Timing calibration of *Resolve* microcalorimeter spectrometer on XRISM

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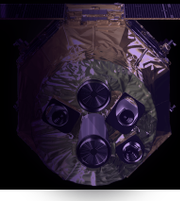
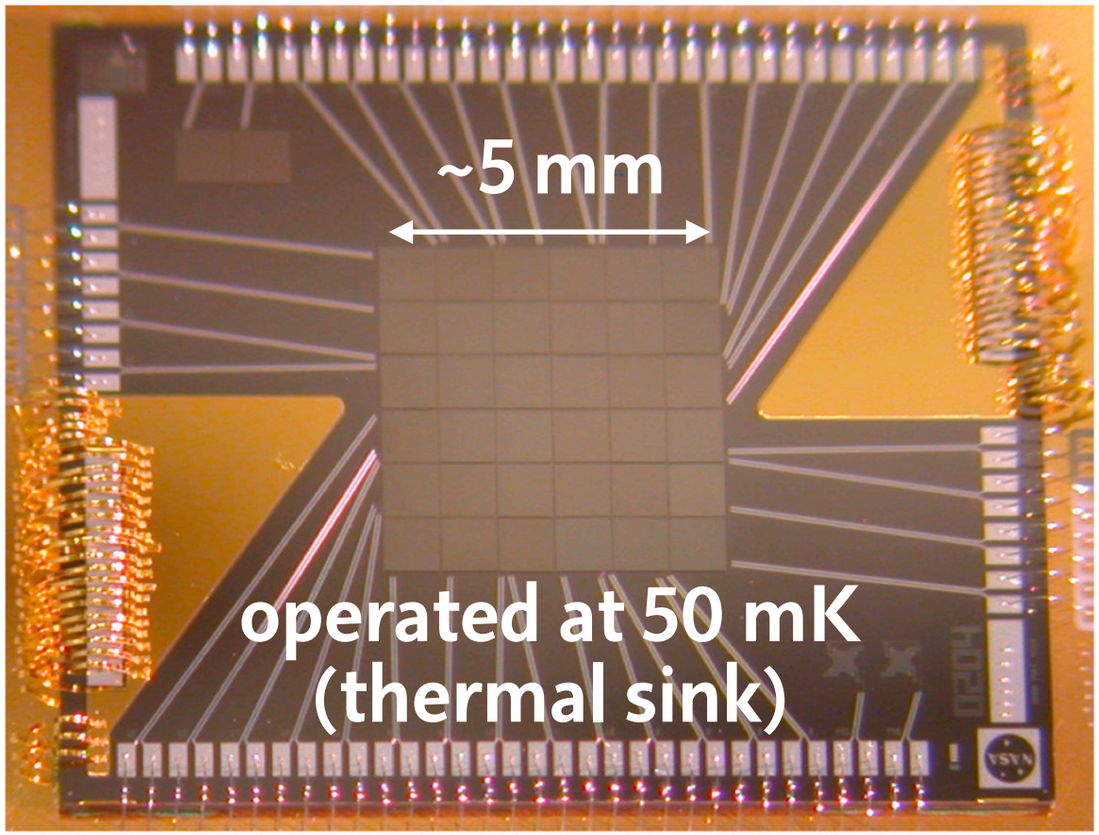
At the 14th IACHEC meeting

Outline

1. **Introduction**
   - Time assignment in SXS and Resolve
   - Time correction in SXS and Resolve
2. **Results from SXS**
3. **Plan for Resolve**



= Non-dispersive high-resolution spectrometer with nearly identical design/performance to Hitomi/SXS



SXS spare array (≠ Resolve FM array)

6x6 pixels for 3'x3' FoV

ΔE = 5-7 eV (FWHM)

0.3-12 keV band pass

Nearly identical detector & pulse processor

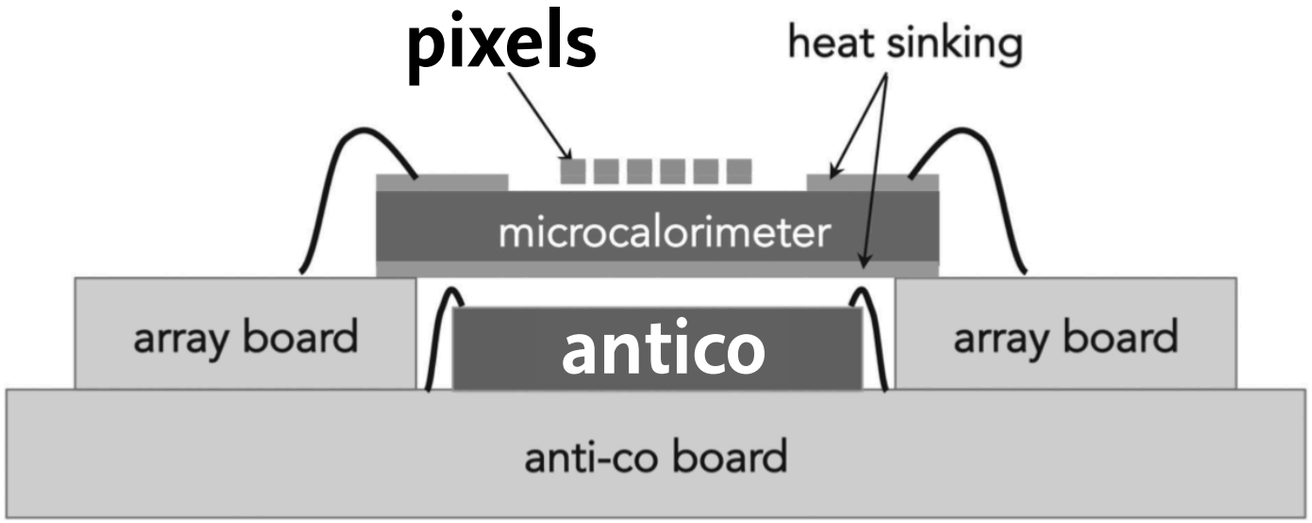
→ timing capability will also be identical to SXS

