Computing at PANDA

The PandaRoot Simulation and Analysis Framework

15.2.2018 TOBIAS STOCKMANNS

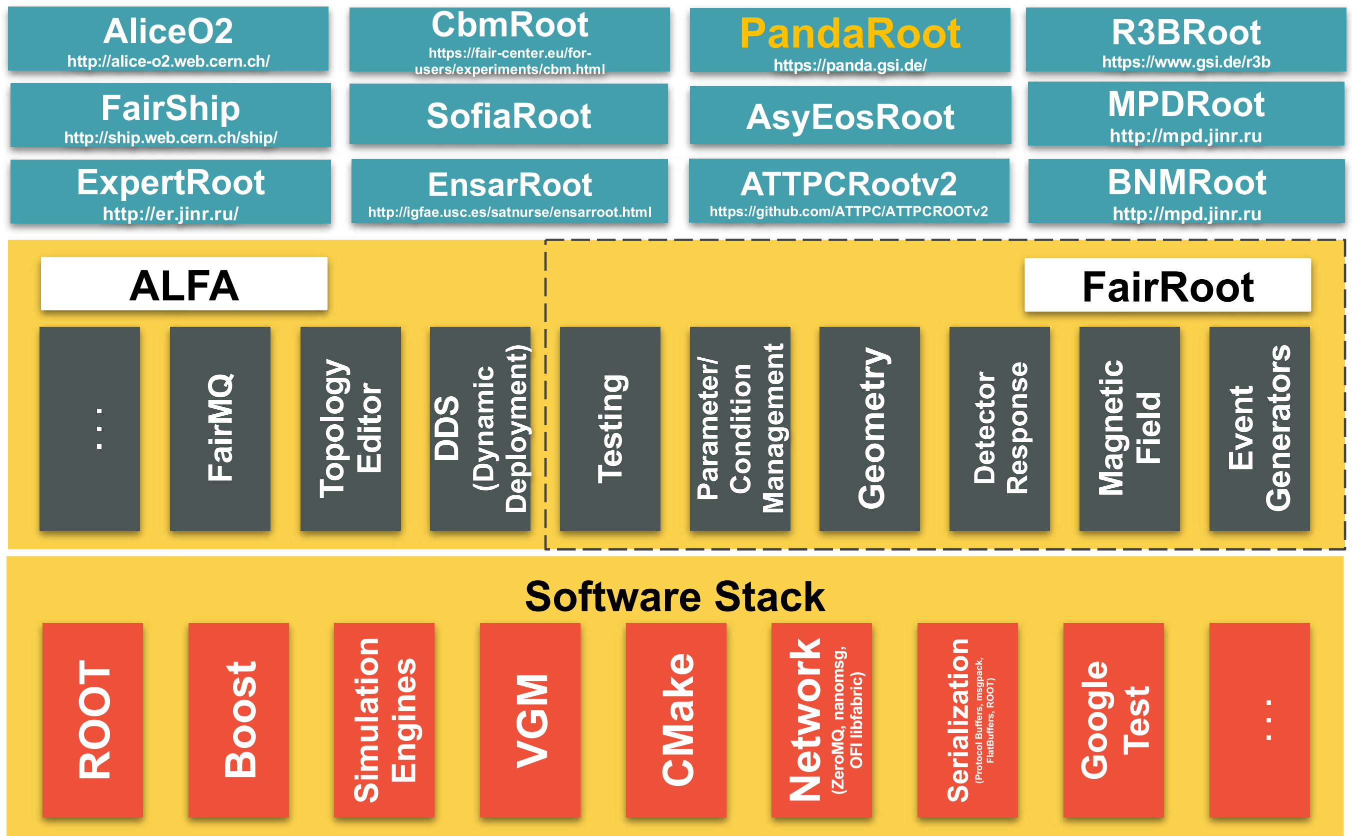
JÜLICH
Forschungszentrum

Motivation

- Determine the operation parameters of the detector
  - Rates, energy deposition, radiation dose, ...
- Optimize the detector layout
  - Where to put which detector
- Develop the reconstruction algorithms
- Develop the analysis tools and strategies
- Determine the performance of the PANDA detector
- Reconstruct the raw data
- Performe physics analysis
- Simulation of the expected event signatures

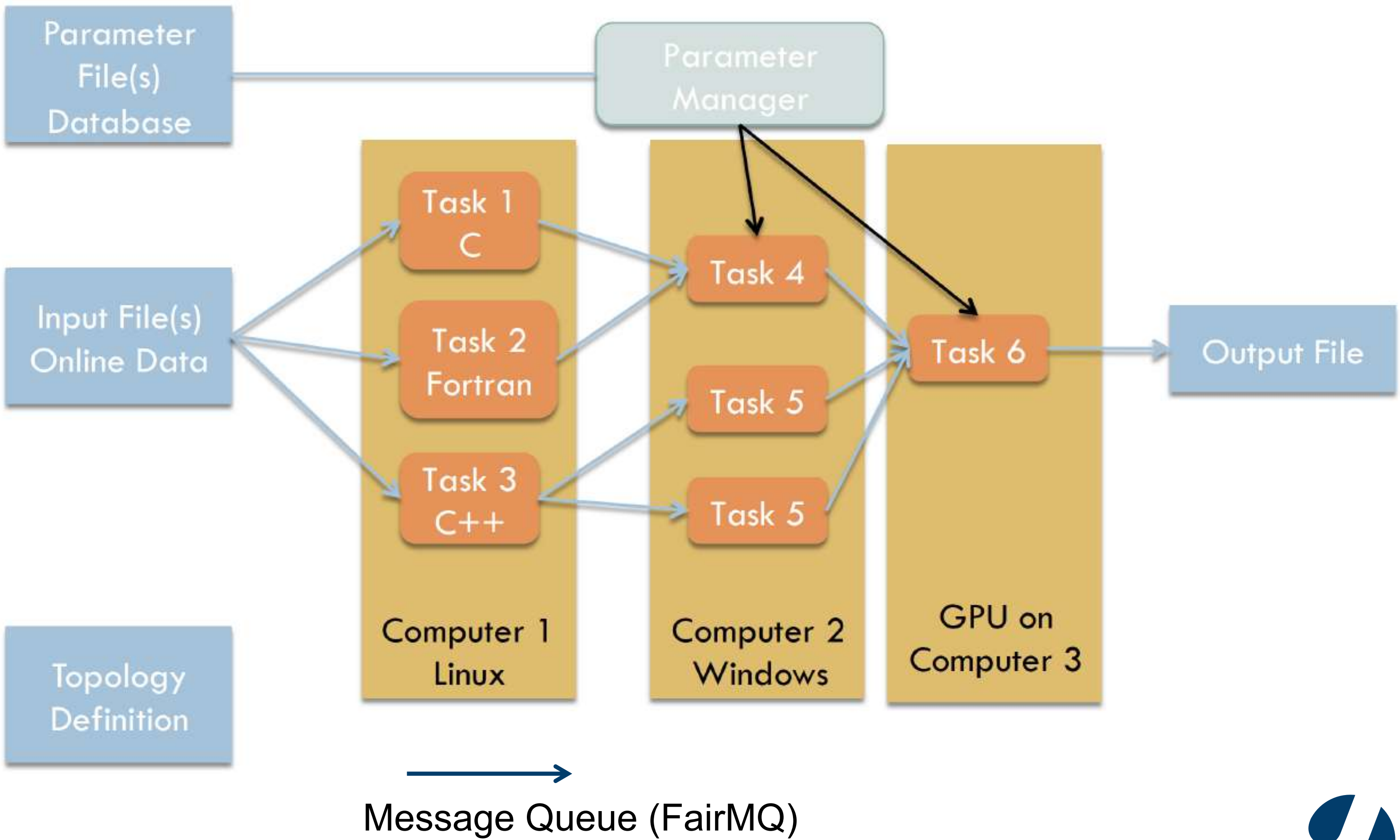
FairRoot

Structure



FairRoot

FairMQ

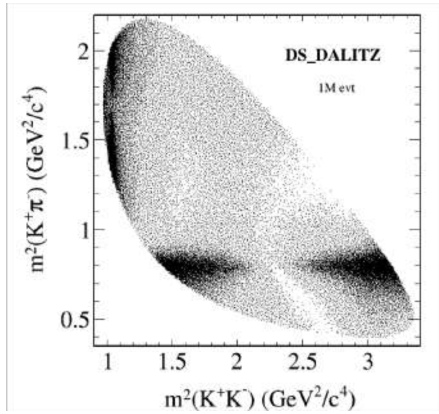


PANDAROOT

Simulation Stages

Event Generation

- Many different event generators available
  - EvtGen:
    - Simulation of dedicated physics channels
    - Can be extended by individual decay models
  - Dual-Parton-Model (DPM):
    - Background generator for anti-proton – proton interactions
  - UrQMD:
    - Background generator for anti-proton – nucleus interactions
  - FTF generator:
    - New development of a combined background generator used also in Geant4
  - Box generator:
    - Particle gun

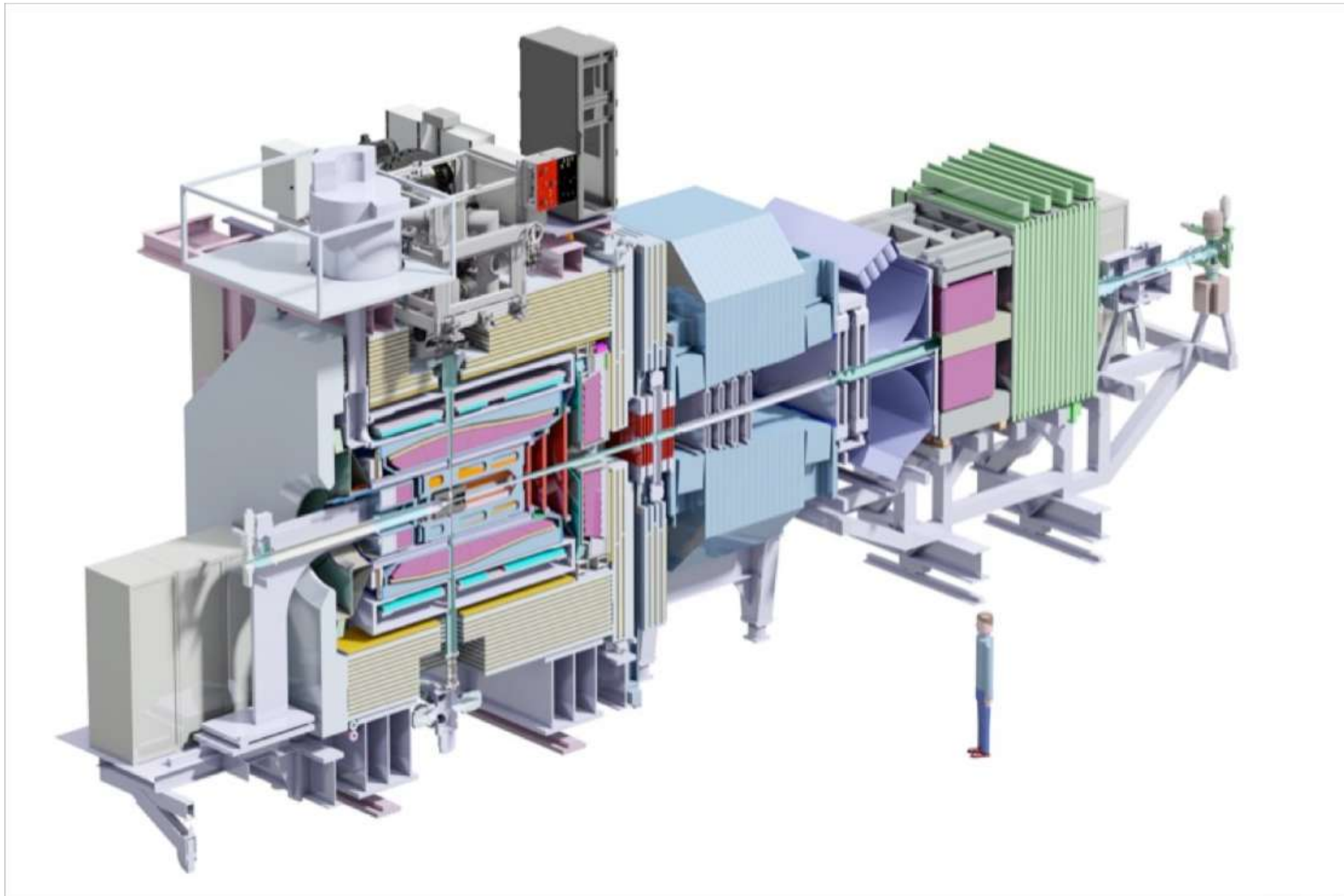


Particle Propagator

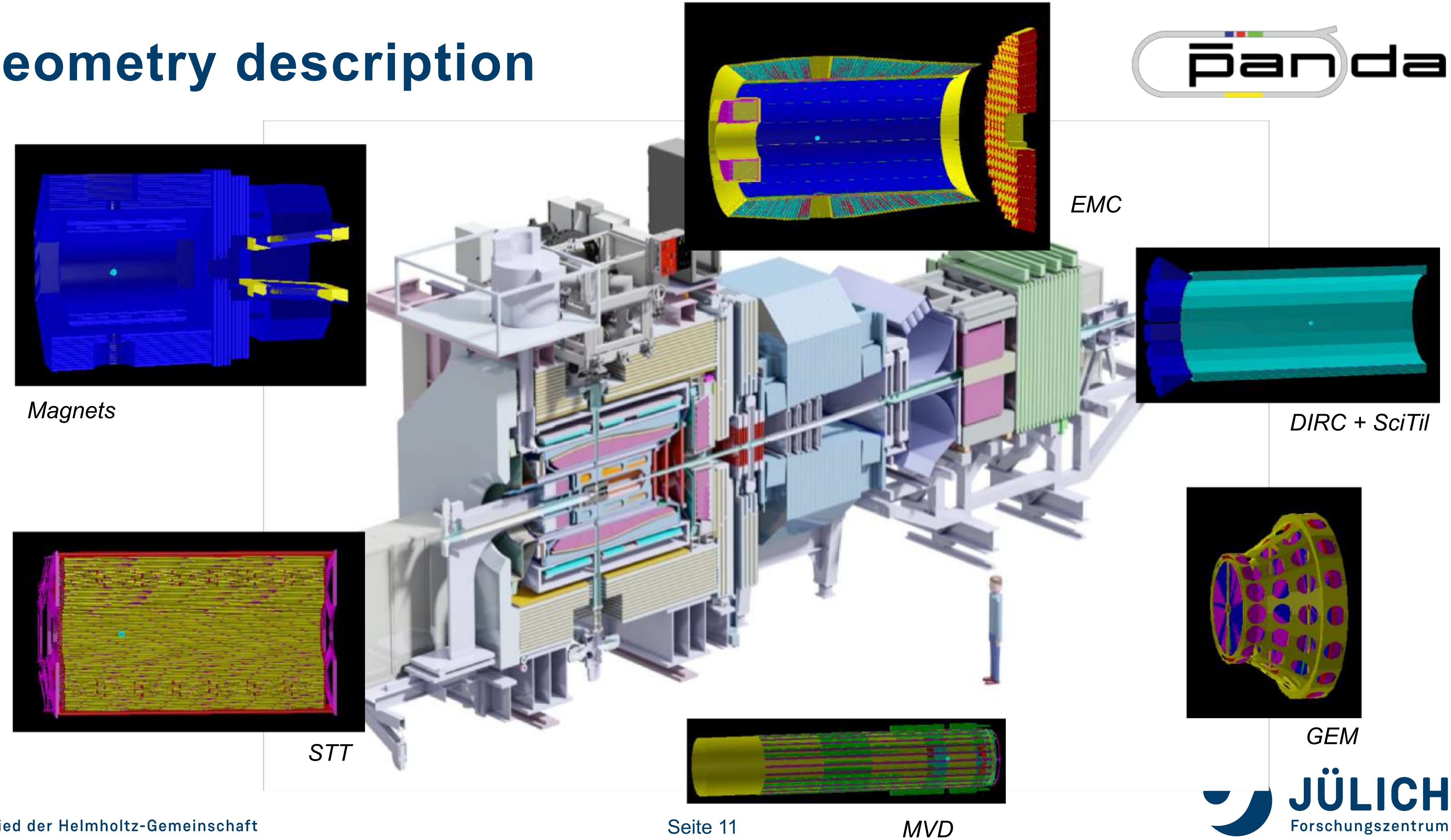
- Usage of Virtual Monte Carlo allows seamless change of propagation engine
- Available:
  - Geant3
  - Geant4
  - (Fluka)

