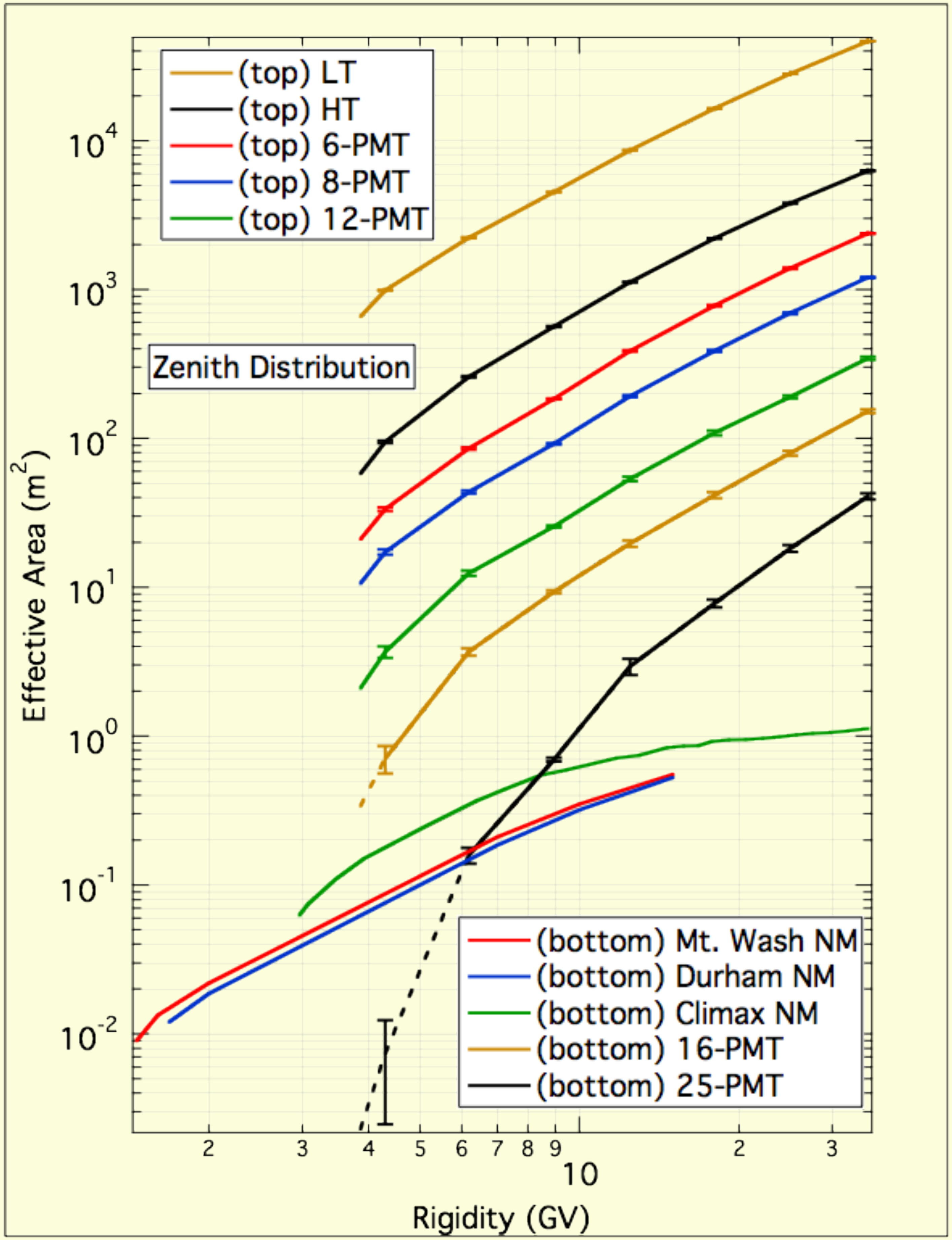
Charged particles emit Çerenkov light, registered by PMTs.

Can be either 'single' muons or full blown showers.

Single low-E muons often trigger only 1 PMT, while showers trigger dozens (50 GeV).

So-called **High Threshold** is the lowest threshold, ~5 GV.

