Feasibility Study of ϕ(1020)-meson collective flow measurements at MPD experiment with enhanced particle production in Bi+Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV

30th International Scientific Conference of Young Scientists and Specialists
(2026 AYSS Awards Competition)

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Outline

- Anisotropic flow in heavy ion collision
- Motivation to enhance ϕ-meson signal
- Afterburner general work flow
- Dataset
  - Parameters for generator
  - Selection criteria
- Reconstructed signal for UrQMD 4.0 Bi+Bi at 9.2 GeV
  - Reconstruction efficiency ϵ and $\delta(p_T)$
  - Reconstructed elliptic flow signal with significance by four times more
  - Reconstructed and efficiency corrected realistic signal
- Summary and outlook

Anisotropic flow in heavy ion collision

The azimuthal angle distribution:

$$f(\varphi) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\varphi - \Psi_n))\right],$$

v_n are a flow amplitudes

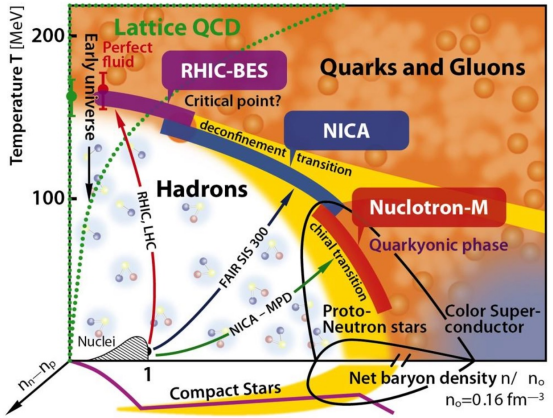
Ψ_n are a symmetry planes

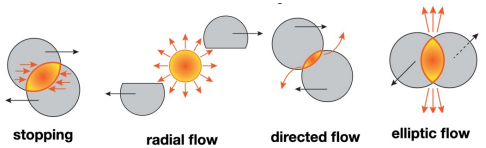
Elliptic flow: $v_2 = \langle\cos(2(\varphi - \Psi_2))\rangle$

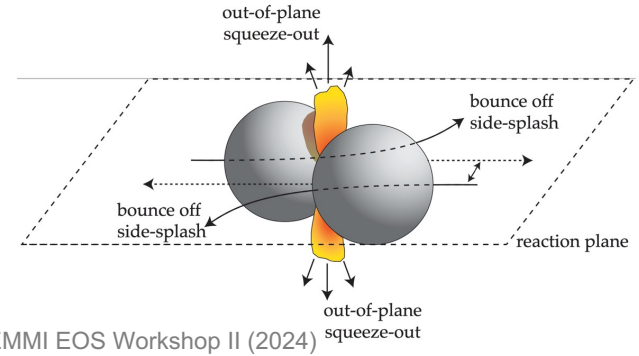
is sensitive to:

- early pressure gradients
- azimuthal momentum space anisotropy

Phase diagram of QCD







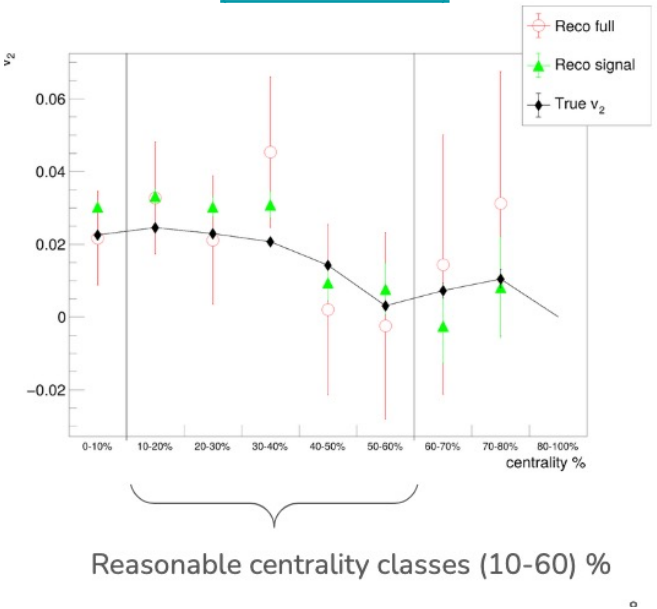
S. Voloshin and Y. Zhang, Z.Phys. C70 (1996)
Ante Bilandzic, LXX International Conference "NUCLEUS – 2020" (Saint Petersburg Oct 12, 2020) Indico Contribution 3983631

B. Kardan, EMMI EOS Workshop II (2024)

Motivation to enhance ϕ-meson signal

- The ϕ-meson is a sensitive probe of the **early collision stage** and provide information about **collectivity effect** [1,2]
- Precise measurements of **elliptic flow** of ϕ-mesons require **high statistics**
- STAR added ϕ-meson sample for testing the detector and analysis recover [3]
- Important for analysis with low reconstruction efficiency (e.g. direct photons, resonances, ϕ-mesons, Σ, Λ…)
- ϕ production probes hidden-strangeness enhancement

A.Taranenko, XVI Collaboration Meeting of the MPD Experiment at NICA, JINR, Dubna (28-30 October 2025)



Reconstructed data and true data based on $\Delta\varphi$-based method for 50M events

[1] Md. Nasim (for the STAR Collaboration), *Acta Phys. Pol. B Proc. Suppl.* **5**, 317 (2012)
[2] STAR Collaboration, arXiv:2605.27815 [nucl-ex] (2026).
[3] B. I. Abelev *et al.* (STAR Collaboration), *Phys. Rev. C* **79**, 064903 (2009)

Afterburner general workflow

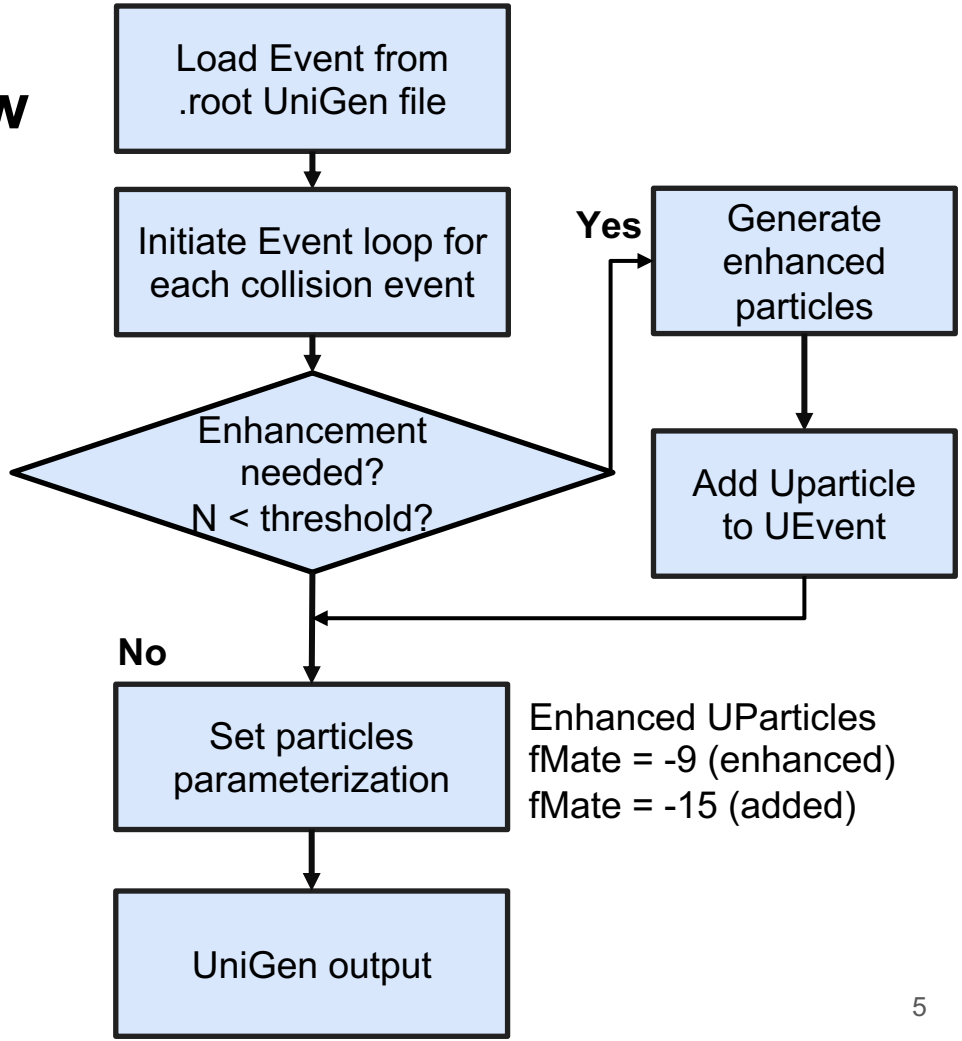
- Each particle is used as a template to generate new ones
- New statistically independent particles preserve original correlations
- Output format identical to the input (Unigen)

Already was used for analysis :

-global polarization of Λ-hyperon

-collective flow of Λ-hyperon

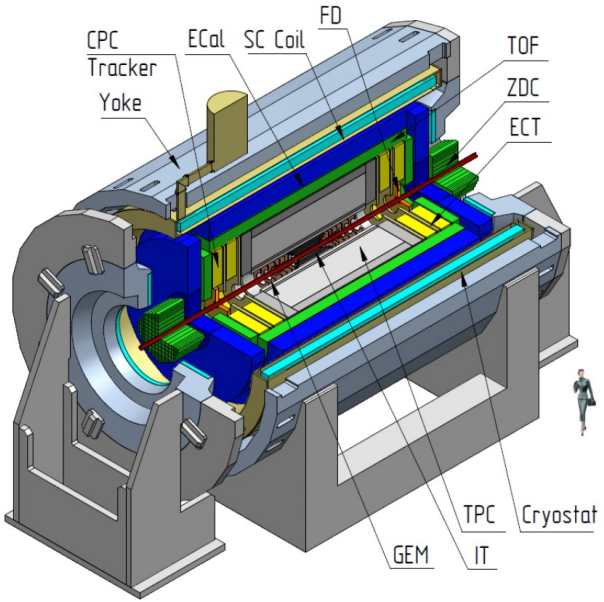
-also reduce statistical uncertainty from **48** % to **4.4** % [2]



