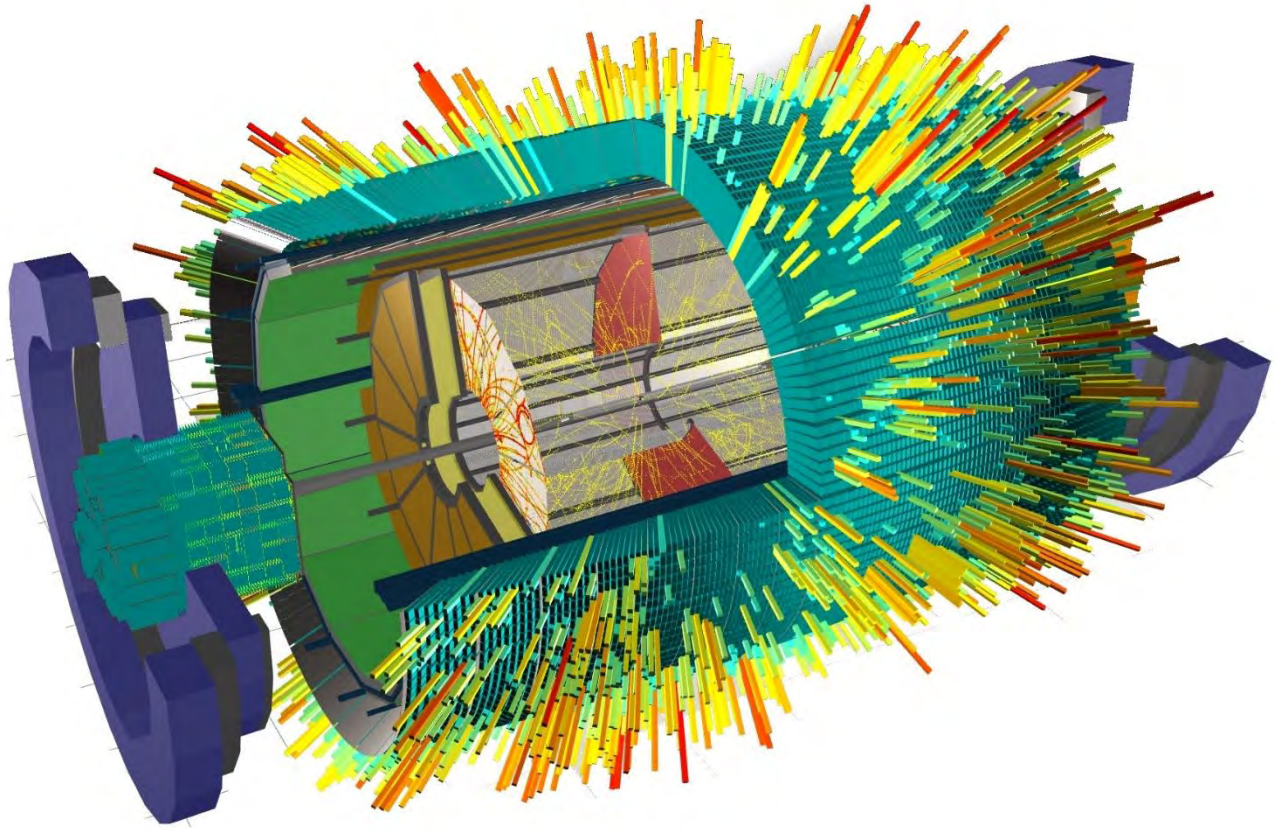
ACTS based MPD TPC reconstruction with TOF and PID ML

HNATIC Slavomir

on behalf of the

MPD Software Development & Computing Team



OUTLINE

- Previous meeting recap
- From Reconstruction Strategy to Large-Scale Performance Studies
- Reconstruction performance
- Ambiguity Resolution performance
- Momentum resolution
- Primary Vertex resolution
- Energy losses
- Track Length resolution
- TOF Matching performance
- PID ML
- Current Status and Next Steps

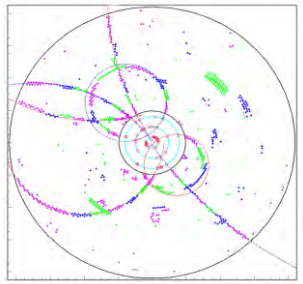
MPD EVENT RECONSTRUCTION IN ACTS

Tracking Philosophy & Flow

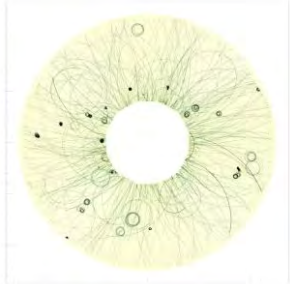
INPUT DATA	Monte-Carlo Simulation or Real Experimental Data
ACTS CKF STRATEGY	Maximize efficiency, minimize fakes, handles many duplicates
CLEANUP & OPTIMIZATION	Identify best tracks, filter fakes/duplicates, improve quality
OUTPUT DATA	Validated track pool ready for PID & Physical Analysis

KEY FACTOR: EVENT MULTIPLICITY

DILUTE (STCF)



DENSE (MPD TPC)



Dense Environment

In high-occupancy environments, combinatorial clutter is overwhelming. **Multi-pass reconstruction** reduces complexity by sequentially isolating and removing specific track populations.

Strategy for MPD Event Reconstruction:

Reconstruct Primary Tracks

PASS 1	Tracks reaching the TPC outer boundaries
PASS 2	Tracks confined to the inner TPC region
PASS 3	Residual tracks

Secondaries

Decays, delta-electrons, material interactions, ...

