Baryon stopping and gluon saturation in heavy-ion collisions at LHC energies

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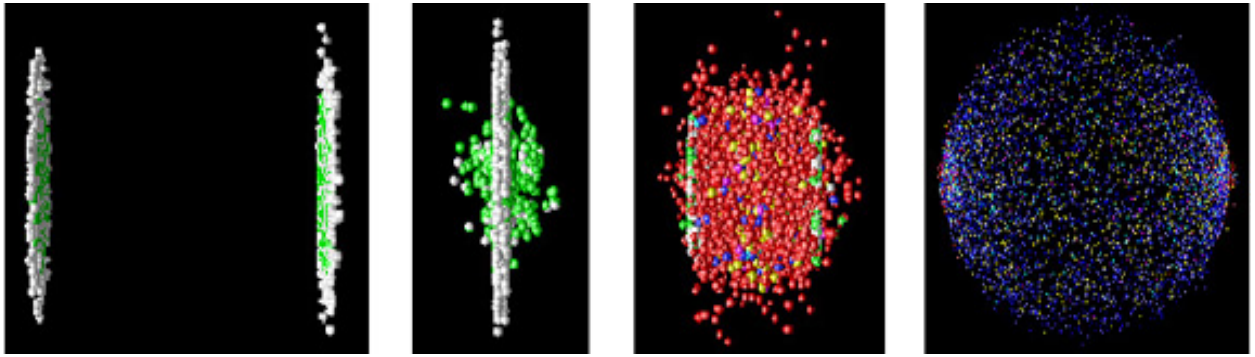
Topics

1. Introduction: Gluon saturation in ep and AA collisions
2. Net-baryon* distributions in a QCD-based approach at forward rapidities y
3. Search for the parton-hadron transition in net protons
4. Conclusion and Outlook

* baryon minus antibaryon

1. Intro: Net baryons and gluon saturation

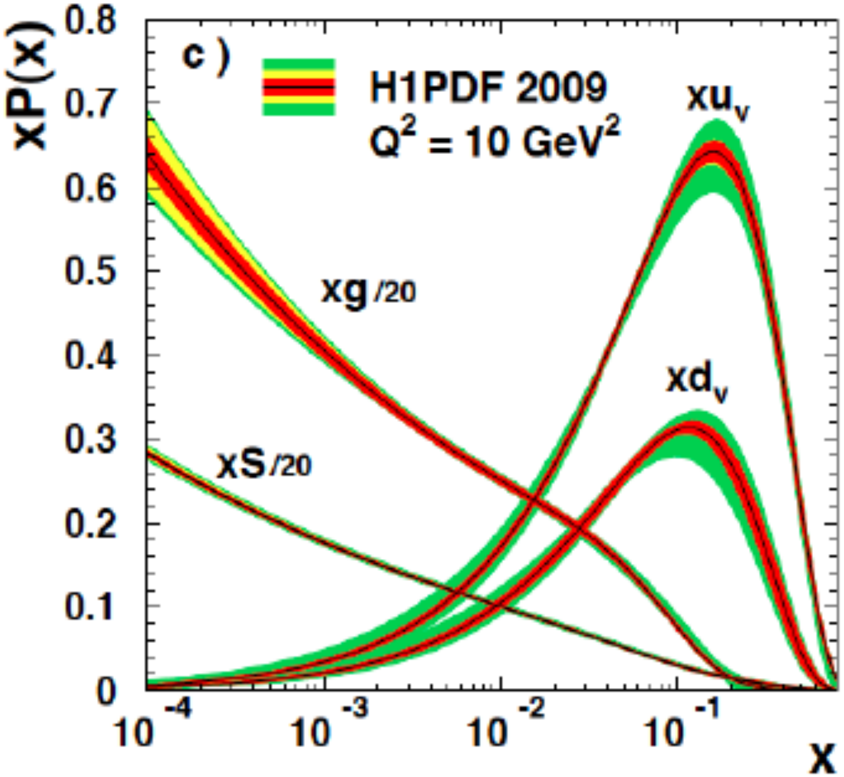


Artwork: UFRA

At RHIC (≤ 0.2 TeV) and LHC (≤ 5.52 TeV) energies, initially a state of very high gluon density is formed, which transforms into a strongly coupled quark-gluon plasma, and then hadronizes after $\approx 10^{-23}$ s into mesons and baryons:

Search for signatures of the initial Gluon Condensate in net-baryon distribution functions at forward rapidities.

