Karlsruher Institut für Technologie

Belle II-Tracking:

Status of Preparation, including Pixel Readout and Data Reduction

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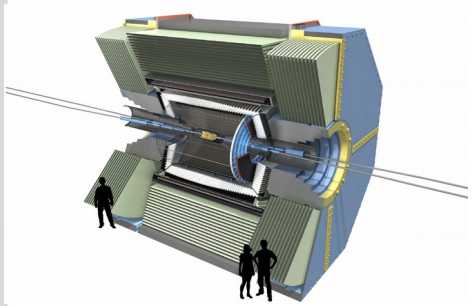
Institut für Experimentelle Kernphysik



Belle II

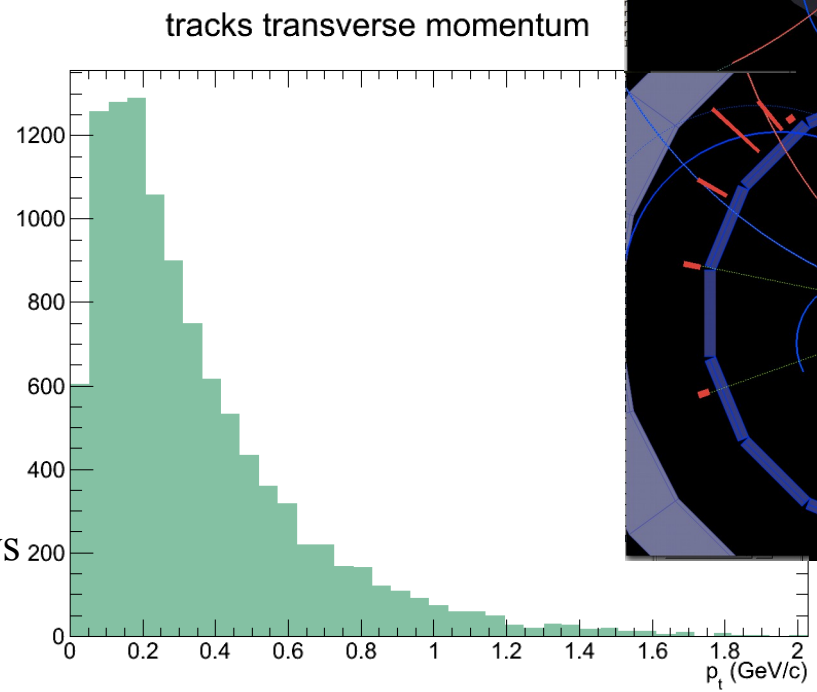
Overview

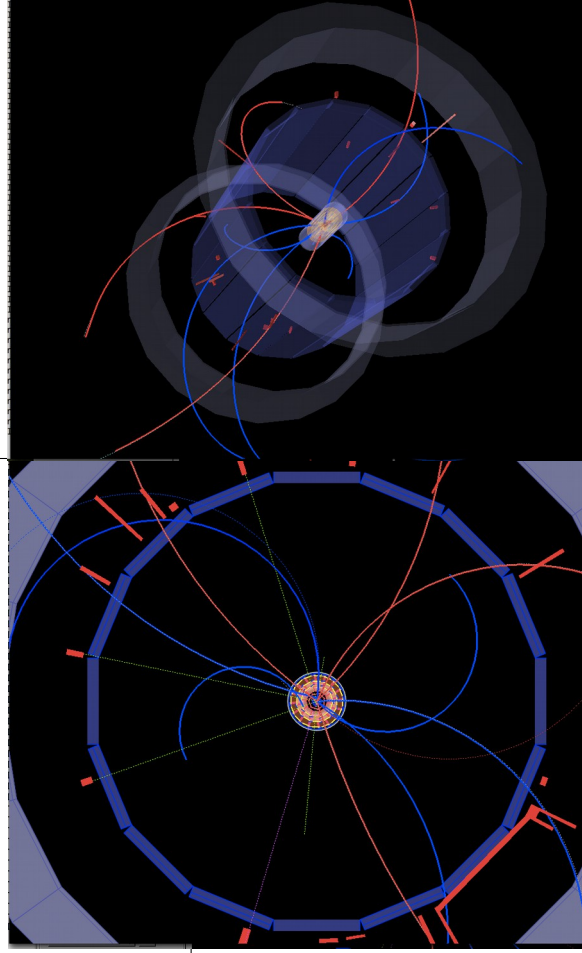
- Reminder of the Challenge;
- Data Acquisition Set-Up, Data Reduction;
- Vertex-Detector Stand-Alone Track-Finding Algorithm;
- Drift Chamber Track-Finding Algorithms;
- Data Reduction with Cluster Analysis;

Reminder of the Challenge

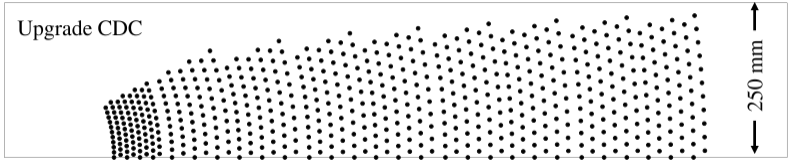
- Creation of $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$;
- On average 11 tracks + photons;
  → Easy?

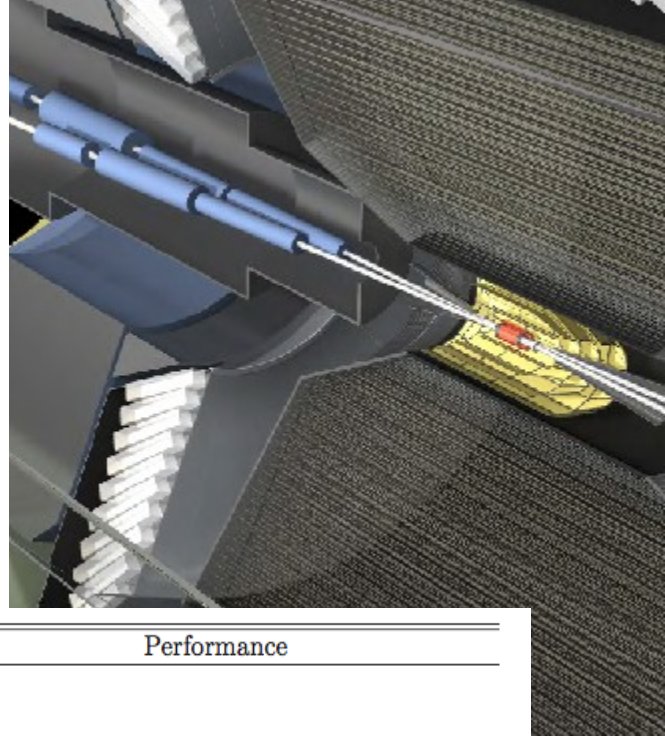
  Unfortunately some issues:
- Need to find all tracks (at zero fake rate) for "Full Event Interpretation" to make analysis of $B \rightarrow h^{(*)} \nu \nu$, etc.;
- Small boost and multi-body decays mean, there are very low momentum particles.