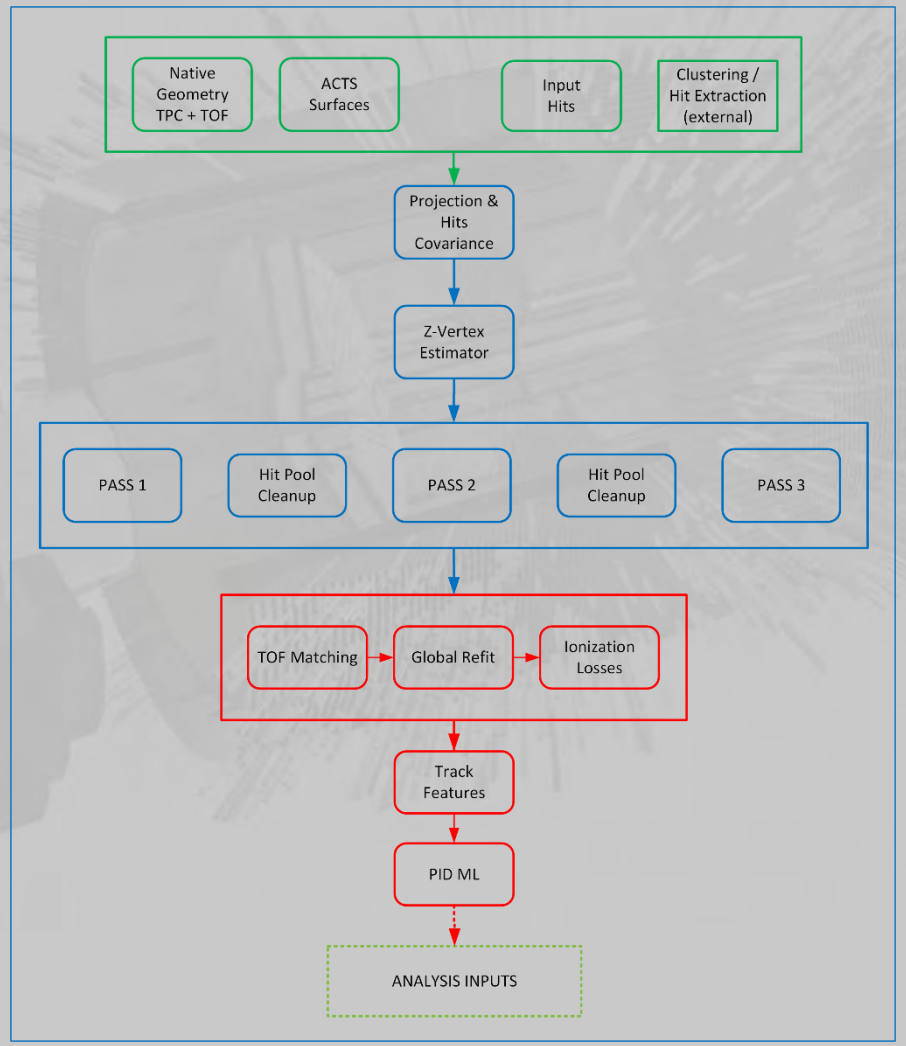
Each successful pass removes associated hits from the global pool, simplifying the search space for the next pass.

FROM STRATEGY TO PERFORMANCE STUDIES

Development Progress

- Multi-pass reconstruction
- Dedicated 4-stage ambiguity resolution
- Momentum and track refitting
- TOF Matching integration
- Track-feature extraction & PID ML

Reconstruction Chain



Simulation & Benchmarks

1000x100 events QA, BiBi $\sqrt{s_{NN}} = 9.2$ GeV

Configuration summary for event generation, clustering and tracking

EGenerators::URQMD
ETpcClustering::MLEM
ETpcTracking::ACTS

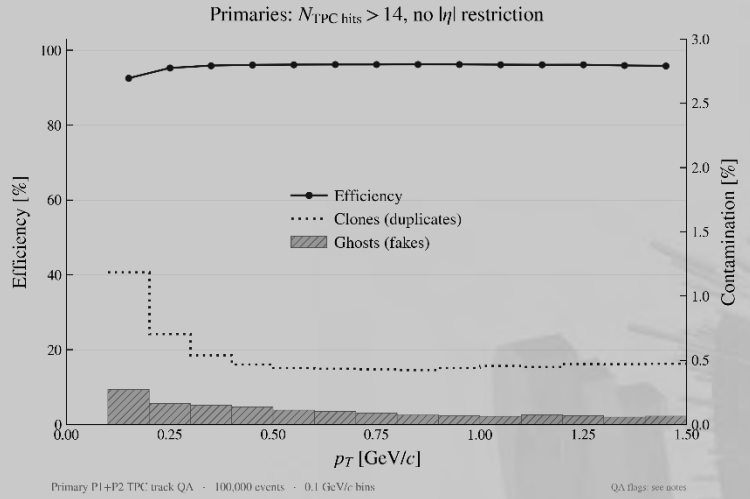
Published reference plots

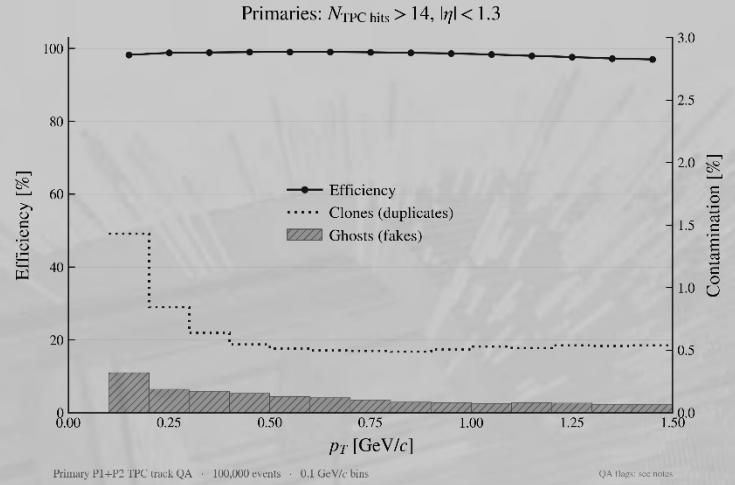
	Reference
AuAu $\sqrt{s_{NN}} = 9$ GeV	Kolesnikov, Mudrokh, Vasendina, Zinchenko (2018)
AuAu $\sqrt{s_{NN}} = 11$ GeV	Babkin et al (2020)

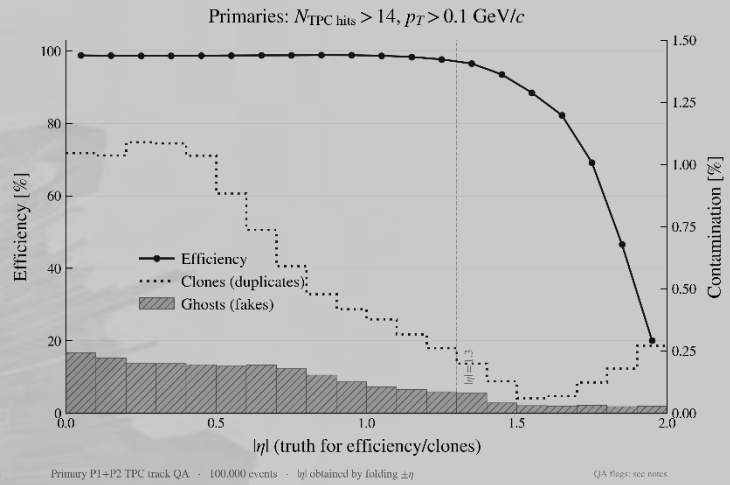
Comparison scope:

Published MPD results are used as performance benchmarks. Differences in collision systems, simulation configurations, and selection criteria should be considered when interpreting the results.

