GENFIT2

General Track-Fitting Toolkit for Nuclear and Particle Physics Experiments

19.09.2018 I ELISABETTA PRENCIPE | FORSCHUNGSZENTRUM JUELICH, IKP1

JÜLICH Forschungszentrum

OUTLINE

- Introduction
- Motivation for a general track-fitting toolkit
- Structure of the code
- Available fitters
- Alignment with Millepede II
- Vertex finder with RAVE
- Performance of GENFIT2 in PandaRoot and BASF2 - comparison
- Summary

INTRODUCTION

- GENFIT2 = general track-fitting tool (Vol. 2)

- Extend and improve the previous GENFIT : NIM A, Vol 620, 518-525 (2010)
- Code of free-access: http://sourceforge.net/projects/genfit/
- Limitation shown in COMPASS and PANDA in 2010 ⇒ needed an update!

- New tendency: to develop general tools to use in every experiment
- Kalman filter: implemented in various flavors, in many experiments

  - RecPack (2004): NIM A, Vol 534 180–183
  - GenFit (2010): NIM A, Vol 620, 518-525

INTRODUCTION

- GENFIT2 = general track-fitting tool (Vol. 2)

- Features of GenFit(1):
  - Can treat several types of detectors:
    silicon strip detectors or multiwire proportional chambers
    silicon pixel detectors
    drift chambers or straw tubes
    TPC (in PandaRoot: STT, with some additional work…. Thanks, Lia!)
    ….

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Hits are defined in detector planes:

1D for strips/wires, 2D for pixels, virtual detector planes in the case of drift tubes, TPC

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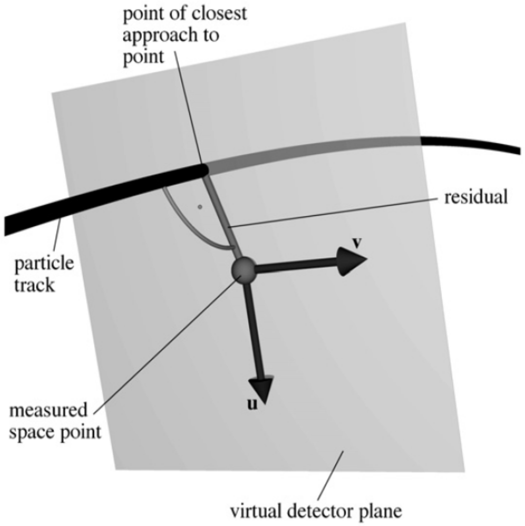


Virtual detector plane (spanning vectors $\vec{u}$ and $\vec{v}$) for a space-point hit.

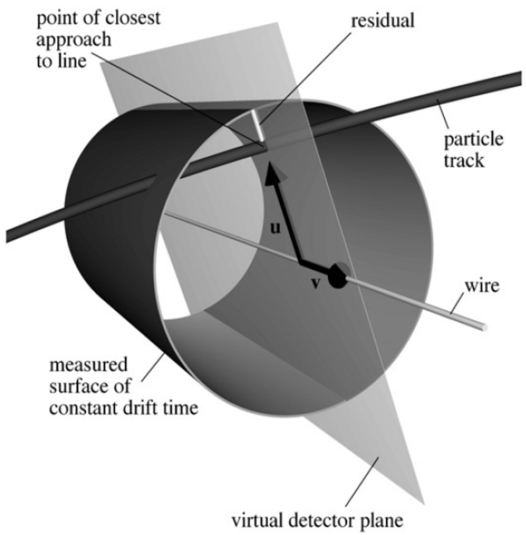


Fig. 3. Virtual detector plane (spanning vectors $\vec{u}$ and $\vec{v}$) for a wire-based drift detector.

Hits are defined in detector planes:

1D for strips/wires, 2D for pixels, virtual detector planes in the case of drift tubes, TPC

FEATURES OF GENFIT2

- Fitting algorithms can be easily implemented

  Validated Kalman filter – 2 types available

  Deterministic Annealing Filter (DAF)

  Global broken line fitter (GBL)

- Extrapolations method

  Runge-Kutta

  Invoke external libraries

- Simultaneous fitting of several tracks to the same set of hits

  Optimize track parameterizations and extrapolation

  Different phase space regions with different track models

  Fit different mass hypotheses

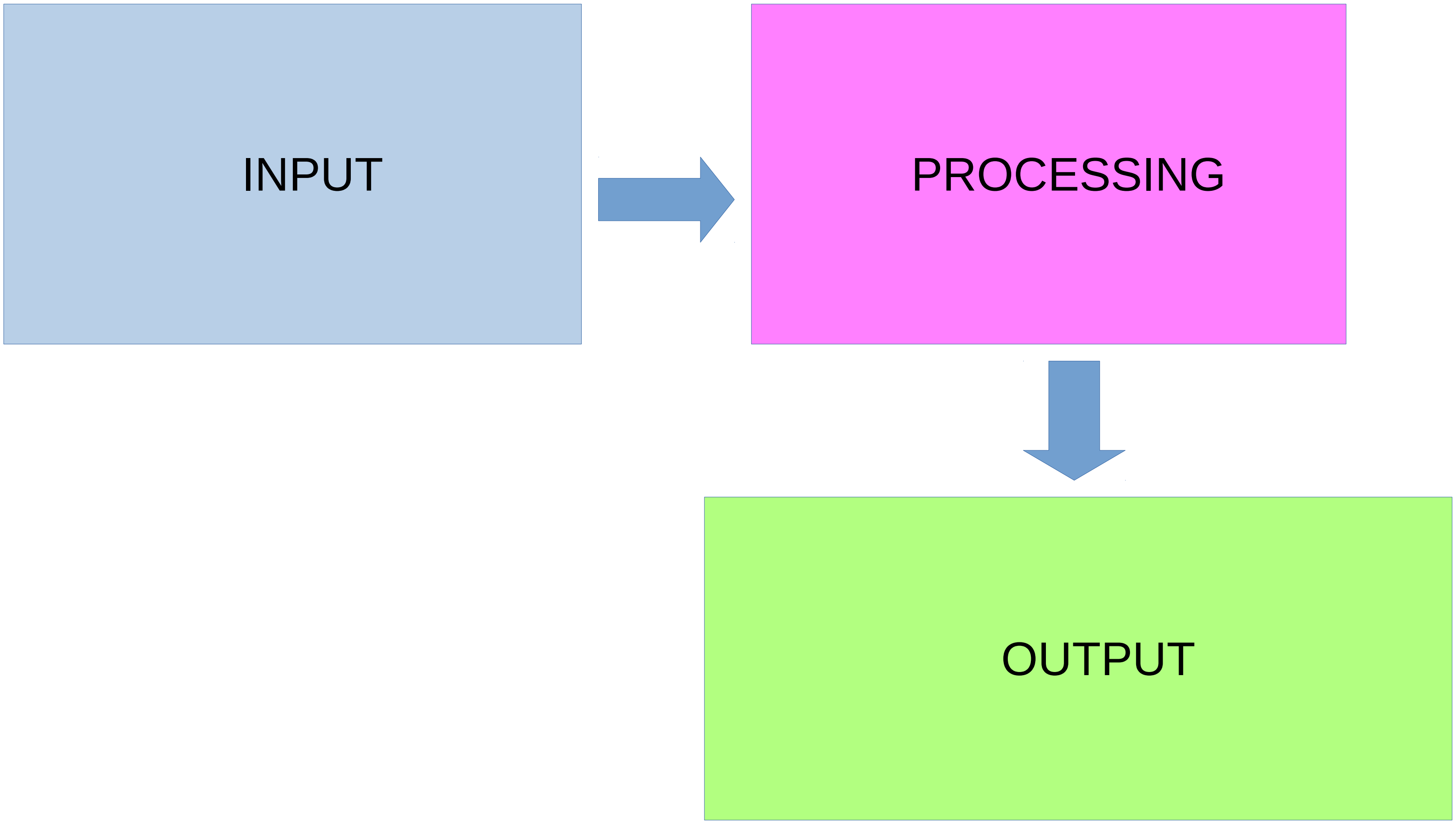
MOTIVATION FOR A GENERAL TRACK-FITTING TOOLKIT

- Several high-energy-physics experiments implement their own track fitters
- They use similar algorithms
- The idea: to provide an open-source, modular and extensible framework, capable of:
  - performing track-fitting and other related tasks;
  - easily be adapted to various experimental setups.

- Who is encouraged to use GENFIT2:
  - smaller experiments → no manpower to develop their own track-fitter;
  - new experiments which need a working tool to do research and development

STRUCTURE OF THE CODE

- GENFIT2 handles all aspects of track-fitting....or is something still missing? 



STRUCTURE OF THE CODE

- GENFIT2 handles all aspects of track-fitting....or is something still missing?

