CBM Performance for identified charged hadron anisotropic flow

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for the CBM Collaboration
Collision geometry

impact parameter

↔

energy density of the interacting matter
Collision geometry

impact parameter
↔
energy density of the interacting matter

spatial asymmetry of the overlap region
↔
asymmetry of energy distribution
Collision geometry and the transverse anisotropic flow

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

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

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

Needed components to calculate $v_n$:
- momentum ($\varphi$, $Y$, $p_T$)
- centrality estimation
- particle identification
- $\Psi_{RP}$ estimation
CBM detector setup

CBM subsystems needed for $v_n$ measurements:

- Particle momentum ($\phi, Y, p_T$): STS+MVD
- Centrality estimation: event classes defined with PSD energy or STS multiplicity
- Particle identification: TOF
- Reaction plane ($\Psi_{RP}$): PSD transverse energy asymmetry / $\phi$ distribution in STS

- Hole size = 10 cm
  Ongoing discussion to increase hole size to 20 cm
## Simulation setup

<table>
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<th>Models</th>
<th>UrQMD (no fragments)</th>
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<td>5M events</td>
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<td>MVD, STS, RICH, TDR, TOF, PSD</td>
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<td>PSD geometry</td>
<td>44 modules, 4 central, 10 cm hole, elongated in x</td>
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Tracks selection

- Number of hits $N_{\text{hits}} > 3$
- Fit quality $\chi^2/\text{NDF} < 3$
- $\chi^2_{\text{vertex}} < 3$

Non-uniformity of azimuthal acceptance – corrections are needed!

CBM simulation
Au+Au, 10AGeV
5M events, UrQMD
Particle identification (PID)

$p_T$-Y efficiency map (pions)

CBM simulation
Au+Au, 10AGeV
1.5M events, UrQMD

For flow performance in this presentation MC-truth PID was used!

https://indico.gsi.de/event/4759/session/25/contribution/16/material/slides/0.pdf
Centrality: estimating model parameters with measured multiplicity

Multiplicity interval $M \pm \Delta M$ gives impact parameter distribution $b$ with width $\sigma$

Experimental estimate of the reaction plane with Q-vector

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

\[ Q_x = \frac{1}{C} \sum_k w_k \cos \phi \]

\[ Q_y = \frac{1}{C} \sum_k w_k \sin \phi \]

**STS**
Sum over all selected tracks normalized on multiplicity
\[ Q_x = \frac{1}{M} \sum \cos \phi \]
\[ Q_y = \frac{1}{M} \sum \sin \phi \]

**PSD**
Sum over group of modules normalized on total energy in group
\[ \bar{Q}_{PSDA} = \frac{1}{E_{PSDA}} \sum_{k \in A} \frac{E_k}{|r_k|} \]

\( E_k \) - energy deposit in the module
\( r_k \) - center of the PSD module
Event plane and scalar product methods

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

- \( v_n \) with respect to symmetry plane estimated using group of particles (subevent) A:
  \[ v_n(A; i) = \frac{\langle 2 u_i Q_i^n(A) \rangle}{R_i^n(A)} \]
  \( \vec{u} = (\cos(n \varphi), \sin(n \varphi)) \)
  \( i = (x, y) \)

- Different components provide independent estimates for flow harmonics
- \( R_i(A) \) shows the sensitivity of subevent A to initial symmetry plane
- Correction factor \( R_i^n(A) \) is calculated via correlations of three subevents
  \( \rightarrow \) standard 3-subevent technique

\[ R_i^n(A; B, C) = \sqrt{\frac{2 \langle Q_i^n(A) Q_i^n(B) \rangle \langle Q_i^n(A) Q_i^n(C) \rangle}{\langle Q_i^n(B) Q_i^n(B) \rangle}} \]

Event plane method:
\[ Q/|Q| = 1 \]
QnVector Corrections Framework

- Developed for ALICE by J. Onderwaater, V. Gonzalez, I. Selyuzhenkov
  https://github.com/jonderwaater/FlowVectorCorrections

- Applies corrections* for azimuthal acceptance non-uniformity
  → corrections calculated from reconstructed azimuthal distributions

- Recentering, twist, rescaling, and rotation corrections are applied separately in different event classes

- Allows to monitor effects of applied corrections

*CBM simulation
  Au+Au, 10 AGeV
  5M events, UrQMD

Framework configuration:
  ✔ recentering
  ✔ twist
  ✔ rescaling

*PRC77 034904 (2008)
Correction factor

\[ R_x^1 = Q_1^x \cos(\Psi_{RP}) \]
\[ R_y^1 = Q_1^y \sin(\Psi_{RP}) \]

Different x-y sensitivity due to the magnetic field

CBM simulation
Au+Au, 10 AGeV
5M events, UrQMD
Correction factor

\[ R_i^n(A;B,C) = \sqrt{\frac{2 \langle Q_i^n(A)Q_i^n(B) \rangle \langle Q_i^n(A)Q_i^n(C) \rangle}{\langle Q_i^n(B)Q_i^n(B) \rangle}} \]

Large differences between true and reconstructed correction factor due to non-flow correlations (momentum conservation)
Correction factor for mixed harmonic

\[ R_i^n(A;B,C,D) \propto \sqrt[2]{\frac{\langle Q_i(A)Q_i(B)Q_i(A)Q_i(C)Q_i^2(D) \rangle}{\langle Q_i(B)Q_i(C)Q_i^2(D) \rangle}} \]

Mixed harmonic calculation removes/suppresses contribution from non-flow (see backup slides for other combinations)

On next slides only y-component is considered
Correction factor for y-component

Central part has worse resolution. Can be improved with higher granularity.

CBM simulation
Au+Au, 10AGeV
5M events, UrQMD
$\pi^- v_1$ vs rapidity

**Graph Details:**
- **STS centrality:** 0-20%
- **$p_T < 2$ GeV/c**
- **CBM simulation:** Au+Au, 10AGeV
  - 5M events, UrQMD

**Notes:**
- Statistical errors from correction factor are not shown.
- Good agreement between simulated and reconstructed values.
Summary

- Reaction plane reconstruction with 3-subvent technique and mixed harmonic method is implemented and results compared to MC-true
- Results for $\pi^{-} \nu_1$ with event plane from PSD are presented

Next steps
- Flow of protons and kaons
- Study other harmonics
- Include particle identification with TOF
- Study different centrality estimators