MPD TPC TRACKER PERFORMANCE







Primary-track reconstruction

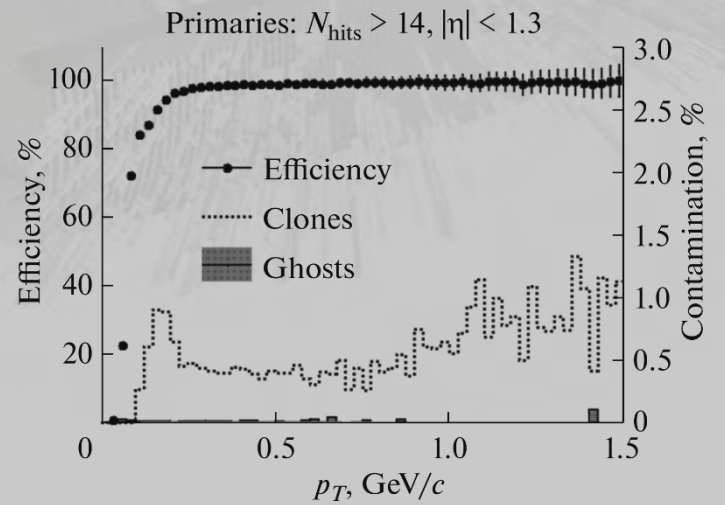
Efficiency / duplicates / fakes by transverse momentum

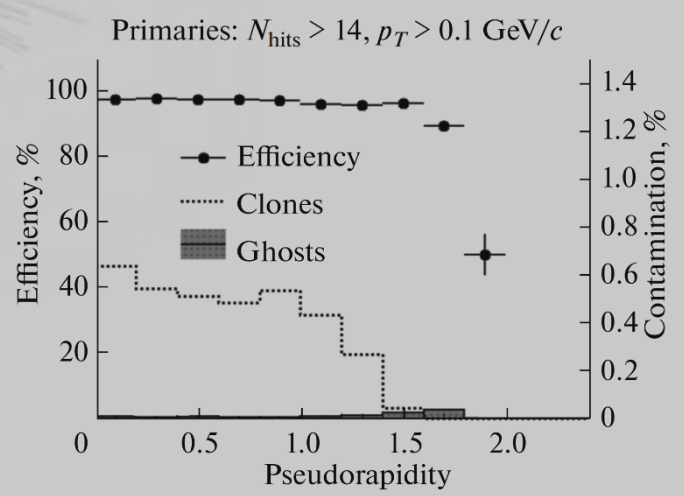
1,000 runs · 100,000 events

p_T [GeV/c]	$\|\eta\| < 1.3$ efficiency / duplicate / fake	Total (no η cut) efficiency / duplicate / fake
0.1–0.2	98.24% / 1.433% / 0.320%	92.54% / 1.185% / 0.271%
0.2–0.3	98.81% / 0.845% / 0.188%	95.28% / 0.705% / 0.163%
0.3–0.4	98.91% / 0.640% / 0.172%	95.92% / 0.540% / 0.149%
≥0.4	98.71% / 0.519% / 0.121%	96.16% / 0.449% / 0.105%

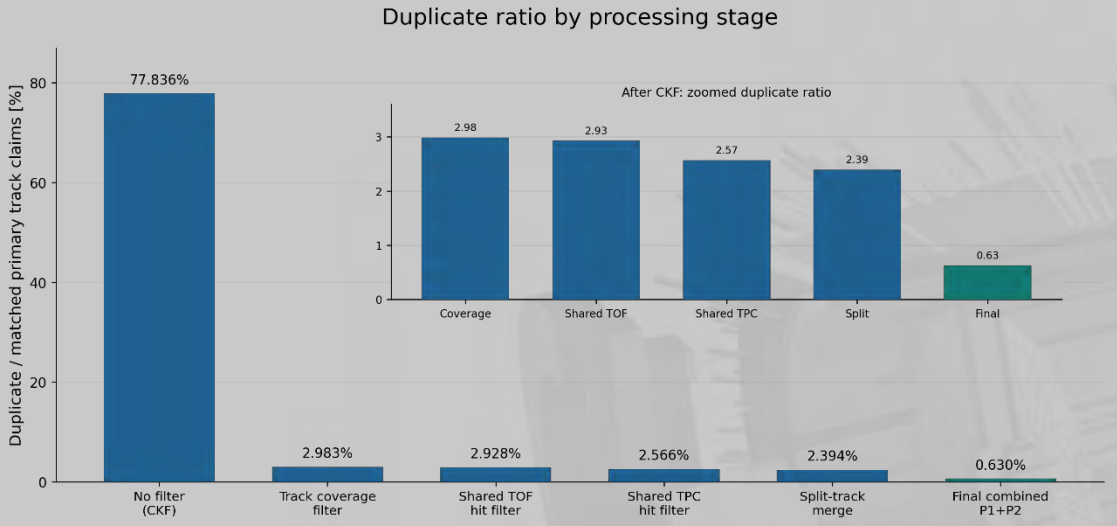
Combined P1+P2 primary tracks · ≥15 TPC hits · final row aggregates 0.4 ≤ p_T < 5.0 GeV/c

Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA
(Kolesnikov V., Mudrokh A., Vasendina V., Zinchenko A. - 2018)



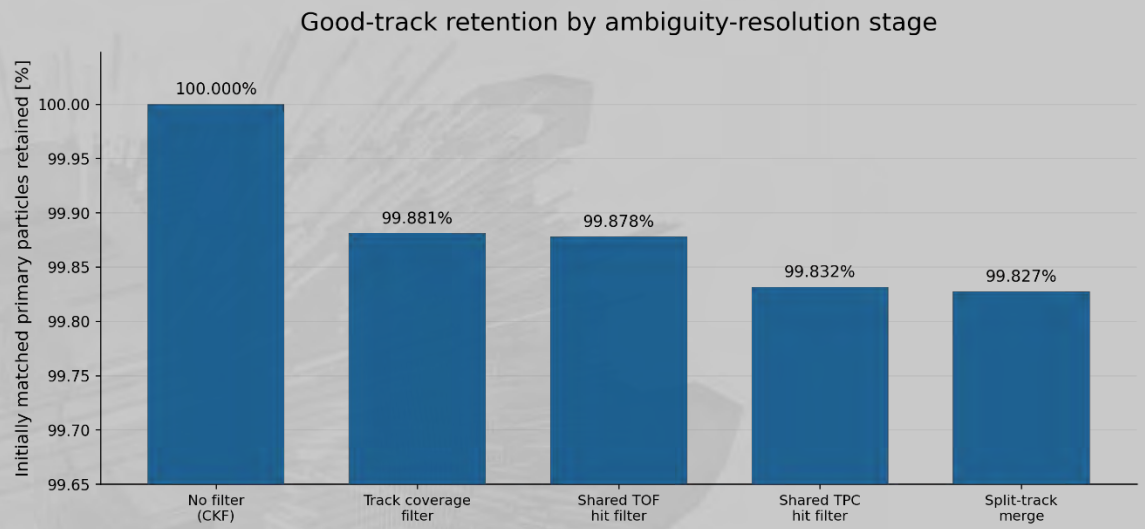


AMBIGUITY RESOLUTION



The first five snapshots are before final combined-track cleanup. The last bar is the final P1+P2 primary-track QA.

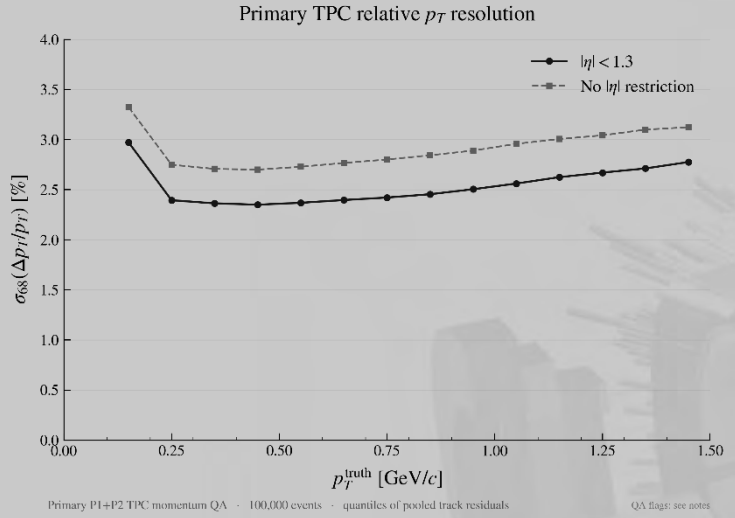
Final duplicate share including fakes in the denominator: 0.629%.