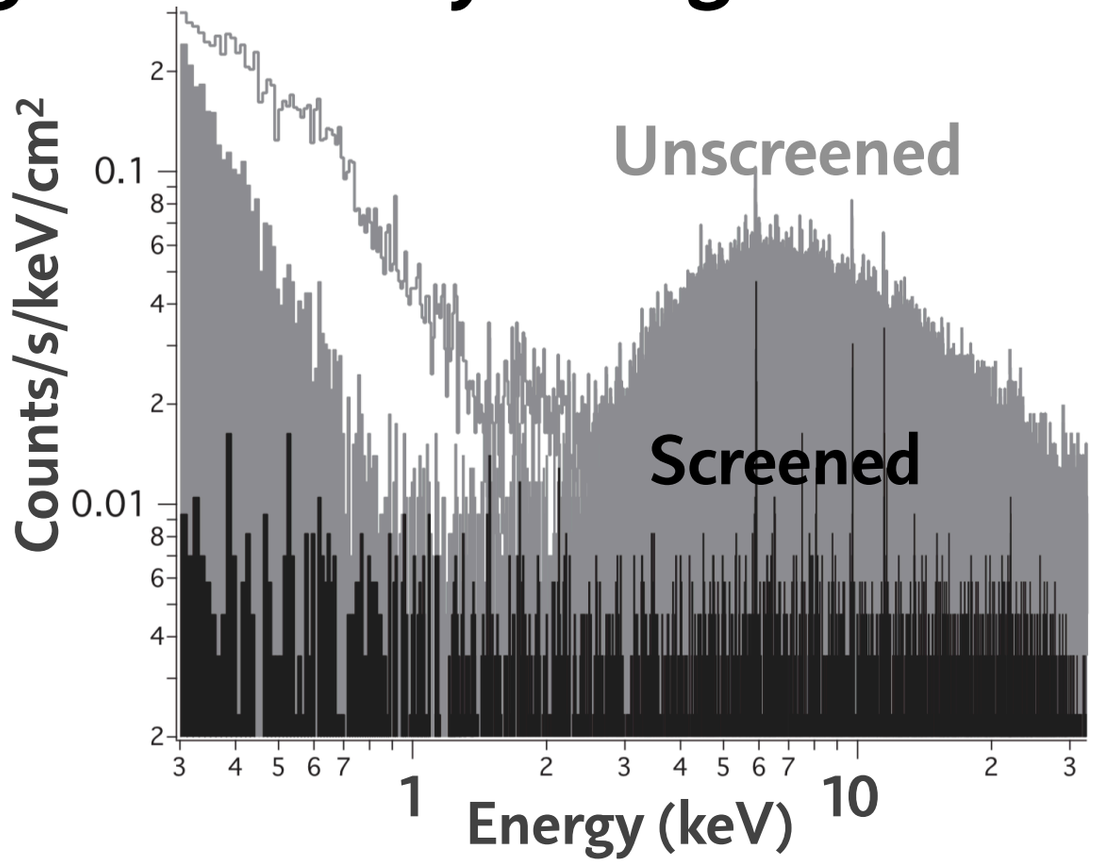
Purpose of timing calibration

1. Relative timing:

Optimize coincidence screening of non x-ray backgrounds

✦Kilbourne, Sawada, et al. PASJ, 2018





antico: ~0.5 cps → time window <2 ms for <0.1% false coincidence

2. Absolute timing:

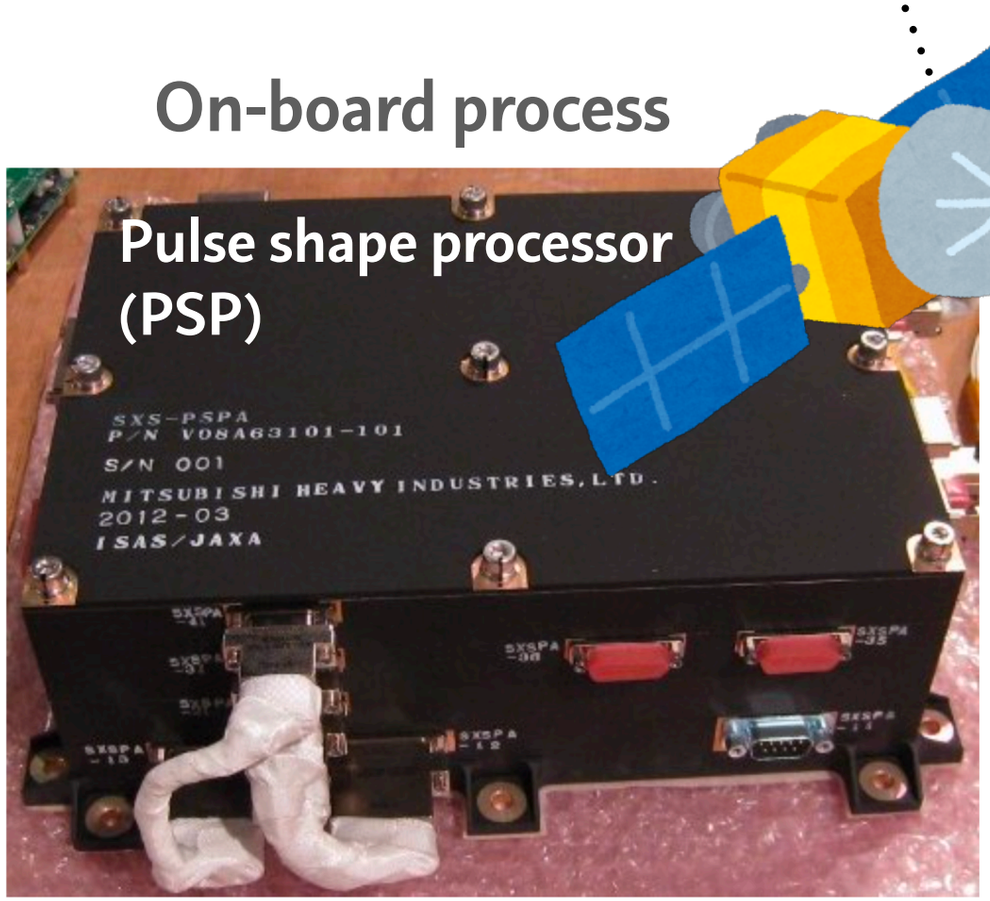
Scientific requirements (LMXBs, pulsars, …) ~ 1 ms

Time assignment of Resolve

The same system as used in Hitomi/SXS

1. **Assign trigger time** ≫ 2. **Apply calibration coefficients to trigger time** ≫ 3. **Convert instrument time to satellite time**

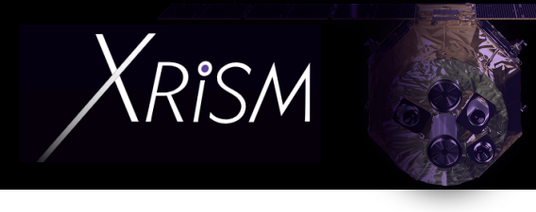
On-board process

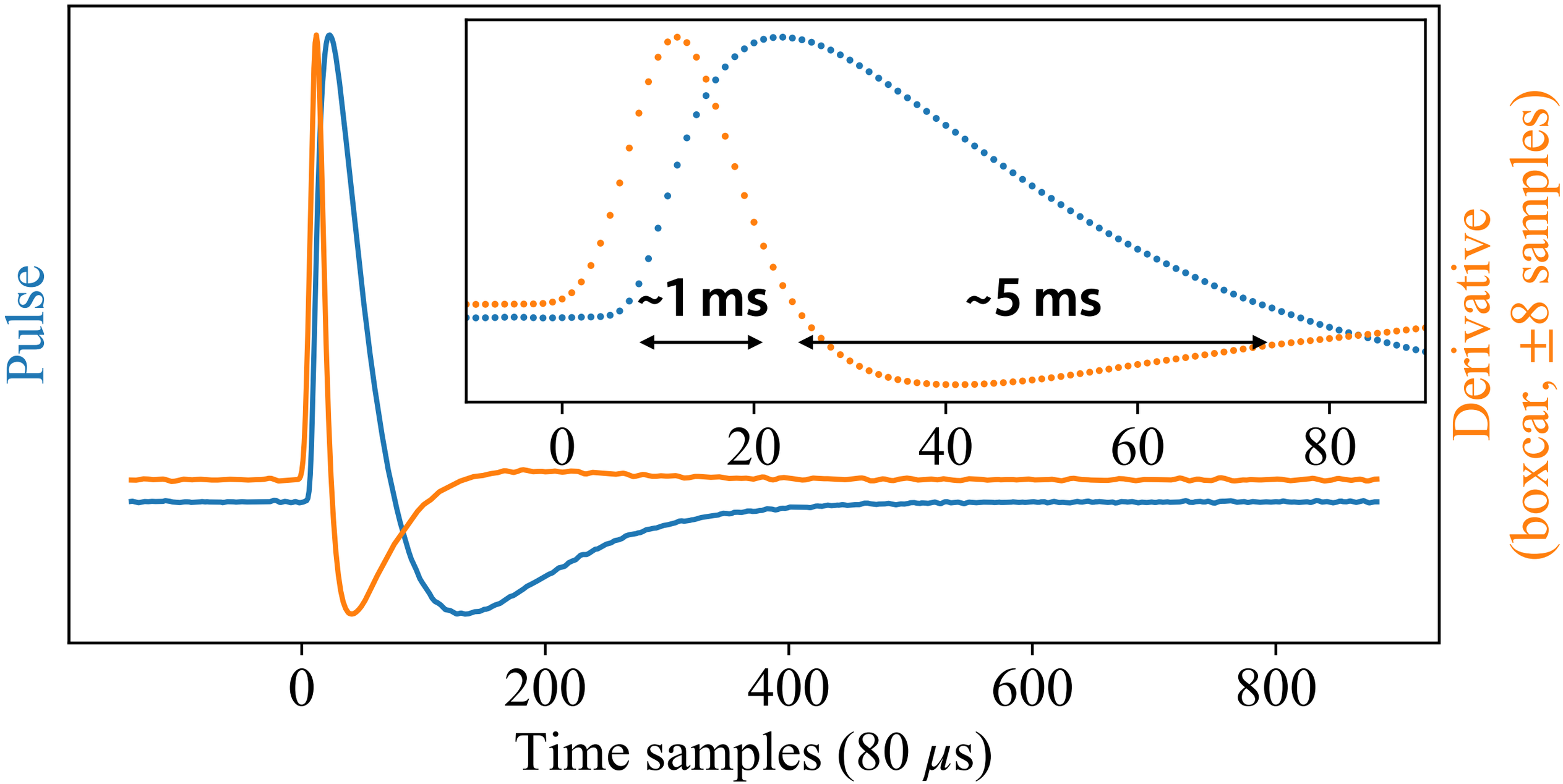


On-ground pipeline process

Design of timing cal. (2.) depends on how PSP assigns trigger times (1.)

