Track Finding with Hough Transformation for TPC Data

Isa Heinze

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Outline

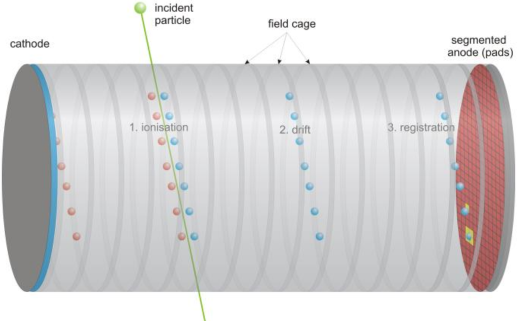
1. Time Projection Chambers
2. Track Reconstruction
3. Efficiency Studies
4. Conclusion and Outlook

Working Principle of Time Projection Chambers

A time projection chamber (TPC) consists of a volume filled with gas with an electrical field applied to it.

Working Principle

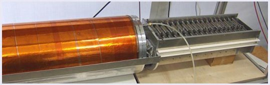
- A charged Particle traverses the volume and ionizes the gas inside the TPC.
- Due to the electric field the electrons drift towards the anode.
- Readout of the electrons at the anode.



Time Projection Chambers

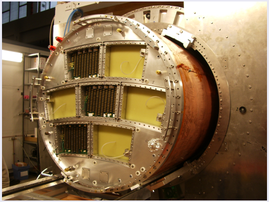
MediTPC

- Ø: 27 cm; length 80 cm
- Maximum drift length: 66 cm
- Pad plane: 60 x 80 mm^2



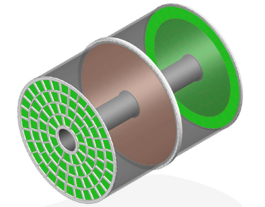
Large Prototype

- Ø: 77 cm; length: 61 cm
- room for up to seven modules

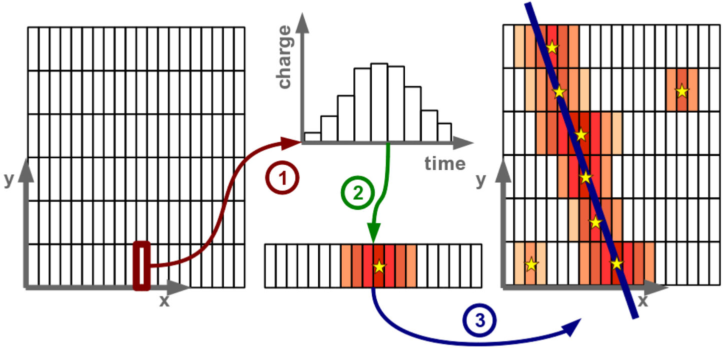


ILD TPC

- Ø: 3.8 m; length 4.3 m
- Tracking system in the future ILD detector



Track Reconstruction



1. For each pad a charge spectrum is recorded; search for pulses in the charge spectrum.
2. Pulses on adjacent pads in the same row are combined to hits (3D space points).
3. Hits are combined to tracks; tracks are fitted.

Pattern Recognition with Hough Transformation

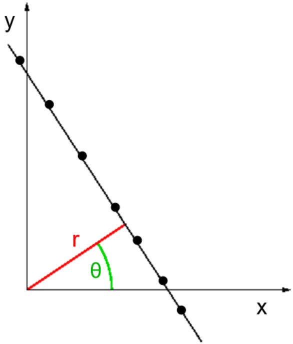
- Global method: all hits enter into the algorithm at the same time and in the same way.
- Works for any track shape which can be described by one set of parameters.
- here: either straight line (without magnetic field) or helix (with magnetic field).

Hough Transformation: Straight Lines

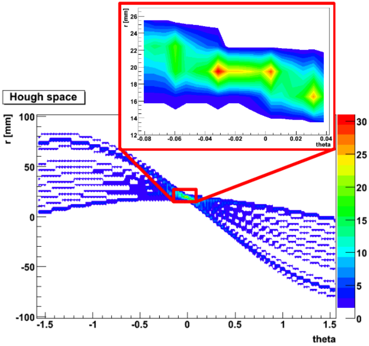
- Track Model: straight line
- Two parameters needed to describe straight line. Here: r, θ

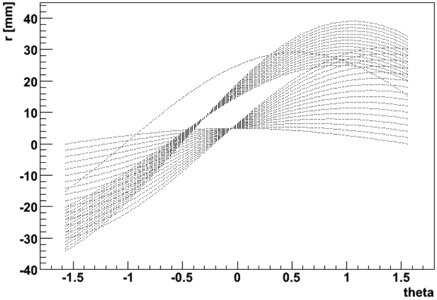
$$\begin{aligned} y(x) &= -\frac{\cos\theta}{\sin\theta}\cdot x + \frac{r}{\sin\theta} \\ \Rightarrow r(\theta) &= \cos\theta \cdot x + \sin\theta \cdot y \end{aligned}$$

- Hit positions are inserted in the function $r(\theta)$.
- If the hits are on a straight line the functions belonging to these hits intersect in one point in 2D Hough Space.
- The point of intersection delivers the parameters of the straight line.



