Performance studies towards flow measurements in BM@N

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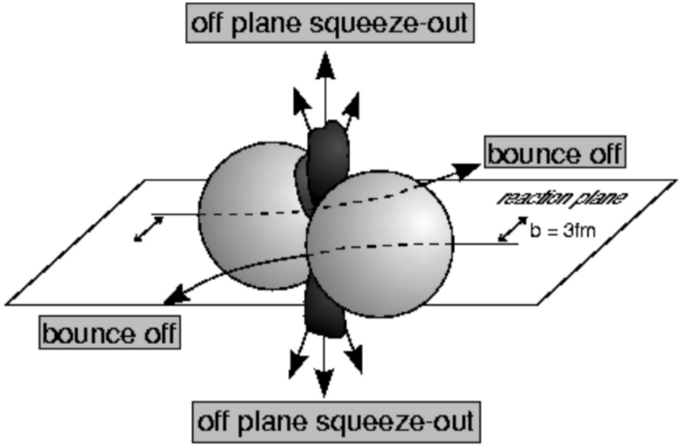
Lomonosov Conference, 29/08/2023

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:

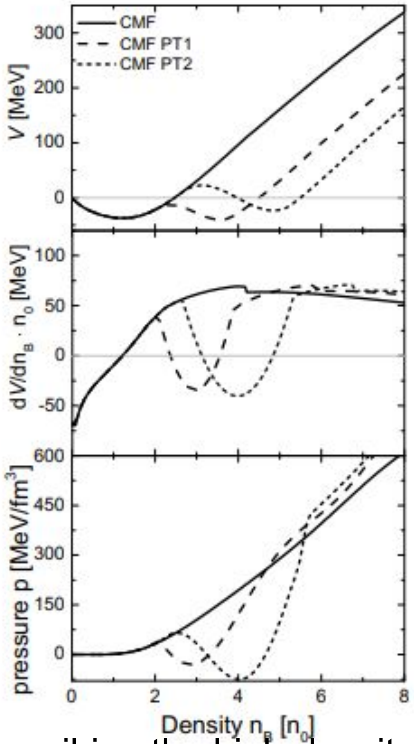
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right] \rangle$$

Anisotropic flow is sensitive to:

