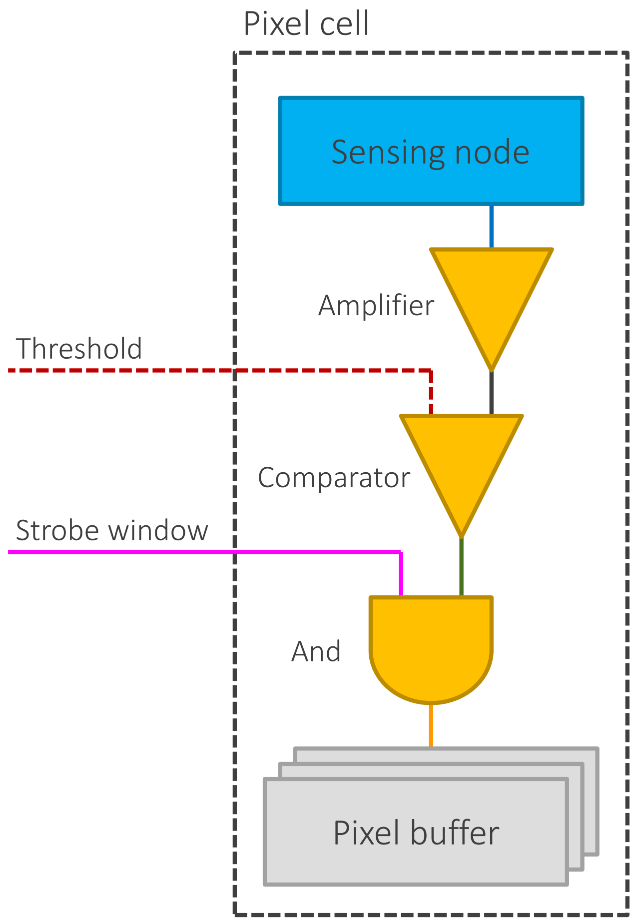
ALICE

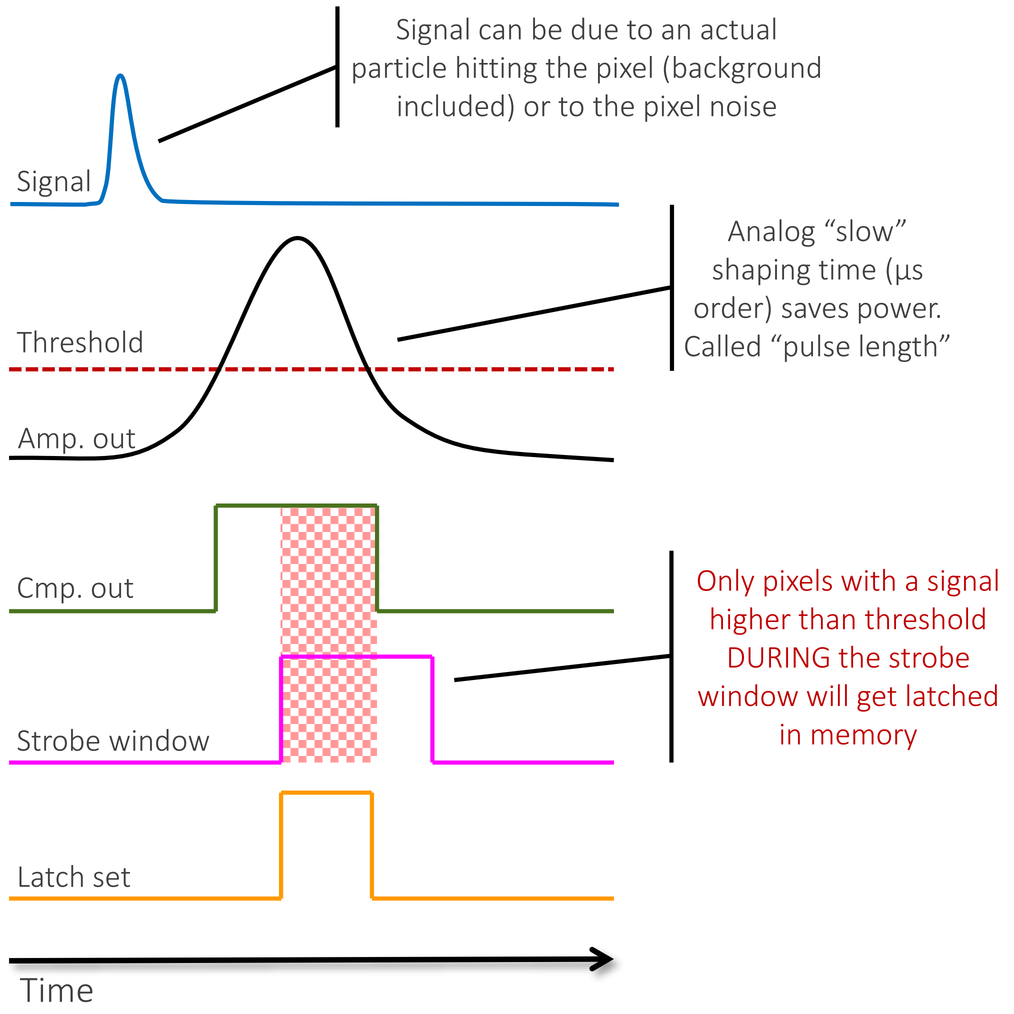
System Timing

ITS Readout Electronic – **Production Readiness Review** – 13 Apr 2018 – CERN

Sensor operation recall

Recall – sensor pixel cell timing



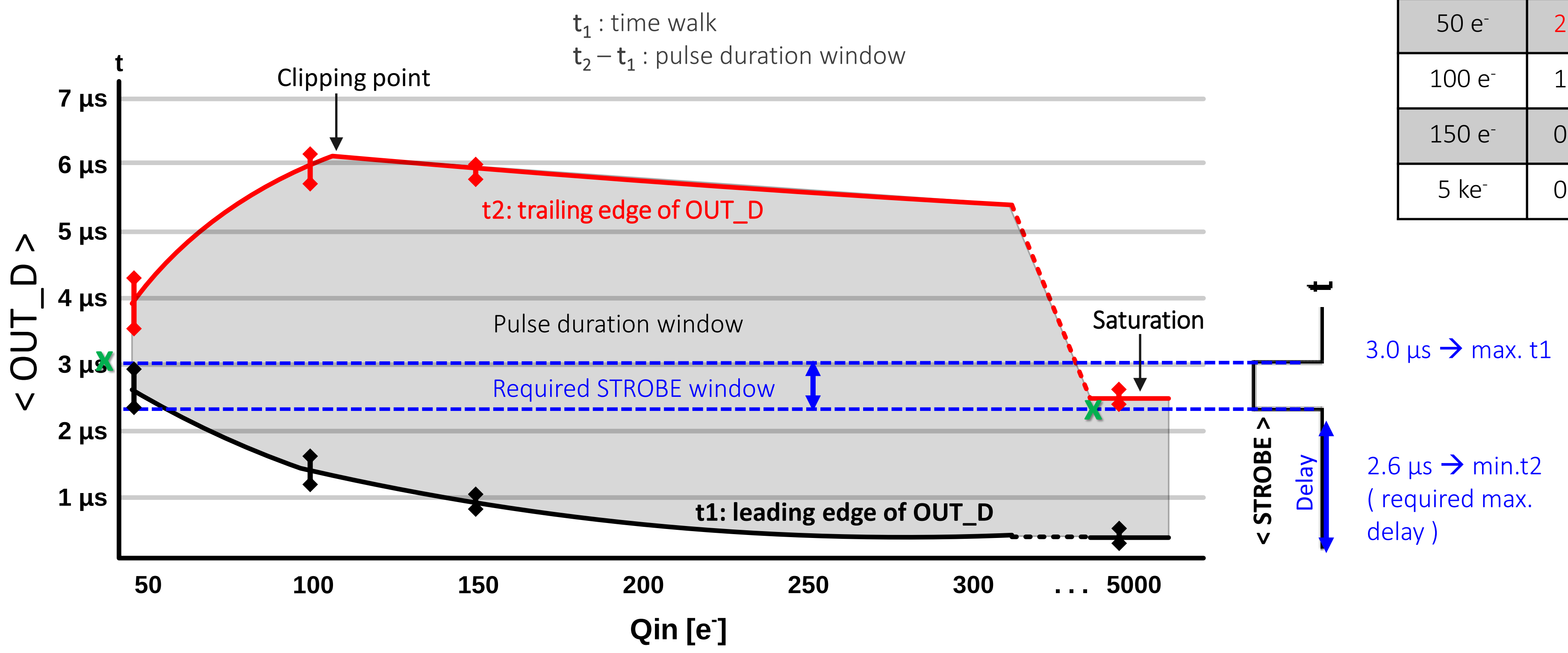


Slow shaping time acts as an analogue memory buffering the signal until the arrival of the trigger (time over threshold of about 5 µs on average). Signals above threshold during the strobe window are latched into one of the pixel memory buffers.

Timing – front end analog pulse time over threshold

- The pixel front-end acts as an analogue memory, maintaining hit information until the STROBE arrives.
- Timing constraints limit the trigger acceptance window.

Q_{in}	t1 [us]	t2 [us]
50 e^-	2.9 ±0.20	3.9 ±0.52
100 e^-	1.5 ±0.16	5.9 ±0.24
150 e^-	0.9 ±0.03	5.7 ±0.09
5 ke^-	0.5 ±0.01	2.6 ±0.07

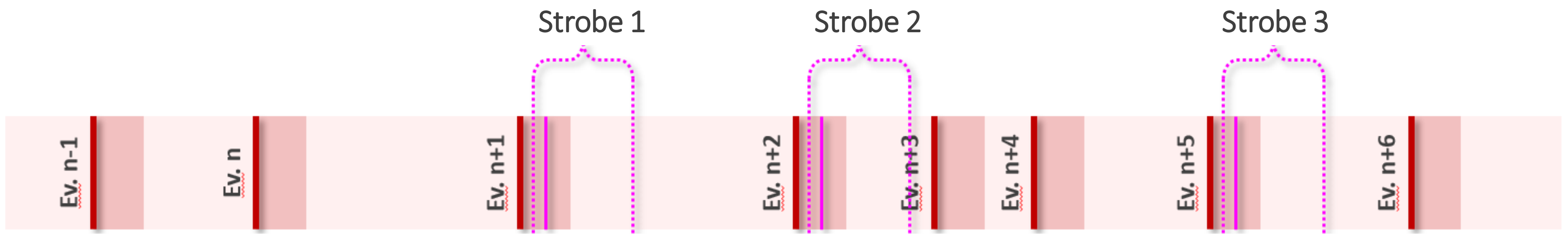


- The signal is latched only when both STROBE and OUT_D are active at the same time. STROBE window can be defined such that it latches all charges above threshold:
  - **STROBE** delay has to be **larger than the trigger latency** (≈1.2 µs)
  - Pulse **timing rms variations** have to be taken into account (error bars at 5 sigma)

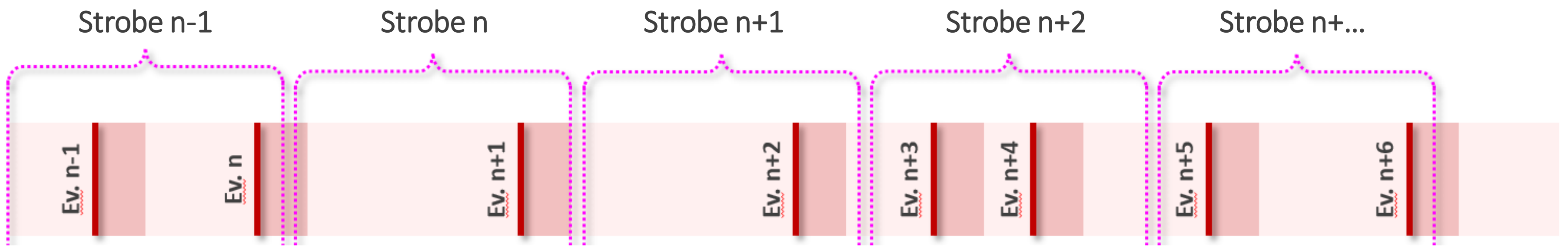
Recall: Modes of Operation

- The ITS plans to operate in two modes:

Triggered mode: Pixels are latched with a short strobe window, followed by read out, based on an external trigger.



Continuous mode: Pixels are latched using long, periodic strobe windows with short inter-strobe periods (≈100 ns) to initiate read out.



Triggered operations

Recall – Trigger distribution to FEE for ITS

- **Triggers are distributed directly from the LTU to the ITS Readout Unit using the GBT protocol.**

- An option could be to distribute triggers via the CRU over PON and GBT (like other ALICE detectors).
  - This path adds a trigger latency of **~1400 ns**[(1)]
  - → ITS needs a dedicated and fast solution for trigger distribution (see sensor description)