- Same geometry description in propagation and reconstruction of events by using the same geometry engine from root

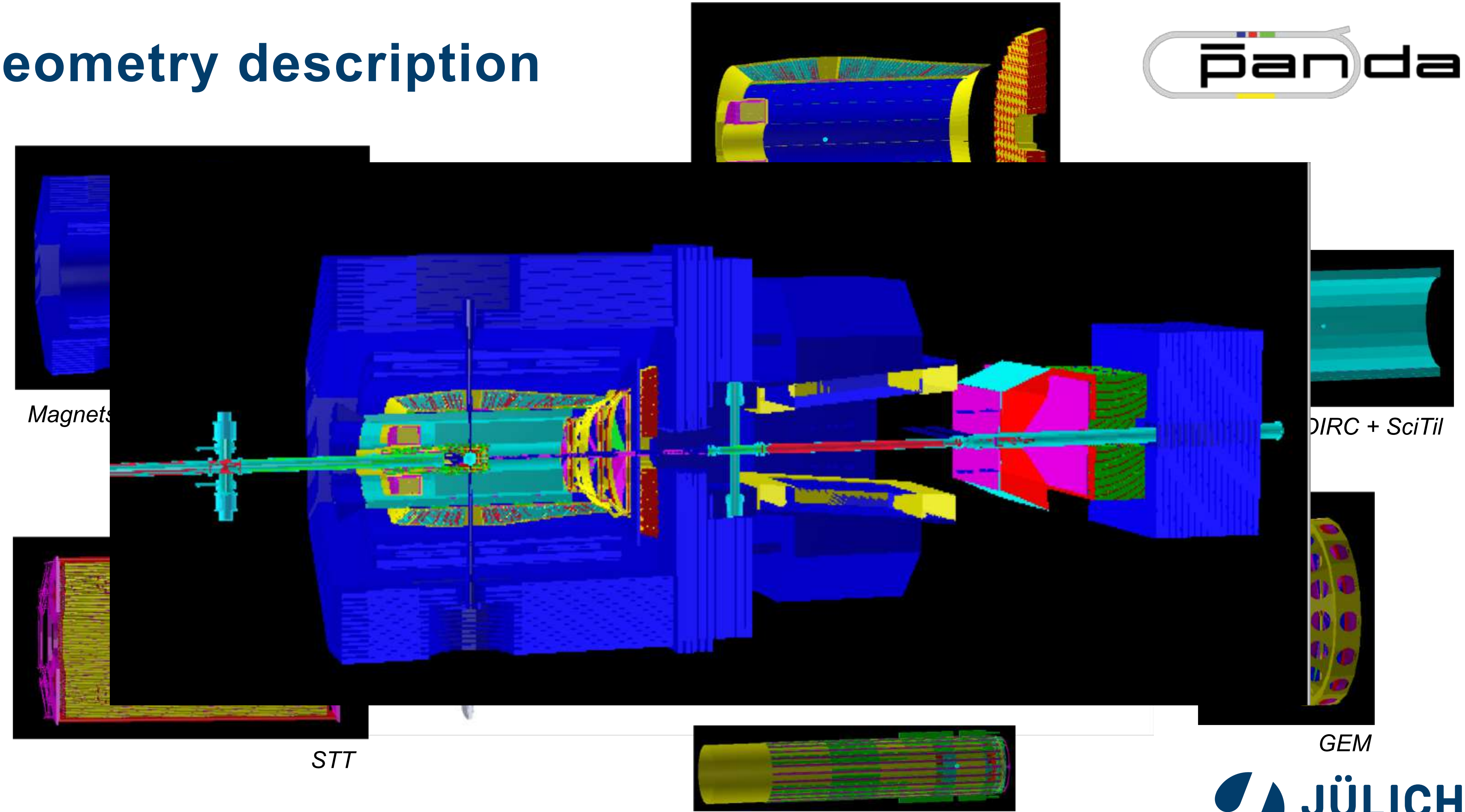
Geometry description



Geometry description



Geometry description

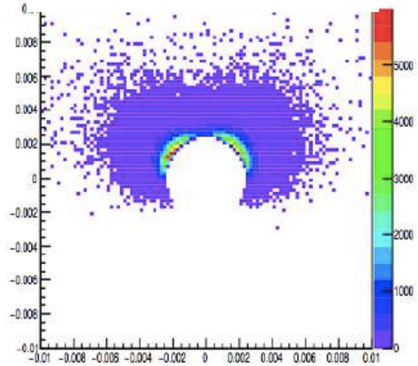


Digitization

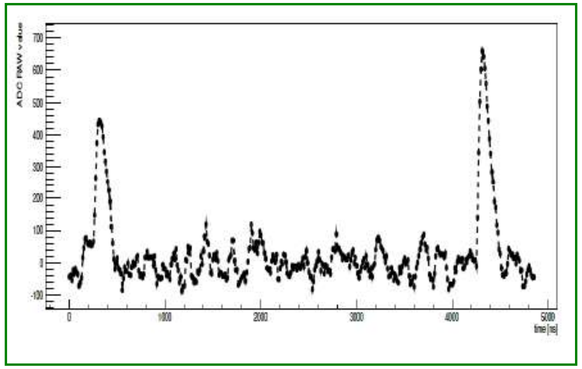
- Translates ideal detector data into realistic data stream
  - 3D space points into channel number
  - Deposited energy into ADC values
  - Adding noise and inefficiencies
  - Charge sharing between neighboring detector elements
  - Dead times and electronics properties

- Data should look like as coming from the final experiment

Avalanche Simulation in MDT



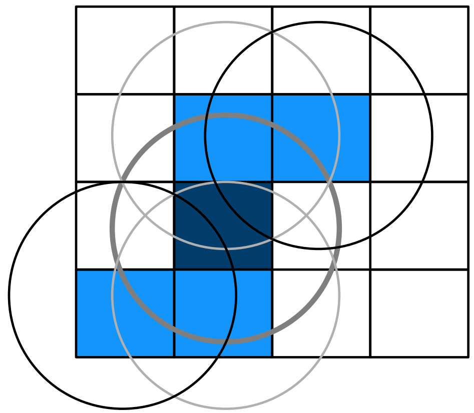
Simulated EMC waveform



Reconstruction - I

- Local reconstruction for each sub-detector
  - Translation from detector data into physical parameters (from channel number to space point, ADC to energy)
  - Calibration
  - Cluster formation
  - Reconstruction algorithms

  - Various different algorithms implemented for each sub-detectors
  - Compared with test beam data
  - PandaRoot used to reconstruct test beam data



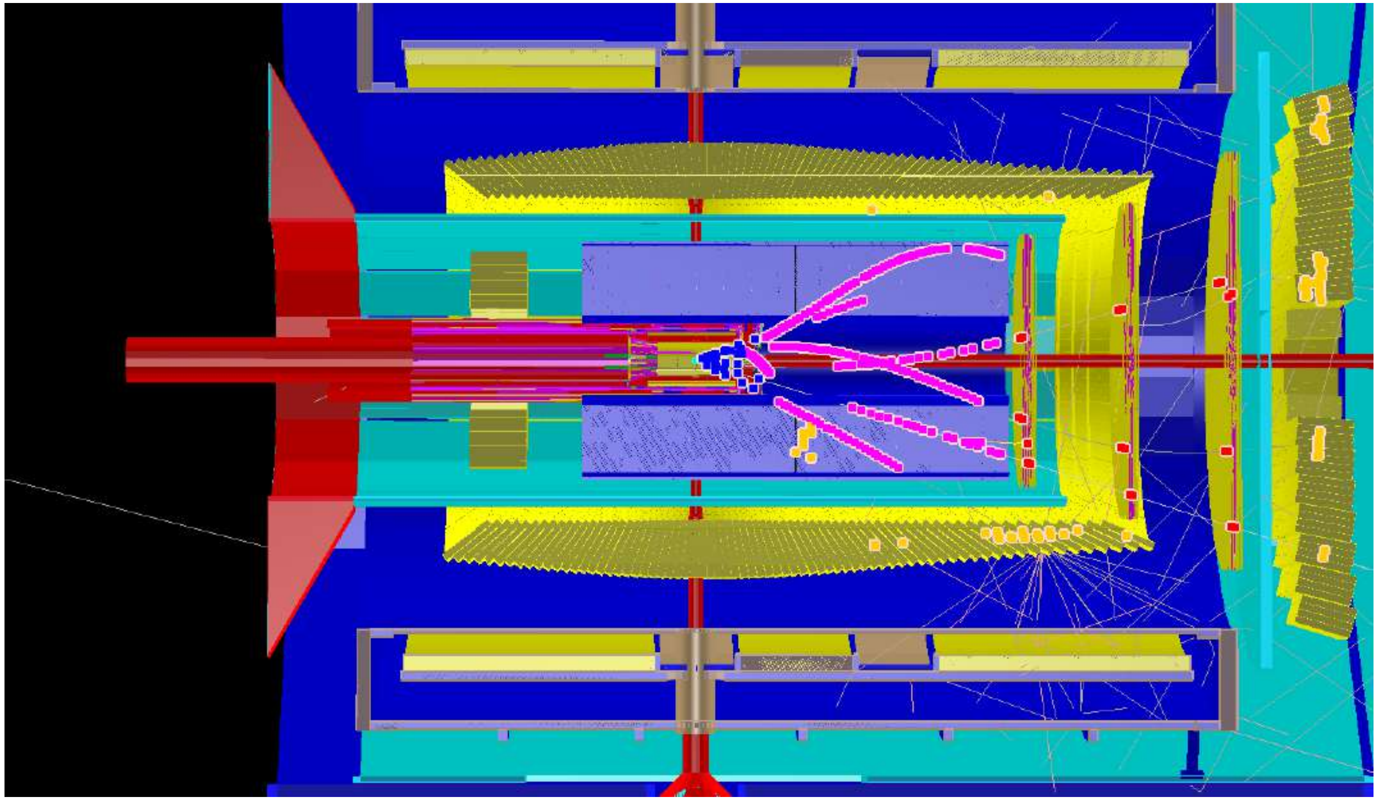
Reconstruction - II

- Global reconstruction
  - Combining different sub-detectors
  - Tracking
  - PID
  - Event building

