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

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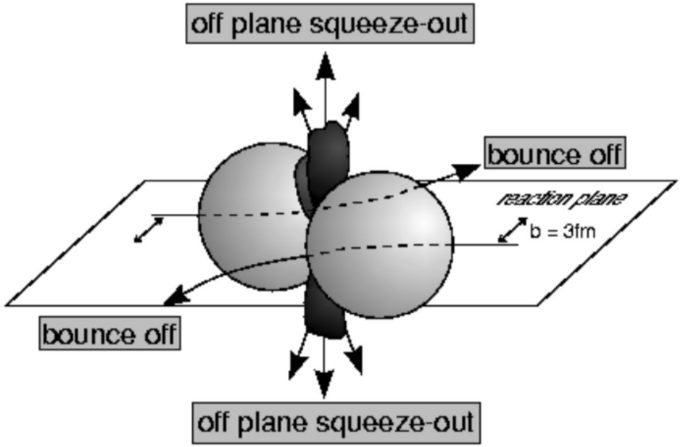
BM@N analysis meeting, 12/03/2023

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:

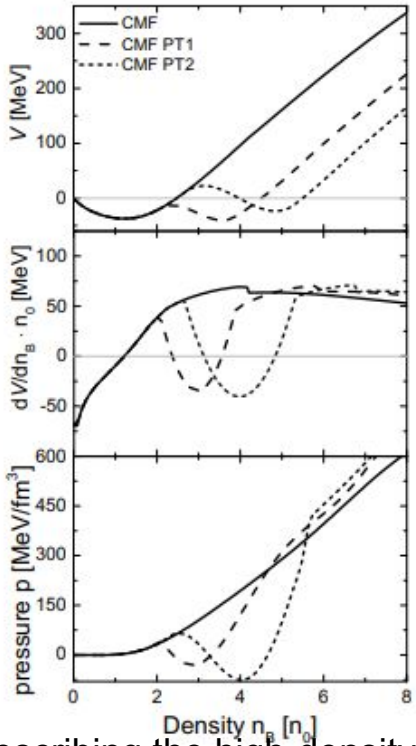
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right] \rangle$$

Anisotropic flow is sensitive to:

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

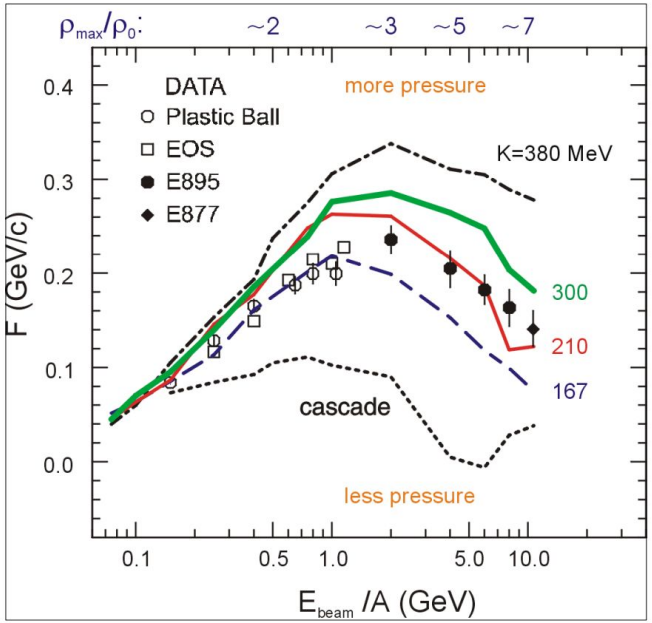
v_n as a function of collision energy

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

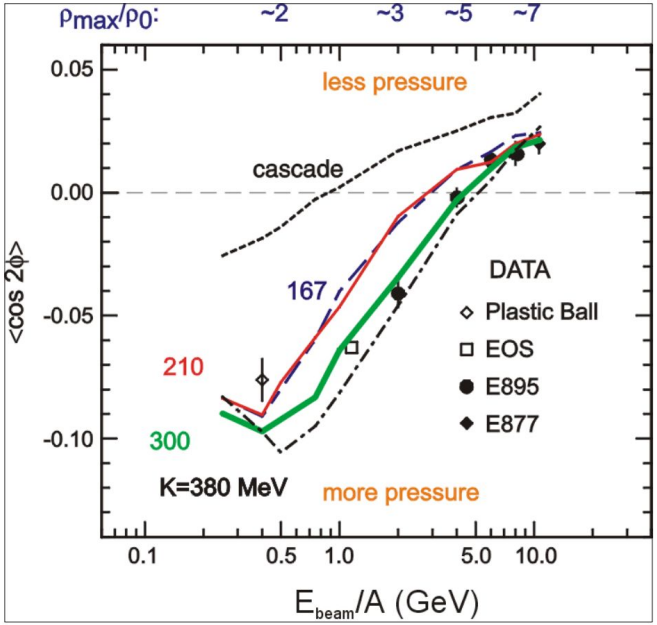


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



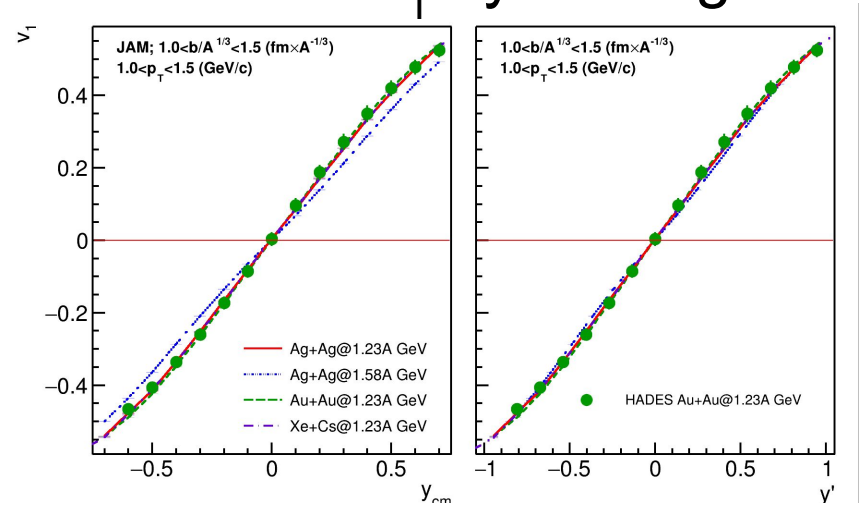
v_2 suggests harder EOS

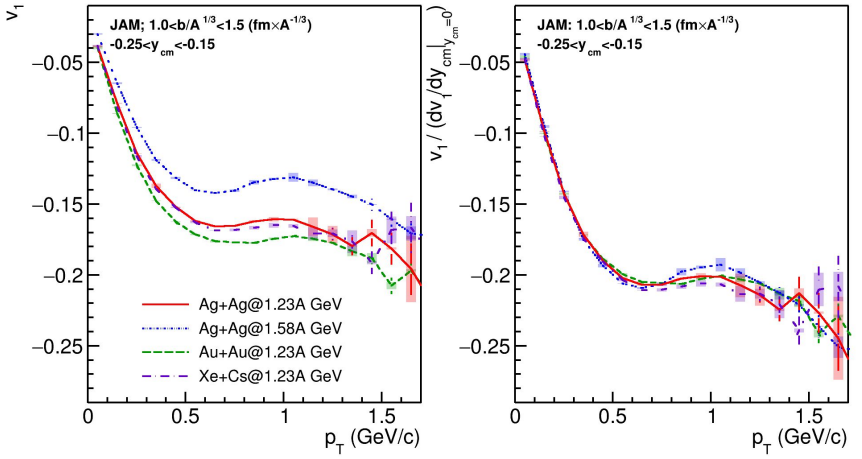


Describing the high-density matter using the mean field
Flow measurements constrain the mean field

Discrepancy is probably due to non-flow correlations

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

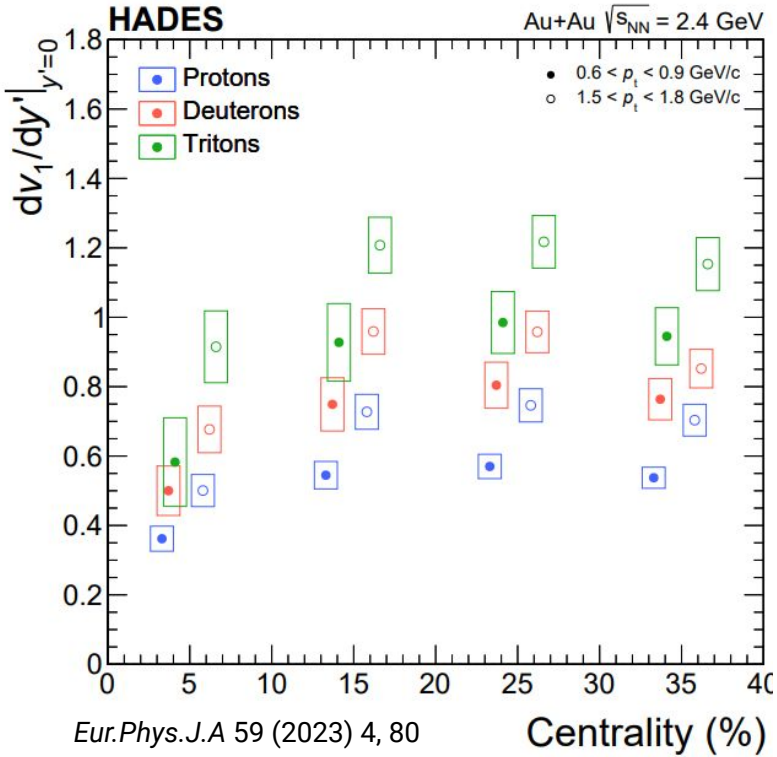




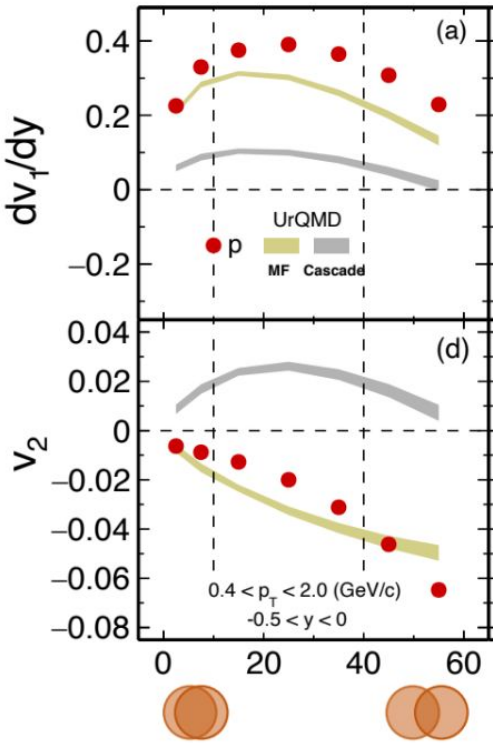
- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

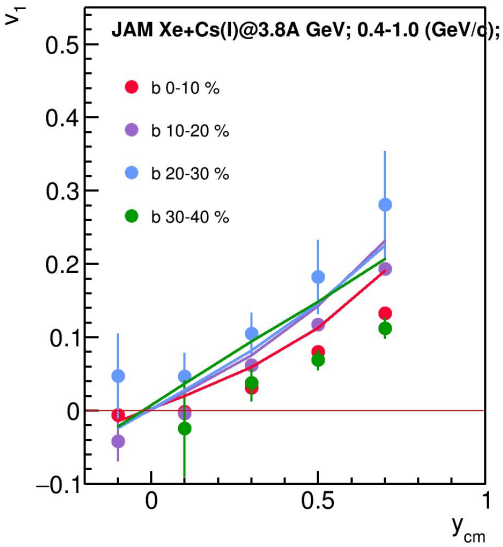
M.Mamaev Particles 2023, 6(2), 622-637

dv_1/dy as a function of centrality



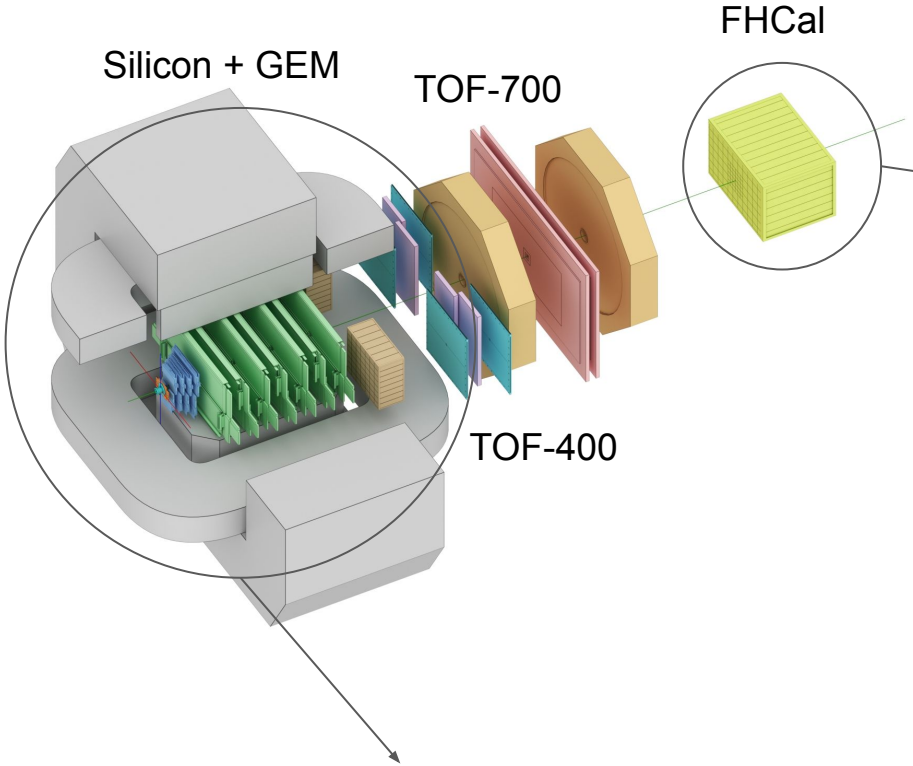
Eur.Phys.J.A 59 (2023) 4, 80

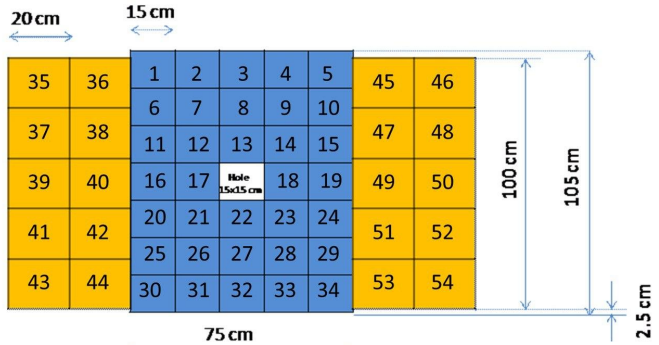


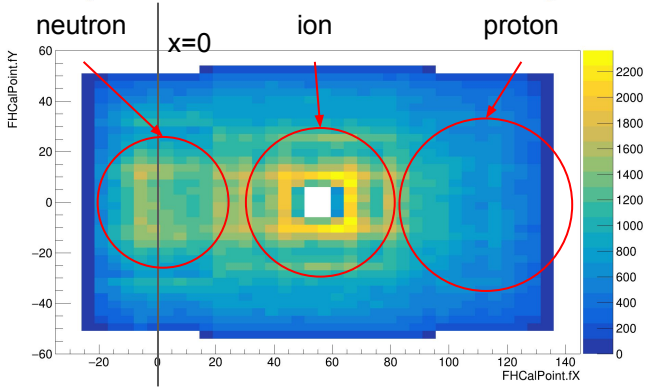


Weak centrality dependence for directed flow

The BM@N experiment (GEANT4 simulation for RUN8)





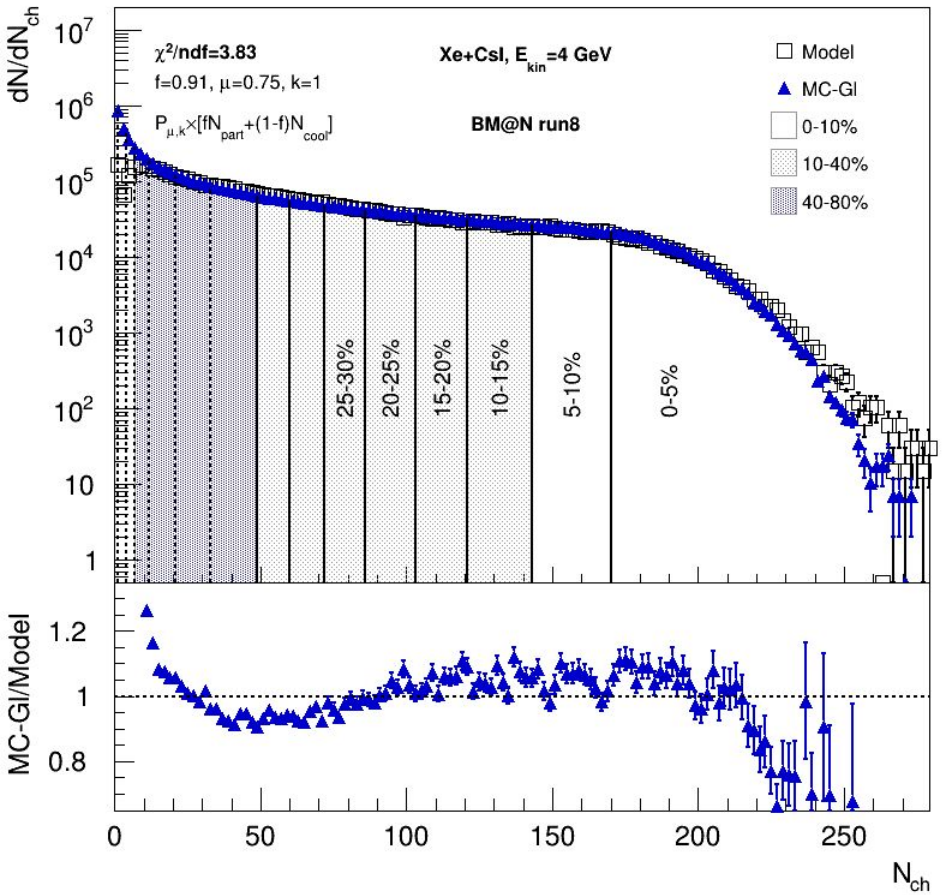


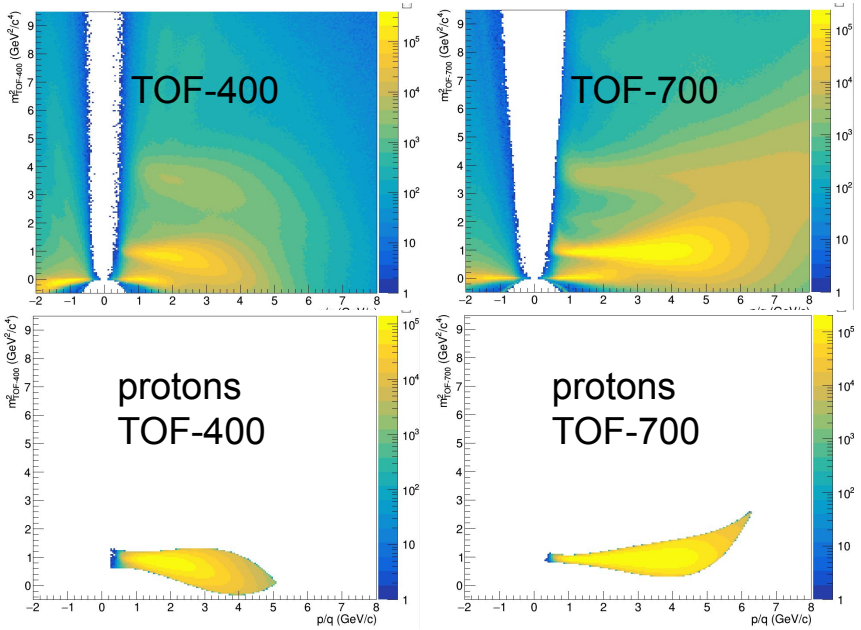
VF tracking was used

The first production was used

Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

Centrality and particle selection





- Half of the recent VF production was analysed
- Event selection criteria (~100M events selected)
  - CCT2 trigger
  - Pile-up cut
  - 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:

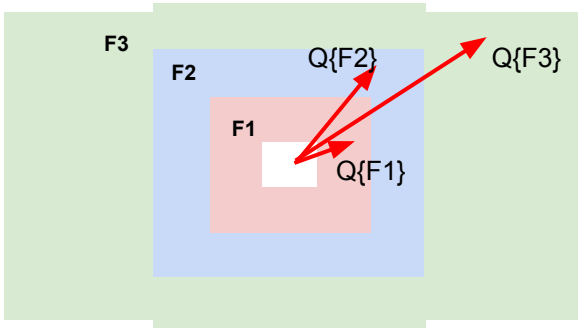
$$u_n = e^{in\phi}$$

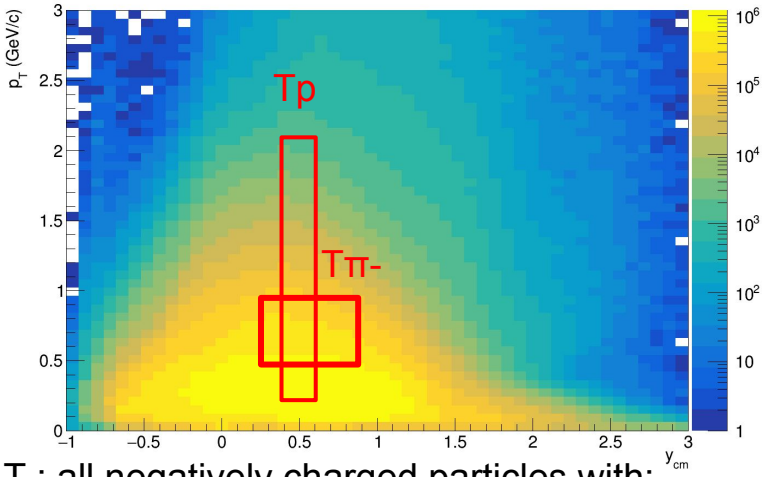
where φ is the azimuthal angle

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:

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

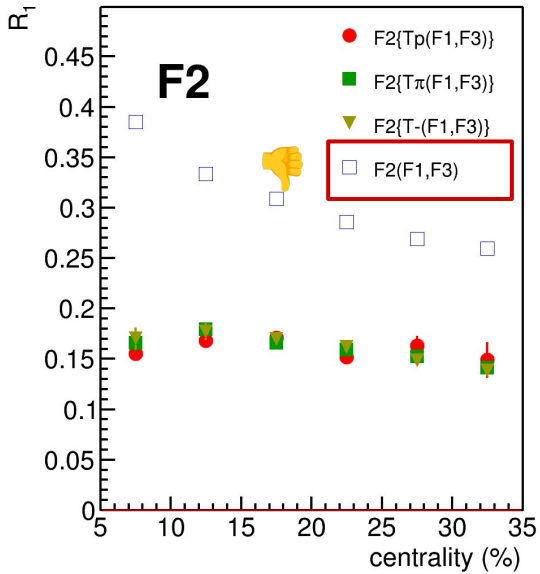
Where R_1 is the resolution correction factor

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

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

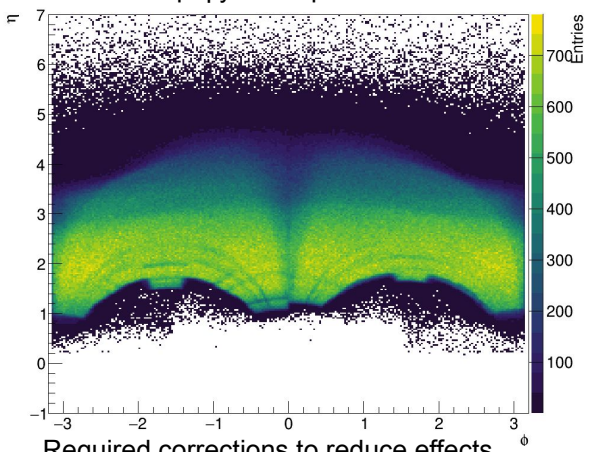


Symbol “F2{Tp}(F1,F3)” means R_1 calculated via (4S resolution):

