Particle production sources in heavy-ion collisions at RHIC and LHC

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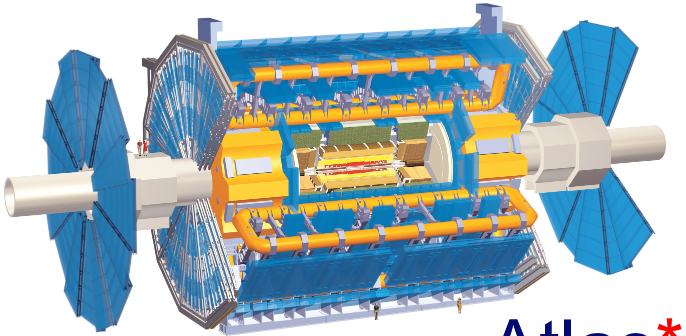
Topics

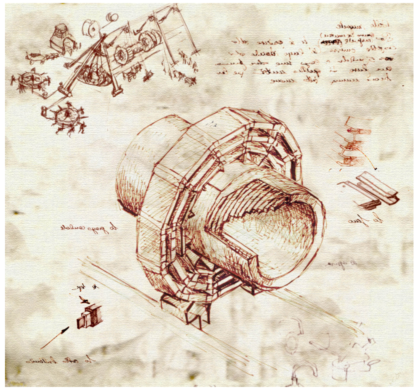
1. Introduction: PbPb @ LHC
2. Relativistic Diffusion Model (RDM)
3. Comparison with RHIC and LHC data
4. Conclusion

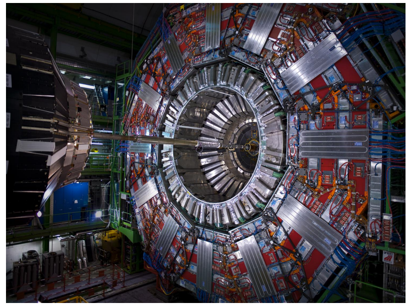
1. LHC Detectors for RHIs



Atlas*

≈ 25 HI people

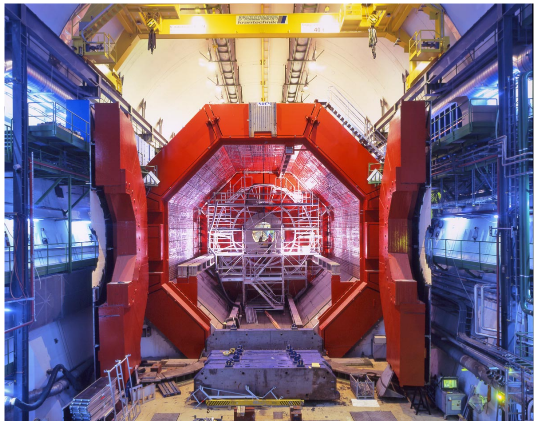


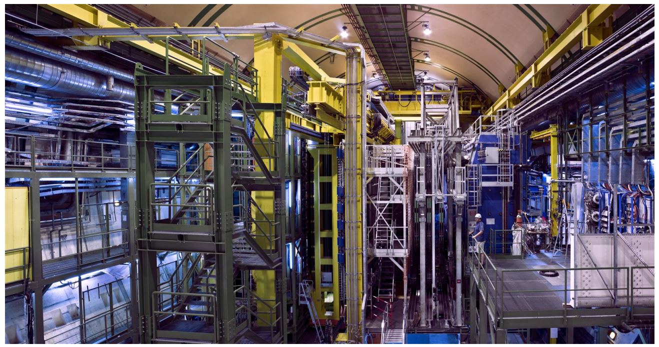


CMS*

da Vinci style

≈ 60 HI people





LHCb

No HI people yet

Alice*: L3 magnet

≈ 1,000 HI people

* heavy-ion capability

2. Particle production: Relativistic Diffusion Model (RDM)

$$\frac{\partial}{\partial t}R(y,t) = -\frac{\partial}{\partial y}\Big[J(y)R(y,t)\Big] + D_y \frac{\partial^2}{\partial y^2}[R(y,t)]^{2-q}$$

R (y,t) Rapidity distribution function. The standard linear Fokker-Planck equation corresponds to q = 1, and a linear drift function. For the three components k = 1,2,3 of the rapidity distribution,

$$\frac{\partial}{\partial t}R_k(y,t) = -\frac{1}{\tau_y}\frac{\partial}{\partial y}\Big[(y_{eq}-y)\cdot R_k(y,t)\Big] + D_y^k \frac{\partial^2}{\partial y^2}R_k(y,t)$$

Linear drift term with relaxation time τ_y Diffusion term, D_y=const.

