Status of analysis of flow of Lambda hyperons in Xe+Cs(I) run

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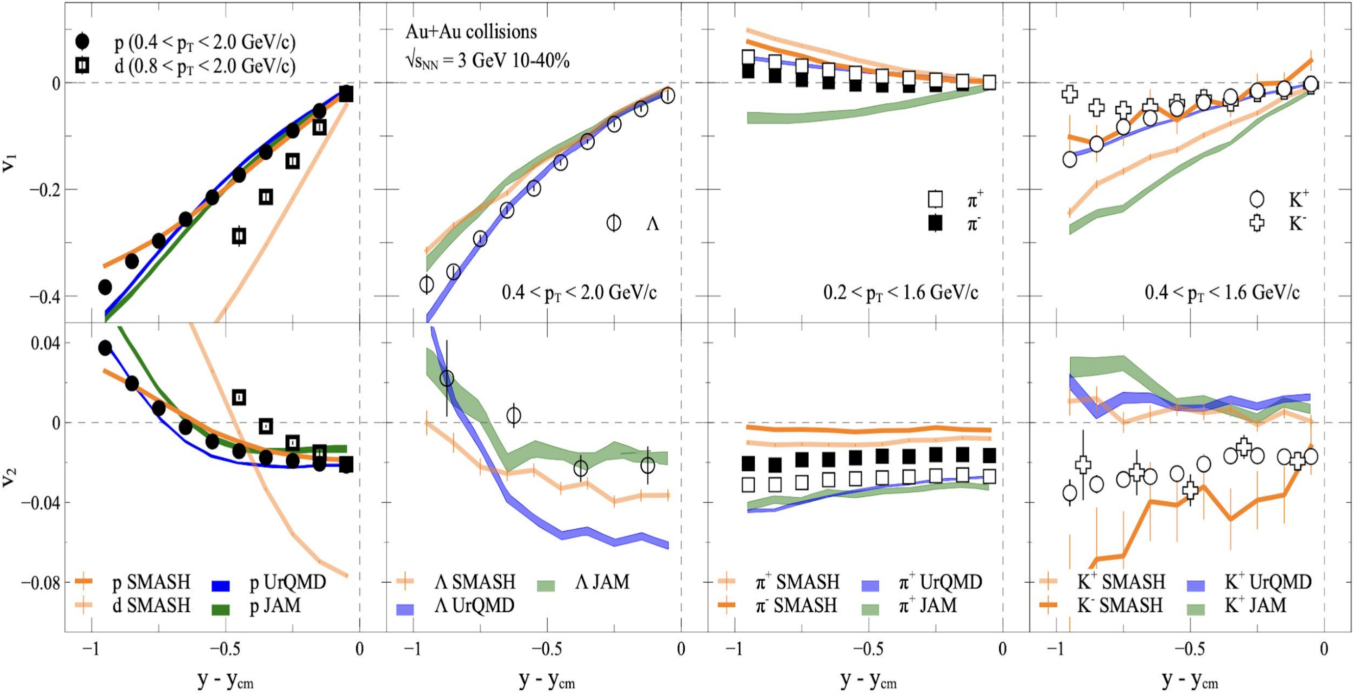
$v_{1,2}(y)$ in Au+Au $\sqrt{s_{NN}}$=3 GeV: model vs. STAR data

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

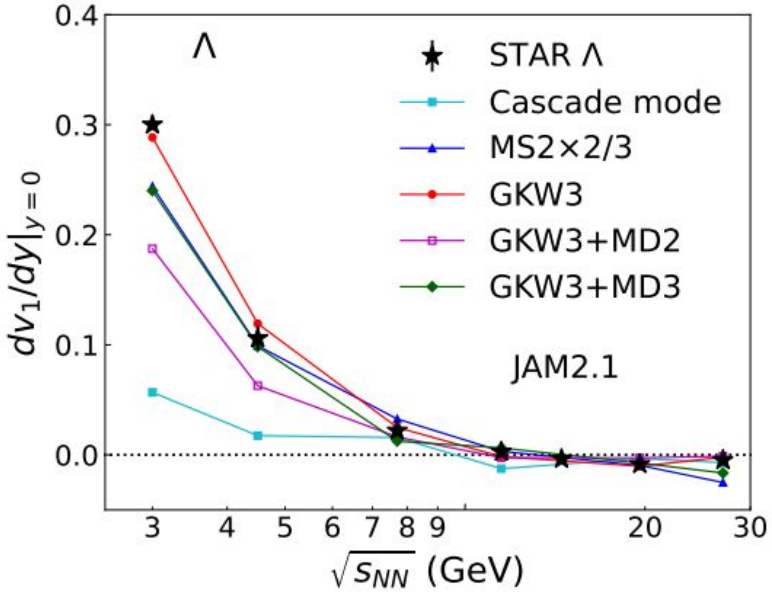


Model description of v_n:

- 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

Λ potential U_Λ



Yasushi Nara et al. *EPJ Web Conf.* 276 (2023) 01021
Yasushi Nara et al. *EPJ Web Conf.* 271 (2022) 08006
Yasushi Nara et al. *Phys.Rev.C* 106 (2022) 4, 044902

Strong repulsive Λ potential U_Λ that is predicted by Λ chiral effective field theory(**χ**EFT) may explain the existence of two-solar-mass neutron stars by suppressing Λ in dense nuclear matter by Λ-N-N three-body interactions, and directed flow of Λ is expected to constrain U_Λ.

The picture shows the dv_1/dy slope of Λ for different potentials and comparison with STAR data. MD2 and MD3 is a different momentum dependences for U_Λ, GKW3 denotes a three-body interactions of Λ. It is shown that three-body interactions in JAM model with mean-field mode gives the best agreement with STAR data, especially for lower energy.

Anisotropic transverse flow

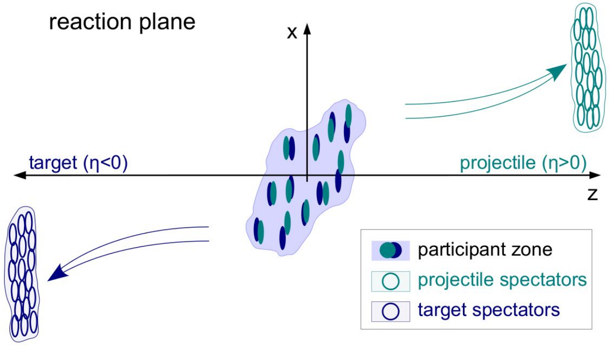
Spatial asymmetry of energy distribution at the initial state is transformed, through the strong interaction, into momentum anisotropy of the produced particles.