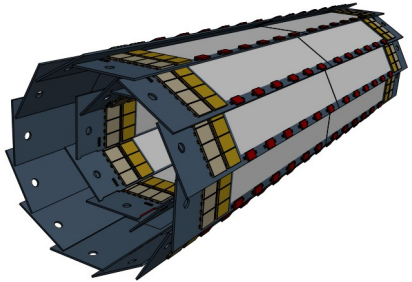


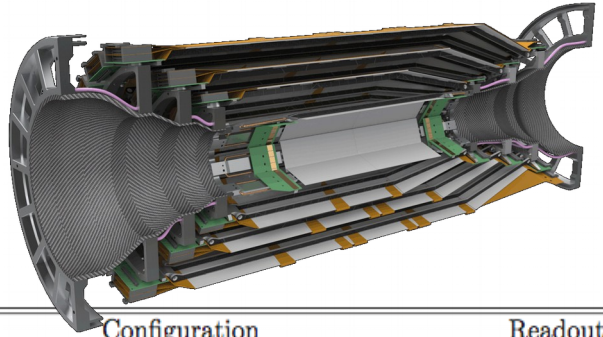
Tracking Hardware





- Pixel (PXD), Strip (SVD), and drift chamber (CDC)

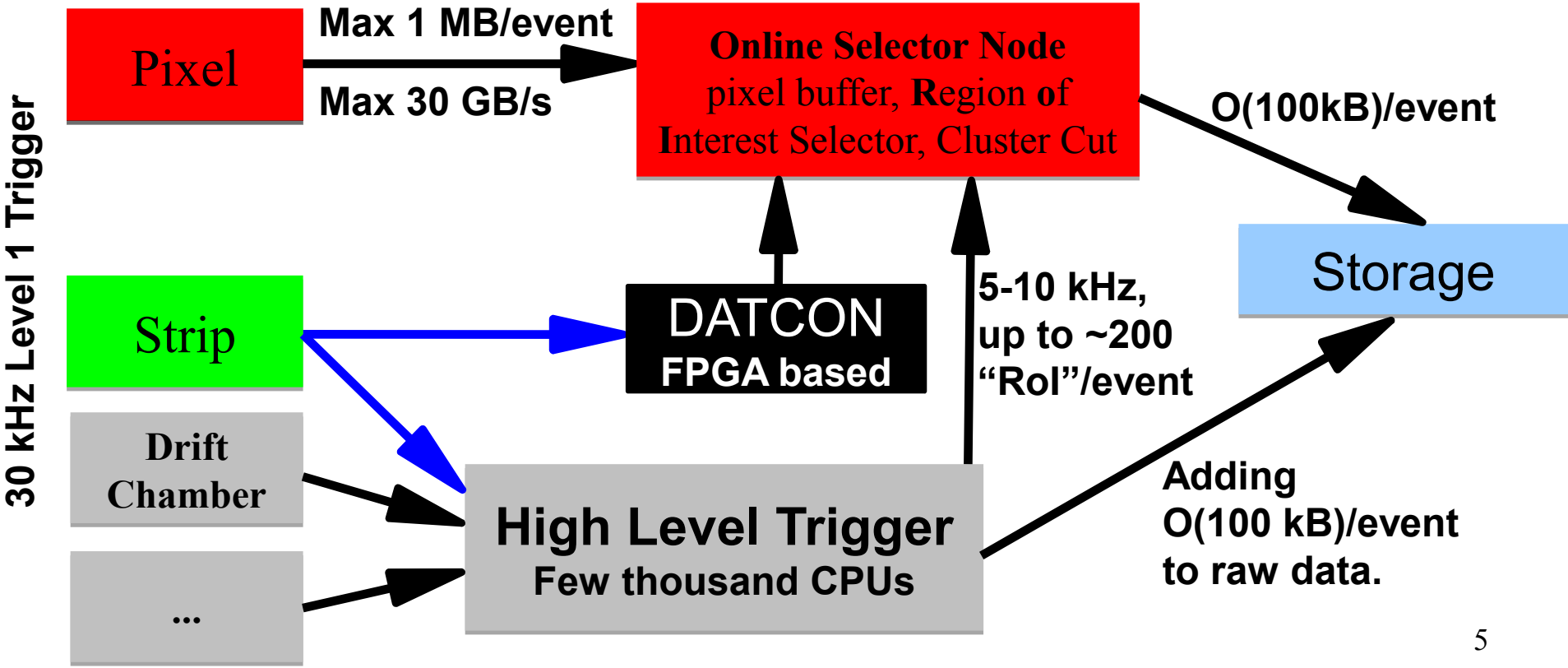




Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20$ μm (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100$ μm, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

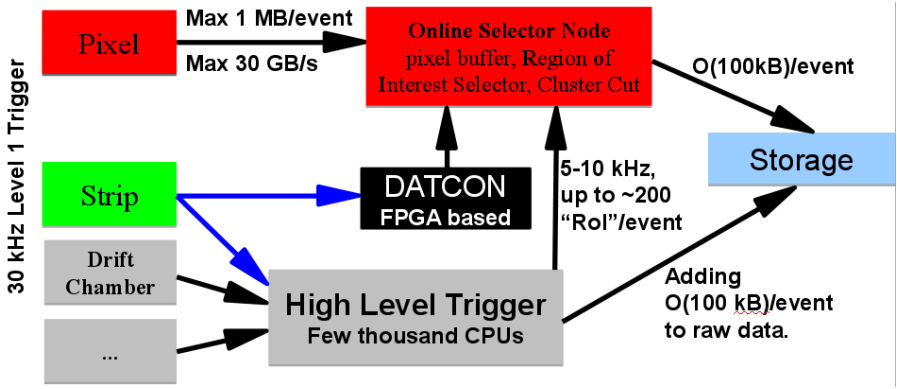
Built

Data Acquisition Set-Up



Why Data Reduction?