- Detector geometry
- Flexible classes
- Track candidate handling
- Interfaces between tracks, hits, alignment information

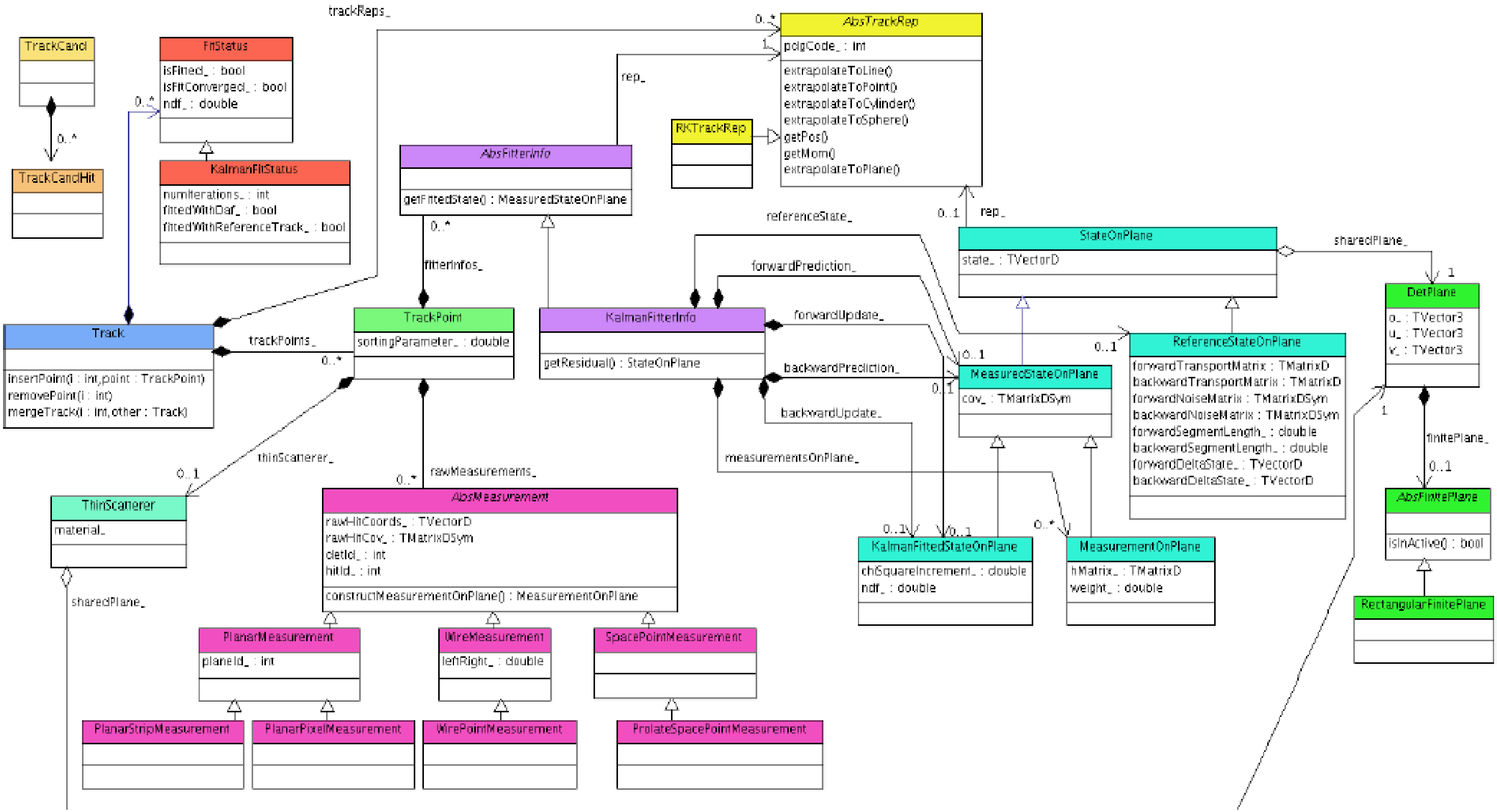
→

- Extrapolation code
- Fitting algorithms: KF, DAF, GBL
- Flexible convergence criteria

↓

- Storage fitted tracks (ROOT)
- Interface with Millepede II and RAVE
- Visualization (eventDisplay)

GENFIT2 DESIGN



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GENFIT2 DESIGN

- Measurements
  - PlanarMeasurement
  - WireMeasurement
  - SpacePointMeasurement
  - Virtual detector plane, measurement coordinates, covariance
- Track Representations
  - Track parameterization
  - Extrapolation through material and magnetic field
  - Propagate time of flight
  - Particle hypothesis
- Track fitting algorithms
  - Use *measurements* and *TrackReps* to calculate fit results
  - Start value for fit needed, *e.g.* from pattern recognition

BASIC CONCEPTS

- Track:
  contain measurements;
  measurements can be from different detectors;

  Track can be fitted with different trackReps
  (*e.g.*, can be fitted with different particle hypothesis)

- Measurements:
  serve as objects containing measured coordinates from a detector.
  Base class: *AbsMeasurement*

- *TrackPoints* can contain *measurements*, *FitInfo objects*,....

- *TrackCand* serves as helper class:
  it stores indices of raw detector hits in *TrackCandHits* objects

- *WireTrackCandHits* objects can store the left/right ambiguity

FITTING ALGORITHMS

Fitting flows

Create track

↳Create initial with track from MC truth

↳Smear the start position and momentum

↳Create the track representation with mass hypothesis

Add measurements on track

↳Create a space-point truth-hit position coming from particle

↳Smear hit (digitization)

Smear pixel measurement with gauss at (r-phi, z)=0.02x0.02 mm for both barrel and endcap

Smear strip measurement with gauss at (r-phi, z)= 0.05x0.1 mm for both barrel and endcap

↳Create virtual detector plane by the plane perpendicular to momentum direction at this hit

↳Put detector resolution : 1/sqrt(12) * detector element width

Fit track with DAF (Deterministic Annealing Filter)

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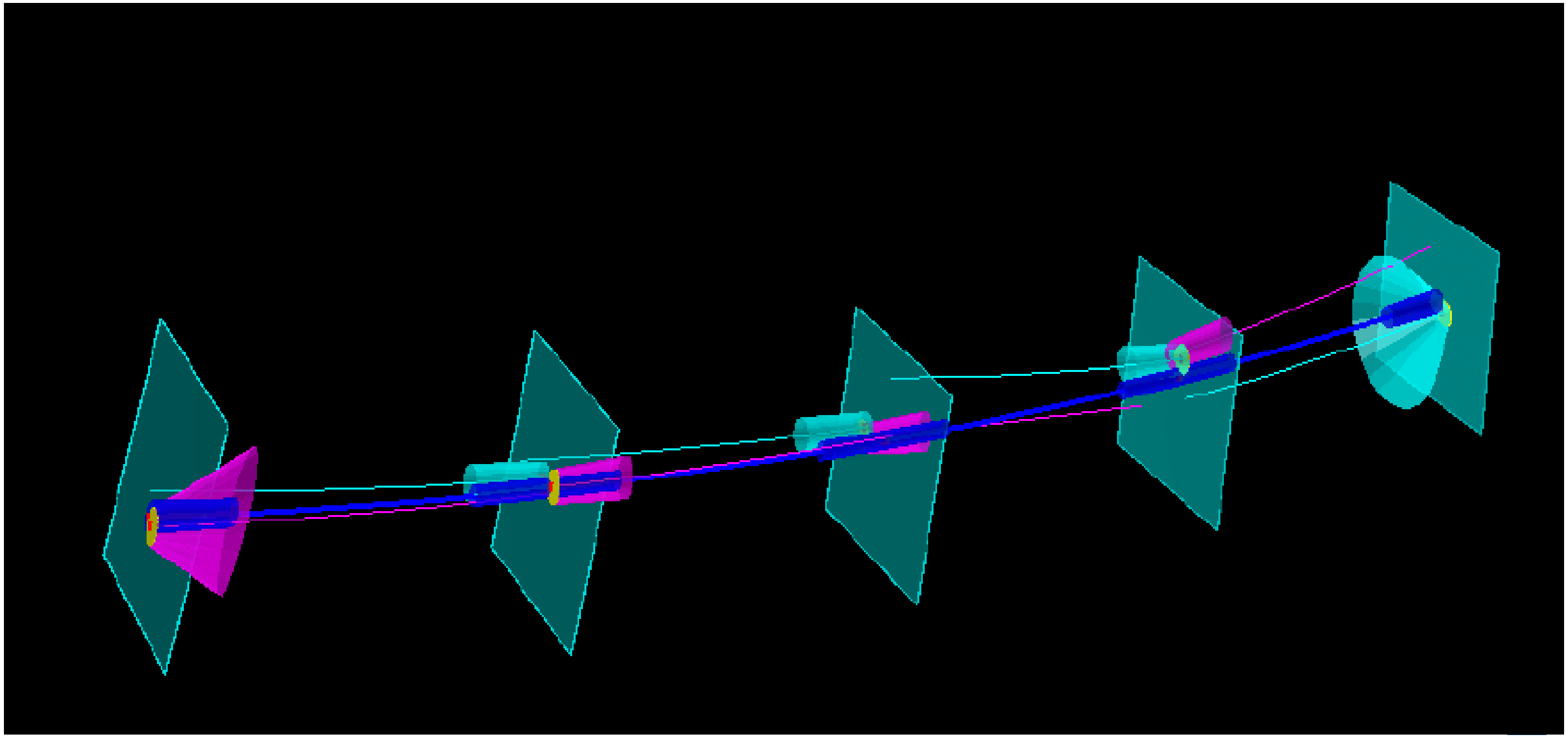
FITTING ALGORITHMS

Kalman filter

- Prediction step: extrapolate state and covariance to next measurement
- Update step: calculate a weighted average between prediction and measurement
- Prediction + update: iterate over measurements, forth- and back-, until convergence
- Linearization. Kalman filter is a linear estimator: need to linearize the transport



Smoothed track: weighted average between forward fit and backward fit.