QCD: Gluon structure fcts



Structure functions (pdfs) from e + p deep inelastic scattering (DIS) at HERA (DESY) where $x = Q^2/s$

See also: The H1 and ZEUS Collaborations, JHEP 1001, 109 (2010)

- Gluon structure functions grow with increasing Q and 1/x: At small x and high energy, gluons dominate the dynamics.

- The gluon distribution should saturate at very small x due to the non-linear contributions in the evolution equations; saturation momentum Q_s

Geometric scaling at HERA: e + p collisions

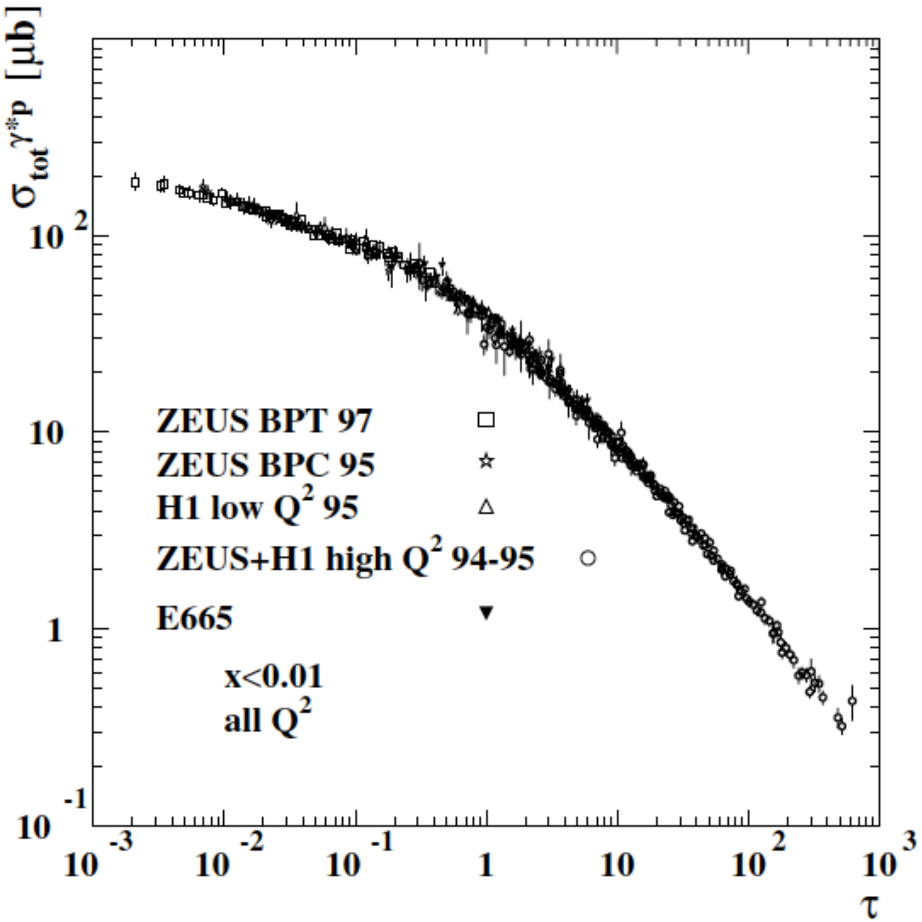


FIG. 1. Experimental data on $\sigma_{\gamma^* p}$ from the region $x < 0.01$ plotted versus the scaling variable $\tau = Q^2 R_0^2(x)$.

