Flow analysis in CBM experiment at FAIR

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Outline

1. The CBM experiment at FAIR.
**FAIR - The International Facility for Antiproton and Ion Research**

**CBM Experiment / FAIR**

**The Compressed Baryonic Matter Experiment**

**SIS-100**

10^9 ions/s beam intensity

<table>
<thead>
<tr>
<th>Beam</th>
<th>Plab,max</th>
<th>√S_{NN} max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy ions (Au)</td>
<td>11AGeV</td>
<td>4.7 GeV</td>
</tr>
<tr>
<td>Light ions (Z/A =5)</td>
<td>14AGeV</td>
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<td>Protons</td>
<td>29AGeV</td>
<td>7.5 GeV</td>
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**SIS-300**

Nuclei Z/A = 0.5(0.4) till 45 GeV A
Protons till 89 GeV

**Near future** – (2 -10/11) AGeV

An Experimental Exploration of the QCD Phase Diagram

nucl-ex > arXiv:1007.2613
Flow analysis - motivation

Flow analysis = the study of the azimuthal distribution of particles emitted after collisions relative to the reaction plane.

Termalization ???

Signature of quark-gluon plasma

Strong collective flow

Exotic phenomena

Parity or time - reversal violation

Anisotropies distribution of outgoing particles

carry information about

EOS
Anisotropic flow

Directed flow

$$v_1(p_T, y) = \left\langle \cos(\phi_i - \Psi_{RP}) \right\rangle_{\text{events}}$$

Eliptic flow

$$v_2(p_T, y) = \left\langle \cos 2(\phi_i - \Psi_{RP}) \right\rangle_{\text{events}}$$

Reaction plane angle, can only be estimated

Flow coefficients measure the anisotropy degree

Directed flow average

Eliptic flow average

Reaction plane

bounce off of the spectators
side splash of the participants

bounce off of the spectators

bounce off of the spectators
### Flow at FAIR’s energies

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$\nu_2$ change the sign $\approx 2 - 4$ GeV

PbPb 20-30% nucl-ex/arXiv:1011.3914
Methods for flow analysis

1. Correlations with the event plane
   Event Plane Method
   
   \[ v_n[\text{EP}] = \frac{\langle \cos \left( n(\varphi_i - \Psi^n_{\text{EP}}) \right) \rangle}{R_n} \]

2. Correlations between particles
   
   Two-particles correlations (2A)
   Four-particles correlations (2B)
   .... Multi-particles correlations

   **Cumulants method**
   
   (2A)
   (2B)

   **All - particles correlations Lee-Yang Zeroes**

   This work

Non-flow effects which affect the flow

- Resonance decays, Jets, Quantum statistics effects, Strong/Coulomb interactions

Detectors used for event plane estimations in CBM experiment
Lee-Yang Zeros Method

1. For each event one define the global observable
\[ Q^\theta = \sum_{i=1}^{M} \omega_i \cos(n(\varphi_i - \theta)) , \]
n the Fourier harmonic under study, n=2 for elliptic flow, \( \theta \) arbitrary reference direction

2. Construct a generating function
\[ G_n^\theta (ir) = \left( e^{irQ_n^\theta} \right)_{\text{events}} \] LYZS sum
or
\[ G_n^\theta (ir) = \left( \prod_{i=1}^{M} (1 + ir\omega_i \cos(n(\varphi_i - \theta))) \right)_{\text{events}} \] LYZP product

3. Evaluate \( |G_n^\theta (ir)| \), \( r \) real positive number, plot \( |G_n^\theta (ir)| \) function of \( r \),
find the first minimum \( r_0 \).

4. \( v_n^\theta = \frac{j_{01}}{Mr_0^\theta} \), \( j_{01} = 2.405 \) the first positive root of the Bessel function \( J_0(x) \)

5. Differential flow
\[ \frac{v_n^\theta (p_T, \eta)}{v_n^\theta M} = \text{Re} \left( \frac{\left\langle \cos(n(\varphi_i - \theta)) e^{ir_0^\theta Q^\theta} \right\rangle_p}{\left\langle Q^\theta e^{ir_0^\theta Q^\theta} \right\rangle_{\text{events}}} \right) \] LYZS

Average over all events

\( p \) means average for all particles in an event

R.S. Bhalerao, N. Borghini, J.Y. Ollitrault

validated from RHIC to LHC energies
Lee-Yang Zeros Method

### Method limitations

- **statistical errors**, if the flow and/or event multiplicity are too small.

