Азимутальные потоки протонов в эксперименте BM@N

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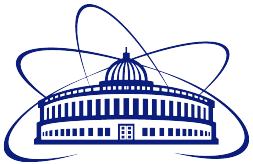
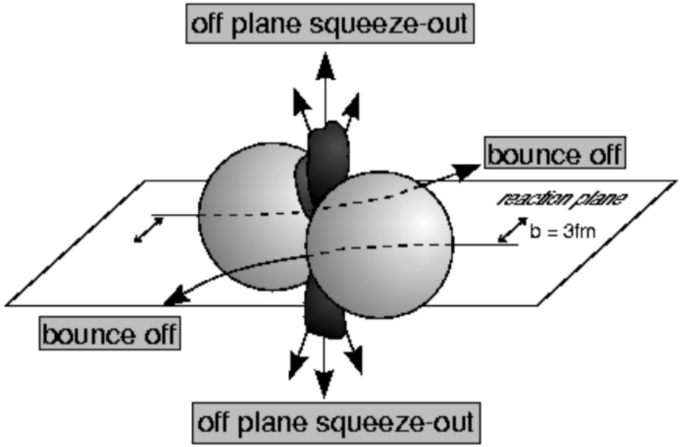
This work is supported by: RSF grant No. 22-12-00132



Научная сессия секции ядерной физики ОФН РАН, 01/04/2024

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:

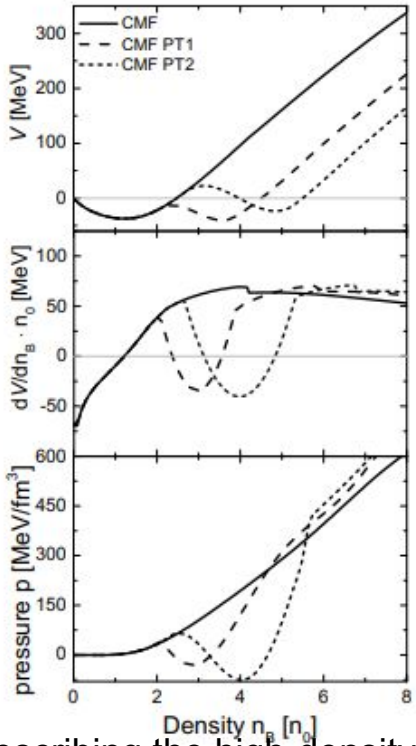
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right] \rangle$$

Anisotropic flow is sensitive to:

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

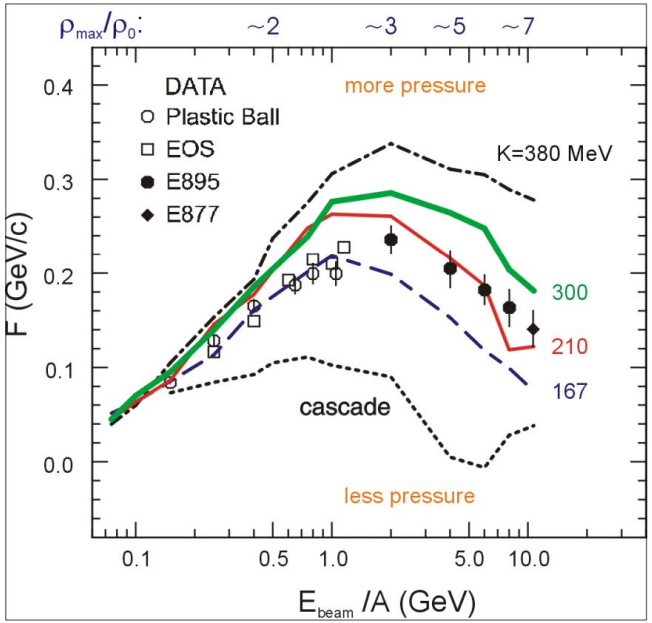
v_n as a function of collision energy

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

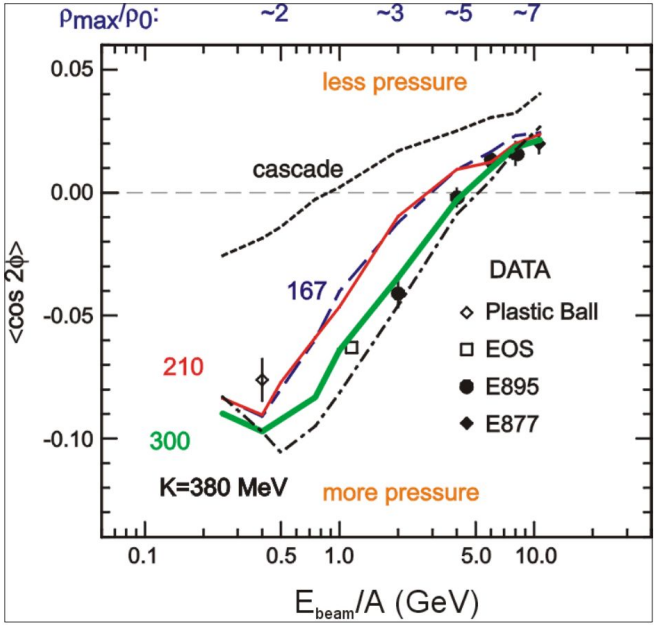


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



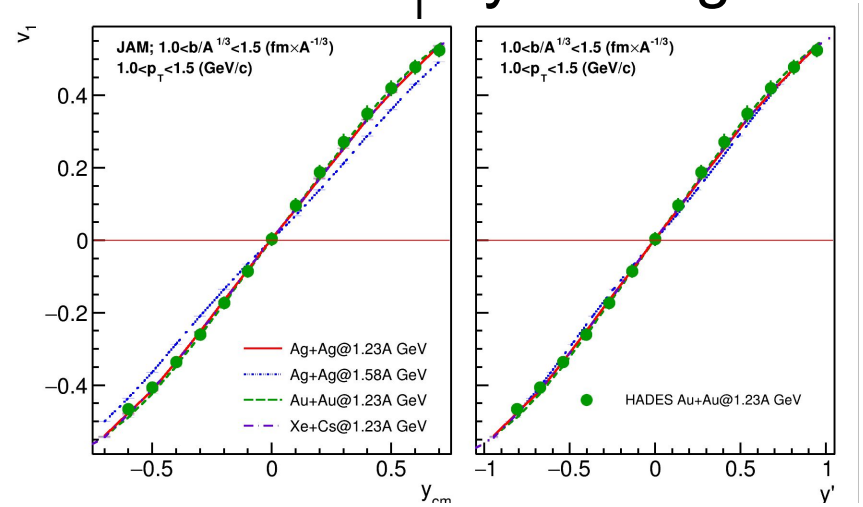
v_2 suggests harder EOS

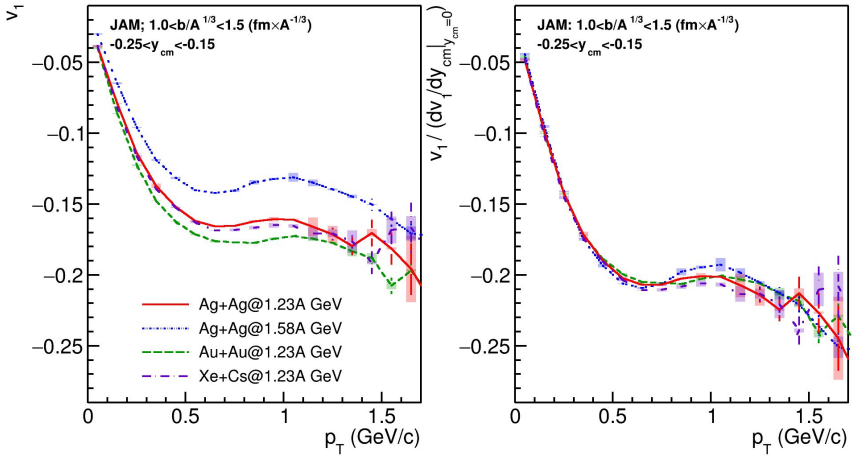


Describing the high-density matter using the mean field
Flow measurements constrain the mean field