- DIS cross-section is a function of the scaling variable

$$\tau = Q^2/Q_s^2(x)$$

$$Q_s^2(x) \sim x^{-\lambda}; \lambda \sim 0.3$$

The saturation scale from the data is consistent with theoretical results.

Saturation effects scale with $A^{1/3}$ and hence, should be more pronounced in nuclei and in particular, in relativistic heavy-ion collisions.

Stasto, Golec-Biernat, Kwiecinski, PRL 86, 596 (2001)

2. Microscopic formulation of baryon transport for RHIC, LHC physics

- The net-baryon transport occurs through valence quarks:
- Fast valence quarks in one nucleus scatter in the other nucleus by exchanging soft gluons, and are redistributed in rapidity space.
- The valence quark parton distribution is well known at large x, which corresponds to the forward (and backward) rapidity region, and it can be used to access the small-x gluon distribution in the target.

Y. Mehtar-Tani and GW, Phys. Rev. Lett. 102,182301 (2009);
Phys. Rev. C80, 054905 (2009);
Phys. Lett. B688, 174 (2010).

The differential cross-section for valence quark production with rapidity y and transverse momentum p_T in a high-energy heavy-ion collision is

$$\frac{dN}{d^2p_T dy} = \frac{1}{(2\pi)^2} \frac{1}{p_T^2} x_1 q_v(x_1, Q_f)\, \varphi(x_2, p_T)$$

The contribution of the valence quarks in the forward moving nucleus to the rapidity distribution of hadrons is then (integration over p_T):

$$\frac{dN}{dy} = \frac{C}{(2\pi)^2} \int \frac{d^2p_T}{p_T^2} x_1 q_v(x_1, Q_f)\, \varphi(x_2, p_T)$$

Valence quarks

Gluons

Where the transverse momentum transfer is p_T,

the longitudinal momentum fraction carried by the valence quark is $x_1 = p_T/\sqrt{s}\exp(y)$

and the soft gluon in the target carries $x_2 = p_T/\sqrt{s}\exp(-y)$.

Relativistic heavy-ion collisions

As in deep inelastic scattering, geometric scaling is expected:

The gluon distribution depends on x and p_T only through the scaling variable $p_T^2/Q_s^2(x)$ with the saturation scale

$$Q_s^2(x) = A^{1/3} Q_0^2 x^{-\lambda}$$

where $\lambda \approx 0.1 - 0.3$ (fit value in DIS at HERA is $\lambda \approx 0.3$ in agreement with next-to-leading order BFKL result).

Test this in comparison with SPS, RHIC and LHC data.

Perform a change of variables

$$x \equiv x_1, \quad x_2 \equiv x\, e^{-2y}, \quad p_T^2 \equiv x^2 s\, e^{-2y}$$

then the rapidity distribution can be written as a function of a single scaling variable τ

