CONNECTING SOLAR FLARE HARD X-RAY SPECTRA TO IN-SITU ELECTRON SPECTRA USING RHESSI AND STEREO/SEPT OBSERVATIONS

N. Dresing,
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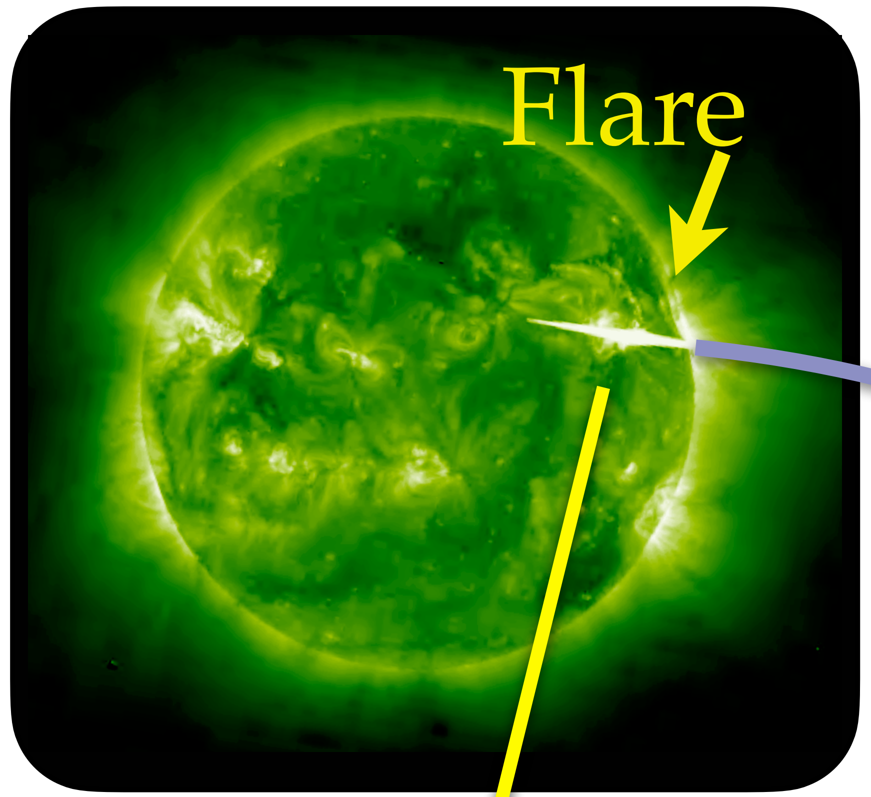
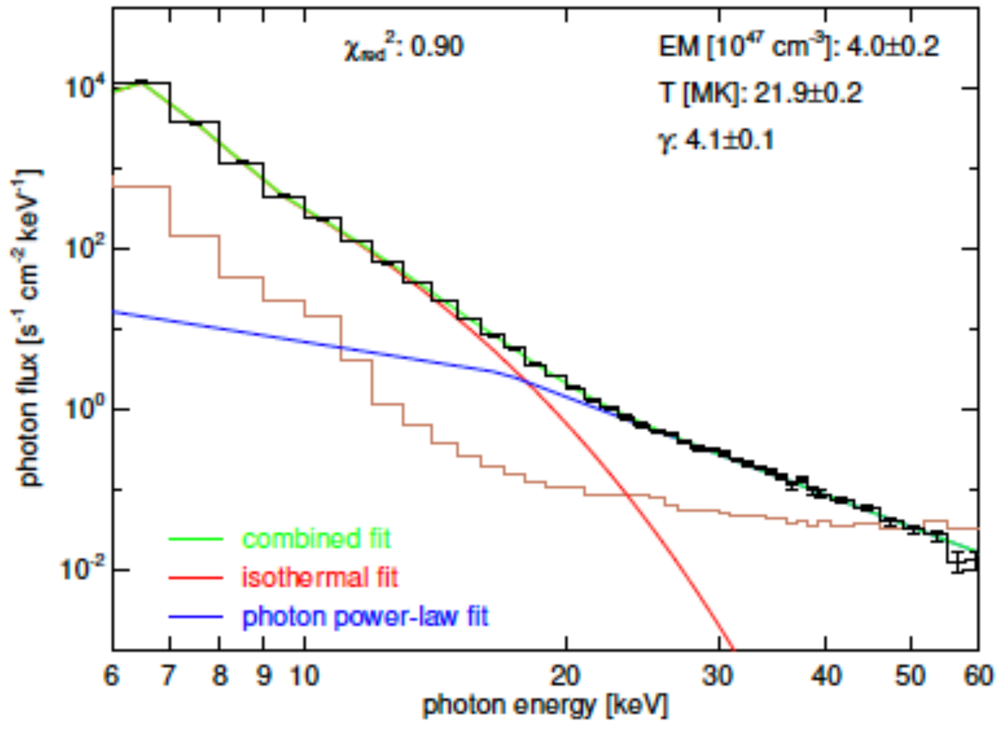


Energetic electrons

Hard X-Rays

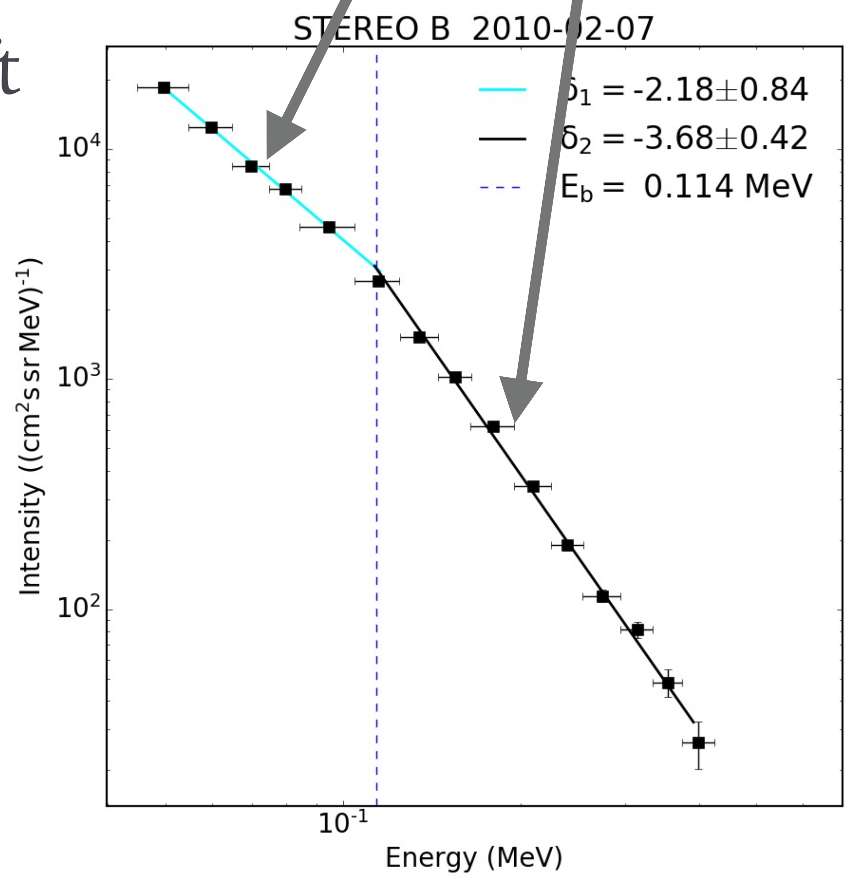
RHESSI spacecraft



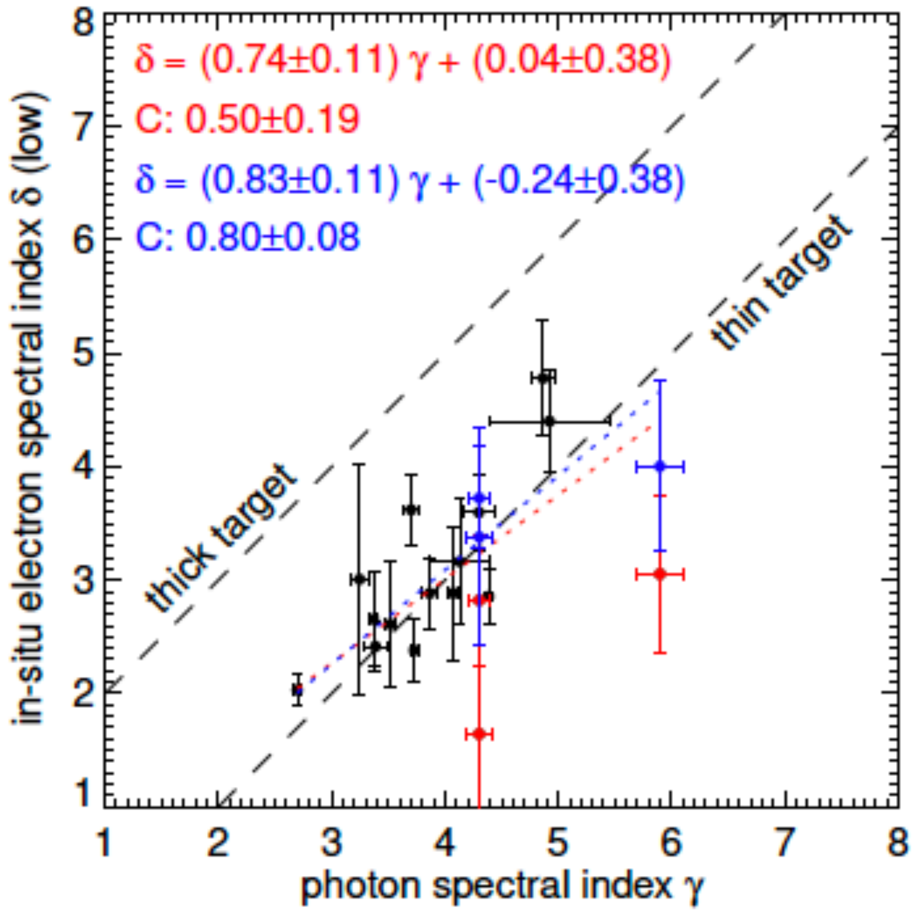
STEREO spacecraft

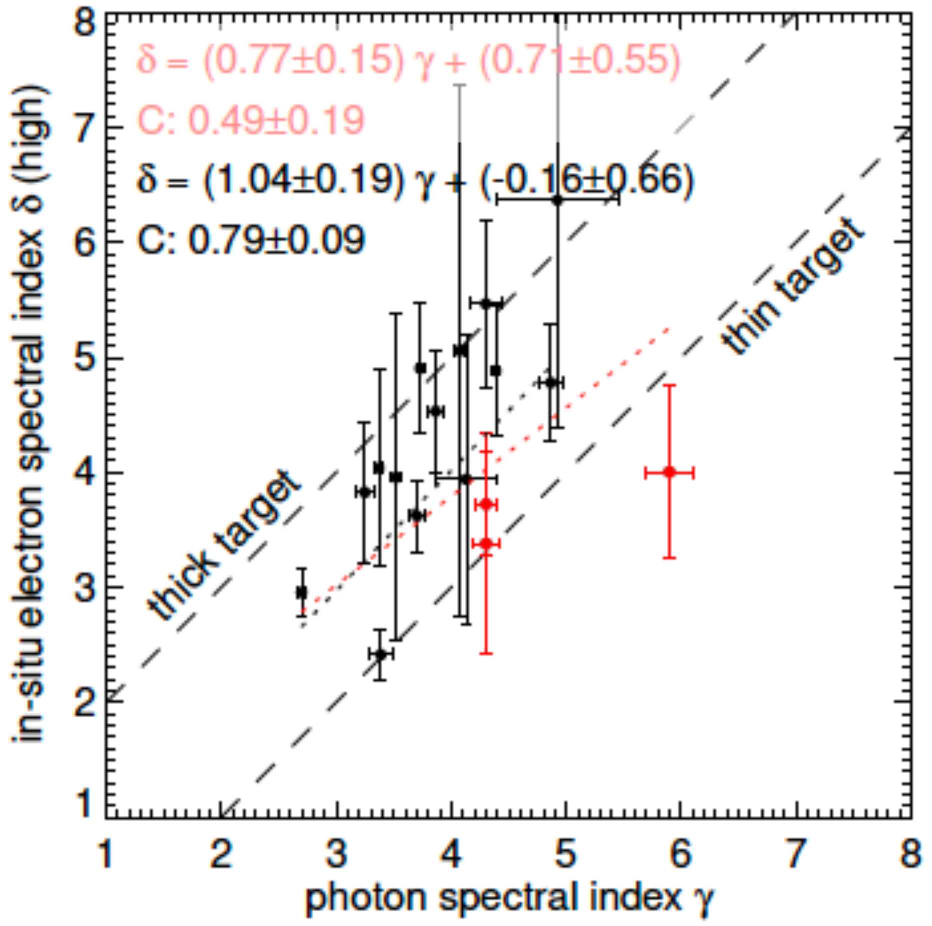
We analyze 17 common events for spectral correlations

Which part of the in-situ spectrum should be used for correlation?



- Despite the frequent presence of CMEs and the observed electron onsets delays we find good correlations **of c=0.8 (δ_{low}) and c=0.79 (δ_{high})** for both parts of the double power law spectra
- However, a careful choice of the correct in-situ spectral index is required
- We find an improved correlation for events with significant anisotropy





UNIVERSITY OF TURKU

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N. Dresing[1,7], A. Warmuth[2], F. Effenberger[3,4], K.-L. Klein[5], S. Musset[6], L. Glesener[6], M. Bruedern[7]

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2 Leibniz-Institut für Astrophysik Potsdam (AIP), Potsdam, Germany

3 Institut für Theoretische Physik, IV, Ruhr-Universität Bochum, 44780 Bochum, Germany

4 Bay Area Environmental Research Institute, CA, USA

5 LESIA – Observatoire de Paris, Univ. PSL, CNRS, Sorbonne Univ., Univ. de Paris, Meudon, France

6 University of Minnesota, Minneapolis, MN, USA

7 IEAP, University of Kiel, Germany

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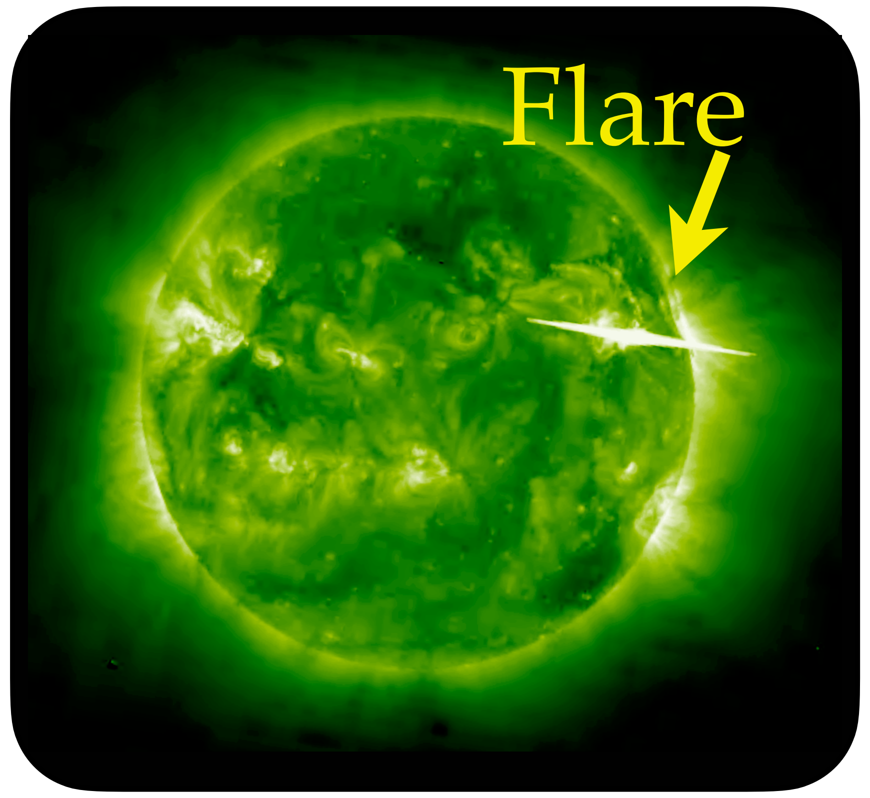
OUTLINE

- Motivation and data selection
- Potential modifications of the in-situ spectrum and the choice of the correct spectral part for comparison
- Correlation of photon and in-situ electron spectra
- Discussion & Summary

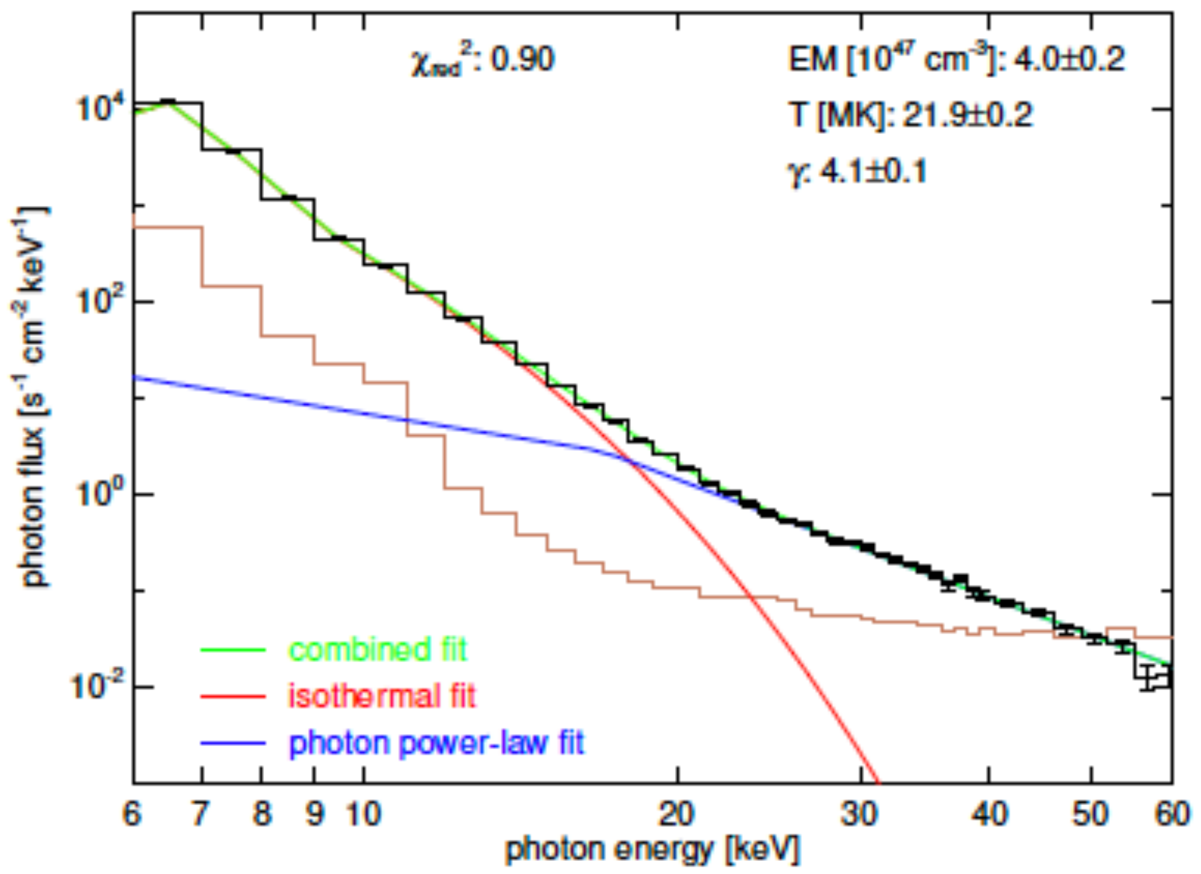
MOTIVATION AND DATA SELECTION



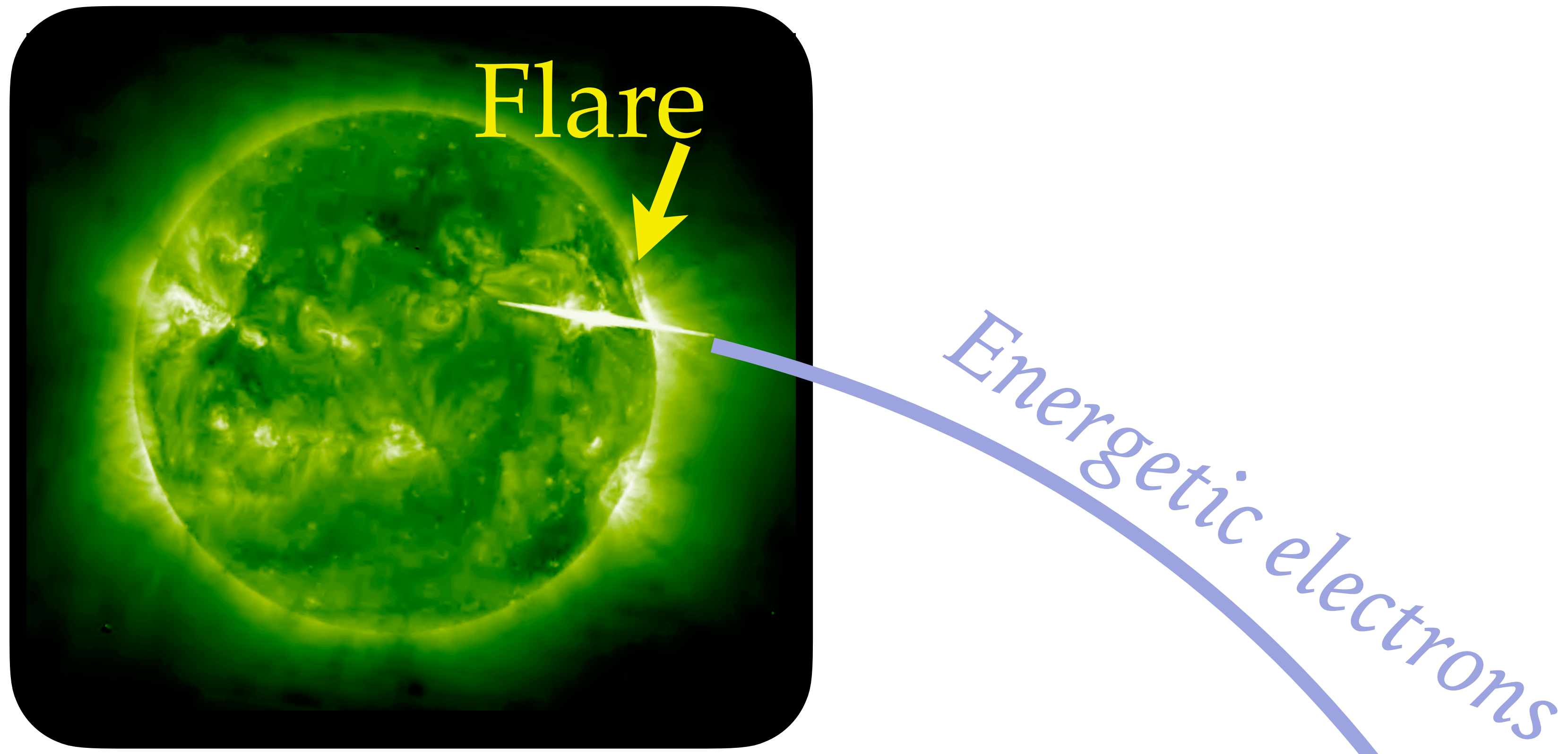
Hard X-Ray (HXR) flares are produced by energetic electrons that produce bremsstrahlung when precipitating onto the solar surface

