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SI LAB
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Tracking Performance and Implementation of DATCON

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Content

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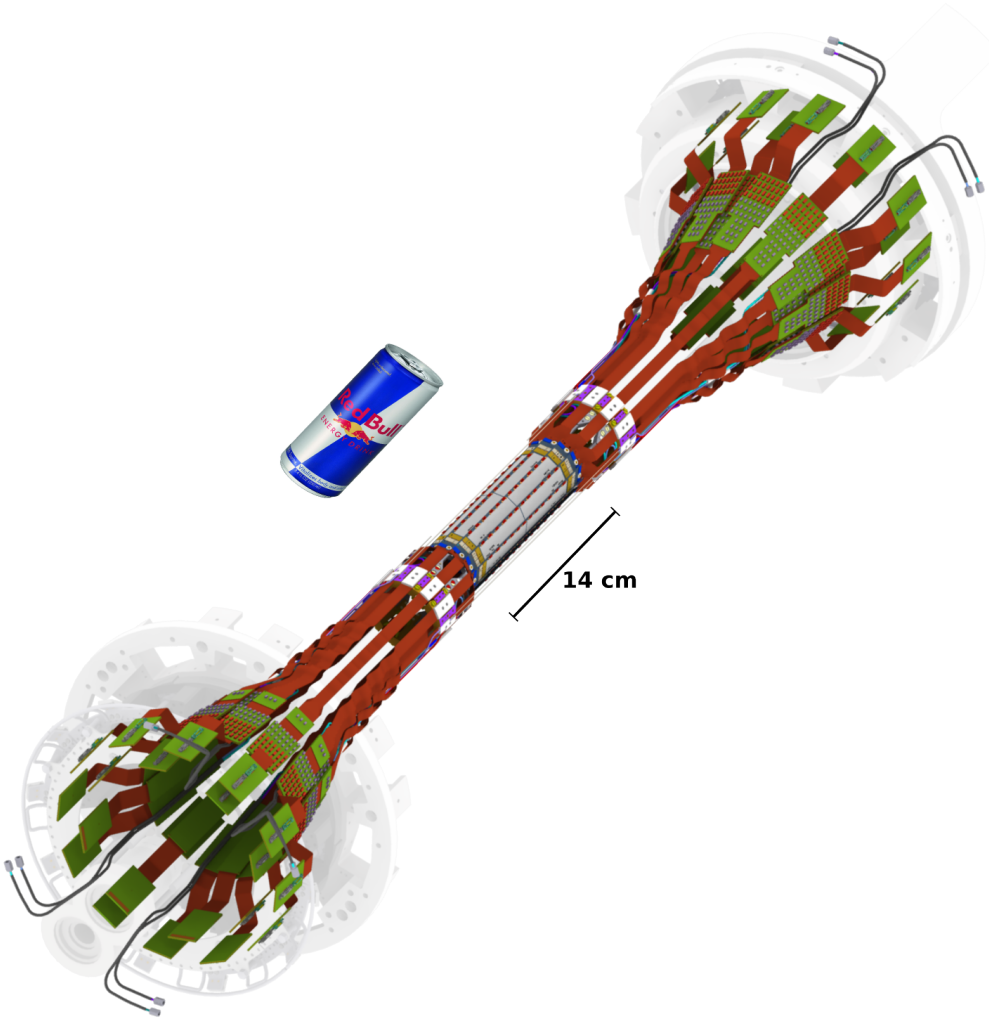
1. Introduction to the DATCON System
2. Simulation with BASF2
3. FPGA Implementation

Belle II Vertex Detector



- 2 layers DEPFET Pixel Detector (PXD) with 8 million pixels (avg: 60 Gbps, max 256 Gbps)
- Data reduction required for PXD data (factor ~ 10)
- 4 layers Silicon strip Vertex Detector (SVD)
- Idea: Use hits in the surrounding strip detector, and extrapolate them to the PXD to select usable Pixels

Belle II Vertex Detector

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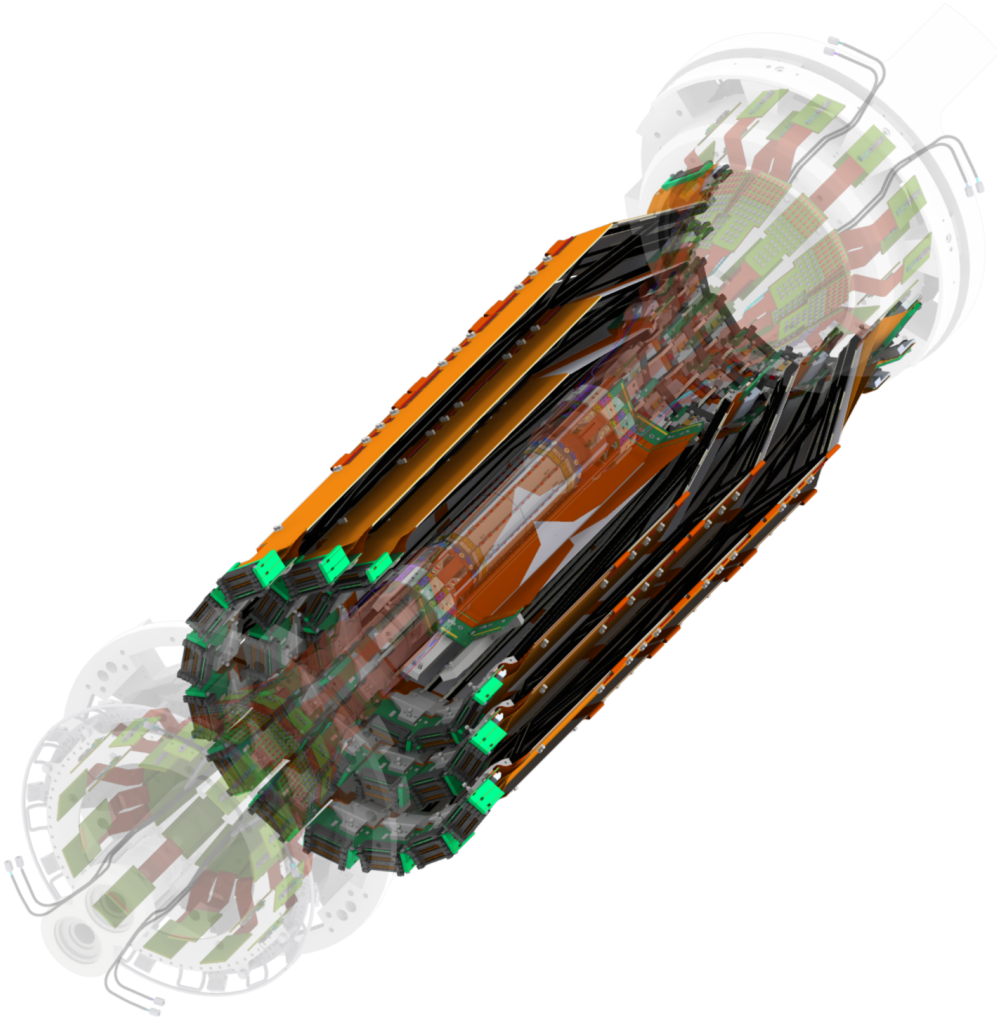

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Data Reduction Idea with SVD Tracking

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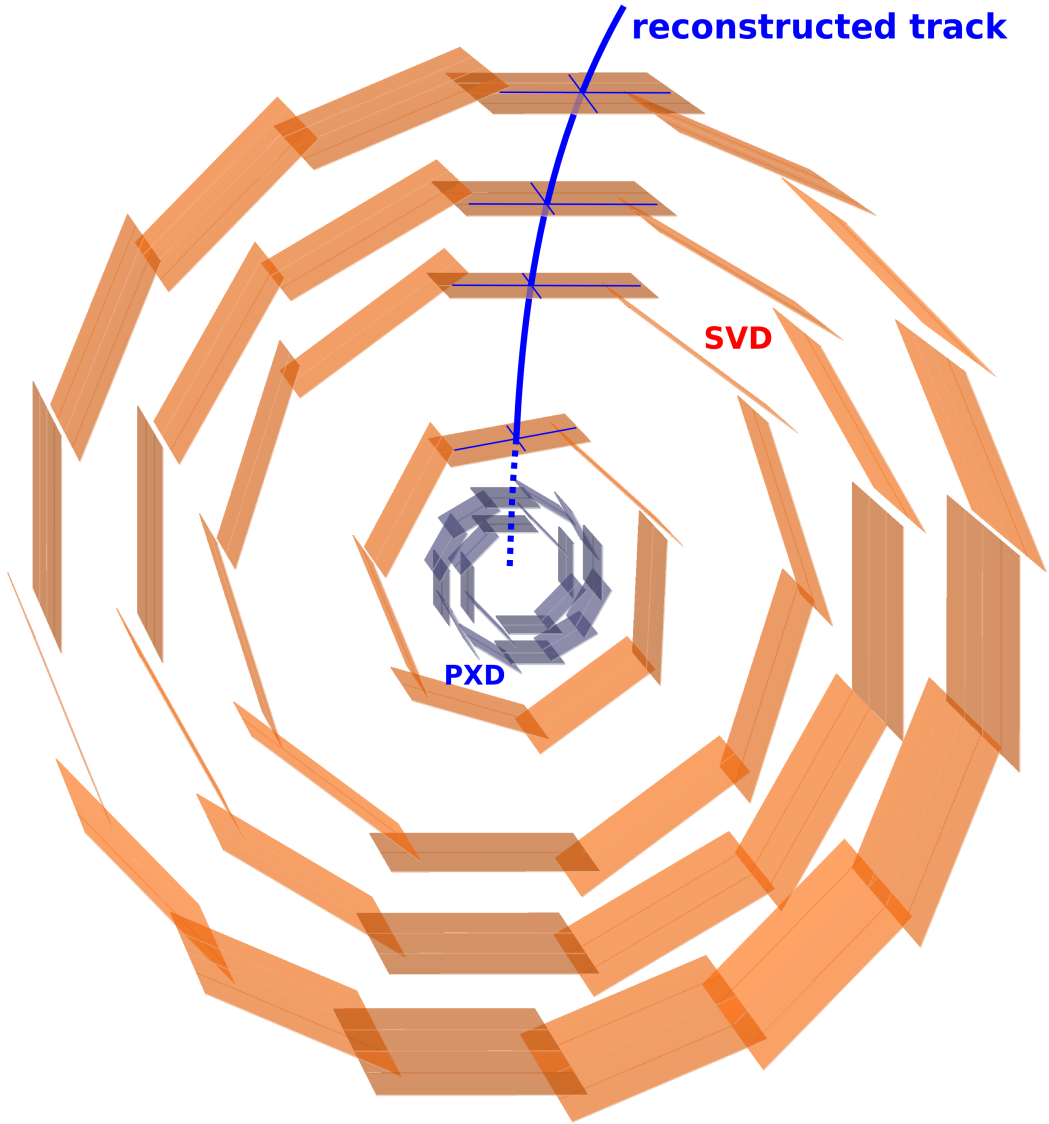
- Complementary approach with two systems to save as much physics data as possible
- HLT: Track reconstruction based on sector-neighbour finding and neural network
- DATCON: Fast FPGA-based track reconstruction system using the Fast Hough Transformation



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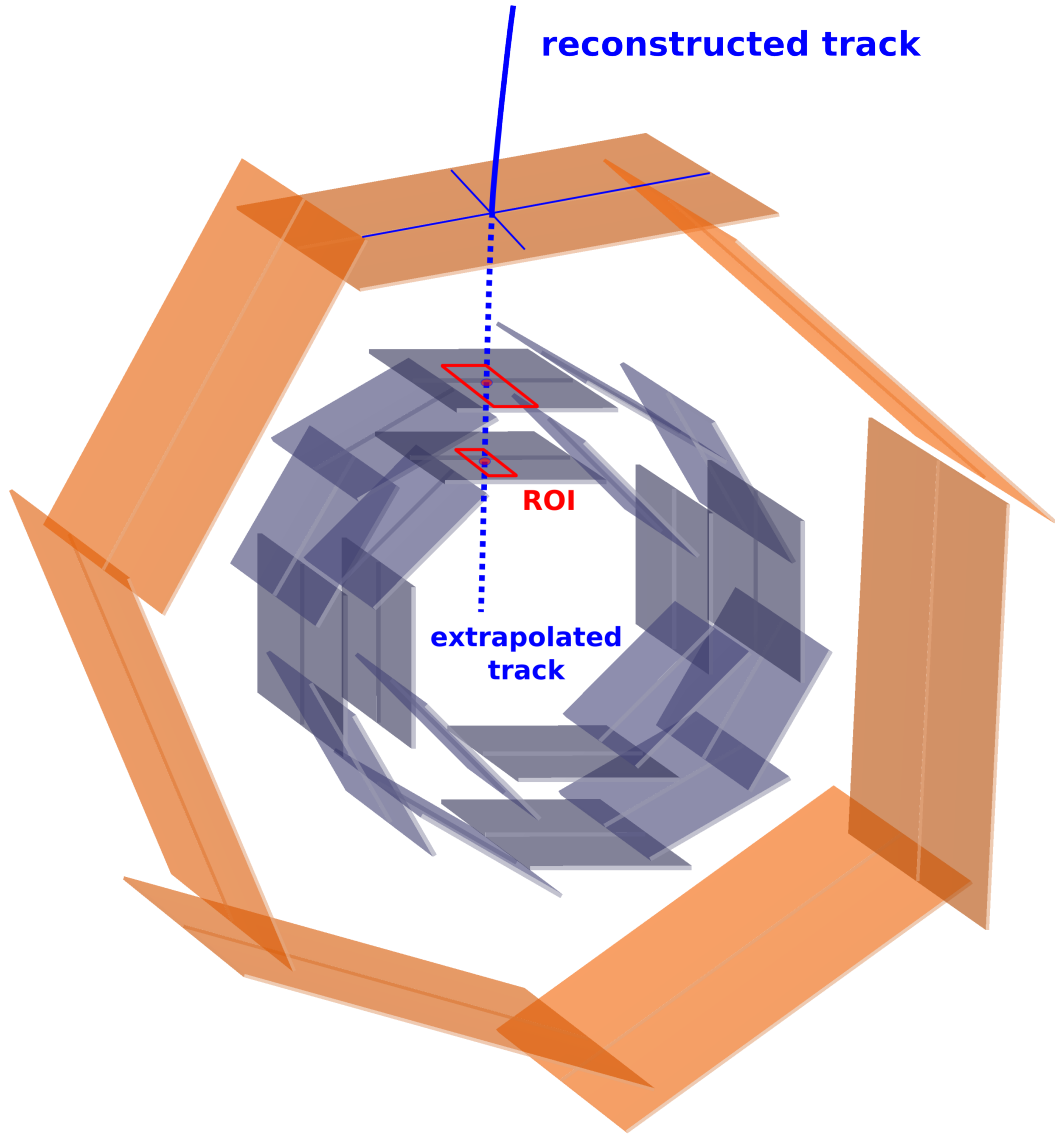

