Diffraction in ep$\to$e+ VM + Y at low, intermediate and large t

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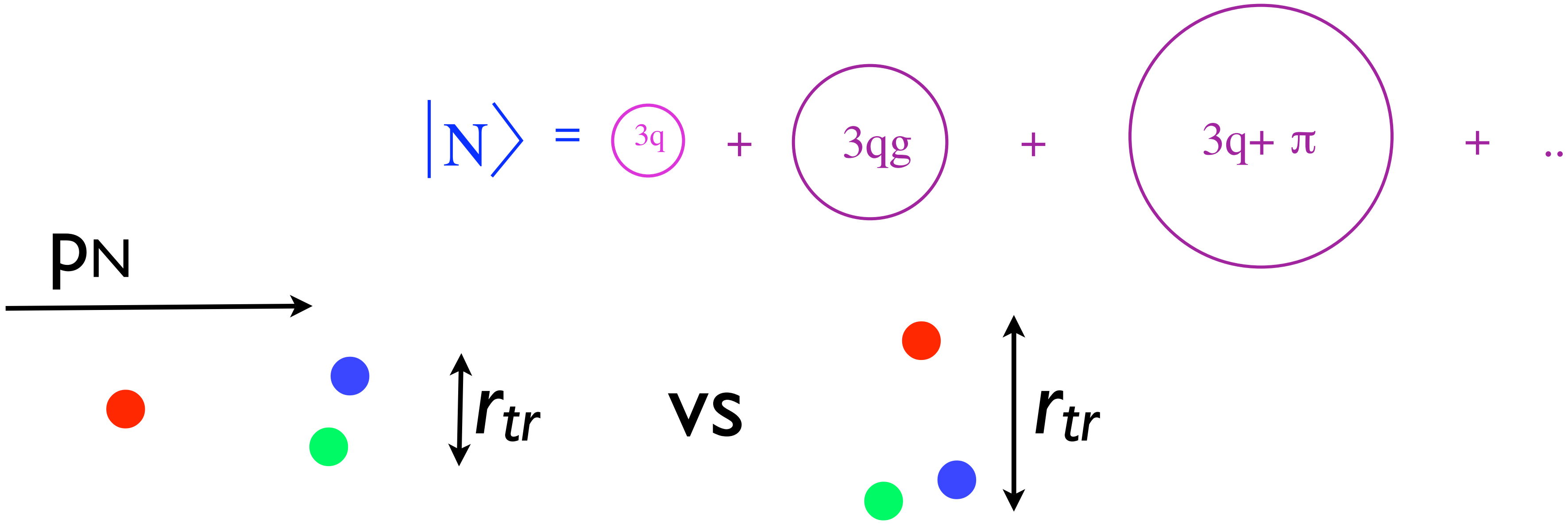
Inelastic diffraction: VM + gap + Y was for years a considered an annoying background to elastic channel is trove of gold

Will discuss only proton case, though a lot of extra information from the nucleus case

Are there global fluctuations of the strength of interaction of a fast nucleon, for example due to fluctuations of the size /orientation

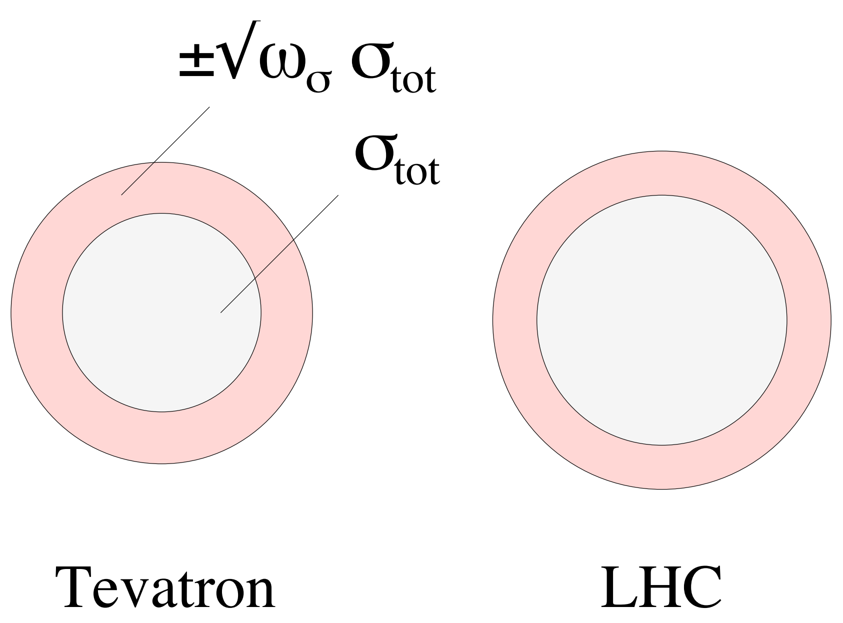


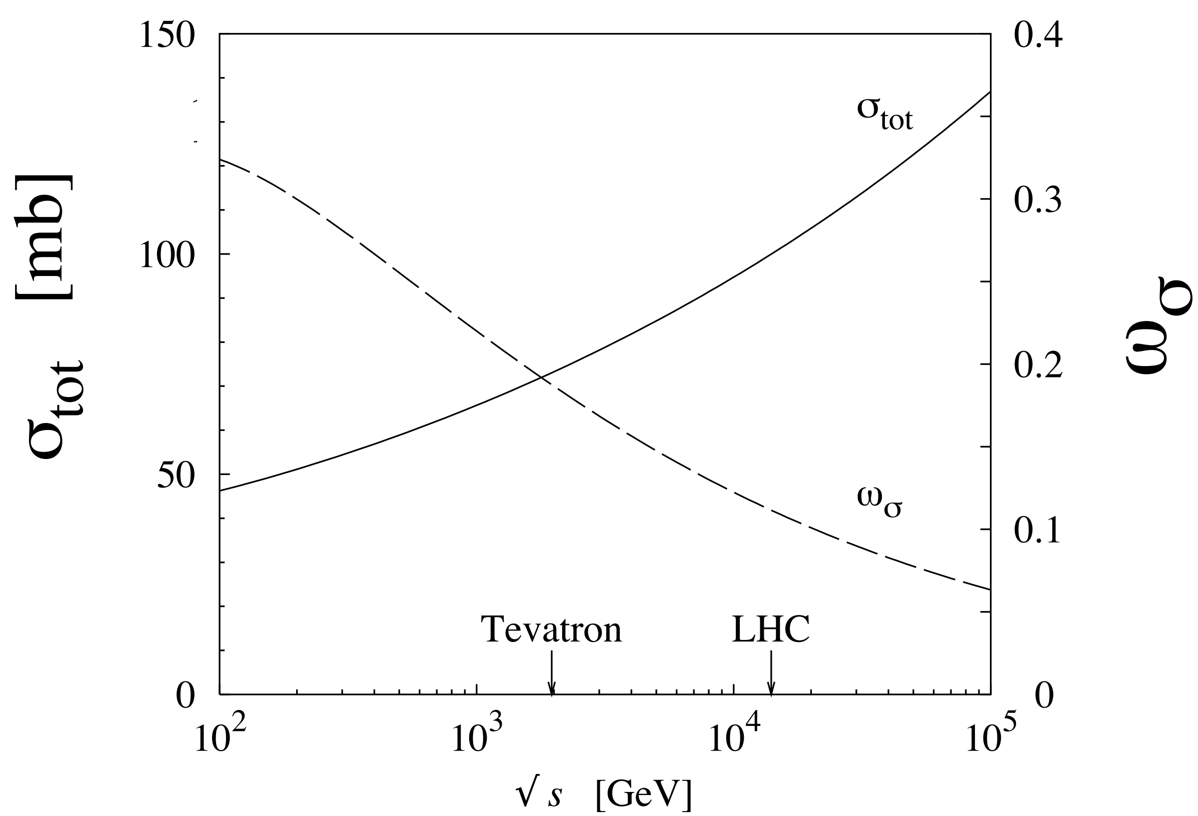
Due to a slow space-time evolution of the fast nucleon wave function one can treat the interaction as a superposition of interaction of configurations of different strength - Pomeranchuk & Feinberg, Good and Walker, Pumplin &Miettinen (in QCD this is reasonable for total cross sections and for diffraction at very small t)