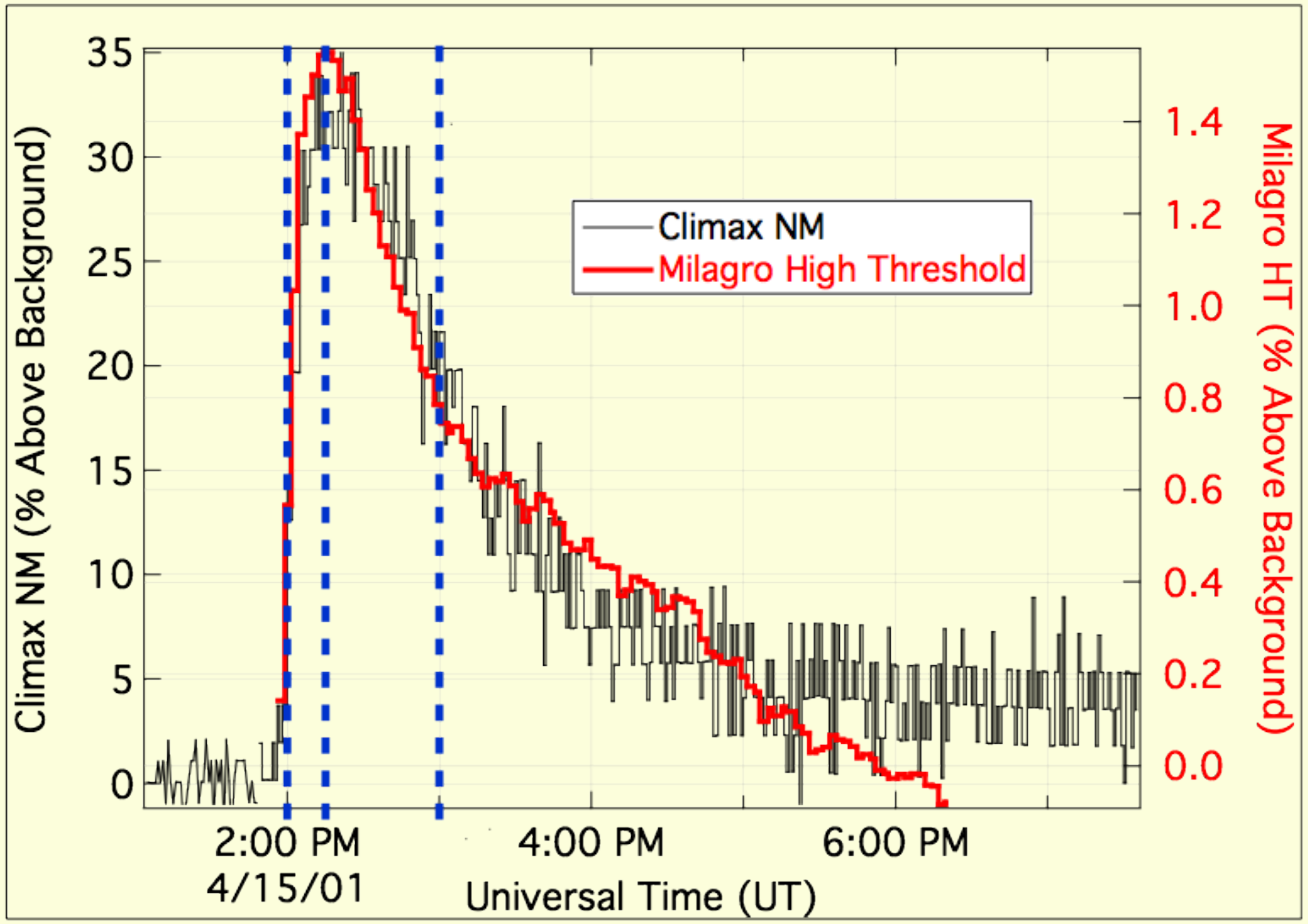
Records rates with differing numbers of 'hit' PMTs.



