Anisotropic flow measurements of Λ hyperons: performance study for MPD and BM@N experiments at NICA energies

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Anisotropic transverse flow

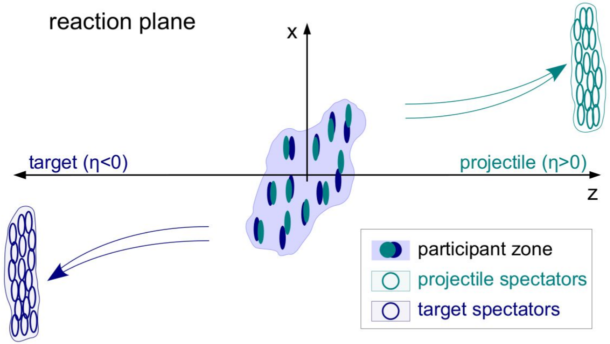
Spatial asymmetry of energy distribution at the initial state is transformed, through the strong interaction, into momentum anisotropy of the produced particles.

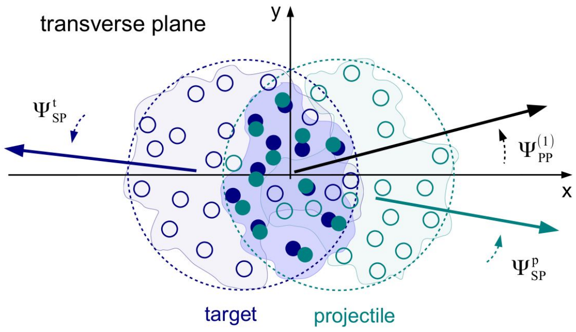
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi_{RP}))\right)$$

$\Downarrow$

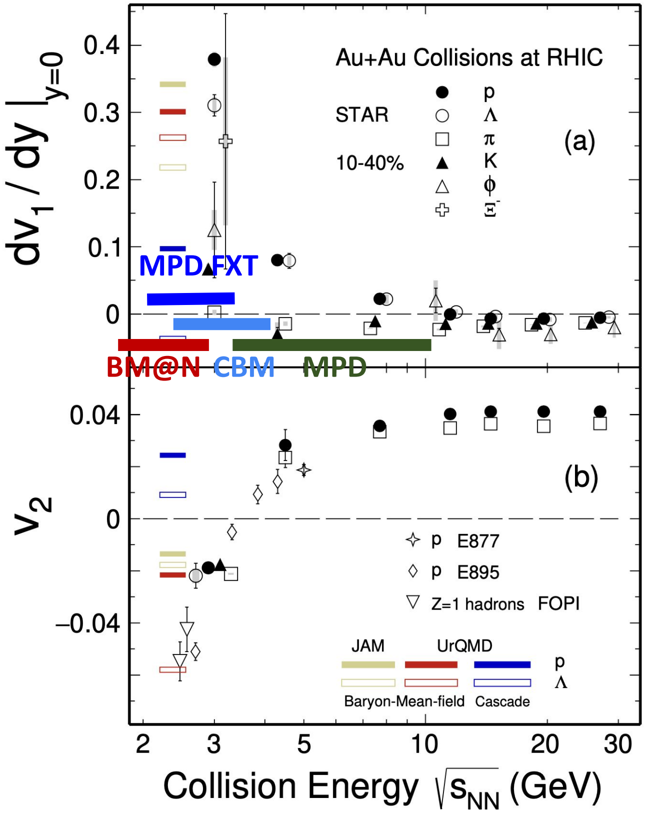
$$v_n = \langle \cos(n(\phi-\Psi_{RP}))\rangle$$

In the experiment reaction plane angle Ψ_{RP} can be approximated by participant Ψ_{PP} or spectator Ψ_{SP} symmetry planes.





Anisotropic transverse flow in heavy-ion collisions at Nuclotron-NICA energies



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).

