Limiting fragmentation in hadronic collisions

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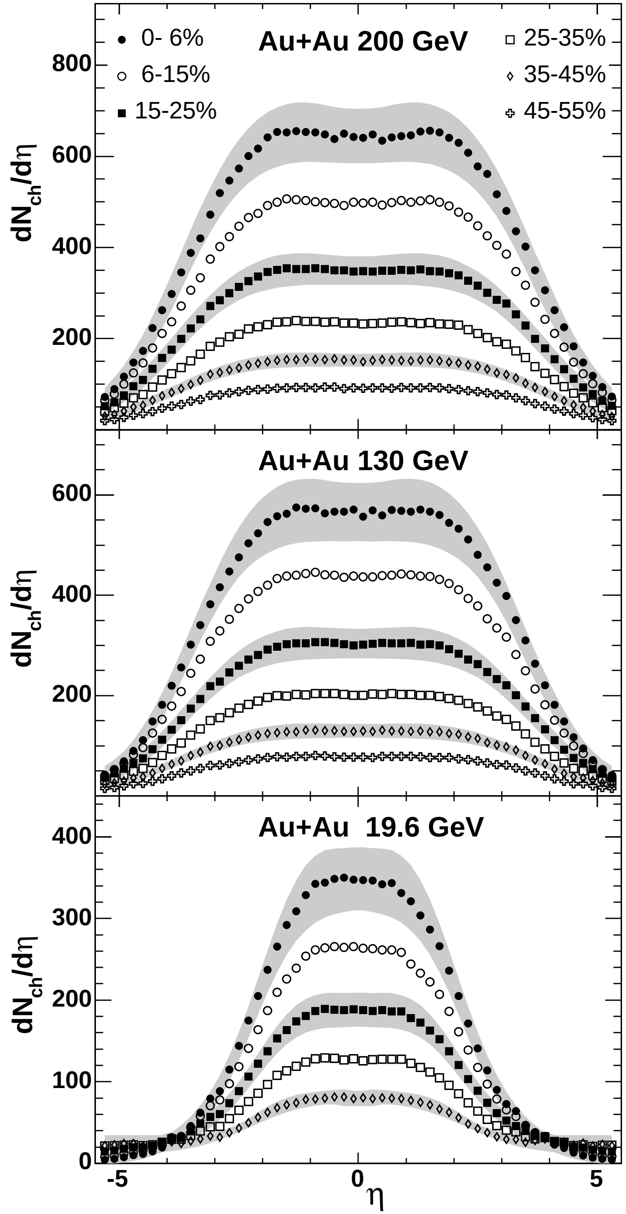
Outline:

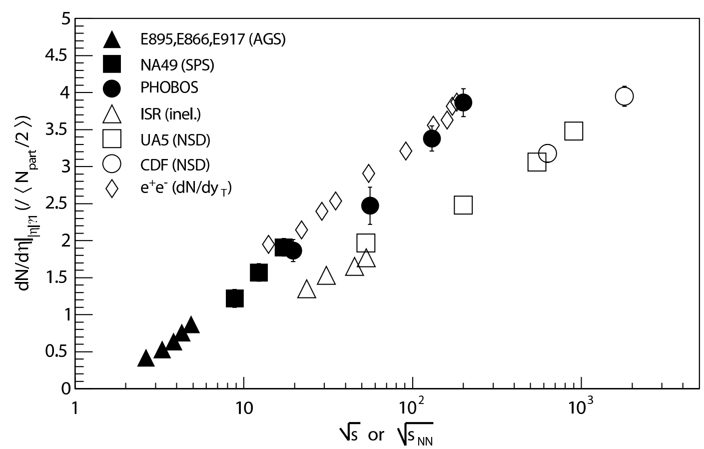
- Limiting fragmentation: the original statement
- The model: particle production within CGC formalism
- Qualitative analysis
- Comparison with data
- Summary and Outlook

