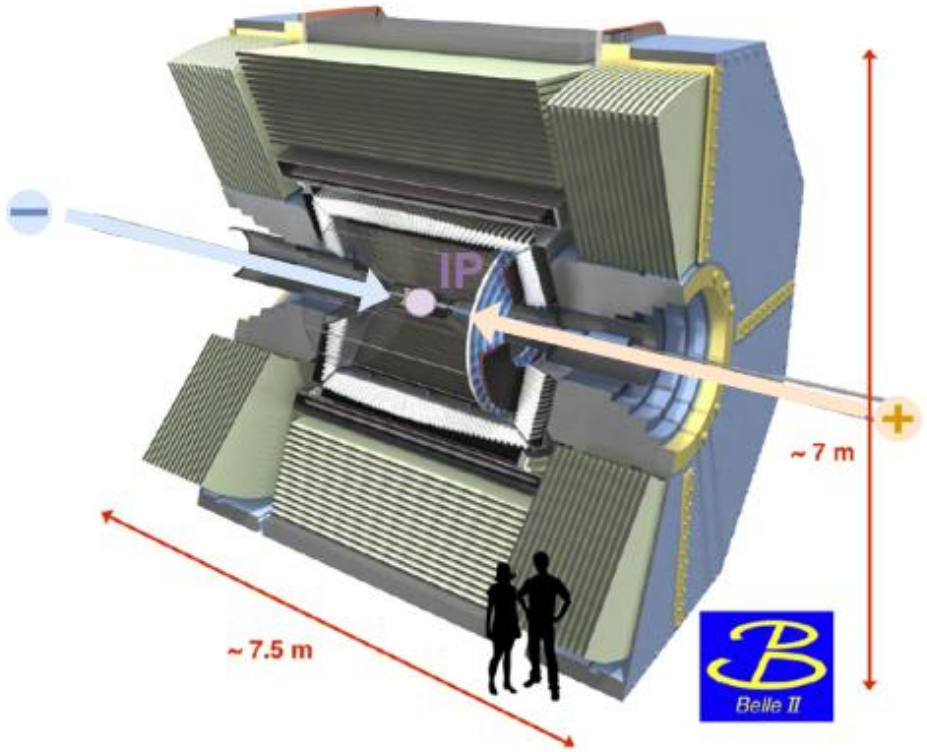
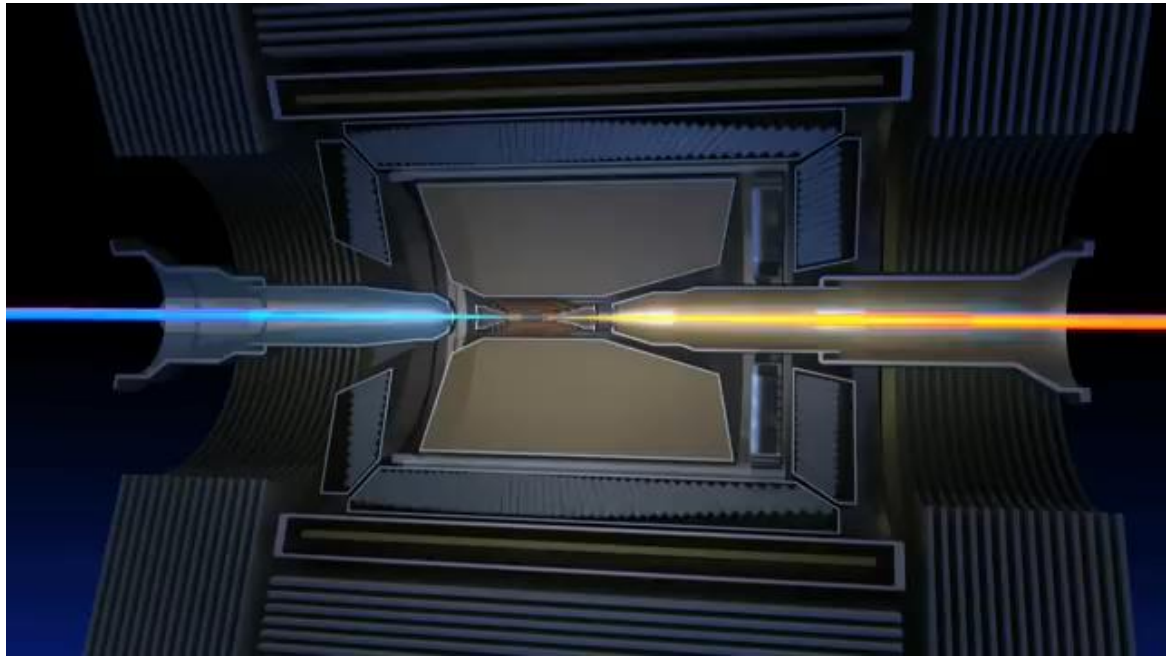
Karlsruher Institut für Technologie

Kai Unger

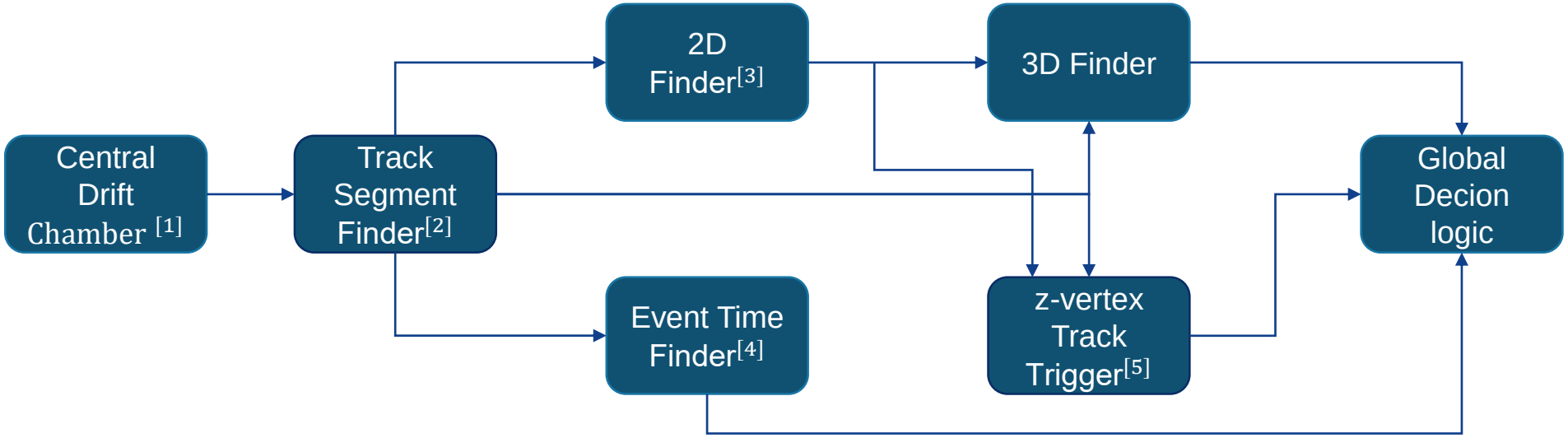
3D Hough Hardware Trigger

Belle II Central Drift Chamber



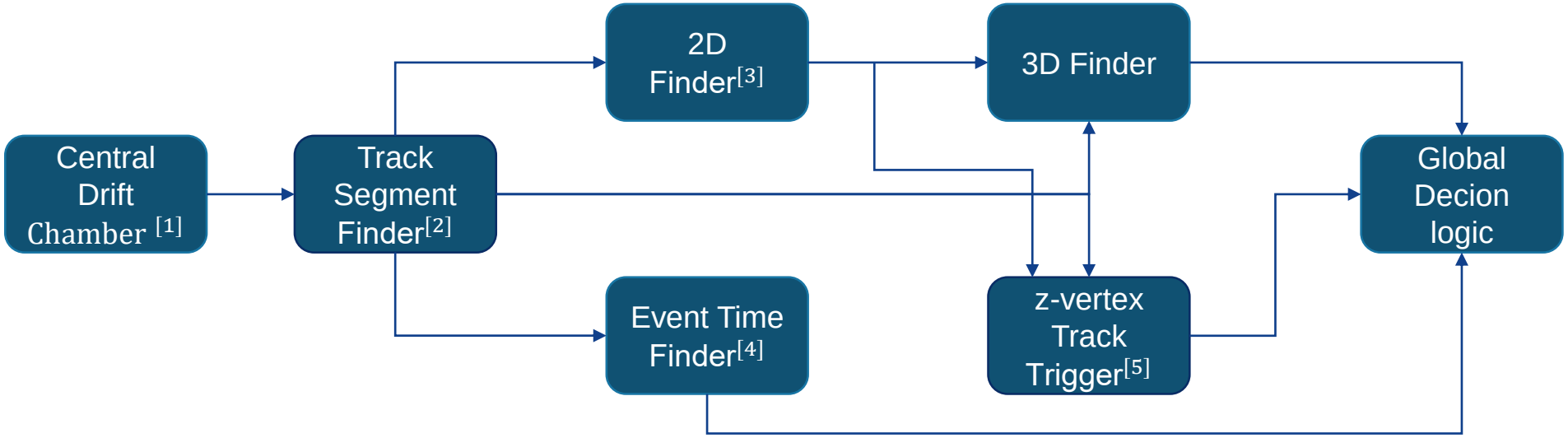


Belle II Track Trigger System



[1] Taniguchi, N. et all; „Central Drift Chamber for Belle-II“; 2017; Journal of Instrumentation
[2] Unger, K. et all; „Realization of a state machine based detection for Track Segments in the Trigger System of the Belle II Experiment”; 2019; Topical Workshop on Electronics for Particle Physics TWEPP2019
[3] Lai, Y et all; “Level-1 track trigger with Central Drift Chamber detector in Belle II experiment”; 2018; 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC)
[4] Yuki, S et all; “The Event Timing Finder for the Central Drift Chamber Level-1 Trigger at the Belle II experiment”; 2022; Journal of Physics: Conference Series
[5] Unger, K. et all; „ Operation of the Neural z-Vertex Track Trigger for Belle II in 2021-a Hardware Perspective” 2021; Journal of Physics: Conference Series