[1] D.Flusova *et al.*, *Phys. Part. Nucl.* **57**, 1337 (2026).
[2] D. Flusova *et al.*, *Phys. Part. Nucl. Lett.* **23** (2026).
[2] V. Troshin *et al.*, *Phys. Part. Nucl.* **57** (2026)

Dataset

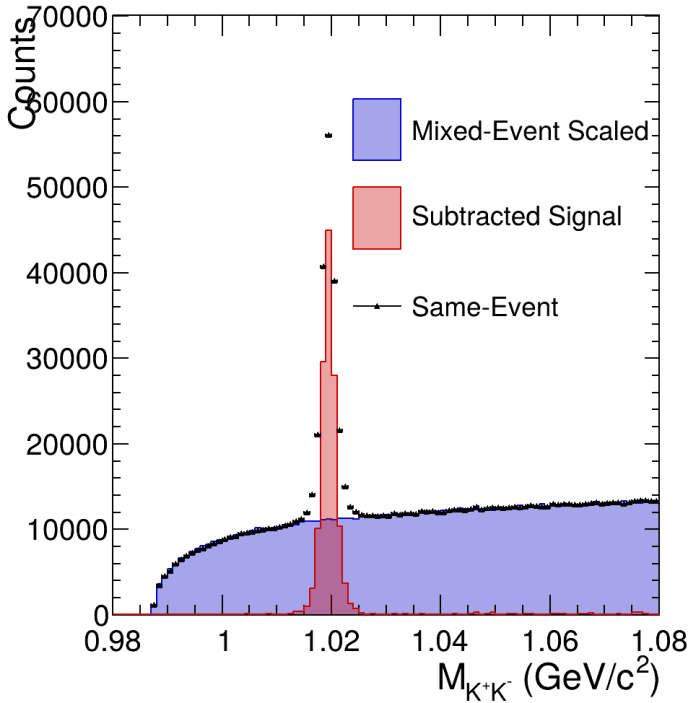
- UrQMD 4.0 Bi+Bi at $\sqrt{s_{NN}}$ = 9.2 GeV ~150k event
- 50 additional ϕ-meson within an event
- Reparametrized ϕ-meson kinematics
- GEANT4 transport
- For reconstruction **UniGen** generator was used
- Particle identification: **evPID** wagon
- Event plane measurements: **evPlane** wagon
- ϕ-meson flow measurements: **flowEpPairKK**
- Centrality based on impact parameter



MPD in collider mode

Signal and background estimation

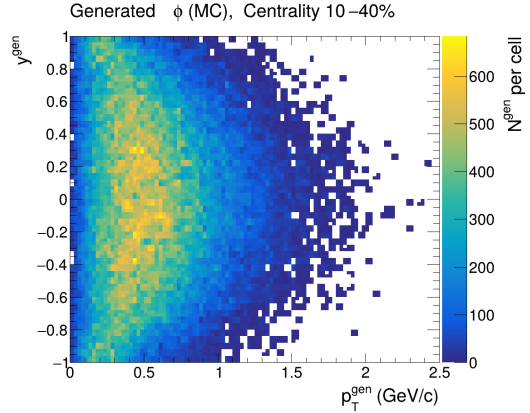
- **Background modeling**: Mixed-event invariant mass pairs matched in V_z and centrality
- **Normalization**: Scaled to same-event spectrum in high-mass sidebands outside the peak
- **Subtraction**: Mixed background subtracted directly from same-event distribution
- **Yield extraction**: Residual spectrum fitted with signal peak function plus residual background baseline
- **Systematics**: Assessed by varying normalization windows and integration boundaries

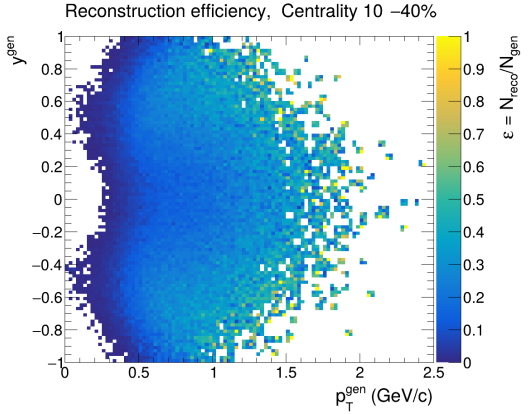


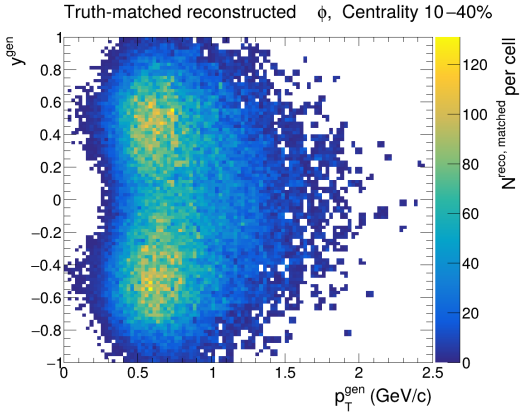
Signal yield extraction

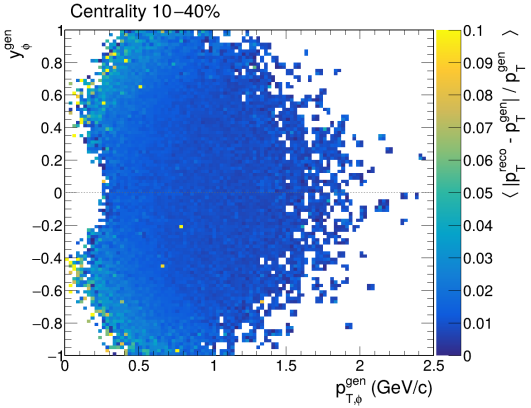
Acceptance of the detector

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (p_T, y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$
- The efficiency for 10-40 % $\epsilon = 13$ %

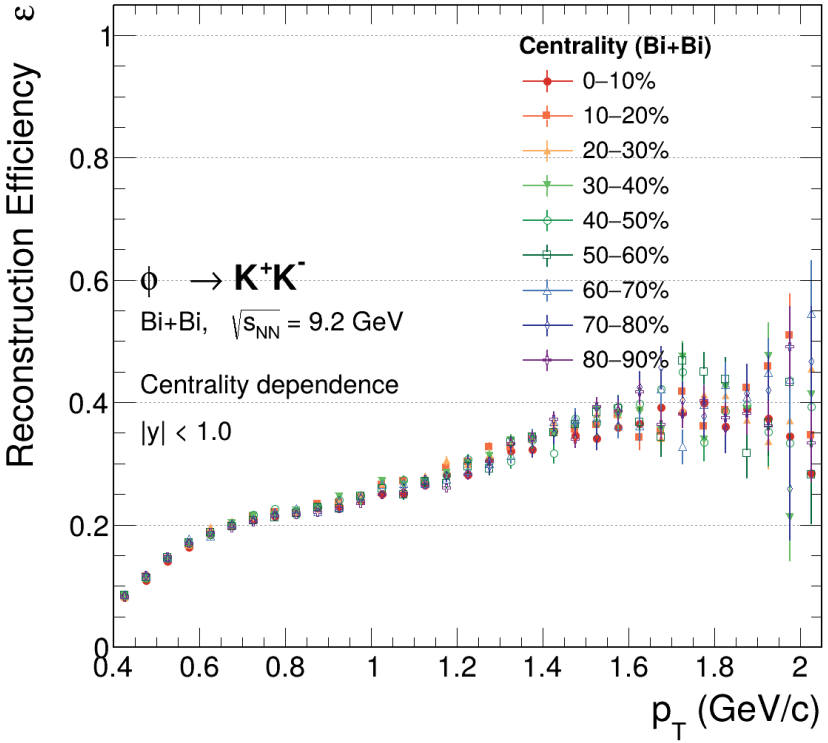








$\epsilon(p_T)$ for matched and generated tracks

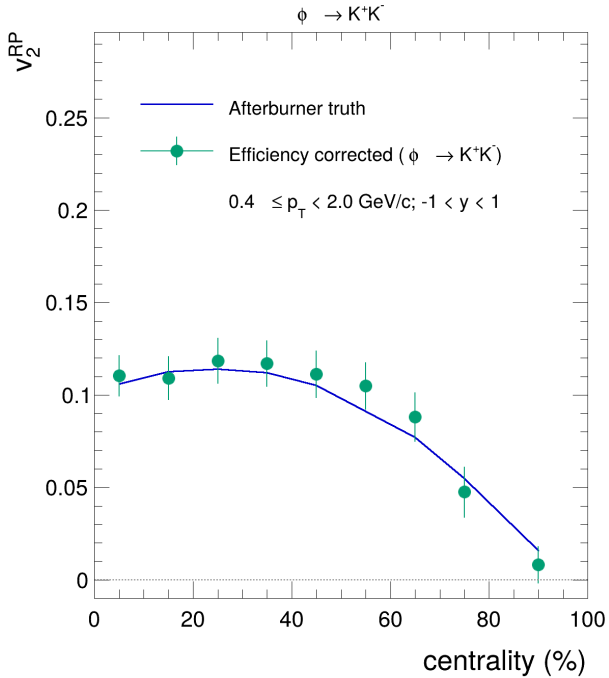


The efficiency relative to p_T for all centralities

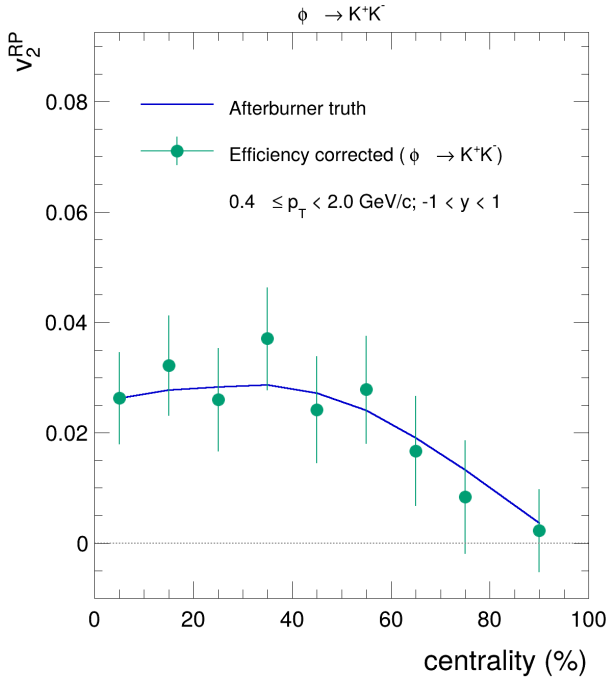
- relative efficiency around 13%
- the efficiency is low for soft ϕ-meson
- same trend for all centrality bins; does not create a bias relative to transverse momentum

