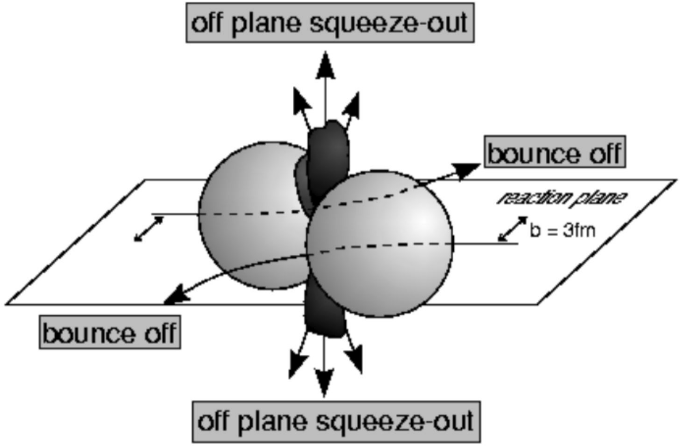
Азимутальные потоки протонов в эксперименте BM@N

Mikhail Mamaev (JINR, MEPhI)
Arkady Taranenko (MEPhI, JINR)
Timofei Kuimov (MEPhI)

The work has been supported by the Ministry of Science and Higher Education of the Russian Federation, Project "Fundamental and applied research at the NICA megascience experimental complex" № FSWU-2024-0024

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:

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

Anisotropic flow:

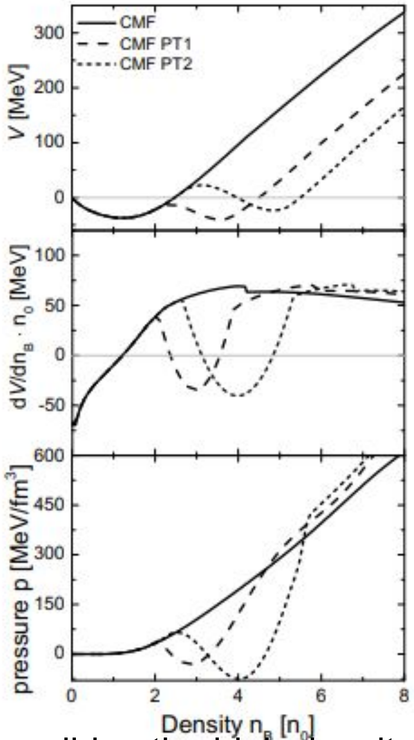
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right]\rangle$$

Anisotropic flow is sensitive to:

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

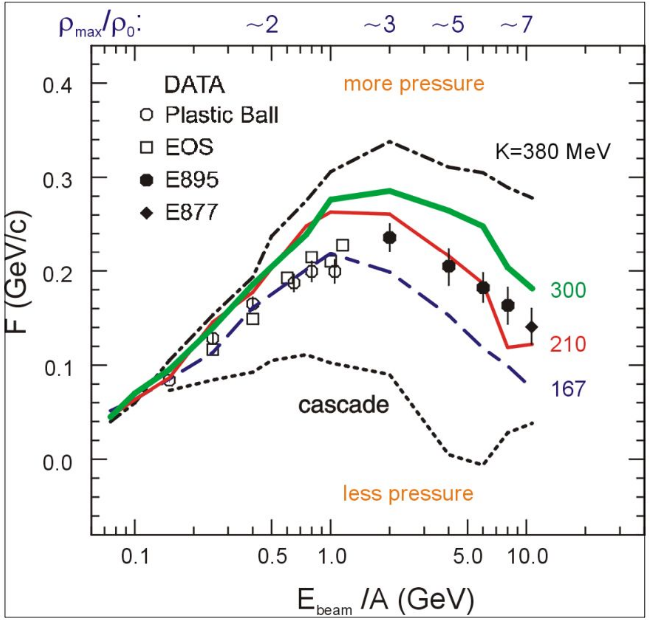
v_n as a function of collision energy

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

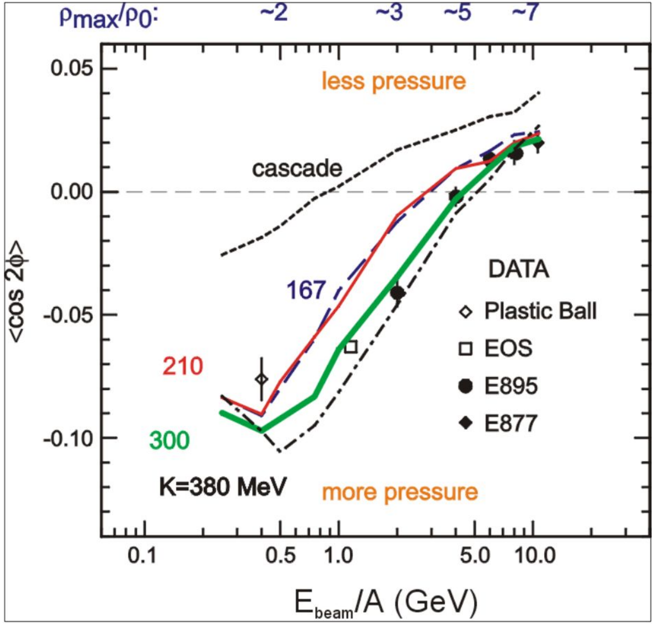


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



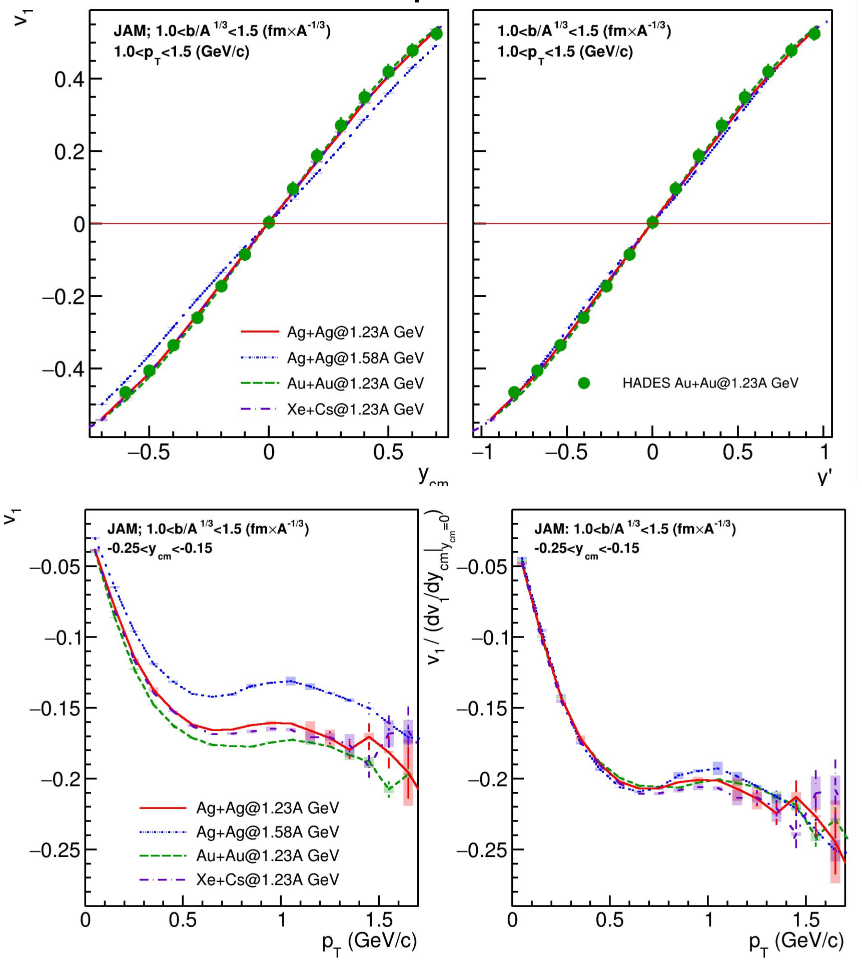
v_2 suggests harder EOS



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

Discrepancy is probably due to non-flow correlations

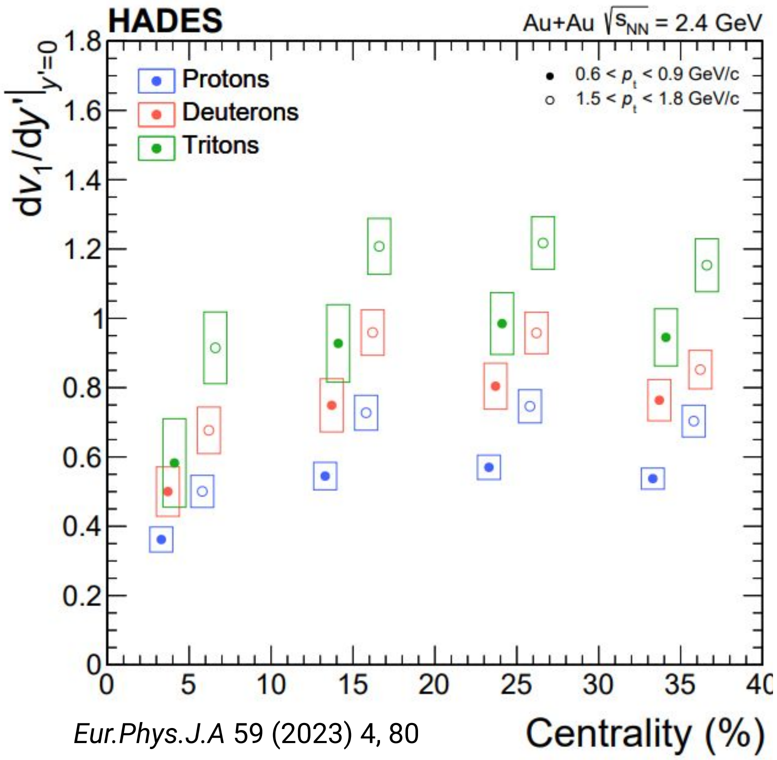
HADES: dv_1/dy scaling with collision energy and system size