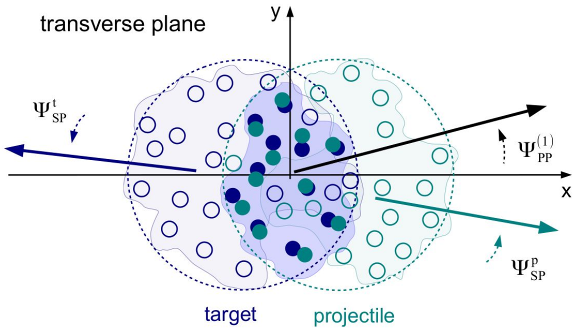
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_{RP}))\right)$$

⇩

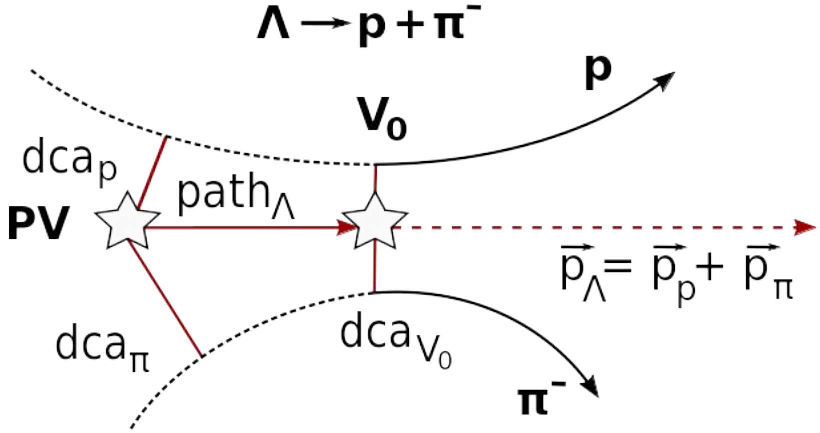
$$v_n = \langle \cos(n(\phi - \Psi_{RP}))\rangle$$

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





Λ hyperon reconstruction and directed flow measurements

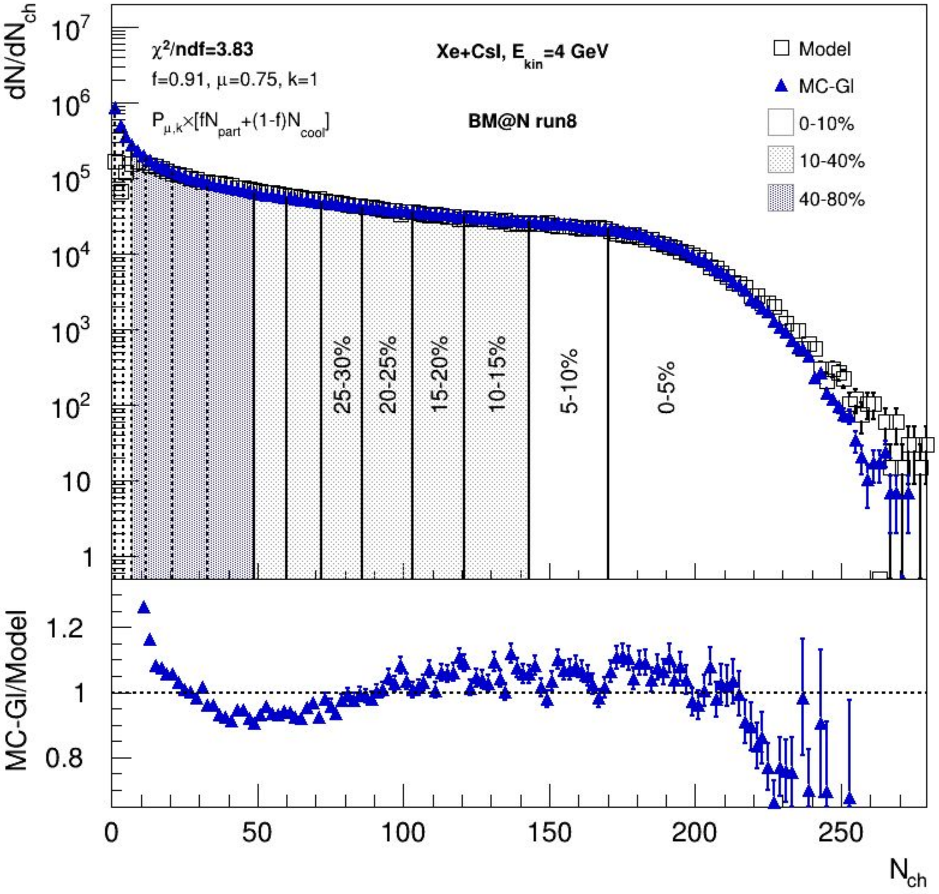


1. Centrality and track selection
2. Build Λ - positive charges as p, negative charges as π^-
3. Selection with Particle Finder software
4. Fitting the m_{inv} distributions
5. Obtain R_1
6. Fitting v_1 as a function of m_{inv}

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

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

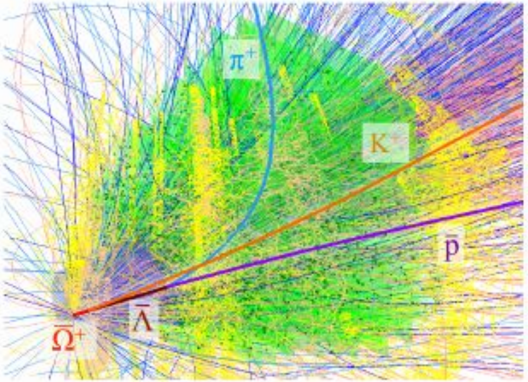
Centrality and track selection



- Entire of the recent VF production was analysed
- Event selection criteria:
  - CCT2 trigger
  - Pile-up cut
  - Number tracks for vertex > 1
- Track selection criteria:
  - Nhits > 5
  - tracks with charge>0 are protons
  - tracks with charge<0 are π^-

KFParticle formalism

Particles in heavy-ion collision:



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

Cut's dictionary

χ^2 prim(1;2)	dca_{topo}	L	L/dL	χ^2geo	χ^2topo	cos_topo
χ^2 of daughter particle to primary vertex	Distance between daughter tracks in their closest approach	Length of interpolated track from secondary to primary vertex	Distance between primary and secondary vertices divided by error	χ^2 of daughters' tracks in their closest approach	$\chi^2$of the mother's track to the primary vertex	Cosine of the angle between reconstructed mother's momentum and mother's radius vector beginning in the primary vertex
$\chi^2(p)>10$ $\chi^2(pi)>200$	$dca_{topo}<0.7$ cm	$L>1$ cm	$L/dL>6$	$\chi^2geo<30$	$\chi^2topo<40$	$cos\_topo>0.999$