Hardware: Advanced Mezzanine Card

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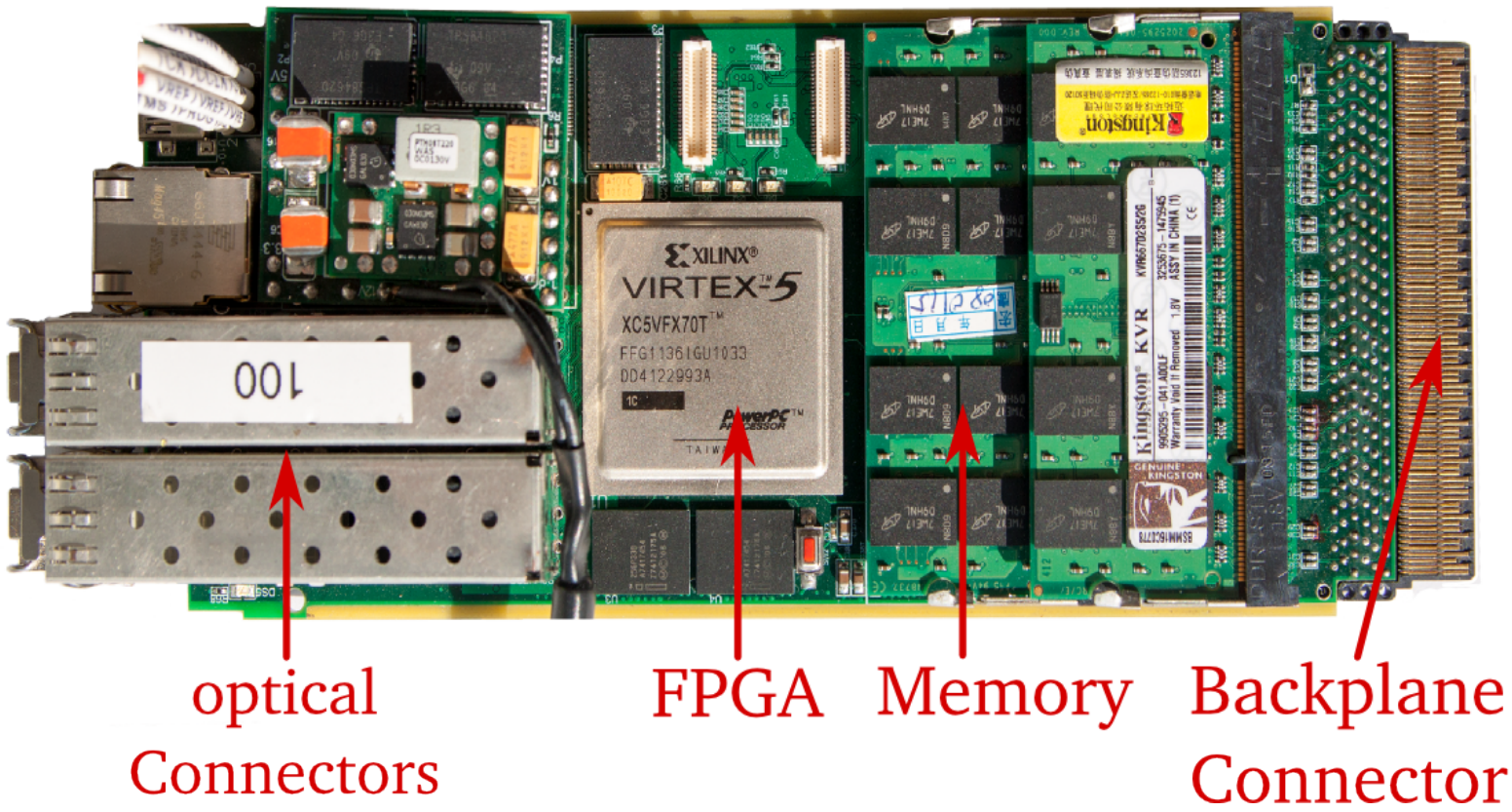
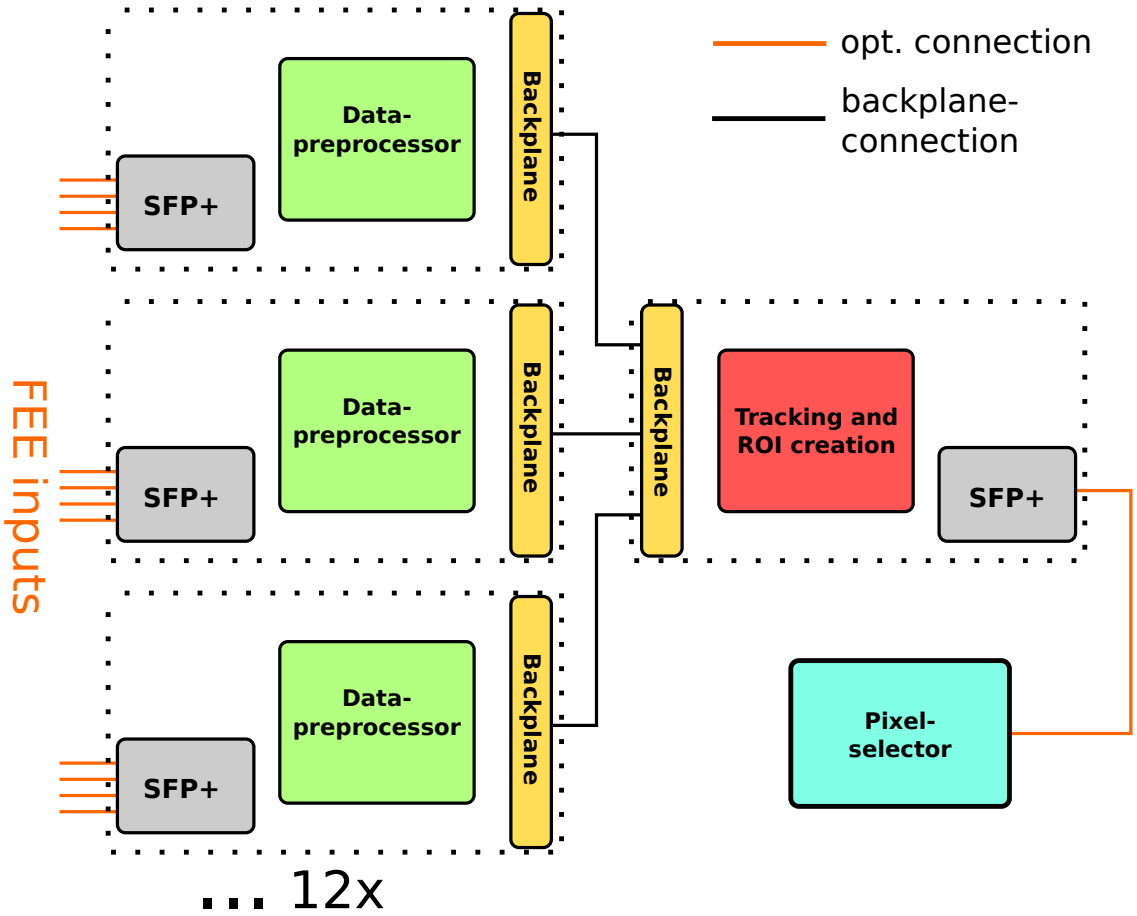
- Virtex 5 FPGA with 4 optical 6.25 Gbps transceivers
- Backplane with 6 ports and 1x Gbit Ethernet port
- 128x DSPs and 4 GB external memory

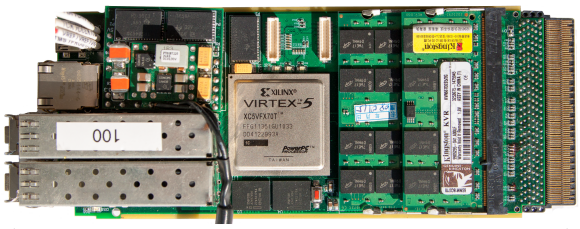


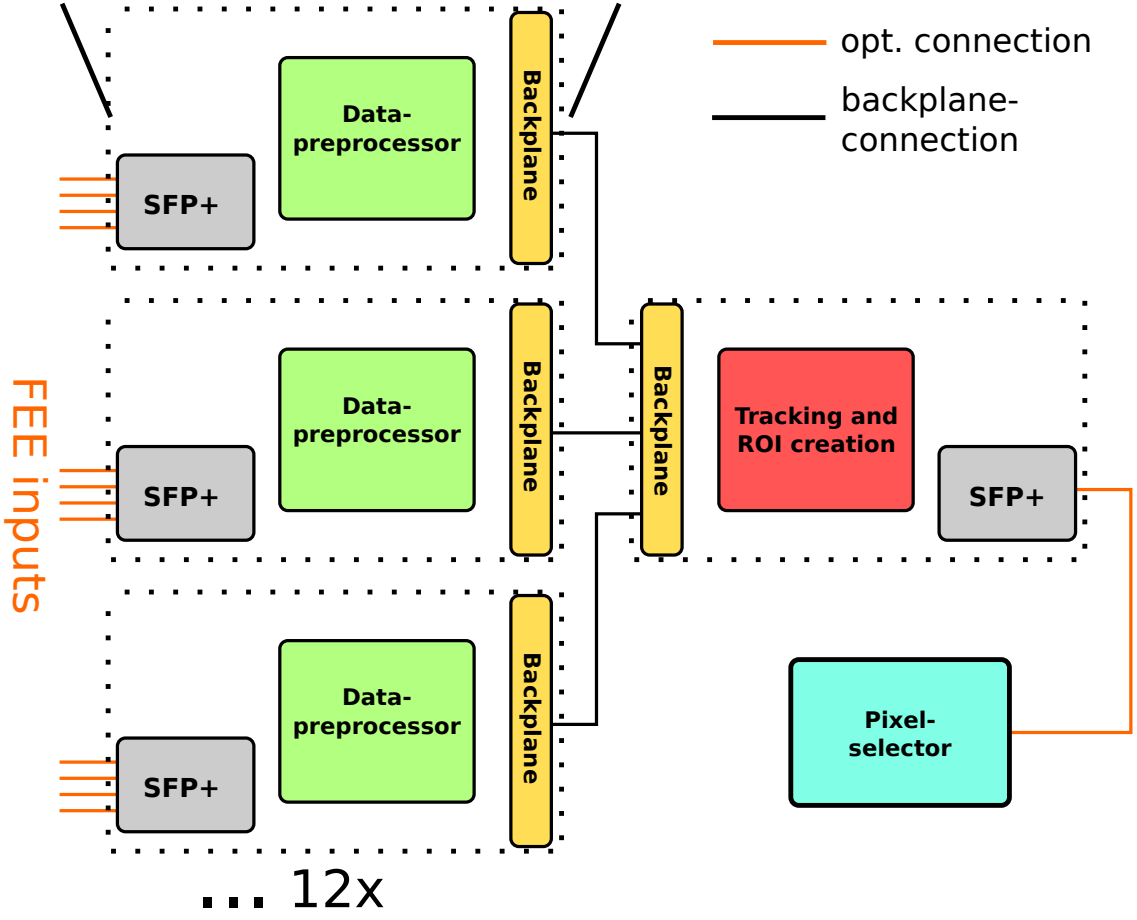
DATCON Connection



- Data Acquisition Tracking Concentrator Online Node (DATCON)
- 48 optical links from the SVD Front End Electronics (FEE)
- Average expected data rate: 6 Gbps
- 12x AMCs for data acquisition and preprocessing
- 2x AMC for Tracking and ROI calculation

DATCON Connection





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Hough Transformation Basics

- Tracking is based on Fast Hough Transformation
- Hough Transformation is able to find and fit straight tracks

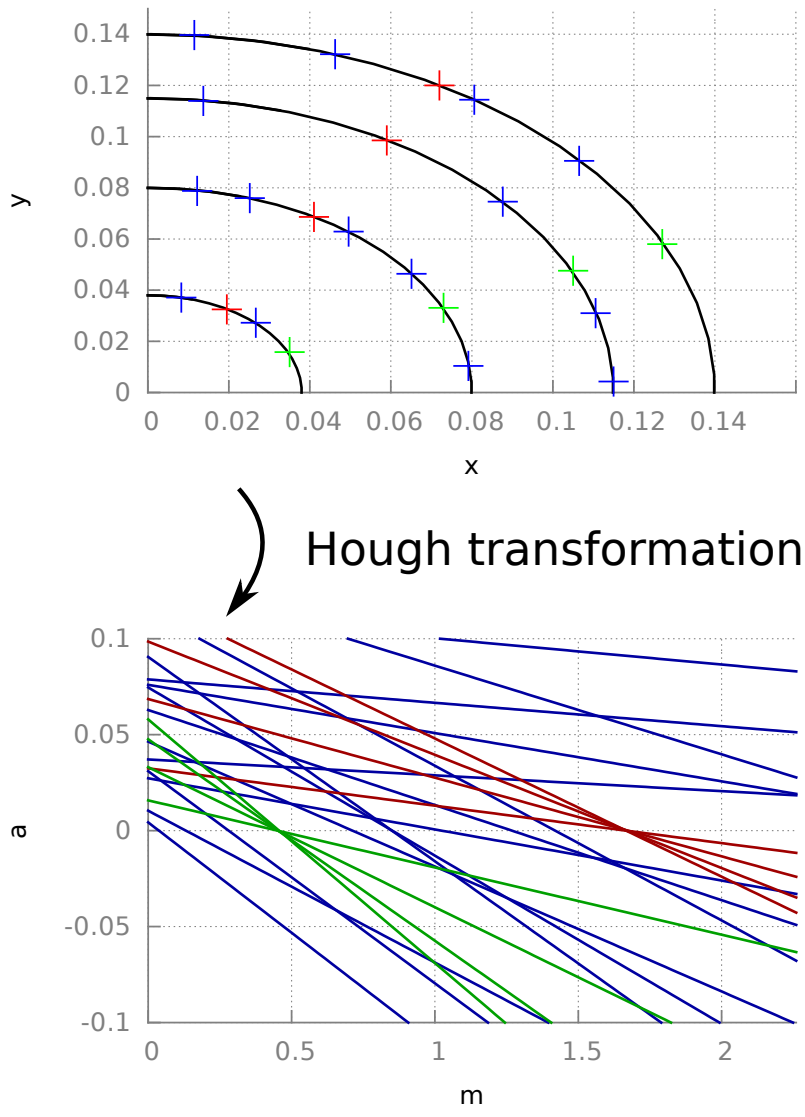
Simple Hough Transformation

$$y_i = m \cdot x_i + a \xrightarrow[trafo]{Hough} a = -m \cdot x_i + y_i$$

- Also works for arc tracks after conformal transformation

Conformal Transformation

$$x' = \frac{x}{(x-x_n)^2+(y-y_n)^2}$$
$$y' = \frac{y}{(x-x_n)^2+(y-y_n)^2}$$



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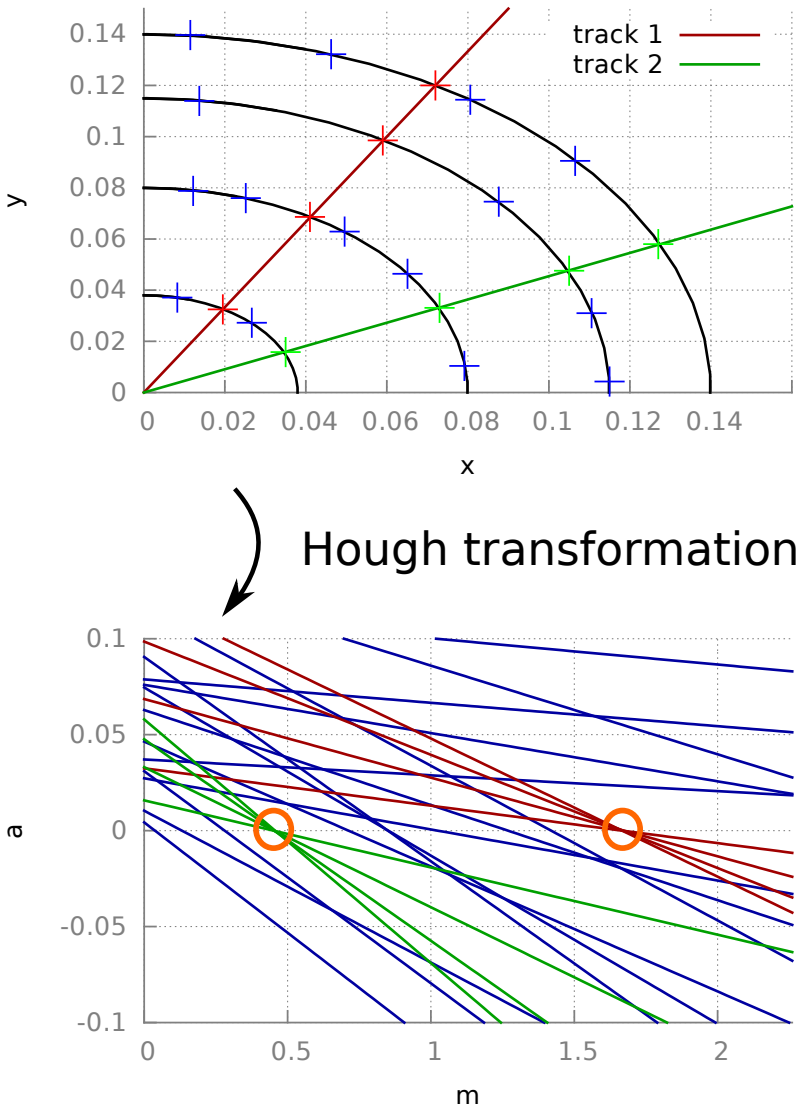