Increased four times and realistic signal

- Evaluated $v_2(centrality)$ for realistic and $4\times$amplified signal
- Uncertainties increase significantly at lower signal levels
- Provides a baseline for future feasibility studies and error estimation



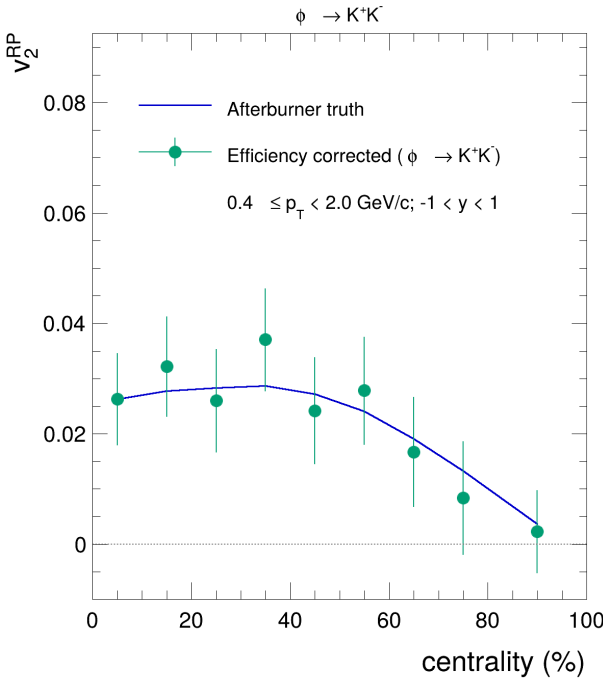
~ 100k events

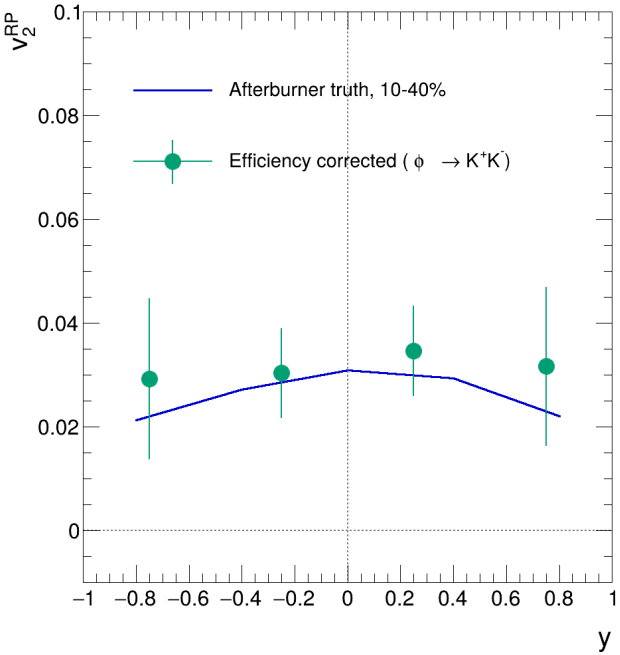


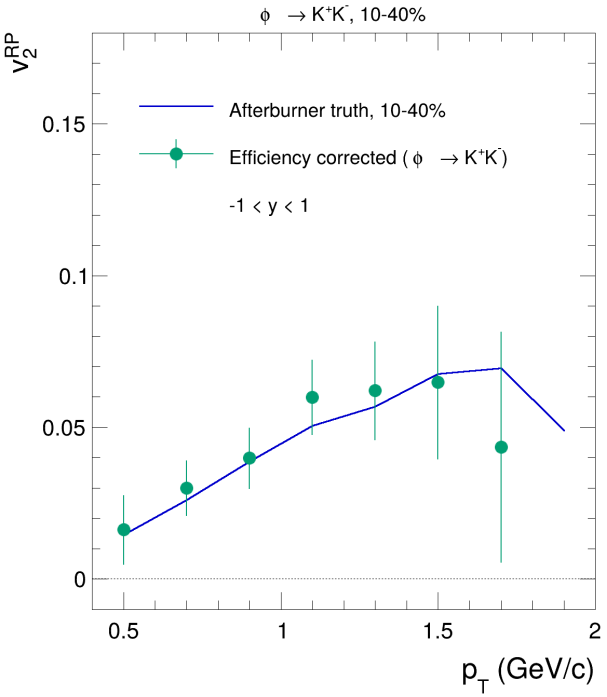
~ 200k events

~ 200k events

Realistic signal







- for production 25 mean flow ~0.03

- for lower signal uncertainty raises;
- realistic signal require a larger statistic

Summary

- Artificially embedded ϕ-mesons were propagated through the detector simulation and reconstruction chain and were identified through Monte Carlo truth matching during track selection.
- The reconstructed data reproduce the elliptic flow base on PID track selection and also realistic signal
- The momentum resolution better for high p_T^{ϕ} and smaller for soft ϕ;
- The analysis uses an efficiency correction $\epsilon(p_T, y, centrality)$ for reconstructed $\phi \rightarrow K^+K^-$candidates;

Outlook:

- To study better PID cuts and tune those;
- Use more realistic (low) signal for detailed feasibility study
- Detailed systematic estimation

Relevant information about scientific activity

List of publications:

- **Flusova D.S.**; Parfenov P.E.; Troshin V.V.; Taranenko A.V.; Feasibility Studies Using Enhanced Particle Production: An Afterburner for the MPD Experiment // Physics of Particles and Nuclei Letters - 2026 - Vol. 23 - Issue: 5 - p. 566-568
- **Flusova D.S.;** Parfenov P.E.; Troshin V.V.; Taranenko A.V.; Global Polarization of Lambda Hyperons in the MPD Experiment at NICA Energies // Physics of Particles and Nuclei - 2026 - Vol. 57 - Issue: 5 - p. 1337-1341
- Troshin V.V.; **Flusova D.S**.; Taranenko A.V.; Collective Flow of Λ Hyperons in the MPD-FXT Experiment // Physics of Particles and Nuclei - 2026 - Vol. 57 - Issue: 5 - p. 1346-1351

Conferences:

- The XXVIth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"
- 15th Collaboration Meeting of the BM@N Experiment at NICA
- 29th International Scientific Conference of Young Scientists and Specialists (AYSS-2025)
- 30th International Scientific Conference of Young Scientists and Specialists (AYSS-2026)
- 8th International Conference on Particle Physics and Astrophysics (ICPPA-2026)



Grants:

- The work has been supported by the Ministry of Science and Higher Education of the Russian Federation, Project "**Fundamental and applied research at the NICA (JINR) megascience experimental complex**" № FSWU-2025-0014
- TPU development program Priority 2030

BACKUP

PID selection criteria

Event selection:

- cut on vertex z coordinate: *130*

PID cuts:

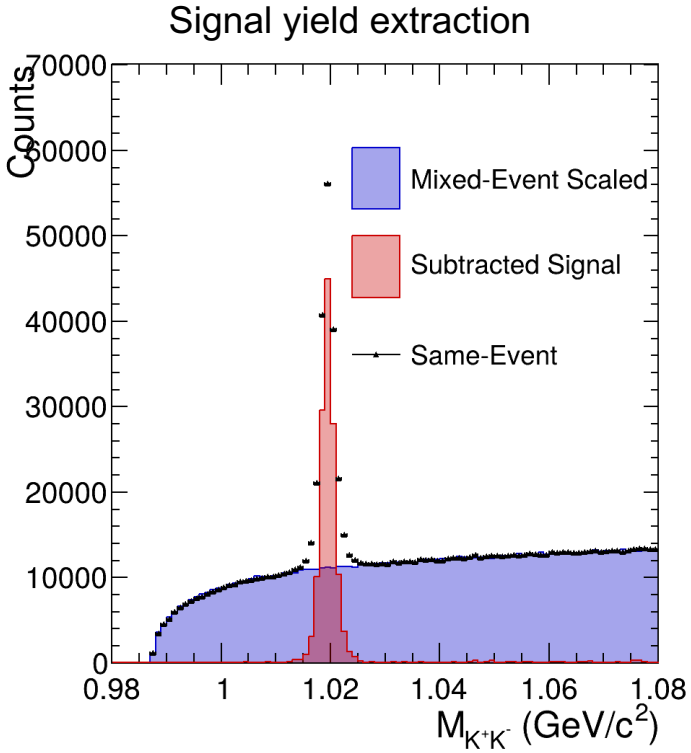
- dE/dx PID parameters: *2*
- Beta PID parameters: *2*

Track cuts:

- minimal number for a track: *15*
- maximal pseudorapidity for a track: *1*
- minimal pt for a track: *0.1*
- maximum DCA for a track: *2*

Pair cuts:

- pair cut: *1*



Matched tracks:

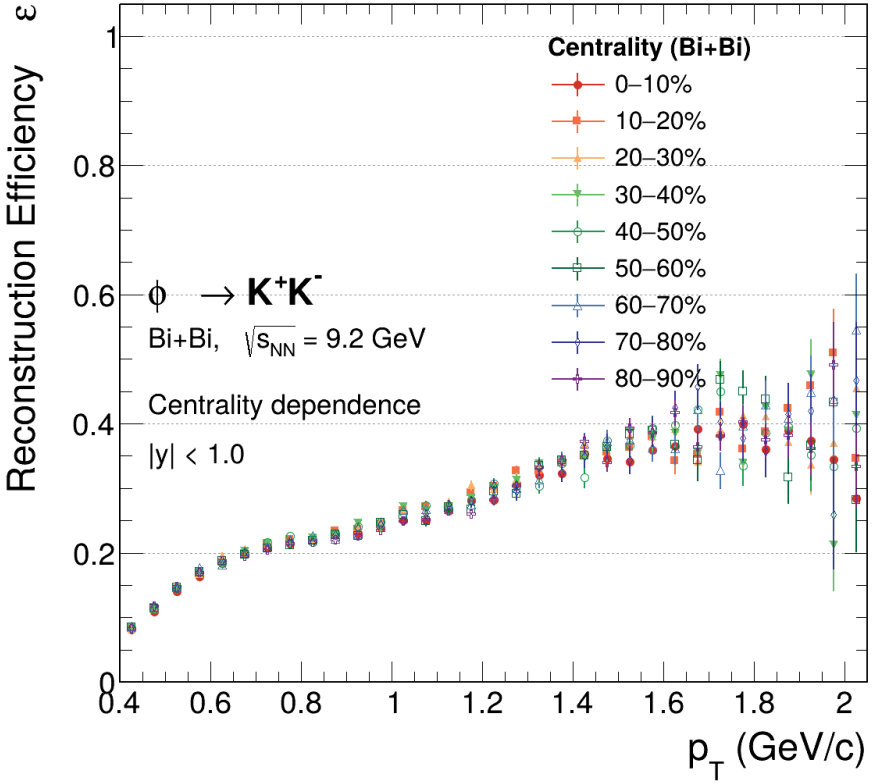
- ***same*** mother *PDG = 333*
- daughter tracks: *PDG = +-321*
- mother track has enhancement flag (*-9* and *-15*)

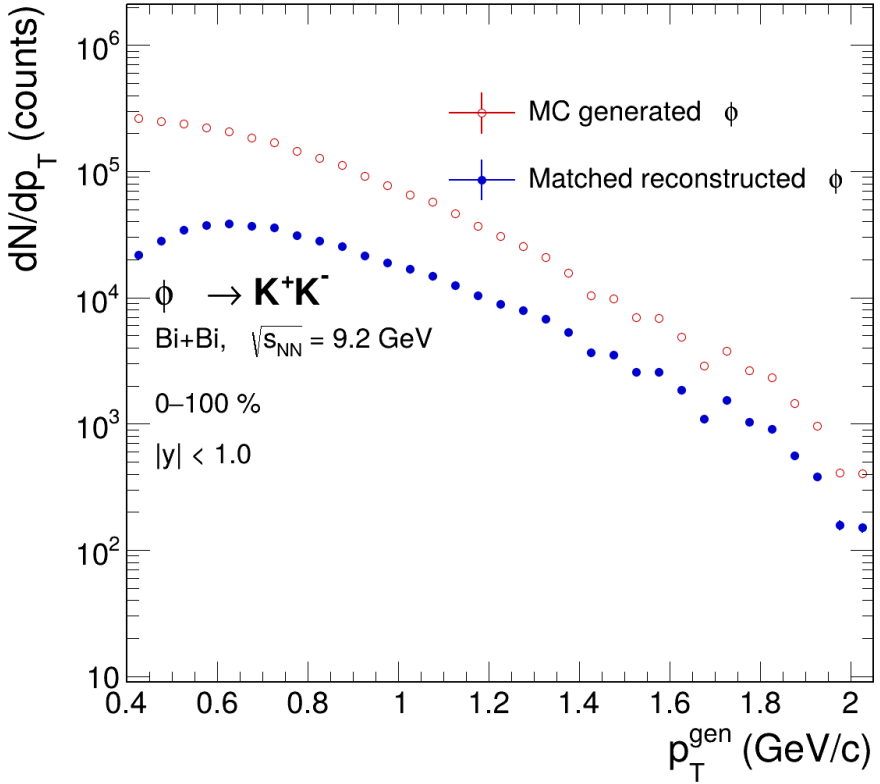
UniGen format

- Code available in MPDROOT repository (dev branch)
- **TFile**
- ├─ **URun** run/header metadata
- └─ **TTree** "events" sequence of UEvent objects
- └─ **UEvent** one collision snapshot (can be time-stepped)
- └─ **TClonesArray<UParticle>** particles in that snapshot

- **URun**: generator name, beam/target parameters (A, Z, momentum), impact parameter range, cross section, requested number of events.
- **UEvent**: : event number, impact parameter value, reaction plane angle, optional. Holds the **list of particles**.
- **UParticle**: Stores information about **a single particle**. PDG code, momentum (p_x, p_y, p_z, E), space-time coordinates (x, y, z, t)...

$\epsilon(p_T, y)$ for matched and generated tracks





Previous result for prod.25

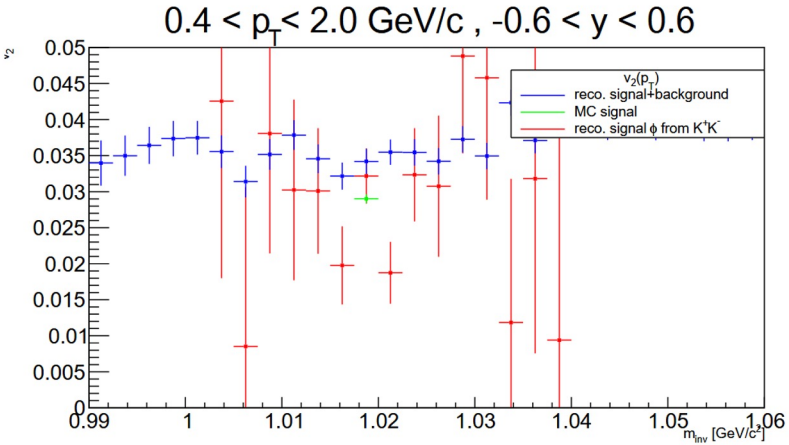
Used cuts:

Event selection: $|z_{vrtx}| < 130$ cm

Track selection:

- Kaons identification within 2σ (TPC and TOF)
- $N_{hits} > 24$
- $p_T > 0.1$ GeV/c
- $|DCA| < 2\sigma$
- Kaon pair $-0.6 < y_{K^+K^-} < 0.6$

Mixed events selection: $-0.6 < y_{K^+K^-} < 0.6$

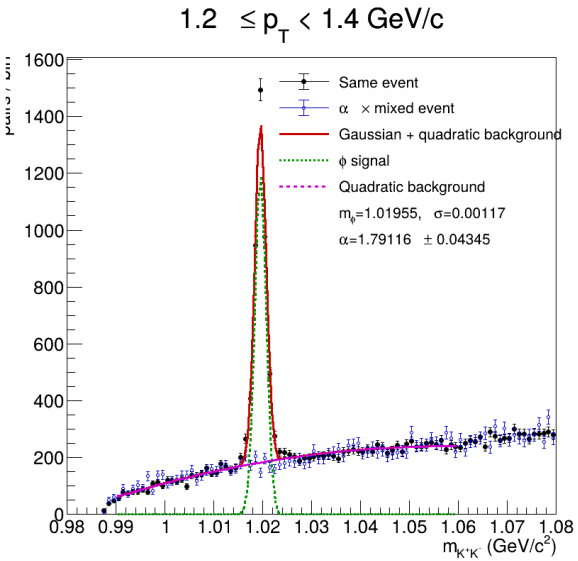


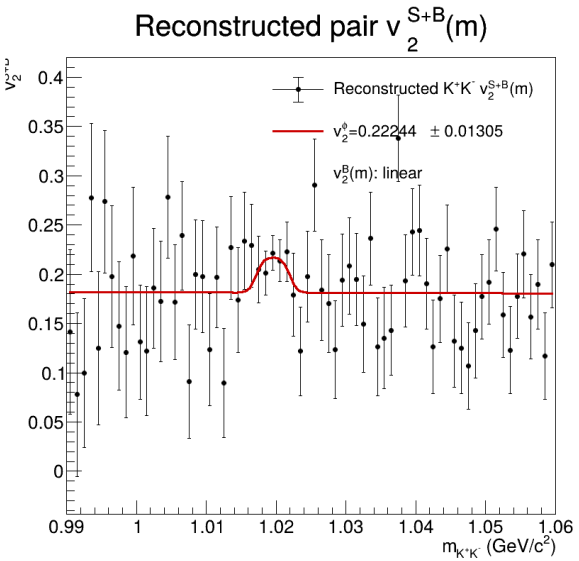
mass invariant method 10-60 %

Signal v2 and background v2 are similar - can not distinguish between them very well.

Signal construction: mass-invariant fit method

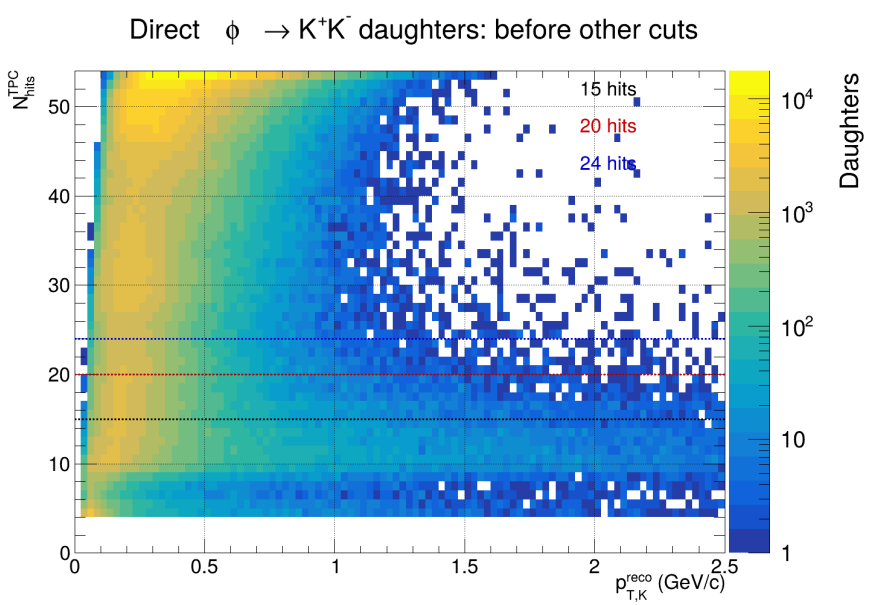
- Combinatorial background normalized and scaled;
- The true signal obtained by subtracting the total distribution from the background

