Models for RHIC and LHC: New Developments

Klaus WERNER, Nantes

- Presently used models for the initial stage are inconsistent
- Main problem: energy conservation not done properly
- Big effects

==> New ideas are needed

(H. Drescher,
S. Ostapchenko,
T. Pierog,
K. W.)

Open Problems
(Gribov-Regge Approach and Parton Model)

Gribov Regge Theorie

- Multiple scattering approach (parallel i.a.)
- Elementary interaction = Pomeron
- Ignoring energy sharing: simple formulas

Inelastic cross section

$= \text{sum of topological c.s.}$

$$\sigma_{\text{inel}} = \sum_m \sigma^{(m)}$$

$$= \sum_m \int d^2b \frac{[2\chi(s,b)]^m}{m!} e^{-2\chi(s,b)}$$

$$= \int d^2b \{1 - e^{-2\chi(s,b)}\}$$

Particle production:

- Model:
  Pomeron = cylinder
- Doubles scattering:
  double cylinder
  => chains of hadrons
- <u>Full energy conservation</u>

BUT:

- **Energy conservation is not at all considered in cross section calculations**
- **Wrong by itself**
- **And inconsistent with particle production**

Parton Model

- Inclusive cross section as convolution of parton distributions with parton-parton cross section ...
- QCD … but how to deal with multiple scattering?

- Via the eikonal approach => same formula as in GRT (no energy conservation)

Same problems

What to Do?

- Formulate (topol.) cross section calculations and particle production within <u>one</u> consistent approach
- Respect energy conservation in a rigorous way

- **This is a MUST, dictated by theoretical consistency**
- **Increases predictive power enormously**

Solution: Parton-based Gribov-Regge Theorie

hep-ph/0007198 (213 pages)

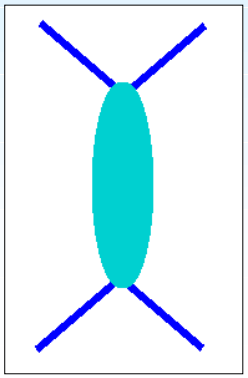
to be published in Physics Reports

H. Drescher,
S. Ostapchenko,
T. Pierog,
K. Werner

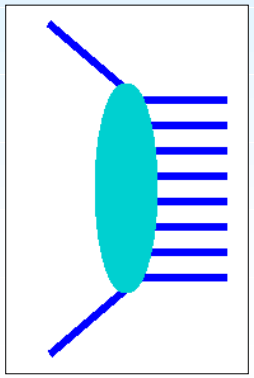
Guideline:
theoretical consistency

Reminder (Basic QM)

