Multiparton interactions: from RHIC to LHC

Mark Strikman, PSU

Jlab 10/22/10

Based on several recent papers with B.Blok, Yu.Dokshitzer, L.Frankfurt, W.Vogelsang, C.Weiss

Studies of generalized parton distributions in nucleons
➜ information about transverse distribution of partons in nucleons

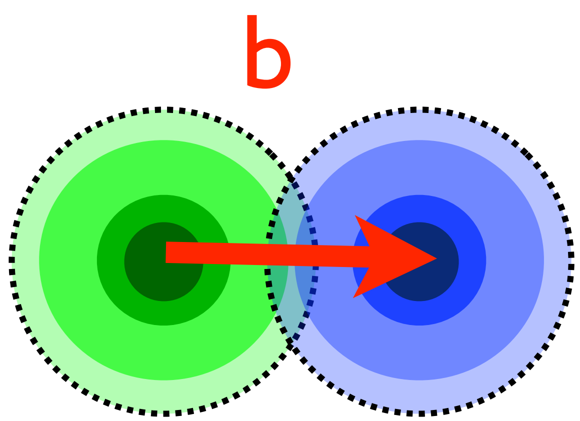
Information on properties of high energy pp collisions with hard triggers

High energy multiparton interactions

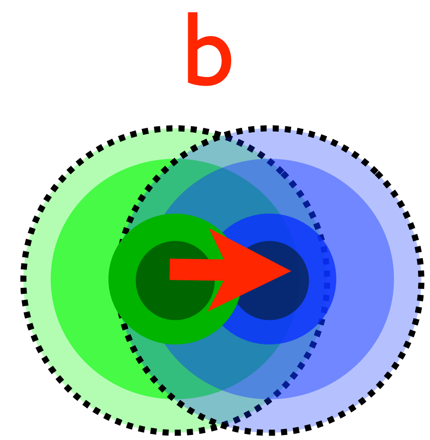
Correlation of partons in nucleons

Important characteristic of high energy collisions is the impact parameter of collision. Well defined since angular momentum is conserved and $L = bp$

Different intensity of interactions for small and large impact parameters



Peripheral pp collisions



Central pp collisions

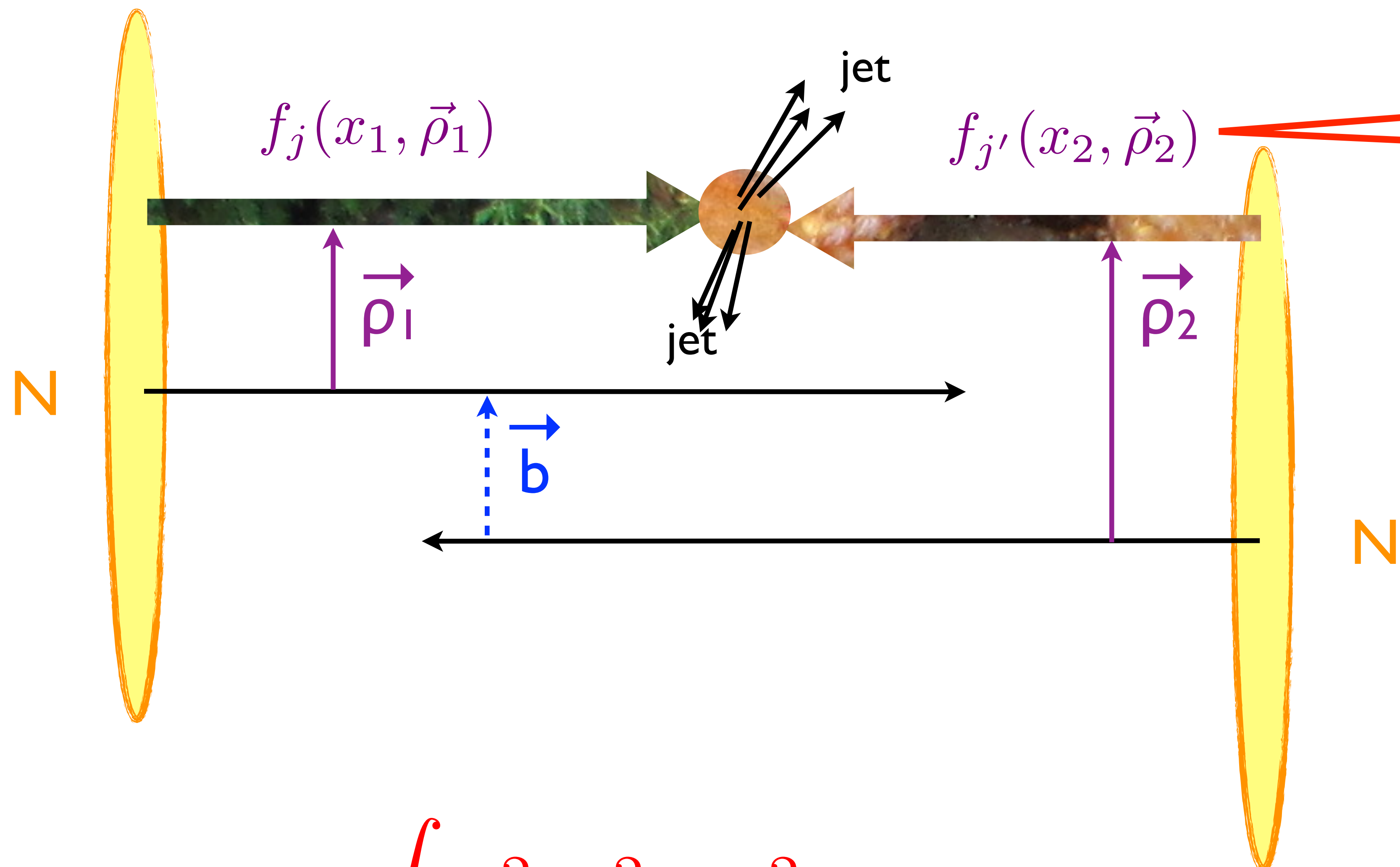
transverse view

Small b ➠ large overlap of parton densities

↓

Large probability of multiparton, soft/hard interactions

Geometry of pp collision with production of dijet in the transverse plane



Diagonal Generalized Parton distribution

For hard collision

$$\vec{\rho}_1 + \vec{b} - \vec{\rho}_2 \propto 1/p_{tjet} \sim 0$$

$$\sigma_h \propto \int d^2b d^2\rho_1 d^2\rho_2 \delta(\rho_1 + b - \rho_2) f_1(x_1, \rho_1) f_2(x_2, \rho_2) \sigma_{2\to 2}$$

$$= \int d^2\rho_1 d^2\rho_2 f_1(x_1, \rho_1) f_2(x_2, \rho_2) \sigma_{2\to 2} = f_1(x_1) f_2(x_2) \sigma_{2\to 2}$$

For inclusive cross section at high virtuality *transverse structure does not matter* - convolution of parton densities

⇓

Ignored by many pQCD people

Build into many current MC's of pp collisions at LHC/ Tevatron, cosmic rays at highest energies (GZK) - but <u>does not include constrains on the transverse structure of the nucleon originating from HERA studies.</u>

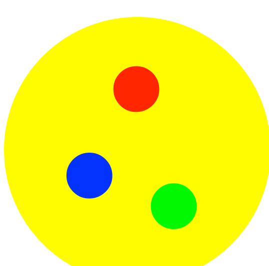
Critical for interpretation of structure of the events with dijets at the colliders, multiple collisions. Multiparton interactions have significant probability at Tevatron and large probability at LHC - *rates scale as 1/(transverse area occupied by partons), depend on the shape of the transverse distribution and on the degree of the overlap.*

First quantitative analysis including information on the transverse structure from HERA -

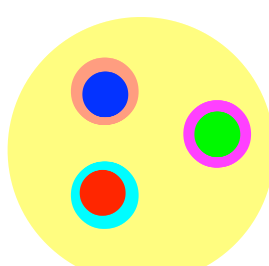
Frankfurt, MS, Weiss, 2003

Goals for colliders - realistic account of the transverse structure of the nucleon, the global structure of the events with Higgs, SUSY,...

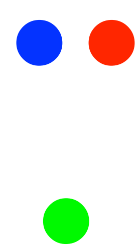
Goals for nucleon structure - probing correlations between quarks, gluons, ...; Distinguish



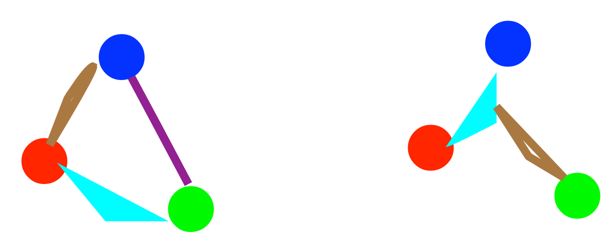
MIT bag



Constituent quark model with localized gluon fields

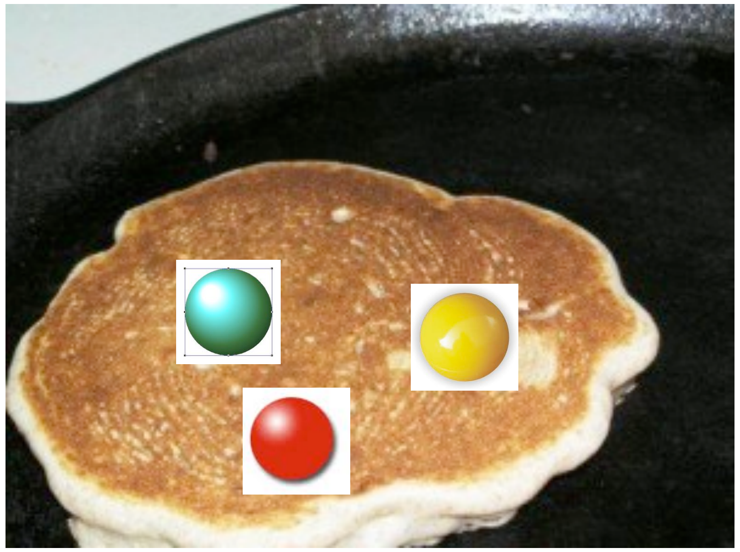


quark - diquark

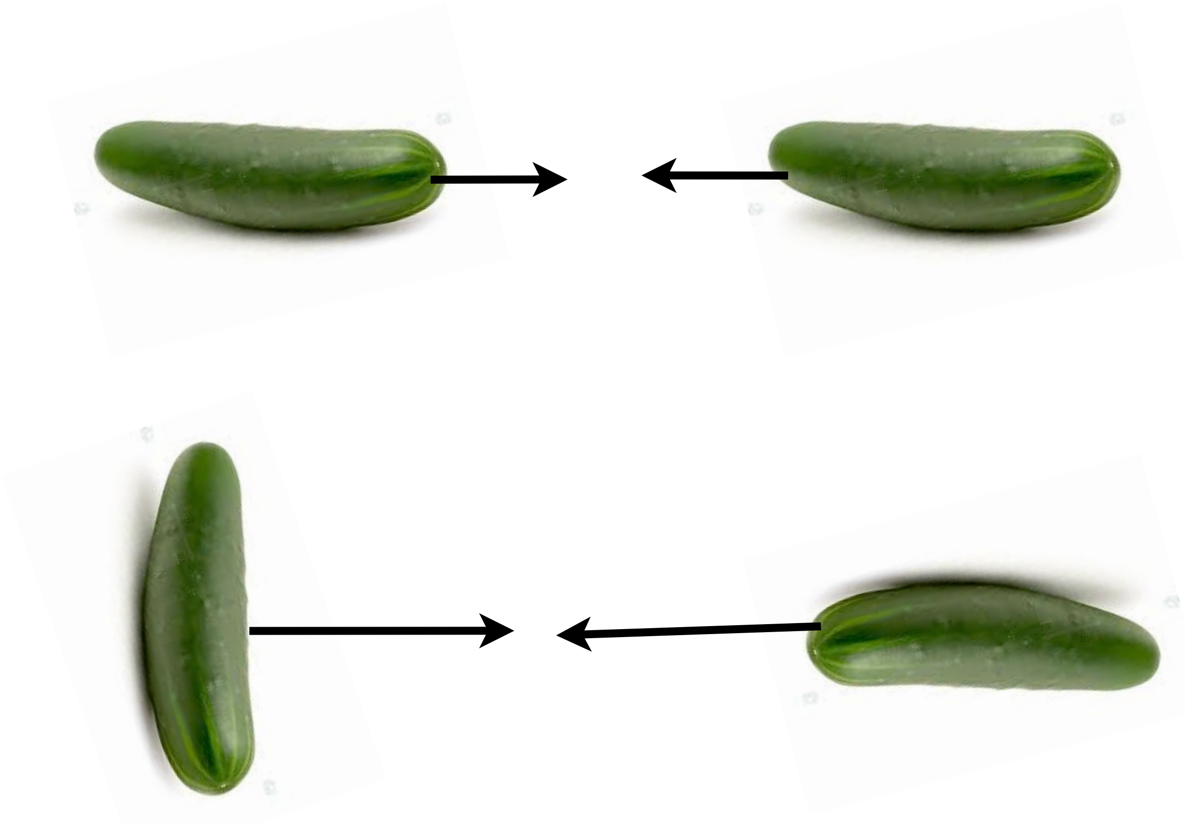


String models

Can nucleon look as a pancake?



Does it make a difference?



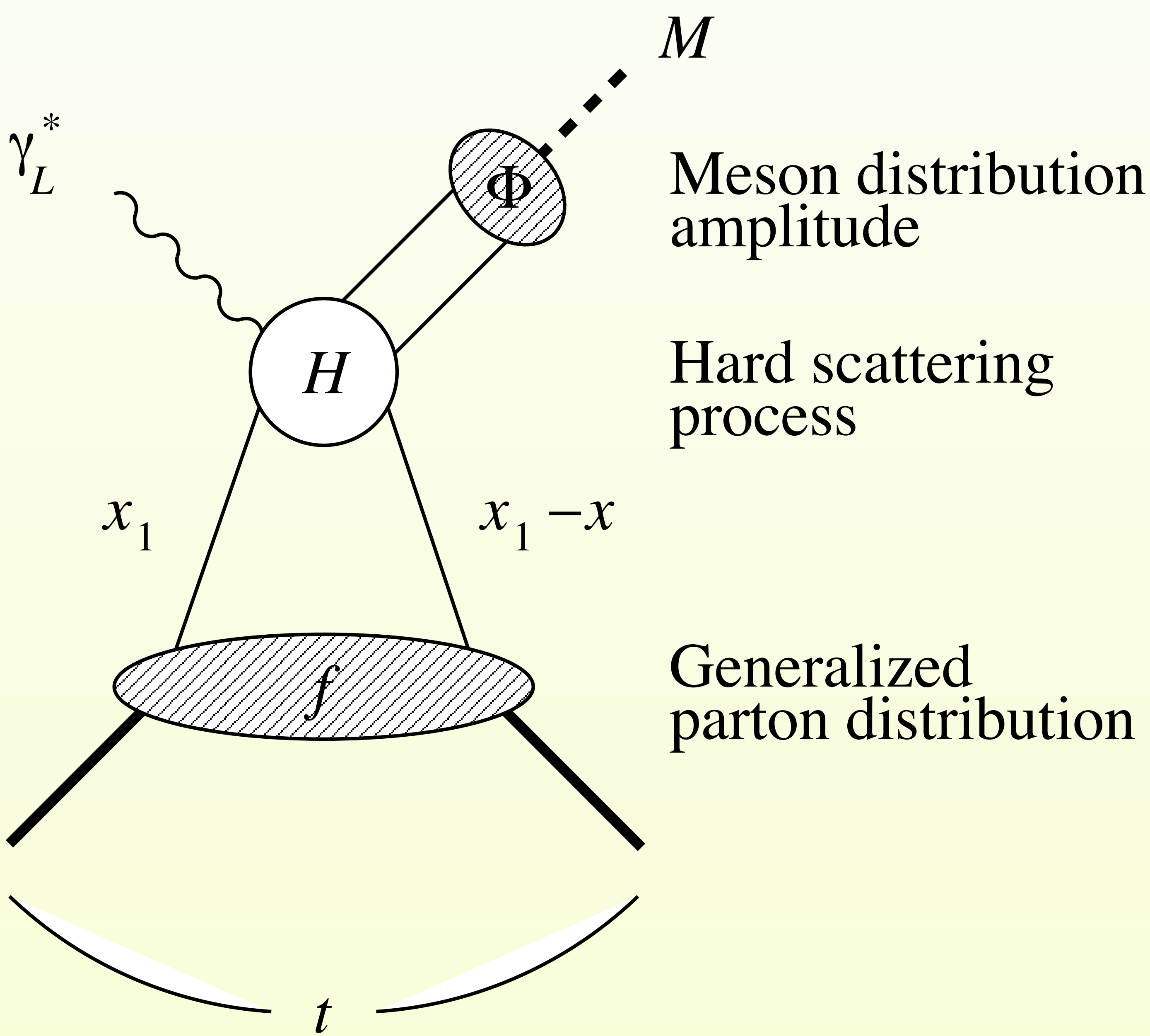
or a cucumber?