Flow vectors

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

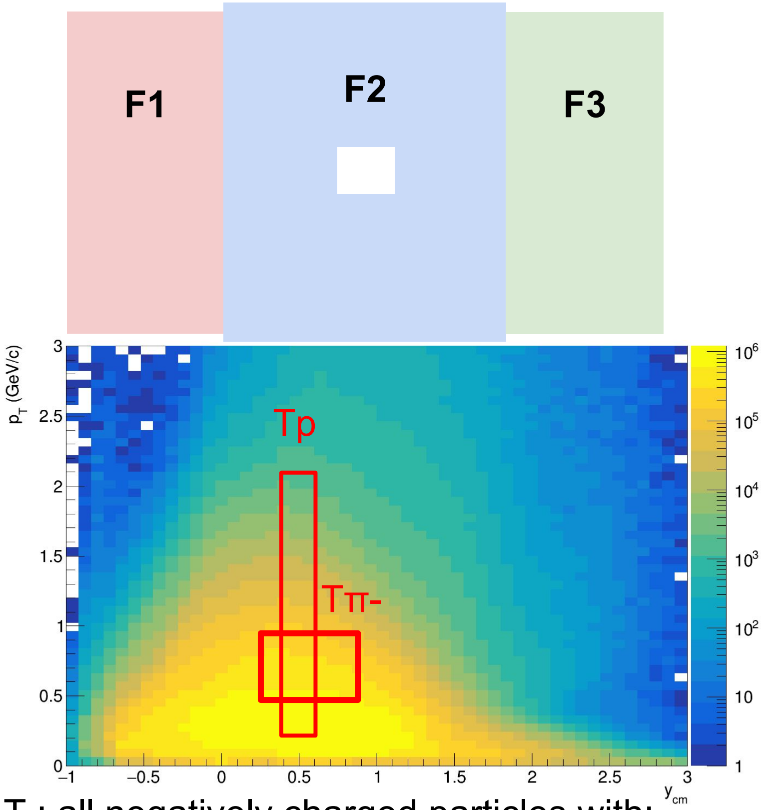
$$u_n = e^{in\phi}$$

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:

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

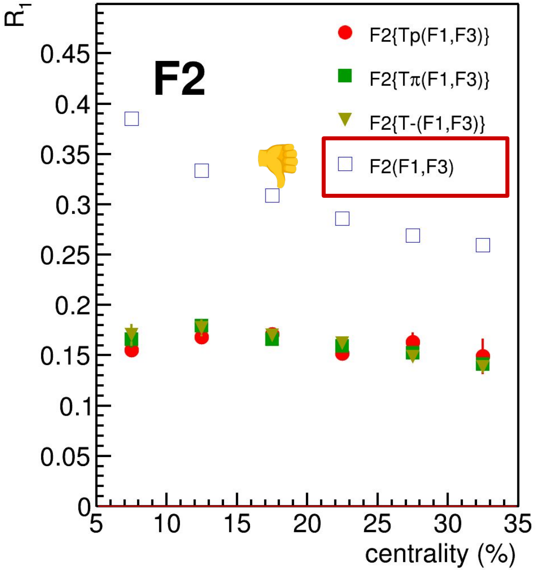
Where R_1 is the resolution correction factor

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

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

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

Method helps to eliminate non-flow
Using 2-subevents doesn't



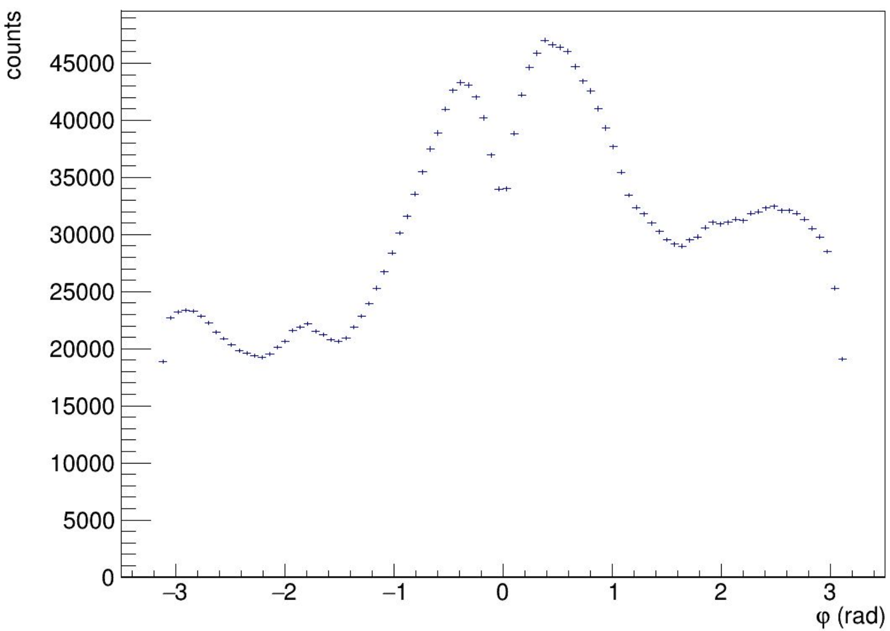
Symbol "F2{Tp}(F1,F3)" means R_1 calculated via (4S resolution):

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

<u>Originally implemented for protons, see M. Mamaev talk 08/10, 14:20</u>

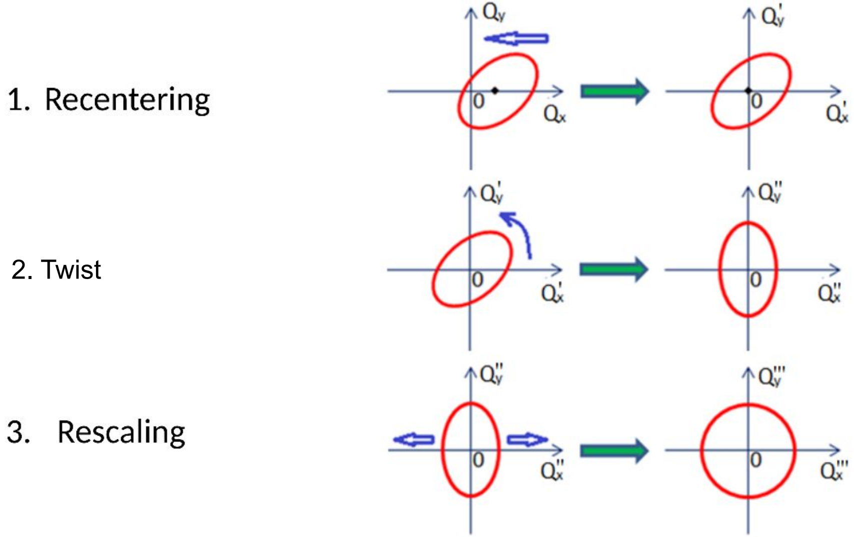
Azimuthal asymmetry of the BM@N acceptance