Convenient quantity - $P(\sigma)$ -probability that nucleon interacts with cross section σ

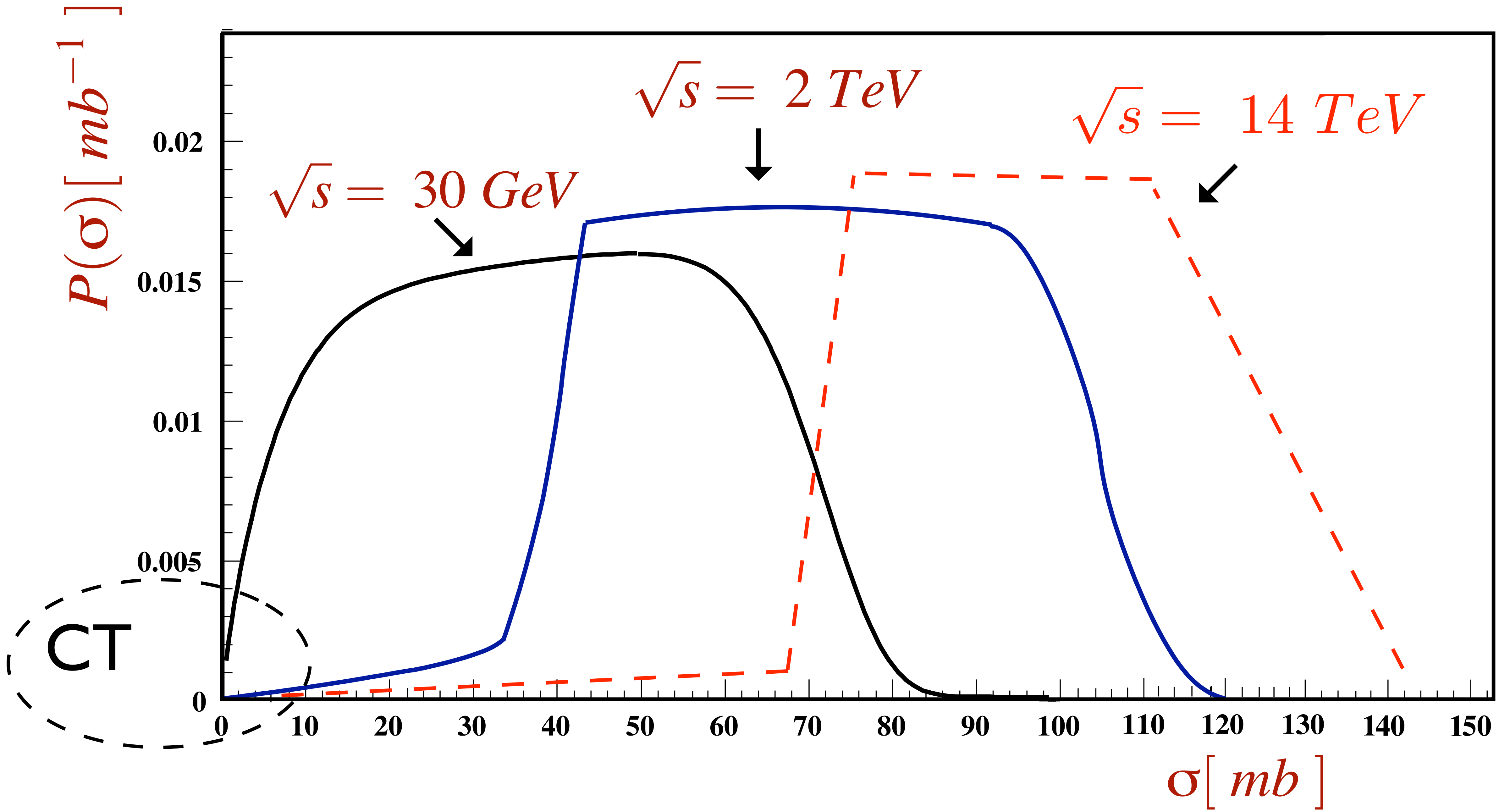
If there were no fluctuations of strength - there will be no inelastic diffraction at t=0:

$$\left.\frac{\frac{d\sigma(pp\to X+p)}{dt}}{\frac{d\sigma(pp\to p+p)}{dt}}\right|_{t=0} = \frac{\int(\sigma-\sigma_{tot})^2 P(\sigma)d\sigma}{\sigma_{tot}^2} \equiv \omega_\sigma \quad \text{variance}$$





Both small and large configurations grow. Periphery remains- still there is a correlation between σ and parton distributions -smaller σ, harder quark



The 30 GeV curve is result of the analysis (Baym et al 93) of the FNAL diffractive pp and pd data which explains FNAL diffractive pA data (Frankfurt, Miller, MS 93-97). The 14 and 2TeV curves are my guess based on matching with fixed target data and collider diffractive data.

Strength of the gluon field should depend on the size of the quark configurations - for small configurations the field is strongly screened - gluon density much smaller than average.

