Dynamics of small impact parameter pp collisions

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TeV-LHC workshop, February 4, 2005

Two ingredients crucial for building a realistic description of pp interactions at LHC energies:

- Realistic implementation of information about transverse structure of the parton distributions in nucleon - generalized parton distributions - studied at HERA in exclusive processes.

- Breakdown of the leading twist approximation for the interaction of partons up to rather large virtualities (approach to the black body limit). ***Problem*** *- current MC are forced to introduce a cutoff on minimal pt of the jets which is a strong function of energy.*

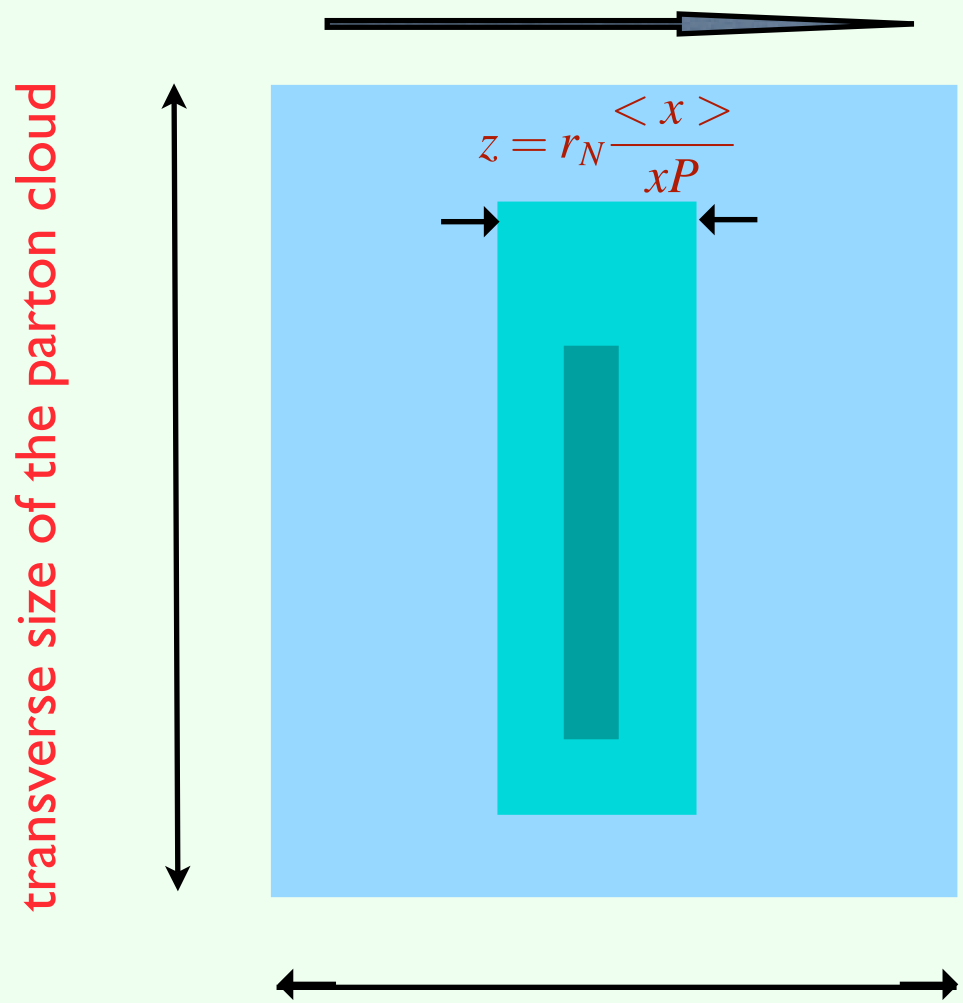
Another effect which maybe important:

transverse correlations between the partons

z-x cut of the fast nucleon

the rate of increase of transverse size with x decreases with increase of the resolution scale