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

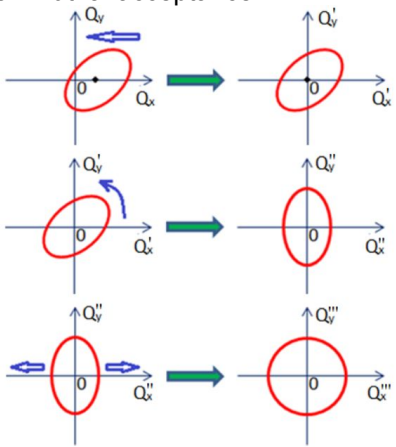
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

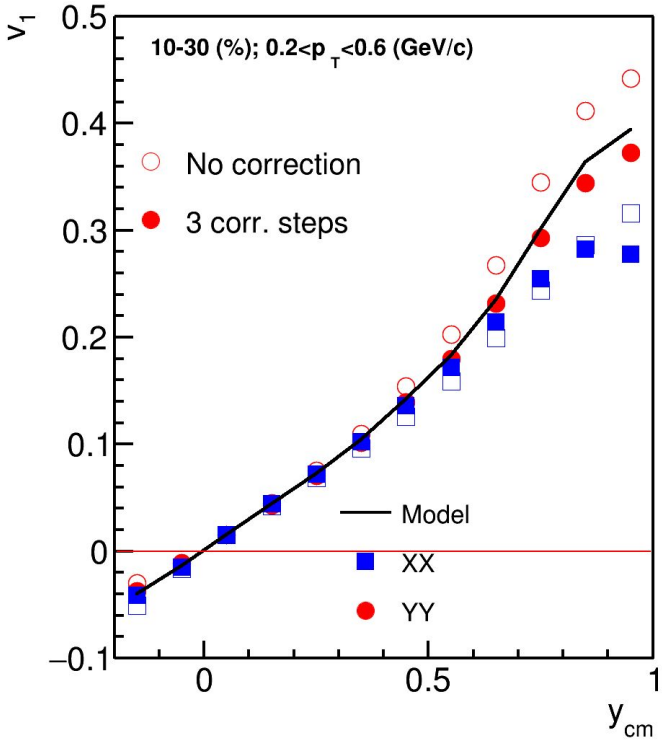


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

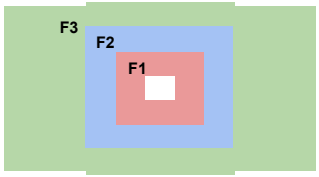


Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)

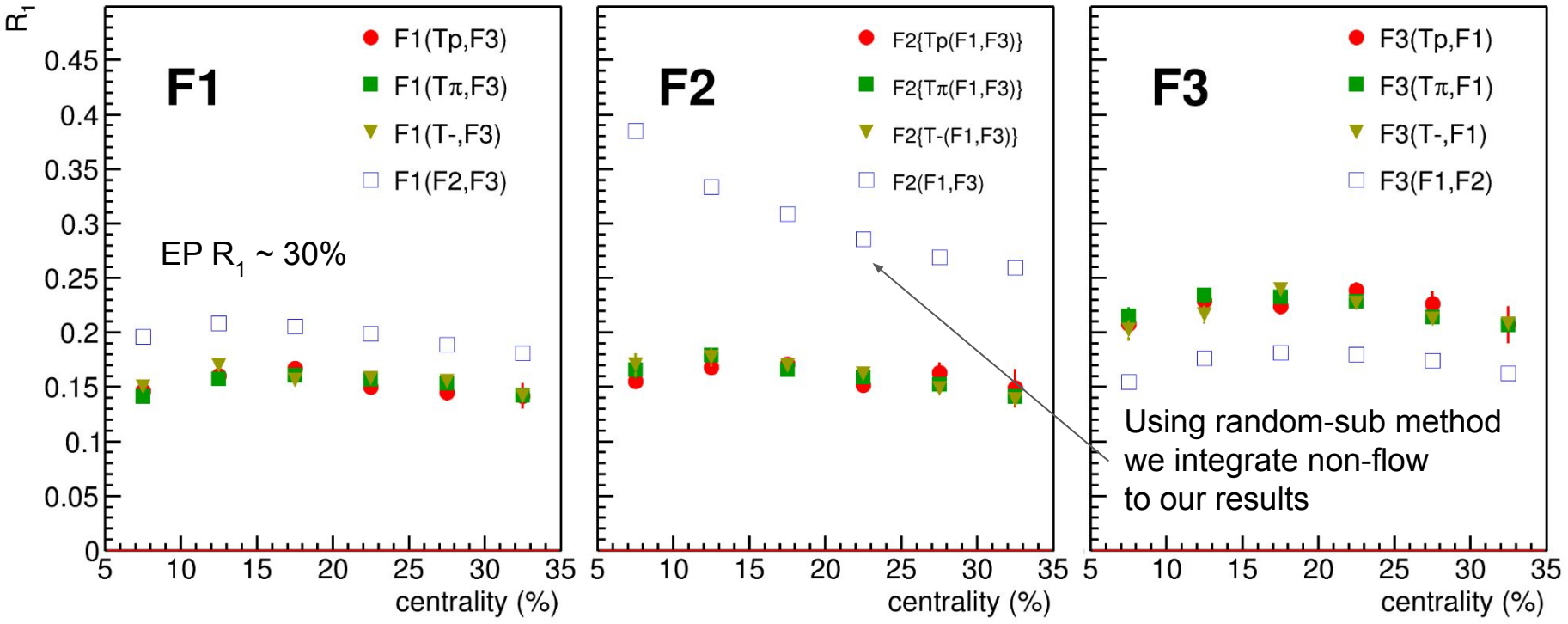


- Better agreement after rescaling for YY
- XX component has too large bias (due to magnetic field)

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

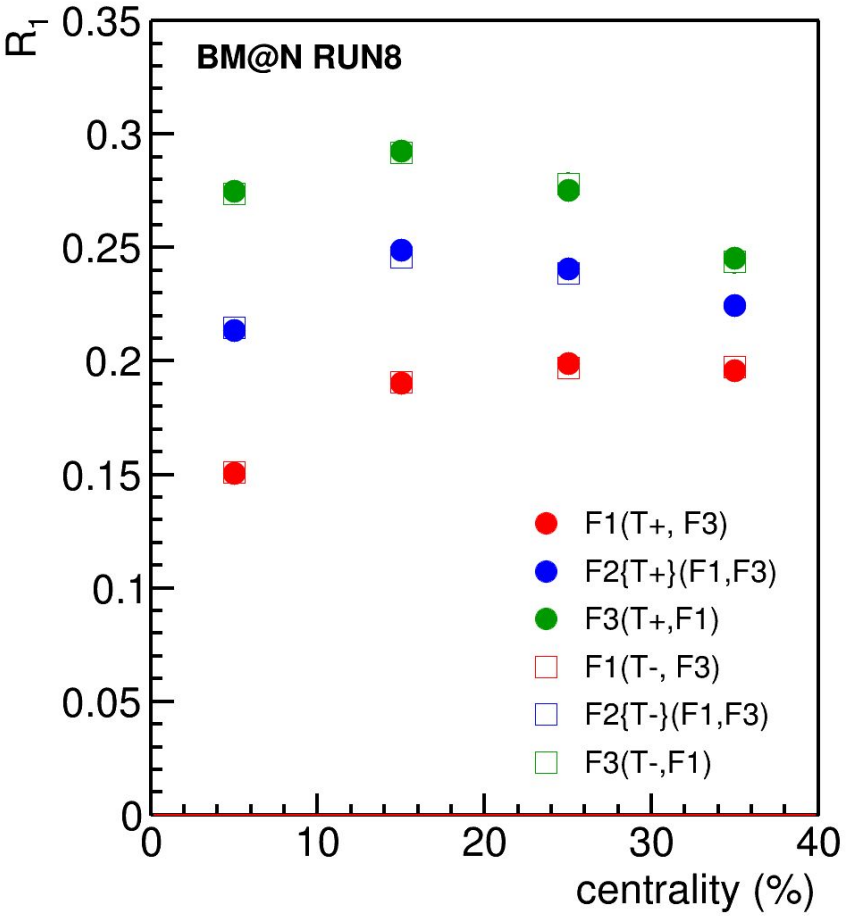


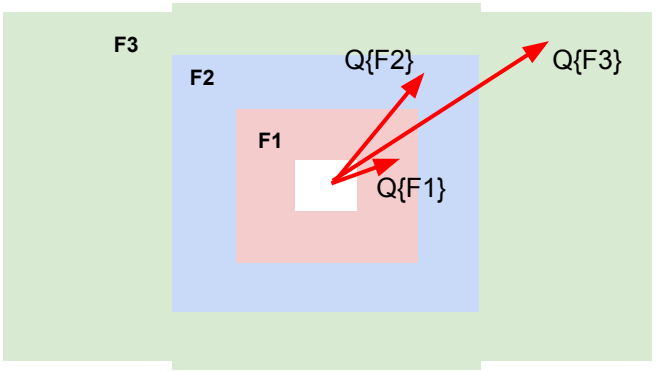
SP gives unbiased estimation of v_n (root-mean-square)
EP gives biased estimation (somewhere between mean and RMS)



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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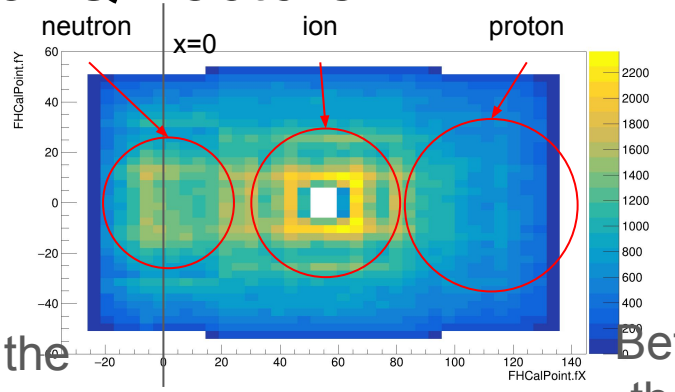
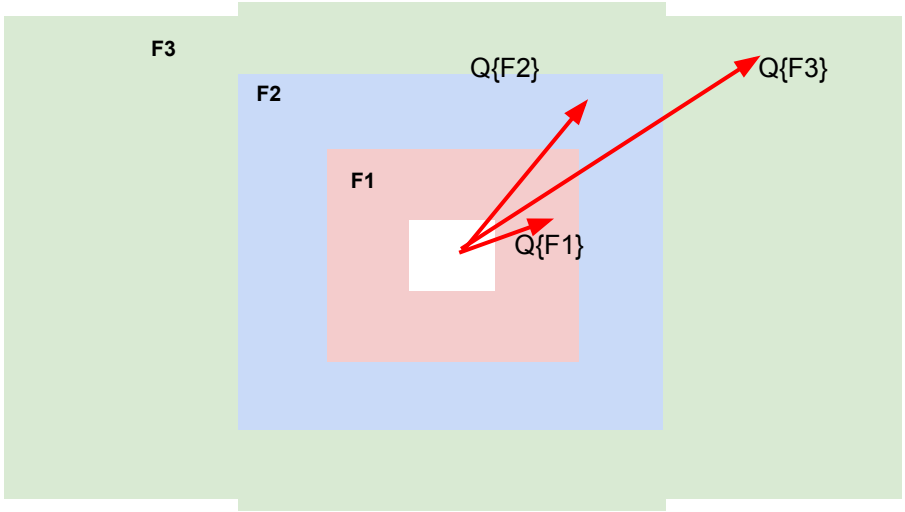
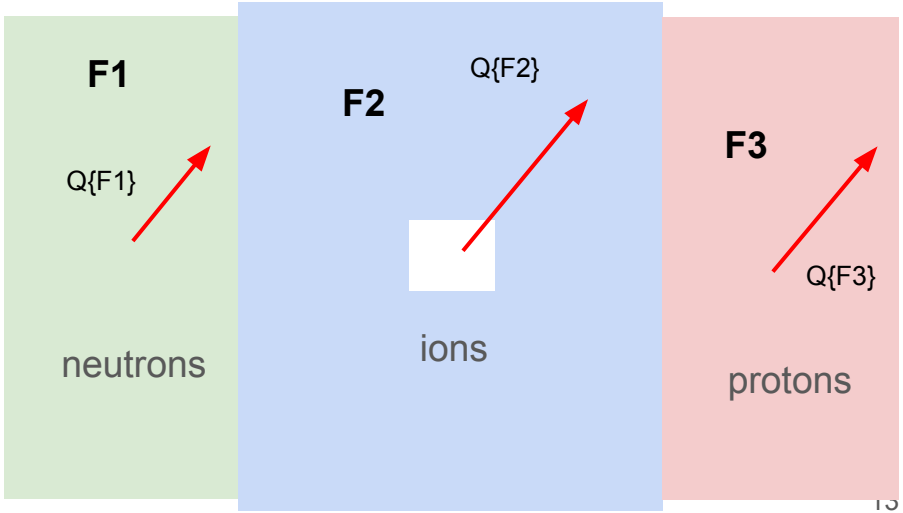
New layout for fhcal Q-vectors