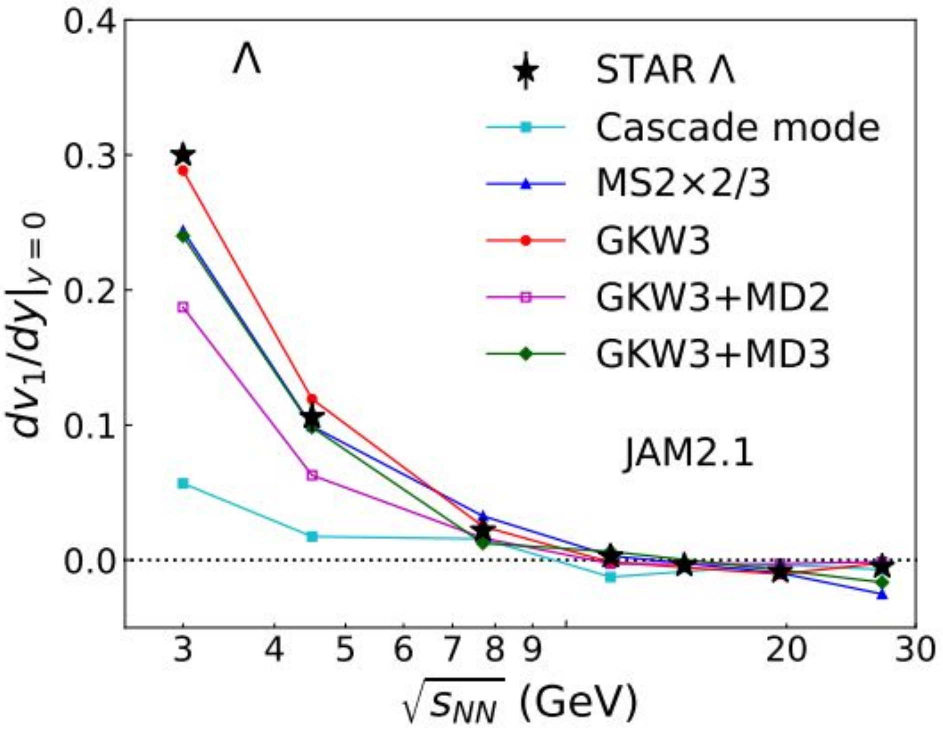
Differential flow measurements $v_n(\sqrt{s_{NN}}$, centrality, pid, p_T, y) will help to study:

- effects of collective (radial) expansion on anisotropic flow
- interaction between collision spectators and produced matter
- baryon number transport

Several experiments (MPD, BM@N, STAR FXT, CBM, HADES, NA61/SHINE) aim to study properties of the strongly-interacted matter in this energy region.

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

Aims to study flow of Λ



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

- Λ potential is important to explanation of existence of two-solar-mass neutron stars
- Constrained by directed flow of Λ
- Models cannot fully describe anisotropic flow for NICA energy range
- Best agreement with model includes interactions with hyperons

MPD experiment at NICA

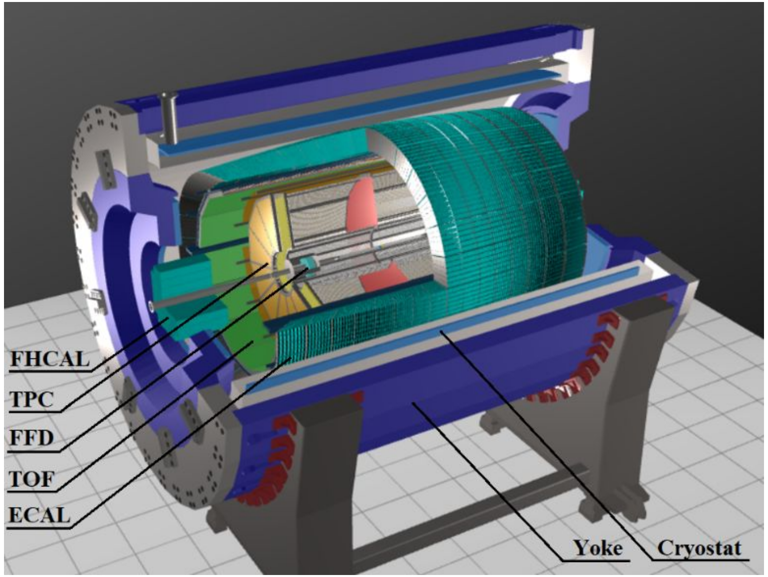
Main subsystems at Stage-I:

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):

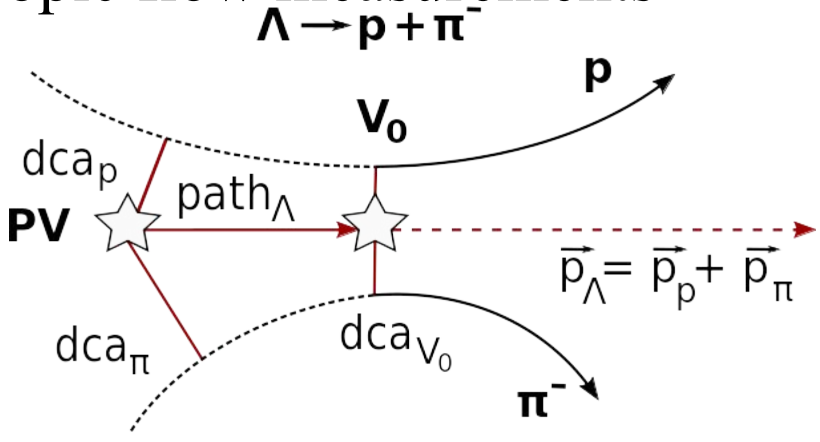
- MPD-CLD: Xe/Bi+Xe/Bi at $\sqrt{s_{NN}} \sim 7$ GeV
- MPD-FXT: Xe/Bi +W at $\sqrt{s_{NN}} \sim 3$ GeV

