CBM performance for charged hadrons anisotropic flow measurements

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Collision geometry and anisotropic transverse flow

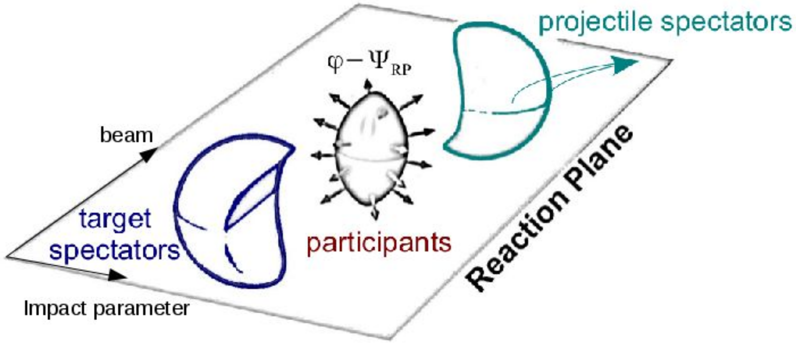
Asymmetry in coordinate space converts due to interaction into

momentum asymmetry with respect to the symmetry plane (reaction plane - RP)

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

$$\Downarrow$$

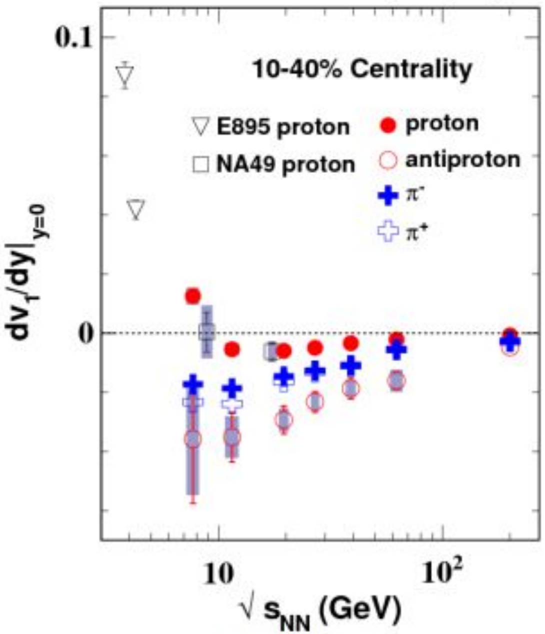
$$v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$



Measurements of anisotropic transverse flow allow to constrain the transport coefficients of the matter created in heavy ion collisions

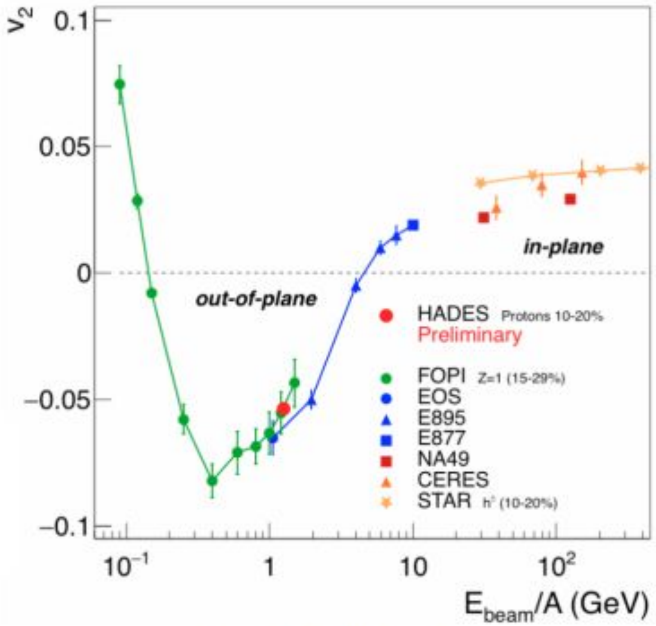
Collective flow at FAIR energies

Directed flow (slope)



STAR Collaboration
PRL 112 (2014) 162301

Elliptic flow

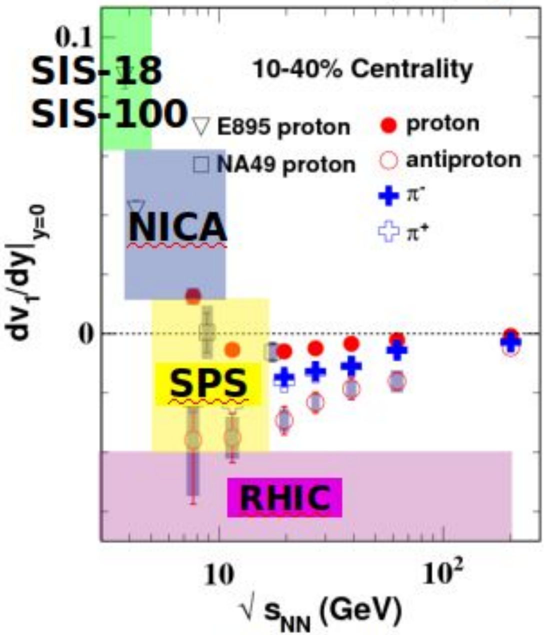


HADES Collaboration
JPCS 742 (2016) 012008

CBM will extend existing data and provide new measurements for identified charged hadrons, di-leptons and multistrange hyperons (see talk by O. Lubynets, 27/08)

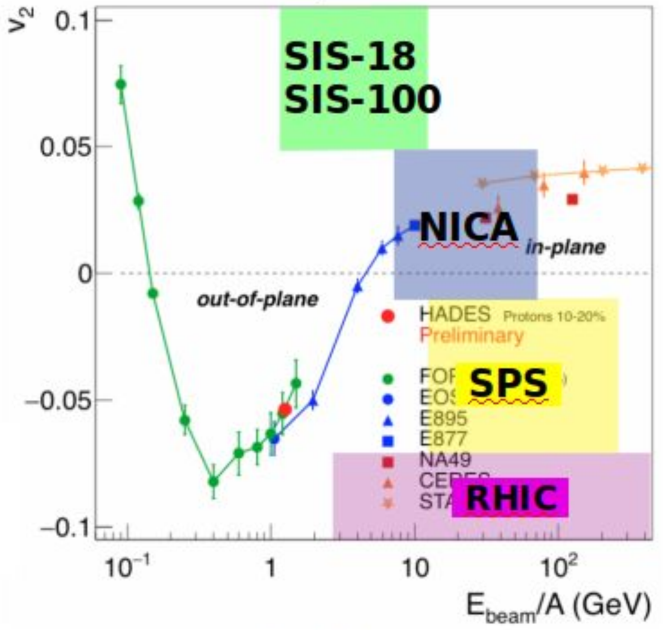
Collective flow at FAIR energies

Directed flow (slope)



STAR Collaboration
PRL 112 (2014) 162301

Elliptic flow



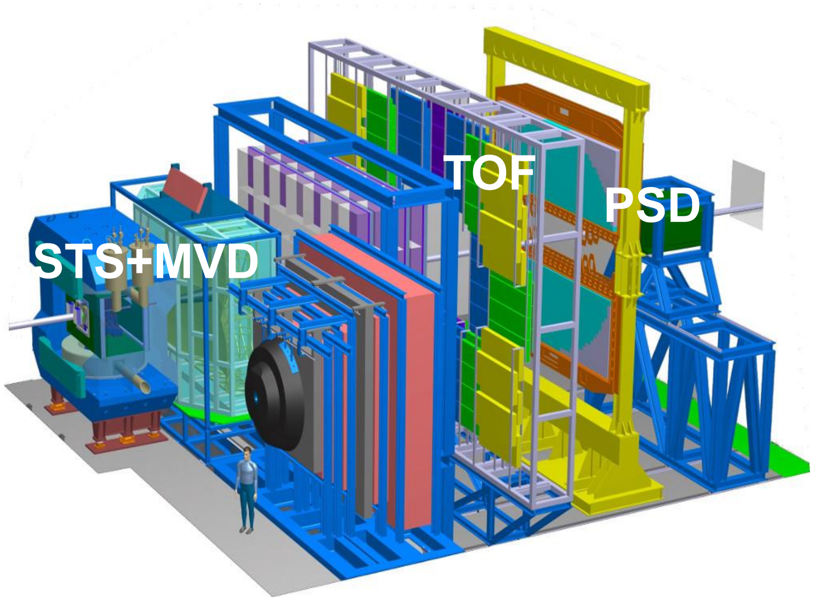
HADES Collaboration
JPCS 742 (2016) 012008

CBM will extend existing data and provide new measurements for identified charged hadrons, di-leptons and multistrange hyperons

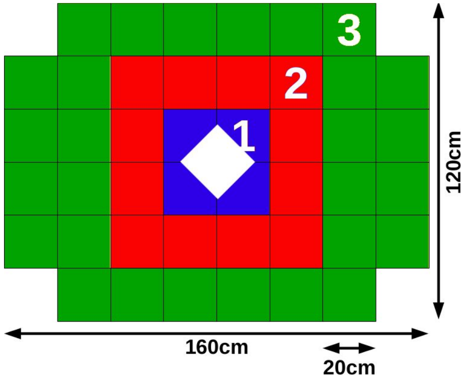
Detector subsystems used for flow analysis

CBM subsystems important for v_n measurements:

- Particle momentum (φ,y, p_T): STS+MVD
- Centrality estimation: event classes defined with PSD energy or/and STS multiplicity
- Particle identification: TOF
- Reaction plane (Ψ_{RP}): PSD transverse energy asymmetry (φ distribution in STS)

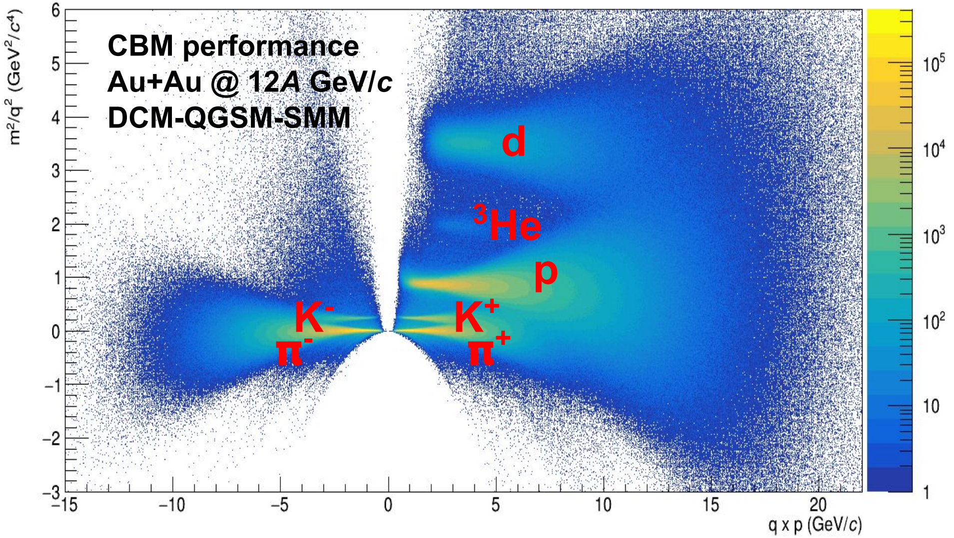


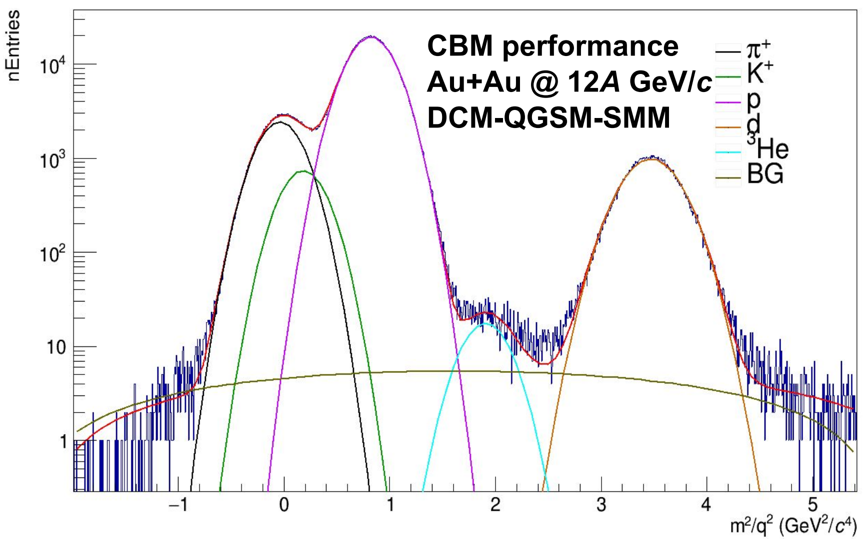
PSD transverse layout



Hole size: 20 cm
(side of the square)

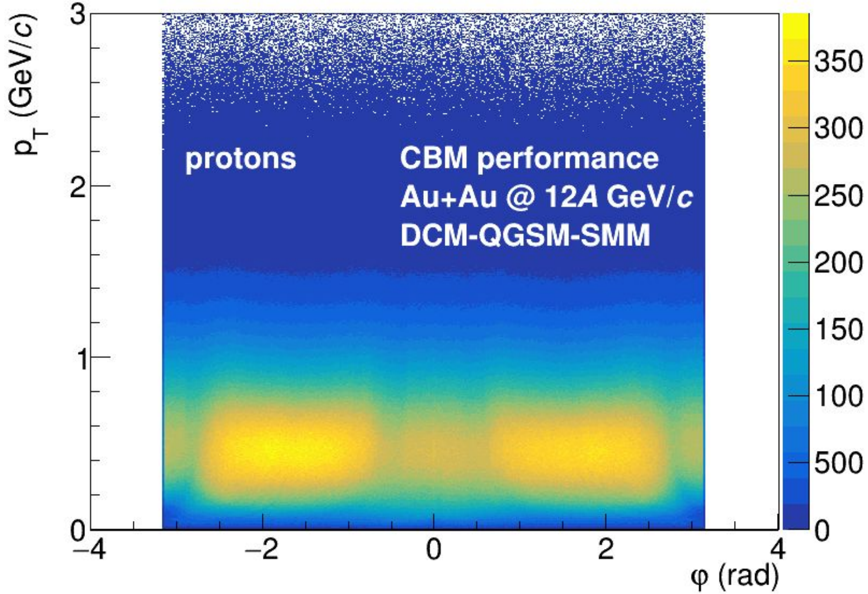
Bayesian charged hadron identification with TOF

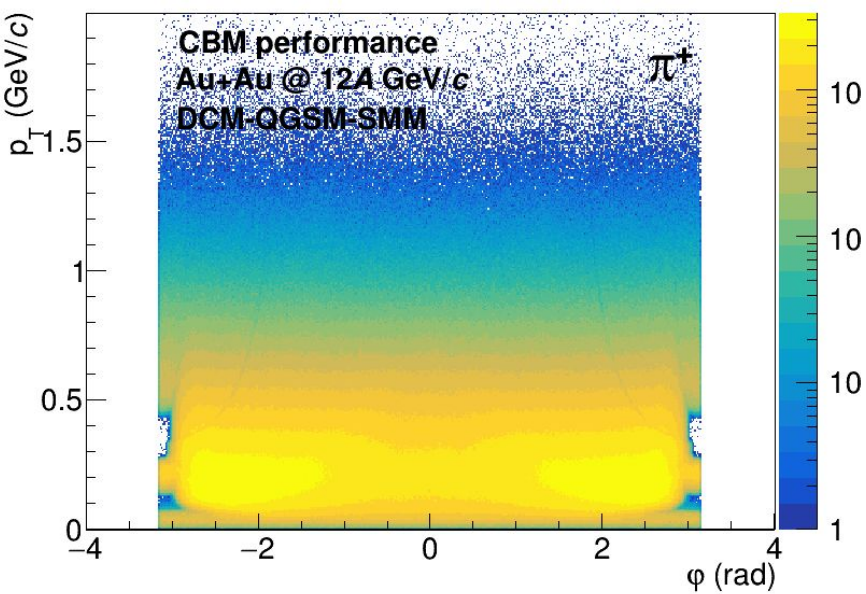




Time-of-Flight technique provides clear separation between charged hadrons

Azimuthal non-uniformity of the CBM response





Azimuthal non-uniformity of the CBM detectors response:
(p_T,y)-differential corrections are needed!

Scalar product method for v_n measurement

u and **Q**-vectors:

$$\mathbf{u_1} = \{u_{1,x}; u_{1,y}\} = \{\cos\phi; \sin\phi\}$$

$$\mathbf{Q_1} = \{Q_{1,x}; Q_{1,y}\} = \frac{1}{\sum_k w_k}\{\sum_k w_k \cos\phi_k; \sum_k w_k \sin\phi_k\}$$

Scalar product method:
v_n with respect to symmetry plane estimated using group of particles "*a*":

$$v^a_{1,i}(p_T, y) = \frac{2\langle u_{1,i}(p_T, y) Q^a_{1,i}\rangle}{R^a_{1,i}},\ i = x, y.$$

$R^a_{1,i}$ is a 1st order event plane resolution correction (see next slide)

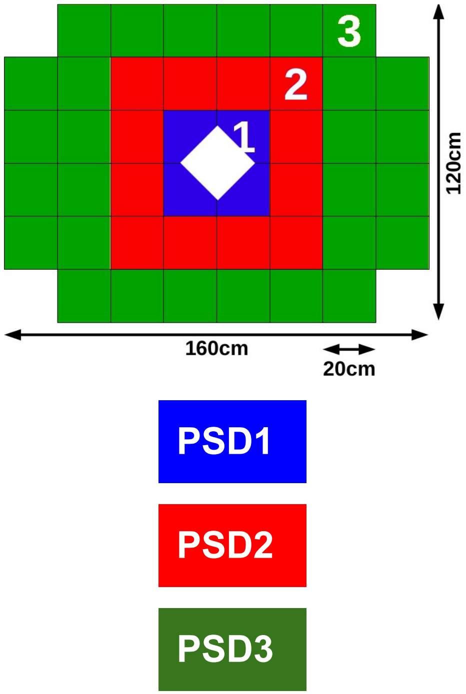
Resolution correction factor with 3-subevent method

$$R^a_{1,i}\{b,c\} = \sqrt{2\frac{\langle Q^a_{1,i}Q^b_{1,i}\rangle\langle Q^a_{1,i}Q^c_{1,i}\rangle}{\langle Q^b_{1,i}Q^c_{1,i}\rangle}},\ \ i = x, y$$