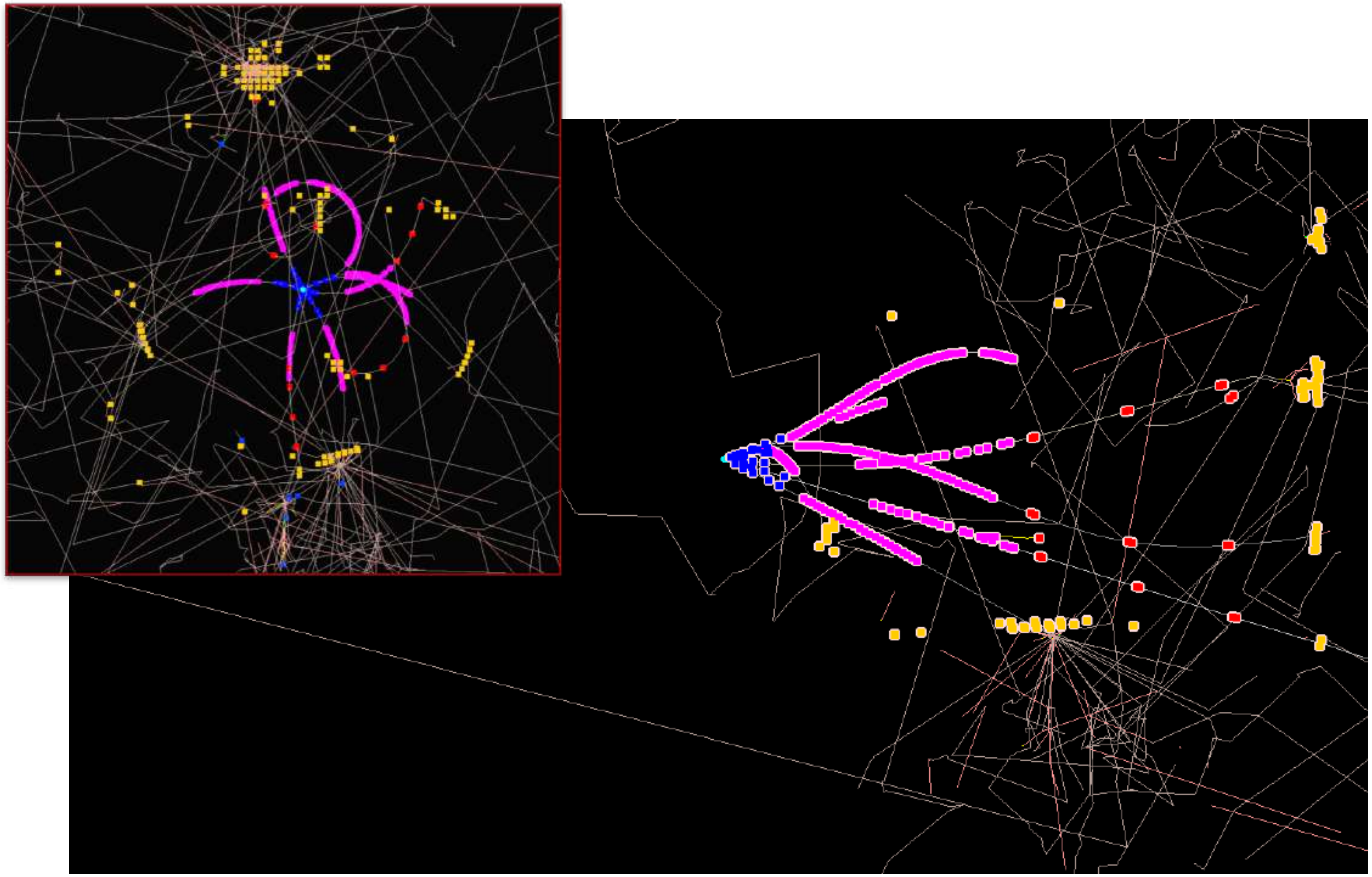
Tracking

Tracking

Event Simulation



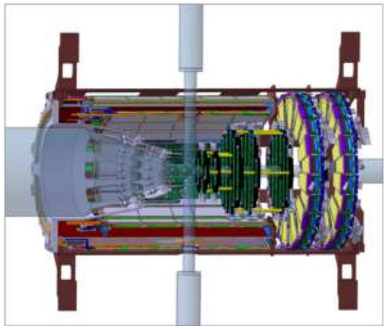
Tracking



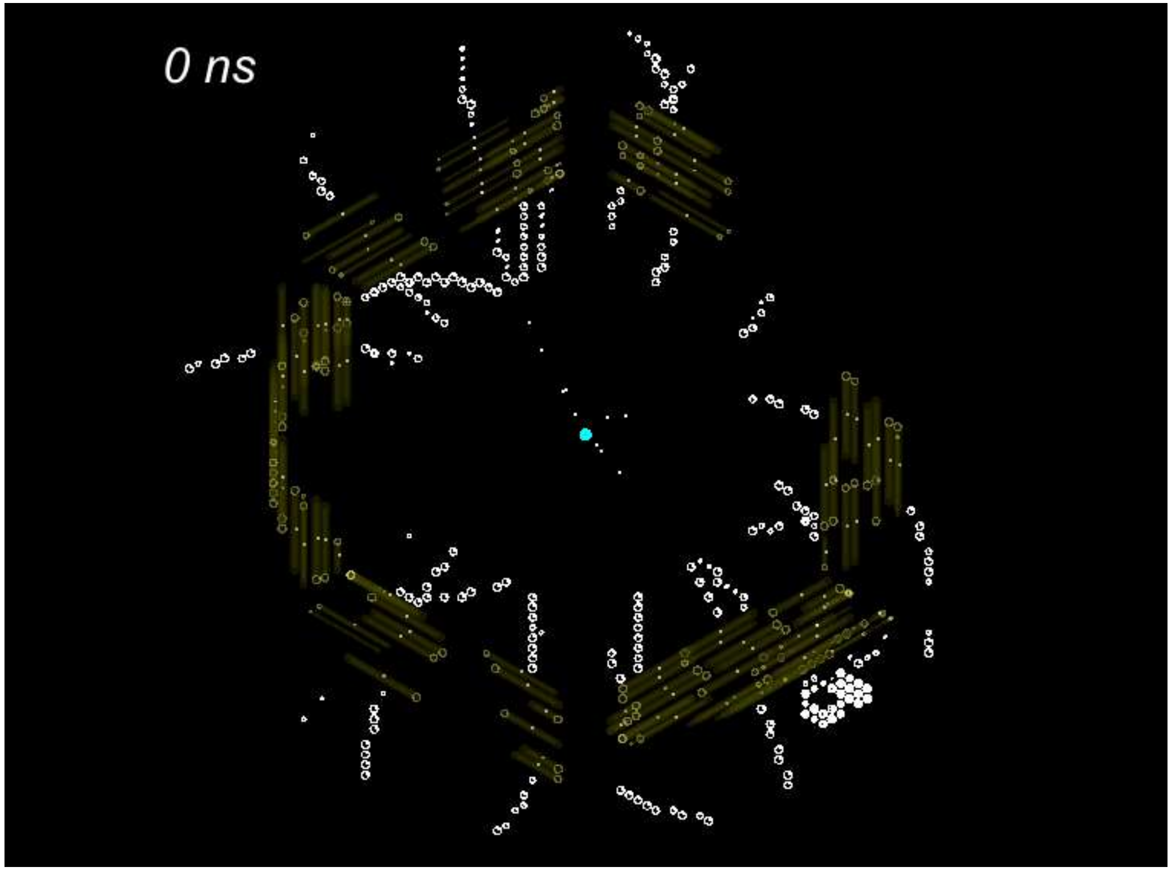
Simulated Events

MVD

- 4 barrel layers
- 6 disks
- 3D space points
- < 30 µm point resolution
- < 10 ns time resolution



MVD

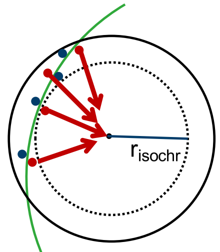


Time series of MVD and STT detector signals in PANDA (view along beam axis)

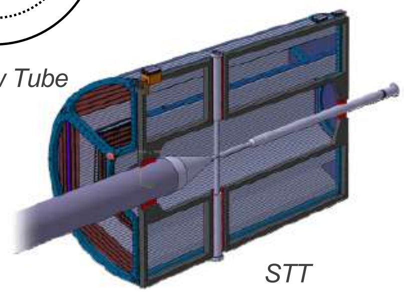
STT

- ~ 4200 straws
- Dense packaging
- Isochrones (2D)
- Up to 250 ns drift time
- < 150 µm resolution
- No start time

➔ 4D tracking needed



Straw Tube



STT

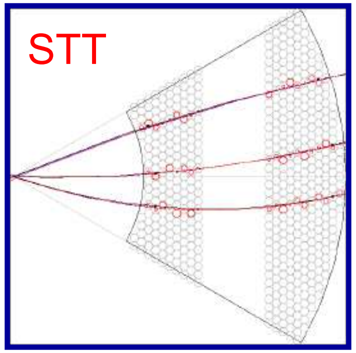
Tracking Procedure

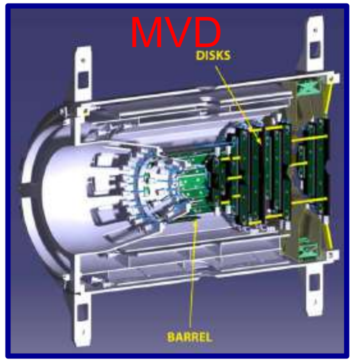
- Full track reconstruction happens in various steps:

1.	Group the hits which belong to the same track	pattern recognition / track finding
2.	Fast evaluation of the track parameters	pre-fit
3.	Precise fitting of the track parameters	Kalman fit
4.	Propagate track parameters to the point where they are needed	propagation / extrapolation

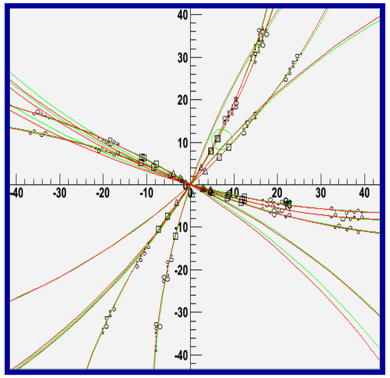
Offline Barrel Tracking

1. Local pattern recognition in STT and MVD

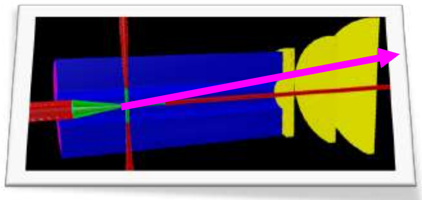




2. Correlation of STT and MVD tracklets



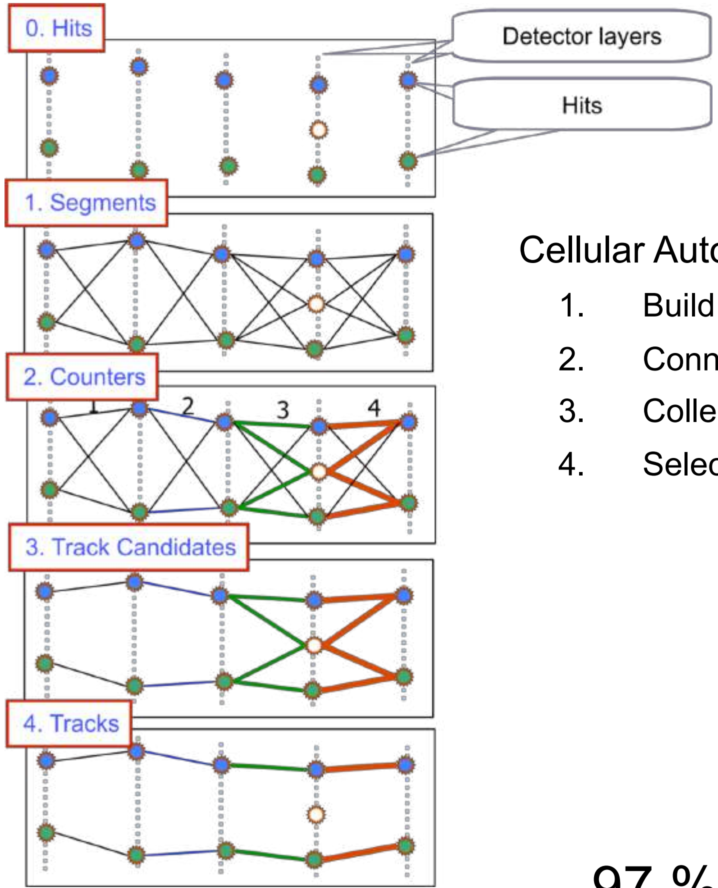
3. Extrapolation to GEM



4. Kalman Filter

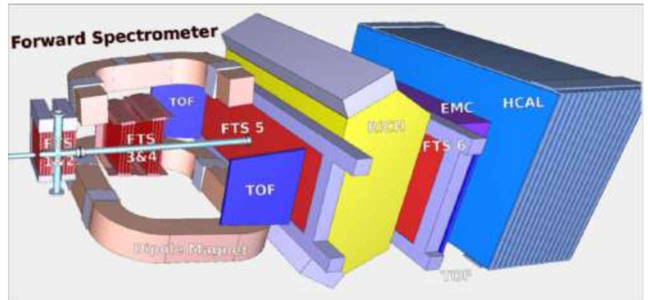
Forward Tracking

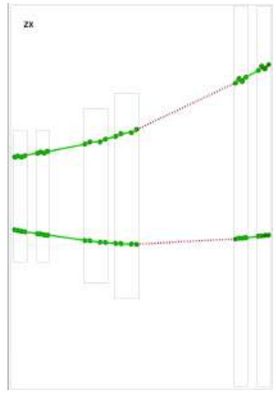
Cellular Automaton

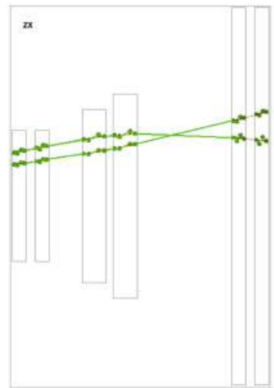


Cellular Automaton

1. Build short track segments
2. Connect according to track model
3. Collect segments into track candidates
4. Select best track candidates

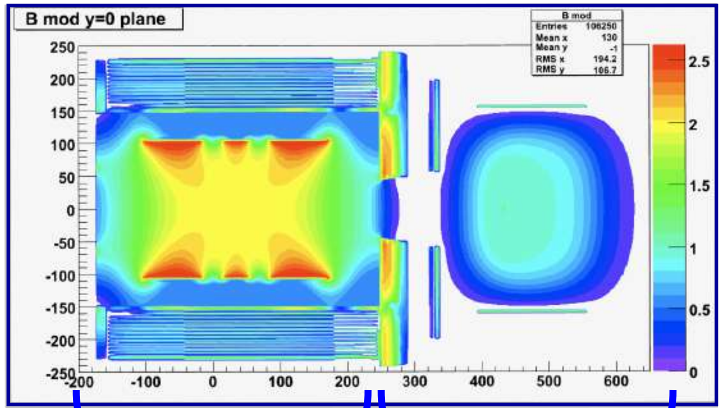






97 % track finding efficiency

Tracking: Global Fit



barrel forward

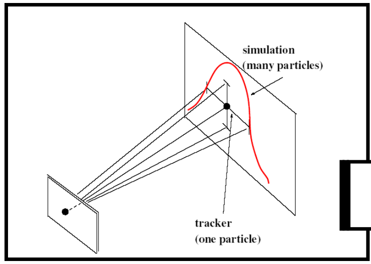
Energy loss
Not homogeneous magnetic field
Different detector hits

- planar hits – MVD/GEM
- tube + drift time – STT/FTS

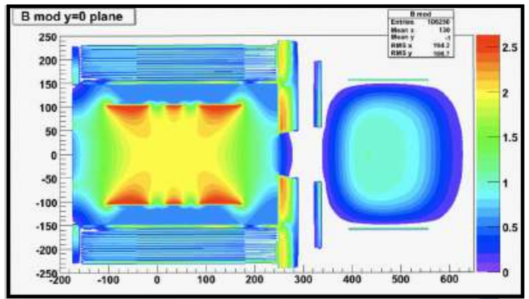
Prefit Track

Kalman Filter (GENFIT)

Detector Hits



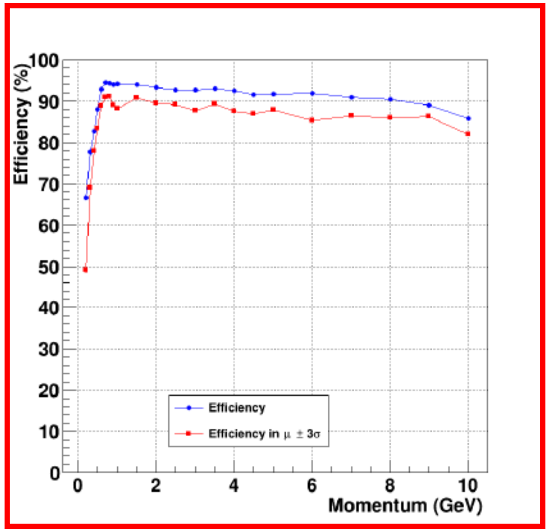
Track Follower (GEANE)

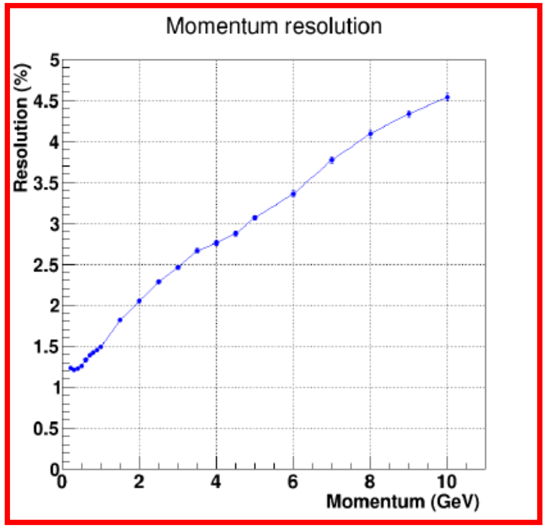


same geometry for simulation and track following

Tracking - offline

- Track finding and fitting working in Central and Forward Spectrometer
- Kalman filter used as second stage developed by TUM (GenFit 1 + 2)
- Efficiency above 90 % (for beam above 3 GeV/c)
- Momentum resolution between 1% and 5% depending on momentum





