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

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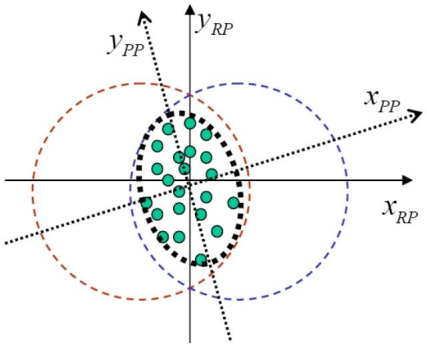
4-5 March 2025

Anisotropic flow

Spatial asymmetry of the initial state matter transforms into momentum anisotropy of the produced particles

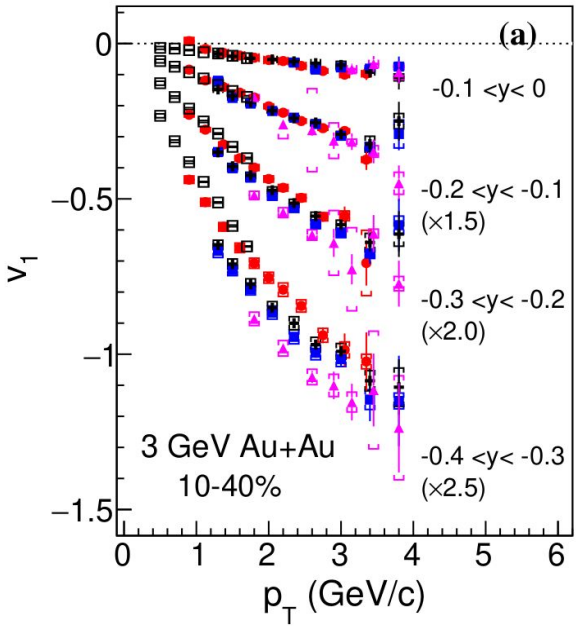
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_r)))$$

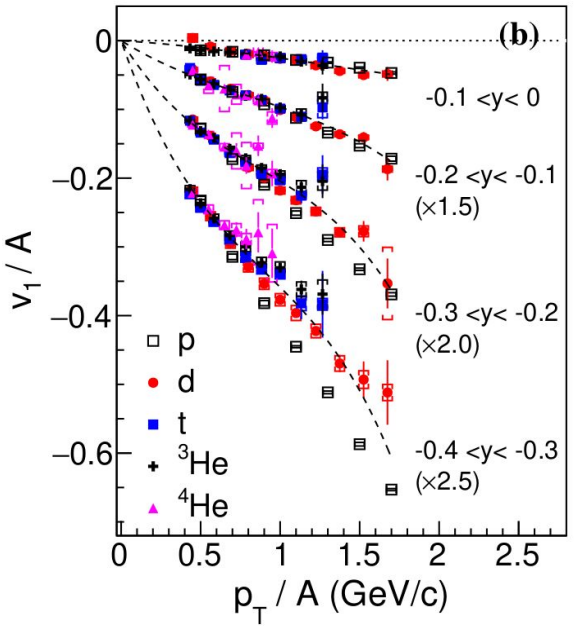
$$v_n = \langle \cos(n(\phi - \Psi_r)) \rangle$$



Coalescence mechanism: assuming $v_n^p \approx v_n^n$

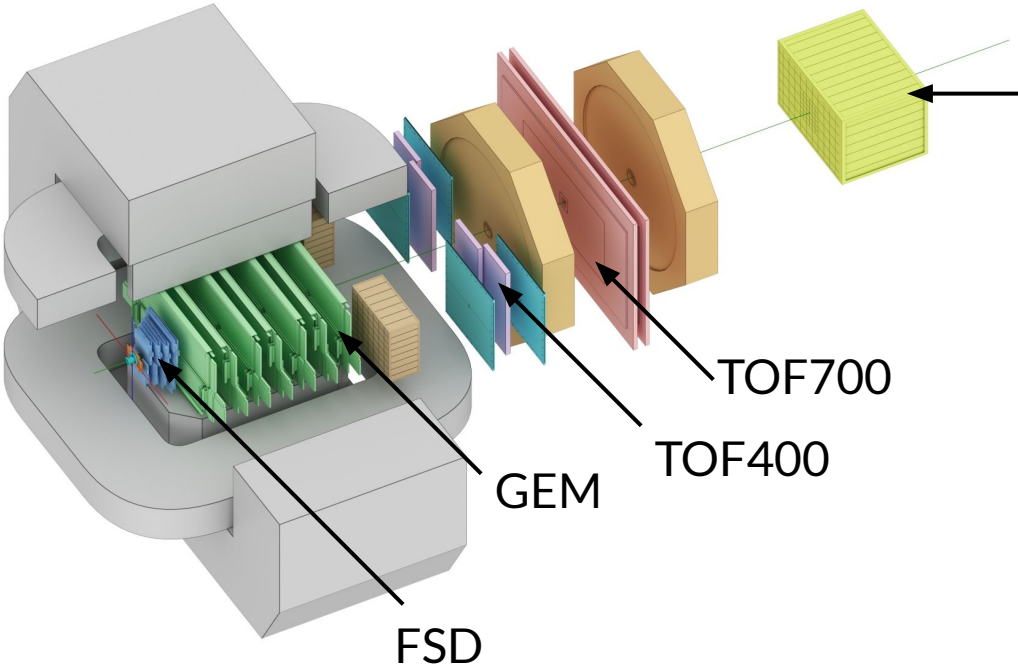
$$v_n^A(p_T, y)/A \approx v_n^p(p_T/A, y)$$

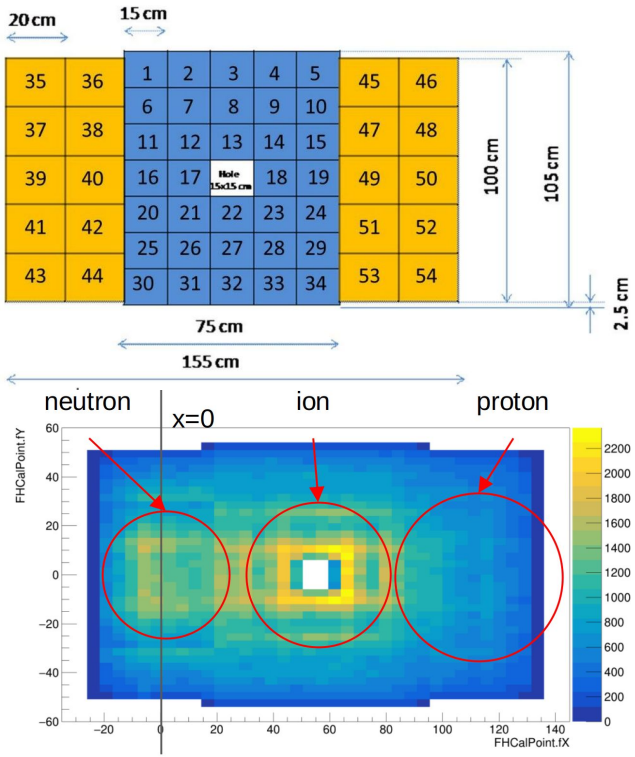




M. S. Abdallah, et al., STAR Collaboration, Phys. Lett. B 827, 136941 (2022).

The BM@N Setup: Xe+CsI 3.8A Gev





Determination of the symmetry plane from the spectator energy deposition

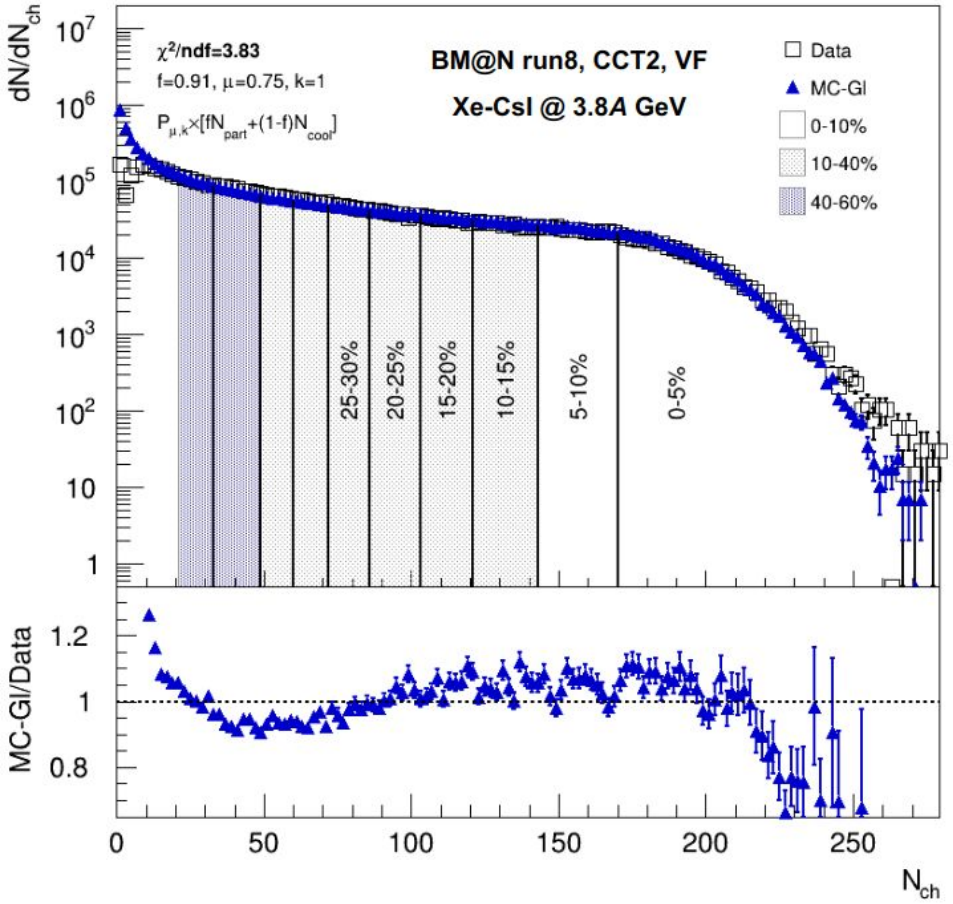
Event and track selection criteria

<u>Event selection criteria:</u>

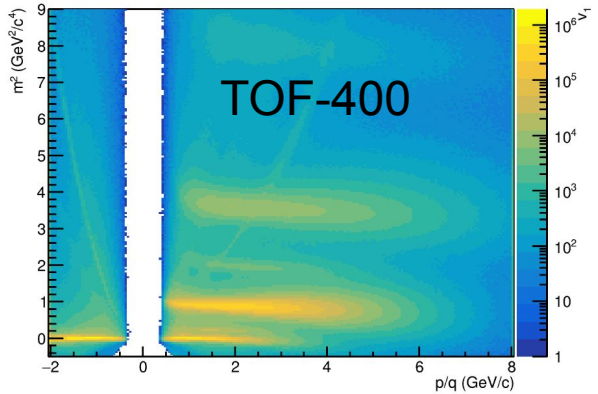
Physical runs
Central collision trigger CCT2
at least 2 tracks in vertex
Vtx_R < 1 cm
Vtx_Z < 0.1 cm