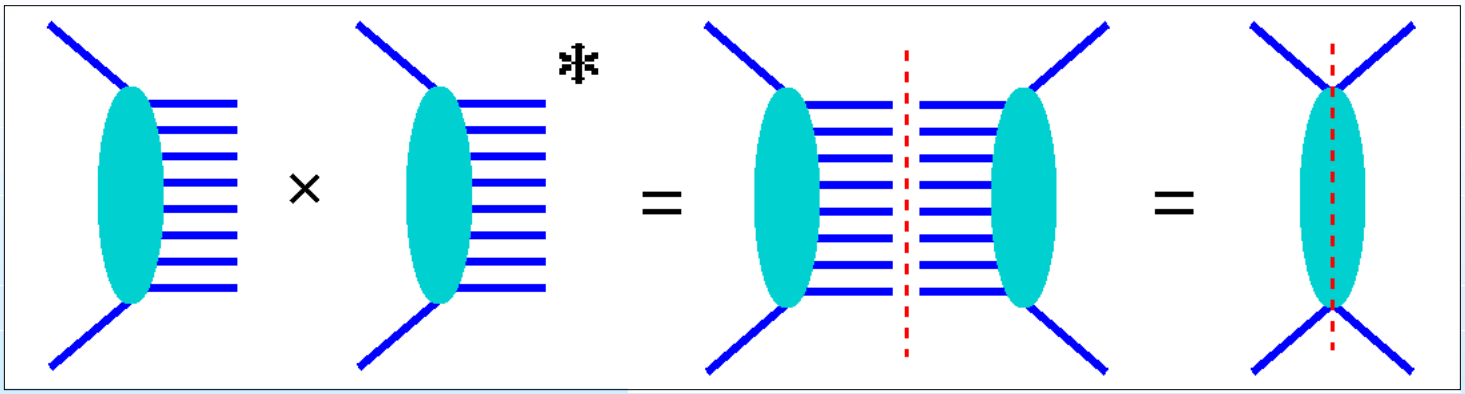
Elastic amplitude $T_{2\to 2}$



Inelastic amplitude $T_{2\to X}$



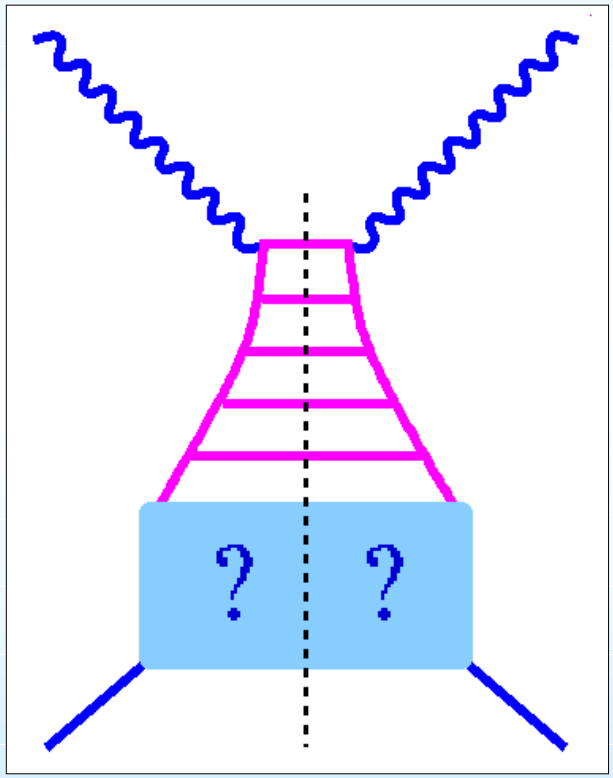
Unitarity: $2\mathrm{Im}T_{2\to 2} = \sum_X \mathrm{T}^*_{2\to X} T_{2\to X} \equiv \text{cut diagram} \downarrow$



Structure of the Nucleon

Deep inelastic scattering (photon-nucleon scattering):

- Successive parton emissions
- Ordered virtualities down to some minimum value Q_0^2
- Below: soft physics (?)



Emission of the first (softest) parton:

Mass of the soft object emitting the first parton:

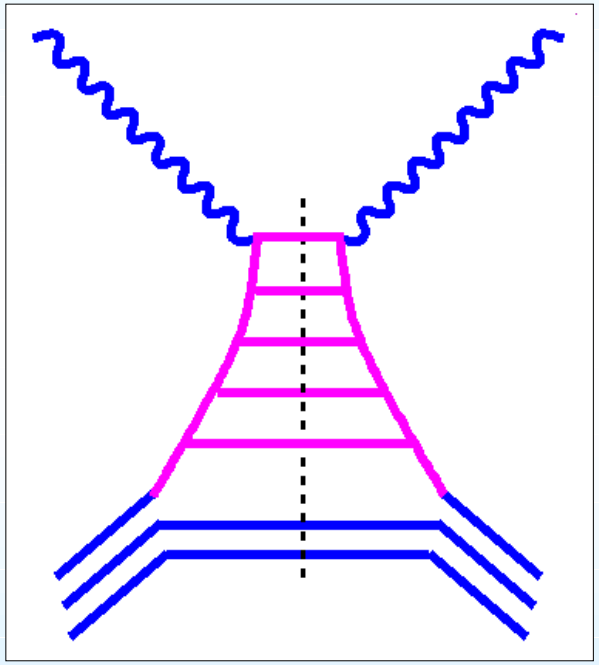
$$m^2 = \frac{Q_0^2}{x}$$

x being the momentum fraction of the parton

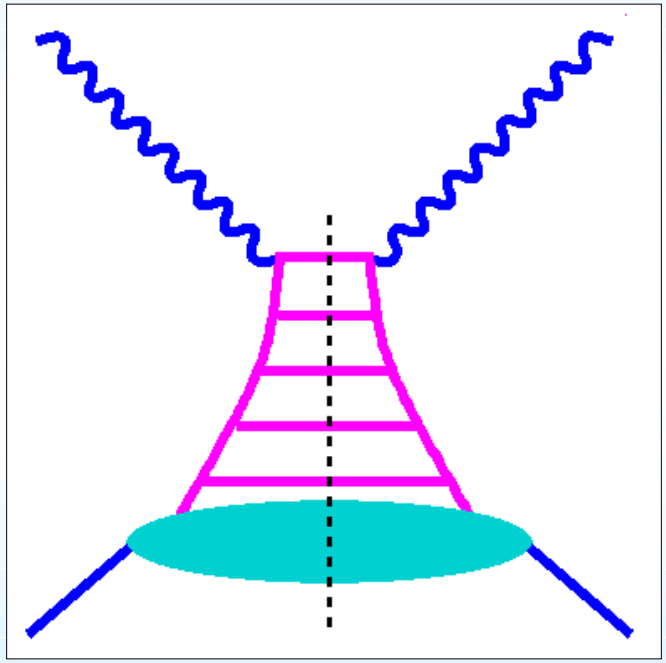
- if sea quark
  $\Rightarrow$ distribution 1/x
  $\Rightarrow$ <u>large mass</u> !!!
- if valence quark
  $\Rightarrow$ distribution $1/\sqrt{x}$
  $\Rightarrow$ small mass

Two contributions:

Valence:



Sea:



Large mass object
$\Rightarrow$soft Pomeron

Elementary Interaction in NN

- Straightforward generalization of photon-nucleon
- hard scattering in the middle ⇒ successive parton emission towards both ends
- at each end: valence (v) or sea (s) ⇒ four contributions (ss,vs,sv,vv)

