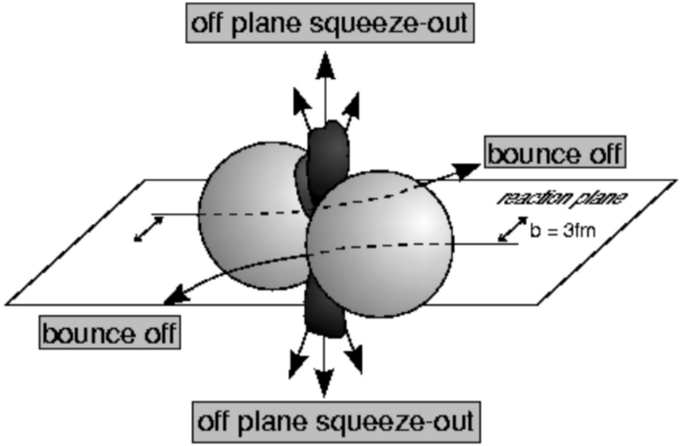
Performance studies towards flow measurements in the recent BM@N physical run

Mikhail Mamaev (MEPhI, INR RAS)
Arkady Taranenko (MEPhI, JINR)
Timofei Kuimov (MEPhI)
Valeriy Troshin (MEPhI)

This work is supported by: the Special Purpose Funding Programme within the NICA Megascience Project in 2023 and the RSF grant No. 22-12-00132

11th BM@N collaboration meeting, 11/30/2023

Anisotropic flow & spectators



The azimuthal angle distribution is decomposed in a Fourier series relative to reaction plane angle:

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

Anisotropic flow:

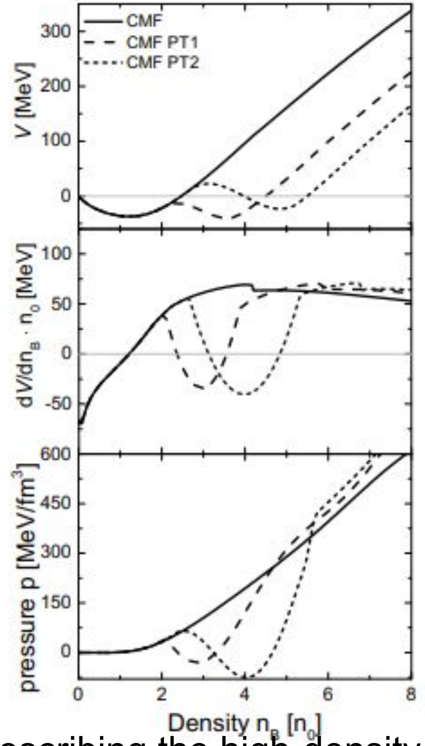
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right]\rangle$$

Anisotropic flow is sensitive to:

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

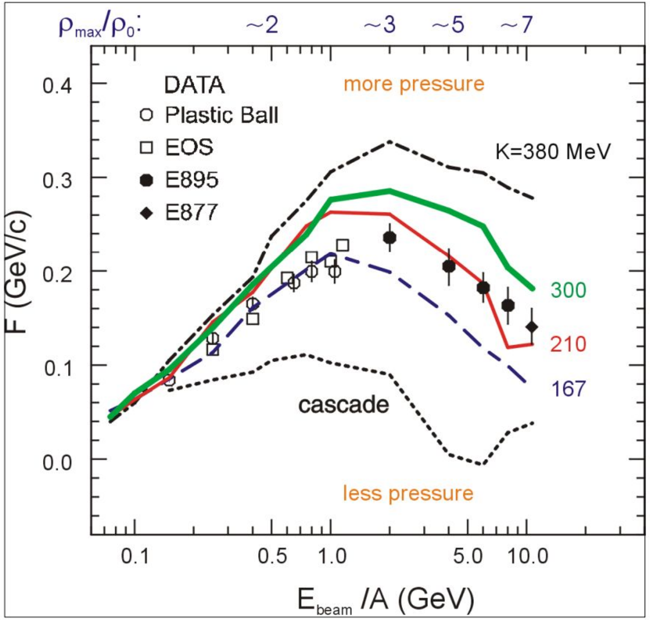
v_n as a function of collision energy

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

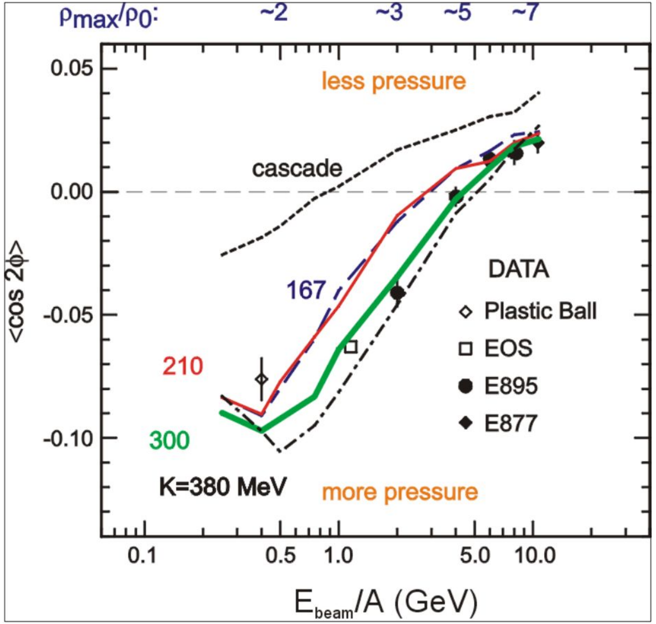


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



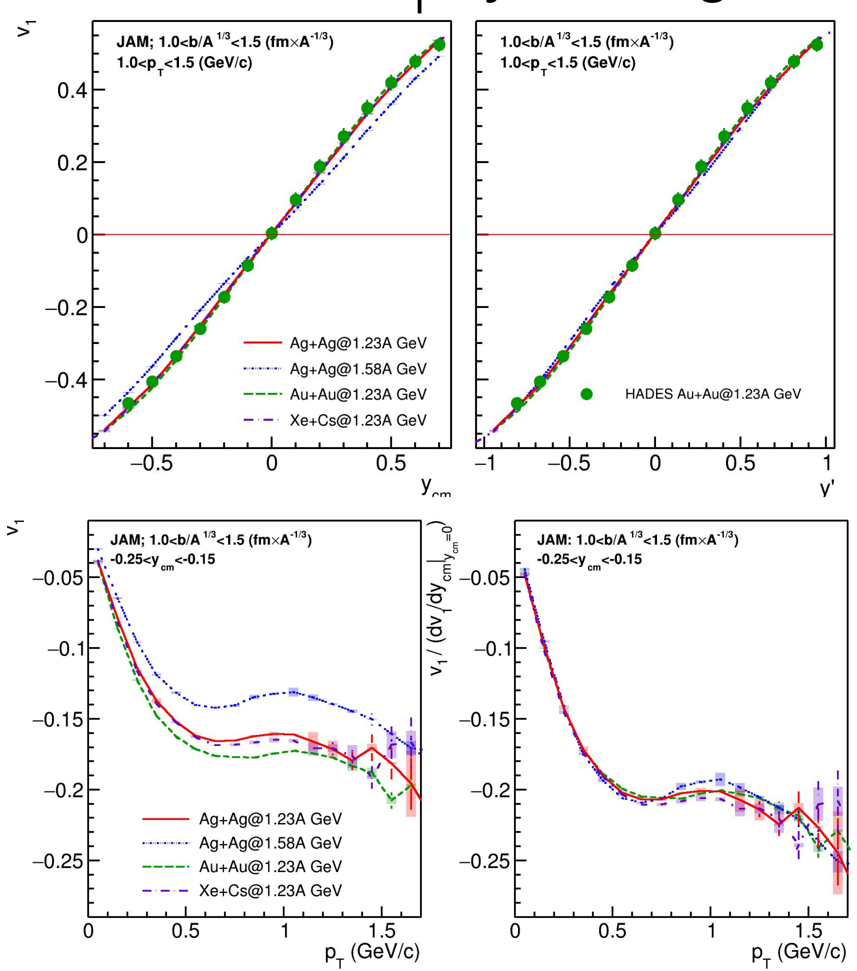
v_2 suggests harder EOS



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

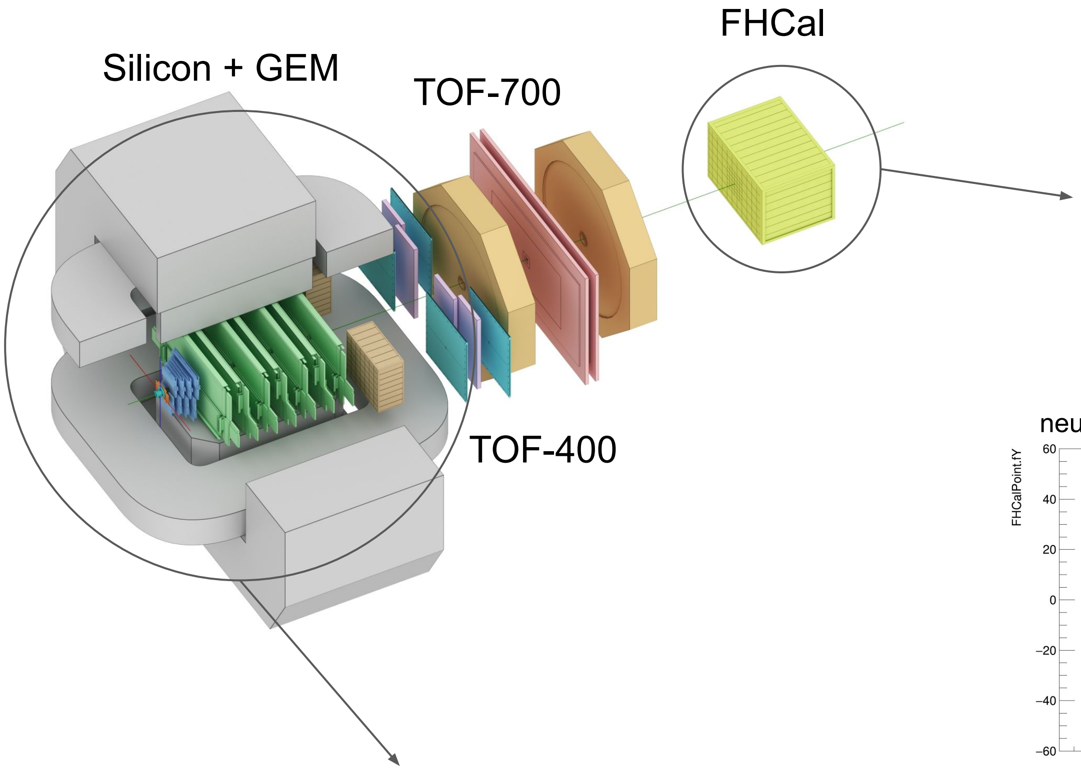
Discrepancy is probably due to non-flow correlations

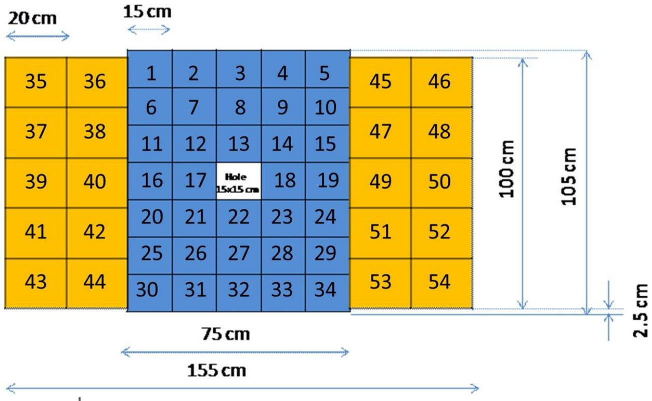
HADES: dv_1/dy scaling with collision energy and system size

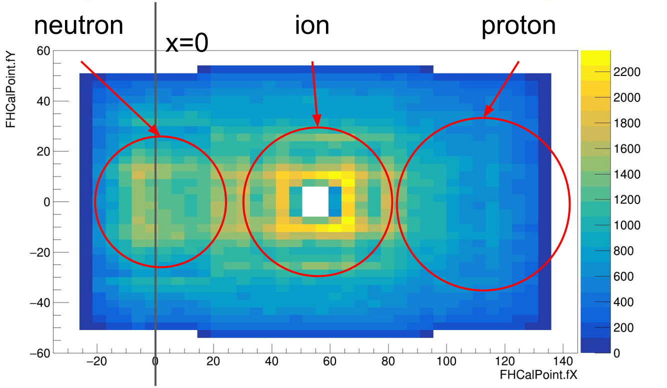


- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

The BM@N experiment (GEANT4 simulation for RUN8)







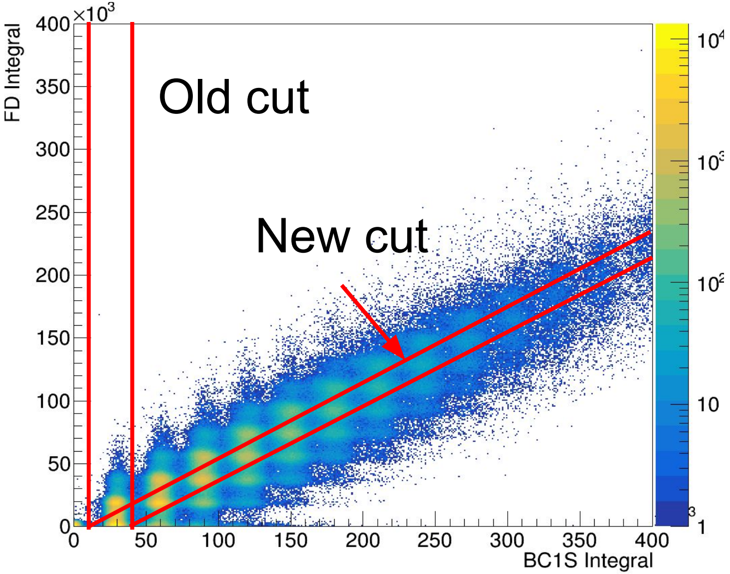
VF tracking was used

Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

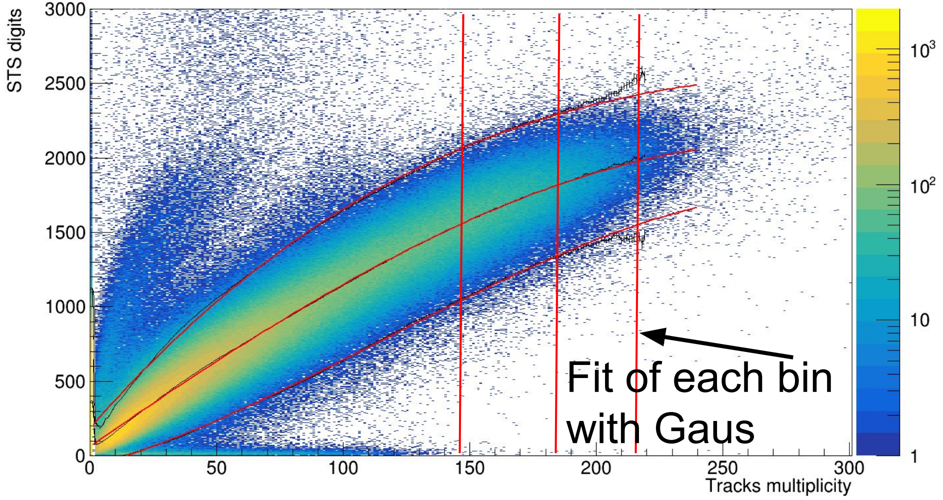
The first production was used

Selection criteria

See the talk of I.Segal for details



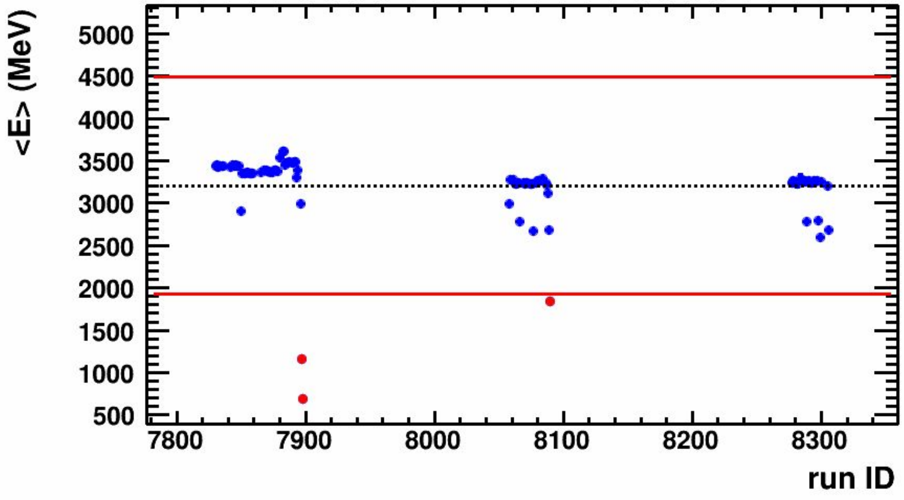
BC1 new cut



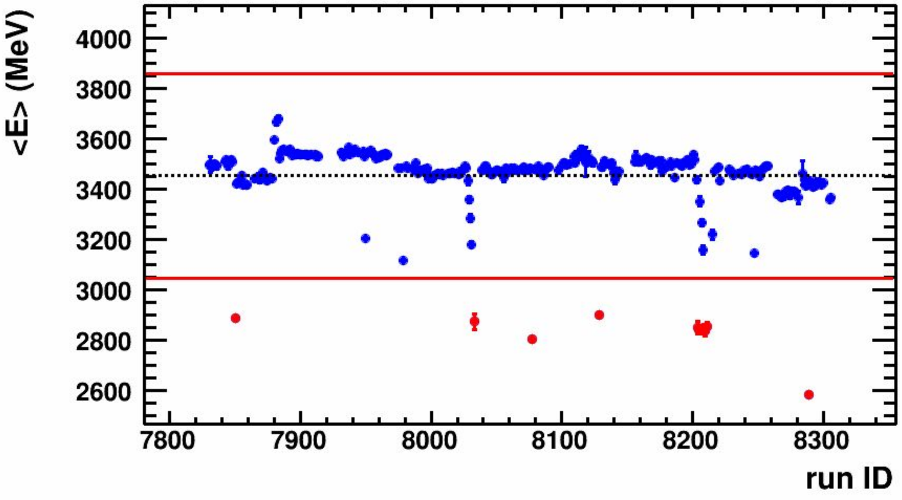
- CCT2 trigger
- Cuts on pile-up
- More than 1 track for vertex reconstruction

