Antibaryon to Baryon Production Ratios in Pb-Pb and p-p collision at LHC energies using the DPMJET-III Monte Carlo

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What is the Aim of the Talk?

LHC predictions for *pp* and *PbPb*
within framework of our ***multichain Monte Carlo DPMJET-III***
based on an analysis of RHIC data

For our general LHC prediction we refer to Ranft's CERN talk.

Here the focus is on a particular aspect: **baryon stopping.**
A sizable component of stopped baryons is predicted.

There are different components to baryon stopping.
Our interest here is the component **without leading quarks**
where the actual baryon transport is a color effect determining
the ***orientation of the color-compensation*** by $q\bar{q}$ chains.

Baryon Exchange Historically?

The baryon exchange phenomenology was developed 30 years ago. Critical are various baryonium Regge intercepts

$$\alpha^0_{Barionium}, \ \alpha^1_{Barionium}, \ \text{or} \quad \alpha^2_{Barionium}$$

which determine the slope of the corresponding inclusive baryon contribution involving $0, 1$ or 2 exchanged valence quarks.

Their values were determined at that time.
Some ambiguity remained for the quarkless intercept.

Why is Baryon Slowing Interesting Today?

Within semi-hard QCD calculations there is ***a firm prediction of a long range quarkless baryon exchange contribution***.

As phenomenological string models are closely related to semi-hard QCD calculations this prediction ***also holds for soft processes***.

My understanding of the soft/semihard connection:

A Fundamental Difference between QED and QCD

- **QCD** processes have mathematically **compact final states.**
- To make **QED** processes compact the consideration has to be restricted to observable systems which can **radiate off entropy** into invisible photons.

This difference in the entropy is irrelevant for hard processes but it is important in the soft limit.

Soft Limit – The Usual Picture and its Possible Flaw

$\alpha_s^{\bar{MS}}(Q^2) \rightarrow \infty$ means:

first: more elaborate calculations!

then (usual argument):

Some radius of convergence is reached. Perturbative results get meaningless after a discontinuous transition.

then (alternate view):

As the number of partons exceeds the limit from the entropy of the final state the partonic theory has to be truncated. Otherwise would operate in a ***phantasy space***.

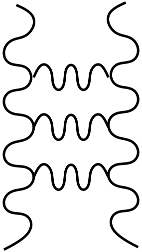
Soft Limit – Where is the Entropy Limit reached?

Final states have lots of particles with lots of entropy. However, structures in the final state reduce the entropy.

String models postulate a simple prefinal state consisting just of a few independently decaying strings states spanned between partons.

In such a hadronisation model the entropy limit should be very low. The ***radius of convergence*** should ***never be reached***. Then there is an analytic continuity. Calculable **semi-hard processes** can act as a ***guidence to model the soft limit***.

Under specified conditions very high energy QCD scattering can be understood with BFKL Pomeron exchanges described by ladders of dispersion graphs of exchanged reggeized gluons.



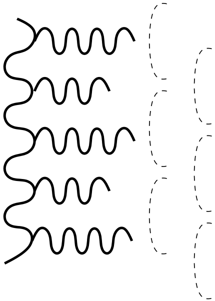
To stay in the perturbative region a $|p_\perp| > 1$ GeV cutoff of the s-channel gluons is introduced and $\alpha_s(Q^{2)}$ is taken to be constant.

The calculated Pomeron intercept energy dependence is $\alpha^{\mathrm{hard}}_{\mathrm{Pom.}}(0) = 1.3 \cdots 1.8$.

BFKL Pomeron and Two String Hadronization

The inelastic contribution can be pictured as a cut through s-channel gluons.

To lowest order in a topological expansion the final state then consists of two fermion chains which neutralize triplet colors and connect the s-channel gluons.
At the flatly distributed rapidities of these gluons the chains contain spots with the corresponding $|p_\perp|$. The multiplicity of these $|p_\perp|$ spots is roughly poisson distributed.



Extraplolation of the BFKL Pomeron in the Soft Region

Our central assumption is that such results can be extended in the soft region without changing its basic structure.

- The entropy limit requires some kind of truncation affecting low $|p_\perp|$ contributions and $\alpha_s(Q^{2)}$ below the semihard region.
- The energy dependence of the Pomeron should reach the experimentally required value with the intercept $\alpha^{hard}_{\mathrm{Pom.}} = 1.08$,
- At present energies it should suffice to consider very few large $p_\perp$ spot.