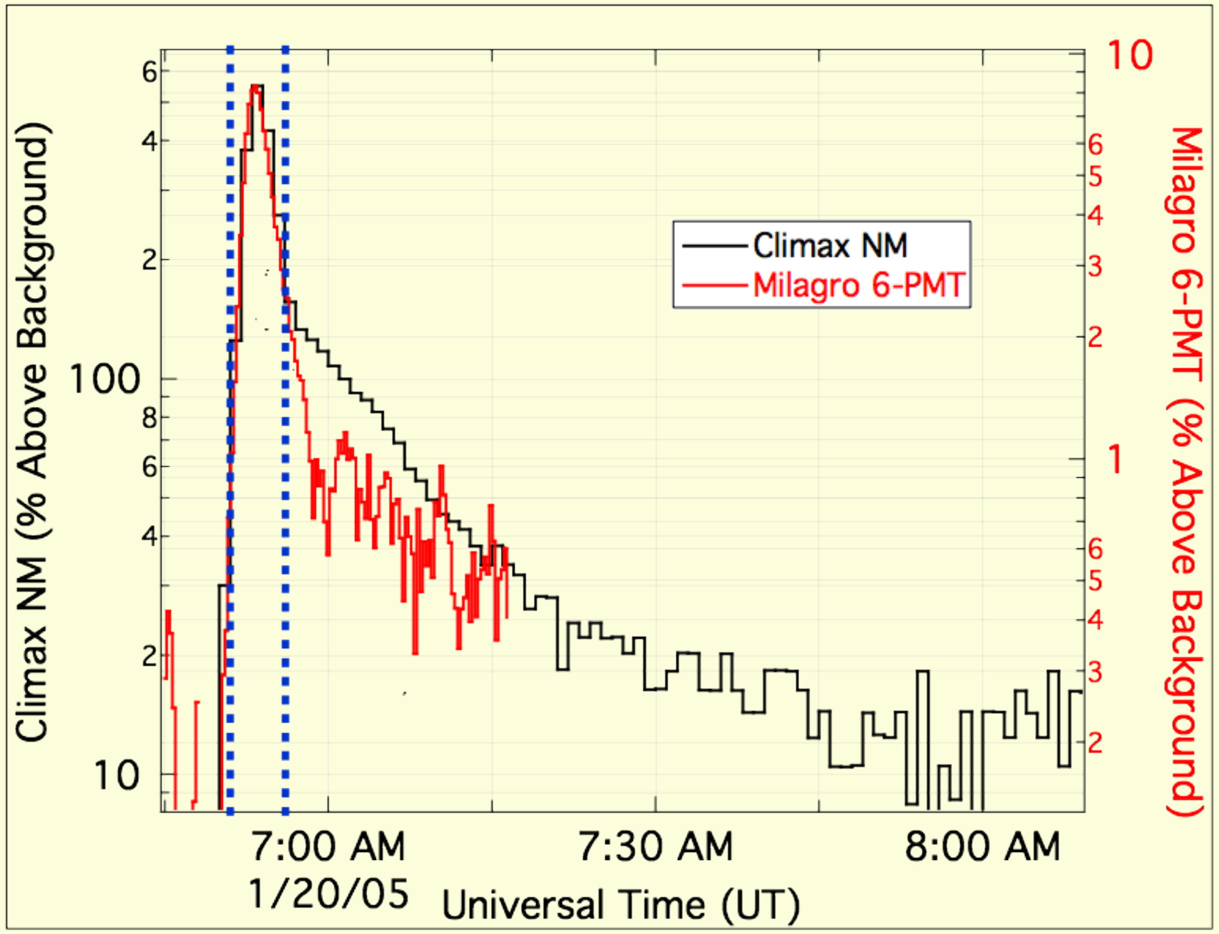
Yield Function for Milagro, Climax and NH NMs. Milagro more sensitive to higher rigidity protons

A study of the evolution of the intensity, spectrum and pitch-angle distribution allows one to investigate the nature of the accelerating shock

Station	Instrument Type	Vertical Cutoff (GV)	Depth (g-cm^{-2})	Trajectory Difference
Mount Washington	IGY (12)	1.68	828	10.6°
Durham	NM64 (18)	1.88	1013	
Climax	IGY (12)	2.96	658	23.2°
Milagro	muon	3.9	734	