QA Run-by-Run: FHCal

VF prod



L1 prod

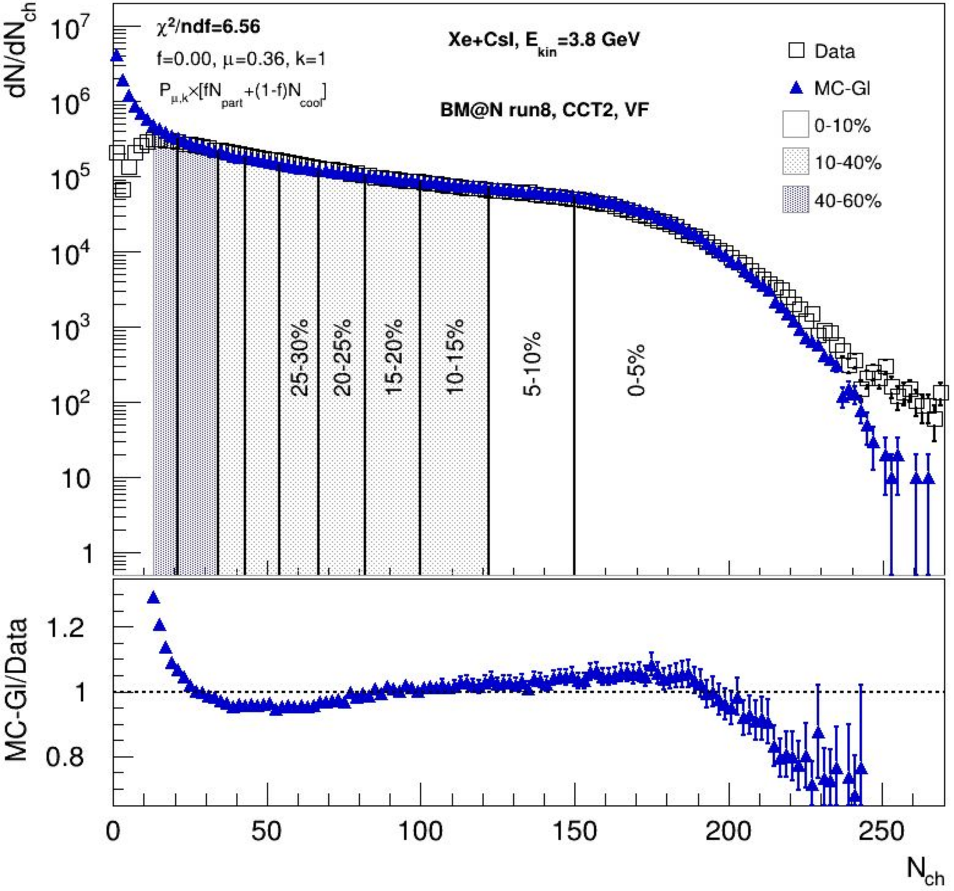


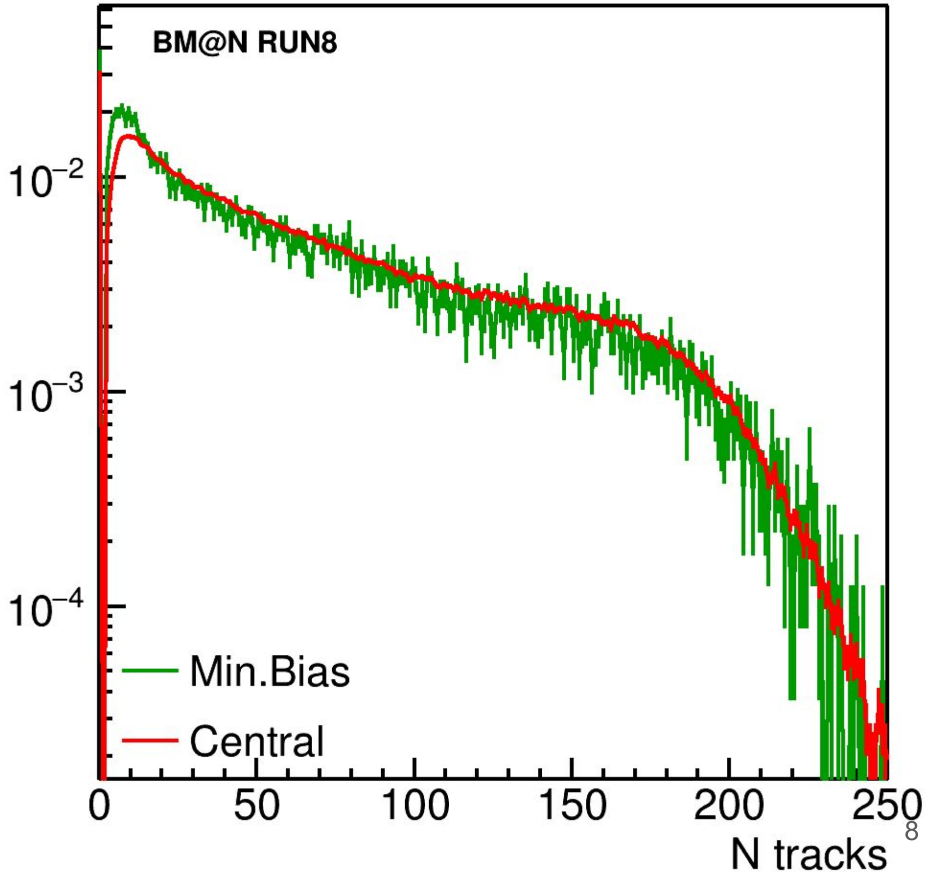
VF production was made with different versions of BmnRoot:

- ~7800-7900, 8050-8100, 8070-8300 -> v23.08.0
- other runs -> later version (dev)
- Different versions are incompatible

New centrality with MC-Glauber for RUN8

(See the talk of I.Segal)





Flow vectors

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

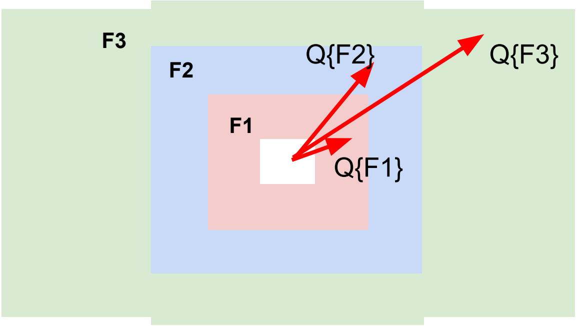
$$u_n = e^{in\phi}$$

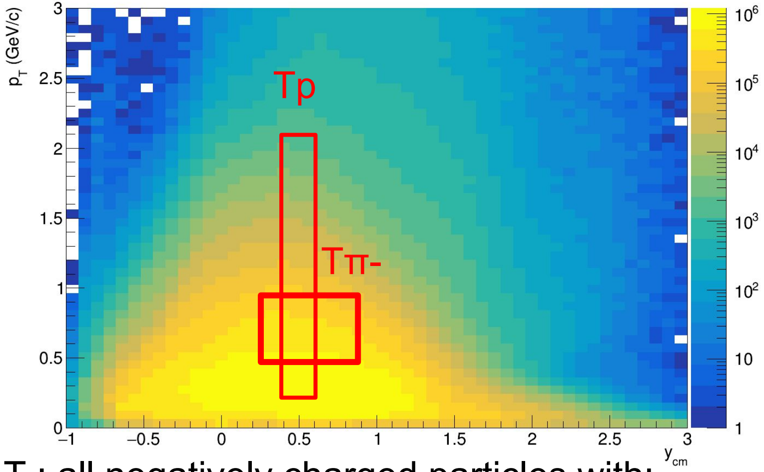
where φ is the azimuthal angle

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

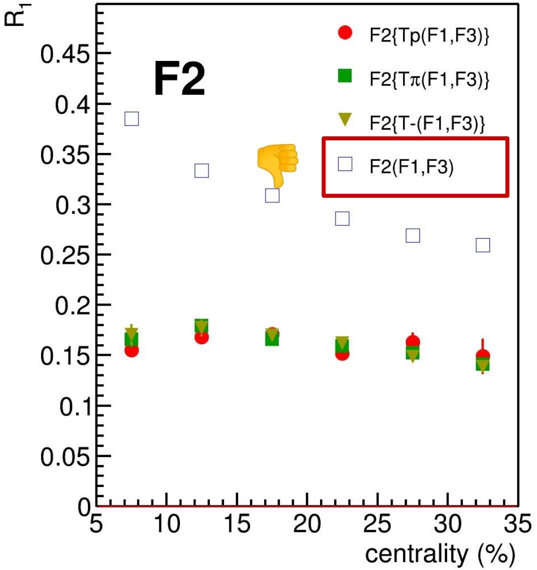
Scalar product (SP) method:

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

Where R_1 is the resolution correction factor

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

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



Symbol "F2(F1,F3)" means R_1 calculated via (3S resolution):

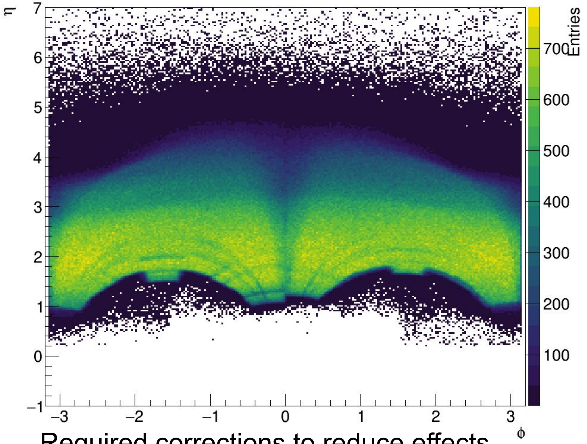
$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

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

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

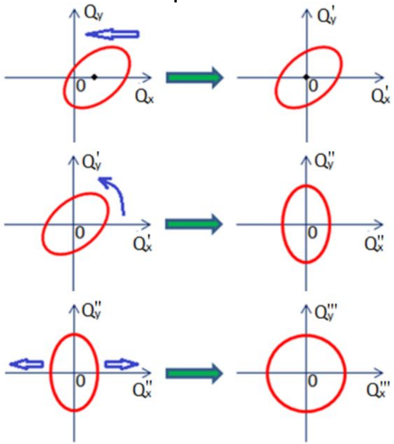
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

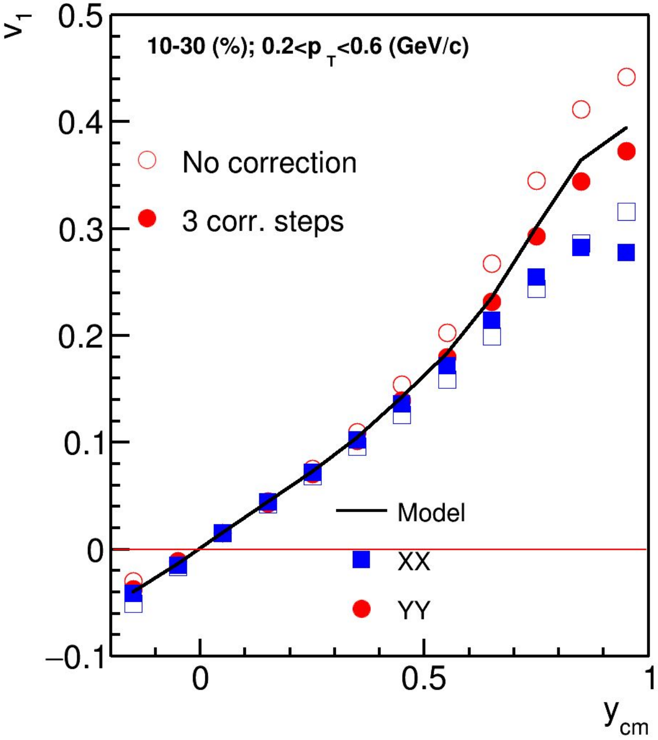


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

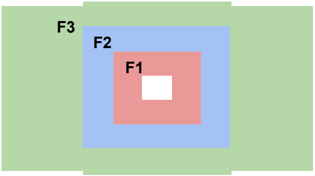


Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)

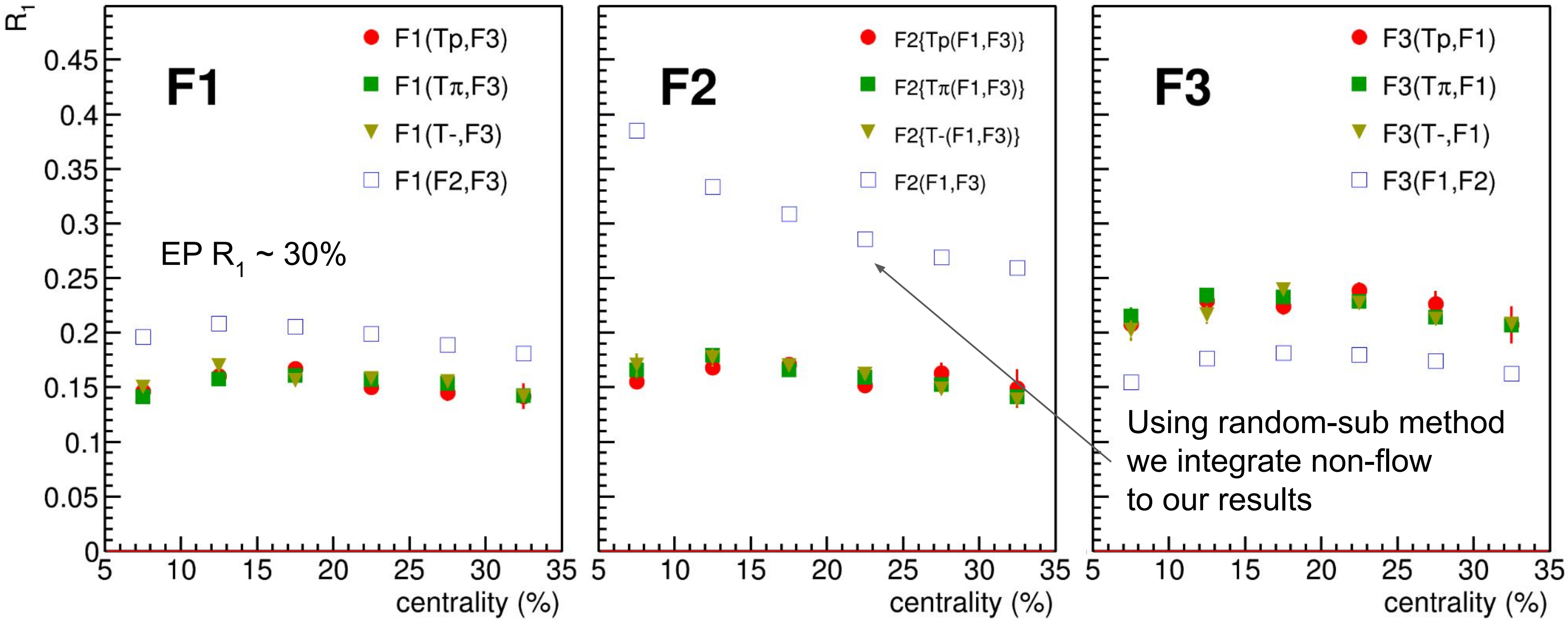


- Better agreement after rescaling for YY
- XX component has too large bias (due to magnetic field)

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

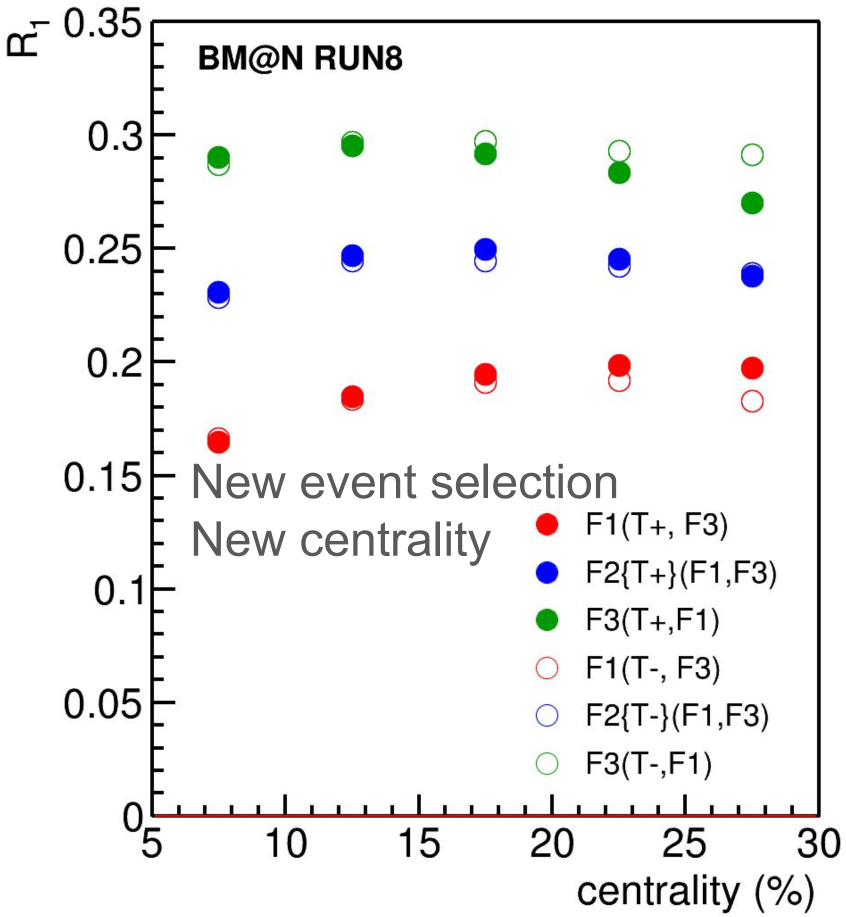


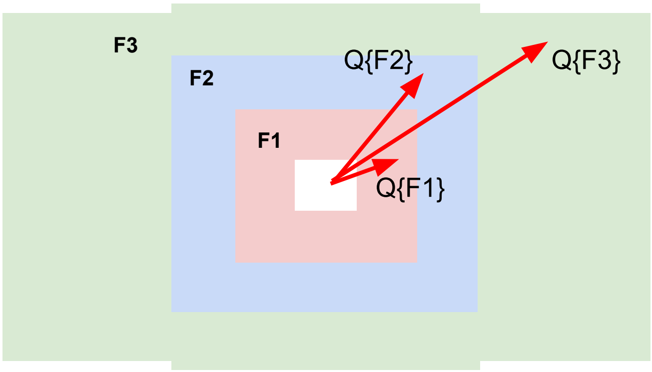
SP gives unbiased estimation of v_n (root-mean-square)
EP gives biased estimation (somewhere between mean and RMS)