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

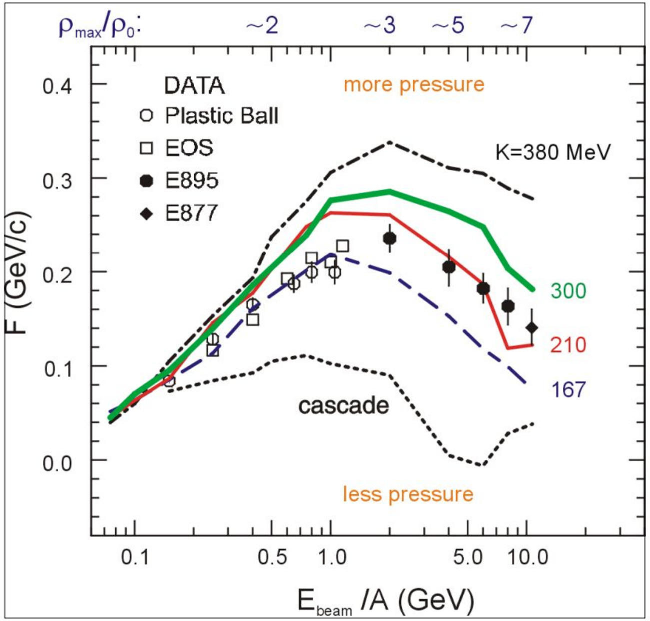
v_n as a function of collision energy

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

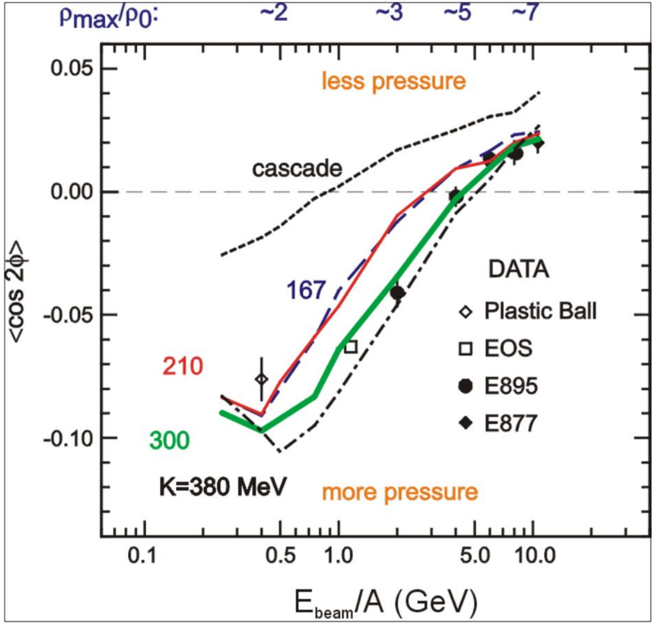


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



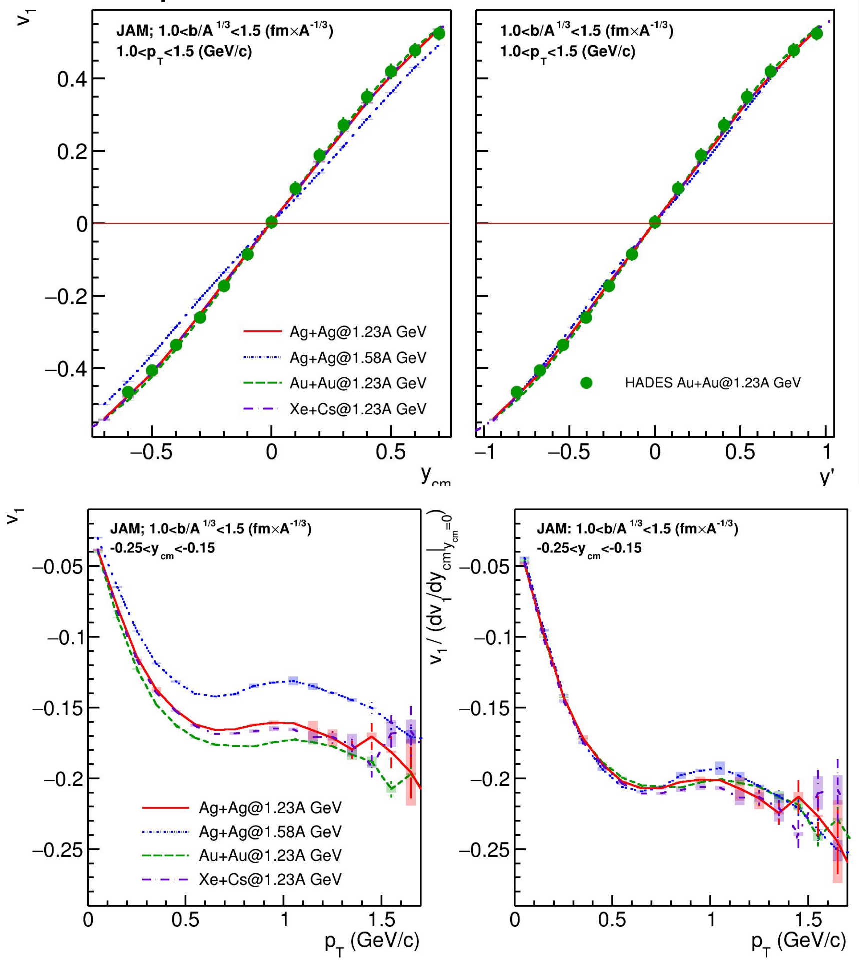
v_2 suggests harder EOS



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

Discrepancy is probably due to non-flow correlations

dv_1/dy scaling with collision energy and system size

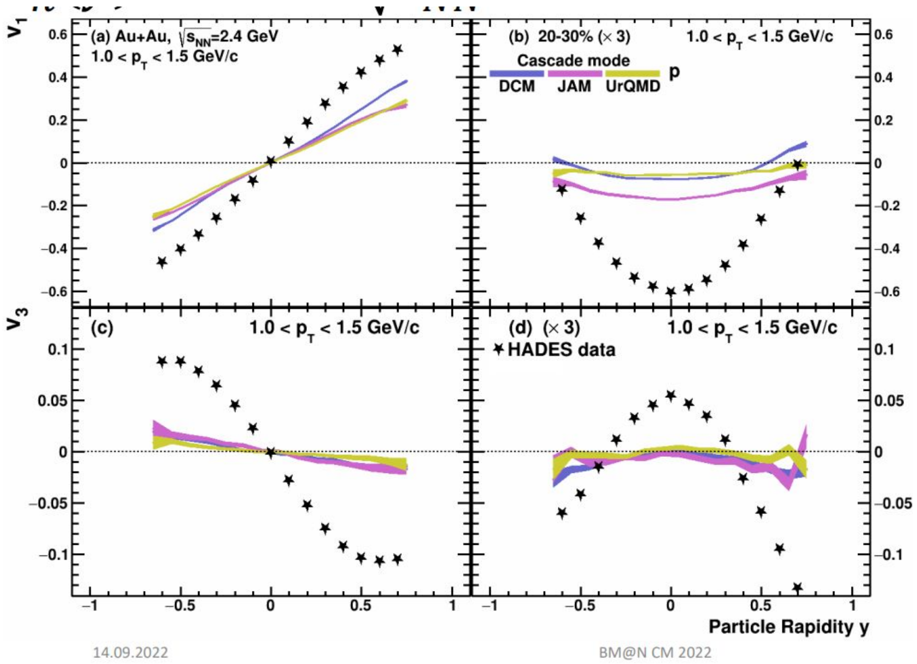


- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