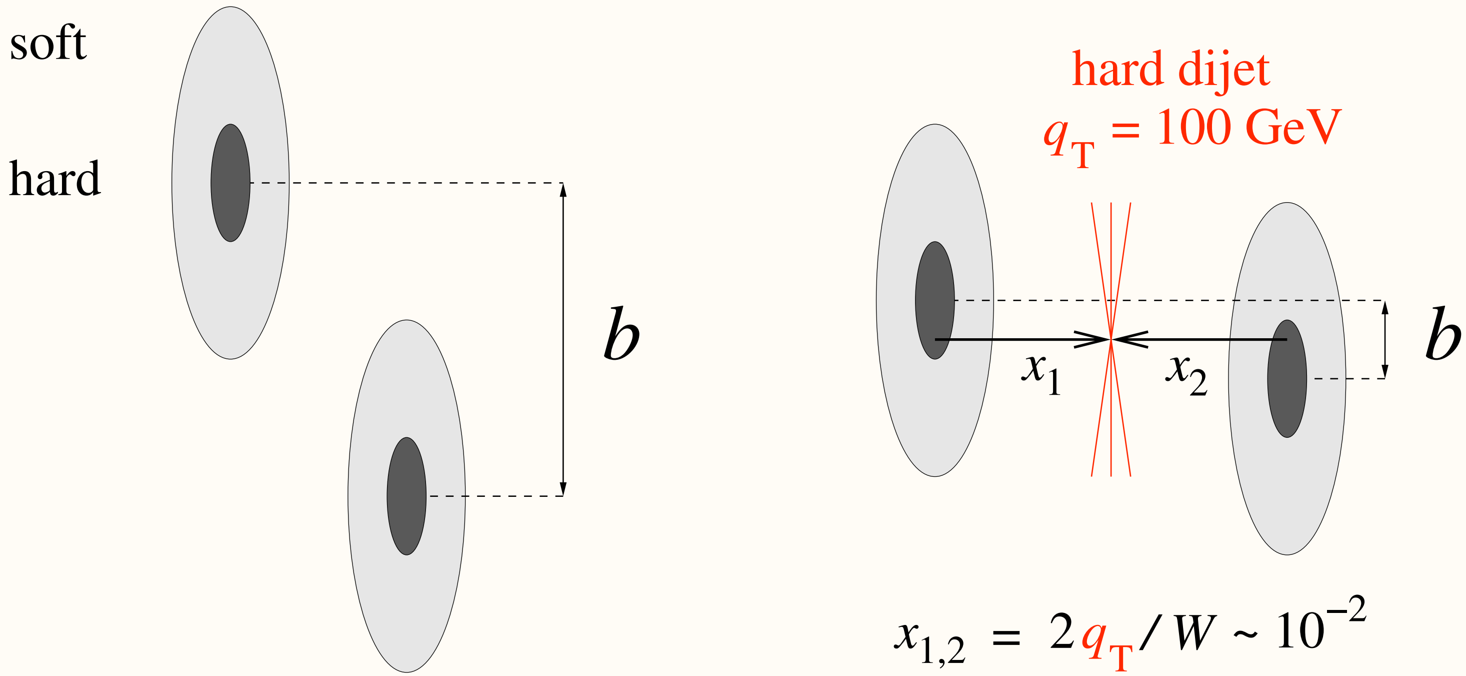
Momentum P in z direction



Transverse size of x>0.1 quarks and gluons is smaller than the average proton size due to the pion predominantly due to the pion cloud effects - Frankfurt, MS, Weiss

wee parton are spread over 1 fm even at high energies

Implication - hard processes correspond to collisions where nucleons overlap stronger & more partons hit each other - use hard collision trigger to study central collisions. New particle production corresponds to central collisions.



"peripheral"
(dominate total cross section)

"central"

Frankfurt, Strikman, Weiss, Phys.Rev. 69, 114010 (2004) [arXiv:hep-ph/0311231].

Impact parameter distribution in pp interaction

Study of the elastic scattering allows to determine how the strength of the interaction depends on the impact parameter, b:

$$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t)\,;\;\; ImA = s\sigma_{tot}\exp(Bt/2)$$

