

Statistical Study of Solar Energetic Electron Spectra with STEREO/SEPT

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Alexander Kollhoff¹, Du Toit Strauss³

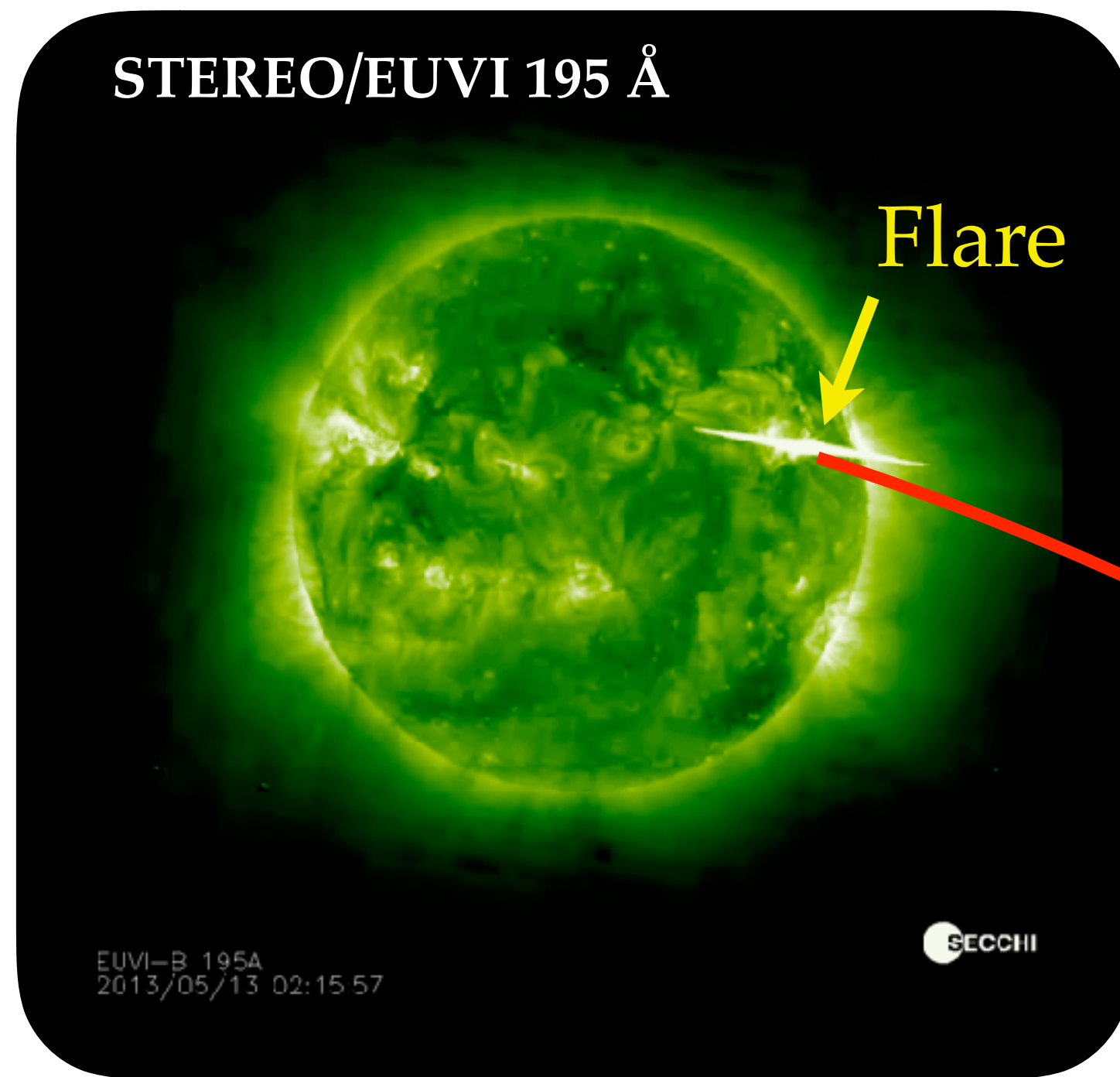
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⁴ GFZ Potsdam, Germany

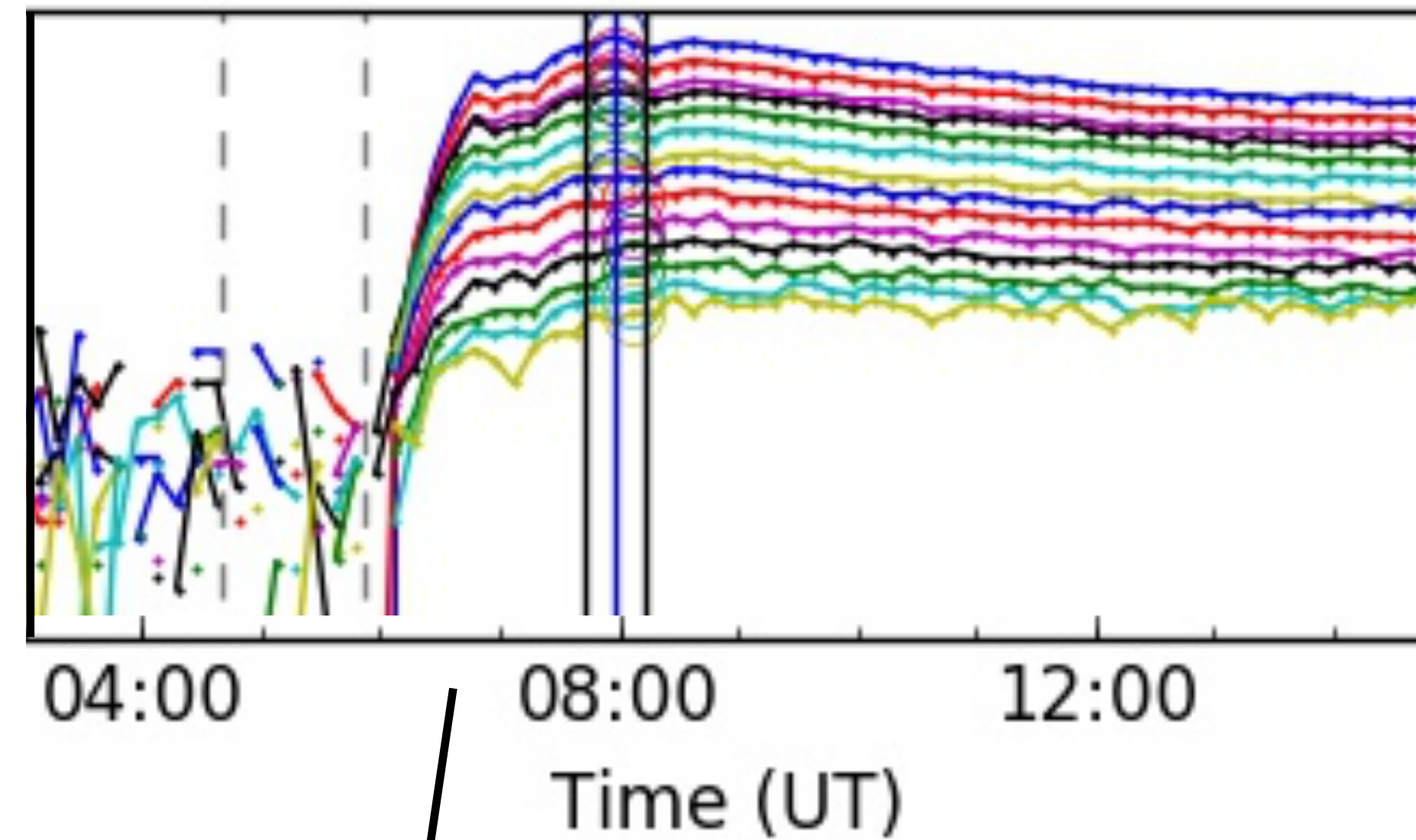
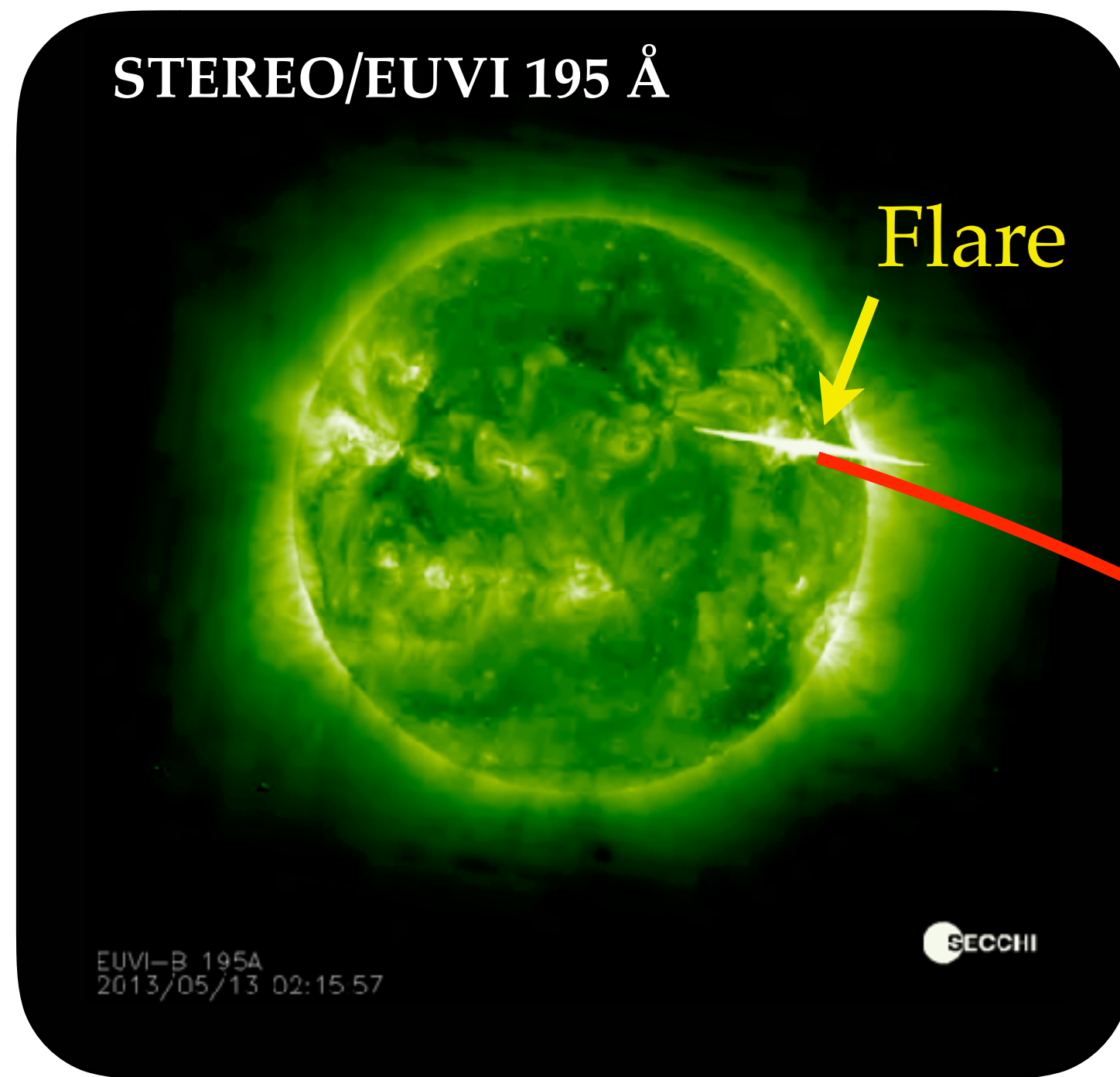
Solar Energetic Particle (SEP) Events



Acceleration in magnetic
reconnection region



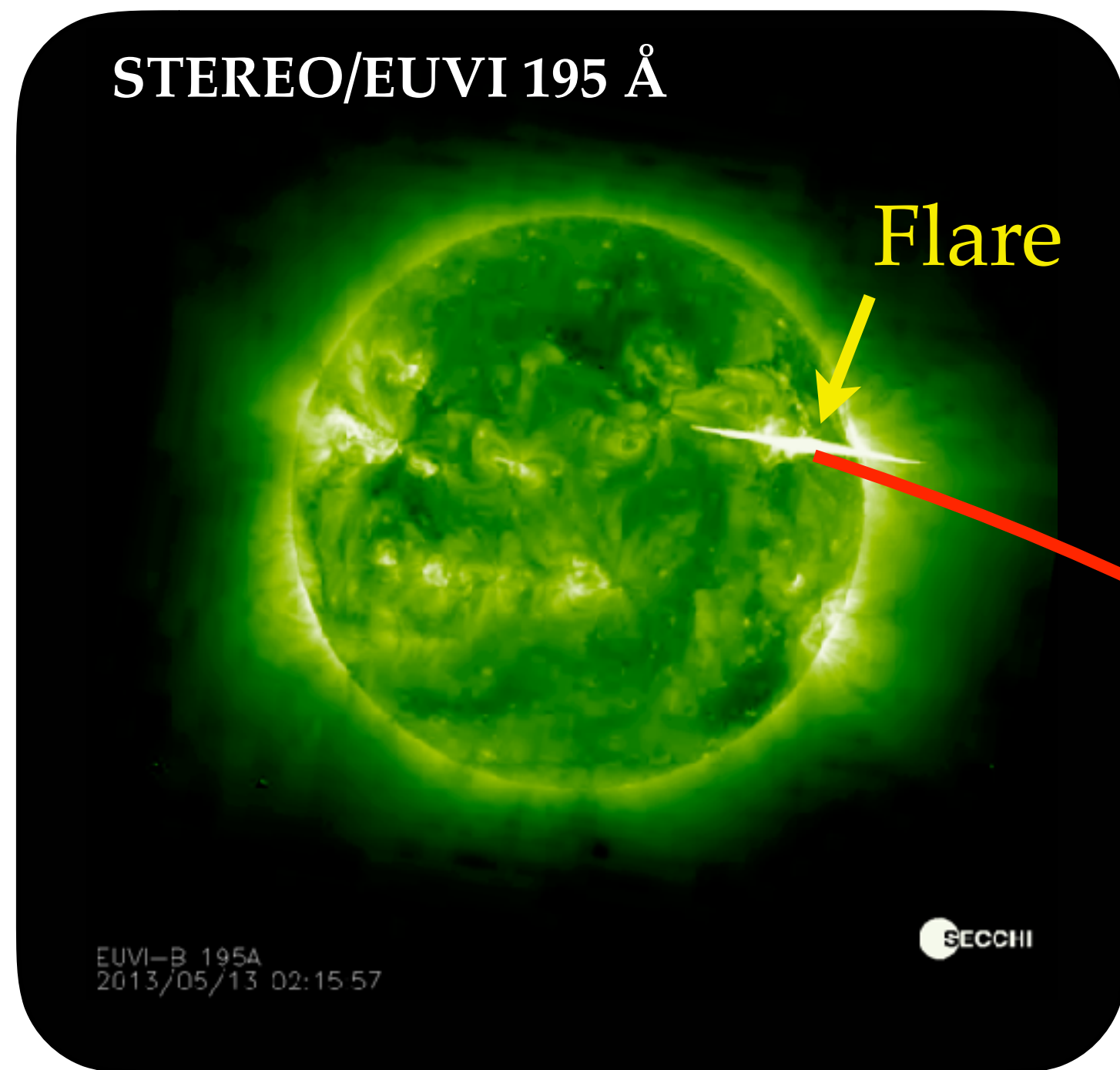
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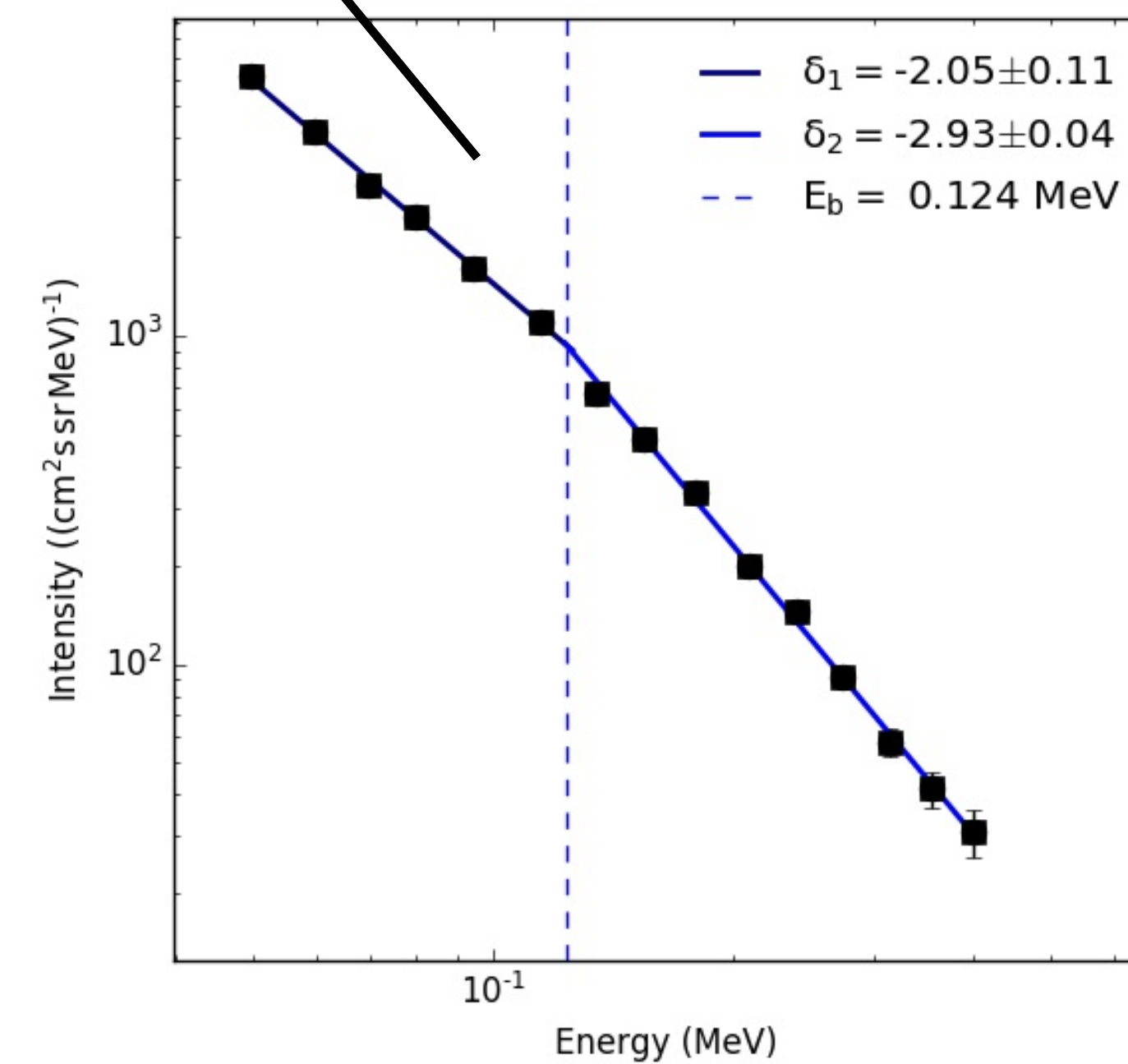
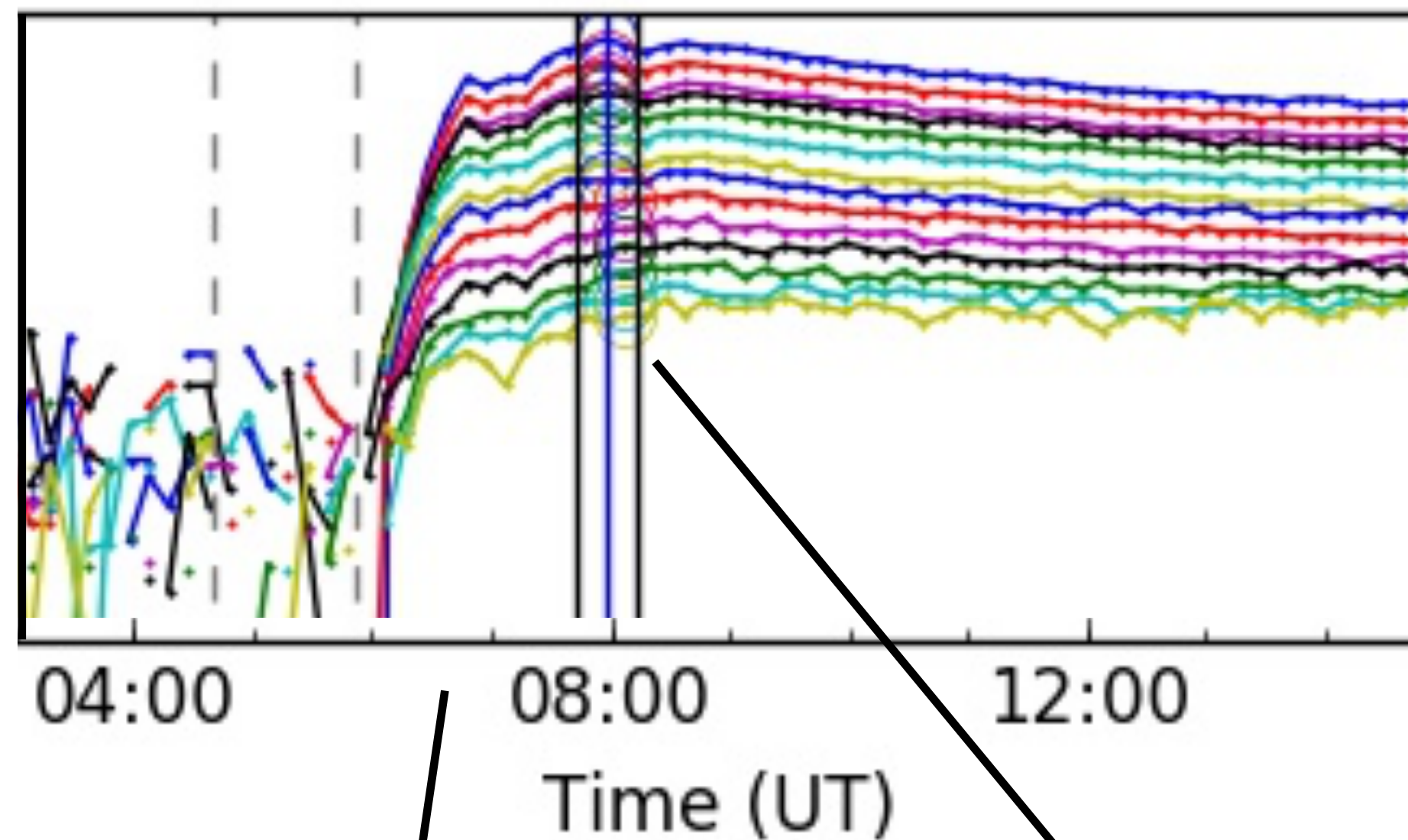
Acceleration in magnetic reconnection region