- 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

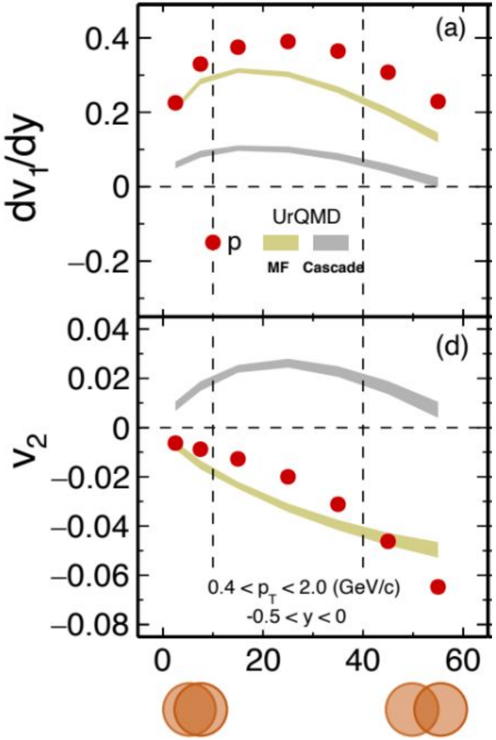
M.Mamaev Particles 2023, 6(2), 622-637

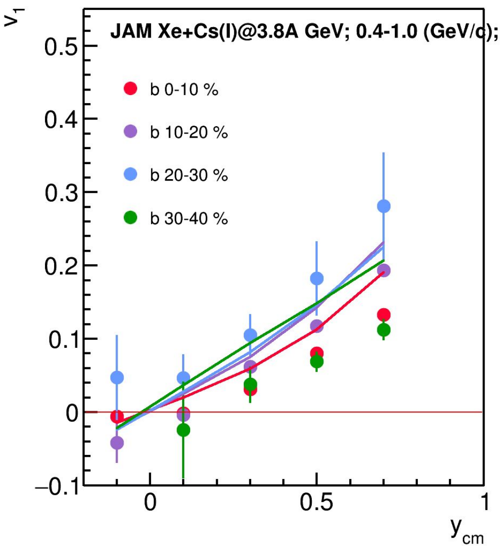
dv_1/dy as a function of centrality



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

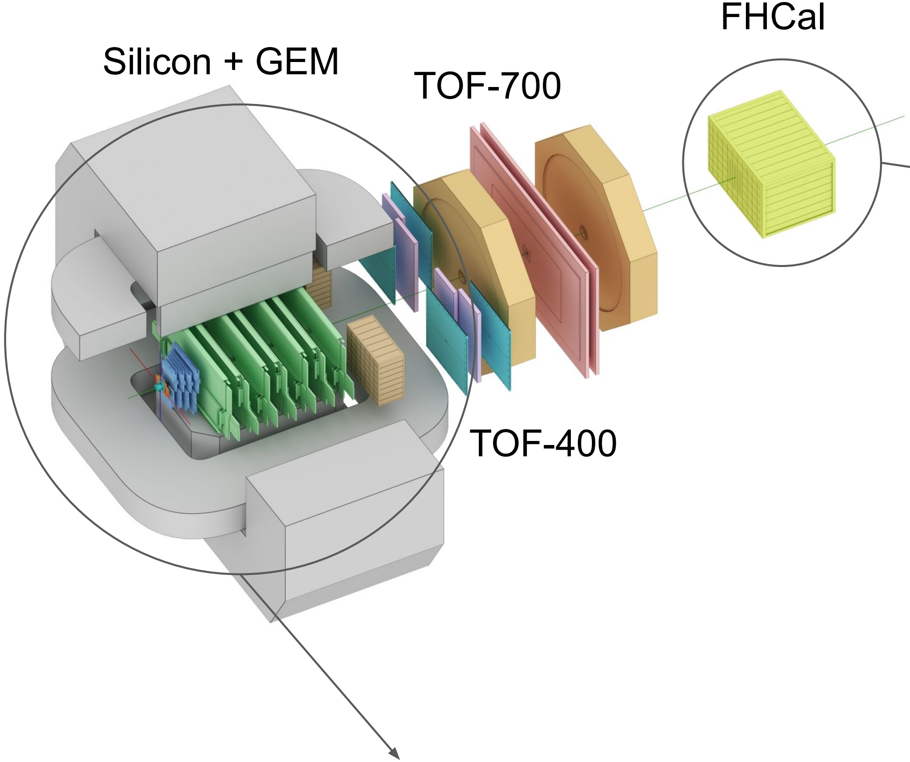
STAR FXT

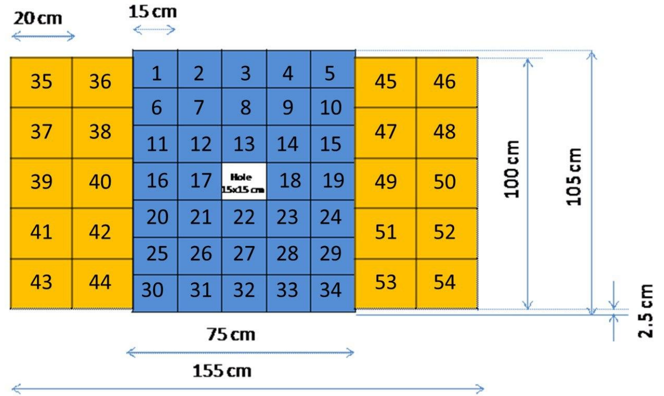


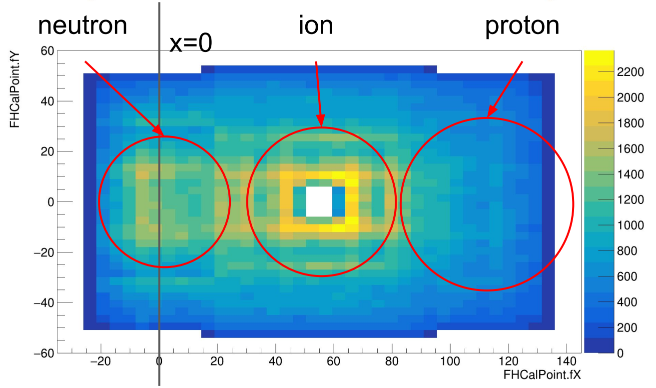


Weak centrality dependence for directed flow

The BM@N experiment (GEANT4 simulation for RUN8)





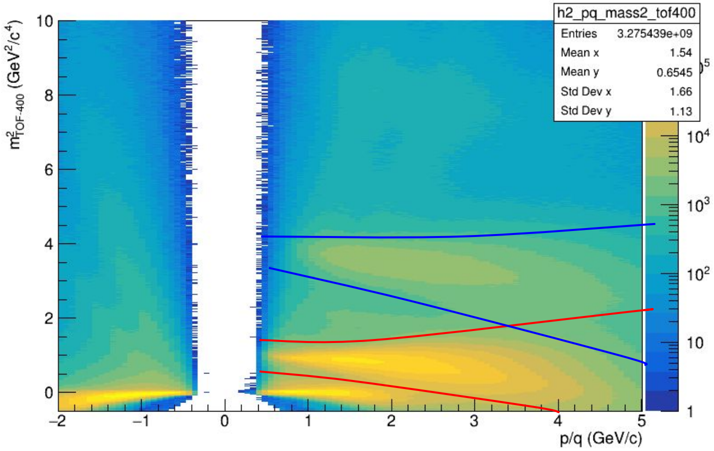


VF tracking was used

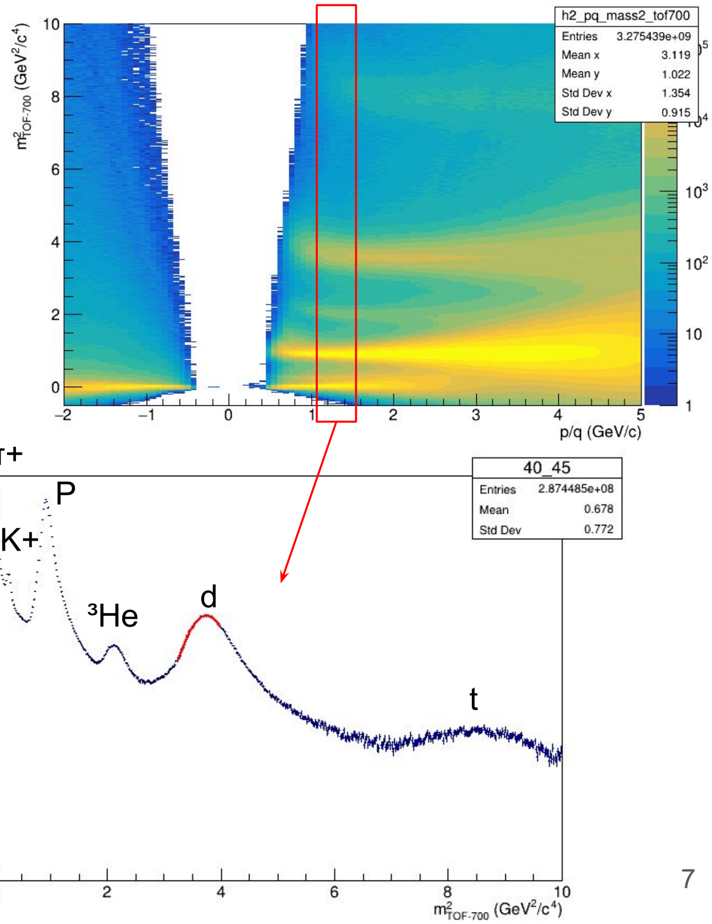
Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