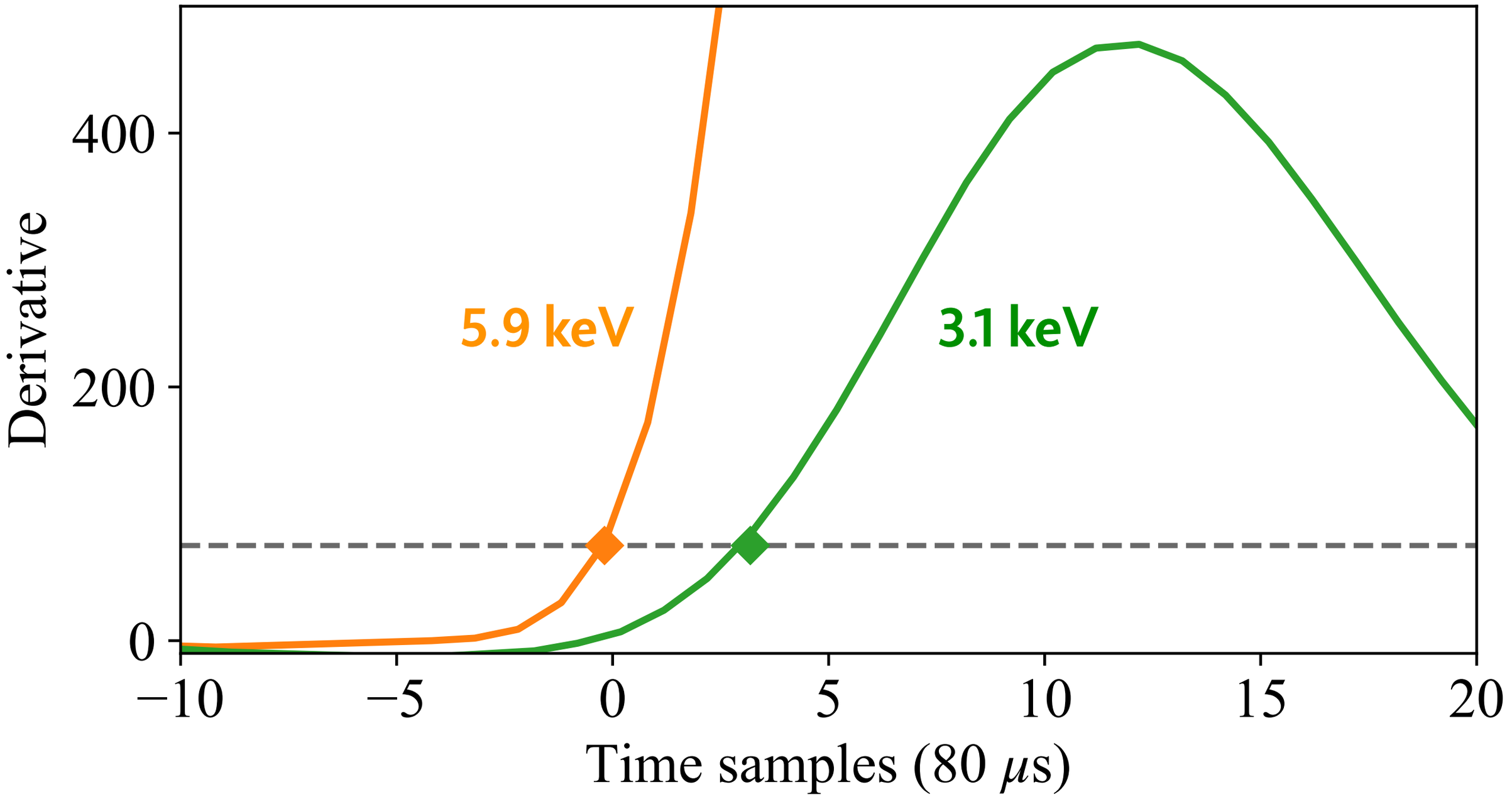
Pulse of a microcalorimeter event





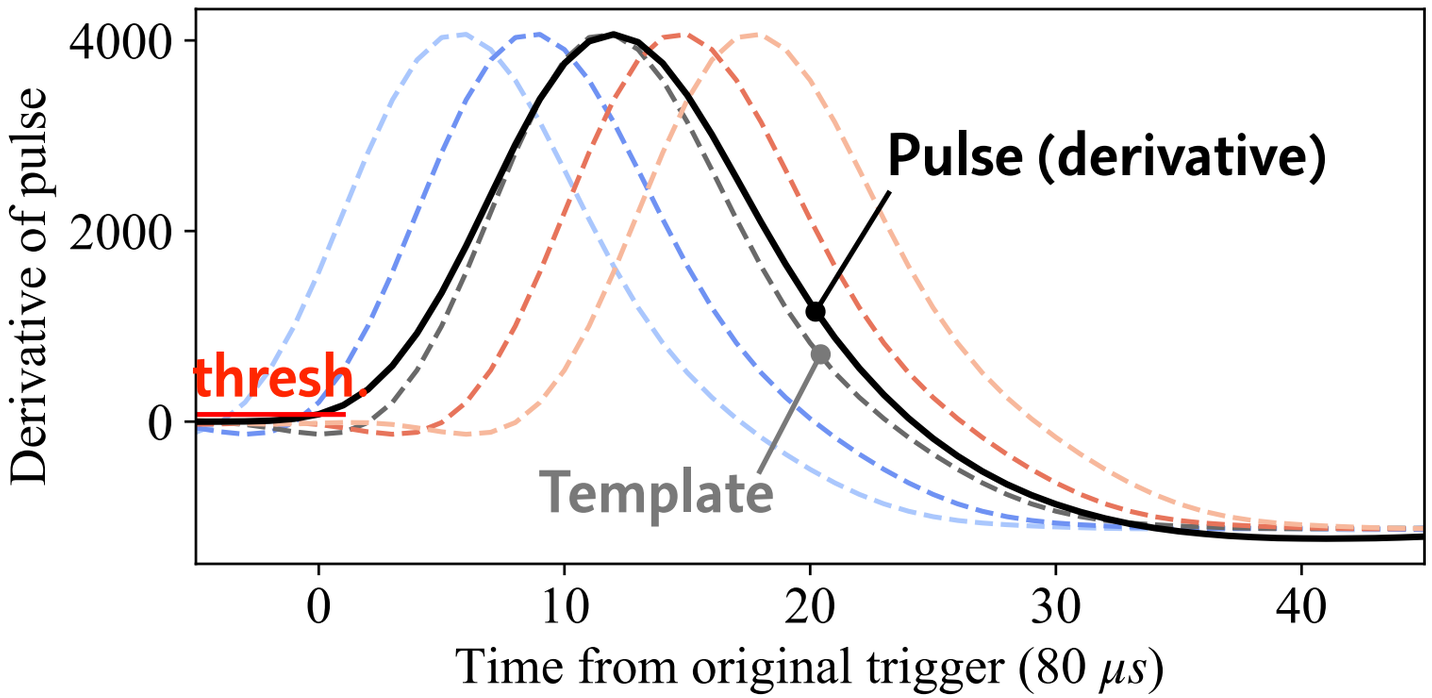
Trigger time by PSP

- **Apply a threshold to derivative**

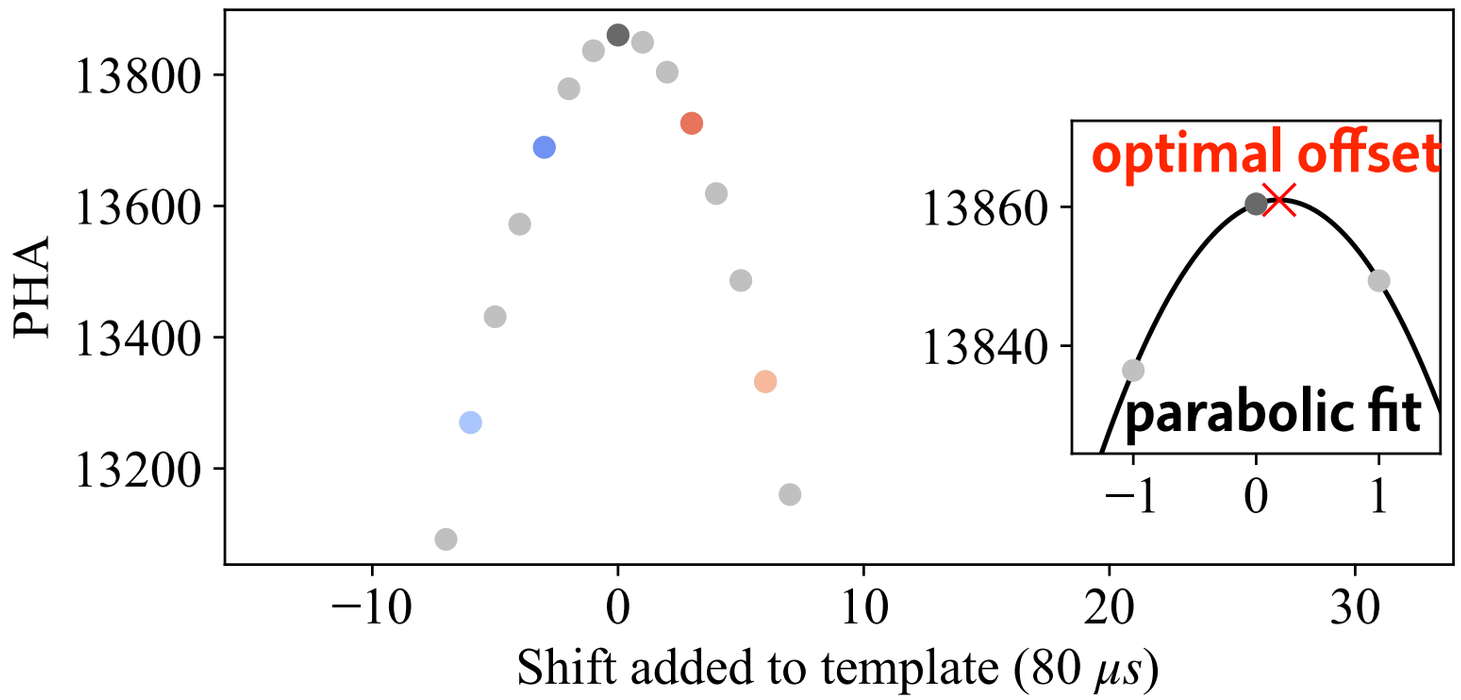


- **Energy dependent offset → corrected by “optimal filtering”**

Time assignment by PSP



1. **Get trigger time. (80 µs resolution)**



2. **Calculate PHA w/template. Repeat for various offsets.**

