Phenomenology of Diffractive DIS (overview)

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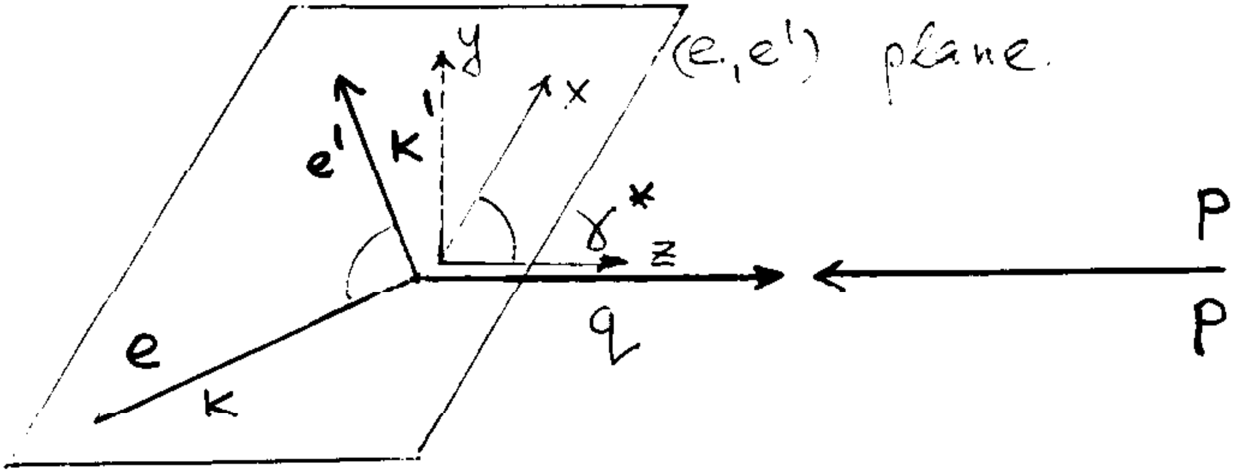
- Diffractive DIS: variables, natural conventions & normalizations, menagery of SF's
- Microscopic origin of diffractive DIS
- pQCD and (non)factorization properties of diffractive DIS
- Vector mesons: 1S vs. 2S, flavor symmetry
- Exclusive (vector mesons) vs. inclusive (continuum) diffractive DIS: duality
- Q^2 evolution of diffractive SF's
- Heavy flavors and jets
- Diffraction slope
- Azimuthal asymmetries: i) L/T separation, ii) diffraction vs. DIS
- Diffraction in Charged Current DIS. Flavor dependence. Nonconservation of weak currents.
- Diffraction as an origin of tensor structure functions of the deuteron

- Kinematics, definitions, normalizations



$$Q^2 = -q^2 = -(k-k')^2$$

$$y = \frac{(pq)}{(pk)}$$

$$x = \frac{Q^2}{2(pq)}$$

- 3 polarizations of the virtual γ^*:

Transverse: $\vec{e} = \vec{n}_x = \vec{t}$ (in plane)

$\vec{e} = \vec{n}_y = \vec{w}$ (out of plane

Scalar: $e_\mu = s_\mu$ $\quad (qs) = 0$

[Misnomer: longitudinal]

Helicity basis: $\vec{e}_\pm = -\frac{1}{\sqrt{2}}(\vec{e}_x \pm i\vec{e}_y)$

- The γ^* polarization density matrix

Gourdin 61

$$L_{\mu\nu} \propto (1-y) S_\mu S_\nu \qquad (S = L)$$

$$+ \left(1-y+\frac{1}{2}y^2\right) \frac{1}{2}\left(t_\mu t_\nu + w_\mu w_\nu\right) \qquad (T)$$

$$+ (1-y) \cdot \frac{1}{2}\left(t_\mu t_\nu - w_\mu w_\nu\right) \qquad (TT')$$

$$+ 2\left(1-\frac{1}{2}y\right)\sqrt{1-y}\; \frac{1}{2}\left(S_\mu t_\nu + S_\nu t_\mu\right) \qquad (ST = LT$$

+ extra terms for polarized leptons and/or charged currents

$$\left[y\left(1-\frac{1}{2}y\right)\frac{i}{2}\left(w_\mu t_\nu - t_\mu w_\nu\right) + y\sqrt{1-y}\;\frac{i}{2}\left(w_\mu S_\nu - S_\mu w_\nu\right)\right.$$

- Inclusive DIS: LT interference vanishes

$$Q^2 x \frac{d^2\sigma}{dQ^2 dx} = \frac{\alpha_{em}}{\pi}\left[\left(1-y+\frac{1}{2}y^2\right)\sigma_T + (1-y)\sigma_L\right]$$

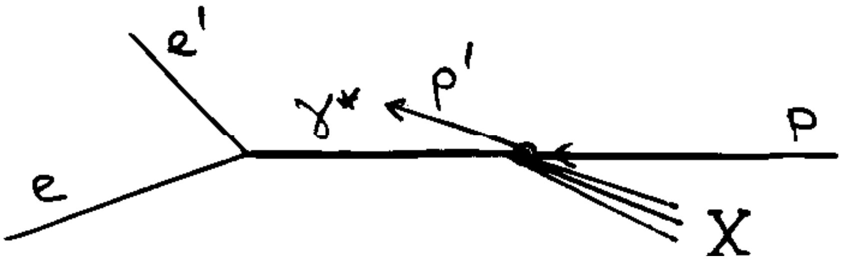
- Structure functions & parton densities

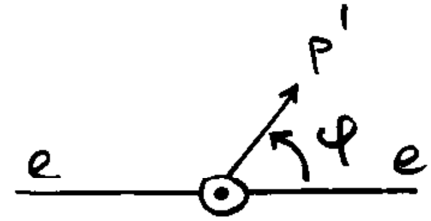
$$F_{T,L} = \frac{Q^2}{4\pi^2 \alpha_{em}} \sigma_{T,L}$$

$$F_2 = F_T + F_L$$

- GLDAP/BFKL evolution with Q^2 & x.

- Diffractive DIS: hadronic plane





$p' \simeq (E x_L, \vec{p}_\perp, x_L p)$

- New variables: φ, $|t| \simeq \vec{p}_\perp^{\,2}$, $M^2 = p_X^2$

- ST (LT) & TT' interference:

Gourdin 1961

$$
\begin{aligned}
Q^2 x \frac{d^5\sigma}{dQ^2\,dx\,dM^2\,dp_\perp^2\,d\varphi} = \frac{\alpha_{em}}{\pi} \cdot \Big[& \\
& \left(1 - y + \tfrac{1}{2}y^2\right) \frac{d^3\sigma_T(\gamma^* p \to p' X)}{dM^2\,dp_\perp^2\,d\varphi} + \\
& (1-y)\, d^3\sigma_L + \\
& + (1-y)\cos 2\varphi \, d^3\sigma_{TT'} + \\
& + 2\left(1 - \tfrac{1}{2}y\right)\sqrt{1-y}\,\cos\varphi\, d^3\sigma_{LT} \\
& \left\{ \begin{array}{l} + \text{ extra terms for charged current} \\ y\left(1 - \tfrac{1}{2}y\right) d^3\sigma'_T + y\sqrt{1-y}\,\cos\varphi\, d^3\sigma'_{LT} \end{array} \right\} \Big]
\end{aligned}
$$

NC: Bartels, Ewerz, Lotter, Wüsthoff (1996)
Arens, Diehl, Landshoff, Nachtmann (1996)

CC: Bertini, Genovese, Nikolaev, Zakharov (1997)

- Diffractive variables and SF's:

* Q^2 sets a scale for M^2: $\beta = \frac{Q^2}{Q^2+M^2}$

* $x_{\mathbb{P}} = \frac{Q^2+M^2}{Q^2+W^2}$ = the fraction of the total energy consumed in excitation of the photon into hadrons

* $x_L = 1 - x_{\mathbb{P}}$, $x_{\mathbb{P}} = \frac{x}{\beta}$

- Each and every $d^3\sigma_i(\gamma^* p \to p' X)$ define the diffractive SF which must be: i) dimensionless, ii) similar to F_2, F_L, ii) not tied to any model for diffraction

$$(Q^2+M^2)\frac{d^3\sigma_i(\gamma^* p \to p' X)}{dM^2\, dp_\perp^2\, d\varphi} =$$

$$= \frac{1}{2\pi} \cdot \frac{\sigma_{tot}^{pp}}{16\pi} \cdot \frac{4\pi^2 \alpha_{em}}{Q^2} \cdot F_{Di}^{(5)}(\varphi, p_\perp^2, x_{\mathbb{P}}, \beta, Q^2)$$

* Educated guess: $F_{Di}^{(5)}$ is a smooth function of $x_{\mathbb{P}}$, Q^2.

* $\sigma_{tot}^{pp} \simeq 40\,\text{mb}$ as a reminder of the proton target

! The absolute normalization is subject to convention.

$$F_D^{(4)} = \int \frac{d\varphi}{2\pi} F_D^{(5)}(\varphi, p_\perp^2, x_{I\!P}, \beta, Q^2)$$

★ $F_D^{(3)}(x_{I\!P}, \beta, Q^2) =$

$$\int \frac{\sigma_{tot}^{pp}\, dp_\perp^2}{16\pi} \cdot F_D^{(4)}(p_\perp^2, x_{I\!P}, \beta, Q^2)$$

$F_D^{(3)}$ still dimensionless !

★ The total fraction of $F_2(x, Q^2)$ which comes from diffractive DIS:

$$\tilde{F}_D(x, Q^2) = \int_x^{x_{I\!P}^{max}} \frac{dx_{I\!P}}{x_{I\!P}} F_D^{(3)}\left(x_{I\!P}, \beta = \frac{x}{x_{I\!P}}, Q^2\right)$$

- $F^{D(3)}(H1 + ZEUS) =$

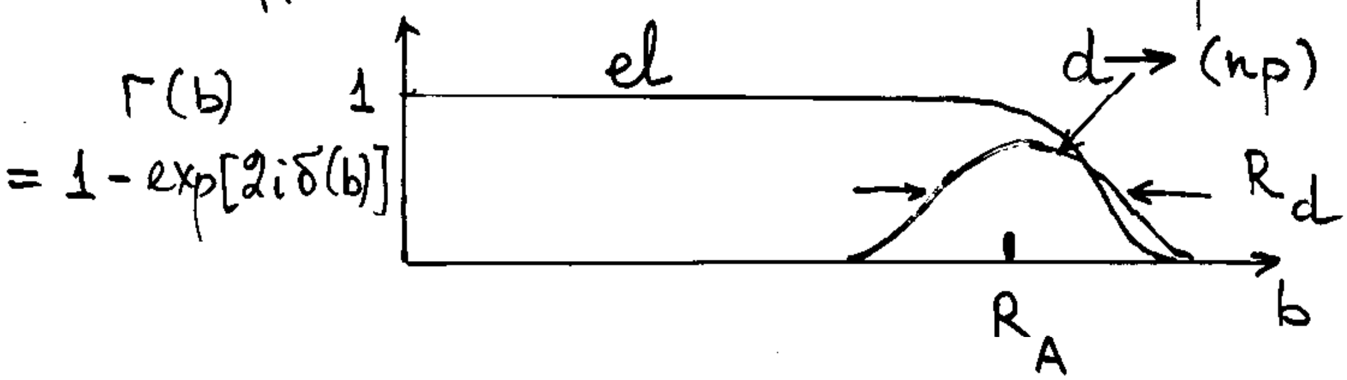
$$= \frac{1}{x_{I\!P}} F_D^{(3)}(\text{NATURAL})$$

The former blows up at small $x_{I\!P}$, the latter is smooth and is more convenient and is strongly recomended

The origin of diffraction: absorption & distortion of the beam WF.

Landau, Pomeranchuk, Feinberg, Sitenko, Akhiezer, Glauber (1953–56)
Good, Walker (1961)

- (Structureless) protons + Black nucleus
  Absorption $\Longrightarrow$ $\sigma_{in} = \pi R_A^2$
  ★ The absoption driven (via unitarity) elastic scattering: $\sigma_{el} = \sigma_{in} = \pi R_A^2$
- (Composite) deuteron + Black nucleus ($R_D \ll R_A$)
  Absorption: $\sigma_{in} \simeq \pi R_A^2$
  The absorption driven $\sigma_{el} \simeq \pi R_A^2$
  ★ The distortion of the intrinsic WF of the deuteron $\Longrightarrow$ excitation of the continuum np states
  Diffraction dissociation $dA \to (np)A$



★ $\sigma_D \sim \pi R_A R_d$ exhibits the same (in)dependence on energy as does σ_{el}

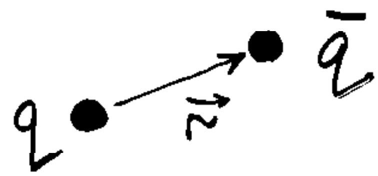
★ Diffraction slope: $B_D \sim B_{el} \sim \frac{1}{4} R_A^2$

Diffraction in DIS

- Composite structure of the photon

$$|\gamma^*\rangle_{physical} = |\gamma^*\rangle_{bare} + \sum_X \Psi_X |X\rangle$$

$X = q\bar{q}$, color dipole



$X = q\bar{q}g$

$X = q\bar{q}gg \ldots\ldots$

- $$\sigma_{tot}(\gamma^* p) = \int d\{X\} |\Psi_X|^2 \sigma_{tot}(Xp)$$

- Distortions of the WF of γ^* give rise to diffractive DIS

$$\left.\frac{d\sigma_D}{dt}\right|_{t=0} = \int d\{X\} |\Psi_X|^2 \frac{\sigma^2_{tot}(Xp)}{16\pi}$$

Diffractive DIS is a sum of grazing, quasielastic scatterings of Fock states of the γ^* on the target proton (nucleus)

NNN, B.G. Zakharov (92)

The microscopic models:

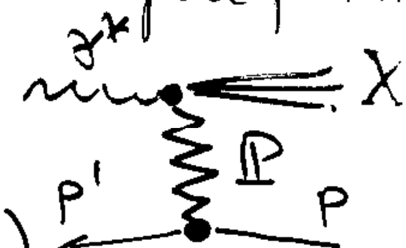
- The color dipole picture
  NNN, Zakharov (92)

  1993-94: systematic treatment of Ψ_X and $\sigma_{tot}(Xp)$ for higher Fock states of the photon
  NNN, Zakharov, Zoller (94
  Mueller, Patel (94)

  Intimate relation to the BFKL picture
  Much quantitative phenomenology:
  Genovese, NNN, Zakharov (95,96)
  Bartels, Lotter, Wüsthoff (96)
  Levin, Martin, Ryskin, Teubner (96)
  . . . .