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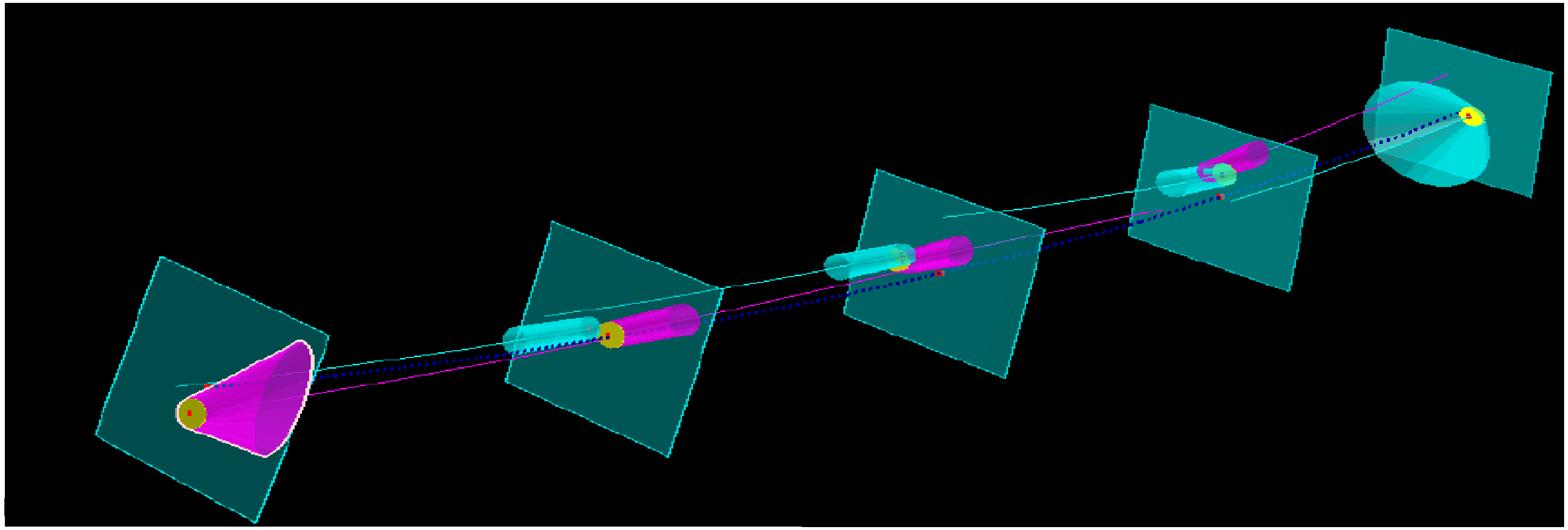
FITTING ALGORITHMS

Kalman filter with reference track

- Problems when linearizing around predictions:
  state predictions can be far off the real trajectory (*e.g.*, first few hits);
  outliers can bend the prediction away.

- Consequence: linearization makes not sense, and fit can fail

- Solution: use reference track ⇒ Take estimated track parameters from pattern recognition or previous fit as expansion point for linear approximation (*i.e.*, linearize around reference track, instead of state prediction)



Reference track, forward- and backward fit.

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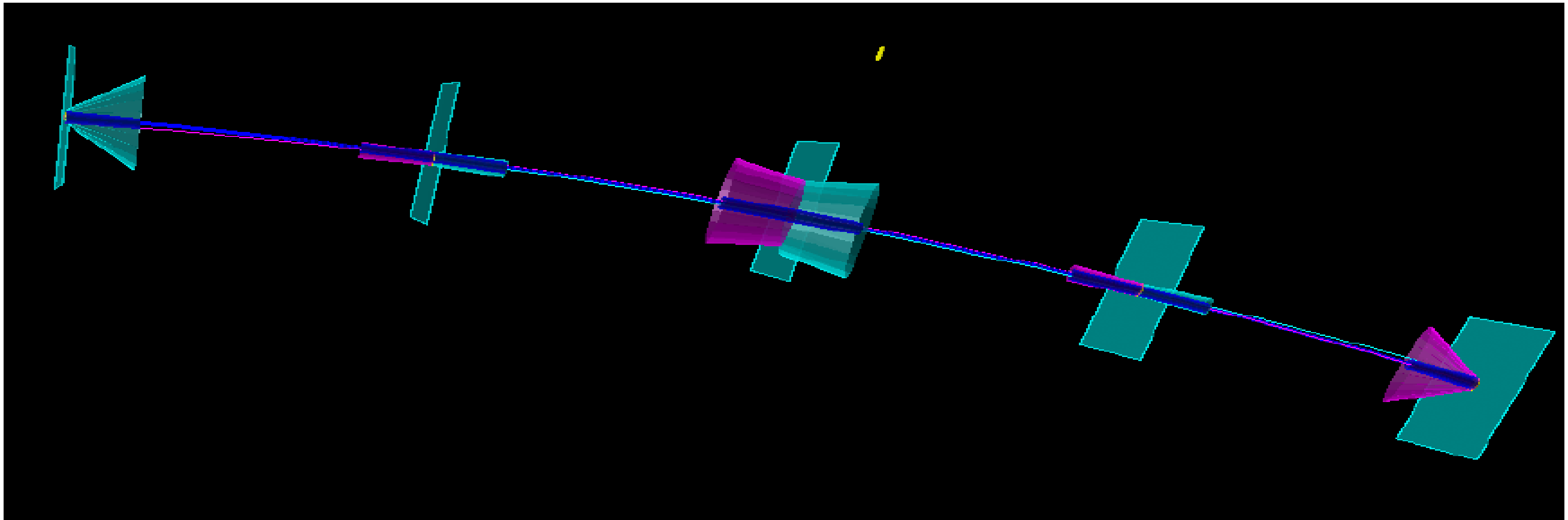
FITTING ALGORITHMS

Deterministic Annealing Fitter (DAF)

- Robust track fitter
- Produces assignment probabilities of measurement (*e.g.*, weights)
- Iterative Kalman filter with weighting and annealing to find the best fit
- Can reject outliers or resolve left/right ambiguities of WireMeasurements.



after 6 iterations

DAF

How the weighting procedure work?

- Useful to solve left/right ambiguities
- Weight of the *MeasurementOnPlane* must be initialized
- Basic solution: to assign both left and right measurements a weight = 0.5

- Wire positions are taken as measurements in the first iteration:
  covariance is twice the mean of the individual covariances
    - all wire positions have same covariace
    - systematic false estimate of the covariance biases the fit.

- Novel technique implemented in genfit2:
  - measurements with larger drift radii are assigned smaller weights ⇒ larger cov.;
  - measurements with smaller drift radii are assigned larger weights ⇒ smaller cov.

↓

efficiency improvement

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RUNGE-KUTTA REPRESENTATION

- *RKTrackRep* based on extrapolator from Geant3
- An abstract interface class interacts with detector geometry
- During fitting, material properties are used to calculate:
  - Energy loss
  - Energy loss straggling according to Bethe-Block formula (code ported from Geant3)
  - Multiple scattering (Highland-Lynch-Dahl) formula
  - Bremsstrahlung energy loss and energy loss straggling for electrons
- Field inhomogeneity and curvature taken into account
- Provide different methods to find the POCA of the tracks to non planar measurements

TRACK PARAMETRIZATION

momentum

direction cosines relative to the plane

charge

local coord. on the plane

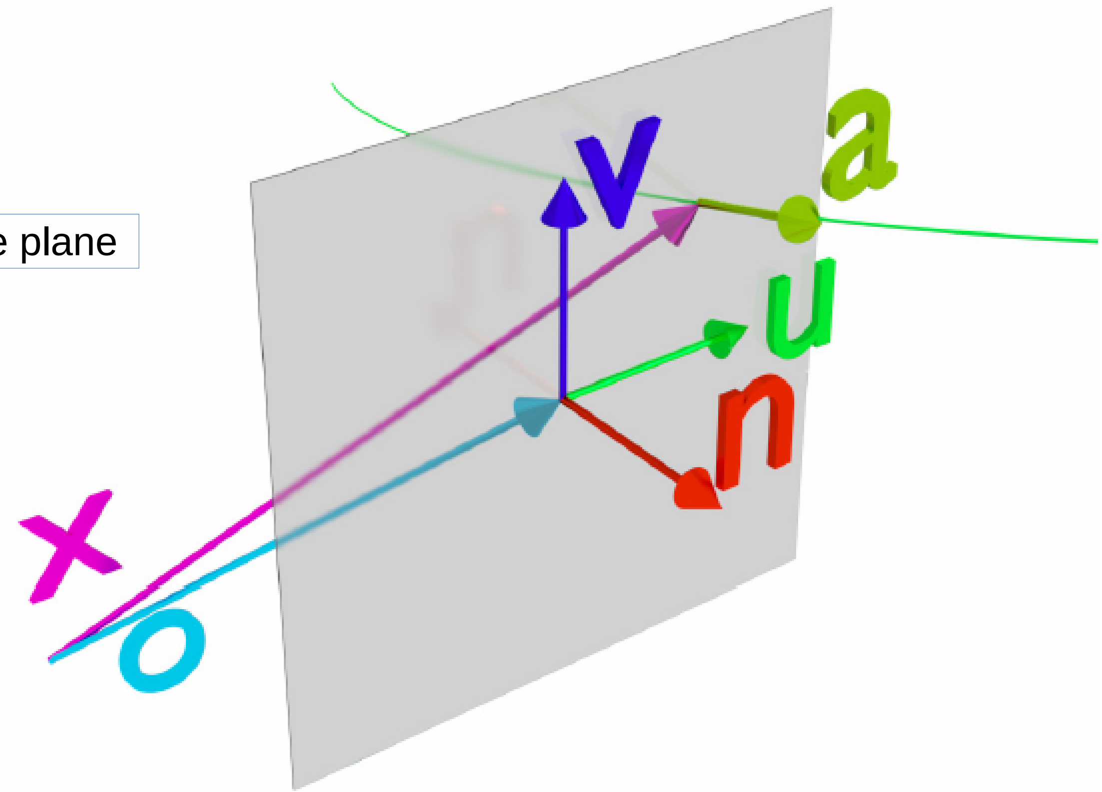
$$\mathbf{p} = \left(q/p, u', v', u, v\right)^T$$

$$u' = \frac{\vec{a}\cdot\vec{u}}{\vec{a}\cdot\vec{n}}$$

$$v' = \frac{\vec{a}\cdot\vec{v}}{\vec{a}\cdot\vec{n}}$$

$$u = (\vec{x} - \vec{o})\cdot\vec{u}$$

$$v = (\vec{x} - \vec{o})\cdot\vec{v}.$$



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FITTING ALGORITHMS

Generalized Broken Line fitter (GBL)