For p(pbar) < 3 GeV/c

B = 1T

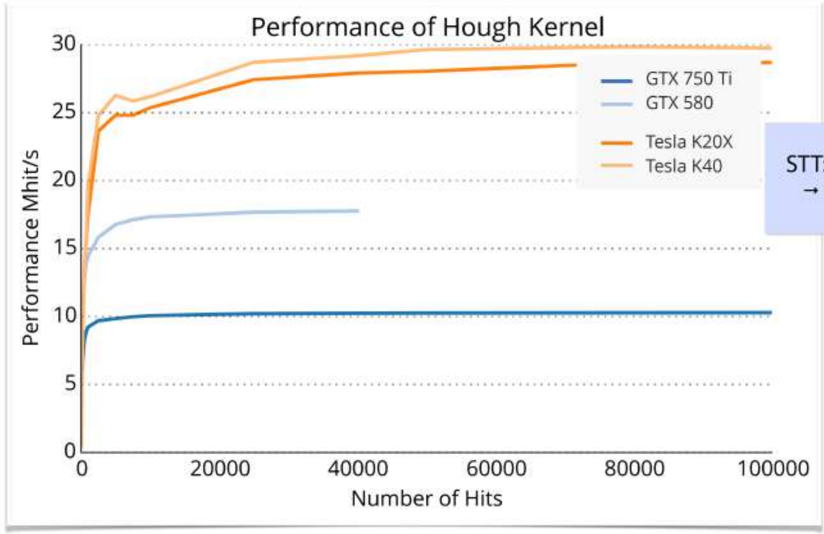
p resolution doubles

low p efficiency increases

Tracking - online

- Find and fit tracks with the production speed at Panda up to 20 MHz
- Alternative hardware:
  - FPGA:
    - Helix tracking algorithm
  - GPGPU:
    - Cellular automaton
    - Hough transformation
    - Triplet finder
    - Riemann transformation
    - Direct switch in PandaRoot between CPU and GPU