Consider $\gamma_L^* + p \to V + X$ for Q^2 > few GeV^2

In this limit the QCD factorization theorem (BFGMS03, CFS07) for these processes is applicable

Expand initial proton state in a set of partonic states characterized by the number of partons and their transverse positions, summarily labeled as $|n\rangle$

$$|p\rangle = \sum_n a_n |n\rangle$$

Each configuration n has a definite gluon density $G(x, Q^2| n)$ given by the expectation value of the twist--2 gluon operator in the state $|n\rangle$

$$G(x, Q^2) \;=\; \sum_n |a_n|^2 G(x, Q^2|n) \;\equiv\; \langle G \rangle$$

Making use of the completeness of partonic states, we find that the elastic($X = p$) and total diffractive (X arbitrary) cross sections are proportional to

$$(d\sigma_{\rm el}/dt)_{t=0} \quad \propto \quad \left[\sum_n |a_n|^2 G(x, Q^2|n)\right]^2 \equiv \langle G \rangle^2,$$

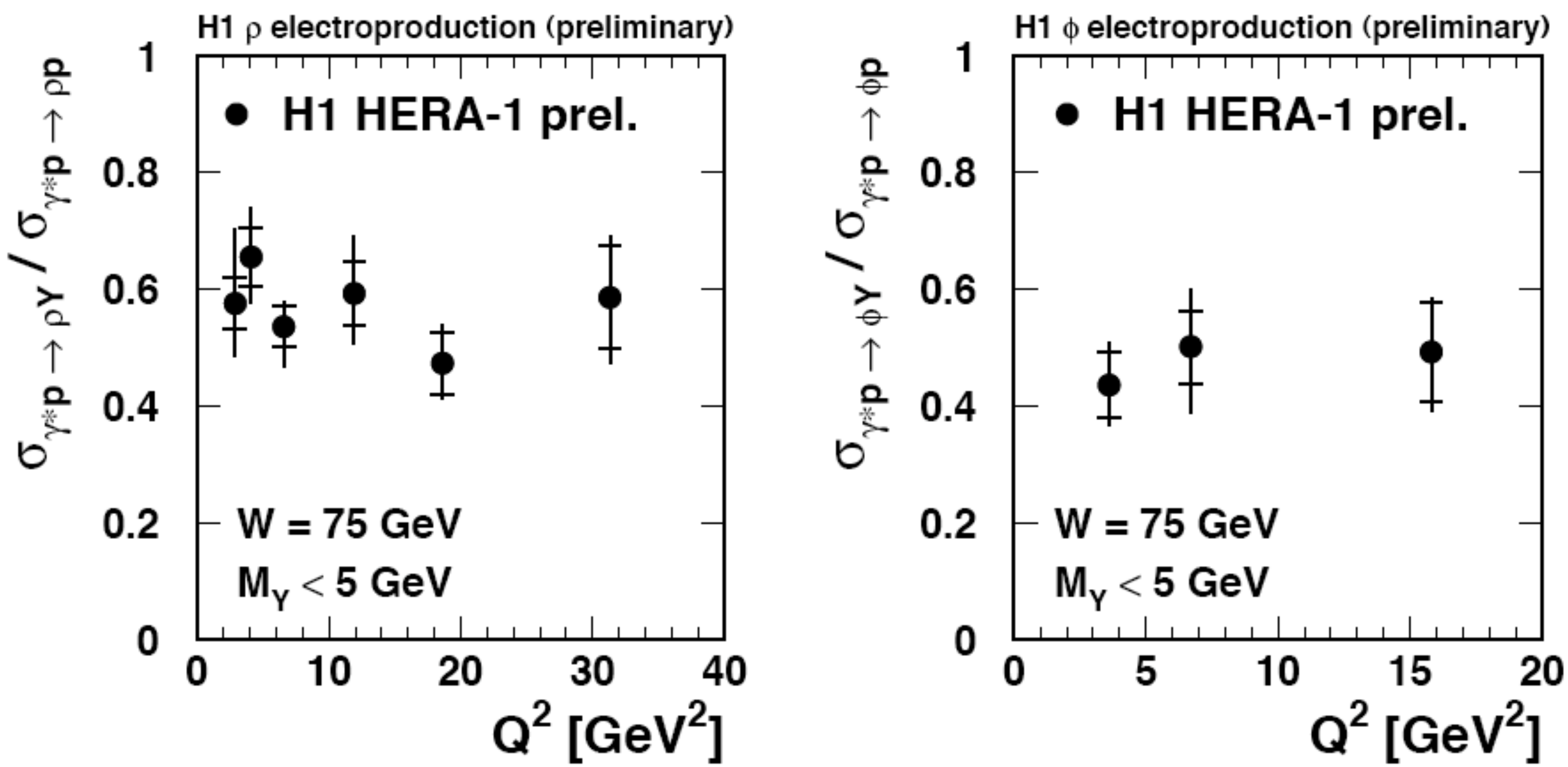
$$(d\sigma_{\rm diff}/dt)_{t=0} \quad \propto \quad \sum_n |a_n|^2 \left[G(x, Q^2|n)\right]^2 \equiv \langle G^2 \rangle.$$

Hence cross section of inelastic diffraction is $\sigma_{\rm inel} = \sigma_{\rm diff} - \sigma_{\rm el}$

$$\Rightarrow \boxed{\omega_g \equiv \frac{\langle G^2 \rangle - \langle G \rangle^2}{\langle G \rangle^2} = \left. \frac{d\sigma_{\gamma^* + p \to VM + X}}{dt} \middle/ \frac{d\sigma_{\gamma^* + p \to VM + p}}{dt} \right|_{t=0}}.$$

MS + LF + C.Weiss, D.Treliani PRL 08

p-diss. / Elastic Ratio - vs. (Q^2)



- p-diss. / elastic ratio independent of Q^2
- Similar ratio within errors for ρ and ϕ

No official numbers for t -slopes - educated guess:

$B_{el} / B_{inel} \sim 3 \div 4$

$$\Rightarrow \quad \omega_g(Q^2 \sim \text{few GeV}^2, x \sim 10^{-3}) \sim 0.15 \div 0.2$$

pretty broad distribution

Simple "scaling model" based on two assumptions

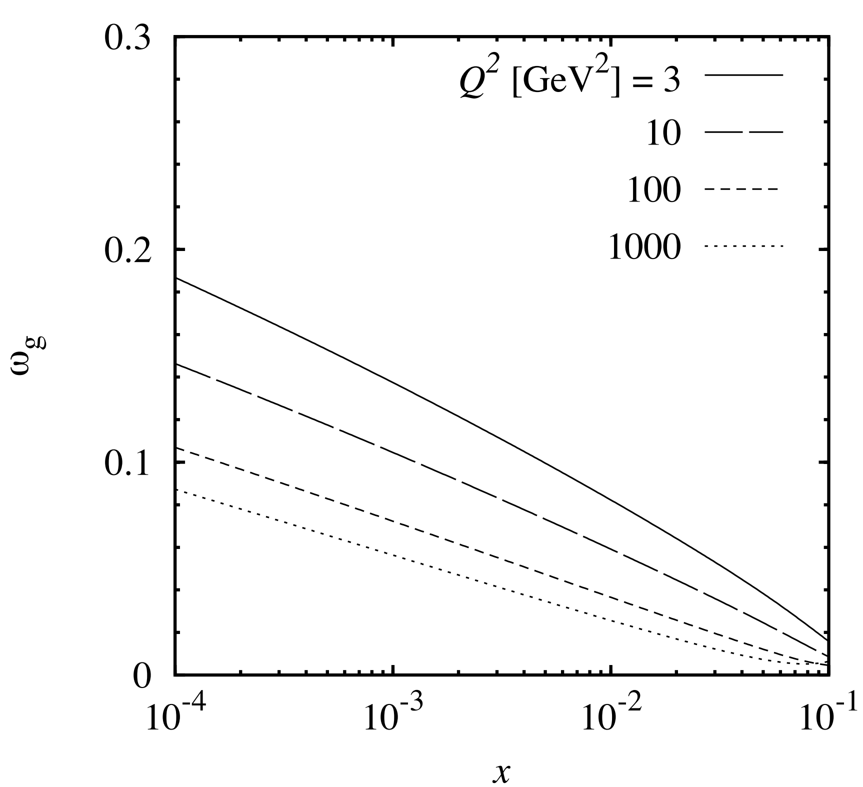
- At moderate energies $\sqrt{s}$ = 20 GeV the hadronic cross section of a configuration is proportional to the transverse area occupied by the color charges in that configuration,

