Track Reconstruction in Time Projection Chambers

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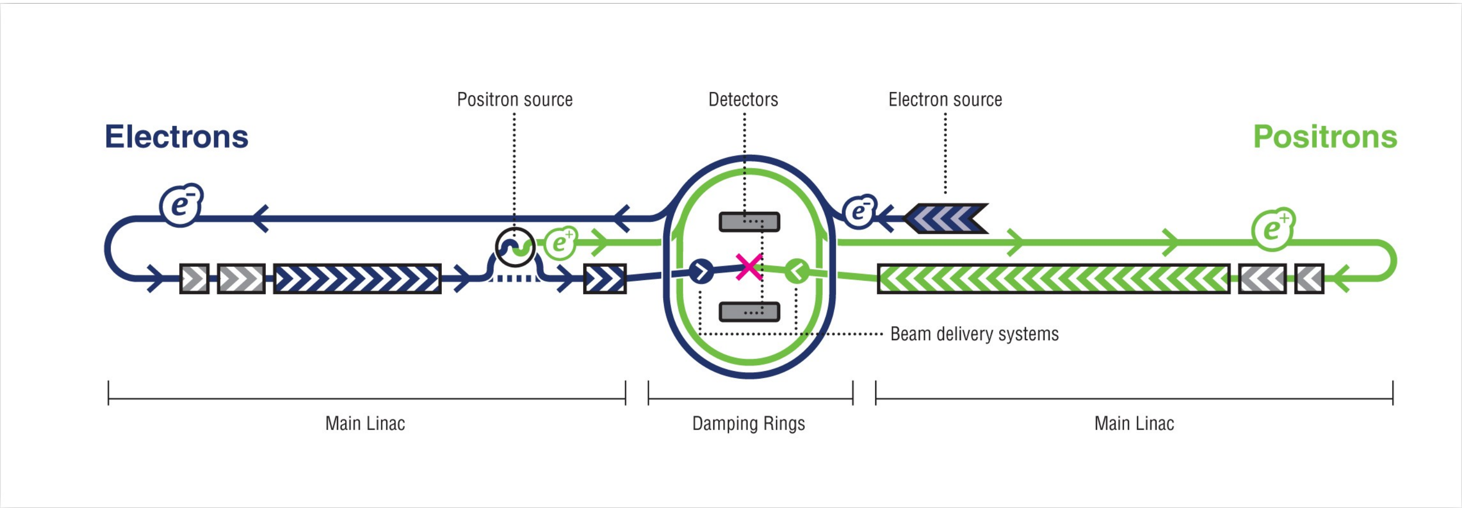
Outline

- The International Linear Collider
- The ILD Detector Concept
- Time Projection Chamber
- Reconstruction Software
- Low Level Reconstruction
- Track Finding
- Track Fitting
- Summary

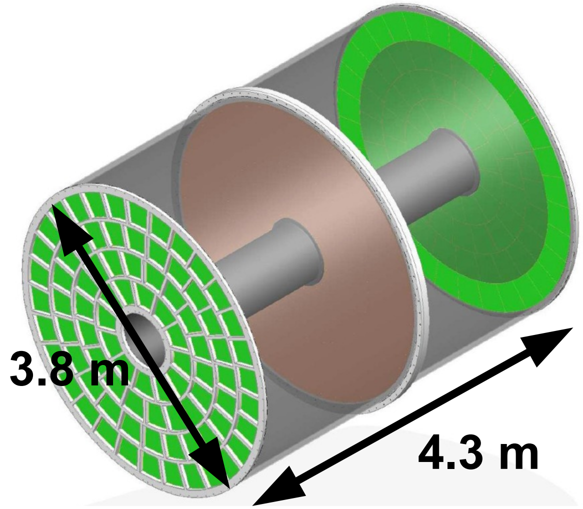
The International Linear Collider

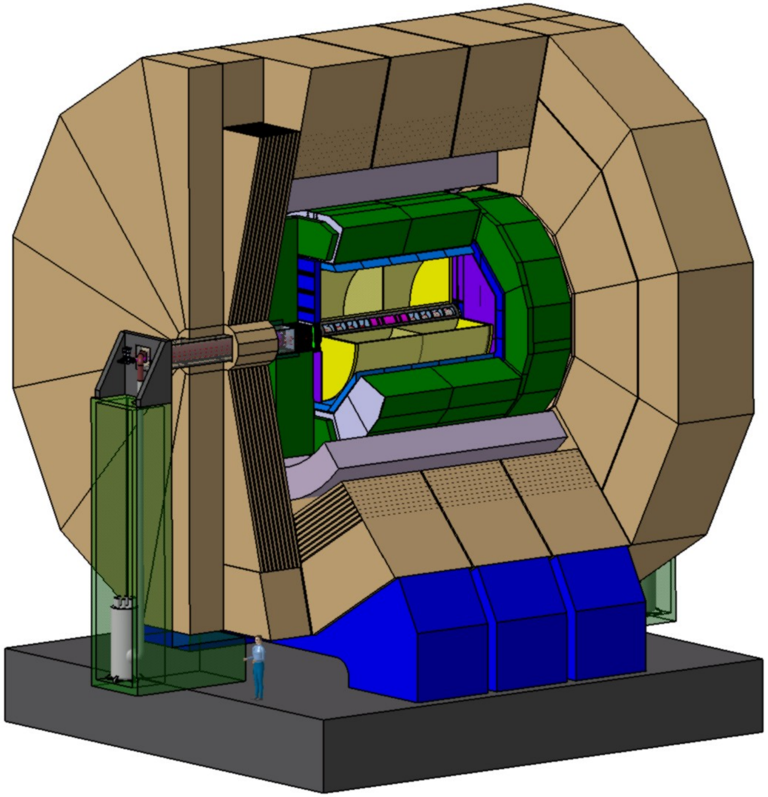
- Linear accelerator
- Electron-positron collisions at 200- 500 GeV (possible upgrade to 1 TeV)
- Length: 31km
- 2 detectors



The ILD Detector Concept

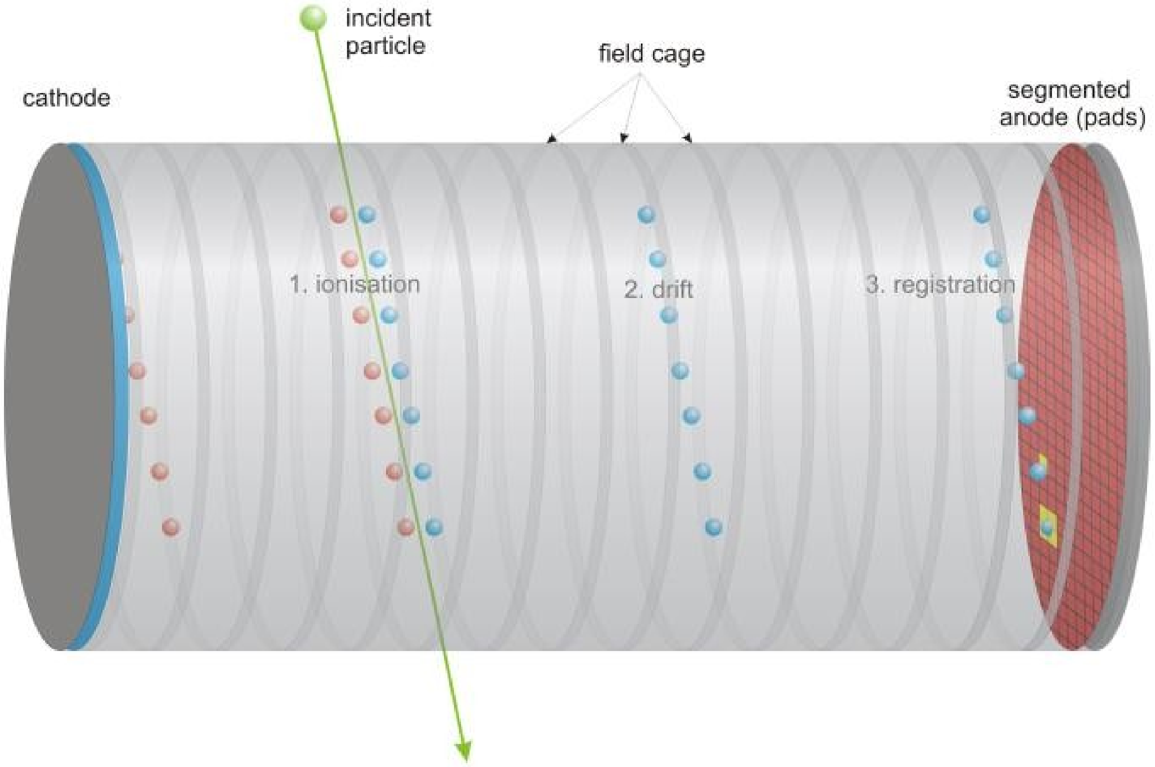
- International Large Detector
- Size:
- Particle Flow Concept
- Central Tracking System: Time Projection Chamber (TPC)
- Size: diameter: 3.8 m; length 4.3 m