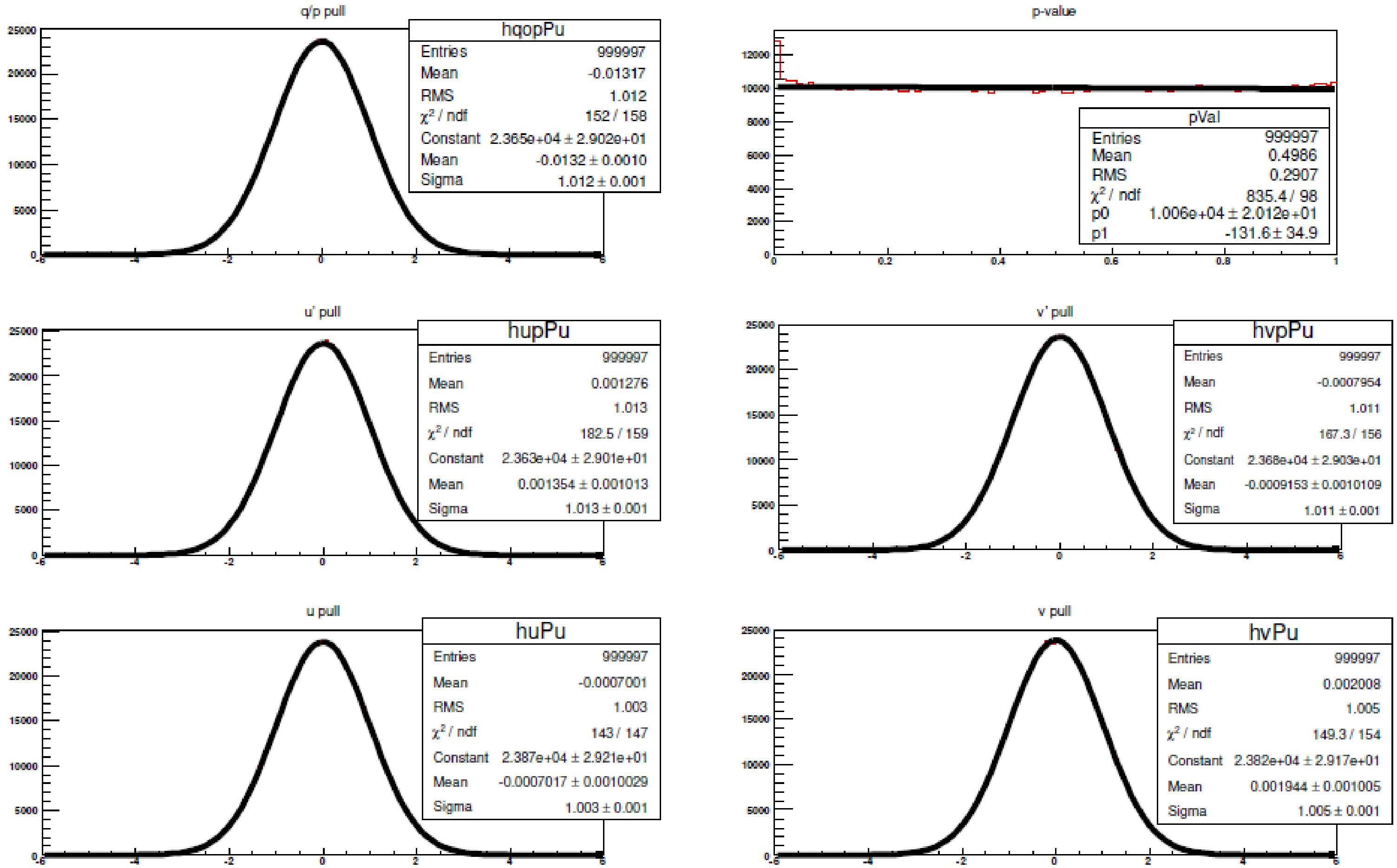
- GBL is implemented for using Millepede II
- Mathematically equivalent to the Kalman fitter

STILL NOT IN PANDAROOT

PERFORMANCE

GENFIT2 as standalone toolkit

p = 1 GeV/*c*



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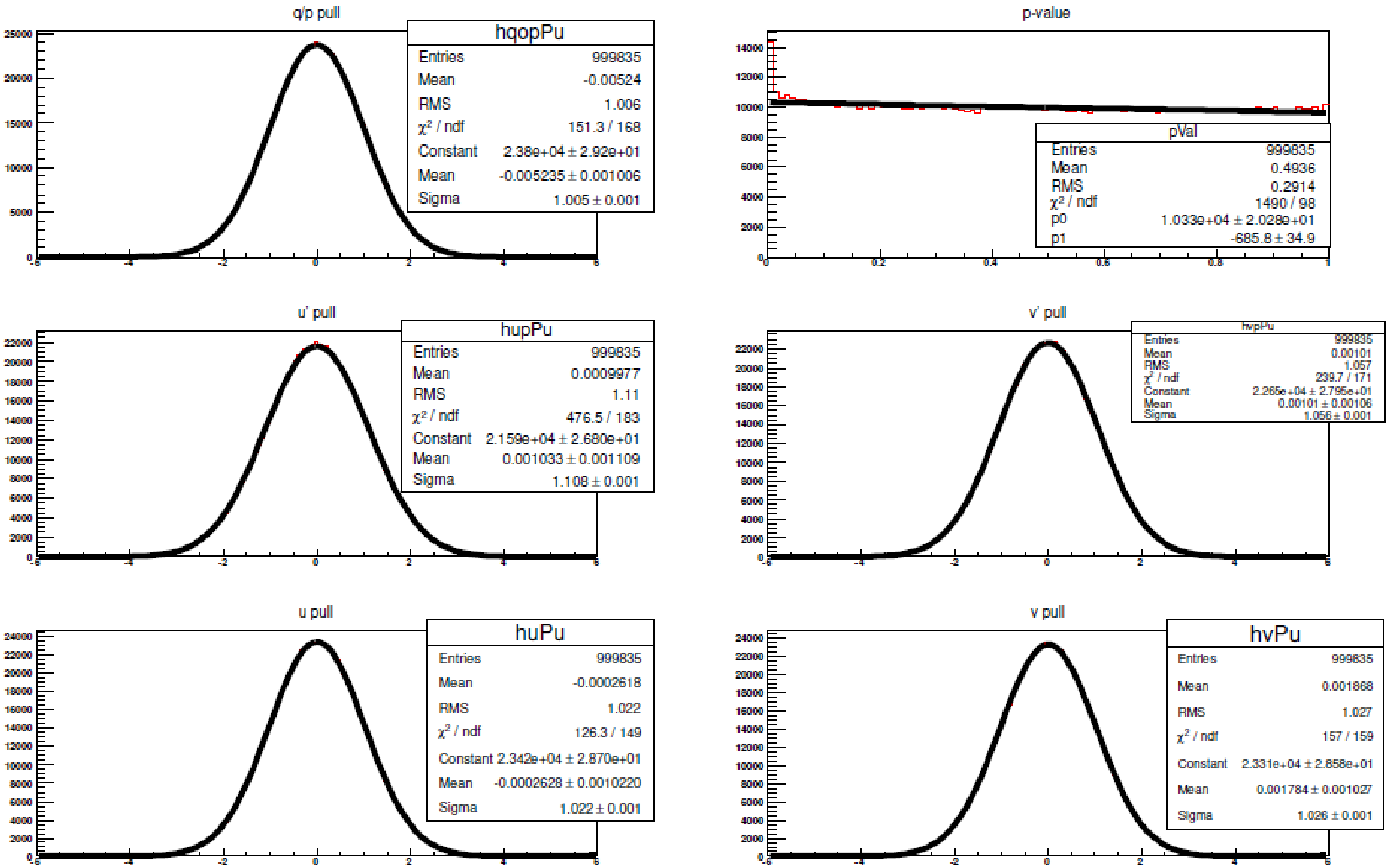
PERFORMANCE

GENFIT2 as standalone toolkit

p = 100 MeV/c



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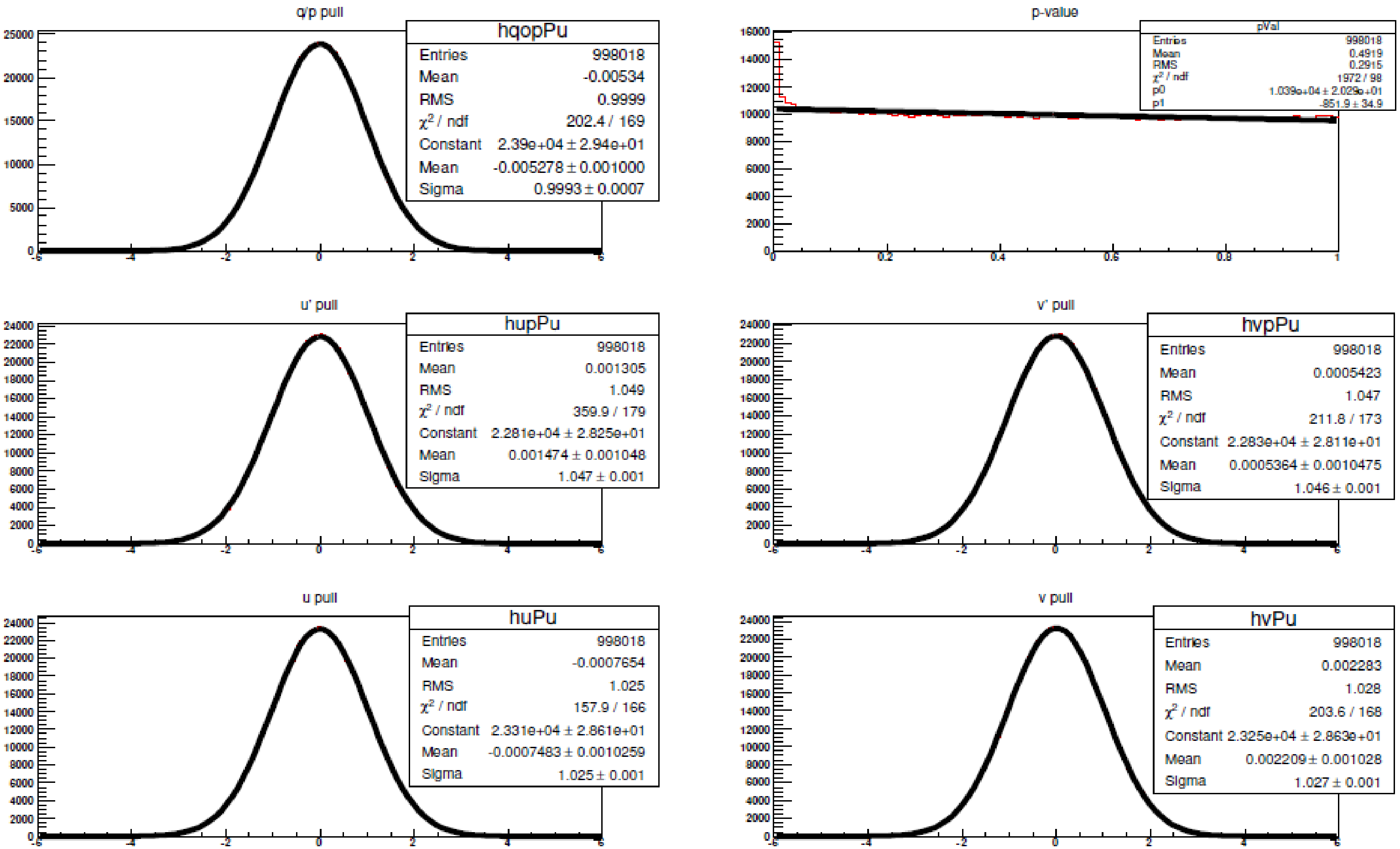
PERFORMANCE