Belle II Track Trigger System



[1] Taniguchi, N. et all; „Central Drift Chamber for Belle-II“; 2017; Journal of Instrumentation
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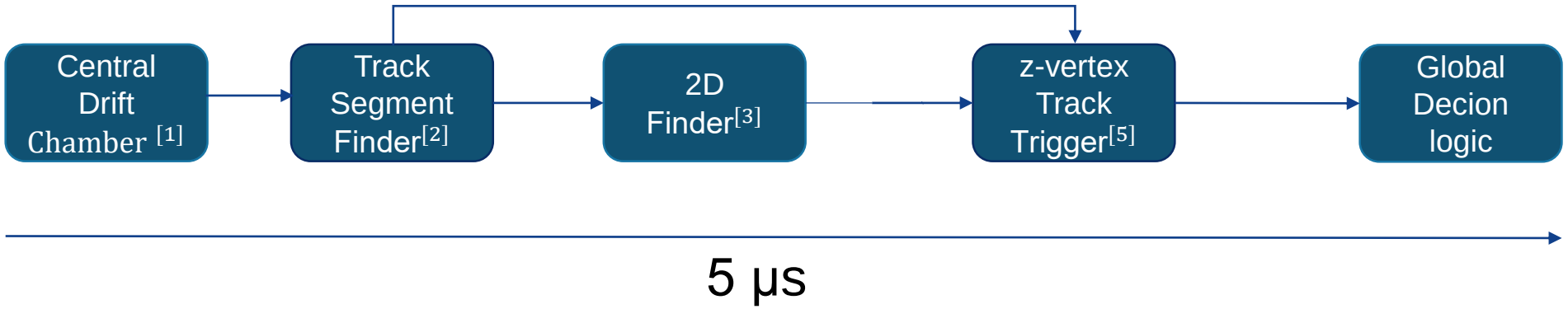
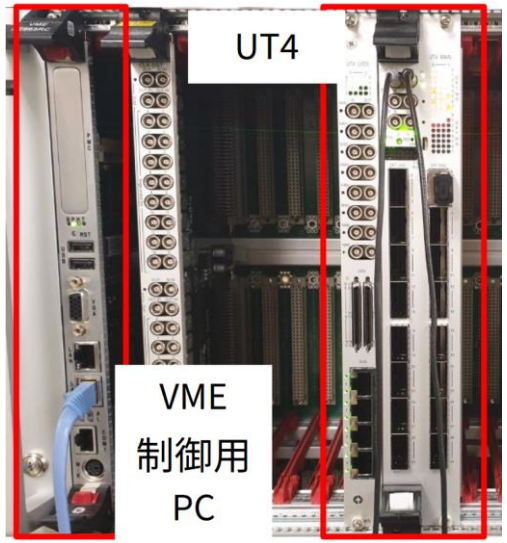
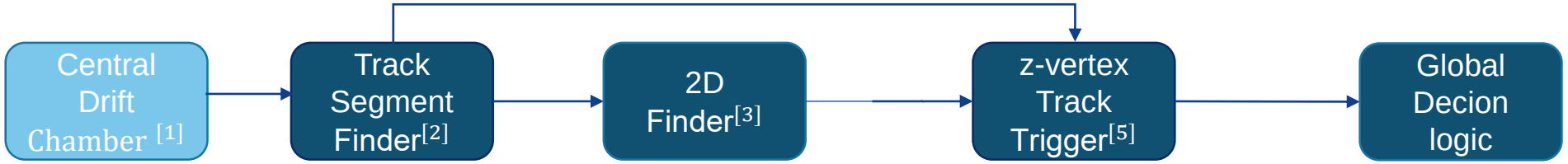
Belle II Track Trigger System



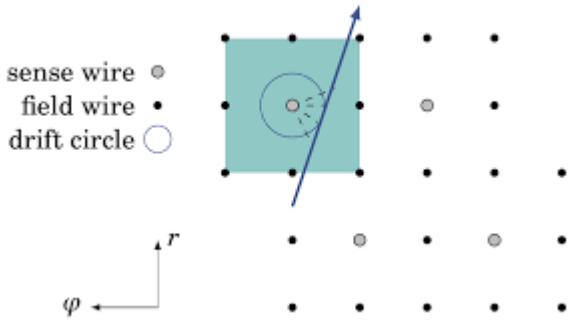
- FPGA based readout
- 5 µs for the entire trigger decision
- Universal Trigger Board 4 (UT4)
  - Virtex UltraScale

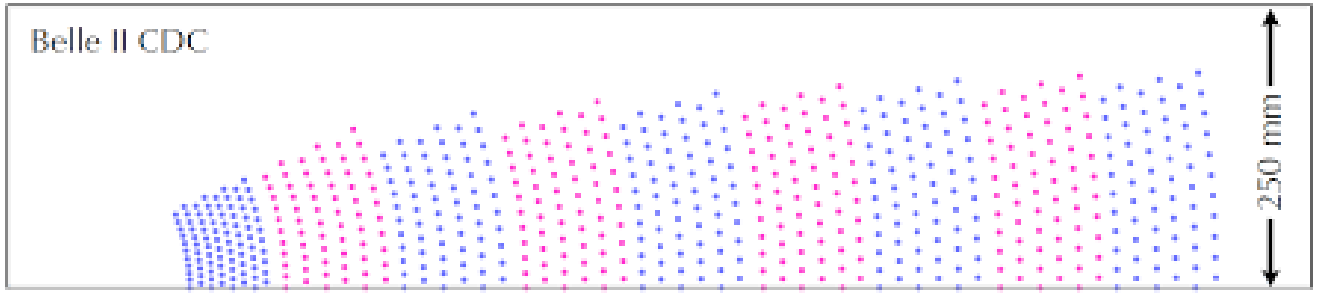


Belle II Central Drift Camber (CDC)

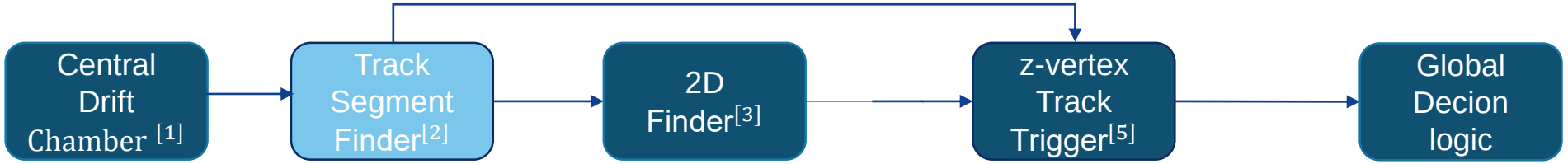


- Gas-filled track detector
- 14337 drift cells arranged in 9 super layers (SL)

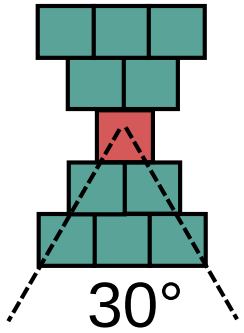




Belle II Track Segment Finder (TSF)

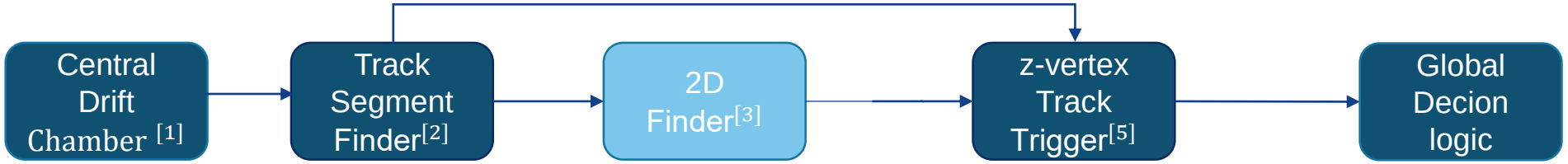


- Reduces the CDC data from to 2334 track segments
- Pattern based filter
- Filters on partial tracks 30° around the IP

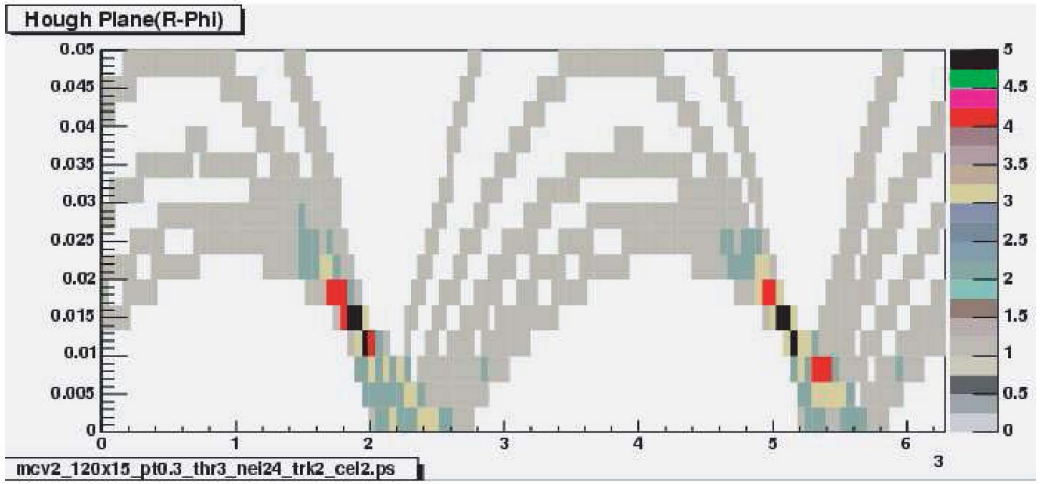


Track Segment (TS)

Belle II 2D Finder

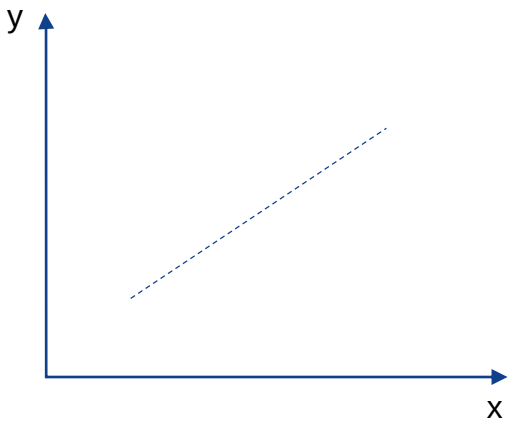


- Finds 2D tracks with Hough Transformation



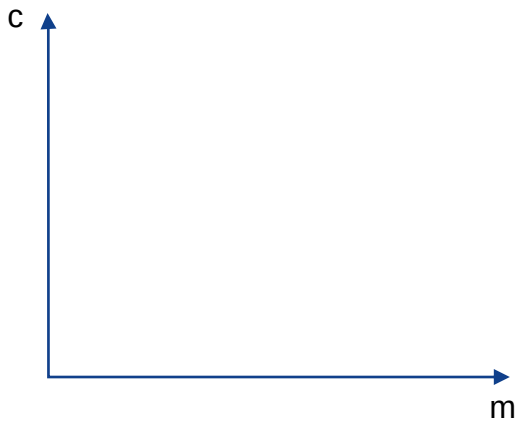
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



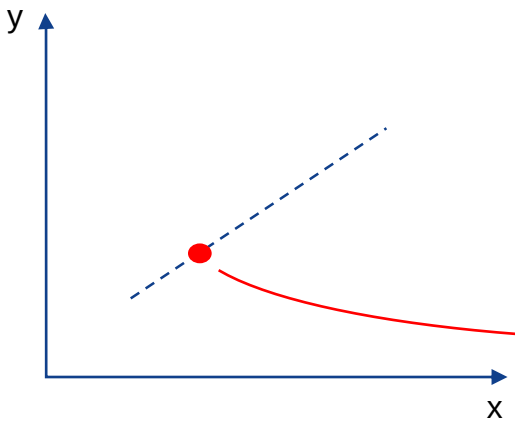
$$c = -mx_i + y_i$$

Parameter Space Hardware

0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

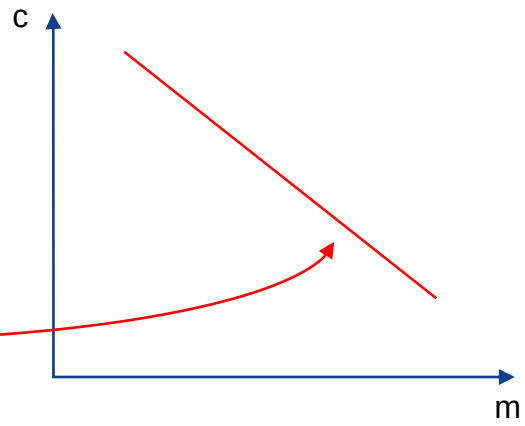
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



