Directed flow v_1 of protons in Xe+CsI collisions at 3.8*A* GeV

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for the BM@N collaboration

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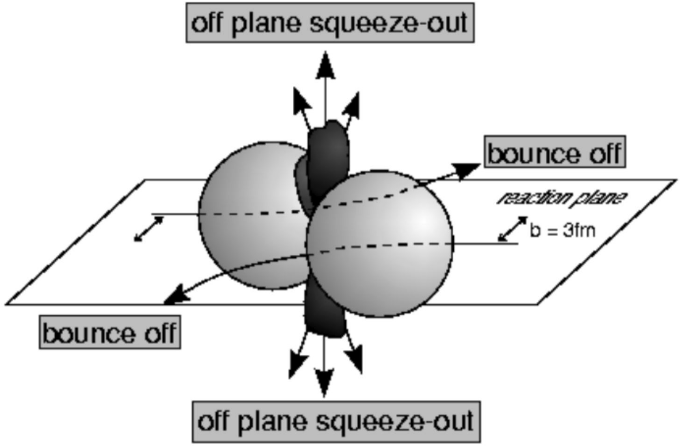
LXXIV International conference Nucleus-2024
03/07/2024

Anisotropic flow & spectators



The azimuthal angle distribution is decomposed in a Fourier series relative to reaction plane angle:

$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_{RP}))$$

Anisotropic flow:

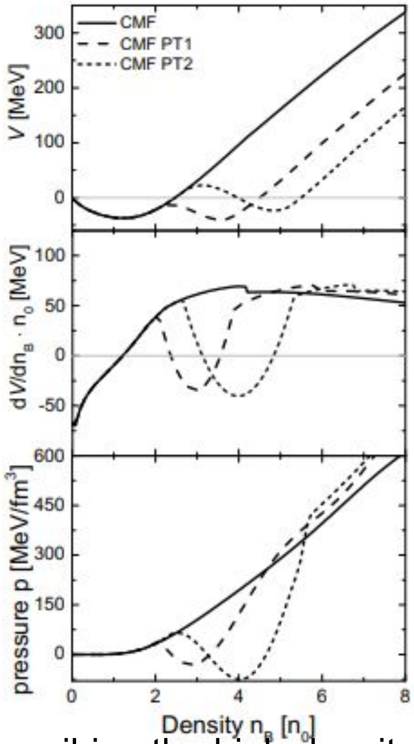
$$v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

Anisotropic flow is sensitive to:

- Time of the interaction between overlap region and spectators
- Compressibility of the created matter