- 20 µs readout time of Pixel;
  → ~10 000 bunch crossings per readout;
  → designed for up to 3% occupancy
  with 8 M pixels;
  → 1 MB / event,
  while rest of detector totals ~100 kB;

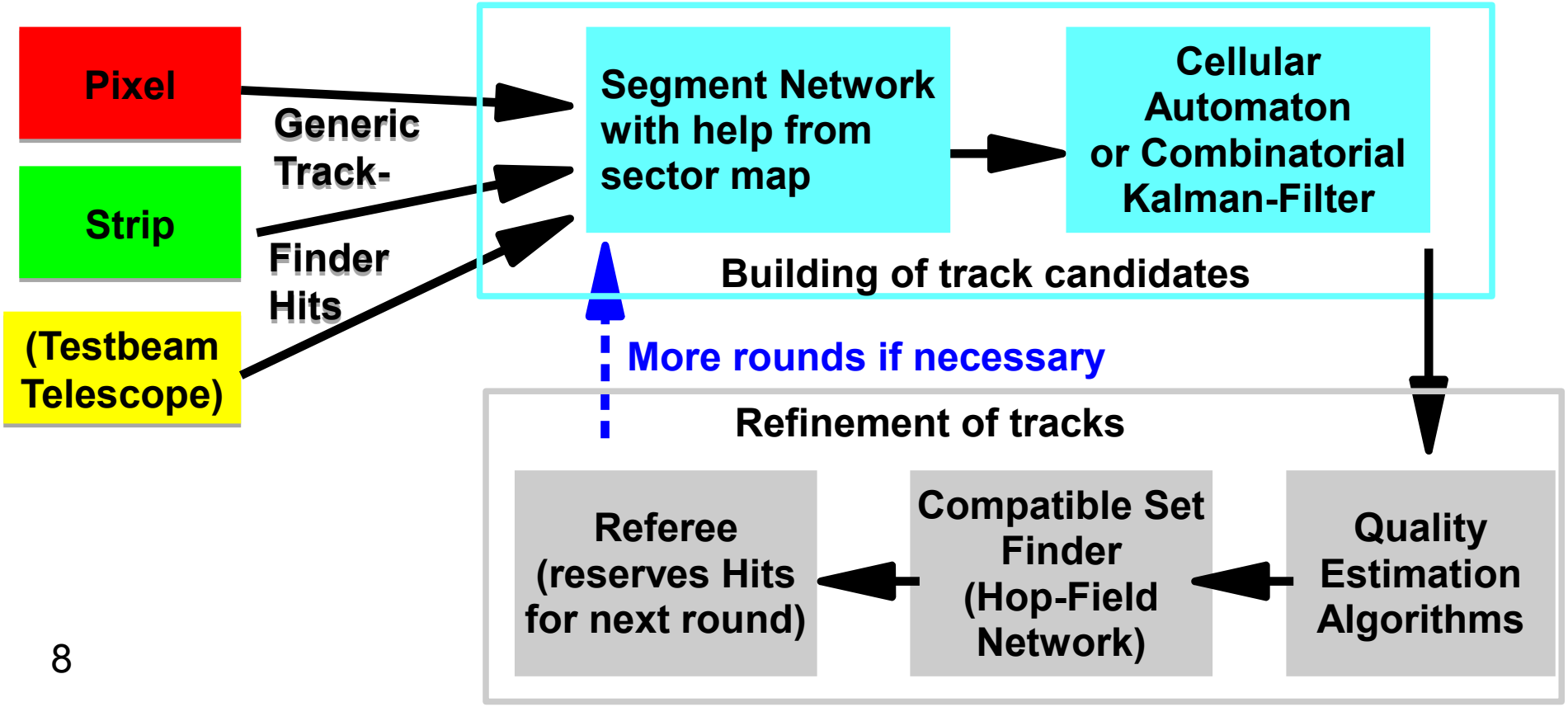


- "Deal": Pixel is allowed to same bandwidth/storage as rest of detectors combined.
  → In worst case factor 10 of data reduction is necessary.

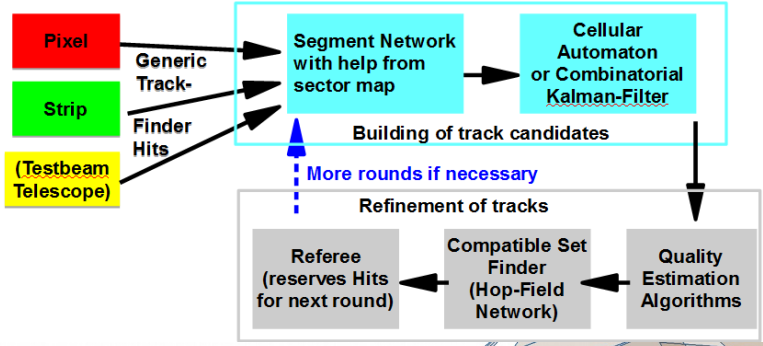
Two Way Solution

- find tracks in all detectors but Pixel and extrapolate;
  - most important part here: silicon-strip detector stand-alone tracking;
  - but drift chamber algorithms help as well;
- analysis of cluster properties;
  - charge deposition → low momentum tracks
  - cluster position → edge of acceptance...

Vertex-Detector Stand-Alone Track-Finding Algorithm

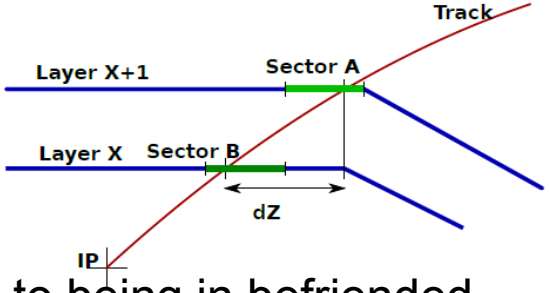


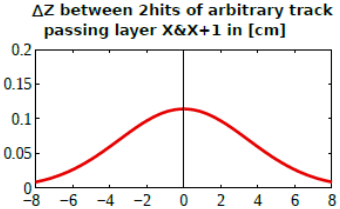
Why the Sector Map?