φ yield of Λ candidates

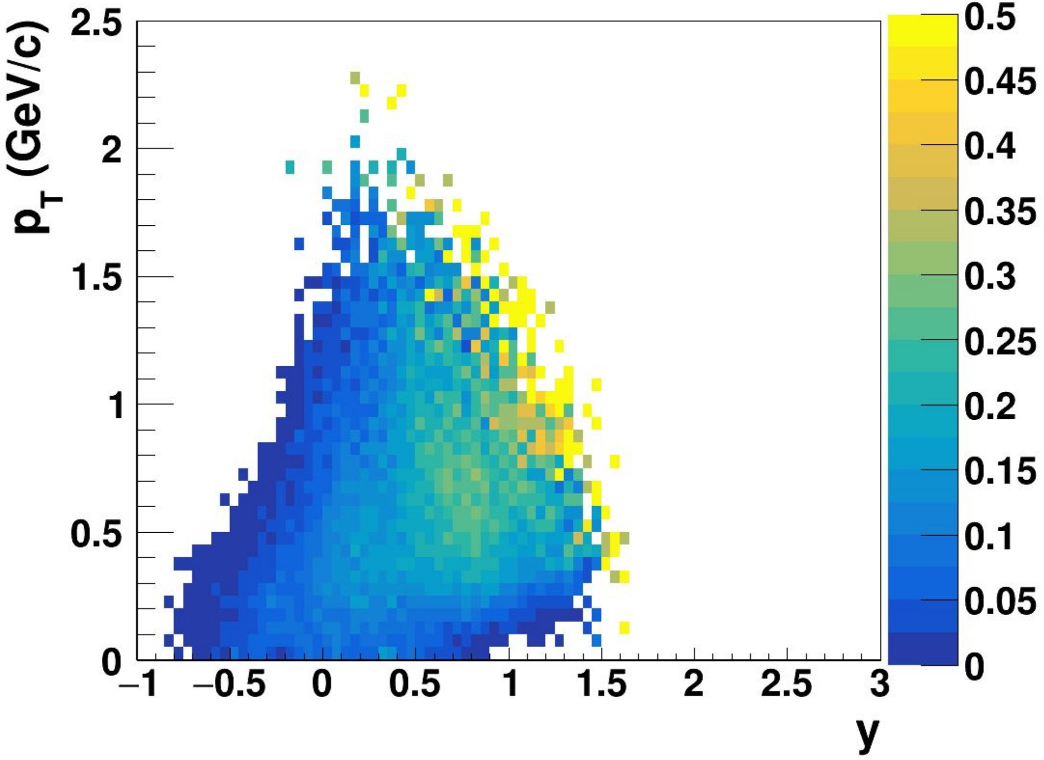


Non-uniform acceptance - corrections are required

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



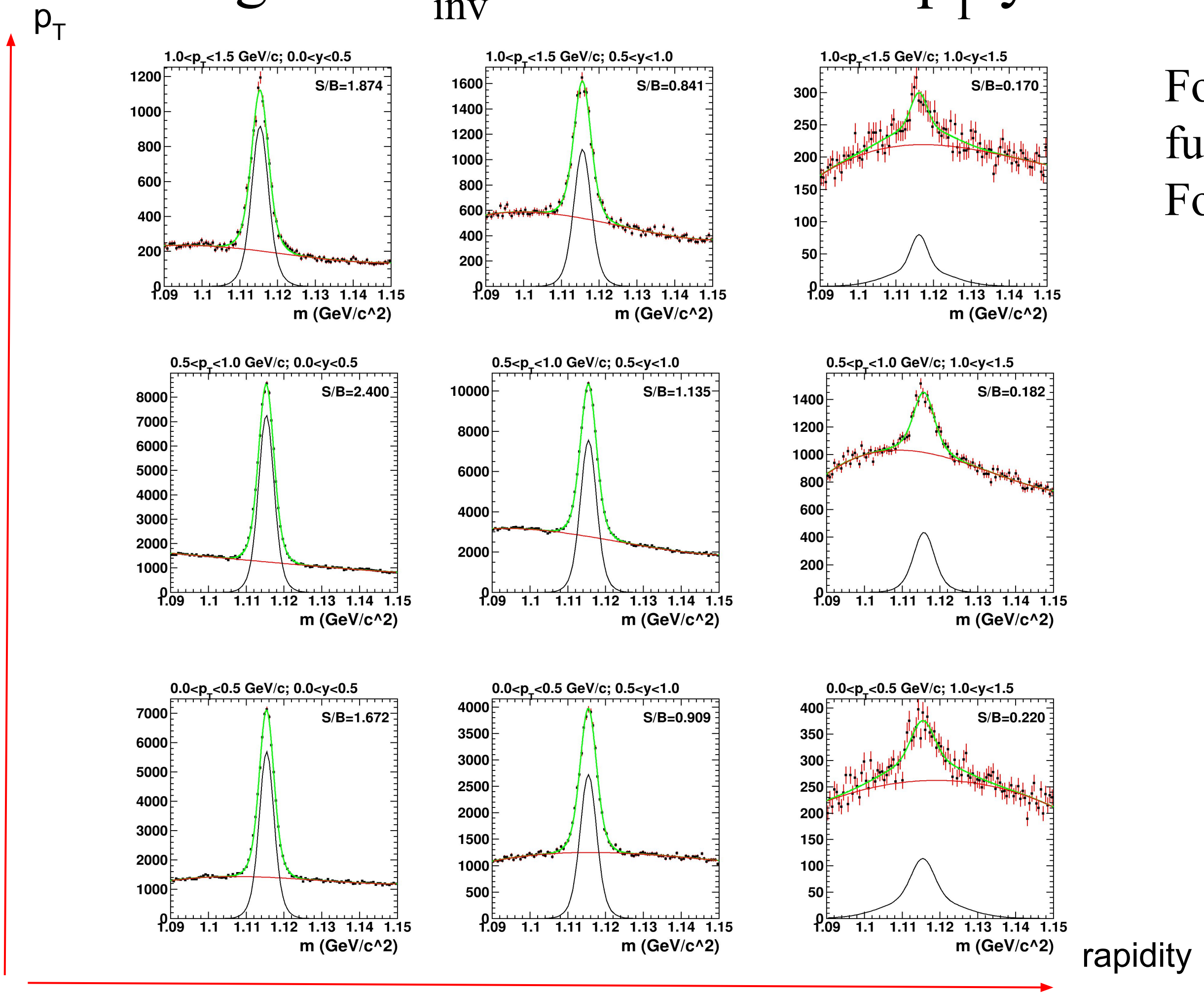
Efficiency map



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

Very limited p_T-rapidity coverage

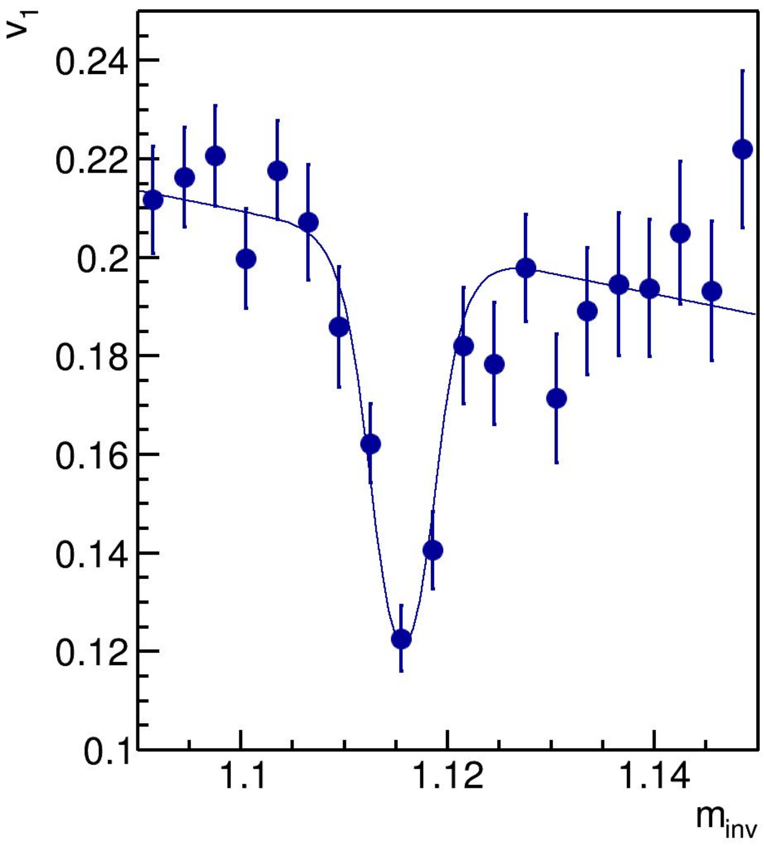
Fitting the m_{inv} distributions in p_T-y bins



