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

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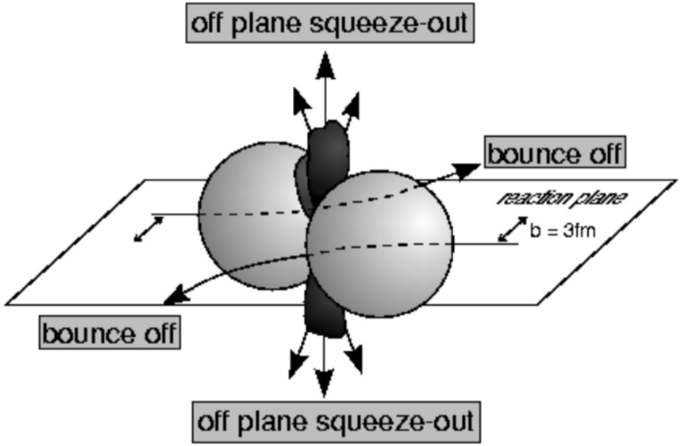
BM@N Analysis Meeting, 04/03/2025

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:

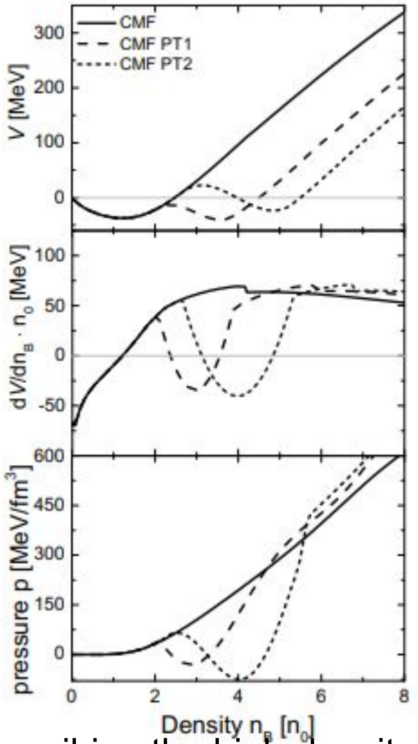
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right] \rangle$$

Anisotropic flow is sensitive to:

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

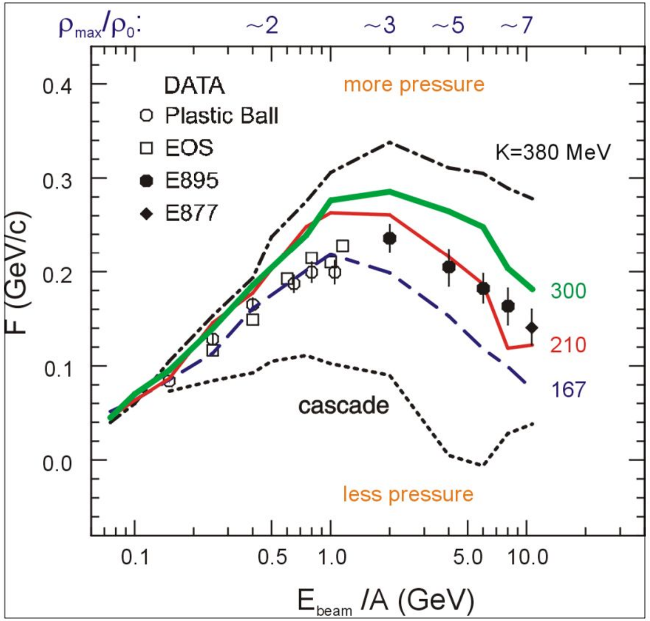
v_n as a function of collision energy

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

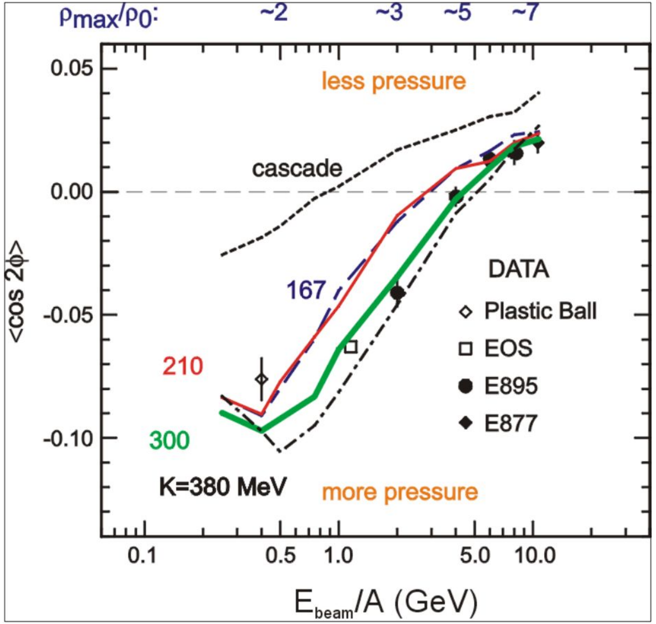


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



v_2 suggests harder EOS

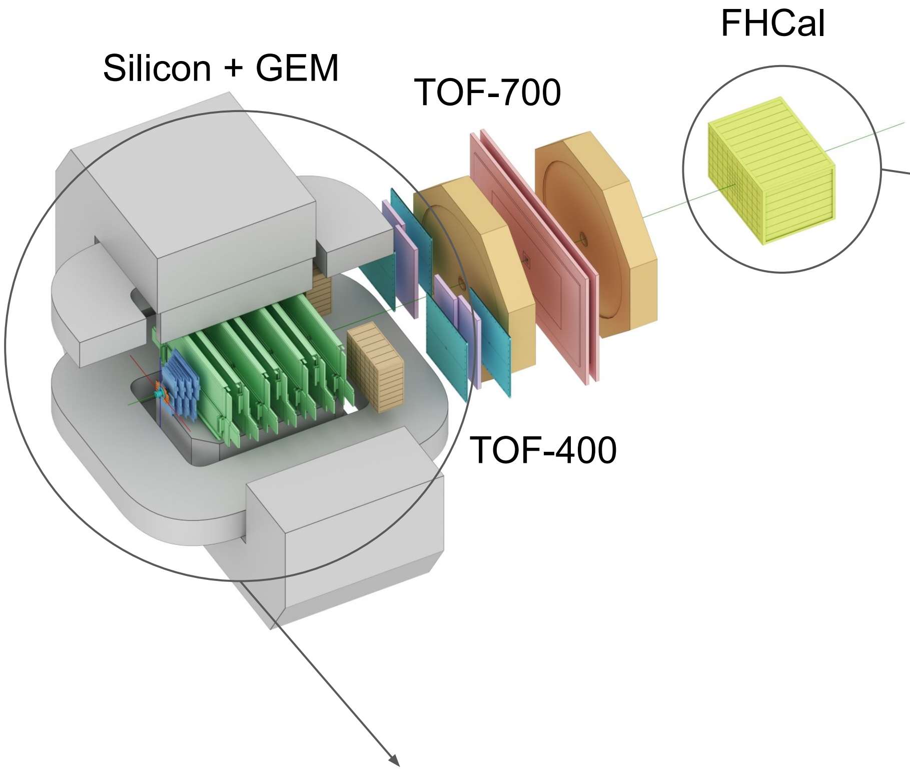


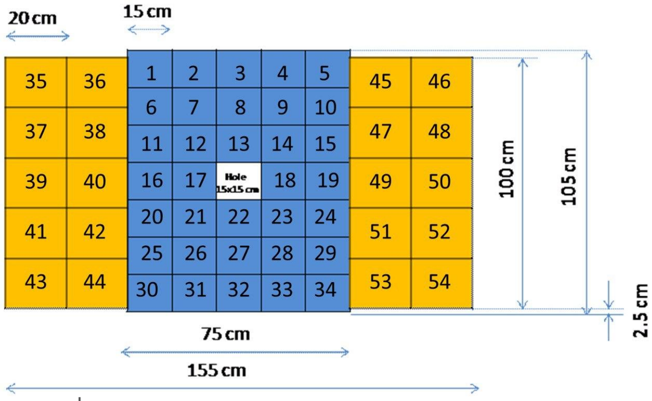
Describing the high-density matter using the mean field

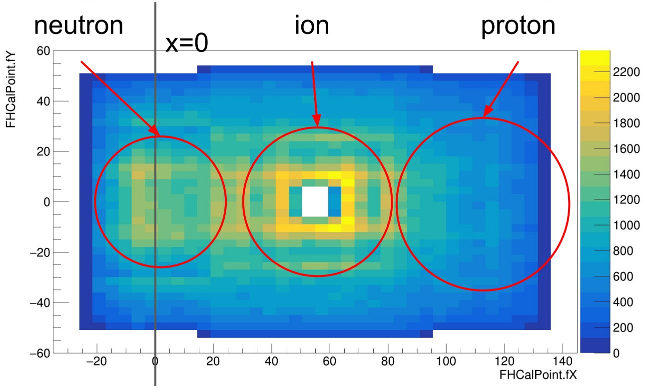
Flow measurements constrain the mean field

Discrepancy is probably due to non-flow correlations

The BM@N experiment (GEANT4 simulation for RUN8)







VF tracking was used

Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

The last production was used

Flow vectors

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

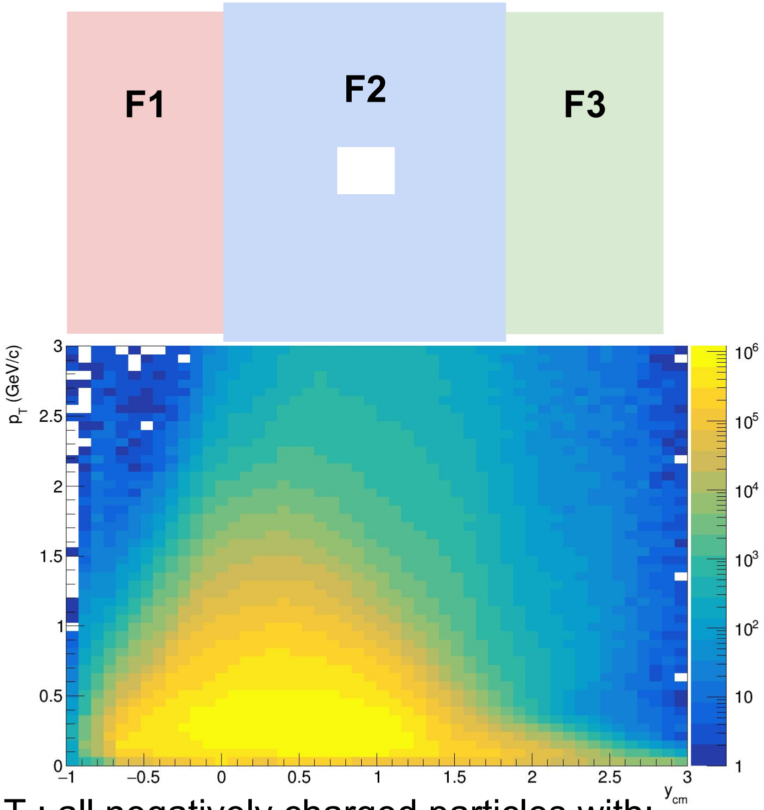
$$u_n = e^{in\phi}$$

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:

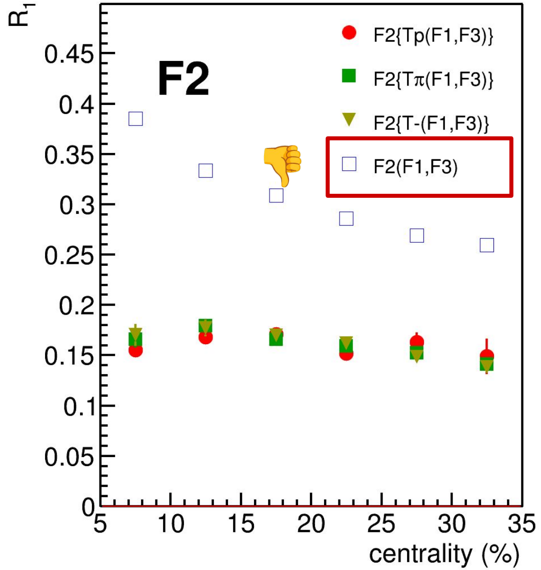
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

T+: all positively charged particles with:

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

Flow methods for v_n calculation

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



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):

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

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

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

Preliminary results for proton v_1

Analysis Note

Directed flow v_1 of protons in the Xe+Cs(I) collisions at 3.8 AGeV (BM@N run8)

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National Research Nuclear University MEPhI, Moscow, Russia

Joint Institute for Nuclear Research, Dubna, Russia

Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

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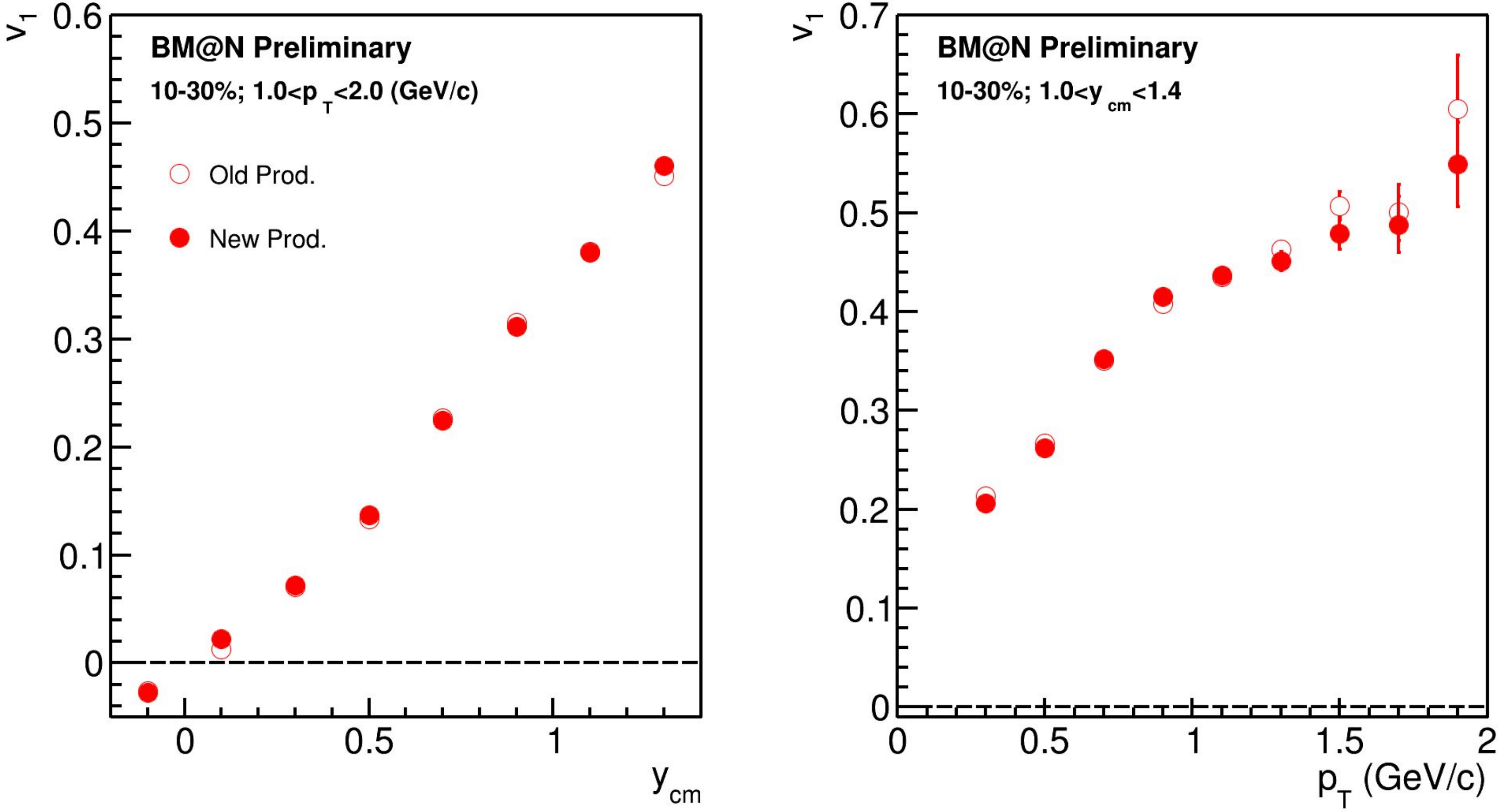
In this note, we present the directed flow v_1 measurements of protons from Xe+Cs(I) collisions at 3.8 AGeV (BM@N run8). We show the datasets, event and track selection cuts, centrality definition, event plane reconstruction and resolution. The v_1 results are presented as function of transverse momentum (p_T) and rapidity (y_{cm}) for 10-30% central Xe+Cs(I) collisions. The systematic uncertainty study will also be presented and discussed. The v_1 measurements are compared with results of JAM transport model calculations and published data from other experiments.

