Charged-particle multiplicity, centrality and the Glauber model at 2.76 TeV with ALICE

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XII International Conference on Ultrarelativistic Nucleus-Nucleus collisions
Why measure multiplicity?

- "Easy", day-1 observable determines
  - Density of system
  - Initial conditions
  - Background for hard-probe signals
- "Difficult", convoluted for theory
  - Perturbative vs Non-perturbative,
  - Various scales, hadronization
  - Application of factorization schemes
- Naive parametrization (Npart \sim A, Ncoll \sim A^{4/3}):
  \[
  \frac{dN_{AA}}{d\eta} \bigg|_{\eta=0} = \frac{dN_{NN}}{d\eta} \bigg|_{\eta=0} \left[ \frac{1-x}{2} N_{\text{part}} + x N_{\text{coll}} \right]
  \]
  - Ncoll scaling (x=1) for Collinear factorization
  - Npart scaling (x->0) for shadowing, non-linear QCD dynamics, saturation, collectivity

PHOBOS, PRC 70, 021902(R) (2004)

At RHIC, approximate participant scaling and factorization of energy +centrality was found
Predicted multiplicities for LHC energies

Charged multiplicity for mid-rapidity in central Pb+Pb @ 2.76 TeV

Compilation from N. Armesto
(Talk@CERN, 03 Sep 2010)

Monte Carlo, coherence via collectivity, strong gluon saturation

Saturation ideas

Data driven, limiting frag.

Miscellaneous: superposition, WNM, diffusion eqs., DPM + shadowing/percolation

Blue are unscaled model results
ALICE detector and trigger setup

- Minbias triggers: Coincidences of
  - SPD (≥2 pixel hit)
  - V0 (A side)
  - V0 (C side)
- Trigger requirements tightened throughout the run period
  - “2-out-of-3”, “V0AND”, “3-out-of-3”

Relevant for this talk:
- VZERO scintillator hodoscopes (2.8<η<5.1) and (-3.7<η<1.7)
- nZDC (beam rapidity)
- ITS (SPD): First layer (|η|<2)
  Second layer (|η|<1.4)
- TPC (|η|<0.9)
Example VZERO amplitude distribution

Peak:
Very peripheral collisions
Trigger/data selection inefficiency
Background contributions

Cleanup+Centrality classification needed
Trigger efficiency

Efficiency estimated with pp data and HIJING/AMPT
Background (simulated cocktail)

Cocktail (HIIJING, QED, SLIGHT/RELDIS) vs data:
- 3-out-2: clean from 87%
- Others: clean from 90%

- **EM processes**
  - **QED pair production**
    - $O(100 \text{ kbarn})$
    - $e^+e^-$ very soft
  - **EM dissociation**
    - $O(100 \text{ barn})$
    - One or few neutrons in ZDC
  - **Photonuclear interactions**
    - $O(10 \text{ barn})$
    - Photon energies $O(100 \text{ GeV})$, can produce hadrons at mid-rapidity (Kinematics like pA)

![Graph showing cocktail and data comparison](image)

- Offline Trigger: 2-out-of-3
- Data (online trigger: 2-out-of-3)

**STARLIGHT/RELDIS**

- C.Oppedisano talk

**QED**

- J.Nystrand #533

**Purity** = "HIIJING/ALL"
Glauber Monte Carlo

- Geometrical picture of inelastic nucleus+nucleus collision
  - Distribution of nucleons according to Wood-Saxon (2pF)
    - Radius \((6.62 \pm 6\) fm), skin depth \((0.546 \pm 0.01\) fm)
    - Inter-nucleon distance \((0.4 \pm 0.4\) fm)
  - Straight-line nucleon trajectories
  - Interaction radius given by \(\sigma_{NN}\)
    - \(64 \pm 5\) mb used (interp. pp/pp data)
    - Subsequent interactions equally probably