Flares are therefore signatures of energetic particle acceleration

Hard X-Ray (HXR) spectrum observed by RHESSI



MOTIVATION AND DATA SELECTION



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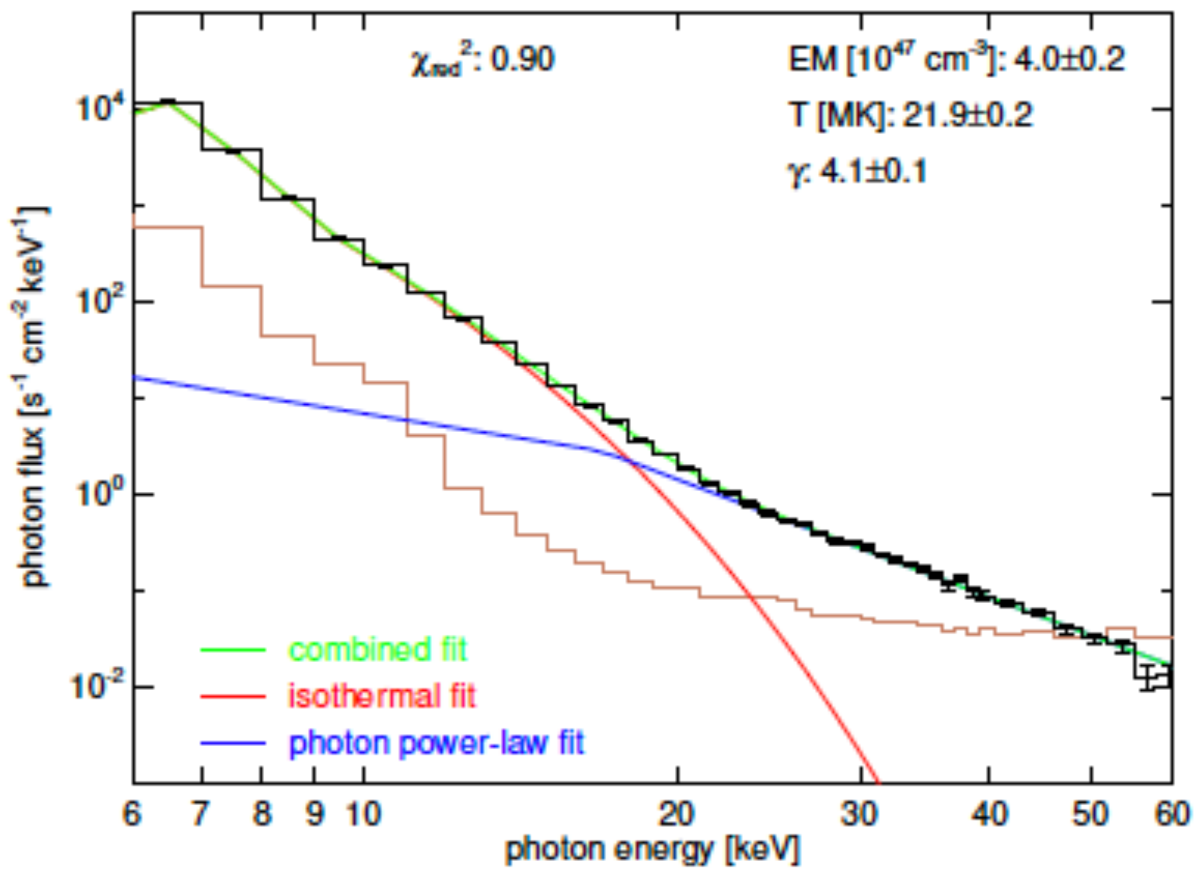

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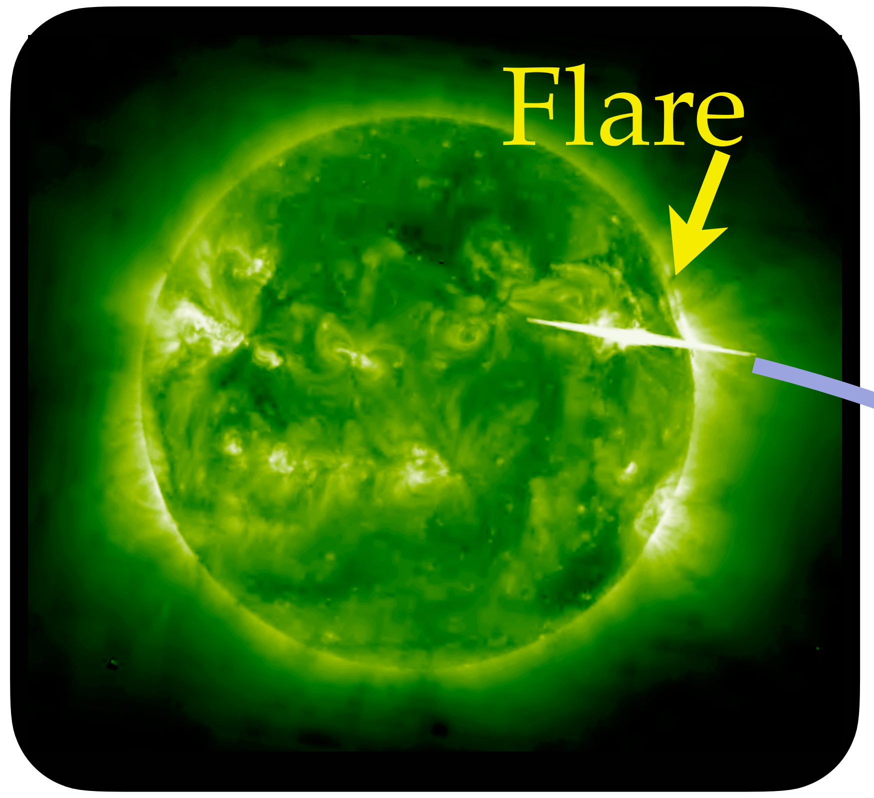
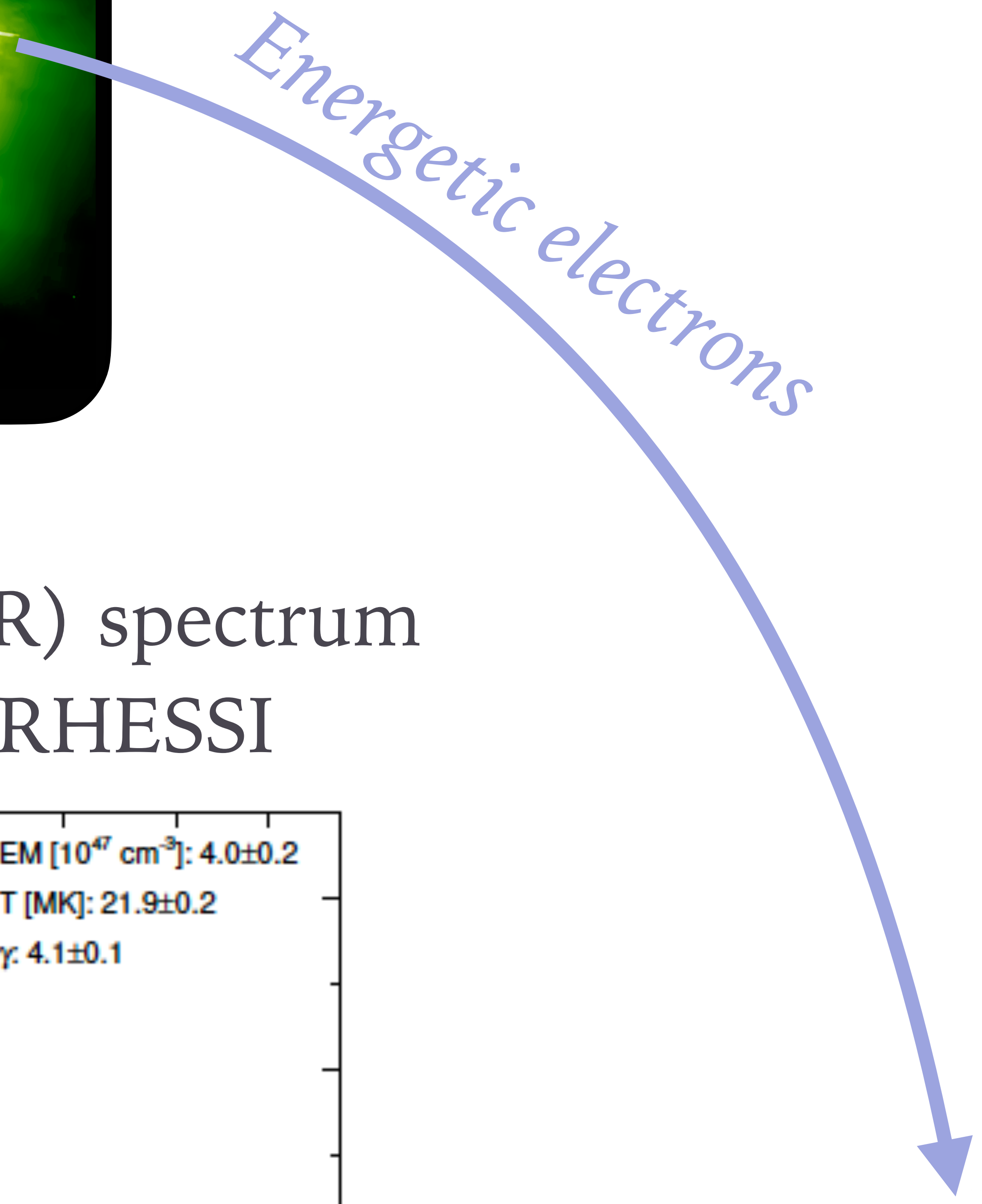
Part of this accelerated population can be injected into interplanetary space and can be measured as a Solar Energetic Particle (SEP) event at spacecraft

MOTIVATION AND DATA SELECTION





SEP events observed in-situ are a combination of acceleration, injection, and transport processes which are often hard to disentangle.

However, the energy spectrum of impulsive electron events is believed to carry the imprint of the flare acceleration process characterized by the HXR spectrum.

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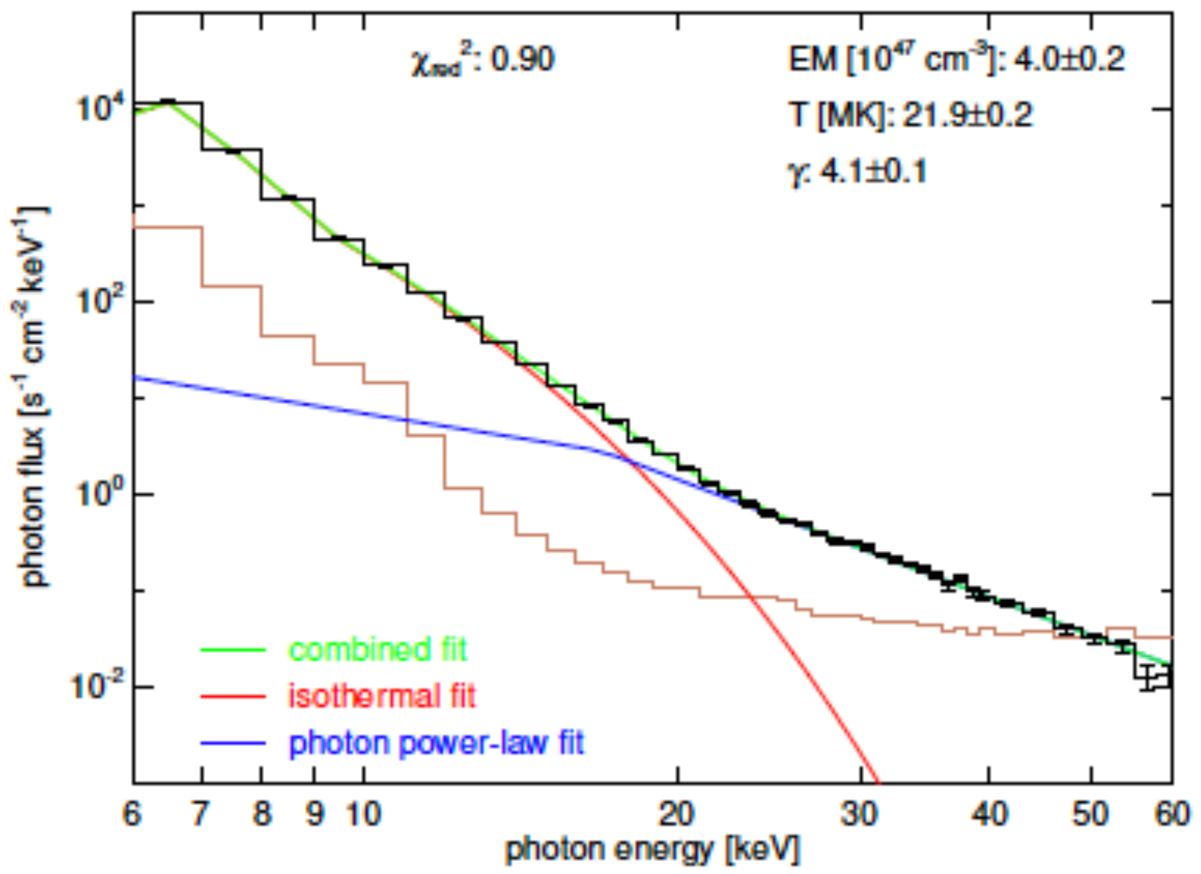

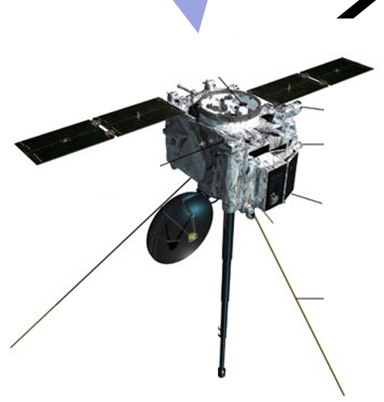

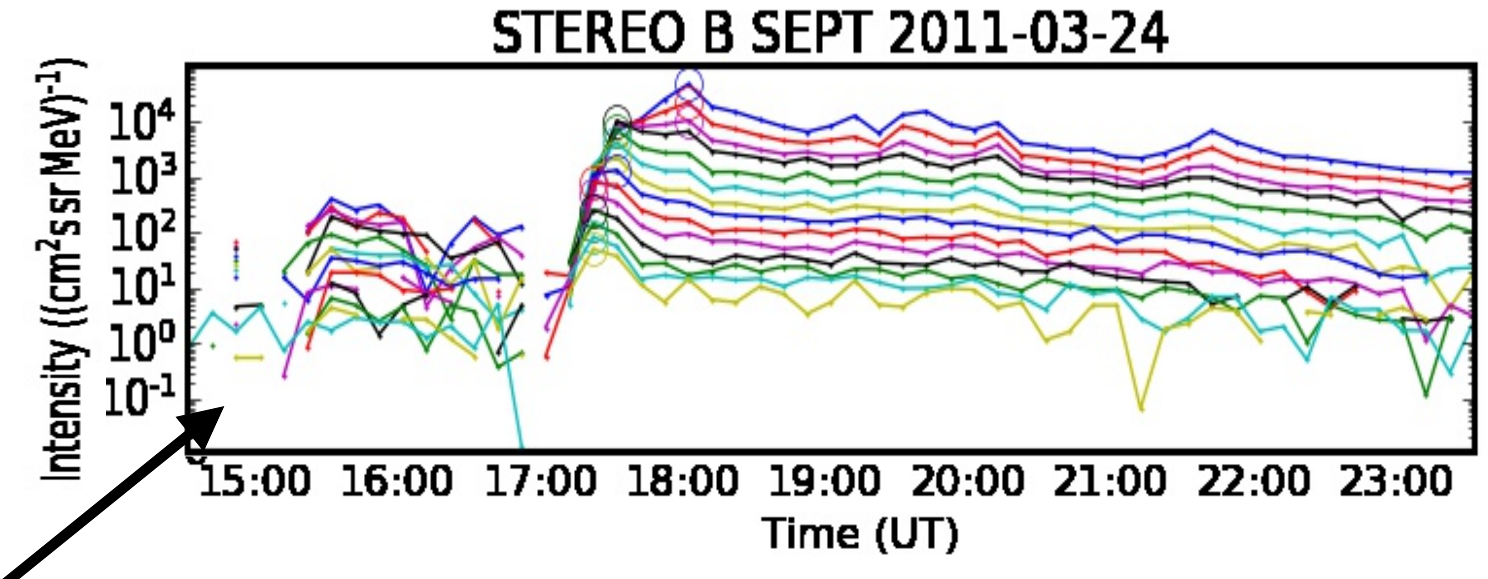

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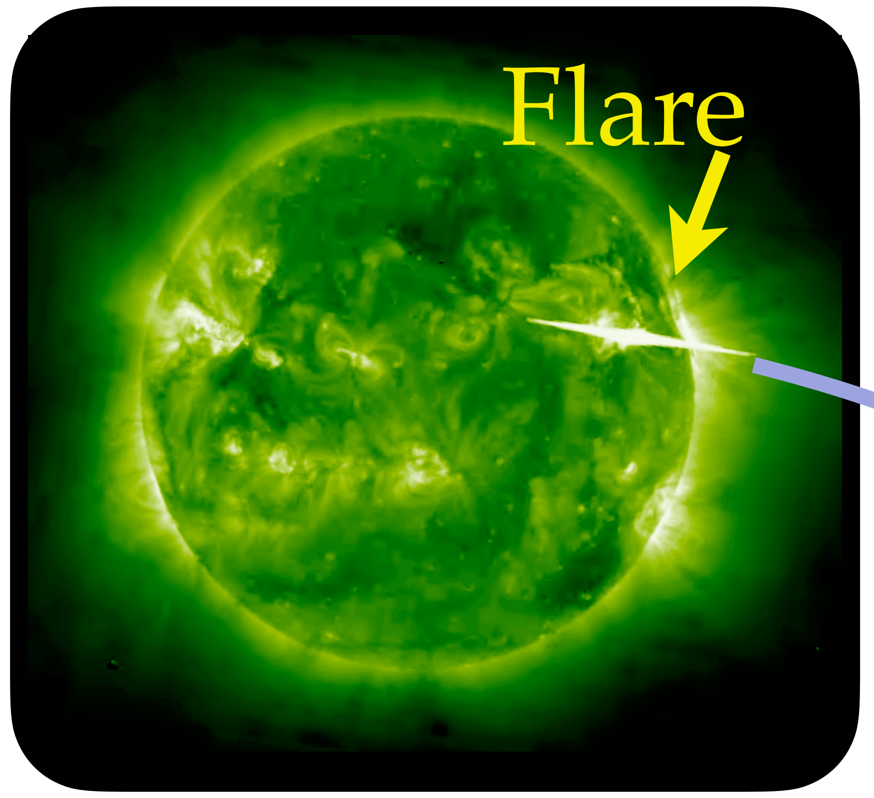