- Distortions of WF of the γ^* by color fields in the proton.
  Buchmuller, McDermott, Hebecker (96)
  Much similarity to the color dipole pictur

- Pomeron as a particle:



  Regge theory motivation:
  Kaidalov, Ter-Martirosyan (74)
  Extensions to DIS: Ingelman, Schlein (85)
  Donnachie, Landshoff (84,87). Fritzsch, Streng (85)

- Aligned Jet Model (Bjorken 72, Bj, Kogut 73)
  An integral part of the color dipole picture.

Exclusive limit of diffractive DIS

$$\gamma^* p \to V p'$$

- $$M_{T,L} = \int d^2\vec{r}\, dz\, \Psi_{V^*}\, \sigma(r, x_{eff})\, \Psi_{\gamma^*}$$

★ The dominat contribution from

$$r \sim r_S = \frac{6}{\sqrt{Q^2 + m_V^2}}$$

Kopeliovich Zakharov (91)
Kopeliovich et al (93, 94)

Small scanning radius $r_S \longleftrightarrow$ pQCD

- The relationship to the gluon structure function of the proton

Barone et al (94
NNN, Zakharov (94)

$$\sigma(r, x) = \frac{\pi^2}{3} r^2 \cdot \alpha_S(r)\, G\left(x, q^2 \sim \frac{B}{r^2}\right)$$

$$B \simeq 10$$

- $$M_L \propto r_S^4\, G(x_{eff}, q_L^2) \cdot \frac{\sqrt{Q^2}}{m_V}$$

$$M_T \simeq \frac{m_V}{\sqrt{Q^2}} \cdot M_L$$

Kopeliovich et al (94)

Ryskin (93), Brodsky et al. (9

★ Very small pQCD scale: Nemchik et a (94

$$q_L^2 \sim (0.1 - 0.2) \cdot (Q^2 + m_V^2)$$

- Flavor symmetry restoration in a natural scaling variable $(Q^2+m_V^2)$

Kopeliovich et al. (93)
Nemchik et al. (96)
NNN, Zakharov, Zoller (95)

- $$\sigma(\gamma^* \to V) \propto \frac{1}{(Q^2+m_V^2)^3}\, \sigma(x_{eff}, \tau \cdot (Q^2+m_V^2))$$

$$\tau \simeq 0.1 - 0.2$$

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

Good agreement with the experiment [Fig.]

- The same universal $\sigma(x_{eff}, r_S)$ enters different $\gamma^* \to V$ [Fig.]

- The larger is $(Q^2+m_V^2)$ the steeper is the dependence on x_{eff}^{-1} and/or W^2

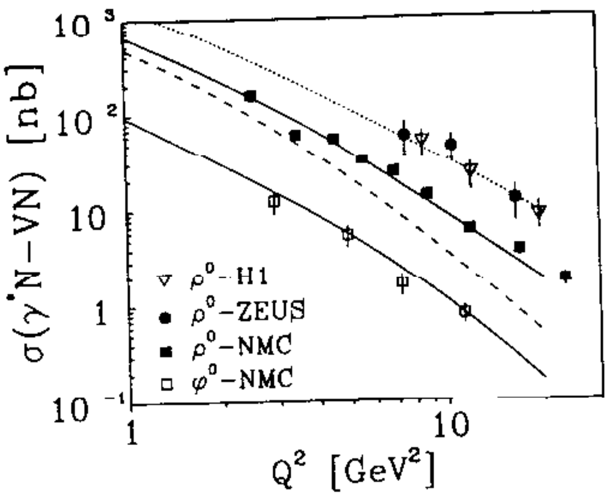
[Fig.]

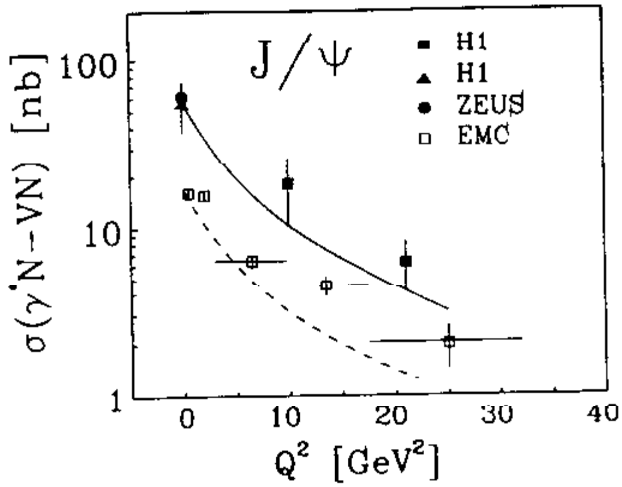
- The scanning radius sets a scale for the contribution from the $\gamma^* \to V$ vertex to the diffraction cone: shrinkage with Q^2 [Fig.]

- The Regge shrinkage at all Q^2.
NNN, Zakharov, Zoller (96) [Fig.]

- Test of the QCD predictions for Q^2 dep.

Nemchik et al. (96)

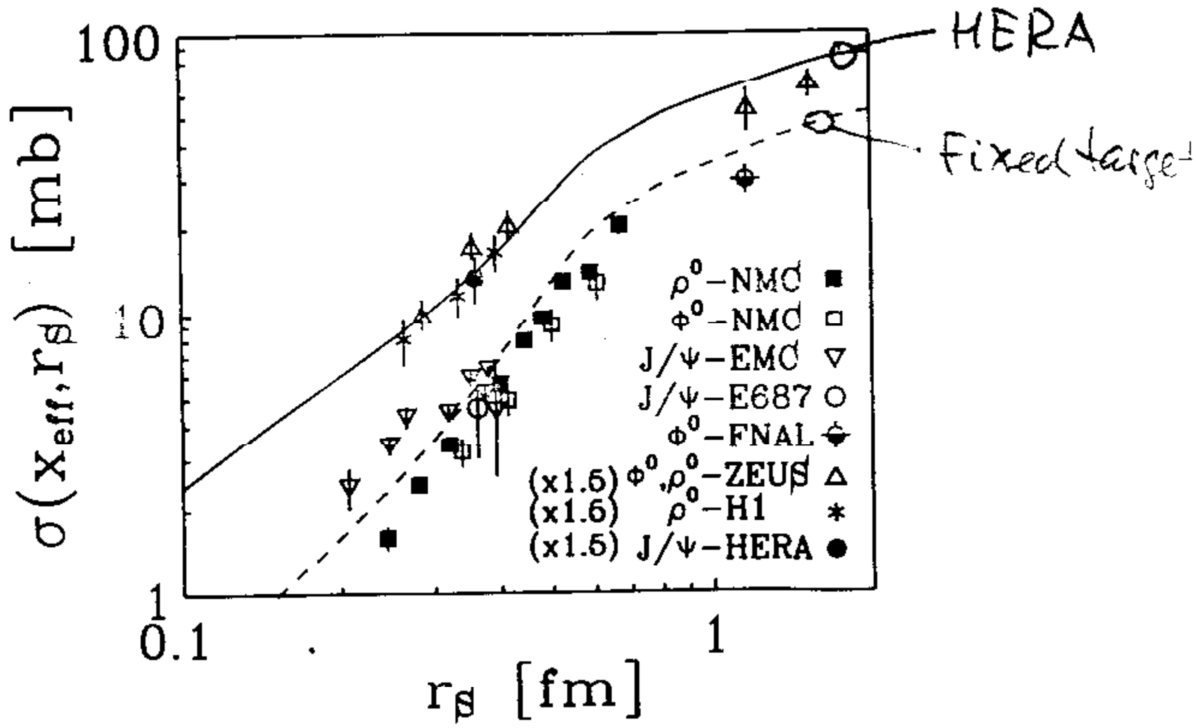




- Invert the problem: find $\sigma(x, r)$ at $r = r_S = 6/\sqrt{Q^2+m_V^2}$ from the expt. data on $\sigma(\gamma^* \to V)$.

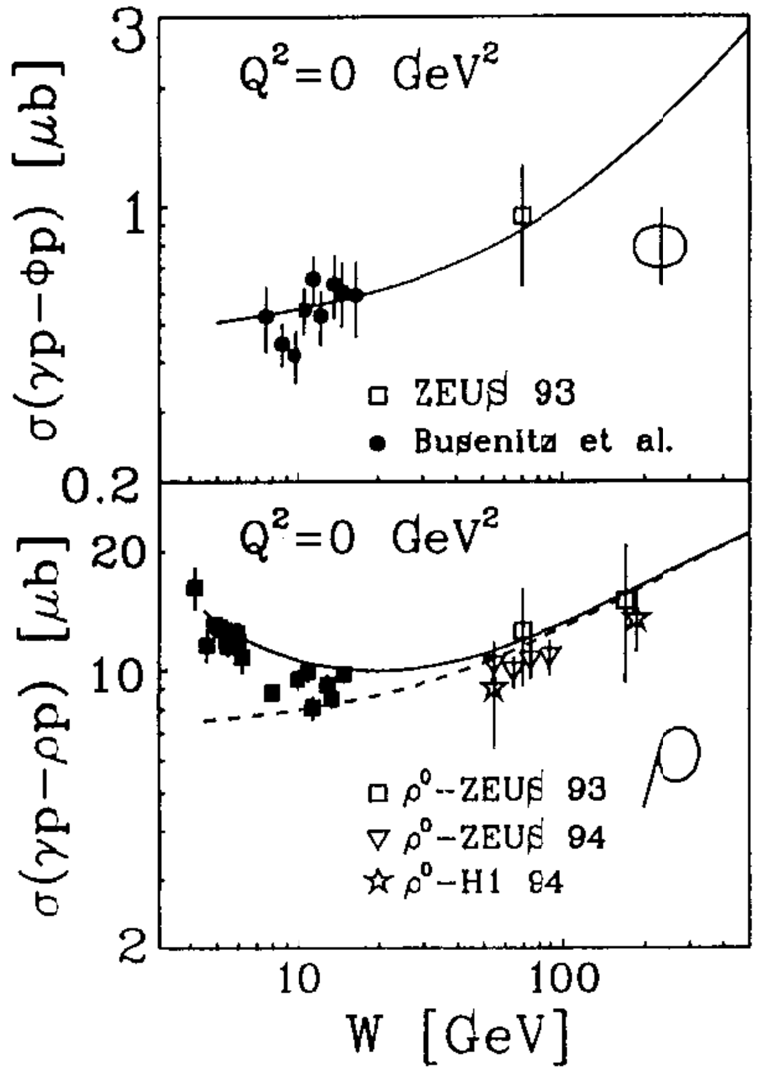
★ Test of the flavor symmetry: universal $\sigma(x, r)$ from data on $\rho, \varphi, J/\psi$.

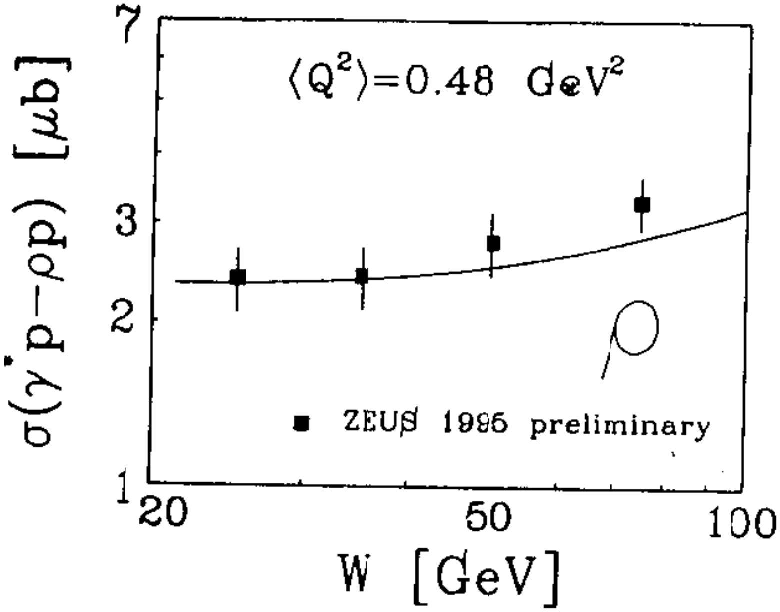
Nemchik et al. (96)

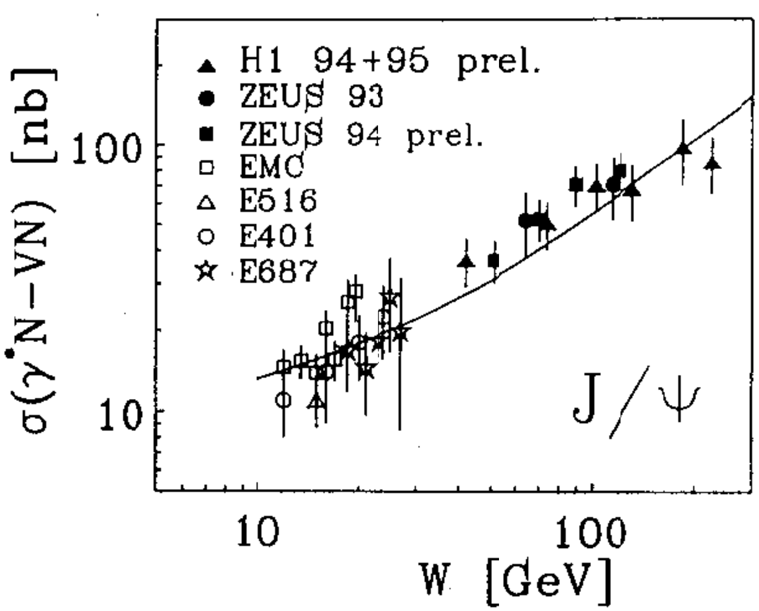


Energy dependence vs. Q^2 and M_V^2

Nemchik et al. (96)