General features of multiplicities



- Growth with energy and centrality.
- Apparent flat region in the mid-pseudorapidity. In the rapidity space the distributions are however gaussian and no hint of plateau is seen.
- Growth with energy at mid-rapidity is mild:

$$\frac{2}{N_{\rm part}}\frac{dN}{d\eta}\Big|_{\eta<1} \sim \ln\sqrt{s}$$

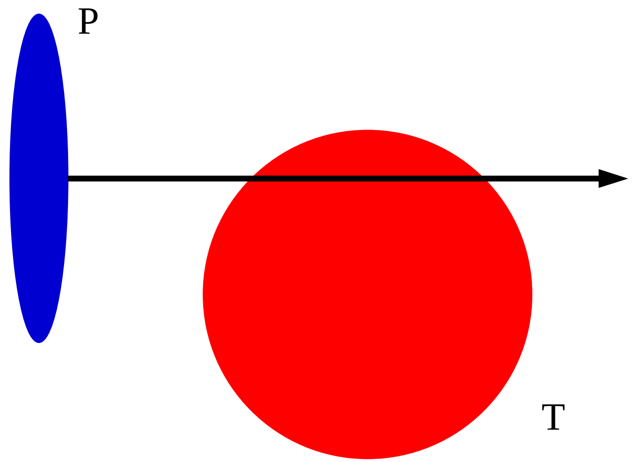


Hypothesis of limiting fragmentation

Benecke, Chou, Yang, Yen:

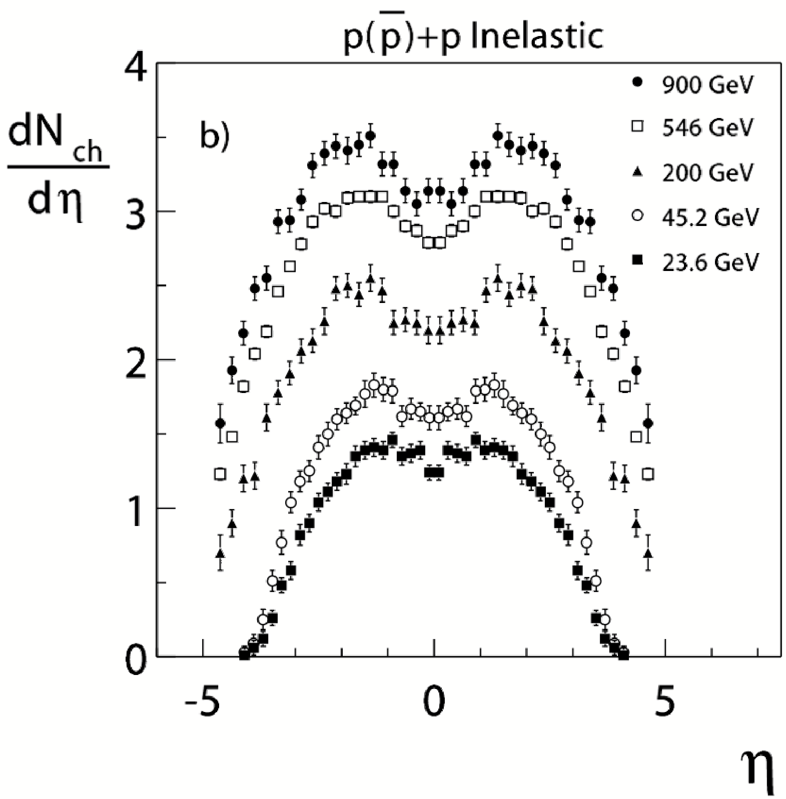
- For very high energy collisions in the lab system (target at rest) or a projectile system (projectile at rest) some of the outgoing particles approach *limiting distributions*.
- The limiting distributions represent the broken-up fragments of the target. The fragments of the projectile move with increasing velocity as $\sqrt{s} \to \infty$ (in the lab frame) and do not contribute to the limiting fragmentation. To study these fragments one has to go to the projectile system.
- In the laboratory frame the incoming particle is a Lorentz contracted system which passes through the target. The excitation of the target may cause a break up of the target.

Hypothesis of limiting fragmentation (contd.)

