Yandex
SCHOOL OF DATA ANALYSIS

SHiP

Comparison of pattern recognition methods for the SHiP Spectrometer Tracker

Mikhail Hushchyn, Alenkin Oleg, Andrey Ustyuzhanin, Eric Van Herwijnen

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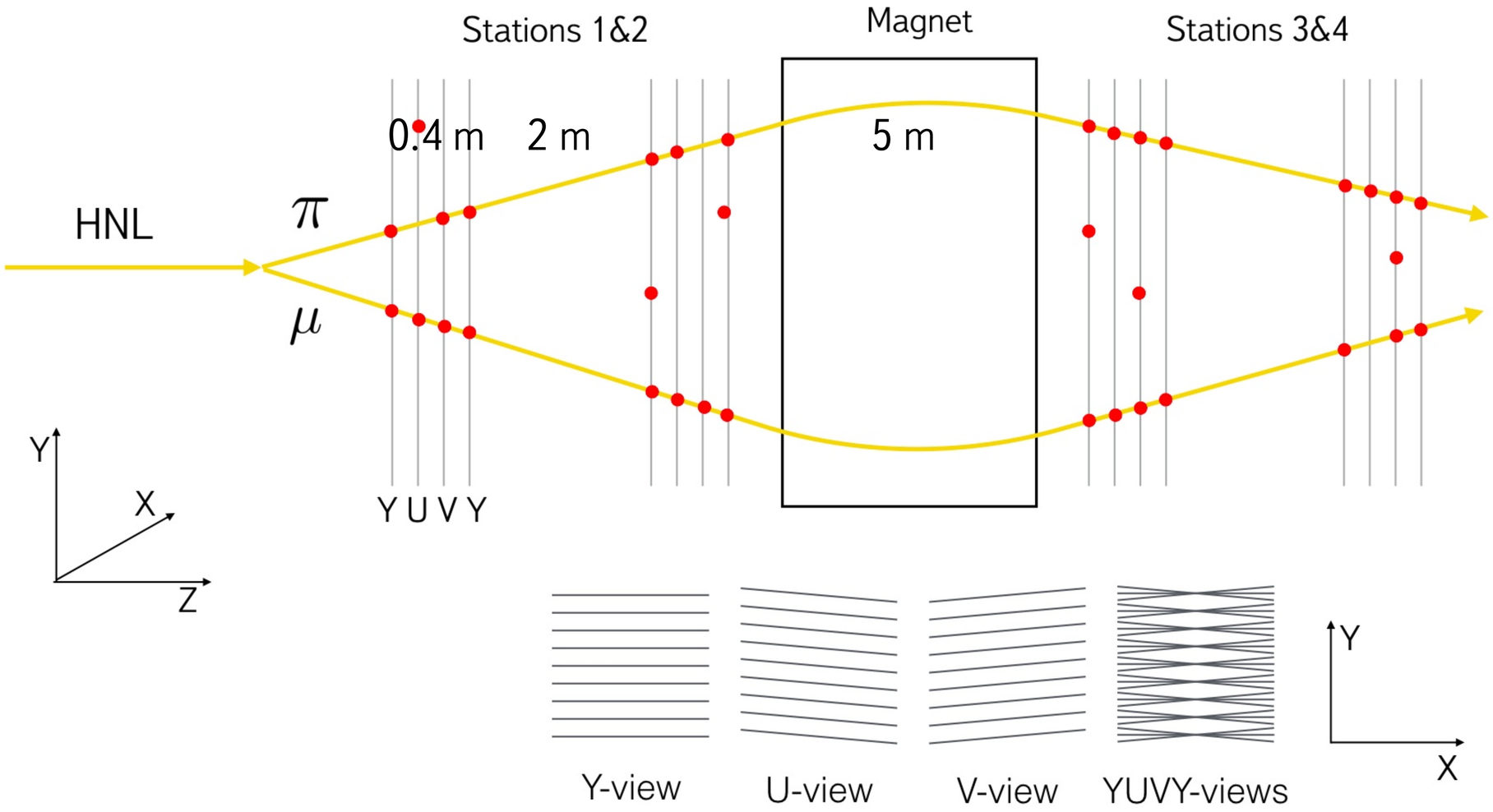
SHiP- Search for Hidden Particles

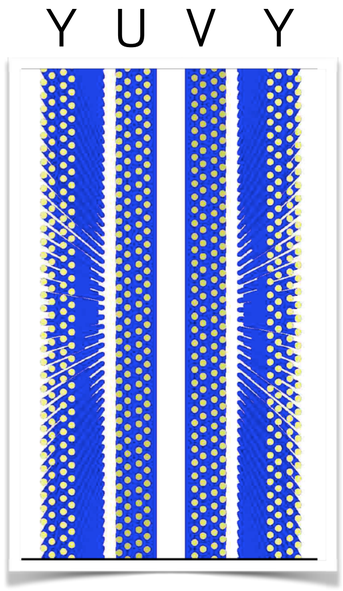
SHiP is a new proposed fixed-target experiment at the CERN SPS accelerator. The purpose of the SHiP experiment is to search for very weakly interacting long lived particles including Heavy Neutral Leptons (HNL) - right-handed partners of the active neutrinos.

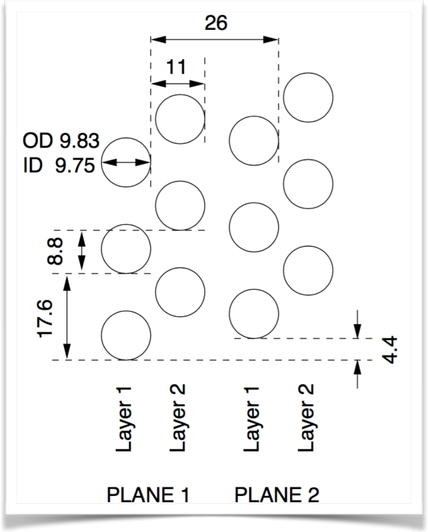
In this talk, a decay of HNL into a pion and a muon is considered. The goal is to recognize pion, muon tracks and compare the performances of different track pattern recognition methods adapted to the SHiP Spectrometer Tracker geometry.

