Collective flow of Λ hyperons in the MPD experiment at NICA energies

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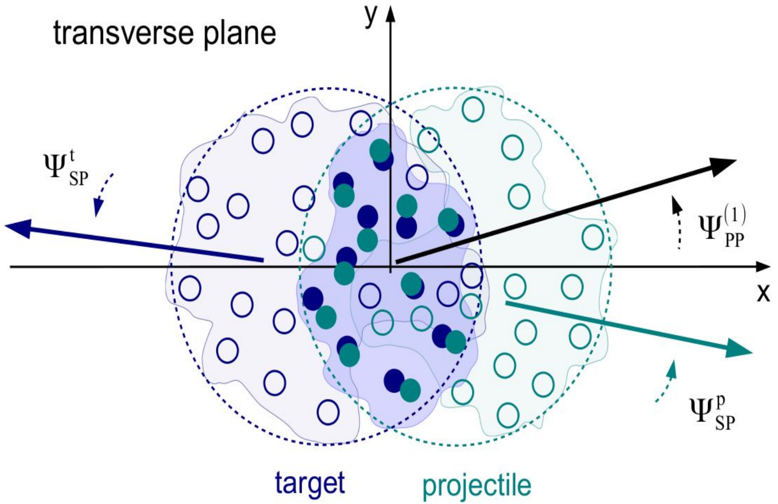
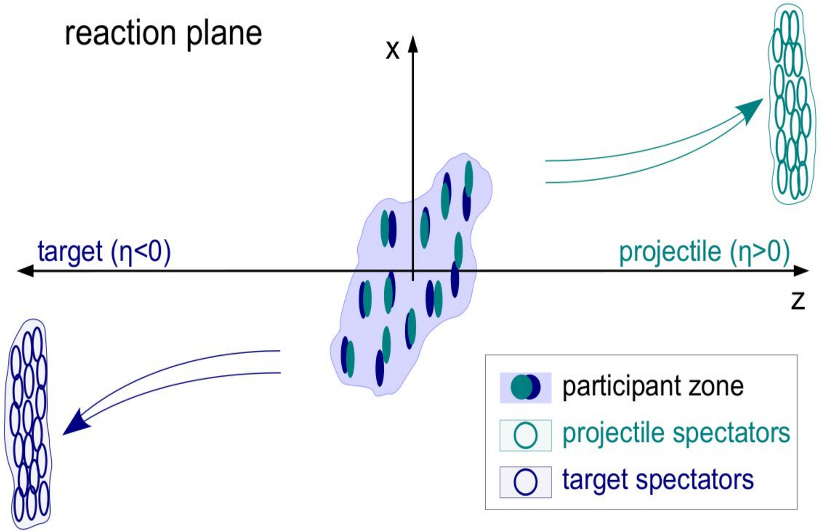
The XXVI International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"
15-20 September, 2025

The work was funded 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

Anisotropic transverse flow



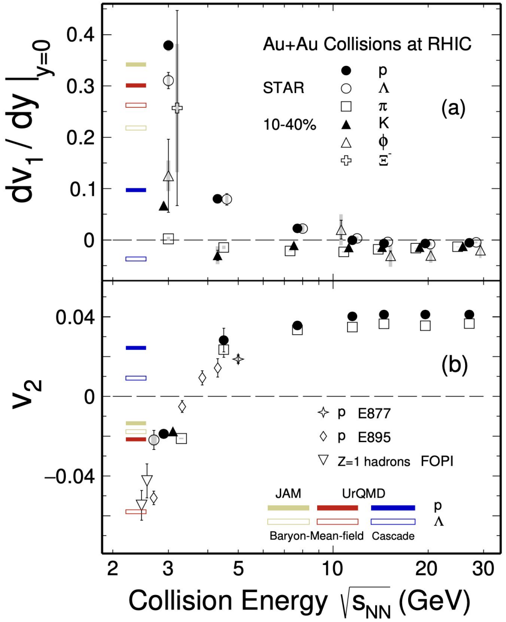


$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi_{RP}))\right)$$

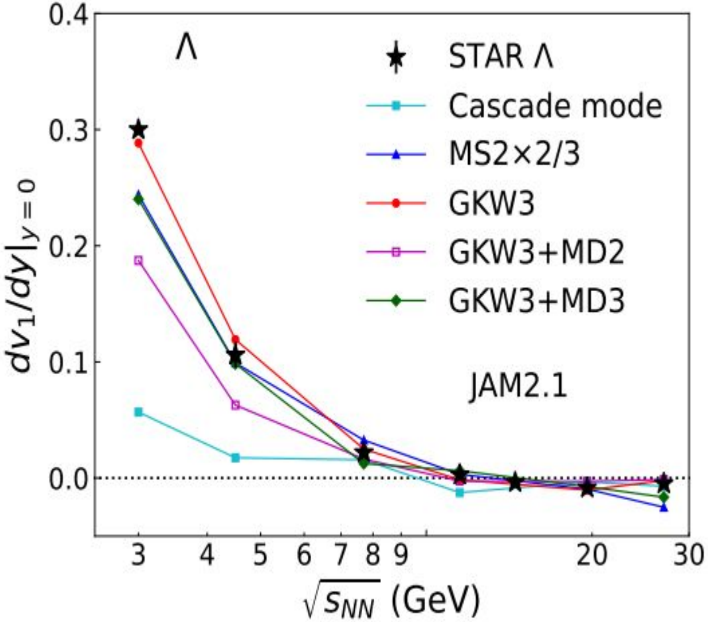
$$v_n = \langle \cos(n(\phi-\Psi_{RP}))\rangle$$

Spatial asymmetry of energy distribution at the initial state is transformed, through the strong interaction, into momentum anisotropy of the produced particles.