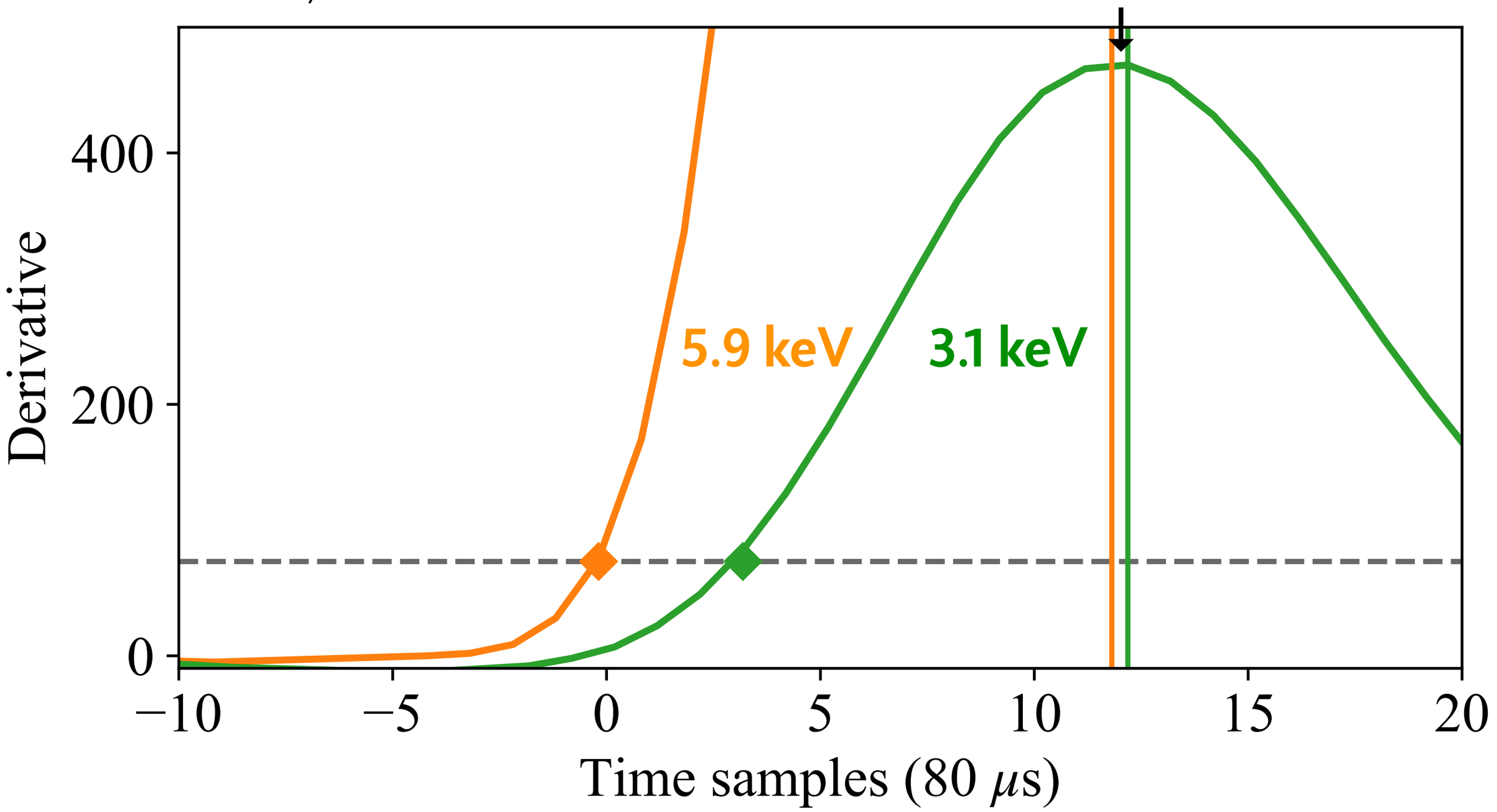
3. **Find optimal offset. (5 µs resolution)**

4. **Record trigger time shifted by optimal offset.**

PSP assigns (almost) *E*-independent trigger times at 5 µs resolution

Trigger time for “Low-res” events

- If two pulses are too close, PSP cannot use opt. filtering (Low-res)
- For L-res, use time when derivative hits the maximum