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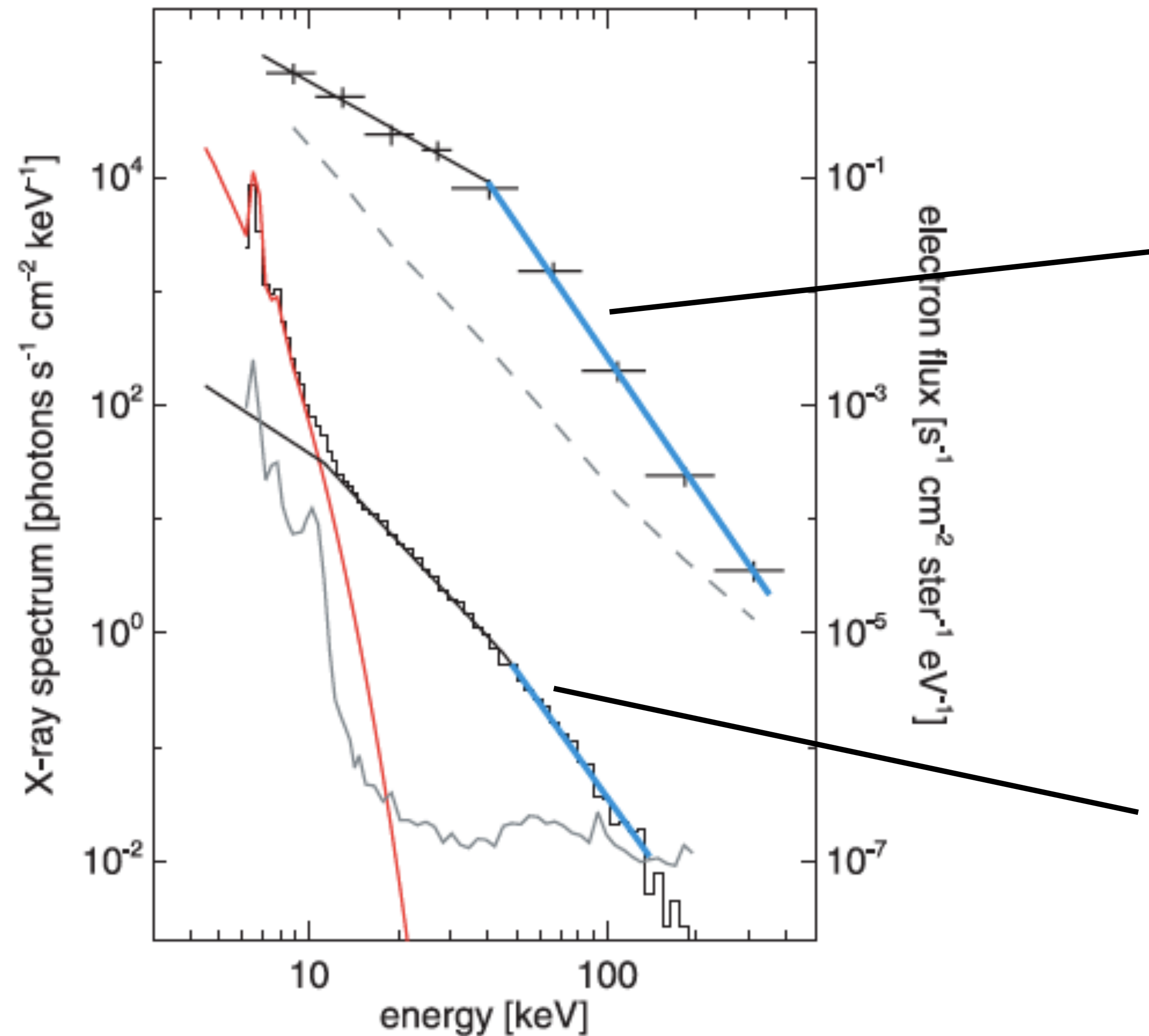


Acceleration in magnetic reconnection region

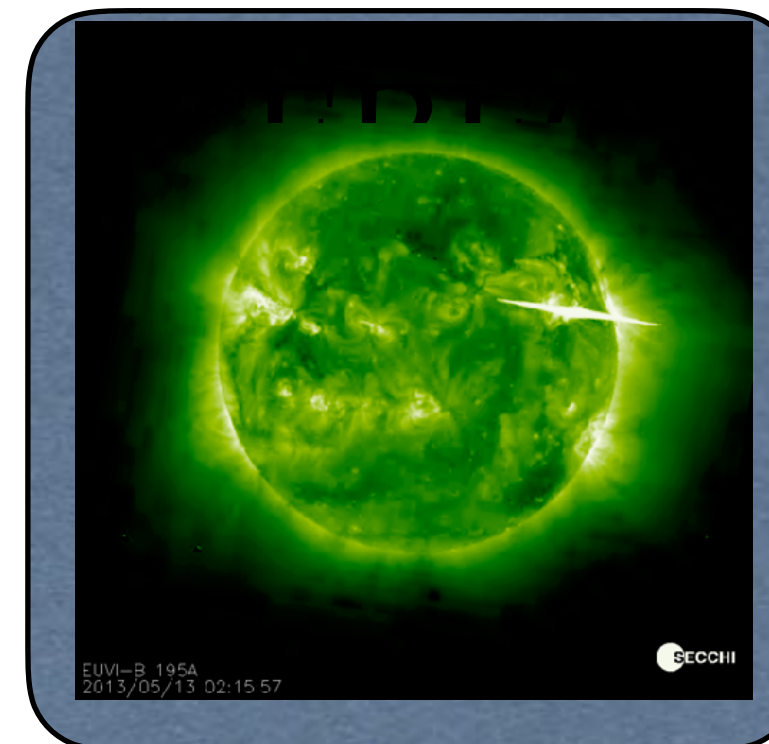


Previous Work on Electron Spectra

Krucker et al. (2007): 132 impulsive electron
3DP compared to RHE



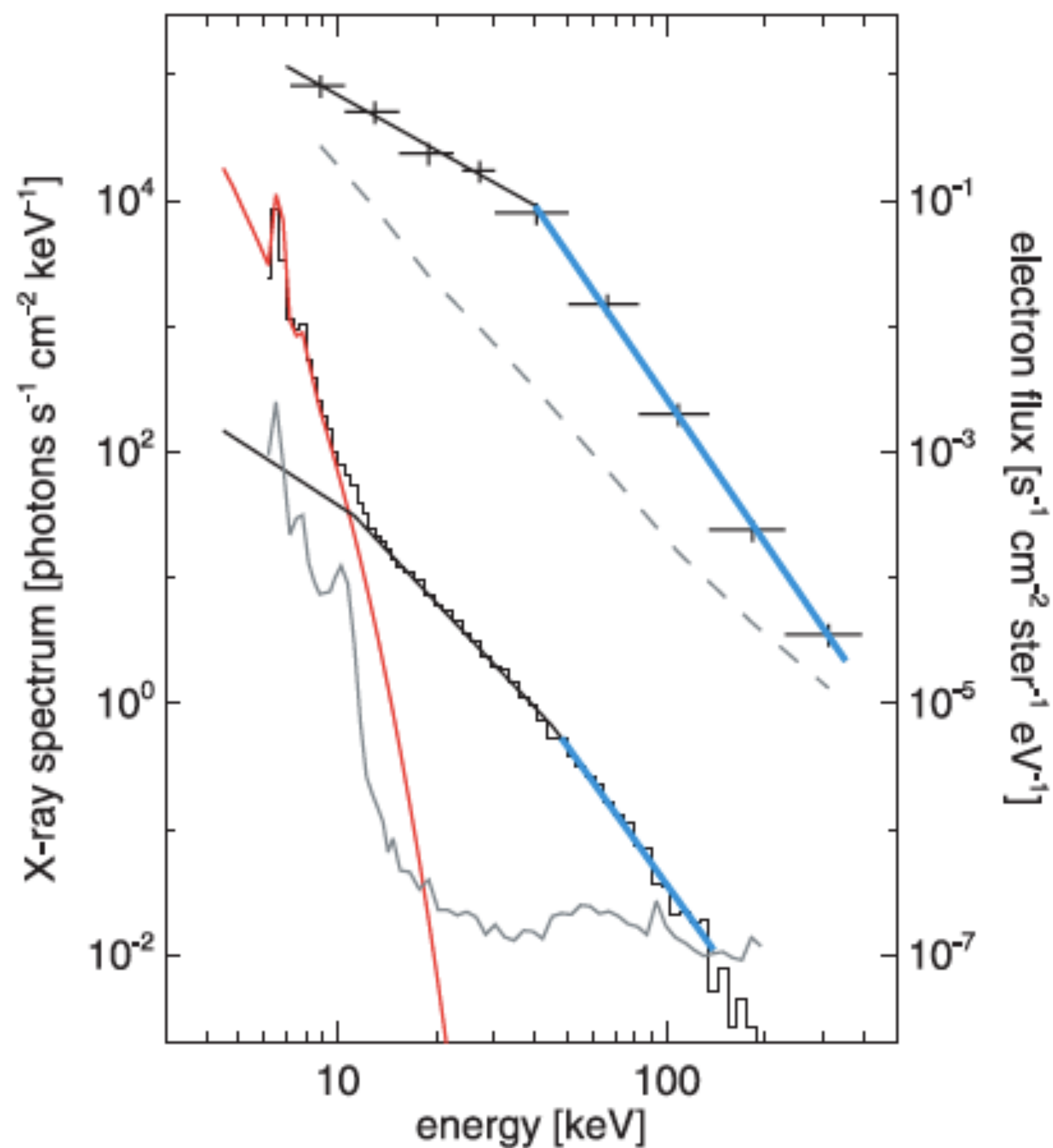
In-situ at the
spacecraft



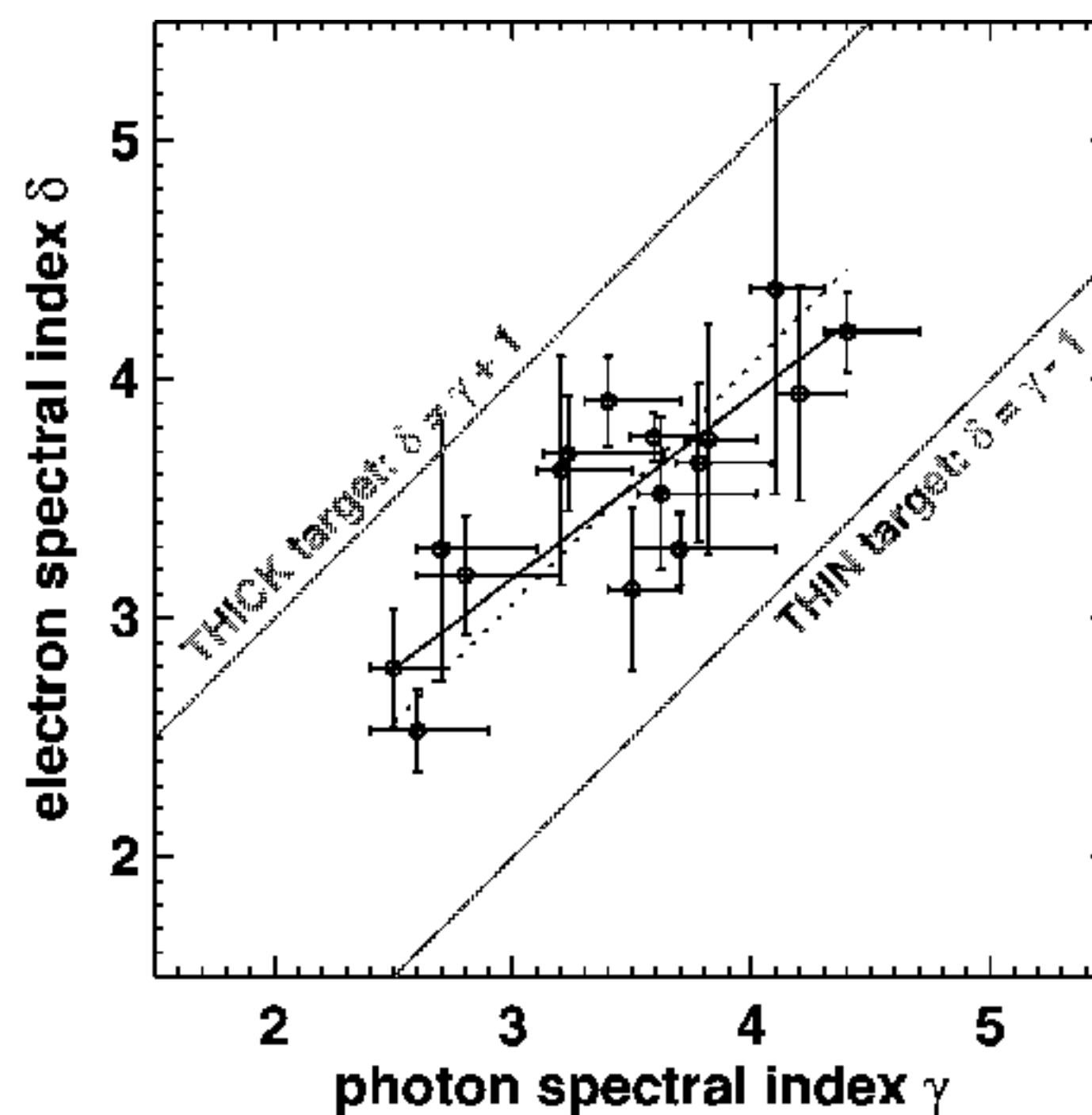
Remotely at the Sun

Correlation between in-situ Electrons and X-ray Emitting Electrons

Krucker et al. (2007): 132 impulsive electron events observed by Wind / 3DP compared to RHESSI / HXR spectra

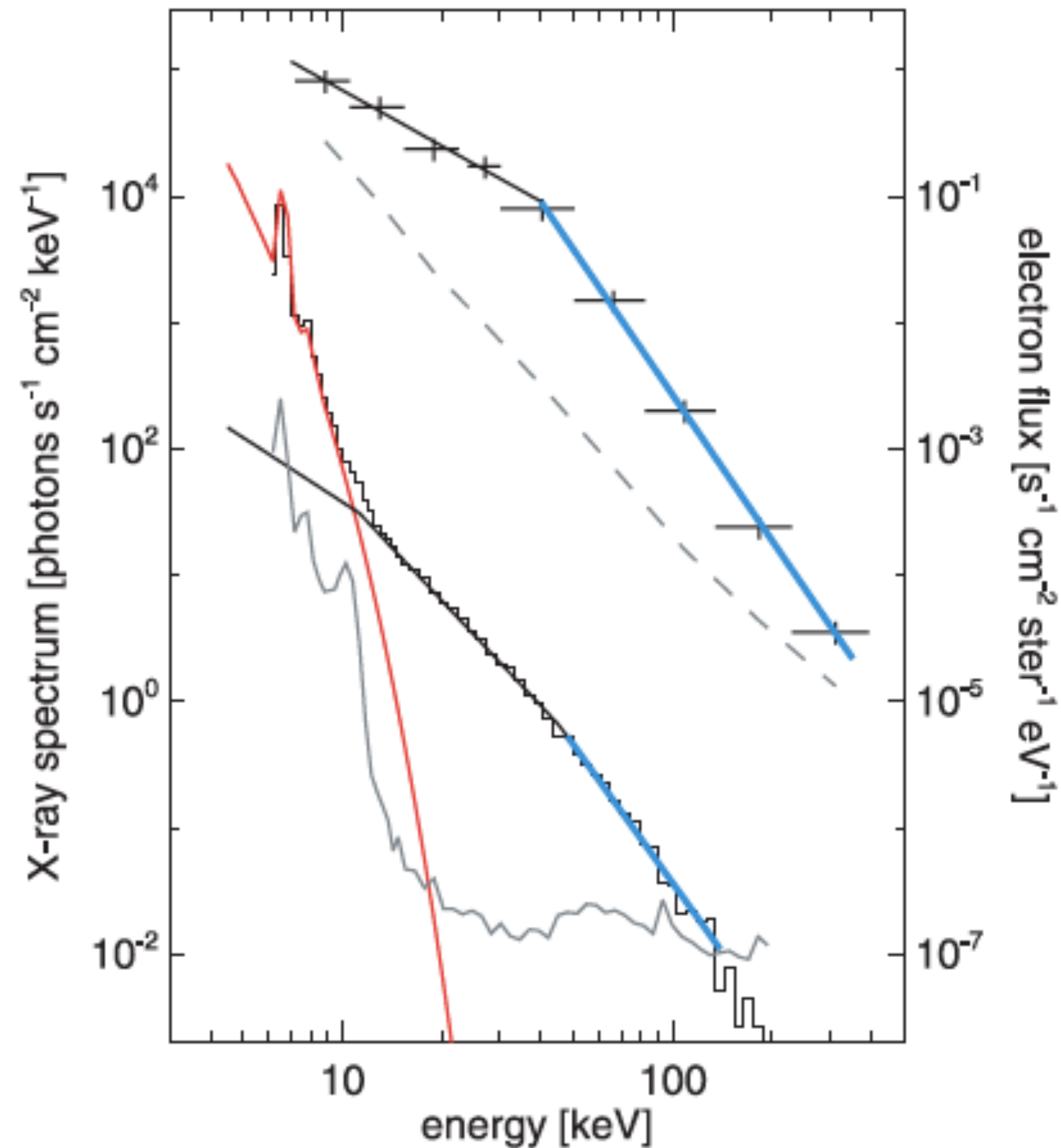


prompt events

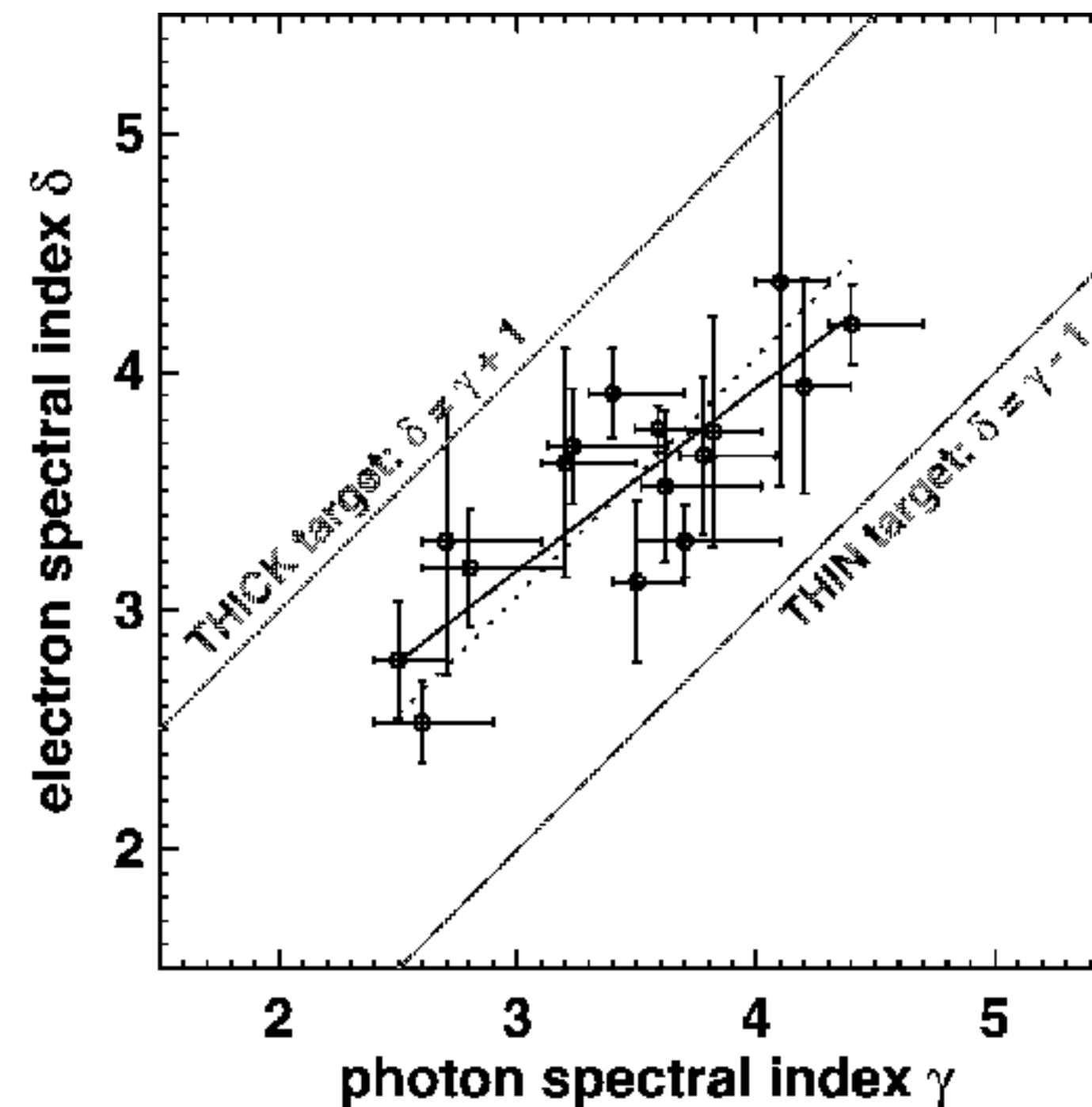


Correlation between in-situ Electrons and X-ray Emitting Electrons

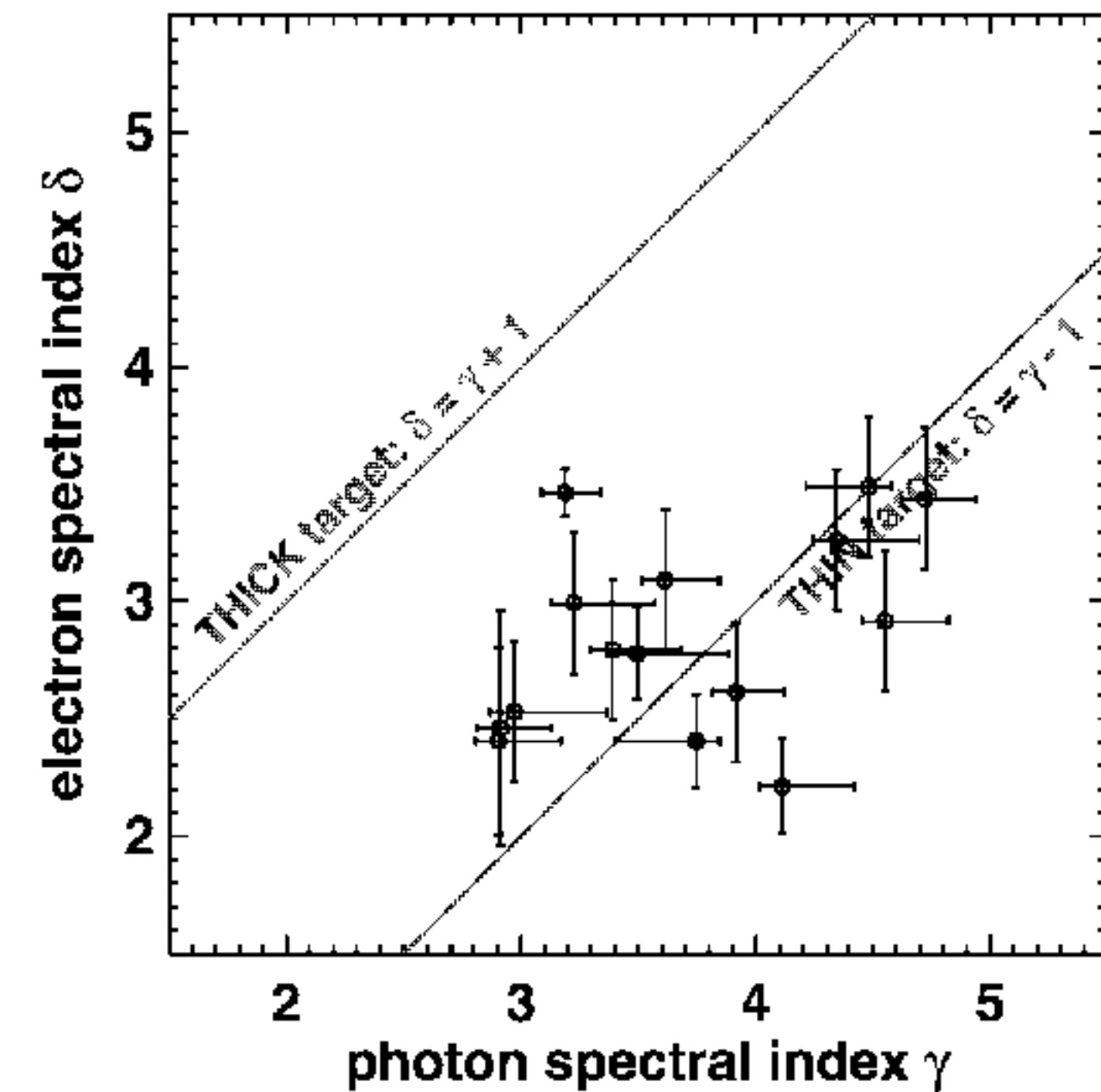
Krucker et al. (2007): 132 impulsive electron events observed by Wind / 3DP compared to RHESSI / HXR spectra



