Heavy ions at the LHC:
personal predictions &
overview of the CERN TH Institute

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Heavy ion collisions at the LHC

“Personal” predictions:
mostly, agnostic extrapolations of trends observed in the data


CERN Theory Institute:

heavy ion collisions at the LHC
Last Call for Predictions
Monday May 14th to Friday June 8th 2007

http://fpaxp1.usc.es/nestor/predhiclhc.html

What are the more elaborate predictions of the community?
(19 seminars + 85 talks... I shall present a biased overview!)

Jour fixe, Bielefeld, July 6, 2007
Heavy ion collisions at the LHC

When at last the accelerator people inject Pb^{82+} nuclei into the LHC, what will ALICE, ATLAS and CMS first measure?

the multiplicity of charged particles

... as a function of the position in their detectors

\[
\eta \equiv -\ln \tan \left( \frac{\theta}{2} \right) = \frac{1}{2} \ln \left( \frac{|p| + p_z}{|p| - p_z} \right)
\]

(z beam axis)
Charged hadron multiplicity

What is the multiplicity of charged hadrons at midrapidity $\eta = y = 0$? (i.e., hadrons emitted at $\theta = 90^\circ$ from the beam)

A number... not so trivial to predict: cf. the range of RHIC predictions... and the measured value (taken from K.Eskola @ QM’01)
Charged hadron multiplicity

Au-Au collisions 0-6% centrality
Charged hadron multiplicity

Au-Au collisions 0-6% centrality

We boost everything to the rest frame of one nucleus ("projectile")

\[ \ln \sqrt{s_{NN}} \]

grows like

universal

"limiting fragmentation"

N.Borghini — 4/29

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Charged hadron multiplicity

Au-Au collisions 0-6% centrality

We boost everything to the rest frame of one nucleus ("projectile")

\[ \ln \sqrt{S_{NN}} \]
grows like

\[ -y_{\text{beam}} \] @ LHC

\[ \eta^* = \eta - y_{\text{beam}} \]

universal

"limiting fragmentation"

Busza 2004; N.B. & Wiedemann 2007

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Charged hadron multiplicity

The naive extrapolation of RHIC data yields \( \frac{dN_{\text{ch}}}{d\eta} \approx 1100 \) at \( \eta = 0 \) with an increase, in opposition to conventional power-law rise.

- Hijing + baryon junctions: 3500
- EPOS (multiple scattering): 2500
- pQCD minijets + saturation (EKRT) of produced gluons: 2570
- AMPT (Hijing+ZPC): \( \approx 2500 \)
- Percolating strings:
  - DMPJET III: \( \approx 1900 \)
  - Pajares et al.: 1500–1600
- 2-component + shadowing: \( \approx 1700 \)

- “Geometric scaling” (Armesto, Salgado, Wiedemann): 1700–1900
- Gluon saturation (Kharzeev, Levin, Nardi 2000–05): 1800–2100
- B–K eq.+ running coupling (Albacete, Kovchegov): \( \approx 1400 \)
- “CGC” (Gelis, Stasto, Venugopalan): \( 1000–1400 \)
- ALCOR (quark–antiquark plasma + recombination): \( 1250–1830 \) = \( \frac{dN_{\text{ch}}}{dy} \)
Charged hadron multiplicity

modified Hijing: Topor Pop et al.

DPMJET III: Bopp, Engel, Ranft, Roesler
Charged hadron multiplicity

B-K+running coupling: Albacete

CGC: Gelis, Stasto, Venugopalan

Extrapolation to 5500 GeV

\( \frac{dN_{ch}}{d\eta} \approx 1000 - 1400 \)

\( \approx 2100 \div 1800 \)

\( \approx 1700 \)

\( \approx 1400 \)

\( \approx 1100 \)
Charged hadron multiplicity

Saturating the saturation scale $Q_s^2$?

\[
\frac{4}{\alpha_s \pi} \frac{d Q_s^2(Y)}{dY} = Q_s^2(Y) - B Q_s^4(Y)
\]

