Methods for event plane determination in flow measurements with HADES at SIS18

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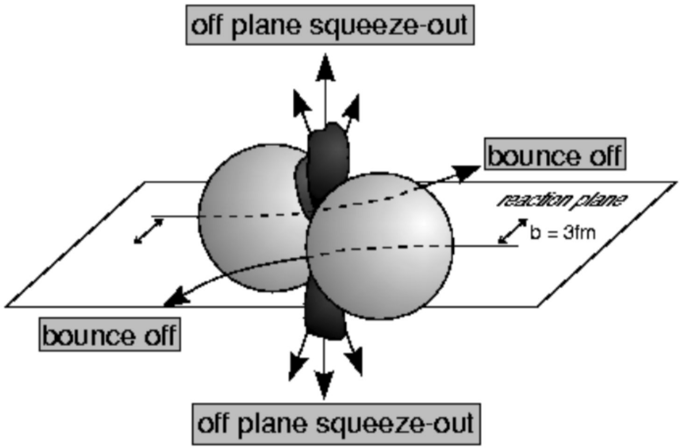
Anisotropic flow & spectators

spatial asymmetry of the initial energy distribution transforms via interaction into anisotropic emission of produced particles



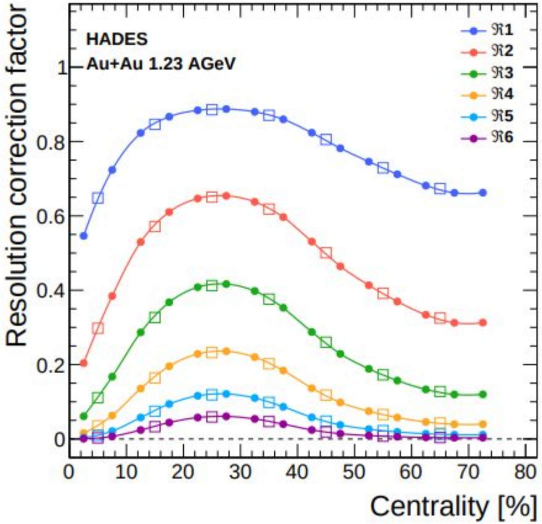
The azimuthal angle distribution is decomposed in a Fourier series relative to reaction plane angle:

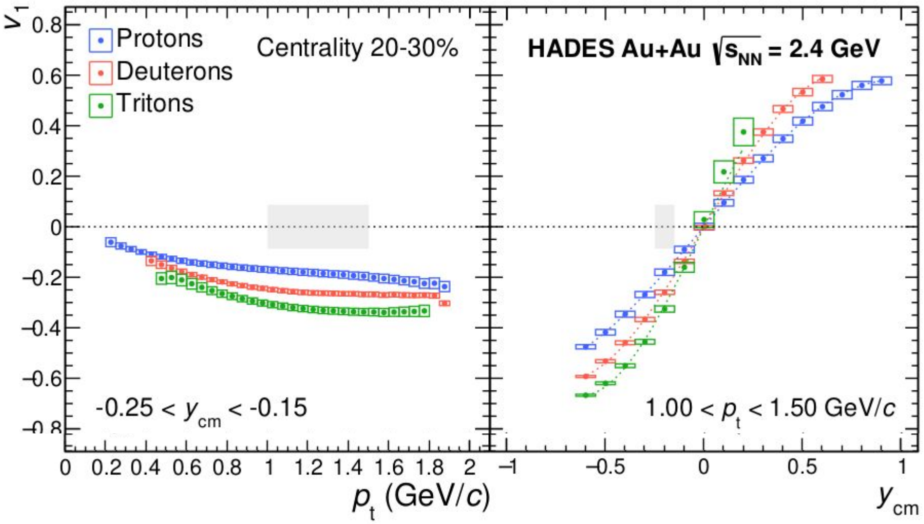
$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_{RP}))$$

directed flow:

$$v_1 = \langle \cos\left(\varphi - \Psi_{RP}\right) \rangle$$

v_n of protons, deuterons and tritons in Au+Au collisions with HADES





HADES Collaboration, arxiv:2005.12217

Flow vectors

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

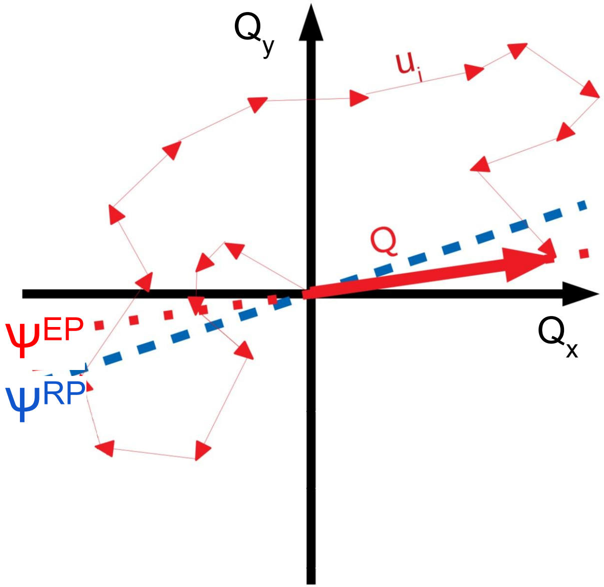
$$u_n = e^{in\phi}$$

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



Flow methods for v_n calculation

Event plane (EP) method:

$$v_1 = \frac{\langle \cos(\phi - \Psi_1^{EP}) \rangle}{R_1}$$

Resolution correction from random subevent (RND):

$$R_1^{sub} = \sqrt{\langle \cos(\Psi_n^a - \Psi_n^b) \rangle}$$

Extrapolation to full event plane is implemented following J.Y. Ollitrault [arXiv:nucl-ex/9711003]

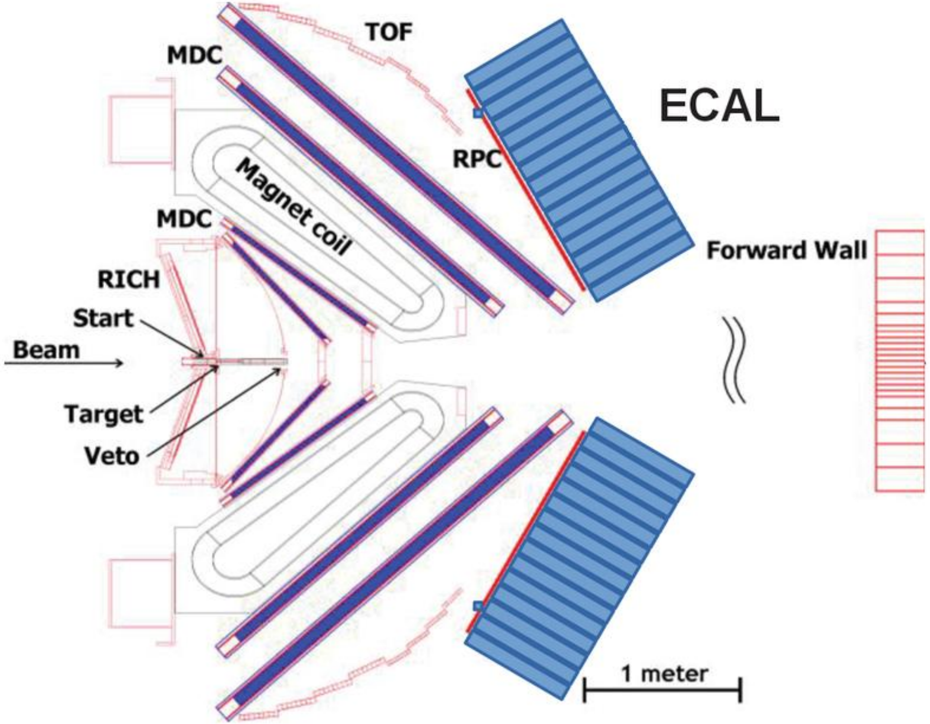
Scalar product (SP) method:

$$v_1 = \frac{\langle u_1^a Q_1^a \rangle}{R_1}$$

Where

$$R_1^a = \frac{\sqrt{\langle Q_1^a Q_1^b \rangle \langle Q_1^a Q_1^c \rangle}}{\sqrt{\langle Q_1^b Q_1^c \rangle}}$$