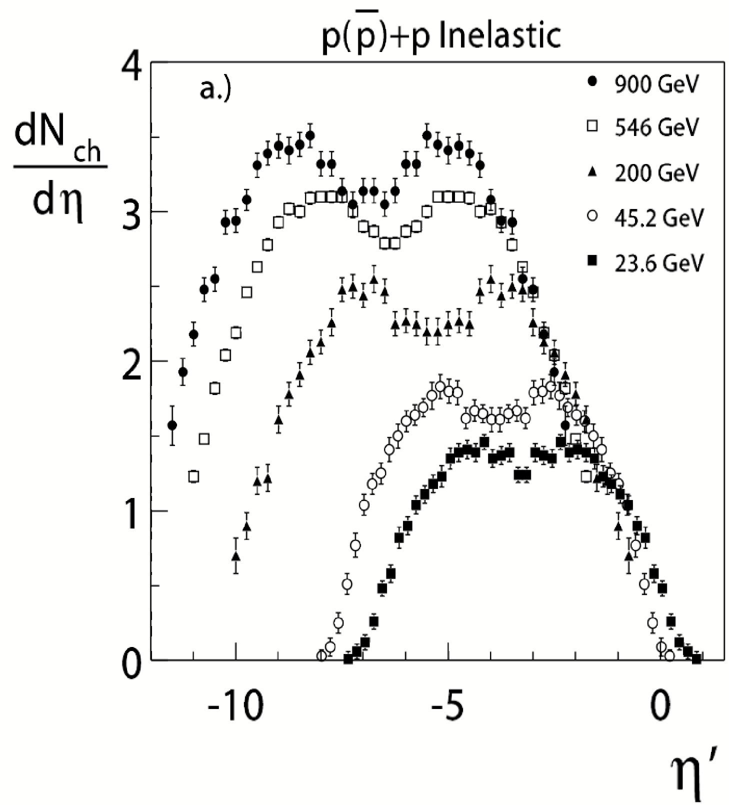


- *The (approximate) constancy of the total cross section and of the elastic scattering cross section* suggests that the momentum and quantum-number transfer process between the projectile and the target does not appreciably change when the projectile is further and further compressed.
- The hypothesis of limiting fragmentation gives emphasis to the lab and projectile systems. In this it is very different from the statistical model. In the latter model model the two incoming particles collide and arrest each other in c.m. system the final product of the collision being emitted from this arrested amalgamation of the original particles.