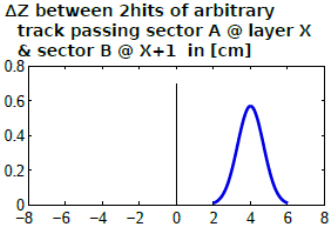


With the help from the sector map, we

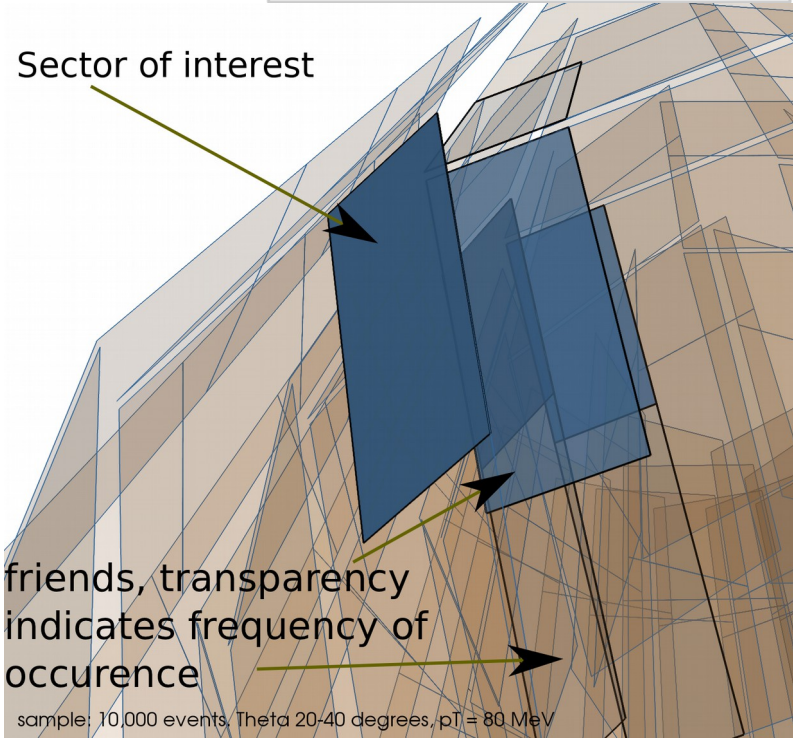
- start the actual track finding only with somewhat reasonable combinations;
- avoid for the cellular automaton expensive extrapolation calculations;



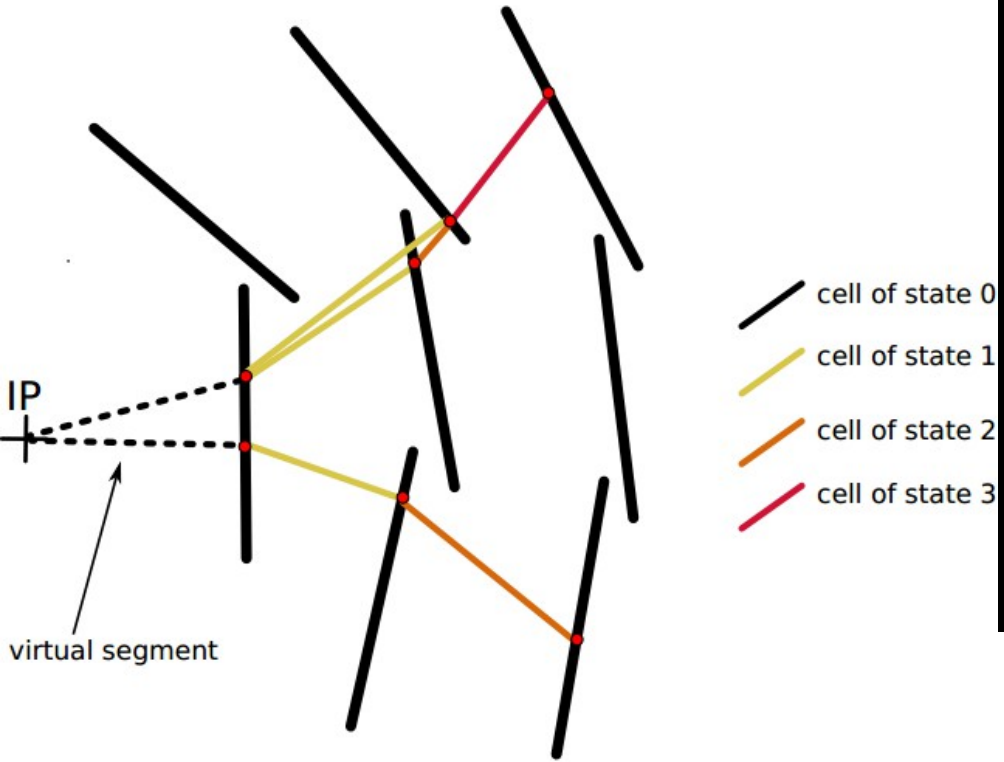


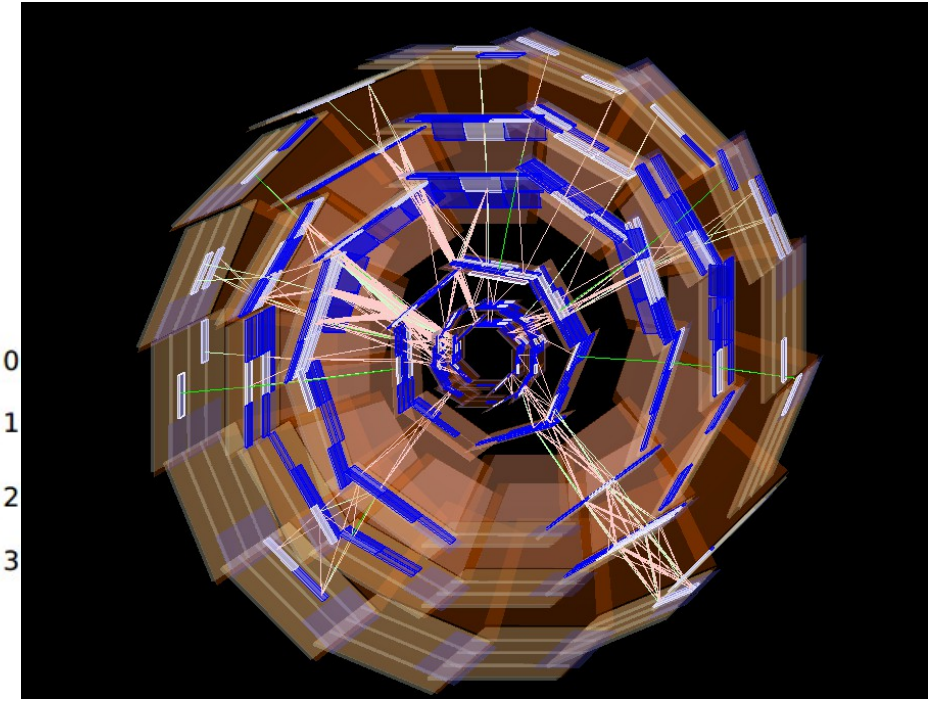


Additional to being in befriended sectors, there are sector-dependent 2-, 3-hit filters, that need to be passed to form a segment. 4-, 5-Hit Filters are Sector independent.