prompt events



delayed events



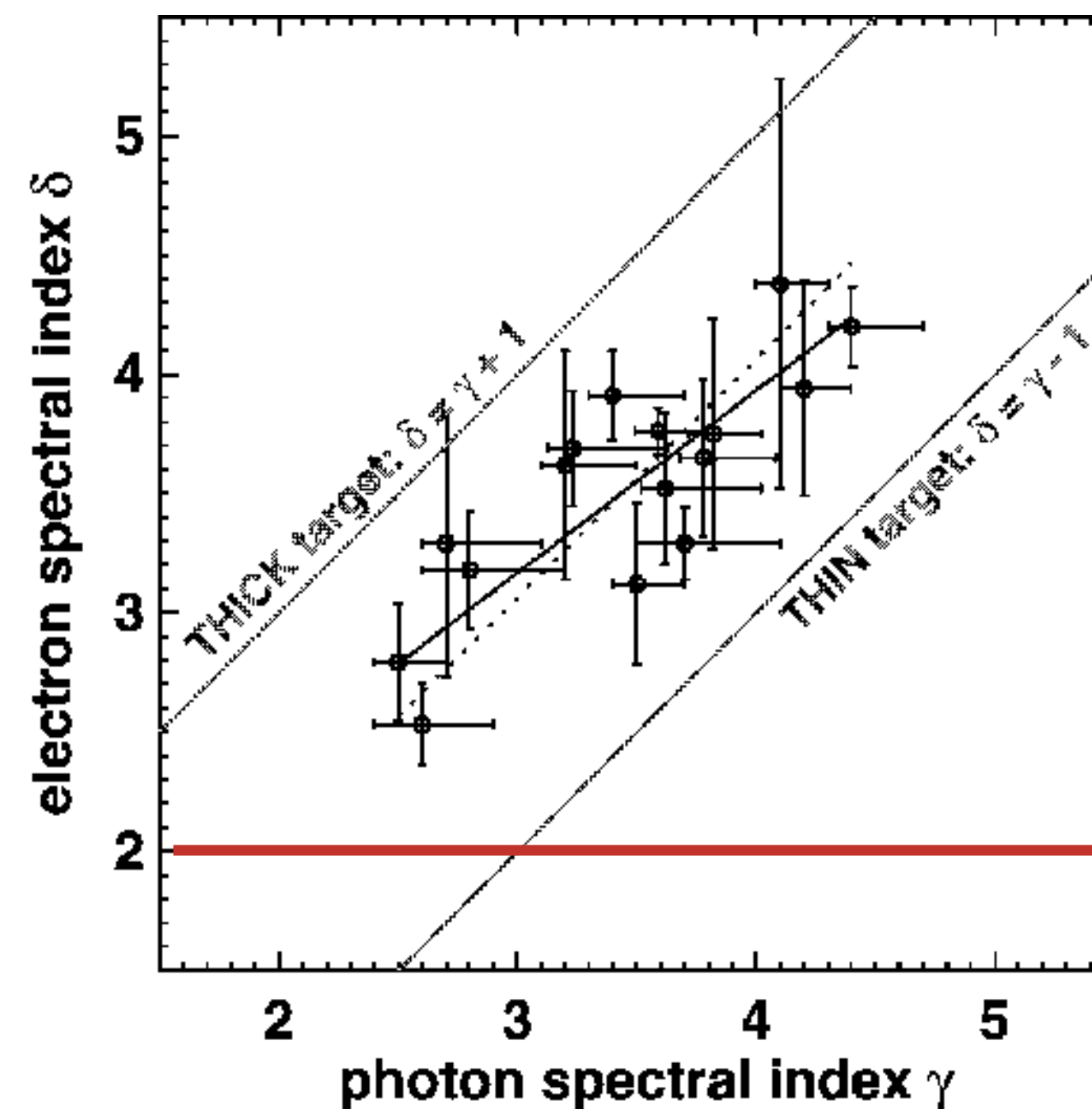
Correlation between in-situ Electrons and X-ray Emitting Electrons

Krucker et al. (2007): 132 impulsive electron events observed by Wind / 3DP compared to RHESSI / HXR spectra

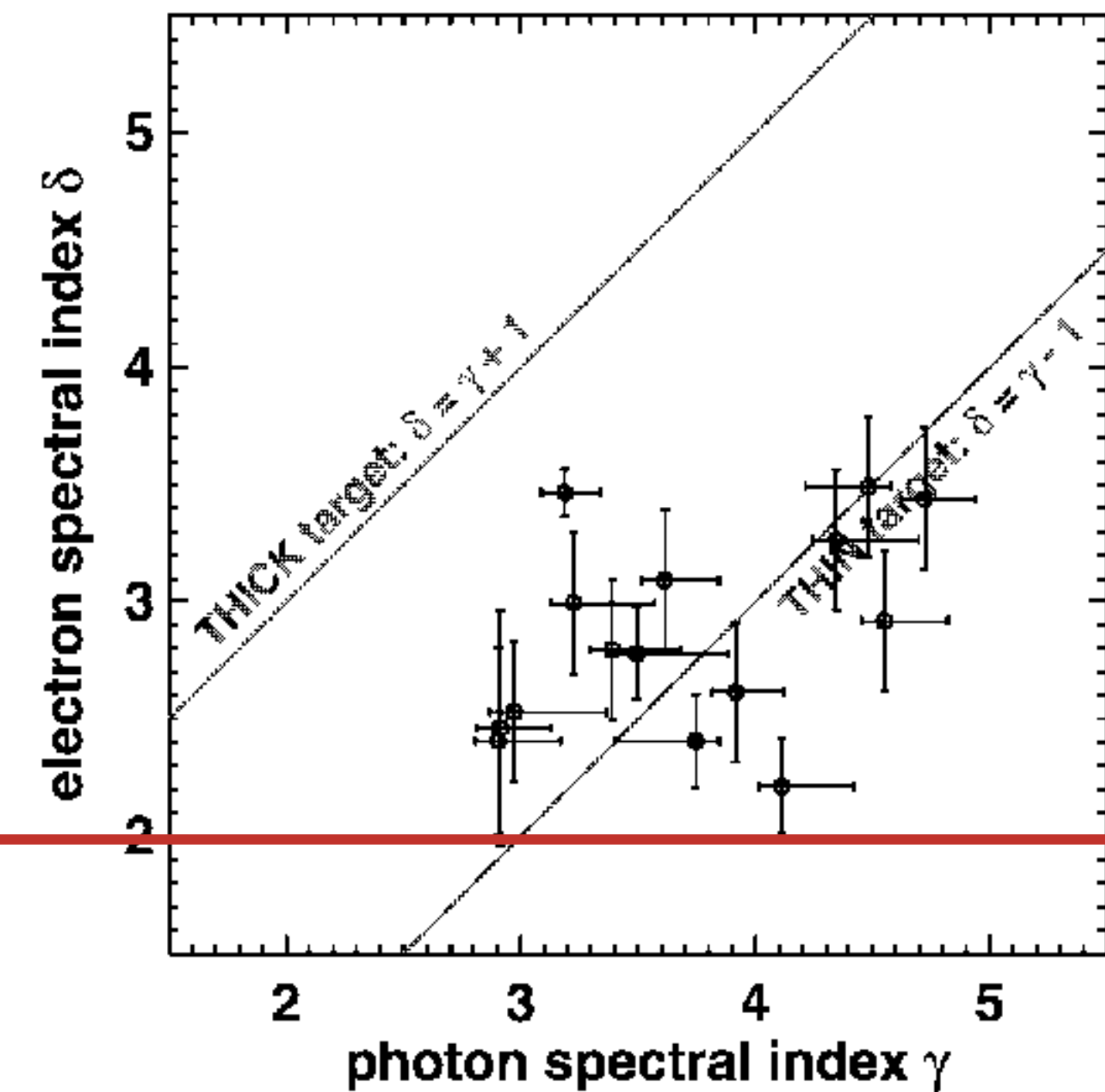
Delayed events: suggest the presence of an additional acceleration process

- Shock acceleration?
- Re-acceleration of flare seed particles in the CME environment (e.g., Petrosian, 2016)?
- Ongoing acceleration (e.g. post-flare loops, Klein et al., 2005)?

prompt events



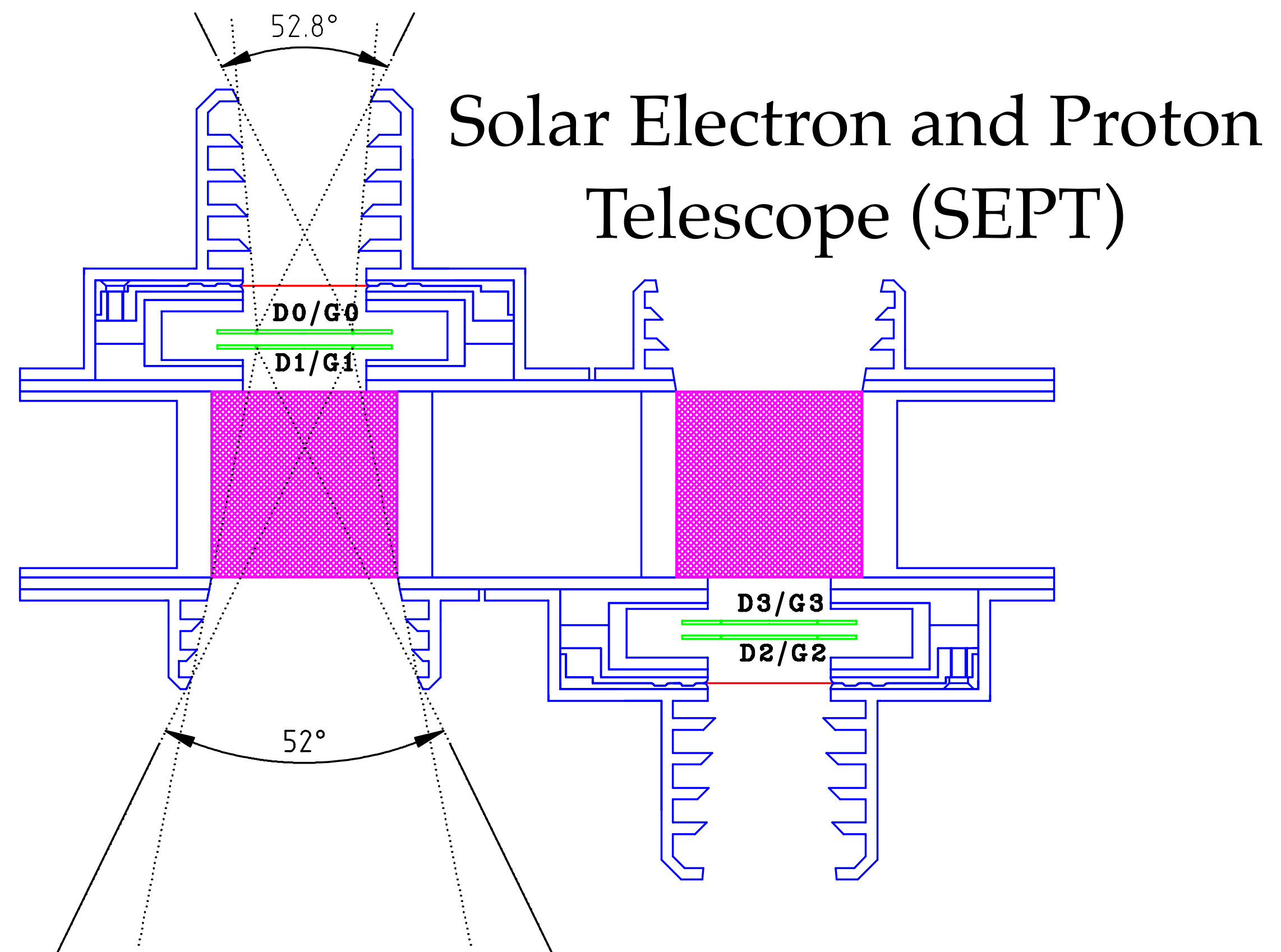
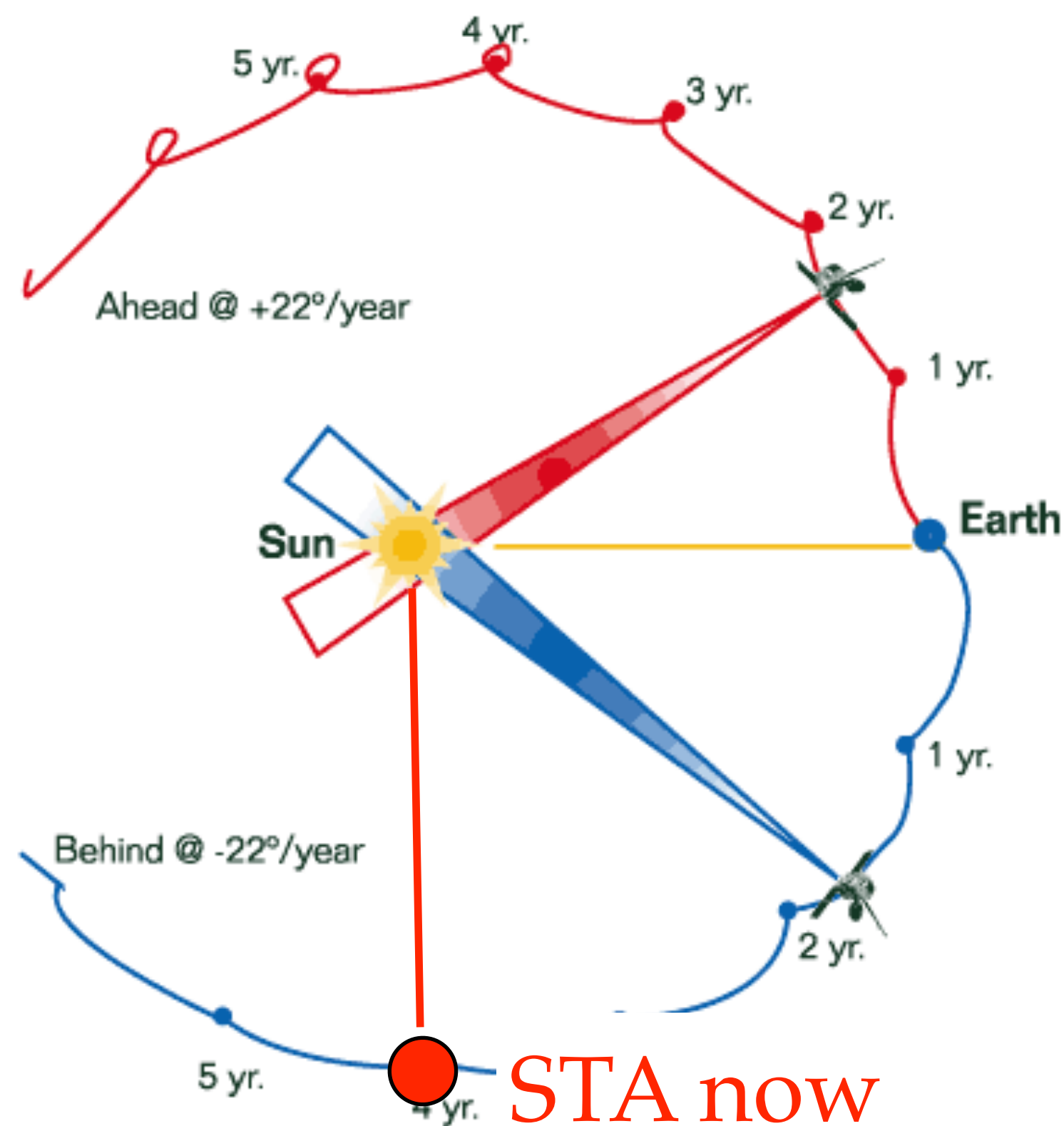
delayed events



Statistical Study of Electron Events with STEREO/SEPT

Using STEREO/SEPT observations 2007-2018

- We focus on near-relativistic electrons (STEREO/SEPT)
- 15 energy channels, 45-400 keV, four viewing directions
- 7 years of STEREO A+B data (12 years of STEREO A data)



Using STEREO/SEPT Observations

- We focus on near-relativistic electrons (STEREO/SEPT)
- 15 energy channels, 45-400 keV, four viewing directions
- 7 years of STEREO A+B data (12 years of STEREO A data)
- All electron events observed with SEPT aboard STEREO A&B (925 events)

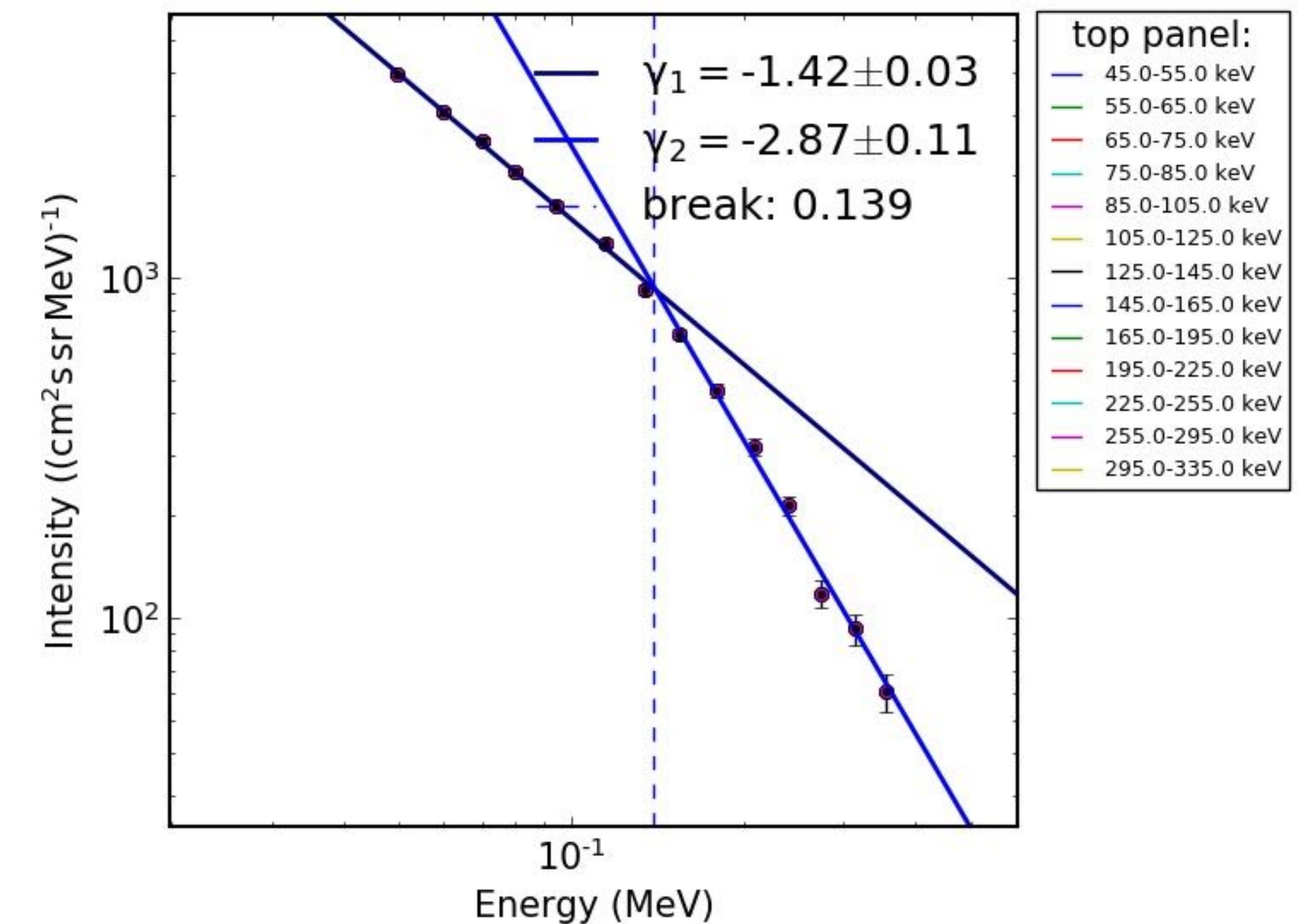
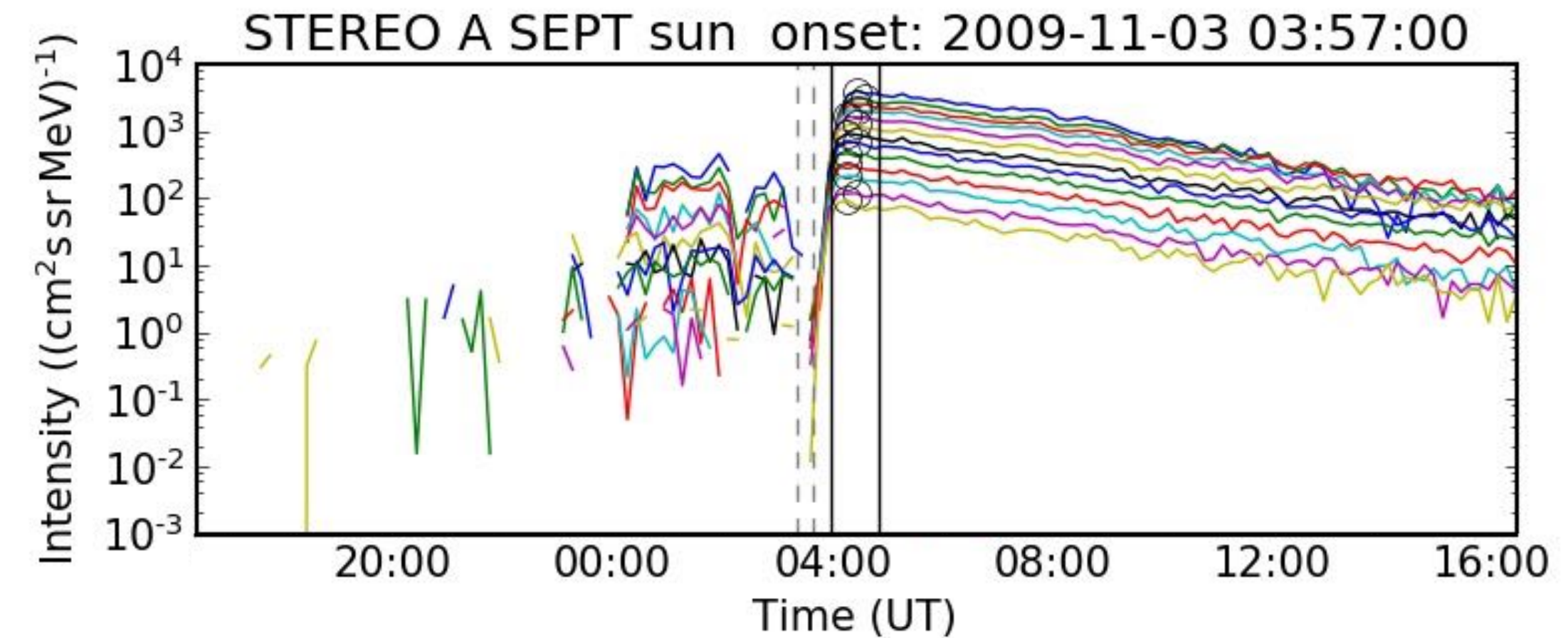
http://www2.physik.uni-kiel.de/stereo/downloads/sept_electron_events.pdf