The HADES experiment



Tracking system ($0.09 < \eta < 1.84$)

- Multi-wire drift chambers (MDC)
- Magnet coil

Particle identification ($0.09 < \eta < 1.84$)

- Time Of Flight (TOF)
- Resistive Plate Chambers (RPC)

Event plane reconstruction

- Forward Wall (FW)
  $2.68 < \eta < 5.38$

Q-vectors for protons and charged fragments

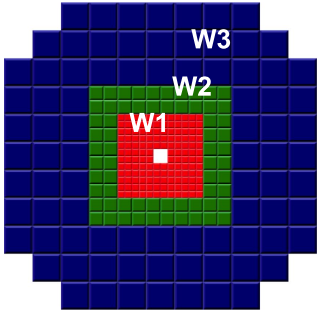
Protons with $p_T < 2$ GeV/c

for 2 rapidity regions:

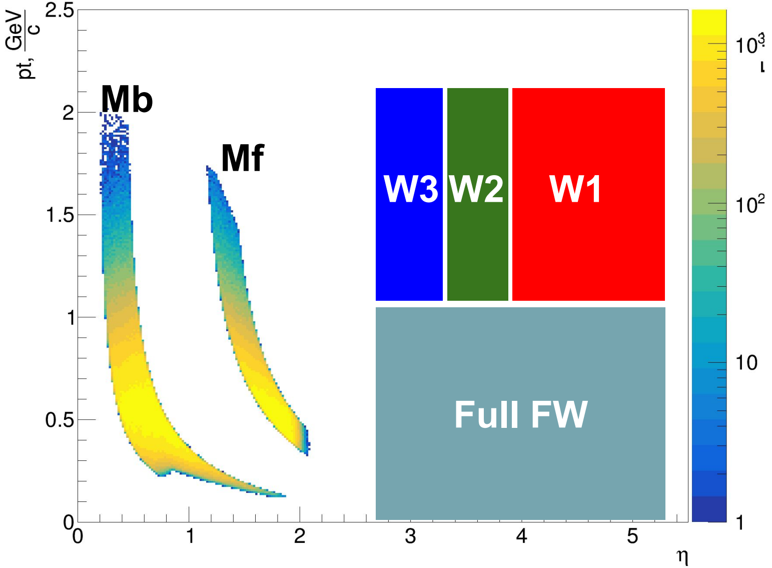
- Mf — y_{cm} [0.35, 0.55]
- Mb — y_{cm} [-0.55, -0.35]

Charged fragments from FW:

W1: 3.77 < η < 5.38
W2: 3.28 < η < 3.88
W3: 2.68 < η < 3.35



Rapidity coverage of different subevents



Full FW (sum over all modules) 2.68 < η < 5.38

RND-sub: all modules randomly split into 2 groups

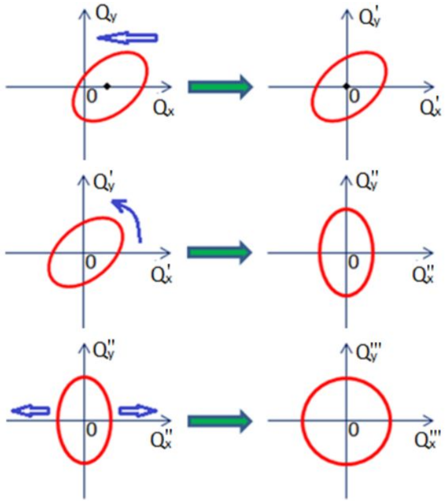
QnTools framework

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

Originally implemented as QnCorrections framework for ALICE experiment at CERN:
J. Onderwaater, I. Selyuzhenkov, V. Gonzalez