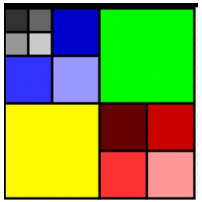
Advance in the Cellular Automaton





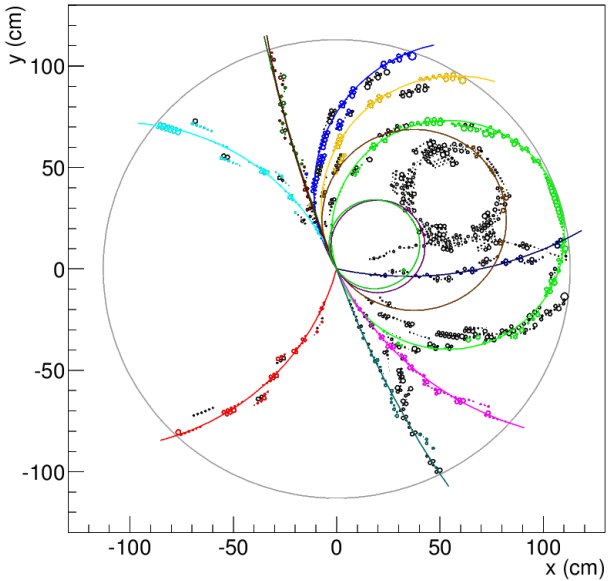
Drift Chamber Tracking

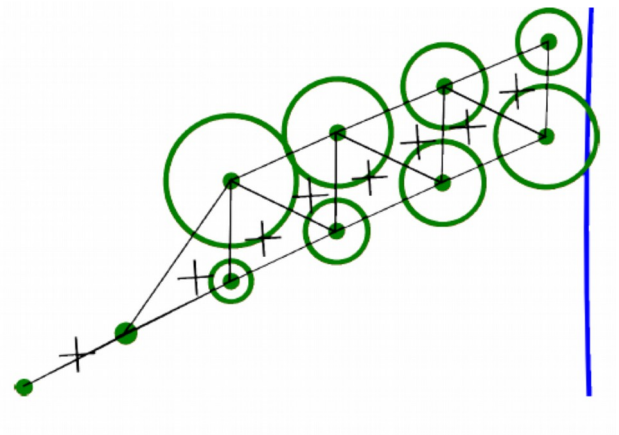
- Two main algorithms
  - One based on Legendre transformation (1) using a Quadtree;



(Iterative, but keeping the information)

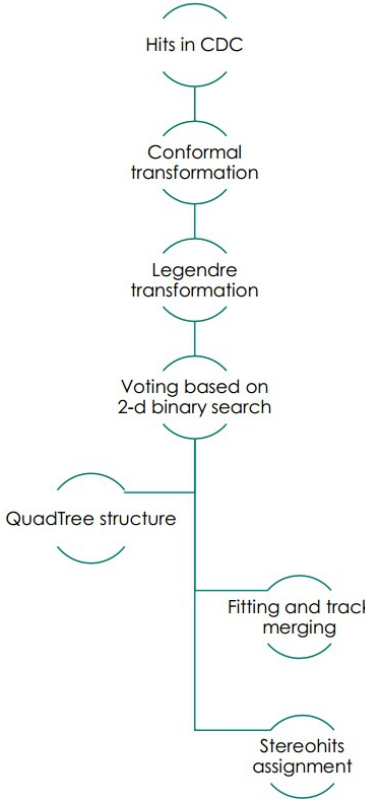
- Based on hit following/cellular automaton;

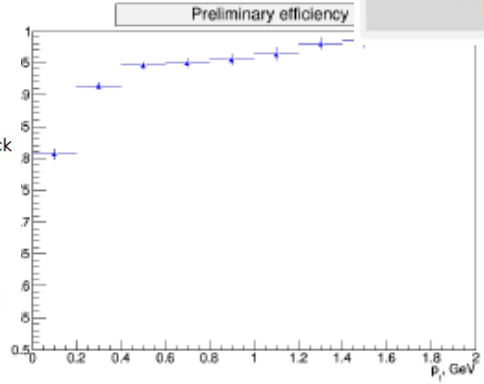


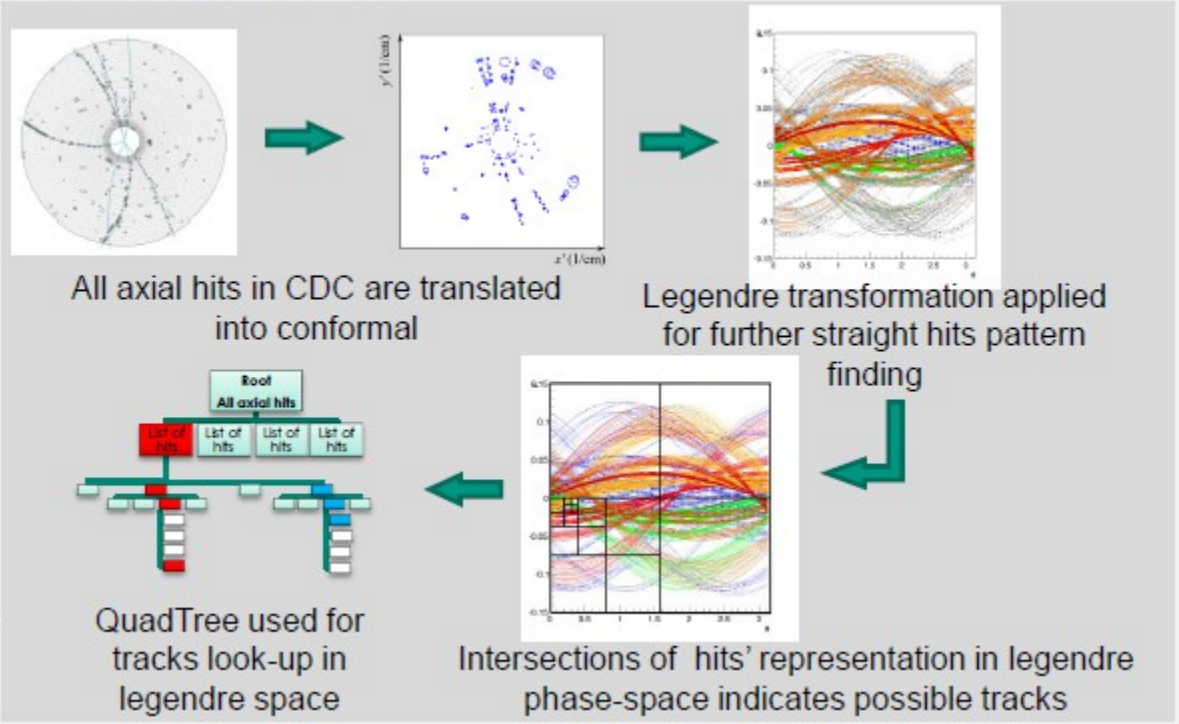


(1) T. Alexopoulos et al. "Implementation of the Legendre transform for the muon track segment reconstruction in the ATLAS MDT chambers" Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE

“Legendre Finder”







