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Track reconstruction in the MPD detector at NICA

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Outline

1. Basic formalism of the Kalman filter
2. MultiPurpose Detector (MPD) at the collider NICA
3. Software framework
4. Track reconstruction algorithms
5. Some very preliminary control reconstruction results for Monte Carlo events
6. Summary and outlook

Kalman filter [1]

- Evolution of a state vector x (change of track parameters from point *k-1* to point *k)*

$$x_k = F_{k-1} x_{k-1} + w_{k-1}$$

where F_{k-1} - linear transformation (track propagator),
w - process noise (multiple scattering) with $\langle w_k \rangle = 0$
and cov $\{w_k\} = Q_k$

- Measurements are linear functions of state vector

$$m_k = H_k x_k + \varepsilon_k$$

where ε - measurement noise with $\langle \varepsilon_k \rangle = 0$ and
cov$\{\varepsilon_k\} = V_k$

[1] R. Fruhwirth, "Application of Kalman filtering to track and vertex fitting", NIM A262 (1987) 444

Analysis of a dynamic system

There are three types of operations to be performed in the analysis of a dynamic system:

Filtering - estimation of the ”present” state vector, based on all “past” measurements

Prediction - estimation of the state vector at a “future” time

Smoothing – estimation of the state vector at some time in the “past” based on **ALL** measurements taken up to the “present” time

Some notations

x_k^i = estimate of x_k, using all measurements up to time i ($i<k$ - prediction, $i=k$ - filtered estimate, $i>k$ - smoothed estimate);

$C_k^i = \text{cov}\{x_k^i - x_k\}$;

$r_k^i = \text{residual}\ \{m_k - H_k x_k\}$;

$R_k^i = \text{cov}\{r_k^i\}$

Prediction

- Extrapolation of the state vector:

$$x_k^{k-1} = F_{k-1} x_{k-1}^{k-1}$$

- Extrapolation of the covariance matrix:

$$C_k^{k-1} = F_{k-1} C_{k-1}^{k-1} F_{k-1}^T + Q_k$$

- Residuals of predictions:

$$r_k^{k-1} = m_k - H_k x_k^{k-1}$$

- Covariance matrix of predicted residuals:

$$R_k^{k-1} = V_k + H_k C_k^{k-1} H_k^T$$

Filtering (1)

- Kalman gain matrix:

$$K_k = C_k^k H_k^T (V_k)^{-1}$$

- Update of the state vector:

$$x_k^k = x_k^{k-1} + K_k (m_k - H_k x_k^{k-1})$$

- Update of the covariance matrix:

$$C_k^k = (I - K_k H_k) C_k^{k-1}$$

Filtering (2)

- Filtered residuals:

$$r_k^k = m_k - H_k x_k^k$$

- Covariance matrix of filtered residuals:

$$R_k = V_k - H_k C_k^k H_k^T$$

- χ^2-increment :

$$\chi_+^2 = r_k^T R_k^{-1} r_k$$

- χ^2-update :

$$\chi_k^2 = \chi_{k-1}^2 + \chi_+^2$$

Smoother steps (1)

- Smoother gain matrix:

$$A_k = C_k^k F_k^T (C_{k+1}^k)^{-1}$$

- Smoothed state vector:

$$x_k^n = x_k^k + A_k (x_{k+1}^n - x_{k+1}^k)$$

- Covariance matrix of the smoothed state vector:

$$C_k^n = C_k^k + A_k (C_{k+1}^n - C_{k+1}^k) A_k^T$$

Smoother steps (2)

- Smoothed residuals:

$$r_k^n = m_k - H_k x_k^n$$

- Covariance matrix of smoothed residuals:

$$R_k^n = V_k - H_k C_k^n H_k^T$$

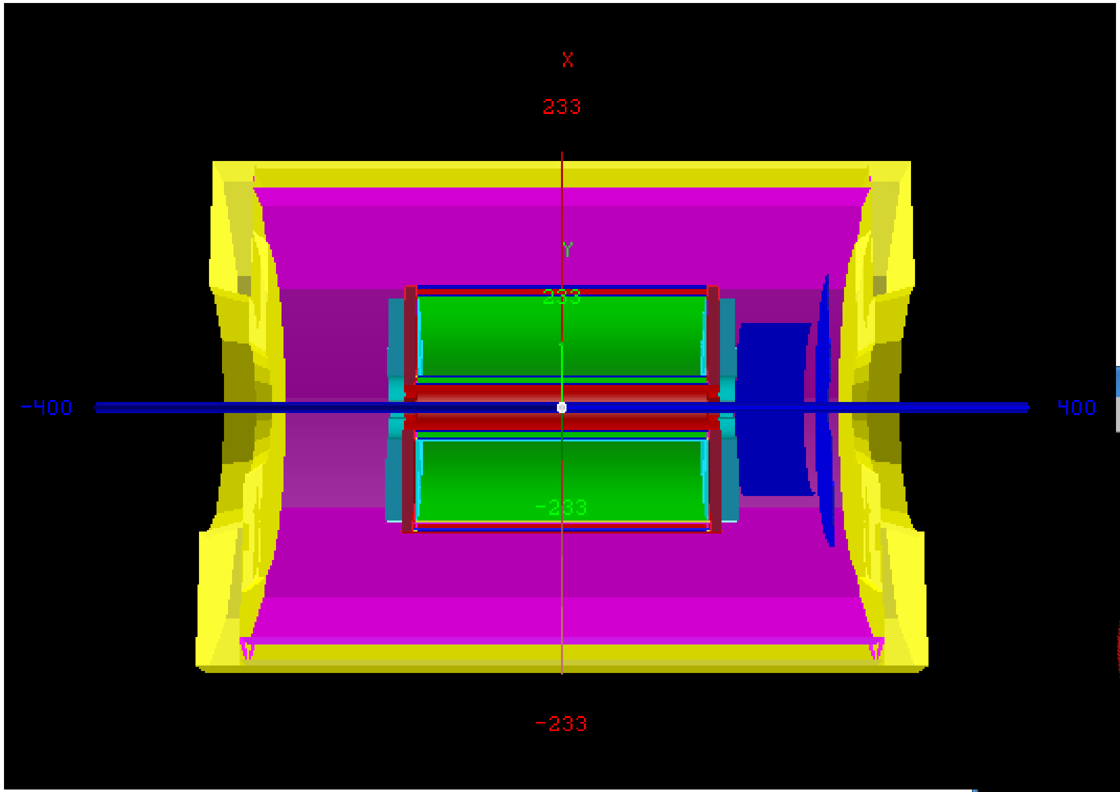
- Smoothed χ^2 :

$$\chi^2 = r_k^{nT} (R_k^n)^{-1} r_k^n$$

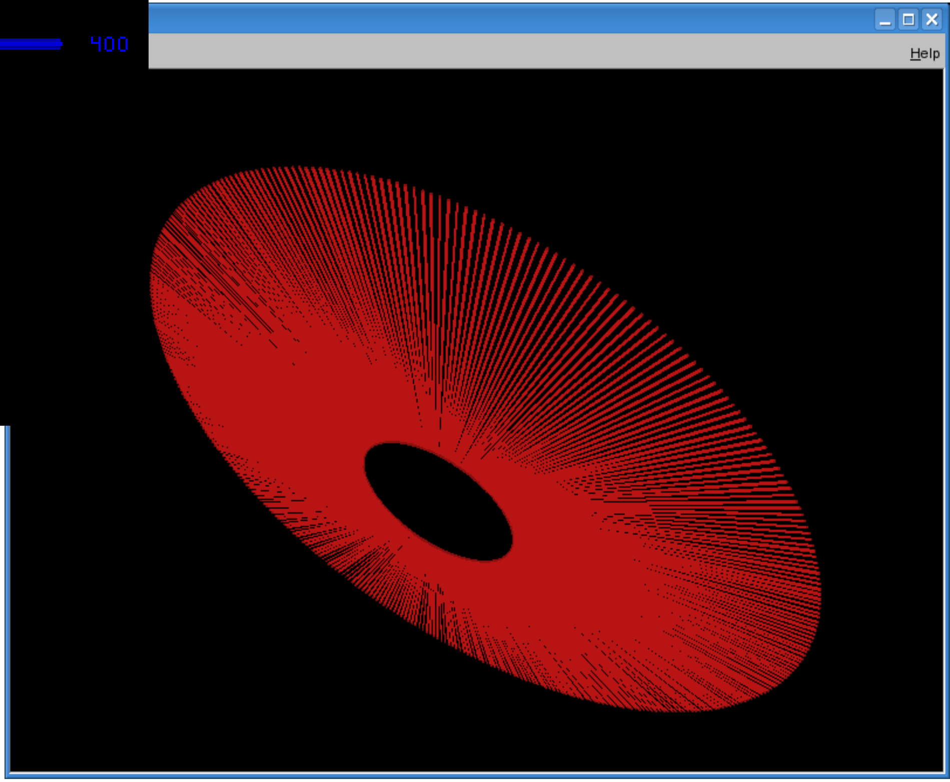
Software

ROOT: FairRoot as a basis (the core software) → NicaRoot for further developments