2001 April 15 GLE
Well connected. Sharpest leading edge of any NM, anisotropic until 1500 UT.



2005 January 20 GLE
Intense, with resolvable impulsive spike, relaxing into isotropic decay. Fully isotropic at 0730 UT.

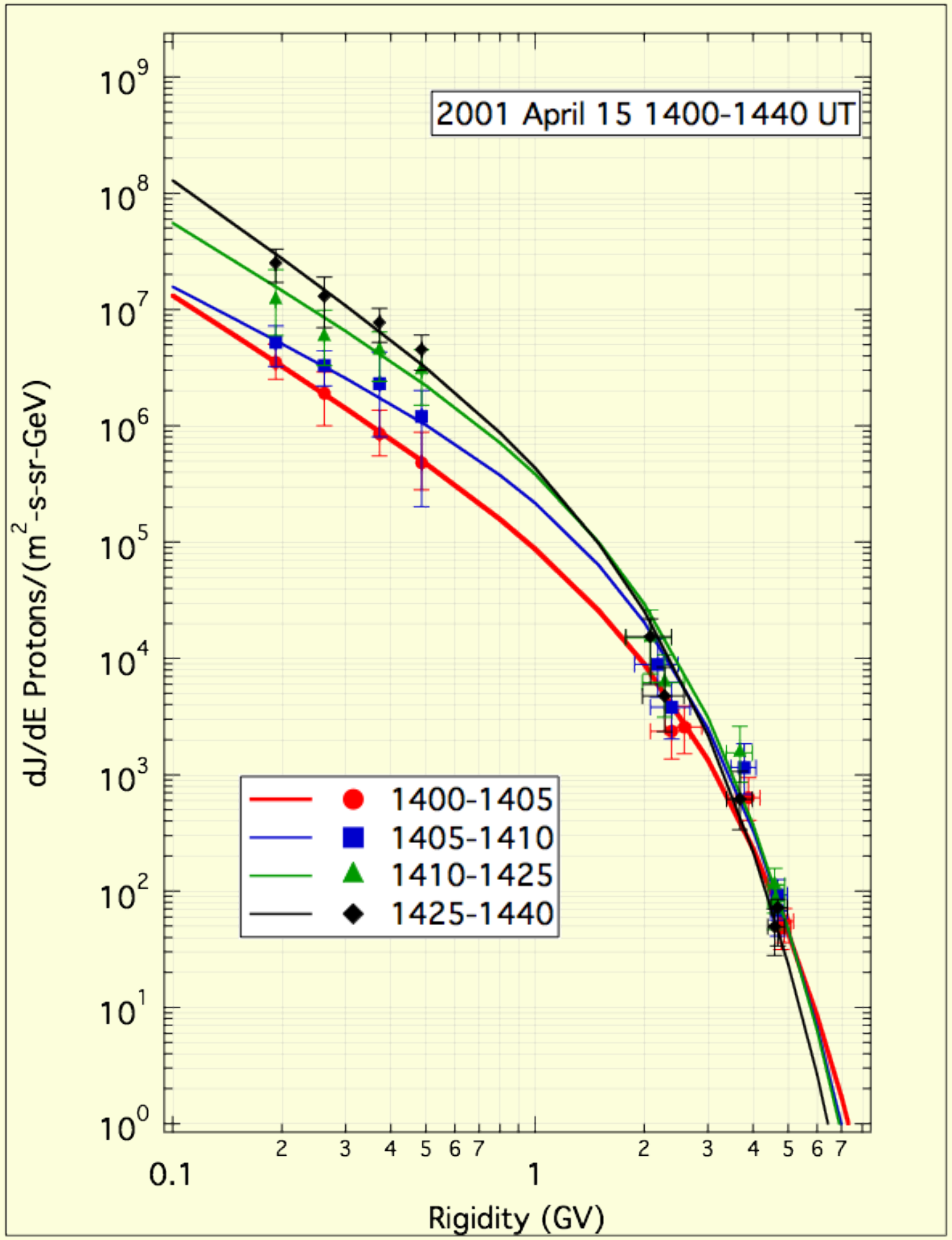
Fitting Spectrum

- Find interplanetary particle data for low end.
- Assume power law $\times$ exponential spectrum.
- Iterate power law normalization and index and E_0 in exponential tail, representing maximum accelerating energy. Find minimum χ^2.