http://ship.web.cern.ch

Straw Tracker

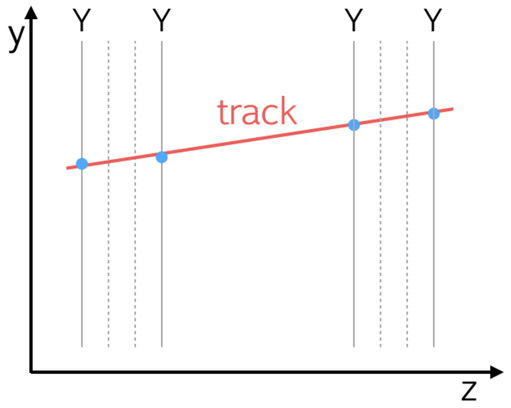






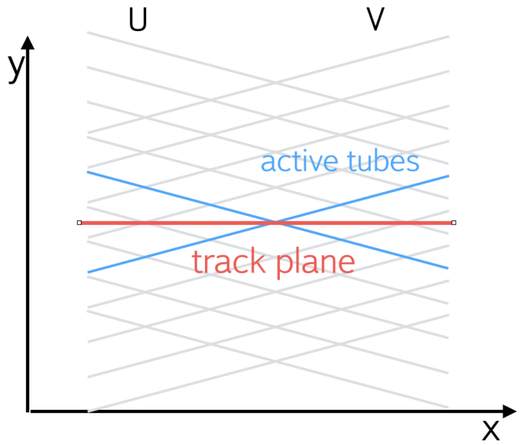
General Scheme

1



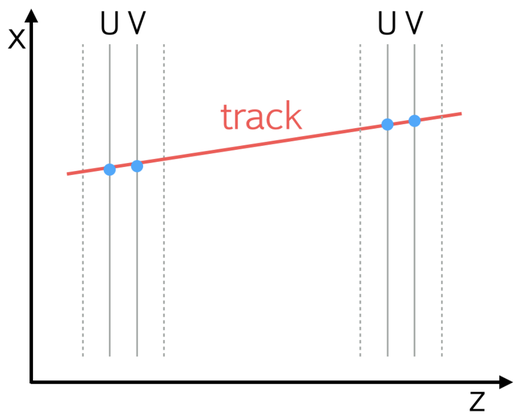
Look for tracks in the 16 layers with horizontal straw tubes (Y-views, y-z plane).

2



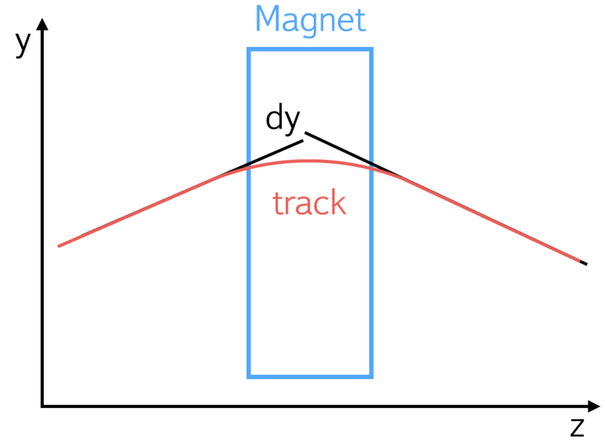
For each track found in the Y-view, intersect the plane defined by this track and the x-axis with the stereo (U,V) hits. This gives (z,x) coordinates.

3



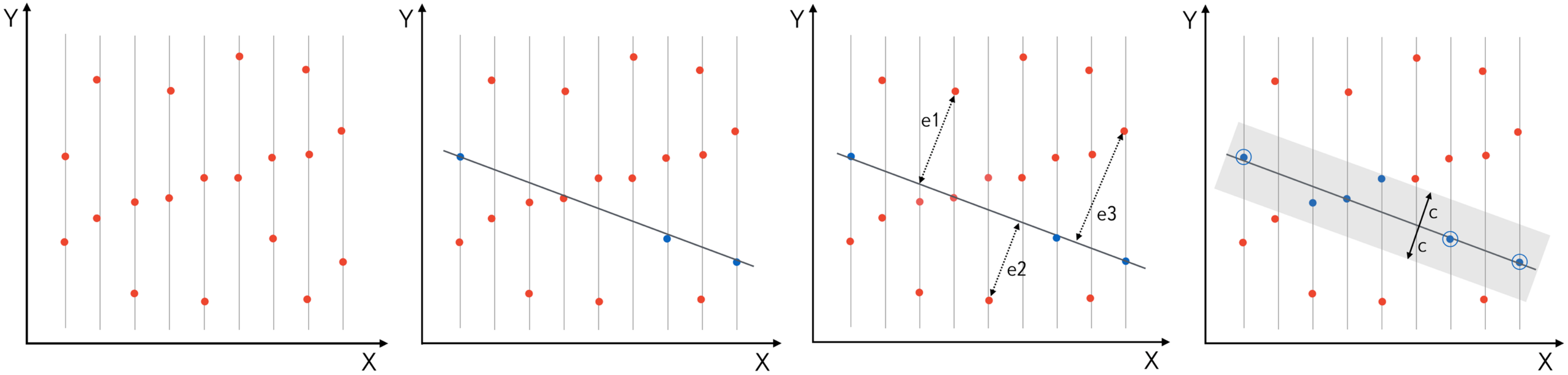
Look for tracks in 16 layers of stereo-views in x-z plane using (z, x) coordinates of the intersections.

4



Combine tracks before and after the magnet. Reconstruct a particle momentum and charge.