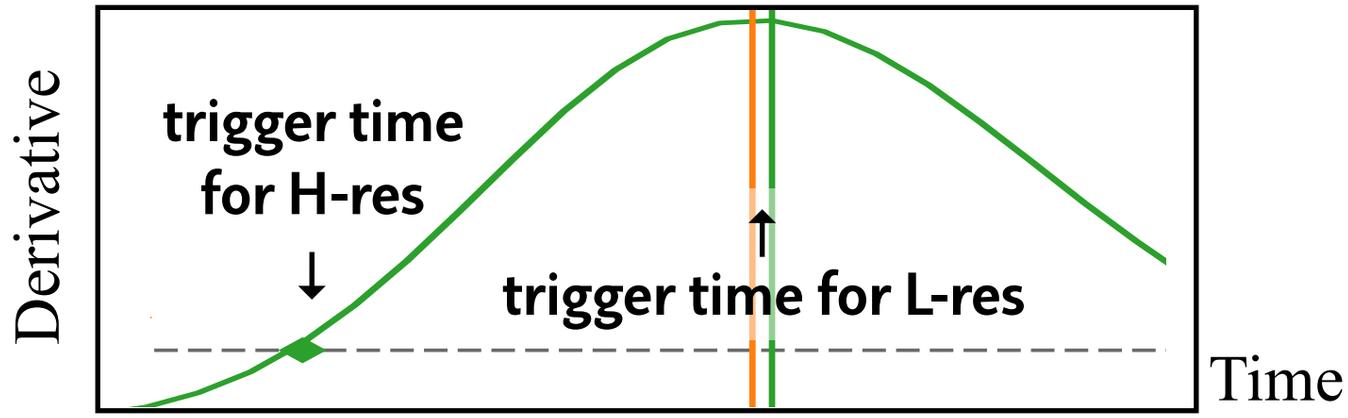


- Less energy dependent than the original trigger

Anticipated calibration terms

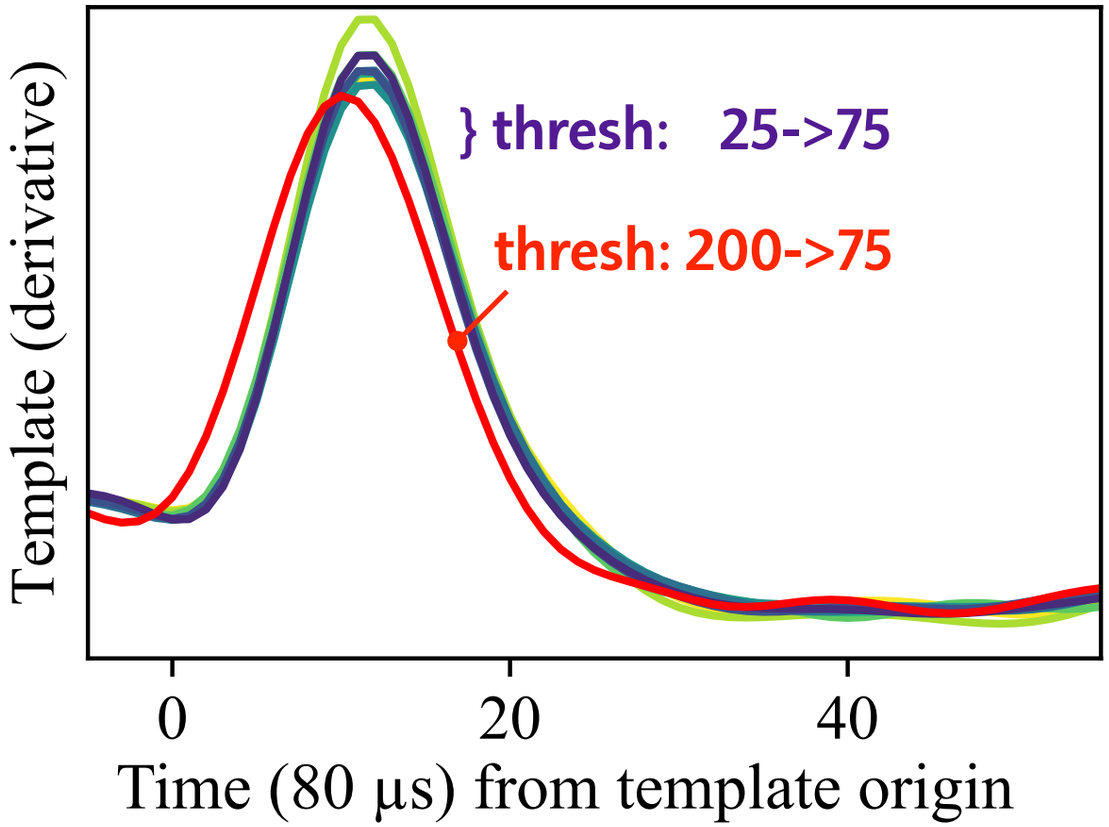
✦Grade dependence

→trigger point definition



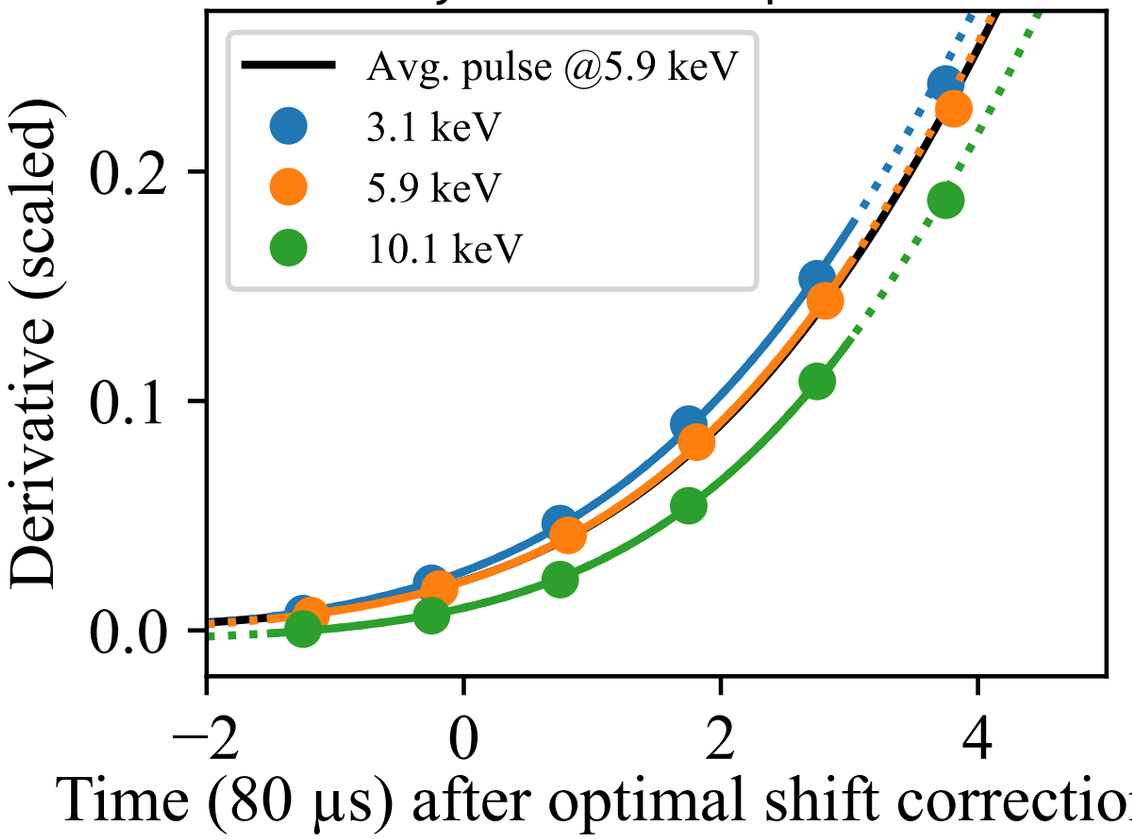
✦Pixel dependence

→threshold update after template generation



✦Energy dependence

→non-linearity of detector pulses

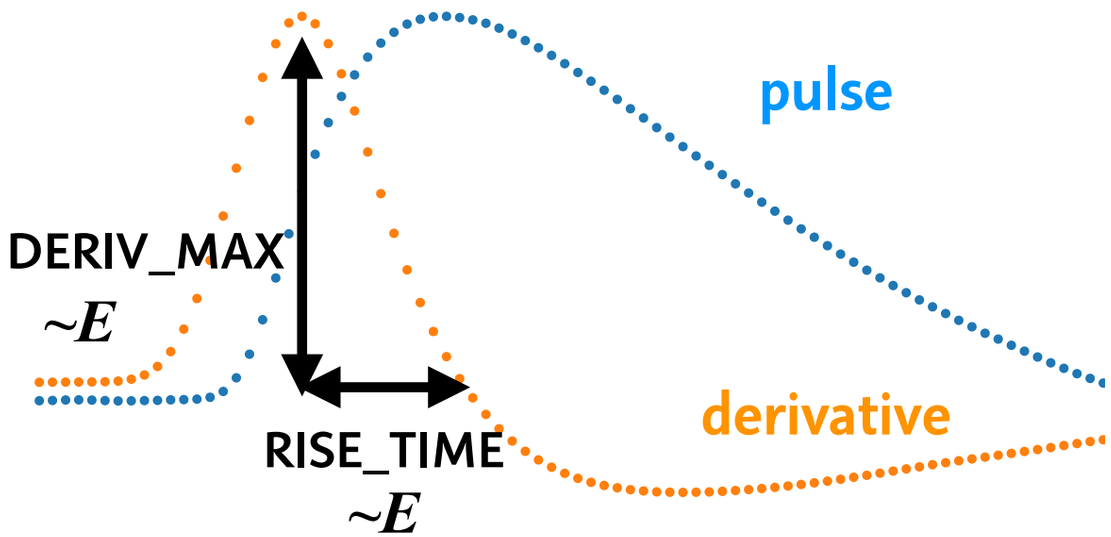


All these dependences are caused by imperfectness of optimal filtering

Time correction in pipeline

✦ Calibration formula

Calibrated time = Trigger time – (a * RISE_TIME + b * DERIV_MAX + c)



a and **b** for *E*-dependence
(we didn't use a in SXS)