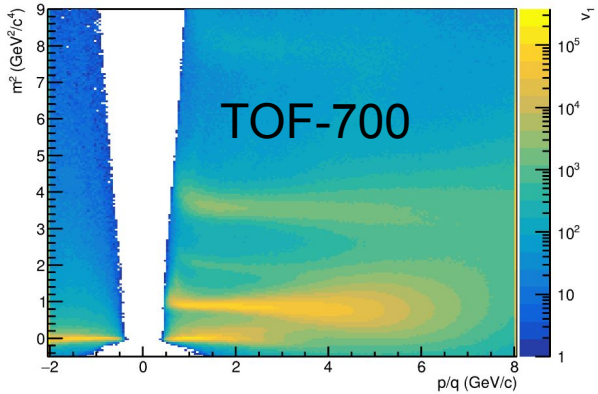
<u>Track selection criteria:</u>

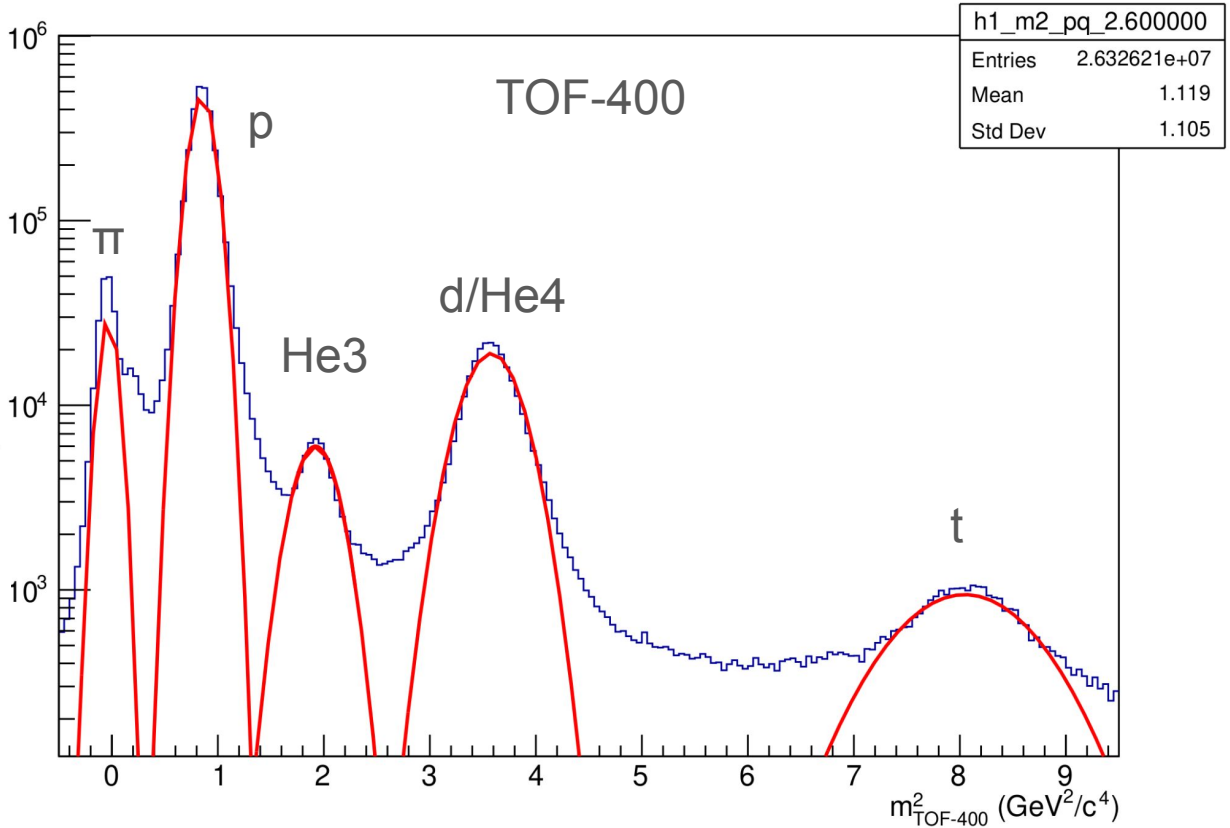
Outside the FHCal acceptance
N_{hits} > 5
$\chi 2$ < 5
DCA < 5 cm



Particle Identification



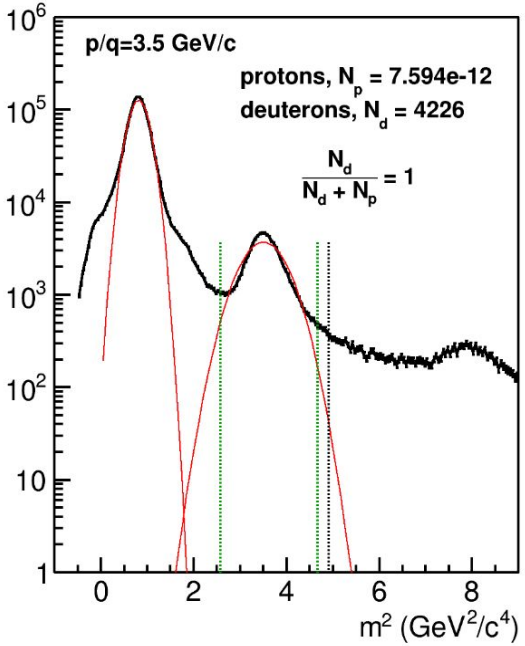




m^2-distribution in narrow p/q ranges

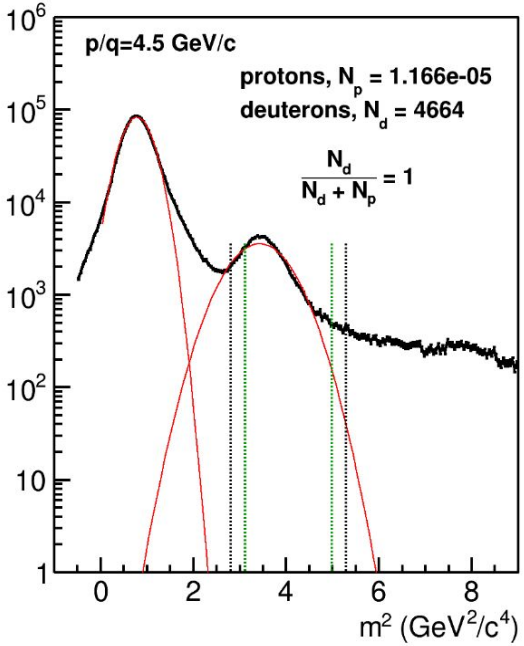
$-2\sigma < m^2 - \langle m^2 \rangle < 3\sigma$

$-2\sigma < m^2 - \langle m^2 \rangle < 2.5$



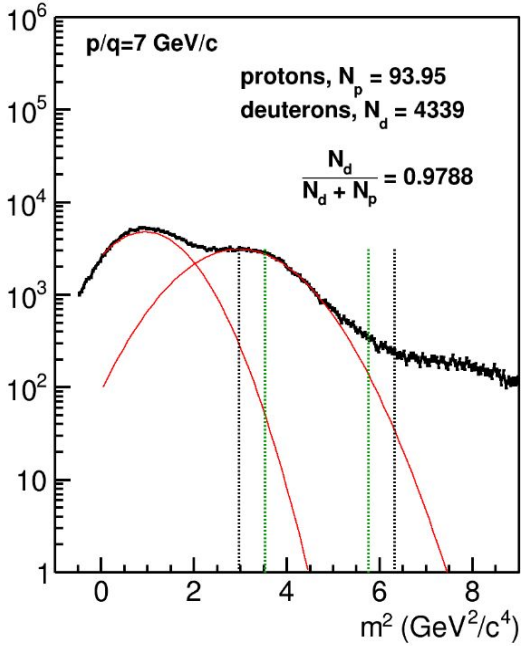
$-\sigma < m^2 - \langle m^2 \rangle < 3\sigma$

$-0.5\sigma < m^2 - \langle m^2 \rangle < 2.5$



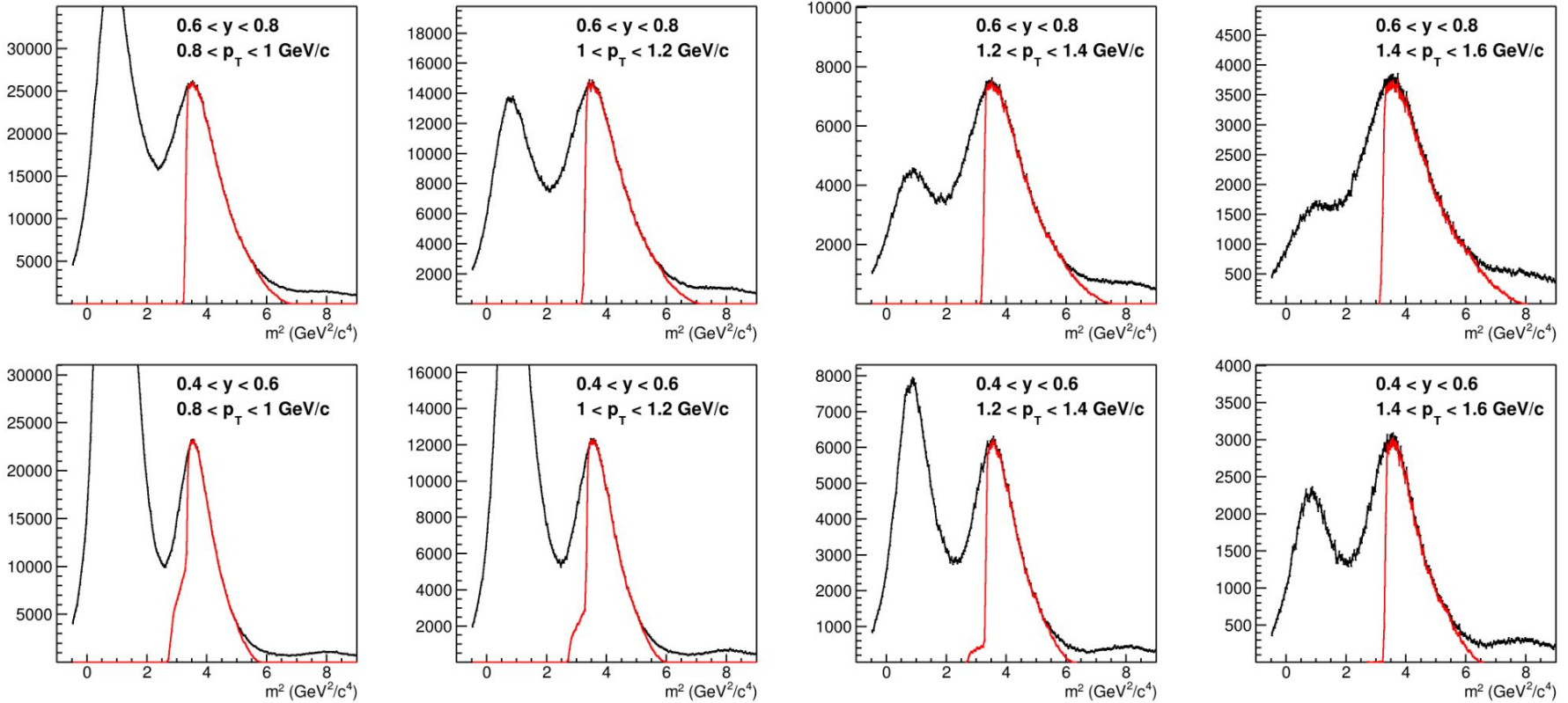
$0 < m^2 - \langle m^2 \rangle < 3\sigma$

