Experience from vertex triggering at LHC

NIKHEF

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On behalf of the LHCb PileUp group

LHCb

Vertex 2010 - 19th International Workshop on Vertex Detectors
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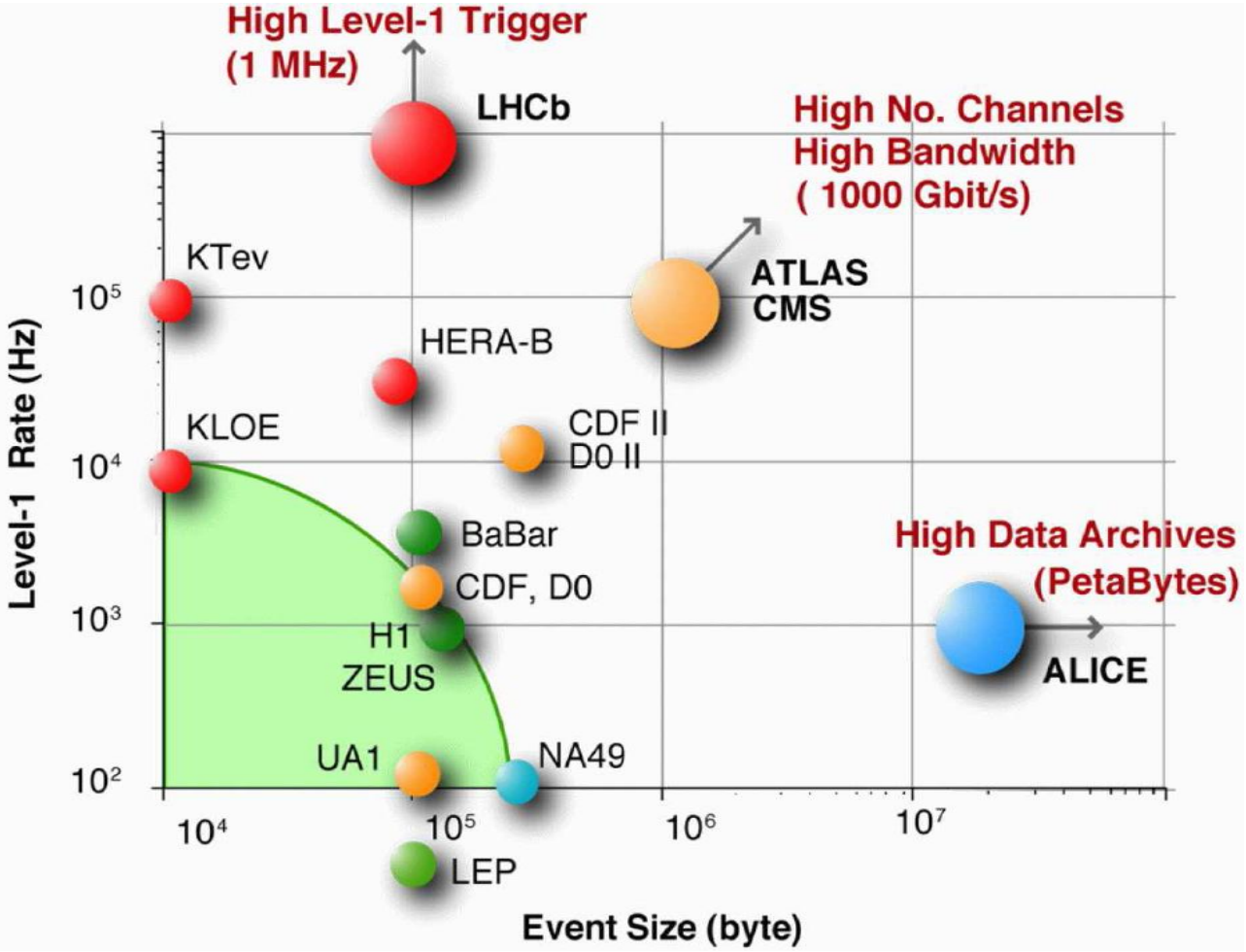
Outline

- Introduction
- Hardware vertex triggering
- Alice Pixel Trigger
- LHCb PileUp detector
  - Why, where, how
  - Preliminary results
- High Level vertex Triggering
- Summary

Trigger rate & Data volume



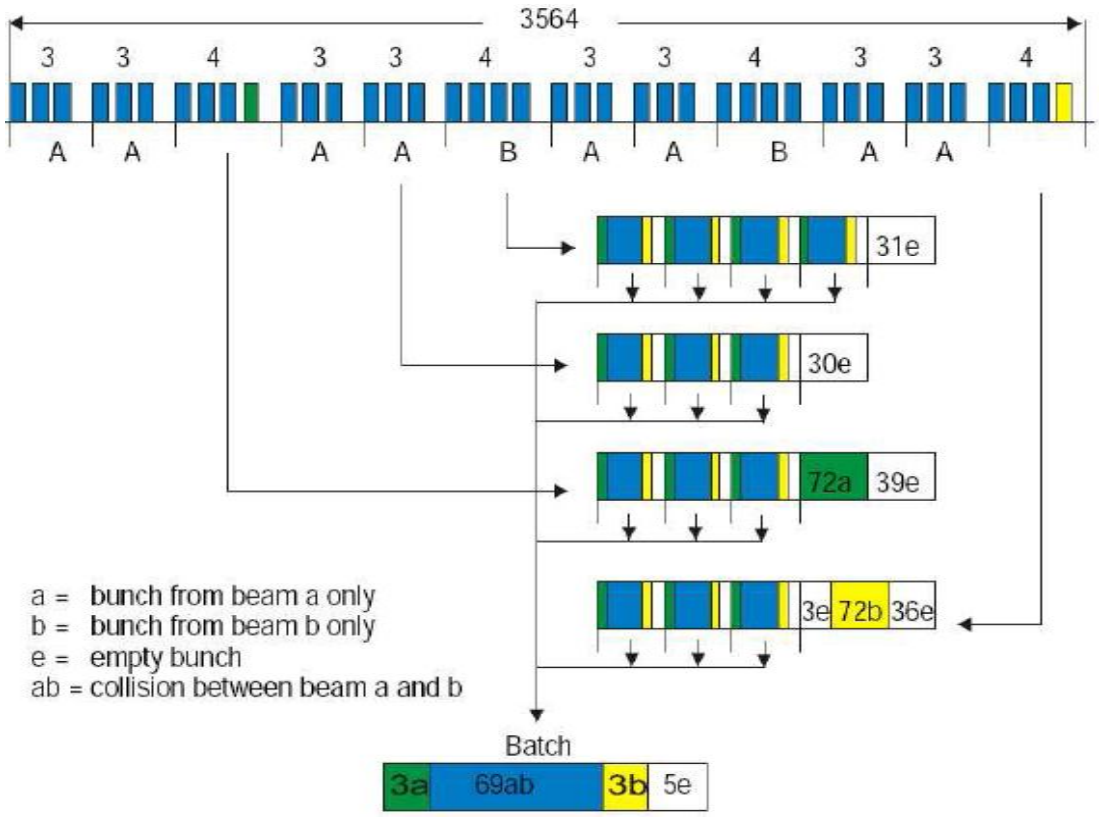
Atlas/CMS

- 30 MHz (x20 pileup)
  - -> 100 kHz (L1 – HW)
  - -> ~200 Hz (HLT)

LHCb

- 10 MHz
  - -> 1 MHz (L0-HW)
  - -> 2 kHz (HLT)

Reminder: LHC bunch structure



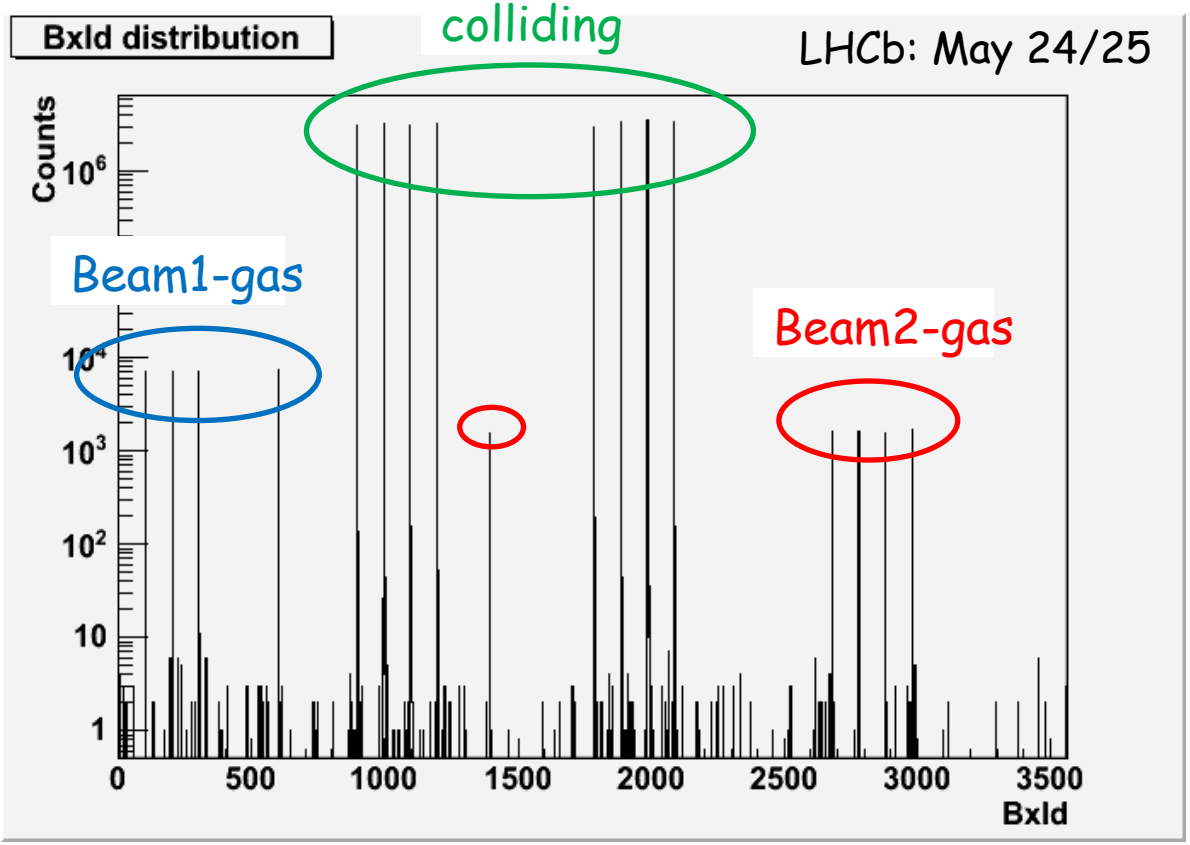
Ultimately:

- 2808 bunches of 3564 filled
- ~ 30 MHz of beam-beam crossings
- 10^{11} protons per bunch
- $\beta^* = 0.55$ m (LHCb: 5 m)
- Luminosity 10^{34} (Atlas/CMS)
- $2\text{-}5 \cdot 10^{32}$ LHCb

Sofar achieved:

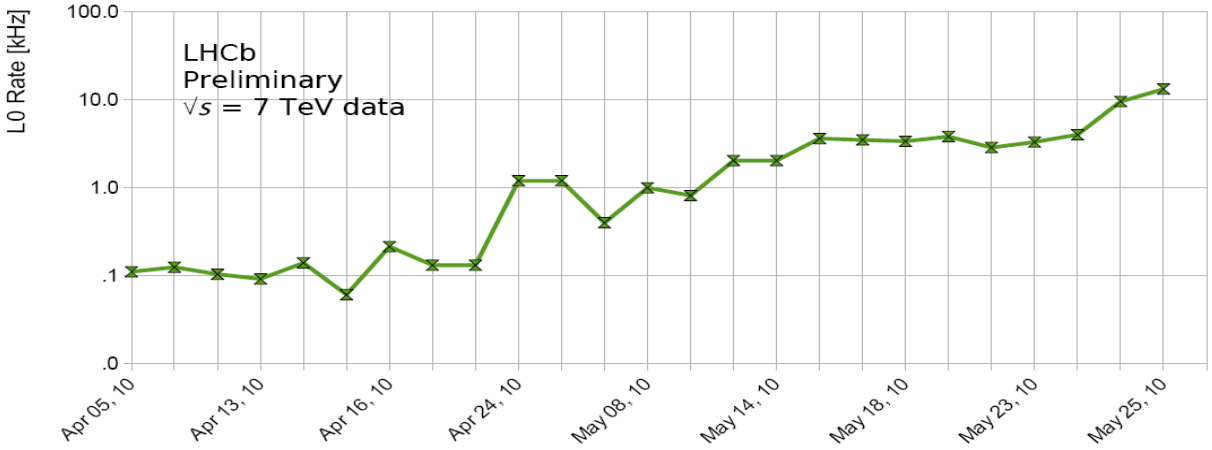
- 13x13 bunches
- ~100 kHz x-ings
- several 10^{10} per bunch
- $\beta^* = 2$ m
- Luminosity $2 \cdot 10^{29}$

13 x 13 bunches

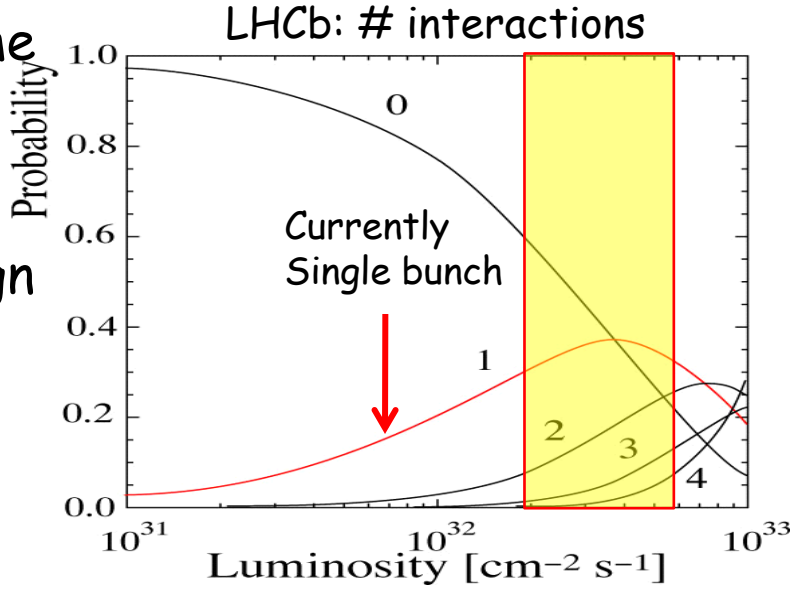


- 13 bunches per beam
  - 8 colliding
  - 5 beam-gas
- Ratio colliding/beam-gas events will increase with bunch charge
  - Another factor 5 to come soon
- Beam-gas interactions used for luminosity measurements
- Time alignment of trigger detectors OK

Multiple interactions



- LHC luminosity: factor 10^3 to $5 \cdot 10^4$ to come
  - Luminosity increases stepwise
- Still low due to small #bunches
- Bunch charge only factor 5 less than design
- Luminosity/bunch for LHCb significant
- Event pile-up is not rare!
- Good test case for trigger



First Level Hardware Triggers

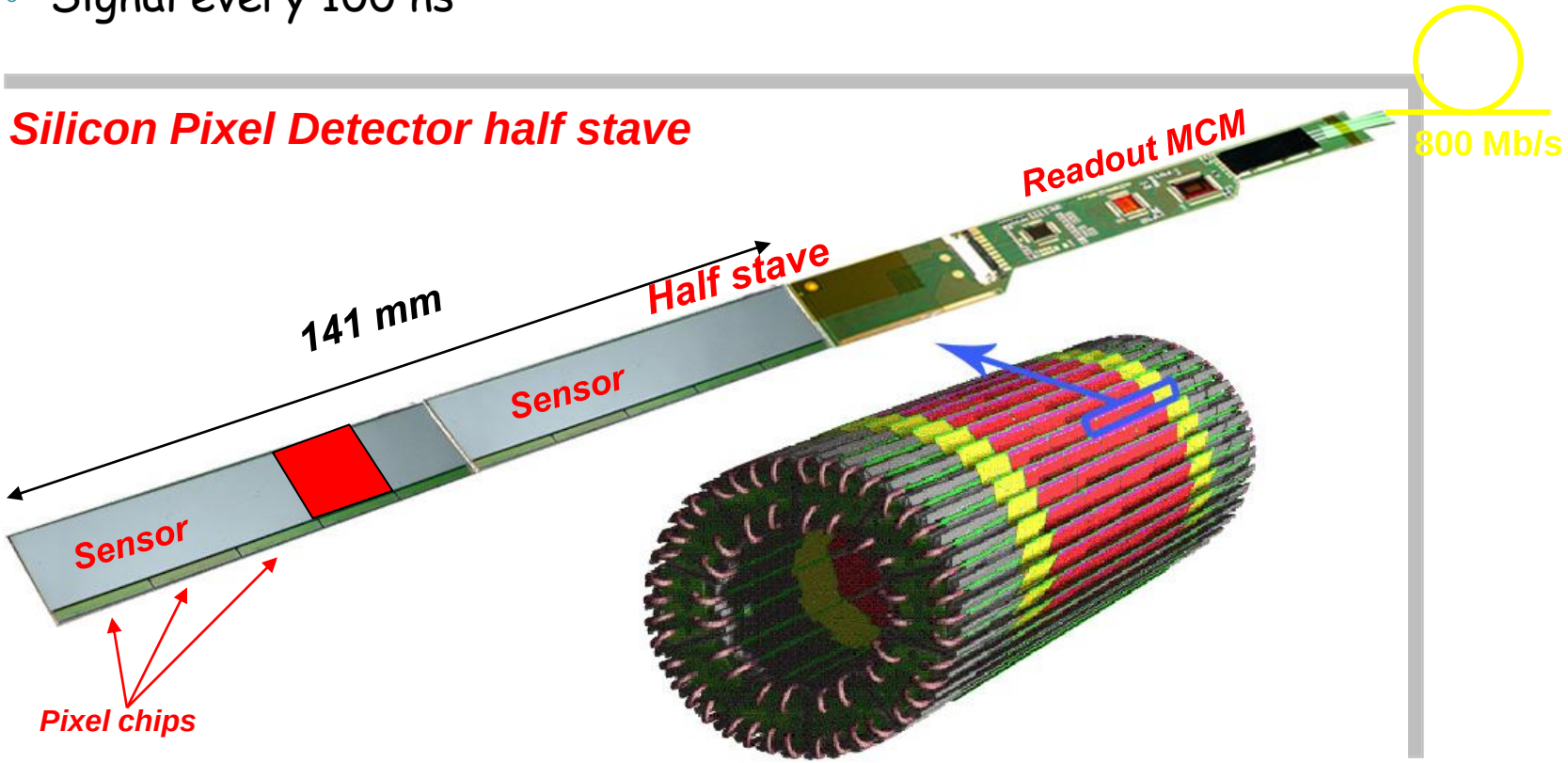
- No deadtime / multi-event buffer on Front-End electronics
- Low latency: 1.2 μs (Alice) to 4 μs (LHCb)
- Use simple primitives for event selection
  - High Pt muons and high Et hadron/e-/γ, missing mass, etc.
- No vertex detector information, except:
  - Alice: Pixel Trigger
  - LHCb: PileUp detector
- First level trigger initiates readout of full detector
  - LHCb + CMS : all data to CPU farm
  - Atlas: Data in Readout Buffers, only Region Of Interest to Level-2
    - Full event to Event Filter farm
    - Lower bandwidth DAQ network

