Timestamps as hot potatoes – a brief overview of VELO dataflow in LHCb

Nikhef Jr Colloquium 25/09/2024

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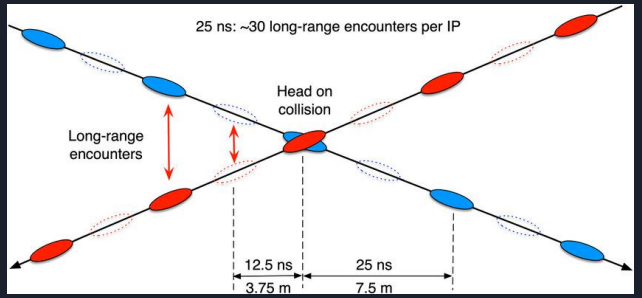
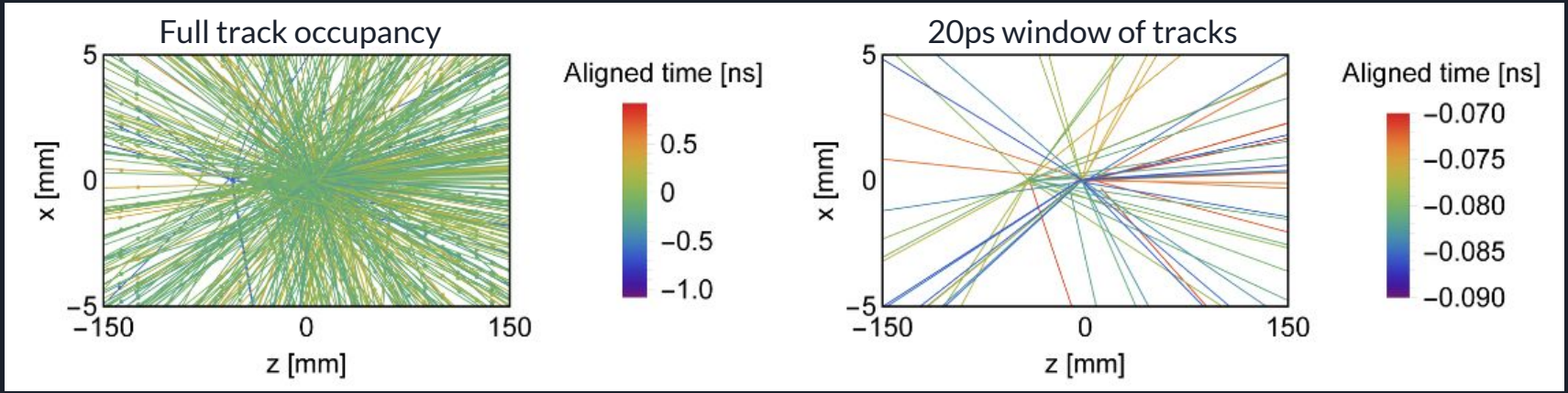
Motivation – LHC Upgrades



[2]

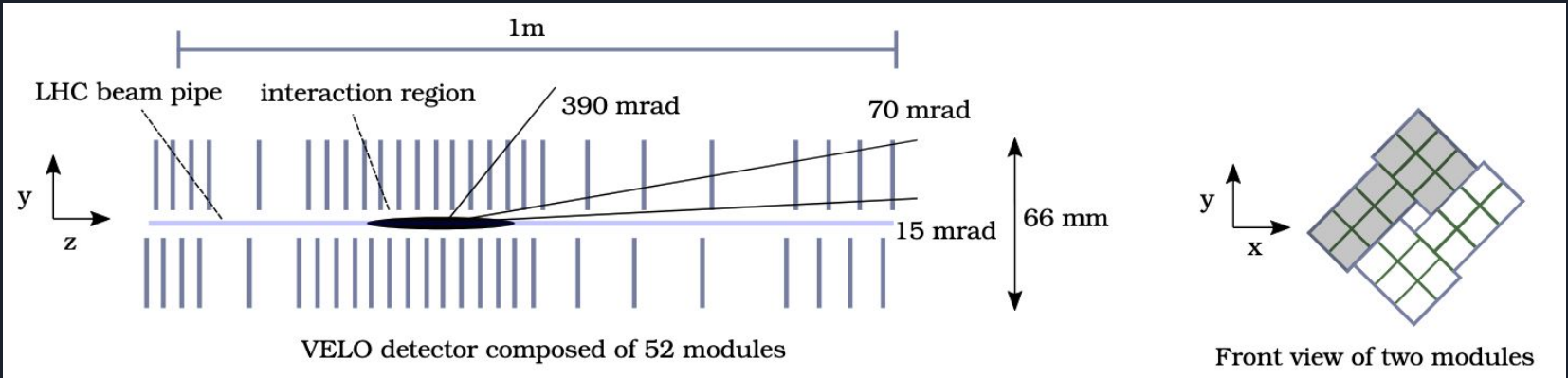
- HL-LHC: Vastly increased expected pile-up: From ~5 to ~40-50 collisions/bunch crossing [1]
- → Much higher detector occupancy
- → Increasing need to separate tracks with a fourth dimension