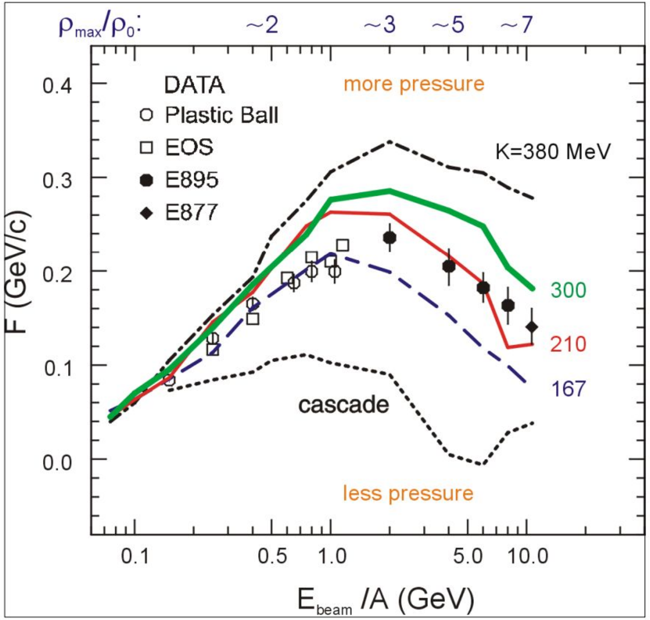
v_n as a function of collision energy

P. DANIELEWICZ, R. LACEY, W. LYNCH
10.1126/science.1078070

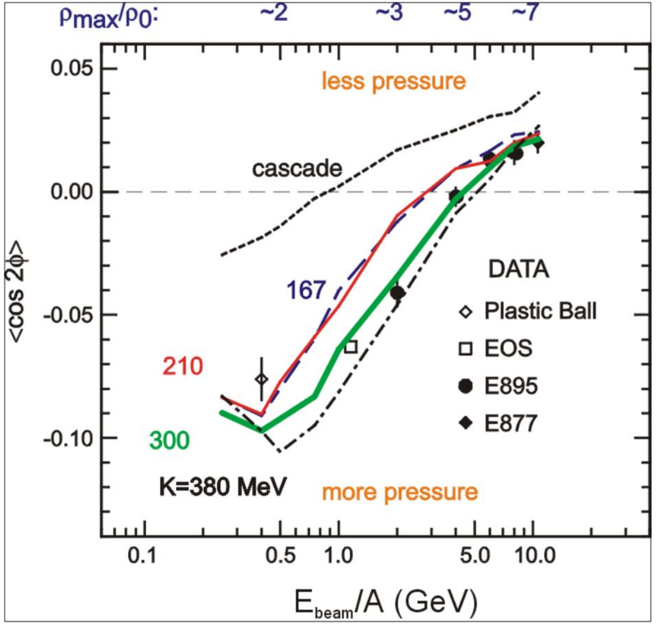


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



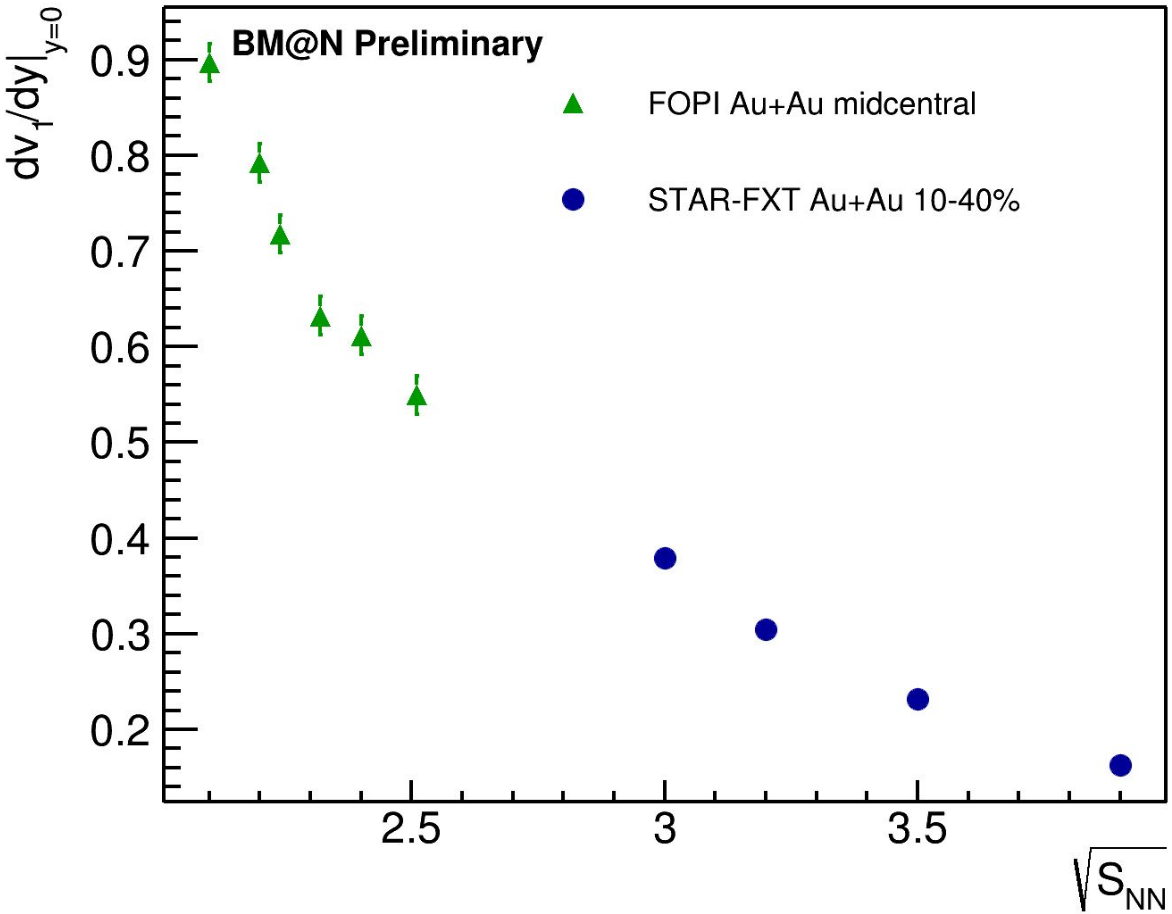
v_2 suggests harder EOS



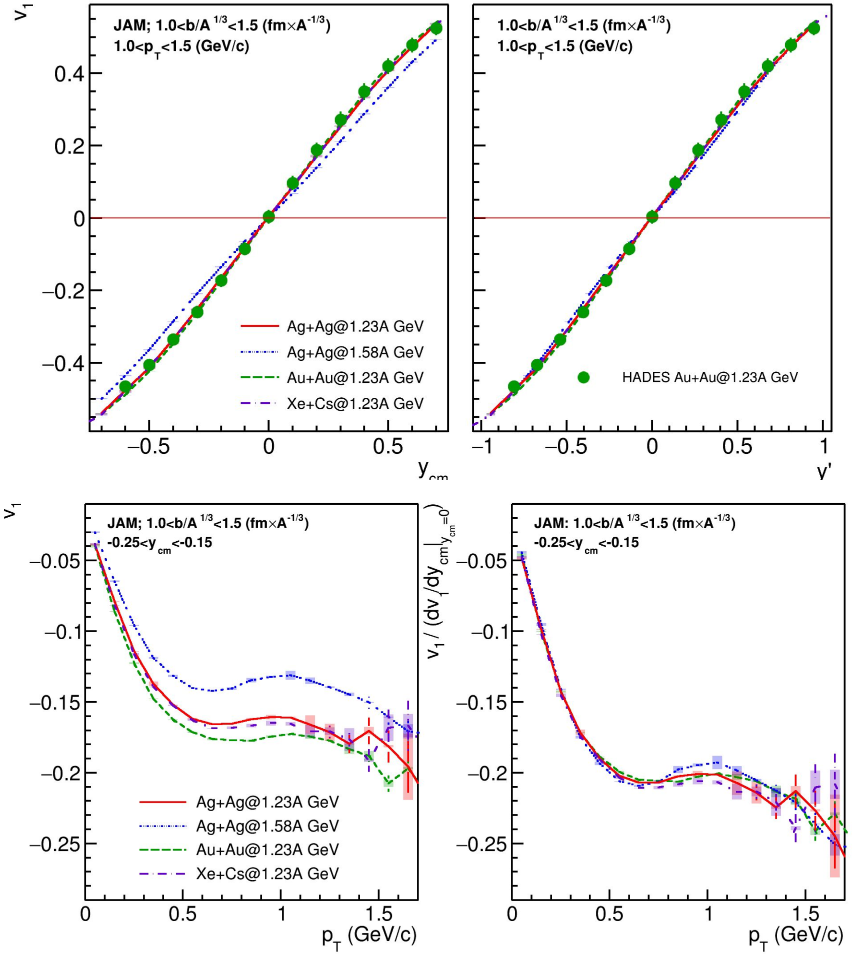
Describing the high-density matter using the mean field
Flow measurements constrain the mean field

Discrepancy is probably due to non-flow correlations

$dv_1/dy|_{y=0}$ vs collision energy



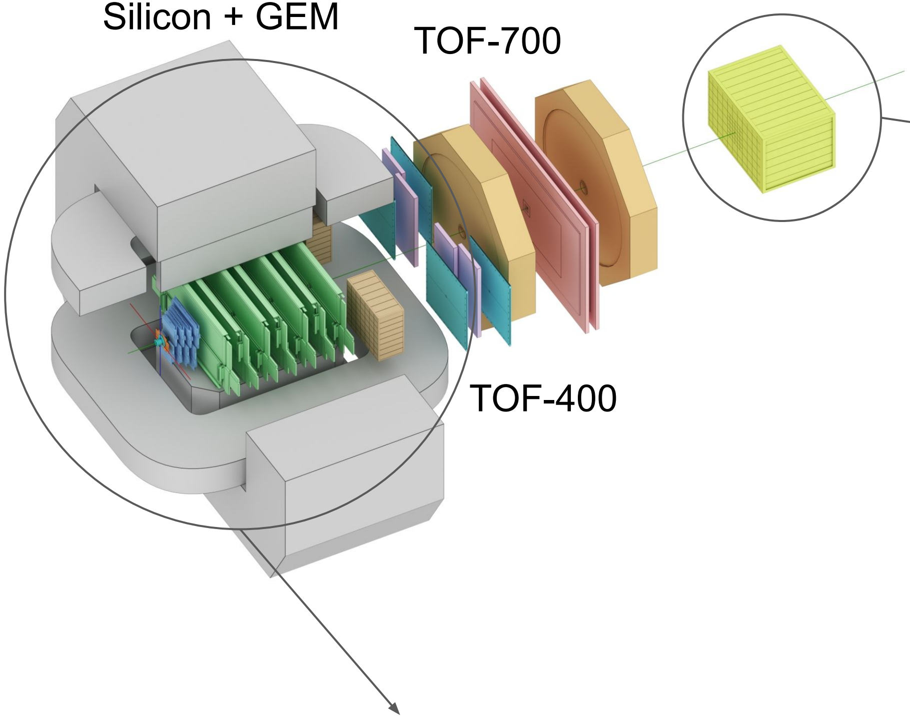
HADES: dv_1/dy scaling with collision energy and system size

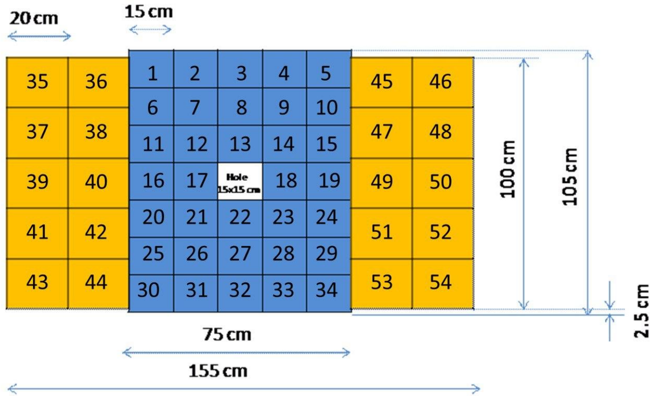


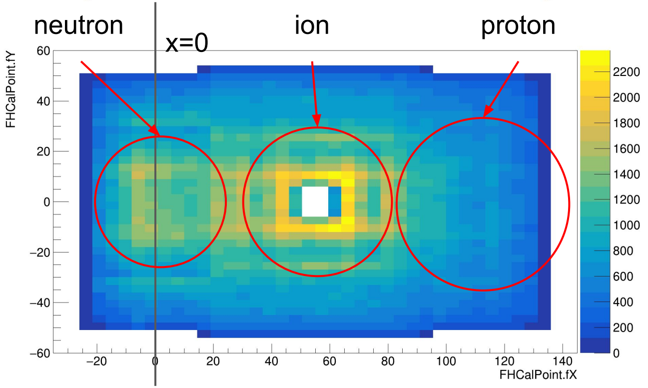
- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

M.Mamaev Particles 2023, 6(2), 622-637

The BM@N experiment (GEANT4 simulation for RUN8)