For signal fit double gaussian function is used

For background fit - pol5

Fitting the m_{inv} distributions of v_1

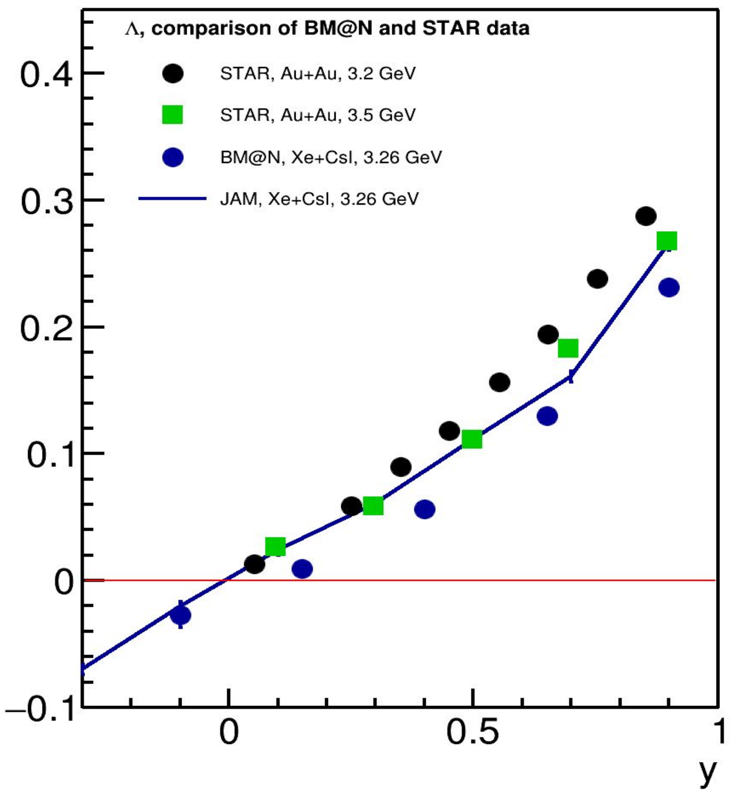


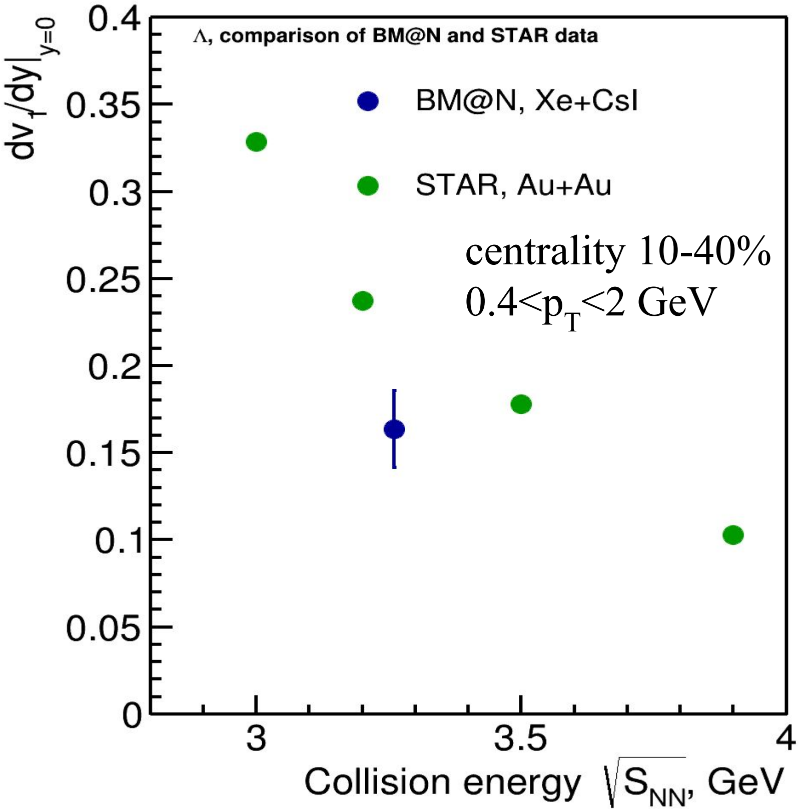
$$v_1^{SB}(m_{inv}, p_T) = v_1^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_1^B(m_{inv}, p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$

