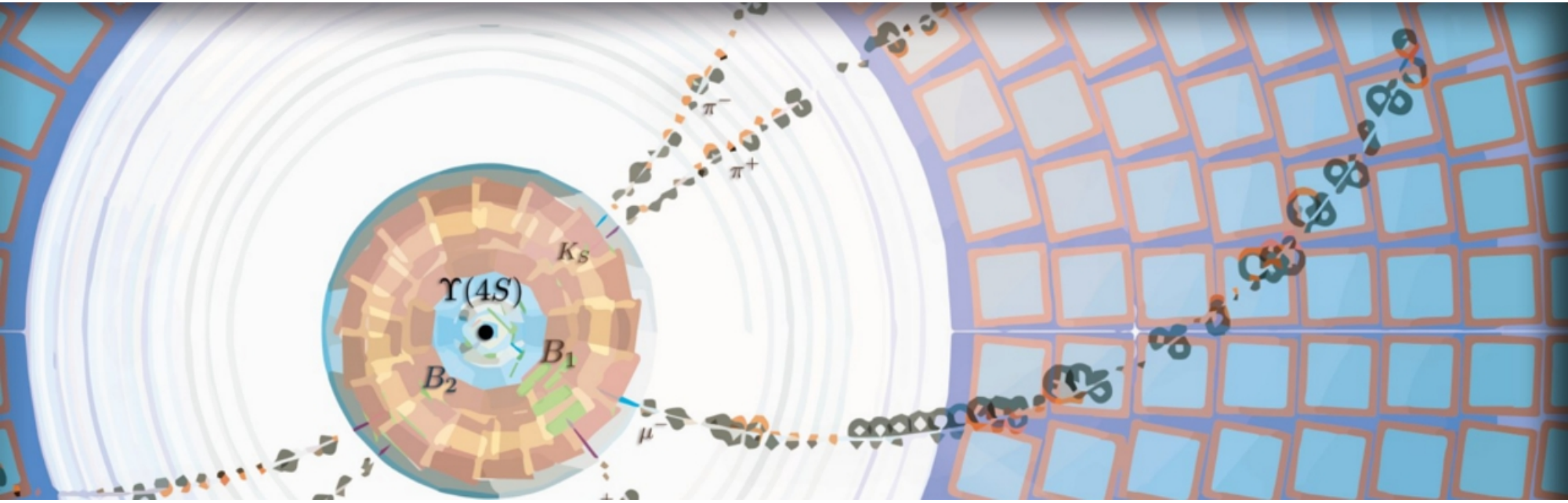
CDC track finding - Legendre and more.

F2F Meeting - Karlsruhe 2015



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Belle II

Overview

- Weighted hough transformation
  - New implementation
- Using higher dimensional hough spaces

Weighted hough transformation

Rethinking the layout of the fast Hough algorithm

Goals

1. Allow for weights of the objects in the hough nodes for instance to grade by the likelihood of that particular node.
2. Flexible division schemes
   - > Division factors other than 2 individually for each dimension. 3 or 4 seem feasable.
   - > Generally division should at least half the bins necessary to be investigated.
   - > Sectorisation: Starting with finer binning in the top node to step to specific region of the detector
   - > Alinear divisions (e.g. to allow finer binning in low curvature regions)
   - > Better overlap specifications.
   - > Potentially other partition shapes then rectangles (circles, spheres come to mind, remember that the ordinary hough peaks have butterfly shape)
3. Higher dimensional hough spaces 3, 4, or even 5.
   - > *for a simultaneous finding of* d_0, ϕ_0, *and* ω
   - > for a simultaneous finding of ϕ_0, ω and $\tan\lambda$
   - > or even more
4. Single best bin searches
5. Priorisation of expansion by quality criteria

Implementation details

Modularisation

- More radical separation of all strategies
- Weighting / containment in Hough space
- Division / Dimensions
- Expansion stop / Postprocessing
- Expansion priorisation (wish list)

Optimisation

- Refrain from using virtual functions
- Hold on to the memory, such that no memory allocation need after warmup phase.
- Performance measurements in unit test events showed a 5-6x improvement
- Initial integrate with the real data flow yield more pessimistic results.