Study at Nuclotron-NICA energies



M. Abdallah et al. [STAR Collaboration] 2108.00908 [nucl-ex]



Yasushi Nara et al. *Phys.Rev.C* 106 (2022) 4, 044902

Strong energy dependence of dv_1/dy and v_2 at $\sqrt{s_{NN}}$ = 4-11 GeV. Anisotropic flow at FAIR/NICA energies is a delicate balance between:

- The ability of pressure developed early in the reaction zone
- Long passage time (strong shadowing by spectators)

- Λ potential is important to explanation of existence
- of two-solar-mass neutron stars
- Constrained by v_1
- Best agreement with model includes interactions with hyperons

MPD experiment at NICA

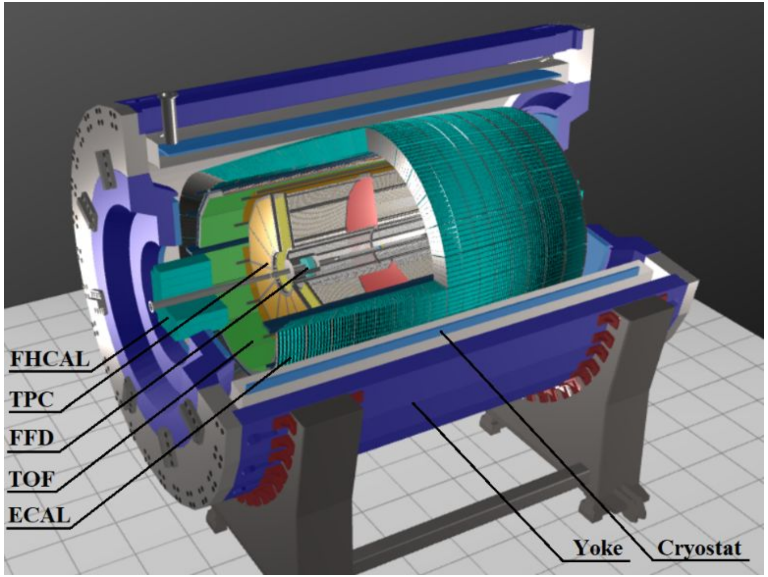
Main subsystems at Stage-I:

TPC ($|\eta| \leq 1.6$): charged particle tracking + momentum reconstruction + dE/dx identification

TOF ($|\eta| \leq 1.4$): charged particle identification

ECal ($2.9 < |\eta| < 1.4$): energy and PID for $\gamma/e^{\pm}$

FHCal ($2 < |\eta| < 5$) and **FFD** ($2.9 < |\eta| < 3.3$): event triggering + event geometry



Expected beams at the first year(s) of operation (Stage-I):

- MPD-CLD: Xe/Bi+Xe/Bi at $\sqrt{s_{NN}} \sim 7$ GeV
- MPD-FXT: Xe/Bi +W at $\sqrt{s_{NN}} \sim 3$ GeV

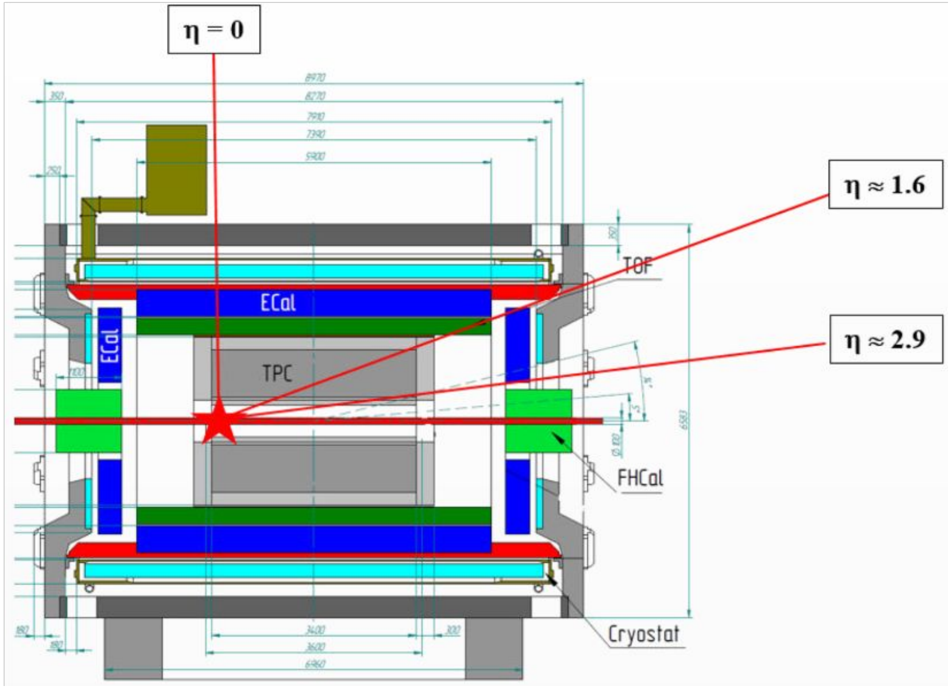
Model → **Simulation of MPD setup** → **GEANT4** → **Realistic data reconstruction** → **Obtaining results**