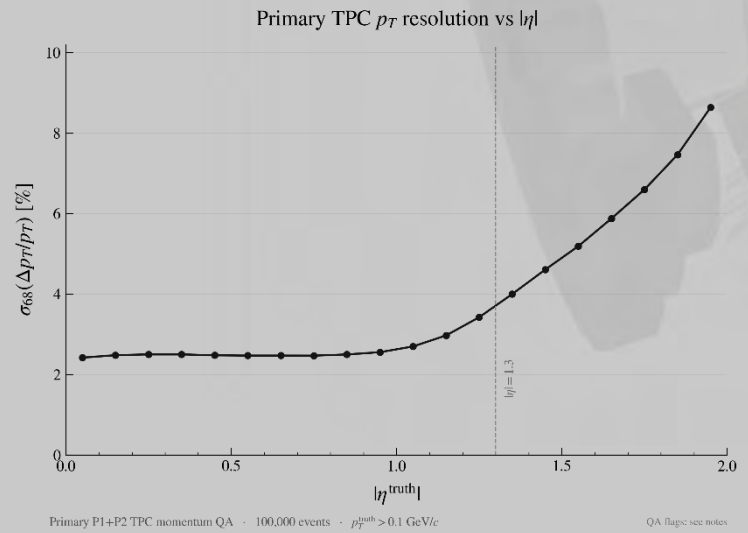


Final combined retention requires the additional cross-pass QA stages; the archived AWK files omitted these rows.

- For real experimental data, track-candidate ambiguities must be resolved at multiple stages of the reconstruction chain.
- Potentially one of the most computationally demanding and algorithmically challenging tasks in MPD track reconstruction.
- ACTS available AR algorithms do not provide satisfactory performance for MPD TPC reconstruction.
- Dedicated 4-stage AR algorithm: track-coverage filtering, shared TOF-hit filtering, shared TPC-hit filtering, split-track merging.

MOMENTUM RESOLUTION

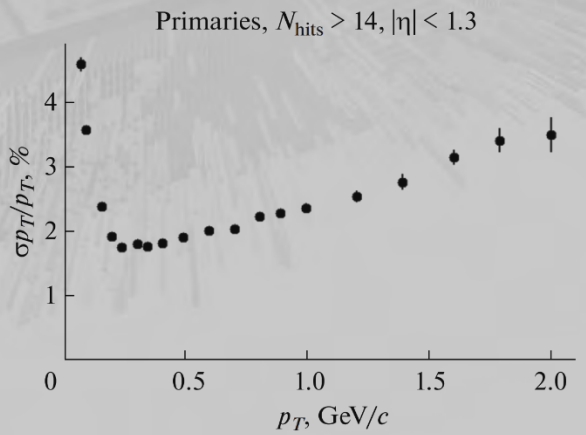


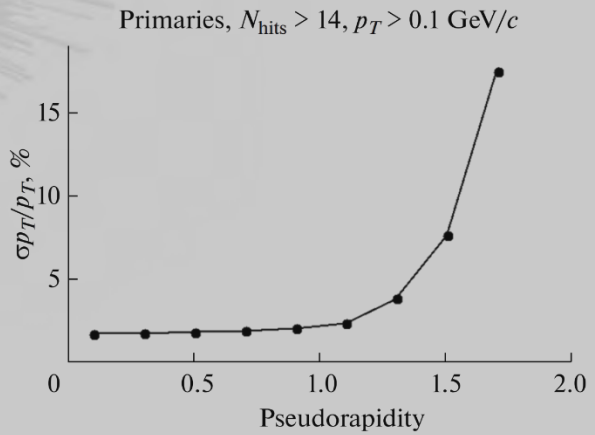


ACTS Refitting options

- **Kalman refit** – Local, sequential track refitting, effective when energy-loss effects are significant
- **Global Chi2 refit** – Global track refitting, effective for stiff, high-momentum tracks

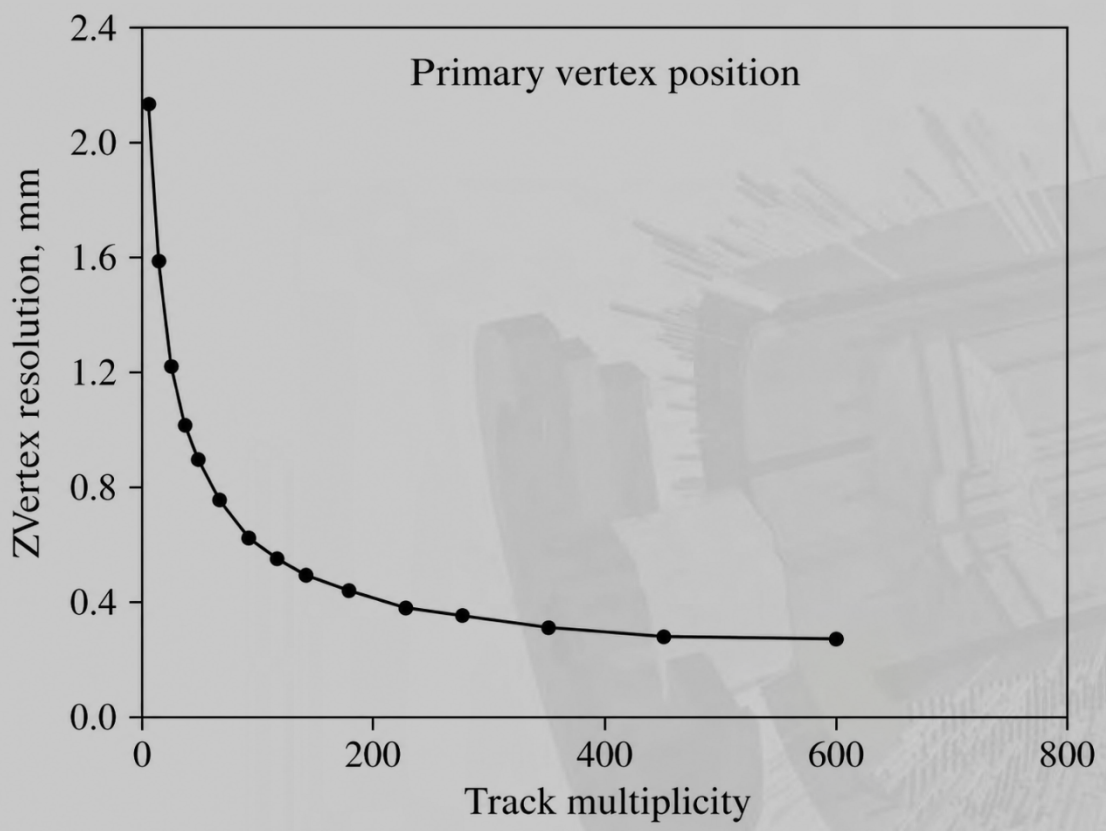
Mixed performance: worse at low p_T, better at higher p_T