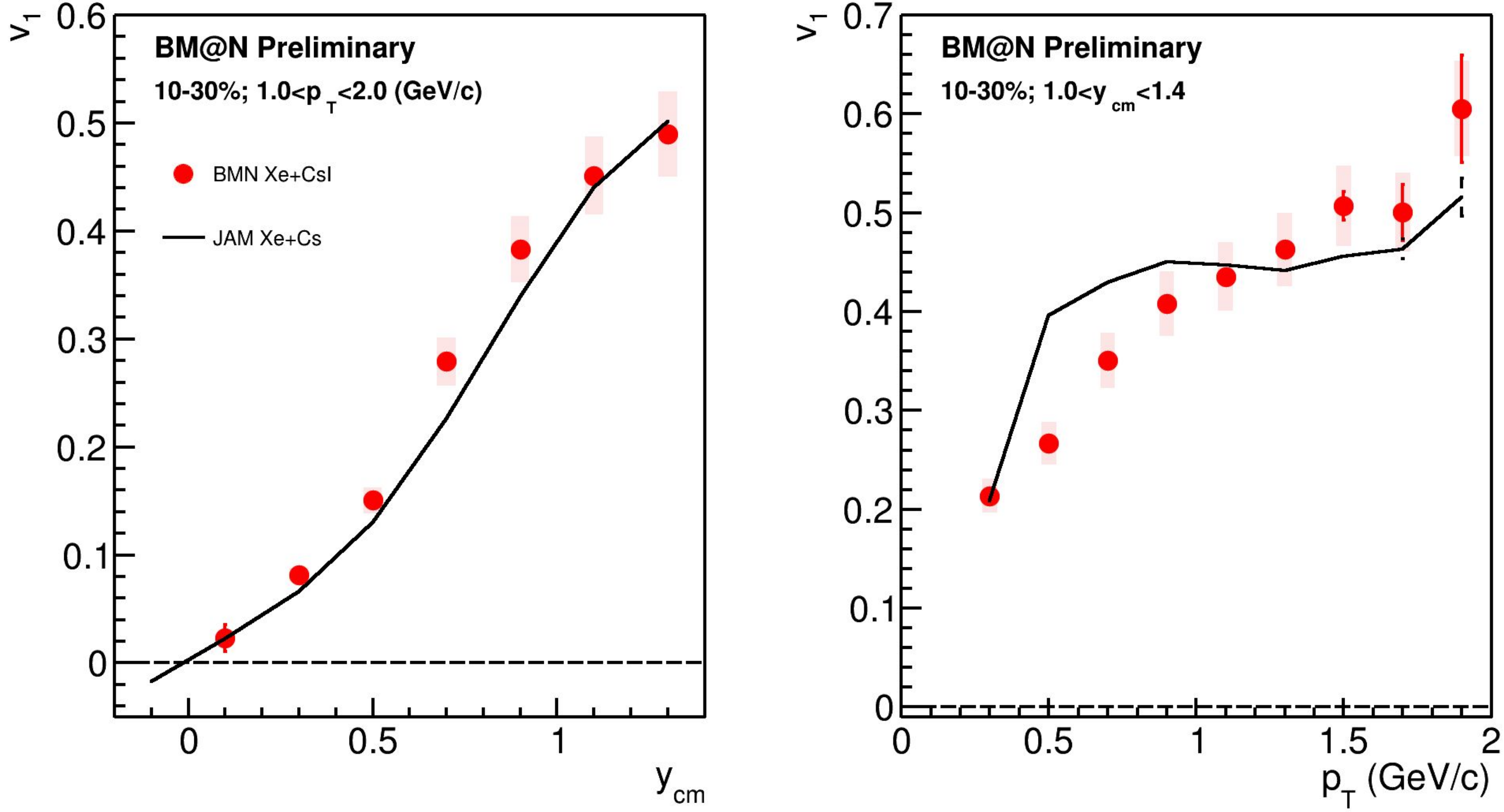




Tracks are reconstructed in tracking system

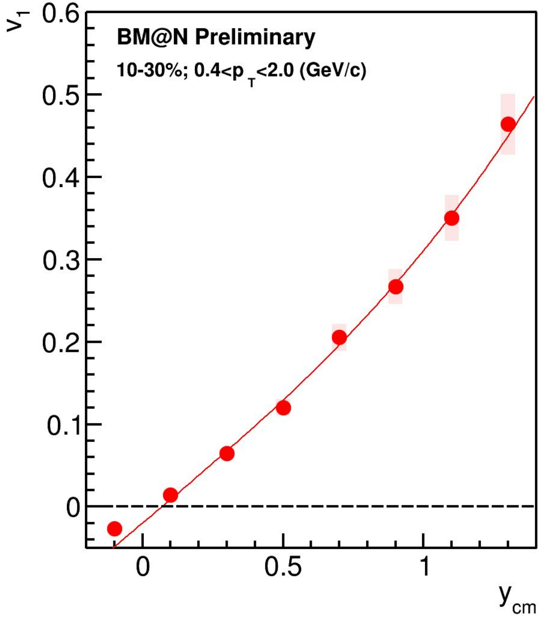
Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

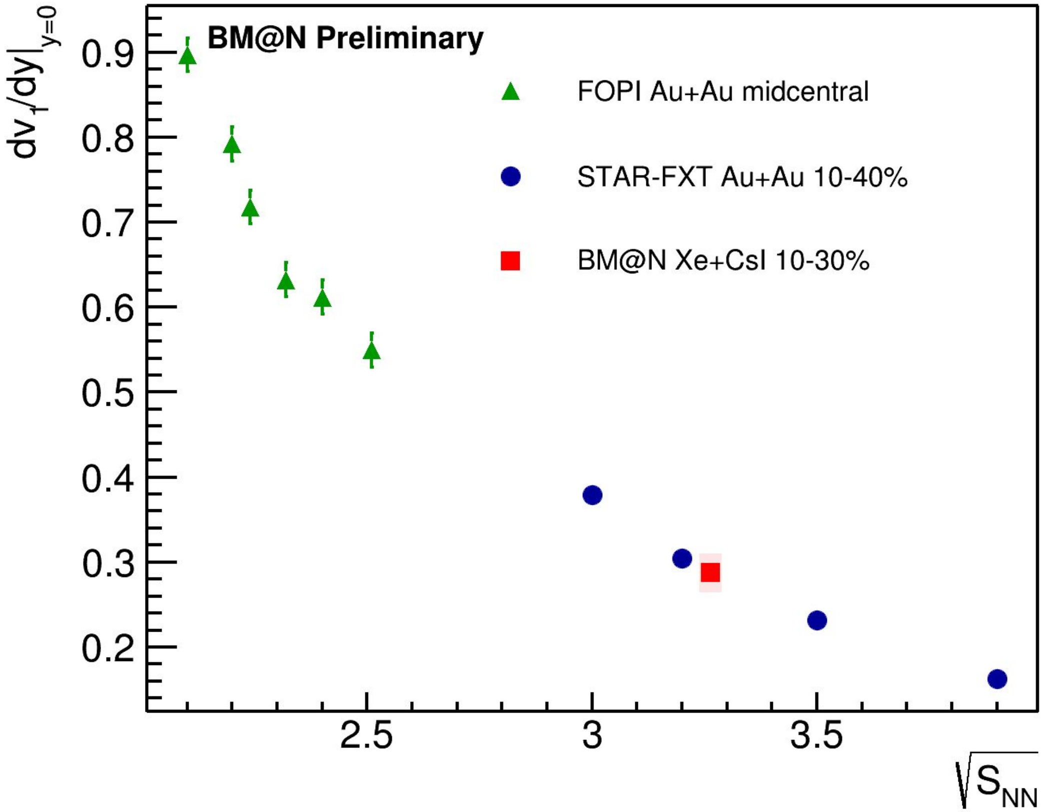
v_1 as a function of pT and y



JAM model describes $v_1(y)$ well

$dv_1/dy|_{y=0}$ vs collision energy





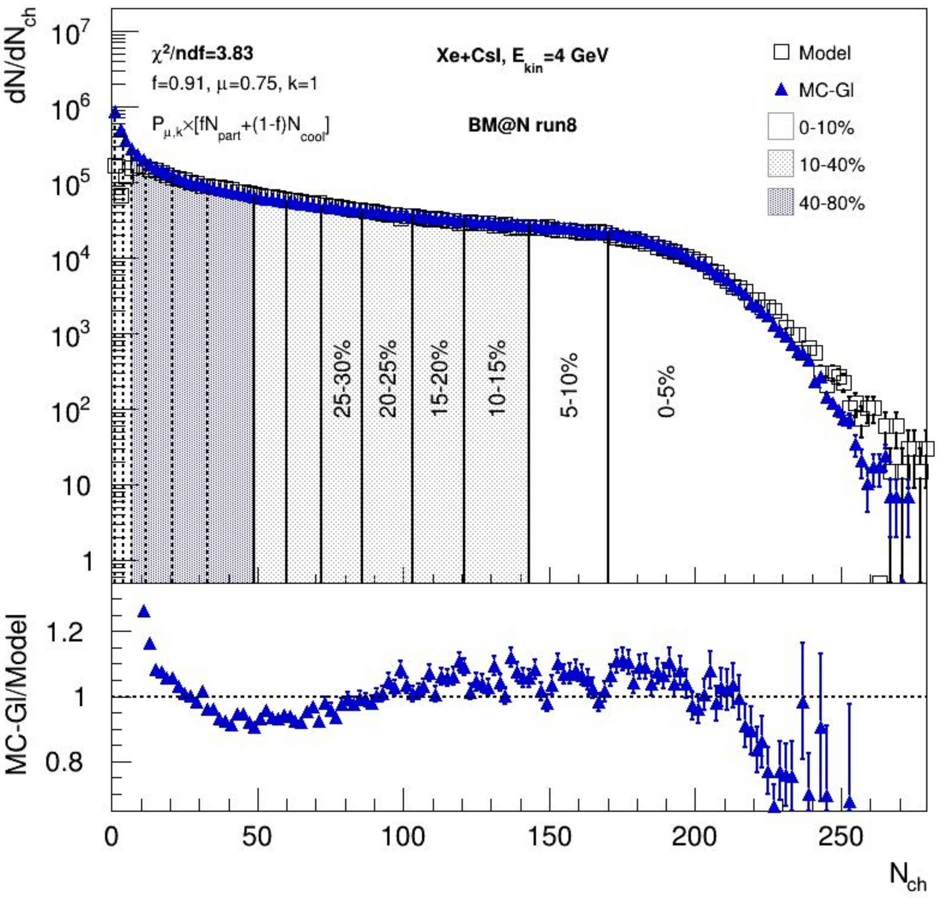
dv_1/dy is in a good agreement with the world data

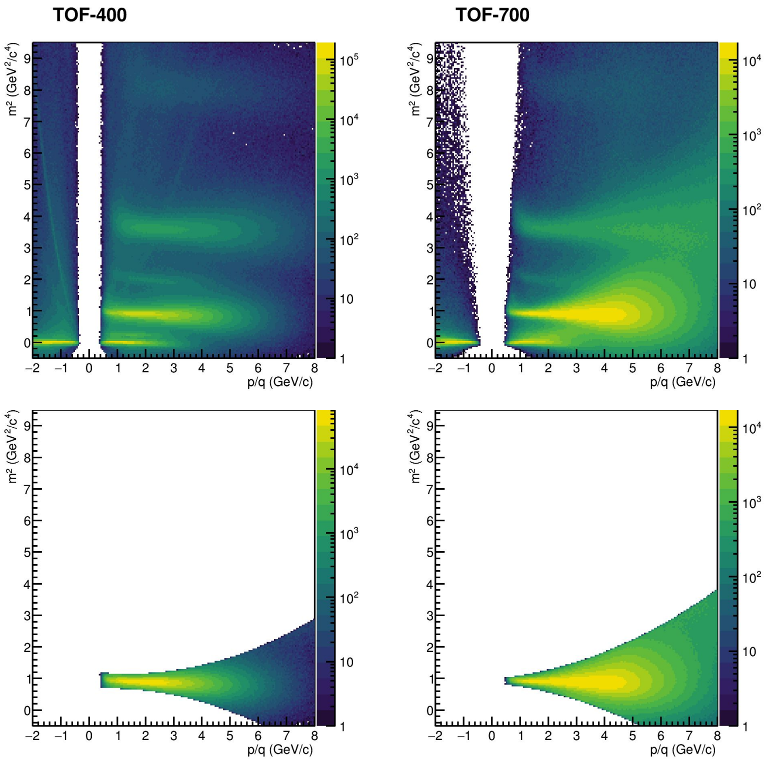
Summary

- Directed flow of protons is measured multidifferentially as a function of p_T, y and centrality
- The JAM model describes the $v_1(y)$ reasonably well in high transverse momentum region
- The directed flow slope at midrapidity $dv_1/dy|_{y=0}$ was extracted
- The results for directed flow slope dv_1/dy of protons are in a good agreement with the world data