Time Projection Chamber

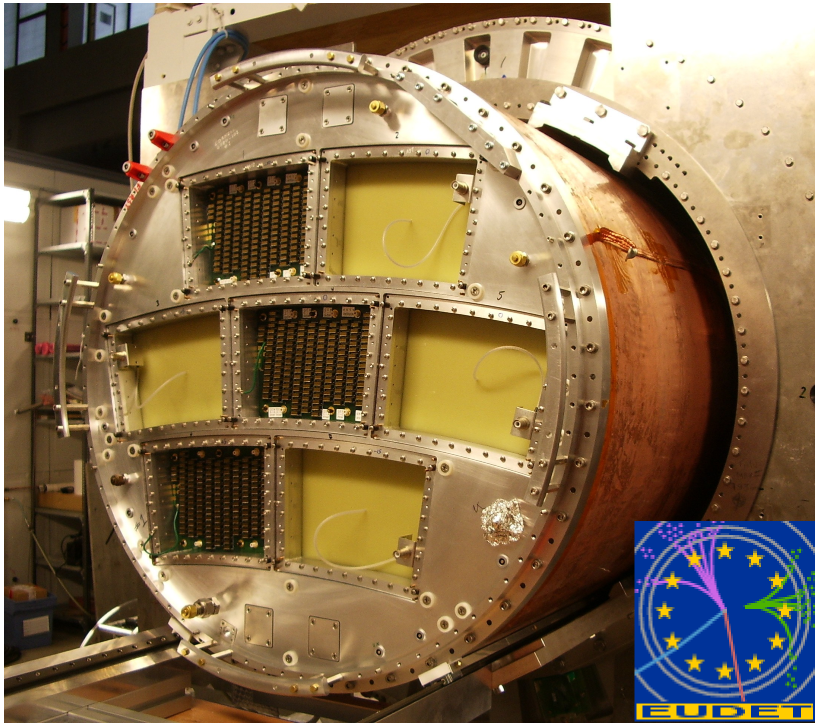
- In principle a cylinder filled with gas in an electric field
- A charged particle ionizes the gas, the electrons drift to the anode where they can be read out



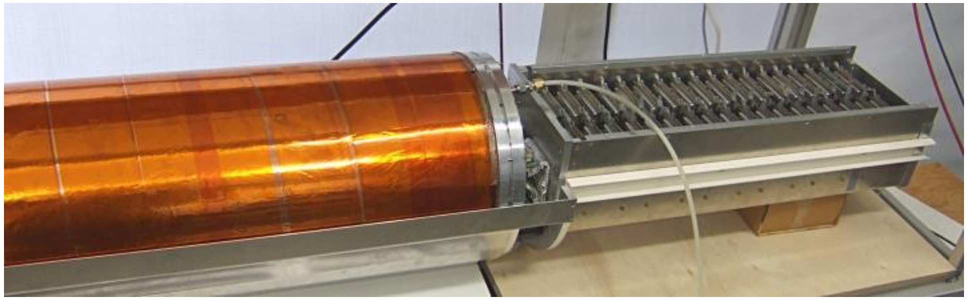
TPC Prototypes

Small TPC
Ø: 25 cm; Length: 22 cm

Large Prototype
Ø: 77 cm; Length 61 cm



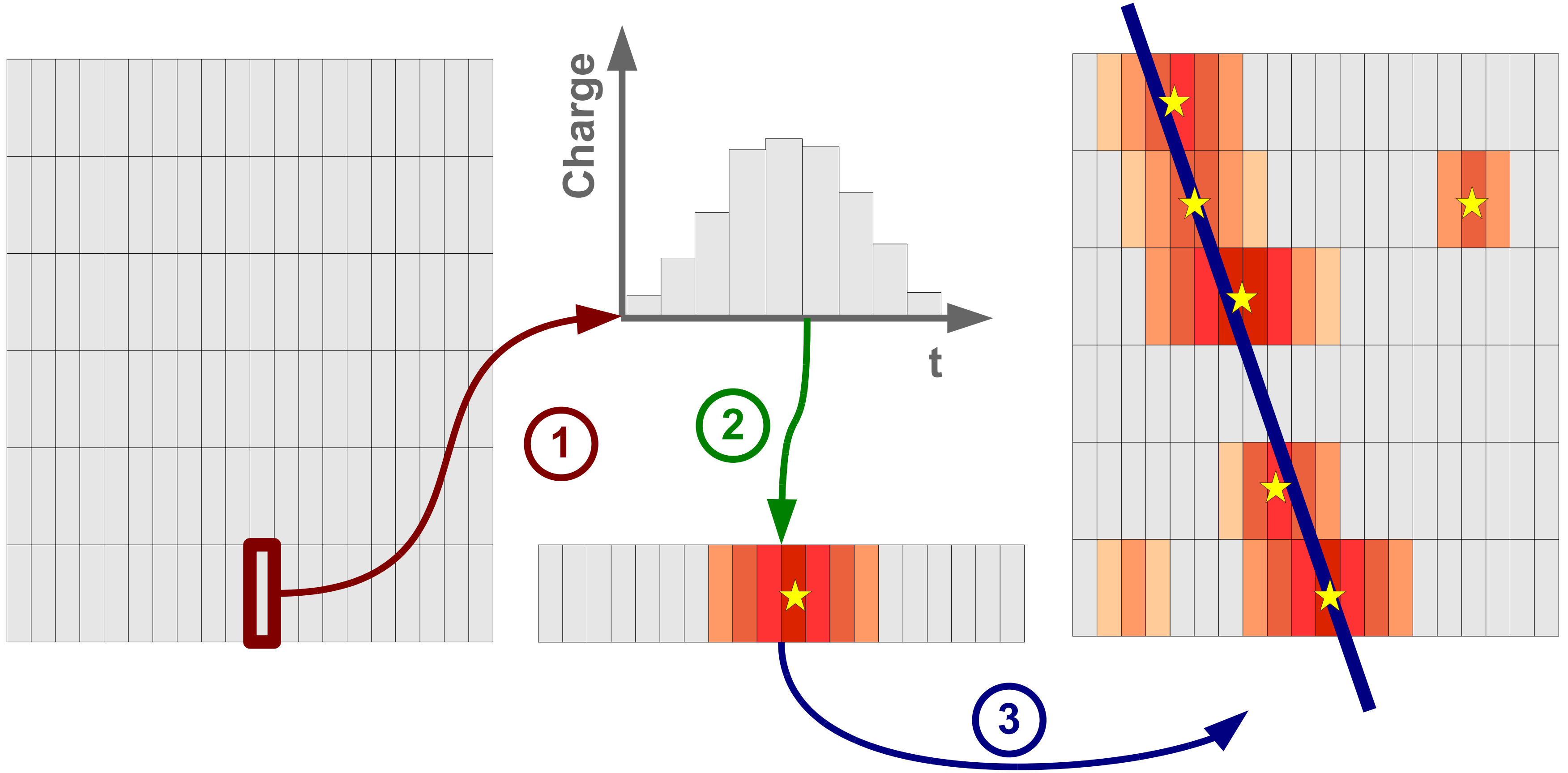
MediTPC
Ø: 27 cm; Length: 80 cm



Reconstruction Software MarlinTPC

- For small prototypes only reconstruction software with very limited functionality was available
- Idea: Have a common reconstruction software for all prototypes
- MarlinTPC is based on Marlin (**M**odular **A**nalysis & **R**econstruction for the **Lin**ear Collider)
- Allows parallel development of different reconstruction chains