55-85 keV electron events

Event				Onset	dt	Max (UT)	Max Int.	Remarks	Browse plot
Number	slc	Doy	Date	(UT)	(min)	10 min av.	10 min av.		
2007	1	A	023	2007-01-23	18:58	4	19:25	3.18E+02	Link
	1	B	023	2007-01-23	18:54	4	19:45	2.67E+02	Link
	2	A	024	2007-01-24	01:05	1	01:35	4.51E+02	Link
	2	B	024	2007-01-24	01:06	1	01:25	3.45E+02	Link
	3	A	024	2007-01-24	05:50	1	06:05	7.81E+02	Link
	3	B	024	2007-01-24	05:45	1	06:25	7.13E+02	Link
	4	A	139	2007-05-19	13:50	4	18:05	7.28E+02	Link
	4	B	139	2007-05-19	13:54	4	18:45	7.18E+02	Link
	5	A	140	2007-05-20	06:30	30	10:25	5.56E+02	On the decay phase of previous event Link
	5	B	140	2007-05-20	07:00	60	11:30	3.60E+02	On the decay phase of previous event Link
	6	A	142	2007-05-22	15:45	10	19:45	1.09E+02	Inside ICME Link
	6	B	142	2007-05-22	16:05	10	17:15	6.81E+01	Inside ICME Link
	7	A	143	2007-05-23	08:22	1	11:25	8.97E+02	Onset during ICME. Decay during CIR (ion contamination) Link
	7	B	143	2007-05-23	08:12	1	13:15	6.63E+02	Onset during ICME. Decay during CIR (ion contamination) Link

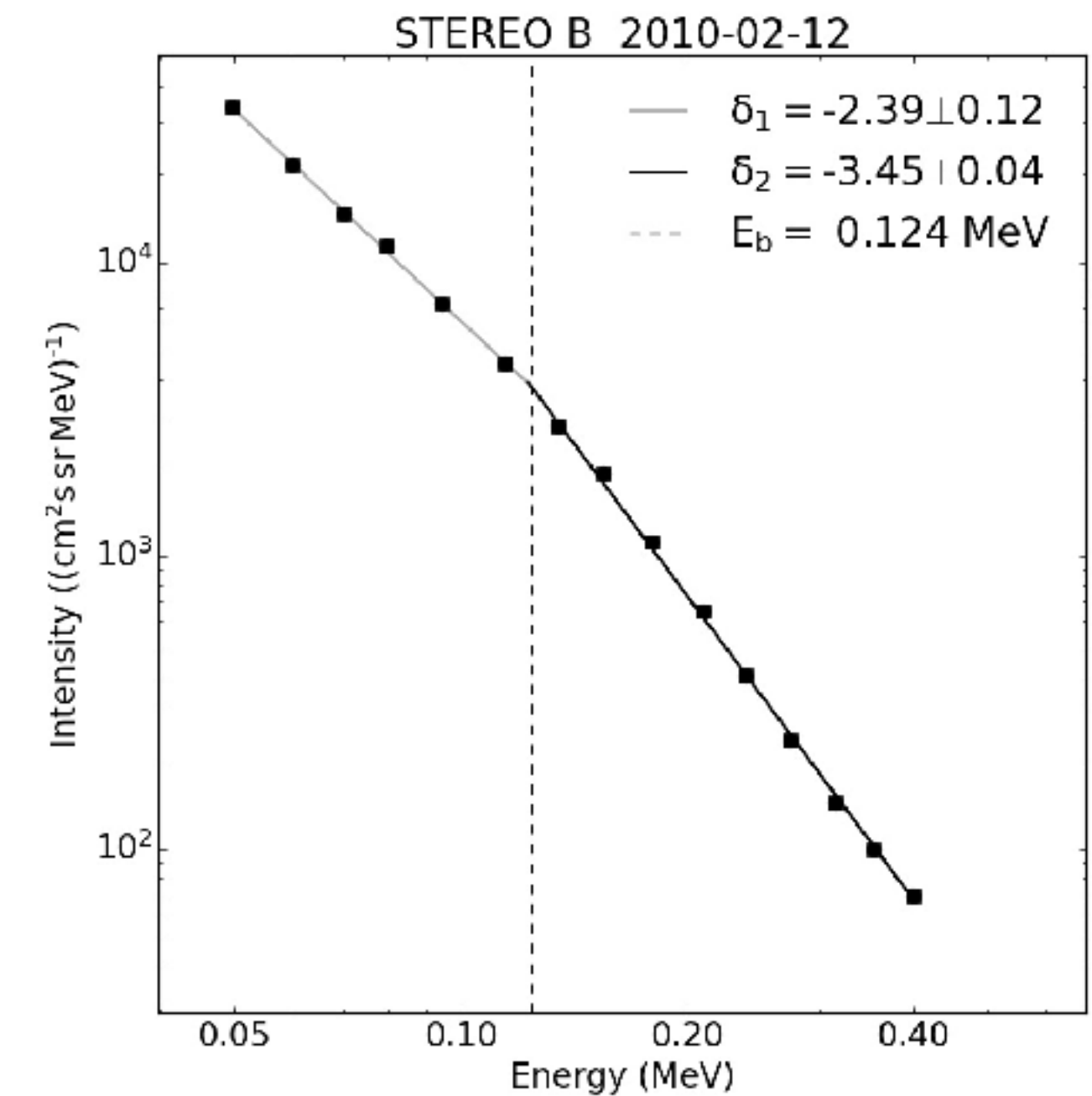
Solar Energetic Electron Spectra

- All SEPT electron events in the list: 925
- Sufficient statistics / significant increase above background:
 - ➔ 810 events selected
- Pre-event background subtracted
- Spectrum at maximum (to account for velocity dispersion)
- Use the telescope observing the highest intensity
- Fit a broken power law, exclude events with poor fits (**766 events left**)



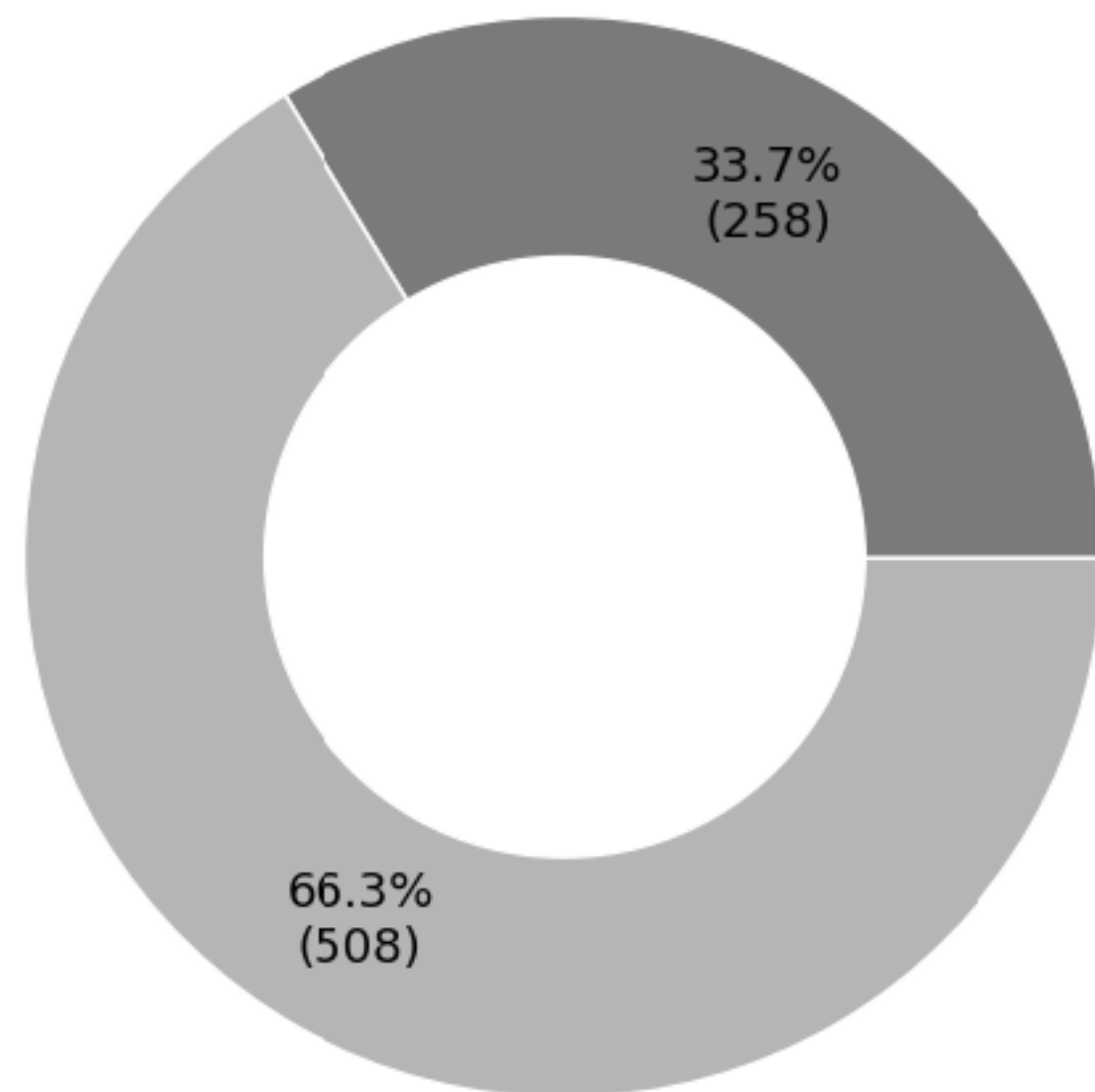
Solar Energetic Electron Spectra

- Only one third shows impulsive rise times
- Impulsive: Time from onset to maximum $t < 30\text{min}$
- Break point limits due to SEPT binning: $\sim 70\text{-}300\text{ keV}$