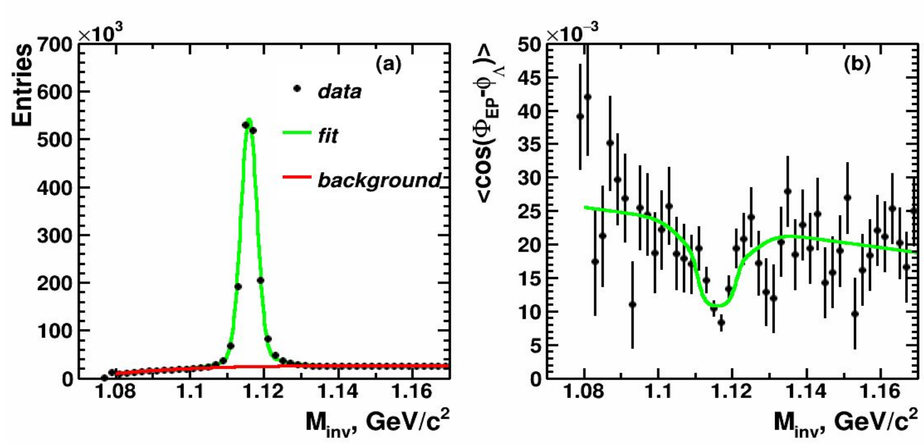
Model → Simulation of MPD setup → GEANT4 → Realistic data reconstruction → Obtaining results

Λ hyperon reconstruction and anisotropic flow measurements

1. Centrality and track selection
2. Build Λ - from p and π^-
3. Selection of Λ candidates
4. Fitting the m_{inv} distributions
5. Obtain R_n
6. Fitting v_n as a function of m_{inv}

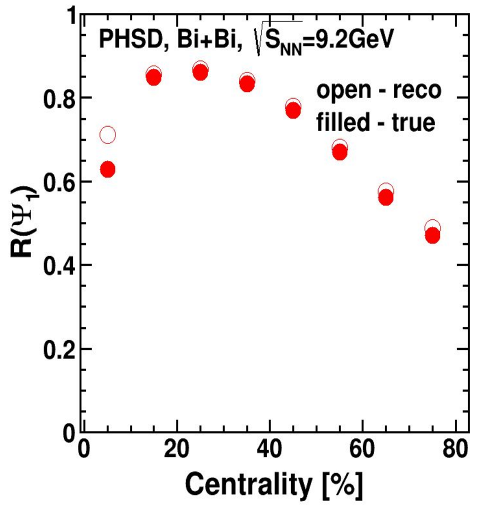
$$v_n^{SB}(m_{inv}, p_T) = v_n^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_n^B(m_{inv}, p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

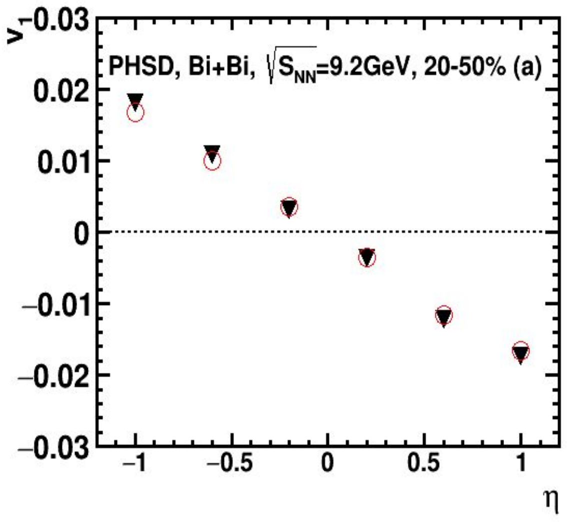


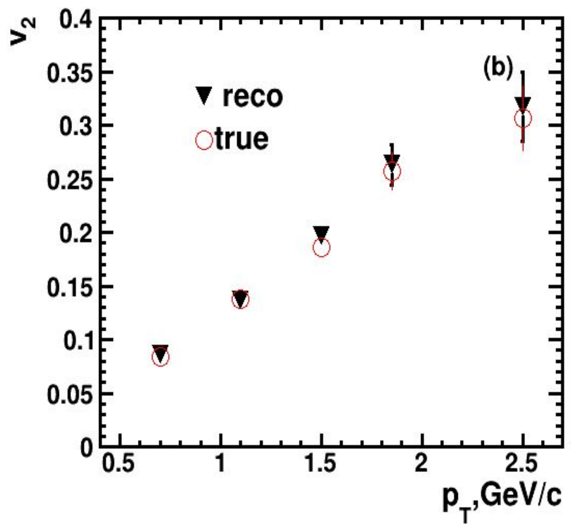


- PV — primary vertex
- V_0 — vertex of hyperon decay
- dca — distance of closest approach
- path — decay length