MPD Fixed Target (FXT)

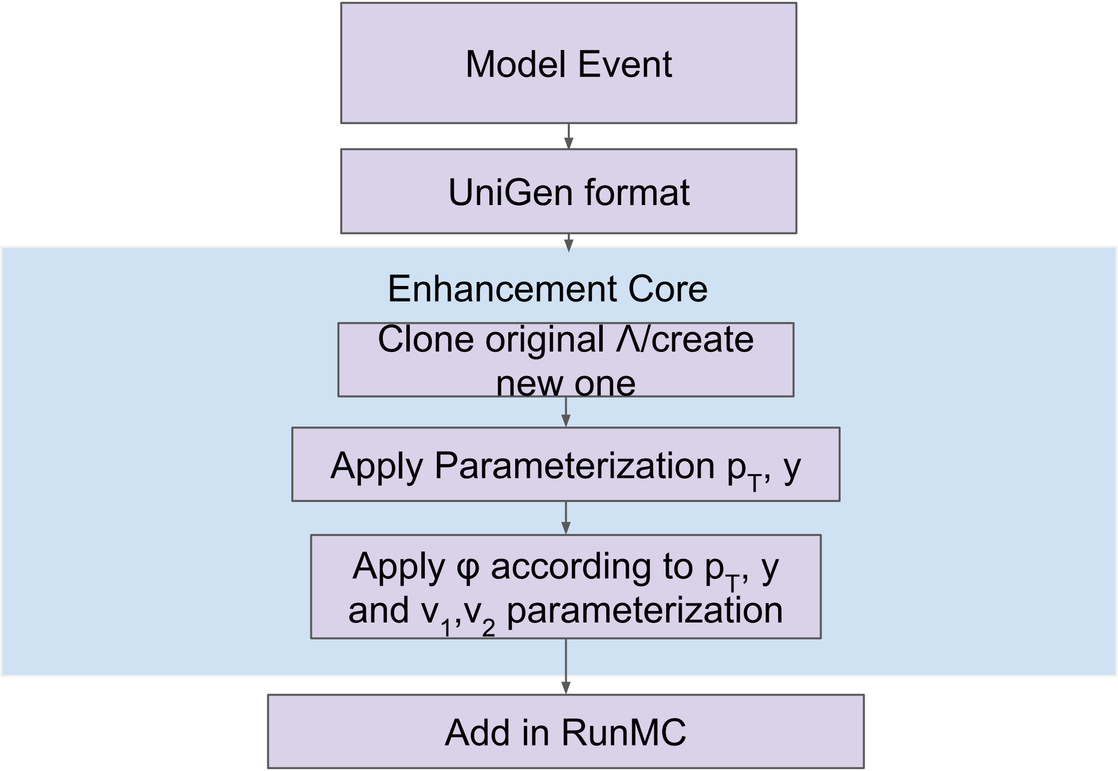
- Model used: UrQMD 3.4 mean-field
  - Xe+Xe, Ekin = 2.5 AGeV ($\sqrt{s_{NN}}$=2.87 GeV)
- Point-like target at z = -85 cm, y = 1 cm
- UniGen afterburner
  - Enhanced Λ production(5 in event)
  - Realistic v_1, v_2 parameterization
- GEANT4 transport

Enhanced production is necessary to obtain statistically significant results w/o modeling huge amount of data.

MPD-FXT



Enhanced Λ production

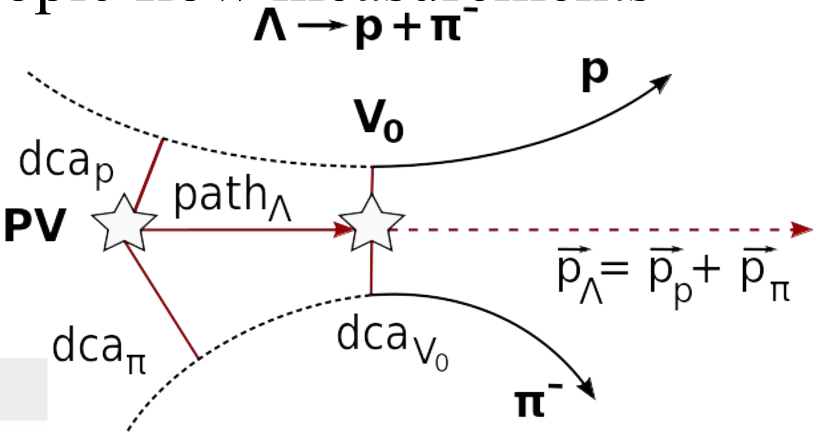


- 10M events
- 5 Λ in each event

Λ hyperon reconstruction and anisotropic flow measurements

1. Centrality determination and track selection
2. Building Λ with p π^- pairs
3. Applying topological selection cuts
4. Fitting the m_{inv} distributions and $v_n(m_{inv})$