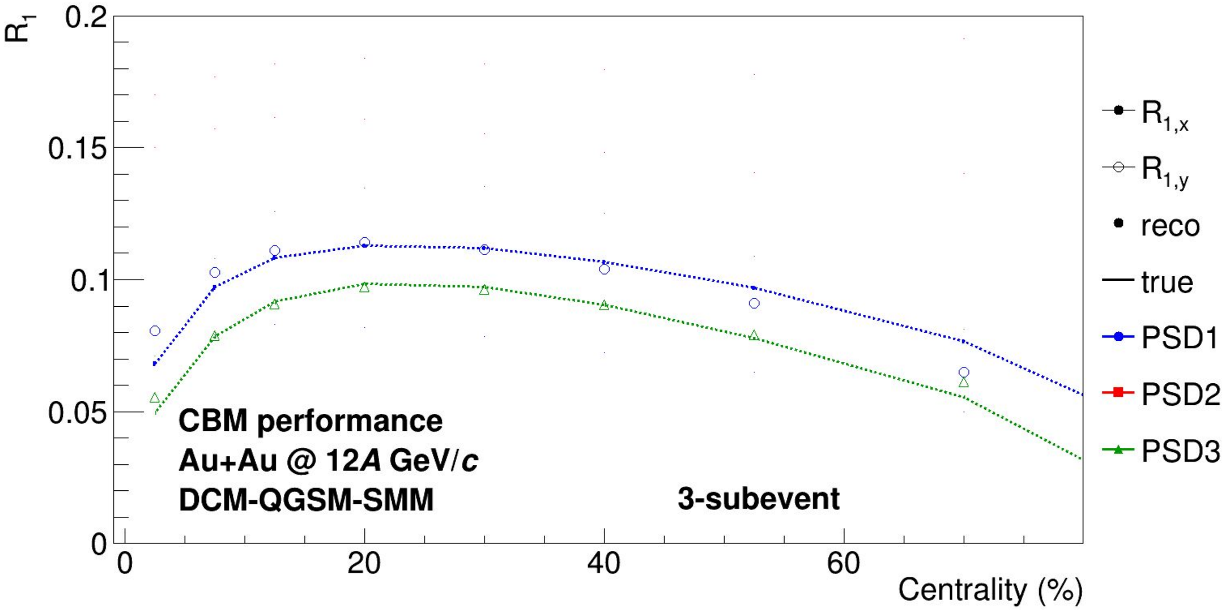
MC-true subevent resolution correction for performance checks:

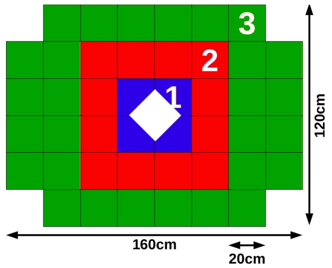
$$R^{a,MC}_{1,x} = \langle Q^a_{1,x}\cos\Psi_{RP}\rangle,\ \ R^{a,MC}_{1,y} = \langle Q^a_{1,y}\sin\Psi_{RP}\rangle$$

PDS modules layout with rectangular beam hole



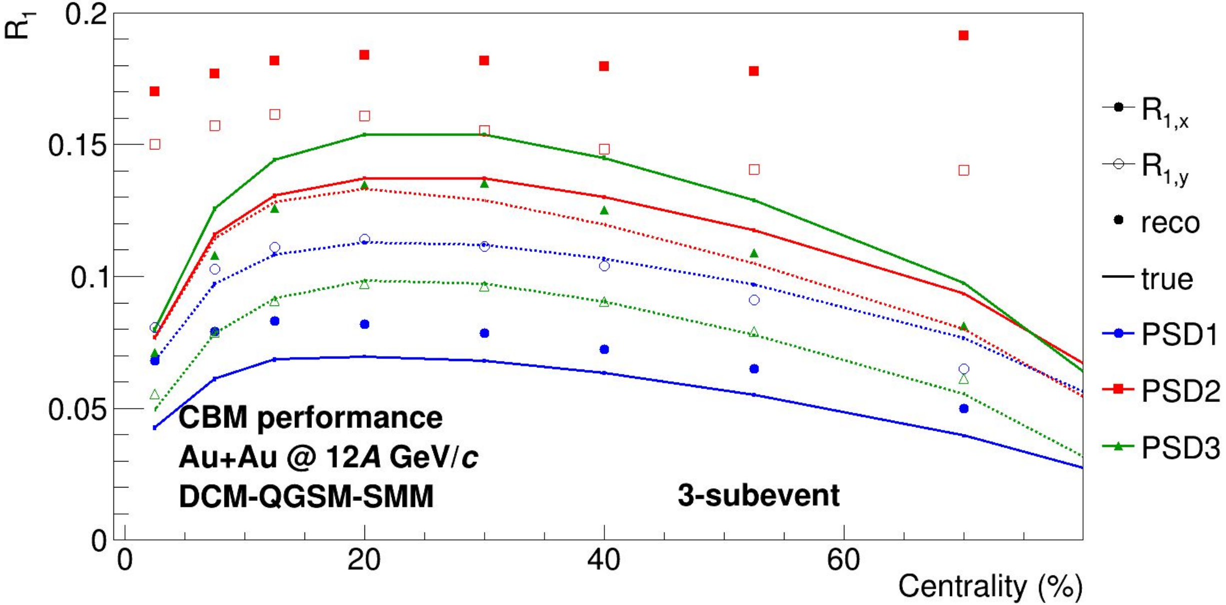
Resolution correction factor with 3-subevent method

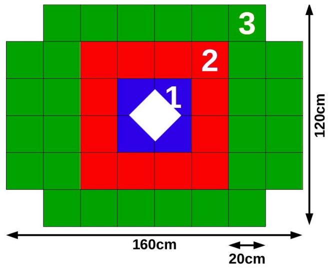




Reasonable agreement between true and reconstructed values
of the esolution correction factors for some of the PSD subevents

Resolution correction factor with 3-subevent method





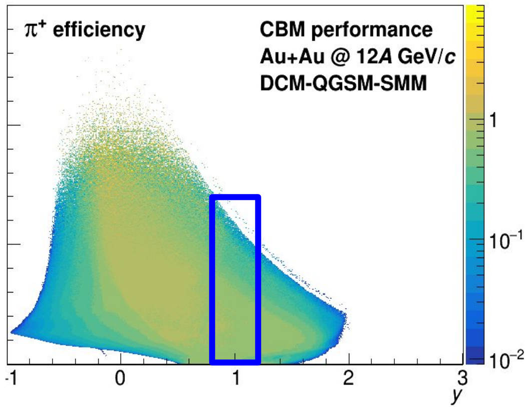
Significant bias in correlations due to hadronic shower leakage among the neighbouring PSD subevents

Resolution correction factor with 4-subevent method

$$R_{1,i}^{PSD1,3} = \frac{\langle Q_{1,i}^{PSD1} Q_{1,i}^{PSD3} \rangle R_{1,i}^{STS}\{PSD1, PSD3\}}{\langle Q_{1,i}^{PSD1,3} Q_{1,i}^{STS} \rangle},$$

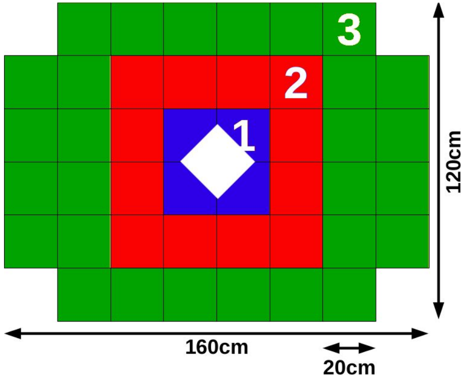
$$R_{1,i}^{PSD2} = \frac{\langle Q_{1,i}^{PSD2} Q_{1,i}^{STS} \rangle}{R_{1,i}^{STS}\{PSD1, PSD3\}},$$