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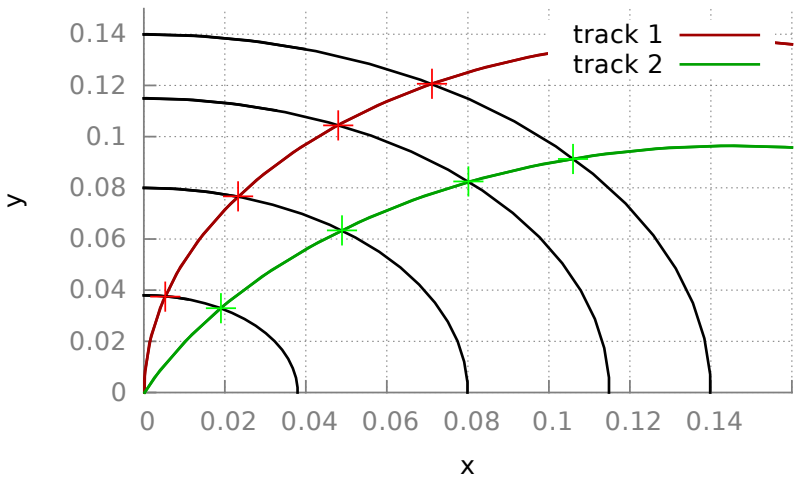

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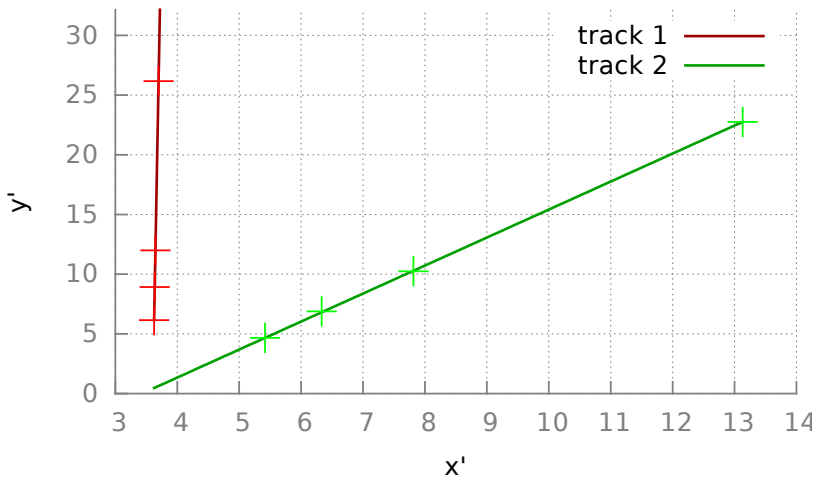

Fast Hough Transformation

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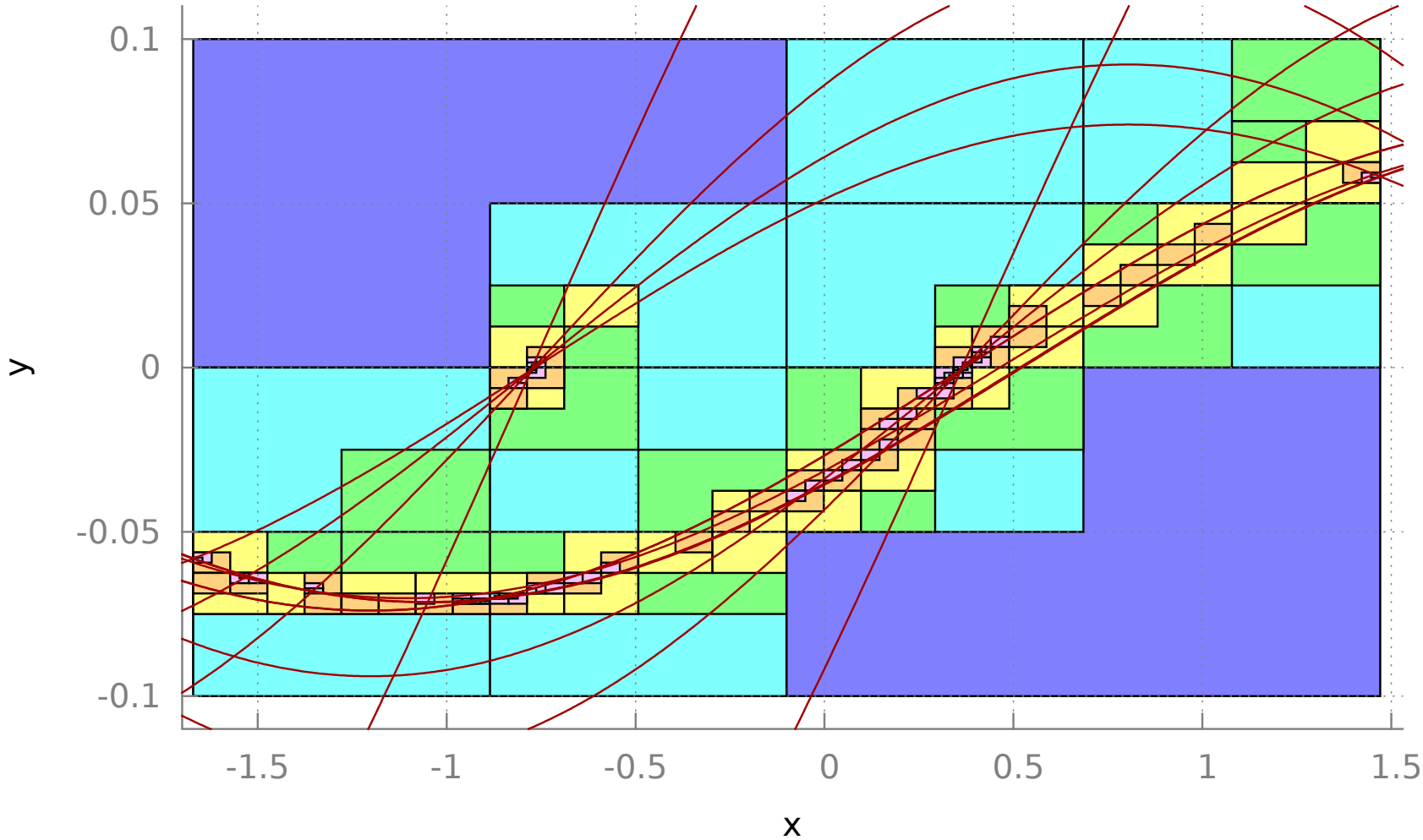
Colors represent depth of iteration



Visualization: One Track @500 MeV

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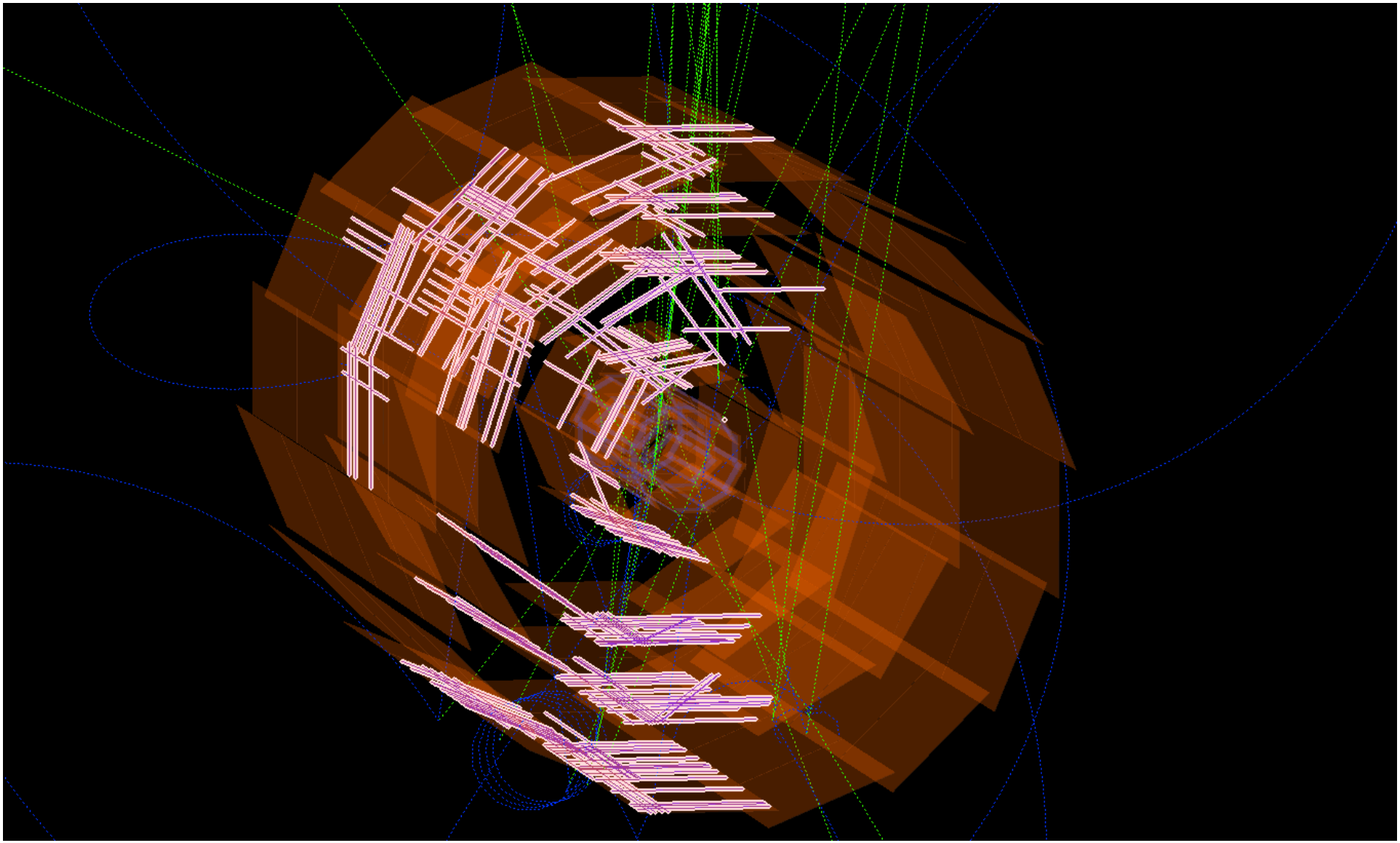

Corresponding Hough Space

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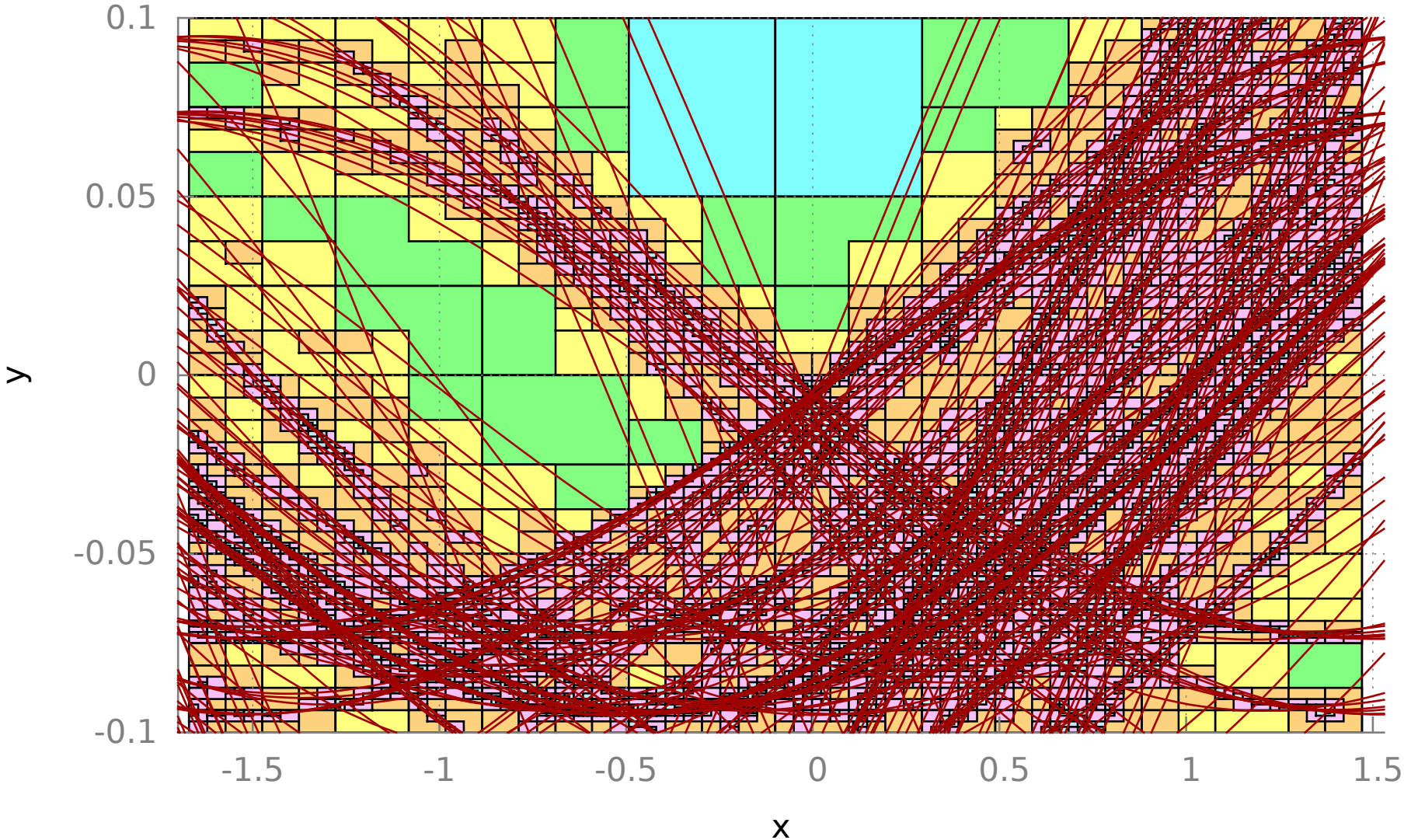

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BASF2 Status

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- BASF2 Hough tracking module committed in official repository (*tracking/modules/svdHoughtracking*)
- Mimic and test features for the FPGA algorithm
  - Clustering: Next-neighbour with simple center of gravity
  - Optional: True-/Simhit converter instead of clustering
  - Simple sector-neighbour finder as pre-filter (Testbeam)
  - Hough Transformation with layer filter and track merger
  - Track extrapolation to PXD and ROI creation

Simulation Setup and Optimization

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- Full detector simulation, 3 billion events (10 tracks per event)
- Momentum from 50 MeV to 3 GeV and most recent background (QED, RBB, Touschek, Coulomb)
- Optimization of Hough tracking parameters in:
  - Number of critical and maximum iterations
  - Start position in Hough space
  - Shape of the rectangular
  - Different candidate and track merger algorithm
- Improvements:
  - Several bug fixes in the TC merger
  - Minimum of 3 (4 before) hits enough for TC
  - ...