The Resulting DPM / QGSM Picture

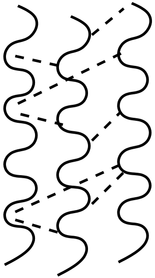
Without $p_\perp$ spots and assuming eikonalistion of all exchanges the basic scenario of the ***dual parton model*** or ***quark gluon string model*** is obtained.

In our ***two component dual parton code*** single simple hard scattering processes are added to account for one large $p_\perp$ spot.

All known observation on densities and correlations starting from very low energies are represented in an acceptable way.

So everything looks very nice, but ...

Beside Pomerons the semi-hard theory predicts



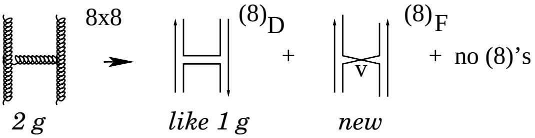
Odderons

It is a necessary ingredient involving the exchange of three reggeized gluons.

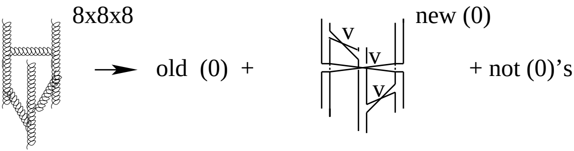
In comparison to the Pomerons they have a similar, somewhat lower intercept

The Color structure of Three Gluon Exchanges

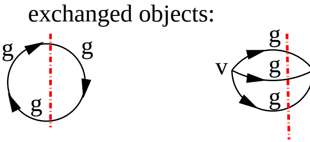
Two gluons can couple into (8)'s in two ways:



Three gluons can couple into (0)'s in a new C-odd way:

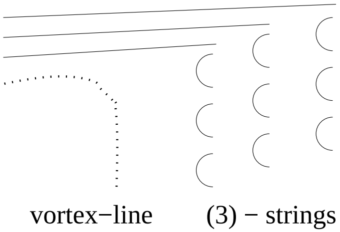


The obtained exchanged topological objects can be cut in the indicated ways:
In the second cut there is a vortex line on each side.



The Interesting Inelastic Contribution of the Odderon

In inelastic exchanges cut Odderons can therefore contribute to baryonic charge exchange with three strings:



- hard -

The difference between the soft and hard Odderon should be similar to that of the soft and hard Pomeron.

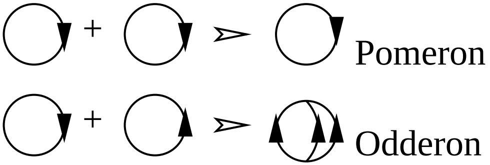
- soft? -

To conclude there is a rather solid theoretical support for quite flat net baryon contribution at the central region.

String Fusion and Baryon Transport

Guided by Kwiecinski's and Balitskij's, Kovchegov's calculations for semihard processes **strings can fuse.**

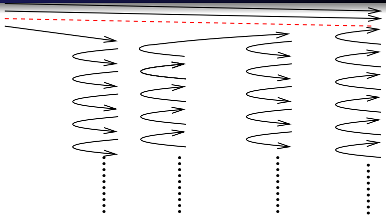
Topologically there are two posibilities

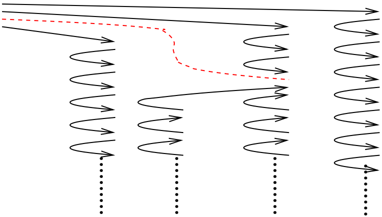


The fusion probability should be mainly determined by geometry. There must be plenty of Odderons. Ignoring direct Odderon exchanges we attribute all quarkless baryon transport to such fusion processes:

Implementation as String Rearrangement

A sea quark which would normally end up on a meson string





can also pick up the vortex line as shown resulting in an Odderon exchange on the top. It is implemented as a flip from the initial configuration to the second one.

Asymptotically the vortex line picks up the intercept of the sea quarks. In the presently used version of DPMJET the resulting intercept is only 0.5 . The needed flip probability is 7% .

What is the Situation a RHIC Energies?

As RHIC runs *pp* or *heavy ions* this question could be addressed much better than in older $p\bar{p}$ hadronic colliders where there are cancellations for central asymmetries.