positive pion



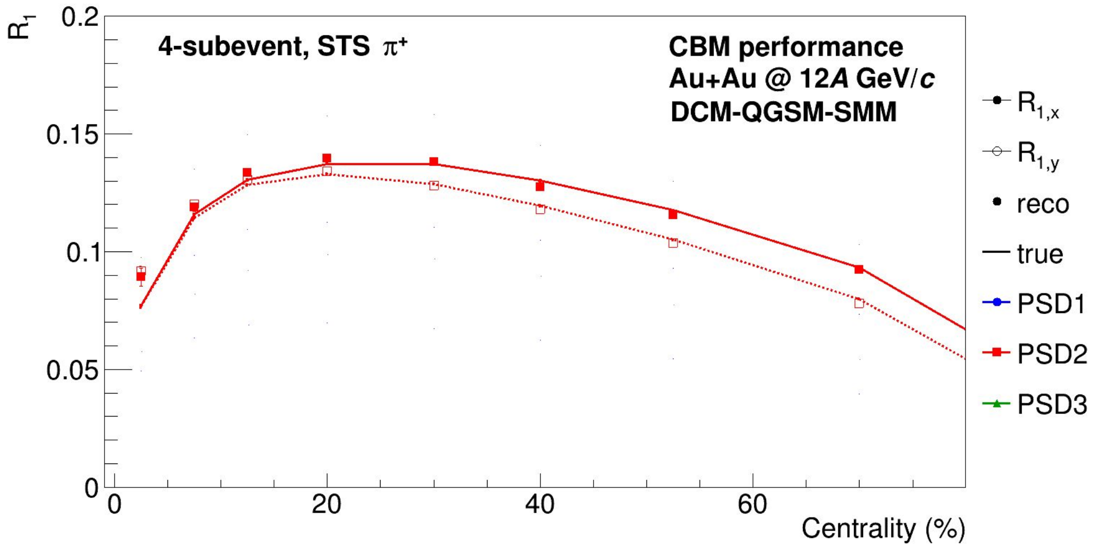
$p_T \in [0, 1.4]$, $y \in [0.8, 1.2]$

PDS modules layout with rectangular beam hole



Resolution correction factor with 4-subevent method

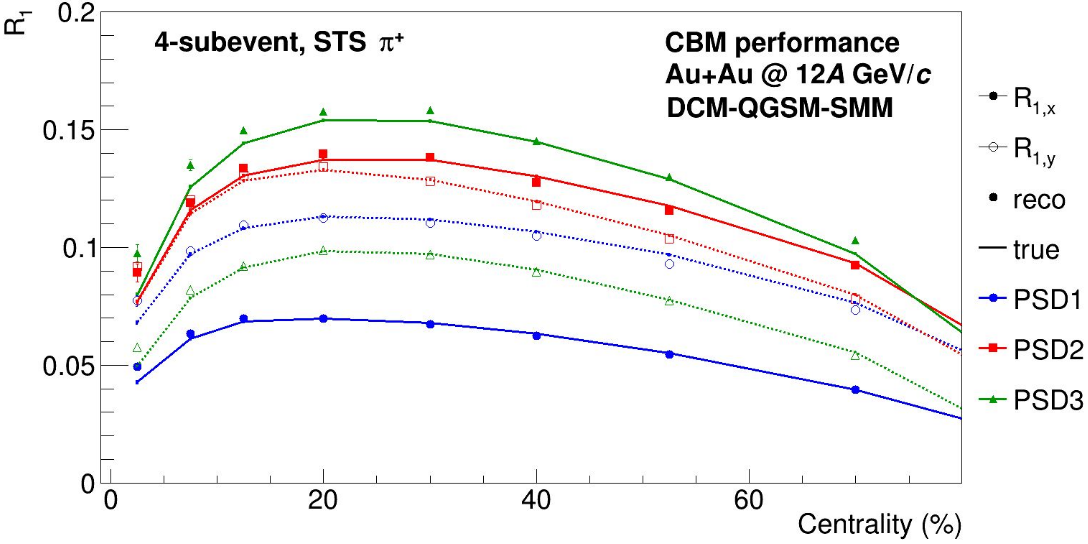
4th subevent: positive pions



Overall good agreement between MC-true and reconstructed values of R_1

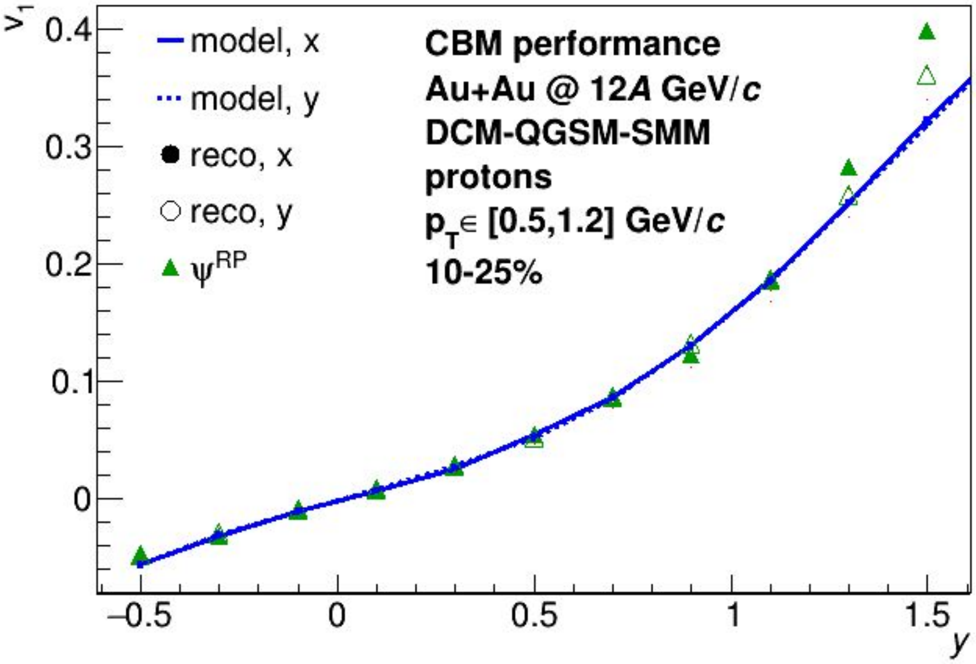
Resolution correction factor with 4-subevent method

4th subevent: positive pions



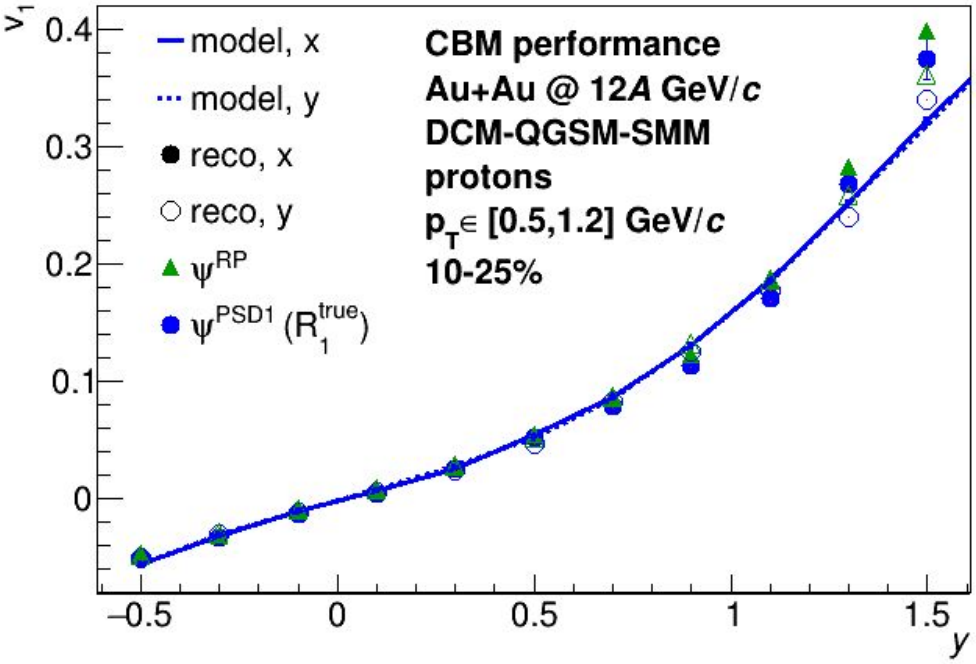
Much better performance than 3-subevent method

Proton v_1 vs. rapidity



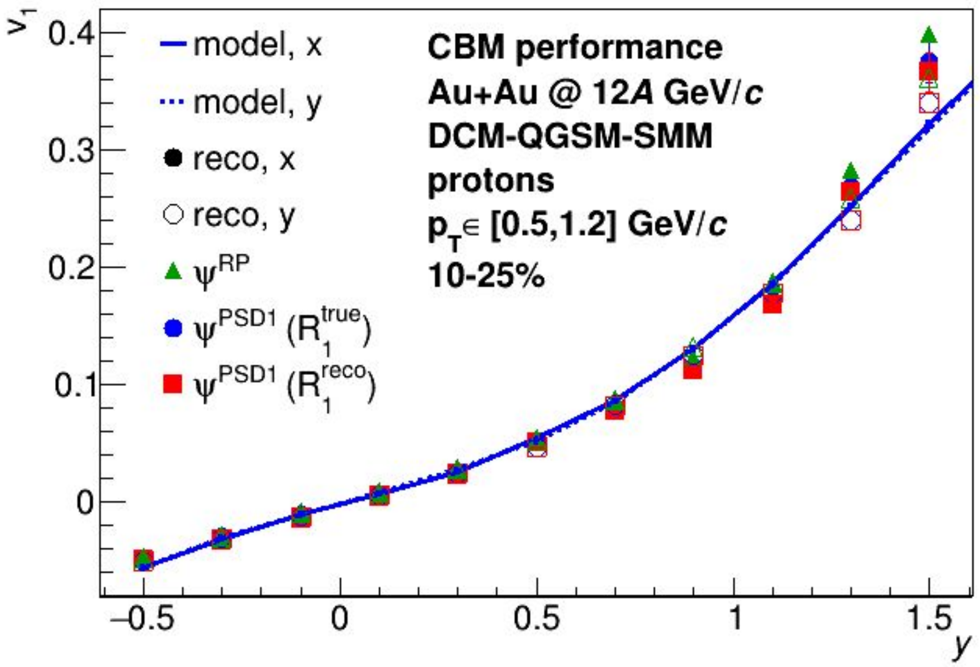
Results with reconstructed protons relative to the reaction plane agrees with the input v_1