Very different fluctuations of final states - can easily explain CMS ridge

A tool to learn about transverse parton distributions:

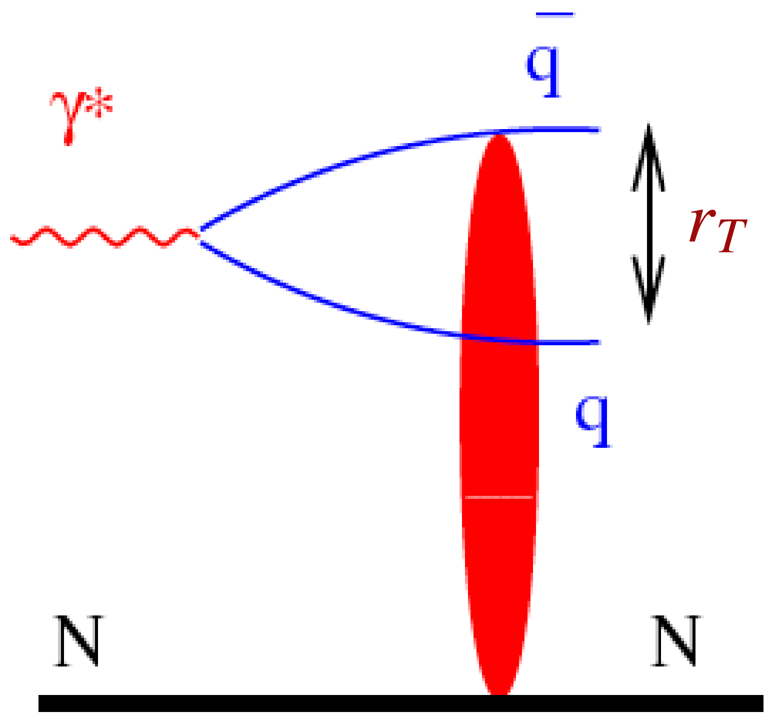
QCD factorization theorem for DIS exclusive meson production

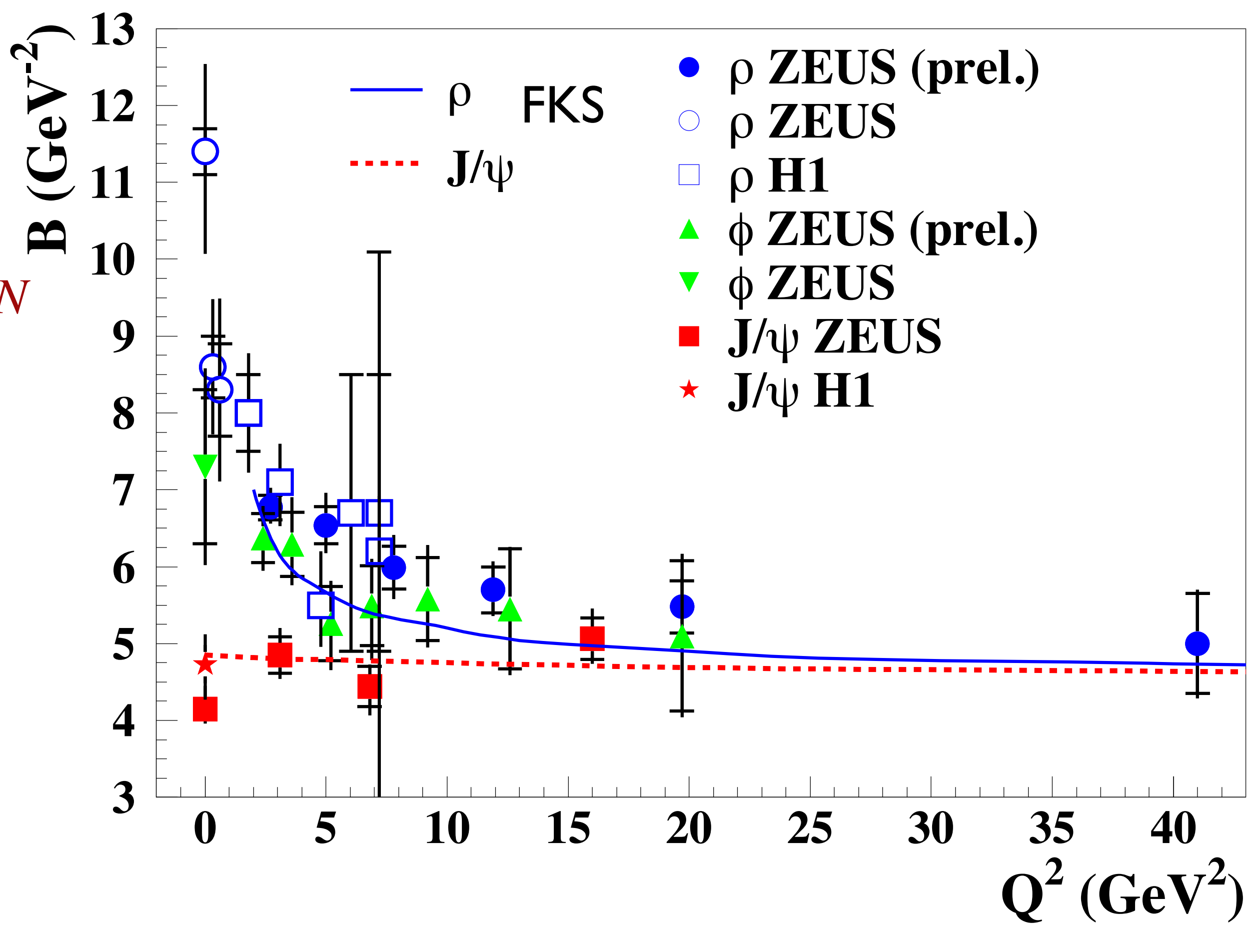
(Brodsky,Frankfurt, Gunion,Mueller, MS 94 - vector mesons, small x; general case Collins, Frankfurt, MS 97)



- Universal t-slope: process is dominated by the scattering of quark-antiquark pair in a small size configuration - t-dependence is predominantly due to the transverse spread of the gluons in the nucleon - two gluon nucleon form factor, $F_g(x,t)$. $d\sigma/dt \propto F_g^2(x,t)$.

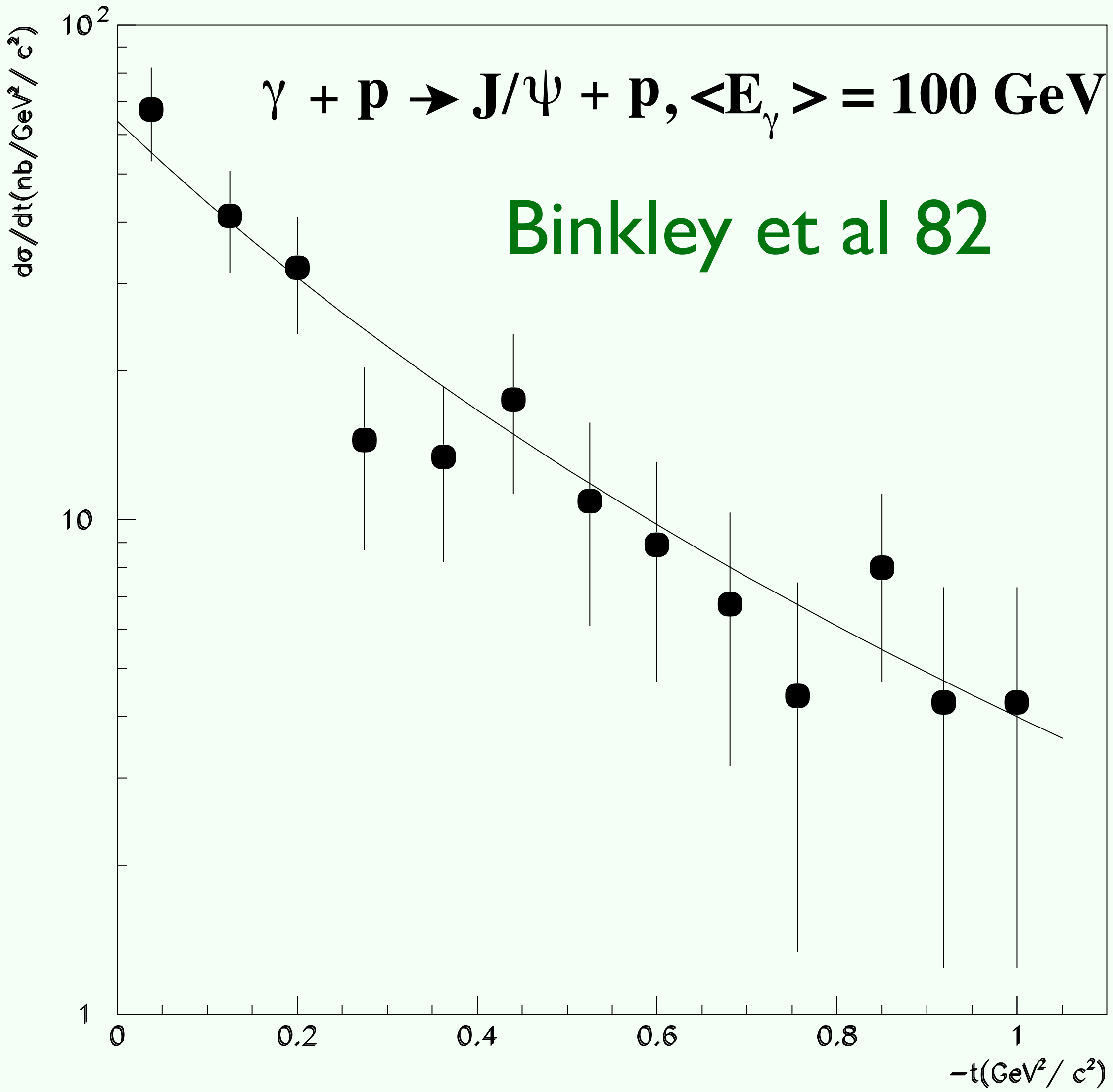
Onset of universal regime FKS[Frankfurt,Koepf, MS] 97.





Convergence of the t-slopes, (B - $\frac{d\sigma}{dt} = A\exp(Bt)$),
of ρ-meson electroproduction to the slope of
J/ψ photo(electro)production.

⇒ Transverse distribution of gluons can be extracted from $\gamma + p \to J/\psi + N$



Theoretical analysis of J/ψ photoproduction at $100\ GeV \geq E_\gamma \geq 10\ GeV$ corresponds to the two-gluon form factor of the nucleon for $0.03 \leq x \leq 0.2,\ Q_0^2 \sim\ 3\ GeV^2, -t \leq 2\ GeV^2$

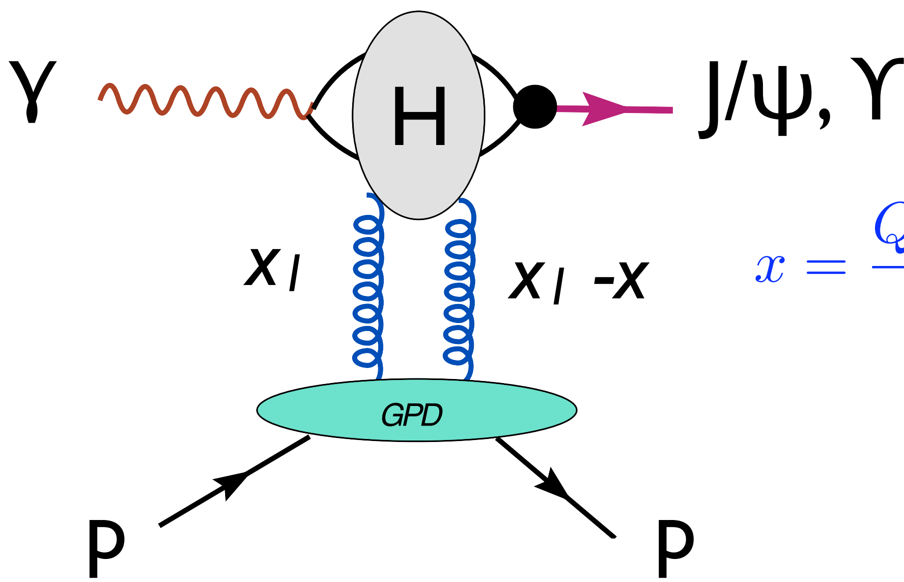
$$F_g(x,Q^2,t) = (1-t/m_g^2)^{-2}.\ m_g^2 = 1.1\ GeV^2$$

which is larger than e.m. dipole mass

$$m_{e.m.}^2 = 0.7\ GeV^2.$$ (FS02)

A part of the difference is due to the chiral dynamics - lack of scattering off the pion field at x>0.05 (Weiss &MS 03)

Enters into calculation of the gap survival probability in the double Pomeron exclusive Higgs production in a very sensitive way



$$x = \frac{Q^2 + m_V^2}{W^2}$$

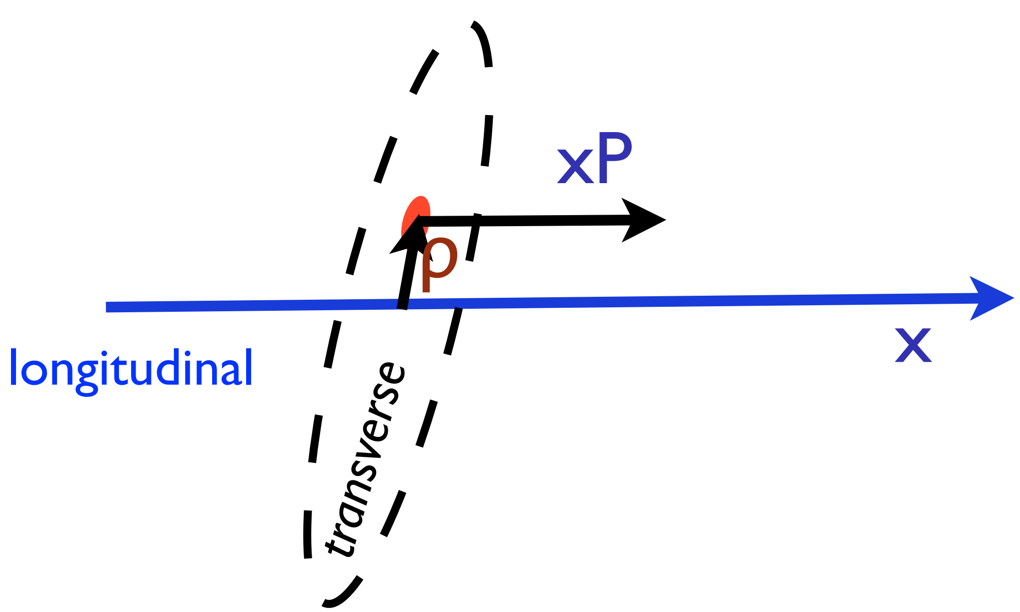
In LT limit $x_1 - x \ll x_1$

however due to DGLAP evolution skewed GPD kinematics for large Q probes diagonal GPD at Q_0 scale

$$A(\gamma^* + p \to \text{"}Onium\text{"} + p) \propto G(x_1, x1 - x, t)$$

$$G(x,x,t) \equiv G(x,t) = \int d^2\rho e^{-i\vec{\Delta}_\perp \rho} G(x,\rho)$$

