

CBM performance for charged hadrons anisotropic flow measurements

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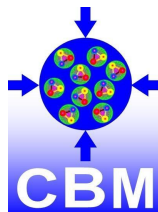
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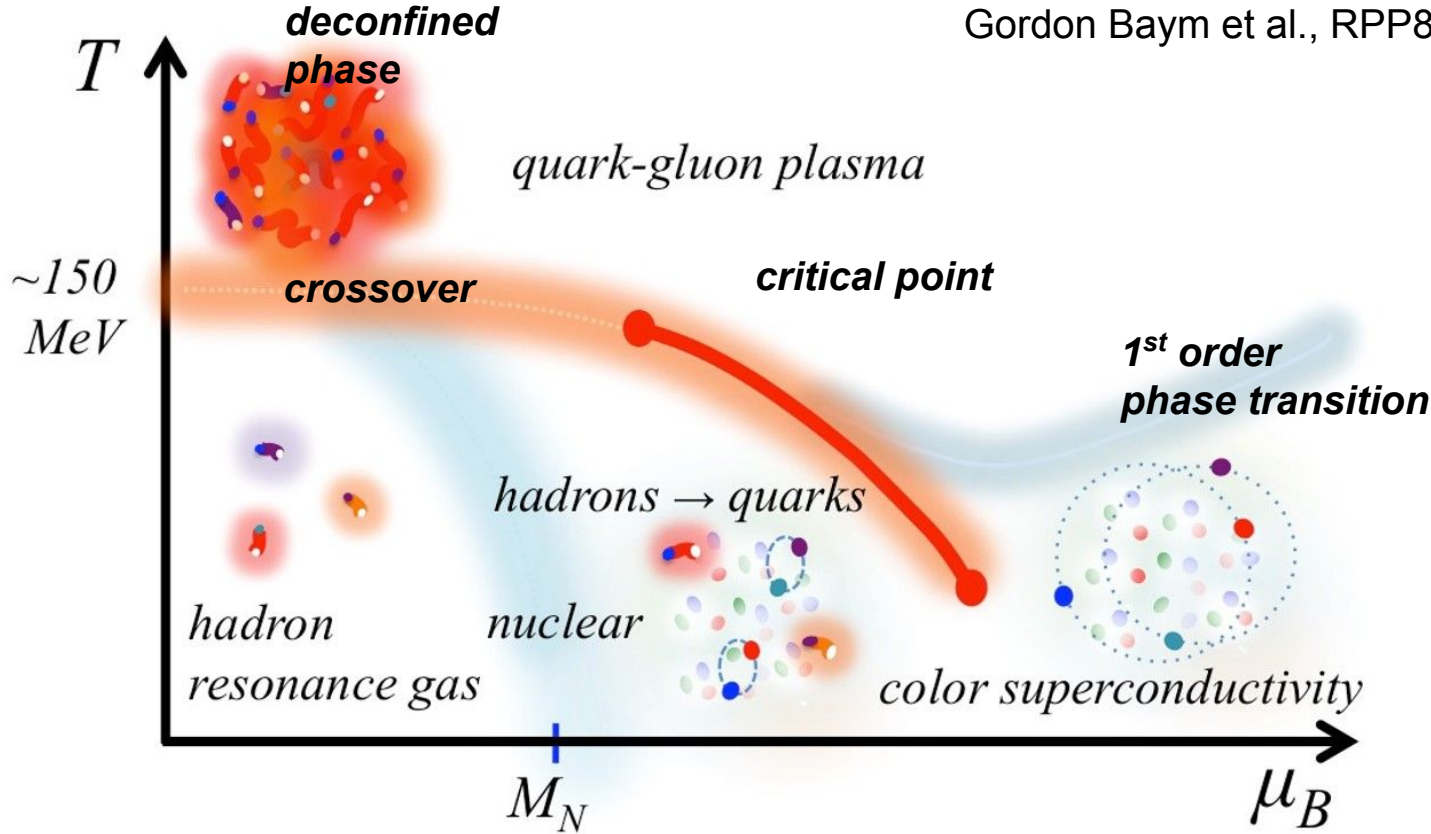
D. Blau (NRC “Kurchatov Institute”)

for the CBM Collaboration



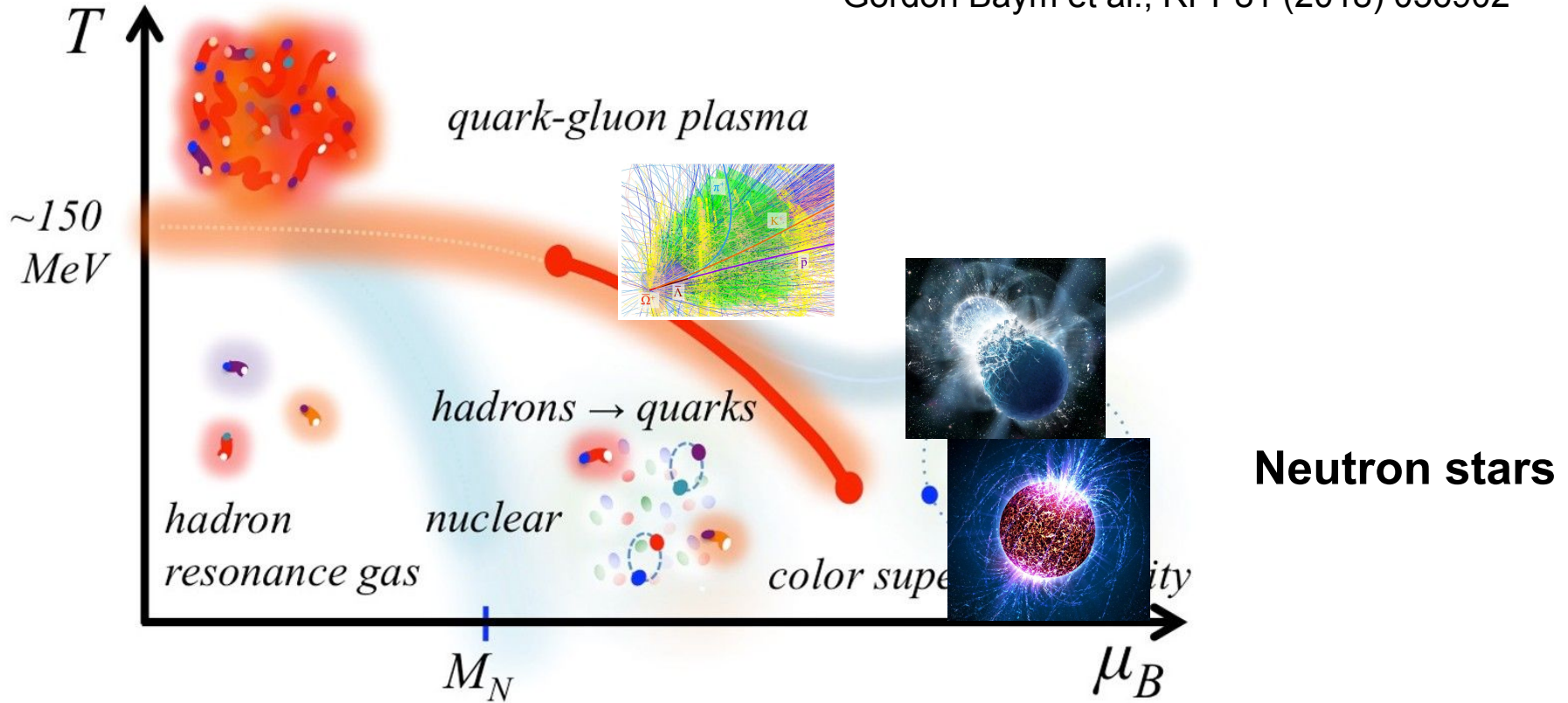
Structure of the QCD matter phase diagram

Gordon Baym et al., RPP81 (2018) 056902



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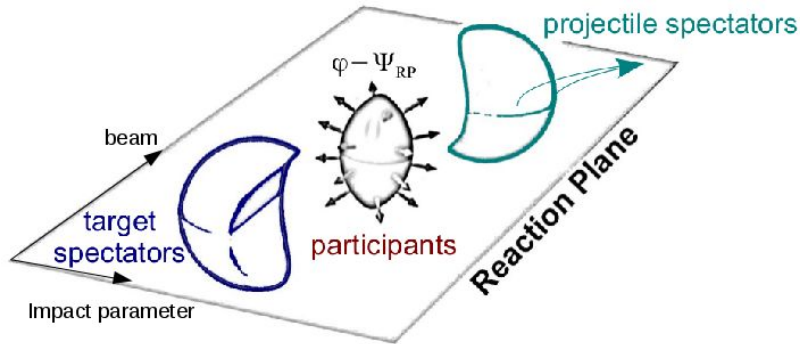
Collision geometry and anisotropic transverse flow

Asymmetry in coordinate space converts due to interaction into momentum asymmetry with respect to the symmetry plane (reaction plane - RP)