Proton v_1 vs. rapidity



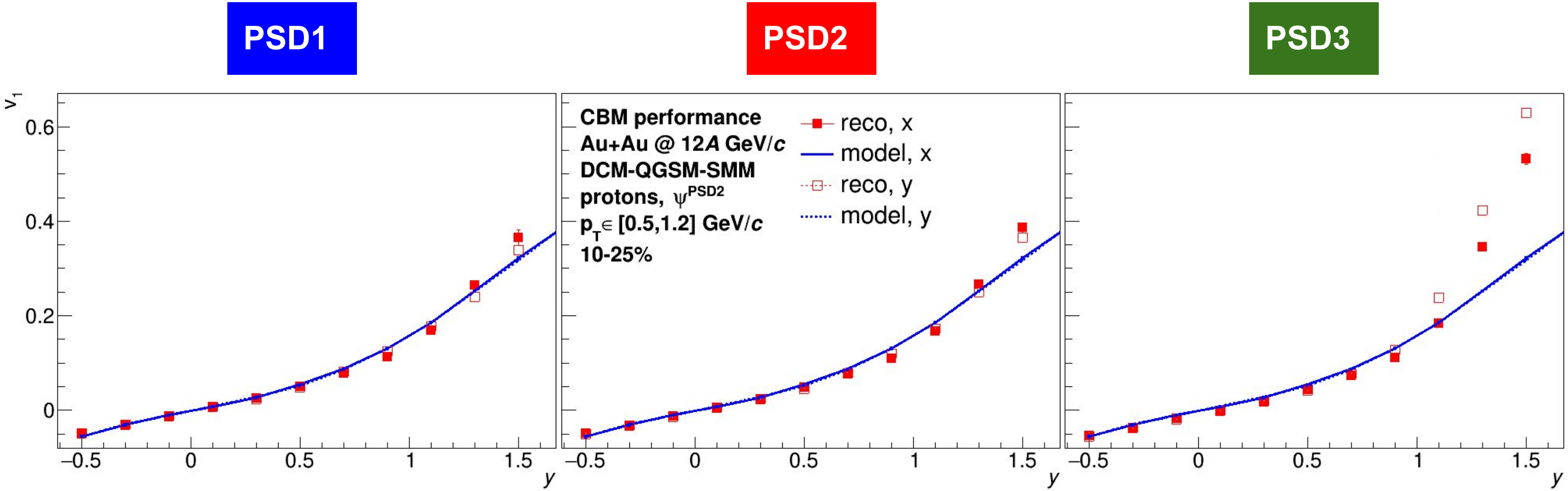
Results with reconstructed protons & PSD1 subevent (with true resolution correction) agrees with the input v_1

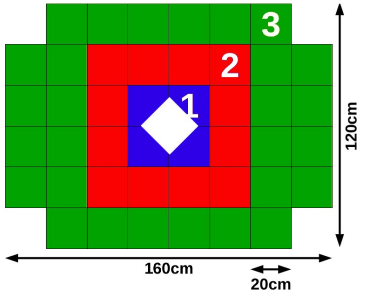
Proton v_1 vs. rapidity



Results for complete data driven analysis agrees with the input v_1

Proton v_1 with different PSD subevents

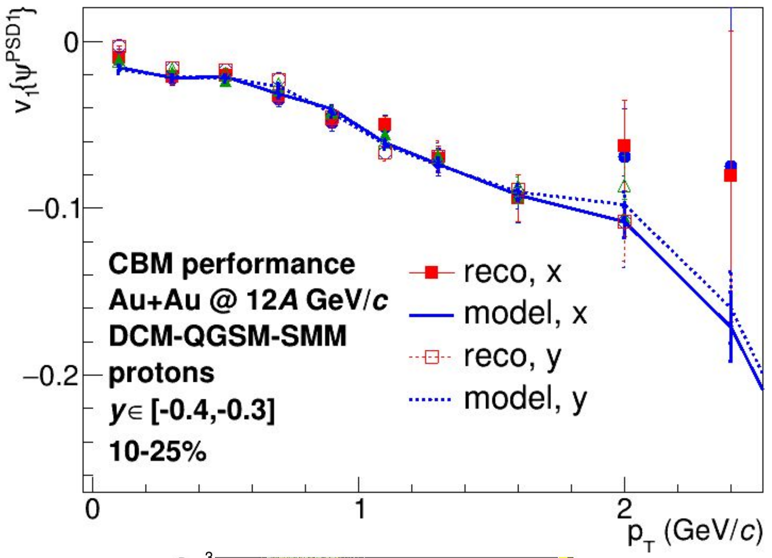




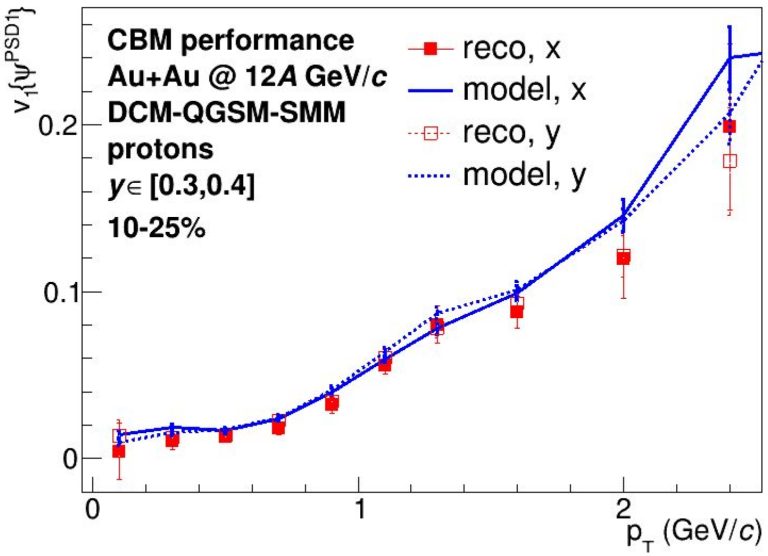
Bias at forward rapidity with PSD3 subevent.
Magnitude depends on rapidity separation
between protons in STS and PSD subevent (largest for PSD3)

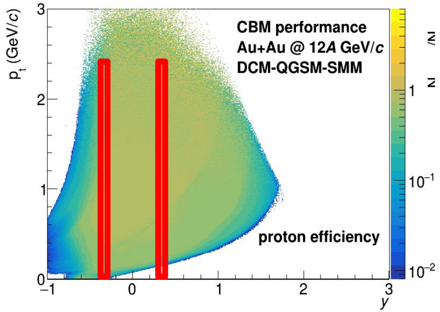
Proton v_1 vs. p_T for back/fwrd. rapidity windows