Simulation datasample

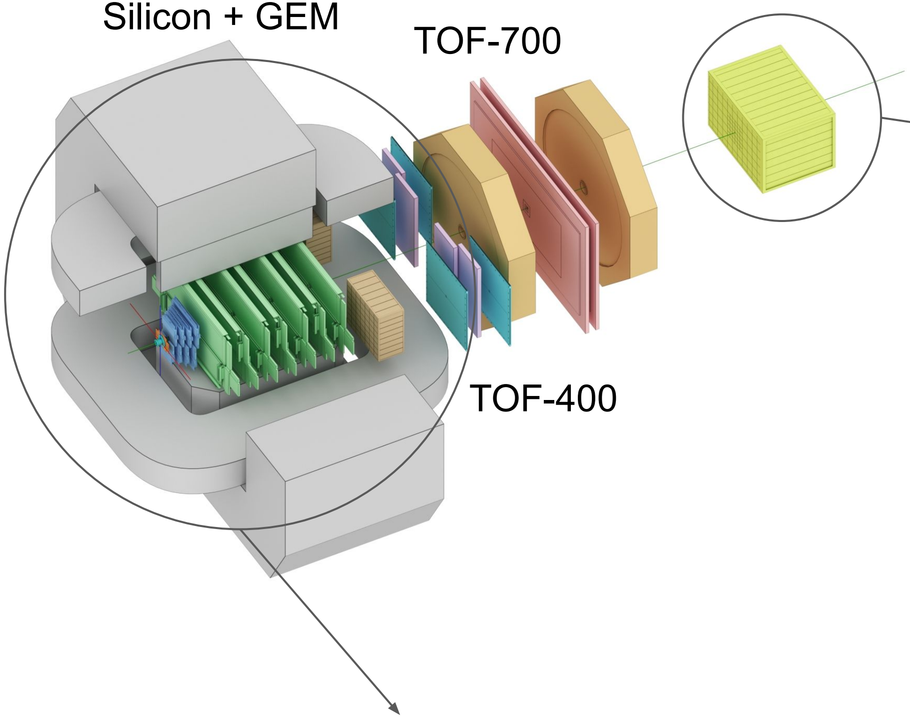
See talk of P.Parfenov

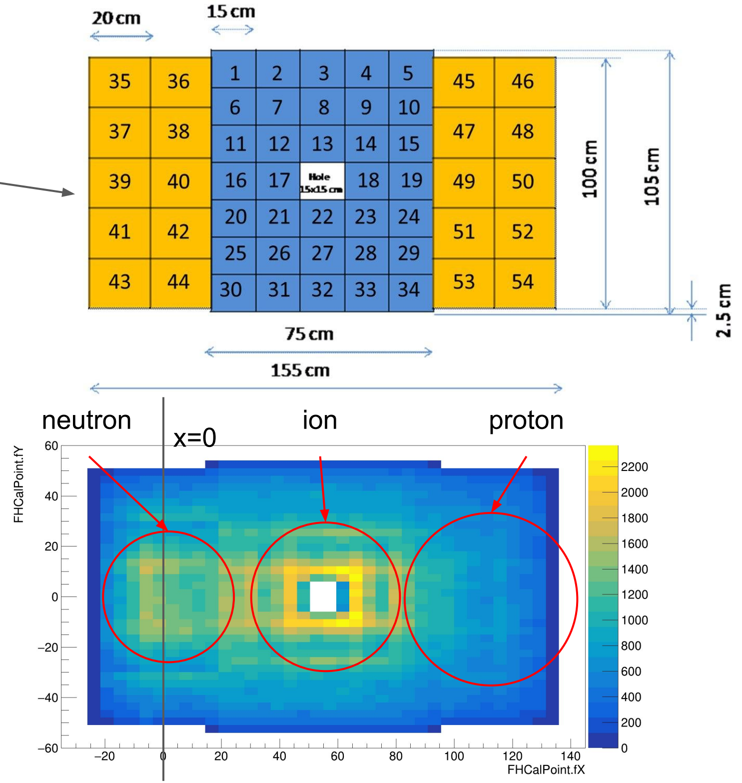
- Xe+Cs nuclei collisions
- DCMQGSM-SMM model (realistic yields of spectator fragments), describes flow poorly
- JAM model (realistic flow signal)
- Geant4 transport code (important for simulation of hadronic showers in the forward calorimeter)



	2A GeV	3A GeV	4A GeV
DCMQGSM-SMM	6M	6M	2M
JAM MD2	3M	3M	5M

The BM@N experiment (GEANT4 simulation for RUN8)





L1 tracking was used together with true-MC PID

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:

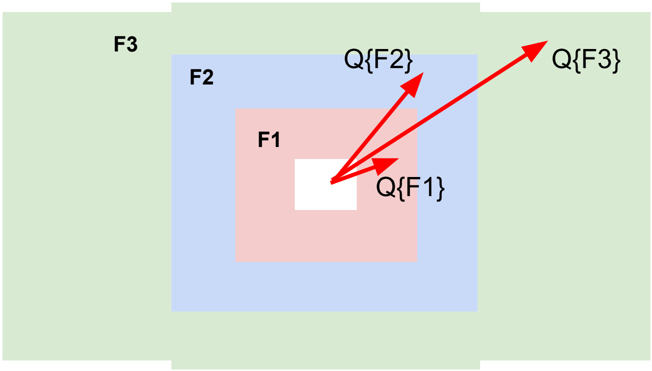
$$u_n = e^{in\phi}$$

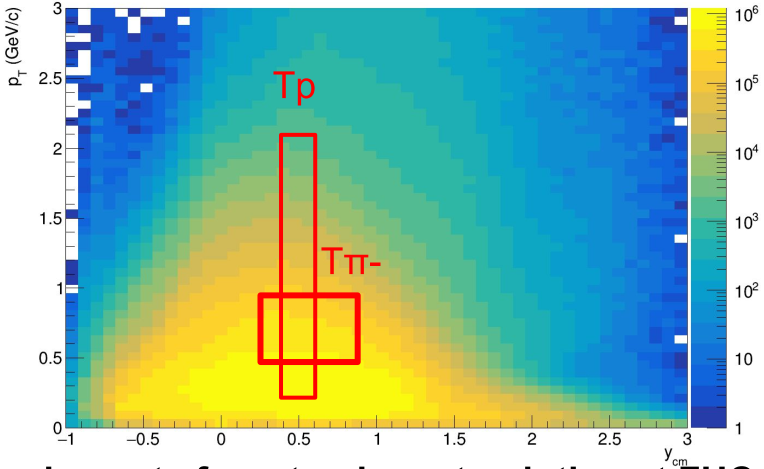
where φ is the azimuthal angle

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





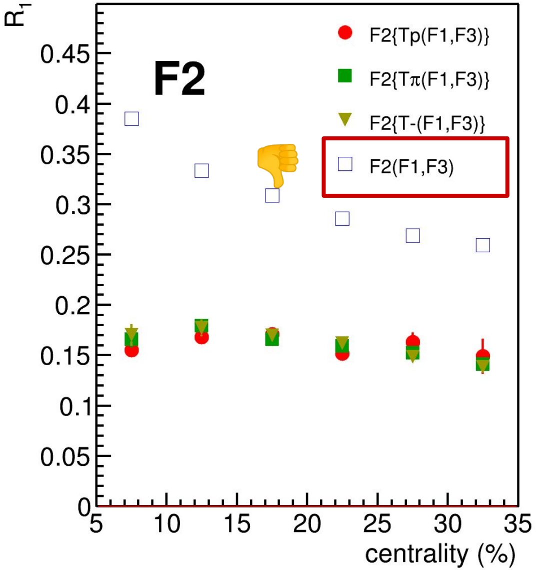
Additional subevents from tracks not pointing at FHCal:
Tp: p; 0.4<y<0.6; 0.2 < p_T < 2 GeV/c; w=1/eff
Tπ: π-; 0.2<y<0.8; 0.1 < p_T < 0.5 GeV/c; w=1/eff
T-: all negative; 1.0<η<2.0; 0.1 < p_T < 0.5 GeV/c; w=1/eff

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

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



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):

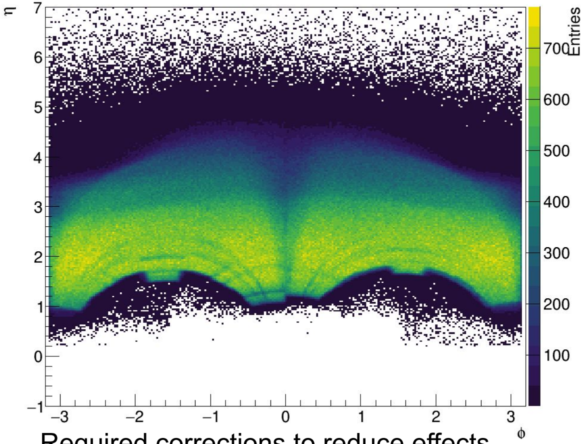
$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

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

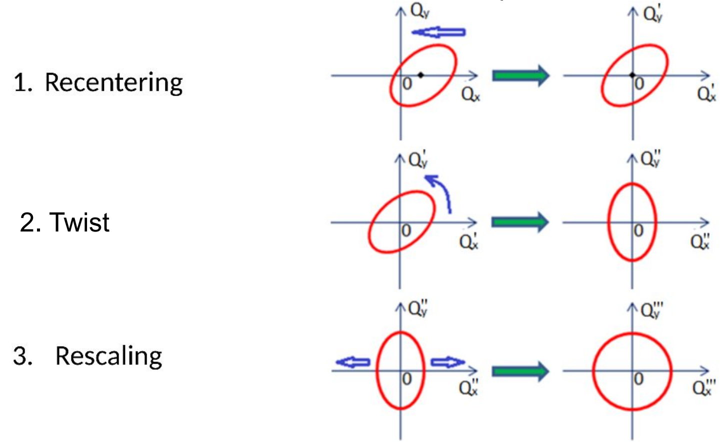
$$R_1^{F2\{Tp\}(F1,F3)} = \langle Q_1^{F2} Q_1^{Tp} \rangle \frac{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{Tp} Q_1^{F1} \rangle \langle Q_1^{Tp} Q_1^{F3} \rangle}}$$