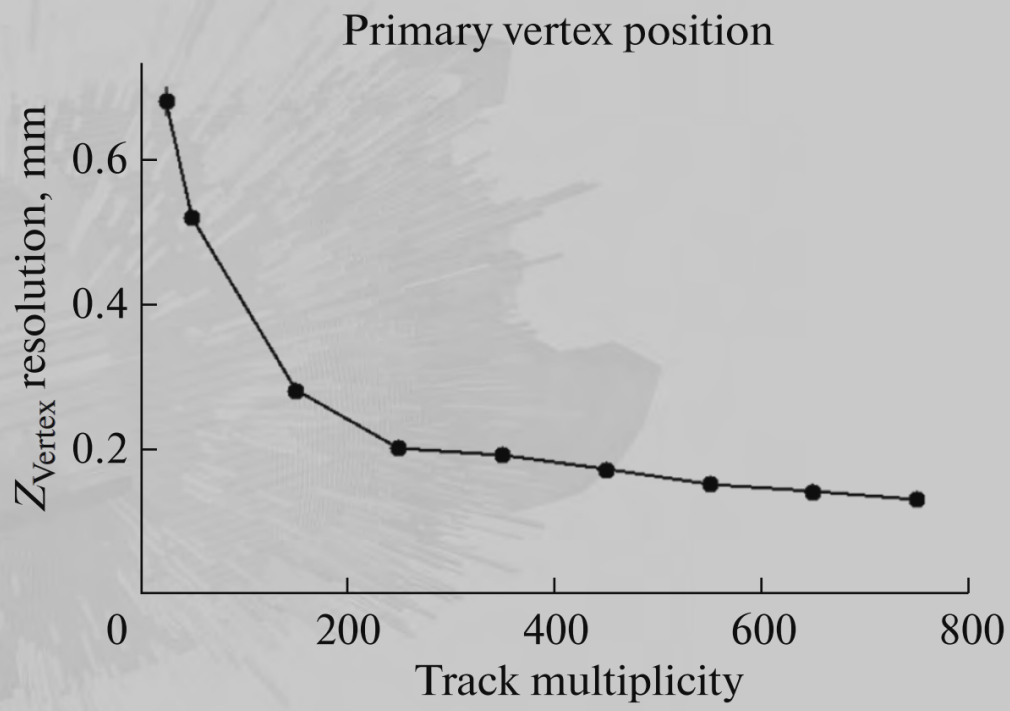


Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA (Kolesnikov V., Mudrokh A., Vasendina V., Zinchenko A. - 2018)

PRIMARY VERTEX RESOLUTION



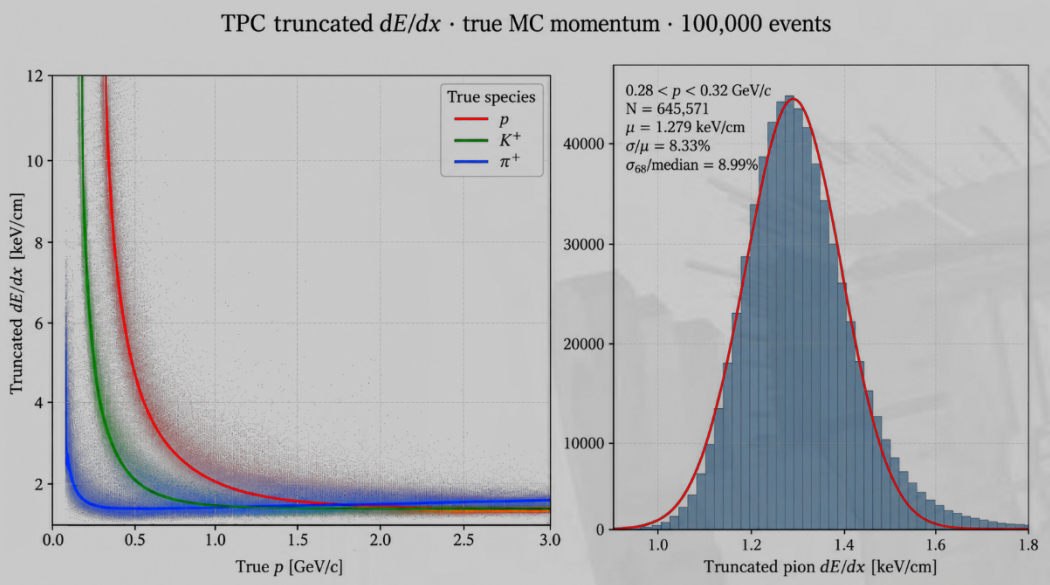
ACTS AMVF

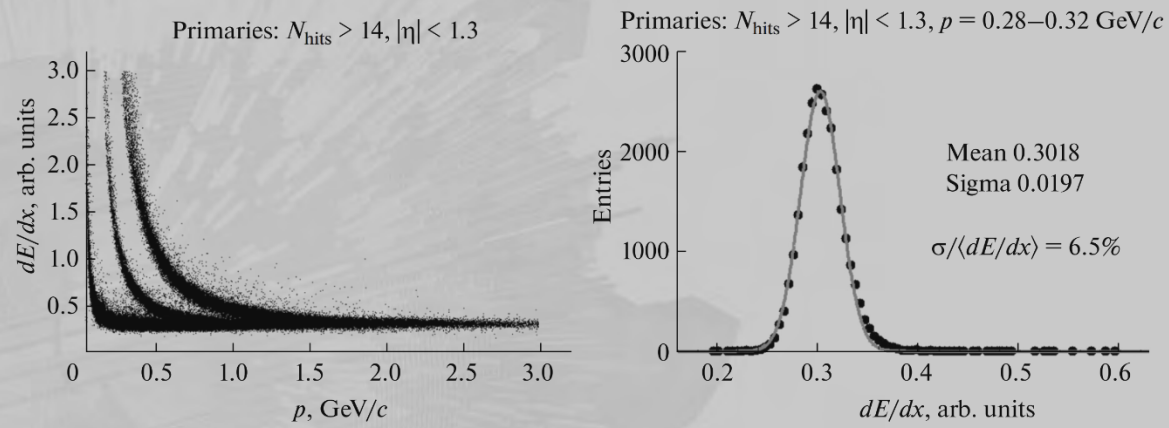


Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA
(Kolesnikov V., Mudrokh A., Vasendina V., Zinchenko A. - 2018)

- Primary-vertex resolution was **not a primary optimization target** in the ACTS-based chain.
- Unlike the legacy tracker, the ACTS-based TPC reconstruction **does not use the PV during seeding**.
- Resolution is currently worse, AMVF tuning remains possible.