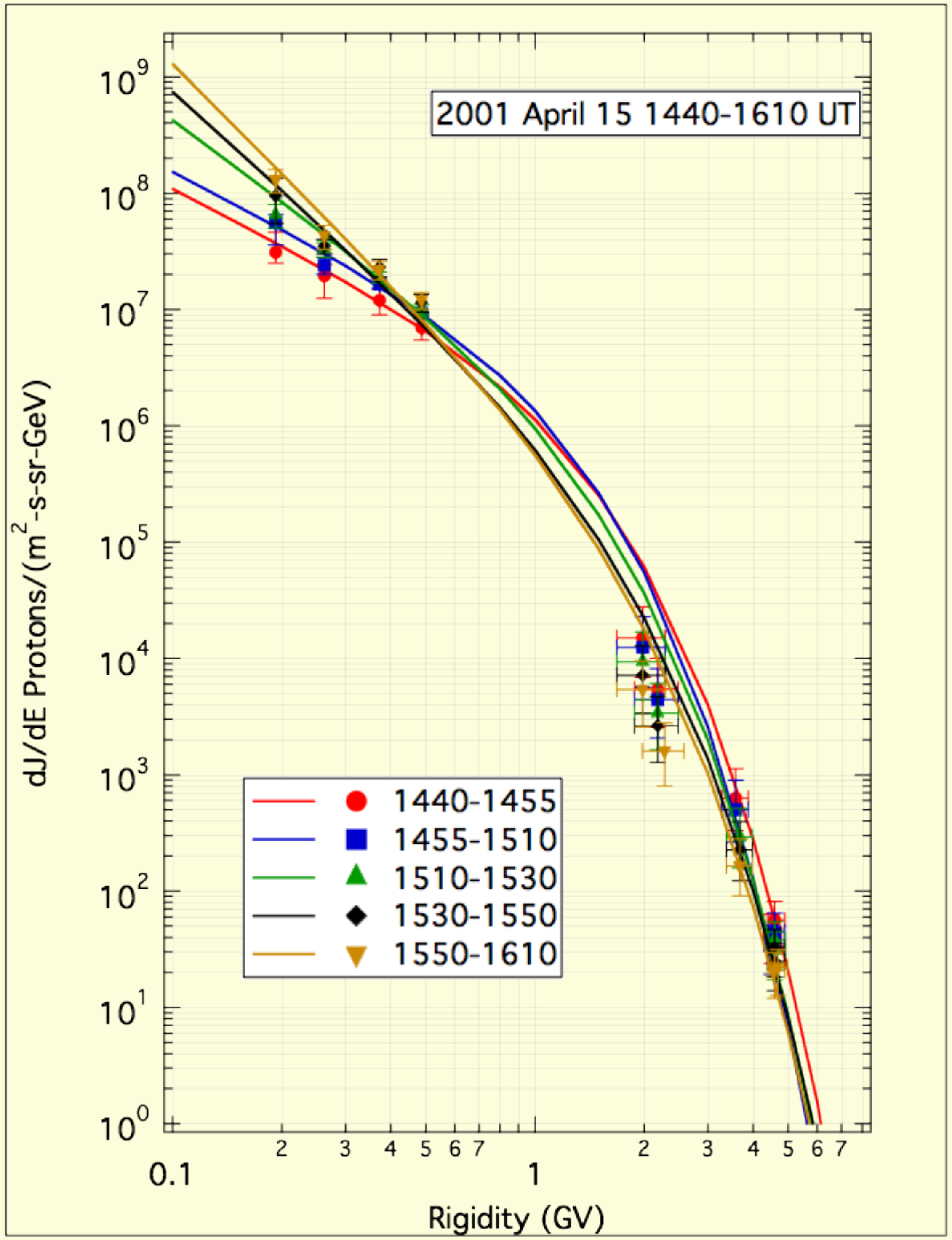
Consistency check:

- With many channels, the instrument response is sensitive to the pitch angle distribution of particles. For both events the leading edge response was not consistent with an isotropic proton distribution (**not enough many-PMT counts**).
- Used plane-parallel beam simulation for the yield function for leading edge in Milagro data.
- Used isotropic simulation for remainder of event.

