Observing Bright Sources with Resolve

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for the XRISM Science Team

2024-01-17 — XRISM Data Analysis Workshop — University of Maryland

Agenda

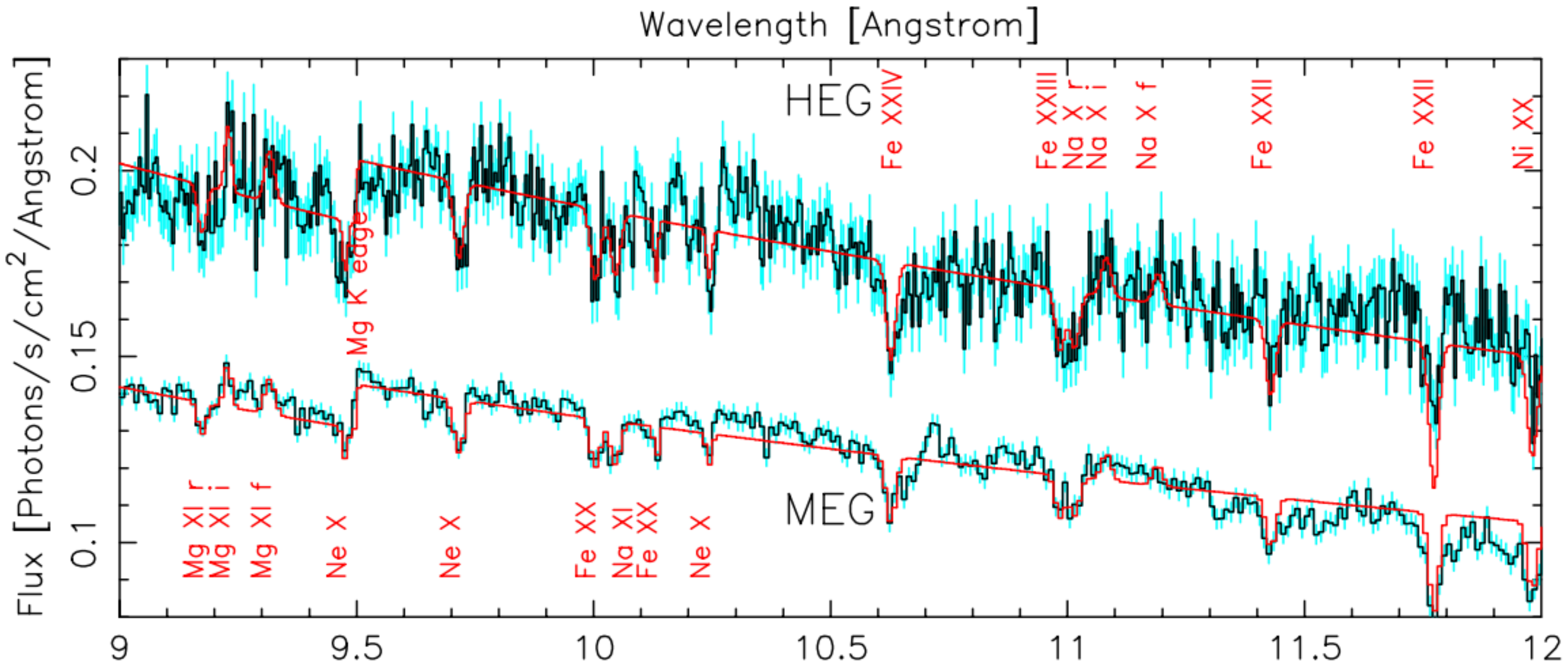
- Why do we want to observe bright sources with Resolve?
- Why are bright sources challenging?

- What is the best way to observe bright sources?
- What is the best way to analyze bright sources?

- Walkthrough of simulating a bright source for proposing

Why observe bright sources?

- Some transient and rapidly variable phenomena can only be studied in sources with high count rates (high S/N in a short interval)
- XRISM can efficiently study phenomena like disk winds in bright sources



Cyg X-1
2-10 keV $F_X > 10^{-8}$ erg s^{-1} cm^{-2}

Miller+ 2002

How Bright is “Bright”?

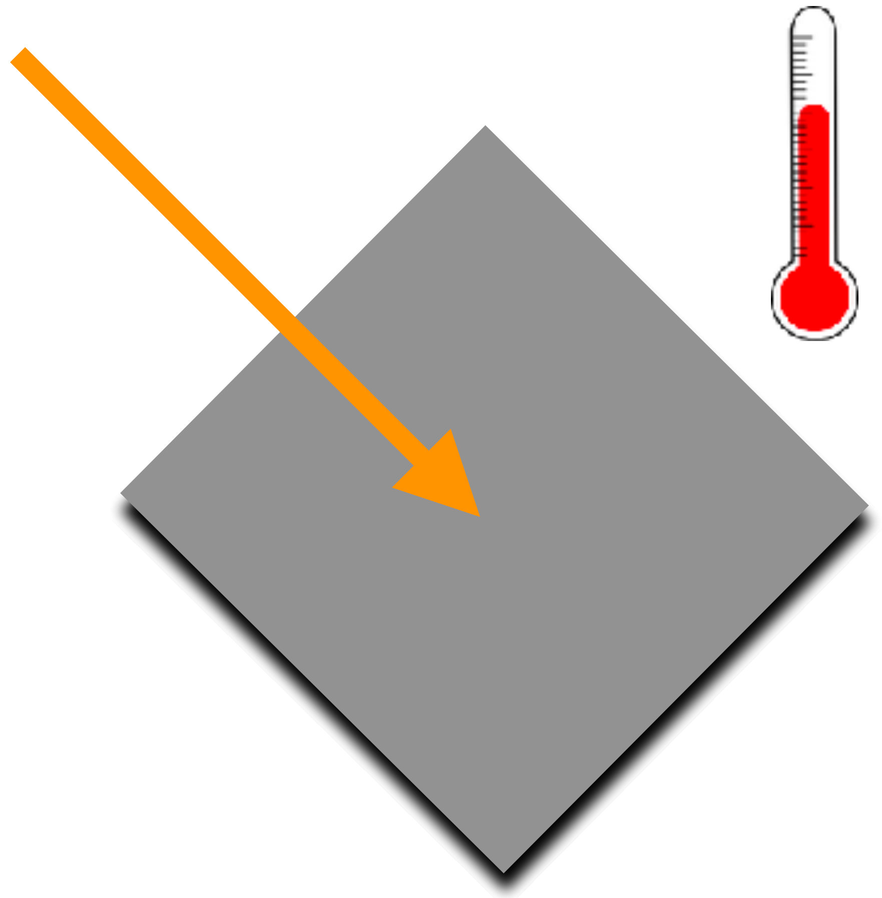
Flux	Array Count Rate	Array Count Rate (with Gate Valve)	Suboptimal H+Mp rate?	CPU Limit Effects?	Cross-Talk Impact?
<1 mCrab	<2	0.4	Check email or go to the bathroom		
10 mCrab	20	4	No	No	No
100 mCrab	200	45	Minor (No)	Minor (No)	No
1 Crab	2,000	450	Yes (Yes)	Yes (Yes)	Yes (Minor)
10 Crab	20,000	4500	Extreme (Extreme)	Extreme (Extreme)	High (High)

Bright Source Challenges

Why are bright sources challenging?

- The fraction of high resolution events is a function of count rate
- The onboard computer (pulse-shape processor; PSP) can only process so many events per unit time
- Electrical cross-talk can degrade event resolution

From Detection to Measurement



HgTe Detector

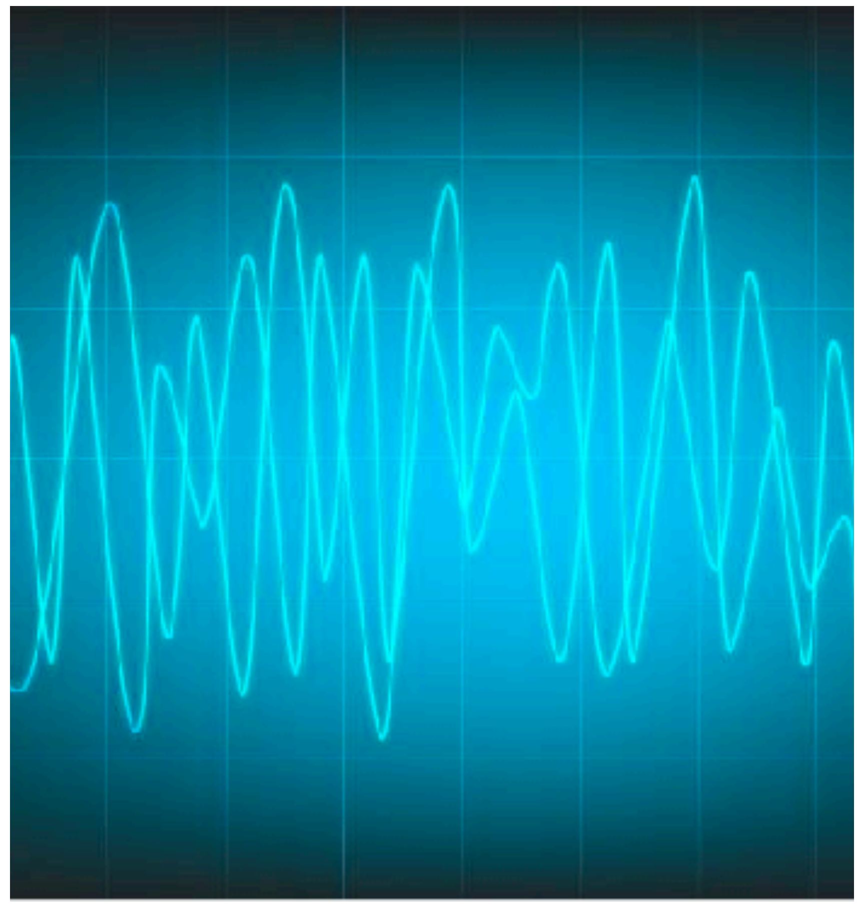
X-ray strikes pixel

XBOX ADC

Signal amplified, digitized

PSP FPGA

Event (pulse) triggered



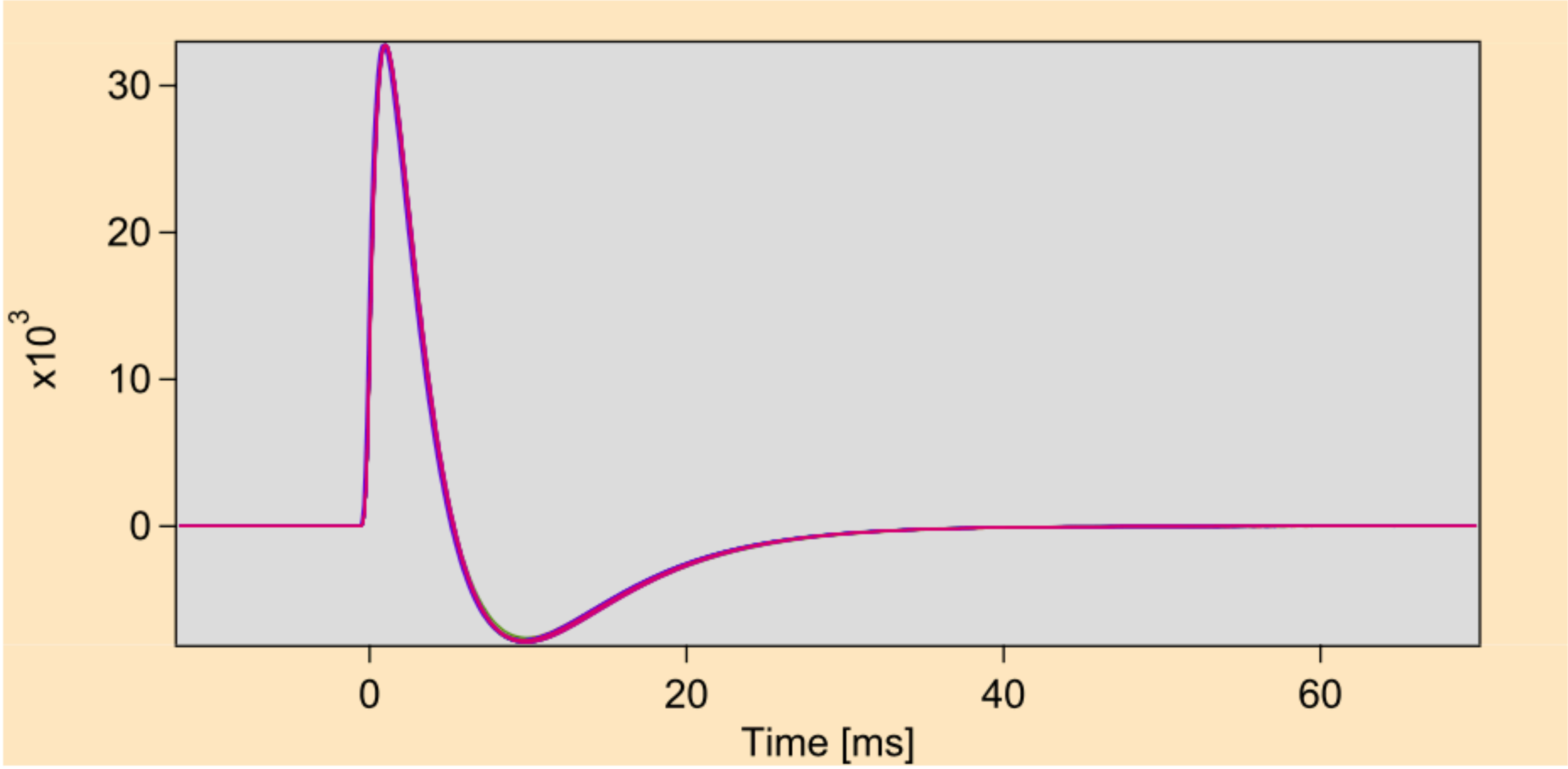
PSP CPU

Energy measured

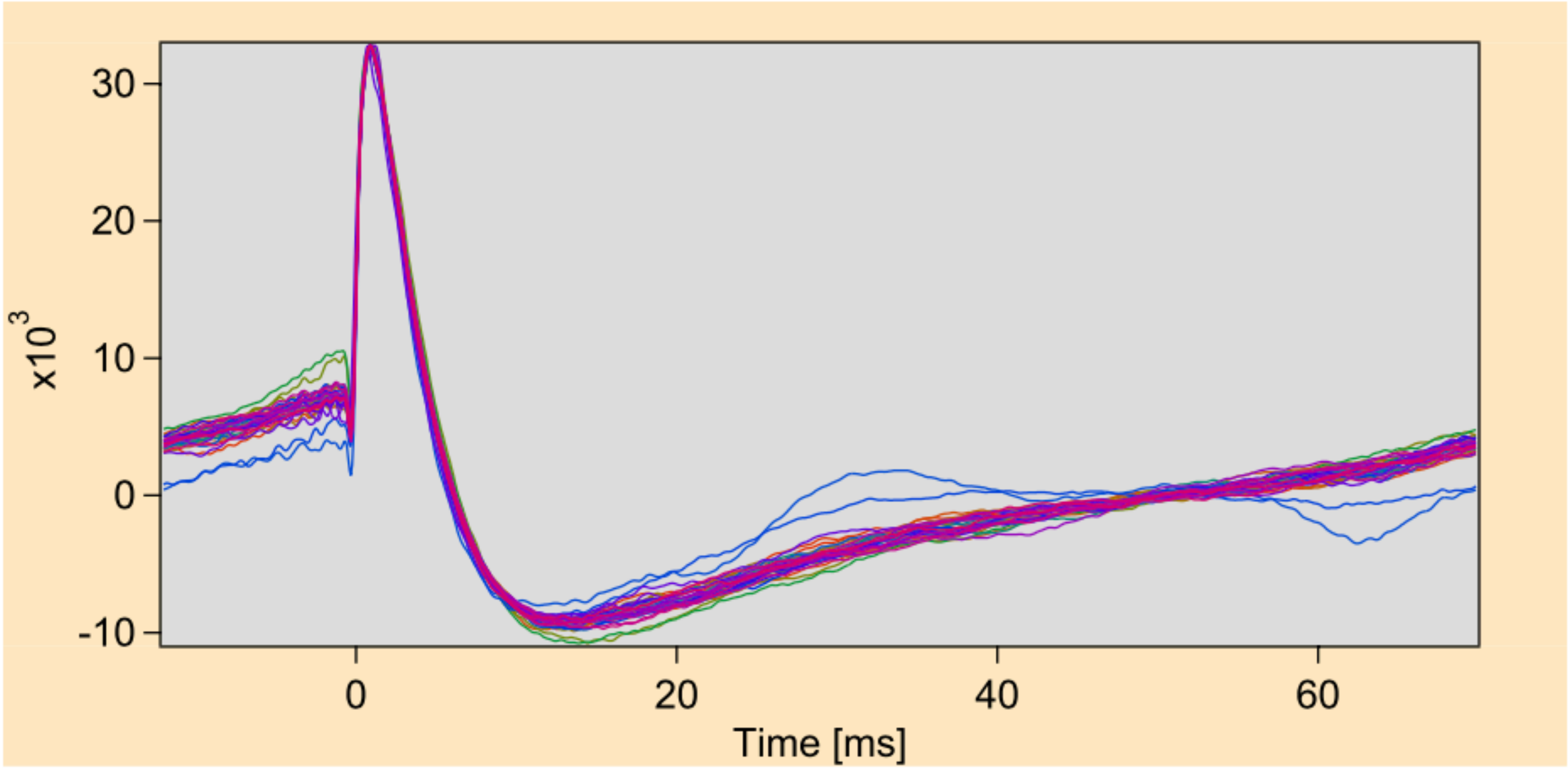
How does XRISM measure energy?

- Incident photons produce a pulse with a characteristic shape in the detector electronics whose amplitude is proportional to the photon energy

- The pulse-shape processor cross-correlates a normalized pulse template with each pulse to measure the amplitude

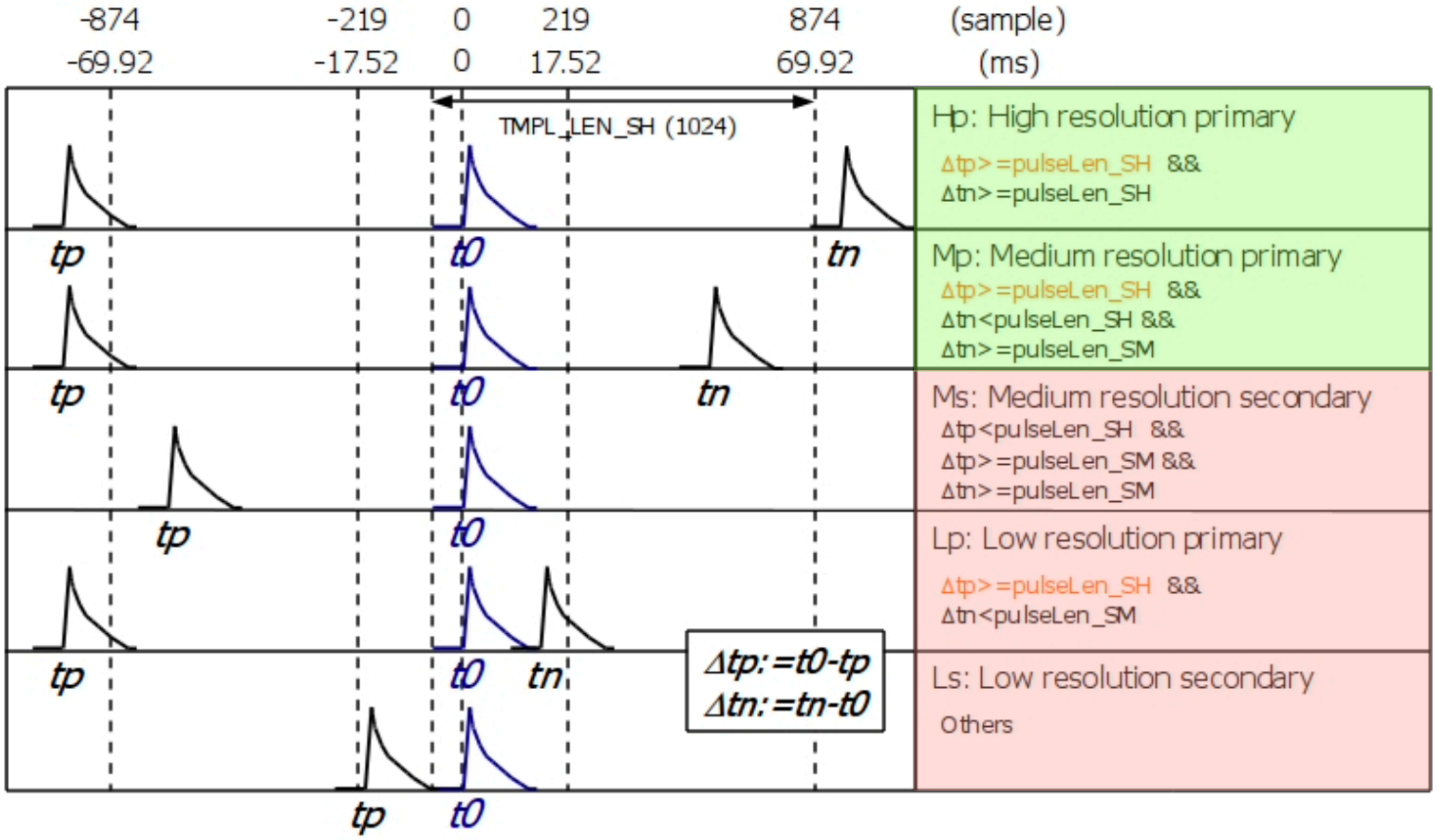


(a) Average profile $S(t)$



(c) Filter template $F(t)$

XRISM Calorimeter Grades



Hp: High resolution primary
Δtp>=pulseLen_SH &&
Δtn>=pulseLen_SH

Mp: Medium resolution primary
Δtp>=pulseLen_SH &&
Δtn<pulseLen_SH &&
Δtn>=pulseLen_SM

Ms: Medium resolution secondary
Δtp<pulseLen_SH &&
Δtp>=pulseLen_SM &&
Δtn>=pulseLen_SM