Temporary agreement

- Use the new development as a play ground for new ideas.

Side product - simplified simulation facility for the CDC

Testing, testing

- Debug your own assumptions.
- Gain confidence in the implementation
- Backbone for refactoring
- Tight feed back

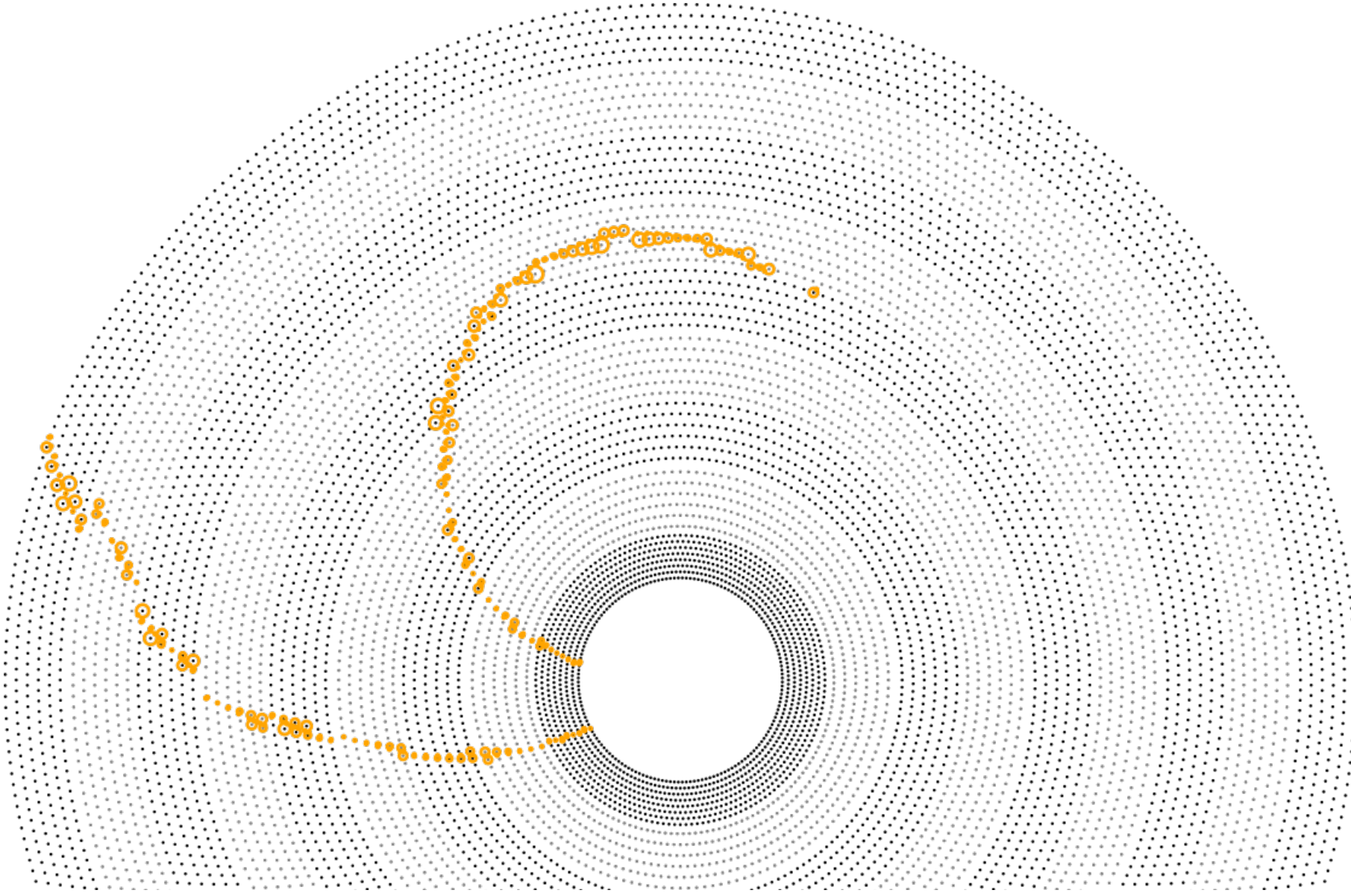
Missing input

- Most of the algorithms require at least some sort of input data
- Loading the full simulation for a unit test is undesireable

CDCSimpleSimulation

- Generates hits from ideal trajectories without energy loss.
- May serve as input during test runs.