QnTools analysis package:
https://github.com/HeavyIonAnalysis/QnTools

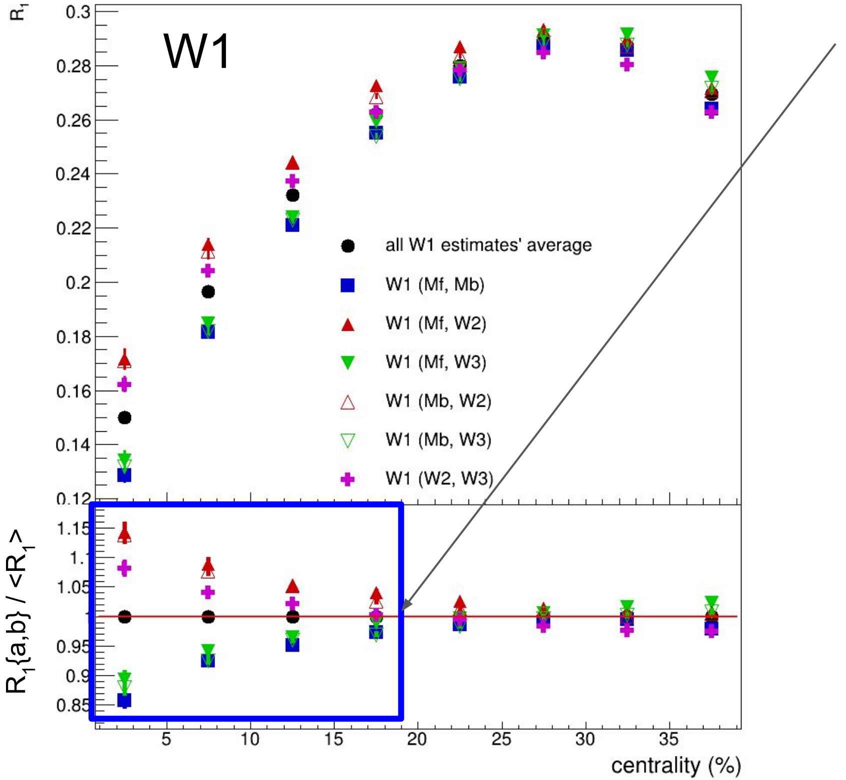
1. Recentering
2. Twist
3. Rescaling



QnTools configuration

Q-vector	Q_n weight	Correction axes	Correction steps	Error calculation	Q_n Normalization
Protons	1	p_T [0.0, 2.00], 10 bins y_{cm}[-0.75, 0.75], 15 bins Centrality, 8 bins	Recentering Twist Rescaling	Bootstrapping, 100 samples	Sum of Weights
Charged Fragments	Module charge	Centrality, 8 bins	Recentering		

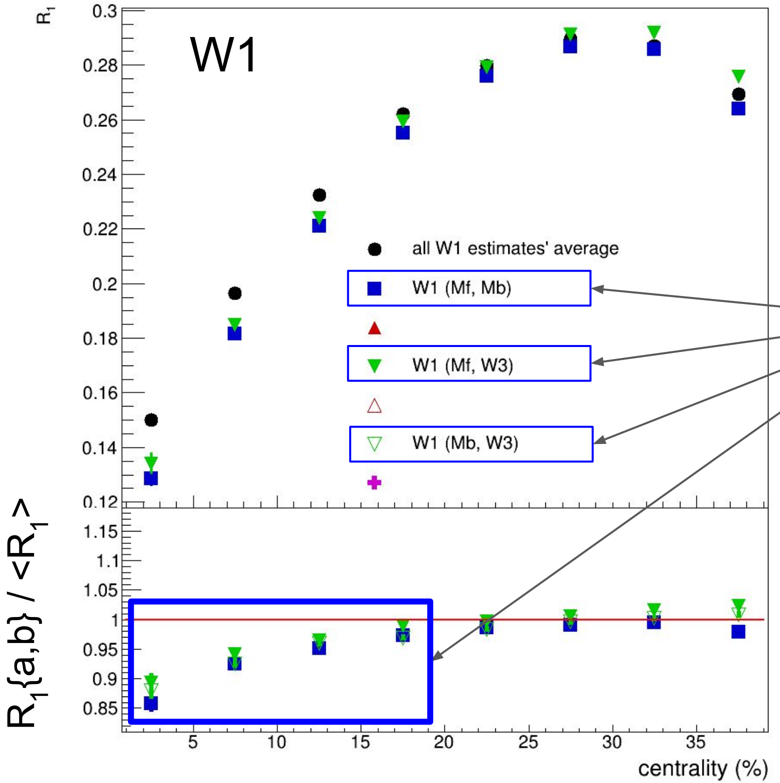
Quantifying non-flow correlations in R_1