Relaxation time and diffusion coefficient are related through a dissipation-fluctuation theorem. The broadening is enhanced due to collective expansion.

$$< y_{1,2}(t) >= y_{eq}[1-\exp(-t/\tau_y)] \mp y_{max}\exp(-t/\tau_y)$$ mean value

$$\sigma^2_{1,2,eq}(t) = D_y^{1,2,eq}\tau_y[1-\exp(-2t/\tau_y)]$$ variance

Linear Model: G. Wolschin, Eur. Phys. J. A5, 85 (1999); with 3 sources: Phys. Lett. B 569, 67 (2003); PLB 698, 411 (2011); M. Biyajima, M. Ide, M. Kaneyama, T. Mizoguchi, and N. Suzuki, Prog. Theor. Phys. Suppl. 153, 344 (2004)

Equilibrium value of the rapidity determined from
energy and momentum conservation as

$$y_{eq}(b) = -0.5 \cdot \ln \frac{\langle m_1^T(b)\rangle \exp(y_{max}) + \langle m_2^T(b)\rangle \exp(-y_{max})}{\langle m_2^T(b)\rangle \exp(y_{max}) + \langle m_1^T(b)\rangle \exp(-y_{max})}$$

with transverse masses

$$\langle m_{1,2}^T(b)\rangle = \sqrt{m_{1,2}^2(b) + \langle p_T\rangle^2}$$

For large beam rapidities (LHC) this reduces to

$$y_{eq}(b) \simeq 0.5 \cdot \ln \frac{\langle m_2^T(b)\rangle}{\langle m_1^T(b)\rangle}$$

And the impact-parameter dependent numbers of participants can be determined from
the geometric overlap, or the Glauber model.

Diffusion of produced particles in pseudorapidity space

Pseudorapidity distributions of produced particles are obtained through the Jacobian transformation

$$\frac{dN}{d\eta} = \frac{dN}{dy}\frac{dy}{d\eta} = \frac{p}{E}\frac{dN}{dy} \simeq J(\eta, \langle m\rangle/\langle p_T\rangle)\frac{dN}{dy}$$

$$J(\eta, \langle m\rangle/\langle p_T\rangle) = \cosh(\eta)\cdot [1 + (\langle m\rangle/\langle p_T\rangle)^2 + \sinh^2(\eta)]^{-1/2}.$$

Use $\langle m \rangle = m_\pi$ and determine $\langle p_T \rangle$ as in D. Roehrscheid and GW, PRC C 86, 024902 (2012)

with the rapidity distribution in the three-sources model

$$\frac{dN_{ch}(y, t=\tau_{int})}{dy} = N_{ch}^1 R_1(y, \tau_{int}) + N_{ch}^2 R_2(y, \tau_{int}) + N_{ch}^{eq} R_{eq}(y, \tau_{int}).$$

