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

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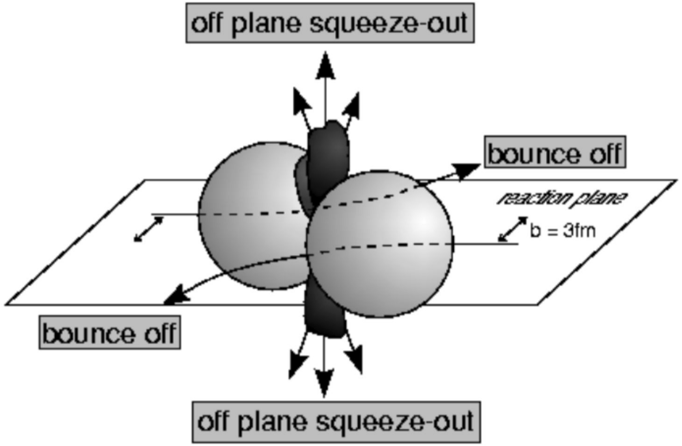
BM@N collaboration meeting, 13/05/2023

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:

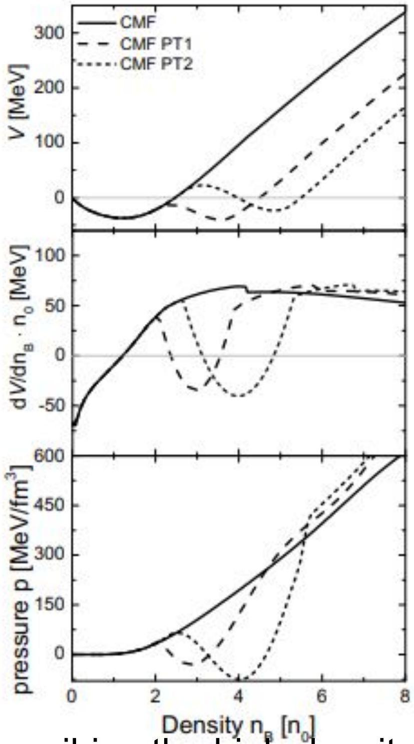
$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right]\rangle$$

Anisotropic flow is sensitive to:

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

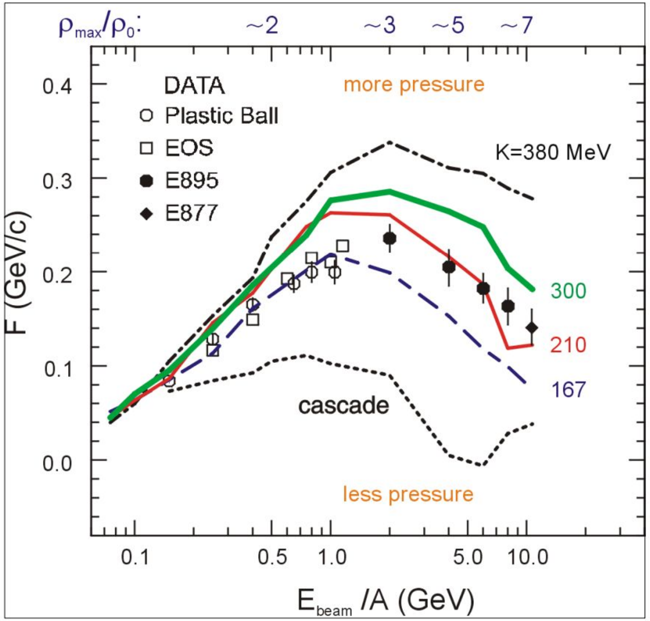
v_n as a function of collision energy

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

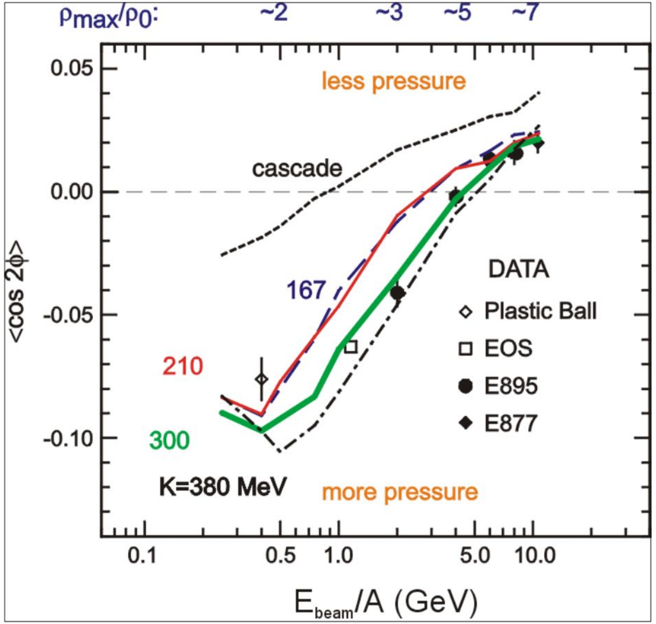


EPJ Web of Conferences 276, 01021 (2023)

v_1 suggests softer EOS



v_2 suggests harder EOS

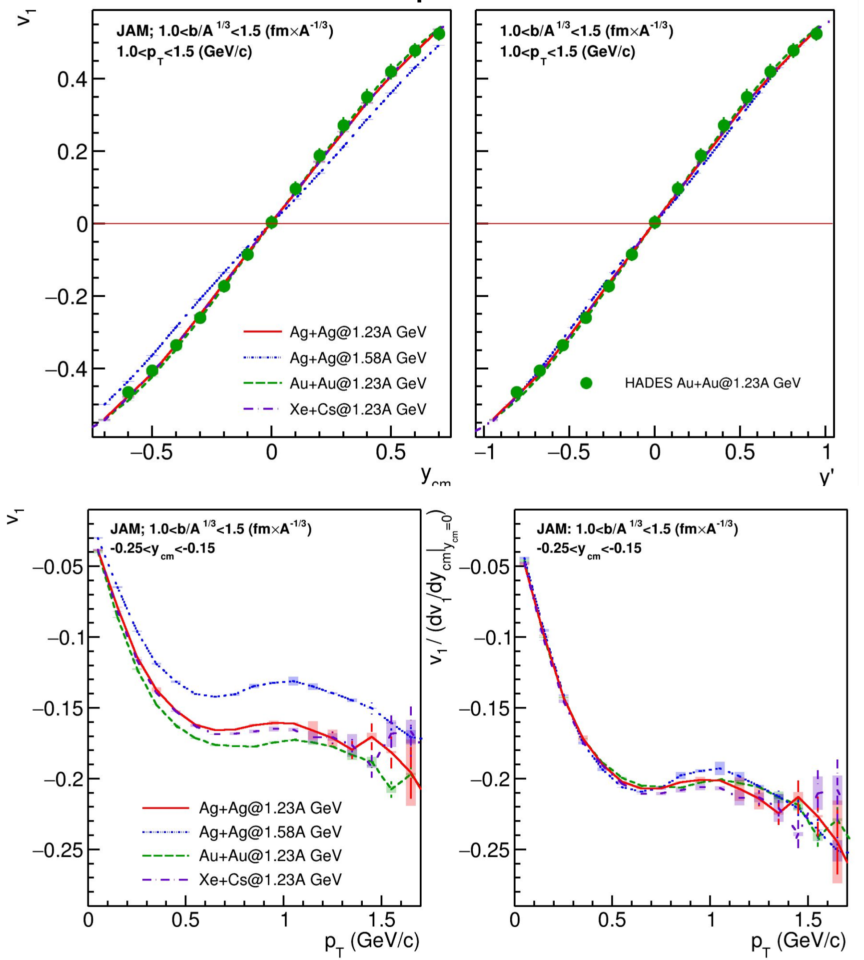


Describing the high-density matter using the mean field

Flow measurements constrain the mean field

Discrepancy is probably due to non-flow correlations

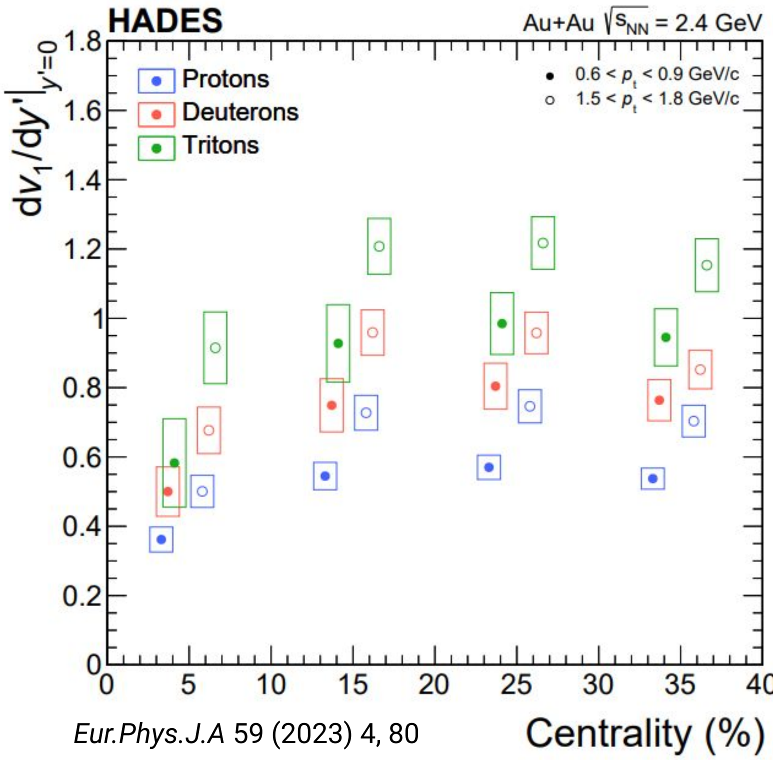
HADES: dv_1/dy scaling with collision energy and system size



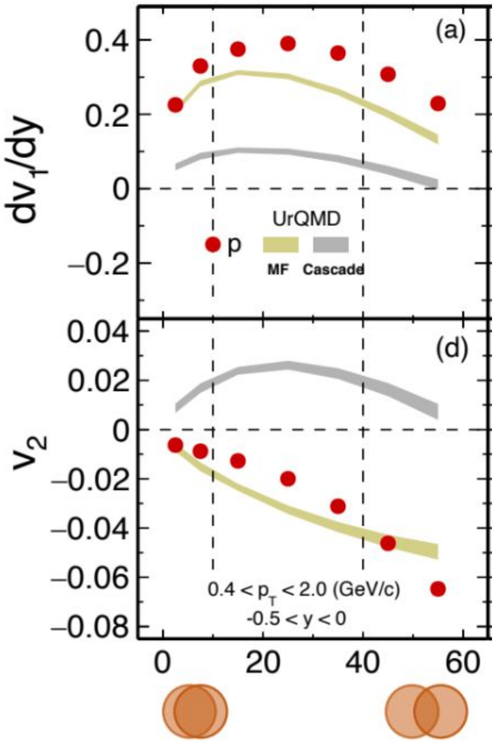
- Scaling with collision energy is observed in model and experimental data
- Scaling with system size is observed in model and experimental data
- We can compare the results with HIC-data from other experiments(e.g. STAR-FXT Au+Au

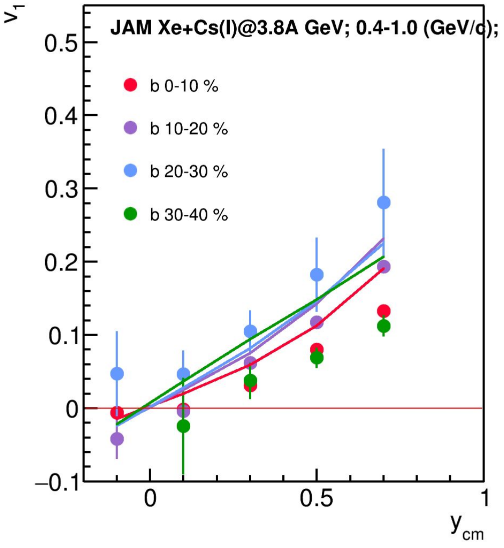
M.Mamaev Particles 2023, 6(2), 622-637

dv_1/dy as a function of centrality



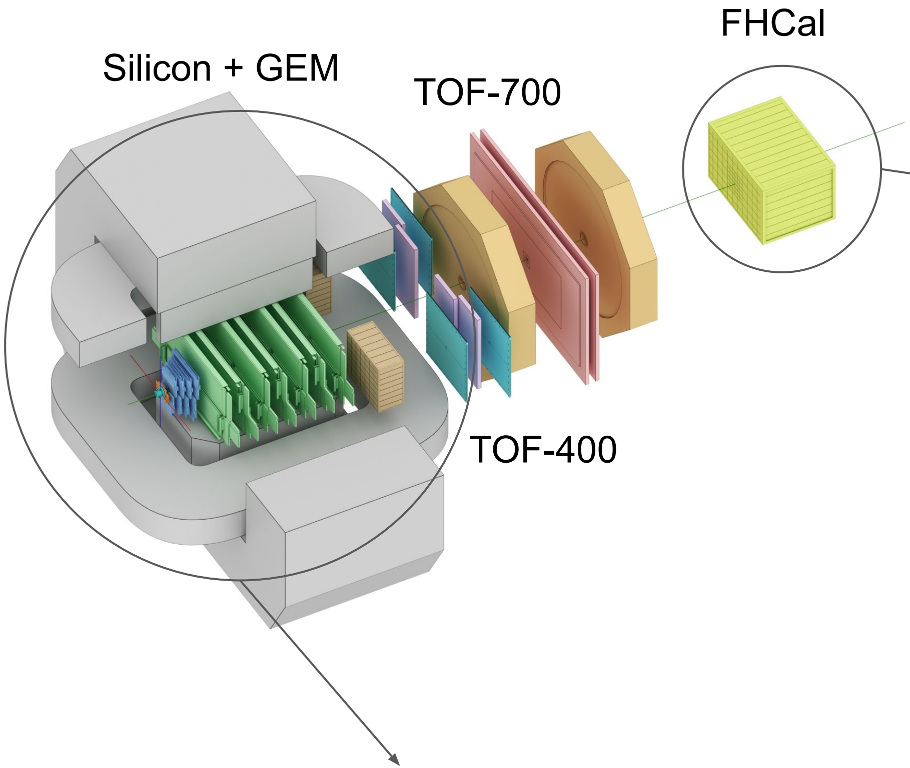
Eur.Phys.J.A 59 (2023) 4, 80

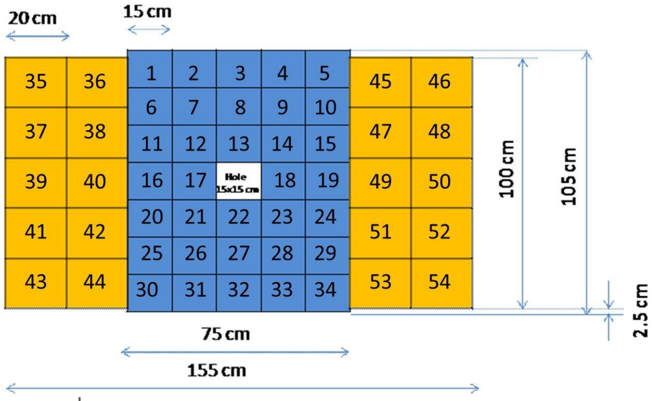


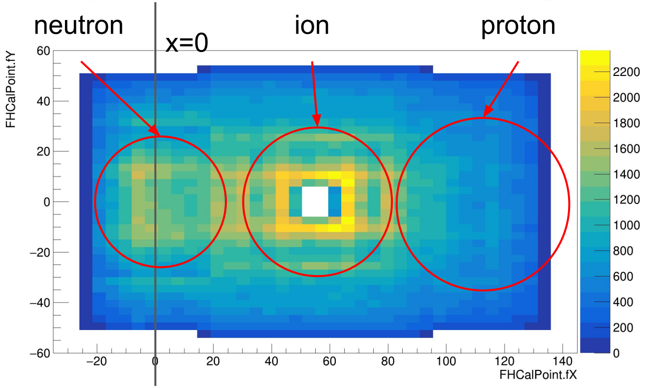


Weak centrality dependence for directed flow

The BM@N experiment (GEANT4 simulation for RUN8)







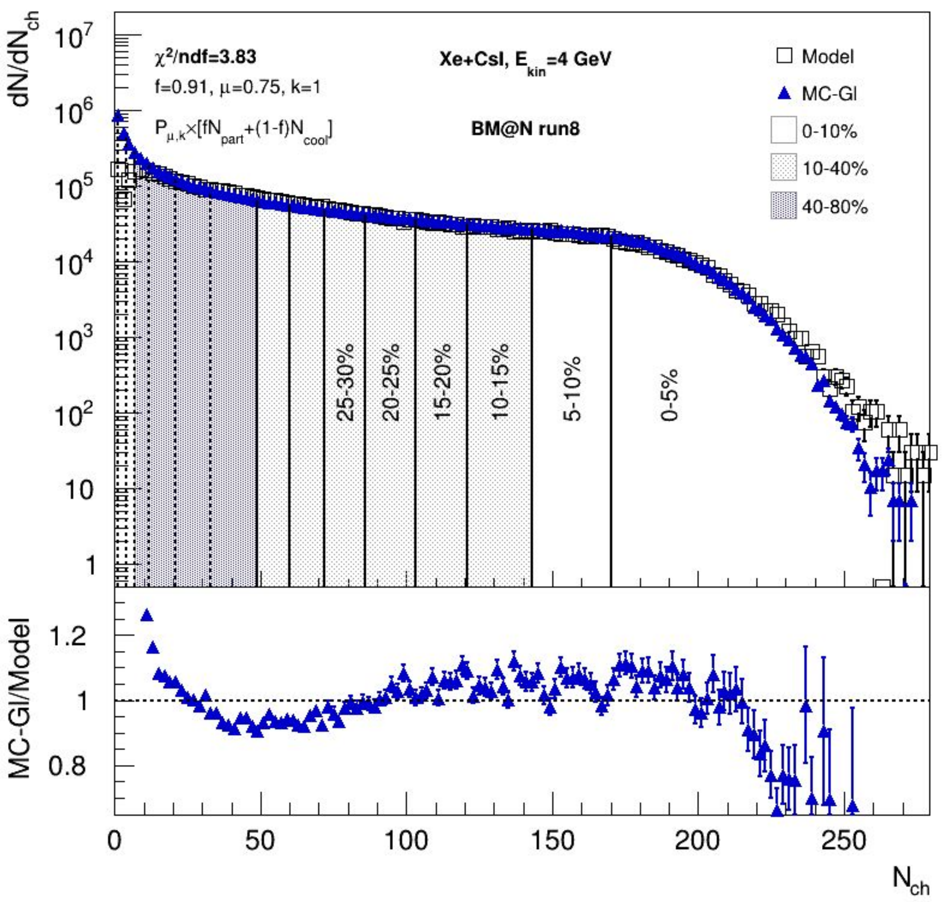
VF tracking was used

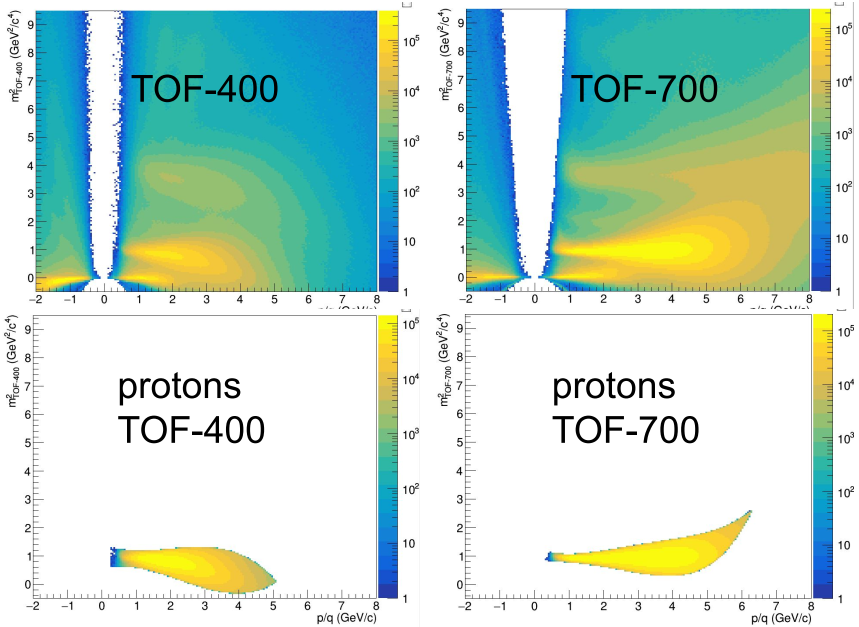
Symmetry plane estimation with the azimuthal asymmetry of projectile spector energy

The first production was used

Centrality and particle selection

February production





- 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:

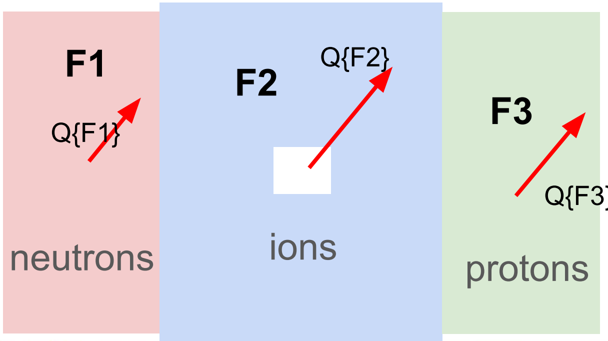
$$u_n = e^{in\phi}$$

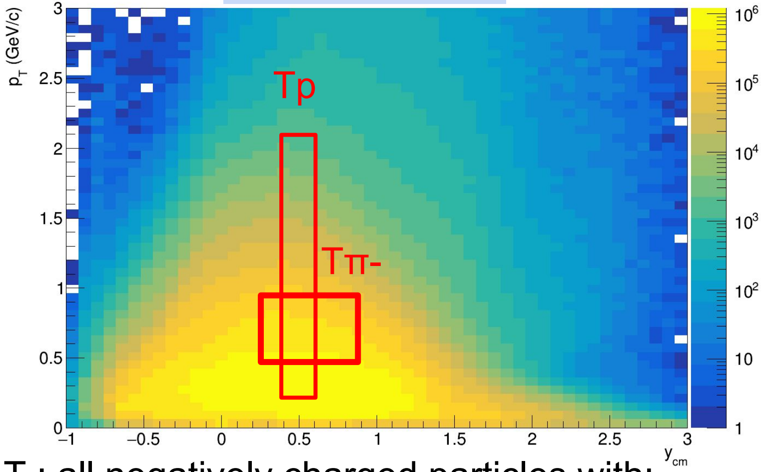
where φ is the azimuthal angle

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

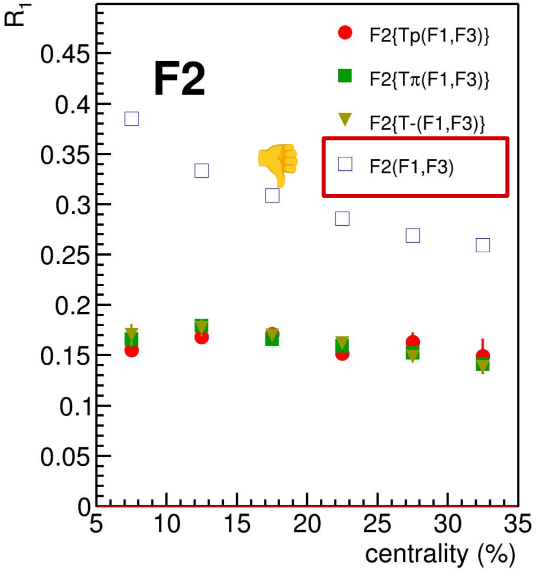
Scalar product (SP) method:

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

Where R_1 is the resolution correction factor

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

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



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

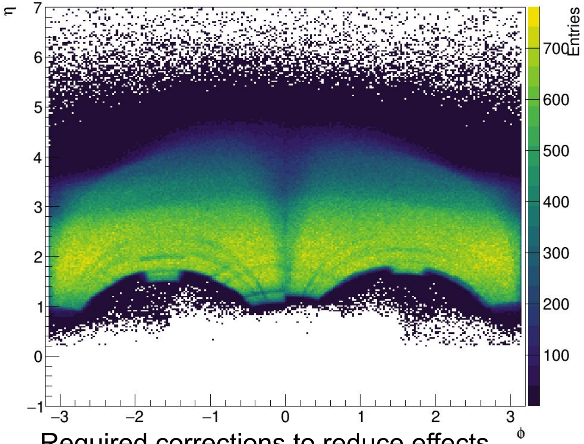
$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

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

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

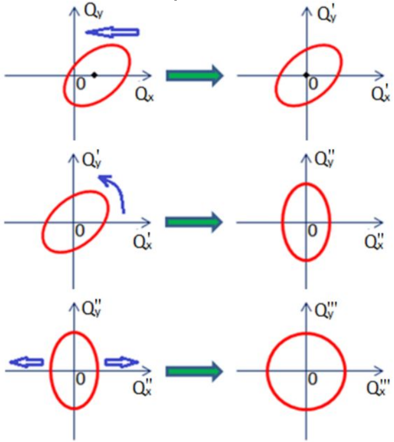
Azimuthal asymmetry of the BM@N acceptance