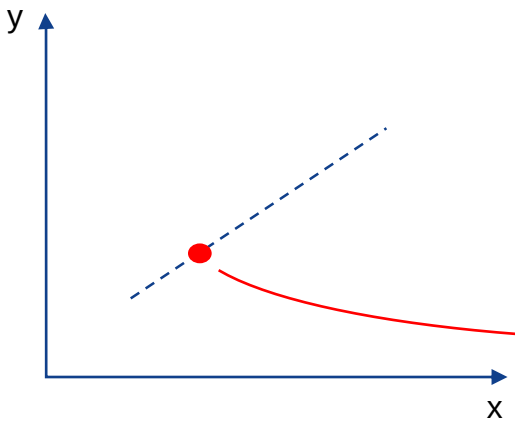
$$c = -mx_i + y_i$$

Parameter Space Hardware

0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

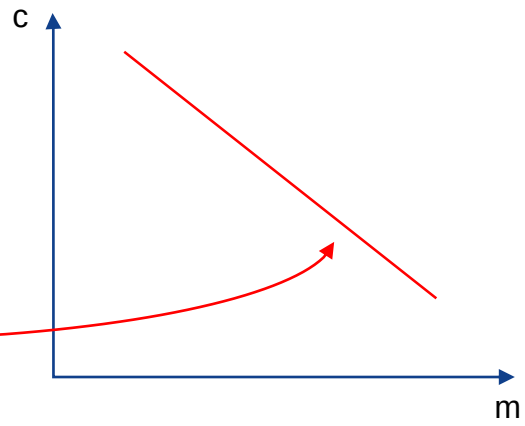
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



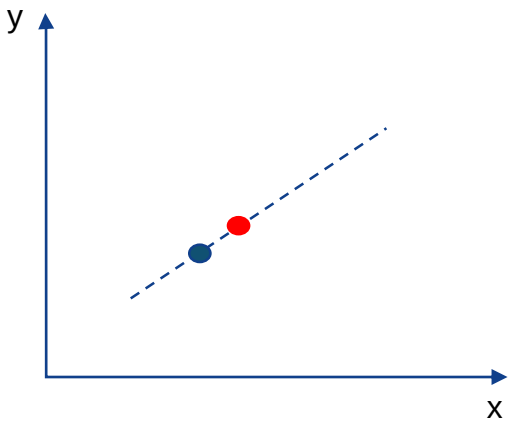
$$c = -mx_i + y_i$$

Parameter Space Hardware

1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
0	0	0	0	1

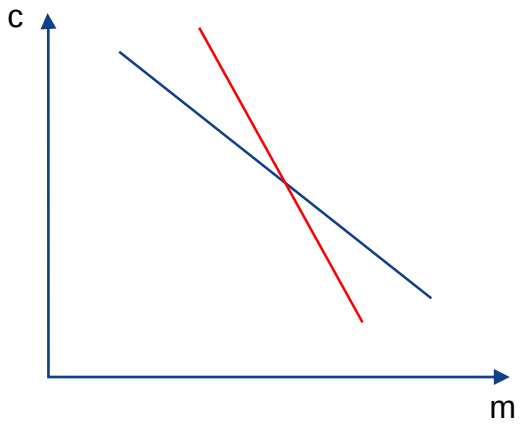
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



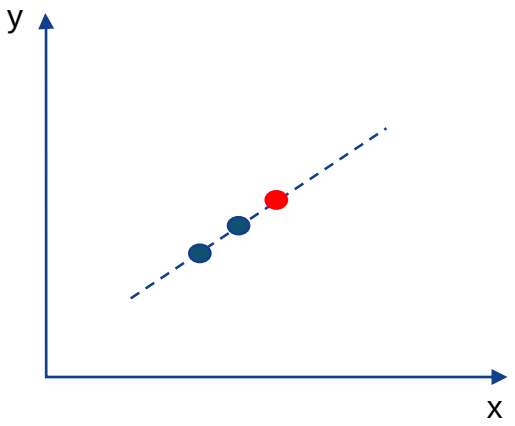
$$c = -mx_i + y_i$$

Parameter Space Hardware

1	1	0	0	0
0	2	0	0	0
0	0	2	0	0
0	0	0	2	0
0	0	0	1	1

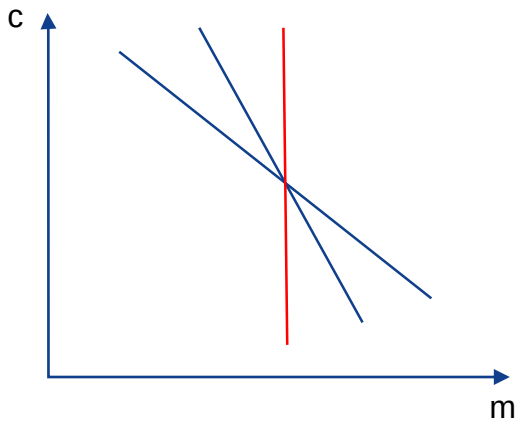
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



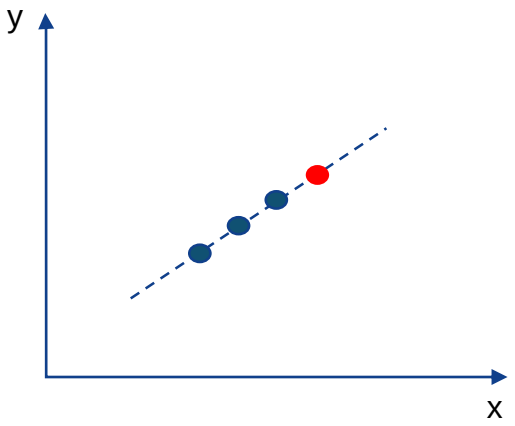
$$c = -mx_i + y_i$$

Parameter Space Hardware

1	1	1	0	0
0	2	1	0	0
0	0	3	0	0
0	0	1	2	0
0	0	1	1	1

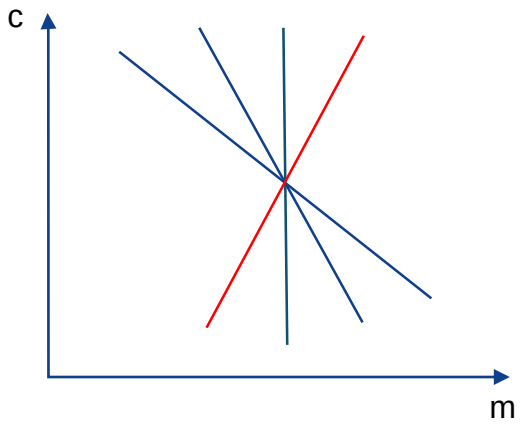
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



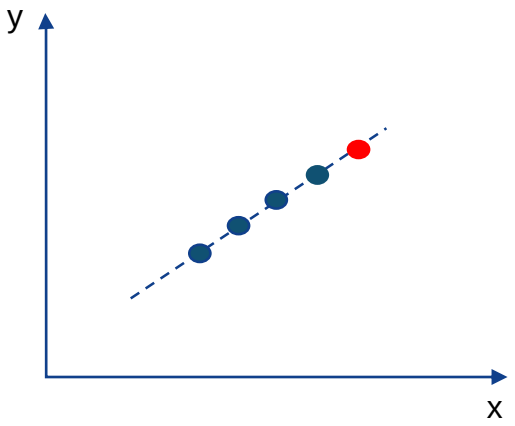
$$c = -mx_i + y_i$$

Parameter Space Hardware

1	1	1	1	0
0	2	1	1	0
0	0	4	0	0
0	1	1	2	0
0	1	1	1	1

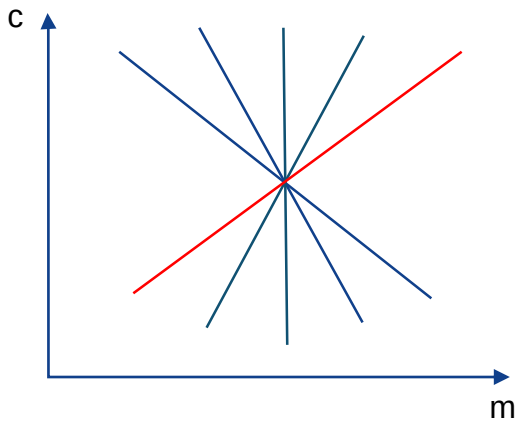
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space