and the rapidity

$$y = 0.5 \cdot \ln((E+p)/(E-p))$$

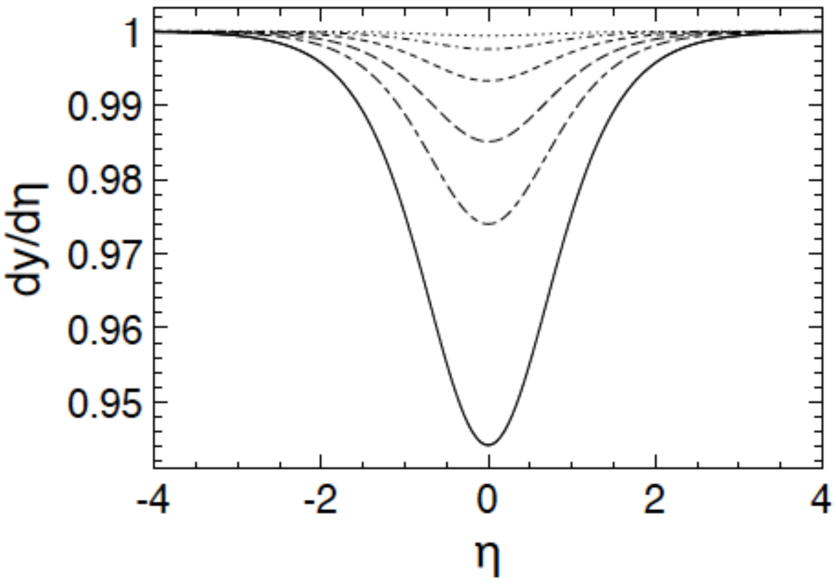
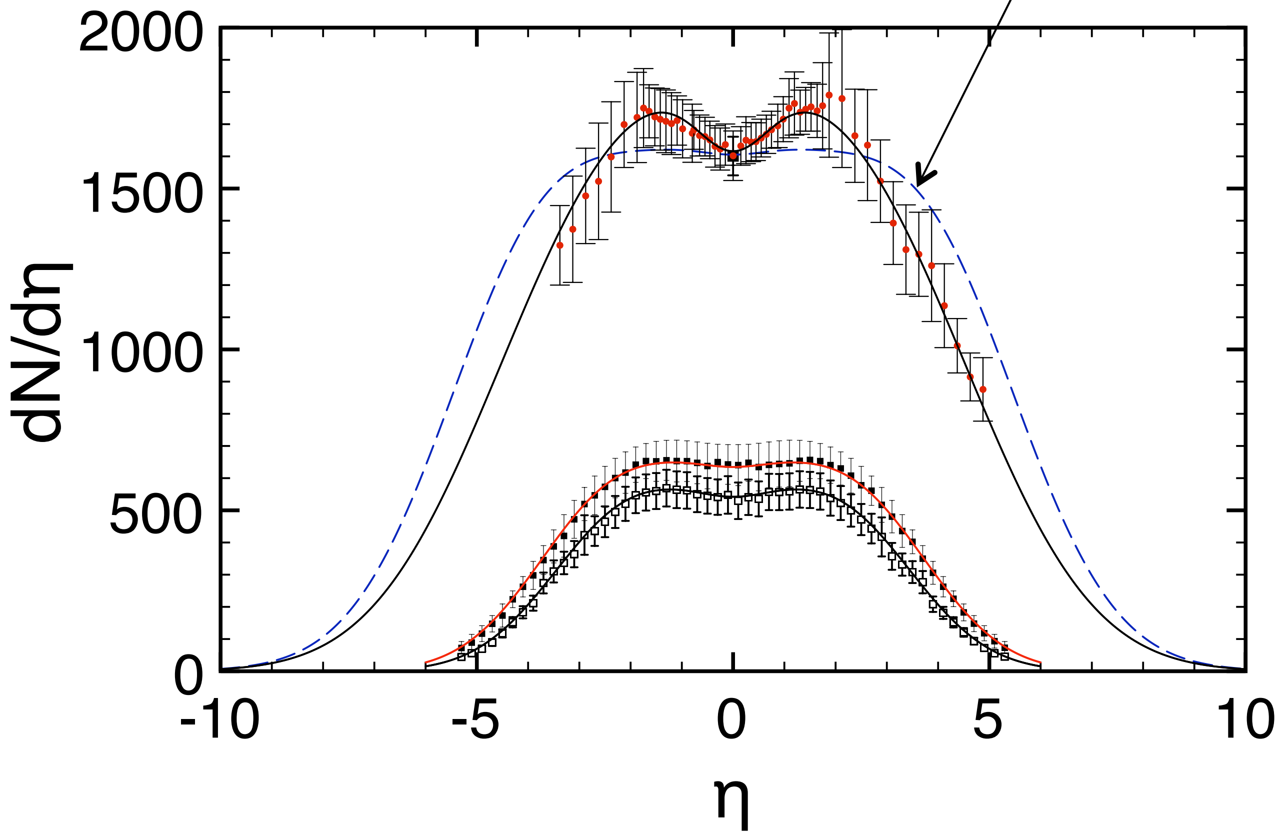


Figure 1: The Jacobian $dy/d\eta$ for $< m >= m_\pi$ and average transverse momenta (bottom to top) $< p_T >= 0.4, 0.6, 0.8, 1.2, 2$ and 4 GeV/c.

3. Comparison with the RDM prediction

Central PbPb @ 2.76 TeV

Prediction GW in PLB 698, 411 (2011)