Lp: Low resolution primary
Δtp>=pulseLen_SH &&
Δtn<pulseLen_SM

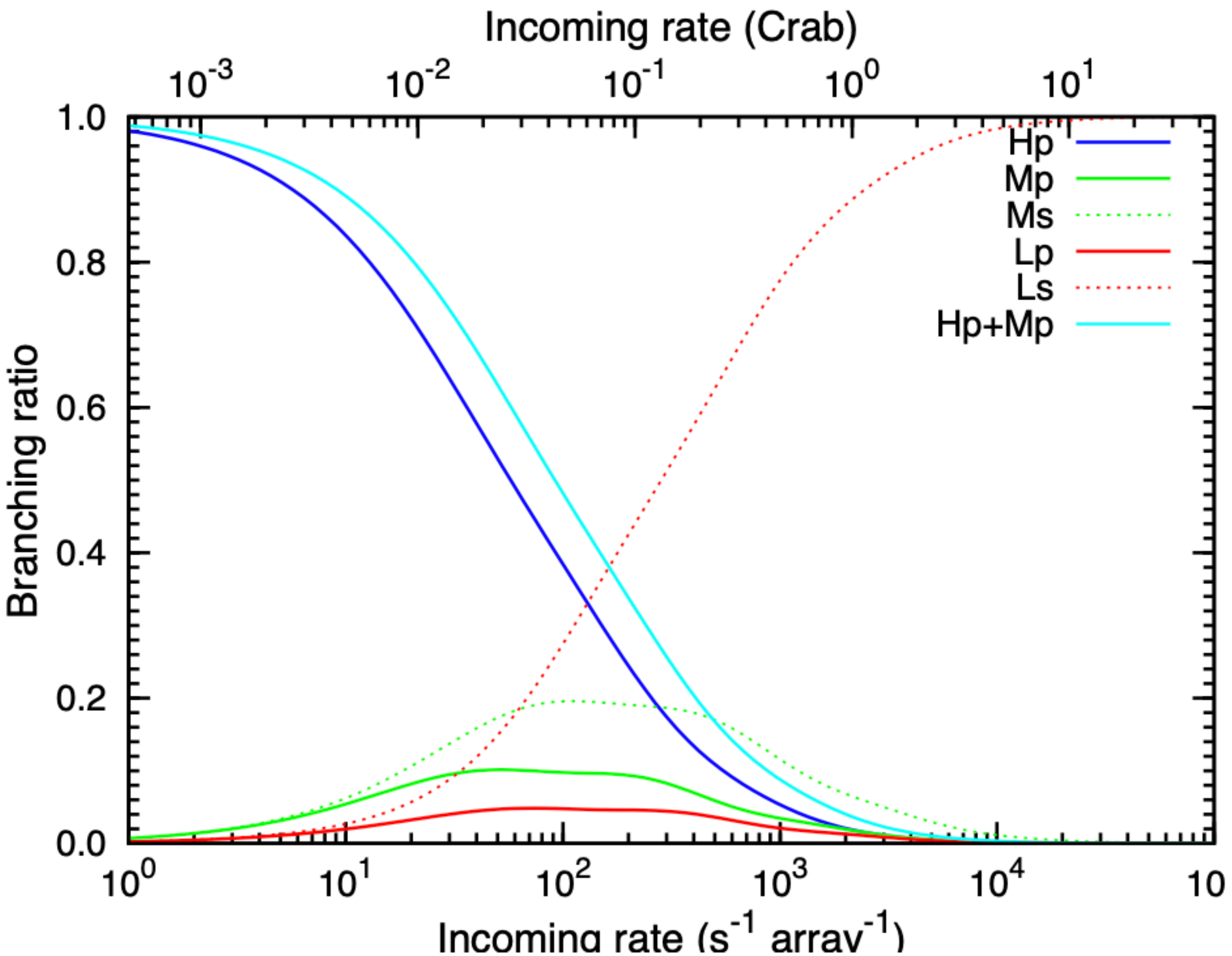
Ls: Low resolution secondary
Others

Photons separated by >81 ms

More than one photon in the 81 ms window

Photons arrive too close together, optimal filtering not performed

Fraction of High-res Events

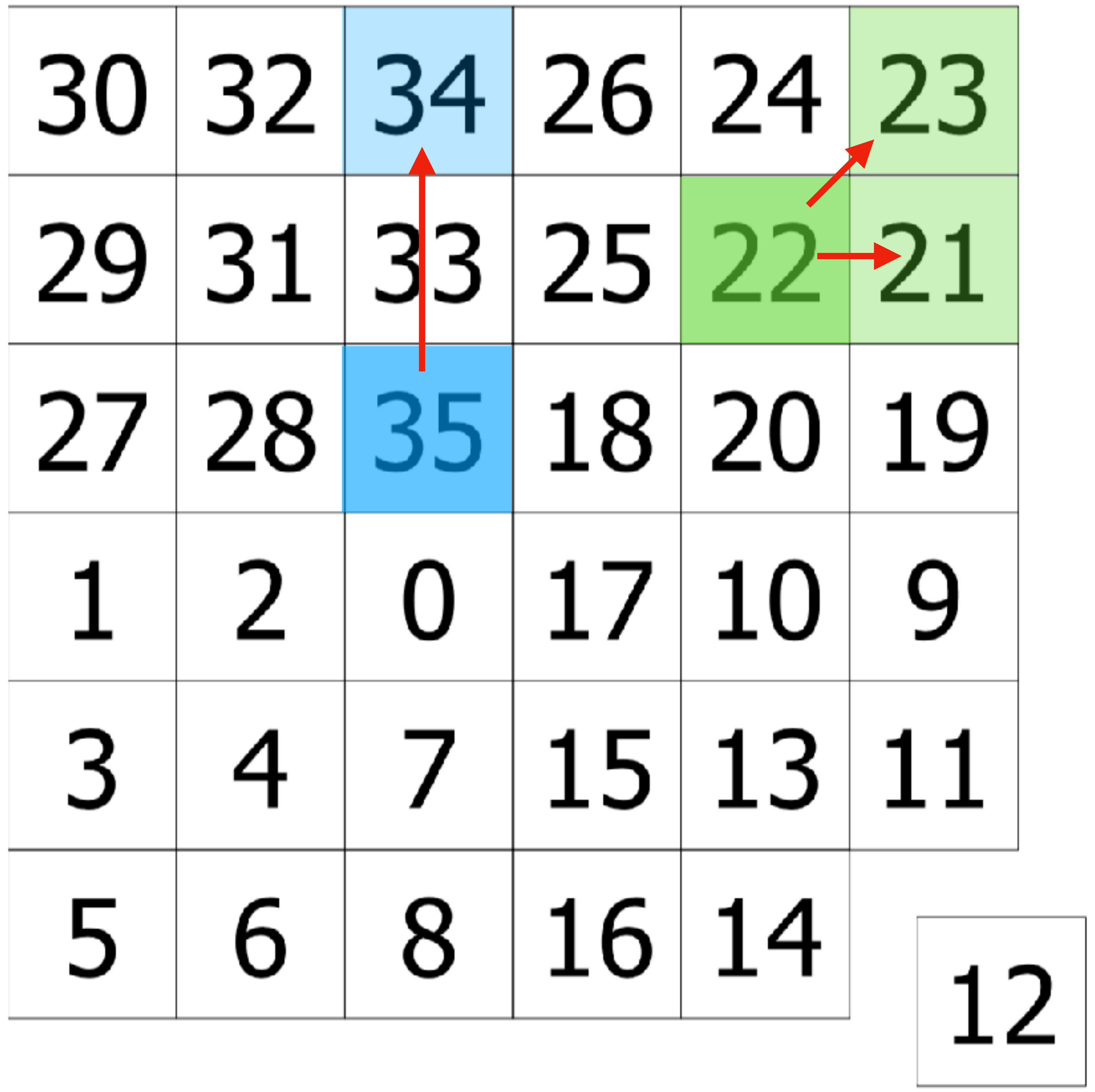


CPU Limits

- Events are detected in an FPGA board and stored in a memory buffer while waiting to be processed
- The PSP computer ingests events (one CPU per quadrant) and performs the cross-correlation and recursive searches for secondary events
- If the buffer fills up before the events within are processed, it gets dumped (event loss) and starts filling up again
- Bright sources can clog the buffer with low-resolution events and lead to further loss of high-resolution events
- On average, CPUs saturate at ~200 count/s/array (~100 mCrab), or 50 counts/s/quadrant, which produces 75 H+Mp (“calorimeter-grade”) events/s

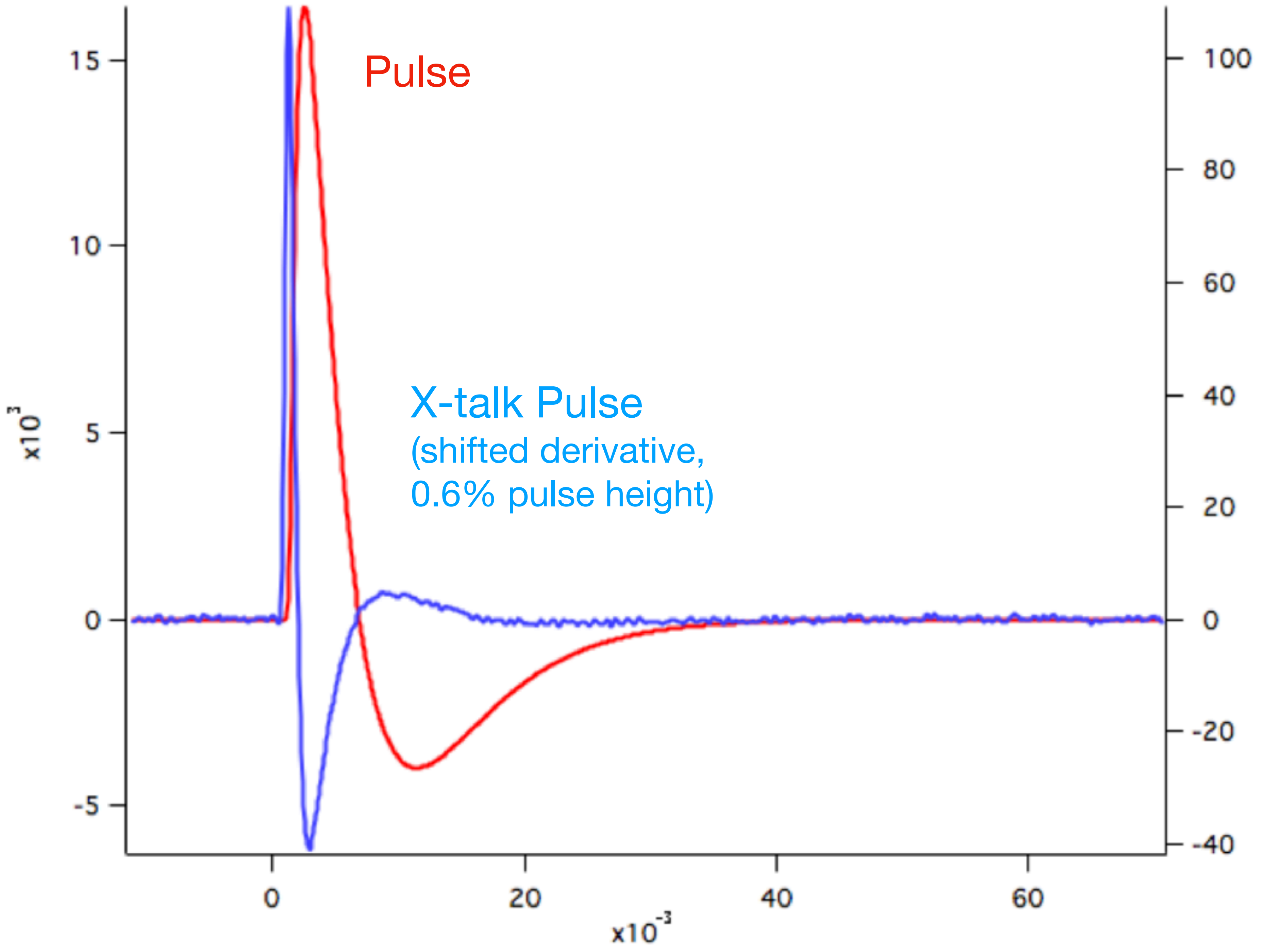
Cross Talk

- Signals in the wire from one pixel induce signals in neighboring wires with an amplitude proportional to the event energy
- Cross-talk signals are generally too weak to be detected as "events" but add noise that reduces the energy resolution of H+Mp events

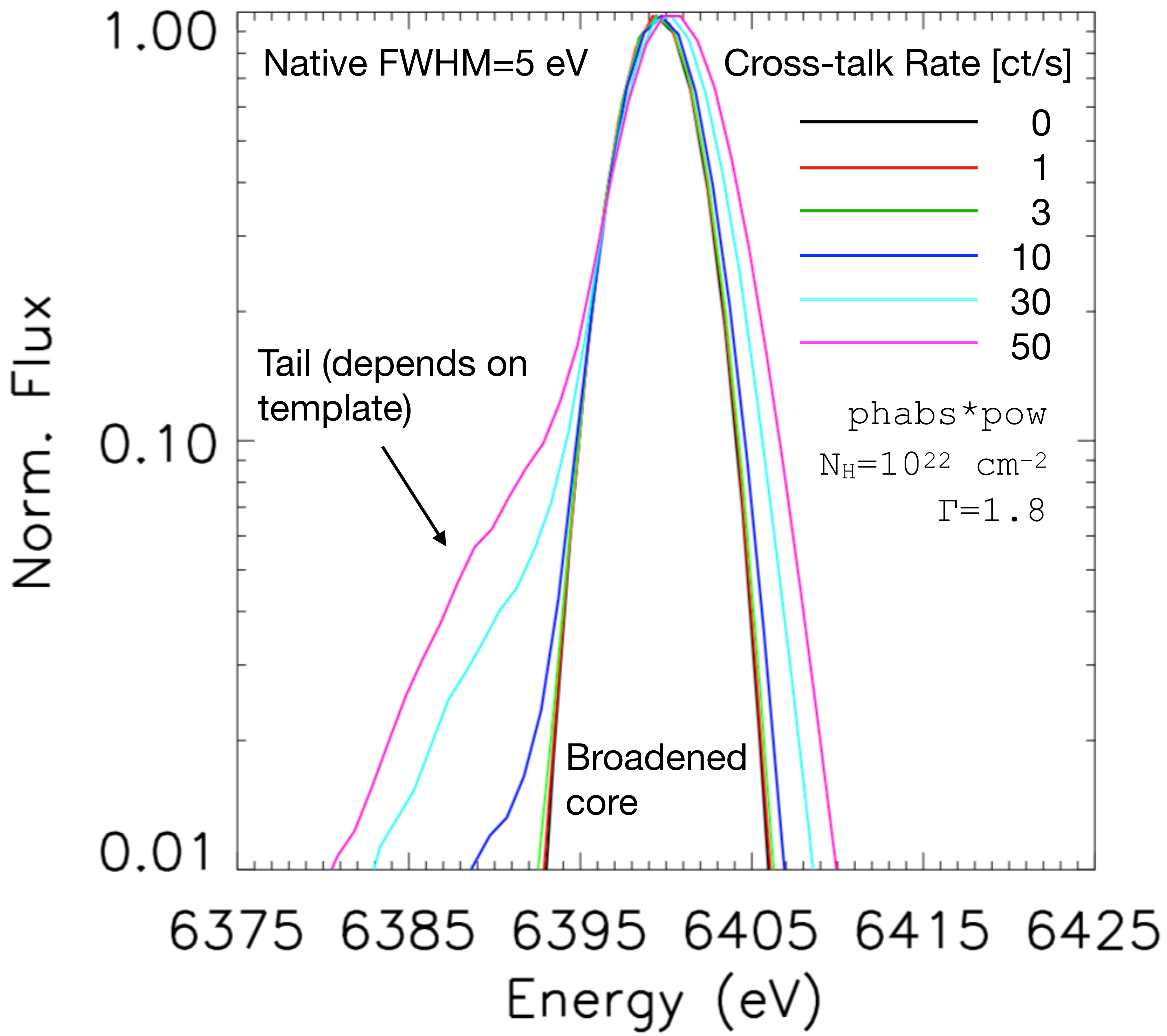


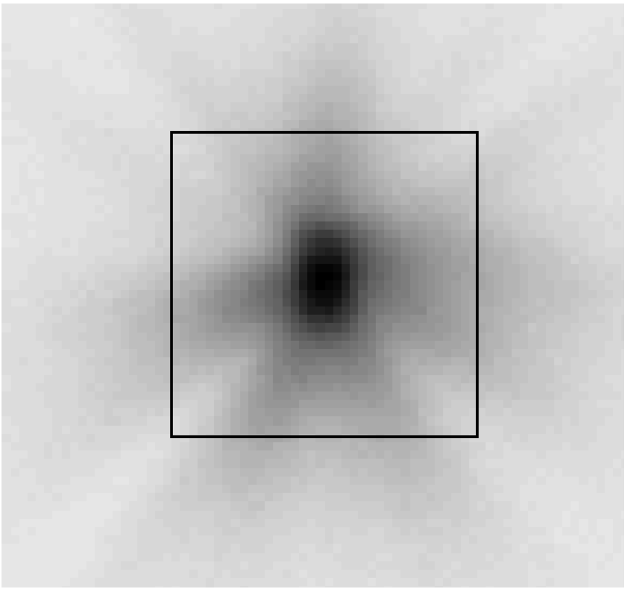
30	32	34	26	24	23
29	31	33	25	22	21
27	28	35	18	20	19
1	2	0	17	10	9
3	4	7	15	13	11
5	6	8	16	14	

12



Cross Talk



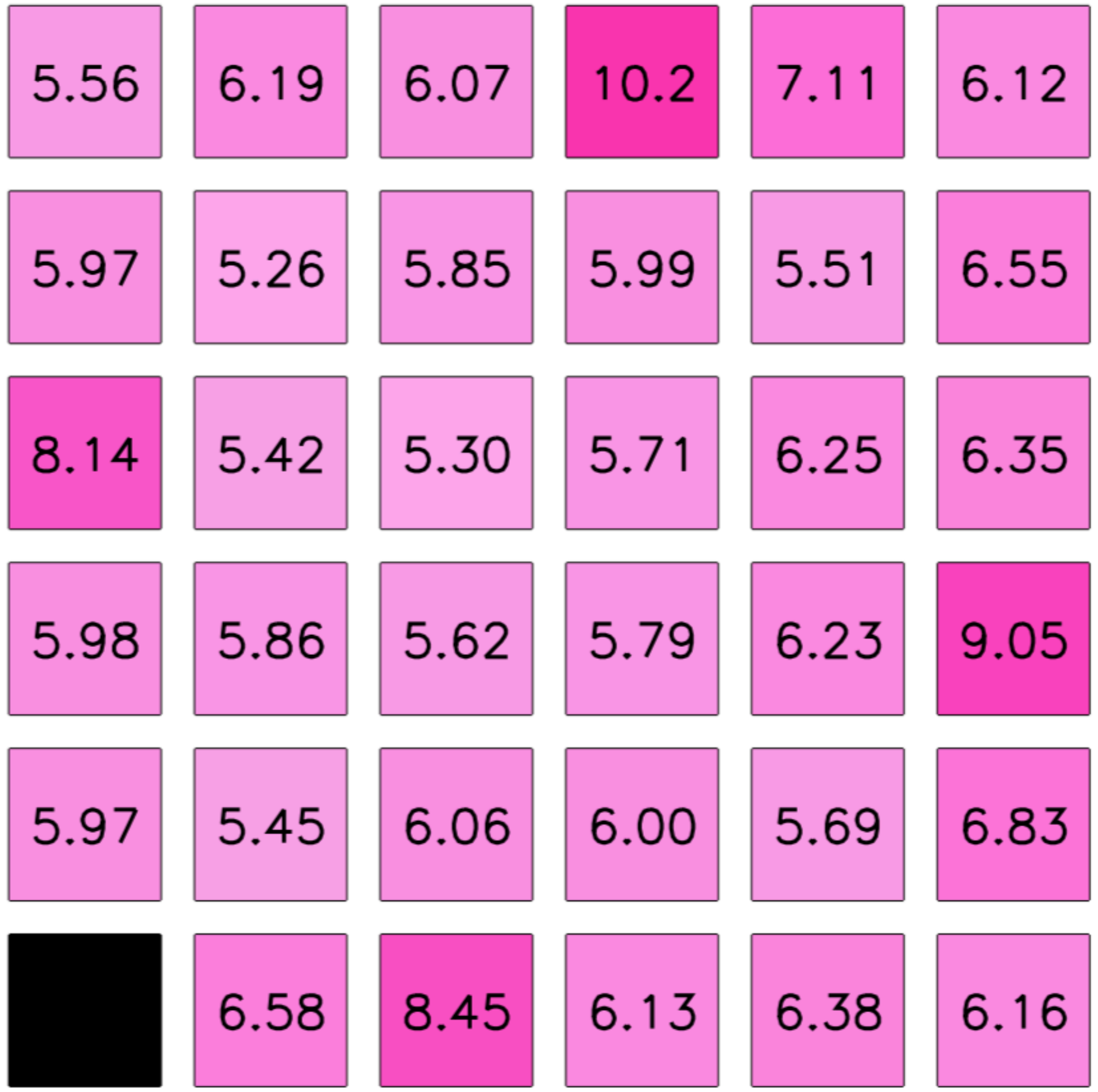


phabs(pow+gauss)

$N_H = 1 \times 10^{21}$ cm^{-2}
$\Gamma = 1.8$
$E_{line} = 6.4$ keV
$F_{line} = 1 \times 10^{-9}$ erg/s
$F_X = 2.4 \times 10^{-8}$ erg/s [2-10 keV]

5 eV native FWHM

1 Crab
Gate Valve Open



5.56	6.19	6.07	10.2	7.11	6.12
5.97	5.26	5.85	5.99	5.51	6.55
8.14	5.42	5.30	5.71	6.25	6.35
5.98	5.86	5.62	5.79	6.23	9.05
5.97	5.45	6.06	6.00	5.69	6.83
■	6.58	8.45	6.13	6.38	6.16

ΔE [eV, FWHM]