Display of simple simulation event



Using higher dimensional hough spaces

What is the hough transformation about

- Fast hough ansatz partitions parameterized families of curves levelwise by dividing each parameter range by a fixed number of bounds.
- A hit is assoziated to a family, if it lies on one curve of the family.
- Since families are usually simply connected and distance measures are smooth, it is sufficient to find two curves to assziate a hit.
- Approximations check the distance signs of all extermal parameter combinations.
- $\rightarrow$ needs only the sign of a distance measure.

Conformal space revealed

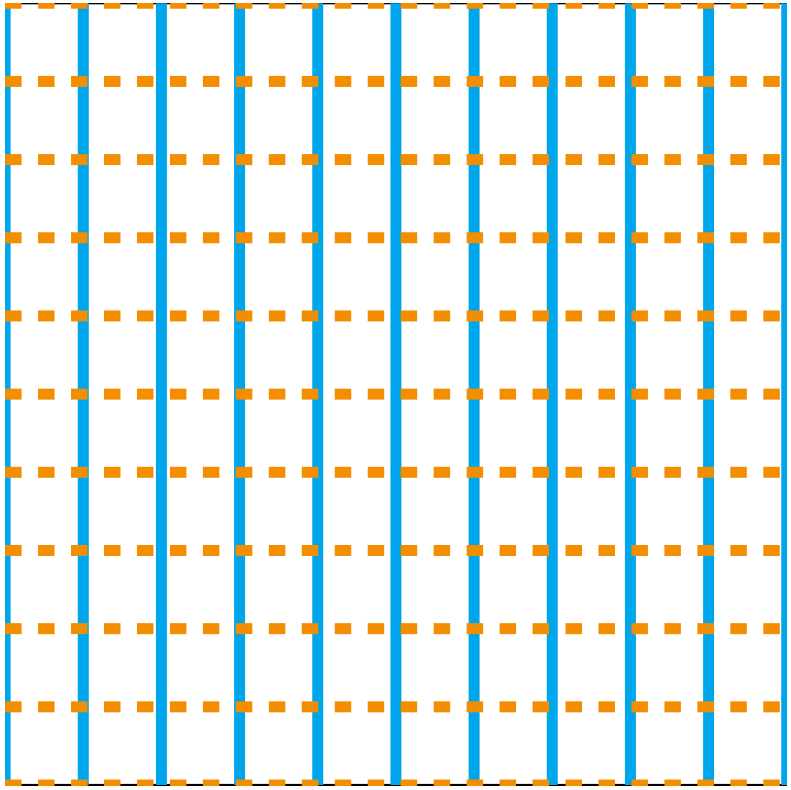


Figure 2: Normal space

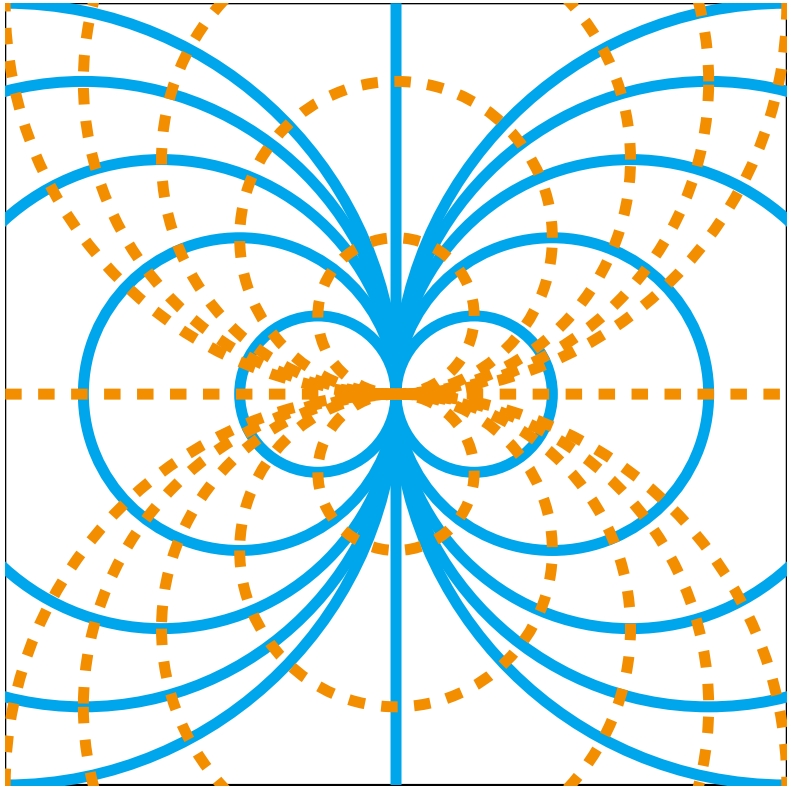


Figure 3: Conformal space

Conformal space considered evil

Conformal transformation

$$X = \frac{x}{x^2 + y^2 - l^2} \qquad Y = \frac{y}{x^2 + y^2 - l^2} \qquad L = \frac{l}{x^2 + y^2 - l^2} \quad \text{(drift length)}$$

Distance of trajectory in conformal space