c for absolute timing

✦ CALDB format

Column	Name	Format
2	AH	36D
3	BH	36D
4	CH	36D
5	AM	36D
6	BM	36D

Grade **Pixel**

separate CALDB entries for different grades and pixels

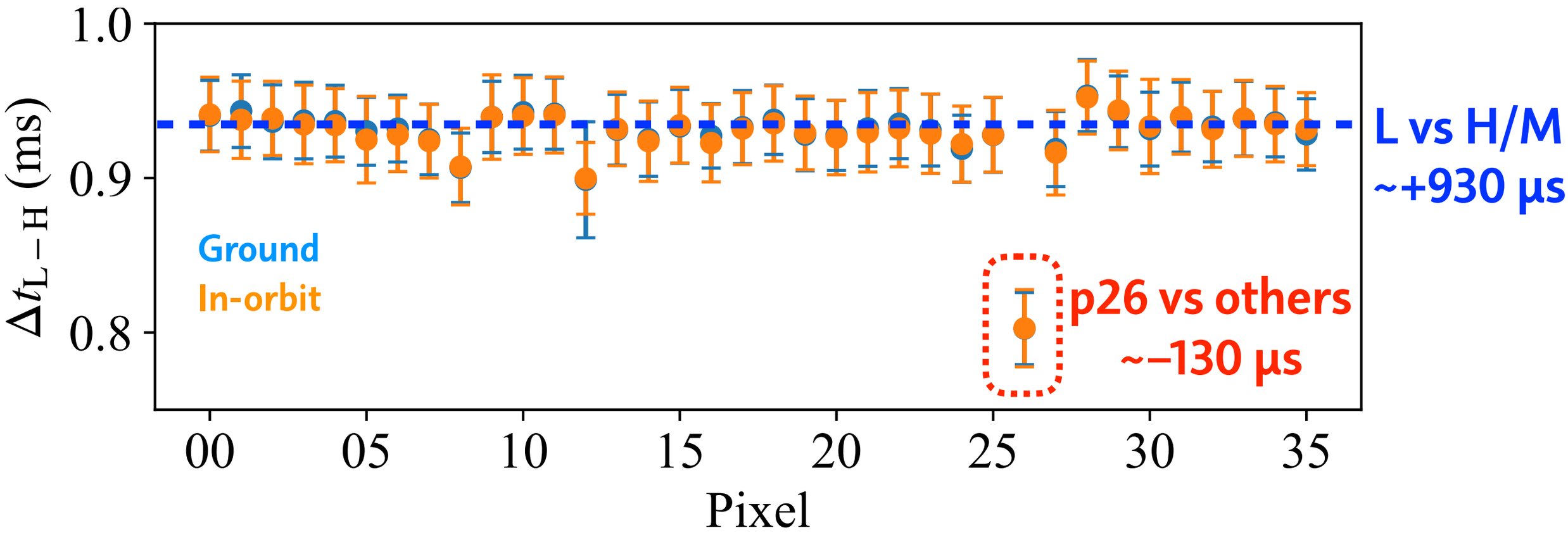
This formalization worked well for SXS, and will be used for Resolve

Summary of timing calibration

		Major mechanism	In SXS, calibrated by	
			Ground	In-orbit
Relative	Pixels	trigger threshold inconsistency	pulse records of cosmic-ray events	←Ground cal. confirmed w/cosmic ray events in orbit
	Grades	trigger point definition	pulse records of cosmic-ray events	←Ground cal. confirmed w/Crab pulsar
	Energies	non-linearity of pulse shape	N/A	folded light curve of Crab pulsar
Absolute		offset from real photon arrival time	N/A	folded light curve of Crab pulsar

SXS results - Pixel/grade dependence

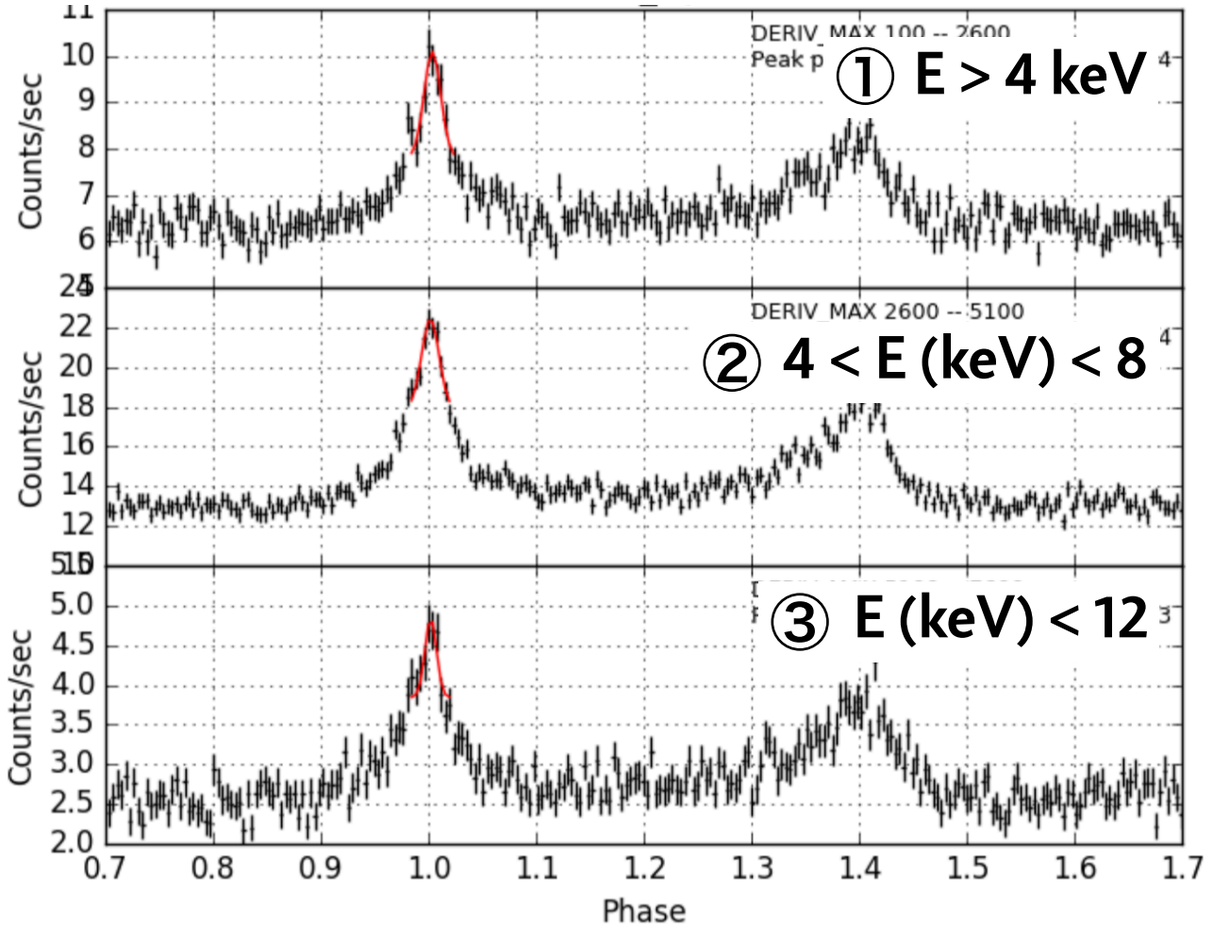
- **Pulse records of cosmic ray events in the ground tests**
  - Calculate L-res times for H-res events and compare these
    - → grade-to-grade (L to H/M) offset
  - L-res times are insensitive to trigger thresholds
    - → pixel-to-pixel offsets