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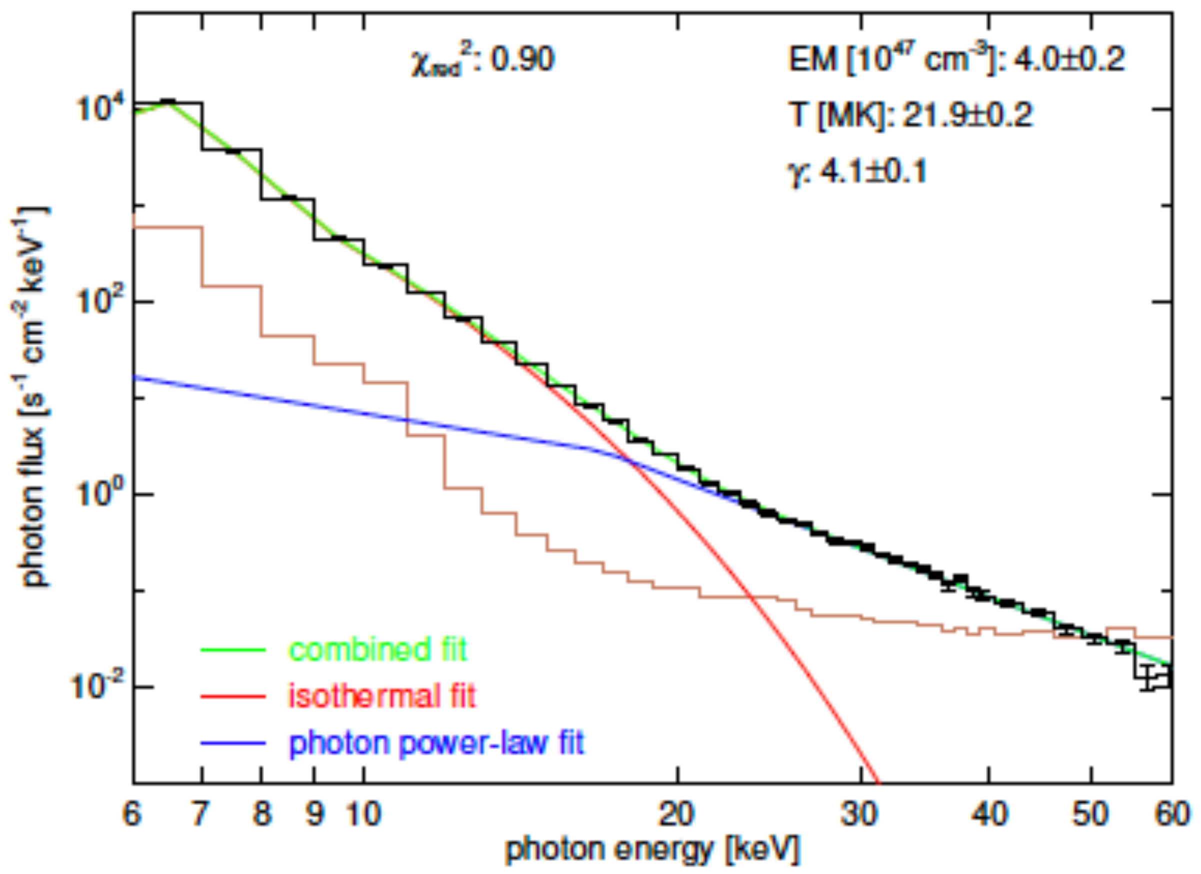

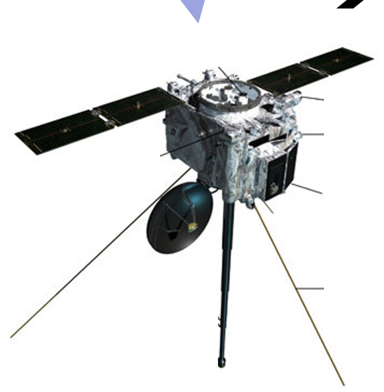

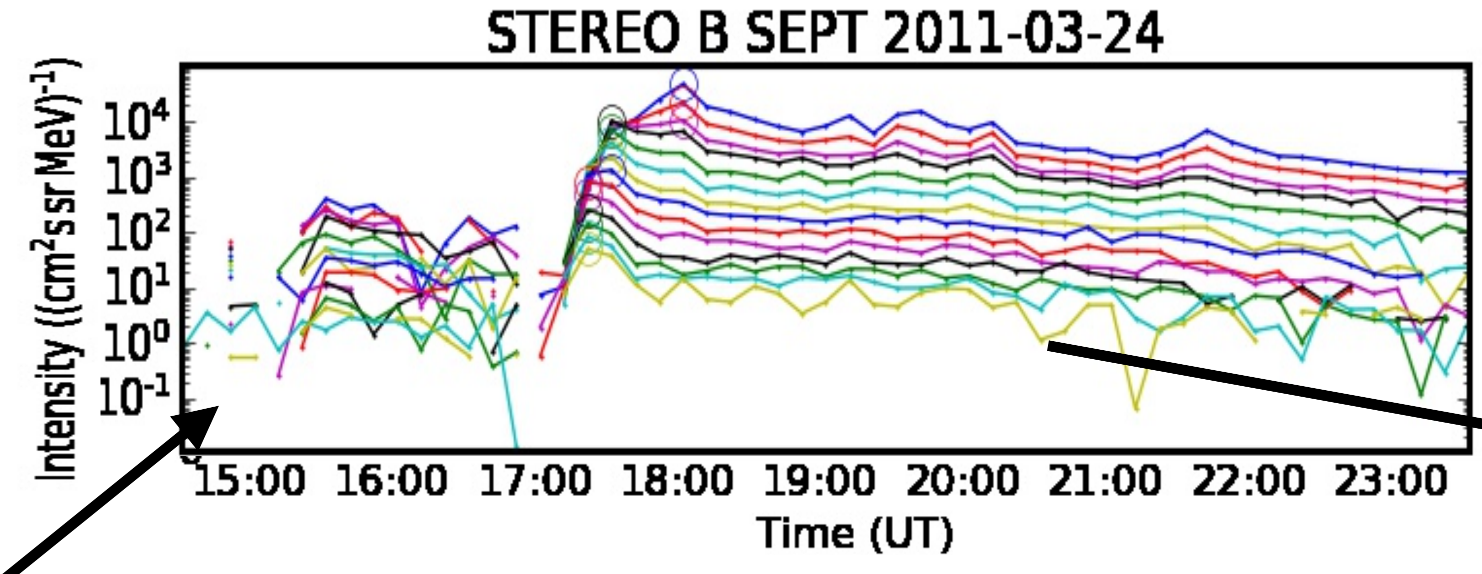

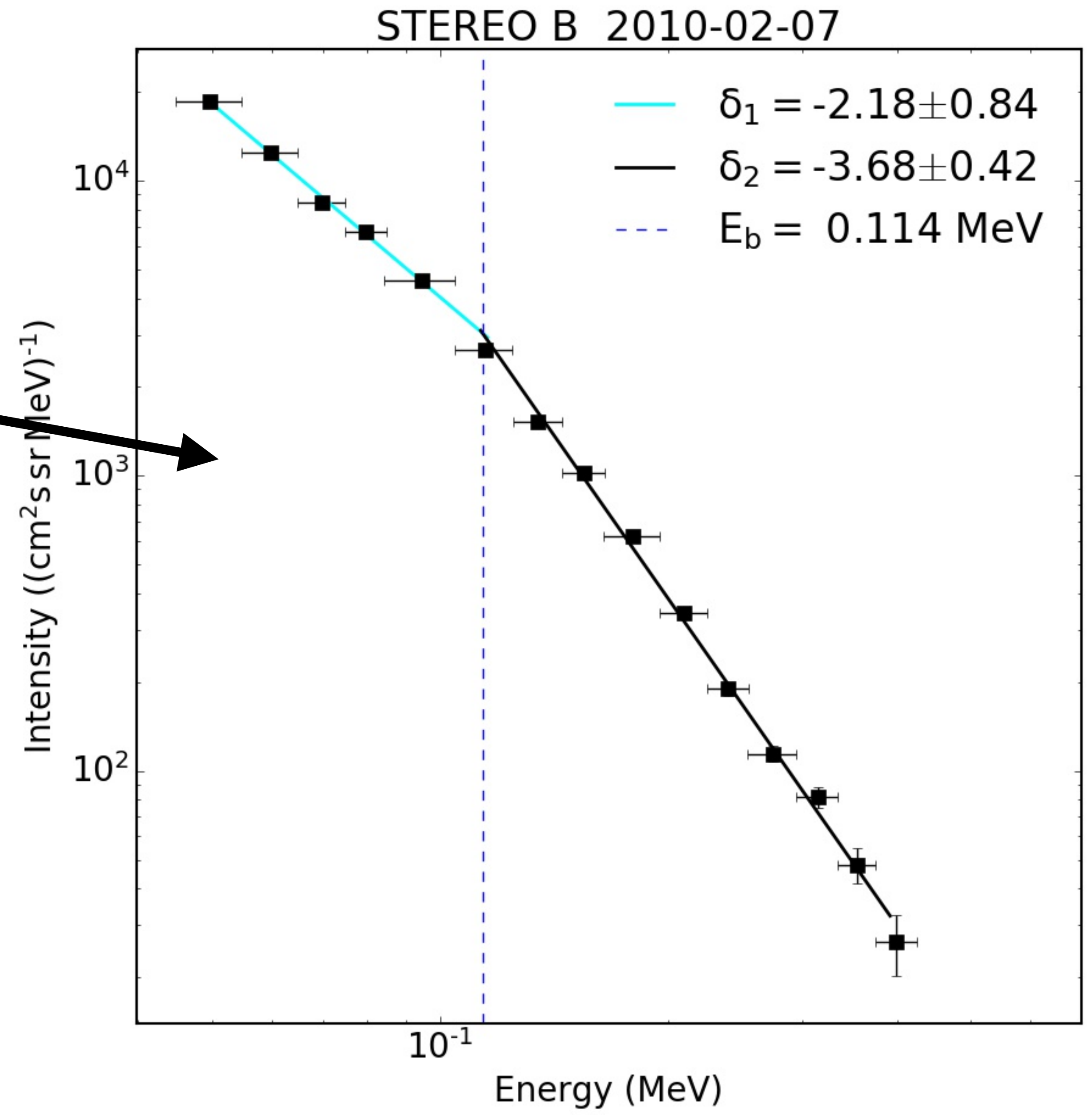

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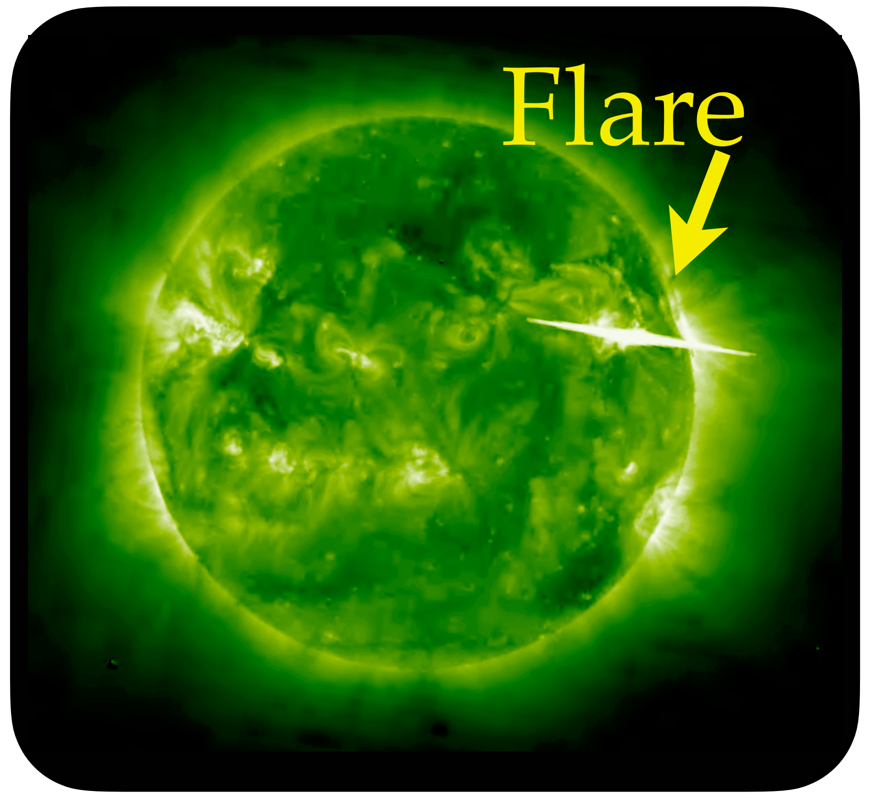
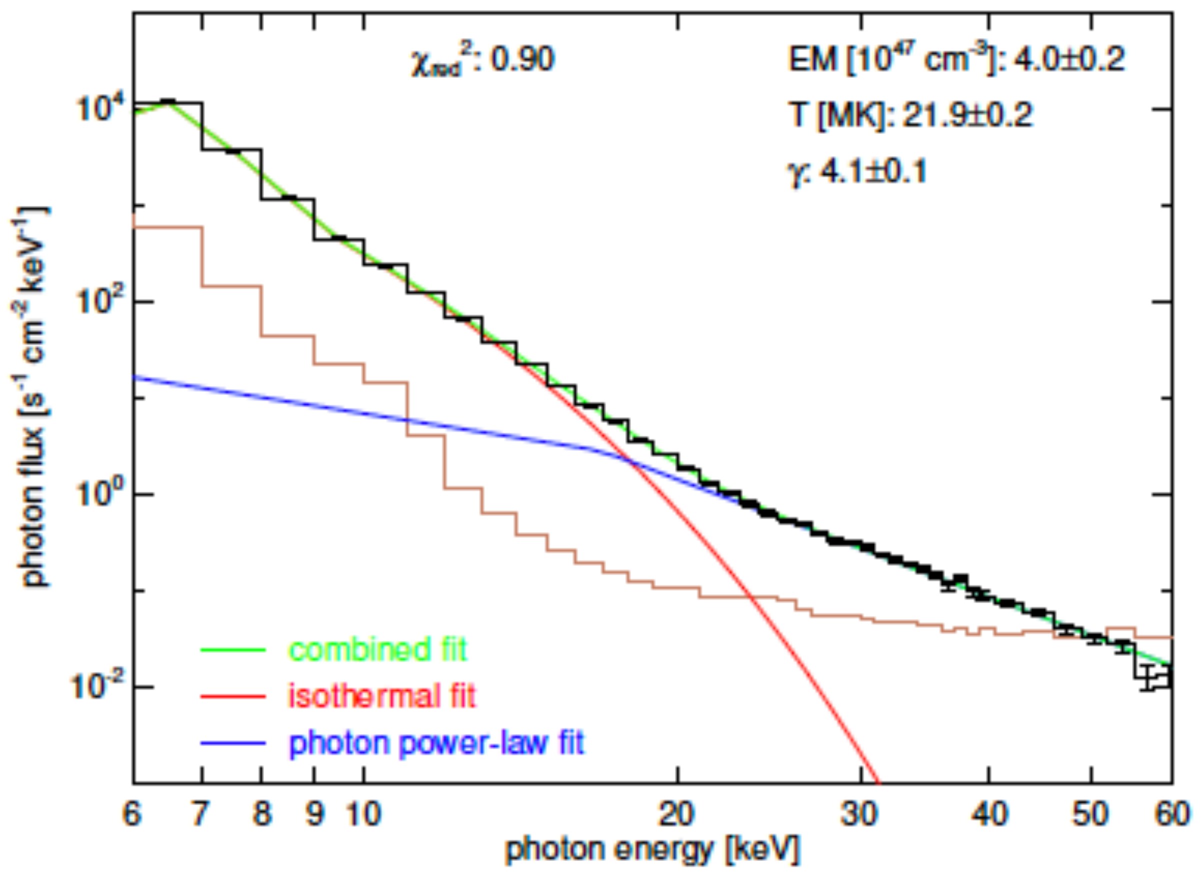
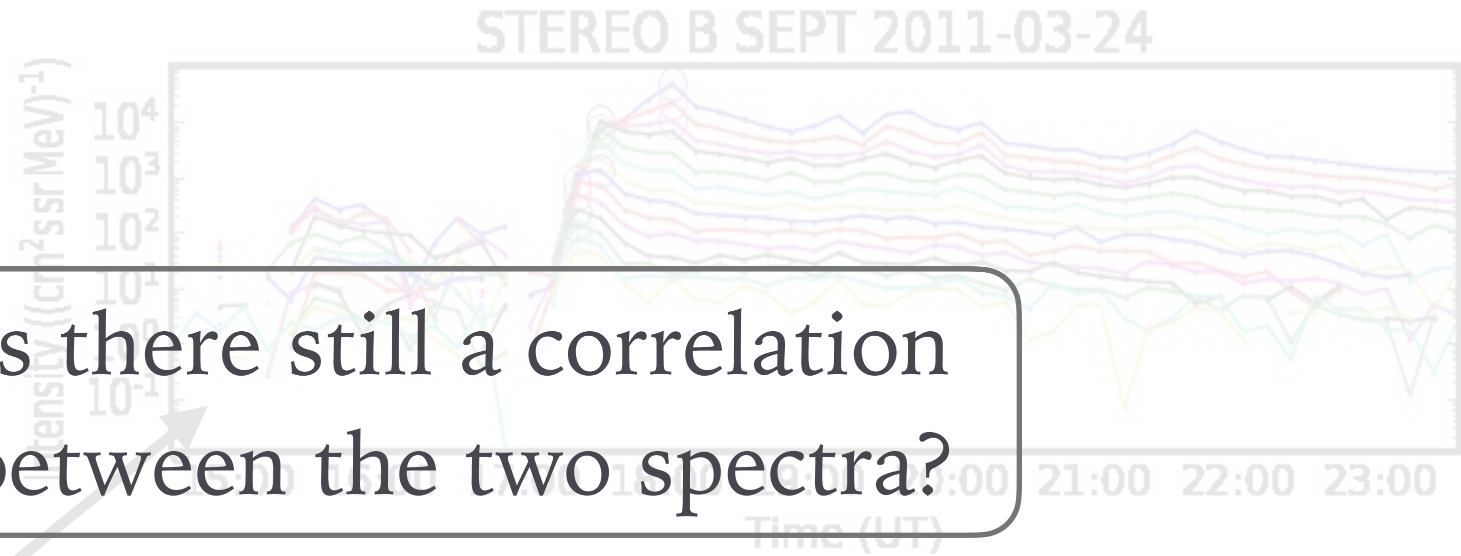


We aim to compare the flare HXR spectra with in-situ near-relativistic electron spectra which are assumed to represent the same accelerated electron population

However, near-relativistic electron spectra reveal often a double power law shape