$$\sigma_{tot} = 2\int d^2b \mathrm{Re}\Gamma(s,b)$$

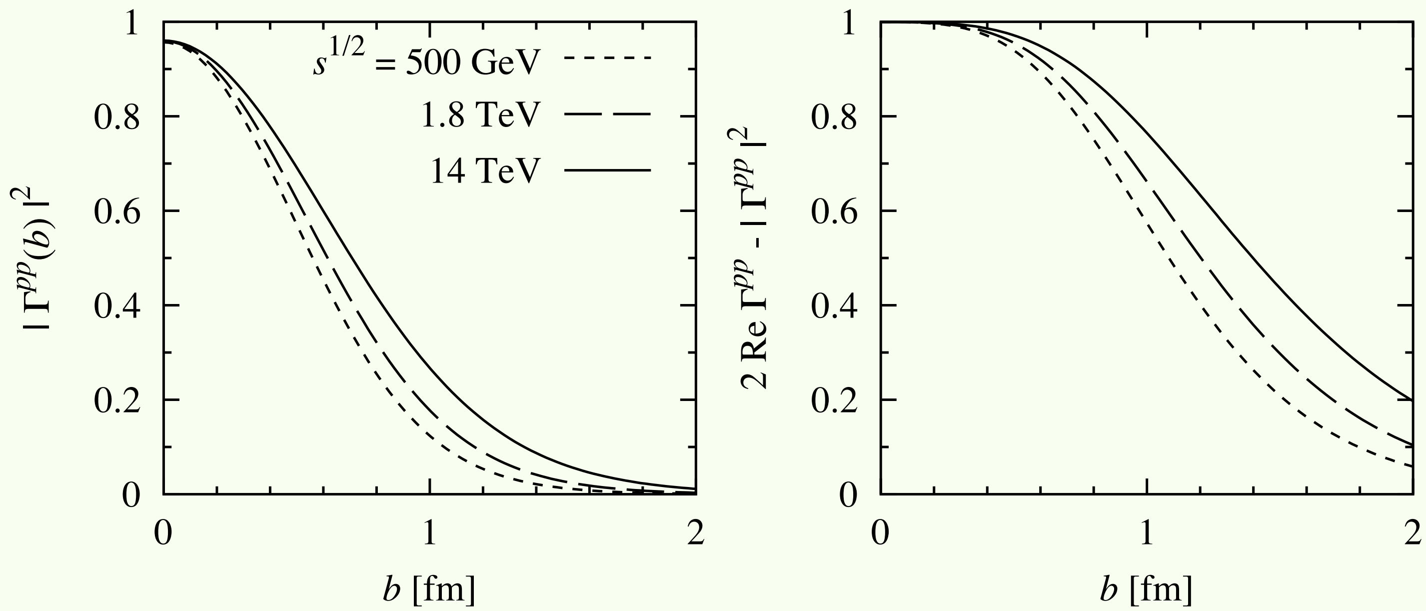
$$\sigma_{el} = \int d^2b|\Gamma(s,b)|^2$$

$$\sigma_{inel} = \int d^2b(1-(1-\mathrm{Re}\Gamma(s,b))^2 - [\mathrm{Im}\Gamma(s,b)]^2\,)$$

$$\Gamma(b) = 1 \;\equiv\; \sigma_{inel} = \sigma_{el}$$

- black body limit.

Note that elastic unitarity: $\frac{1}{2}ImA = |A|^2 + \ldots$ allows $\Gamma(b) \leq 2$