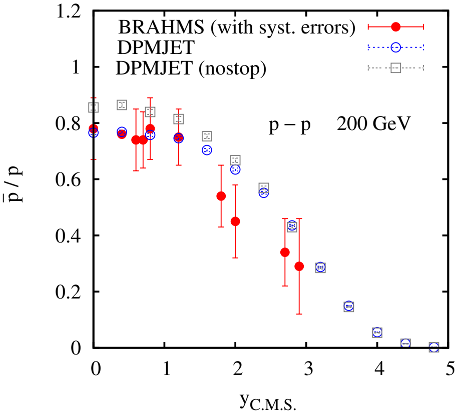
At these energies the multi-Pomeron component is small. The data seem to require the obtained contribution:

RHIC Data on $\bar{p}/p$ in $p-p$ scattering compared to the DPMJET III Monte Carlo

The ratio as function of y_{cm} compared with BRAHMS data (red and blue).

Besides fusions here is a number of other less long range baryon contribution which almost fits (squares).

For $p-p$ scattering at RHIC energies most of the stopping still comes from non-fusion effects.



This changes for nuclei
where multiple Pomeron exchanges appear
as required by Glauber theory.

For nuclear scattering fusion of complete strings
which are geometrically close (< 0.75fm)
is needed to reduce the spectral density.
It also leads to quarkless baryonium exchances.

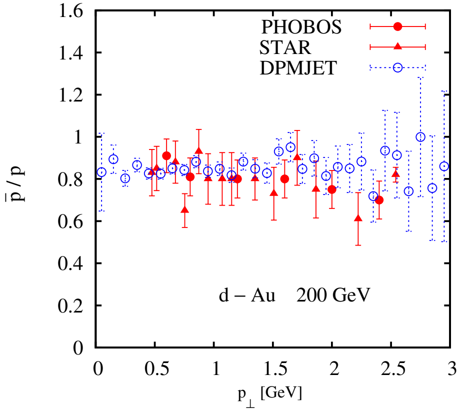
RHIC Data on $\bar{p}/p$ in $d - Au$ scattering compared to the DPMJET III Monte Carlo (cont.)

The ratio as function of $p_\perp$ compared with PHOBOS and STAR.

There is a significant asymmetry.

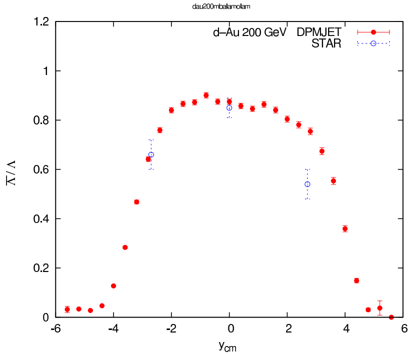
There is no visible $p_\perp$ dependence in the considered soft range

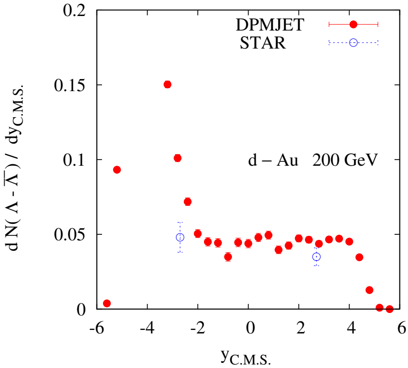
The same applies to the centrality dependence.



RHIC Data on $\bar{\Lambda}/\Lambda$ in $d - Au$ scattering compared to the DPMJET III Monte Carlo

Data on Λ's of the STAR collaboration are also reproduced:



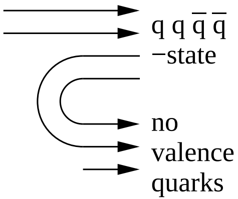


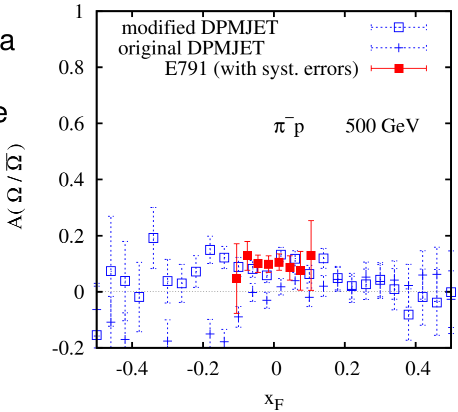
Another way to enhance the quarkless baryon transfer component is to consider completely strange baryons.