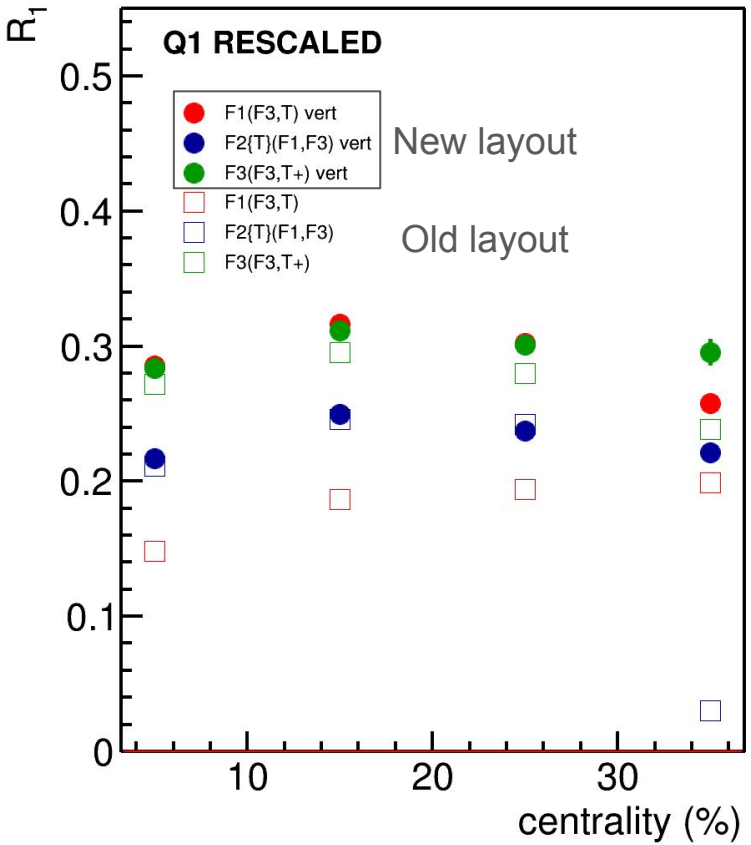
Old
poor coverage of the Y component

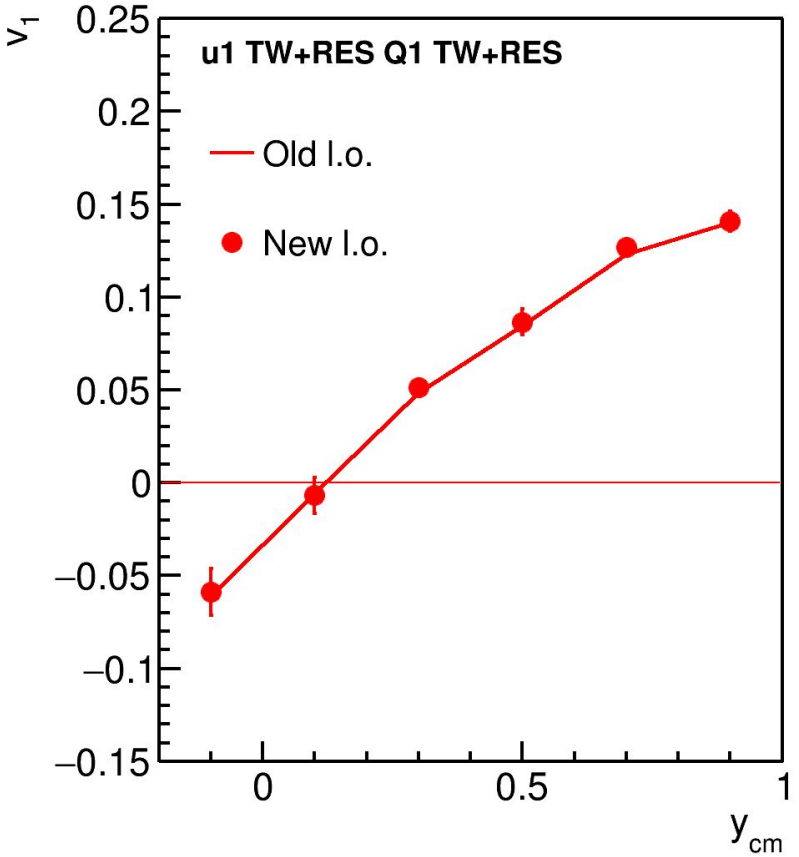
New
Better coverage of the Y component





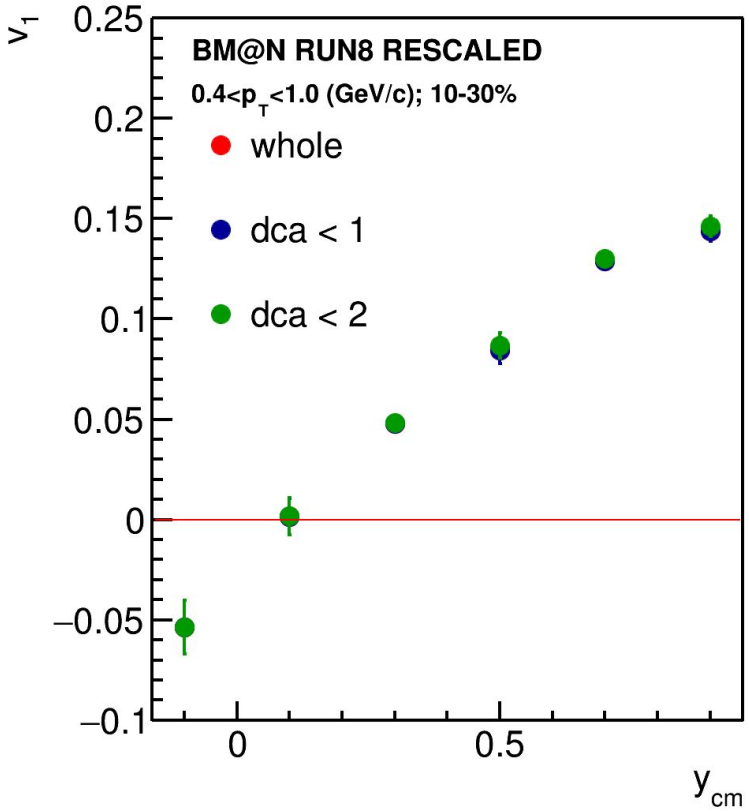
Results for new layout

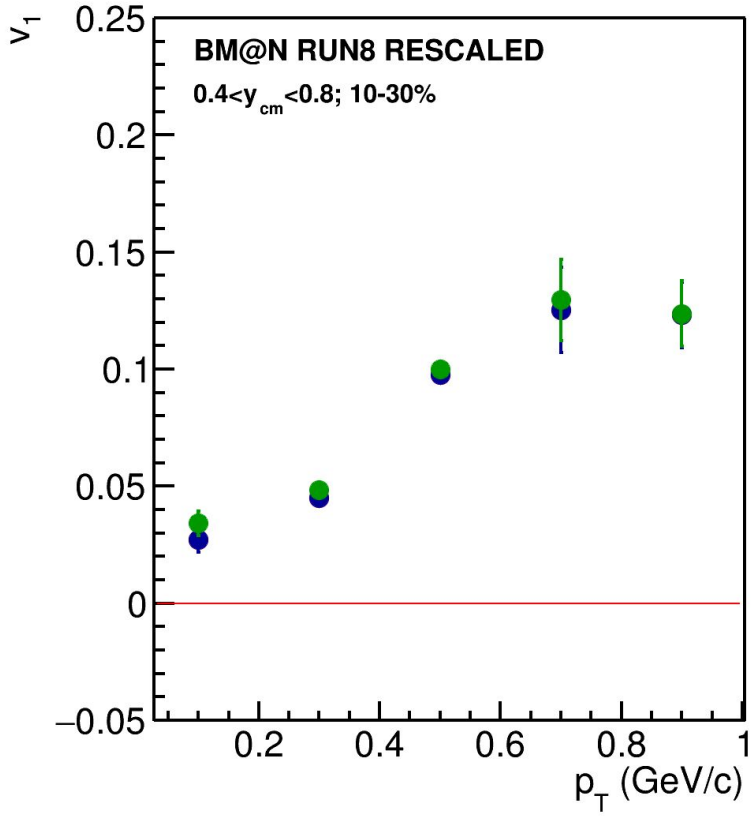




New layout produces larger resolution => less statistics is needed

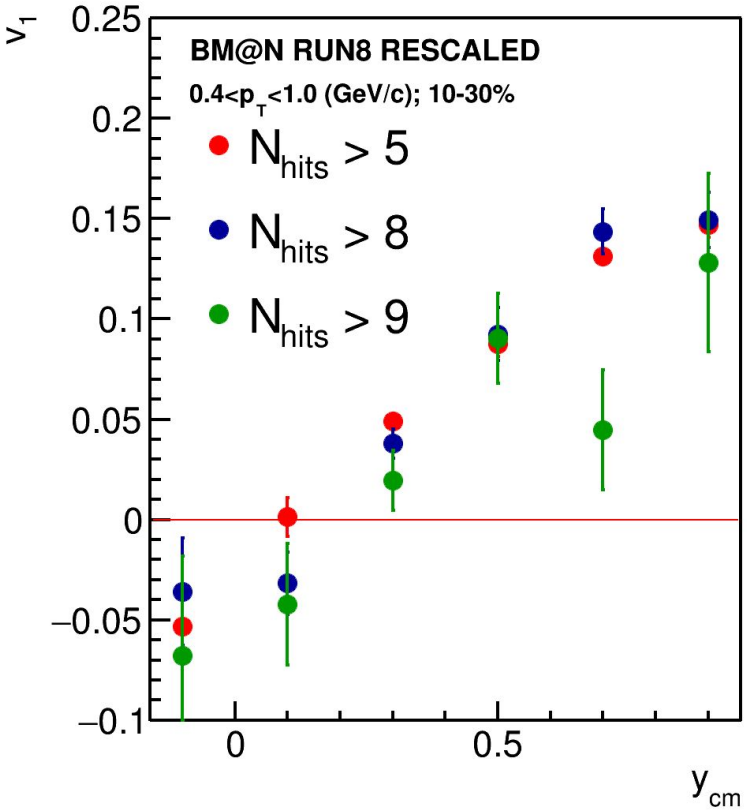
Systematics due to DCA cut

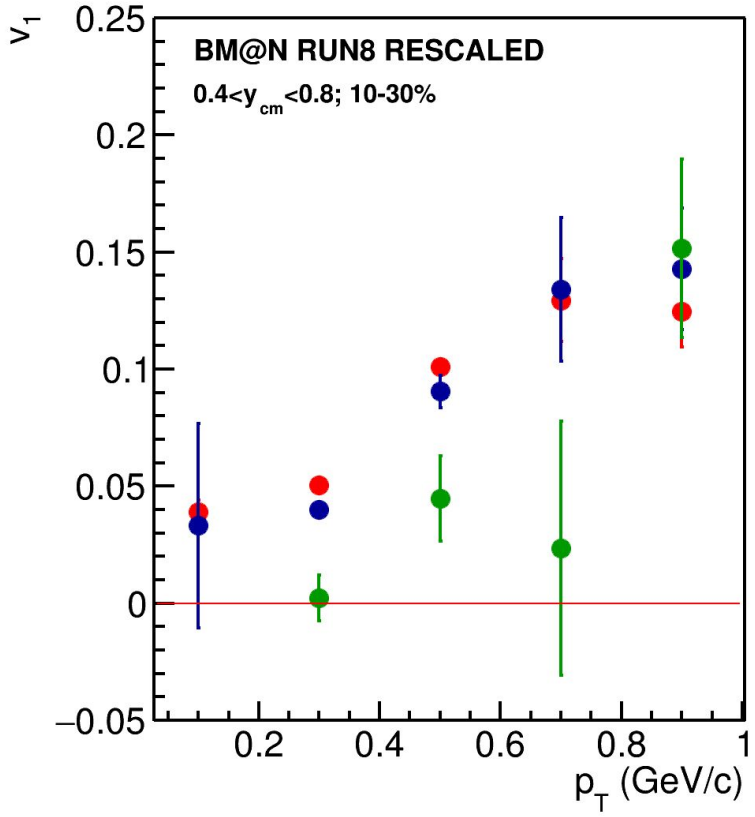




We observe practically no variation due to dca cut => small systematics

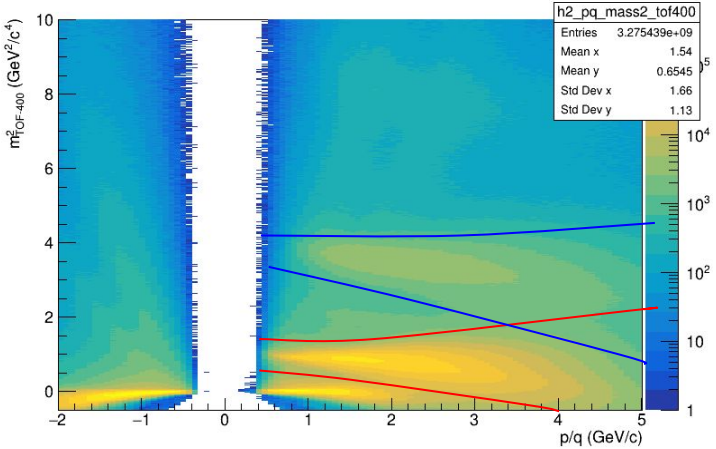
Systematics due to nhits cut



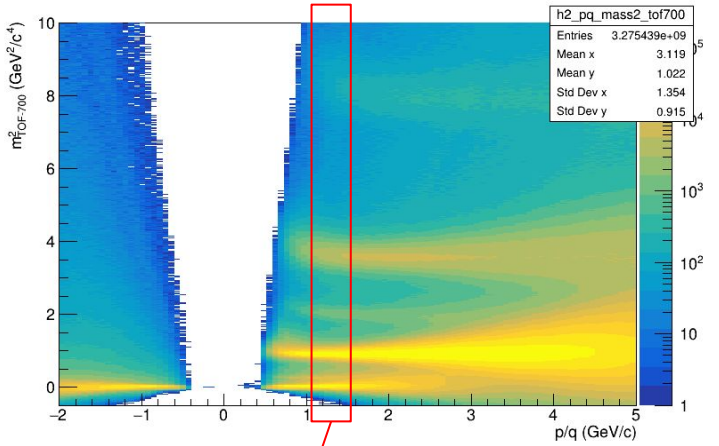


We observe small variation due to Nhits cut => small systematics

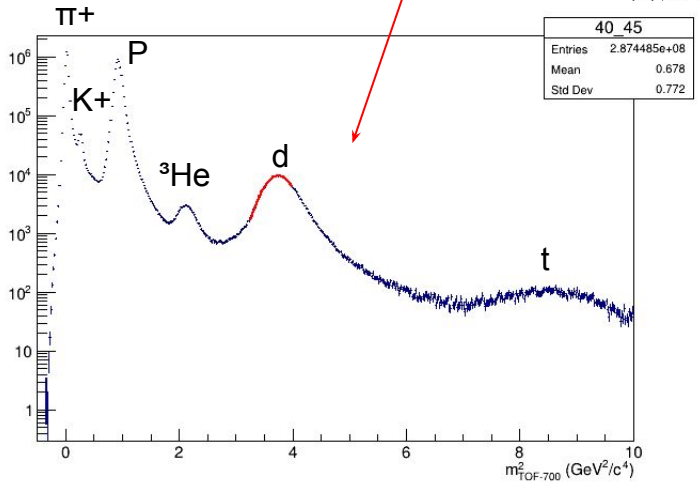
Identification procedure



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



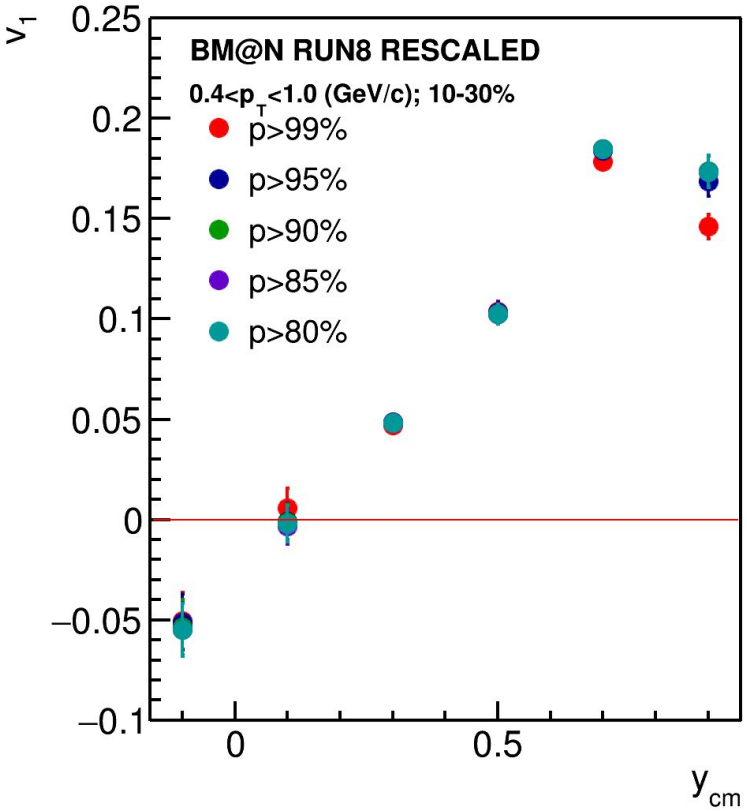
- Mass squared distribution is fitted in narrow bins of p/q
- Protons, pions, deuterons, tritons and helium are fitted

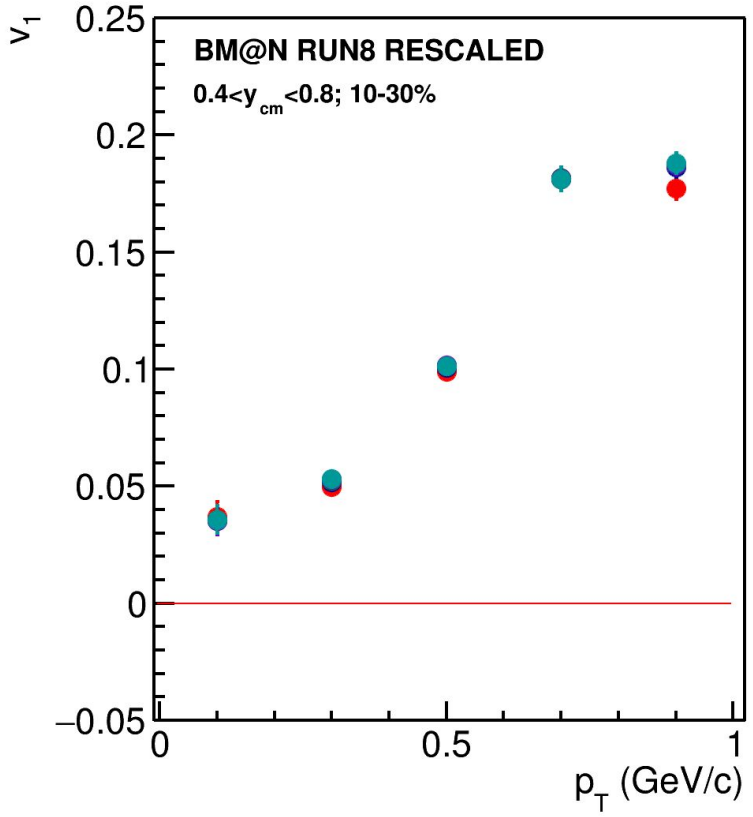


Purity is the function showing possible contamination

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

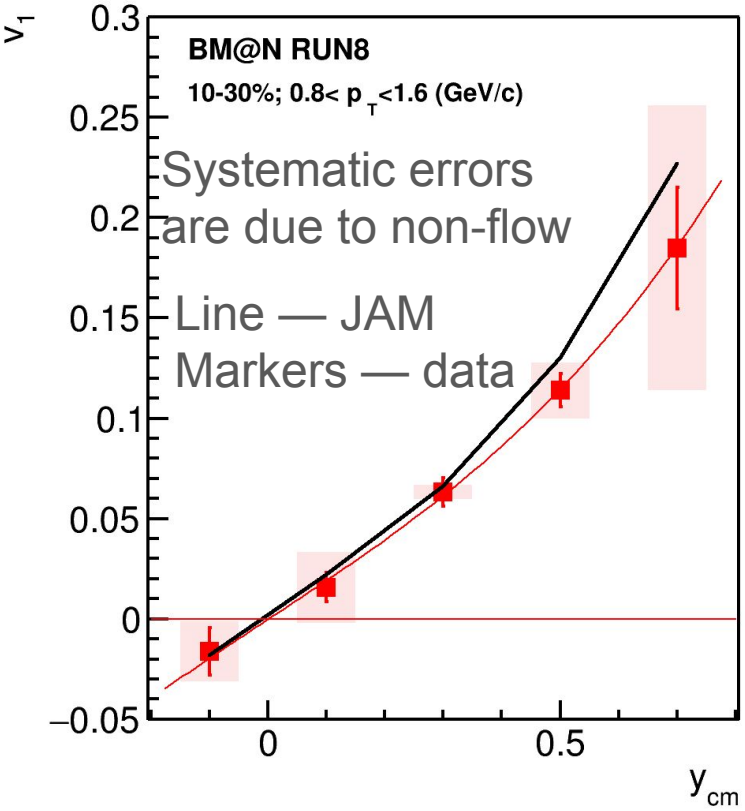
Systematics due to identification

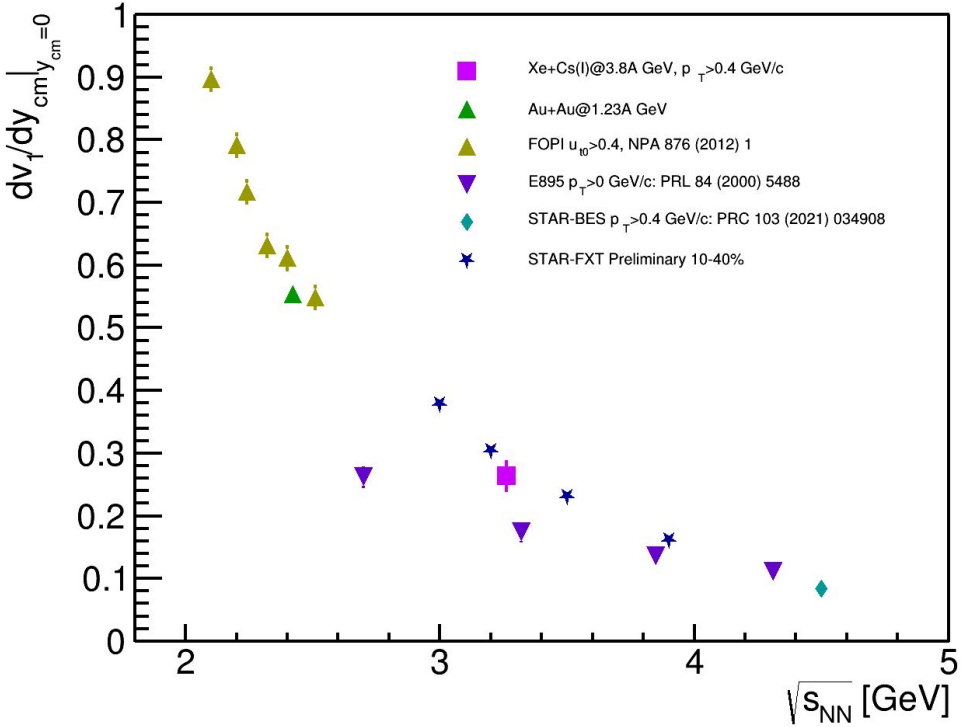




We observe small variation due to cut on purity => small systematics

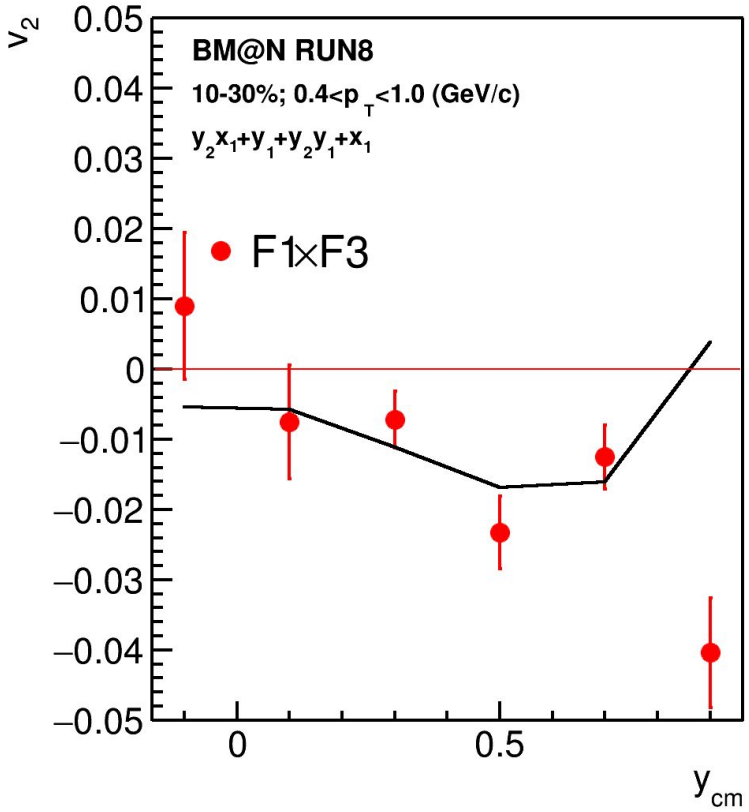
v_1 as a function of pT and y (systematics due to non-flow)

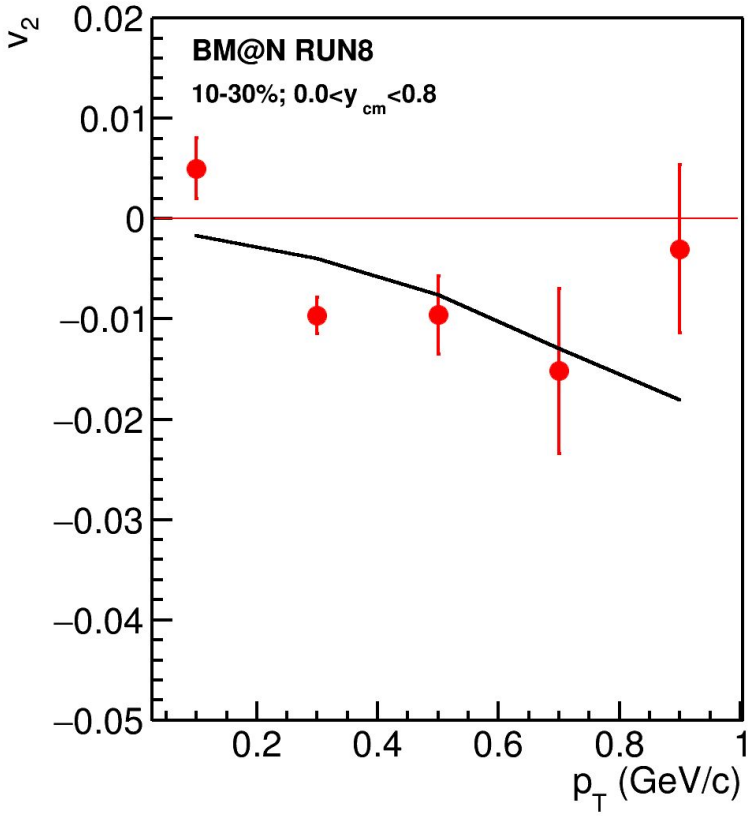




JAM model reproduces the y-dependence of v_1 for larger p_T

v_2 as a function of pT and y (systematics due to non-flow)



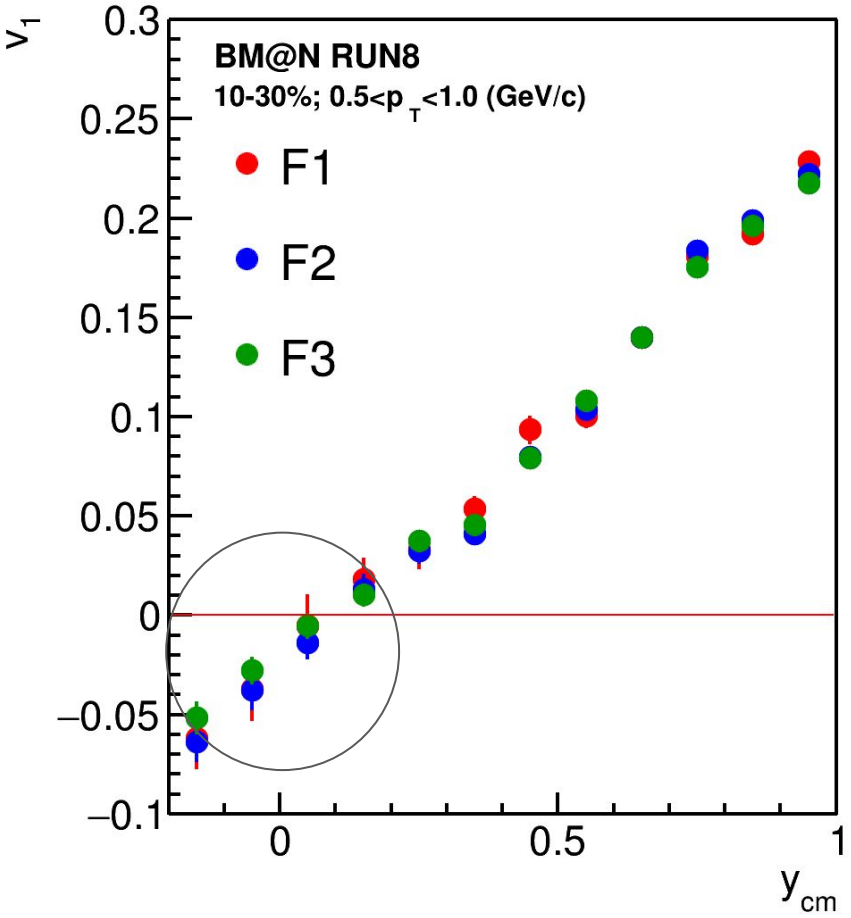


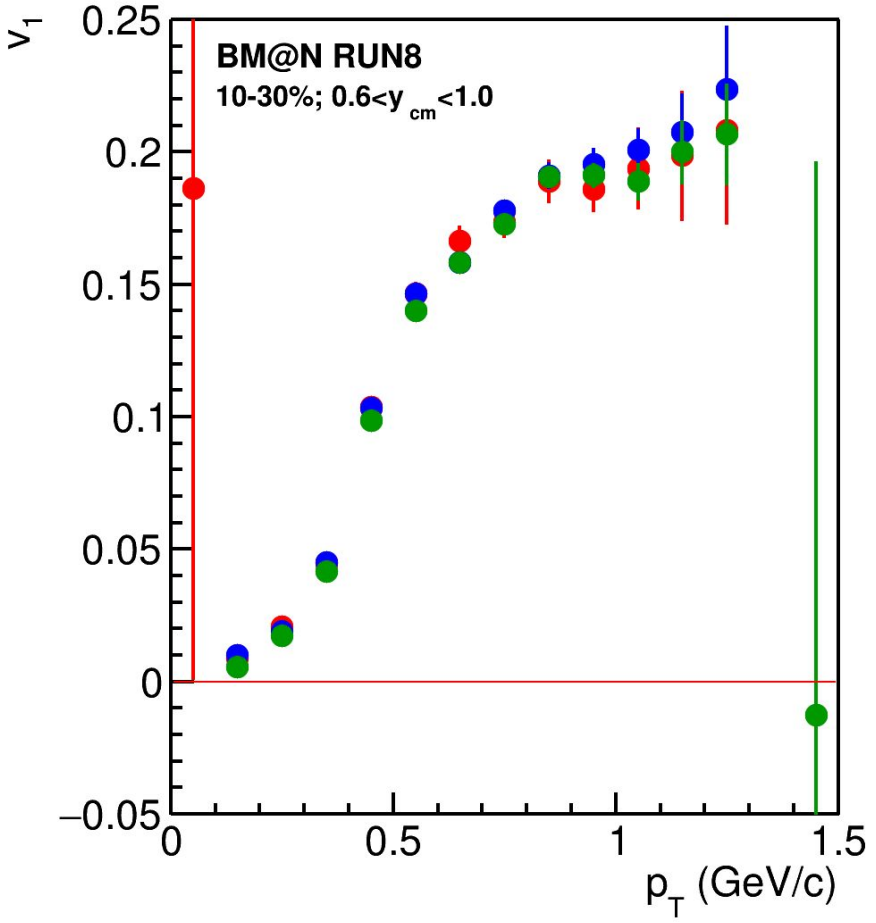
Half of all the available systematics was used

Summary

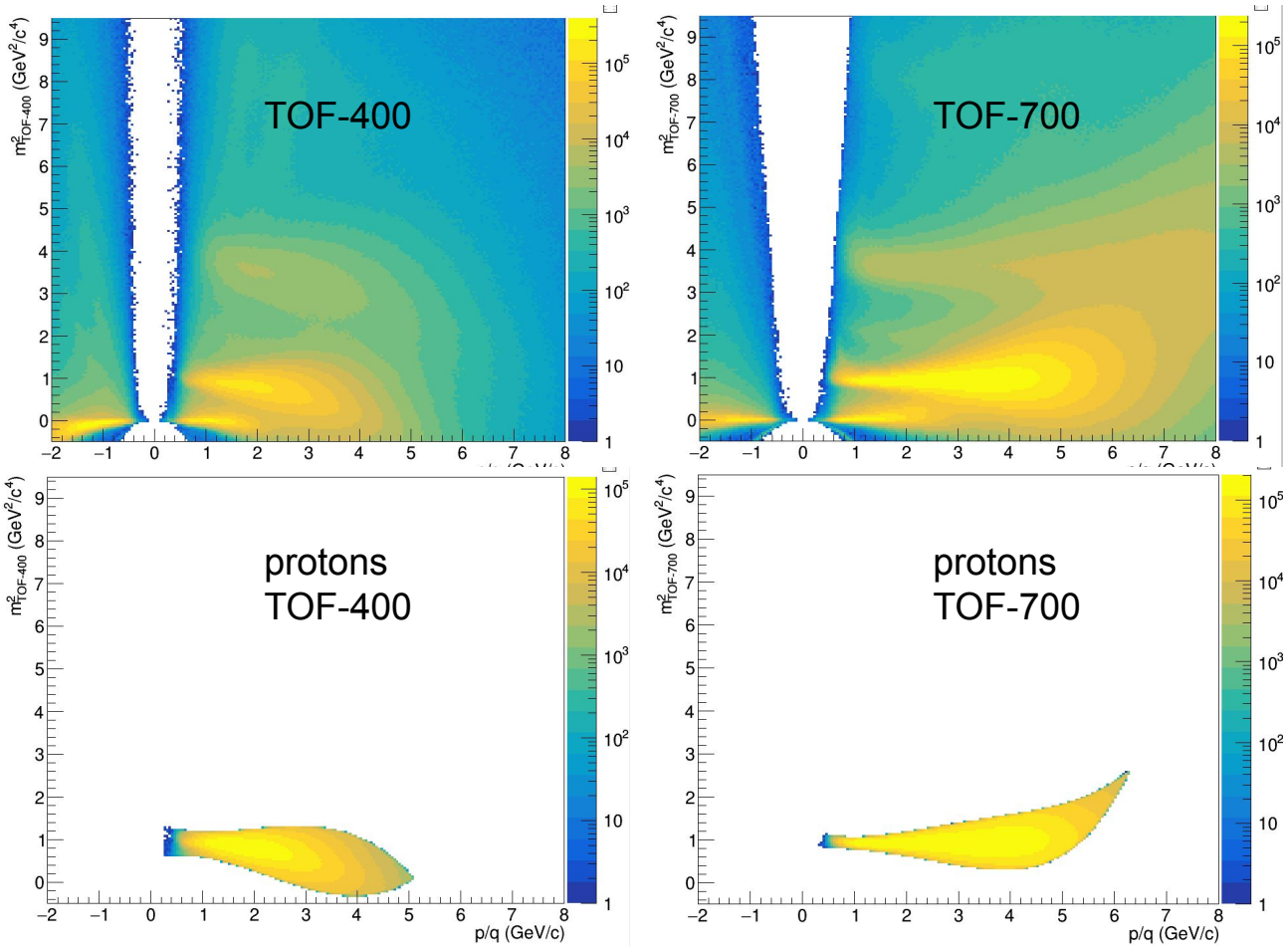
- New layout for the FHCal sub-events yields in larger resolution correction factor for all three sub-events
- v_1 systematics was studied varying the track selection criteria: small systematic errors is observed
- Measured v_1 is in agreement with JAM data for larger p_T values
- Slope of the directed flow in midrapidity is in agreement with STAR-FXT data
- Elliptic flow measured using half the available statistics: large statistical errors are observed, multidifferential measurements are not possible