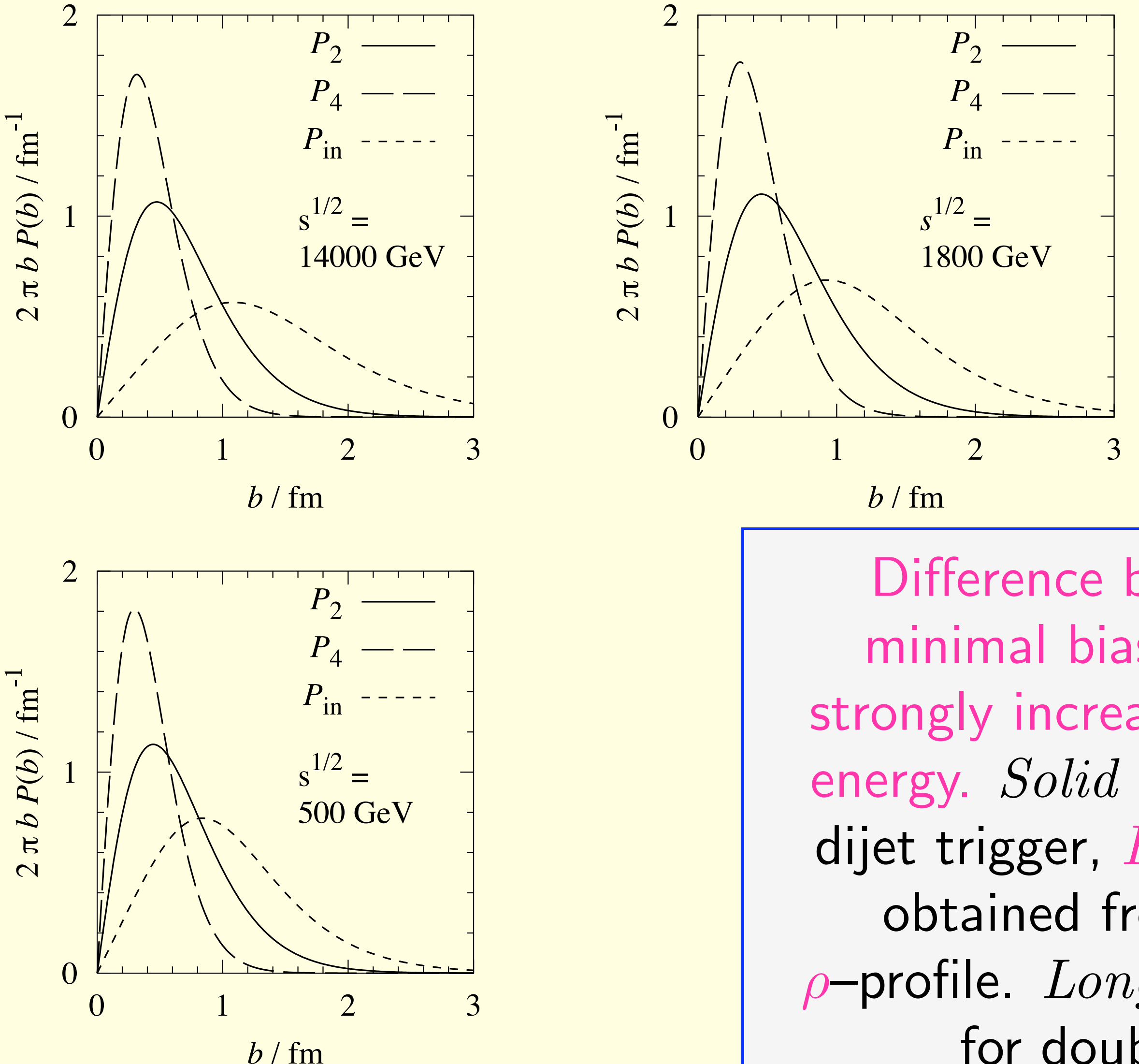


Calculation uses model of Islam et al; use of the model of Khoze et al leads to similar results.

Probability of inel. interaction:

$$P(b) = 2\,Re\Gamma(b) - |\Gamma(b)|^2$$

Using information on $\Gamma(s,b)$ and on generalized pdfs we can study dependence of b distribution on a trigger



Difference between b-distributions for minimal bias and dijet, four jet events strongly increases with increase of incident energy. *Solid lines:* b–distributions for the dijet trigger, $P_2(b)$, with $q_\perp = 25\,GeV$, as obtained from the dipole–type gluon ρ–profile. *Long–dashed line:* b–distribution for double dijet events, $P_4(b)$. *Short–dashed line*: b–distribution for generic inelastic collisions.

What happens when a parton goes through strong gluon fields? It will be resolved to its constituents if interaction is strong. To estimate the transverse momenta of the resolved system use a second parton as a regularization - consider the propagation of a small dipole of transverse size d, which interacts in LO pQCD with cross section:

$$\sigma_{inel} = \frac{\pi^2}{3} F^2 d^2 \alpha_s(\lambda/d^2) x G_T(x.\lambda/d^2)$$

F^2 Casimir operator of color SU(3)