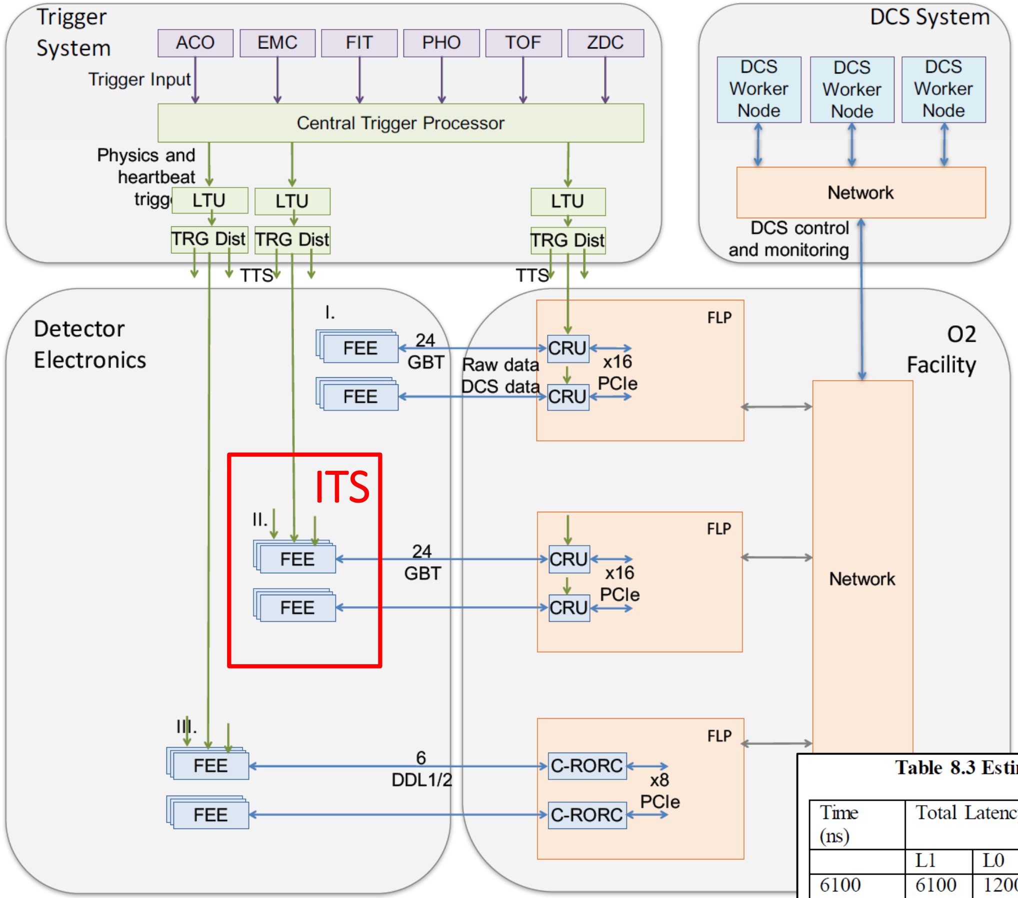


Table 8.3 Estimated Latencies for trigger distribution to FEE via CRU

Time (ns)	Total Latency (ns)			Description
	L1	L0	LM	
6100 /1200 / 425	6100	1200	425	L1/ L0 / LM inputs to CTP board
100	6200	1300	525	CTP processing time
85	6285	1365	610	CTP-LTU fan-out time
25	6310	1410	635	LTU processing time
600	6910	2010	1235	120 metres of optical cable to CRU (ALI-CR4)
86	6996	2096	1321	PON downstream latency (only active components)
25	7021	2121	1346	CRU latency
130	7151	2251	1476	GBT downstream latency (using Aria 10 FPGA)
600	7751	2851	2076	120 metres of optical cable CRU to detector FEE
TOTAL: 7751 / 2851 / 2076				**Total latency from interaction to detector FEE for L1 /L0 / LM triggers**

[1] Values taken from D. Evans et. al *«Trigger System Design Review, v 2.0»*, May 2016

Timing – trigger detailed latency

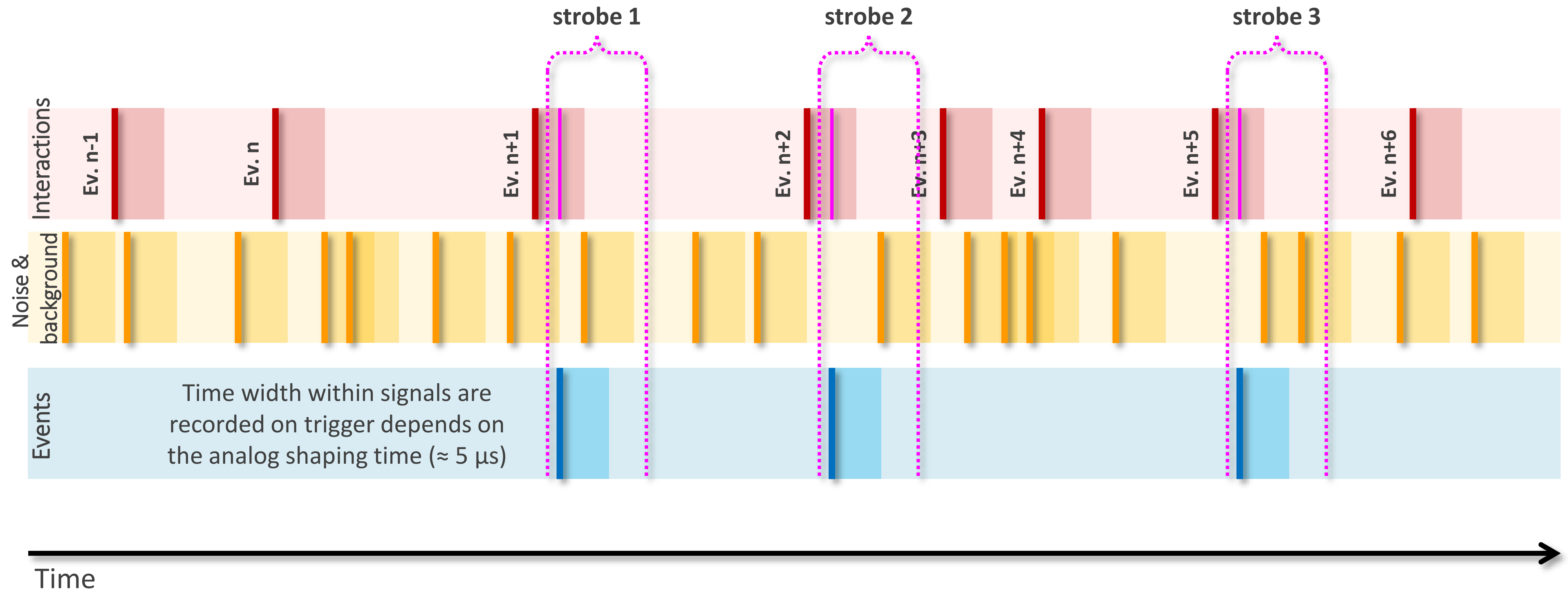
- Latency estimation for LM trigger / L0 trigger[1]:

	Dedicated network LTU→ RU		Distributed via CRU
	LM trigger [ns]	L0 trigger [ns]	LM trigger [ns]
Trigger inputs at CTP	425	1200	425
CTP processing + Low latency + LTU	100 + 85 + 25 = 210	100 + 85 + 25 = 210	100 + 85 + 25 = 210
PON cable + PON downstream latency + CRU latency + GBT downstream latency + optical cables CRU→ FEE	-	-	600 + 86 + 25 + 130 + 600 = 1441
GBT downstream latencies (Kintex-7 FPGA)	150	150	-
Optical fibers (35 m long) from CTP to the RU	175	175	-
Electrical cables from the RU to sensor	250	250	250
Total	1210	1985	2326

This is baseline solution!

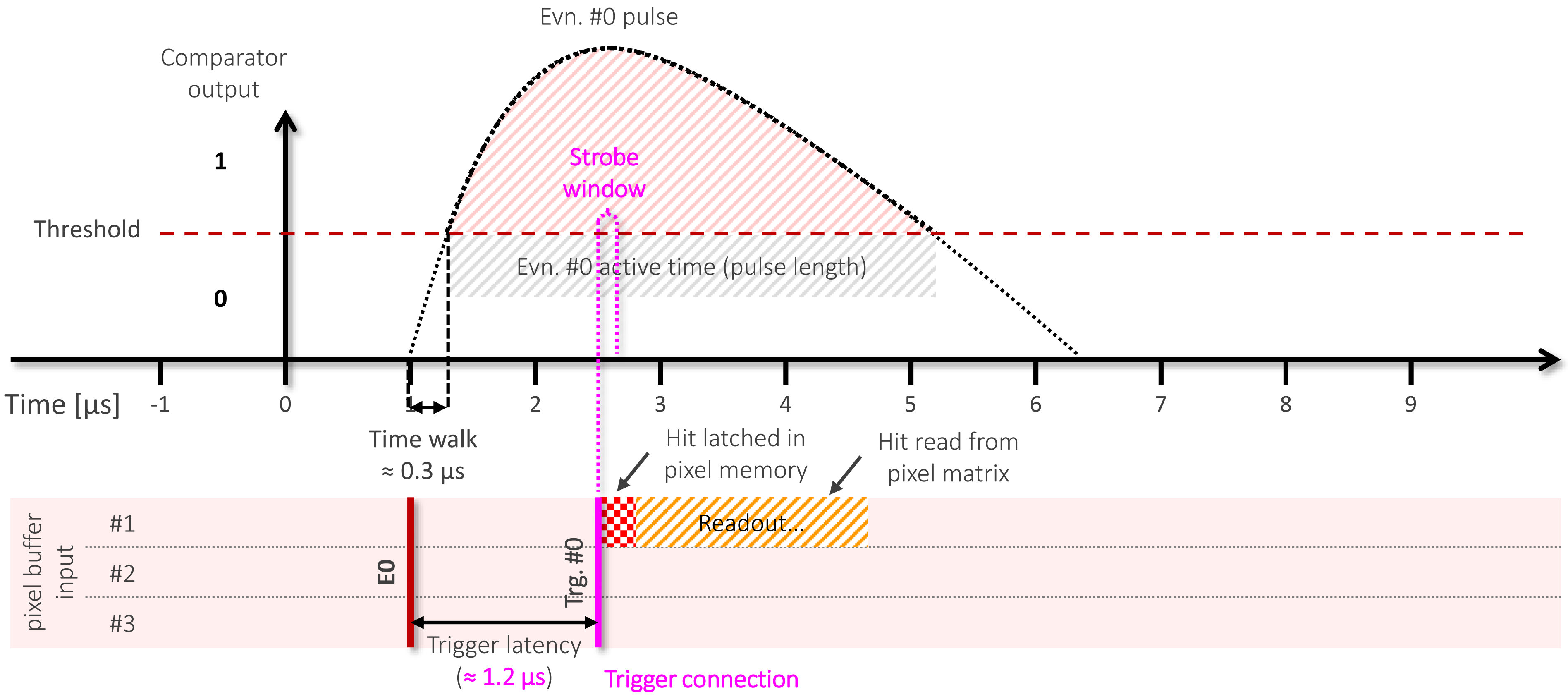
[1] Values taken from D. Evans et. al «*Trigger System Design Review, v 2.0*», May 2016