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

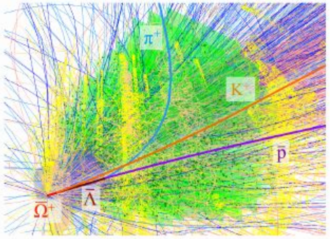


- PV — primary vertex
- V_0 — vertex of hyperon decay
- dca — distance of closest approach
- path — decay length

KFParticle formalism

Particles in heavy-ion collision:

STAR ALICE CBM



KFParticle:

- developed for complete reconstruction of short-lived particles with their P, E, m, $c\tau$, L, Y

Main benefits:

- based on the Kalman filter mathematics
- idependent in sense of experimental setup (collider, fixed target)
- allows one reconstruction of decay chains (cascades)
- daughter and mother particles are described and considered the same way
- daughter particles are added to the mother particle independently

Selection criteria

- **Event selection:**
  - Centrality based on the impact parameter
- **Track selection:**
  - $N_{hits} > 10$
  - p/π^- selection based on charge
  - **lambda candidates selection:**
    - dca < 1 cm
    - L > 2.5 cm
    - L/dL > 20
    - $\chi^2_{geo} < 100$
    - $\chi^2_{topo} < 100$
    - $\chi^2(p) > 60$
    - $\chi^2(\pi^-) > 200$

Flow vectors

From momentum of each measured particle define a u_n-vector in transverse plane:

$$u_n = e^{in\phi}$$

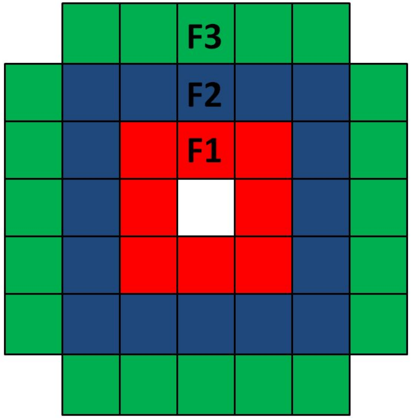
where φ is the azimuthal angle

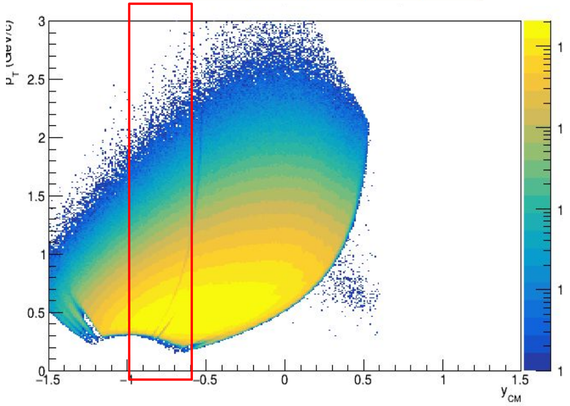
Sum over a group of u_n-vectors in one event forms Q_n-vector:

$$Q_n = \frac{\sum_{k=1}^{N} w_n^k u_n^k}{\sum_{k=1}^{N} w_n^k} = |Q_n| e^{in\Psi_n^{EP}}$$

Ψ_n^{EP} is the event plane angle

FHCal module rings as subevents





Additional subevent from tracks not pointing at FHCal:
Tp: p; -1.0<y<-0.6;

Flow methods for v_n calculation

Tested in HADES:

M Mamaev et al 2020 PPNuclei 53, 277–281
M Mamaev et al 2020 J. Phys.: Conf. Ser. 1690 012122

Scalar product (SP) method:

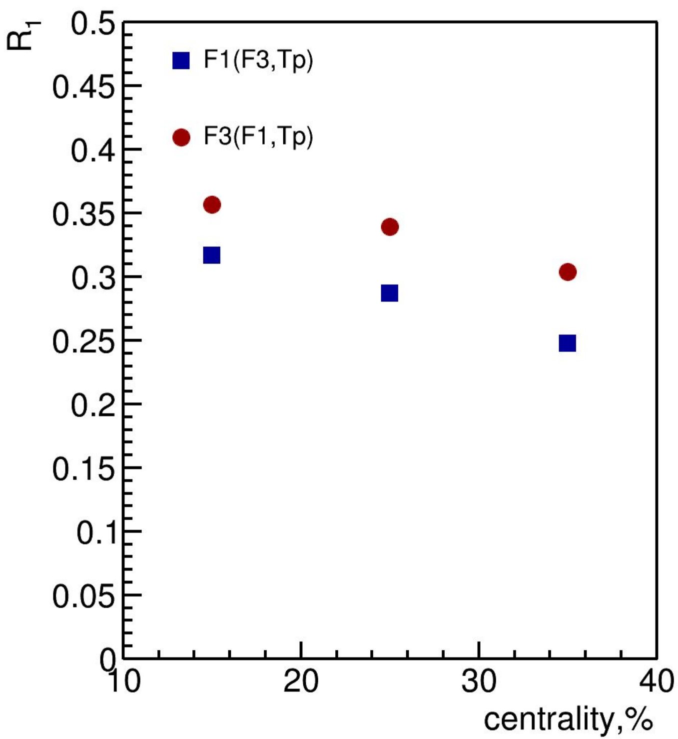
$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad v_2 = \frac{\langle u_2 Q_1^{F1} Q_1^{F3} \rangle}{R_1^{F1} R_1^{F3}}$$

