Tracking in SAND

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DUNE Italia Collaboration Meeting – Ferrara

October 29, 2024

Outline

- Latest results with KF
- Current status of the reconstruction algorithms
- What’s next

Trajectory parametrization

- **Trajectory state vector (a_k)**

$$\begin{pmatrix} x \\ y \\ q/R \\ \tan\lambda \\ \phi \end{pmatrix}$$

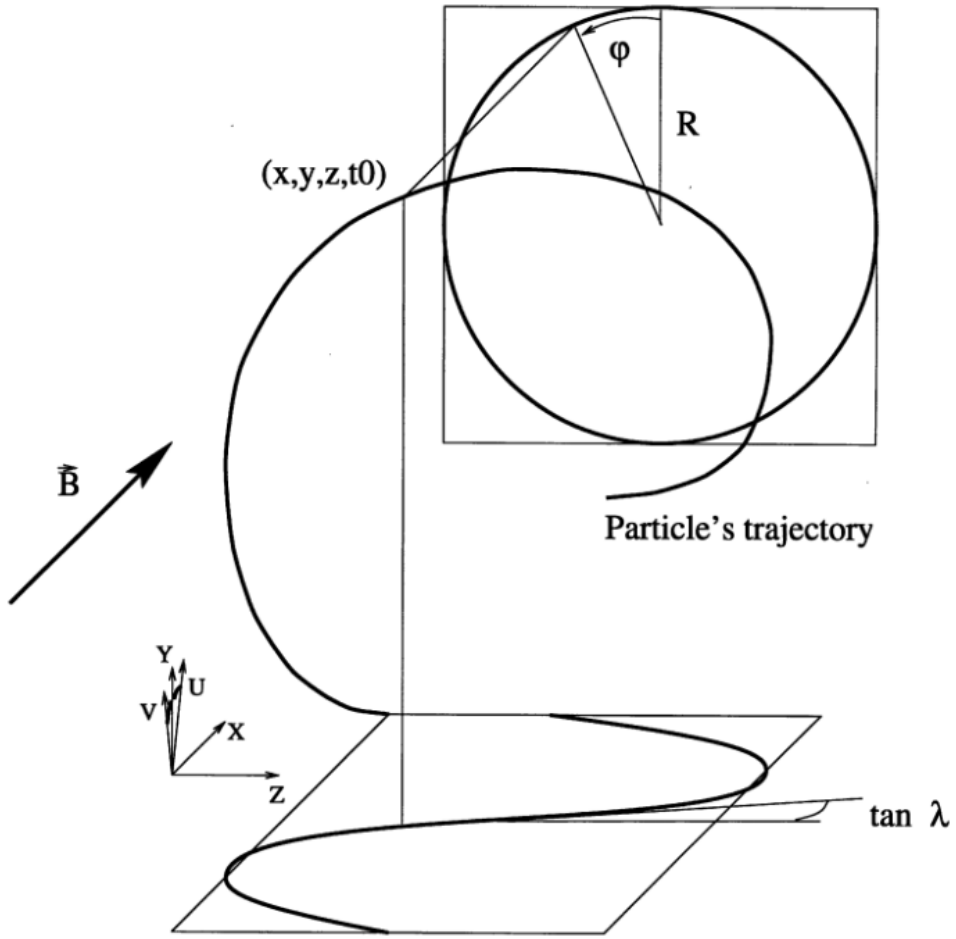
- x → x coordinate
- y → y coordinate
- q/R → signed inverse radius
- $\tan\lambda$ → tangent of dip angle
- ϕ → rotation angle

- **Measurement vector (m_k)**

$$m_x = \begin{pmatrix} x \\ \theta_{xz} \end{pmatrix}$$ Angle in the horizontal plane wrt z-axis

$$m_y = \begin{pmatrix} y \\ \theta_{yz} \end{pmatrix}$$ Angle in the vertical plane wrt z-axis

- KF propagation from downstream to upstream



Recap of last year presentation

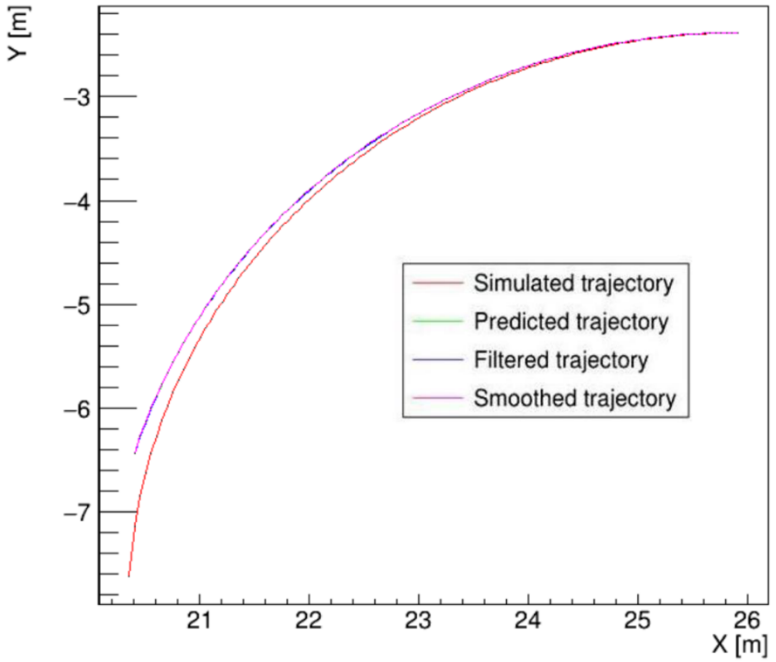
- Kalman filter tested with ideal circular trajectories:
  - No energy loss
  - No MCS
  - No track finding

- No convergence of the algorithm

Current checks

The reconstructed trajectory diverge even for small smearing of the initial state, suggesting the existence of a wrong implementation of the code.

