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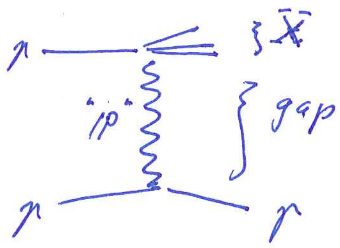
Diffraction

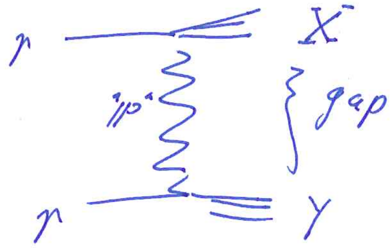
≡ scattering w/o exchange of quantum numbers,
(via "pomeron")

Exp. signature : rapidity gap. What does this look like?

pp :

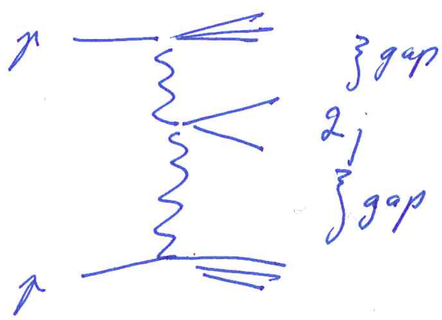


SD
Single diffraction



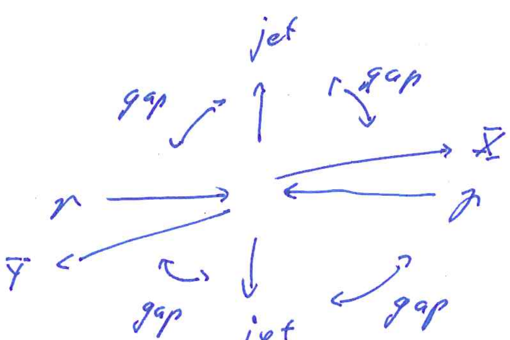
DD
Double diffraction

a)

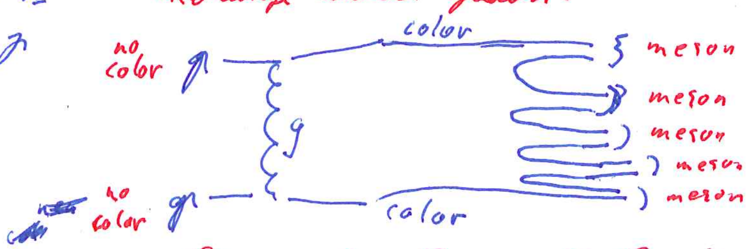


gap + jet + gap, or
jet + gap + jet + gap + jet
from fragmenting beam

Remember: All these diagrams have rapidity as the vertical axis. In a detector, rapidity ~ angle w. r. t. the beam axis. So for example the diffractive dijet production a) looks like.



Why is a gap a signature of color neutral exchange?
Exchange colored gluon:



⇒ Rapidity interval between two receding colored particles is filled with $q\bar{q}$ pairs that form mesons to neutralize color.

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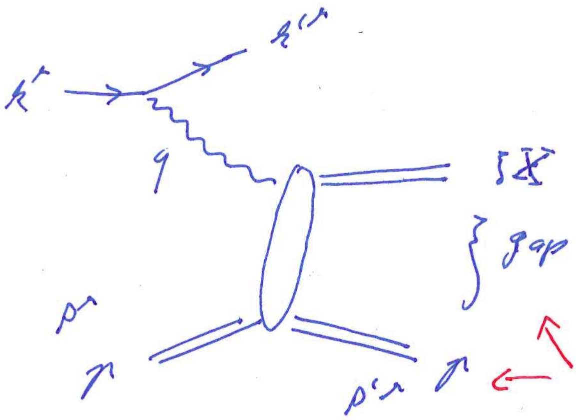
DDIS, kinematics

Recall usual kinematics:

$$W^2 = (P+q)^2$$

$$x = \frac{Q^2}{2P\cdot q}$$



← proton intact, separated by rapidity interval from diffractive system X

Should again think of rapidity as the vertical axis on this plot

Now additional kinematical variables

$t = (P-P')^2$ small ($|t| \lesssim \frac{1}{R_p^2}$)

Remember: t is essentially a transverse momentum squared. It has to be small, otherwise the proton breaks up.