proton-(anti)proton collisions



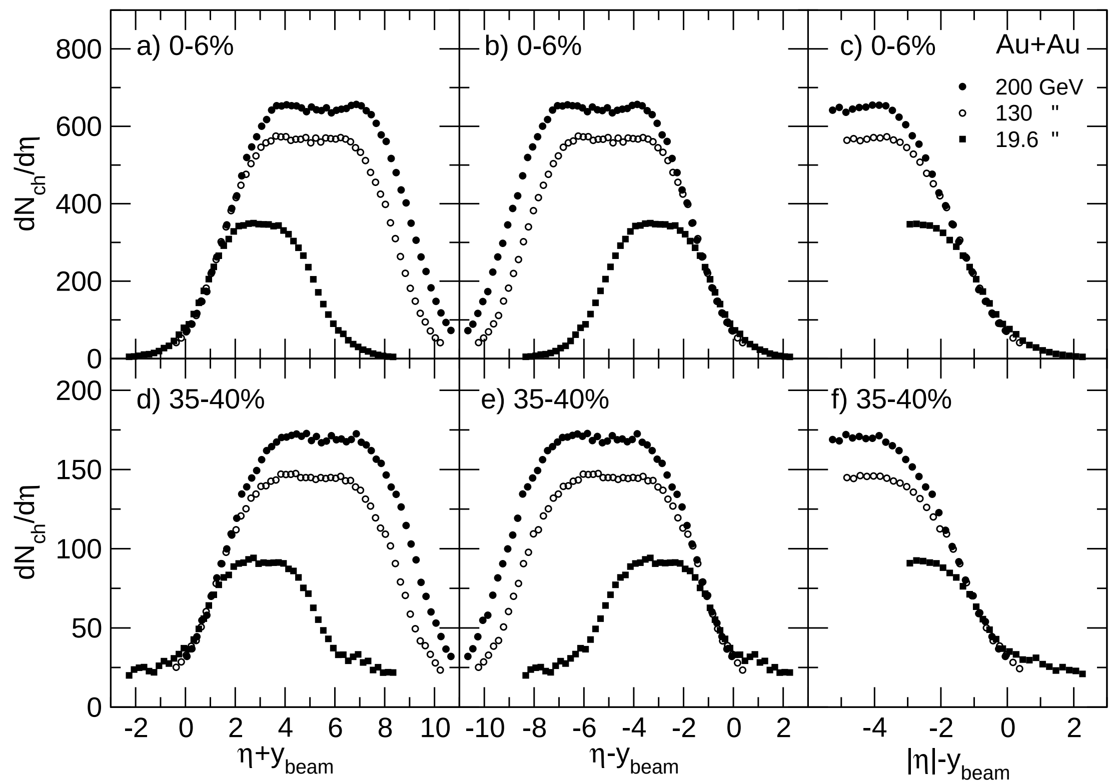
Pseudorapidity distrbution



Shifted pseudorapidity distribution in $\eta' \equiv \eta - Y_{beam}$

$$Y_{beam} = \ln \frac{\sqrt{s}}{m_p}$$

Nucleus-nucleus collisions

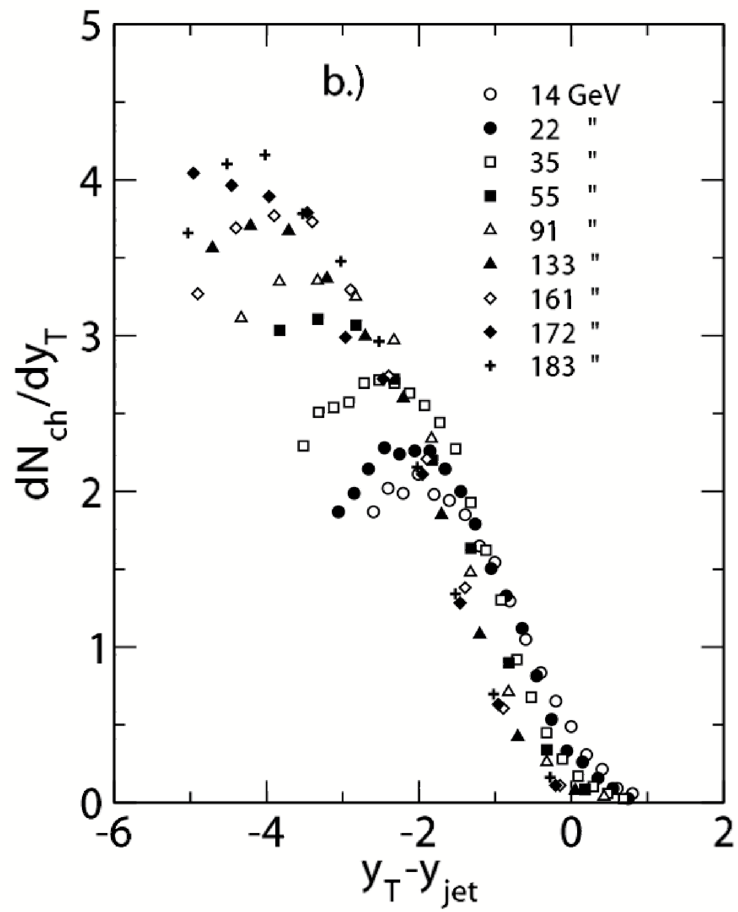


PHOBOS

Limiting fragmentation for both central and peripheral collisions.

e^+e^- *annhilation*

Does it work for e^+e^- too ? Not convincing . . .



Distribution vs $y - Y_{jet}$, the motion is described along the thrust axis.

Variety of models

- Bremsstrahlung from color charges, *Białas, Jeżabek*
- Color string model, *Braun, Pajares*
- k_T factorization and gluon saturation in Color Glass Condensate, *Kharzeev, Levin, Nardi; Jalilian-Marian; Gelis, Venugopalan, A.S.*
- . . .

k_T ***factorization and gluon saturation***

k_t factorization for gluon production at high energy $s \gg p_T$:

$$\boxed{\frac{dN}{dy d^2 p_T} = \frac{\alpha_s S_{AB}}{2\pi^4 C_F S_A S_B} \frac{1}{p_T^2} \int \frac{d^2 k_T}{(2\pi)^2} \phi_A(x_1, k_T)\, \phi_B(x_2, |p_T - k_T|)}$$