$0.5\sigma < m^2 - \langle m^2 \rangle < 2.5$



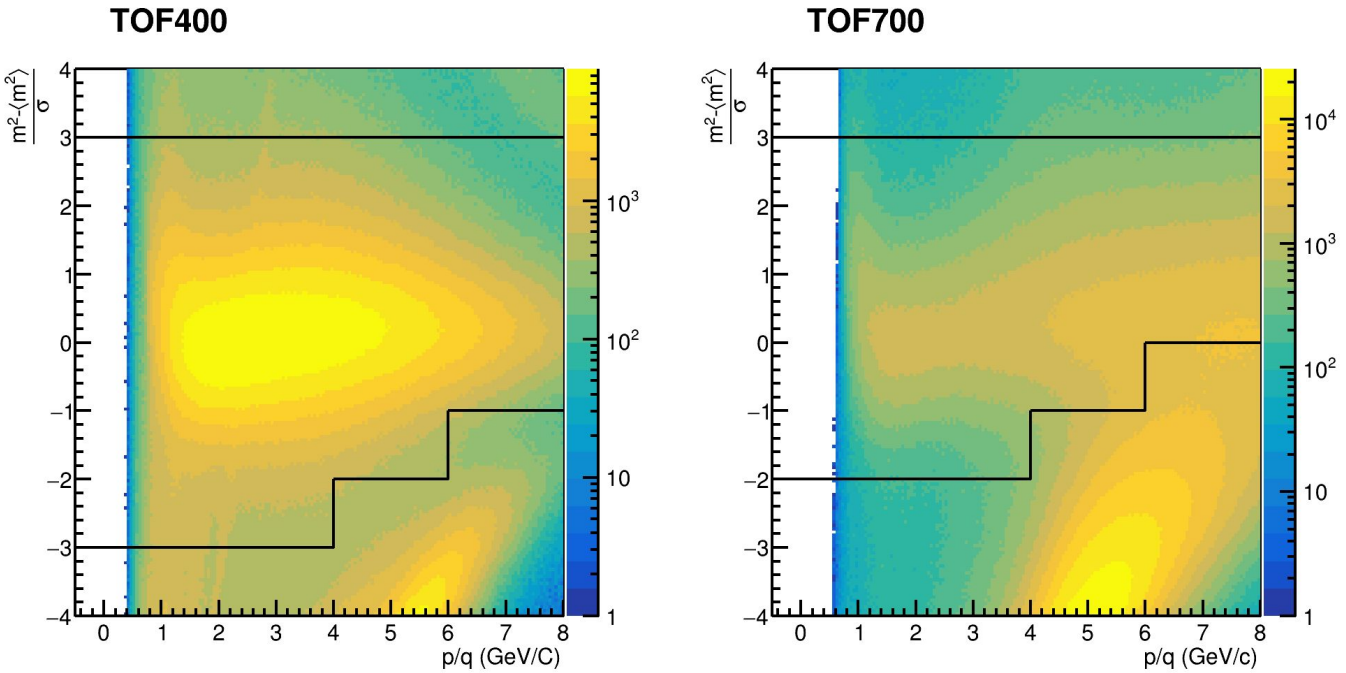
m^2 particle distribution for p/q corresponding to different (m^2 —$\langle m^2 \rangle$) selection criteria in the TOF700

m^2 -distribution in p_T-y windows



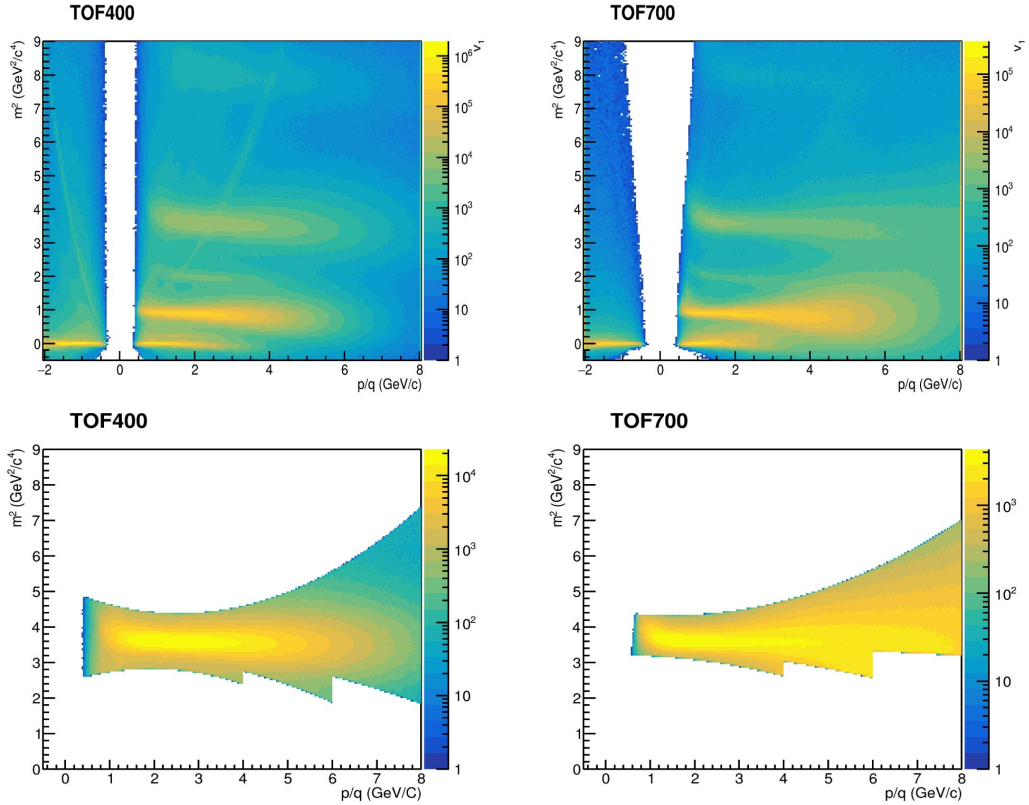
m^2 particle distribution in p_T and y bins in the TOF700

Deuteron identification criteria



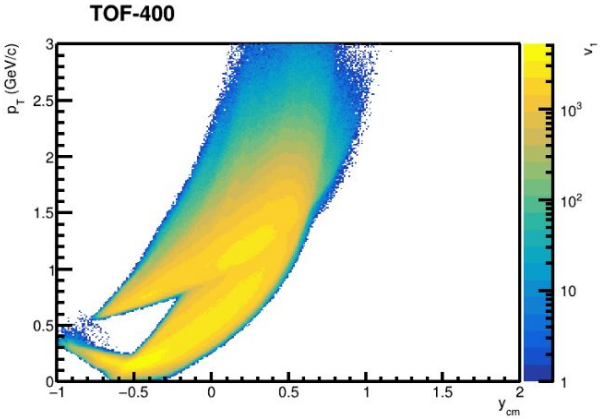
N-σ distributions for deuteron candidates
Solid lines represent the selection criteria for different p/q ranges.

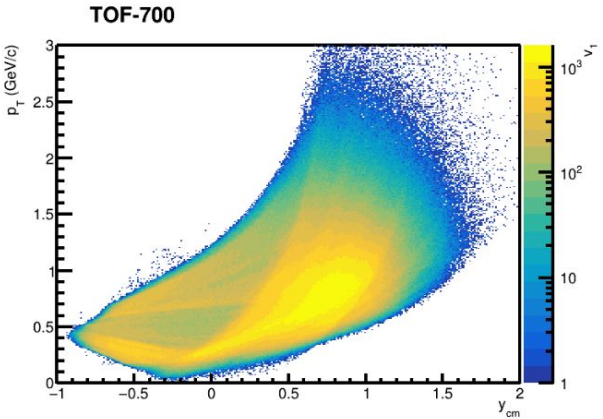
Particle Identification

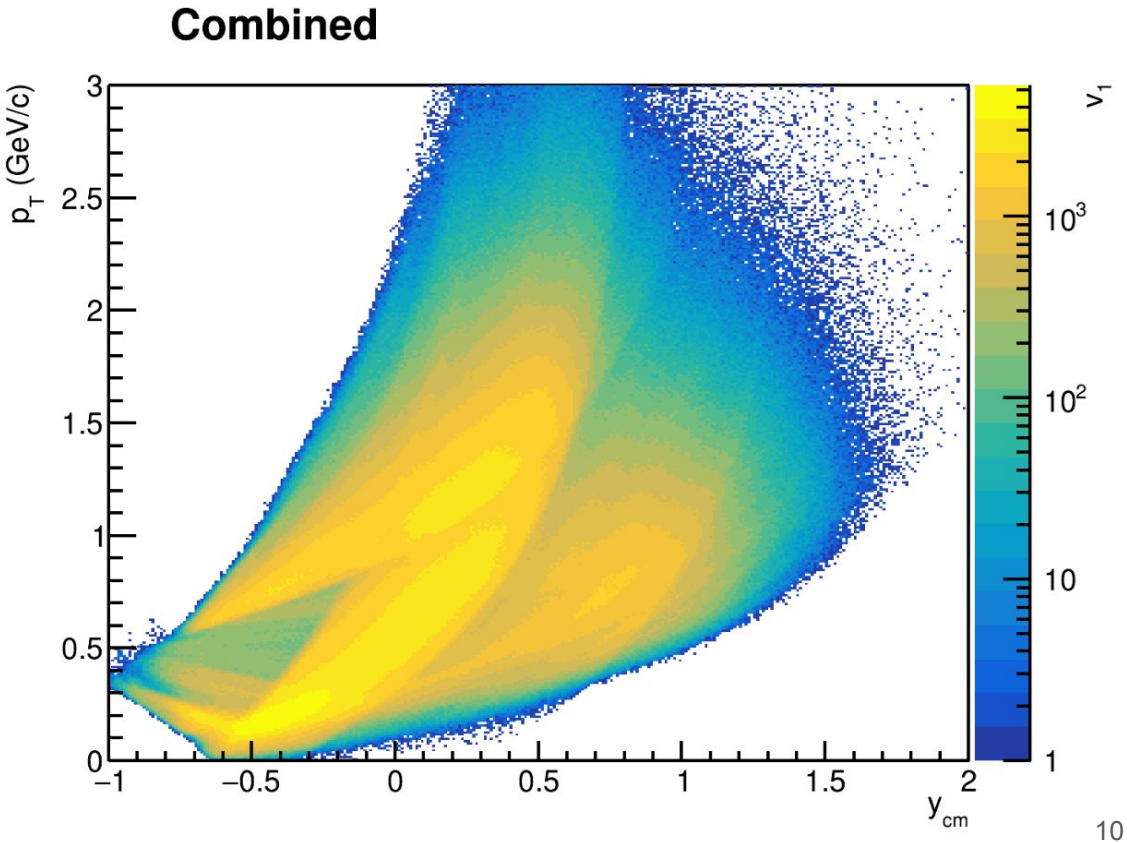


m^2 *versus* p/q distribution of the selected deuteron candidates

Deuteron p_T-y acceptance







Flow vectors and SP method

A unit vector is defined in the transverse plane for each particle k:

$$u_{n,k} = e^{in\phi_k}$$

Event flow vector Q_n - an estimate of the reaction plane:

$$Q_n = \frac{\sum_{k=1}^{M} w_k u_{n,k}}{\sum_{k=1}^{M} w_k} = |Q_n| e^{in\Psi_n^E}$$