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



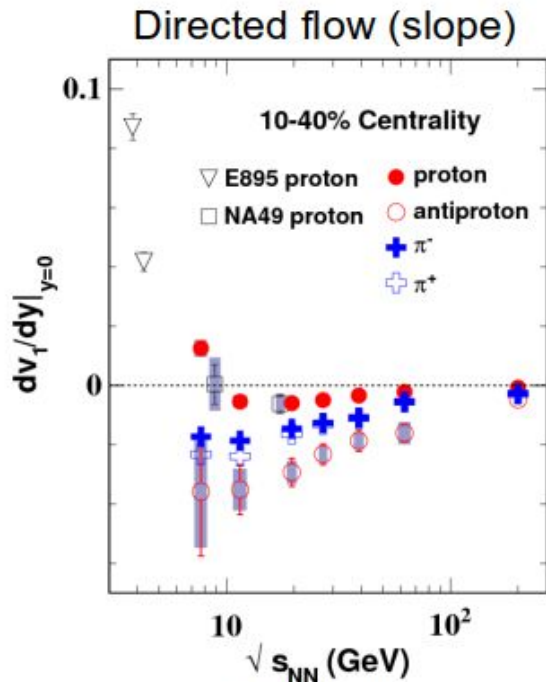
$$v_n = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$



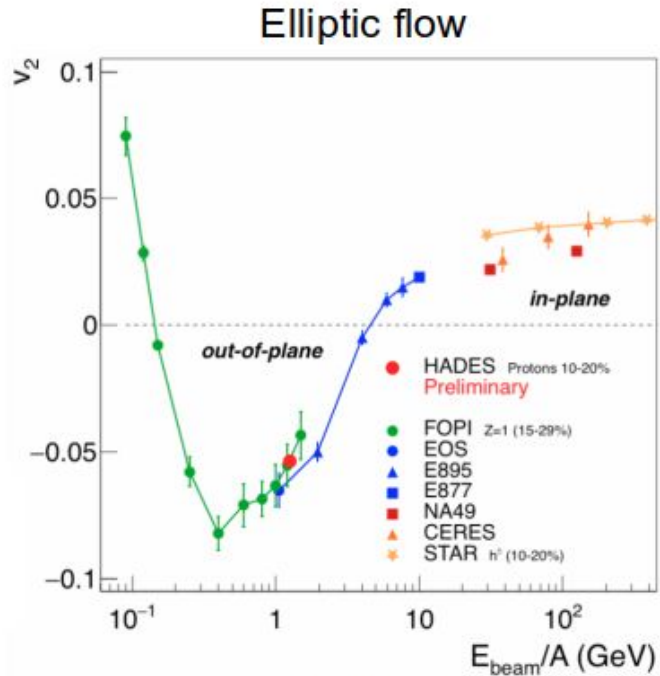
Needed components to measure v_n :

- momentum (φ , y , p_T)
- centrality estimation
- particle identification
- Ψ_{RP} estimation

Collective flow at FAIR energies



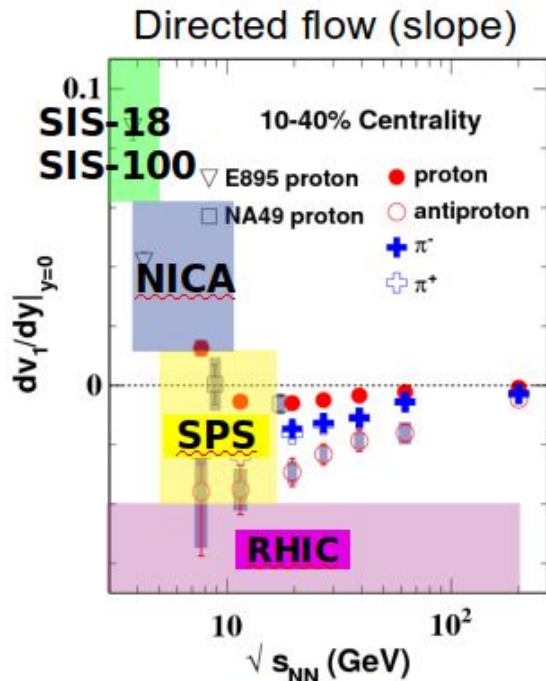
STAR Collaboration
PRL 112 (2014) 162301



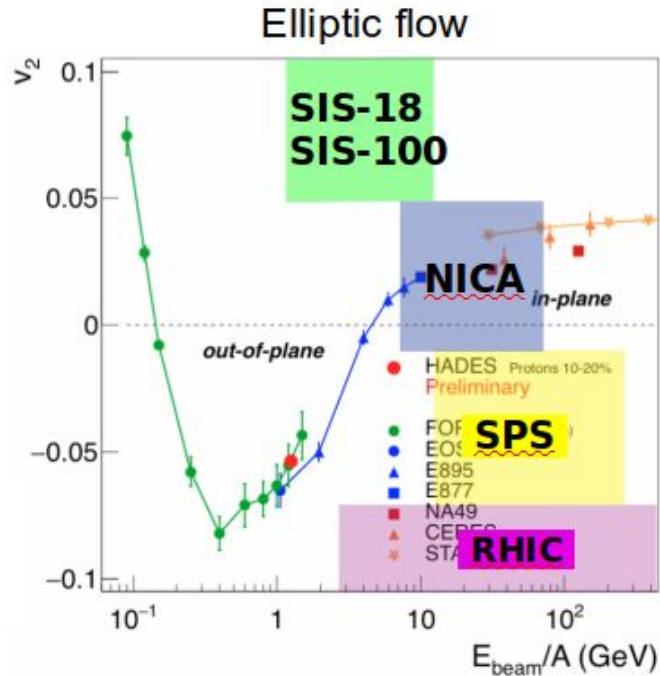
HADES Collaboration
JPCS 742 (2016) 012008

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

Collective flow at FAIR energies



STAR Collaboration
PRL 112 (2014) 162301



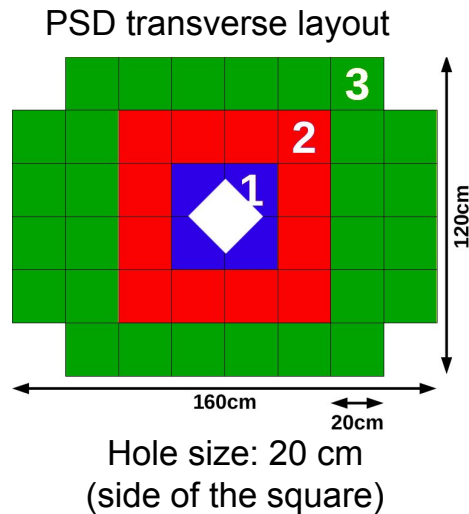
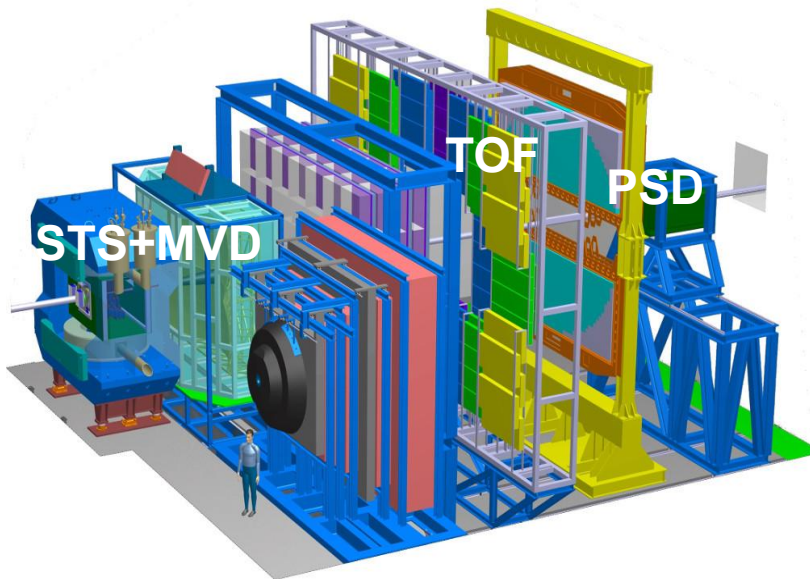
HADES Collaboration
JPCS 742 (2016) 012008

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)

Detector subsystems used for flow analysis

CBM subsystems important for v_n measurements:

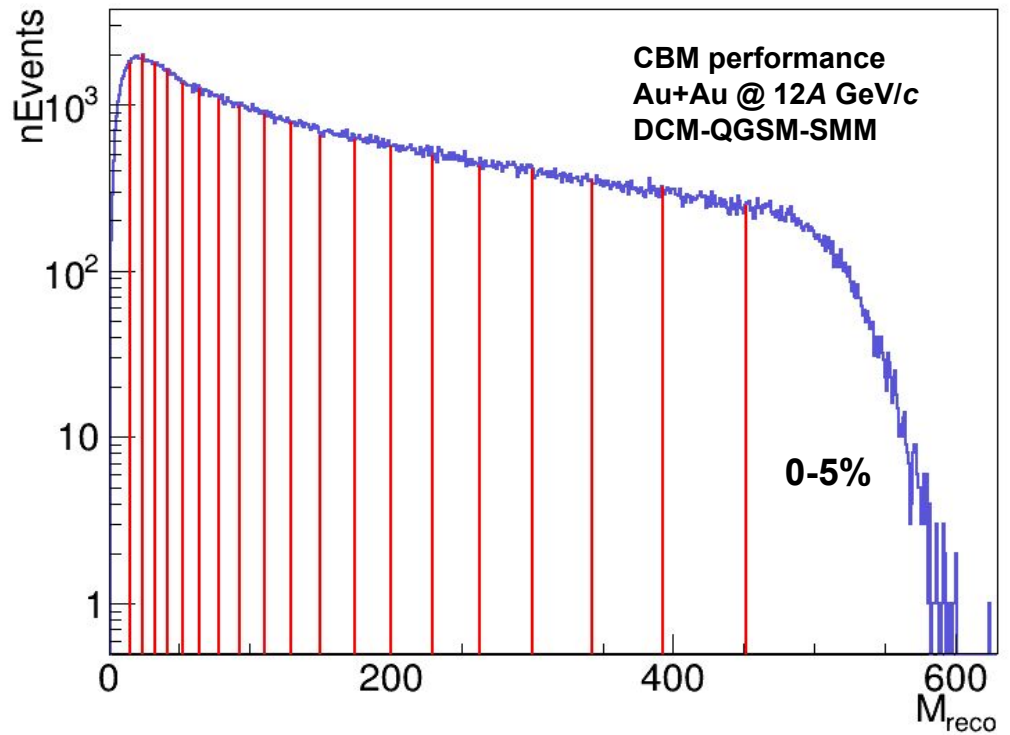
- Particle momentum (ϕ, y, p_T): STS+MVD
- Centrality estimation: event classes defined with PSD energy or/and STS multiplicity
- Particle identification: TOF
- Reaction plane (Ψ_{RP}): PSD transverse energy asymmetry (ϕ distribution in STS)



Simulation setup

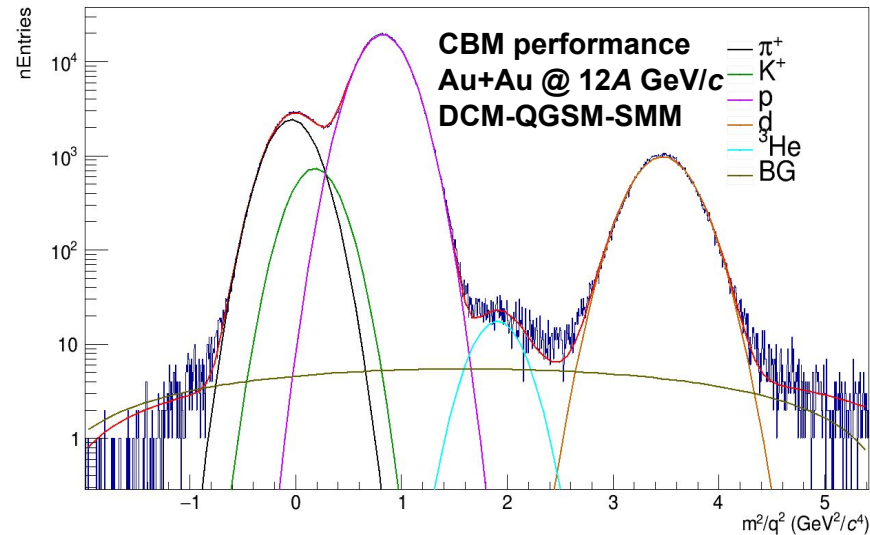
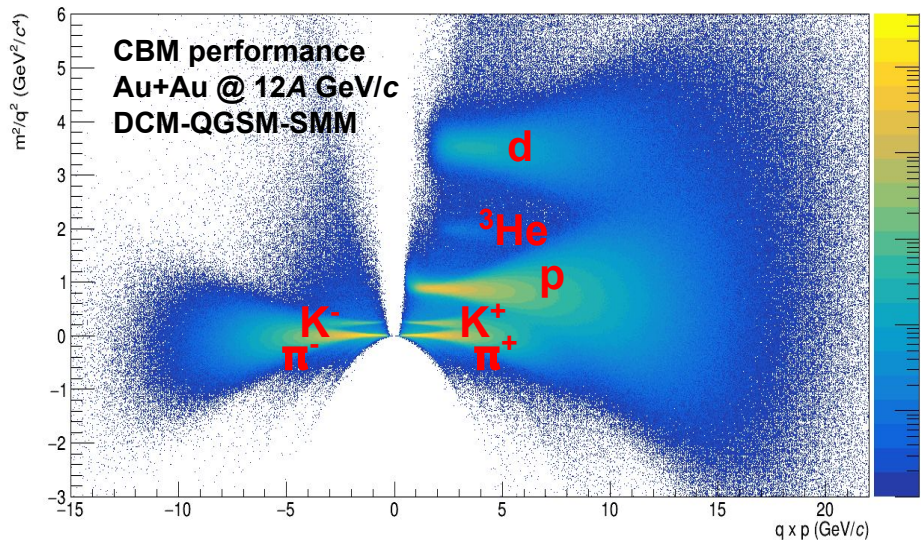
Model	DCM-QGSM-SMM (with fragments)
System	Au+Au
Beam momentum	12A GeV/c
Statistics	5M events
CBM geometry	MVD, STS, RICH, TDR, TOF, PSD
PSD geometry	20 cm hole size 44 modules
Transport code	GEANT4
Detector response	CBMROOT OCT19

Centrality determination (charged hadron multiplicity)



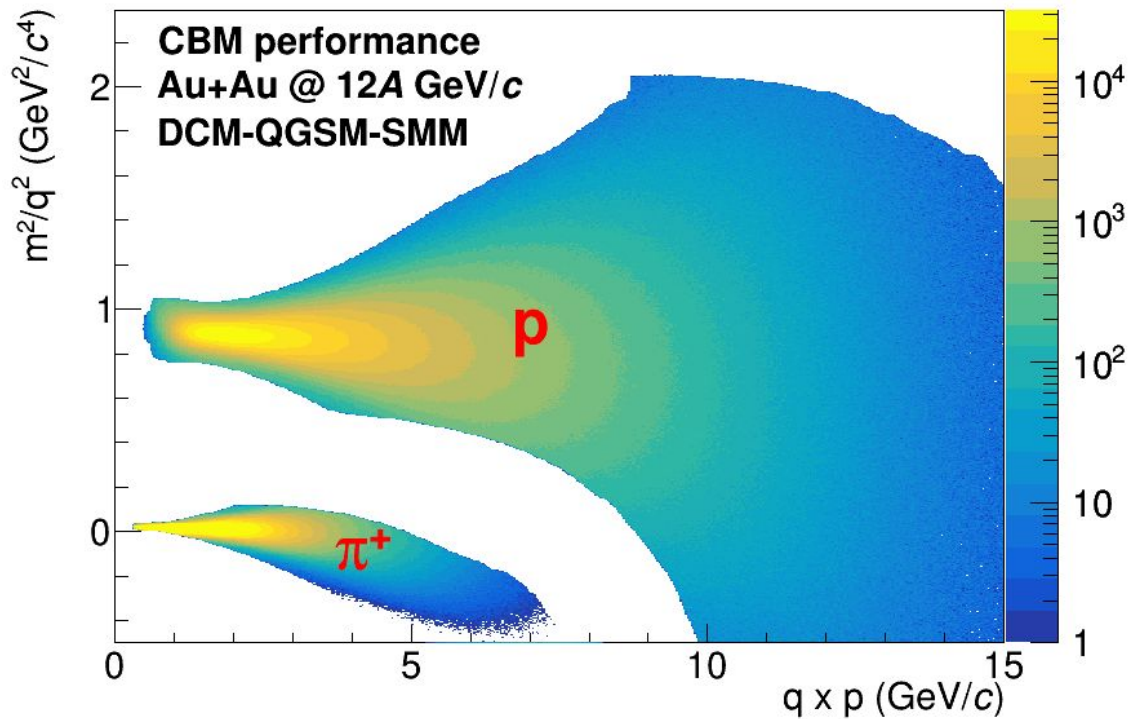
See talk by I. Segal (24/08)