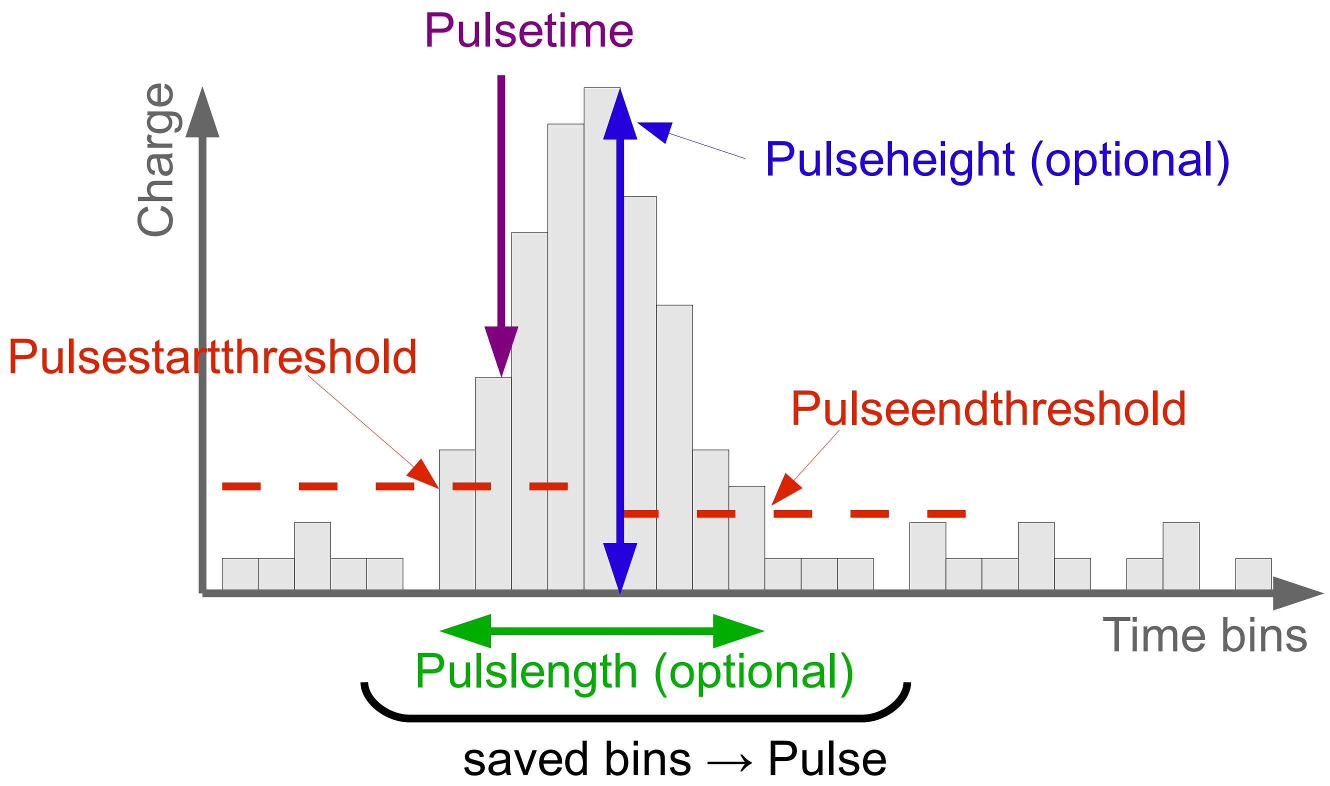
Track Reconstruction Algorithm



1. Look for pulses on pads.
2. Combine pulses on neighboring pads in a row to hits.
3. Tracking (track finding and track fitting).

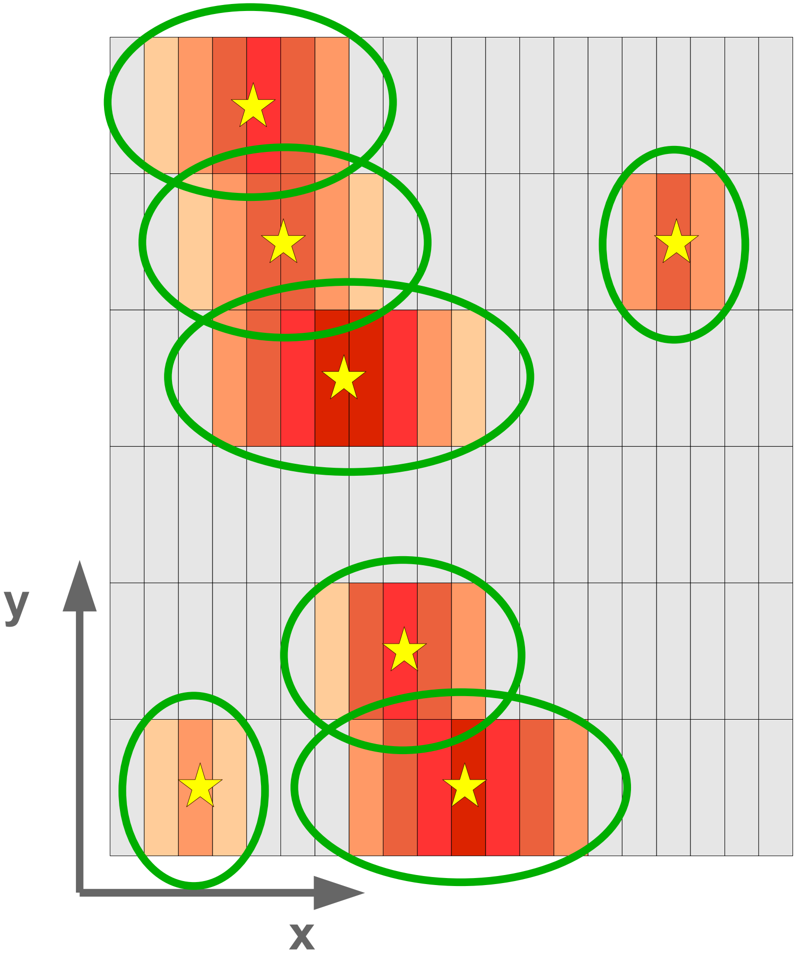
Low Level Reconstruction: Pulses

- Pulse Time: mean of rising edge
- Pulse Charge: Sum of charge in all time bins belonging to the pulse



Low Level Reconstruction: Hits

- Pulses on adjacent pads in the same row
- Hit maximum (maximum of highest pulse)
- X position: Center of gravity of charge
- Y position: Center of Pad in y direction
- Z position: calculated from the pulse time of the highest pulse