Azimuthal asymmetry of the BM@N acceptance

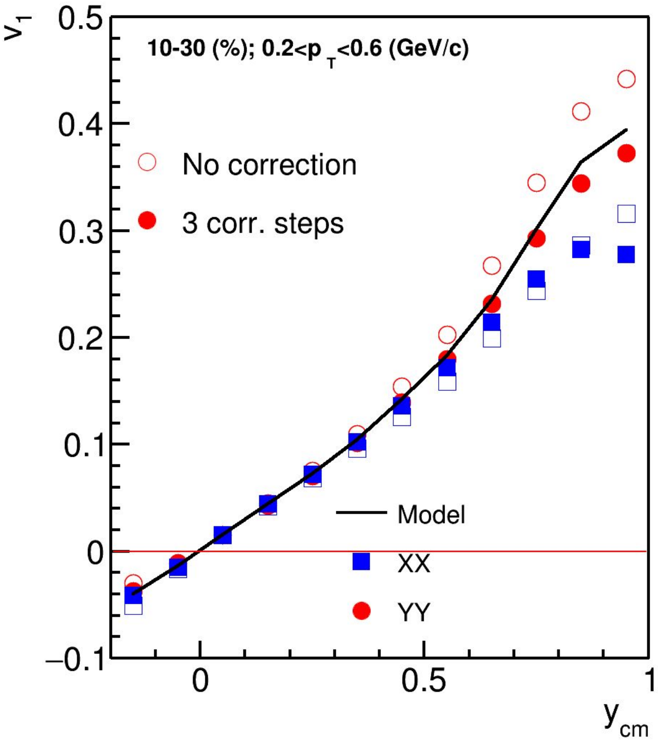
φ-η yield of protons



Required corrections to reduce effects of non-uniform azimuthal acceptance

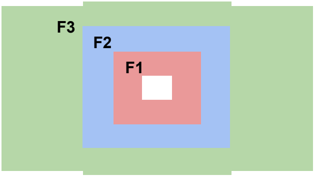


Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)

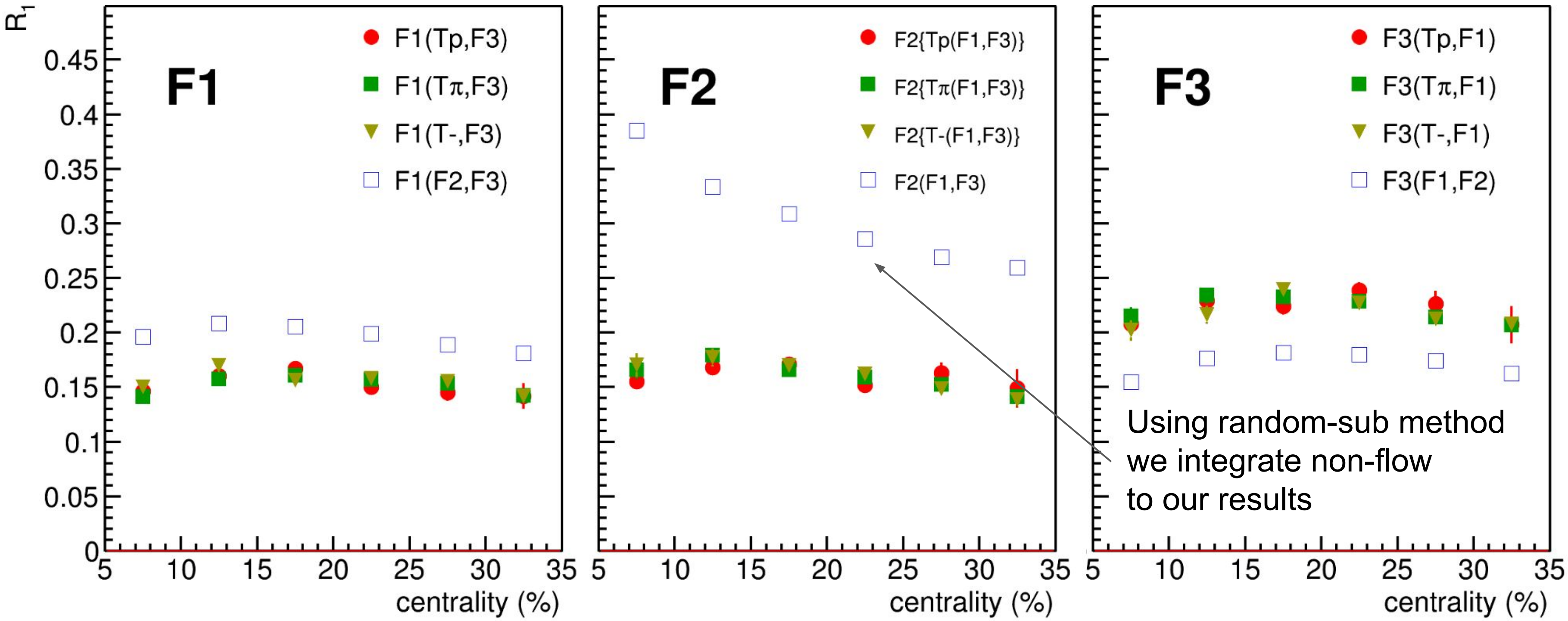


- Better agreement after rescaling for YY
- XX component has a large bias (due to magnetic field)