Discrepancy is probably due to non-flow correlations

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

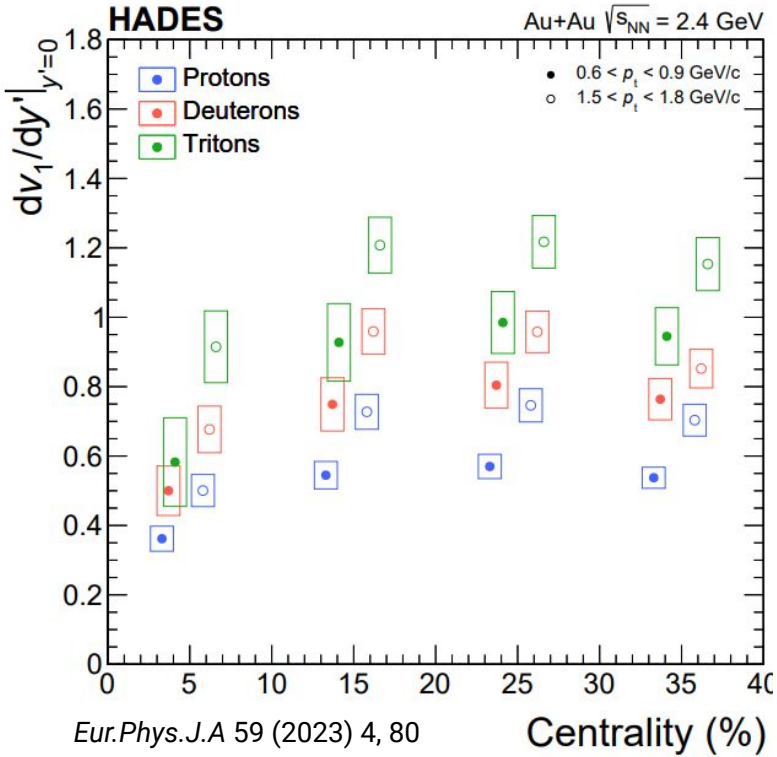




- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

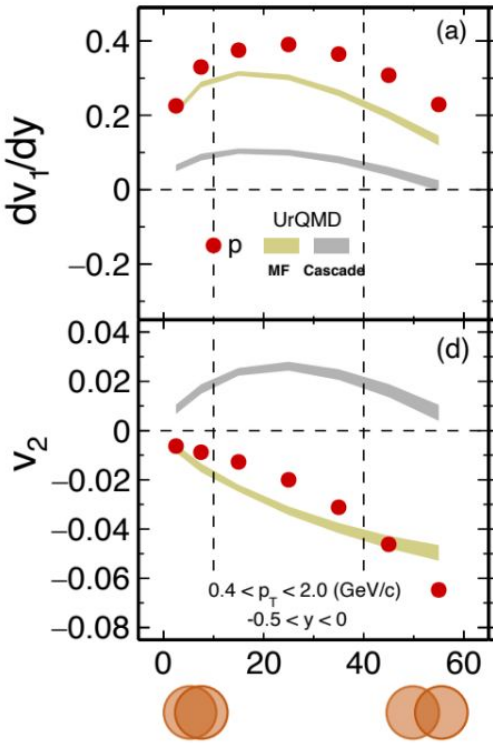
M.Mamaev Particles 2023, 6(2), 622-637

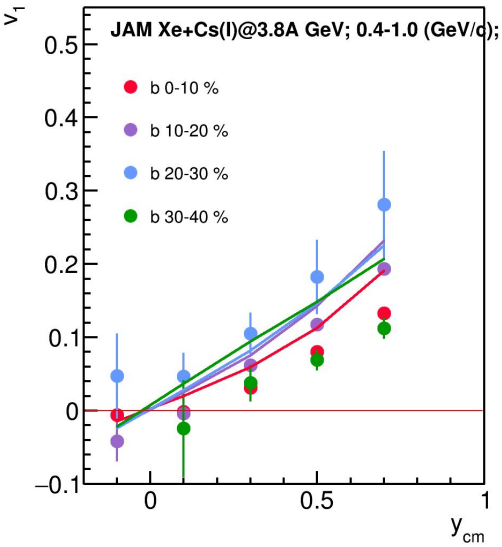
dv_1/dy as a function of centrality



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

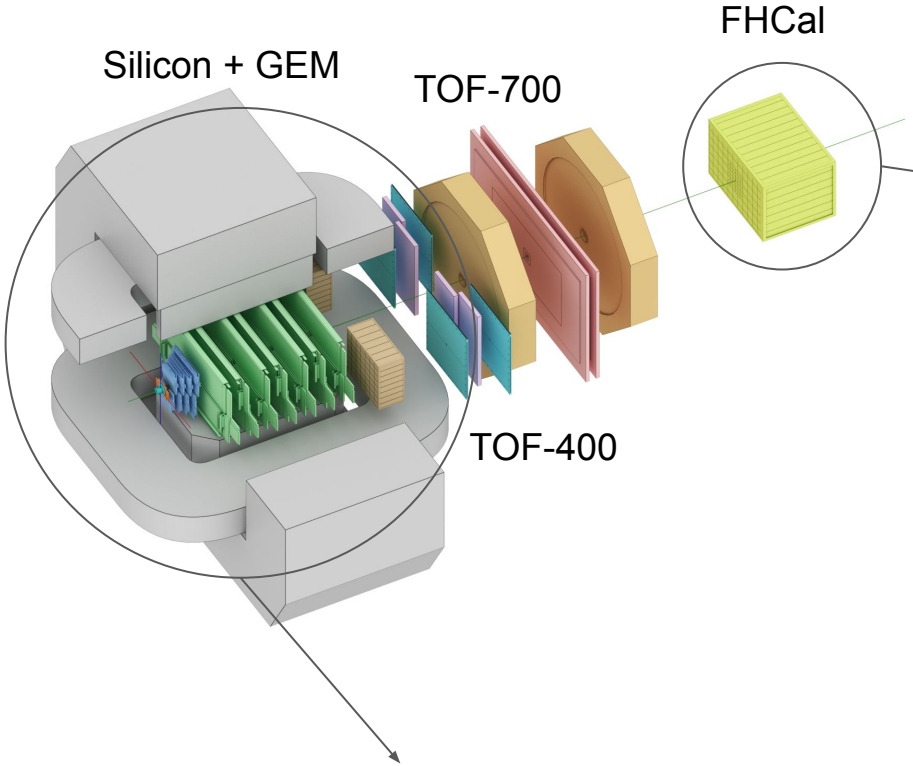
STAR FXT

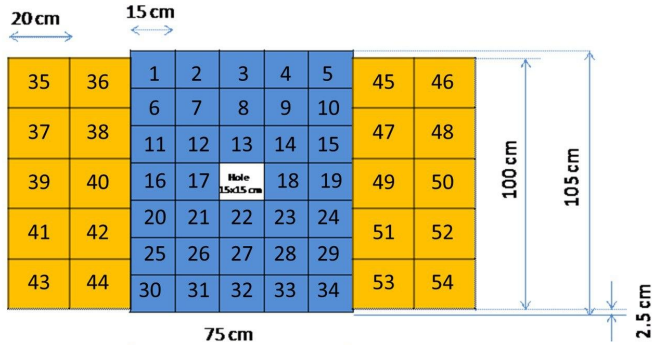


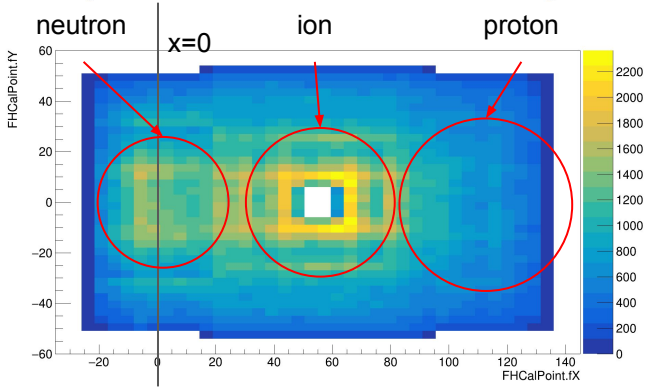


Weak centrality dependence for directed flow

The BM@N experiment (GEANT4 simulation for RUN8)