Where R_1 is the resolution correction factor

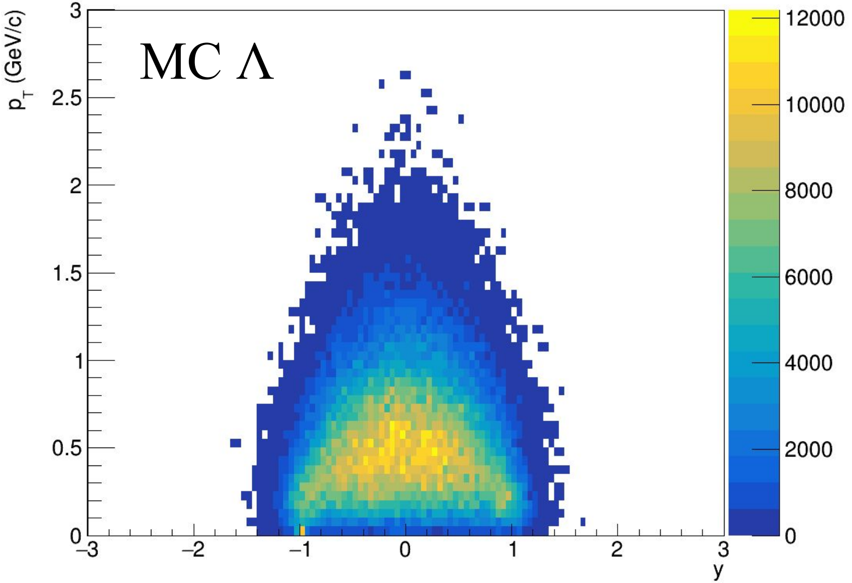
$$R_1^{F1} = \langle \cos(\Psi_1^{F1} - \Psi_1^{RP}) \rangle$$

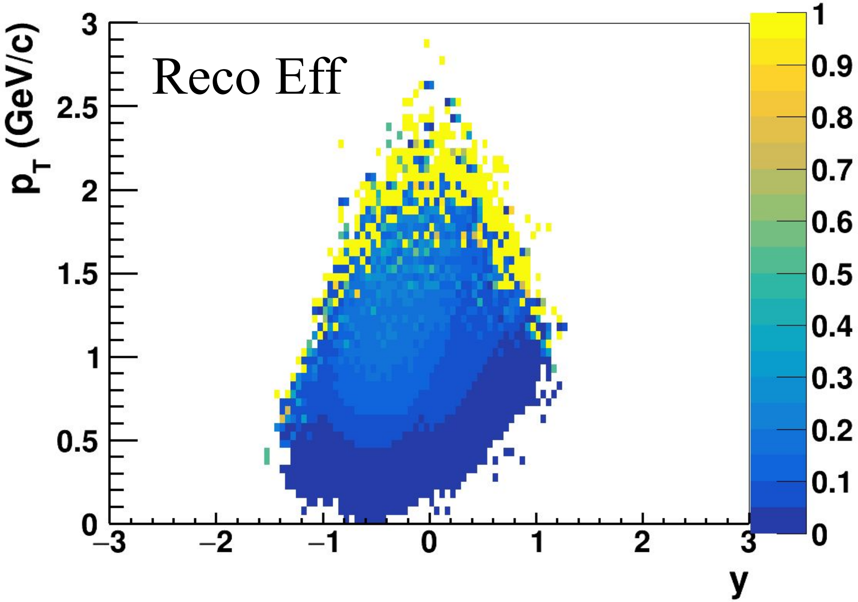
Symbol "F1(F3,Tp)" means R_1 calculated via (3S resolution):

$$R_1^{F1(F3,Tp)} = \frac{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle \langle Q_1^{F1} Q_1^{Tp} \rangle}}{\sqrt{\langle Q_1^{F3} Q_1^{Tp} \rangle}}$$



Λ hyperon reconstruction efficiency

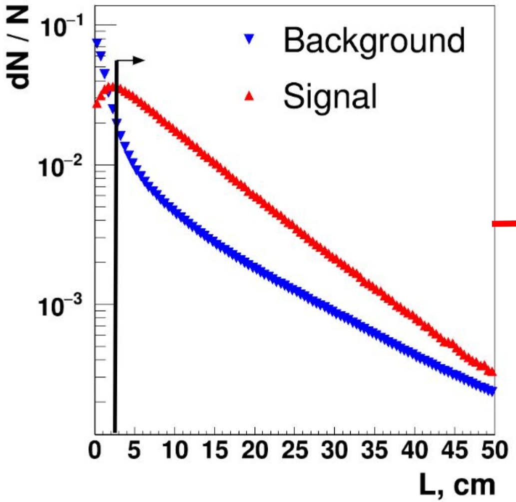




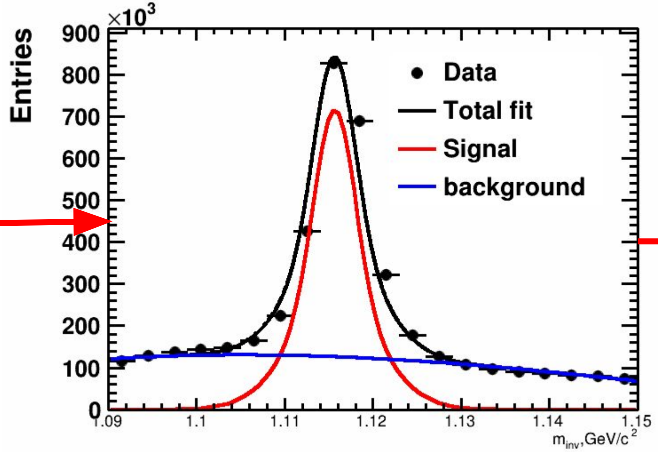
MPD-FXT acceptance covers midrapidity for Λ reconstruction in CM, that gives the opportunity for collective flow measurements