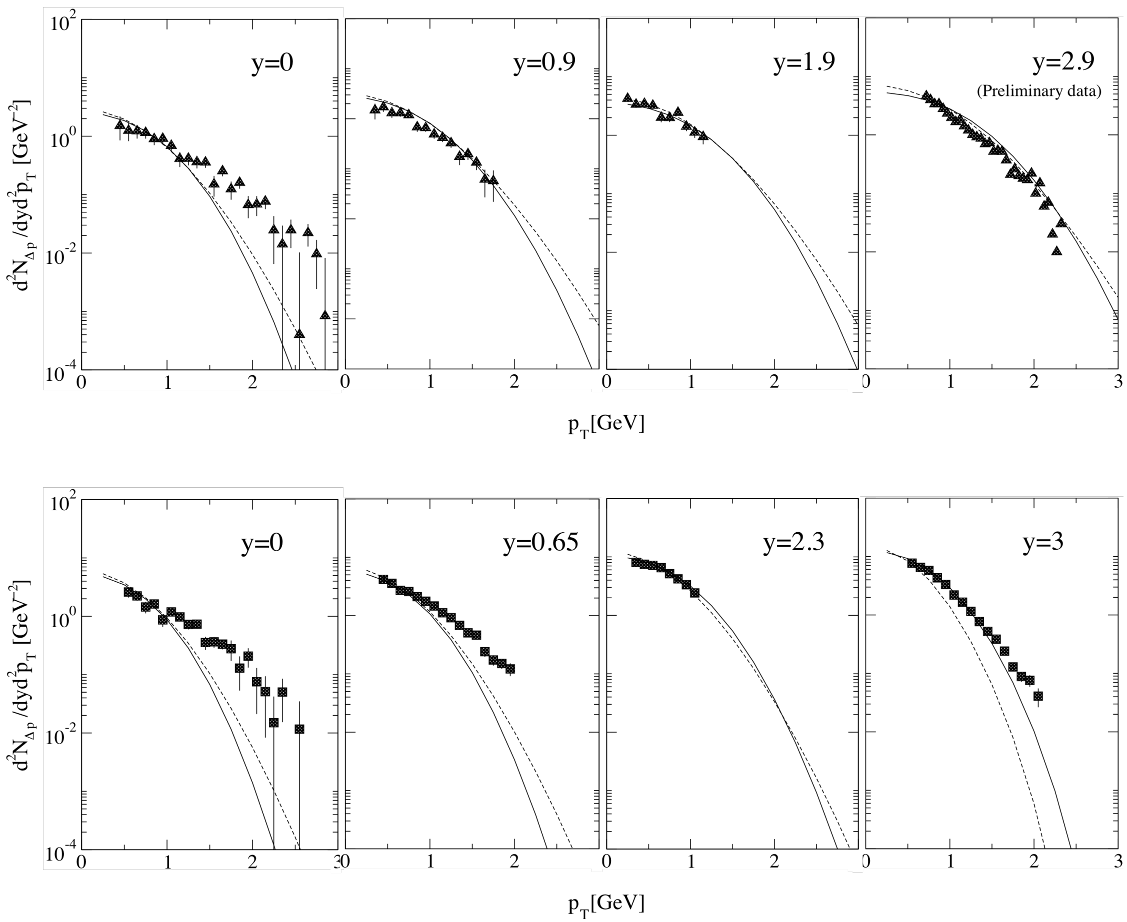
$$\tau = \ln(s/Q_0^2) - \ln A^{1/3} - 2(1+\lambda)y$$

$$\frac{dN}{dy}(\tau) = \frac{C}{2\pi}\int_0^1 \frac{dx}{x}\, x q_v(x)\, \varphi(x^{2+\lambda}e^{\tau}).$$

For sufficiently large values of x, or the corresponding rapidity, the net-baryon rapidity distribution is a function of a **single** variable that relates the energy (s) dependence to the rapidity (y) and mass number (A) dependence.

There are 3 parameters: C, λ, Q_0.

Net-baryon transverse momentum distributions at RHIC energies



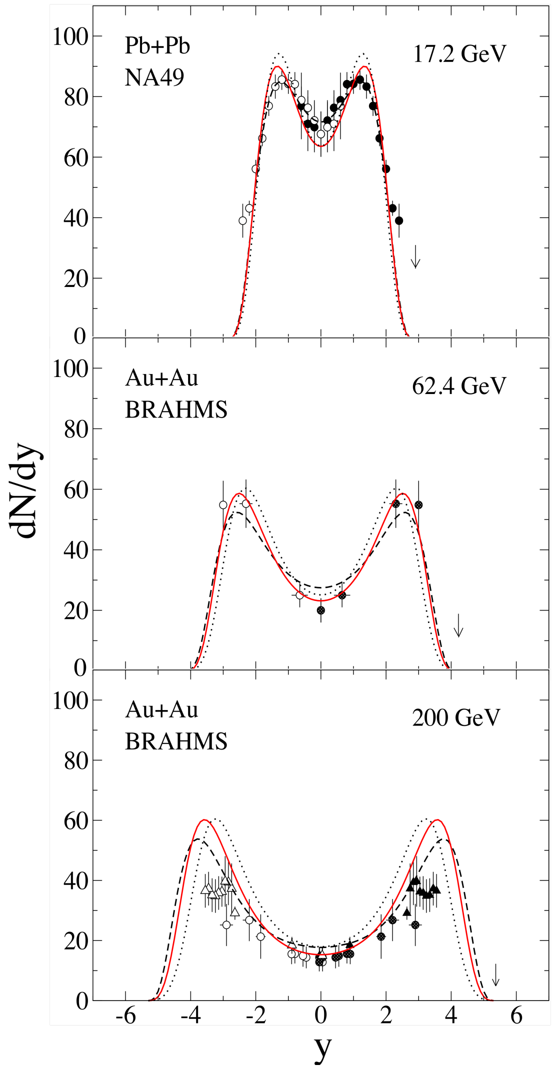
200 GeV (top) and 62.4 GeV (bottom) Au+Au (RHIC) at various rapidities in comparison with BRAHMS data.