Bayesian charged hadron identification with TOF



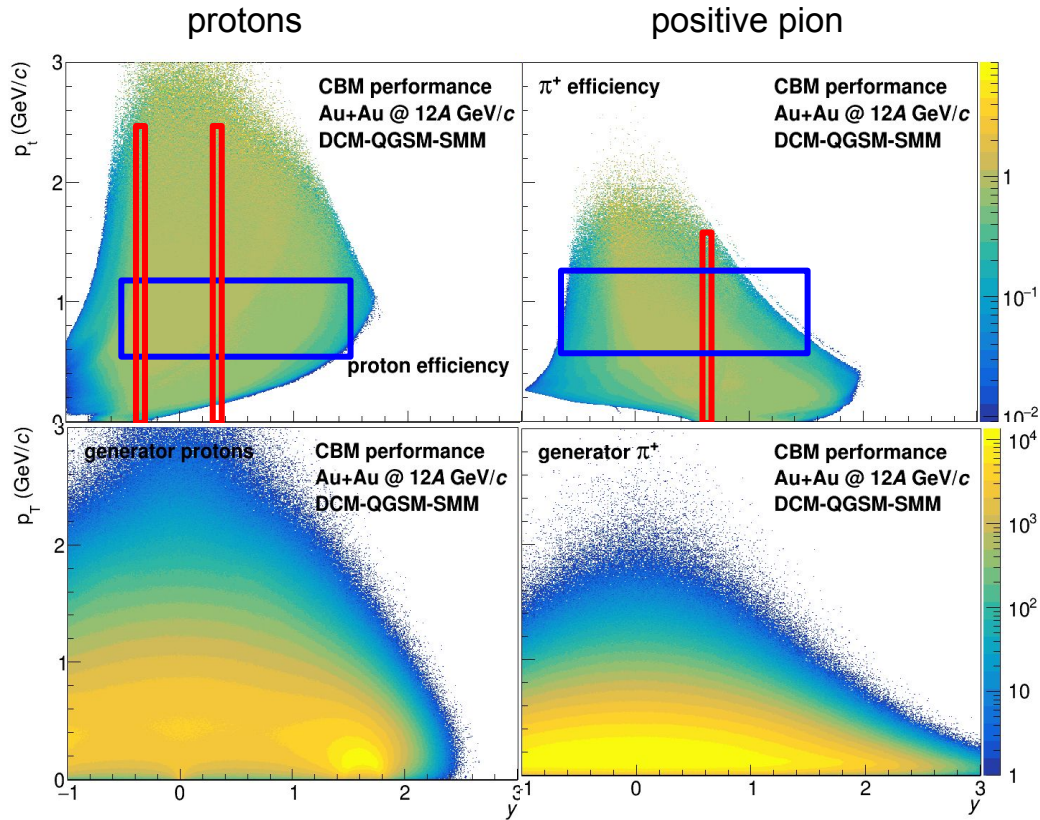
Time-of-Flight technique provides clear separation between charged hadrons

Bayesian selection of positive pions and protons

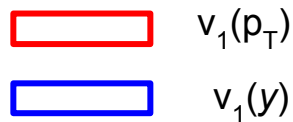


Proton and pion selection with 90% purity requirement

Proton and pion acceptance & efficiency maps

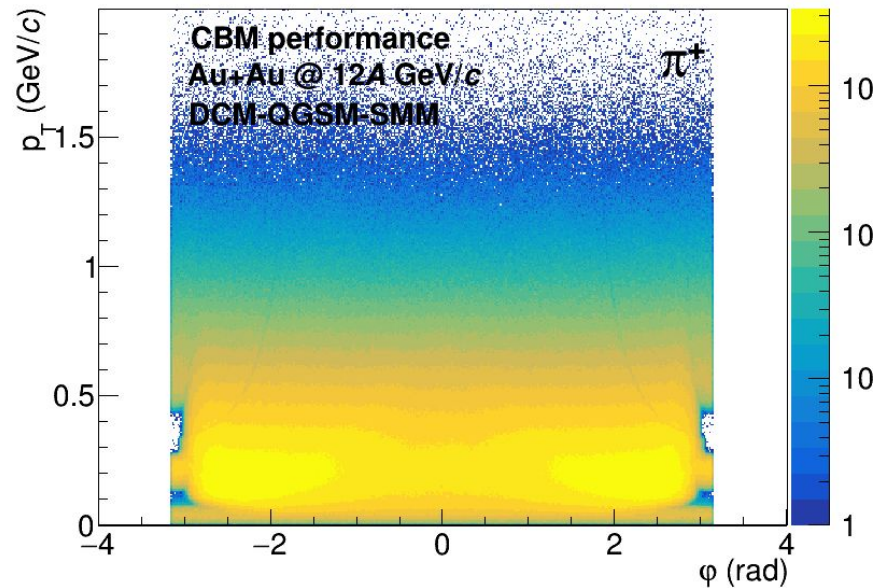
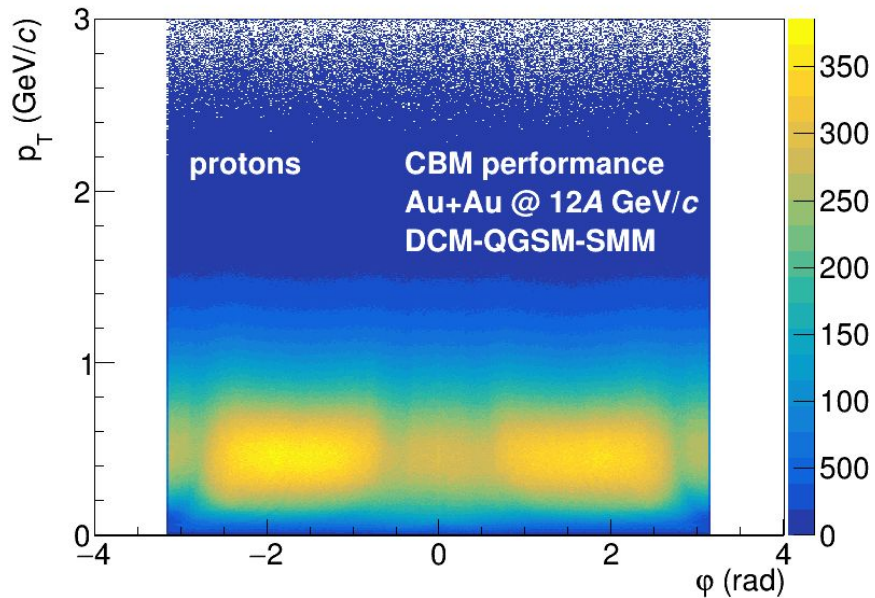


(p_T, y) -differential v_1 results are reported for kinematic regions with high efficiency



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

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

\mathbf{u} and \mathbf{Q} -vectors:

$$\mathbf{u}_1 = \{u_{1,x}; u_{1,y}\} = \{\cos \phi; \sin \phi\}$$

$$\mathbf{Q}_1 = \{Q_{1,x}; Q_{1,y}\} = \frac{1}{\sum_k w_k} \left\{ \sum_k w_k \cos \phi_k; \sum_k w_k \sin \phi_k \right\}$$

Scalar product method:

v_n with respect to symmetry plane estimated using group of particles “a”:

$$v_{1,i}^a(p_T, y) = \frac{2 \langle u_{1,i}(p_T, y) Q_{1,i}^a \rangle}{R_{1,i}^a}, \quad i = x, y.$$

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

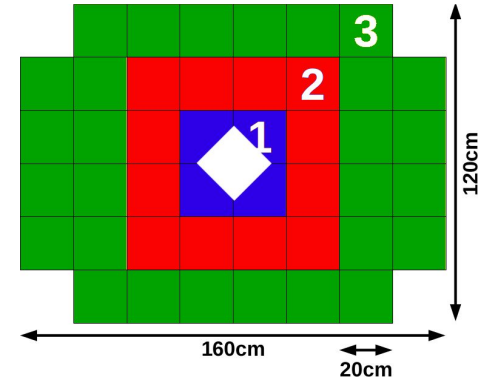
Resolution correction factor with 3-subevent method

$$R_{1,i}^a\{b, c\} = \sqrt{2 \frac{\langle Q_{1,i}^a Q_{1,i}^b \rangle \langle Q_{1,i}^a Q_{1,i}^c \rangle}{\langle Q_{1,i}^b Q_{1,i}^c \rangle}}, \quad i = x, y$$

MC-true subevent resolution correction for performance checks:

$$R_{1,x}^{a,MC} = \langle Q_{1,x}^a \cos \Psi_{RP} \rangle, \quad R_{1,y}^{a,MC} = \langle Q_{1,y}^a \sin \Psi_{RP} \rangle$$

PDS modules layout with rectangular beam hole



PSD1

PSD2

PSD3

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

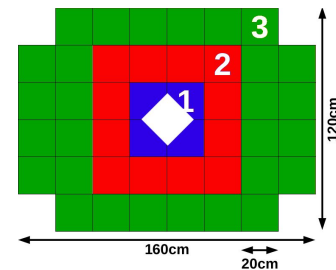
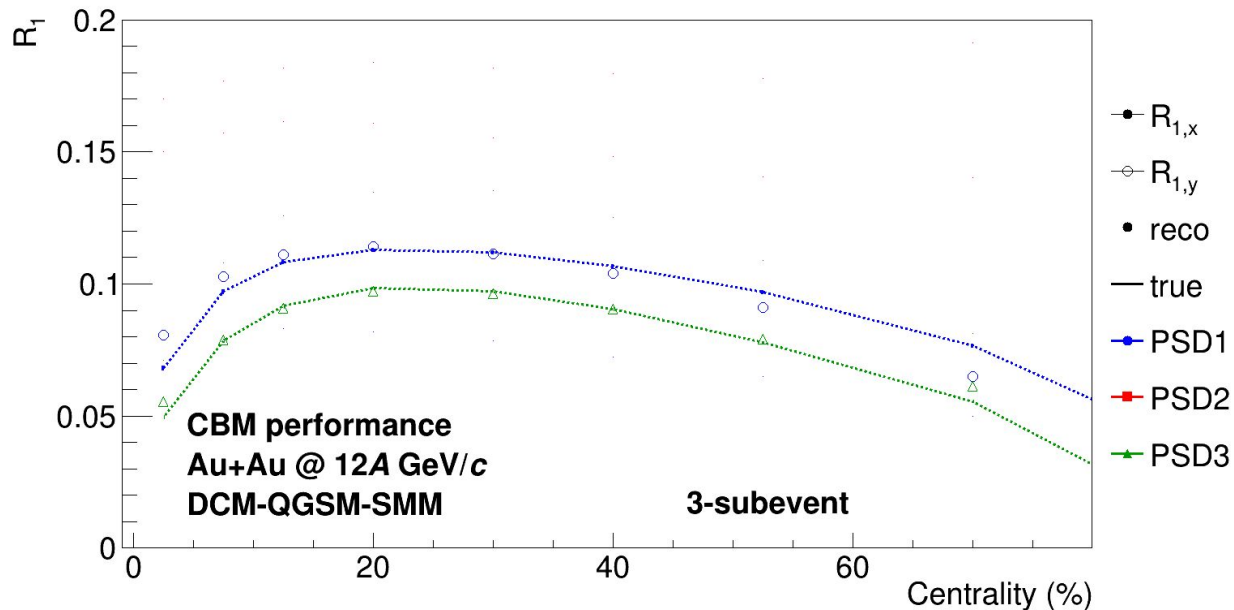
<https://github.com/FlowCorrections/FlowVectorCorrections>