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

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





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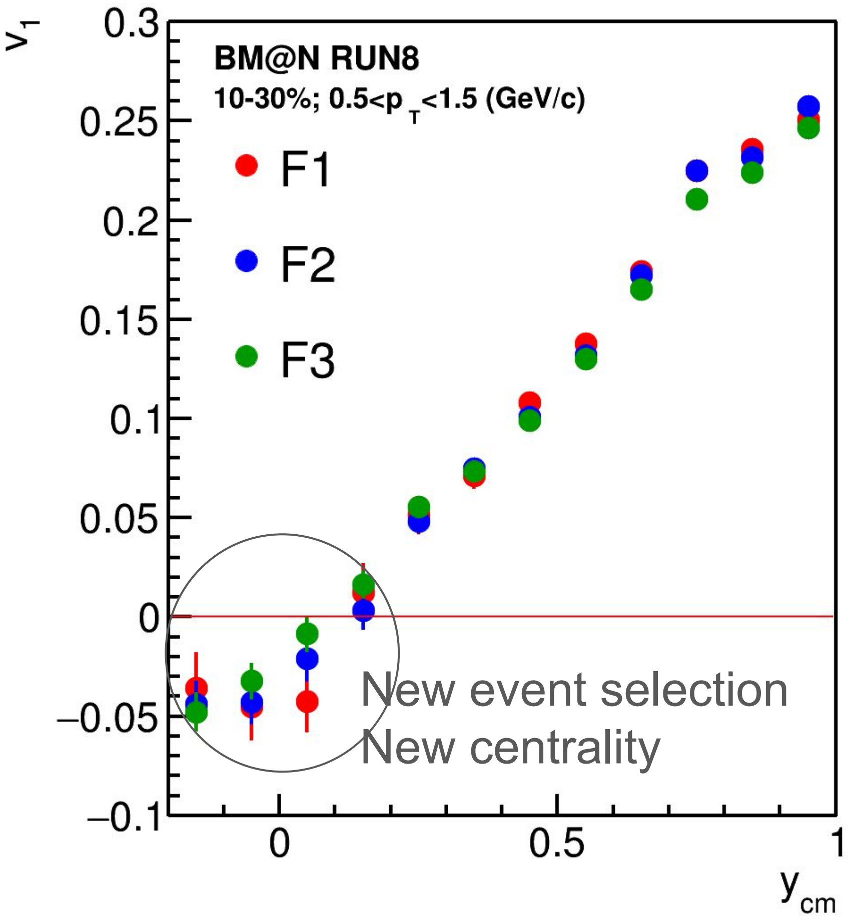
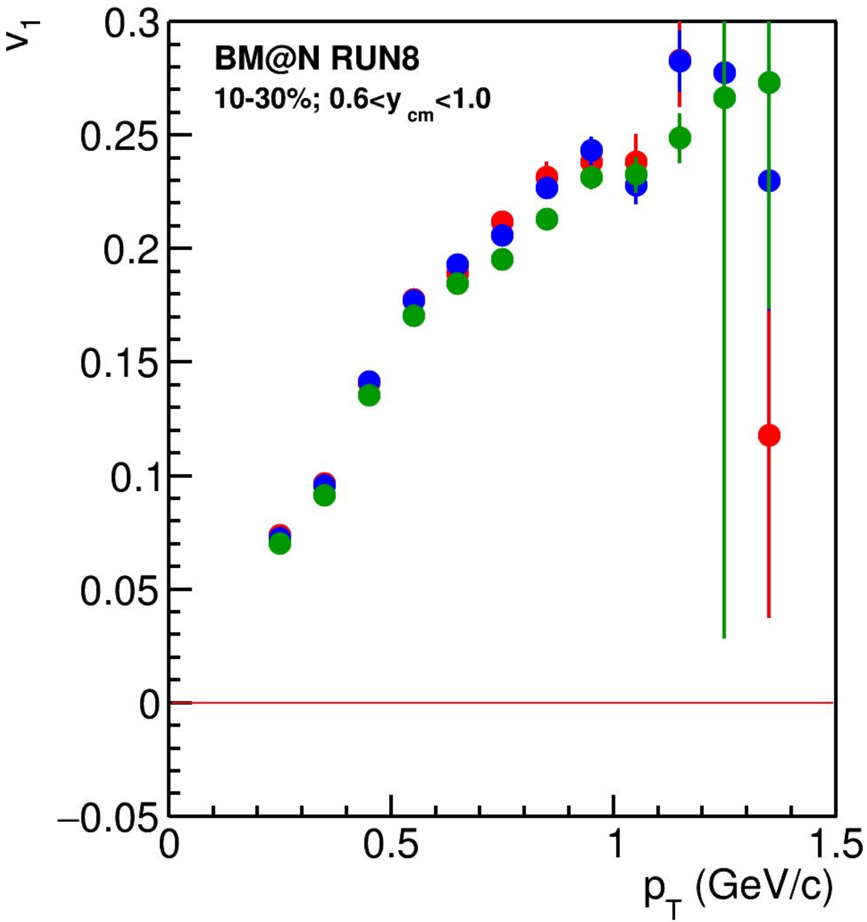
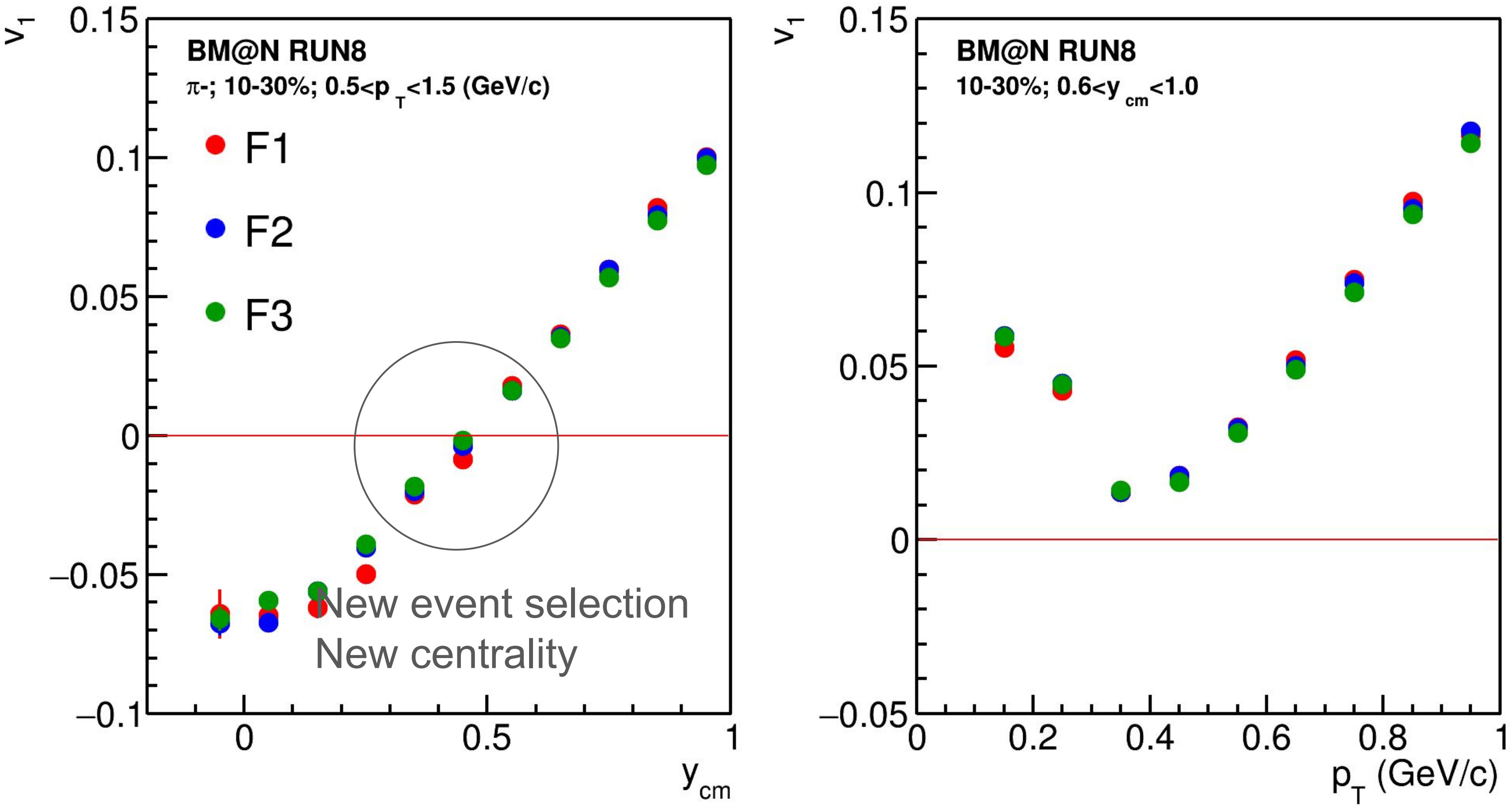
v1: p; BM@N Run8 DATA: Xe+Cs@3.8A GeV