Solid curves: Q_0^2 = 0.04 GeV^2, λ=0.2, without fragmentation functions.

Dashed curves: With fragmentation function, Q_0^2 = 0.1 GeV^2.

Y. Mehtar-Tani and GW, Phys. Rev. C80, 054905 (2009)

Net-baryon rapidity distributions at SPS, RHIC, and LHC



- Central (0-5%) Pb+Pb (SPS) and Au+Au (RHIC) Collisions

- Dashed black curves: Q_0^2 = 0.08 GeV^2 , λ=0
  Solid red curves: Q_0^2 = 0.07 GeV^2, λ=0.15
  Dotted black curves: Q_0^2 = 0.06 GeV^2, λ=0.3

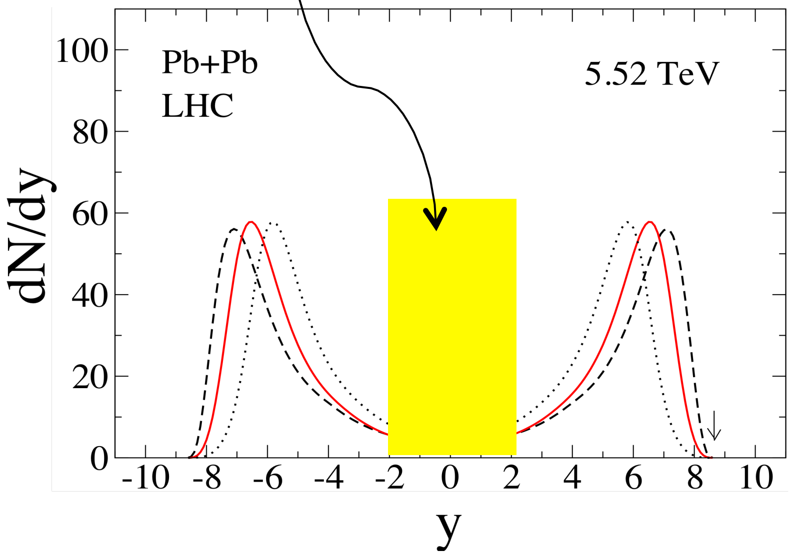
- A larger gluon saturation scale produces more baryon stopping, as does a larger value of A.