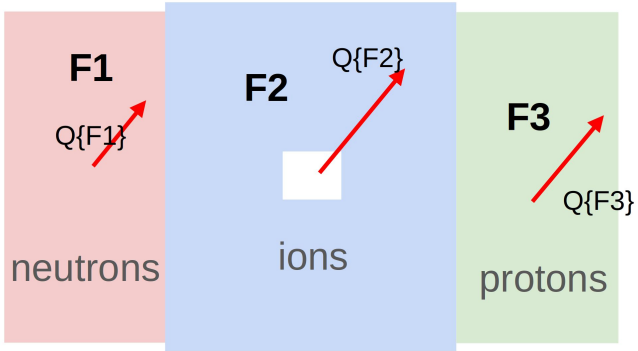
Scalar product method and the resolution correction factor R:

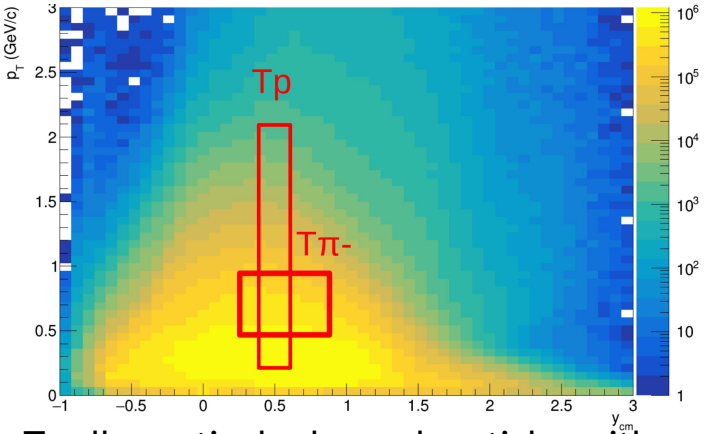
$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad R_1^{F1} = \langle \cos(\Psi_1^{F1} - \Psi_1^{RP}) \rangle$$

Using three groups of particles and the pairwise correlations of Q_1, R_1 reads

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

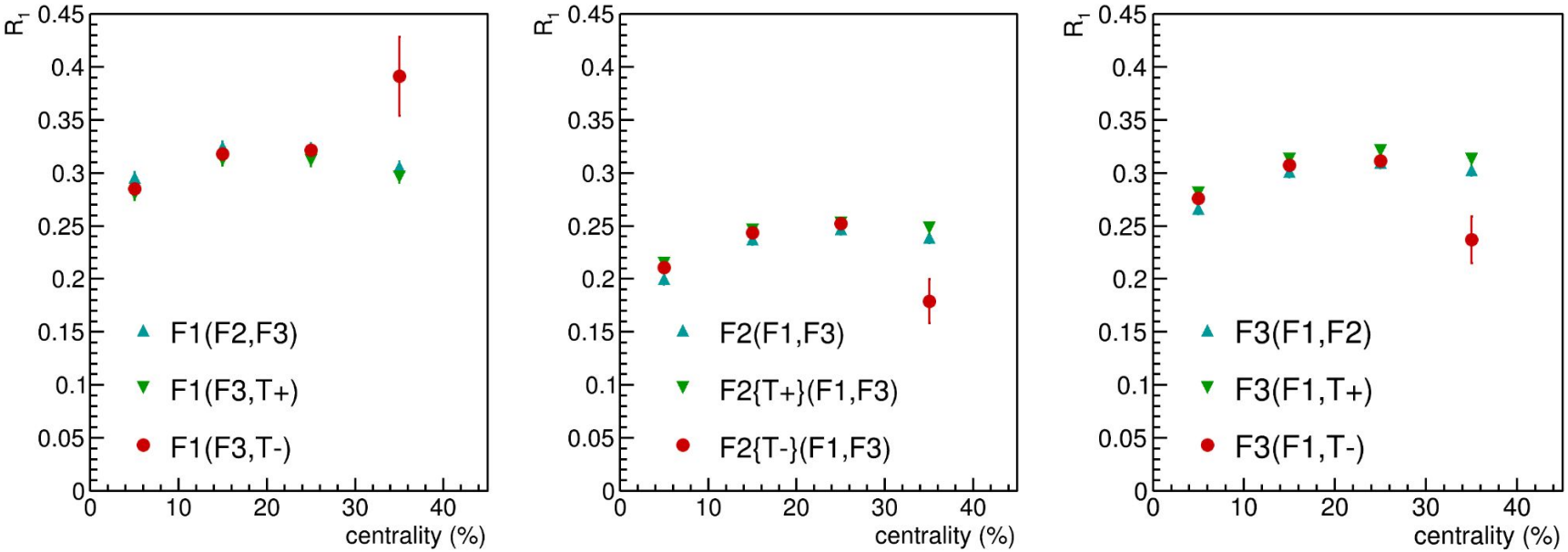
$$R_1^{F2\{Tp\}(F1,F3)} = \langle Q_1^{F2} Q_1^{Tp} \rangle \frac{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{Tp} Q_1^{F1} \rangle \langle Q_1^{Tp} Q_1^{F3} \rangle}}$$





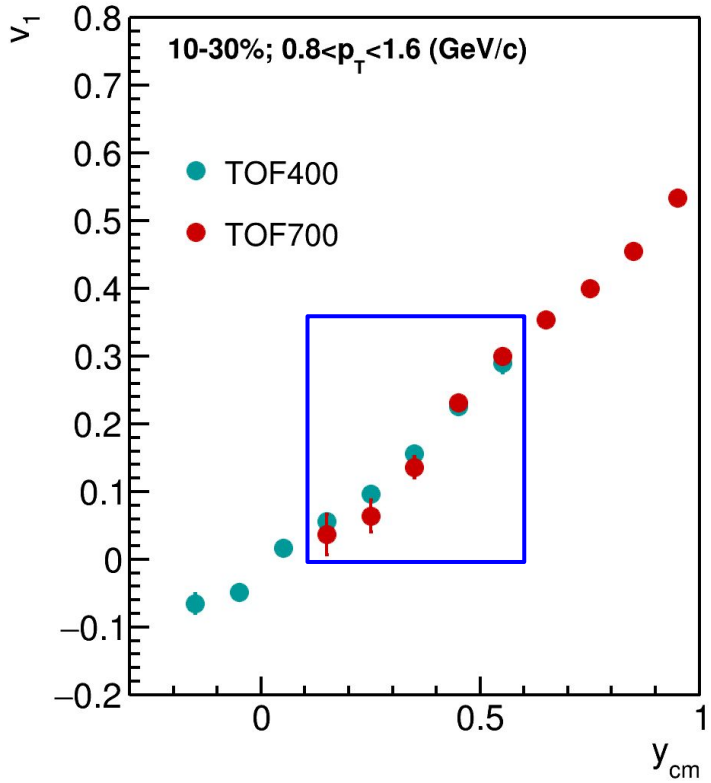
T-: all negatively charged particles with:
1.5 < η < 4
pT > 0.2 GeV/c
T+: all positively charged particles with:
2.0 < η < 3
pT > 0.2 GeV/c

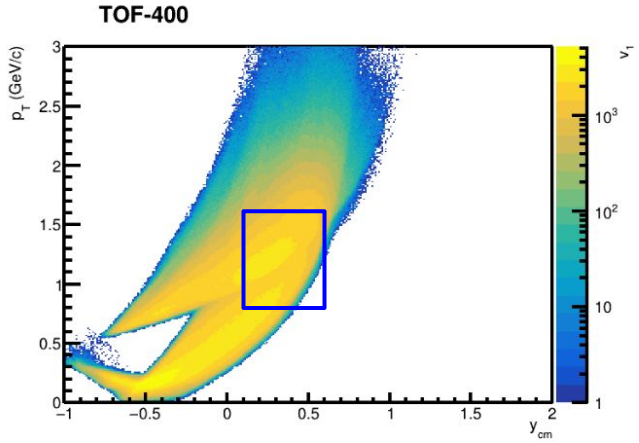
Symmetry plane resolution as a function of centrality

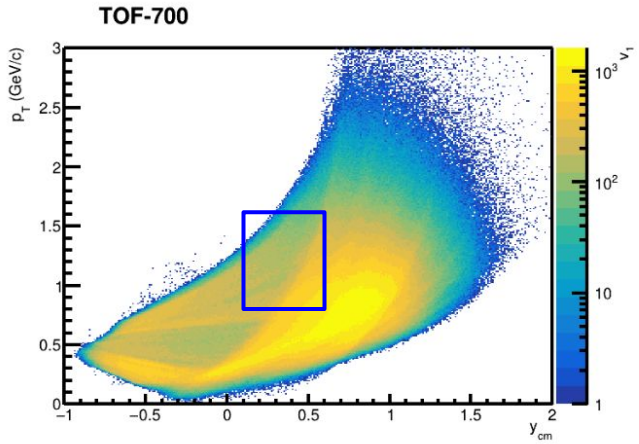


Different estimations of R_1 are in reasonable agreement for all three symmetry planes.

v_1 for deuterons from the TOF400 and TOF700





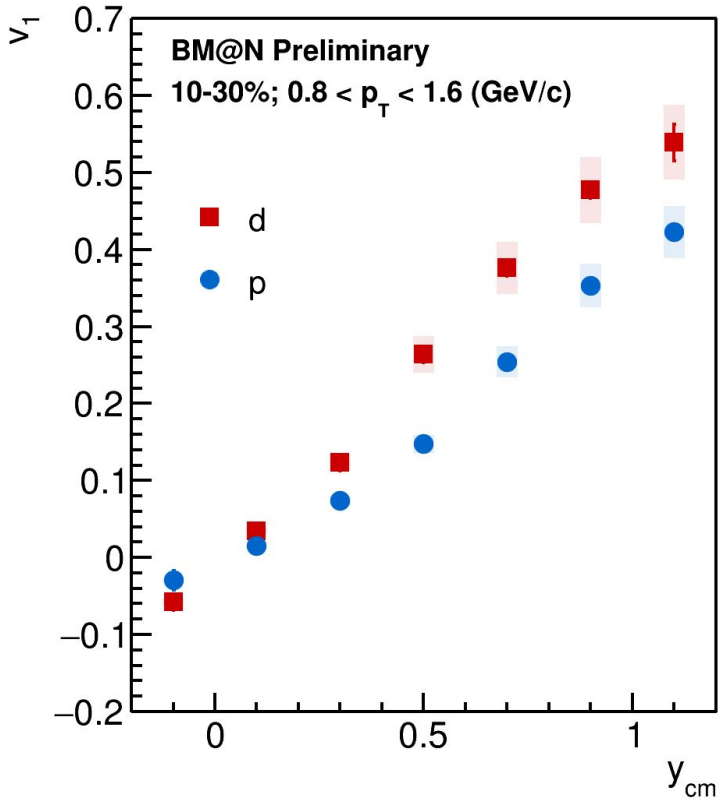


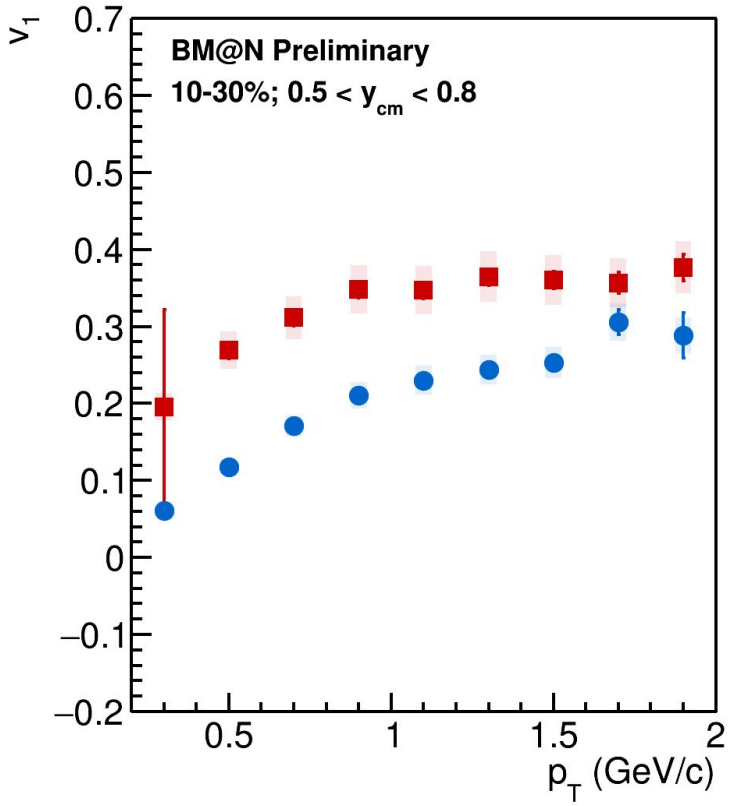
v_1 for deuterons identified separately with TOF400 and TOF700 are in a good agreement