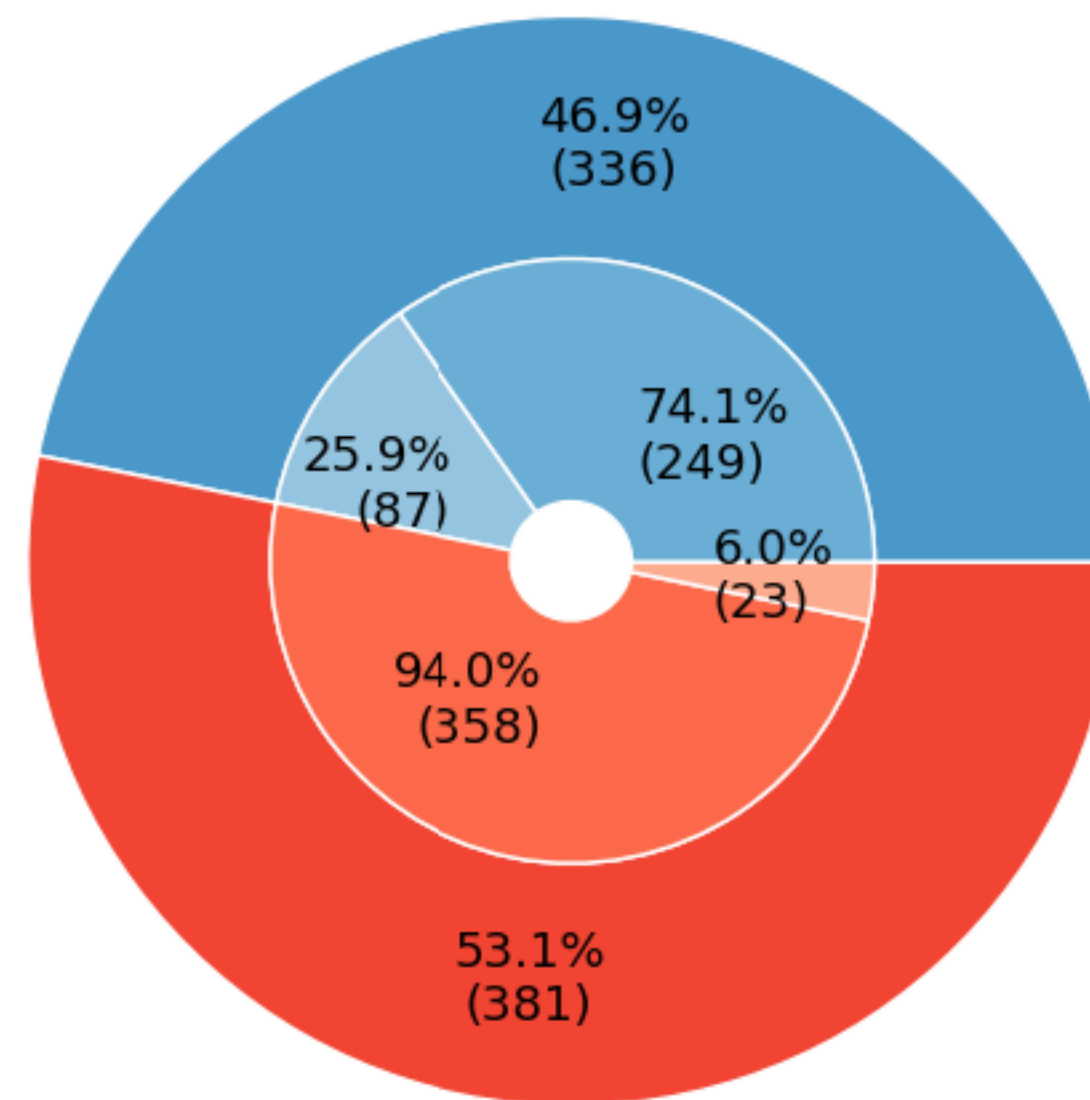


All events

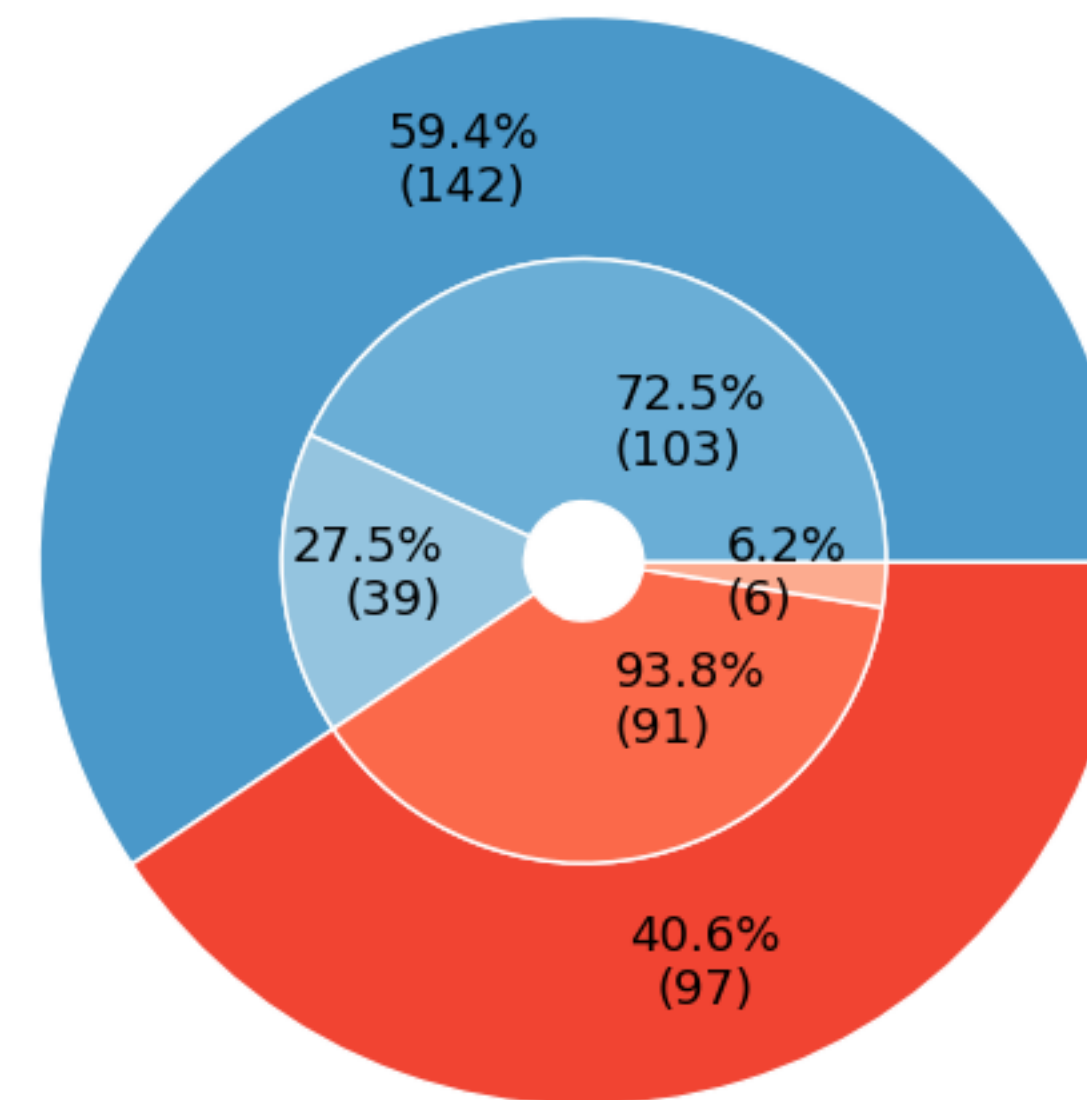
Impulsive events



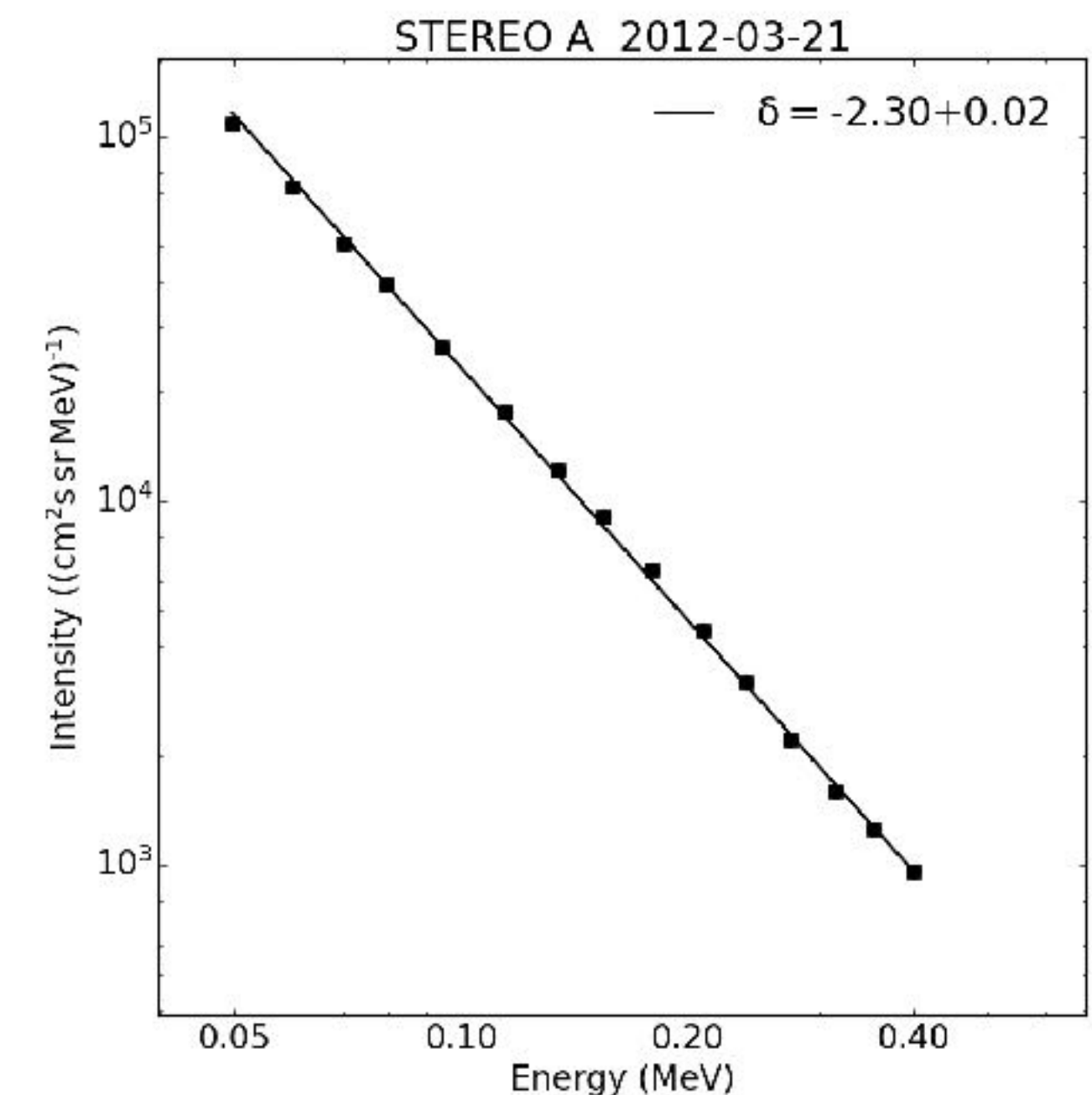
■ Impulsive
 ■ Non-impulsive



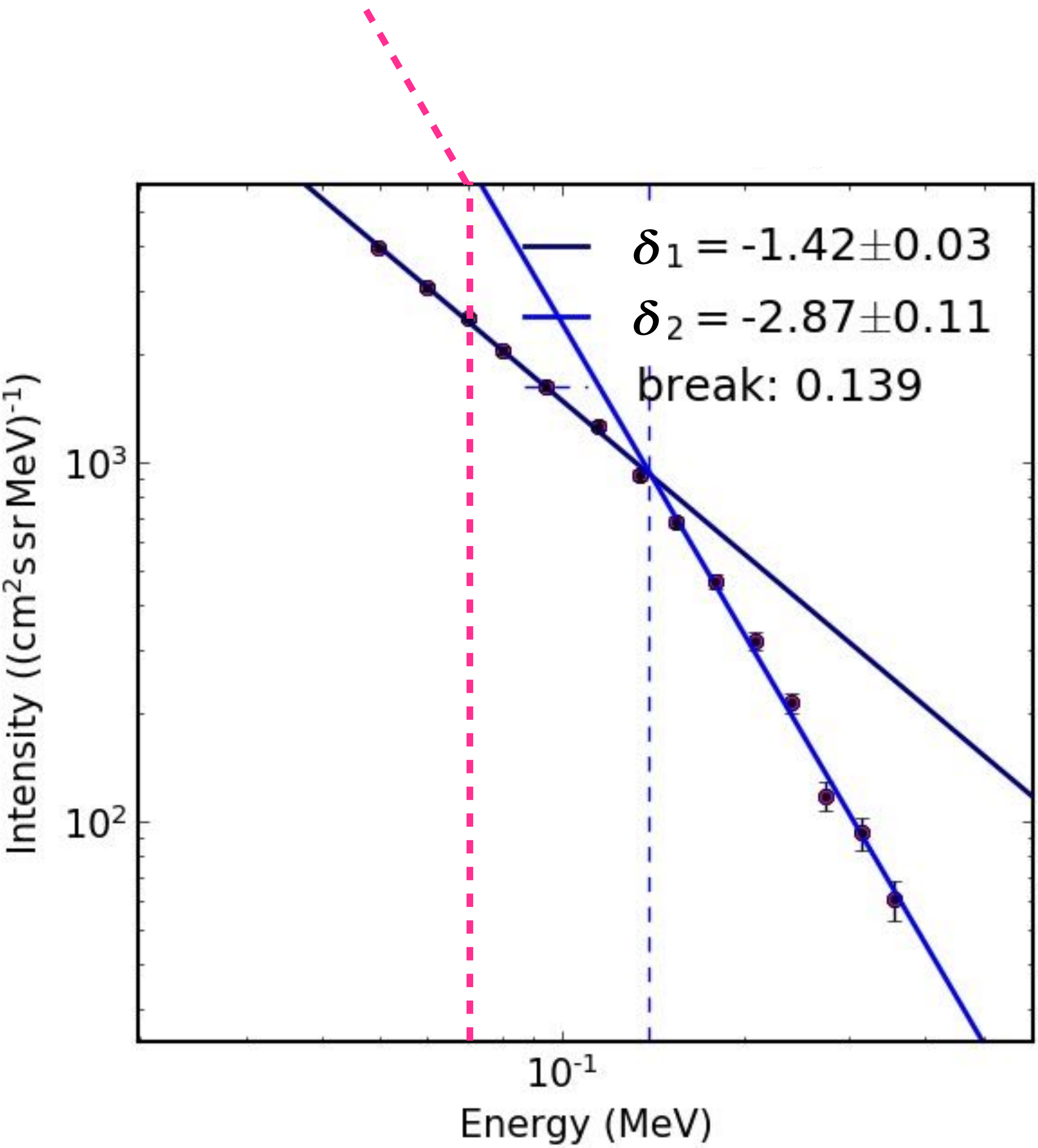
■ Single PL ■ E > 150 keV
 ■ Broken PL ■ E < 150 keV
 ■ E > 150 keV
 ■ E < 150 keV



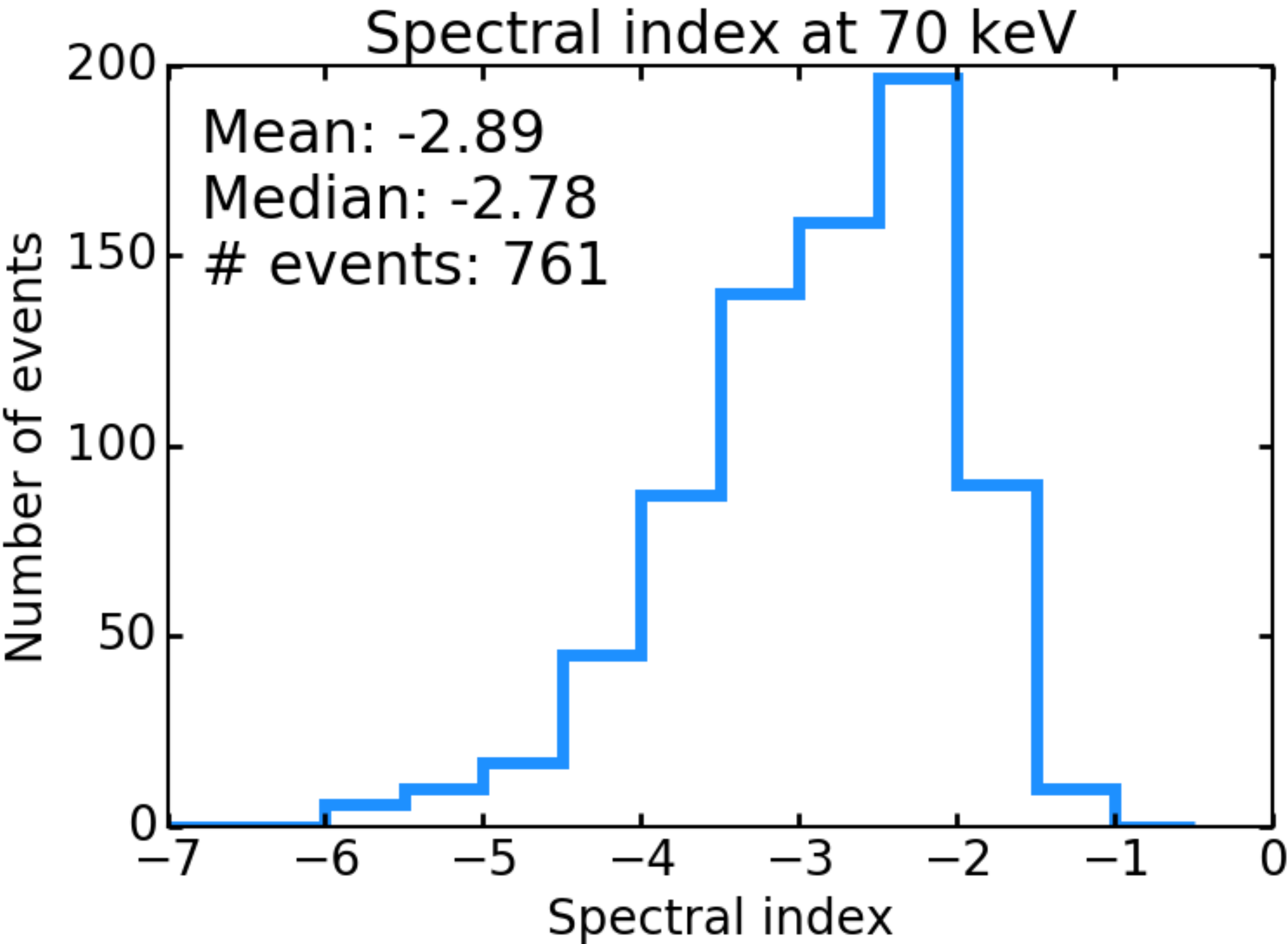
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 ■ E < 150 keV



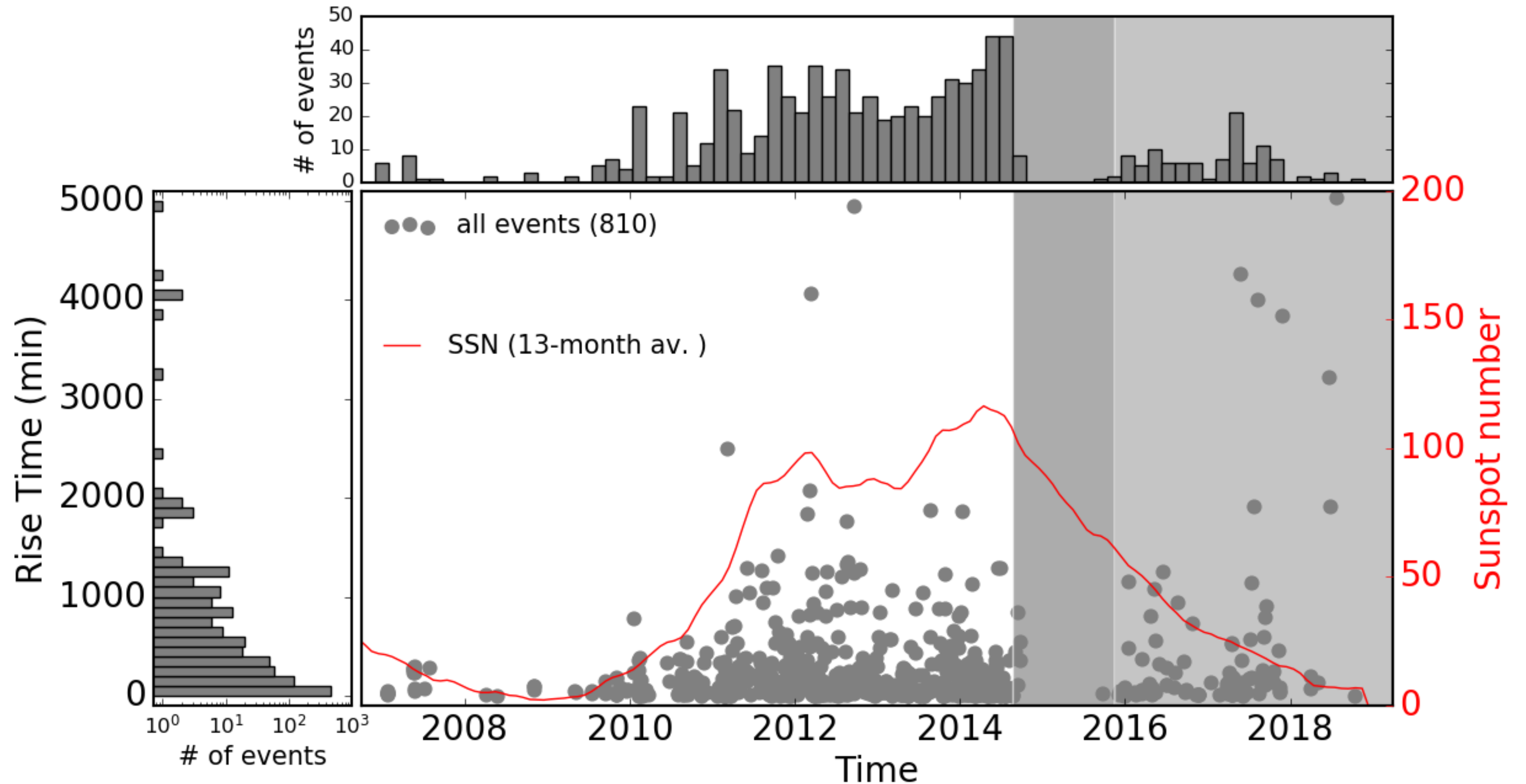
Distribution of spectral indices at 70 keV



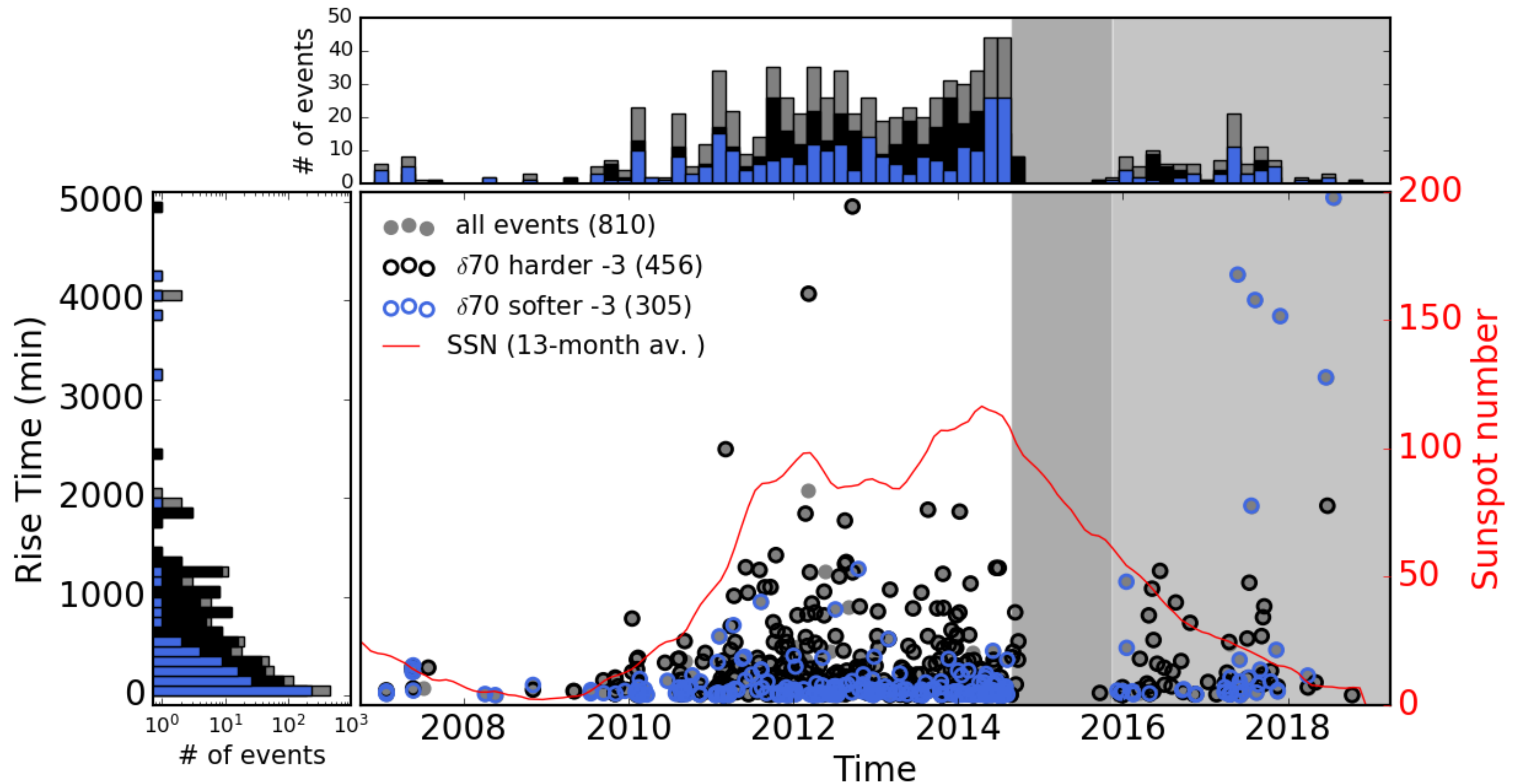
$\langle \delta \rangle = -2.89$



Rise Time of the Events

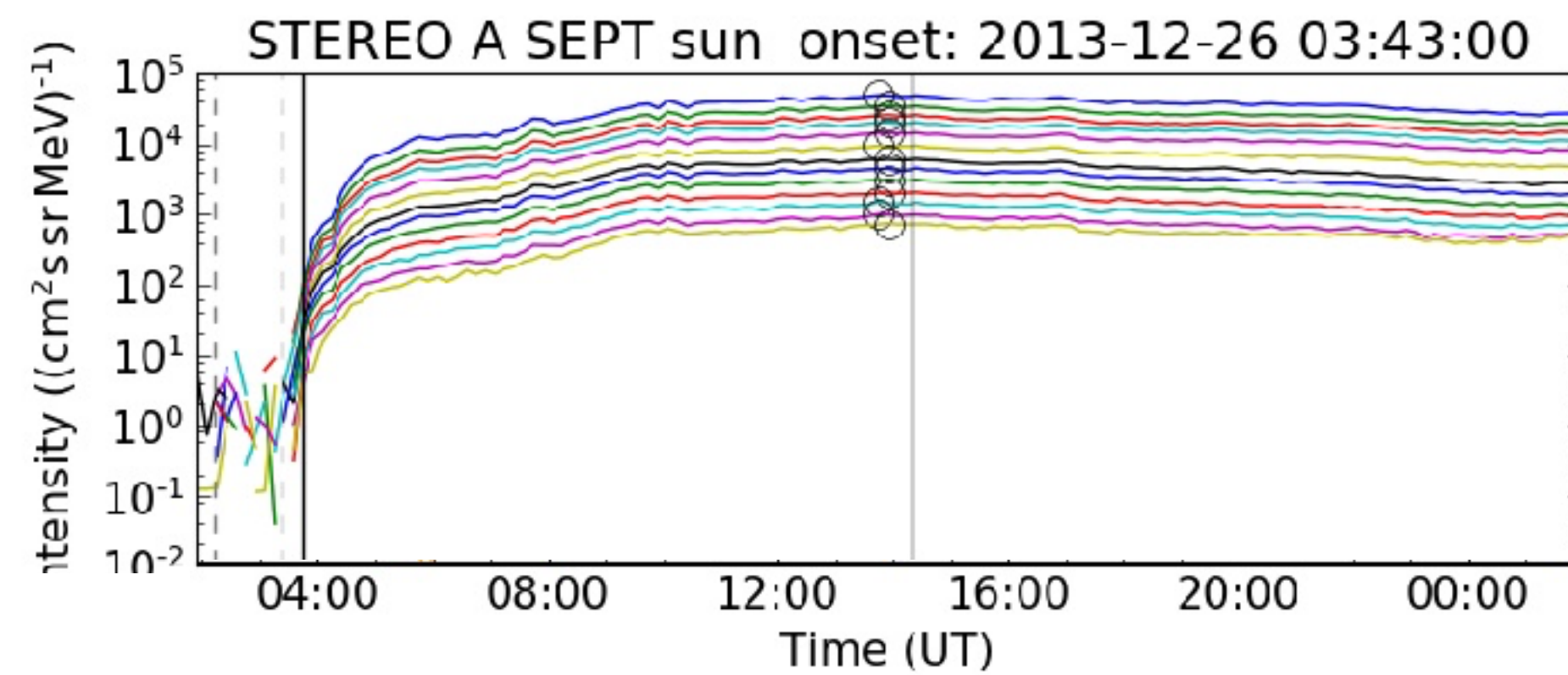


Rise Time of the Events

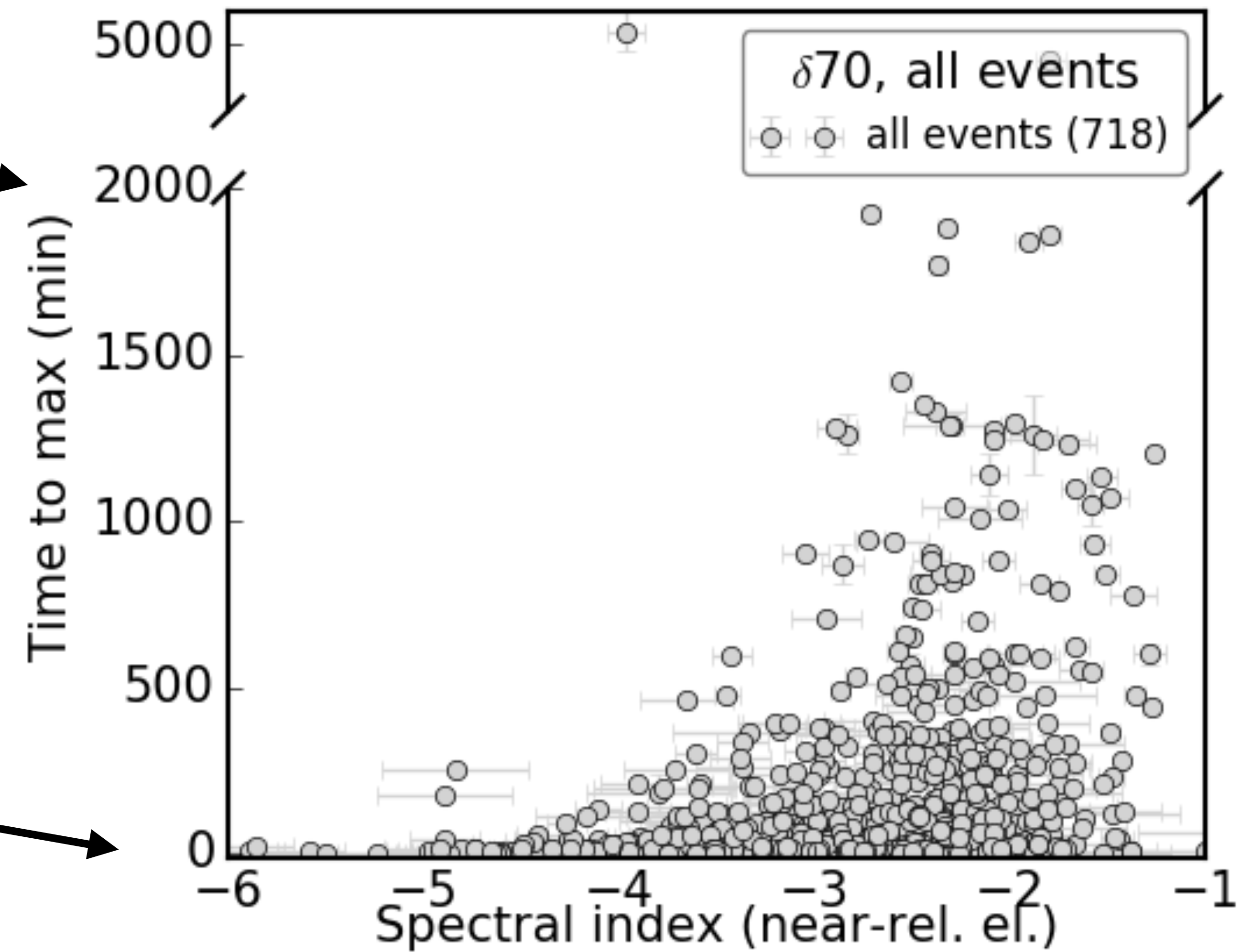
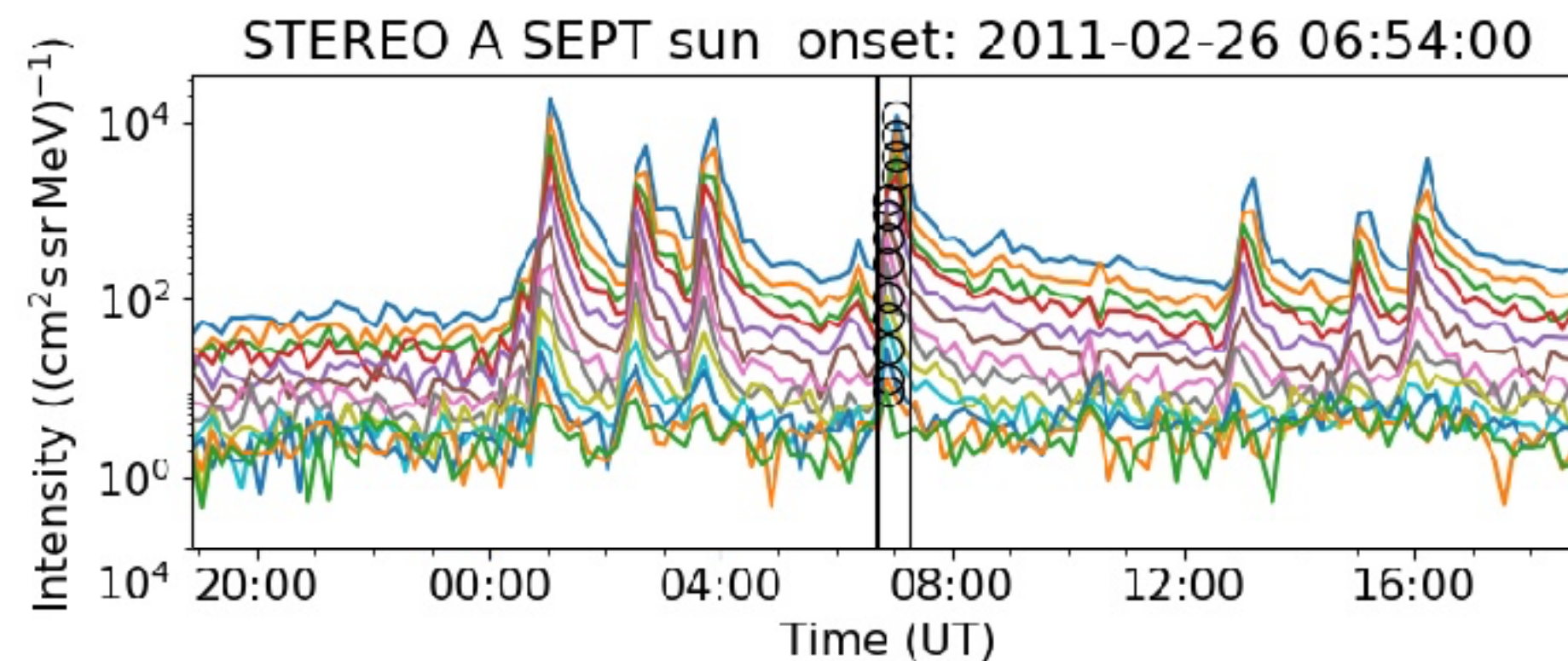