Invariant mass fit method

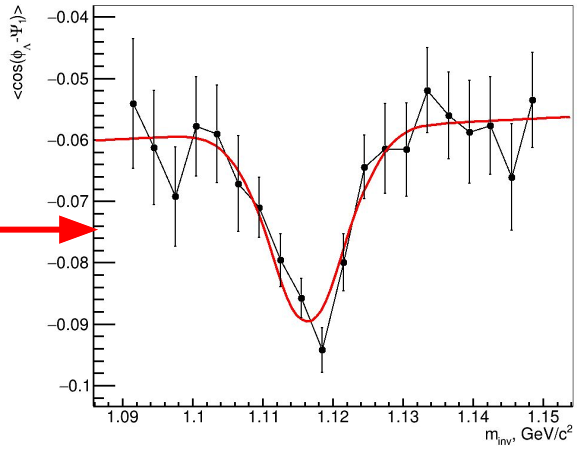
$$v_n^{SB}(m_{inv}, p_T) = v_n^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_n^B(m_{inv}, p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$



Selection



m_{inv} fit



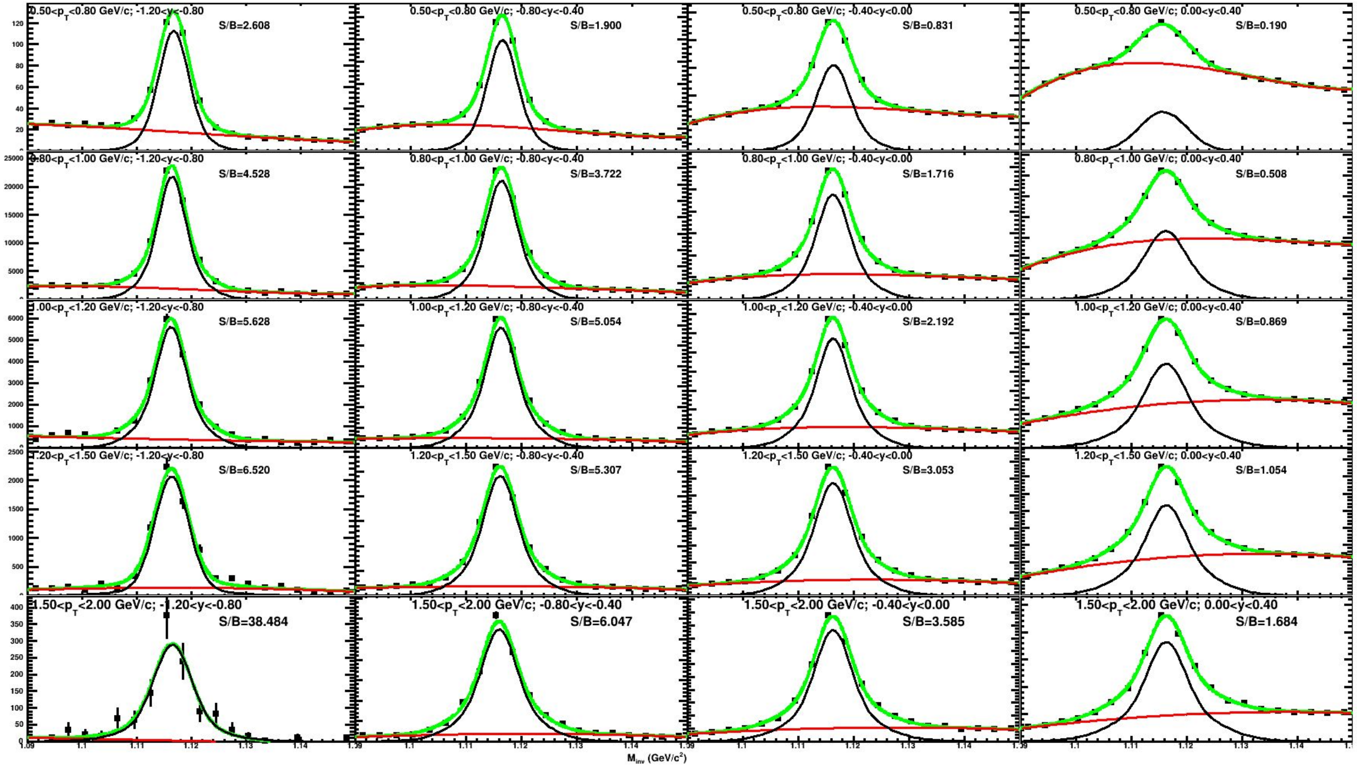
$v_n(m_{inv})$ fit

Iterative procedure of finding relevant values of topological selection cryteria, then extracting the S/B and v_n