Alice pixel trigger

Alice pixel trigger

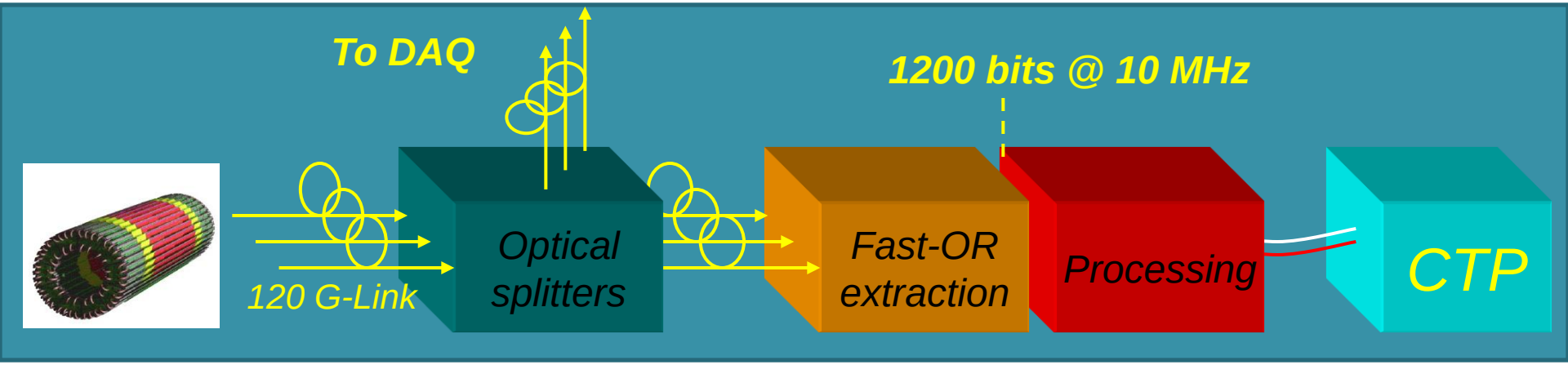
G. Aglieri Rinella

- Prompt fast 'or' output per pixel chip (13x14 mm2)
  - Active if at least one pixel is hit
- -> Low latency pad detector with 1200 pads
  - Signal every 100 ns

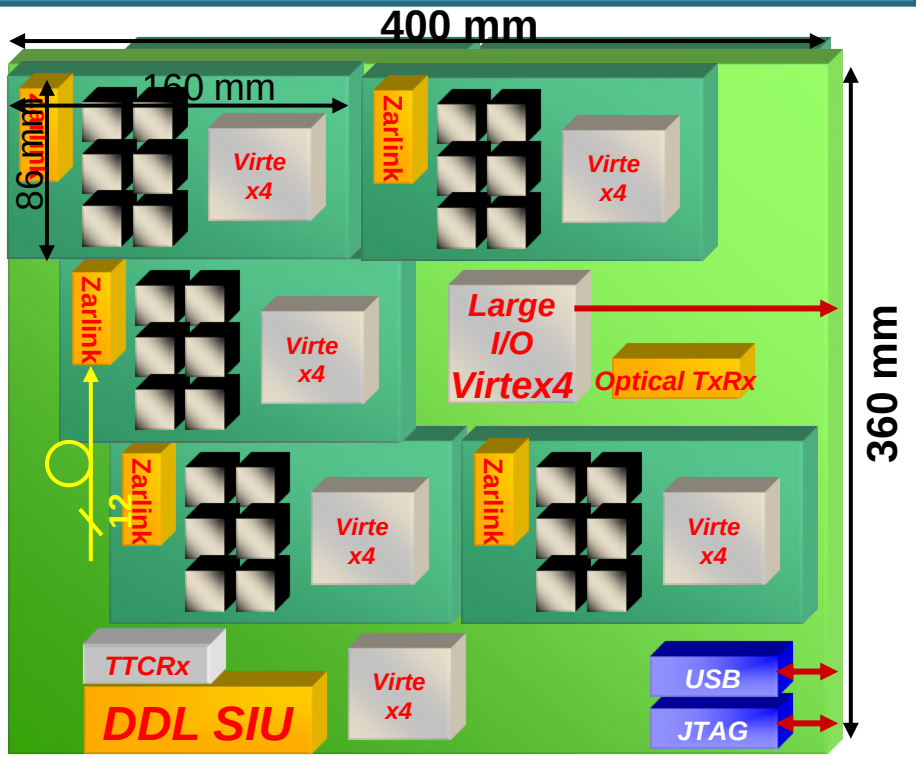


Alice Pixel Trigger

G. Aglieri Rinella



- Processing on Brain board
  - large Virtex4 FPGA
  - Input via 10 optical mezzanines
  - 1200 bits @ 10 MHz
- Total latency of 800 ns
  - Includes transmission
  - Only <200 ns for algorithm!
- Up to 10 parallel algorithms possible
  - Topology trigger, multiplicity



Status of Alice pixel trigger

G. Aglieri Rinella

- System fully commissioned
- Used as min. bias trigger for first Alice paper
  - Trigger on multiplicity
- Not enough resolution to determine vertex position
  - Pads too large w.r.t. distance to beam
- Investigating use as jet-trigger
  - Topology trigger requiring 1 pad from inner layer and 2-3 pads from outer layer

LHCb PileUp Trigger

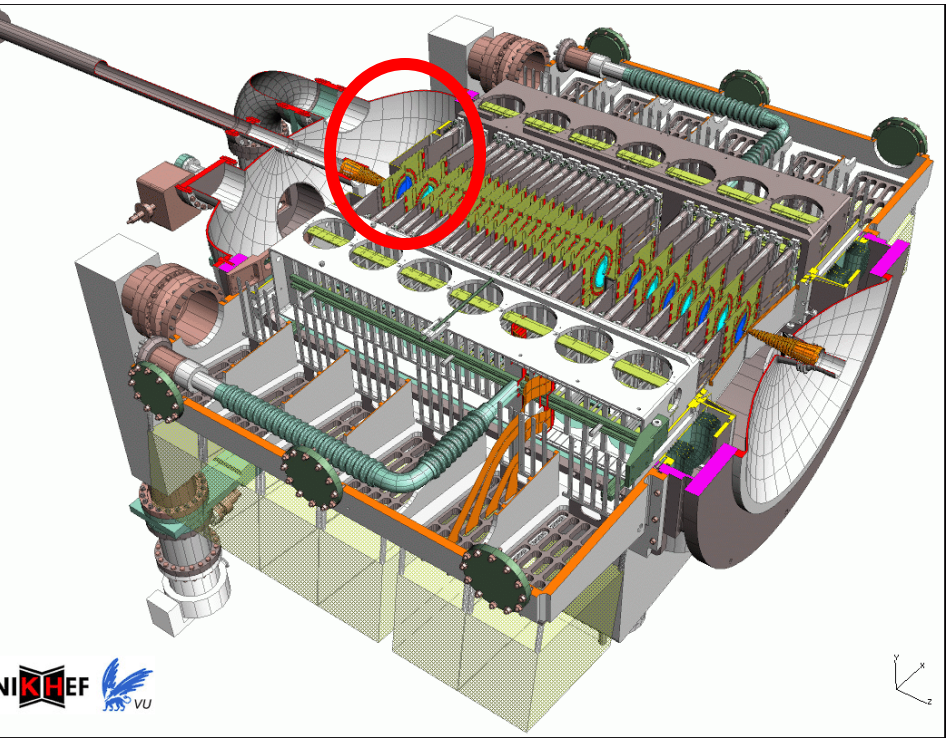
LHCb PileUp: Why

- Designed to Veto bunch crossings with > 1 interaction
  - More effective use of CPU farm
- PileUp detector sends info on the number of primary vertices and their position, and multiplicity every 25 ns to the L0 trigger decision unit (which takes the actual decision)

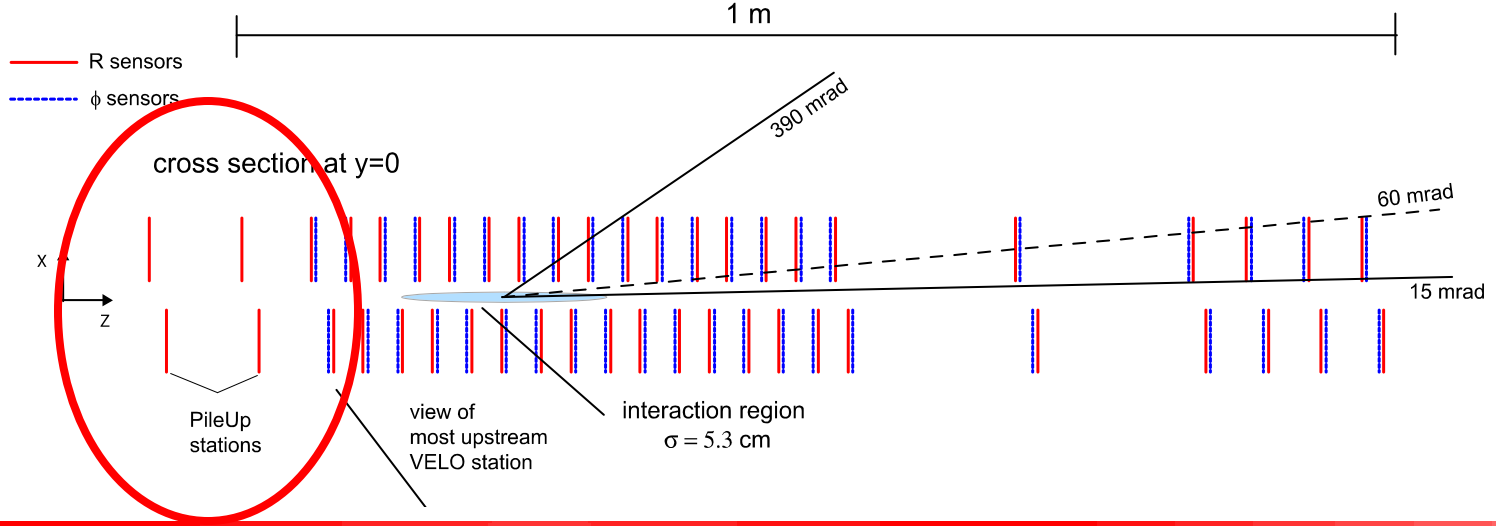
In addition:

- Is the only detector in LHCb that can provide a multiplicity trigger in backward direction (beam2-gas)
  - Currently being used in all trigger configurations
  - Multiplicity threshold >= 4
- PileUp detector can be used for luminosity measurements
  - Count #vertices or multiplicity
  - Online histogramming at 40 MHz