Rise Time and Spectral Index

Gradual rise

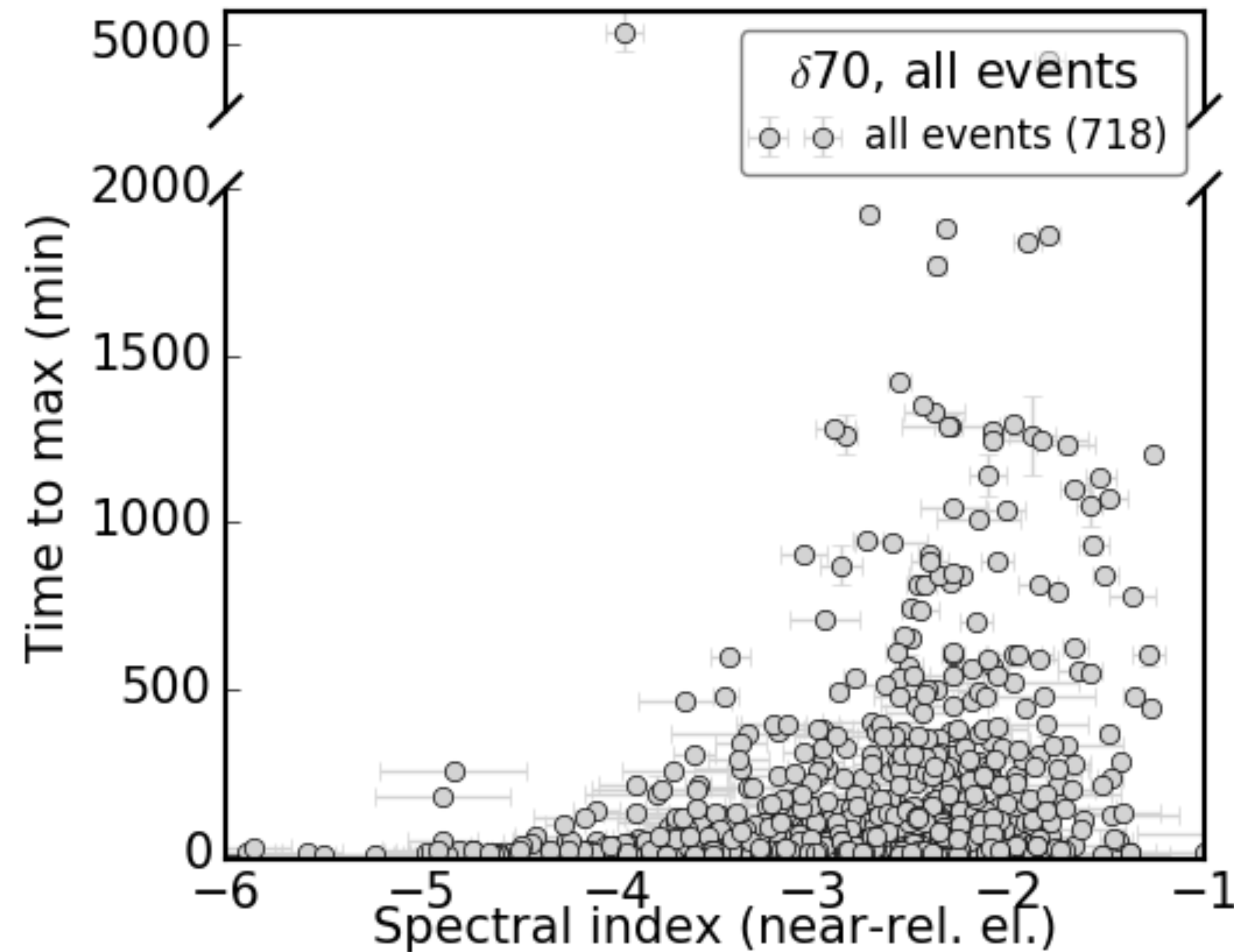


Impulsive rise



Rise Time and Spectral Index

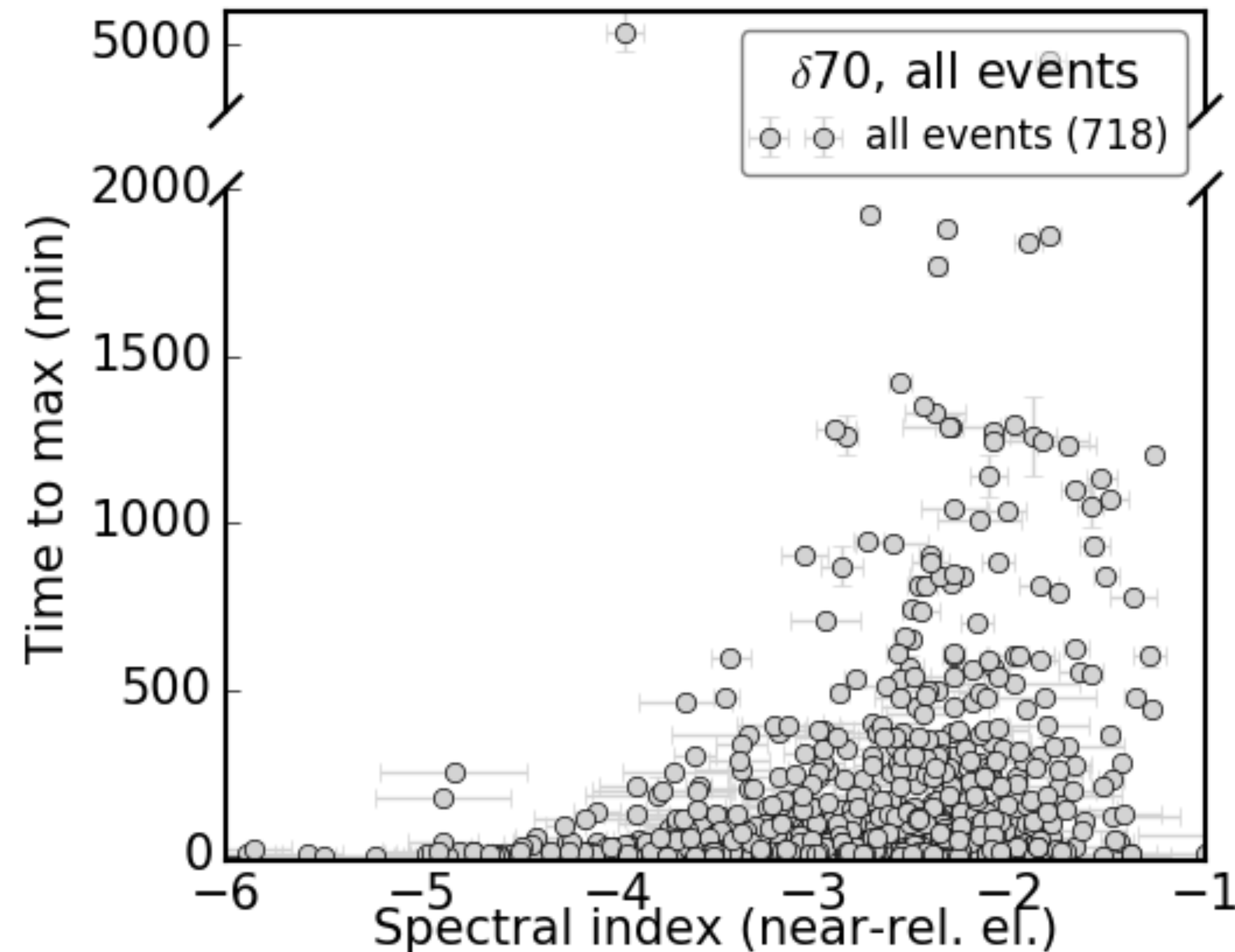
- The softer the spectrum, the smaller the variation in rise times
- No soft spectra with long rise times!
- Reasons for long rise times:
 - A long-lasting injection (and / or acceleration)
 - Scattering in the IP medium



[spectral index at 70 keV, rise times and peak intensities of 55-85 keV electrons]

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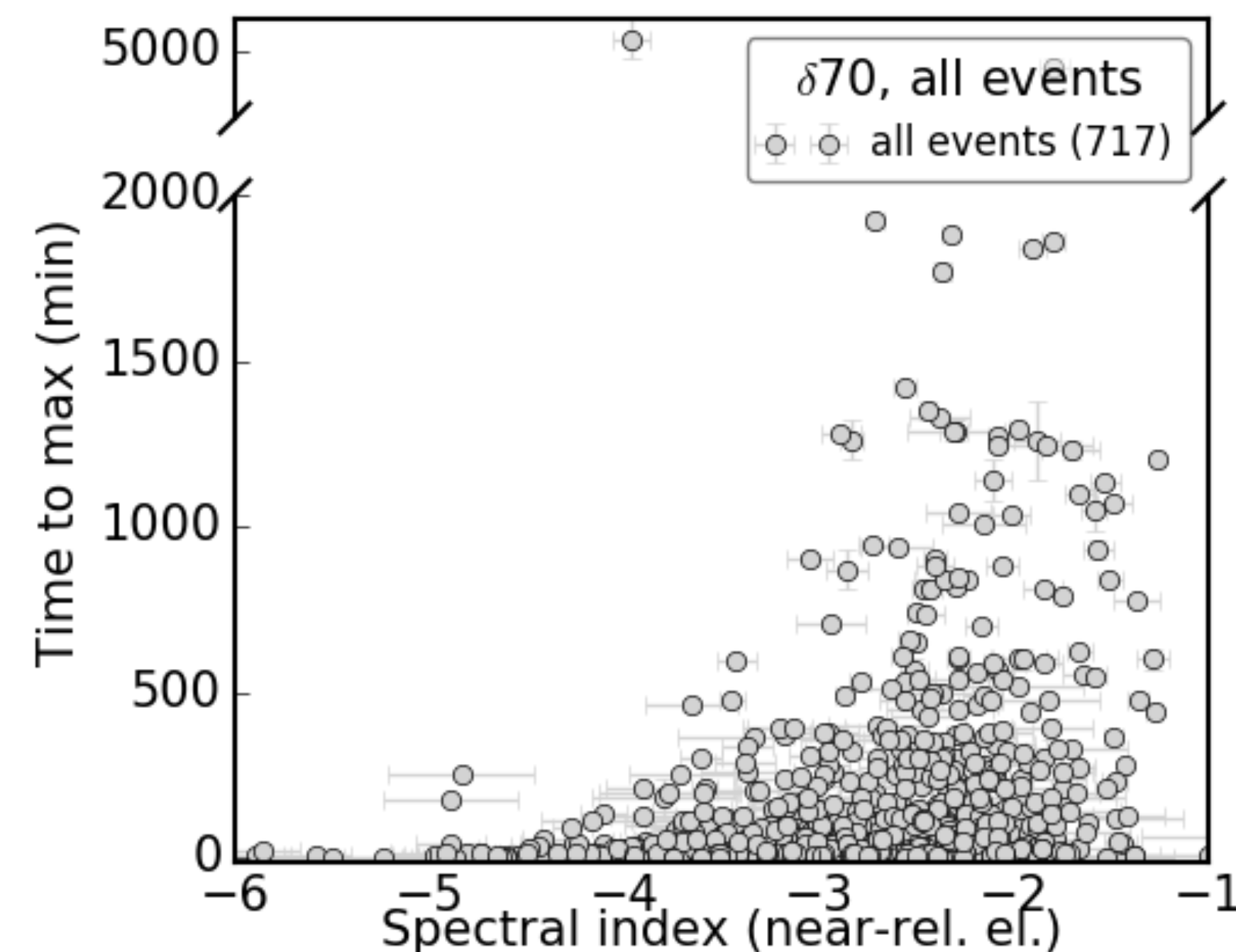


[spectral index at 70 keV, rise times and peak intensities of 55-85 keV electrons]

Rise Time and Spectral Index

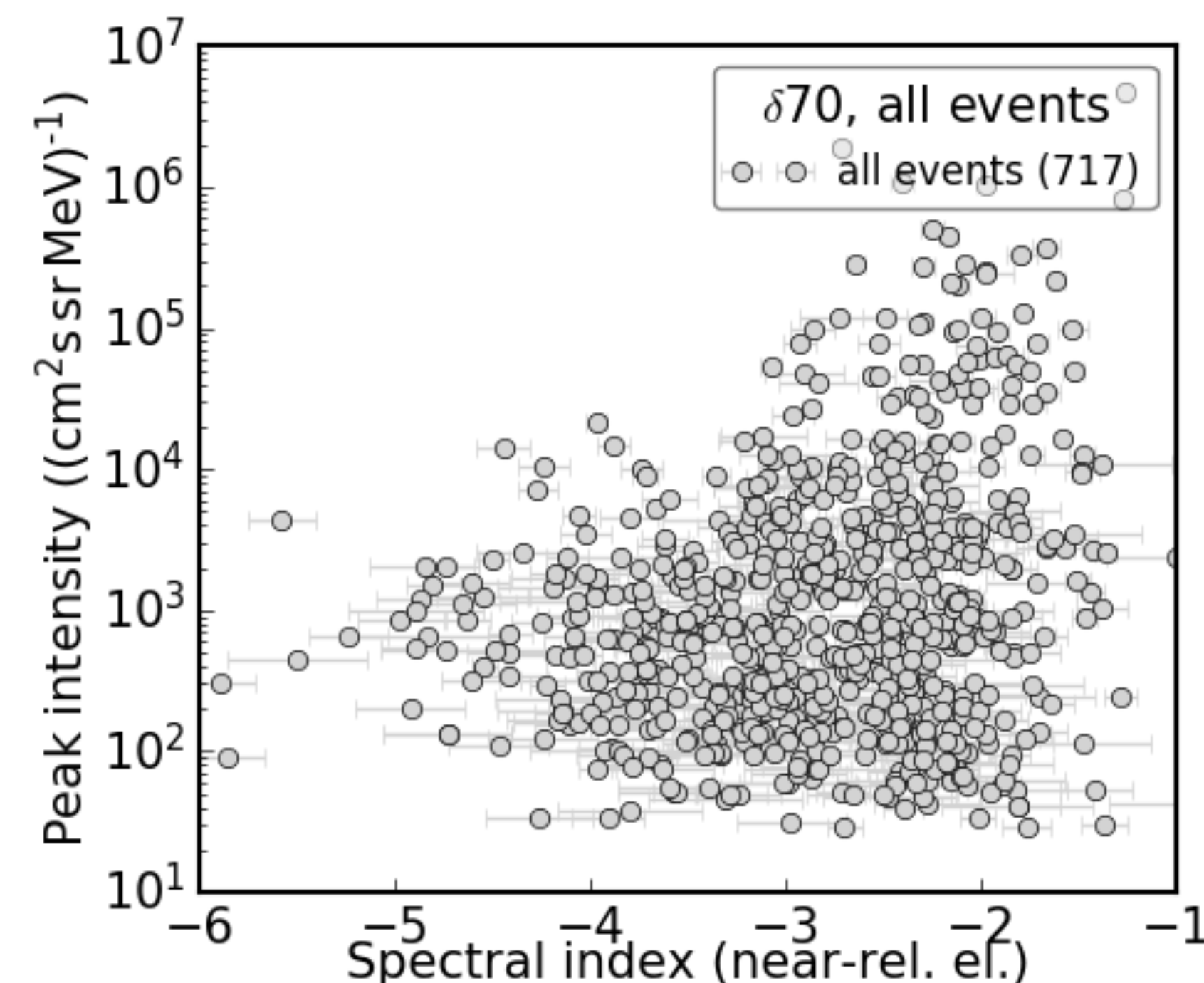
Correlation between spectral index and rise time

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Peak intensities tend to be higher for harder events

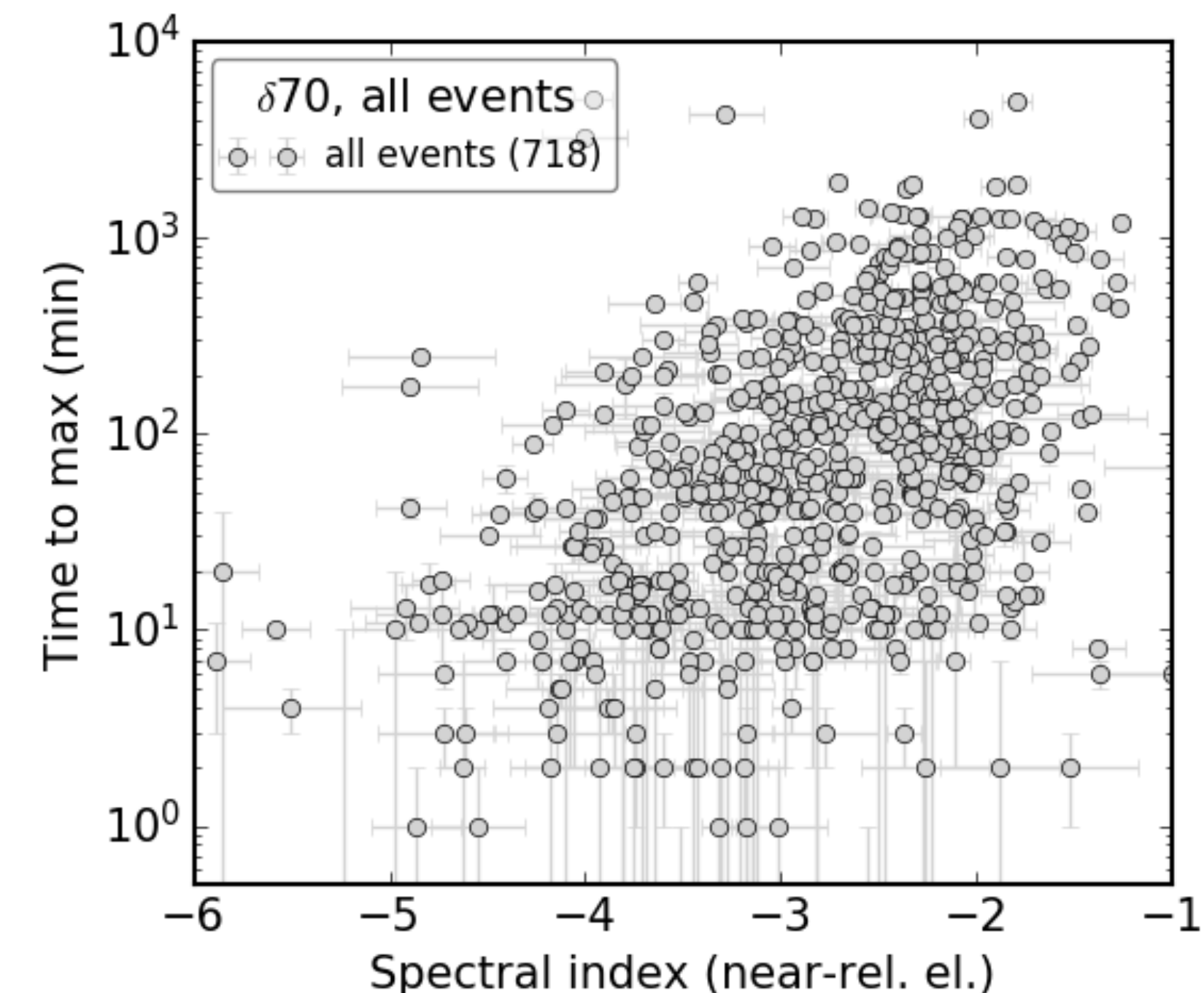
[spectral index at 70 keV, rise times and peak intensities of 55-85 keV electrons]