MPD Geometry



End-Cap Tracker layer
(4 mm tube diameter)



B = 0.5 T

MPD geometry

TPC (active volume):

Rin = 29.195 cm, Rout = 99.81 cm, Z = +-124.5 cm

(η_{max} = 2.16)

50 layers; σ_Z = 1 mm, $\sigma_{R\varphi}$ = 0.5 mm

ECT:

1 module:

Rin = 30.0 cm, Rout = 121.0 cm, Z = 155-215 cm

η_{max_front} = 2.34, η_{max_rear} = 2.67

60 layers (20 triplets)

Triplet: U-layer (+7^o), radial layer, V-layer (-7^o); σ = 0.2 mm

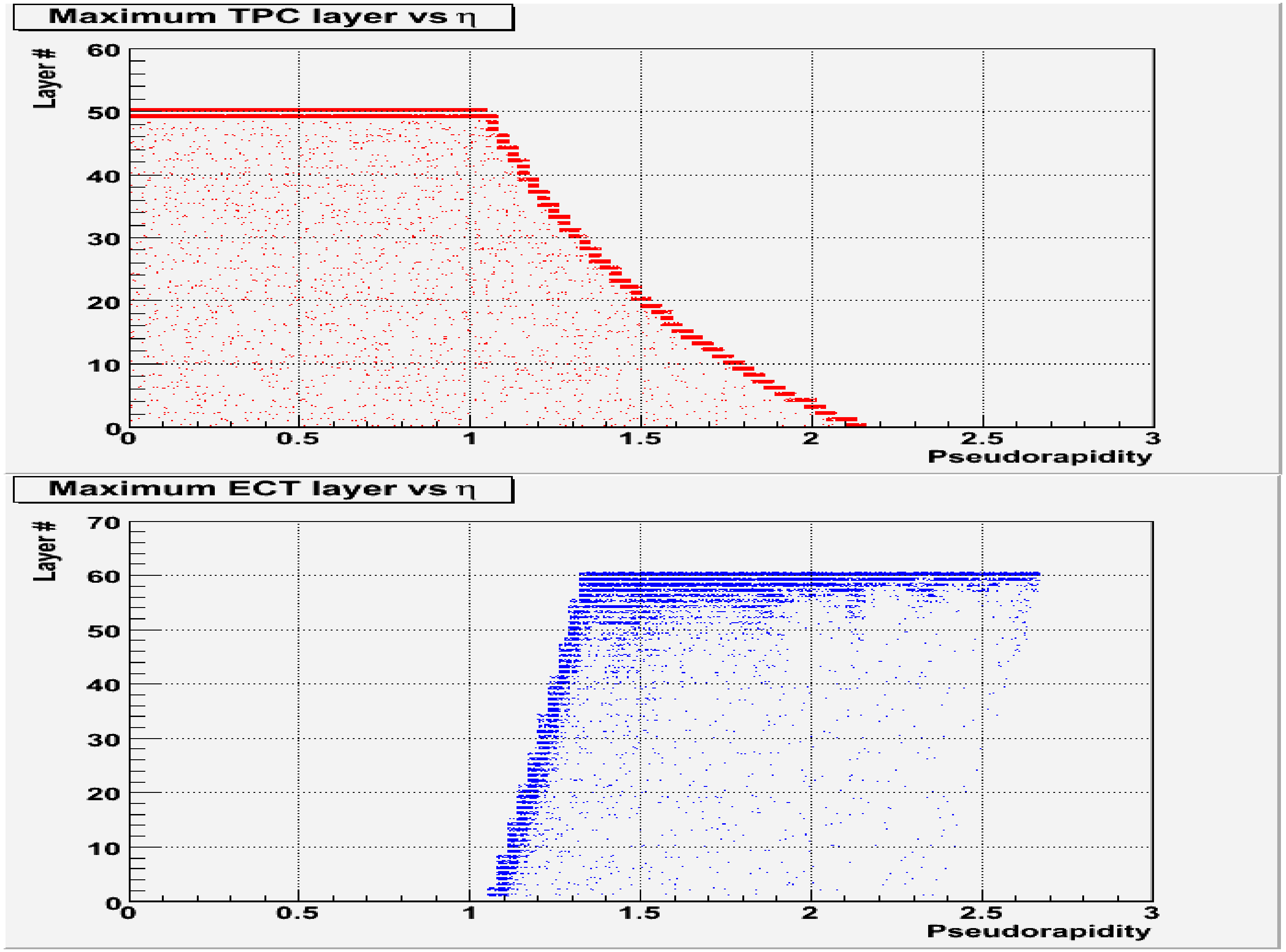
ETOF:

Rin = 30.0 cm, Rout = 121.0 cm, Z = 230 cm; 2x2 cm^2 cells

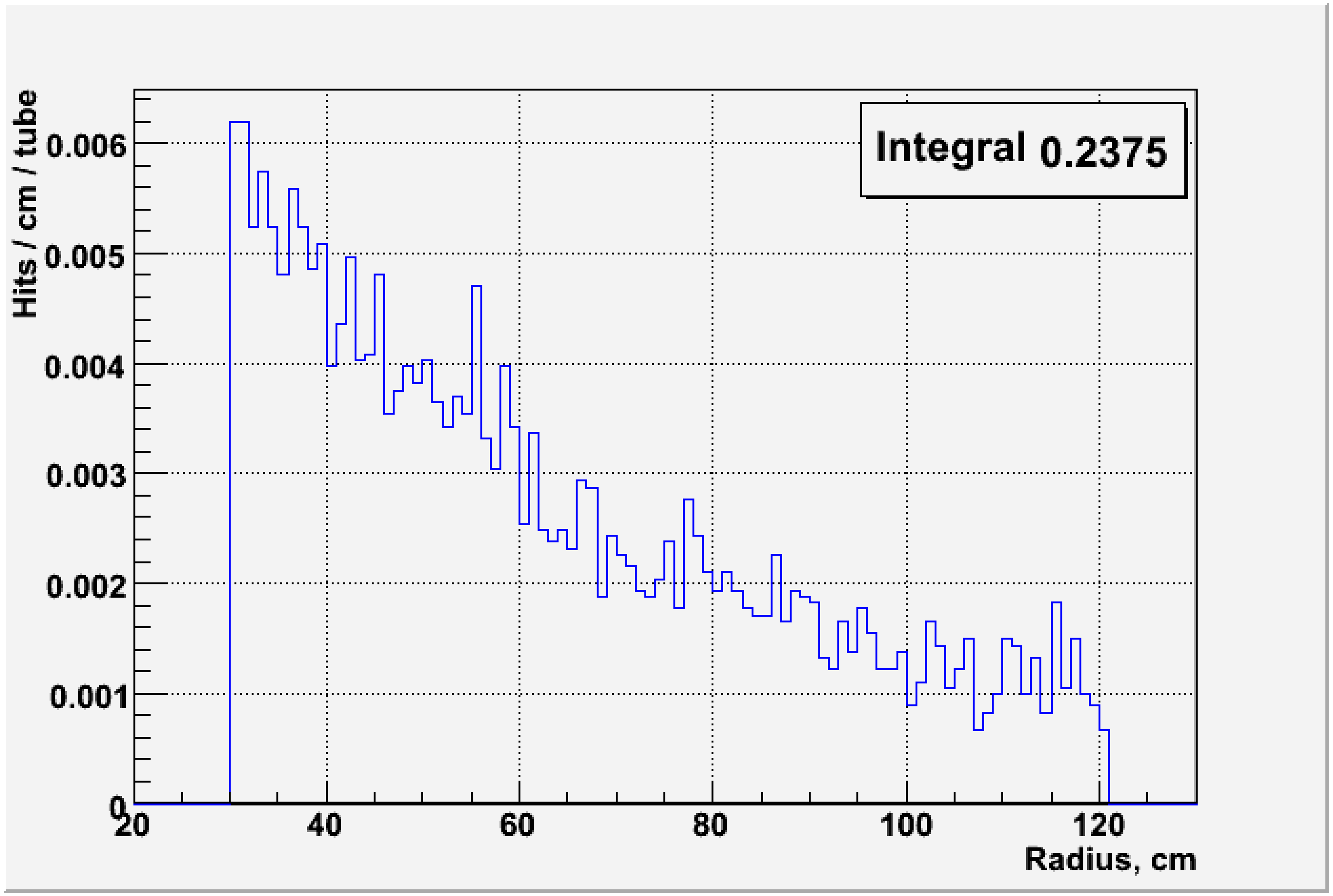
Event generator output

50 central (b=0-3 fm) Au-Au events @ 9 GeV from UrQMD

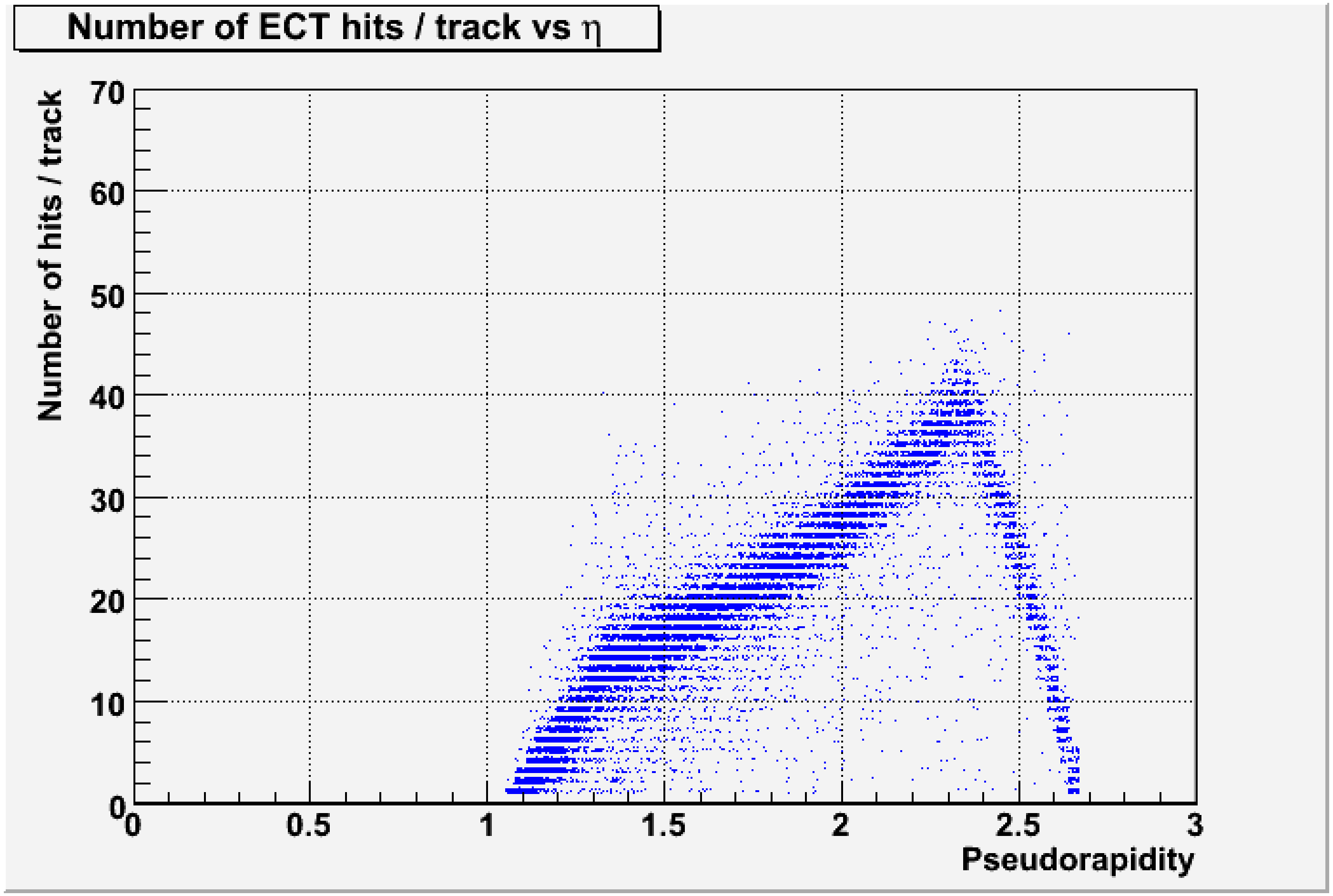
Maximum detector layer reached by primary tracks vs pseudorapidity



ECT “occupancy” (number of hits per tube per 1 cm of length) vs radius



Number of ECT hits per primary track vs pseudorapidity



TPC tracking method

Kalman filter with 2 passes:

1st pass: track following from outside inward;

2nd pass: removing used hits and track following from inside outward.