v_1 and v_2 of Λ hyperons for Bi+Bi at $\sqrt{S_{NN}}$=9.2 GeV with PHSD

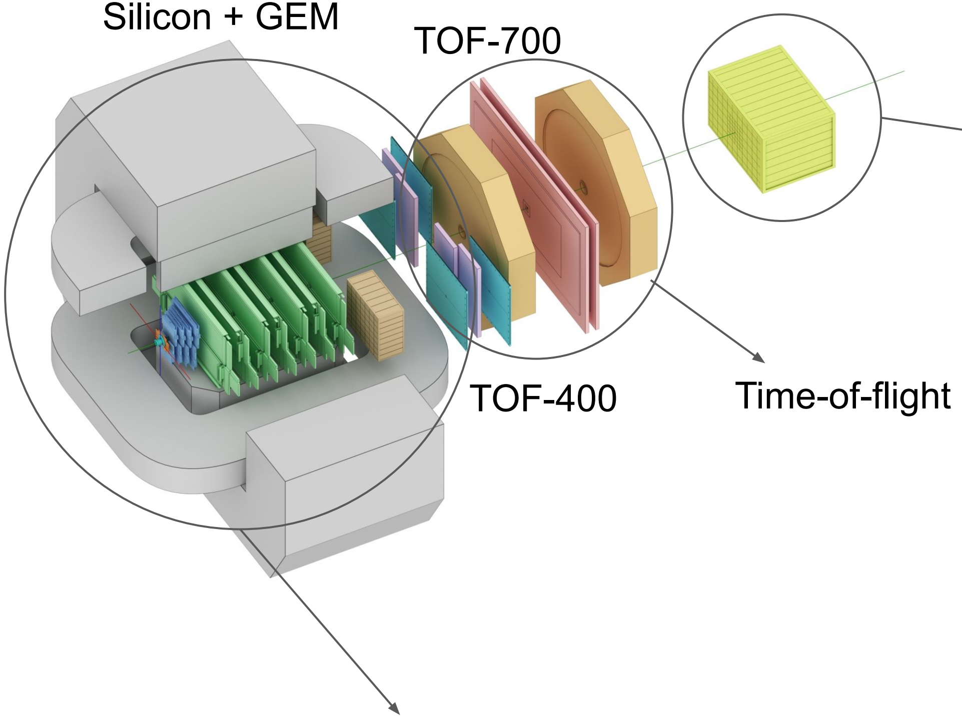


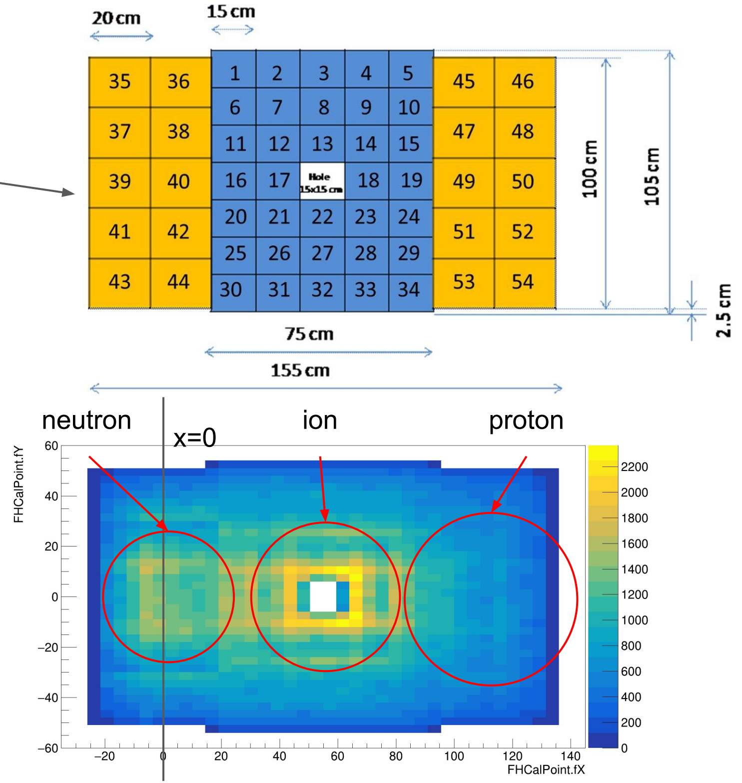




Full scale reconstruction shows reasonable agreement with simulated data

The BM@N experiment: recent Xe+Cs(I) 3.8 AGeV run





Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

Flow vectors

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

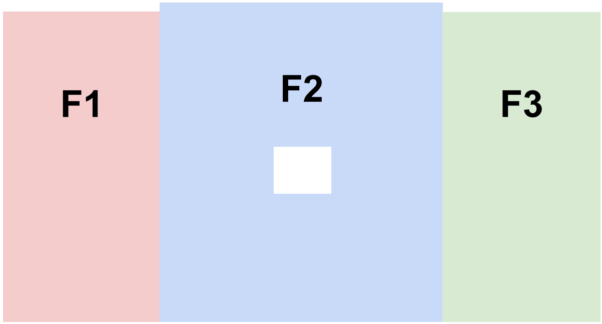
$$u_n = e^{in\phi}$$

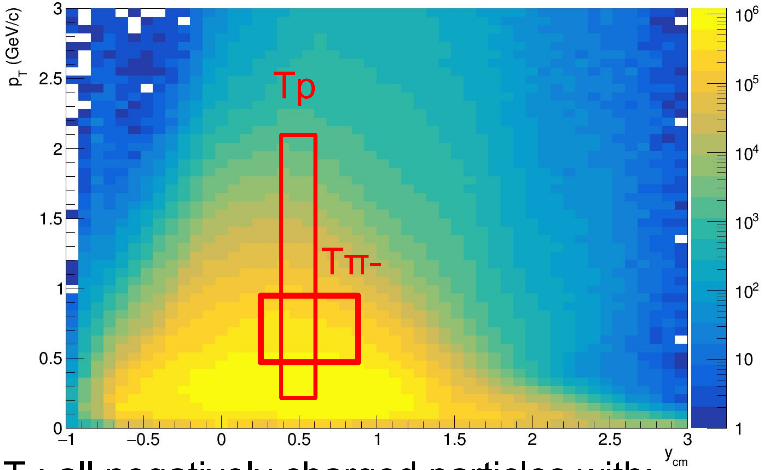