ENERGY LOSSES

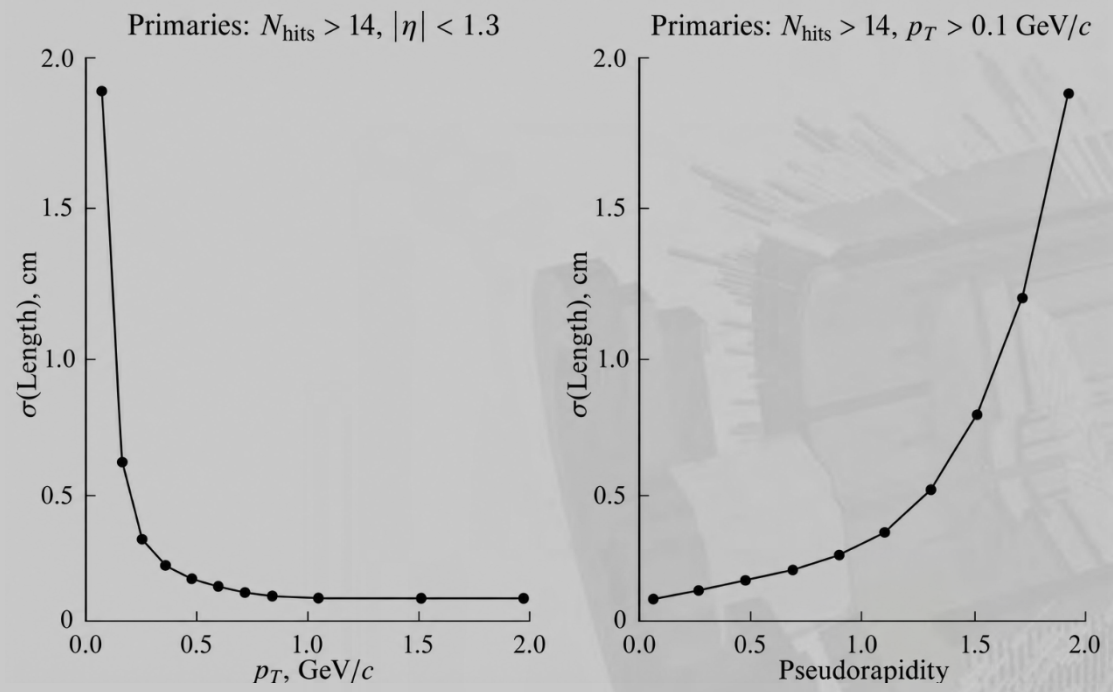


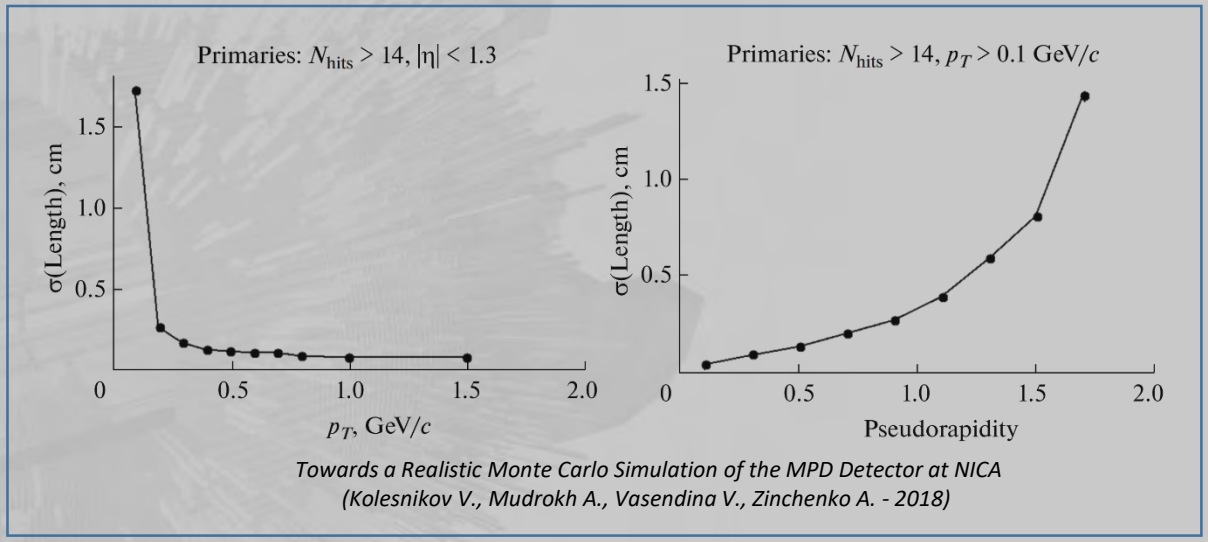


Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA
(Kolesnikov V., Mudrokh A., Vasendina V., Zinchenko A. - 2018)

- **Current (dE/dx) resolution is worse than the published reference,** but the present estimate does not apply the (|eta| < 1.3) cut.
- **Detailed truncation analysis needed.**

TRACK LENGTH RESOLUTION

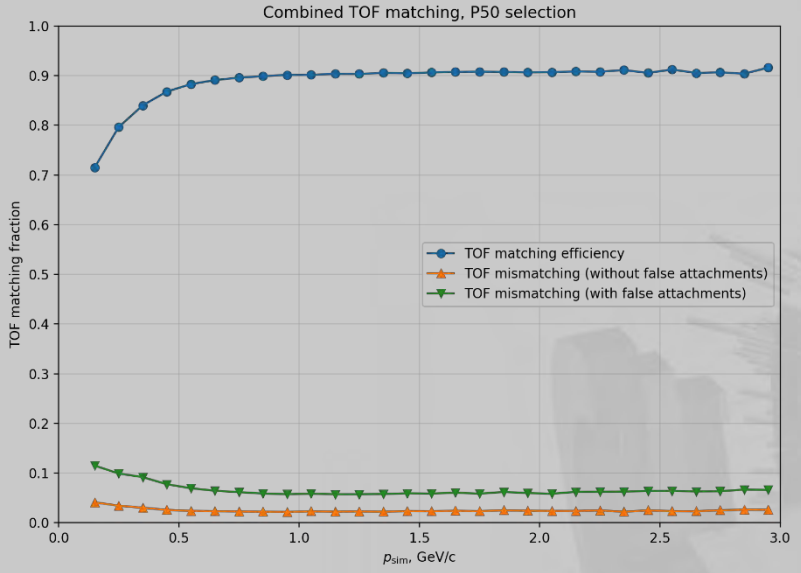




Towards a Realistic Monte Carlo Simulation of the MPD Detector at NICA
(Kolesnikov V., Mudrokh A., Vasendina V., Zinchenko A. - 2018)

- Track-length resolution **broadly comparable** to legacy tracker.
- Resolution **improves with increasing pT** and **degrades toward larger pseudorapidities**.