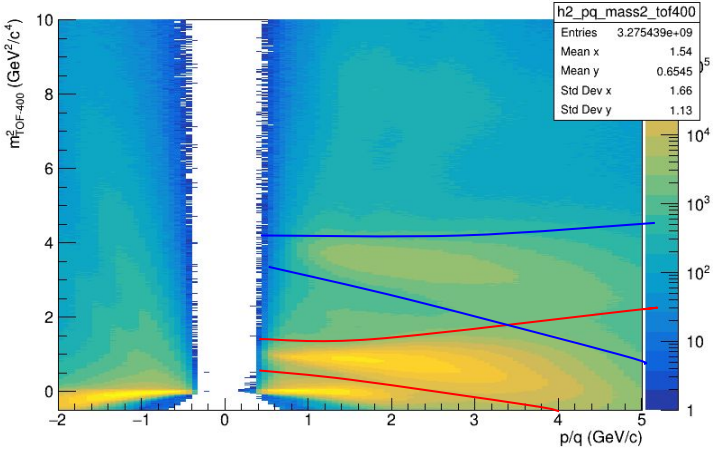


VF tracking was used

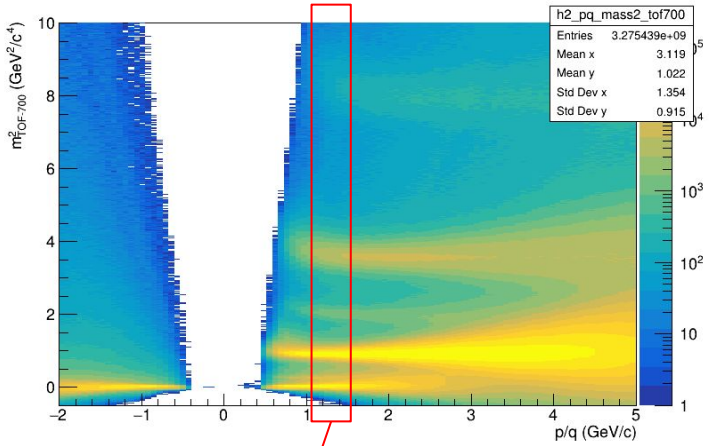
The first production was used

Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

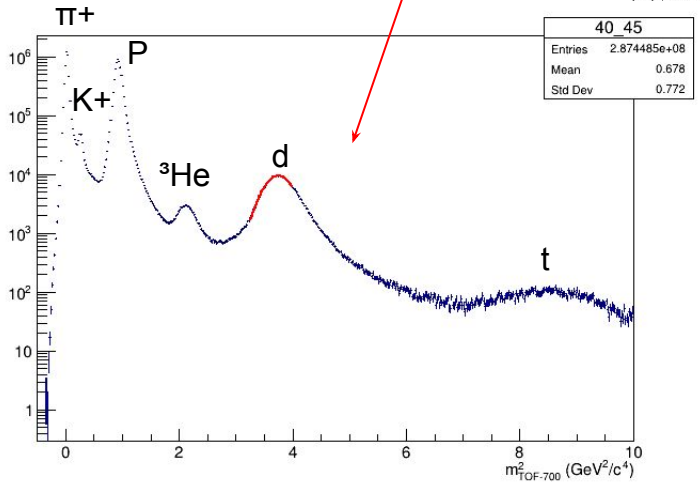
Identification procedure



$$m^2 = \frac{(1-\beta^2) * p^2}{\beta^2}$$



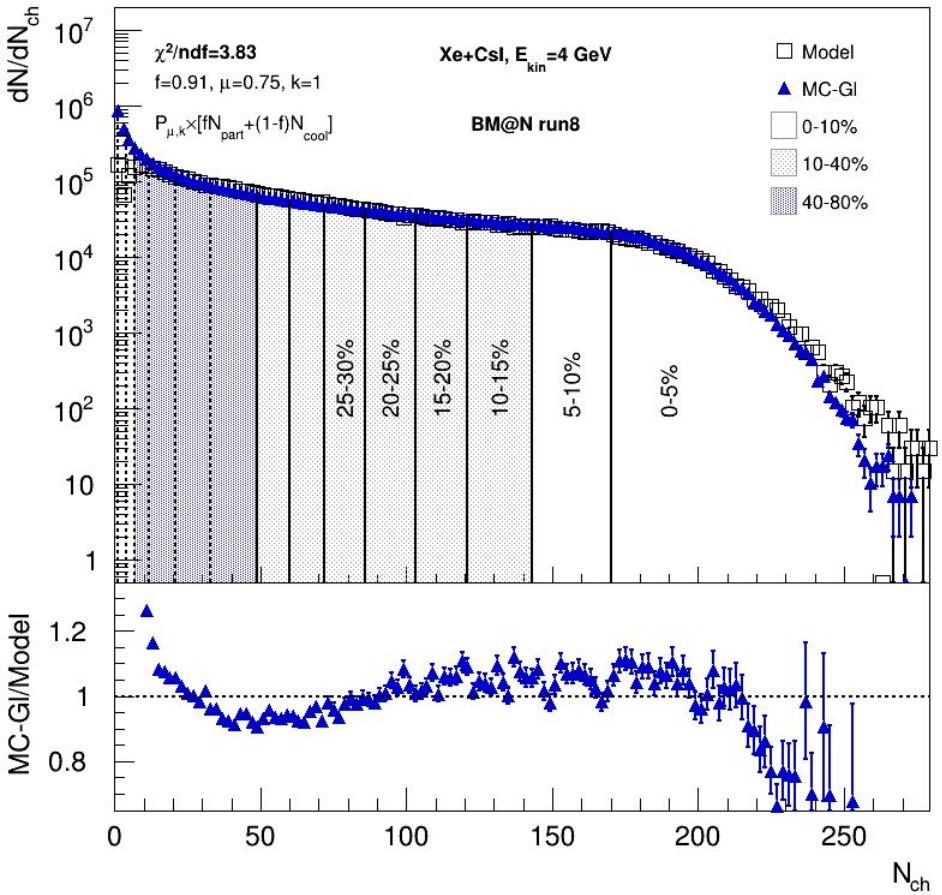
- Mass squared distribution is fitted in narrow bins of p/q
- Protons, pions, deuterons, tritons and helium are fitted

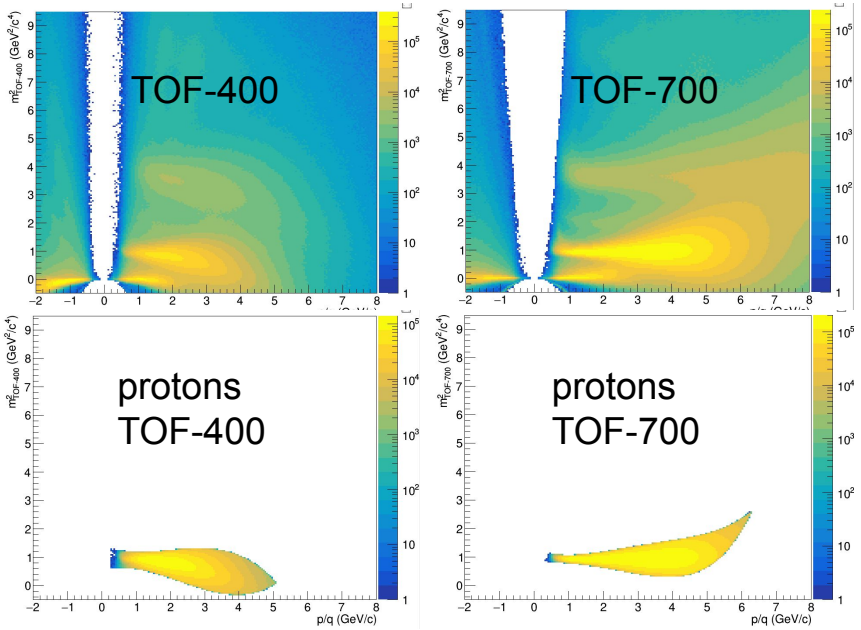


Purity is the function showing possible contamination

$$p_i(m^2, p/q) = \frac{f_i(m^2, p/q)}{\sum_{i=1}^{N} f_i(m^2, p/q)}$$

Centrality and particle selection





- Whole recent VF production was analysed
- Event selection criteria (~100M events selected)
  - Central trigger
  - Number tracks for vertex > 1
- Track selection criteria : $\chi^2 < 5$; $M_p^2 - \sigma < m^2 < M_p^2 + \sigma$; Nhits > 5

Flow vectors

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

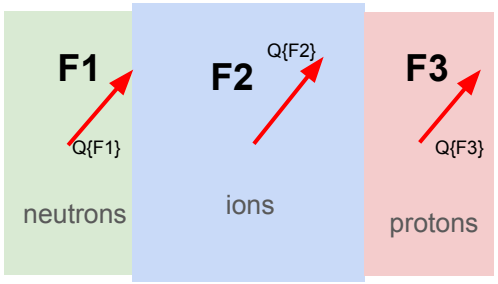
$$u_n = e^{in\phi}$$

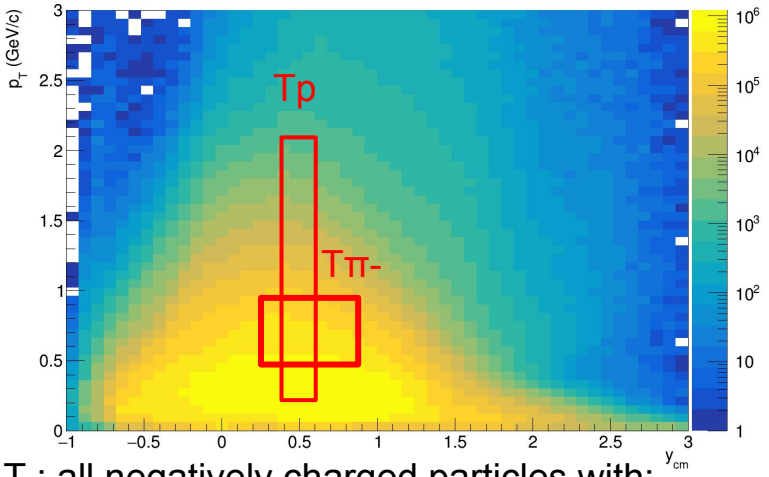
where φ is the azimuthal angle

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:

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

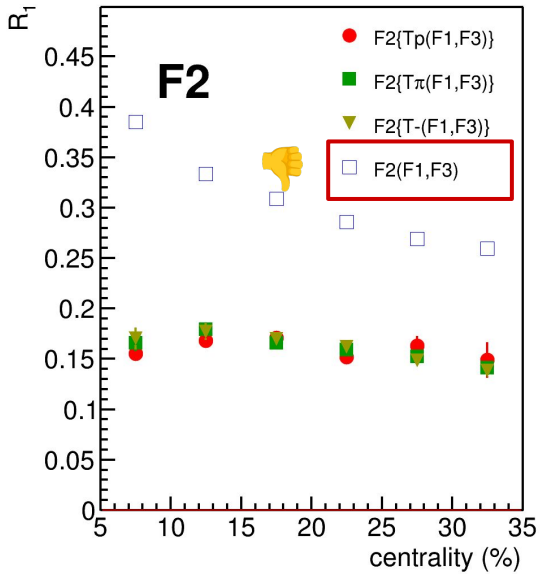
Where R_1 is the resolution correction factor

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

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

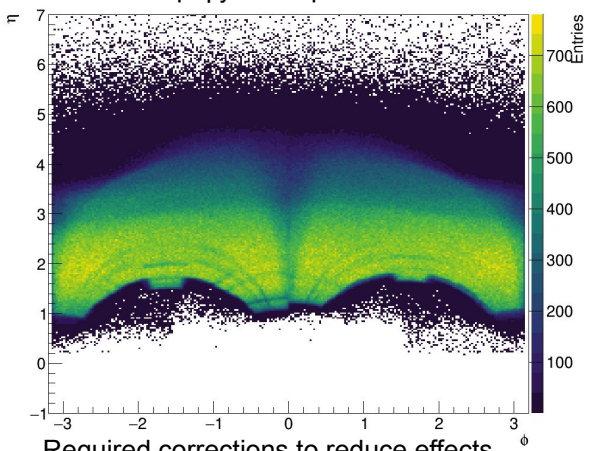


Symbol “F2{Tp}(F1,F3)” means R_1 calculated via (4S resolution):