- The saturation scale is $Q_s^2(x) = A^{1/3} Q_0^2 x^{-\lambda}$

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

Net-baryon rapidity distributions at LHC: prediction

Particle identification region in ALICE

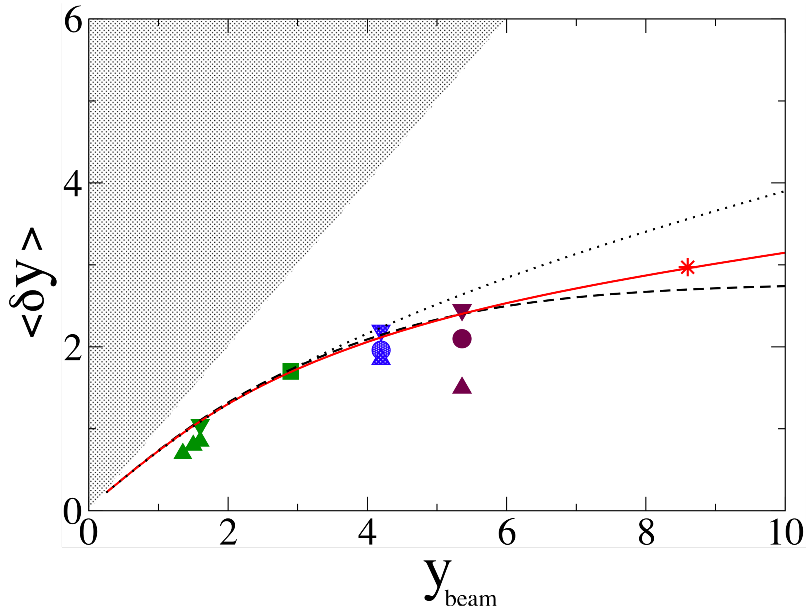


$x_1 = 2\cdot10^{-4}$ $9\cdot10^{-3}$ 1

- Central (0-5%) Pb+Pb collisions, $y_{beam} = 8.68$
- Dashed black curve: λ= 0
  Solid red curve: λ = 0.15
  Dotted black curve: λ= 0.3
- The midrapidity value of the net-baryon distribution is small, but finite: dN/dy (y = 0) ≈ 4. The **total yield** is normalized to the number of baryon participants, $N_B \approx 357$.
- A larger gluon saturation scale produces more baryon stopping; the fragmentation peak position is sensitive to λ

Forward rapidity measurements with PID highly desirable

Mean rapidity loss: from AGS to LHC



Dotted black curve: λ=0.3
Solid red curve: λ=0.2
Dashed black curve: λ=0
(no x-dependence: the mean rapidity loss reaches a limit at large beam rapidities)

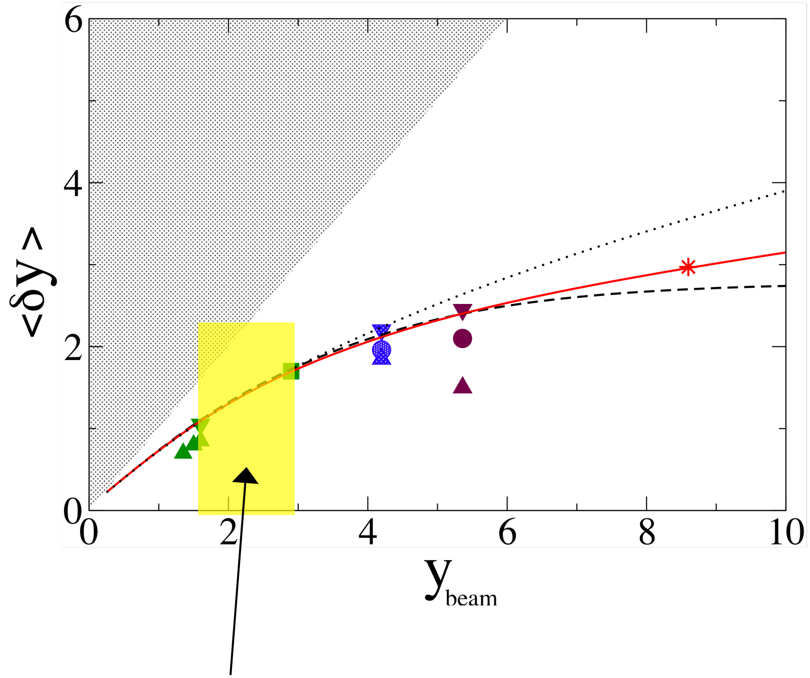
red star: theoretical prediction for LHC

Hence, the value of λ could be determined in heavy-ion collisions at large energies (beam rapidities) above RHIC energies from the mean rapidity loss, or the peak position.