Timing – sensor operations (triggered)



- Event rate – average number of interactions per second, Poisson distributed. Design goal is 100 kHz Pb-Pb collisions and 400 kHz p-p collisions.
- Background – QED interactions, depends linearly to the beam intensity and on integration time. It significantly affects the inner layers only.
- Noise – electronic pixel noise (thermal, RTS, etc.), generates fake pixel hits.
- Trigger – all pixels with a signal over threshold during the strobe window (due to an event, background, noise, etc.) store a hit into their buffer.

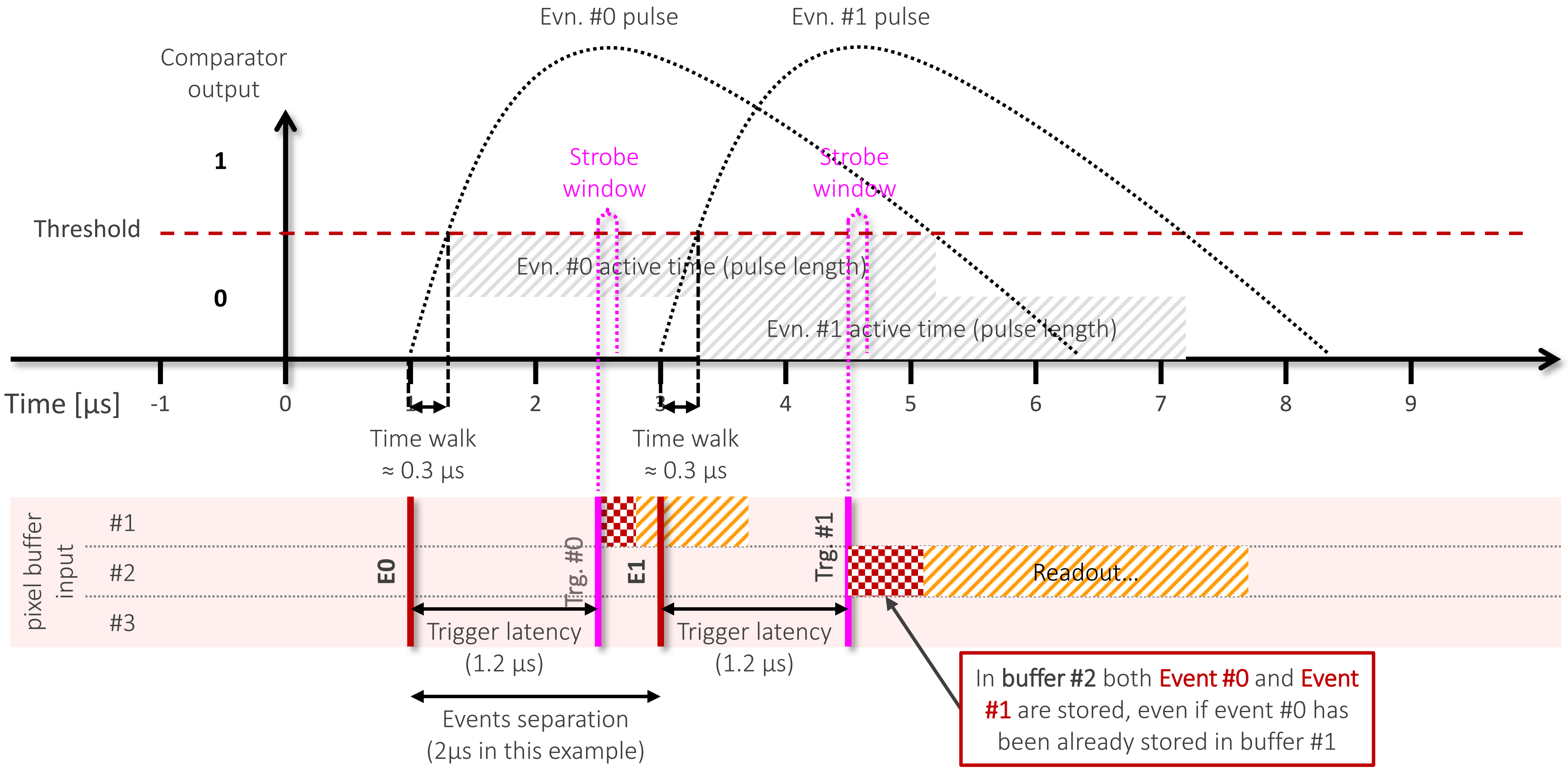
Timing – detailed strobe and latching timing



Trigger connection
The trigger latency (to the matrix, including delay due to transmission and processing from the Readout Electronic) will be about **1.2 µs**.