Track Finding

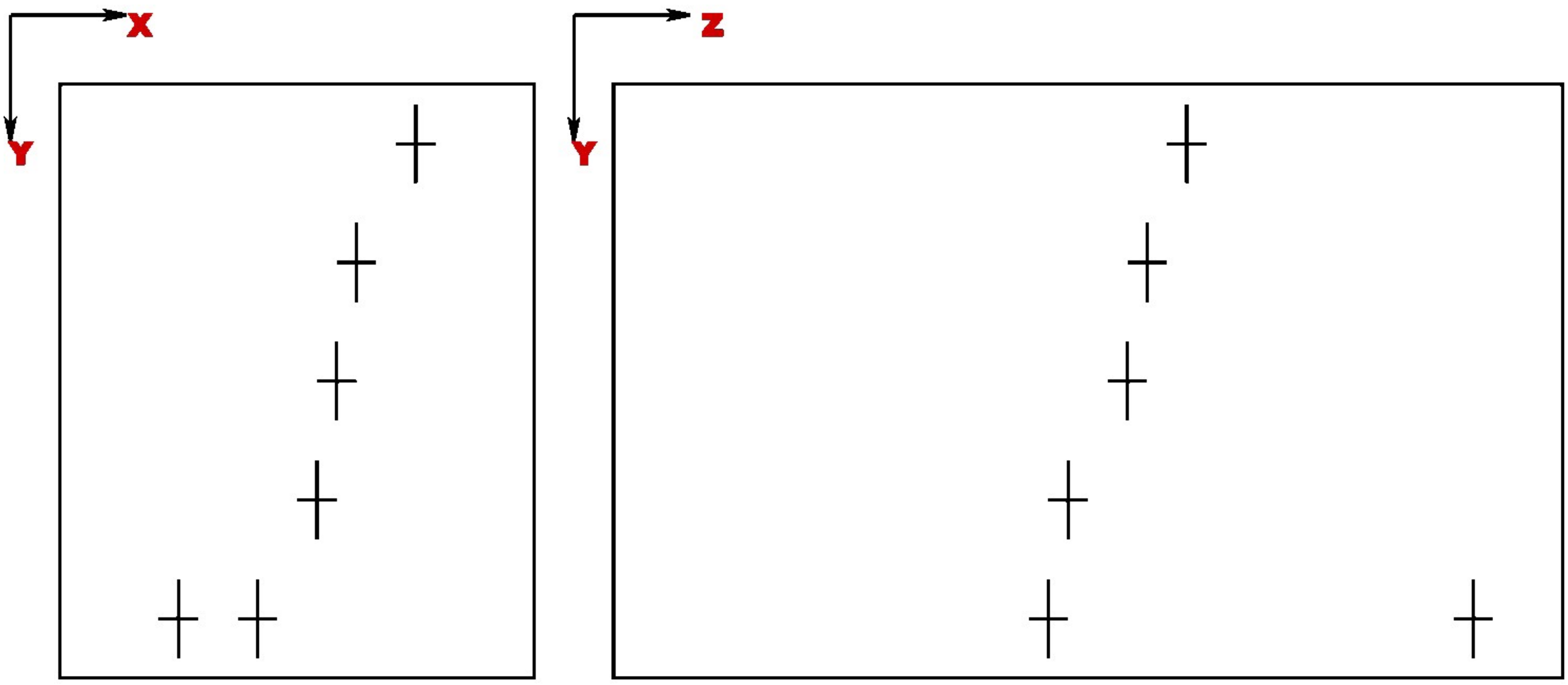
- Pattern recognition, find hits which are on a track
- A lot of different methods
- <u>Local methods:</u>

  selecting track candidates first, with only a few hits, then step by step add more hits
- <u>Global methods:</u>

  all hits enter into the algorithm at the same time and in the same way
- Two implemented track shapes: straight line or helix

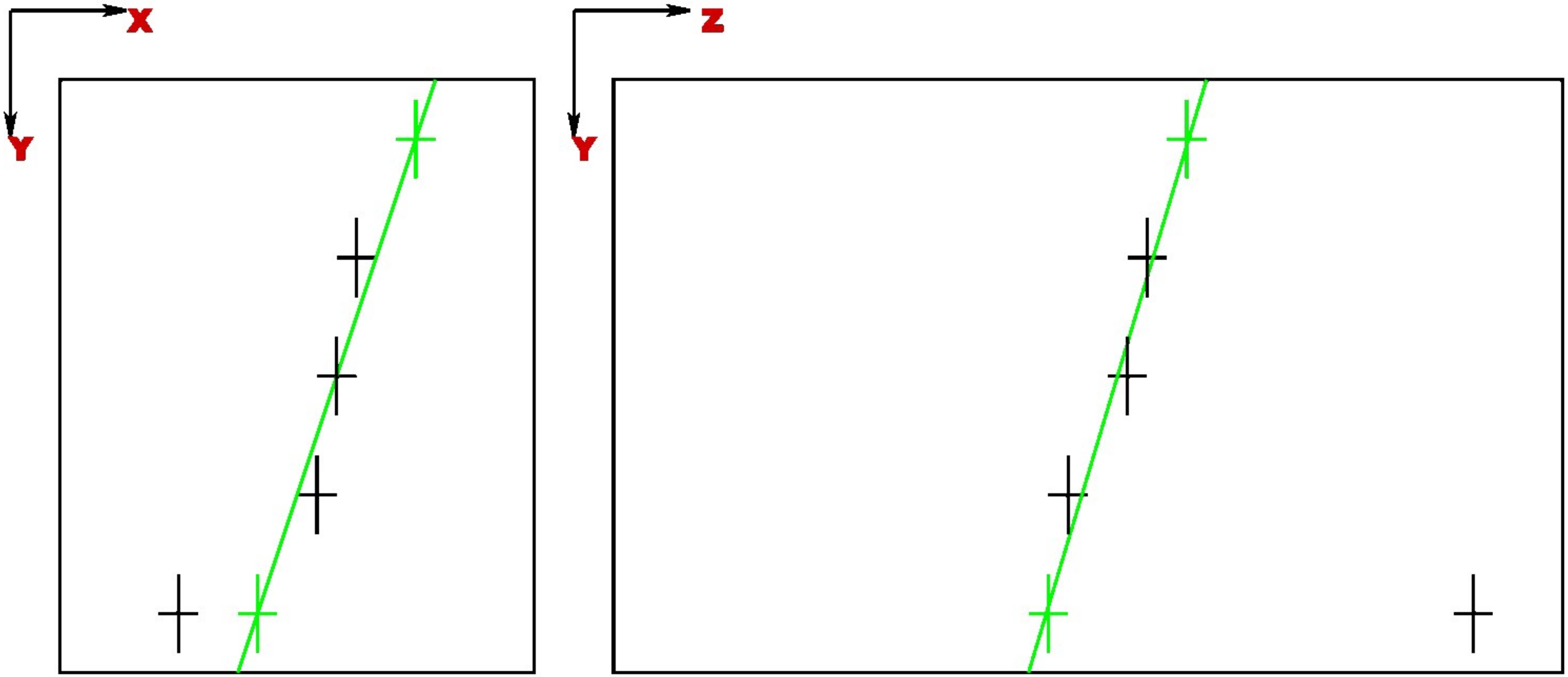
Track Finding: Local Methods
Simple Linear Track Finding

