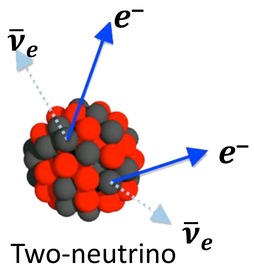
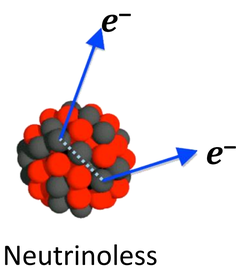
Reconstruction of Complex Particle Trajectories in the SuperNEMO Detector

SuperNEMO detector

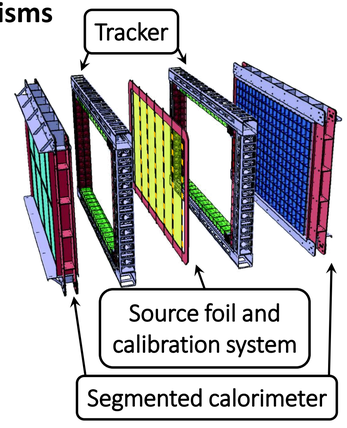
- **Powerful tool to study the physics of double beta ($\beta\beta$) decays**
- **Taking data** since April 2025
- $\beta\beta$ standard observable – sum of the two electrons' energies
- **Unique design = calorimetry + tracking:**
  - Full event topology reconstruction (decay angle, single e⁻ energy)
  - Allows to study **exotic $\beta\beta$ modes** and its **mechanisms**



Two-neutrino $\beta\beta$ decay



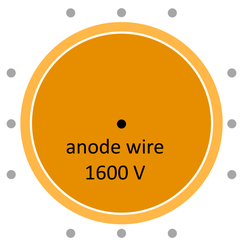
Neutrinoless $\beta\beta$ decay

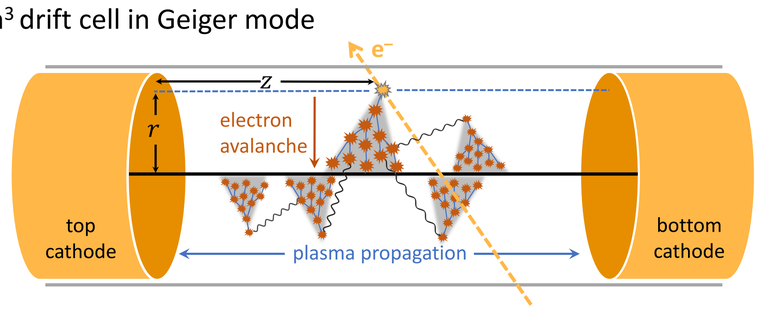


- **Main components:**
  - **Source foil:** 6.11 kg of ^{82}Se
  - **Tracker:** multiwire chamber (2034 drift cells) → **topology**
  - **Segmented calorimeter:** 712 optical modules → **energy**
  - **^{207}Bi calibration system:** 7 x 6 grid of point-like deployable sources

Tracker cell

- 44 x 44 x 3030 mm^3 drift cell in Geiger mode



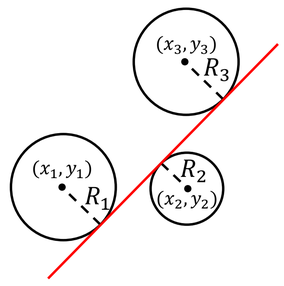


- Measures position of a passing charged particle:
  - Electron avalanche → Distance to anode wire (r)
  - Plasma propagation → Vertical position (z)

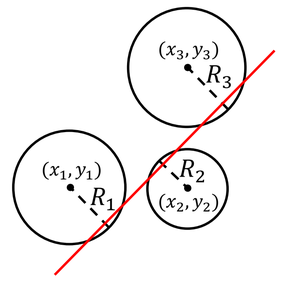
Tracker hit = circle tangent to the track

Track reconstruction problems

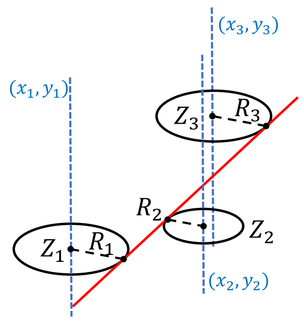
- Magnetic field currently turned off → **straight line trajectories**
- The problem is in 3D, but the difficult part is in the horizontal plane:
  - 3 exemplary tracker hits = 3 triggered anode wires (x_i, y_i) and 3 measured distances R_i = 3 circles
  - **Goal: find common tangent line**



Ideal situation:
Mathematically precise data



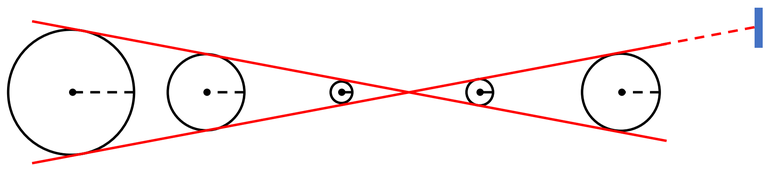
Realistic situation:
measurement errors
(no exact solution)



Full 3D problem
(simple if the 2D solution is known)

Problem of ambiguity – which track is real?