Minimum Hits Down To 3 Per TC

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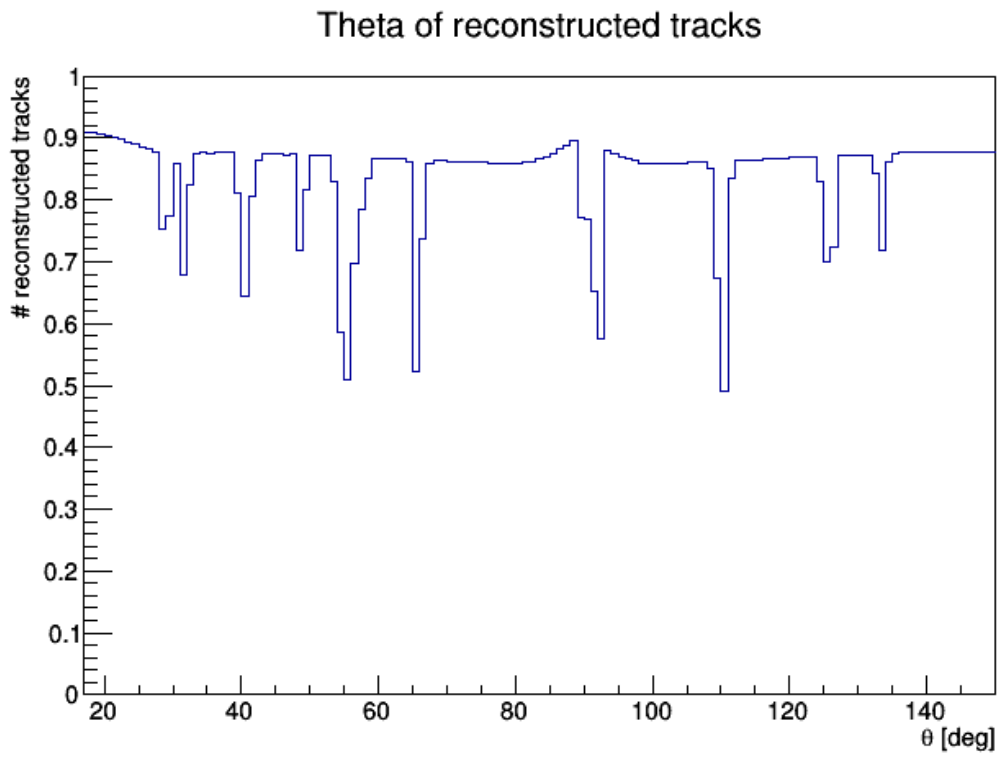
- 4 Hits, at least one hit per layer to create TC
- Works only for ideal detector: inefficiency in the sensors, masked strips, insensitive material ...
- Reducing the minimum number of hits in layers to 3 per TC



- Significant increase in performance while moderate increase in fakes

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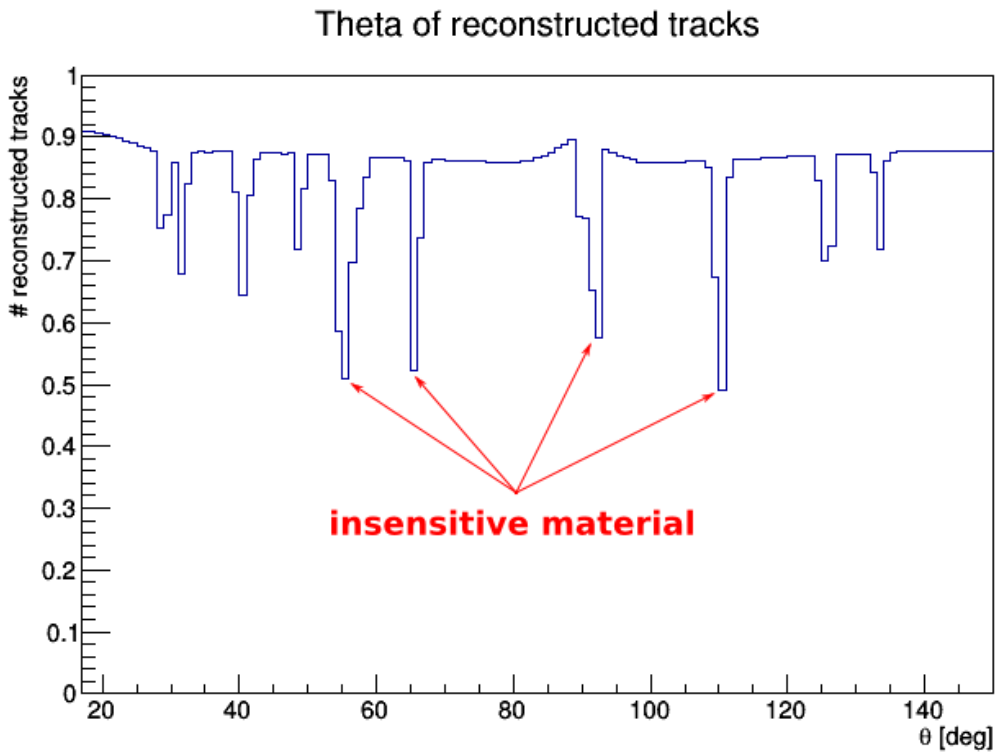

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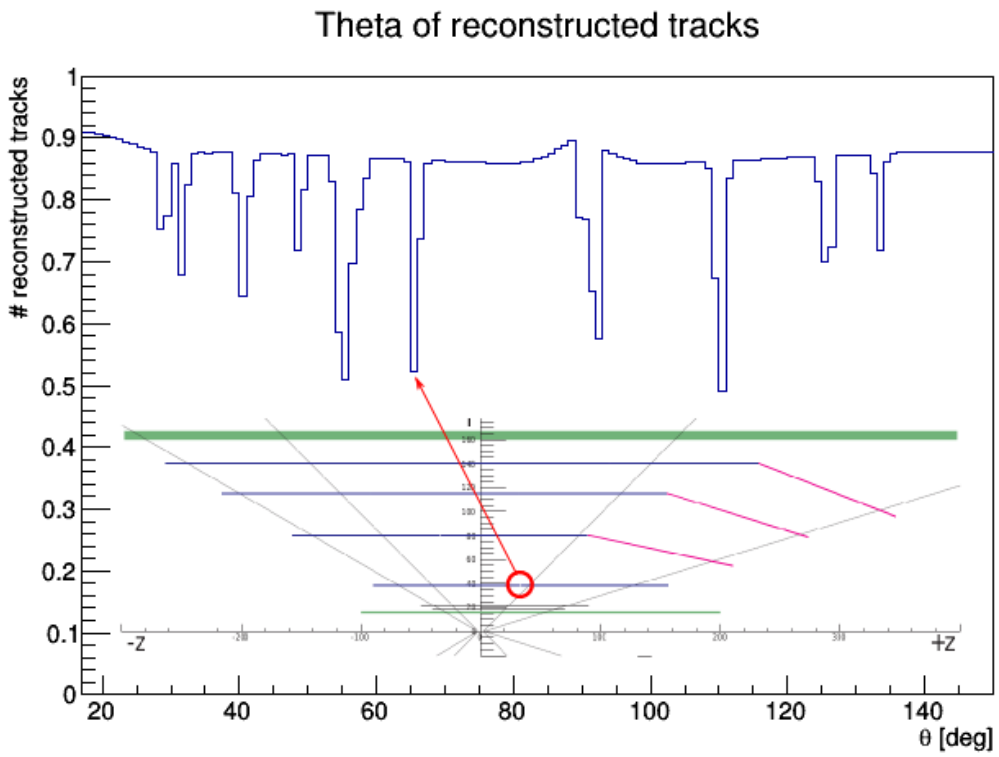

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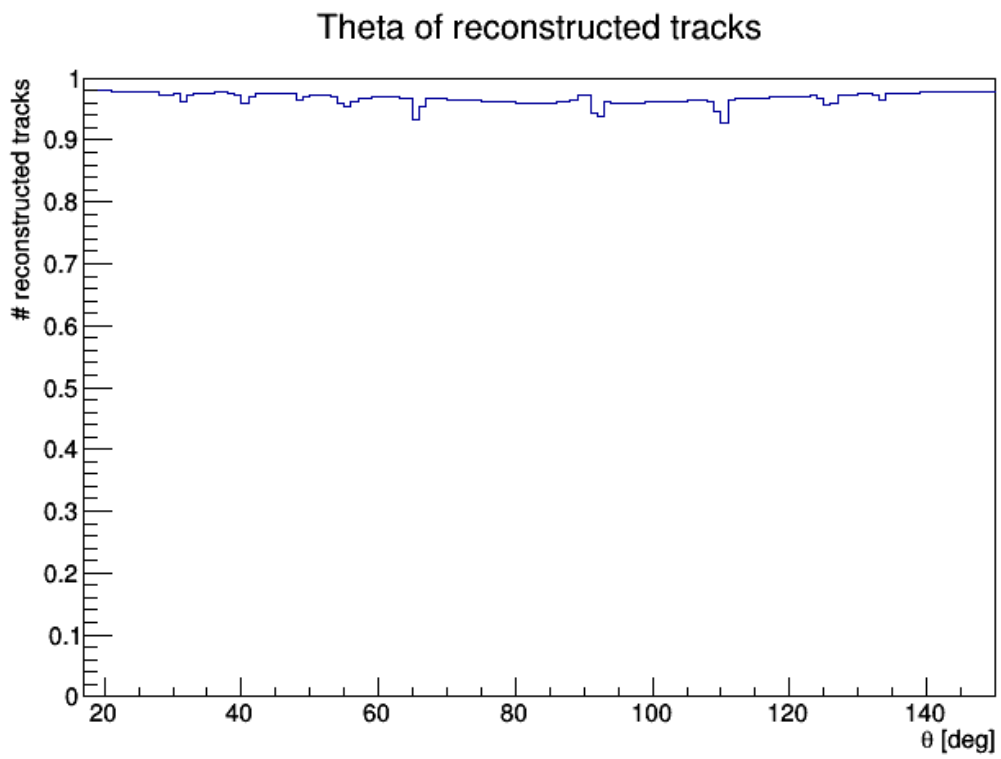

- Significant increase in performance while moderate increase in fakes

A Few Definitions

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- Efficiency: $\frac{\#\ correctly\ reconstructed\ tracks}{\#\ primary\ MCParticles}$
- Correctly reconstructed means difference between reconstructed $angle and generated MCParticle < 1.0 deg
- Fake rate: Average Number of additional found tracks (compared only to number of primary MCParticle!)
- Remember: Task of DATCON is to create good ROI, not precise tracking, meaning:
  - Even angle margins of more than 1 deg will still create sufficient small ROI
  - Additional tracks are okay as long as we achieve the expected data reduction rate

Angle Spread in Phi e^-, e^+ @ 2 GeV

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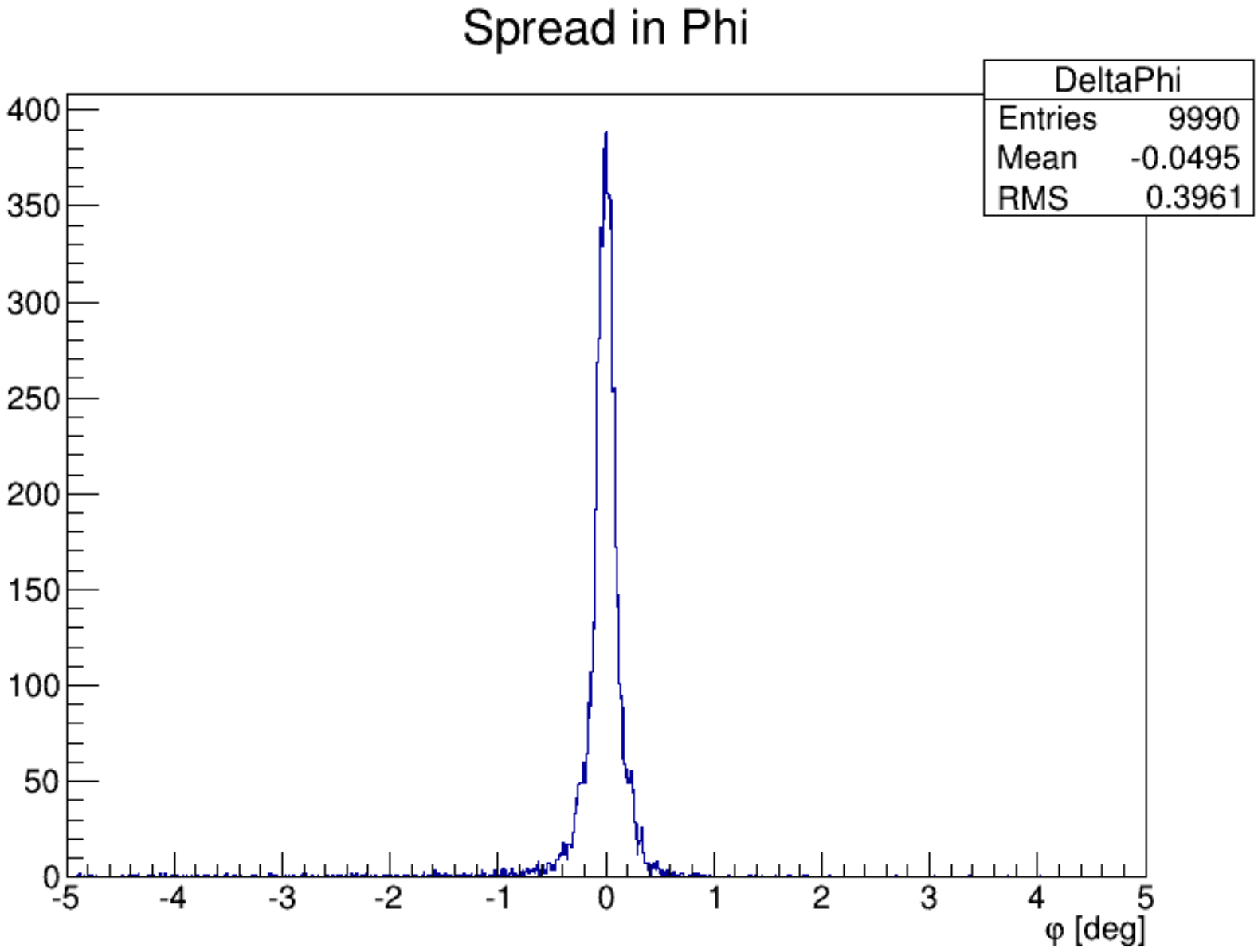