Fermilab Data on $\bar{\Omega}/\Omega$ in π^--Nucleon scattering compared to the DPMJET III Monte Carlo

The initial results are the dashed points which drop on the left.

To reproduce the data baryonia production had to be added in the string fragmentation for the leading rank:

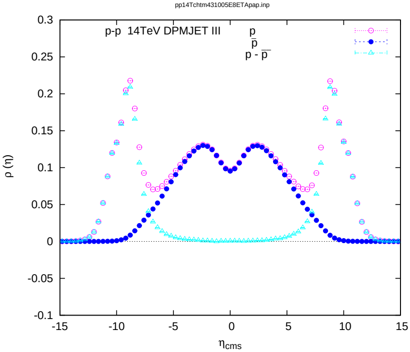


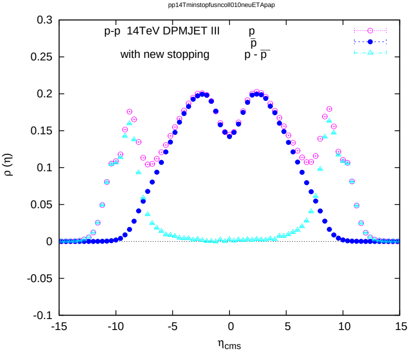


Then Ω can be produced in the second rank (squared points with baryonium probability 2%) .

The rise of the bar Pomeron cross section gives increasing importance to unitarity effects.
At LHC energies even in *pp* scattering multiple, eikonal Pomeron exchanges become important.

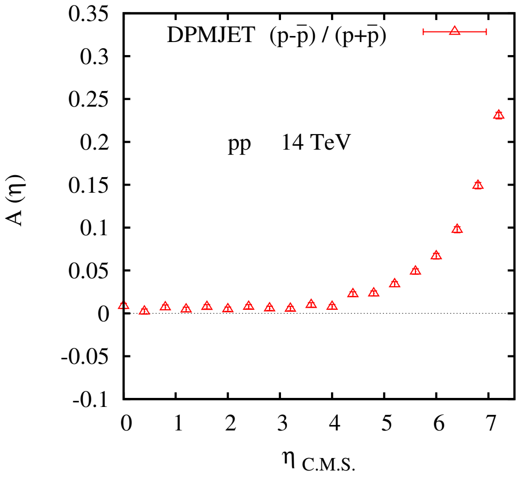
A left right comparison of the MC results shows that the string-fusion baryon stopping is now an observable effect.





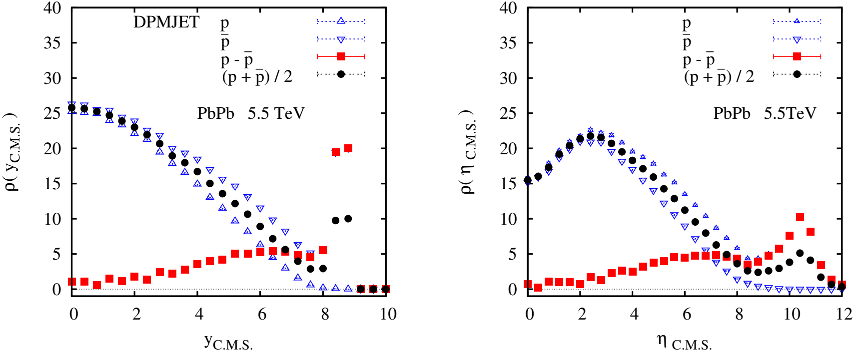
It might be clearer in the asymmetry.

With stopping the central prediction for asymmetry is in the percent region.



We also run the program for heavy ion scattering.

The rapidity and pseudorapidity proton distributions are:



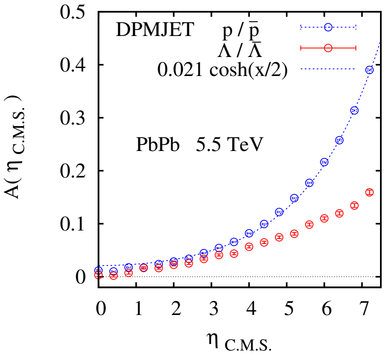
DPMJET III Prediction for Central *PpPp* LHC

For the most central 10% of the heavy ion events the asymmetries show a non-vanishing central component.

There is some uncertainty in the prediction in this figure as the model in its present form does not reproduce the full eliptic flow. Hopefully the net baryon distribution is not effected by missing non-initial state effect.