Hard X-Ray (HXR) spectrum observed by RHESSI





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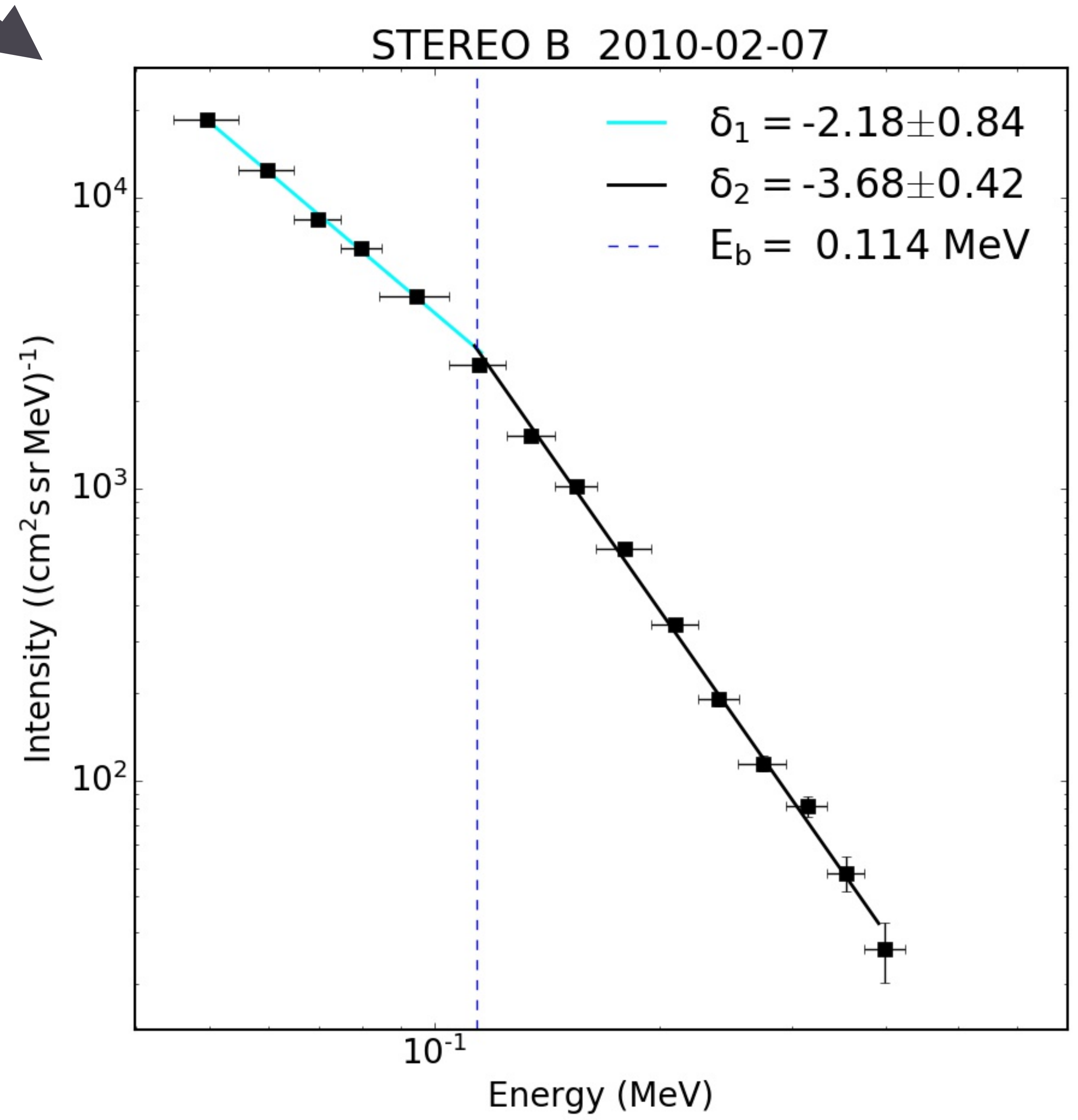
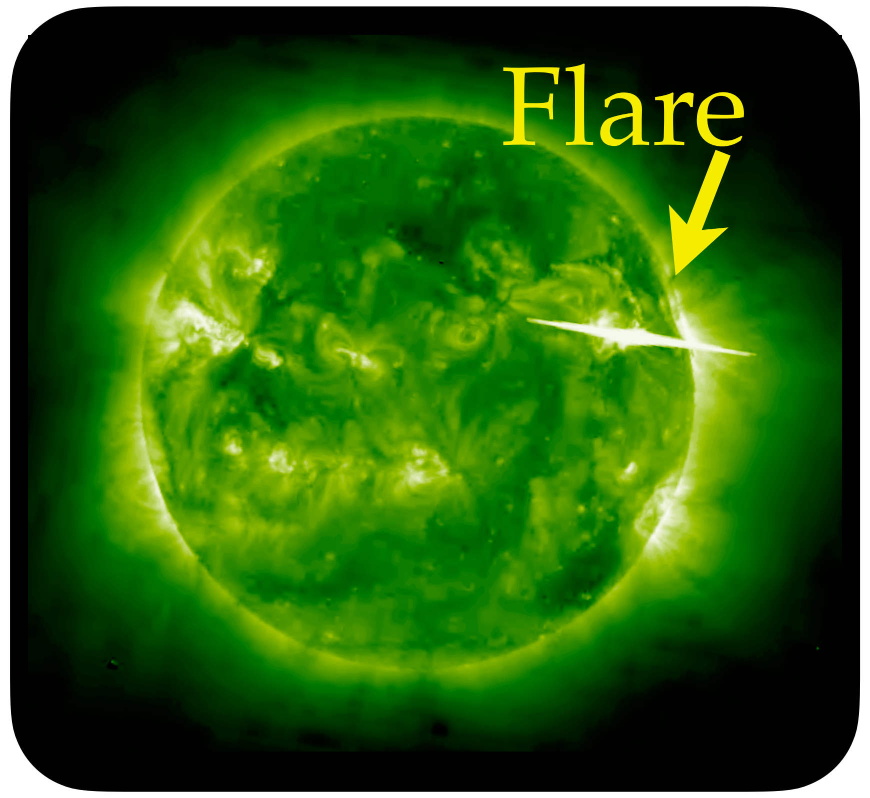


THE CHOICE OF THE CORRECT SPECTRAL PART OF THE IN-SITU SPECTRUM



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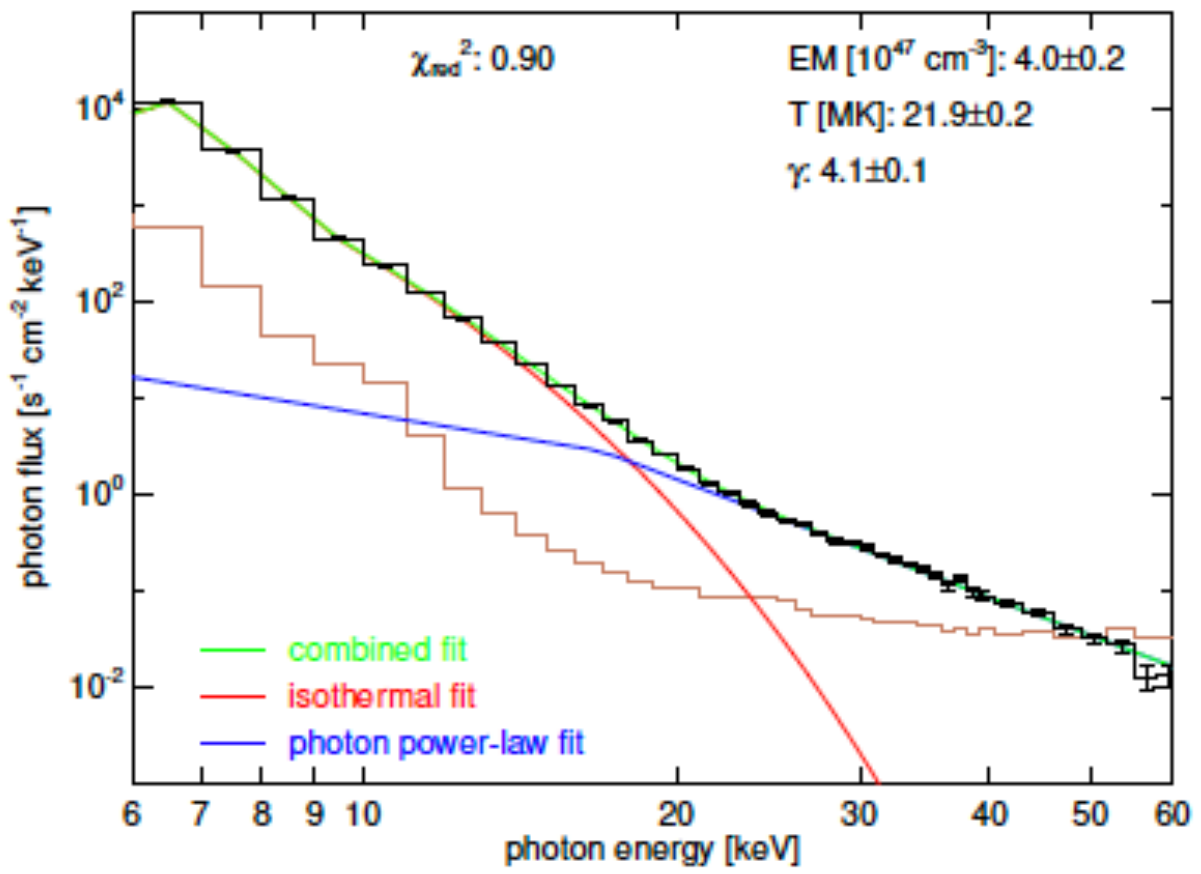

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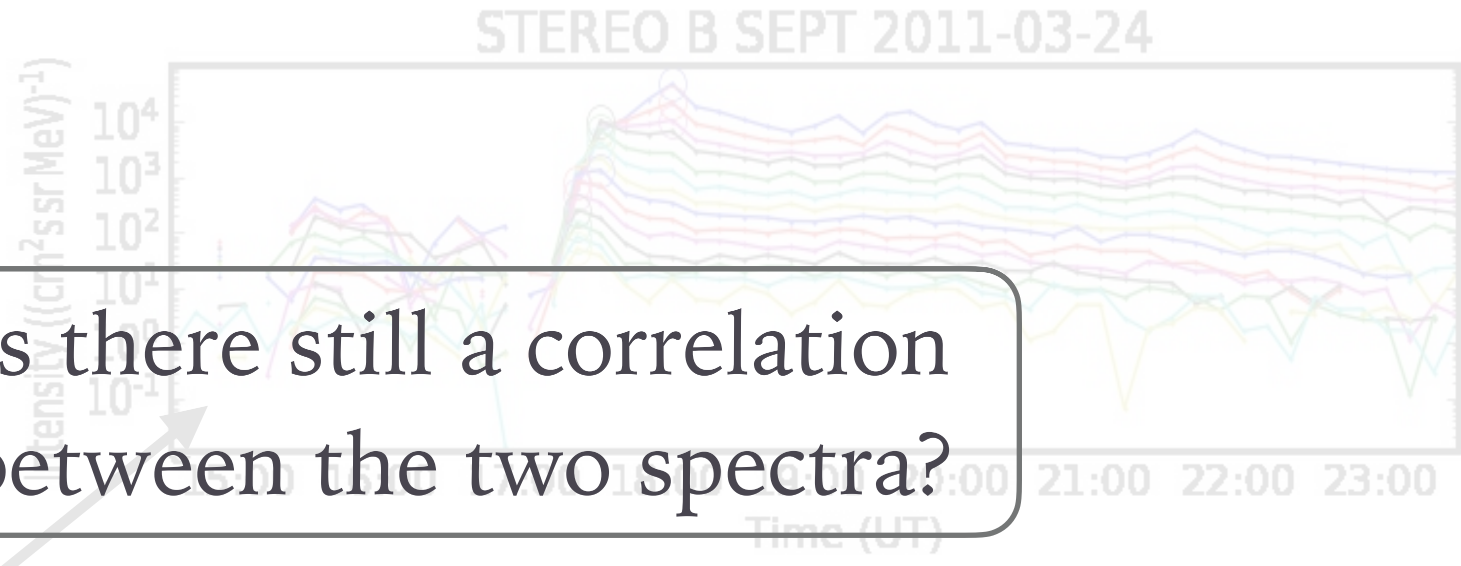

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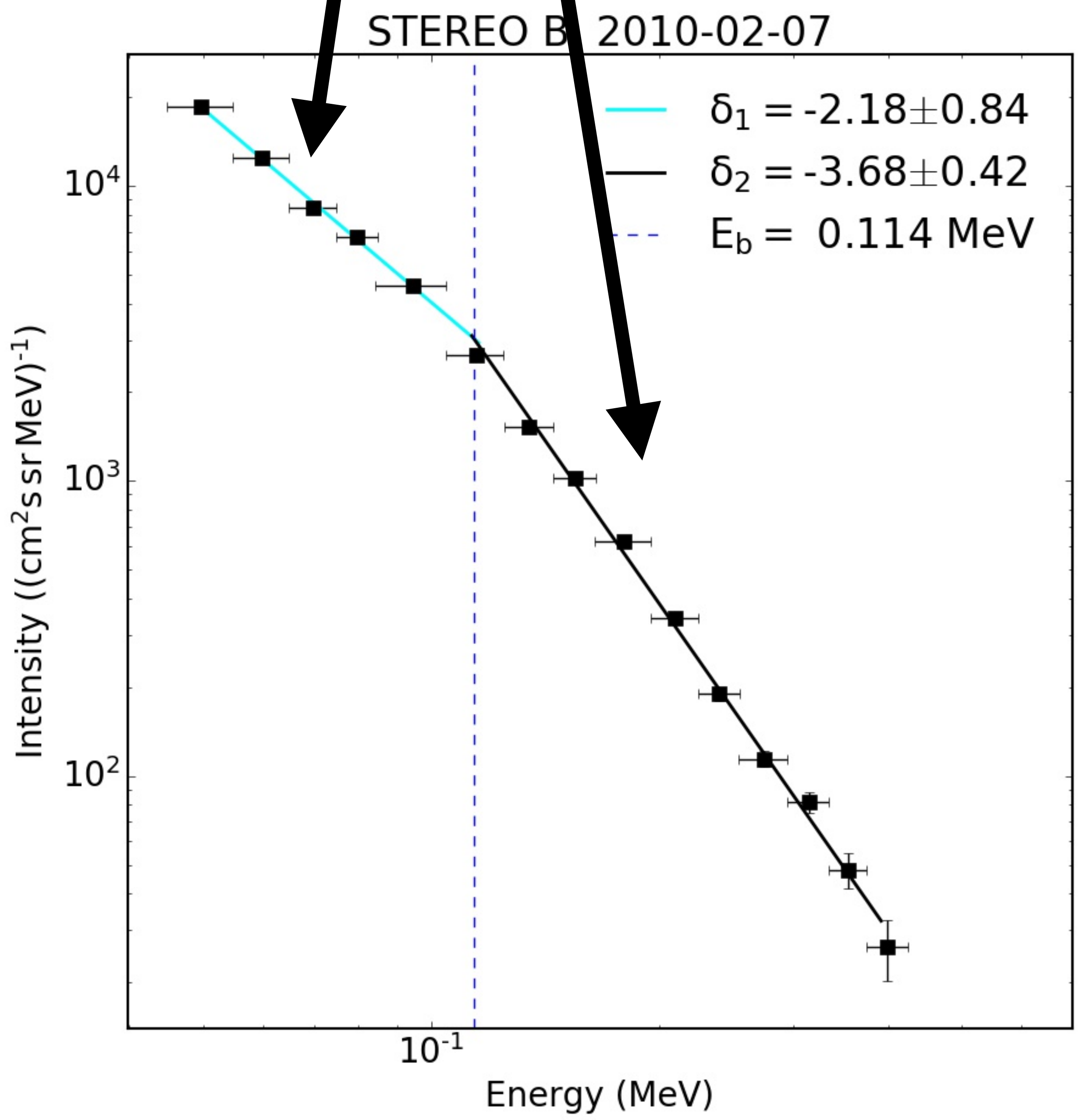

MODIFICATIONS OF THE ORIGINAL SPECTRUM

There are at least two potential transport-related processes that can cause spectral transitions:

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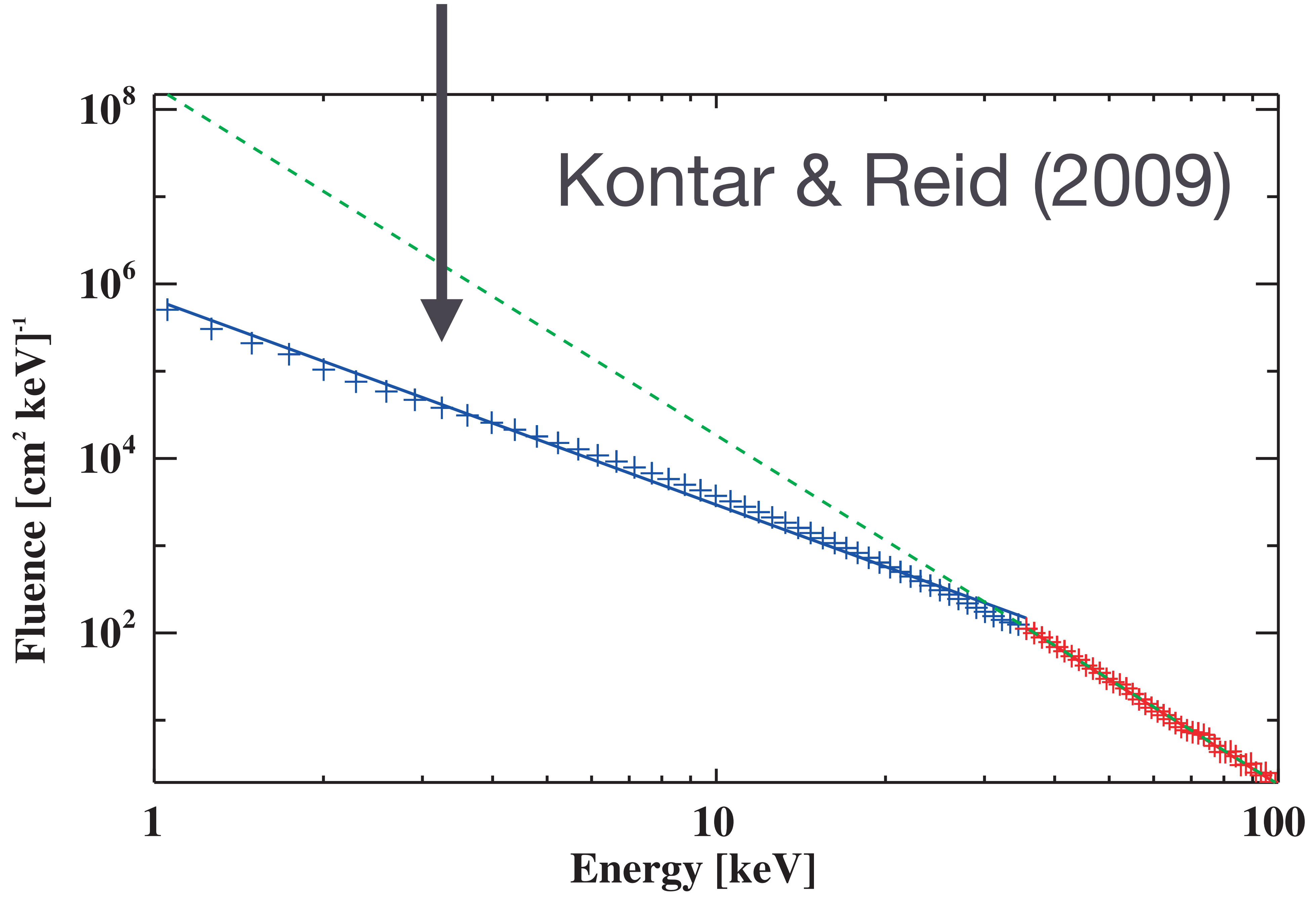