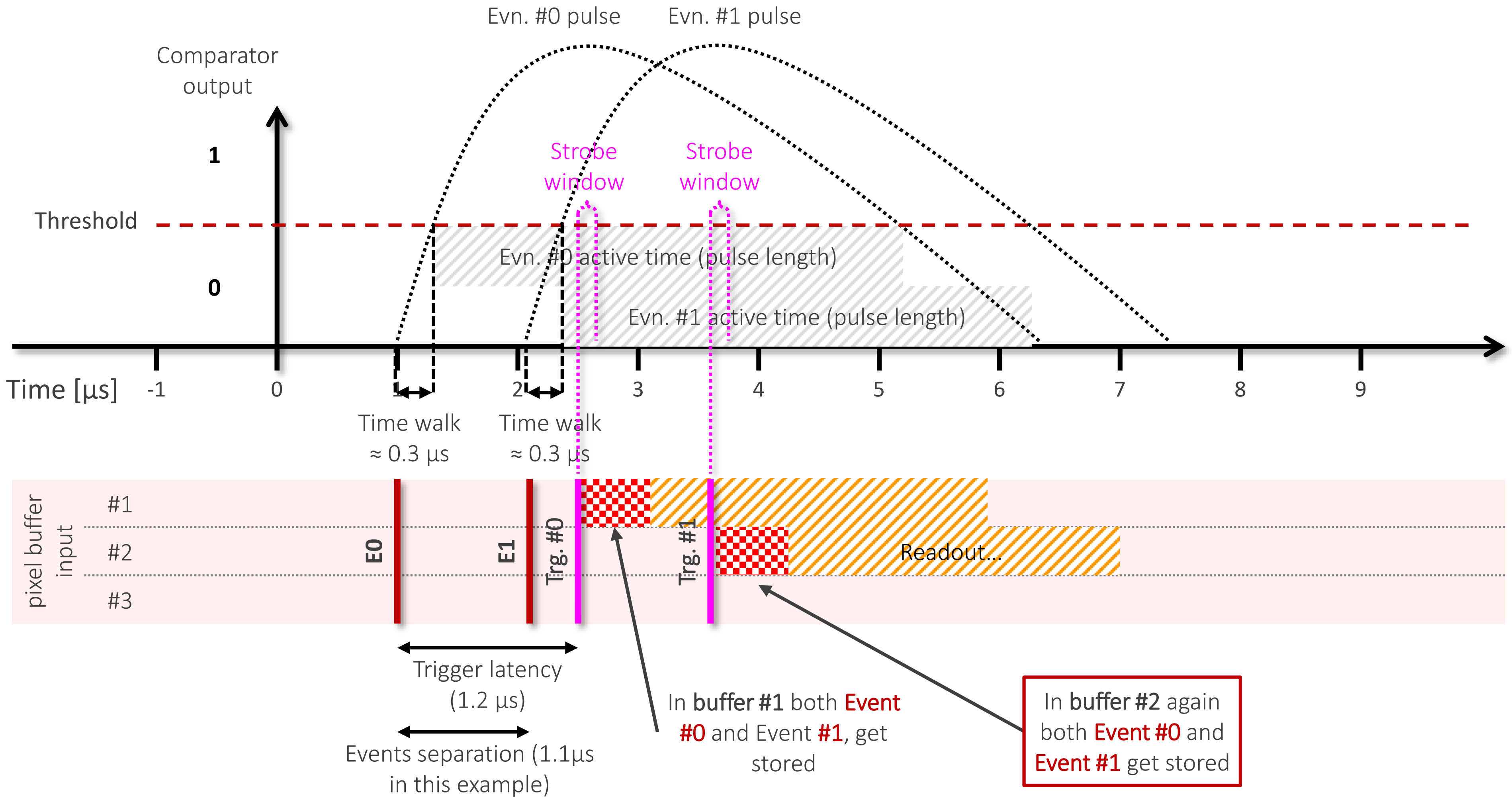
- Drawings are (reasonably) to scale. Timing figures are indicative, not precise.
- Strobe signal is driven by trigger.
- The analogue pulse duration behaves as an analogue memory, holding the hit information until the arrival of the trigger strobe. The pulse duration must therefore be long enough for the trigger to arrive.

Timing – strobe re-latching previous strobe data



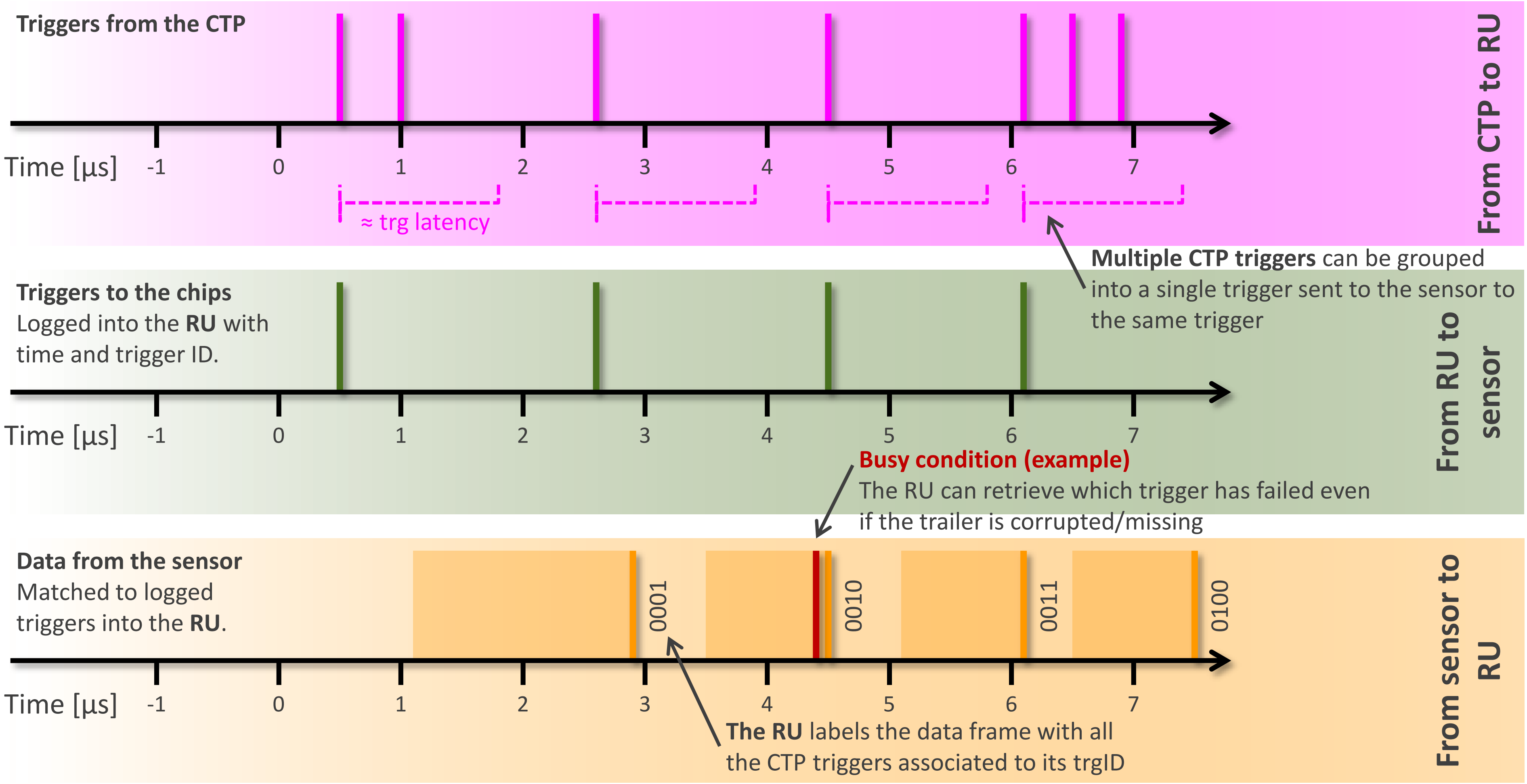
- Drawings are (reasonably) to scale. Timing figures are approximated, not precise!
- Strobe signal is driven by trigger.
- In this example, the second trigger (Trg. #1) actually stores Evn. #1 and Evn. #0.
- For simplicity, strobe delay and width are not illustrated here.

Timing – trigger overlapping and storing two times the data



In this example, the second trigger (Trg. #1) is useless, as both Evn. #0 and Evn. #1 are stored at the occurrence of Trg. #0 (look at the strobe window). Trg. #1 will store again both events in a new buffer. Therefore we can "filter" such triggers (see next slide).