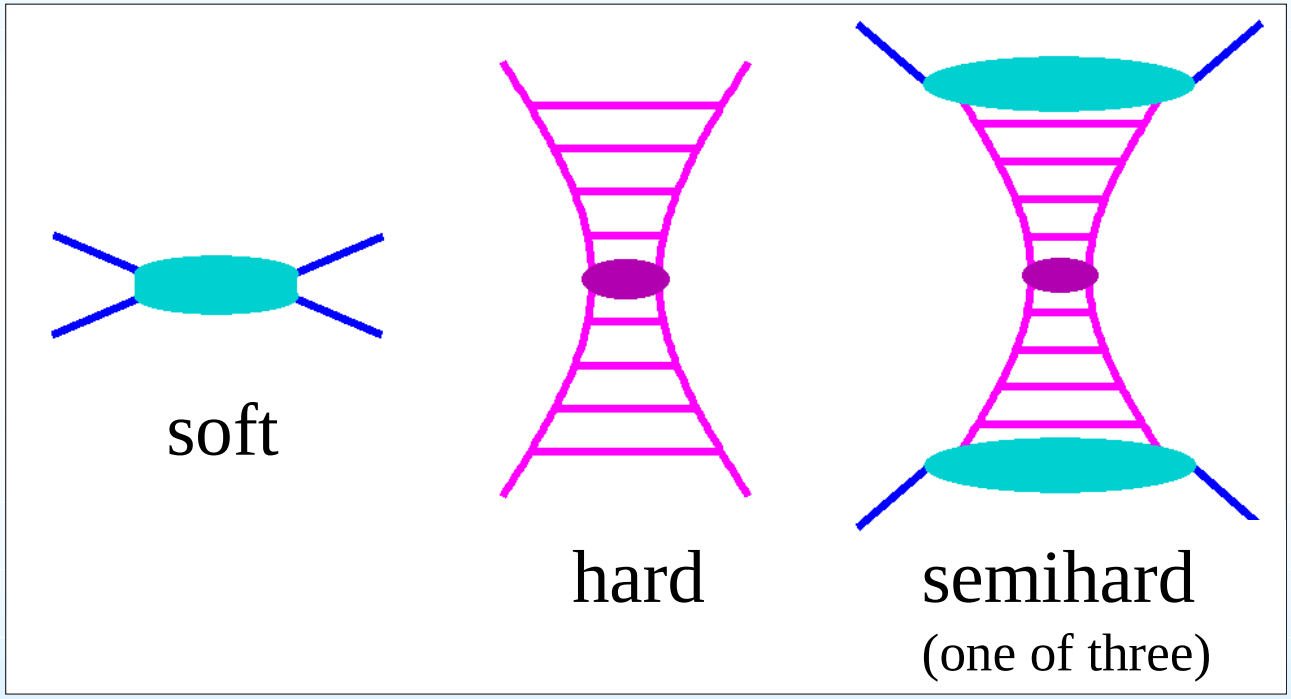
  ss,vs,sv -- semihard

  vv -- hard

- In addition: purely soft contribution

The elastic amplitude:

$$T_{2\to 2} = T_{\text{soft}} + T_{\text{hard}} + T_{\text{semi}}$$



Soft: parameterization - hard: pQCD - semihard: convolution soft/hard

Symbols: full and dashed line $\Rightarrow$ elastic and cut diagram

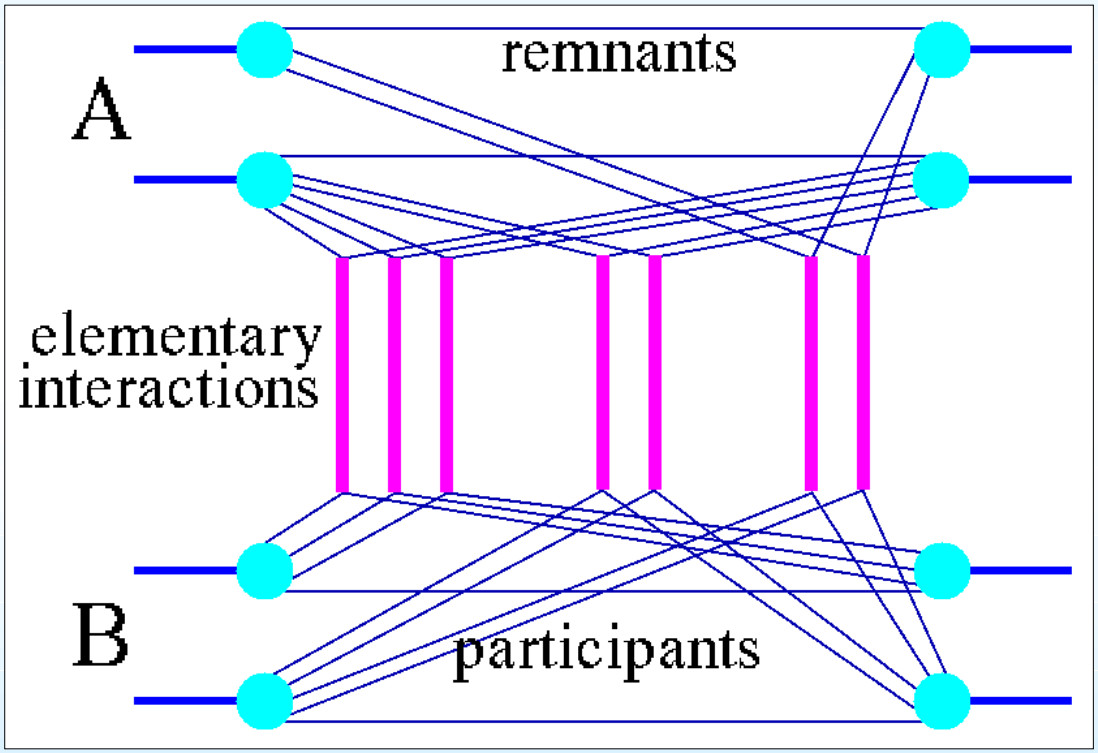
$$= \; i\, T_{2\to 2}$$

$$= \frac{1}{2s}\sum_X T^*_{2\to X} T_{2\to X} = \frac{1}{2s}\, 2\,\mathrm{Im}\, T_{2\to 2}$$