GENFIT2 as standalone toolkit

p = 50 MeV/c



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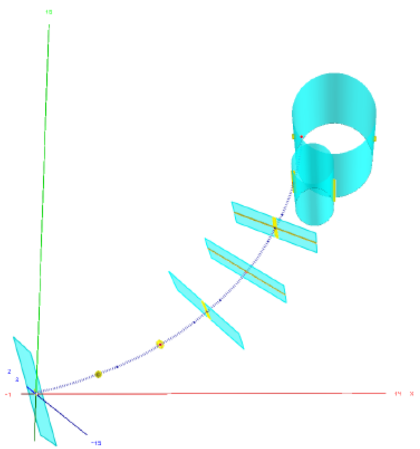
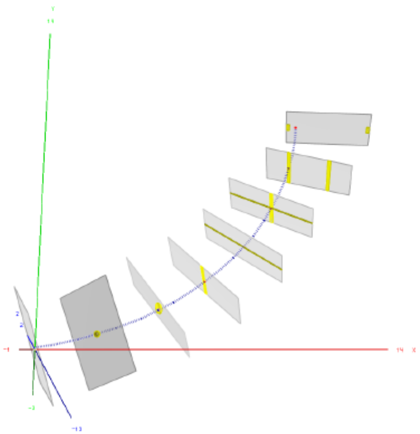
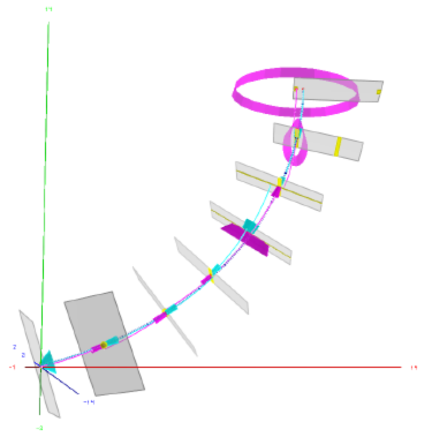
EVENT DISPLAY IN GENFIT2



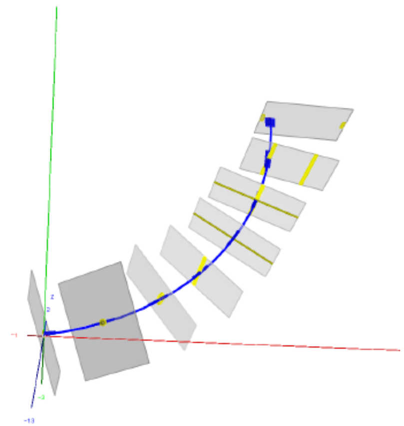
(a) Measurements with covariance (yellow), planar detectors and drift isochrones (cyan), respectively, and reference track (blue).



(b) Detecor planes (grey). For the spacepoint- and wire-hits, virtual detector planes have been constructed.



(c) Forward (cyan) and backward (magenta) fit with covariances of the state updates.



(d) Smoothed track with covariance (blue).

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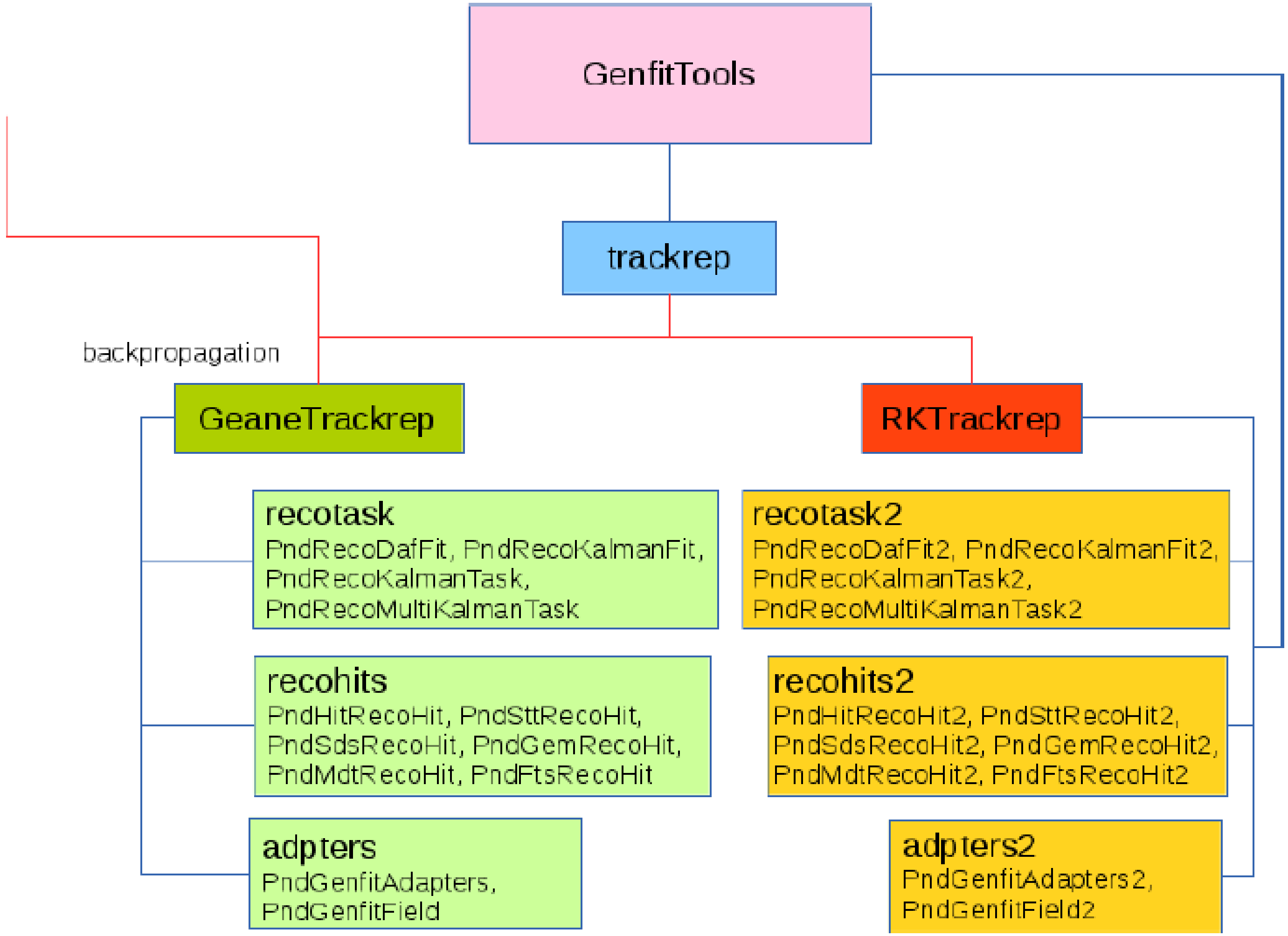
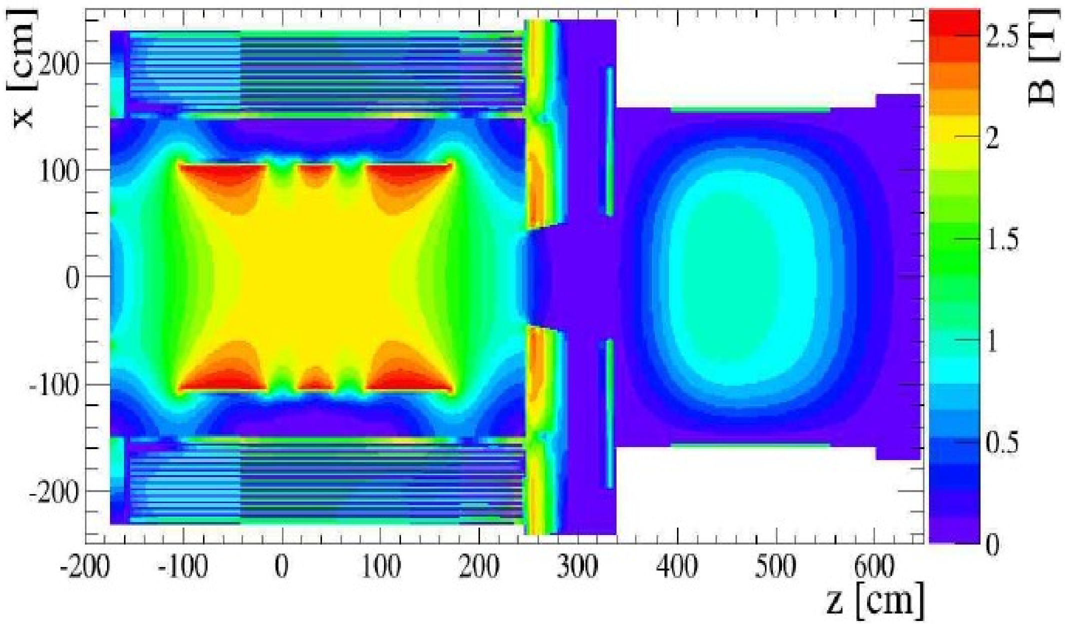
HOW DOES IT WORK IN PANDAROOT?



