Common Event Characterization in the RHIC Experiments

Alexei Denisov, IHEP (Protvino) Russia, for the PHENIX collaboration

*Related talks:
S. White, "Calorimetry for Global Event Characterization in PHENIX"
A. Milov et al., "Charged Particle Multiplicity and Transverse Energy in Au+Au Collisions at $\sqrt{s_{nn}} = 130$ GeV"
ZDC modules design

Cosmic ray calibration:
RMS in light yield for the 24 modules is <4%.
Outline

• Goals of the ZDCs as common & identical detectors for all HI experiments at RHIC:
  – luminosity & collisions parameters monitoring/measurement;
  – consistent normalization of cross sections between experiments;
  – trigger for minimum bias HI events.

• ZDC performance in the RUN 2000:
  – energy, coordinate & time resolution, acceptance ....

• Cross sections :
  \[ \sigma_{tot} = \sigma_{geo} + \sigma_{cd}; \sigma_{ln, xn}, \sigma_{ln, ln}, \sigma_{ln, 2n}, \ldots \text{ (for CD)} \]

• ZDC performance for centrality characterization.
ZDC layout in the RHIC IR’s

“Beam-eye” view of the ZDC location

ZDC installation in 1999

Plane view of the ZDC layout at RHIC
**Luminosity measurements**

\[
R_{\text{ZDC}} = L_{\text{bb}} \ast \sigma_{\text{tot}} ; \quad L_{\text{bb}} = (N_{\text{au}})^2 \ast N_{\text{bunch}} \ast v_{\text{rev}} / \{4\pi(\sigma_t)^2\}
\]

$L_{\text{bb}}$ is derived from machine parameters $\Rightarrow \sigma_{\text{tot}}$ measurement.
ZDC performance @ $\sqrt{S} = 130\text{GeV}$

- Energy resolution for 1n is 26\% (simulation), 25\% (exp.)

- 24\% of neutrons out of ZDC acceptance for nuclear events

- $\sim$100\% of neutrons from Coulomb Dissociation events in ZDC acceptance
**ZDC vertex and time resolution**

ZDC vertex resolution $\sigma_Z \approx 2\text{cm}$

$t_0$ resolution $\approx 120\text{ps}$
ZDC minimum bias trigger

Fraction of Coulomb Dissociation events $\approx 1/3$

Neutron multiplicity distribution in single arm of ZDC

Au X Au at $\sqrt{s} = 130$ GeV

PHENIX data. [Preliminary]

"Minimum bias" events
"Coulomb dissociation" events
"Hadronic" events
Cross Sections (consistency check)

- **Definitions:**
  \[ \sigma_{\text{tot}} = \sigma_{\text{cd}} + \sigma_{\text{geo}} \] - total cross section triggered by ZDC
  \[ \sigma_{\text{cd}} \] - Coulomb Dissociation cross section
  \[ \sigma_{\text{geo}} \] - "geometrical" (nuclear) cross section

- **Efficiencies:**
  \[ \epsilon_{\text{bbc}} = (92 \pm 2)\% \text{ (HIJING sim.)} \]
  \[ \epsilon_{\text{bb}} = (93 \pm 2)\% \text{ (JAM sim.)} \]
  \[ \epsilon_{\text{zdc}} = (98 \pm 2)\% \text{ (conservative)} \]
  \[ \epsilon_{\text{zdc}} = (99.5 - 1.5)\% \text{ (realistic)} \]

- \( \sigma_{\text{tot}} \) is derived from luminosity and beam characteristics (underway ?).