	Starting state	Smeared state
X	0	0.00027
Y	-2.385	-2.384
1/R	-0.1779	-0.175
$tan\lambda$	0	0.0092
ϕ	1.571	1.576



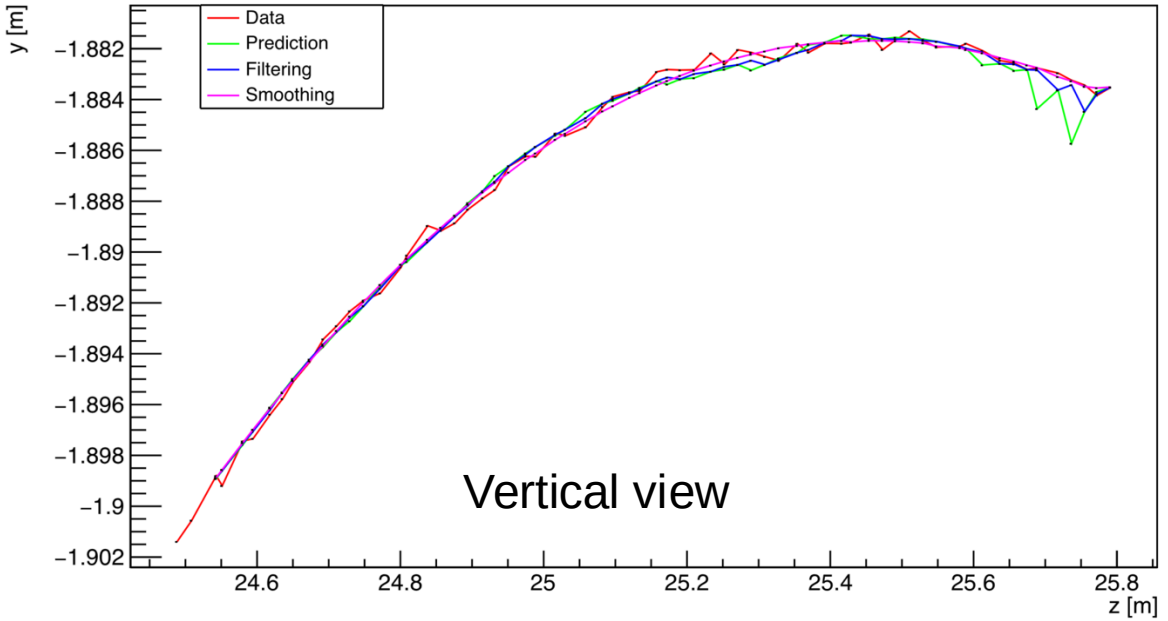
16 7th November 2023 Kalman Filter status update

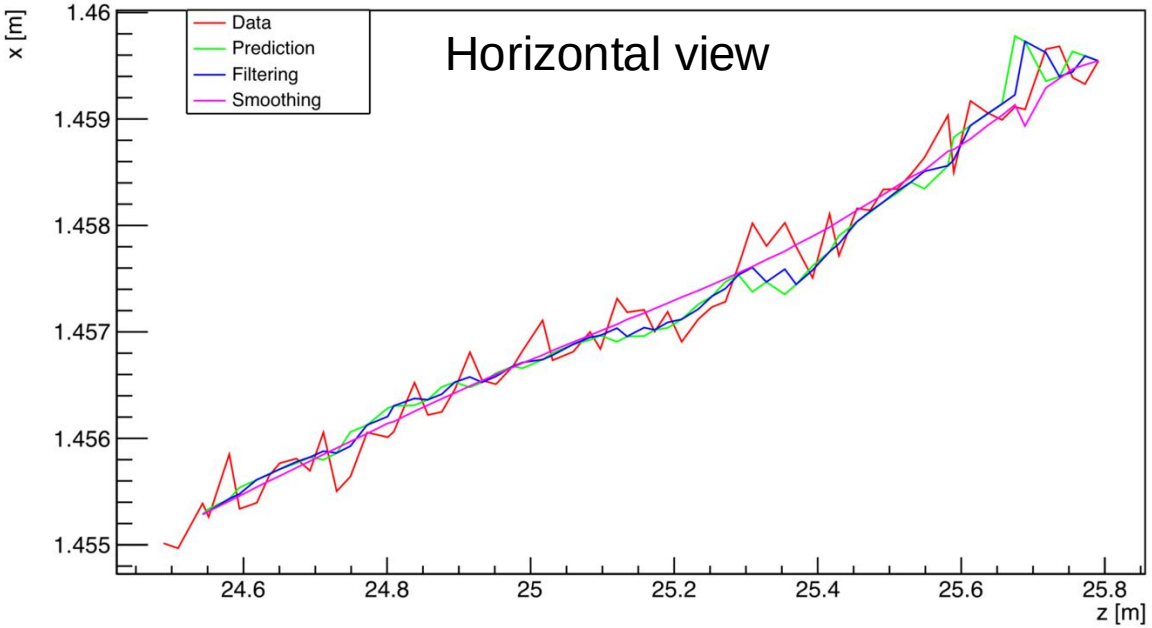
Past year KF activities

- Fixed algorithm implementation
- Added energy loss
- Added MCS
- Added simulated trajectories as input

- Performed statistical tests to validate the algorithm

- Preliminary performance evaluation of the algorithm





[Giulia Lupi Thesis]

[ND Simu/Reco presentation]

KF Standard consistency checks

Test applied to the KF algorithm to verify its consistency:

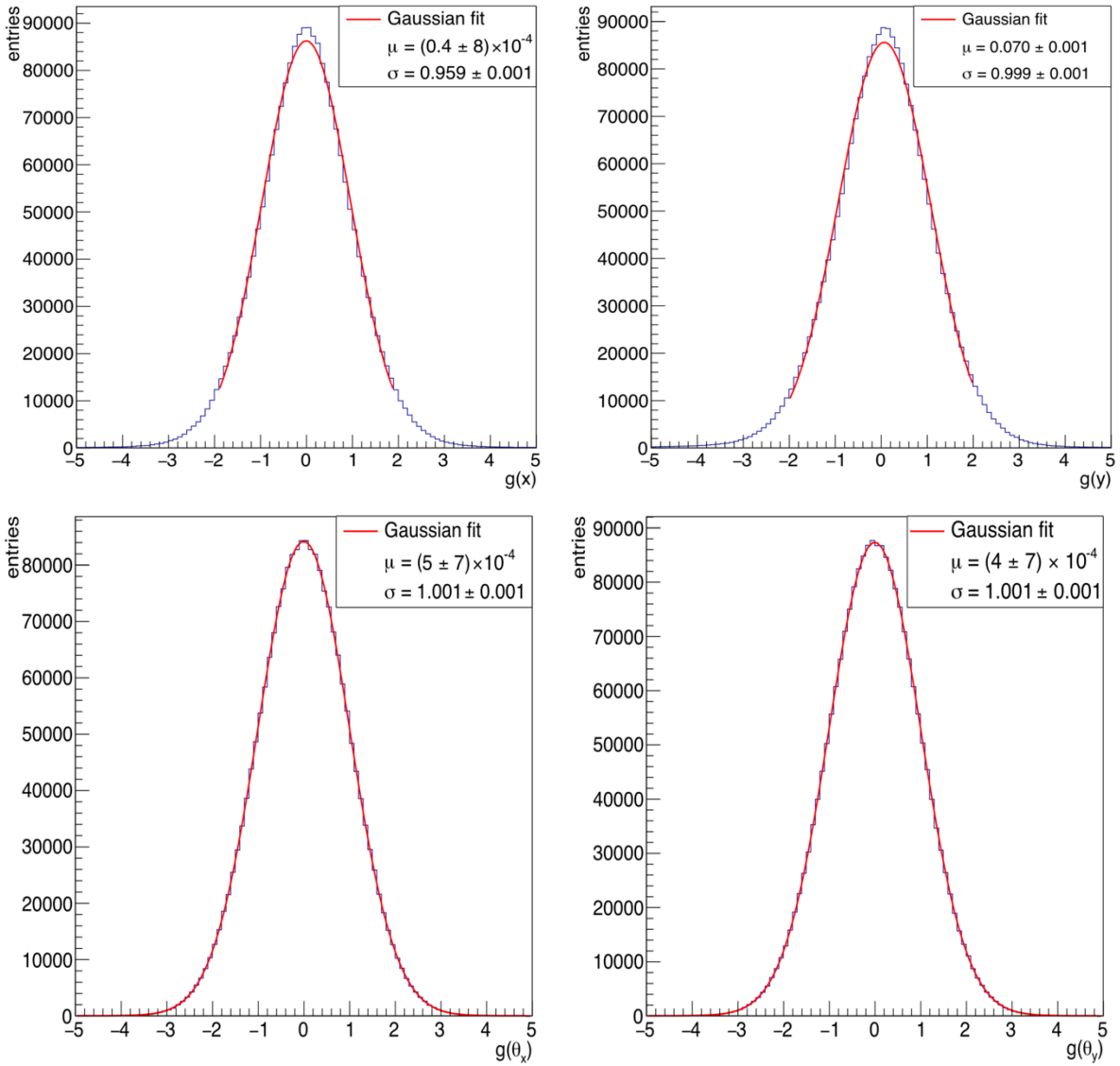
$$g(i)_k = \frac{r(i)_k}{\sqrt{C(i)_k}}$$

$$r_k = m_k^{pred} - m_k^{true}$$

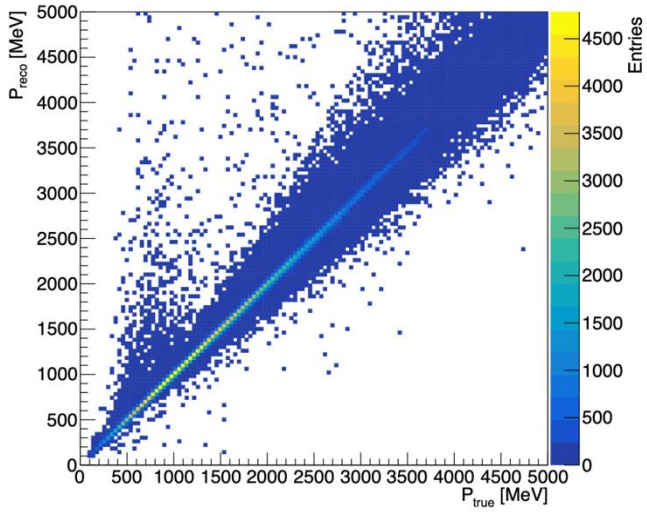
$r_k^i = i$-th element of the innovation at step k

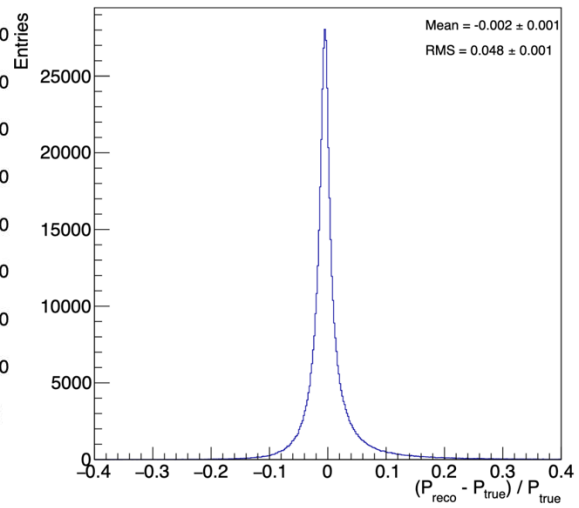
$C_k^i =$ corresponding element of the measurement covariance matrix

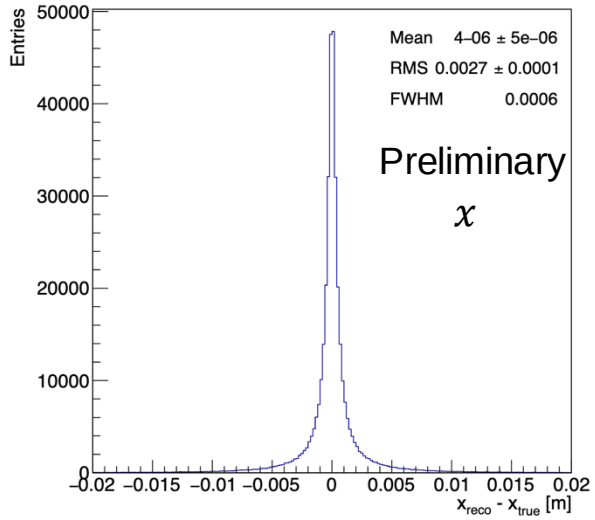
If the prediction is correct each $\boldsymbol{g^i}$ should be distributed as a **standard gaussian distribution** $(\boldsymbol{\mu = 0,\ \sigma = 1})$