2001 April 15

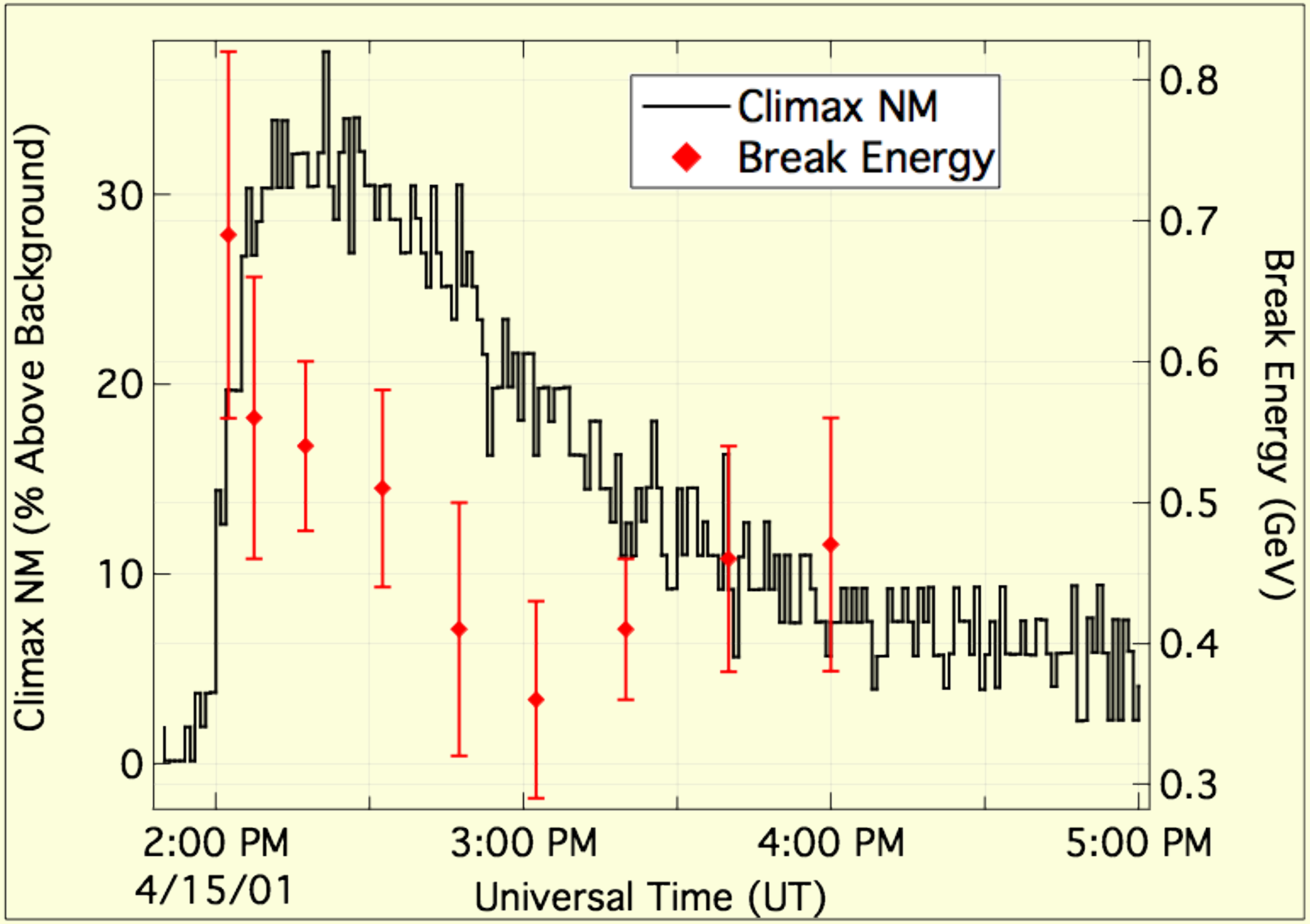


Leading Edge up to isotropic phase



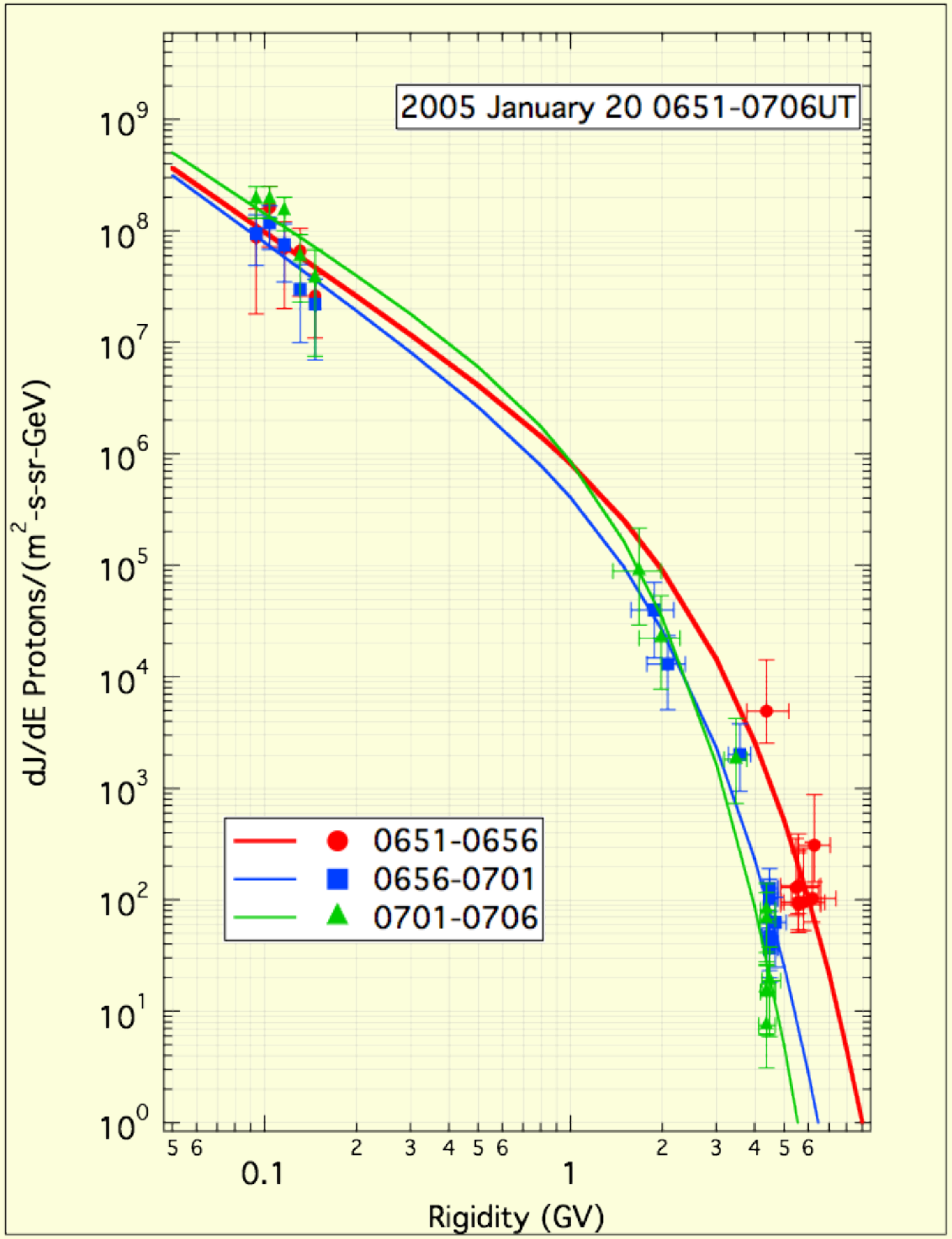
Isotropic phase

2001 April 15