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

QnTools

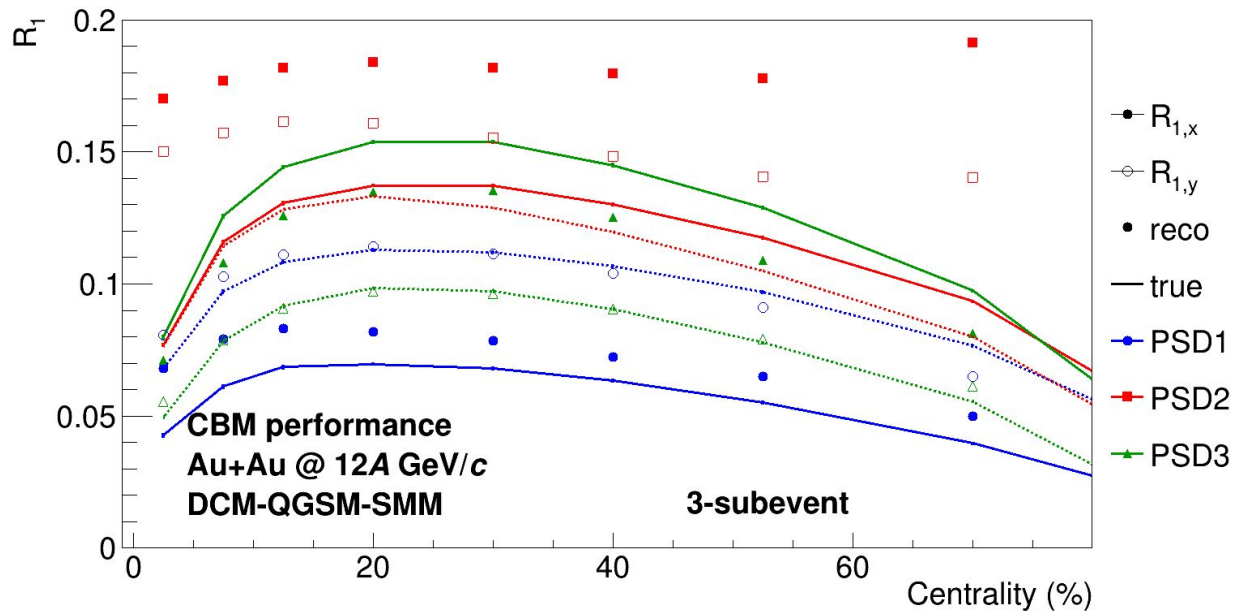
- Extended QnCorrections framework for p_T/y -differential
 - Multi-dimensional Q-vector correlation analysis
- L. Kreis (GSI / Heidelberg) and I. Selyuzhenkov (GSI / MEPHI)
- <https://github.com/HeavyIonAnalysis/QnTools>

Resolution correction factor with 3-subevent method



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

Resolution correction factor with 3-subevent method



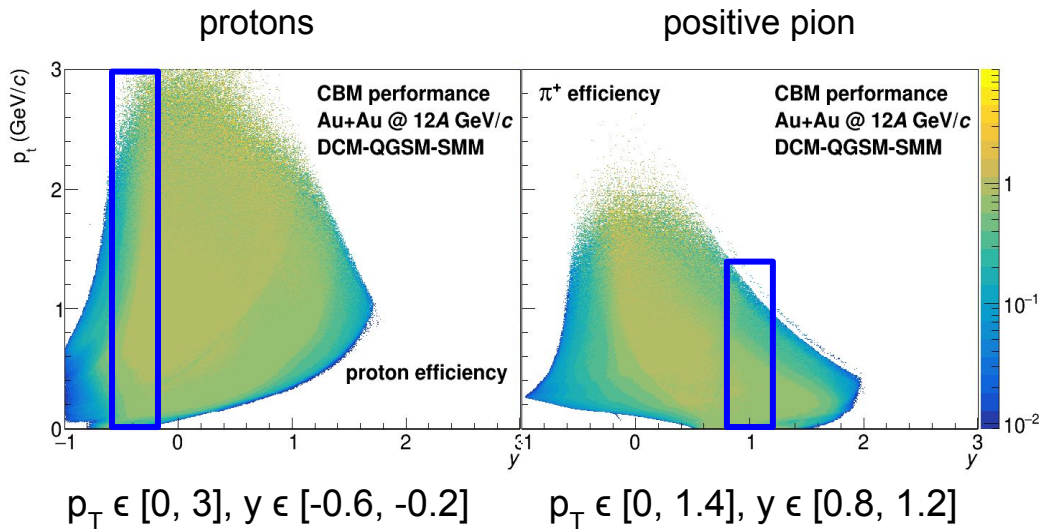
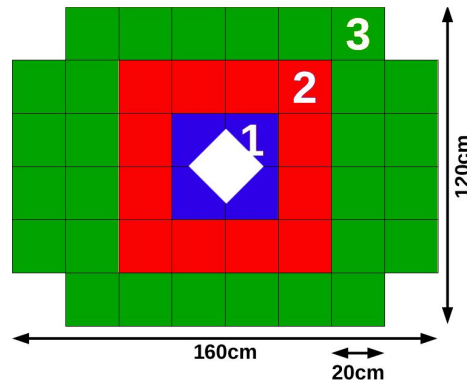
Significant bias in correlations due to hadronic shower leakage among the neighbouring PSD subevents

Resolution correction factor with 4-subevent method

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

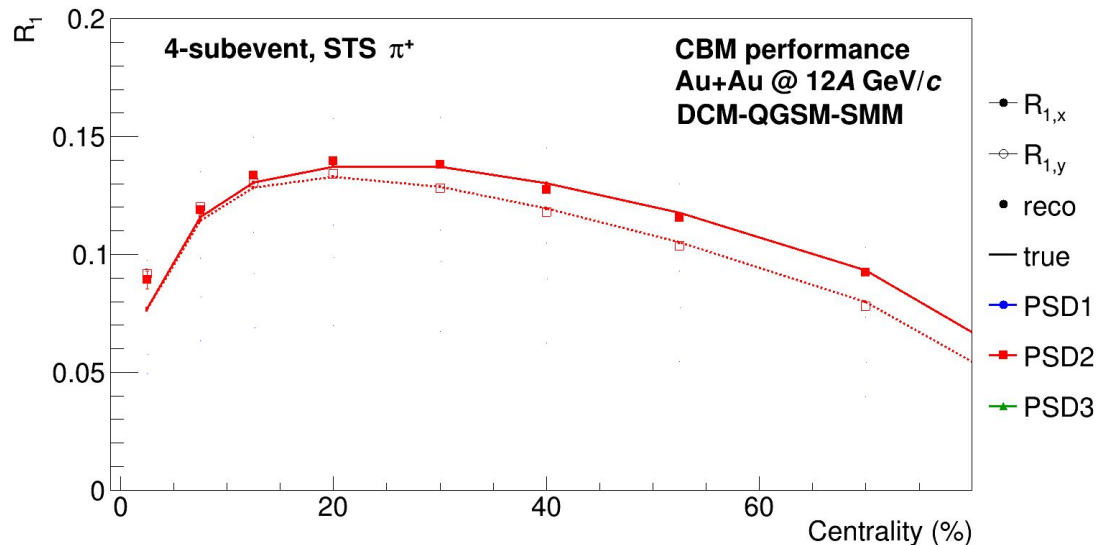
$$R_{1,i}^{PSD2} = \frac{\langle Q_{1,i}^{PSD2} Q_{1,i}^{STS} \rangle}{R_{1,i}^{STS} \{PSD1, PSD3\}},$$