Remember: $x \sim$ momentum fraction $\sim$ rapidity of struck parton.
We define two new variables to divide the rapidity interval from the target to the struck parton:

$$x_{I\!P} = \frac{(P-P')\cdot q}{P\cdot q}$$

$$\beta = \frac{Q^2}{2q\cdot(P-P')}$$

IMF interpretation:

$(p^+_{I\!P} = x_{I\!P} P^+)$

$(p^+_{quark} = \beta p^+_{I\!P})$

P^+, q^- large → proton in $+z$-direction, γ^* in $-z$-direction

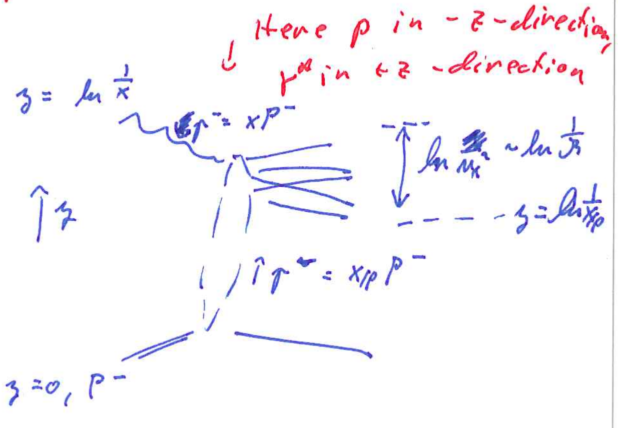
$$x_{I\!P} = \frac{M_X^2+Q^2-t}{W^2+Q^2-m_N^2} \approx \frac{M_X^2+Q^2}{W^2+Q^2}$$

$$\beta = \frac{Q^2}{M_X^2+Q^2-t} \approx \frac{Q^2}{M_X^2+Q^2}$$

$$\beta x_{I\!P} = x$$

$$\underbrace{\ln\frac{1}{x}}_{\text{tot. rapidity}} = \underbrace{\ln\frac{1}{\beta}}_{\text{size of } X,\ \sim \ln M_X^2} + \underbrace{\ln\frac{1}{x_{I\!P}}}_{\text{size of gap}}$$

Sudakov/MRK:



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DDIS in dipole picture

Analoguously to the normal parton distribution functions one can define diffractive pdf's (evolving with DGLAP). ~~[illegible]~~ Physical interpretation: probability to find quark/$\bar{q}$/gluon in proton with the condition that the proton stays intact in the scattering. These are, however, much less useful than conventional pdf's. In particular, a diffractive pdf measured in DIS cannot be used in diffractive pp-scattering.

A much more natural way to describe diffractive DIS is the dipole picture.

We had for the inclusive cross sections

$$\sigma^{\gamma^* p}_{L,T} = \int d^2 r \int_0^1 dz \, |\Psi_{L,T}(r,z)|^2 \, 2\,\mathrm{Im}\, A_{q\bar{q}p}(r,x)$$

$$|\Psi_L|^2 = \frac{\alpha_{e.m}}{2\pi^2} N_c e_f^2 \, 4Q^2 z^2 (1-z)^2 K_0^2(\varepsilon r)$$

$$|\Psi_T|^2 = \frac{\alpha_{e.m.}}{2\pi^2} N_c e_f^2 \left([z^2 + (1-z)^2] K_1^2(\varepsilon r) + m_f^2 K_0^2(\varepsilon r) \right)$$

$$\varepsilon^2 = z(1-z)Q^2 + m_f^2$$

$$e_f = \begin{cases} \frac{2}{3} & u, c \\ -\frac{1}{3} & d, s \end{cases}$$

$A_{q\bar{q}p}$ ~ purely imaginary

Recall that $A_{q\bar{q}p}$ is the forward elastic scattering amplitude (i.e. color singlet amplitude). It is predominantly imaginary both in Regge theory and in QCD (BFKL ladders etc.). The color octet (= not elastic) amplitude was mostly real.