Cross talk broadens lines *and* shifts centroids

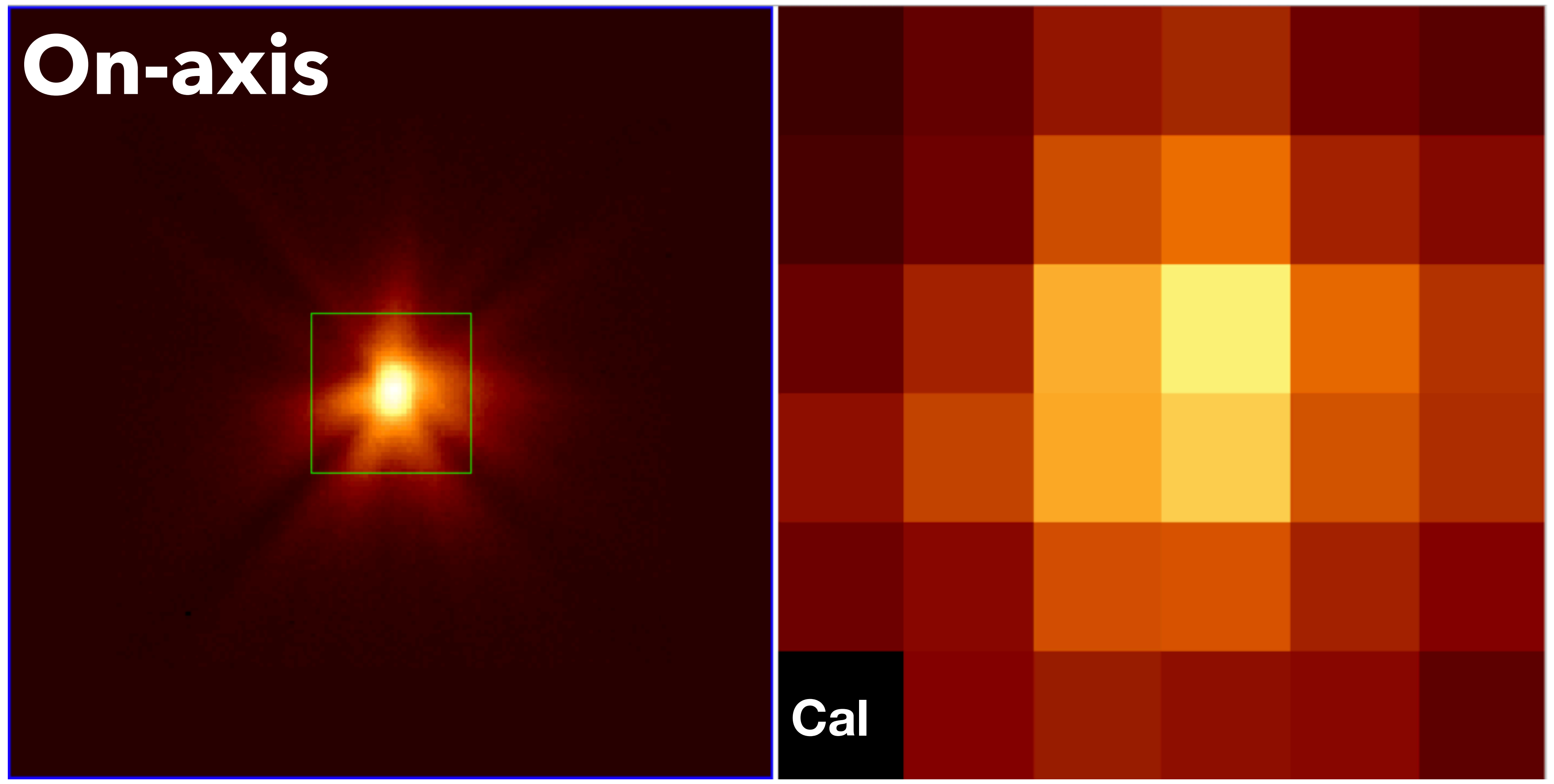
Energy resolution in each pixel for an on-axis, 1 Crab source due to cross talk (native resolution is 5 eV)

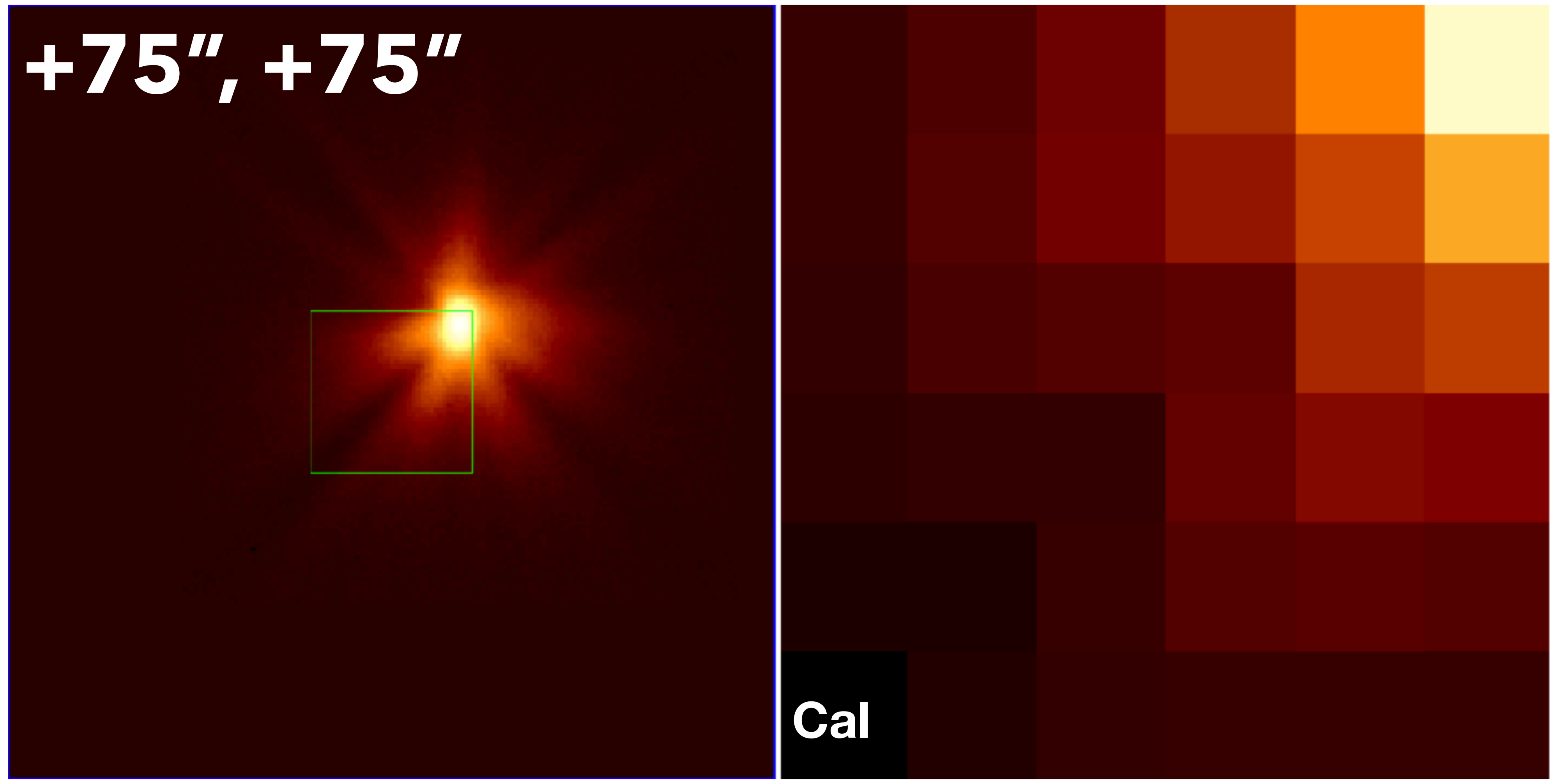
Observing Bright Sources

Observing Bright Sources

- Goal: Maximize H+Mp event rate
  - Off-axis pointing
  - Be25 filter, neutral density filter [mostly irrelevant for GV-closed]

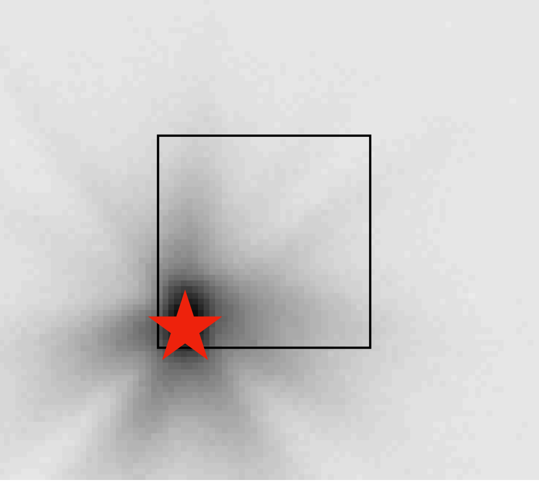
Observing Bright Sources





- Off-axis pointing reduces the incident flux (normally bad!) but can help maximize H+Mp rate
- Sacrificing a quadrant to low-resolution events can also help
- `heasim` already includes a way to estimate the H+Mp rate for an input spectrum and the PSP limit

Observing Bright Sources

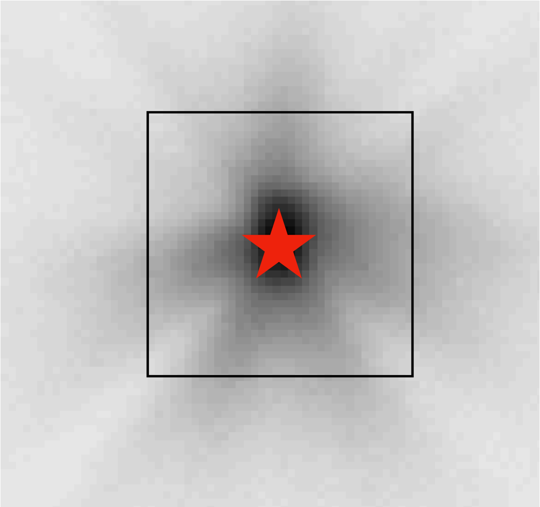


1 Crab
Off-axis

ΣH+Mp=44.8

H+Mp Rate [counts/s after PSP]

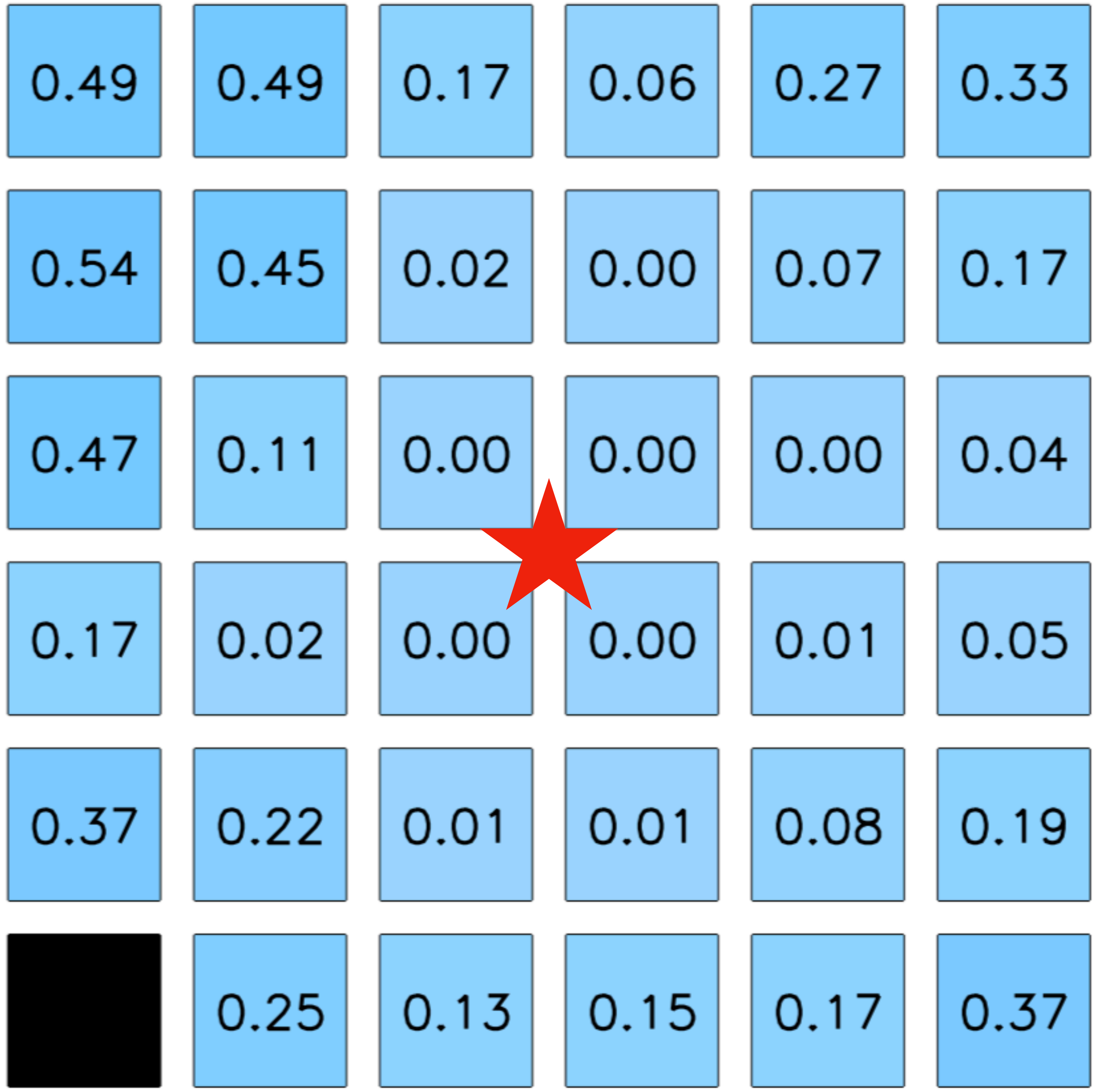
1.68	1.64	1.08	2.37	1.72	1.11
1.57	1.71	1.40	2.75	1.82	2.43
0.75	1.31	1.70	3.44	3.55	2.86
0.02	0.09	0.25	1.29	1.28	0.95
0.00	0.00	0.04	0.69	1.26	1.30
★	0.00	0.01	0.44	1.02	1.31



1 Crab
On-axis

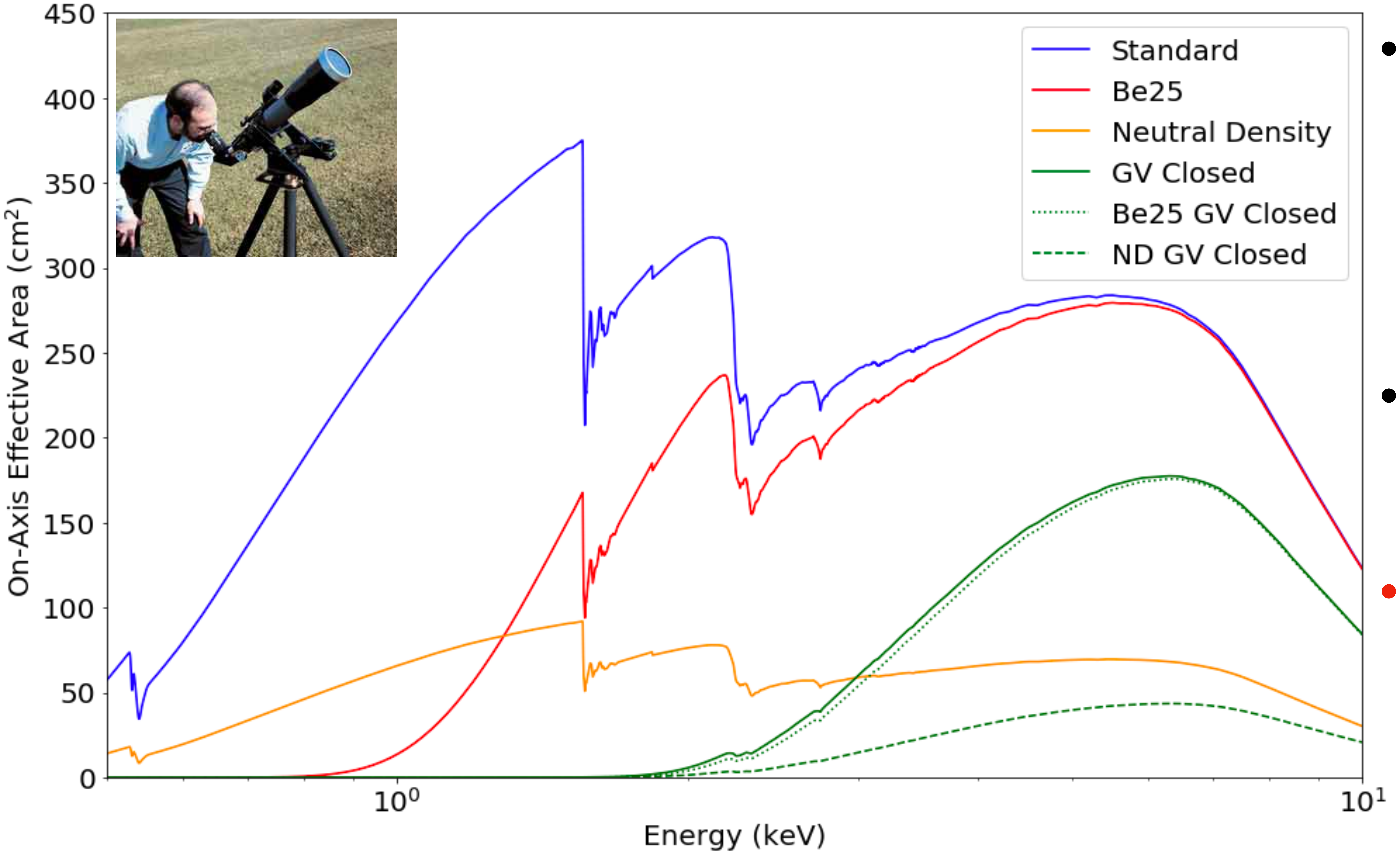
ΣH+Mp=5.9

H+Mp Rate [counts/s after PSP]



0.49	0.49	0.17	0.06	0.27	0.33
0.54	0.45	0.02	0.00	0.07	0.17
0.47	0.11	0.00	0.00	0.00	0.04
0.17	0.02	0.00	0.00	0.01	0.05
0.37	0.22	0.01	0.01	0.08	0.19
■	0.25	0.13	0.15	0.17	0.37

Observing Bright Sources

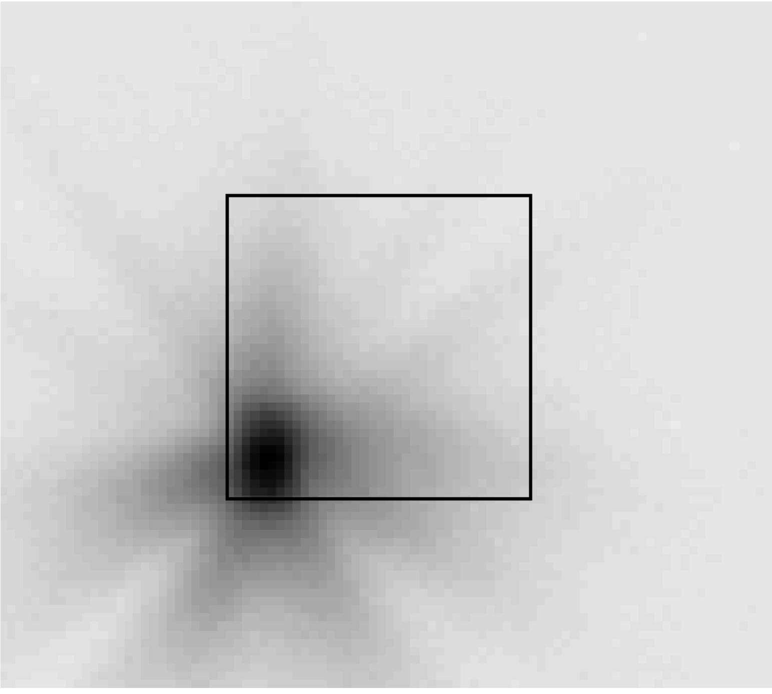


- Power-law spectra typically have the largest photon flux at low energies. Be25 filter can remove most low-energy photons and preserves Fe K region
- Neutral density filter can be a good option if the source is extremely bright
- Filters, especially Be-25, are less useful with the gate valve closed

Analyzing Bright Source Data

- Most science cases, focusing on lines/features, simply select only H+Mp events
- Select Clean Events
  - Iterate through each pixel and exclude time within ±10 ms of an cross-talk parent
  - Be wary of very fine velocity structure (compared to line-spread function)
  - In some cases, just extract a spectrum from selected pixels to minimize cross talk
- Estimate total flux from FPGA data if events are lost
  - The FPGA event-finder records the number of events it found without measuring energy; lost events have the same energy spectrum

Analyzing Bright Source Data



phabs(pow+gauss)

N_H=1x10^{21} cm^{-2}
Γ=1.8
E_{line}=6.4 keV
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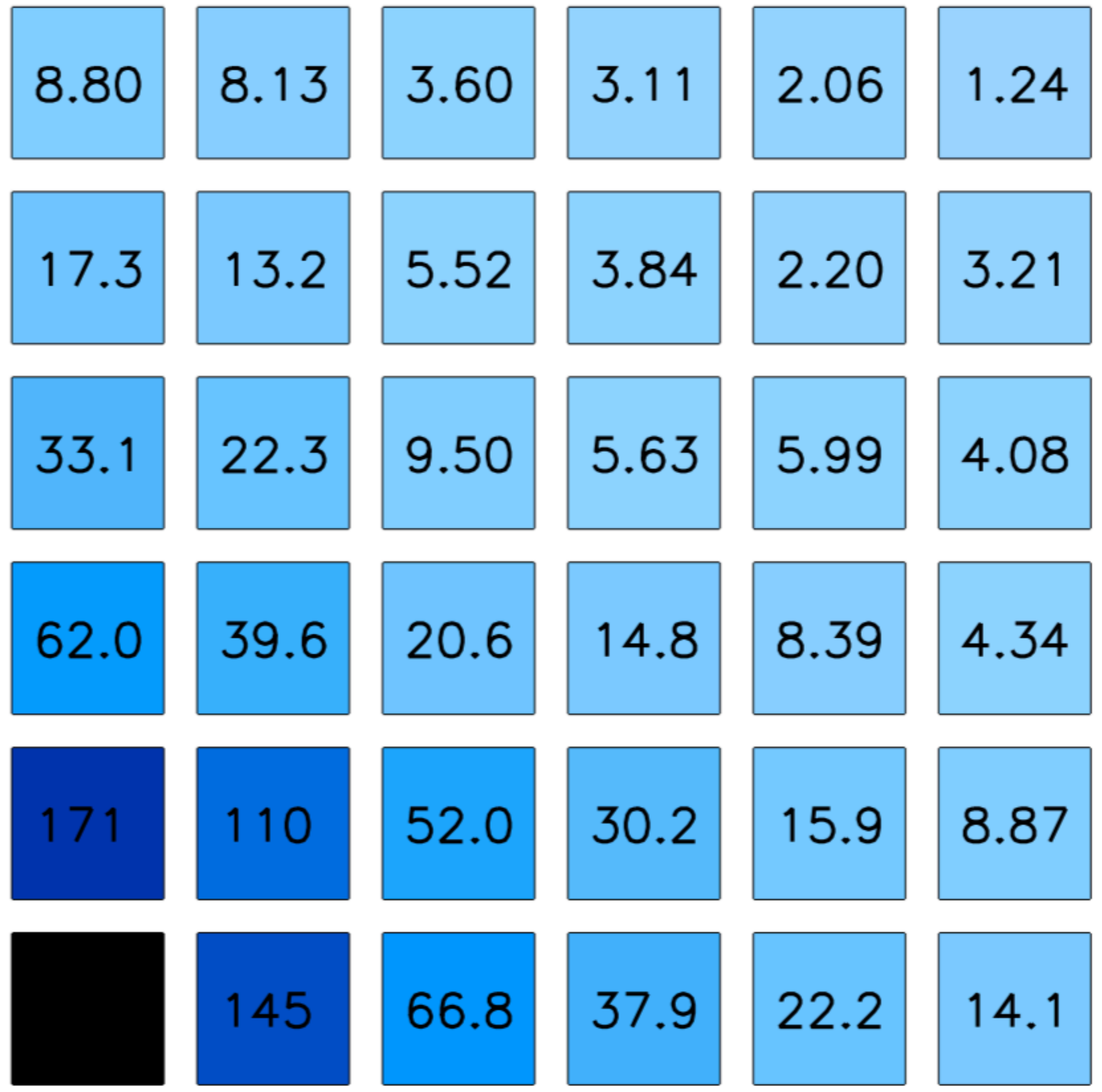
[2-10 keV]