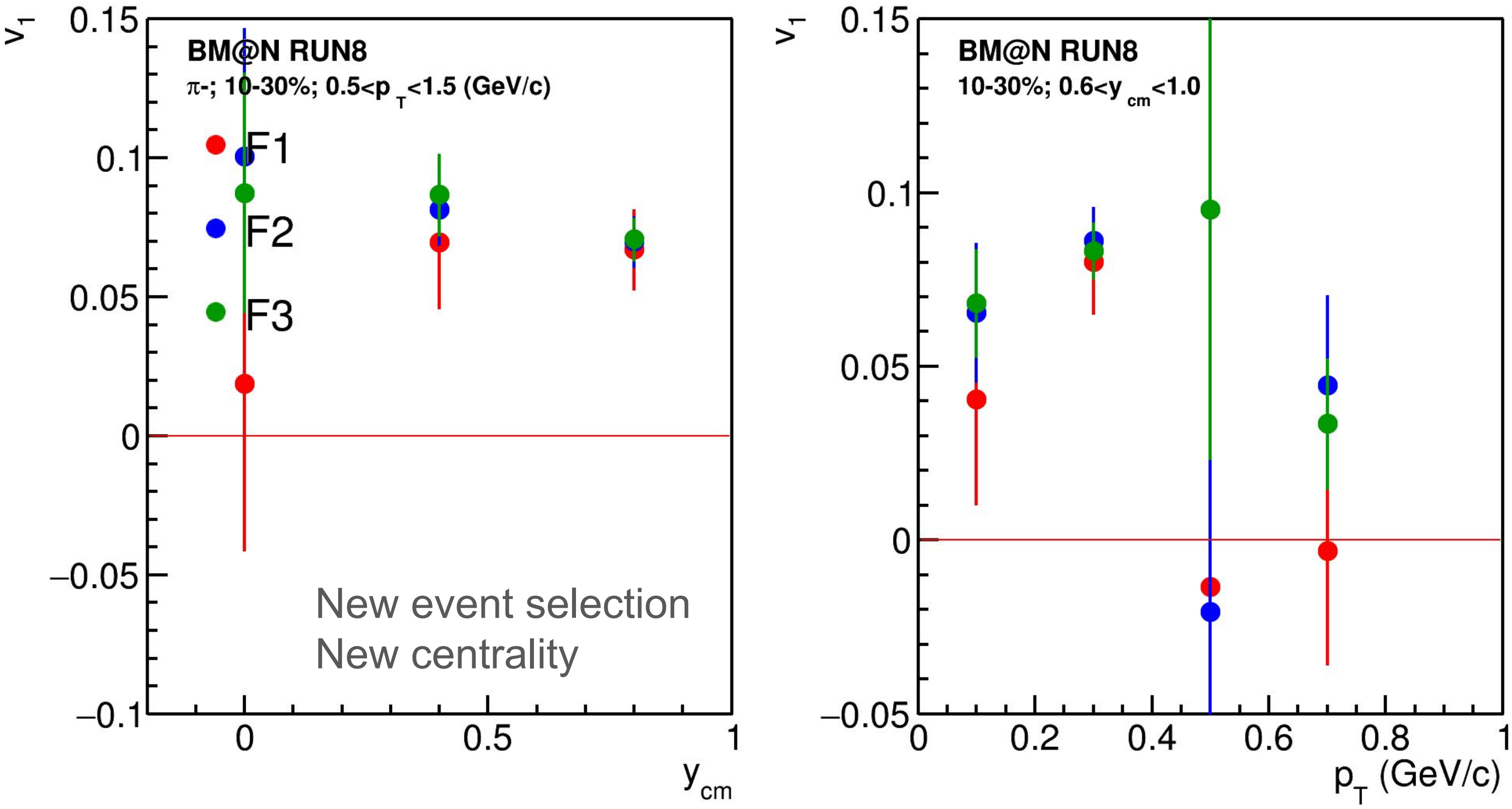




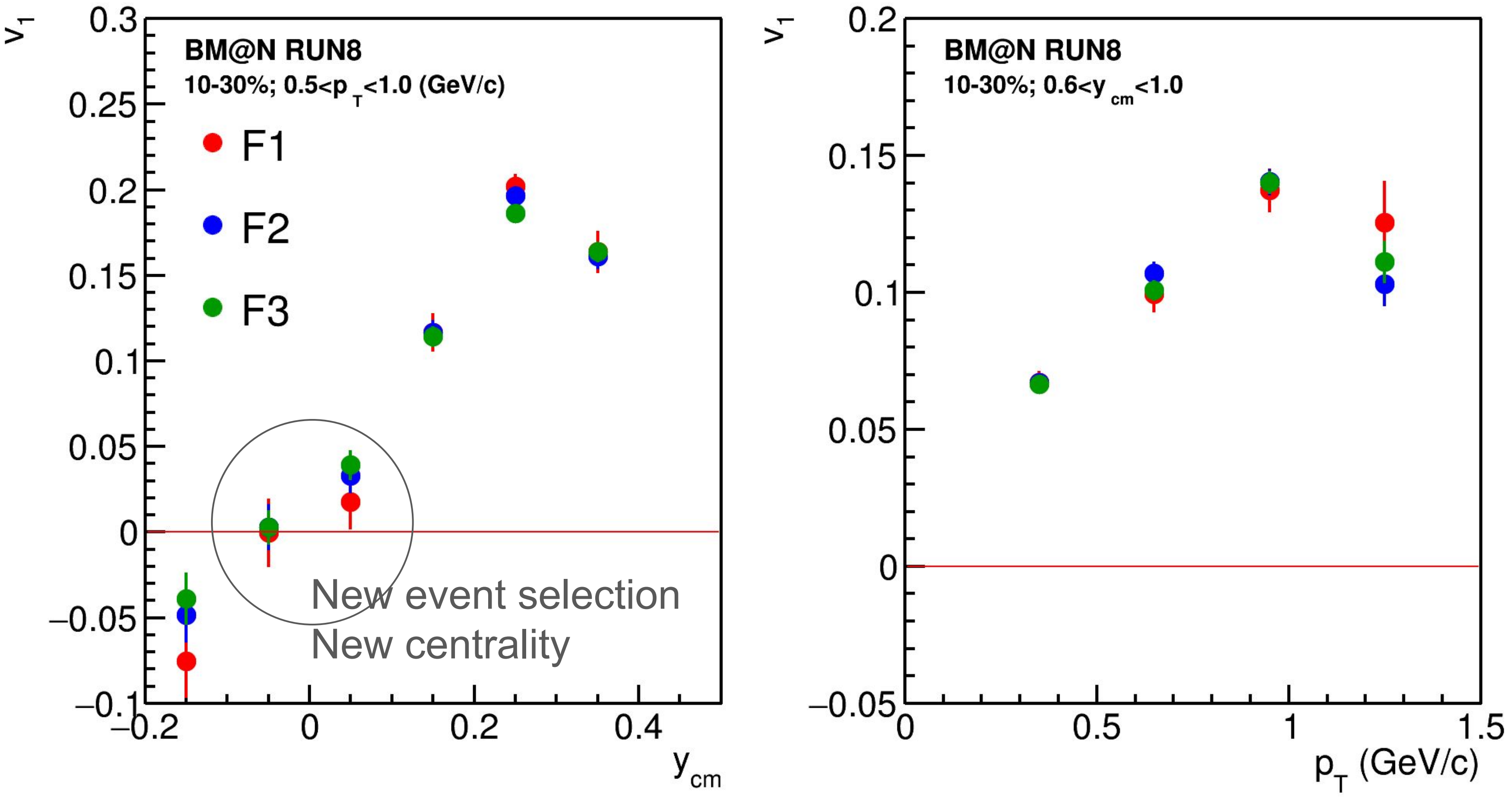
v1: π-; BM@N Run8 DATA: Xe+Cs@3.8A GeV



v1: π+; BM@N Run8 DATA: Xe+Cs@3.8A GeV

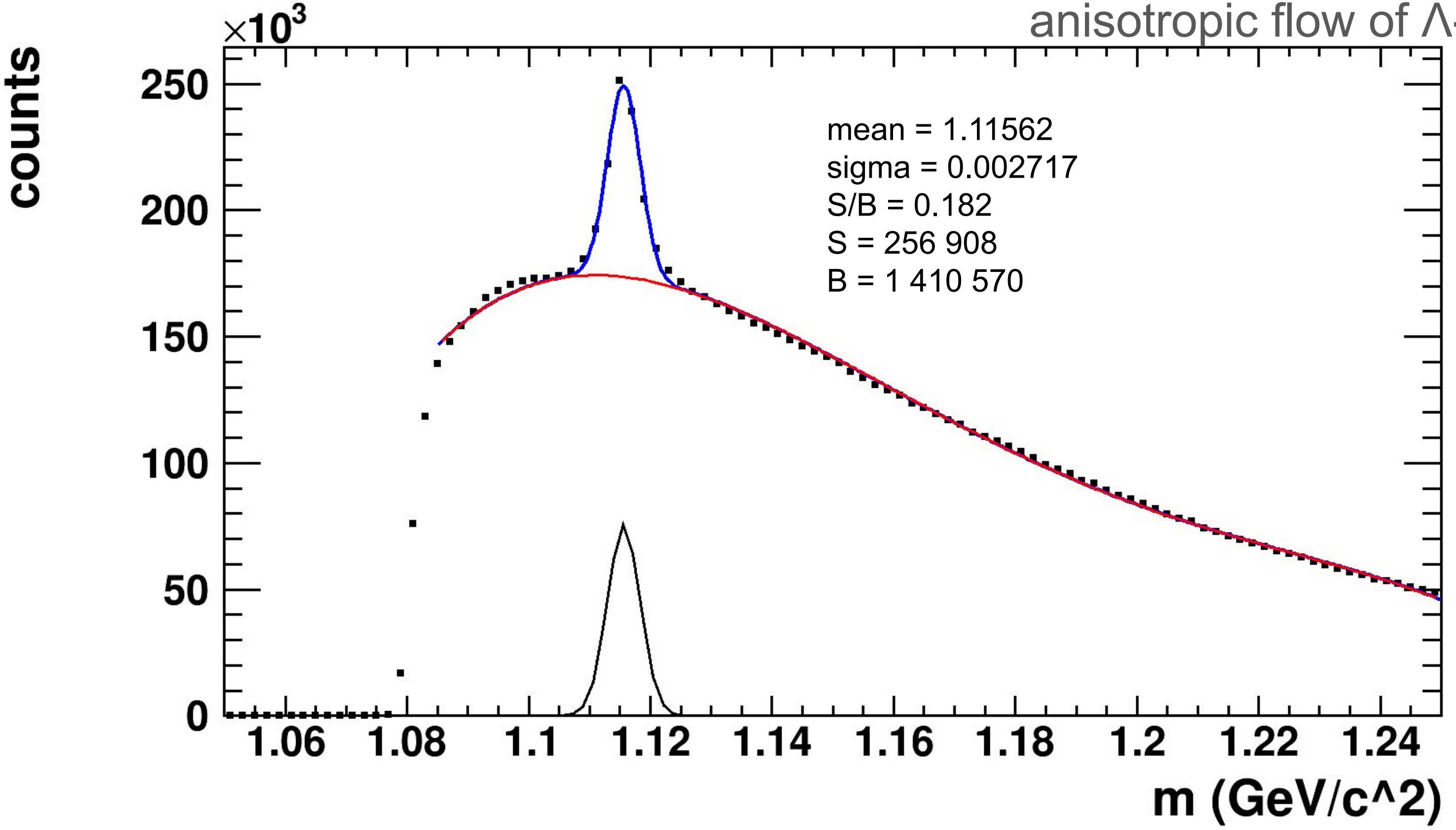


v1: d; BM@N Run8 DATA: Xe+Cs@3.8A GeV



Plans on future: measuring the Λ-hyperon flow

Valery Troshin is analyzing the anisotropic flow of Λ-hyperon



Decay length L>2.25

Reverse relative error L/dL>6.25

DCA < 0.7

$\cos(r_{\Lambda} p_{\Lambda}) > 0.998$

$X_{prim}\{p\} > 10$

$X_{prim}\{pi\} > 400$

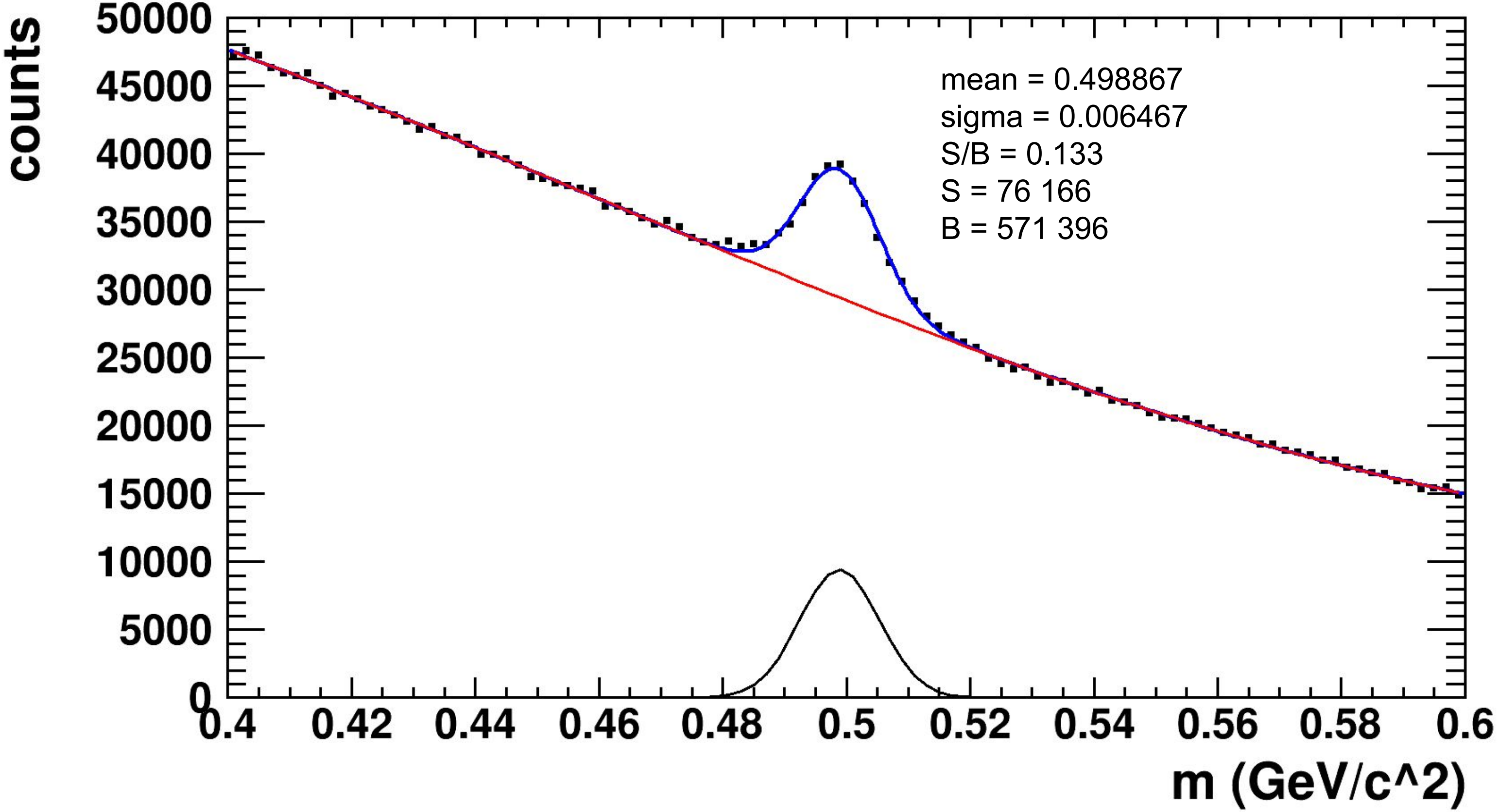
$X_{TOPO} < 50$

$X_{GEO} < 20$

$0.9998 > \cos(p_p p_{\Lambda}) > 0.997$

Plans on future: measuring the K-short flow

And of K-shorts as well

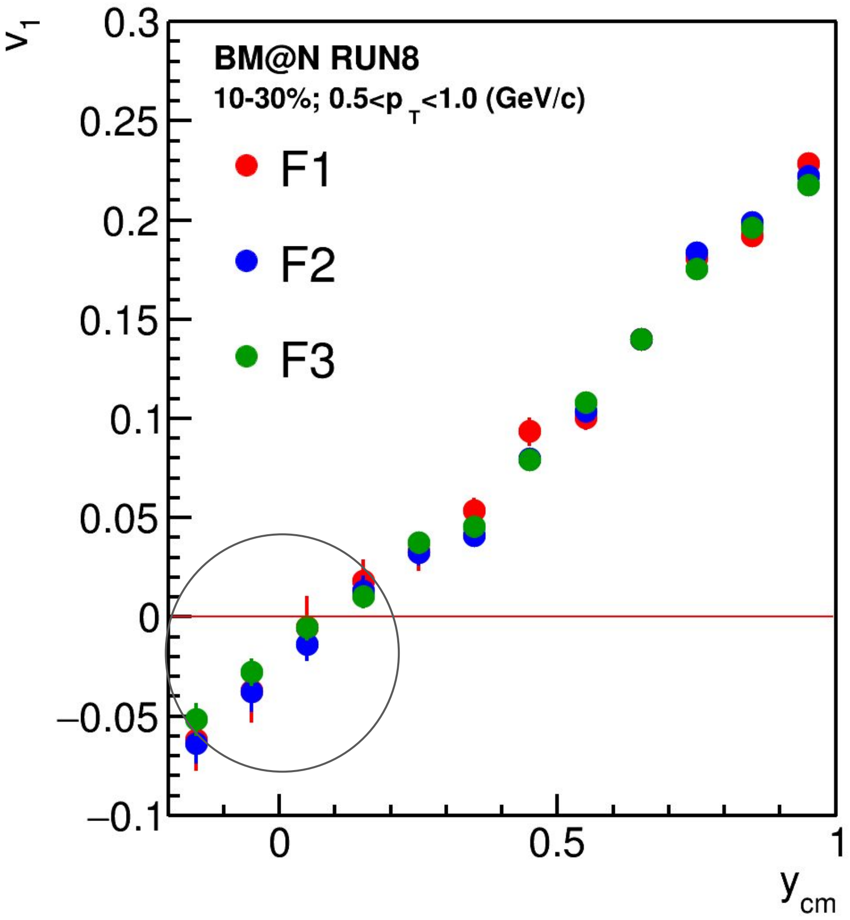


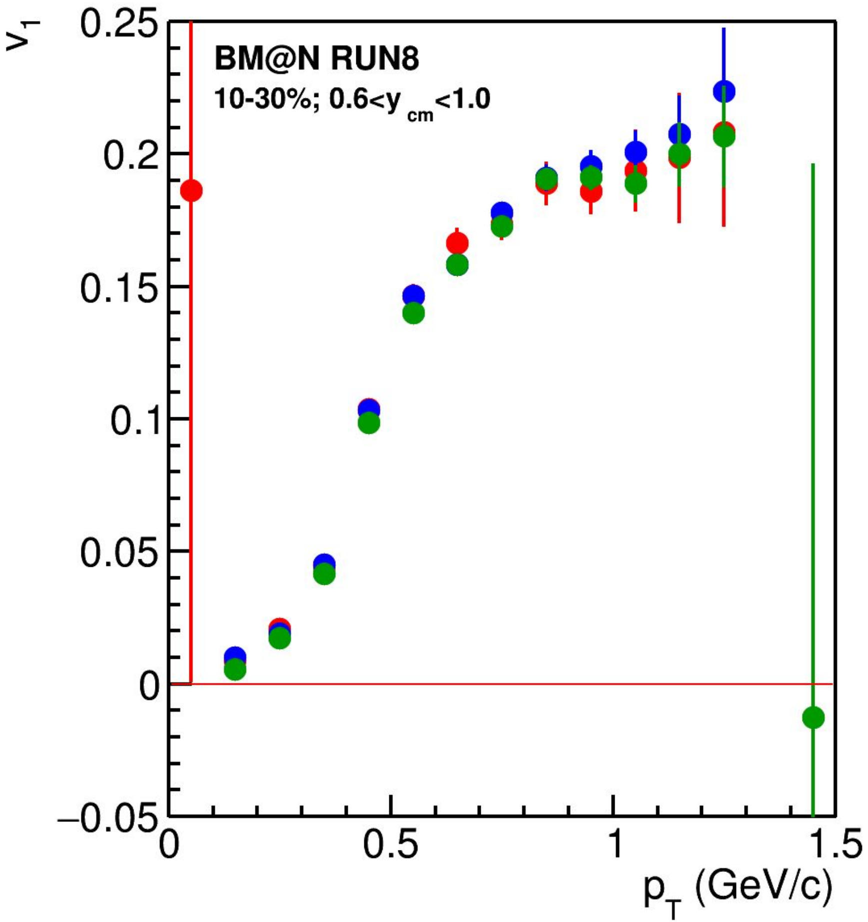
Decay length L>1
Reverse error L/dL>6.25
DCA < 0.7
$\cos(r_k p_K) > 0.995$
X_{prim}\{pi+\} >100
X_{prim}\{pi\} >100
X_{TOPO}40
$\chi_{GEO} < 20$
$0.9998 > \cos(p_{pi+} p_K) < 0.999$
2m*Δm<0.06

Summary

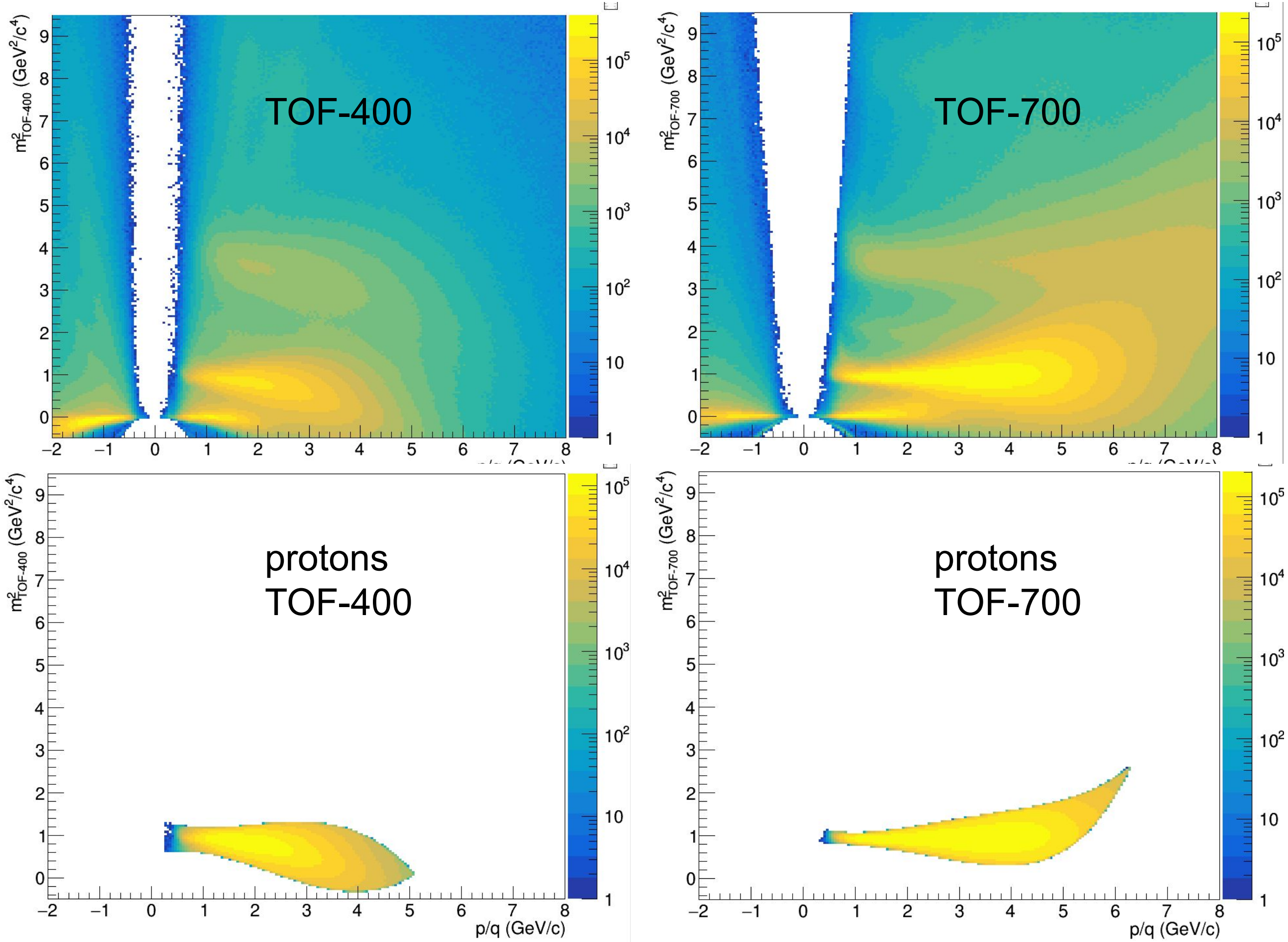
- Resolution correction factor is calculated for RUN8 Xe+CsI collisions at beam energy of 3.8A GeV:
  - Using additional sub-events from tracking provides with a robust estimation
- Directed flow v_1 was calculated for RUN8 Xe+CsI collisions at beam energy of 3.8A GeV with respect to different spectator symmetry planes from FHCal
  - Good agreement between v_1 obtained with respect to different FHCal symmetry planes is observed for both y_{cm} and p_T dependencies
- Outlook:
  - The comparison with VF tracking results is ongoing
  - Rub-by-run systematics will be studied