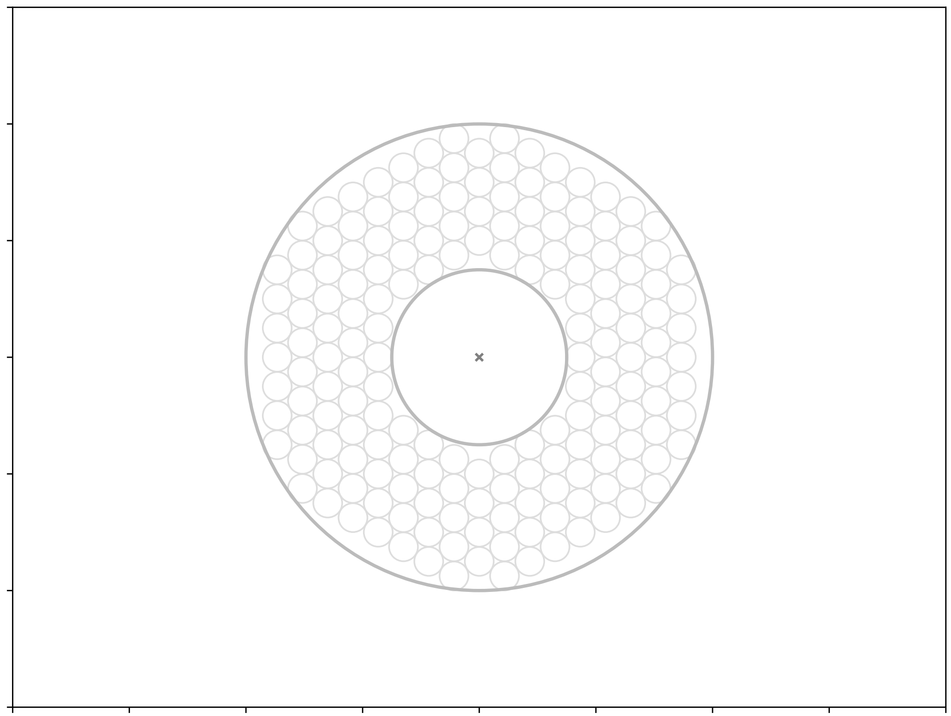
Work in progress



STT: 1000 Mhit/s
→ <100 GPUs

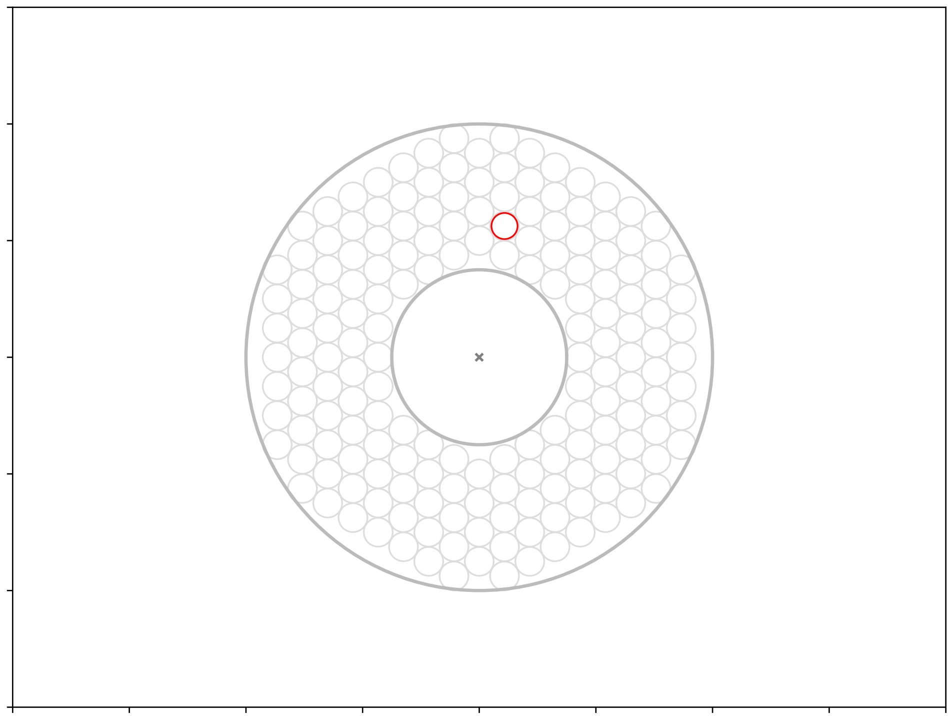
Online Track Finding

Circle Hough



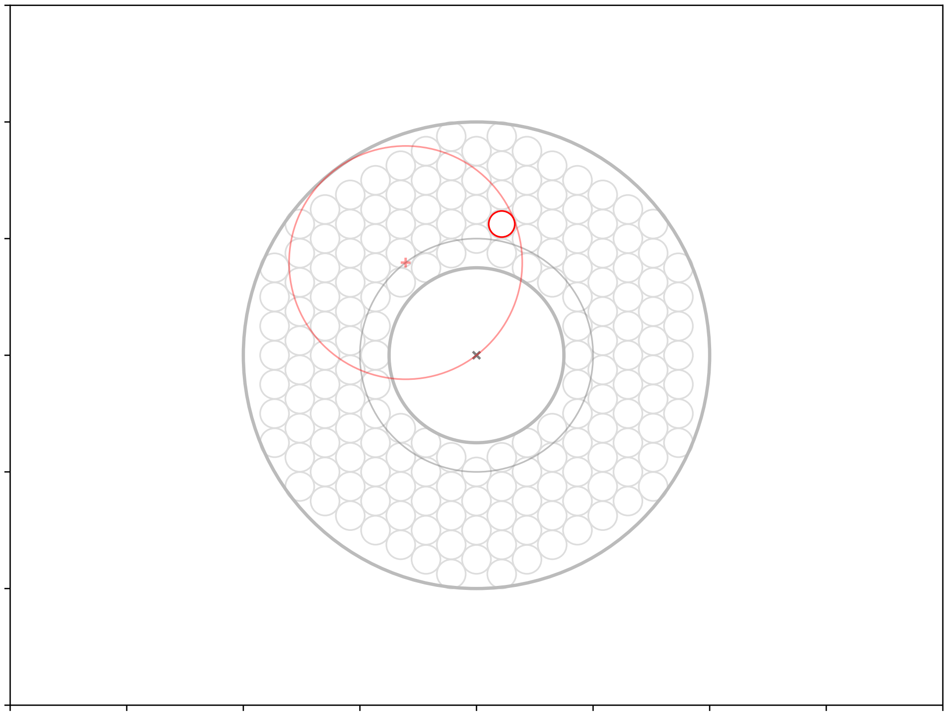
Online Track Finding

Circle Hough



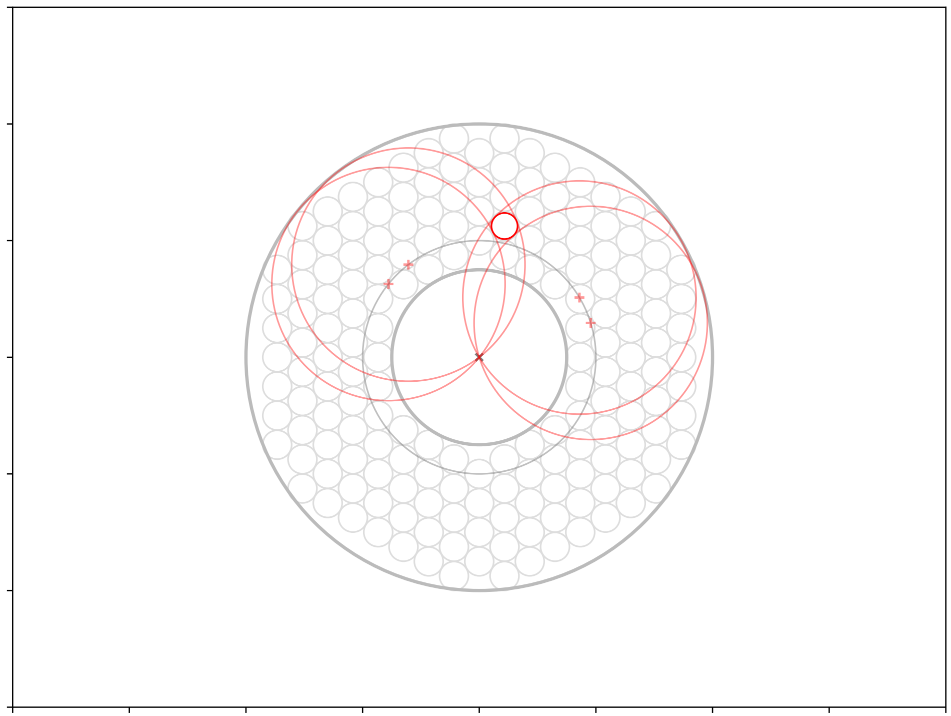
Online Track Finding

Circle Hough



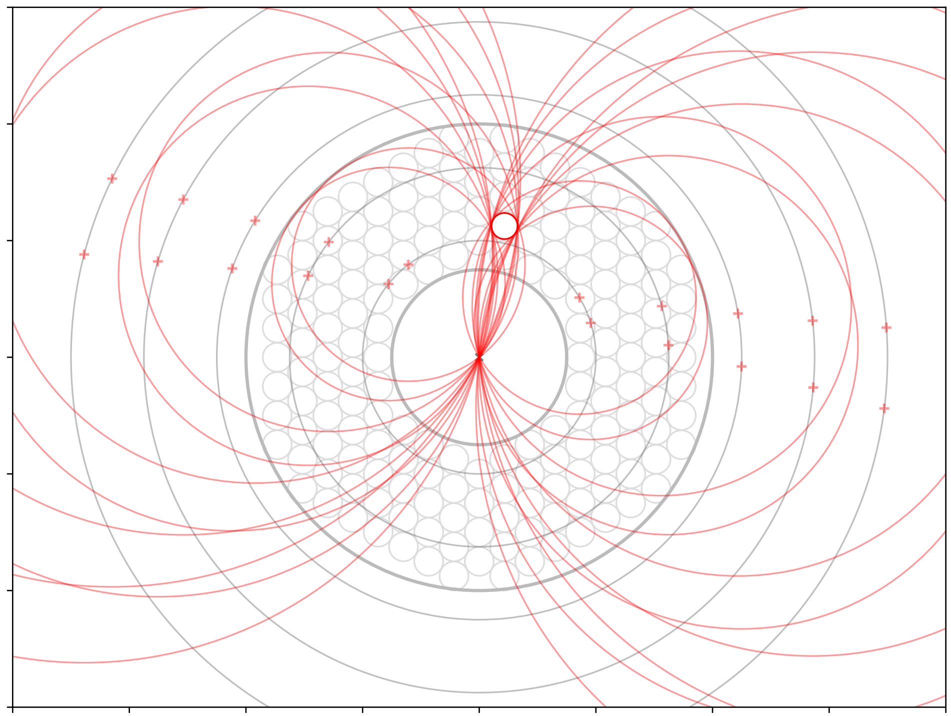
Online Track Finding

Circle Hough



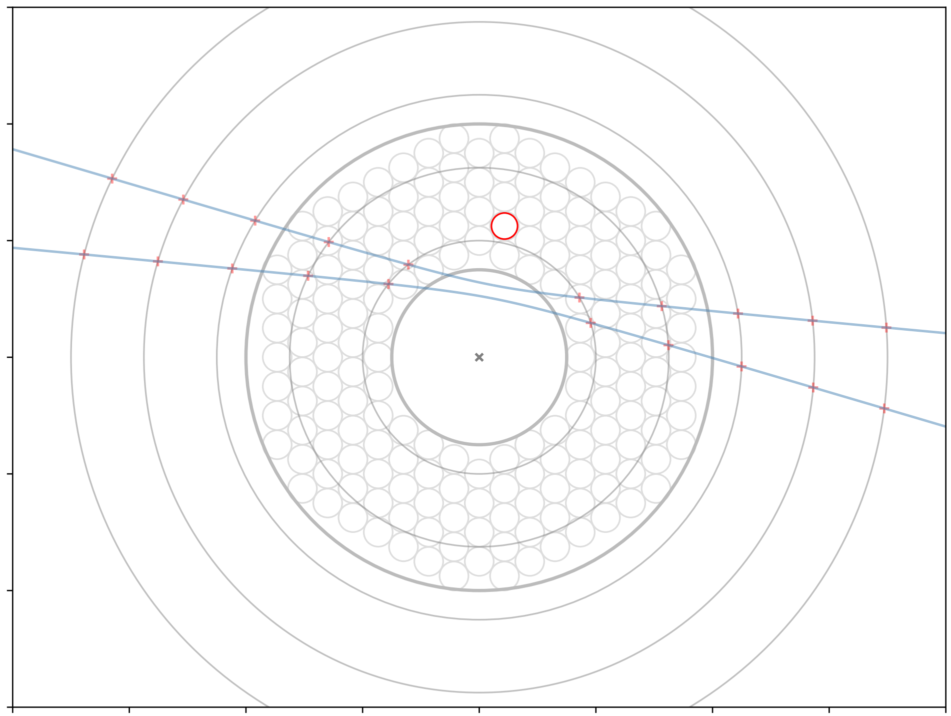
Online Track Finding

Circle Hough



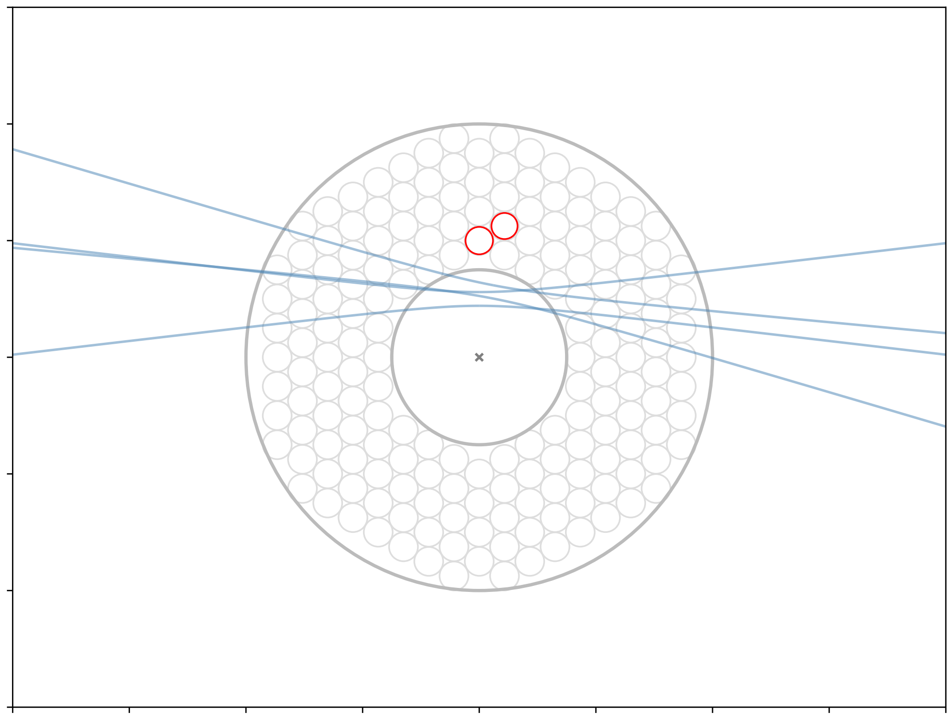
Online Track Finding

Circle Hough



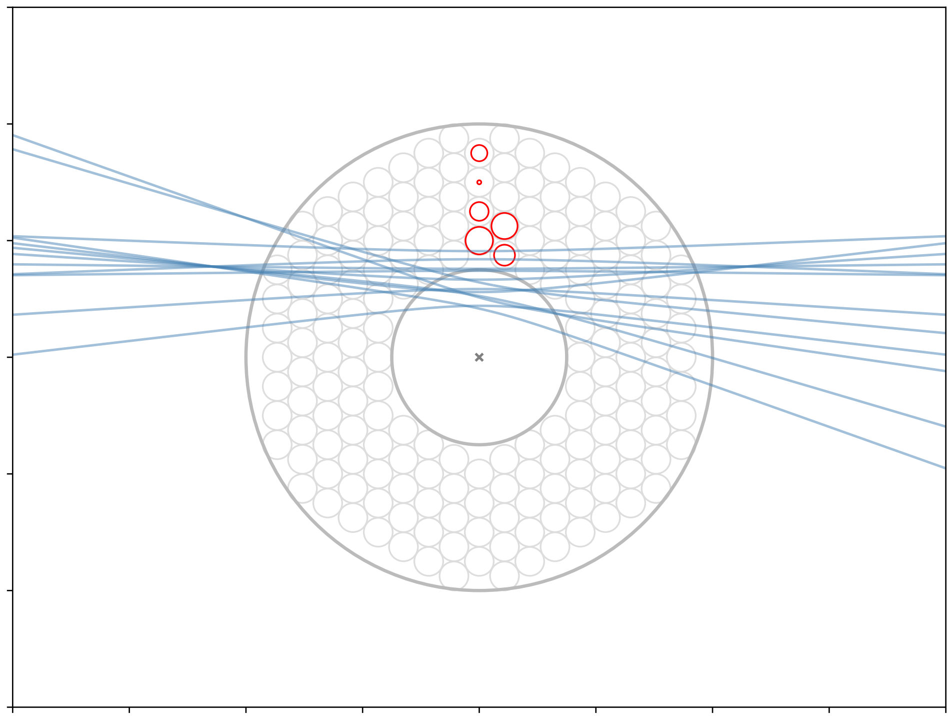
Online Track Finding

Circle Hough



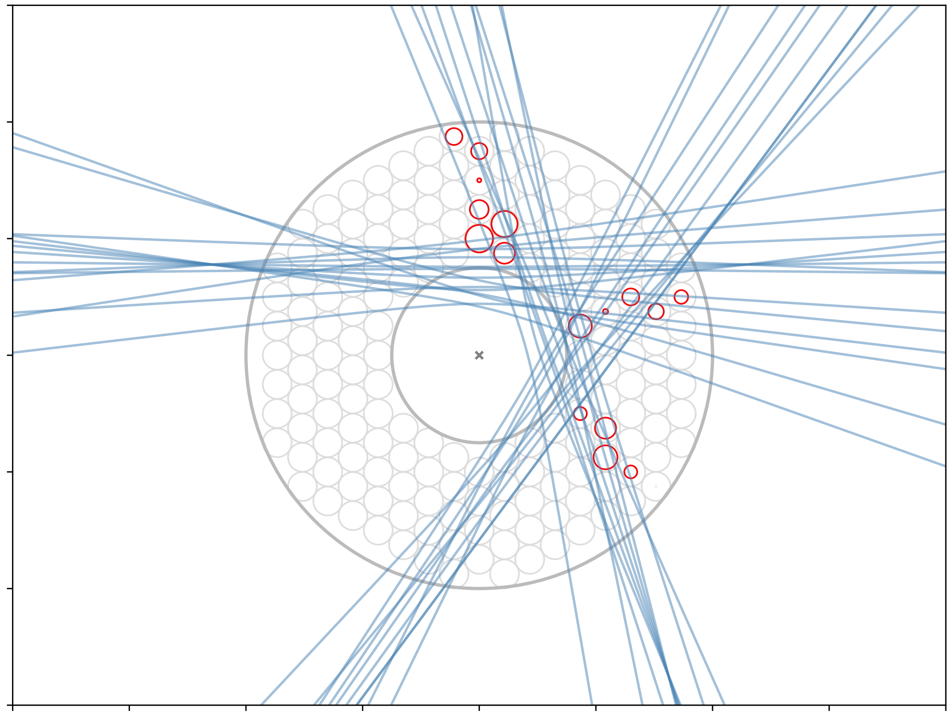
Online Track Finding

Circle Hough



Online Track Finding

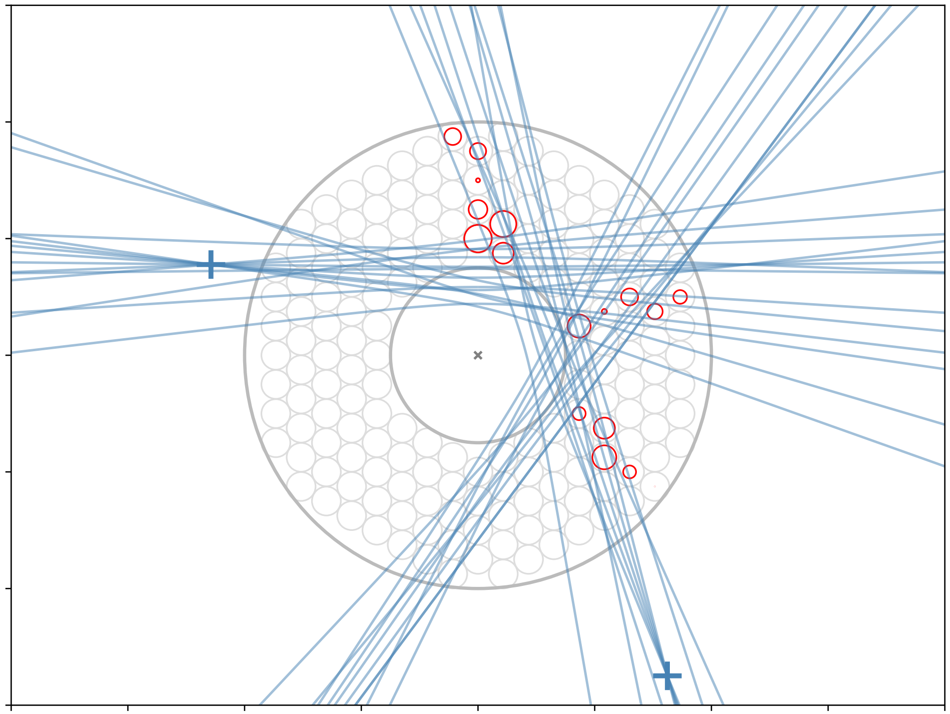
Circle Hough



JÜLICH Forschungszentrum