LHCb PileUp: Where

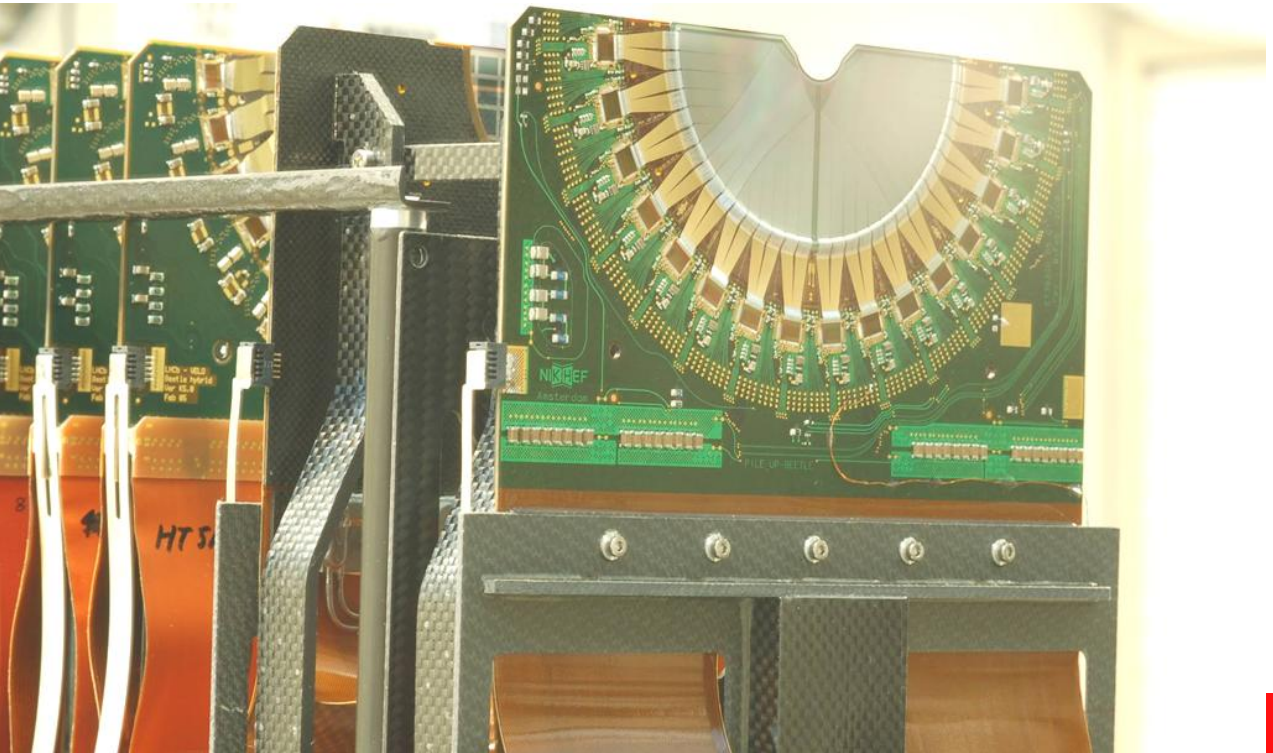


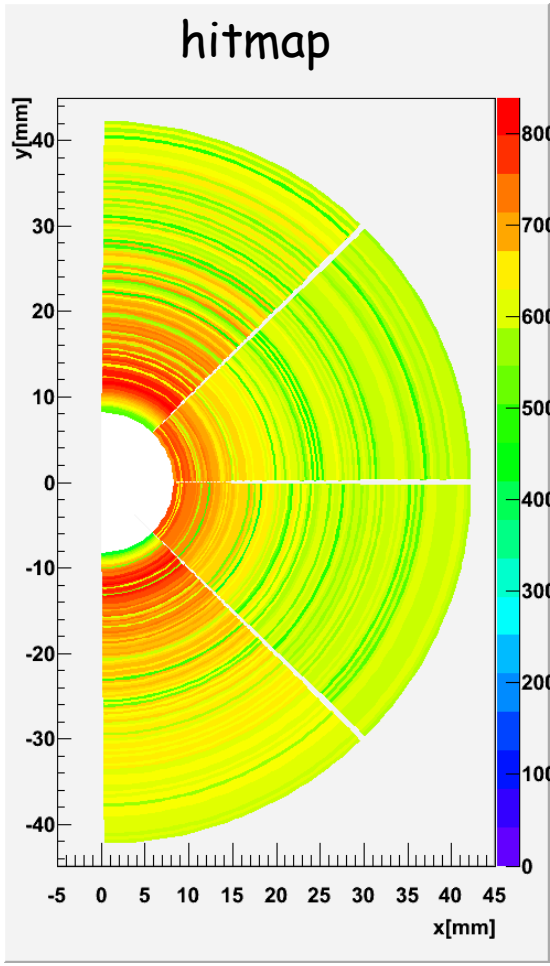
- Part of VELO infrastructure
- Complete dedicated subdetector!
- 2 silicon stations in backward direction
  - At z=-220/235 mm and z=-300/315 mm



Sensor / Front-end

- Same silicon as VELO: 300 μm thick R –sensors
- Uses discriminator per strip in Beetle chip
- Logic "or" of 4 discriminator signals
  - Prompt binary output (80Mbit/s)
- Effective pitch from 160 um to 400 μm
- < 1% dead/hot strips, 4% due to connector problem
- Beam induced common mode noise is negligible