TOF MATCHING PERFORMANCE

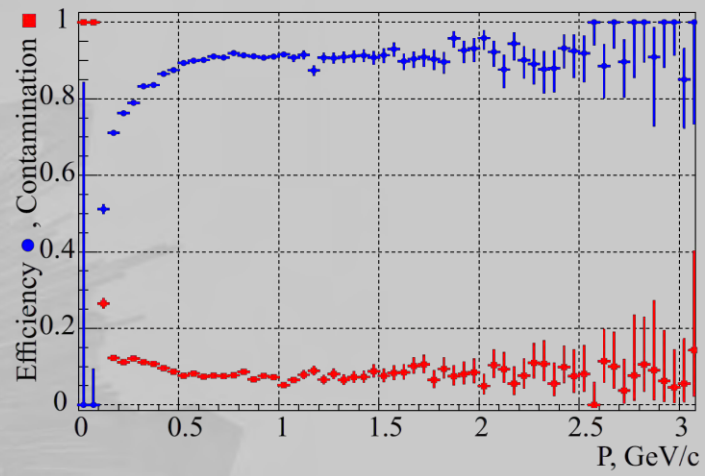


TOF matching (combined, P50 selection)

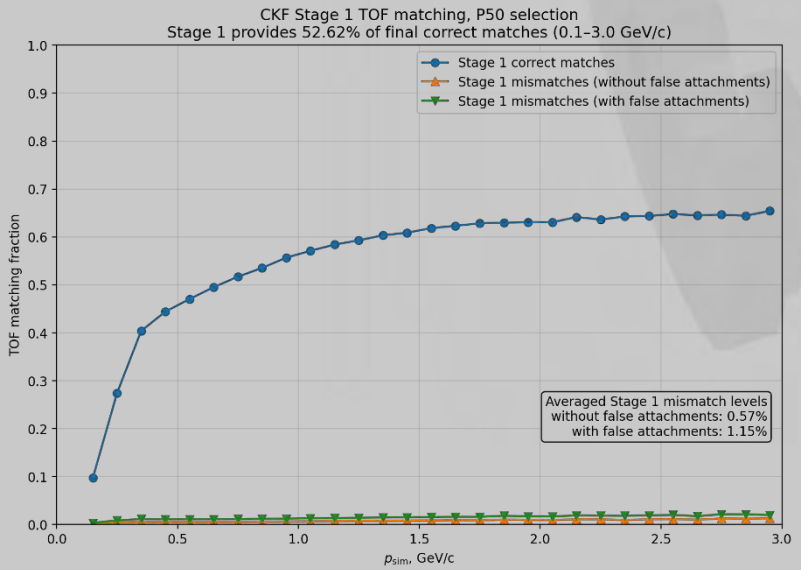
Efficiency and mismatches vs. true momentum (0.1 – 3.0 GeV/c) 1,000 runs · 100,000 events

p [GeV/c]	Efficiency (no mismatches)	Mismatch (without false attachments)	Mismatch (with false attachments)
0.1 – 0.2	71.47%	4.13%	11.54%
0.2 – 0.3	79.62%	3.44%	9.92%
0.3 – 0.4	83.99%	3.02%	9.18%
0.4 – 0.5	86.78%	2.60%	7.75%
0.5 – 0.6	88.25%	2.40%	6.96%
≥ 0.6	89.99%	2.29%	6.02%

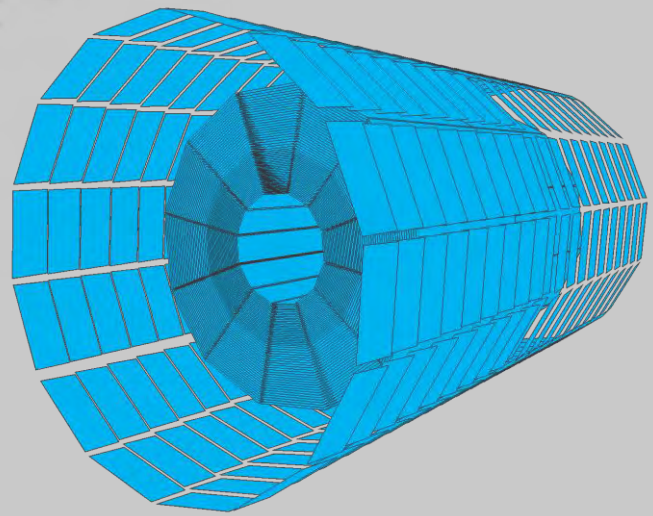
1. efficiency increases from **71.47%** at low momentum to approximately **90%** for $p \geq 0.6$ GeV/c
2. mismatches without false attachments decrease from **4.13%** to **2.29%**, stabilizing around **2–3%** at higher momenta
3. mismatches with false attachments decrease from **11.54%** to **6.02%**, stabilizing around **6%** at higher momenta



Time-of-flight particles identification in the MultiPurpose Detector at NICA (Babkin et al - 2020)



A substantial fraction of reconstructed TPC tracks extrapolated to the TOF barrel lack a corresponding MC TOF point, leading to false TOF-hit attachments.

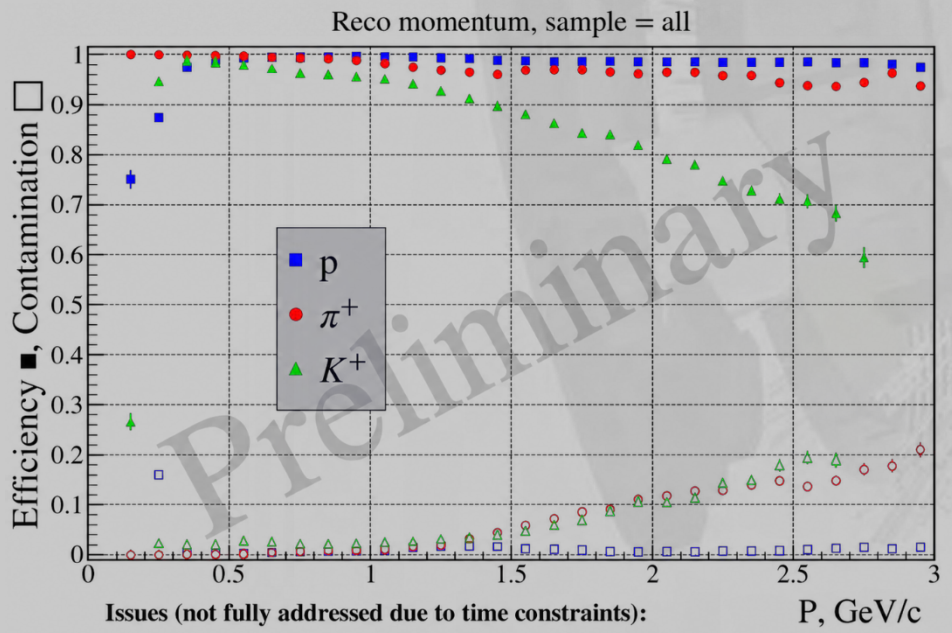


PIDML PERFORMANCE (PRELIMINARY)