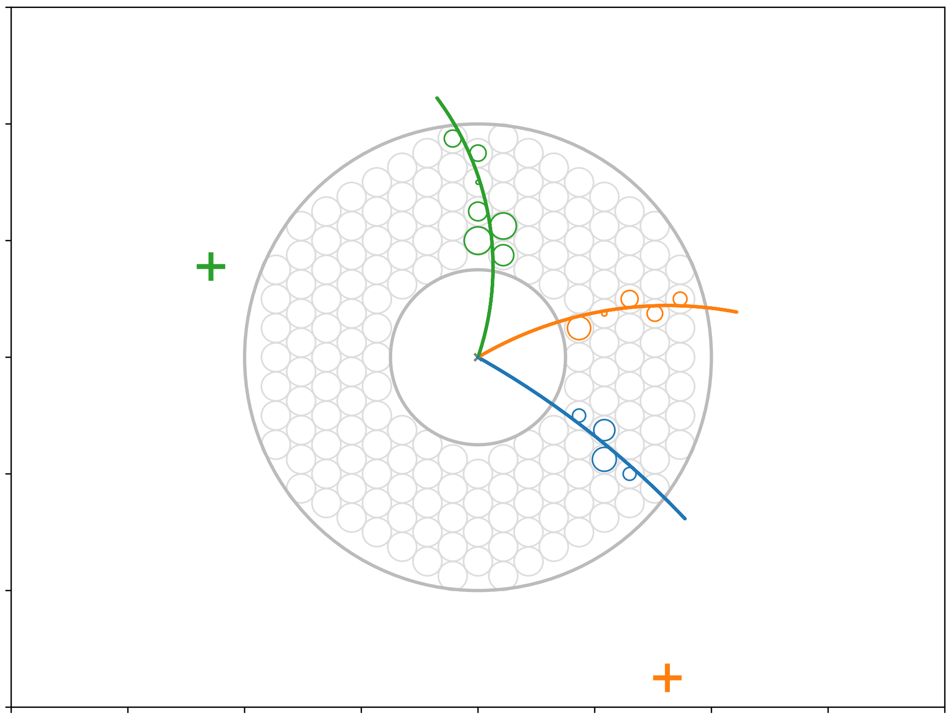
Online Track Finding

Circle Hough

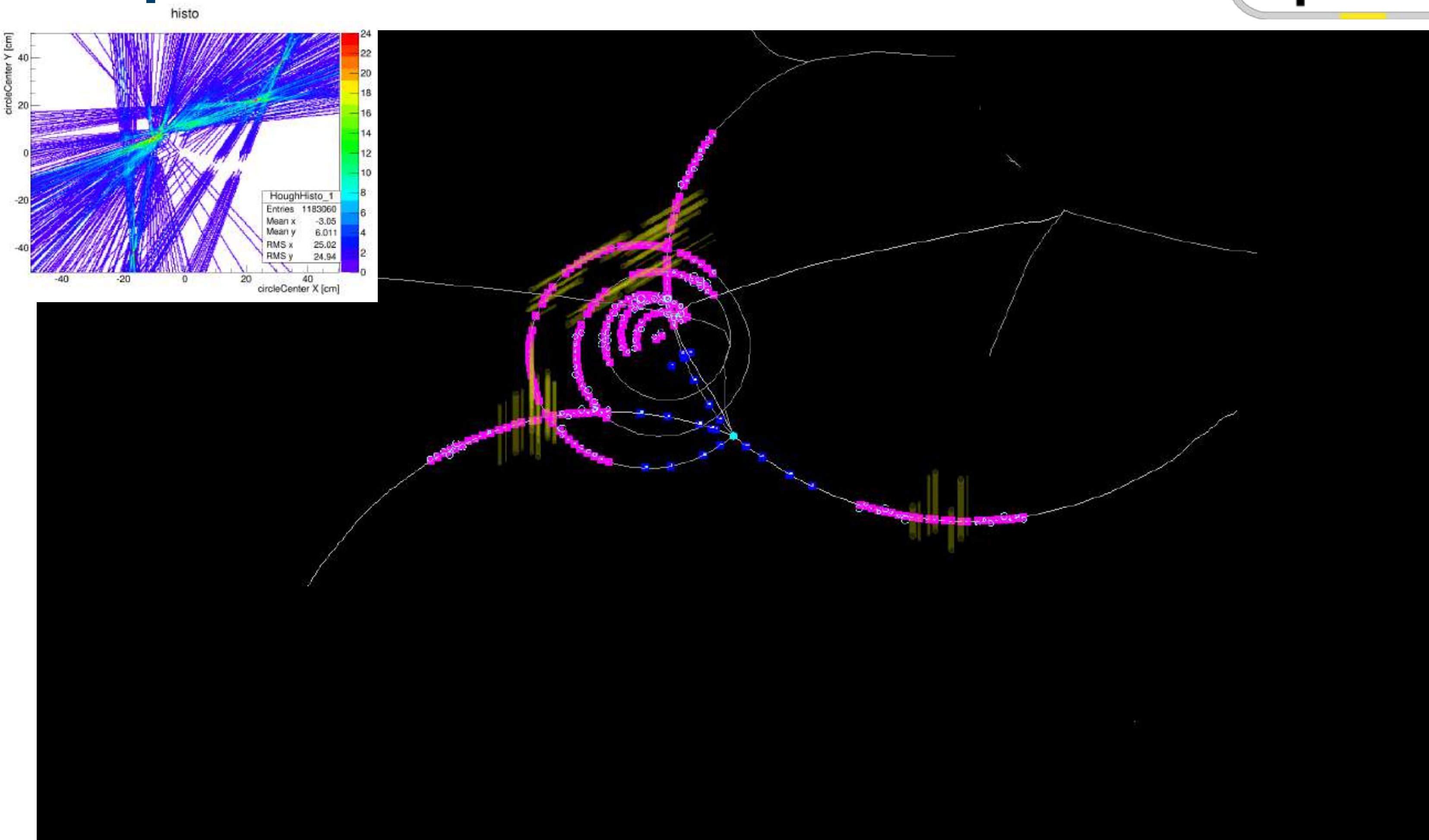


Online Track Finding

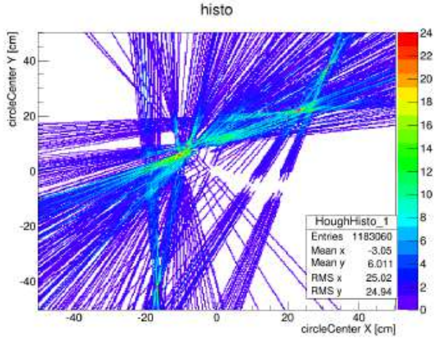
Circle Hough

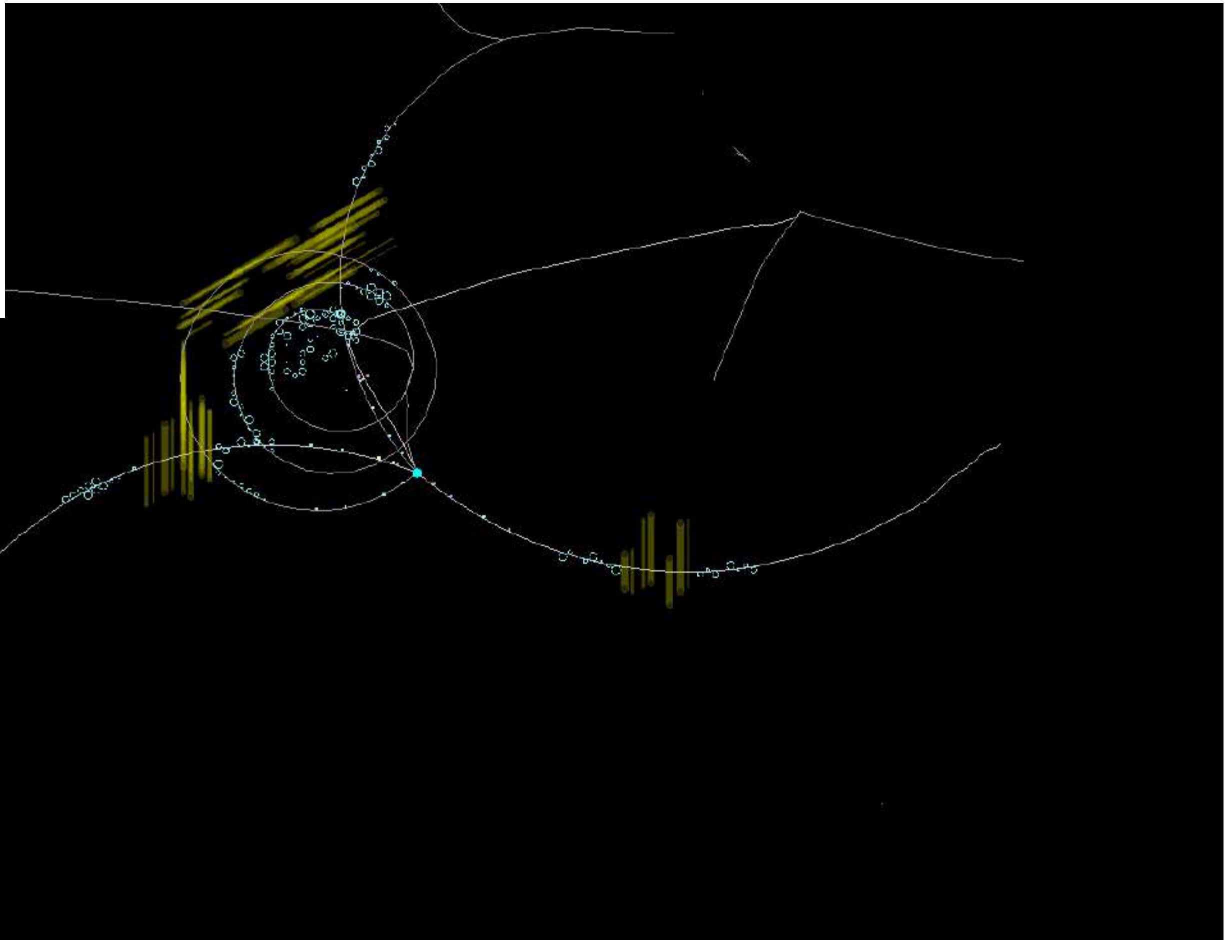


DPM Example 2

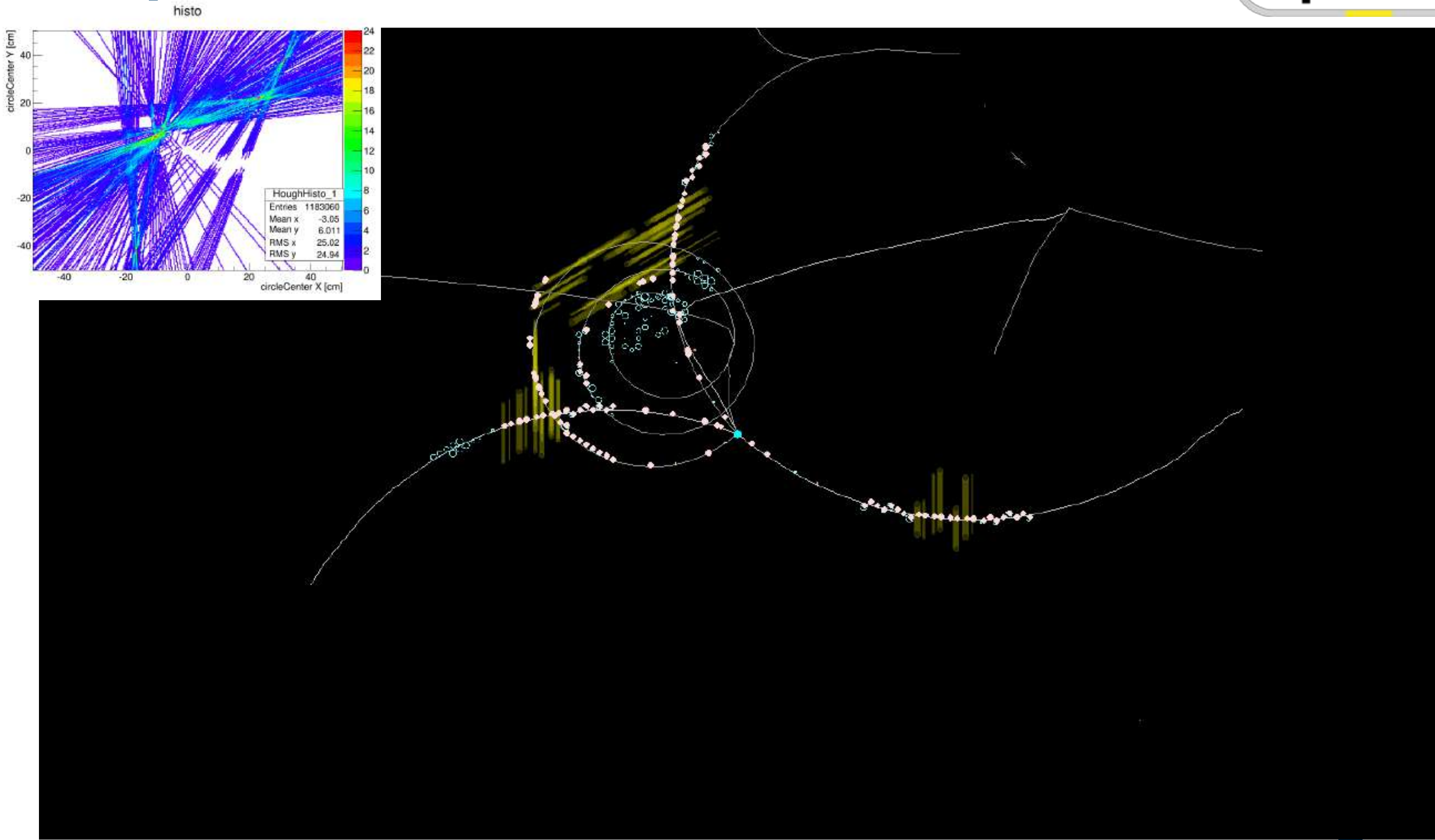


DPM Example 2

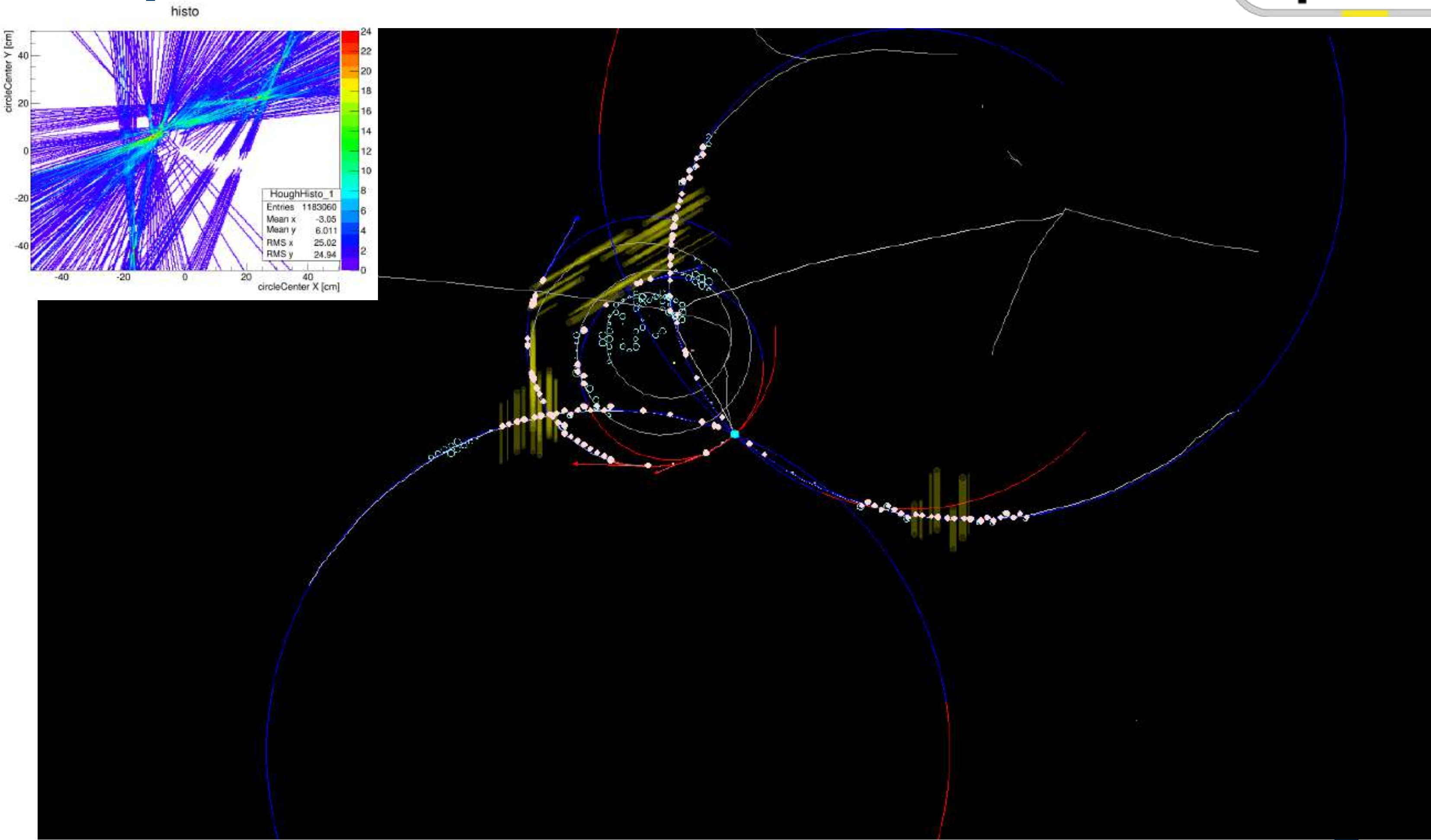




DPM Example 2

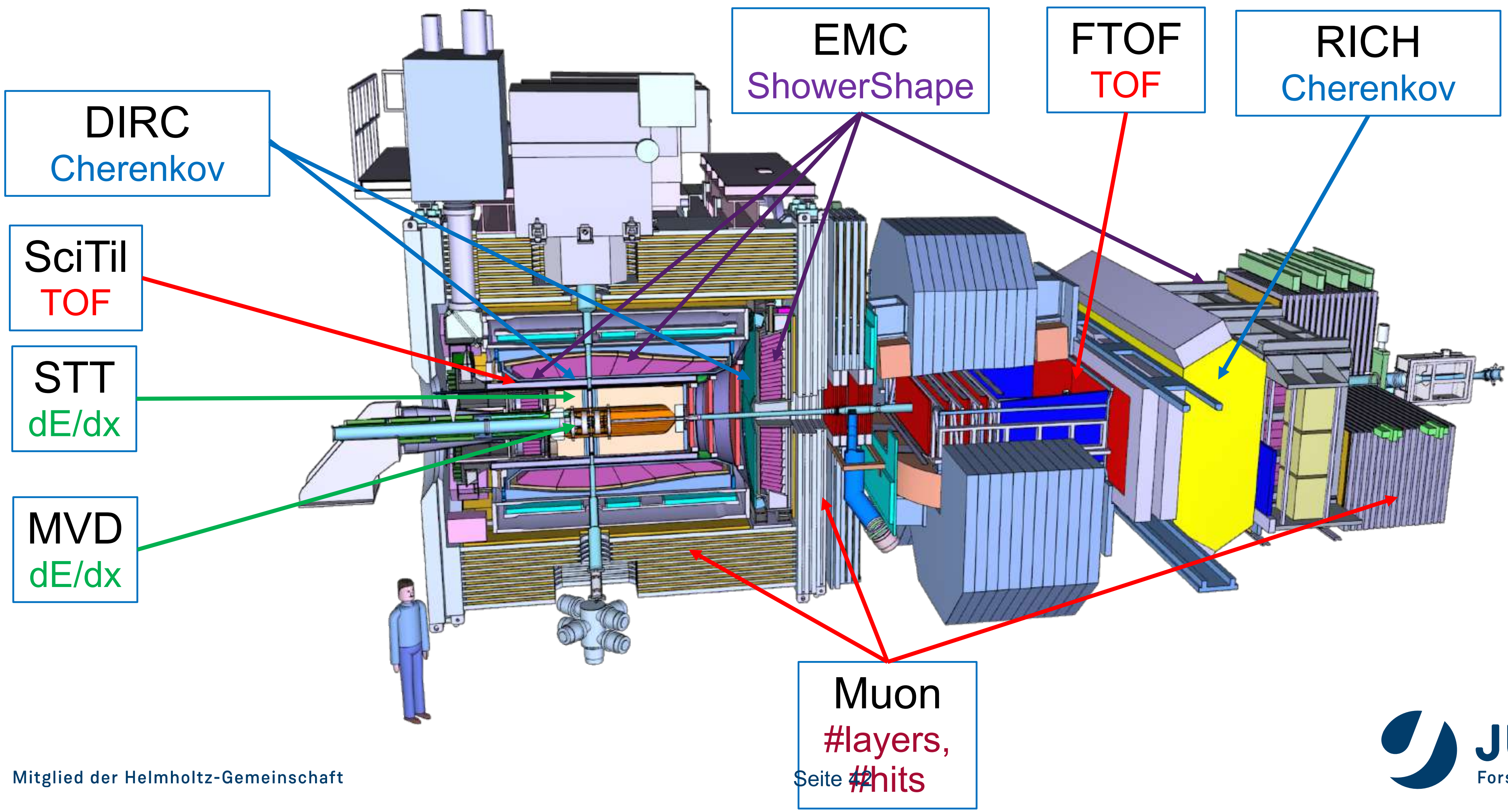


DPM Example 2



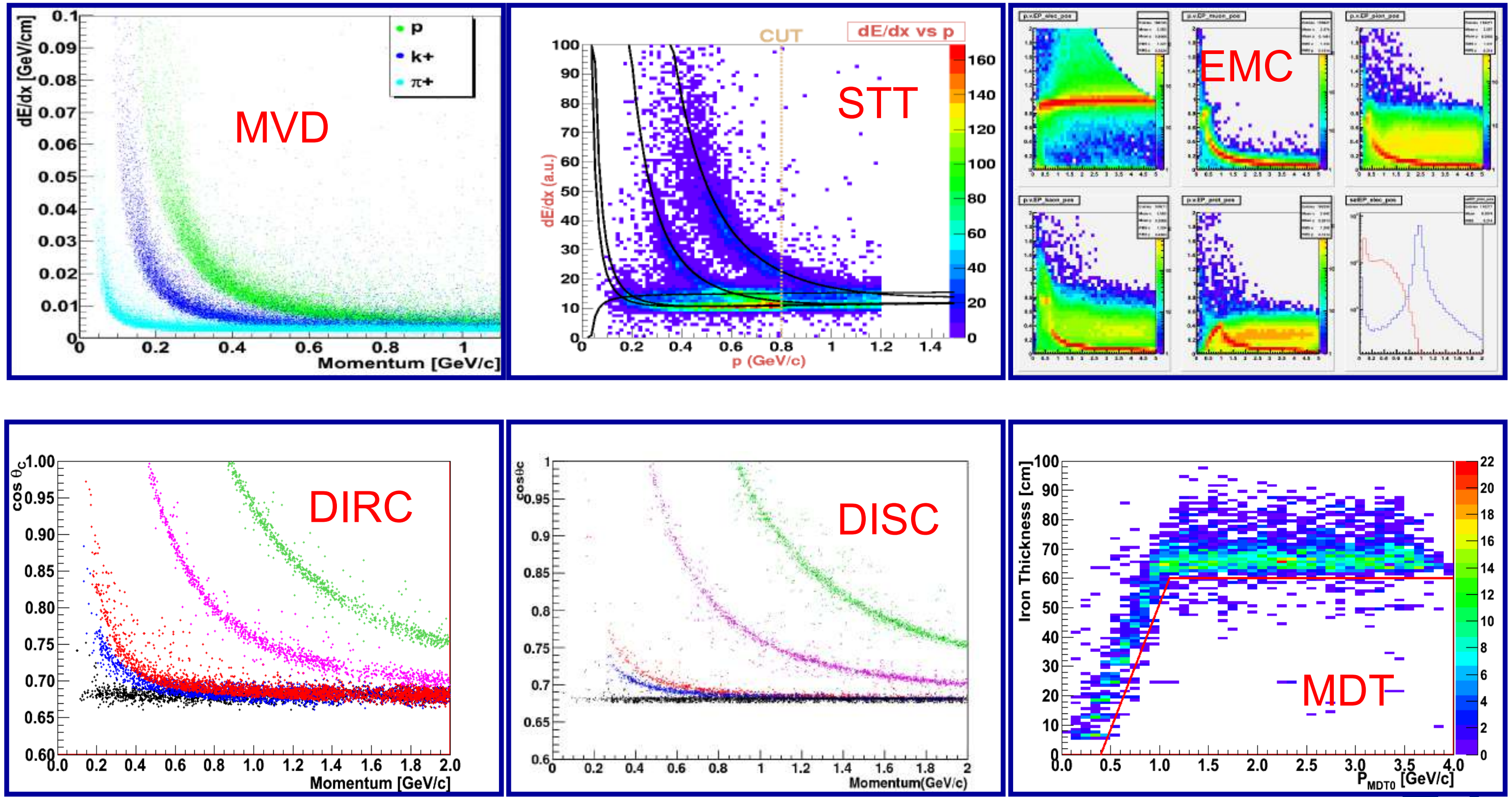
Particle Identification

Geometry description



Particle Identification

Implemented PDFs for many detectors (Bayes)



PID

Bayes Theorem

- If many detectors/alogirhtms contribute to PID

Global Likelihood

$$L(\vec{x} \mid h) = \prod_k p_k(\vec{x} \mid h)$$

k = MVD dE/dx, DRC θ_C…

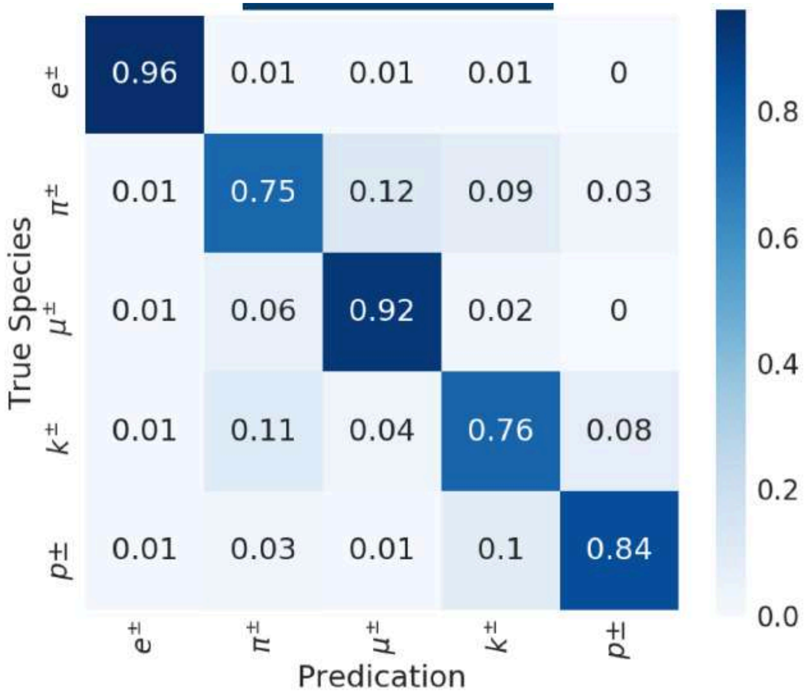