Backup

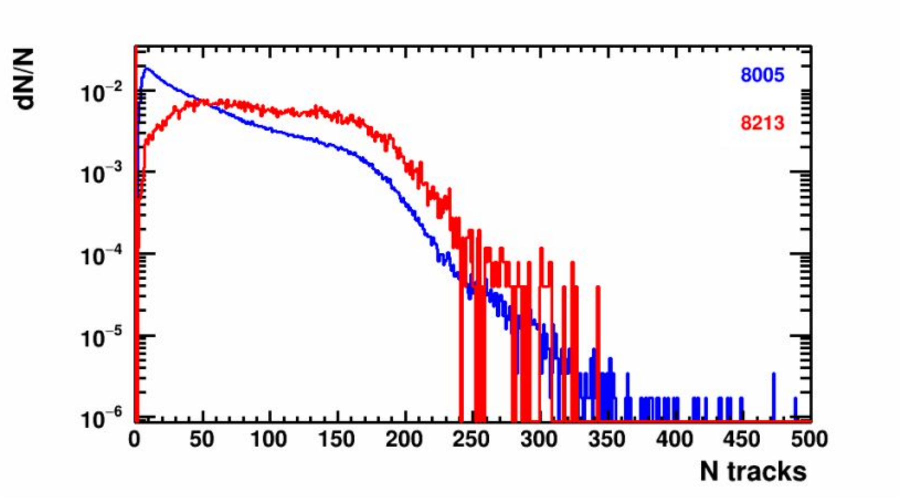
Centrality and particle selection

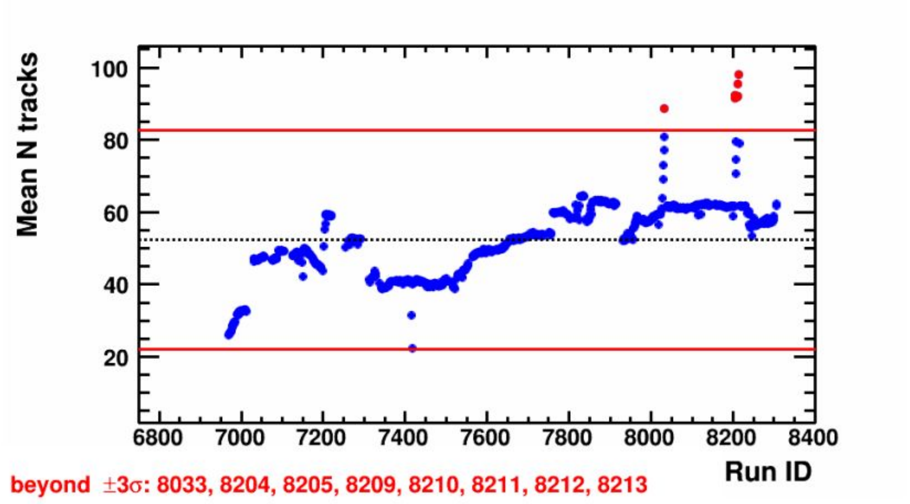




- Half of the recent VF production was analysed
- Event selection criteria (~100M events selected)
  - CCT2 trigger
  - Pile-up cut
  - Number tracks for vertex > 1
- Track selection criteria : $\chi^2 < 5$; $M_p^2 - 3\sigma < m^2 < M_p^2 + 3\sigma$; Nhits > 5

Quality assurance for the recent data





The preliminary list of bad runs based on QA study [18M events] RunId: 6968, 6970, 6972, 6973, 6975, 6976, 6977, 6978, 6979, 6980, 6981, 6982, 6983, 6984, 7313, 7326, 7415, 7417, 7435, 7517, 7520, 7537, 7538, 7542, 7543, 7545, 7546, 7547, 7573, 7575, 7657, 7659, 7679, 7681, 7843, 7847, 7848, 7850, 7851, 7852, 7853, 7855, 7856, 7857, 7858, 7859, 7865, 7868, 7869, 7907, 7932, 7933, 7935, 7937, 7954, 7955, 8018, 8031, 8032, 8033, 8115, 8121, 8167, 8201, 8204, 8205, 8208, 8209, 8210, 8211, 8212, 8213, 8215, 8289.

Flow vectors

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

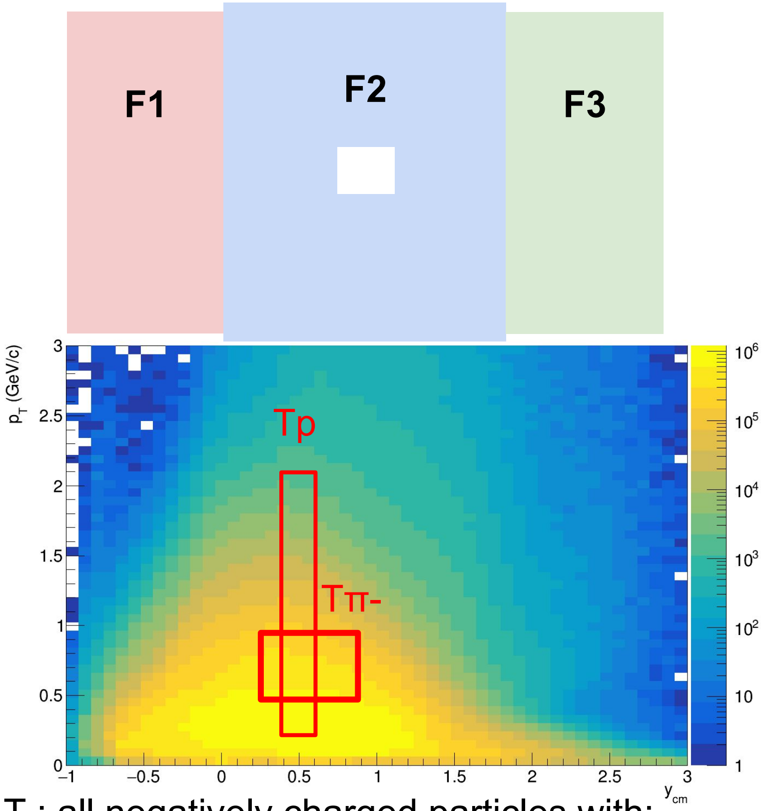
$$u_n = e^{in\phi}$$

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:

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

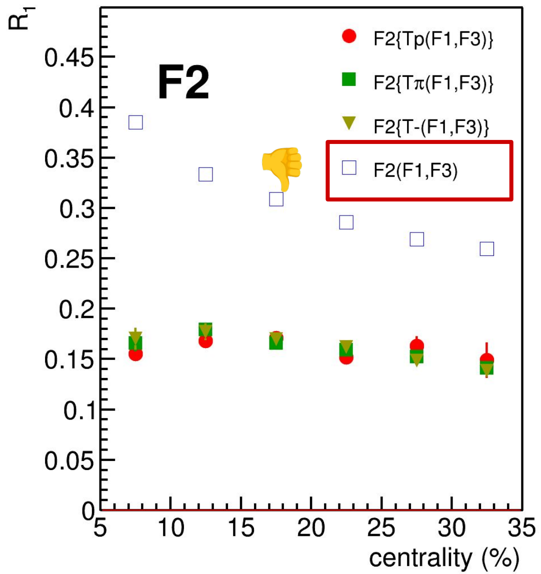
Where R_1 is the resolution correction factor

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

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

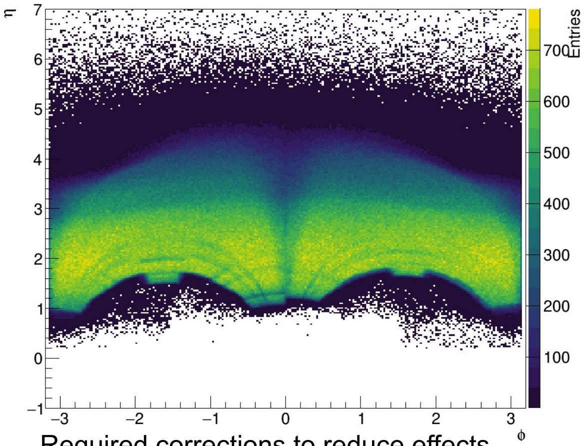


Symbol "F2{Tp}(F1,F3)" means R_1 calculated via (4S resolution):

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

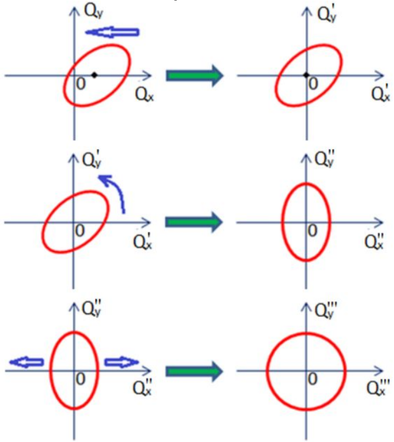
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