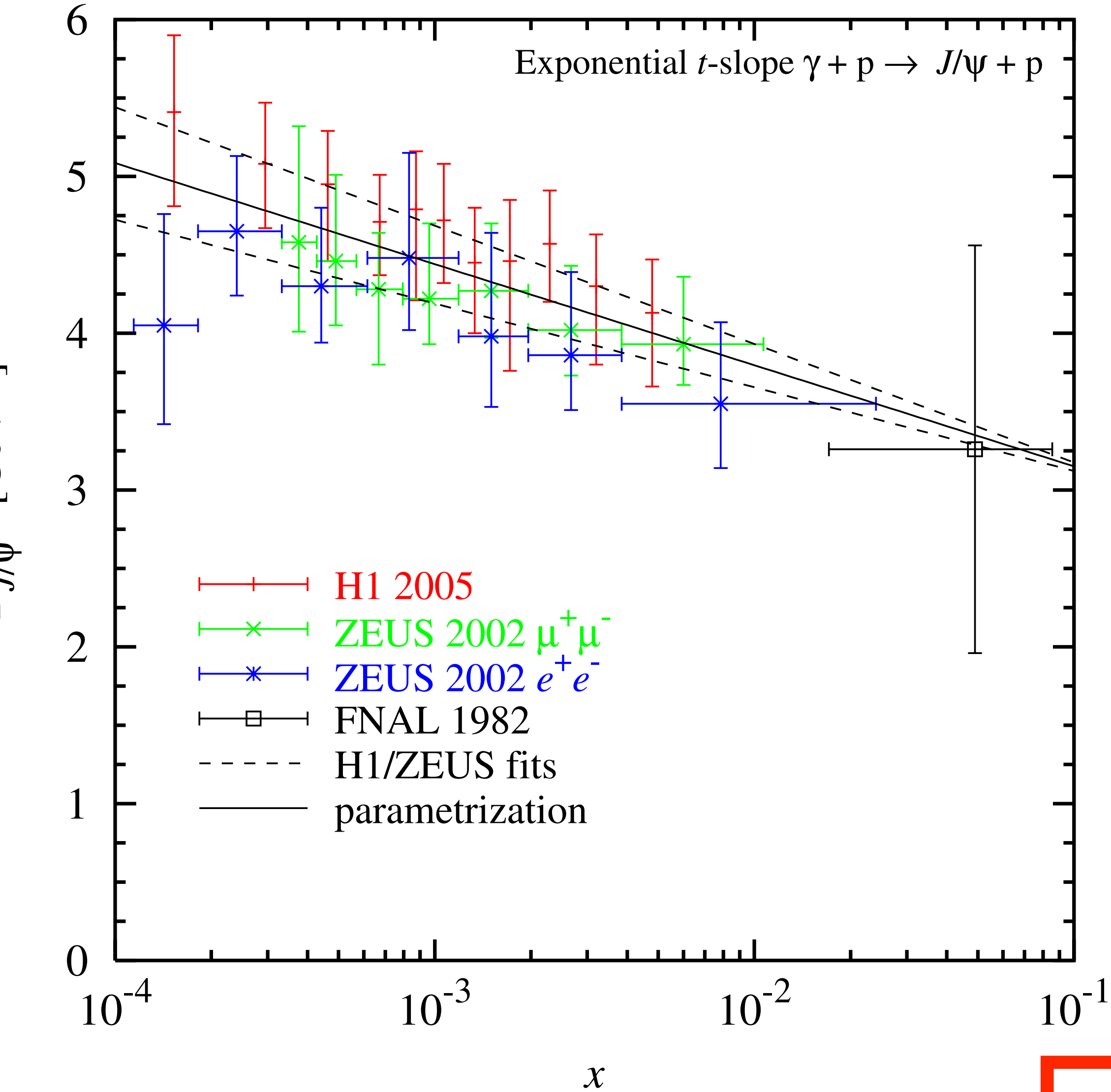
transverse spatial distribution of gluons



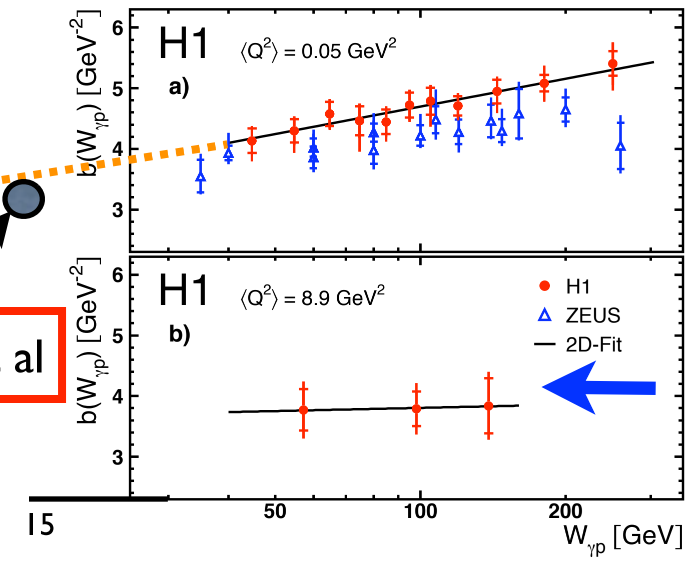
$$\int d^2\rho G(x,\rho) = G(x)$$

total gluon density

J/ψ elastic photo and electro production

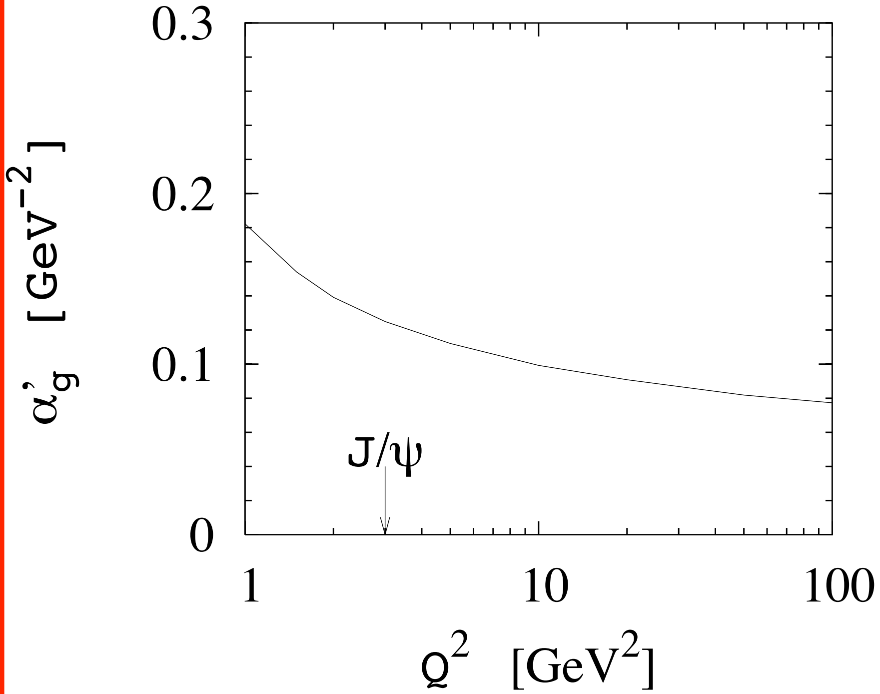


$$B = B(W_0) + 2\alpha' \ln(W^2/W_0^2)$$



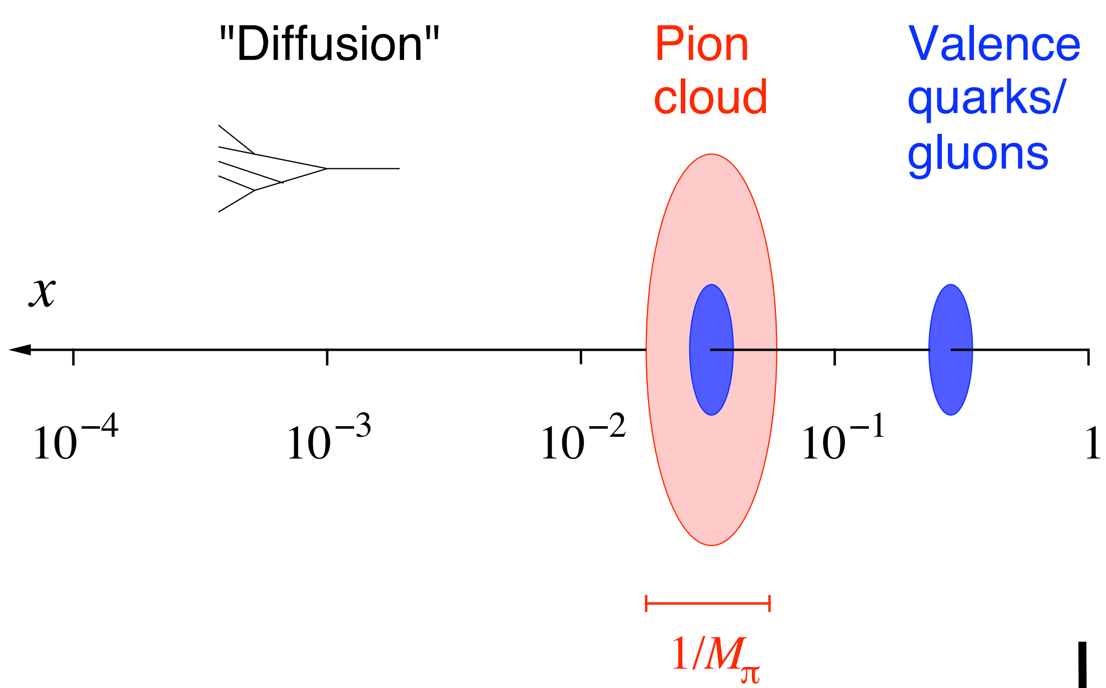
α' – consistent with zero!!!

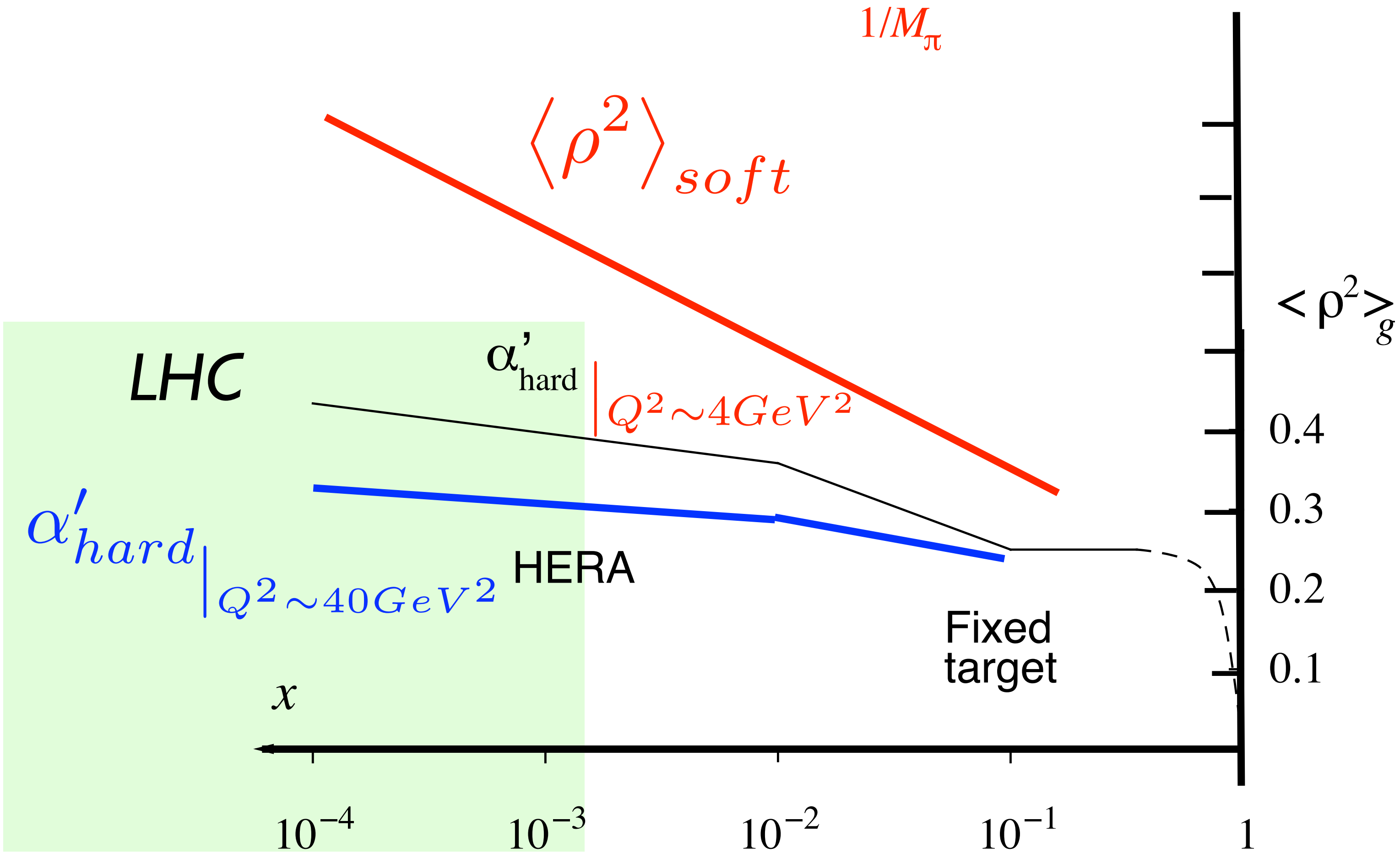
t-slope for J/ψ especially at Q^2=9 GeV^2 is systematically lower than for DVCS and for ρ - production



pQCD (DGLAP approximation) - rather weak Q evolution of α' - Frankfurt, MS, Weiss

Gluonic transverse size - x dependence





Can be measured in ultraperipheral collisions at LHC

Gluon transverse size decreases with increase of x

Pion cloud contributes for $x<M_\pi/M_N$ [MS &C.Weiss 03]