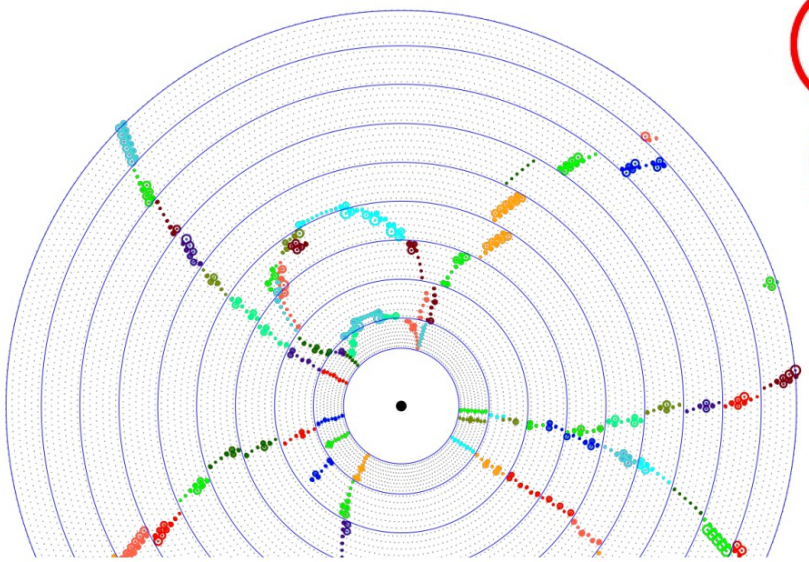
Runtime information:

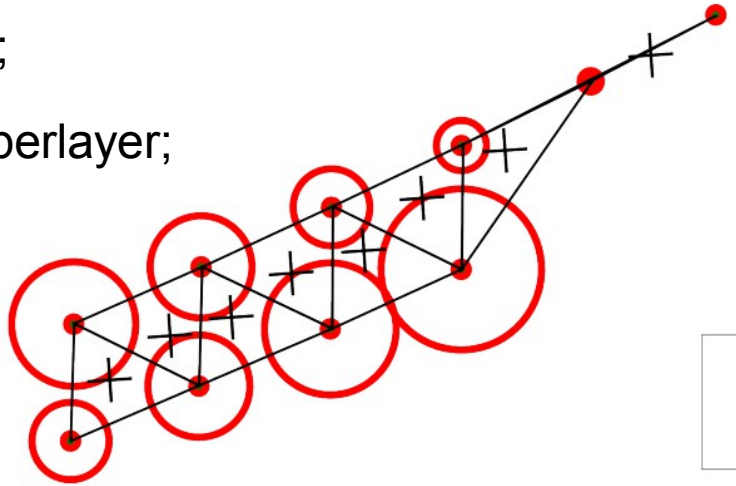
Compiler optimization (-O3), default vectorization

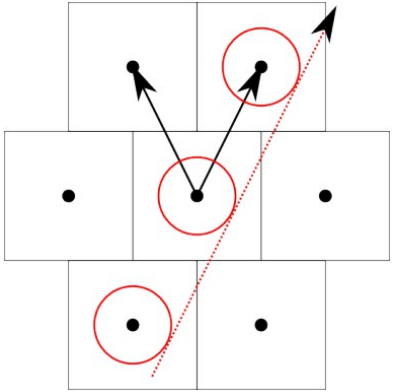
270 ms/event @ Intel Xeon 2.27GHz 8MB cache

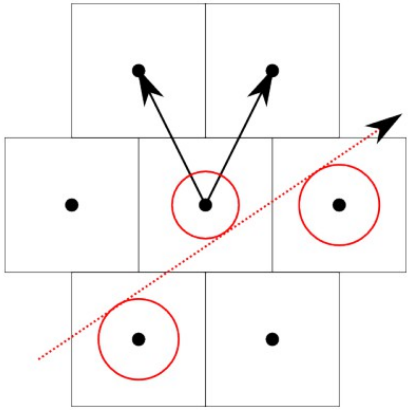
“Cellular Automaton Finder”

- Cells are made up of triplets;
- CA works well within one superlayer;
- No Origin requirement;