$$\sigma \propto R^2_{\rm config}$$

- the normalization scale of the parton density changes proportionally to the size of the configuration $\mu^2 \propto R^{-2}_{\rm config} \propto \sigma^{-1}$ (in the spirit of Close et al 83 - EMC effect model)

$$G(x,Q^2\,|\sigma) = G(x,\xi Q^2) \quad \xi(Q^2) \equiv (\sigma/\langle\sigma\rangle)^{\alpha_s(Q_0^2)/\alpha_s(Q^2)}$$

$$where\, Q_0^2 \sim 1\,\mathrm{GeV}^2$$



The dispersion of fluctuations of the gluon density, ω_g, as a function of x for several values of Q^2, as obtained from the scaling model

Warning: the model designed for small $x < 0.01$. There maybe other effects which could contribute to ω_g for large x

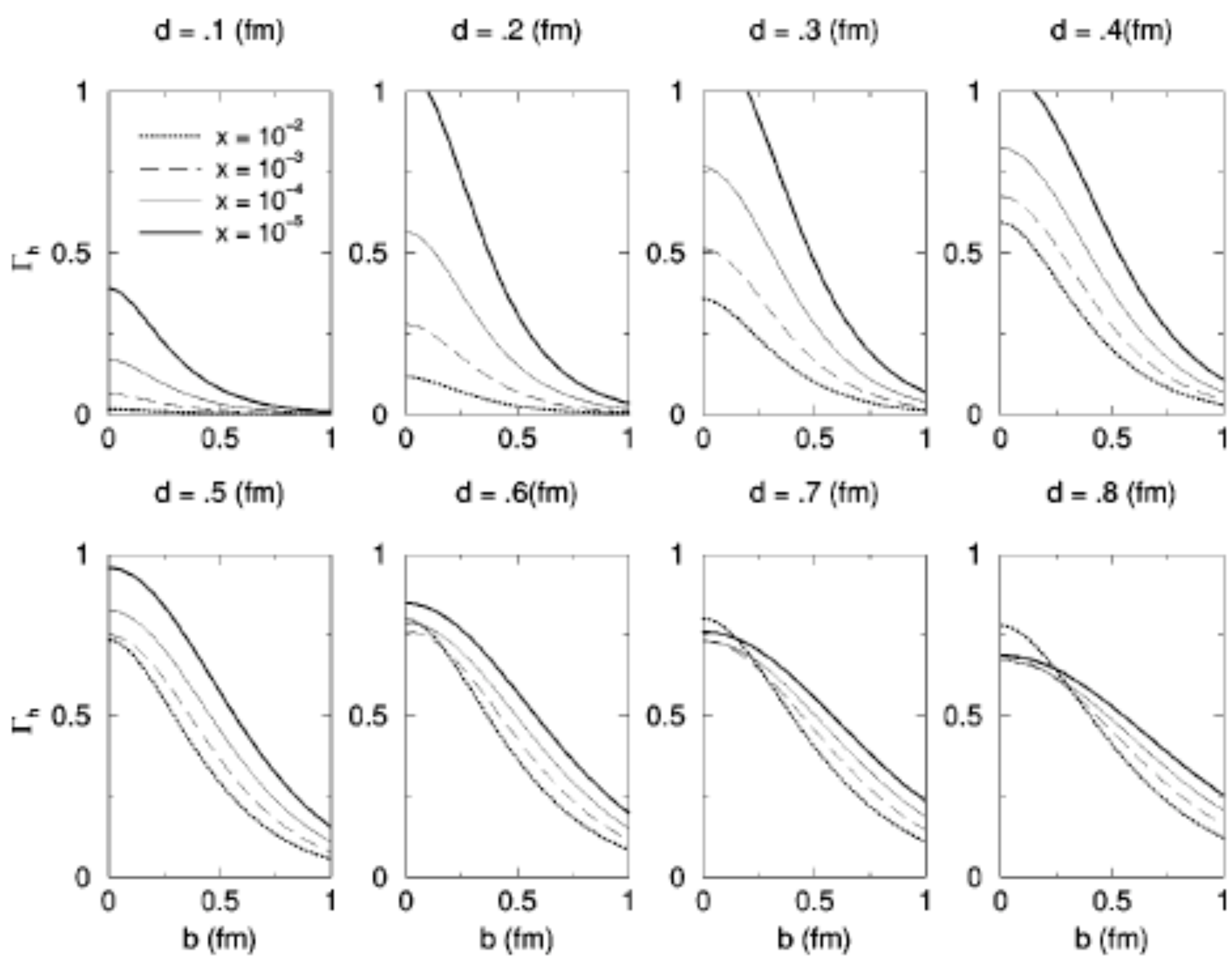
At the same time decrease of ω_g with Q^2 at x=const - generic effect

Intermediate t

Major task for exclusive small x processes is to determine transverse distribution of gluons and also explore

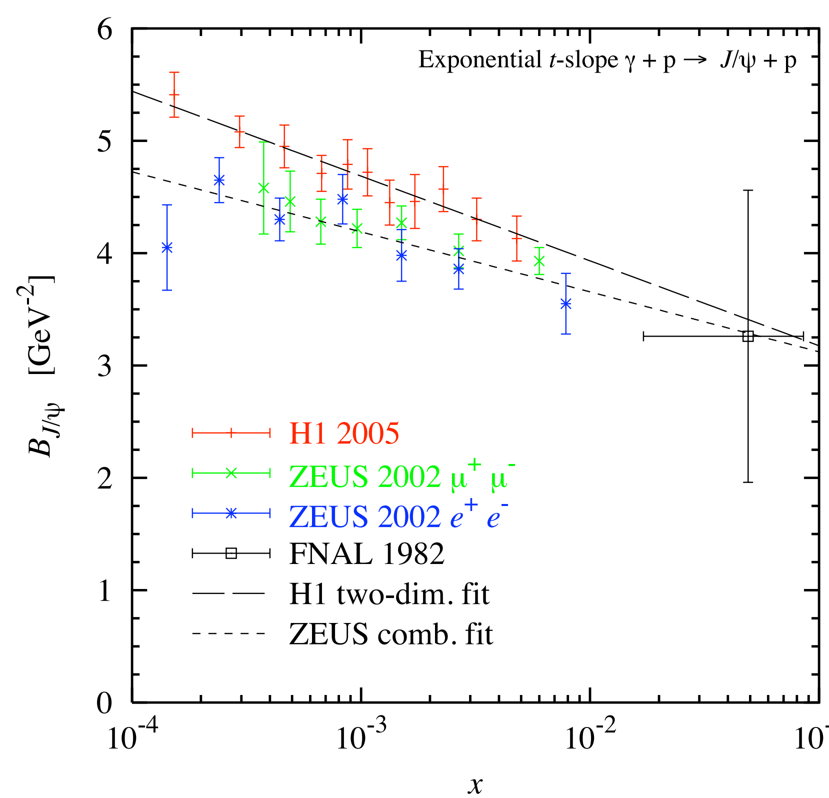
$$\Gamma_h(s,b) = \frac{1}{2is(2\pi)^2}\int d^2\vec{q}\exp(i\vec{q}\cdot\vec{b})A_{hN}(s,t)$$