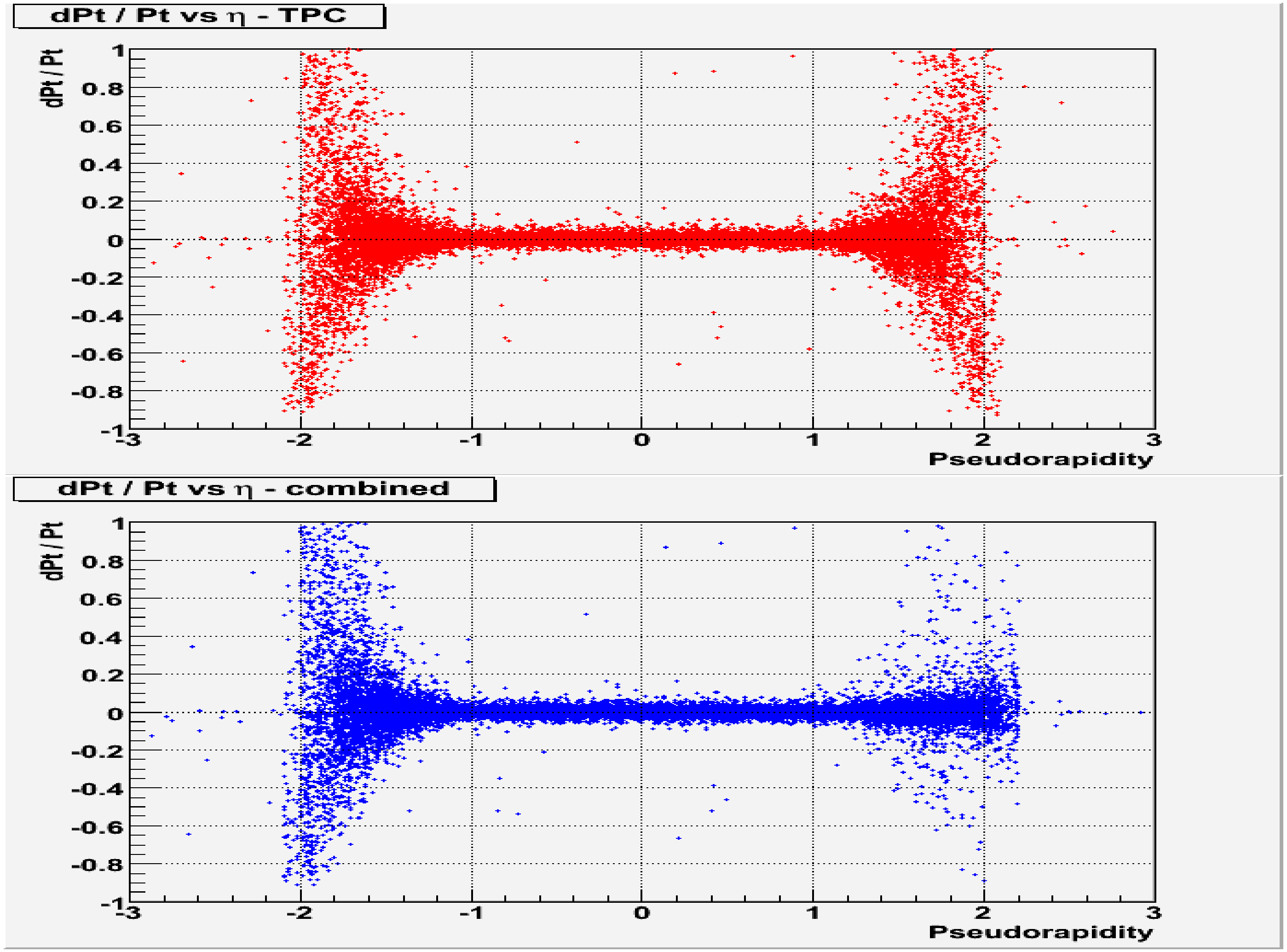
ECT tracking method

Kalman filter with different seeding:

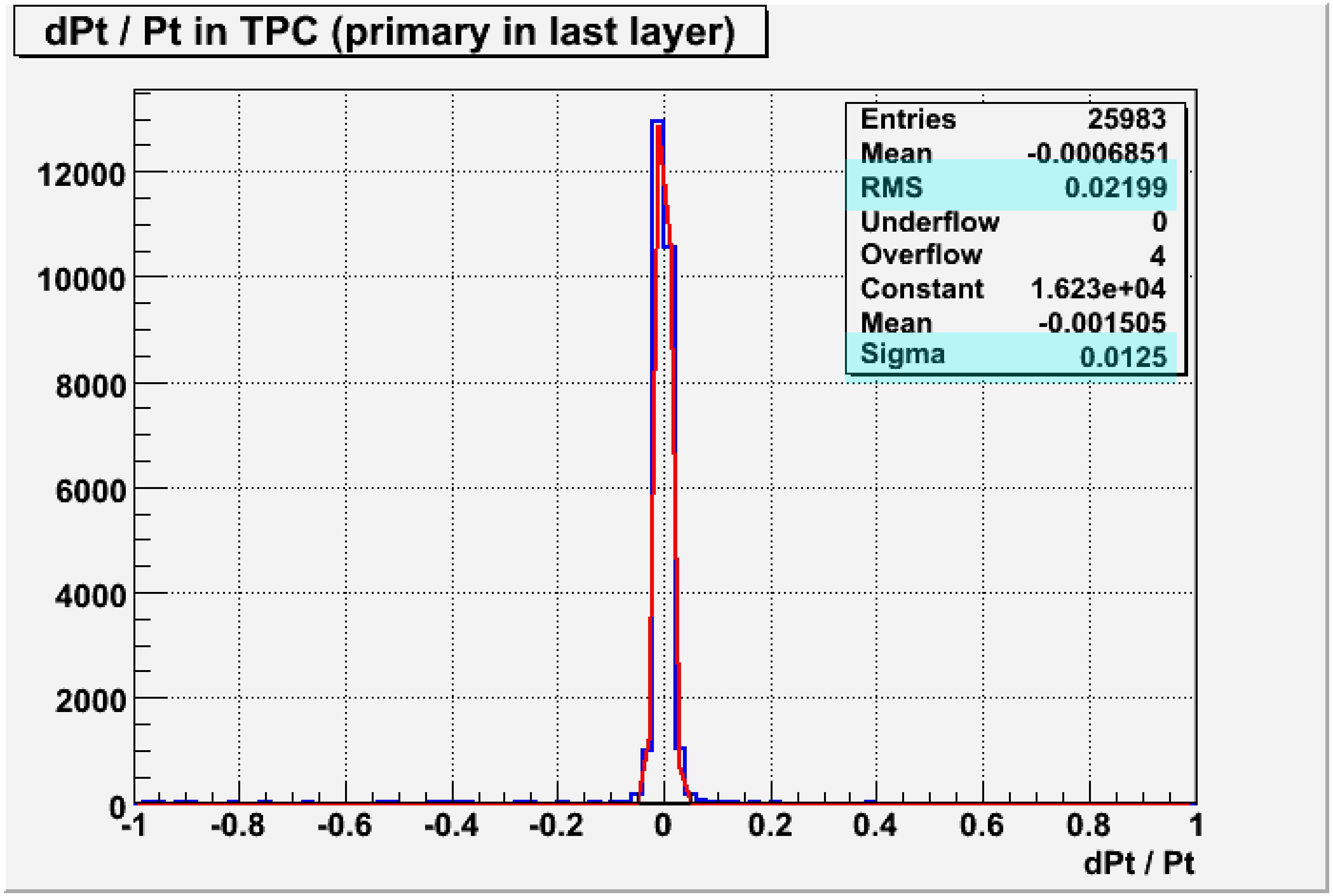
1) TPC tracks (> 3 points)
2) 3-point seeds from TPC, ETOF and primary vertex
3) 3-point seeds from ETOF, ECT and primary vertex

To account for a low single straw tube layer efficiency, multiple track hypotheses are built from a single seed, i.e. track branches are started from ECT hits in layer #1, 2,...,10. The best branch is selected among them.