Total systematics estimation

N_{hits}	Chi2/NDF	DCA	Vtx	runId	centrality	non-flow	Identification	total
3 %	2 %	1 %	3 %	4 %	5 %	2 %	5%	9 %

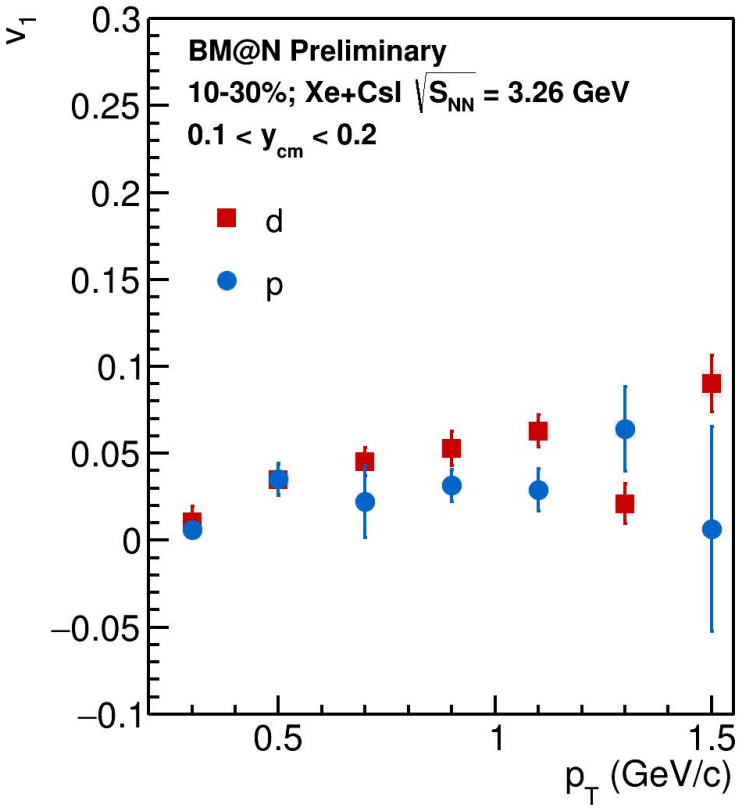
v_1 of protons and deuterons as a function of y and p_T

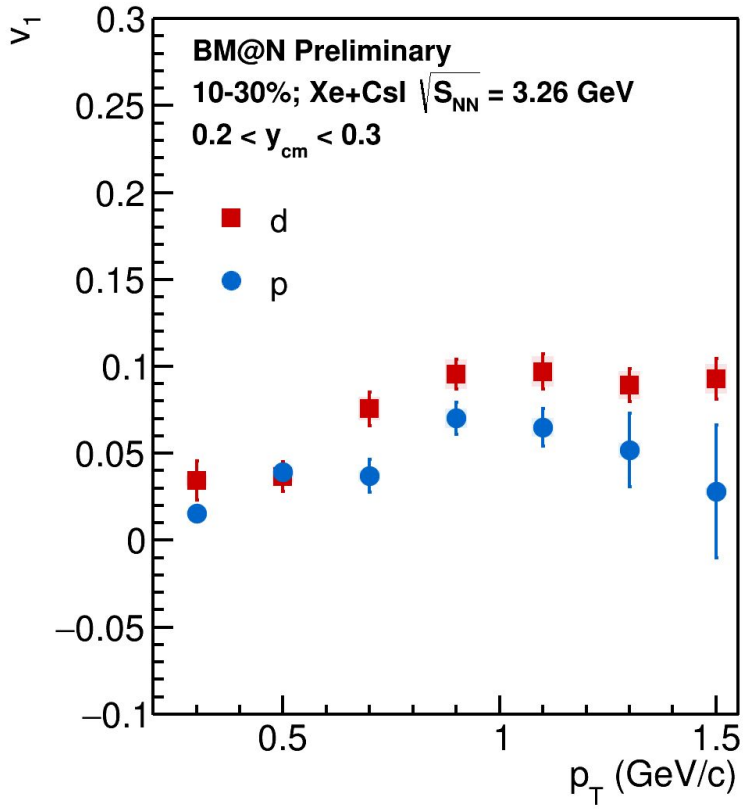




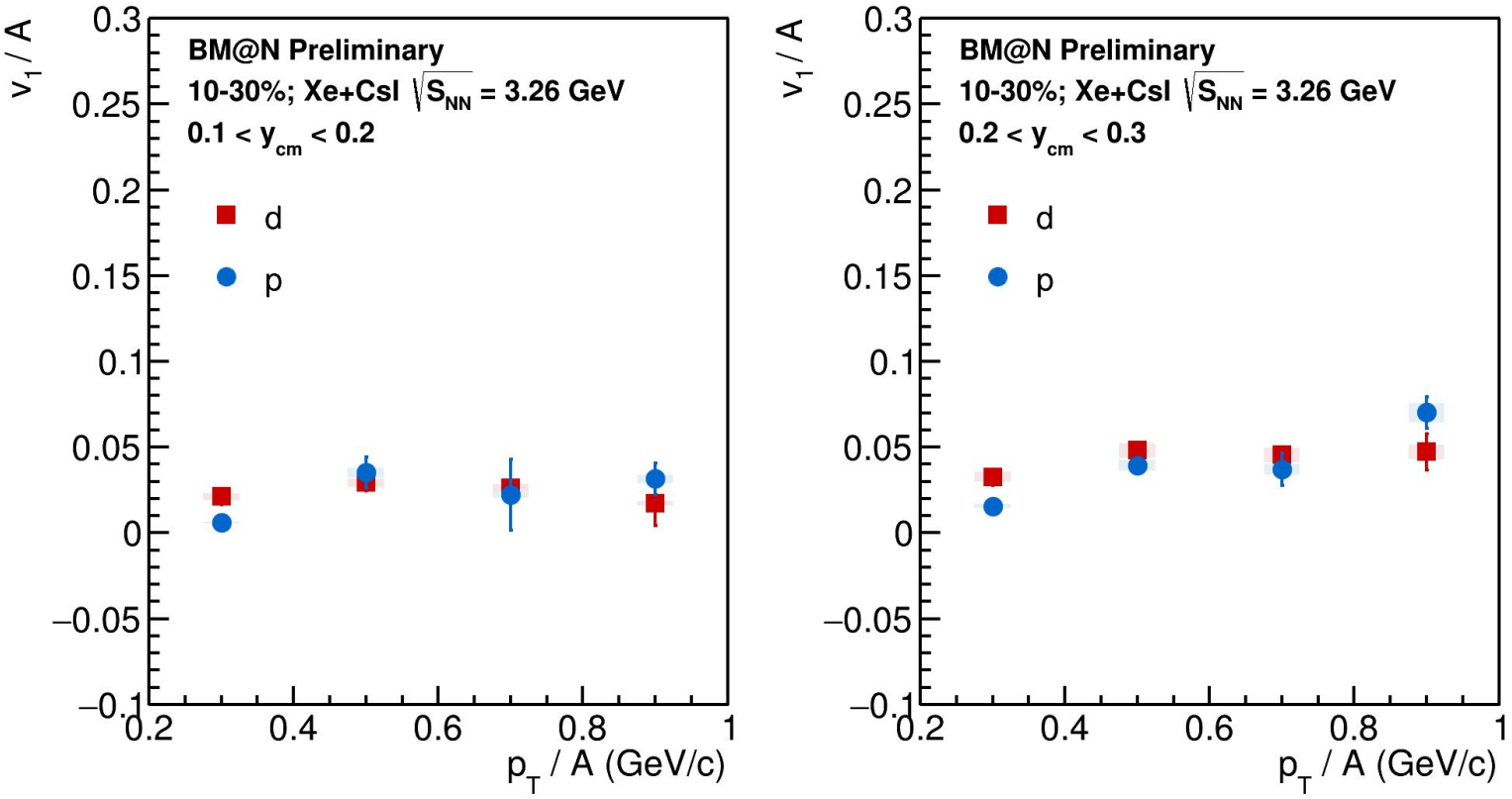
v_1 of deuterons is larger than v_1 of protons as expected.

v_1 of protons and deuterons as a function of p_T



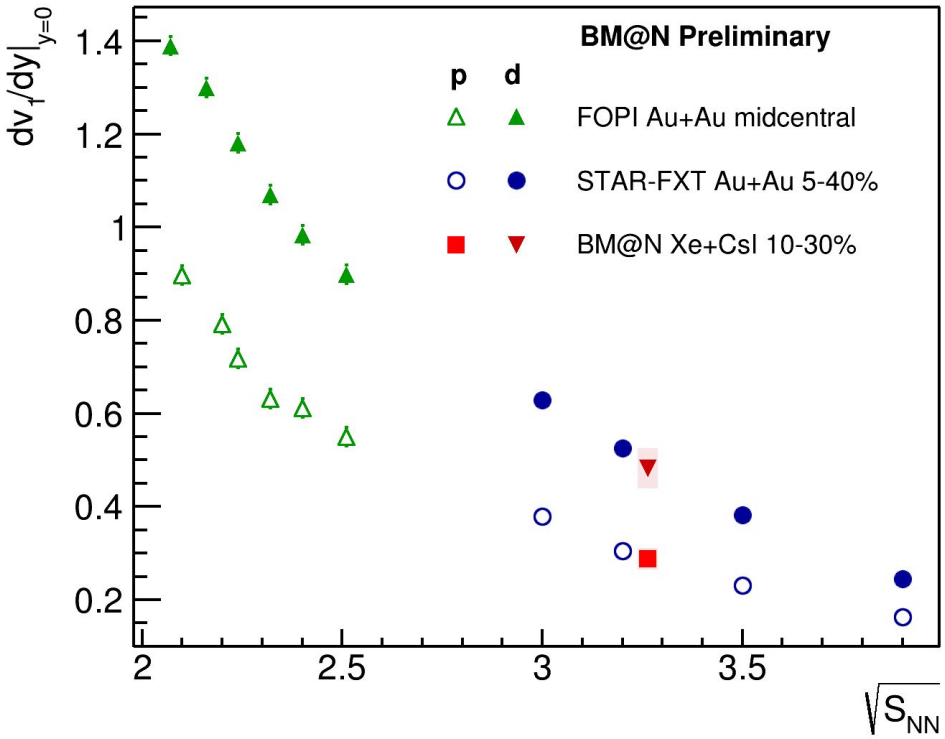


Scaled v_1 of protons and deuterons as a function of scaled p_T/A



v_1 follows the scaling with mass number A.