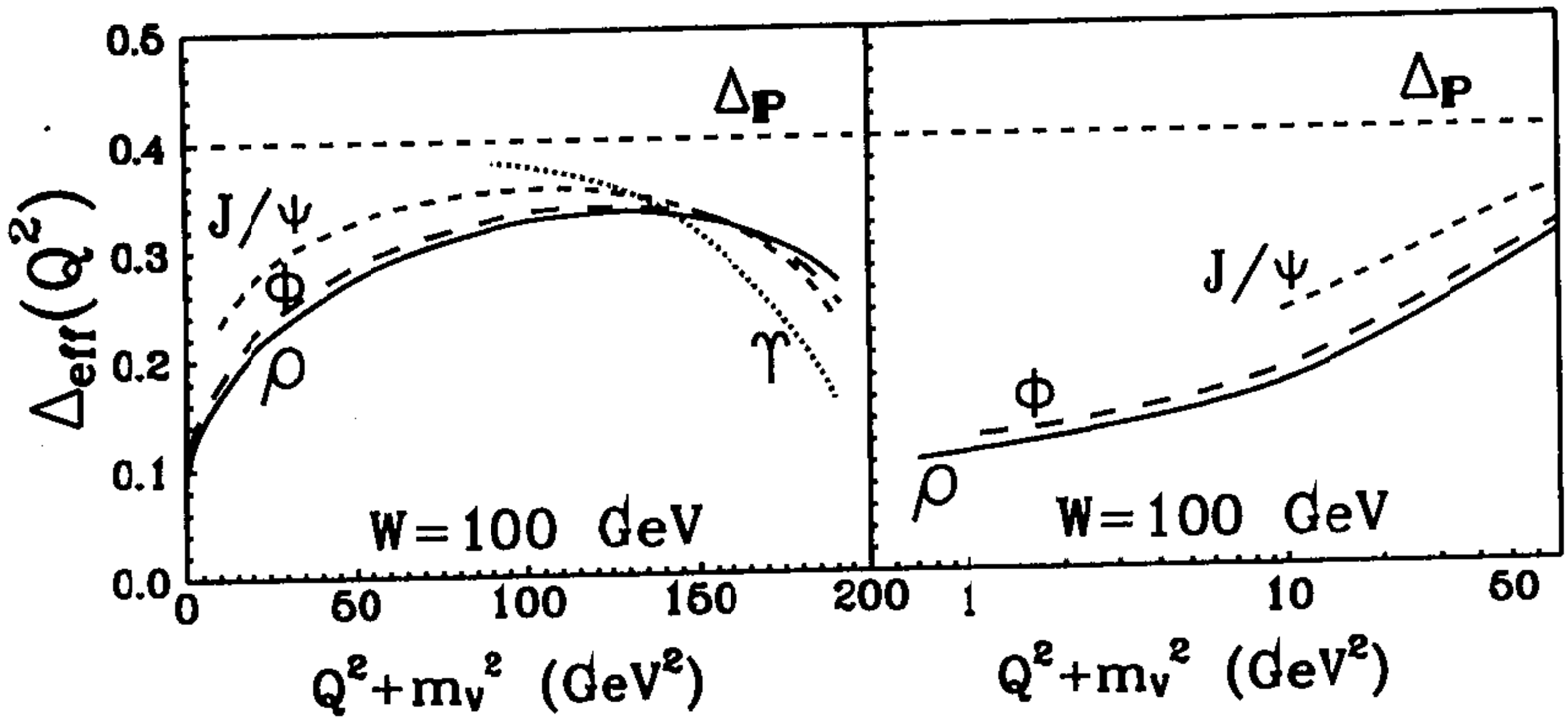




$$\frac{d\sigma}{dt}(\gamma^* p \to V p) \sim (W^2)^{2\Delta_{eff}}$$

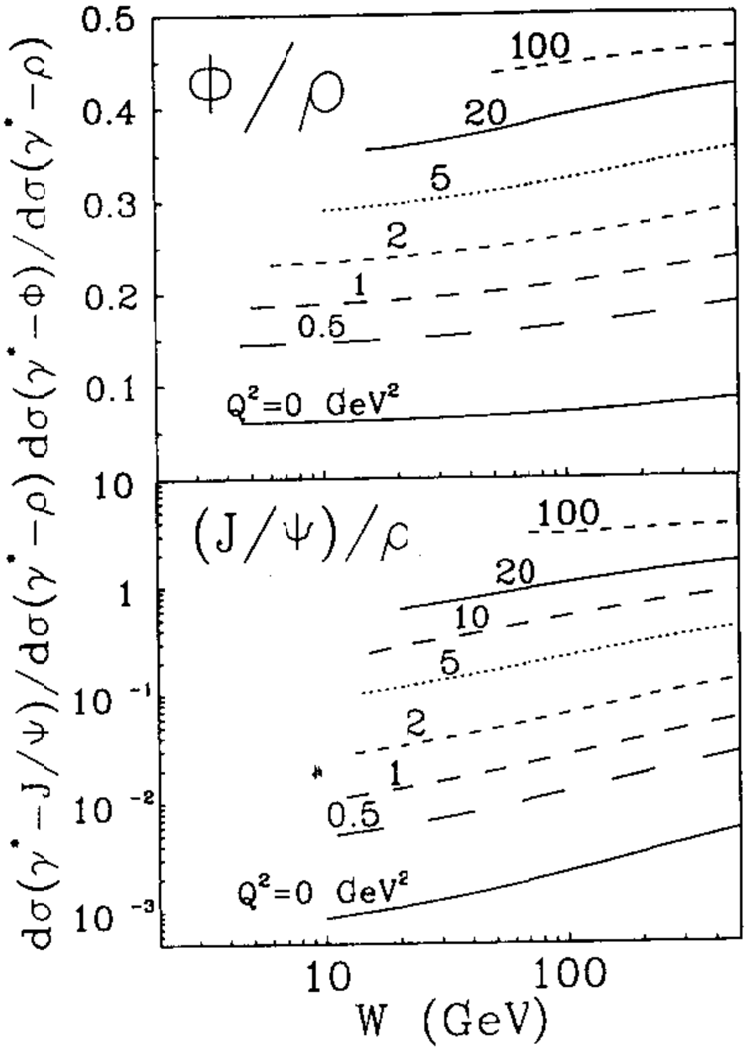
Weak flavor dependence in $(Q^2+m_V^2)$.

Nemchik, NNN, Predazzi, BGZ 96)

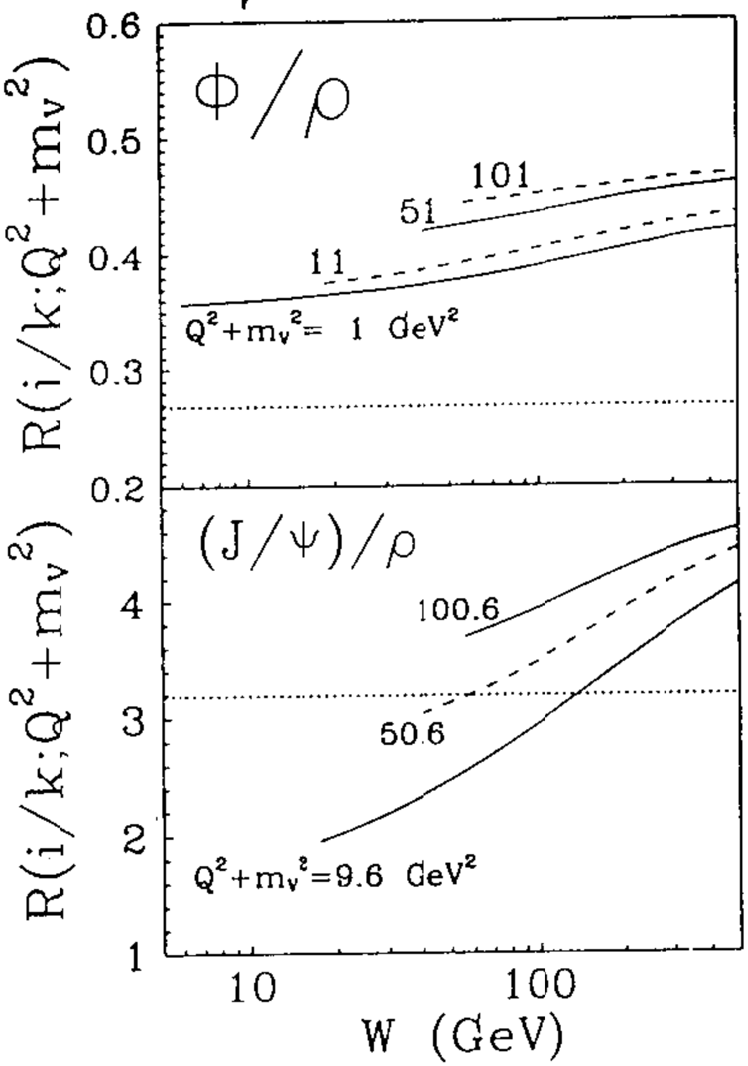


Flavor symmetry restoration in $(Q^2+m_V^2)$

Equal Q^2



Equal $Q^2+m_V^2$

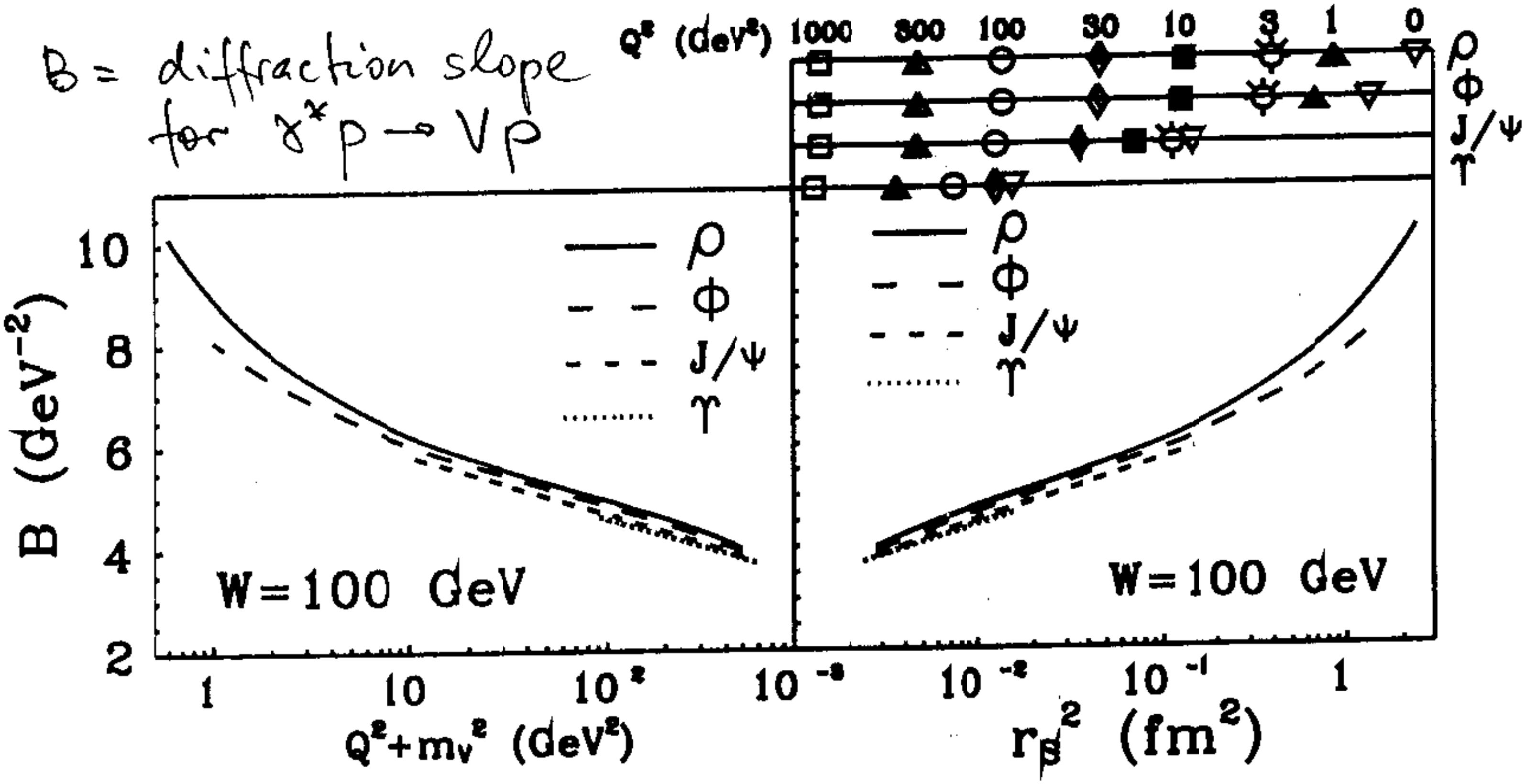


Nemchik et al. (96)

Flavor symmetry restoration in $Q^2+m_V^2$.

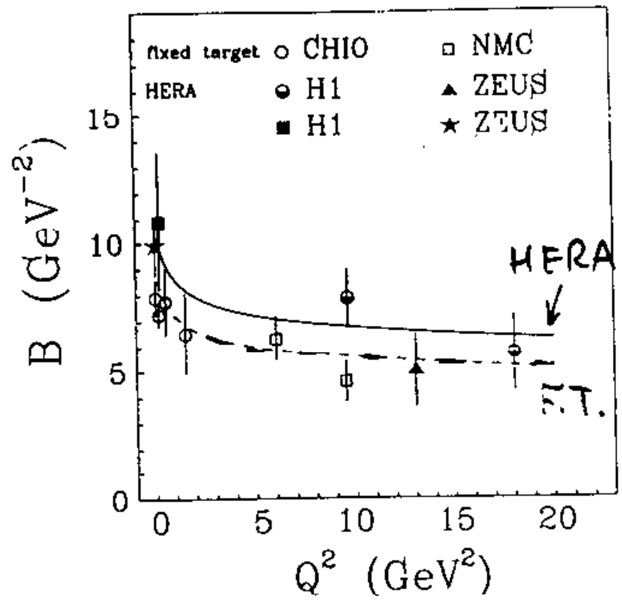
Nemchik, NNN, Predazzi, Zakharov, Zoller (97)

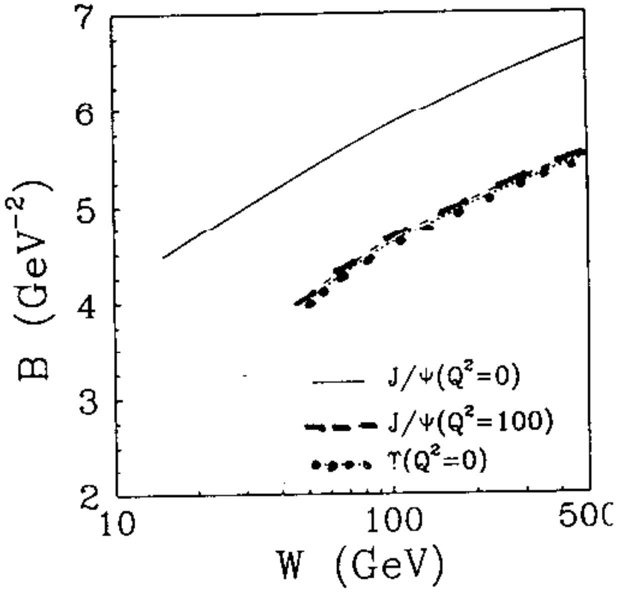
B = diffraction slope for $\gamma^* p \to V p$



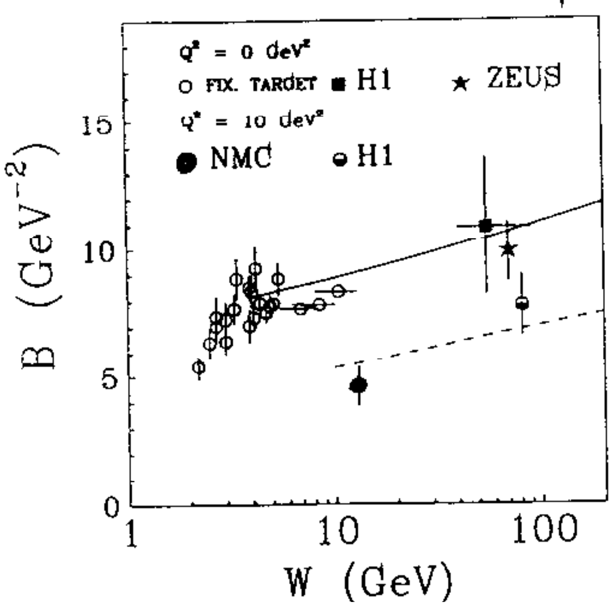
- Test of the shrinkage of diffraction cone with increasing Q^2
- The expected Regge shrinkage for the BFKL pomeron

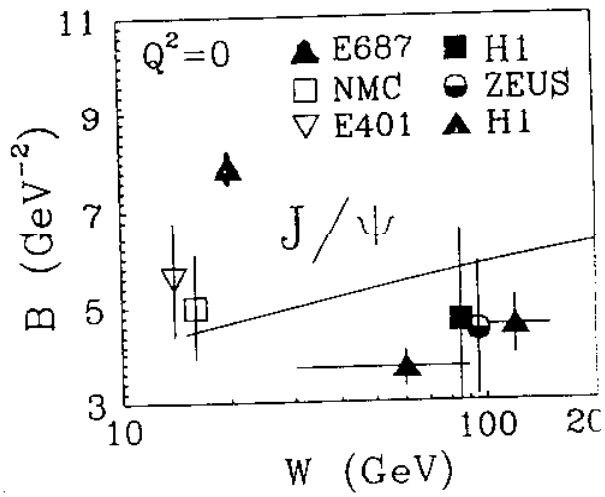
NNN, Zakharo[v], Zoller (96...)