The first production was used

Identification procedure



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

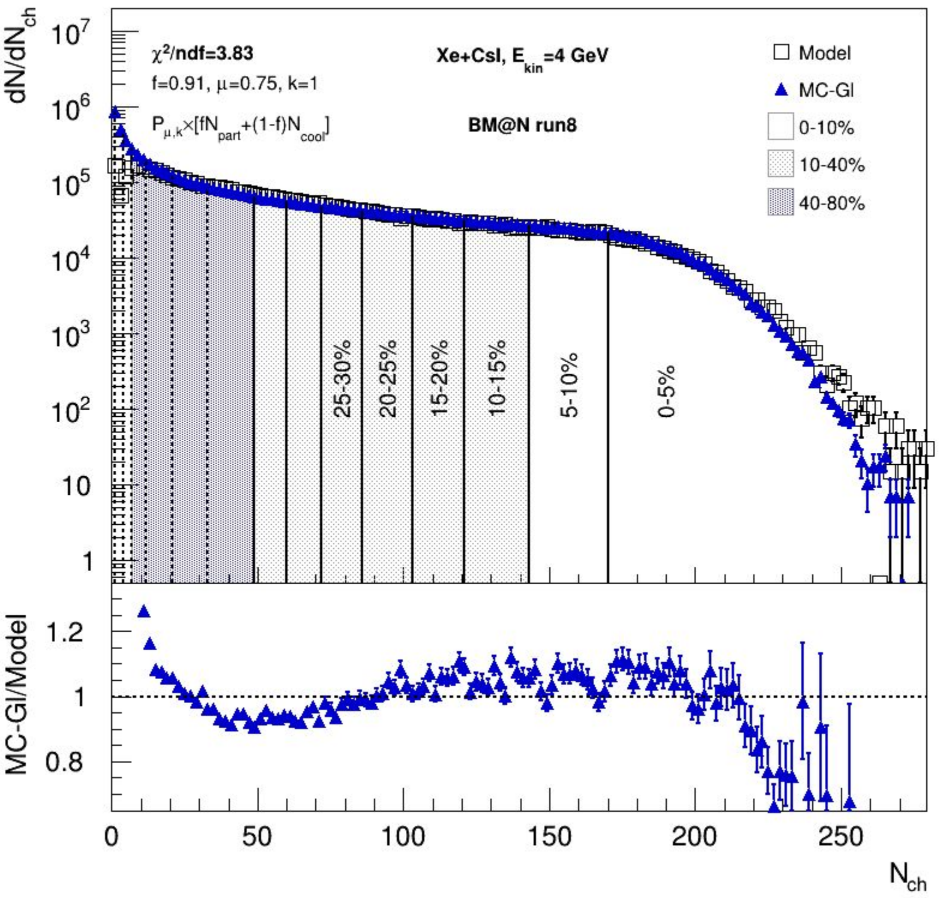


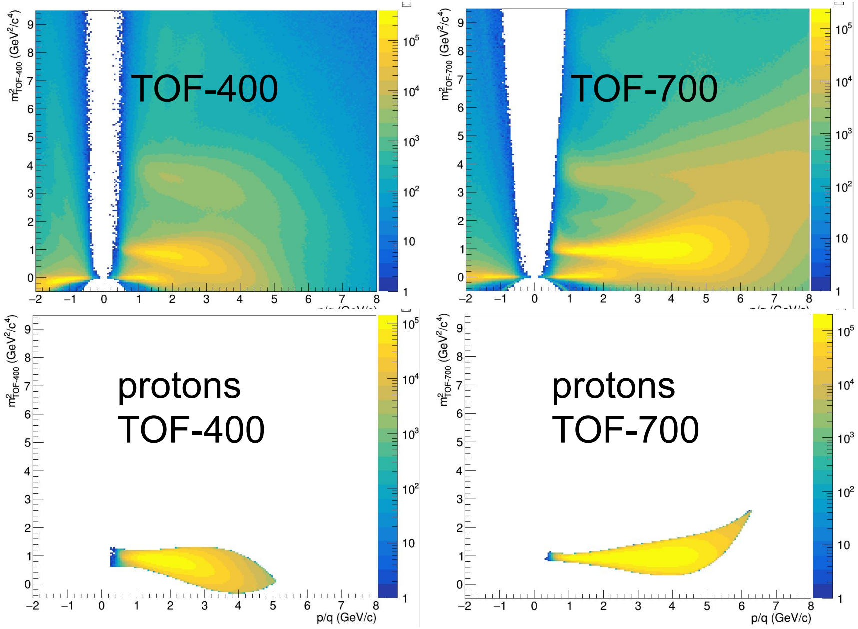
- Mass squared distribution is fitted in narrow bins of p/q
- Protons, pions, deuterons, tritons and helium are fitted

Purity is the function showing possible contamination

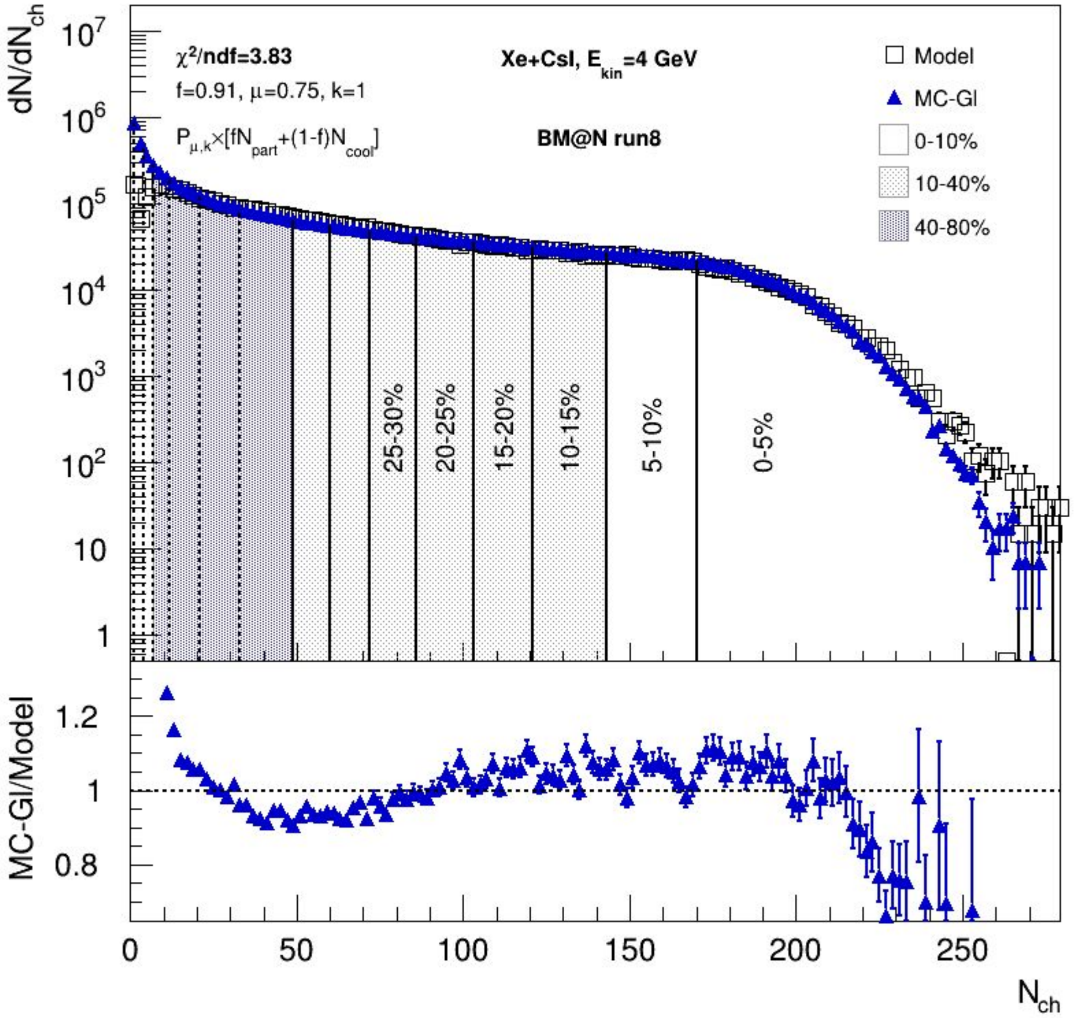
$$p_i(m^2, p/q) = \frac{f_i(m^2, p/q)}{\sum_{i=1}^{N} f_i(m^2, p/q)}$$

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



dN/dN_ch
χ²/ndf=3.83
f=0.91, μ=0.75, k=1
P_μ,k×[fN_part+(1-f)N_cool]
Xe+CsI, E_kin=4 GeV
BM@N run8
Model
MC-Gl
0-10%
10-40%
40-80%
25-30%
20-25%
15-20%
10-15%
5-10%
0-5%
MC-Gl/Model
N_ch

Flow vectors

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

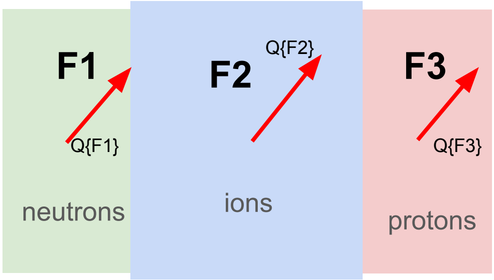
$$u_n = e^{in\phi}$$

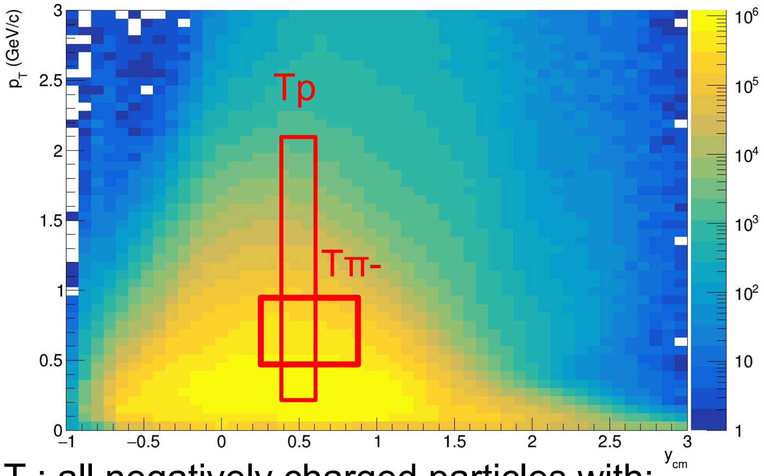
where φ is the azimuthal angle

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:

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

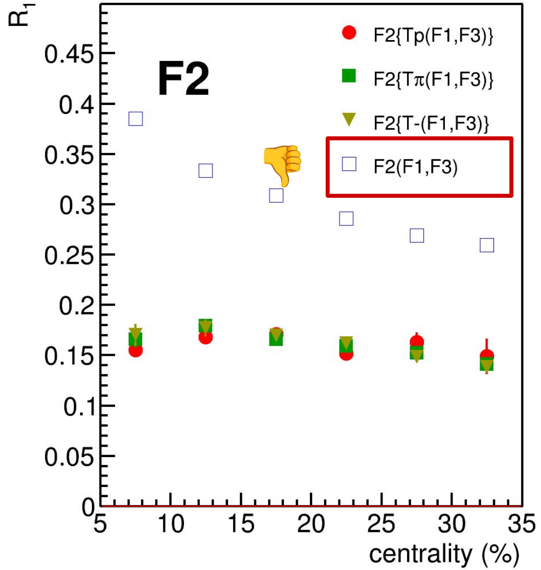
Where R_1 is the resolution correction factor

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

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

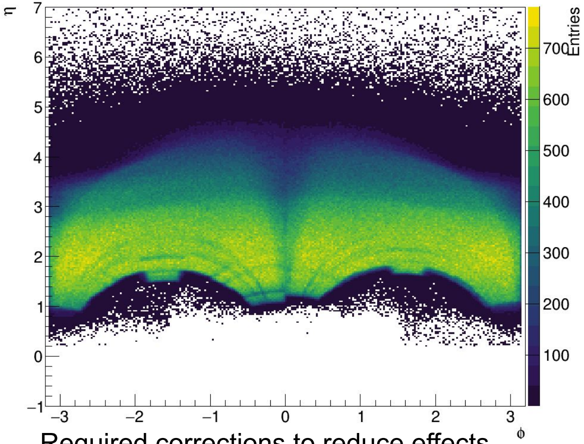


Symbol "F2{Tp}(F1,F3)" means R_1 calculated via (4S resolution):

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

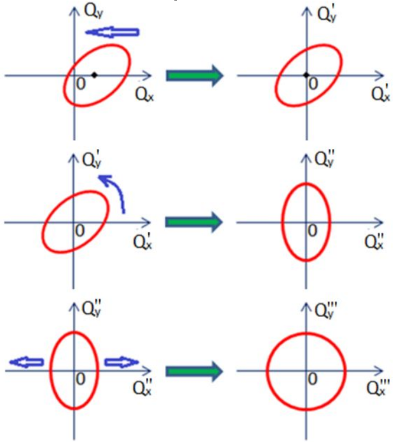
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

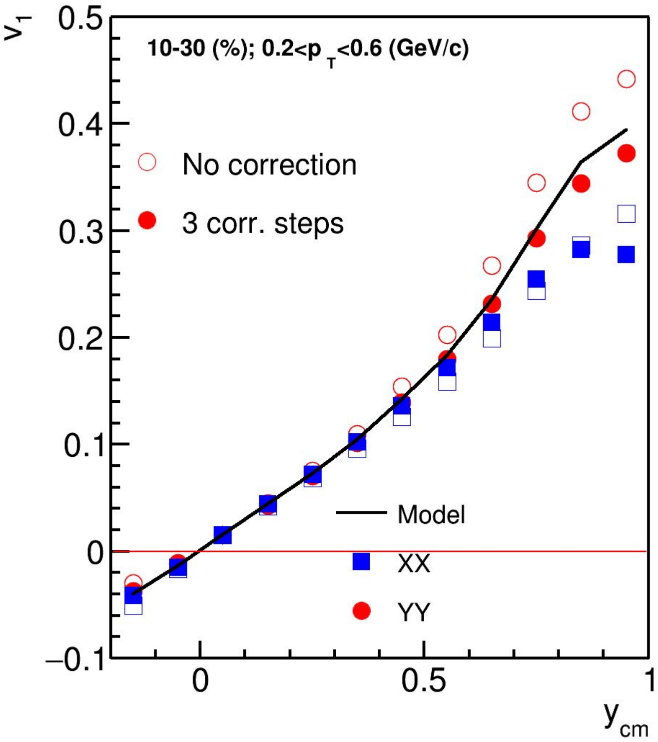


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

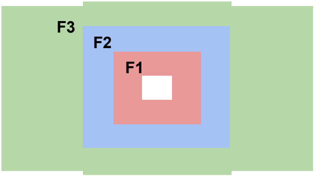


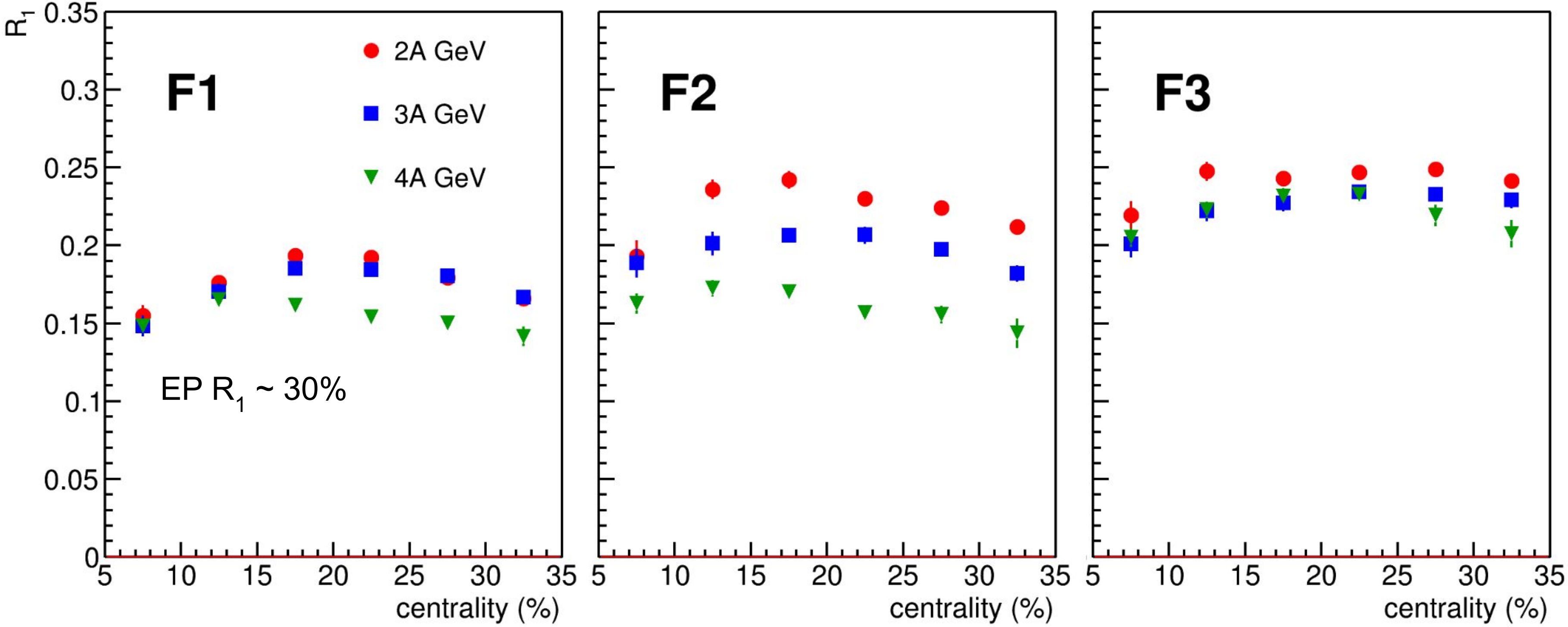
Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)