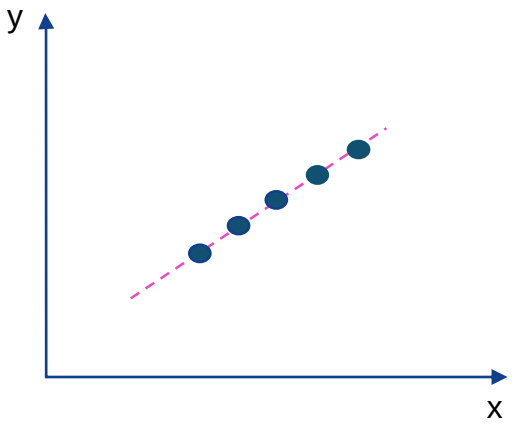
$$c = -mx_i + y_i$$

Parameter Space Hardware

1	1	1	1	1
0	2	1	2	0
0	0	5	0	0
0	2	1	2	0
1	1	1	1	1

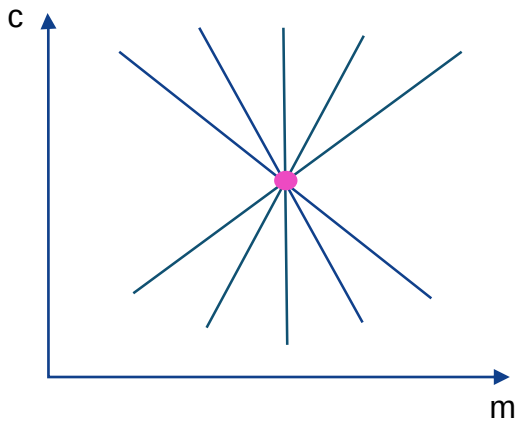
Excursion: Hough transformation

Image Space



$$y_i = mx_i + c$$

Parameter Space

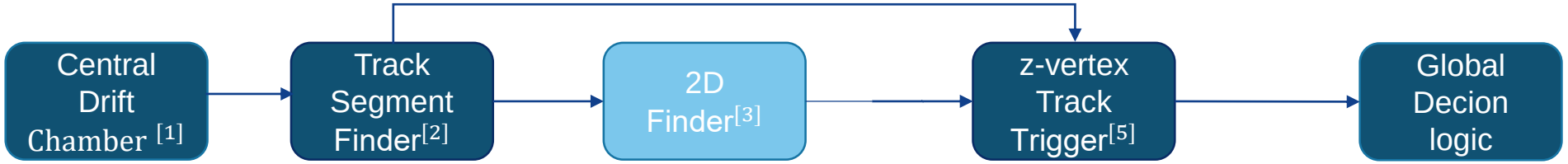


$$c = -mx_i + y_i$$

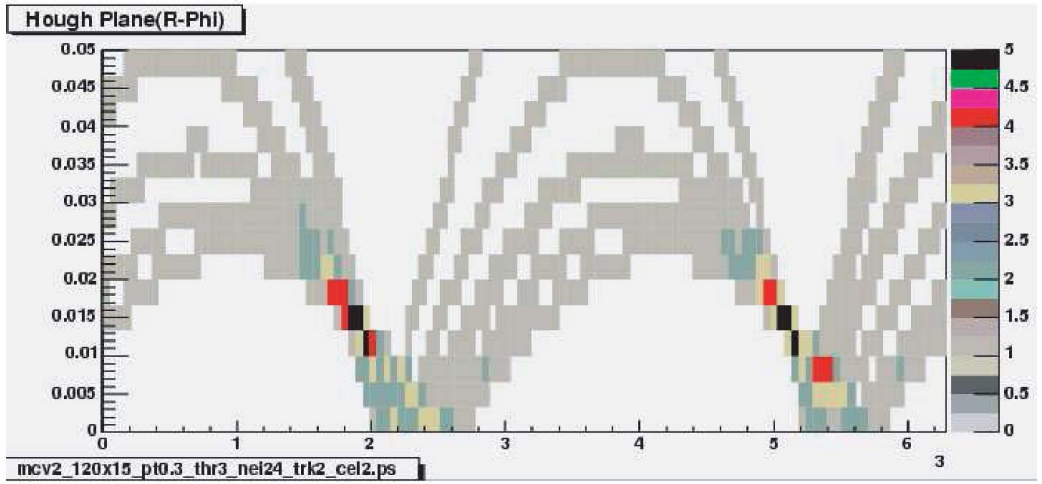
Parameter Space Hardware

1	1	1	1	1
0	2	1	2	0
0	0	5	0	0
0	2	1	2	0
1	1	1	1	1

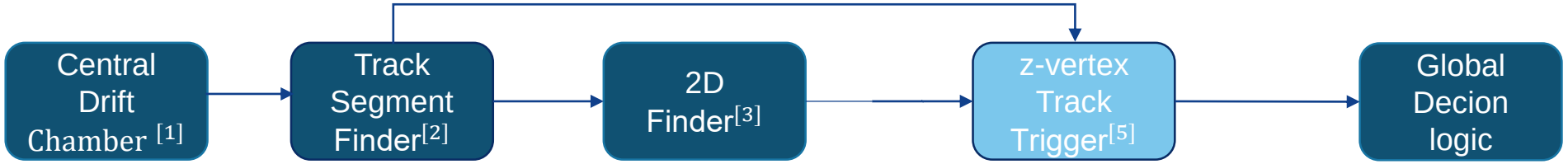
Belle II 2D Finder

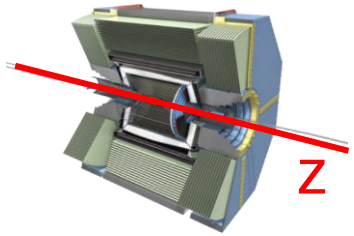


- Finds 2D tracks with Hough Transformation
- Calculates 2D track and curve information

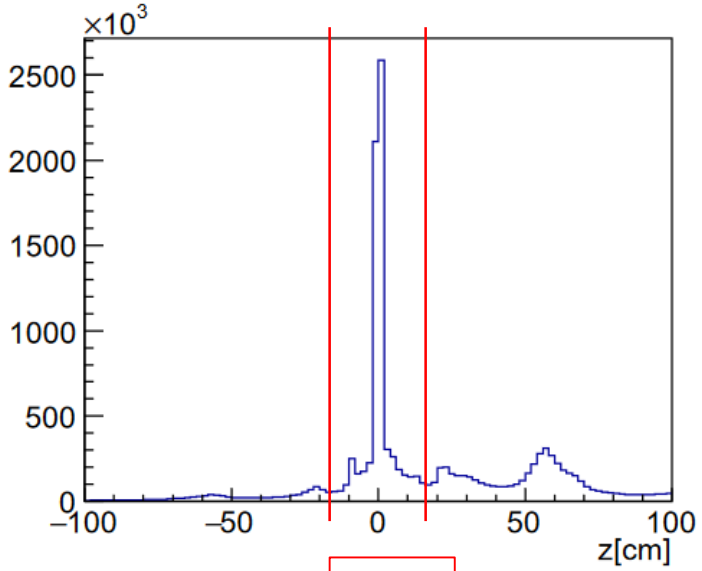


Belle II z-Vertex-Track Trigger (NNT)

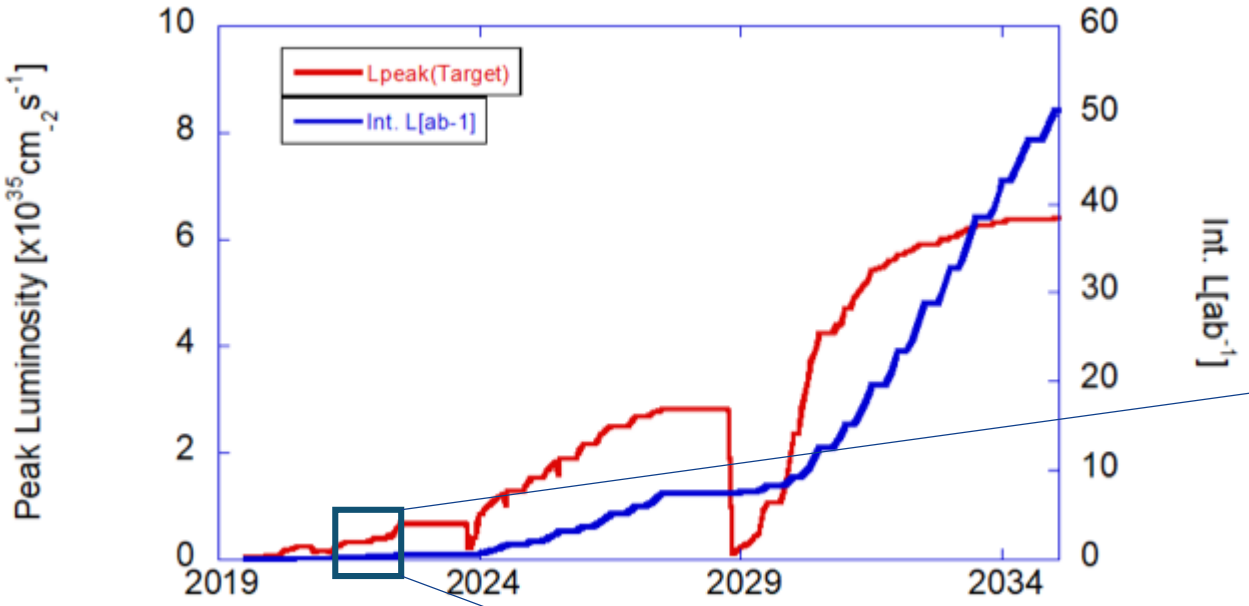


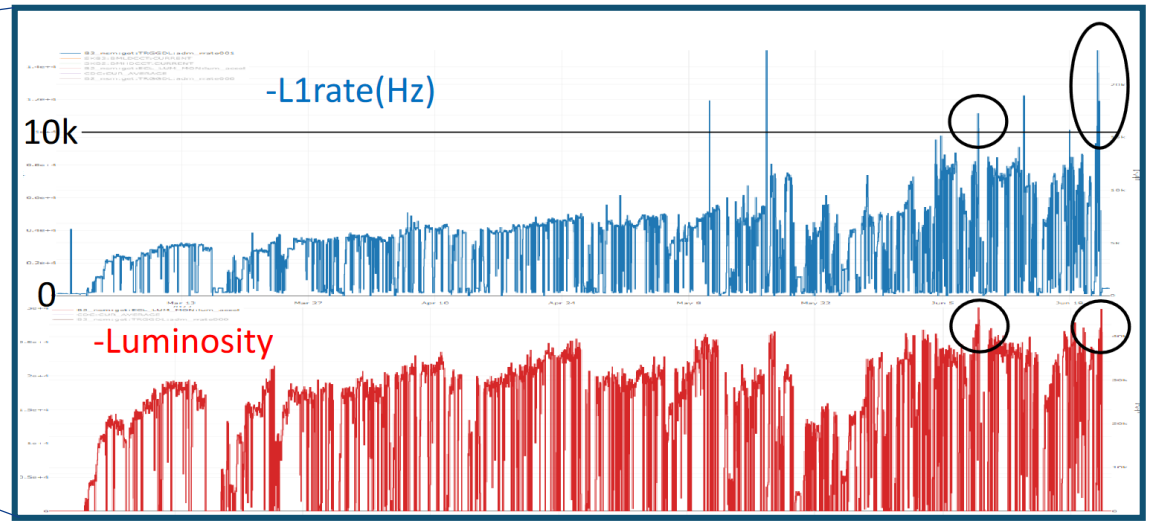


- MLP (27/81/2) estimates the origin of the track on the Z axis and the polar scattering angle Θ
- Anything outside of +15/-15 cm is classified as fake track
- First neural net trigger in a level 1 trigger