φ-η yield of protons

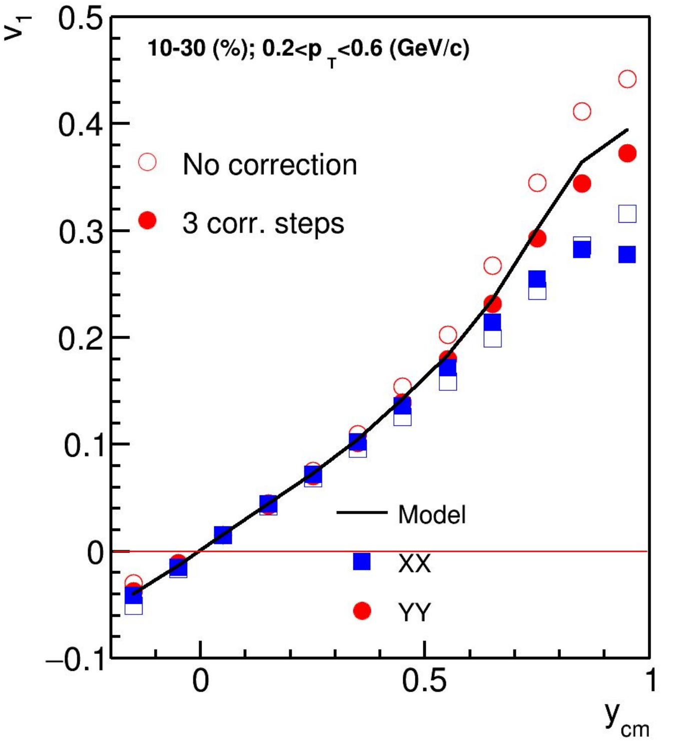


Required corrections to reduce effects of non-uniform azimuthal acceptance

1. Recentering
2. Twist
3. Rescaling

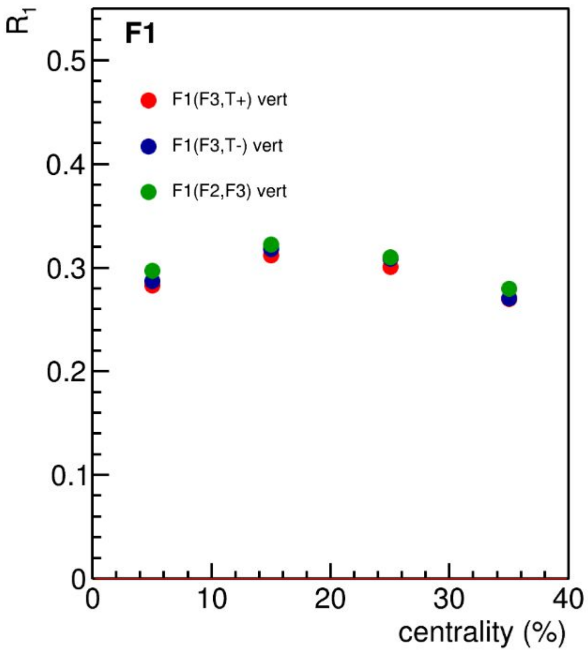


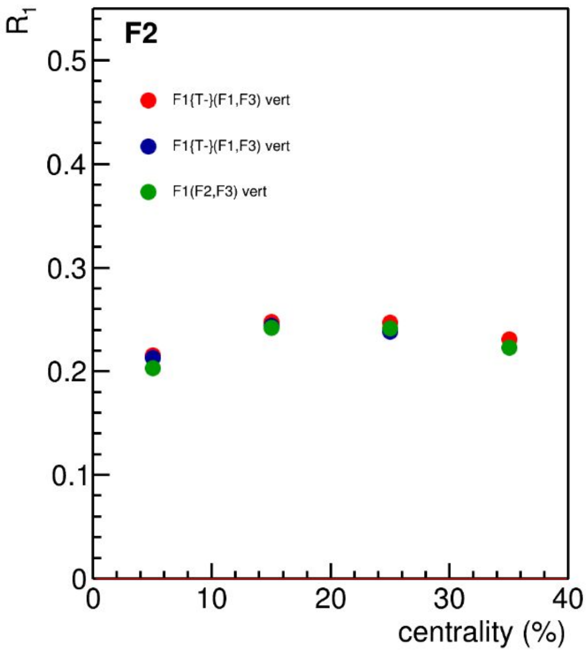
Corrections are based on method in:
I. Selyuzhenkov and S. Voloshin PRC77, 034904 (2008)

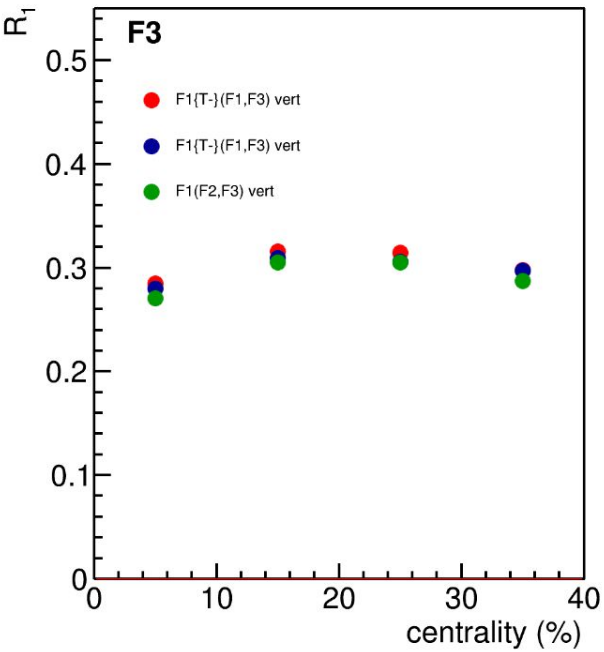


- Better agreement after rescaling for YY
- XX component has too large bias (due to magnetic field)

Symmetry plane resolution in Xe+Cs(I) collisions

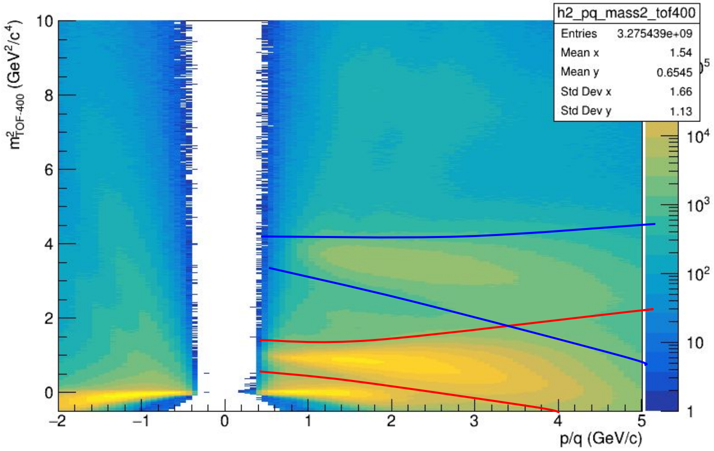




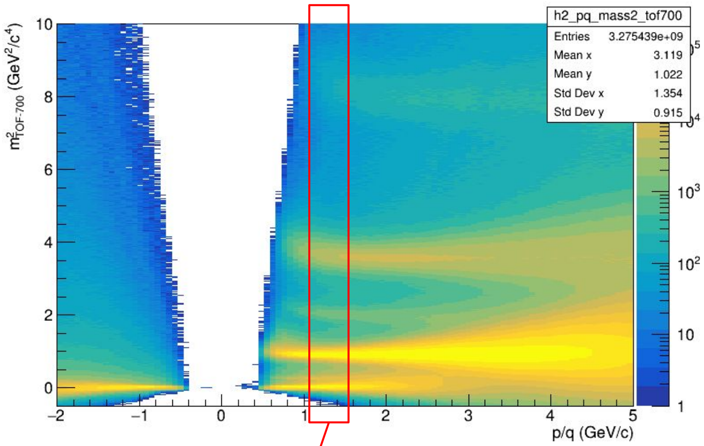


All the estimations for symmetry plane resolutions are in a good agreement

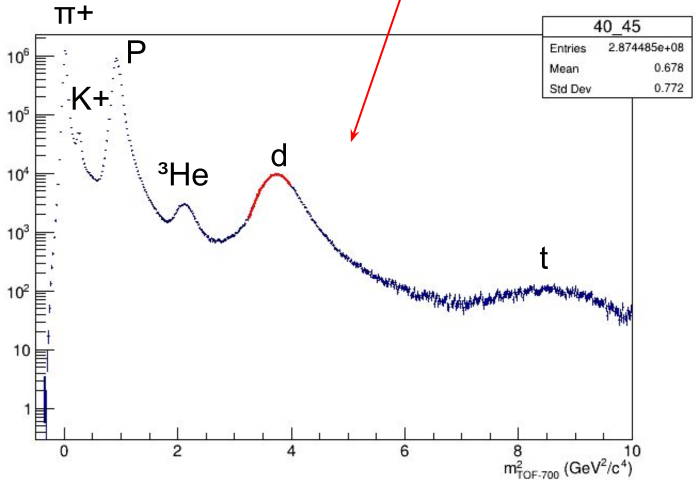
Identification procedure



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



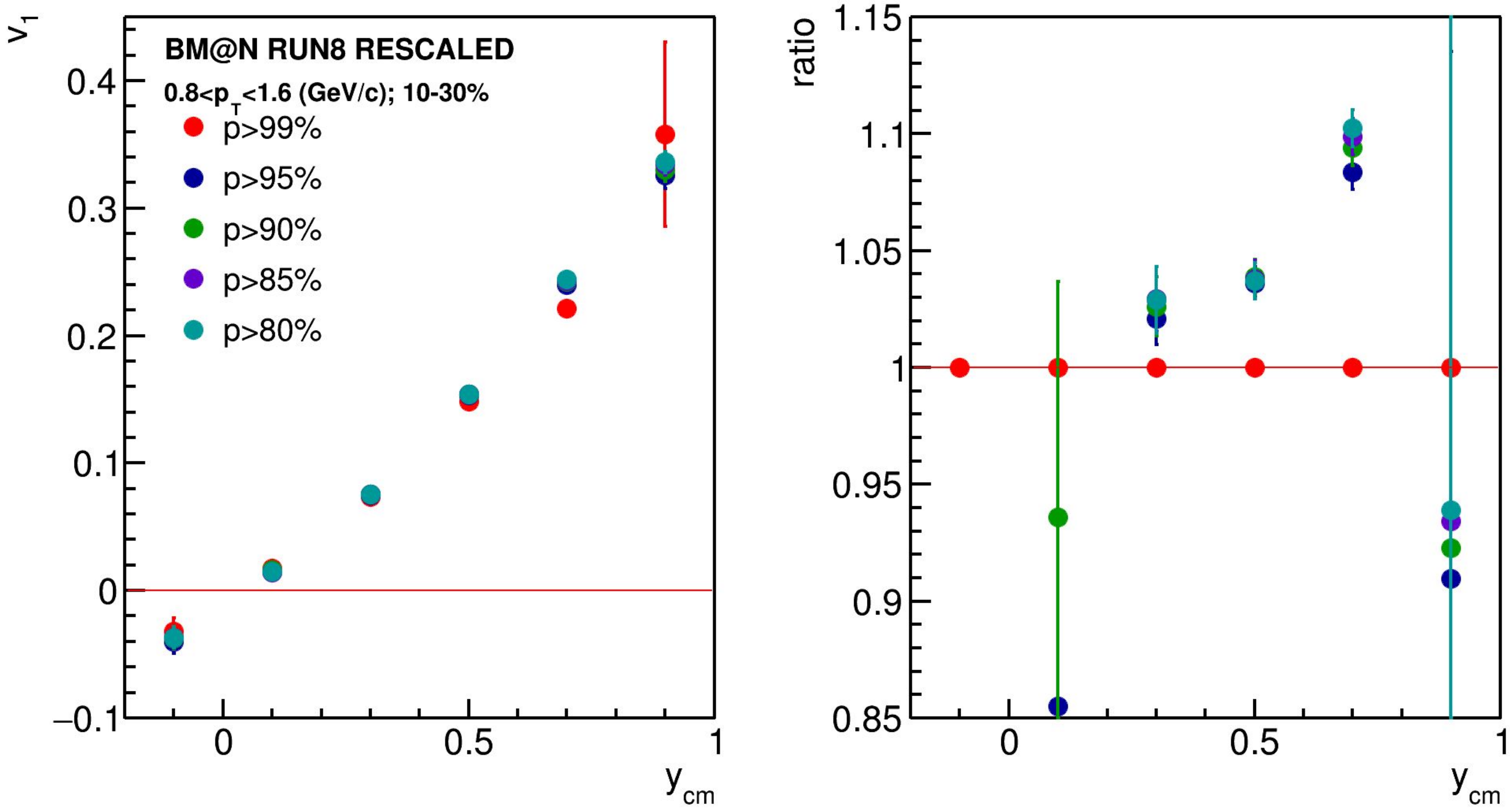
- Mass squared distribution is fitted in narrow bins of p/q
- Protons, pions, deuterons, tritons and helium are fitted



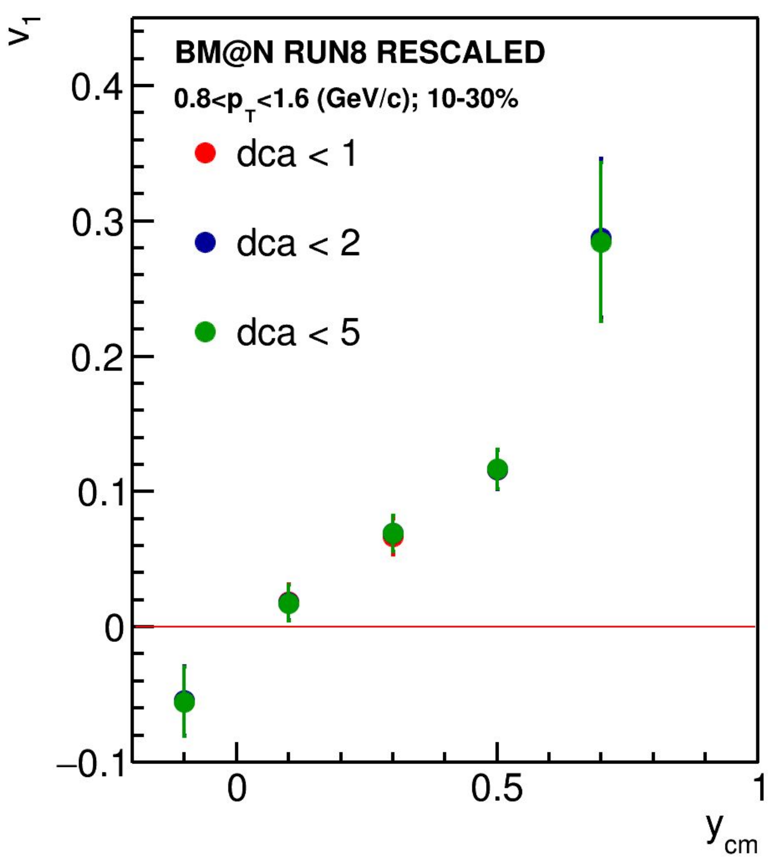
Purity is the function showing possible contamination

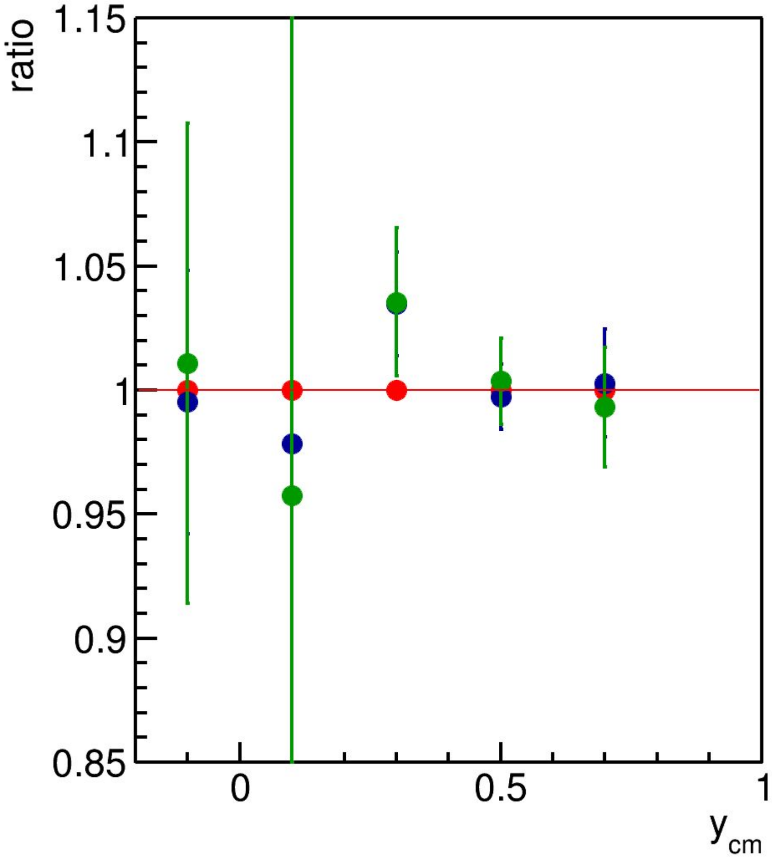
$$p_i(m^2, p/q) = \frac{f_i(m^2, p/q)}{\sum_{i=1}^{N} f_i(m^2, p/q)}$$

Systematics due to identification

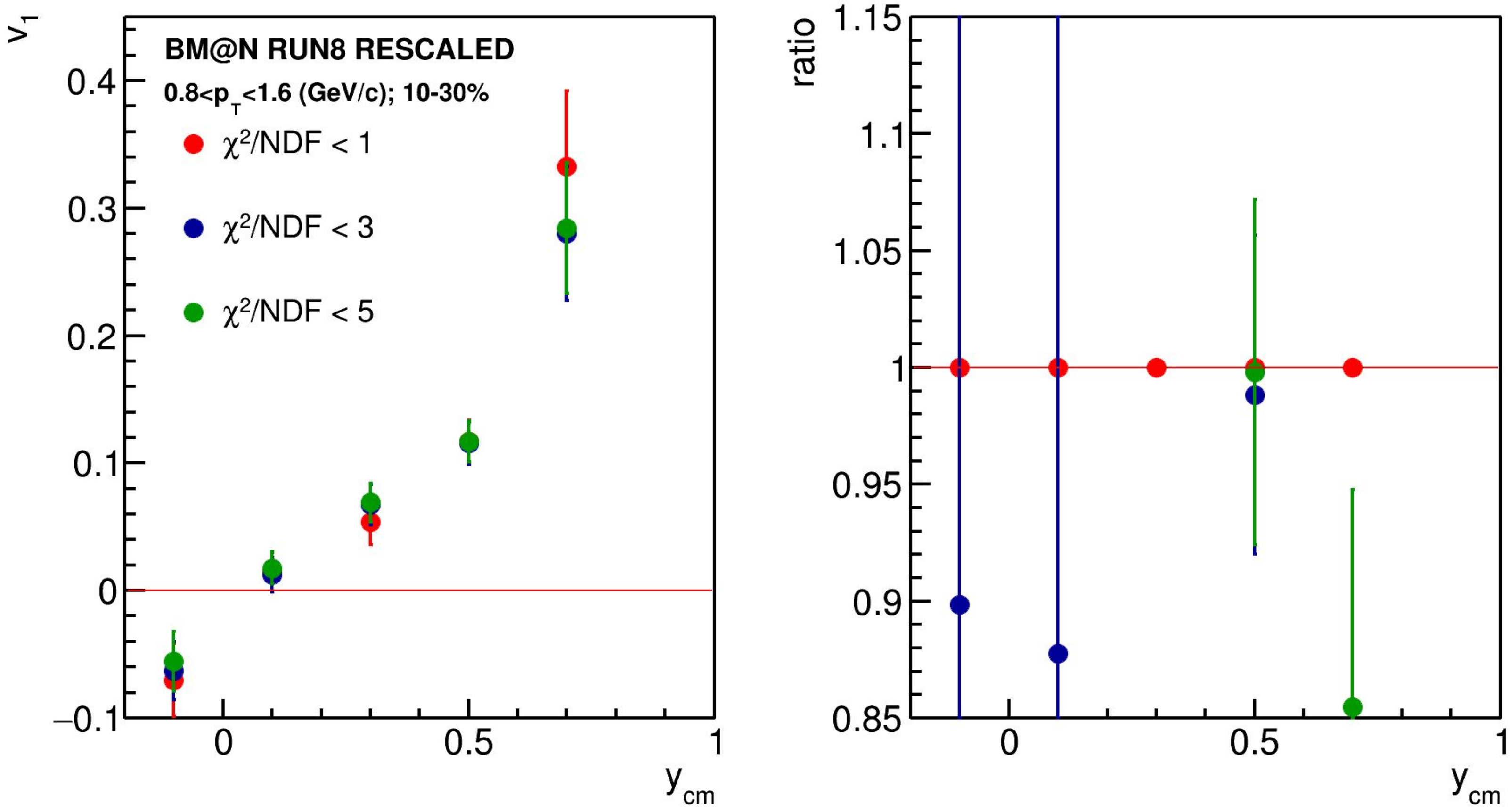


Systematics due to identification (partial statistics)

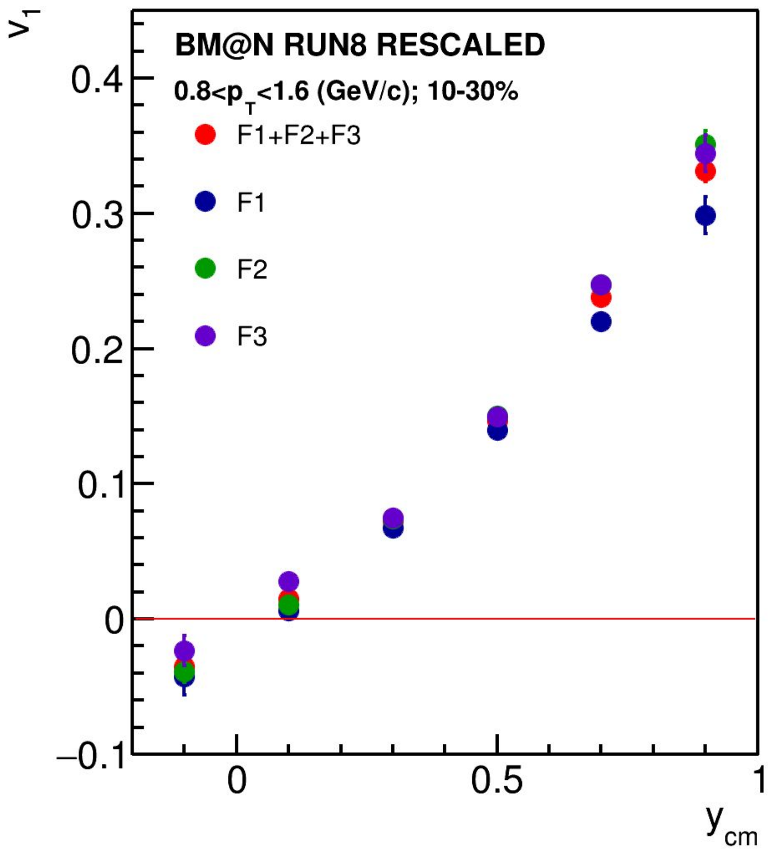


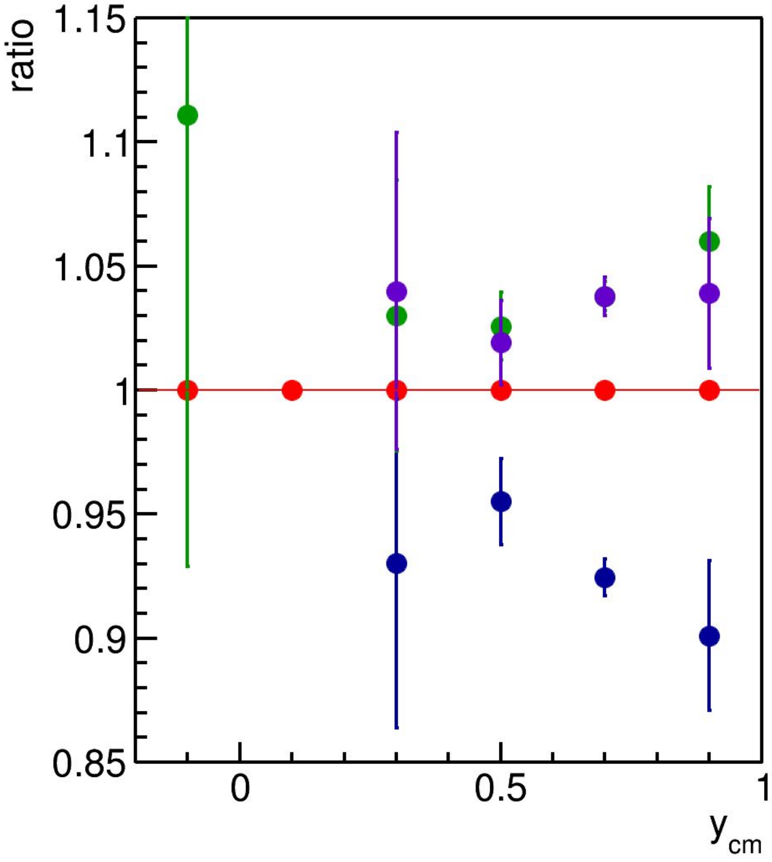


Systematics due to tracking inefficiency (partial statistics)

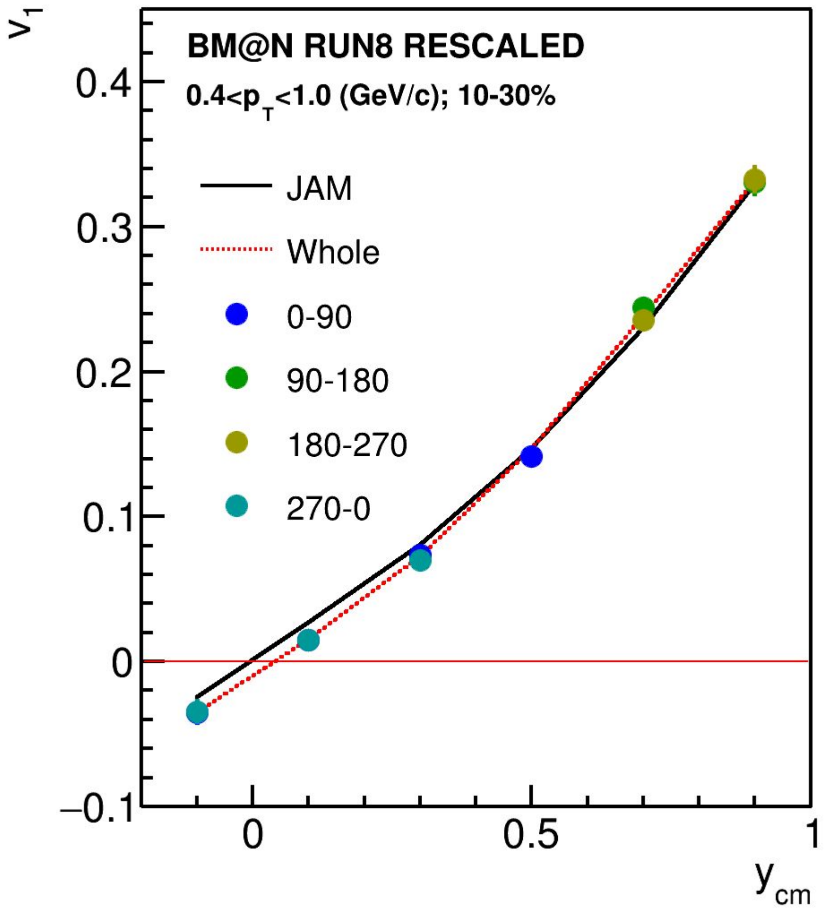


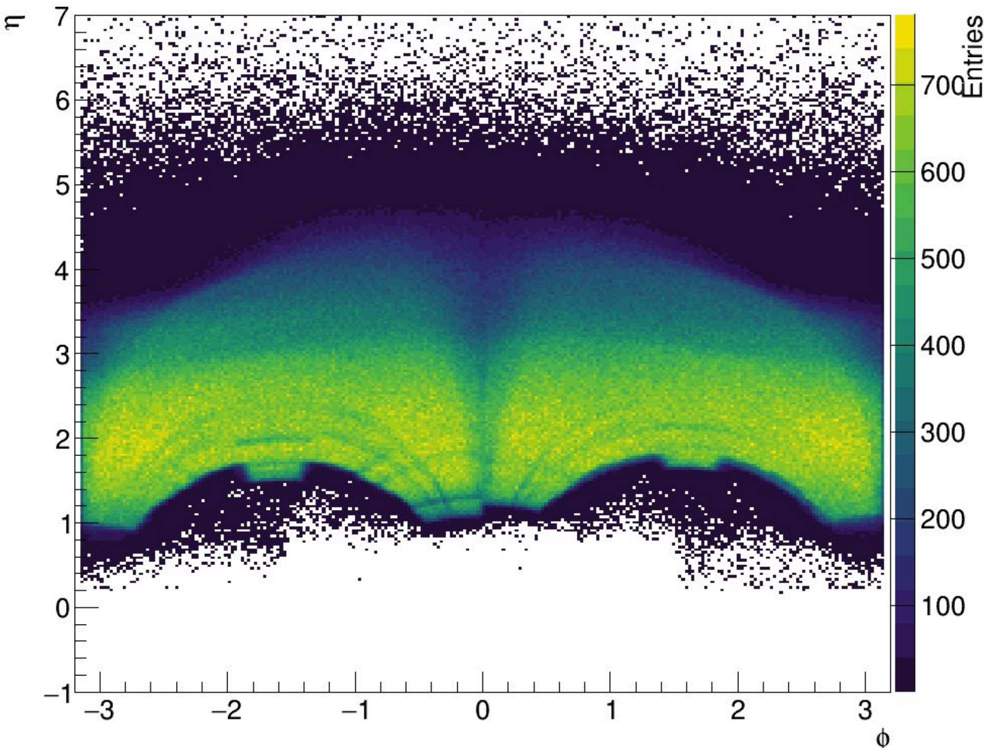
Systematics due to symmetry plane selection