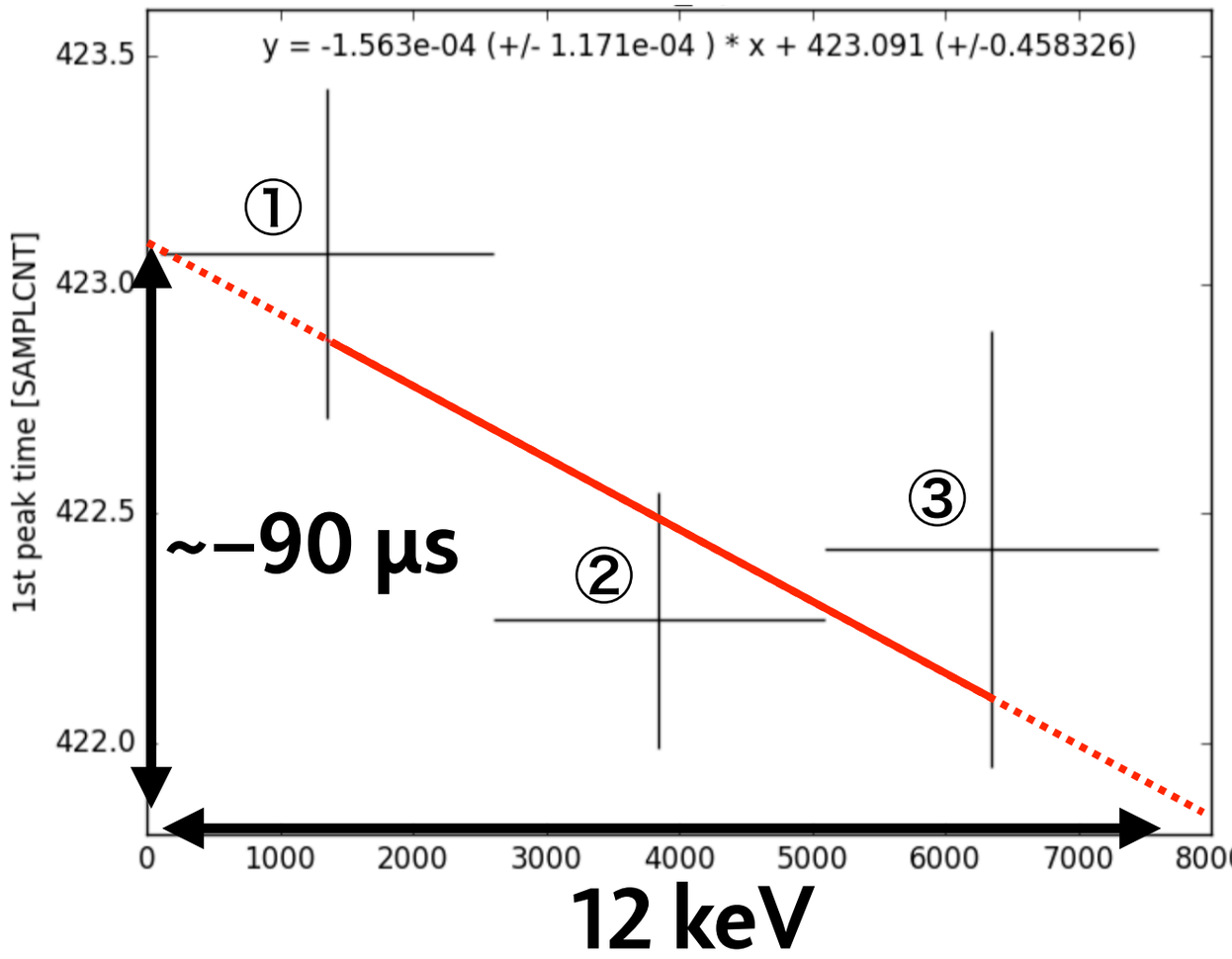


SXS results - Energy dependence

- **In-orbit Crab pulsar data** (3/25, 9.7 ks after screening)
  1. Divide events for grades and three ranges of DERIV_MAX (~*E*)
  2. Make folded light curve for each and get peak phases
  3. Derive slope of peak phases as a function of DERIV_MAX