Analysis note: https://indico.jinr.ru/event/4750/attachments/19780/34163/ANoteFlowRun8.pdf

Total systematic uncertainty

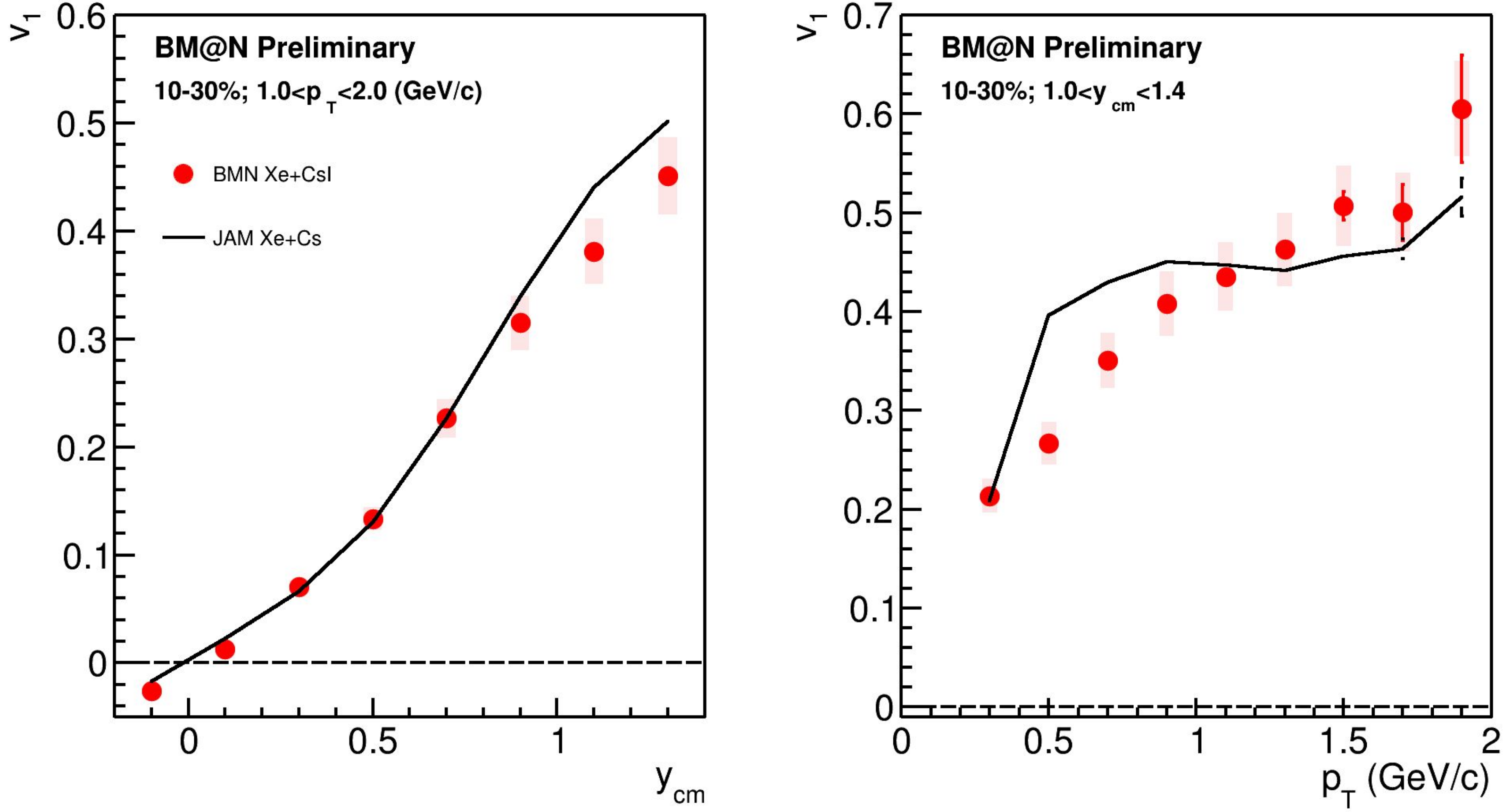
Nhits	chi2	Identification	Secondary	Non-flow	Non-zero v_1 at y_{cm}=0	vtx	Total
5%	2%	2%	1%	4%	2%	5%	8%

v_1 in new production compared with old one



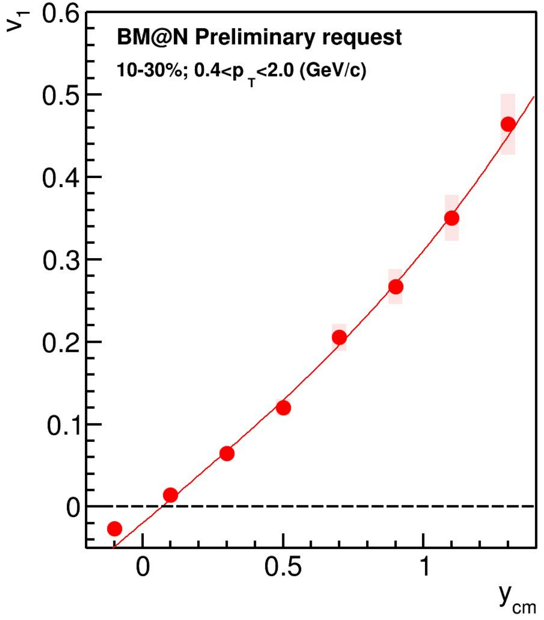
JAM model describes $v_1(y)$ well

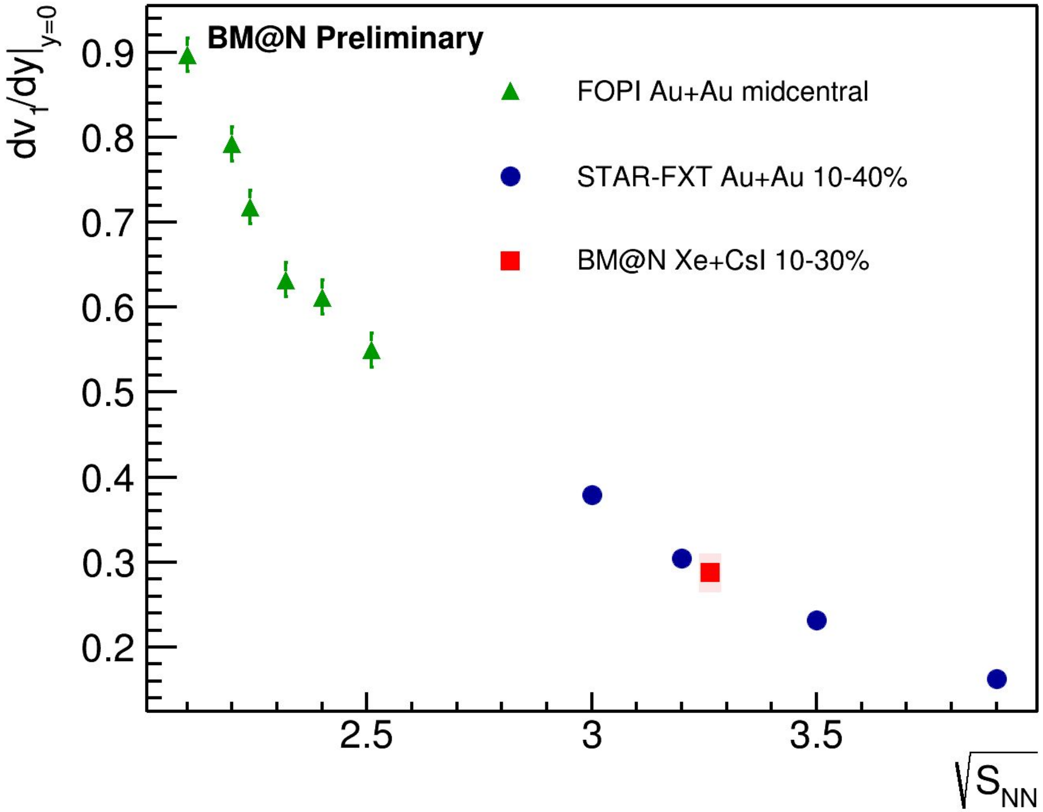
v_1 as a function of pT and y



JAM model describes $v_1(y)$ well

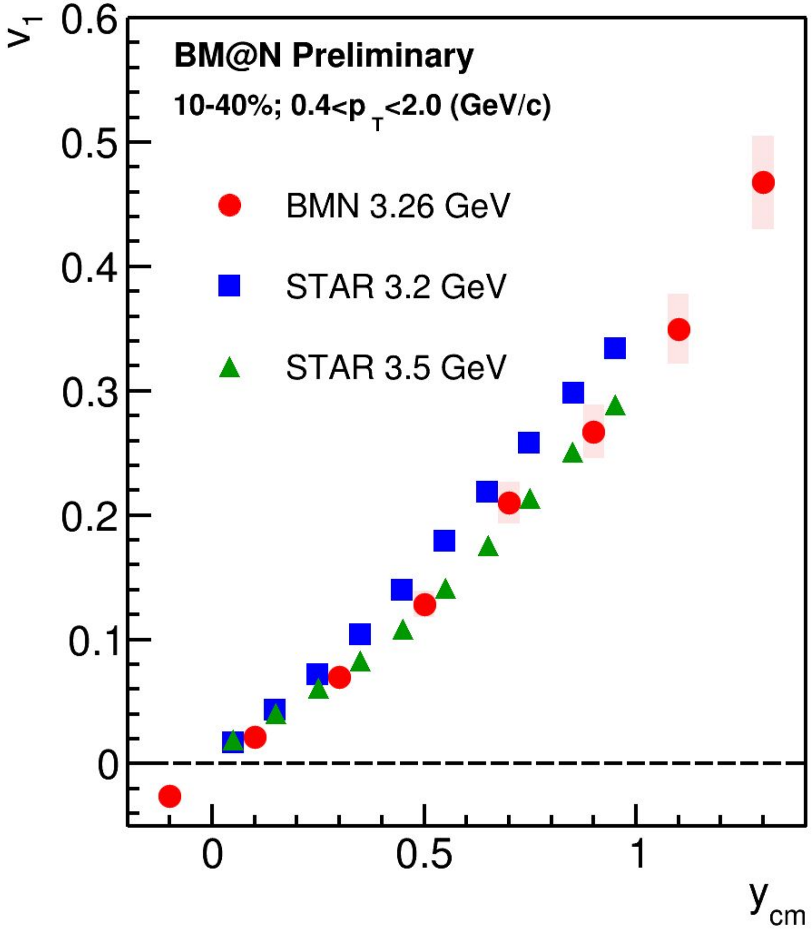
$dv_1/dy|_{y=0}$ vs collision energy





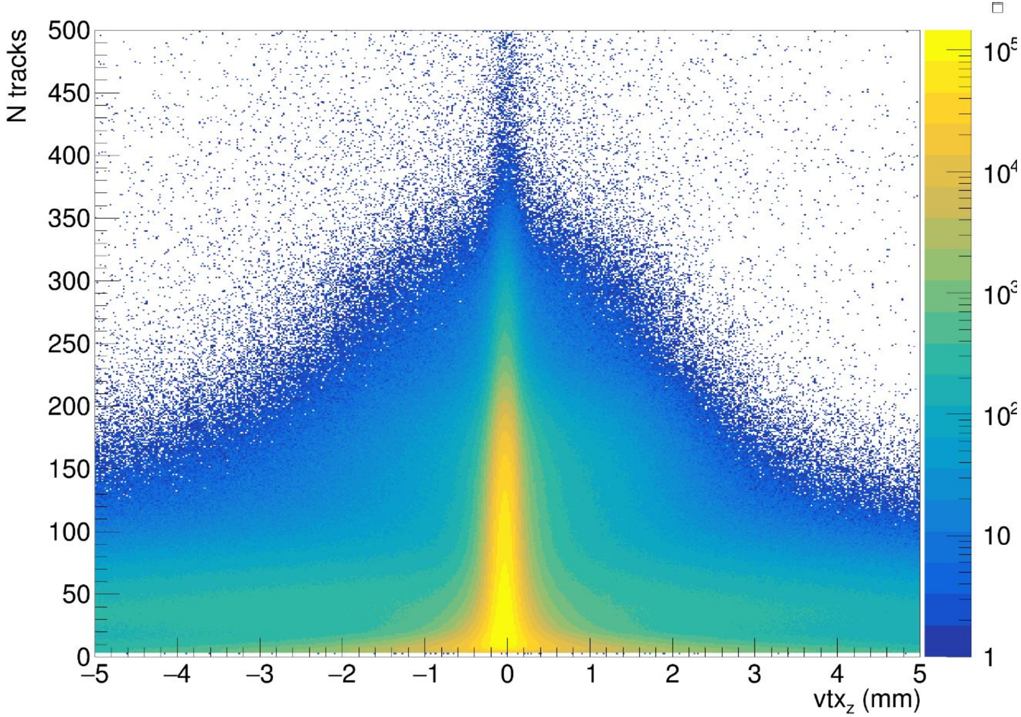
dv_1/dy is in a good agreement with the world data