- $S_{A,B}$ total transverse area for nuclei, S_{AB} transverse area for an overlap region.
- p_T transverse momentum of the produced gluon.
- $x_1 = \frac{p_T}{m} e^{y - Y_{\mathrm{beam}}}$, $x_2 = \frac{p_T}{m} e^{-y - Y_{\mathrm{beam}}}$; longitudinal momentum fractions of the gluons probed in target and projectile.
- Functions $\phi(x, k_T)$ are *unintegrated* gluon distributions:

$$\boxed{xg(x, Q^2) \sim \int^{Q^2} d^2 k_T\, \phi(x, k_T)}$$

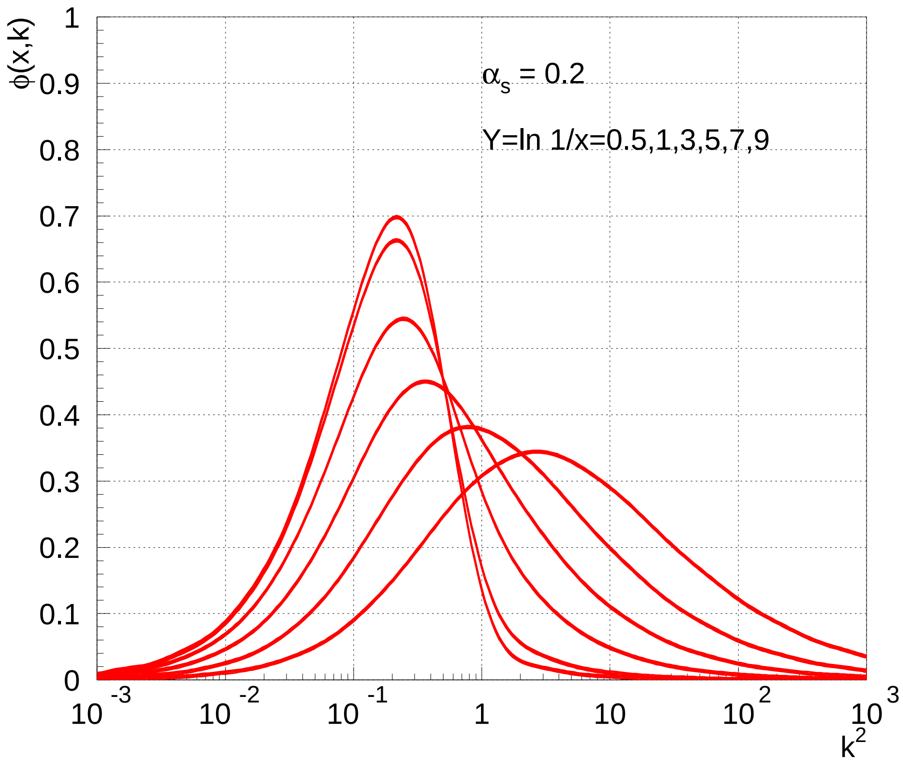
- Experimentally measure hadrons, need to include the fragmentation from gluons (quarks) to pions.

Kharzeev, Levin, Nardi; Kovchegov, Tuchin; Czech, Szczurek …

Unintegrated parton distributions

- Distributions obtained from the linear evolution equations with additional small x effects (CCFM evolution) see ex. *Czech, Szczurek*.
- Saturation models: taking into account possibly high parton density *Kharzeev, Levin, Nardi*.
- ϕ from QCD nonlinear evolution equation (Balitsky-Kovchegov BK equation) , which includes high density corrections *Albacete, Armesto, Salgado, Wiedemann; Gelis, Venugopalan, A.S.*.