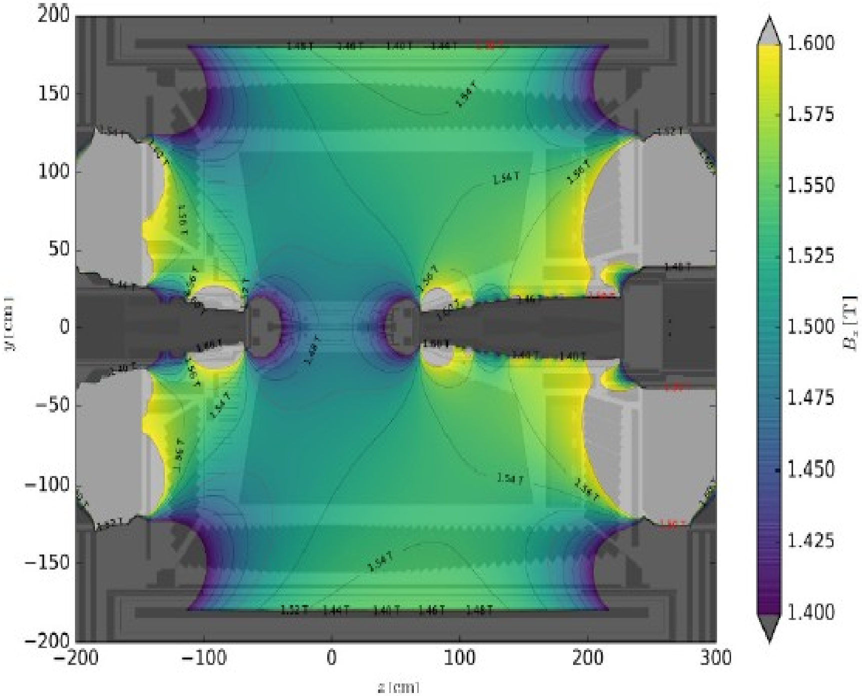
MAGNETIC FIELD MAP

E. P., JPCS 898, 042037 (2017)



PANDA

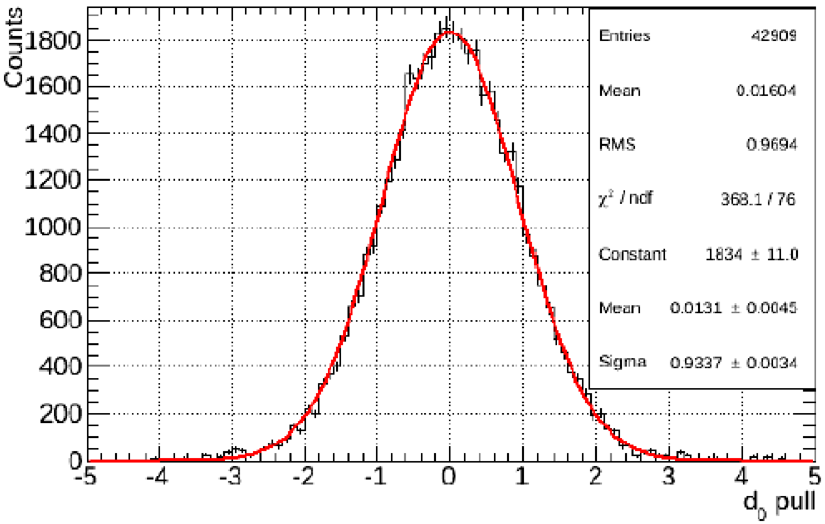
arXiV:1808.10567

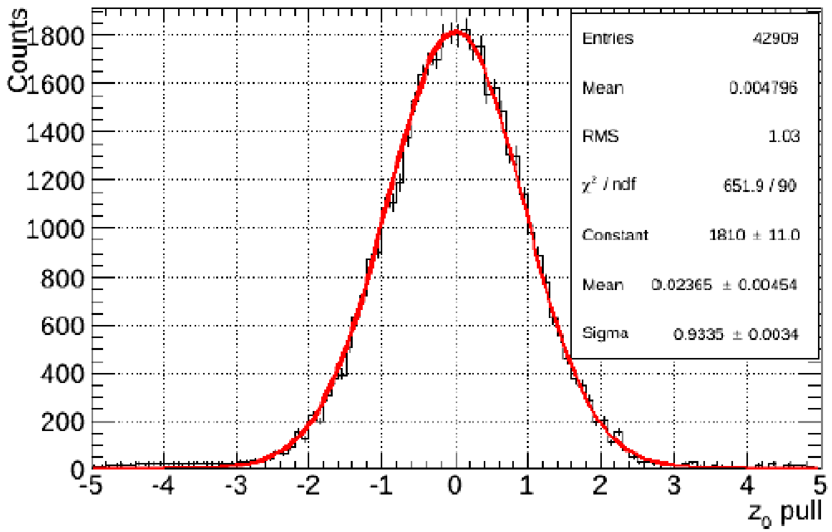


Belle II

TEST: D0 AND Z0 PULL IN PANDAROOT

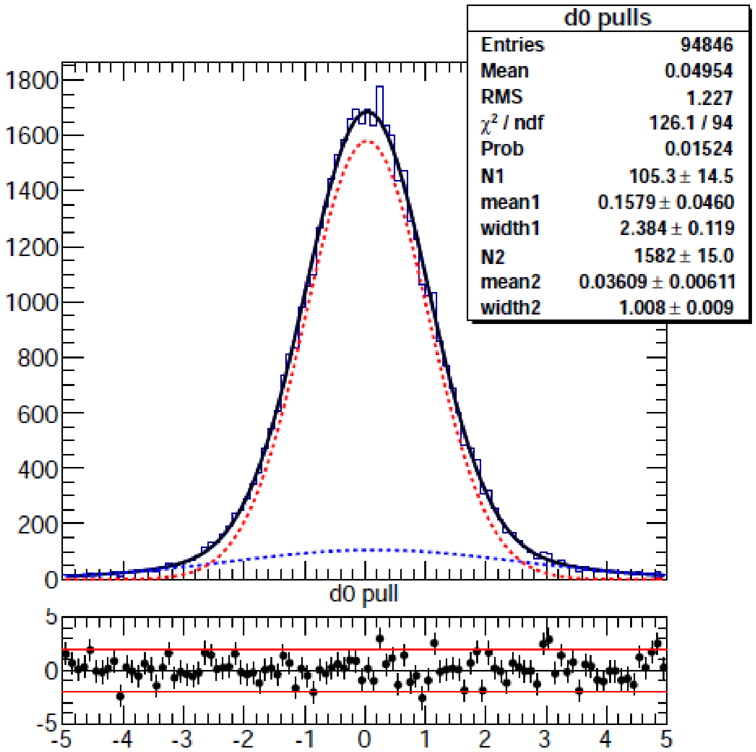
E. P., JPCS 898, 042037 (2017)