Angle Spread in Phi e^-, e^+ @ 60 MeV

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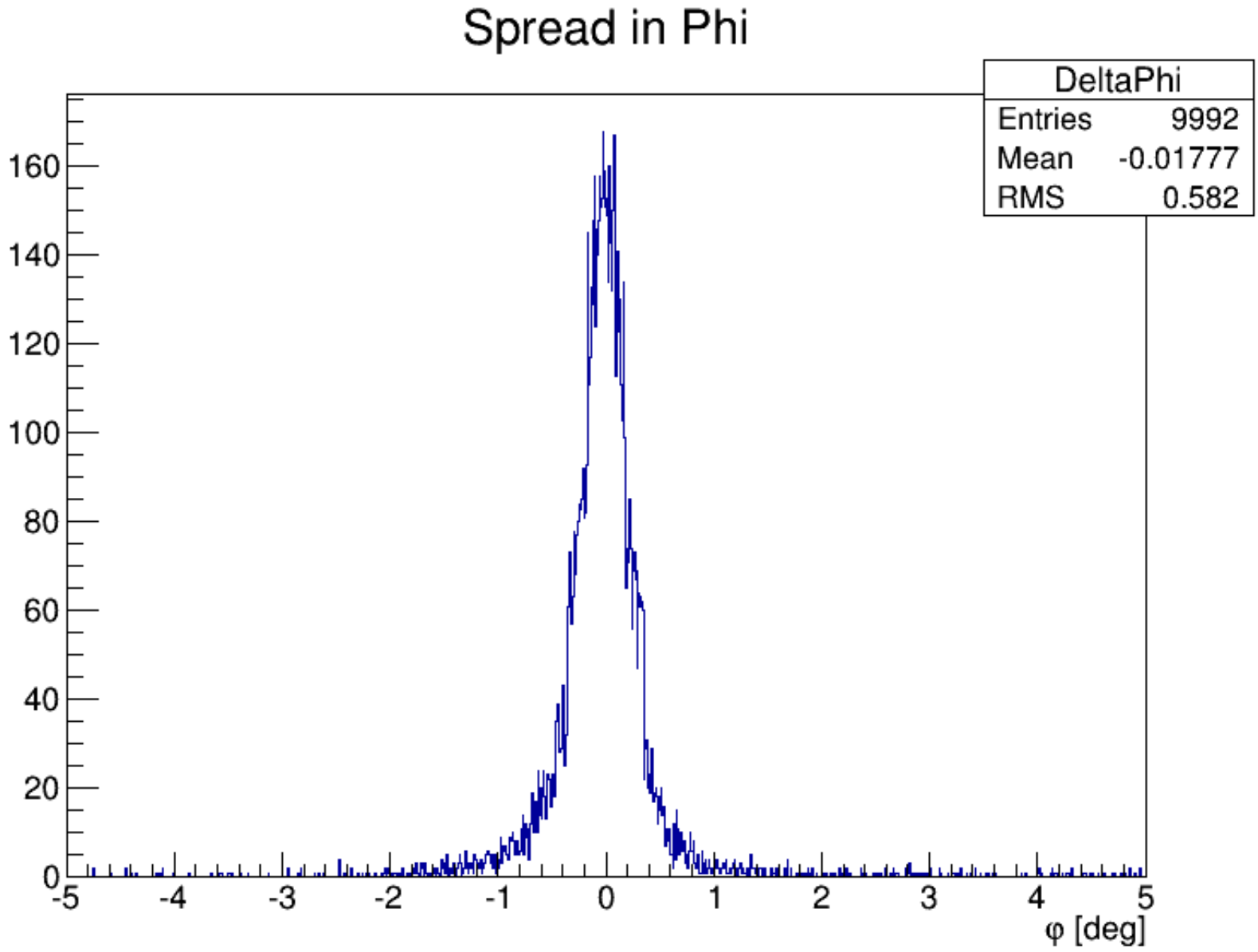

Performance: Efficiency with Bkg

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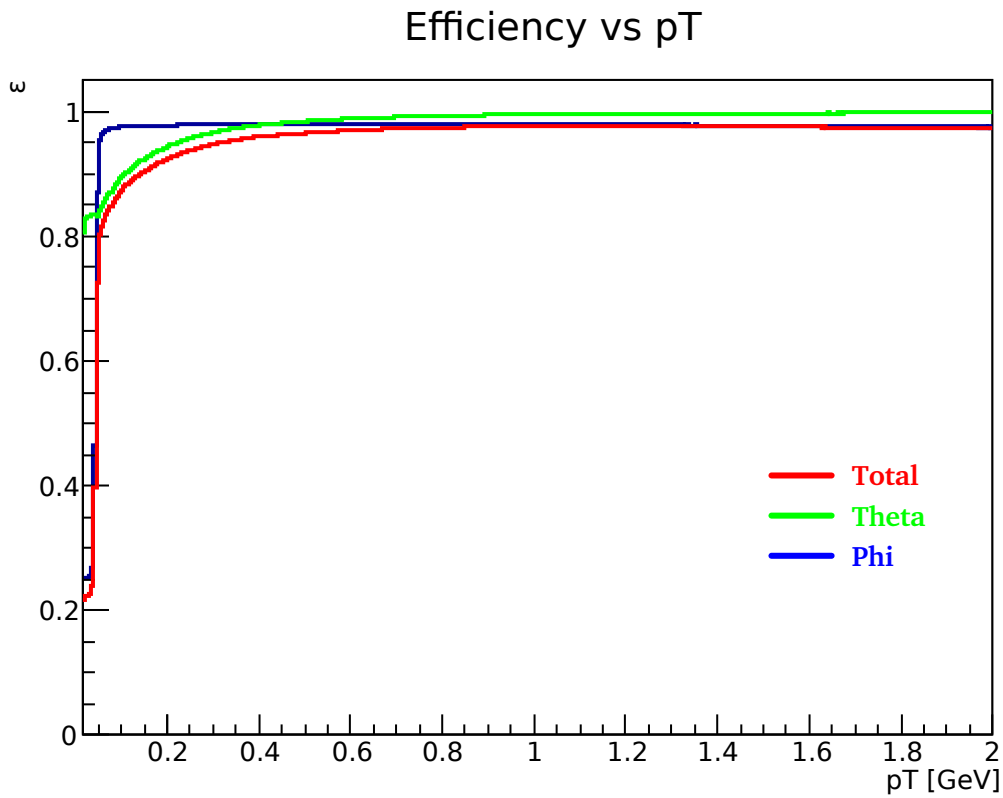
- Constant high efficiency in r-φ @ 0.98 % down to 40 MeV
- Theta efficiency falls under r-φ-efficiency at 300 MeV
- Caused by linear fit of sine-shape like function in z-direction



- Total efficiency limited by theta (later compensated in ROI extrapolation, small but long ROIs)

Fake Rate vs pT

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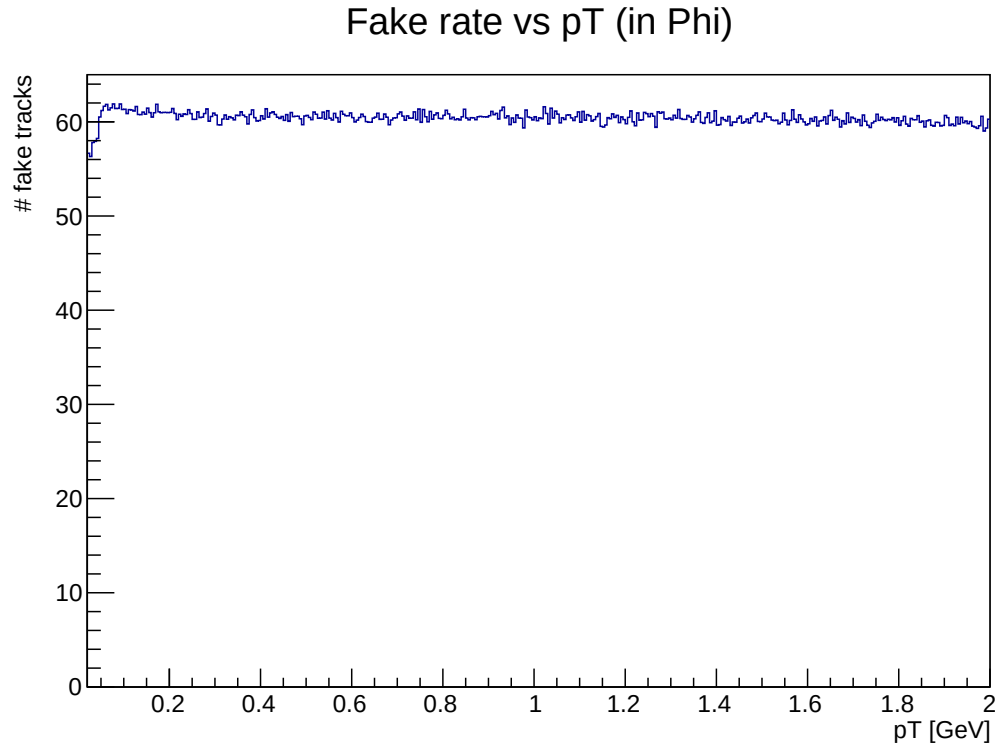
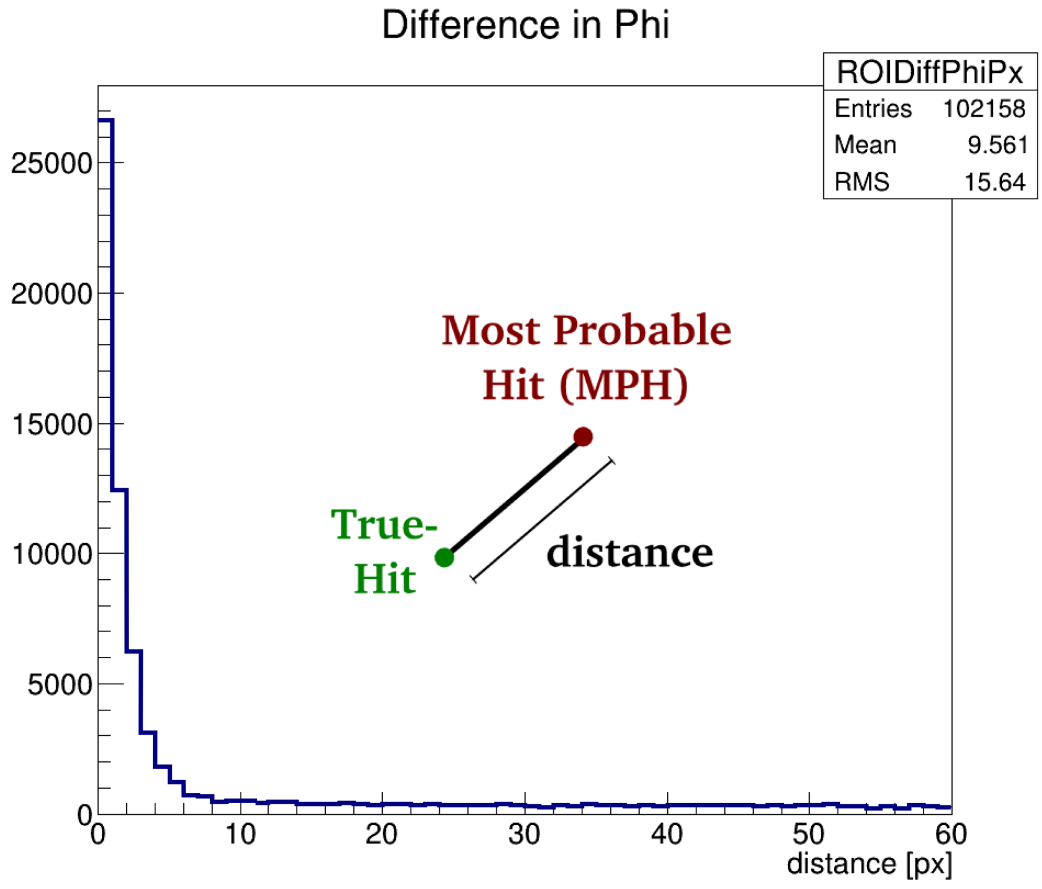
- Average fake hits constant at 60 hits/event
- High number of fake hits caused by high occupancy events
- Or by close tracks events



- Caused by the TC merger algorithm (lots of combinatorics in hits)
- Should be fixed with new Hough Space clustering algorithm and cut-off threshold

Data Reduction Performance

- Flexible ROI size from 8x16 px up to 12x160 px (depending on momentum estimated by *r*)
- Curler extrapolation still missing! (only two Most Probable Hits (MPH) per track)



- Total ROI efficiency (number of primary track hits on the PXD inside ROI): 95.2 percent
- Data Reduction Factor (DRF): 45