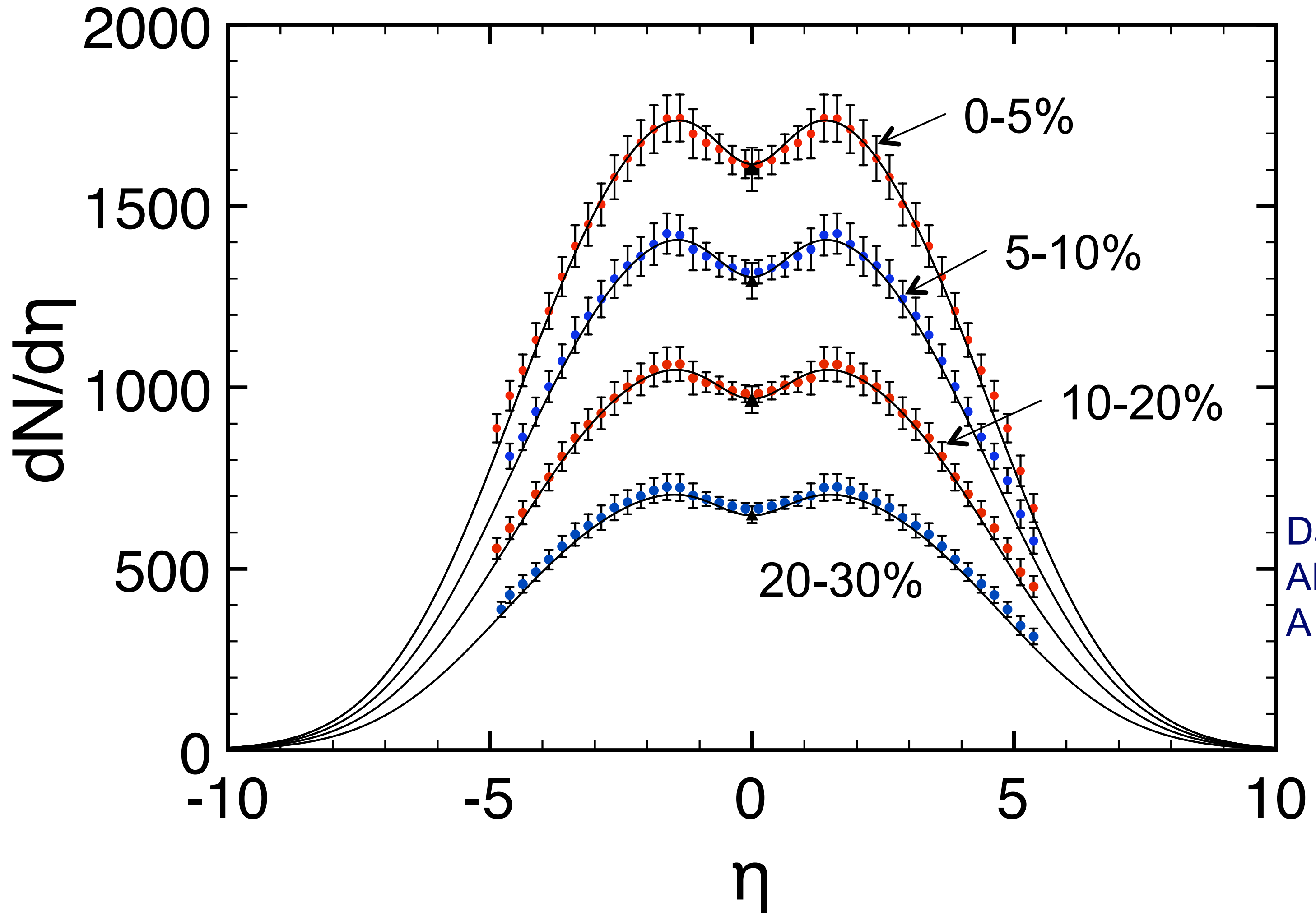


GW, J. Phys. G40, 045104 (2013)

Prel. ALICE data (2012)
(QM Annecy)

RDM χ^2 fits to LHC/ALICE results for 2.76 TeV PbPb

GW, J. Phys. G40, 045104 (2013)



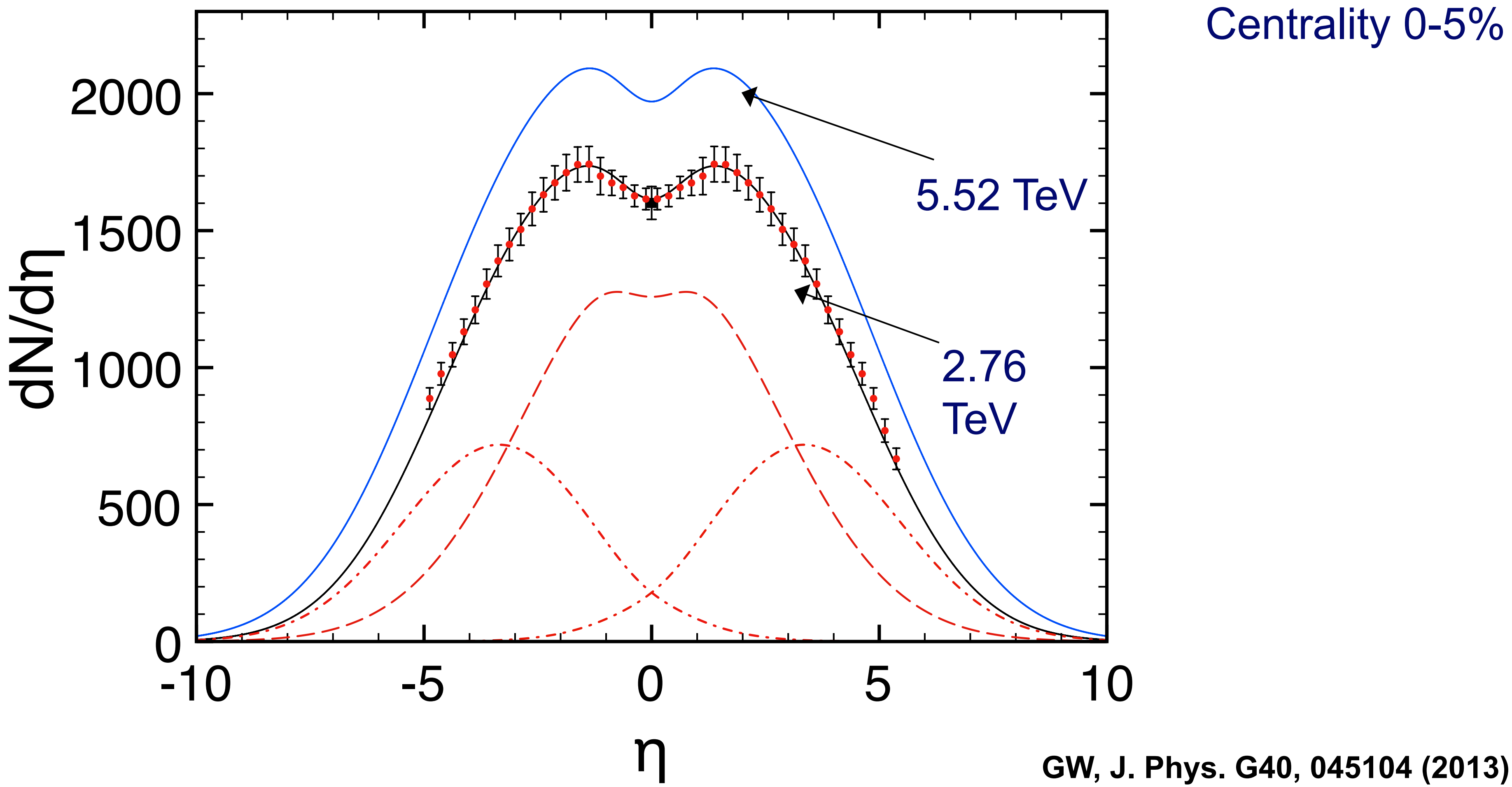
Data: M. Guilbaud et al., ALICE Coll., Nucl. Phys. A 904-905, 381c (2013)