~

We are now using a normalization (like in the optical model), where the flux factor is absorbed into the amplitude, and corresponds to an integral over impact parameters. We thus write:

$$\underbrace{A_{q\bar{q}p}}_{\text{GeV}^{-2}} = i \int d^2 \underline{b}\, \underbrace{N(\underline{b}, \underline{r}, x)}_{\text{dim. less}}$$

DDIS = elastic dipole - target scattering

Note difference in terminology between pp and DIS:

DIS: $\sigma_{tot} = \sigma_{diff} + \sigma_{inel}$

pp: $\sigma_{tot} = \sigma_{inel} + \underbrace{\sigma_{el} + \sigma_{diff}}_{\text{"}I\!P\text{ exchange"}}$

$$\sigma_{q\bar{q}p}^{elastic} = \int d^2\underline{b}\, (N(\underline{b}, \underline{r}, x))^2$$

$$\Rightarrow \sigma_{L,T}^{\gamma^* p\ diff} = \int d^2\underline{r} \int_0^1 dz\, |\Psi_{L,T}|^2 \int d^2\underline{b}\, (N(\underline{b}, \underline{r}, x))^2$$

Thus if we know N, we can get both the total (inclusive) and diffractive DIS cross-sections from the same dipole cross section. (Also need to have an impact parameter dependence)

This is in contrast to pdf picture, where it is not possible to calculate the diffractive pdf's from the usual ones.

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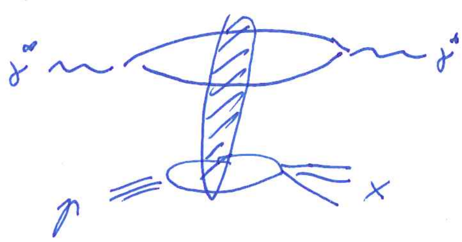
If we also know the LC wave function of the diffractive state in the final state (typical example: vector meson like J/ψ) we can also compute exclusive cross section (= to a final state with a specific particle in it)!

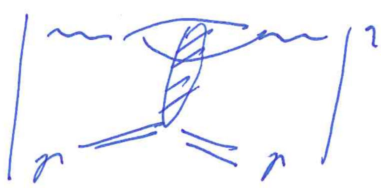
$$\sigma_{L,T}^{\gamma^* p \to J/\psi\, p} = \int d^2 b \left| \int d^2 r \int dz \left(\Psi_{\gamma^* \to q\bar{q}}(z,\underset{\sim}{r})\right)^* \left(\Psi_{q\bar{q} \to J/\psi}(z,\underset{\sim}{r})\right) \right|^2 \times \left(\mathcal{N}(\underset{\sim}{b},\underset{\sim}{r},x)\right)^2$$

tot:



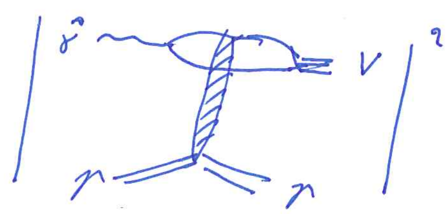
$\sigma^{tot} \sim 2\,\mathrm{Im}A$

tot elastic



$\sigma \sim |A|^2$

tot excl.



$\sigma \sim |A_{q\bar{q}p}|^2 |\langle \gamma^* | V \rangle|^2$