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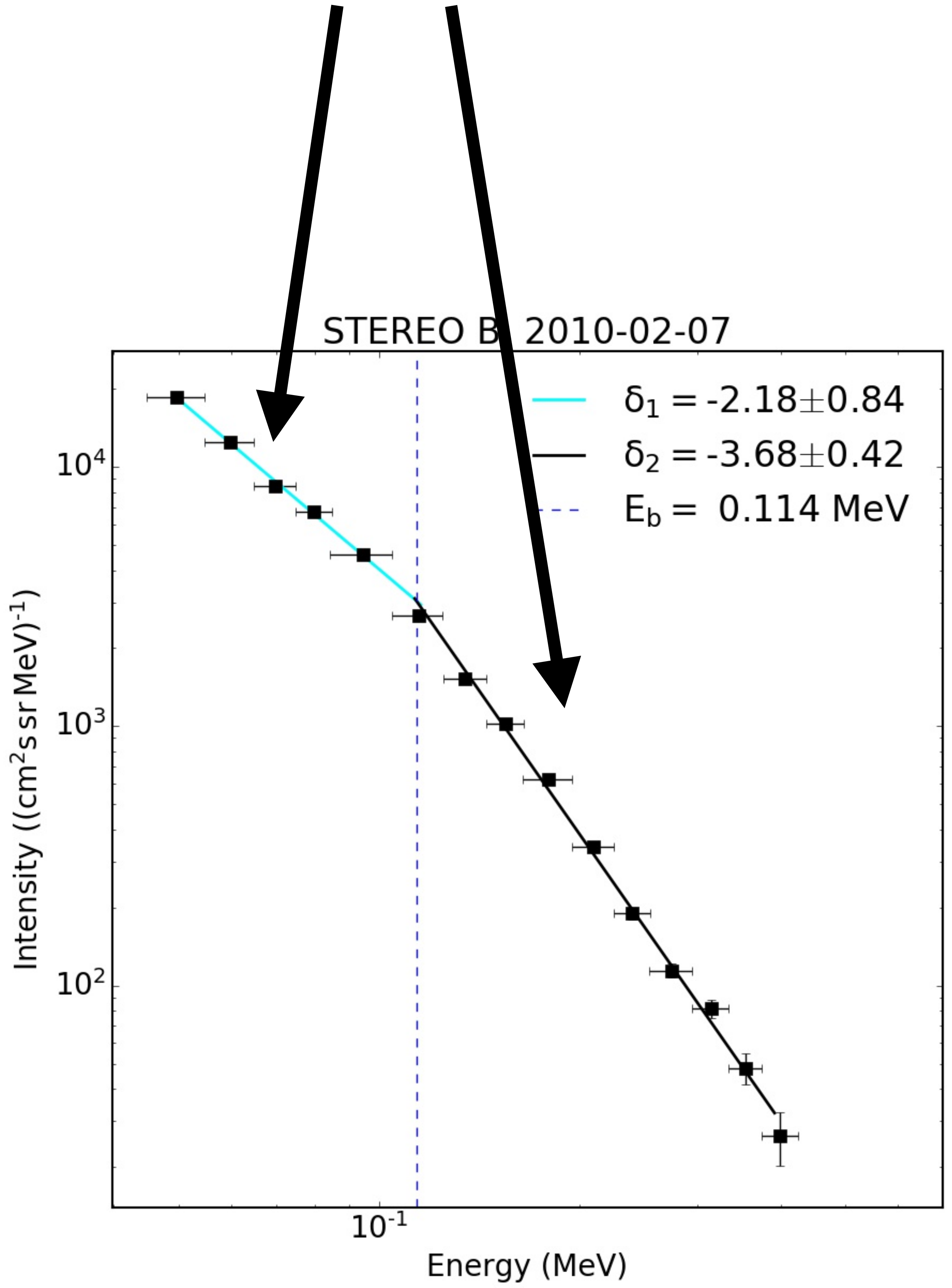

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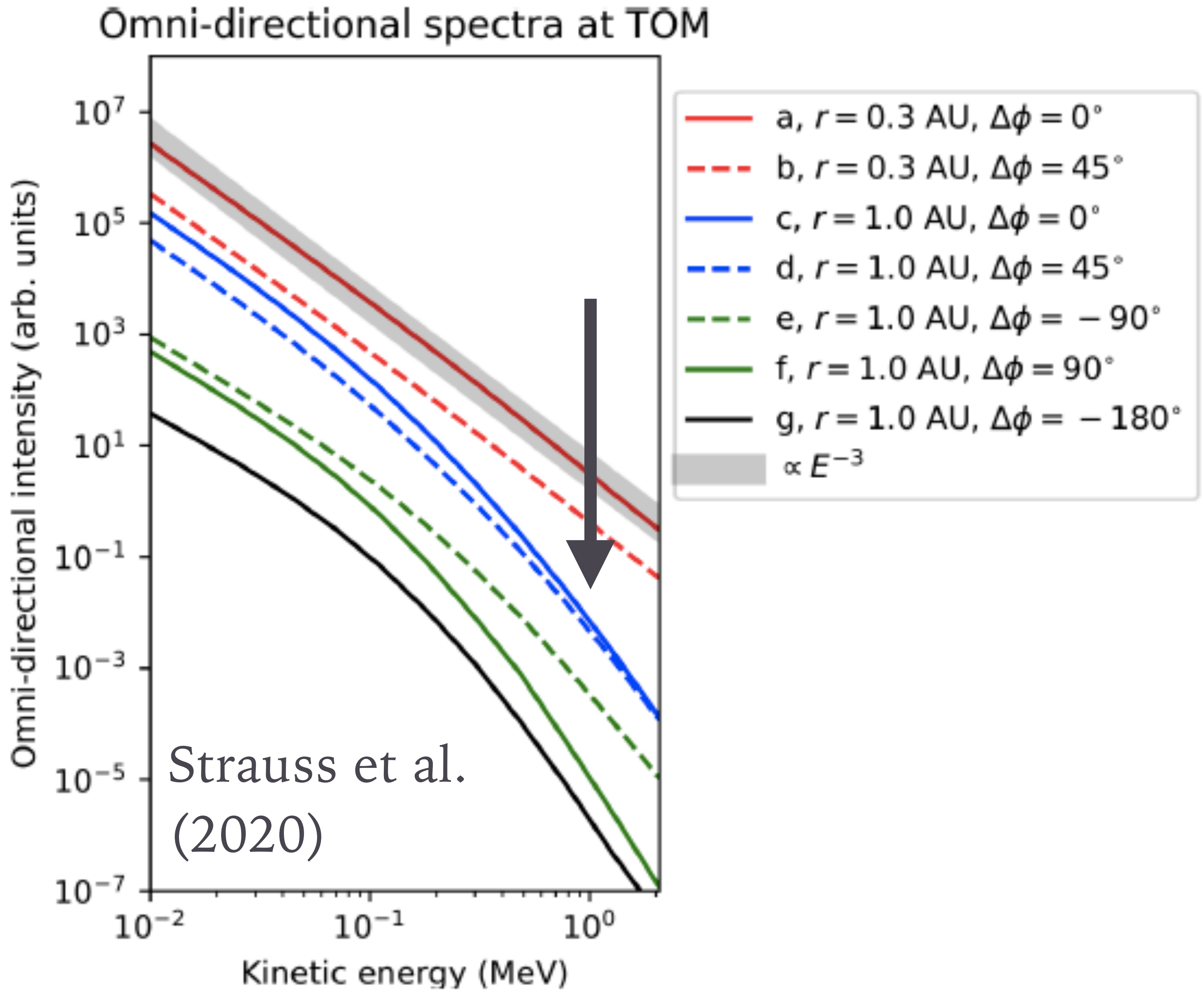

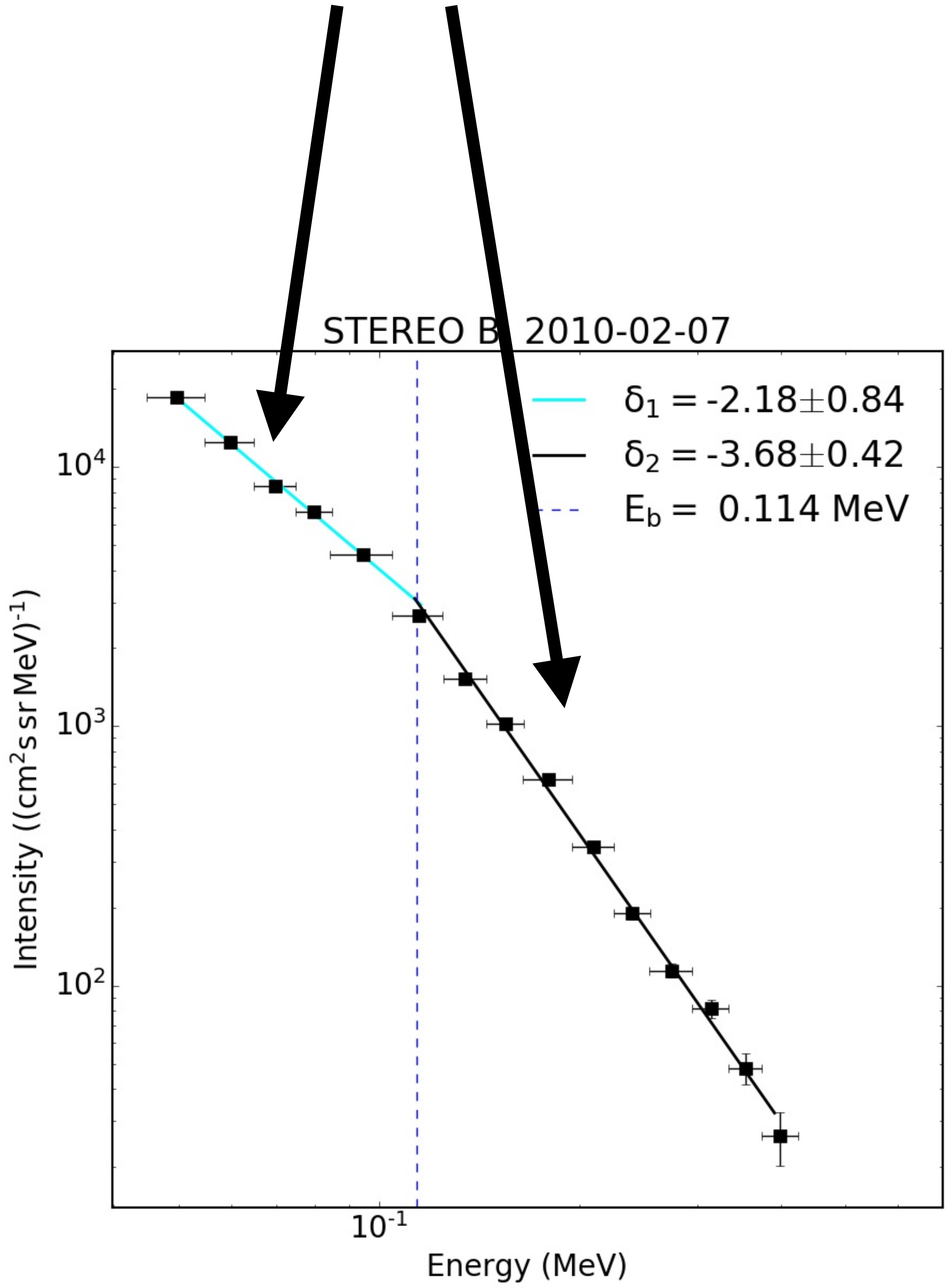

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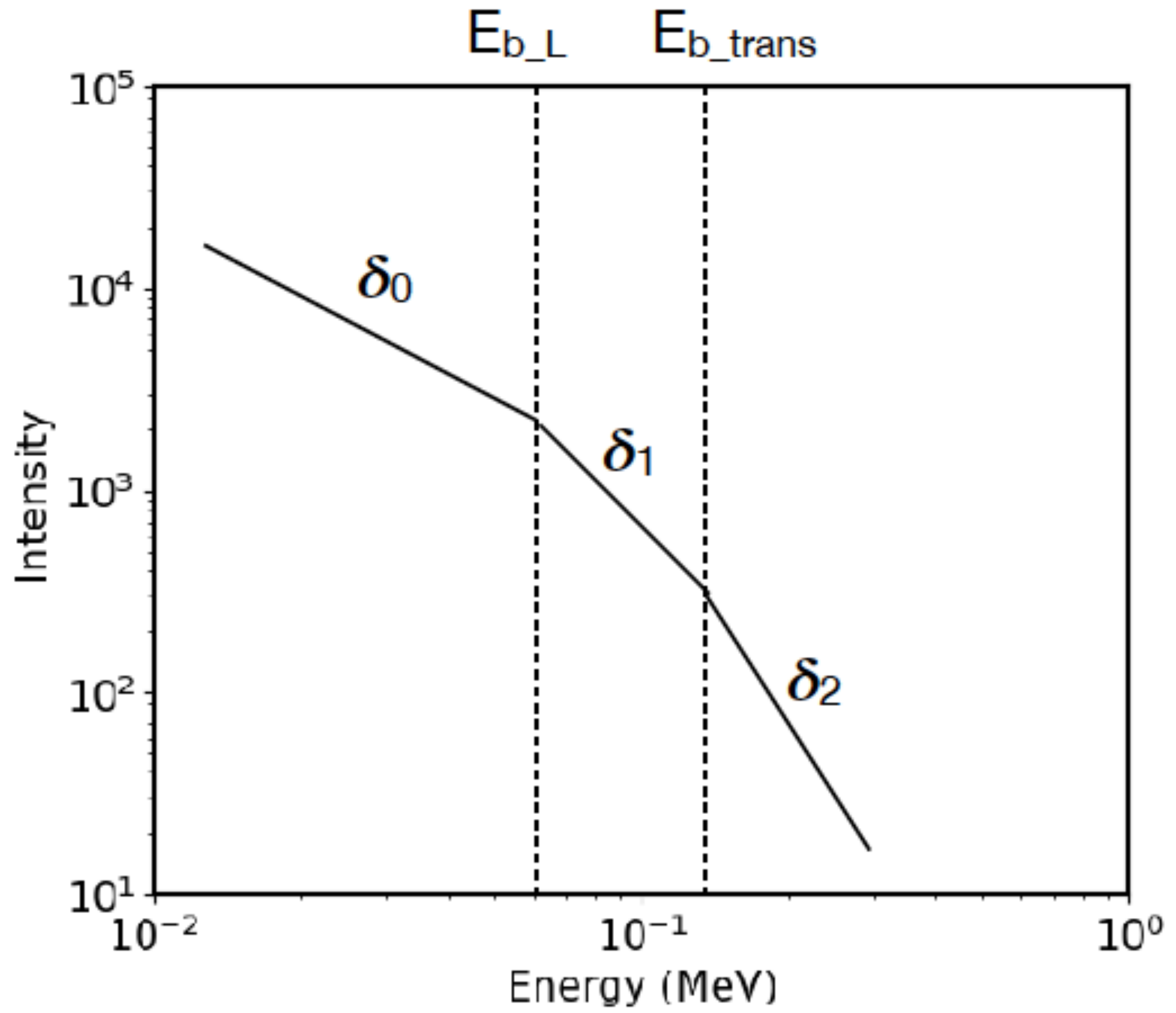
It is therefore possible that two different kinds of spectral breaks exist. These were not yet clearly resolved in a single spacecraft measurement and could also overlap.

However, the mean position of the spectral breaks found by Krucker et al. (2009) $E_b \approx 60$ keV and those found by Dresing et al. (2020) $E_b \approx 120$ keV differ significantly and are both in agreement with one each of the two potential processes.



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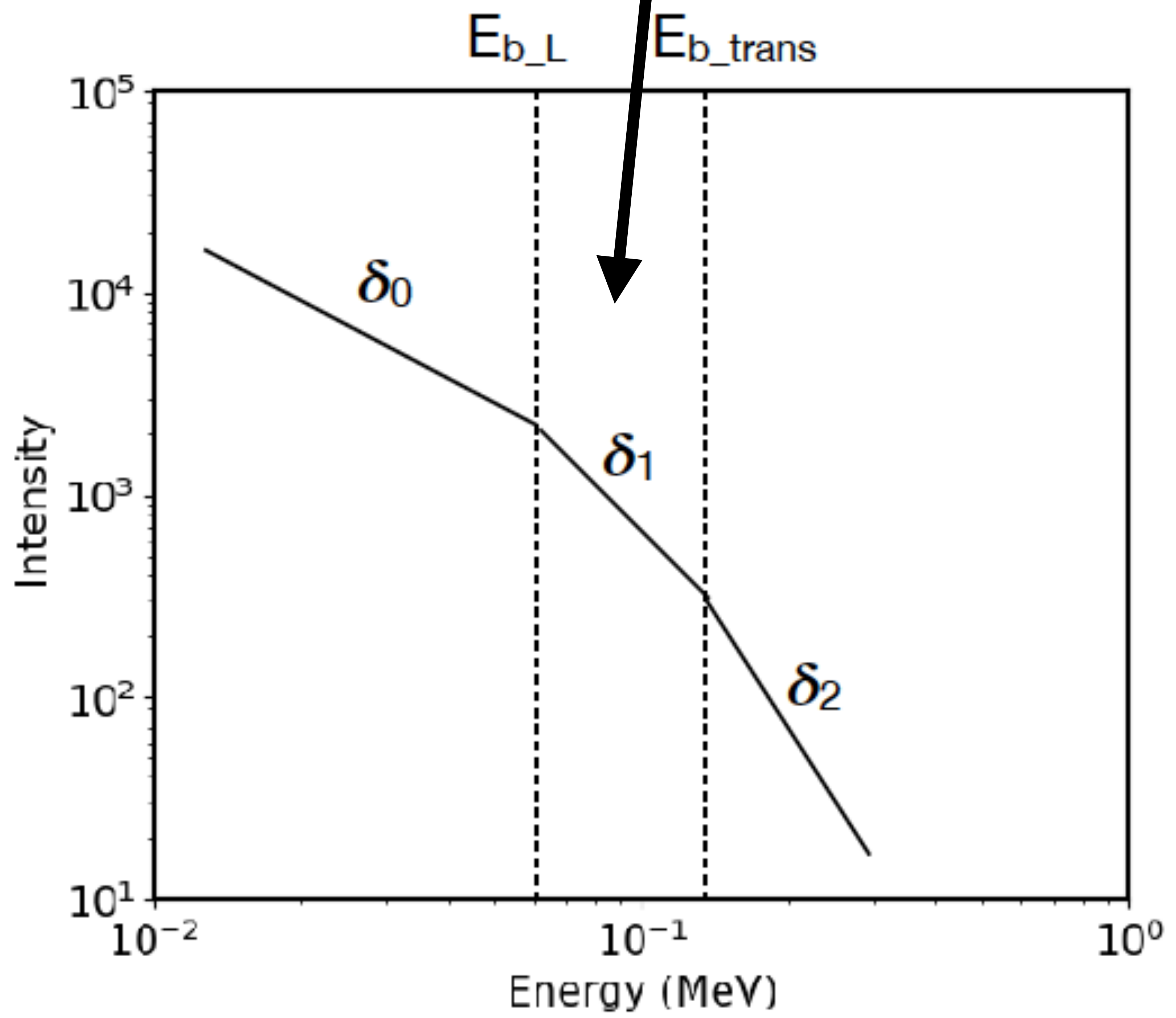
Strauss et al. (2020) therefore suggest to use the spectral range between ~50-100 keV as it might be least modified by transport effects



STEREO ELECTRON EVENTS WITH ASSOCIATED RHESSI HXR FLARE OBSERVATIONS

Using RHESSI HXR flare observations and STEREO/SEPT near-relativistic electron observations between 2007 and 2018 we find 17 common events which allow for a spectral comparison

Preliminary

HXR peak time	GOES class	flare location	γ	δ_1	δ_2	E_b [keV]	s/c
00:31:24	B5.1	S05W61	3.2 ± 0.09	3.0 ± 1.0	3.8 ± 0.6	79	A
00:31:24	B5.1	S05W61	3.2 ± 0.09	2.7 ± 1.0	3.6 ± 0.9	107	B
05:16:09	B6.8	S05W64	4.1 ± 0.26	3.6 ± 0.3	–	–	B
05:16:09	B6.8	S05W64	4.1 ± 0.26	3.2 ± 0.6	3.9 ± 1.3	98	A
04:56:10	C7.2	S28W47	2.7 ± 0.04	2.0 ± 0.1	3.0 ± 0.2	122	B
03:12:24	C6.2	N22E00	3.4 ± 0.10	2.4 ± 0.2	–	–	B
03:53:41	C1.0	S21E02	3.7 ± 0.06	3.6 ± 0.3	–	–	B
08:01:54	C1.5	S23W01	3.9 ± 0.08	2.9 ± 0.3	4.5 ± 0.5	118	B
04:36:44	B7.8	S34E21	4.3 ± 0.11	1.6 ± 1.7	3.4 ± 1.0	69	B
17:04:34	C9.1	S15E41	4.1 ± 0.05	2.9 ± 0.6	5.1 ± 2.3	195	B
00:51:58	C1.5	N21E20	4.9 ± 0.53	4.4 ± 0.4	6.4 ± 2.0	87	B
00:27:54	C3.0	N20E26	3.4 ± 0.03	2.7 ± 0.4	4.0 ± 0.9	110	B
00:26:14	C1.8	N13E89	4.9 ± 0.10	4.8 ± 0.5	–	–	B
03:21:58	C2.7	N13E67	4.4 ± 0.03	2.9 ± 0.2	4.9 ± 0.6	106	B
12:36:00	C3.4	N15E64	3.7 ± 0.03	2.4 ± 0.3	4.9 ± 0.6	90	B
02:12:24	C2.6	N17E56	4.3 ± 0.09	2.8 ± 0.6	3.7 ± 0.4	90	B
07:14:44	C5.4	N16E11	4.3 ± 0.14	3.6 ± 0.3	5.5 ± 0.7	104	B
16:26:14	C3.3	S12E81	5.9 ± 0.20	3.1 ± 0.7	4.0 ± 0.7	101	B
17:05:04	C8.8	S19E90	3.5 ± 0.05	2.6 ± 0.5	4.0 ± 1.4	90	B

