Centrality classes, shadowing and model dependence in p-A collisions

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Motivation:

**Centrality and Fluctuation**

- **Fluctuations** in physical observables in heavy-ion collisions have been a topic of interest for some years as they may provide important signals regarding the formation of quark-gluon plasma (QGP).
- For studying fluctuation and searching delicate effect it is necessary to determine precisely measurement’s parameters (to fix the centrality classes) when the induced observable’s fluctuation will be minimal.

\[
\omega_x = \frac{\sigma_x^2}{\langle x \rangle}
\]

- dispersion

\[
\langle x \rangle
\]

- the mean value

Nucleus is an extended object. Collisions with nuclei could be characterized by centrality with respect to impact parameter.
**Nucleus-nucleus collision experiment**

- Opposite bunches particle scattering

\[ N_B = B - N_{col}^R \]
\[ N_A = A - N_{col}^L \]

- Fix nucleus-target collision

\[ N_A = A - N_{col}^L \]
\[ N_{col}^L = \frac{E_{col}^L}{E_0} \]

- Number of wounded nucleons
- Number of nucleons-spectators

\[ N_{col}^R = \frac{E_{col}^R}{E_0} \]
\[ E_{col}^L (E_{col}^R) \] - Total Energy of collision fixed by calorimeters

**ALICE** (LHC)

\[ E_0 \] - Energy of a nucleon

2 methods of fixing centrality:
- Multiplicity
- Nucleon-spectators

**NA61** (SPS)
Aim of the analysis:

- Minimization of trivial fluctuations of observables
- Applicability of the centrality determination methods for pA collisions

Analysis:

Influence of the centrality classes width on the fluctuations of Number of participants

Method:

Monte-Carlo simulation of nucleus-nucleus collision

Why we use Monte-Carlo (Glauber model; HIJING)?

Information about

- $b$ – Impact Parameter
- $N_{\text{part}}$ – Number of wounded nucleons

Distinctions for different classes of centrality are evident
What is the CENTRALITY?

If $y(x)$ is a function of events distribution versus of impact parameter of AA collision.

Then $F(x)$ – square under the plot

**Peak value** $F(x) = F(0)$

**normalization $F(x)$:**

For Impact Parameter
- $G(0) = 0\%$
- $G(x_{\text{max}}) = 100\%$

For Multiplicity
- $G(0) = 100\%$
- $G(x_{\text{max}}) = 0\%$

$G(x)$ - function compares value of centrality of the collisions (expressed in percentage) to value of the impact parameter.

- Borders of intervals of the centrality are equal to values of function $G(x)$ in the points limiting the given interval.

Example:
- Centrality classes in ALICE experiment
Centrality in \textbf{Pb-Pb} collisions at 2.76 TeV based on Glauber Model
Centrality from multiplicity

MC Glauber, PbPb 2.76TeV

Some multiplicity centrality classes

Npart distribution in the different centrality classes
With decrease of width of centrality bin the RMS decreases

Plato (~5-10) is reached at centrality width
For central events near 3%
For peripheral 10% is enough

See details in T.Drozhzhova poster report ISSP 2014
Centrality in $p$-Pb collisions at 5.02 TeV

HIJING 1.38
HIJING [1]

- It was based on a two-component geometrical model of minijet production and soft interaction.
- It has incorporated nuclear effects such as nuclear modification of the parton distribution functions (gluon shadowing).

Gluon shadowing [2]

- Without shadowing nucleons interaction will be independent.
- There are differences between nuclear and proton PDF (parton distribution function) (observed in experiments).
- This leads to decrease of nucleon-nucleon cross section at low $x$.
- Similar effect is also present in Models with energy conservation in elementary nucleon-nucleon collisions (see refs [3-5]).

Dependence on a shadowing parameter

Experimental data is better described by HIJING with shadowing.
Centrality from Multiplicity in p-Pb
Centrality from Multiplicity in p-Pb
Normalization of Multiplicity yields

\[ <N_{\text{part}}>=7.9 \pm 0.6 \]

From Glauber model

<table>
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<th>$S_g$</th>
<th>$&lt;N_{\text{part}}&gt;$</th>
<th>$&lt;\text{Mult}&gt;$</th>
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<tr>
<td>0.28</td>
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</table>

Number of participants is depended on models

No straight forward treatment of experimental data on multiplicity, based on normalization to Npart

Summary and Conclusions:

• The method of centrality evaluation initially developed for ion-ion collisions was applied for p+Pb

• Large fluctuations of number of participants in multiplicity classes make dividing of the events in classes according to Npart problematically

• Model dependence of Npart makes questionable normalization of multiplicity yields to Npart
• Back-up slides
Centrality from impact parameter p-Pb

Impact parameter distribution

Centrality and Impact Parameter

Impact parameter distribution and different width of impact parameter classes

Number of participants distribution
Centrality from impact parameter p-Pb

**Impact parameter distribution**
- Entries: 10000000
- Mean: 5.93
- RMS: 2.22

**Centrality and Impact Parameter**

**Impact parameter distribution and different width of impact parameter classes**
- Entries: 68871
- Mean: 7.398
- RMS: 0.1116

**Number of participants distribution in different width impact parameter**
- Entries: 10000000
- Mean: 6.536
- RMS: 4.227
Pb-Pb

$$\sqrt{s_{NN}} = 2.76\, TeV$$

- Nucleons are meant as black disks here

Nuclear density

Woods-Saxon distribution:

$$\rho(r) = \rho_0 \left\{ 1 + \exp\left( \frac{r - R_A}{a} \right) \right\}^{-1}$$

where:

- $$R_A = R_0 \cdot A^{1/3}$$ - nuclear radius,
- $$R_0 = 1.07\, fm$$
- $$a = 0.545\, fm$$
Particle multiplicity is proportional to number of produced strings, which is proportional to participants’ number and collisions’ number.

\[ P(M_c) = e^{-\rho} \frac{\rho^M_c}{M_c!} \]

\[ \langle M_c \rangle = \rho, \quad \rho = m_f \cdot N_{str}(\beta) \]

\[ m_f = \Delta y \cdot \omega \]

\[ N_{str}(\beta) = x N_{NN}^{str} N_c(\beta) + (1 - x) N_{AB}(\beta) \]

\[ N_{NN}^{str} = 2.56 - 0.478 \ln E + 0.084 (\ln E)^2 \]

\[ x \in [0, 1] \]