Backward



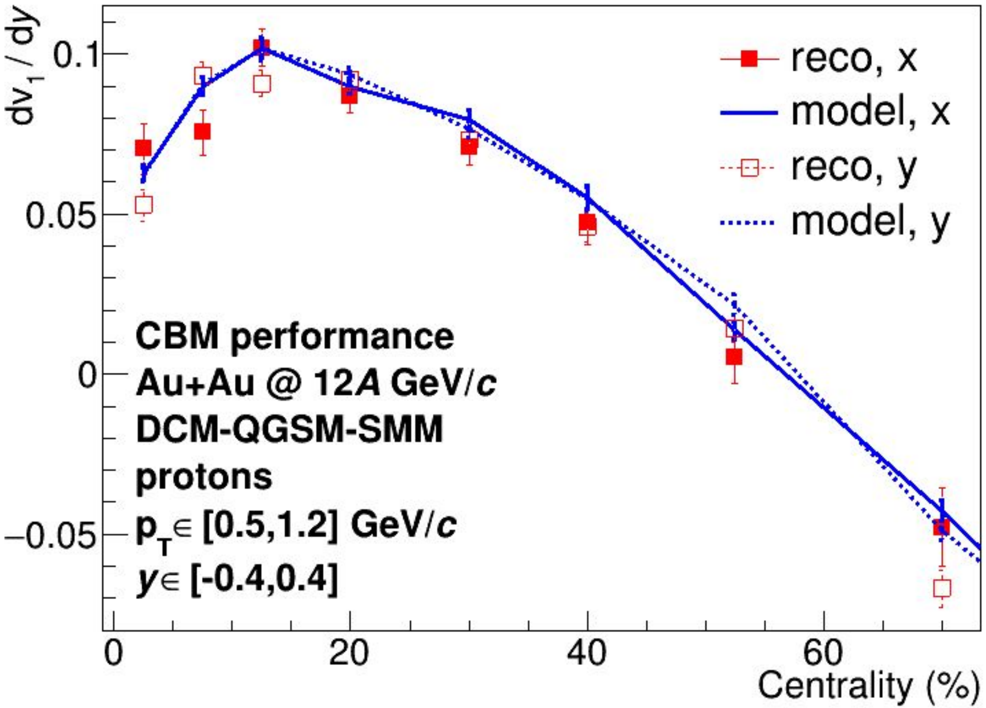
Forward





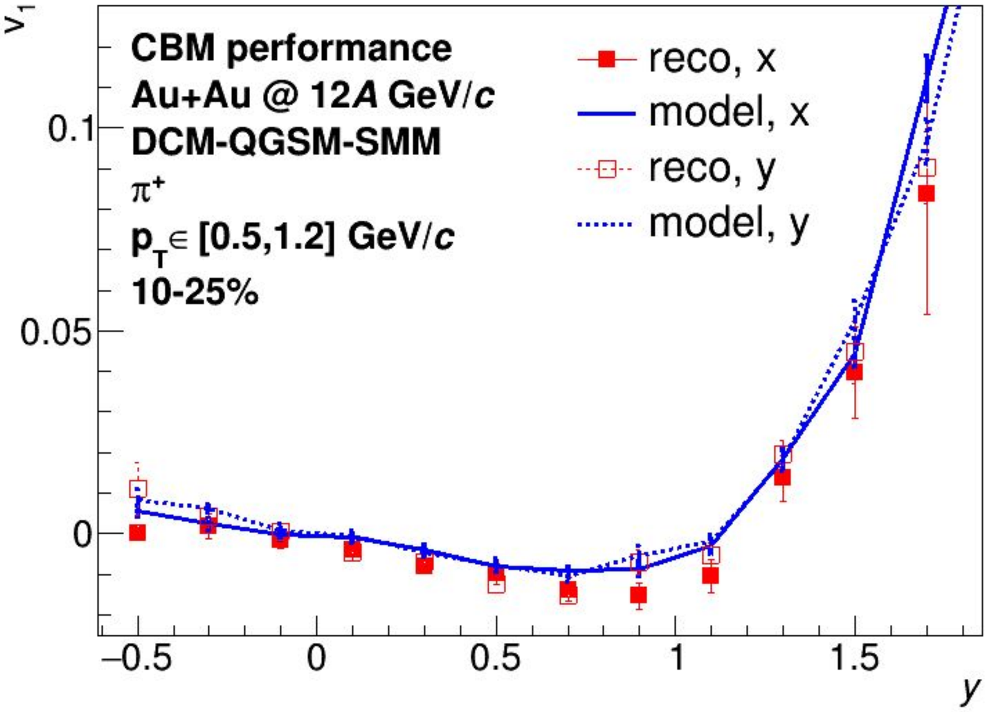
Better reconstruction efficiency at forward rapidity result in a more precise measurement

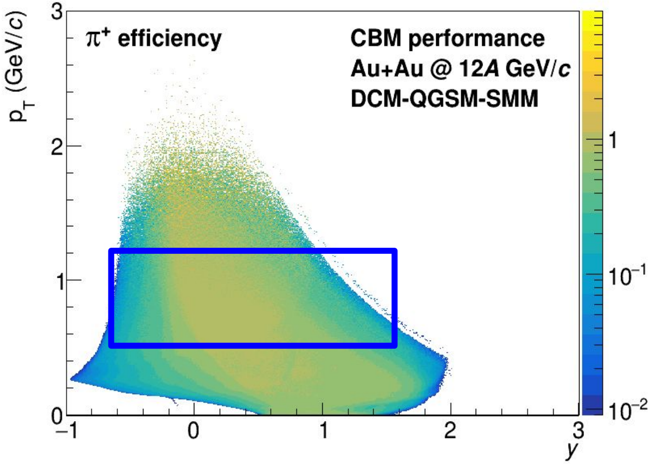
Proton v_1 slope at midrapidity (dv_1/dy) vs. centrality



Change of sign in peripheral collisions

Pion directed flow vs. rapidity





Poor reconstruction efficiency for backward rapidity:
more statistics needed for slope extraction

Summary

Presented performance for charged pion and proton directed flow as a function of p_T, y and centrality for Au+Au collisions at 12*A* GeV/*c*

- Investigated effects of the spectator plane estimation
- Centrality using track multiplicity
- Bayesian identification with TOF information

TODO:

- Implement (p_T,y)-dependent efficiency correction
- Investigate charged hadrons (negative pions, charged kaons)
- Other harmonics (elliptic flow v_2, et. al.)

Acknowledgements

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- the Ministry of Science and Higher Education of the Russian Federation, project "Fundamental properties of elementary particles and cosmology" № 0723-2020-0041
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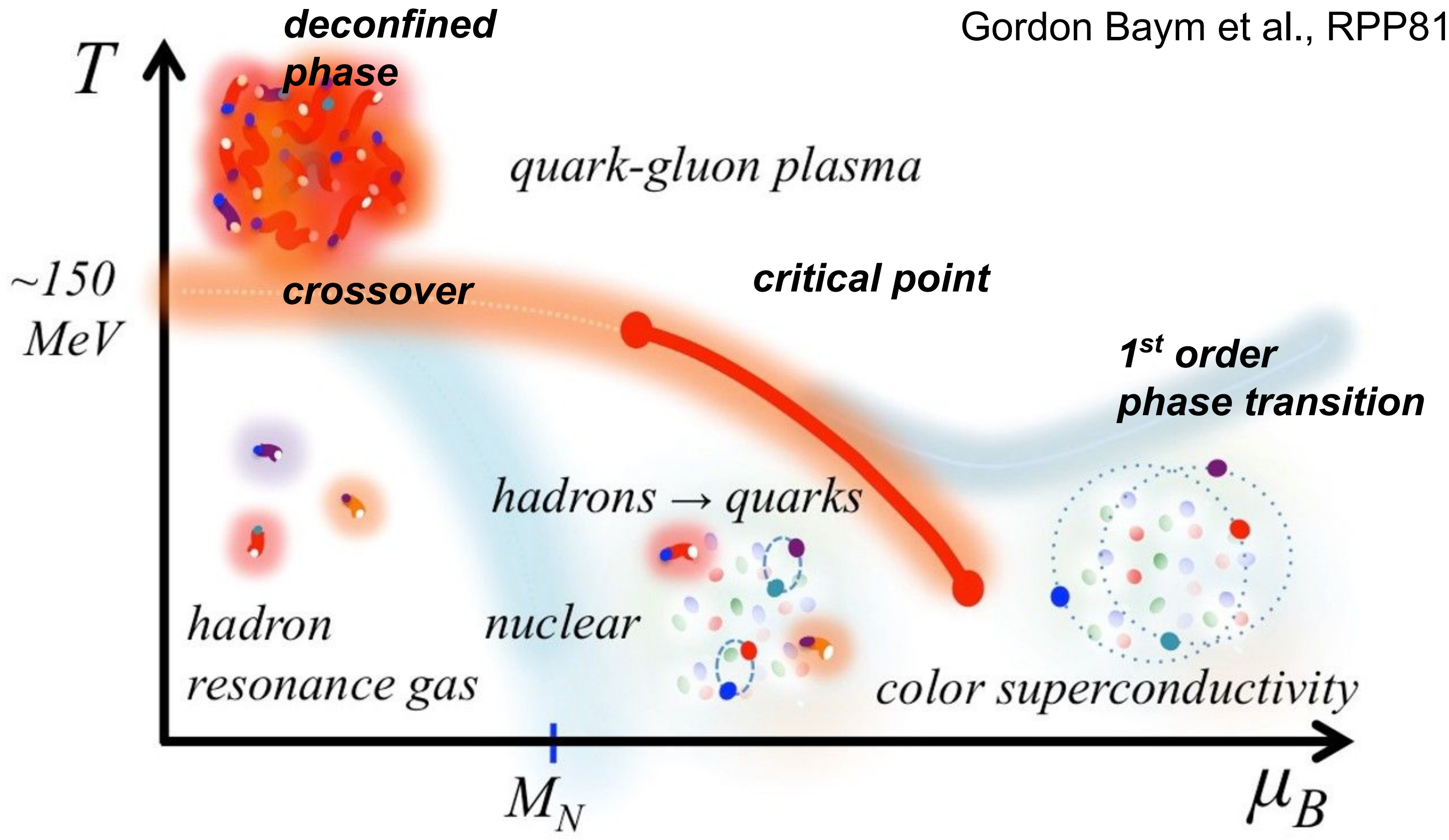
- Russian Science Foundation grant 17-72-20234