The slope of v_1 of deuterons at midrapidity as a function of collision energy



Directed flow slope of deuterons at midrapidity dv_1/dy is found to be in a good agreement with existing world data.

Summary

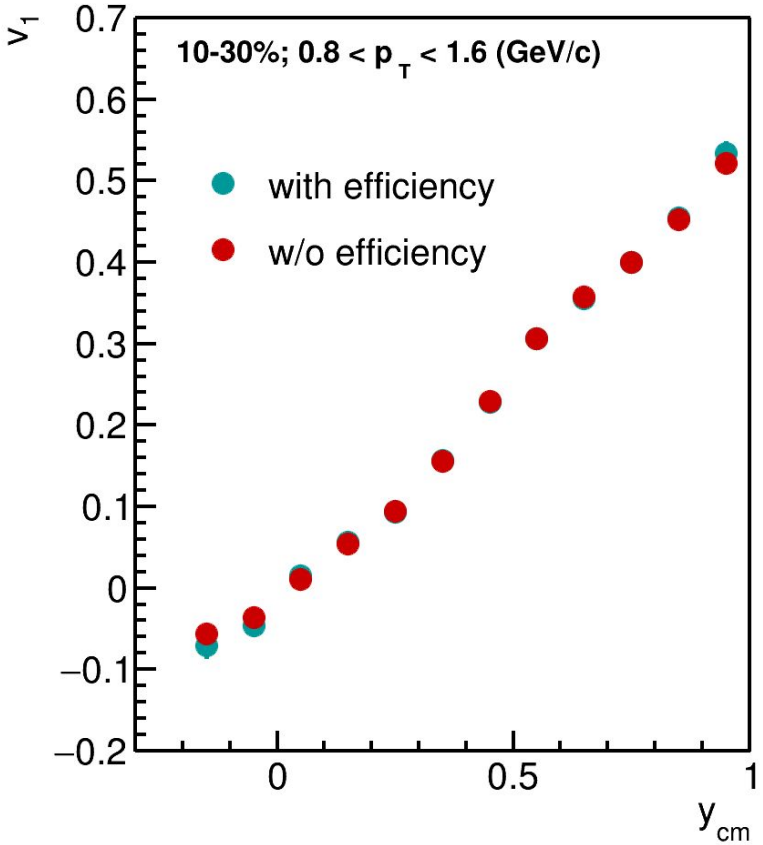
- v_1 of deuterons was measured differentially as a function of transverse momentum, rapidity and centrality
- The systematic uncertainty due to track quality, secondaries contamination, contamination from different particle species and run-by-run variations were estimated. The total systematic uncertainty was found to be bellow 9%
- The directed flow v_1 of protons and deuterons was studied for mass-number scaling. v_1 for protons and deuterons follow the scaling
- The directed flow slope at midrapidity $dv_1/dy|_{y=0}$ was extracted. Value for $dv_1/dy|_{y=0}$ is found to be in agreement with the world data

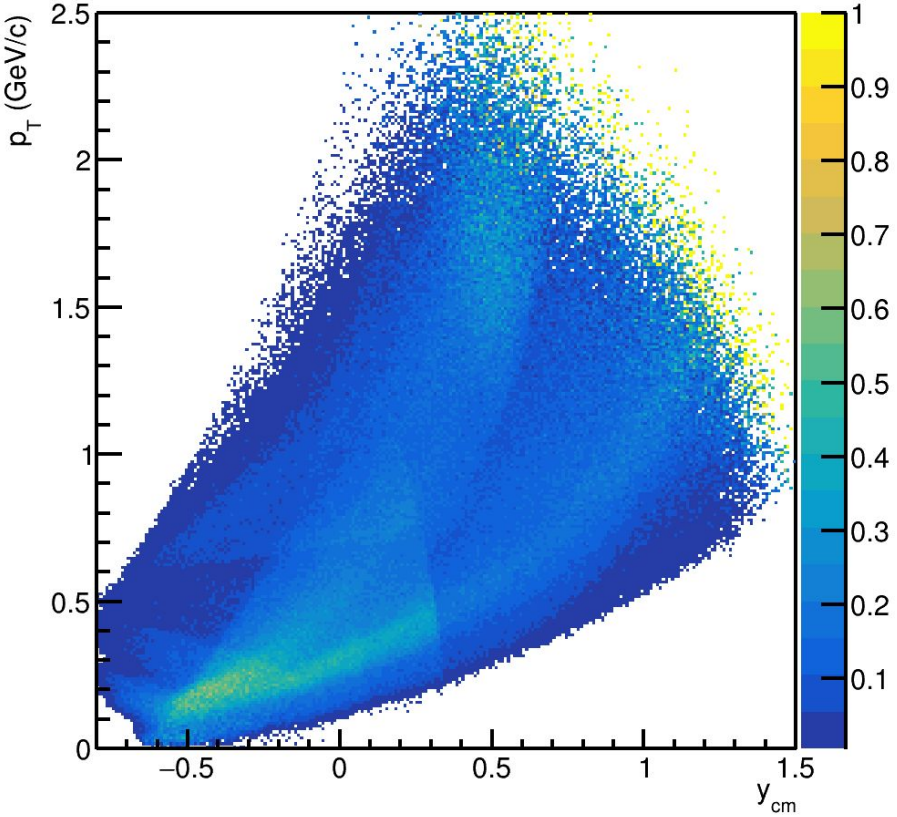
Outlook

- Perform PID with fitting peaks from different particle species to account for background, possible ^{3}He contamination and misidentification; estimate purity.
- Apply dE/dx to differentiate between ^{4}He and deuterons.
- Compare the experimental result with theoretical predictions from models (e.g. PHQMD, THESEUS event generator).

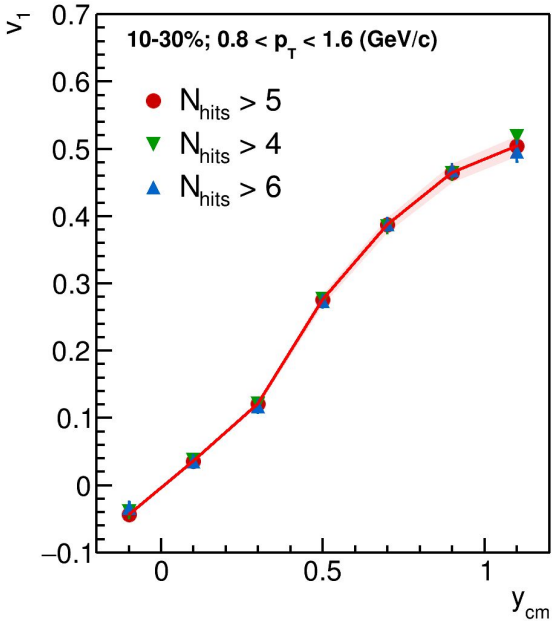
Backup

v_1: effect of applying efficiency correction

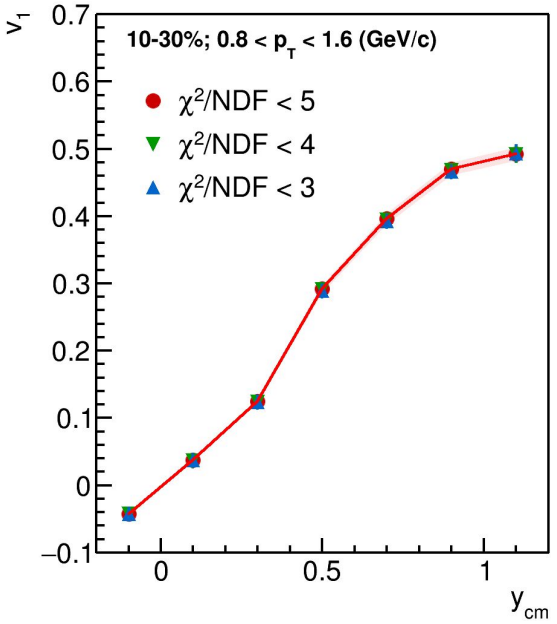




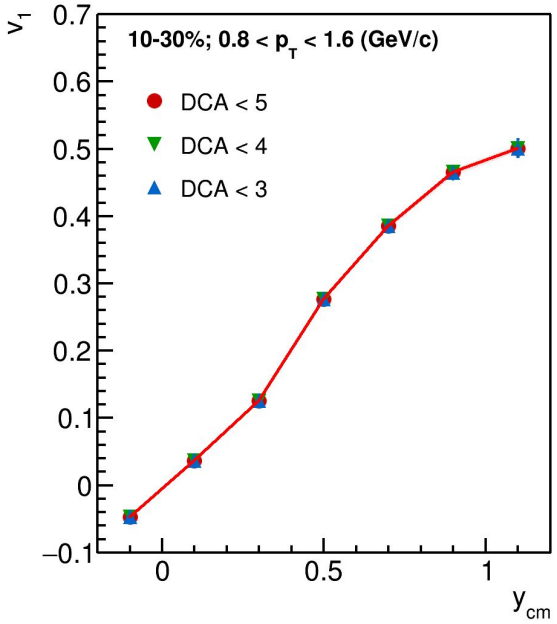
Systematics due to tracking and secondary particles