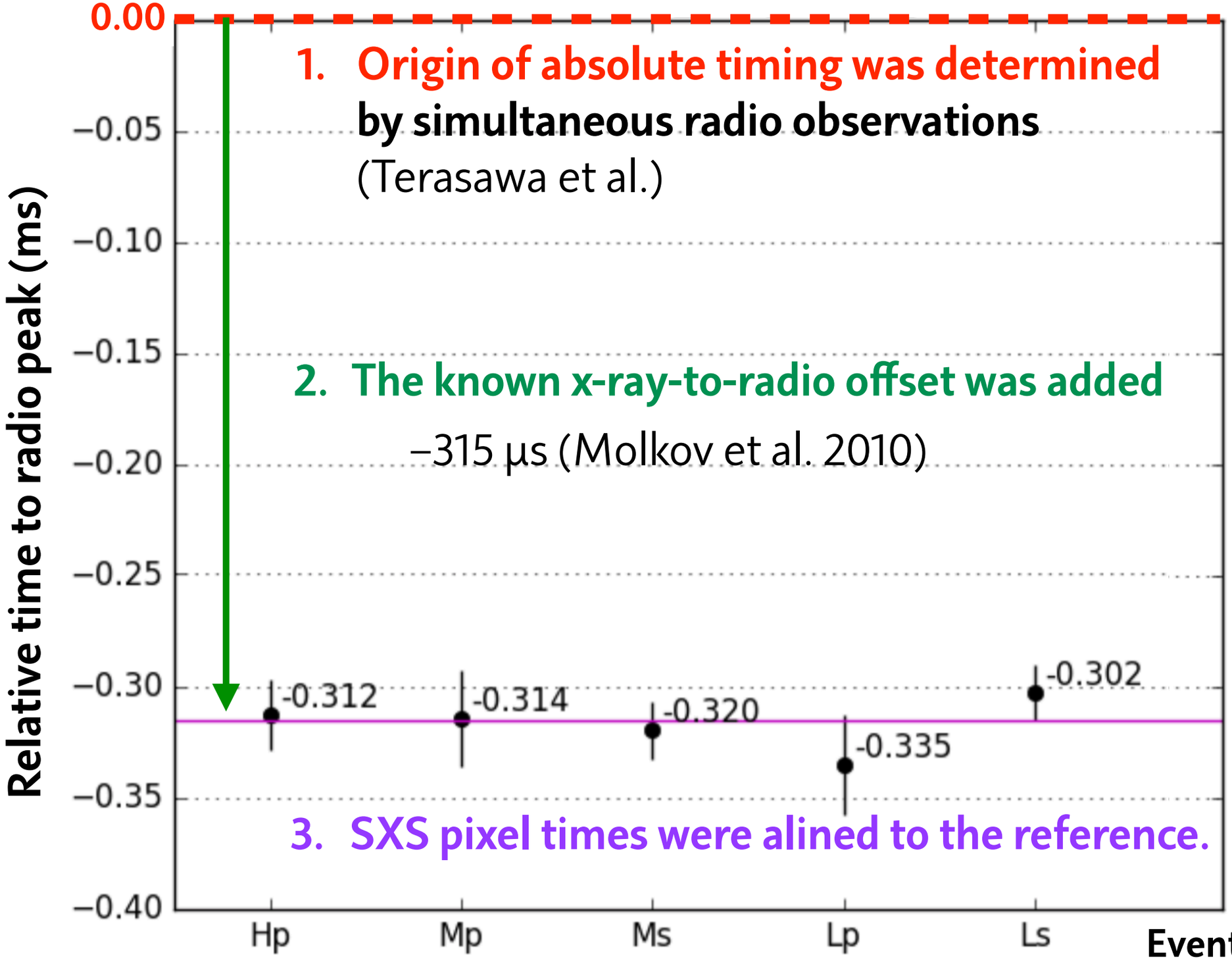
An example from H-res case





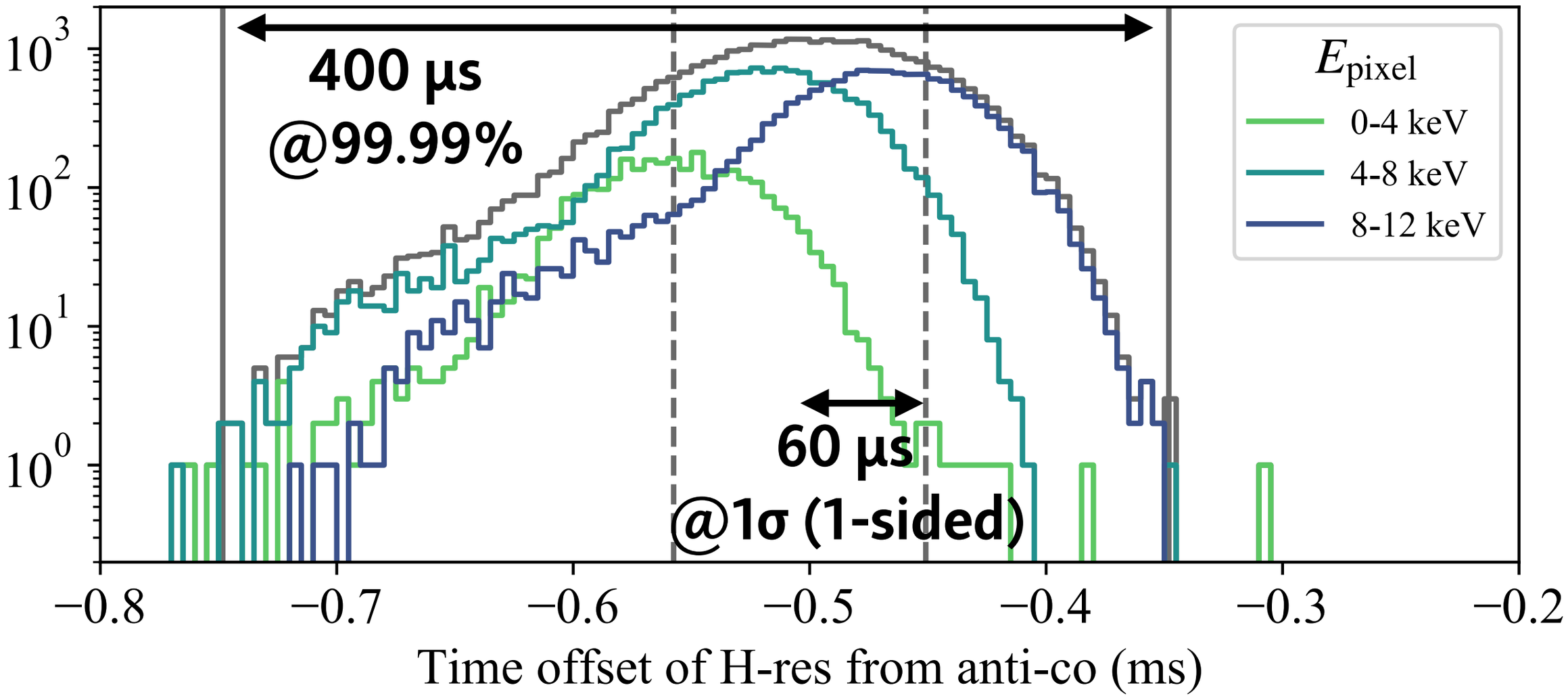
SXS results - Absolute timing

- Calibrated by Crab pulsar coordinated radio observations



SXS results - Relative timing to antico

- After all the corrections were applied, pixel event times were compared to associated antico event times



- Coincidence window size was set to 500 μs.
  - 0.5 cps (ave.) * 500 μs ~ 0.03% false coincidence … small enough.

Resolve timing cal.

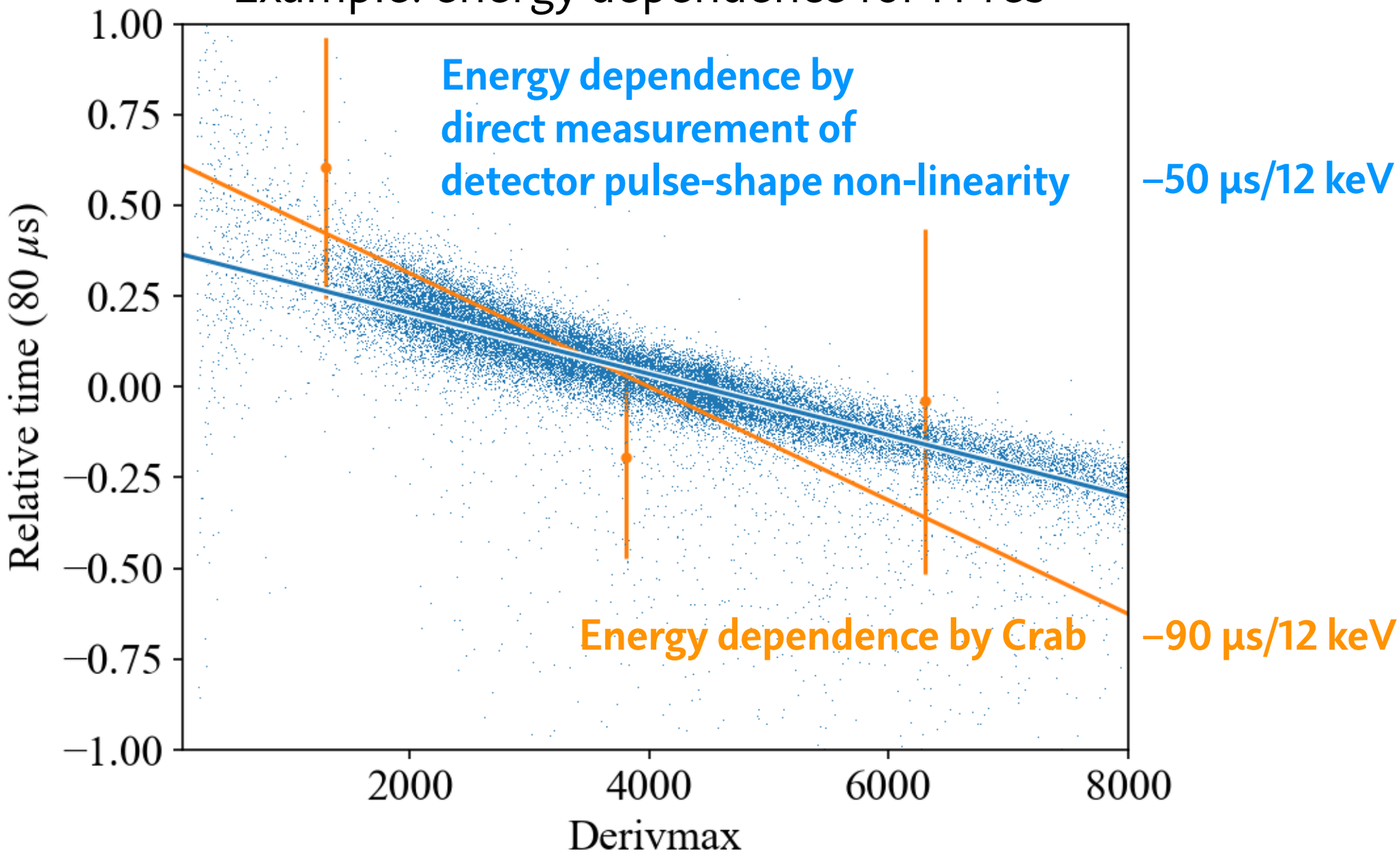
- **We need to**

  1. **Evaluate uncertainties in SXS timing cal.**
  2. **Set *Resolve* timing cal. requirement**
  3. **Make plan for *Resolve* timing cal.**

Uncertainty in SXS timing cal.

- **Source of uncertainty** - sampling, statistical, and **systematic**
- **Any rel. timing can also be calibrated using detector pulse records**

Example: energy dependence for H-res



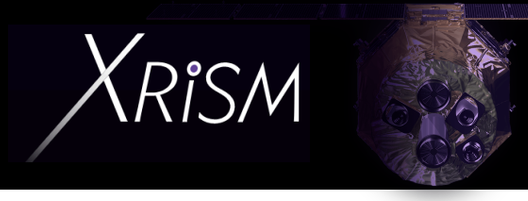
- **Although marginal, there is some discrepancy … need to watch in Resolve**

Resolve timing cal. requirement (tentative)

- **(Tentative) timing cal. requirement is set based on SXS results**

		H & M-res	L-res	antico
Uncertainty (SXS)	Time assignment Resolution	5 μs	80 μs	80 μs
	Statistical (Crab, 1σ)	20 μs	30 μs	40 μs
	Systematic	40 μs	120 μs	N/A
Relative timing requirement (1σ)		**80 μs**	**160 μs**	**160 μs (~1 ms window)**
Absolute timing requirement (1σ)		**1 ms**		

Resolve timing cal. plan (tentative)



✦ Guiding principle: do what we did (successfully) in SXS

- **Ground calibration**
  - ✓ Pixel-to-pixel & grade-to-grade
    - **Detector pulse records of cosmic-ray events**
    - **Modulated X-ray Source (MXS) data**
- **In-orbit calibration**
  - ✓ Energy dependence
    - **Folding analysis of Crab pulsar** (hopefully with longer exposure)
    - **Detector pulse records in orbit**
  - ✓ Absolute timing
    - **Folding analysis of Crab pulsar**
      - Coordinated radio observations are required, as done in SXS

Used in SXS CALDB

Newly added for cross-check

Summary

1. **XRISM/Resolve will use the same time assignment and correction system as Hitomi/SXS.**

2. **Timing requirement for Resolve is (tentatively) set based on the SXS calibration results.**

3. **Started discussion on Resolve timing calibration plan. Lessons from SXS will be used to improve the plan.**