v_1 as a function of y: comparison with STAR

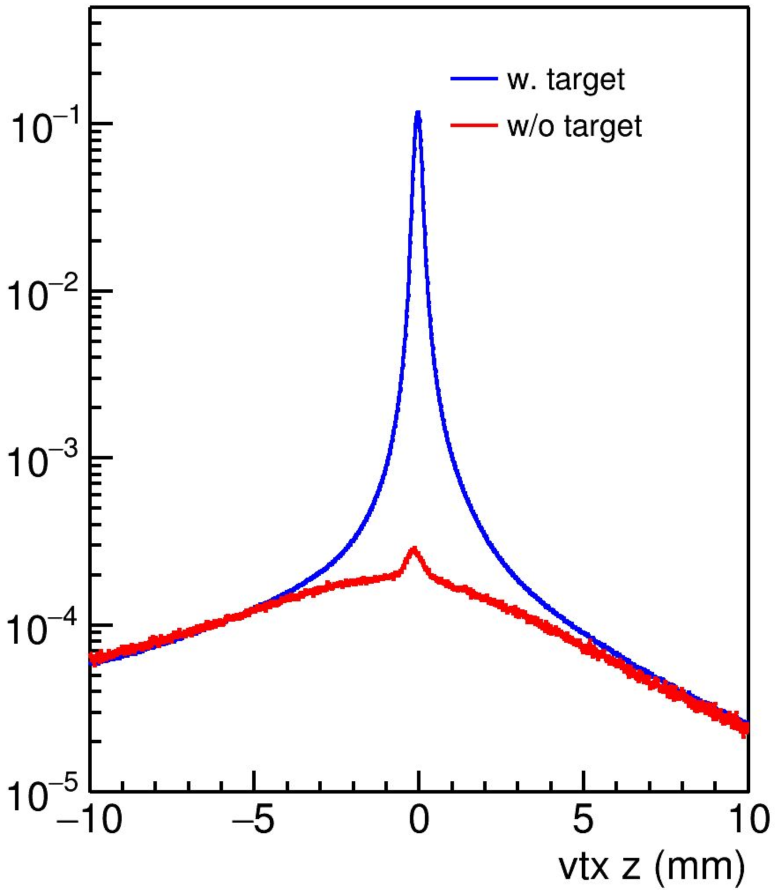


$v_1(y)$ is in a reasonable agreement with STAR DATA

Off-target collisions contribution

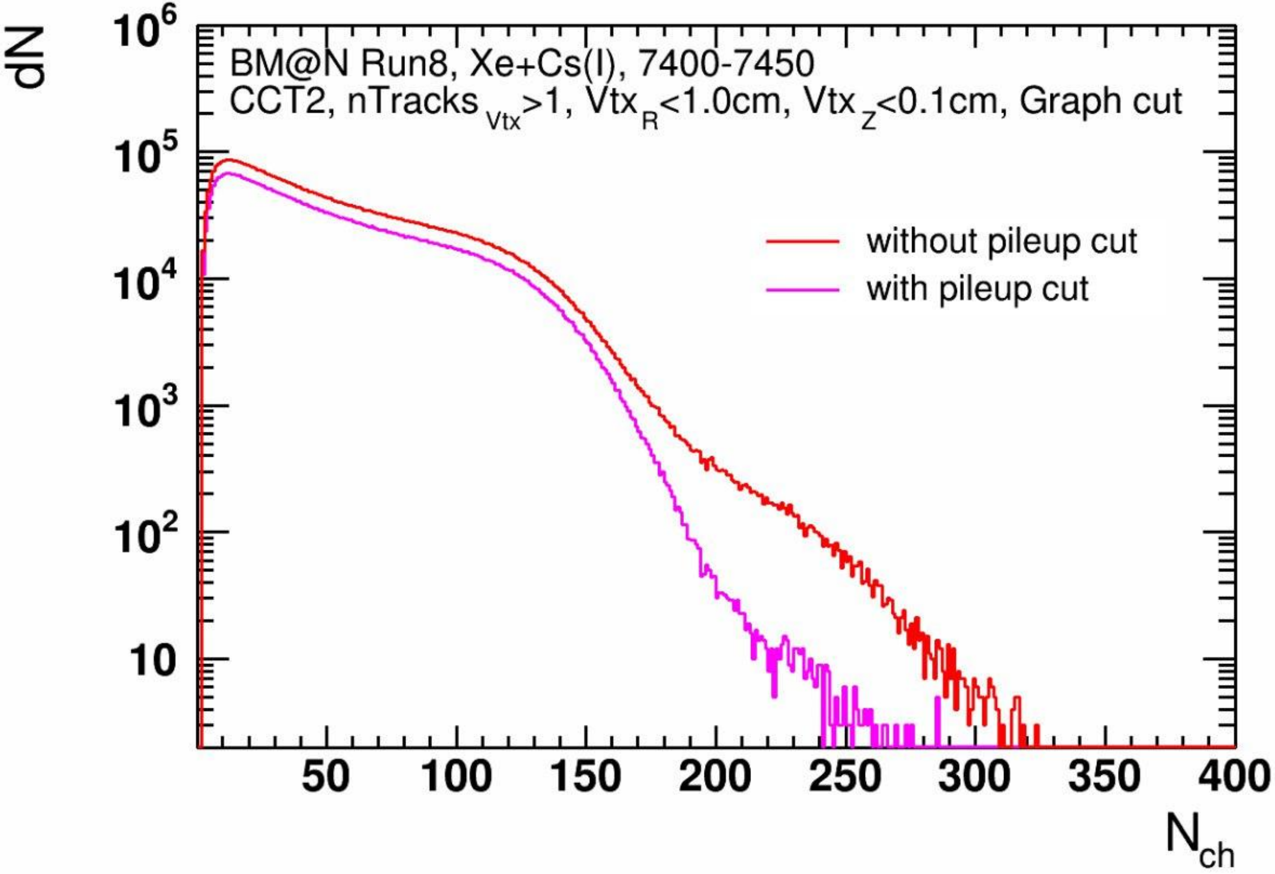


Total empty target contribution: ~5%
In the selected region (-0.1, 0.1): ~0.2%



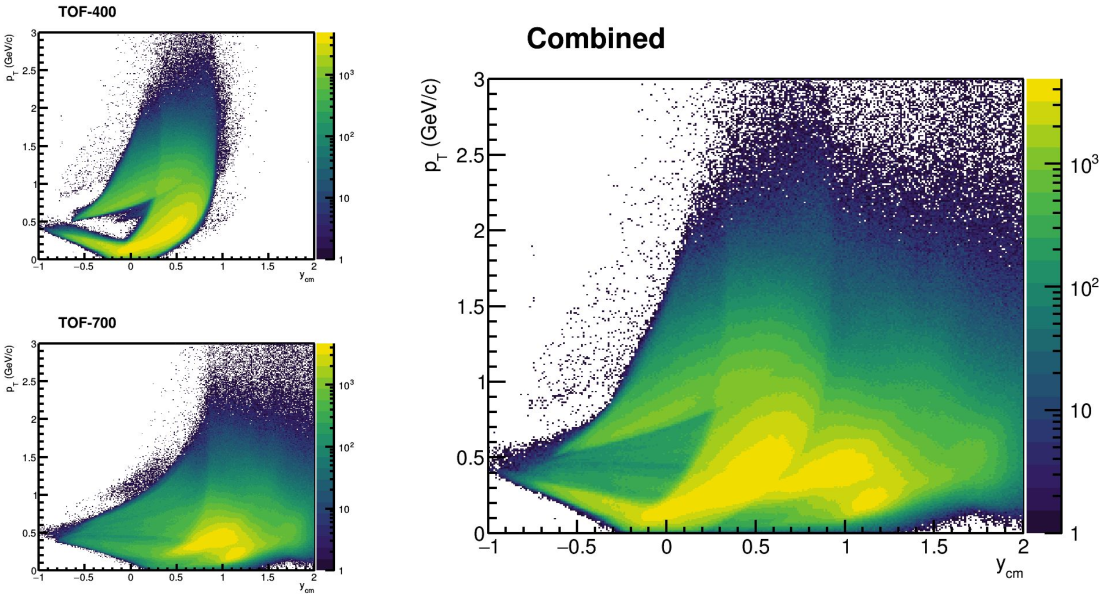
- With target — with all selection criteria used in analysis
- Without target — empty target runs + selection criteria
- Normalized to number of events, then scaled

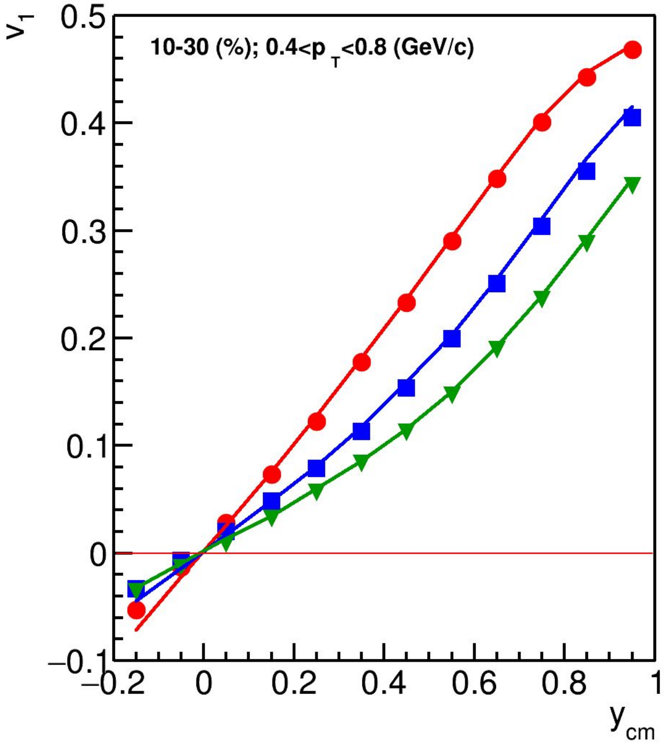
Outlook: Pilleup effect



We are going to study the pille-up effect using the selection based on Oleg Golosov's analysis

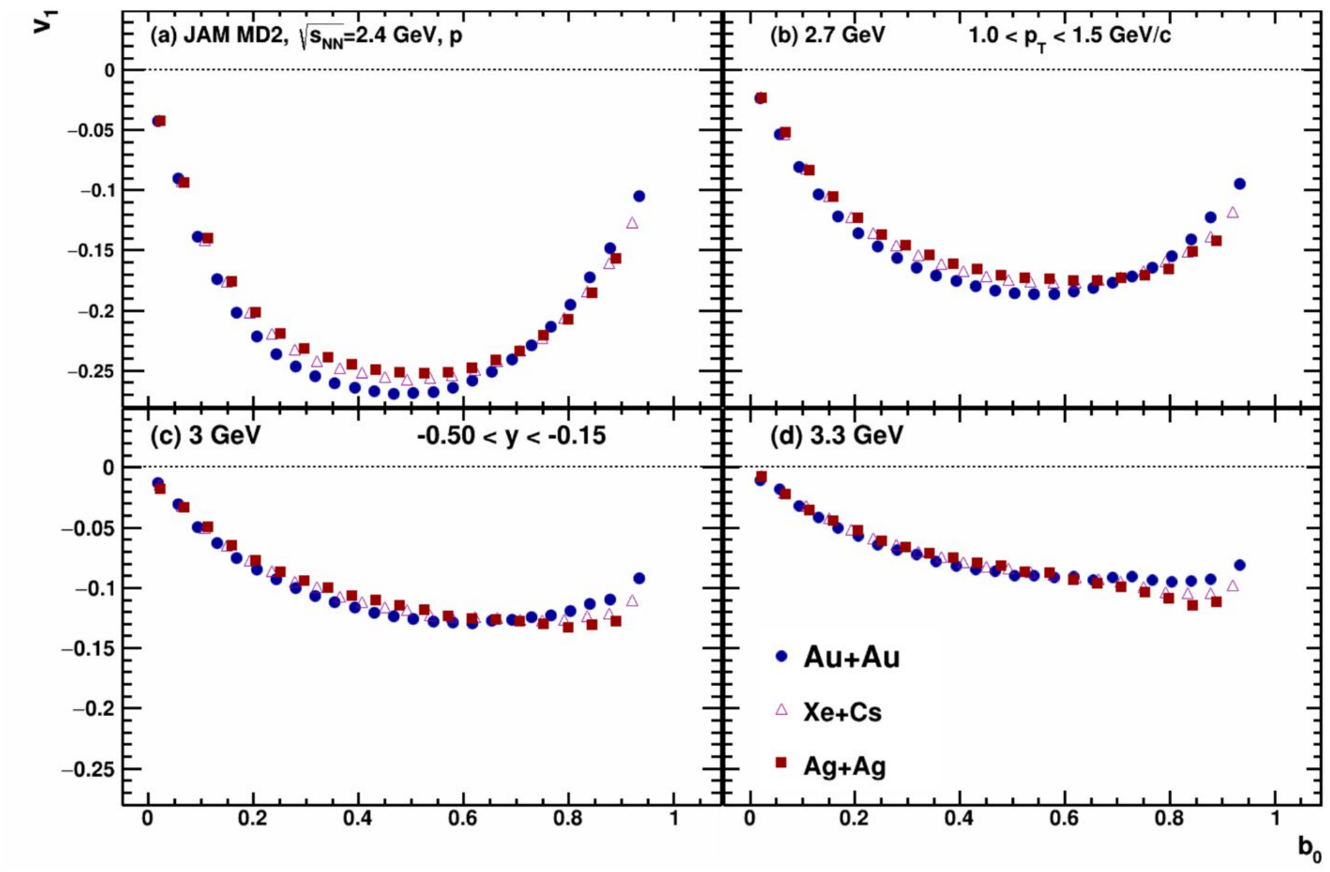
Increasing the acceptance of TOF-subsystems





- We need to increase the coverage of the TOF-subsystems in midrapidity
- Measuring the v_n at lower energies are required to study the system size dependence of v_n

v_1 with system size and collision energy



The results from JAM model in mean-field mode suggest v_1 in lighter systems will be comparable with Au+Au collisions

Particles 2022, 5, 561–579.

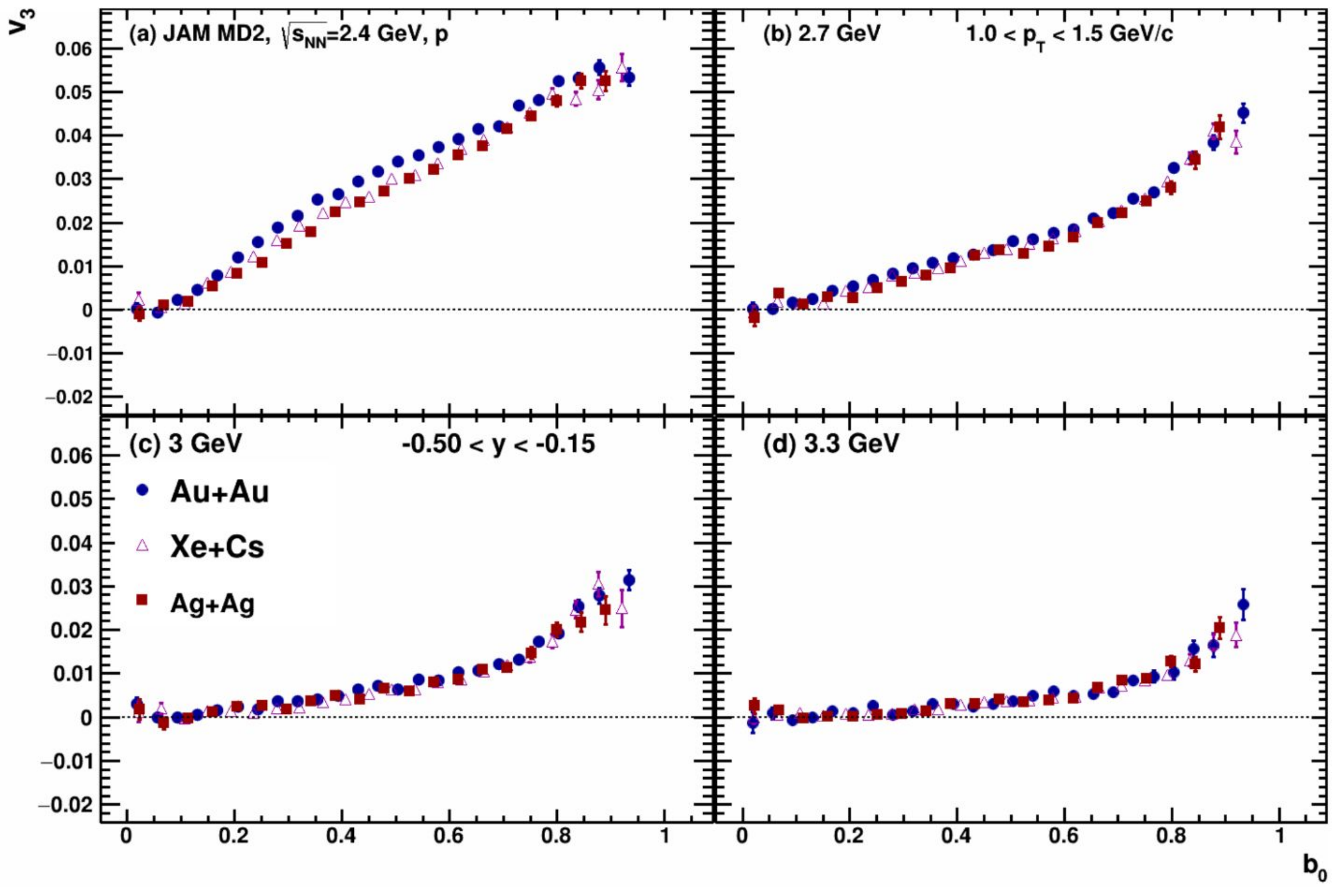
Summary

- Directed flow of protons is measured as a function of y, p_T and centrality
- v_1 as a function of y is found to be in a reasonable agreement with STAR data