The color dipole model calculations (96...)
Nemcik et a[l.]



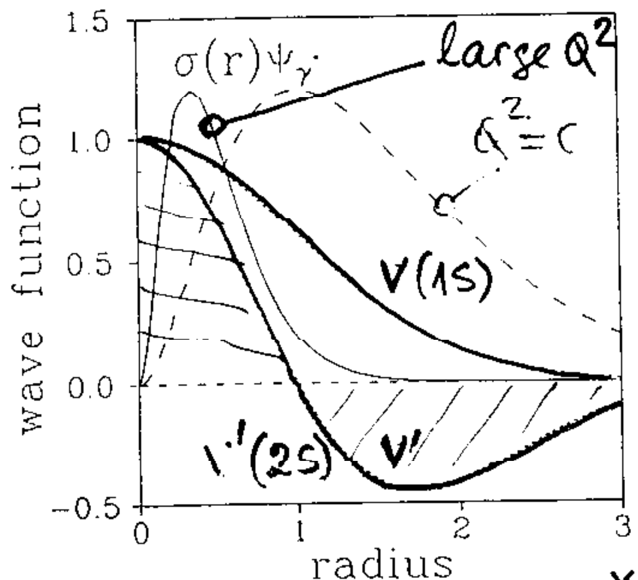


$B(\gamma \to J/\psi)$ is much too small?

- $B(\pi p)$, $B(pp)$ kept rising with time
- and with accuracy of the data

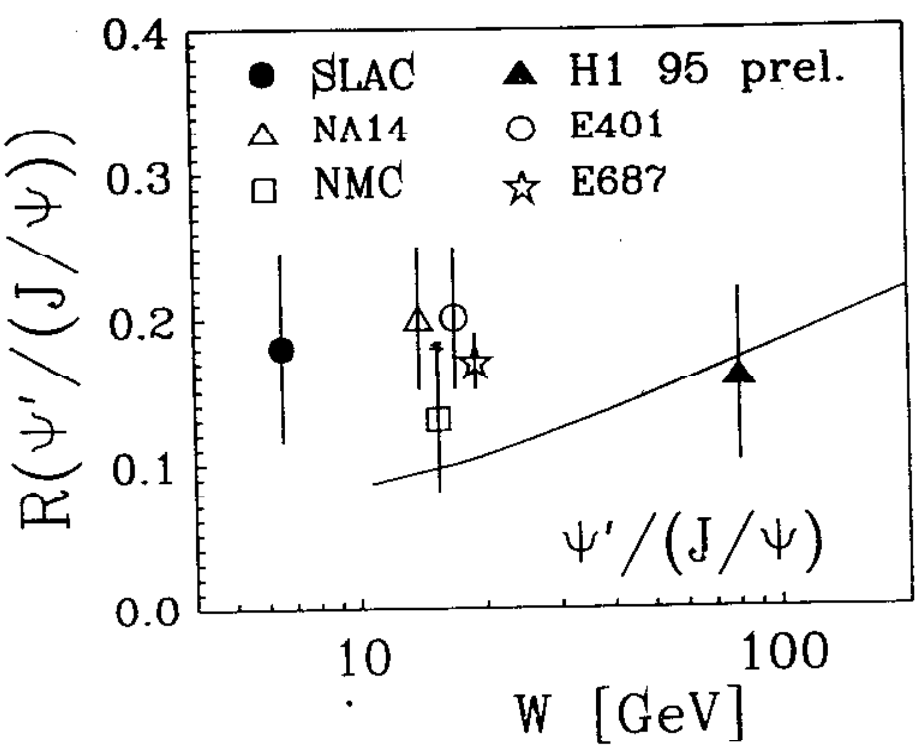
$\gamma^* p \to V' p$: the node effect

Kopeliovich
Zakharov (91)
NNN (92)

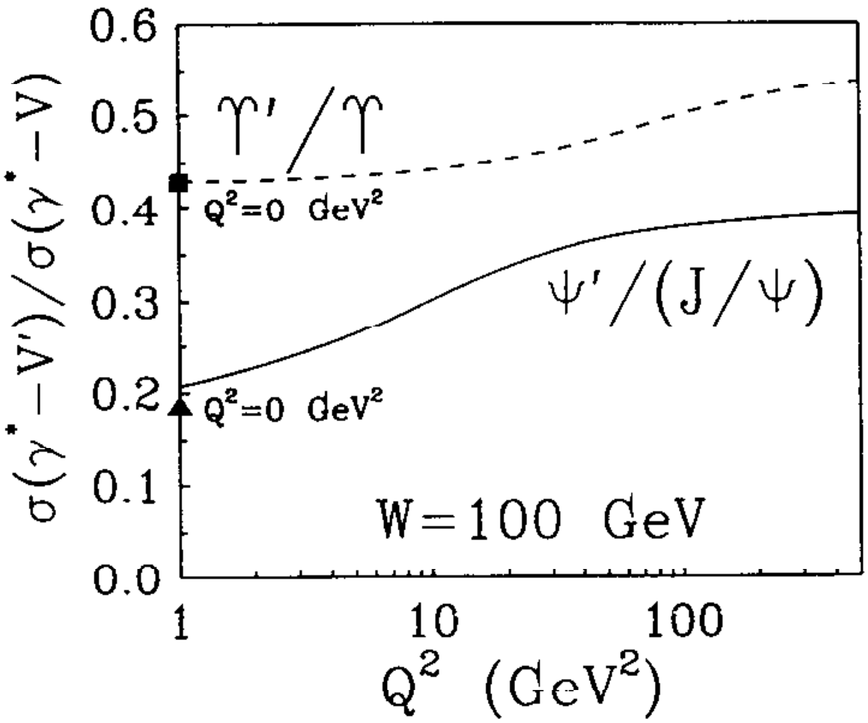


- Cancellations in the $\gamma^* \to V'(2S)$ transition matrix element
- Cancellations diminish at large Q^2 when the scanning radius r_S is smaller than the node position

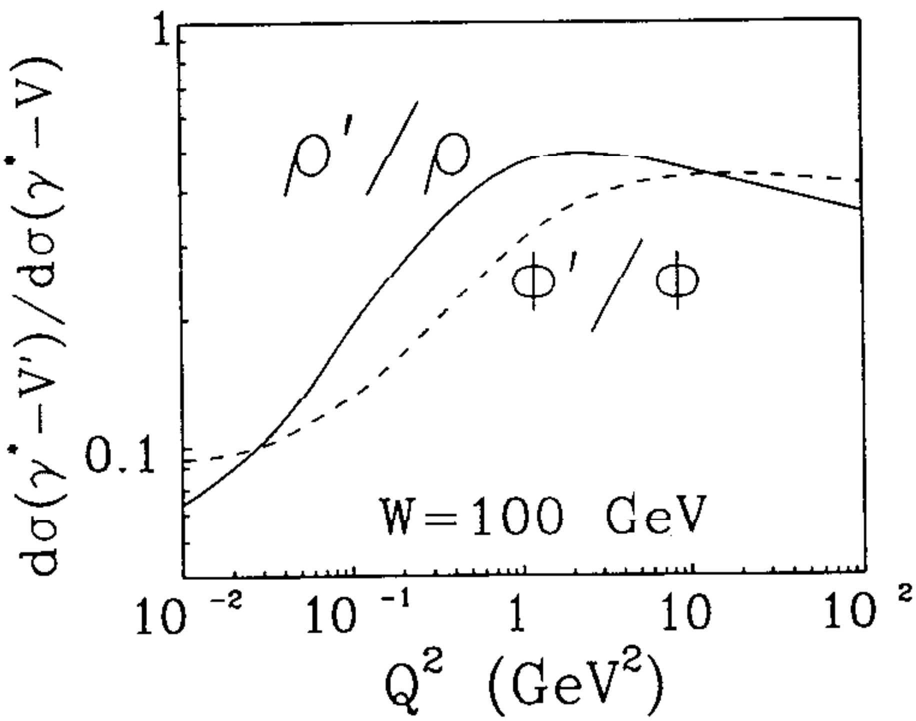
Nemchik
NNN
Predazzi
Zakharov
(96)



The node effect vs. Q^2



Nemchik
NNN
Predazzi
Zakharov
(96)



$\rho'(2S)$
$\varphi'(2S)$!

D- wave sta.
behaves
differently.

The node effect and diffraction slope for $\gamma^* p \to V(2S)\, p$

$r_n \simeq R_V(1S)$

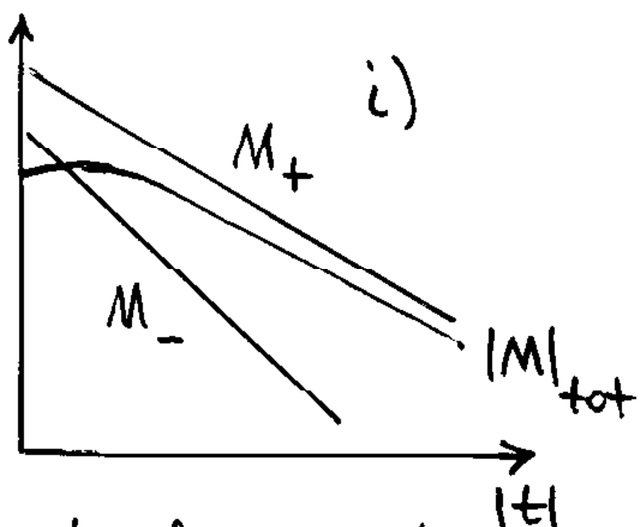
- $M(\gamma^* \to V(2S)) = M_+ - M_-$

$$M_+ = M(r \lesssim r_n) \cdot \exp\left[-\tfrac{1}{2} B_+ |t|\right]$$

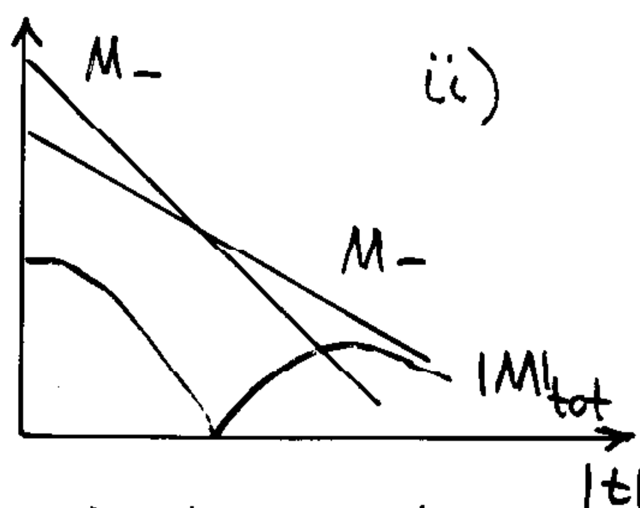
$$M_- = |M(r \gtrsim r_n)| \cdot \exp\left[-\tfrac{1}{2} B_- |t|\right]$$

- $B_- > B_+$

- The two scenarios:
  - i) Undercompensation: $M_+ > M_-$
  - ii) Overcompensation: $M_- > M_+$

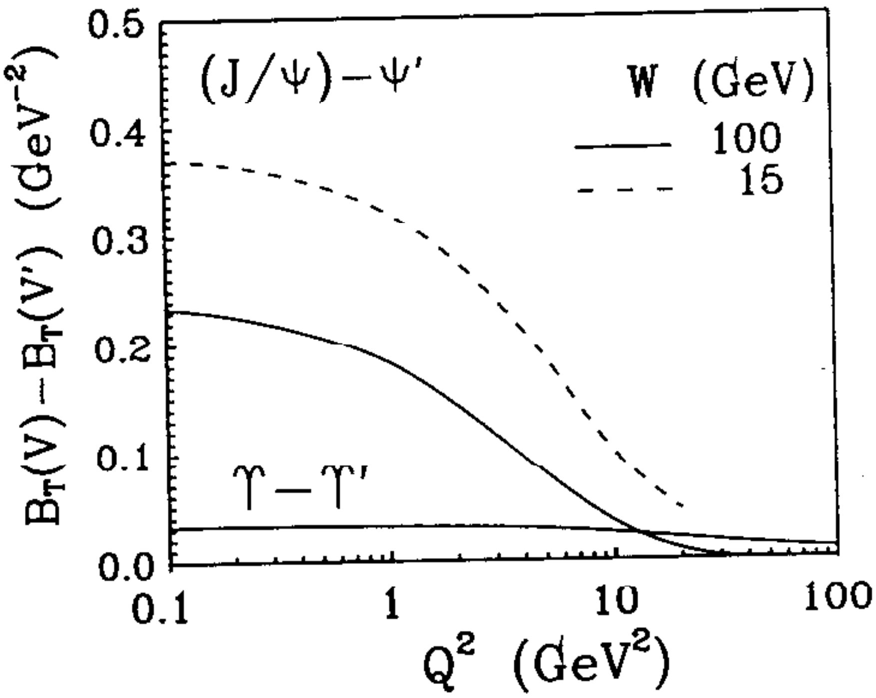


i) The forward dip or shoulder



ii) The dip at a small finite $|t|$

- $B(1S)$ and $B(2S)$ converge at large Q^2



- $\rho'(2S)$: $t = 0$!

$$B(2S) \sim 0 \quad , \quad Q^2 = 0$$

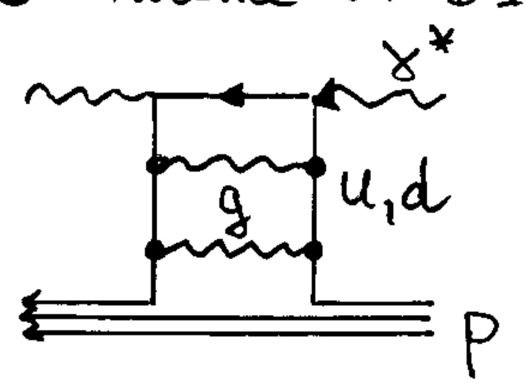
$$B(2S) \sim \frac{1}{2} B(\rho^0) \quad , \quad Q^2 = 0.5\,GeV^2$$

$$B(2S) \sim B(\rho^0) \quad , \quad Q^2 \gtrsim 2\text{–}3\,GeV^2$$

- Deck effects ? Söding–Pumplin contributions ?