v1: BM@N Run8 DATA: Xe+Cs@3.8A GeV





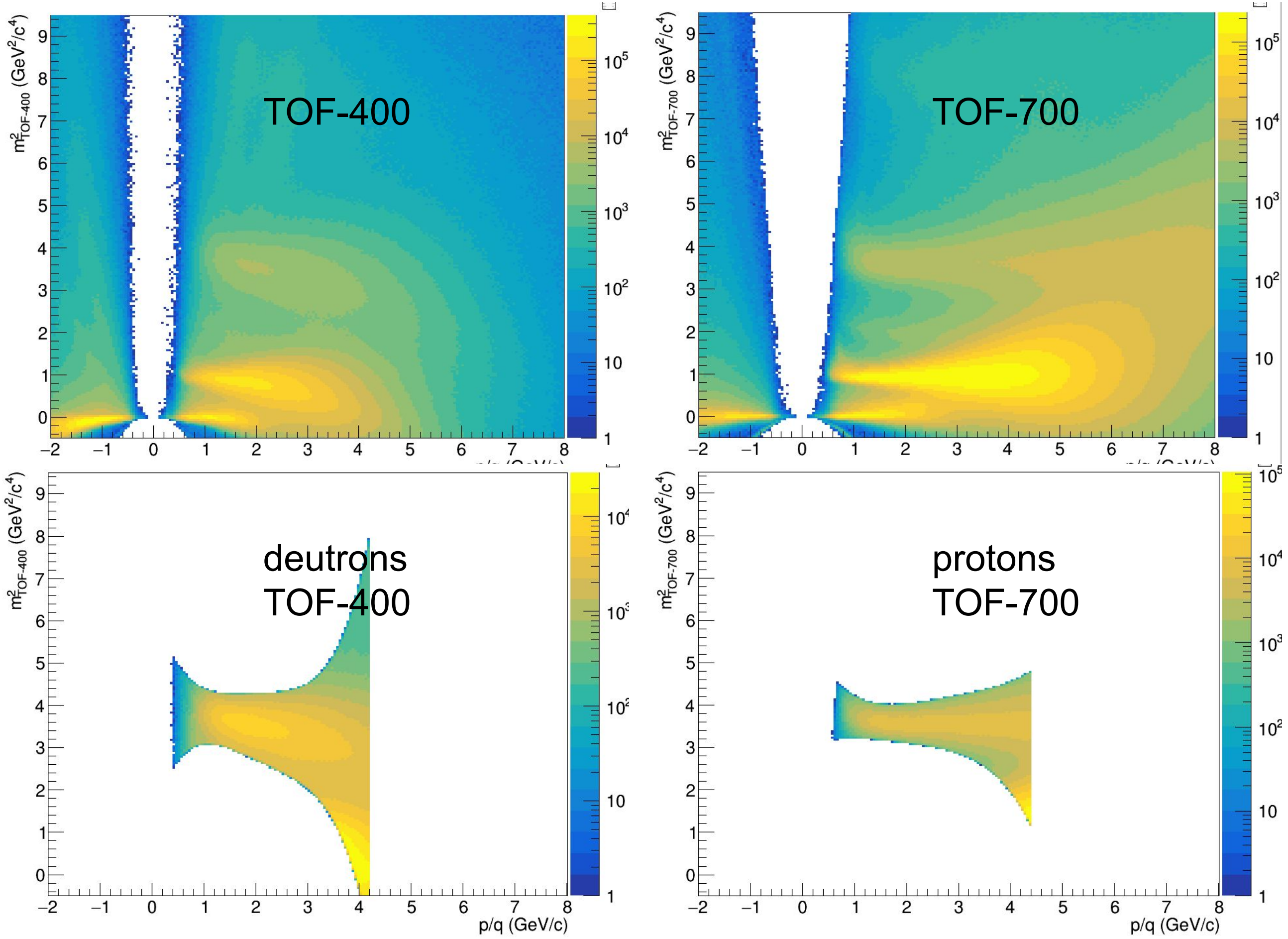
Proton identification



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

Selection criteria: <m>±2σ

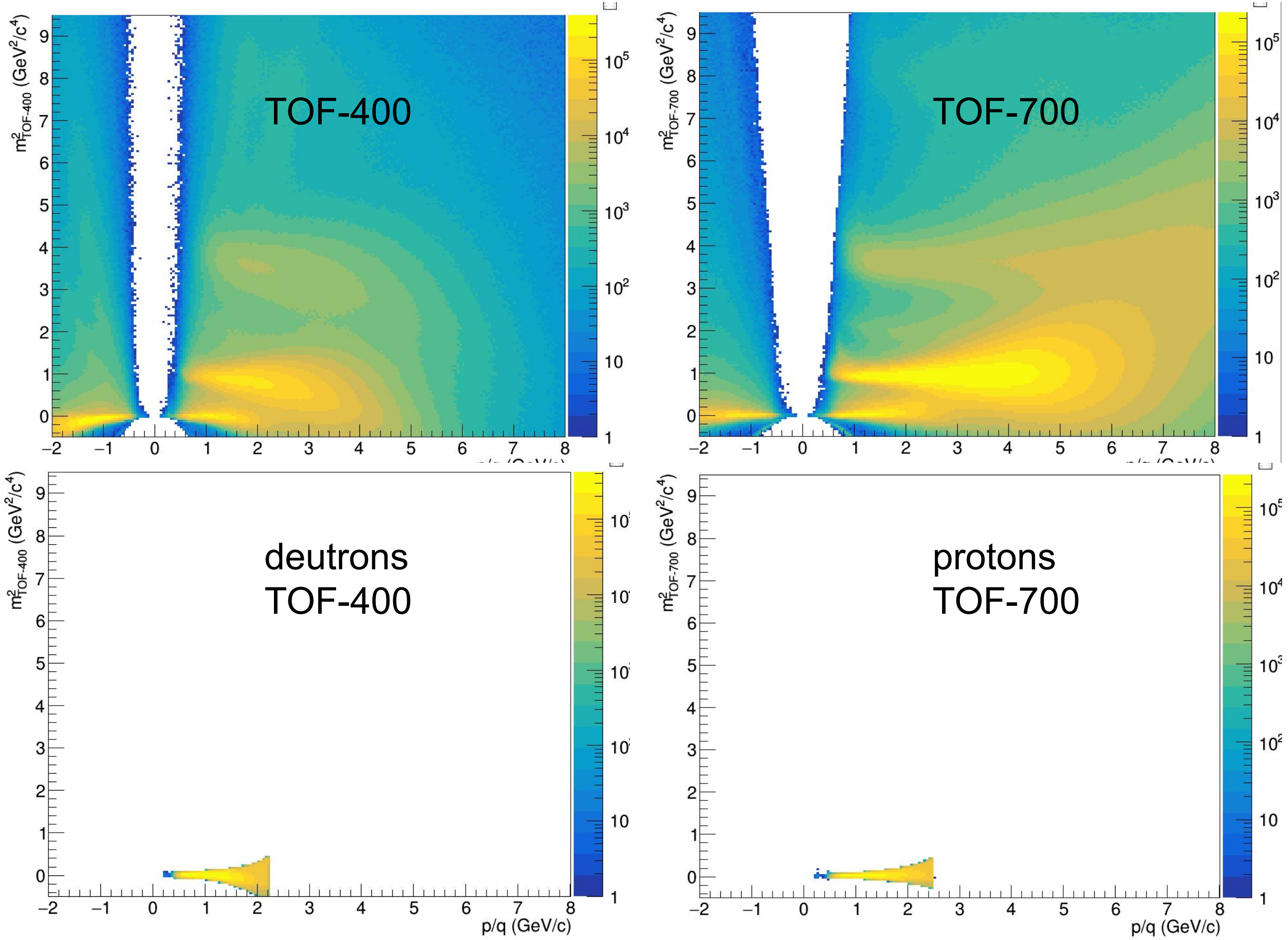
Deutron identification



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

Selection criteria: <m>±2σ

Positive pions identification

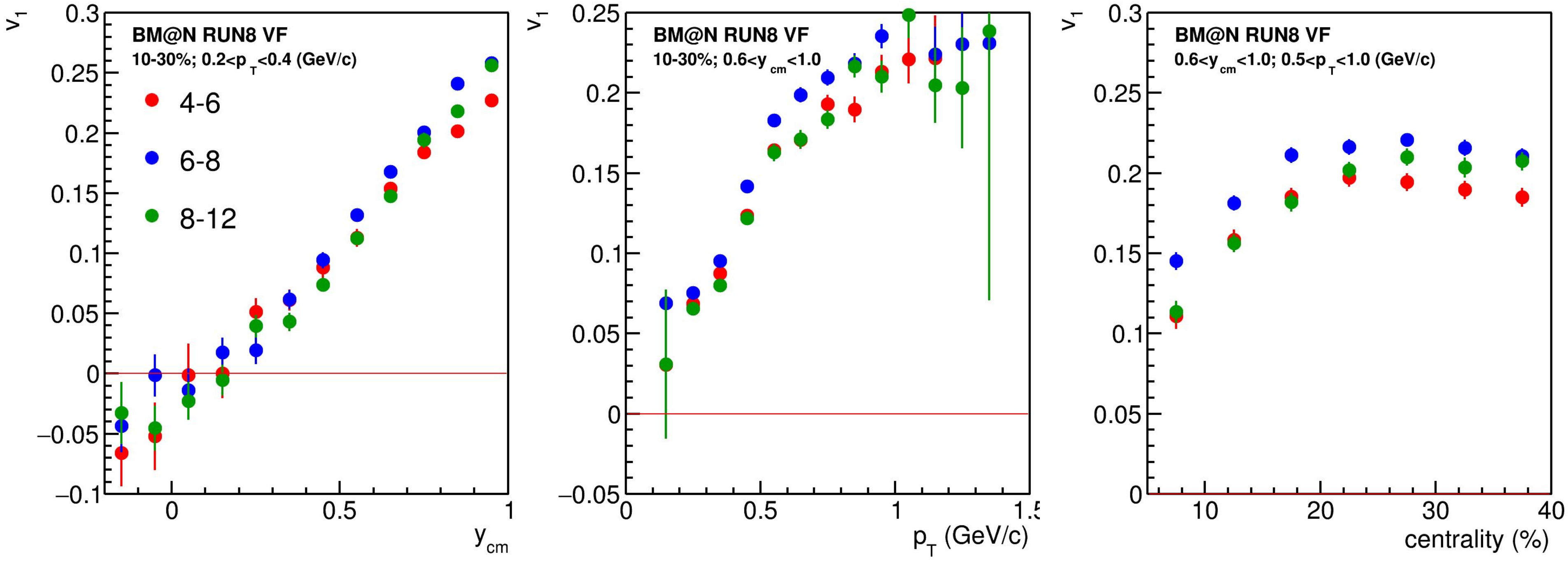


Proton candidates were selected with fitting the m^2 vs p\q

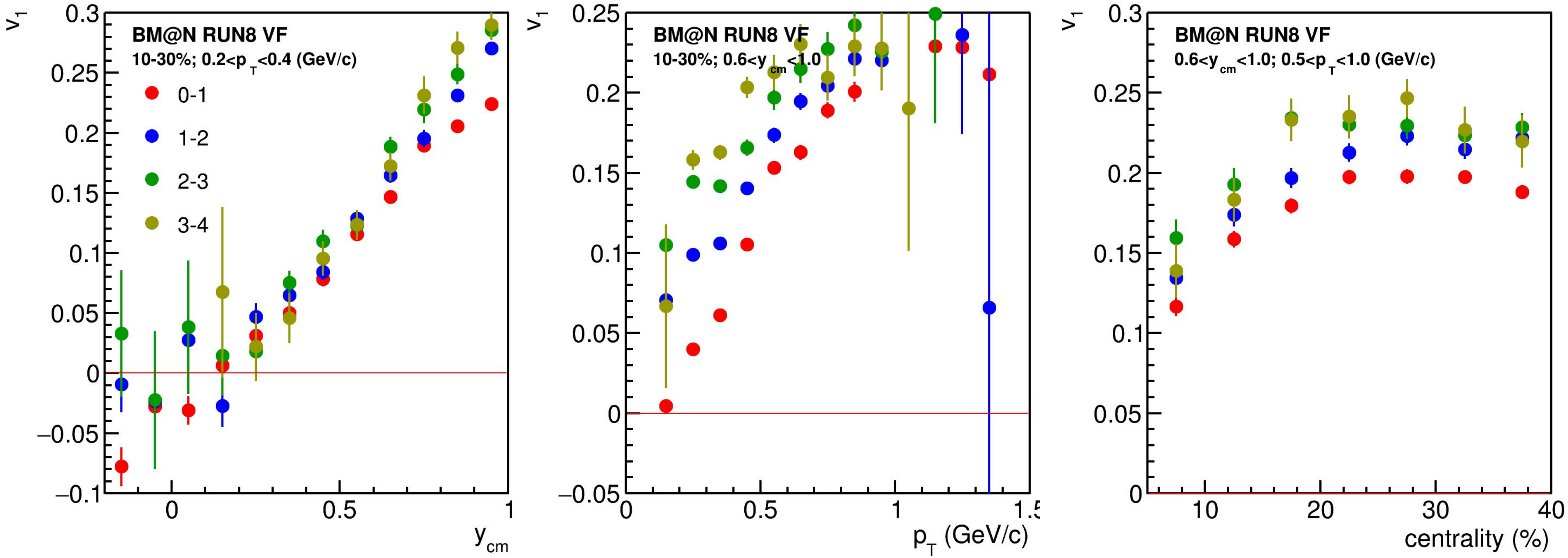
Selection criteria: <m>±2σ

Backup

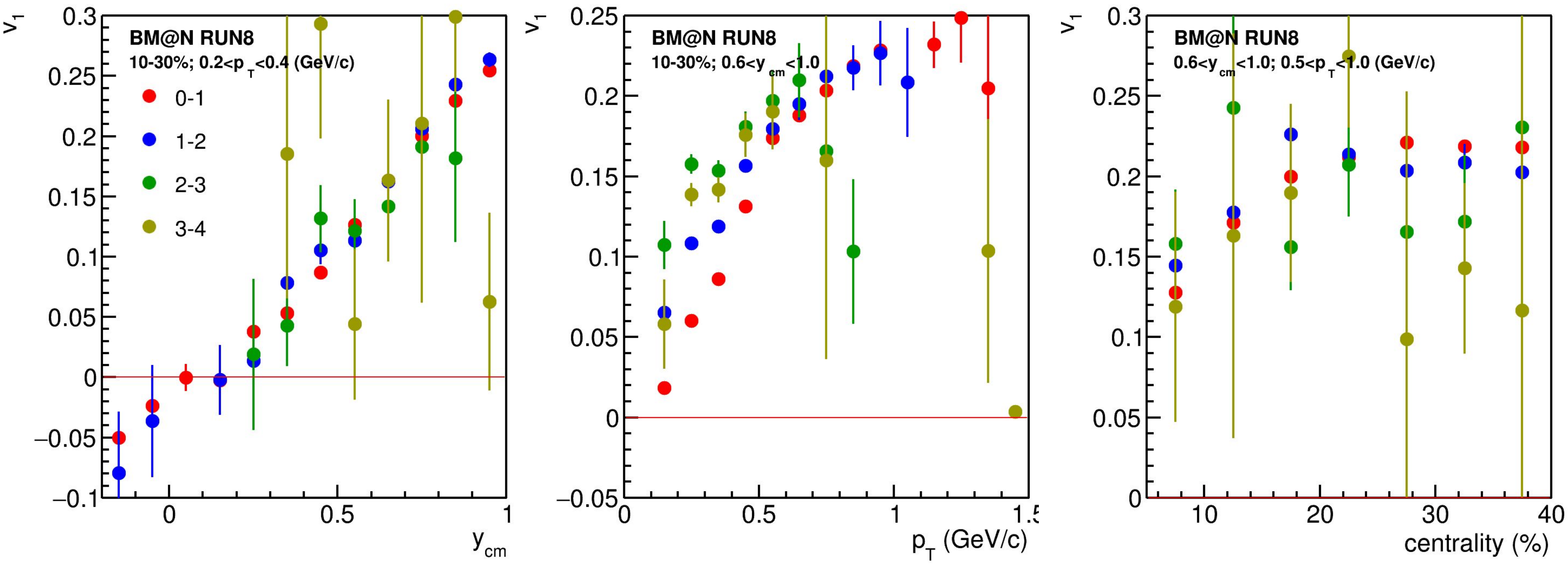
(VF) v_1 vs y: Systematic variation due to Nhits-cut



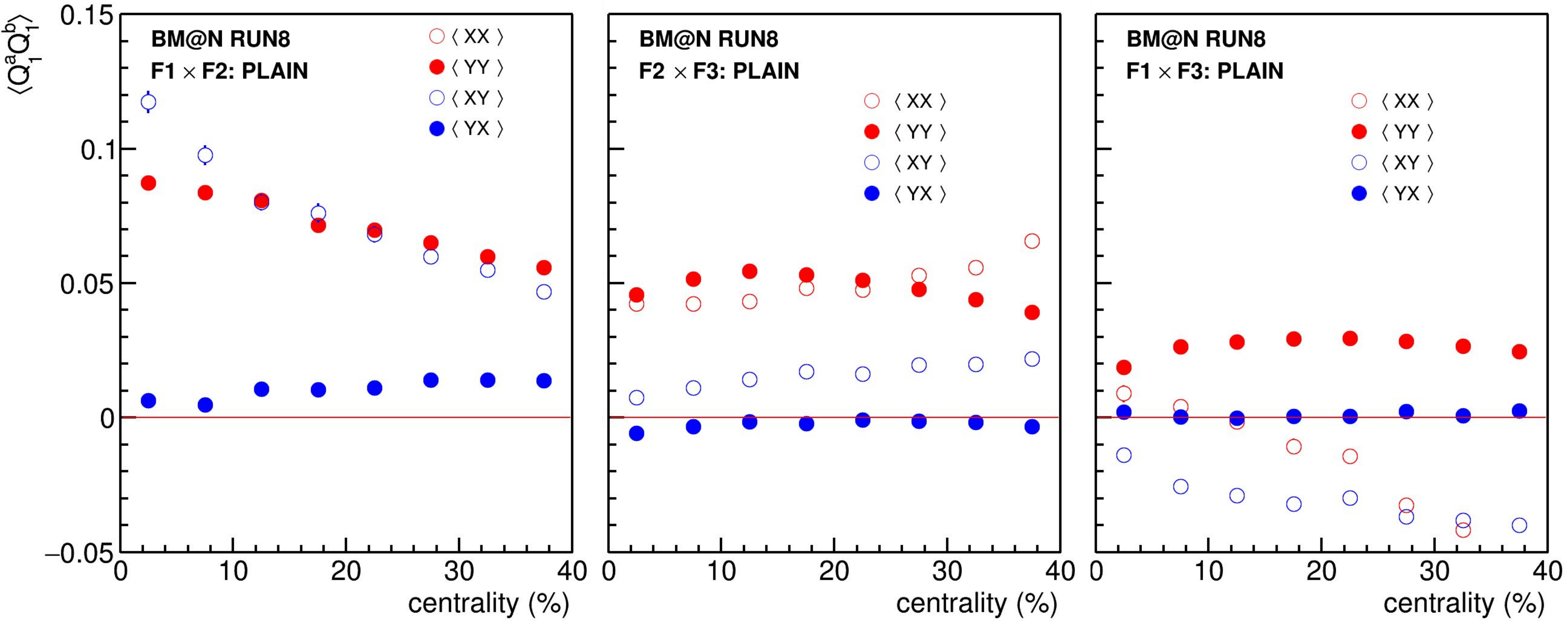
(VF) v_1 vs y: Systematic variation due to chi2-cut



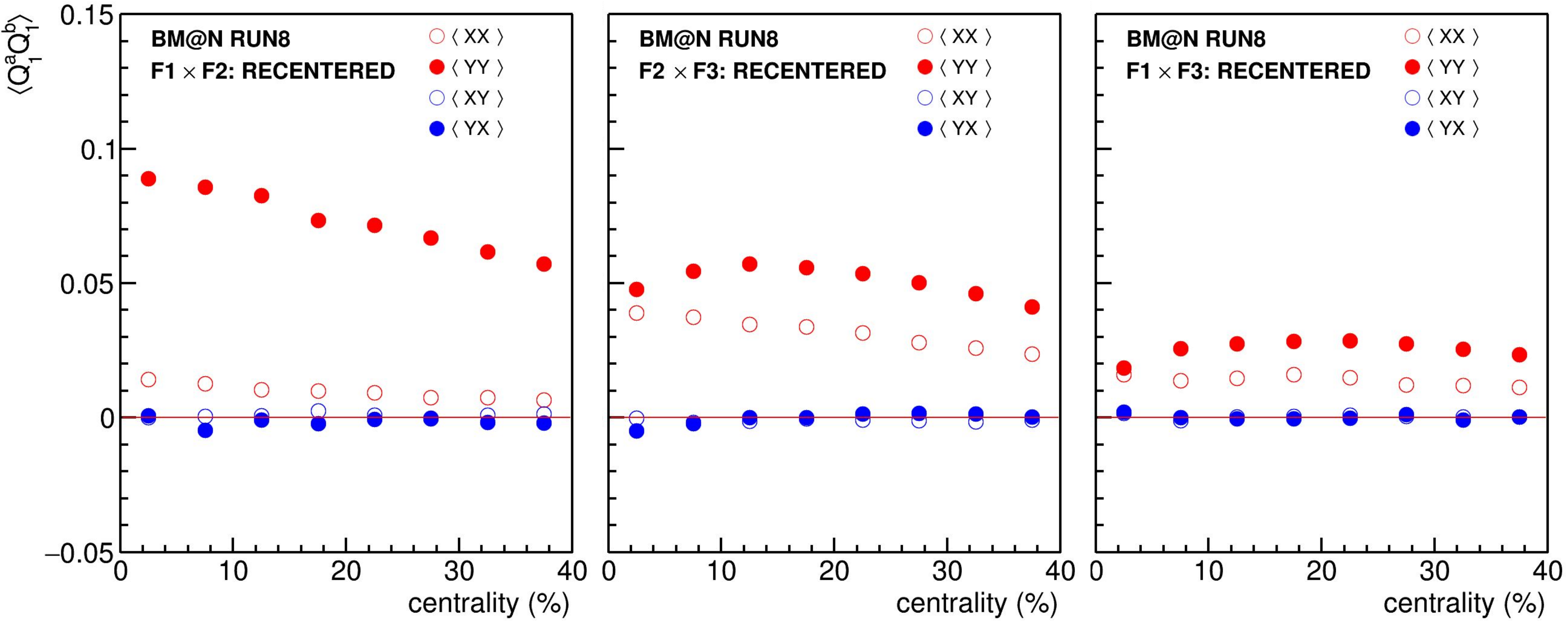
(VF) v_1 vs y: Systematic variation due to DCA-cut



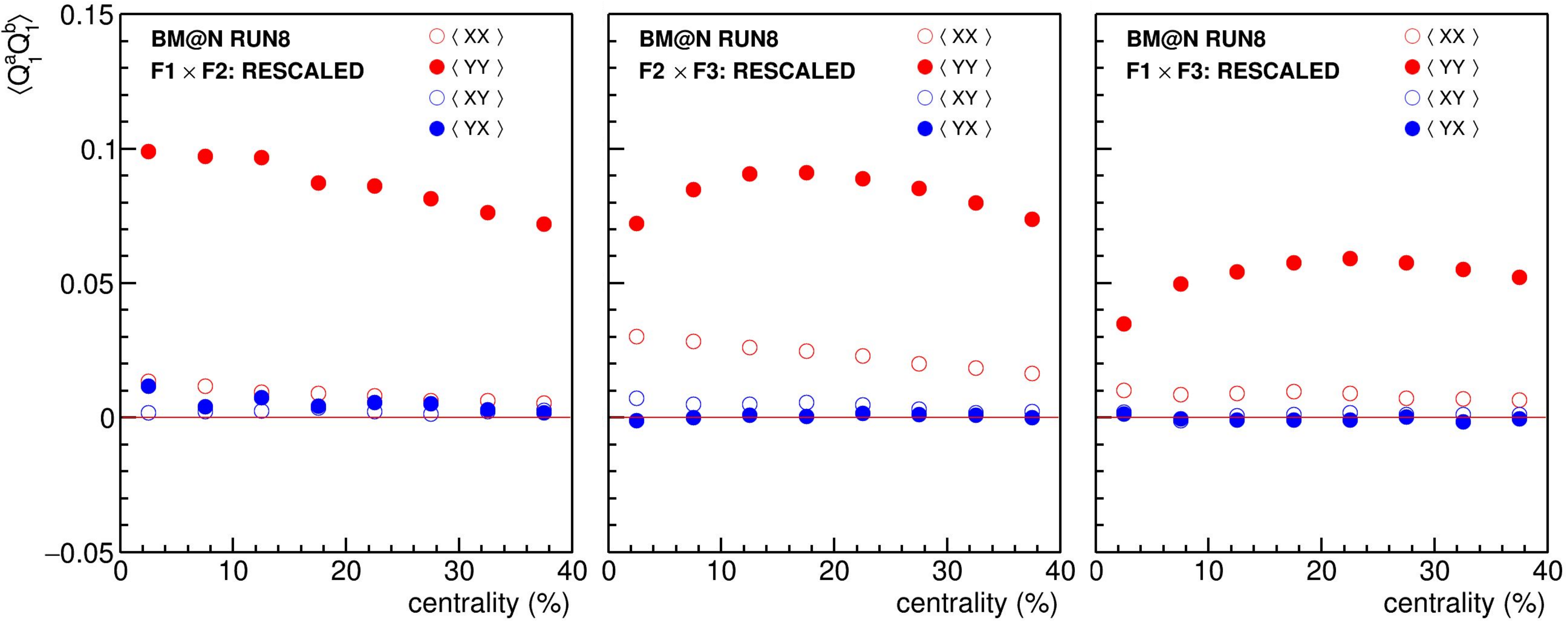
FHCal Q-vector correlations (PLAIN)