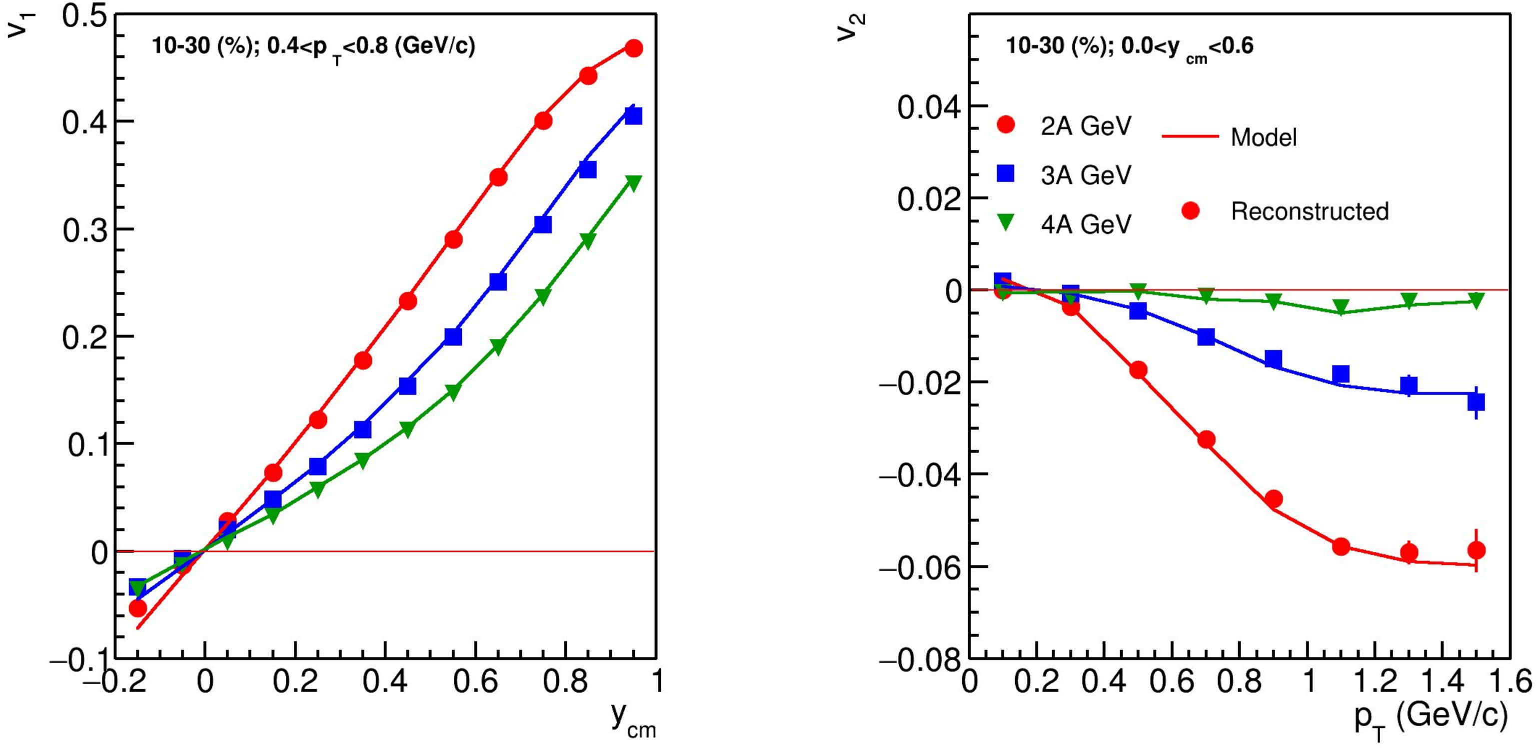
Finalizing the result:

- Pile-up rejection based on Oleg Golosov analysis will be applied
- The off-target events contribution is found to be ~0.2%

v_3 dependence on system size and collision energy

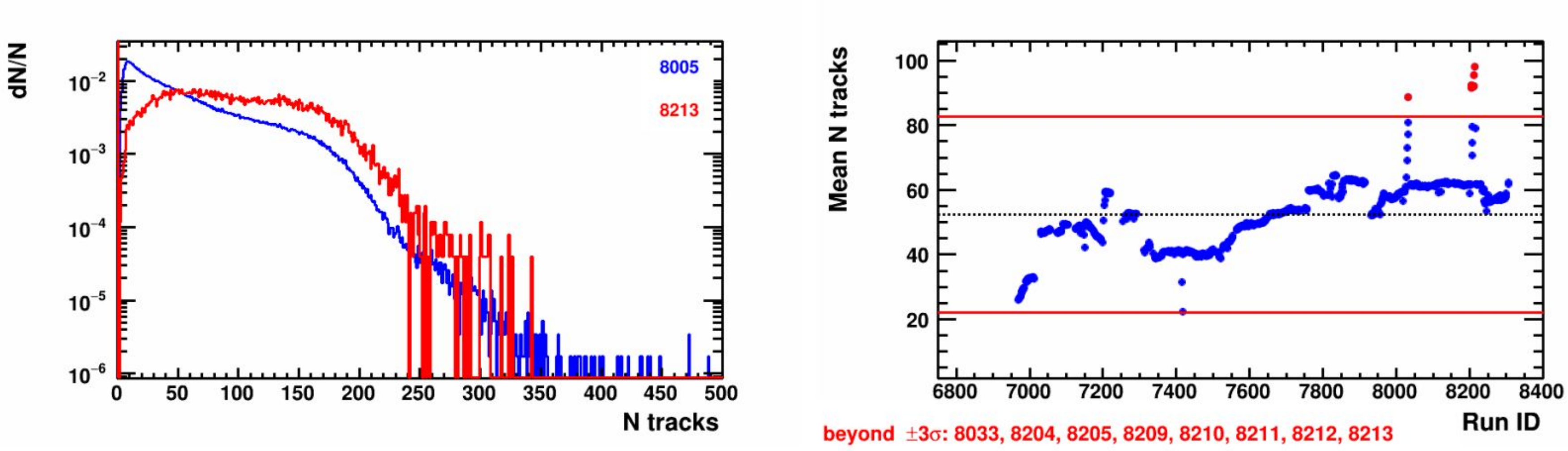


Performance for v_1 and v_2 in Xe+Cs (JAM+GEANT4)



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

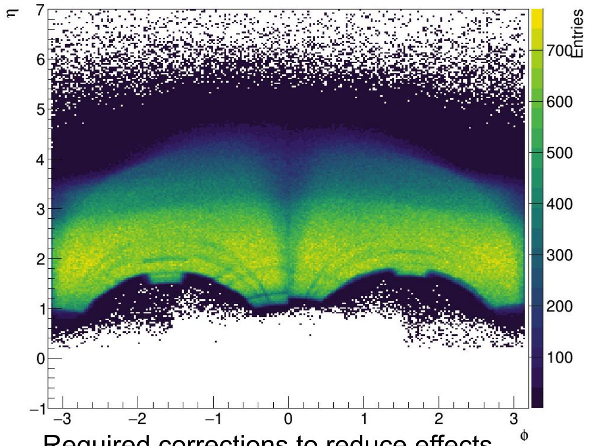
Quality assurance for the recent data



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.

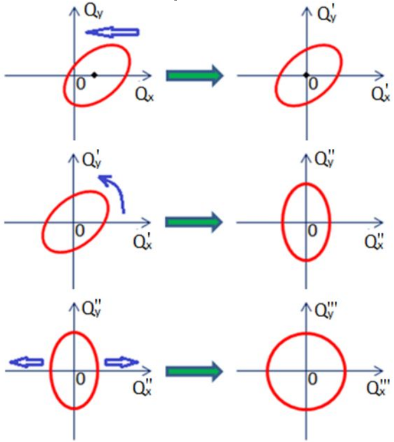
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

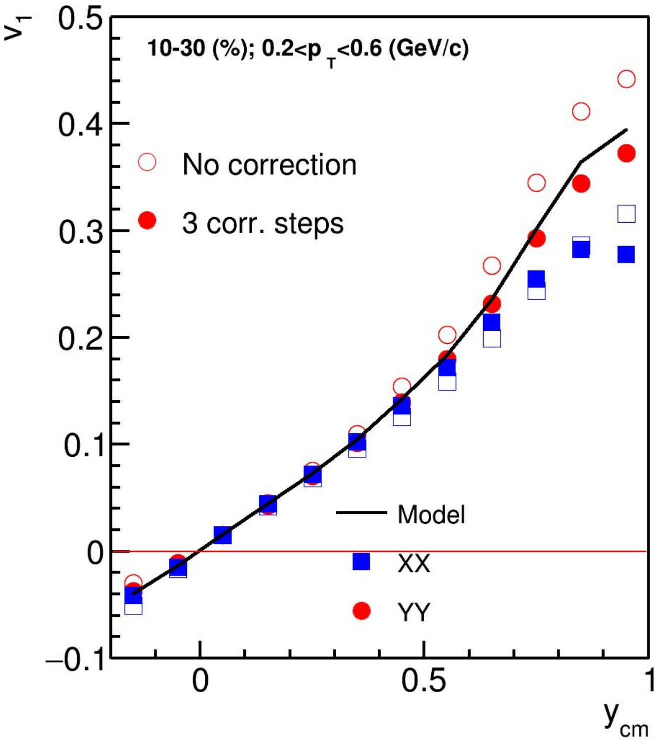


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

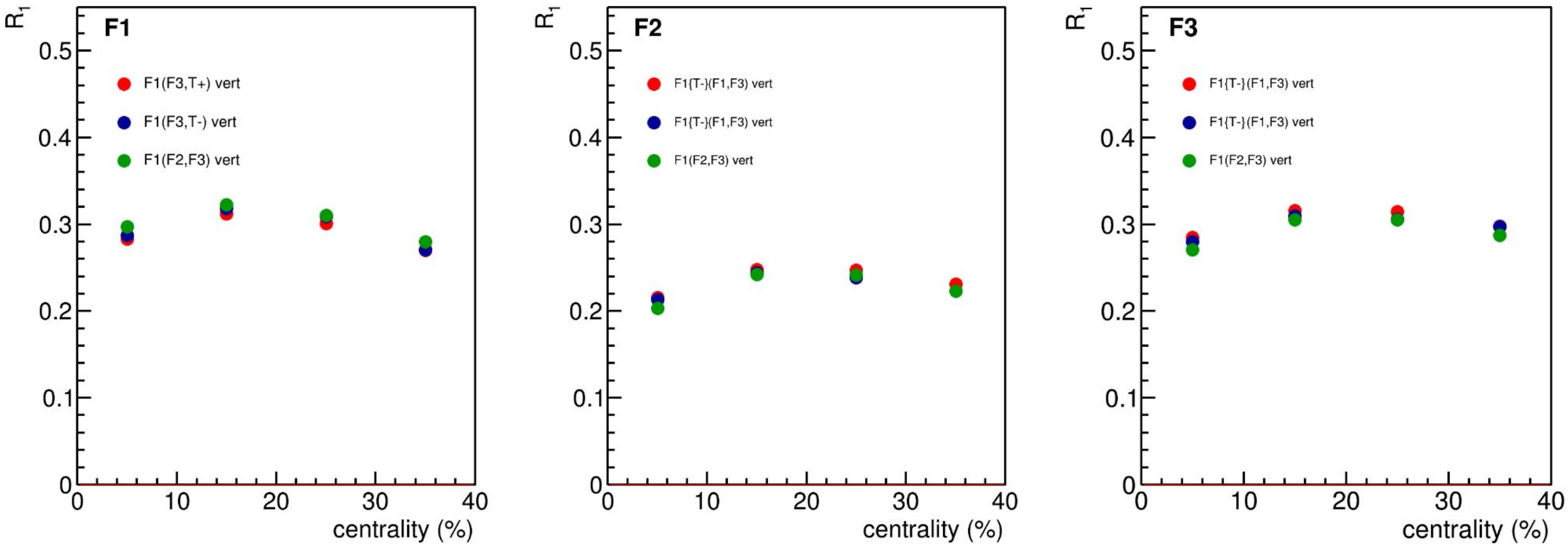


Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)



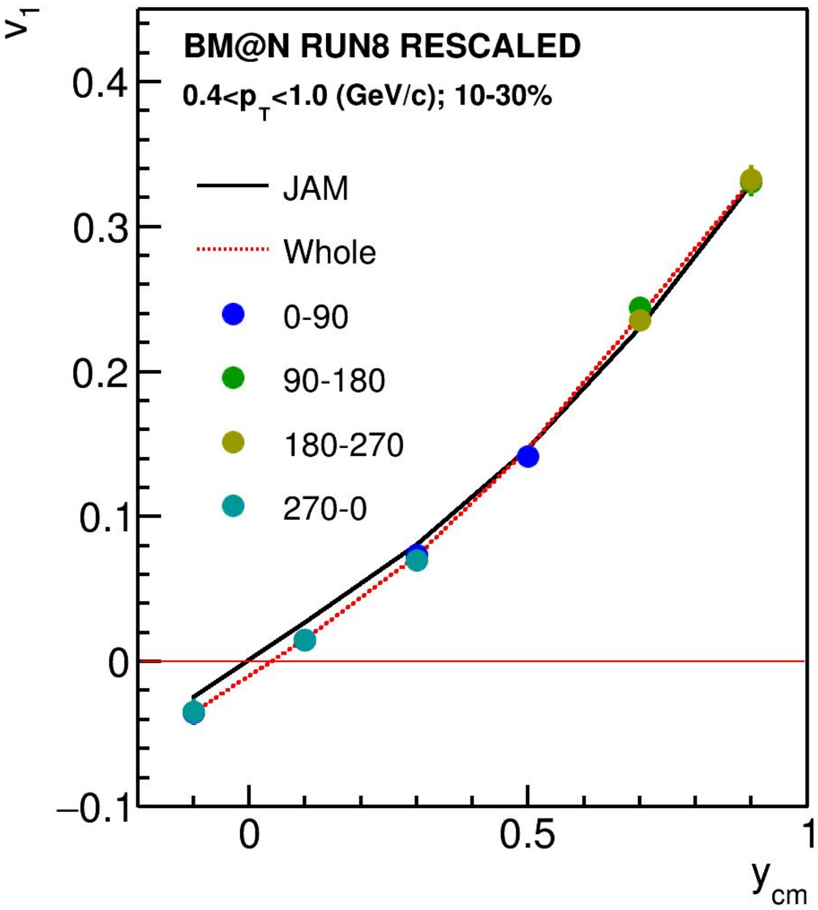
- Better agreement after rescaling for YY
- XX component has too large bias (due to magnetic field)

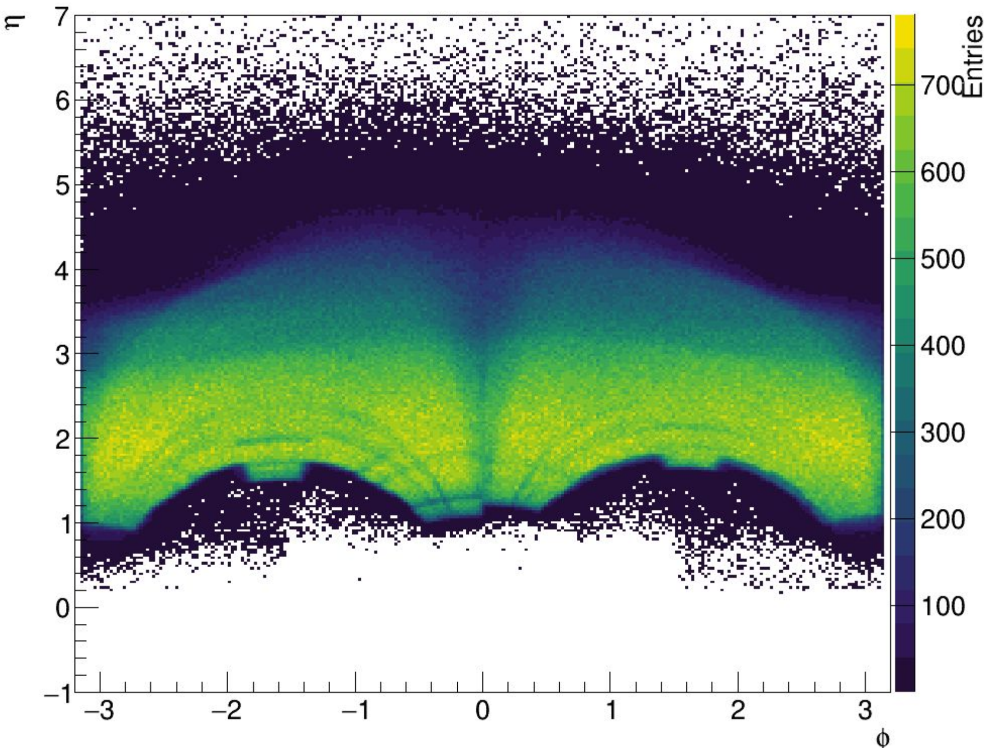
Symmetry plane resolution in Xe+Cs(I) collisions