Strauss et al. (2020) therefore suggest to use the spectral range between ~50-100 keV as it might be least modified by transport effects

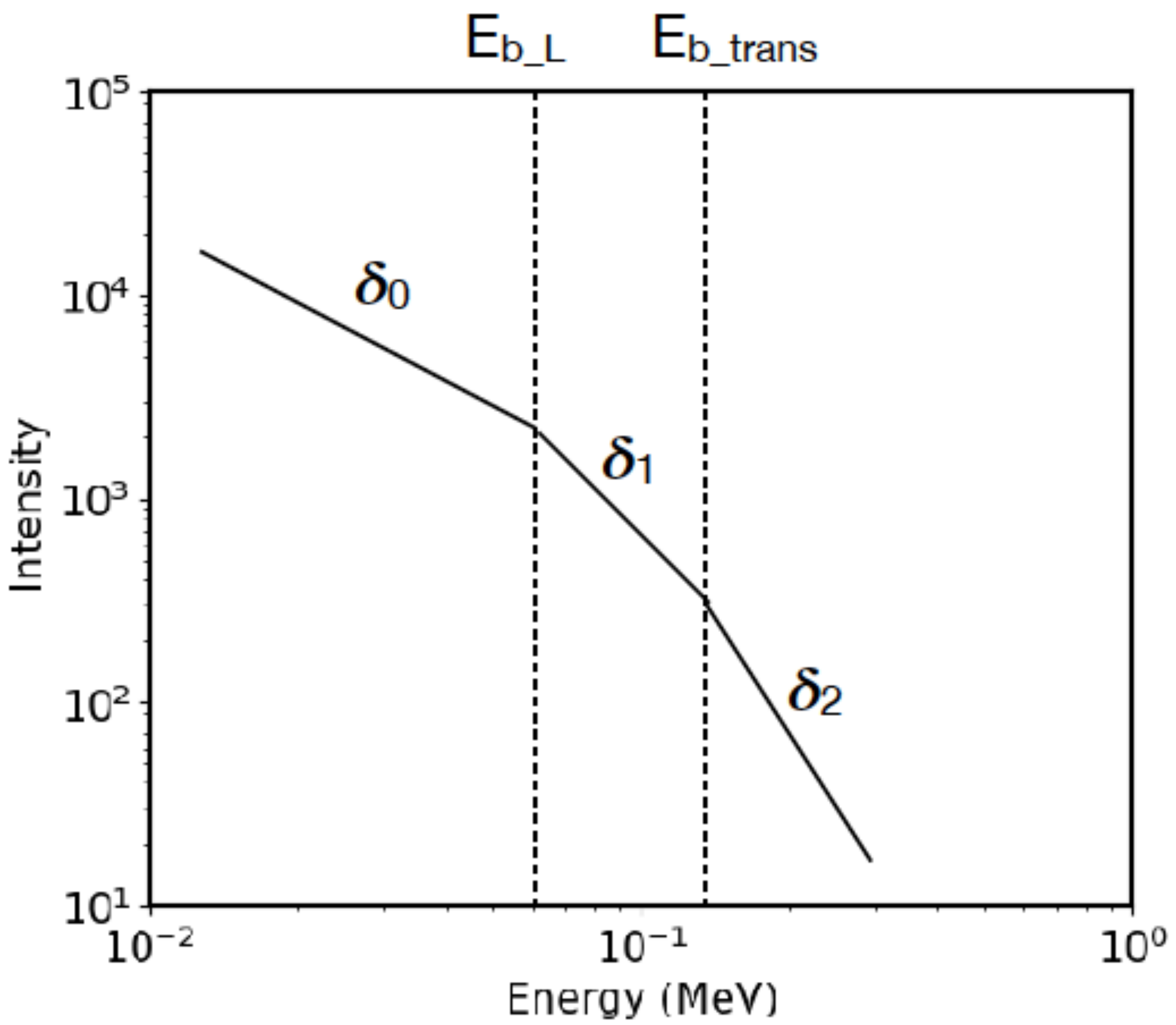
Unfortunately, many spectral breaks of our sample are lying in the suggested range making a choice between the two spectral indices difficult.

CORRELATING HXR AND IN-SITU ELECTRON SPECTRAL INDICES

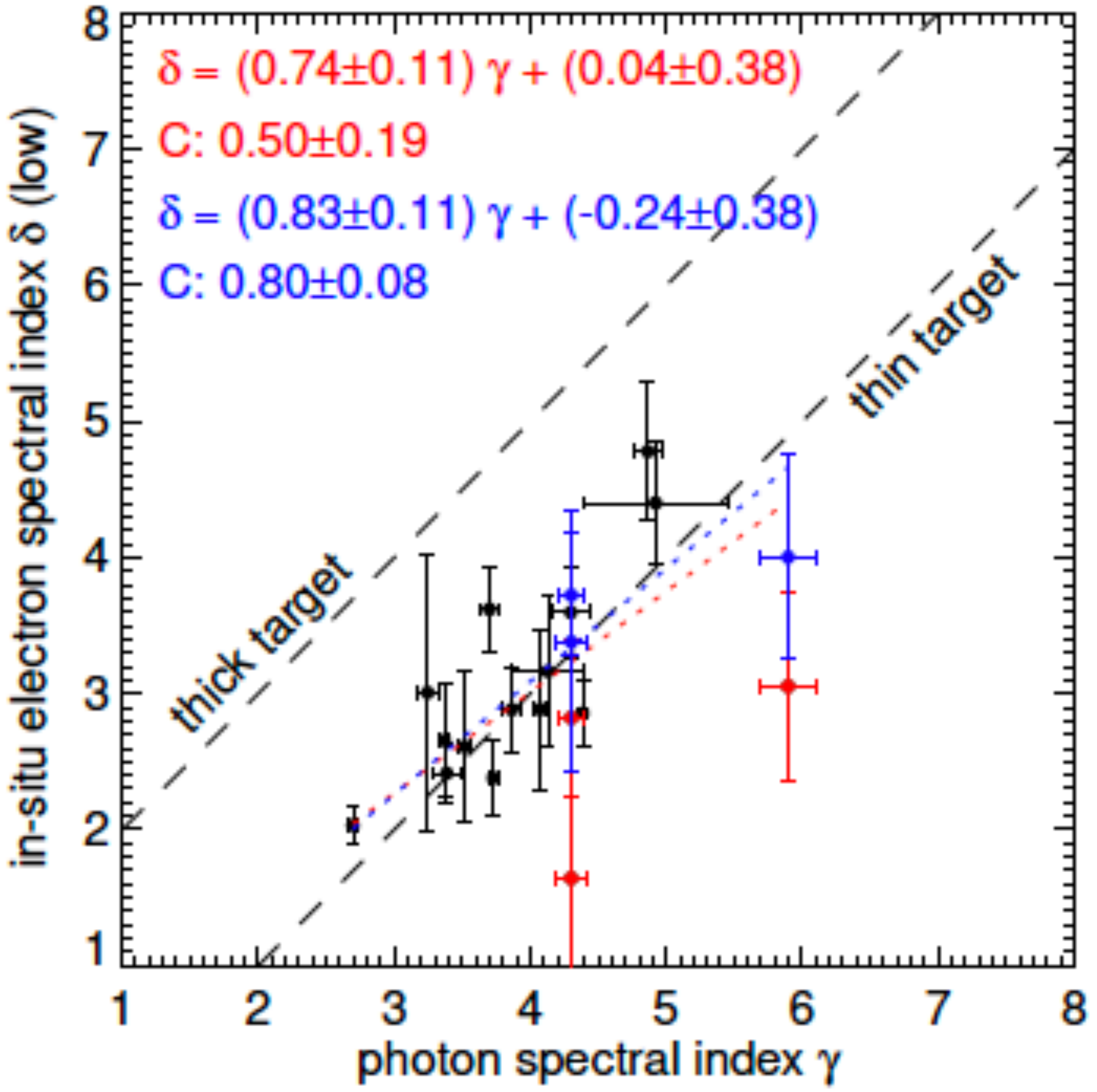
We correlate the HXR spectral index γ separately with the in-situ spectral index δ_{low} and δ_{high}

Three events stand out of each distribution (red points). We assume that these are events with a spectral break due to Langmuir-wave generation while the other events show breaks caused by pitch-angle scattering

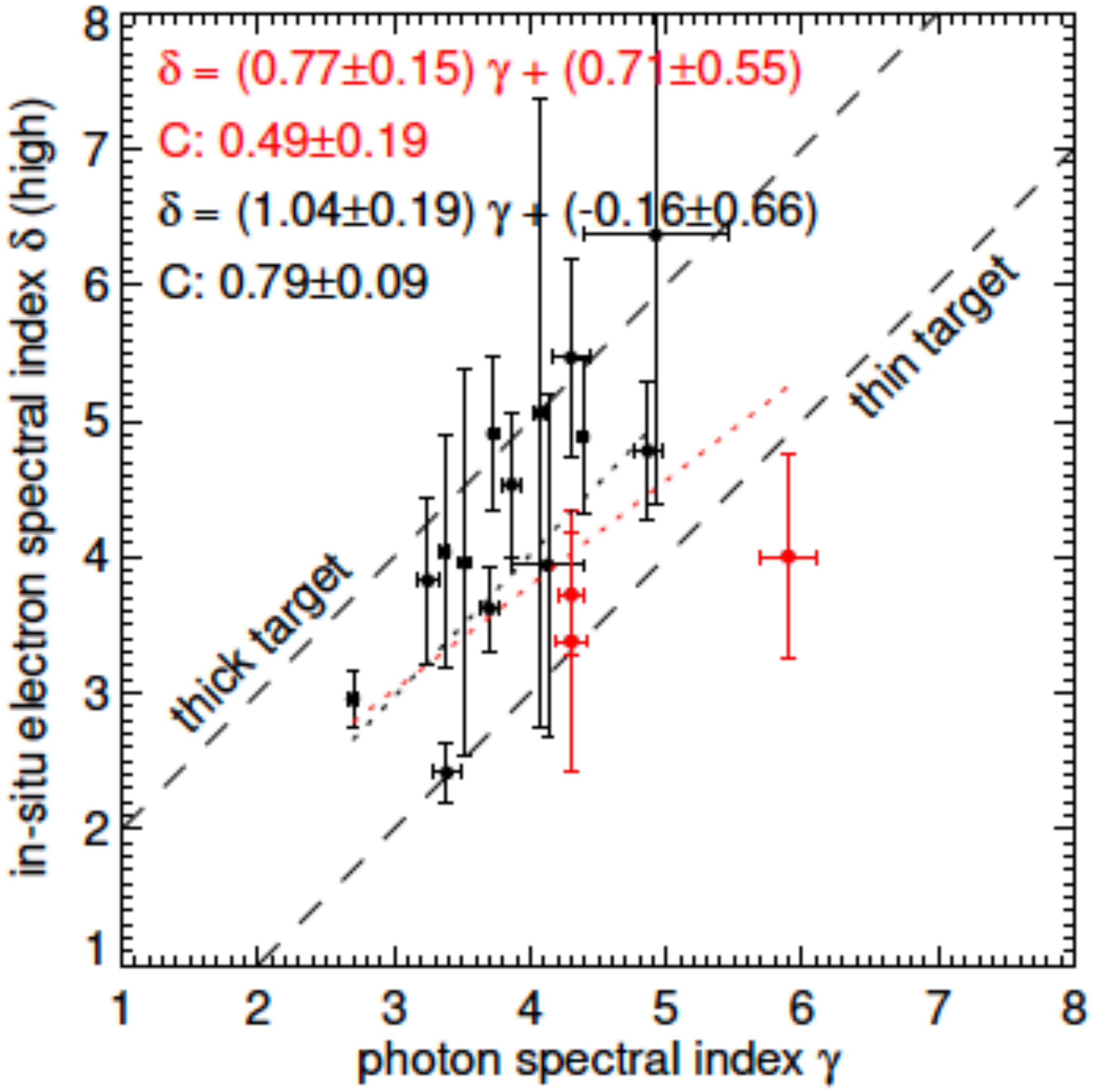
Treating these three events accordingly yields **good correlations of c=0.8 (δ_{low}) and c=0.79 (δ_{high}) for both sets of value pairs**



δ_{low}



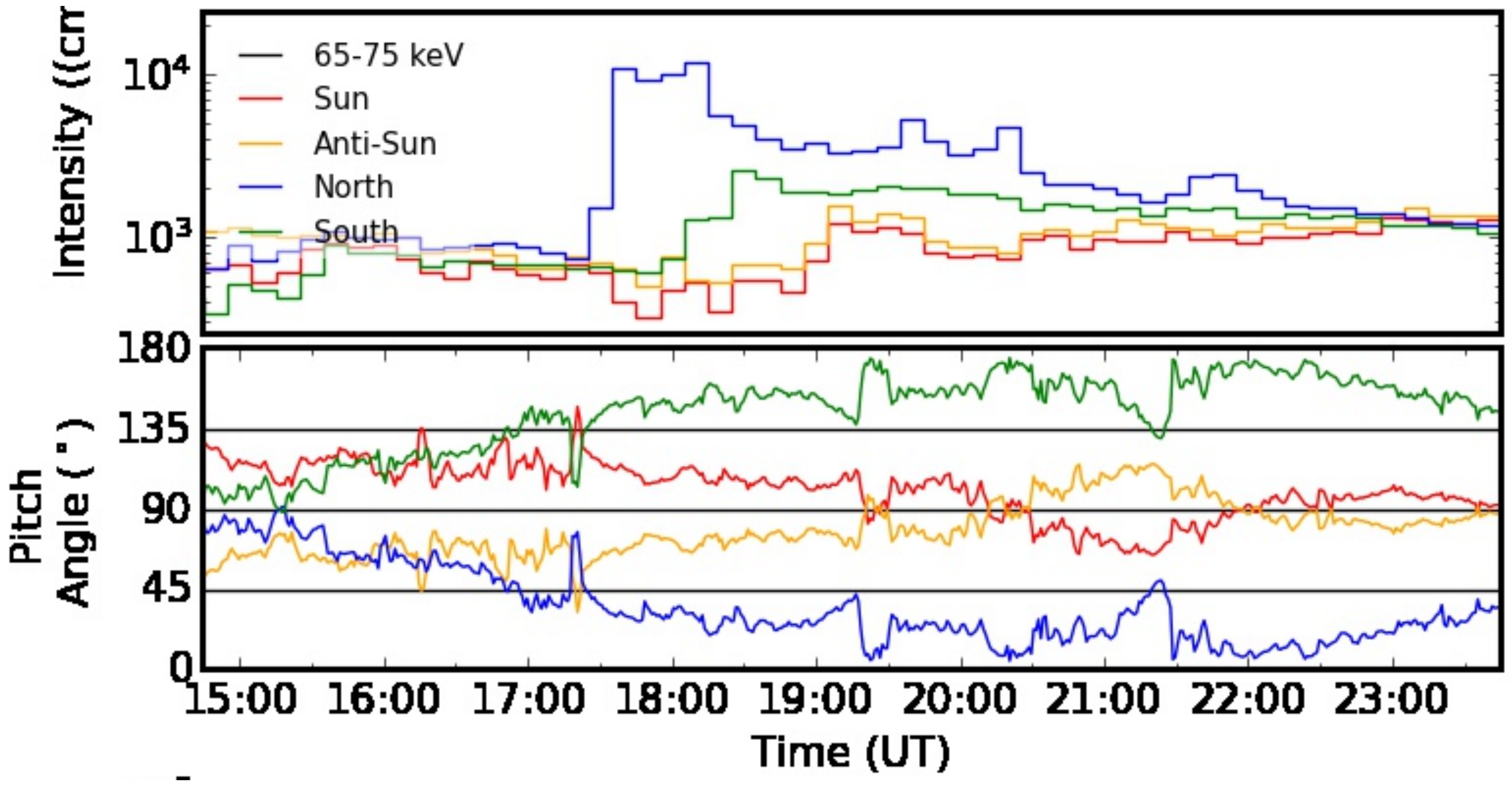
δ_{high}

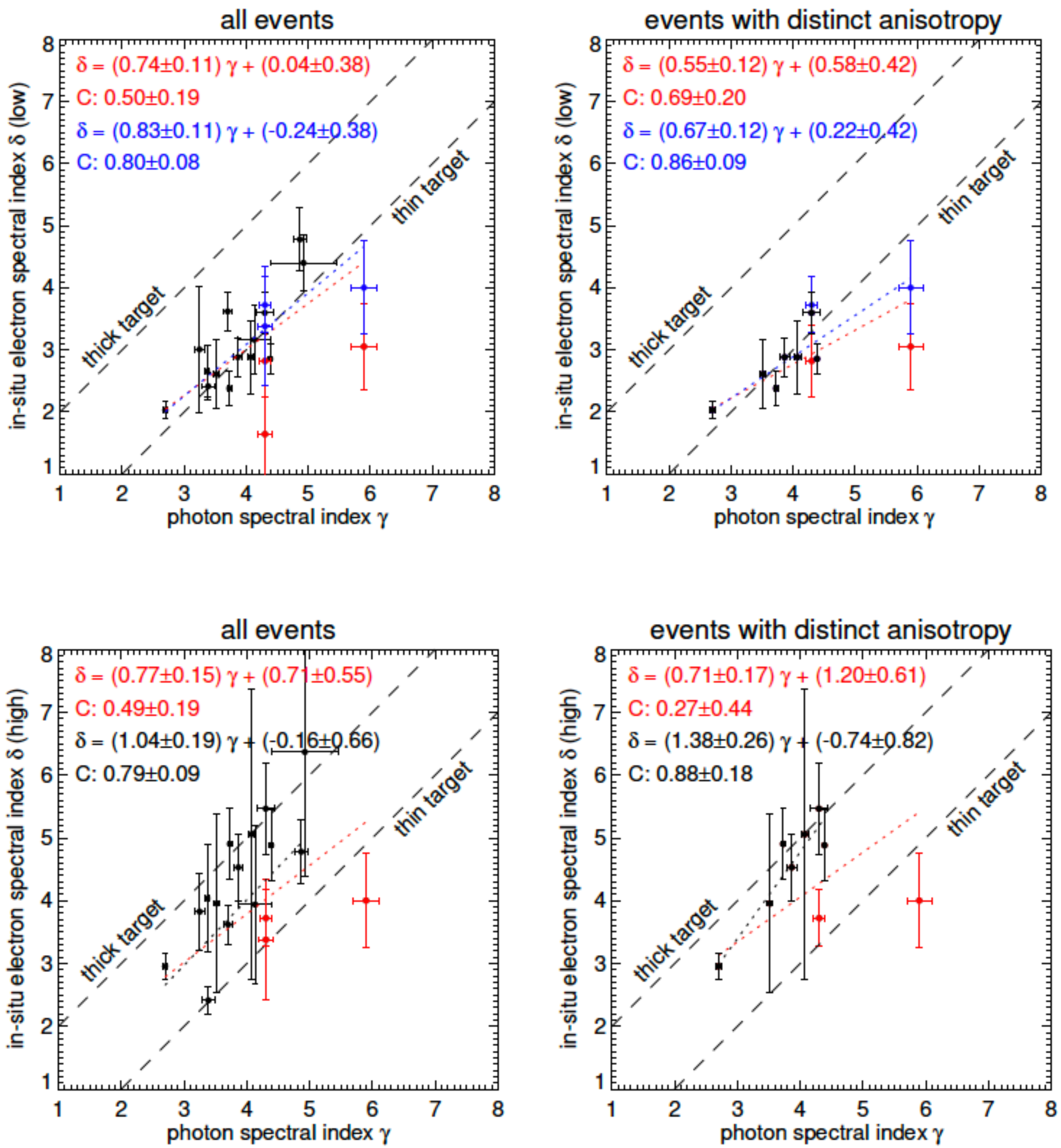


THE ROLE OF THE ANISOTROPY

When only using those events with medium to high anisotropies we find that the correlations improve