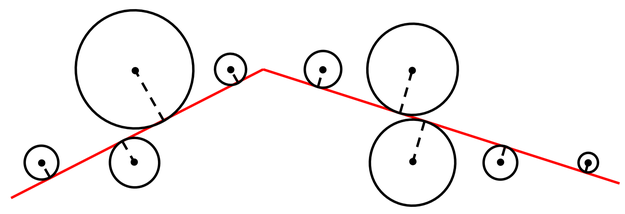
- Tracker hits aligned on a line → **mirror symmetry** = 2 equal solutions
- Impossible to decide based on tracker data only → **We need both solutions!**
- Different possible orientations of the symmetry line



Non-tracker data can help decide! For example, ^{207}Bi calibration source position

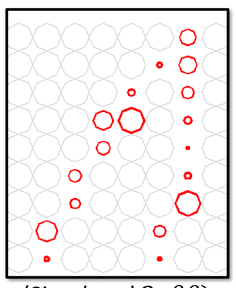
Problem of kinked trajectories

- Sudden change in direction of the particle → **kinked trajectory** (polyline model)
- How do we distinguish between two straight tracks and one kinked track?



Cimrman Reconstruction Module

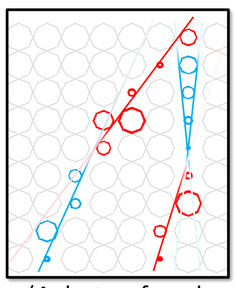
Input tracker data → **Clustered data** → **Fitted linear parts** → **Polyline trajectories**


(Simulated $2\nu\beta\beta$)

Clustering phase

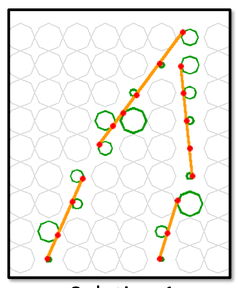
Iteratively switching between:

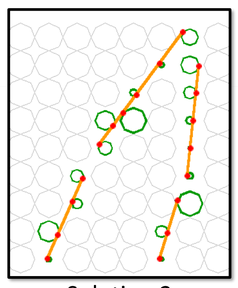
1. Spatial separation of hits → optimization (uses local characteristics)
2. Legendre transform method → 2D line fit estimates (uses global characteristics)


(4 clusters found, 5 line fits estimated)

Fitting phase

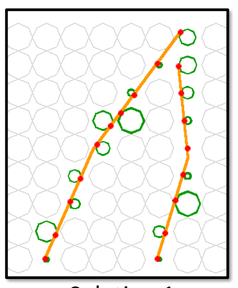
1. Maximum likelihood fits of identified clusters → Precise 3D line fits
2. Detection of ambiguities → mirroring 3D line fits
3. Combining ambiguities into alternative solutions

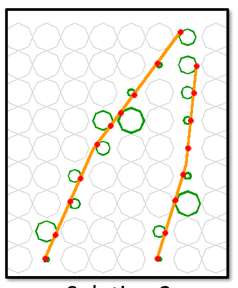

Solution 1

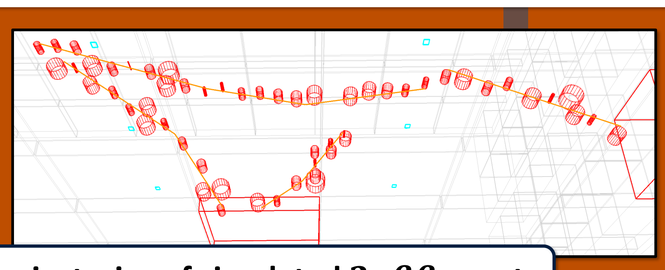

Solution 2

Connection phase

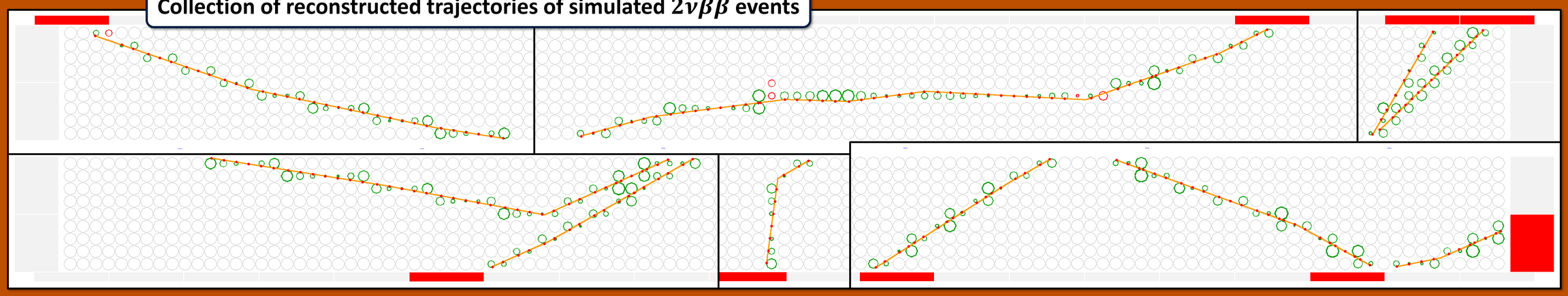
1. Connecting linear segments into polyline trajectories based on:
   - vertical distance
   - horizontal distance
   - kink angle
   - kink position
   - etc.
2. Additional refinements of clustering and fitting decisions based on the trajectory shape


Solution 1


Solution 2



Collection of reconstructed trajectories of simulated $2\nu\beta\beta$ events



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Tomáš Křižák on behalf of the SuperNEMO collaboration

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