- Systematic uncertainties by varying model parameters
  - Small effect on \(\langle N_{\text{part}} \rangle\)
  - Uncertainty in \(\sigma_{NN}\) dominant for \(\langle N_{\text{coll}} \rangle\)
Measured cross-sections

Cross sections (total, inelastic, elastic):

- $\sigma_{\text{tot}}$ [PDG p-p data]
- $\sigma_{\text{tot}}$ [PDG p-$\bar{p}$ data]
- $\sigma_{\text{tot}}$ [COMPETE fit]
- $\sigma_{\text{el}}$ [Fit]
- $\sigma_{\text{inel}} = \sigma_{\text{tot}} - \sigma_{\text{el}}$

ATLAS:
$69.4 \pm 2.4 \pm 6.9$ mb
(arXiv:1104.0326)

CMS (Prel.):
$70.4 \pm 1.1 \pm 3.5$ mb
(M.Marone, DIS'11)

ALICE (Prel.):
$72.7 \pm 1.1 \pm 5.1$ mb

Inel. pp cross section at 2.76 TeV:
- ALICE preliminary: $62.1 \pm 1.6 \pm 4.3$ mb
- Pre-LHC interpolation: $64$ mb $\pm 5$ mb
  (K.Reygers/D.d'Enterria)

K.Oyama talk
M.Poghosyan talk
Centrality definition

- Anchor point with Glauber fits
  - Source distributed by \( f \cdot N_{\text{part}} + (1-f) \cdot N_{\text{coll}} \)
  - Typically \( f \sim 0.8 \)
  - Particle production per source modeled via NBD
  - Robust results anchoring between 30% and 90% percentile bins
    - Region with 100% trigger eff
    - Negligible background
  - Tight correlation between various centrality measures
- Relation to Glauber values (Npart, etc.) values from model
  - Difference in \( \langle N_{\text{part}} \rangle \) is \(<1\%\), except for 70-80% with \(<3.5\%\)
Multiplicity measurement

- Tracklet based
  - \( \frac{dN}{d\eta} \sim \alpha(1-\beta)N_{\text{tracklets}} \)
  - \( \alpha \): Acceptance and efficiency corrections
    - Dominated by acceptance (varies little with centrality)
  - \( \beta \): Combinatorial background
    - 3 ways to estimate
    - Varies by 1% to 14%
- Tracks with zero-\( p_T \) extrapolation as cross check

<table>
<thead>
<tr>
<th>Centrality</th>
<th>( dN_{\text{ch}} / d\eta )</th>
<th>( \langle N_{\text{part}} \rangle )</th>
<th>( \frac{(dN_{\text{ch}} / d\eta)}{\langle N_{\text{part}} \rangle / 2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5%</td>
<td>1601 ± 60</td>
<td>382.8 ± 3.1</td>
<td>8.4 ± 0.3</td>
</tr>
<tr>
<td>5–10%</td>
<td>1294 ± 49</td>
<td>329.7 ± 4.6</td>
<td>7.9 ± 0.3</td>
</tr>
<tr>
<td>10–20%</td>
<td>966 ± 37</td>
<td>260.5 ± 4.4</td>
<td>7.4 ± 0.3</td>
</tr>
<tr>
<td>20–30%</td>
<td>649 ± 23</td>
<td>186.4 ± 3.9</td>
<td>7.0 ± 0.3</td>
</tr>
<tr>
<td>30–40%</td>
<td>426 ± 15</td>
<td>128.9 ± 3.3</td>
<td>6.6 ± 0.3</td>
</tr>
<tr>
<td>40–50%</td>
<td>261 ± 9</td>
<td>85.0 ± 2.6</td>
<td>6.1 ± 0.3</td>
</tr>
<tr>
<td>50–60%</td>
<td>149 ± 6</td>
<td>52.8 ± 2.0</td>
<td>5.7 ± 0.3</td>
</tr>
<tr>
<td>60–70%</td>
<td>76 ± 4</td>
<td>30.0 ± 1.3</td>
<td>5.1 ± 0.3</td>
</tr>
<tr>
<td>70–80%</td>
<td>35 ± 2</td>
<td>15.8 ± 0.6</td>
<td>4.4 ± 0.4</td>
</tr>
</tbody>
</table>