$$D = -\frac{\omega}{2} + X \cdot \cos\phi_0 + Y \cdot \sin\phi_0 \pm L$$

Distorted conformal distance measure

$$D \approx \frac{d_{real}}{x^2 + y^2 - l^2}$$

Points close to the reference are send to infinity with huge errors in the distance

Stick to normal space

Distance of trajectory in real space

$$d = -\frac{\omega}{2} \cdot (r^2 - l^2) + x \cdot \cos\phi_0 + y \cdot \sin\phi_0 \pm l$$

- Undistorted
- Easier to extend.
- Caching $r^2 - l^2$ instead of conformal X, Y and L.

Extension to higher dimensions

All perigee parameters

$$d = -\frac{\omega}{2} \cdot \left(x^2 + (y + d_0)^2 - l^2 \right) + x_{stereo} \cdot \cos\phi_0 + y_{stereo} \cdot \sin\phi_0 + d_0 \pm l$$

$$x_{stereo} = x + \frac{\partial x}{\partial z} \cdot (s \cdot \tan\lambda + z_0)$$

$$y_{stereo} = y + \frac{\partial y}{\partial z} \cdot (s \cdot \tan\lambda + z_0)$$

$$s = s(\omega, r)$$

Here x, y are the reference position of the wire, while $\frac{\partial x}{\partial z}$, $\frac{\partial y}{\partial z}$ are the relative additional displacement per unit z.