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





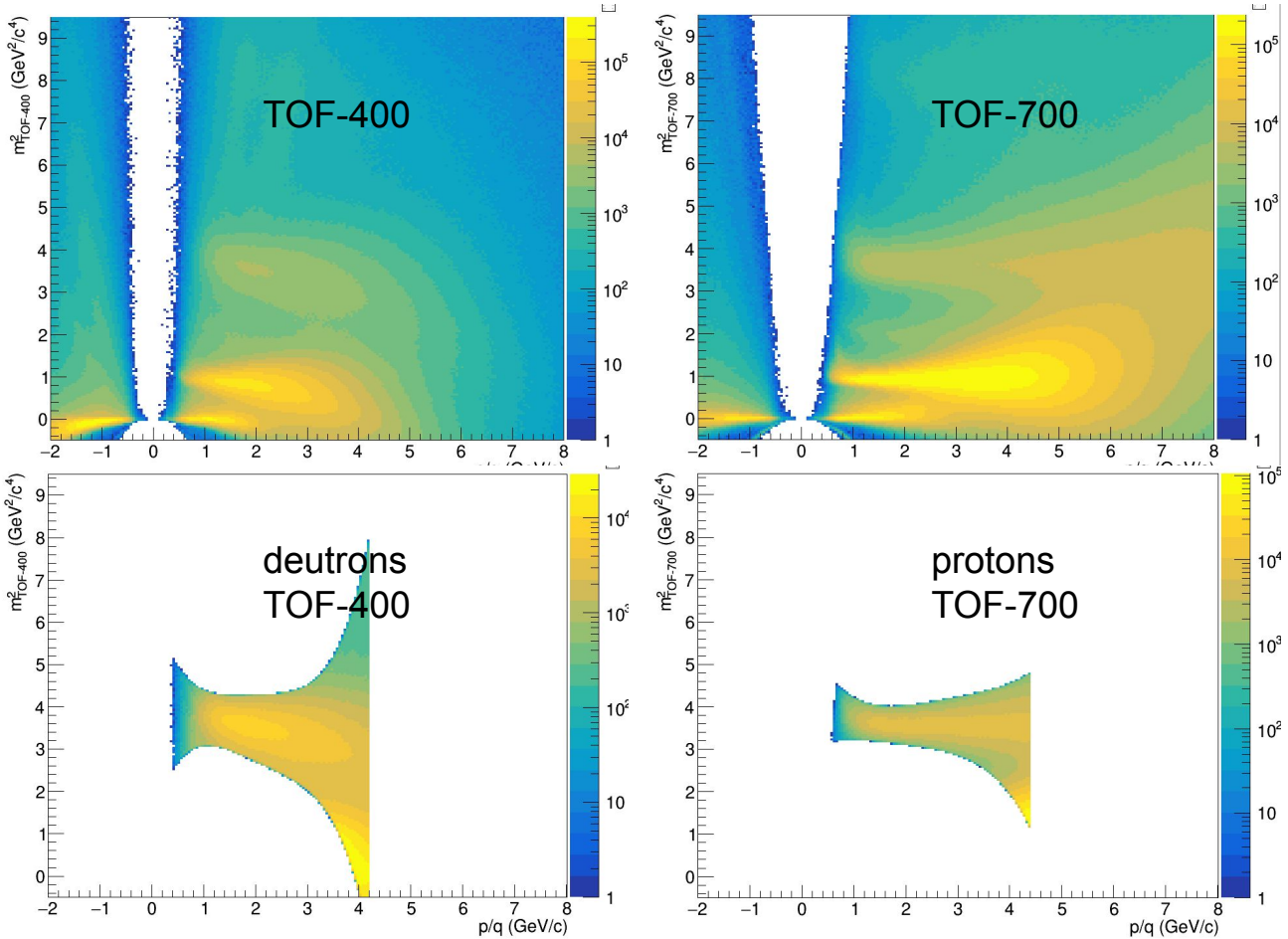
Proton identification



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

Selection criteria: <m>±2σ

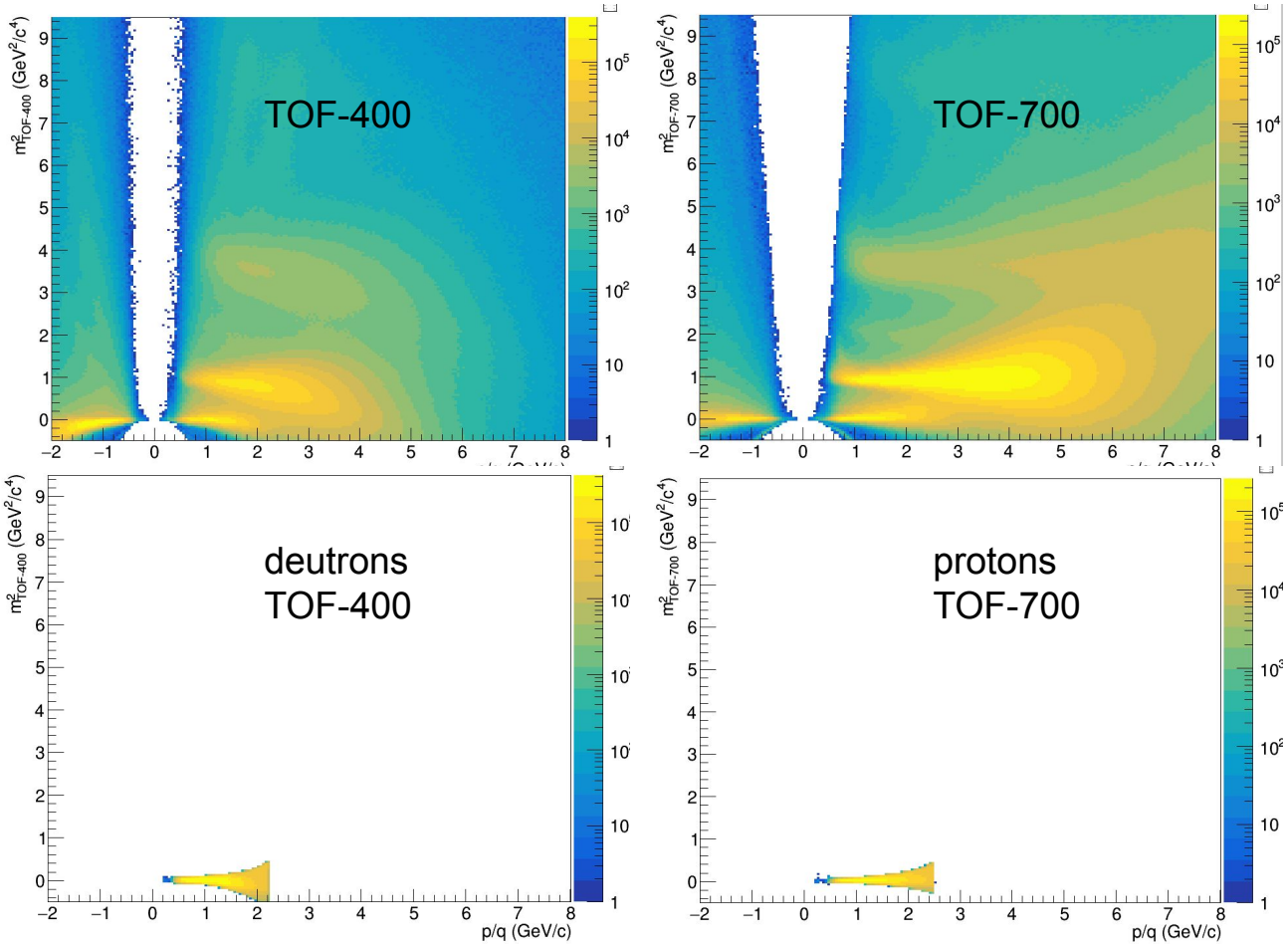
Deutron identification



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

Selection criteria: <m>±2σ

Positive pions identification

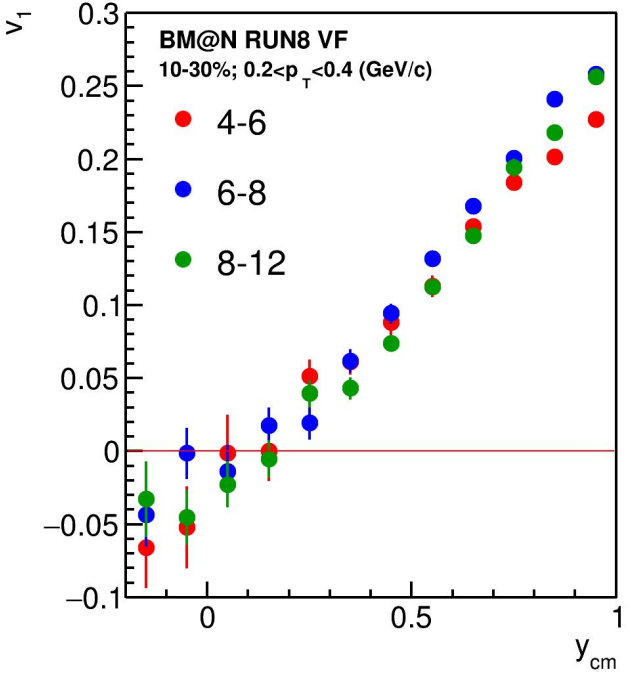


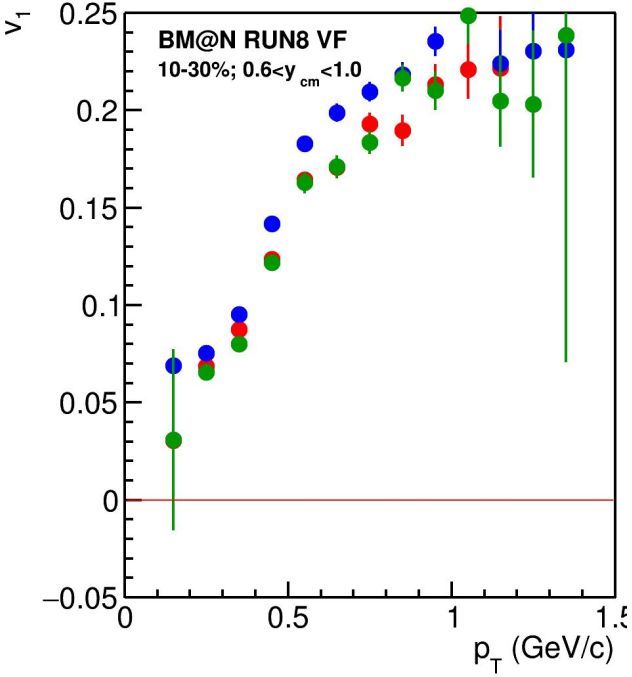
Proton candidates were selected with fitting the m^2 vs p\q

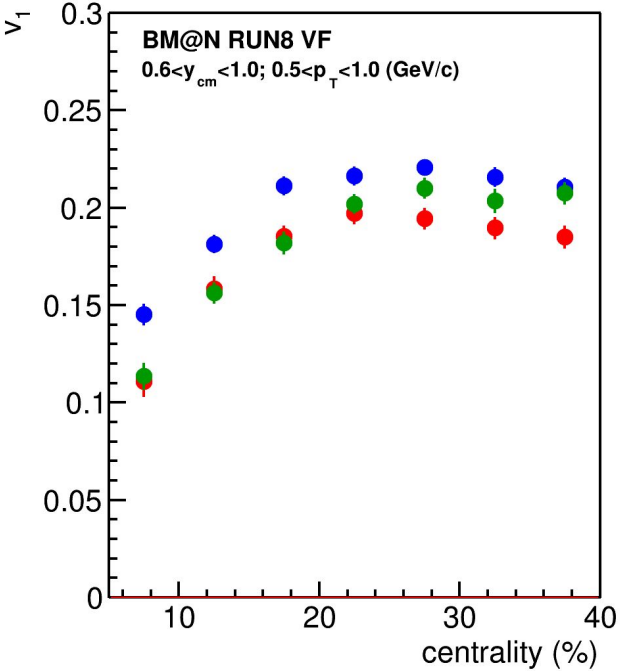
Selection criteria: <m>±2σ

Backup

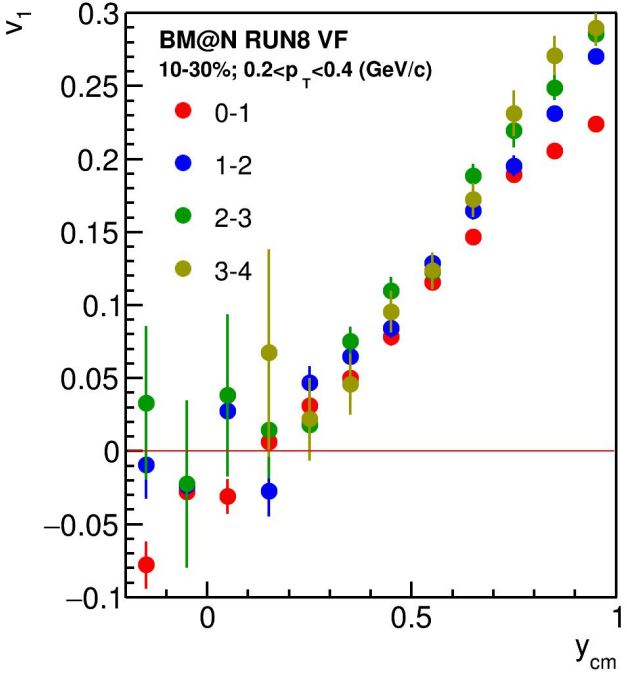
(VF) v_1 vs y: Systematic variation due to Nhits-cut

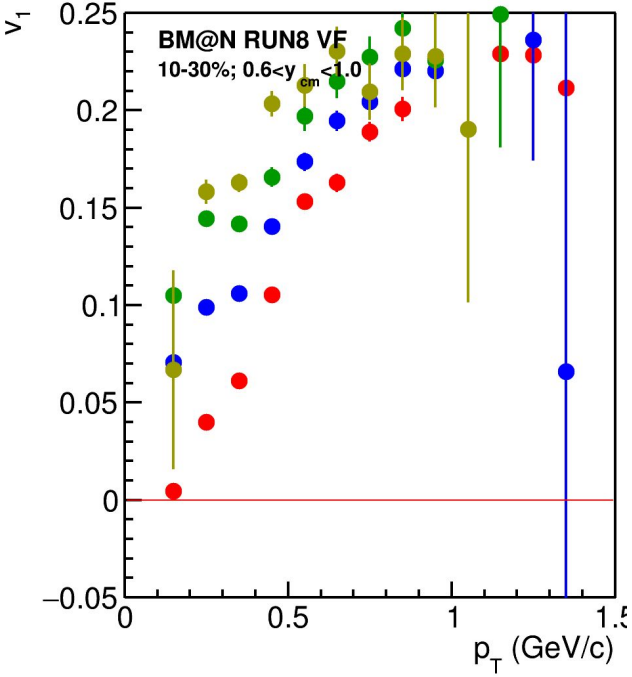


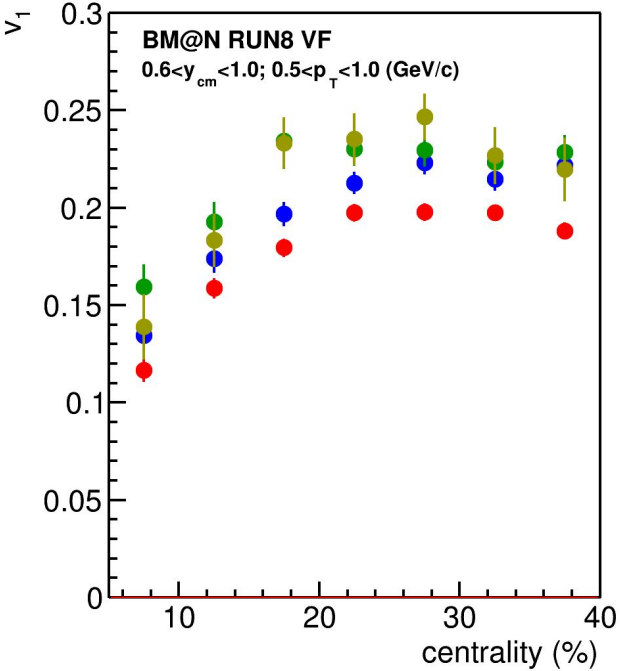




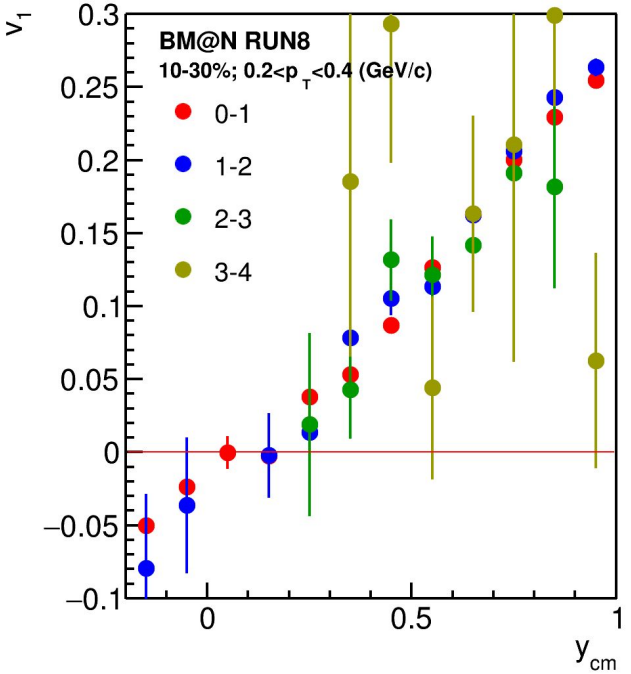
(VF) v_1 vs y: Systematic variation due to chi2-cut

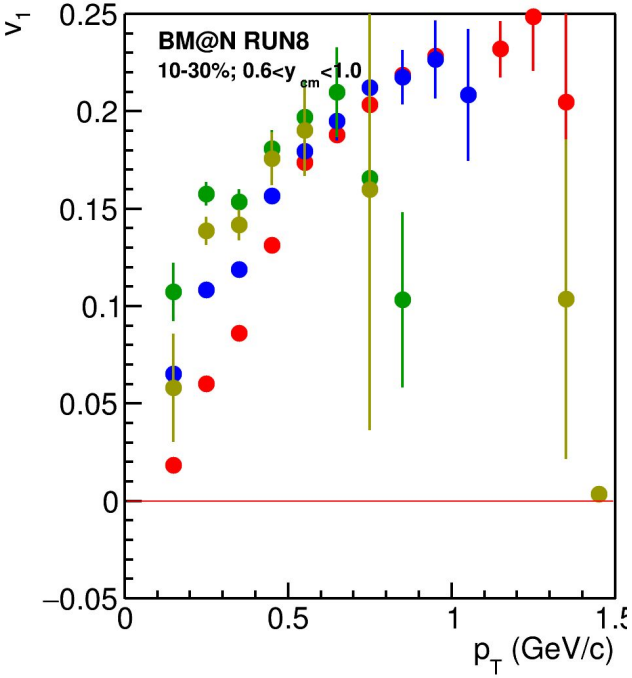


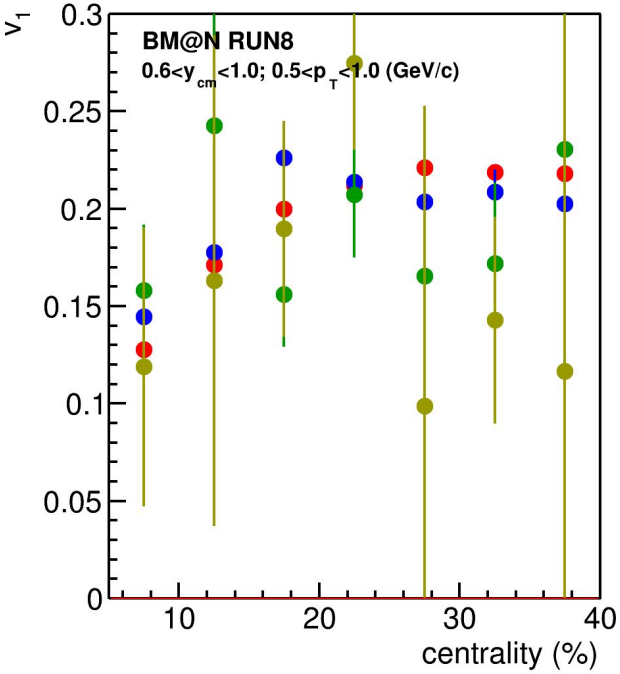




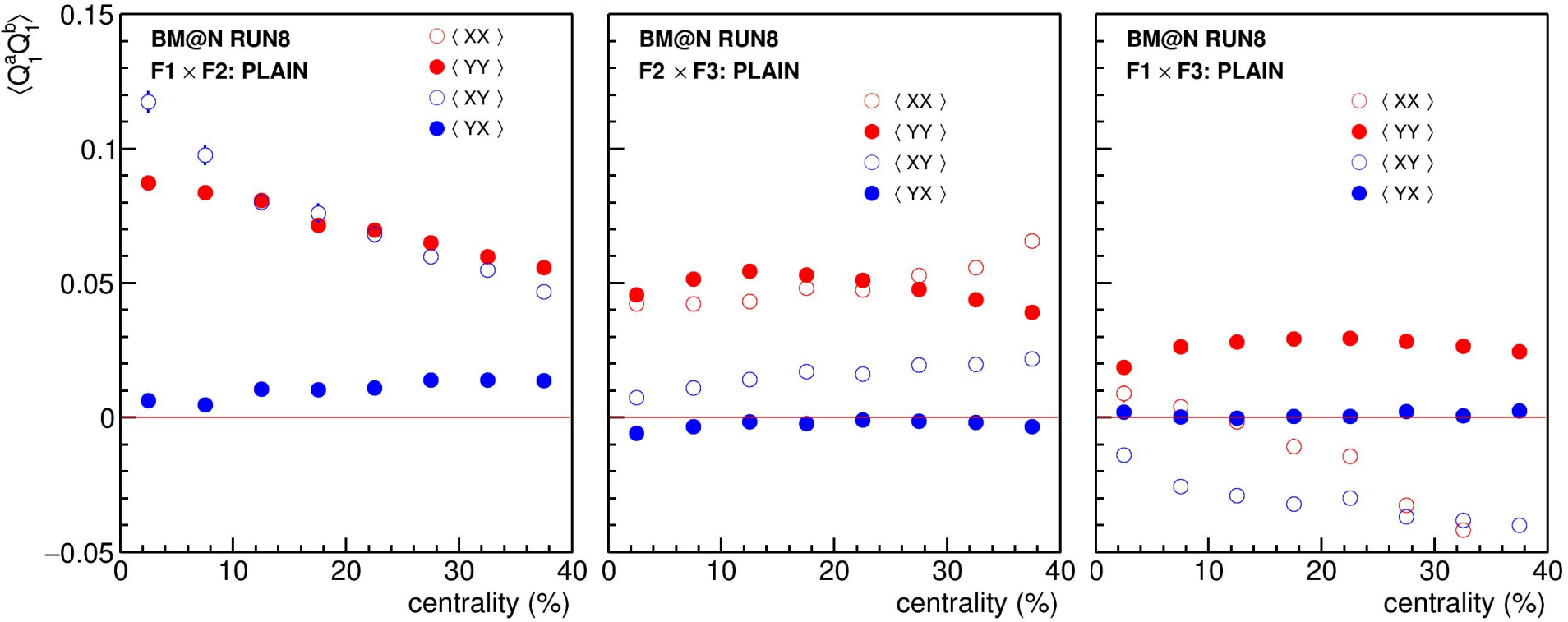
(VF) v_1 vs y: Systematic variation due to DCA-cut