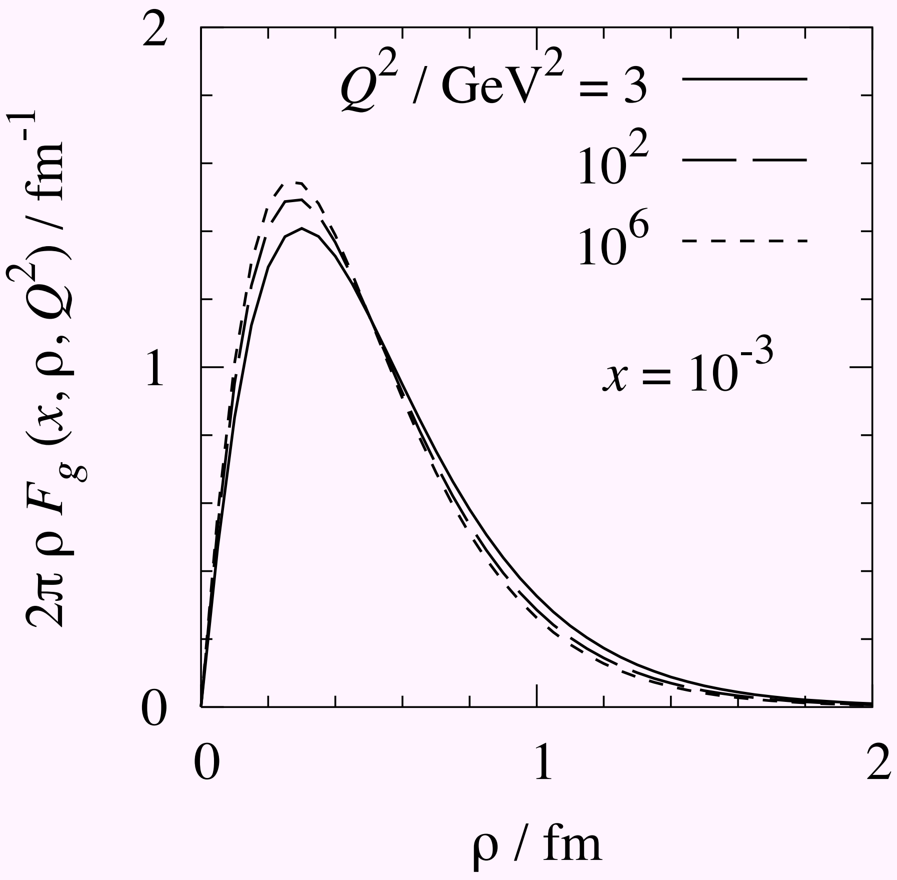
Transverse size of large x partons is much smaller than the transverse range of soft strong interactions

$$\langle\rho^2\rangle_g = \frac{\partial}{\partial t}\frac{G(x.t)}{G(x,0)}$$

$$\langle\rho^2(x>10^{-2}\rangle \ll R^2_{soft}$$

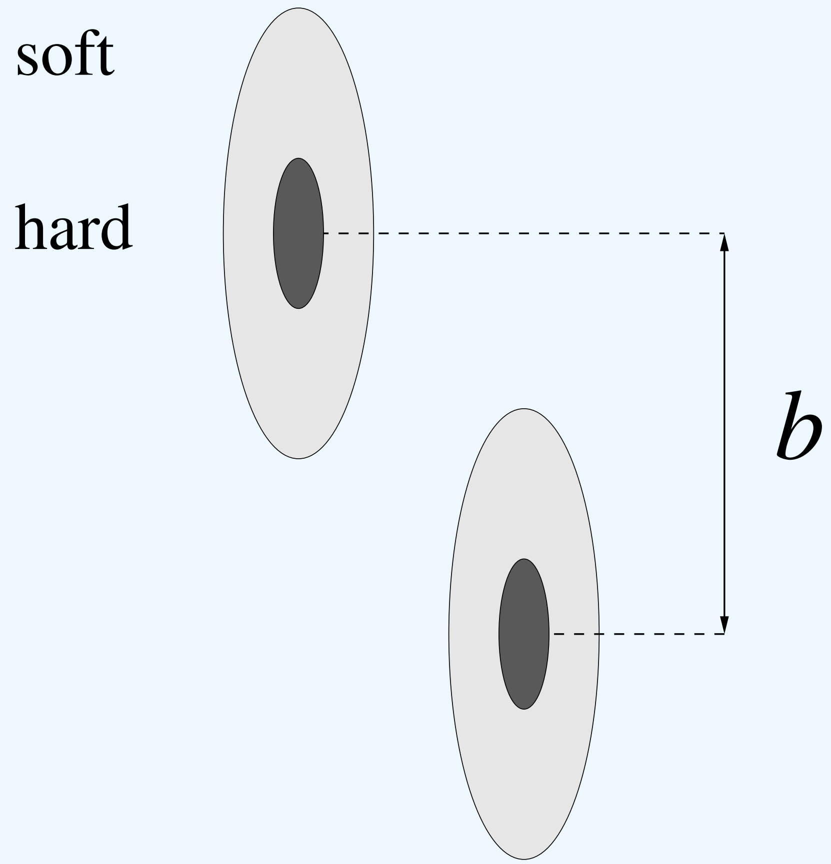
$\Downarrow$

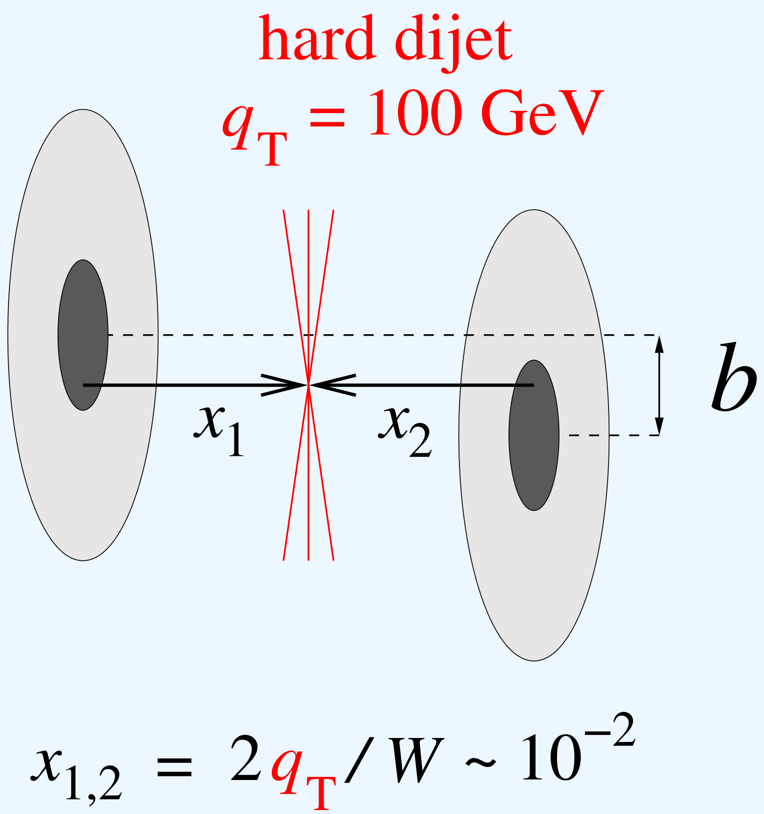
Two scale picture



The change of the normalized ρ–profile of the gluon distribution, $F_g(x, \rho; Q^2)$, with Q^2, as due to DGLAP evolution, for $x = 10^{-3}$. The input gluon distribution is the GRV 98 parameterization at $Q_0^2 = 3\,GeV^2$, with a dipole–type b–profile.

Implication - hard processes correspond to collisions where nucleons overlap stronger & more partons hit each other - use hard collision trigger to study central collisions/ all new physics LHC craves to discover corresponds to central pp collisions.





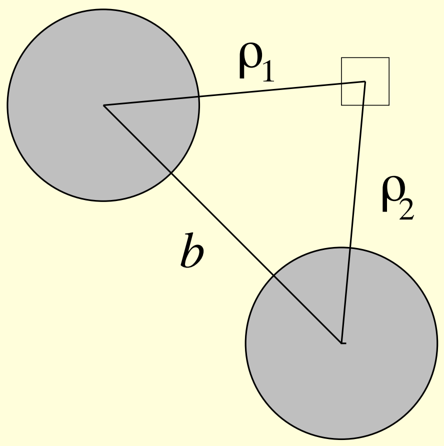
"peripheral"
(dominate total cross section)

"central"

Impact parameter distribution for a hard multijet trigger.

For simplicity take $x_1 = x_2$ for colliding partons producing two jets with $x_1 x_2 = 4q_\perp^2/s$. Answer is not sensitive to a significant variation of x_i for fixed $q_\perp$.

The overlap integral of parton distributions in the transverse plane, defining the b–distribution for binary parton collisions producing a dijet follows from the figure:



Hence the distribution of interactions over b for events with dijet trigger (Higgs production,...) is given by

$$P_2(b) = \int d^2\rho_1 \int d^2\rho_2 \delta^{(2)}(\vec{b} - \vec{\rho}_1 + \vec{\rho}_2) F_g(x_1, \rho_1) F_g(x_2, \rho_2),$$

$$F_g(x, \rho) = \frac{m_g^2}{2\pi} \left(\frac{m_g \rho}{2}\right) K_1(m_g \rho)$$

for $$F_g(x, t) = 1/(1 - t/m_g(x)^2)$$

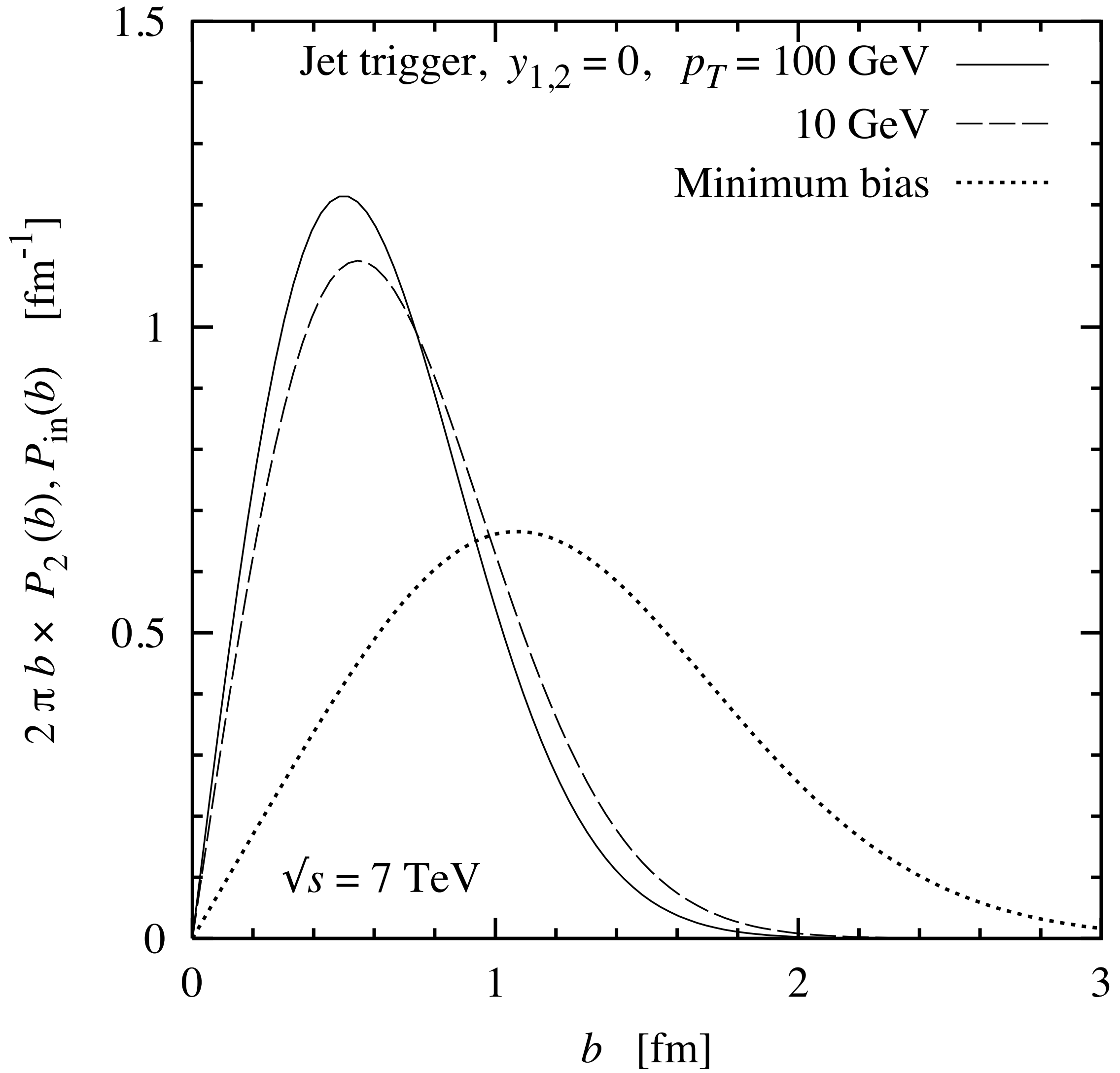
$$P_2(b) = \frac{m_g^2}{12\pi} \left(\frac{m_g b}{2}\right)^3 K_3(m_g b)$$

Need to compare with b-distribution for minimal bias (generic) inelastic pp scattering

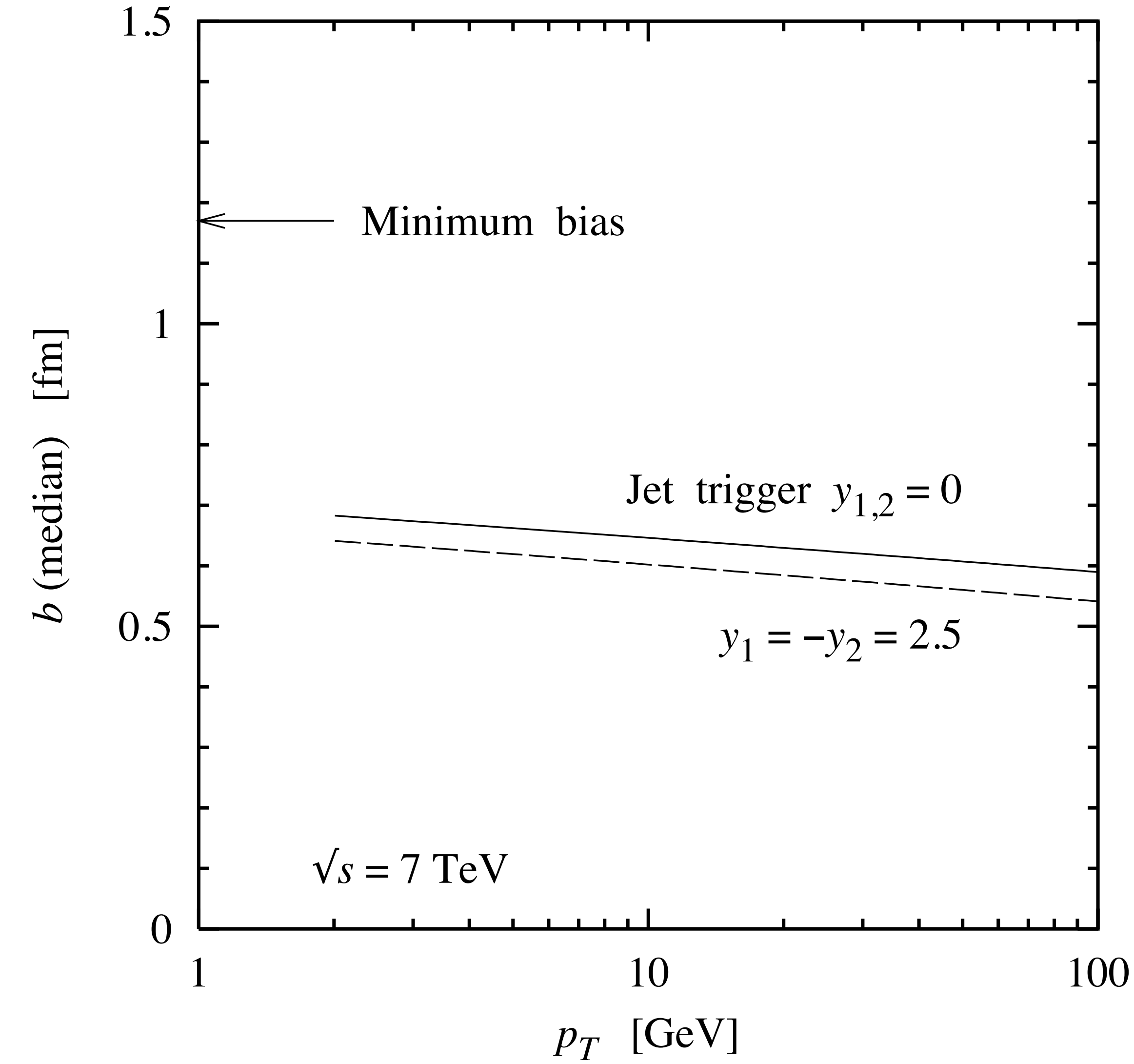
$$P_{in}(s,b) = \frac{2Re\,\Gamma^{pp}(s,b) - |\Gamma^{pp}(s,b)|^2}{\sigma_{in}(s)}$$

where $$\Gamma_h(s,b) = \frac{1}{2is}\frac{1}{(2\pi)^2}\int d^2\vec{q}e^{i\vec{q}\vec{b}}A_{hN}(s,t)$$

$\Gamma(b) = 1 \equiv \sigma_{inel} = \sigma_{el}$ - black disk regime (BDR).