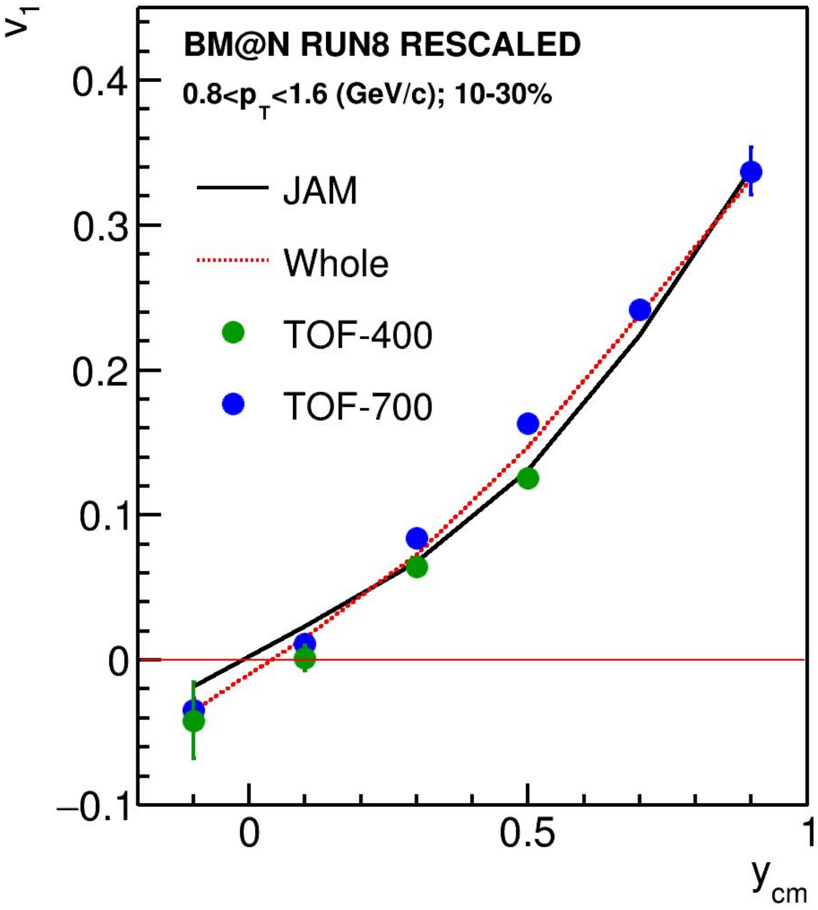


Residual effects of detector non-uniformity

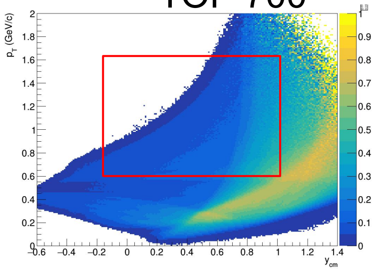


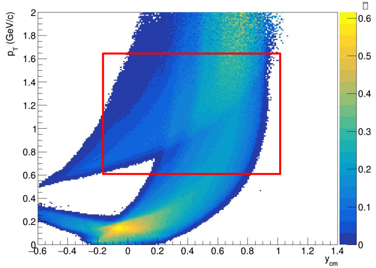


v_1 for protons identifies with TOF-400 and TOF-700

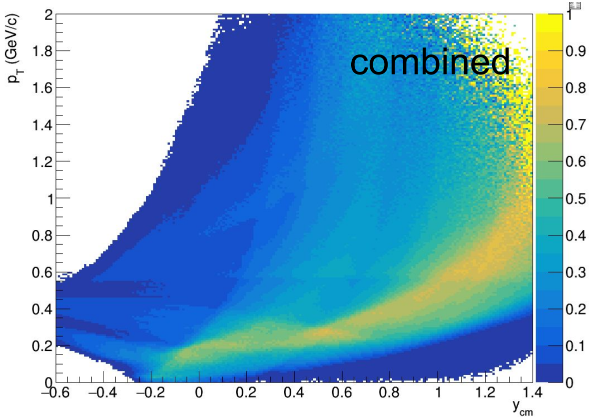


TOF-700





TOF-400

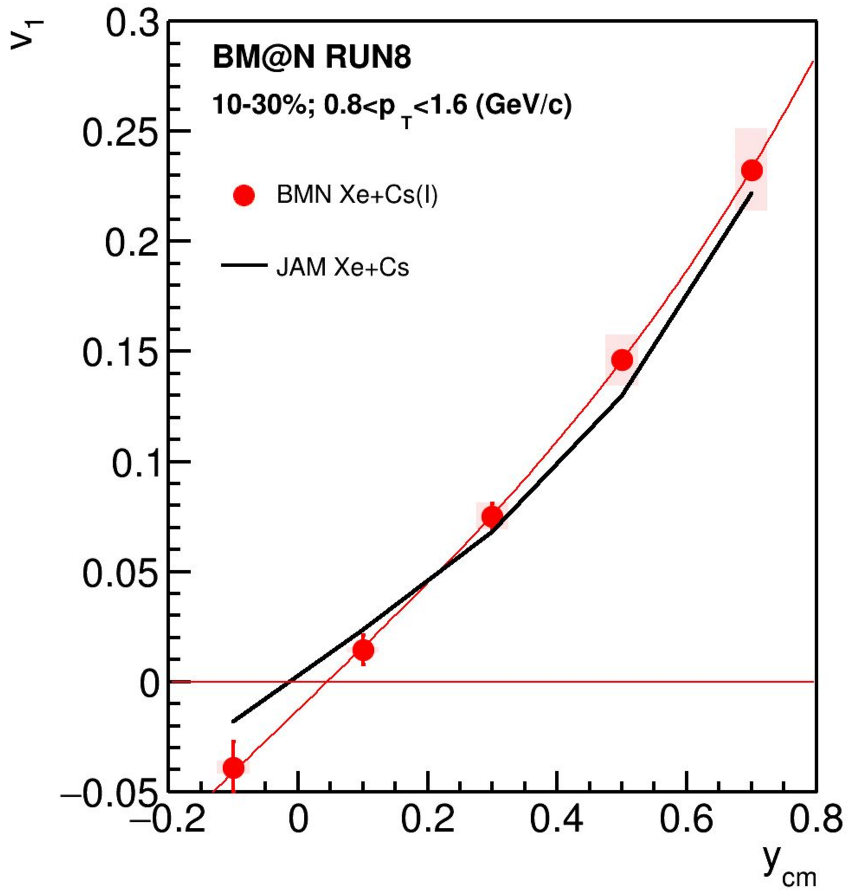


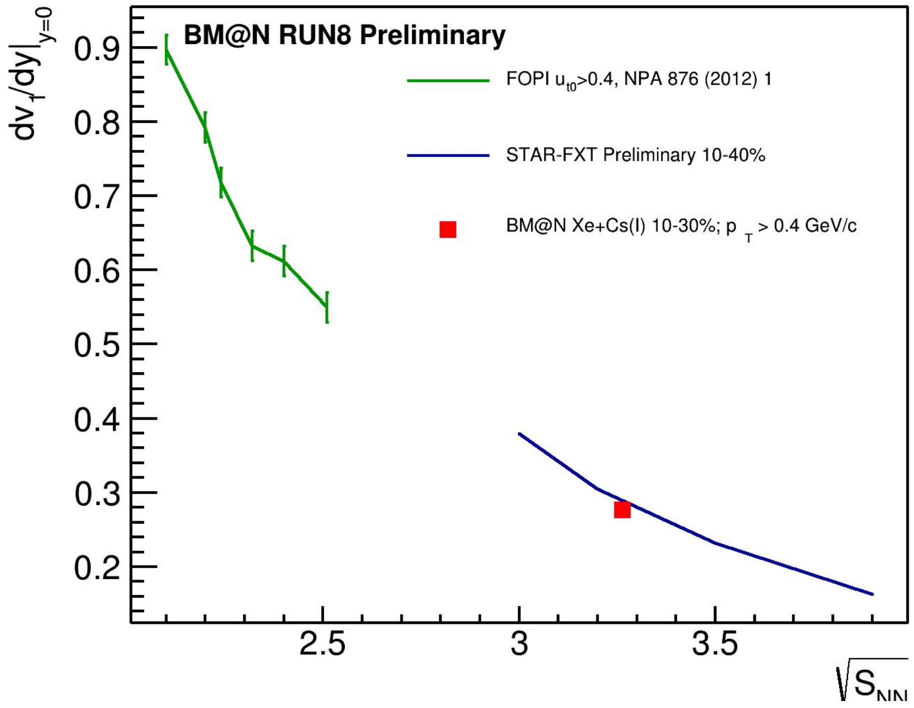
Systematic errors on partial statistics

Tracking	Identification (purity)	Secondary	Non-flow	Non-zero v_1 at y_{cm}=0	Total
Less than stat.	5%	2%	5%	2%	8%

Additional sources of systematics will be added

v_1 as a function of p_T and y_{cm}

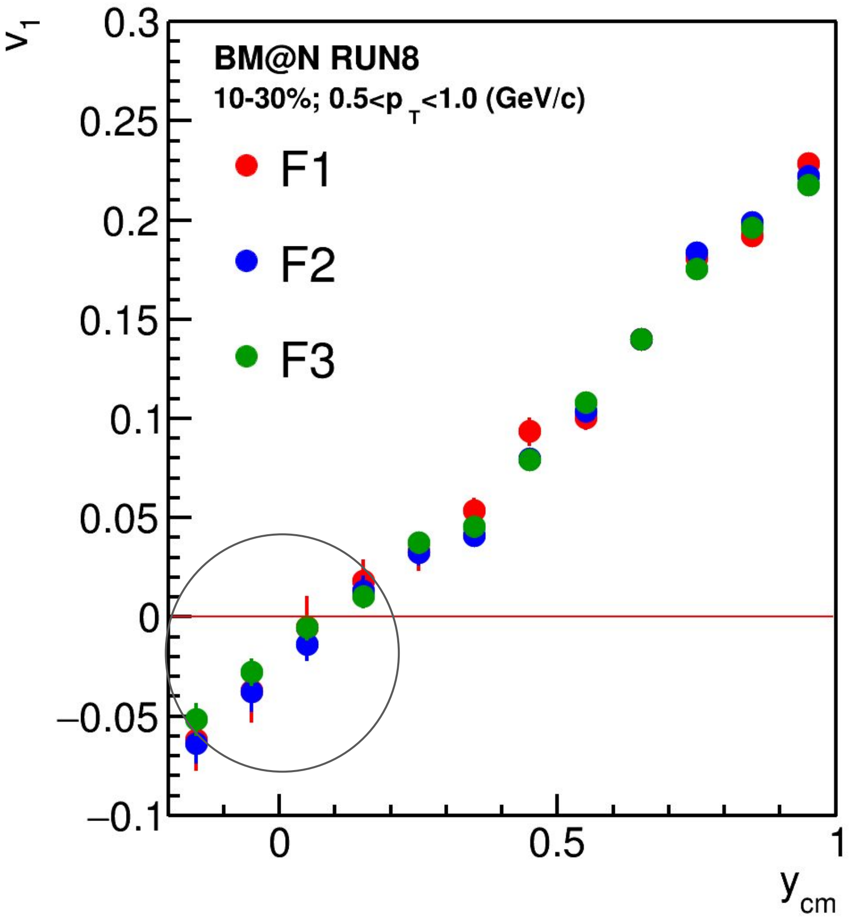


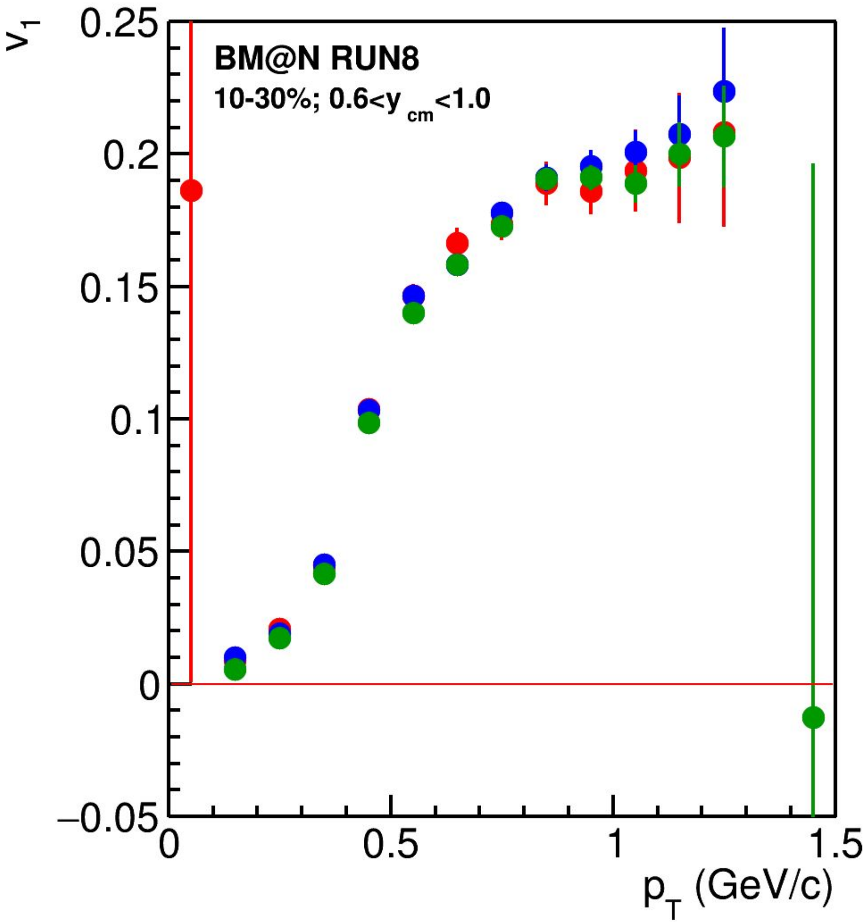


Summary

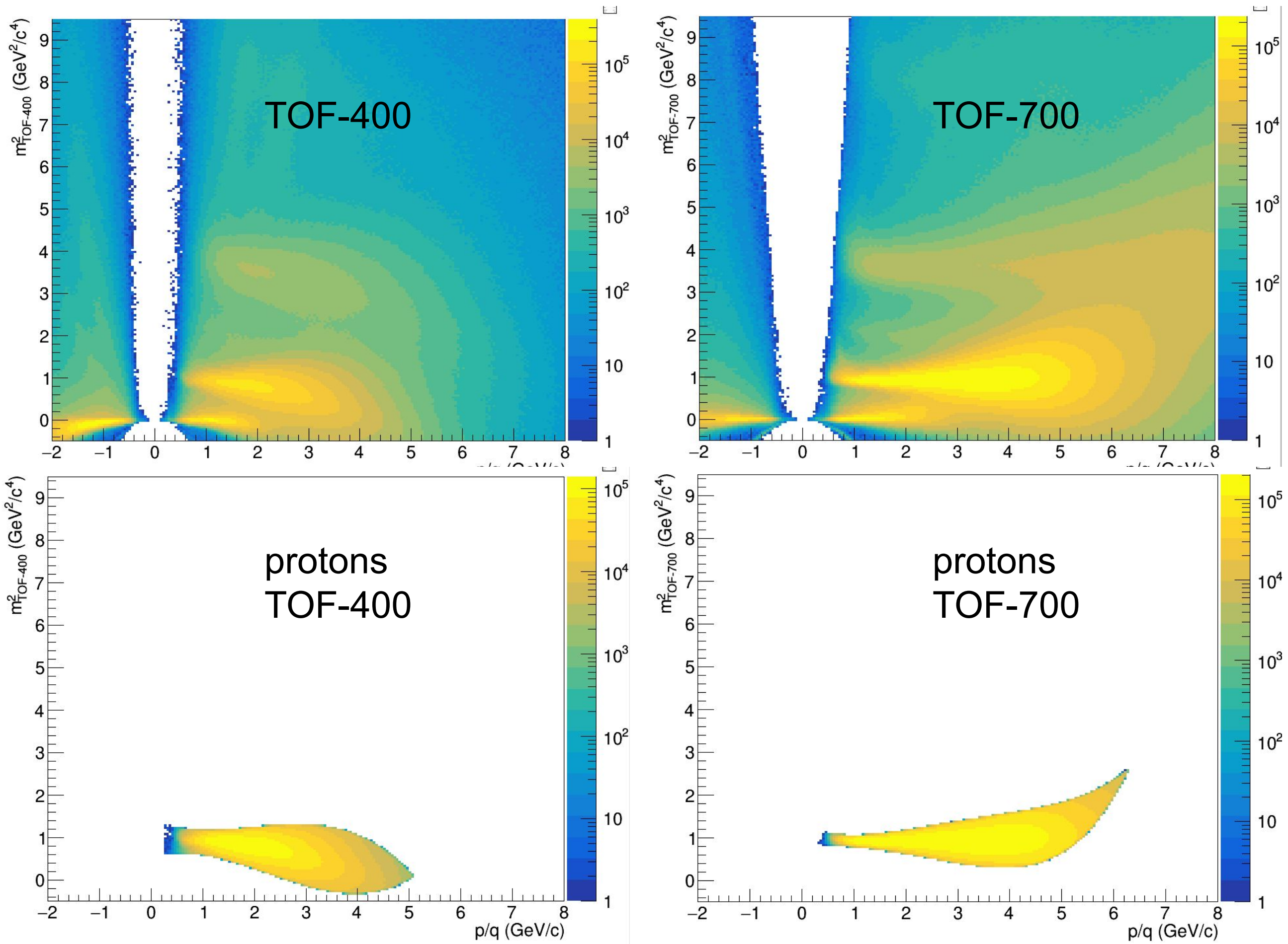
- New layout for the FHCal sub-events yields in larger resolution correction factor for all three sub-events
- v_1 systematics was studied varying the track selection criteria: small systematic errors is observed
- Measured v_1 is in agreement with JAM data for larger p_T values
- Slope of the directed 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