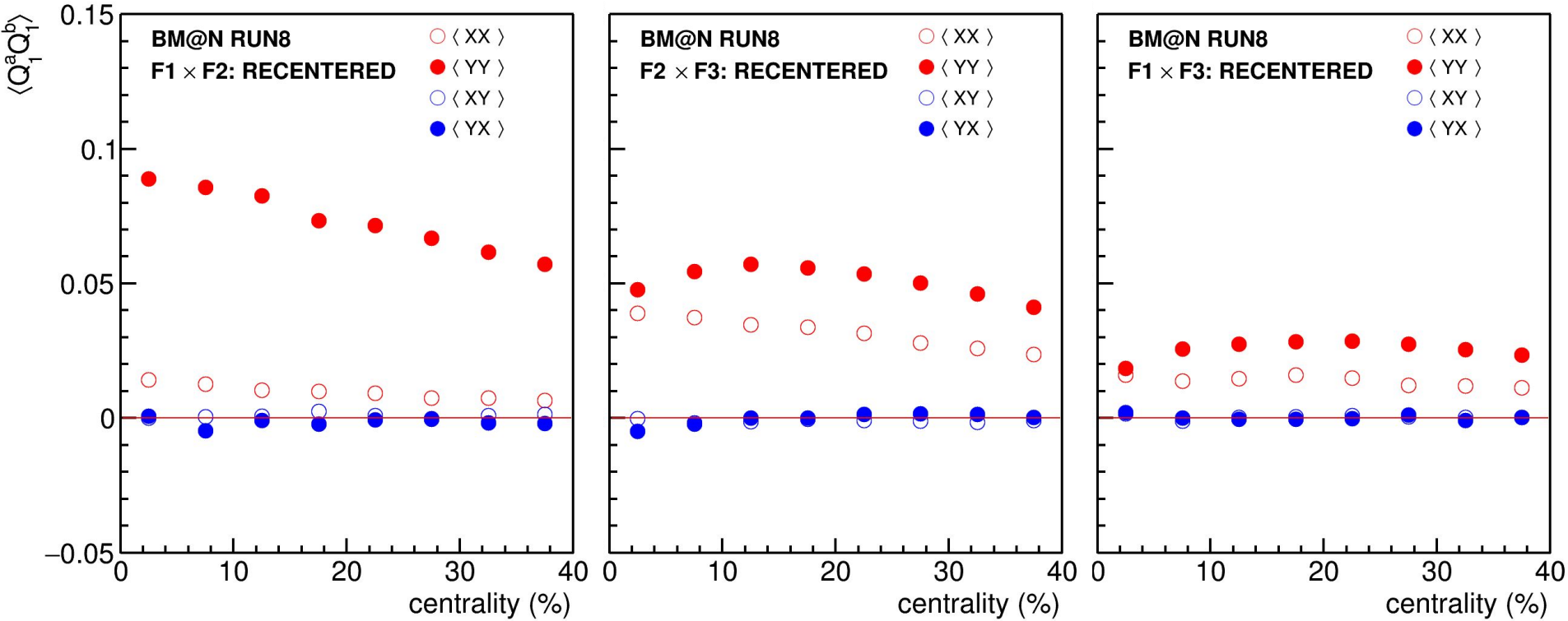




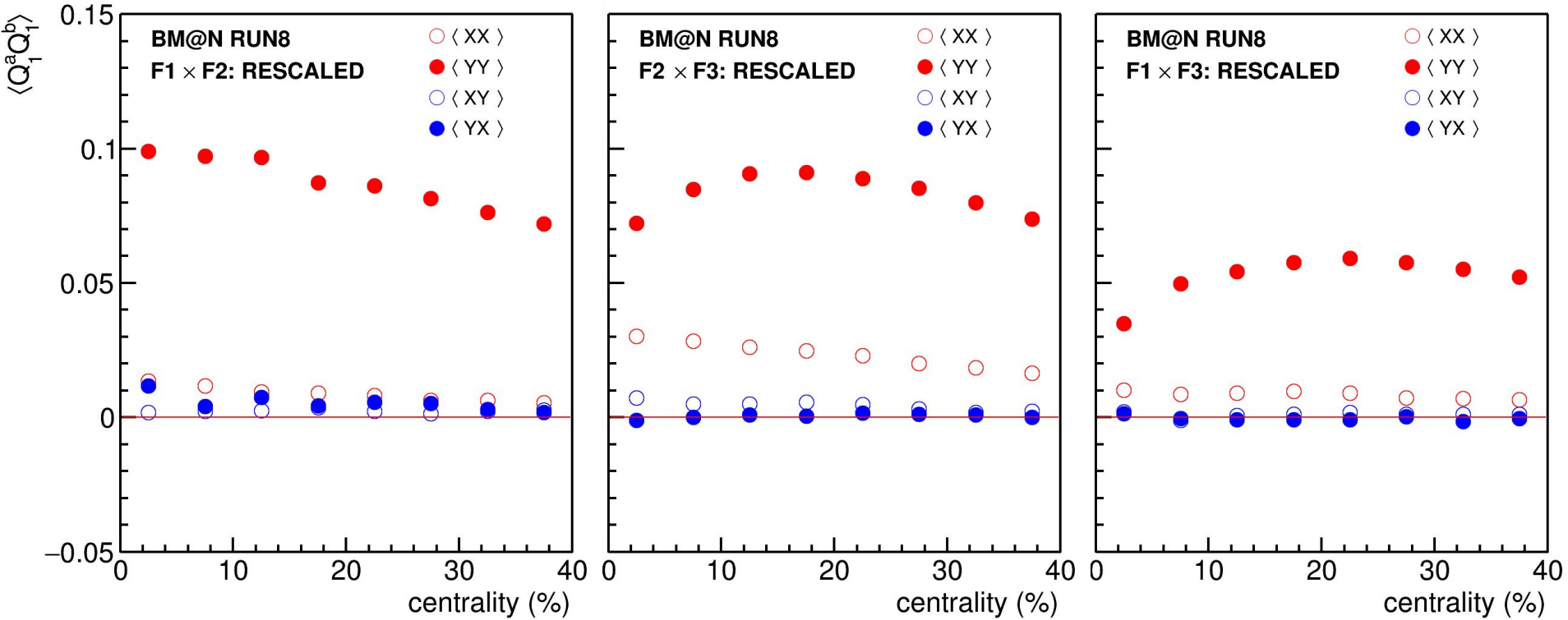
FHCal Q-vector correlations (PLAIN)



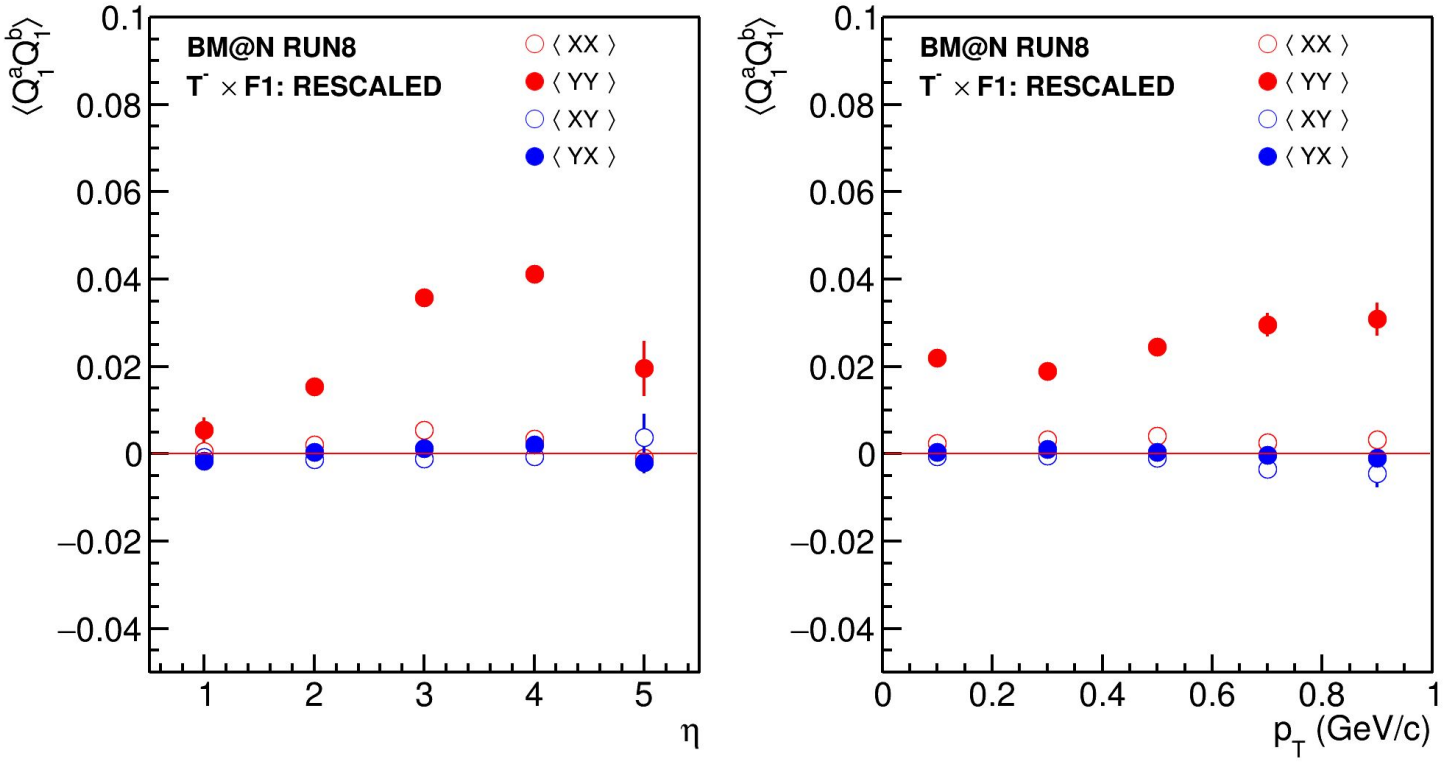
FHCal Q-vector correlations (RECENTERED)



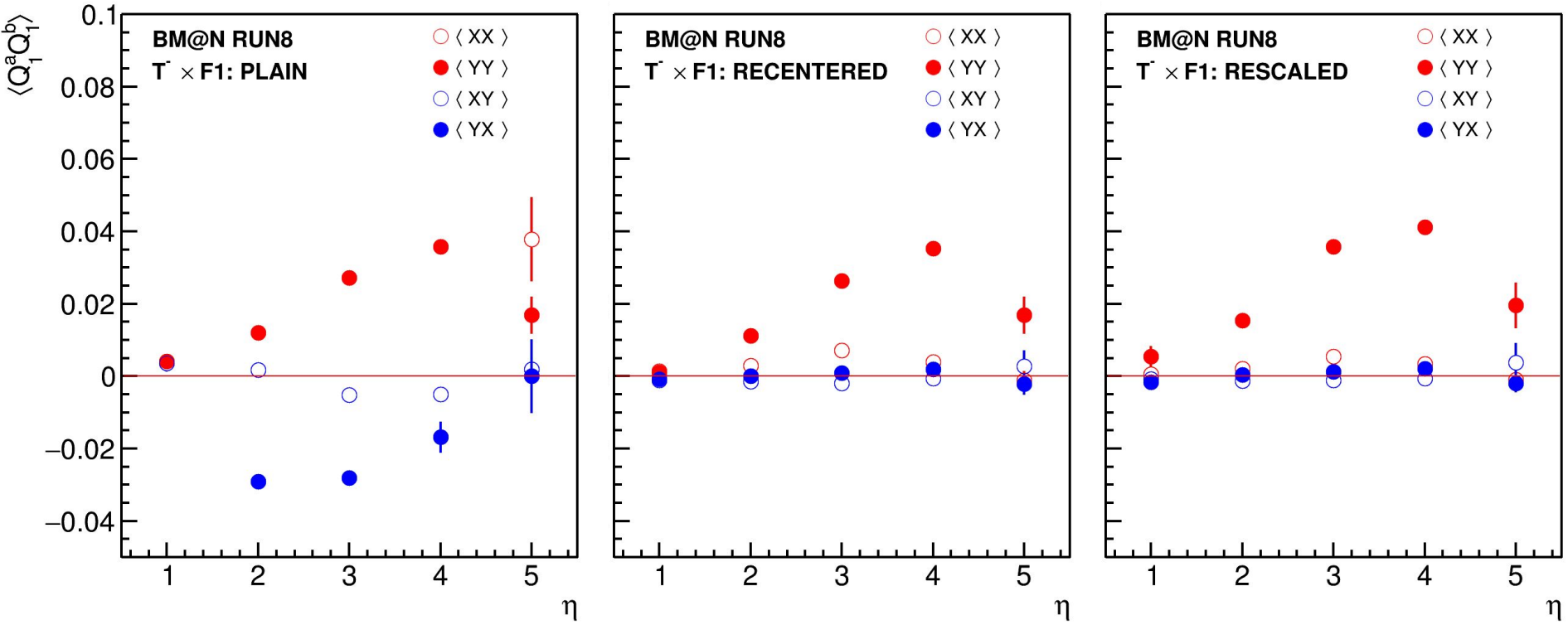
FHCal Q-vector correlations (RESCALED)



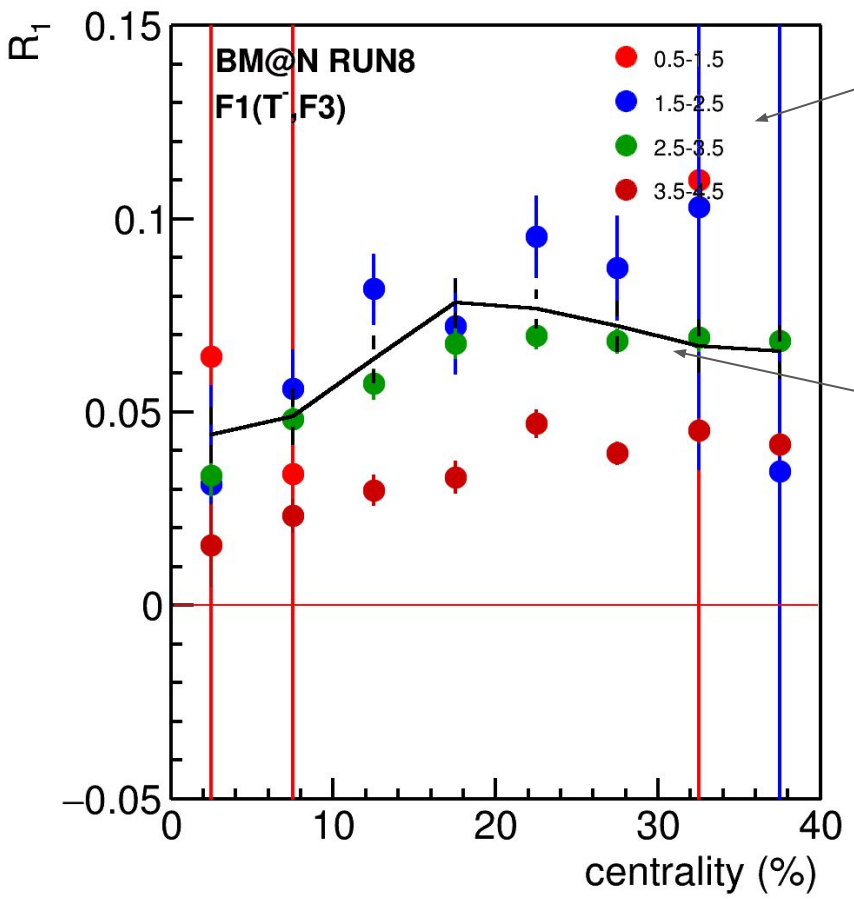
T- x F1 correlations



T- x F1 correlations (all steps)



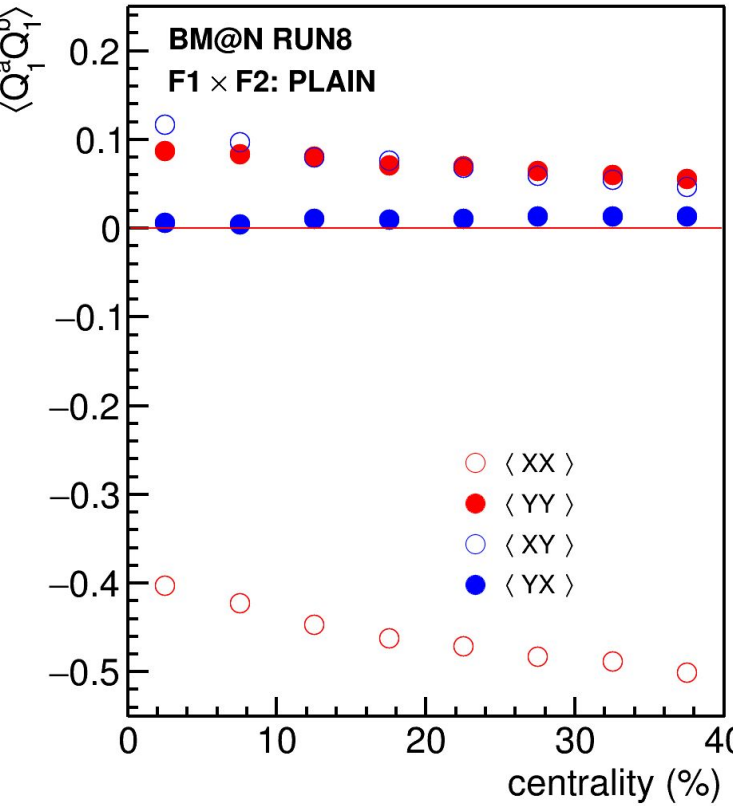
Selecting the pseudorapididty window for T+ vector



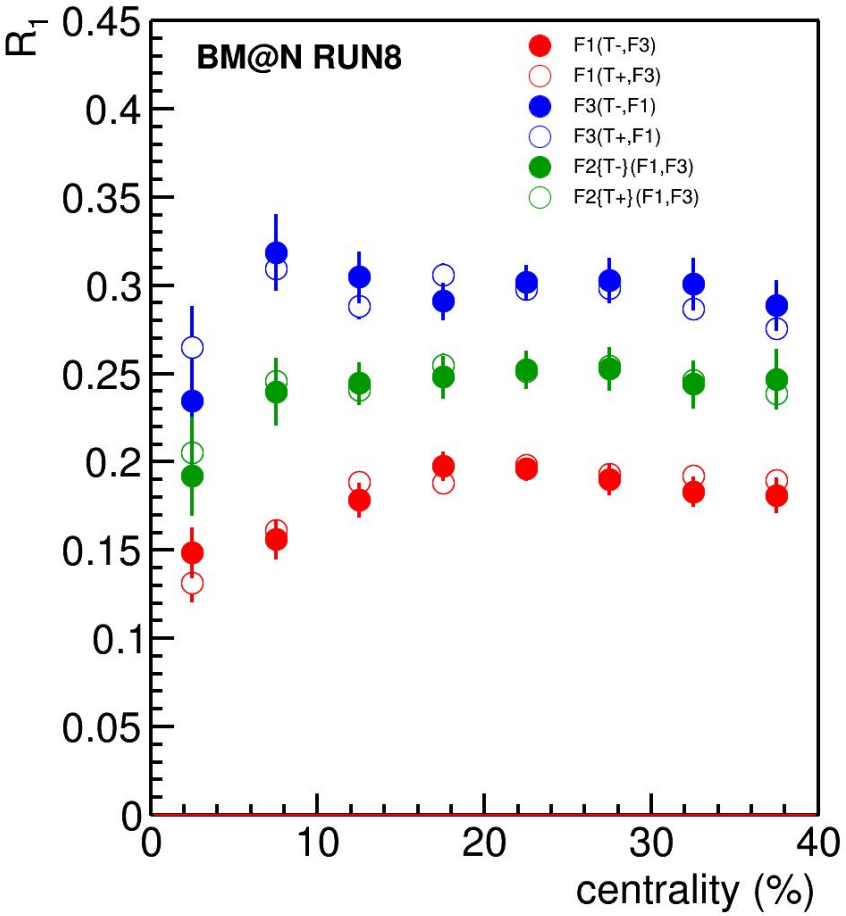
Variating eta

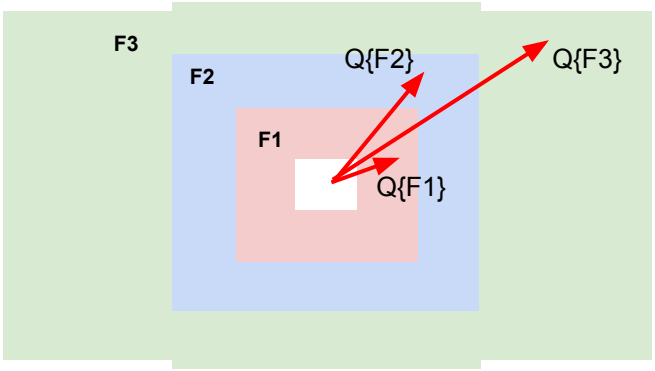
Same combination with T-

Q-vector correlations (PLAIN)



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

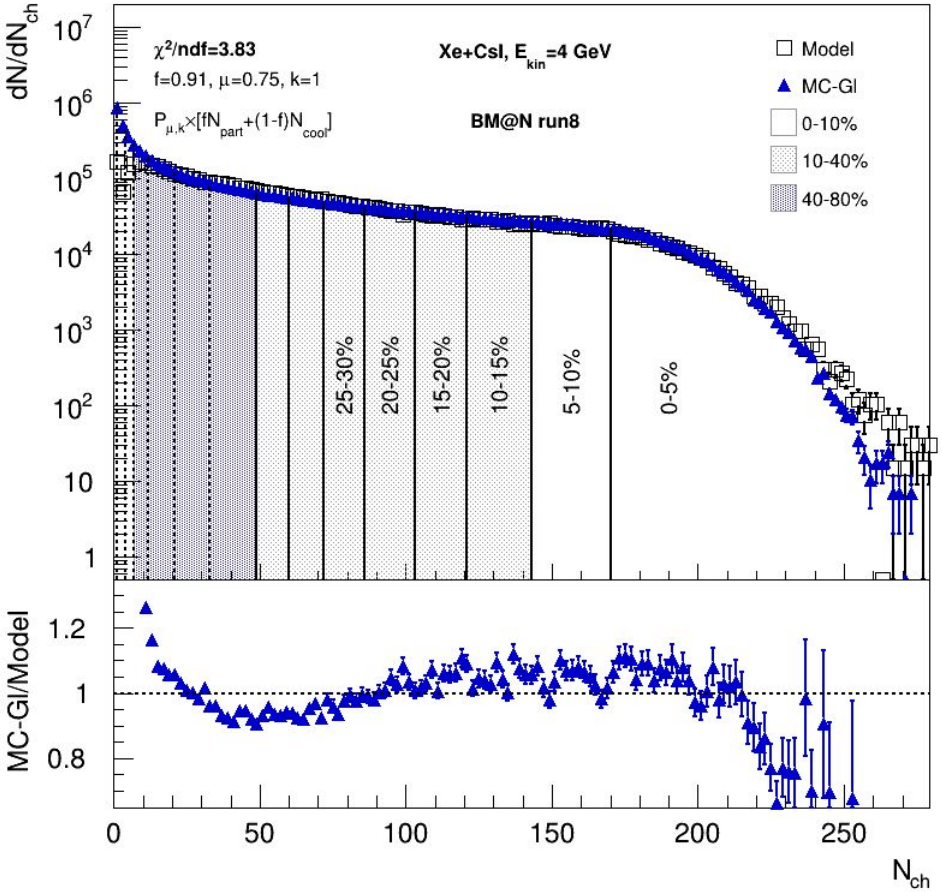




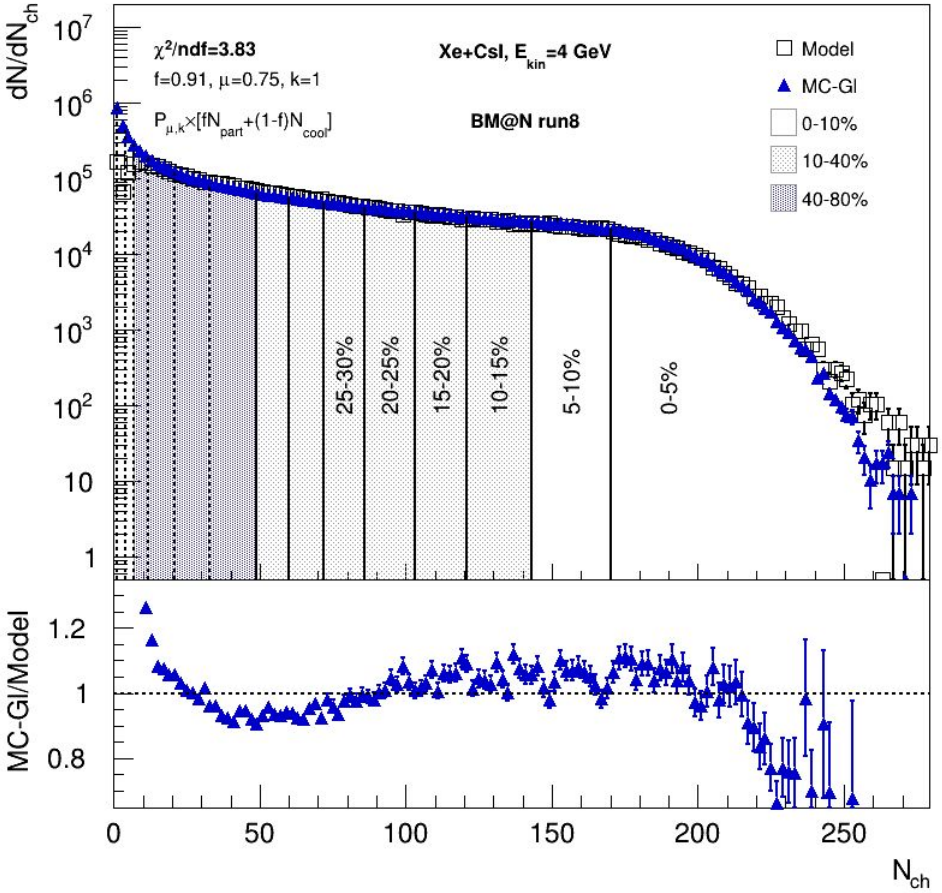
T-: all negatively charged particles with:
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