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

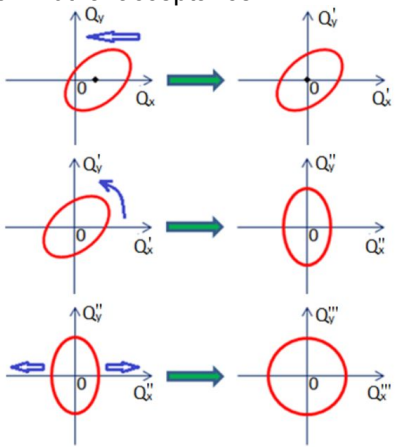
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

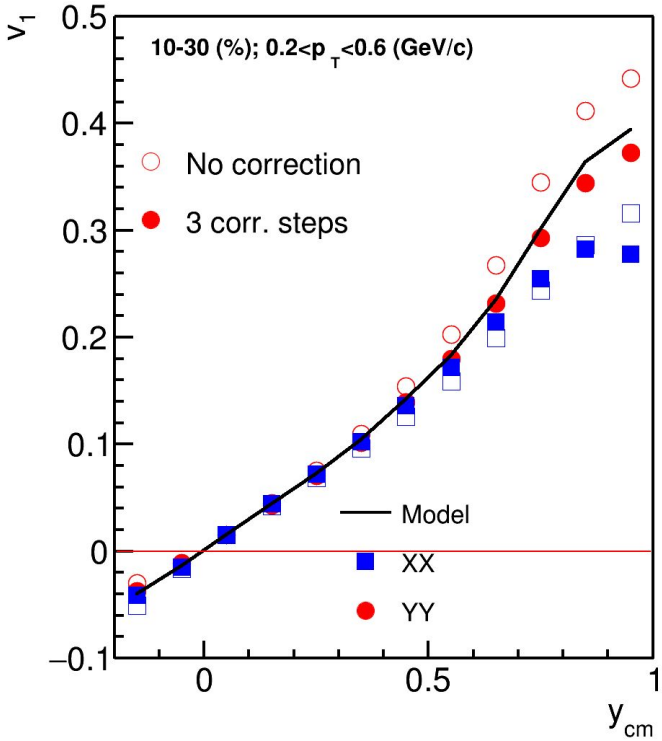


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

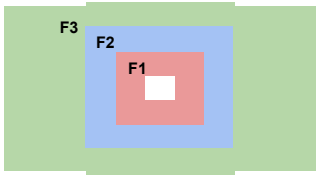


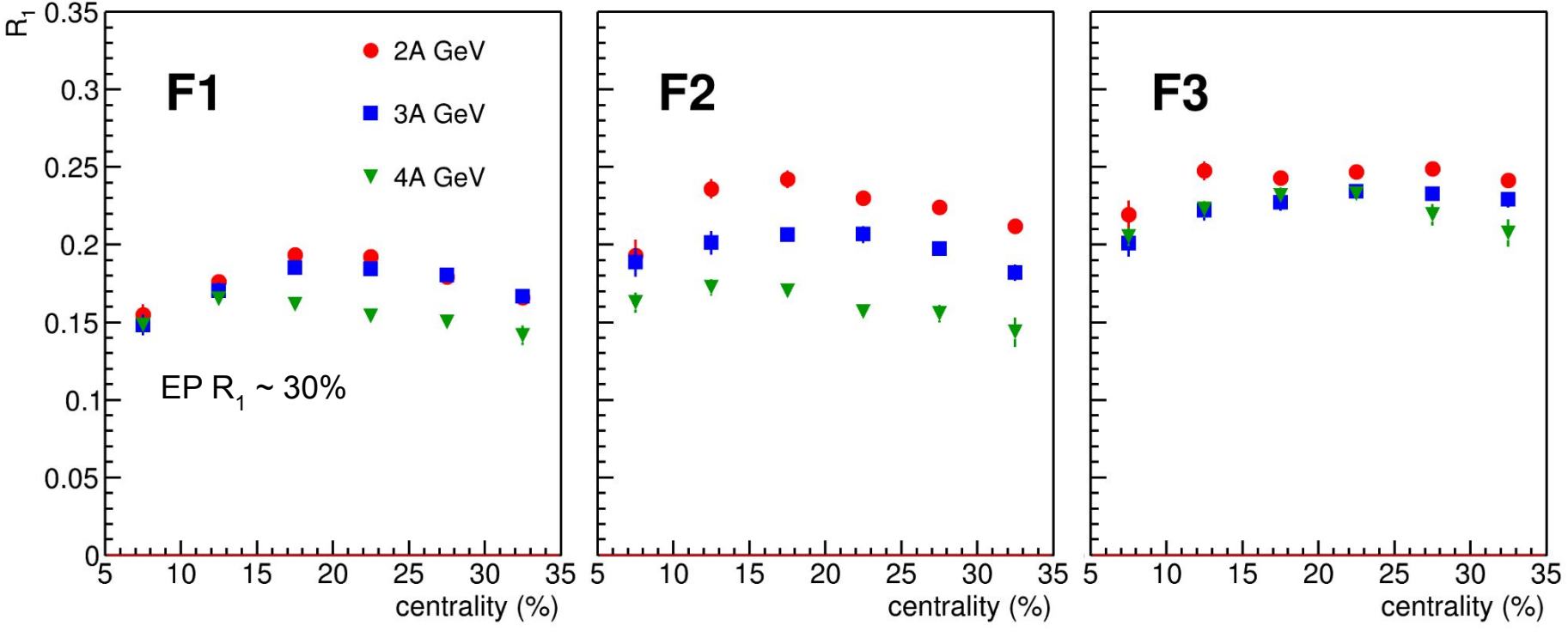
Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)



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

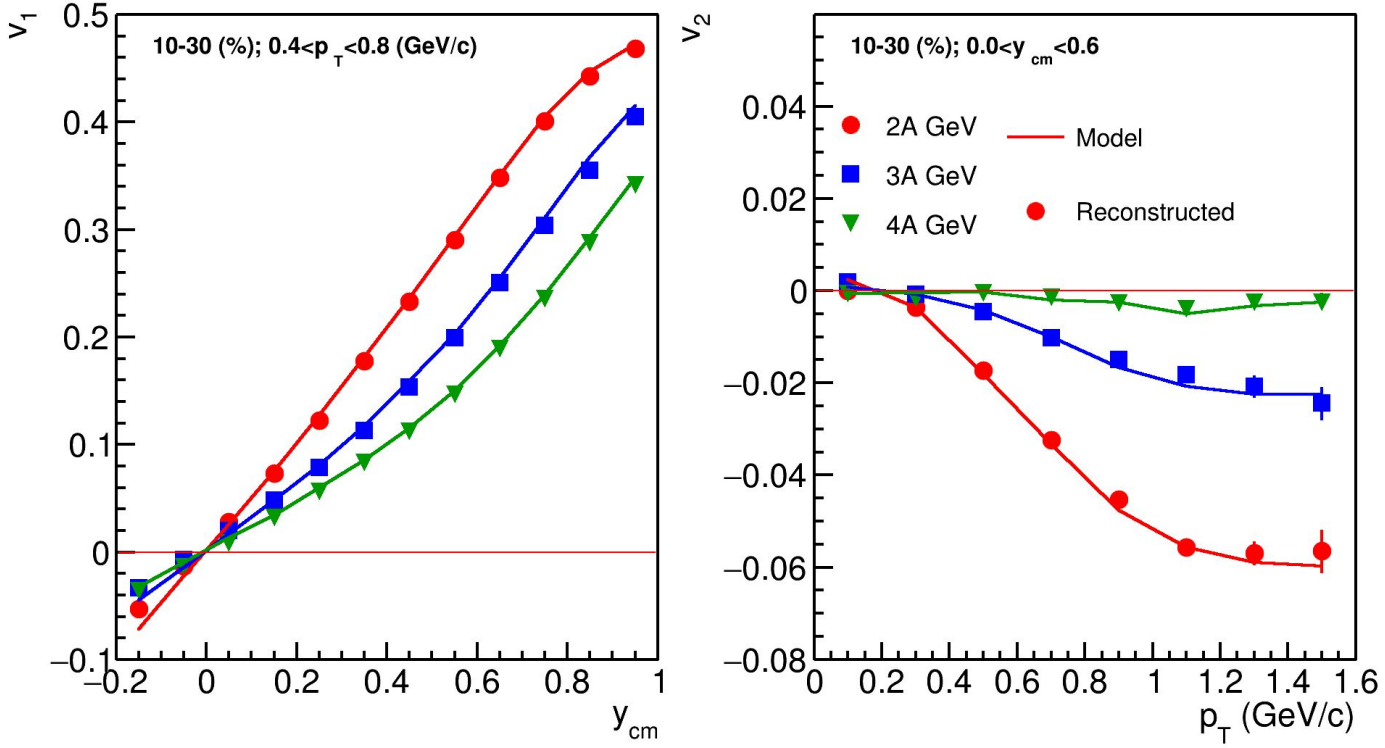
Rec R1: DCMQGCM-SMM Xe+Cs





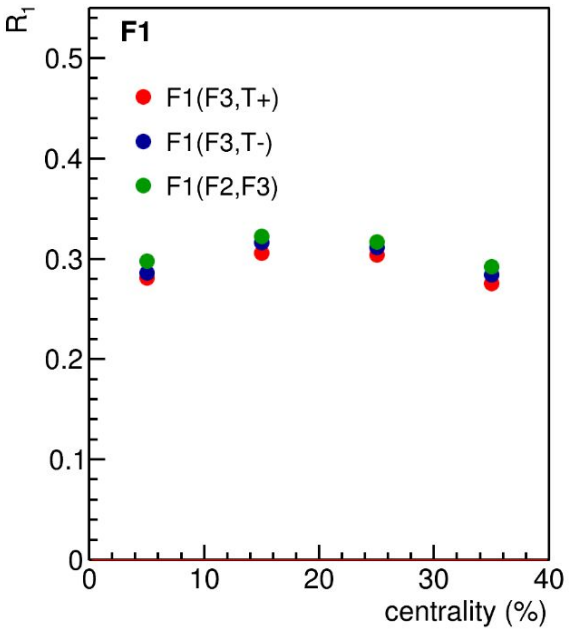
Resolution is lower for higher energies due to lower v_1