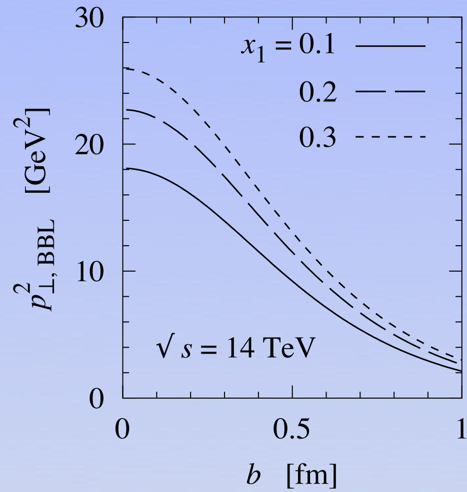
F^2 (quark) =4/3 F^2 (gluon)=3

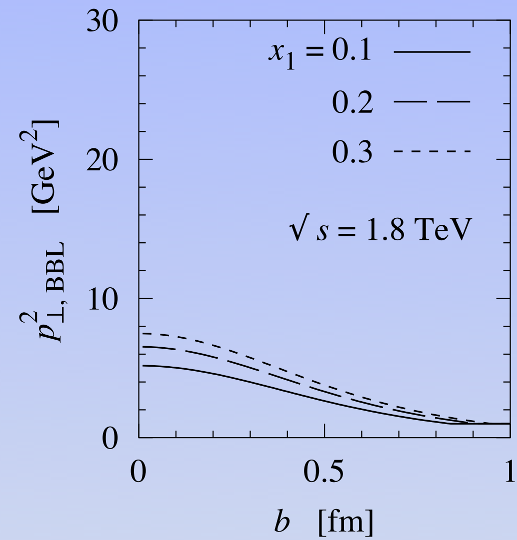
Let us estimate what average transverse momenta are obtained by a parton in the collision at a fixed b. Estimate involves several steps.

- Fixing fast parton's x (x_1) resolved by collision with partons in other proton
- Determining what minimal x are resolved in the second proton for given virtuality $x = \frac{4p_\perp^2}{x_1 s}, Q^2 = 4p_\perp^2$ $small\, x \leftrightarrow large\, x_1$
- for given ρ – distance of the parton from the center of another nucleon – determining maximum virtuality - minimal size of the dipole- d, for which Γ =0.5.
- converting from d to average $< p_\perp^2 >$

$p_\perp$ acquired by a spectator parton	$\approx$	Maximal $p_\perp$ for which interaction remains black for given x_1

- taking into account distribution over ρ for given b





$$P_{black} > P_{crit} \sim 0.5$$

The critical transverse momentum squared, below which the interaction of a leading gluon (momentum fraction x_1 with the other proton is close to the black body limit, as a function of the impact parameter of the pp collision, b. For leading quarks, the values of $p^2_{\perp,\mathrm{BBL}}$ are about half of those for gluons shown here. Shown are the estimates for LHC (left panel) and Tevatron energies (right panel).

Also, a spectator parton in the BBL regime loses a significant fraction of its energy *similar to electron energy loss in backscattering of laser off a fast electron beam.*

☺ In central pp collision at collider energies leading quarks get transverse momenta > 1 GeV/c

If a leading parton got a transverse momentum $p_\perp$

probability for a nucleon to remain intact is $P_q \sim F_N^2(p_\perp^2)$

If $\langle p_\perp \rangle > 1GeV/c \Longrightarrow P_q \ll 1/2$

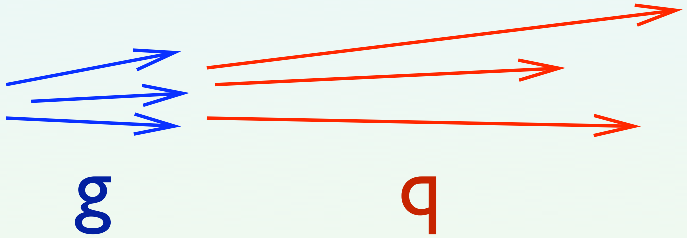
However there are three leading quarks (and also leading gluons) in each nucleon.

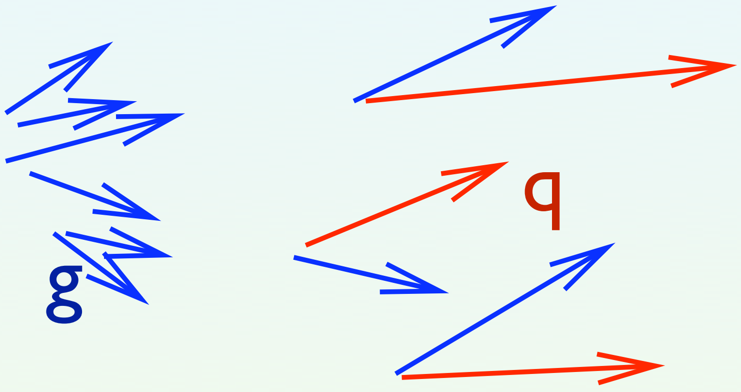
$\Rightarrow$ Probability not to interact $\equiv |1-\Gamma(b)|^2 \leq [P_q]^6 \sim 0$

☛ $$\Gamma(b\sim 0) = 1 \;!!!$$

Explains the elastic pp data for small b, predicts an increase of b range, $b<b_F$ where $\Gamma=0$, $b_F=c \ln s$ - Froissart regime.