5 eV native FWHM

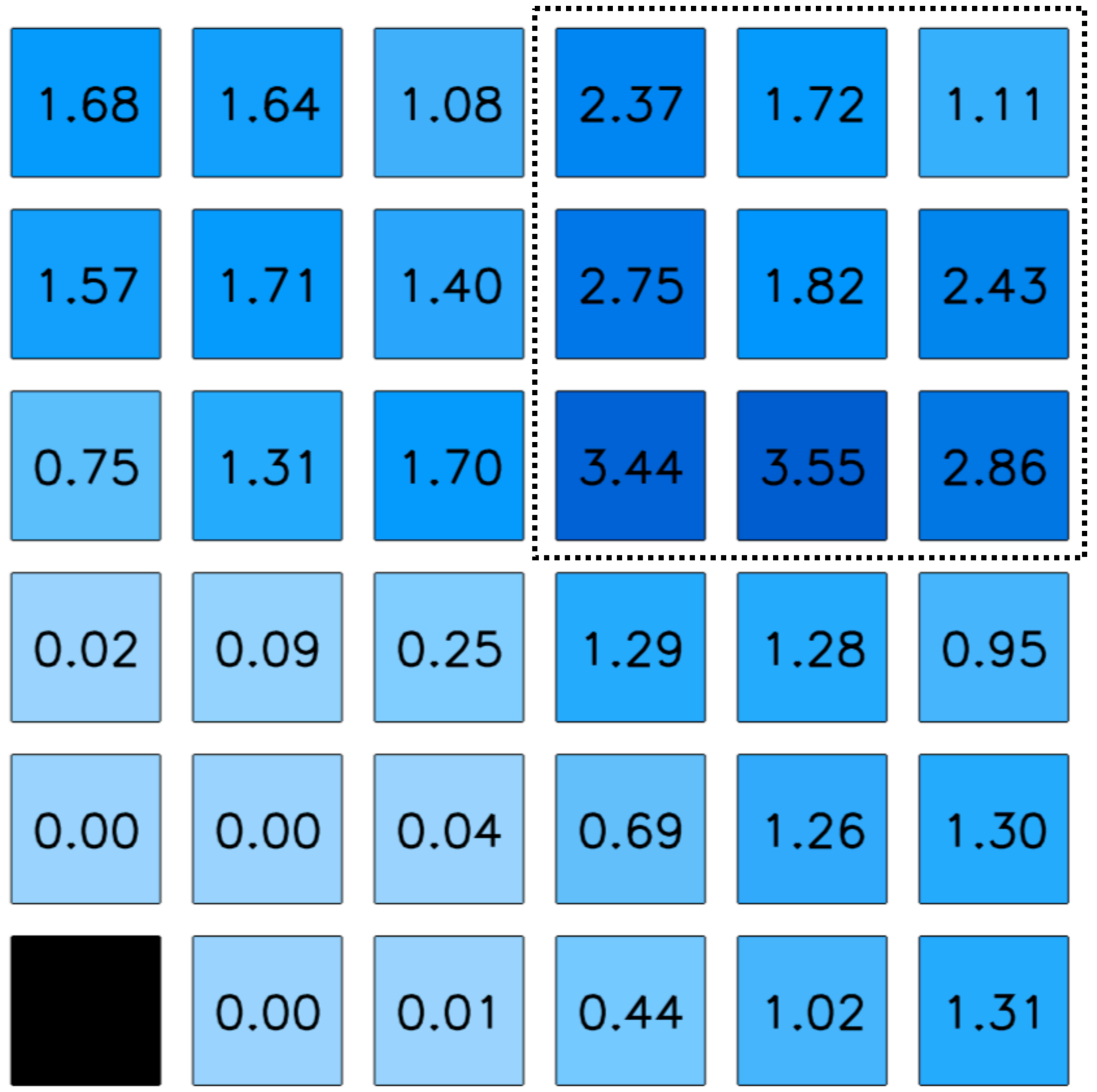
1 Crab

Incident Count Rate (raw)



8.80	8.13	3.60	3.11	2.06	1.24
17.3	13.2	5.52	3.84	2.20	3.21
33.1	22.3	9.50	5.63	5.99	4.08
62.0	39.6	20.6	14.8	8.39	4.34
171	110	52.0	30.2	15.9	8.87
	145	66.8	37.9	22.2	14.1

H+Mp rate (after PSP)



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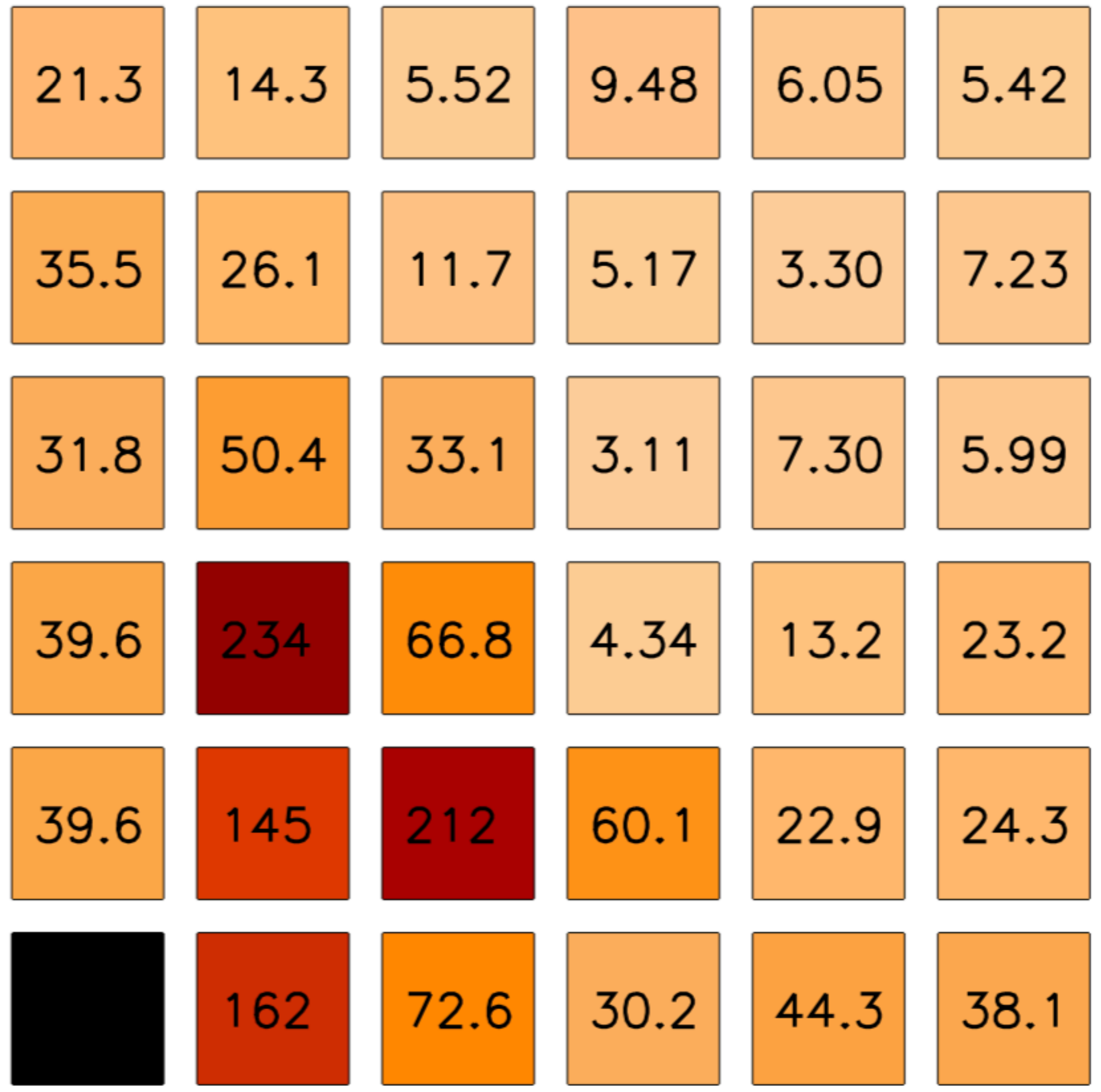
0.02	0.09	0.25	1.29	1.28	0.95
0.00	0.00	0.04	0.69	1.26	1.30
	0.00	0.01	0.44	1.02	1.31

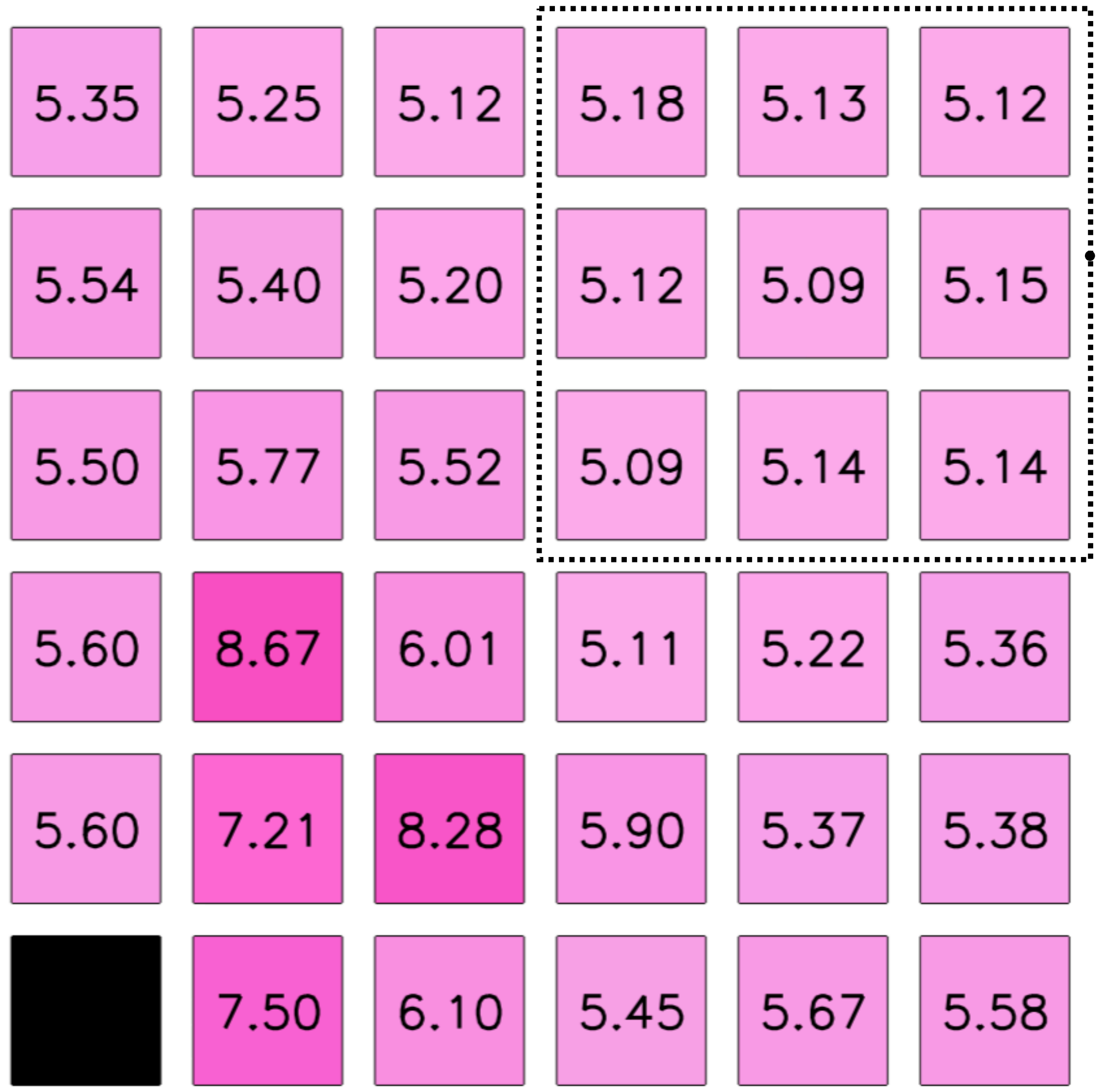
This quadrant has the highest rates per pixel…

Cross-talk Child Pulse Rate



21.3	14.3	5.52	9.48	6.05	5.42
35.5	26.1	11.7	5.17	3.30	7.23
31.8	50.4	33.1	3.11	7.30	5.99
39.6	234	66.8	4.34	13.2	23.2
39.6	145	212	60.1	22.9	24.3
	162	72.6	30.2	44.3	38.1

ΔE [eV, FWHM]



5.35	5.25	5.12	5.18	5.13	5.12
5.54	5.40	5.20	5.12	5.09	5.15
5.50	5.77	5.52	5.09	5.14	5.14
5.60	8.67	6.01	5.11	5.22	5.36
5.60	7.21	8.28	5.90	5.37	5.38
	7.50	6.10	5.45	5.67	5.58

… and the least cross talk noise

Summary

- We hope and expect proposers to observe bright sources
- Above 100 mCrab (~500 mCrab with the gate valve closed), maximizing the high-resolution count rate requires creative observing strategies
- The optimal solution depends on the spectral shape as well as the flux
- Electrical cross-talk can degrade the energy resolution of each pixel in different ways. A combination of off-axis pointing and excluding the most affected pixels can keep this to a small fraction of the native resolution

APPENDIX

CPU Load

Resolve Count Rate Limits

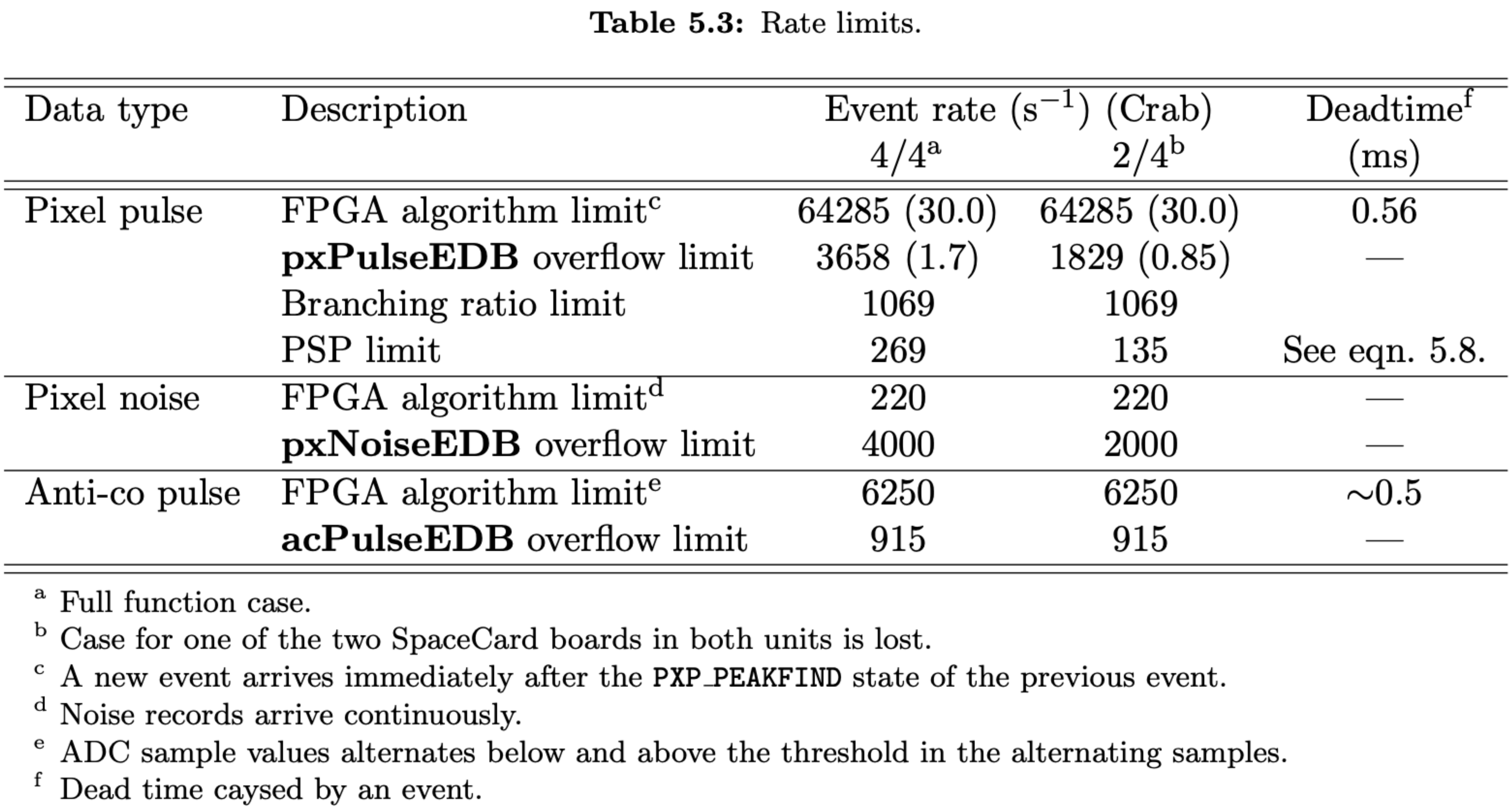


Table 5.3: Rate limits.

Data type	Description	Event rate (s^{-1}) (Crab) 4/4[a]	2/4[b]	Deadtime[f] (ms)
Pixel pulse	FPGA algorithm limit[c]	64285 (30.0)	64285 (30.0)	0.56
	pxPulseEDB overflow limit	3658 (1.7)	1829 (0.85)	—
	Branching ratio limit	1069	1069	
	PSP limit	269	135	See eqn. 5.8.
Pixel noise	FPGA algorithm limit[d]	220	220	—
	pxNoiseEDB overflow limit	4000	2000	—
Anti-co pulse	FPGA algorithm limit[e]	6250	6250	~0.5
	acPulseEDB overflow limit	915	915	—

[a] Full function case.

[b] Case for one of the two SpaceCard boards in both units is lost.

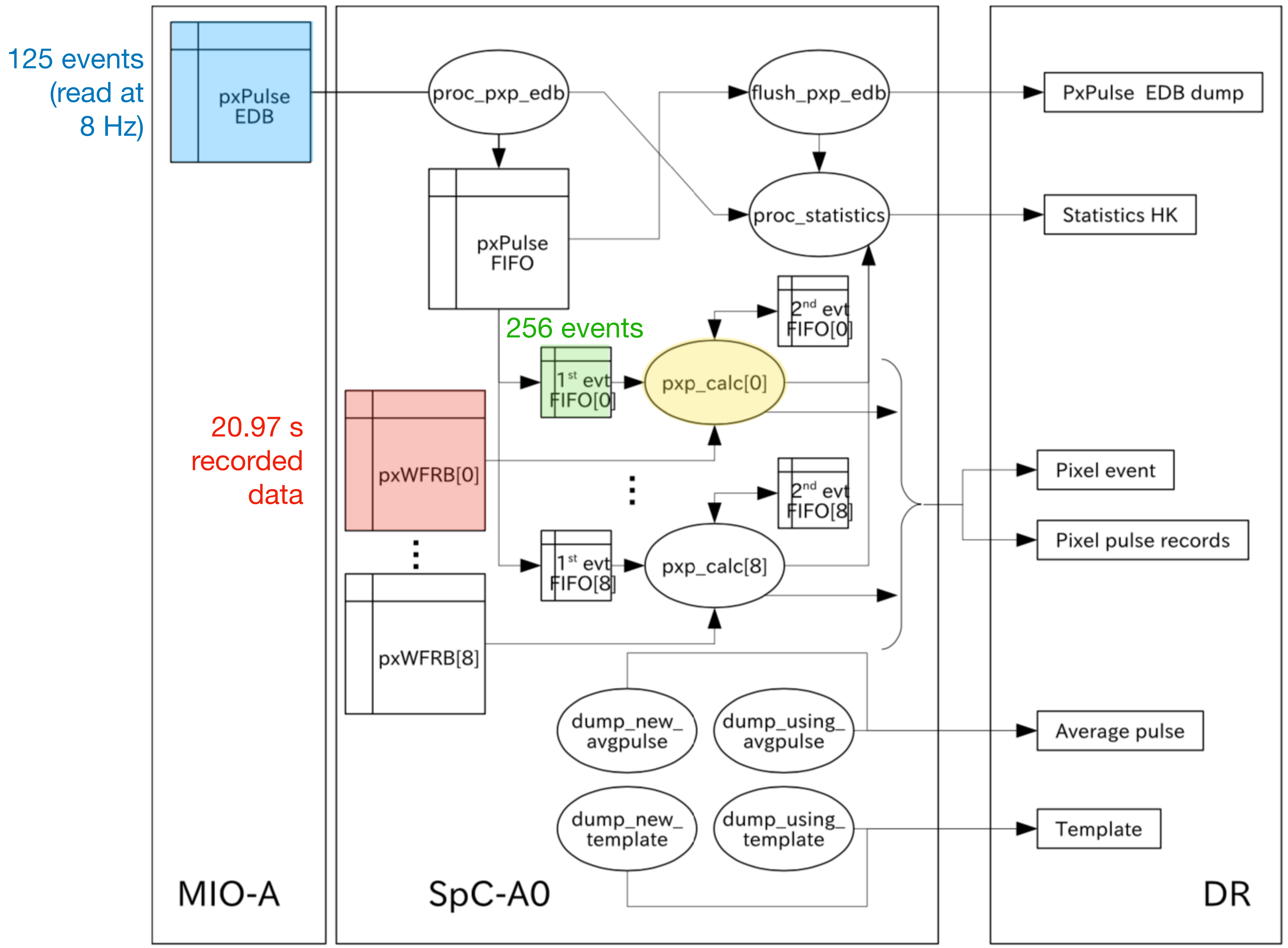
[c] A new event arrives immediately after the `PXP_PEAKFIND` state of the previous event.

[d] Noise records arrive continuously.

[e] ADC sample values alternates below and above the threshold in the alternating samples.

[f] Dead time caysed by an event.

Event Processing Diagram



Event candidates detected in the MIO board are stored in an “event dual buffer” and read by the SpC board at 8 Hz. When events are read in (by proc_pxp_edb), they are distributed among pixels into FIFO buffers 1-9. The data stream is also copied over and stored in the pxWFRB waveform ring buffer for each pixel.