Fitting the m_{inv} distributions in p_T-y bins

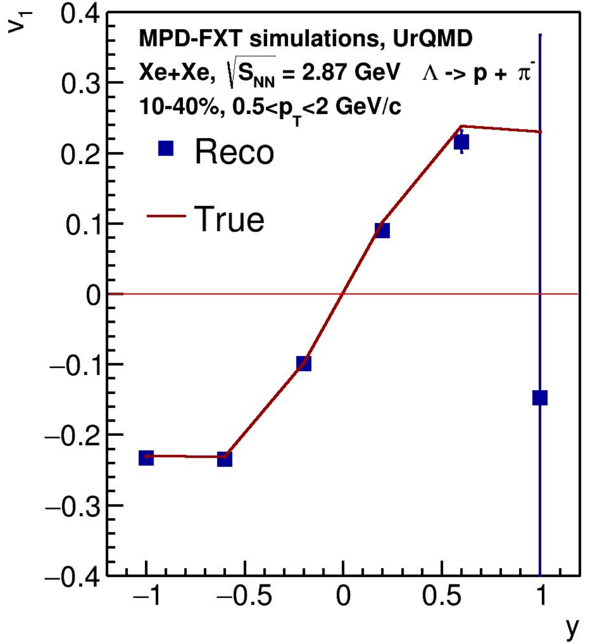
Y

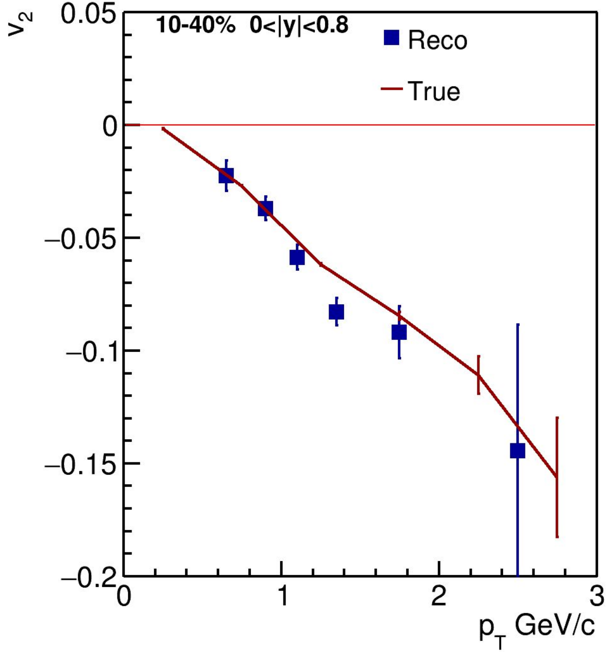
p_T



Robust fit results in all p_T-y intervals

v_1 and v_2 of Λ hyperons for Xe+Xe at E_{kin}=2.5 AGeV for MPD-FXT





Full scale reconstruction shows reasonable agreement with simulated data

Summary

- Performance study for flow measurements of Λ hyperons for Xe+Xe at E_{kin}=2.5 AGeV with UrQMD at MPD-FXT is provided
- Invariant mass fit method for reconstructed data show an agreement with simulated data
- Enhanced production with UniGen afterburner gives huge increase in statistics w/o affecting physical results