v_1^S - have to find
v_1^B - pol1

centrality: 10-40%
p_T 0.5-1 GeV/c
y_{CM} 0.4-0.6

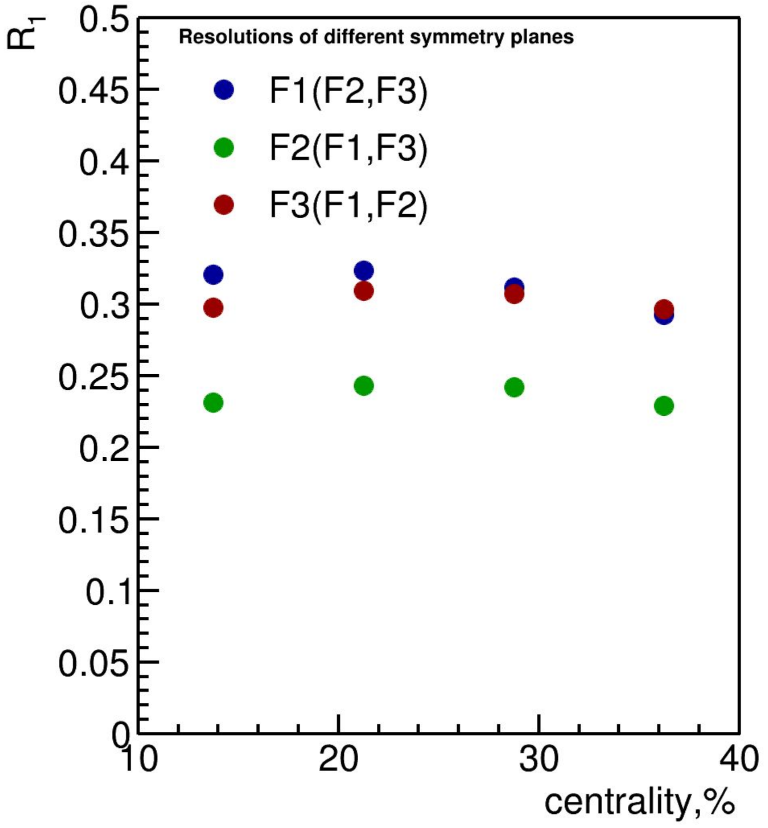
STAR- BM@N comparison + JAM

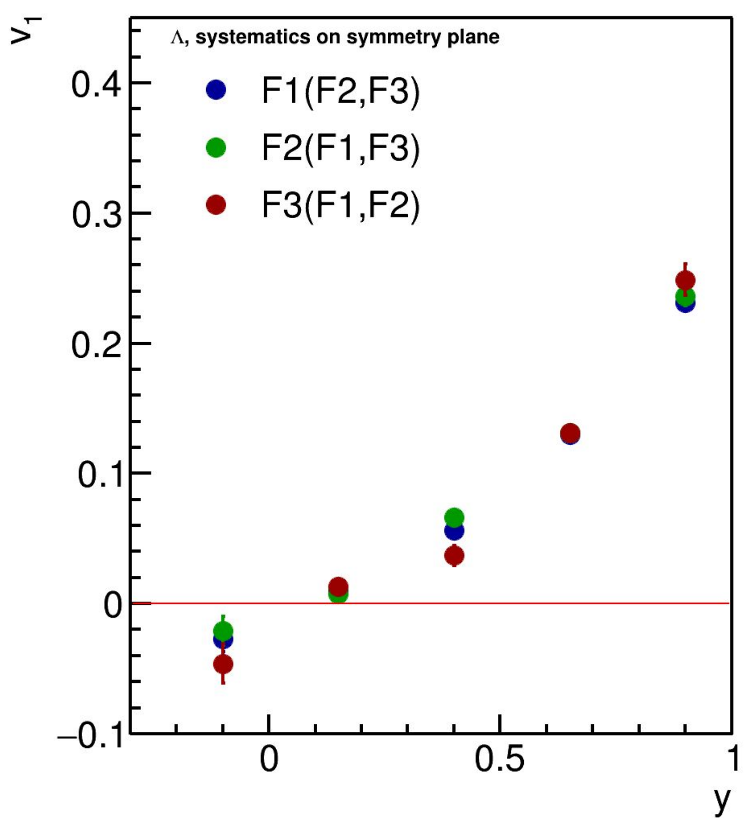




$dv_1/dy|_{y=0}$ differs from STAR data - investigation in progress

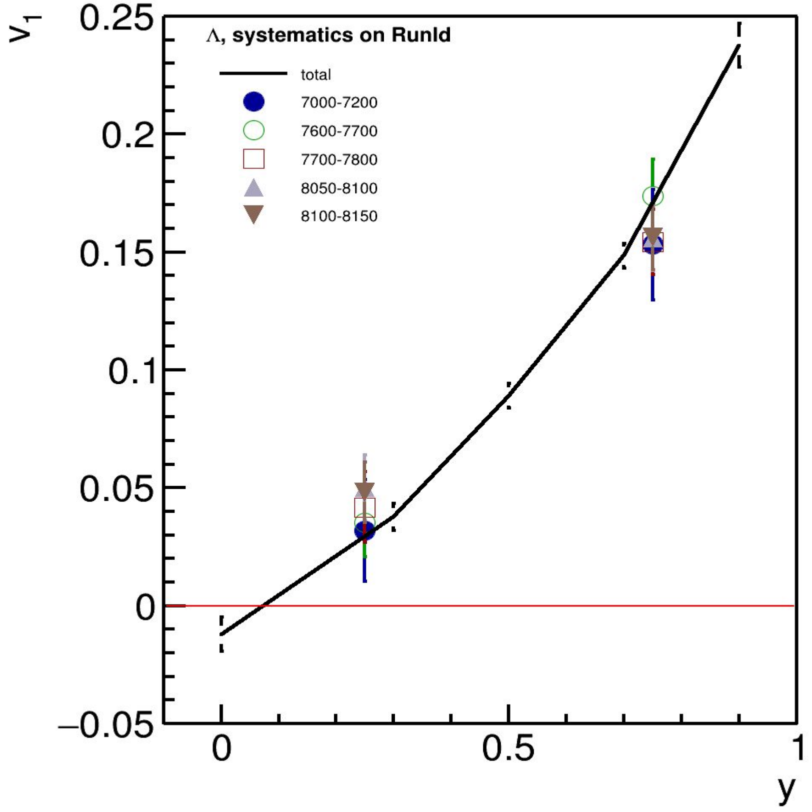
Symmetry plane resolution and systematics