Track Density plots



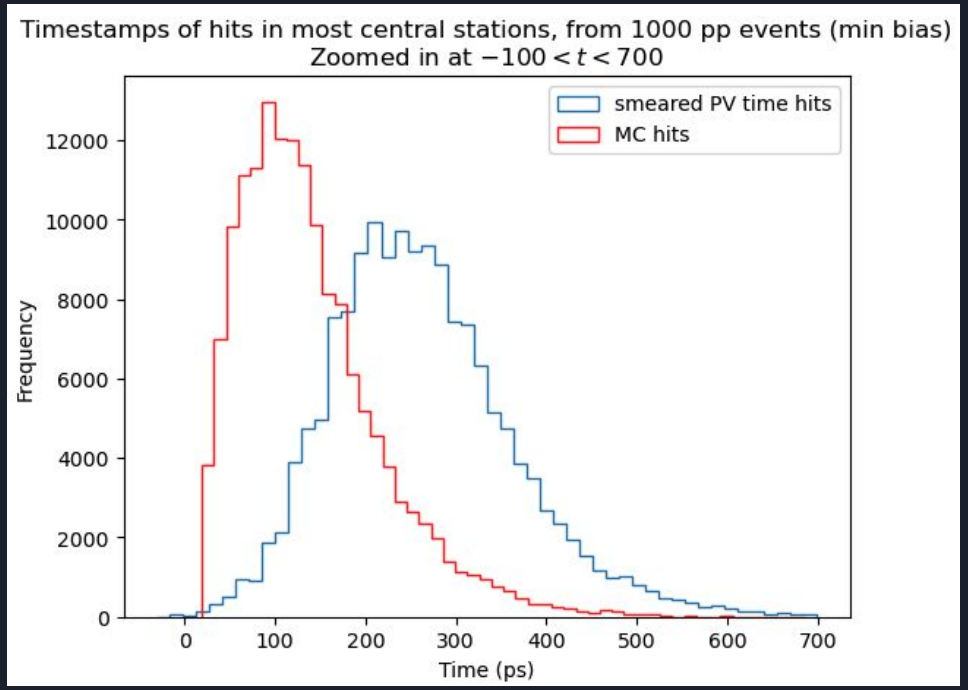
[1] *CERN. Geneva. The LHC experiments Committee ; LHCC*, **Parkes, Chris; Lindner, Rolf**: "Framework TDR for the LHCb Upgrade II : Opportunities in flavour physics, and beyond, in the HL-LHC era", https://cds.cern.ch/record/2776420/?ln=en
[2] Oliver Brüning et al 2022 Rep. Prog. Phys. 85 046201

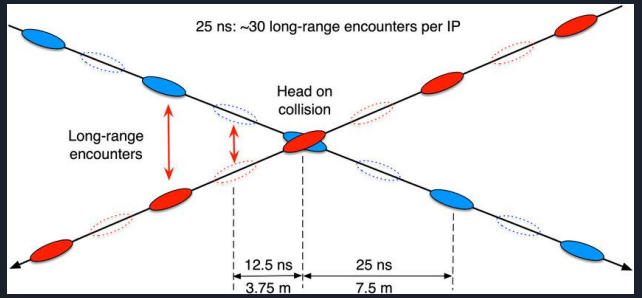
The VELO detector – Schematic



Pérez, Daniel & Neufeld, Niko & Núñez, Agustín. (2022). Search by triplet: An efficient local track reconstruction algorithm for parallel architectures.