When an event is ready to be processed, the pxp_calc task runs the optimal filtering and other tasks. It reads in the event data, locates the event in the WFRB data stream, and processes it. This includes checking to see if it’s a real event, categorizing it as high, medium, or low-res, searching for secondaries, and measuring the energy.

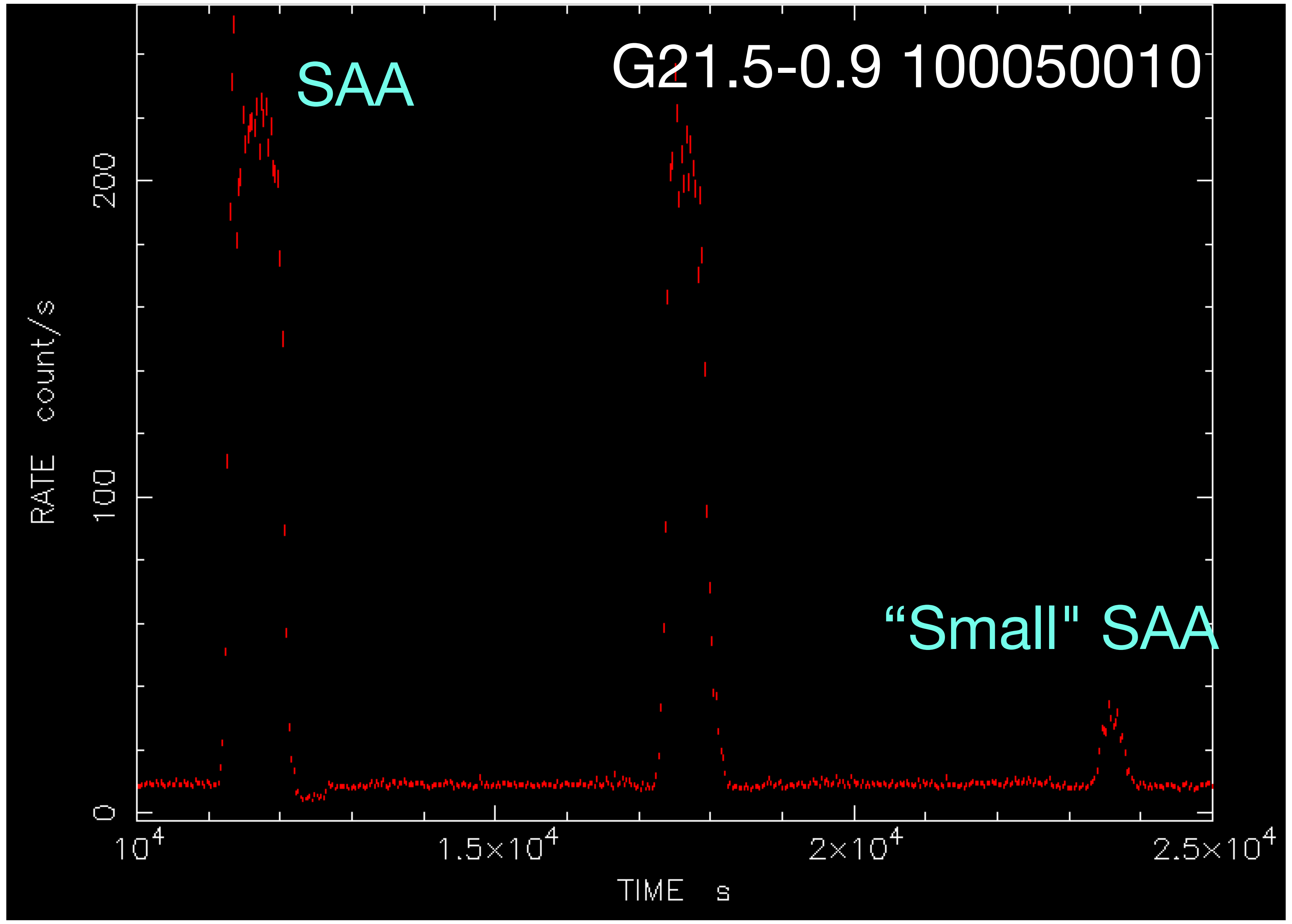
The pxp_calc tasks are run simultaneously. They all have the same priority in the operating system for the SpaceCard CPU (TOPPERS). Within a priority level, if the CPU has spare capacity then it will begin running the next available process. Once a pixel has processed an event, that pxp_calc thread schedules itself at the back of the queue for its priority level. This is “round robin” scheduling.

Event Processing

- Each pixel has a task to process events (pxp_calc[i]), an event log, and a data stream.
- If an event enters the buffer, pxp_calc[i] wakes up and processes it. Afterwards, pxp_calc[i] returns to sleep unless there is another event waiting.
- If there is an event waiting, pxp_calc[i] moves itself to the back of the line. The CPU scheduler activates the next task in line as it has capacity. This is ‘round robin’ scheduling. Multiple pxp_calc tasks can be active.
- Note that pixels may process different numbers of events. Hp events take longer to process than Lp events. If pxp_calc[i] finishes but no other tasks are ‘done,’ the CPU will select pxp_calc[i] next by default. This still favors H/M events.
- Events are lost on a per-pixel basis unless the FPGA event dual buffer overflows. **At low count rates, pixels may never lose events even at 100% CPU load.**
- Live time (per pixel) and H+M rate can be more accurately predicted if we know the CPU load per event.

CPU Load per Event

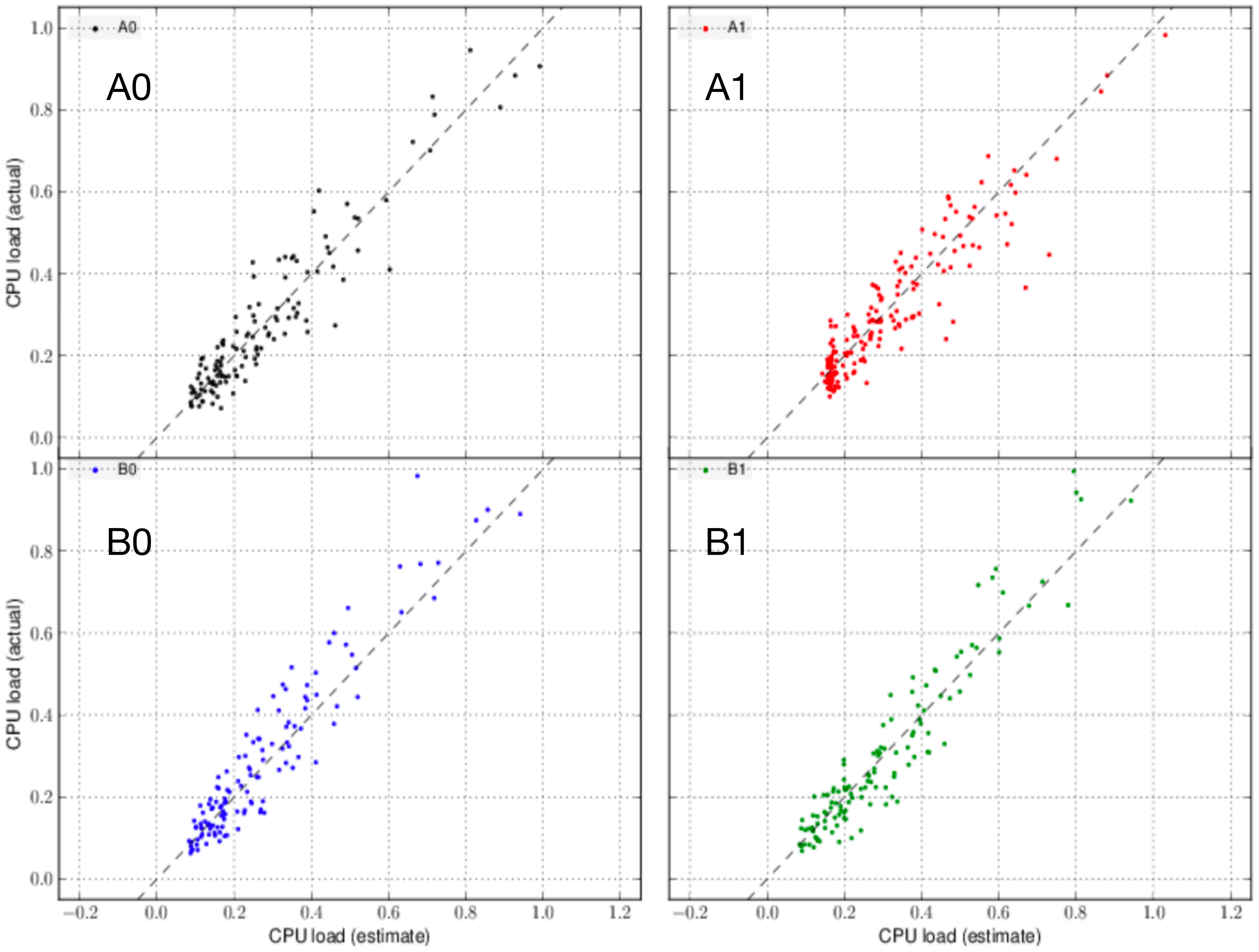
$$
\begin{aligned}
(\text{CPU load}) = {} & a\sum_{\text{IPIX}}(\text{Hp count}) + b\sum_{\text{IPIX}}(\text{Mp} + \text{Ms count}) \\
& + c\sum_{\text{IPIX}}(\text{Lp} + \text{Ls count}) \\
& + d\sum_{\text{IPIX}}(\text{FPGA count}) + e,
\end{aligned}
$$



- Model Hitomi data at moderate/high count rate.
- CPU has 1000 ms to "spend." Use average count rate to estimate CPU load per event. Assume each CPU is identical with the same base load.
- Secondary events are found recursively, but we measure the *average* time per event.
- Use periods when count rate exceeds baseline (to get many low-res events) but is not saturated ("small" SAA).

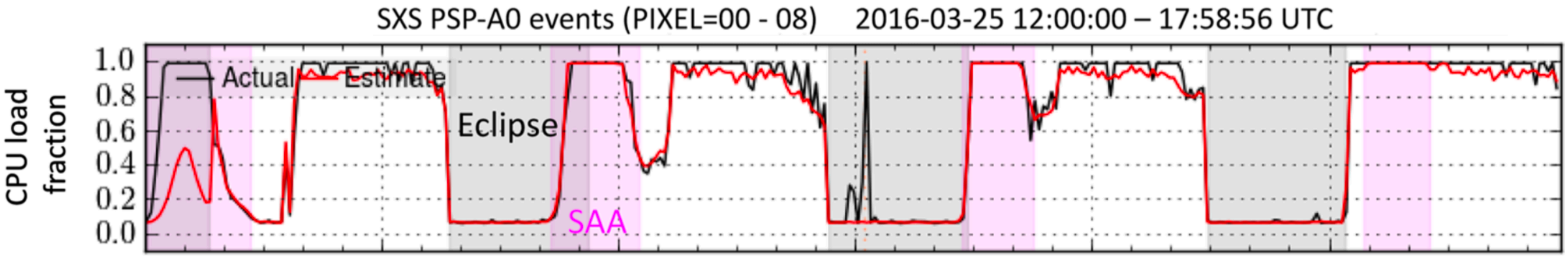
Tsujimoto 2016, Ishisaki+2018

CPU Load per Event



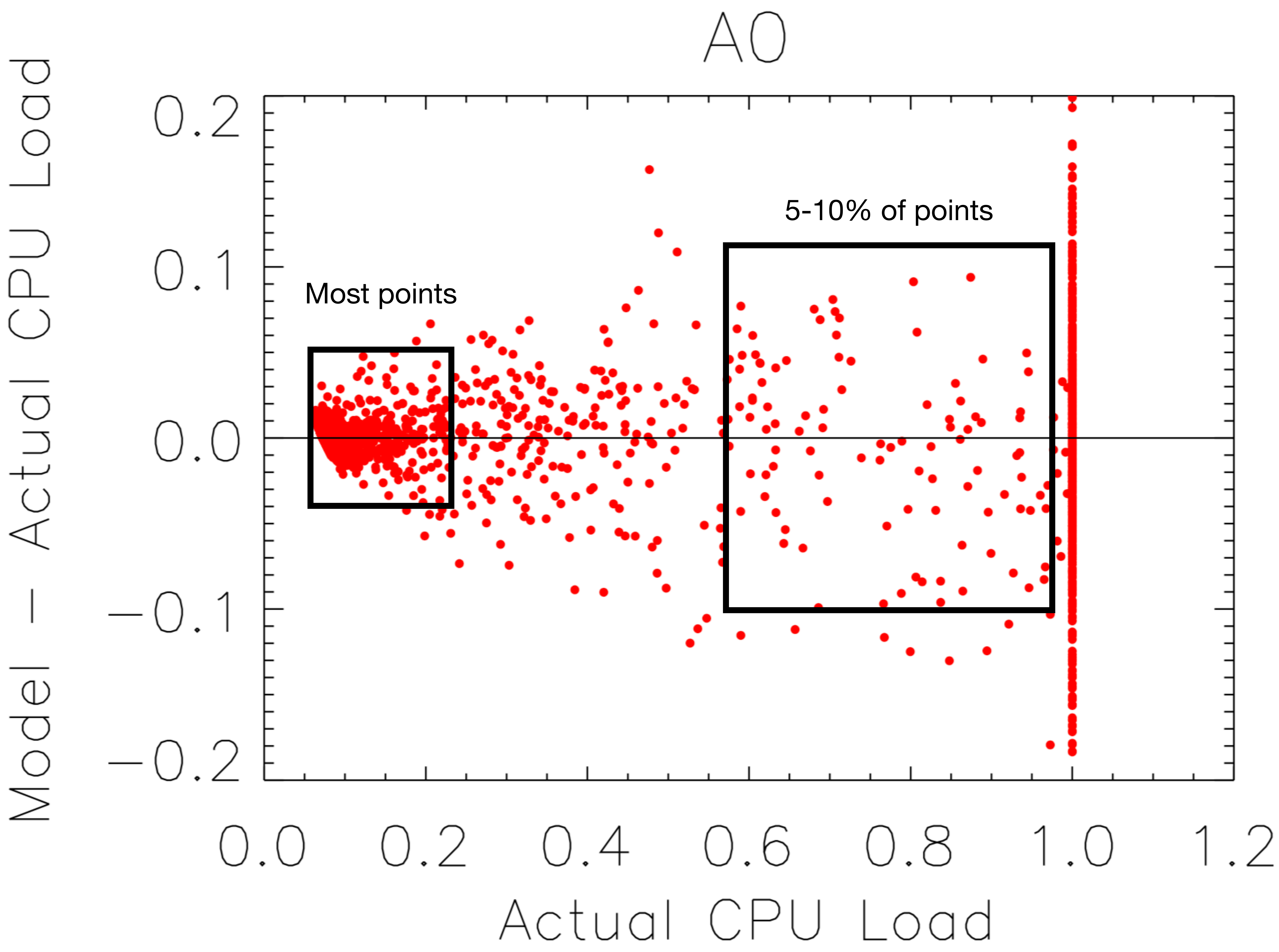
```
[[Fit Statistics]]
    # function evals   = 291
    # data points      = 542
    # variables        = 5
    chi-square         = 2.353
    reduced chi-square = 0.004
    Akaike info crit   = -2933.281
    Bayesian info crit = -2911.804
[[Variables]]
    a:    0.01336677 (init= 0.03)
    b:    0.01468106 (init= 0.03)
    c:    0.00016663 (init= 0.001)
    d:    0.00045255 (init= 0.001)
    e:    0.06598735 (init= 0.08)
[[Correlations]] (unreported correlations are <  0.100)
```

Simple model reproduces Hitomi Crab data


SXS PSP-A0 events (PIXEL=00 - 08)   2016-03-25 12:00:00 – 17:58:56 UTC

Tsujimoto 2016, Ishisaki+2018

CPU Load per Event

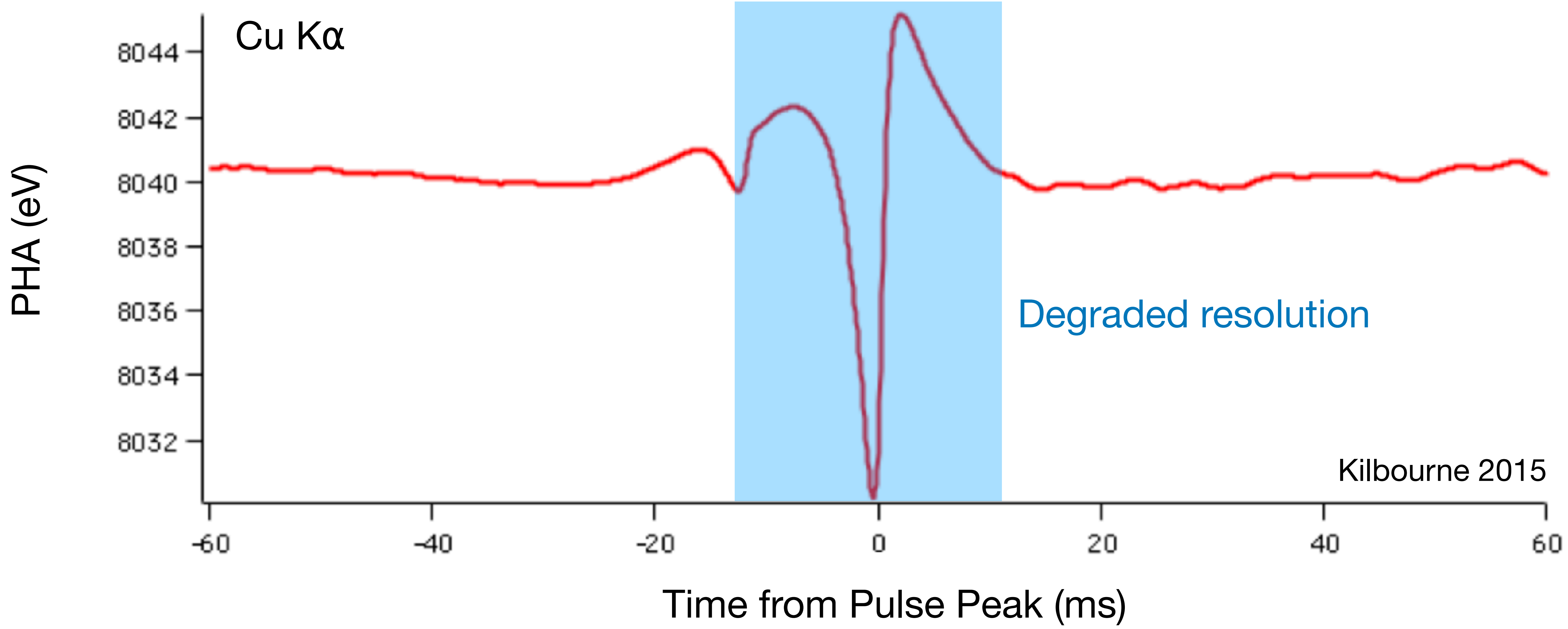


- The model is degenerate because there are few periods where Hitomi experienced a moderate count rate
- Data stream dominated by high-resolution and low-resolution events
- Better calibration this time around
- New model to be developed