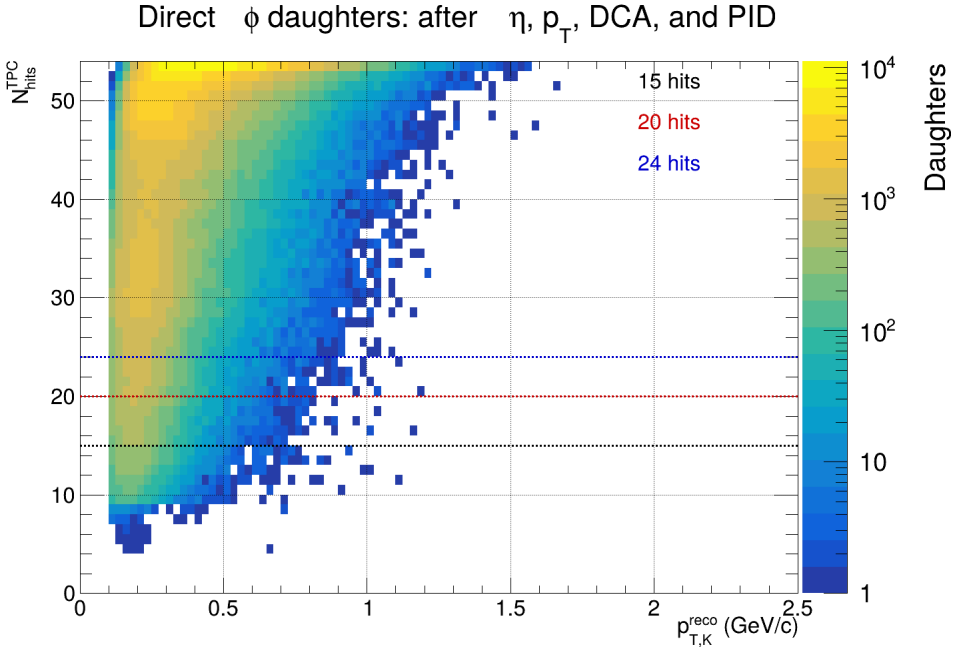




$$v_2^{SB}(m_{inv}, p_T) = v_2^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_2^B(m_{inv}, p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

TPC N_{hits} for $\phi \rightarrow K^+K^-$ daughters



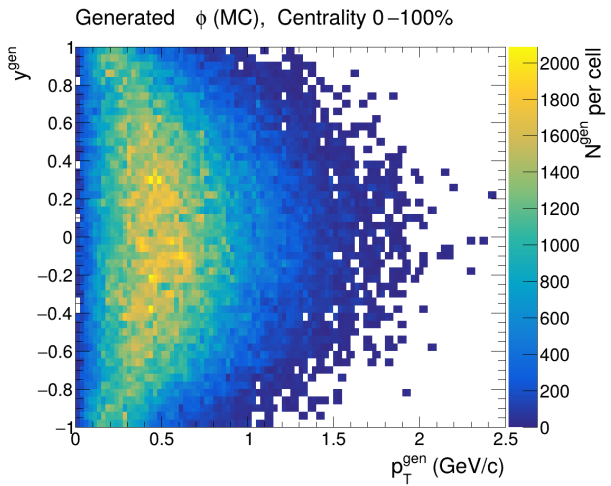


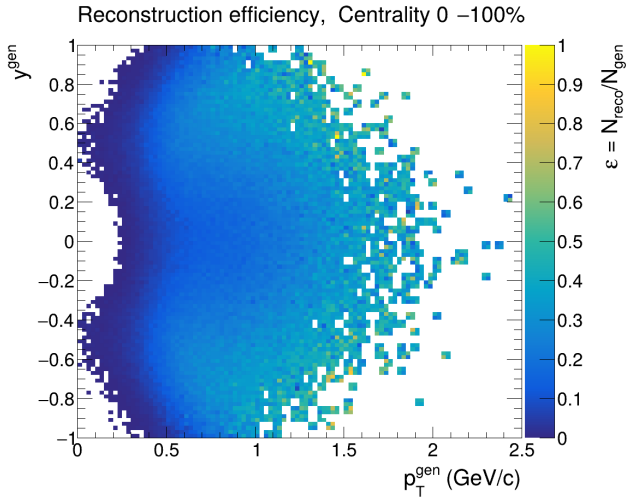
- Strict N_{hits} criteria reduce statistics of low-p_T K
- For ϕ reconstruction both of the K^+K^- must be presented

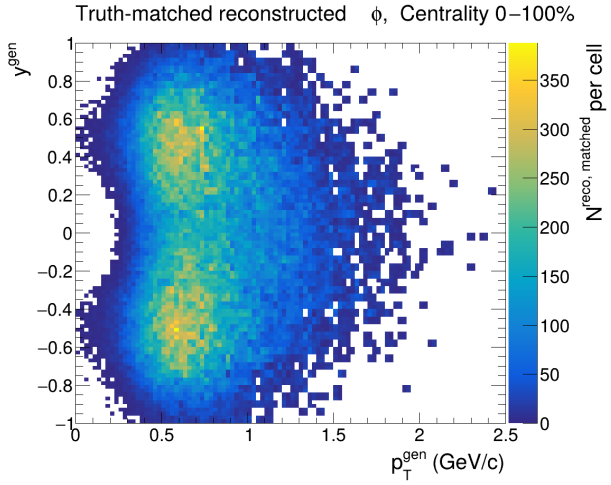
The cut should be optimized

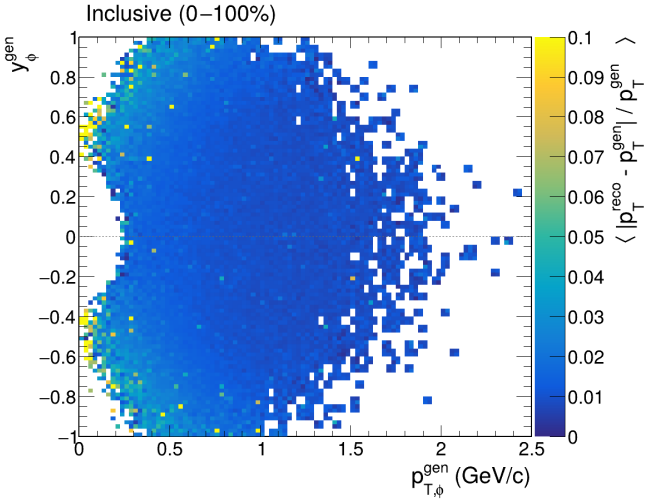
$\phi \rightarrow K^+K^-$ 0-100 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



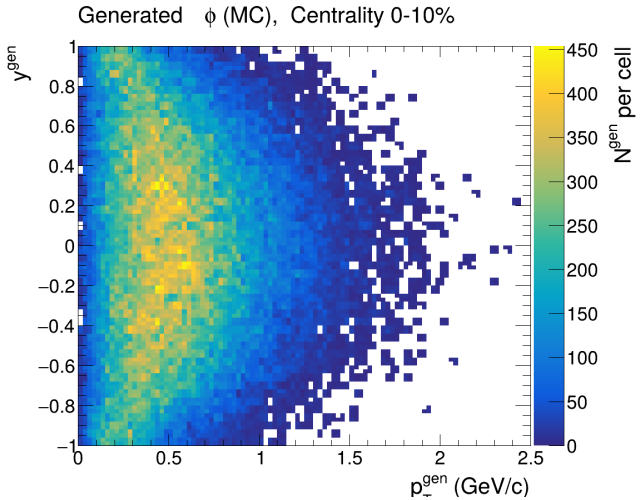


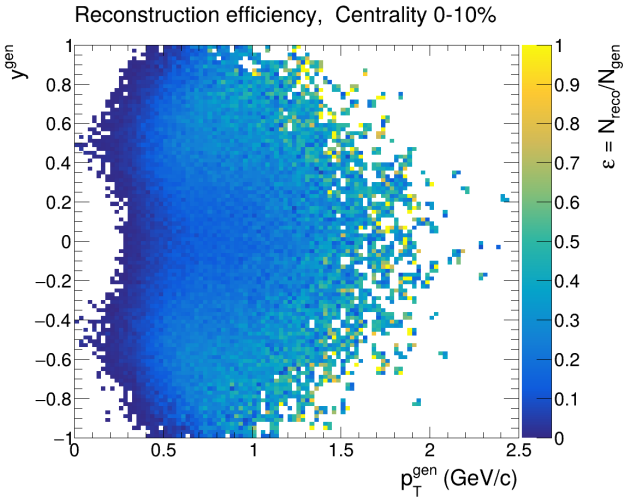


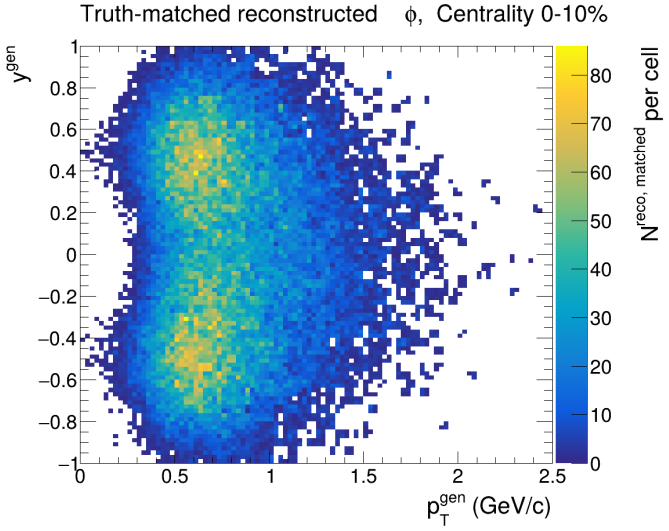


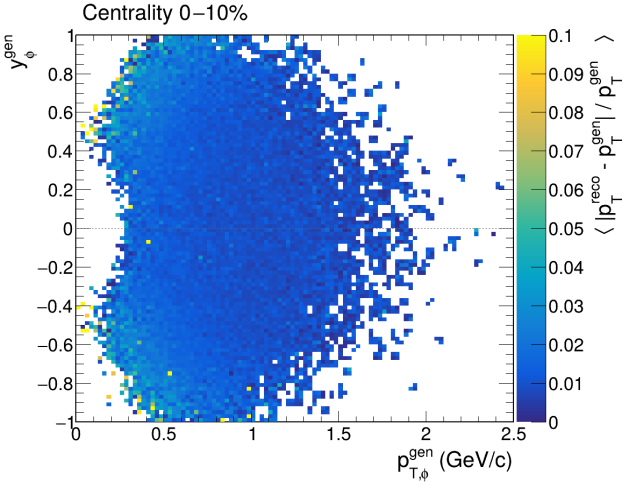
$\phi \rightarrow K^+K^-$ 0-10 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