- For Straight Tracks: Linear Track Finding
- Mainly used for small prototypes



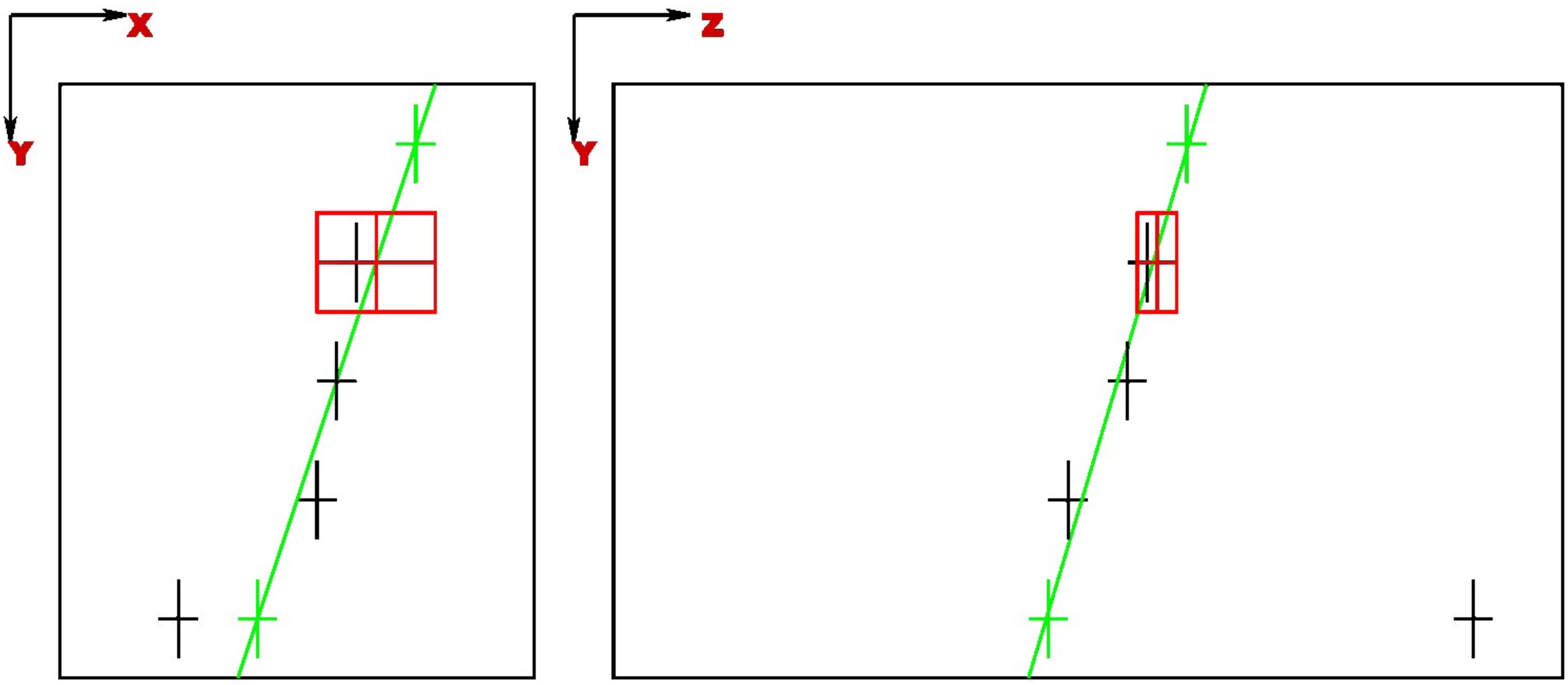
Track Finding: Local Methods
Simple Linear Track Finding

- Guess a track candidate by choosing two hits
- Fit a straight line



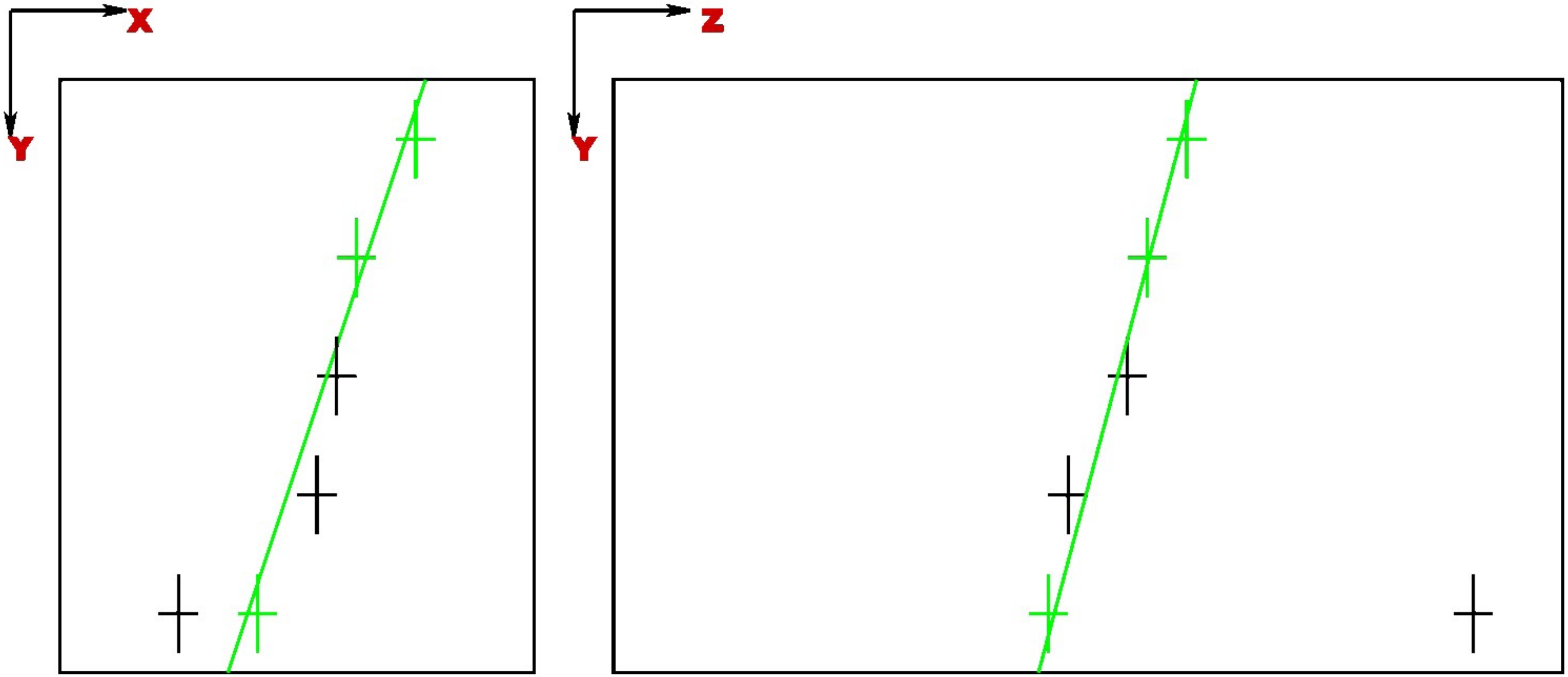
Track Finding: Local Methods

- Search inside a certain window for a hit in the next line



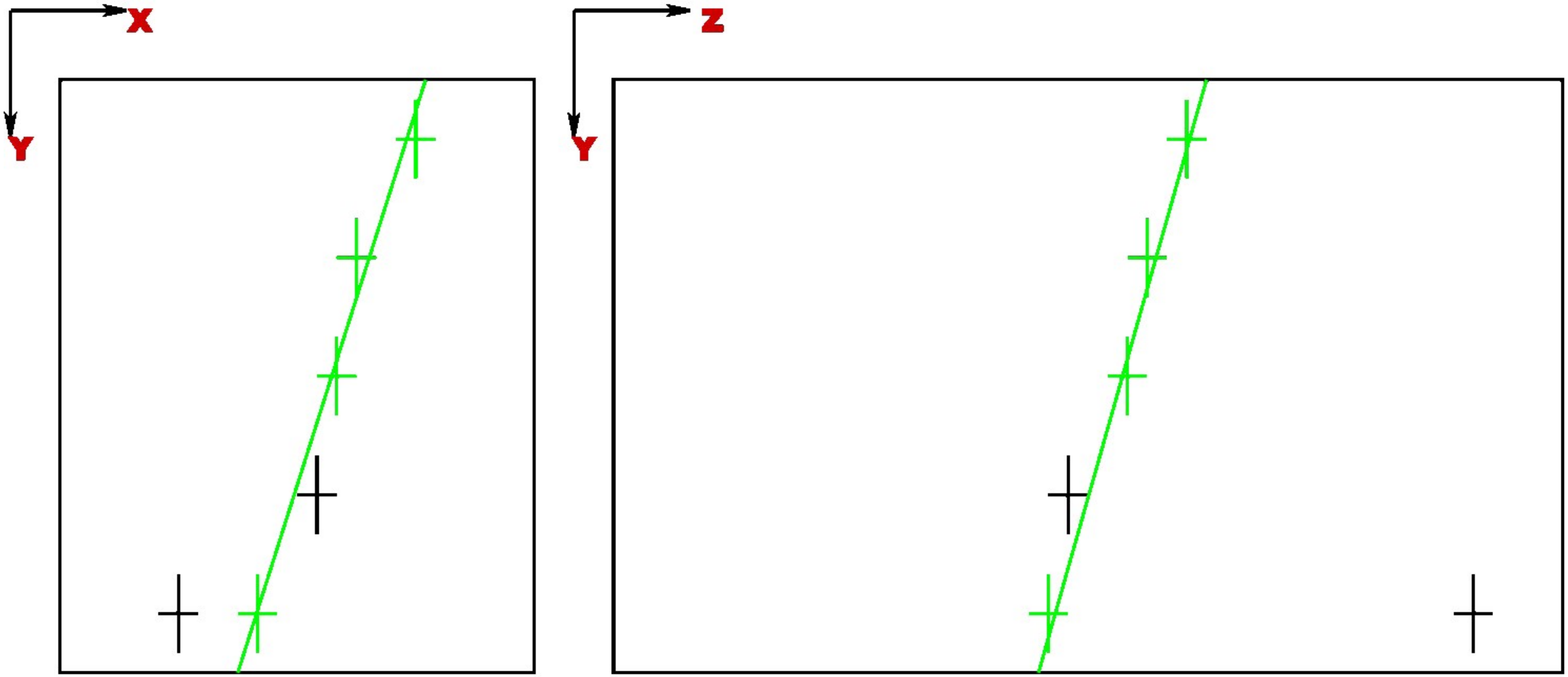
Track Finding: Local Methods
Simple Linear Track Finding