SP R1: DCMQGCM-SMM Xe+Cs@4A GeV

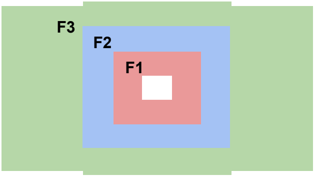


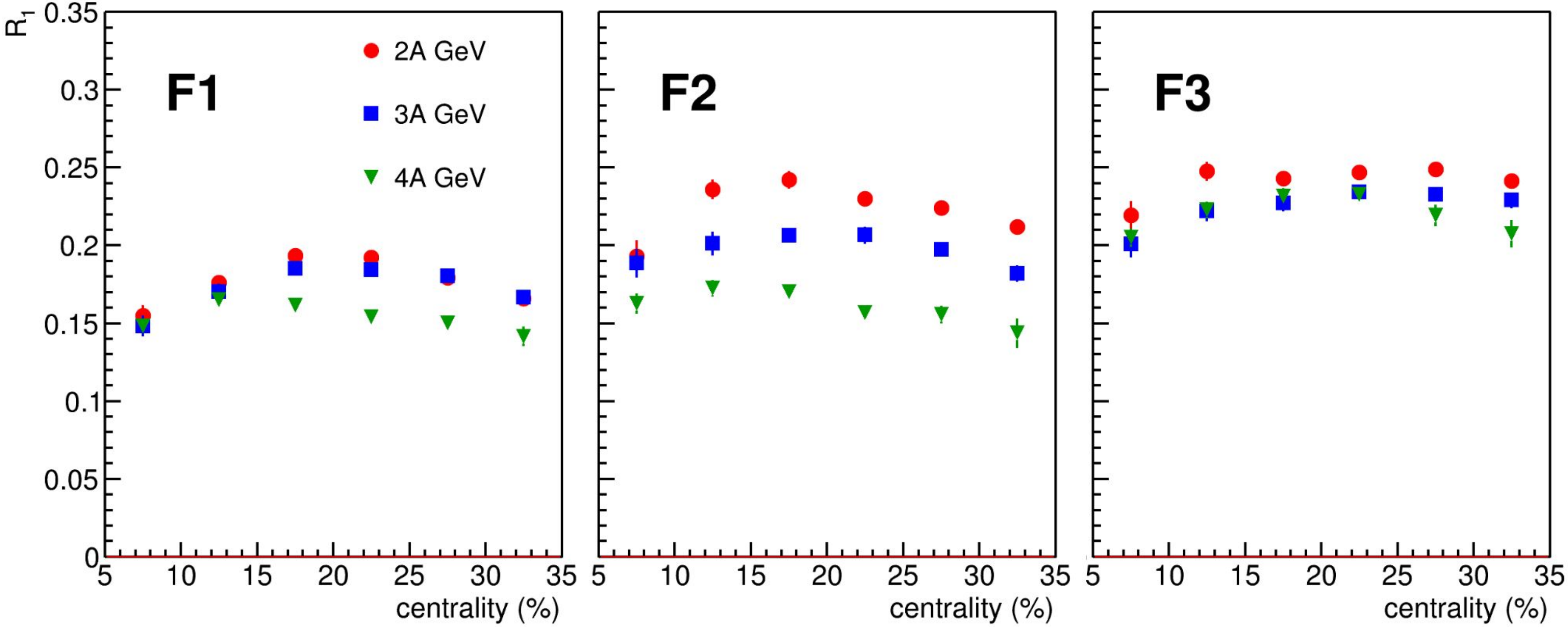
SP gives unbiased estimation of v_n (root-mean-square)
EP gives biased estimation (somewhere between mean and RMS)



Using the additional sub-events from tracking provides a robust combination to calculate resolution