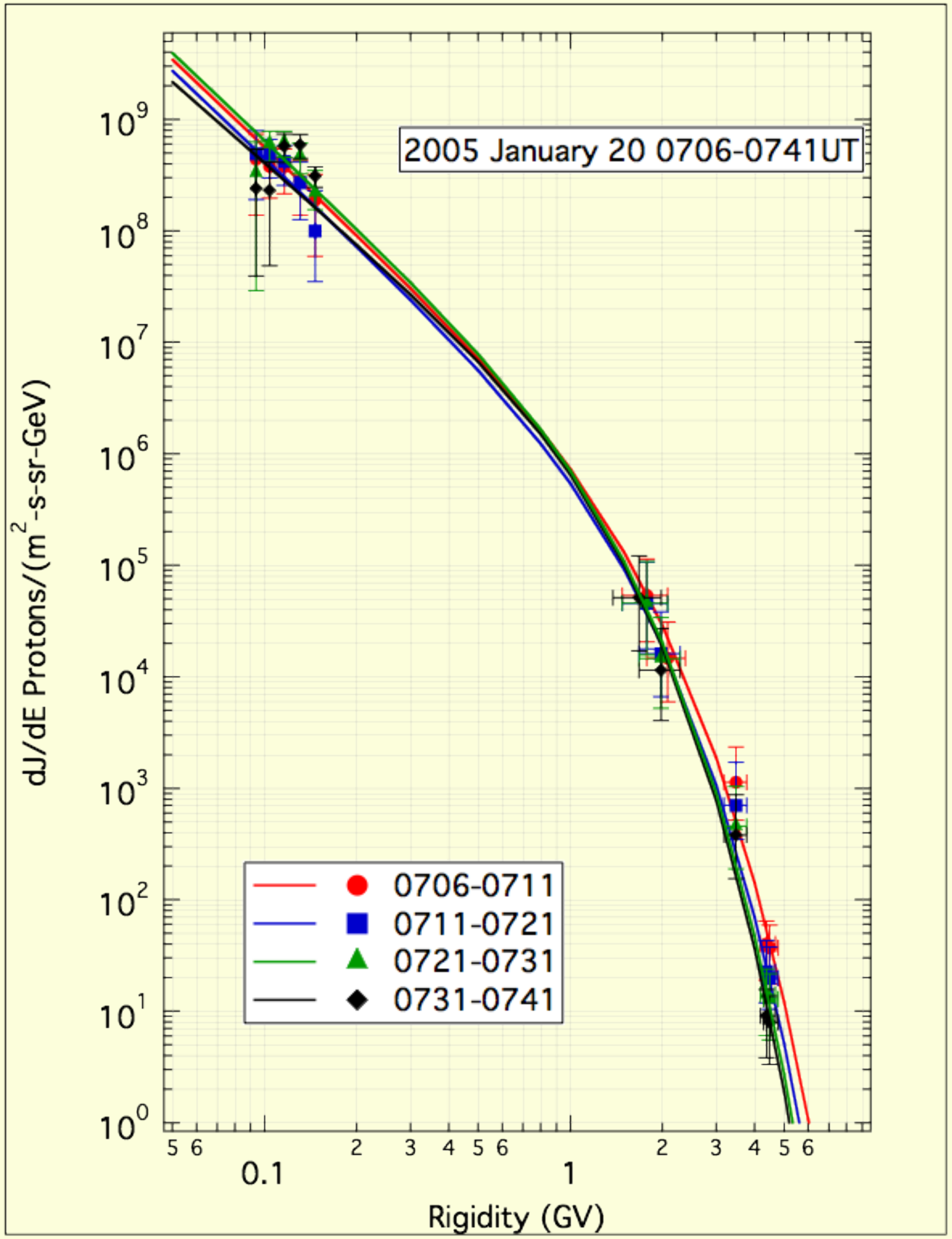


Break energy for exponential tail starts out high, decreases, then stabilizes once the event is isotropic (1500 UT)