1. Rapidity-separated and unseparated combinations split on two branches

Resolution estimates with rapidity-separated subevents are consistent with each other within 3-5%. Other combinations deviate by up to ~30% in central collisions

Quantifying non-flow correlations in R_1

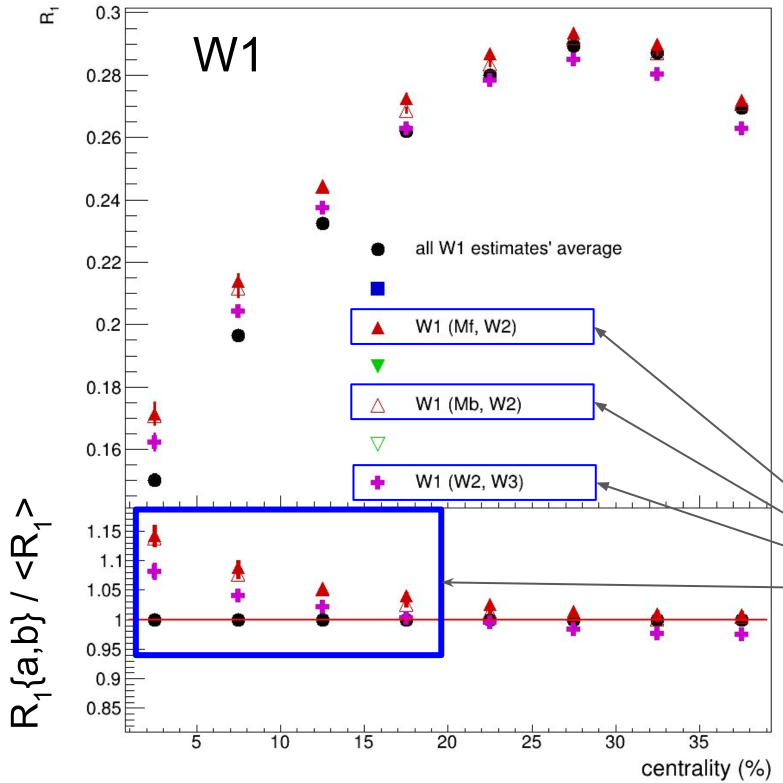


1. Rapidity-separated and unseparated combinations split on two branches

2. Rapidity-separated combinations are consistent with each other

Resolution estimates with rapidity-separated subevents are consistent with each other within 3-5%. Other combinations deviate by up to ~30% in central collisions

Quantifying non-flow correlations in R_1



1. Rapidity-separated and unseparated combinations split on two branches

2. Rapidity-separated combinations are consistent with each other

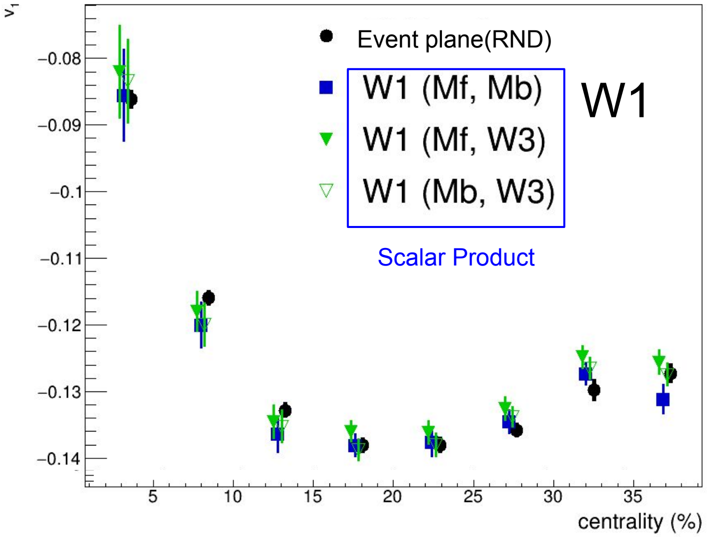
3. Combinations with no rapidity separation deviate from each other