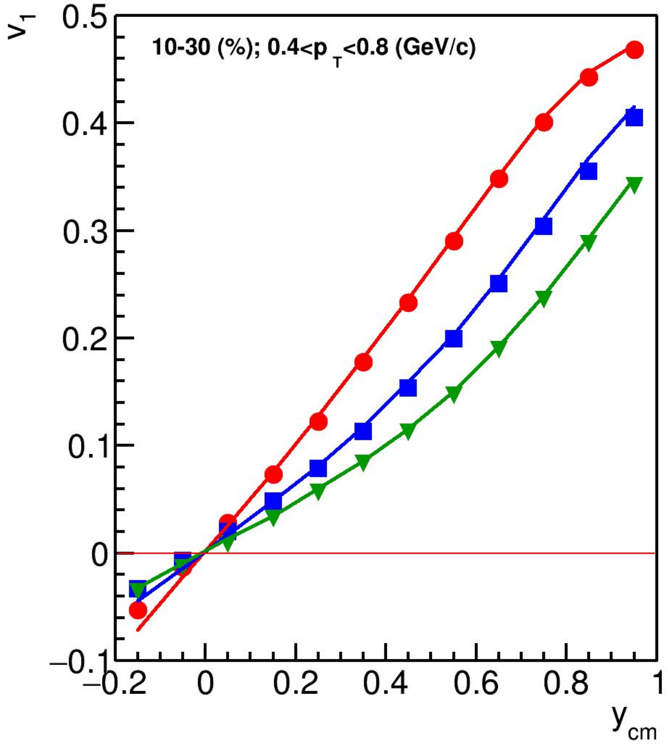
Rec R1: DCMQGCM-SMM Xe+Cs

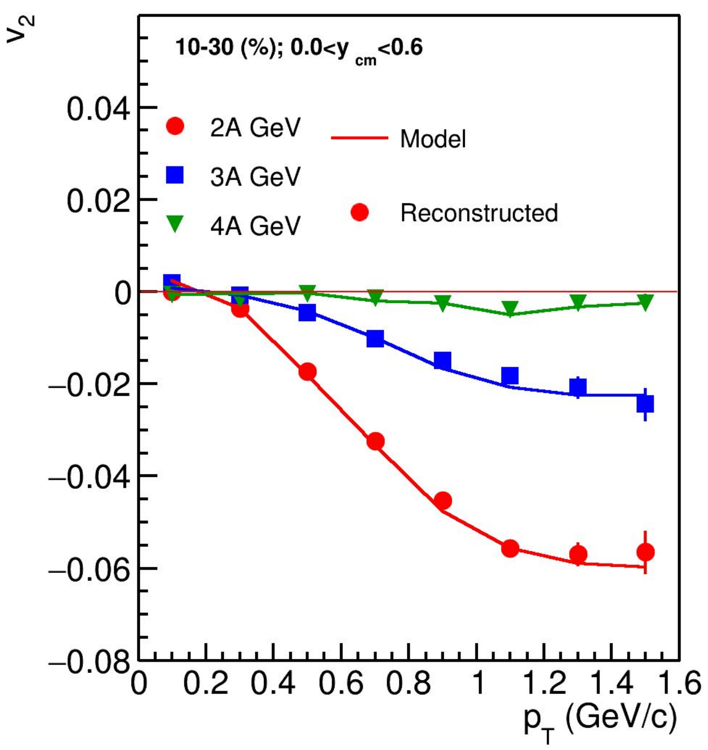




Resolution is lower for higher energies due to lower v_1

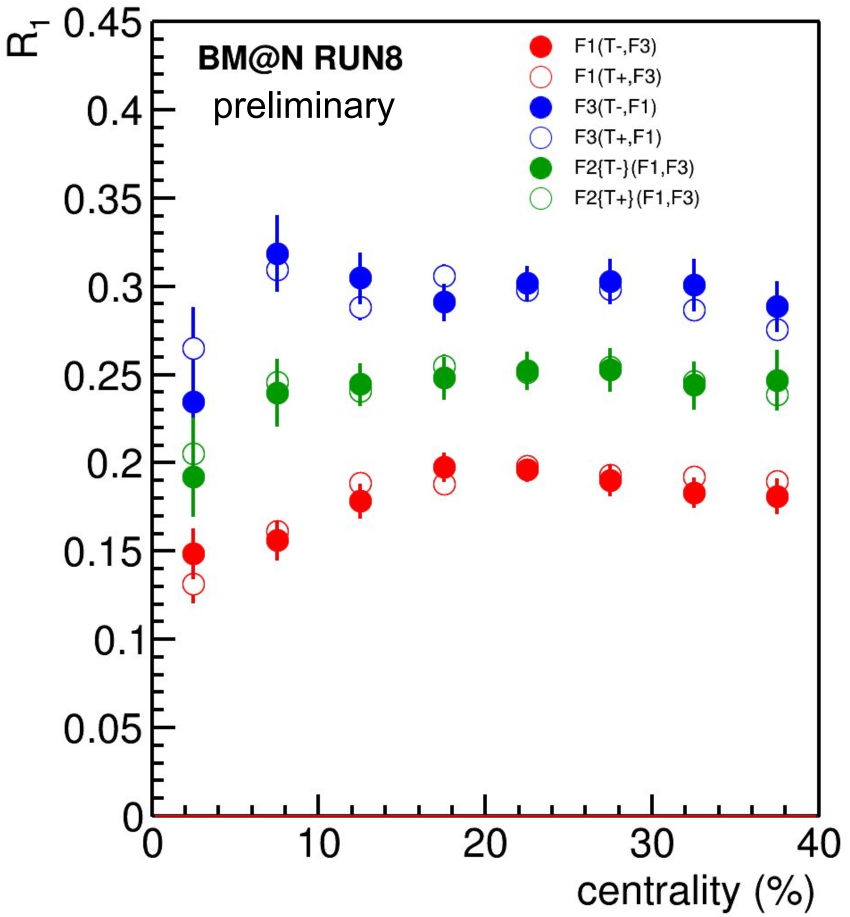
Directed and elliptic flow in Xe+Cs (JAM)

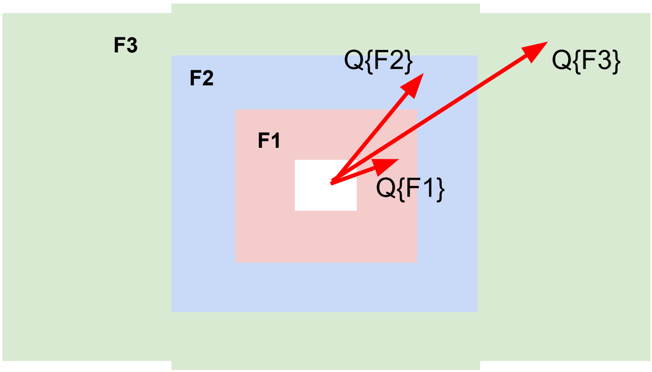




- Good agreement between reconstructed and pure model data for all three energies