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

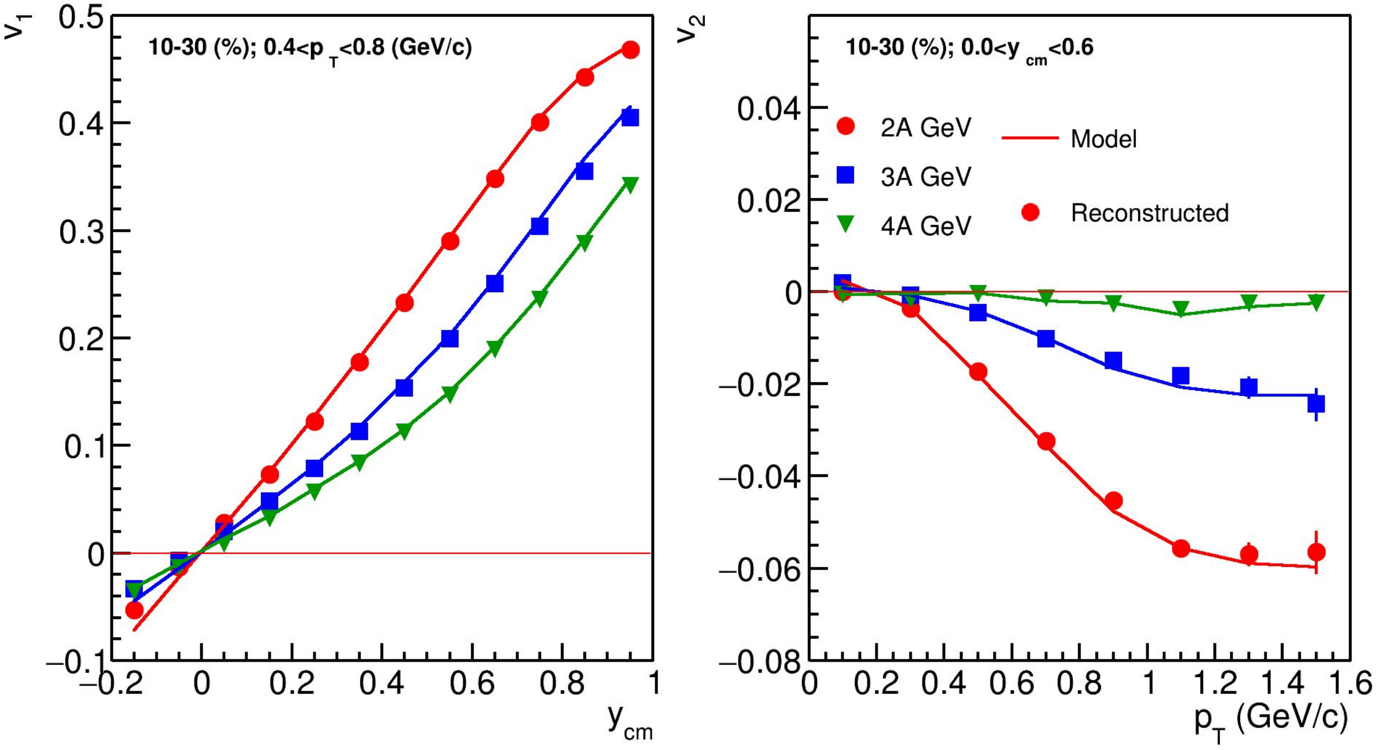
Rec R1: DCMQGCM-SMM Xe+Cs





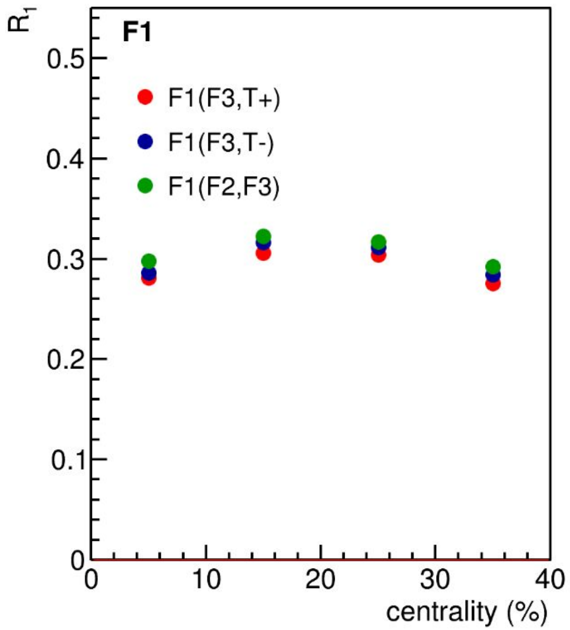
Resolution is lower for higher energies due to lower v_1

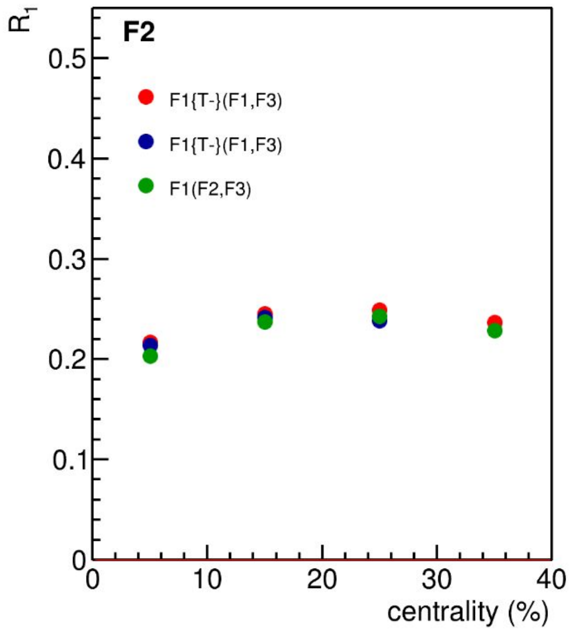
Directed and elliptic flow in Xe+Cs (JAM)

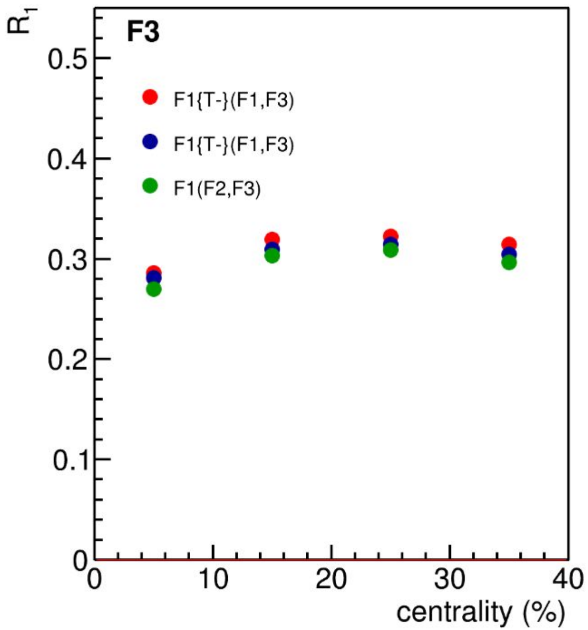


- Good agreement between reconstructed and pure model data for all three energies

Symmetry plane resolution in Xe+Cs(I) collisions







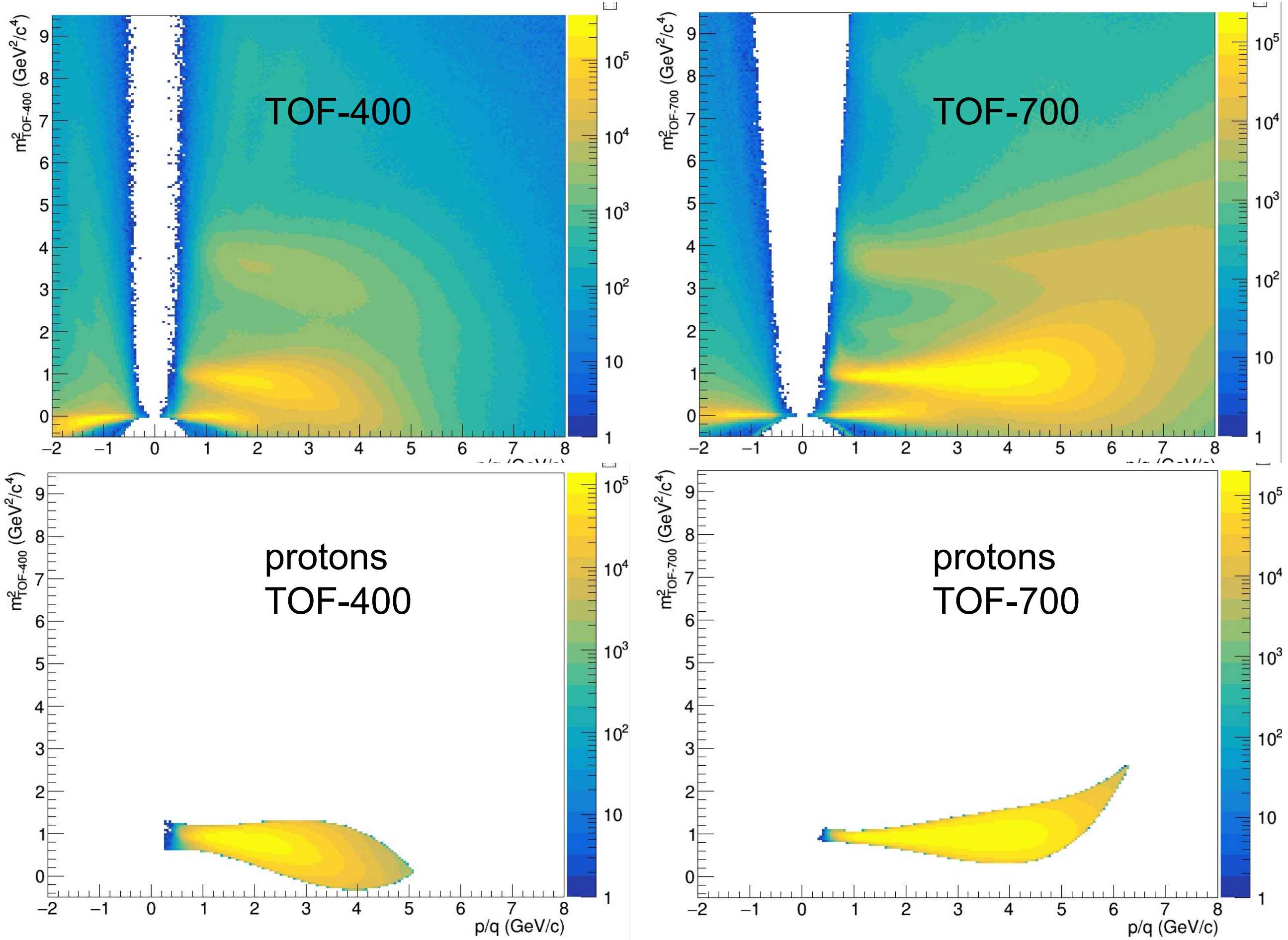
All the estimations for symmetry plane resolution are in a good agreement