and hence investigate proximity to the black disk regime of $\Gamma \sim 1$

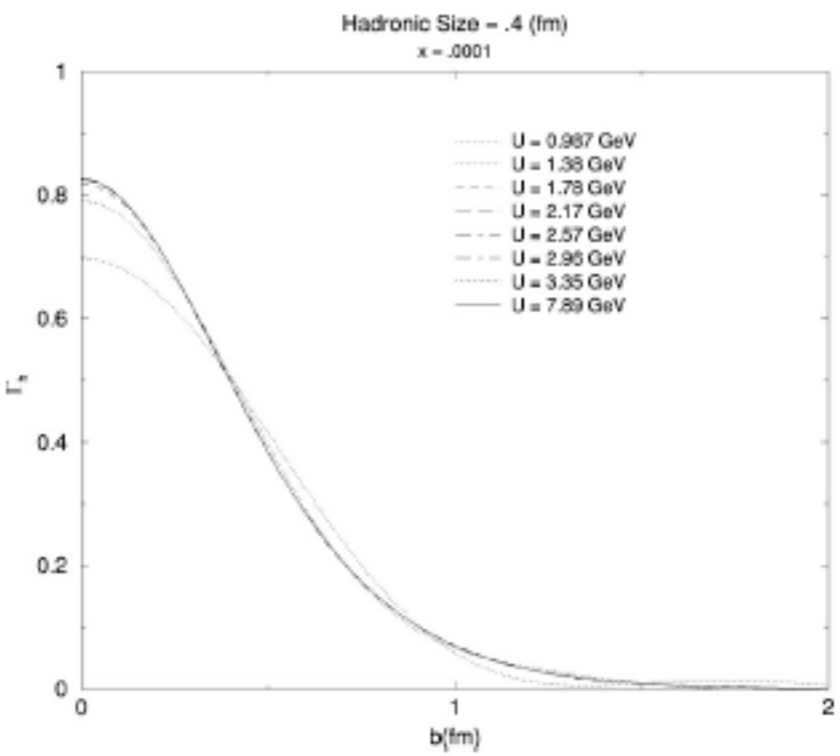


Rogers et al 04

used information about J/psi photo production at FNAL



What is the maximal t for which one needs to do measurements to determine Γ(b=0) ?



The profile function for different values of the upper limit, $U = (-t)^{1/2}$.

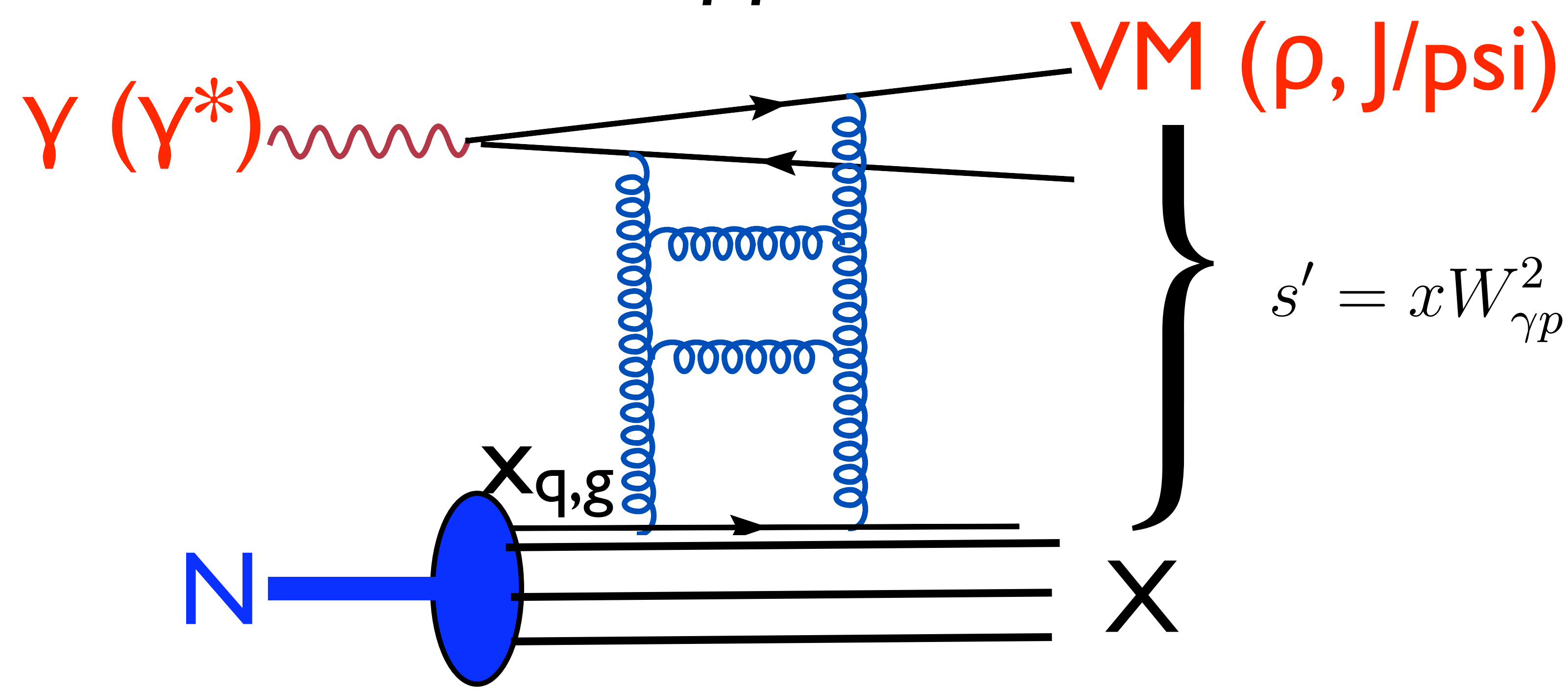
Need to reach $-t \sim 2\ \mathrm{GeV}^2$!!!

Challenge: $$R(t) = \frac{\sigma(\gamma^* + p \to V + Y)}{\sigma(\gamma^* + p \to V + p)} \approx 0.2 \exp(-4t) \sim 10_{|-t=1GeV^2}$$

Need either direct detection of proton or very good model for inelastic diffraction. Current model assumes soft factorization. Can we trust it?