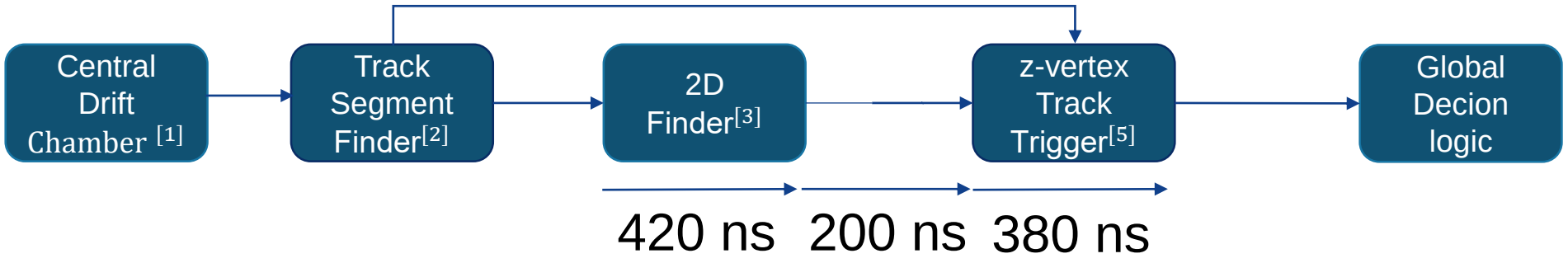
Fake tracks





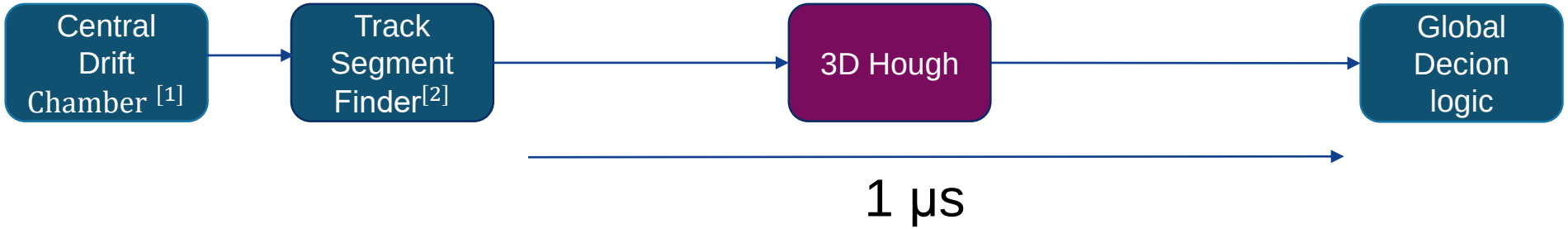
2022ab

Belle II 3D Hough Trigger



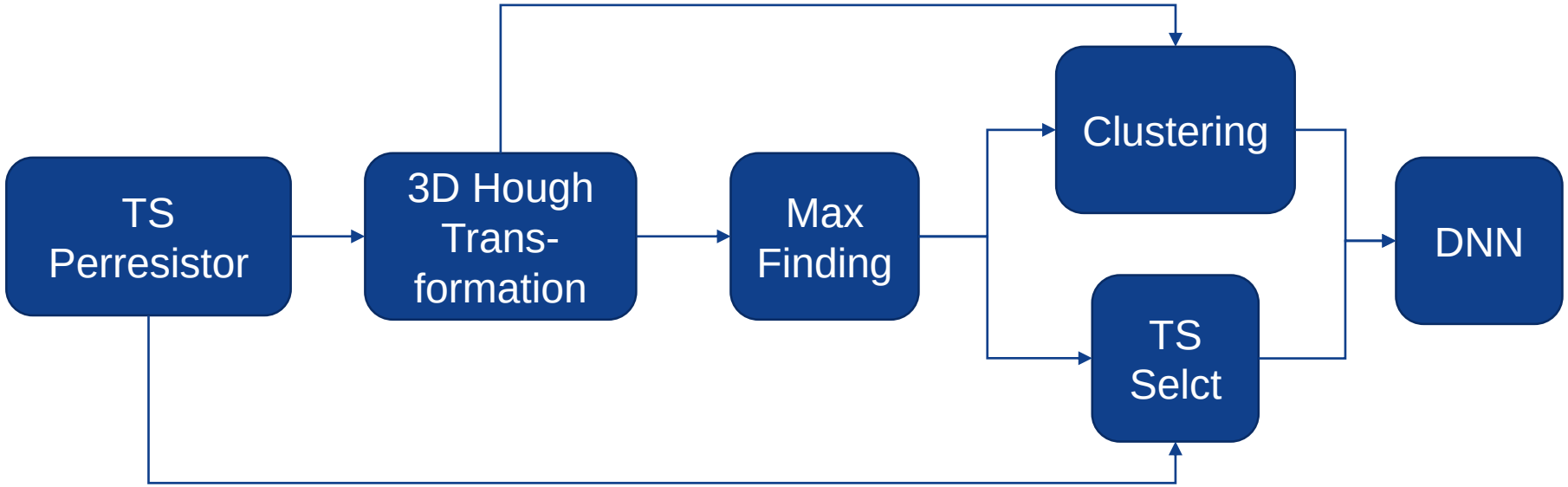
- 3D Hough Trigger
  - More time for data processing
    - More latency for deep neural network (DNN)
  - More accurate resolution through 3D processing
    - Better resolution on the z-axis and the polar scattering angle Θ

Belle II 3D Hough Trigger

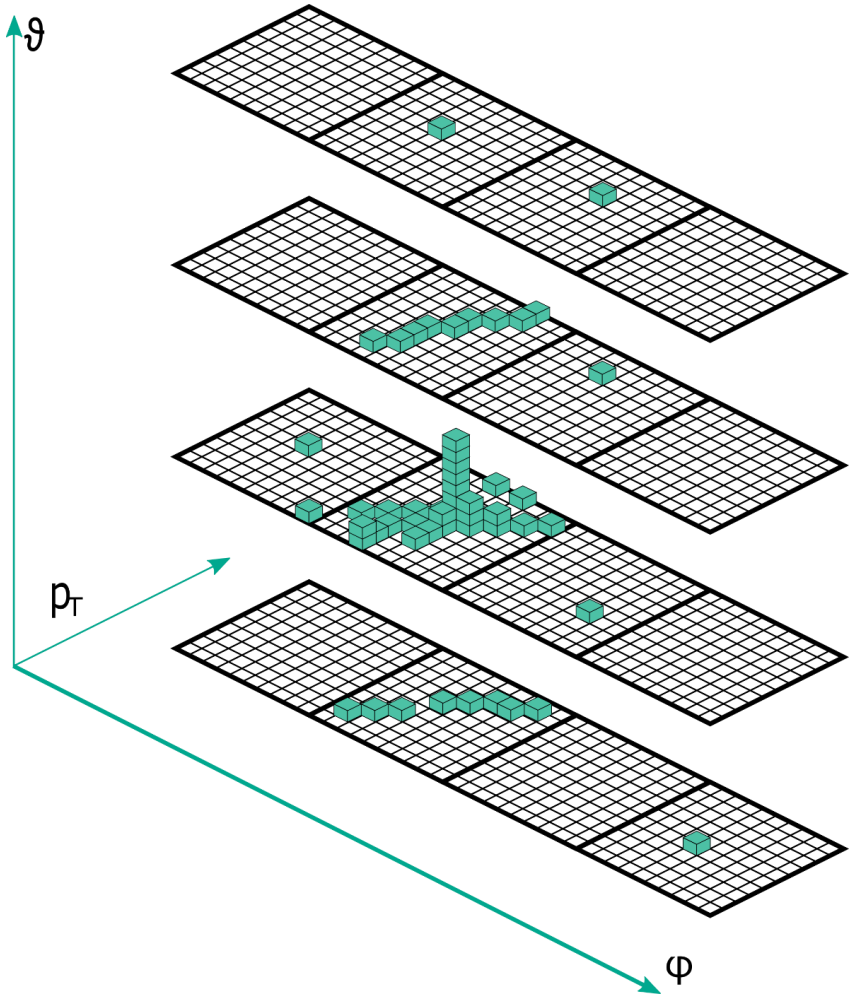


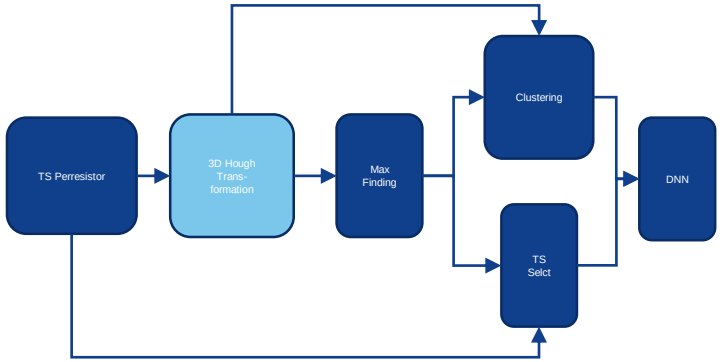
- 3D Hough Trigger
  - More time for data processing
    - More latency for deep neural network (DNN)
  - More accurate resolution through 3D processing
    - Better resolution on the z-axis and the polar scattering angle Θ

3D Hough Architektur



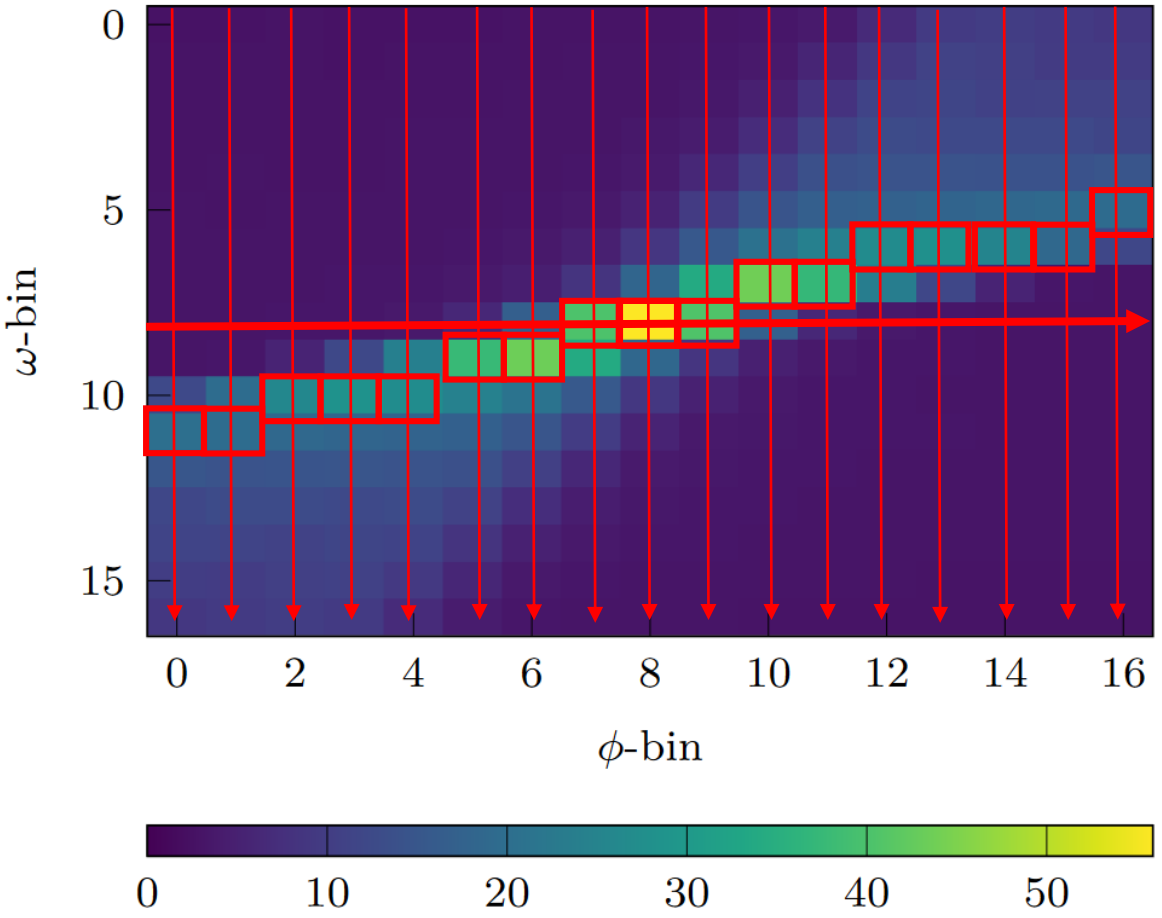
3D Hough Transformation

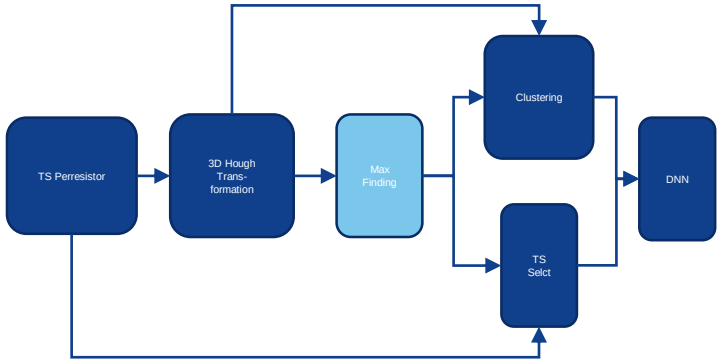




- 3 dimensional Hough plane
- Curves are created with the help of pre-calculated look-up tables 90 of 2334 possible track segments (TS)