Backup

Structure of the QCD matter phase diagram

Gordon Baym et al., RPP81 (2018) 056902



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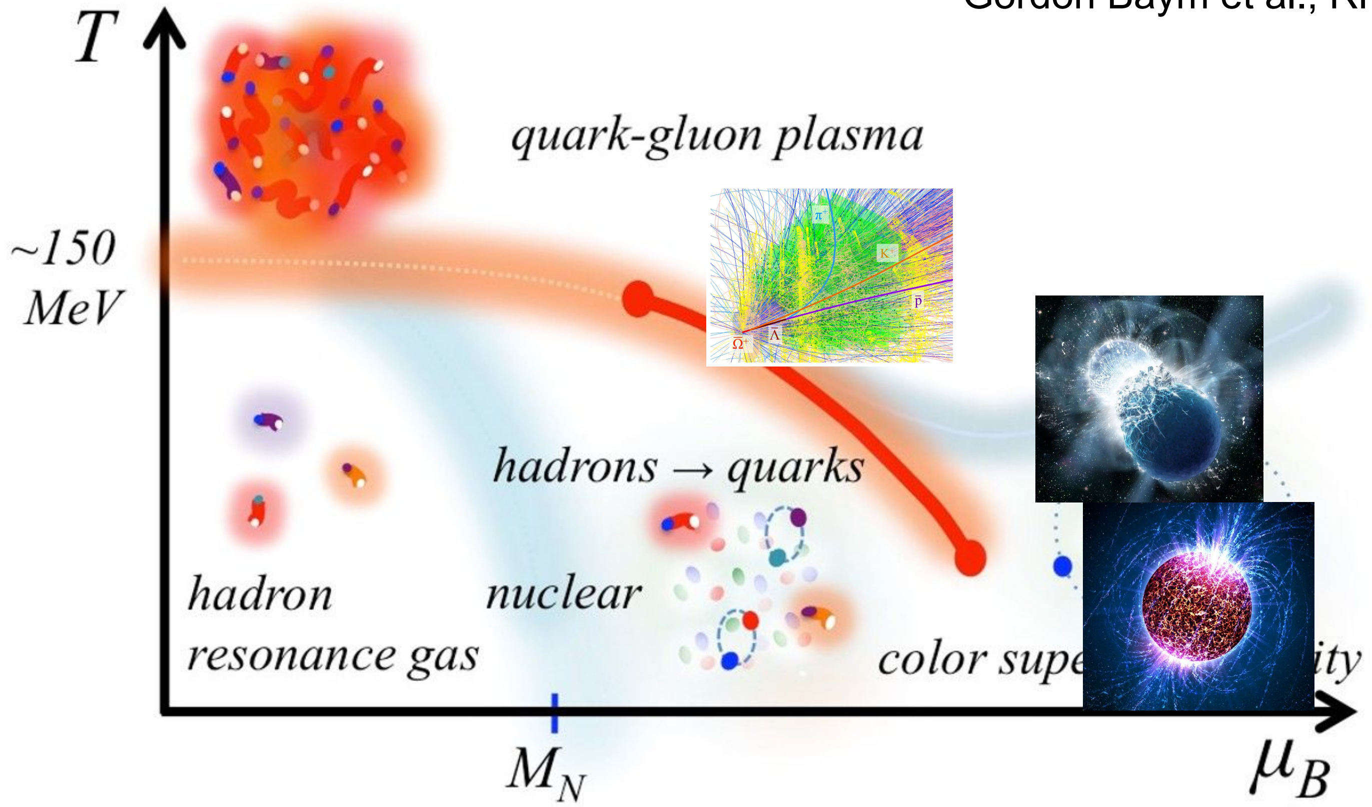
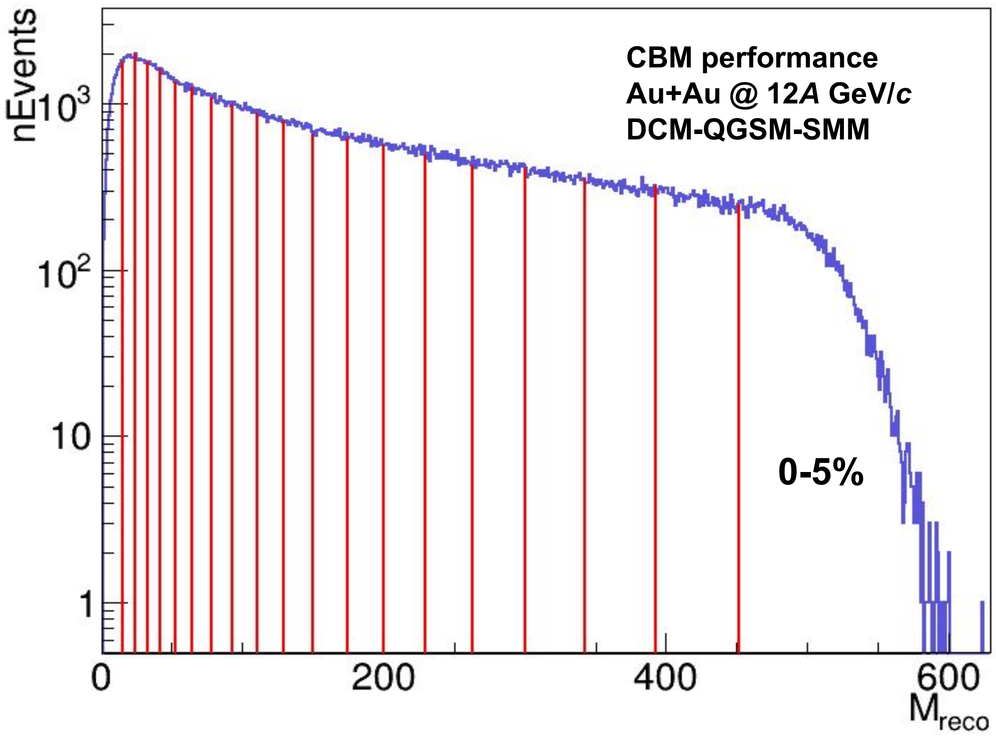


Neutron stars

Simulation setup

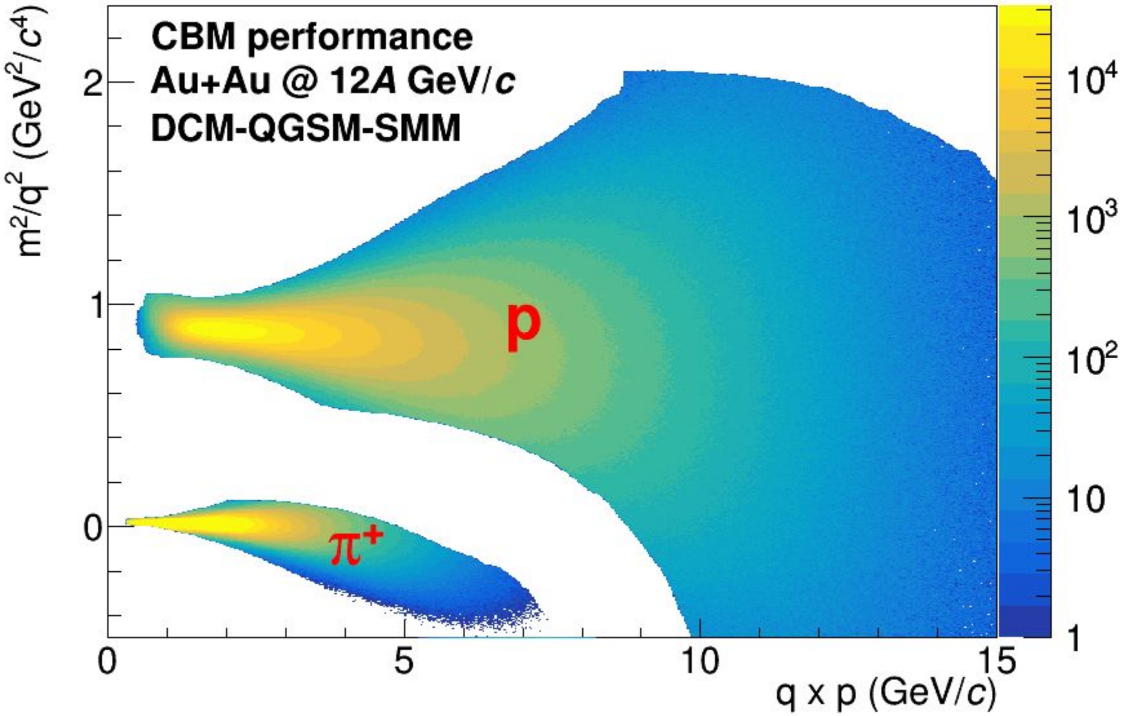
Model	DCM-QGSM-SMM (with fragments)
System	Au+Au
Beam momentum	12*A* GeV/*c*
Statistics	5M events
CBM geometry	MVD, STS, RICH, TDR, TOF, PSD
PSD geometry	20 cm hole size 44 modules
Transport code	GEANT4
Detector response	CBMROOT OCT19

Centrality determination (charged hadron multiplicity)



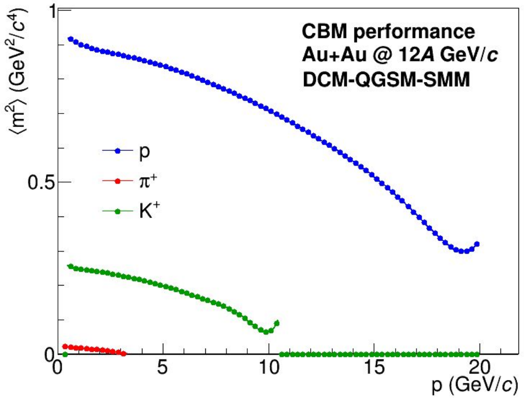
See talk by I. Segal (24/08)

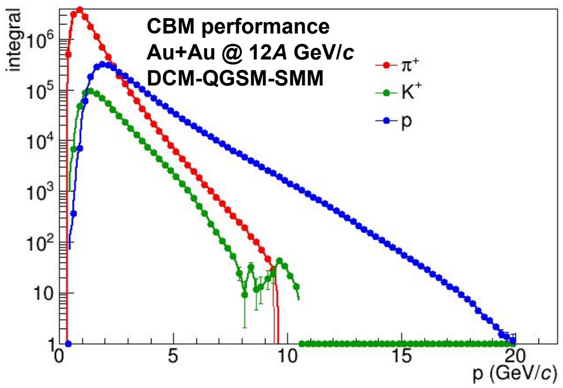
Bayesian selection of positive pions and protons

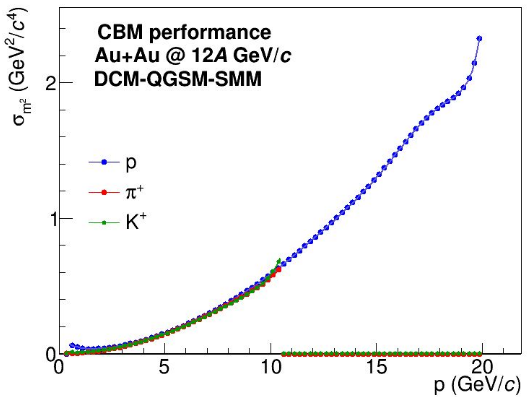


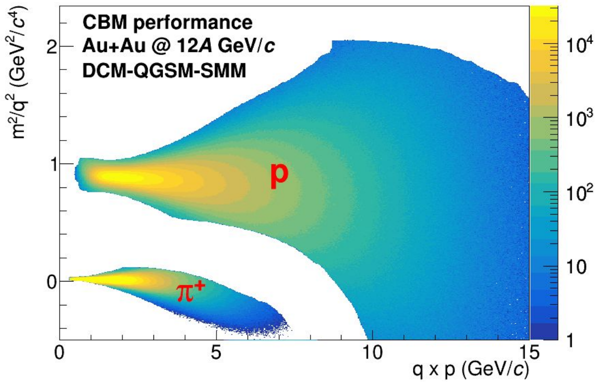
Proton and pion selection with 90% purity requirement