Parameters of the 3-sources RDM at RHIC and LHC energies

Table 1. Three-sources RDM-parameters τ_{int}/τ_y, $\Gamma_{1,2}, \Gamma_{gg}$, and N_{gg}. N_{ch}^{1+2} is the total charged-particle number in the fragmentation sources, N_{gg} the number of charged particles produced in the central source. Results for $< y_{1,2} >$ are calculated from y_{beam} and τ_{int}/τ_y. Values are shown for 0–5% PbPb at LHC energies of 2.76 and 5.52 TeV in the lower two lines, with results at 2.76 TeV from a χ^2-minimization with respect to the preliminary ALICE data [2], and using limited fragmentation as constraint. Corresponding parameters for 0–6% AuAu at RHIC energies are given for comparison in the upper four lines based on PHOBOS results [1]. Parameters at 5.52 TeV denoted by * are extrapolated. Experimental midrapidity values (last column) are from PHOBOS [1] for $|\eta| < 1$, 0-6% at RHIC energies and from ALICE [13] for $|\eta| < 0.5$, 0-5% at 2.76 TeV.

$\sqrt{s_{NN}}$ (TeV)	y_{beam}	τ_{int}/τ_y	$< y_{1,2} >$	$\Gamma_{1,2}$	Γ_{gg}	N_{ch}^{1+2}	N_{gg}	$\frac{dN}{d\eta}\|_{\eta\simeq0}$
0.019	$\mp$3.04	0.97	$\mp$1.16	2.83	0	1704	-	314±23[1]
0.062	$\mp$4.20	0.89	$\mp$1.72	3.24	2.05	2793	210	463±34[1]
0.13	$\mp$4.93	0.89	$\mp$2.02	3.43	2.46	3826	572	579±23[1]
0.20	$\mp$5.36	0.82	$\mp$2.40	3.48	3.28	3933	1382	655±49 [1]
2.76	$\mp$7.99	0.87	$\mp$3.34	4.99	6.24	7624	9703	1601±60 [13]
5.52	$\mp$8.68	0.85*	$\mp$3.70	5.16*	7.21*	8889*	13903*	1940*

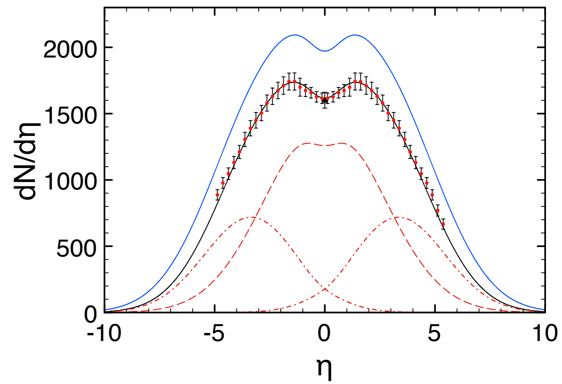
3 sources, and prediction for 5.52 TeV PbPb