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

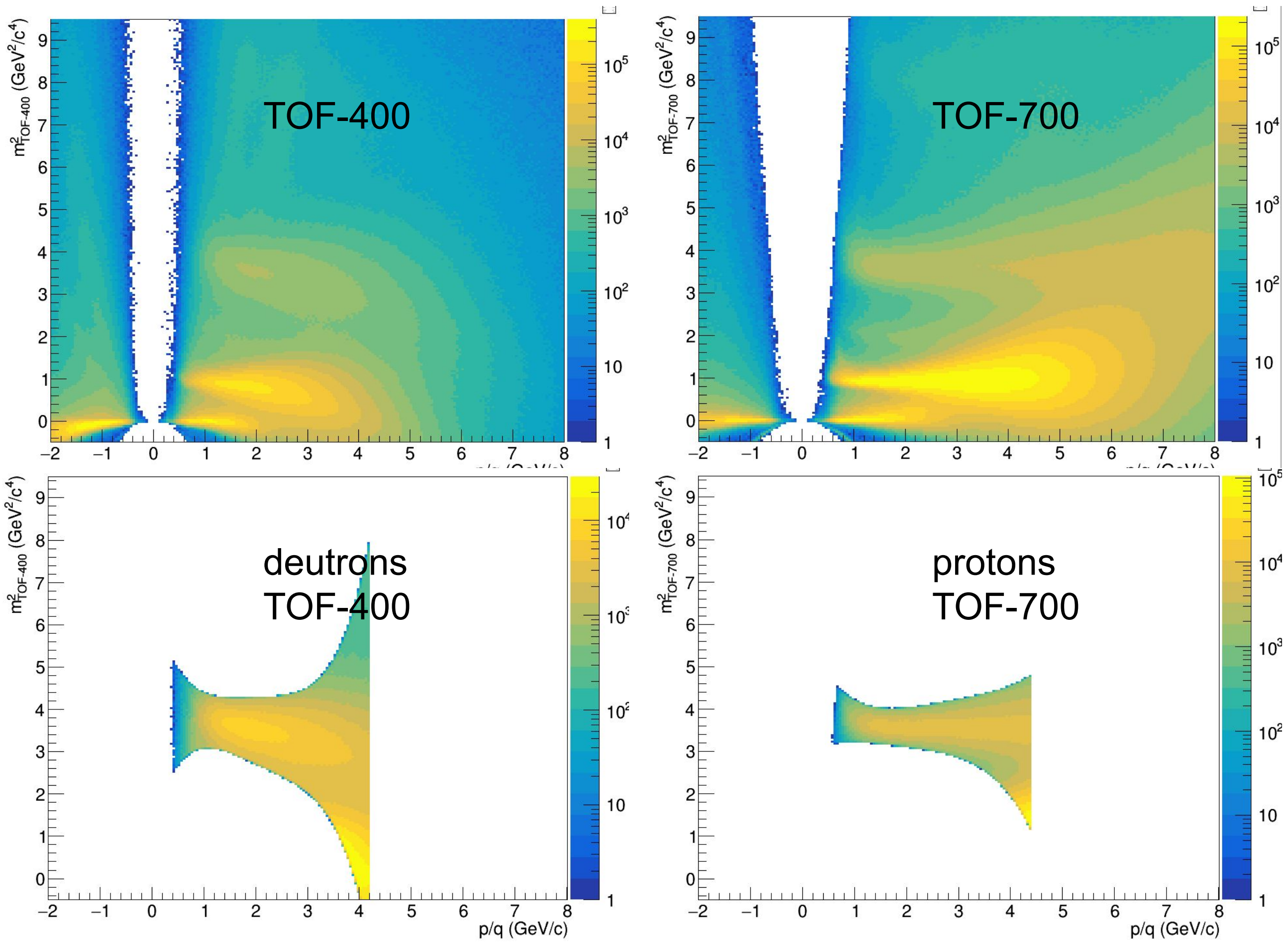
Proton identification



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

Selection criteria: <m>±2σ

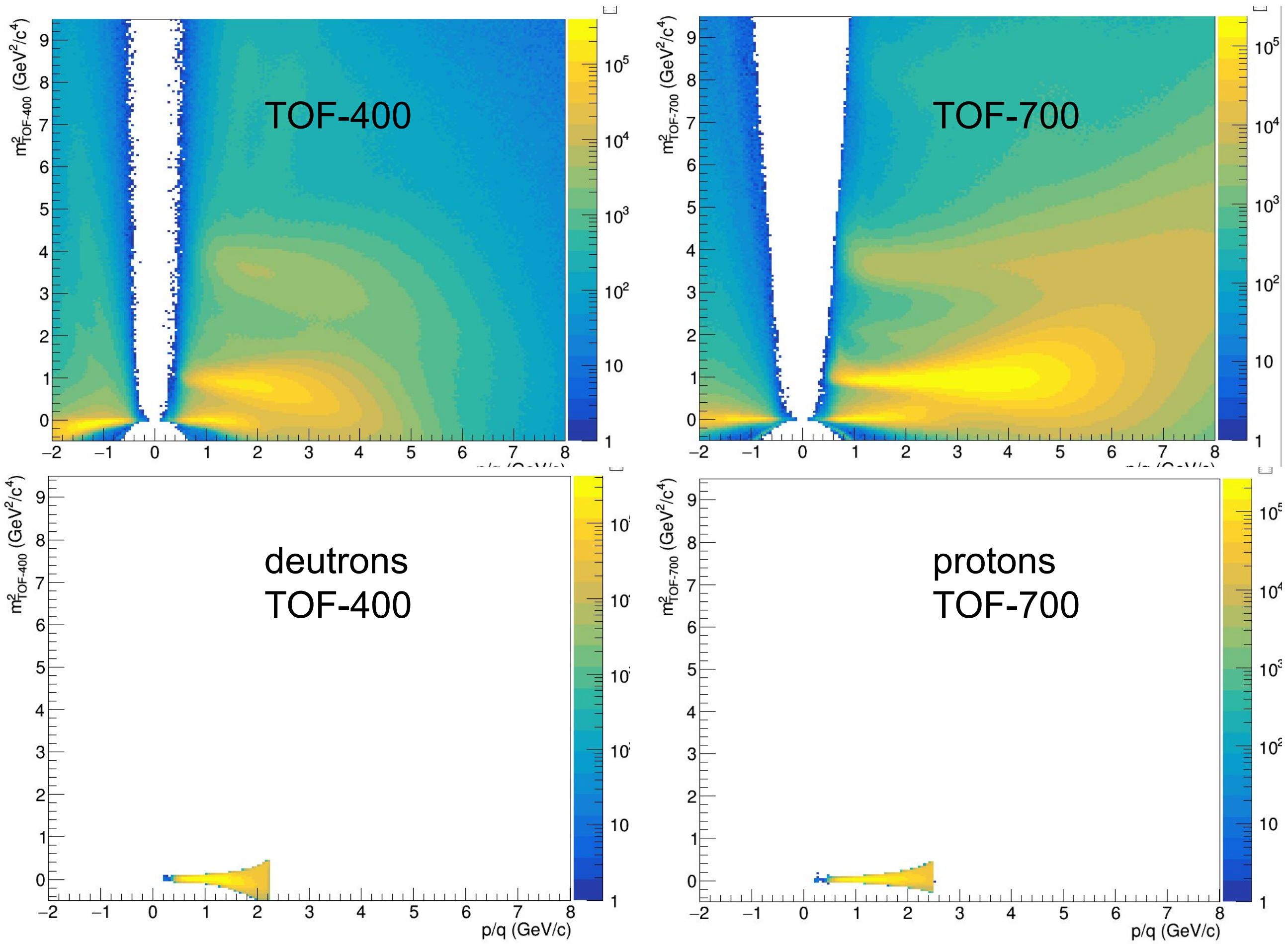
Deutron identification



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

Selection criteria: <m>±2σ

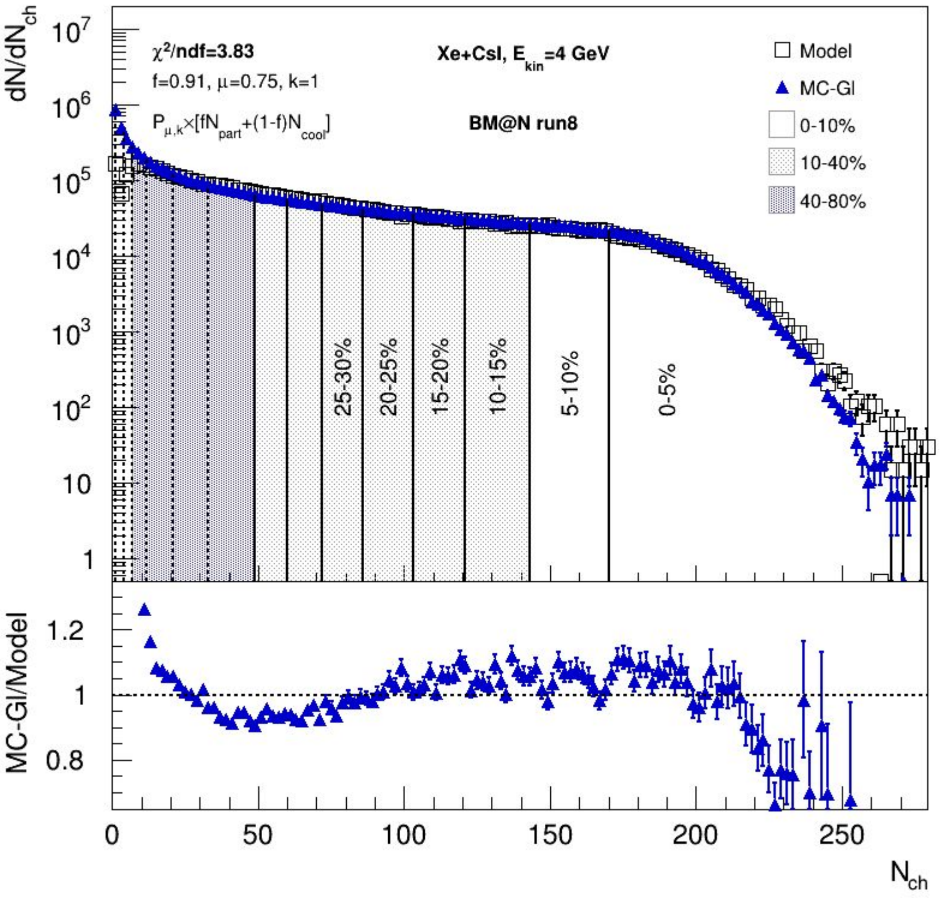