Very useful for nucleus-nucleus

Multiple Scattering (AB or pp)

Define model via elastic amplitude $T_{AB \to AB}$



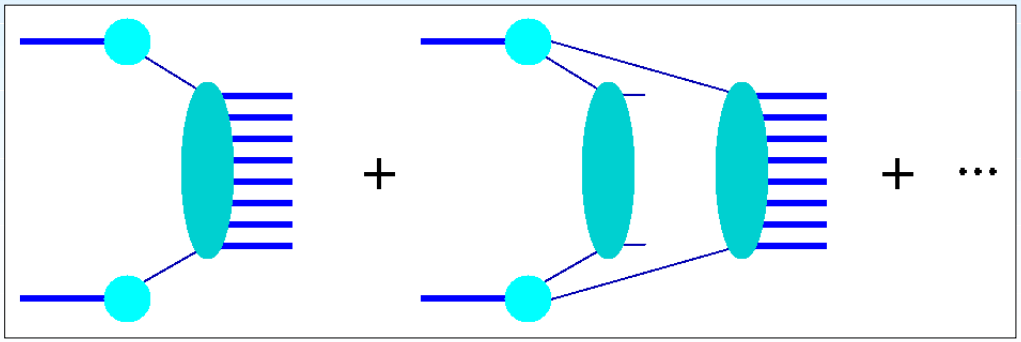
Basic version: parallel inter-actions

Full energy conservation

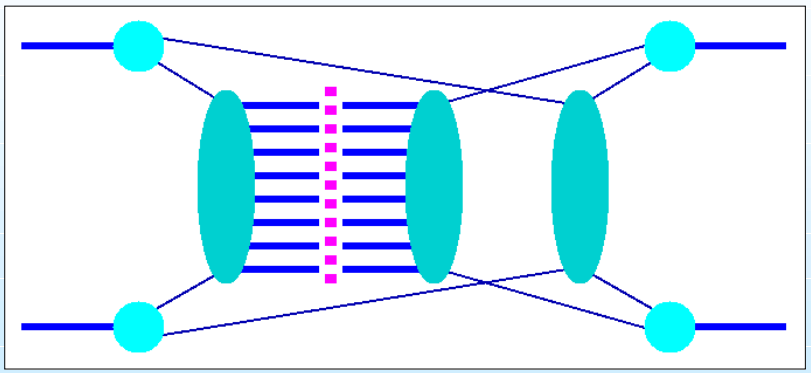
Inelastic scattering: deduced in a self-consistent way

Inelastic scattering in pp:

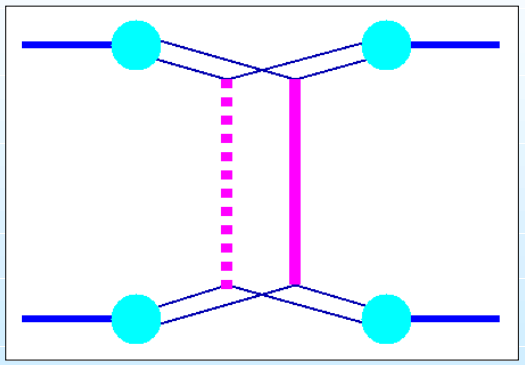
Amplitude:



Squared amplitude
=> interference terms:



=> Symbolic notation



Inelastic scattering in AB:

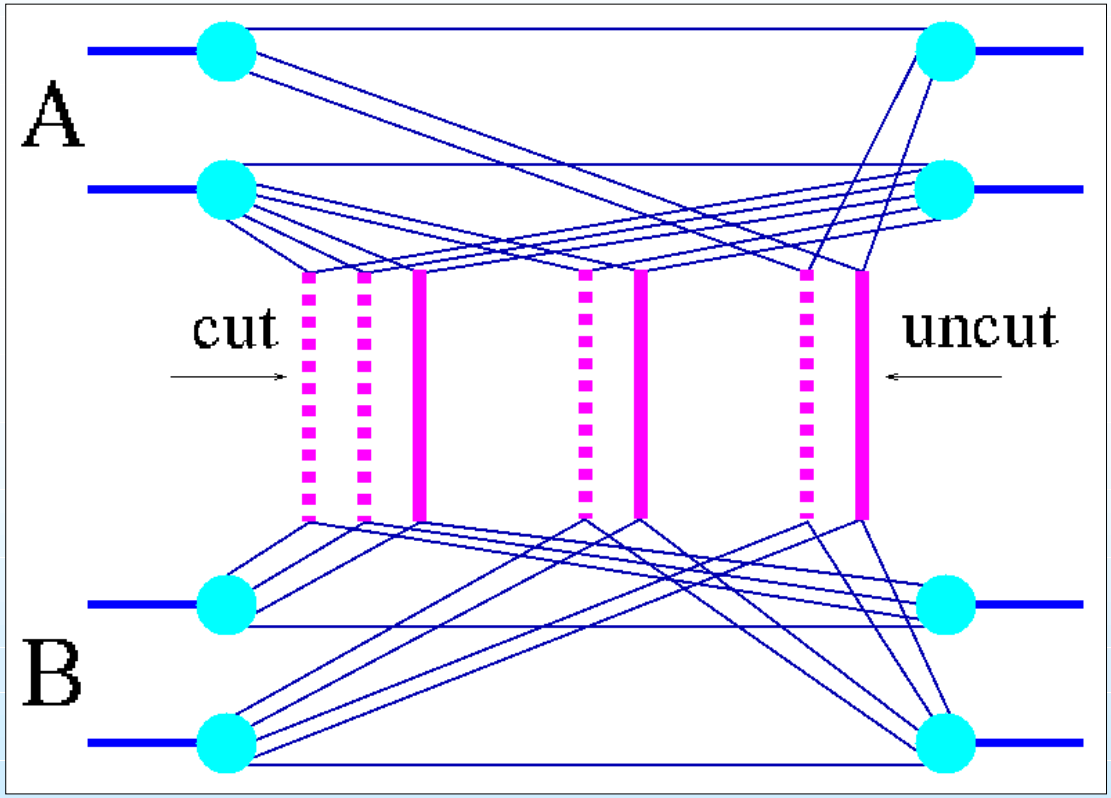
$$T_{AB \to X} = \sum_i T^{(i)}_{AB \to X}$$

(Elastic and inelastic elem. Interactions)

Squaring amplitude
⇒interference terms

expressed via cut and uncut elementary diagrams

full energy conservation!!



Probability distribution Ω

We define classes *K* of interference terms
and sum all terms in a class => Ω(K) =>

$$\sigma_{AB}(s) = \sum_K \underbrace{\int d^2b\, \Omega^{(s,b)}(K)}_{\text{topological c.s.}}$$

Symbol *b*
= impact parameter
+ nuclear coordinates

$$K = \{m_k, x^+_{k\mu_k}, x^-_{k\mu_k}\}_{1 \le k \le AB, 1 \le \mu_k \le m_k}$$

m_k - Number of cut diagrams for kth NN pair

$x^+_{k\mu_k}, x^-_{k\mu_k}$ - Momentum fractions of elementary interactions

$\Omega^{(s,b)}(\{m_k, x^+_{k\mu_k}, x^-_{k\mu_k}\})$ is probability distribution for these variables

Ω serves clearly as basis to calculate (topological) cross sections but also particle production conserving energy in both cases !!