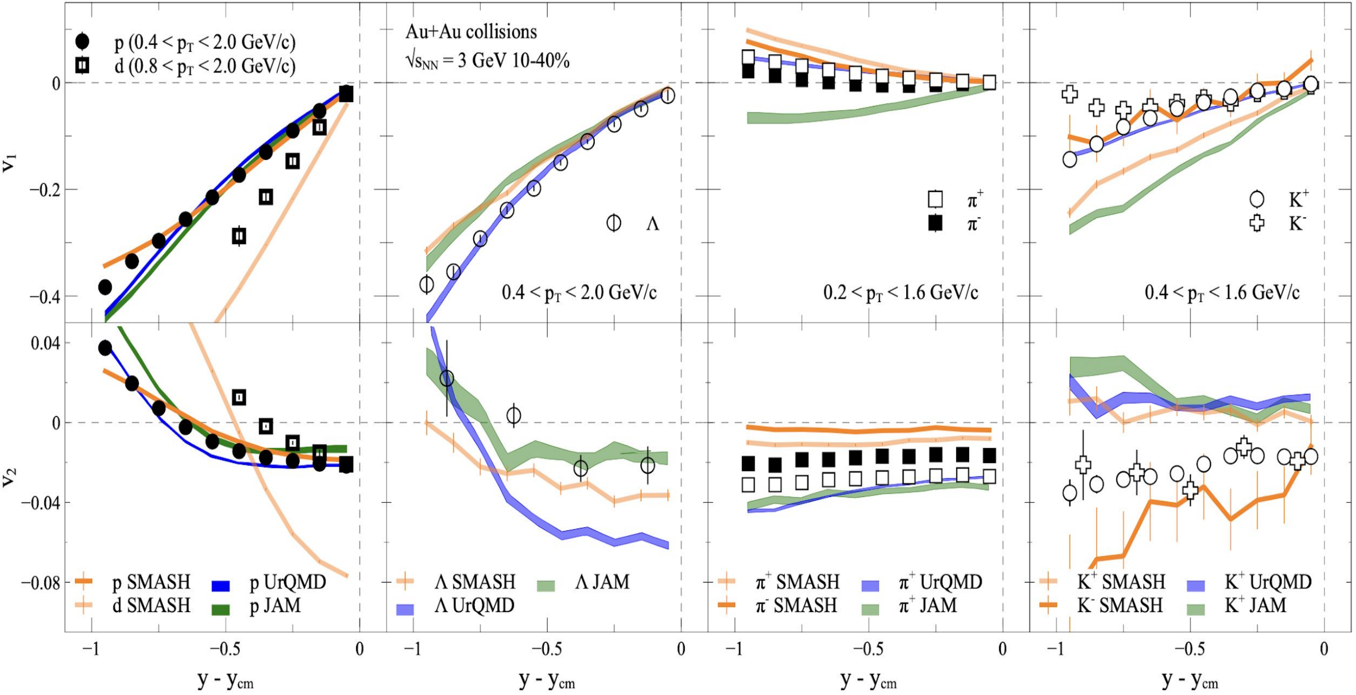
Outlook

- Refine reconstruction and selection procedures
- Check the effect of enhanced statistics on the other observables
- Xe+W at E_{kin}=2.5 AGeV analysis as the most probable system in the first MPD-FXT run

BACKUP

$v_{1,2}(y)$ in Au+Au $\sqrt{s_{NN}}$=3 GeV: model vs. STAR data

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080

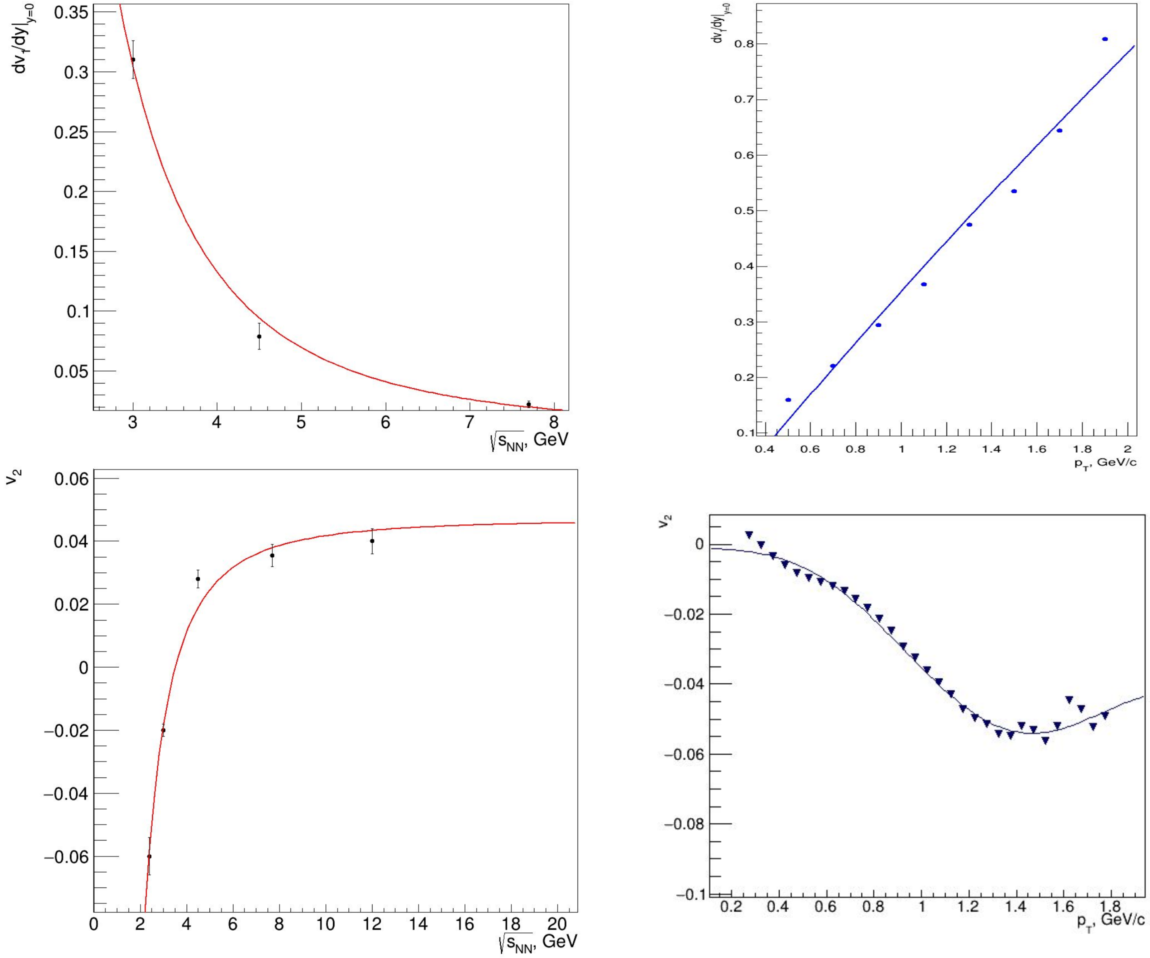


Model description of v_n:

- Good overall agreement for v_n of protons
- v_n of light nuclei is not described
- v_n of Λ is not well described
  - nucleon-hyperon and hyperon-hyperon interactions
- Light mesons (π,K) are not described
  - No mean-field for mesons

Models have a huge room for improvement in terms of describing v_n

Realistic v_1, v_2 parameterization



Existing exp data was used for parameterization, then extrapolated to our energy