Data to work with

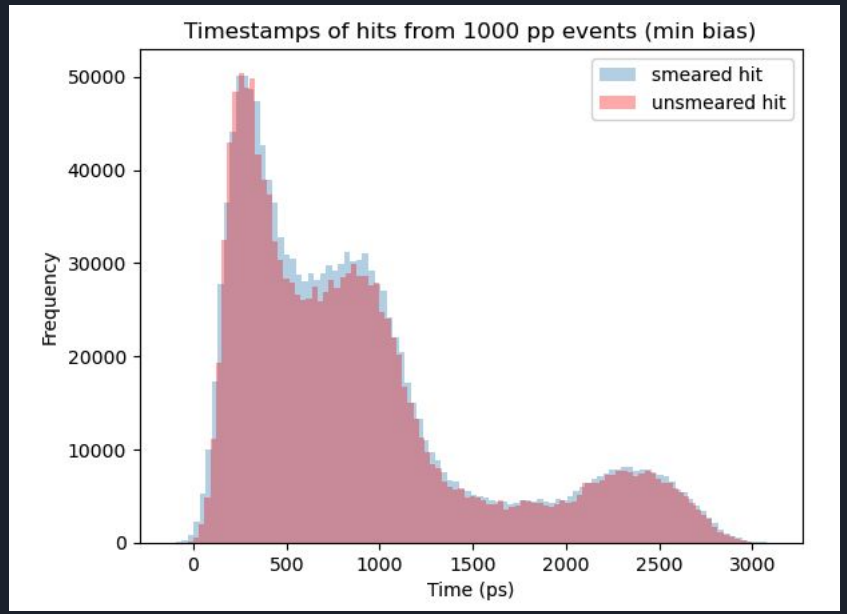


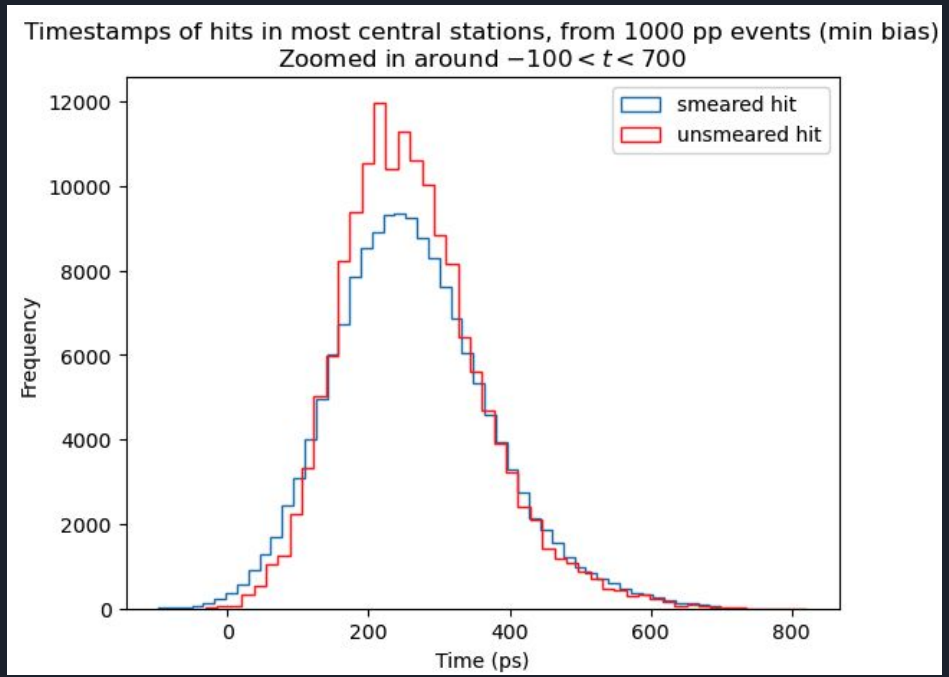


- Current MC hit data contains only relative time to primary vertex
- Every primary vertex (PV) is at t = 0
- → Introduce smearing over PVs
  - Width of bunch at collision ~7.5cm
  - ~180ps crossing time
- → σ = 45ps reasonable: 95% within nominal bunch crossing time (Gaussian probably not physical)