62.4 GeV and 200 GeV RHIC data are from BRAHMS, Phys. Lett. B 677, 267 (2009). 17.3 GeV SPS data are from NA49, low-energy data from AGS.

Y. Mehtar-Tani and G.Wolschin, Phys. Rev. Lett. 102,182301 (2009).

3. The expected deconfinement region at SPS energies in net protons



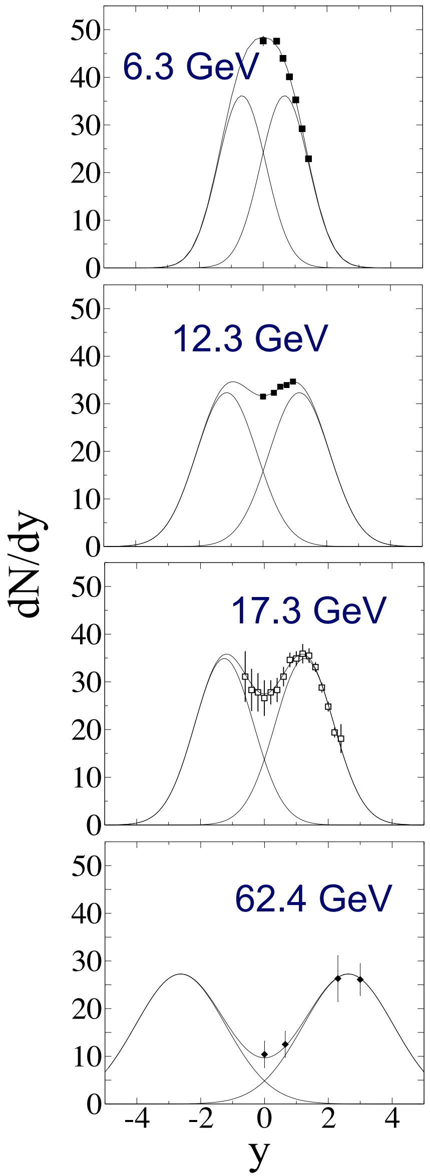
Solid red curve: λ=0.2

red star: theoretical prediction for LHC

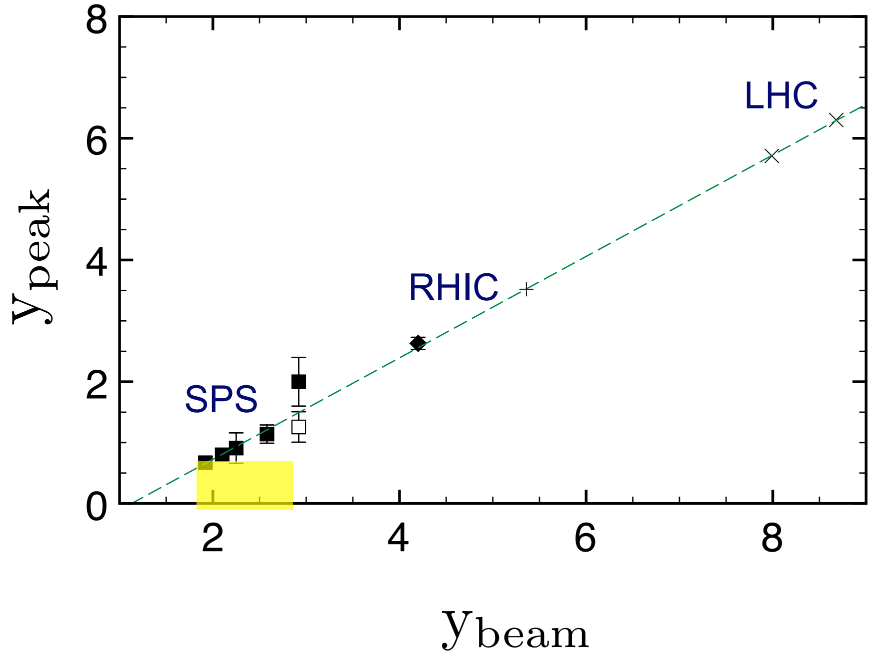
62.4 GeV and 200 GeV RHIC data are from BRAHMS, Phys. Lett. B 677, 267 (2009). 17.3 GeV SPS data are from NA49, low-energy data from AGS.