where φ is the azimuthal angle

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





T-: all negatively charged particles with:

- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

T+: all positively charged particles with:

- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

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:

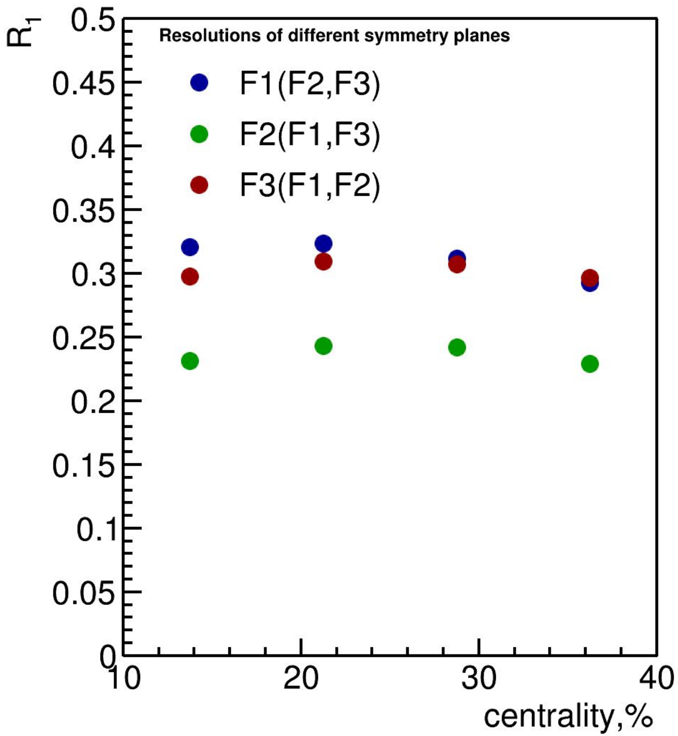
$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad v_2 = \frac{\langle u_2 Q_1^{F1} Q_1^{F3} \rangle}{R_1^{F1} R_1^{F3}}$$