Characteristics of the final state in the central pp collisions





fast partons in a nucleon before collisions

fast partons in a nucleon after central collisions

Qualitative predictions for properties of the final states with dijet trigger

- The leading particle spectrum will be strongly suppressed compared to minimal bias events since each parton fragments independently and splits into a couple of partons with comparable energies. The especially pronounced suppression for nucleons: for $z \geq 0.1$ the differential multiplicity of pions should exceed that of nucleons.

- A large fraction of the dijet tagged events will have no particles with $z \geq 0.02 - 0.05$. This suppression will occur simultaneously in both fragmentation regions, corresponding to the emergence of long--range rapidity correlations between the fragmentation regions ⇒ **large energy release at rapidities y=4 -6.**

- Average transverse momenta of the leading particles $\geq 1\ GeV/c$

Many similarities with expectations for spectra of leading hadrons in central pA collisions.

Implications for the searches of new heavy particles at LHC.

- Background cannot be modeled based on study of minimal bias events.

- Events with production of heavy particles should contain a significant fraction of hadrons with transverse momenta $p_\perp \sim p_{\perp,BBL}$ originating from fragmentation of partons which passed through by the strong gluon field. Transverse momenta of these hadrons are unrelated to the transverse momenta of the jets. Strong increase of multiplicity at central rapidities: a factor ~2 increase observed at FNAL, much larger at LHC.

$\Rightarrow$ Difficult to identify jets, isolated leptons,... unless $p_\perp\,(jet) \gg p_{\perp,BBL}$

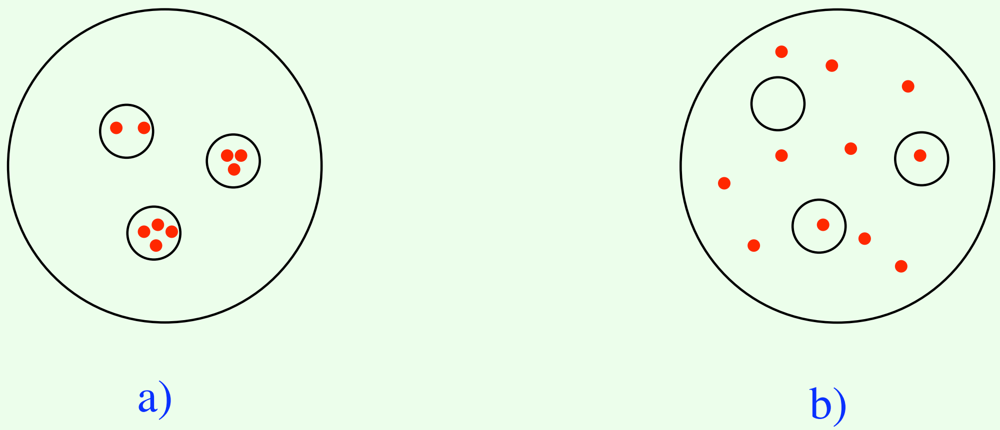
$\Rightarrow$ Significant corrections to the LT approximation results for total cross sections and small $p_\perp \leq p_{\perp,BBL}$ differential cross setions of new particle production.