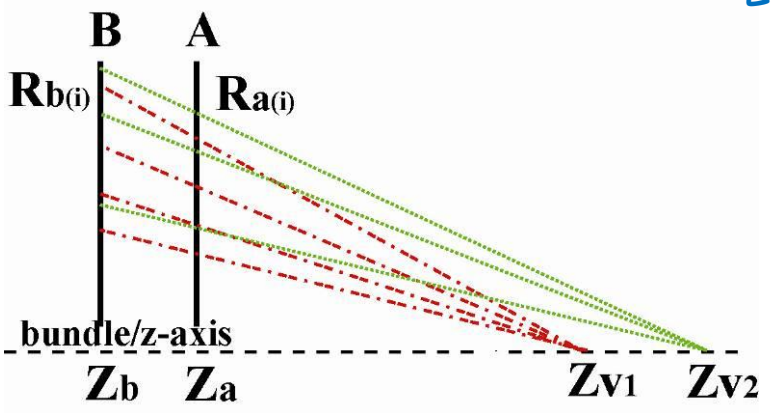




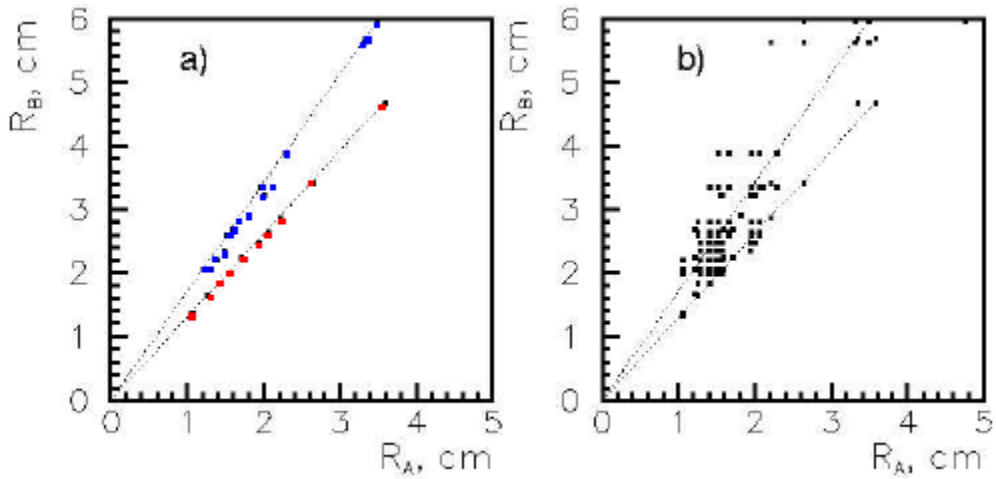
LHCb PileUp: How

- Use simple geometrical relation

$$k = \frac{R_A}{R_B} = \frac{Z_{PV} - Z_A}{Z_{PV} - Z_B}$$



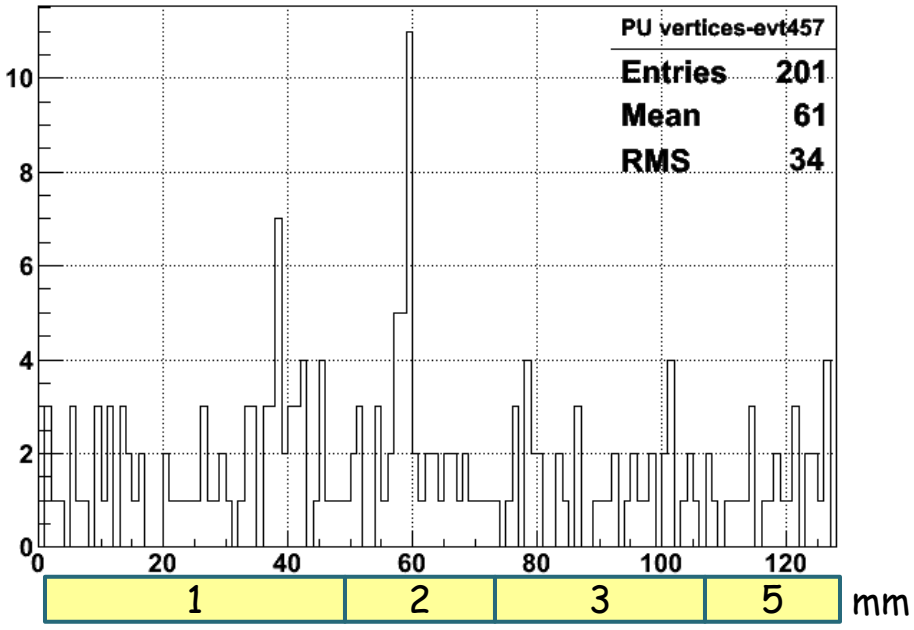
LHCb

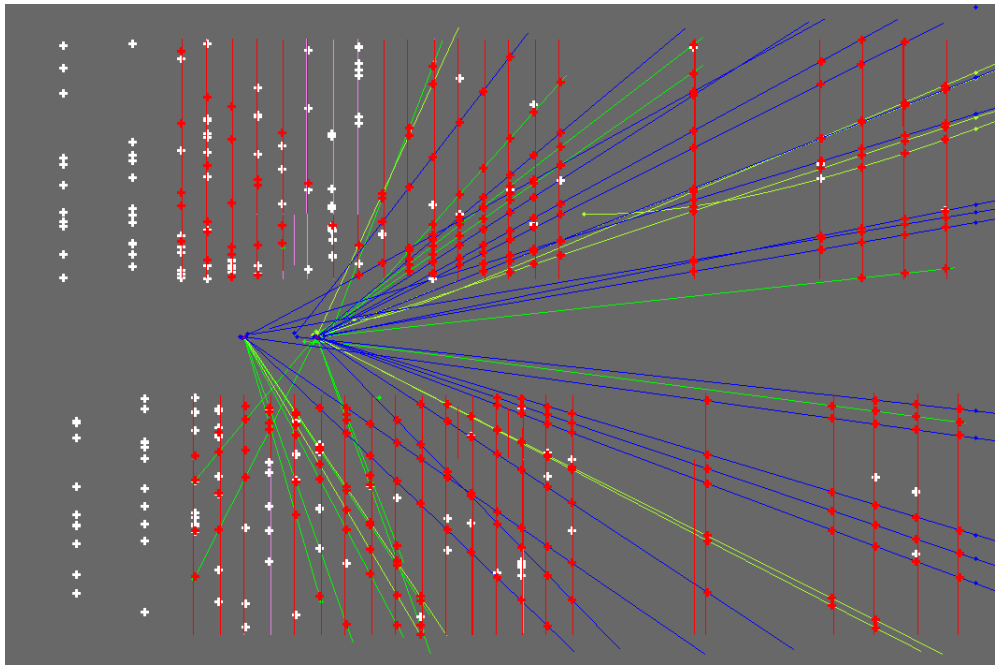


- Evaluates 7676 R-z track segments per 45 degree phi section
- Creates vertex position histogram with 128 bins by counting segments
  - Ranges from z=-150 to +150 mm (> +/- 3 σ_{beam})
  - Z bin width from 1 mm to 5 mm (in steps) increasing with z
    - Flattens combinatorial background

Example vertex histogram

- Search peak of distribution
- Apply threshold (typically 3)
- Remove hits which contributed to first peak
- Search again for second peak





The Hardware

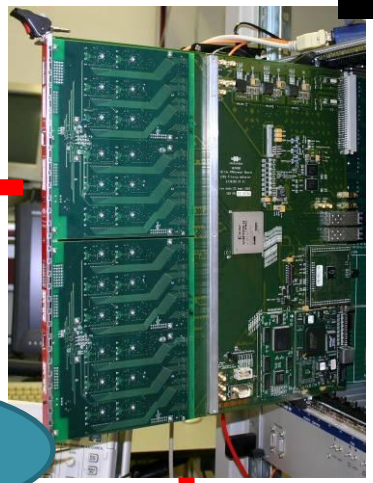
4 silicon sensors
512 strips each

4x

1024 Cu links
@ 80Mbits/s
20meter

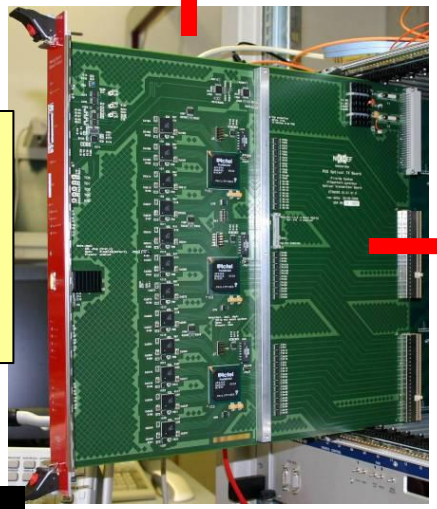
96 opt. links
@ 1.6Gbits/s
50 meter

4x



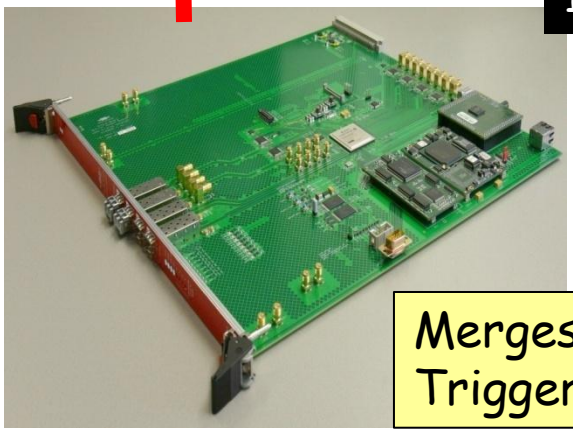
4 processor boards
in round robin
Processing in Virtex2 FPGA
Latency ~ 1 us

Time alignment
Electrical to optical
Distributes events to processors



8x

1x

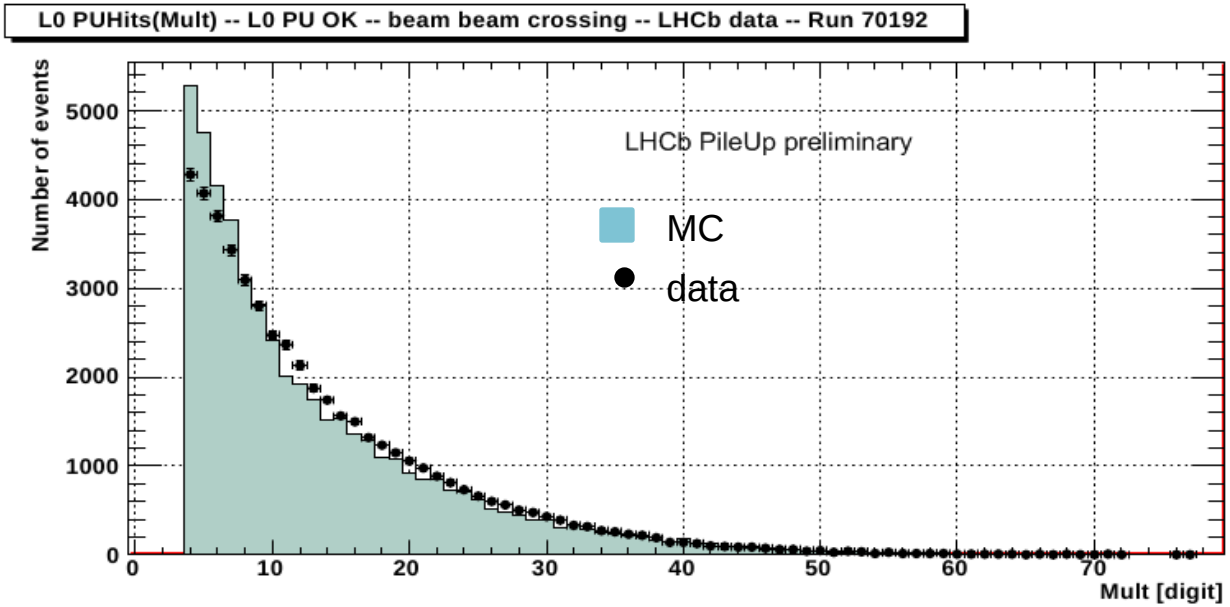


Merges and orders
Trigger decisions

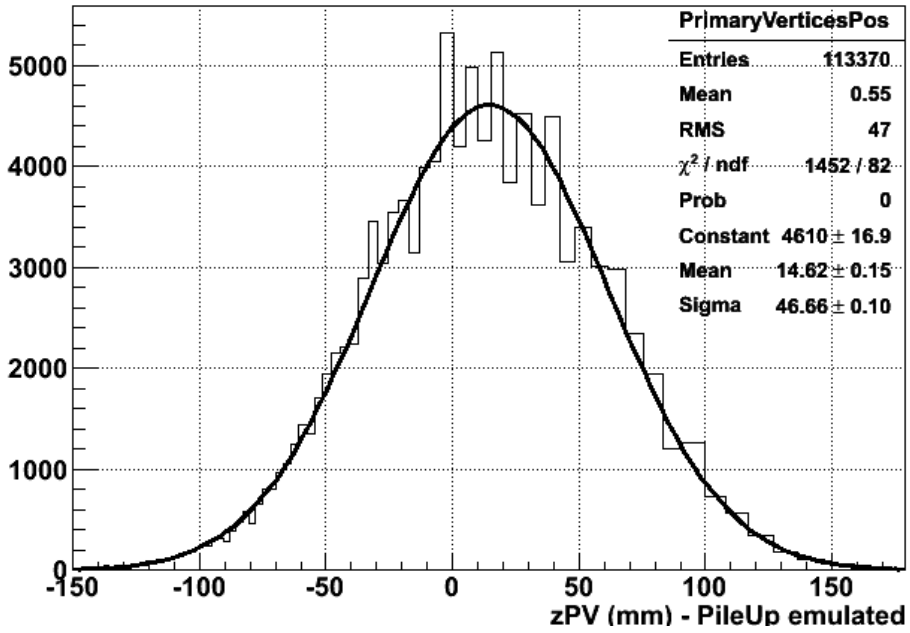
Latency to LODU 2us

PileUp commisioning

- Time alignment of detector done
  - Sampling of FE discriminator outputs (0.5 ns resolution/ Beetle chip)
  - Cable delay of binary outputs (1k channels, 3 ns resolution)
  - Time align PileUp to correct bunch crossing (align with Calo/Muon det.)
- Threshold tune done, some fine-tuning ongoing
  - Threshold ~ 7ke-
- Multiplicity trigger (>3 hits in sensors closest to interaction region) in all LHCb trigger configurations
  - PileUp noise trigger rate < 0.05 Hz