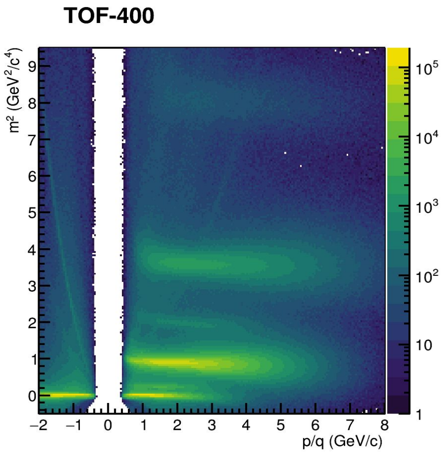
All the estimations for symmetry plane resolutions are in a good agreement

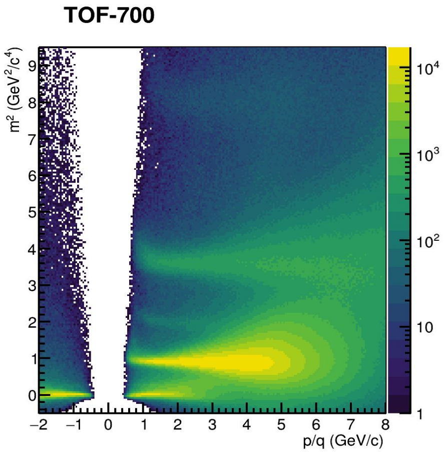
Residual effects of detector non-uniformity