Impact parameter distributions of inelastic pp collisions at $\sqrt{s}$ = 7TeV. Solid (dashed) line: Distribution of events with a dijet trigger at zero rapidity, $y_{1,2} = 0$, c, for p_T = 100 (10) GeV . Dotted line: Distribution of minimum–bias inelastic events

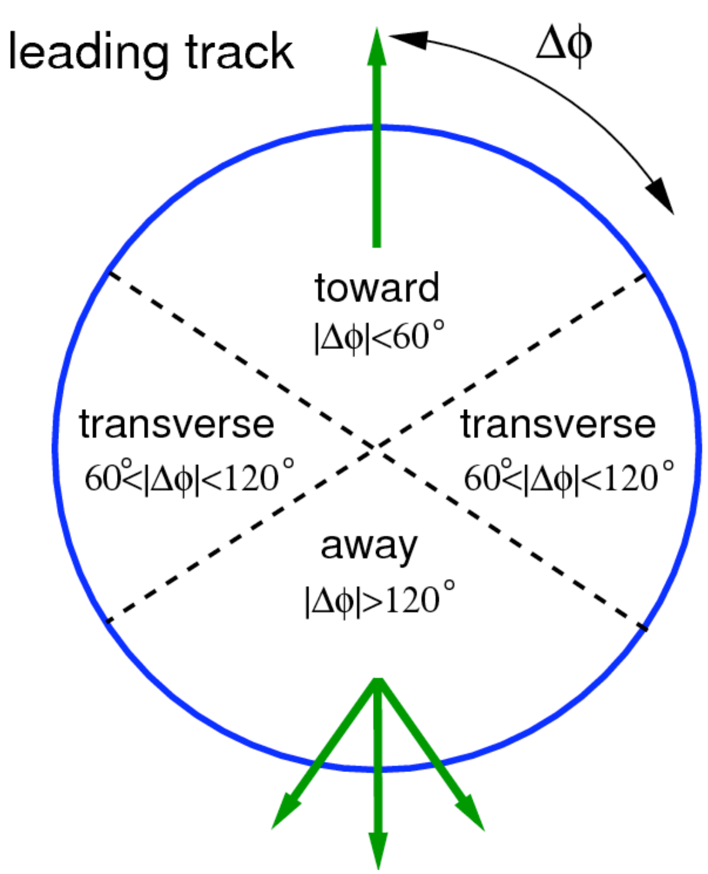


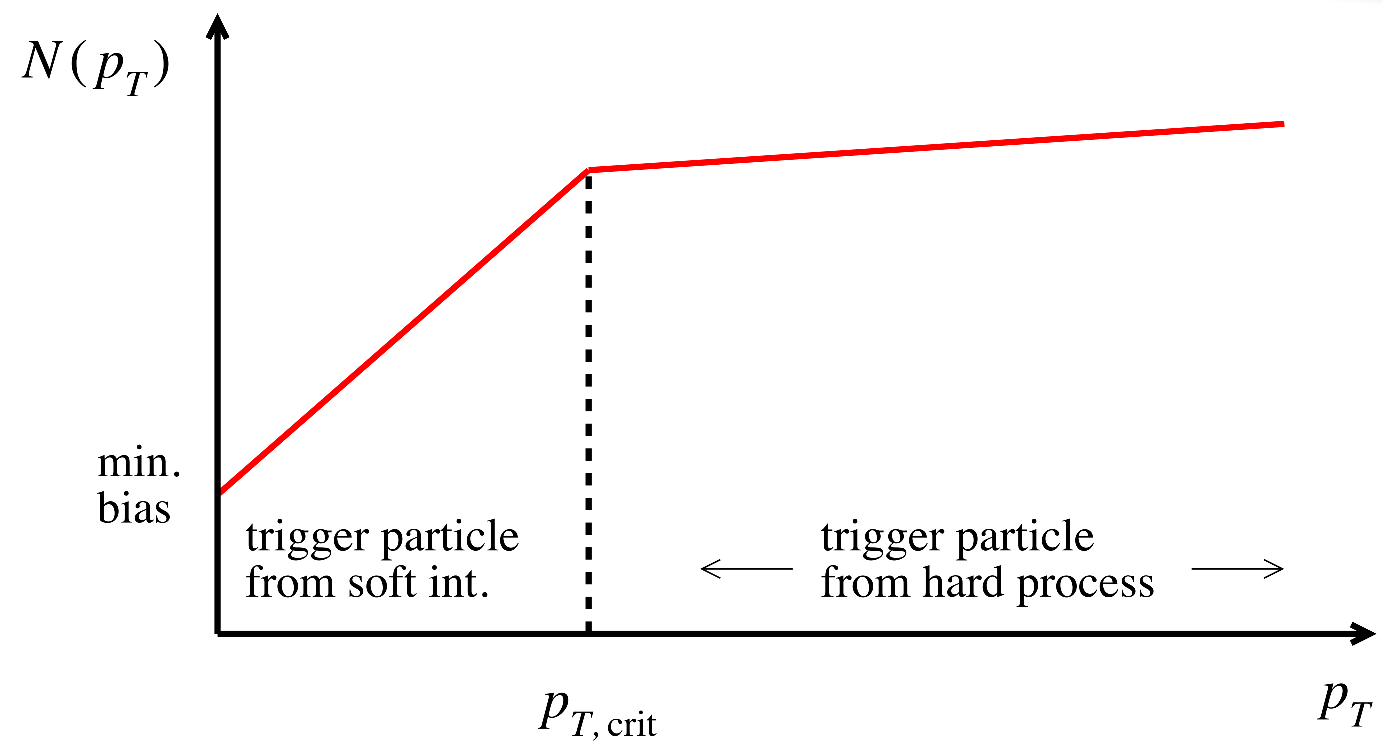
Median impact parameter b(median) of events with a dijet trigger, as a function of the transverse momentum p_T , cf. left plot. Solid line: Dijet at zero rapidity $y_{1,2} = 0$. Dashed line: Dijet with rapidities $y_{1,2} = \pm 2.5$. The arrow indicates the median b for minimum–bias inelastic events.

Much smaller impact parameters for hard dijet trigger

Impact parameters for hard dijet triggers with different rapidities, p_t's are practically the same

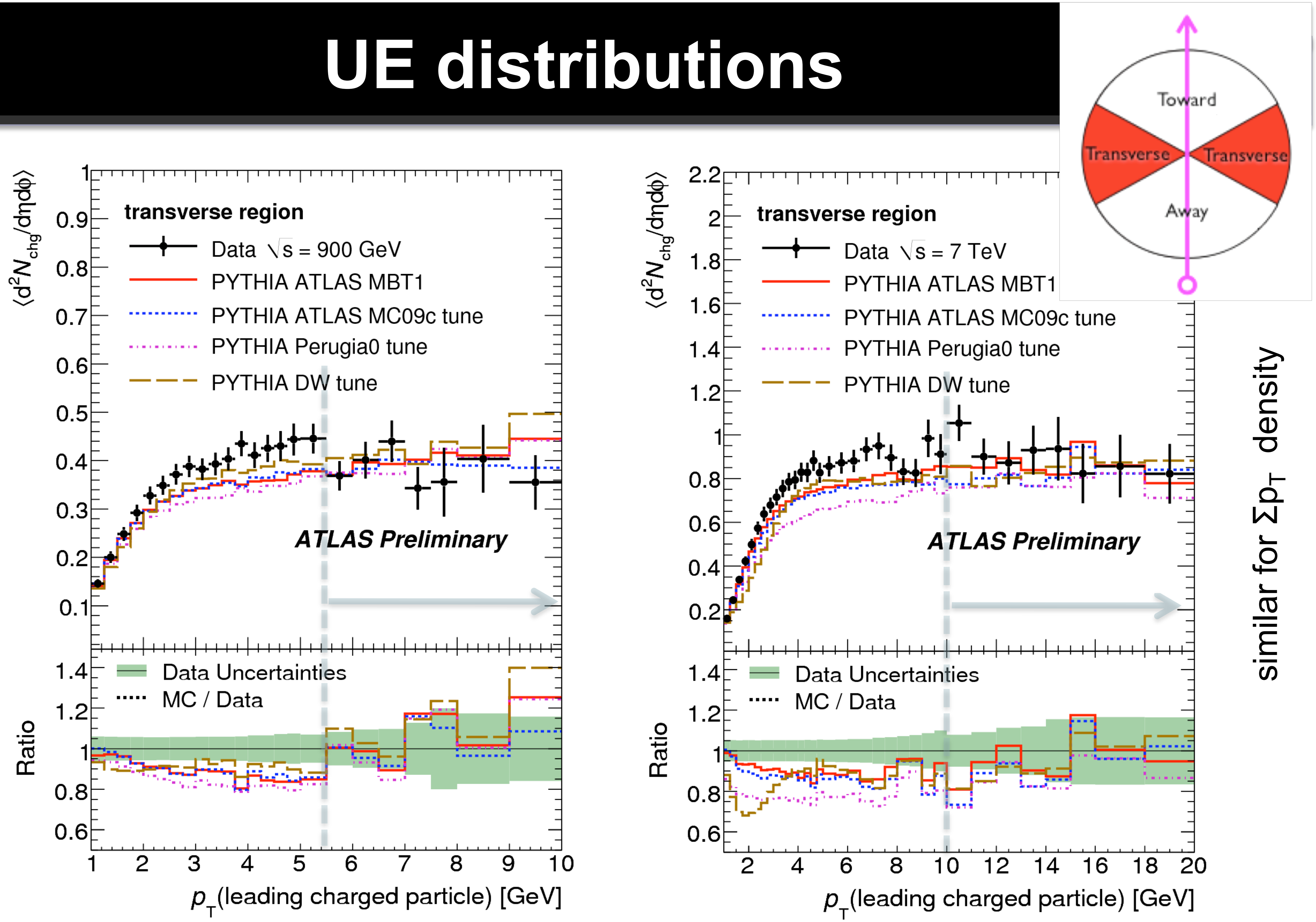
Universal underlying event for dijet triggers which is much higher than for minimal bias events





Schematic illustration of the expected dependence of the transverse multiplicity, $N(p_T)$, on the p_T of the trigger.

UE distributions



similar for Σp_T density

Conclusion from analysis of the ATLAS and CMS data

pQCD starts to dominate charged particle production at relatively large and growing with s p_T:

$$p_{T,crit}(\sqrt{s} = .9\ \mathrm{TeV}) \sim 4\ \mathrm{GeV/c},$$
$$p_{T,crit}(\sqrt{s} = 1.8\ \mathrm{TeV}) \sim 5\ \mathrm{GeV/c},$$
$$p_{T,crit}(\sqrt{s} = 7.0\ \mathrm{TeV}) \sim 6 - 8\ \mathrm{GeV/c}$$

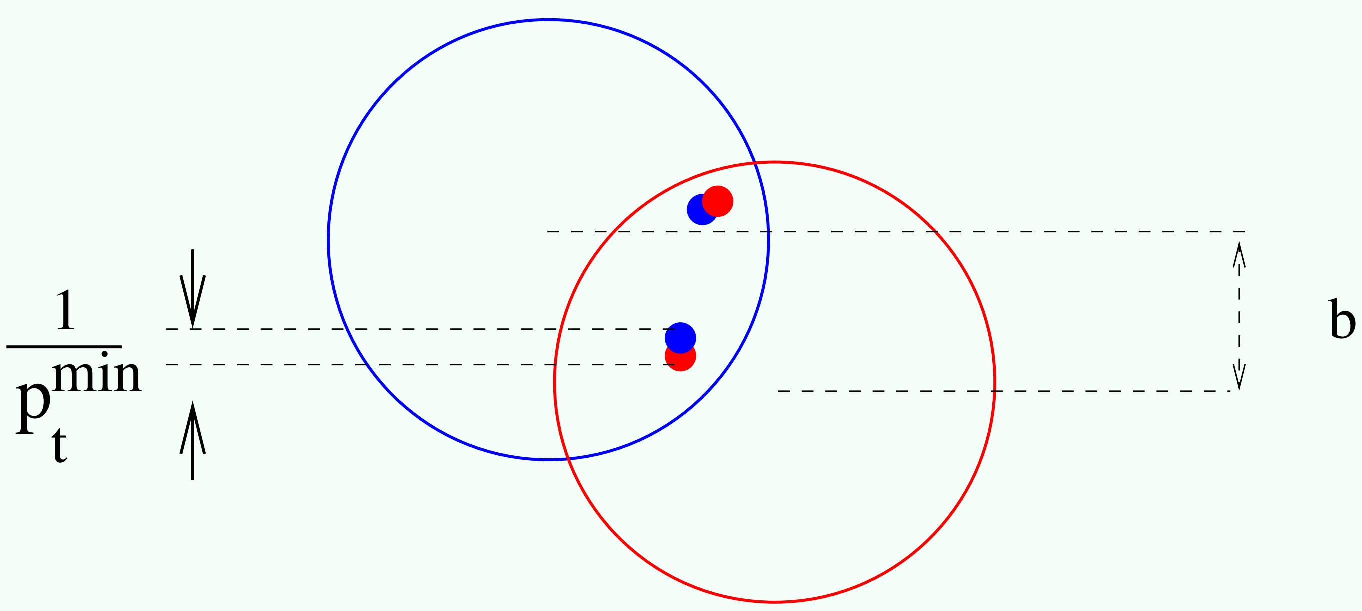
Flattening of dependence on p_T for $p_T > p_{T,crit}$

Data confirm difference of the impact parameter scales of hard and soft interactions in pp collisions which is determined by the value of $\langle\rho^2_g\rangle$ as compared to much larger radius of soft interactions. Note that MCs like PYTHIA, HERWIG assume $\langle\rho^2_g\rangle = \langle\rho^2_q\rangle$ a factor ~ 2 smaller than given by analysis of GPDs and neglect also their x-independence. Note also that from analysis DVCS there is evidence that $\langle\rho^2_g\rangle$ somewhat smaller than $\langle\rho^2_q\rangle$

Multi-jet production - probe of parton correlations in nucleons

a) b)

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 multi-jet events which have distinctive kinematics from the process two partons → four partons.