systematics is below 3%

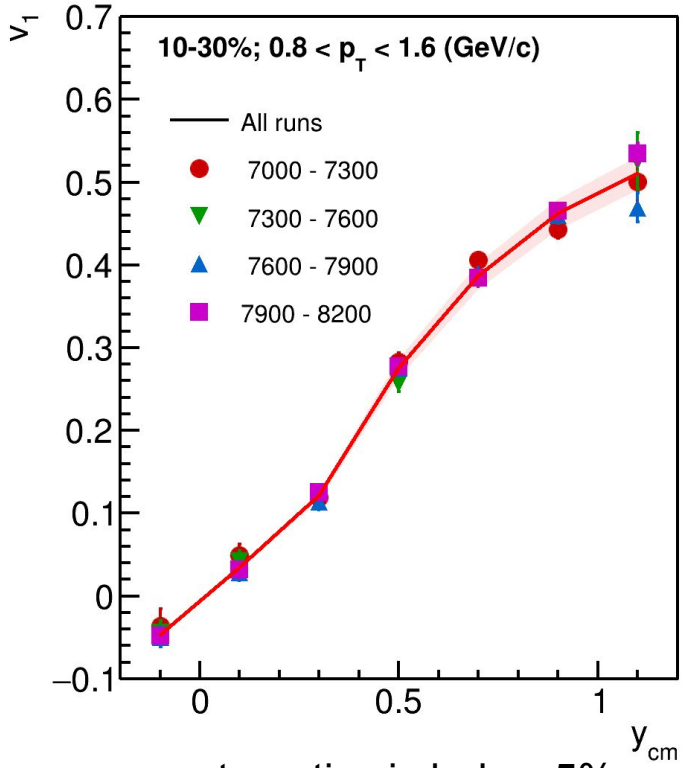


systematics is below 2%



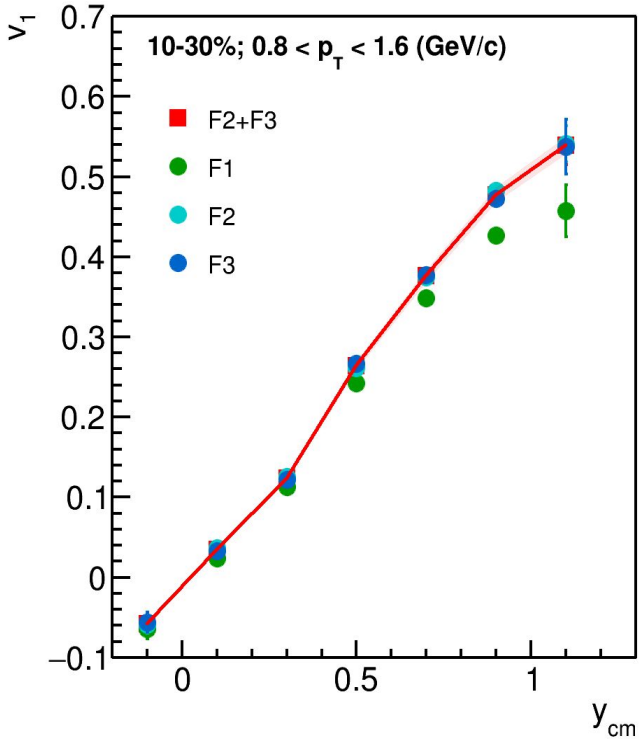
systematics is below 1%

Systematics due to run-by-run variations

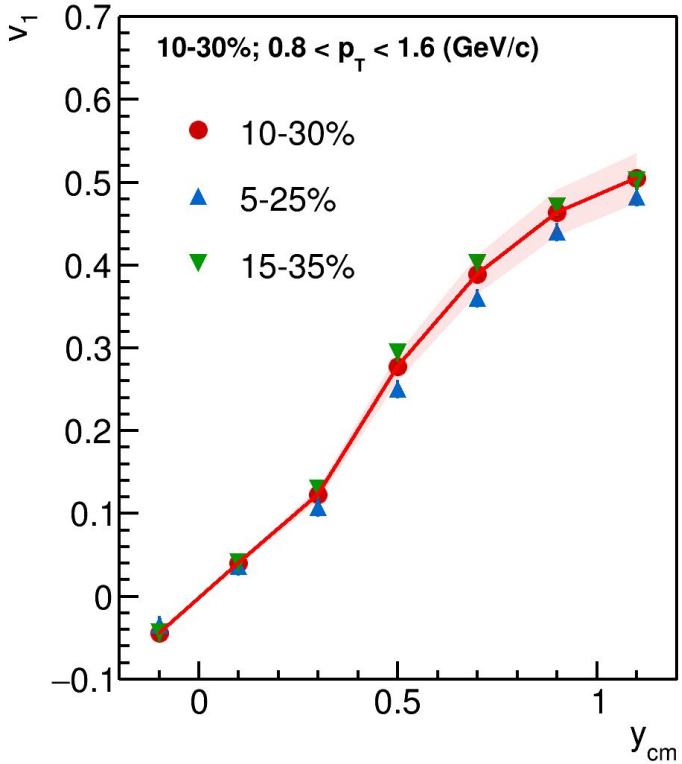


systematics is below 5%

Systematics due to symmetry plane estimation (non-flow)

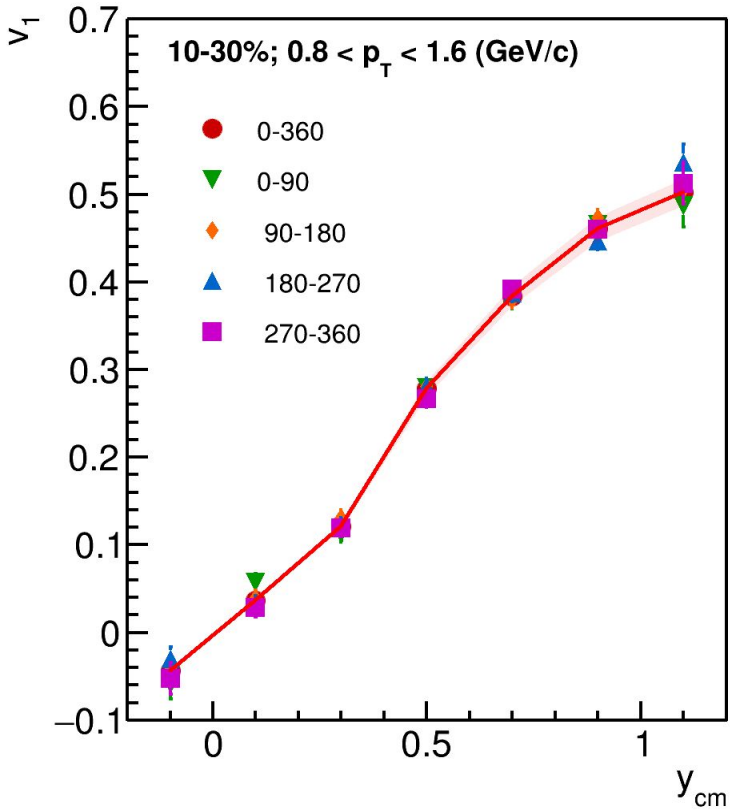


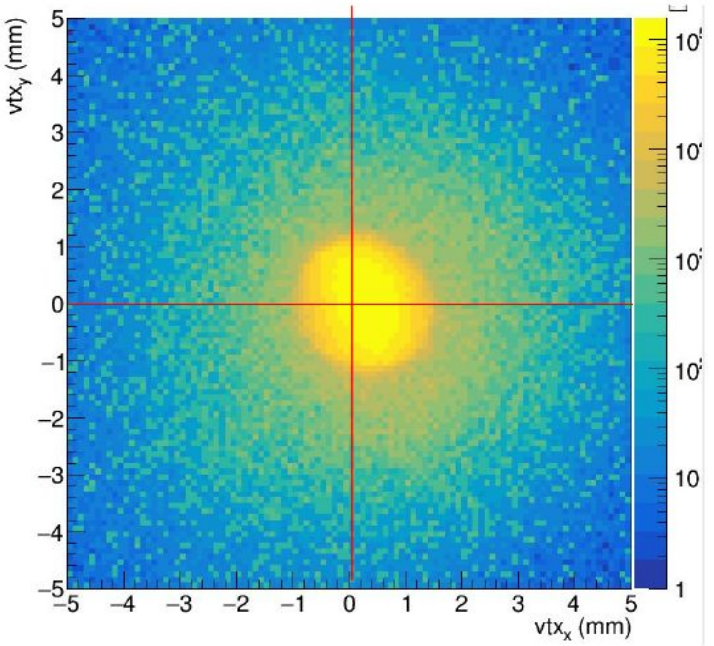
The systematics for combined (F2+F3) planes is below 2%