- Resolution parameter $\chi$, related to the event plan resolution
  1. $\chi > 1$, statistical error not a problem
  2. $0.5 < \chi < 1$, optimize weights $\omega_i$, method can be used
  3. $\chi < 0.5$, statistical error large, increase nr events. !!!

**Ilya Selyuzhenkov**, 25th CBM Collaboration meeting, 20 April 2015

$$v_n[\text{EP}] = \frac{\langle \cos n(\varphi_i - \Psi^n_{\text{EP}}) \rangle}{R_n}$$

$R_n$ - event plane resolution correction factor

2nd order event plane resolution with PSD is good ($\sim 0.4$)
Simulations AuAu 10 AGeV – Urqmd 3.4

100 000 events minbias  \(0.6 < y < 2.6\)
all charges particles

\[
v_2(p_T, y) = \left\langle \cos 2(\varphi_i - \Psi_{RP}) \right\rangle_{\text{particles}} \right\rangle_{\text{events}}
\]

<table>
<thead>
<tr>
<th>(b (\text{fm}))</th>
<th>c</th>
<th>(v_2) integral</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 4.5</td>
<td>10-20%</td>
<td>0.0119</td>
</tr>
<tr>
<td>4.5 - 6.4</td>
<td>20-30%</td>
<td>0.0244</td>
</tr>
<tr>
<td>6.4 - 7.8</td>
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<td>0.0276</td>
</tr>
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<td>7.8 - 9.05</td>
<td>40-50%</td>
<td>0.0270</td>
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<tr>
<td>9.05 - 10.13</td>
<td>50-60%</td>
<td>0.0247</td>
</tr>
<tr>
<td>10.10-11.08</td>
<td>60-70%</td>
<td>0.0135</td>
</tr>
<tr>
<td>11.05-12</td>
<td>70-80%</td>
<td>0.0065</td>
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AuAu 10 GeV A – LYZS

10 000 events for each centrality class
0.6 < y < 2.6
all charges particles

Integral elliptic flow

<table>
<thead>
<tr>
<th>Centrality</th>
<th>v2 Urqmd</th>
<th>v2 LYZS/flow only</th>
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<tr>
<td>10-20%</td>
<td>0.0119</td>
<td>0.0291 ± 0.0005</td>
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Nr. Events for LYZS should be higher
AuAu 30 GeV A – LYZS

1.1 < y < 3.1
all charges particles

\[ |G(\theta)\rangle | \]

Differential elliptic flow \( v_2(p_T) \) (Urqmd)

Integral elliptic flow

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<th>9.05 - 10.13</th>
<th>10.10 - 11.08</th>
<th>11.05 - 12</th>
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<tr>
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<td>0.0124</td>
<td>0.0238</td>
<td>0.0305</td>
<td>0.0263</td>
<td>0.0305</td>
<td>0.0239</td>
<td>0.0095</td>
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Differential elliptic flow
Conclusions

1. The aim of this presentation was to analyze the possibility of using multiparticles correlation method, Lee-Yang Zeroes, for the elliptic flow study as an alternative to Event Plan Method. Preliminary results on the feasibility of the LYZ applied on AuAu 10 and 30 GeV A are presented.

2. The limitation of LYZ method is related to statistical fluctuations.
   
   Statistical fluctuations decrease like $\frac{1}{\sqrt{M N_{ev}}}$
   
   Necessary statistics $v_2^\theta > \frac{j_{01}}{\sqrt{2M \ln N_{ev}}}$
   
   The method doesn’t work very well in central and peripheral events.

3. Need for more simulations (increase $N_{ev}$), testing LYZP, need comparisons with other methods, need analysis for nonflow components, interaction with detectors (CBMROOT simulations).