PIdML Interface in MpdRoot

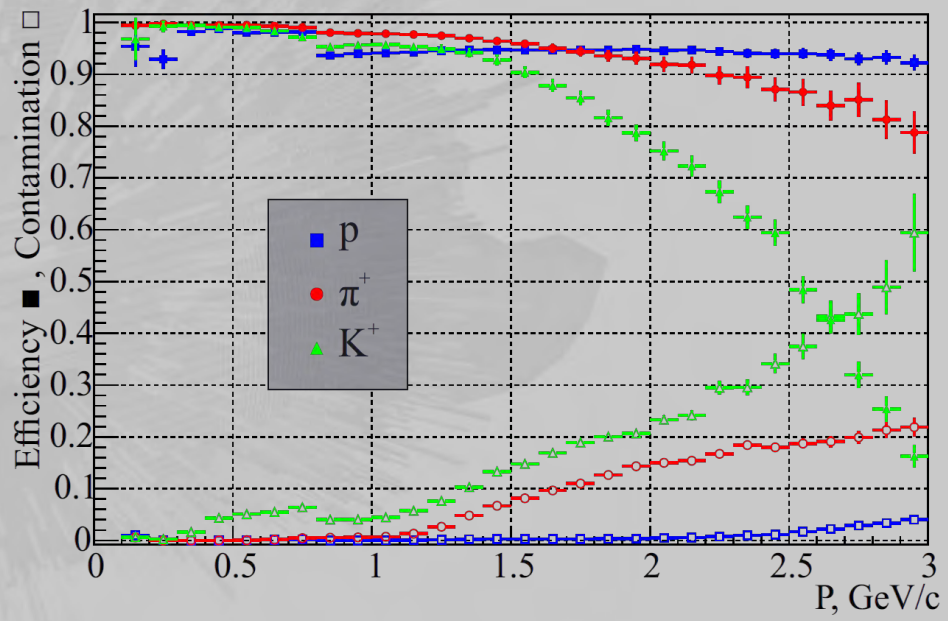
PIdML separates model training from inference in MpdRoot through a unified ONNX interface, supporting classifiers trained with different algorithms.

- Provides a unified API for ML-based particle identification.
- Returns both the most probable particle type and the full class-probability vector.
- Allows models to be replaced or updated without changing MpdRoot analysis code.



Issues (not fully addressed due to time constraints):

- The PIDML model was trained on a different dataset.
- The low-momentum region requires further investigation.
- Points with bin count < 500 were removed.



Time-of-flight particles identification in the MultiPurpose Detector at NICA (Babkin et al - 2020)

CURRENT STATUS AND NEXT STEPS

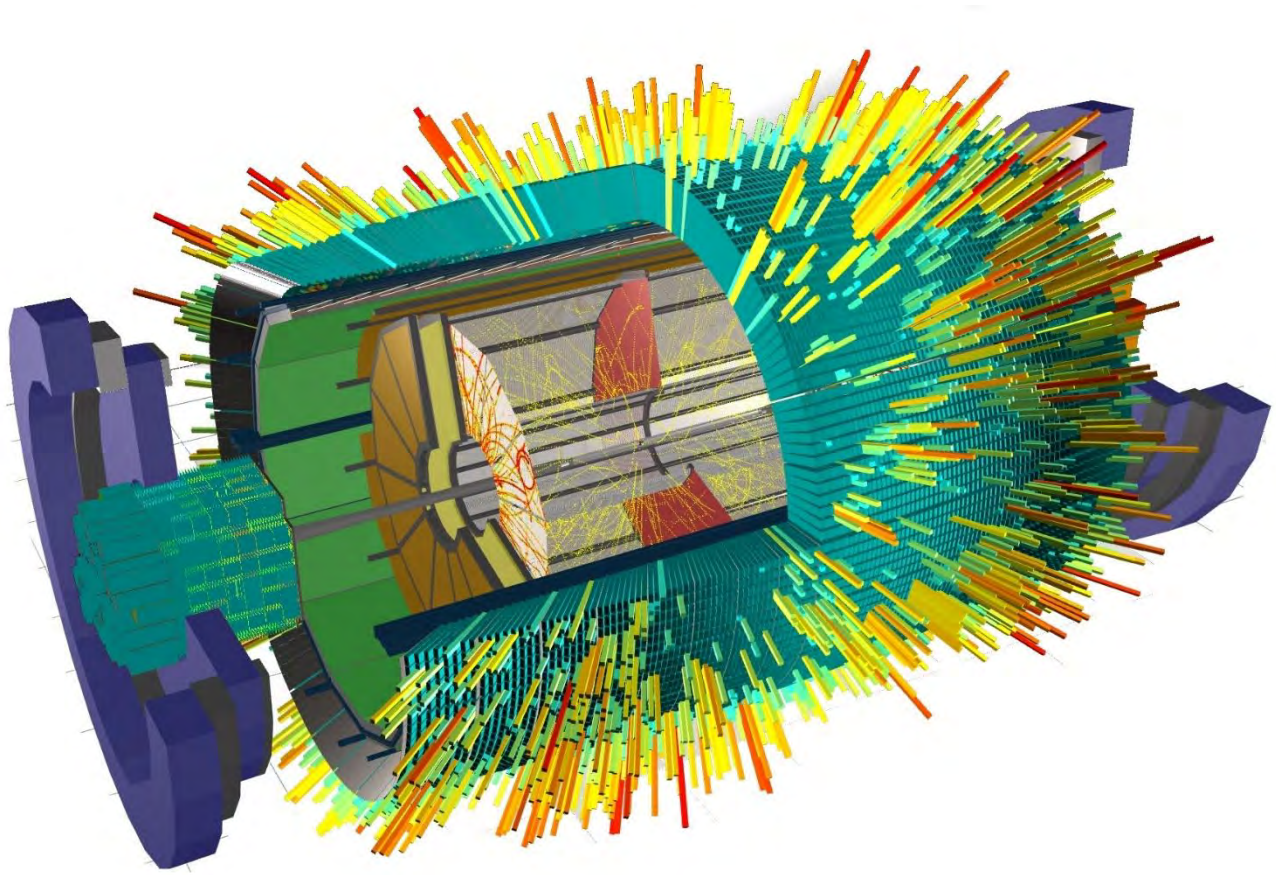
Reconstruction performance summary

Reconstruction aspect	Performance estimate	Improvement	Priority
Efficiency / Duplicates / Fakes	comparable	pass 3 residuals	medium
Momentum resolution	mixed (high p_T – better, low p_T – worse)	Kalman Refit	high
Primary-vertex resolution	worse	tune AMVF	low
Energy losses	?	truncation analysis	medium
Length resolution	comparable	–	lowest
TOF matching	promising	stage 2 algorithm rewrite, use losses constraint	high
PID ML	–	in-depth analysis	highest

- **move diagnostics into separate library** (reusable in experiment)
- **fast mlem clustering ready** (benchmark & add)
- **API for physics analysis**

Thank You !

Q & A



MPD Software Development & Computing Team

Rogachevsky O.	Coordinator
Krylov V.	Clustering, Microservices
Krylov A.	MPD Event Display
Bychkov A.	Detector Simulation
Kuzmin V.	Detector Alignment
Moshkin A., Pelevanyuk I.	Distributed Computing
Alexandrov E., Alexandrov I.	Databases
Papoyan V.	PID ML
Busa J.	Build System, Refactoring
Hnatic S.	Architecture, Tracking

Acknowledgements to MLIT JINR, VBLHEP JINR