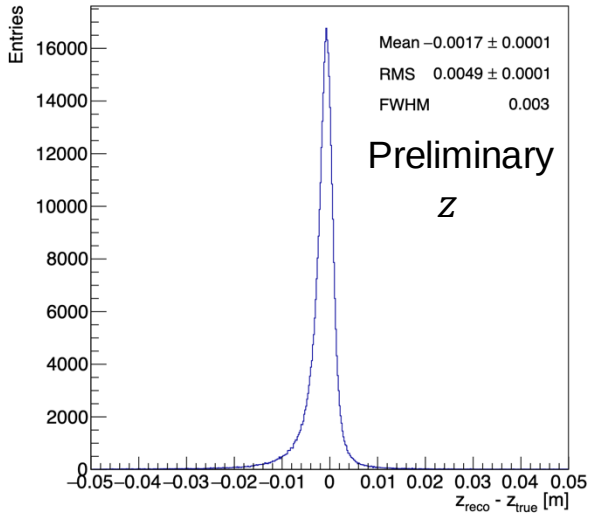


Track and vertex reconstructions









Preliminary performances of the algorithm evaluated by comparing true and **reconstructed values at the most upstream measurement** layer and by a preliminary **vertex reconstruction**

x [mm]		$\tan\lambda$		ϕ[mrad]		P [%]	
Mean	RMS	Mean	RMS	Mean	RMS	Mean	RMS
$< 10^{-6}$	0.4	$< 10^{-6}$	0.006	1.1	3.5	−0.2%	4.9%

	x [m]	y [m]	z[m]
Mean	10^{-6}	10^{-4}	−0.0017
RMS	0.0027	0.0019	0.0049
FWHM	0.0006	0.0006	0.003

Caveats

- Measurements obtained with a *fast* digitization
  - True particle info smeared and sampled at defined steps
- One measurement per layer
  - no track finding needed/performed
- Seeding from MC-truth
- PID from MC-truth
  - Mass and charge of the particle known

Caveats

- Measurements obtained with a *fast* digitization
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- One measurement per layer
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Realistic digitization algorithm