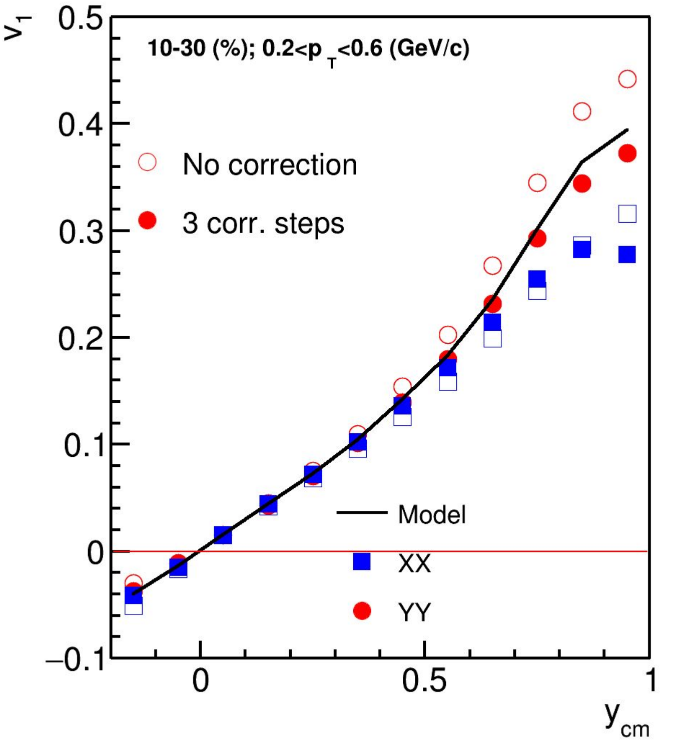


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

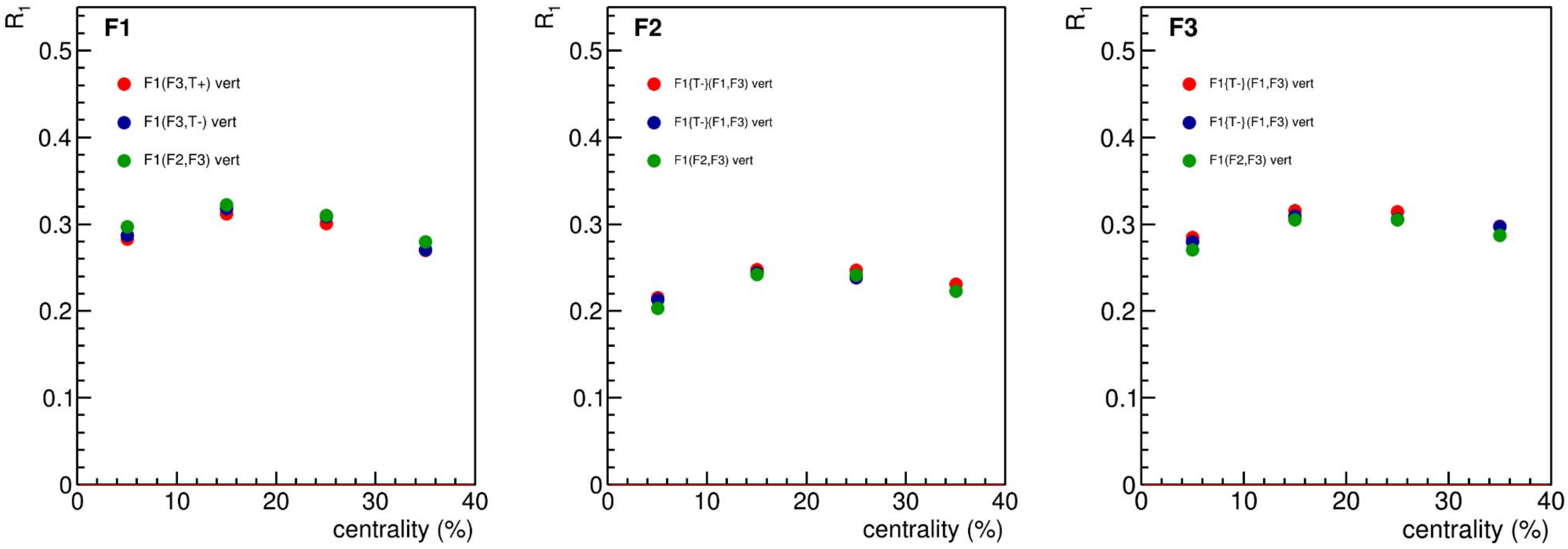


Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)



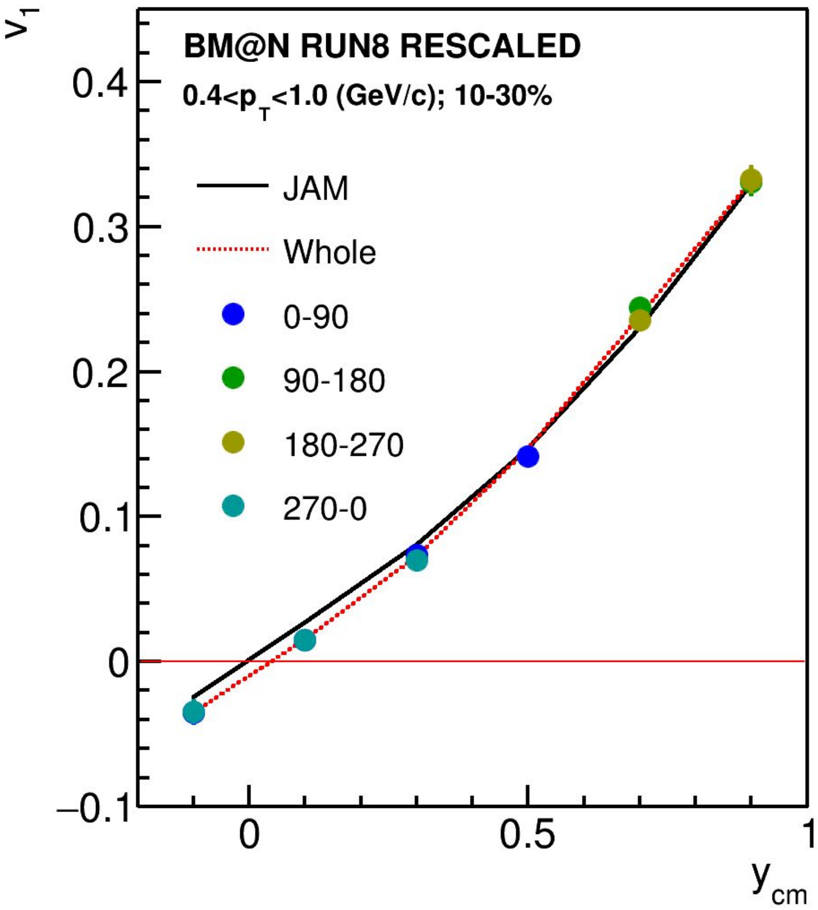
- Better agreement after rescaling for YY
- XX component has too large bias (due to magnetic field)

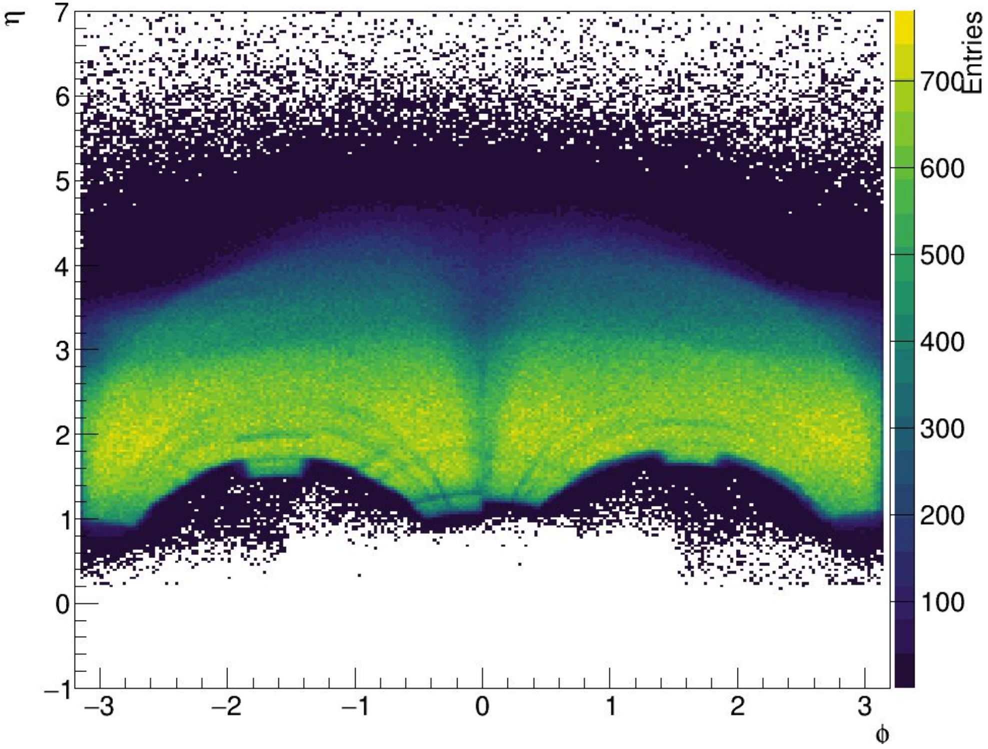
Symmetry plane resolution in Xe+Cs(I) collisions



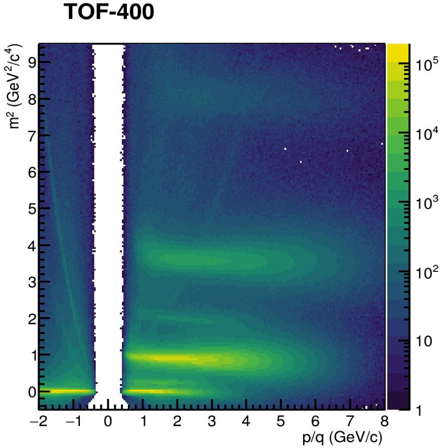
All the estimations for symmetry plane resolutions are in a good agreement

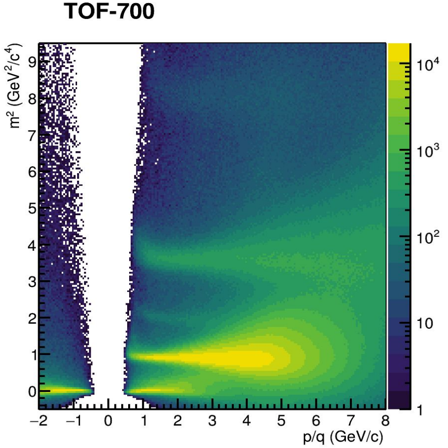
Residual effects of detector non-uniformity