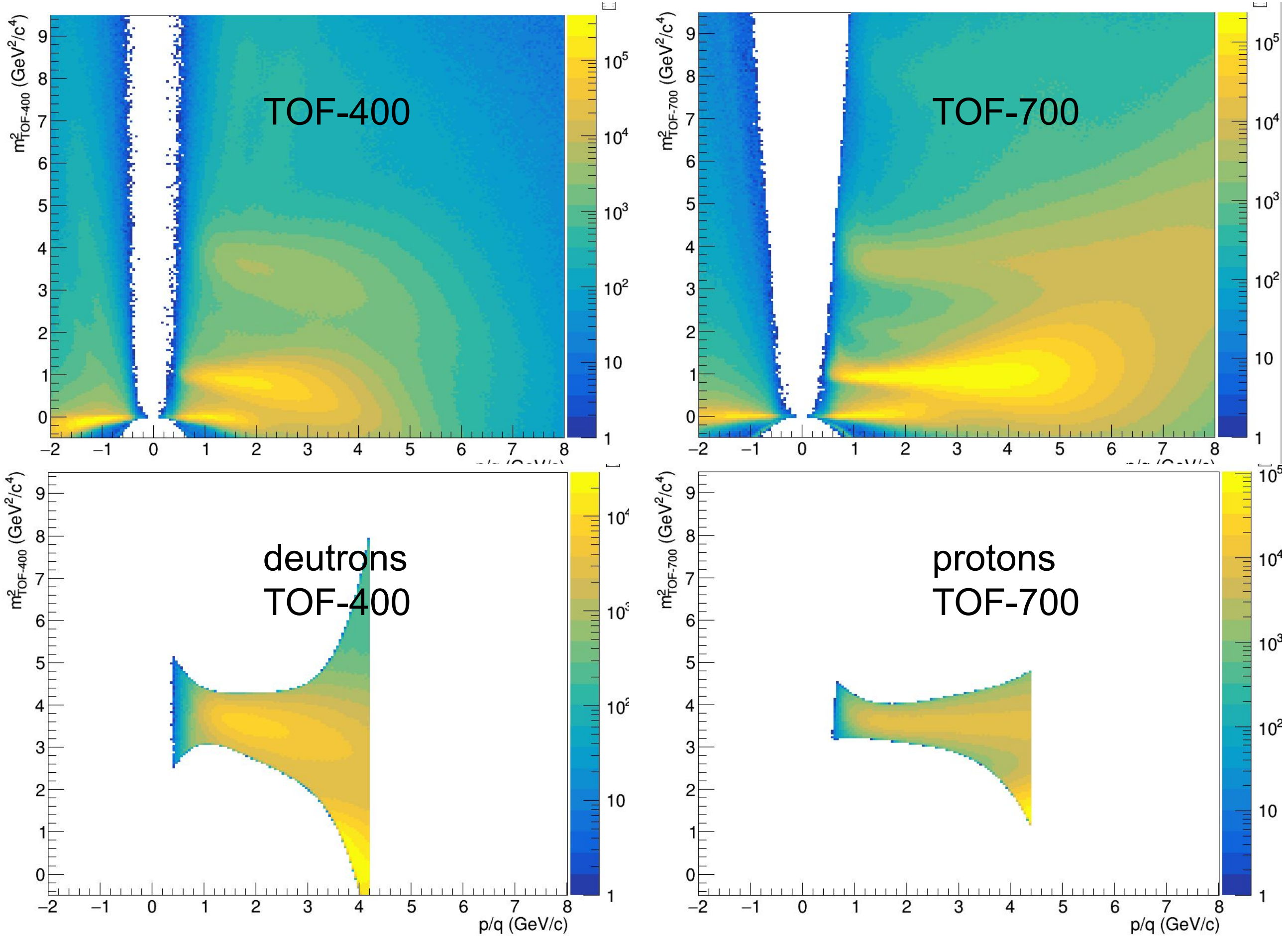
Proton identification



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

Selection criteria: <m>±2σ

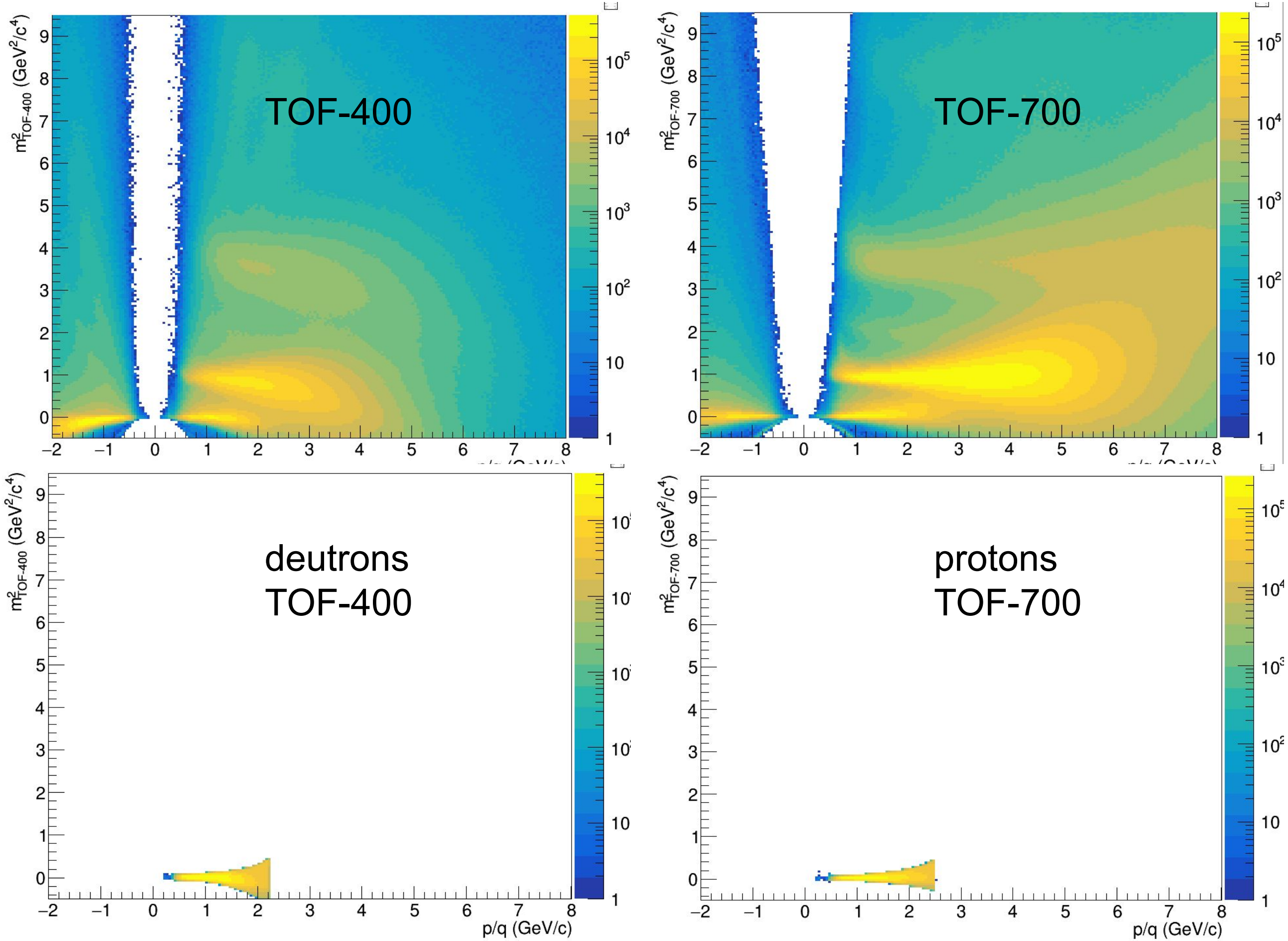
Deutron identification



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

Selection criteria: <m>±2σ

Positive pions identification

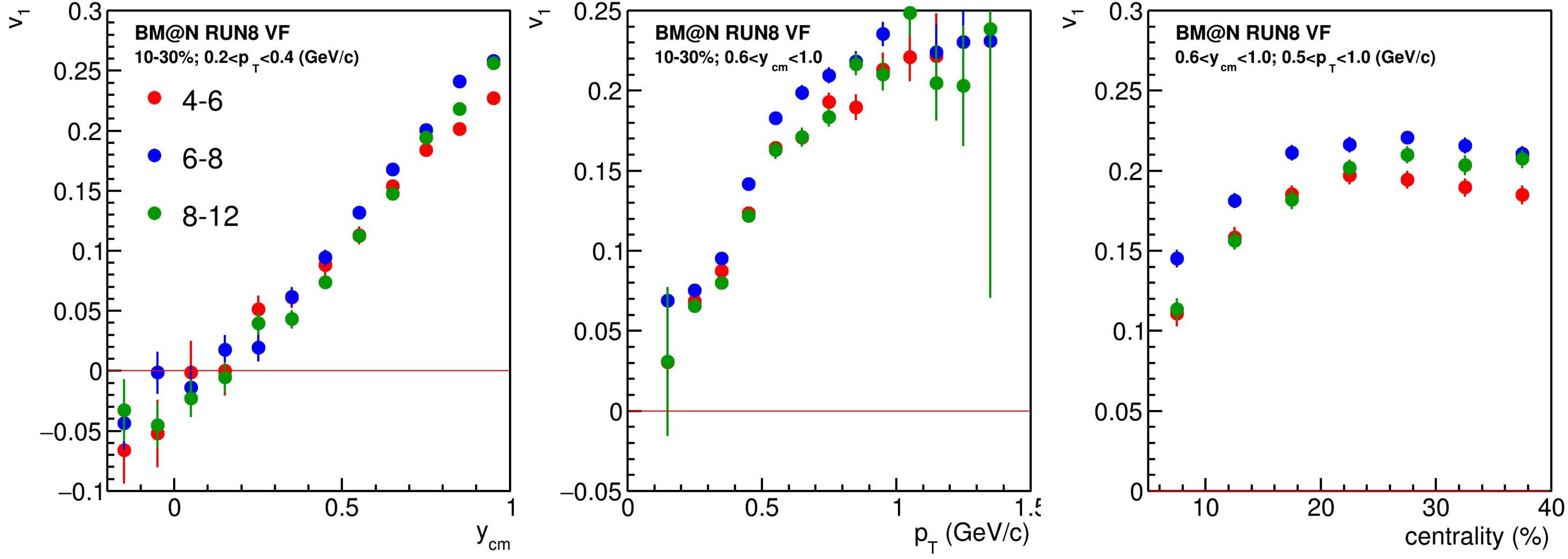


Proton candidates were selected with fitting the m^2 vs p\q

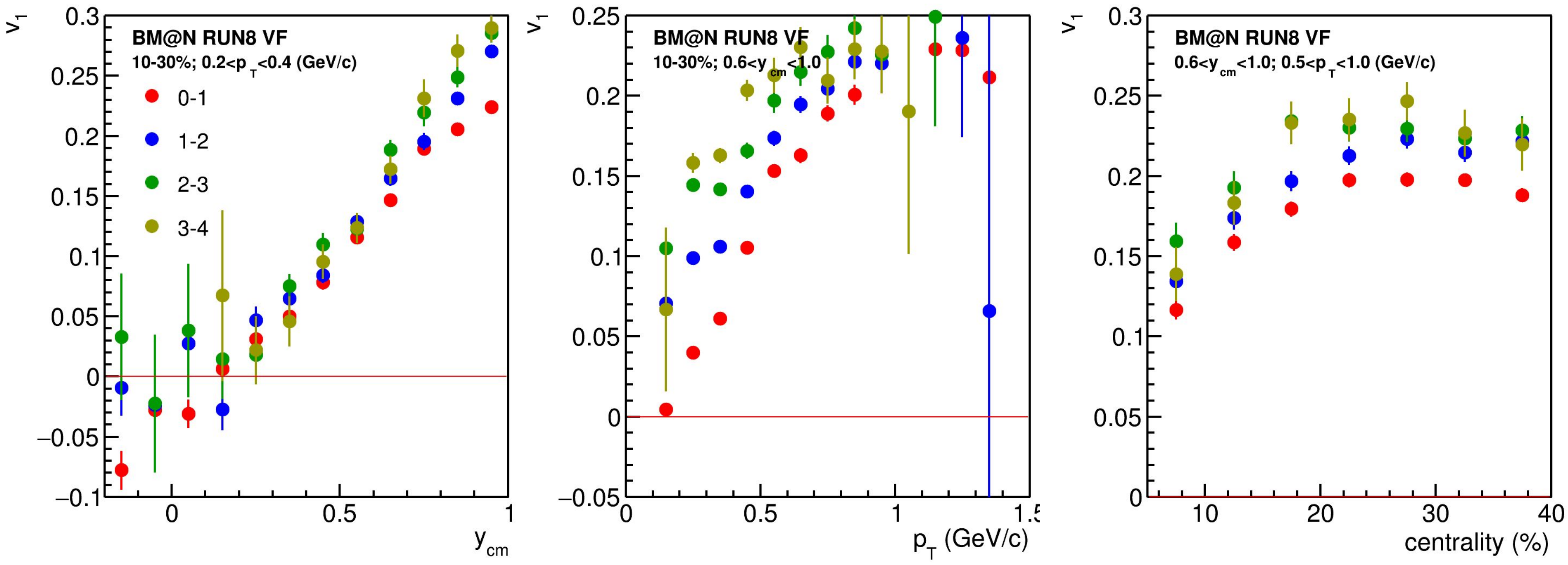
Selection criteria: <m>±2σ

Backup

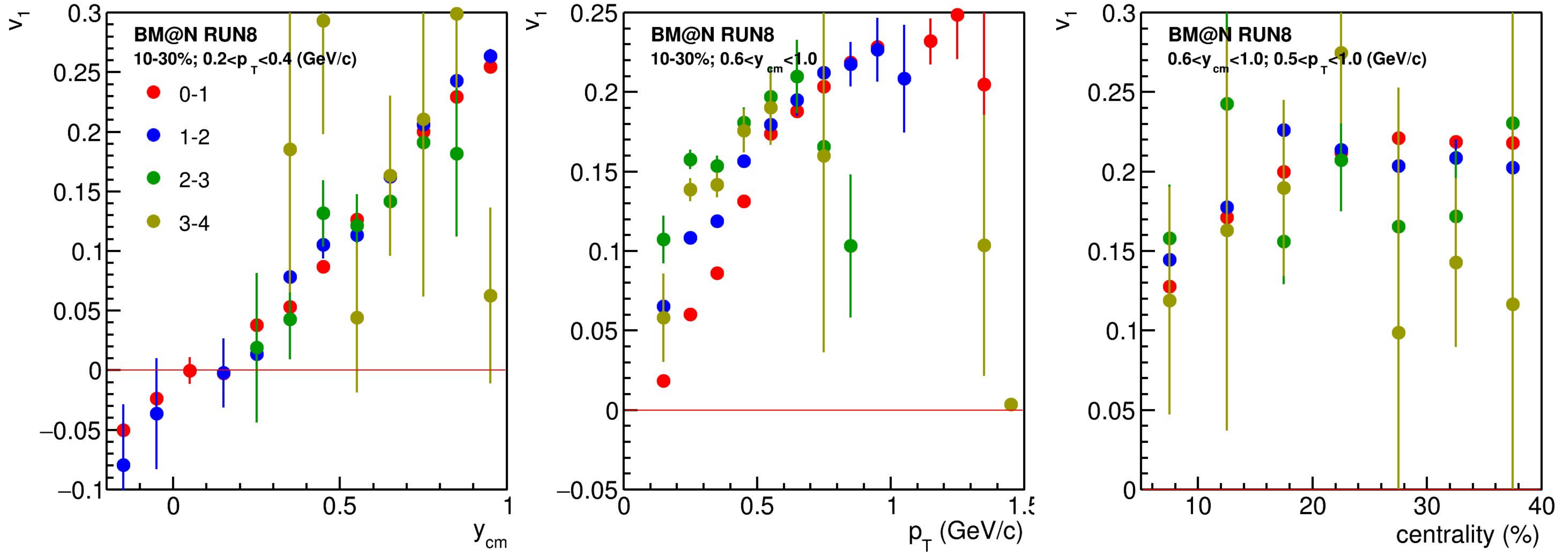
(VF) v_1 vs y: Systematic variation due to Nhits-cut



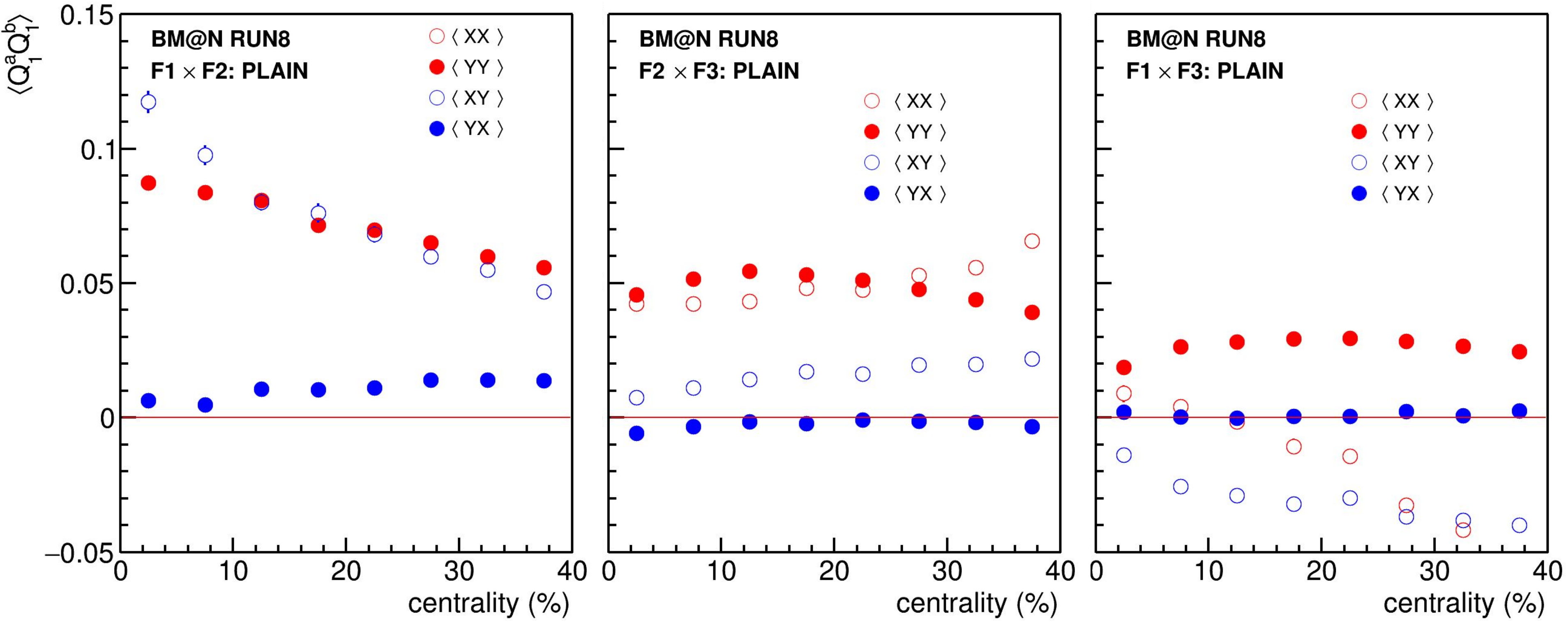
(VF) v_1 vs y: Systematic variation due to chi2-cut



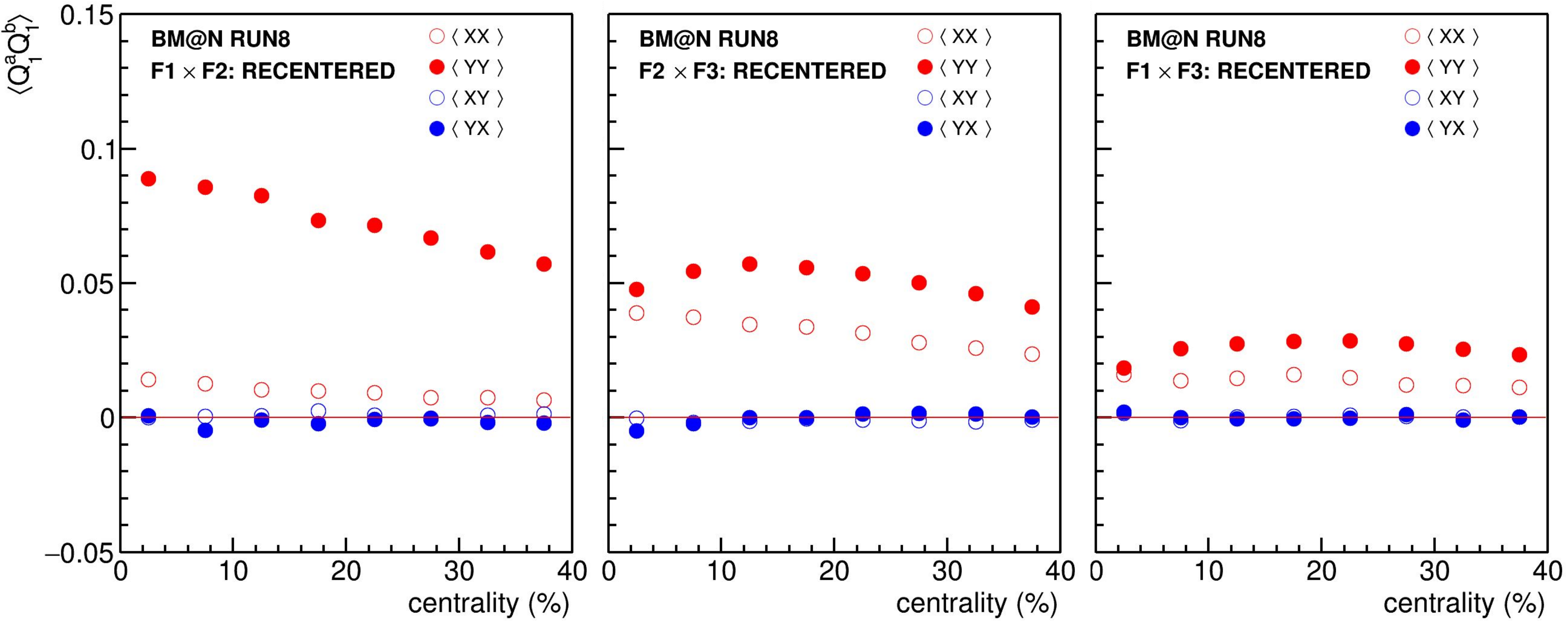
(VF) v_1 vs y: Systematic variation due to DCA-cut



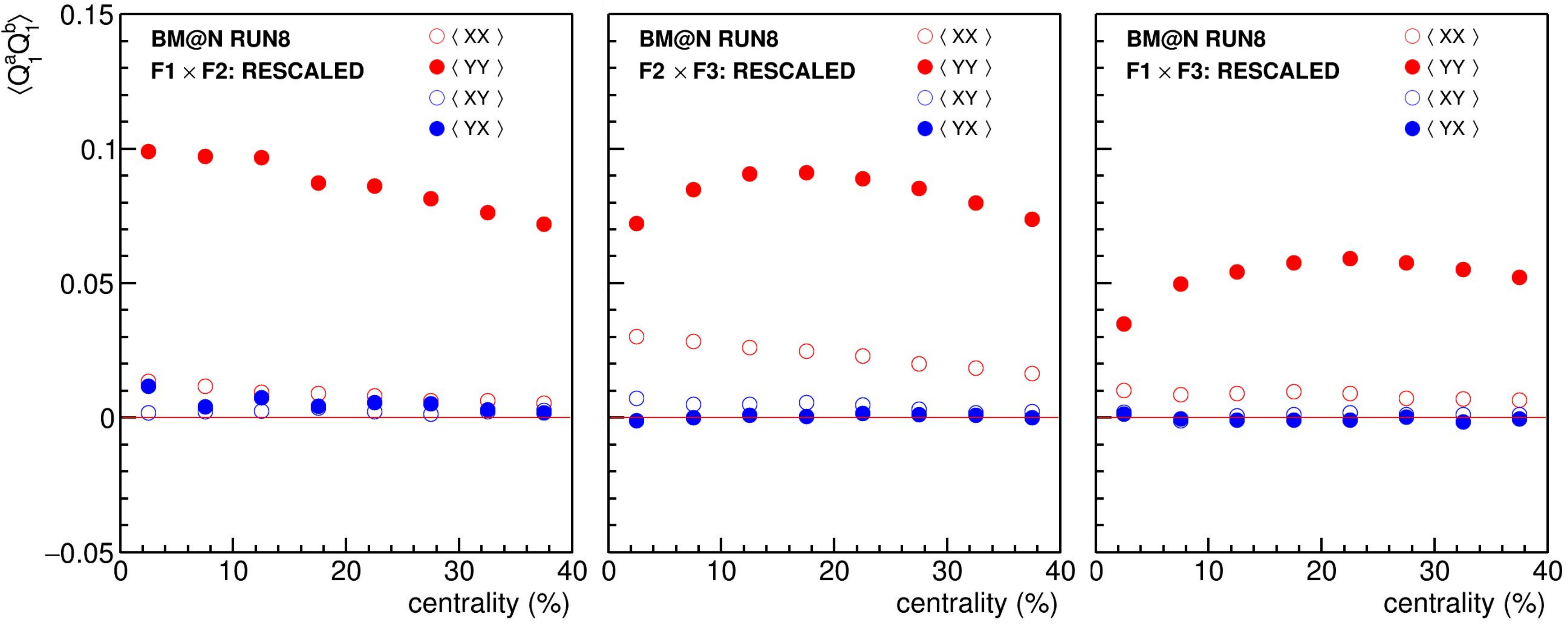
FHCal Q-vector correlations (PLAIN)



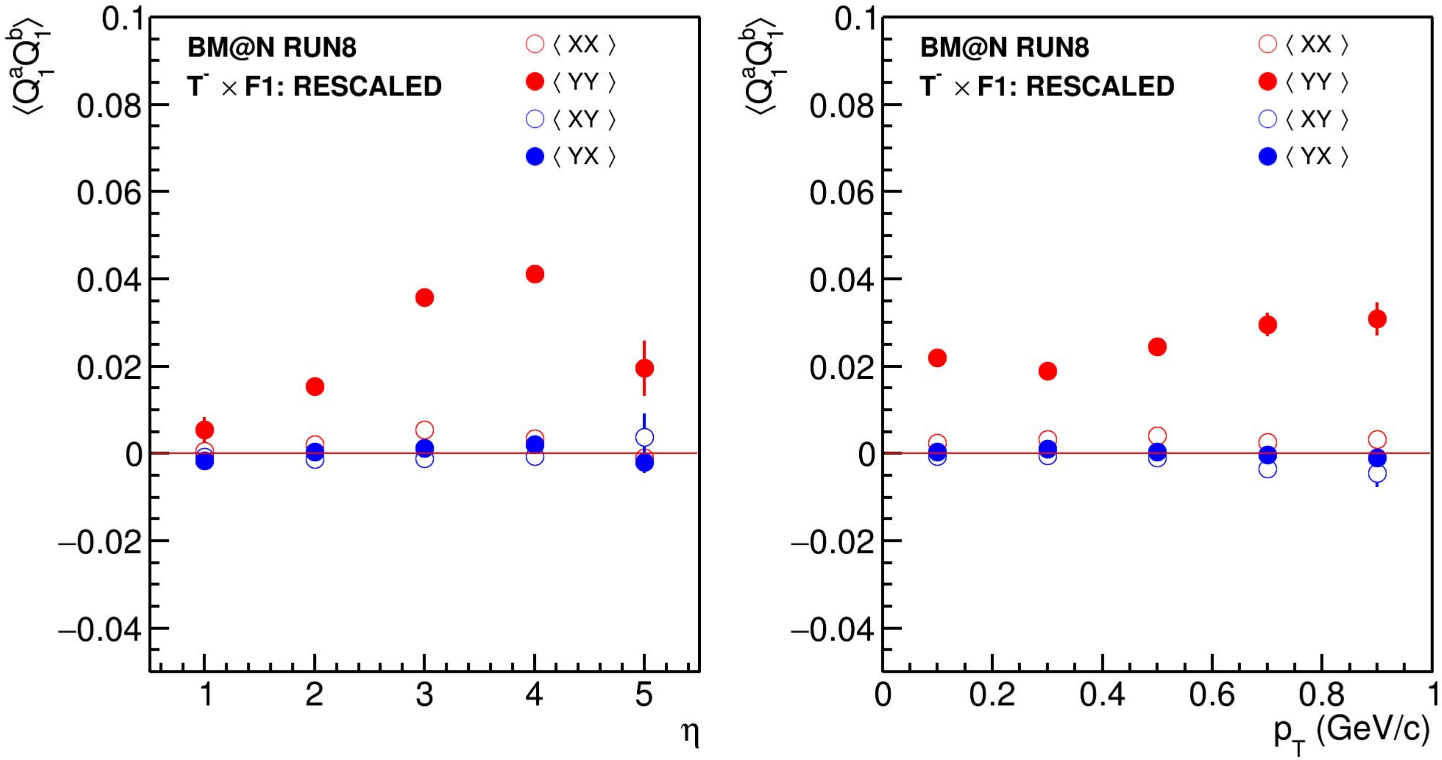
FHCal Q-vector correlations (RECENTERED)



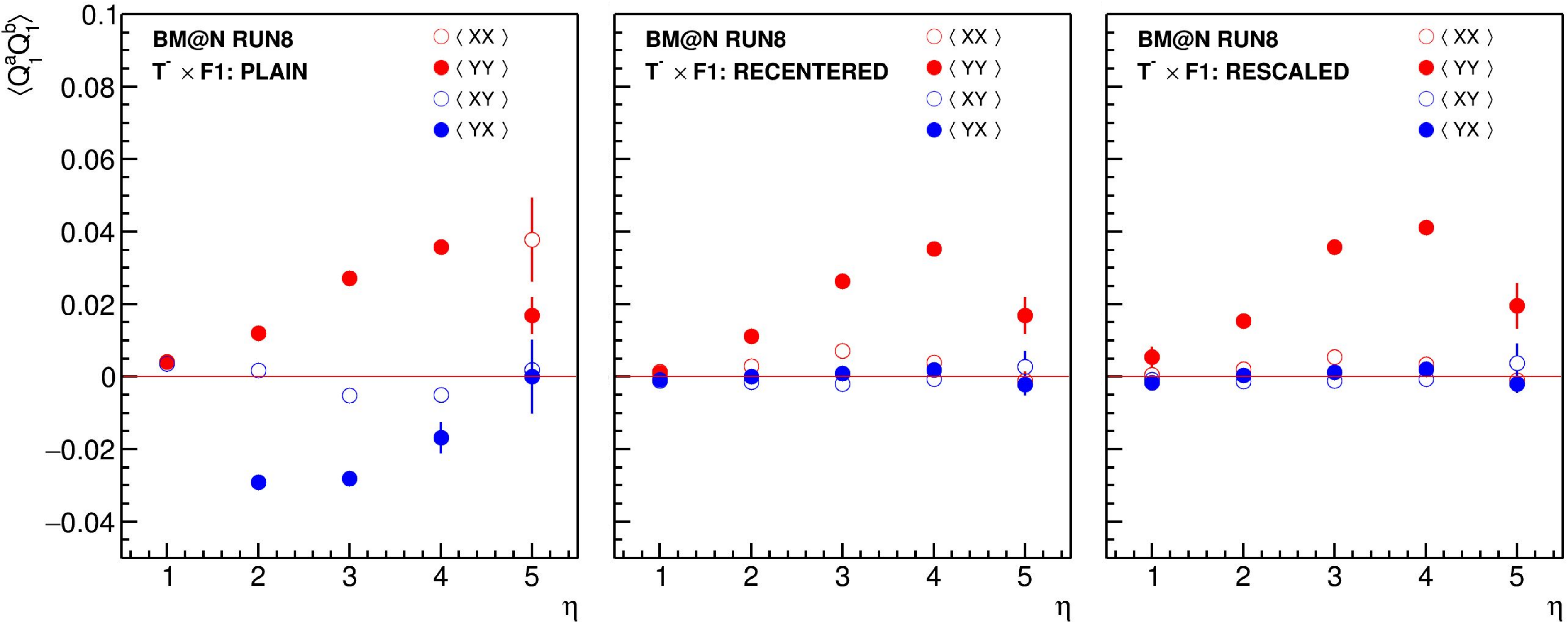
FHCal Q-vector correlations (RESCALED)



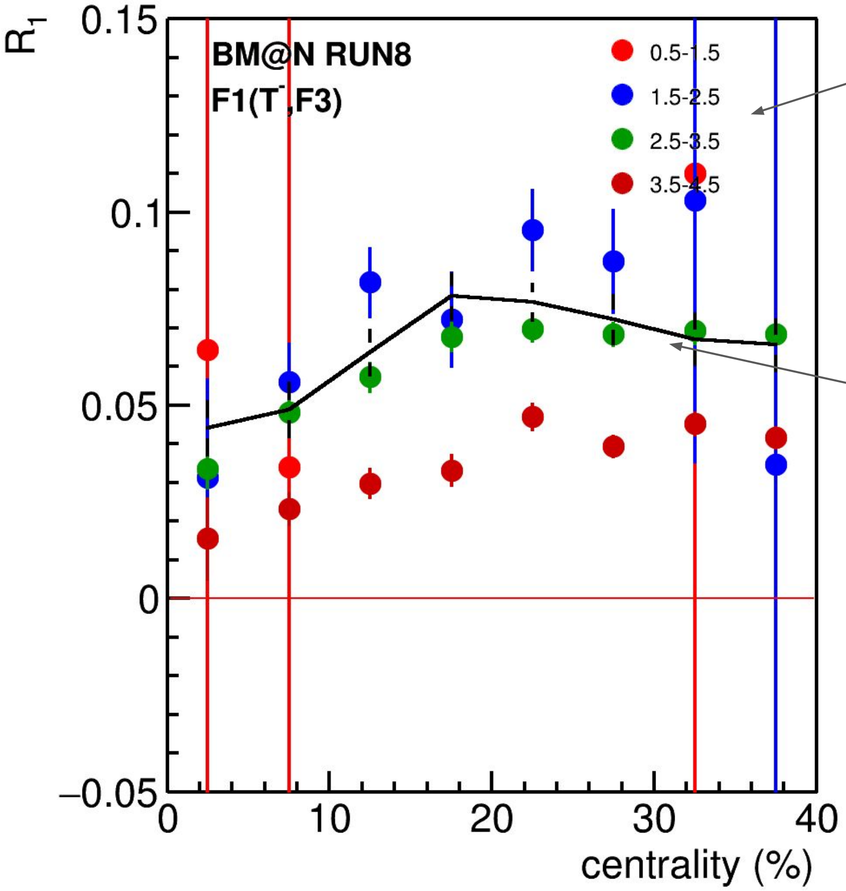
T- x F1 correlations



T- x F1 correlations (all steps)