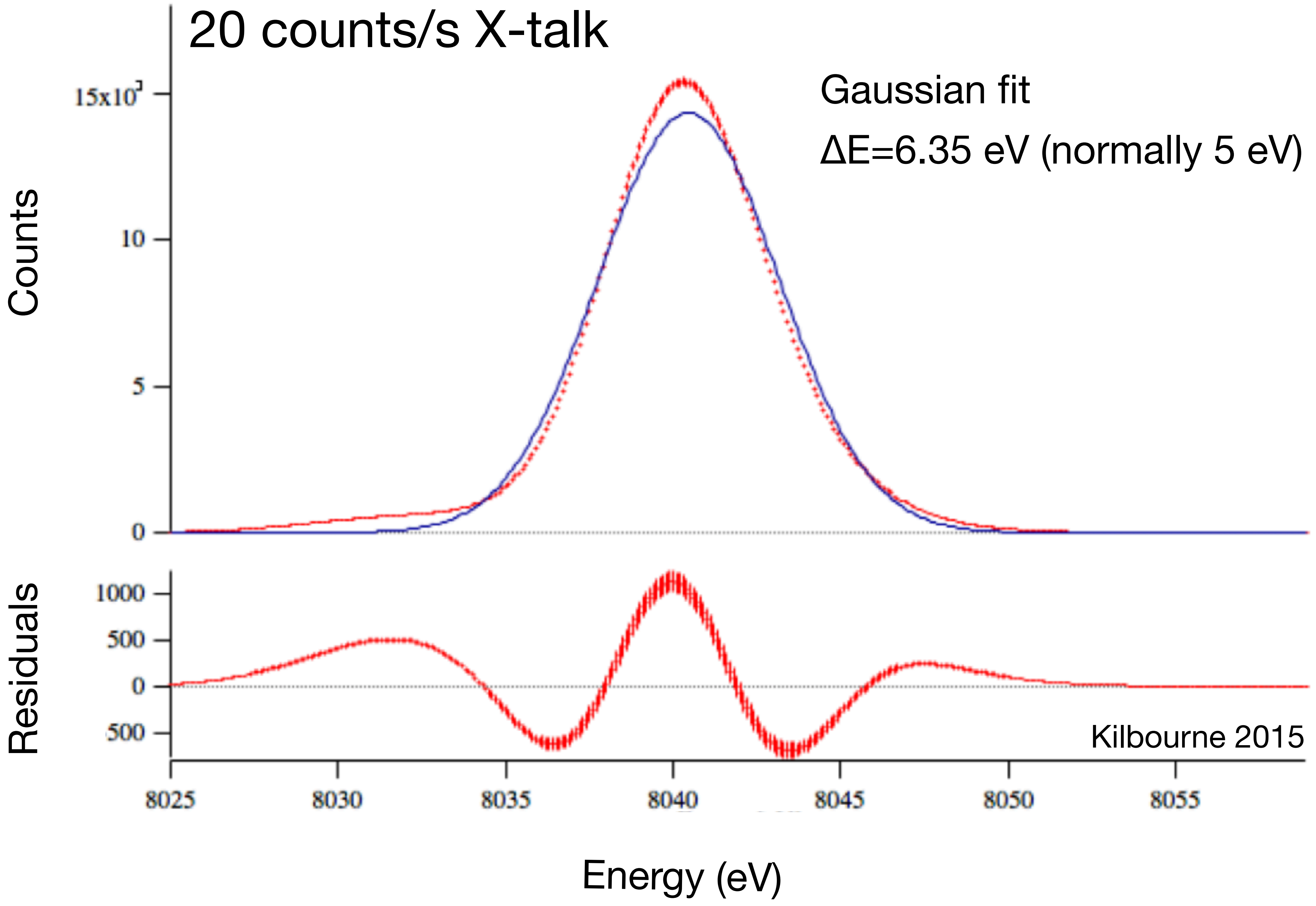
Electrical Cross-Talk

xTalk Impact

Measured pulse energy as a function of X-talk arrival time



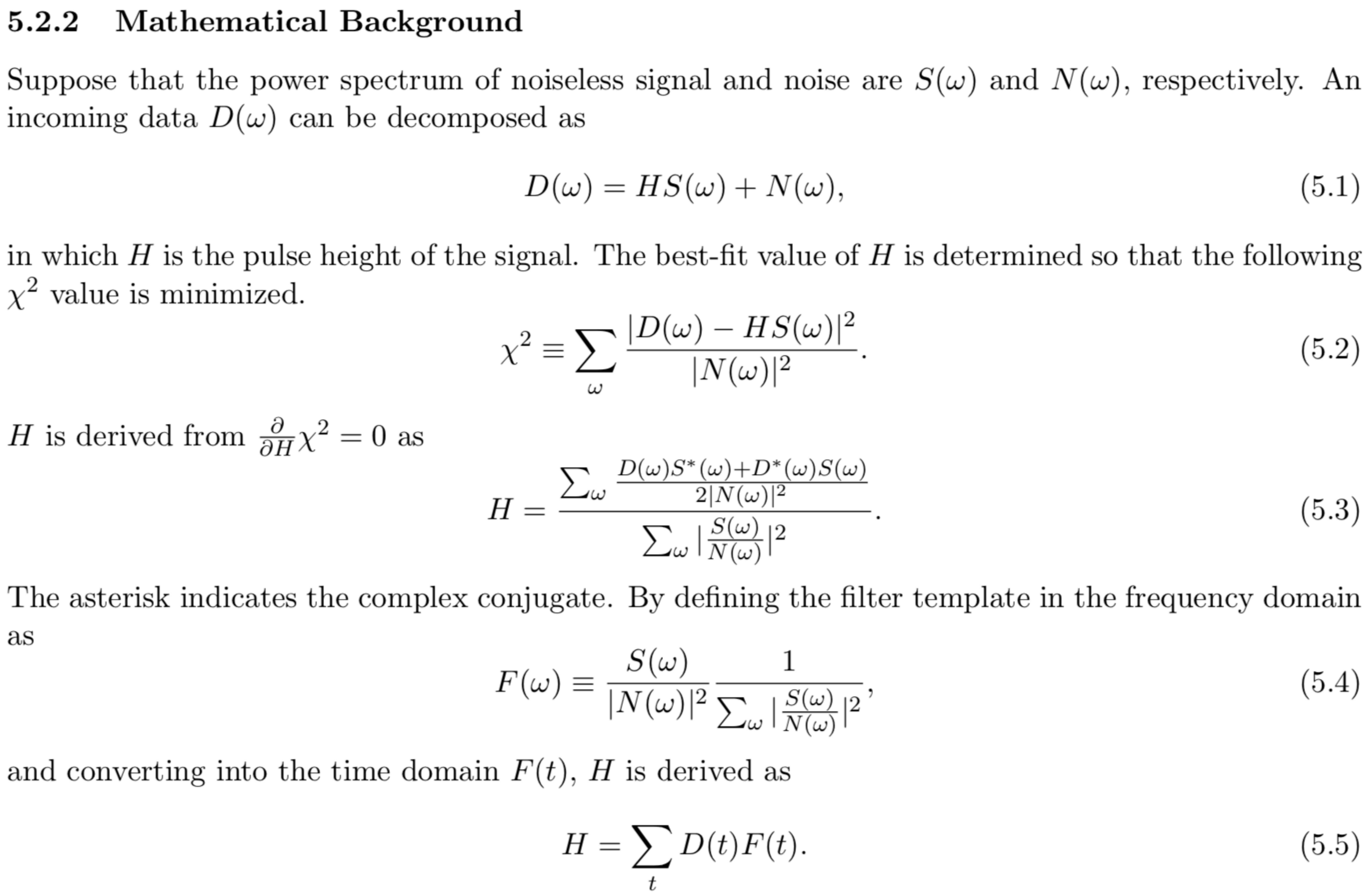
Kilbourne 2015



Kilbourne 2015

Untriggered X-talk can degrade energy resolution and perturb gain

xTalk Impact



5.2.2 Mathematical Background

Suppose that the power spectrum of noiseless signal and noise are $S(\omega)$ and $N(\omega)$, respectively. An incoming data $D(\omega)$ can be decomposed as

$$D(\omega) = HS(\omega) + N(\omega), \tag{5.1}$$

in which H is the pulse height of the signal. The best-fit value of H is determined so that the following χ^2 value is minimized.

$$\chi^2 \equiv \sum_{\omega} \frac{|D(\omega) - HS(\omega)|^2}{|N(\omega)|^2}. \tag{5.2}$$

H is derived from $\frac{\partial}{\partial H}\chi^2 = 0$ as

$$H = \frac{\sum_{\omega} \frac{D(\omega)S^*(\omega)+D^*(\omega)S(\omega)}{2|N(\omega)|^2}}{\sum_{\omega} |\frac{S(\omega)}{N(\omega)}|^2}. \tag{5.3}$$

The asterisk indicates the complex conjugate. By defining the filter template in the frequency domain as

$$F(\omega) \equiv \frac{S(\omega)}{|N(\omega)|^2} \frac{1}{\sum_{\omega} |\frac{S(\omega)}{N(\omega)}|^2}, \tag{5.4}$$

and converting into the time domain $F(t)$, H is derived as

$$H = \sum_{t} D(t)F(t). \tag{5.5}$$

xTalk Impact

Let $P(t)$ be the pulse profile for an event

$X(t)$ be the (shifted) X-talk child pulse profile

$\bar{P}(t)$ be the average pulse profile

$T(t)$ be the filter template for optimal filtering

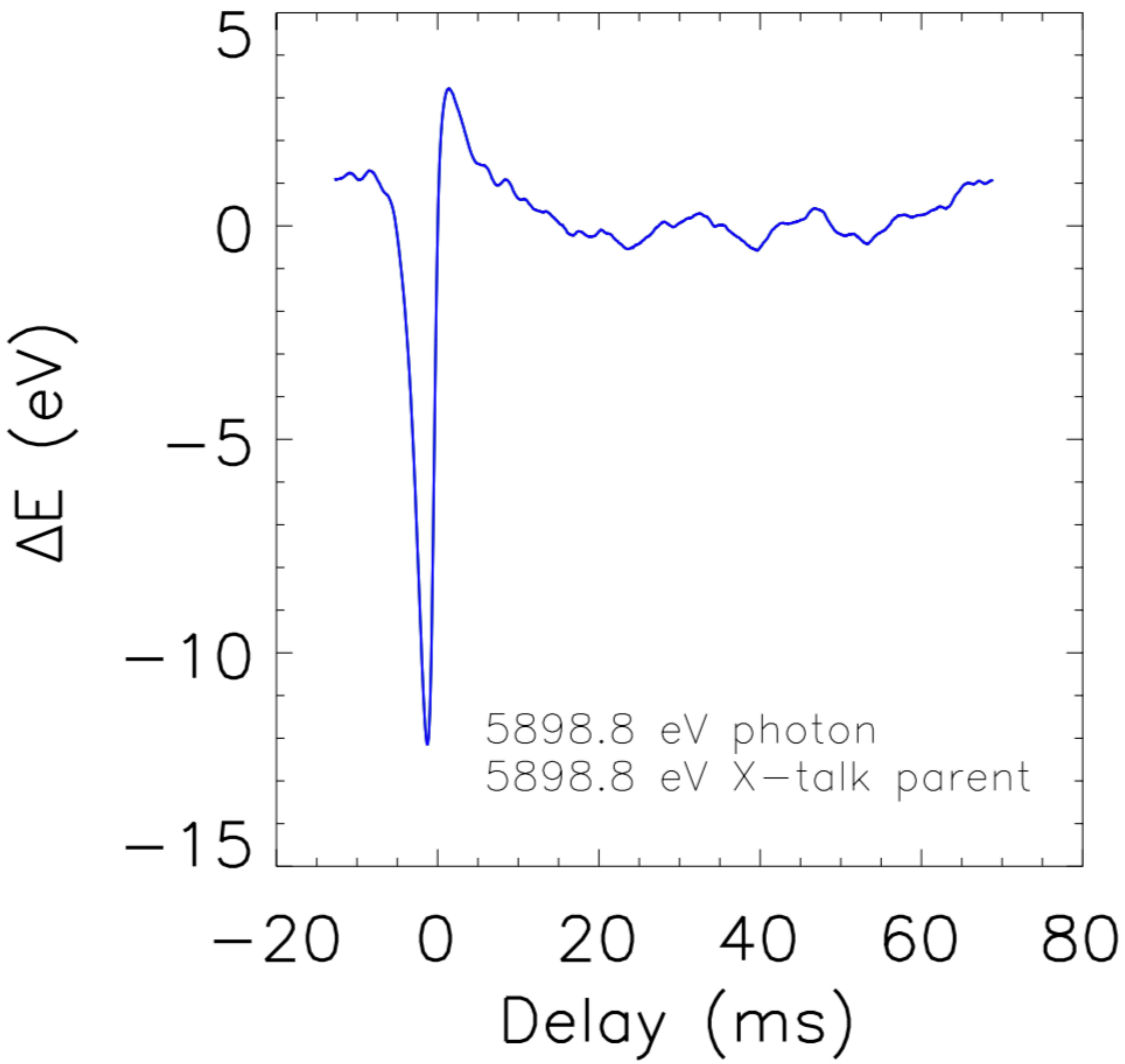
b be a normalization (144000 for 0.3 eV/channel)

Then $P'(t) = P(t) + X(t)$ is the contaminated pulse

$$\mathrm{PHA} = b\frac{\Sigma P'(t)T(t)}{\Sigma \bar{P}(t)T(t)}$$ is the PHA

$$\mathrm{PHA} = \frac{b}{\Sigma \bar{P}(t)T(t)}\left[\Sigma P(t)T(t) + \Sigma X(t)T(t)\right]$$

$$\Delta\mathrm{PHA} = b\frac{\Sigma X(t)T(t)}{\Sigma \bar{P}(t)T(t)}$$ is independent of P(t)



ΔPHA for a 5.9 keV Mn Ka photon as a function of xTalk delay relative to measured photon

xTalk Impact

Define the energy resolution

*X-talk broadening is not symmetric

$$\sigma = \sqrt{\sigma^2_{\mathrm{RMF}} + \sigma^2_{\mathrm{XT}}}$$

5 eV X-talk

Illuminate the array with a spectrum, folded through the ARF

$$F_\nu \rightarrow \dot{N}_i(E)$$

in pixel i

Assume all X-talk is undetected and calculate average number of contaminating pulses per event for electrical neighbors.

$$\dot{N}_i(E) \rightarrow \lambda_{i-1}, \lambda_{i+1}$$

Use Poisson sampling and random arrival times for 10^6 simulated events to create PHA distribution with native 5 eV. Fit with a Gaussian to measure σ and solve for σ_{XT}.

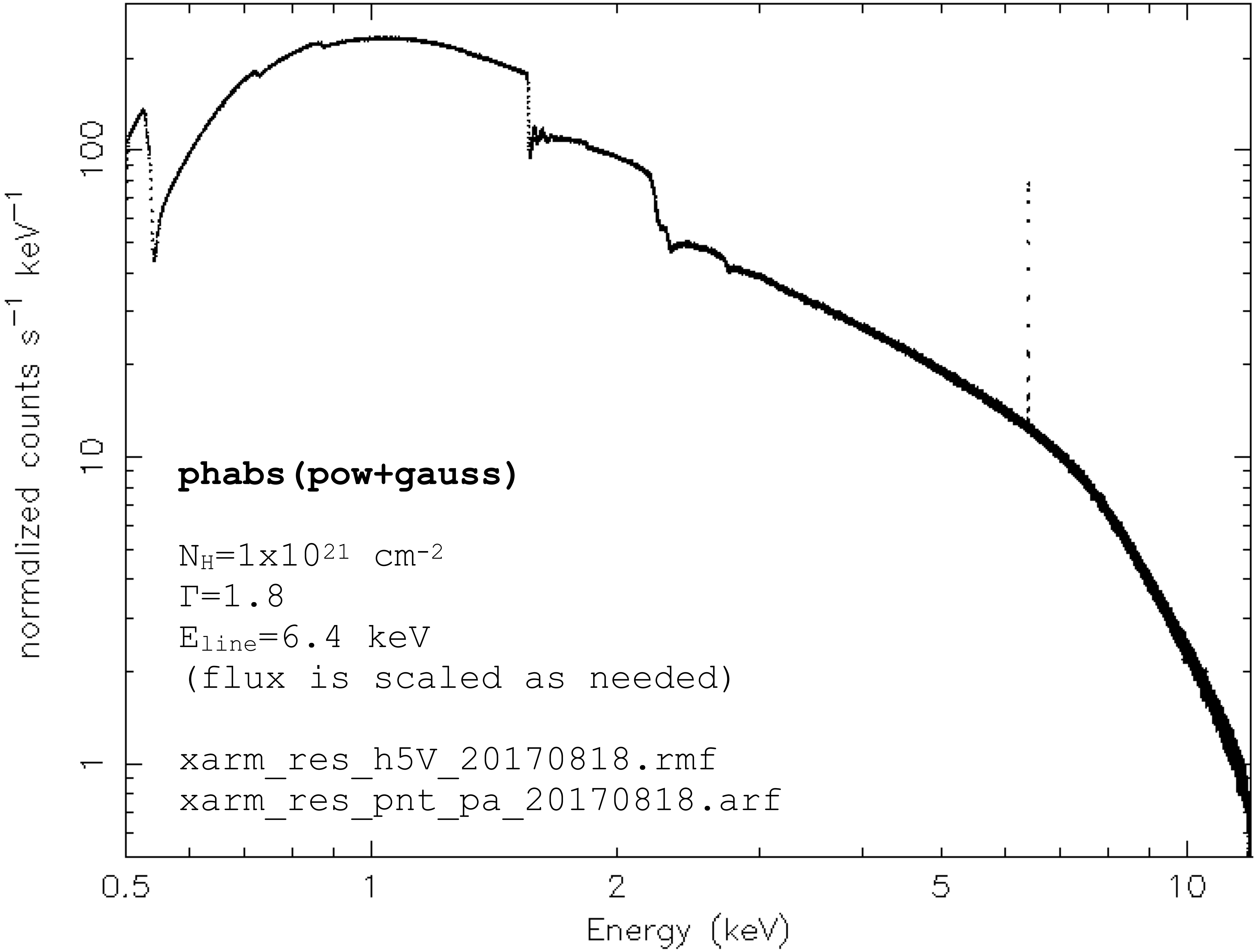
$$F_\nu, \lambda_i \rightarrow \sigma_i$$

Since σ depends only on X-talk rate and spectrum, can calculate a single σ per pixel.

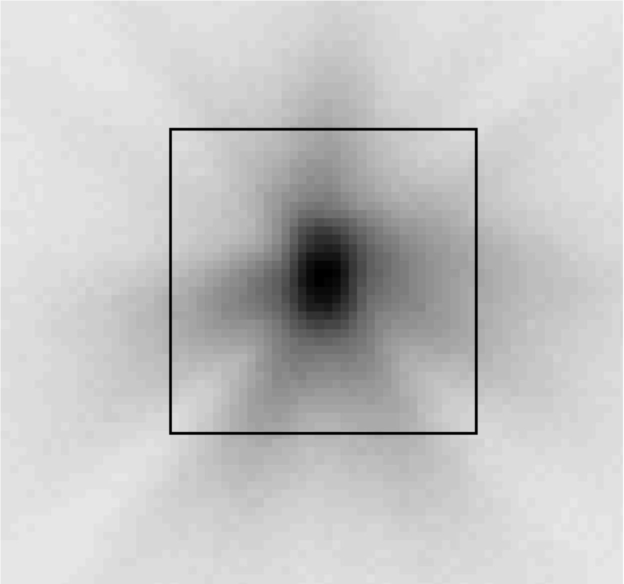
* Caveats: Assume no removal of known X-talk contamination, no secondary searches, Hp templates only, used a single pulse, X-talk, average pulse, and filter template for just one pixel.

xTalk Impact

- Let’s try it for an example spectrum



On-axis Line Broadening



phabs(pow+gauss)

N_H=1x10^{21} cm^{-2}
Γ=1.8
E_{line}=6.4 keV
F_{line}=1x10^{-9} erg/s
F_X= 2.4x10^{-8} erg/s
[2-10 keV]

5 eV native FWHM

1 Crab

Incident Count Rate (raw)

7.00	17.6	38.6	46.7	20.5	13.2
9.53	20.1	72.3	94.8	45.3	30.9
18.9	46.0	155	231	90.2	54.1
36.0	65.3	147	186	74.6	52.5
21.4	32.1	74.1	76.7	45.1	30.4
■	29.3	41.0	34.9	33.0	14.9

H+Mp rate (after PSP)

0.49	0.49	0.17	0.06	0.27	0.33
0.54	0.45	0.02	0.00	0.07	0.17
0.47	0.11	0.00	0.00	0.00	0.04
0.17	0.02	0.00	0.00	0.01	0.05
0.37	0.22	0.01	0.01	0.08	0.19
■	0.25	0.13	0.15	0.17	0.37

X-talk Child Pulse Rate

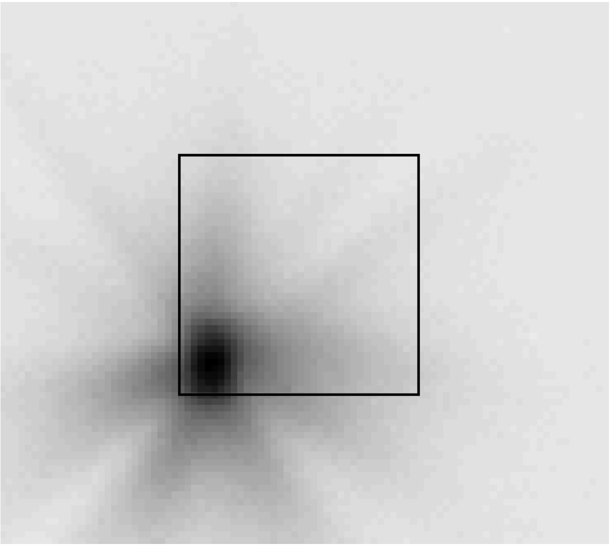
37.6	79.3	72.3	326	140	76.2
66.1	16.5	56.2	67.2	33.7	103
201	28.4	18.9	46.7	84.9	90.2
65.3	57.4	41.0	52.5	82.9	260
65.3	29.3	70.3	67.9	45.3	119
■	106	221	76.7	91.6	78.1

ΔE [eV, FWHM]

5.56	6.19	6.07	10.2	7.11	6.12
5.97	5.26	5.85	5.99	5.51	6.55
8.14	5.42	5.30	5.71	6.25	6.35
5.98	5.86	5.62	5.79	6.23	9.05
5.97	5.45	6.06	6.00	5.69	6.83
■	6.58	8.45	6.13	6.38	6.16

Off-axis Line Broadening

XRISM X-Ray Imaging and Spectroscopy Mission



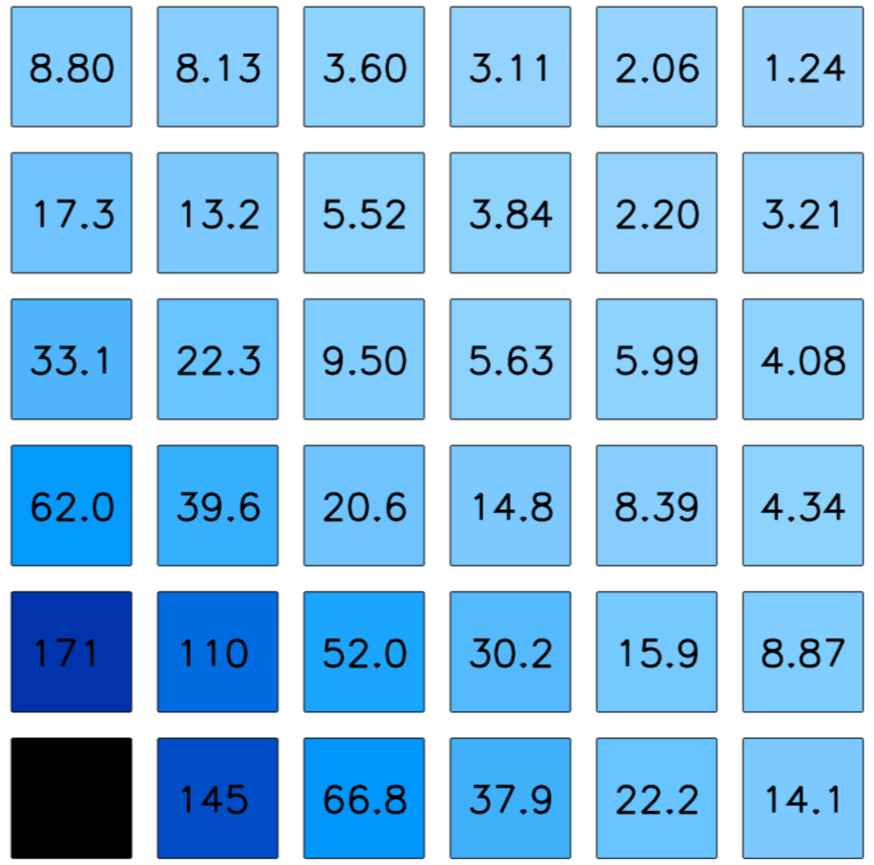
phabs(pow+gauss)

N_H=1x10^{21} cm^{-2}
Γ=1.8
E_{line}=6.4 keV
F_{line}=1x10^{-9} erg/s
F_X= 2.4x10^{-8} erg/s [2-10 keV]