PDS modules layout with rectangular beam hole



Resolution correction factor with 4-subevent method

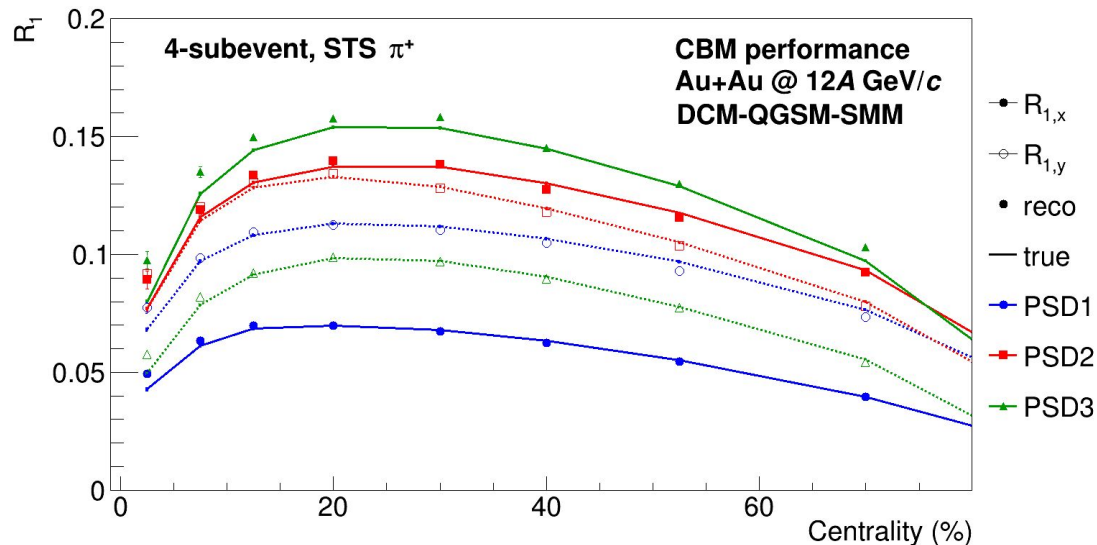
4th subevent: positive pions



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

Resolution correction factor with 4-subevent method

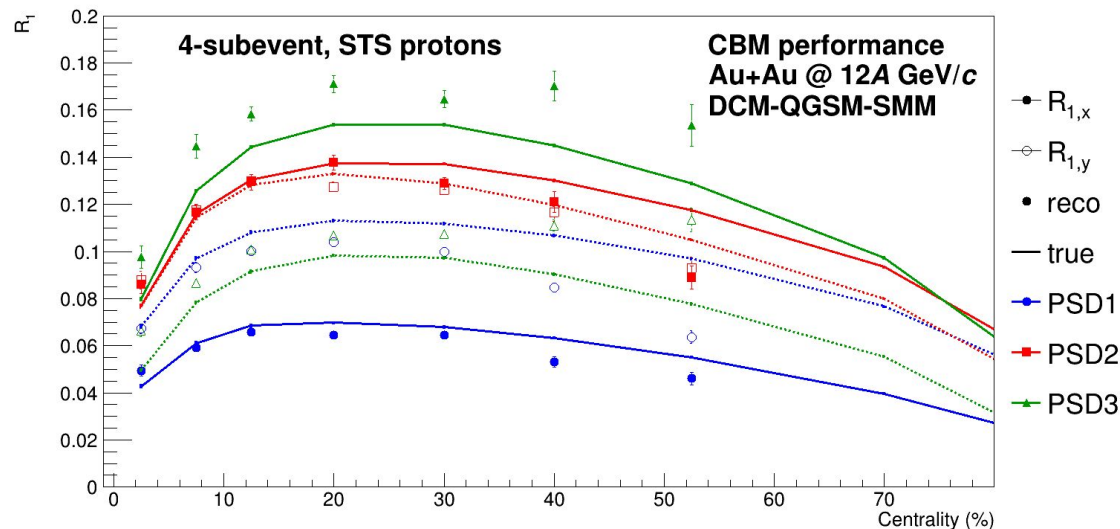
4th subevent: positive pions



Much better performance than 3-subevent method

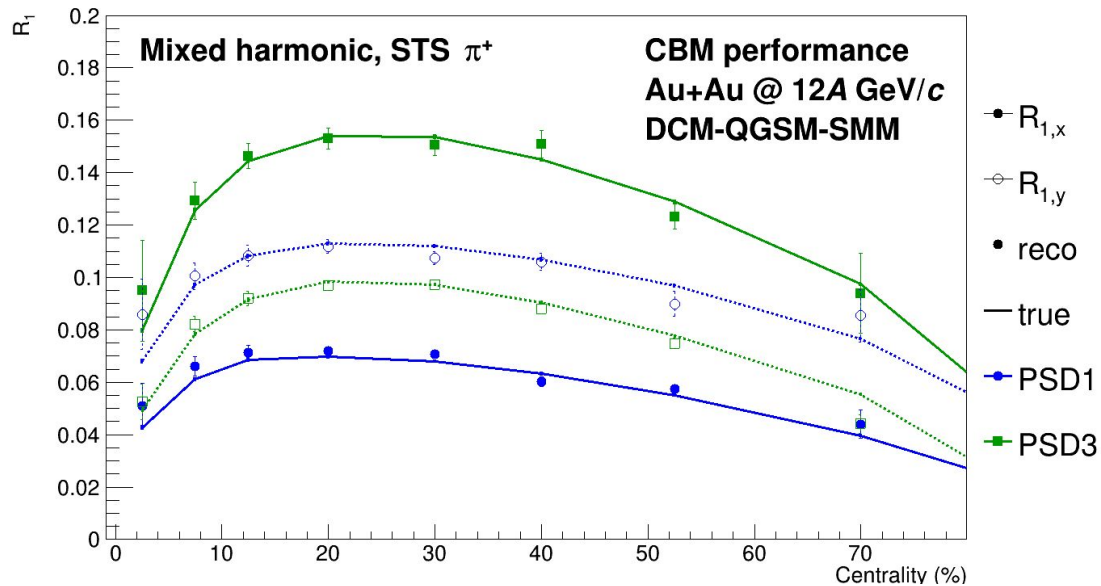
Resolution correction factor with 4-subevent method

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



$$R_{1,i}^A\{B, C, D\} = \sqrt{2 \frac{\langle Q_{1,i}^A Q_{1,i}^B \rangle \langle Q_{1,i}^A Q_{1,j}^C q_{2,k}^D \rangle}{\langle Q_{1,i}^B Q_{1,j}^C q_{2,k}^D \rangle}}, \quad (i,j,k) = (x,x,x), (x,x,y), (y,x,y), (y,y,x)$$

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).

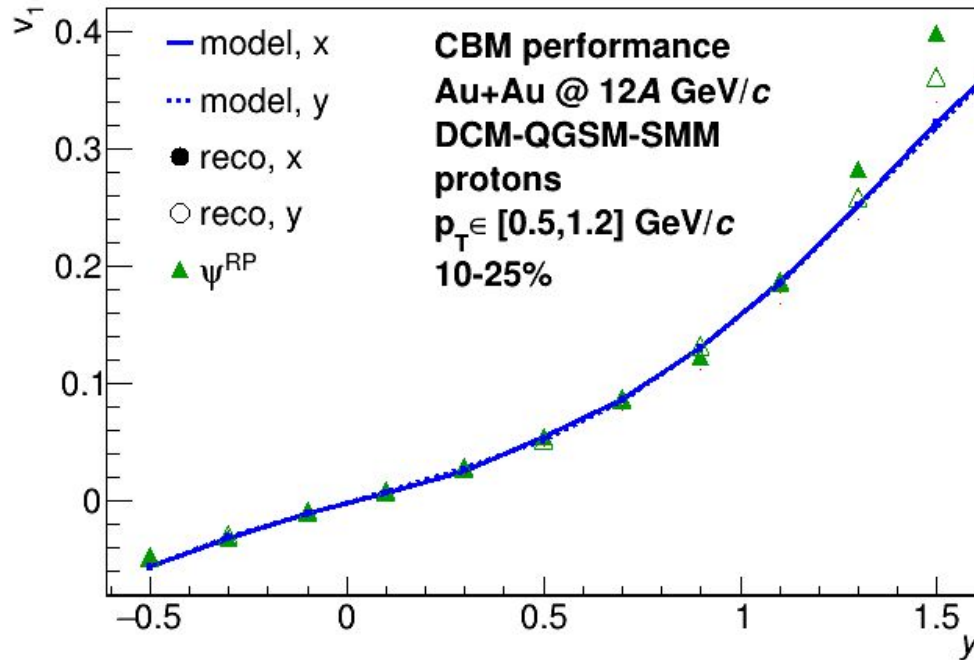
The results are corrected for detector non-uniformity.

Resolution correction performed with 4-subevent method (3 PSD + STS positive pions)

Correction for PID and tracking efficiency is not yet done.