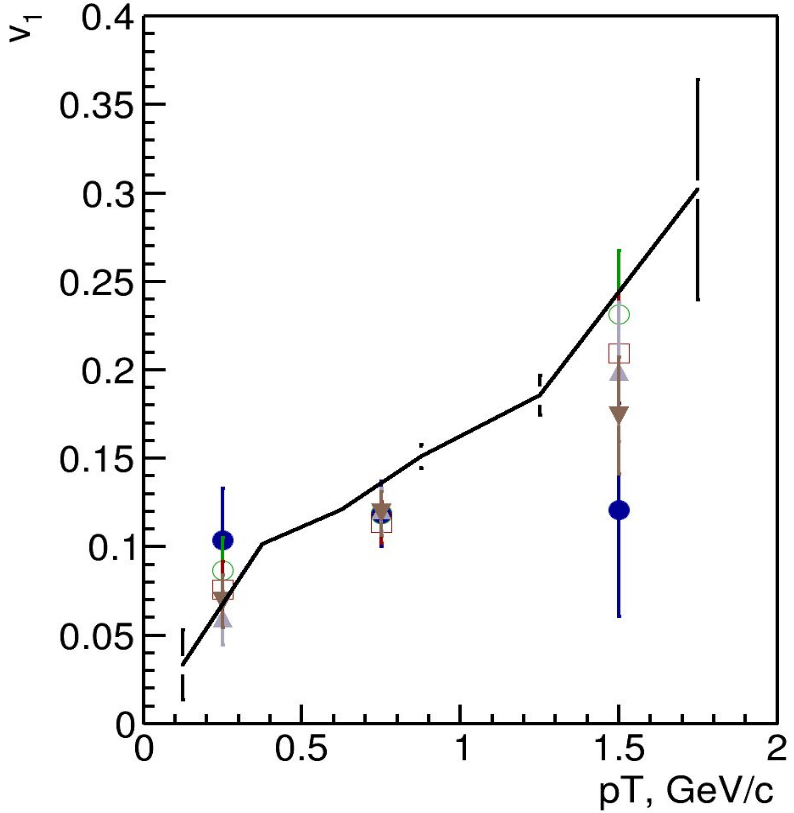




All the estimations for symmetry plane resolutions are in a good agreement

RunId systematics of v_1





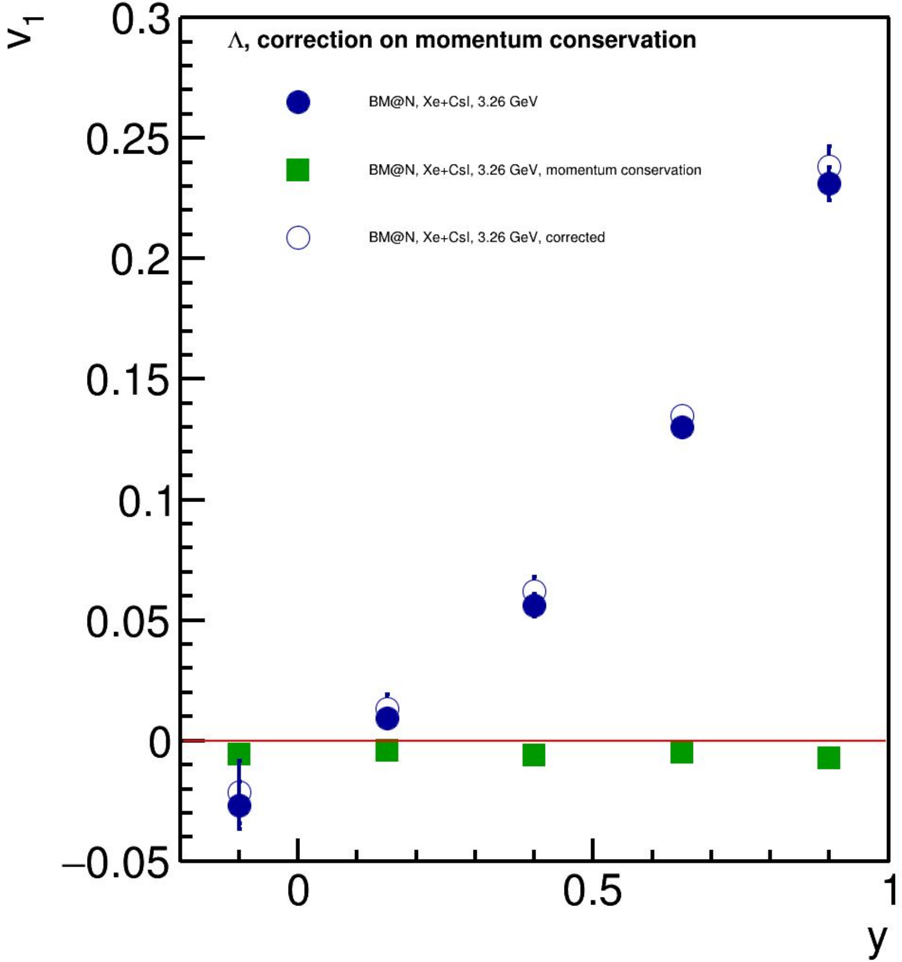
Results from different RunId intervals are in agreement within the errors

Summary

- First result of directed flow of Λ in Xe+Cs(I) run is provided
    - Study of systematics on symmetry plane and RunId shows deviation of no more than 5-10%
    - Efficiency of reconstructed Λ from JAM simulations implementation shows small effect
    - $dv_1/dy|_{y=0}$ differs from STAR data - investigation in progress
- Outlook
    - Apply differential fit procedure
    - Perform analysis with identified protons
    - Further efficiency study
    - Investigation of “feed-down” effect and momentum conservation
    - Write the Analysis Note