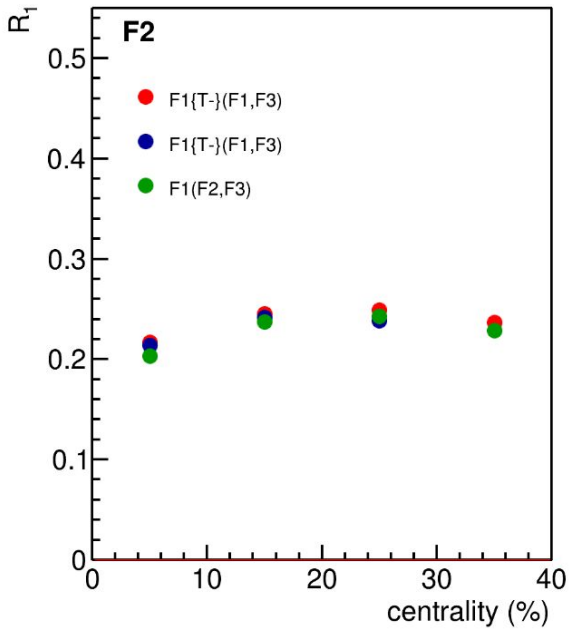
Directed and elliptic flow in Xe+Cs (JAM)

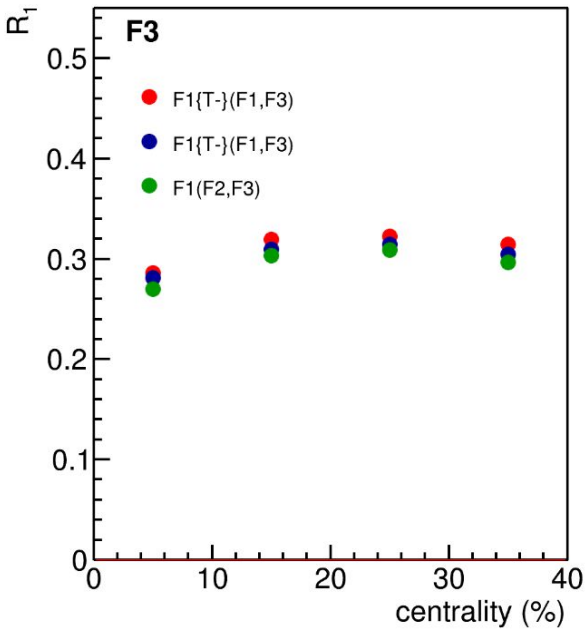


- Good agreement between reconstructed and pure model data for all three energies

Symmetry plane resolution in Xe+Cs(I) collisions







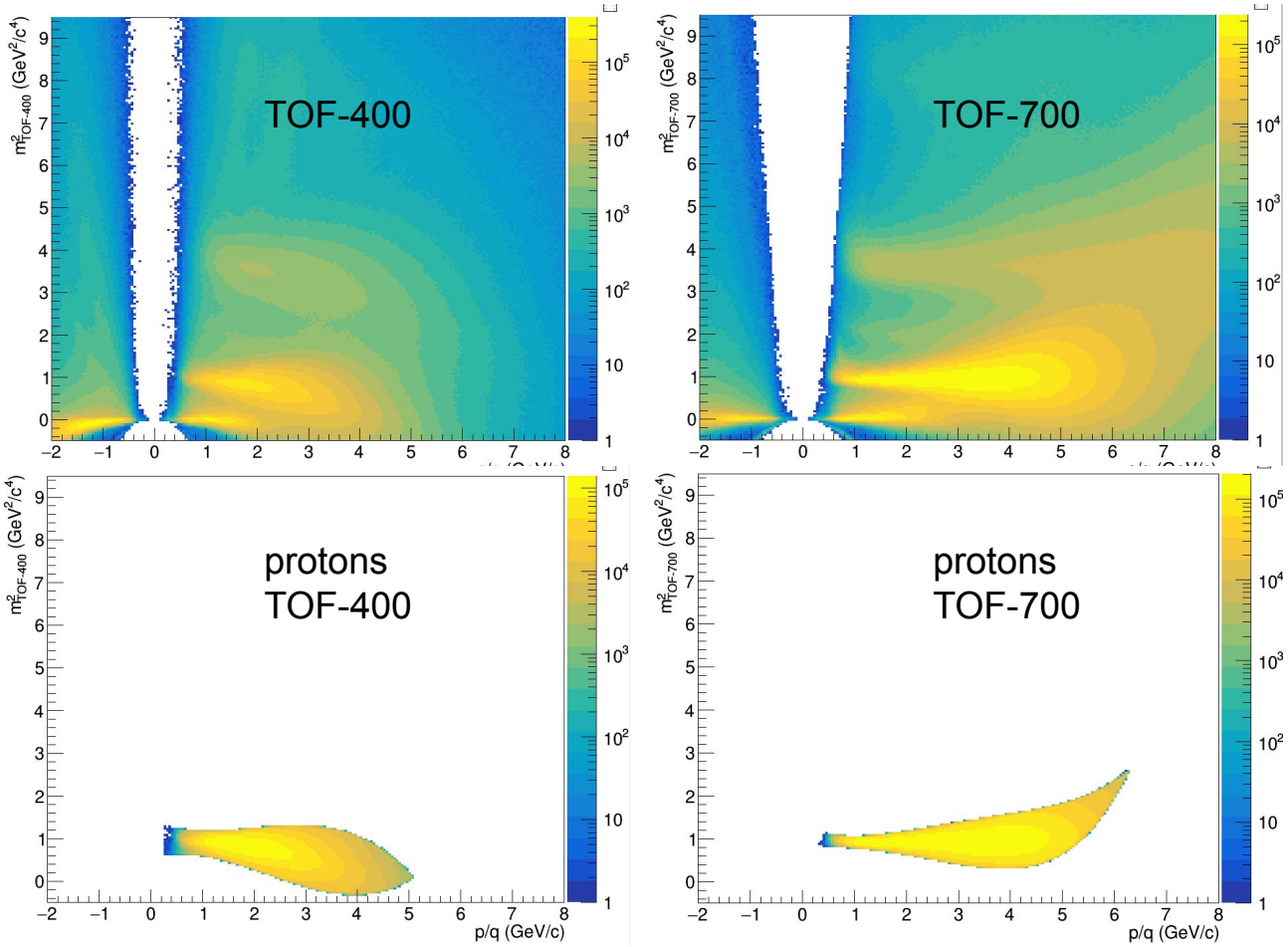
All the estimations for symmetry plane resolution are in a good agreement

Summary

- Resolution correction factor is calculated for DCMQGSM-SMM Xe+Cs collisions at beam energies of 4A, 3A and 1.5A 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