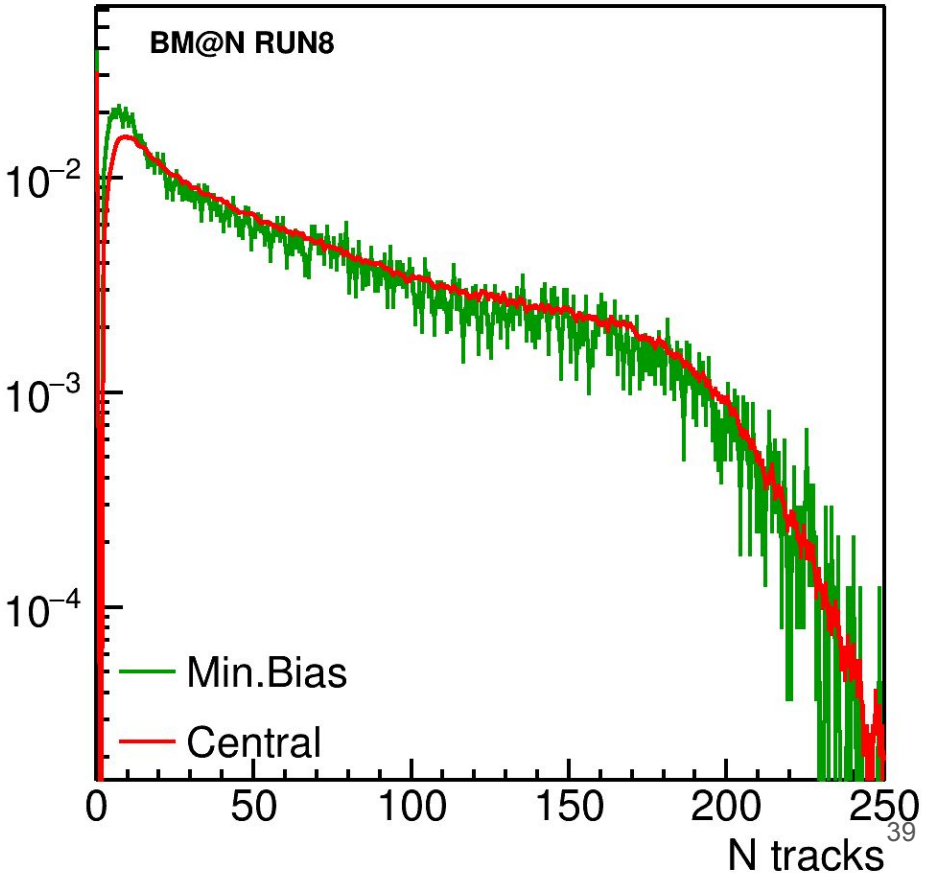
T+: all positively charged particles with:
- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

Centrality with MC-Glauber for RUN8

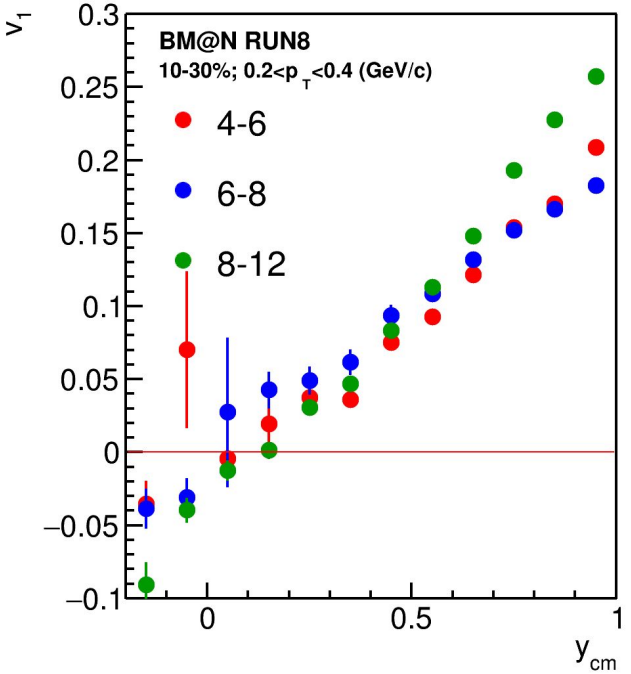


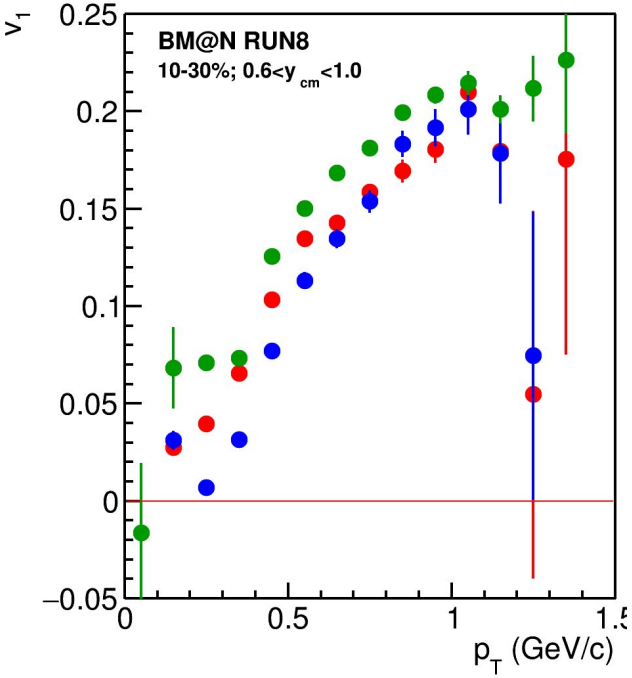
Centrality with MC-Glauber for RUN8

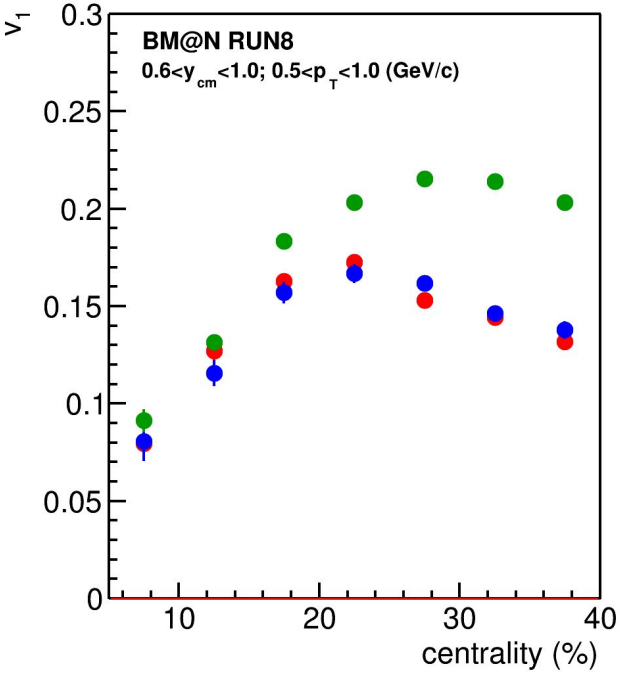




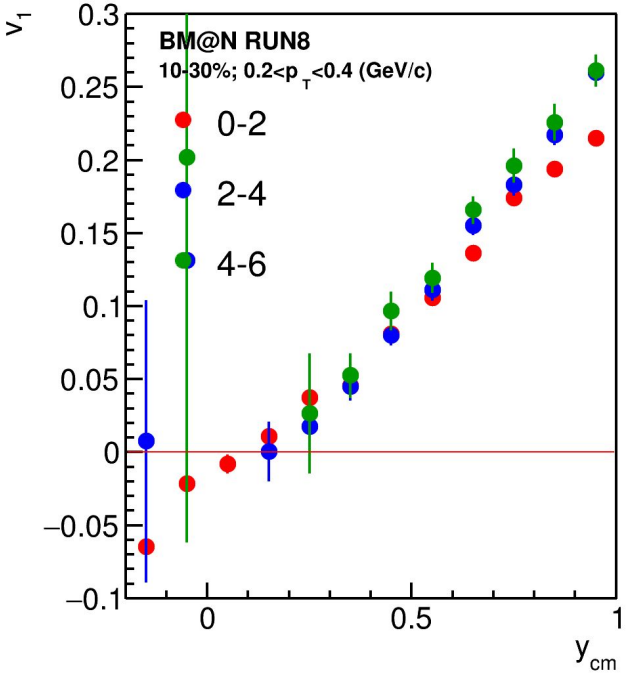
v_1 vs y: Systematic variation due to Nhits-cut

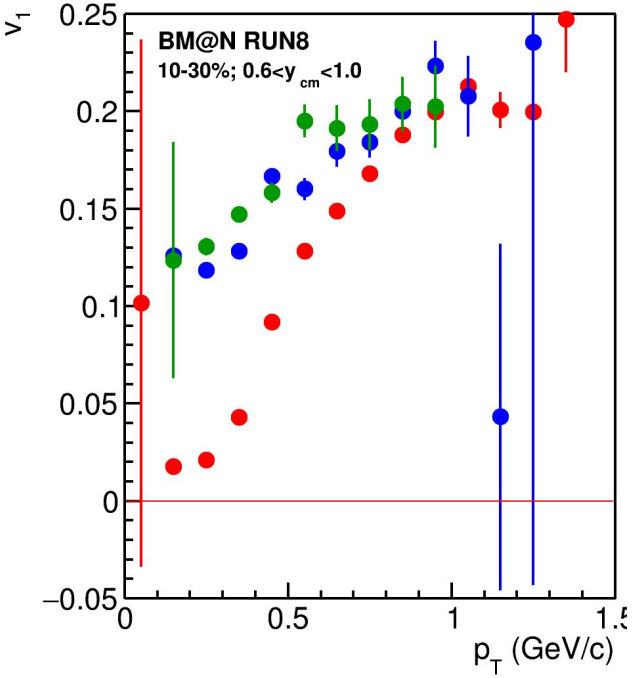


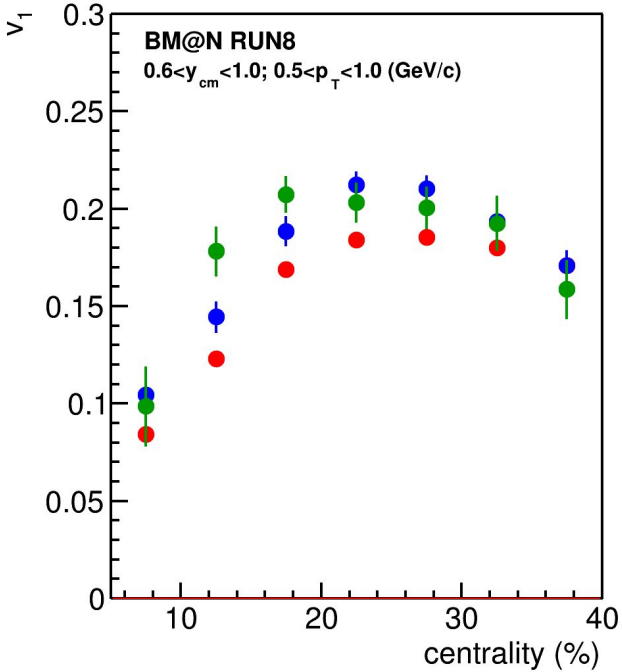




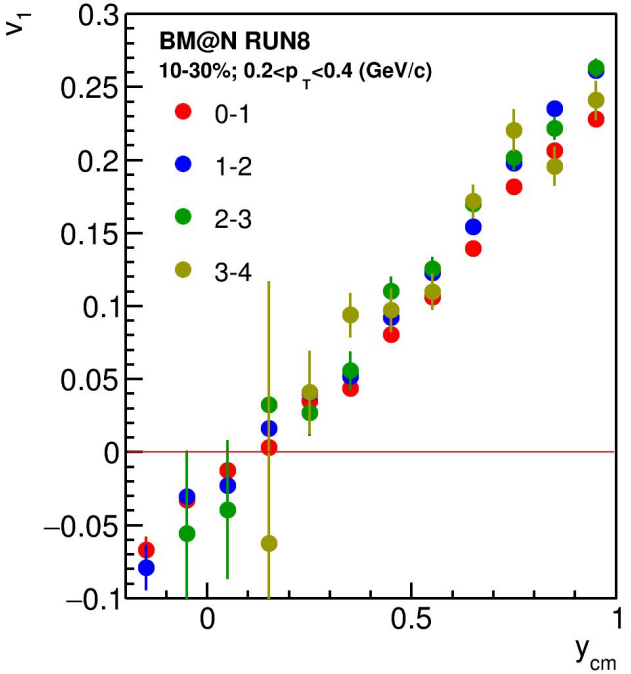
v_1 vs y: Systematic variation due to chi2-cut

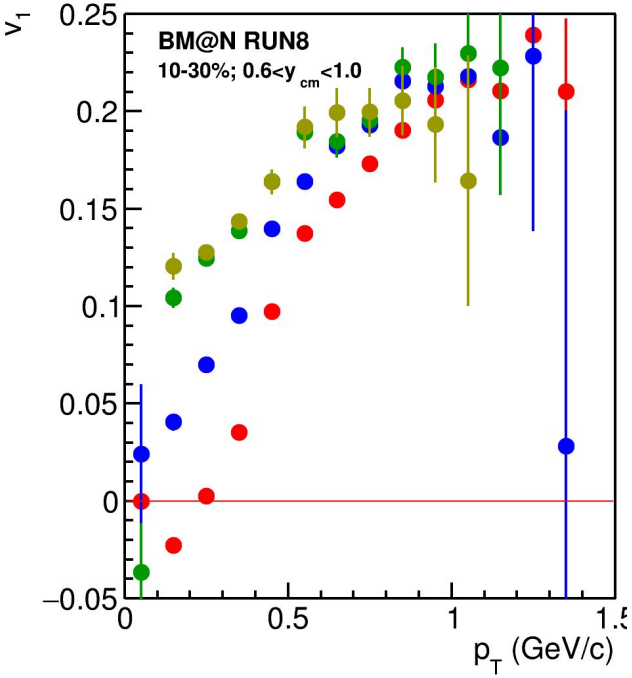


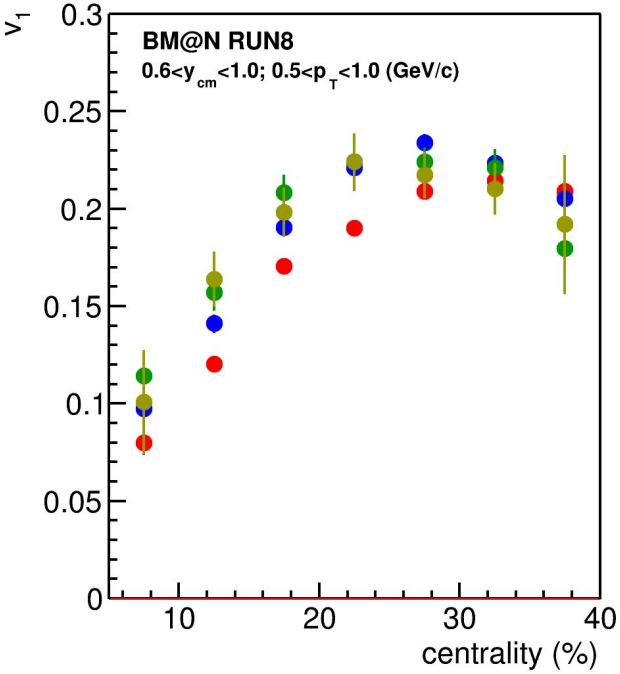




v_1 vs y: Systematic variation due to DCA-cut



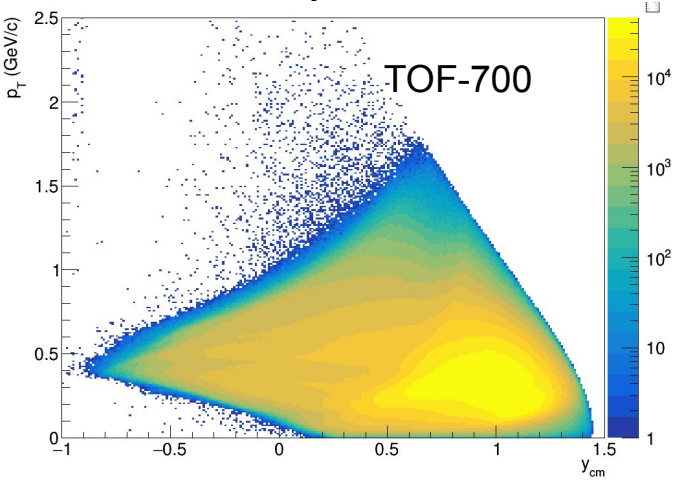


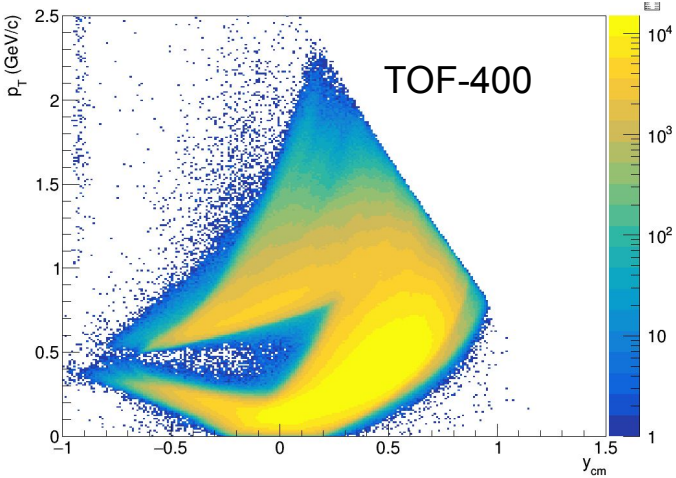


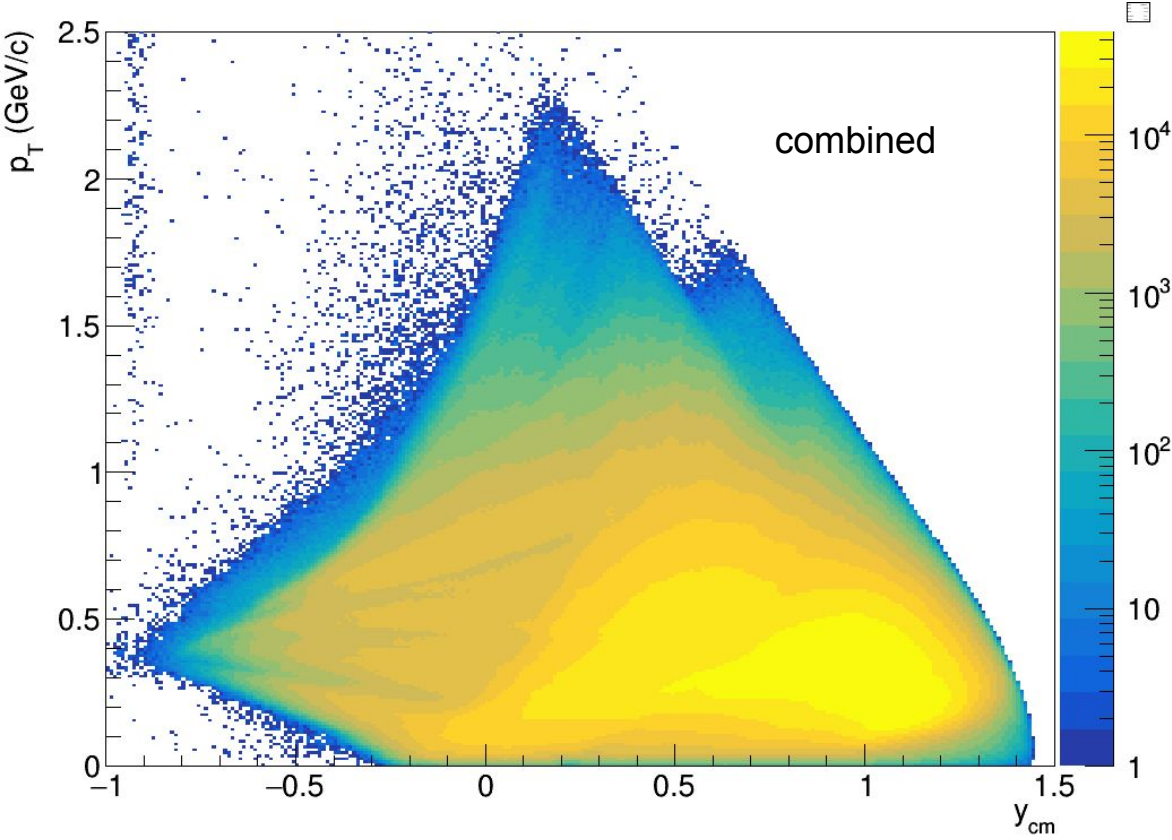
Analysis setup

- 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
  - $\chi^2 < 5$
  - $M_p^2 - 2\sigma < m^2 < M_p^2 + 2\sigma$