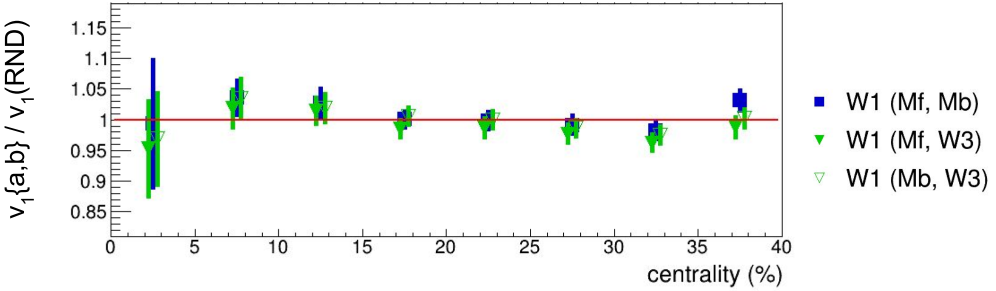
Resolution estimates with rapidity-separated subevents are consistent with each other within 3-5%. Other combinations deviate by up to ~30% in central collisions

Systematic uncertainty of directed flow, v_1

proton v_1 vs. centrality
y_{cm} [-0.25; -0.15]
p_T [0.0; 2.0] GeV/c

Rapidity separated only are shown



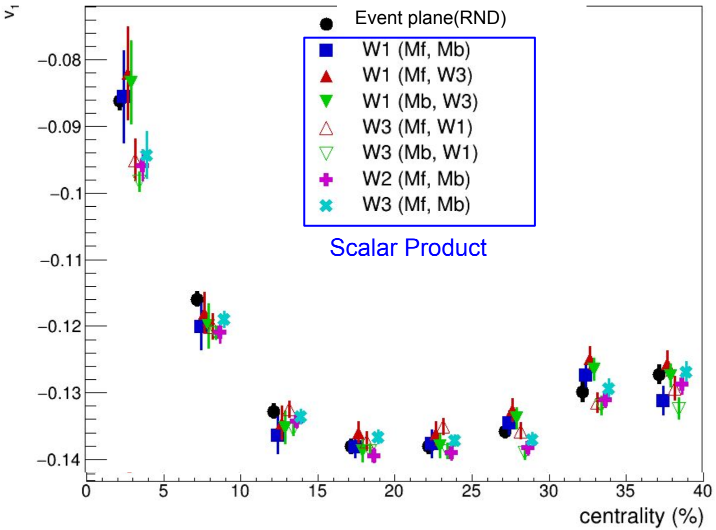


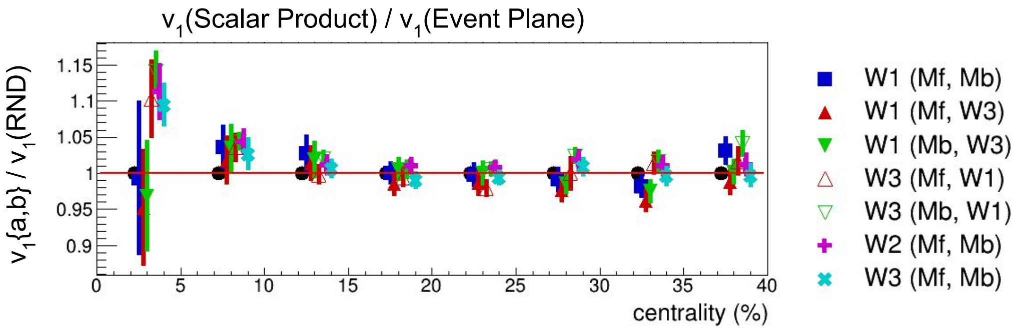
Results for event plane and scalar production
(with rapidity separated subevents) are consistent within stat. uncertainties.