systematics is below 5%

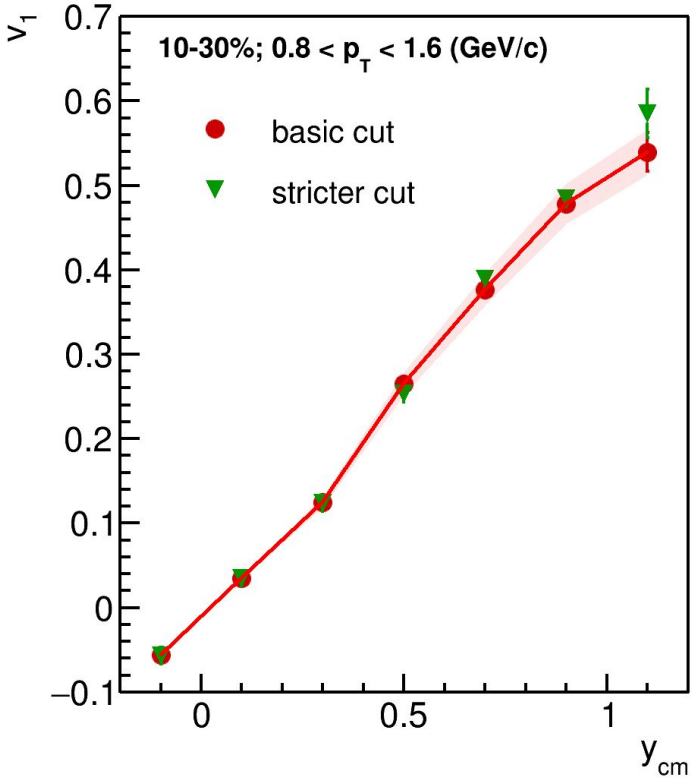
Systematics due to vertex position



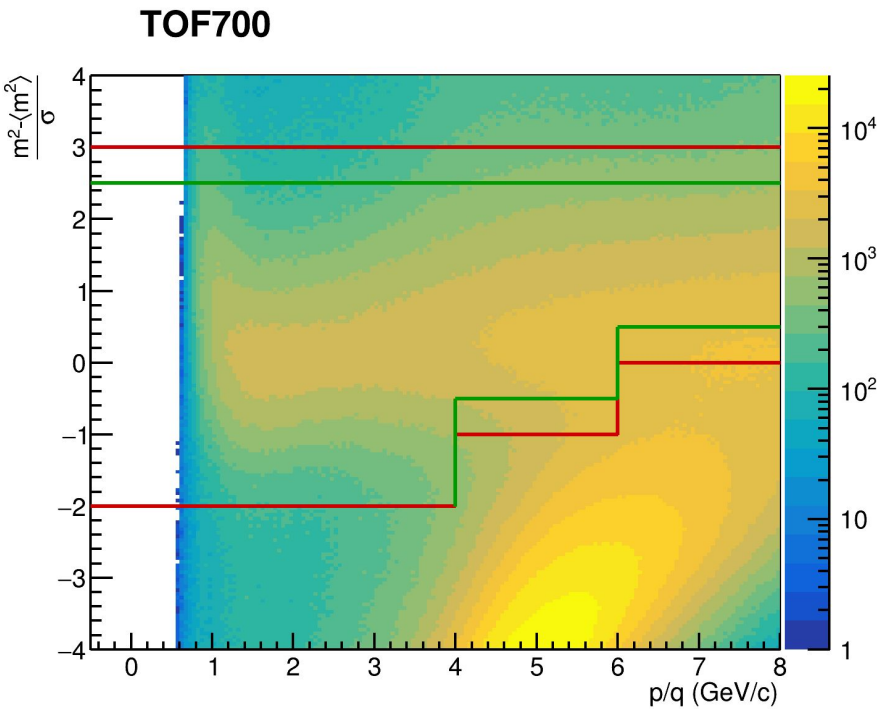


systematics is below 3%

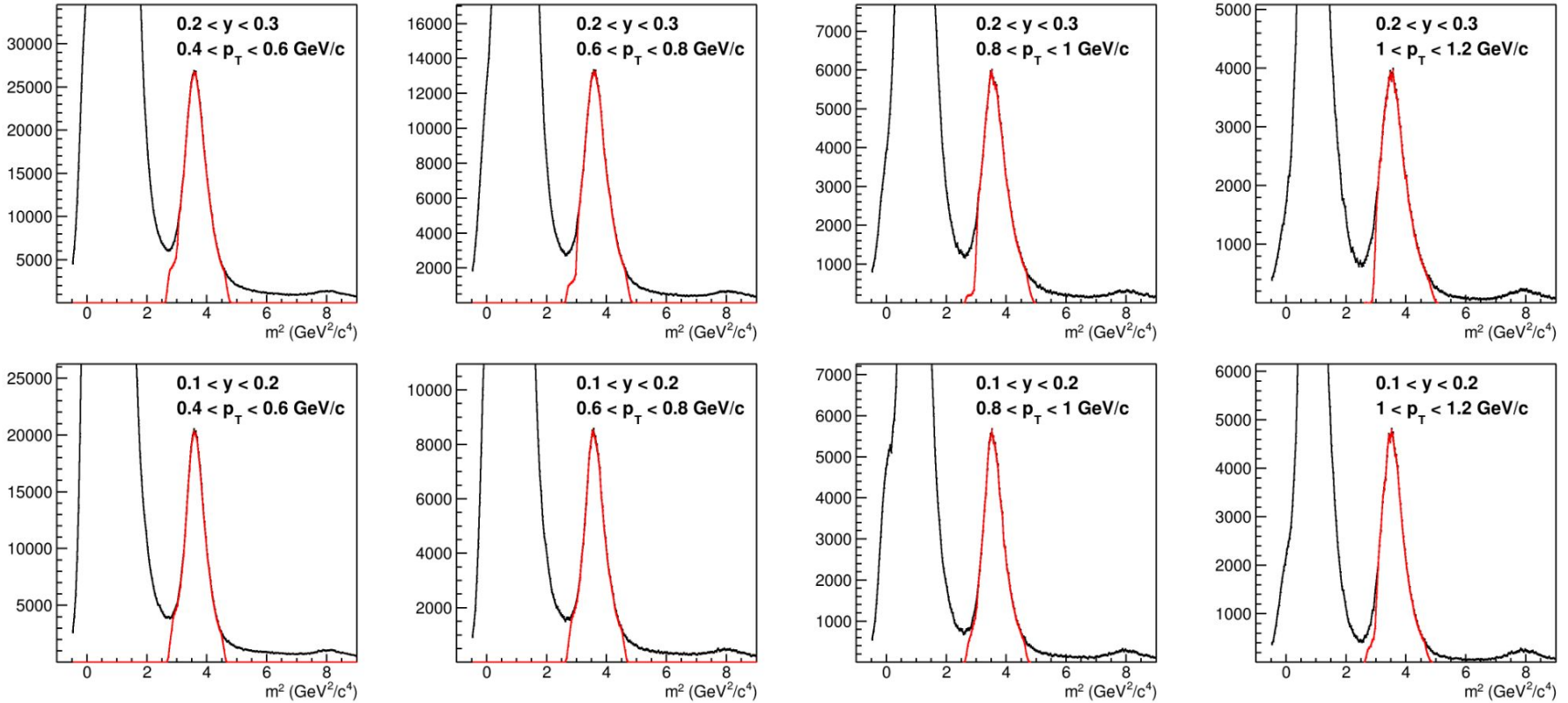
Systematics due to contamination from other particle species



systematics is below 5%

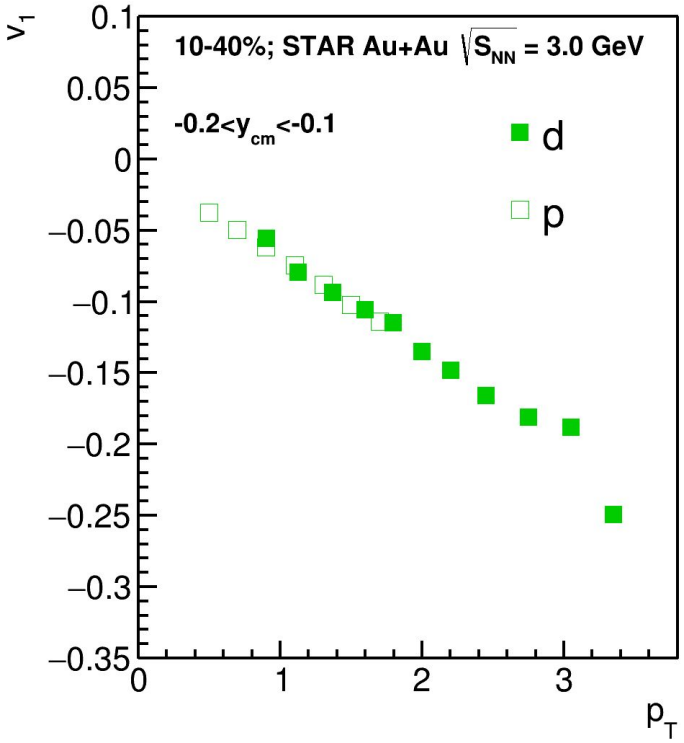


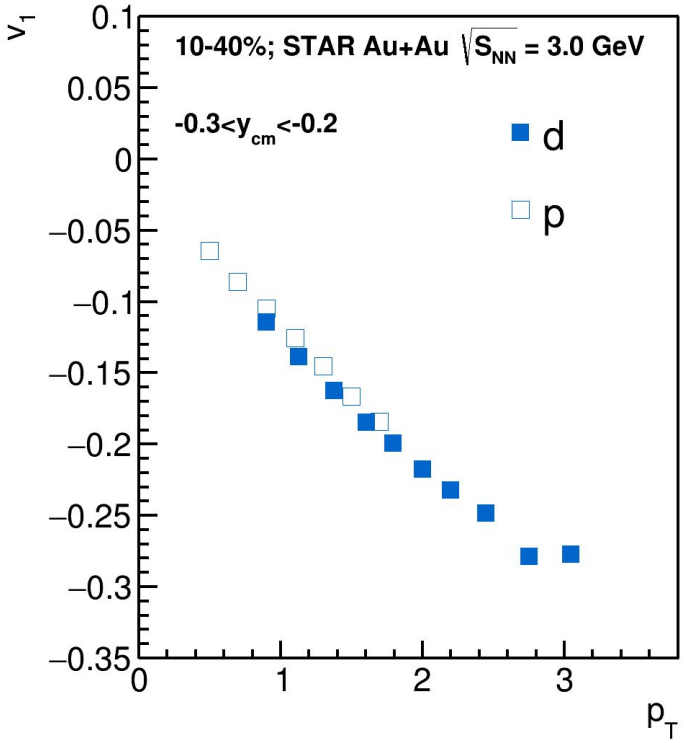
Particle Identification



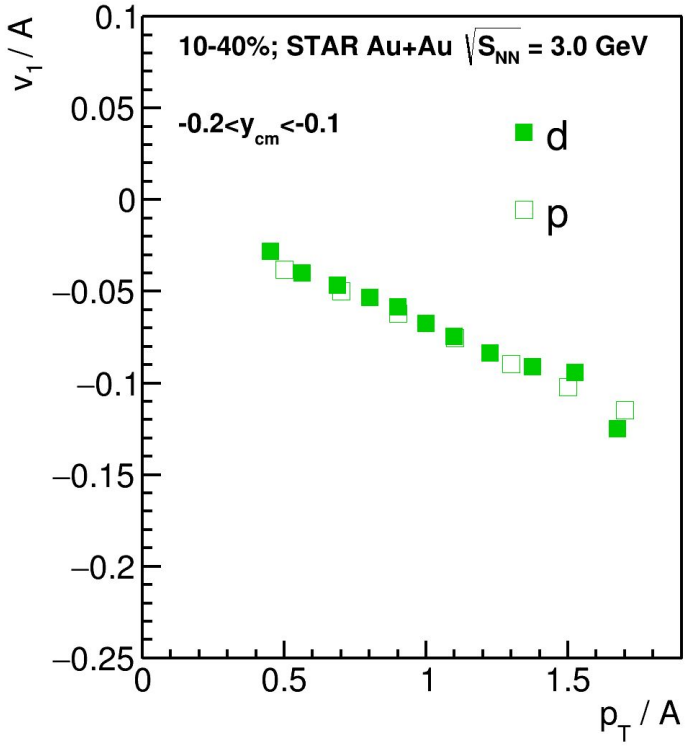
m2 particle distribution in p_T and y bins in the TOF700

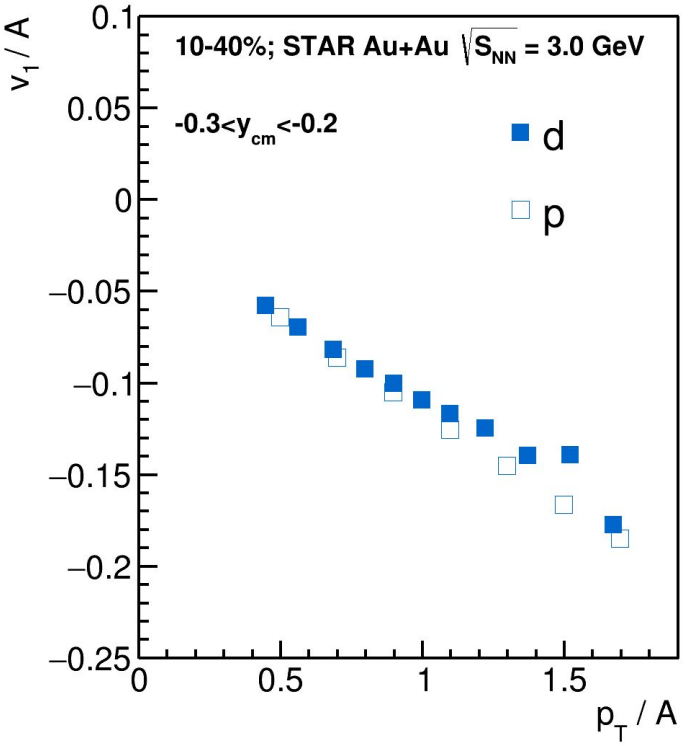
STAR data: v_1 of protons and deuterons as a function of p_T



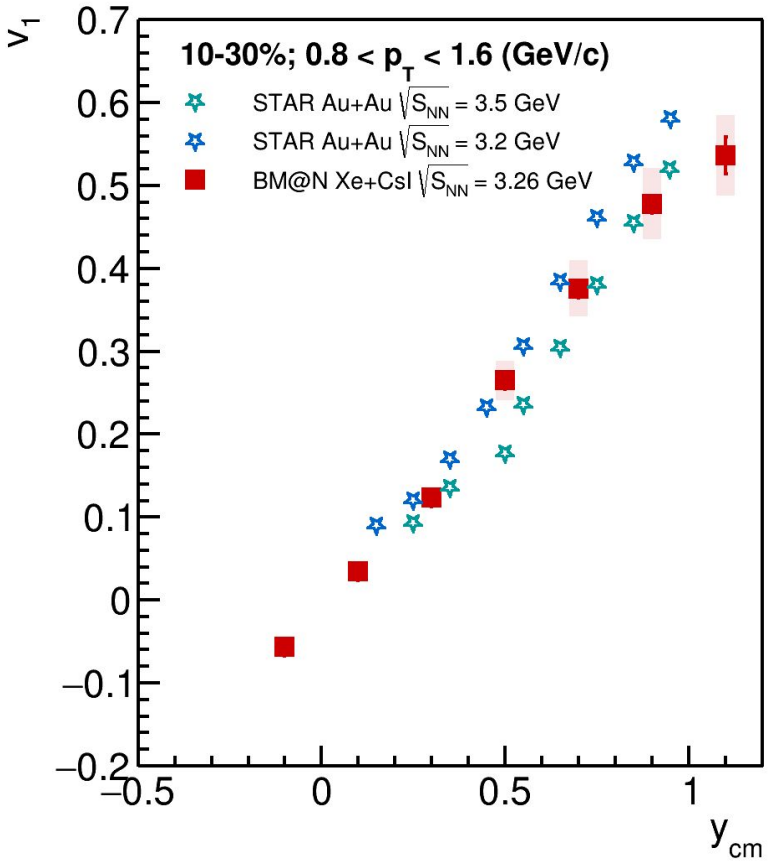


STAR data: scaled v_1/A of protons and deuterons as a function of scaled p_T/A





v_1 of protons and deuterons as a function of y and p_T



centrality 10-30% - for the BM@N data
centrality 5-40% - for STAR