Positive pions identification

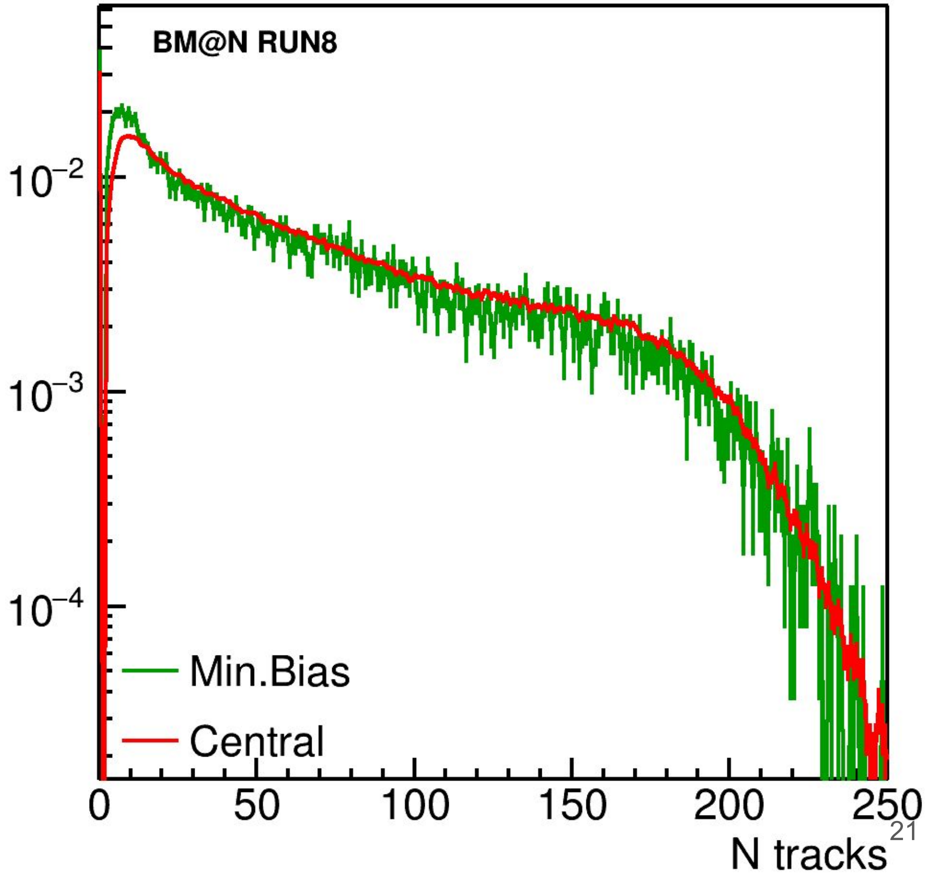


Proton candidates were selected with fitting the m^2 vs p\q

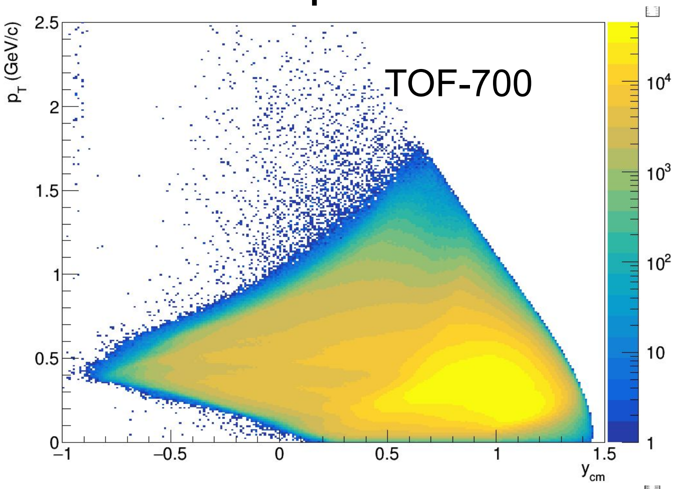
Selection criteria: <m>±2σ

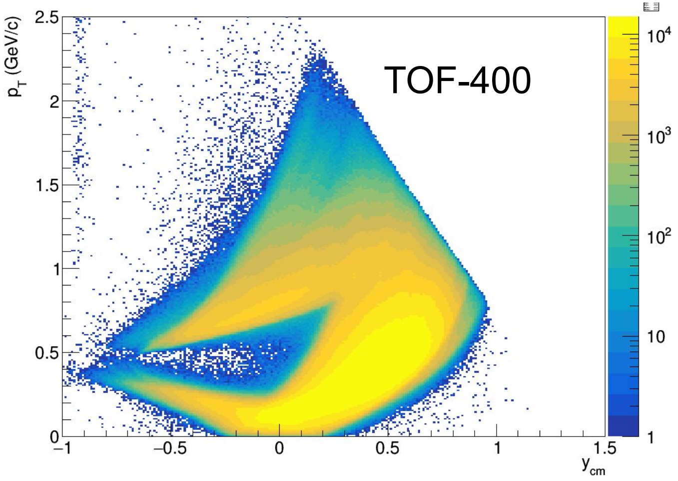
Centrality with MC-Glauber for RUN8

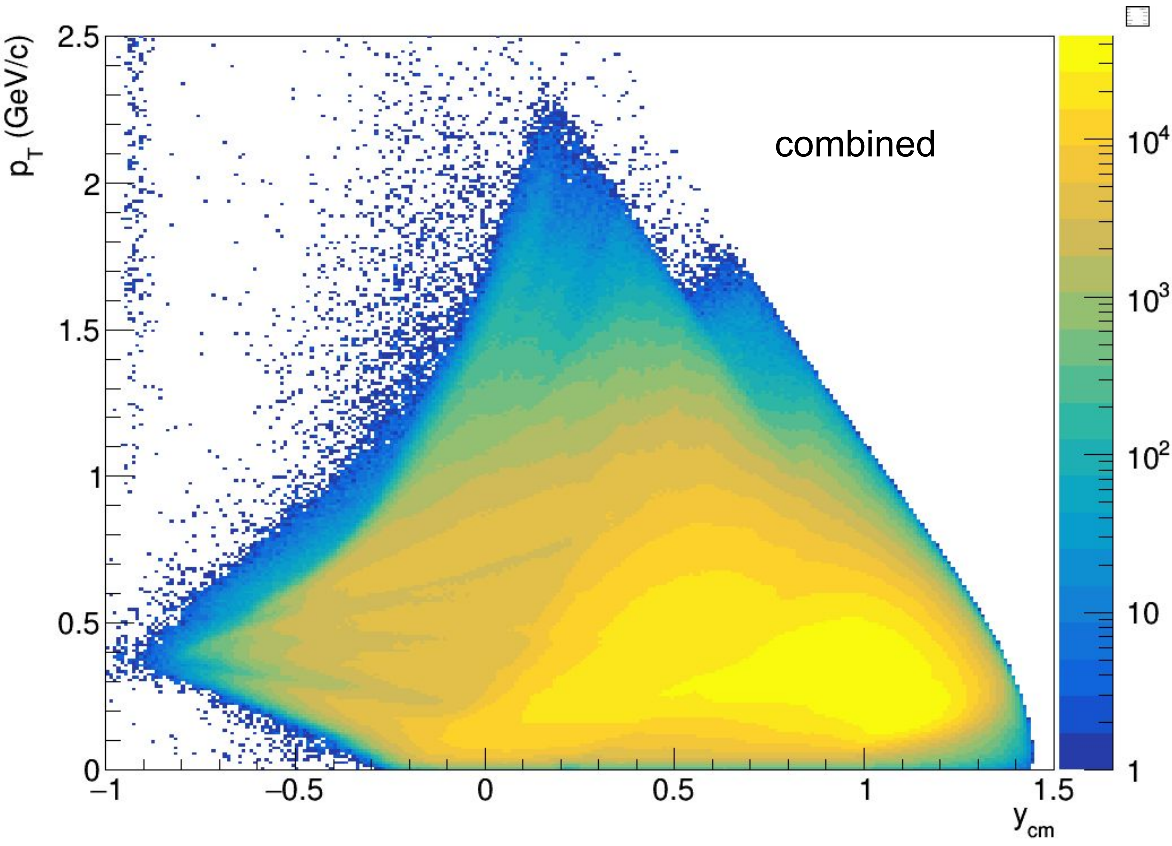




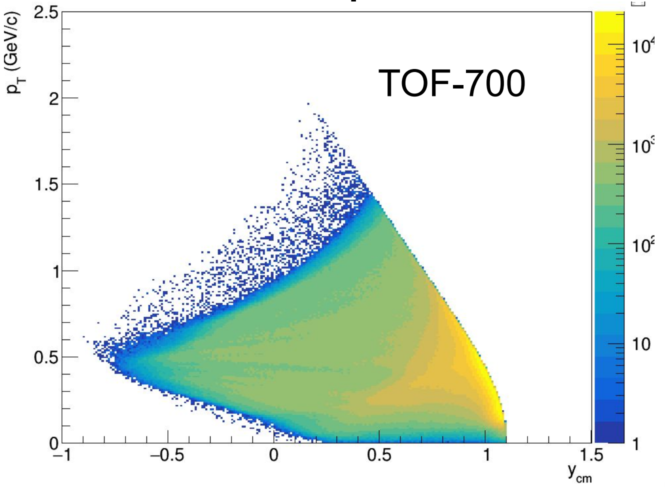
Proton p_T-y acceptance