Particle identification with Bayesian approach





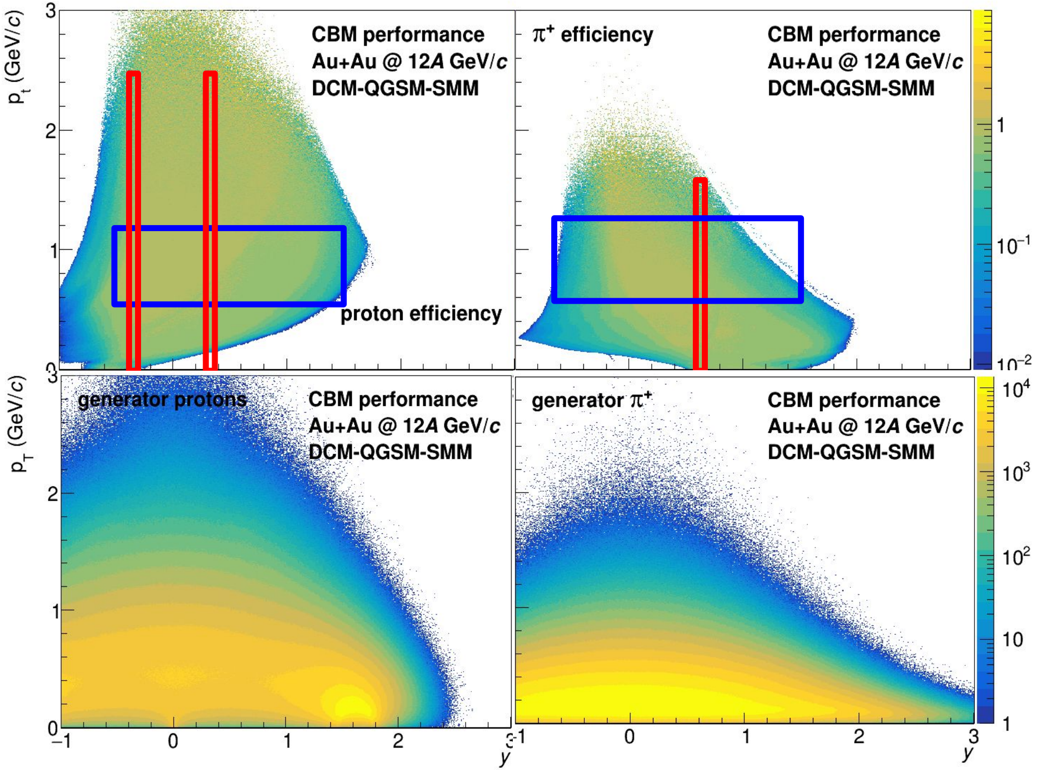




Polynomial fits of gaussian parameters and final identification

Proton and pion acceptance & efficiency maps

protons positive pion



(p_T, y)-differential v_1 results are reported for kinematic regions with high efficiency

$v_1(p_T)$ (red box)

$v_1(y)$ (blue box)

(p_T, y) integrated v_n analysis will require efficiency corrections (future studies)

QnTools: flow corrections and analysis framework

Based on data driven procedure for azimuthal acceptance non-uniformity corrections
I. Selyuzhenkov and S. Voloshin, PRC77 034904 (2008)

QnCorrections Framework (originally developed for ALICE)
J. Onderwaater, V. Gonzalez, I. Selyuzhenkov
https://github.com/FlowCorrections/FlowVectorCorrections

- Recentering, twist, and rescaling corrections applied
- time dependent (run-by-run) and as a function of centrality

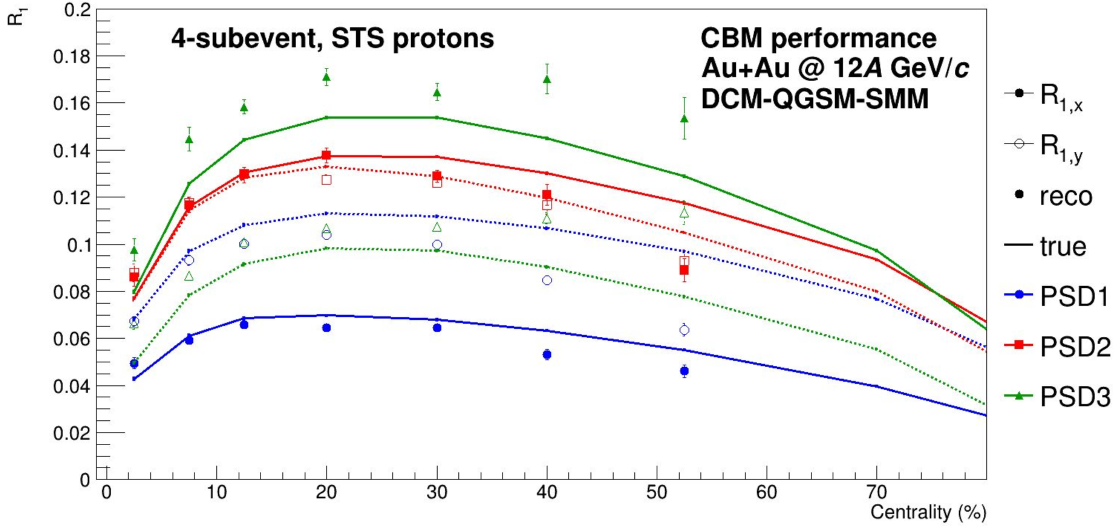
QnTools

- Extended QnCorrections framework for p_T/y-differential
- Multi-dimensional Q-vector correlation analysis

L. Kreis (GSI / Heidelberg) and I. Selyuzhenkov (GSI / MEPhI)
https://github.com/HeavyIonAnalysis/QnTools

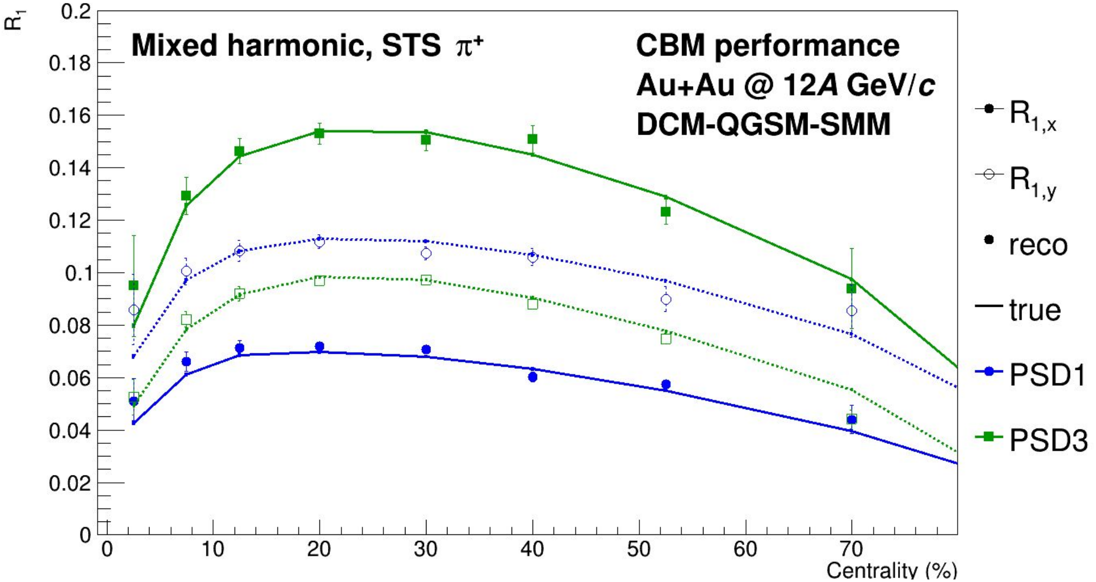
Resolution correction factor with 4-subevent method

4th subevent: protons



Worse performance compared to 4th subevent from positive pions.
Additional bias (correlation) between protons in STS and PSD

Resolution correction factor with mixed harmonic method



$$R^{A}_{1,i}\{B,C,D\} = \sqrt{2\frac{\langle Q^{A}_{1,i}Q^{B}_{1,i}\rangle\langle Q^{A}_{1,i}Q^{C}_{1,j}q^{D}_{2,k}\rangle}{\langle Q^{B}_{1,i}Q^{C}_{1,j}q^{D}_{2,k}\rangle}},\quad (i,j,k)=(x,x,x),\ (x,x,y),\ (y,x,y),\ (y,y,x)$$

Mixed harmonic method needs more statistics to get precise value of R_1

Results for pion and proton v_1

Results obtained for correlations between positively charged identified hadrons (pions and protons in STS) and all hadrons at forward rapidity (PSD acceptance).

The results are corrected for detector non-uniformity.
Resolution correction performed with 4-subevent method (3 PSD + STS positive pions)
Correction for PID and tracking efficiency is not yet done.
Only statistical uncertainties are shown.