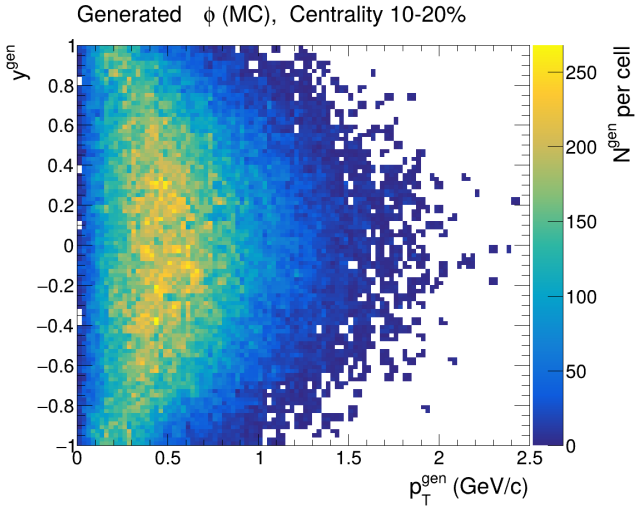


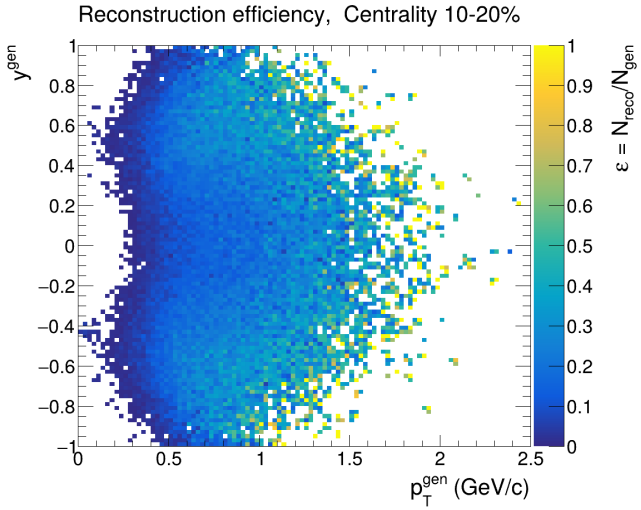


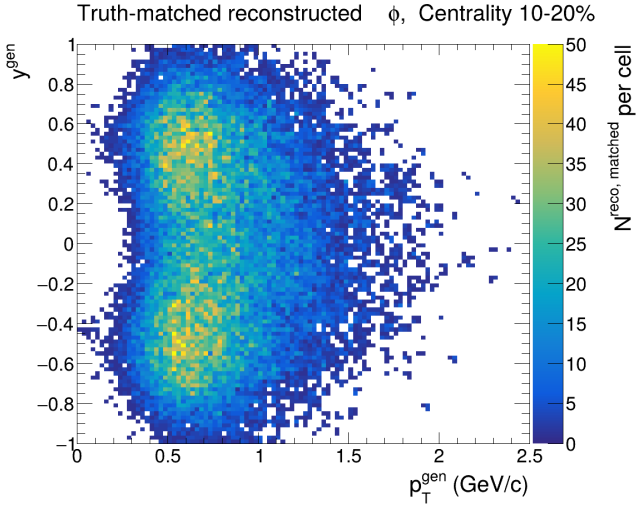


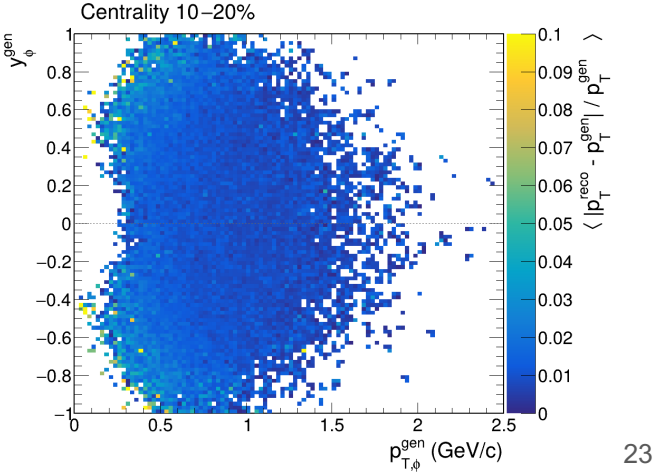
$\phi \rightarrow K^+K^-$ 10-20 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



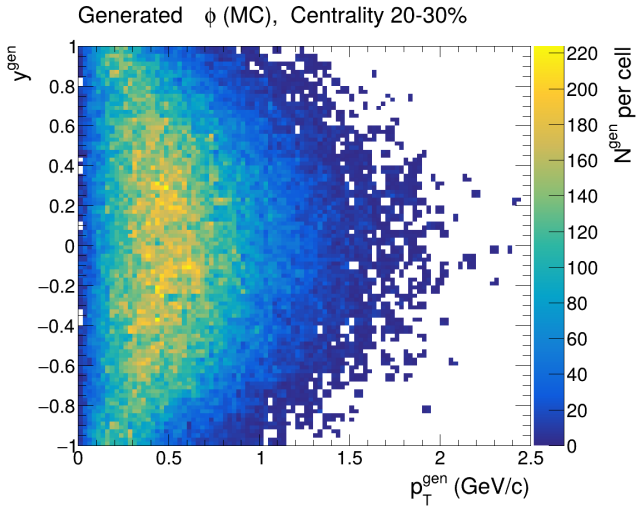


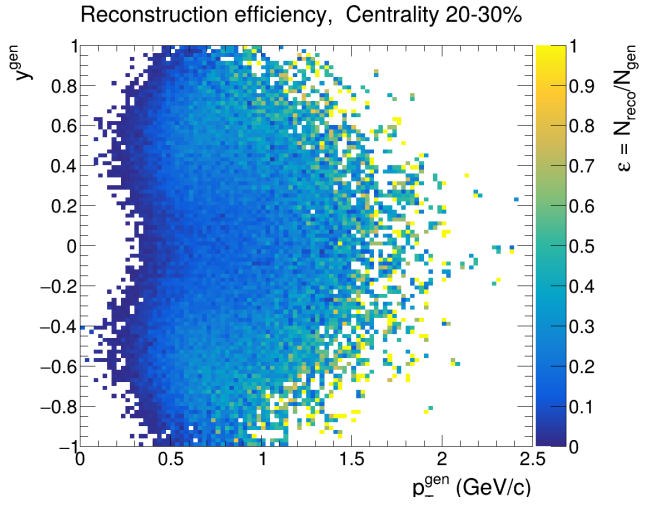


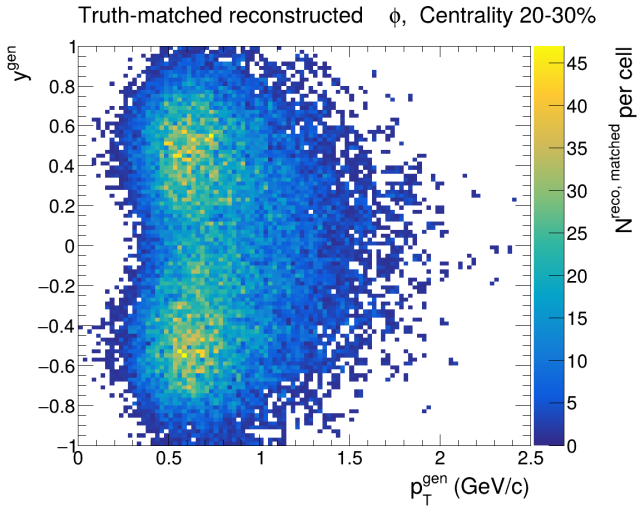


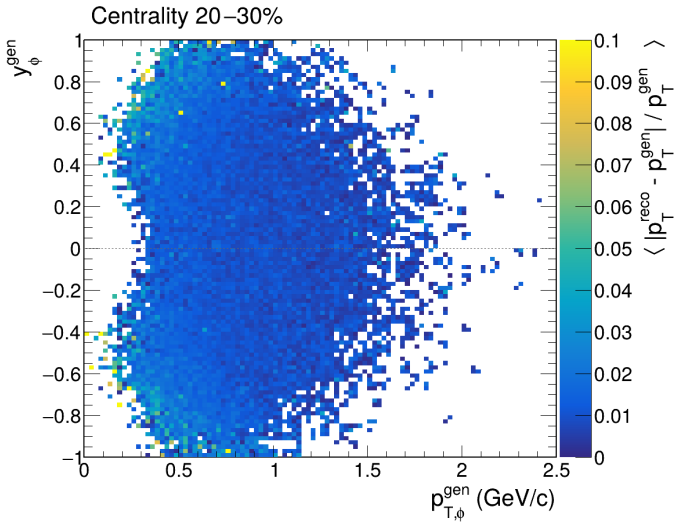
$\phi \rightarrow K^+K^-$ 20-30 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