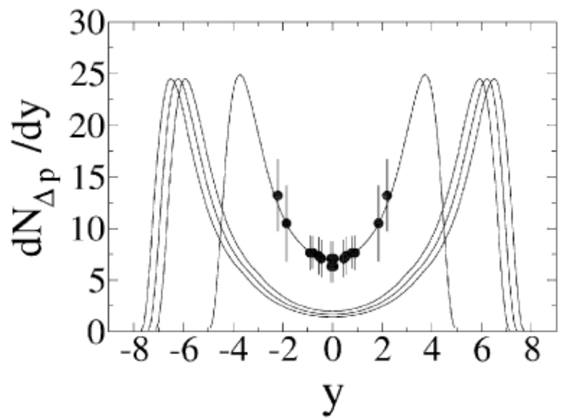


GW, J. Phys. G40, 045104 (2013)

LHC: Small fragmentation-source contributions at midrapidity

Charged hadrons





Net protons

PbPb @ 2.76 TeV:

The smallness of the fragmentation sources at midrapidity is in qualitative agreement with results from our QCD-based microscopic model

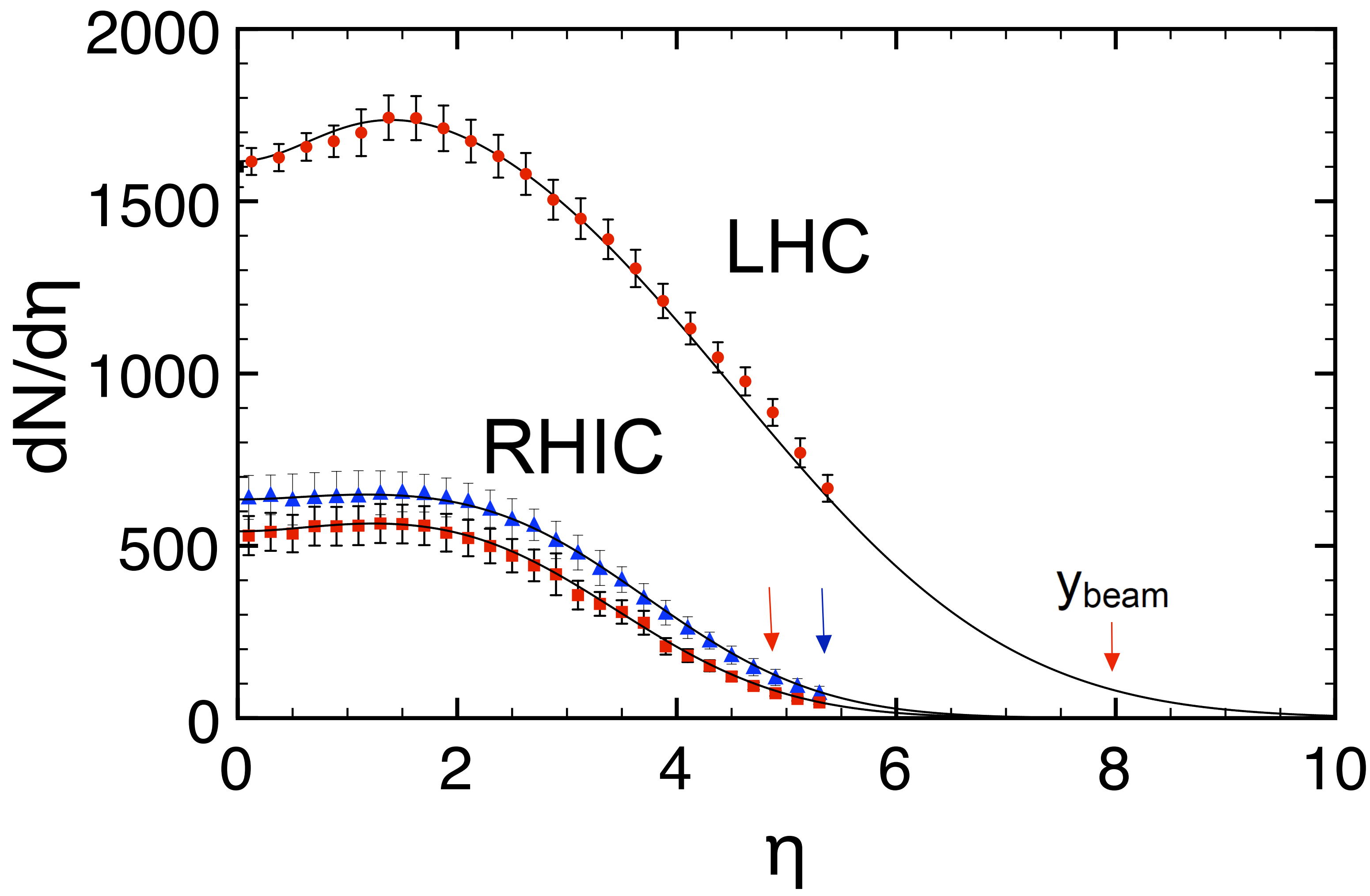
Y. Mehtar-Tani and GW, Phys. Rev. Lett. 102,182301 (2009); PRC C80, 054905 (2009)

for net-baryon distributions, which indicates a midrapidity net-baryon yield dN/dy(y=0) ≈ 4, corresponding to 12 valence quarks, as cp. to 1248 valence quarks in the system (the net-baryon distribution has no gluon-gluon source)