Where R_1 is the resolution correction factor

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

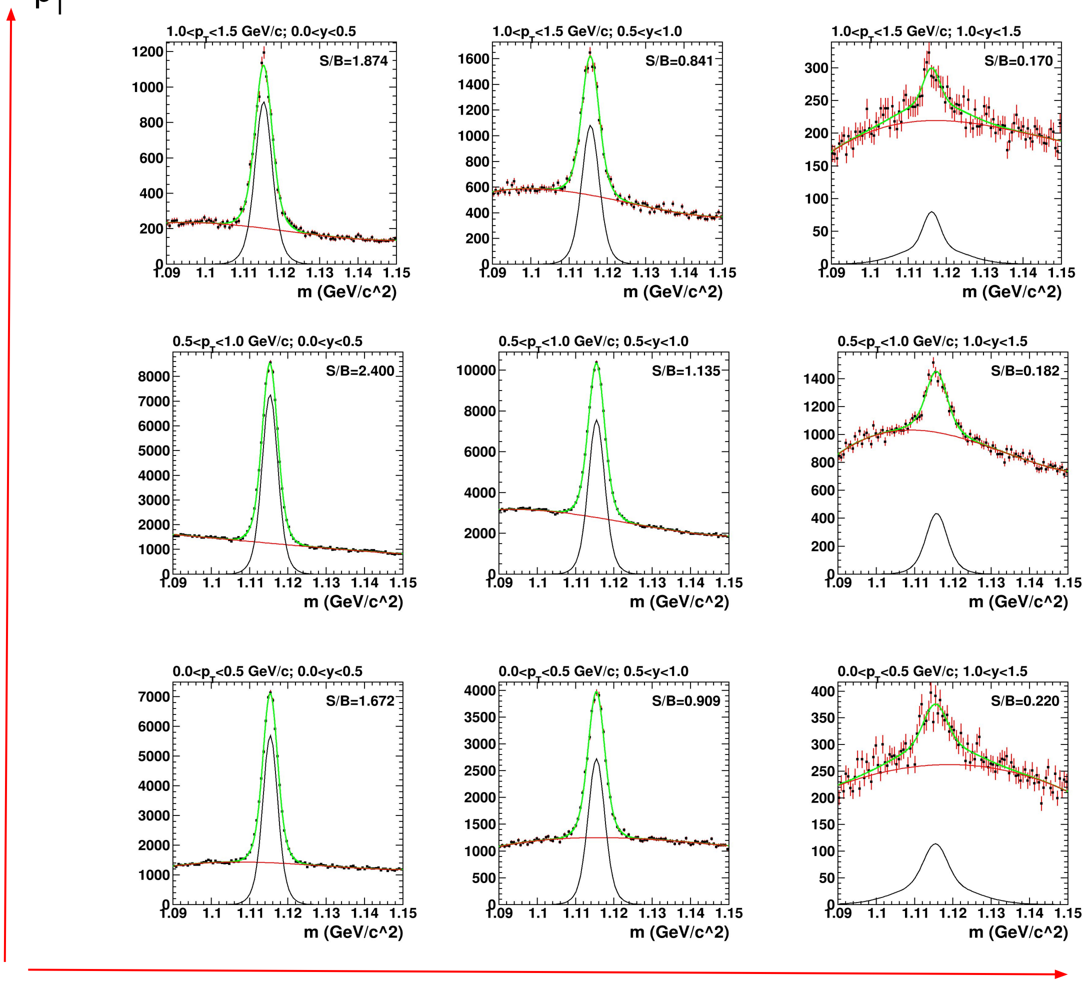
Symbol "F2(F1,F3)" means R_1 calculated via (3S resolution):

$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

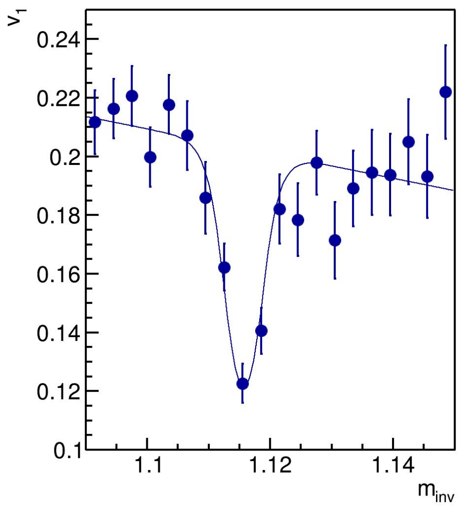


Corrections for non-uniform acceptance - see slide №14

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



Directed flow of Λ hyperons in Xe+Cs(I) collisions at 3.8 AGeV



$$v_1^{SB}(m_{inv}, p_T) = v_1^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_1^B(m_{inv}, p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

Summary

- Performance study for flow measurements of Λ hyperons for Bi+Bi at $\sqrt{S_{NN}}$=9.2 GeV with PHSD at MPD experiment is provided
  - Invariant mass fit method for reconstructed data show an agreement with simulated data
- Application of invariant mass fit method for directed flow measurements at recent BM@N Xe+Cs(I) experiment run is shown
  - Further analysis is under work