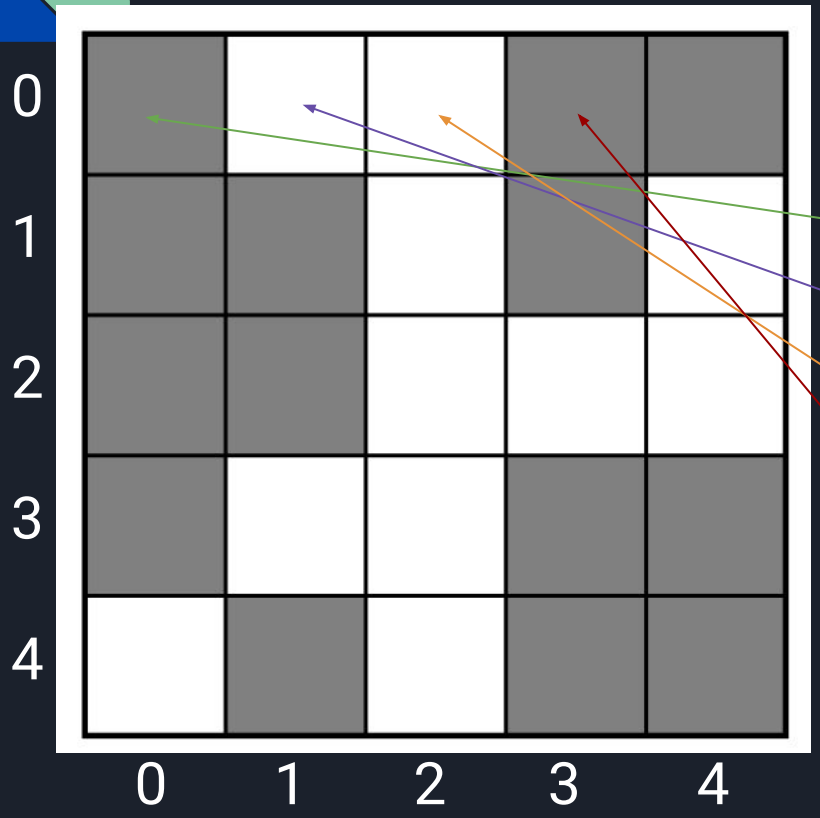
Data to work with – smeared PV timestamp

Also add 50ps smear on hits:





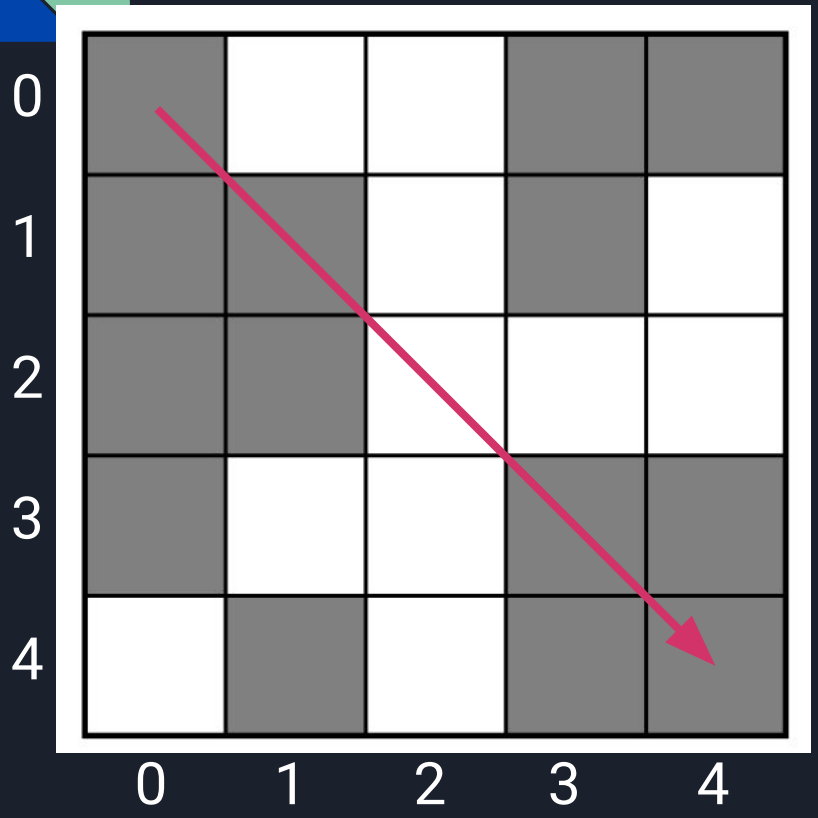
How to pass pixel information?