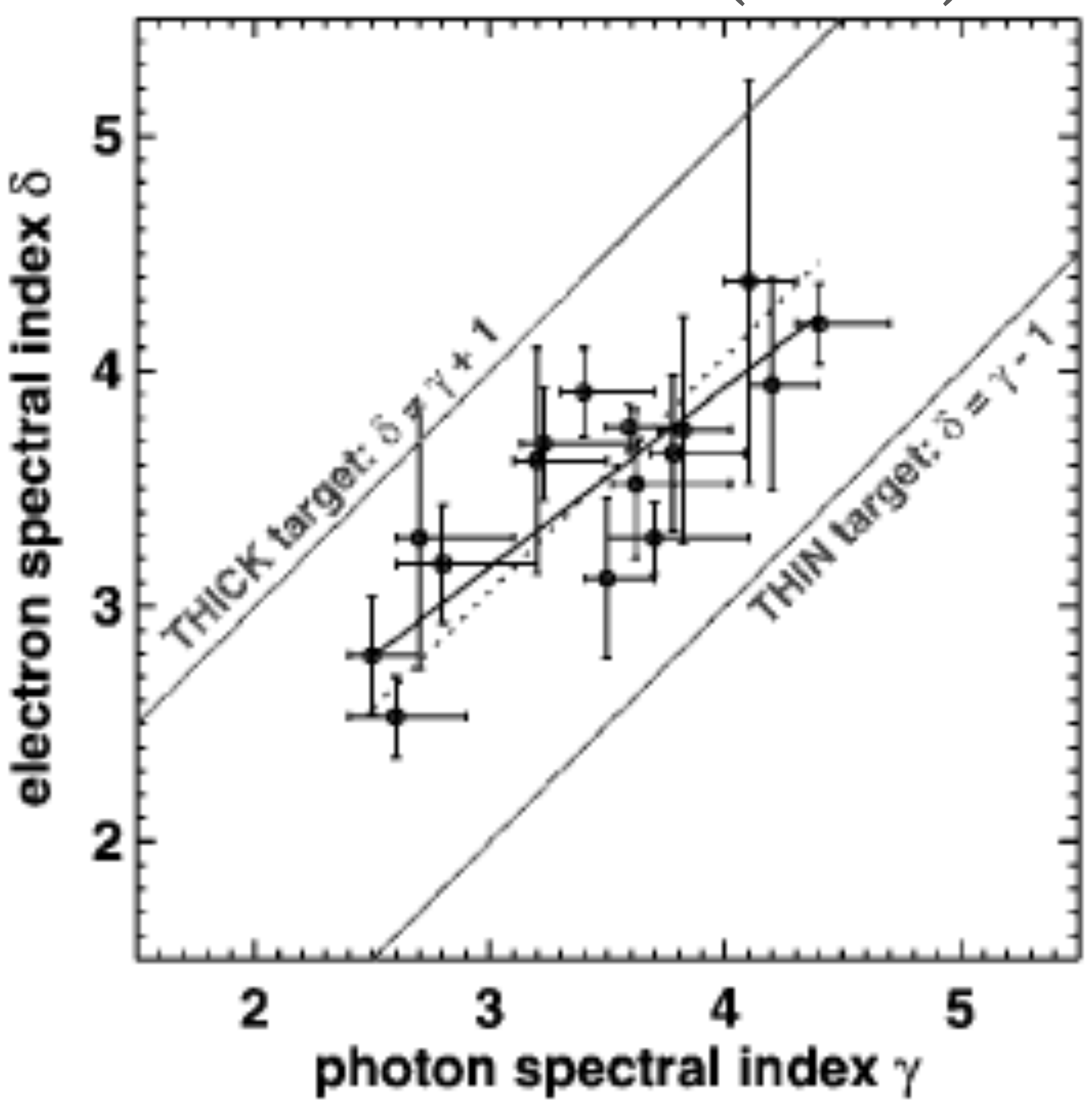
STEREO/SEPT sectored intensities showing large anisotropy:





DISCUSSION & SUMMARY

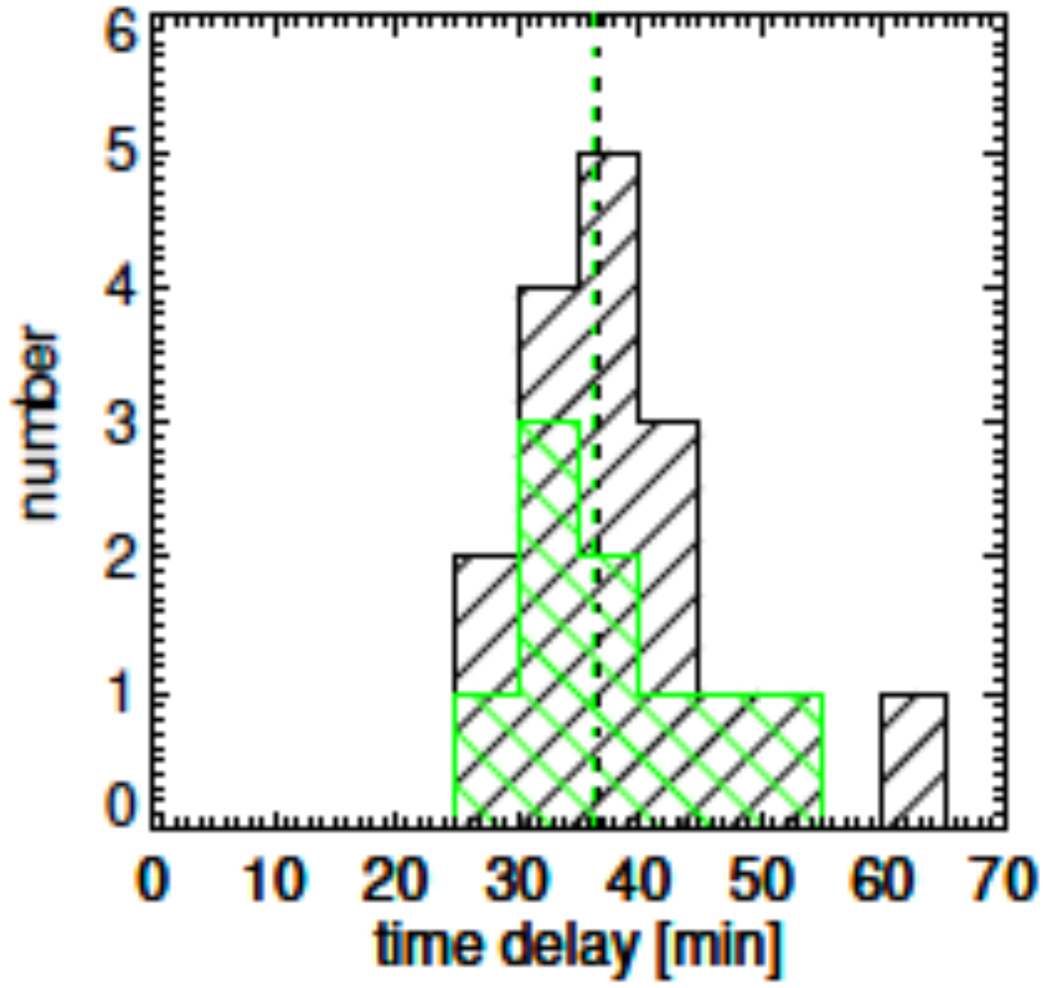
Krucker et al. (2007)

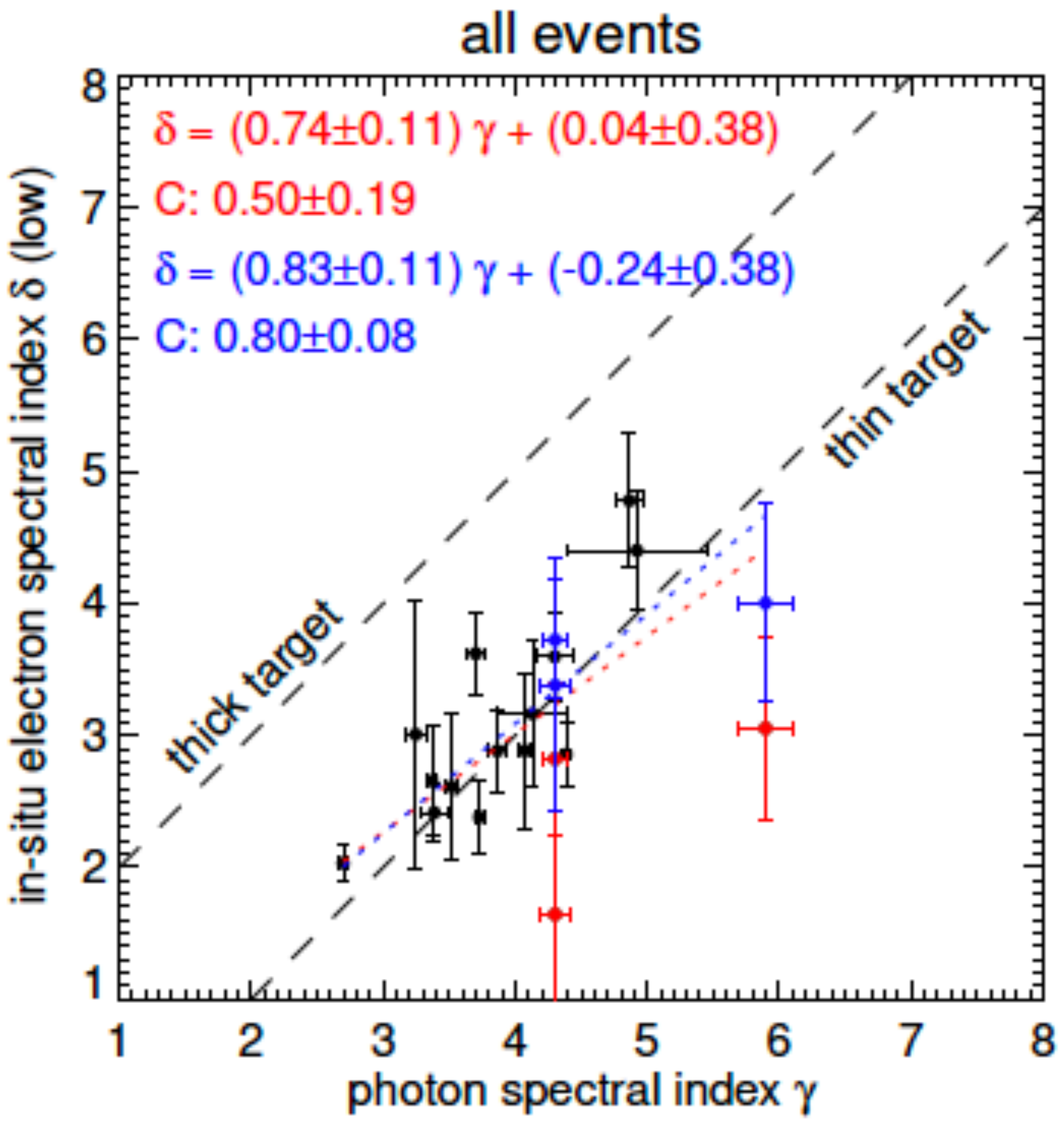


We find a clear correlation between the flare HXR and the in-situ electron spectra

Our correlation coefficients are similar to the those by Krucker et al. (2007) using Wind/3DP observations for events that did show no significant delays between flare and expected electron onset.

However, our events do show such delays and our value pairs align rather along the thin-target solution





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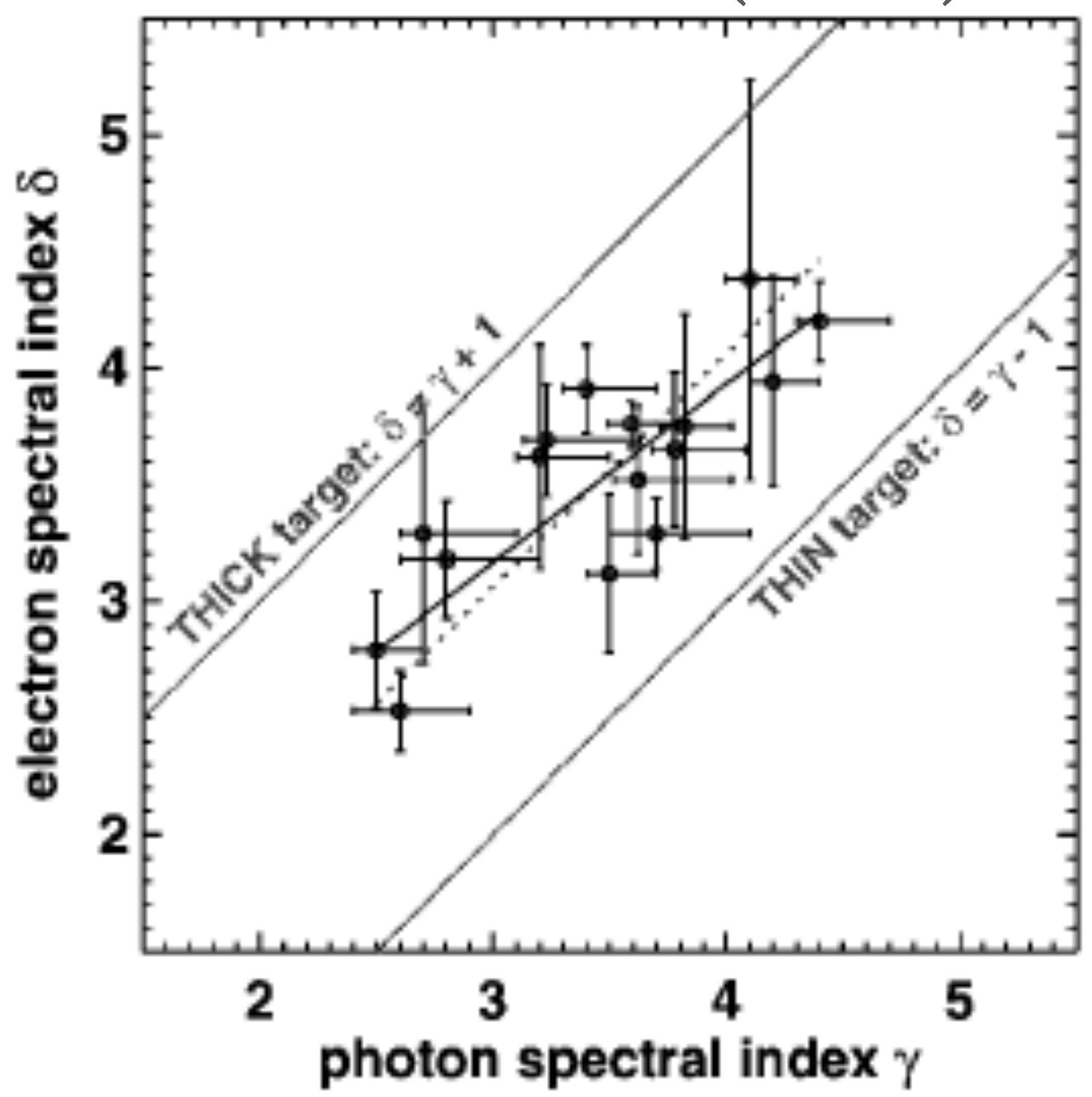
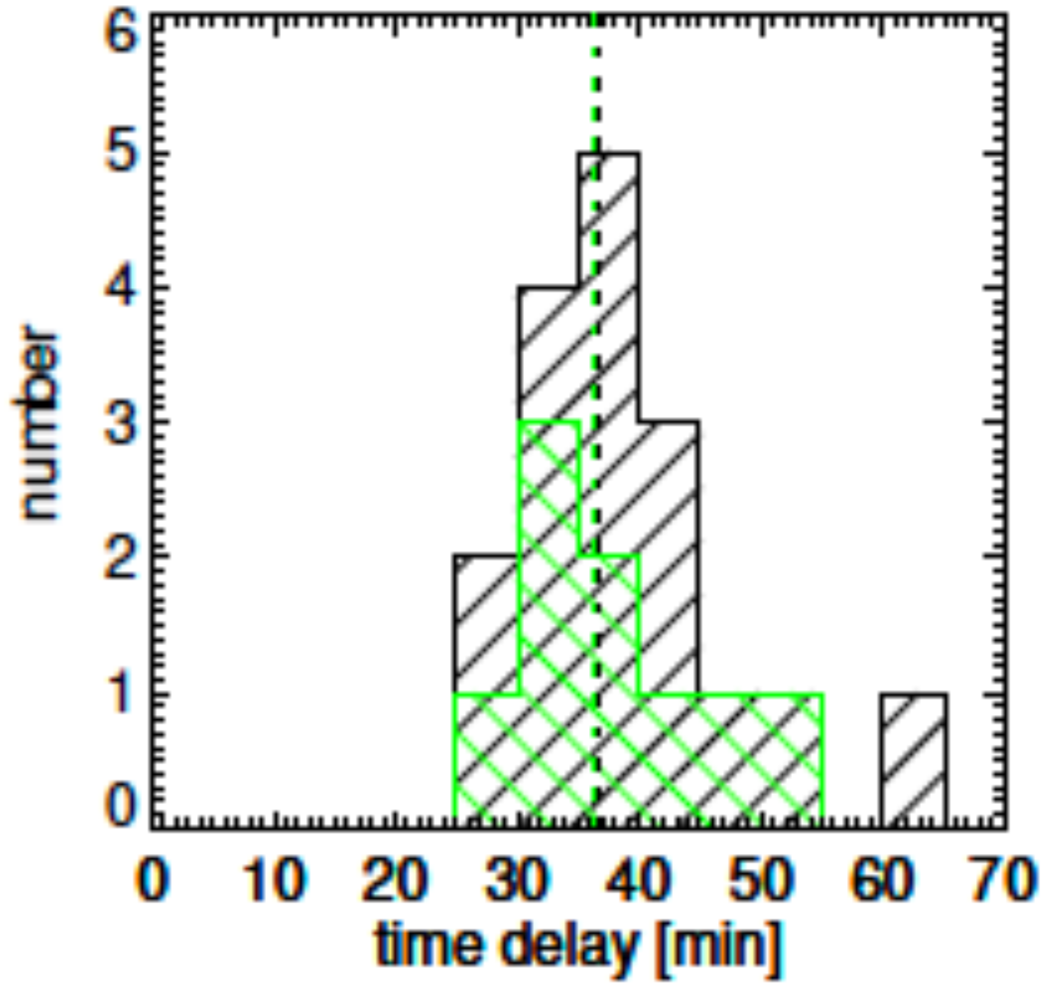
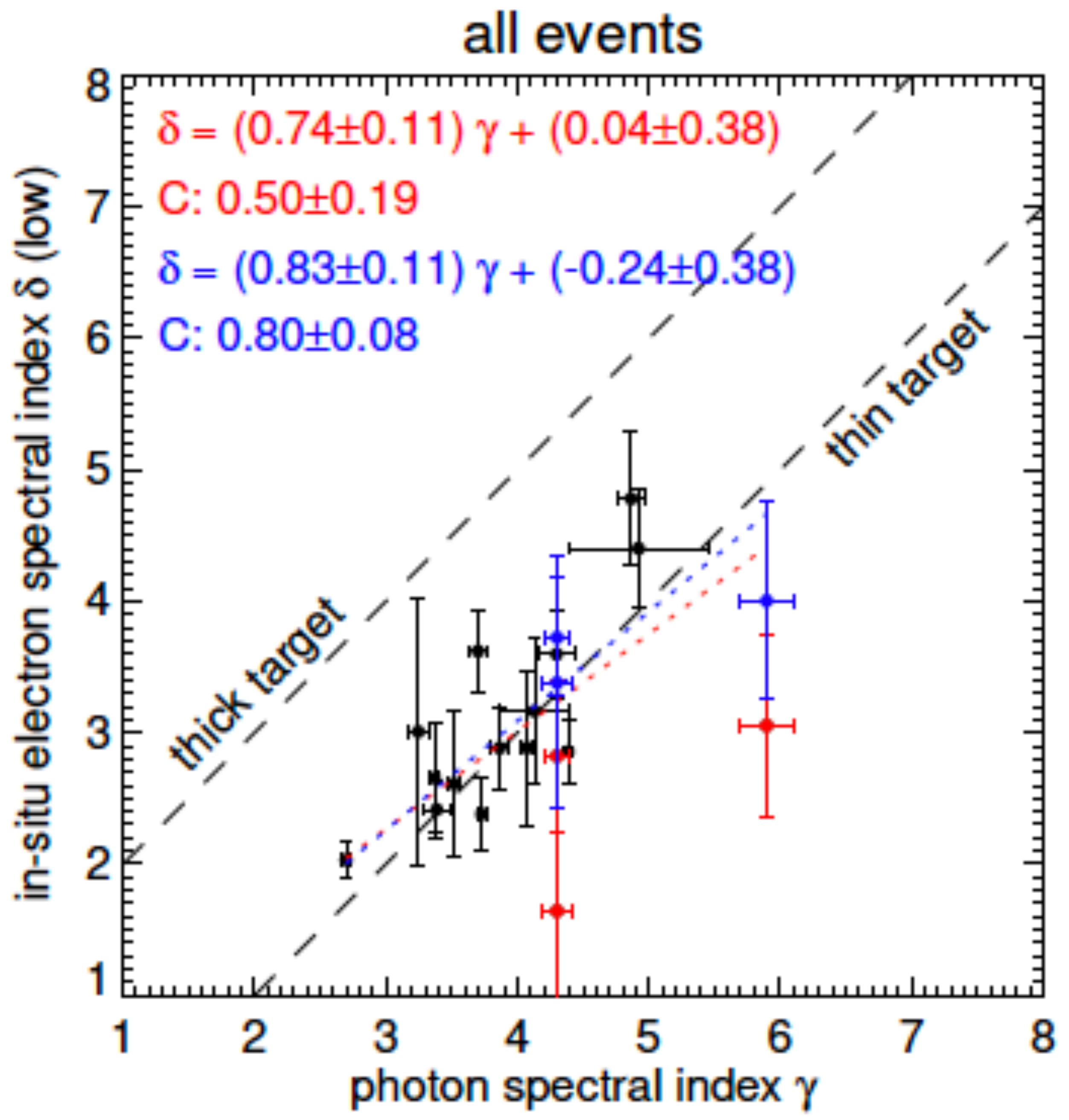
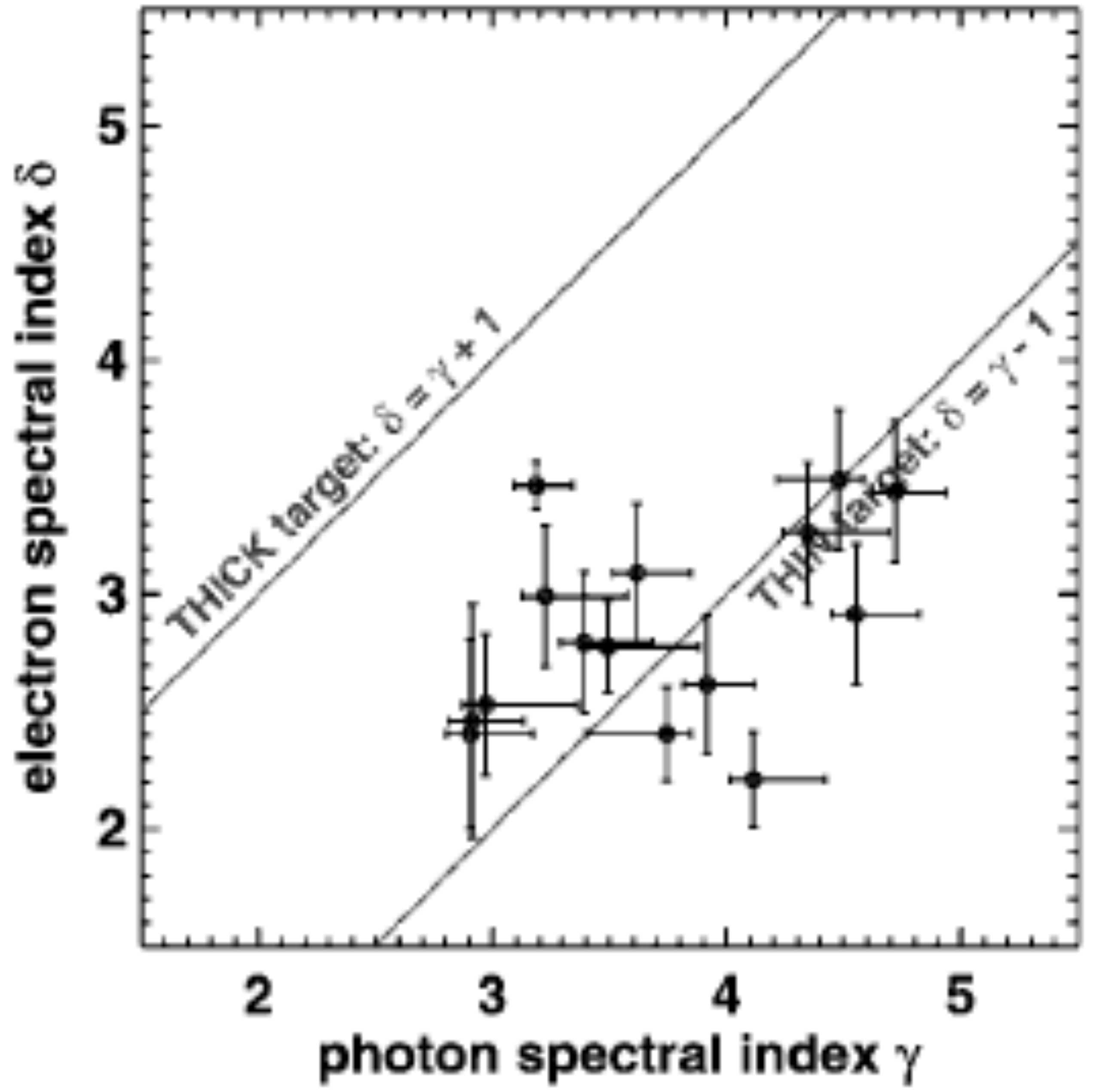