YMT&GW, Phys. Lett. B688, 174 (2010);
GW, Phys. Lett. B 698, 411 (2011)

Cross section contributions beyond the beam rapidity

Charged hadrons

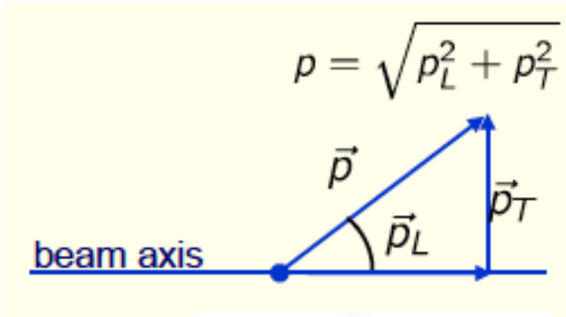


Cross section contributions beyond the beam rapidity

The relation between rapidity $y = \frac{1}{2} \ln \frac{1+\beta_{||}}{1-\beta_{||}}$

and pseudorapidity $\eta = -\ln\left(\tan(\theta/2)\right)$

is given by $y = \frac{1}{2} \ln \frac{\sqrt{(m/p_T)^2 + \cosh^2 y} + \sinh \eta}{\sqrt{(m/p_T)^2 + \cosh^2 y} - \sinh \eta}$



$$\beta_{||} = \frac{\exp(2y) - 1}{\exp(2y) + 1}$$

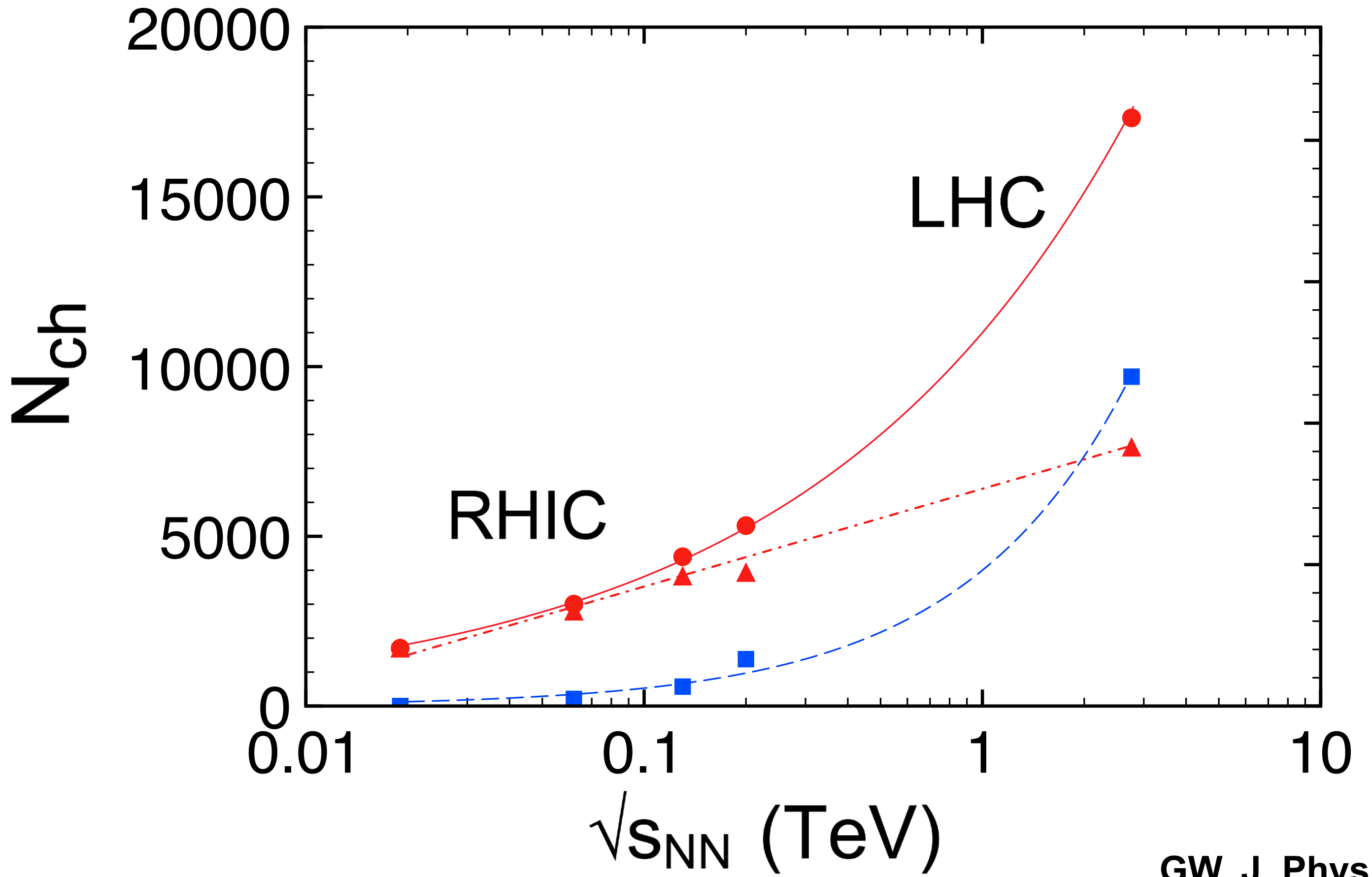
which has the limits (1st order expansion)