Expected deconfinement region (≈ 6 – 17 GeV)
hadrons-partons: Are there signatures in the net-baryon data?

SPS/RHIC net proton data



Investigate the peak position of the net-proton distribution as function of sqrt(s_NN), or y_beam with emphasis on the expected deconfinement region (from double-gaussian fits).
Expected transition region hadrons-partons: 6-17 GeV.



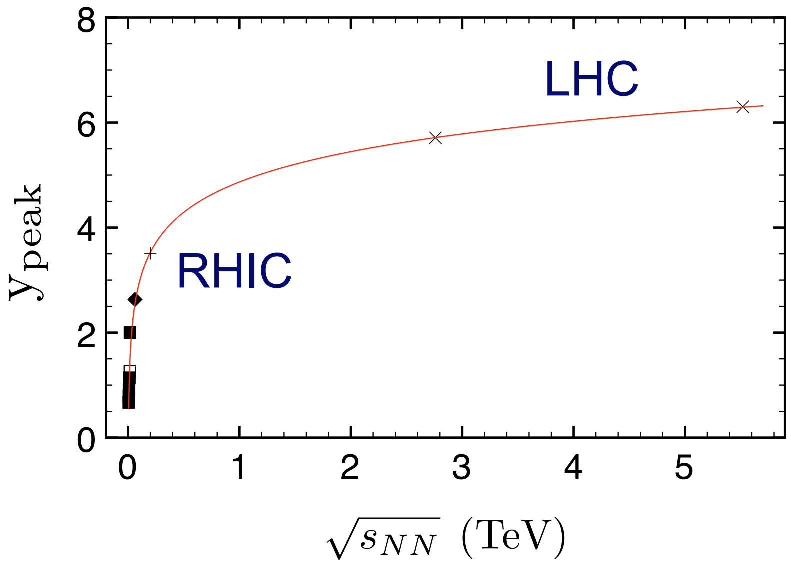
□ NA49 PRL 82, 2471 (1999)

■ NA49 2010 (C. Blume et al.)
62.4 GeV BRAHMS, PLB 677, 267 (2009)

$$y_p = 1/(1+\lambda)(y_b - \ln(A^{1/6}))$$

Y. Mehtar-Tani and GW
Europhys. Lett. 94, 62004 (2011)

Compare with partonic calculation



$$y_p = 1/(1+\lambda)(y_b - \ln(A^{1/6}))$$

Investigate the peak position of the net-proton distribution as function of sqrt(s_NN), or y_beam with emphasis on the expected deconfinement region

62.4 GeV RHIC data are from BRAHMS, Phys. Lett. B 677, 267 (2009).
6.3 - 17.3 GeV SPS data are from NA49 (priv. comm. C. Blume).

No evidence for the parton-hadron transition from SPS net-proton data in comparison with the partonic calculation:

Need other observables that are closer to equilibrium such as produced ϕ−mesons as cross-over signatures.

□ NA49 PRL 82, 2471 (1999)

■ NA49 2010 (C. Blume et al.)

5. Conclusion

- In a QCD-based microscopic model, we have calculated the net-baryon transverse momentum and rapidity distributions for heavy systems at RHIC and LHC energies.

- LHC: The model allows (in principle) to determine the gluon saturation scale from data on the mean rapidity loss, or from the position of the fragmentation peaks of net-baryon distributions in future forward-physics experiments.

- Midrapidity Pb + Pb results at LHC energies have been obtained in the microscopic model, and will be compared to net-proton (and net-kaon) data in 2011/12.

- No signatures for deconfinement at SPS energies are found in the net-proton results: need observables closer to equilibrium.