Backup

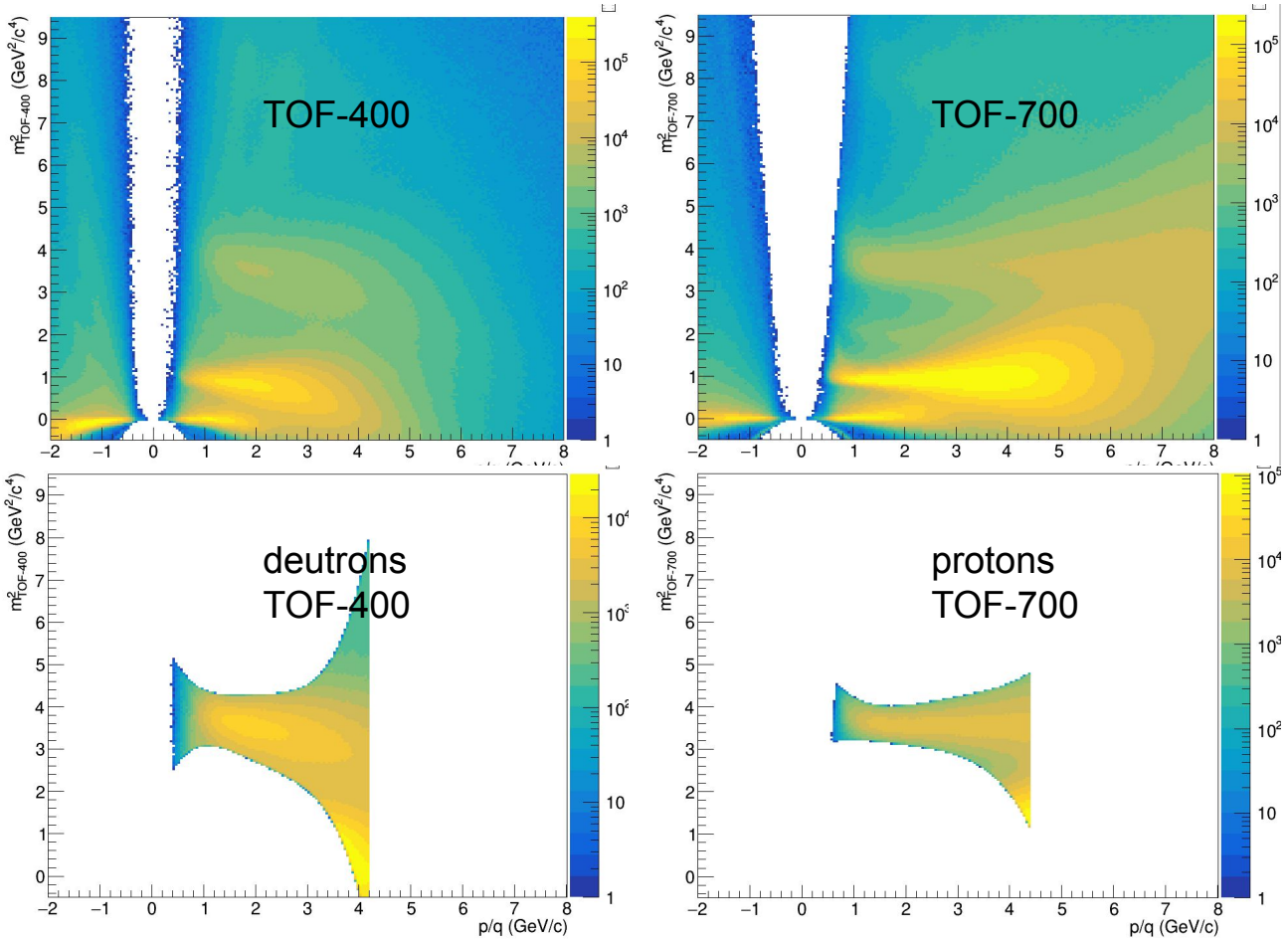
Proton identification



Proton candidates were selected with fitting the m^2 vs p\q

Selection criteria: <m>±2σ

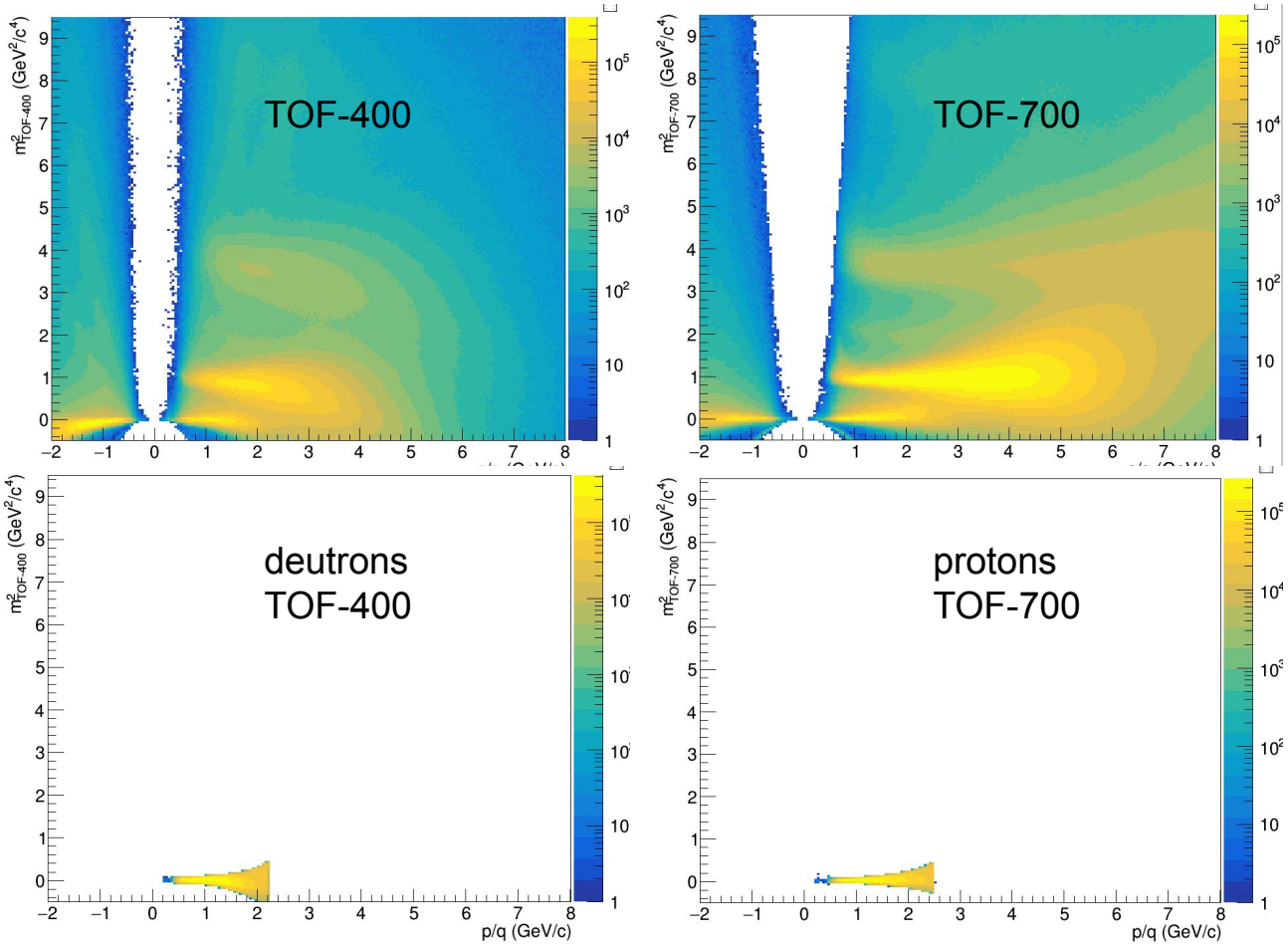
Deutron identification



Proton candidates were selected with fitting the m^2 vs p\q

Selection criteria: <m>±2σ

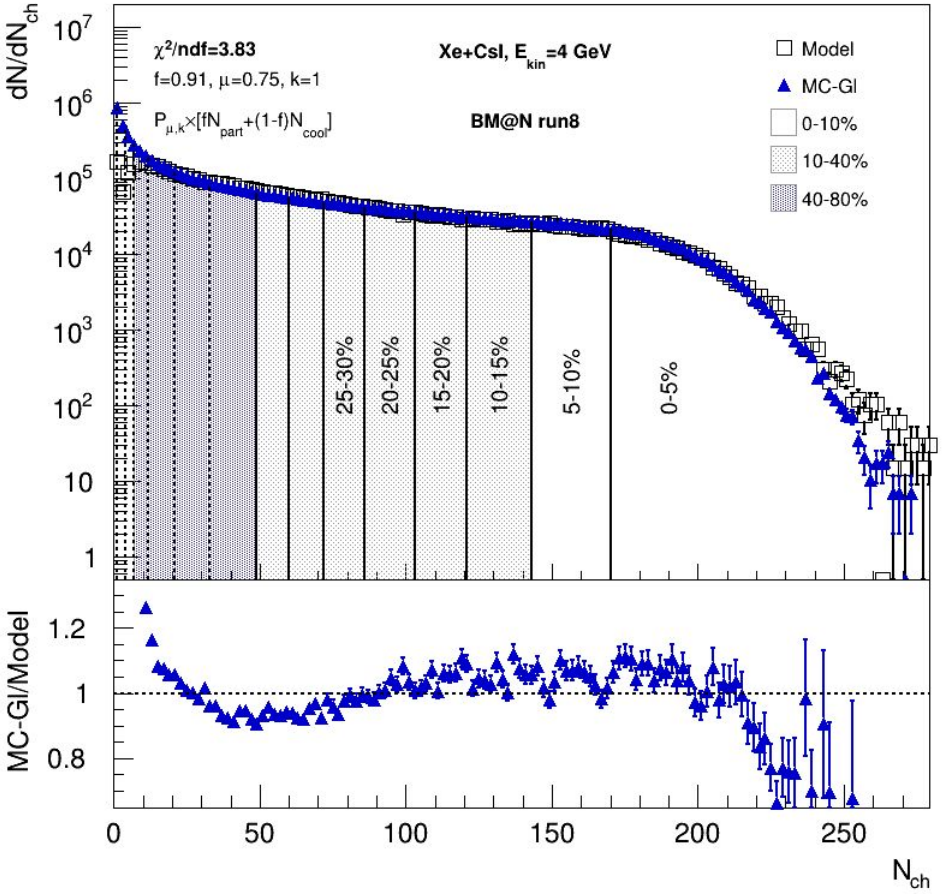
Positive pions identification