Rise Time and Spectral Index

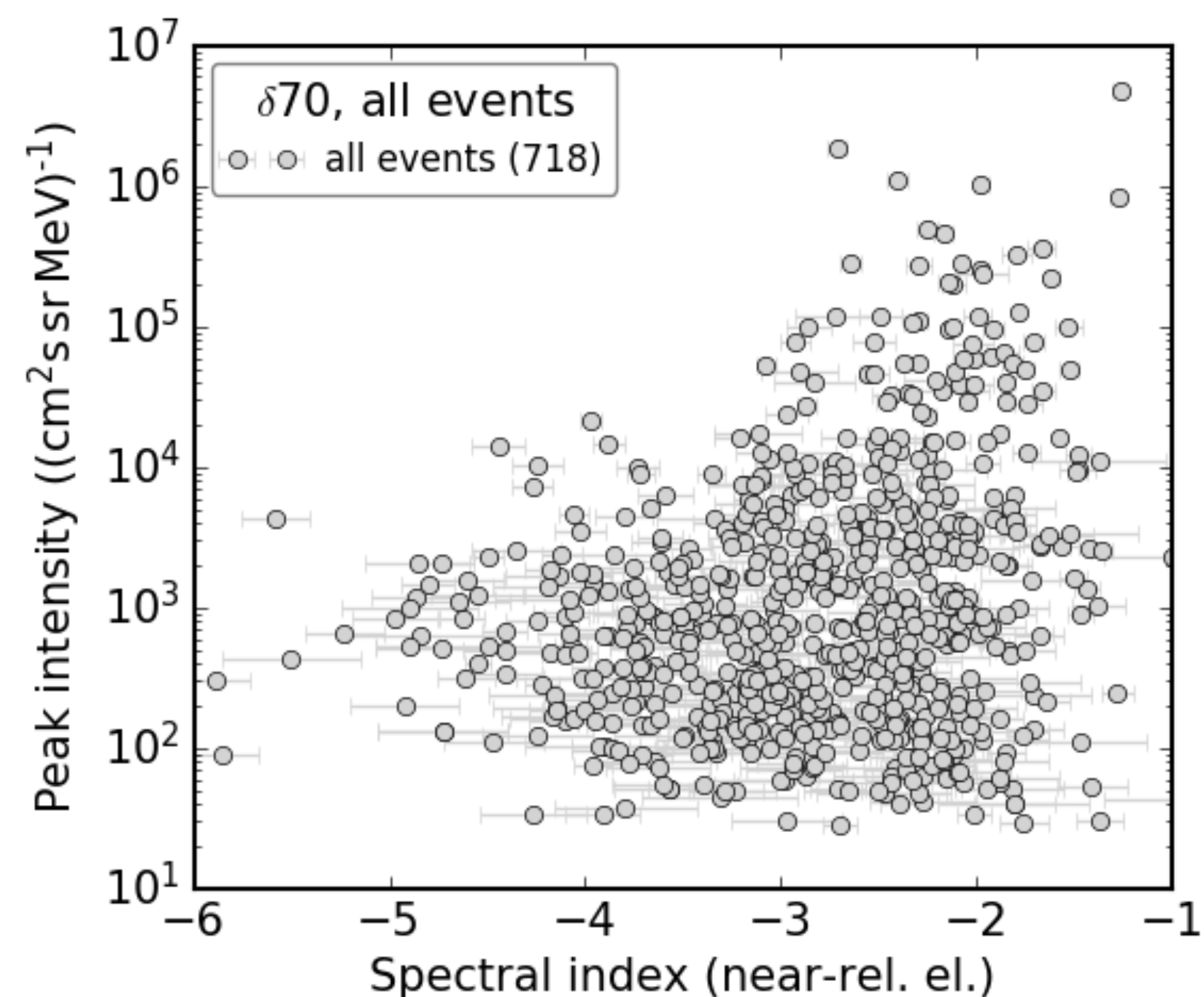
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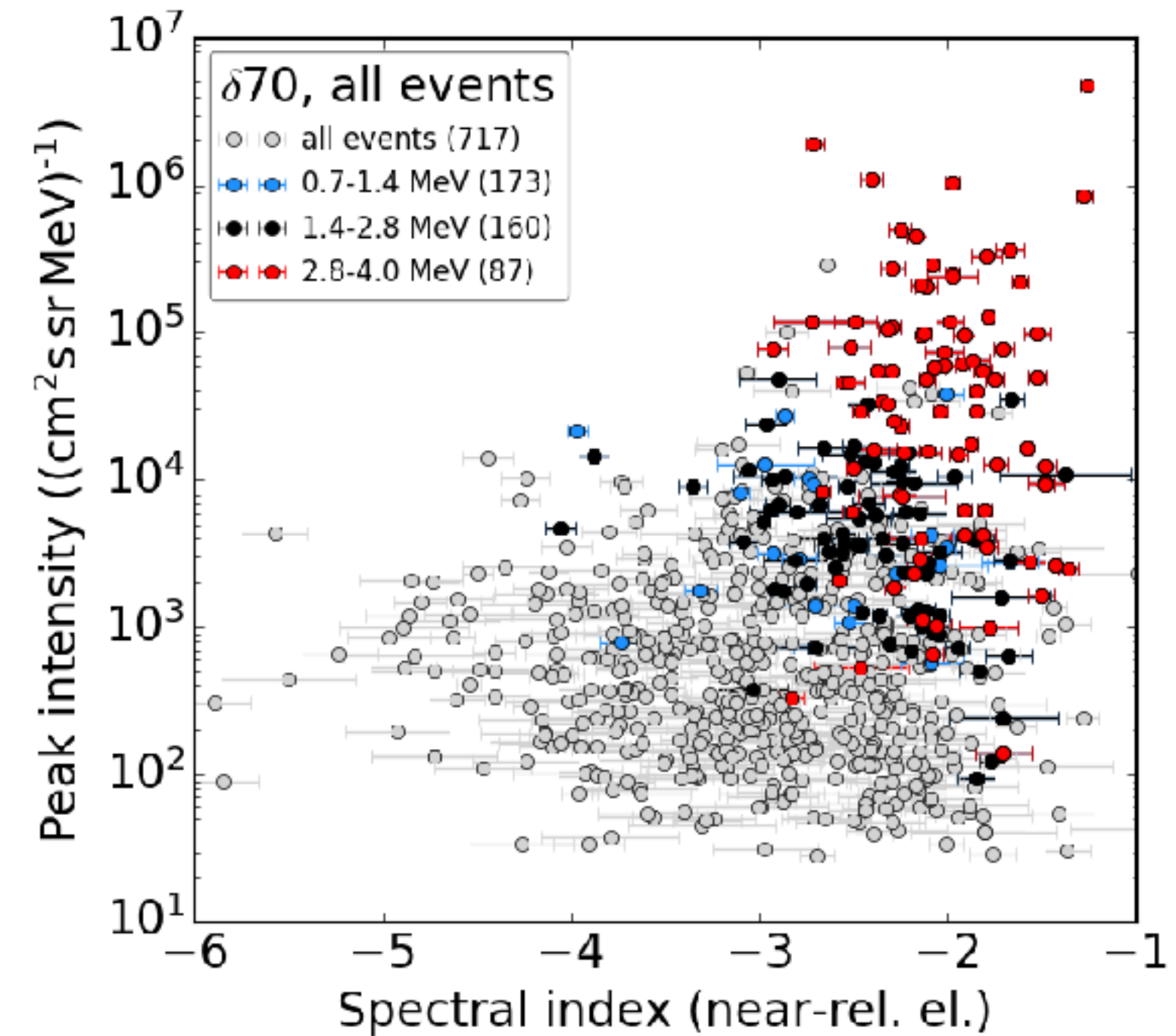
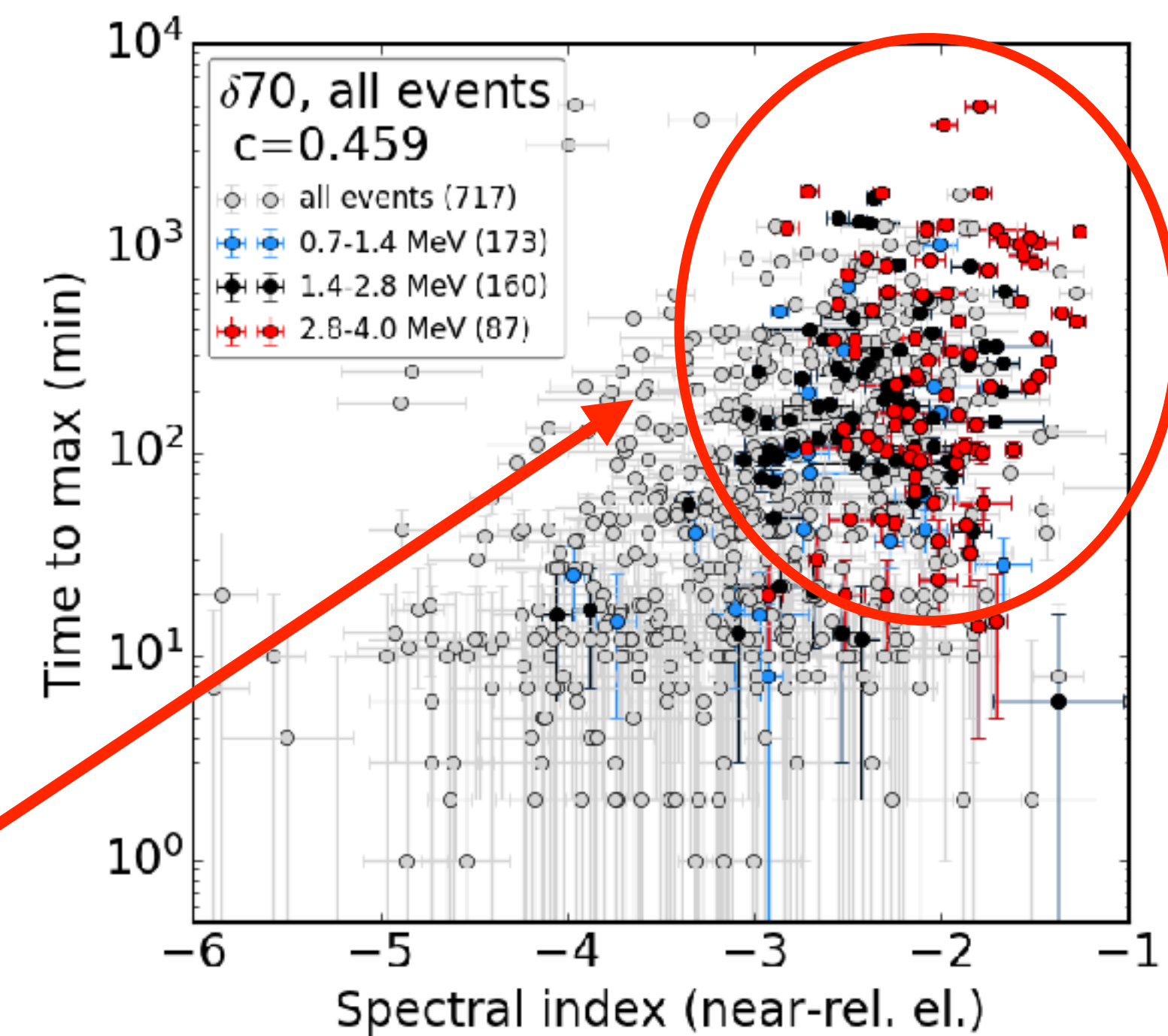
Peak intensities tend to be higher for harder events

[spectral index at 70 keV, rise times and peak intensities of 55-85 keV electrons]



Correlation between spectral index and rise time + presence of MeV electrons suggests:

A temporally extended injection involving another (or an ongoing) acceleration process

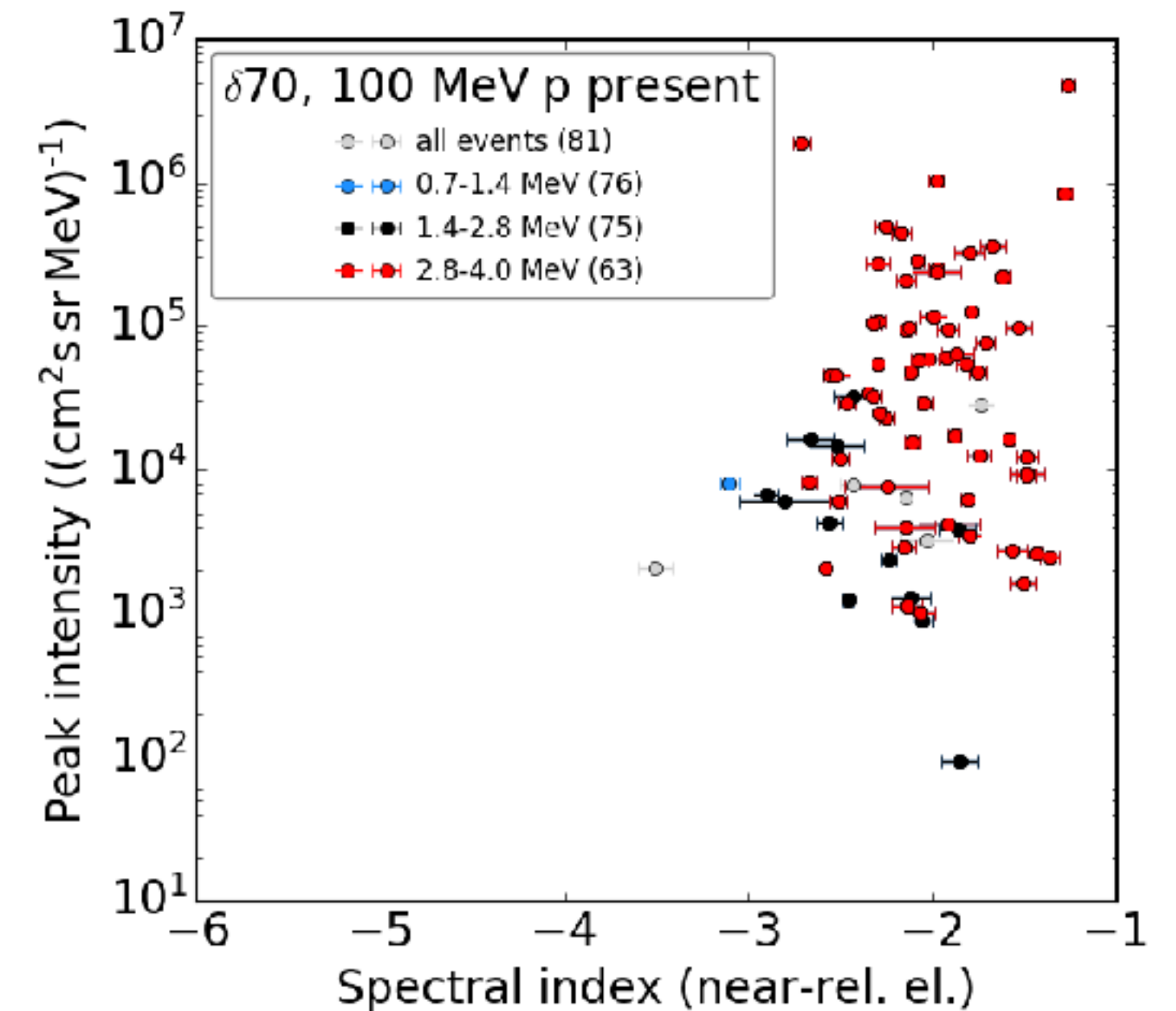
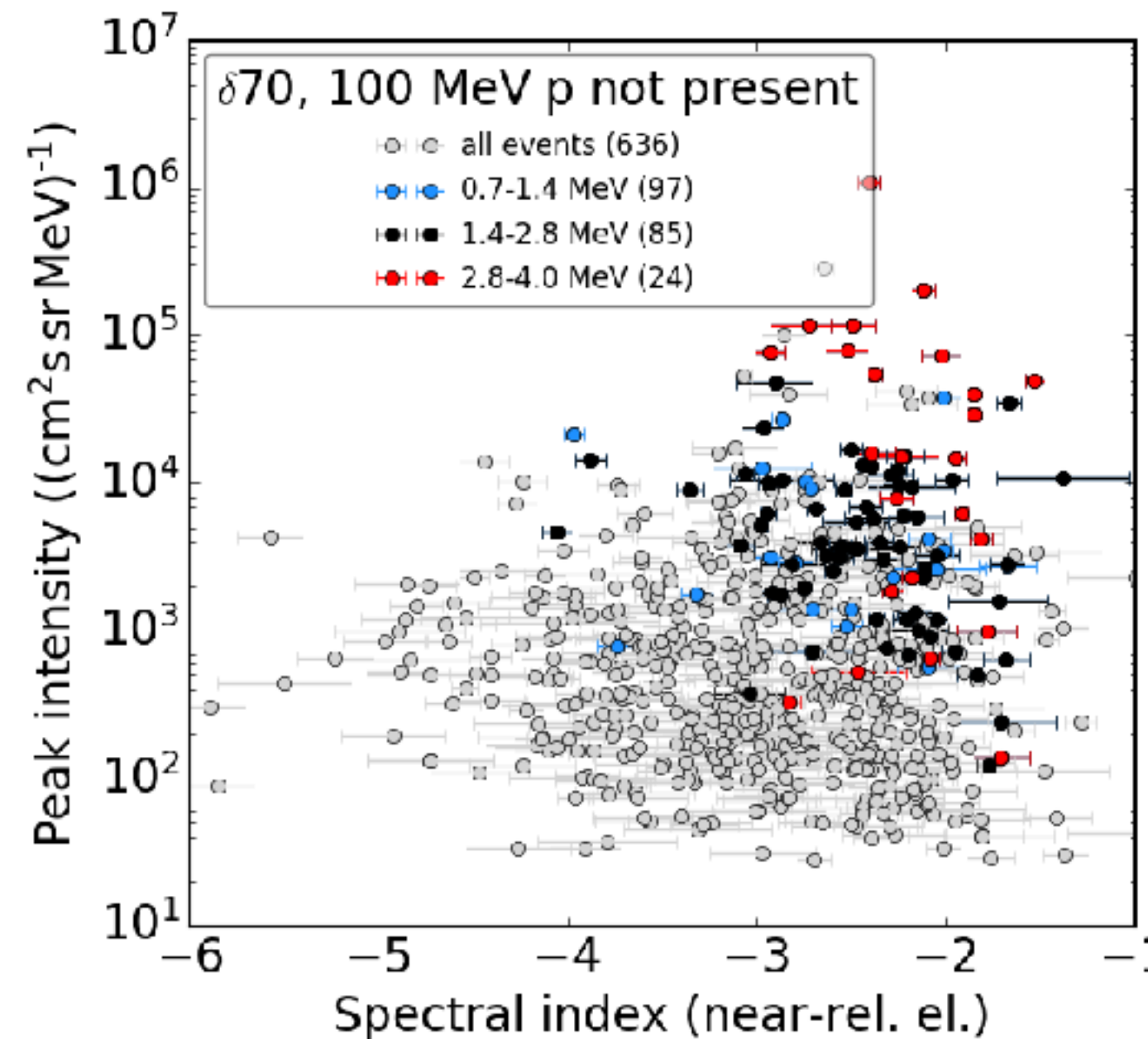
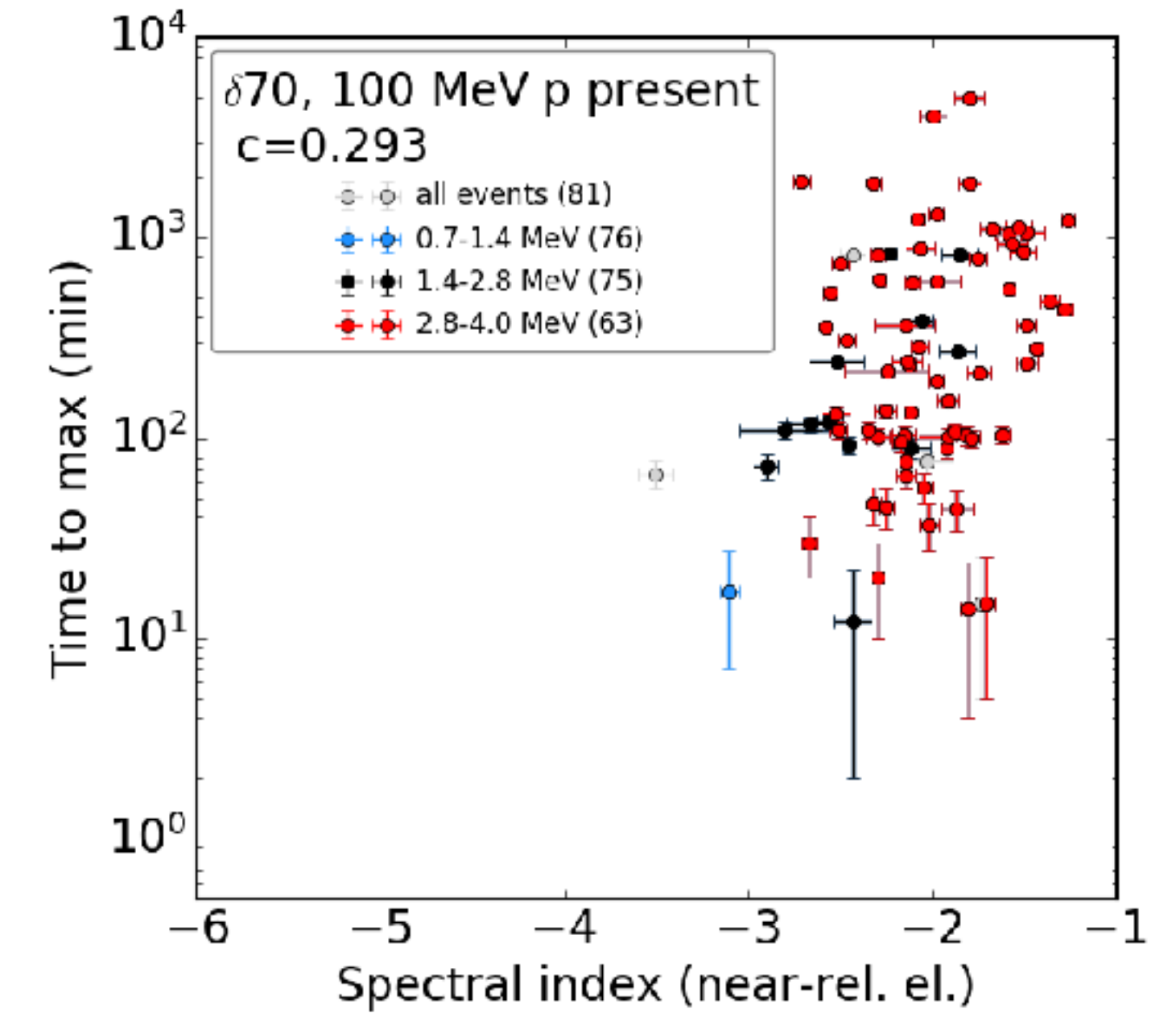
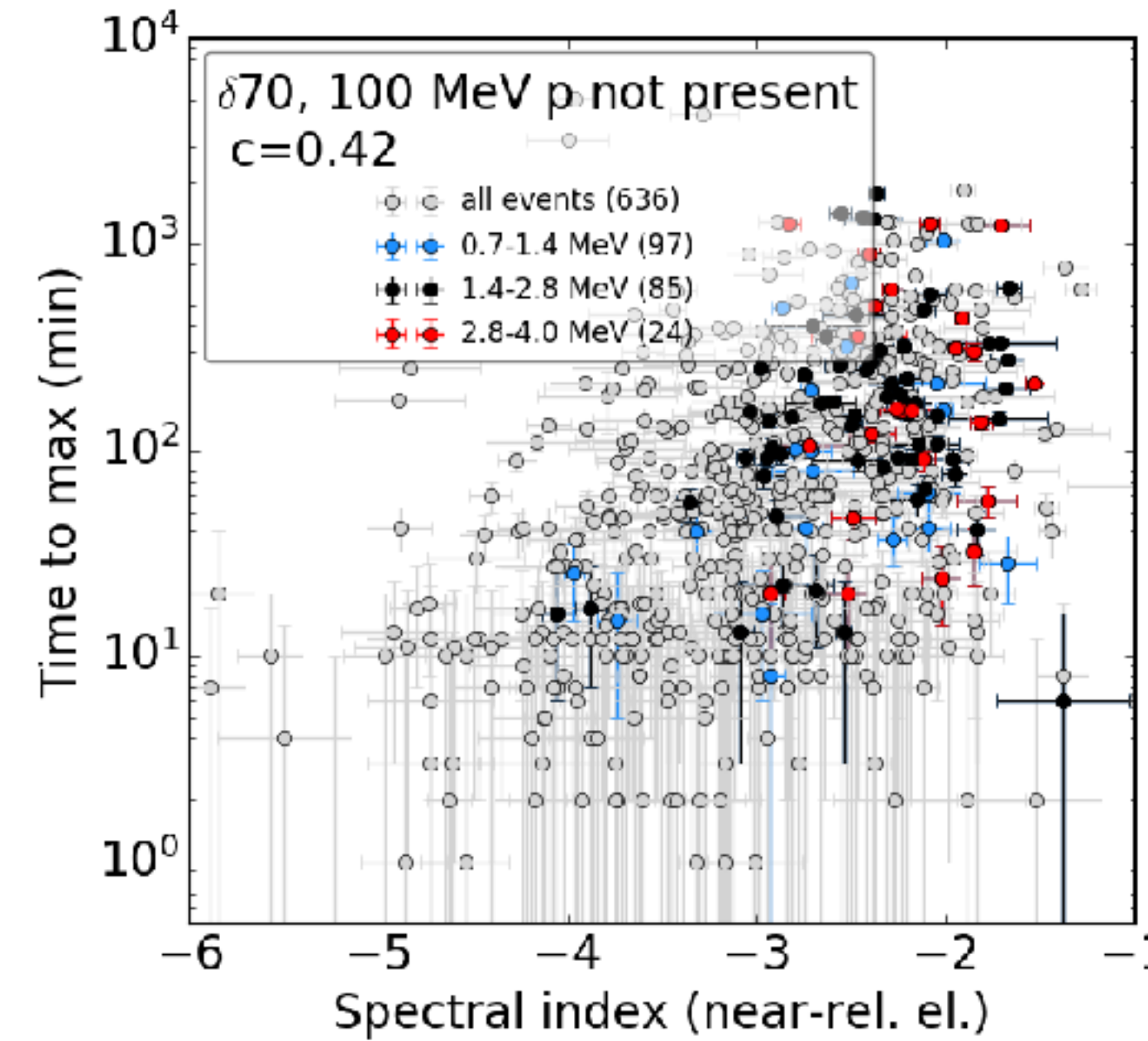