Particle production :

one generates m_k and $x^+_{k\mu_k}$ and $x^-_{k\mu_k}$ according to Ω

for all the Pomerons $\Rightarrow$ Pomerons fully defined

then : Pomeron $\Rightarrow$ partons $\Rightarrow$ hadrons

Consistency problem solved !!

Comparing with conventional approach:

- Pomeron number distribution narrower than in conv. appr.
- Considerably less multiplicity fluctuations in pp

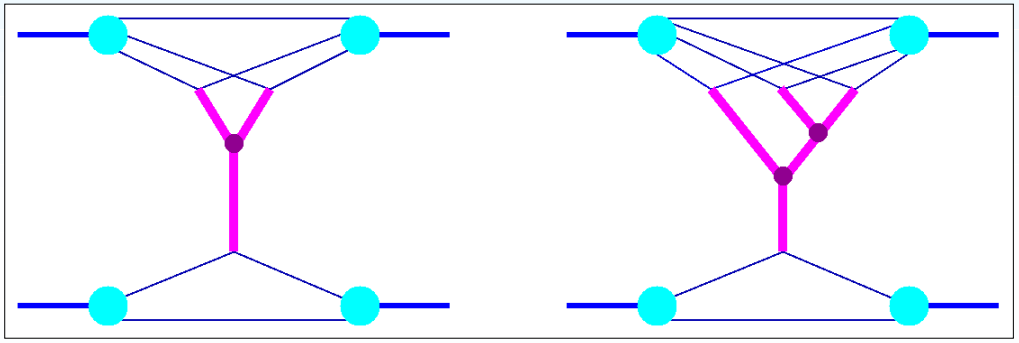
Comparing with data:

- pp multiplicity distributions much narrower than data
- pp total cross section increases too fast with energy
- PbPb multiplicity too high

Nothing to do about due to considerably reduced parameter space !!

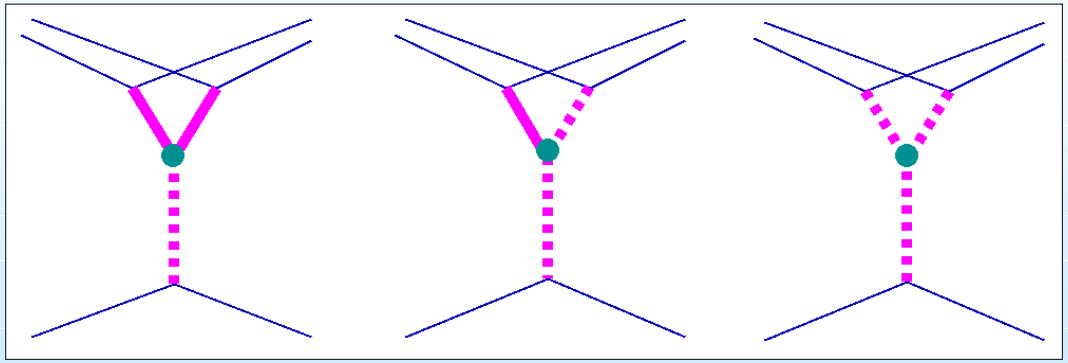
The cure: Pomeron-Pomeron interactions

Elastic scattering:



Reduces increase of cross section with energy (screening)

Interference terms (cut diagrams):



Increases multiplicity fluctuations

Present Status (= NEXUS 2)

- Only lowest oder (Y diagrams) with effective coupling (improves pp considerably) see poster T. Pierog
- no nuclear effects yet (but very soon). This should reduce multiplicity (screening)
- many results in hep-ph/0007198

Summary

- Presently used models (initial stage) are inconsistent

- It is possible to cure this problem and formulate multiple scattering consistently (proper energy conservation)
- But: too narrow multiplicity distributions, too fast increase of total cross section

- Solution: Y diagrams (screening)
- So far only lowest order

- Final remark: we have to be more concerned about the theoretical content of model -- an ill-defined model which fits the data is quite useless ...