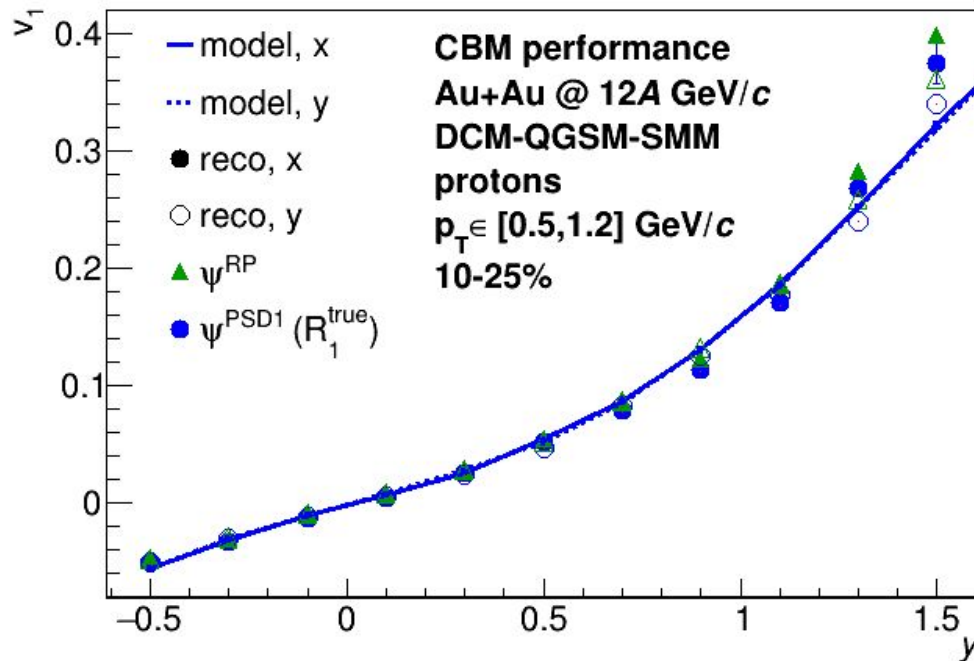
Only statistical uncertainties are shown.

Proton v_1 vs. rapidity



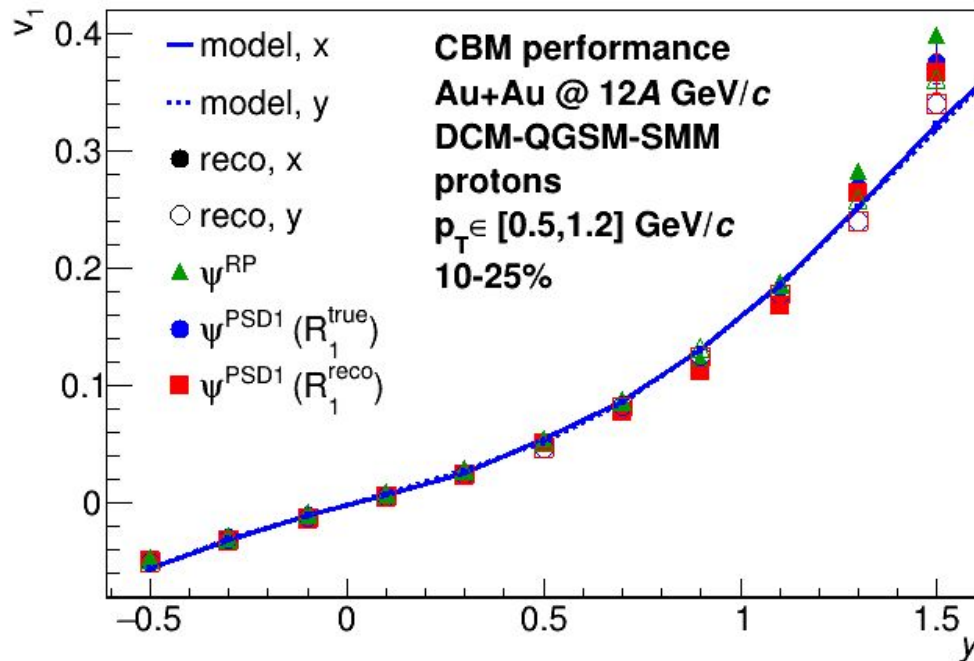
Results with reconstructed protons relative to the reaction plane agrees with the input v_1

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



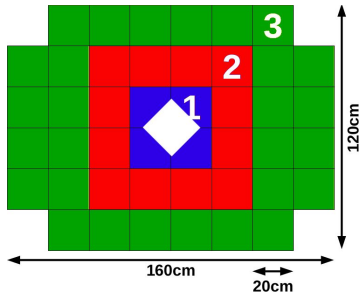
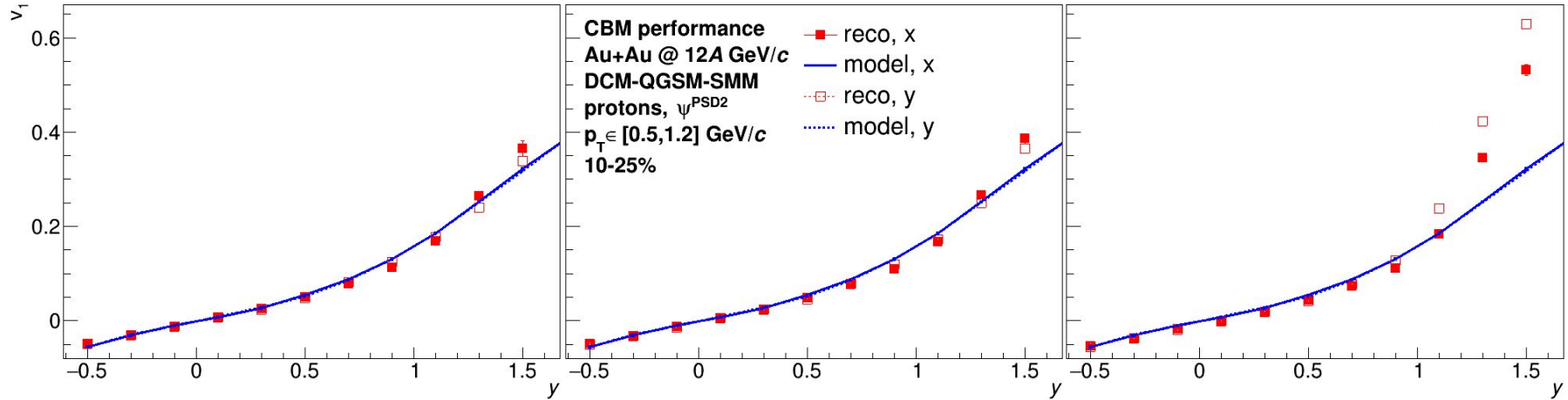
Results for complete data driven analysis agrees with the input v_1

Proton v_1 with different PSD subevents

PSD1

PSD2

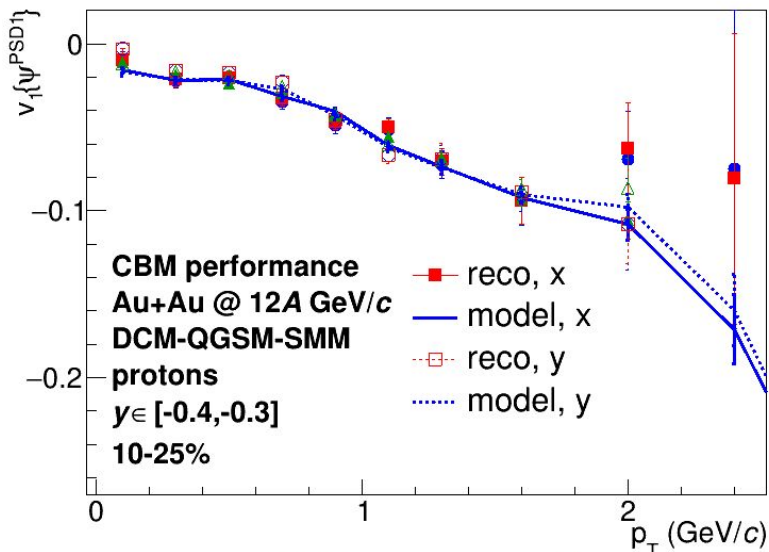
PSD3



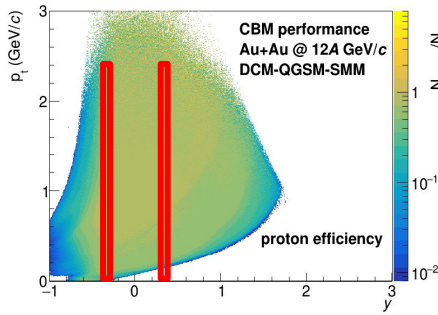
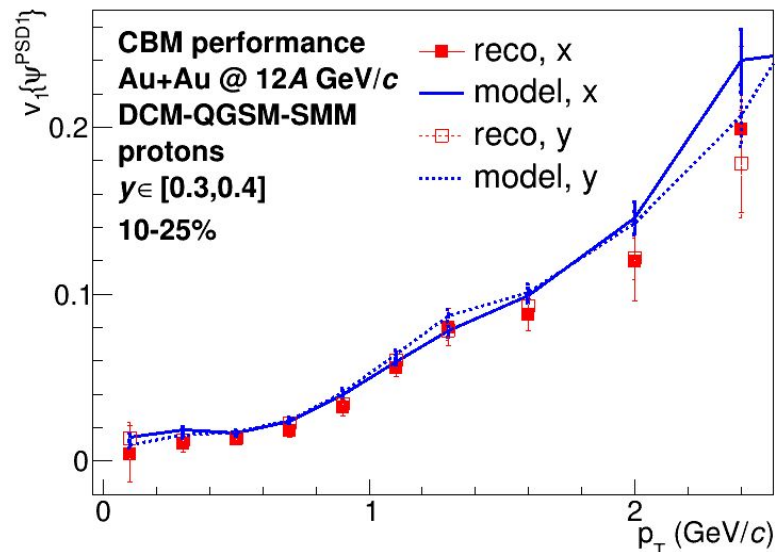
Bias at forward rapidity with PSD3 subevent.
Magnitude depends on rapidity separation
between protons in STS and PSD subevent (largest for PSD3)