- Do a new fit with three hits



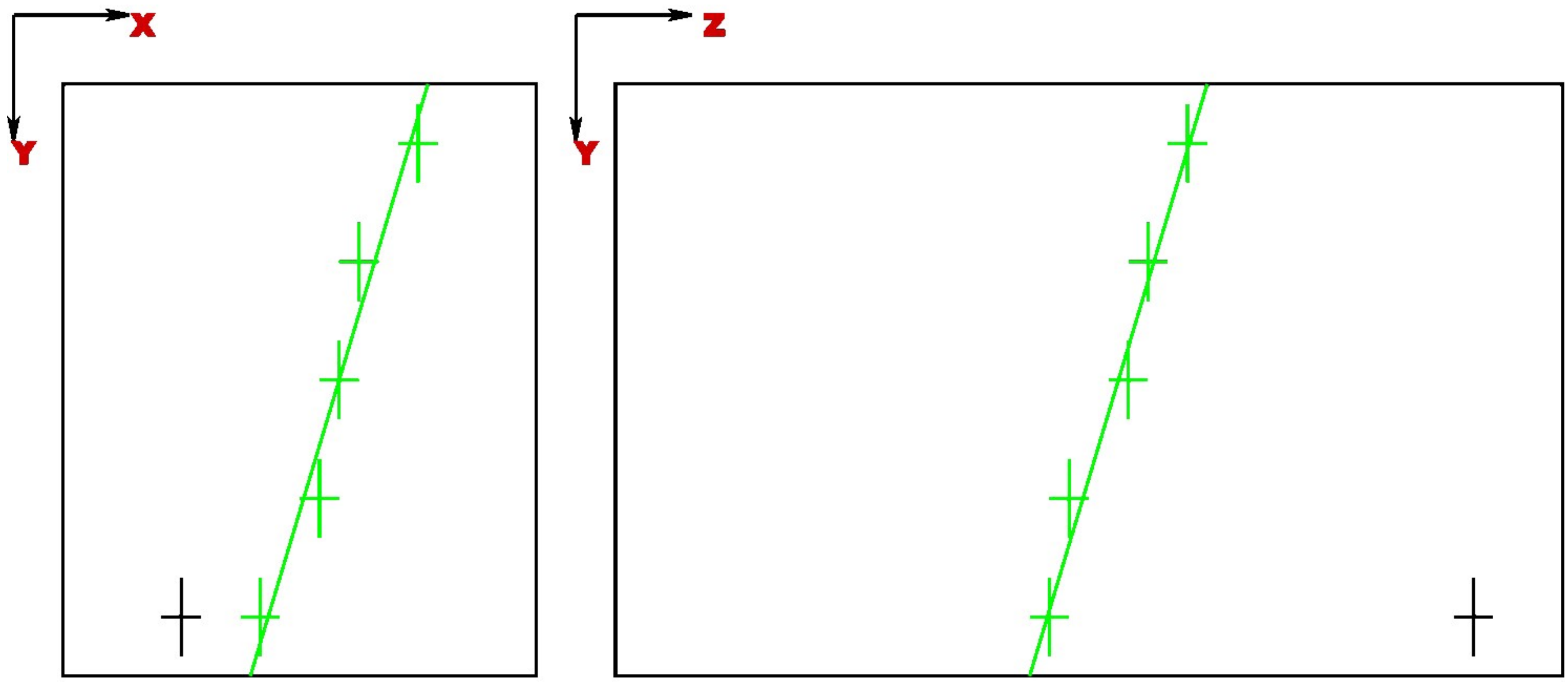
Track Finding: Local Methods
Simple Linear Track Finding

- Continue this procedure ...



Track Finding: Local Methods
Simple Linear Track Finding

- ... until all possible hits are added to the track



Track Finding: Local Methods
Kalman Filter

- Similar to previous method
- Can be used for any track shape
- Fit is not completely redone after every step
- Includes track fitting
- More information can be found in:

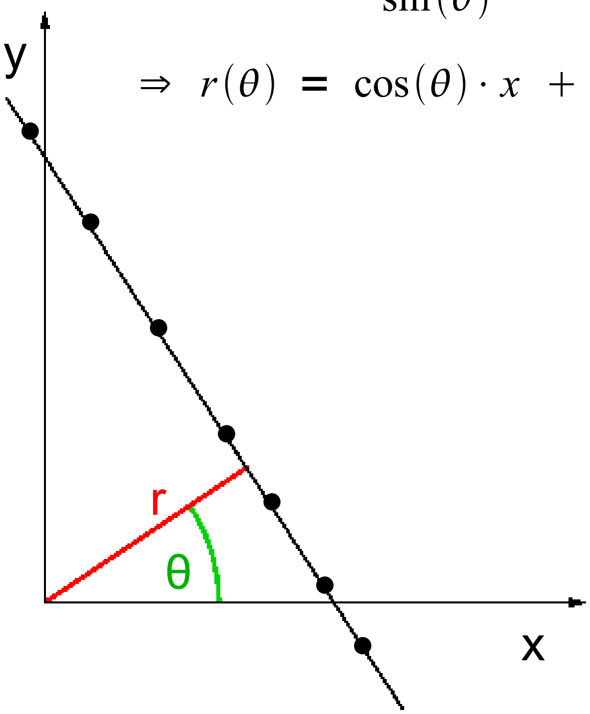
  "Applied Fitting Theory V: Track Fitting Using the Kalman Filter", Paul Avery, 1992

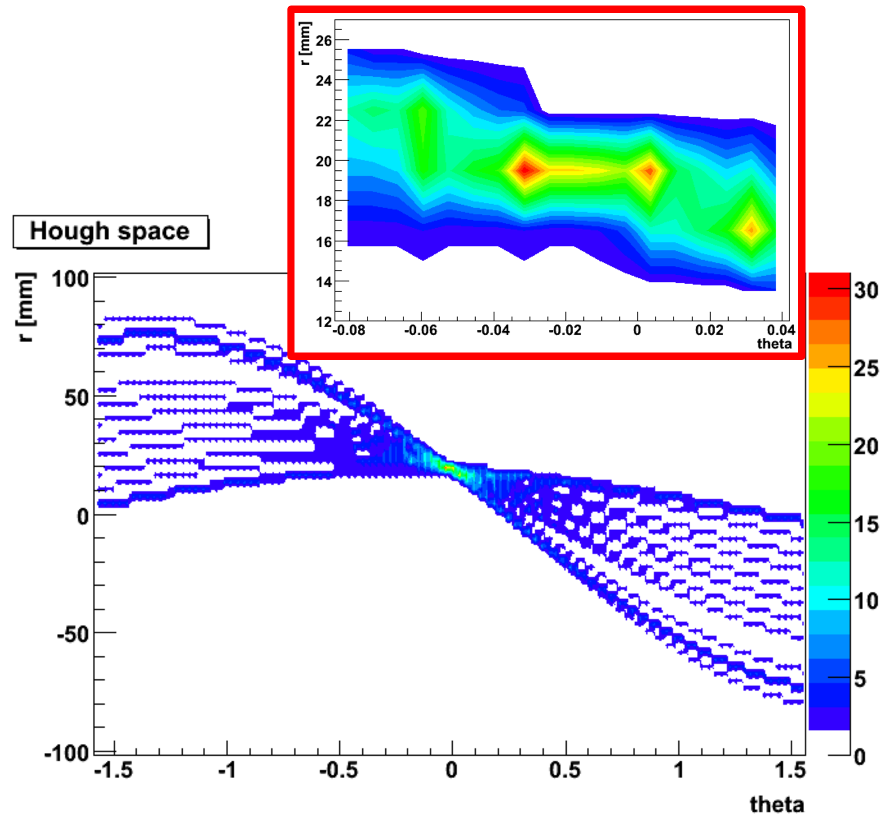
Track Finding: Global Method
Hough Transformation