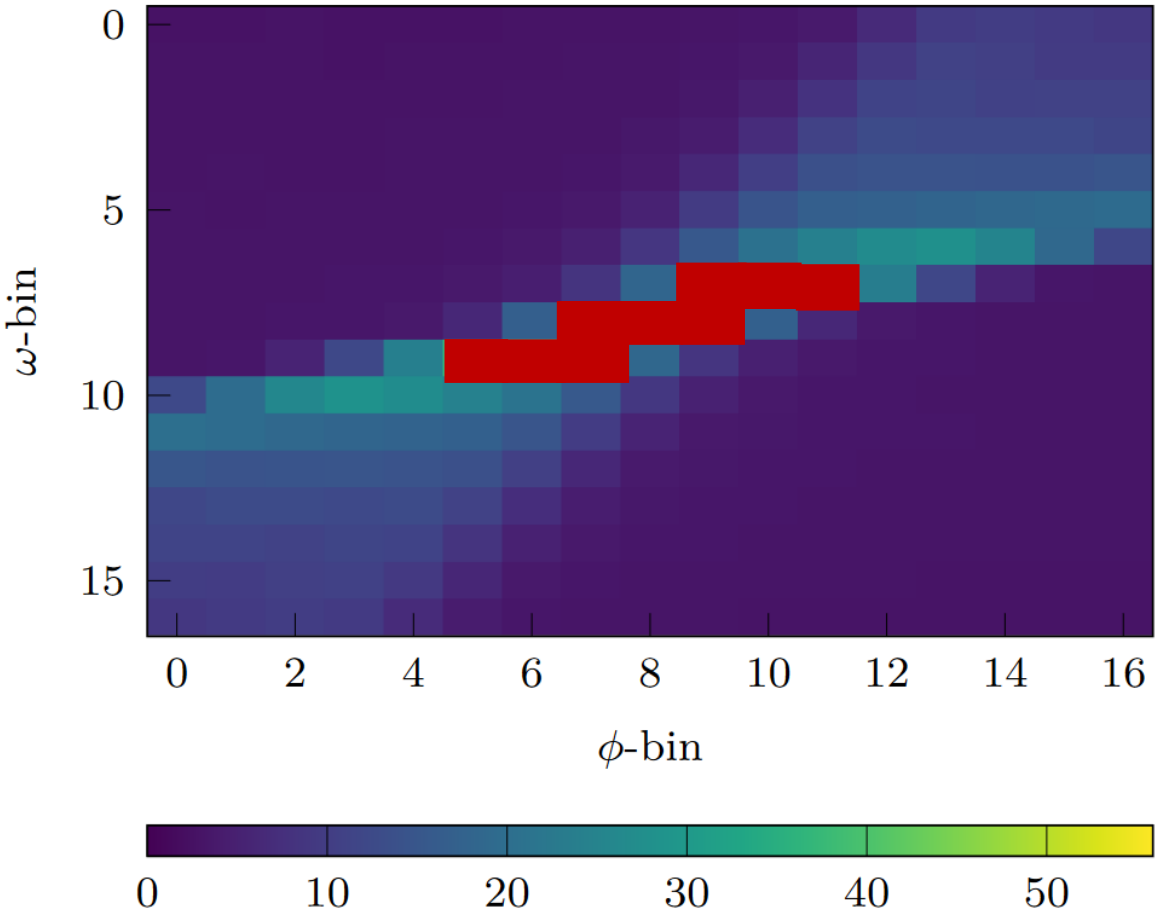
Max Finding

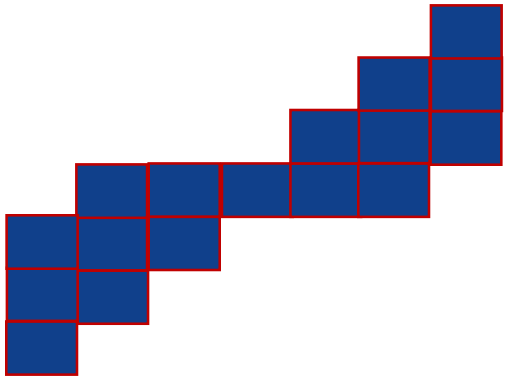


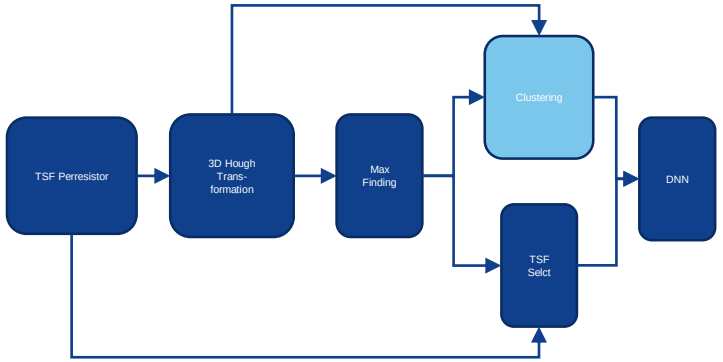


- Maximum finding with position
- Resource-saving FPGA implementation

Fix point Clustering

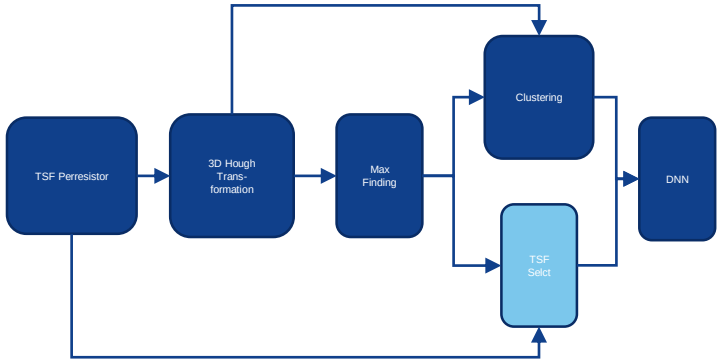






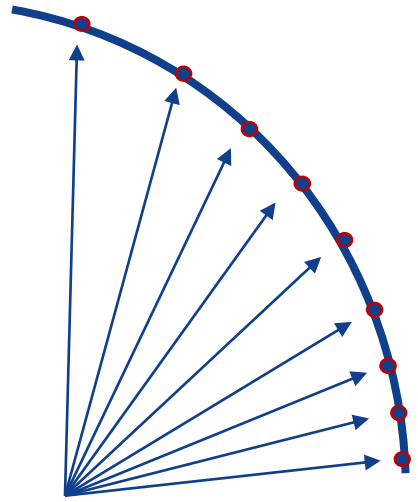
- Fixed cluster for fixed runtime
- Cluster parameters as additional input for the neural network

Track Segment selection



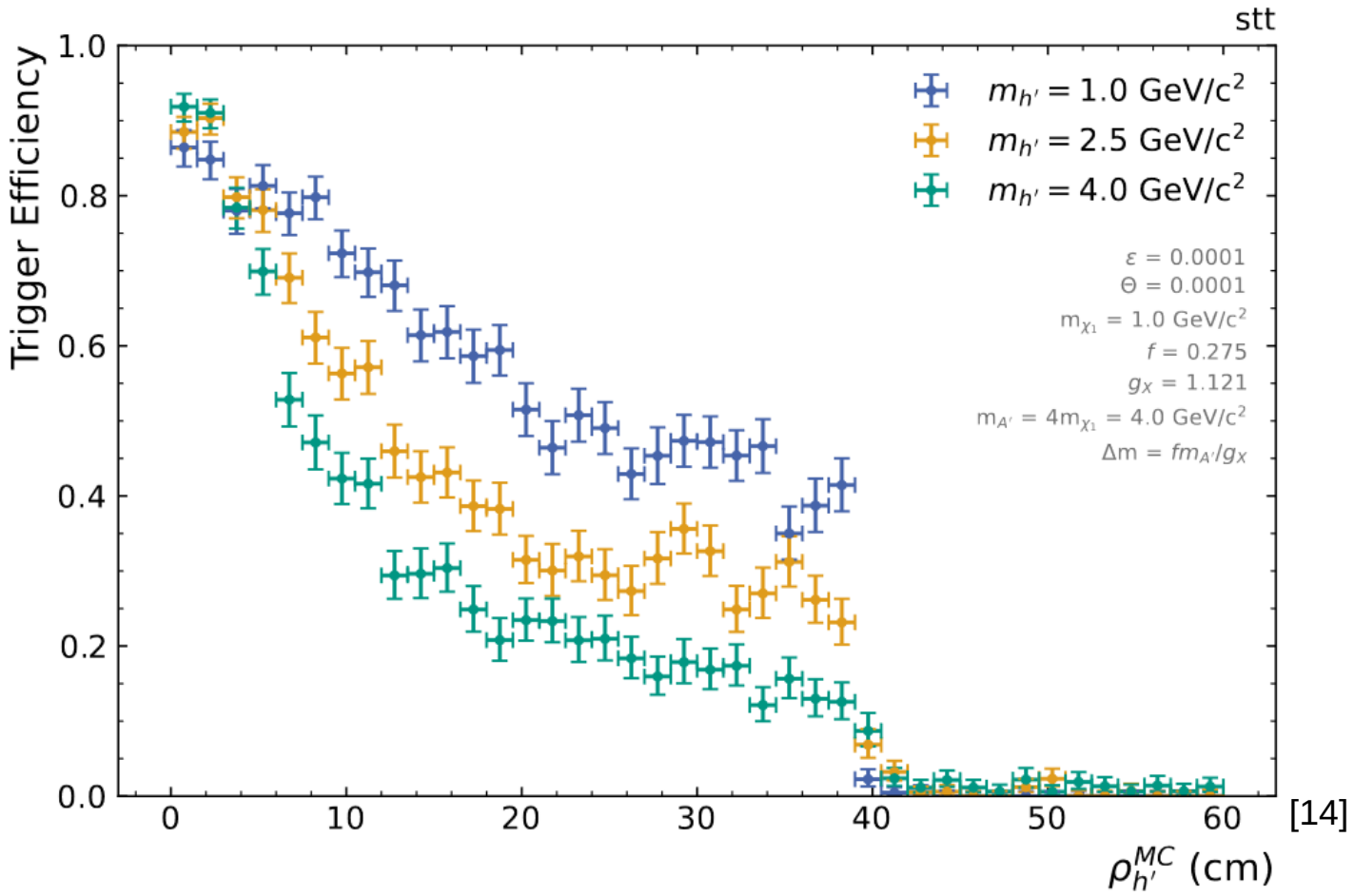
- Input for the neural network are track segments (TS)
- Those that contribute the most to the maximum are selected
- The Hough transformation is performed again only for the maximum
  - No need to save the entire Hough matrix