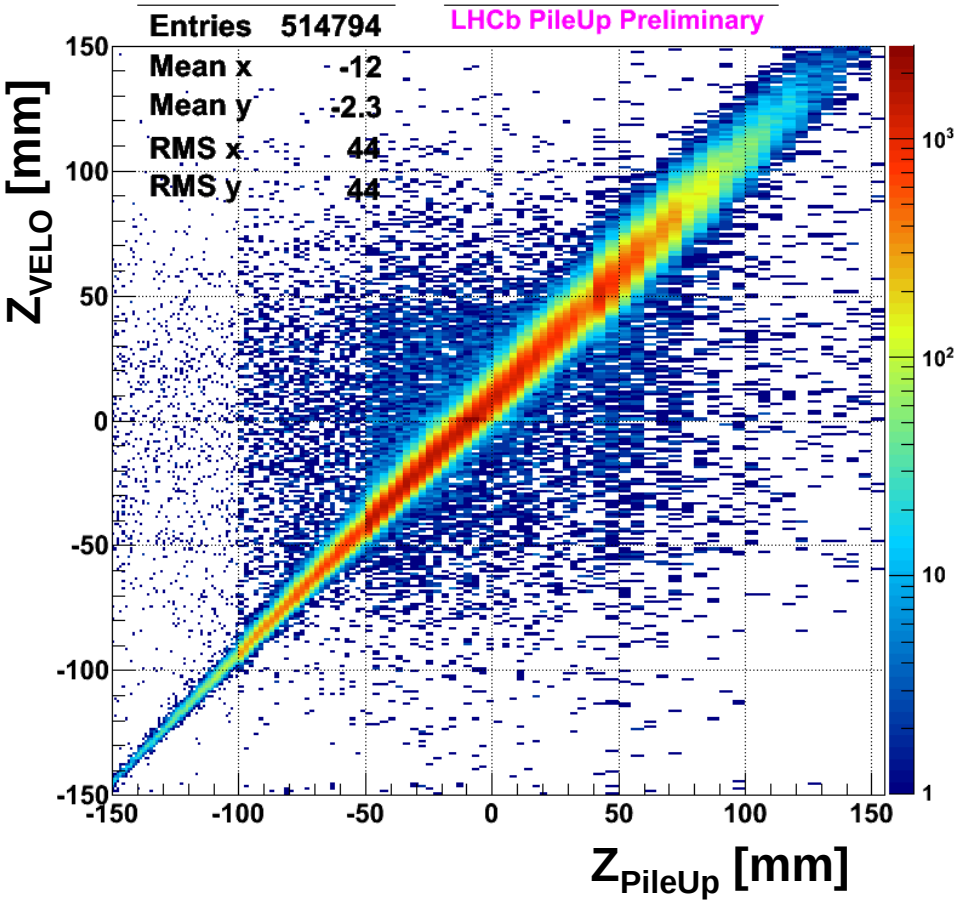
Vertex Z-distribution



85 bins

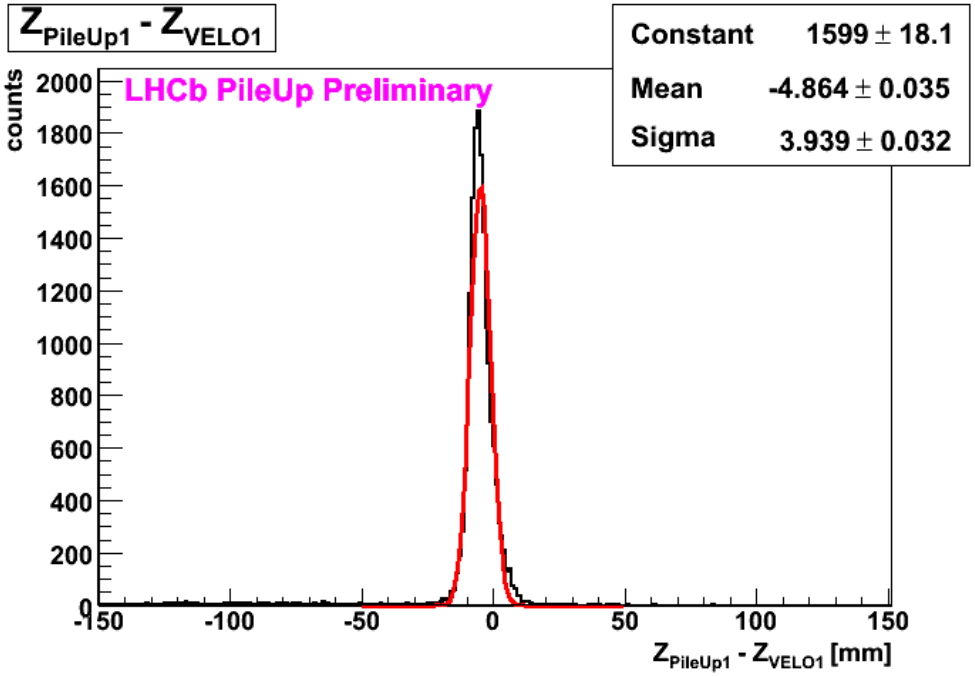
- 128 bins; width 1 .. 5 mm
- Bin-size boundaries clearly visible
  - "step height" depends on # tracks
- Can be reduced by gradual bin size transition
  - Smooth distribution is not the ultimate goal
  - Efficiency / purity to find 1/2/2+ vertices is

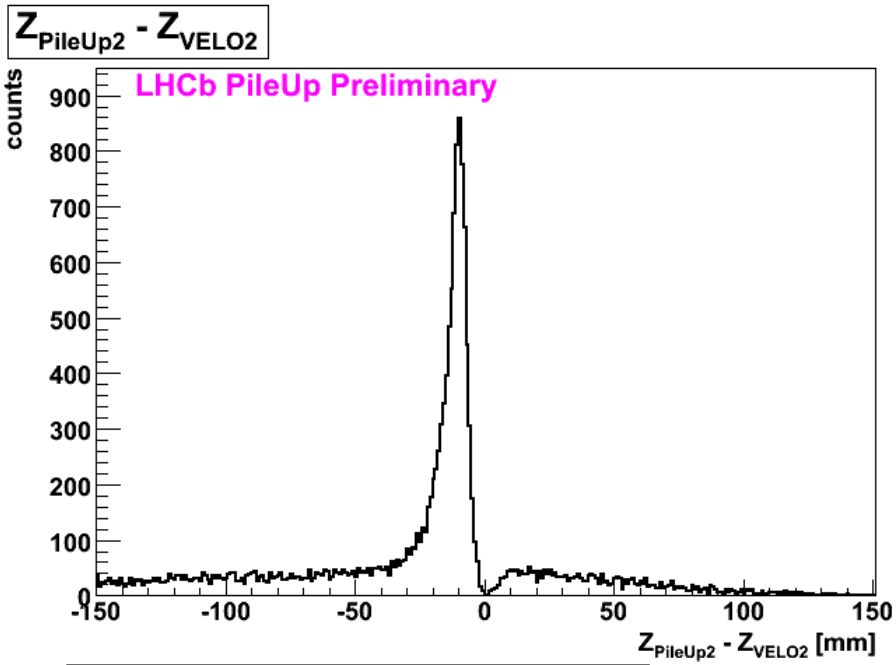
PileUp (online) versus VELO (offline) vertex correlation



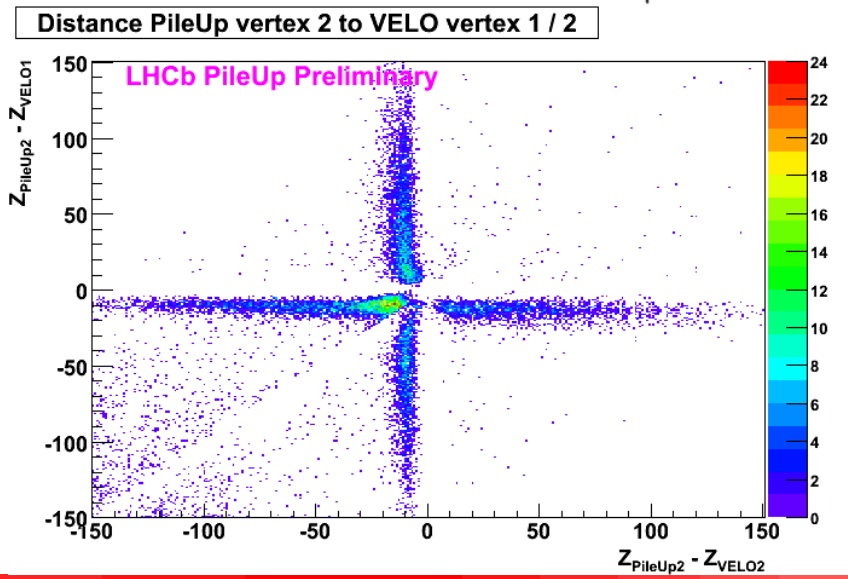
- PileUp finds vertices in the right place!
- VELO resolution < 100 um
  - Negligible w.r.t. PileUp resolution
- PileUp vertex calculated in < 1 μs