- Track model: straight line
- Two parameters needed to describe straight line
- If hits are on a straight line, the Hough transformed functions of these hits intersect in one point in Hough Space

$$y(x) = -\frac{\cos(\theta)}{\sin(\theta)} \cdot x + \frac{r}{\sin(\theta)}$$

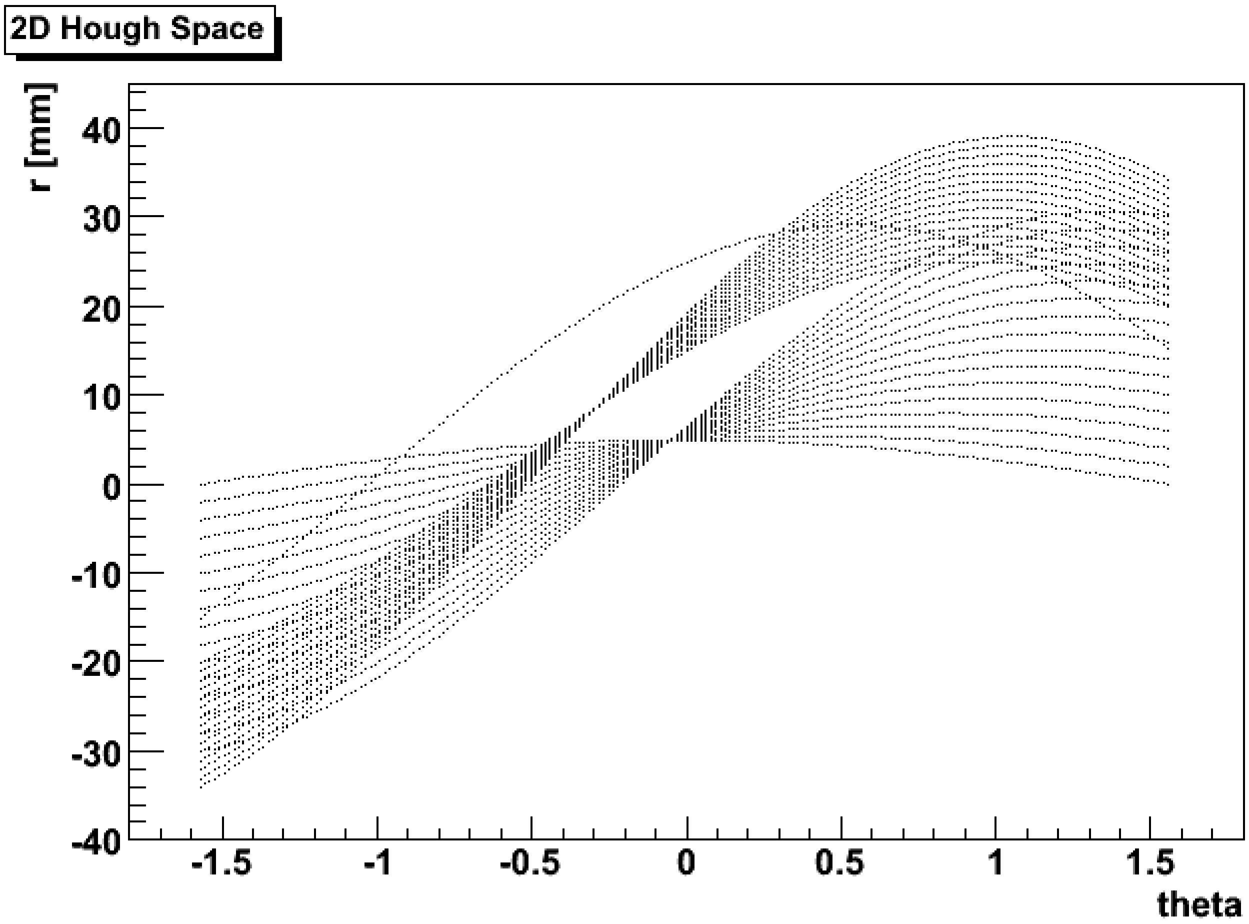
$$\Rightarrow r(\theta) = \cos(\theta) \cdot x + \sin(\theta) \cdot y$$





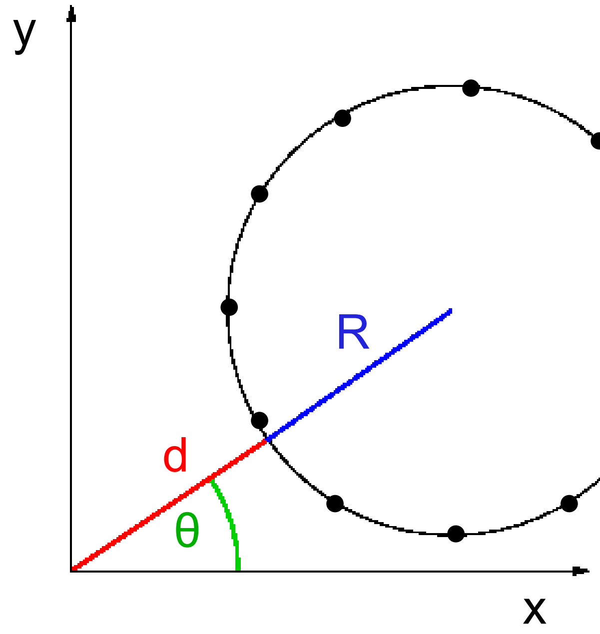
Track Finding: Global Method
Hough Transformation

- Hough Space for two straight lines and one noise hit



Track Finding: Global Method
Hough Transformation

- Track model: circle
- Three parameters needed to describe a circle
- Analogous to straight line



$$R^2 = (x - x_M)^2 + (y - y_M)^2$$
$$x_M = (R + d) \cdot \cos(\theta)$$
$$y_M = (R + d) \cdot \sin(\theta)$$