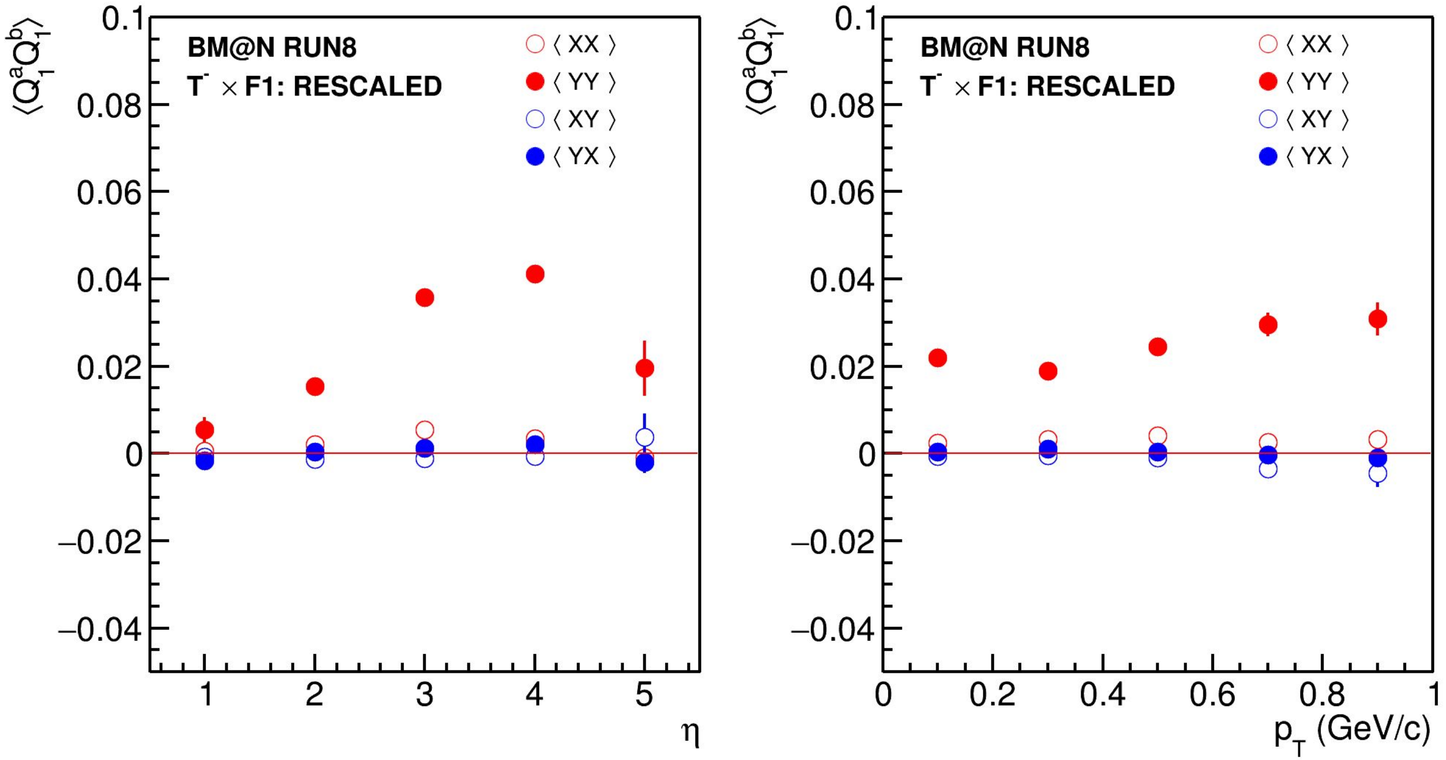
FHCal Q-vector correlations (RECENTERED)



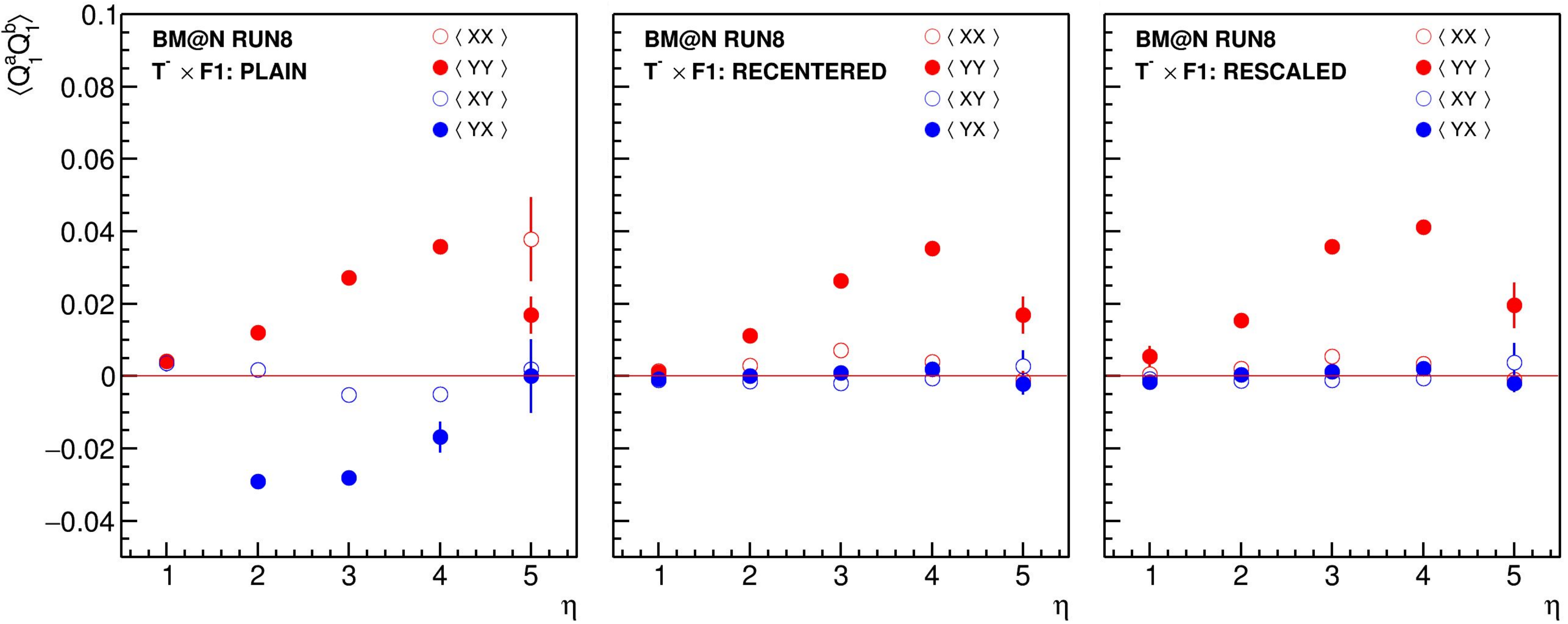
FHCal Q-vector correlations (RESCALED)



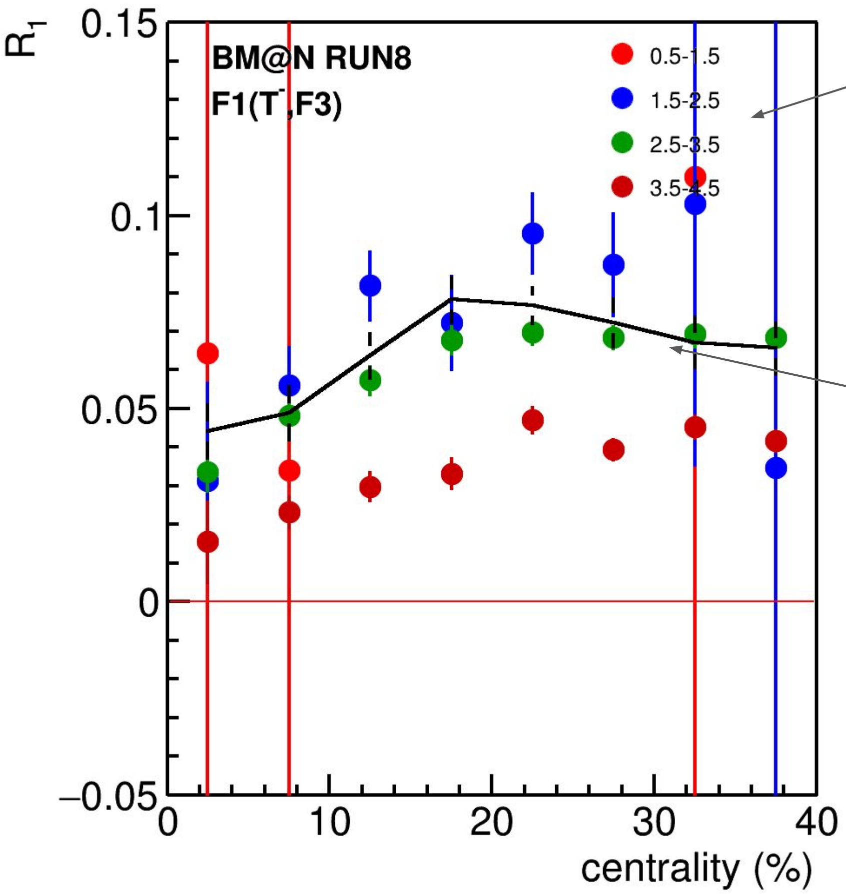
T- x F1 correlations



T- x F1 correlations (all steps)



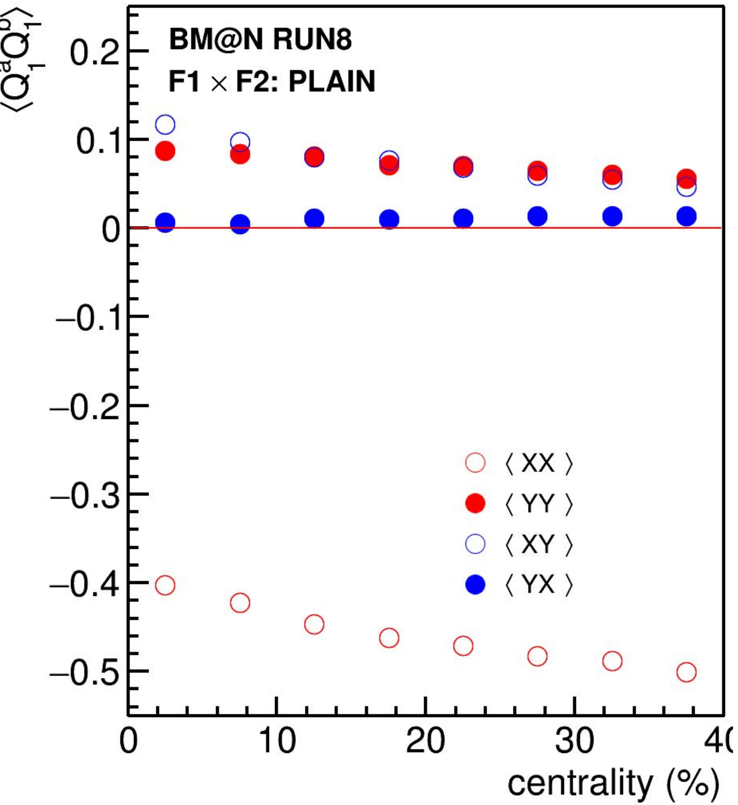
Selecting the pseudorapididty window for T+ vector



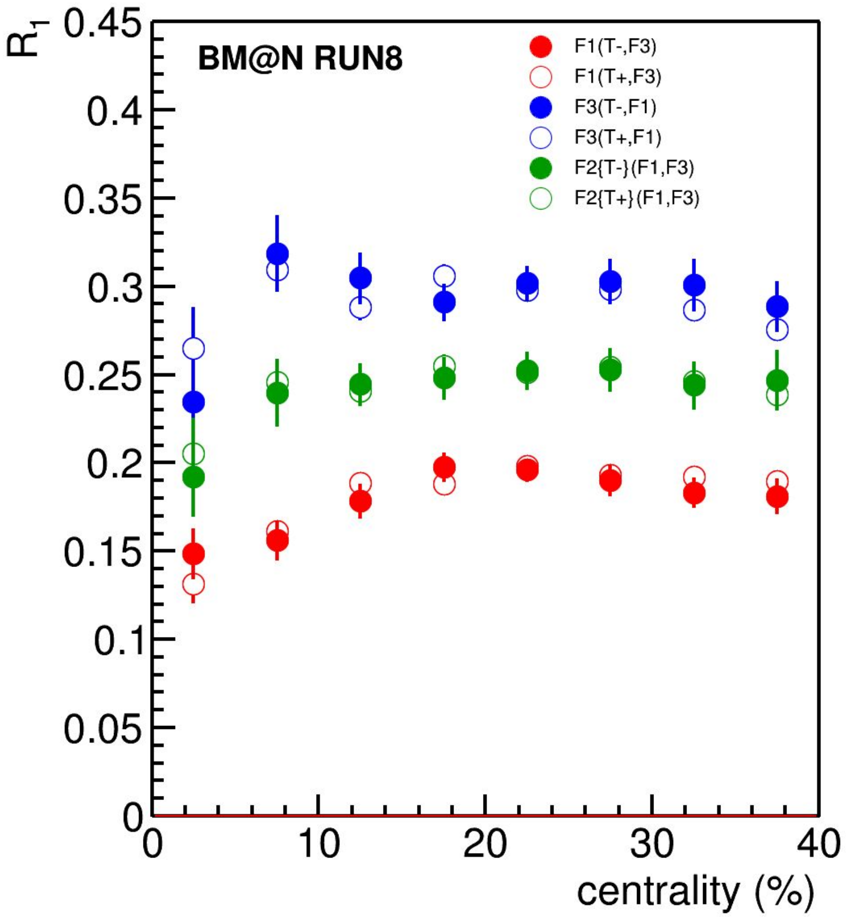
Variating eta

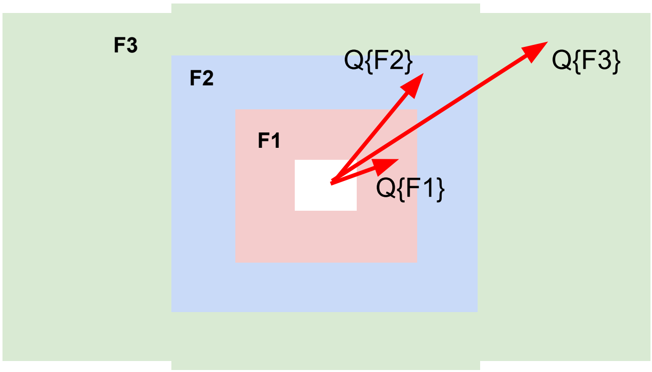
Same combination with T-

Q-vector correlations (PLAIN)



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





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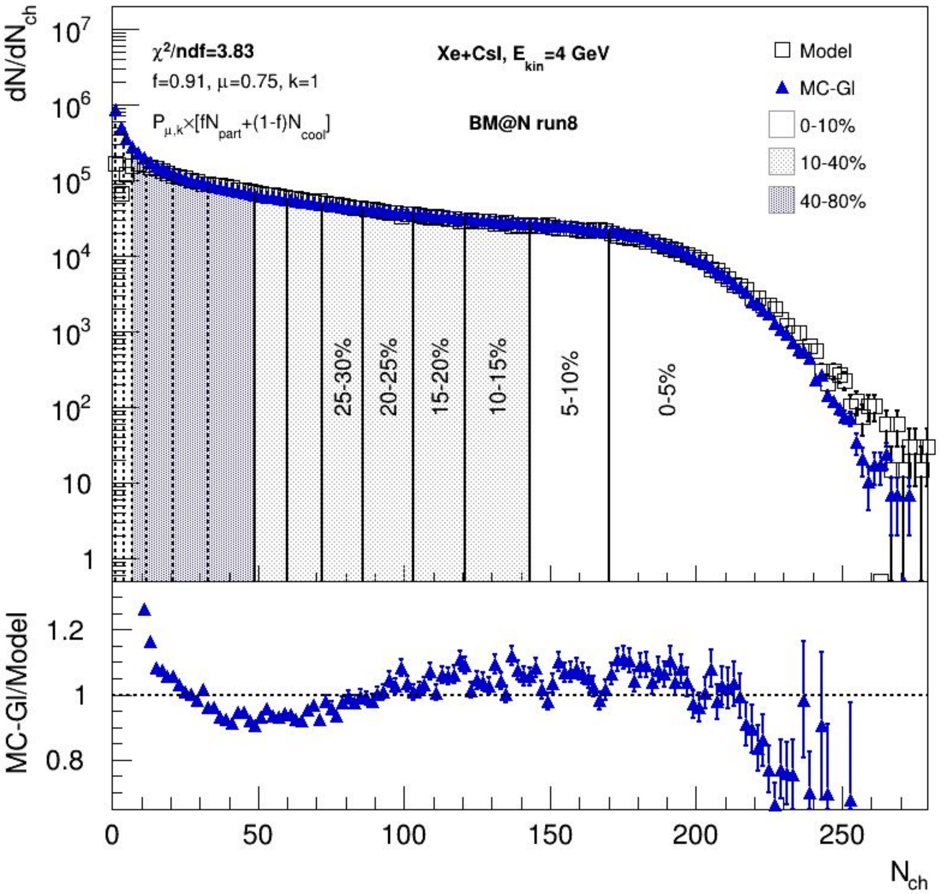
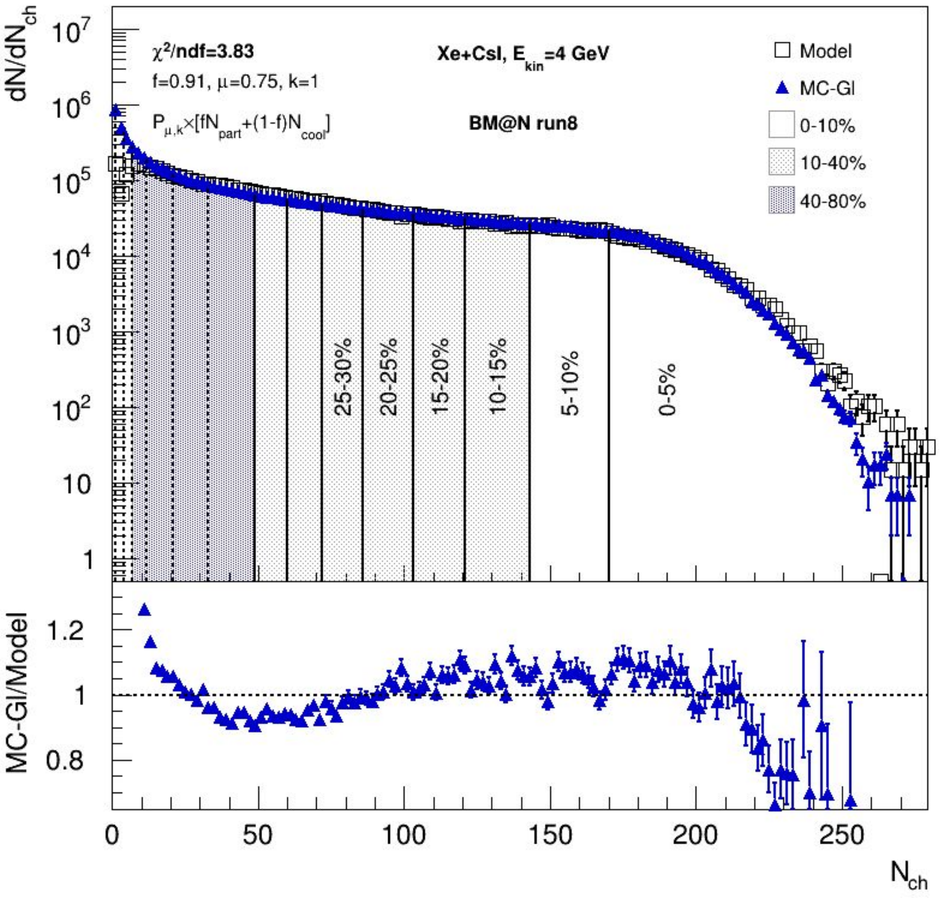
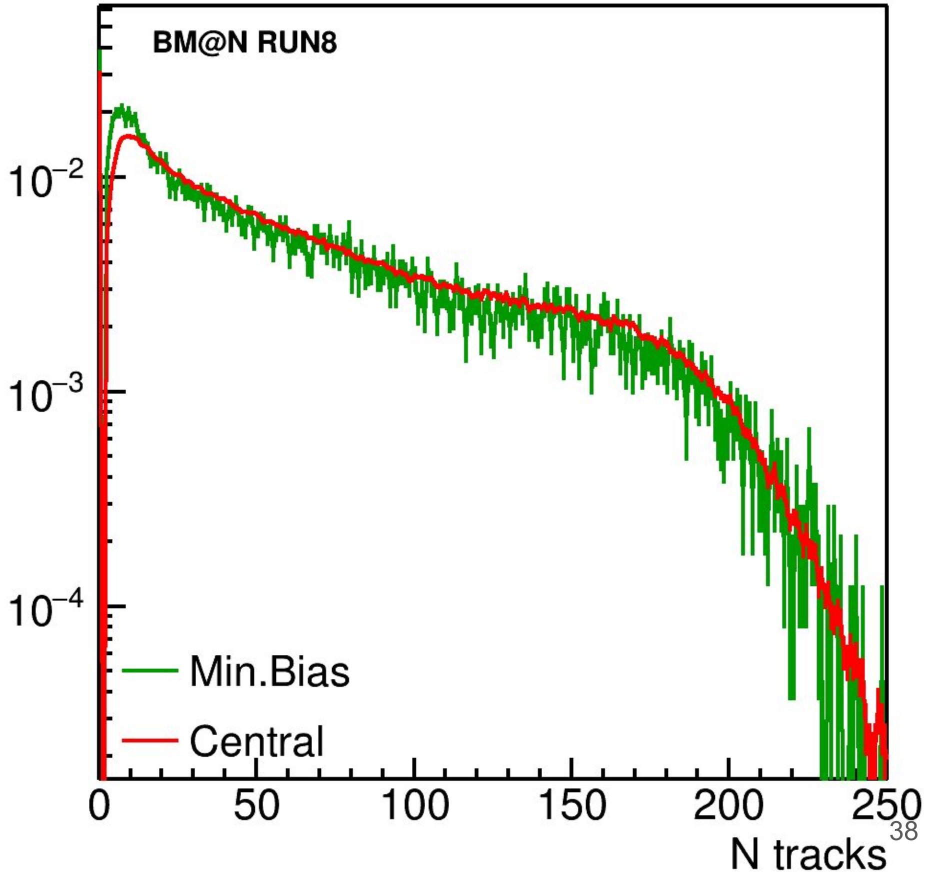
Centrality with MC-Glauber for RUN8