Simplifications for xy parameters

Perigee parameters ϕ_0, d_0 and ω

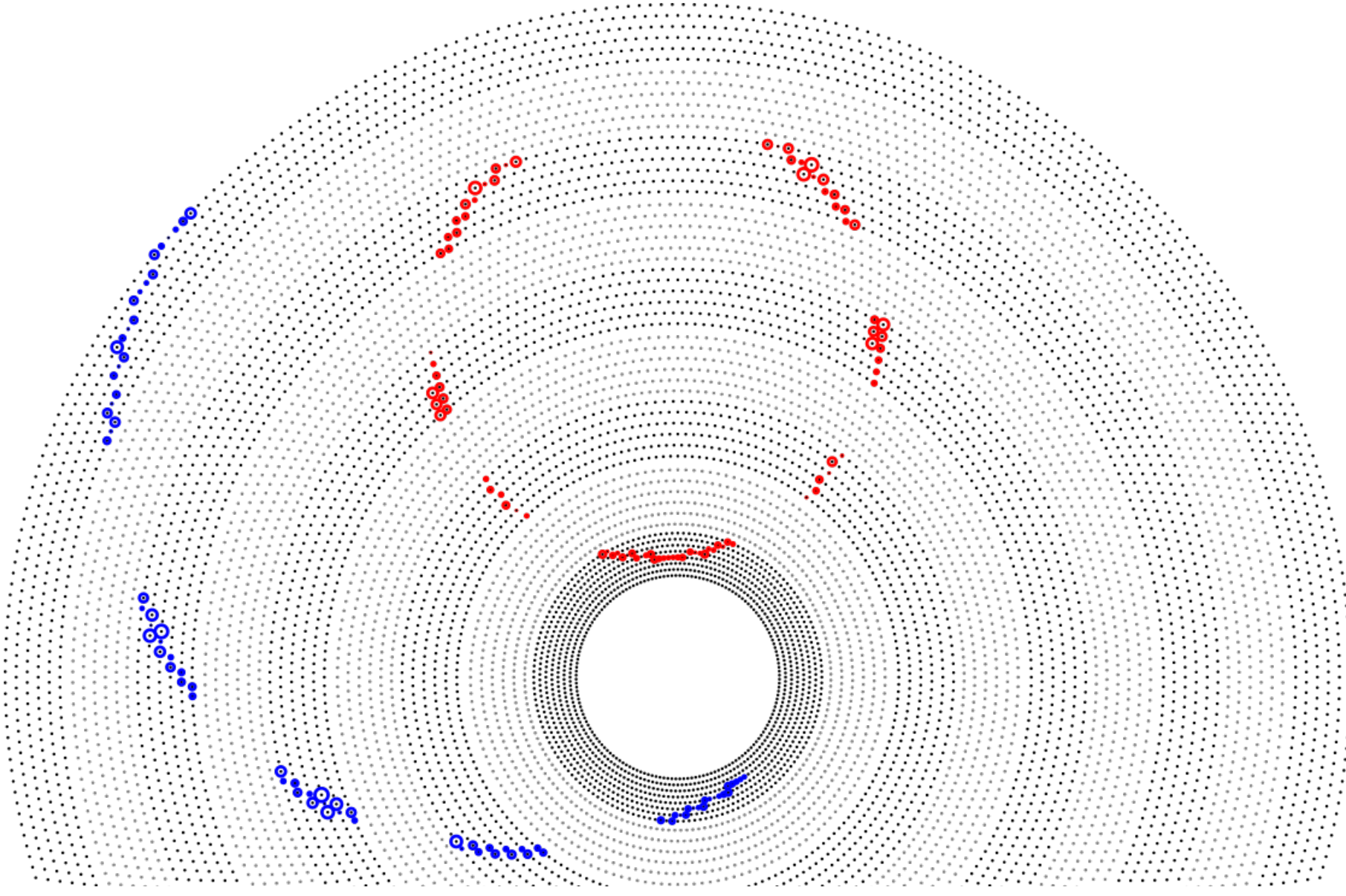
$$d = -\frac{\omega}{2} \cdot \left(x^2 + (y + d_0)^2 - l^2\right) + x_{stereo} \cdot \cos\phi_0 + y_{stereo} \cdot \sin\phi_0 + d_0 \pm l$$

- Ideal for tracking axial part of cosmics

Segments as building blocks

To keep the combinatorics in check whole segments are either accepted or rejected if more than a threshold fraction of hits in the checked Hough space part.

Test on simple simulation



Cosmics finding so far - cellular automaton

Figures of merit

Efficiency	0.996
Hit efficiency	0.726
Clone rate	0.340
Fake rate	0.0027

Time consumption

8 ms per event

Cosmics finding - axial hough + stereo finding

Figures of merit

Integration of stereo part thanks to Nils.

Efficiency	1.00
Hit efficiency	0.915
Clone rate	0.0002
Fake rate	0.0001

- Substantial improvement on first shoot.
- Prospects of the second stage cellular automaton look rather bleak.

Time consumption

42 ms per event

Outlook

Investigate the Hough setup

- Sparse cosmic events only need limited search depth
- Adjusting division in each of the directions
- Divisions in each direction should have the same reduction power.
- Maybe a bachelor thesis.

Hough finding ϕ_0, ω and $\tan\lambda$

- Using axial and stereo hits in the same search for origin tracks
- Ingredients prepared, but not yet top off with a module.
- First attempt will turn out to be slow

More than 3 dimensions?

Feasible but my best guess is that it is even more computational expansive.