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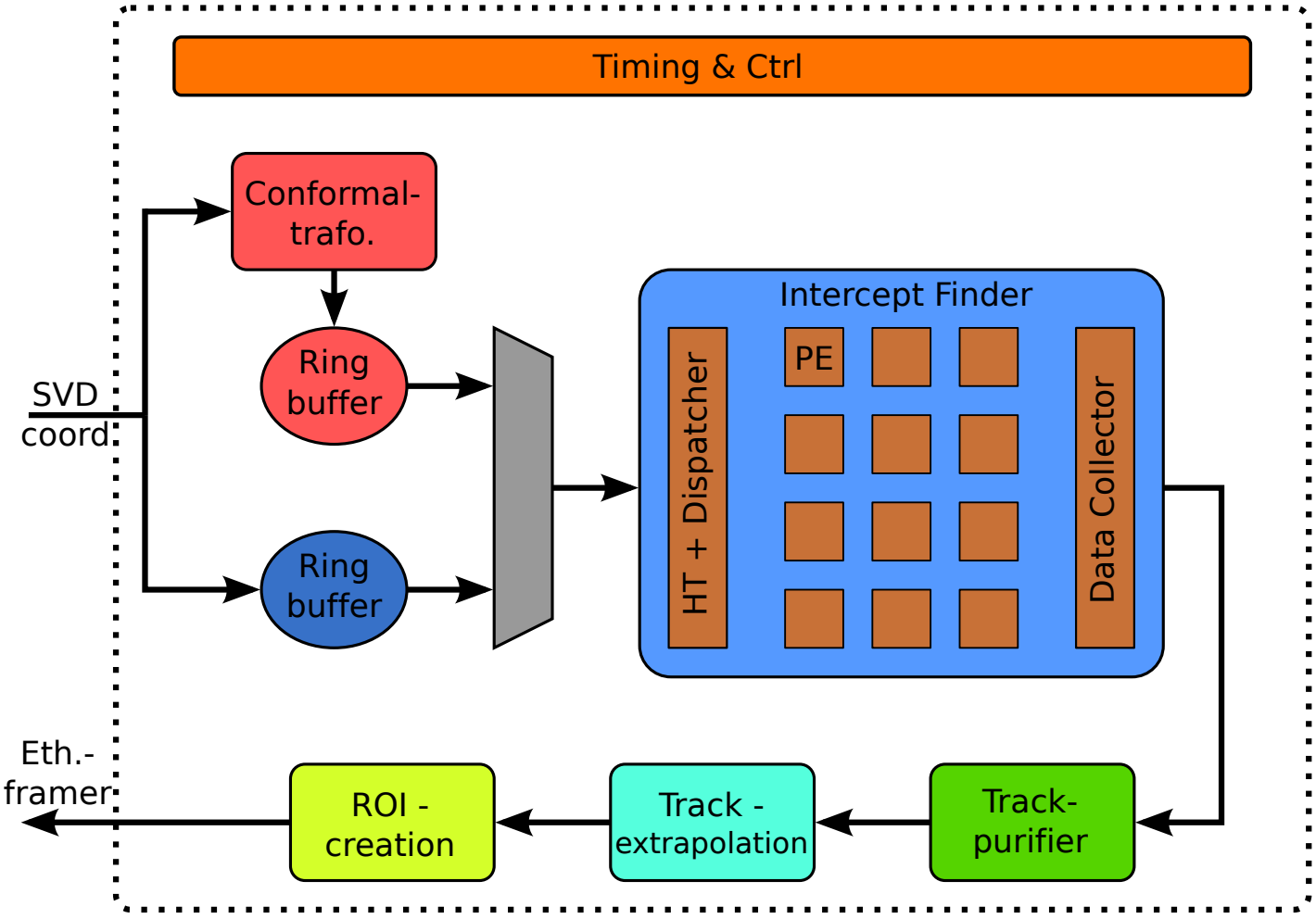
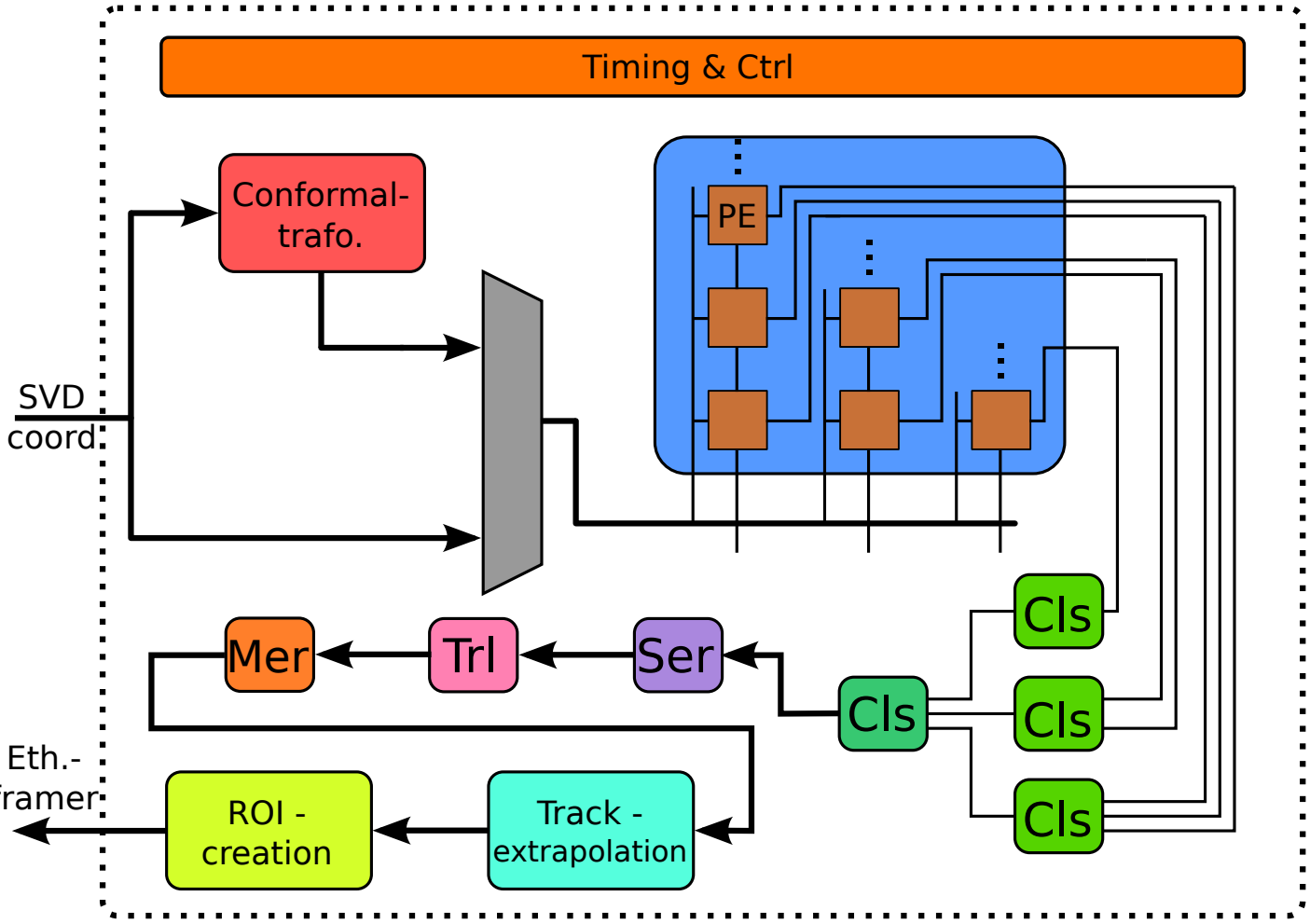
Past FPGA Track Reconstruction



- PE: Processing Element, basic comparator to detect lines in cell
- Track Purifier: Remove duplicated found tracks and combine two 2D-sets

New Implementation



- PE: Processing Element, basic comparator to detect lines in cell and layer filter
- Cls: Clustering unit
- Ser: Serializer
- Trl: Translator
- Mer: Track merger

Illustration of New Implementation

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- Simple one track example (colors denote to different layers)

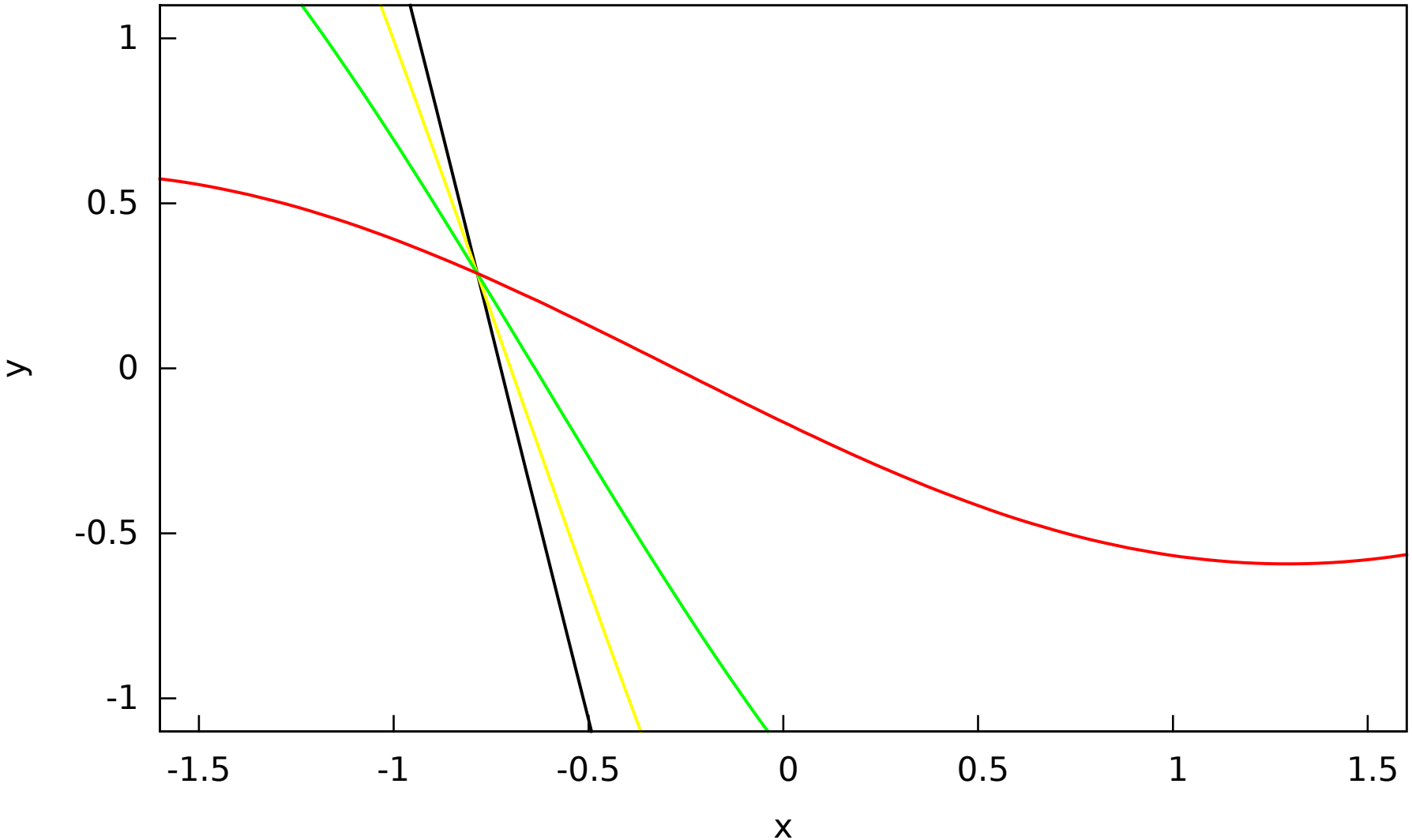

Illustration of New Implementation

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- Hough Space divided into pre-calculated sectors, 64x16

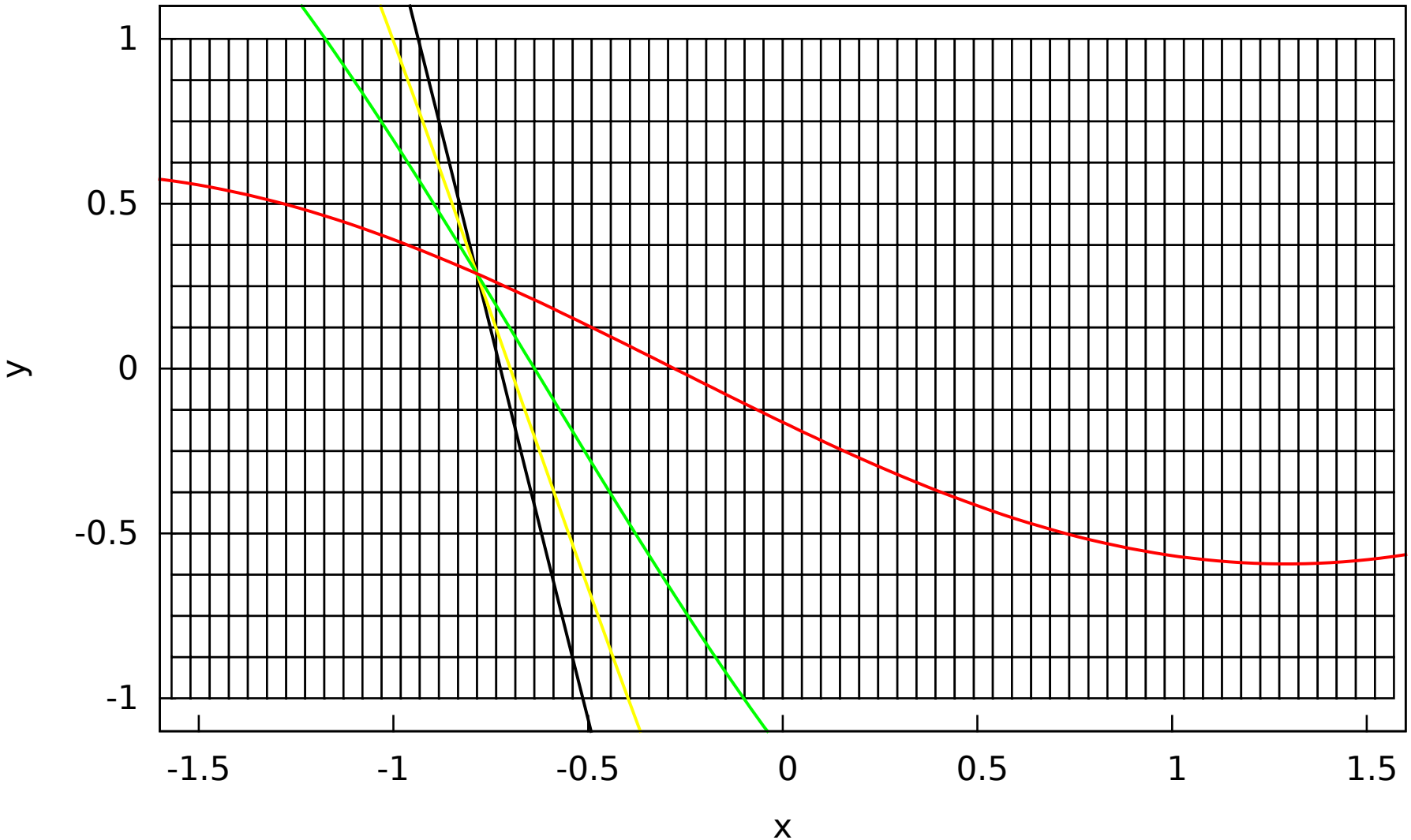

Illustration of New Implementation

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- Count number of traversing lines