- Probability that a given track with parameters x corresponds to particle type h

$$P(\vec{x} \mid h) = \frac{L(\vec{x} \mid h) \times P(h)}{\sum_{h=e,\mu,\pi,K,p} L(\vec{x} \mid h) \times P(h)}$$

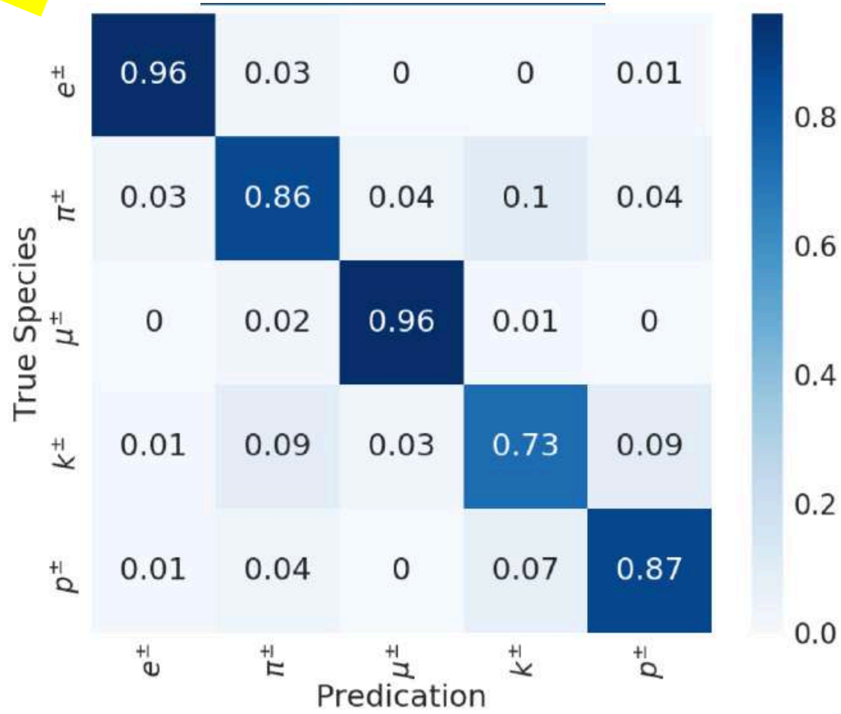
Machine Learning for PID

Work in progress

Artifitial Neural Network



Boosted Decision Tree



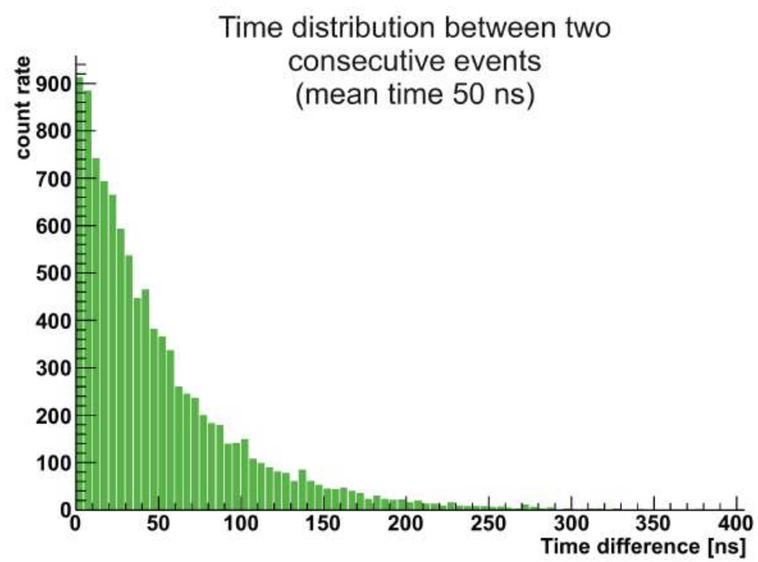
Time-Based Simulation

Mitglied der Helmholtz-Gemeinschaft

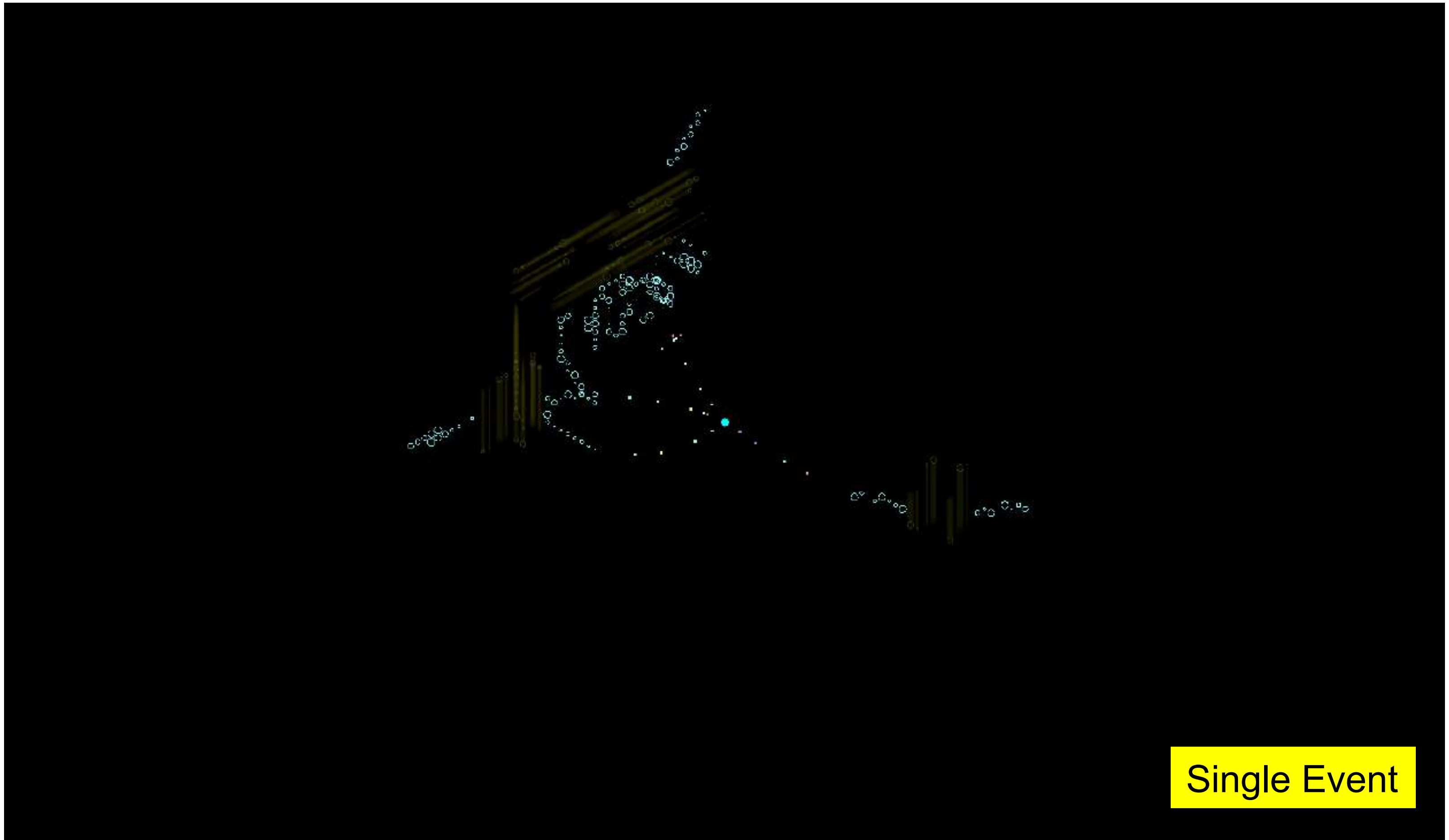
JÜLICH
Forschungszentrum

Time-Based Simulation

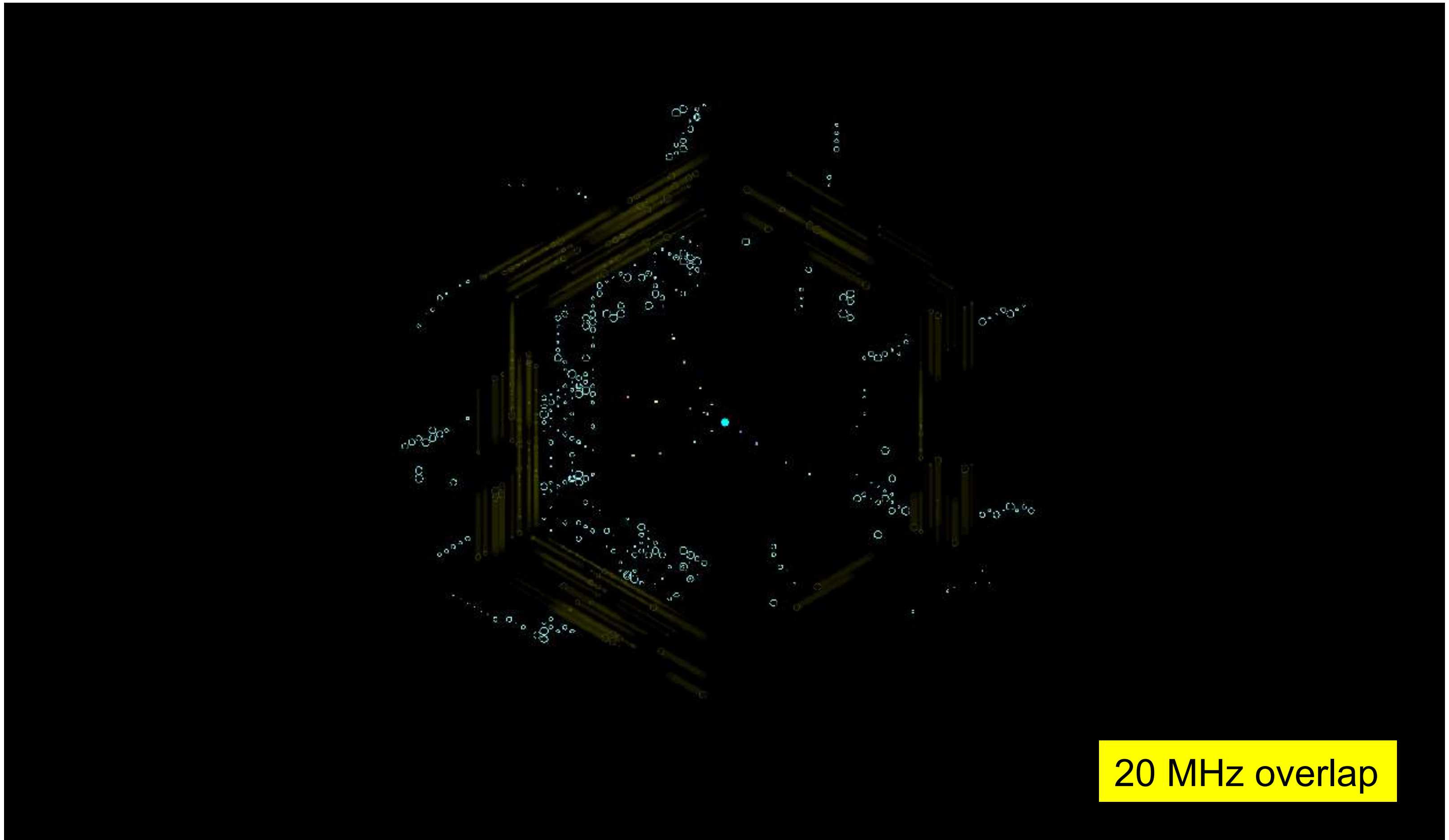
- Signal and background-events very similar ➔ no hardware trigger possible
- Quasi continuous beam with maximum interaction rate of 20 MHz
  ➔ Poisson distribution
- Raw data rate of 200 GByte/s
- Reduction of 1000 needed for permanent storage *O*(PByte/year)
  ➔ Online Event Filte