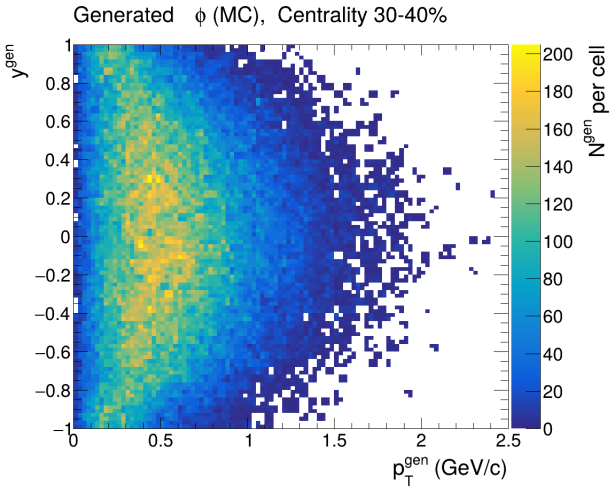


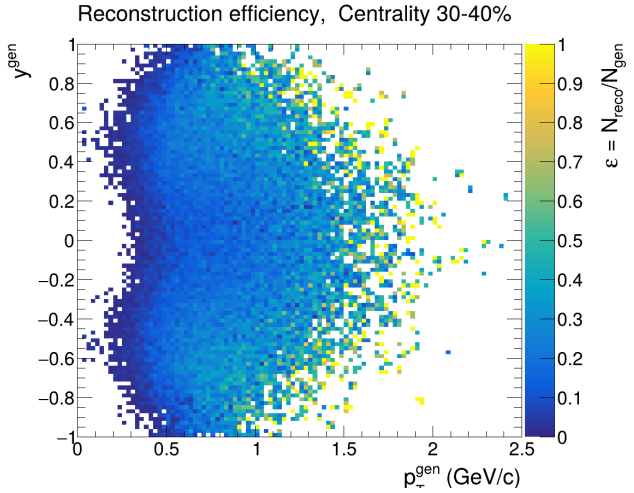


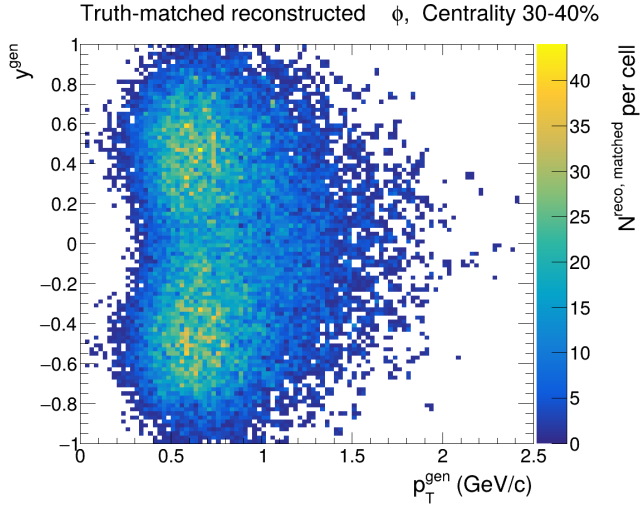


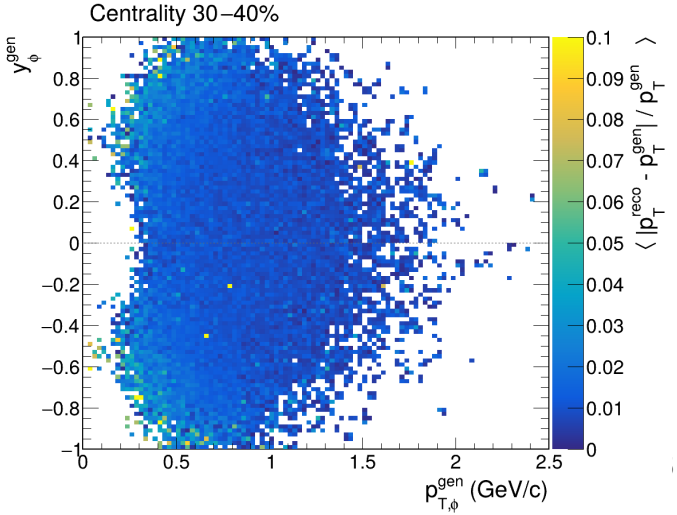
$\phi \rightarrow K^+K^-$ 30-40 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



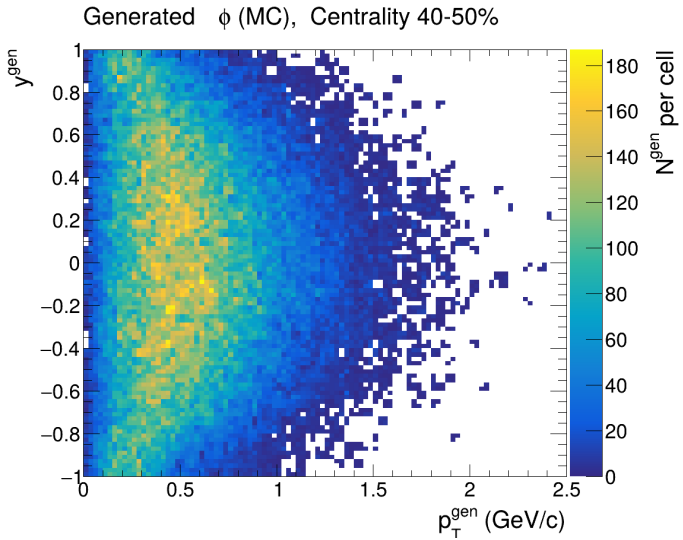


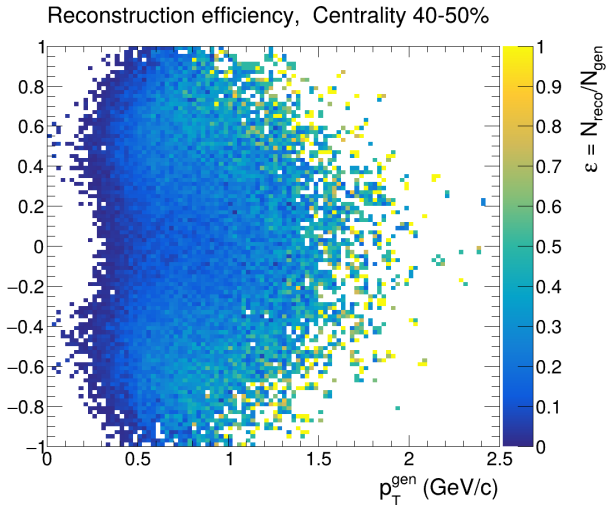


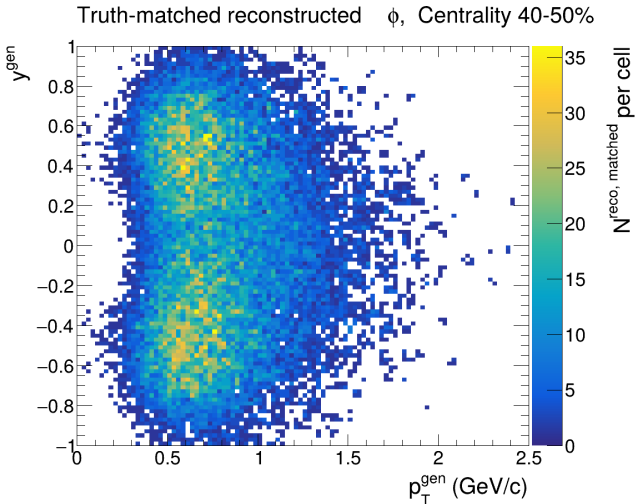


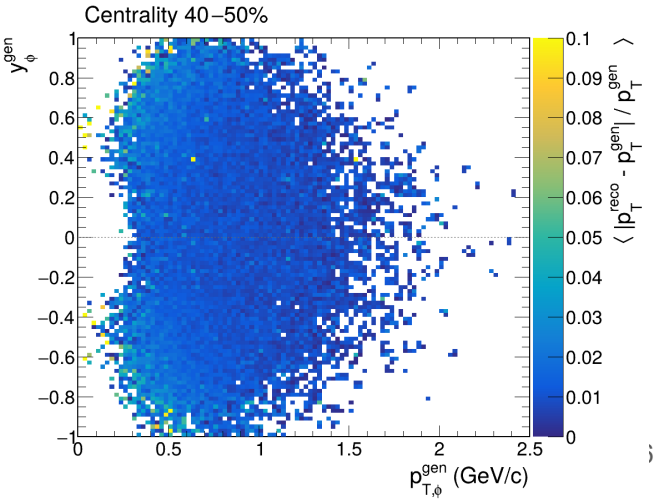
$\phi \rightarrow K^+K^-$ 40-50 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



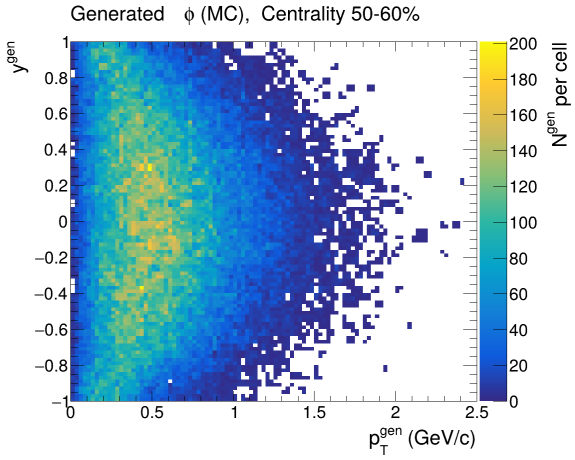


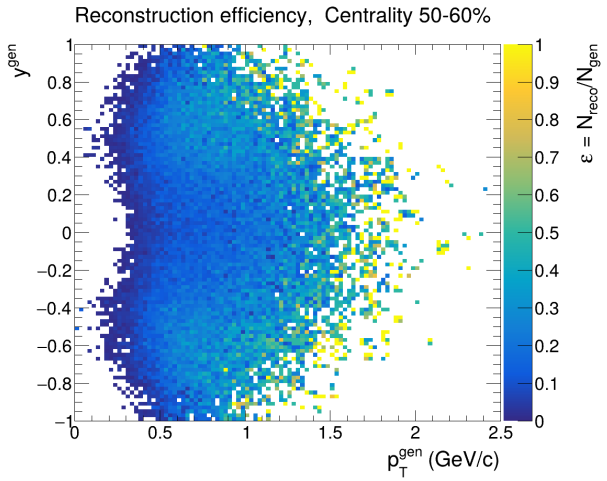


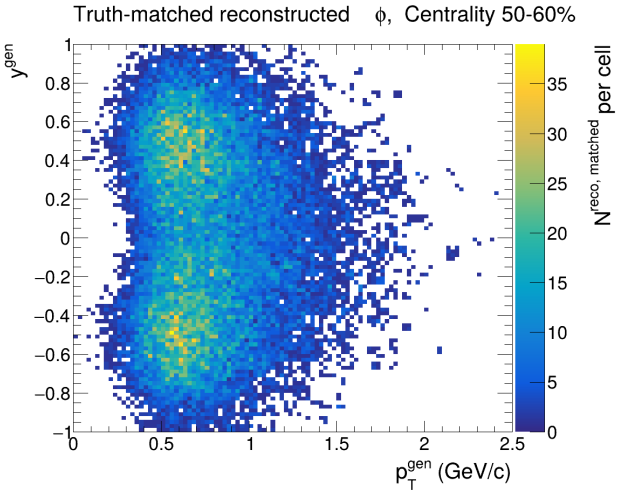


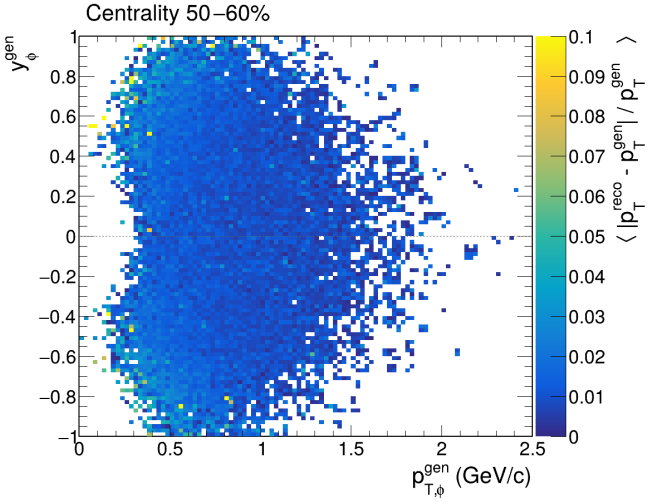
$\phi \rightarrow K^+K^-$ 50-60 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