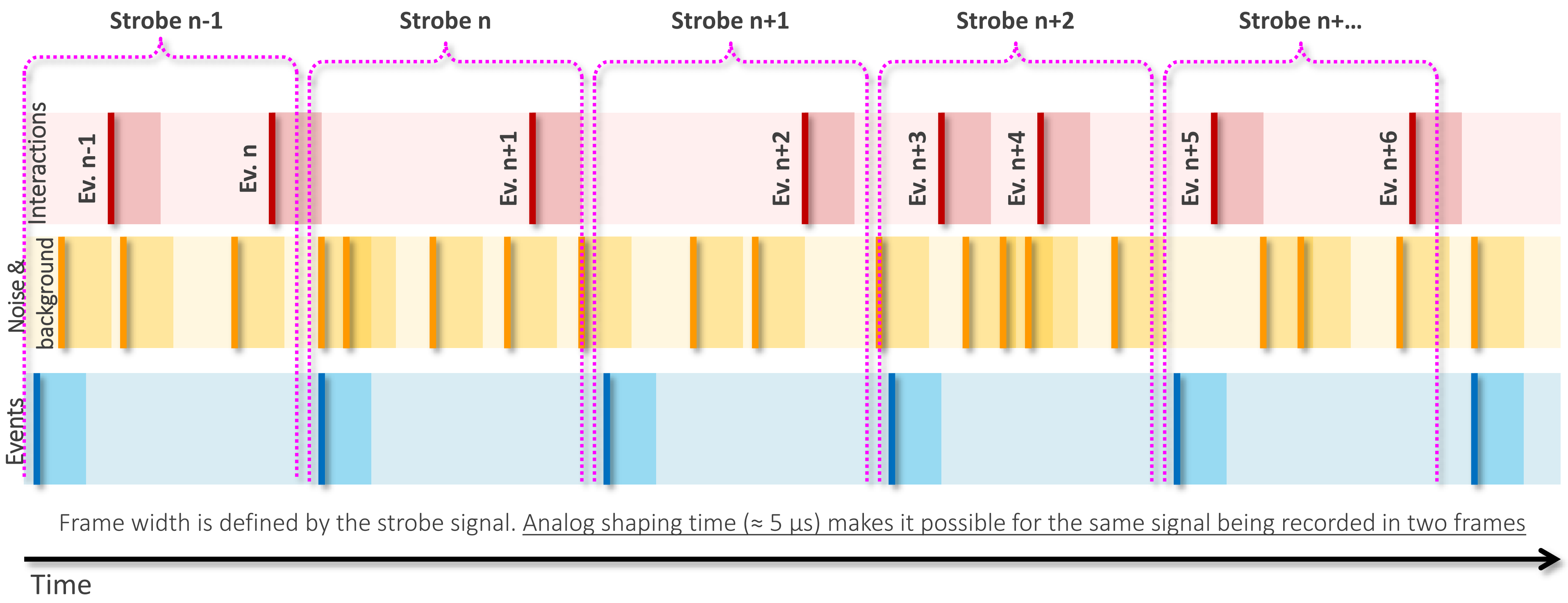
Timing – Readout Unit trigger filtering



Triggers close in time re-record the same information, and the sensor can handle a minimum trigger spacing of about 1 μs. The RU will therefore “filter” close-in-time (≈ < 1 μs) triggers. This also allows for the busy flag to be propagated to the readout unit before another trigger is issued (see next slide).

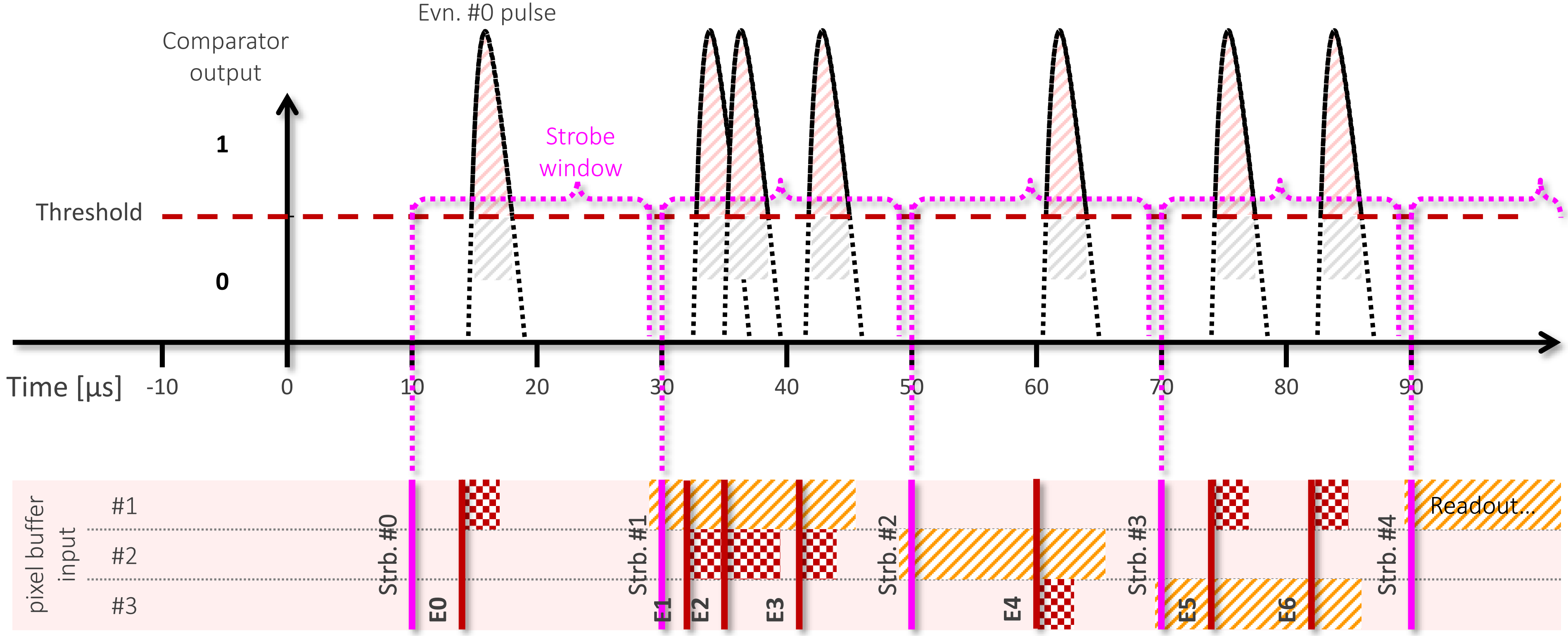
Continuous operations

Timing – sensor operations (continuous)