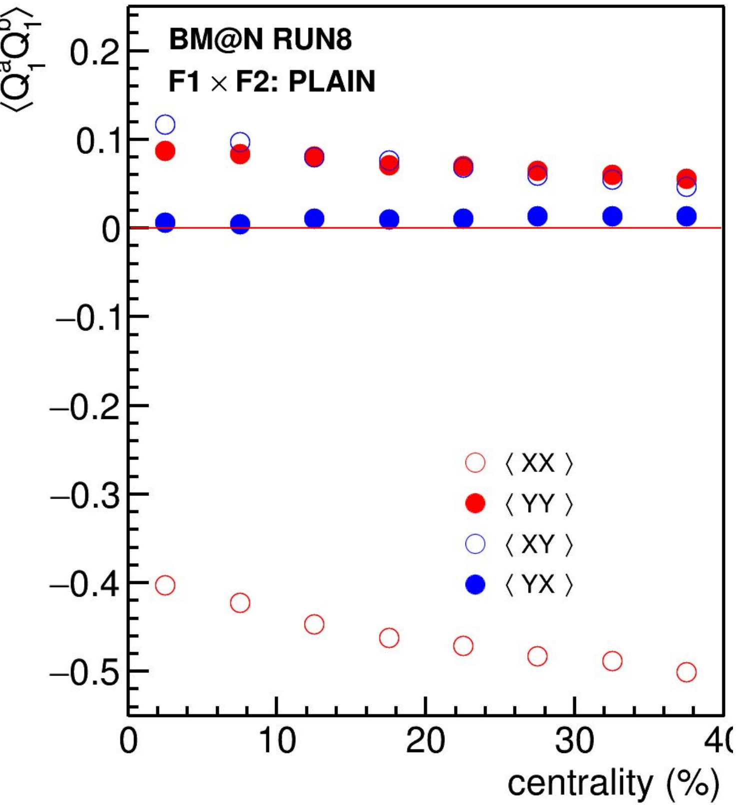
Selecting the pseudorapididty window for T+ vector



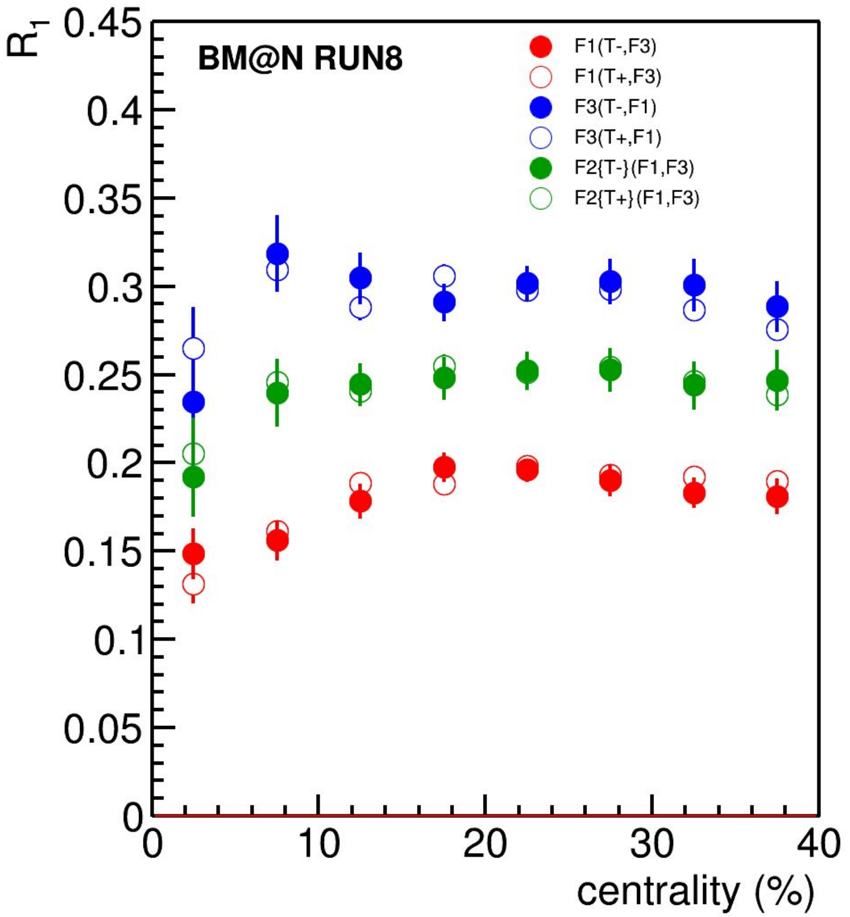
Variating eta

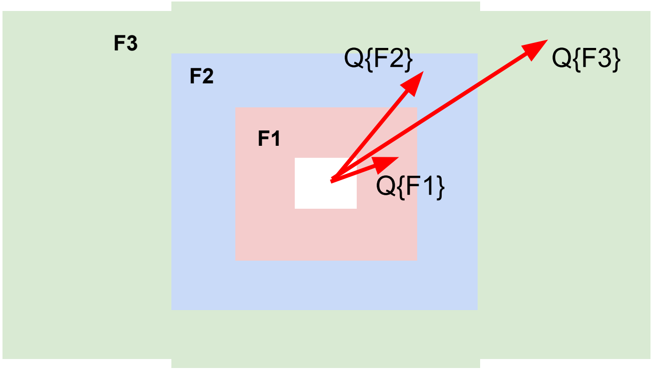
Same combination with T-

Q-vector correlations (PLAIN)



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





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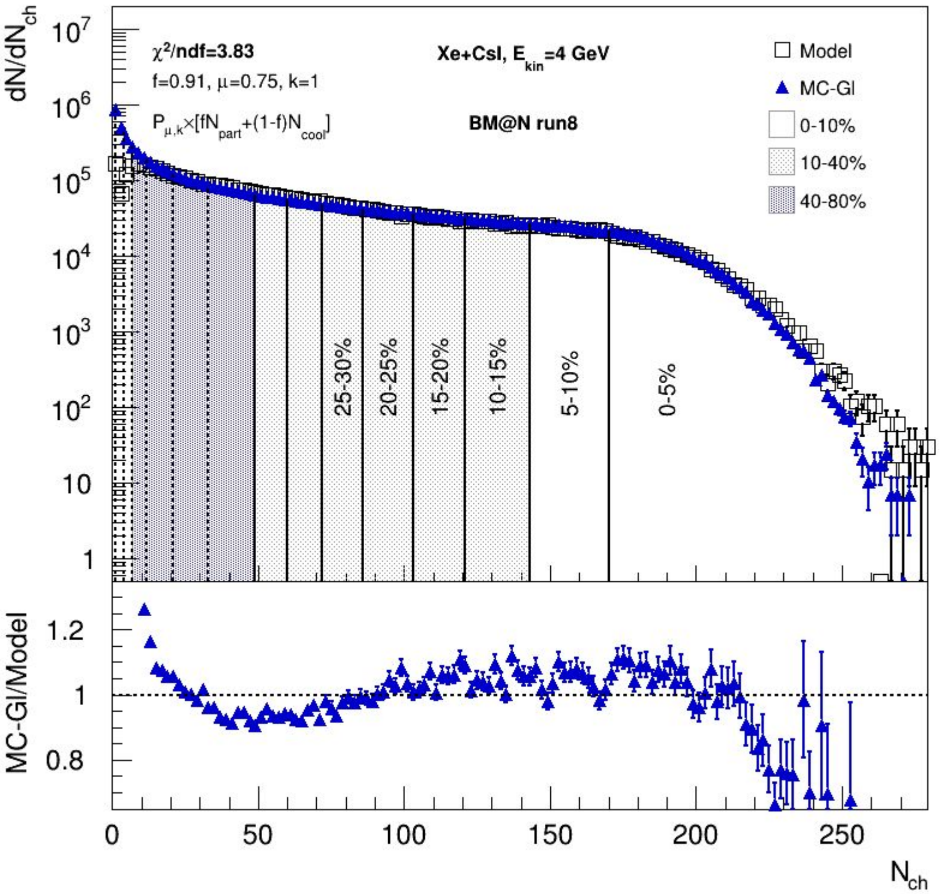
- $p_T > 0.2$ GeV/c

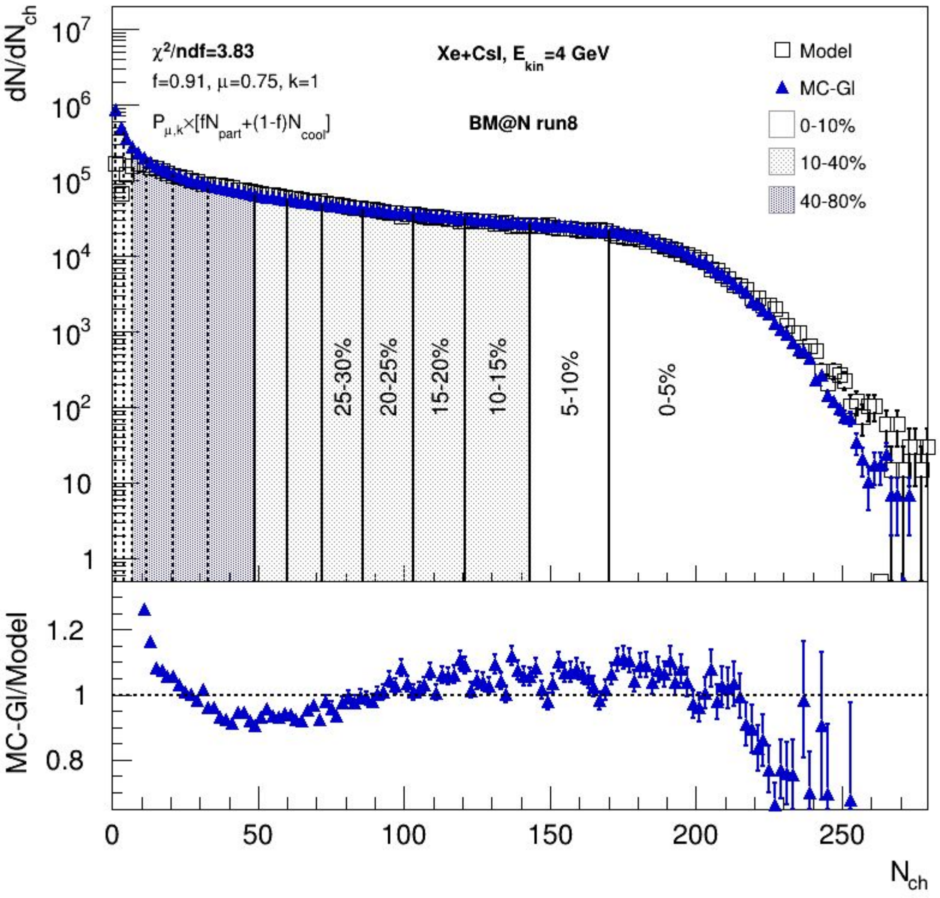
T+: all positively charged particles with:

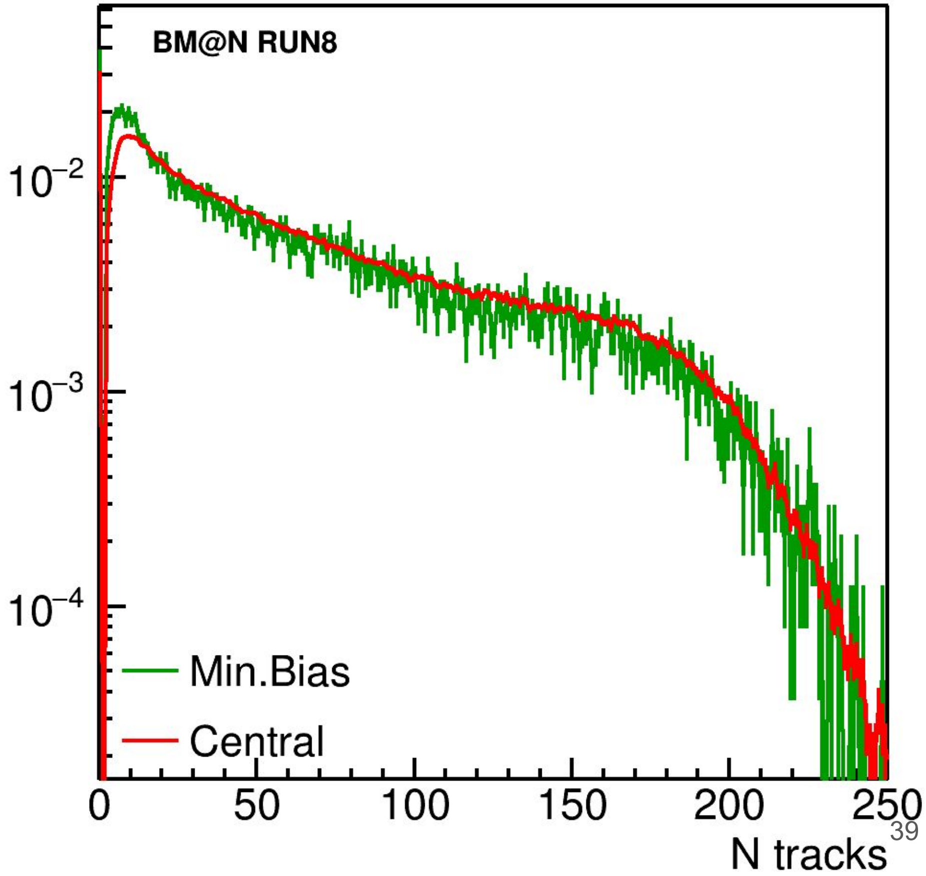
- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

Centrality with MC-Glauber for RUN8

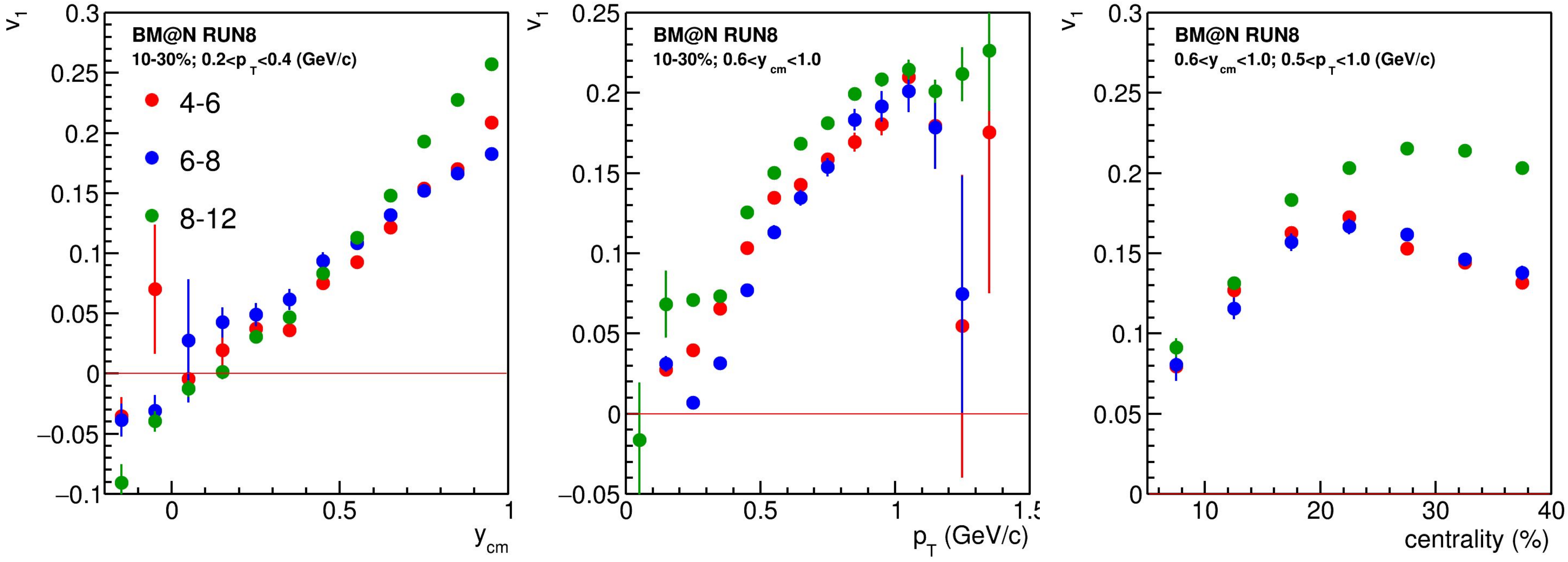


Centrality with MC-Glauber for RUN8

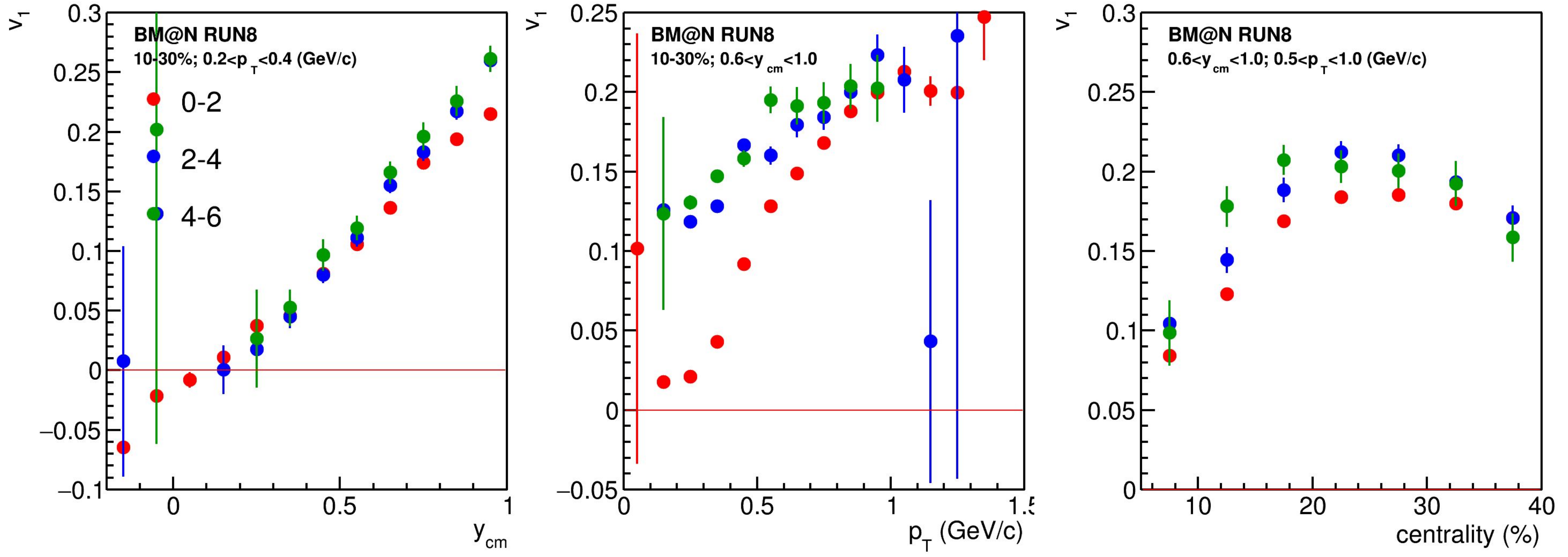




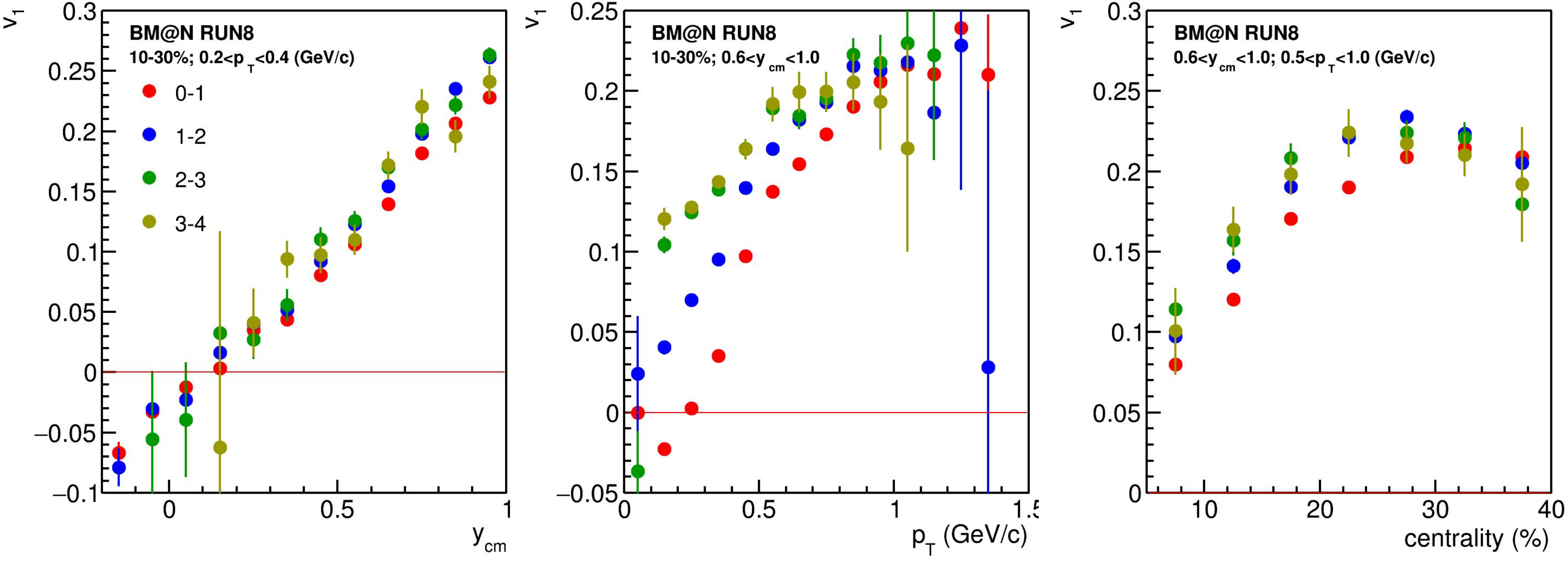
v_1 vs y: Systematic variation due to Nhits-cut



v_1 vs y: Systematic variation due to chi2-cut



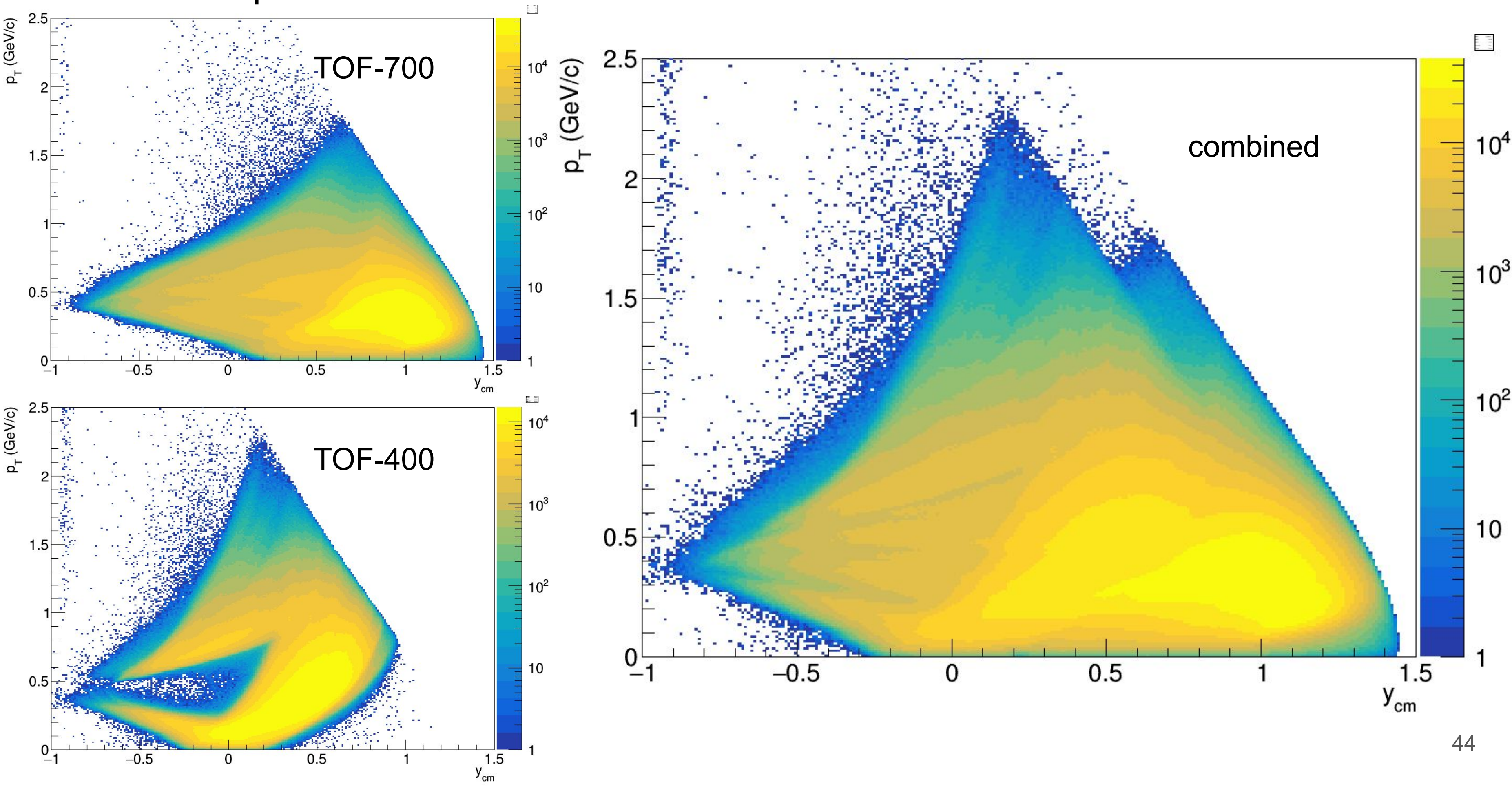
v_1 vs y: Systematic variation due to DCA-cut



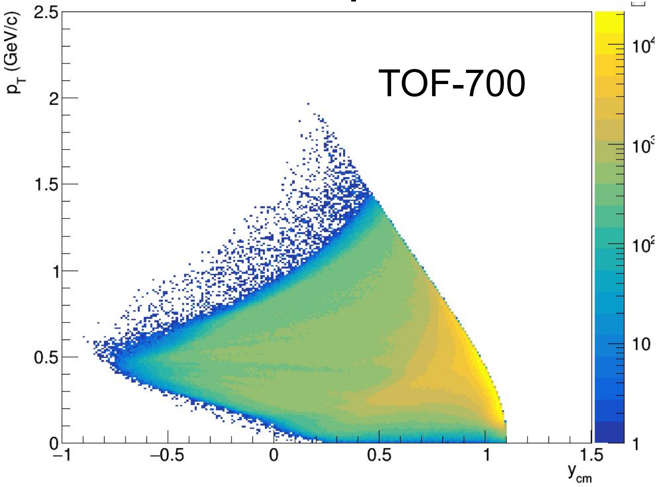
Analysis setup

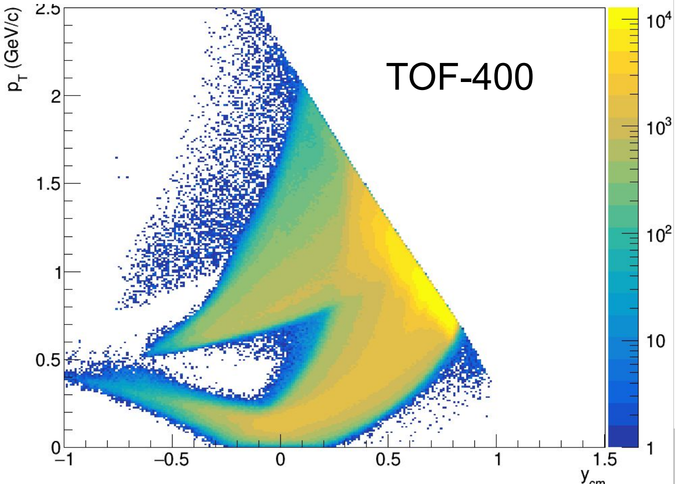
- The whole L1 production was analysed
- Event selection criteria (~40M events selected)
  - CCT2 trigger
  - $10^4 <$ Integral BC1 $< 4\times10^4$
  - Number tracks for vertex > 1
- Track selection criteria
  - $\chi^2 < 5$
  - $M_p^2 - 2\sigma < m^2 < M_p^2 + 2\sigma$