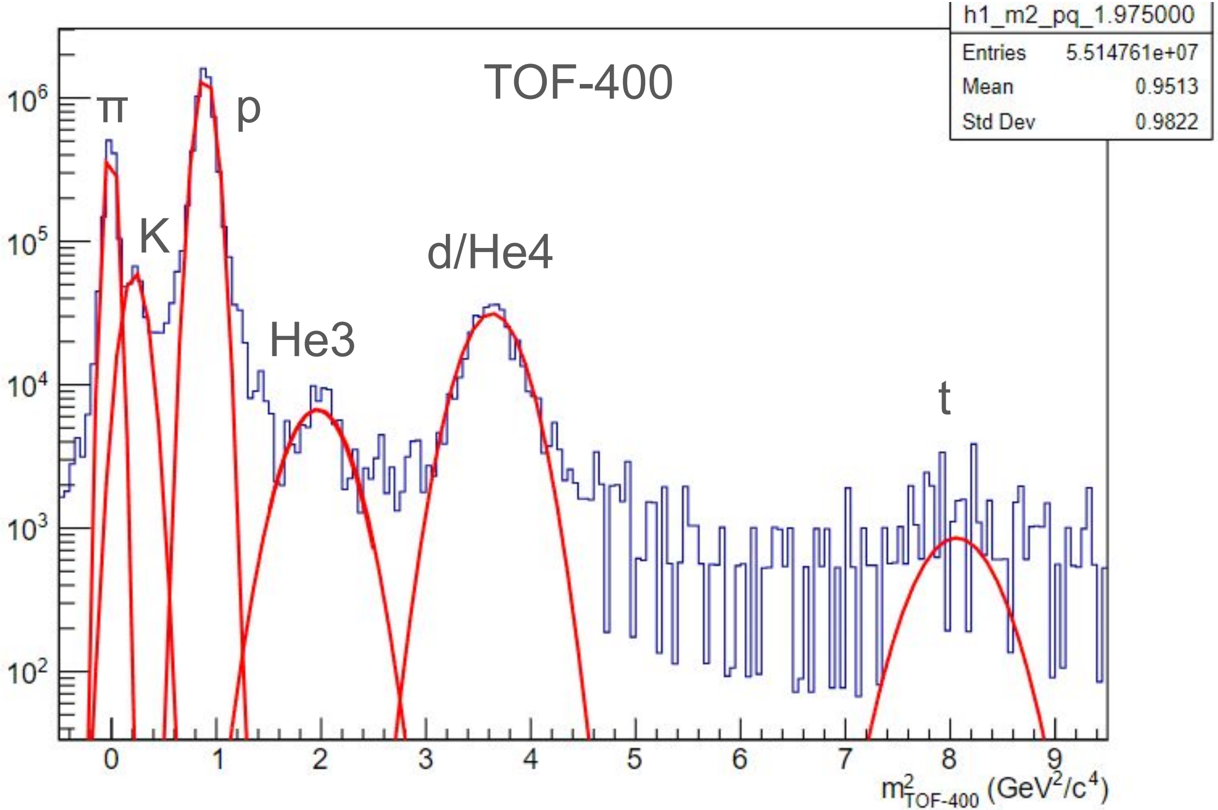




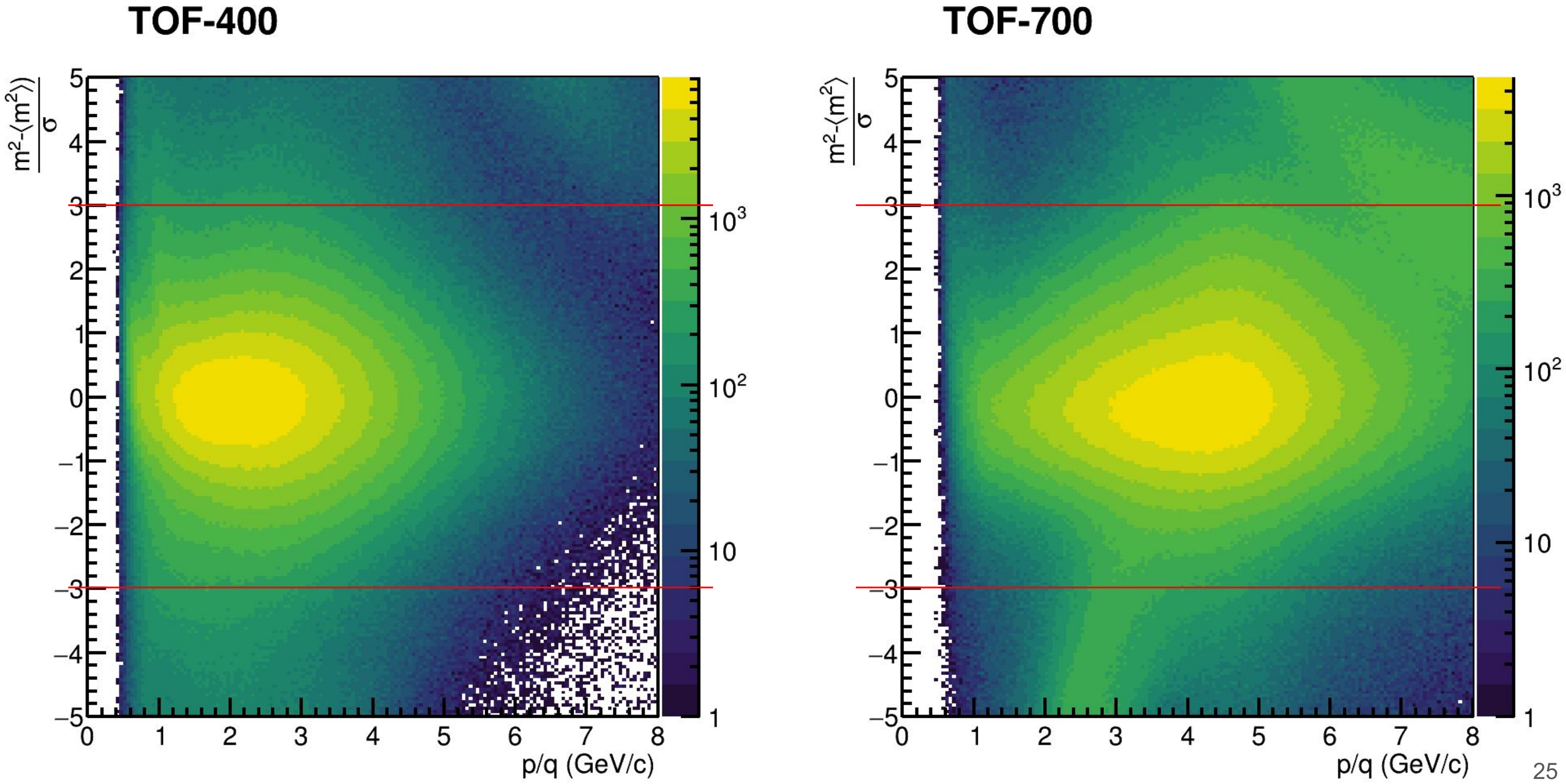
Particle identification



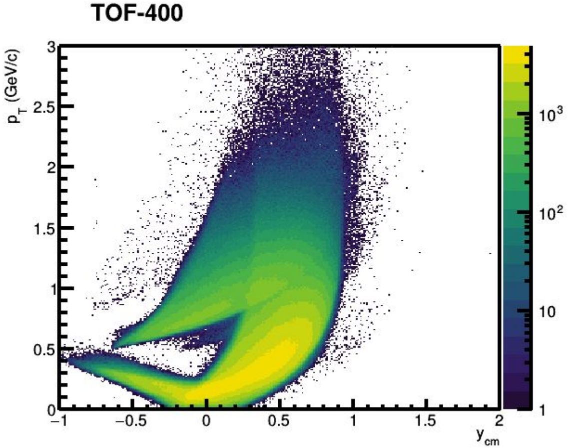


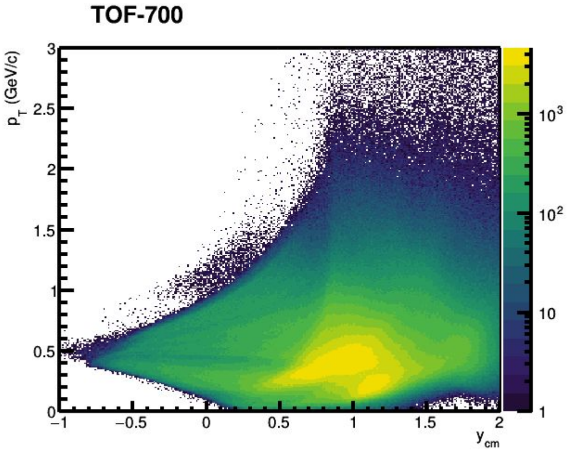


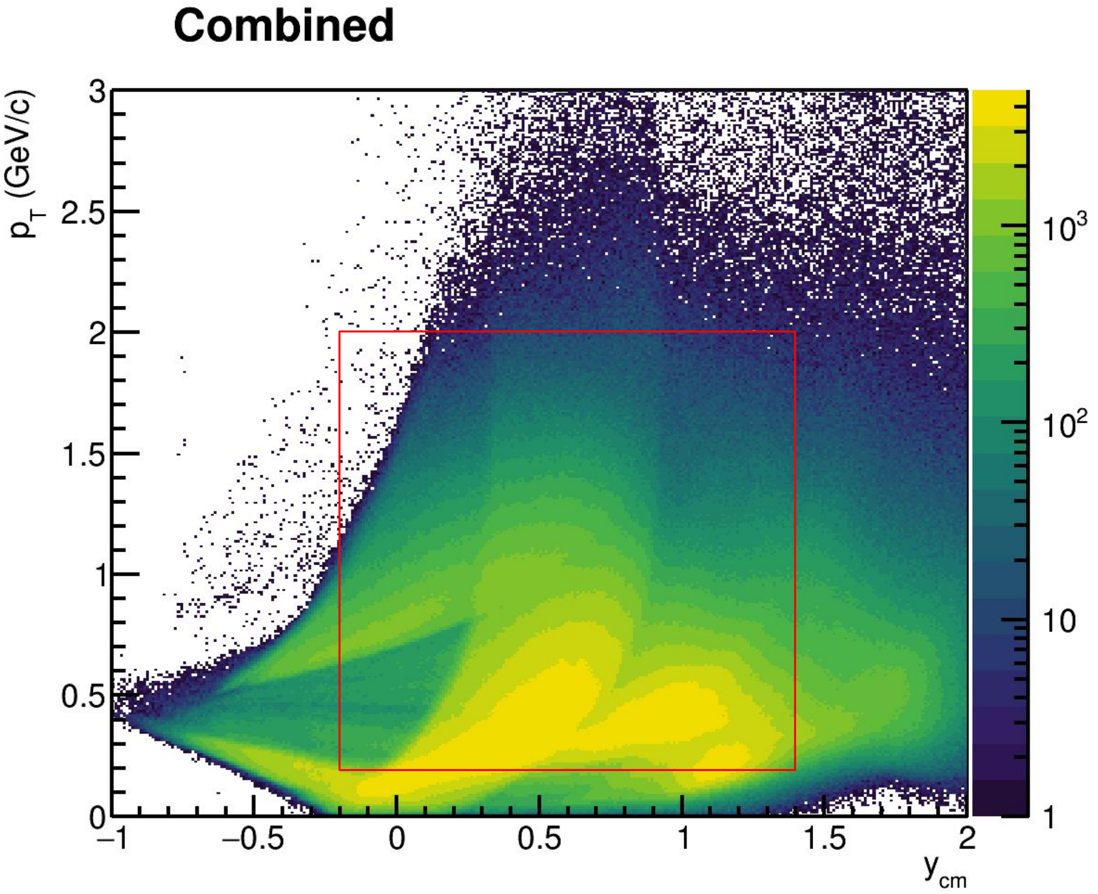
Proton N-sigma distributions



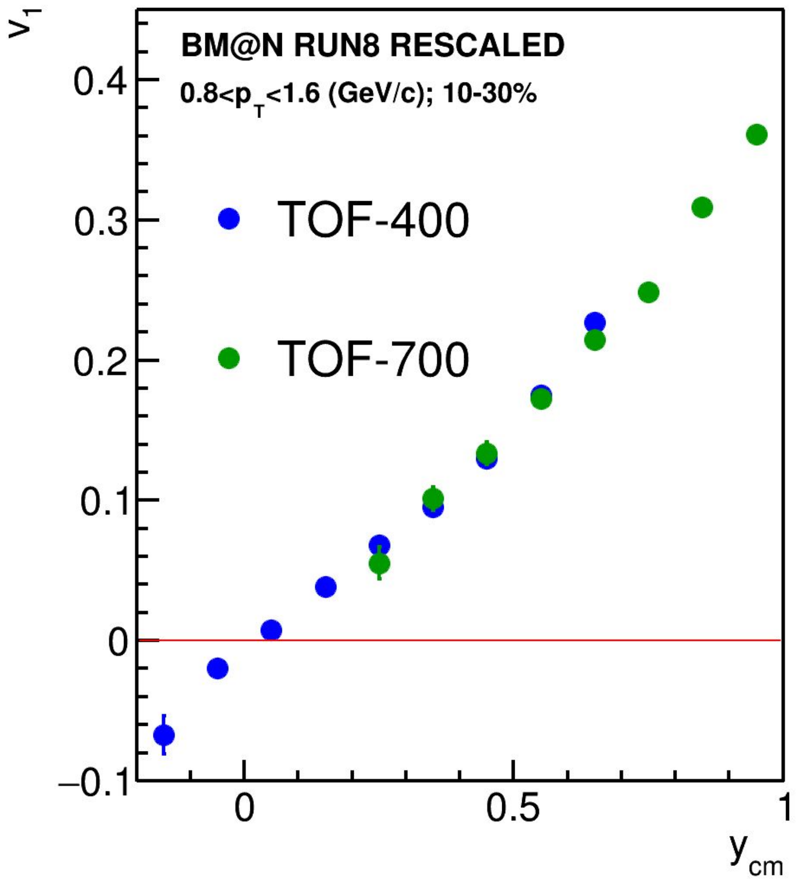
Proton p_T-y acceptance





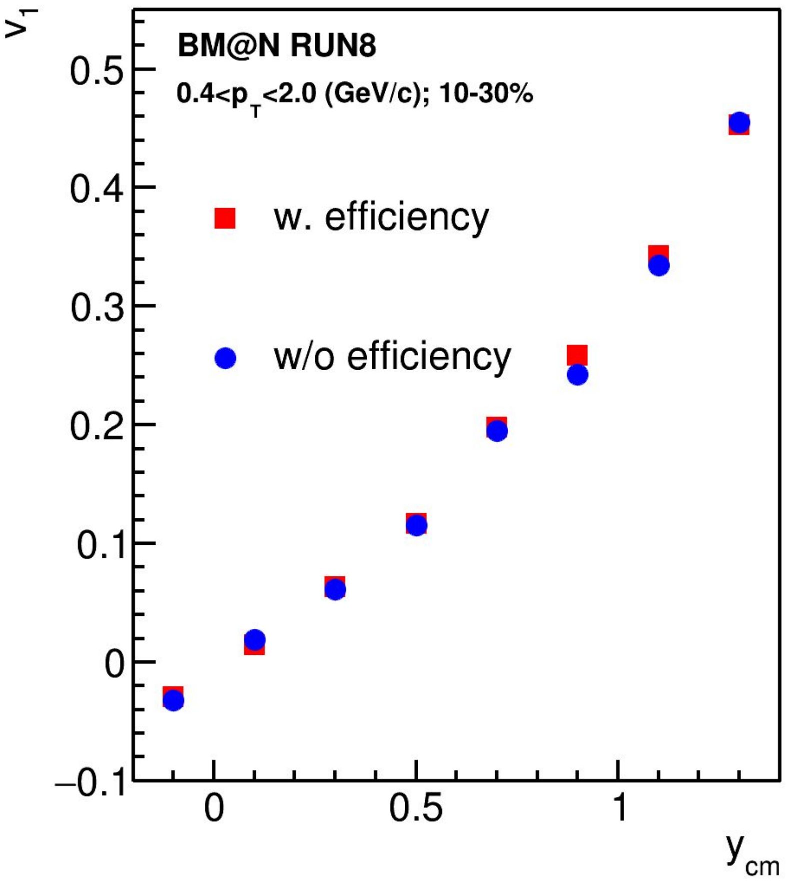


Comparison of the TOF performances

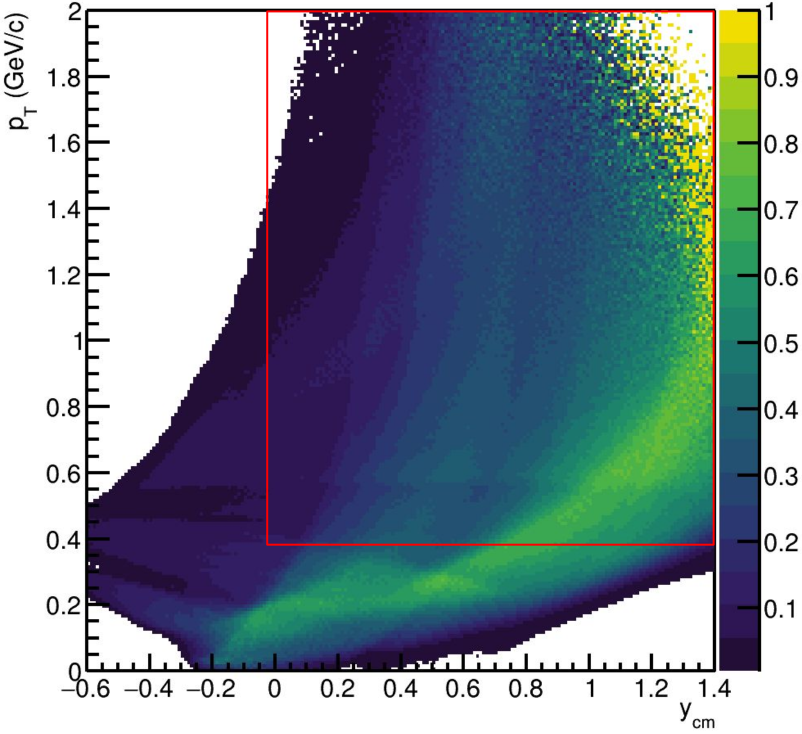


The results from TOF-400 and TOF-700 are in a good agreement

Comparison of the TOF performances

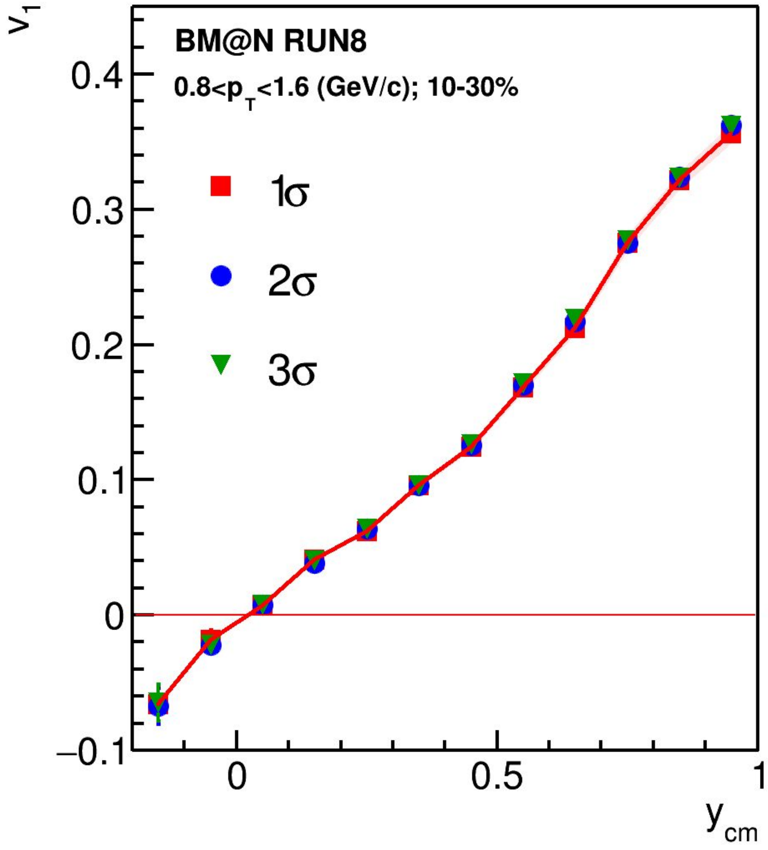


Efficiency using JAM

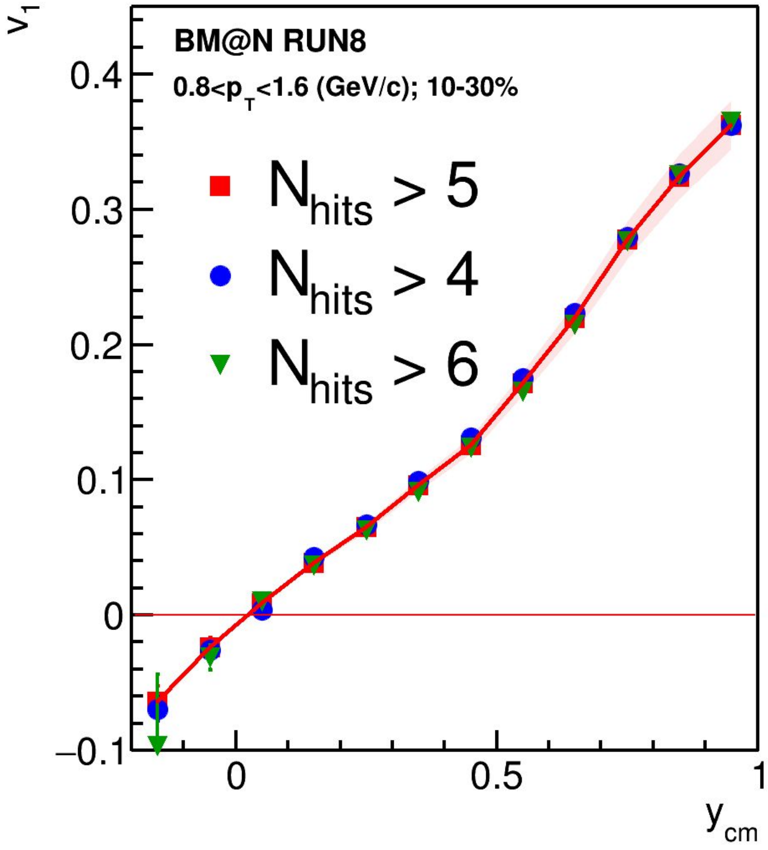


Results with and without efficiency are in a good agreement

Systematics due to identification and tracking

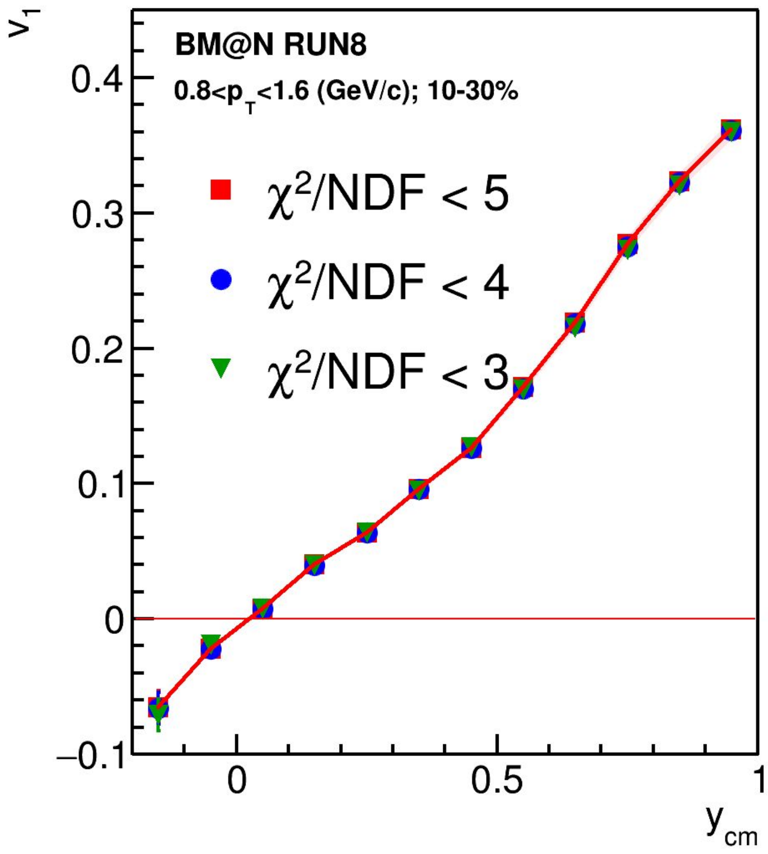


The systematics is below 2%

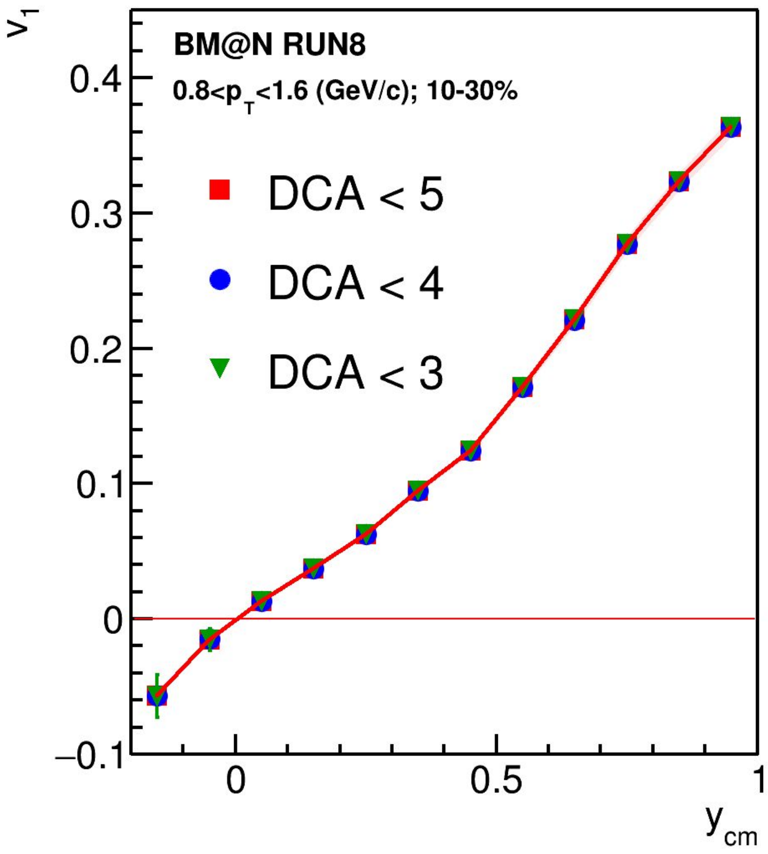


The systematics is below 5%

Systematics due to tracking and secondary

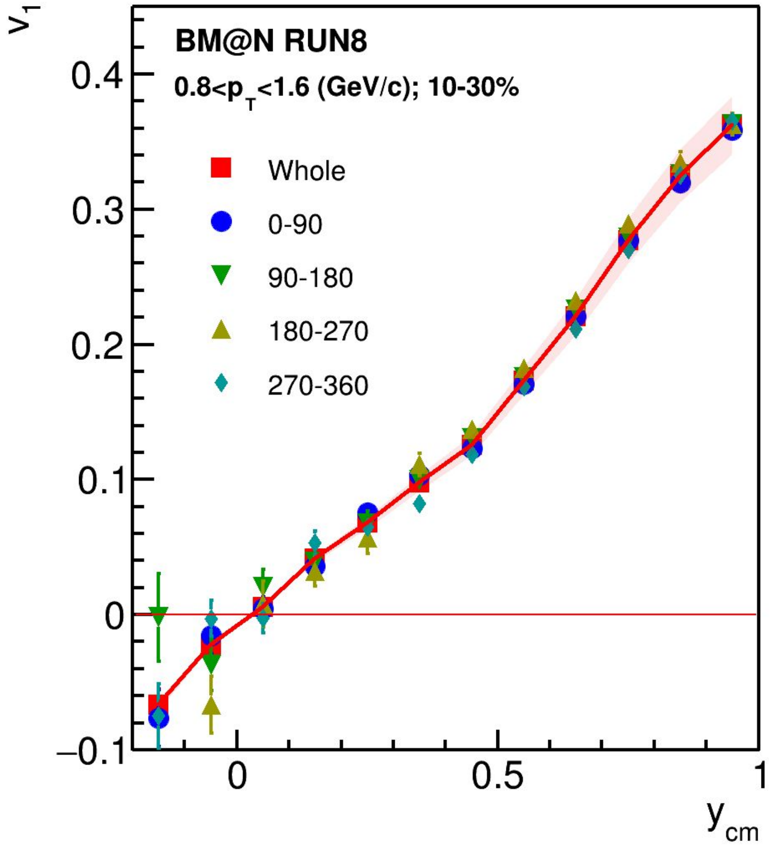


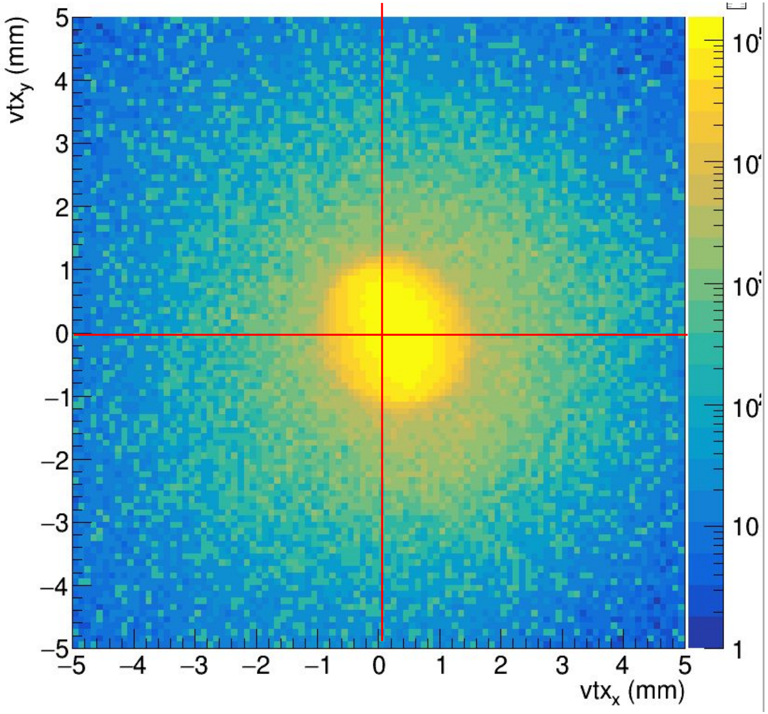
The systematics is below 2%



The systematics is below 1%

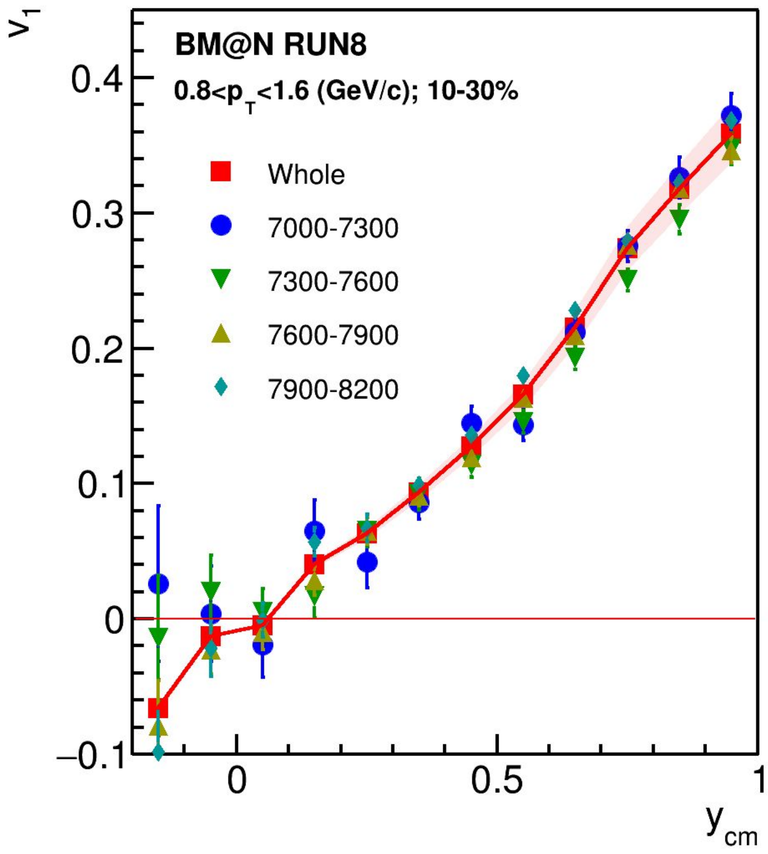
Systematics due vtx position



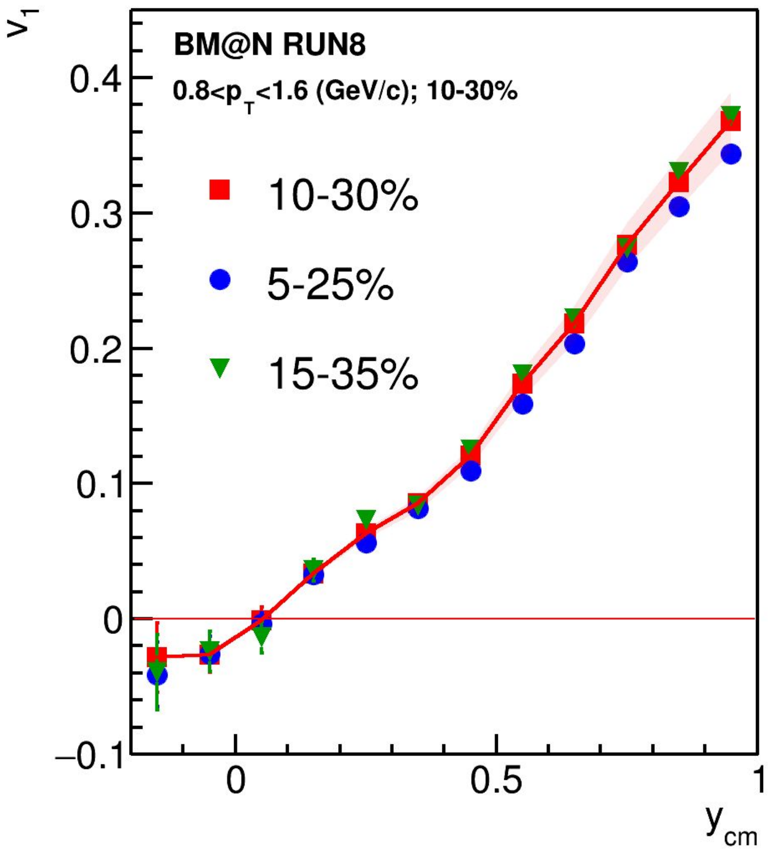


The systematics is below 5%

Cross-check of run-by-run variations and centrality

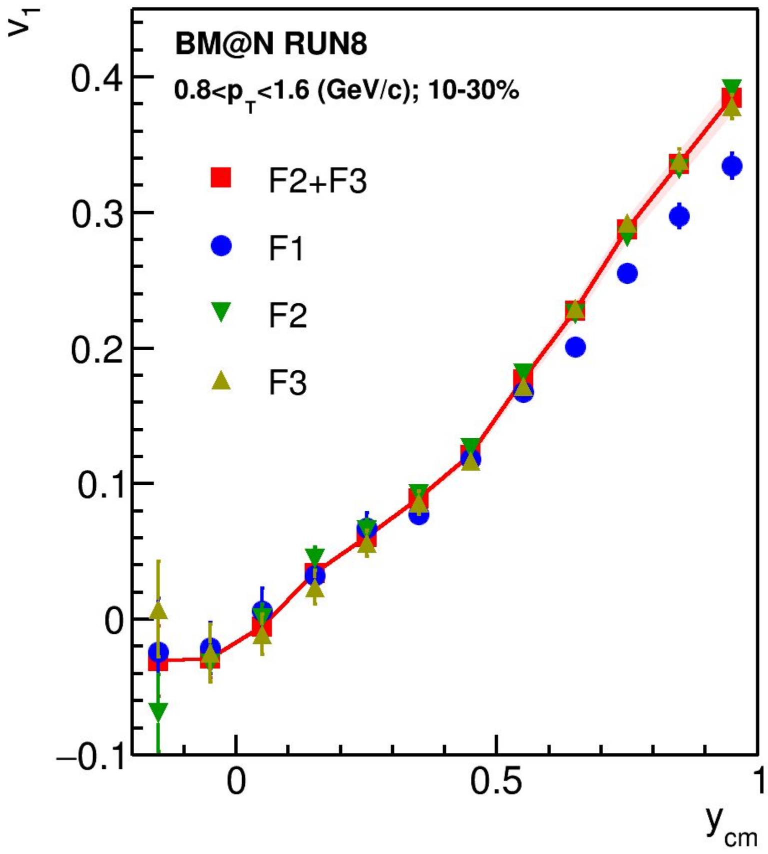


The systematics is below 6%



The systematics is below 6%

Systematics due to symmetry plane estimation (non-flow)



The systematics is below 3%

List of presentations

Weekly meetings (BERDS)

1. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/13.%20BERDS%20Meeting%2004052022/
2. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/14.%20BERDS%20Meeting%2018052022/
3. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/15.%20BERDS%20Meeting%2001062022/
4. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/17.%20BERDS%20Meeting%2015062022/
5. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/20%D1%8E%D0%98%D0%A3%D0%9A%D0%92%D0%AB%20%D0%AC%D1%83%D1%83%D0%B5%D1%88%D1%82%D0%BF%2013.07.2022/
6. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/21.%20BERDS%20Meeting%2020.07.2022/
7. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/22.%20BERDS%20Meeting%2003082022/
8. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/23.%20BERDS%20Meeting%2010082022/
9. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/24.%20BERDS%20Meeting%2012092022/
10. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/26.%20BERDS%20Meeting%2026102022/
11. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2022/28.%20BERDS%20Meeting%2023112022/
12. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2023/07.%20BERDS%20Meeting%2005042023/
13. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2023/16.%20BERDS%20Meeting%2019072023/
14. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2023/20.%20BERDS%20Meeting%2020092023/
15. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2024/04.%20BERDS%20Meeting%2007022024/
16. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2024/06.%20BERDS%20Meeting%2021022024/
17. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2024/07.%20BERDS%20Meeting%2028022024/
18. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2024/09.%20BERDS%20Meeting%2027032024/
19. https://bmn-wiki.jinr.ru/bin/view/Meetings/6.%20Meetings/5.7.2%20Reconstruction/2024/13.%20BERDS%20Meeting%2019062024/

Collaboration and Analysis meetings

9th Collaboration Meeting of the BM@N Experiment at the NICA Facility
https://indico.jinr.ru/event/2912/contributions/17313/
https://indico.jinr.ru/event/2912/contributions/17312/
https://indico.jinr.ru/event/2912/contributions/17407/

10th Collaboration Meeting of the BM@N Experiment at the NICA Facility
https://indico.jinr.ru/event/3531/contributions/20552/
https://indico.jinr.ru/event/3531/contributions/20553/
https://indico.jinr.ru/event/3531/contributions/20554/

Analysis & Software Meeting of the BM@N Experiment
https://indico.jinr.ru/event/3876/contributions/22787/\
https://indico.jinr.ru/event/3876/contributions/22788/
https://indico.jinr.ru/event/3876/contributions/22863/

11th Collaboration Meeting of the BM@N Experiment at the NICA Facility
https://indico.jinr.ru/event/3961/contributions/23786/
https://indico.jinr.ru/event/3961/contributions/23787/
https://indico.jinr.ru/event/3961/contributions/23783/

Analysis and Detector Meeting of the BM@N Experiment
Azimuthal collective anisotropy in the recent Xe+Cs(I) physical run
Report on the QA and run-by-run systematics in the Xe+Cs(I) run

12th Collaboration Meeting of the BM@N Experiment at the NICA Facility
https://indico.jinr.ru/event/4395/contributions/26533/
https://indico.jinr.ru/event/4395/contributions/26539/
https://indico.jinr.ru/event/4395/contributions/26536/

Backup

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

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

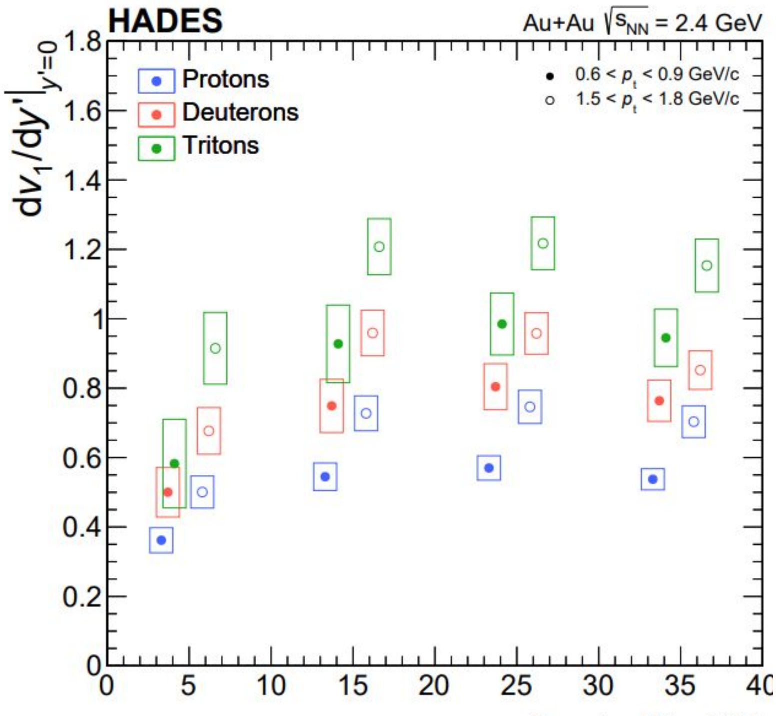
At N→∞ (N≫1)

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

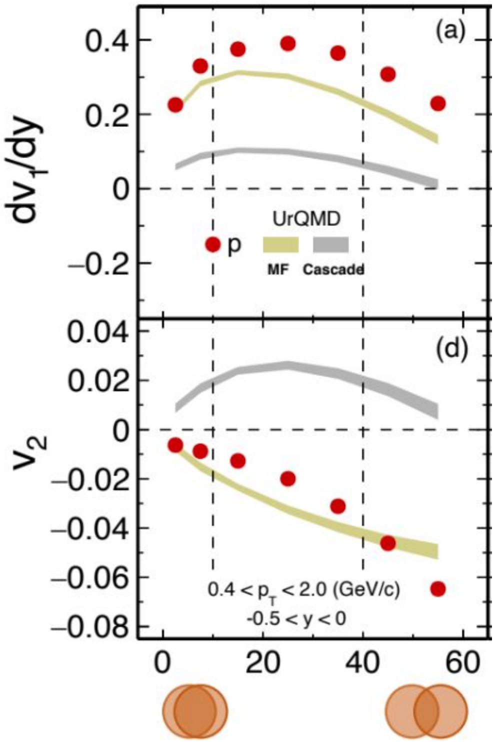
$$\langle u_n Q_n{}^* \rangle = \frac{\int d\vec{v} \int d\phi \int d\Psi_{RP} w(\phi, \Psi_{RP}, \vec{v}) e^{in\phi} V_n(\Psi_{RP}) e^{-in\Psi_n^{EP}} \rho(\phi - \Psi_{RP})}{\int d\vec{v} \int d\phi \int d\Psi_{RP} w(\phi, \Psi_{RP} \vec{v}) \rho(\phi - \Psi_{RP})}$$