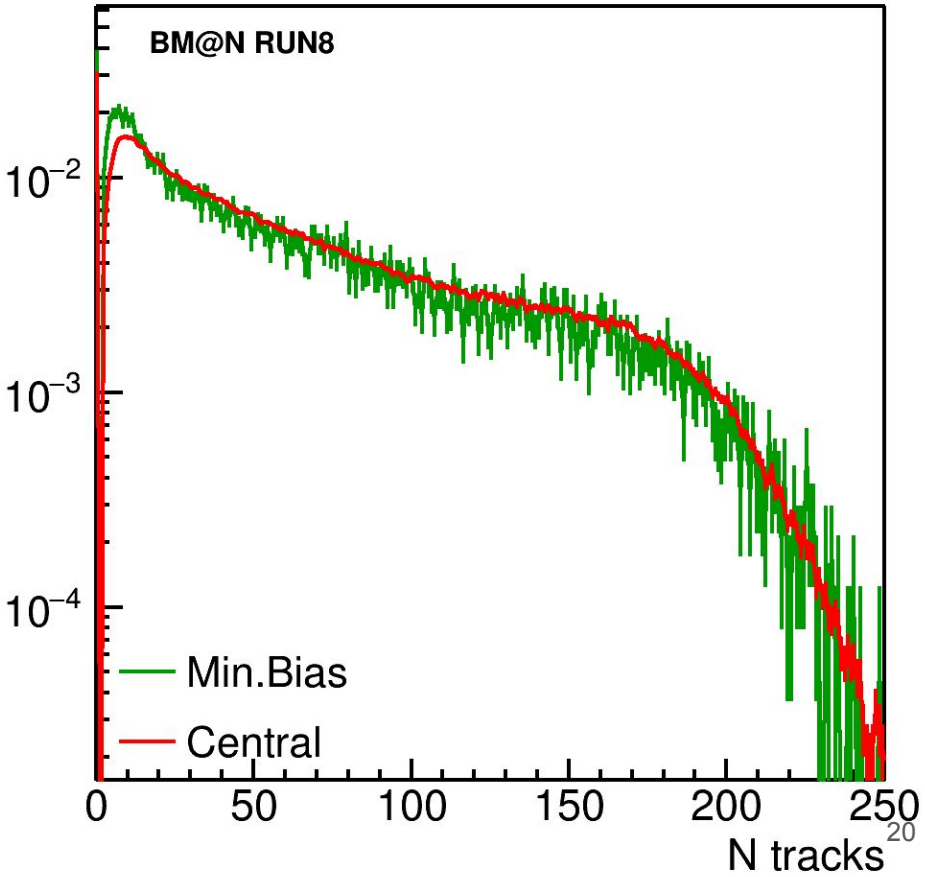


Proton candidates were selected with fitting the m^2 vs p\q

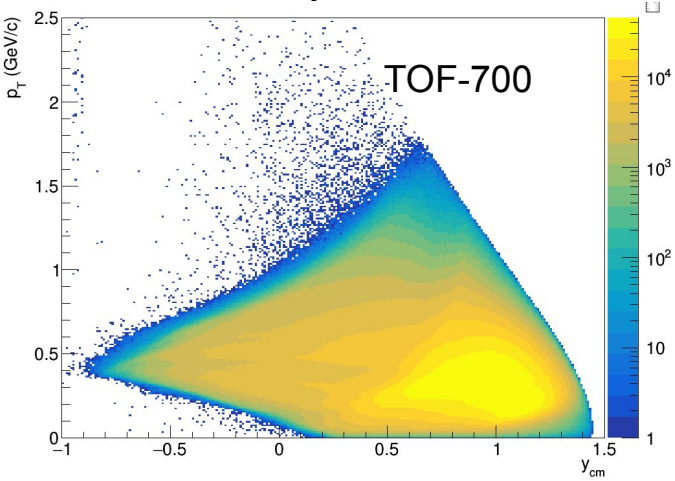
Selection criteria: <m>±2σ

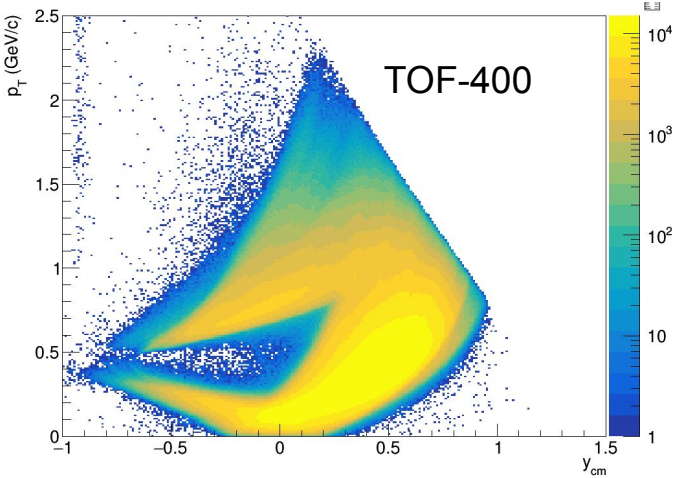
Centrality with MC-Glauber for RUN8

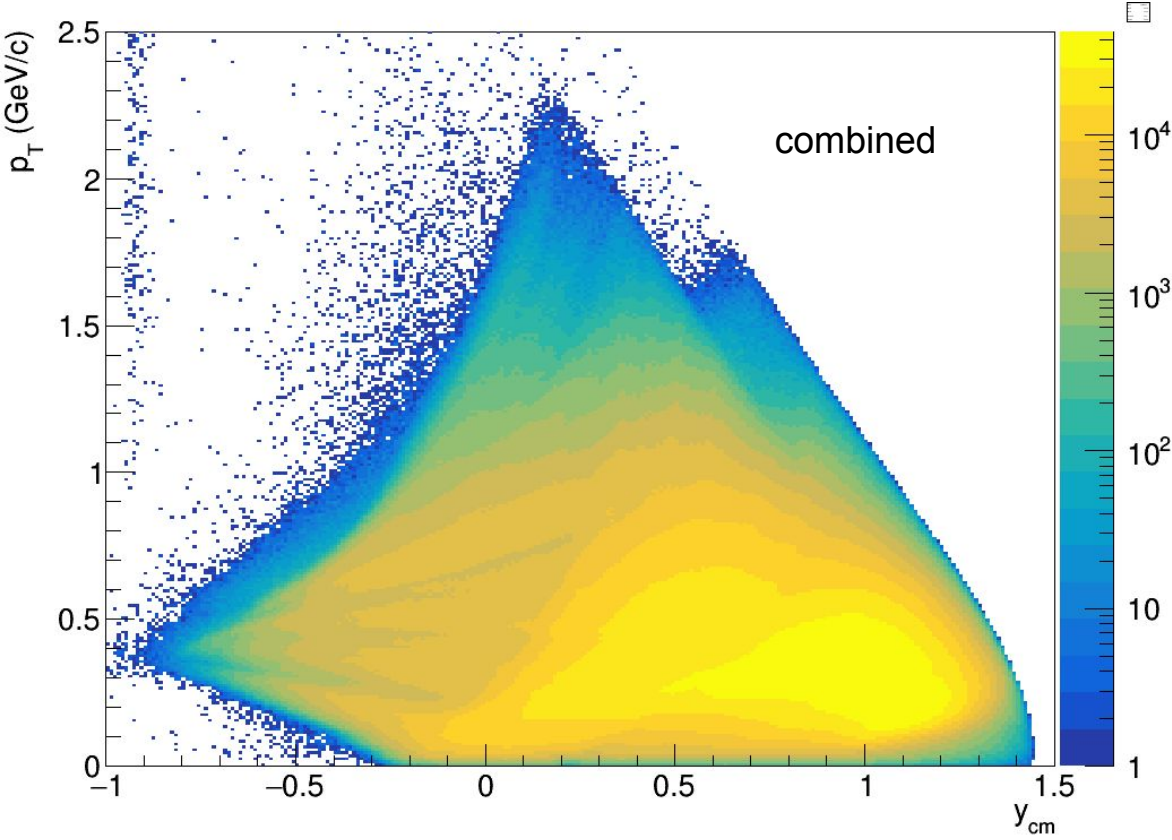




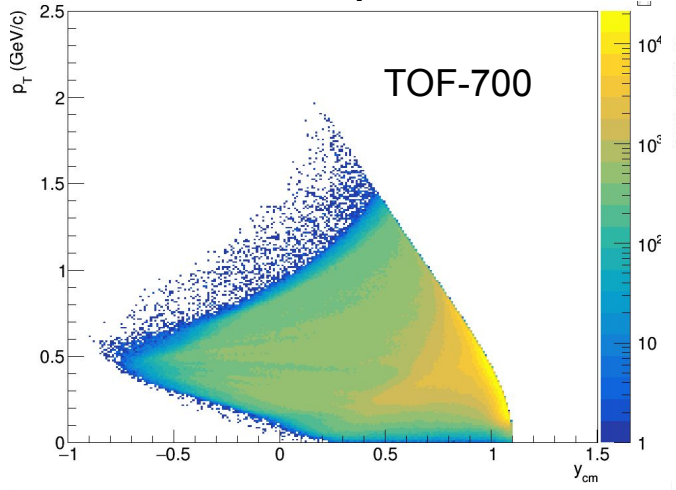
Proton p_T-y acceptance

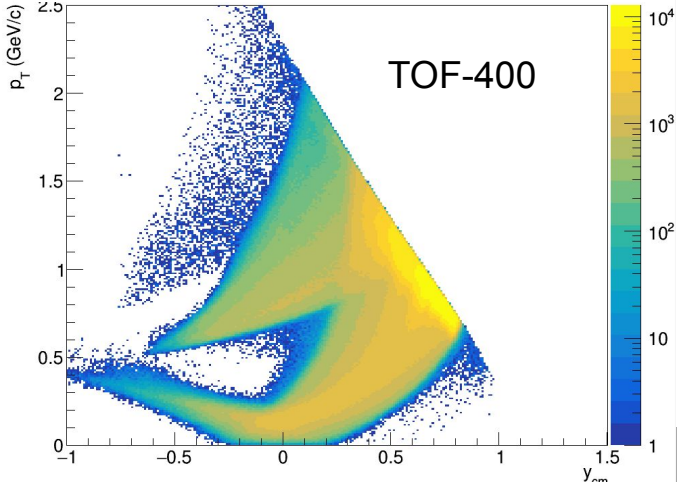