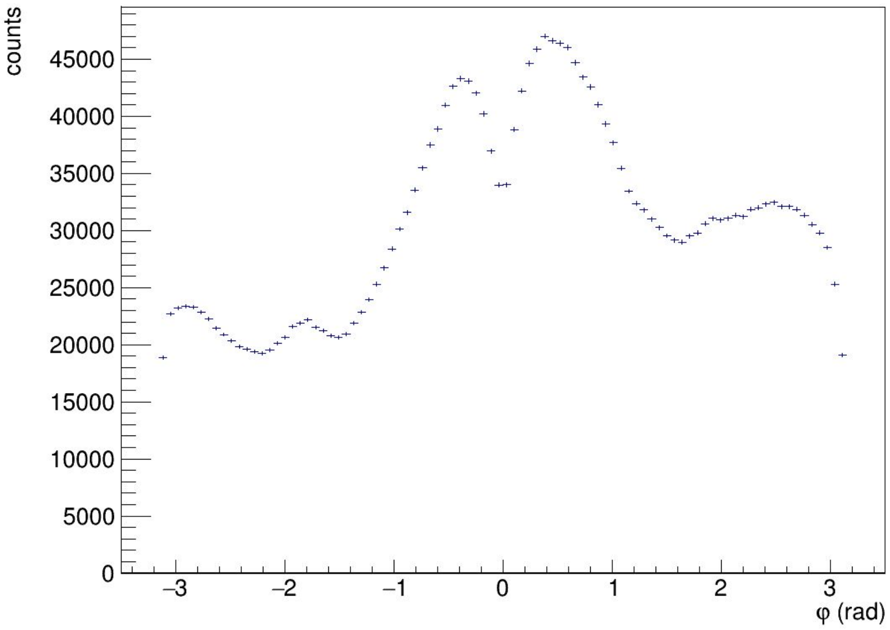
Outlook

- Perform analysis with identified particles
- Further efficiency study
- Investigation of “feed-down” effect and momentum conservation
- Comparison results with existing data from other experiments