Position:x	Position:y	Value	Total bits
000	000	1	7 (8)
001	000	0	7 (8)
010	000	0	7 (8)
011	000	1	7 (8)

8 bits per pixel →
25× 8 = 200 bits

How to pass pixel information?



Sender and receiver agree on order:

Position:x Position:y Value

000 000 10011 11010 11000 10011 01011

31 bits in total
→ ONE 32 bit “word” to send vs 6 or 7 with naive method

How to pass pixel information: Superpixels

Superpixel format: Settle on info of 8 pixels shipped together

6.1 SuperPixel format

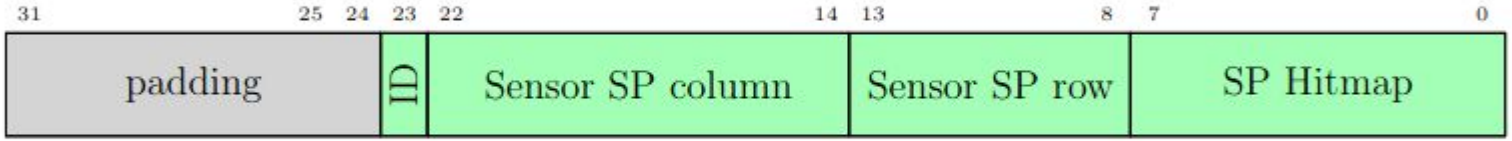


Figure 7: Velo SuperPixel data fragment

A. Fernandez Prieto, K. Hennessy, G. Bassi; LHCb Upgrade VELO
TELL40 data processing; EDMS 2086526 v.5 status In Work access Public;
VELO_TELL40_Data_Processing_v5.pdf modified 2023-03-29 09:28

Superpixel hitmap

3	7
2	6
1	5
0	4

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Superpixel format: Settle on info of 8 pixels shipped together

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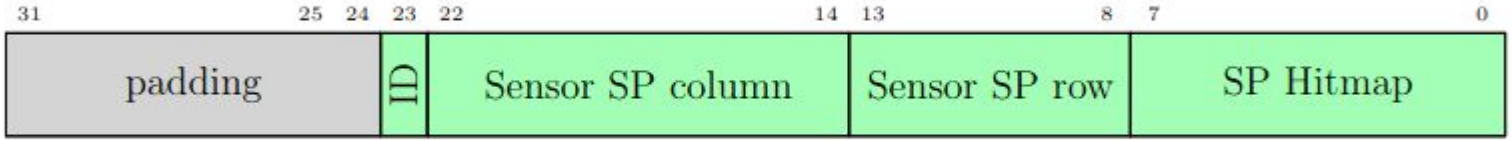

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Problem: Space: 1 bit/pp, while Time: O(10) bits/pp. Why?

Bit requirements for timestamps

- Goal is 50ps resolution
- Design choice: for some wiggle room: 16ps resolution on software side
  - I.e. the 16 bit word 0000 0000 0000 0001 corresponds to 16ps
  - Can increase this to 50 to match resolution
- Bunch spacing: 25ns
  - → Allowing for spillover: use a 50ns window
- → Bits needed: 50ns / 16ps ~ 3000 > 2^{11}, so 12 bits needed.
- In processing, 12 bits means 16 bits → work with 16 bits per timestamp
  - Subject to change on the data transfer side. How?