ϕ distribution from the BK equation

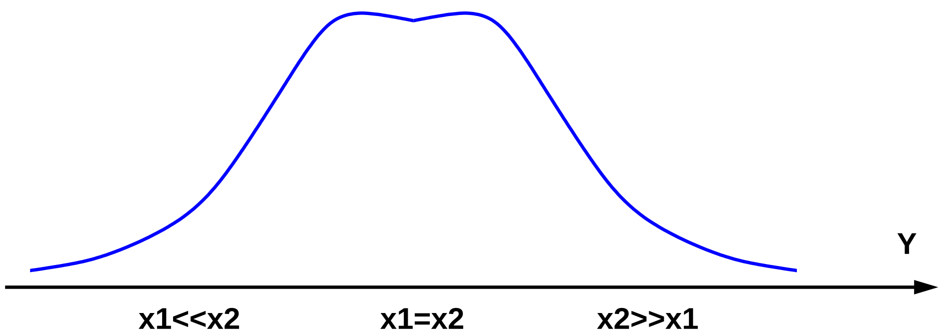


- Peak of the distribution is at the saturation scale $Q_s(Y = \ln 1/x)$, typical scale that emerges when solving the nonlinear equations.
- Distribution moves to higher k's as x becomes smaller.
- The area under the integral is constant, conserved during the evolution in x

$$\int \frac{d^2k}{k^2}\,\phi(x,k) = \,Const.$$

Qualitative analysis

Pseudo-rapidity distribution:



Recall:

$$x_1 = \frac{p_T}{m} e^{Y - Y_{beam}}$$

$$x_2 = \frac{p_T}{m} e^{-Y - Y_{beam}}$$

$$\boxed{\frac{dN}{dy} \sim \int \frac{d^2 p_T}{p_T^2} \int d^2 k_T \, \phi_A(x_1, |k_T|) \, \phi_B(x_2, |p_T - k_T|)}$$

- When $x_1 \sim x_2$: $Q_s^A(x_1) \sim Q_s^B(x_2) \rightarrow$ entanglement in momenta.
- When $x_1 \gg x_2$: $Q_s^A(x_1) \ll Q_s^B(x_2) \rightarrow$ separation in transverse momenta,

$$\boxed{\frac{dN}{dy} \sim \int \frac{d^2 p_T}{p_T^2} \int d^2 k_T \, \phi_A(x_1, |k_T|) \, \phi_B(x_2, |p_T|)}$$

Qualitative analysis

When $x_1 \gg x_2$ (or $x_2 \gg x_1$) we have separation of integrals in k_T space:

$$\frac{dN}{dy} \sim \int \frac{d^2 p_T}{p_T^2} \phi_B(x_2, |p_T|) \int d^2 k_T \phi_A(x_1, |k_T|)$$

- Integral over projectile density constant: $\int \frac{d^2 p_T}{p_T^2} \phi_B(x_2, |p_T|) = const.$
- Integral over target density:

$$\boxed{\int^{Q_s(x_2)} d^2 k_T\, \phi_A(x_1, |k_T|) = x_1 f(x_1, Q_s(x_2))}$$

Integrated parton density at large values of x_1:

$$\boxed{x_1 f(x_1, Q_s(x_2)) = x_1 f(x_1)}$$

shows x_1 (Bjorken) scaling.

Scaling in limiting fragmentation

$$\boxed{\frac{dN}{dY} \simeq \mathcal{N} x_1 f(x_1) = \mathcal{F}(Y - Y_{beam}), x_1 \gg x_2}$$

scaling with $Y - Y_{beam}$ (recall $x_1 \sim \exp(Y - Y_{beam})$).

For comparison with data:

- Need to model $\phi_A(x_1, k_T)$ at large x_1.
- Since $x_1 f(x_1)$ should obey x_1 scaling