[spectral index at 70 keV, rise times and peak intensities of 55-85 keV electrons]

Rise Time and Spectral Index (+ MeV Electrons & 60-100 MeV Protons)

Correlation between the presence of 60-100 MeV protons and MeV electrons

This suggest a common acceleration process (or a common ingredient) of 60-100 MeV protons and MeV electrons

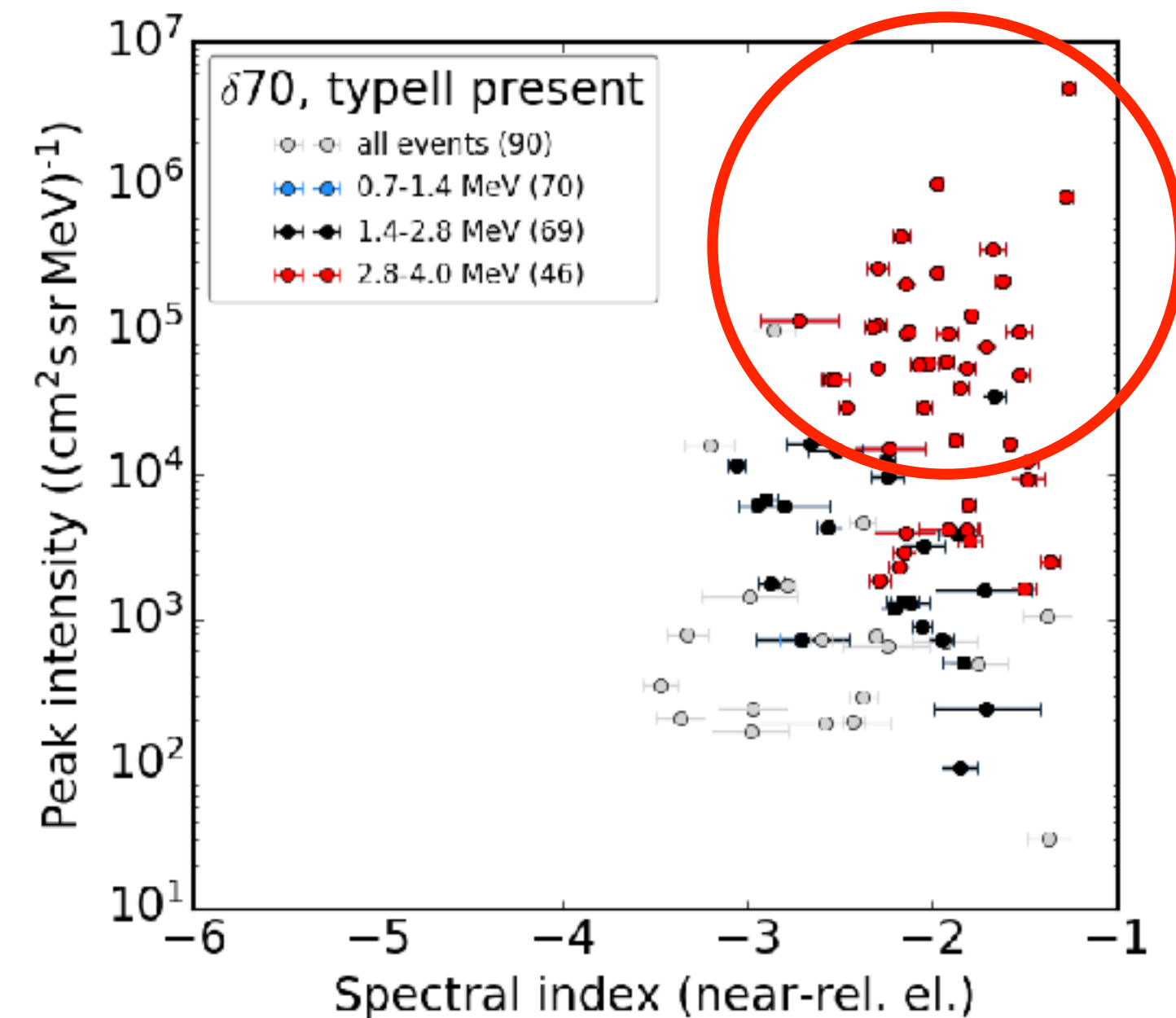
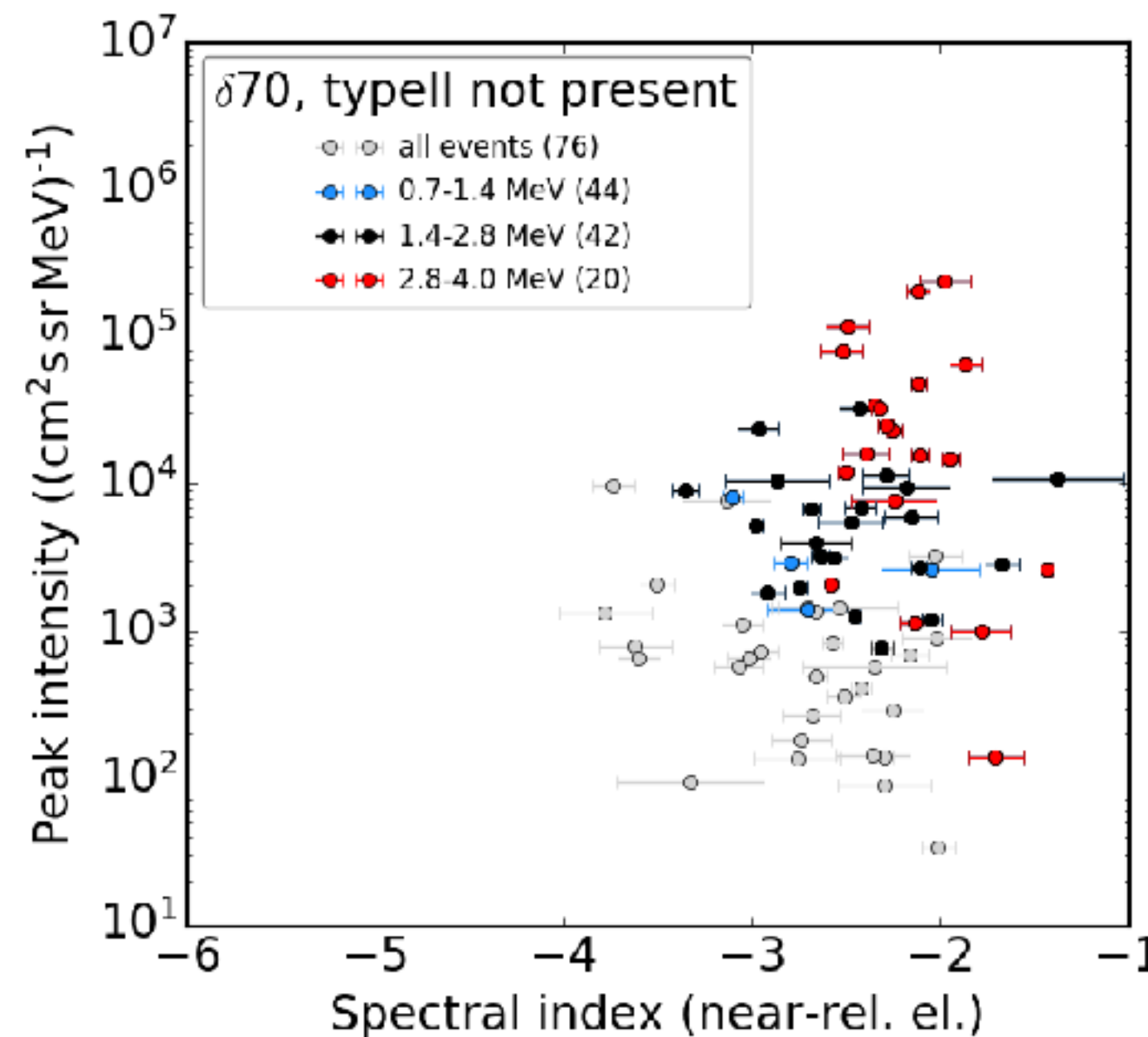
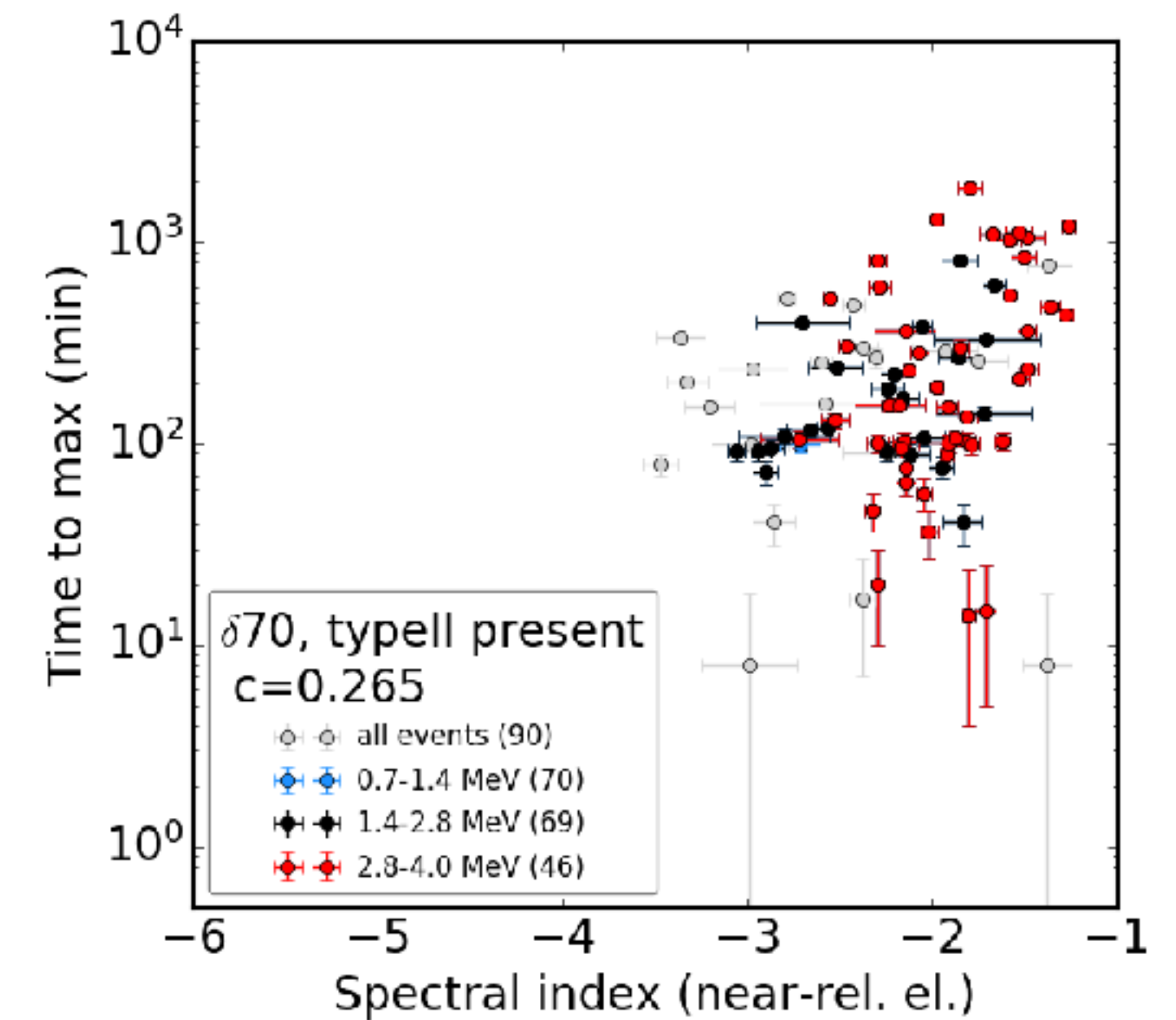
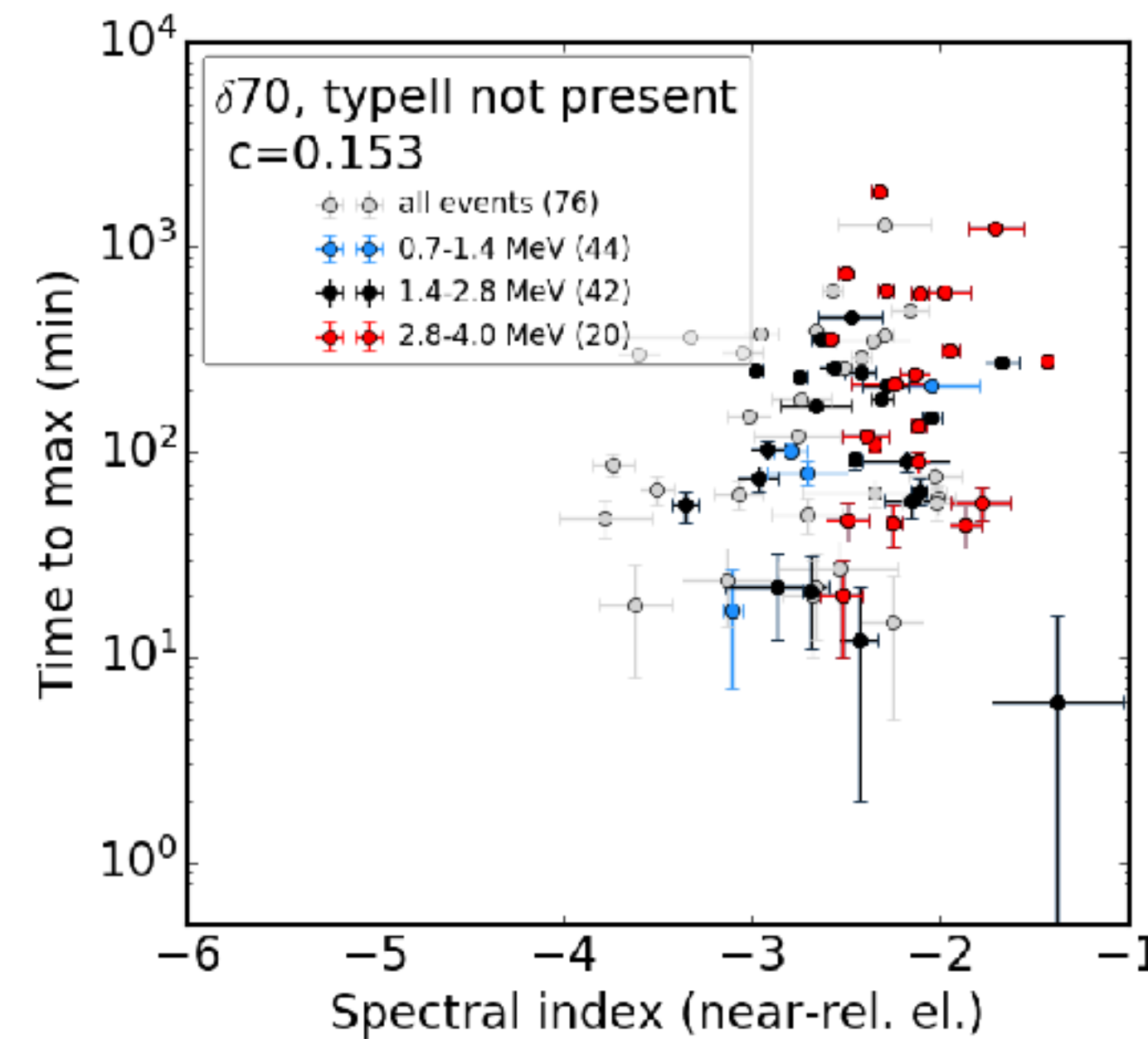


Rise Time and Spectral Index (+ MeV Electrons & Type II)

**!Subsample: associated to
>25 MeV proton events
Richardson et al. (2014)**

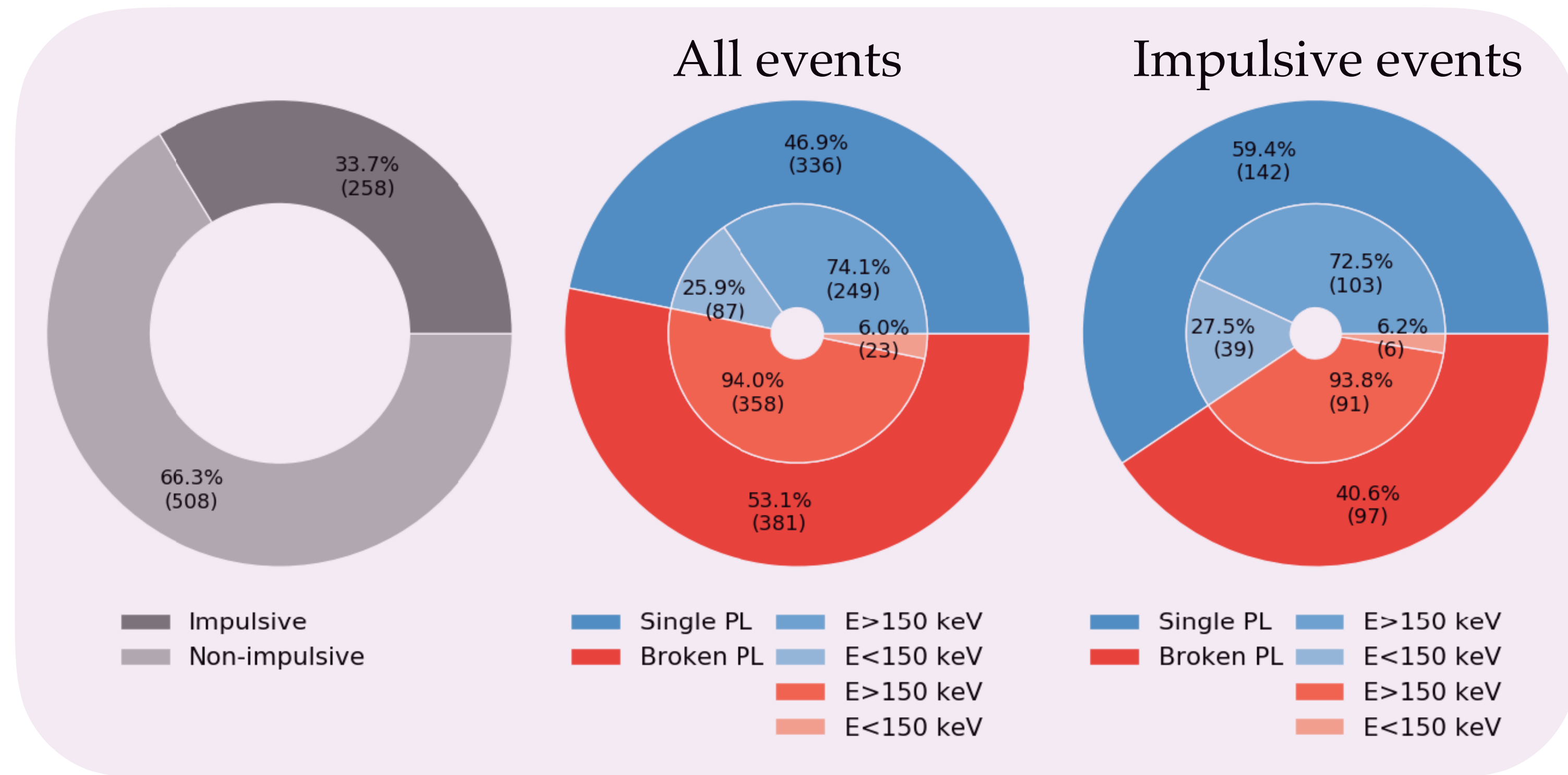
No clear difference
between events with/
without type II burst

However, the largest SEPT
peak intensities are
observed on the 'type II
side'



Summary

- Statistical study of near-relativistic electron spectra observed over 11 years with STEREO/SEPT
- 766 events



Dresing et al. (2019), in preparation

- Rise times show a solar cycle effect
- Only one third of the events show impulsive rise times
- Correlation between spectral index, rise time, and presence of MeV electrons suggests a **different acceleration process to be present for the gradual hard-spectra events**