Conclusions

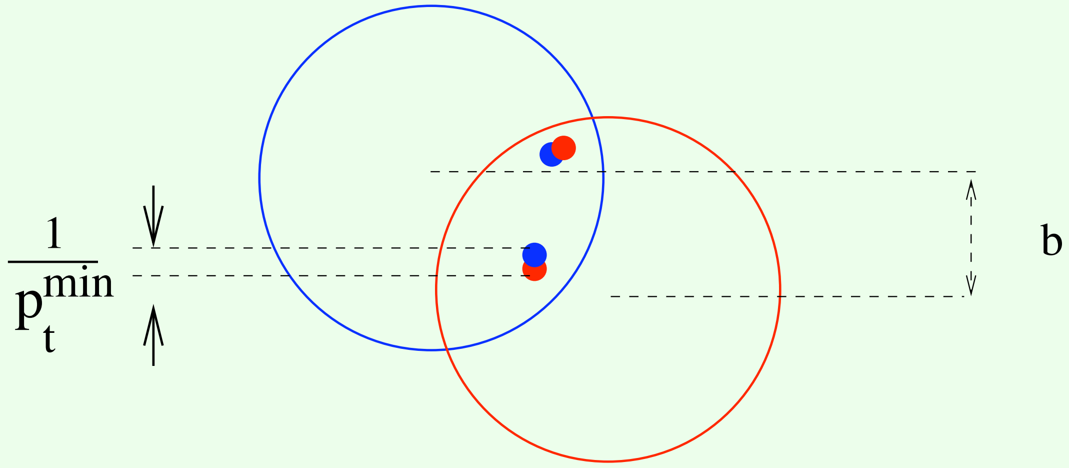
- ★ *Small x physics is an unavoidable component of the new particle physics production at LHC. Significant effects already for Tevatron.*
- ★ *Minijet activity in events with heavy particles should be much larger than in the minimum bias events or if it is modeled based on soft extrapolation from Tevatron.*
- ★ *Significant corrects for the LT predictions especially for moderate transverse momenta.*
- ★ *Double hard processes at Tevatron provides evidence for transverse correlations between partons. Maybe due to lumpy structure of nucleon at low scale (constituent quarks) [did not have time to discuss]. Further studies of transverse correlations are necessary both at Tevatron and at RHIC in pp and pA scattering to improve modeling of LHC event structure.*

Extras - on multiparton correlations.

Multi-jet production - study of parton correlations in nucleons



Where is the infinite number of primordial 'sea' partons in the infinite momentum state of the proton: inside the constituent quarks (a) or outside (b) ?



A view of double scattering in the transverse plane.

At high energies, two (three ...) pairs of partons can collide to produce multijet events which have distinctive kinematics from the process two partons → four partons.

Experimentally one measures the ratio

$$\frac{\frac{d\sigma(p+\bar{p}\rightarrow jet_1+jet_2+jet_3+\gamma)}{d\Omega_{1,2,3,4}}}{\frac{d\sigma(p+\bar{p}\rightarrow jet_1+jet_2)}{d\Omega_{1,2}}\cdot\frac{d\sigma(p+\bar{p}\rightarrow jet_3+\gamma)}{d\Omega_{3,4}}} = \frac{f(x_1,x_3)f(x_2,x_4)}{\sigma_{eff}f(x_1)f(x_2)f(x_3)f(x_4)}$$

where $f(x_1,x_3), f(x_2,x_4)$ longitudinal light-cone double parton densities and

σ_{eff} is ``transverse correlation area".

CDF observed the effect in a restricted x-range: two balanced jets, and jet + photon and found $\sigma_{eff} = 14.5 \pm 1.7^{+\,1.7}_{-\,2.3}\, mb$ rather small - a naive expectation is σ_{eff} ~ 60 mb indicating high degree of correlations between partons in the nucleon in the transverse plane. No dependence of σ_{eff} on x_i was observed.

Possible sources of small σ_{eff} for CDF kinematics of x ~0.1-0.3 include:

☺ Small transverse area of the gluon field --accounts for 50 % of the enhancement σ_{eff} ~ 30mb (F&S & Weiss 03)

☺ Constituent quarks - quark -gluon correlations (F&S&W)

If most of gluons are in constituent quarks of radius $r_q/r_N \sim 1/3$ found in the instanton liquid based chiral soliton model (Diakonov & Petrov) *the enhancement as compared to uncorrelated parton approximation is* $\frac{8}{9}+\frac{1}{9}\frac{r_N^2}{r_q^2}\sim 2$

Hence, combined these two effects are sufficient to explain CDF data.

☺ QCD evolution leads to "Hot spots" in transverse plane (A.Mueller). Hot spots do enhance multijet production as well. However this effect is likely not to be relevant in the CDF kinematics as x's are relatively large.