Partikel Track

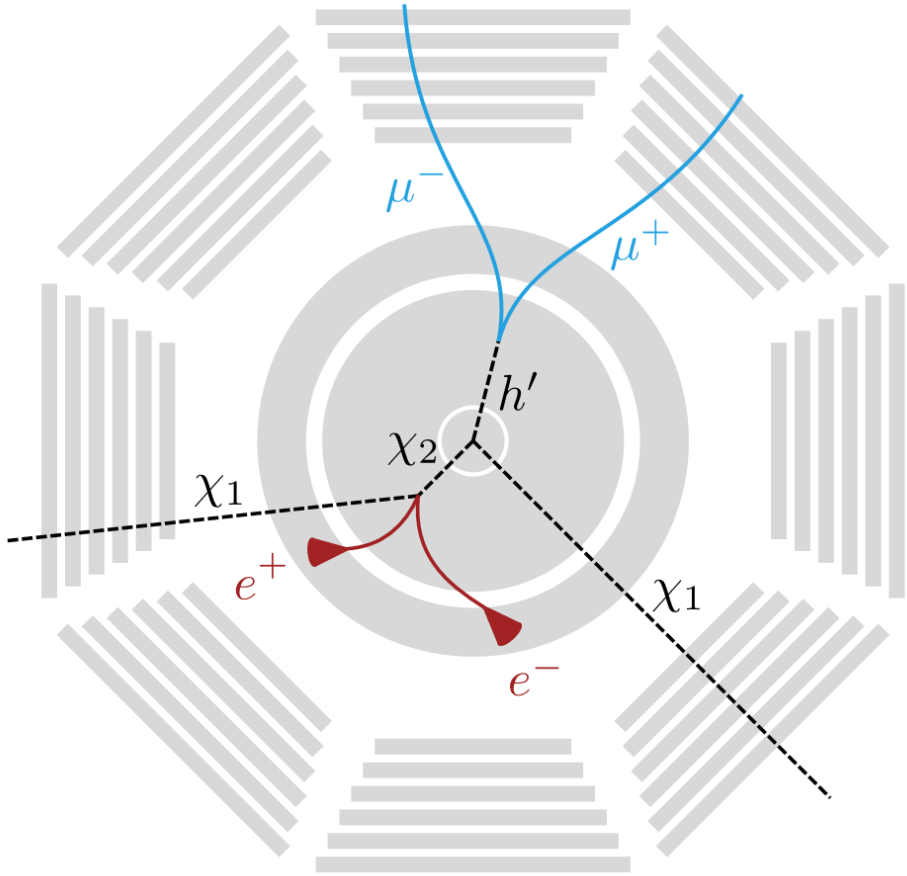


Track Segment

Displaced Vertex



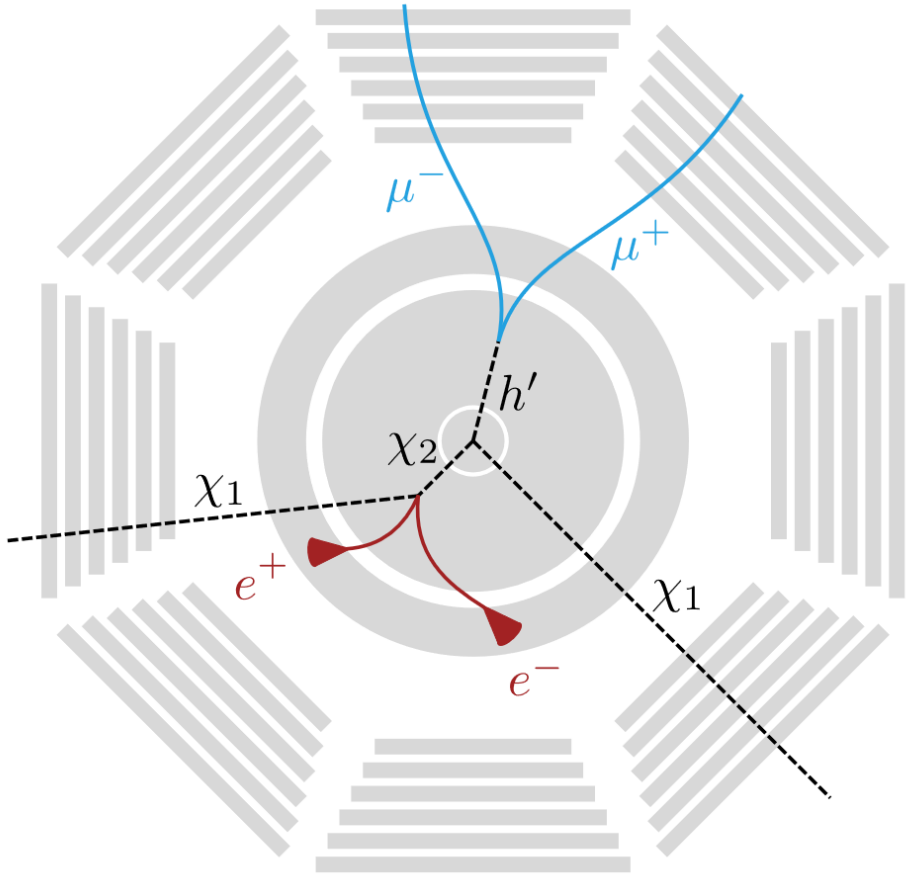
[14]

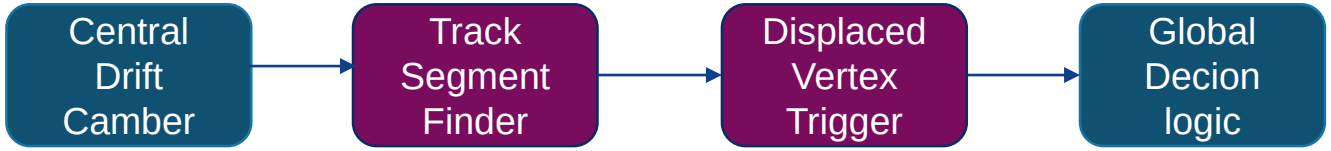


[14Patrick Eckler; 2023 Belle II German Meeting

Displaced Vertex

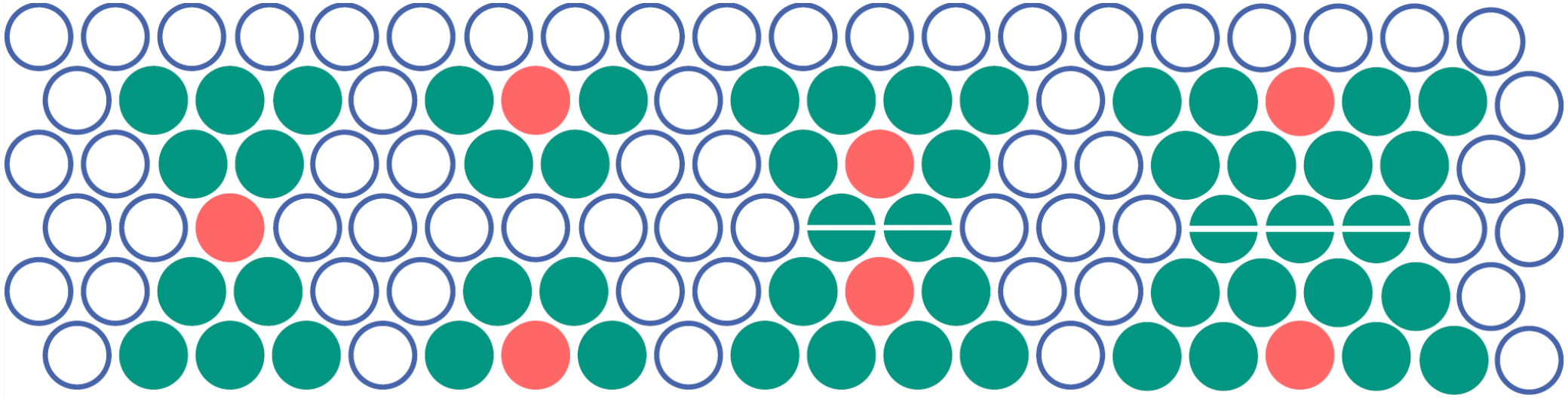
- **Two tracks** from **one point** displaced to the interaction point Vertex
- Changes to Track Segment Finder required
- New Displaced Vertex Trigger required





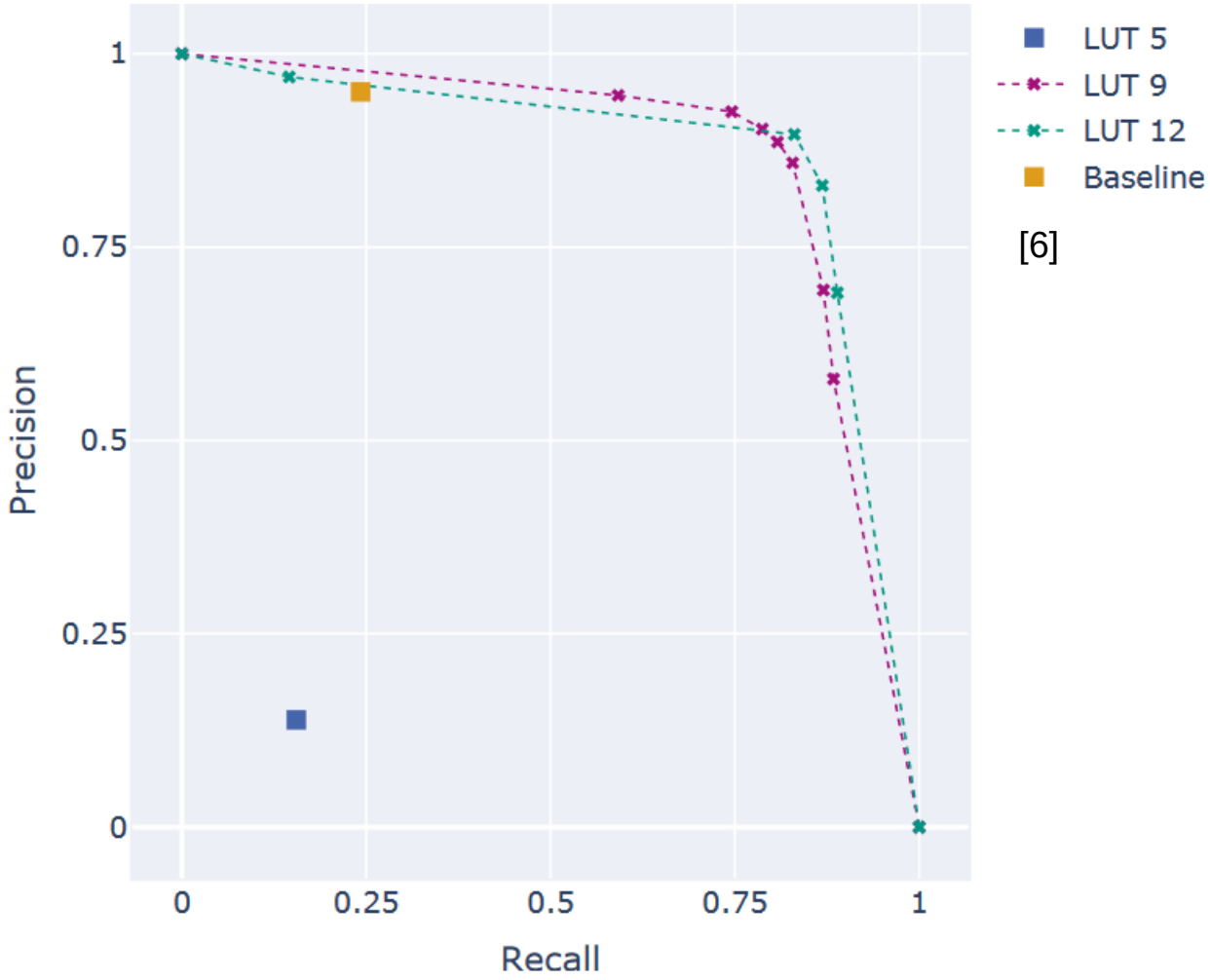
Track Segment Finder

- The Track Segment Finder must become sensitive to flat tracks
- New Track Segment Pattern