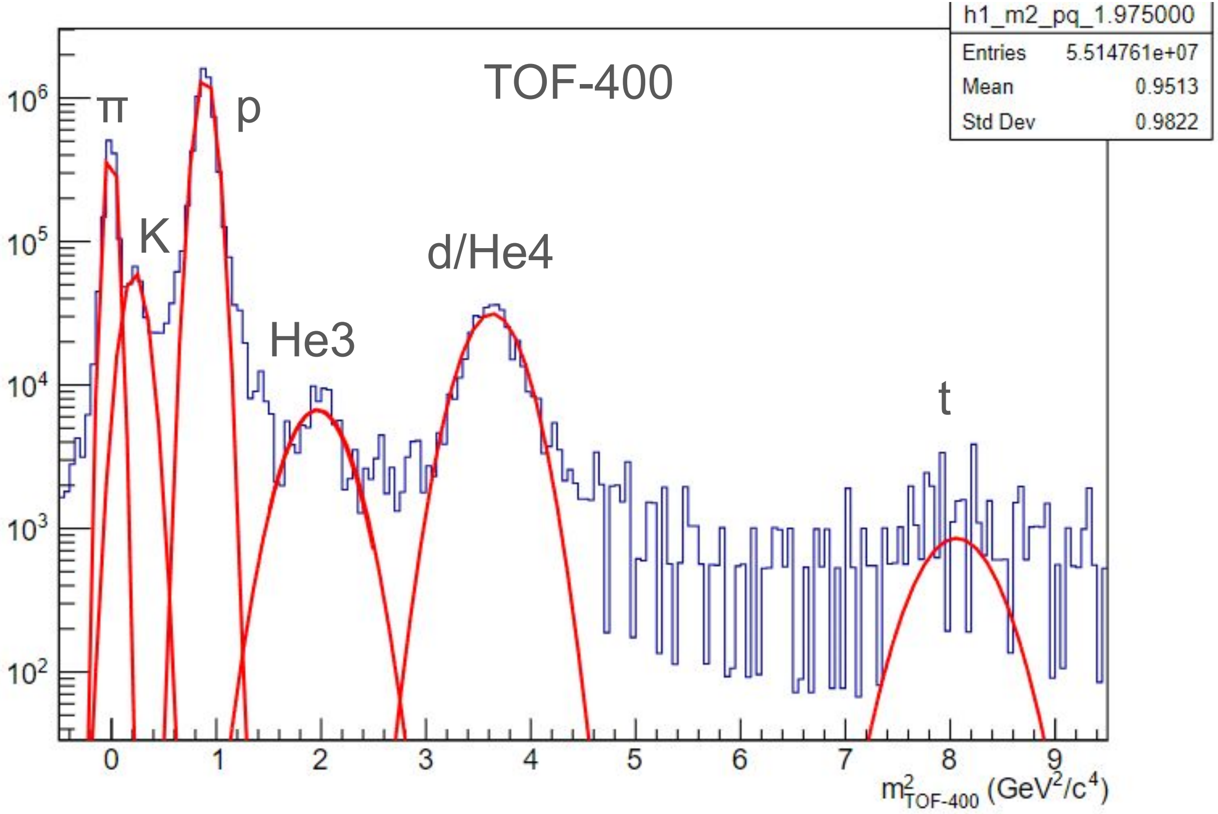




Particle identification

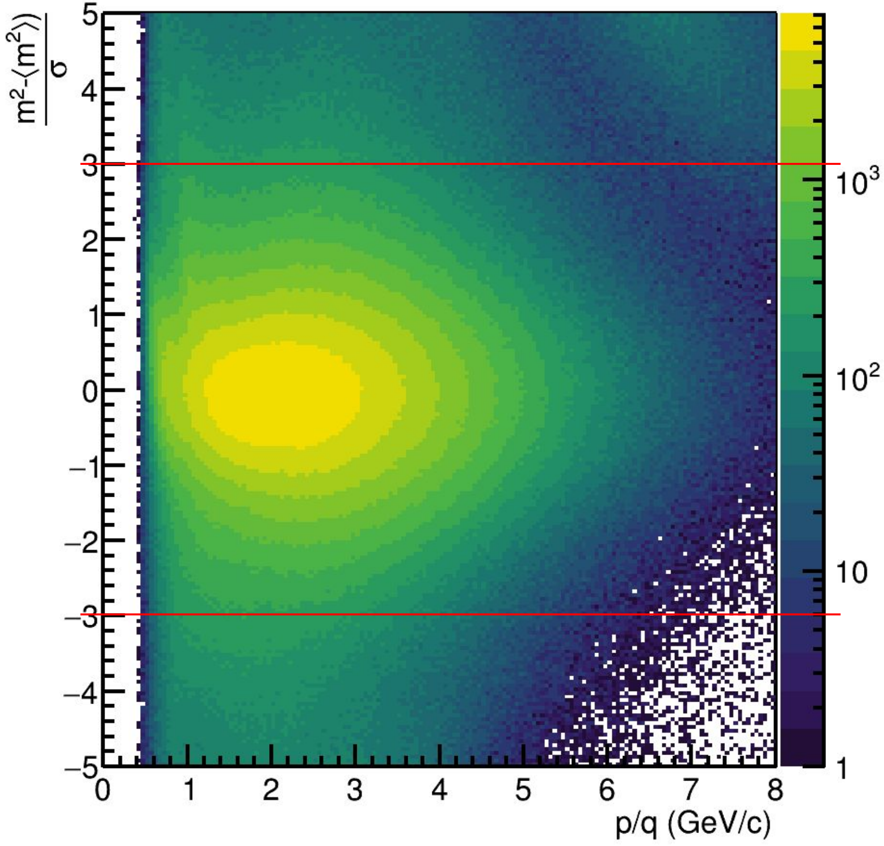




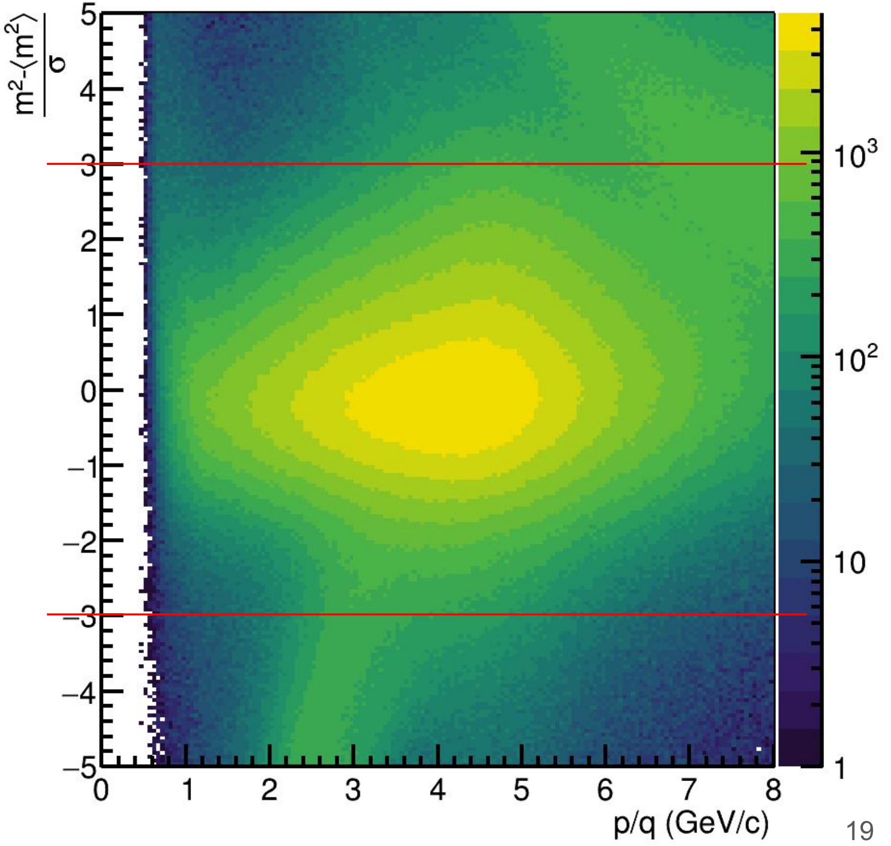


Proton N-sigma distributions

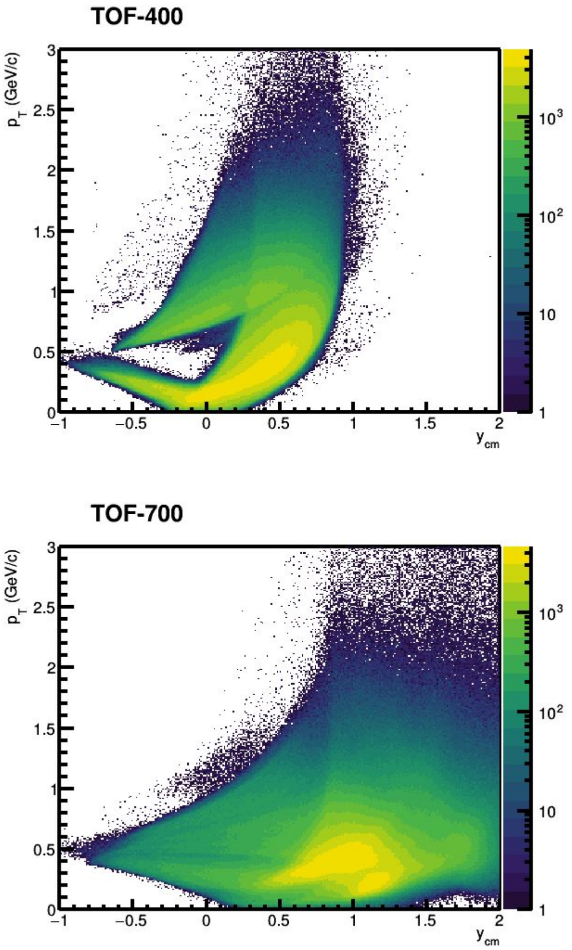
TOF-400

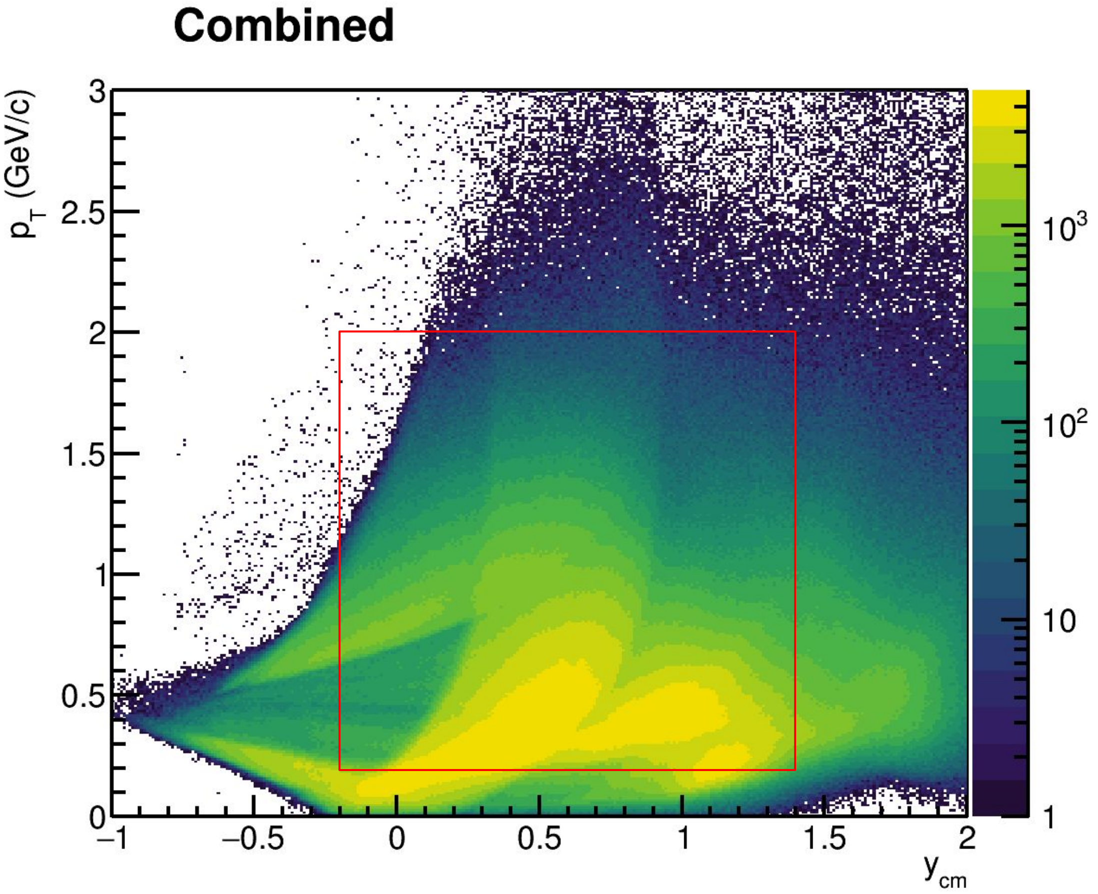


TOF-700

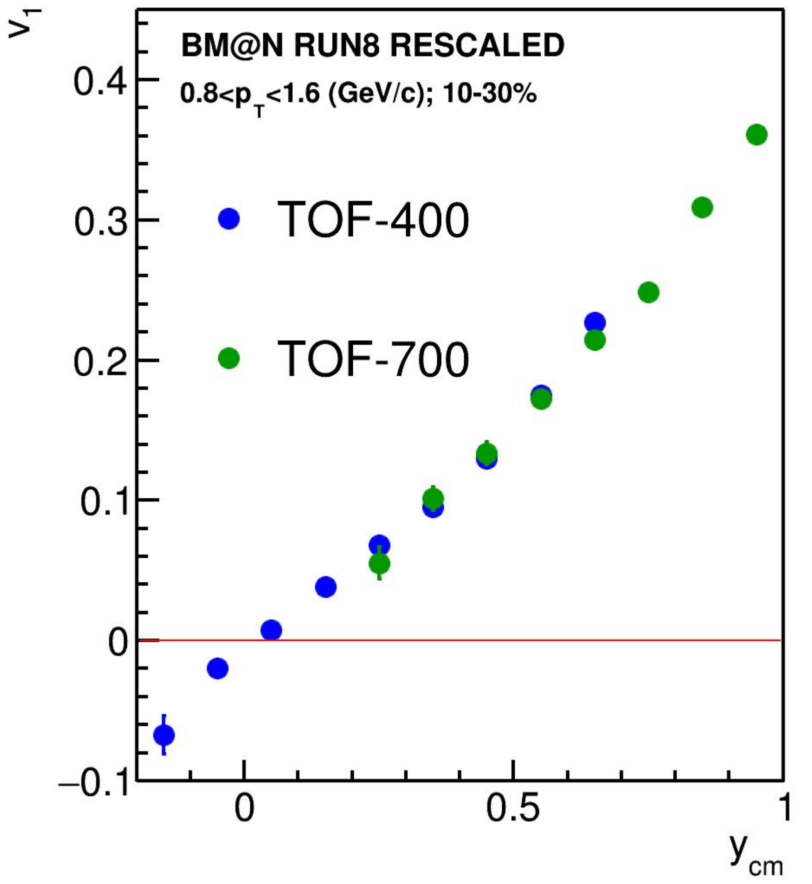


Proton p_T-y acceptance



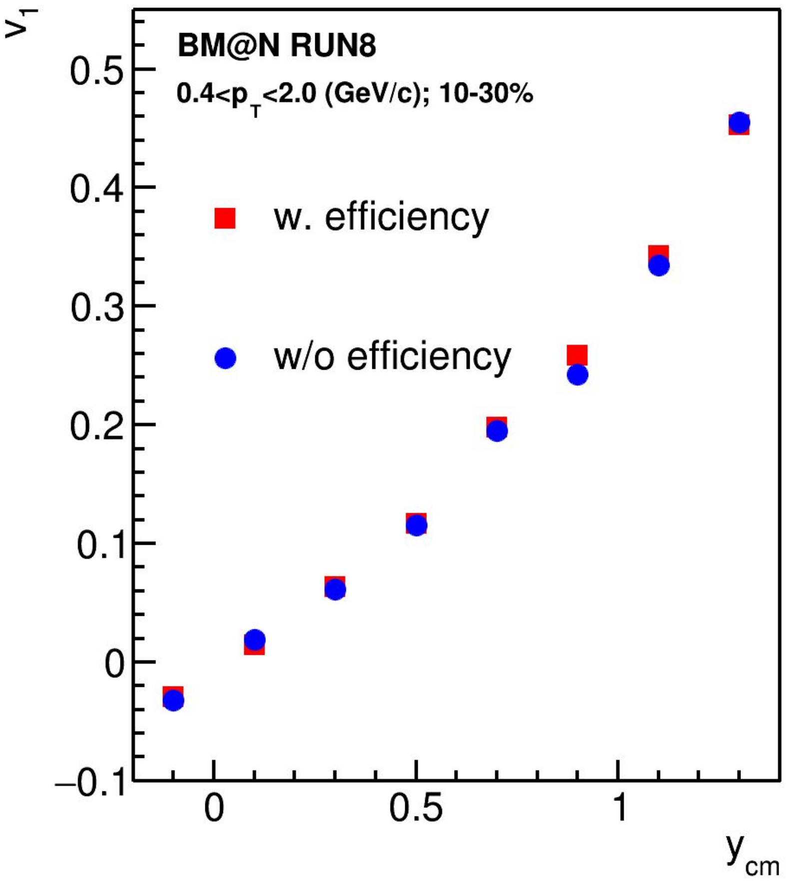


Comparison of the TOF performances

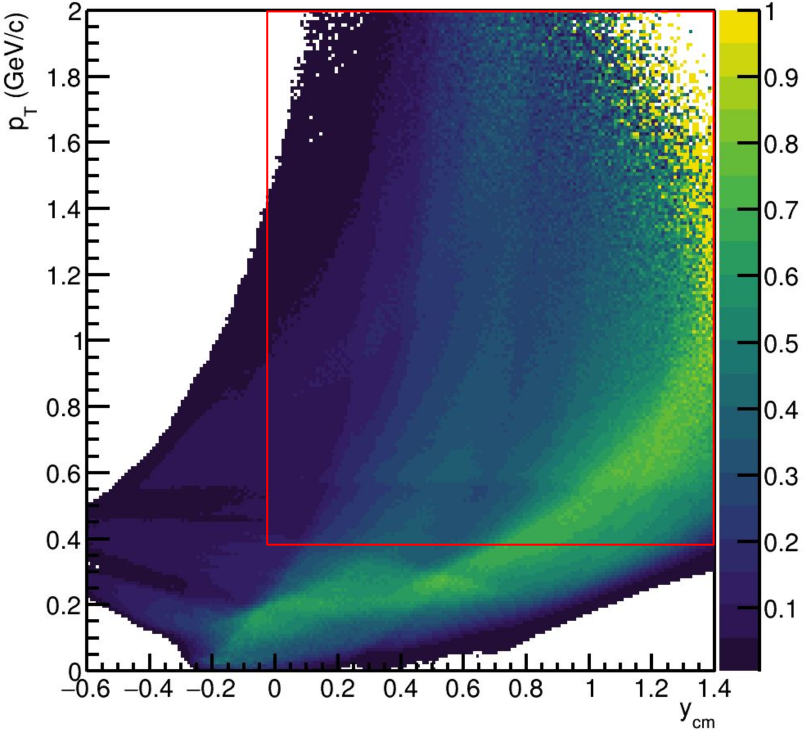


The results from TOF-400 and TOF-700 are in a good agreement

Comparison of the TOF performances



Efficiency using JAM