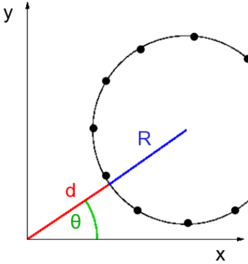
Hough Transformation: Straight Lines





Hough Transformation: Circles

- Track model: circle
- Three parameters needed to describe circle. Here: d, θ, R
- Same procedure as for straight lines
- Intersection of functions $R(d,\theta)$ in 3D Hough Space

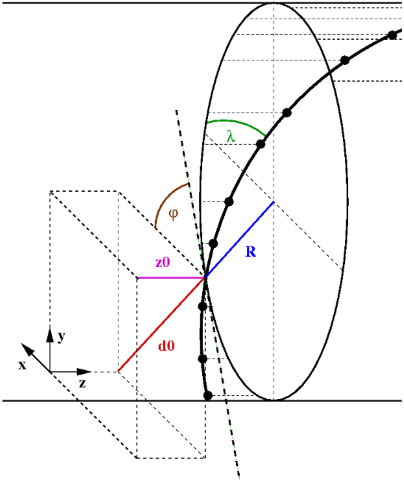


$$\begin{aligned} R^2 &= (x - x_M)^2 + (y - y_M)^2 \\ x_M &= (R + d)\cdot\cos\theta \\ y_M &= (R + d)\cdot\sin\theta \\ \Rightarrow R(d,\theta) &= \frac{x^2 + y^2 + d^2 - 2d\cdot(x\cdot\cos\theta + y\cdot\sin\theta)}{2\cdot(x\cdot\cos\theta + y\cdot\sin\theta - d)} \end{aligned}$$

$\Rightarrow$ 3D Hough Space

Hough Transformation: Helix

- Track model: helix
- Five parameters needed to describe a helix
- LCIO parameter: φ, $\Omega = 1/R$, d_0, z_0, $\tan\lambda$
- Functions would intersect in 5D Hough Space
- Search is done in two projections
  - xy projection (straight line or circle)
  - sz projection (straight line), where s is the arc length in the xy projection

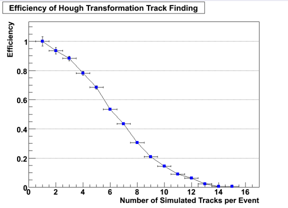


Simulation for track finding in multi track events

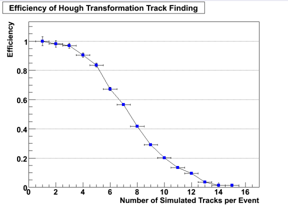
- Volume of MediTPC: 60 x 80 x 666 mm^3
- Straight lines
- Track parameters are created randomly in the volume.
- Tracks are simulated such that they are vertical ($\pm 30^\circ$).
- Y positions are the center of the pads.
- X and z positions are calculated accordingly with the track parameters.
- 12 hits per track (MediTPC like)

Track Finding Efficiencies

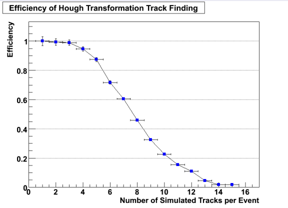
a: 0 wrong hits allowed



b: 1 wrong hits allowed



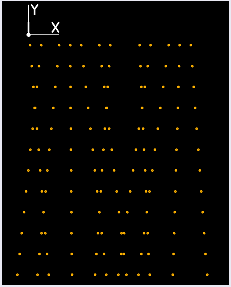
c: 2 wrong hits allowed



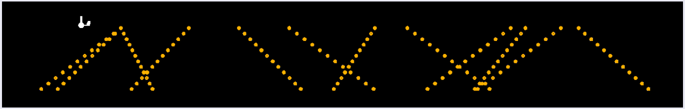
- 1000 simulated events with n tracks
- Volume: MediTPC
- Track was found correctly if all hits (**a**), all but one hit (**b**), all but two hits (**c**) were found correctly.