  **Theoretical prediction:**
  \[ \sigma_{\text{tot}} = (10.7 \pm <0.5) \, \text{b}, \]
  \[ \sigma_{\text{geo}} = 7.2 \, \text{b} \text{ (Glauber calculation at } \sigma_{\text{nn}} = 40 \, \text{mb}) \] ---->
  \[ \frac{\sigma_{\text{geo}}}{\sigma_{\text{tot}}} = (0.673 \pm <0.034) \]
  \[ \frac{N_{\text{bbc}}}{N_{\text{tot}}} = (0.615 \pm 0.015) \] ---->
  \[ \frac{\sigma_{\text{geo}}}{\sigma_{\text{tot}}} = (0.668 \pm 0.022) \]
**Coulomb Dissociation cross sections**

- CD events selection:
  \[ \text{Mult}_{\text{bbc1}} < 2 \text{ OR } \text{Mult}_{\text{bbc2}} < 2 \implies \]
  92% of nuclear events removed.
  Bgd shape from low \text{Mult}_{\text{bb}}

- Model:
  \[ A_{kn} = k^* A_{1n}, \text{ RMS}_{kn} = \sqrt{k^*} \text{ RMS}_{1n} \]
  \( A_{kn} \) defines energy scale.

Neutron multiplicity in single arm for pure CD events
**Exclusive cross sections for CD**

\[
\frac{\sigma_{1n, xn}}{\sigma_t} \quad (0.124 \pm 0.003 \pm 0.006)
\]

\[
\frac{\sigma_{1n, 1n}}{\sigma_{1n, xn}} \quad (0.350 \pm 0.015 \pm 0.02)
\]

\[
\frac{\sigma_{2n, xn}}{\sigma_{1n, xn}} \quad (0.342 \pm 0.015 \pm 0.02)
\]

Calculation

0.127 ± ??  

0.329 ± ??

---
“Centrality” determination

• Direct measurement of $N_{\text{participant}}$ via $N_{\text{spectator}}$:

$$N_{\text{participant}} + E_{\text{spectator}}/(m_n \ast \gamma_{\text{beam}}) = A_{\text{beam}}$$

In collider experiments ZDC can measure only part of $E_{\text{spectator}} \Rightarrow$ large fluctuations + lost of monotonic behavior.

• Using Glauber model, from impact parameter.
Correlation between $N_{\text{participants}}$ & $N_{\text{bbc}}$ & Spectators

Correlation between Participants & Mult in BBC

$N(\text{bbc}) \sim N(\text{partic})^{*1.18}$

Correlation between Participants & Spectators

All Spectators

Neutrons
Limitation on centrality selection with ZDC

- ZDC multiplicity is not monotonic function of impact parameter $\implies$ need a cut on peripheral collisions $\implies$ limit on “unbiased” range.
Calculation of $N_{part}$ and $N_{coll}$

- Use simulated BBC – ZDC response to define centrality cuts.
- Relate them to $N_{part}$ and $N_{coll}$ using Glauber model.
- Straight-line nucleon trajectories
- Constant $\sigma_{NN} = (40 \pm 5) mb$.
- Woods-Saxon nuclear density:

$$\rho(r) = \rho_0 \cdot \frac{1}{1+\exp\left(\frac{r-R}{d}\right)}$$

$$R = 1.19A^{1/3} - 1.61A^{-1/3} = (6.65 \pm 0.03) fm$$

$$d = (0.54 \pm 0.01) fm$$
Systematic errors estimation for $N_{\text{part}}$ and $N_{\text{coll}}$

**Error estimation: $N_{\text{coll}}$**

$$\text{rel. error}(N_{\text{coll}})[\%] = 15 + 400/N_{\text{coll}}$$

**Error estimation: $N_{\text{part}}$**

$$\text{rel. error}(N_{\text{part}})[\%] = 2 + 300/N_{\text{part}}$$
Centrality dependence

- Use BBC – ZDC response to define centrality cuts (in 5% bins of $\sigma_{geo}$)
- Determine $<dN_{ch}/d\eta>$ and $<dE_t/d\eta>$ vs centrality
Conclusions

- ZDCs have been installed and commissioned in all four HI experiments at RHIC;
- ZDC provide highly efficient minimum bias trigger, consistent method for cross sections normalization between experiments, luminosity measurements;
- Geometrical as well as CD cross sections are consistent within ~5%.
- ZDC + BBC provide unbiased method of the centrality characterization.