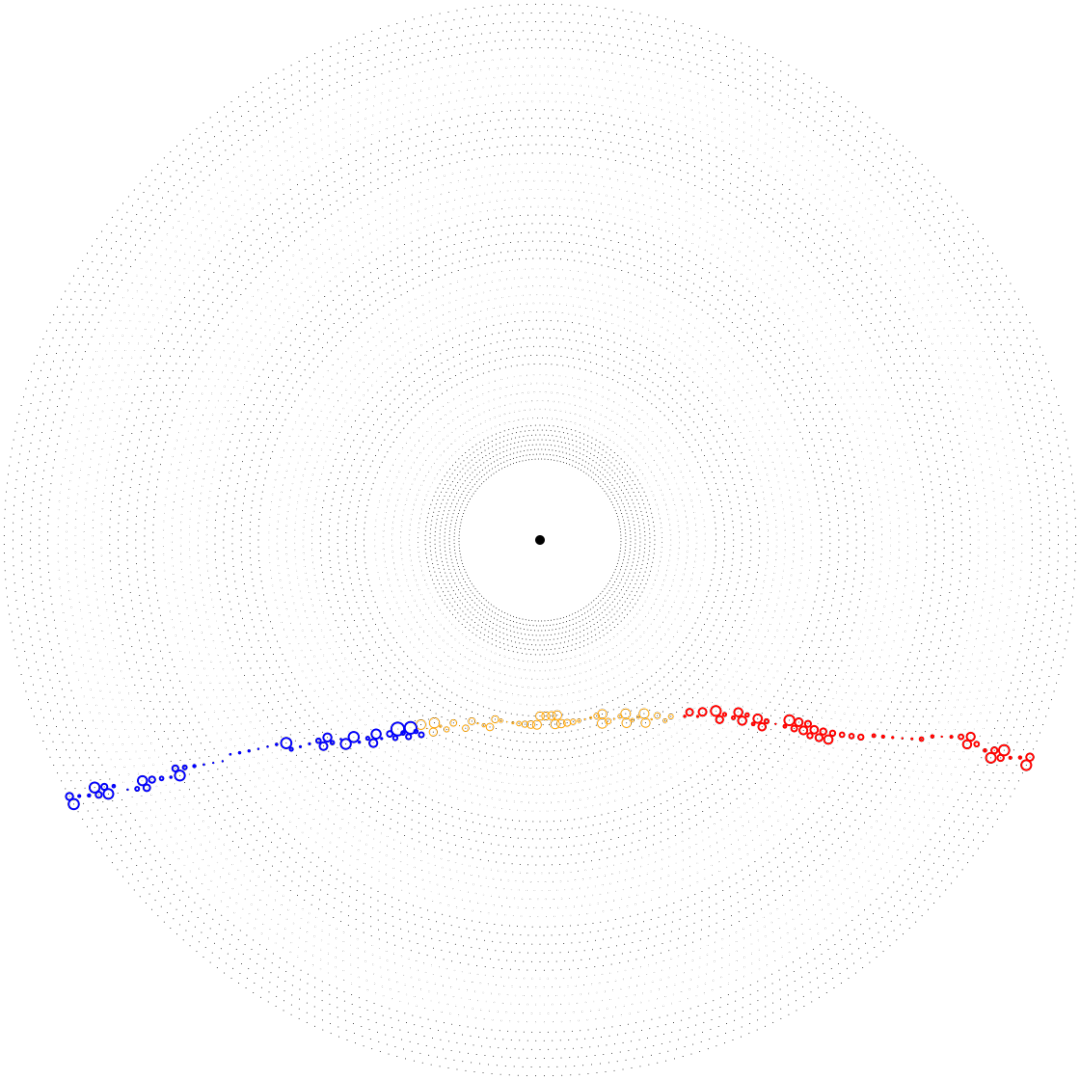








- Segments are fitted with circular fit and then combined.



Fake Rate:	0.0016
Finding Efficiency:	0.9998
Clone Rate:	0.2345
Hit Efficiency:	0.7954

Cosmic track found, ready for cosmics test beam of the drift chamber in spring!

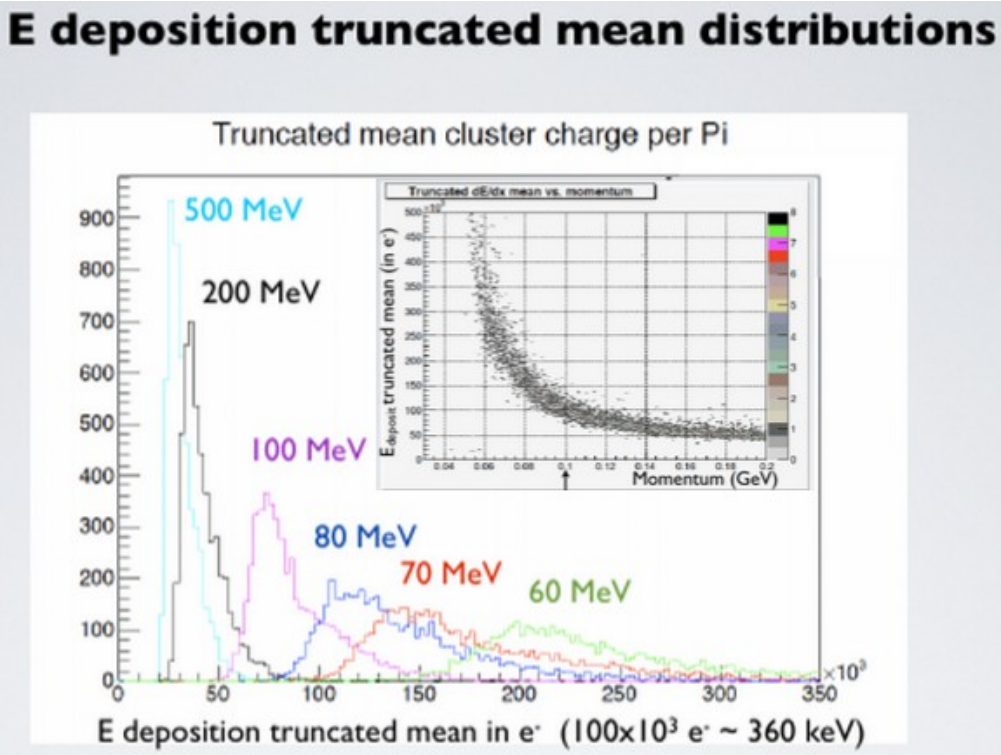
Current Status of Combination

- Tracks found in each detector are separately fitted and combined.
- Extrapolation for adding hits, that were not directly found exists only for the Pixel detector in a useful stage.

- However, we see, that there are pixels from tracks, that can not be reasonably found
  → Cluster Analysis

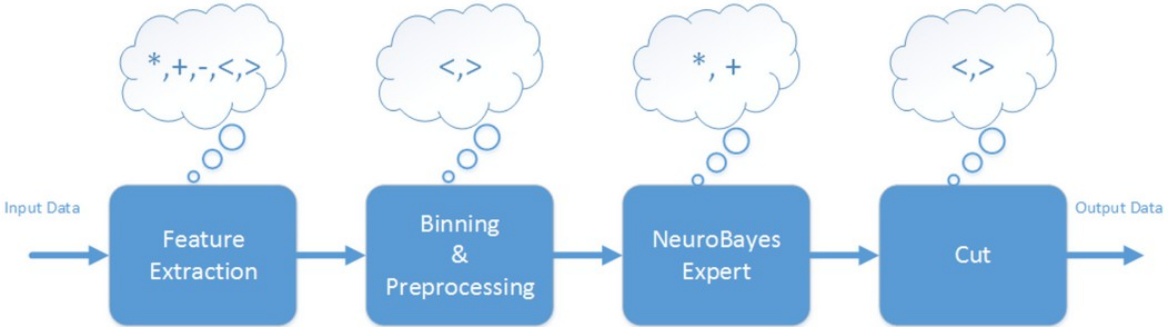
Cluster Analysis Motivation

- only 4 silicon strip layers → danger of inefficiency for low momentum tracks initial motivation;
- special characteristics quite obvious;
- now: consider all primary particles without track candidate;



Cluster Analysis

- Use NeuroBayes package without the neural net part
  - Decorrelation, transformation to “purity space”, …
- Luckily these steps can be compressed into one table-Look-up/feature + vector multiplication; → easy on FPGA



Cluster Feature	Importance
Total Charge	1st
Total Length	2nd
Minimum Pixel Charge	3rd
Length in z	4th
Maximum Pixel Charge	5th
Length in Phi	6th
PXD Layer	7th
Charge Standard Deviation	8th
Number of Pixels	9th

Tracking Design (original)

Legendre Finder in the CDC

- requires IP as constraint
+ very fast

Found tracks should be clean; probably **fit with robust fitter in between** makes sense.

Unused Hits, Track Stubs

CA Finder in the CDC

- comparatively slow
+ doesn't demand IP

Hits are followed locally to find track segments, segments are then connected.
--> complete partially found tracks of the Legendre finder; create new tracks.

Some track-stubs/ r-phi tracks only and potentially fake tracks will remain.

Untrackable-blob-analyzer first?

VXD-Stand-Alone

+ find tracks completely independent
--> good for systematics study
- **no chance to find Ks with** considerable lifetime etc.

Good Partial Tracks

Hits & Stubs

Track-Merging of Good Tracks

CDC good track extrapolation to add additional VXD hits.