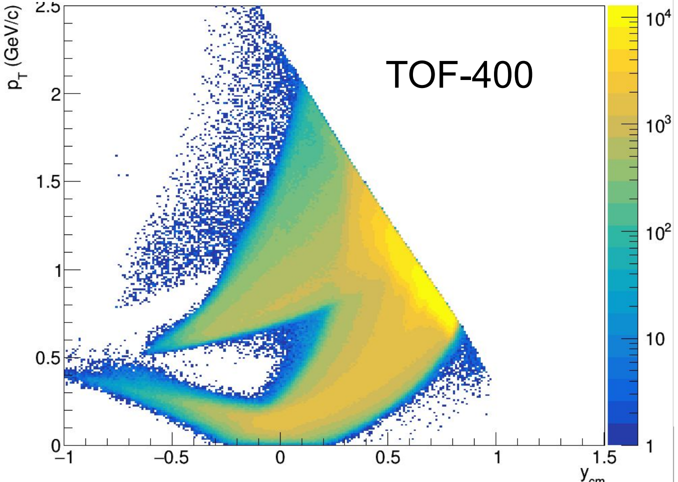


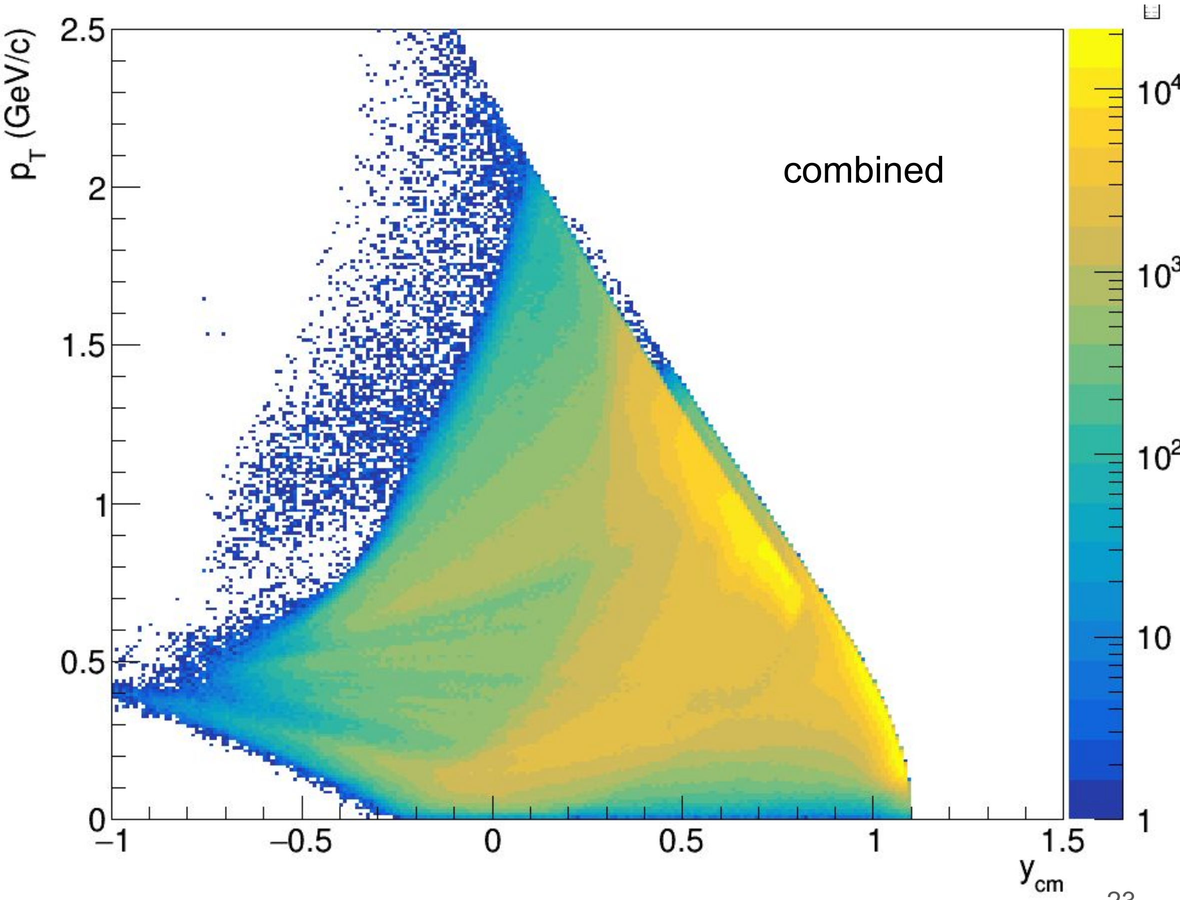




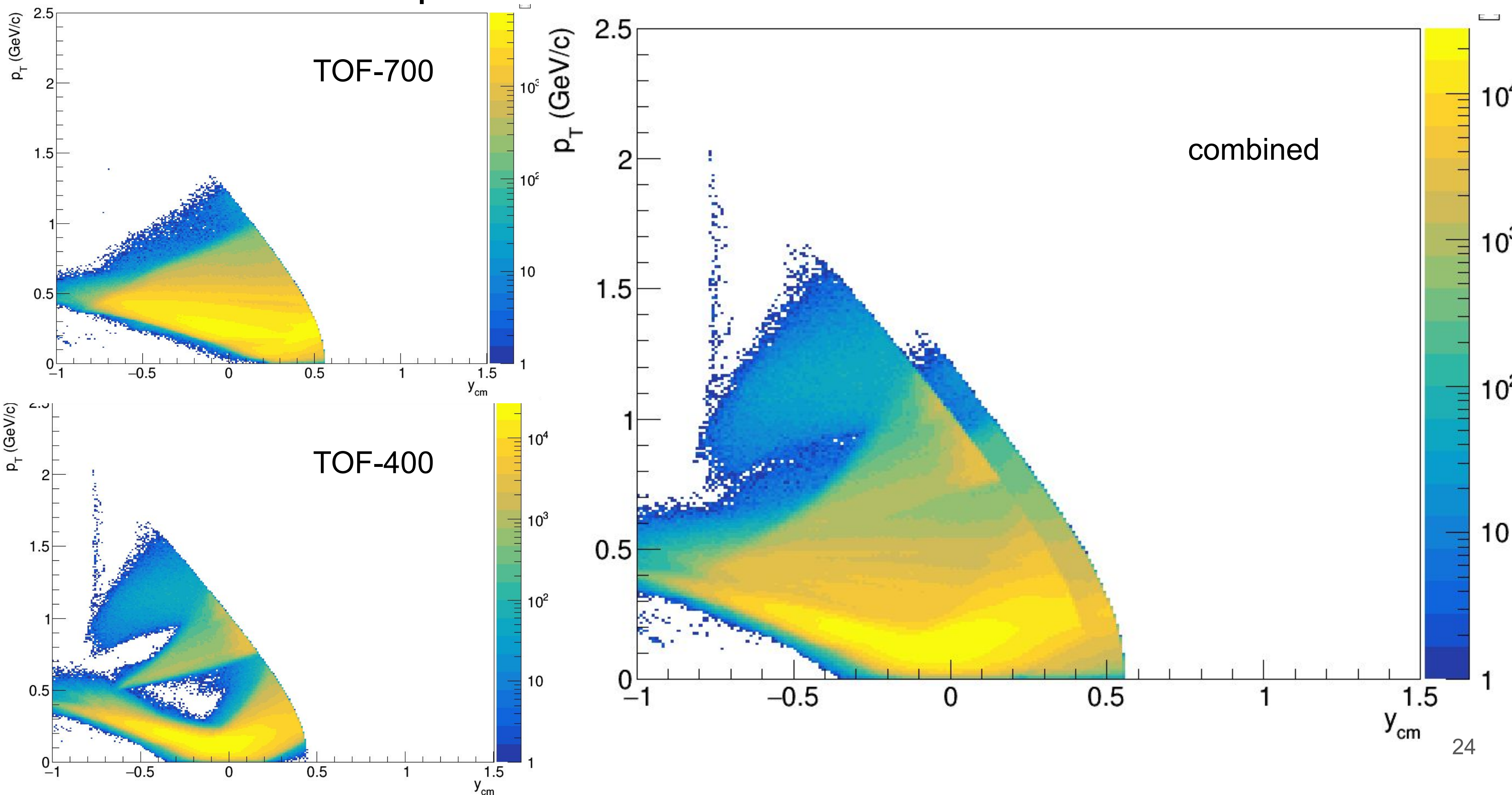
Deutron p_T-y acceptance



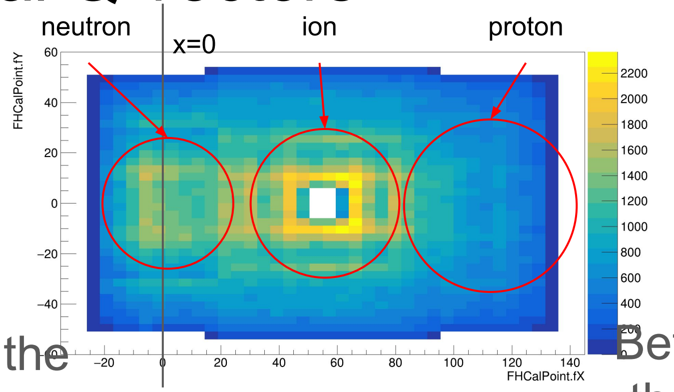




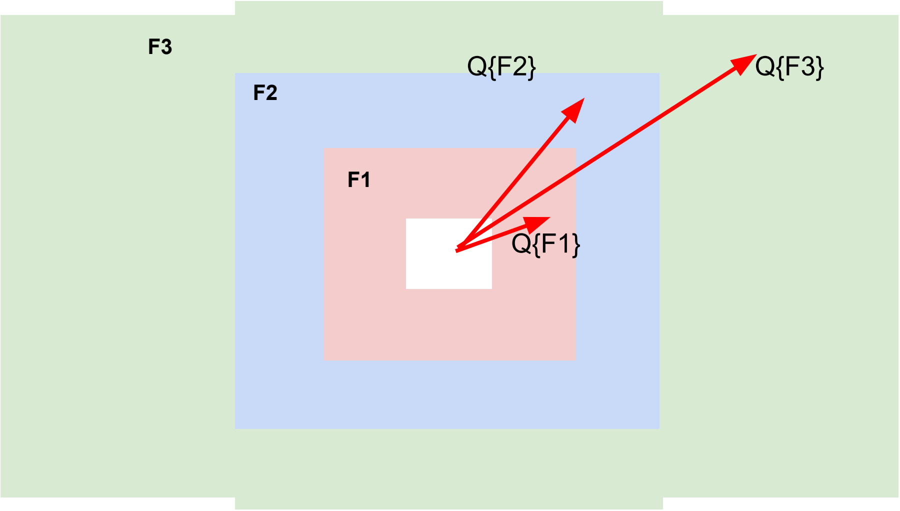
Positive pion p_T-y acceptance



New layout for fhcal Q-vectors



Old
poor coverage of the
Y component



New
Better coverage of
the Y component