Example:

ASIC (Step 1 after pixel readout)

Readout: 279ps → Send 279ps/16ps = 17:

Later Algorithms on other hardware:

Extract & decode: 17 * 16ps = 272ps

Encoding of superpixel words

Superpixel hitmap

3	7
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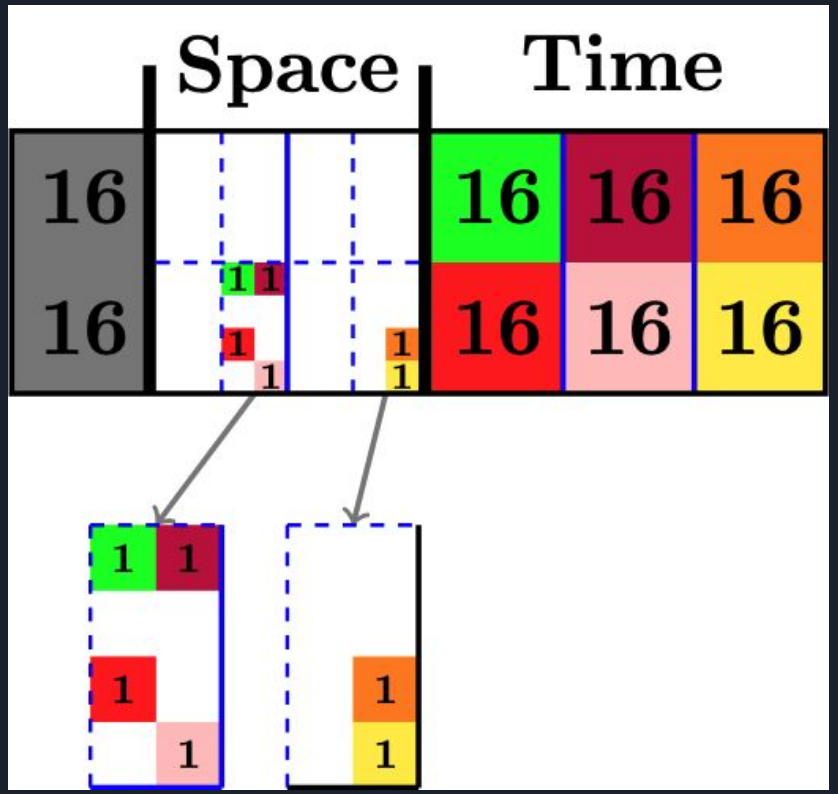
1	5
0	4