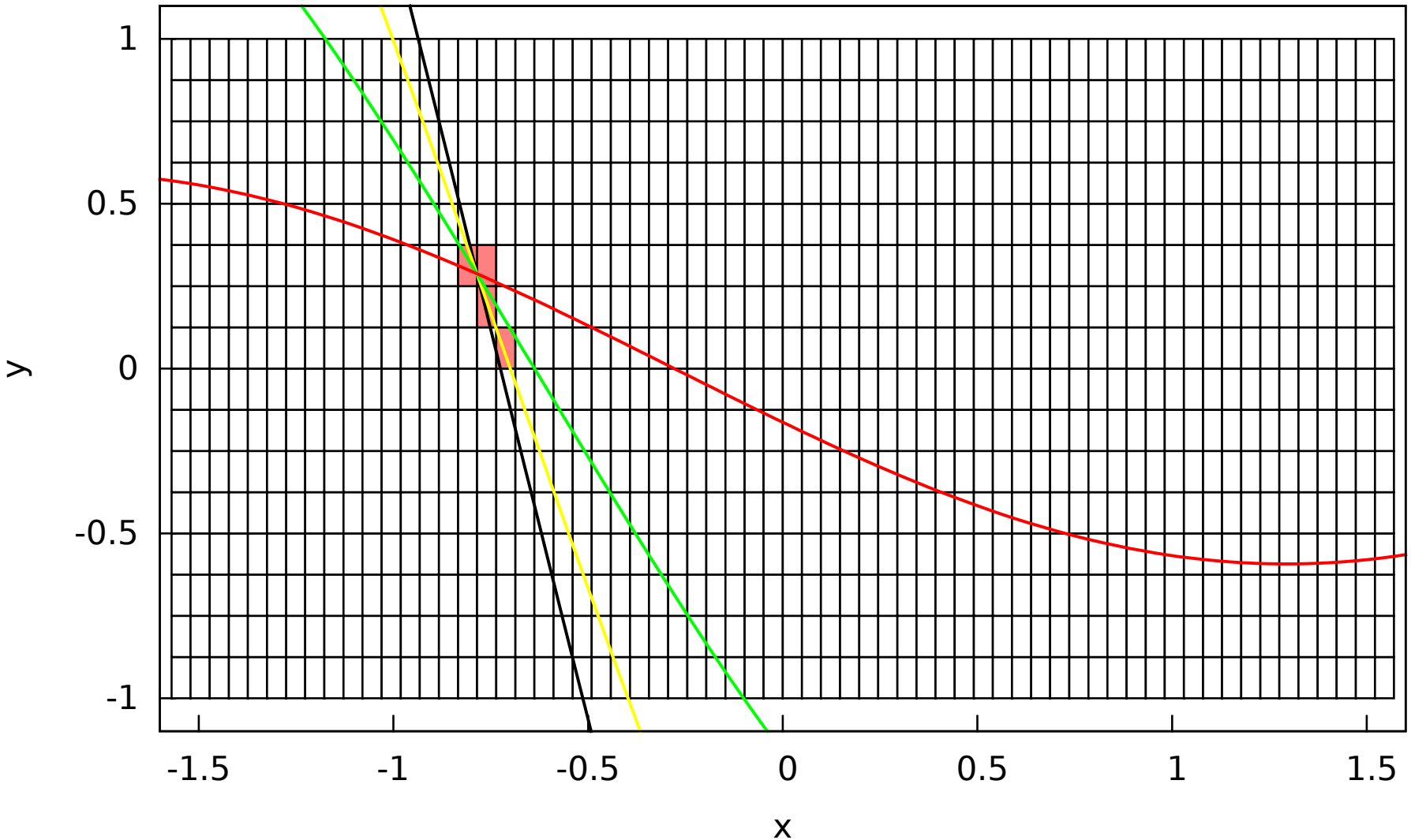

Illustration of New Implementation

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- Clustering column by column

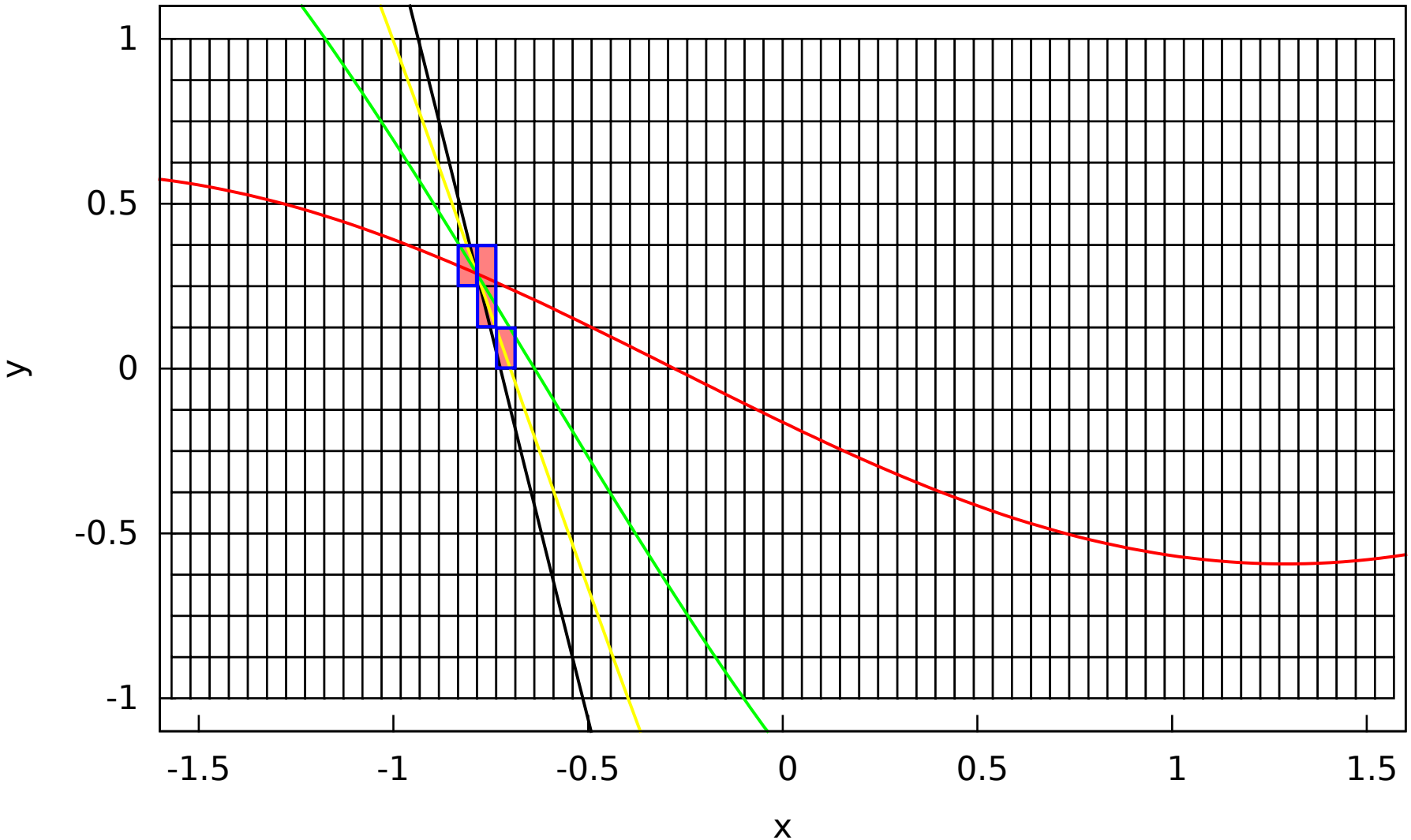

Illustration of New Implementation

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- Clustering row by row

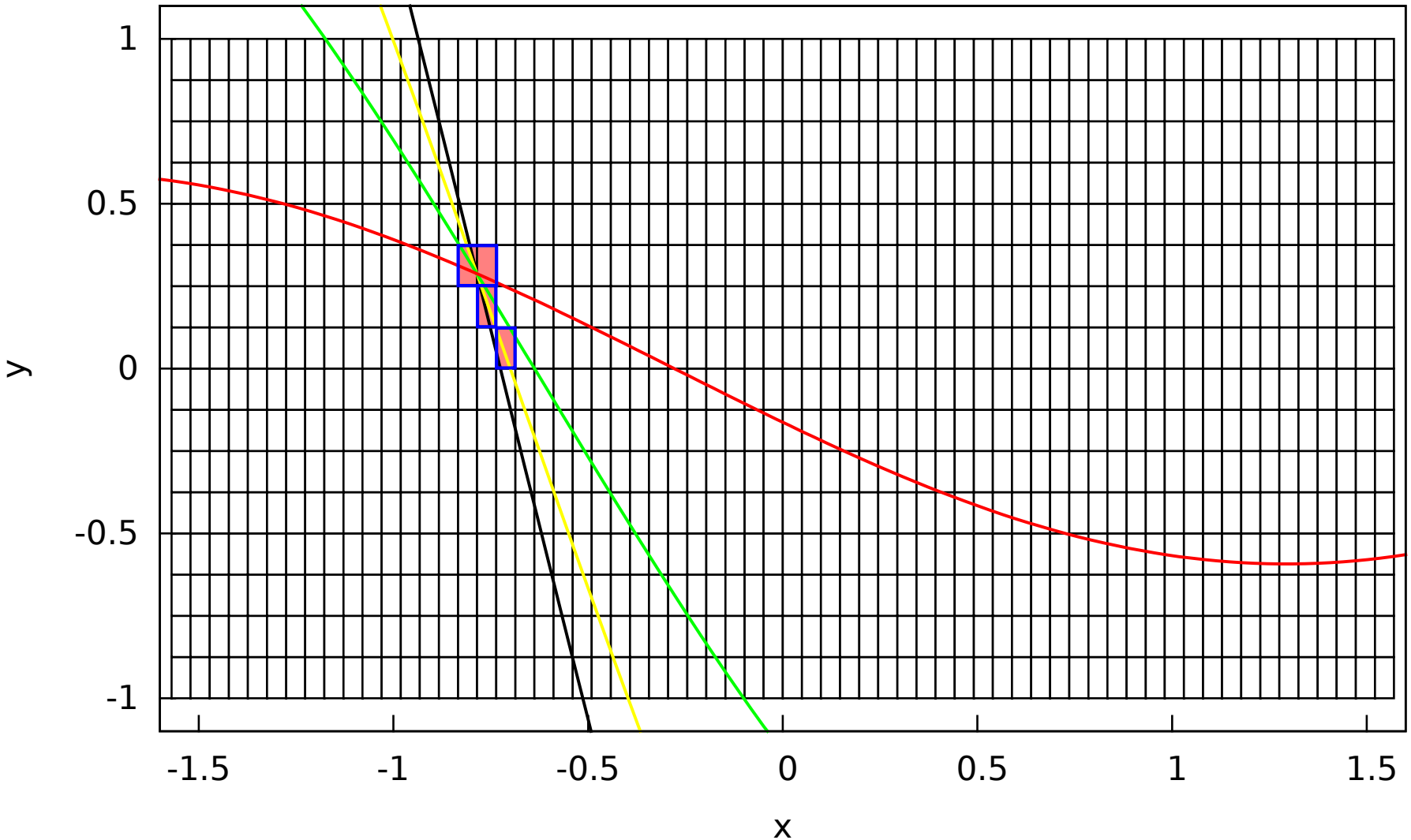

Illustration of New Implementation

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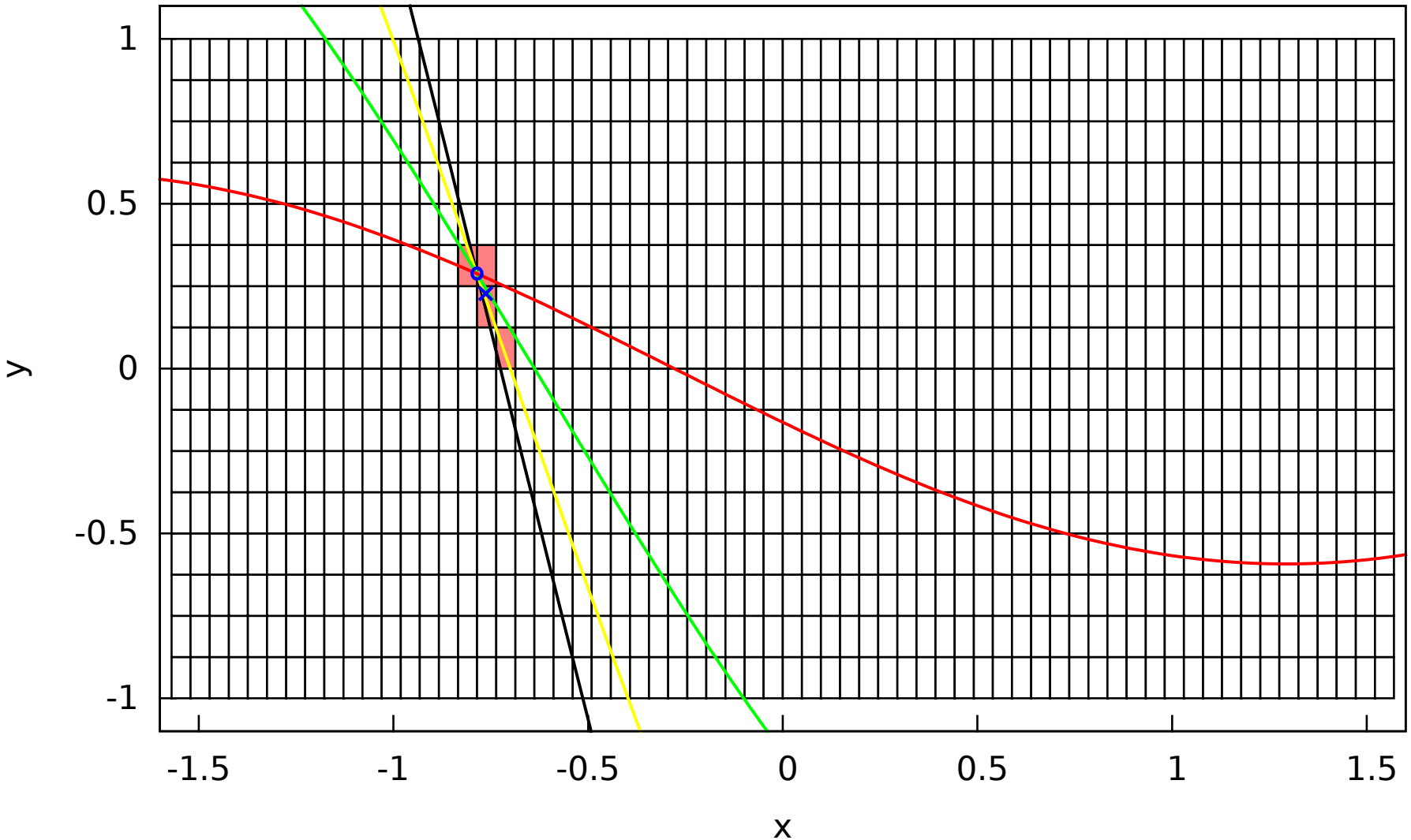
- With average and weighting calculate "center-of-gravity"