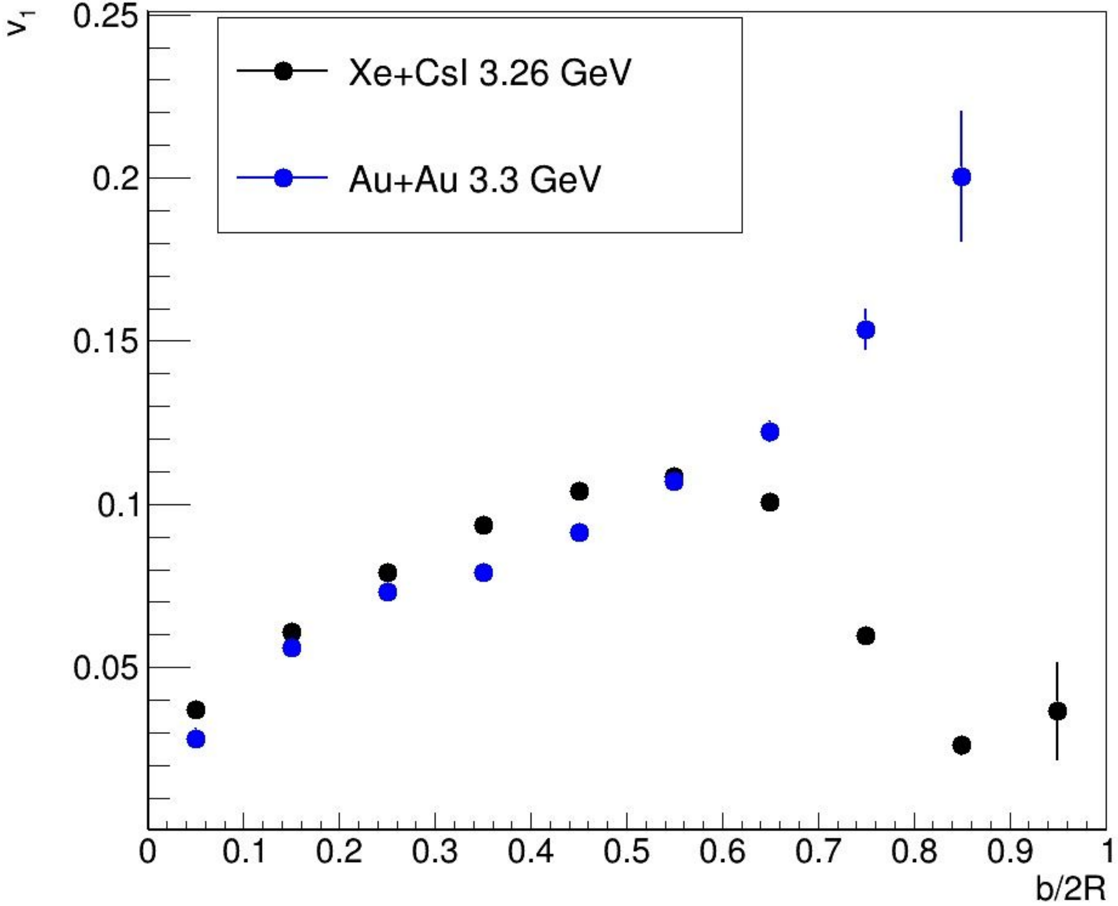
BACKUP

Momentum conservation correction

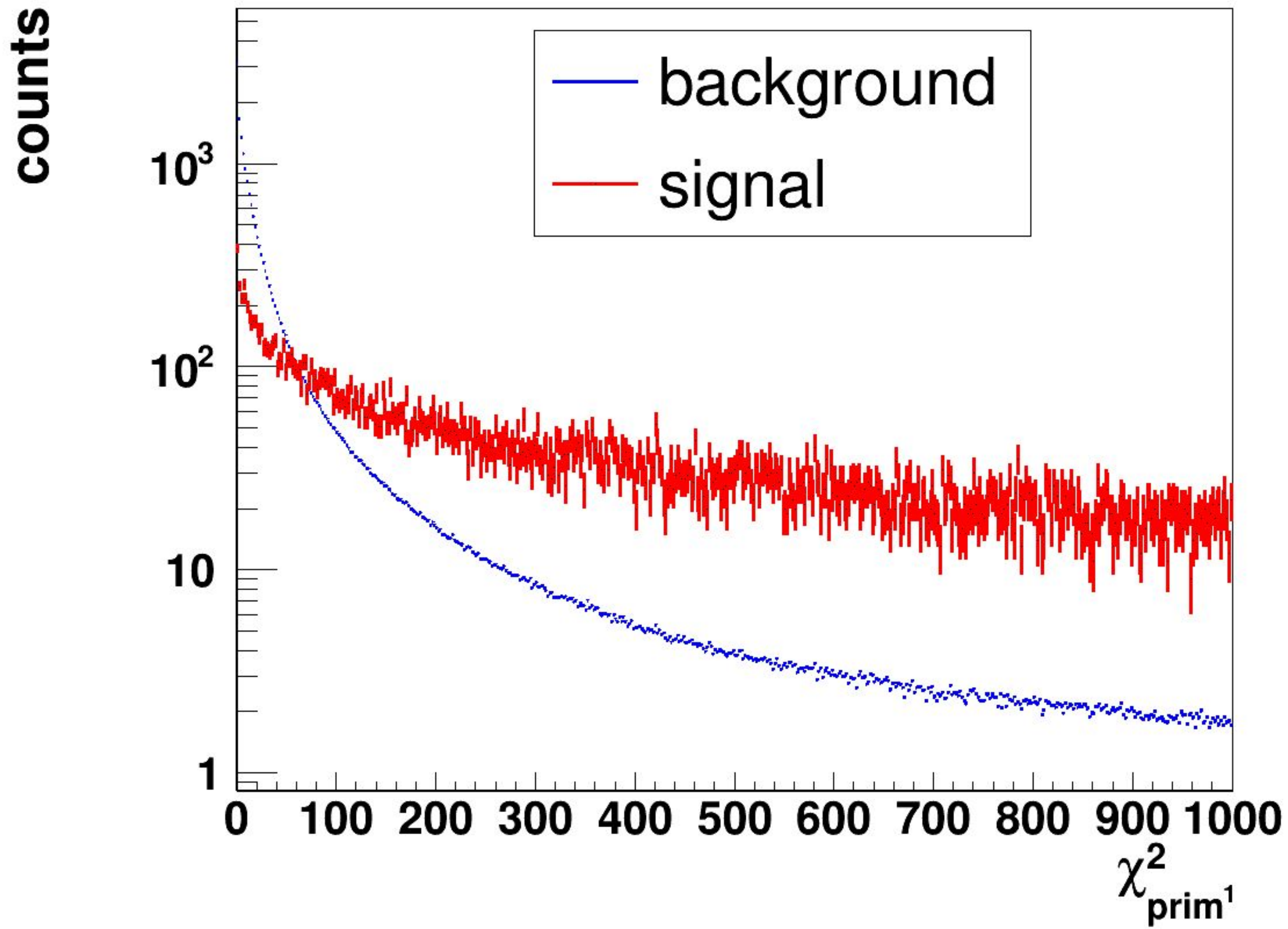


See M. Mamaev talk 08/10, 14:20

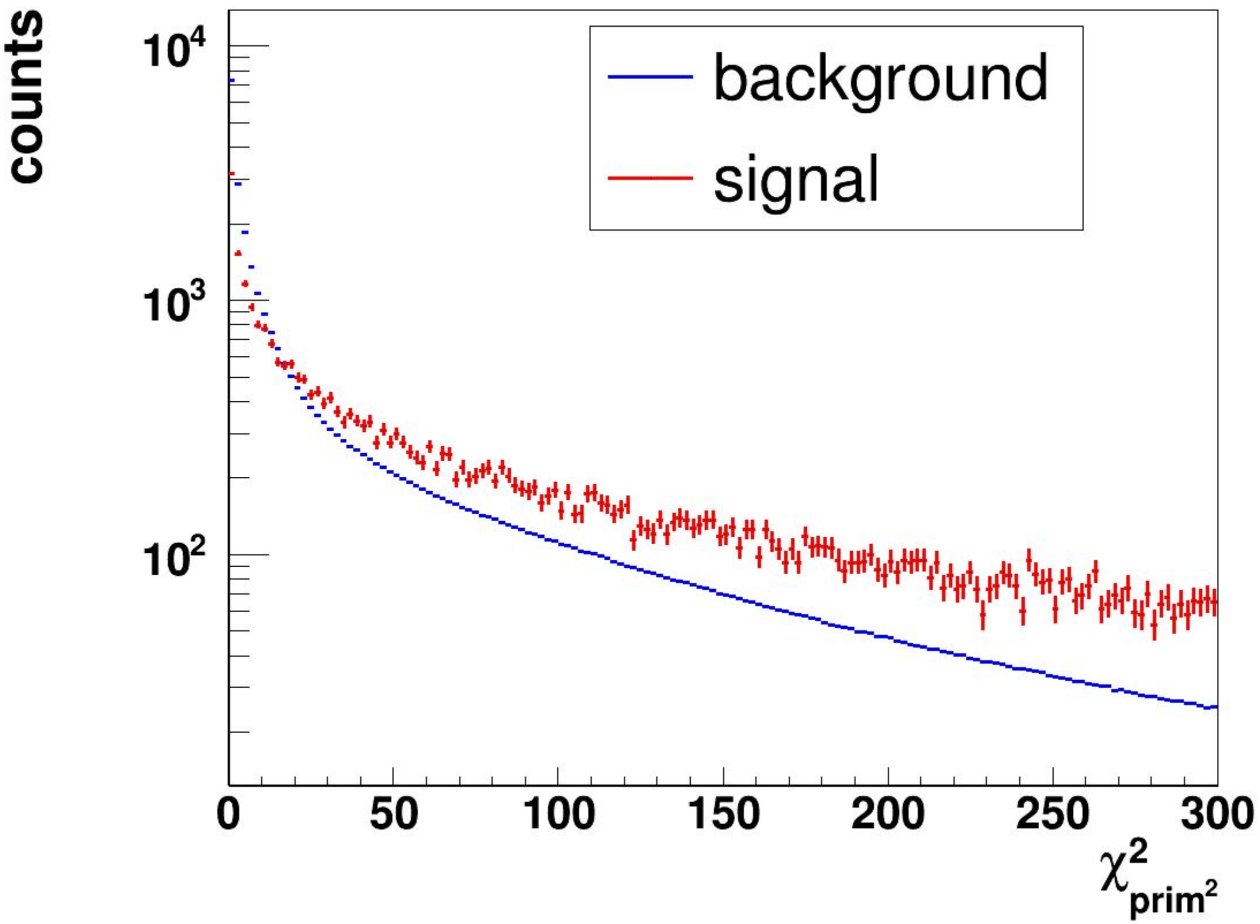
JAM -system-size comparison



χ^2 of pion to primary vertex



χ^2 of proton to primary vertex



χ^2 of daughters' tracks in their closest approach