Results with and without efficiency are in a good agreement

$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_{RP}))$$

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

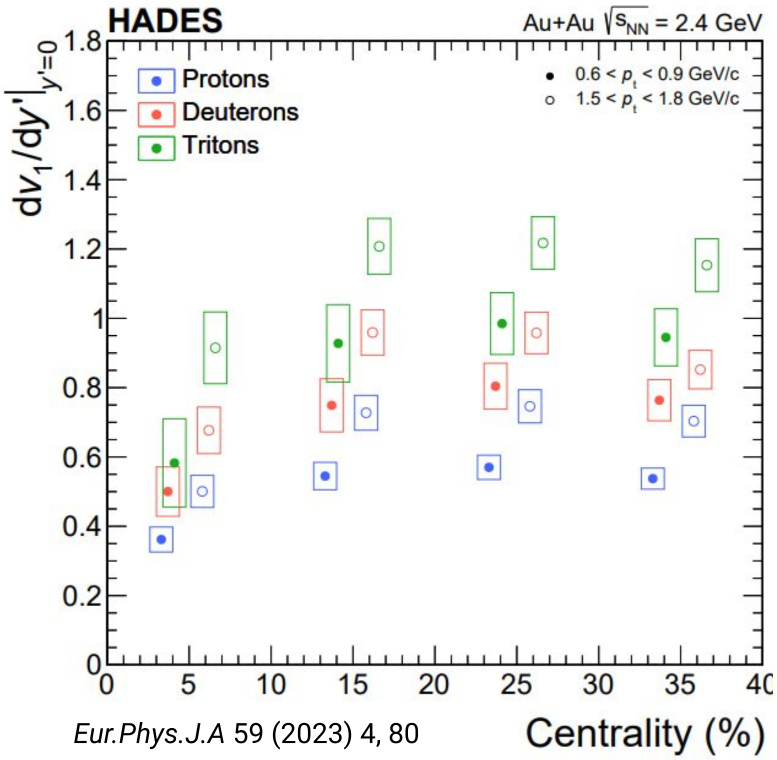
At N→∞ (N≫1)

$$\lim_{n\to\infty} Q_n = \frac{\int d\vec{v} \int d\phi w(\phi, \vec{v}) e^{in\phi} \rho(\phi - \Psi)}{\int d\vec{v} \int d\phi w(\phi, \vec{v}) \rho(\phi - \Psi)} = V_n e^{in\Psi}$$

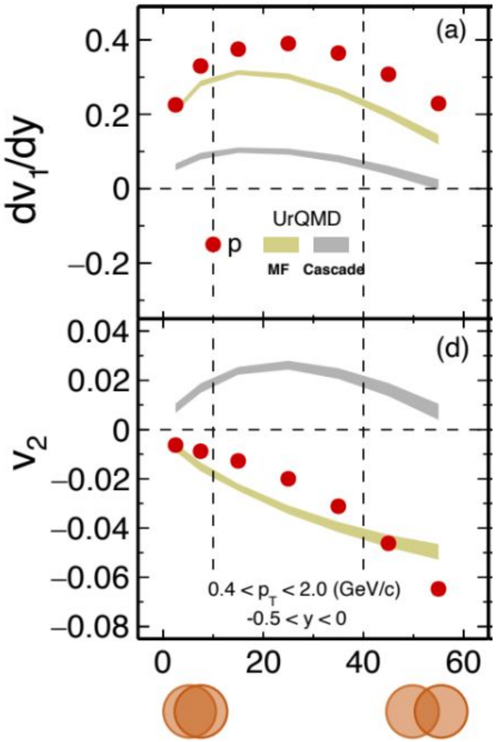
$$\langle u_n Q_n{}^* \rangle = \frac{\int d\vec{v} \int d\phi \int d\Psi_{RP} w(\phi, \Psi_{RP}, \vec{v}) e^{in\phi} V_n(\Psi_{RP}) e^{-in\Psi_n^{EP}} \rho(\phi - \Psi_{RP})}{\int d\vec{v} \int d\phi \int d\Psi_{RP} w(\phi, \Psi_{RP} \vec{v}) \rho(\phi - \Psi_{RP})}$$

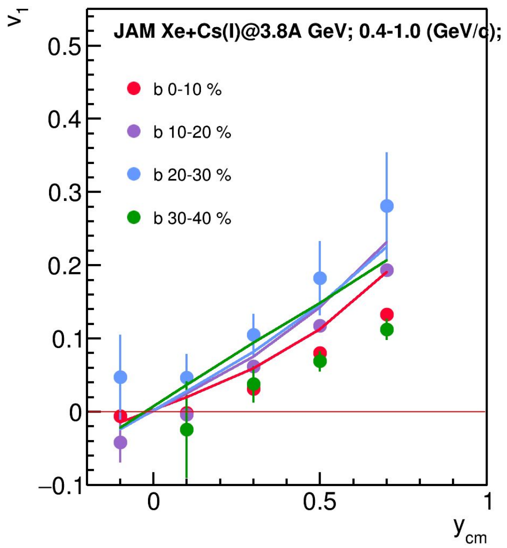
$$= \langle \cos n(\phi - \Psi_{RP}) V_n \cos n(\Psi_{RP} - Psi_n^{EP}) \rangle$$

dv_1/dy as a function of centrality



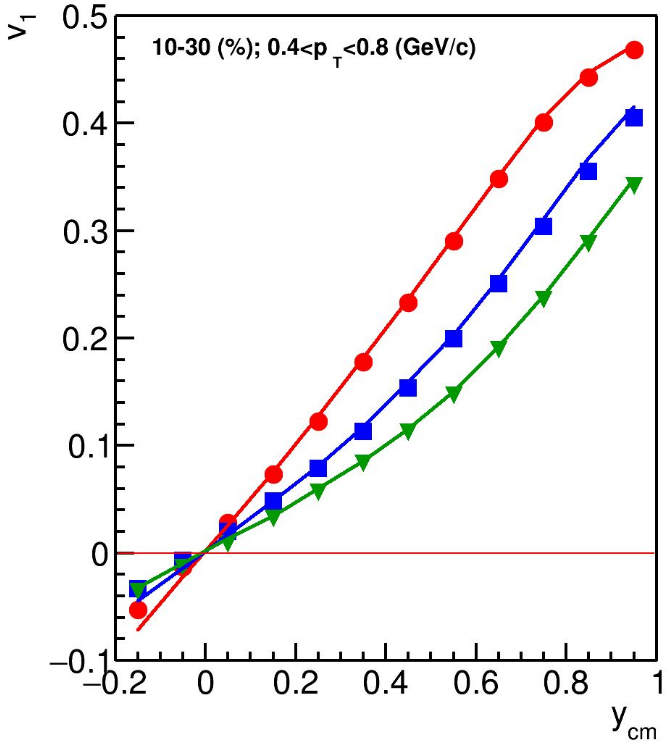
Eur.Phys.J.A 59 (2023) 4, 80

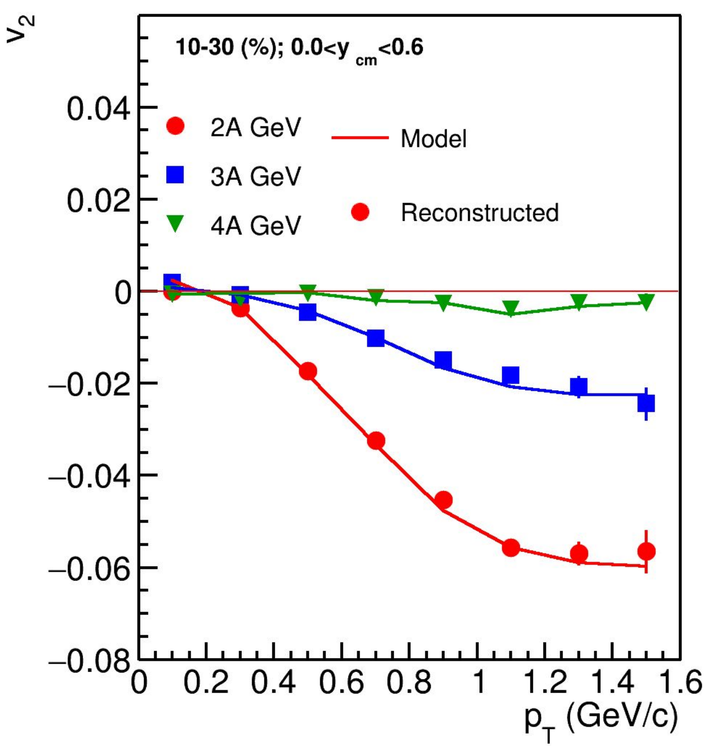




Weak centrality dependence for directed flow

Performance for v_1 and v_2 in Xe+Cs (JAM+GEANT4)





- Good agreement between reconstructed and pure model data for all three energies