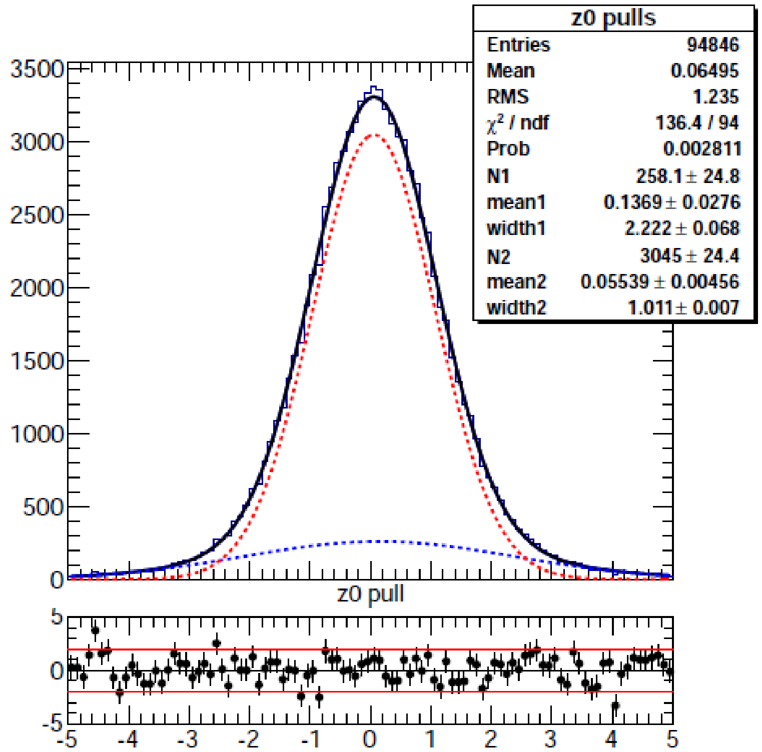




TEST: D0 AND Z0 PULL IN BASF2

arXiV:1808.10567





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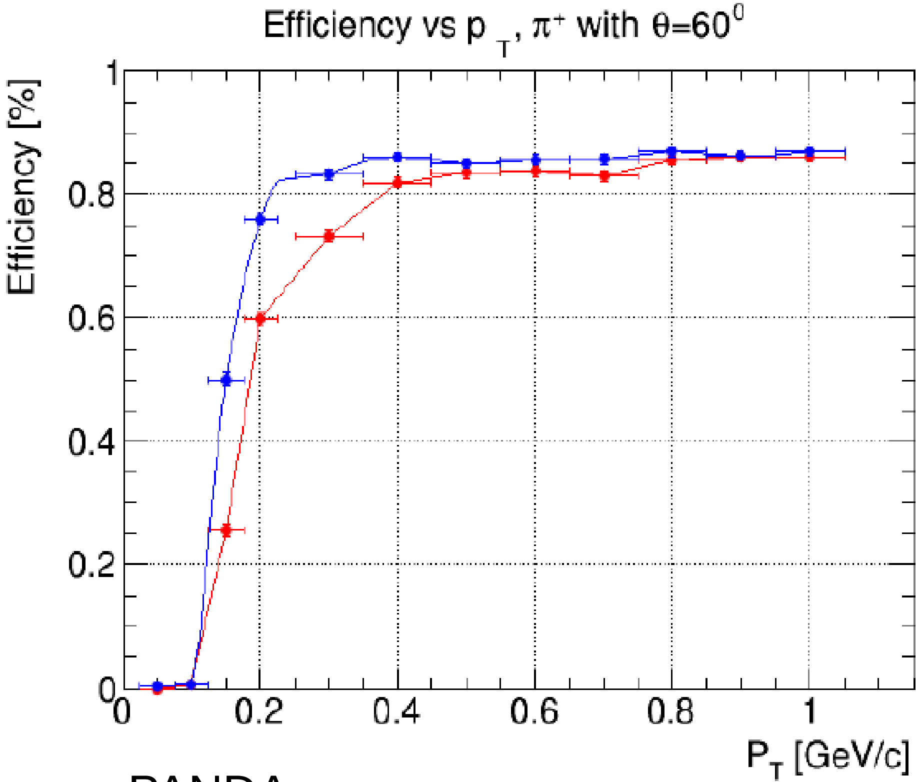
TEST: TRACKING EFFICIENCY

E. P., JPCS 898, 042037 (2017)



PANDA

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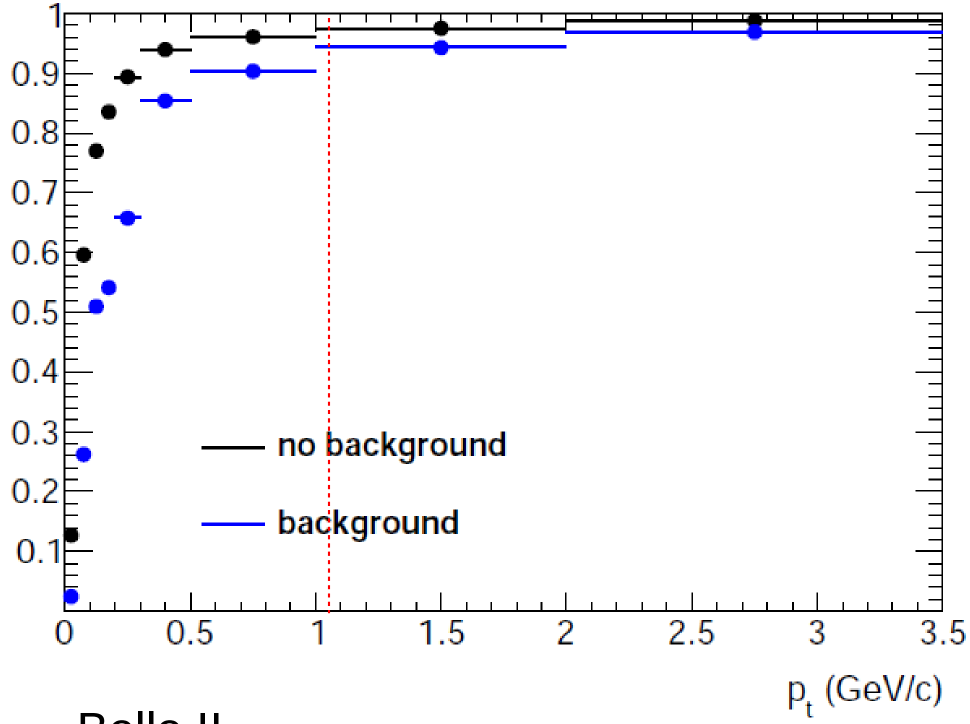

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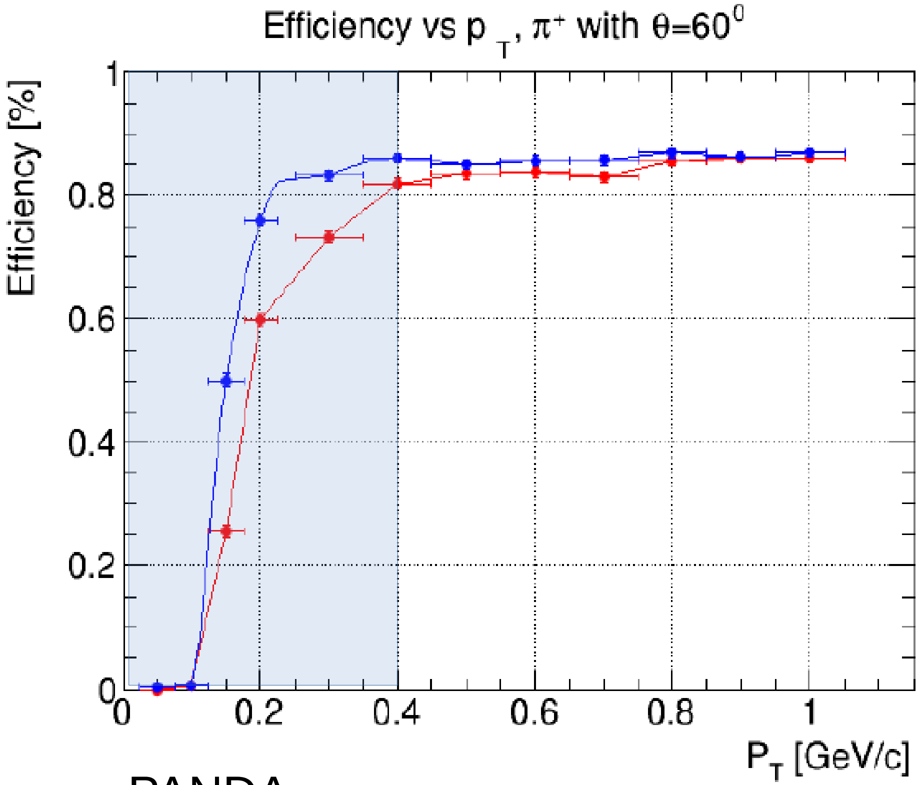

PANDA

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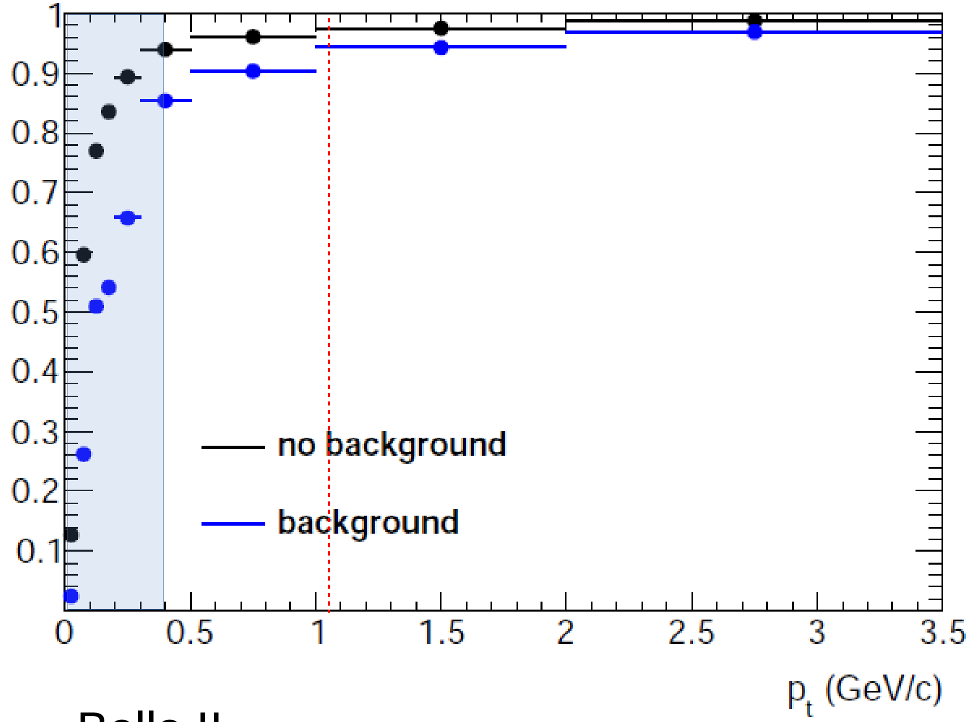

Belle II

TEST IN BASF2

J. Rauch and T. Schlüter, JPCS 608 (2015) 012042

Execution time of the GenFitter module in the Belle II software framework

Fitter	w/o matFX	w/ matFX	∅ iterations
Kalman	3.4 ms	10 ms	3
Reference Kalman	4.0 ms	8.2 ms	2.13
DAF	9.4 ms	17 ms	6

TEST: MORE STUDIES IN PANDAROOT

PandaRoot trunk-rev 28747

n. of events	Virtual memory usage (Mb) (*genfit*)	Virtual memory usage (Mb) (*genfit2*)
1	536	602
100	546	614
500	629	701
1000	641	787
2000	872	960
5000	899	1012
10000	955	1098

Single electron test

TEST: MORE STUDIES IN PANDAROOT

PandaRoot trunk-rev 28747

channel	Virtual usage [Mb] $(genfit)$	Virtual usage [Mb] $(genfit2)$	p_{beam} [GeV/c]
$\bar{p}p \rightarrow e^+e^-$	1052	1310	4.067
$\bar{p}p \rightarrow e^+e^-\pi^0\pi^0$	1275	1508	8.685
$\bar{p}p \rightarrow e^+e^-\pi^+\pi^-$	1199	1555	8.685
$\bar{p}p \rightarrow D_s^+(\eta e^+\nu_e)D_s^-(K^+K^-\pi^-)$	1504	2006	8.000
$\bar{p}p \rightarrow D_s^+(K^+K^-\pi^+)D_s^-(K^+K^-\pi^-)\pi^0$	1501	2001	8.803
$\bar{p}p \rightarrow \Xi(1820)^-\Xi^+$	2775	3466	4.600