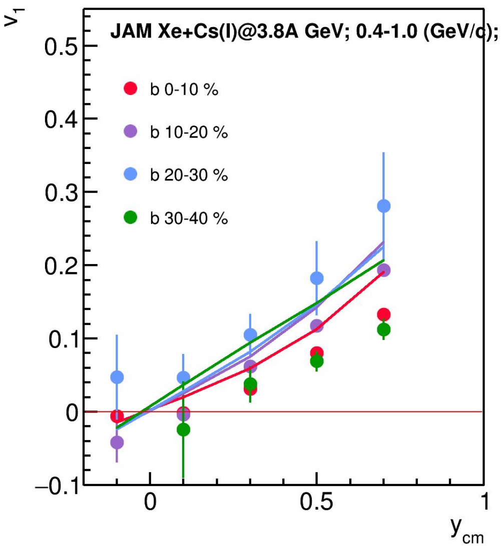
$$= \langle \cos n(\phi - \Psi_{RP}) V_n \cos n(\Psi_{RP} - Psi_n^{EP}) \rangle$$

dv_1/dy as a function of centrality



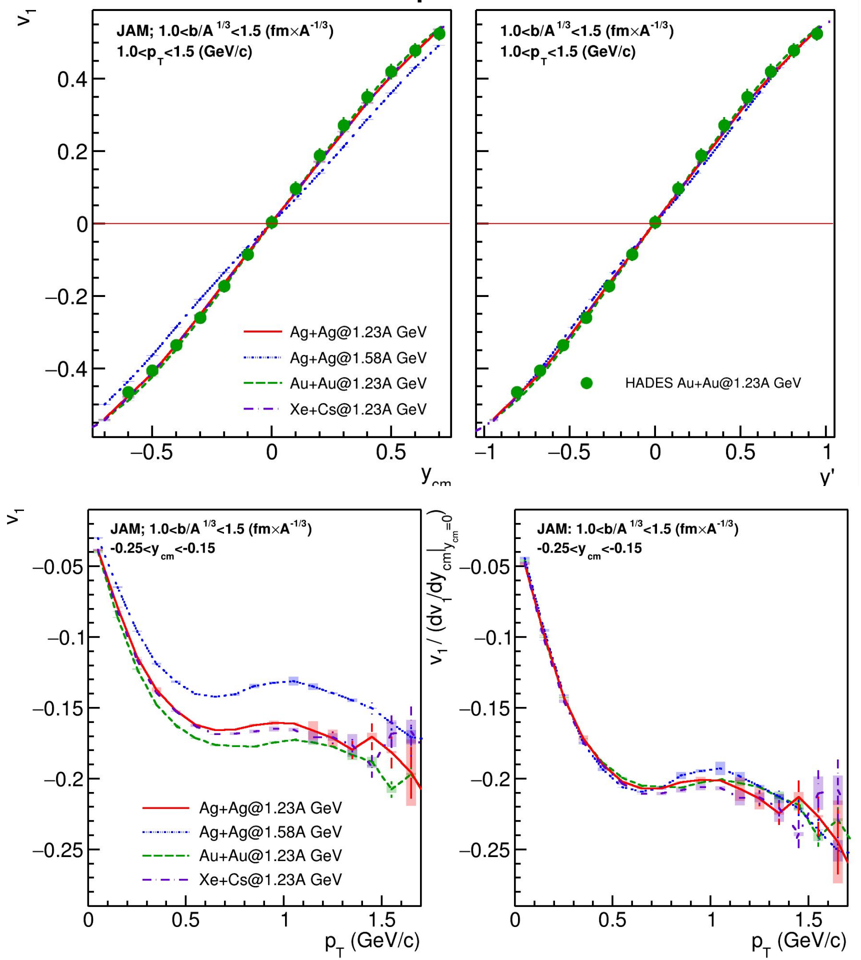
Eur.Phys.J.A 59 (2023) 4, 80





Weak centrality dependence for directed flow

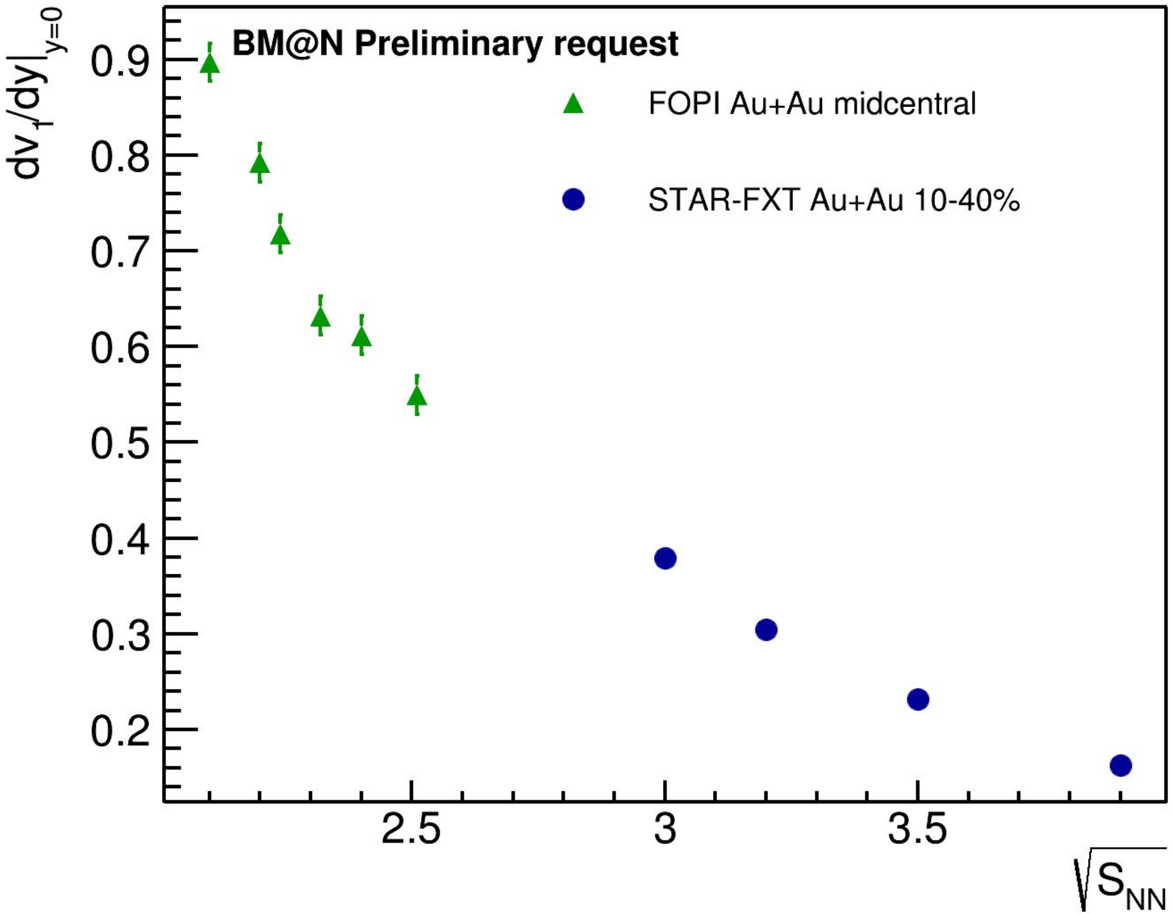
HADES: dv_1/dy scaling with collision energy and system size



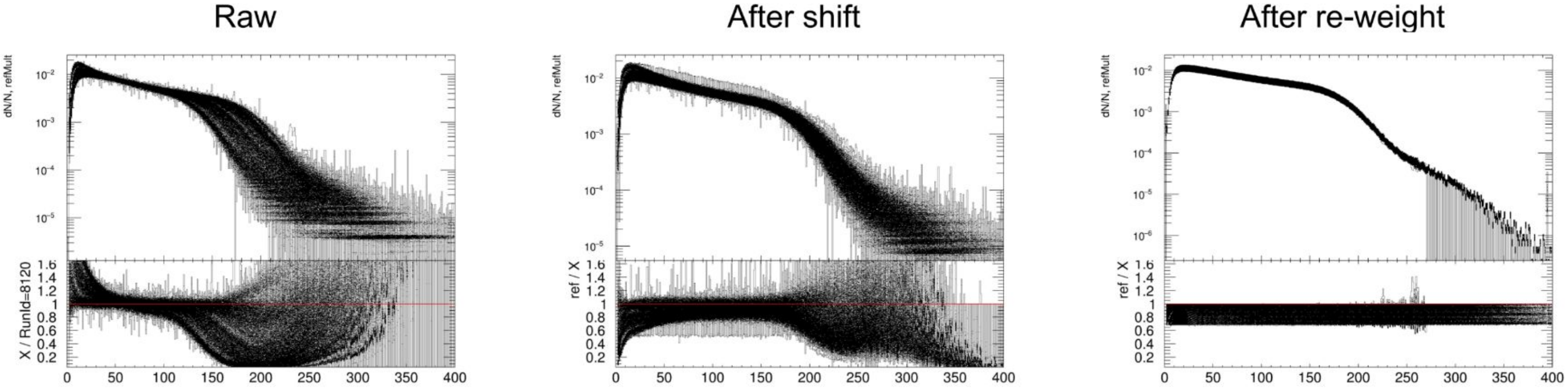
- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

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

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

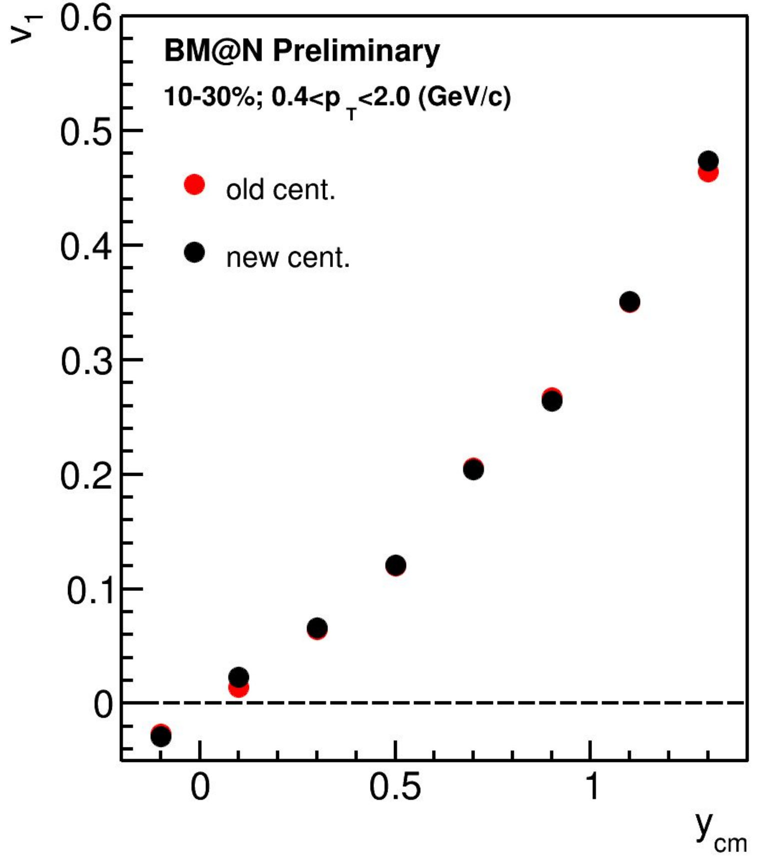


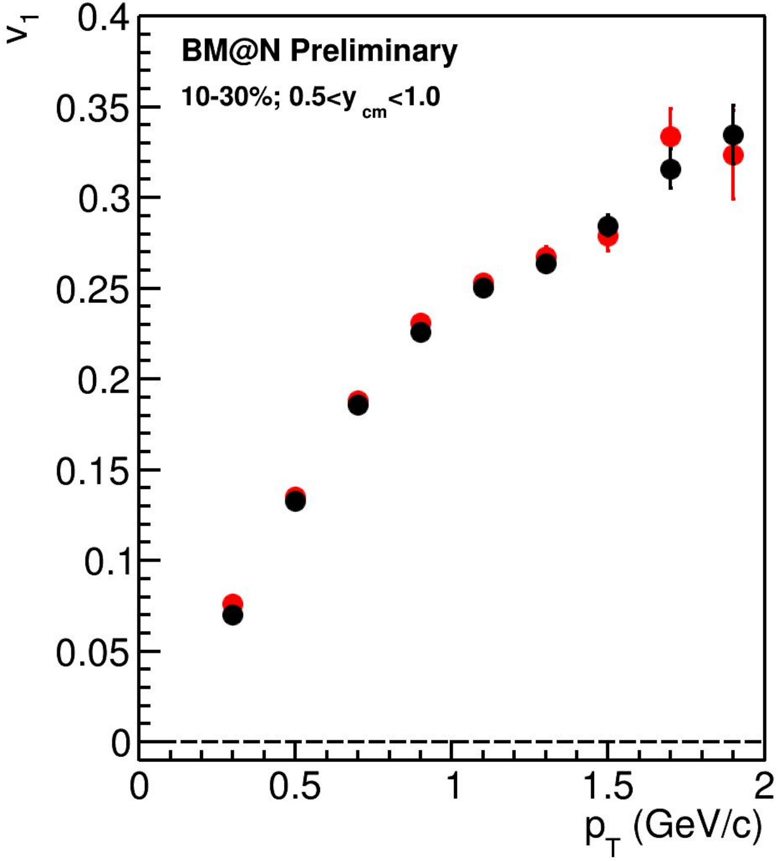
Outlook: Centrality determination



We are planning to use the new centrality based on calibrated multiplicity

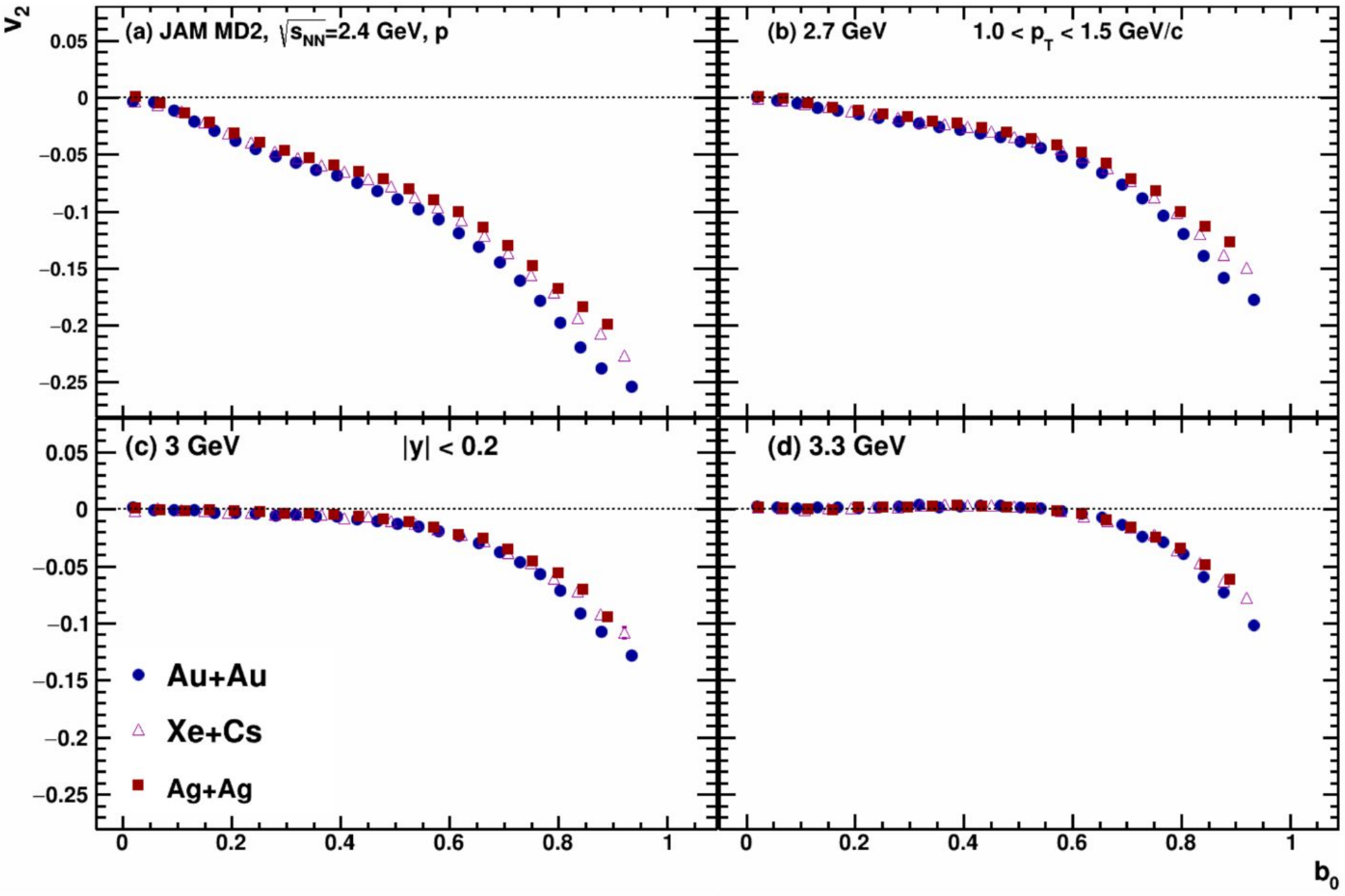
v_1 with different centralities





JAM model describes $v_1(y)$ well

v_2 with system size and collision energy



The results from JAM model in mean-field mode suggest v_2 in lighter systems will be comparable with Au+Au collisions

Particles 2022, 5, 561–579.