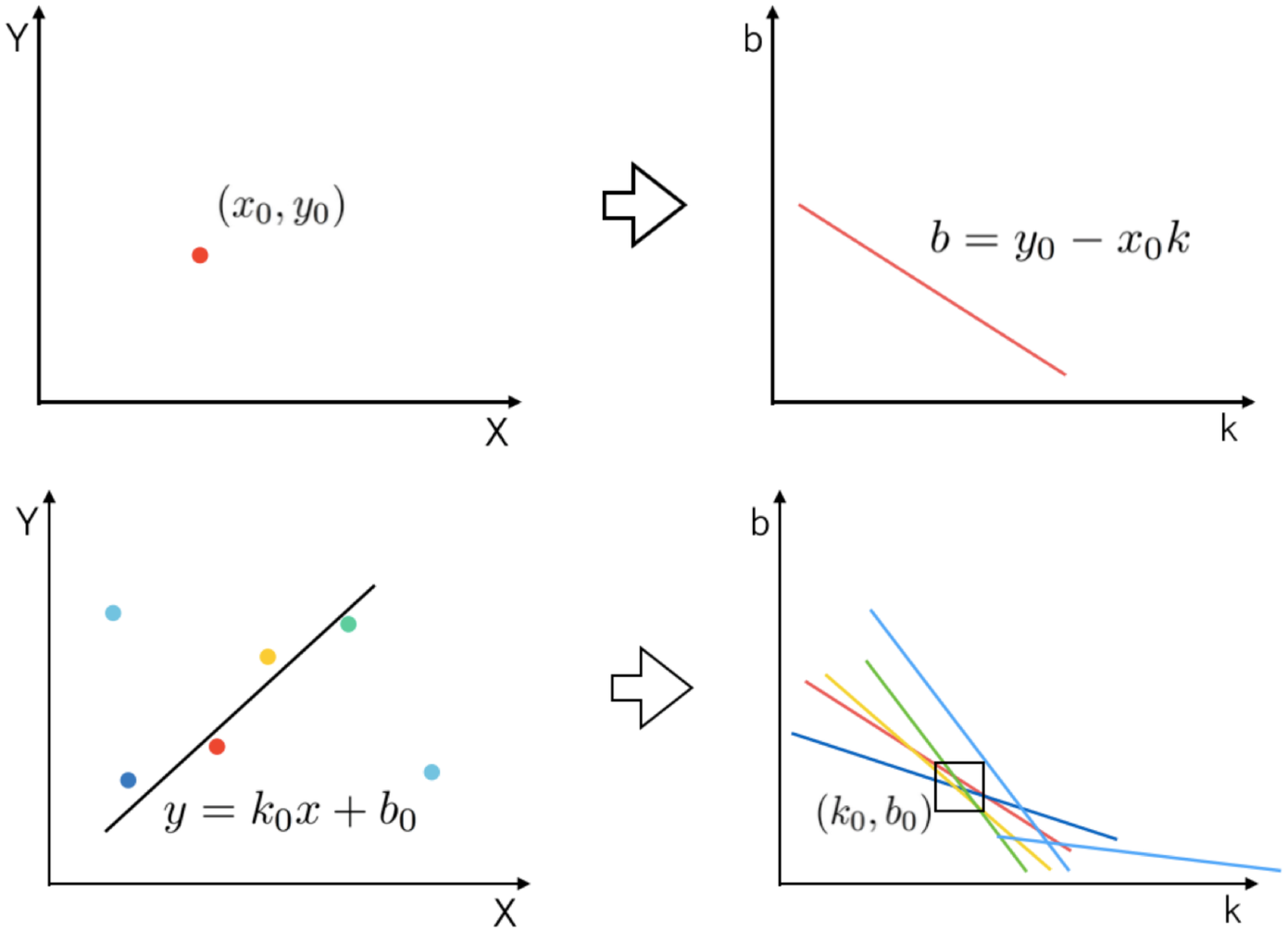
RANSAC

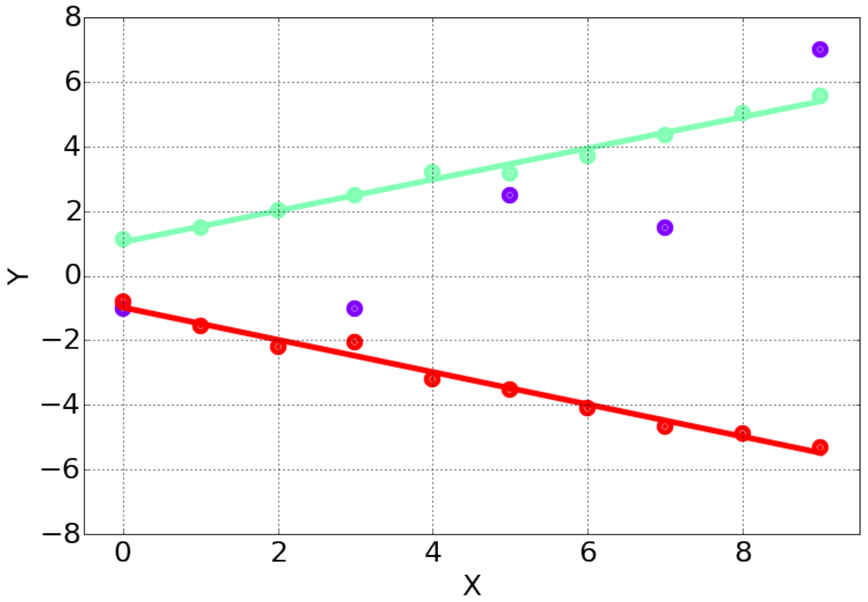


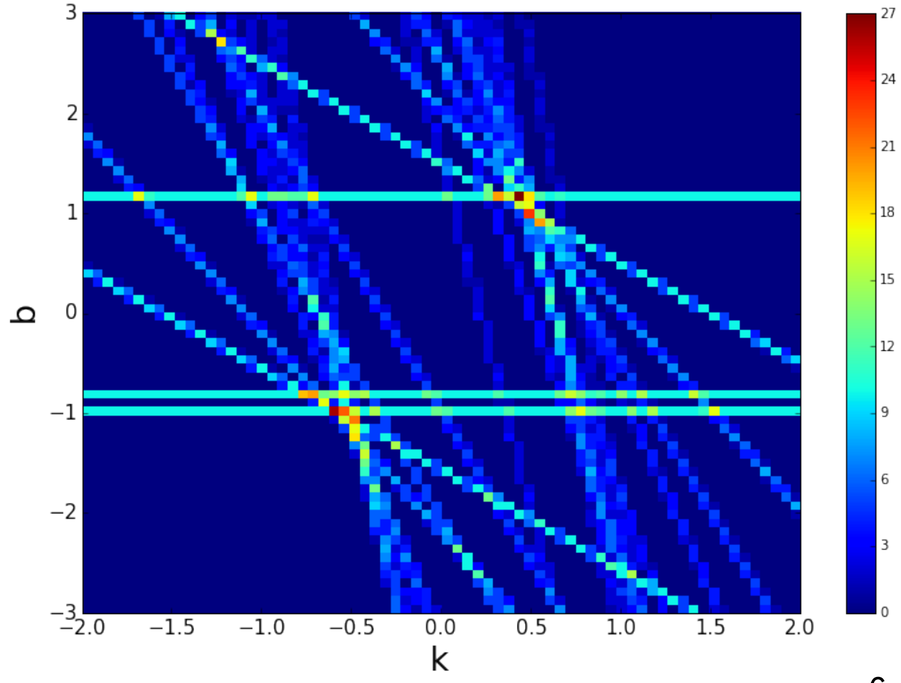
Searching for one track:

1. The RANSAC selects a random subset of the hits.
2. The linear model is fitted using this subset.
3. The error of the data with respect to the fitted model is calculated.
4. The number of inlier candidates is calculated.
5. Steps 1-4 are repeated until the maximum number of iterations.
6. A model with maximum number of inliers is returned.

Hough Transform







Artificial Retina

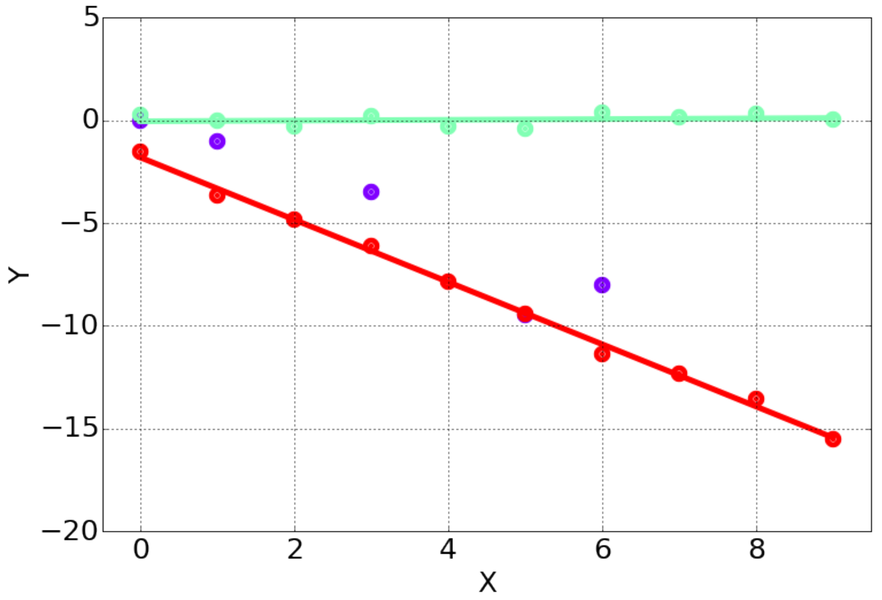
The artificial retina function is defined as:

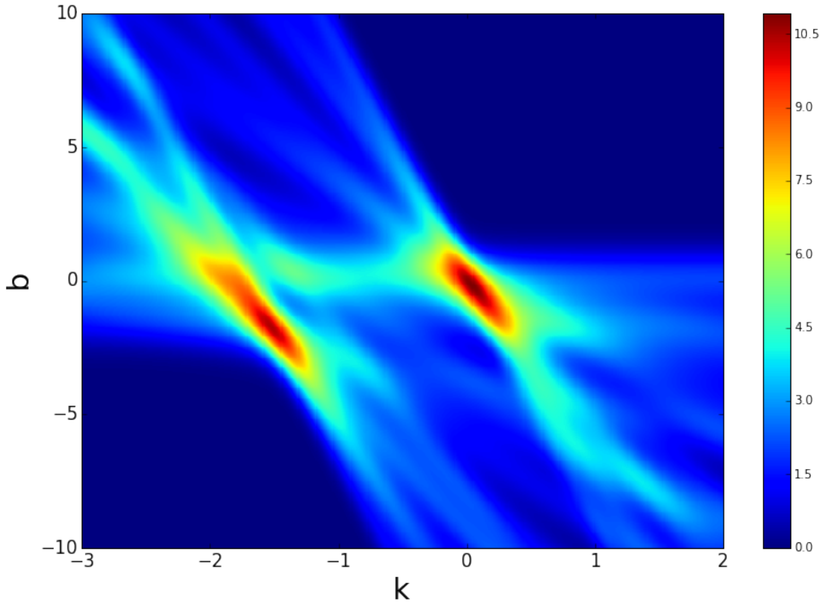
$$R(\theta) = \sum_i e^{-\frac{\rho^2(\theta, x_i)}{\sigma^2}}$$

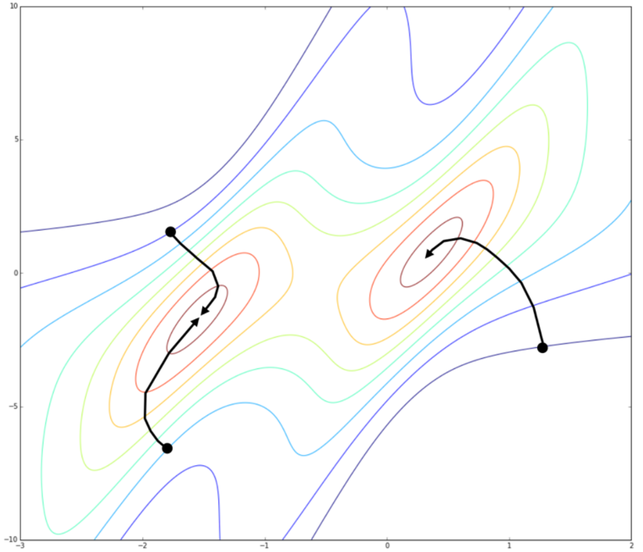
where $\rho(\theta, x_i)$ is distance between the i-th hit and a track with parameters θ .

For 2D tracks:

$$\rho(\theta, x_i) = y_i - (kx_i + b) \qquad \theta = [k, b]$$

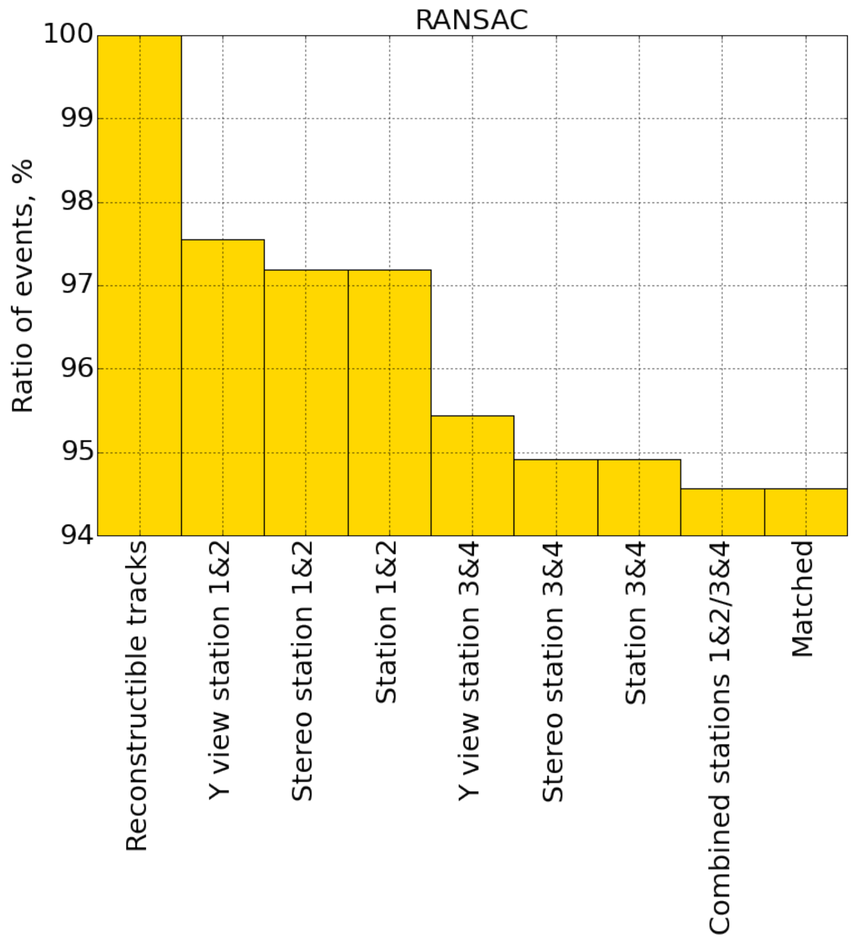


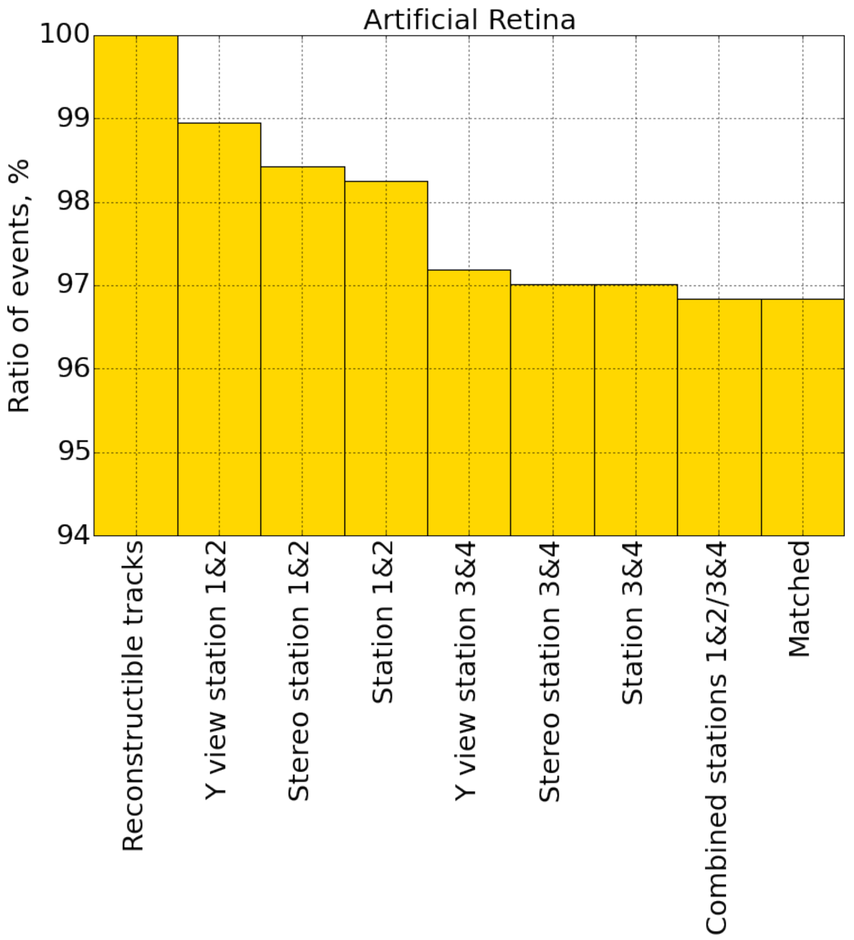


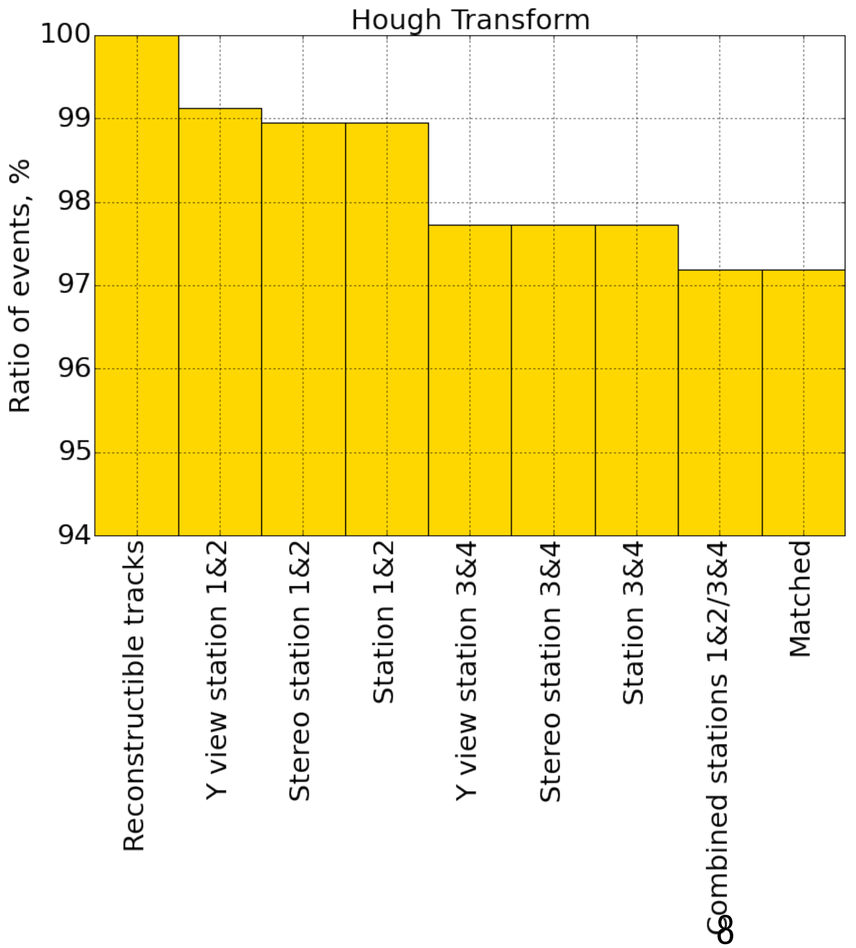


Results

Number of events passed through the track finding steps. If the two tracks (for muon and pion) of an event are not recognized, the event will not go to the next step. The last columns on the graphs below show total reconstruction efficiency.