Note - collisions at the points separated in b by ~ 0.5 fm
⇒ independent fragmentations

Experimentally one measures the ratio

$$\frac{\frac{d\sigma(p+\bar{p}\to jet_1+jet_2+jet_3+\gamma)}{d\Omega_{1,2,3,4}}}{\frac{d\sigma(p+\bar{p}\to jet_1+jet_2)}{d\Omega_{1,2}}\cdot\frac{d\sigma(p+\bar{p}\to jet_3+\gamma)}{d\Omega_{3,4}}}=\frac{f(x_1,x_3)f(x_2,x_4)}{\pi R_{int}^2 f(x_1)f(x_2)f(x_3)f(x_4)}$$

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

πR^2_{int} is ``transverse correlation area". One selects kinematics where 2 →4 contribution is small

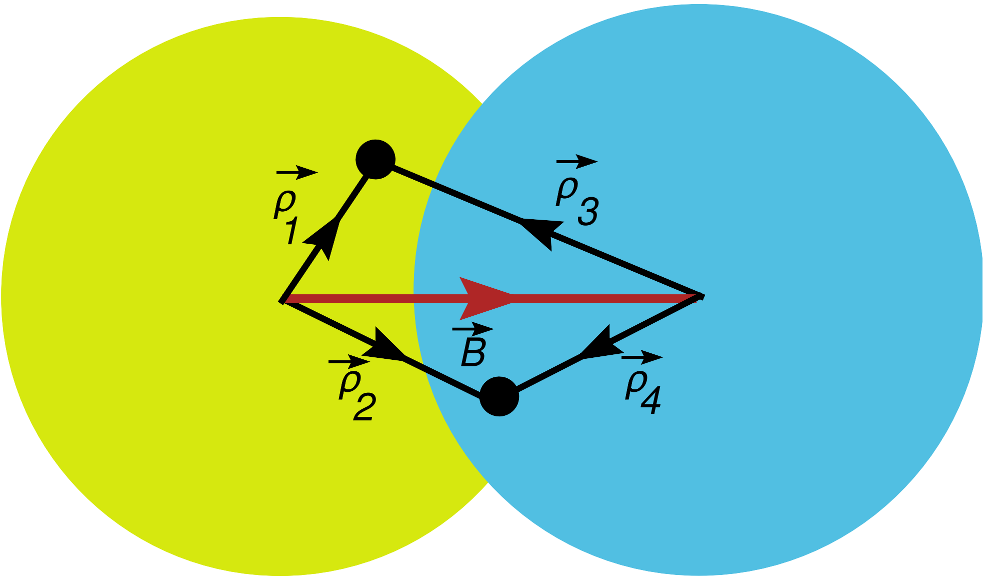
CDF observed the effect in a restricted x-range: two balanced jets, and jet + photon and found

$$\pi R_{int}^2 = 14.5 \pm 1.7^{+\ 1.7}_{-\ 2.3}\ mb$$

No dependence of πR^2_{int} on x_i was observed.

A naive expectation (based on r_N=0.8 fm) is πR^2_{int} ~ 60 mb indicating high degree of correlations between partons in the nucleon in the transverse plane - next 2 slides

Geometric picture of 4 → 4



$$\sigma_4 = \int d^2B d^2\rho d^2\rho_1 d^2\rho_2 d^2\rho_3 d^2\rho_4 D(x_1, x_2, \vec{\rho}_1, \vec{\rho}_2) \times D(x_3, x_4, \vec{\rho}_3, \vec{\rho}_4)$$

$$= \int d^2B d^2\rho_1 d^2\rho_2 D(x_1, x_2, \vec{\rho}_1, \vec{\rho}_2) \times D(x_3, x_4, \vec{B} + \vec{\rho}_1, -\vec{B} + \vec{\rho}_2)$$

Here D's are GPD in the impact parameter space representation

$$D(x_1, x_2, \vec{\rho}_1, \vec{\rho}_2) = \sum_{n=1}^{n=\infty} \int \prod_{i\geq 3}^{i=n} [dx_i d^2\rho_i]$$

$$\psi_n(x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ...x_i, \vec{\rho}_i,) \times \psi_n^+(x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ..., x_i, \vec{\rho}_i, ...)\delta(\sum_{i=1}^{i=n} \vec{\rho}_i).$$

$$\psi(x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ...) = \int \prod_{i=1}^{i=n} \frac{d^2k_1}{(2\pi)^2} \times \exp(i \sum_{i=1}^{i=n} \vec{k}_i \vec{\rho}_i) \psi_n(x_1, \vec{k}_1, x_2, \vec{k}_2, ..)(2\pi)^2 \times \delta(\sum \vec{k}_i).$$

Assuming no correlations between partons in transverse plane distribution of 4 → 4 in b plane, $P_4(b)$ is

$$P_4(b) = \frac{P_2^2(b)}{\int d^2b\, P_2^2(b)}; P_4(b) = \frac{7\, m_g^2}{36\pi}\left(\frac{m_g b}{2}\right)^6 [K_3(m_g b)]^2$$

$$\pi R_{\rm int}^2 = \frac{28\pi}{m_g^2} \sim 34 \text{ mb.}$$

FSW03

For m^2=0.7 GeV^2 ~ 54 mb

Possible sources of small πR^2_{int} for CDF kinematics of x ~0.03-0.3 include:

☺ Small transverse area of the gluon field --accounts for 50 % of the enhancement πR^2_{int} ~ 34 mb (F&S & Weiss 03)

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

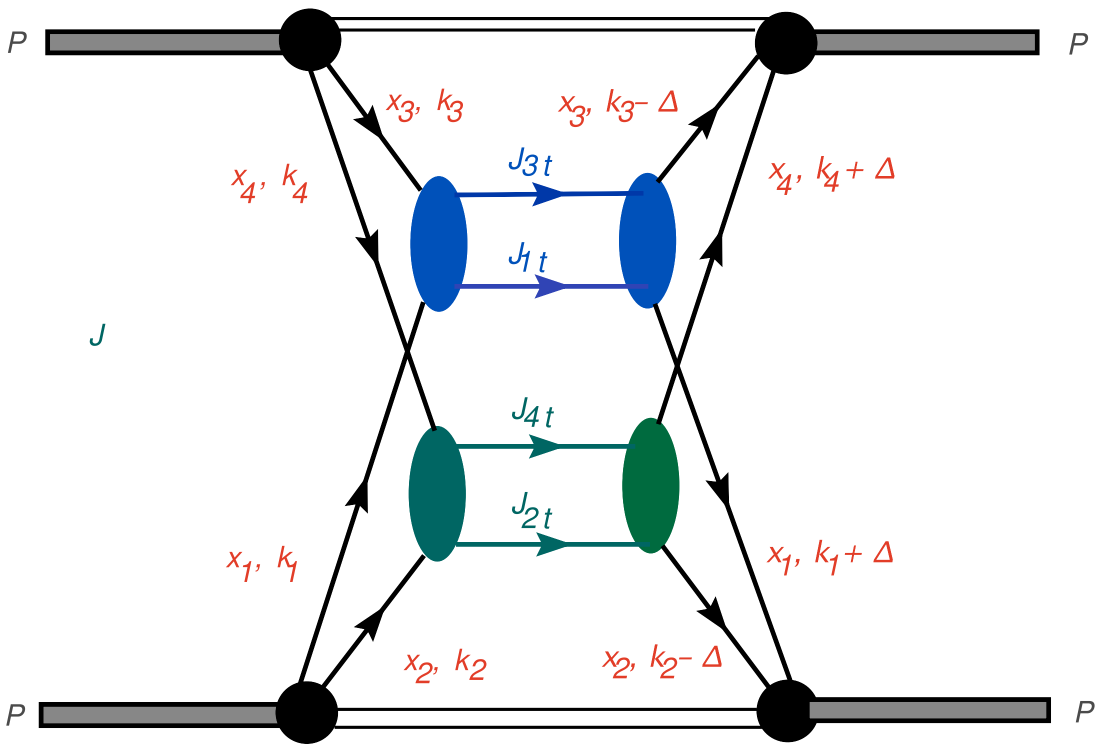
If most of gluons at low Q~ 1GeV scale are in constituent quarks of radius $r_q/r_N \sim 1/3$ found in the instanton liquid based chiral mean field model (Diakonov & Petrov) *the enhancement as compared to uncorrelated parton approximation is* $\frac{8}{9}+\frac{1}{9}\frac{r_N^2}{r_q^2}\sim 2$ Hence, combined these two effects are sufficient to explain CDF data for x>0.1. (F&S&W)

<u>small x</u>

☺ Fluctuations of the transverse size of nucleons (Treliani, &F&S & W) - effect works in right direction but only 15 -- 20% effect.

☺ QCD evolution leads to "Hot spots" in transverse plane (A.Mueller). One observes that such hot spots do enhance multijet production as well. However this effect is likely not to be relevant in the CDF kinematics as x's of colliding partons are relatively large (>0.01). Also it leads to a different structure of the final state.

Can we derive geometric results from the first principles?



$$d\sigma_4 = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \int dx_1 \int dx_2 \int dx_3 \int dx_4$$

$$\times \; D_a(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) D_b(x_3, x_4, p_1^2, p_2^2, -\vec{\Delta})$$

$$\times \; \frac{d\sigma^{13}}{d\hat{t}_1} \frac{d\sigma^{24}}{d\hat{t}_2} d\hat{t}_1 d\hat{t}_2.$$

Here we introduced double GPD

$$D(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) = \sum_{n=3}^{\infty} \int \frac{d^2k_1}{(2\pi)^2} \frac{d^2k_2}{(2\pi)^2} \theta(p_1^2 - k_1^2) \times \theta(p_2^2 - k_2^2)$$

$$\int \prod_{i\neq 1,2} \frac{d^2k_i}{(2\pi)^2} \int_0^1 \prod_{i\neq 1,2} dx_i \times \left[\psi_n(x_1, \vec{k}_1, x_2, \vec{k}_2, ., \vec{k}_i, x_i..) \times \psi_n^+(x_1, \vec{k}_1 + \vec{\Delta}, x_2, \vec{k}_2 - \vec{\Delta}, x_3, \vec{k}_3, ...) + h.c.\right]$$

$$\times (2\pi)^3 \delta\left(\sum_{i=1}^{i=n} x_i - 1\right) \delta\left(\sum_{i=1}^{i=n} \vec{k}_i\right).$$

D is diagonal in the space of all partons except the two partons involved in the collision. No recoil as total momentum transfer is zero.

After several Fourier transforms one can derive from these equation the geometric representation I started with.

General expression for collision of particles a and b

$$\frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\overrightarrow{\Delta}}{(2\pi)^2} D_a(x_1, x_2, -\overrightarrow{\Delta}) D_b(x_1, x_2, \overrightarrow{\Delta})$$

Independent particle approximation which could be reasonable for small x_1, x_2 $\quad D(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) = G(x_1, p_1^2, \vec{\Delta}) G(x_2, p_2^2, \vec{\Delta})$

$$\frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\Delta}{(2\pi)^2} F_{2g}^4(\Delta) = \frac{m_g^2}{28\pi}.$$

Original result we obtained in FSW03 - now we see it is pretty stable - as $F_{2g}^2(\Delta)$ is measured directly.

For N binary collisions

$$\sigma_{2N} \propto \int \prod_{i=1}^{i=N} \frac{d\overrightarrow{\Delta}_i}{(2\pi)^2} D_a(\overrightarrow{\Delta}_1, ...\overrightarrow{\Delta}_N) \times D_b(\overrightarrow{\Delta}_1, ...\overrightarrow{\Delta}_N) \delta(\sum_{i=1}^{i=N} \overrightarrow{\Delta}_i).$$

LHC - plans to study various channels

What partons are more strongly correlated transversely:

a) quark - quark ⟵ diquark model

b) quark - gluon ⟵ constituent quark model

c) gluon - gluon ⟵ QCD evolution (?)

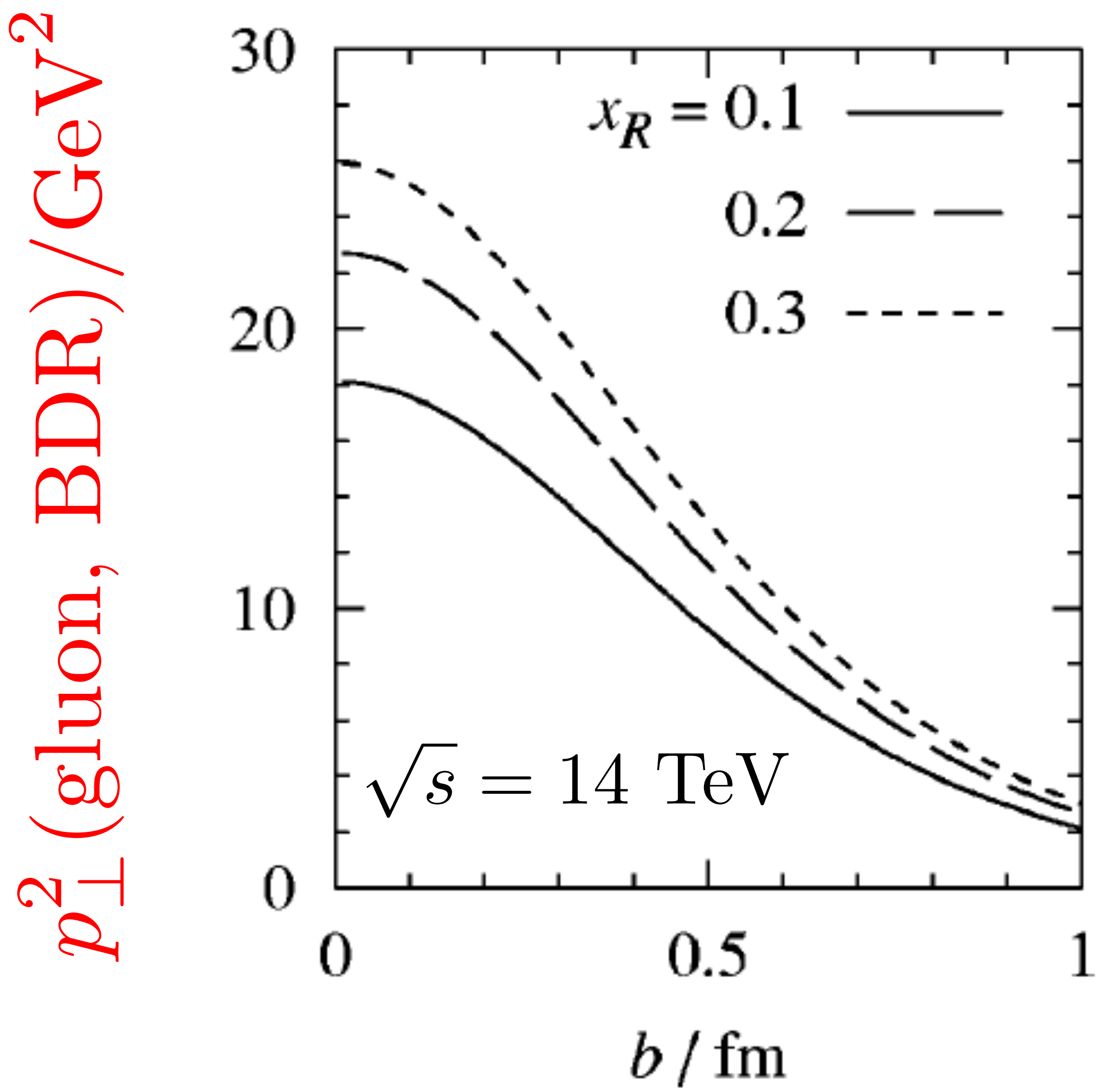
Need to consider samples of four jet events in the double scattering kinematics enriched with quark- (anti)quark (Z, W), gluon-gluon (charm...) , etc collisions