$$y \to \eta - \ln(m/p_T) \text{ for } m << p_T$$

$$y \to \eta \text{ for } p_T << m$$

About 83% of produced charged hadrons at LHC energies are pions, and for pions the limit $\eta \approx y$ is reached at larger values of η than for protons.

Content of the sources as function of energy



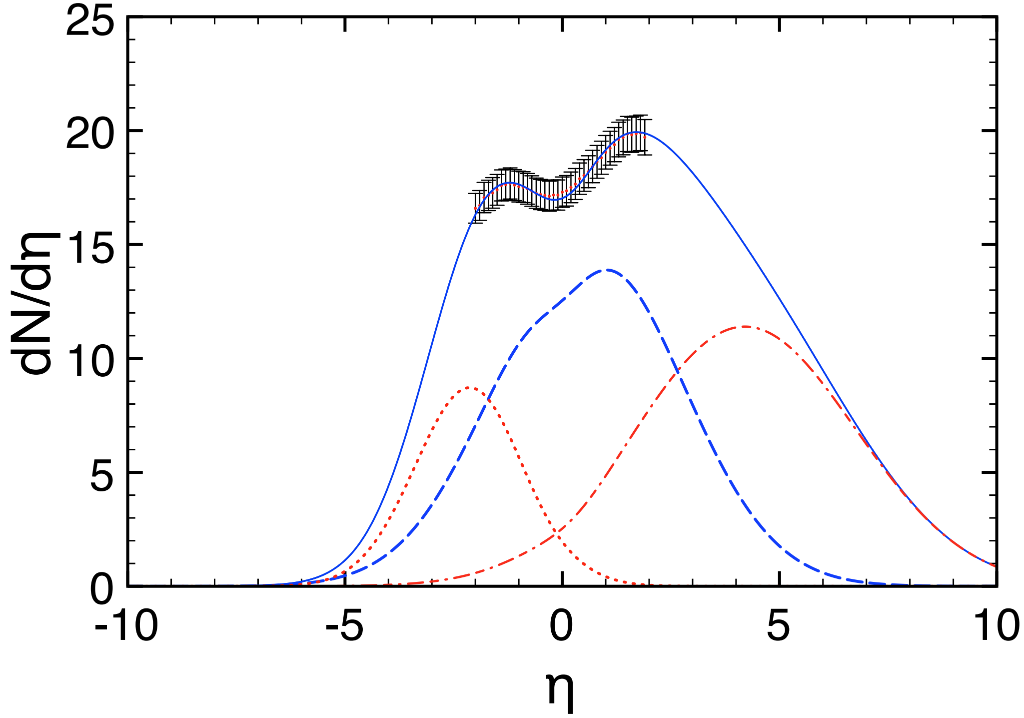
Centrality 0-5%

(RHIC 0-6%)

GW, J. Phys. G40, 045104 (2013)

3-sources model (RDM): central pPb @ 5.02 TeV

Min.bias 5.02 TeV pPb @ LHC



p_p= = 4 TeV/c

$$\sqrt{s_{NN}} = \sqrt{\frac{Z_1 * Z_2}{(A_1 * A_2)}} * 2p_p = 5.02\mathrm{TeV}$$

$$y_{\mathrm{beam}}^{cm} = \mp \ln(\sqrt{s_{NN}}/m_0) = \mp 8.586$$

Data. ALICE collab., PRL 110, 032301 (2013)

Calculation: GW, J. Phys. G40, 045104 (2013)

TOPIC FOR A MASTER THESIS

4. Conclusion

- Charged-hadron production at RHIC and LHC energies has been described in a Relativistic Diffusion Model (RDM).

- Predictions of pseudorapidity distributions $dN/d\eta$ of produced charged hadrons in the 3-sources RDM at LHC energies rely on the extrapolation of the diffusion-model parameters with $\ln(\sqrt{s_{NN}})$

- In agreement with a QCD-based microscopic model, the contribution of the fragmentation sources from quark-gluon collisions at LHC energies is very small at midrapidity, but substantial at larger values of pseudorapidity η.

- **The centrality dependence** of the three sources has been investigated in direct comparison with the preliminary **ALICE data.**