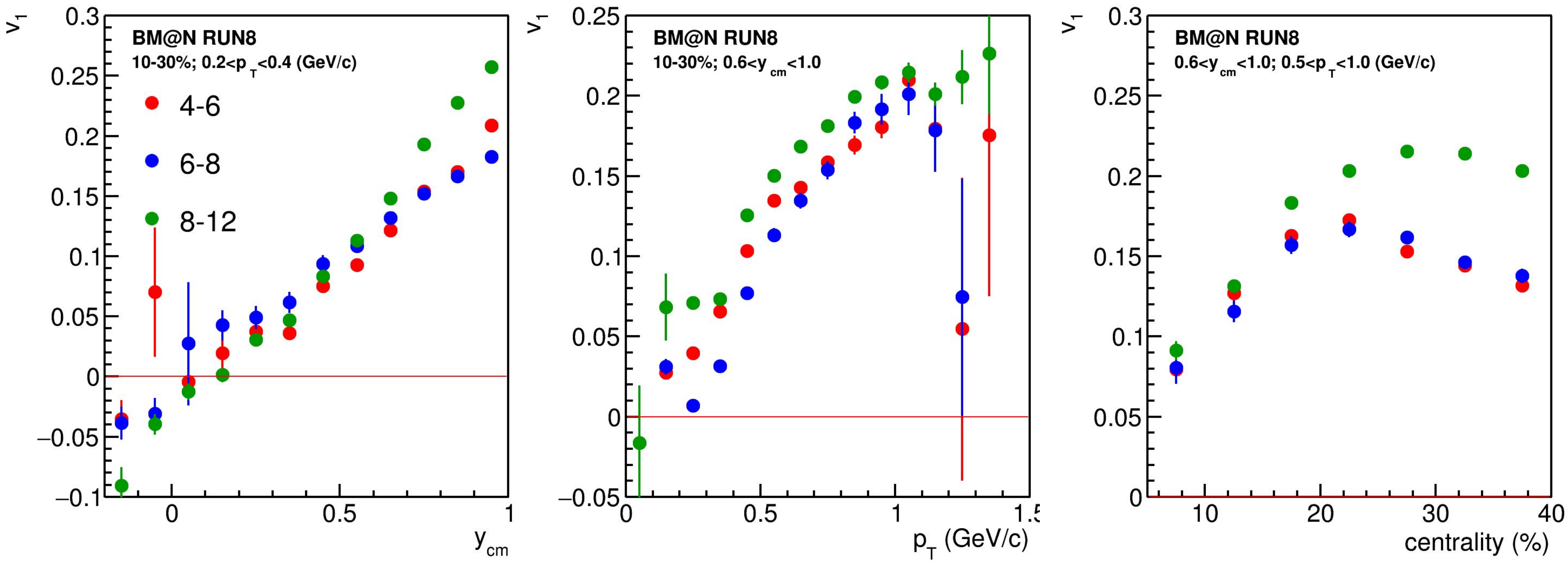


Centrality with MC-Glauber for RUN8

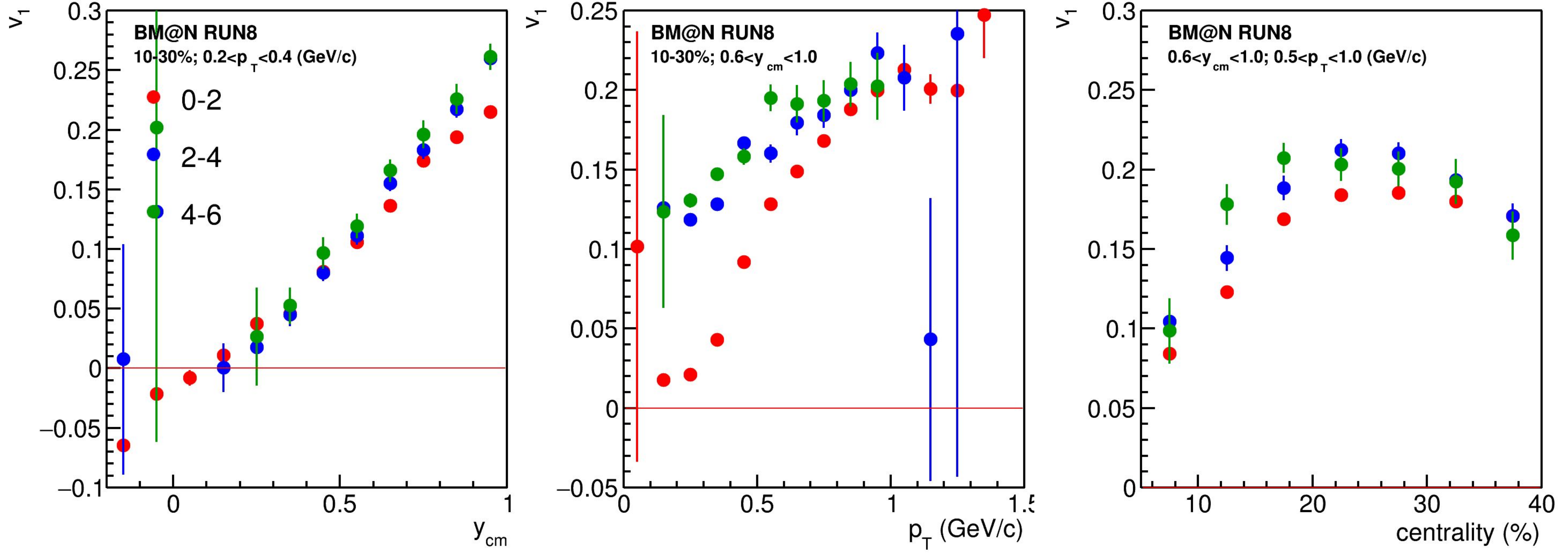




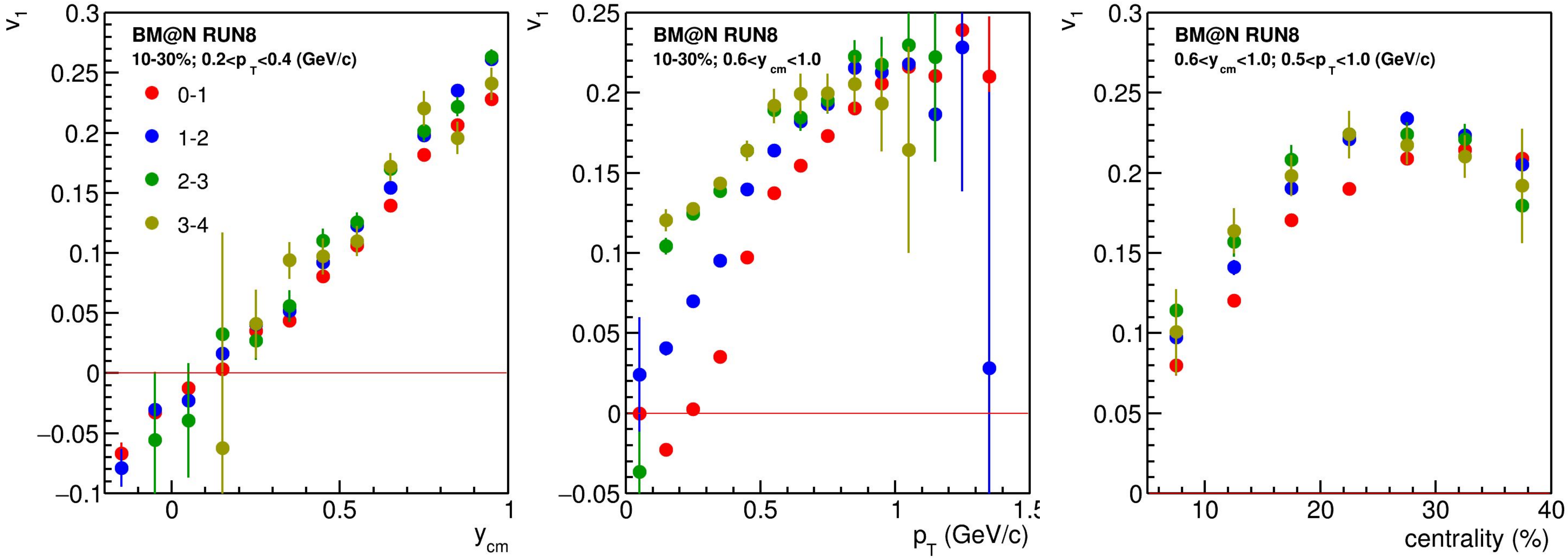
v_1 vs y: Systematic variation due to Nhits-cut



v_1 vs y: Systematic variation due to chi2-cut



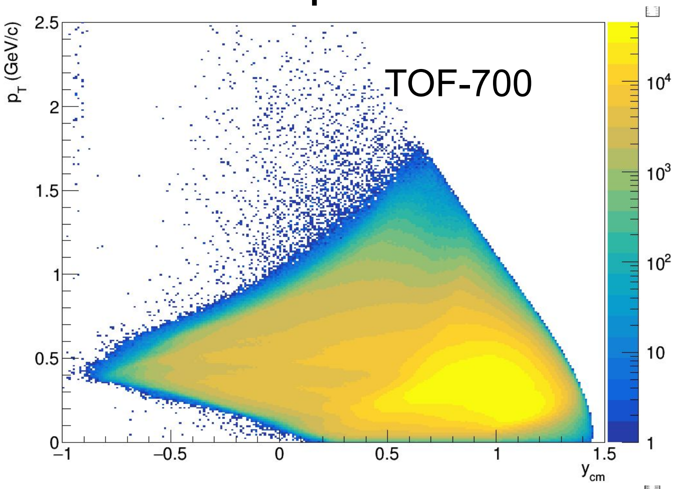
v_1 vs y: Systematic variation due to DCA-cut

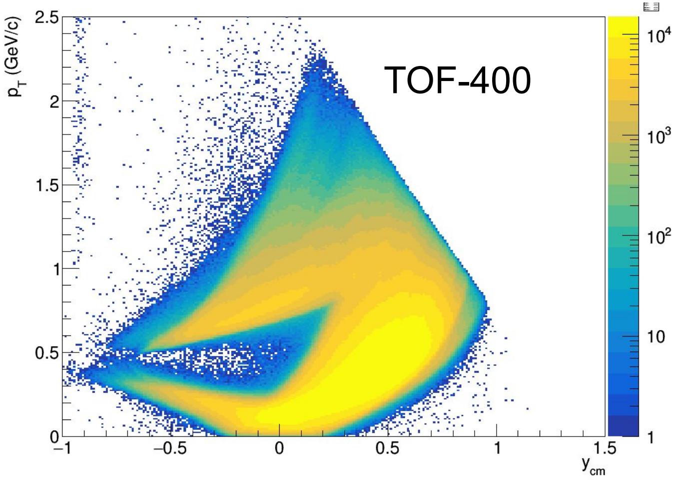


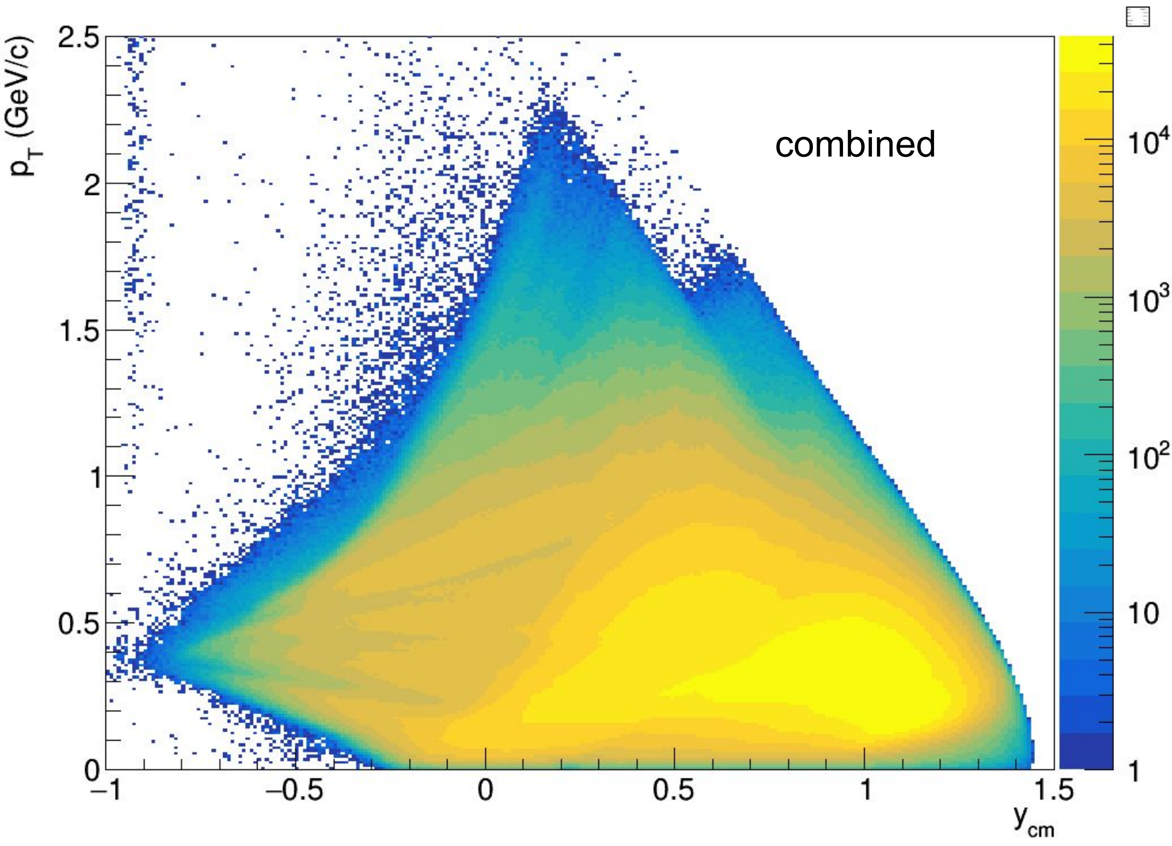
Analysis setup

- The whole L1 production was analysed
- Event selection criteria (~40M events selected)
    - CCT2 trigger
    - 10^4 < Integral BC1 < 4×10^4
    - Number tracks for vertex > 1
- Track selection criteria
    - $\chi^2 < 5$
    - $M_p^2 - 2\sigma < m^2 < M_p^2 + 2\sigma$