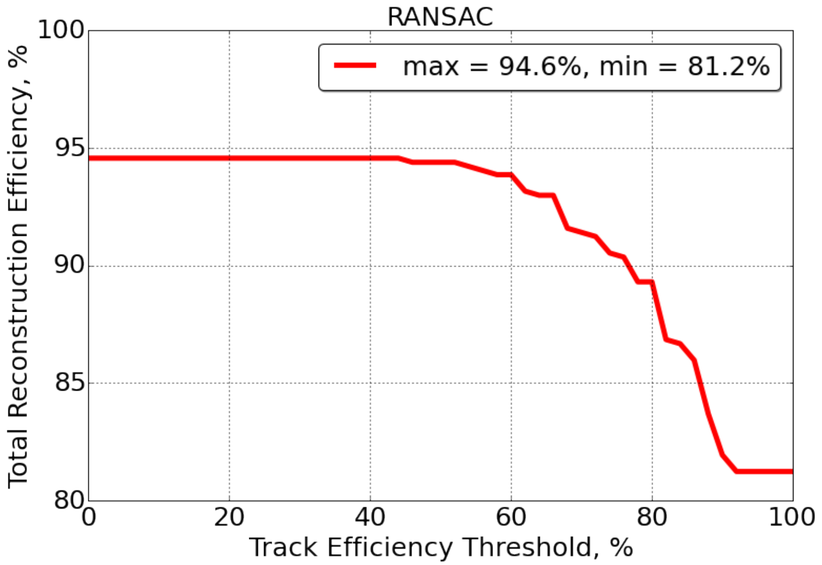


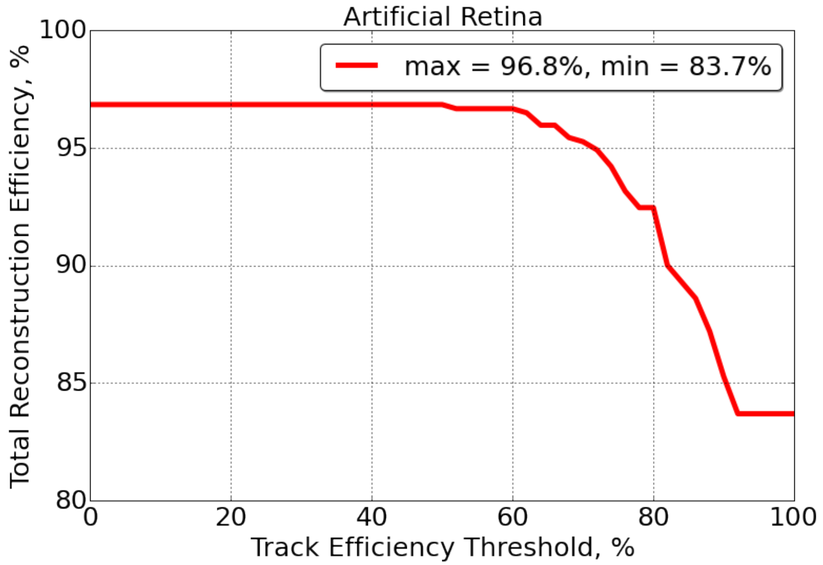


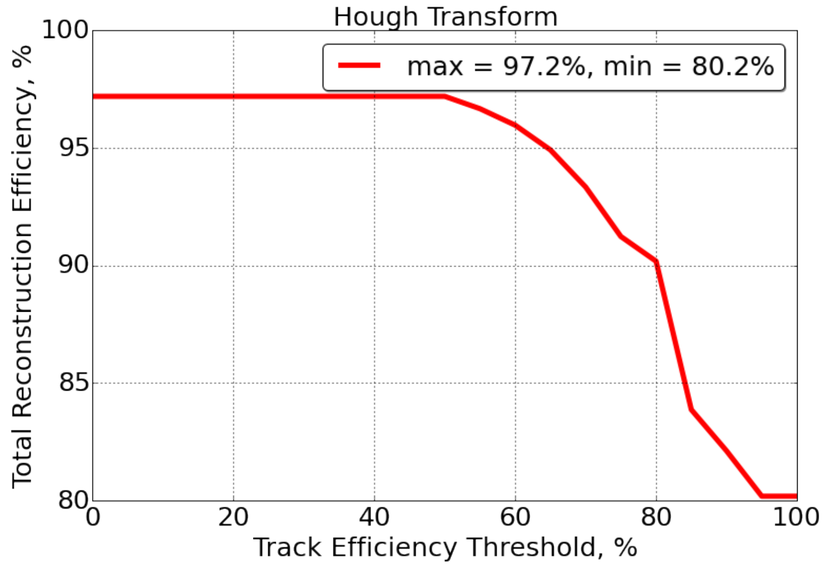


Results

Track efficiency is a criterion which specifies whether a certain particle has been found by the algorithm or not. If the qualified majority of hits, for example at least 70% originates from the same true particle, the track is said to reconstruct this particle. Dependence of total reconstruction efficiency from the track efficiency threshold:

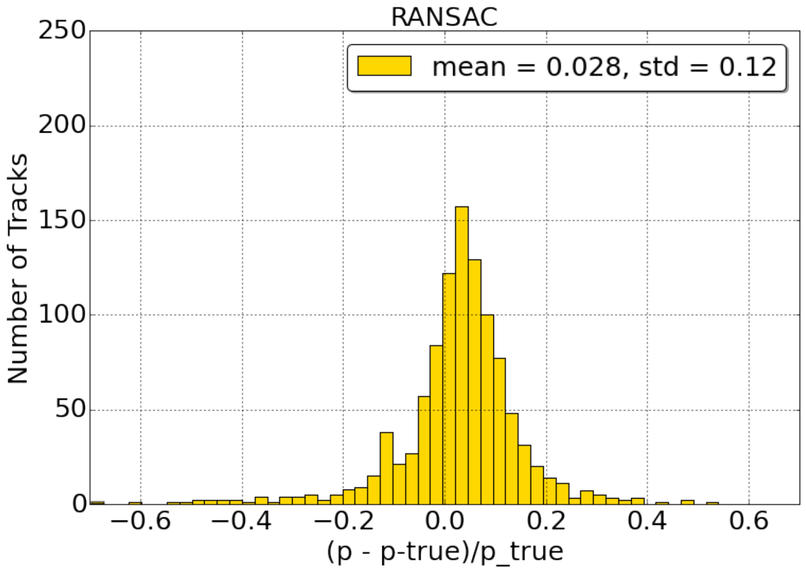


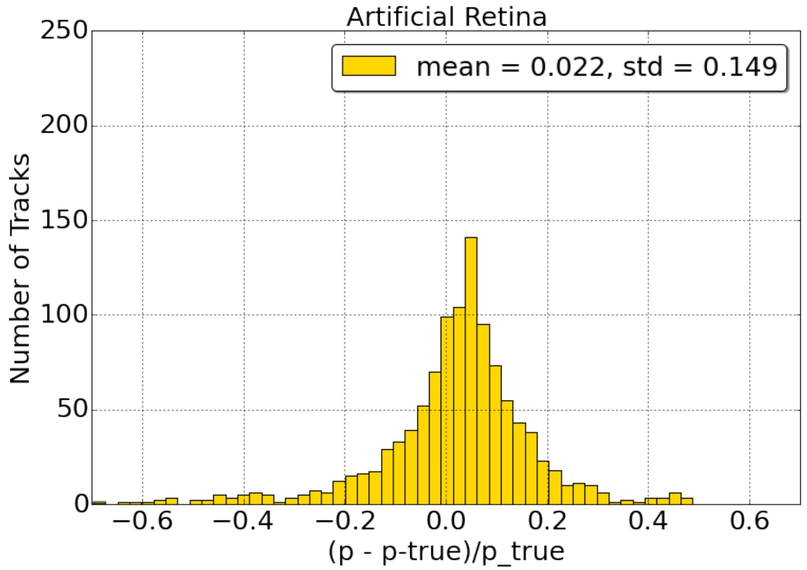


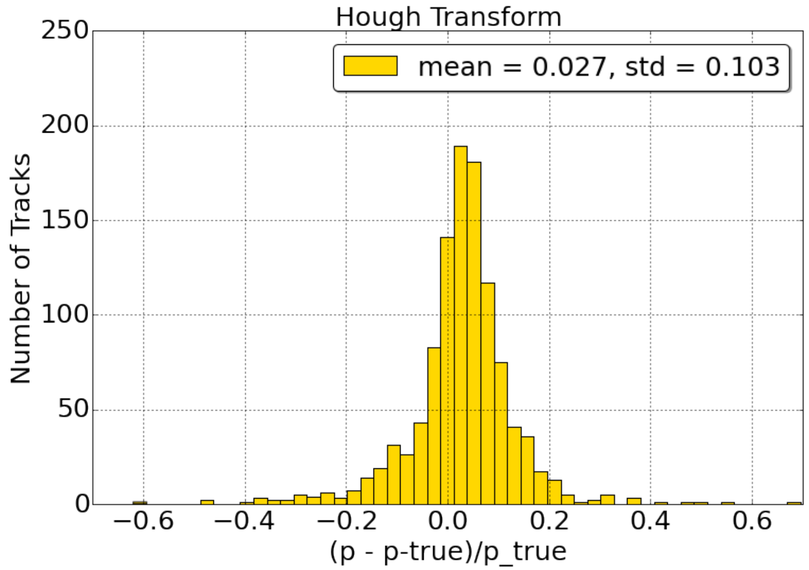


Results

The particles momenta reconstruction accuracy:





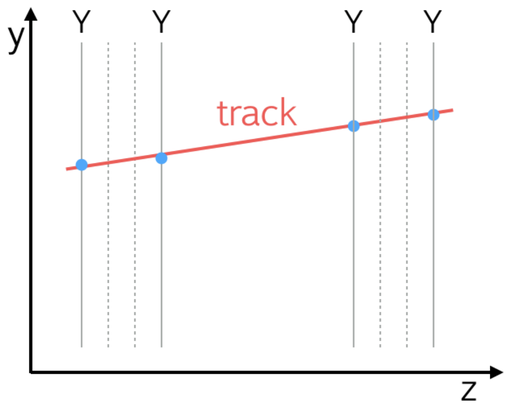


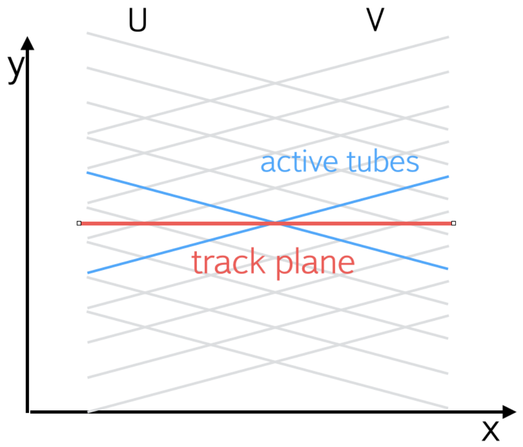
Results

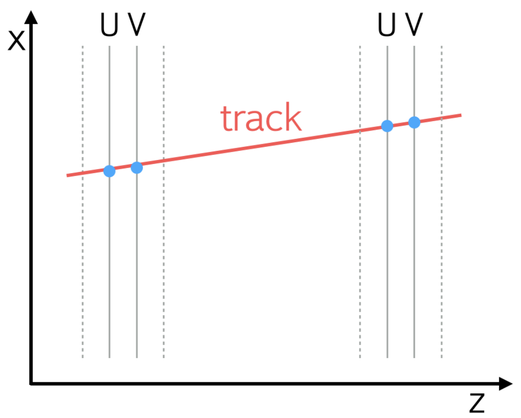
Method	Max Total RecoEff., %	Min Total RecoEff., %	Momentum Mean Rel. Error, %	Momentum Std. Rel. Error, %
Baseline[1]	94.1	-	3.2	-
RANSAC	94.6	81.2	2.8	12
Artificial Retina	96.8	83.7	2.2	14.9
Hough Transform	97.2	80.2	2.7	10.3

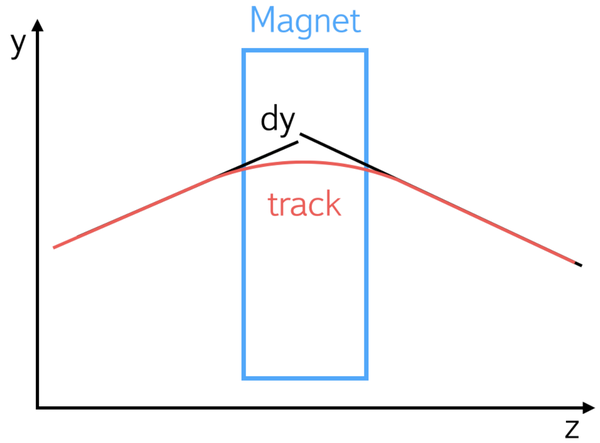
[1] H. Dijkstra, M. Ferro-Luzzi, E. van Herwijnen and T. Ruf Simulation and pattern recognition for the SHiP Spectrometer Tracker, SHiP-PUB-2015-002, March 31, 2015, CERN-SHiP-NOTE-2015-002

Limitations









Limitation of the scheme:

1. Pattern Recognition has 8 steps (see 8th slide).

2. Errors from one step propagate to the others with amplification due to angle between y and stereo views.

3. 3D tracks are recognized in 2D projections.

4. Only part of an event information (hits in y and stereo views before and after the magent) is used at every step.

All these reasons decrease total recognition efficiencies of all methods.

One More Method

Let's search whole track in 3D before and after the magnet simultaneously.

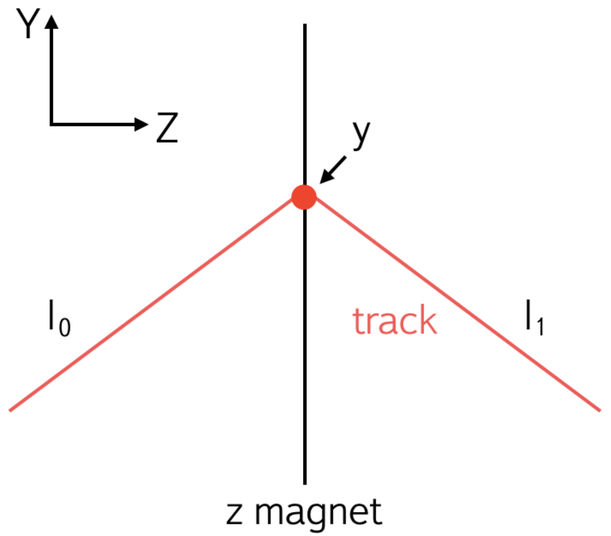
Again, Artificial Retina:

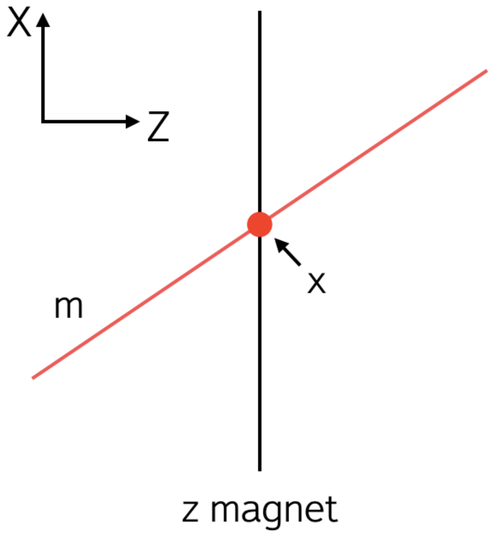
$$R(\theta) = \sum_i e^{-\frac{\rho^2(\theta, x_i)}{\sigma^2}}$$

but in this time, $\rho(\theta, x_i)$ is distance between i-th straw tube and a track in z-plane.

A track parametrization θ:

$$\theta = (l_0, l_1, y, m, x)$$





One More Method

For the better optimization:

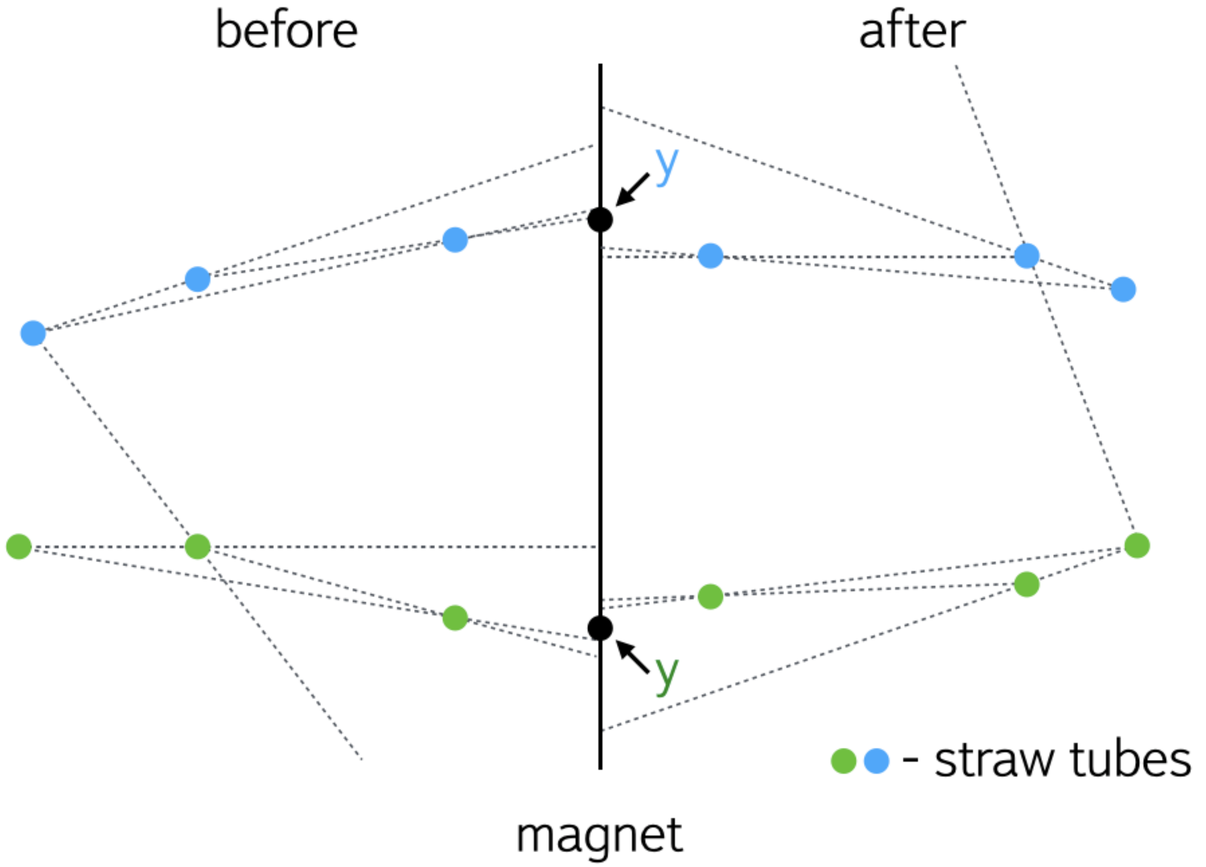
1. Estimate y parameter of a track as shown on the picture.