Example: Straight Line

Simulated tracks in xy projection

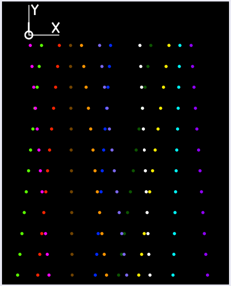


Simulated tracks in zy projection

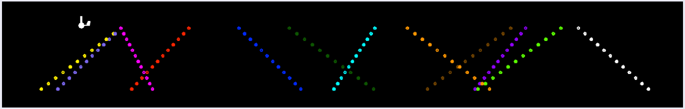


Example: Straight Line

Reconstructed tracks in xy projection



Reconstructed Tracks in zy projection

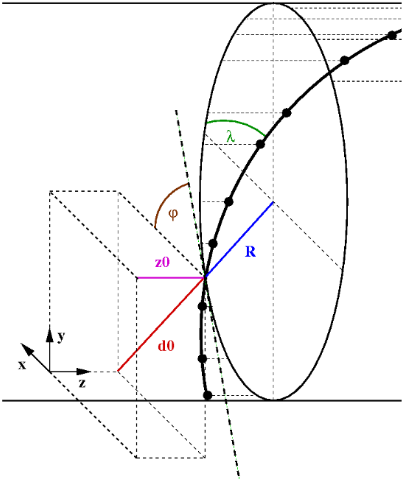


Track Finding Efficiencies

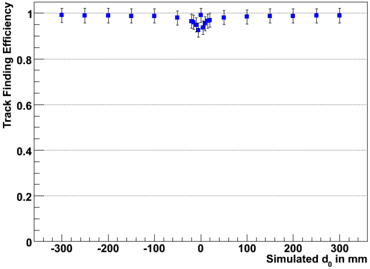
- Hits might not be assigned to the right track if
  - two tracks cross each other.
  - two tracks are very close to each other.
- With very few hits per track the points of intersection in the Hough space might not be defined well.
- Especially in events with many tracks fake tracks might be found.

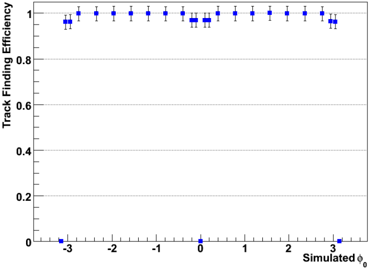
Simulation for Parameter Scans

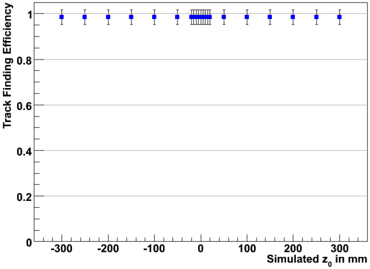
- 1000 events
- 1 track per event
- 200 hits per track (ILD TPC like)
- Y-Positions of hit in the center of pads rows.
- Straight lines ($\Omega = 0$)
- One track parameter fixed, others randomly chosen.
- A track is defined to be found correctly when all hits belonging to that track were found correctly.

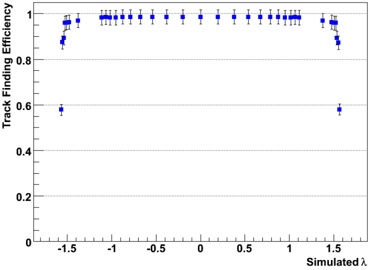


Track Finding Efficiencies









Track Finding Efficiencies

- For one track per event the track finding efficiencies is almost one for nearly all parameter regions.
- Tracks can not be found if they are nearly parallel to the pad rows ($\varphi \approx 0$, $\varphi \approx -\pi$ or $\varphi \approx \pi$) or the drift direction ($\lambda \approx -\frac{\pi}{2}$ or $\lambda \approx \frac{\pi}{2}$).
- The Hough transformation delivers two track candidates for each track. For d_0 close to 0 these two candidates are very close to eachother which leads to a lower track finding efficiency in this region.
- Excluding tracks with parameters in the critical regions leads to an even better track finding efficiency.

Conclusion and Outlook

Conclusion

- A Hough transformation for track finding was implemented.
  - It works for straight lines, helix segments and curler.
  - More than one track per event can be found.
  - Noise hits are rejected.
  - Hits do not need to be exctly on the track.
- Implemented as a library, which is currently used in MarlinTPC, but it can in principle be used in any other software framework.

Outlook

- Efficiency studies ongoing (Multi Track Events with 200 hits per track, helices, track separation, fake tracks).
- Improve the track finding algorithm.
  - Speed needs to be increased, ideas how to improve this exist.
  - Optimize algorithm to find tracks with higher efficiency.