The asymmetries *p* and Λ are shown.

The fit seen as blue line exactly corresponds to the rather conservative 0.5 intercept put in initially in an indirect way.



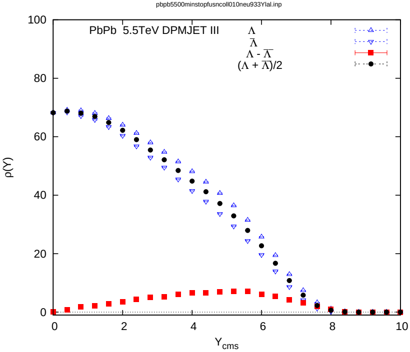
This concludes my presentation.

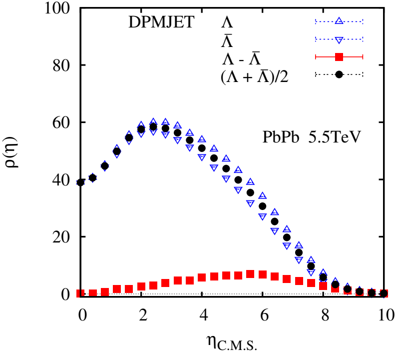
Backup

backup material

DPMJET III Prediction for Central *PpPp* LHC (cont.)

For the most central 10% of the heavy ion events the rapidity and pseudorapidity Λ distributions are:





Multiple Strings

The mechanism requires multiple stringss.

The model incorporates ***unitarity*** requiring multiple strings. For $p-p$ LHC the effect is important, while at $p-p$ RHIC the energy is too normalsize for a significant effect.

In heavy ion scattering a single nucleon has multiple interactions (***Glauber mechanism***).
Multiple strings originating in interactions with separate nucleons on the other side lead to a significant effect at RHIC for (light or heavy ion)-(heavy ion) scattering.

Soft Limit – e^+e^-- Annihilation as Example

A cutoff Q_0^2 in the virtuality of partons is needed to stop the partonic evolution.
It eliminates the phantasy part of the partonic Hilbert space:

- In high Q_0^2 models it determines where on has to considere universally decaying strings.
- In high Q_0^2 models each hadronic final state then essentially originates in a specific "parton-hadron-dual" partonic state.

Soft Limit – e^+e^-- Annihilation as Example (cont.)

To ignore softer emissions make sense on a partonic level as virtual and integrated out real emission cancel.

Including hadronisation mixed contributions appear if a particular final hadronic state can be reached with different partonic states. There is no direct cancelation of such potentially infinite terms.

Needed is the asumption that the amplitude with the extra otherwise irrelevant gluon entering in the hadronisation comes essentially with a random relative phase. Integrated over various contributions its contribution then vanishes.

Baryon Transport in DPMJET III

There are several components affecting the position of the net baryon charge:

initial diquark structure function
during the string decay: $qq \rightarrow$meson$+qq$
during the string decay: $qq \rightarrow$baryonium$+qq$
string fusion effects

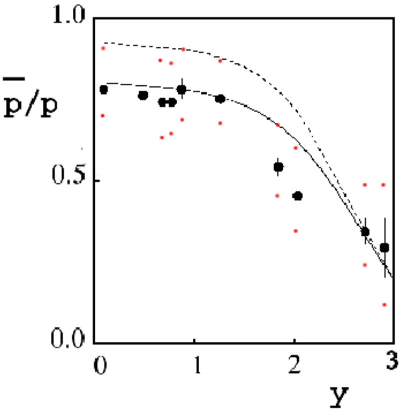
The baryonium (line 3) is just a wide two meson state.
To obtain a long range baryon transport we introduced a new string interaction flipping the standard string configuration in a certain way. Two cases are thereby considered

string rearrangements with glauber sea quarks
string rearrangements with unitary sea quarks

RHIC Data on $\bar{p}/p$ in $p - p$ scattering compared to the Quark-Gluon-String Model:

RHIC BRAHMS *pp* Data are compared to the QGSM.

The fit required diquarks with a probability of $\epsilon = 0.024$ to involve a quarkless vortex line with a slope $\alpha_{\{SJ\}} = 0.9$.



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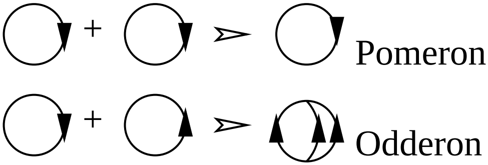

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