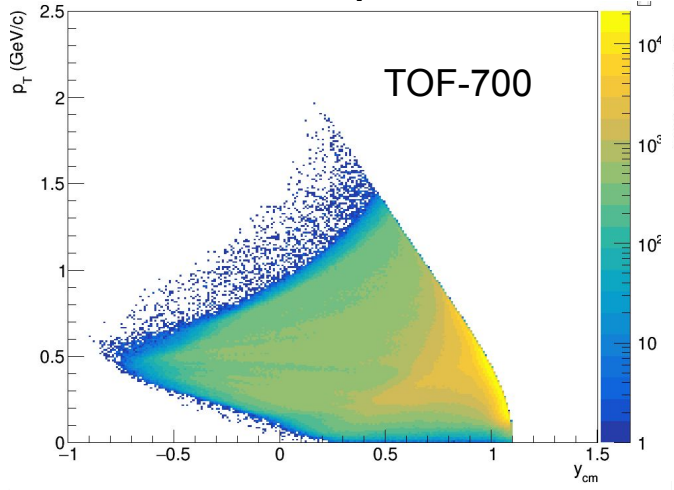
Proton p_T-y acceptance

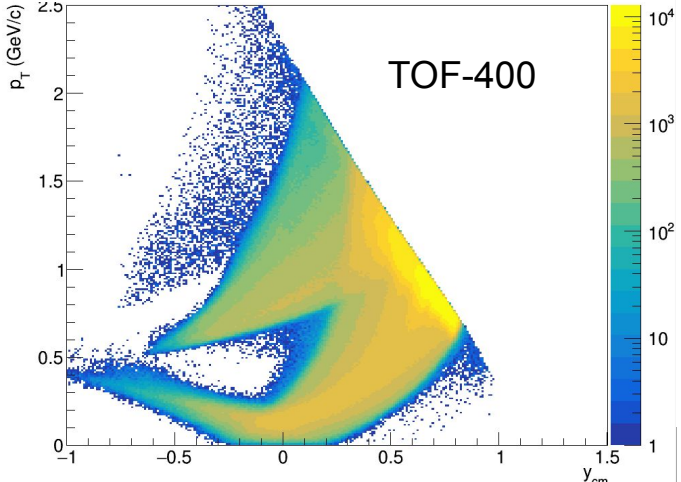


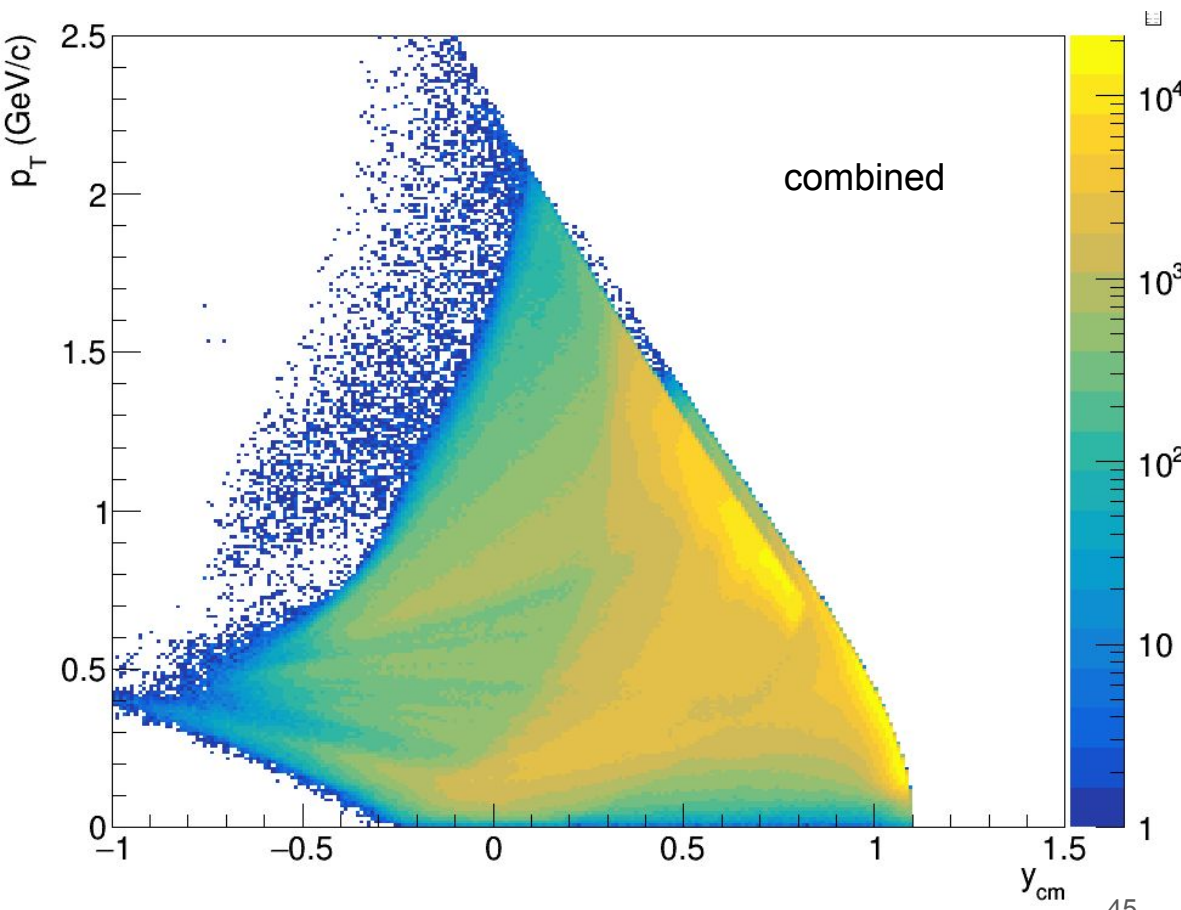




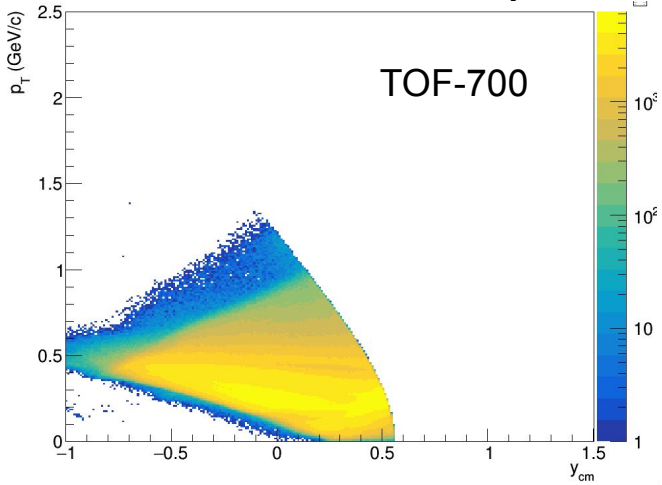
Deutron p_T-y acceptance

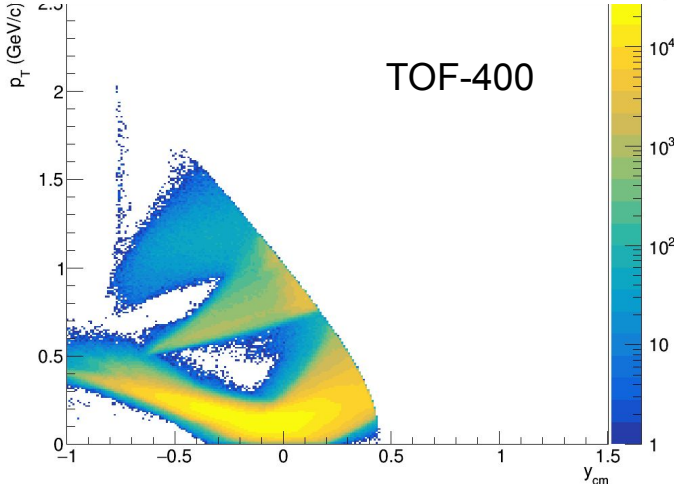


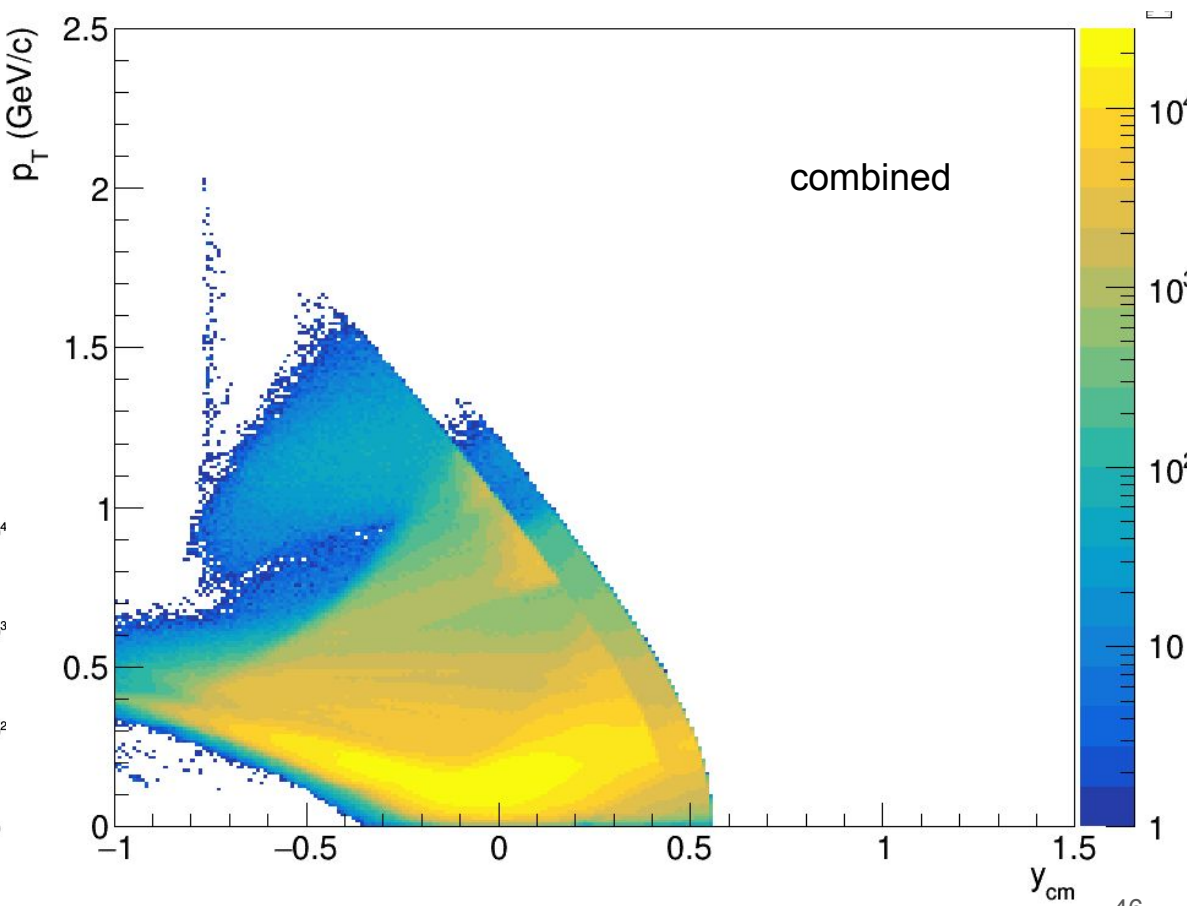




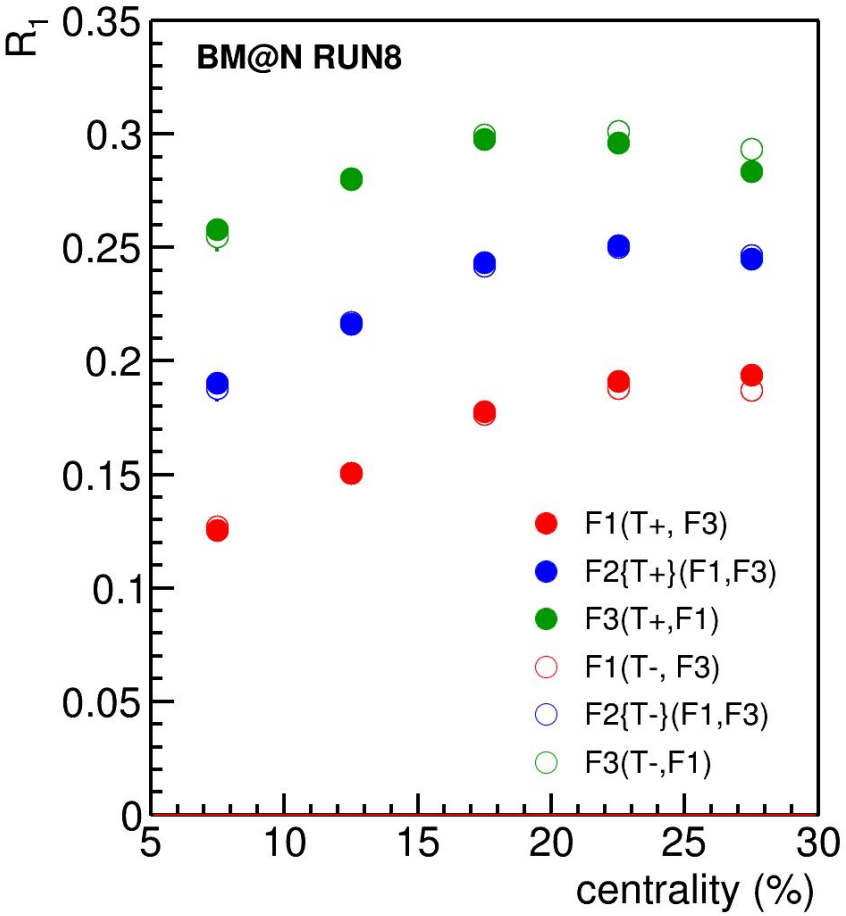
Positive pion p_T-y acceptance

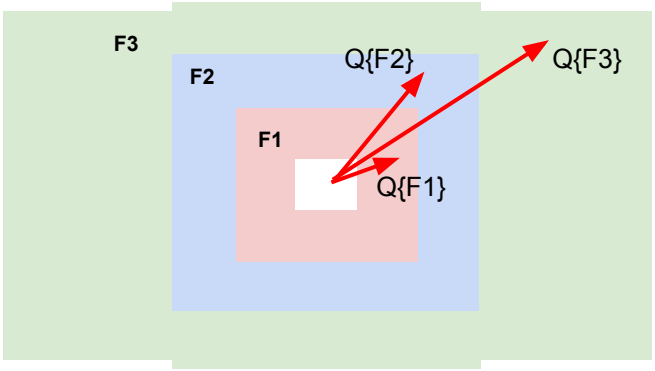






R1: BM@N Run8 DATA: Xe+Cs@3.8A GeV

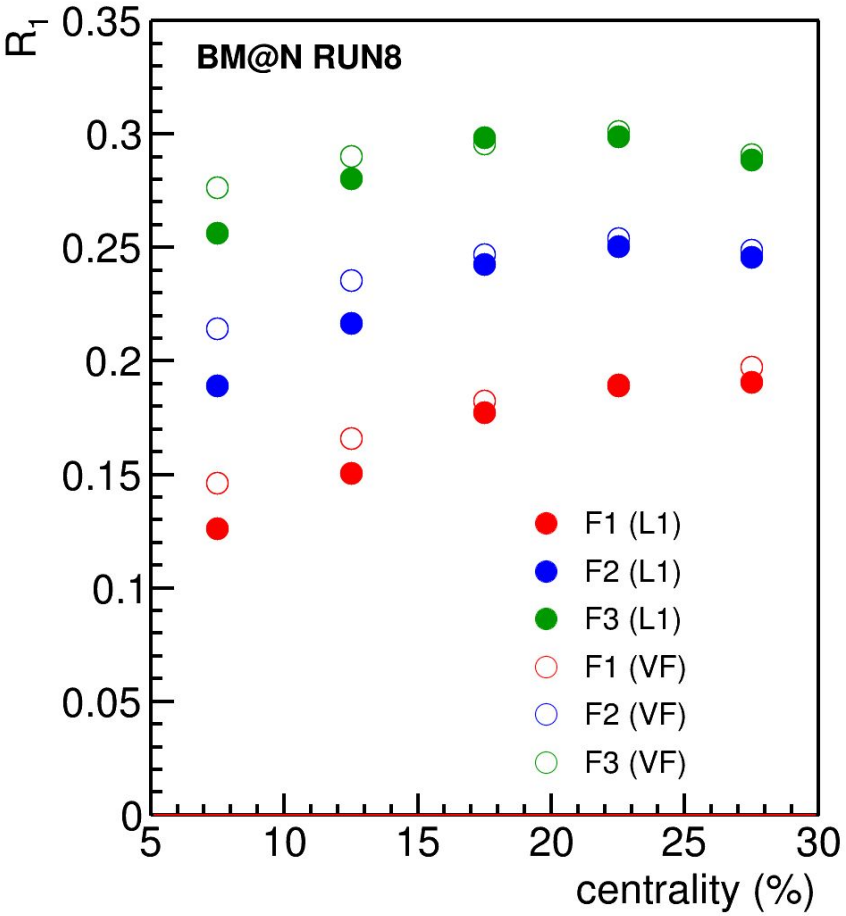


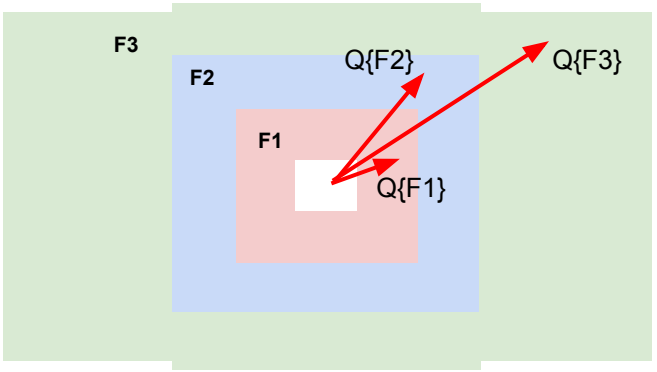


T-: all negatively charged particles with:
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

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

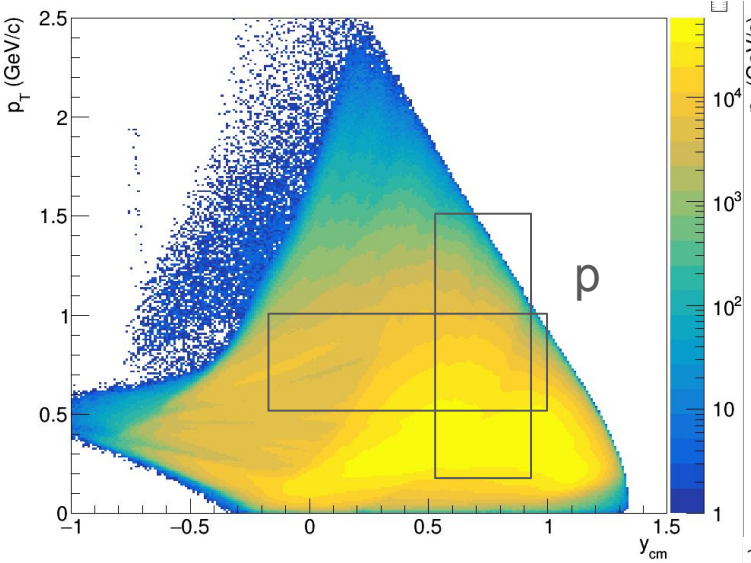


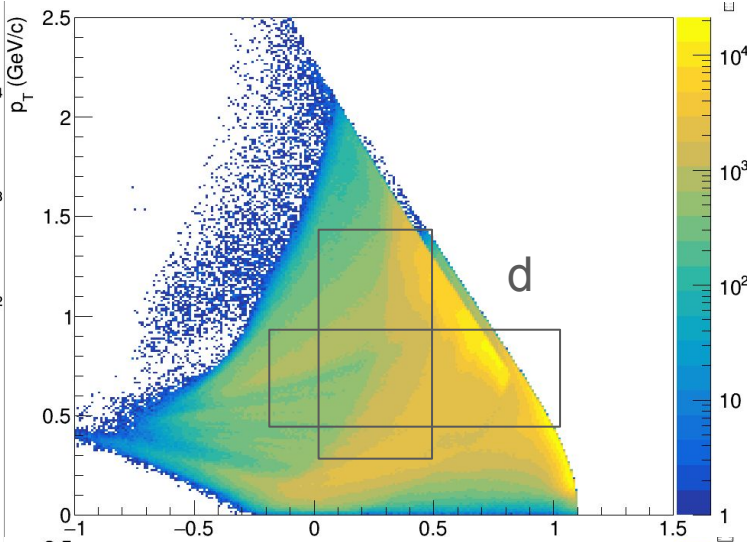


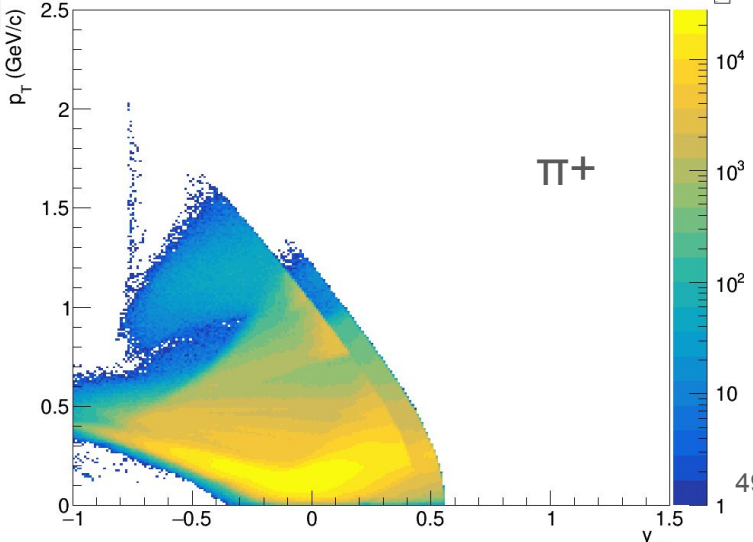
T-: all negatively charged particles with:
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

T+: all positively charged particles with:
- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

Difference can be explained by different centrality

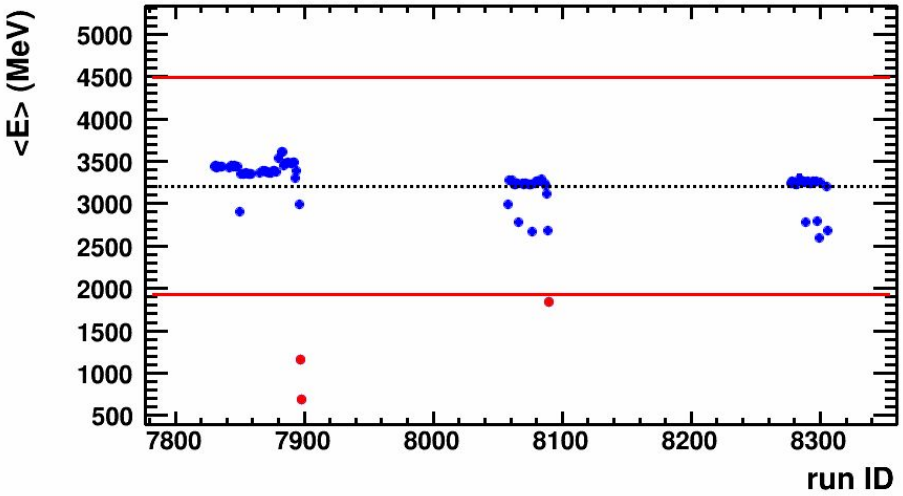

p
p_T (GeV/c)
y_{cm}


d
p_T (GeV/c)