- Seeding from MC-truth

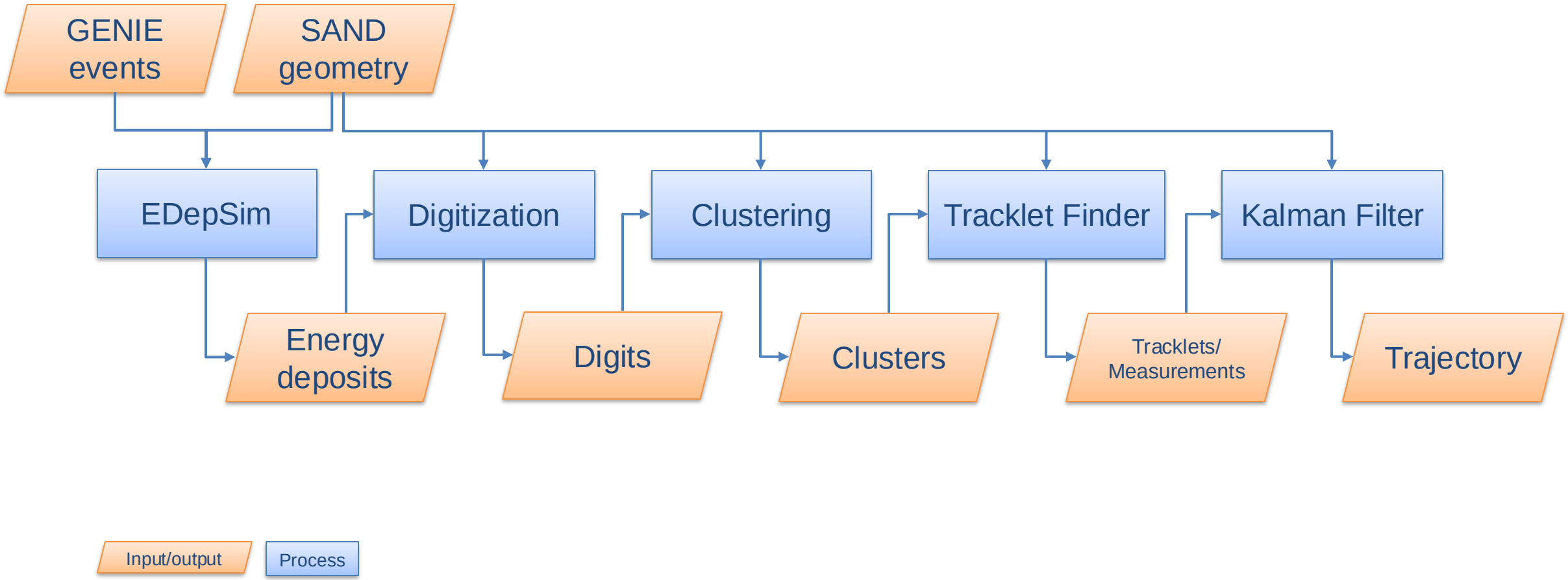
Realistic seeding algorithm

- PID from MC-truth
  - Mass and charge of the particle known

Current Tracking Flow Chart

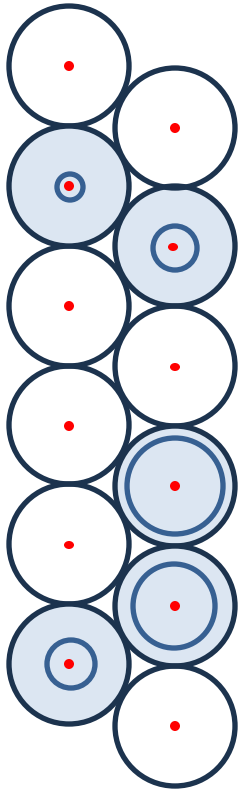
ND Simu/Reco presentation

DUNE Collaboration Meeting



Current Tracking Flow Chart

Digitization



- For each energy deposit it provide a TDC and an ADC for each fired wire

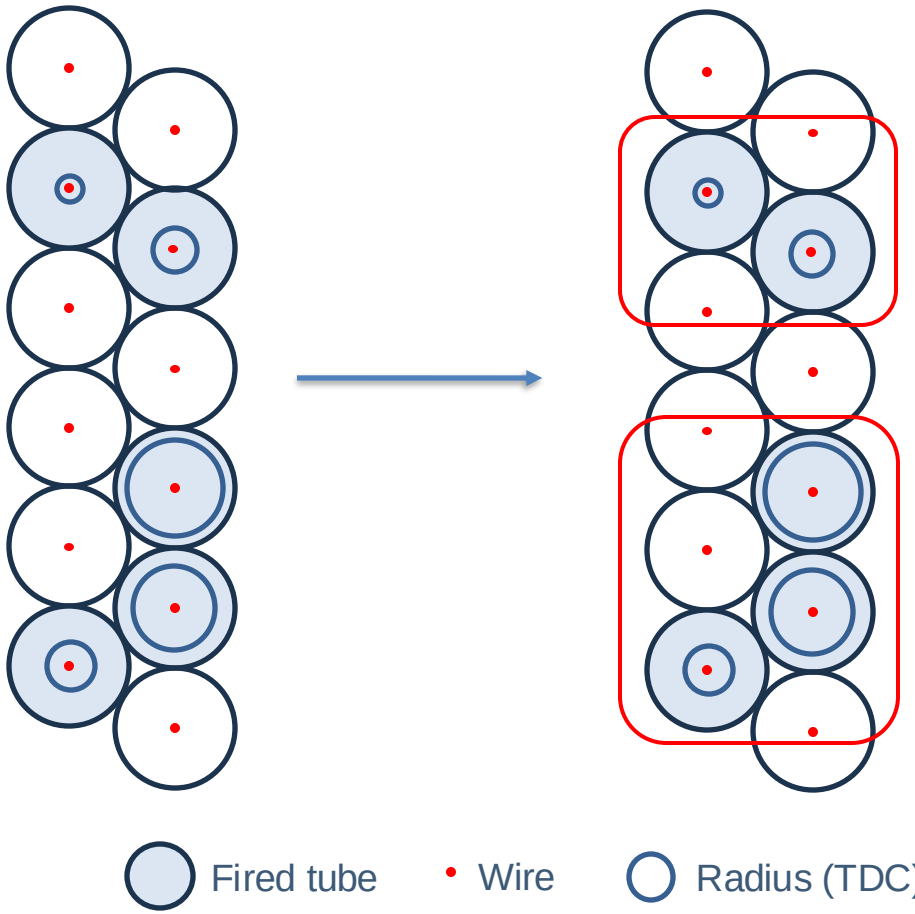
Status

- **Ready** for both the **STT** and the **Drift** geometries
- Works for **any configuration** (number of wires, direction, pitch,…)

Fired tube Wire Radius (TDC)