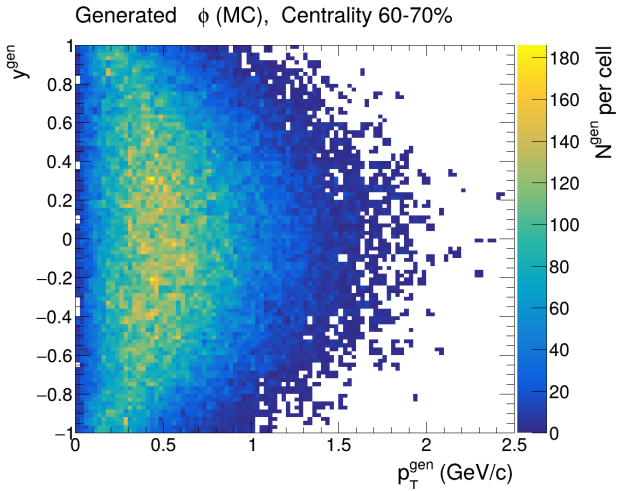


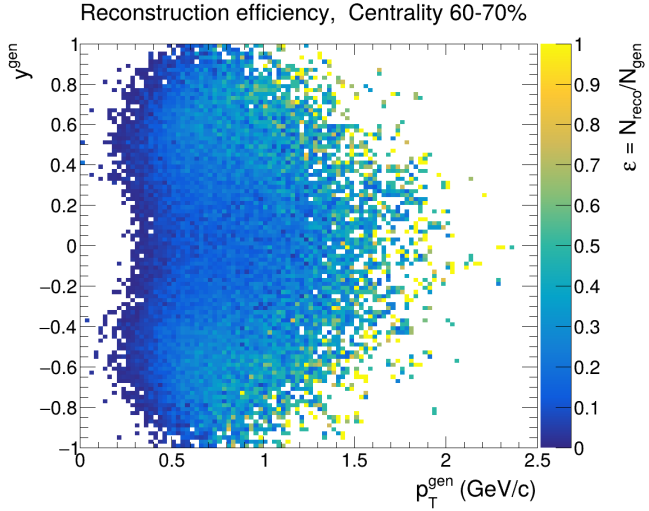


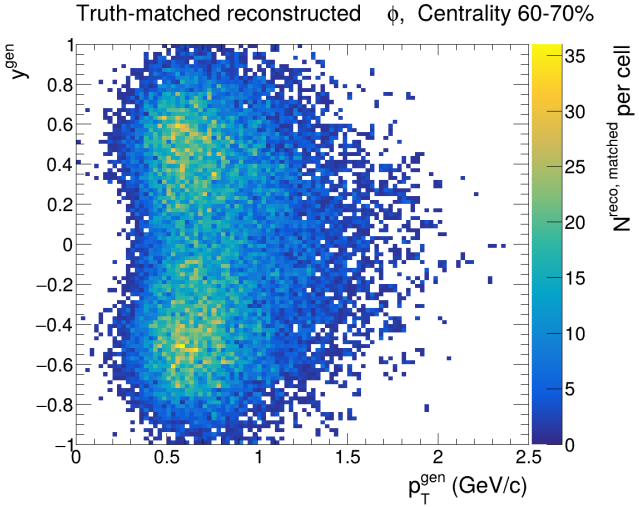


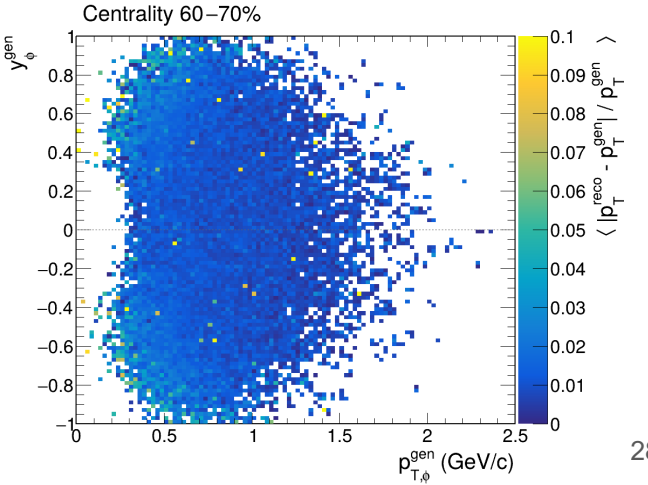
$\phi \rightarrow K^+K^-$ 60-70 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$



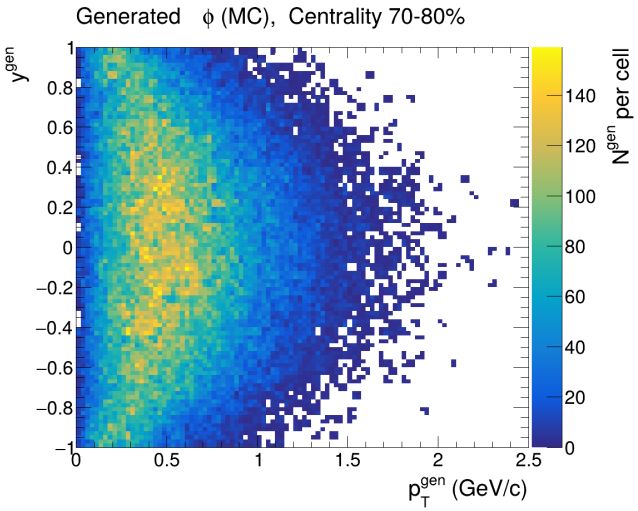


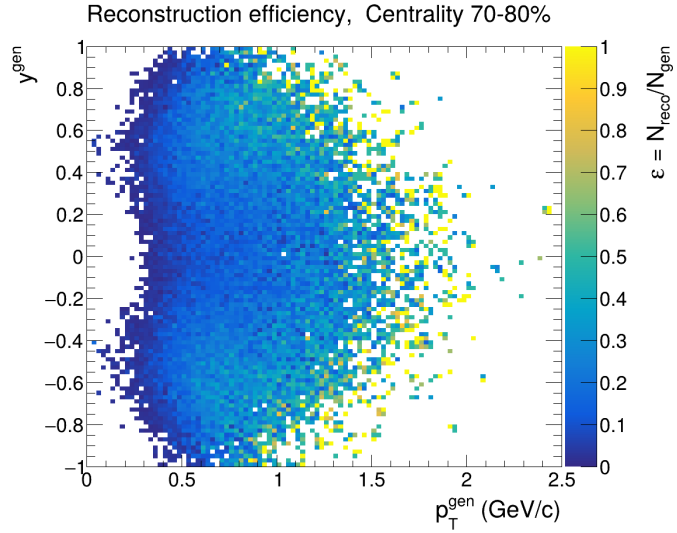


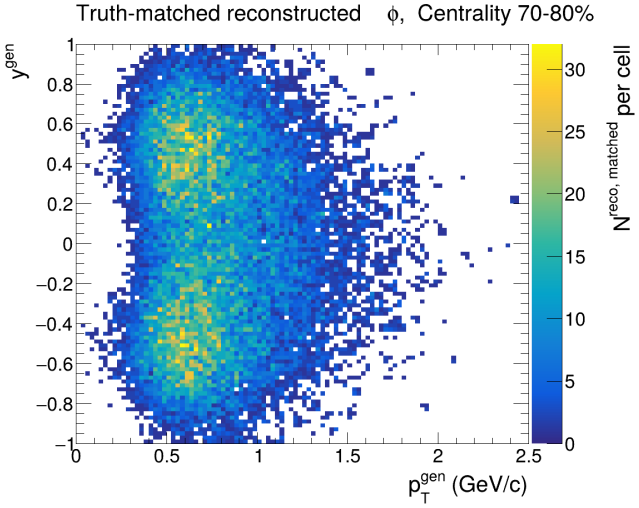


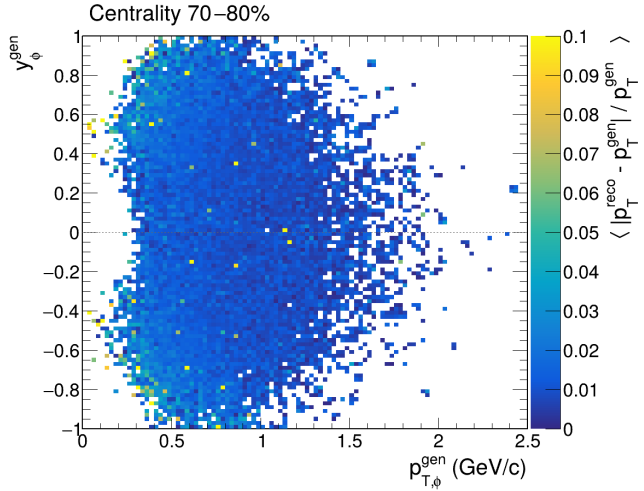
$\phi \rightarrow K^+K^-$ 70-80 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$









$\phi \rightarrow K^+K^-$ 80-100 %

- The reconstructed matched ϕ yield doesn't reproduce the MC distribution (pT,y);
- Reconstruction remove a part of statistics and shift $\langle v_2 \rangle$