BACKUP

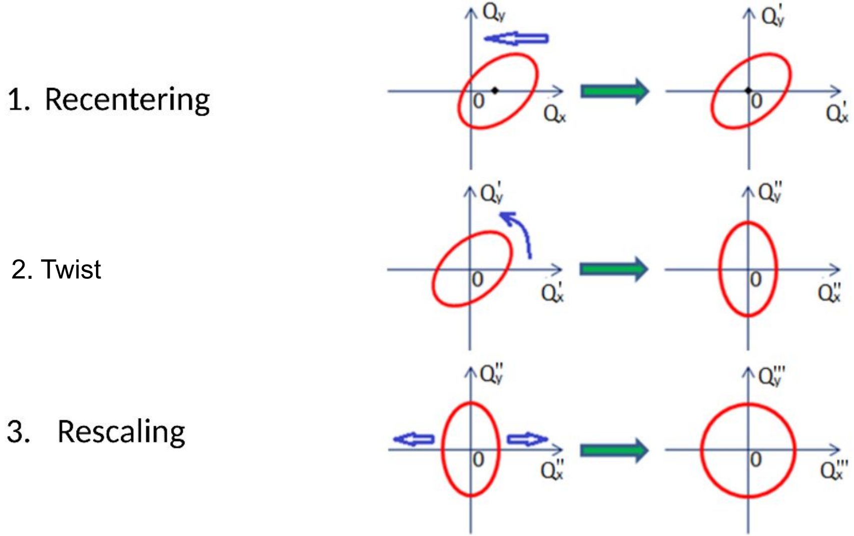
Corrections on acceptance

φ yield of Λ candidates

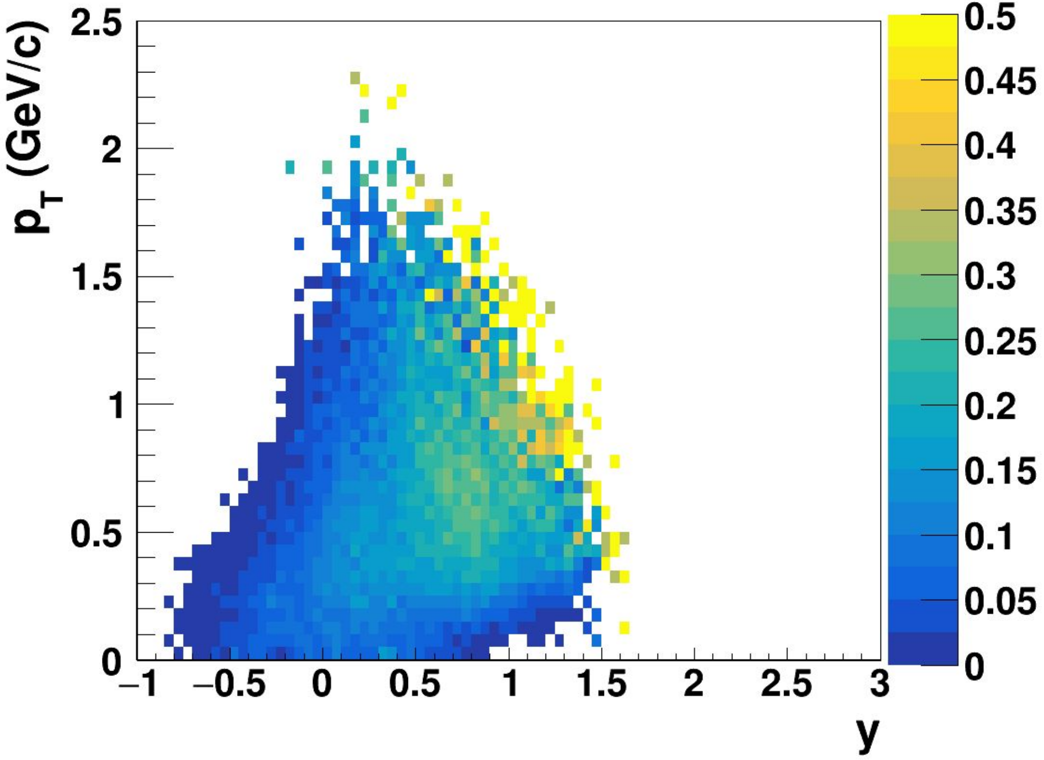


Non-uniform acceptance - corrections are required

Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)



Efficiency map of Λ hyperons

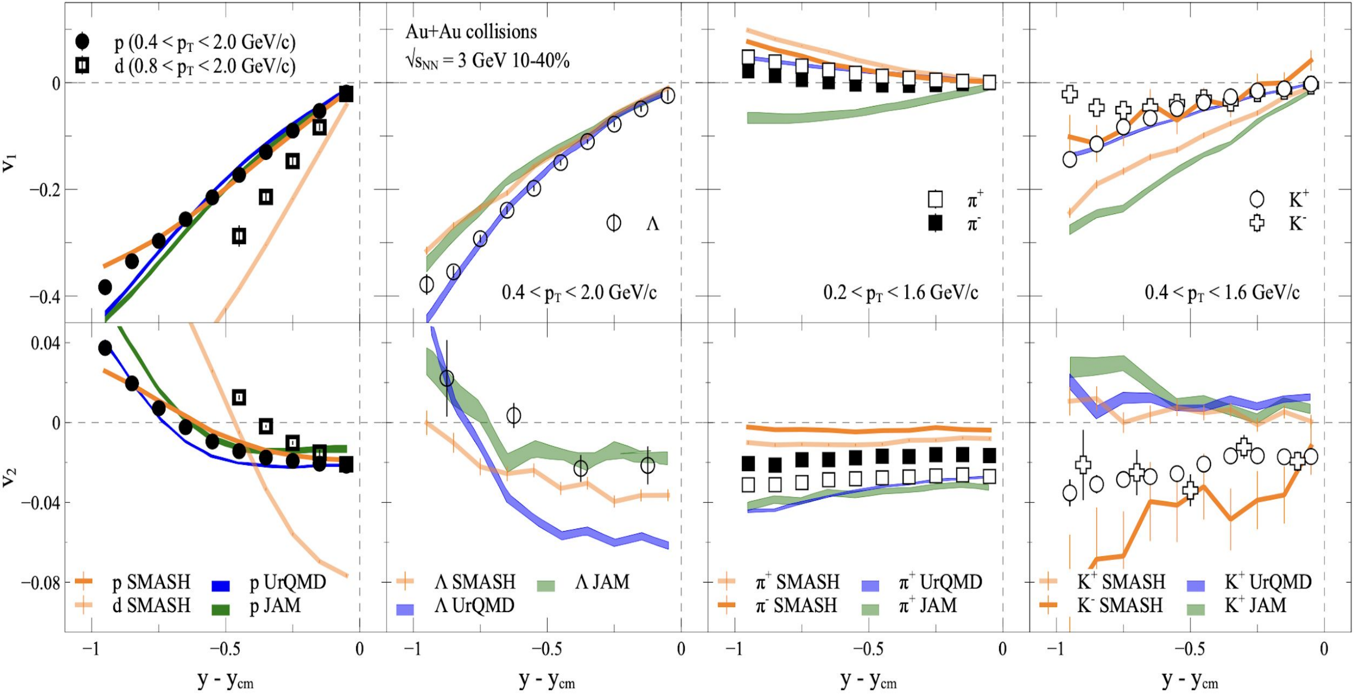


For reconstruction efficiency 15 M events of simulation data with JAM model are used

Very limited p_T-rapidity coverage

$v_{1,2}(y)$ 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