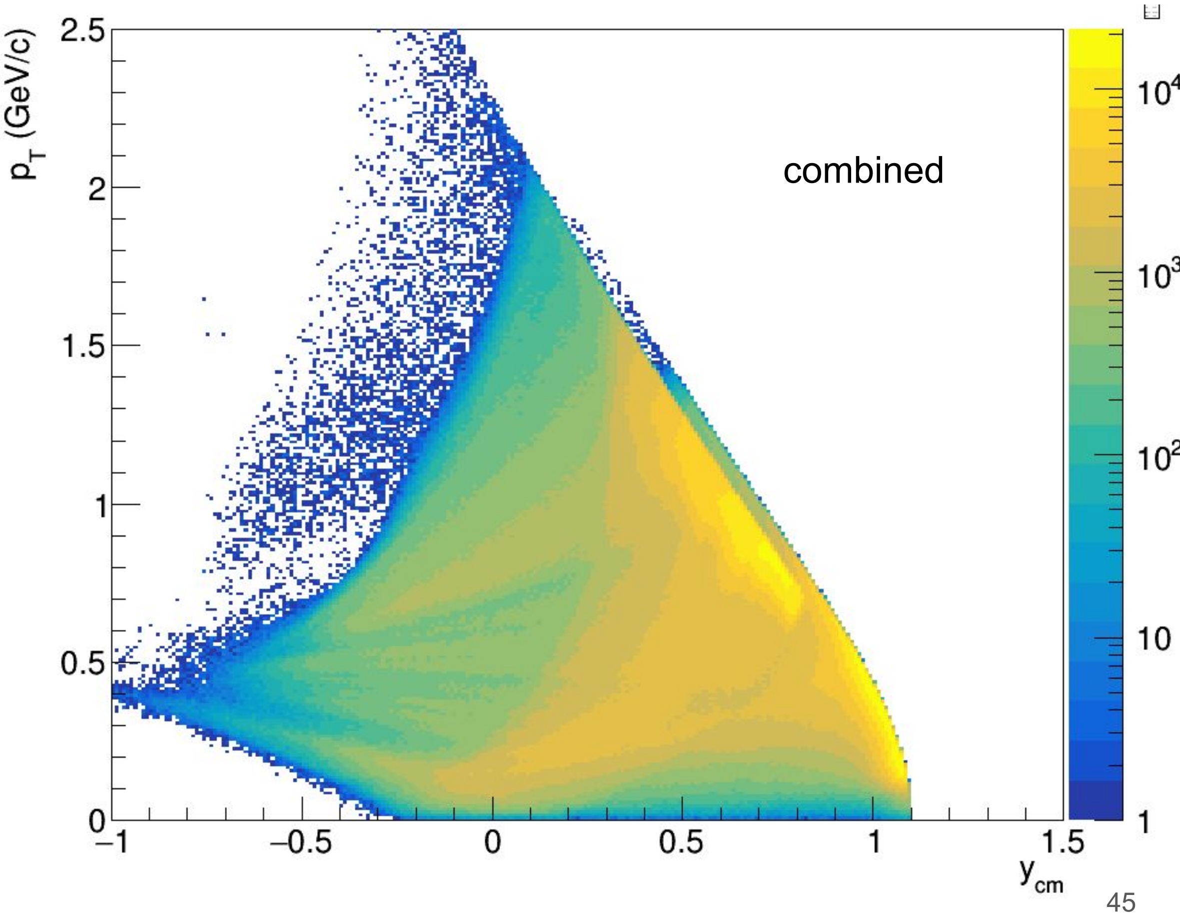
Proton p_T-y acceptance



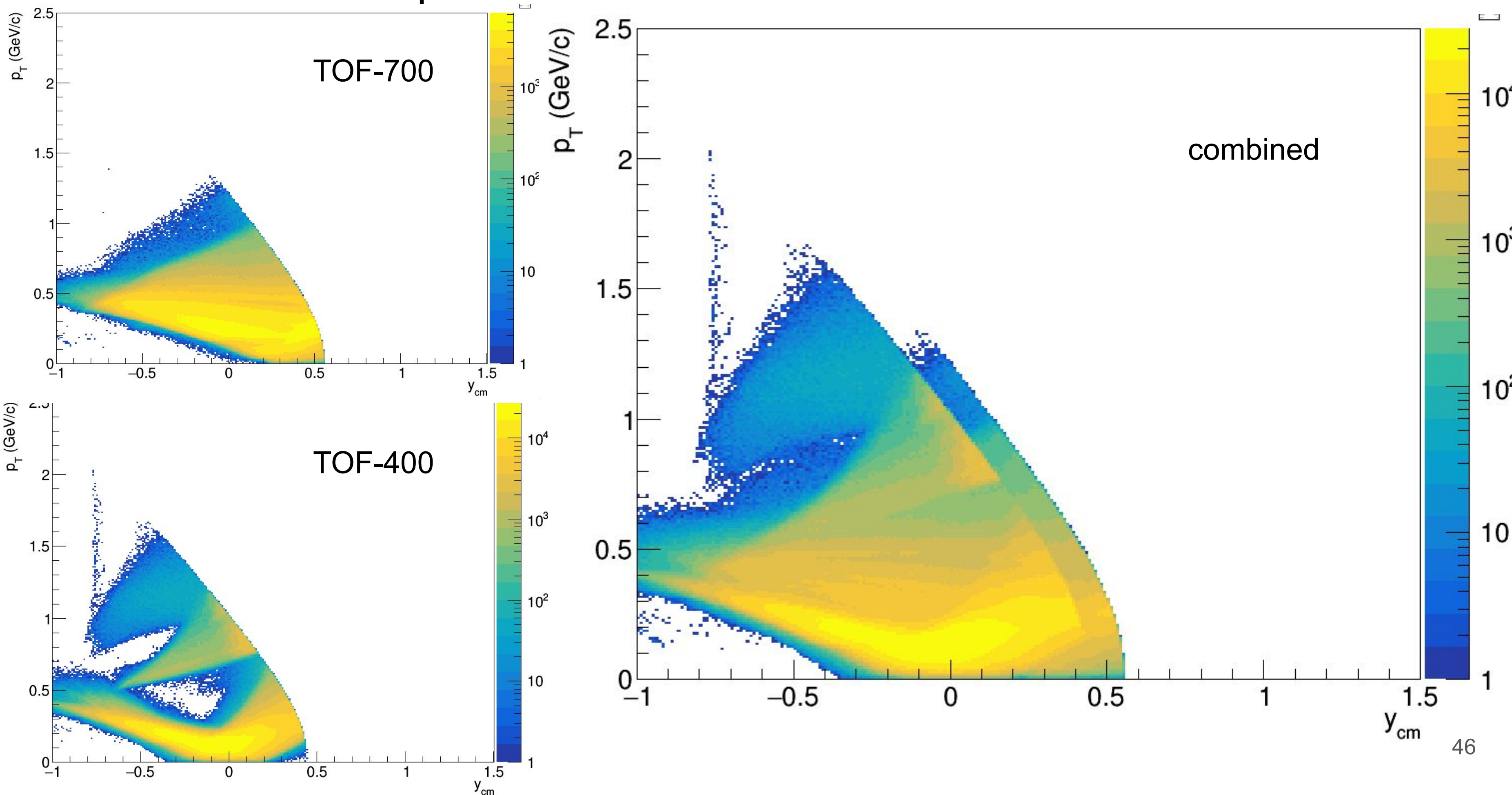
Deutron p_T-y acceptance



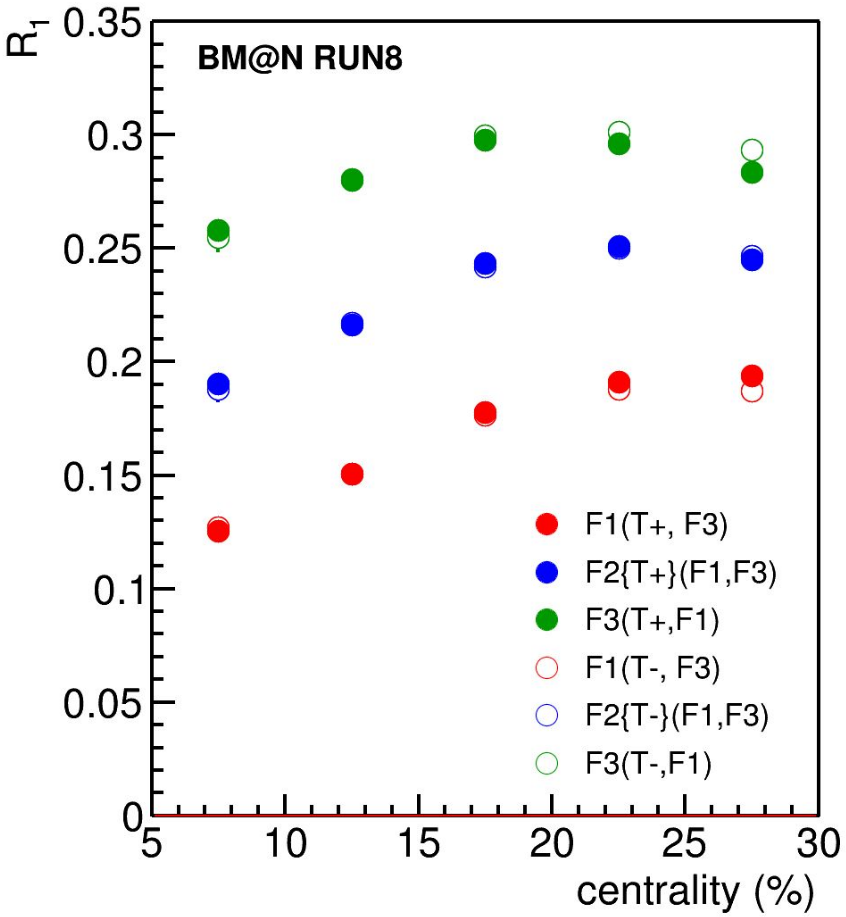


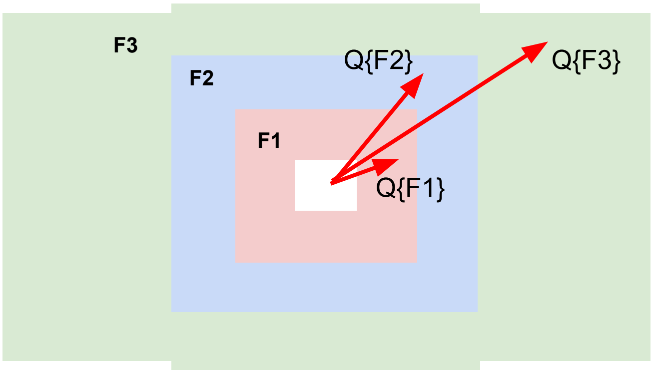


Positive pion p_T-y acceptance



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





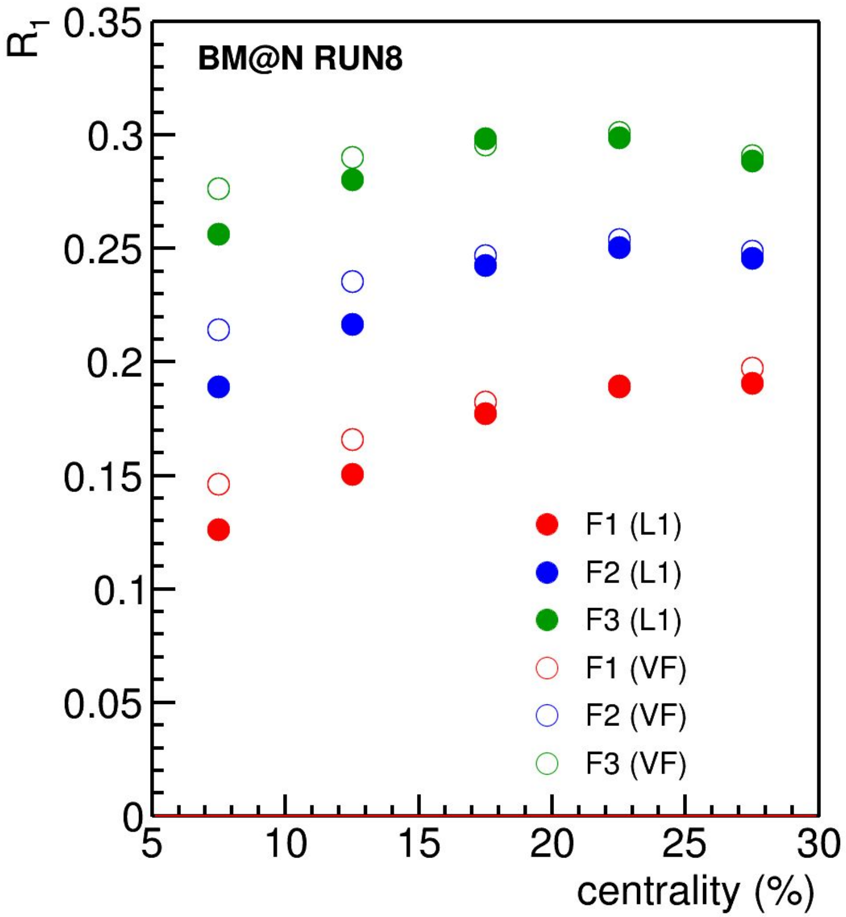
T-: all negatively charged particles with:

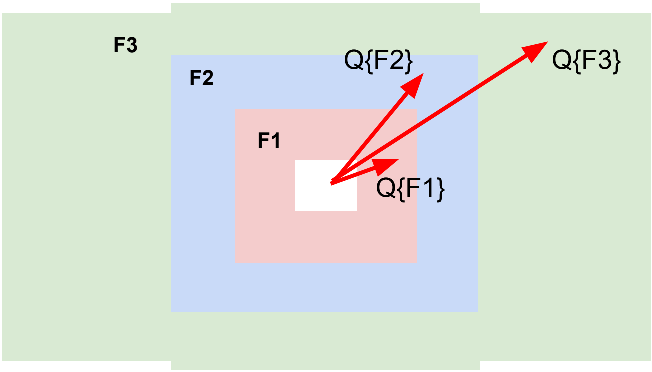
- $1.5 < \eta < 4$
- $p_T > 0.2$ GeV/c

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





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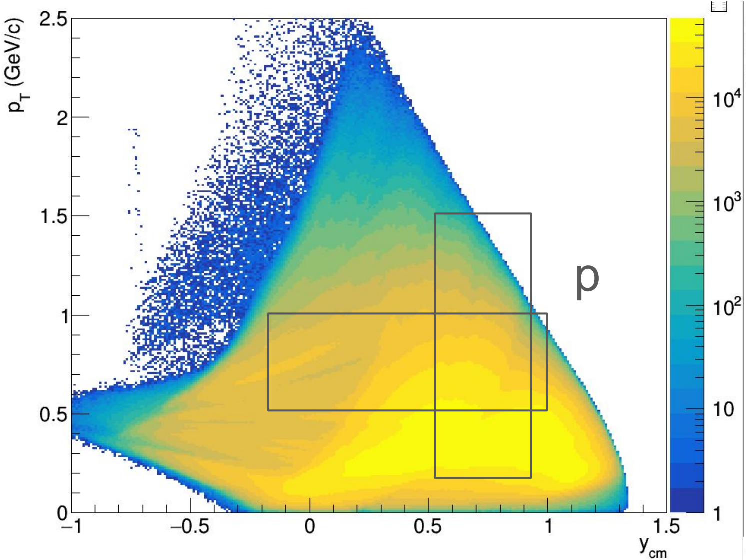
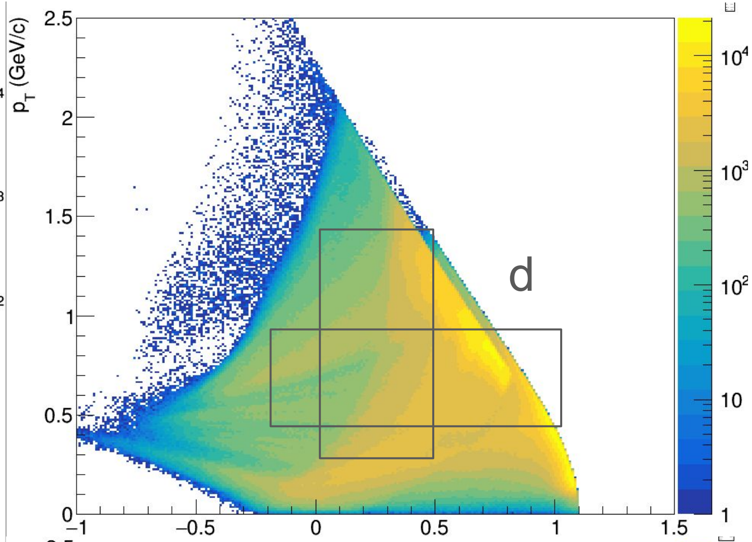
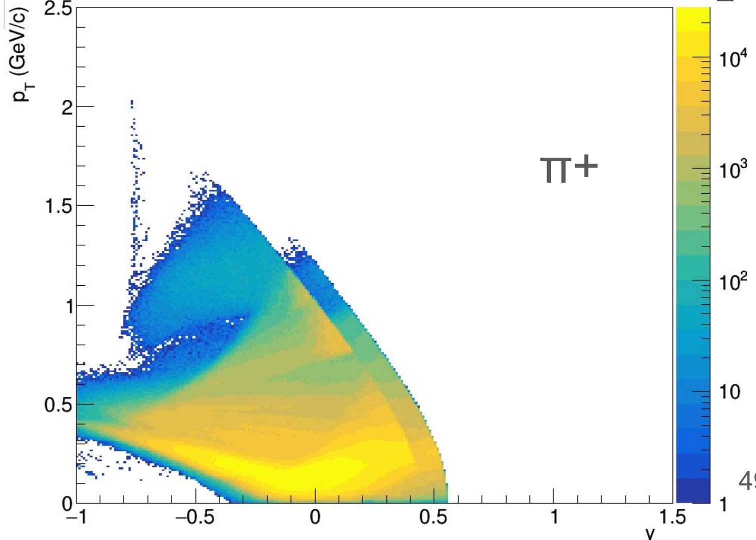
- $p_T > 0.2$ GeV/c

Difference can be explained by different centrality

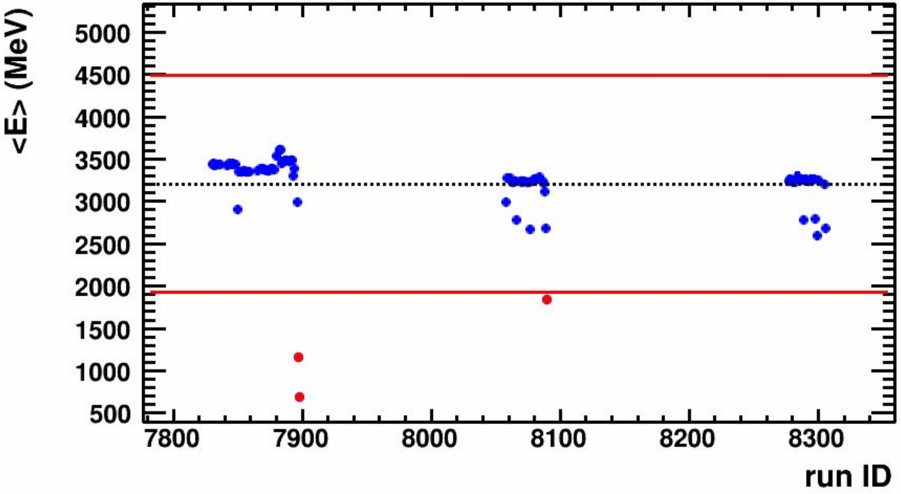

p
p_T (GeV/c)
y_{cm}


d
p_T (GeV/c)

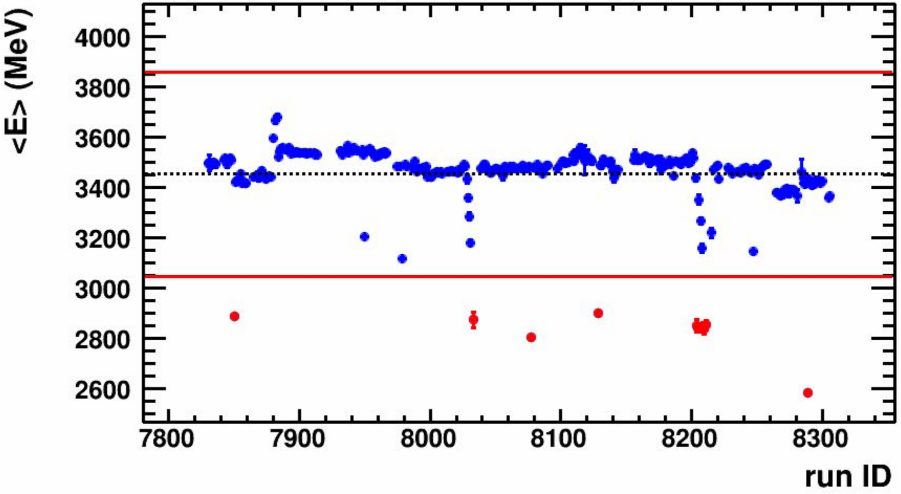

π^+
p_T (GeV/c)

QA Run-by-Run: FHCal

VF prod



L1 prod

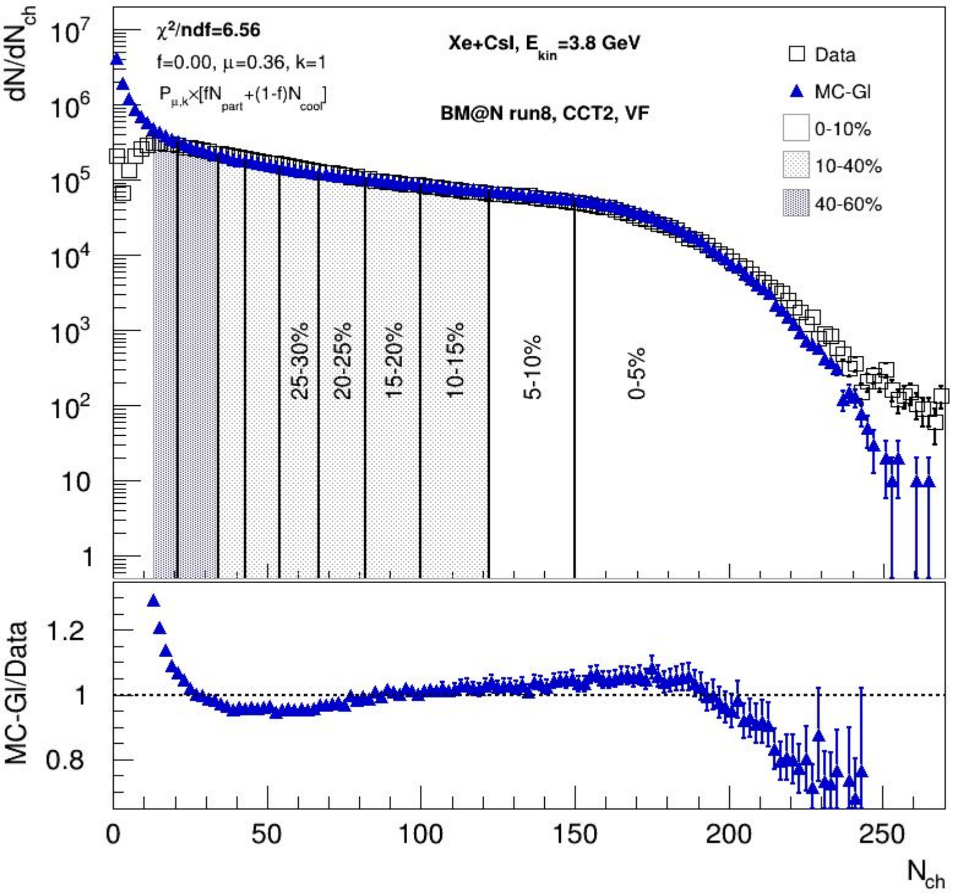


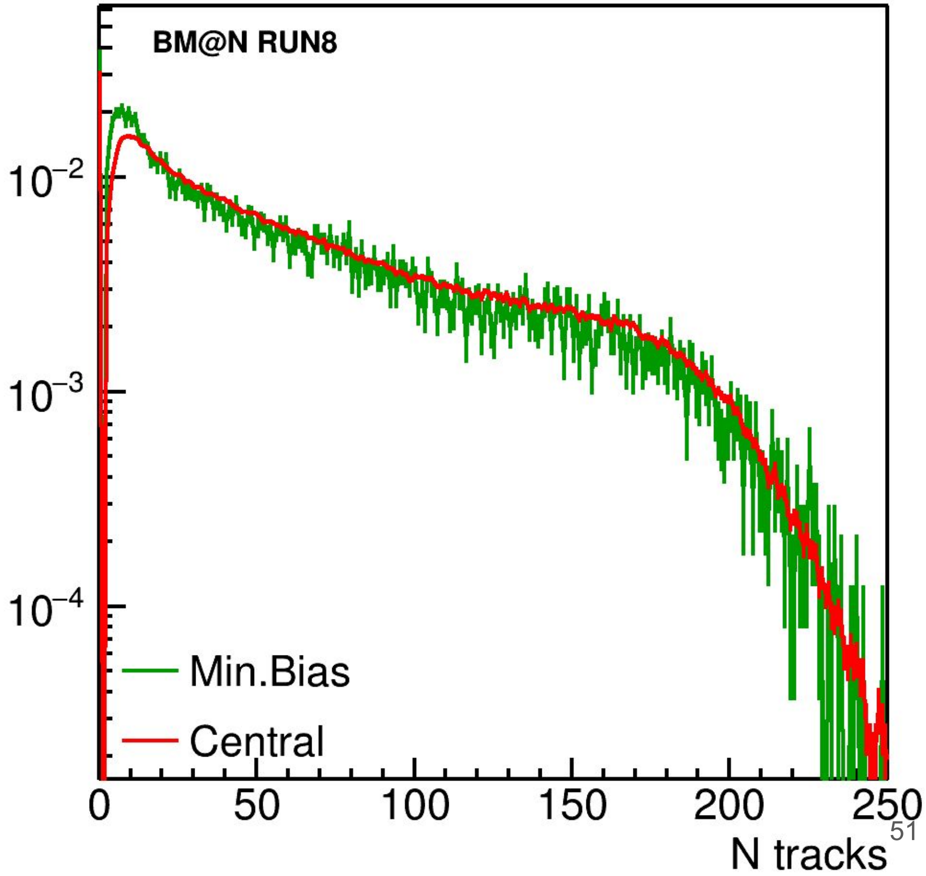
VF production was made with different versions of BmnRoot:

- ~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

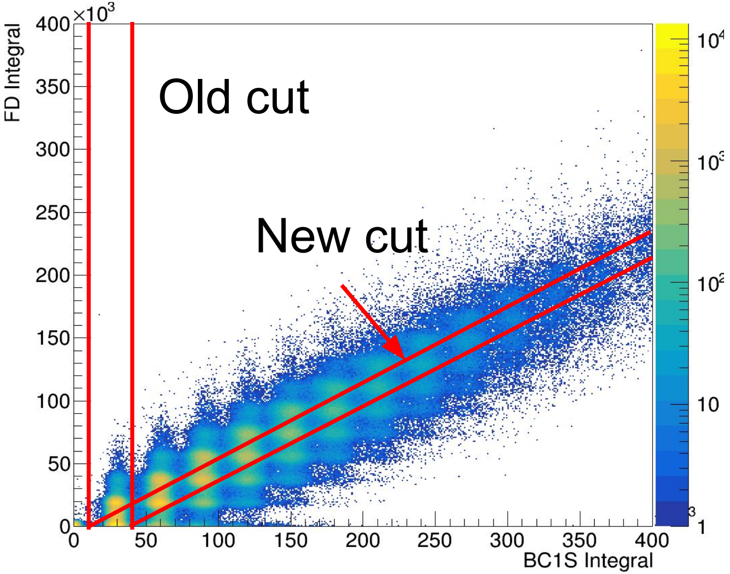
(See the talk of I.Segal)

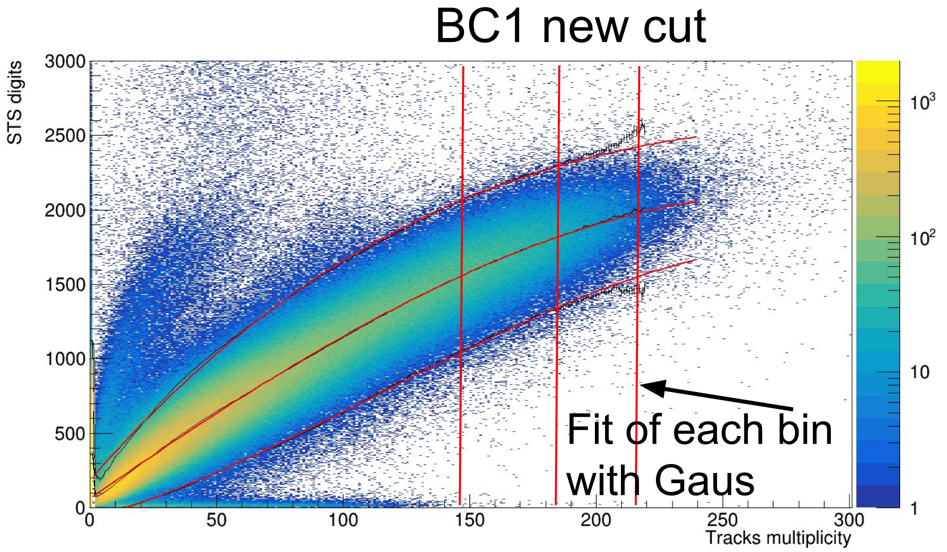




Selection criteria

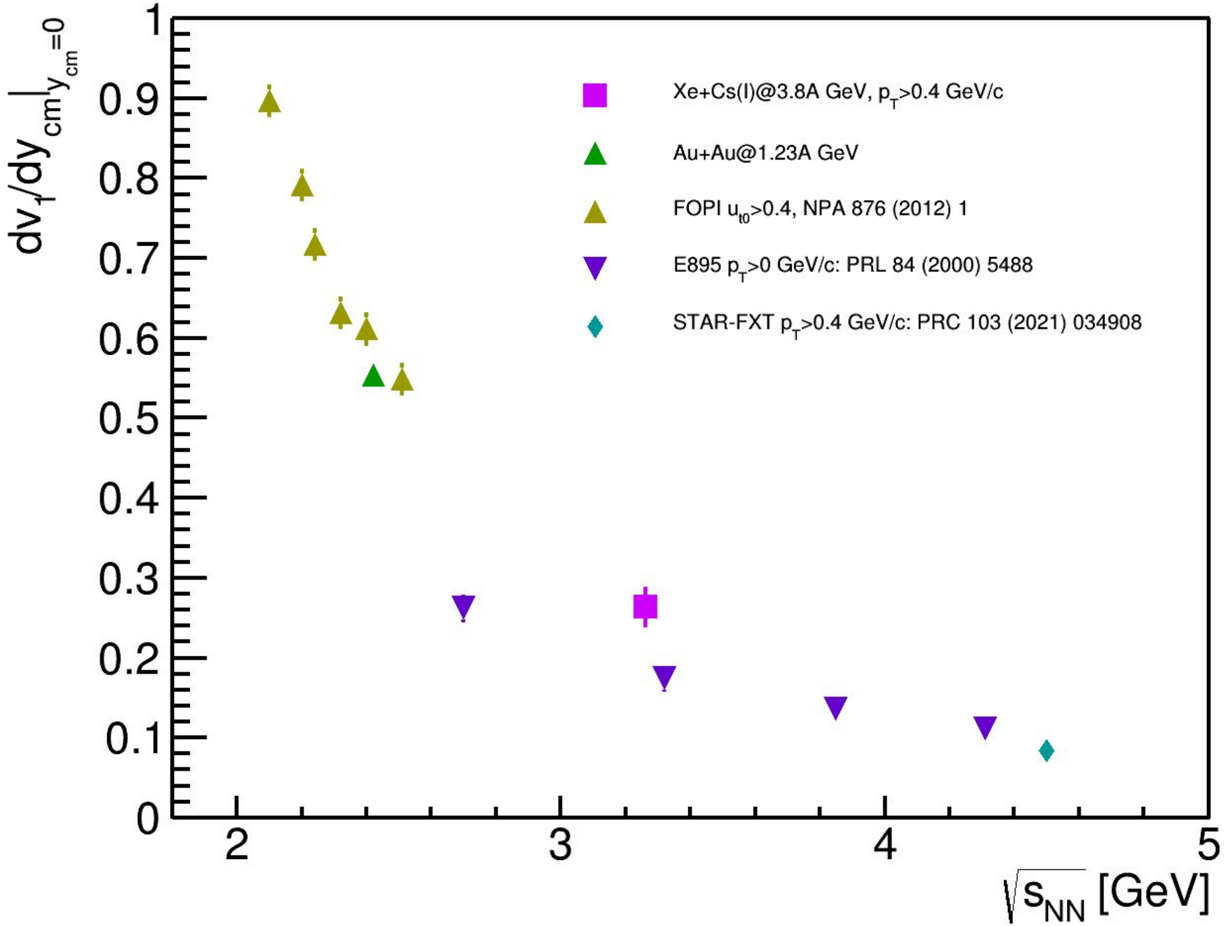
See the talk of I.Segal for details



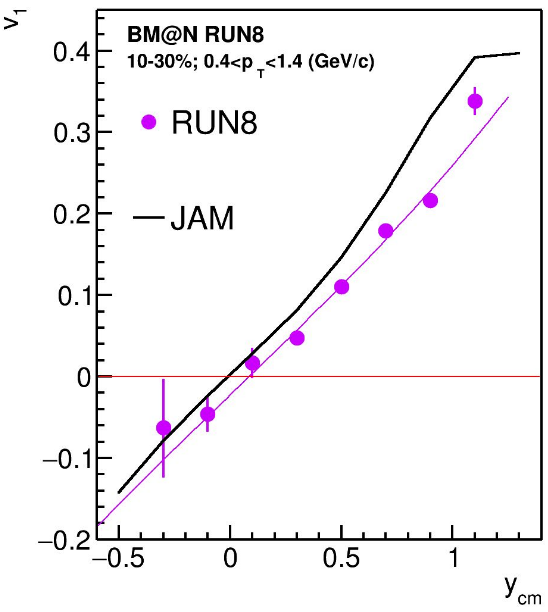


- CCT2 trigger
- Cuts on pile-up
- More than 1 track for vertex reconstruction

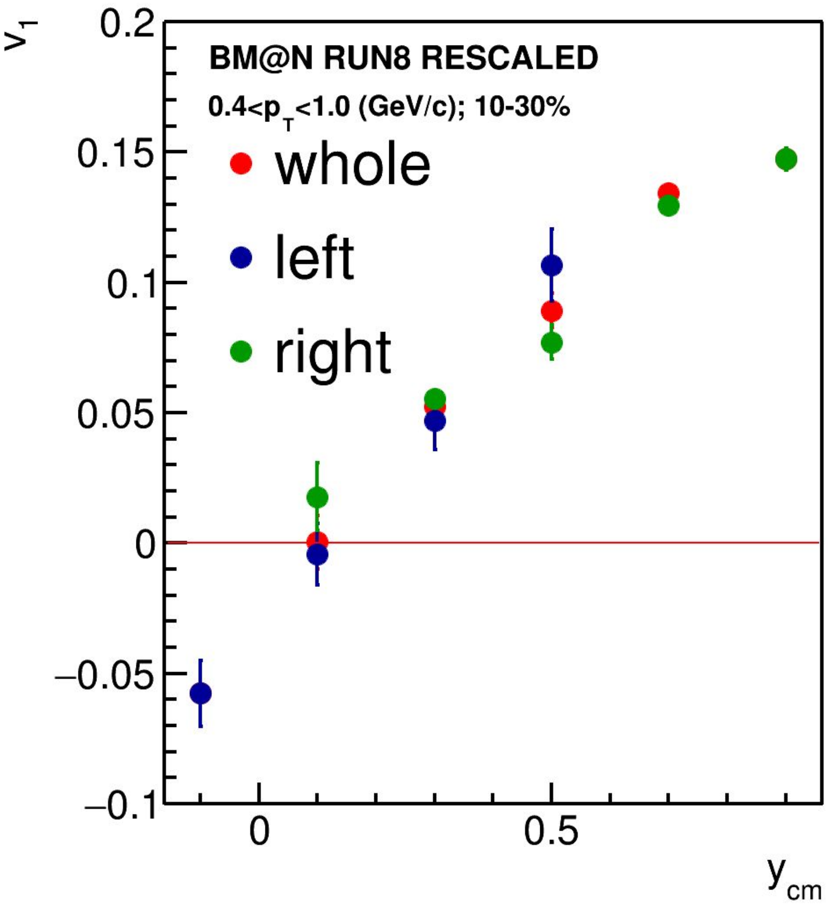
Comparison with the world data

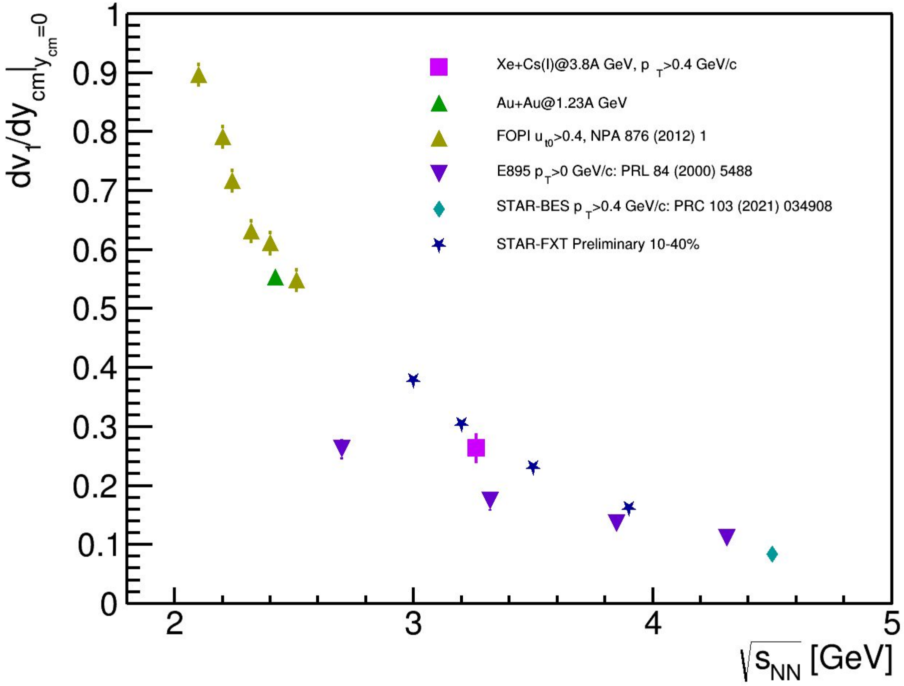


$$p_0 + p_1 x + p_2 x^3$$



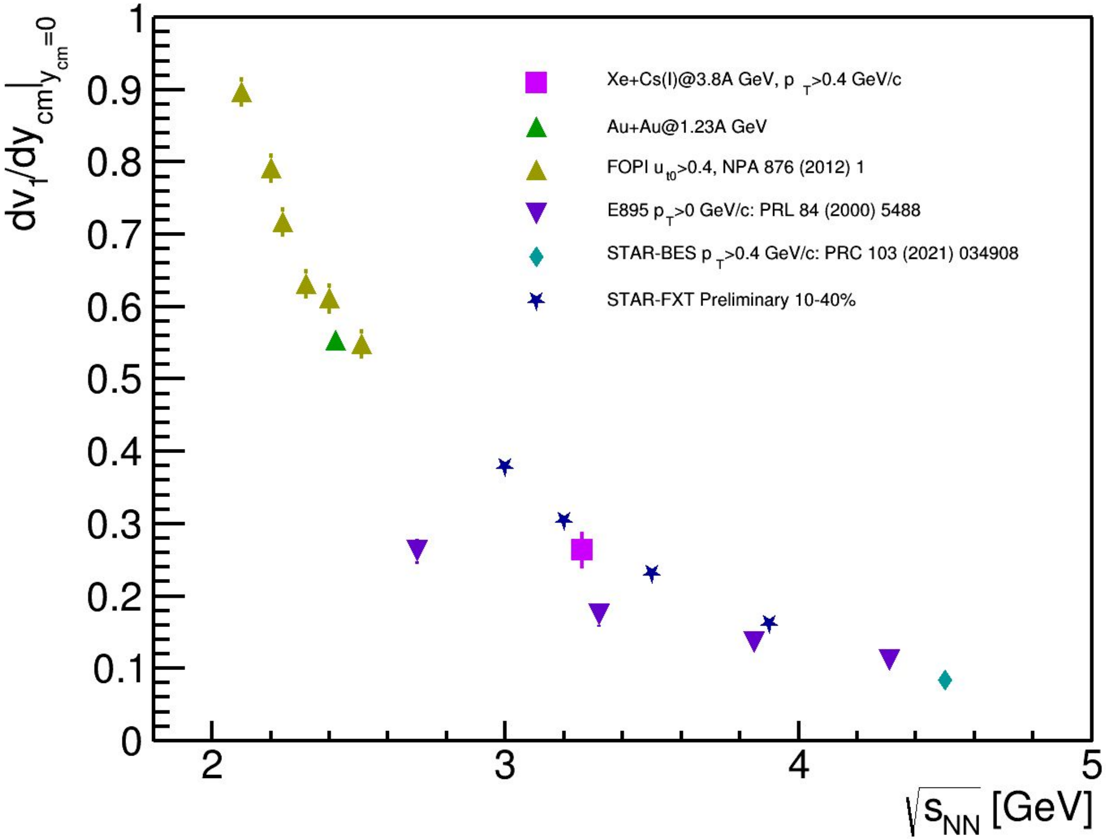
Validating the correction effects on data

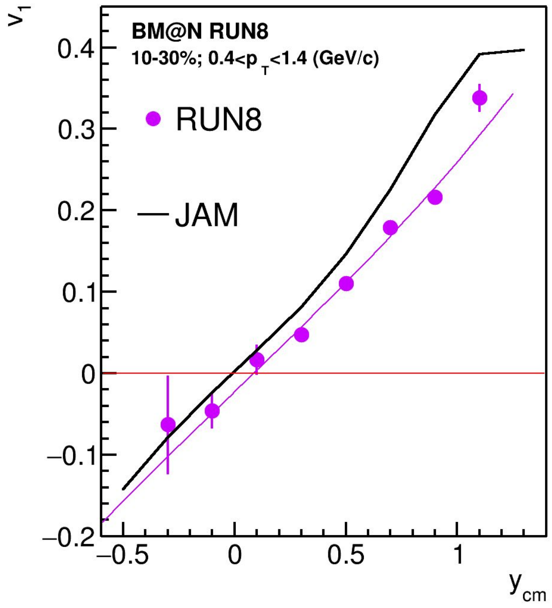




- Agreement between left and right semi-acceptances
- v_1 slope in agreement with world data

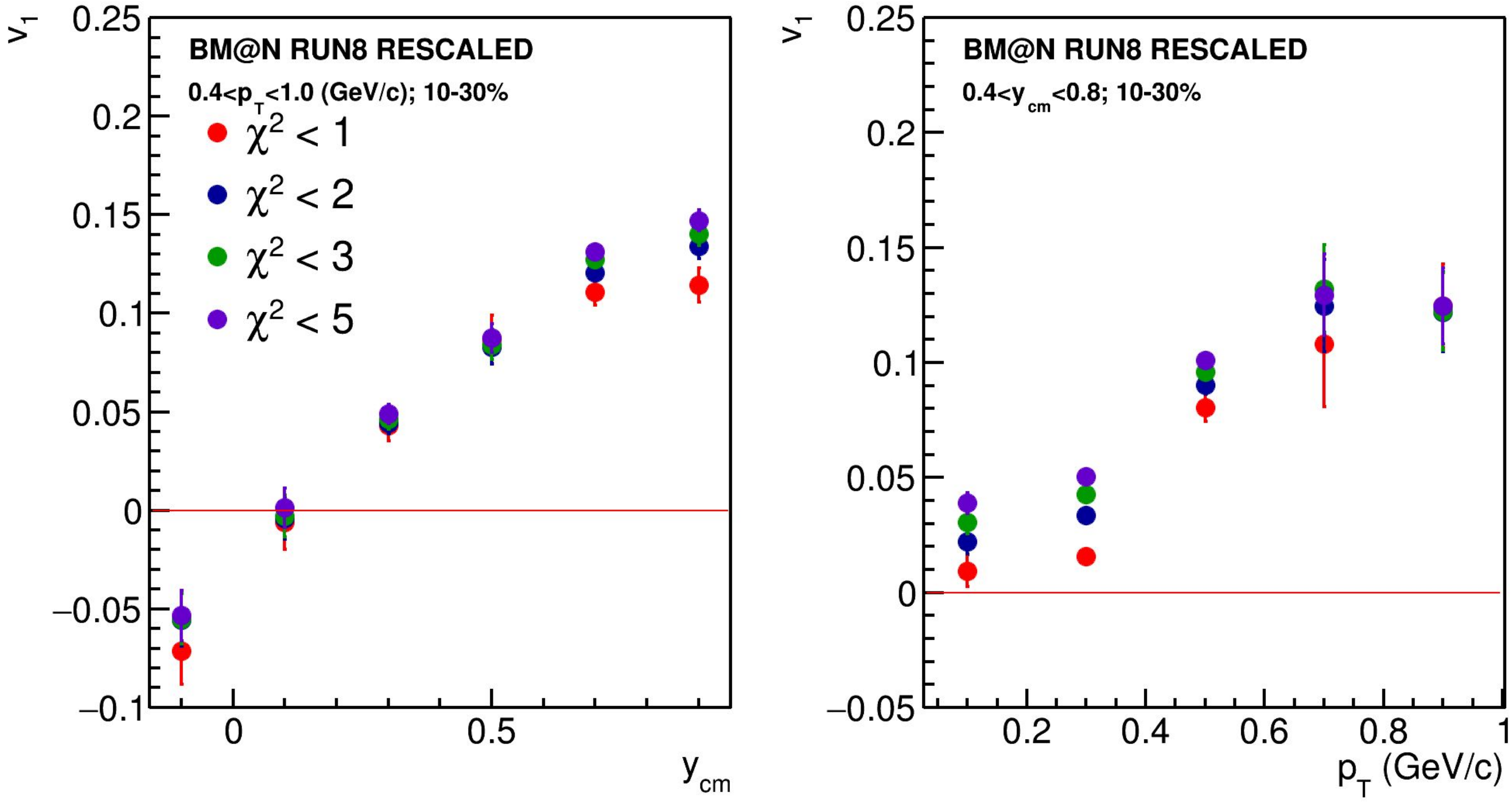
Validating the correction effects on data





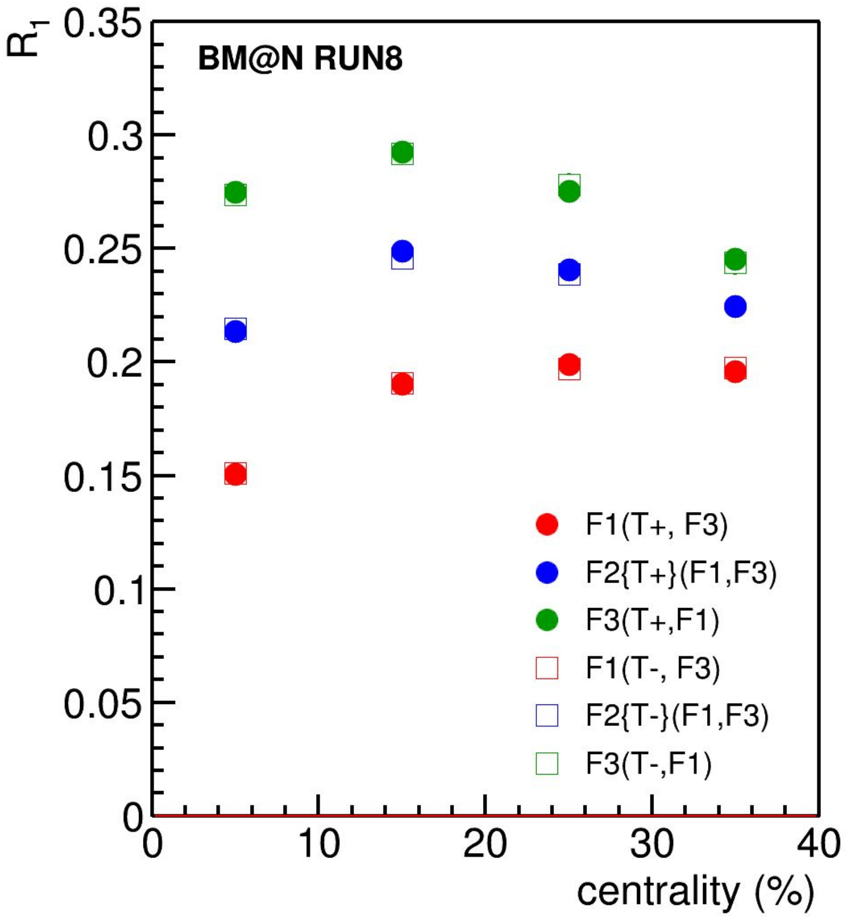
v_1 slope in agreement with world data

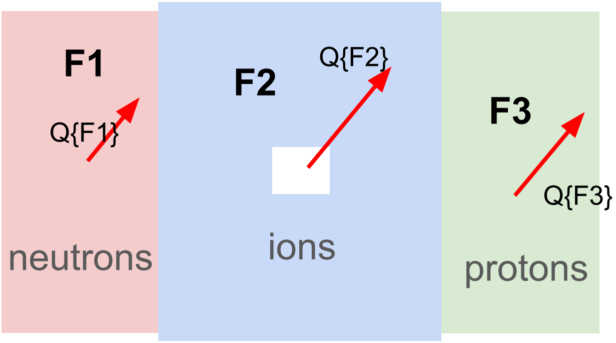
Systematics due to chi2 cut



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

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





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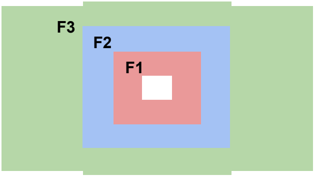
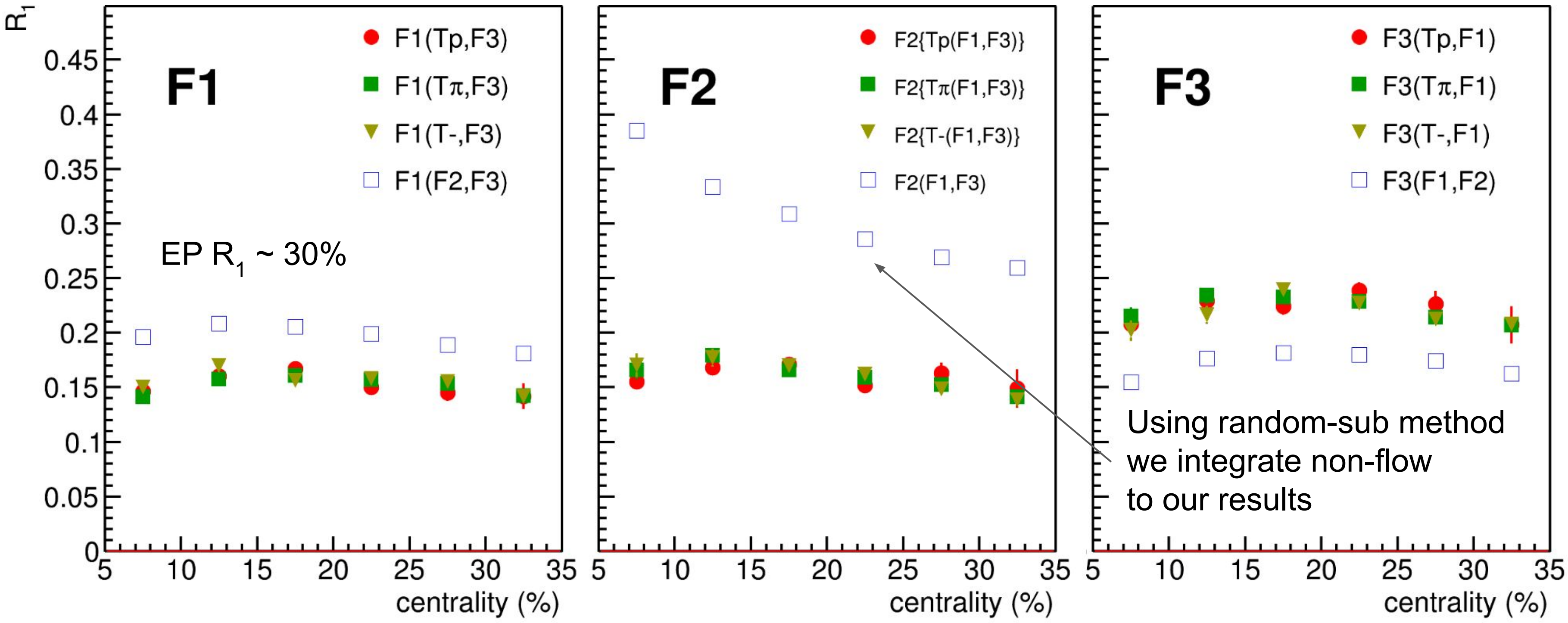
- $2.0 < \eta < 3$
- $p_T > 0.2$ GeV/c

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

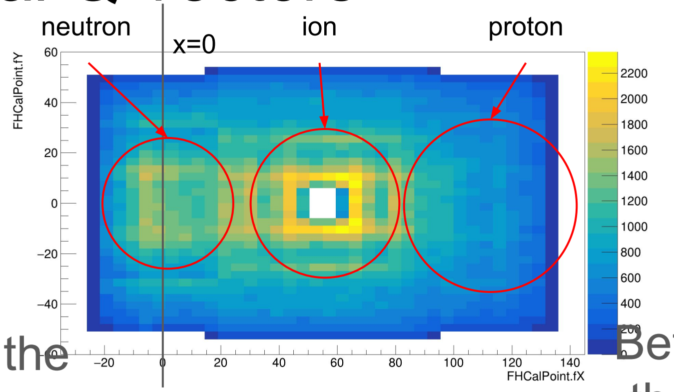


SP gives unbiased estimation of v_n (root-mean-square)
EP gives biased estimation (somewhere between mean and RMS)