Kharzeev, Levin

(2/N_{part})dN_{AA}/d\eta

$\eta=0$, Centrality 0-6 %

"30% below KLN":

$\approx 1200-1500$
Heavy ion collisions at the LHC

Then our experimental friends will get to know their detectors better and provide us with

the $p_T$-spectra of charged particles

(not much to say... the spectra will be stiffer — “more radial flow” — than at RHIC)

the relative abundances (“chemistry”) of identified hadrons
Hadochemistry

From SIS@GSI energies onwards, the relative abundances of hadrons are well described by a statistical distribution: 2 parameters $T, \mu_B$.
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What with the relative yields of $D$- & $B$-mesons? (canonical suppression?)

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Heavy ion collisions at the LHC

The data from the first year (= month) of Pb-Pb collisions will be sufficient to obtain measurements of the anisotropy in particle emission "anisotropic collective flow"
Anisotropic (collective) flow

Consider a non-central collision:

- anisotropy of the source (in the plane transverse to the beam)
- anisotropic emission of particles

⇒ anisotropic emission of particles

“anisotropic collective flow”

\[
E \frac{dN}{d^3p} \propto \frac{dN}{p_T \, dp_T \, dy} \left[ 1 + 2v_1 \cos (\varphi - \Phi_R) + 2v_2 \cos 2(\varphi - \Phi_R) + \cdots \right]
\]

More particles along the impact parameter \((\varphi - \Phi_R = 0\) or \(180^\circ\)) than perpendicular to it

⇒ “elliptic flow” \(v_2 \equiv \langle \cos 2(\varphi - \Phi_R) \rangle > 0\).

average over particles
Anisotropic (collective) flow

Au-Au collisions, 0-40% centrality
Anisotropic (collective) flow

Au-Au collisions, 0-40% centrality

use “limiting fragmentation” again

N.B. & Wiedemann 2007
Anisotropic (collective) flow

Alternative views: $v_2$ increases linearly with $\ln \sqrt{s_{NN}}$; $v_2 / \epsilon$ (eccentricity) increases linearly with $\frac{1}{S} \frac{dN_{ch}}{dy}$

(midcentral collisions)
Anisotropic (collective) flow

Naive predictions: $v_2$ increases linearly with $\ln \sqrt{s_{NN}}$; $v_2 / \epsilon$ (eccentricity) increases linearly with $\frac{1}{S} \frac{dN^\text{ch}}{dy}$.

- Transport model I (Molnár): $v_2(p_T)$ increases from RHIC to LHC

\[
v_2^{\text{LHC,5500}}(p_T) \approx v_2^{\text{RHIC,200}}(p_T \cdot k)
\]

\[k = \frac{Q_s^{\text{RHIC}}}{Q_s^{\text{LHC}}} \approx 1.5\]

- Transport model II (Ko): $v_2(p_T)$ increases for $\pi^\pm$, decreases for $p$

- Transport model III (Ollitrault): $v_2 / \epsilon$ increases; still 12-20% the hydro limit in central Pb-Pb @ LHC

- Hydro I (Bluhm): $v_2(p_T)$ decreases

- Hydro II (Eskola, Niemi, Ruuskanen): $v_2(p_T)$ increases for pions, decreases for protons

- Hydro III (Heinz): $v_2(p_T)$ decreases for pions; yet the average $v_2$ increases, by at most 20% (less then $\ln \sqrt{s_{NN}}$ -linear rise)
Anisotropic (collective) flow

Eskola, Niemi, Ruuskanen
Heavy ion collisions at the LHC

The next, much expected (due to the increased available phase space) measurements will be that of

spectra at high transverse momentum

(remember, however, that we shall miss a proton-proton reference at the same energy $\sqrt{s_{NN}} = 5.5$ TeV)
High-$p_T$ hadron spectra