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

Backward

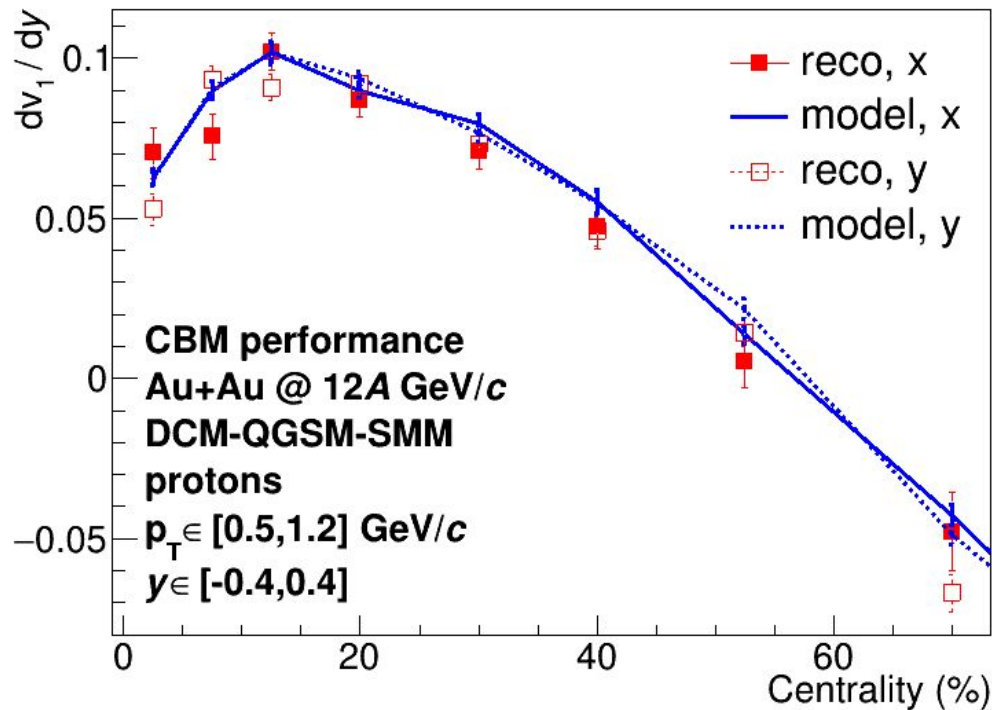


Forward



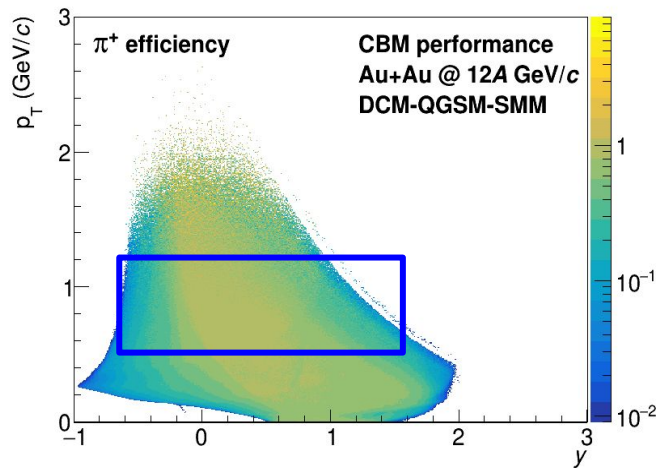
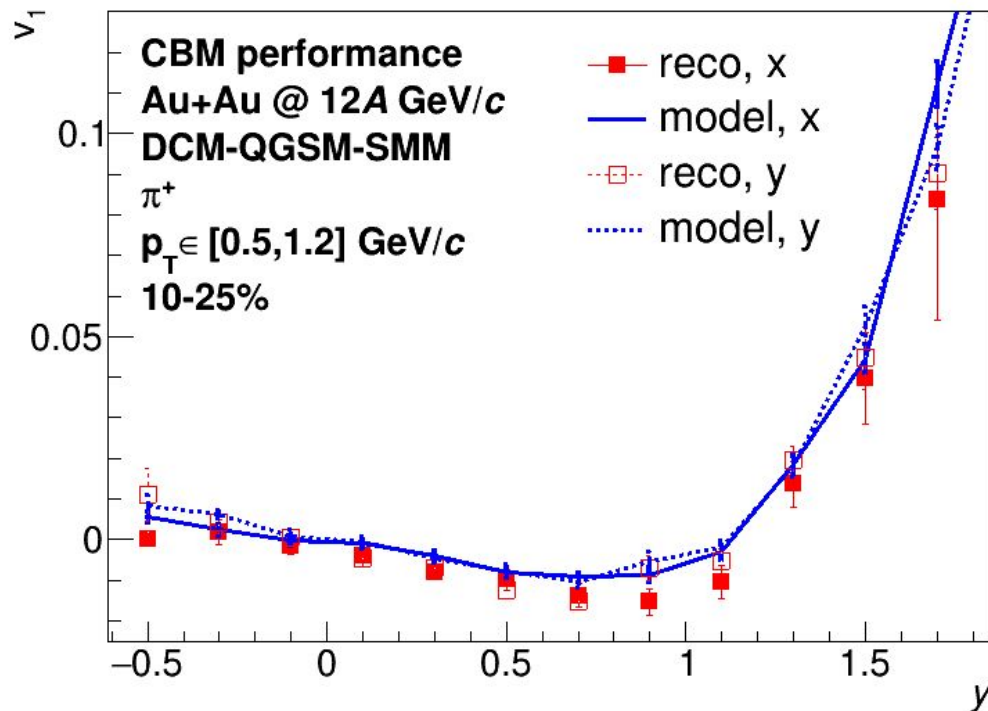
Better reconstruction efficiency at forward rapidity result in a more precise measurement

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 12A GeV/c

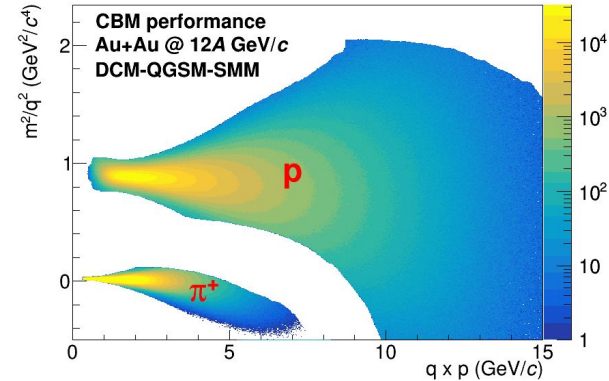
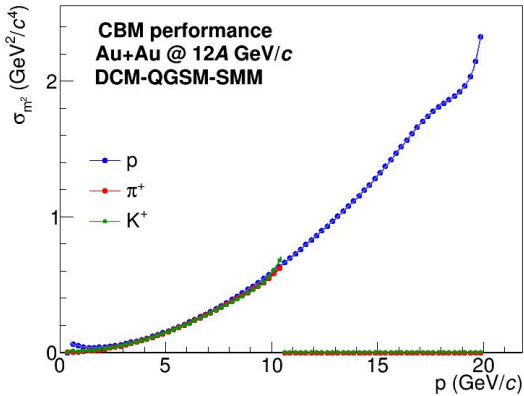
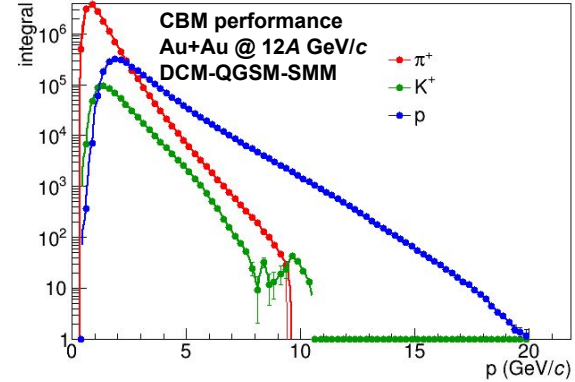
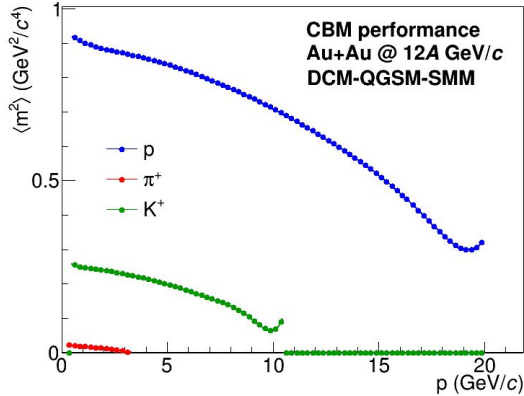
- Investigated effects of the spectator plane estimation
- Centrality using track multiplicity
- Bayesian identification with TOF information

TODO:

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

Backup

Particle identification with Bayesian approach



Polynomial fits of gaussian parameters and final identification