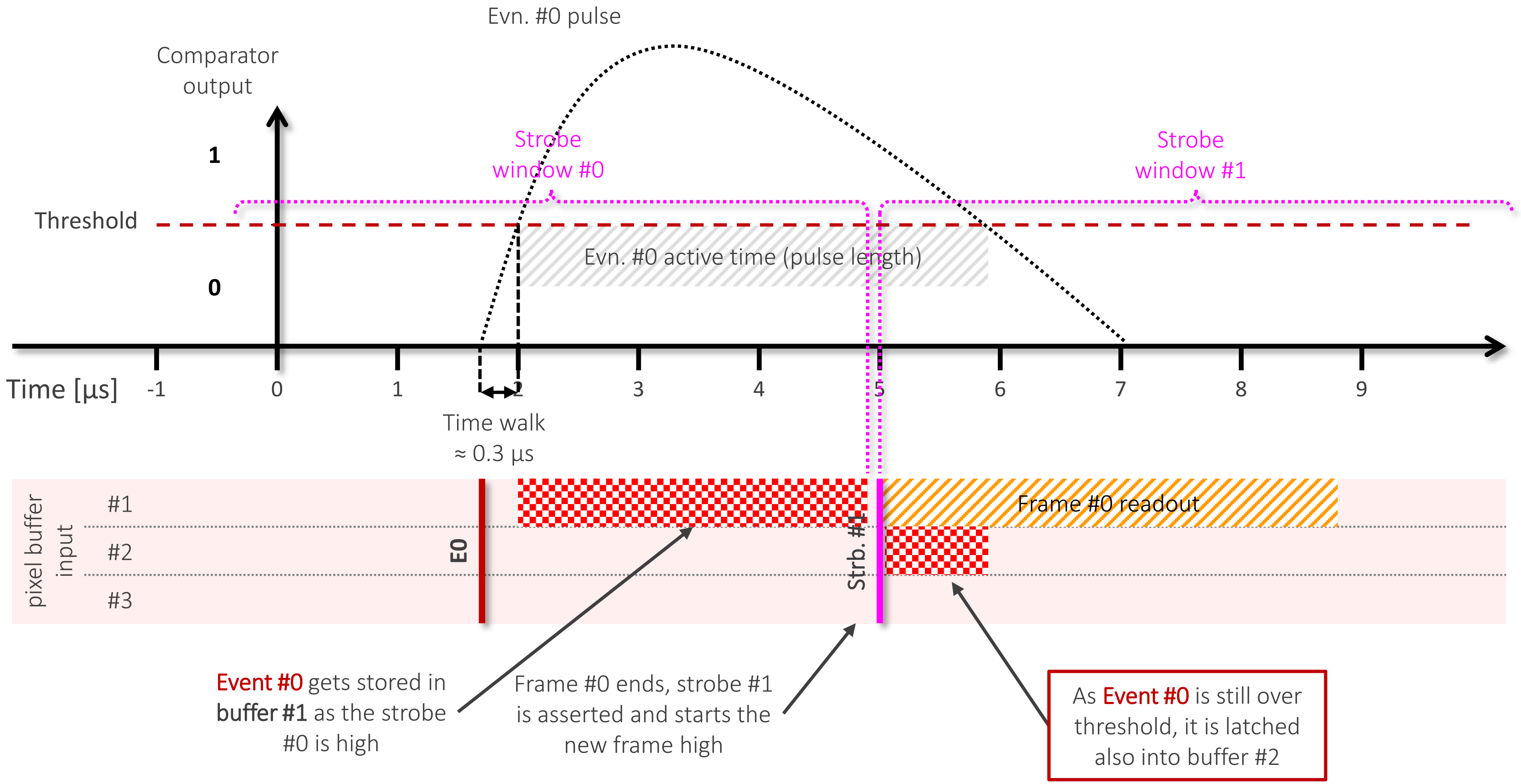
- Event rate – average number of interactions per second, Poisson distributed. Design goal is 100 kHz Pb-Pb collisions and 400 kHz p-p collisions.
- Background – QED interactions, depends linearly to the beam intensity and on integration time. It significantly affects the inner layers only.
- Noise – electronic pixel noise (thermal, RTS, etc.), generates fake pixel hits.
- Frame – time period defined by the strobe window: every signal over threshold is recorded. Time lost between frames is negligible (few ns).

Timing – continuous mode strobe detail



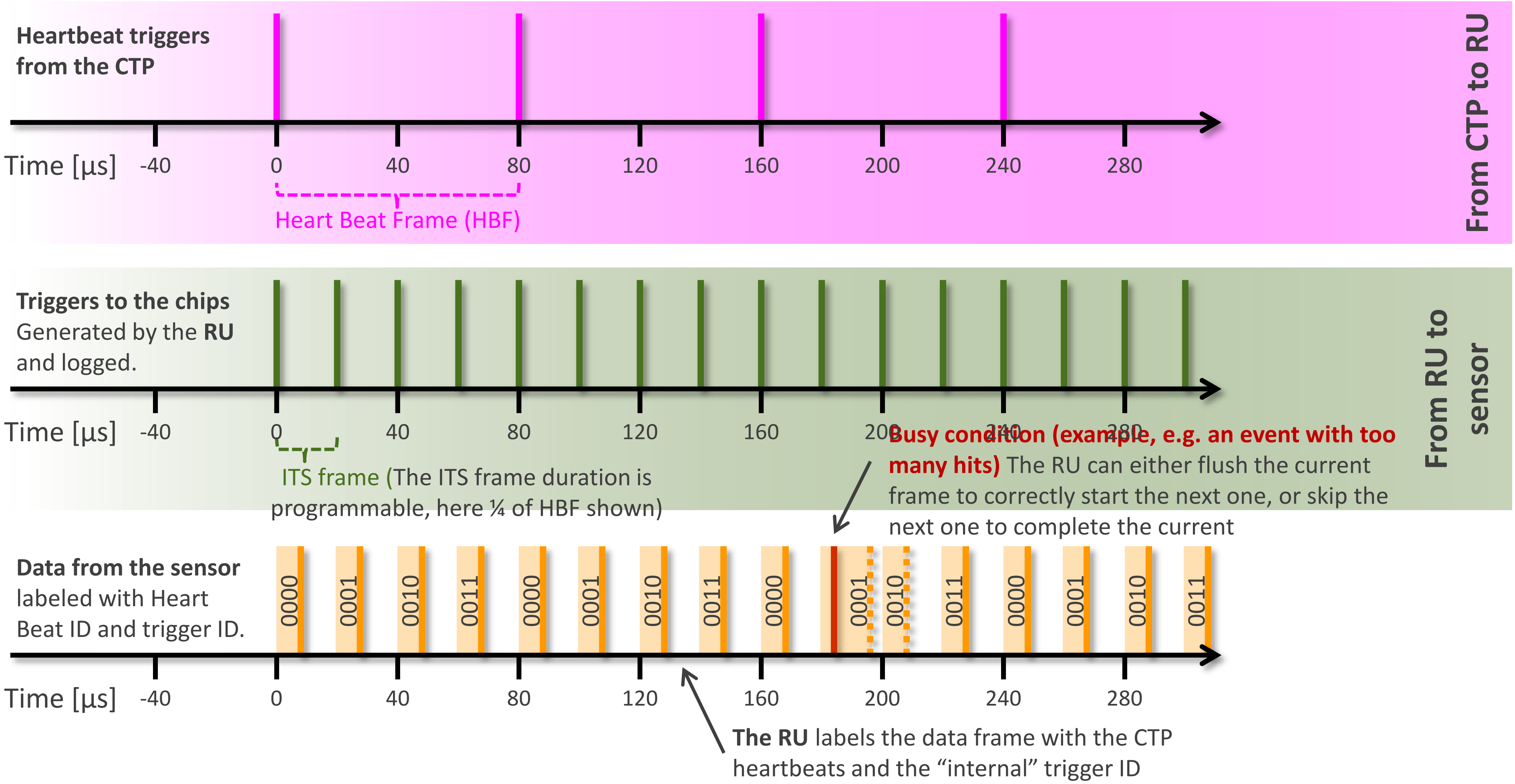
- In continuous mode the strobe window is asserted for almost a full “frame”. The actual gap between frames is programmable, and set at 100 ns as baseline.
- Any signal above threshold is latched in the pixel buffer for the current strobe.
- When the strobe is de-asserted, the readout of the pixel buffers starts, and immediately afterwards a new strobe is asserted

Timing – continuous mode storing the same event in two frames



- In this example, the analog output of the front end stays over threshold across a frame change, hence being recorded in both frames (in different pixel buffers).
- The effect is clearly more important for short frame length (when compared to the about 5 us time over threshold of the front-end).