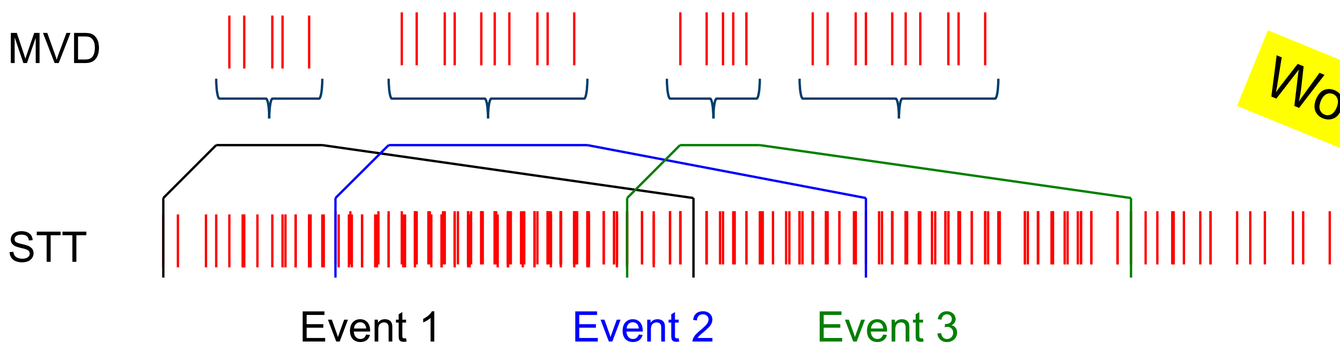
Time-Based Simulation



Time-Based Simulation

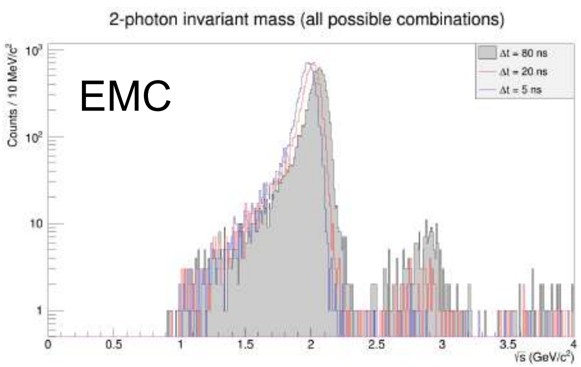


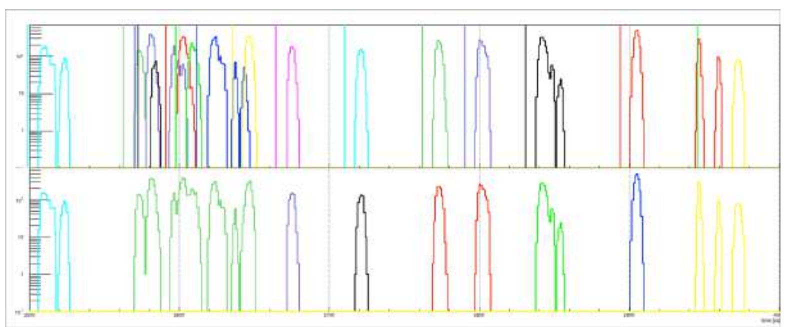
Time-Based Reconstruction



Work in progress

Activities on the central tracker MVD + STT + GEM + SciTil + EMC





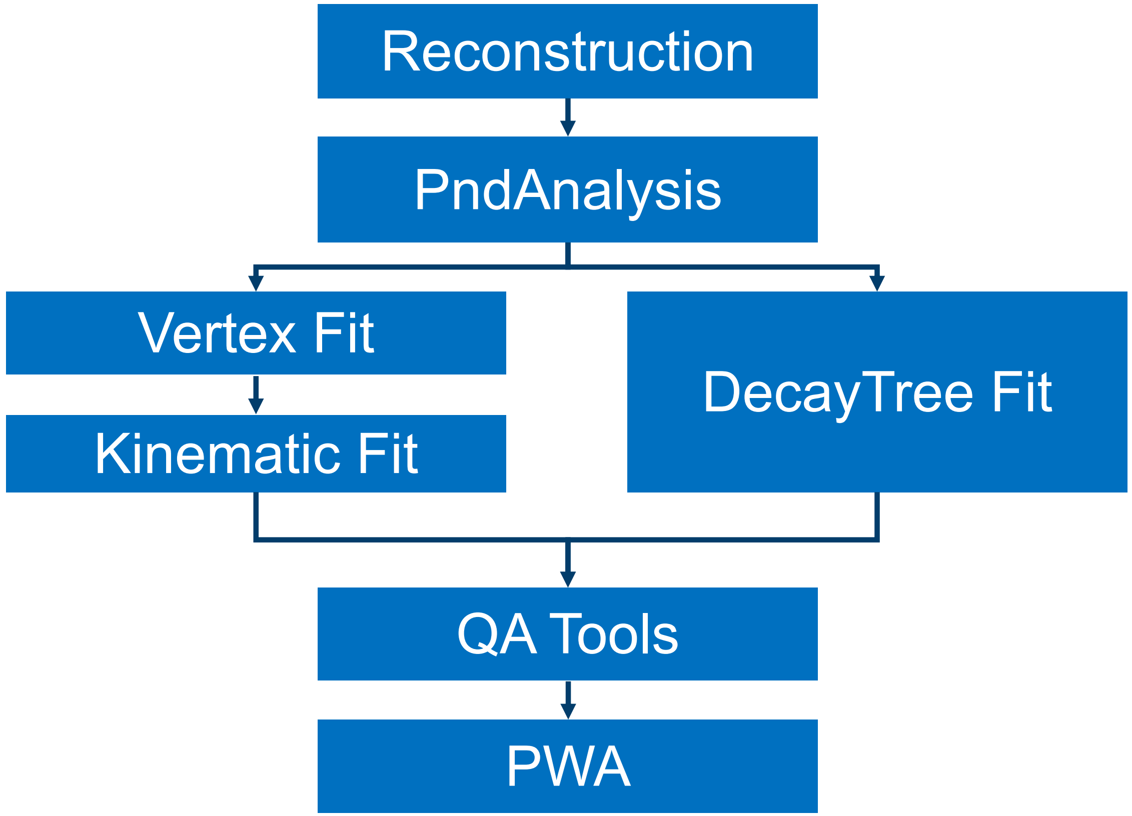
JÜLICH Forschungszentrum

Panda Analysis

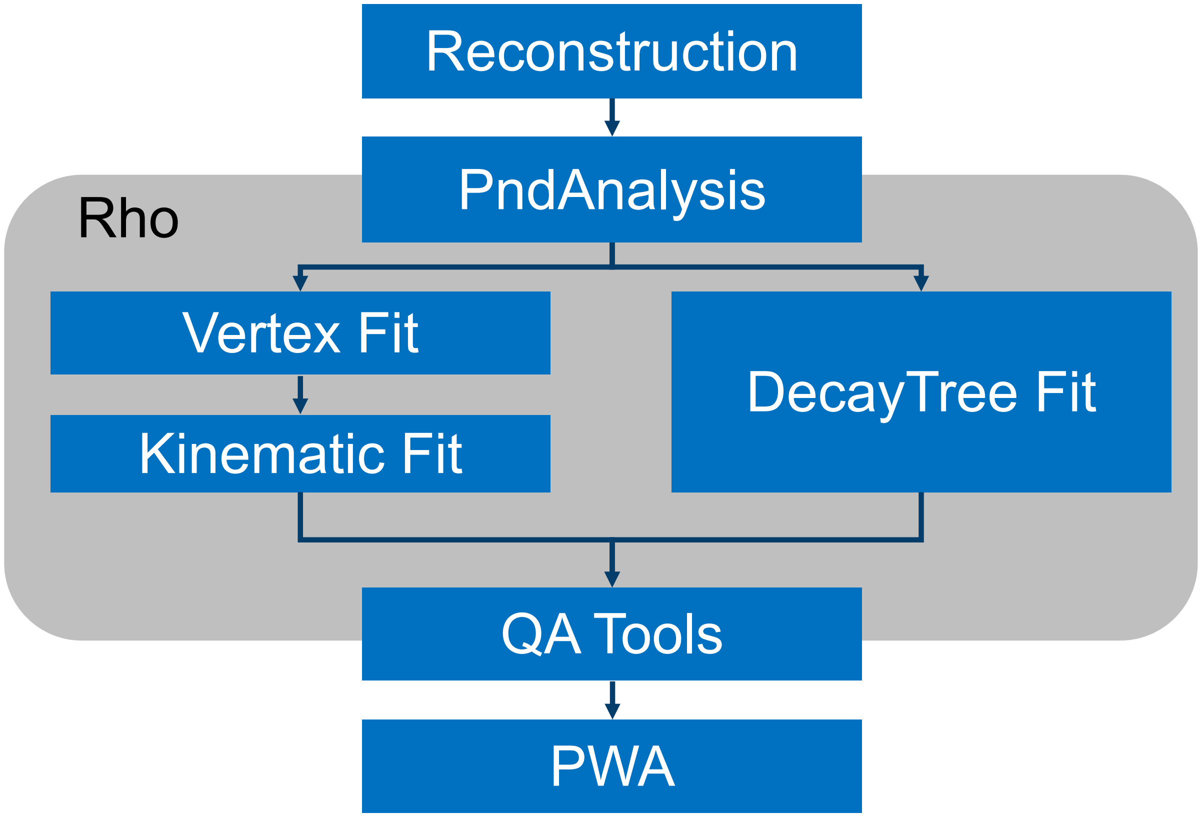
Mitglied der Helmholtz-Gemeinschaft

JÜLICH
Forschungszentrum

Analysis Tools



Analysis Tools



Analysis Framework

Rho and PndAnalysis

- Rho
  - Small framework to handle particle candidates
  - Combinatorics, lists and selectors
  - Smart n-tuple: `RhoTuple`

- PndAnalysis
  - Providing Rho with reconstructed data and basic particle lists
  - PID selections on PndPidProbability
  - Propagation interface to GEANE
  - MC-Truth access & decay chain MC-Matching

Analysis Tools

Particle Fitters

- Vertexing
  - POCA finder
  - RhoKalmanVtxFitter: fast
  - RhoKinVtxFitter: precise

- Kinematic Fits
  - Rho4CFits
  - RhoKinFitter: → Mass, 4C (P3, E)

- Tree Fits
  - Iterative mechanism
  - DecayTreeFitter fits complete decay tree at once

Analysis Framework

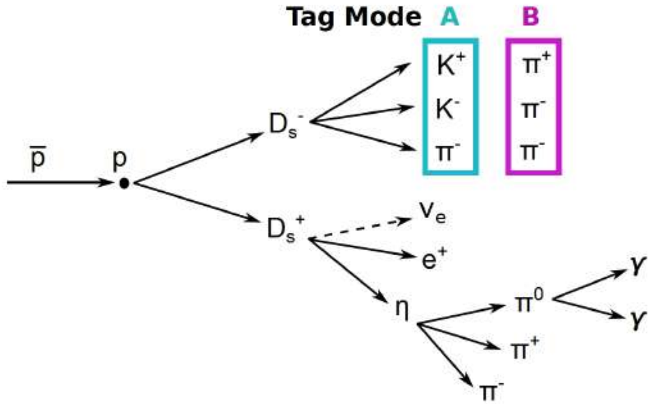
Supporting Tools

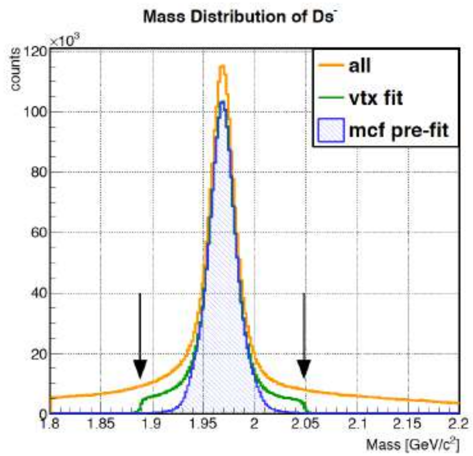
- QaTools
  - Employs smart n-tuples (RhoTuple) as root trees
  - Many automated functions to fill them (p4, daughters, mc, pid, ...)
  - Common nomenclature for fast command line analysis

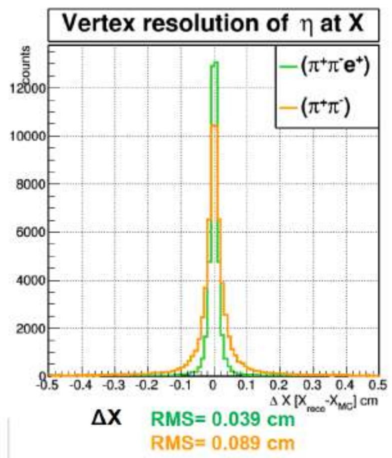
- QuickAnalysis
  - Automated scripts to get large n-tuples by a few settings for: combinatorics, fits and selections
  - Usually enough to make all desired plots!
  - FastSim implementation allows results from one macro

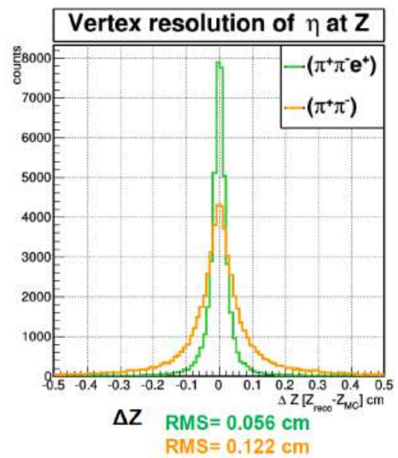
Analysis example

- Rho package
  - Combine hits
  - Fit with constraints
  - Apply cuts









Summary

- Root and FairRoot are the basis for PandaRoot
- Transition to Message Queues allows very flexible online data taking system
- Different event generators and particle propagators available to simulate the physics channels and background of interest for PANDA
- All detectors implemented in PandaRoot with varying level of detail
- Tracking available but needs more optimization for the online part
- Time based simulation implemented to simulate the difficult event building and –selecting process at Panda