Finding multiple vertices



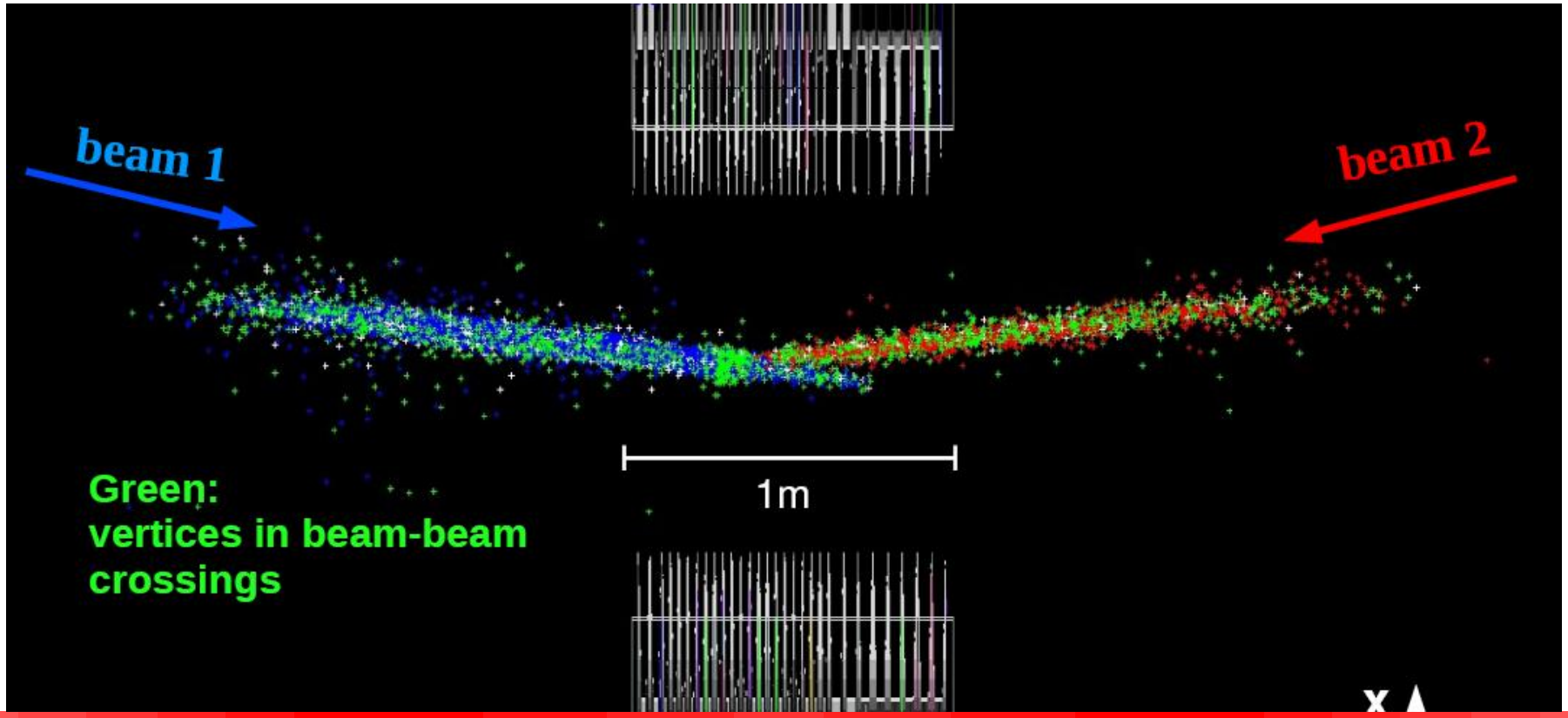


- Event sample with exactly 2 vertices in VELO, 10 tracks/vertex
- Match PileUp vertices to VELO vertices using Z-position
- Resolution will improve (alignment etc.)
- First peak found twice
  - Hit removal not optimal
  - Change in algorithm required



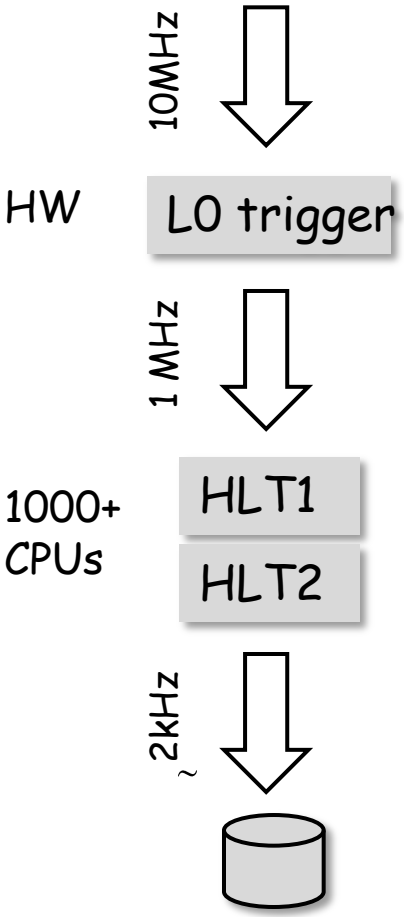
Beam gas trigger

- PileUp is only detector in backward direction that can trigger on beam2-gas interactions
- Luminosity from beam gas interactions (-> S. Redford)
  - M. Ferro-Luzzi, NIM A553 (2005) p338
  - PileUp used to increase rate



High Level Trigger

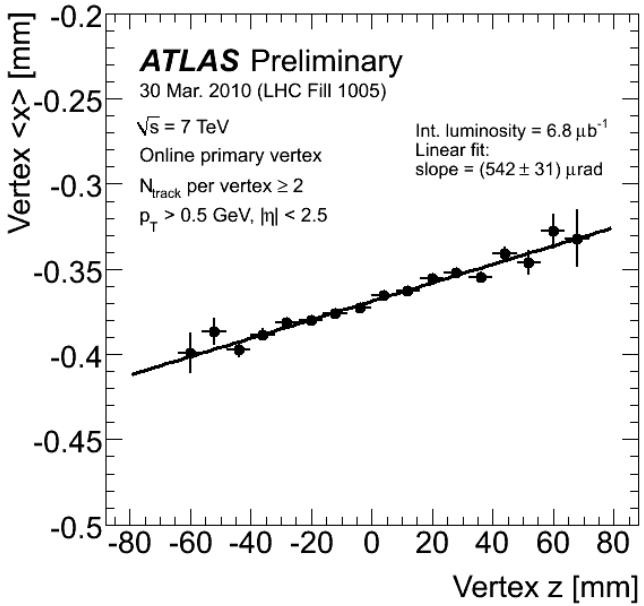
LHCb trigger architecture



- Level-0 trigger
  - Hardware trigger
  - Short latency
- HLT1:
  - Confirm L0 decision using tracking system
  - Reconstruction in region of interest
  - Trigger on simple signatures
  - Increase fraction of B-events
  - Output rate 30 kHz
- HLT2:
  - Selection of interesting B-event
  - Inclusive stream (1800 Hz)
  - Exclusive signal selections (200 Hz)

Vertex triggering in the HLT

- Online vertexing being done in HLT by all experiments
  - Precision only slightly worse than offline
  - Algorithms optimized for speed
  - Vertexing example: online beam spot position monitoring
- No cut/trigger on (secondary) vertex information YET
  - Will soon come as luminosity increases
  - Beauty search: IP cut or decay length cut

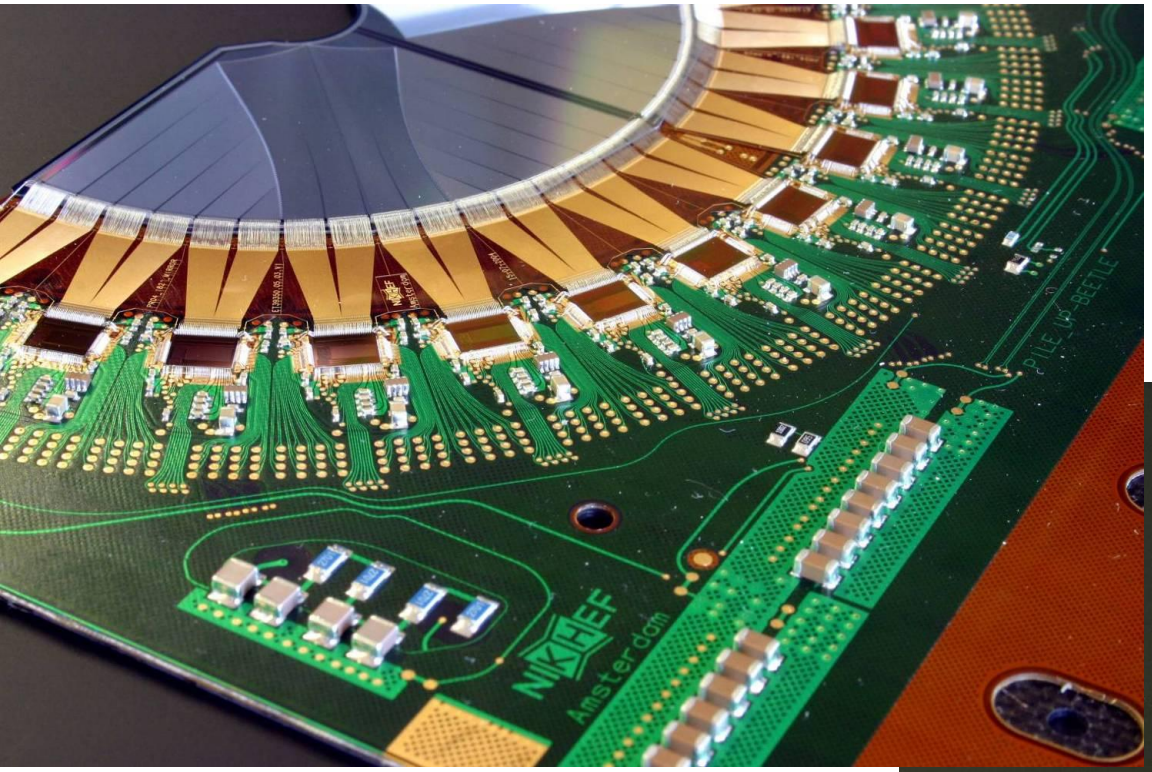


Summary

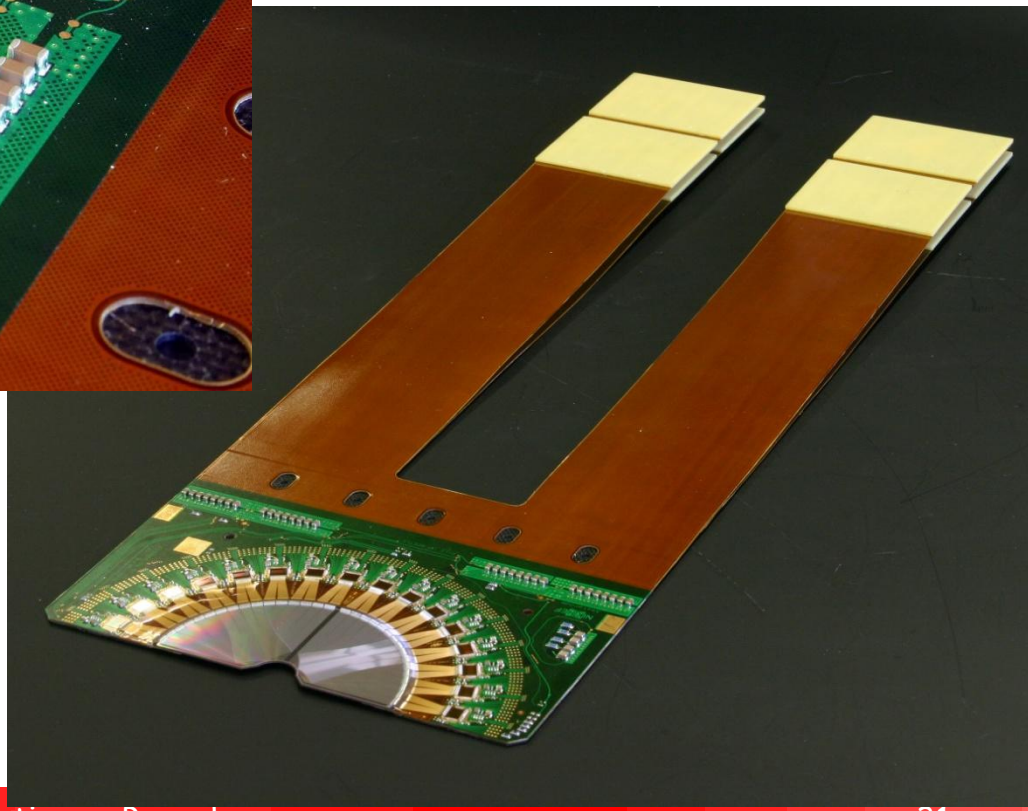
- Alice vertex pixel detector used in first level trigger
- No HW vertex determination except LHCb PileUp
  - Commissioning ongoing
  - Multiplicity trigger operational
  - Beam2-gas trigger for luminosity
  - Tuning the vertexing algorithm
- Higher Level Trigger: vertexing up and running
  - Not yet used for triggering
  - Challenge ahead!