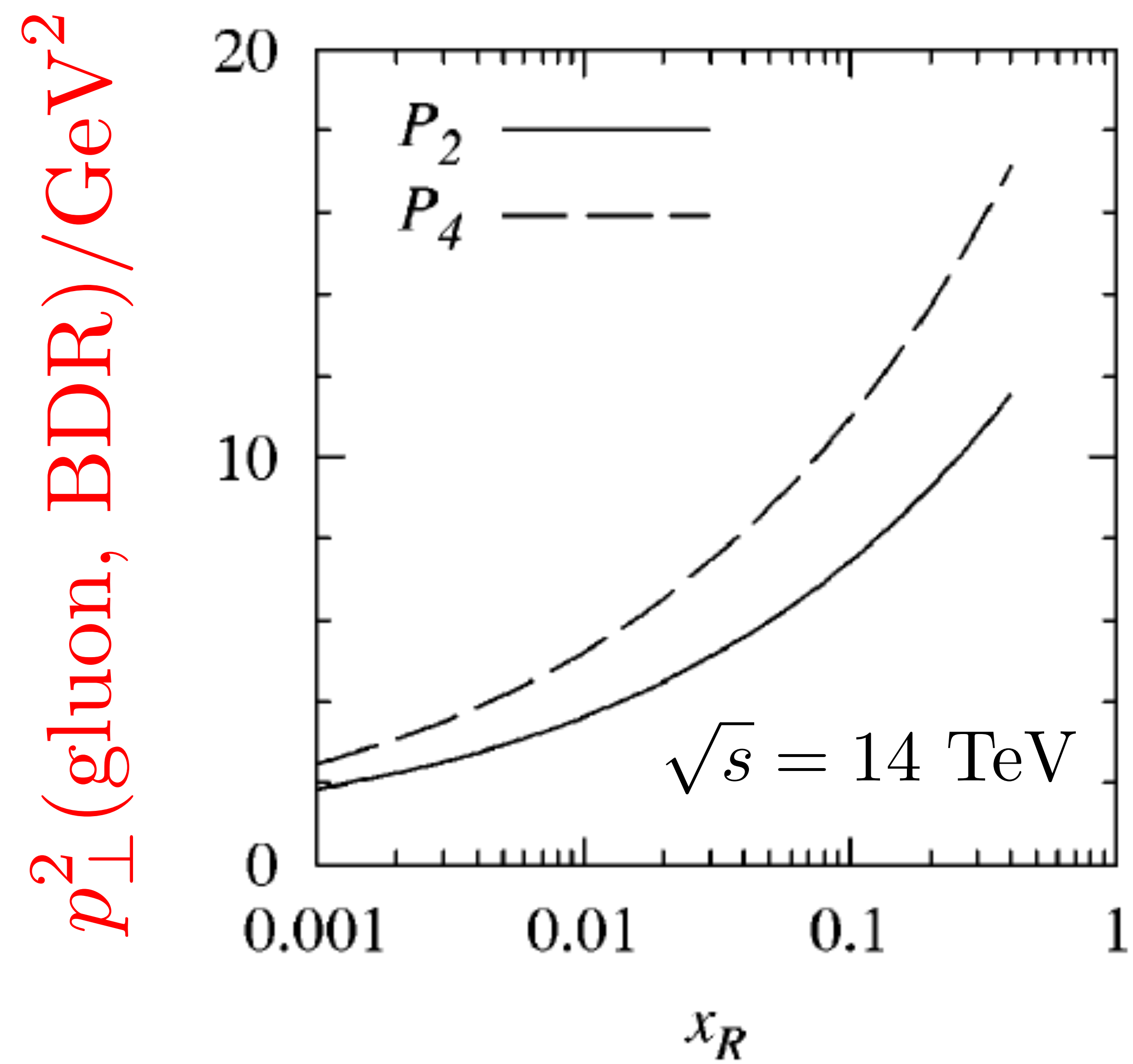
Explore dependence on x's : huge x range at LHC. RHIC can do quark - quark for large x - longitudinal correlations - transverse more difficult

Comment - interaction at small impact parameters is very interesting / important from the QCD angle (on the top of understanding UE for Higgs, SUSY,... searches)

- Amplification of the small x nonlinear effects: in proton - proton collisions a parton with given x_R resolves partons in another nucleon with $x_2 = 4p_\perp^2/x_R s$

At LHC $x_R = 0.01, p_\perp = 2GeV/c \;\Rightarrow\; x_2 \sim 8 \times 10^{-6}$





Evidence for double parton interaction mechanism in the forward production of two pions in pp and d-Au collisions at RHIC

processes studied:

pp (d-Au) $\rightarrow \pi^0 + X$ $\eta \leq 4$ ($x_F \leq 0.5$), $p_T > 1.5$ GeV/c

2003-2006

pp (d-Au) $\rightarrow \pi^0 + \pi^0 + X$ $\eta_{1,2} \leq 4$ ($x_F \leq 0.5$), $p_T > 1.5$ GeV/c

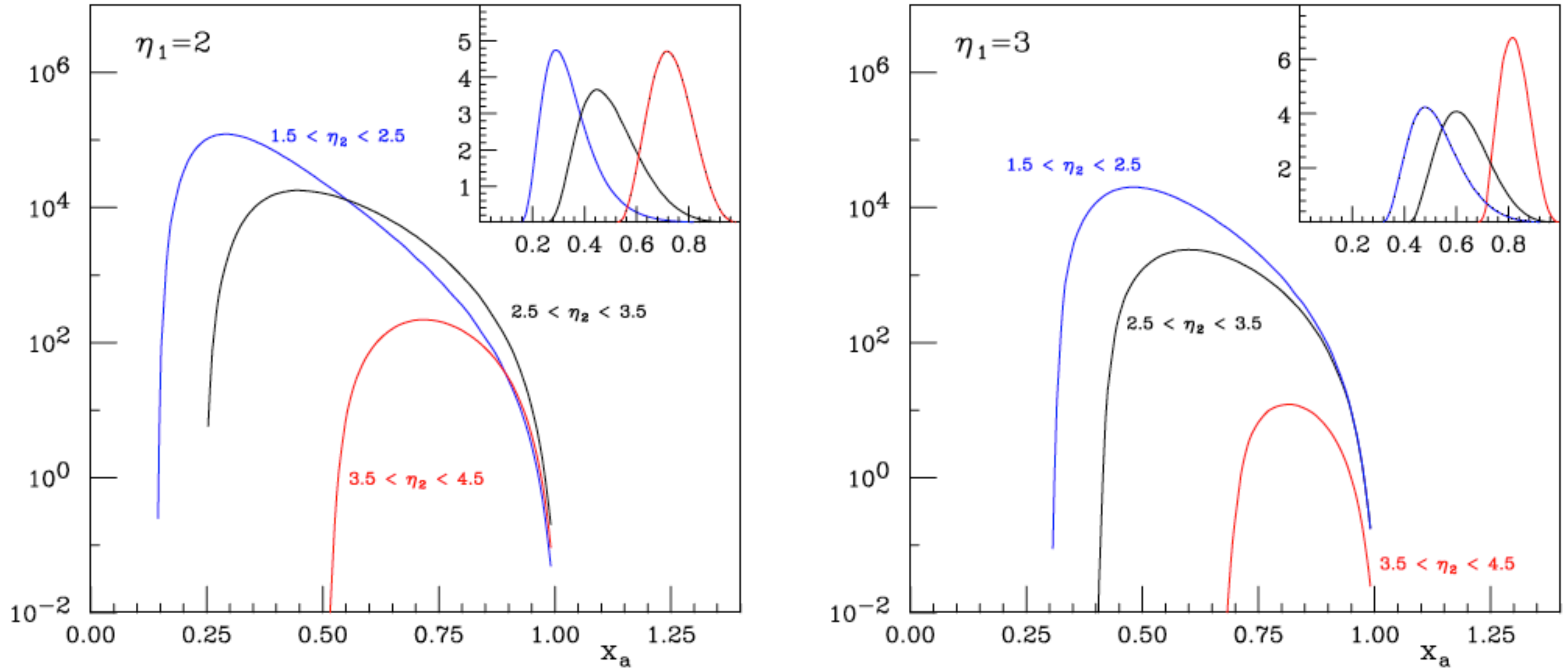
2009-2010

pp data for single pion production described well by pQCD

d-Au data for single pion - large suppression as compared to the impulse approximation - suggested as an evidence for $2 \rightarrow 1$ color glass condensate mechanism

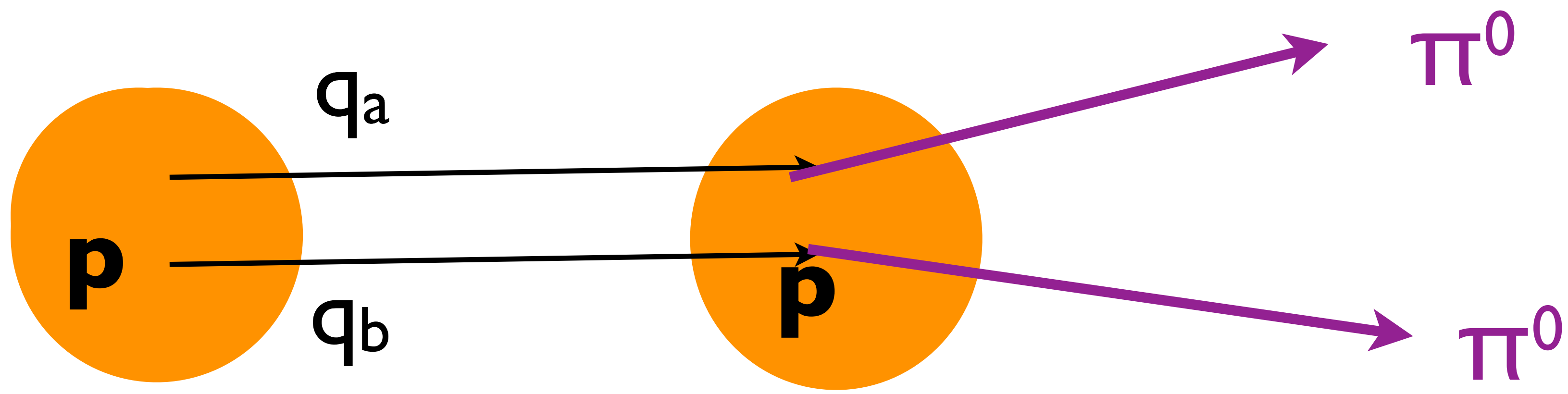
→ dedicated run to measure forward $\pi^0 + \pi^0$ production

Trigger for two forward pions selects even larger x_q than the single pion trigger



fraction of cross section due to given x_a (x of the quark of the proton)

Large enhancement of double parton interactions in pp and especially dAu



$$\frac{d^4\sigma_{\text{double}}}{dp_{T,1}d\eta_1 dp_{T,2}d\eta_2} = \frac{1}{\pi R_{\text{int}}^2} \sum_{abc\,a'b'c'} \int dx_a dx_b dz_c dx_{a'} dx_{b'} dz_{c'} \, f_{aa'}^p(x_a, x_{a'}) f_b^p(x_b) f_{b'}^p(x_{b'})$$

$$\times \frac{d^2\hat{\sigma}^{ab\to cX}}{dp_{T,1}d\eta_1} \frac{d^2\hat{\sigma}^{a'b'\to c'X'}}{dp_{T,2}d\eta_2} D_c^{\pi^0}(z_c)\, D_{c'}^{\pi^0}(z_{c'})\,.$$

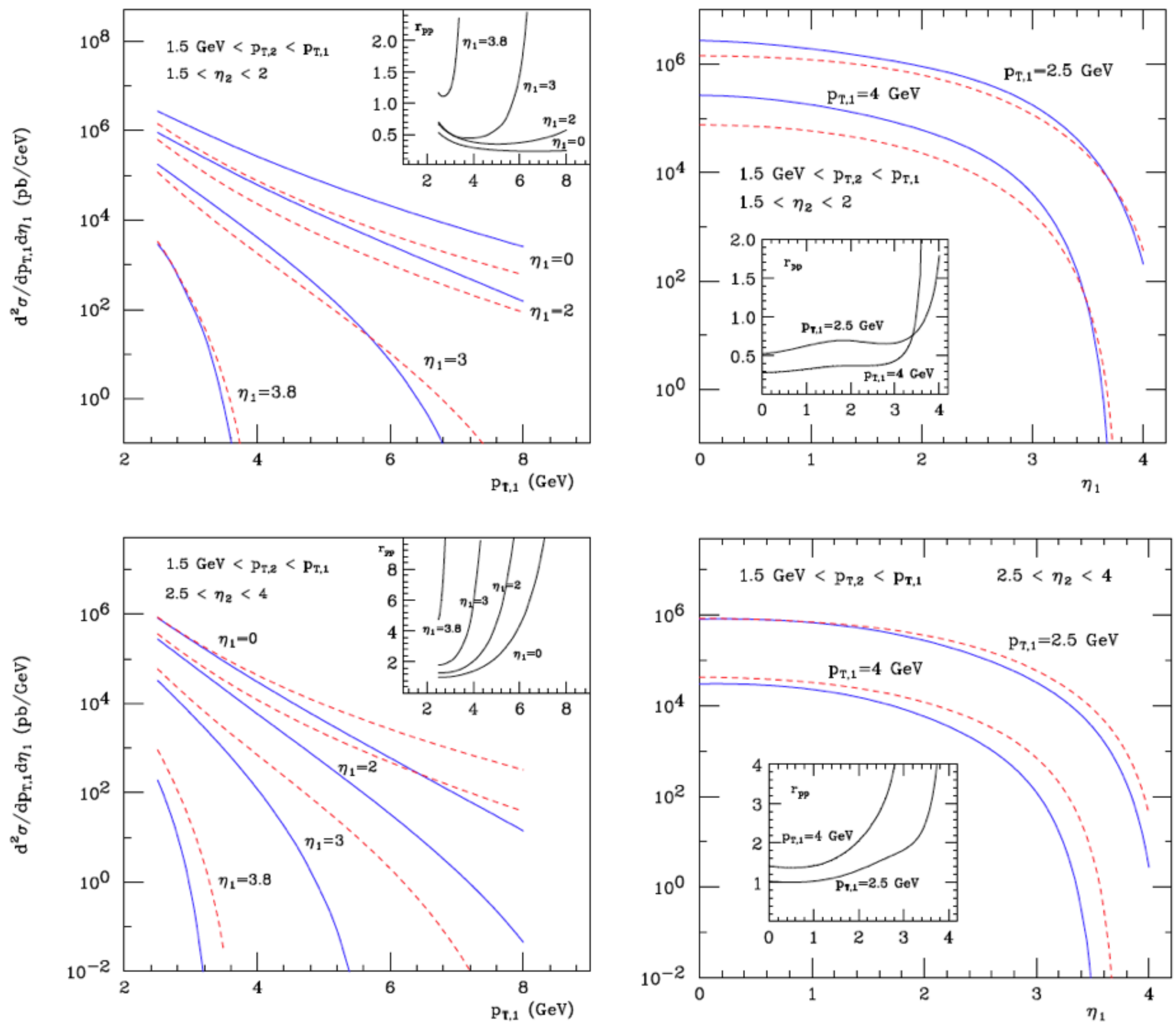
$$f_{qq'}^p(x_q, x_{q'}) = \frac{1}{2}\left[f_q^p(x_q) \times \phi\left(\frac{x_{q'}}{1-x_q}\right) + (q \leftrightarrow q')\right]$$