Sources of error | Relative uncertainty
--- | ---
Background subtraction | 0.1% to 2.0%
Particle composition | 1.0%
Contamination of weak decays | 1.0%
Zero-\( p_T \) extrapolation | 2.0%
Event generator | 2.0%
Centrality | 6.2% to 0.4%
Tracklet + vertex cuts | negl.
Material budget | negl.
Detector efficiency | negl.
Background events | negl.
Total | 7.0% to 3.8%

PRL, 105, 252301 (2010)
PRL, 106, 032301 (2011)
Measured $dN_{ch}/d\eta = 1584 \pm 76$ (sys.)

PRL, 105, 252301 (2010)

Monte Carlo, coherence via collectivity, strong gluon saturation

Data driven, limiting frag.

Saturation ideas

Miscellaneous: superposition, WNM, diffusion eqs., DPM + shadowing/percolation

Blue are unscaled model results

geometrical scaling corr., saturation
strong gluon shadowing corr., RDM
CQM + Landau hydro corr., PACIAE
EPOS corr., URQMD
corr., HYDJET
saturation data driven, limiting frag.
corr., NN superposition
corr., EKS98 + geom. scaling
corr., BAMPS
Percolation
corr., AMPT + gluon shadowing
corr., NG + Gribov shadowing
corr., wounded diquark model
data driven, limiting frag.
corr., DPMJET III
corr., HIJING/BB v2
PSM
corr., log extrapolation
corr., rcBK evolution
corr., logistic evolution eq.

Post-pp

ASW-like ($\lambda = 0.26$)
Levin et al.
HIJING 2.0
Wolschin et al.
Sarkisyan et al.
Sa et al.
Porteboeuf et al.
Mitrovski et al.
Lokhtin et al.
Kharzeev et al.
Jean et al.
Humanic
Fujii et al.
Eskola et al.
El et al.
Dias de Deus et al.
Chen et al.
Capella et al.
Chaudhuri
Bzdak
Busza
Bopp et al.
Topor Pop et al.
Armento et al.
Armento et al.
Arleo et al.
Albacete
Abreu et al.
dNch/dη: Energy dependence

Measured dNch/dη = 1584 ± 76 (sys.)  PRL, 105, 252301 (2010)

\[ \frac{dN_{\text{ch}}}{d\eta} \text{ vs. } \sqrt{s_{\text{NN}}} \text{ (GeV)} \]

- AA(0-5 %) ALICE
- pp NSD ALICE
- AA(0-5 %) NA50
- pp NSD CMS
- AA(0-5 %) BRAHMS
- pp NSD CDF
- AA(0-5 %) PHENIX
- pp NSD UA5
- AA(0-5 %) STAR
- pp NSD UA1
- AA(0-6 %) PHOBOS
- pp NSD STAR

Pre-LHC fit (~ln s_{NN})

- Pb+Pb (\sqrt{s_{NN}}=2.76 TeV) 1.9 x pp (NSD) (\sqrt{s_{NN}}=2.36 TeV)
- 2.2 x central Au+Au (\sqrt{s_{NN}}=0.2 TeV)

\[ \sqrt{s_{NN}}=2.76 \text{ TeV} \text{ Pb+Pb, 0-5% central, } |\eta|<0.5 \]
\[ 2 \frac{dN_{\text{ch}}}{d\eta} / <N_{\text{part}}> = 8.3 \pm 0.4 \text{ (sys.)} \]
dNch/d\eta: Centrality dependence

Interpolation between 2.36 and 7 TeV pp

Pb+Pb, \( \sqrt{s_{NN}} = 2.76 \) TeV

\(|\eta| < 0.5\)