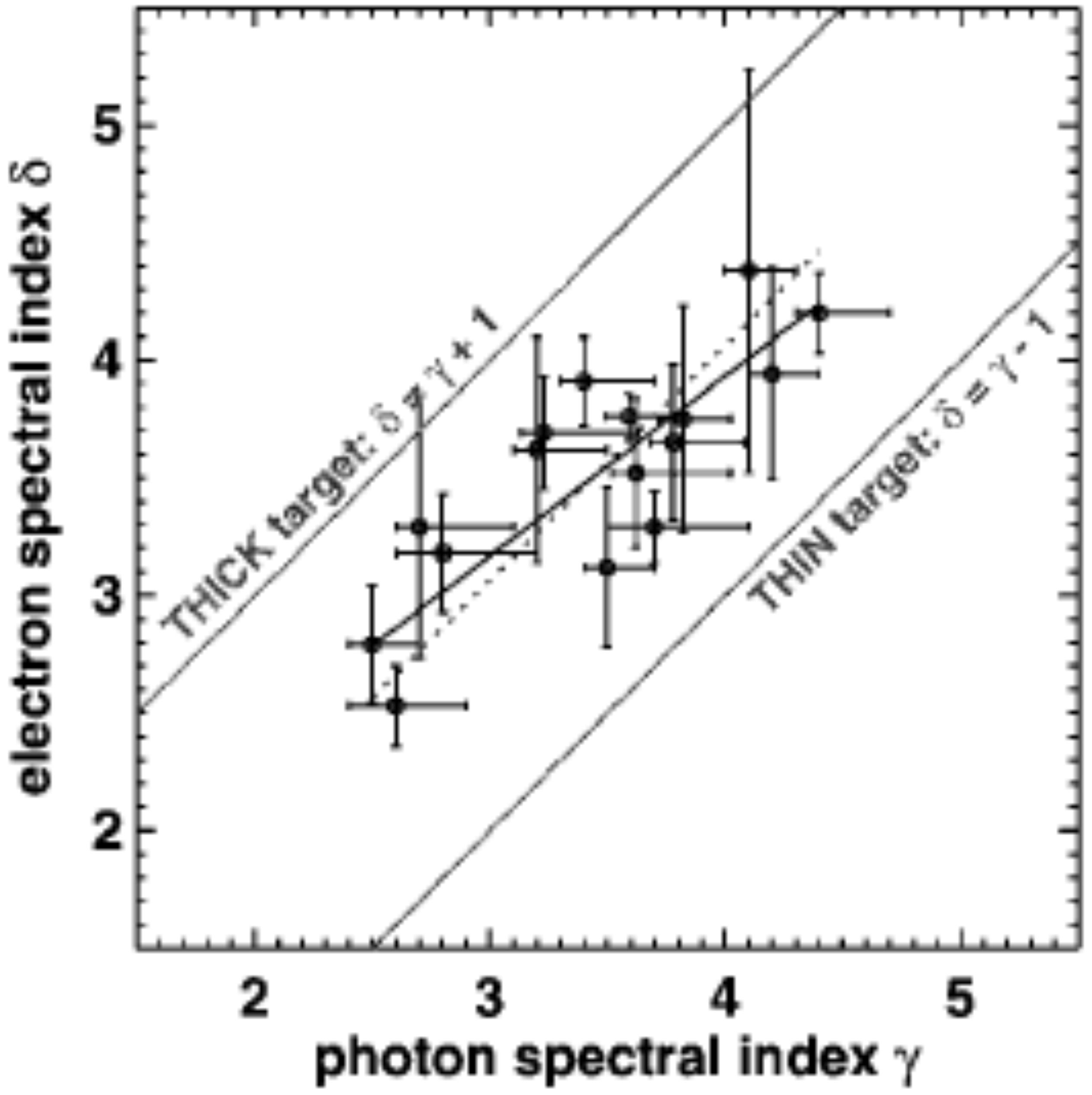




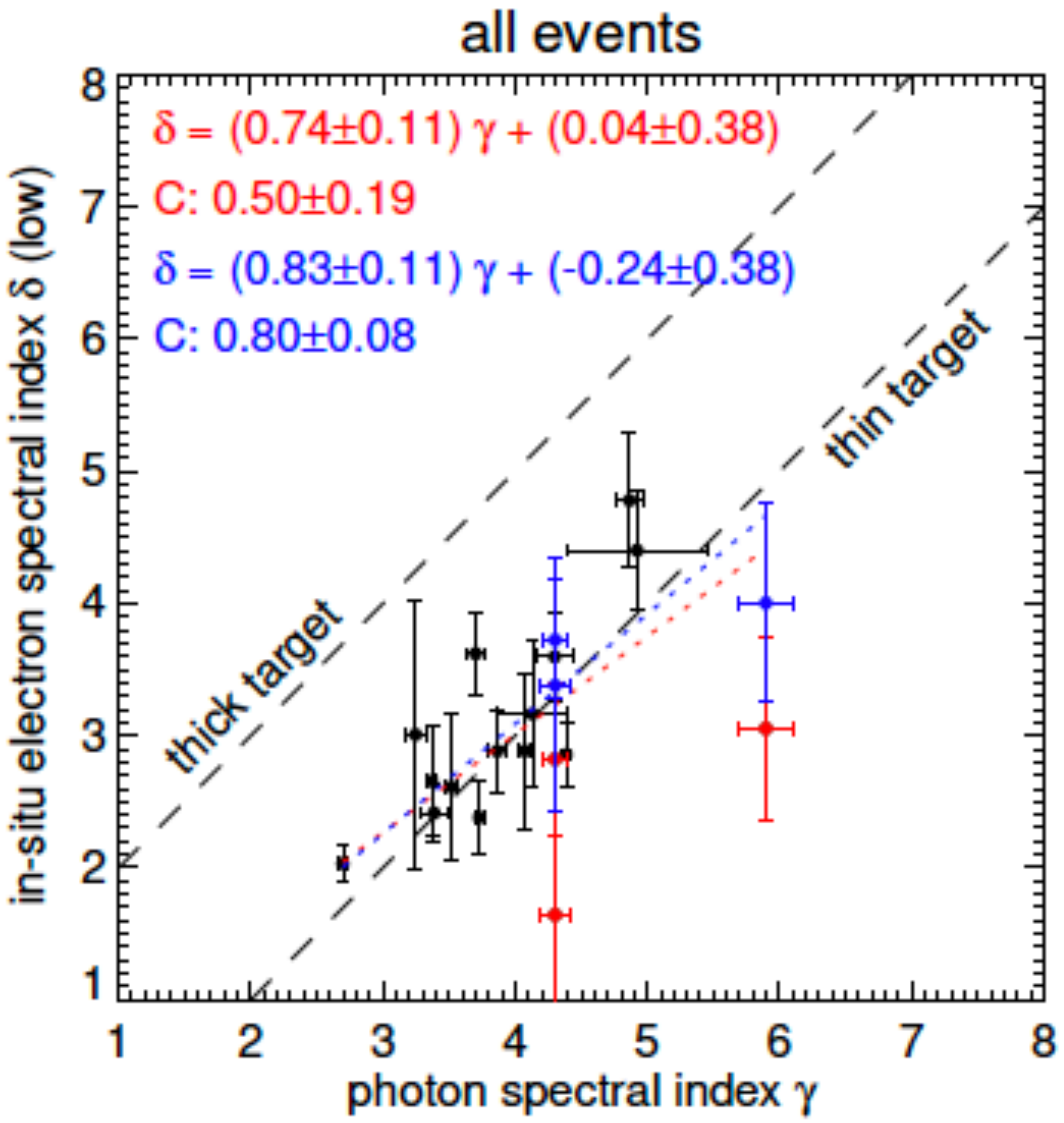
DISCUSSION & SUMMARY

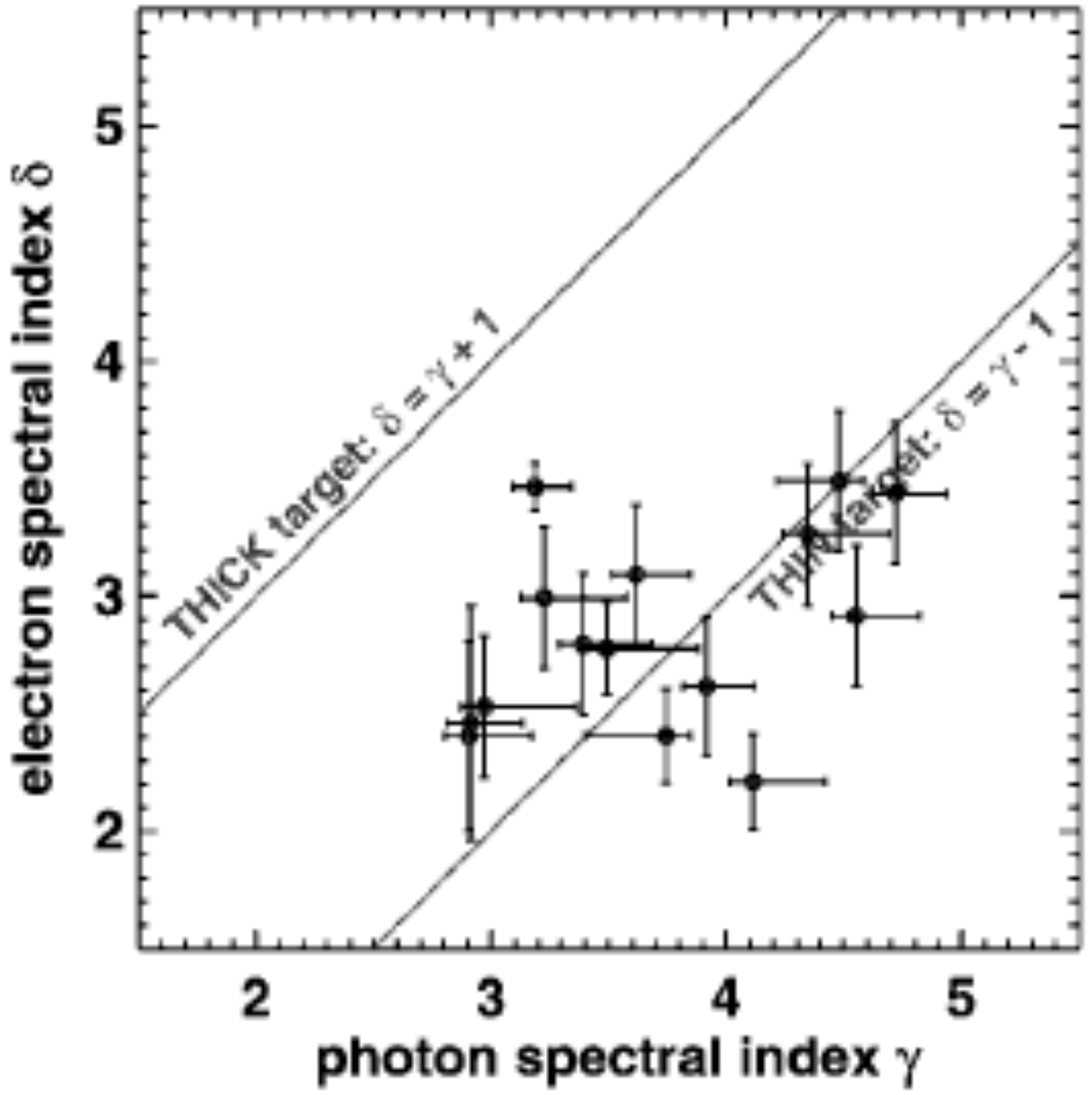
Petrosian 2016 suggested that the delayed events of the Krucker et al. (2007) study experienced a further acceleration possibly connected to CMEs, that caused the delay as well as the hardening of the electron spectra

Krucker et al. (2007)



However, if a further acceleration would have caused the shift of our value pairs to the thin-target line this acceleration should be rather constant or scale with the flare spectral index because of the maintained high correlation



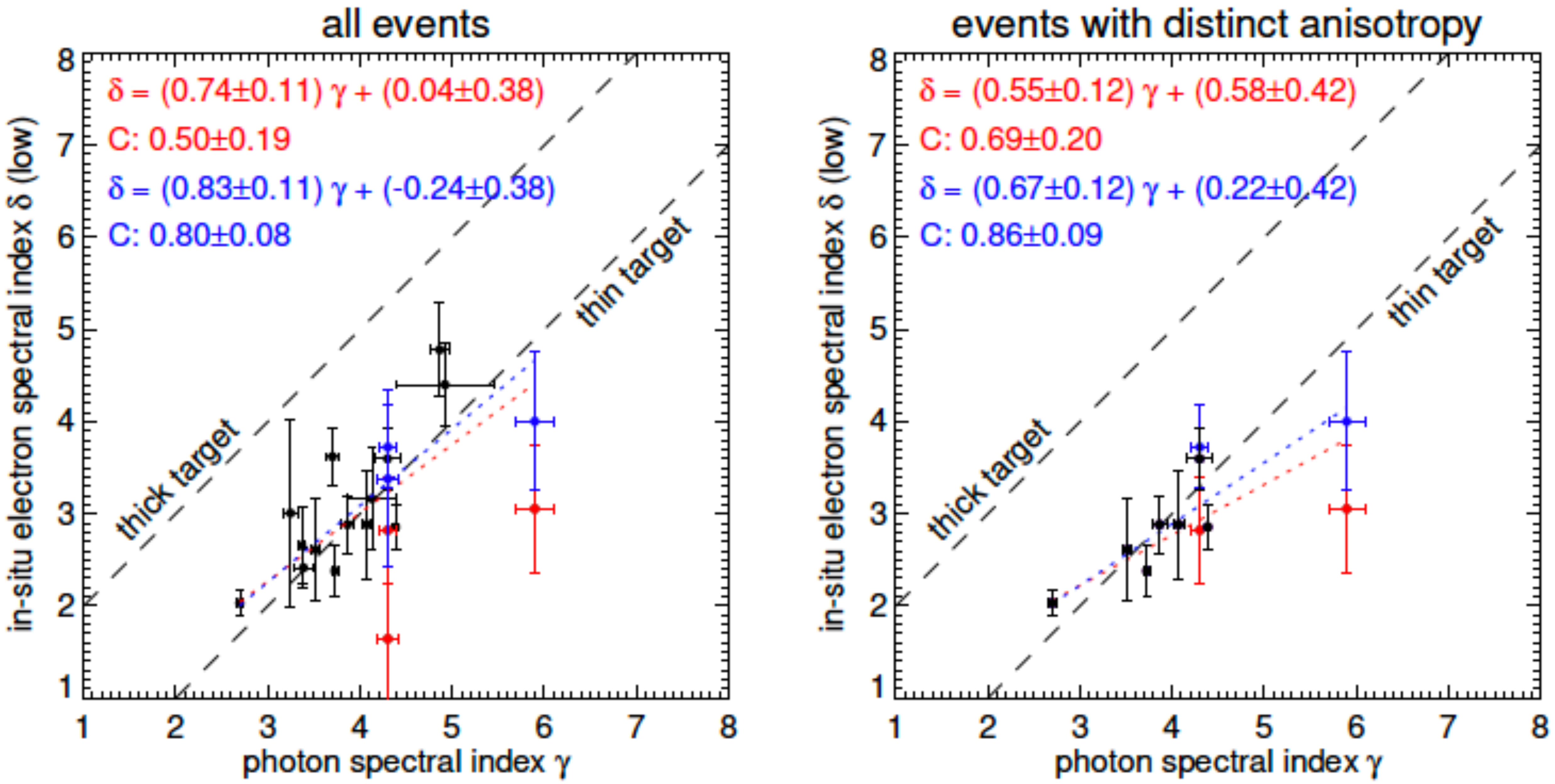


DISCUSSION & SUMMARY

The improved correlations of our anisotropic event sample suggest that pitch-angle scattering can lead to a vanishing imprint of the acceleration.

Because also poor pitch-angle coverage can lead to apparently small anisotropies, it is important to take this into account when connecting in-situ electron observations with HXR of the flare.

We have also shown that the correct choice of the spectral index in near-relativistic broken-power-law events is important and often not straightforward



This study is about to be submitted to A&A as Dresing et al. (2021)