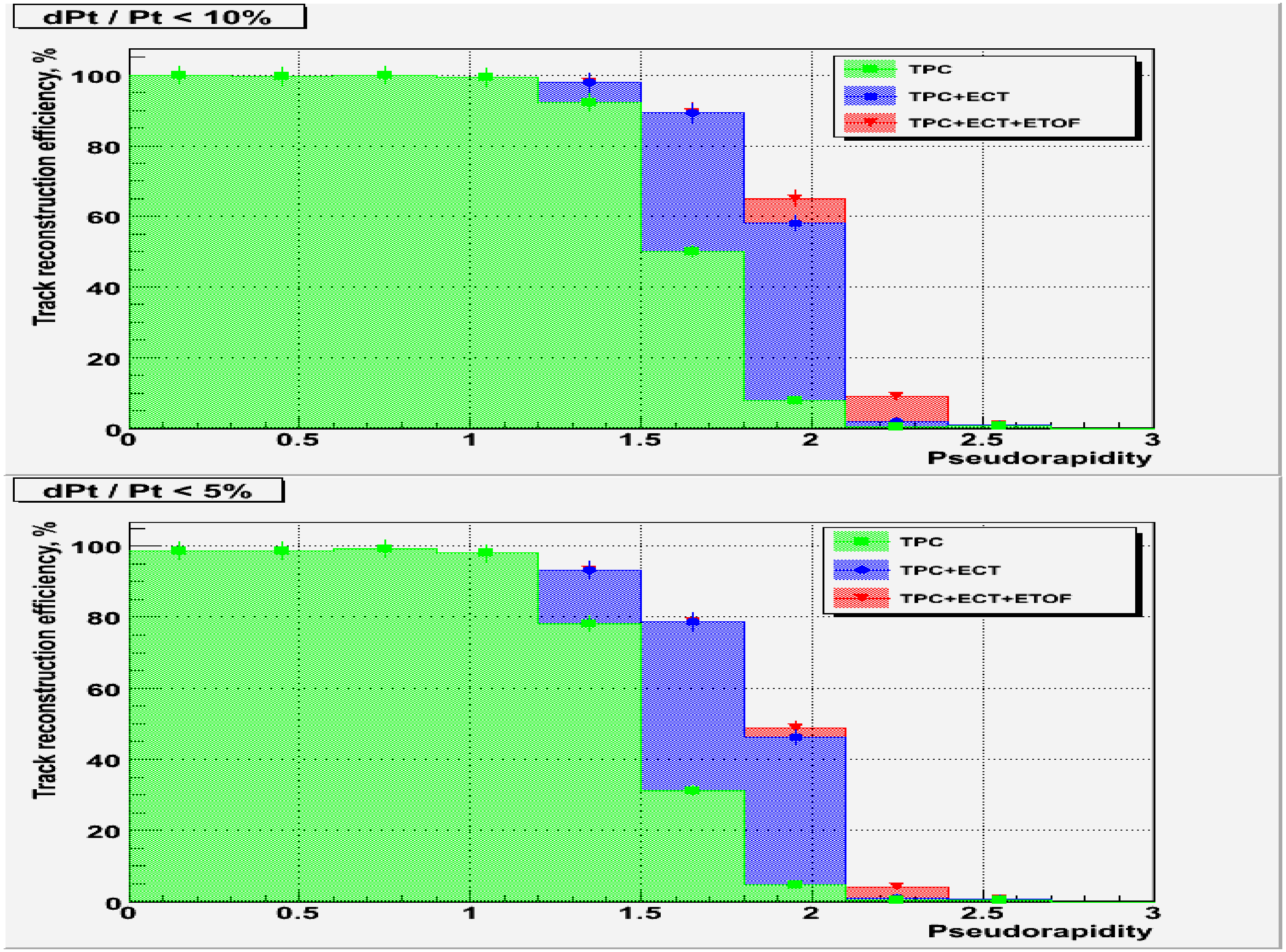
dP_t / P_t vs pseudorapidity



dP_t / P_t for primary tracks with p > 0.2 GeV/c reaching the maximum layer



Primary track reconstruction efficiency for dP_t / P_t cuts of 10% and 5%



Summary / Outlook

- Kalman filter-based track reconstruction algorithms have been developed and implemented for the MPD detector at NICA within the general software framework
- Preliminary reconstruction results seem to look reasonable
- The procedures will be used for further work on detector design and optimization as well for physics studies
- New ideas on event reconstruction are welcome