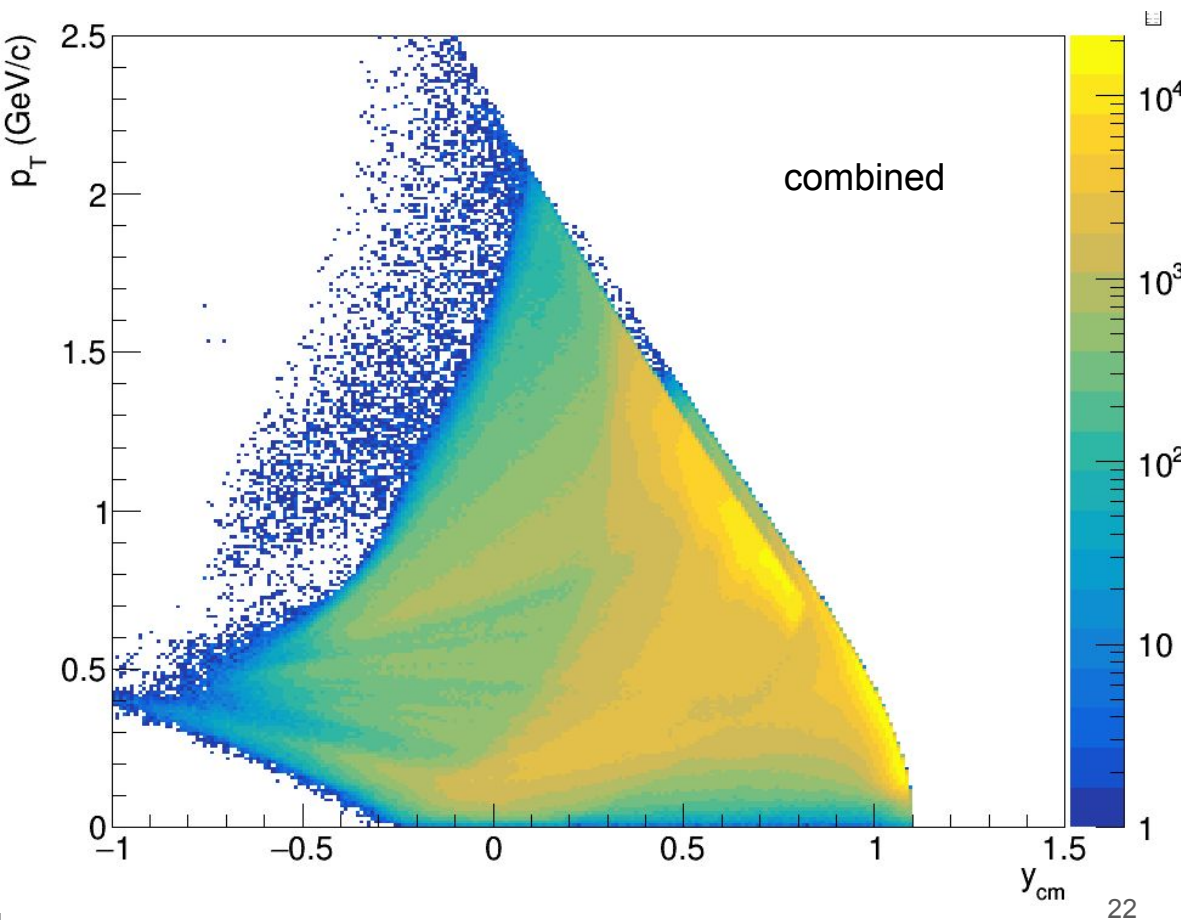




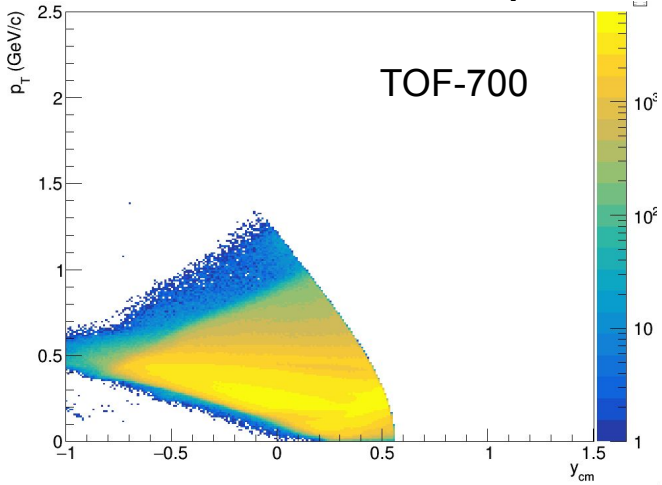
Deutron p_T-y acceptance

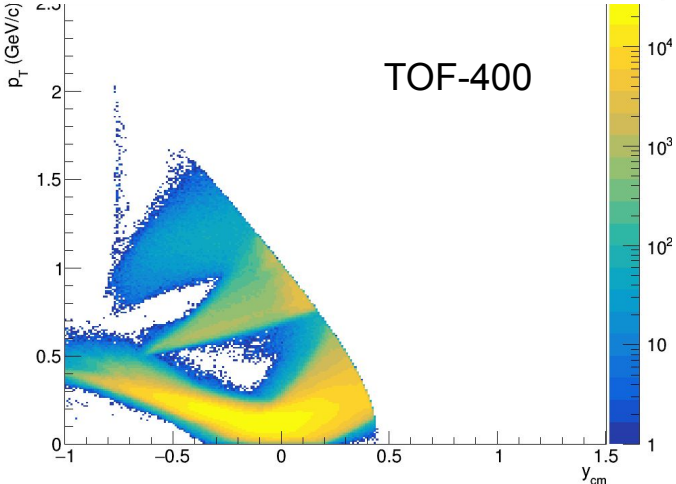


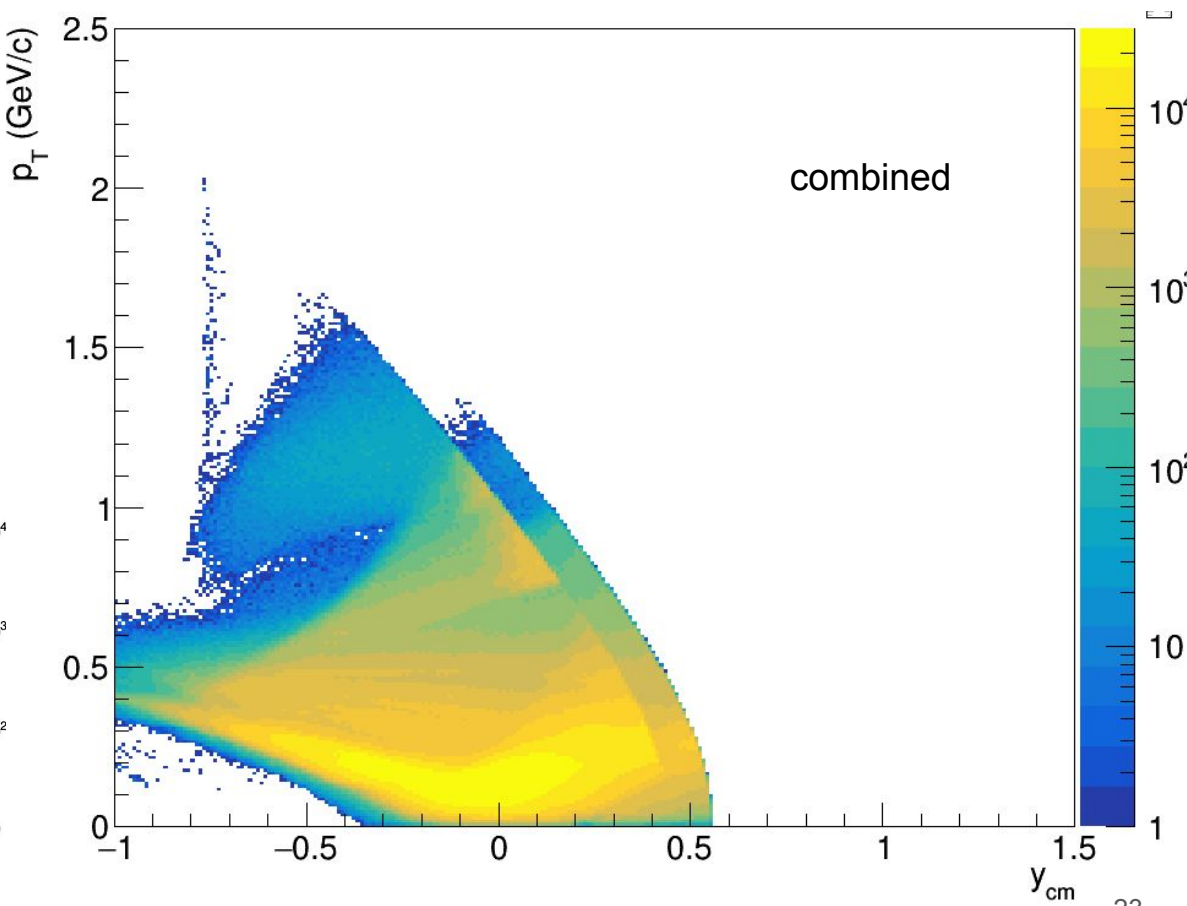




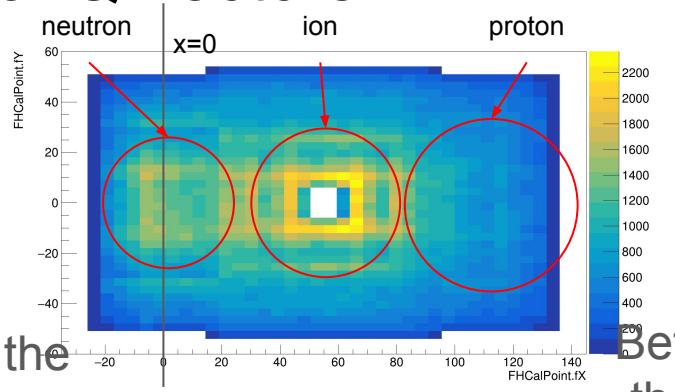
Positive pion p_T-y acceptance







New layout for fhcal Q-vectors



Old
poor coverage of the Y component

New
Better coverage of the Y component