Timing – continuous mode implemented as fixed-rate triggered mode

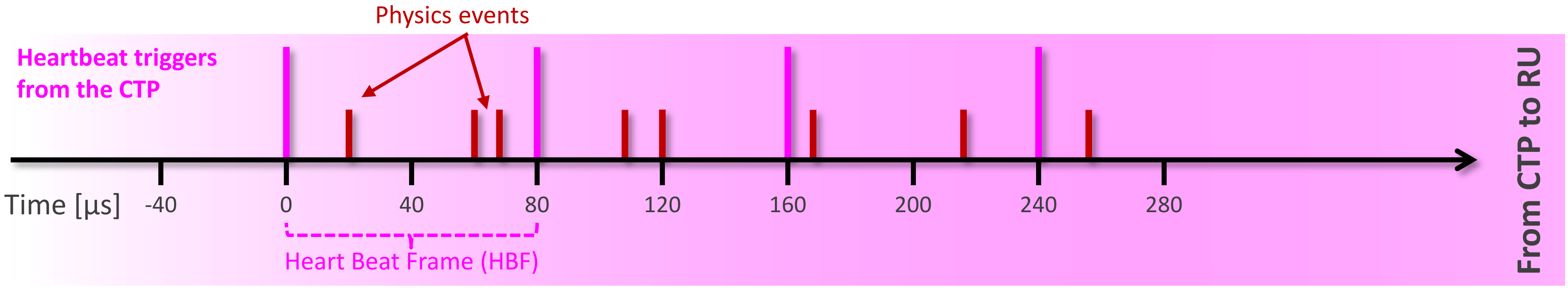


The sensor has an embedded (programmable) trigger generator, *but we will instead issue triggers at a constant frequency from the Readout Unit* for continuous mode operation to ensure more flexibility in managing busy and potential error conditions, as well as for implementing <u>local frame throttling/suppression schemes as needed</u>.

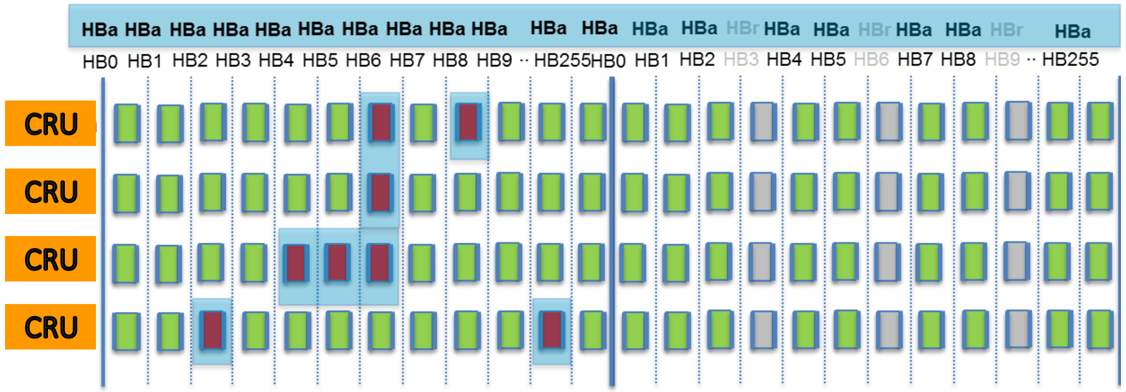
Backup

Timing – Heart Beat and Throttling in continuous mode

In continuous mode the **CTP** will issue a Heart Beat tick every **89.4** µs. Data will be packed into the Heart Beat Frame (**HBF**) they belong to. 256 HBF will form a Time Frame (TF) across the detector.



The CTP also collects a busy condition from each Common Readout Unit for each HBF. In case of excessive busy occurrence in one or more detectors, the CTP will throttle down the overall acquisition speed by sending a special Frame Suppress trigger.



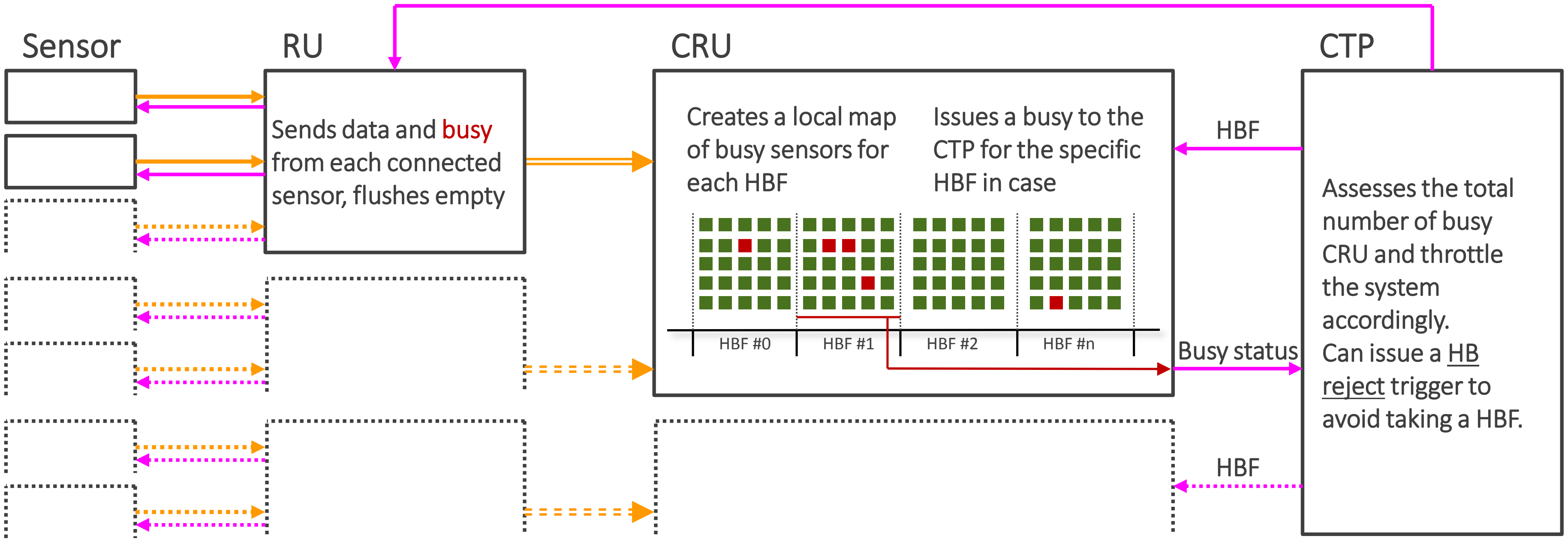
By sending some Heart Beat **Reject** triggers the CTP (resulting suppressed HBF grey rectangles) can effectively throttle down the acquisition bandwidth, improving the likeliness of having aligned data frames.

Each CRU decides whether to assert its own busy condition based on its internal FIFOs status and (if provided) by additional information arriving from the detector front-end electronics.

Timing – busy reconstruction at CRU level

A sensor can answer to a trigger from the RU in three different ways:

- Good data packet(s)
- Empty sensor packet (no data at all in that sensor)
- Busy flag (alone or within data packets, as it has always priority over data). Empty packets will be flushed, while data and busy will be transmitted to the CRU



The CRUs connected to the ITS have all the information to internally compute a "busy map" of all the sensors it is connected with (other detectors CRUs will only check their own internal buffer). They can individually assert a busy condition to the CTP.

Readout – trigger filtering logic scheme

The sensor accepts a trigger or issues a busy if it cannot process it. Triggers are guaranteed to arrive to the sensor with a minimum separation **TW** (at least 1 µs). CTP trigger reference (bunch crossing ID) are anyway stored for every CTP trigger, and later associated to outgoing data by the Readout Electronics.