5 eV native FWHM

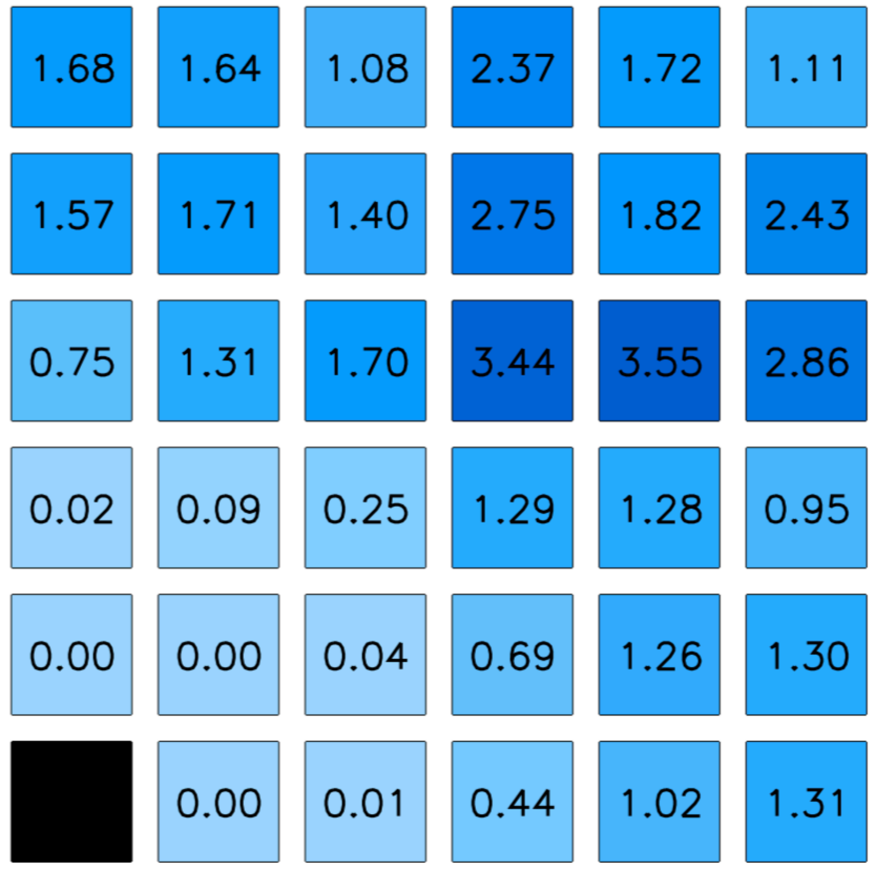
1 Crab

Incident Count Rate (raw)



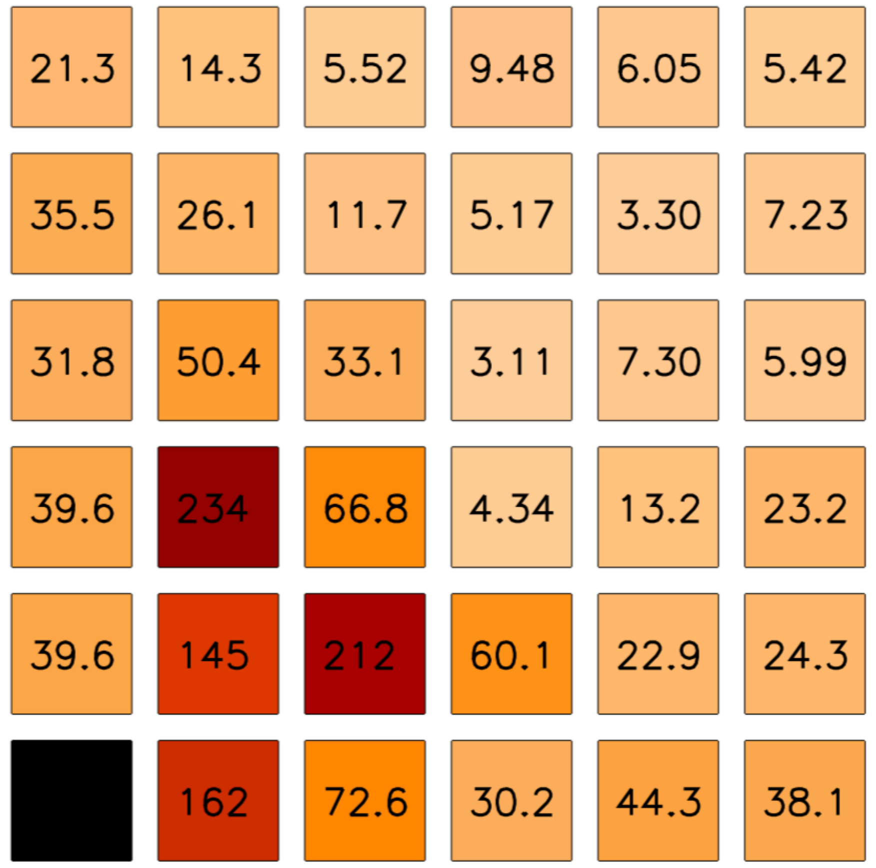
8.80	8.13	3.60	3.11	2.06	1.24
17.3	13.2	5.52	3.84	2.20	3.21
33.1	22.3	9.50	5.63	5.99	4.08
62.0	39.6	20.6	14.8	8.39	4.34
171	110	52.0	30.2	15.9	8.87
■	145	66.8	37.9	22.2	14.1

H+Mp rate (after PSP)



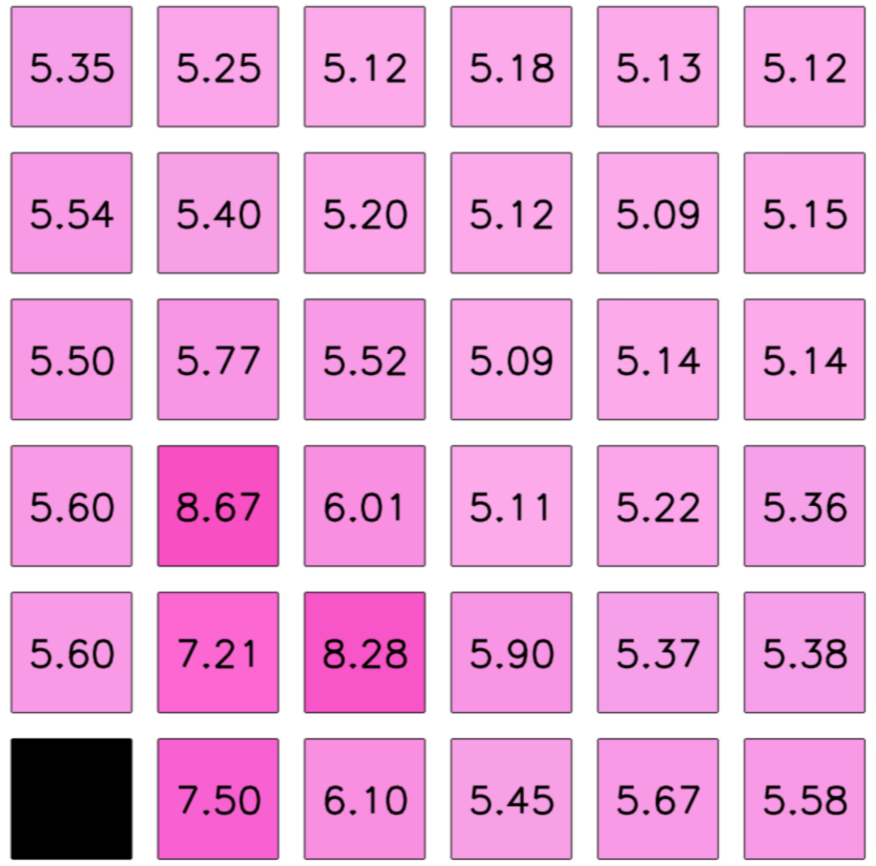
1.68	1.64	1.08	2.37	1.72	1.11
1.57	1.71	1.40	2.75	1.82	2.43
0.75	1.31	1.70	3.44	3.55	2.86
0.02	0.09	0.25	1.29	1.28	0.95
0.00	0.00	0.04	0.69	1.26	1.30
■	0.00	0.01	0.44	1.02	1.31

X-talk Child Pulse Rate



21.3	14.3	5.52	9.48	6.05	5.42
35.5	26.1	11.7	5.17	3.30	7.23
31.8	50.4	33.1	3.11	7.30	5.99
39.6	234	66.8	4.34	13.2	23.2
39.6	145	212	60.1	22.9	24.3
■	162	72.6	30.2	44.3	38.1

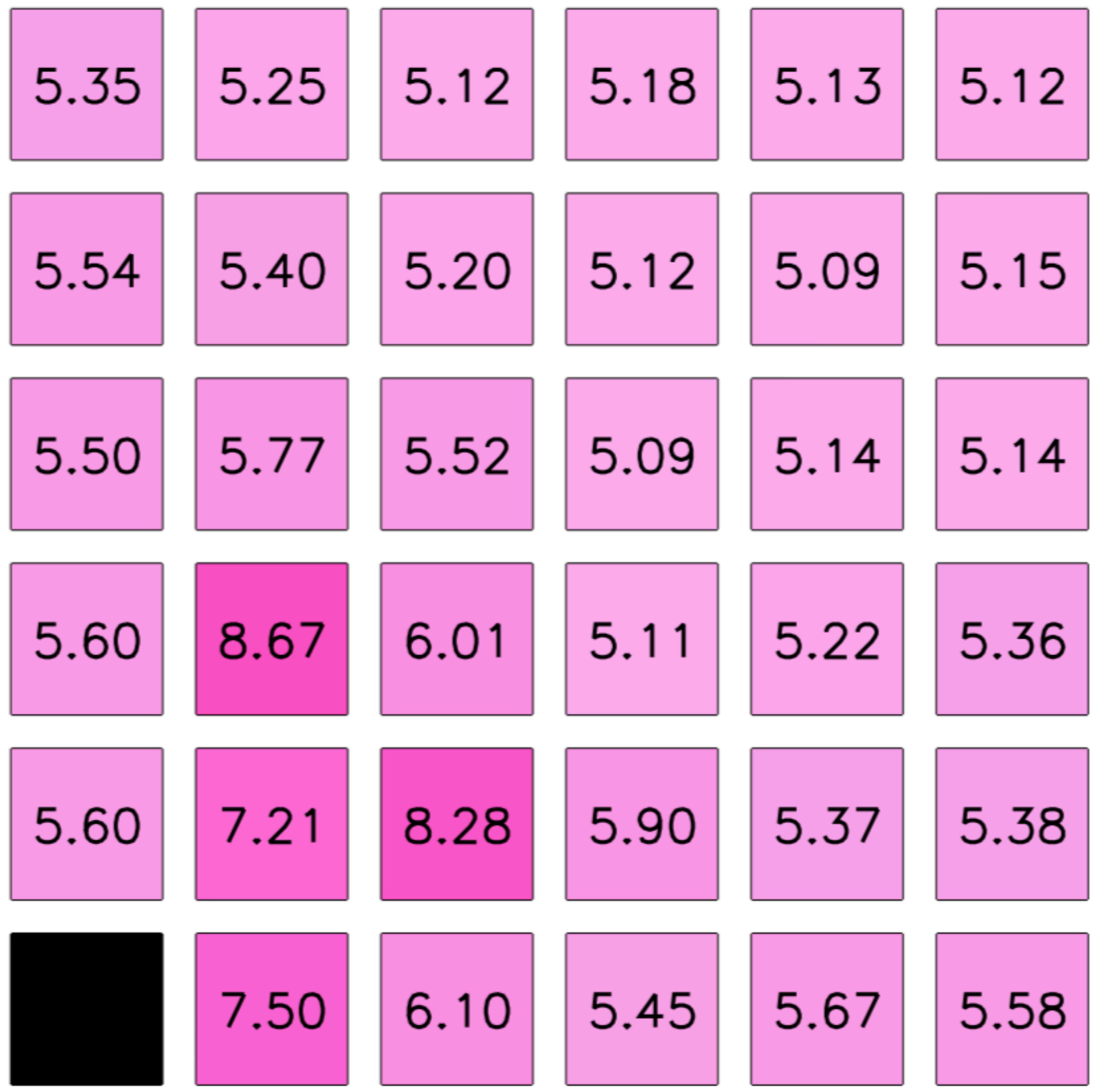
ΔE [eV, FWHM]



5.35	5.25	5.12	5.18	5.13	5.12
5.54	5.40	5.20	5.12	5.09	5.15
5.50	5.77	5.52	5.09	5.14	5.14
5.60	8.67	6.01	5.11	5.22	5.36
5.60	7.21	8.28	5.90	5.37	5.38
■	7.50	6.10	5.45	5.67	5.58

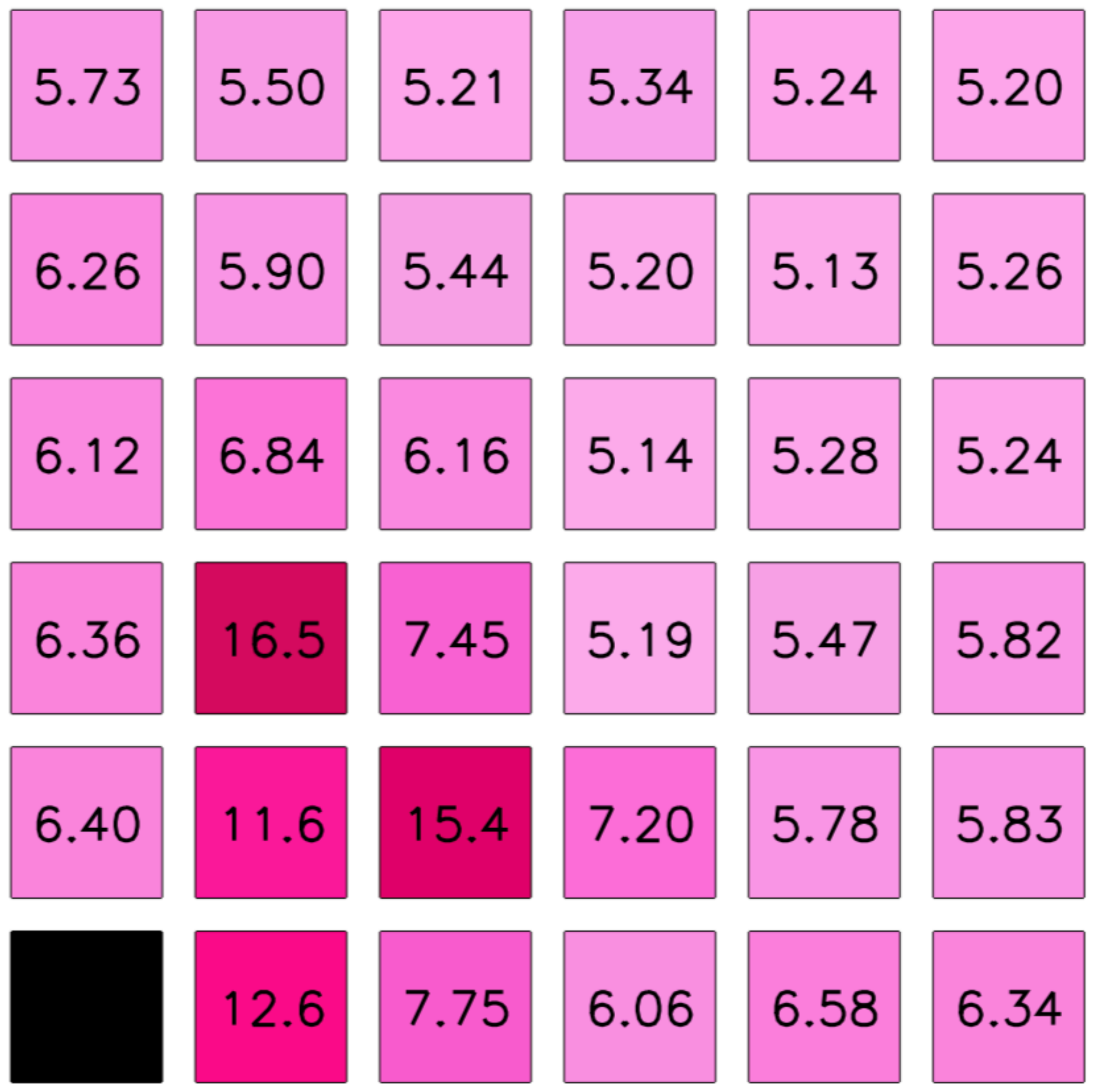
Spectral Hardness

1 Crab ΔE [eV, FWHM]

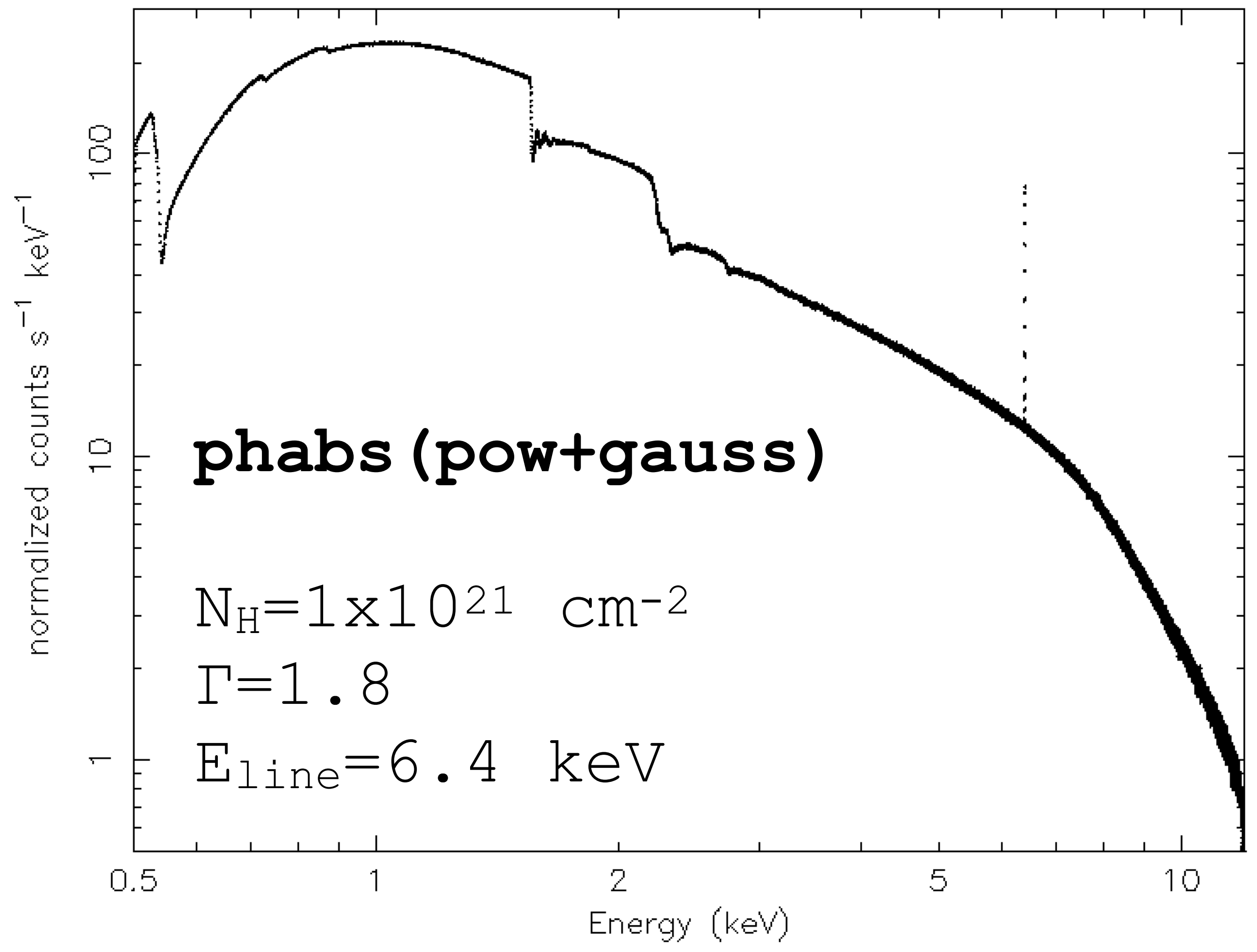


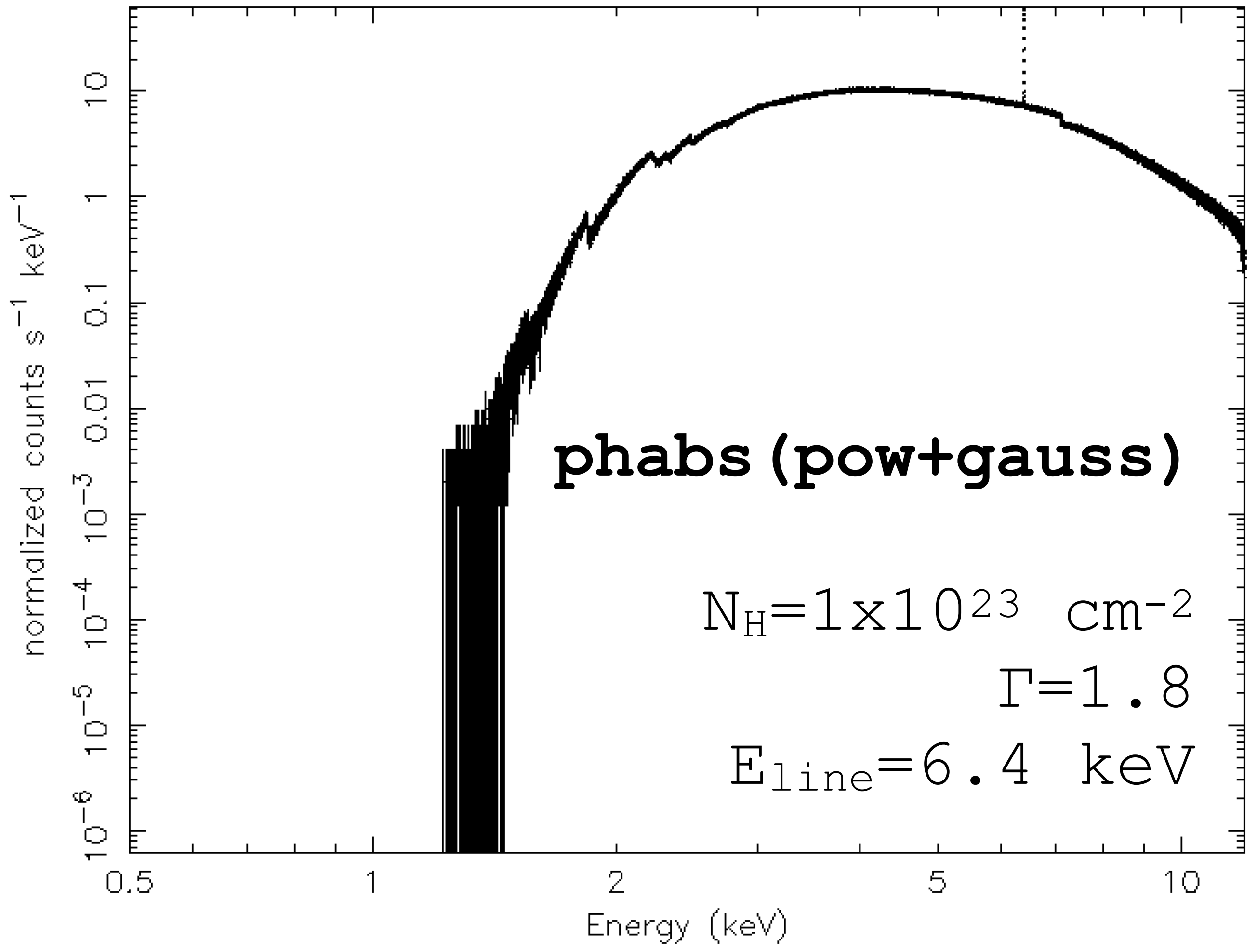
5.35	5.25	5.12	5.18	5.13	5.12
5.54	5.40	5.20	5.12	5.09	5.15
5.50	5.77	5.52	5.09	5.14	5.14
5.60	8.67	6.01	5.11	5.22	5.36
5.60	7.21	8.28	5.90	5.37	5.38
■	7.50	6.10	5.45	5.67	5.58