Rapidity gap processes at large $t=(p_\rho - p_\gamma)^2$: from HERA to LHC & EIC

Allows to address a number of important issues including "What is Asymptotic behavior of the amplitude of the elastic scattering of small dipoles in QCD at large t ? Does BFKL approximation works?"



Elementary reaction - scattering of a hadron (γ, γ*)

off a parton of the target at large $t=(p_\gamma - p_V)^2$

$$x = \frac{-t}{(-t + M_X^2 - m_N^2)}$$

FS 89 (large t pp→p +gap + jet), FS95

Mueller & Tung 91

Forshaw & Ryskin 95

EIC as good as HERA with proper detector - can work at much larger x ~ 0.2

The rapidity gap between the produced vector meson and knocked out parton (roughly corresponding to the leading edge of the rapidity range filled by the hadronic system X) is related to $W_{\gamma p}$ and t (for large t, $W_{\gamma p}$ as

$$y_r = \ln \frac{xW_{\gamma p}^2}{\sqrt{(-t)(m_V^2 - t)}}$$

The choice of large t ensures two important simplifications. First, *the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons*. Second is that *attachment of the ladder to two partons of the target is strongly suppressed*. Also the transverse size $d_{q\bar{q}} \propto 1/\sqrt{-t}$

$$\frac{d\sigma_{\gamma+p\rightarrow V+X}}{dtdx} = \frac{d\sigma_{\gamma+quark\rightarrow V+quark}}{dt}\left[\frac{81}{16}g_p(x,t) + \sum_i (q_p^i(x,t) + \bar{q}_p^i(x,t))\right]$$

scattering off gluons dominates up to large x

$$\frac{d\sigma_{N+q(g)\to N+q(g)}}{dt} \propto \frac{1}{t^6} \qquad \frac{d\sigma_{\gamma+q(g)\to V+q(g)}}{dt} \propto \frac{1}{t^4}$$

real photon & light VM

Energy dependence of $f_q(s',t) \propto [s']^{\delta(t)}$

$\delta(-t >> 1\ \mathrm{GeV}^2)$?

Soft QCD $\delta<-0.5$

Two gluon exchange $\delta=0$

DGLAP / resummed BFKL for t=0 $\delta=0.2$ -- 0.3

subtle points in BFKL analysis for t away from 0

Claims in the literature that data are consistent with LO BFKL !!!

We analyzed the rho-meson data using a fit Frankfurt ,MS, Zhalov 06-08

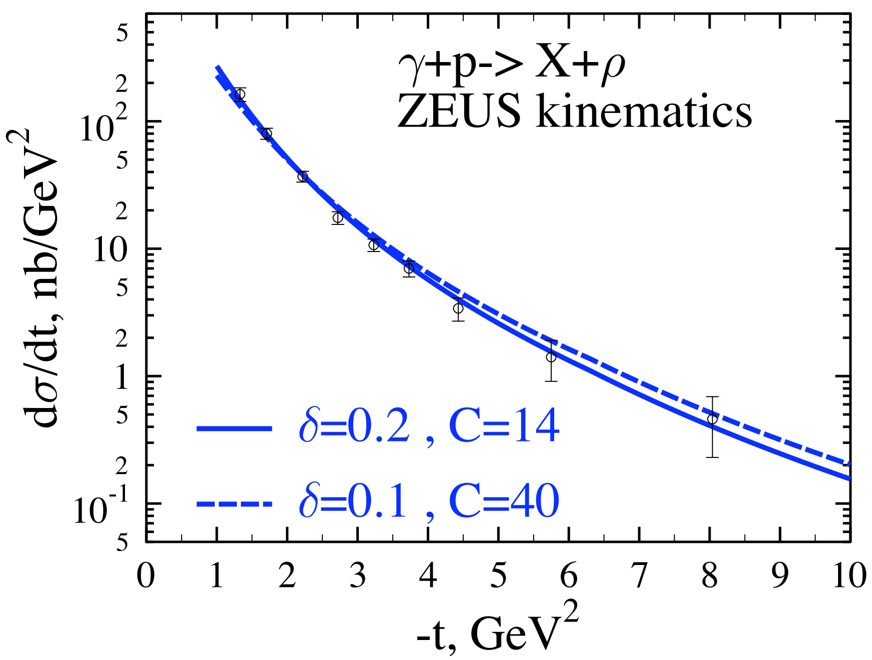
$$\frac{d\sigma_{\gamma+p\to\rho+X}}{dt} = \frac{C}{(1-t/t_0)^4}\left(\frac{s}{{m_V}^2 - t}\right)^{2\delta(t)} I(x_{min}, t)$$

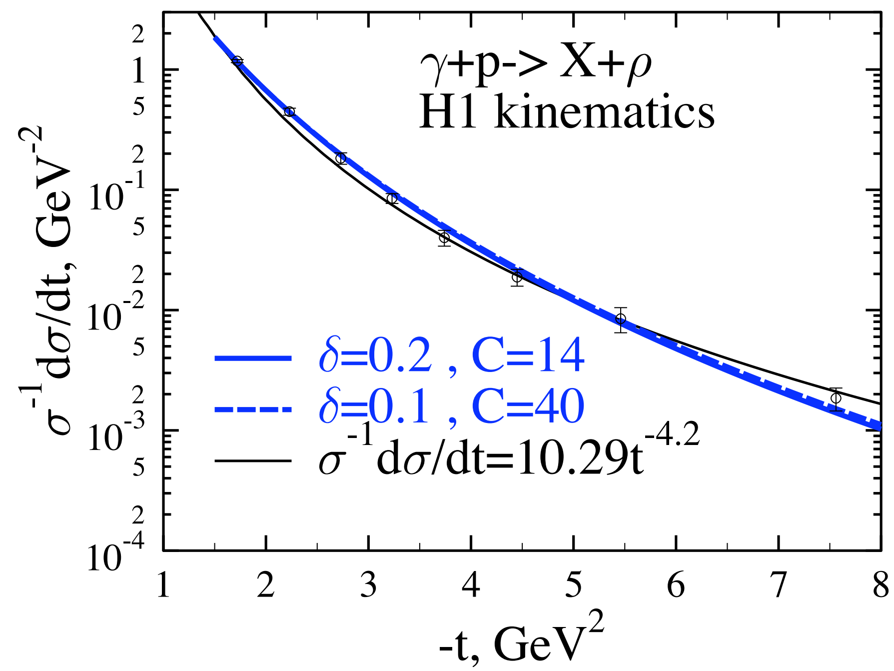
$$I(x_{min}, t) = \int\limits_{x_{min}}^{1} x^{2\delta(t)} \left[\frac{81}{16} g_p(x,t) + \sum_i [q_p^i(x,t) + \bar{q}_p^i(x,t)\right] dx$$