Current Tracking Flow Chart

Digitization **Clustering**



- Should group digits in clusters based on *some criteria*

Status

- Multiple clustering criteria available
- **Geometry independent**

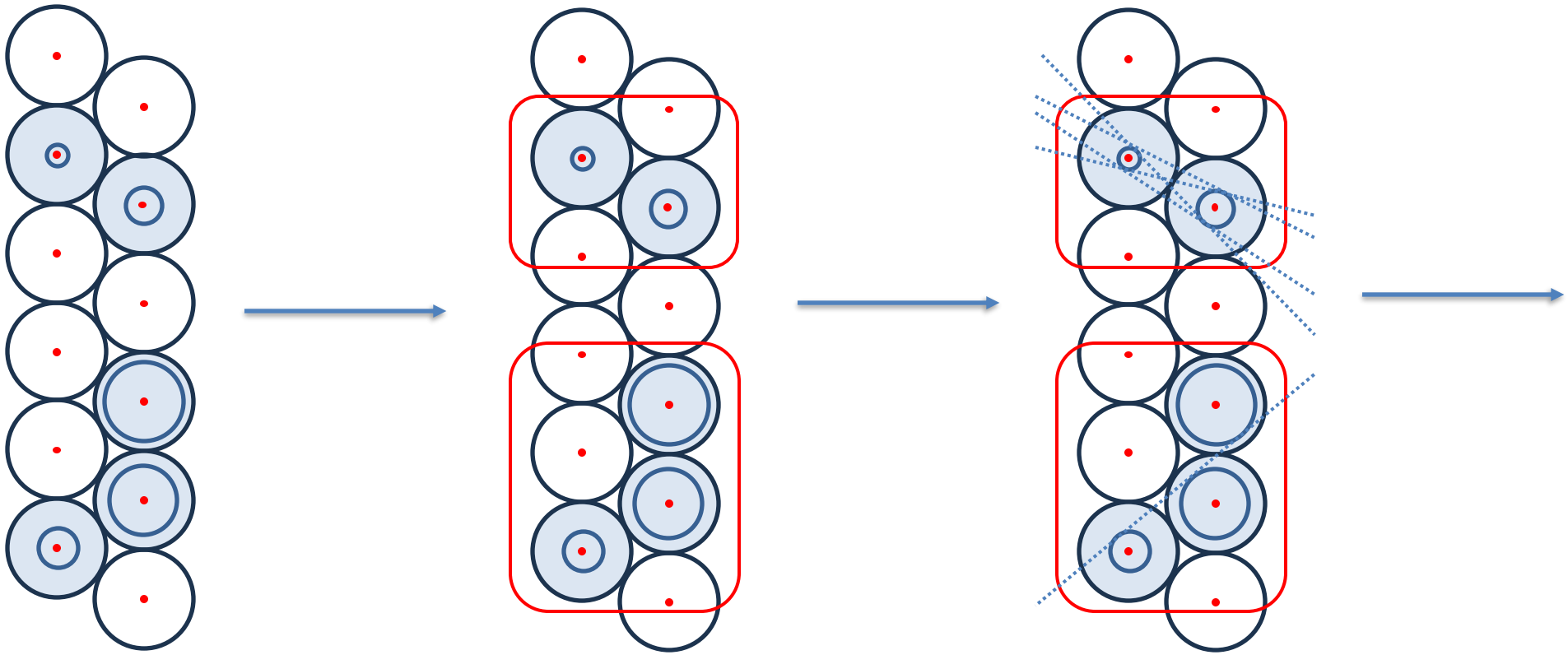
Current Tracking Flow Chart

Digitization

Clustering

Tracklet Finder

Measurements



$$m_x = \begin{pmatrix} x \\ \theta_{xz} \end{pmatrix}$$

$$m_y = \begin{pmatrix} y \\ \theta_{yz} \end{pmatrix}$$

Fired tube · Wire · Radius (TDC) · Cluster · Tracklet

Tracklet finder

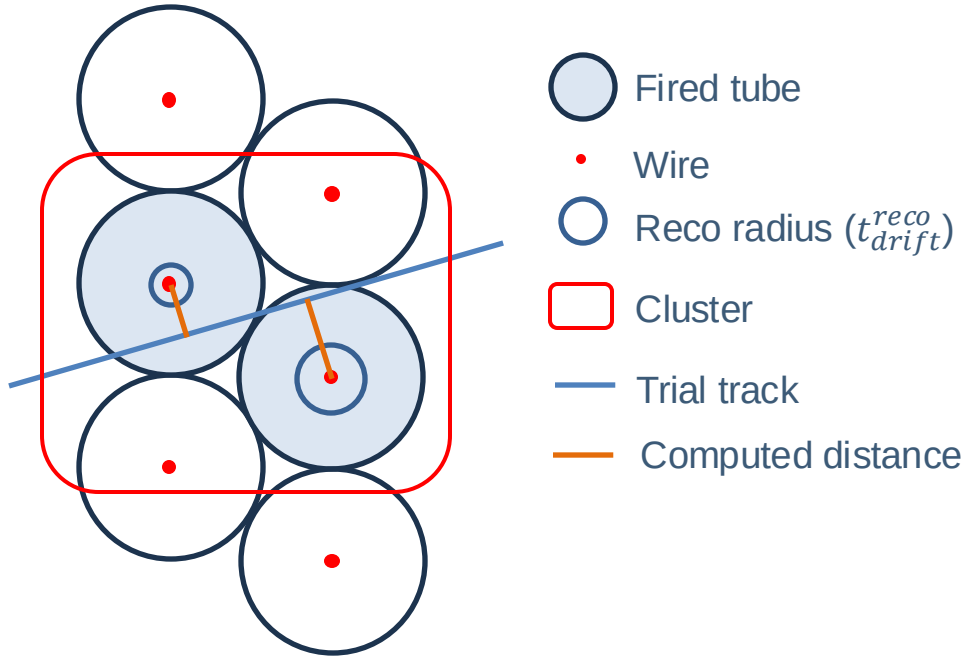
Minimization with migrad of

$$D = \sum_i (d_i - r_i)^2$$

- d_i is the distance between the i-th fired wire and the trial track
- r_i is the radius (from t_{drift}^{reco}) of the i-th fired wire

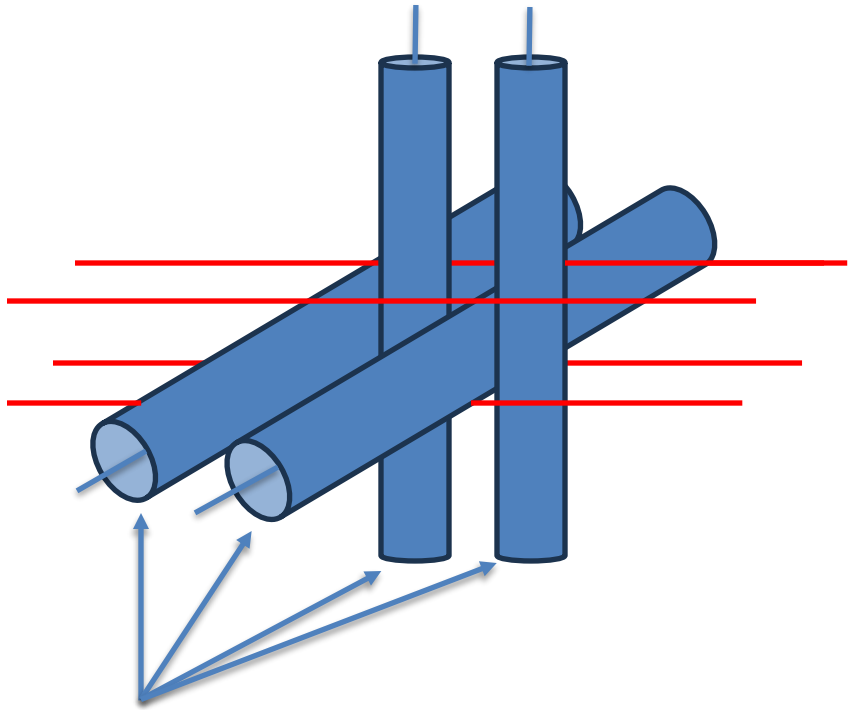
Scan over 4 parameters:

- xz, yz angles, limited in the z+ quadrants
- x,y positions, limited in a region defined by the fired cells

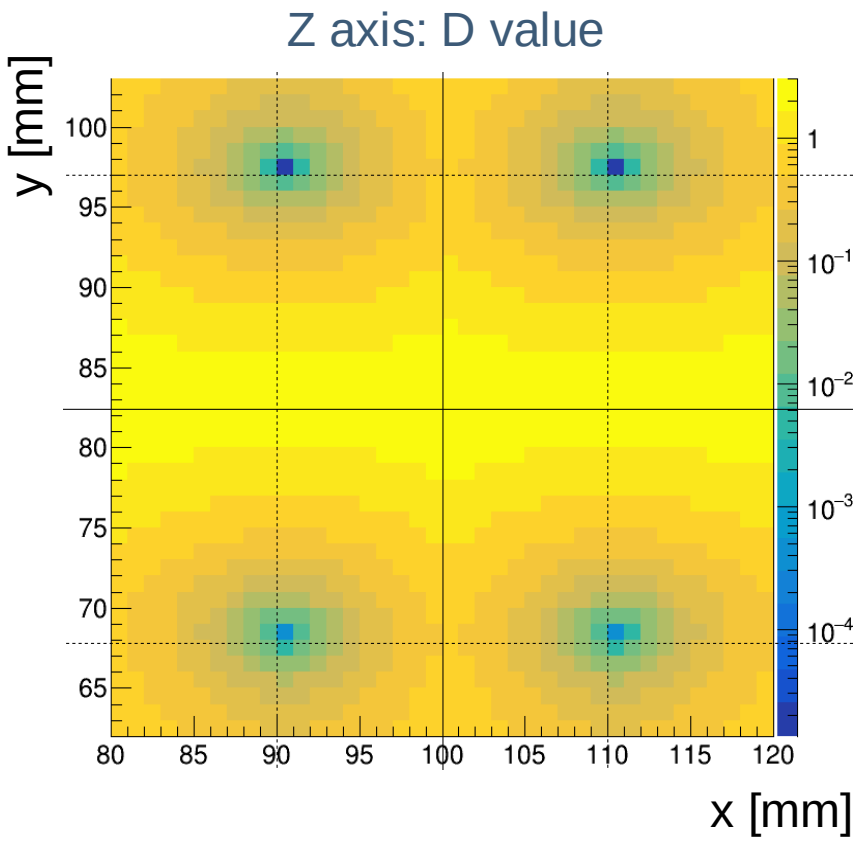


Example

- XYXY wire pattern with particle along the z axis
- t_{drift} computed analytically
- No smearing