~3 Crab ΔE [eV, FWHM]



5.73	5.50	5.21	5.34	5.24	5.20
6.26	5.90	5.44	5.20	5.13	5.26
6.12	6.84	6.16	5.14	5.28	5.24
6.36	16.5	7.45	5.19	5.47	5.82
6.40	11.6	15.4	7.20	5.78	5.83
■	12.6	7.75	6.06	6.58	6.34



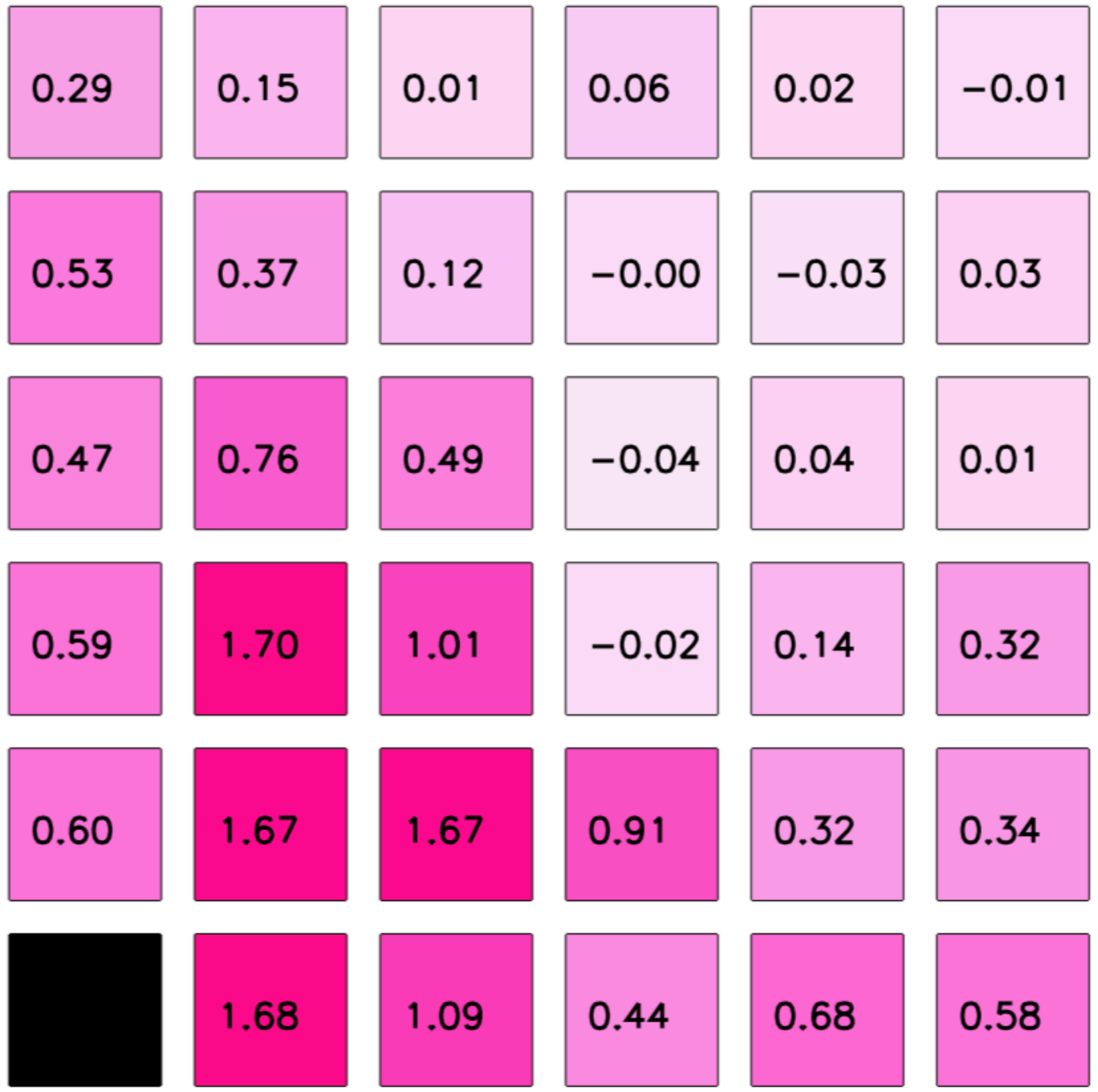


X-talk contamination is worse for a given photon flux with a harder spectrum.

The saving grace is that a harder spectrum will likely have a lower photon flux.

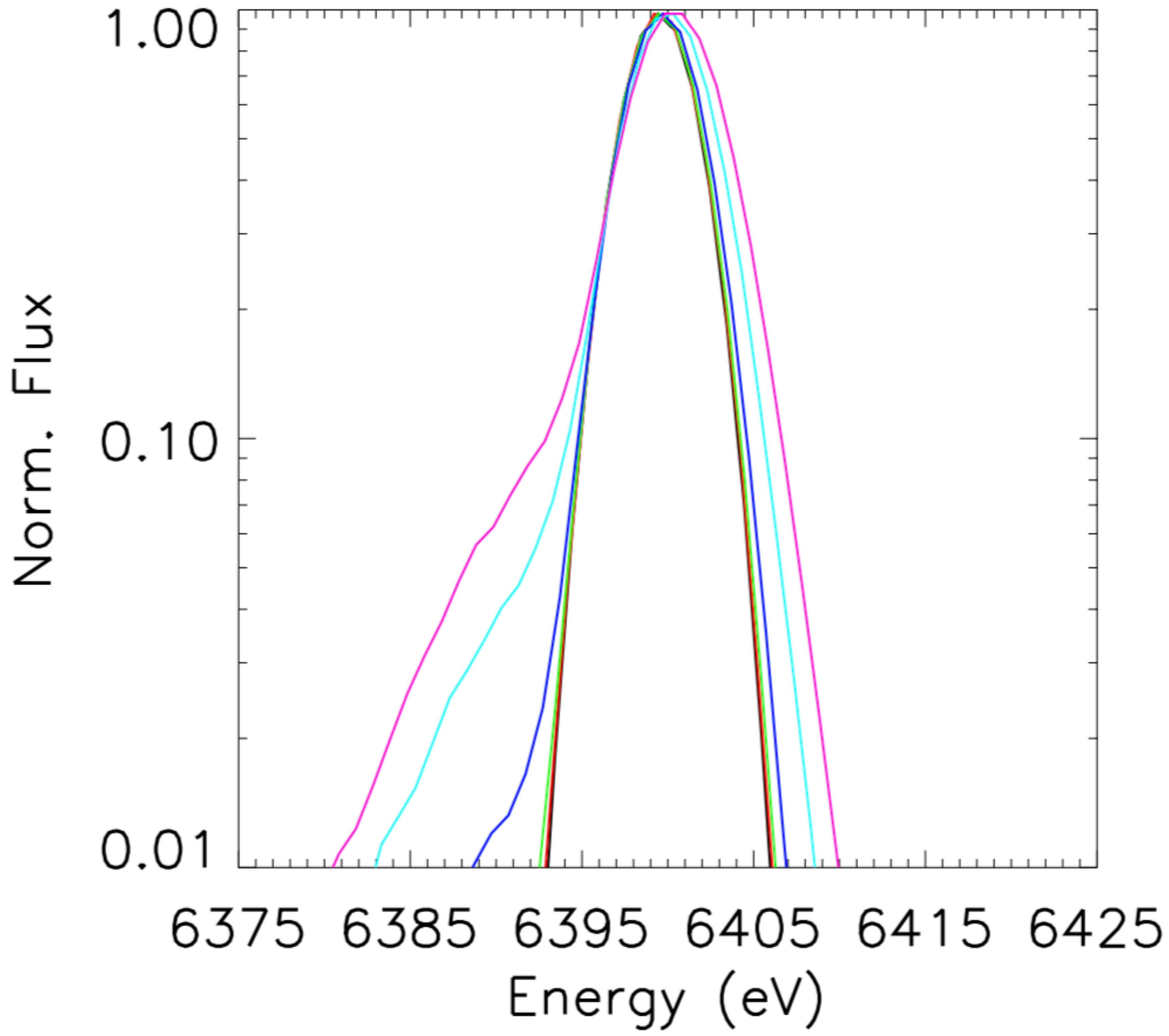
Centroid Shifts

ΔE [eV, Centroid Shift]



0.29	0.15	0.01	0.06	0.02	−0.01
0.53	0.37	0.12	−0.00	−0.03	0.03
0.47	0.76	0.49	−0.04	0.04	0.01
0.59	1.70	1.01	−0.02	0.14	0.32
0.60	1.67	1.67	0.91	0.32	0.34
	1.68	1.09	0.44	0.68	0.58

1 Crab, off-axis source from above



The line profile is not strictly Gaussian, and fitting it with a Gaussian will lead to centroid shift errors that increase with X-talk rate.

xTalk Impact at 1 Crab

Velocity Broadening: $\sigma_{\rm XT} = \sqrt{\sigma^2_{\rm obs} - \sigma^2_{\rm RMF}} \in [0, 1.4]\ \ {\rm eV}$

0-65 km/s at Fe Kα

Centroiding: $\Delta E \in [0, 1]\ \ {\rm eV}$

0-50 km/s at Fe Kα

Absorption Line Sensitivity:

$$\underset{\substack{\uparrow\\ \text{Continuum photons}}}{N_c} > \underset{\substack{\uparrow\\ \text{S/N}}}{S^2} \left(\frac{\Delta E}{\underset{\substack{\uparrow\\ \text{Equivalent width } (\ll\Delta E)}}{W}}\right)^2 \left(1 + \underset{\substack{\uparrow\\ \text{Background/continuum}}}{\frac{F_{\rm b}}{F_{\rm c}}}\right) \rightarrow \left(\frac{5{\rm eV}}{\Delta E}\right)^2 \underset{\substack{\uparrow\\ \text{Fractional sensitivity}}}{\approx 0.7 - 1}$$

Ground testing with the MXS (Porter 2015, Kilbourne 2015) found FWHM~6.1 eV at an X-talk rate of 20 counts/s. We estimate FWHM<5.5 eV for the same rate. Why?

The MXS provides Cu and Cr K lines (8.4 and 5.4 keV), which are significantly more energetic than the average photon from a Crab-like spectrum.

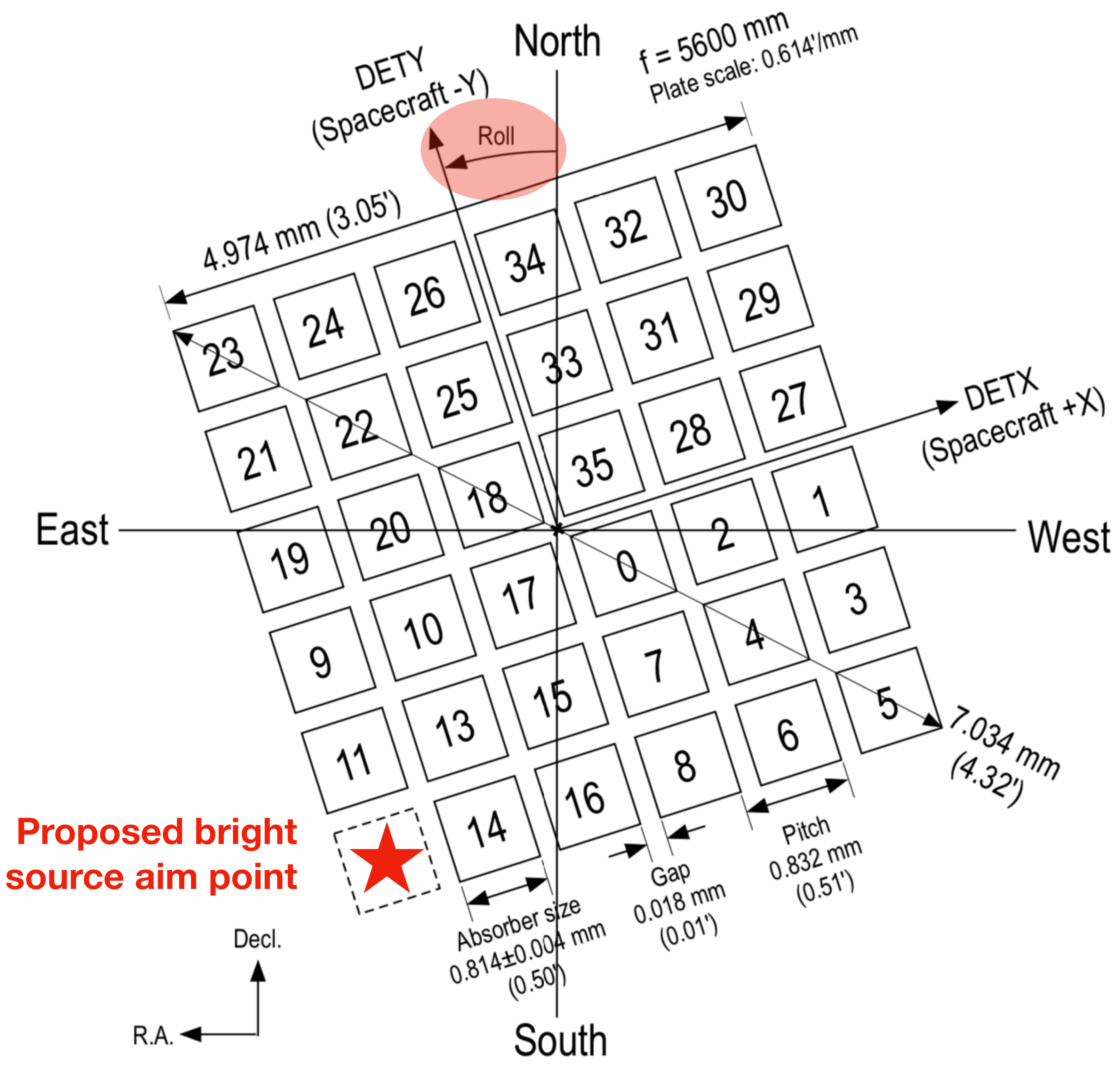
If we use the MXS spectrum, we recover a consistent result. However, note that the actual energy resolution depends quadratically on the event energy.

xTalk Analysis Caveats

- Pointing jitter, source variability, or bursting could make xTalk behave unpredictably
- Jointly fitting data from most pixels may require iterative fitting to constrain xTalk and true velocity structure (which should not differ between pixels for a point source!)

PSF

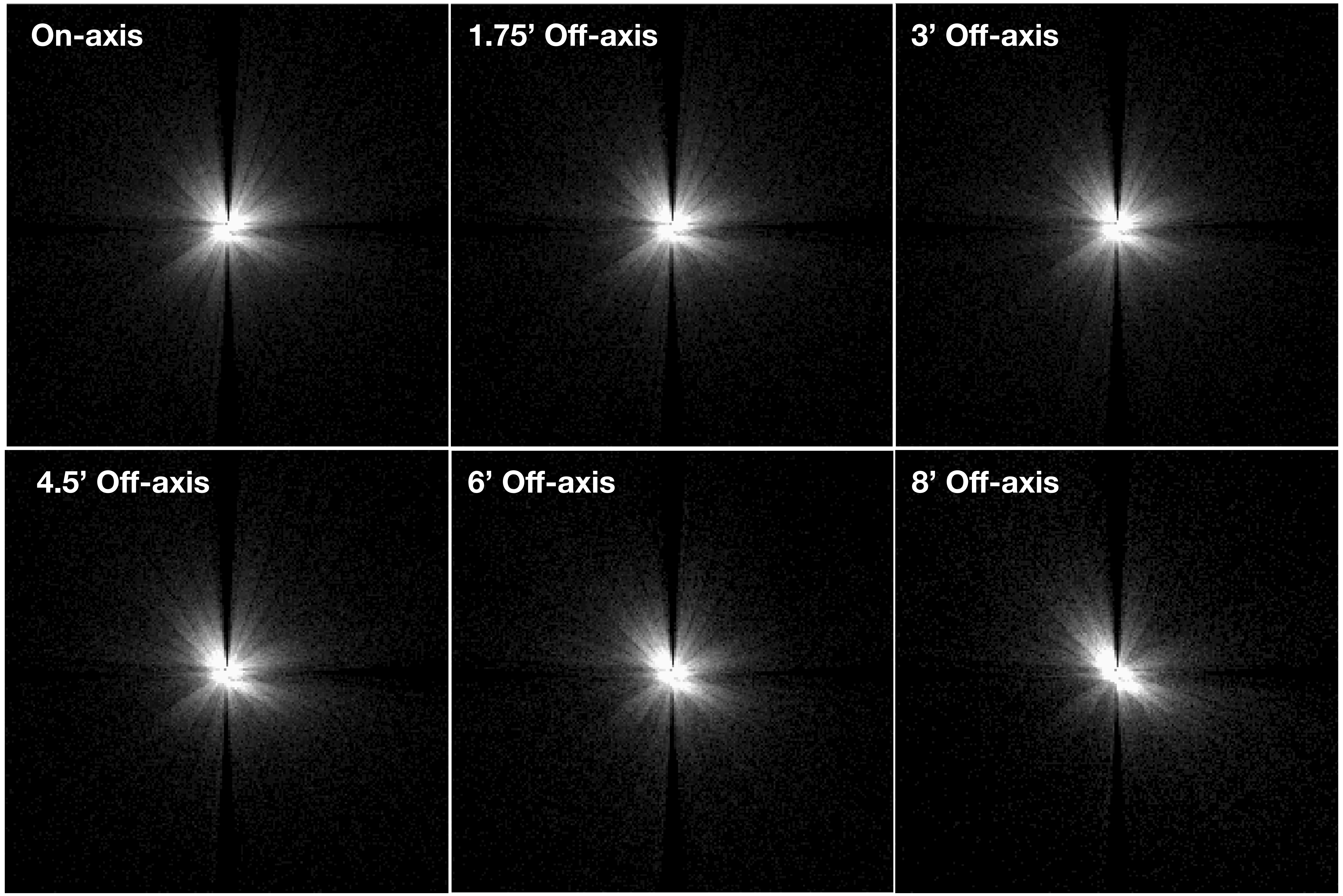
PSF Calibration



Proposed bright source aim point

Look-up map of the SXS detector

(Pixel 12 is the cal pix and is not shown in this figure.)



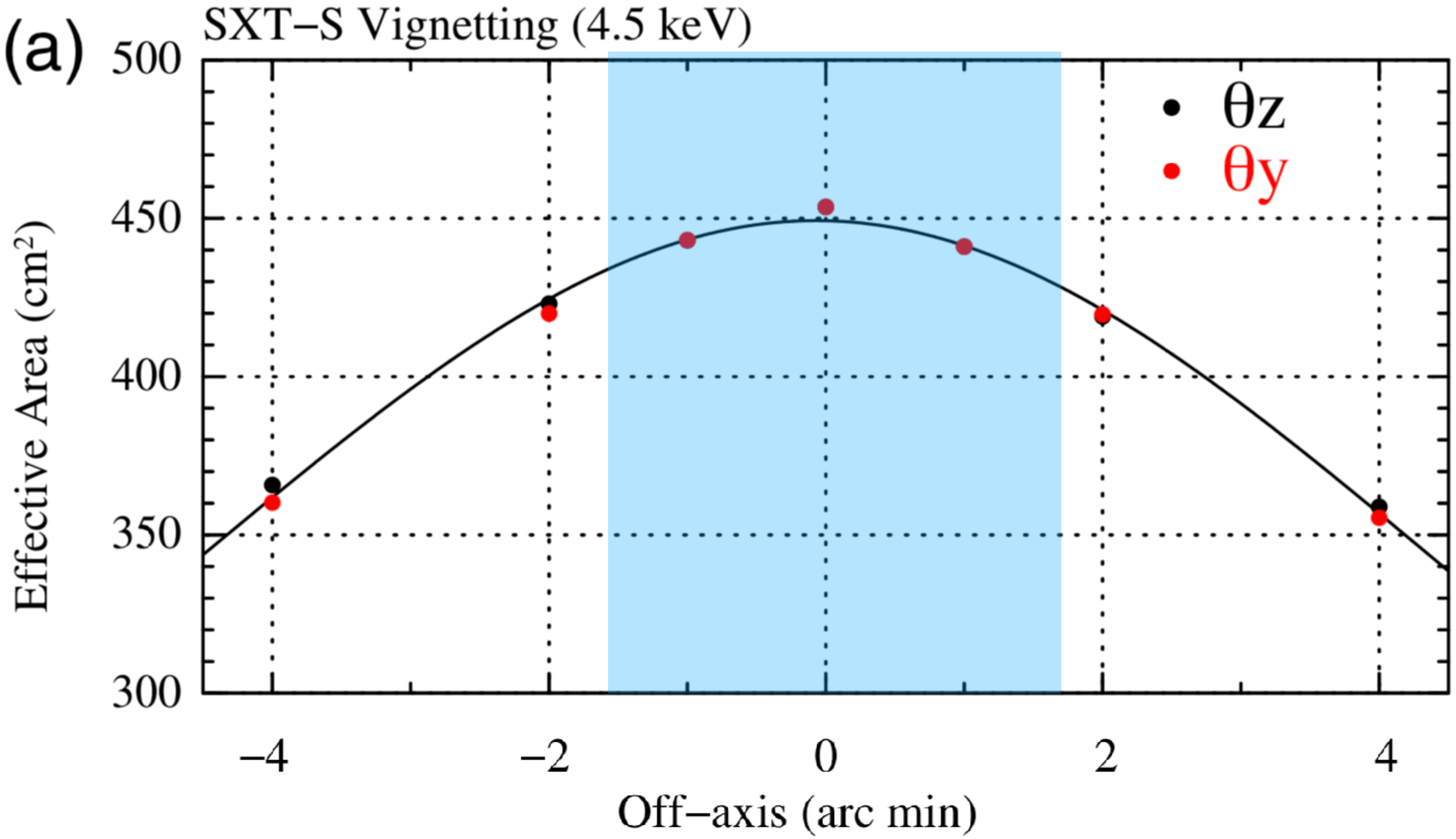
PSF structure is similar with off-axis angle up to 8' off-axis… but it is highly structured, so we need to know to high fidelity where the counts in the wings will fall

PSF Calibration

- PSF was calibrated on the ground near a likely bright source aim point and at nearby angles
- PSF calibration data form inputs to the XRISM ray trace that accounts for all the elements in the optical path and should be used to create simulations (e.g., via `xrtraytrace`)
- The PSF calibration is expected to be validated on orbit, but the PSF will not be measured in detail unless the validation fails, as it will be somewhat degenerate with effective area

Vignetting

Hitomi



For off-axis pointing where the PSF core still falls on Resolve, vignetting is a much smaller factor than the off-detector flux.

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