Centrality in p-A collisions with the ALICE ZDCs: resuming old works and looking for new ideas!

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Centrality in p-A interactions can be defined through the number of collisions $N_{coll}$.

Inclusive measurement of charged particle multiplicity can be poorly correlated with $N_{coll}$.

Measure particle multiplicity vs. centrality $\Rightarrow$ independent method to estimate centrality.

$\Rightarrow$ At fixed target experiments centrality has been determined detecting slow nucleons (classification from emulsion experiments).

Gray nucleons $\Rightarrow$ soft nucleons knocked out by wounded nucleons

Black nucleons $\Rightarrow$ low energy target fragments.

<table>
<thead>
<tr>
<th>SLOW NUCLEONS</th>
<th>$\beta$ [c units]</th>
<th>$p$ [MeV/c]</th>
<th>$E_{kin}$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>$0 \div 0.25$</td>
<td>$0 \div 250$</td>
<td>$0 \div 30$</td>
</tr>
<tr>
<td>Gray</td>
<td>$0.25 \div 0.70$</td>
<td>$250 \div 1000$</td>
<td>$30 \div 400$</td>
</tr>
</tbody>
</table>
Results from existing experimental emulsion and fixed target results on slow nucleon production in hadron-nucleus interaction

[F. Sikler, hep-ph/0304065]

→ multiplicity of produced shower particles is correlated with the number of emitted slow particles

**Number of particle in the shower vs. number of black nucleons**

**Number of particle in the shower vs. number of gray nucleons**
Relationship between $N_{\text{coll}}$ and $N_{\text{gray}}$  


- different models considered, E910 reproduce experimental data assuming $N_{\text{gray}} \propto N_{\text{coll}}$
features of produced particles are highly independent of projectile energy from 1 GeV to 1 TeV
slow nucleons emission dictated by nuclear geometry

kinematical distributions described by independent statistical emission from a moving frame
isotropic emission from a source moving with velocity $\beta$
number distribution of black/gray nucleons follows binomial distributions

From $N_{\text{coll}}$ to $N_{\text{gray}}$ ➔ distribution of the number of projectile collisions from Glauber model
probability distribution of the number of gray nucleons from geometric model

$$N_{\text{gray}} \propto N_{\text{coll}}$$

From $N_{\text{coll}}$ to $N_{\text{black}}$ ➔ emission from equilibrated nucleus
black nucleon multiplicity connected to target excitation

$$N_{\text{black}} \propto N_{\text{coll}}$$

Minimum bias p-A collision ➔

$$\bar{N}_{\text{black}} \approx 0.08A \quad \bar{N}_{\text{gray}} \approx 1.2A^{1/3}$$

Centrality selected collisions on Pb target: values (per collision) ➔

$$\bar{N}_{\text{black}} \approx 4N_{\text{coll}} \quad \bar{N}_{\text{gray}} \approx 2N_{\text{coll}}$$
experiments with lighter ions (O, S) report a saturation effect in $N_{\text{black}}$ vs. $N_{\text{gray}}$

Saturation values $\Rightarrow <N_{\text{black}}> = 12$ for $N_{\text{gray}} > 7$

No experimental data for Pb nuclei
Supposing the number of emitted slow nucleons proportional to the target nucleus thickness $\Rightarrow$ rescaled values for Pb nucleus
$<N_{\text{black}}> \sim 28$ for $N_{\text{gray}} > 15$

the gray track angular distribution is strongly forward peaked


ALICE ZDCs

- placed at 0° w.r.t LHC axis, ~112 m far from IP on both sides, quartz fibre calorimeters
- on both A and C sides we have a proton (ZP) and a neutron (ZN) ZDC

The ZDC system is completed by:
- 2 small (7x7x21) cm³ EM calorimeters (ZEM1, ZEM2) placed at ~7.5 m from the IP, at ±8 cm from LHC axis, only on A side covering the range 4.8<\(\eta\)<5.7
HIJING + slow nucleon model generator (saturation and forward peaked distribution)

**QUESTIONS**

- What generator is better to use for p-A to have both the nucleus and the proton accurately simulated?
- How to take into account the EM processes (particularly important for γ-p)
ZN + ZP calorimeter energy spectrum for minimum bias p-A collisions at $p_p = 4$ TeV
sharp cuts in $E_{ZDC}$

- not more than $3/4$ centrality classes can be defined

- inputs for the slow nucleon model and more in general suggestions about the generators to be used are more than welcome!
BACKUP
Relationship between $N_{\text{coll}}$ and $N_{\text{gray}}$ for different models considered:

1. Geometric cascade model (GCM) \( \overline{N}_{\text{grey}} \propto \overline{v} \)
2. Intranuclear cascade (IC) \( \overline{N}_{\text{grey}} \propto \overline{v}^2 \)
3. Polynomial model (E910) \( \overline{N}_{\text{grey}} = c_0 + c_1 v + c_2 v^2 \)

Fit of data \( c_2 \sim 0 \)

Polynomial model is the more accurate to determine centrality ($<v>$)
Slow nucleons momentum distributions can be parametrized by Maxwell-Boltzmann distributions

⇒ particles emitted isotropically from a source moving with velocity $\beta$

\[
E \frac{d^3\sigma}{dp^3} \propto \exp\left(-\frac{E_{\text{kin}}}{E_0}\right)
\]

Black nucleons emitted from a stationary source ⇒ $\beta = 0$, $E_0 = 5$ MeV
Black nucleons emitted from a frame moving slowly in beam direction ⇒ $\beta = 0.05$, $E_0 = 50$ MeV

**From $N_{\text{coll}}$ to $N_{\text{gray}}$**
Glauber model assuming Wood-Saxon nuclear density ⇒ distribution of number of projectile collisions in the nucleus
Geometric model ⇒ probability distribution of number of slow nucleons

**From $N_{\text{coll}}$ to $N_{\text{black}}$**
Black nucleons production described by thermodynamic or statistical models (remnants undergoes equilibration before breakup)

Each collision provides independent production of prompt gray nucleons with identical excitation of the nucleus, leading to the emission of black nucleons
pA MC RESULTS (I)

n impact point over ZNA

p impact point over ZPA

Primary kinetic energy

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pA@LHC, 5 Jun 2012