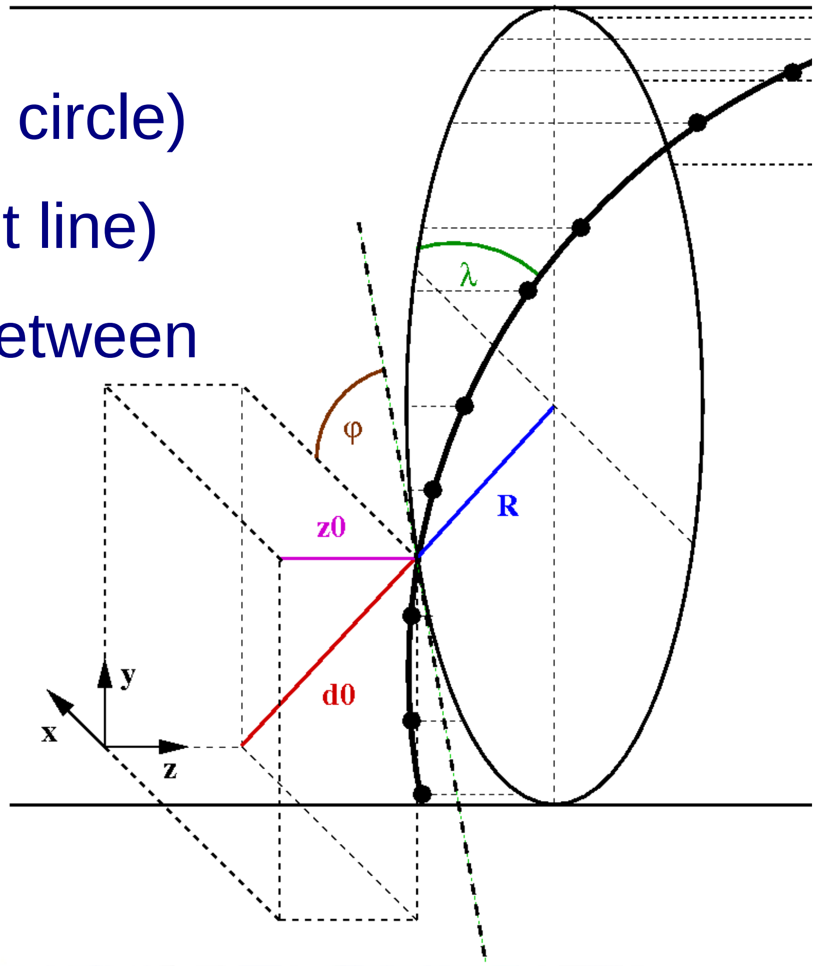
$$\Rightarrow R(d, \theta) = \frac{x^2 + y^2 + d^2 - 2d \cdot (x \cdot \cos(\theta) + y \cdot \sin(\theta))}{2 \cdot (x \cdot \cos(\theta) + y \cdot \sin(\theta) - d)}$$

⬇

3D Hough Raum

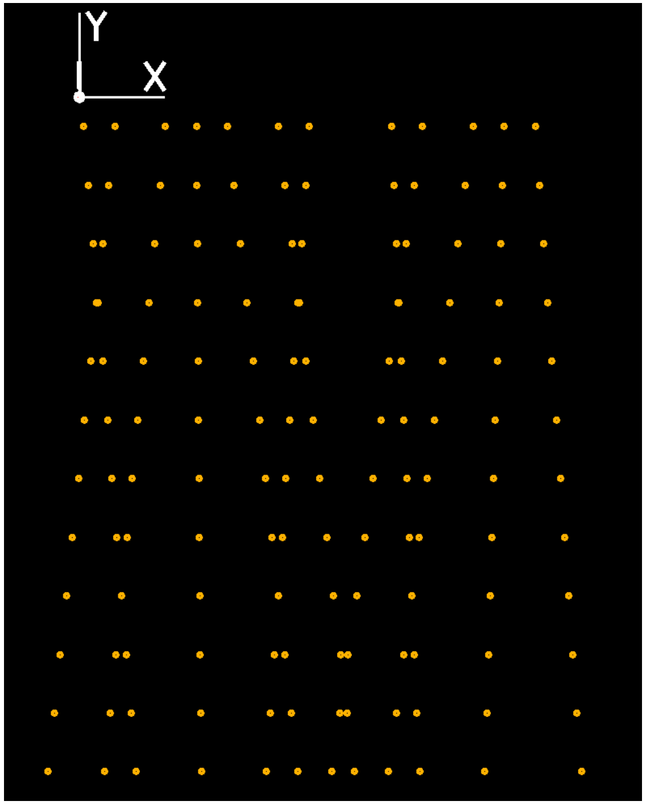
Track Finding Algorithm

- Helix can be described by 5 parameters
- This would mean a 5-dim Hough Space
- Do search in two projections
- Search in xy plane (straight line or circle)
- Search in sz plane (always straight line)
- "s" is the arc length on the circle between a reference point (point of closest approach in xy plane) and the hit



Track Finding Results

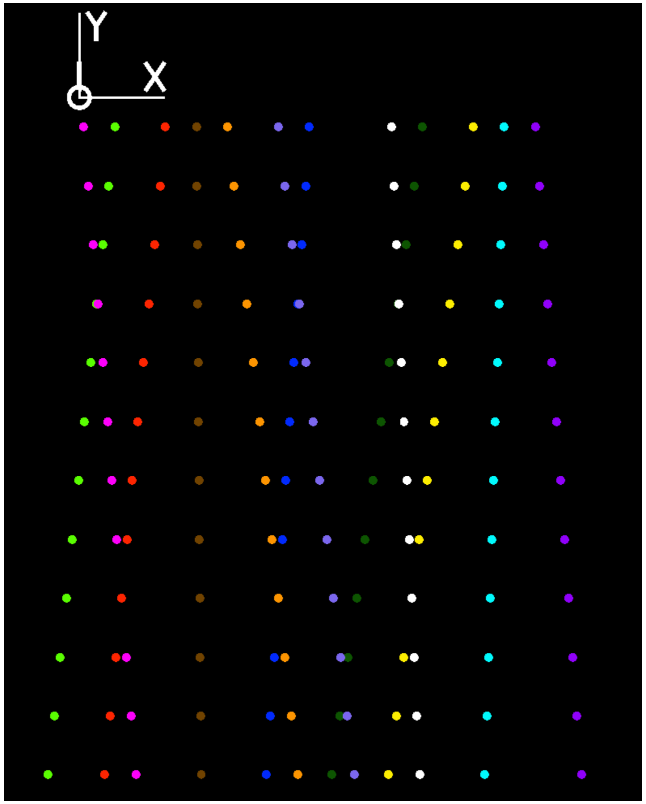
xy projection



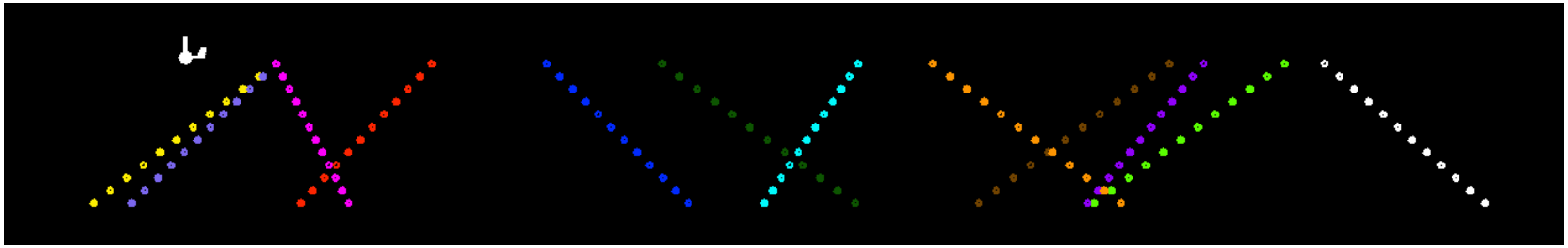
zy projection

Track Finding Results

xy projection



zy projection



Track Fitting

- Determination of track parameters and their errors
- Least squares method
- Kalman Filter: delivers chi squared fit results

Least Squares Method

- N Measurements: y_i
- Uncertainties of measurements: σ_i
- Fit function: $f(x_i; a_1, \ldots, a_M)$
- M Parameters to be determined: $a_1, \ldots, a_M$
- N>M !
- For best set of parameters sum S is minimal:

$$S = \sum_{i=1}^{N} \left[\frac{y_i - f(x_i; a_1, \ldots, a_M)}{\sigma_i} \right]^2$$

- Straight Line: $f(x_i; a_1, a_2) = a_1 \cdot x_i + a_2$
- Circle: $f(x_i; a_1, a_2, a_3) = \pm\sqrt{a_1^{\,2} - (x_i - a_2)^2} + a_3$

Summary

- A time projection chamber is planned for a detector at a future linear collider, various prototypes have been built.
- A new software is written to reconstruct large prototype data.
- There is a variety of methods for track finding.
- The Kalman Filter cannot only do the track finding but also deliver the track fitting result.
- The Hough Transformation is a nice method because the whole event information is used at the same time.

Acknowledgments

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