Radius from t_{drift}



Simulated trajectory

(x, y, z) = (11, 9.7, 0) cm

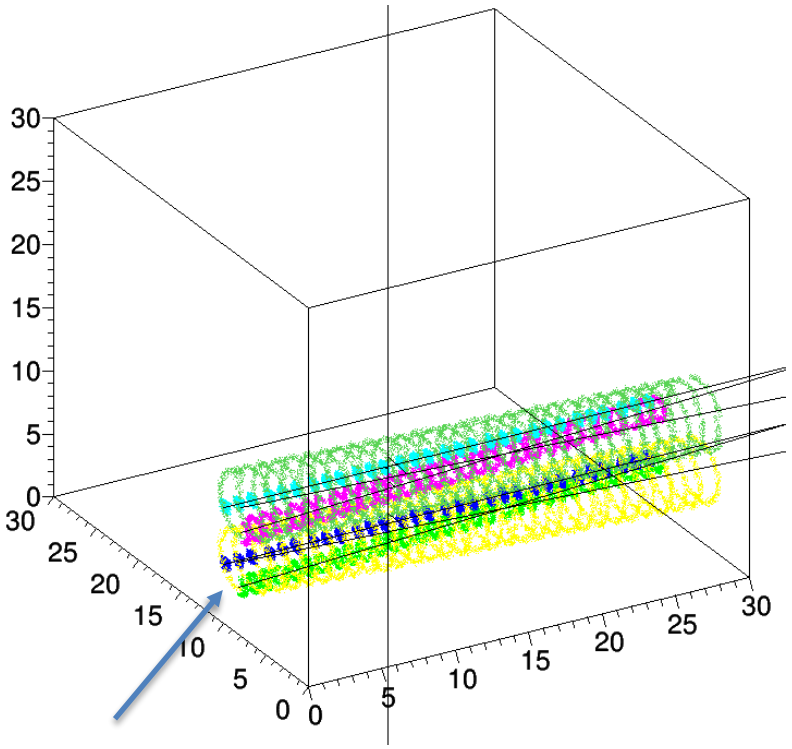
(ax, ay, az) = (0, 0, 1)

Found minima

x [cm]	y [cm]	ax	ay	az
9	6.78	0	0	1
9	9.7	0	0	1
11	6.78	0	0	1
11	**9.7**	**0**	**0**	**1**

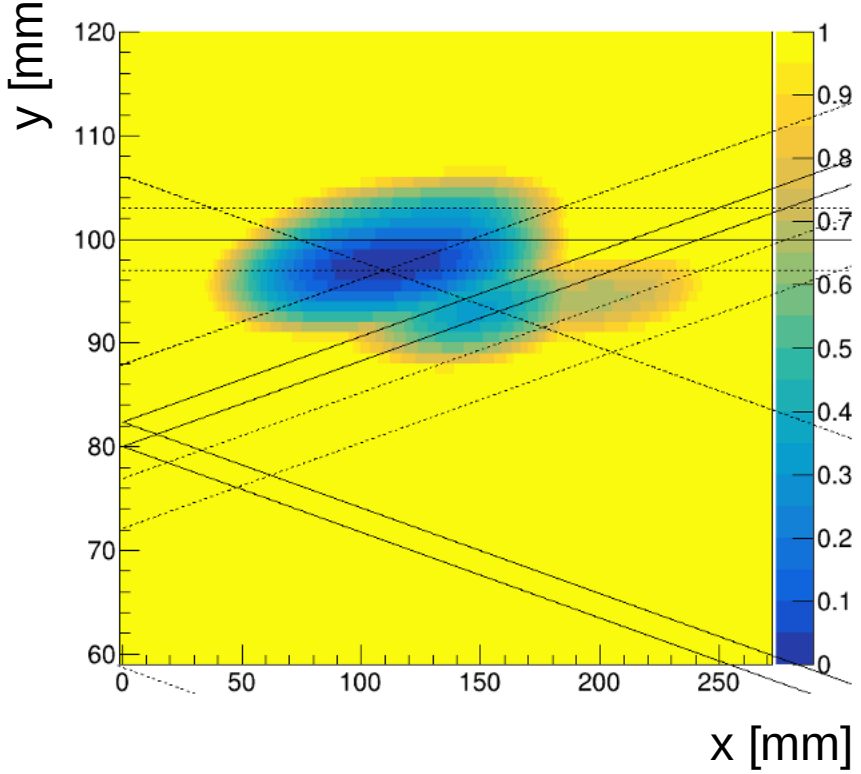
Example

- 0, -5°, +5°, 0, -5°, +5° wire pattern with particle along the z axis
- t_{drift} computed analytically
- No smearing



Radius from t_{drift}

Z axis: D value



Simulated trajectory

(x, y, z) = (11, 9.7, 0) cm

(ax, ay, az) = (0, 0, 1)

Found minima

x [cm]	y [cm]	ax	ay	az
11	**9.7**	**0**	**0**	**1**
19.3	9.4	0.08	-0.04	0.997
15.9	9.8	-0.39	-0.03	0.921