2005 January 20

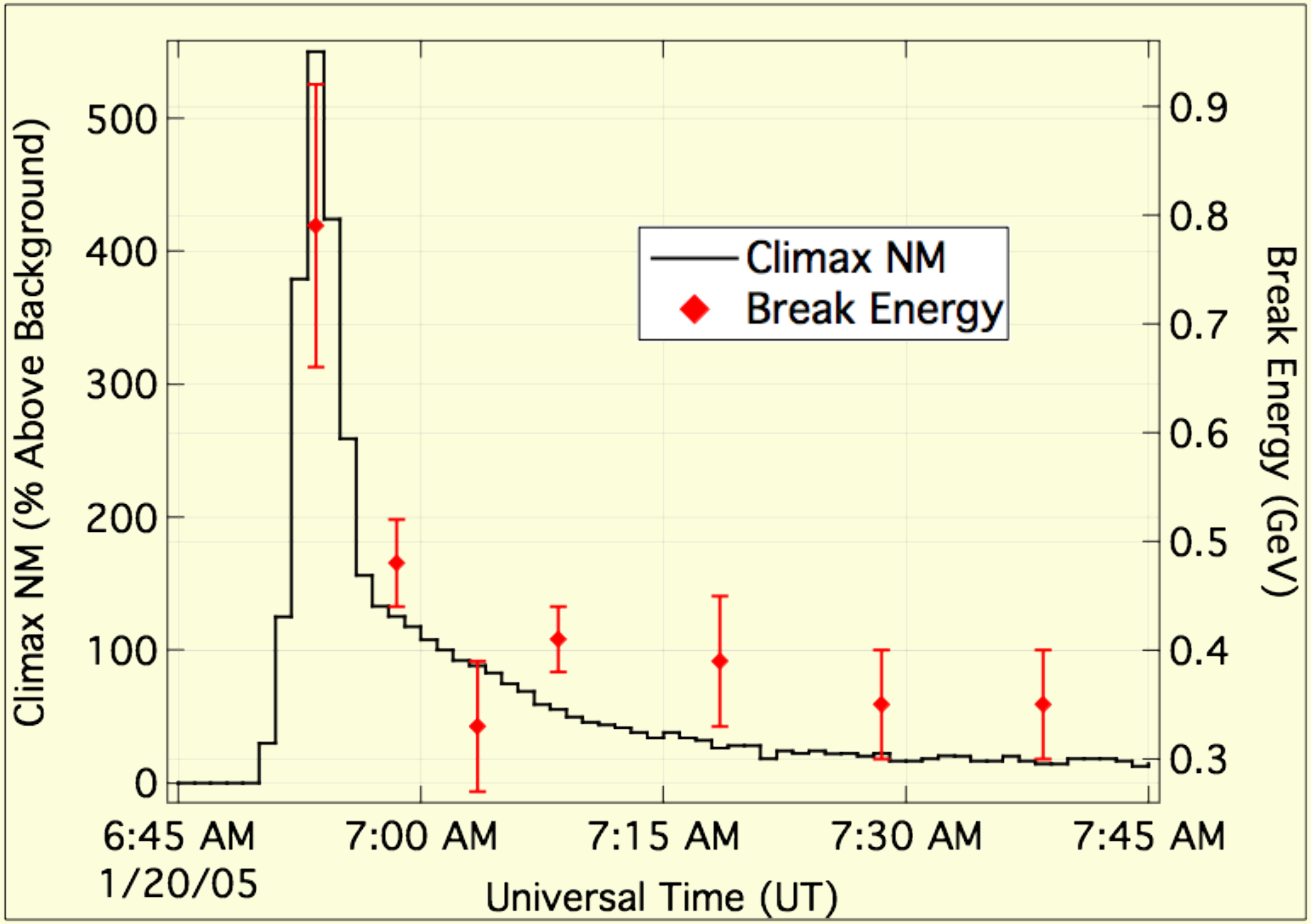


Impulsive spike



Gradual Decay

2005 January 20



Break energy starts out high again, decreases, then stabilizes once the event is isotropic

Last two data points are isotropic