Summary of systematic uncertainty for v_1

proton v_1 vs. centrality
y_{cm} [-0.25; -0.15]
p_T [0.0; 2.0] GeV/c

Rapidity separated only are shown





Overall difference between v_1 with event plane (RND-sub) and scalar product (with rapidity separated combinations) is ~10% in central events and below 5% in mid-central

Summary

- Investigated systematic uncertainties in directed flow of protons measurement relatively to the spectators symmetry plane
- Implemented scalar product, 3-subevents technique for flow measurement
- From the comparison of event plane (random subevents) and scalar product (three subevents) methods the systematic uncertainties due to non-flow effects of spectator symmetry plane estimation was evaluated:~ 10% for proton v_1 in most central and < 5% in mid-central collisions

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Backup

Data Selection

Data: Au+Au collisions at 1.23GeV (subsample of 10M events)

Event selection:

- Minimum bias trigger
- vertex on Z: [-60;0] mm
- vertex on XY < 3 mm
- Good Vertex Cluster
- Good Vertex Candidate
- Good START
- No Pile Up in START
- Good START VETO
- Good START META
- No VETO

Proton selection

- DCA-z<15mm
- DCA-xy<15mm
- Standard HADES TOF selection

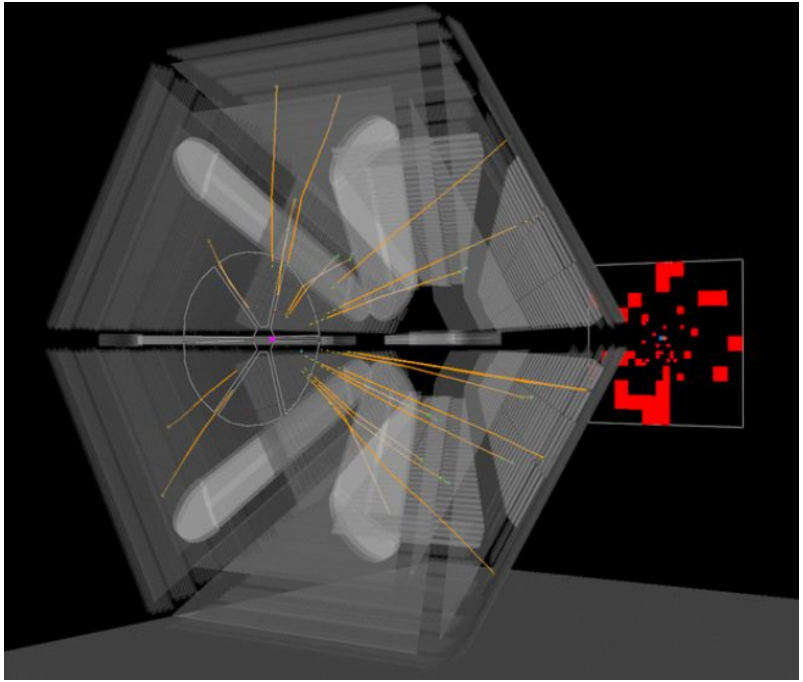
Charged fragment (FW modules) selection

- Wall Ring: 0-4:
  - wallHitCharge > 80
  - wallHitBeta [0.84, 1]
- Wall Ring: 5-6:
  - wallHitCharge > 85
  - wallHitBeta [0.85, 1]
- Wall Ring: 0-4:
  - wallHitCharge > 88
  - wallHitBeta [0.8, 1]

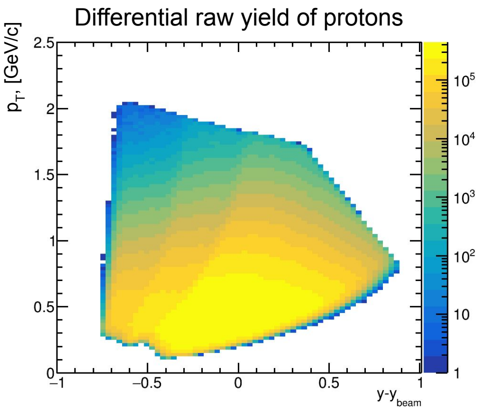
Centrality is determined with selected TOF+RPC hits

HADES event display & subsystem's acceptance

Au+Au collisions at 1.23GeV
(subsample of 10M events)
Minimum bias trigger (PT2), 0-40% centrality



Tracking (MDC) and PID (TOF+RPC)
$0.09 < \eta < 1.84$



Charged fragments (FW)
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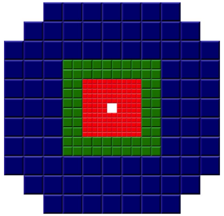

Centrality determined from
TOF+RPC hits