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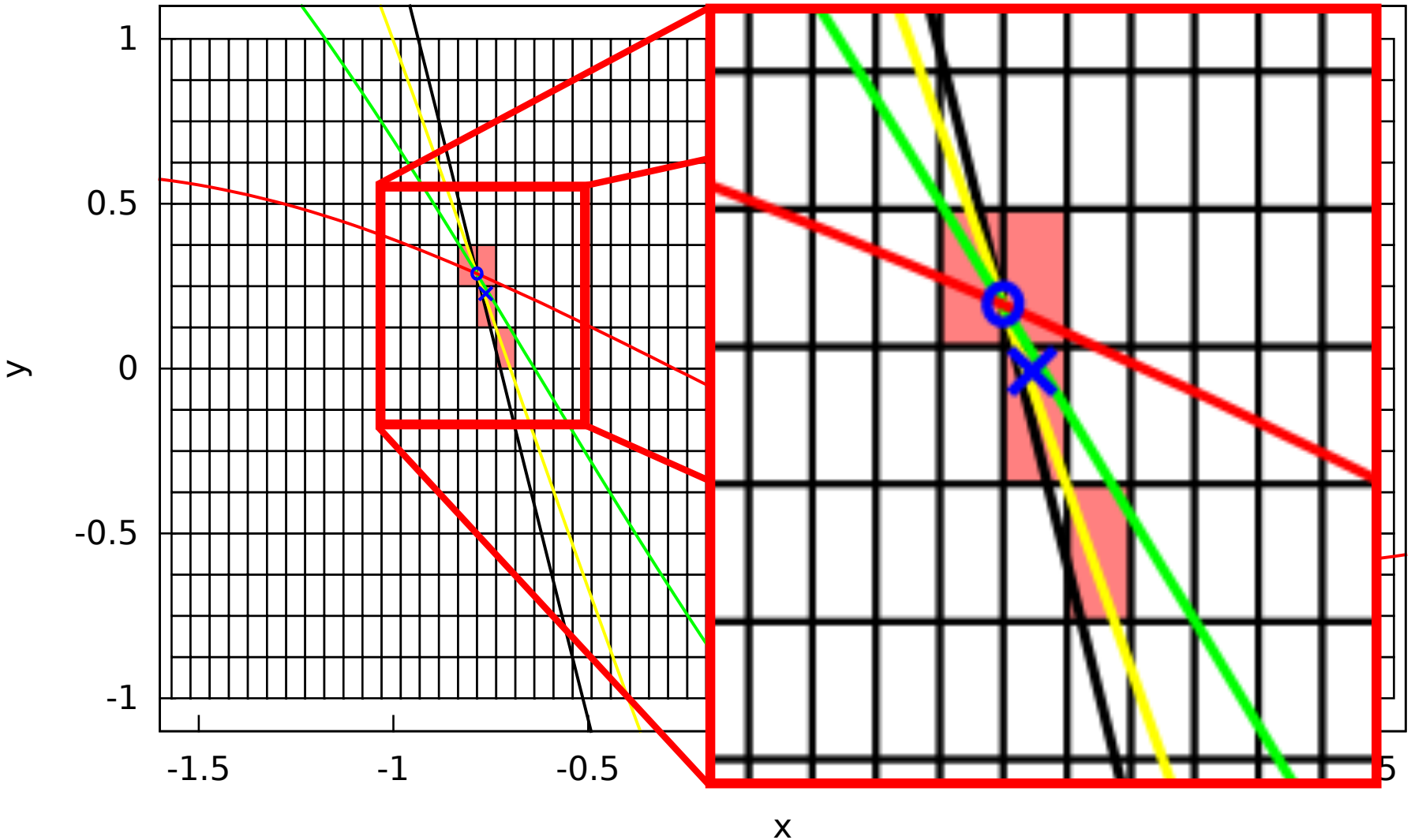

Difference in Detail

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- Old implementation uses Xilinx Ipcore Cordic implementation of trigonometric functions (high resource consumption)
- New implementation uses a pre-calculated sector table, containing only values required for calculation
- Run time: $(256 + 4 + c_n) \cdot \frac{1}{f_c}$, e.g. for 1000 coordinates $\sim 10\ \mu s$ $@f_c = 127.1\ MHz$ and $c_n = 1000$ ($\sim 100\ ms$ on PC)
- Idea/Todo: Direct implementing ROI calculation within each sector-check unit in Hough space

Summary and Conclusion

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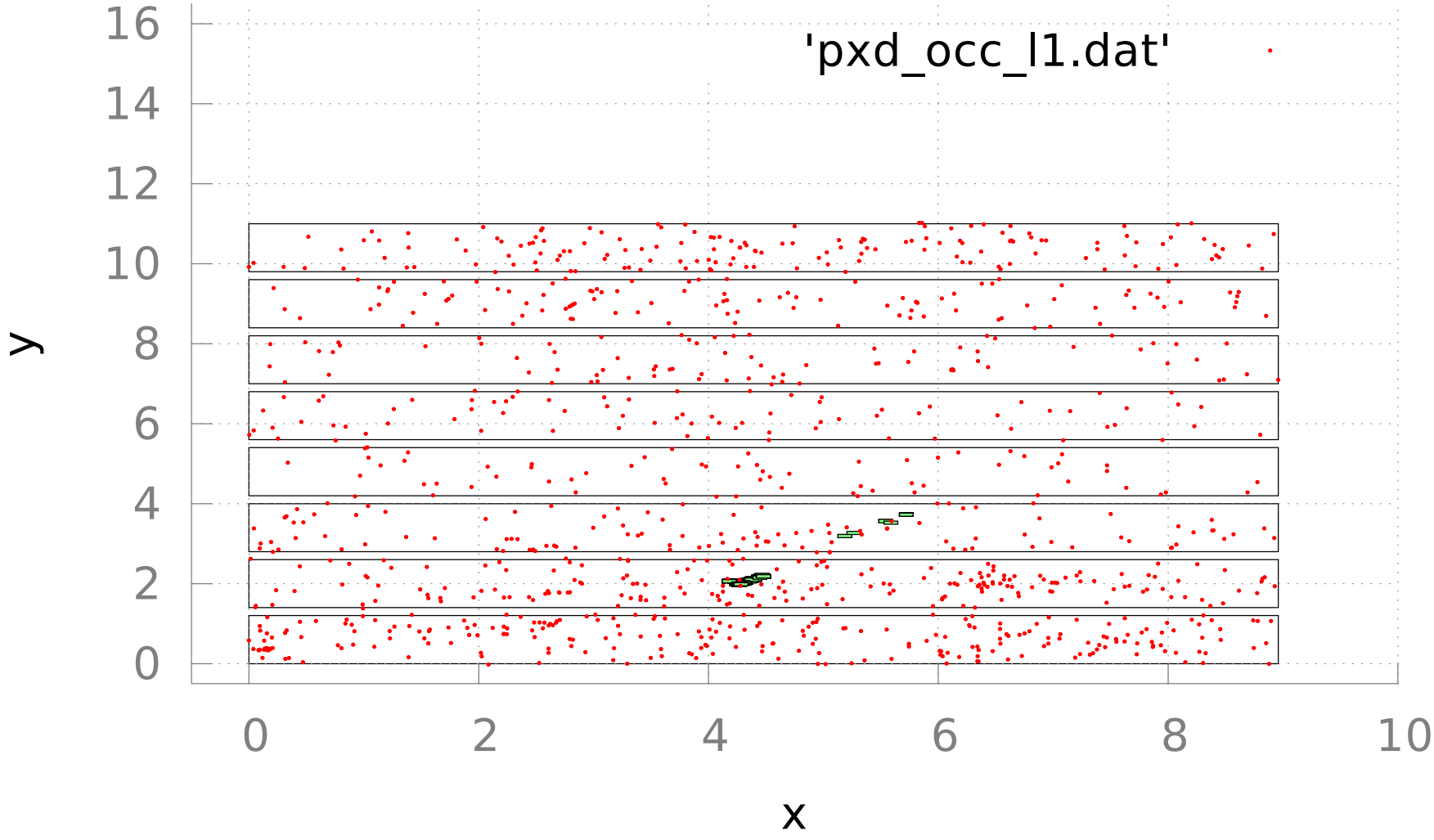
- Performance Studies of Track and ROI efficiency with new basf2 Hough tracking module
- Improvements and Optimization software prepared and tested
- New FPGA implementation of in basf2 tested Hough tracking code ongoing.
- Needs further testing, also in preparation of next testbeam
- Include Curlers extrapolation at a minimum momentum and studies of maximum interaction region we can support required
- Add doxygen documentation and example file to basf2

Thank you for your attention!

Close Tracks Events



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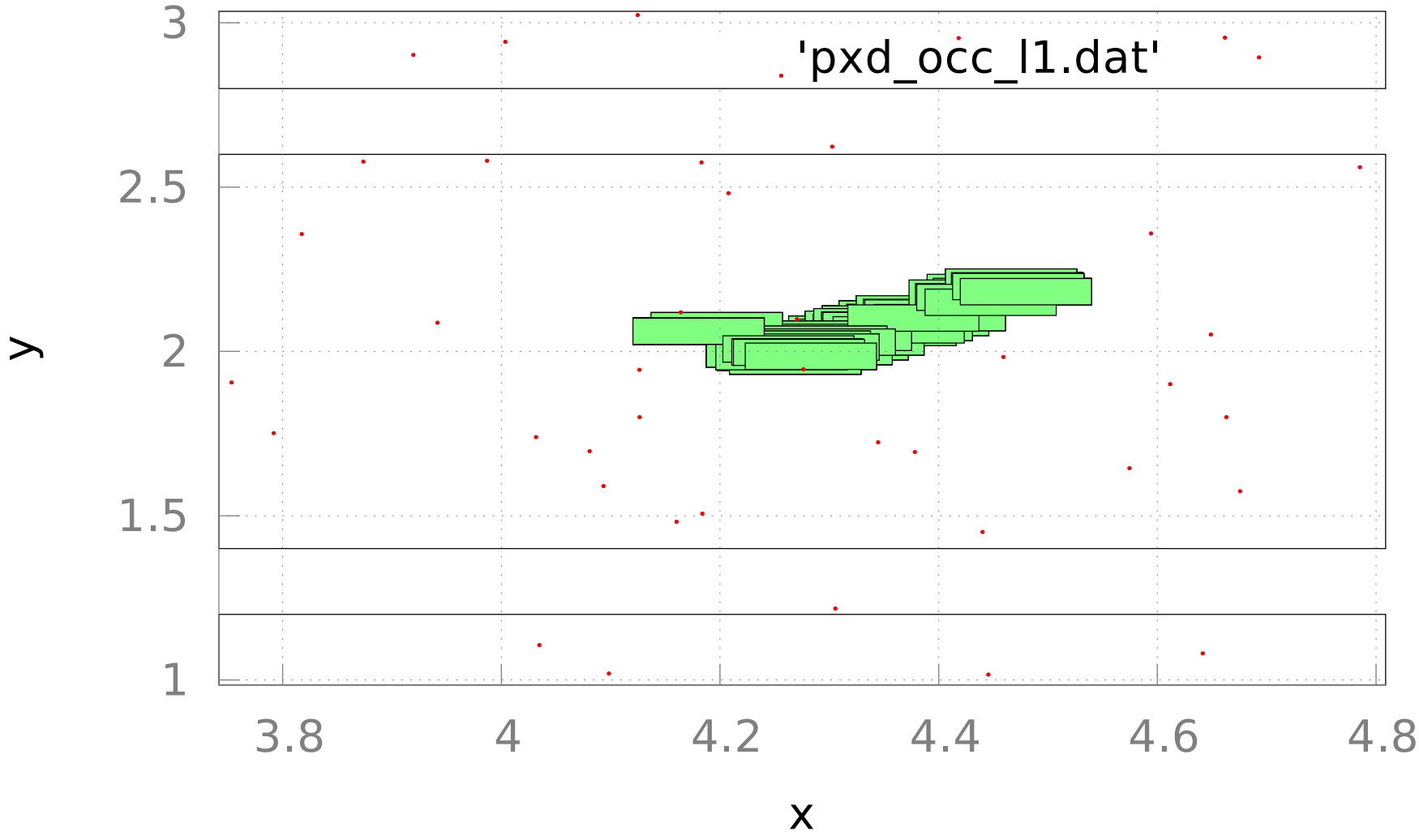
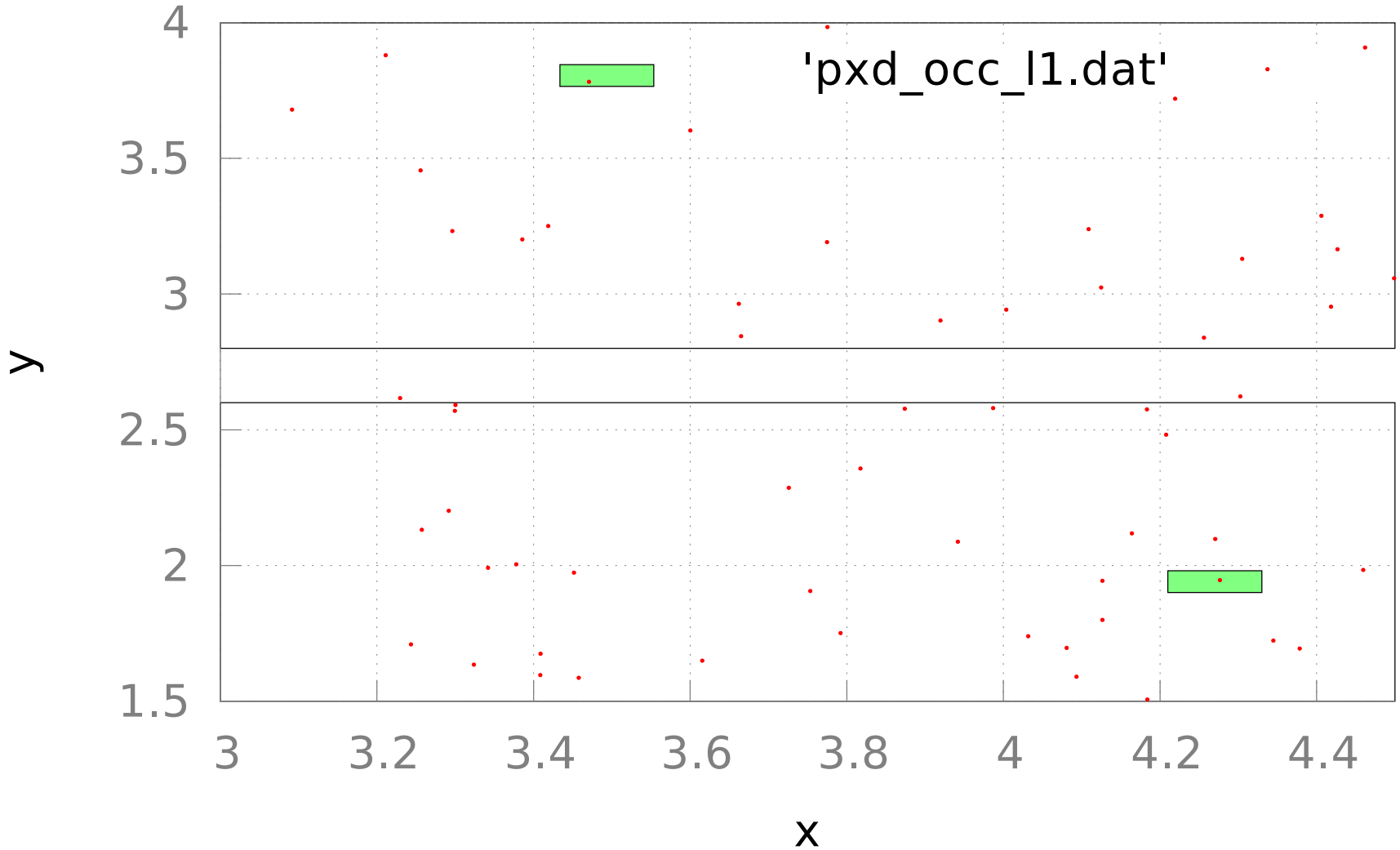


PXD ROI: 1043 Hits, 2 ROIs Reduction: 522



PXD ROI: 1066 Hits, 26 ROIs Reduction: 75