$$\phi(\xi) = \frac{c}{\sqrt{\xi}}(1-\xi)^n$$

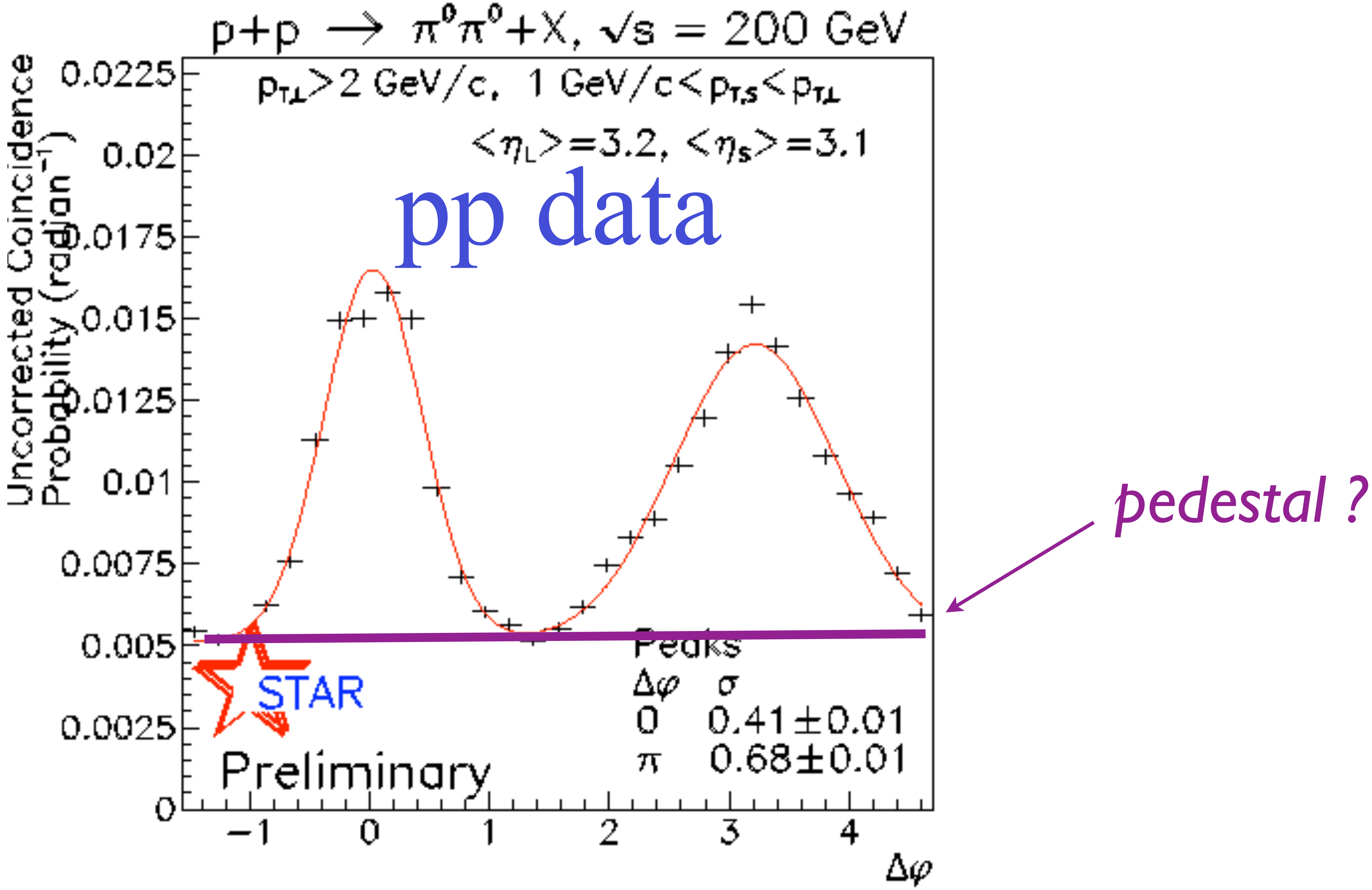
We used experimental value of $\pi R^2_{int} = 15$ mb

Note that if the typical distances between large x quarks are smaller than typical distance for small x gluons we get

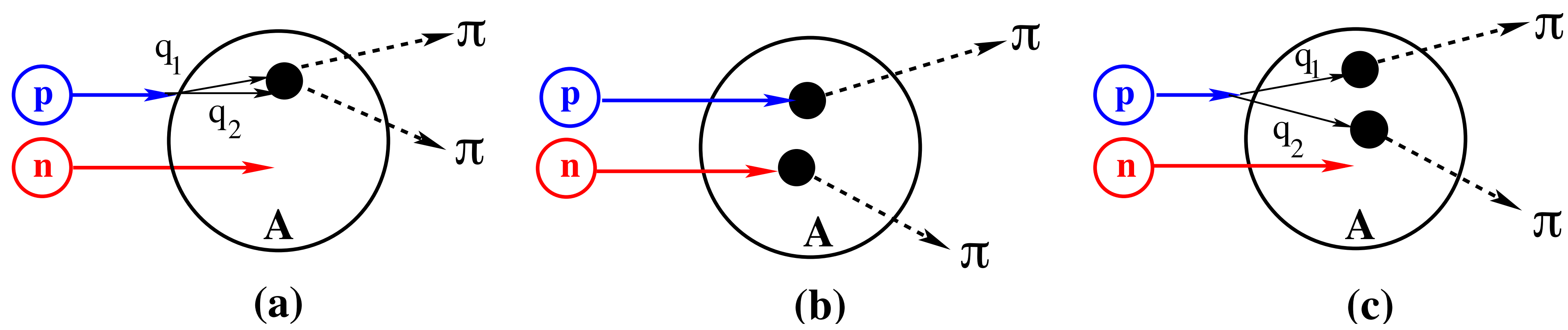
$$\pi R_{\rm int}^2 = \left[\int \frac{d^2\Delta}{(2\pi)^2} F_{2g}^2(\Delta)\right]^{-1} = \frac{12\pi}{m_g^2} \approx 14 \text{ mb}$$



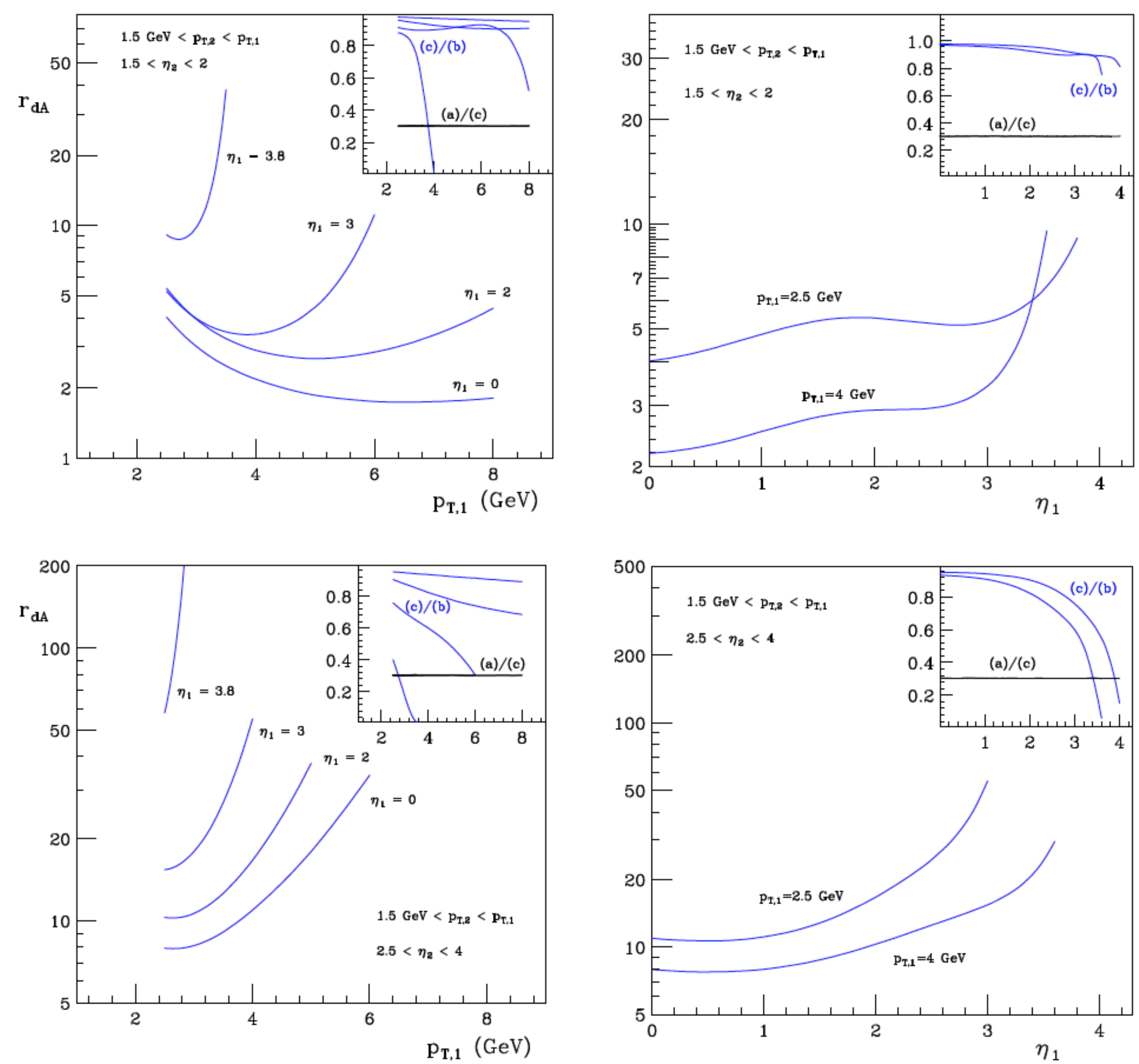
Comparison of the leading-twist cross section for pp→ $\pi^0+\pi^0$ + X (blue) and the double-interaction contribution (red) as functions of $p_{T,1}$ (left) and η_1. Insert the ratio of double and single cross sections.


p+p → π⁰π⁰+X, √s = 200 GeV
p_TL>2 GeV/c, 1 GeV/c<p_T,S<p_TL
<η_L>=3.2, <η_S>=3.1
pp data
Uncorrected Coincidence Probability (radian⁻¹)
Δφ
STAR
Preliminary
Peaks
Δφ σ
0 0.41±0.01
π 0.68±0.01
pedestal ?

Check - look at d-Au should see a large enhancement of the pedestal - two nucleons can hit many nucleons - (MS +Treleani 02)



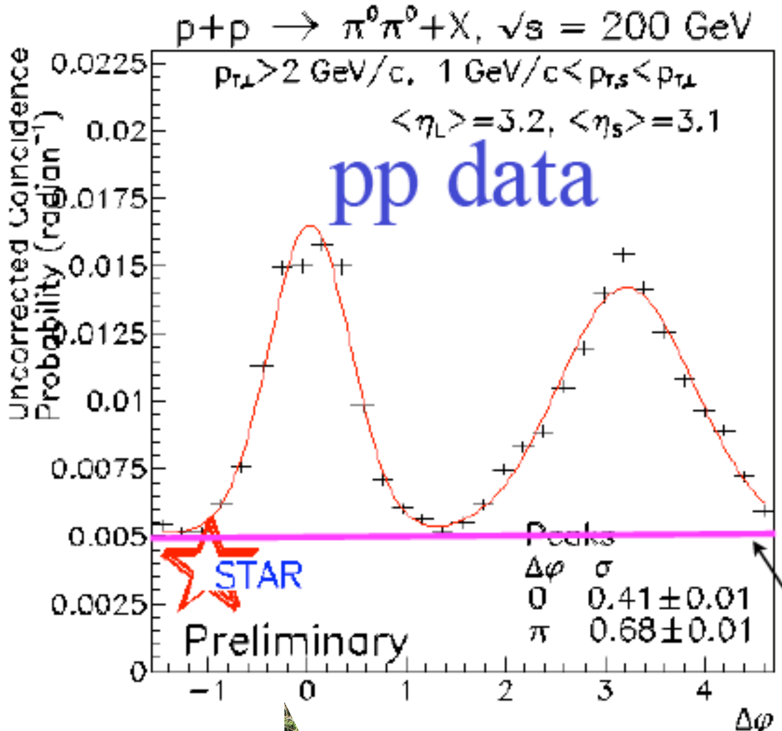
Ratio r_{dA} of double-parton and leading-twist contributions in $dA \to \pi^0\pi^0 X$.



We explained previously various regularities of single pion production as due to post-selection effect in proximity of the black disk regime (Frankfurt, Guzey, McDermott, MS 01) leading to fractional energy losses.

Accounting this effect, and LT gluon shadowing reduces 4→4/ 2→2 ratio:

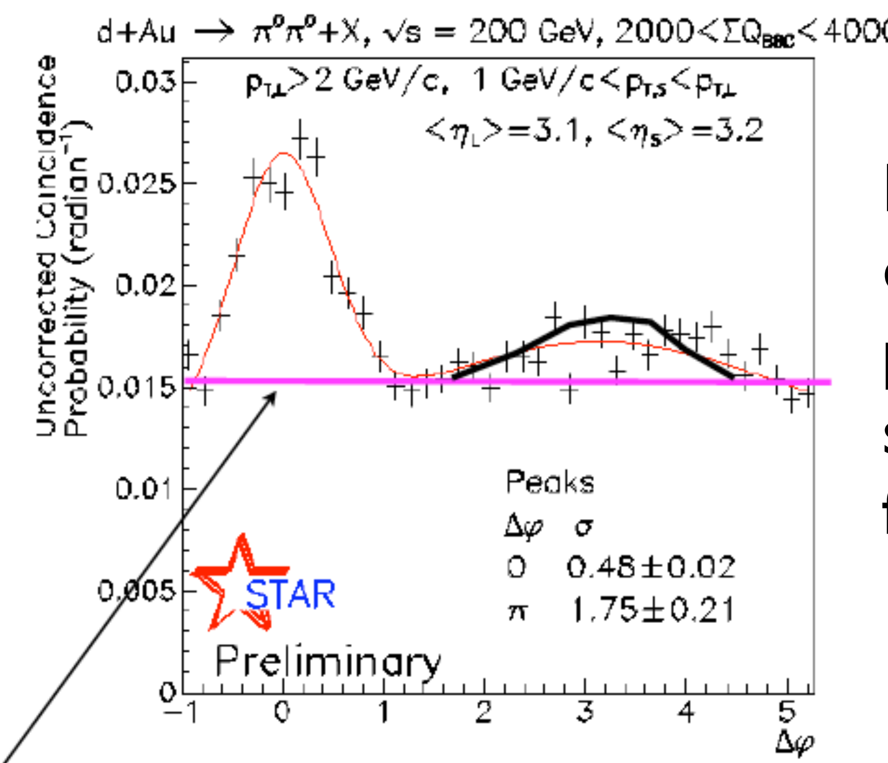
- ✶ $\Delta\phi$ independent pedestal in dA three times larger in pp
- ✶ Suppression of $\Delta\phi$ =180° peak by a factor ~ four



1: 3

pedestal

dAu central



Black curve is the pp data peak above pedestal for φ ~π scaled down by a factor of 4

Large nonlinear effects at the LHC in wide range of rapidities.

Conclusions

- *Understanding of the complexity of the nucleon structure is gradually emerging*
- *Double hard processes at Tevatron provides evidence for transverse correlations between partons. Further studies of transverse correlations are underway at the LHC. RHIC opens new direction of studies of quark - quark correlations in nucleons*
- Double (Triple,...) parton processes probe new multiparton GPDs.
- Lattice QCD,... can calculate double GPDs relevant for multiparton processes
- *Small x physics is an unavoidable component of the new particle physics production at LHC. Significant effects already for Tevatron.*
- *Centrality matterns in pp: Minijet activity in events with heavy particles is much larger than in the minimum bias events or if it is modeled based on soft extrapolation from Tevatron.*
- Challenge- understand dynamic mechanism which is modeled in the current MC by introducing ad hoc cutoff on $p_t > p_{min}$ of the jets (> 3GeV for LHC)

Already first QCD data bring surprises at LHC (as we predicted). More surprises to follow.