Track Segment Finder

- Patterns are trained and saved in the look-up table
- Patterns can be trained for different noise levels.
- LUT-9 and LUT-12 show the best results



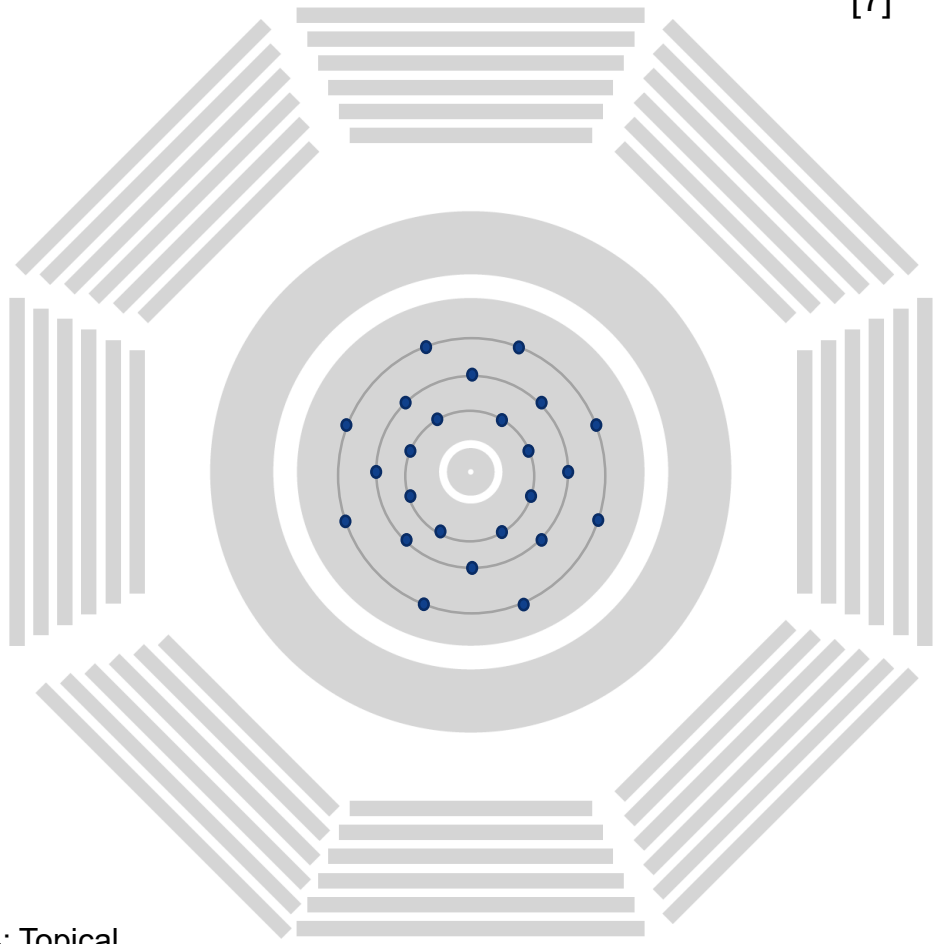
[6]

[6] **Kai Unger** et all; „Data-Driven Design of the Belle II Track Segment Finder“ 2023; Journal of Instrumentation,

Multi Hough Displaced Vertex Trigger

[7]

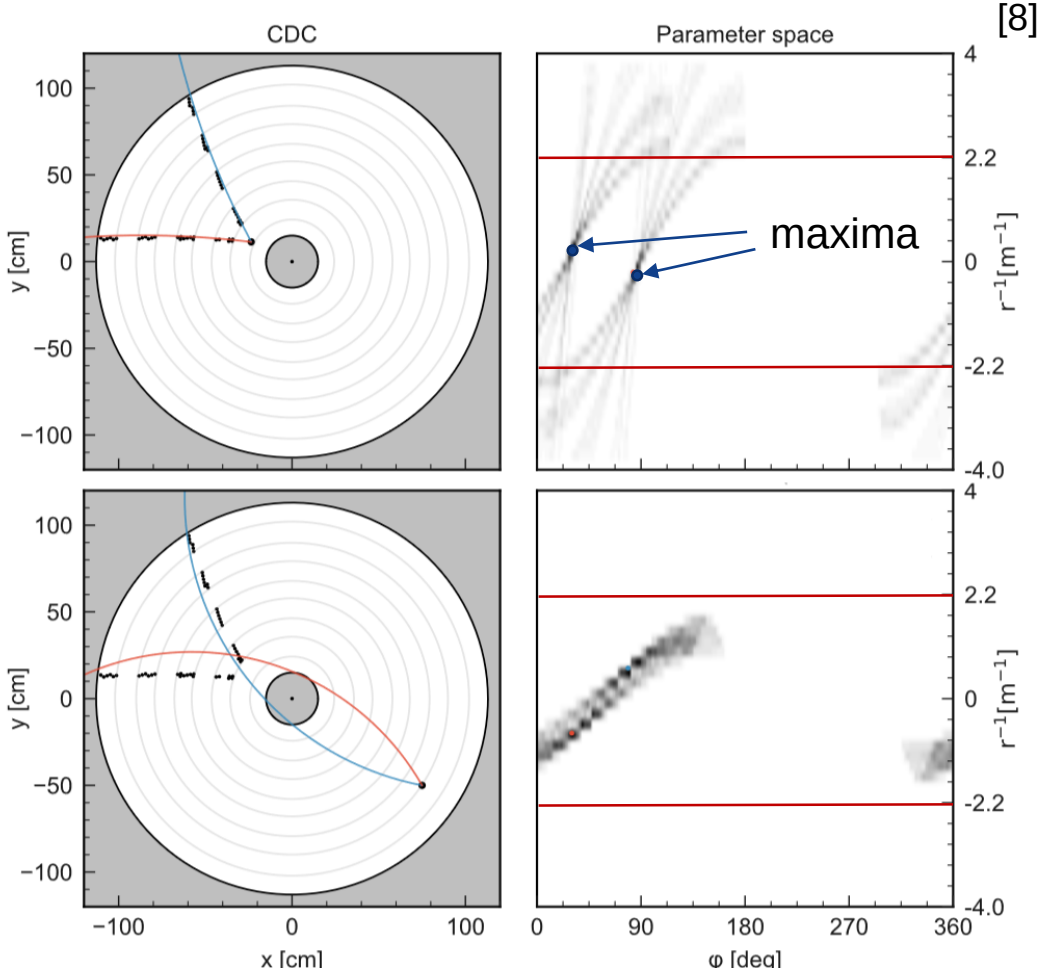
- Idea: Parallel Hough transformations with different origin hypothesis
- Scalable approach as only the hit information is needed
- Requirements: As many Hough transformations as possible on one FPGA



[7] Kai Unger et all; „A multi-Hough-based displaced vertex track trigger for the Belle II Experiment “ 2024; Topical Workshop on Electronics for Particle Physics TWEPP2024

Hough Hypothesen

[8]

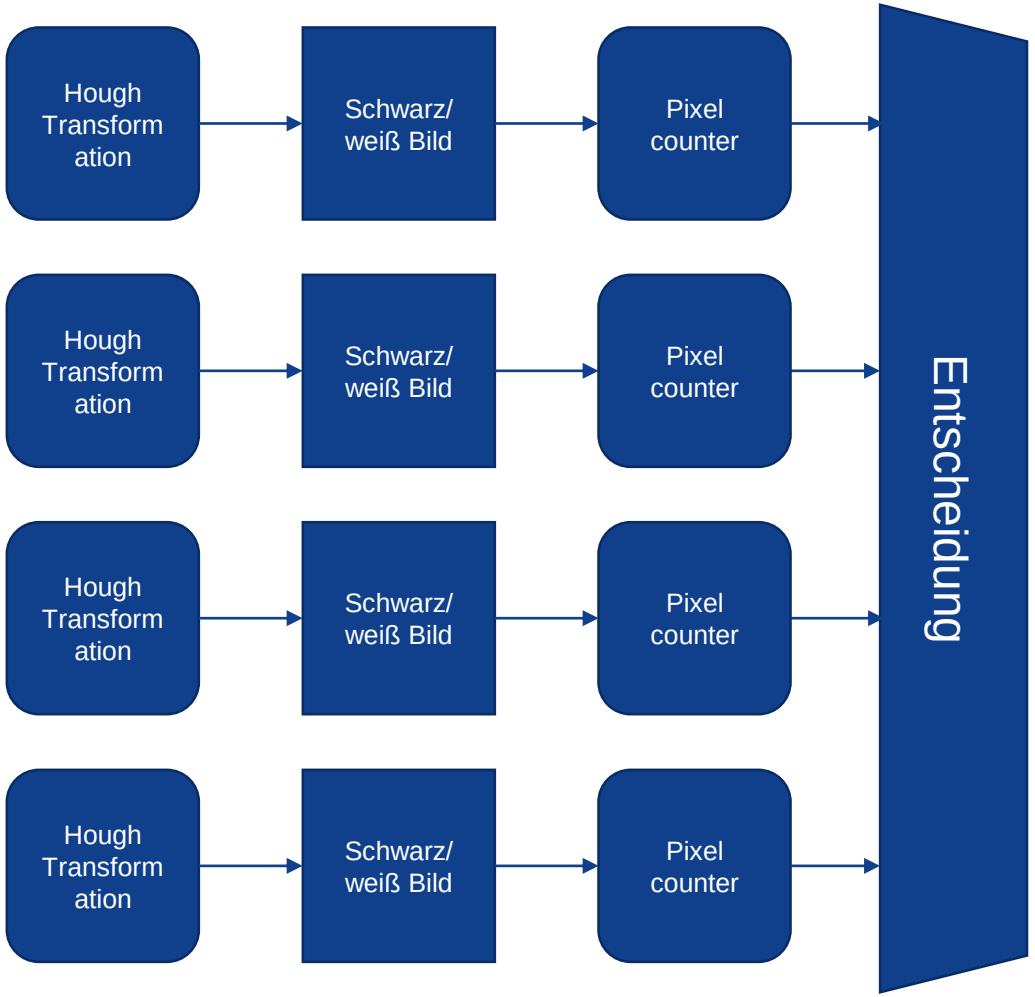


- Maximum calculation requires too many resources
- More distant hypotheses do not result in wide-ranging Hough curves
- Idea: Ratio of upper/lower image section to image centre

[8] Elia Schmidt; „Developing a Displaced Vertex Trigger for Dark Matter Searches at the Belle II Experiment “ 2023; Mastethesis MPI

Hardware

- Parallel Hough Transformation
- Black/white image and then pixel counter
- Up to 12 parallel origin hypotheses on one FPGA



ありがとうございました

THANK YOU