Triggering is like selecting whisky:
It is all about picking out the best ones

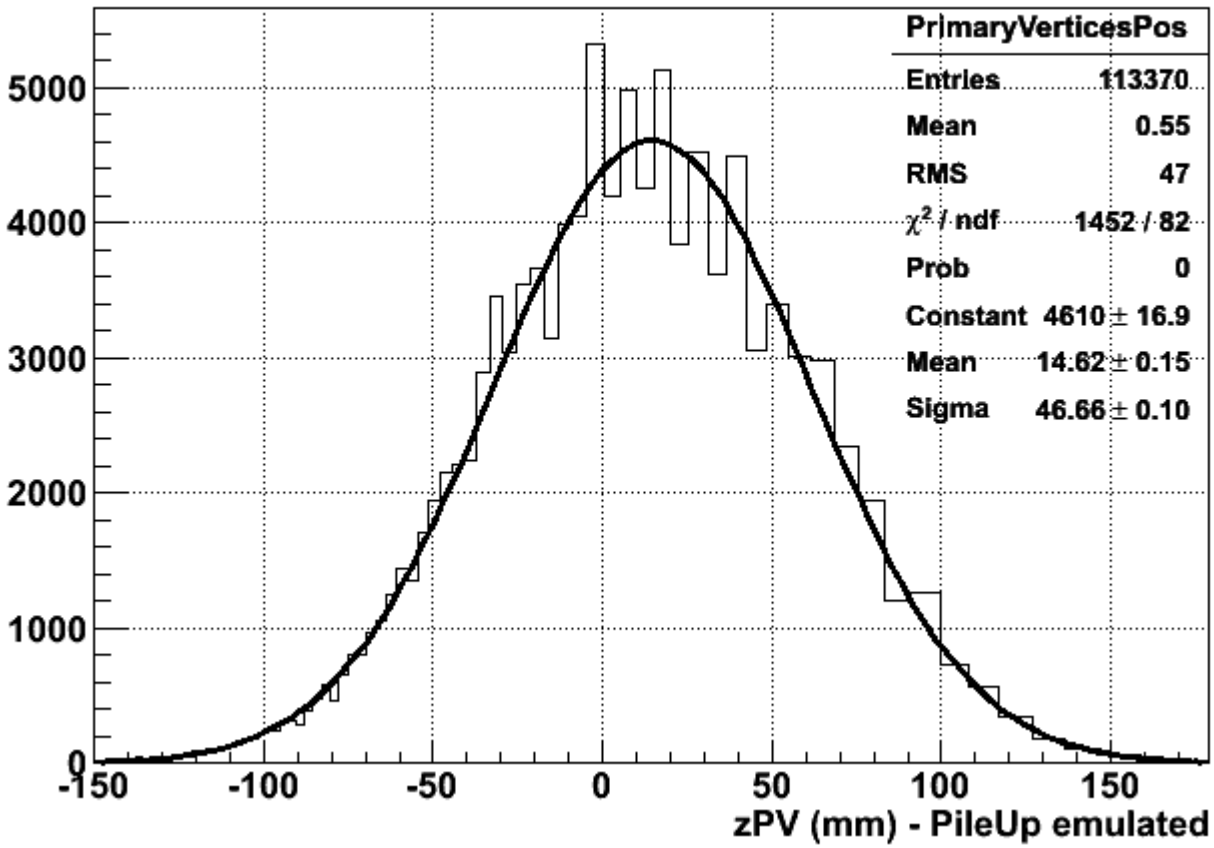
Hybrid close up

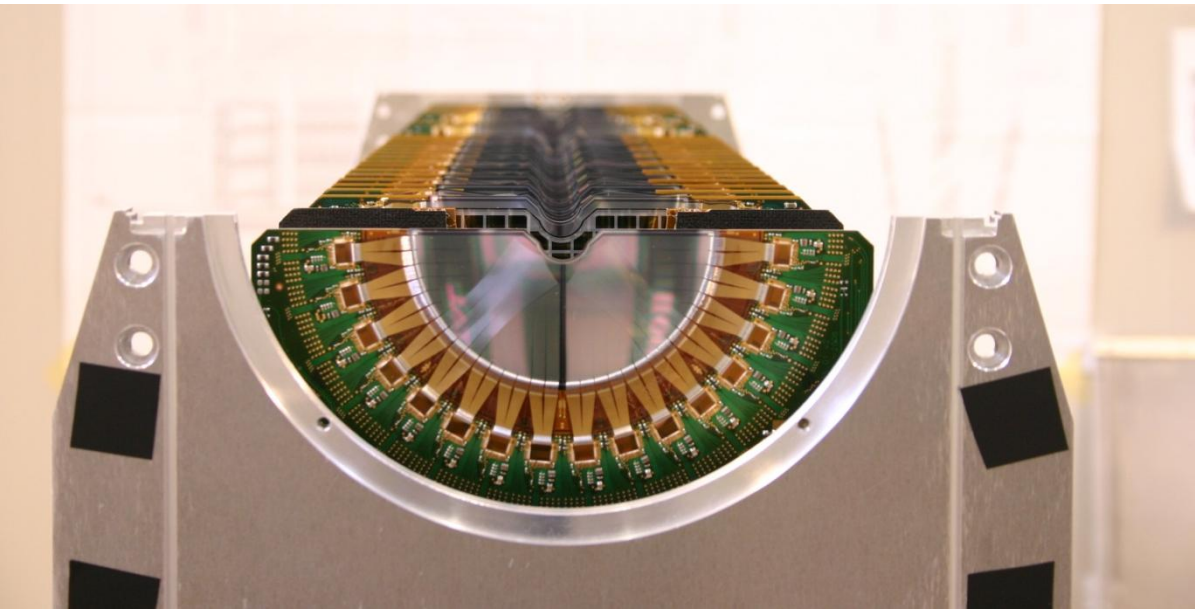


8 layers kapton
Produced by CERN PCB workshop



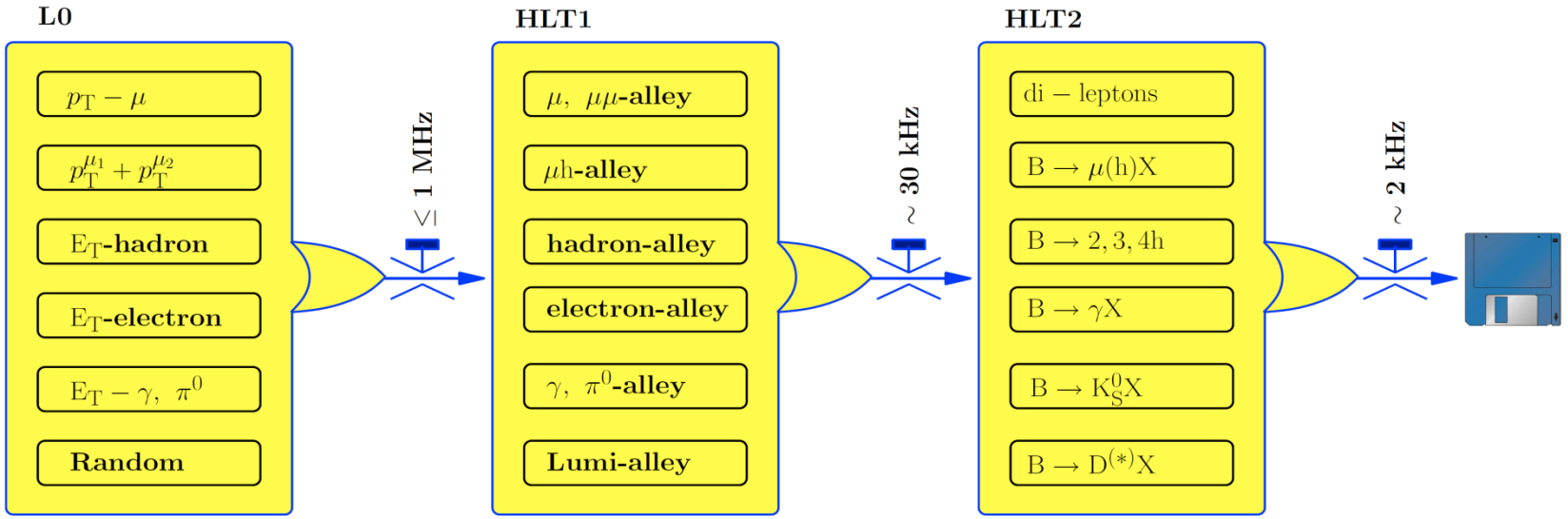
85 bins


PrimaryVerticesPos
Entries 113370
Mean 0.55
RMS 47
χ² / ndf 1452 / 82
Prob 0
Constant 4610 ± 16.9
Mean 14.62 ± 0.15
Sigma 46.66 ± 0.10
5000
4000
3000
2000
1000
0
-150
-100
-50
0
50
100
150
zPV (mm) - PileUp emulated



High Level Trigger of LHCb: 2 stages

- HLT1:
  - Seeded by L0 objects
  - Refines L0 information by adding info from tracking station and VELO
    - Track search in narrow window to minimize processing time
  - Output rate 30 kHz
- HLT2:
  - Tracks from pattern recognition, IP and Pt cuts
  - Output rate 2 kHz



Vertex trigger LHCb upgrade

- Simple muon/calo trigger no longer sufficient at higher luminosities
- Tracking and vertex information needed in trigger
  - -> No more hardware trigger
- Vertex search for all events in High Level Trigger
- All data to BIG CPU farm