R1: BM@N Run8 DATA: Xe+Cs@3.8A GeV





T-: all negatively charged particles with:

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

T+: all positively charged particles with:

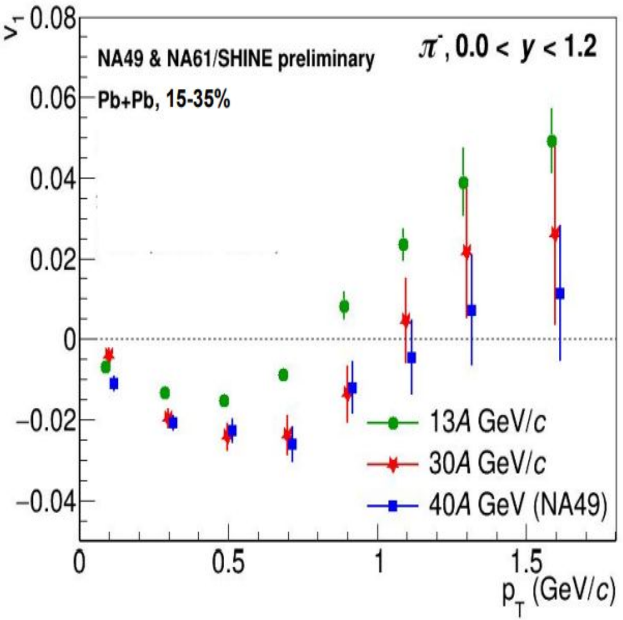
- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

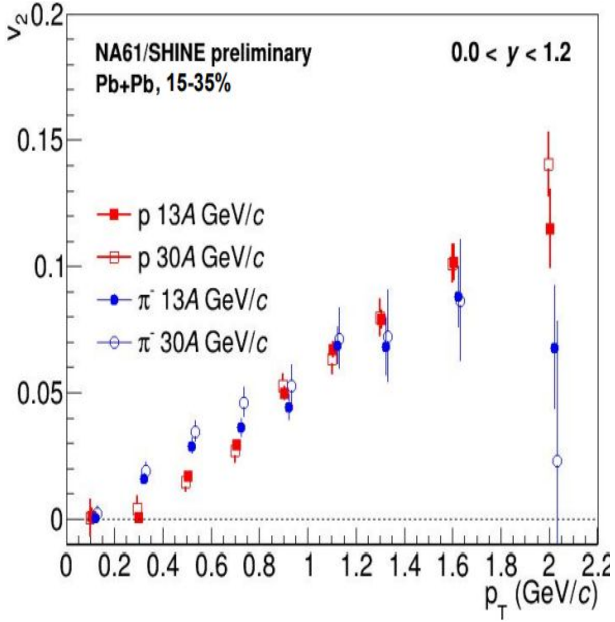
Summary

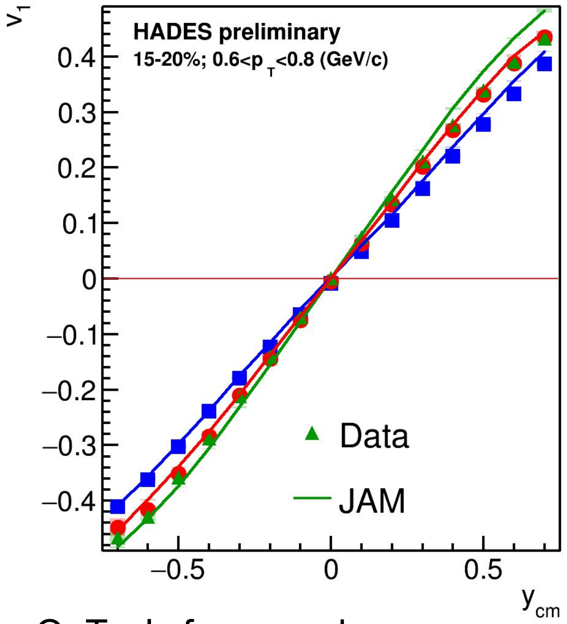
- Resolution correction factor is calculated for DCMQGSM-SMM Xe+Cs collisions at beam energies of 4A, 3A and 2A GeV:
  - Using only FHCal sub-events for resolution calculation gives biased estimation due to transverse hadronic showers propagation
  - Using additional sub-events from tracking provides with a robust estimation
- Good agreement between model and reconstructed data is observed for v_1 and v_2 at 2A, 3A and 4A GeV
- The analysis of the recent BM@N experimental run is ongoing:
  - The R_1 calculated using different combinations of Q-vectors is consistent within the statistical errors

BACKUP

QnTools framework







- All the methods used for performance study were carried out using QnTools framework: https://github.com/HeavyIonAnalysis/QnTools (well documented and well-tested)
- Methods for flow measurements in fixed-target experiments were tested on experimental data from NA61/SHINE, HADES and ALICE
- Tested and implemented in MPD root