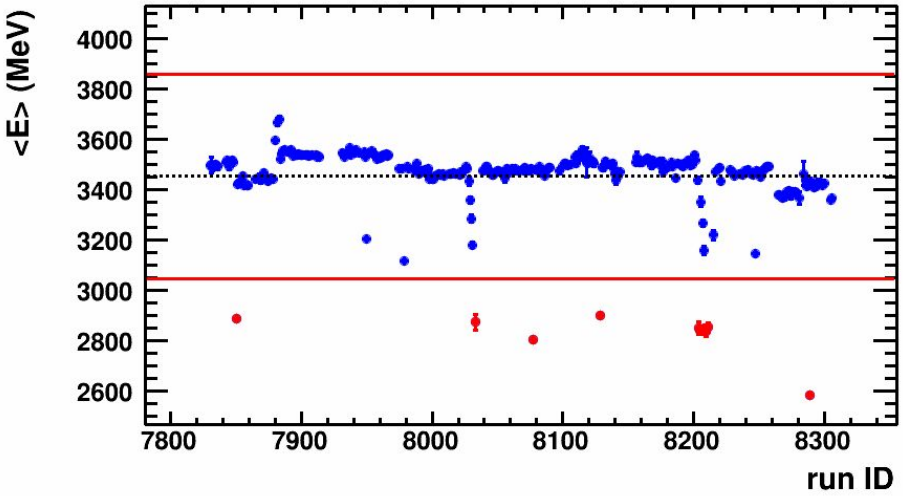

π+
p_T (GeV/c)
y

QA Run-by-Run: FHCal

VF prod



L1 prod

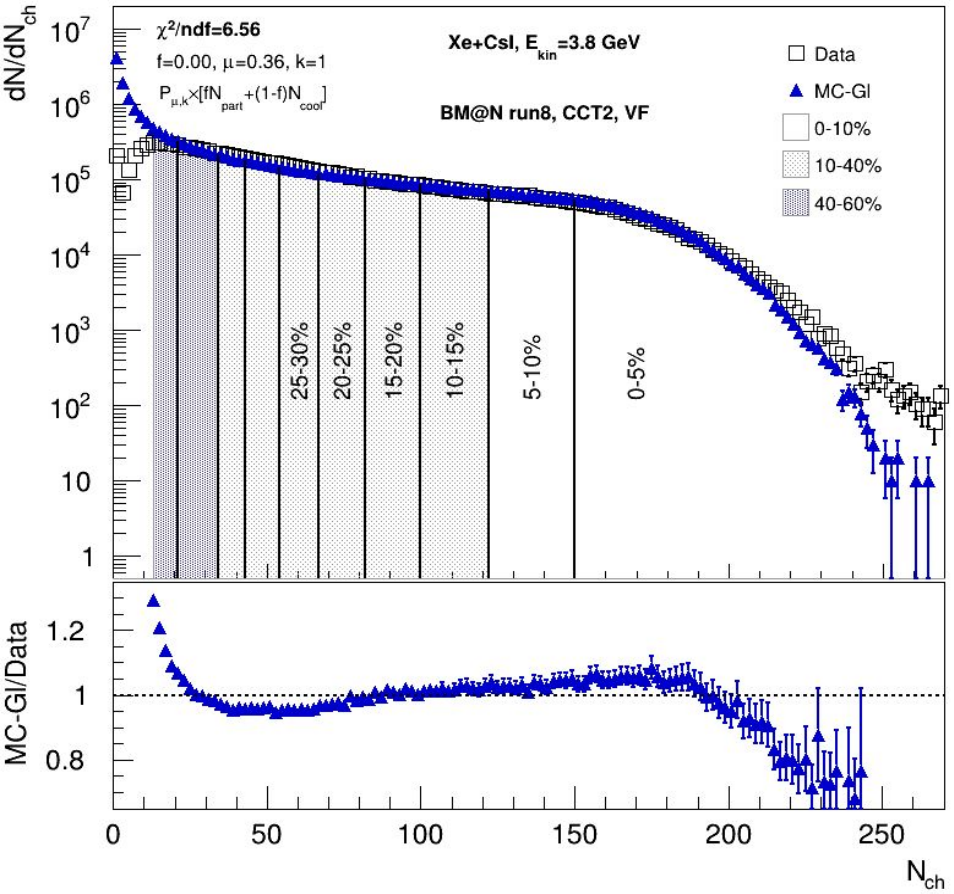


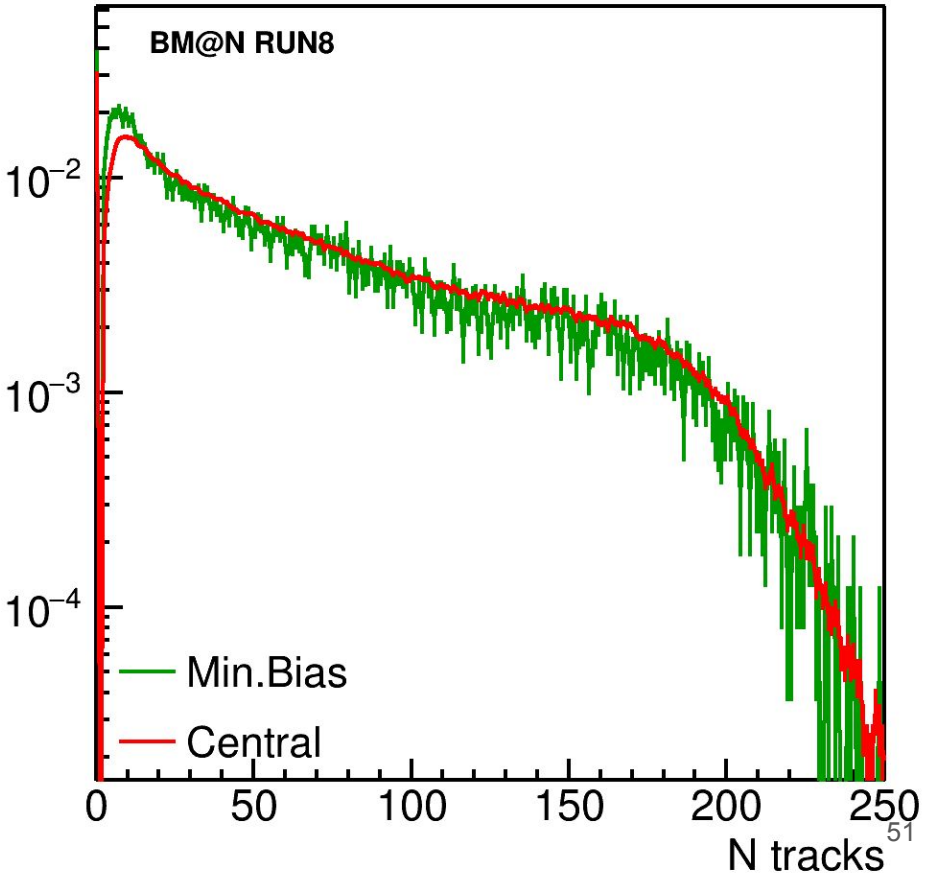
VF production was made with different versions of BmnRoot:

- ~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

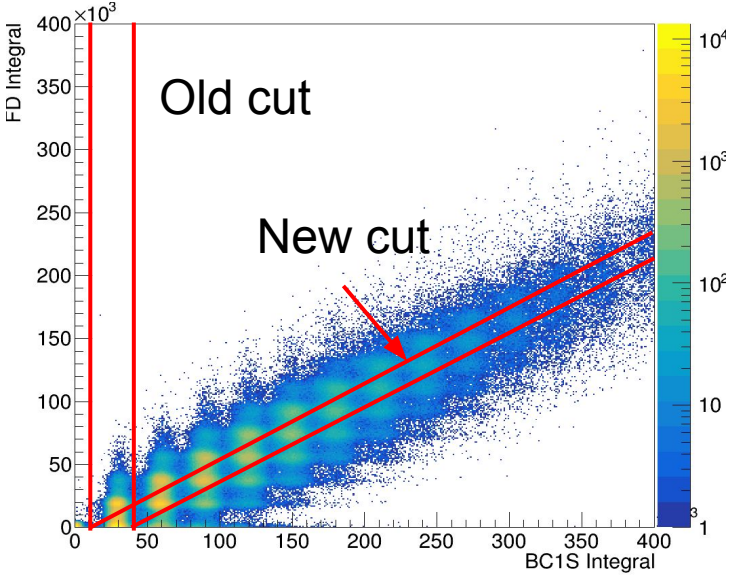
(See the talk of I.Segal)

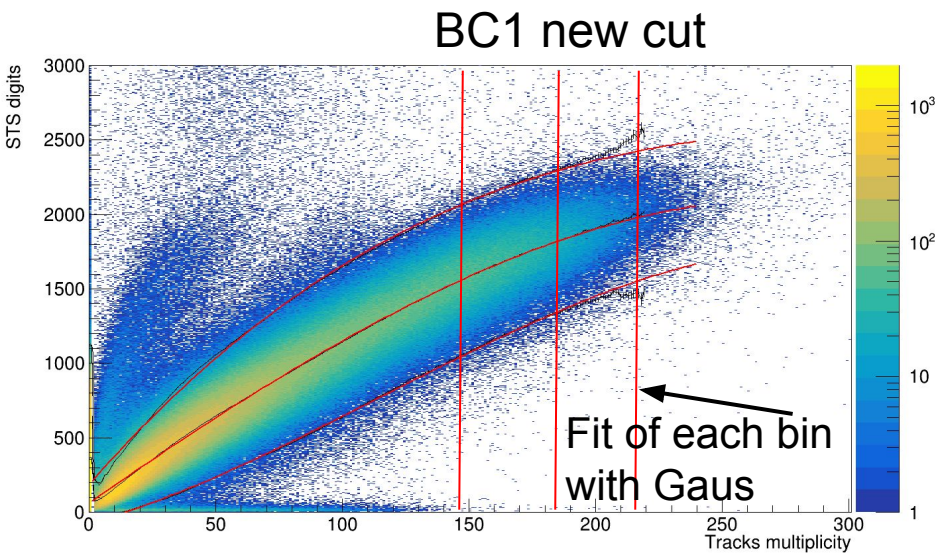




Selection criteria

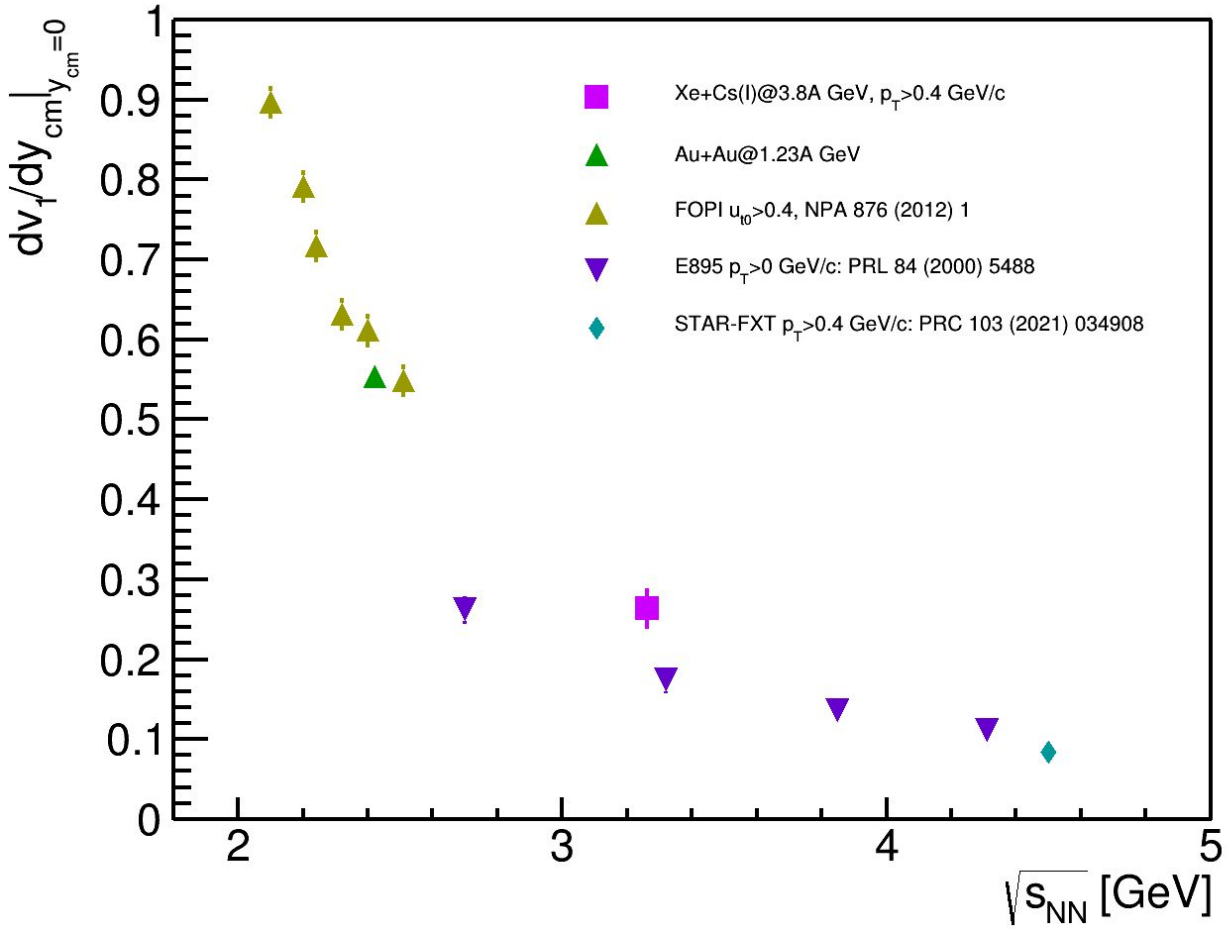
See the talk of I.Segal for details



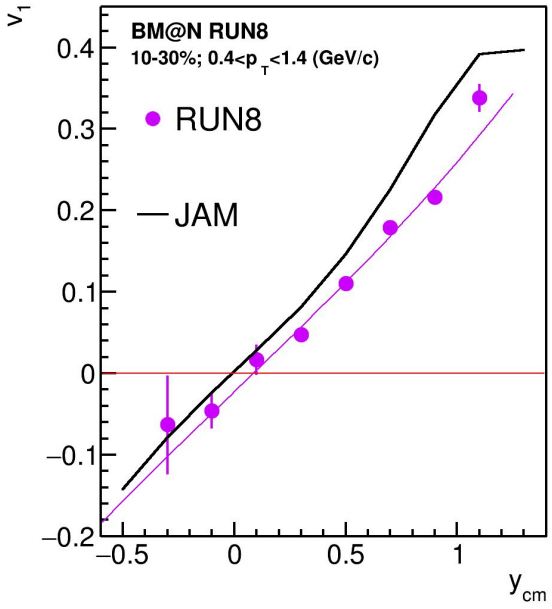


- CCT2 trigger
- Cuts on pile-up
- More than 1 track for vertex reconstruction

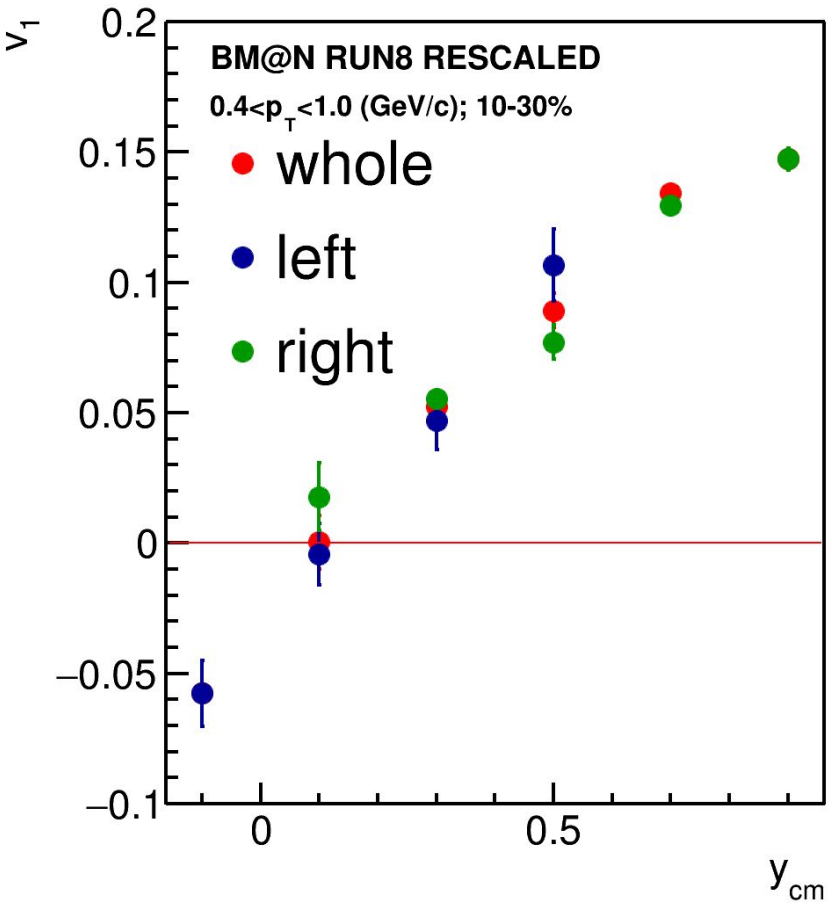
Comparison with the world data

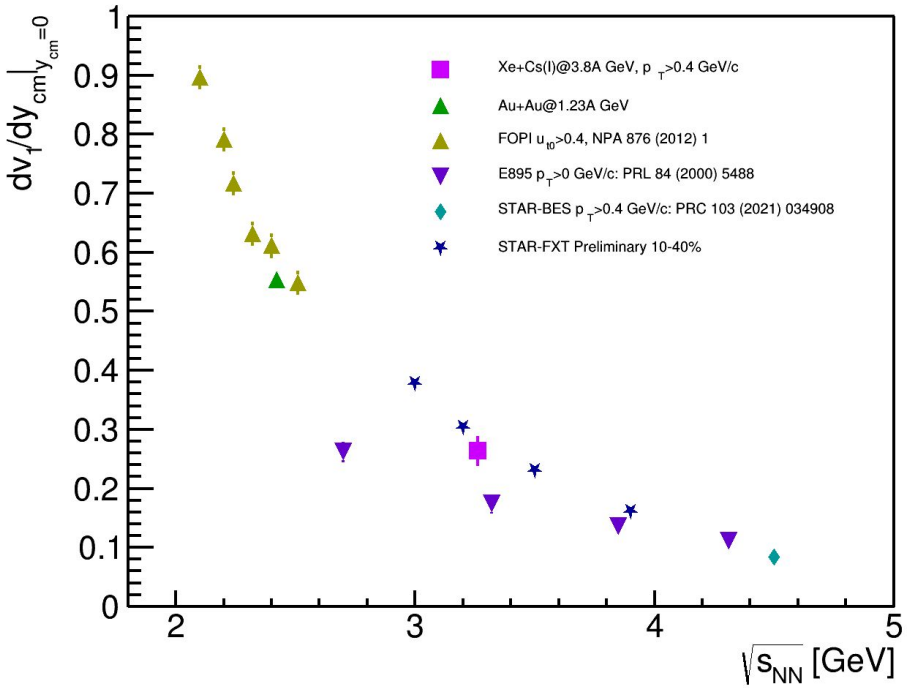


$p_0 + p_1 x + p_2 x^3$



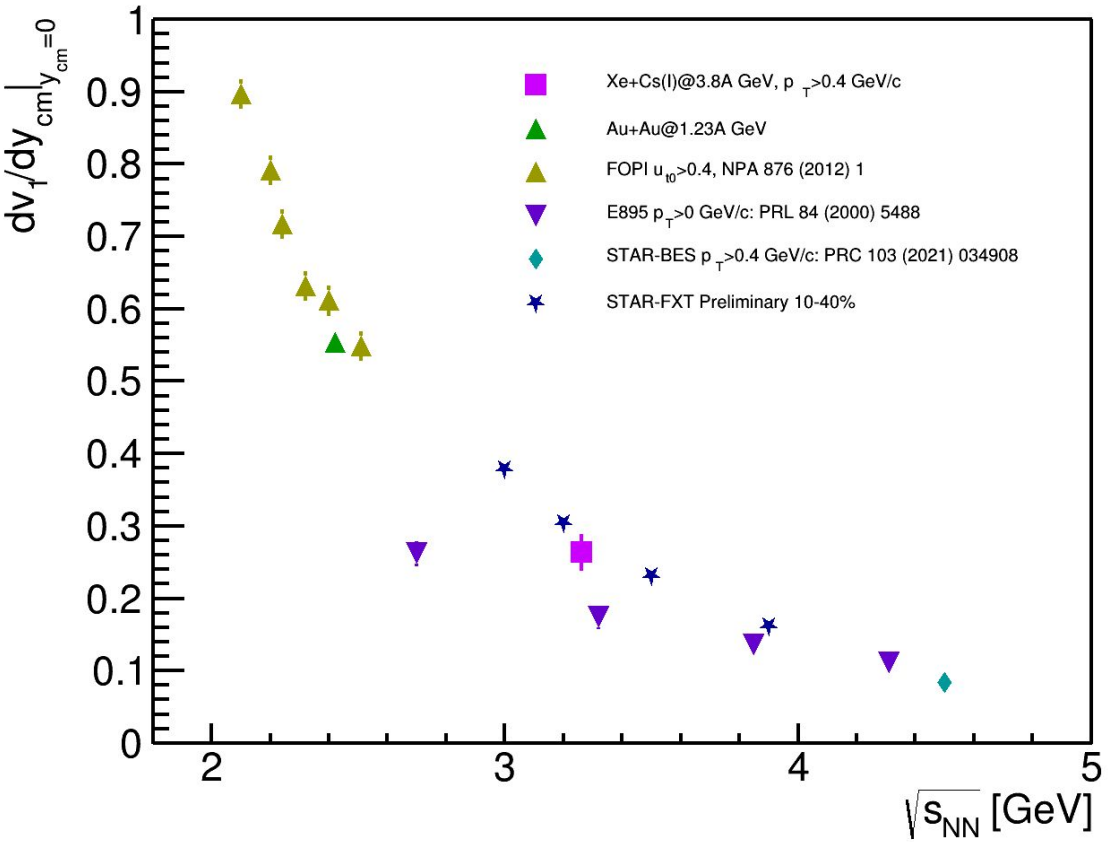
Validating the correction effects on data

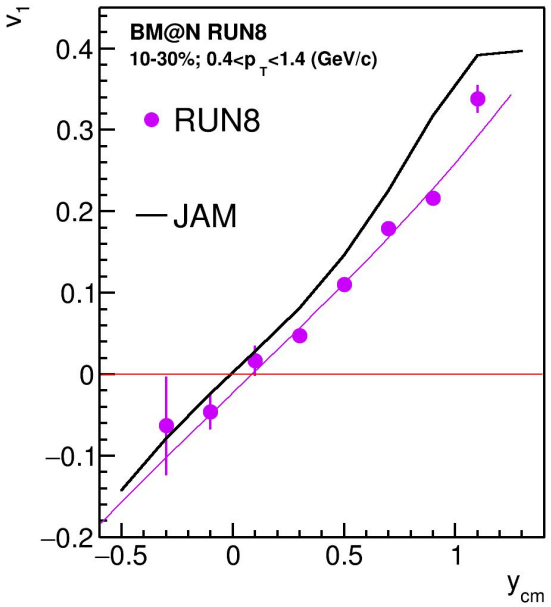




- Agreement between left and right semi-acceptances
- v_1 slope in agreement with world data

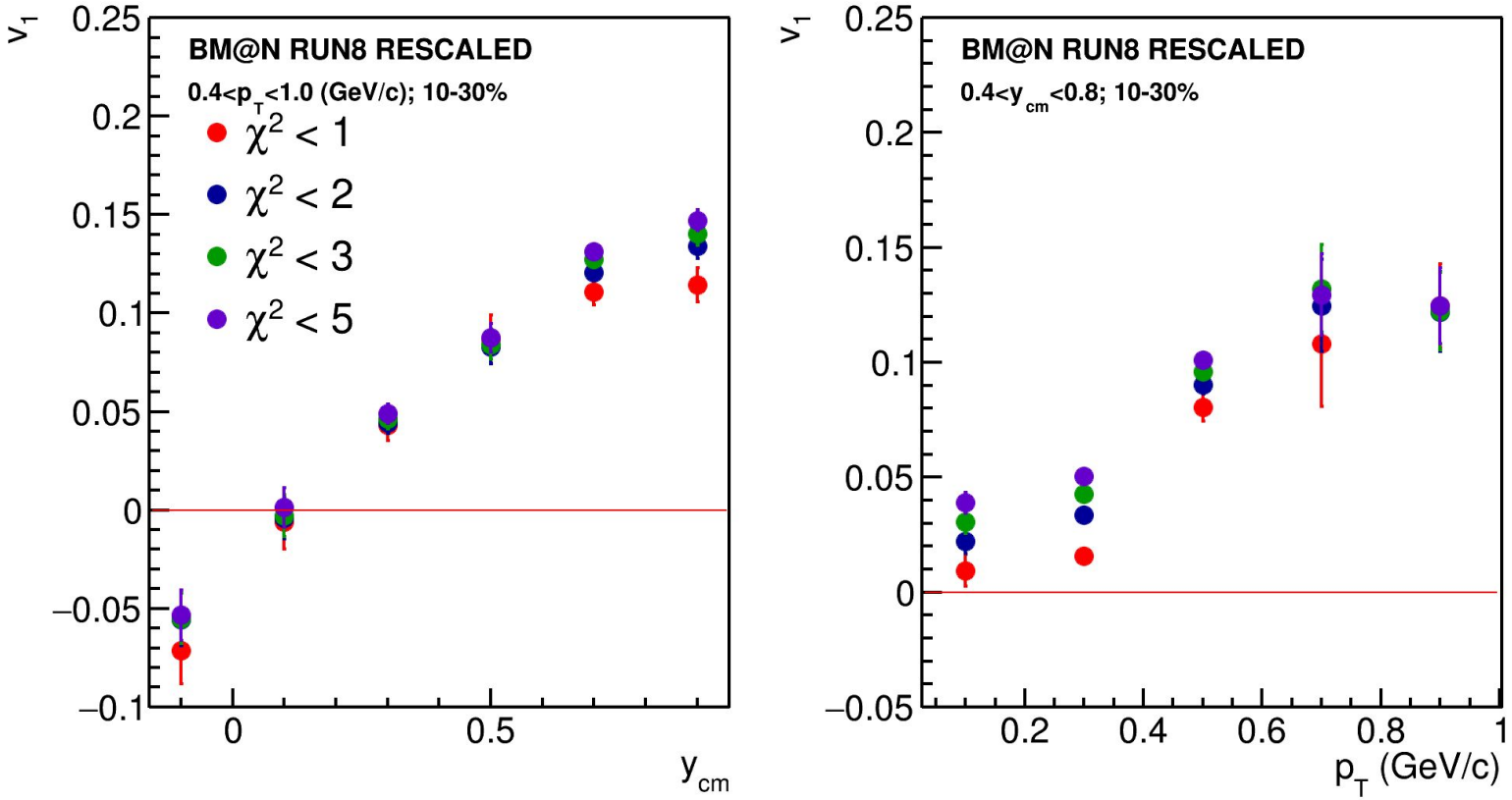
Validating the correction effects on data





v_1 slope in agreement with world data

Systematics due to chi2 cut



We observe small variation due to χ^2/ndf cut => small systematics