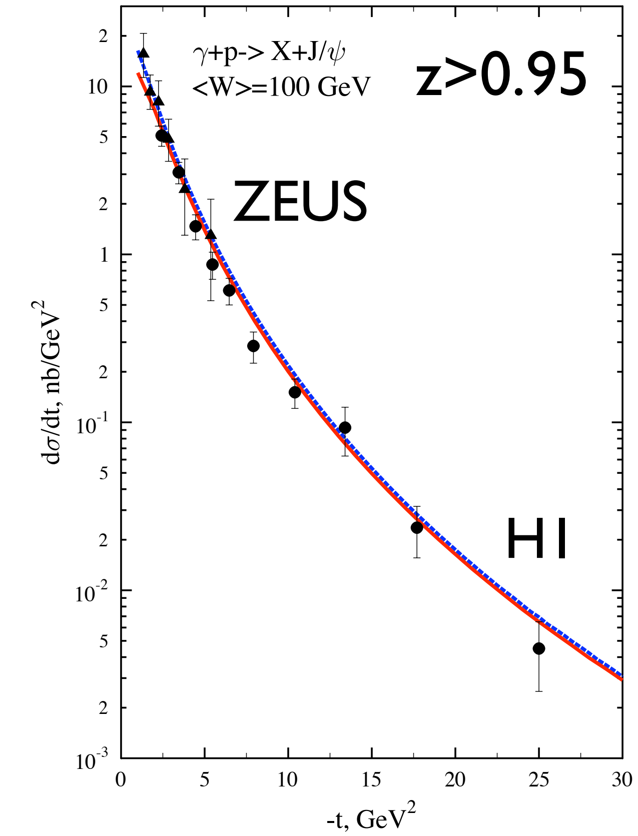
$t_0 \sim 1$ GeV^2, δ=0.1 -0.2 is consistent with the data at large t

For J/ψ we changed $$\frac{1}{(1-t/t_0)^4} \to \frac{1}{(1-t/t_0)(1-t/m^2_{J/\psi})^3}$$