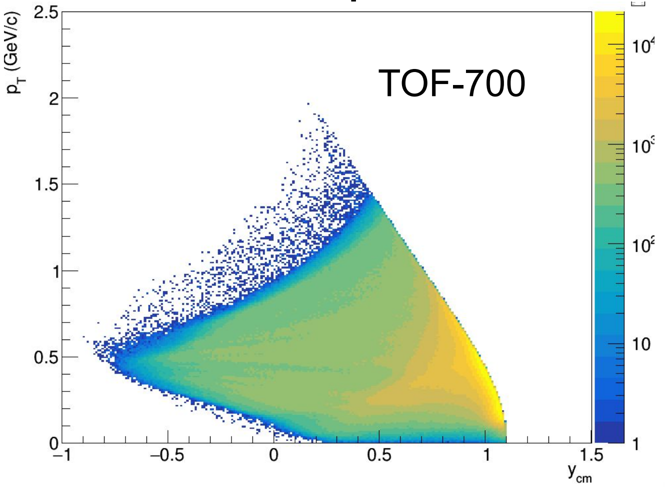
Proton p_T-y acceptance

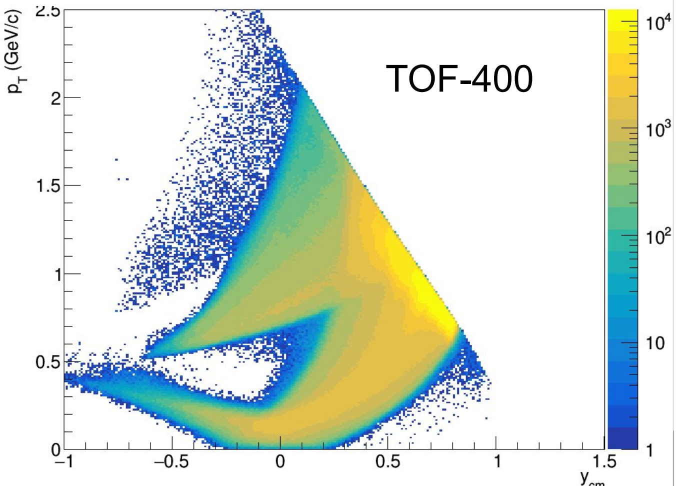


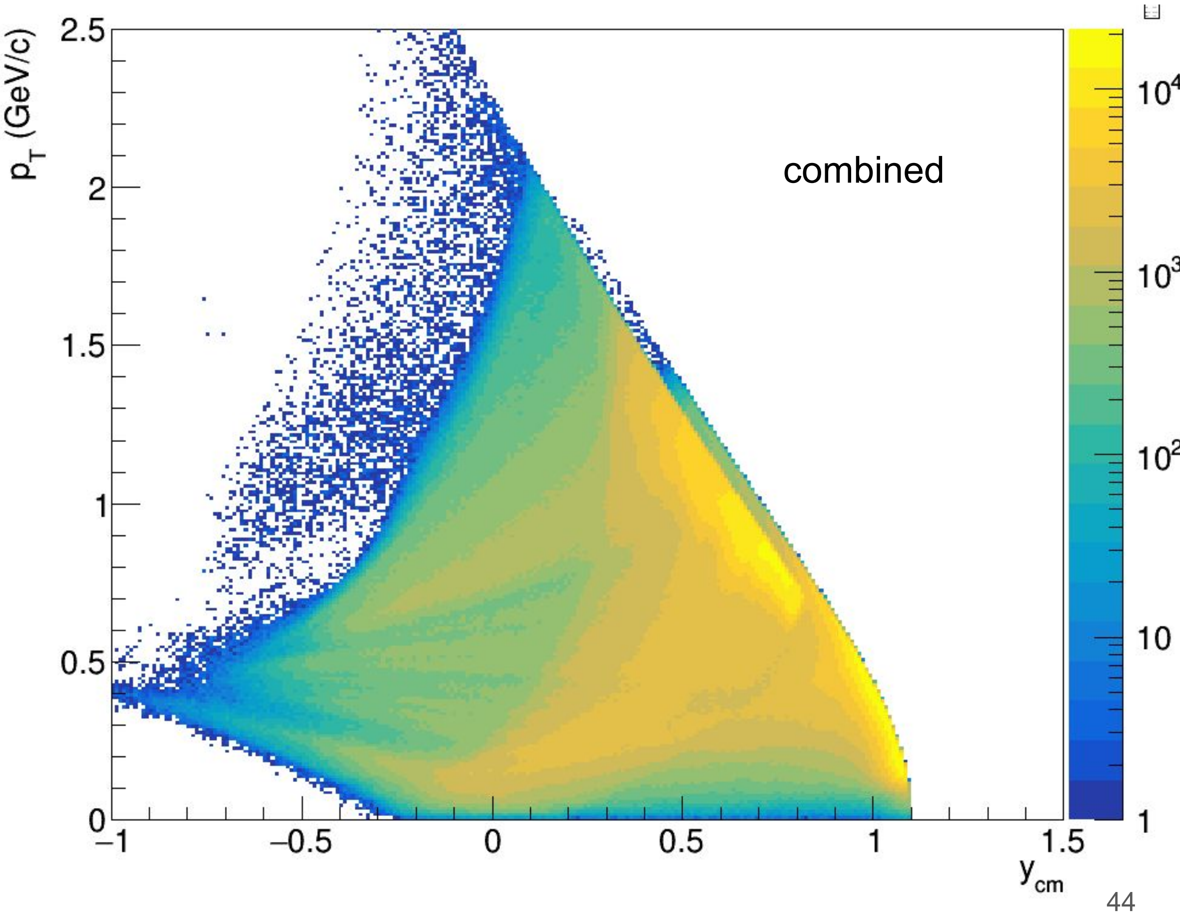




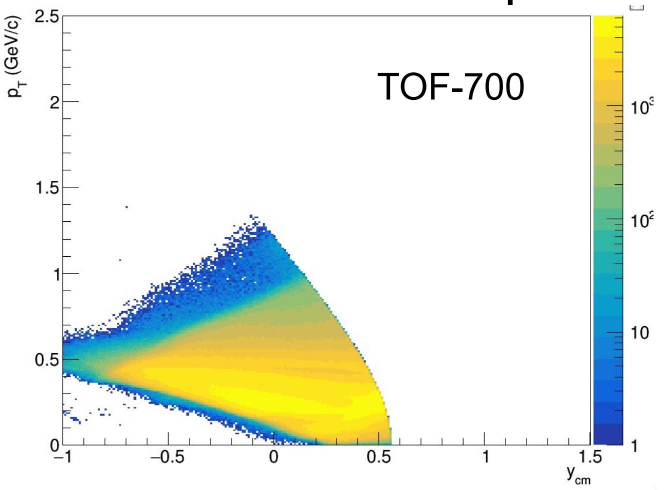
Deutron p_T-y acceptance

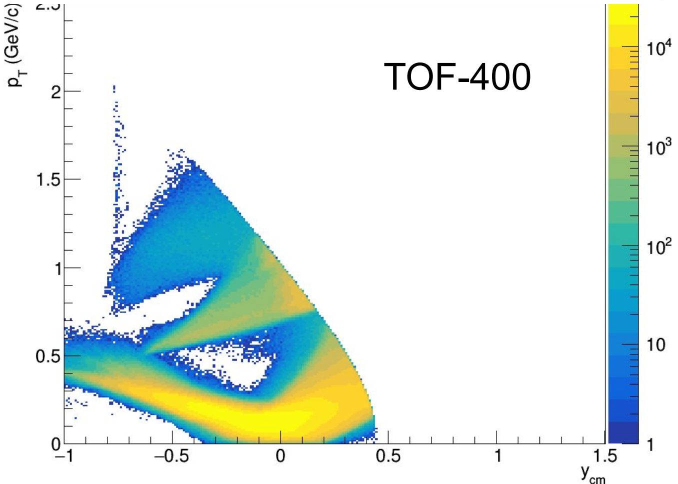


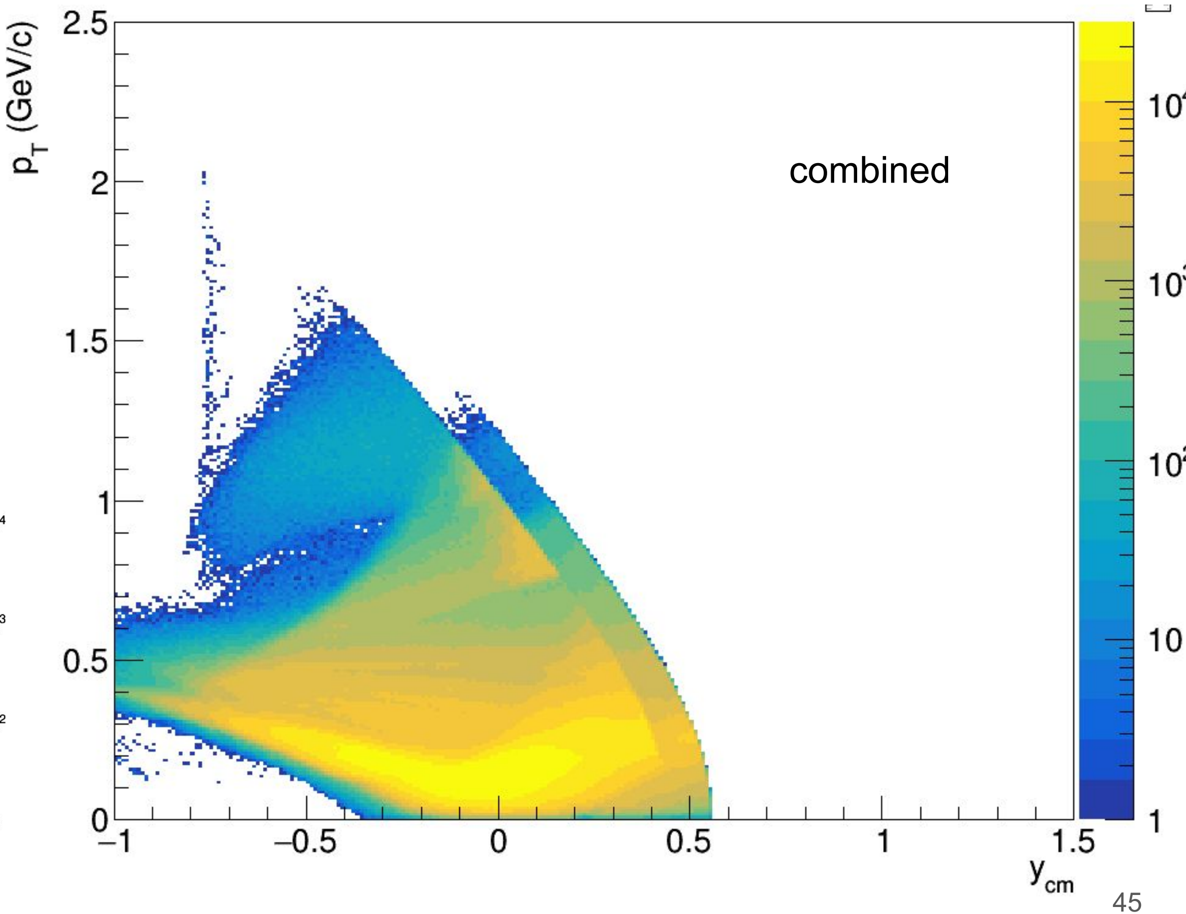




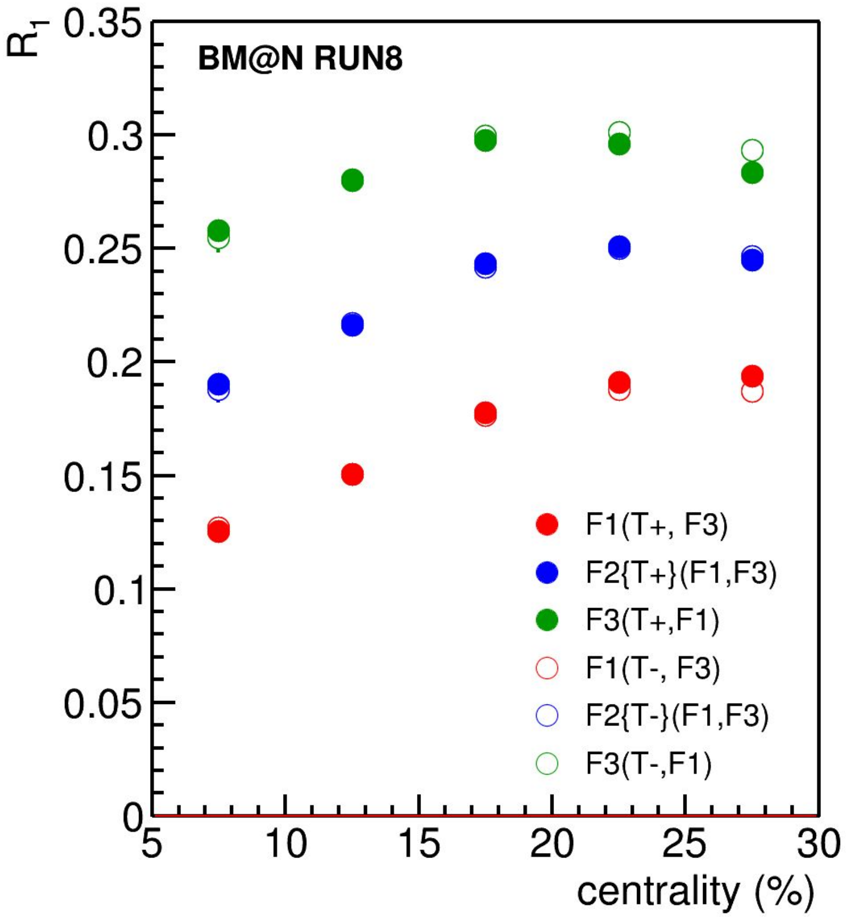
Positive pion p_T-y acceptance

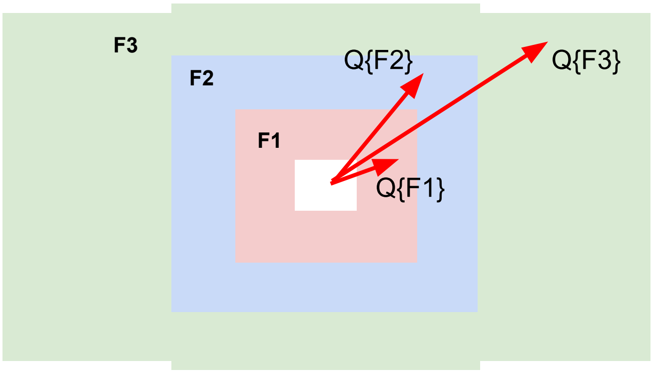






R1: BM@N Run8 DATA: Xe+Cs@3.8A GeV





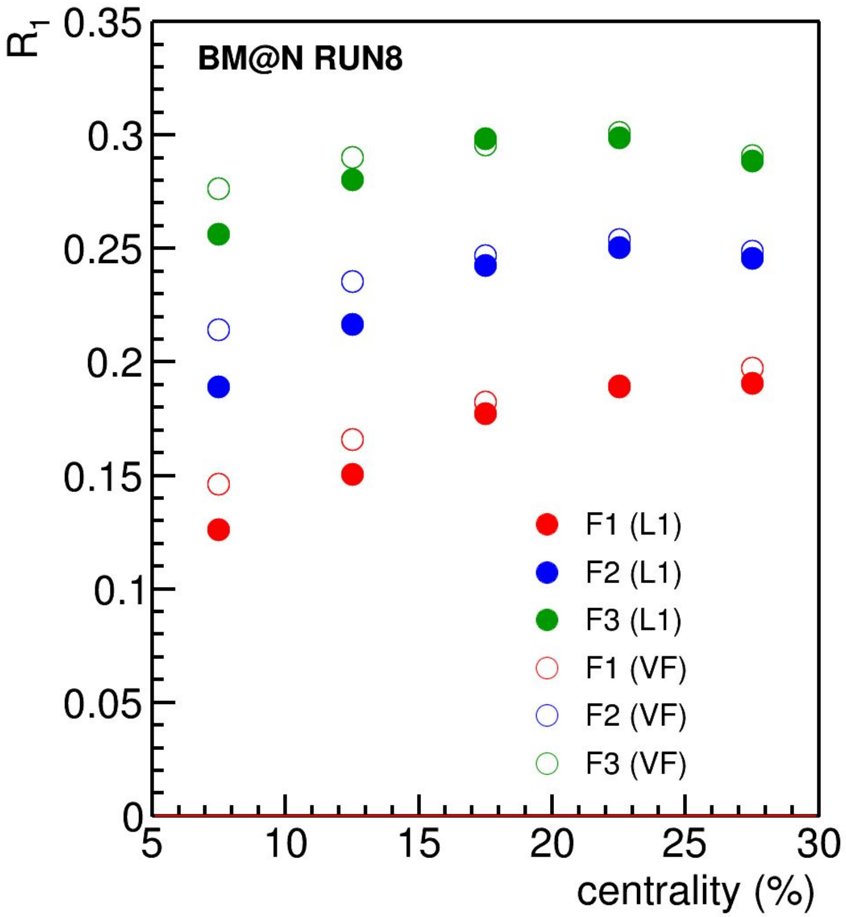
T-: all negatively charged particles with:

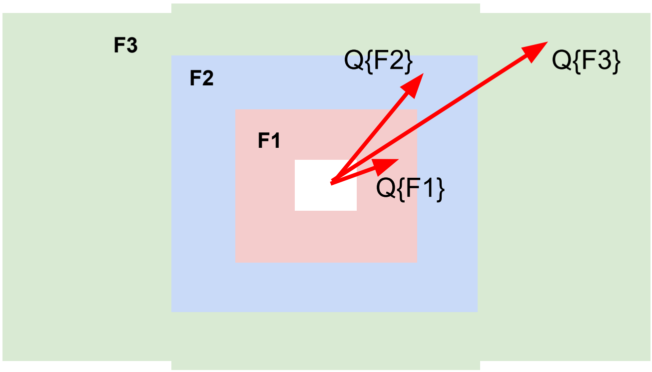
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

T+: all positively charged particles with:

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

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





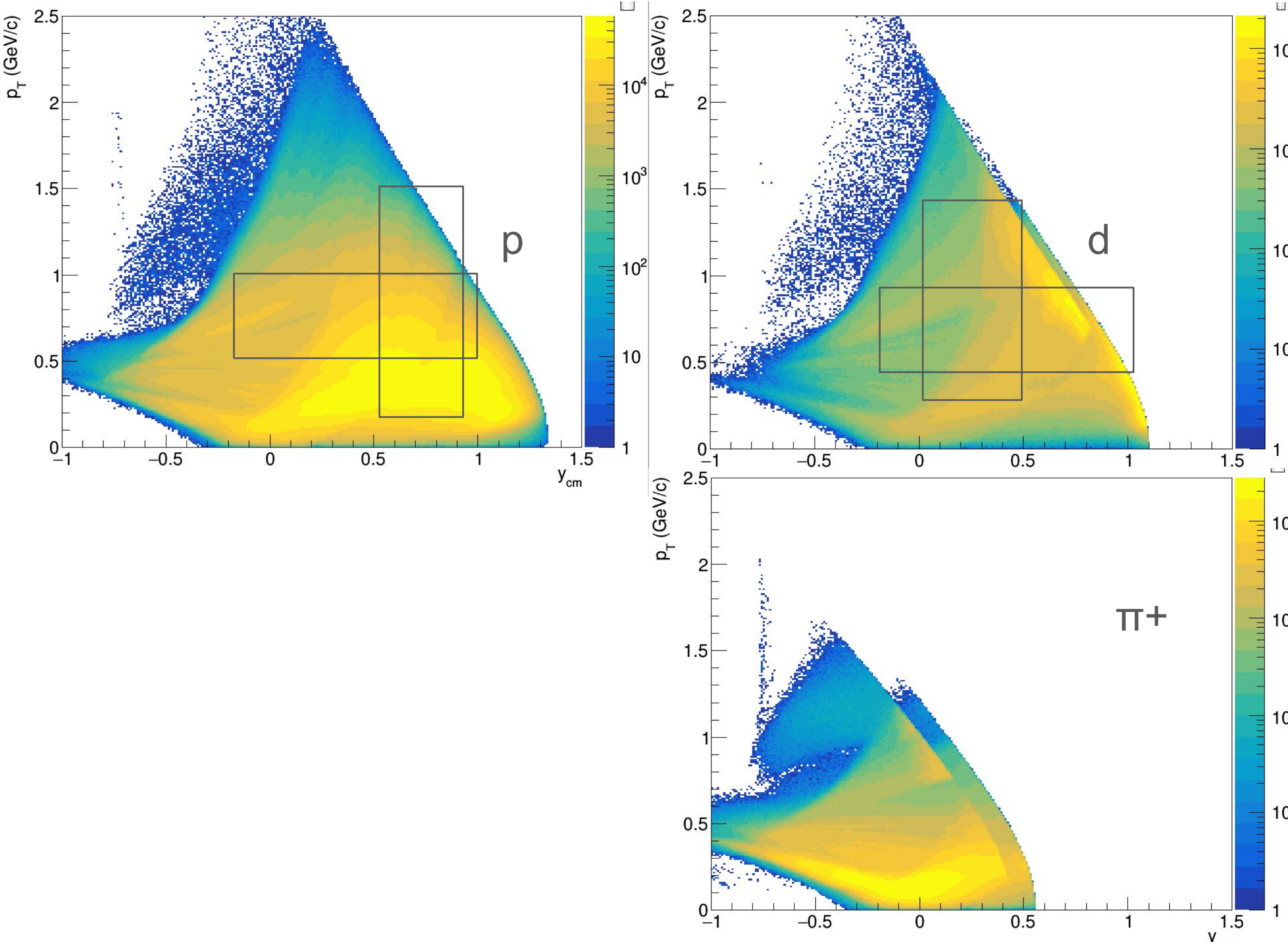
T-: all negatively charged particles with:

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

T+: all positively charged particles with:

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

Difference can be explained by different centrality


p
d
π+
p_T (GeV/c)
y_{cm}
y