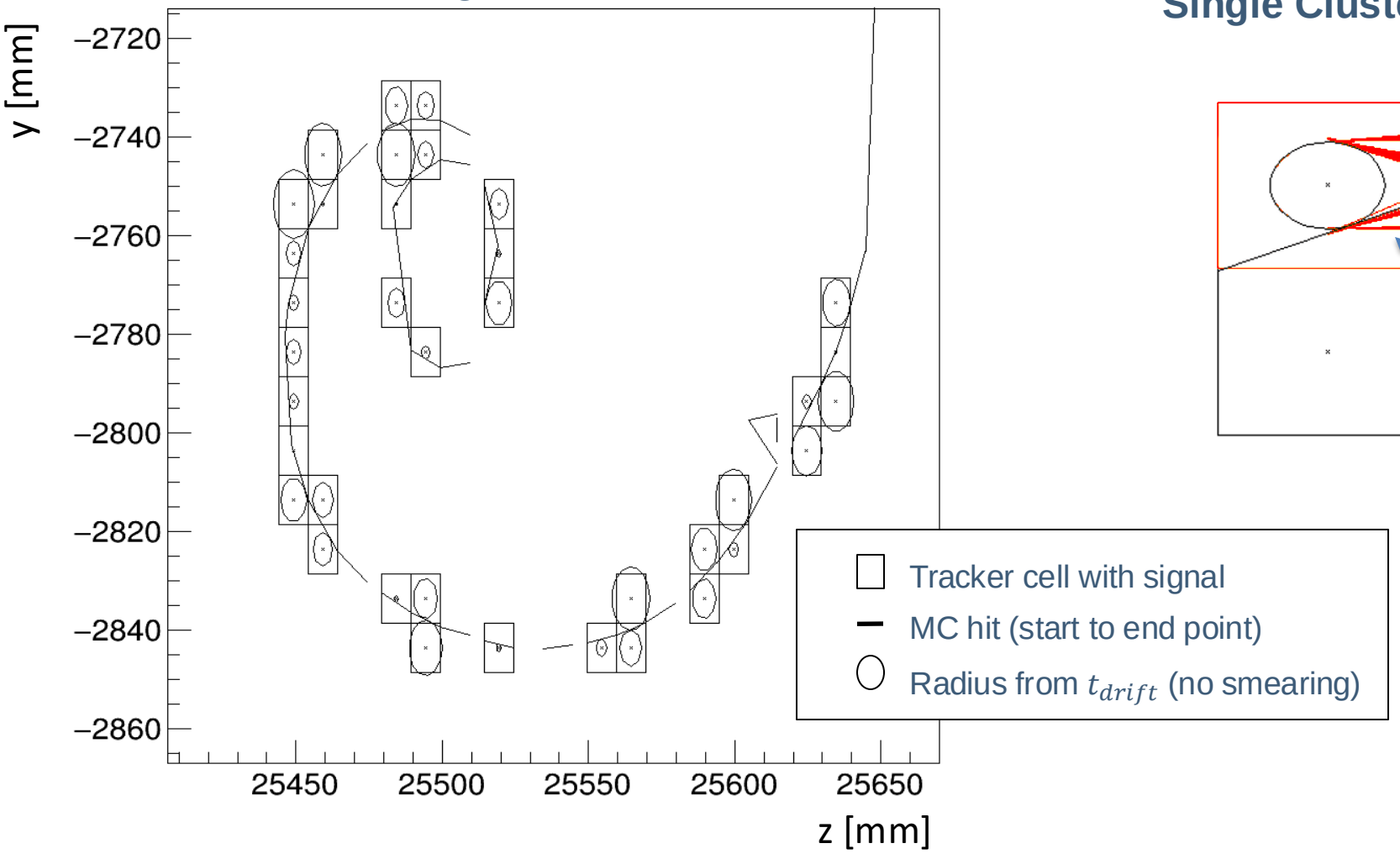
Tracklet finder

- **Different starting conditions** (position and direction) are provided to the tracket finder **to avoid** being stuck in a **wrong local minimum**
- All tracklet are saved
- For each tracklet, the two measurements needed by the Kalman filter are extracted

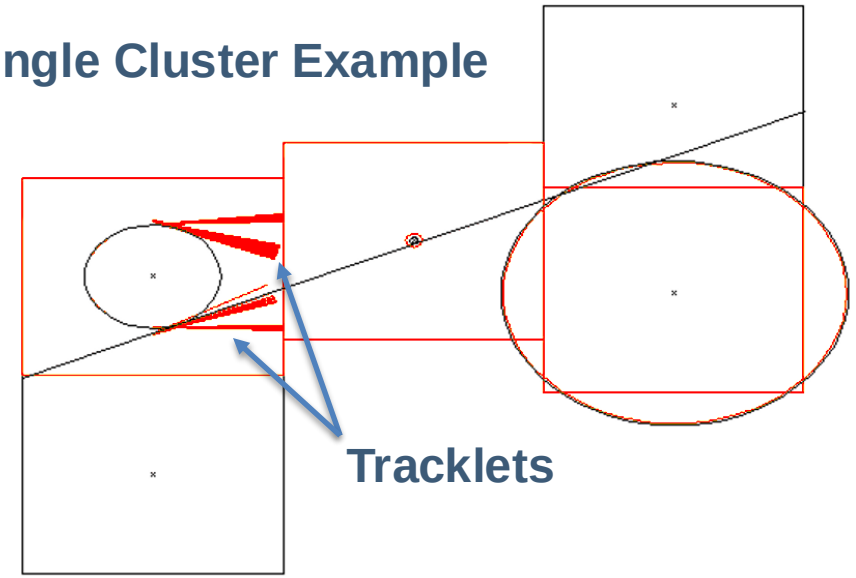
$$m_x = \begin{pmatrix} x \\ \theta_{xz} \end{pmatrix} \quad m_y = \begin{pmatrix} y \\ \theta_{yz} \end{pmatrix}$$

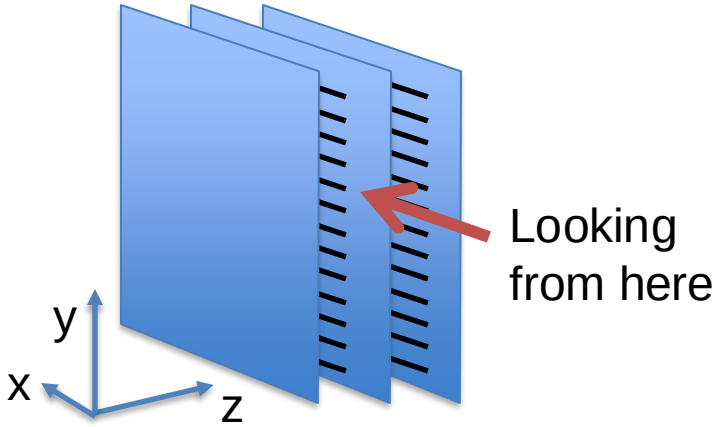
Current Tracking Flow Chart

Digitization



Single Cluster Example





Next steps

- Develop a realistic seeding algorithm

- Validate the KF algorithm with the new software
  - Perform the statistical tests and the particle reconstruction again

- Merge the tracking pipeline in the sand-reco framework to start use it

- Lot of other technical things

Conclusions

- Most of the main steps of the KF algorithm have been implemented

- Statistical test and single-track reconstruction have been performed to validate the KF implementation
  - The code is currently frozen despite some problem are still present

- Complete reconstruction pipeline developed to work for both STT and Drift geometries:
  - Digitization
  - Clustering
  - Tracklet finder