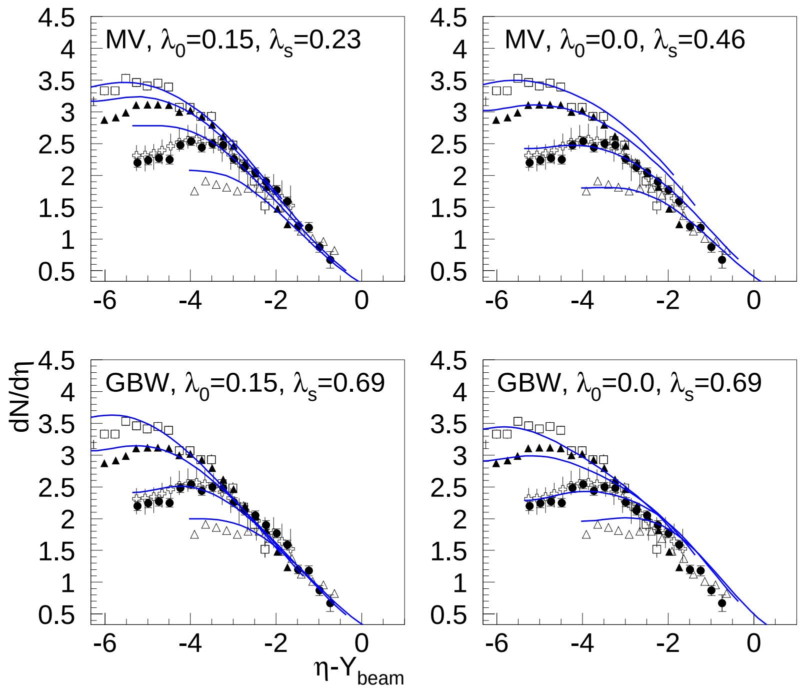
$$\boxed{x_1 f(x_1) = x_1 f(x_1, Q_s^2) = \int^{Q_s^2} dk^2 \phi_A(x_1, k)}$$

  the distribution ϕ_A must be peaked at very low k_T and sharply fall for large k_T.
- $\phi_A(x_1, k_T)$ at large x_1 is the largest source of uncertainty when comparing with the data.

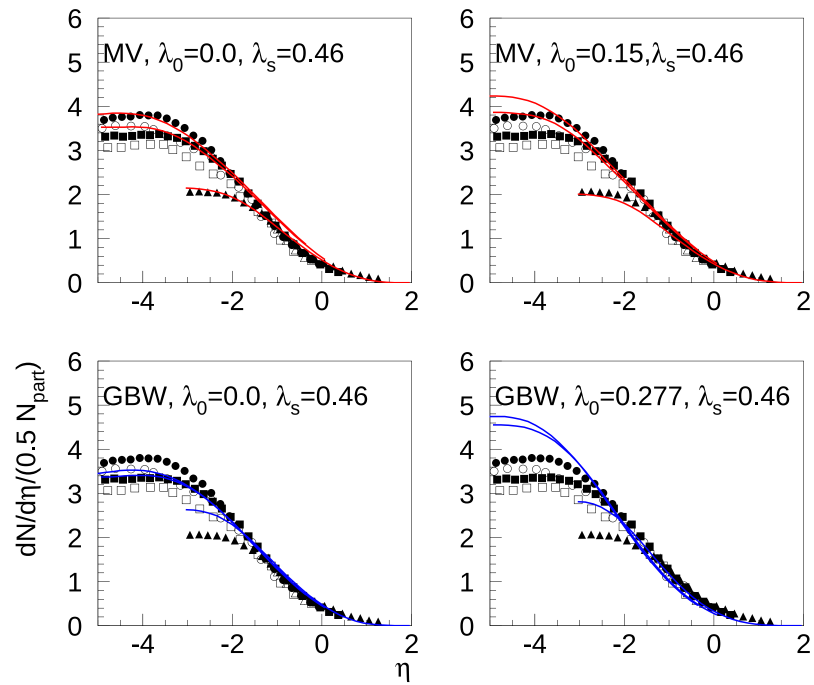
Proton-antiproton and AuAu(central) collisions

Gelis, Venugopalan, A.S.

proton-proton:



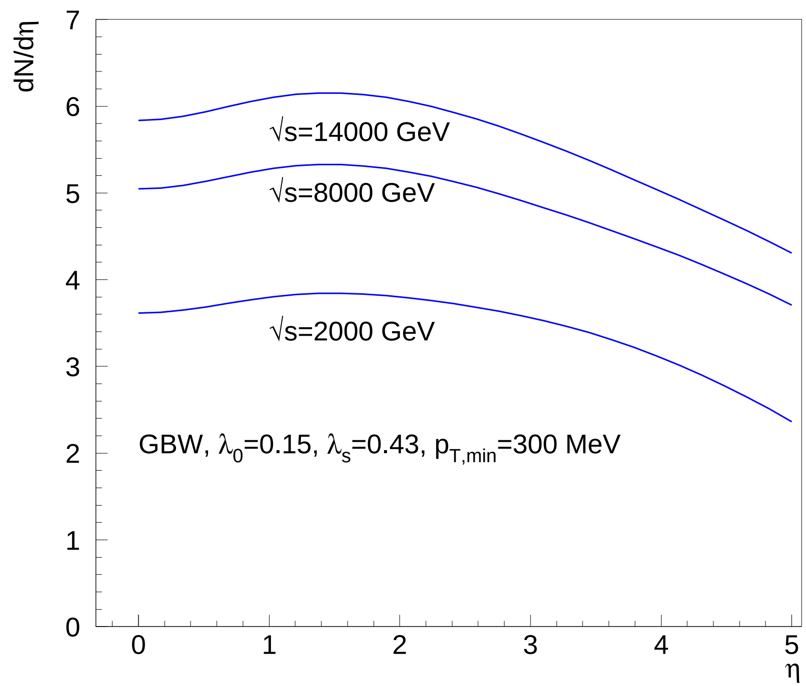
Gold-Gold central:



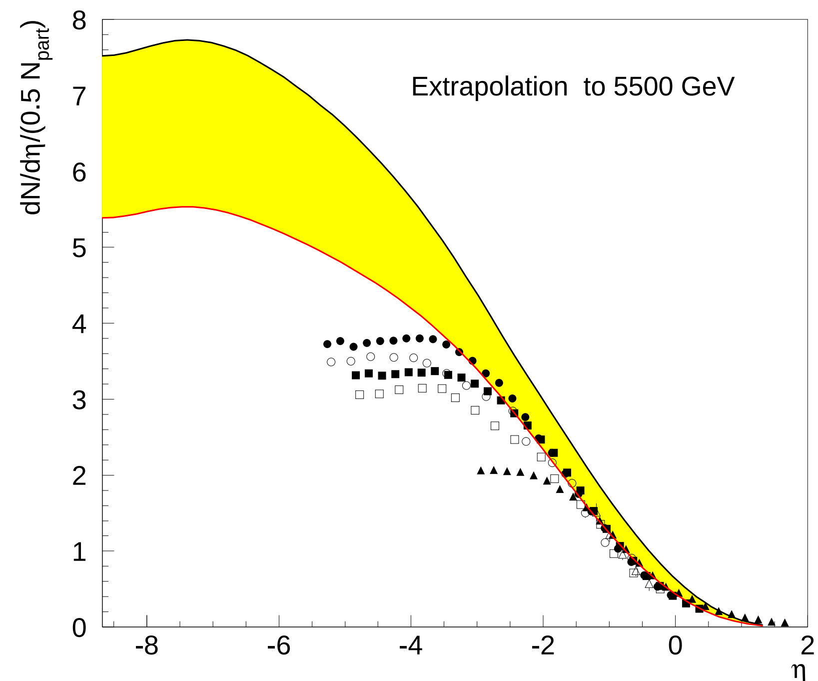
- Small violations of limiting fragmentation scaling due to the fact that in some models we do not have approximately scaling of $x_1 f(x_1)$.
- Additional uncertaintes due to $y \leftrightarrow \eta$ change and fragmentation functions.

Extrapolation to LHC

pp collisions:



AuAu central collisions:



Still there are many parameters: a lot of uncertainty in the predictions. Some models give violations of limiting fragmentation. For example McLerran-Venugopalan input $\phi_A(x_1, k_T)$ at large x_1 has too large tail in k_T.

Limiting fragmentation scaling is related to x_1 scaling at large x_1.

Conclusions:

- Factorization of parton distributions in target and projectile at large rapidities.
- The multiplicity distribution is directly proportional to the parton density in the target (i.e. gluon and quark density at large x) which is independent of the scales in the process, and consequently of the total c.m.s energy in the process.
- These models imply that the limiting fragmentation arises because the rapidity distribution of the produced particles is determined early in the scattering process, essentially by the form of the initial states.
- Caution: model has a lot of assumptions (factorization, extrapolation into soft region, parton-hadron duality, relatively large number of free parameters)
- Outlook: do we have limiting fragmentation at $7\ \mathrm{TeV}$ at LHC? Where does it break down?