Energy dependence was due to $I(x_{min}, t)$ factor. Not BFKL amplitude



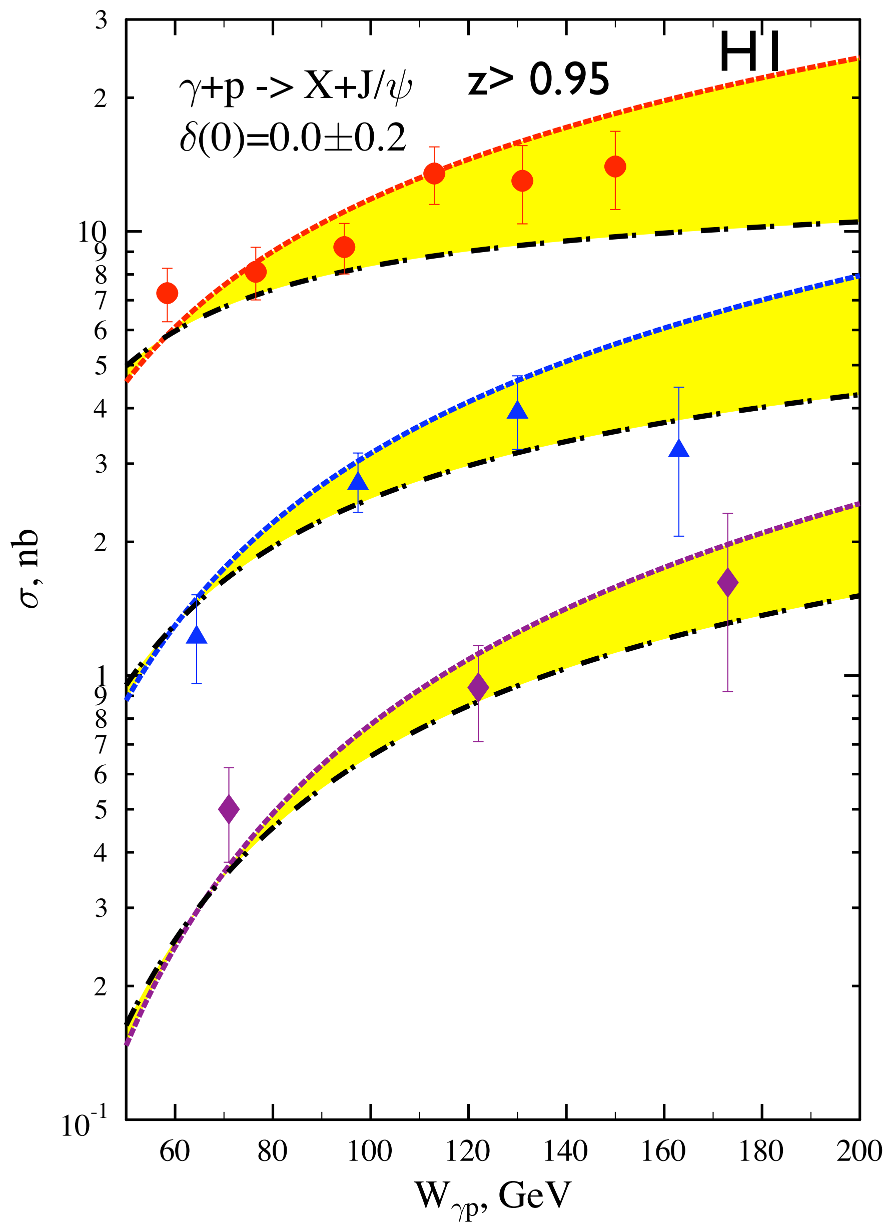


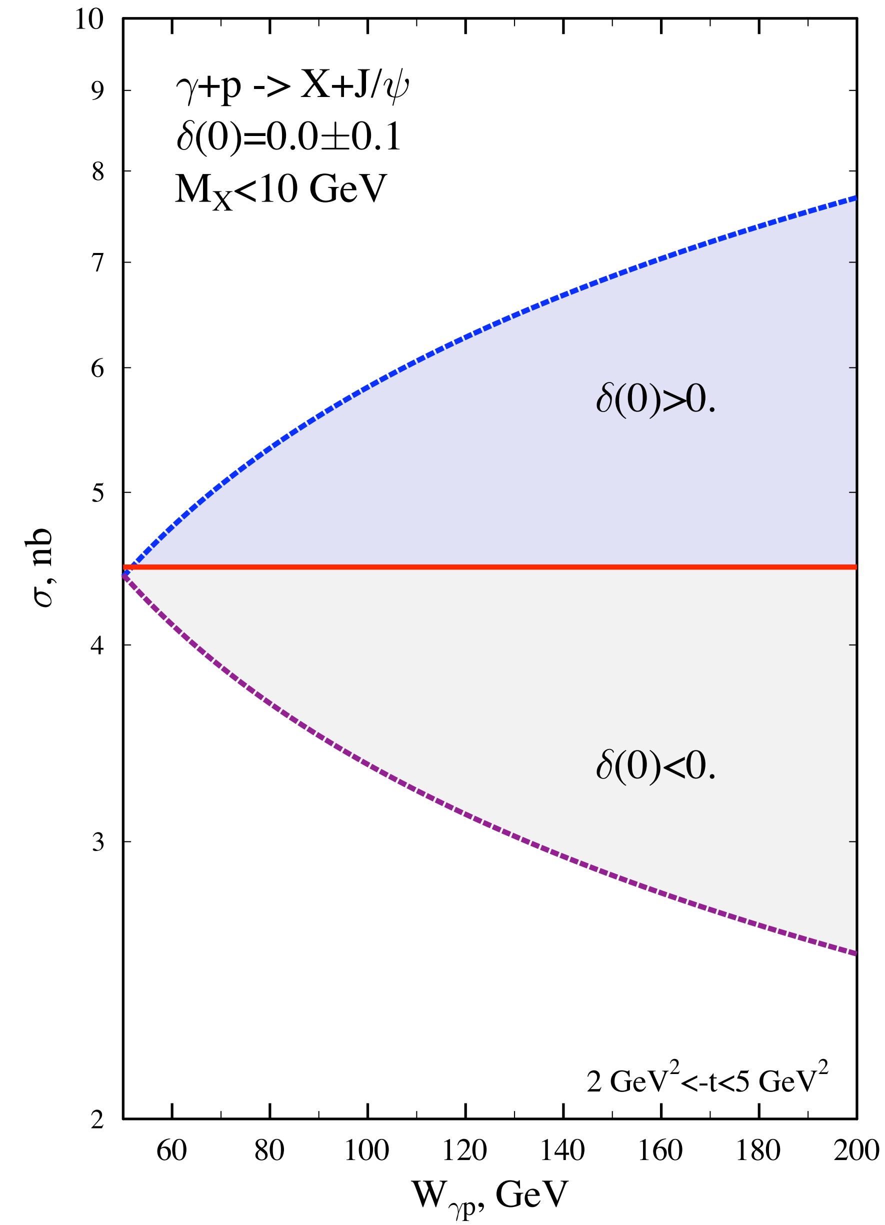


Description of ZEUS and H1 data for t-dependence of the large t and rapidity gap cross section. ZEUS data were taken at average $W_{\gamma p}$=100 GeV with fixed cut M_X < 25 GeV and additional restriction 0.01 <x< 1. The H1 data were taken at average $W_{\gamma p}$=85 GeV and cut M_X < 5 GeV.

Sensitivity to the energy dependence is weak.

t-dependence of J/ψ production is consistent with dominance of hard dynamics





Study of the VM production with gaps is mostly sensitive to gluon pdfs if the cut is on z_{min} or M_X^2/W^2 is made. Sensitivity to the energy dependence of dipole - parton amplitude $f(s',t) \propto s'^{\delta}$ is minor. On the contrary if the cut on $M_X <$ const is made, sensitivity to the value of δ is very high.

Analyses with z cut, M^2_X/s < const cuts are good for study of the dominance of the mechanism of scattering off single partons. However they correspond to rapidity interval between VM and jet which are typically of the order $\Delta y = 2 - 3$.

Optimal way to study BFKL dynamics is to keep

M^2_X < const and vary W

Difficult but not impossible at HERA natural at LHC. Need good coverage of the proton fragmentation to do these measurements at EIC

At LHC one can energy dependence of elastic $q\bar{q}$ - parton scattering at W'=20 GeV - 400 GeV

$$\sigma_{el}(q\bar{q} - q(g)(W' = 400GeV)/\sigma_{el}(q\bar{q} - q(g)(W' = 20GeV) \sim 10\,!!!$$ if δ=0.2

Important limit not studied so far at HERA: $|-t| \ll Q^2$

FS95

$$\frac{\left.\frac{d\sigma^{\gamma_L^* + p \to V + X}}{dt}\right.}{\left.\frac{d\sigma^{\gamma_L^* + p \to V + p}}{dt}\right|_{t=0}} = \frac{9}{8\pi}\alpha_S^2 \left|\ln\frac{Q^2}{k^2}\right|^2 \times \frac{\int_y^1 \left[G_p(y', k^2) + \frac{16}{81} S_p(y', k^2)\right] dy'}{\left[x G_p(x, Q^2)\right]^2}$$

where S_p is the density of charged partons in the proton,

$\nu = 2m_N q_o$, $x = Q^2/\nu$, $k^2 = -t$, $y = -t/2(q_o - p_{Vo})m_N$ with p_{Vo}

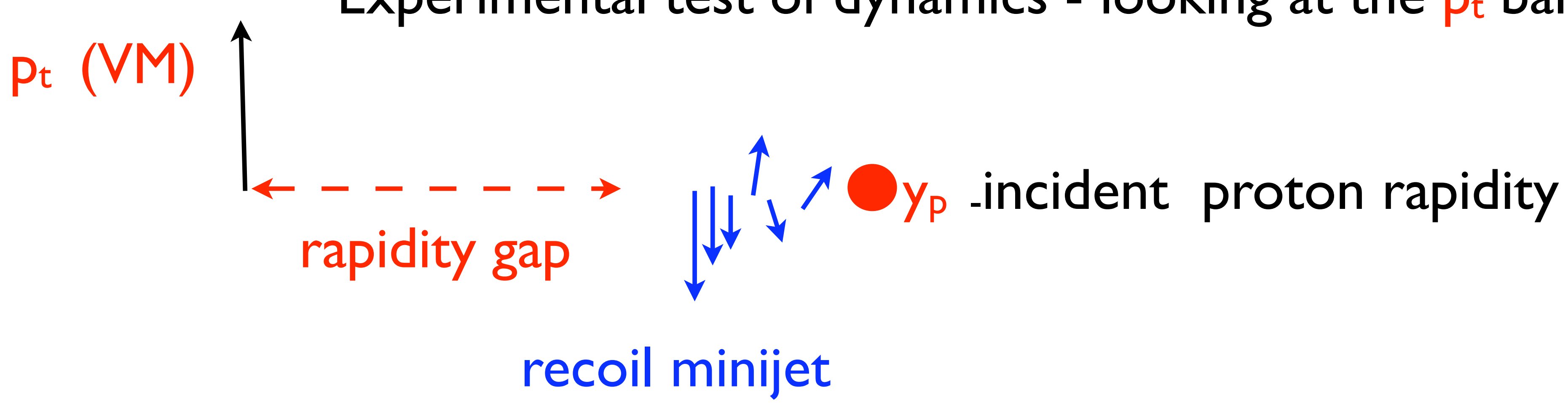
the energy of the vector meson and all variables are defined in the nucleon rest frame.

Very weak t dependence for $|-t| \ll Q^2$

Approximation of attachment of the ladder to one parton may work already for $-t \sim 1$ GeV^2 - early scaling - very different pattern of hadron production from the one used in the MC for background subtraction.

Is mechanism has large enough cross section to dominate already at $-t \sim 1\,\mathrm{GeV}^2$?

Experimental test of dynamics - looking at the p_t balance



Conclusions

Semiinclusive reactions provide new ways to study structure of the nucleon and the high energy dynamics, Good acceptance in the proton fragmentation region is critical for these studies. This adds to the list of arguments in favor of good instrumentation of this rapidity range we put in the white book. In particular, spin effects for polarized protons, studies of isospin 1/2 baryons, baryon 20 plet,...

One more possibility: *The process of knockout of gluon for moderate t (in $\gamma+p \rightarrow VM + Y$) maybe a good way to look for exotic baryons with valence gluons.*