Diffraction into continuum

- Valence in DIS



$\sigma_{tot}(\gamma^* p) \propto x\, v(x, Q^2) \sim x^\mu$

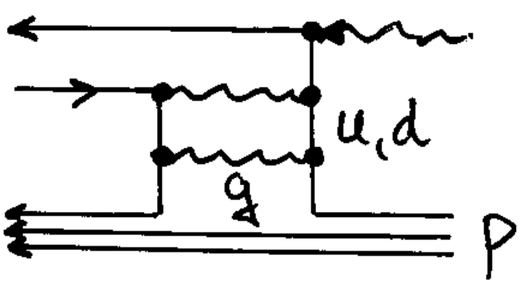
★ Very large part of F_{2p} at $x \sim 0.1$

★ Substantial even at $x \sim 0.01$

Reggeon exchange. Evaluation of the intercept μ:
QED: Gorshkov et al (67); QCD: Ermolayev et al. (95)

★ Not so well known at small x.

- Valence in diffractive DIS



★ Color singlet $q\bar{q}$ exchange in the t-chann
$\Longrightarrow$ Reggeon exchange

★ $d\sigma_D \sim |x_{\mathbb{P}}\, v(x_{\mathbb{P}}, \bar{Q}_D^2)|^2 \sim x_{\mathbb{P}}^{2\bar{\mu}_D}$

$\bar{Q}_D^2 \sim Q^2$, but $\bar{Q}_D^2 \neq Q^2$

$\bar{\mu}_D \sim \mu$, but $\bar{\mu}_D \neq \mu$

NNN
Schäfer (9
Zakharov

! Reggeon exchange in diffractive DIS can be as large as in inclusive DIS

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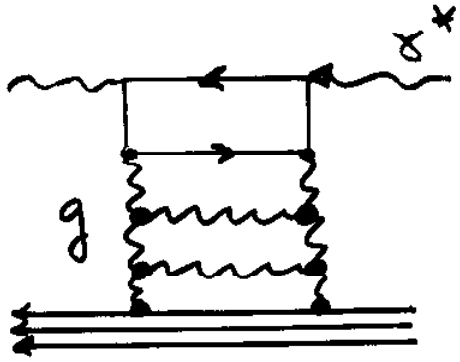
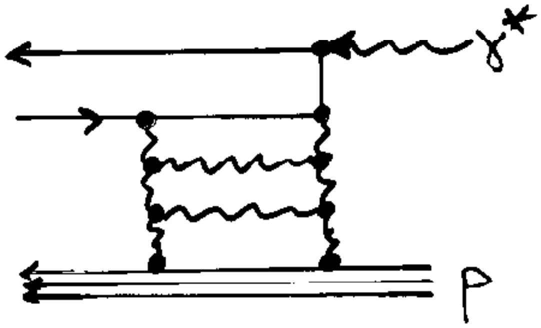
- Sea in DIS



$$F_{2p}(x,Q^2) \propto \int^{Q^2} \frac{dk^2}{k^2}\alpha_s(k^2)\, G(x,k^2$$

BFKL evolution at $\frac{1}{x} \to \infty$

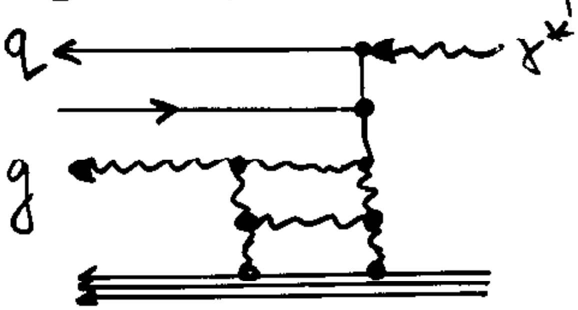
- Sea in diffractive DIS NNN, Zakharov (92, 94)



★ Colour singlet gg exchange in the t-chann.
$\Longrightarrow$ $\mathbb{P}$omeron

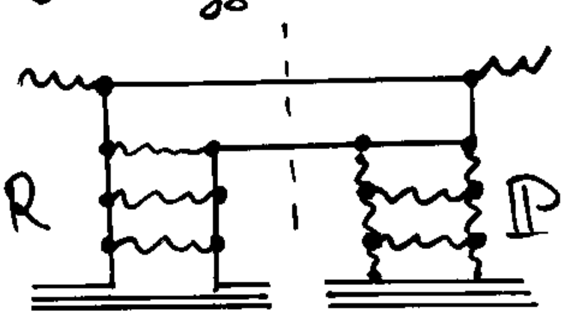
! $\mathbb{P}$omeron $\equiv$ the label for diffraction

- More sea in diffractive DIS NNN, Zakharo (92, 93)



★ Excitation of $M^2 \gg Q$
Precursor of the triple-$\mathbb{P}$ term

- Reggeon-$\mathbb{P}$omeron interference NNN Schäfer (Zakharov



$$d\sigma_D \propto x_{\mathbb{P}}\, v(x_{\mathbb{P}},\bar{Q}^2)\, G(x_{\mathbb{P}},\bar{Q}$$
$$\bar{Q}^2 \sim Q^2$$

★ No special suppression of the $\mathbb{P}R$ interf
Holds to higher orders too.

- $\gamma^* p \to p' \, \bar{q} q$

NNN, Zakharov (92, 94), Genovese et al (96), Bartels et al (96

- The two amplitudes, $\vec{\Phi}_1$ & Φ_2, for the quark helicity changing and conserving transitions

$$d\sigma_T \propto \left(1 - 2\frac{k_\perp^2 + m_f^2}{M^2}\right) \vec{\Phi}_1^{\,2} + m_f^2 \Phi_2^2$$

$$d\sigma_L \propto Q^2 \Phi_2^2$$

- pQCD scales:

$$\frac{d\sigma_T}{dM^2 dk_\perp^2} \propto \frac{1}{(k_\perp^2 + m_f^2)^2} G^2(x_{I\!P}, q_T^2)$$

★ $q_T^2 \simeq (k_\perp^2 + m_f^2)\left(1 + \frac{Q^2}{M^2}\right) \neq Q^2$

★ More perturbative if $M^2 \ll Q^2$

★ σ_T dominated by the contribution from $k_\perp^2 \lesssim m_f^2$, c.f. Bjorken's pre-QCD Aligned Jet Model

$$\frac{d\sigma_L}{dM^2 dk_\perp^2} \propto \frac{1}{k_\perp^2 + m_f^2} \cdot G^2(x_{I\!P}, q_L^2 \simeq q_T^2)$$

★ The genuinely short distance process, $k_\perp^2 \sim \frac{1}{4} Q^2$ NNN, Zakharov (92)

- $\gamma^*_T \to \bar{q}q \qquad \beta = Q^2/(Q^2+M^2)$

$$F^{(3)}_{DT}(x_{\mathbb{P}},\beta,Q^2) \propto \frac{1}{R_\rho^2 m_f^2}\cdot$$

$$\cdot\, \beta\cdot(1-\beta)^2(3+4\beta+8\beta^2)\cdot G^2\left(x_{\mathbb{P}}, \frac{m_f^2}{1-\beta}\right)$$

* The leading twist

* β-dependence $\Longrightarrow$ valence $\bar{q}q$ of the $\mathbb{P}$ [Fig.]

* $(1-\beta)^2$ at $\beta\to 1$ Genovese et al. (96) NNN, Pronyaev (97)

* Explicit breaking of the Regge-Ingelman-Schlein factorization NNN, Zakharov (92) Genovese et al (94,96)

$$F_D^{(3)} \neq F_{\mathbb{P}}(\beta)\cdot f_{\mathbb{P}}(x_{\mathbb{P}})$$

* $\frac{1}{m_f^2}$ suppression of heavy flavors NNN, Zakharov (92)

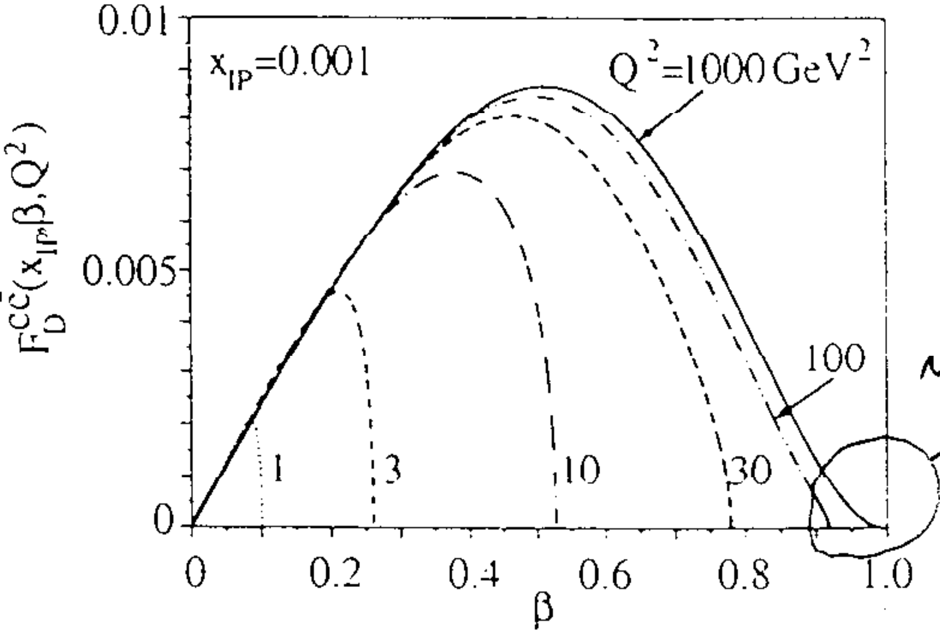
* Steep rise of the heavy flavor content at $x_{\mathbb{P}}\to 0$: [Fig.] Genovese et al (96)

Charm, $\beta=0.5$: $\sim 3\%$ at $x_{\mathbb{P}} = 10^{-2}$

$\sim 9\%$ at $x_{\mathbb{P}} = 10^{-3}$

$\sim 25\%$ at $x_{\mathbb{P}} = 10^{-4}$

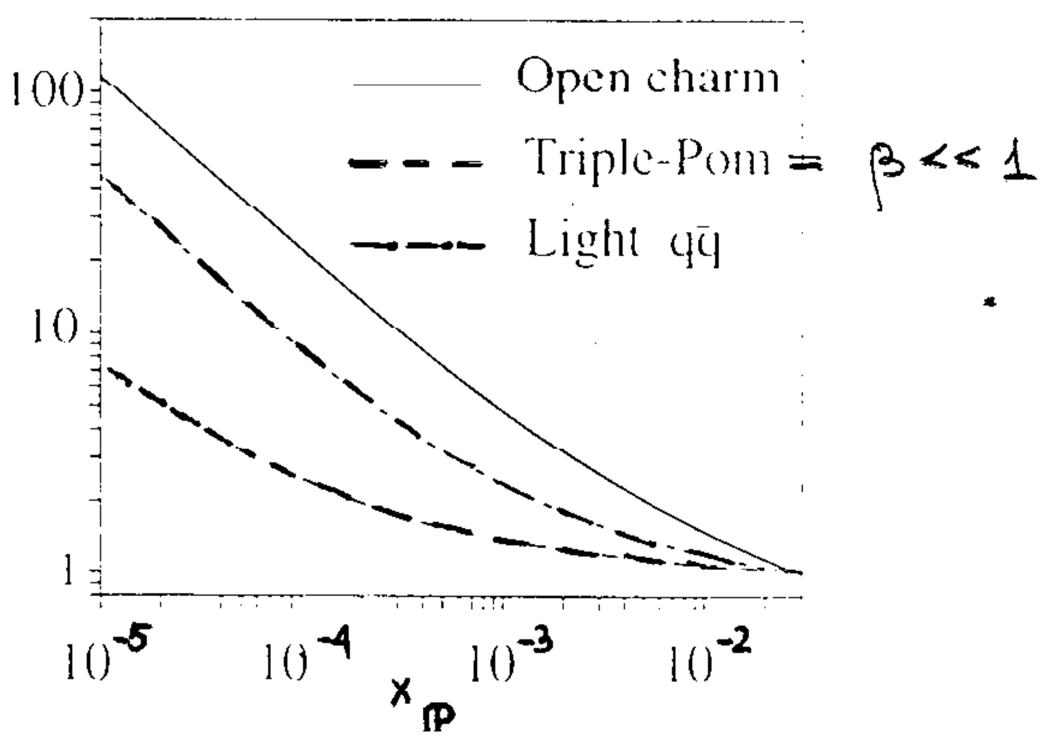
$\gamma^* \to \bar{c}c$



$\sim (1-\beta)^2$

Fig. 5. The contribution of DD into open charm, $F_D^{(c\bar{c})}(x_{\mathbf{P}}, \beta, Q^2)$, to the diffractive structure function at $x_{\mathbf{P}} = 10^{-3}$ as a function of β at different values of Q^2. Threshold: $\beta \leq Q^2/(Q^2+4m_c^2)$

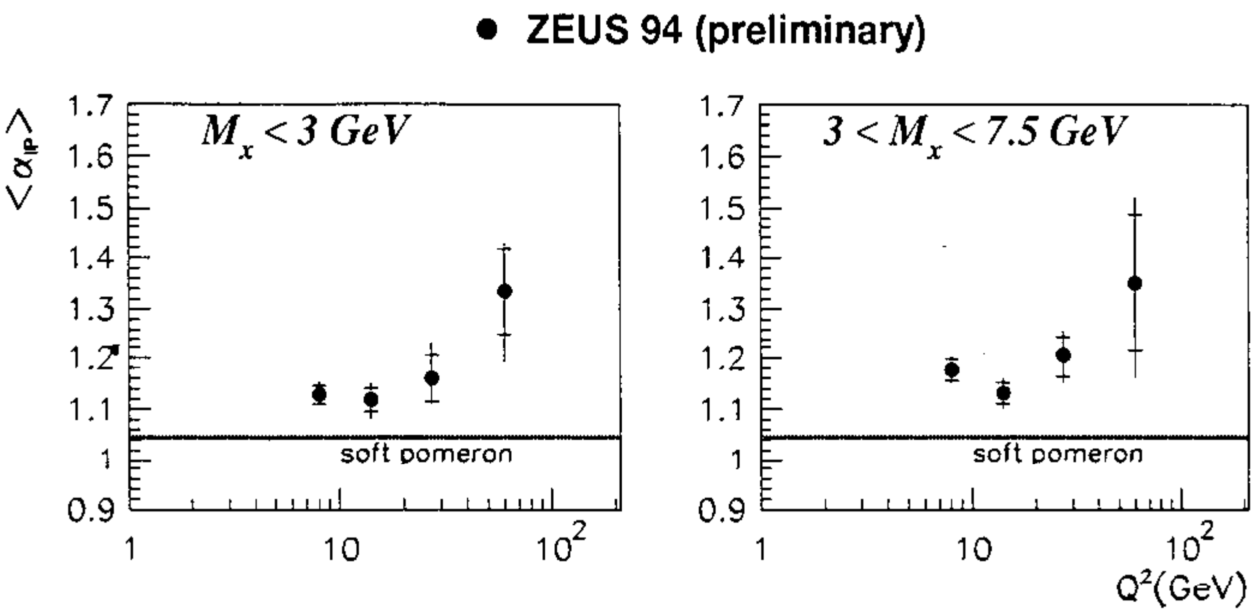
$x_{\mathbb{P}}$ - dependence of $F_D^{(3)}$ (arb. units)



- Test of growth of the factorization scale with Q^2:

$$q^2 \sim \frac{1}{4} m_V^2 \left(1 + \frac{Q^2}{M_X^2}\right)$$

97/03/27 19.