VXD good track extrapolation to add CDC track stubs etc.

Cross Detector Finder to match bad tracklets of both detectors.

Good Complete Tracks

Final Track Collection

Re-fitting, Vee-Zero ...

Summary

- Various algorithms for stand-alone tracking in the detectors are in progress.
- Rescue mechanism “Cluster Analysis” is now proven as concept and doesn't need additional hardware.
- Testbeam setup with full silicon system including Region of Interest
- selection was performed.
- Cosmics test with drift chamber will happen this spring.

- We have substantial progress and work now on refining and tuning of things.

Belle II Tracking Group

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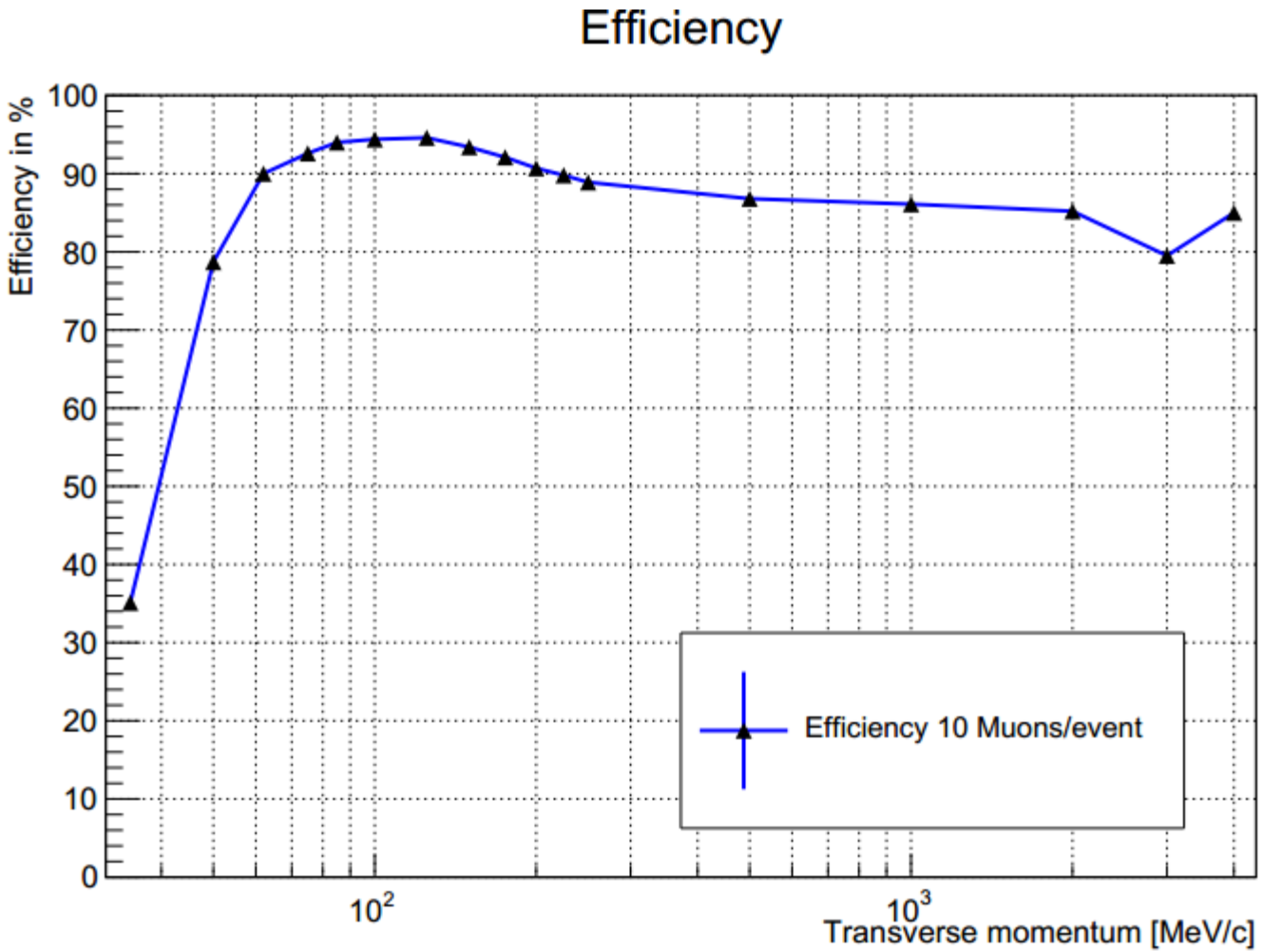
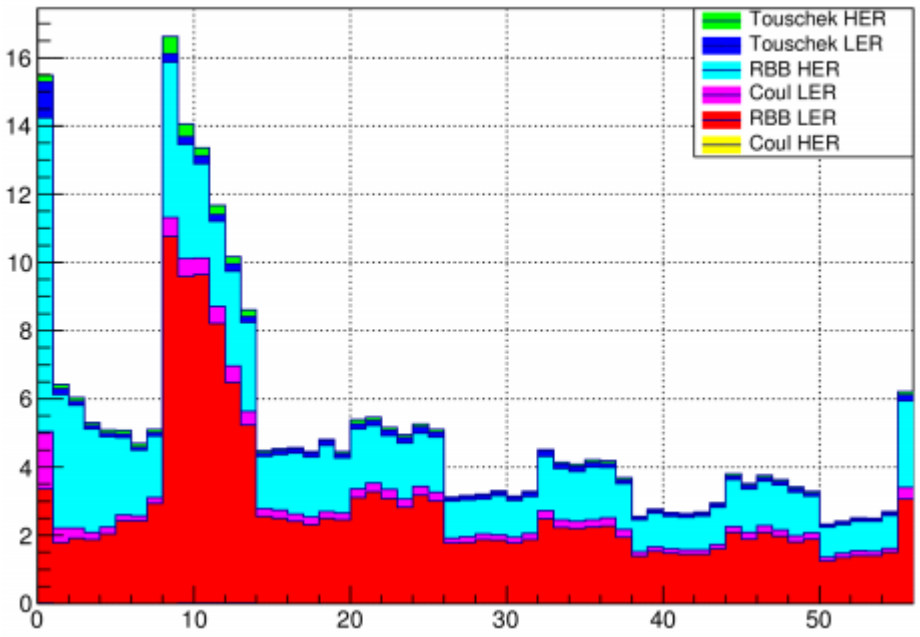
Backup


Efficiency
Efficiency in %
100
90
80
70
60
50
40
30
20
10
0
10^2
10^3
Transverse momentum [MeV/c]
Efficiency 10 Muons/event

CDC Hit Rate by Wire
“20” → ~ 10% occupancy



SVD background occupancy