2.5% bins

Interpolation between 2.36 and 7 TeV pp
$dN_{ch}/d\eta$: Centrality dependence

LHC centrality evolution very similar to RHIC

\begin{align*}
\sqrt{s_{NN}} = 2.76 \text{ TeV} \\
|\eta| < 0.5
\end{align*}

RHIC data scaled by 2.1
- Two-component models
  - Soft (~Npart) and hard (~Ncoll) processes
- Saturation-type models
  - Parametrization of the saturation scale with energy (s) + centrality (A)
- Comparison to data
  - DPMJET (with string fusion) stronger rise than data
  - HIJING 2.0 (no quenching)
    - Strong centrality dependent gluon shadowing
    - Fine-tuned to 0-5% dN/dη
- Saturation models
  - Some saturate too much

Models incorporating a moderation of the multiplicity with centrality are favored by the data (as at RHIC)

PRL, 106, 032301 (2011)
Hadronic transverse energy measured with barrel tracking detectors

- Model dependent correction ($f\sim0.55$) to convert into total transverse energy

From RHIC to LHC

- $\sim2.5$ increase in $2dE_T/d\eta/N_{\text{part}}$
- $\sim2.7$ increase in $dE_T/d\eta$

Energy density estimate

$$\tau \epsilon_{LHC} \geq 3 \times \tau \epsilon_{RHIC}$$

As for $dN/d\eta$, centrality dependence similar RHIC. Larger scale factor (2.5) consistent with increase of $<p_T>$(20%)
Summary

- Charged particle multiplicity (transverse $E_T$) increased from RHIC to LHC by a factor of 2.1 (2.5).
  - Initial energy density is at least 3 times larger
  - Rise with collision energy stronger than expected
  - Centrality dependence found to be similar to RHIC
  - Models have a harder time to describe (predict) the increase in energy than the centrality dependence
- Transverse energy measurement puts additional constraints on models since it is also sensitive to the transverse momentum distribution
Background and offline event selection

- Offline event selection for inelastic collisions required to deal with
- Beam Background
  - Beam gas and Debunching
- EM processes
  - QED pair production
    - $O(100 \text{ k barn})$
    - $e^+e^-$ very soft
  - EM dissociation
    - $O(100 \text{ barn})$
    - One or few neutrons in ZDC
  - Photonuclear interactions
    - $O(10 \text{ barn})$
    - Photon energies $O(100 \text{ GeV})$, can produce hadrons at mid-rapidity (Kinematics like $pA$)
ZDC timing cut

ZDC Timing: Sum vs Difference of ZDC time in A and C sides

- Nominal interactions
- Debunching from A side
- Debunching from C side

ALICE Performance
06/05/2011

M.Guilbaud #413
Data vs simulation (cocktail)

ALICE Performance
16/05/2011

VZERO amplitude (a.u.)

- Offline Trigger: 2-out-of-3
  - data (online trigger: 2-out-of-3)
  - data (online trigger: V0AND)
  - data (online trigger: V0AND + SPD)

- Offline Trigger: V0AND + SPD
- Offline Trigger: V0AND + TPC
- Offline Trigger: V0AND + ZDC

- SLIGHT single (24.2b)
- SLIGHT double (240mb)
- QED (92kb)
- HIJING (7.66b)
- sum

90% of total cross section
80% of total cross section
Glauber fits

- Using two component ansatz
- Distribution of particles with NBD
- Typically (for the tight trigger conditions) fit up to about 90%
Pseudorapidity distribution vs generators

- ALICE 0-5% SPD PRL 106 (2011) 032301
- ALICE 0-5% SPD+FMD preliminary
- Hijing(tuned) 0-5 %
- AMPT 0-5 % (w/o string melting)

\( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

\[
\frac{dN_{ch}}{d\eta} = N \left[ f N_{coll}^{\alpha} + (1-f) N_{part}^{\alpha} \right],
\]

- $f = 0.212 \pm 0.021$
- $\alpha = 1.190 \pm 0.017$
- $\alpha = 0.803 \pm 0.012$

ALICE Preliminary