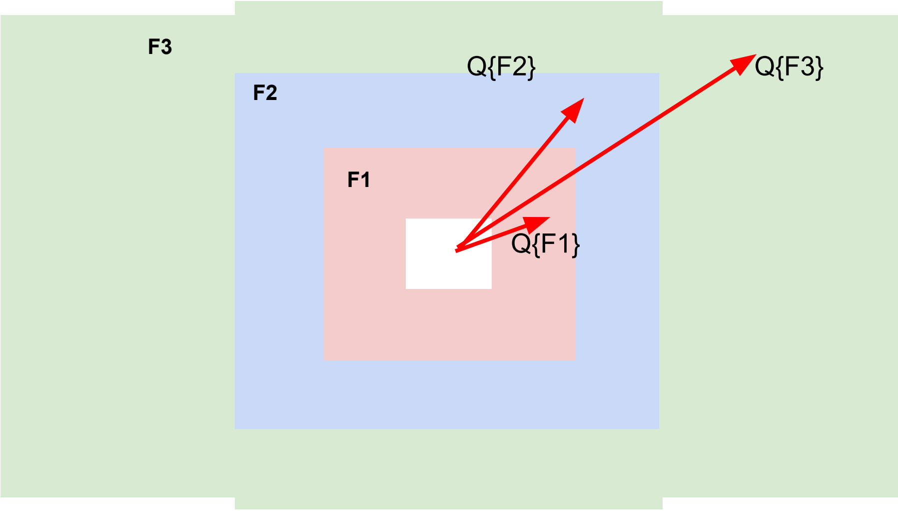


Using the additional sub-events from tracking provides a robust combination to calculate resolution

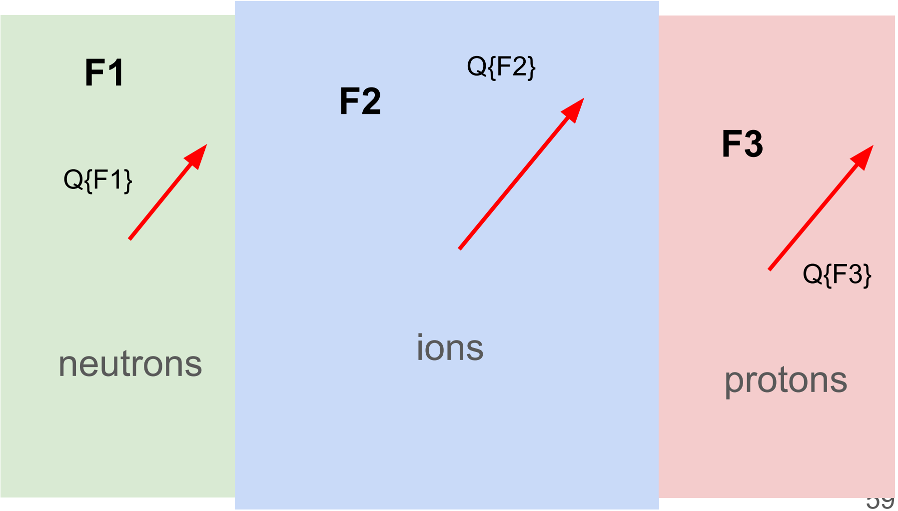
New layout for fhcal Q-vectors



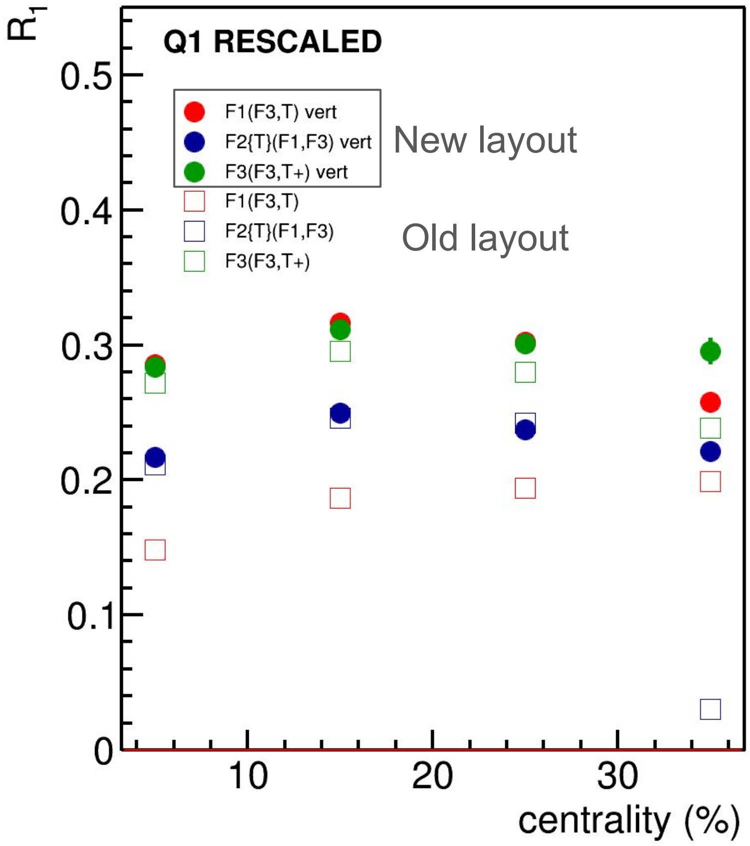
Old
poor coverage of the Y component

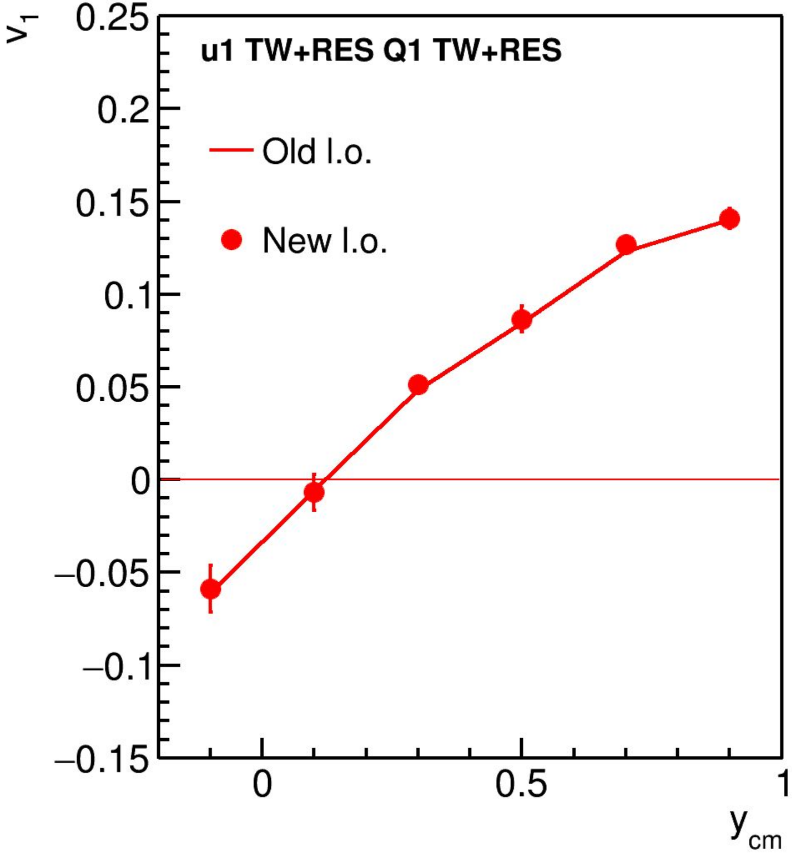


New
Better coverage of the Y component



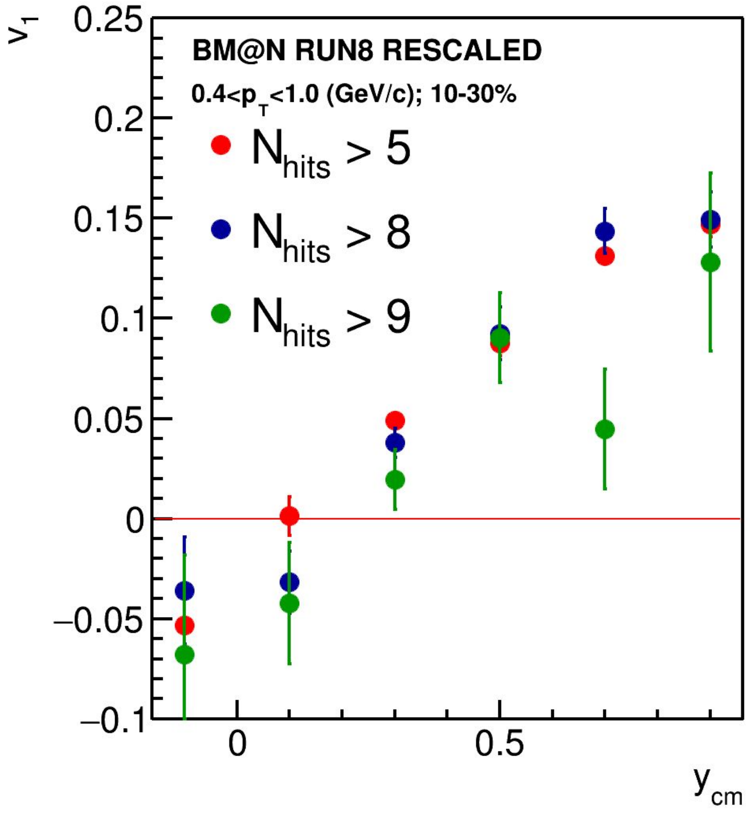
Results for new layout

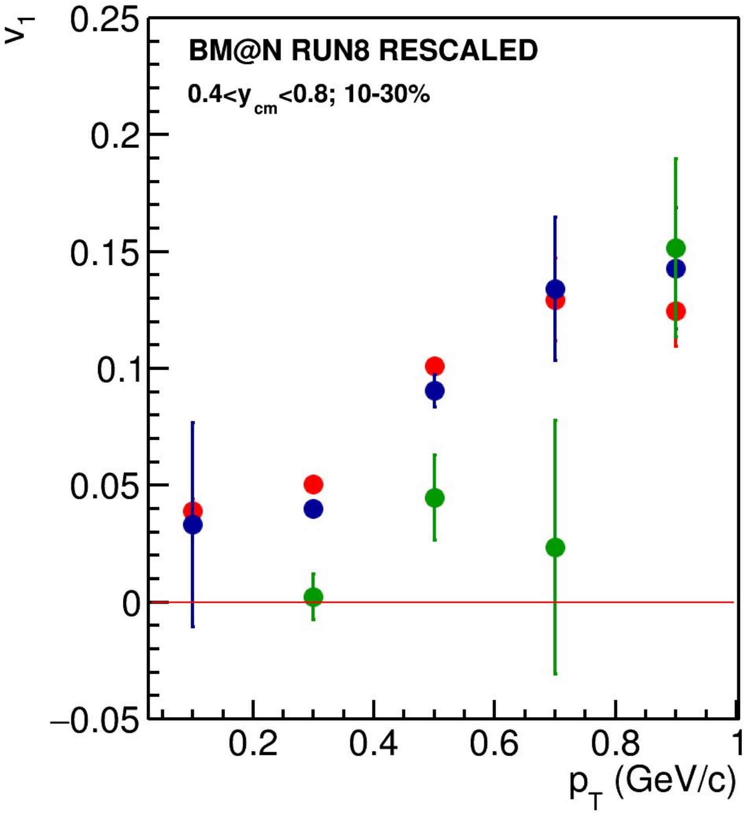




New layout produces larger resolution => less statistics is needed

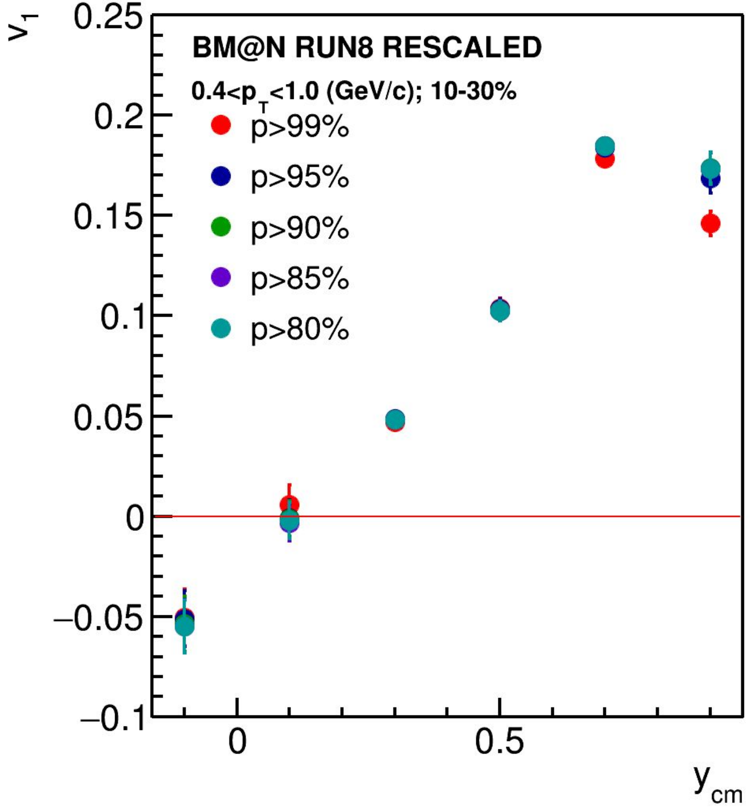
Systematics due to nhits cut

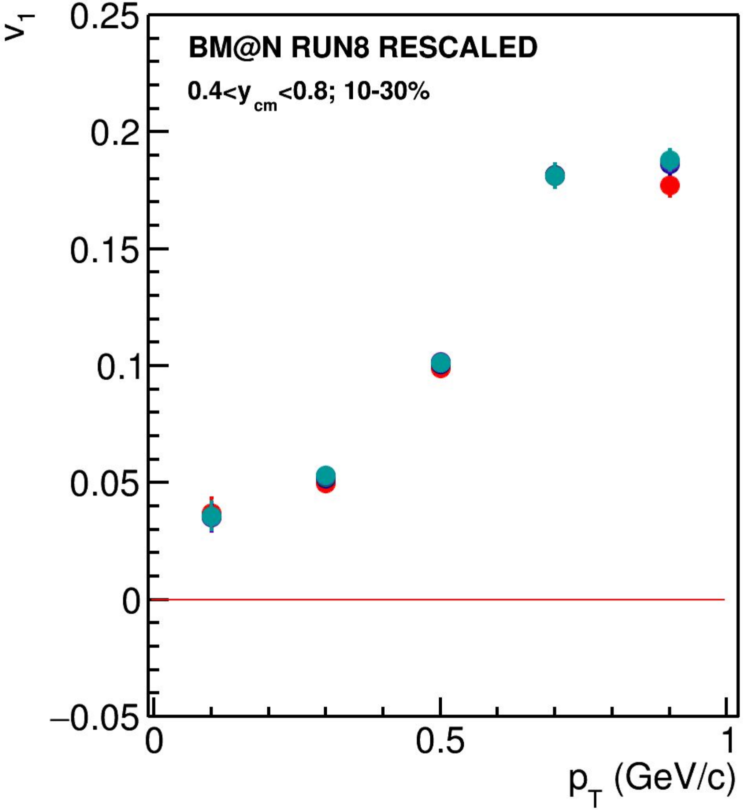




We observe small variation due to Nhits cut => small systematics

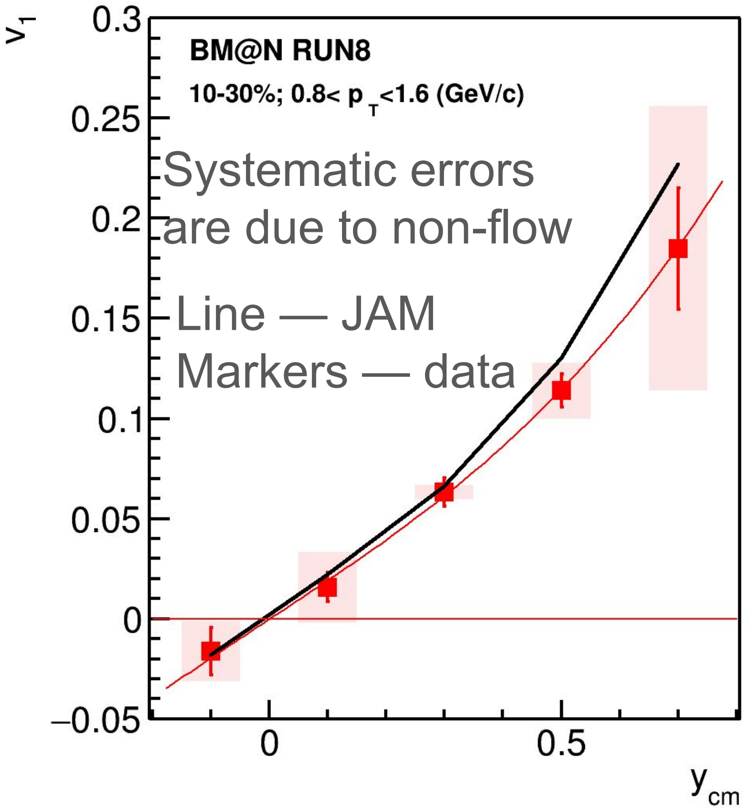
Systematics due to identification

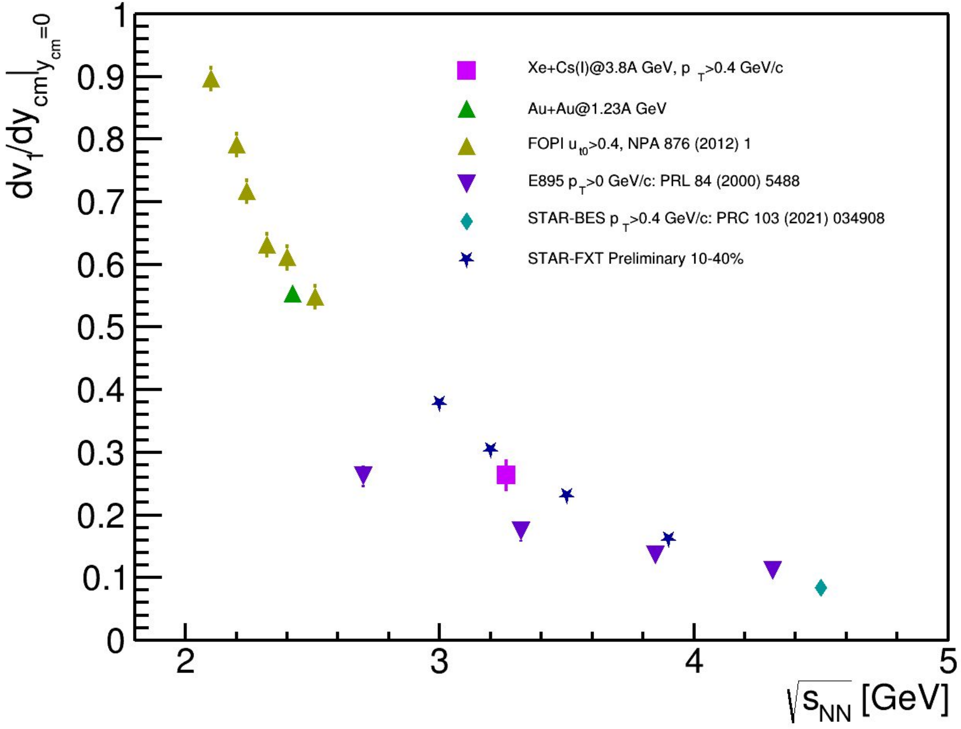




We observe small variation due to cut on purity => small systematics

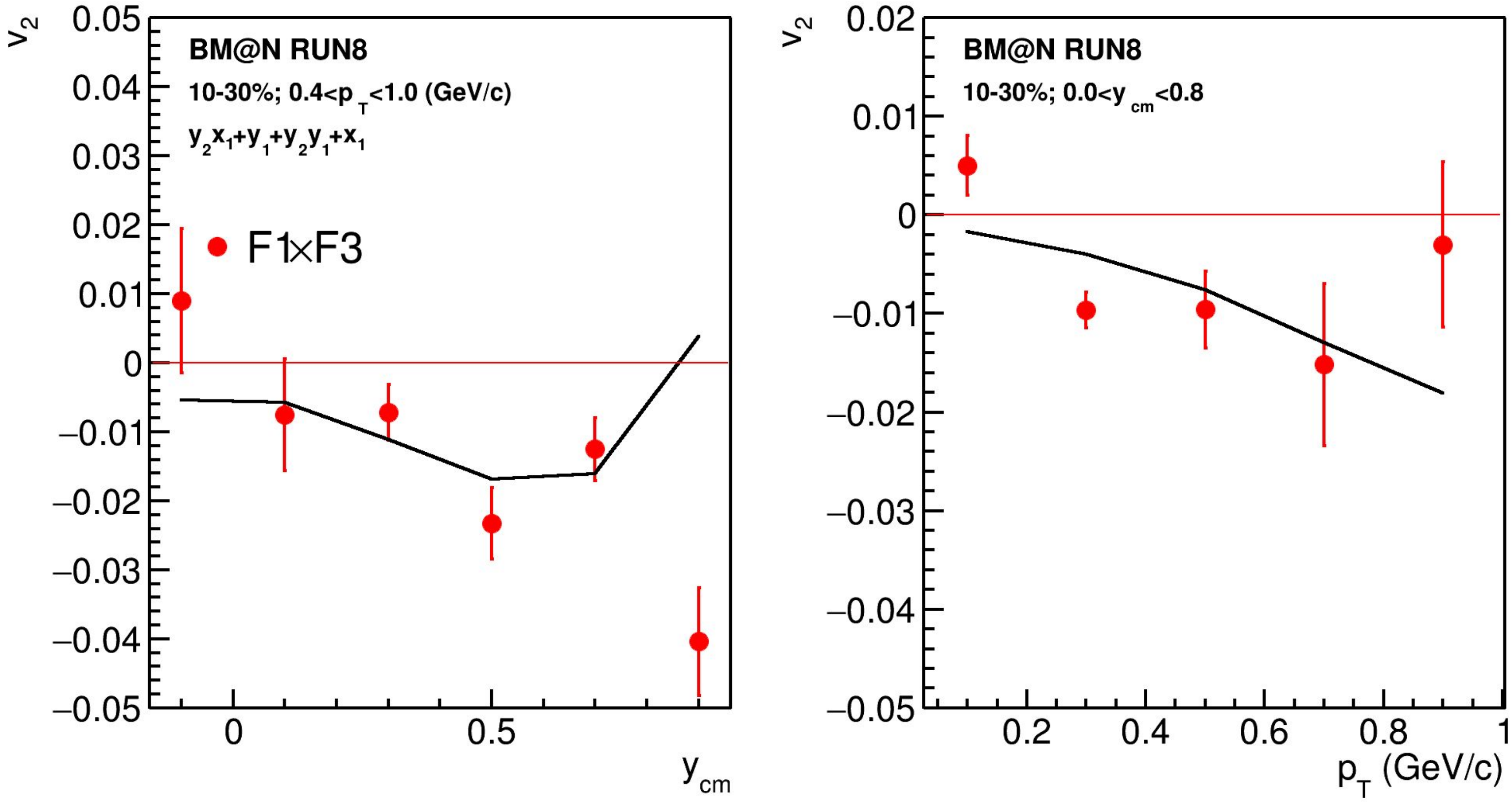
v_1 as a function of pT and y (systematics due to non-flow)





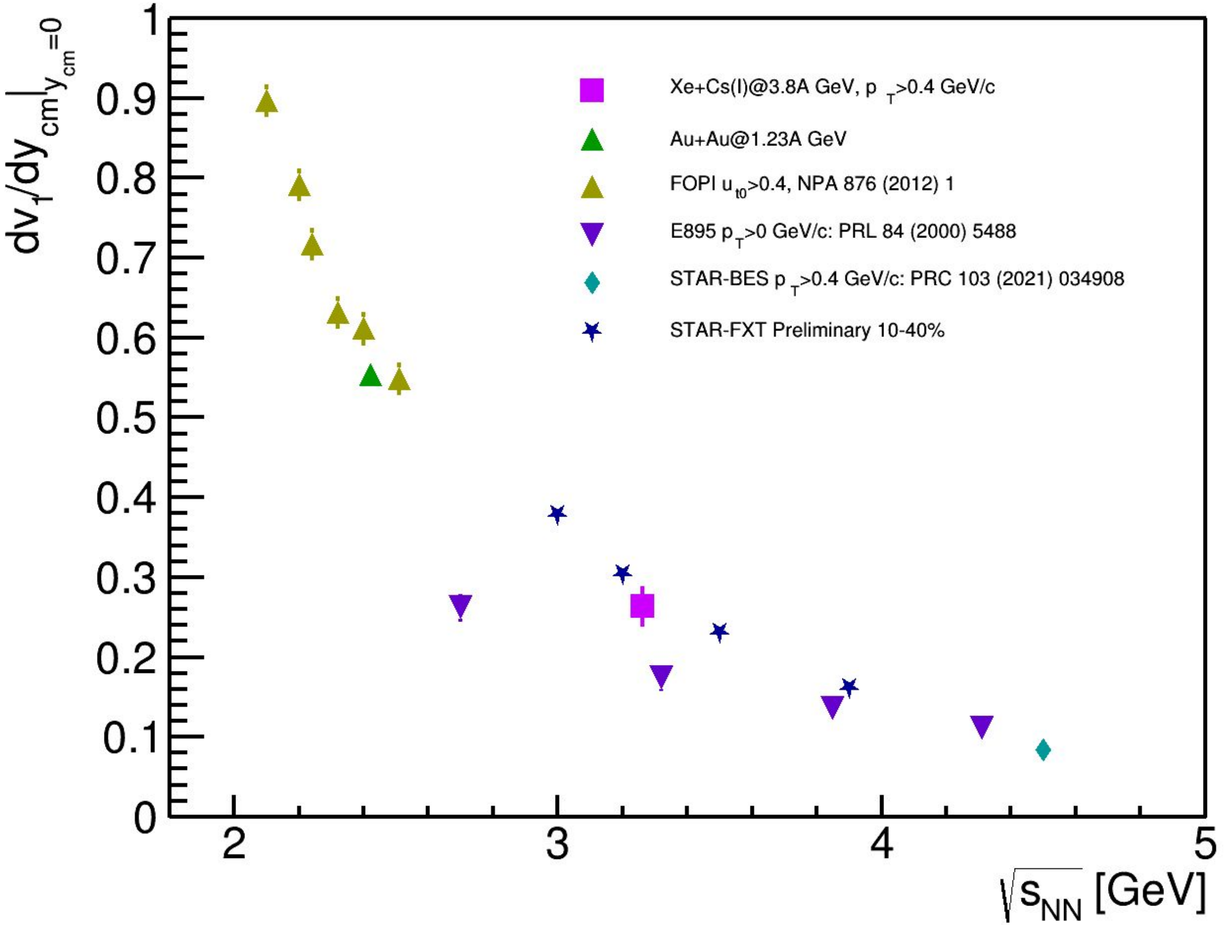
JAM model reproduces the y-dependence of v_1 for larger p_T

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



Half of all the available systematics was used

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



dv_1/dy is in agreement with the world data