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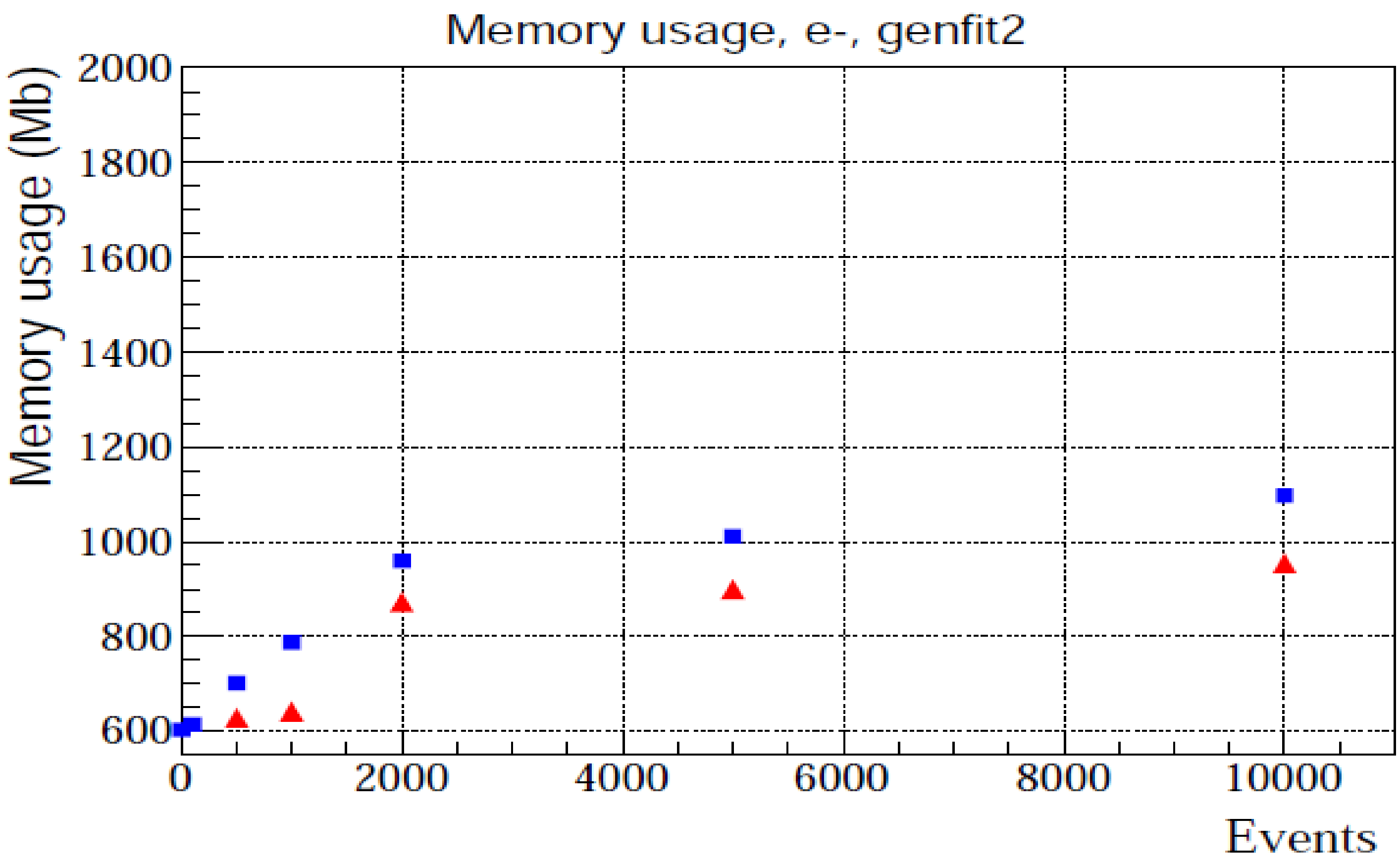
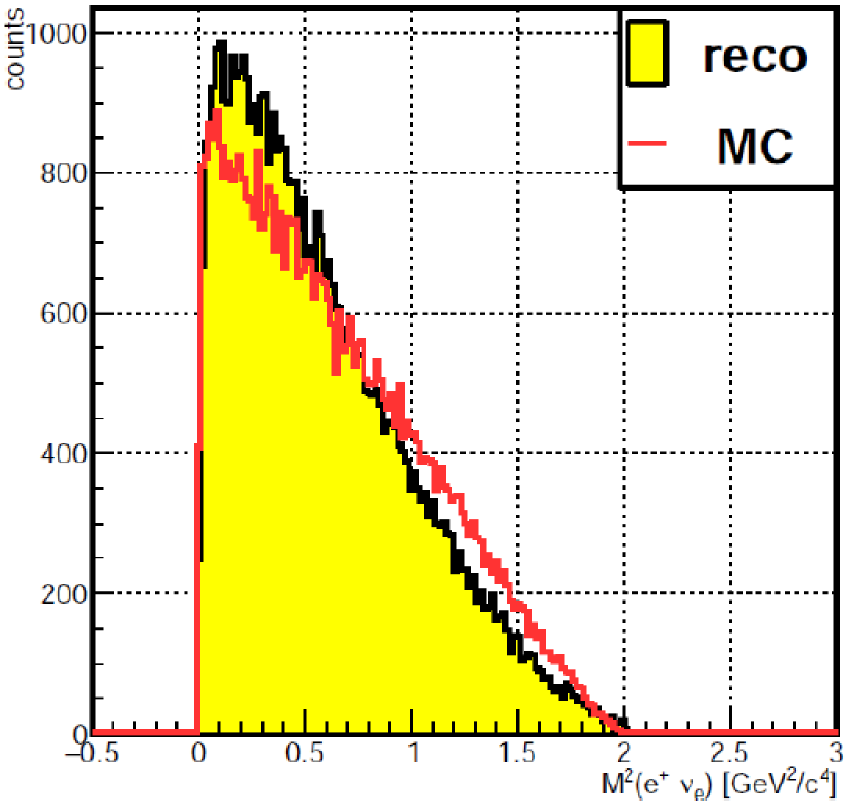


Figure 19: Virtual memory usage in the PandaRoot trunk-rev 28747: *genfit* (red triangles) in comparison with *genfit2* (blue squares) for the reconstruction process. The mass hypothesis is 'electron'.

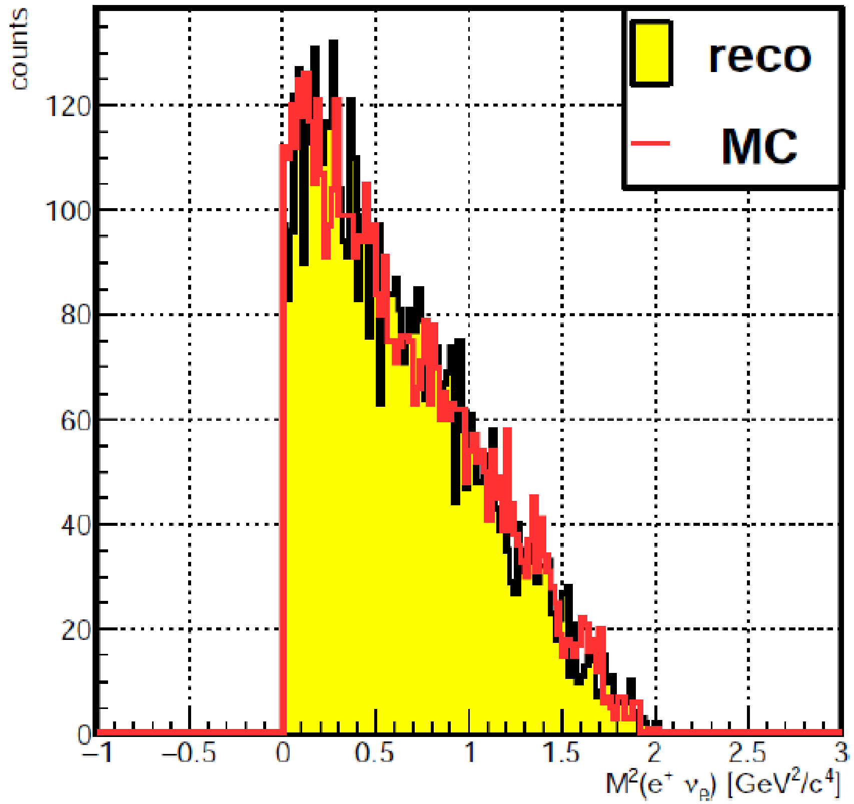
TEST: MORE STUDIES IN PANDAROOT

L. Cao, PhS thesis 2016

Invariant Mass Squared of (e^+ ν_e) in GenFit (10M evt)



Invariant Mass Squared of (e^+ ν_e) in GenFit2 (1M evt)



TEST: MORE STUDIES IN PANDAROOT

p_T [GeV/c]	$\Delta p/p$ res. [%]	ϕ res. [mrad]
0.10	9.09 ± 0.22	67.6
0.15	7.73 ± 0.11	21.8
0.20	5.91 ± 0.12	11.3
0.25	4.86 ± 0.39	7.0
0.30	3.67 ± 0.26	6.6
0.35	2.82 ± 0.34	5.9
0.40	2.26 ± 0.24	5.1
0.50	2.19 ± 0.59	4.2
0.60	2.14 ± 0.53	3.5
0.70	2.07 ± 0.40	3.1
0.80	1.93 ± 0.53	2.8
0.90	1.85 ± 0.66	2.6
1.00	1.81 ± 0.66	2.5

GENFIT2 PUBLICATION – COMING SOON

12 people

Implementation of GENFIT2 as an experiment independent track-fitting software package.

For any question,
please do not hesitate to ask!

e.prencipe@fz-juelich.de

THANK YOU