2. Using Artificial Retina function, find optimal parameters of the track in assumption y = Const:

$$\theta = (l_0, l_1, y{=}\text{Const}, m, x)$$

3. Optimize the all track's parameters:

$$\theta = (l_0, l_1, y, m, x)$$



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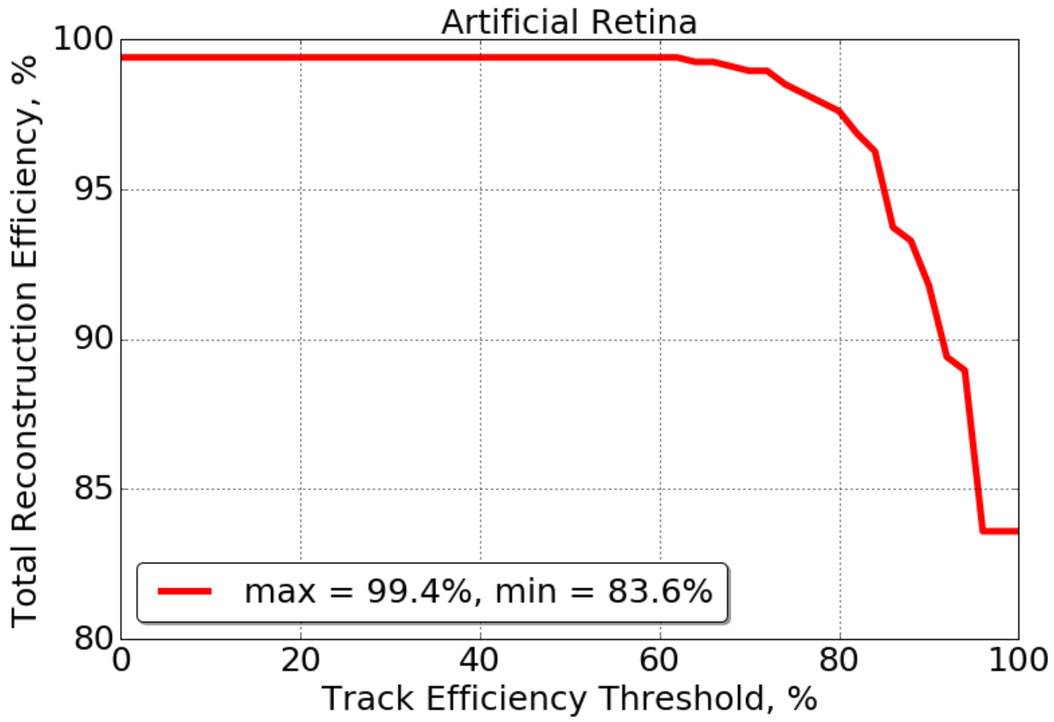

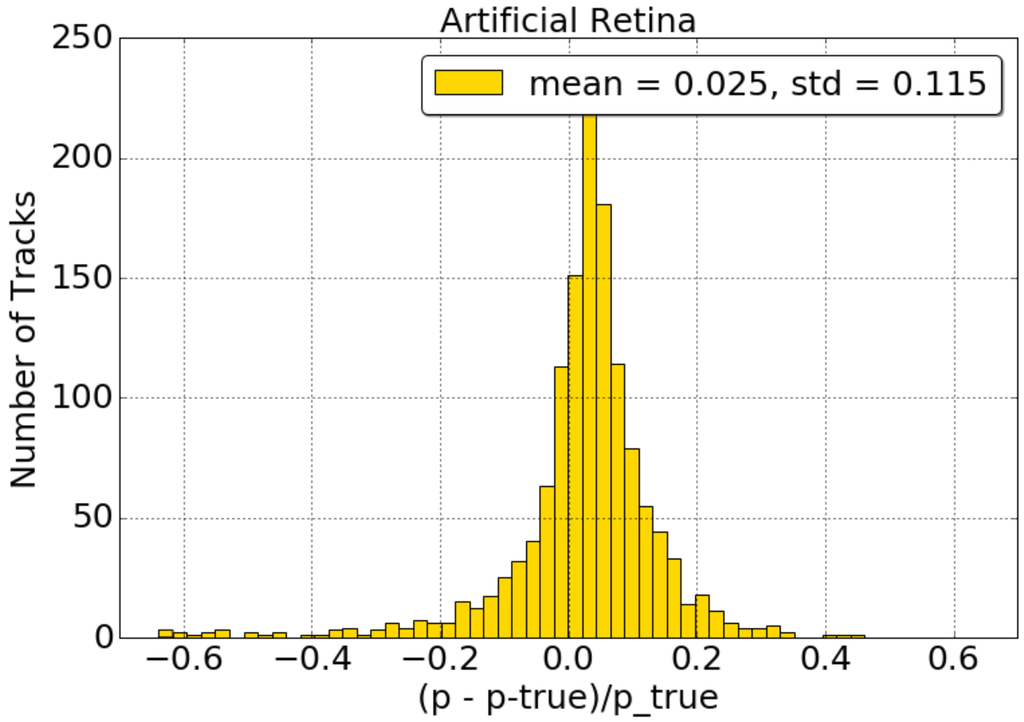

Summary and Conclusion

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Hough Transform	97.2	80.2	2.7	10.3
Artificial Retina in 3D	99.4	83.6	2.5	11.5

Artificial Retina in 3D is the best model. But it should be speeded up.

[1] H. Dijkstra, M. Ferro-Luzzi, E. van Herwijnen and T. Ruf Simulation and pattern recognition for the SHiP Spectrometer Tracker, SHiP-PUB-2015-002, March 31, 2015, CERN-SHiP-NOTE-2015-002