Conveniently characterized by the "nuclear modification factor"

$$ R_{AB}^h \equiv \frac{dN_{AB \to h}^{\text{d}}}{dp_T dy} \bigg/ \left( \langle N_{\text{coll}}^{AB} \rangle \frac{dN_{pp \to h}^{\text{d}}}{dp_T dy} \right) $$

average number of inelastic nucleon-nucleon collisions
High-$p_T$ hadron spectra

Conveniently characterized by the “nuclear modification factor”

$$R_{AB}^h \equiv \frac{\frac{dN^{AB\rightarrow h}}{dp_T dy}}{\left(\langle N_{coll}^{AB}\rangle \frac{dN^{pp\rightarrow h}}{dp_T dy}\right)}$$

flat: factor 5 deficit
Conveniently characterized by the “nuclear modification factor”

$$R_{AB}^{h} \equiv \frac{dN_{AB\rightarrow h}}{dp_T dy} \left/ \left( \langle N_{AB}^{\text{coll}} \rangle \frac{dN_{pp\rightarrow h}}{dp_T dy} \right) \right.$$
High-$p_T$ hadron spectra

The picture: while traversing the hot & dense medium, a fast parton loses energy (through collisions & radiation): "jet quenching"

N-N collision

A-A collision

the final spectrum depends on
1. the initial parton spectrum
2. the jet-quenching parameter $\hat{q}$
High-$p_T$ hadron spectra

"Parton quenching model":
Dainese, Loizides, Paic

charged hadrons, $|\eta^h|<2.5$
Pyquen: Lokhtin, Snigirev
High-$p_T$ hadron spectra

Renk

Gyulassy, Lévai, Vitev

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High-$p_T$ hadron spectra

Gyulassy, Wicks et al.
High-$p_T$ hadron spectra

N.B. & Wiedemann 2007

cf. AdS/CFT

coalescence?

$Q^2$ effects?

$\hat{q}_{LHC} \sim 7\hat{q}_{RHIC}$

$\hat{q}_{LHC} \sim 1.25\hat{q}_{RHIC}$
Heavy ion collisions at the LHC

Eventually, after a few years’ data taking, we shall see results on

charmonium & bottomonium
Charmonium & bottomonium

Should we believe Agnes and Péter?

lattice data does not necessarily imply survival of quarkonia
all states except $\Upsilon$ and $\eta_b$ are dissolved by $1.2 \, T_c$

Dissociation condition:
thermal width $> 2$ binding energy
upper limits

<table>
<thead>
<tr>
<th>J/$\psi$</th>
<th>$\Upsilon$</th>
<th>$\chi_b$</th>
<th>$\Upsilon$</th>
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<td>$1.2 , T_c$</td>
<td>$1.2 , T_c$</td>
<td>$1.3 , T_c$</td>
<td>$2 , T_c$</td>
</tr>
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Upsilon suppressed at LHC
but less suppressed at RHIC

Threshold is enhanced over free propagation
$\Rightarrow$ correlations between Q-Qbar may remain strong
regeneration from primordially correlated, not independent Q-Qbar

Mócsy, Petreczky
Charmonium & bottomonium

Shall we have suppression of the $J/\psi$?
Charmonium & bottomonium

... or an enhancement of the $J/\psi$?

Andronic, Braun-Munzinger, Redlich, Stachel
Heavy ion collisions at the LHC

Sorry for the omitted topics...

- “femtoscopy”: various predictions of the “HBT radius parameters”, within transport (Ko), hydro (Heinz), and mixed (Bass, Sinyukov) models

- fluctuations: of baryon number & strangeness (Karsch), of charge density (Redlich), or of abundance ratios (Torrieri)

- jets: beyond the leading particle, away from midrapidity, response of the traversed medium... see session 6!

- electromagnetic/weak probes: photons (Arleo, d’Enterria; Fries; Rezaeian; Sinha), dileptons (Fries; Sinha; van Hees); no $Z^0$ talk

- “exotica”: black holes (Sarcevic; Stöcker), pentaquarks (Lee)

- predictions for p-Pb collisions (Iancu, Jalilian-Marian, Kopeliovich, Kozlov, Tuchin, Wessels)
The end

Many thanks...

to Urs Wiedemann (for our lasting correlation)

to Néstor Armesto, Sangyong Jeon, & Urs (again) for the fun we had

and to the many theorists / phenomenologists / experimentalists who dared make predictions

and to you, for your patience!