ZEUS diffractive cross sections are not compatible with the Donnachie-Landshoff Soft Pomeron

there is a tendency for α_{IP} to grow with Q^2(GeV) (more data needed)

Inclusive-exclusive duality for diffractive DIS

M. Genovese, NNN, B.G. Zakharov (199

- $$\int^{m_V^2} dM^2 \frac{d\sigma^D_{T,L}(\gamma^* \to X)}{dt\, dM^2}\Big|_{t=0} \propto G^2(x, \bar{Q}^2_{T,L}) \cdot \begin{cases} \bar{Q}_L^{-6}, & L \\ \bar{Q}_T^{-8}, & T \end{cases}$$

$$\bar{Q}_L^2 \simeq \bar{Q}_T^2 \approx \frac{1}{4}(Q^2 + m_V^2)$$

- Exclusive diffraction $\gamma^* p \to V p$

B.Z. Kopeliovich, J. Nemchik, NNN, B.G. Zakharov (1994

$$\frac{d\sigma_{T,L}(\gamma^* \to V)}{dt}\Big|_{t=0} \propto G^2(x, \bar{Q}^2) \cdot \begin{cases} \bar{Q}^{-6}, & L \\ \bar{Q}^{-8}, & T \end{cases}$$

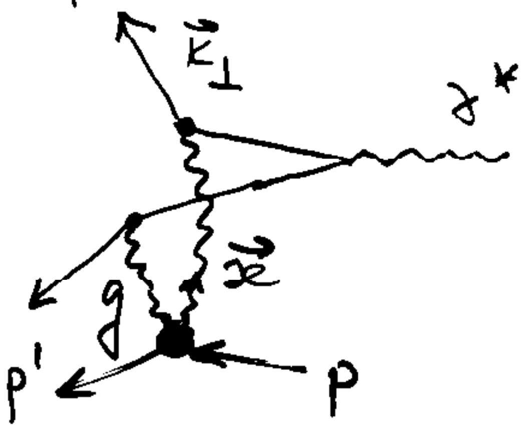
$$\bar{Q}^2 \sim \frac{1}{4}(Q^2 + m_V^2)$$

★ Duality relationship:

$$\int^{m_V^2} dM^2 \frac{d\sigma^D_{T,L}(\gamma^* \to X)}{dt\, dM^2}\Big|_{t=0} \approx \frac{d\sigma_{T,L}(\gamma^* \to V)}{dt}\Big|_{t=0}$$

Derived from pQCD, not postulated.

Special case: $\gamma^* \to \bar{q}q$, high $k_\perp$, $M^2 \gg Q^2$



NNN, Zakharov (94)

* The dominant contribution from $\vec{x} \sim \vec{k}_\perp$

* Probing the transverse momentum of gluons in the $\mathbb{P}$.

$$d\sigma \propto \left| \frac{\partial G(x_{\mathbb{P}}, k_\perp^2)}{\partial k_\perp^2} \right|^2$$

Splitting the pomeron into two jets

- Longitudinal structure function

$\gamma^* \to \bar{q}q$

Genovese et al (9
Bartels et al. (9

$$F_{DL}^{(3)}(x_{\mathbb{P}}, \beta, Q^2) \propto$$

$$\frac{1}{Q^2}(1-2\beta)^2 \beta^3 \alpha_S^2\left(\frac{Q^2}{4\beta}\right) G^2\left(x_{\mathbb{P}}, \frac{Q^2}{4\beta}\right)$$

* Higher twist — NNN, Zakharov (91, 92

* Strongly peaked at $\beta \to 1$

* Breaking of the Regge-Ingelman-Schlein factorization

* σ_L/σ_T blows up at $\beta \to 1$

Diffraction in Charged Current DIS

Bertini, Genovese, NNN, Zakharov ('97)

$W^+ p \to p' u\bar{d}$, $p' c\bar{s}$ $\qquad \alpha = \dfrac{(E + p_z)}{(\nu + q_z)}$

Forward c : $\alpha > \frac{1}{2}$; Backward c : $\alpha < \frac{1}{2}$

- Similar rate of diffraction in CC & NC for light flavors and at large Q^2
- $c\bar{s}$ at $Q^2 \lesssim 10\,\mathrm{GeV}^2$: subtleties with the nonconservation of weak current. Large σ_L/σ_T. C.f. inclusive DIS: Barone et al PL B379, 233(96); PL B328, 143(94), ZPC70, 83 (96)
- c is forward peaked: $\dfrac{B}{F} \sim \dfrac{m_s^2}{m_c^2}$

  Asymmetry persists at large Q^2, dissimilar to inclusive DIS
- Broader $k_\perp$ for backward c:

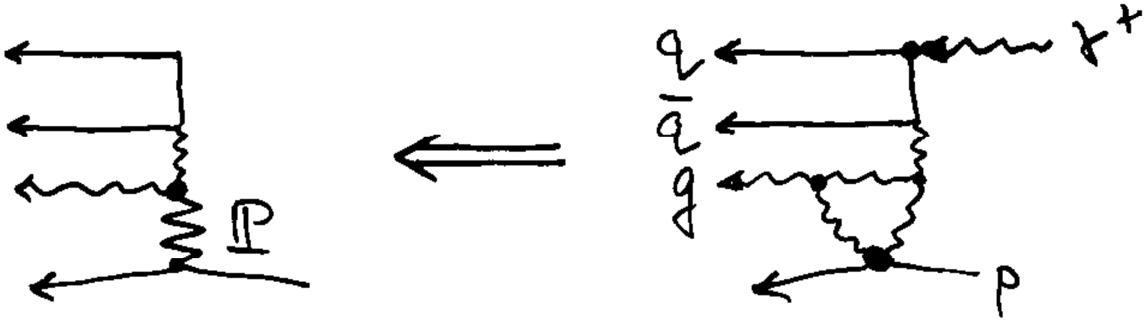
  $\langle k_\perp^2 \rangle_B \sim m_c^2 \qquad \langle k_\perp^2 \rangle_F \sim m_s^2$
- Faster growth with $x_{\mathbb{P}}$ for backward c

★ F_{DL} is approx. flavor symmetric. Peaked at large β at $Q^2 \gg m_c^2$.

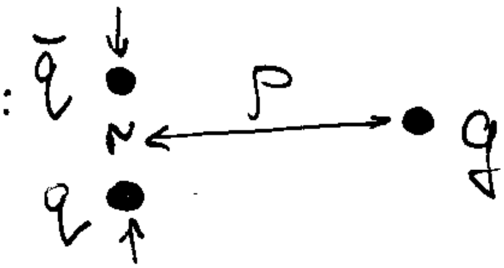
- Sea of the $\mathbb{P}$

NNN, Zakharov (92, 94
Genovese et al (94

$\gamma^* \to \bar{q}qg, \bar{q}qgg \dots$



★ LLQ^2 ordering of dipoles:



$$\frac{1}{Q^2} \lesssim r^2 \ll \rho^2 \lesssim R_c^2$$

- The new nonperturbative scale: the propagation radius for perturbative gluons:
  $R_c \sim 0.2$–0.3 fm Lattice QCD
  Instanton vacuum
  $R_c \sim$ size of constituent quarks

- Defines the factorization scale for $M^2 \gg Q^2$
  $Q^2_{3\mathbb{P}} \sim R_c^{-2} \sim 1\ \mathrm{GeV}^2$

- $d\sigma_D \propto R_c^2\, G^2(x_{\mathbb{P}}, Q^2_{3\mathbb{P}})\, F_{\mathbb{P}}(\beta, Q^2)$

- $Q_{3\mathbb{P}}$ varies with $x_{\mathbb{P}}$ slightly

- The triple-pomeron regime:

Real photons, hadrons:

$$\frac{1}{\sigma_{tot}(ap)} \left. \frac{d\sigma(ap \to p'X)}{dM^2\, dt} \right|_{t=0} \sim \frac{A_{3\mathbb{P}}}{M^2}$$

$A_{3\mathbb{P}} \simeq 0.16\ \mathrm{GeV}^{-2}$, universal for $a = \pi, p, \gamma$

DIS:

$$\frac{1}{Q^2_{3\mathbb{P}}\, \sigma_{\gamma^*}(x_{\mathbb{P}}, Q^2_{3\mathbb{P}})} \cdot \left. \frac{Q^2 d\sigma_D(\gamma^* \to X)}{dM^2\, dt} \right|_{t=0} \simeq$$

$$\simeq \frac{A_{3\mathbb{P}}}{Q^2 + M^2}$$ times smooth dependence on β, Q^2

- $A_{3\mathbb{P}}(\mathrm{DIS}) \approx A_{3\mathbb{P}}(Q^2=0) \propto R_c^{-2}$

NNN, Zakharov (91), Genovese et al [9
[Fig.]

- $F_D^{(3)}$ is GLDAP evolving at small / [at least for fixed $x_{\mathbb{P}}$]

[Fig.]

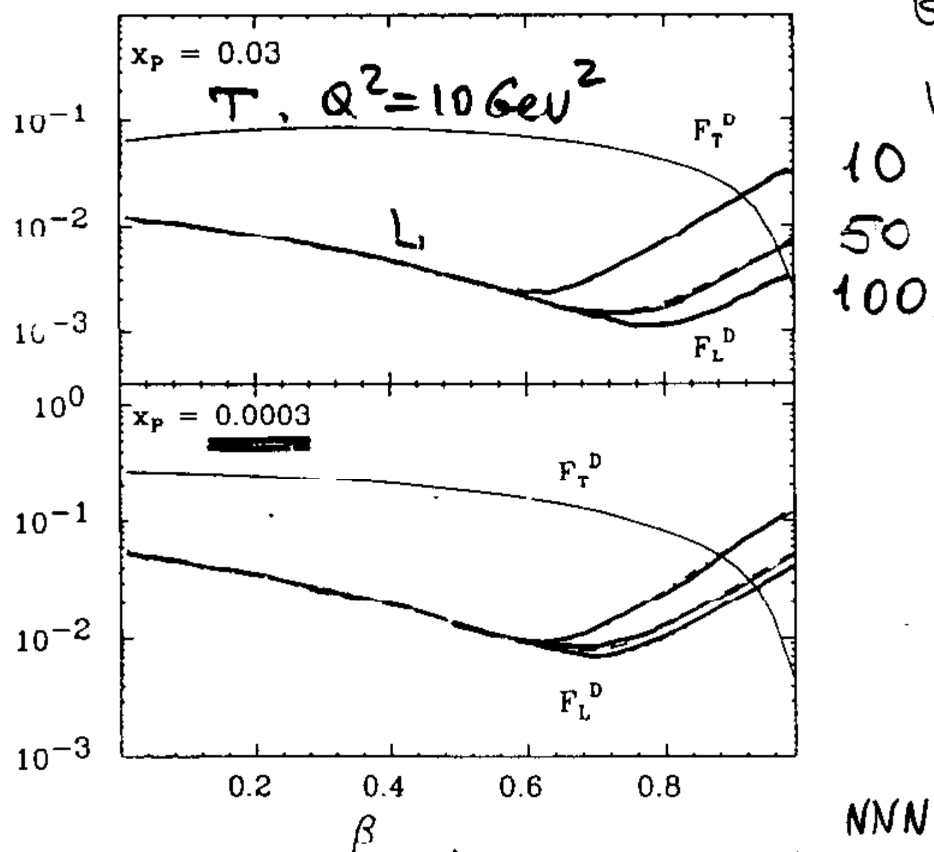
- Charm content: $\sim$ in F_{2p} at small x

no $1/m_c^2$ suppression

- Summary on the "pomeron structure function"

Genovese et al (96

Wüsthoff (96



NNN, Zakharov (93

- GLDAP evolution is OK at small β

★ GLDAP illegitimate at $\beta \sim 1$

i) Very large and predominant higher twist F_L at $\beta \gtrsim 0.9$. Persists at large Q^2

ii) The conventional OPE arguments break down for large factorization scale:

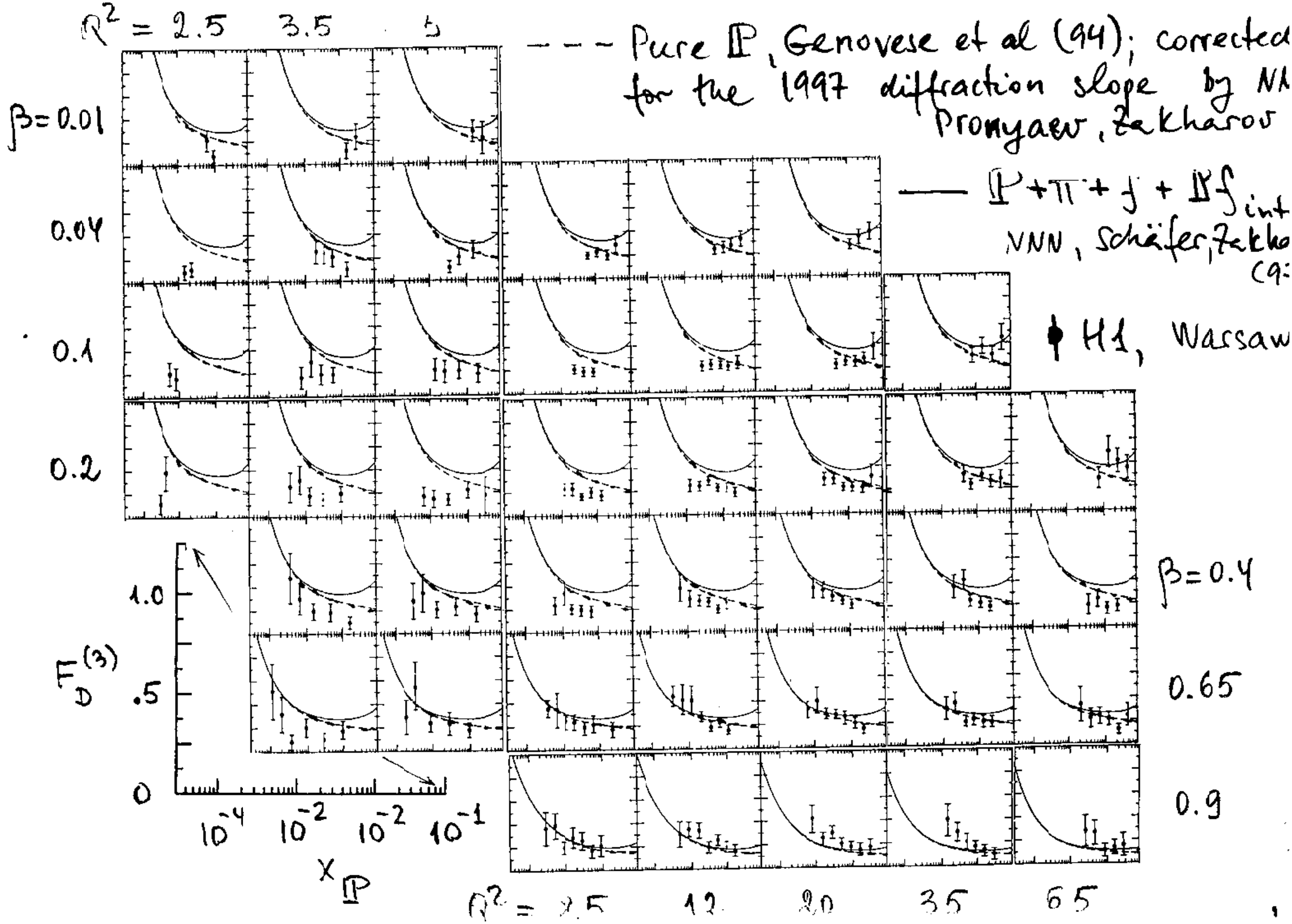
$$q_\perp^2 \sim m_f^2 \cdot \frac{1}{1-\beta} = m_f^2\left(1 + \frac{Q^2}{M^2}\right) \propto Q^2$$

- Conclusions on the "gluon structure function" of the $\mathbb{P}$ from GLDAP analysis at large β are suspect.

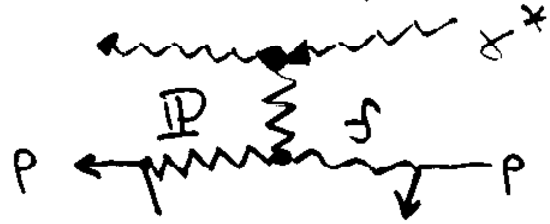
- - - Pure $\mathbb{P}$, Genovese et al (94); corrected for the 1997 diffraction slope by NN, Pronyaev, Zakharov

—— $\mathbb{P} + \pi + f + \mathbb{P}f_{int}$ NNN, Schäfer, Zakharov (9:

H1, Warsaw



Back to triple-Regge: $\mathbb{P}$-f interference



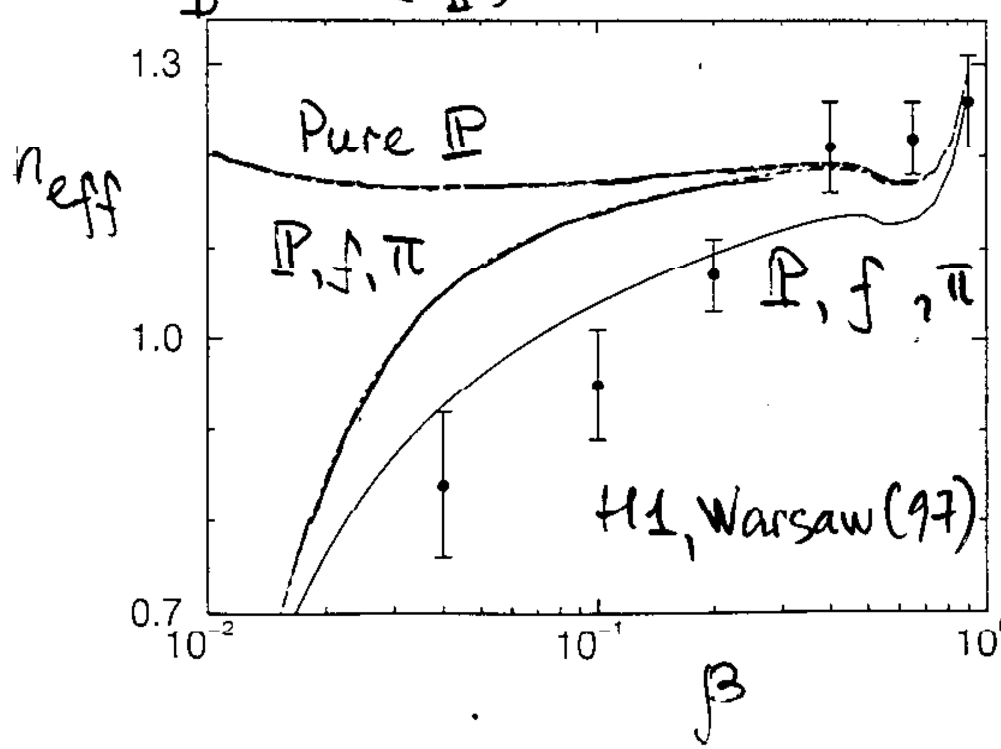
H1, Warsaw (96)
NNN, Schäfer, Zakharov (96
Golec-Bernat et al. (97)

"Diffraction excitation" $\gamma^* \mathbb{P} \to \gamma^* f$

- $\mathbb{P} \to f$ transition and $\mathbb{P}f$ interference are weak if $\mathbb{P}$ and f are hadronlike states
- No special suppression of $\mathbb{P}f$ interference in pQCD. NNN, Schäfer, Zakharov (9·
- Q^2 dependence of the $\mathbb{P}f$ interference? No obvious reasons for weak Q^2 dependence.
- $pp \to pX$ triple Regge analyses inconclusive

$F_D^{(3)} \sim (x_{\mathbb{P}})^{1-n_{eff}}$

NNN, Schäfer
Zakharov (97

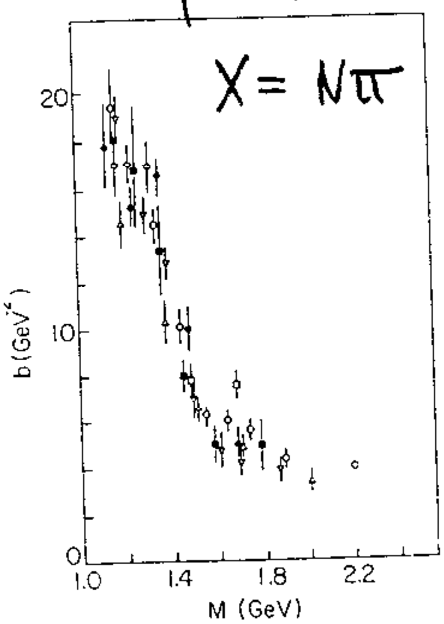


+ maximal $\mathbb{P}f$ interf.

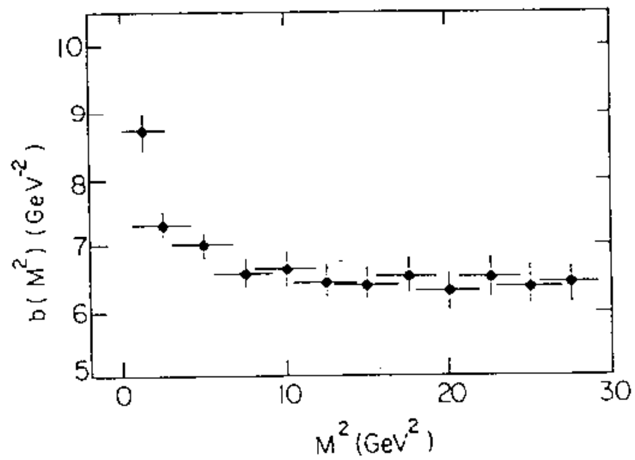
- Diffraction slope vs. excitation energy

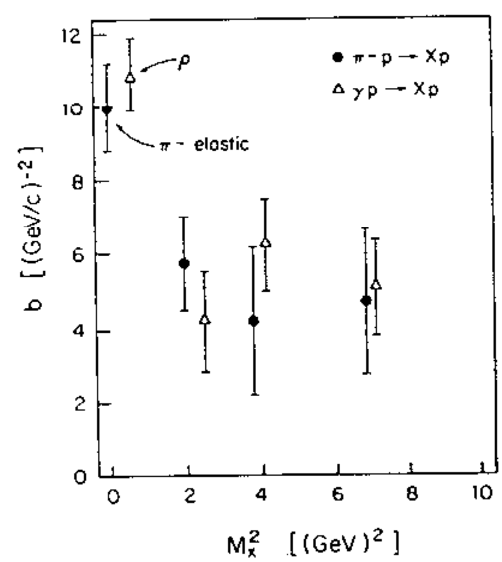
$pp \to pX$

Albesi & Goggi Compilation



Inclusive diffraction
ISR, Abrow et al. (76)





Real photoproduction
Fermilab
Chapin et al. (85)

DIS (ZEUS, LPS):

$B = 7.1 \pm 1.1 {}^{+0.7}_{-1.0}\ \mathrm{GeV}^{-2}$

$0.015 < \beta < 0.5$

★ Large slope for resonances & low-mass excitations

★ $b_D \sim (5\text{–}6)\,\mathrm{GeV}^{-2}$ $\left(\sim \frac{1}{2} b_{el}\right)$ for excitation of continuum states : only the target proton's size contributes to $b_D(\infty)$

Diffraction slope in DIS

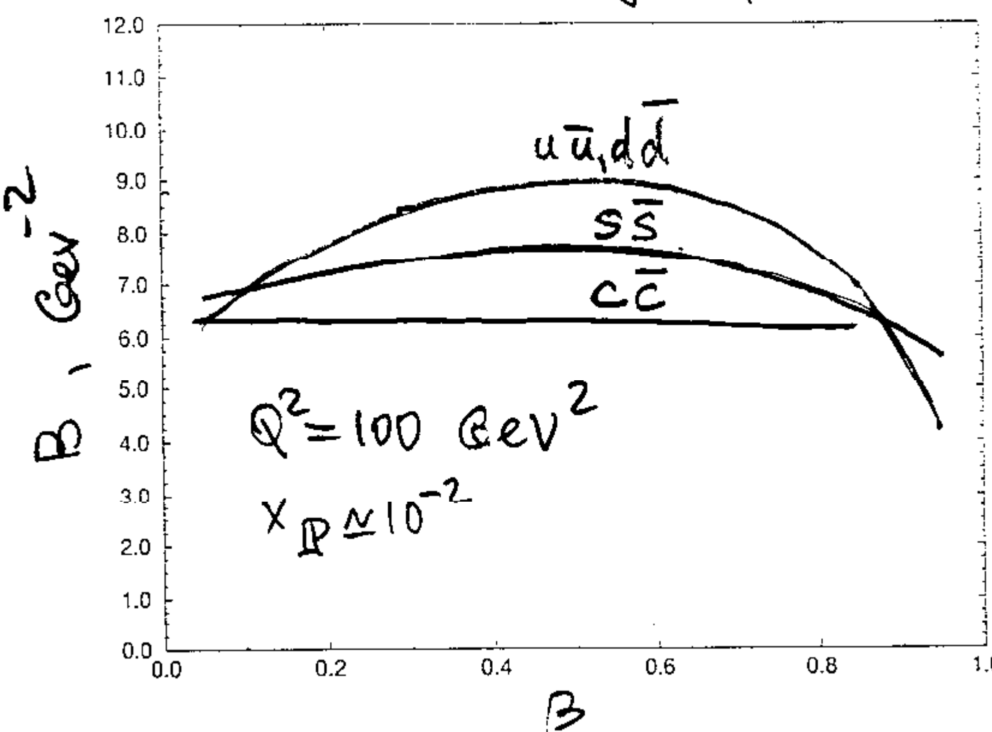
- $\beta \simeq 1$, exclusive limit, small scanning radius $r_S \simeq 6/Q$, only the target proton's size contributes:

  $B(1S) \simeq b_D(\infty)$, but $B(2S) \lesssim b_D(\infty)$

- $\beta \to 0$. The genuine continuum, $B \simeq b_D(\infty)$

- $\beta \sim \frac{1}{2}$, $M^2 \sim Q^2 =$ continuum, but a large diffraction slope $B \simeq b_{el}(\gamma \to \rho^0)$

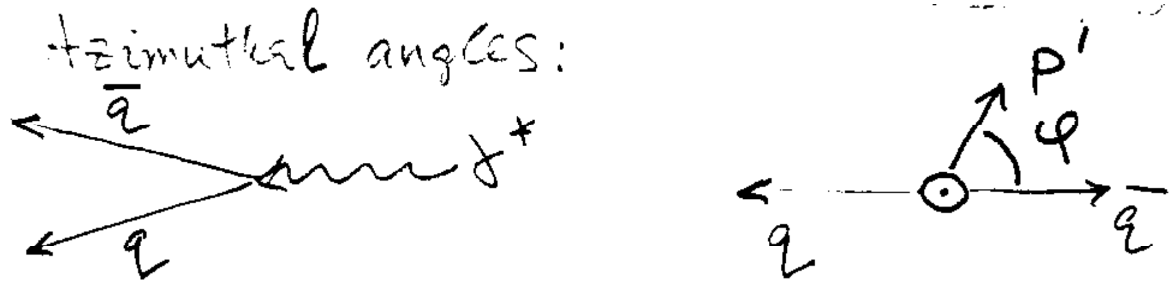
NNN, Pronyaev, Zakharov (97)



★ The origin of large $B(\beta \sim \frac{1}{2})$: the large transverse size of diffracting $\bar{q}q$ pairs in the photon:

$$r^2 \sim \frac{1}{q_T^2} \sim \frac{1}{m_f^2}(1-\beta)$$

Azimuthal angles:



! Intergated over the (e,e') plane orientati

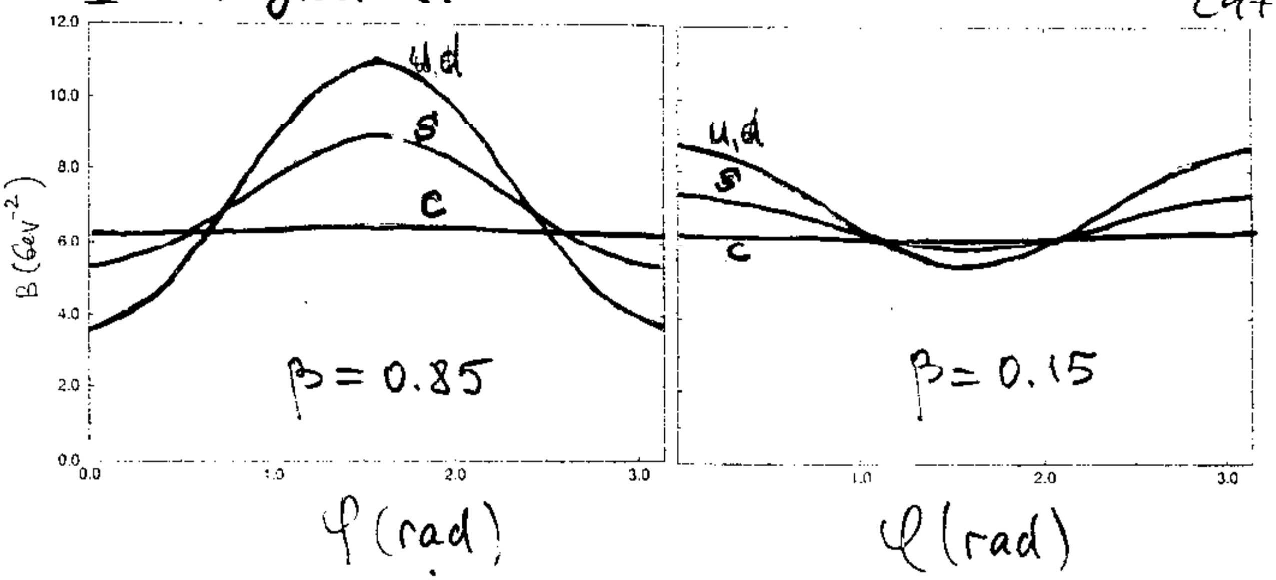
- The both quark helicity conserving & changing diffraction amplitudes depend on the angle φ between the recoil p' and the dijet plane.
- Diffraction slope depends on φ:

$$B = B_0 + \Delta B_2 \cdot \cos 2\varphi$$

- ΔB_2 changes the sign and magnitude from large β to small β
- Reconstruction of the dijet plane at small $\vec{k}_\perp$?

$K_\perp$-integrated.

NNN, Pronyaev, Zakharov (97)



L/T separation is absolutely crucial for the interpretation of the large β data

★ The key: LT interference

$$d\sigma \sim F_T + F_{LT}\cos\varphi + F_L + F_{TT'}\cos 2\varphi$$

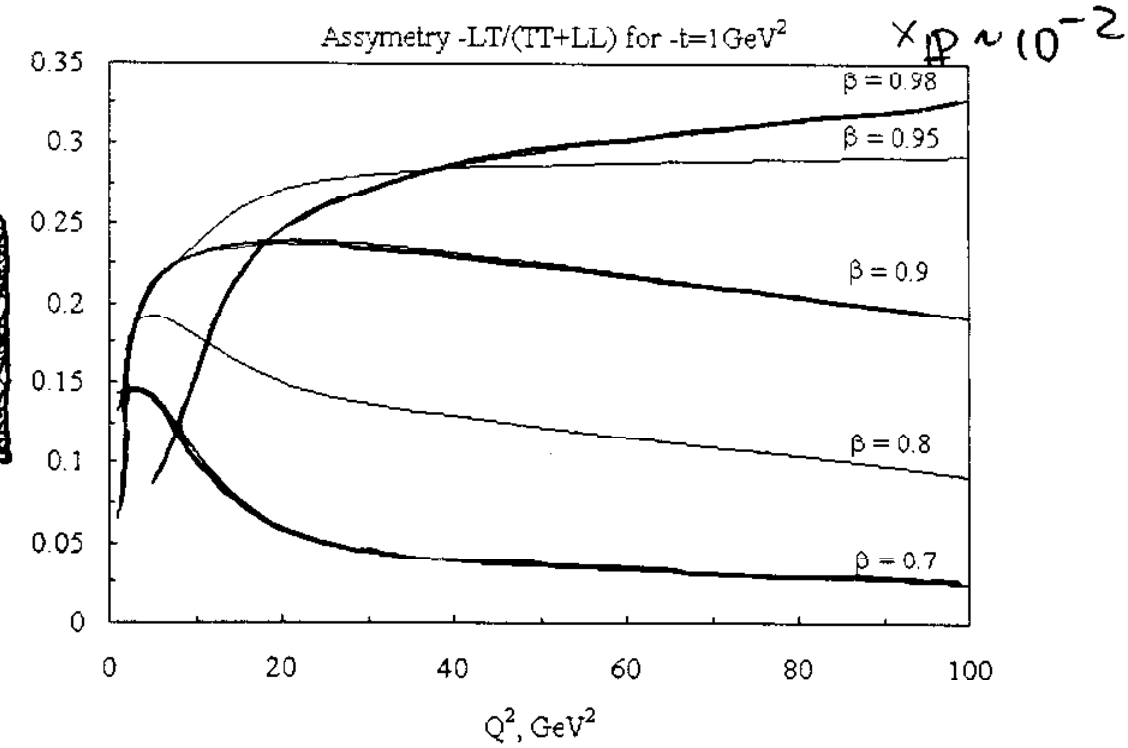
$$F_T \sim (1-\beta)^2 \quad \times \quad (1-y+\tfrac{1}{2}y^2)$$

$$F_L \sim m_f^2/Q^2 \quad \times \quad (1-y)$$

$$F_{LT} \sim k_\perp/Q \cdot (1-\beta) \times (1-\tfrac{1}{2}y)\sqrt{1-y}$$

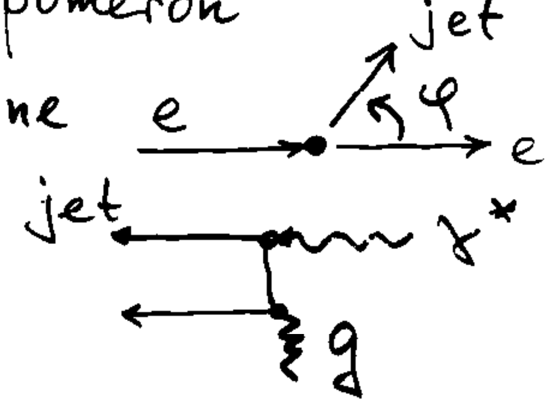
- Large, observable asymmetry at $\beta \sim 1$:

NNN, Pronyaev, Zakharov (97)



Still more azimuthal angles : testing the pQCD structure of the pomeron

★ Jets define hadronic plane



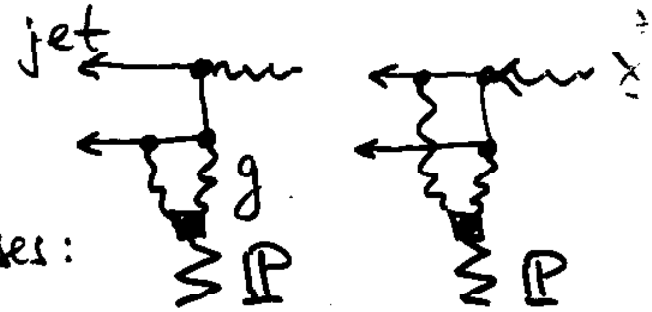
- DIS: $\gamma^* p \to \text{jet} + X$

The pQCD subprocess:

- Diffractive dijets:

$\gamma^* p \to p' \bar{q} q$

The pQCD subrocesses:



pQCD scales: $q_\perp^2(\text{DIS}) \sim k_\perp^2$ or Q^2

Diffraction: $q_\perp^2 \sim k_\perp^2 \left(1 + \frac{Q^2}{M^2}\right)$

- $d\sigma \sim F_T + F_{TT'} \cos 2\varphi + F_L \ldots\ldots$

★ γ^* : $F_{TL} = 0$; W : F_{TL} measurable

★ The emergence of $F_{TT'}$ is trivial, but $F_{TT'}(\text{DIS})$ and $F_{TT'}(\text{diff})$ are of the opposite sign. Bartels et al. (96)

The clear distinction between the pQCD 2g "pomeron" and single gluon in DIS

- Jet in diffractive DIS at $\beta \ll 1$: asymmetry changes the sign to that in the inclusive DIS.

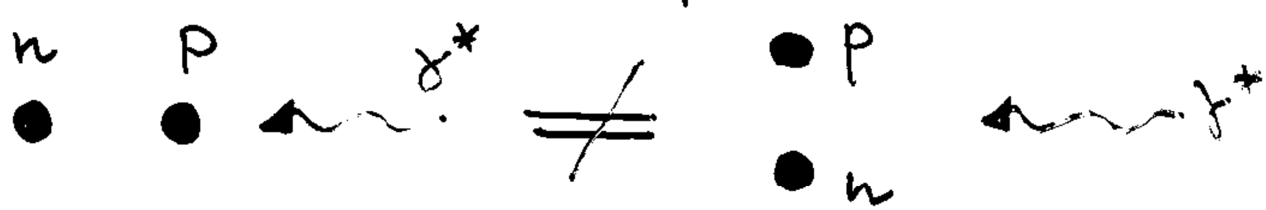
Diffractive DIS and tensor structure functions of the deuteron: $b_1(x)$, $b_2(x)$, $b_L(x)$

NNN, Schäfer (96)

- Spin-1 : the vector and tensor polarizations
- $\gamma^* D$ collision axis = spin quantization axis
- Unpolarized leptons

$$\sigma(S_z=+1) = \sigma(S_z=-1) \neq \sigma(S_z=0)$$

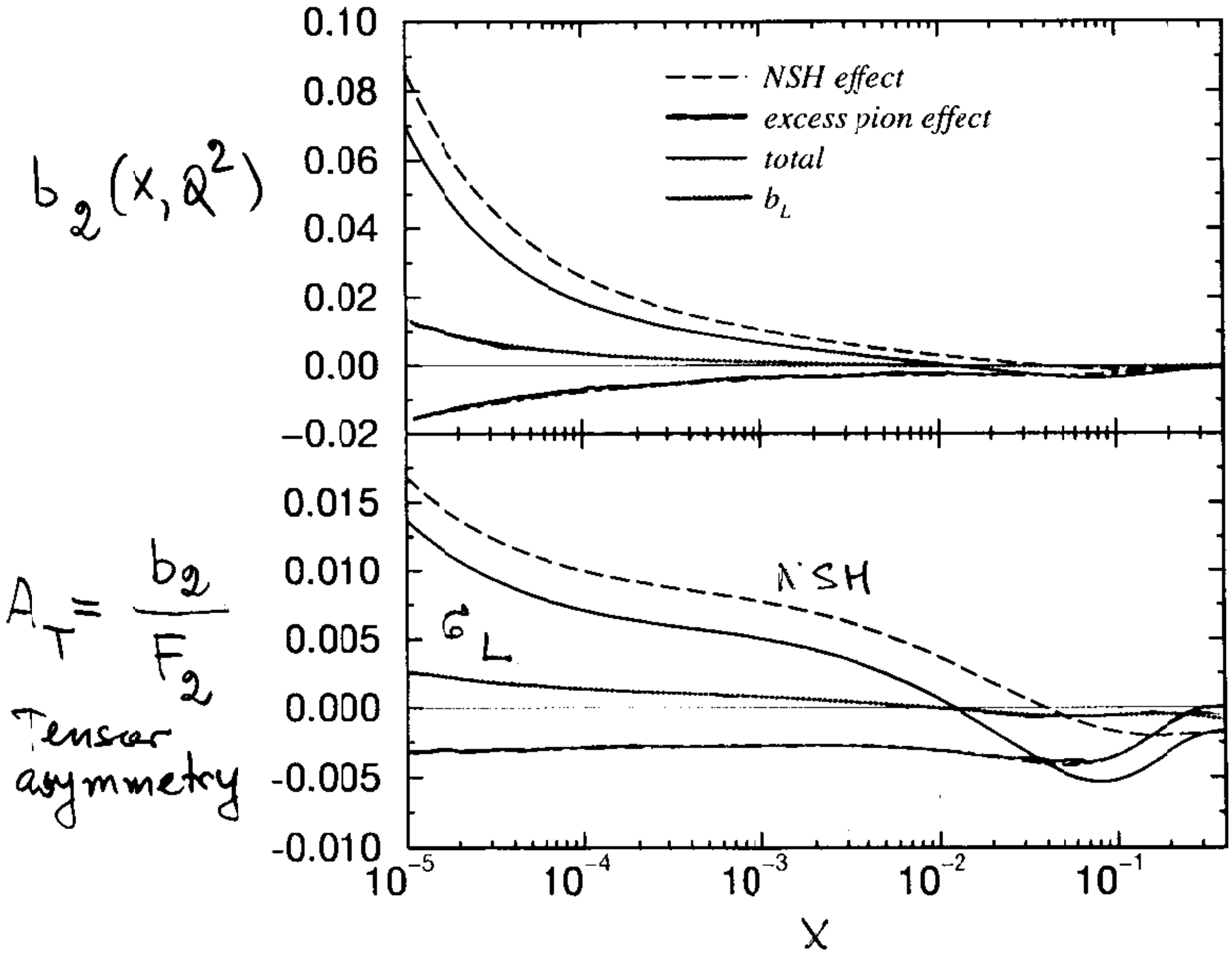
★ The unique spin asymmetry which persists at high energy ($x \to 0$)
S–D wave interference in the deuteron: polarization $\Longrightarrow$ the spatial alignment



★ Different screening of nucleons for $S_z = \pm 1$ and $S_z = 0$

$\Longrightarrow$ ~ 1% tensor polarization of sea quarks and gluons in the deuteron

NNN, A. Schäfer (97)



Conclusions

* Experiment: LPS at H1/ZEUS is a major breakthrough in identifying diffractive DIS
  - New observables
  - The potential of L/T separation
  - Diffraction slope vs. $Q^2, M^2, \beta, x_{\mathbb{P}}$
  - Excited vector mesons ($\rho'(2S), \ldots$)
* Theory: growing beyond the Born approximation.
  - Pomeron (a label for diffraction) $\neq$ hadronic state. Breaking of the Regge factorization.
  - The multiscale problem: GLDAP evolution suspect at $\beta \to 1$.
  - Azimuthal correlations:
    * L/T separation
    * "$\mathbb{P}$omeron" $\neq$ vector particle
  - Diffraction slope vs. β
* DIS98: NLO, NNLO, NNNLO...