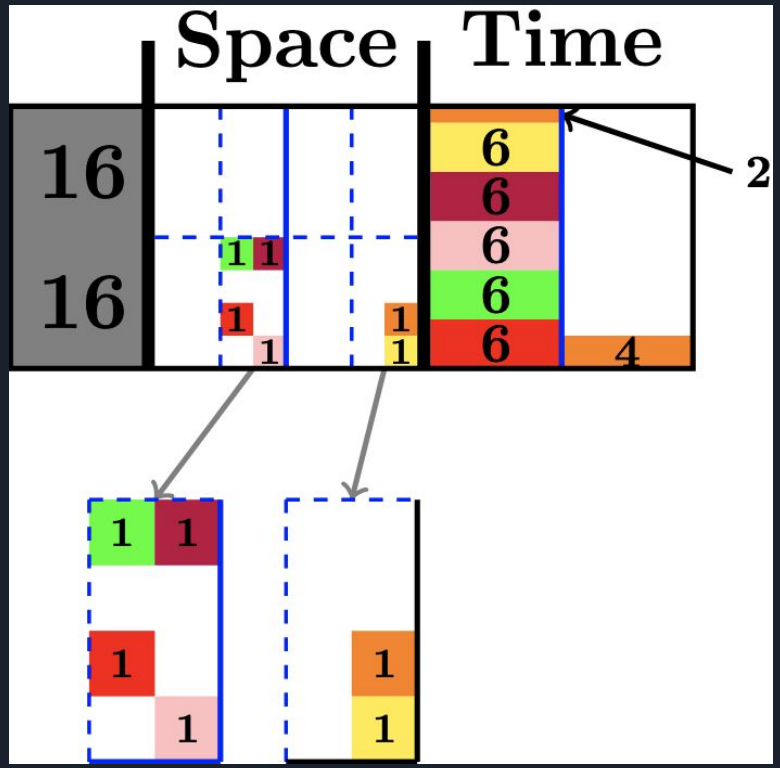


- Data is passed as one large contiguous chunk of memory
- → Writing 12 bits per timestamp is thus technically possible

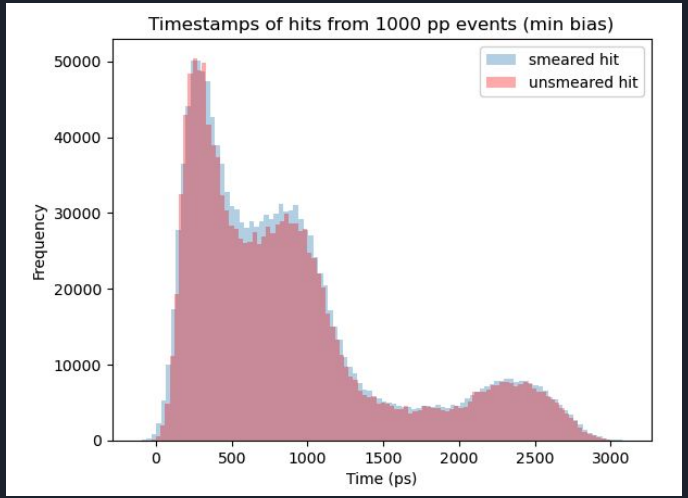
Encoding of superpixel words

Superpixel hitmap

3	7
2	6
1	5
0	4

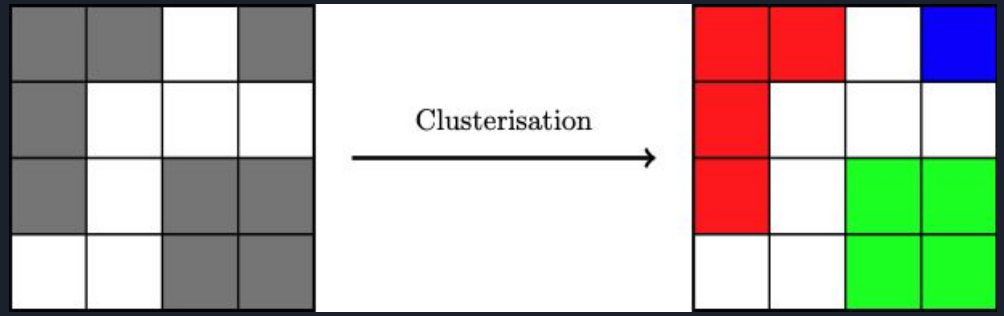


- Or, how about only covering 3.2ns (or even 1.6ns) in 50ps intervals?
- 3.2ns / 50ps = 64
- 64 distinguishable steps: 6 bits
- This covers the vast majority of hits!



Encoding of TimeClusters

- Same as with superpixels, but 32 bits per cluster.
- 16 for the time, 16 for the uncertainty
  - This is to ensure ease of use in future addition of times in clusterisation



Summary and plan

- Investigate timestamps in finalised VELO tracks (consolidated and Kalman filtered)
  - Discrepancies somewhere? (outside of statistical and simulated timestamp uncertainties)
    - first hit time > last hit time?
    - Faster than speed of light travel?
- Look into data with higher pile-up: optimally with Run 4 parameters & expected lumi
- Prepare infrastructure for the point where MC timestamps are more physical
  - Fairly simple: just remove my own smearings
- Start implementing (simple) cuts on clusterisation and tracking with timestamps
  - E.g. a cluster cannot have two pixels with $\Delta t > 1000$ps
  - E.g. two subsequent hits in tracklet creation need to be within $\Delta t <$ Xps, where X can be determined by the slope of the 3-hit tracklet