Factorization Breaking in Diffractive Dijet Production

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Publications

- With G. Kramer

- PLB 508 (2001) 259: $\gamma p \to 2$ jets+n
- EPJC 38 (2004) 39: $\gamma p \to 2$ jets+p
- PRL 93 (2004) 232002: $\gamma^* p \to 2$ jets+p
- JPG 31 (2005) 1391: New fact. scheme

Motivation

Hard diffraction:

→ Does factorization hold?

Deep inelastic scattering: Yes

→ Direct photoproduction

Hadroproduction: No

→ Resolved photoproduction

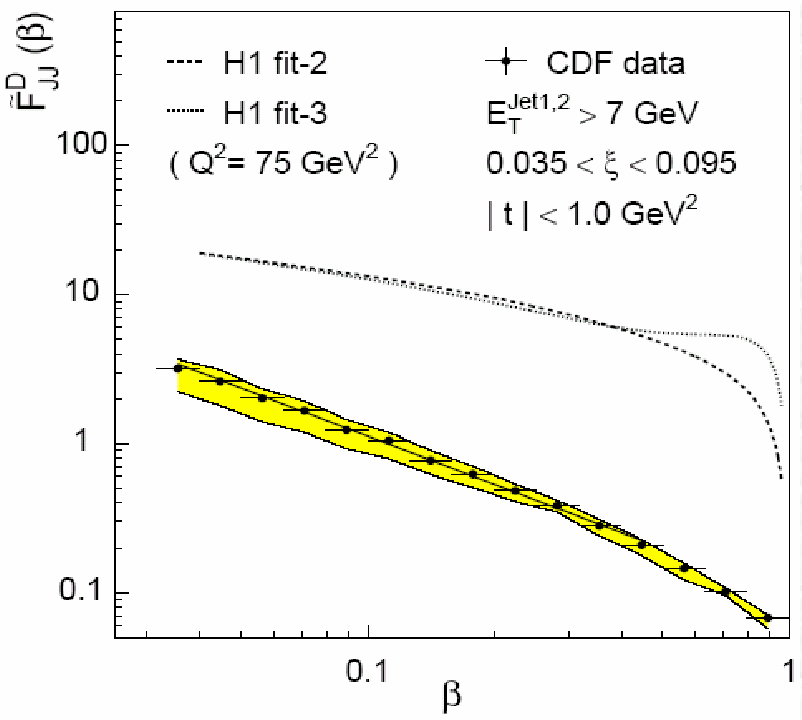
Why next-to-leading order?

→ $\sigma_{tot} = \sigma_{dir}(x_\gamma, M_\gamma) + \sigma_{res}(x_\gamma, M_\gamma)$

→ At LO $x_\gamma = 1$, but at NLO $x_\gamma \leq 1$

→ $\log(M_\gamma)$-dependence cancels

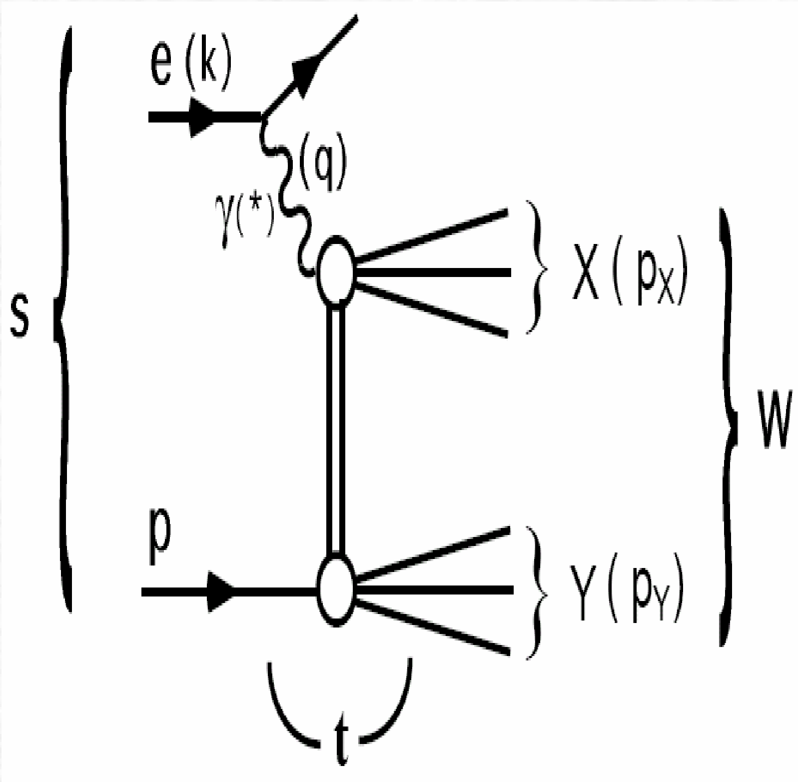
Diffr. hadroproduction of dijets:



CDF Coll., PRL 84 (2000) 5043

Kinematics

Diffractive processes at HERA:



H1 Coll., EPS 2003 and DIS 2004

Inclusive DIS:

$$s = (k+p)^2,\ Q^2 = -q^2,\ \text{and}\ y = \frac{qp}{kp}$$

Diffractive DIS:

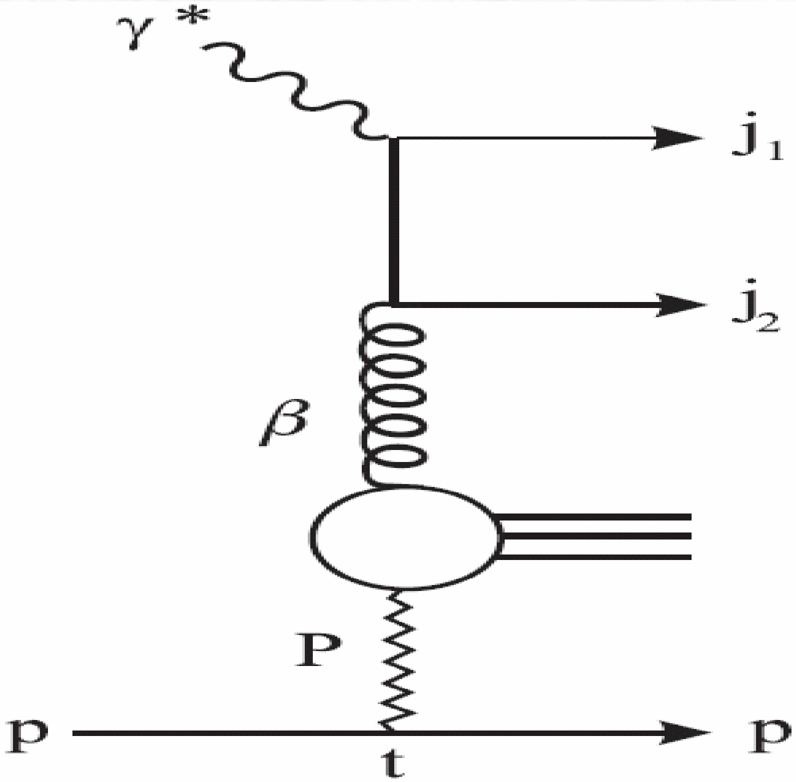
$$M_X^2 = p_X^2 \quad \text{and} \quad t = (p - p_Y)^2,$$
$$M_Y^2 = p_Y^2 \quad \text{and} \quad x_{I\!P} = \frac{q(p-p_Y)}{qp}$$

Experimental cuts:

0.3	$<$	y	$<$	0.65
		Q^2	$<$	$0.01\ \text{GeV}^2$
		E_T^{jet1}	$>$	$5\ \text{GeV}$
		E_T^{jet2}	$>$	$4\ \text{GeV}$
-1	$<$	$\eta_{\text{lab}}^{\text{jet1,2}}$	$<$	2
		$x_{I\!P}$	$<$	0.03
		M_Y	$<$	$1.6\ \text{GeV}$
		$-t$	$<$	$1\ \text{GeV}^2$

Diffractive Parton Distributions

Double factorization:



G. Ingelman, P. Schlein, PLB 152 (1985) 256

Hard QCD factorization:

$$\frac{d^2\sigma}{dx_{I\!P}dt} = \sum_a \int_x^{x_{I\!P}} d\xi \sigma_a^{\gamma^*}(x, Q^2, \xi) f_a^D(\xi, Q^2; x_{I\!P}, t)$$

Regge factorization:

$$f_a^D(x, Q^2; x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) f_{a/I\!P}(\beta = x/x_{I\!P}, Q^2)$$

Pomeron flux factor:

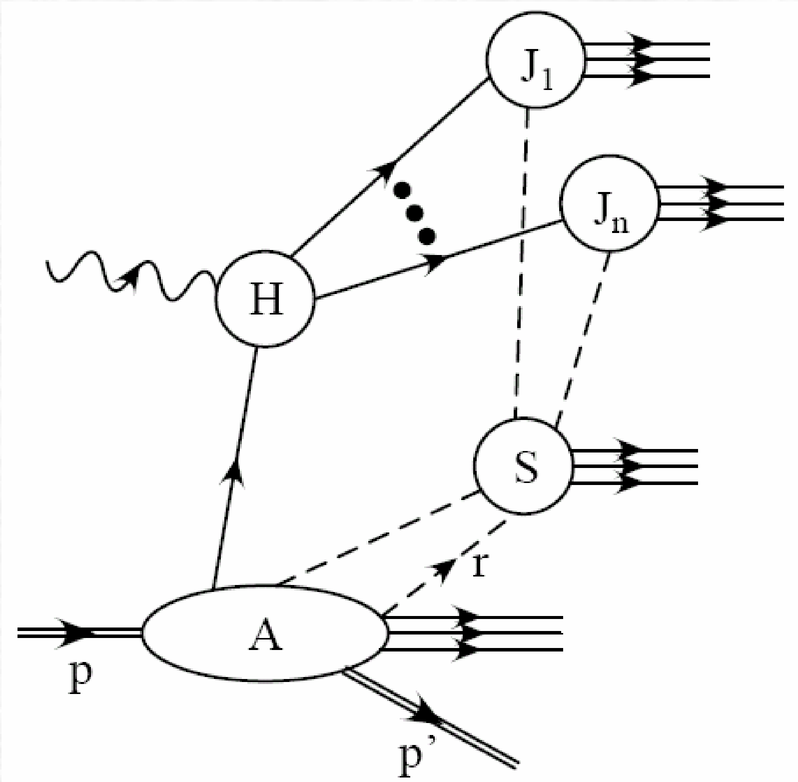
$$f_{I\!P/p}(x_{I\!P}, t) = x_{I\!P}^{1-2\alpha_{I\!P}(t)} \exp(B_{I\!P} t)$$

Pomeron tracectory:

$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t$$

Proof of Hard Factorization

Diffractive deep inelastic scattering:



J.C. Collins, PRD 57 (1998) 3051

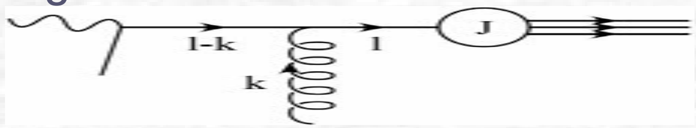
Light cone coordinates:

- $q^\mu = (q^+, q^-, \mathbf{q}_T)$

Leading regions:

- H: $q^\mu \approx O(Q)$
- J: $l^\mu \approx (0, Q/\sqrt{2}, \mathbf{0}_T)$
- A: $|k^\mu| \ll O(Q)$

Soft gluon attachments:

- 

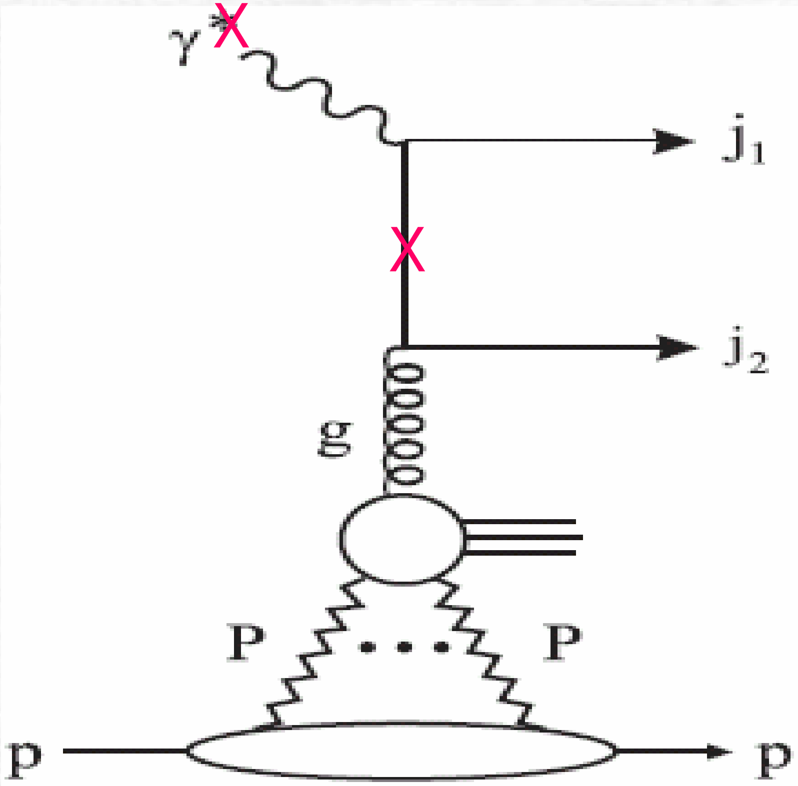
- $\frac{1}{(l-k)^2 - m^2 + i\epsilon} \simeq \frac{1}{-2l^- k^+ + \text{transverse} + i\epsilon}$

Poles in k^+-plane:

- Final state: Upper half-plane
- Initial state: Lower half-plane

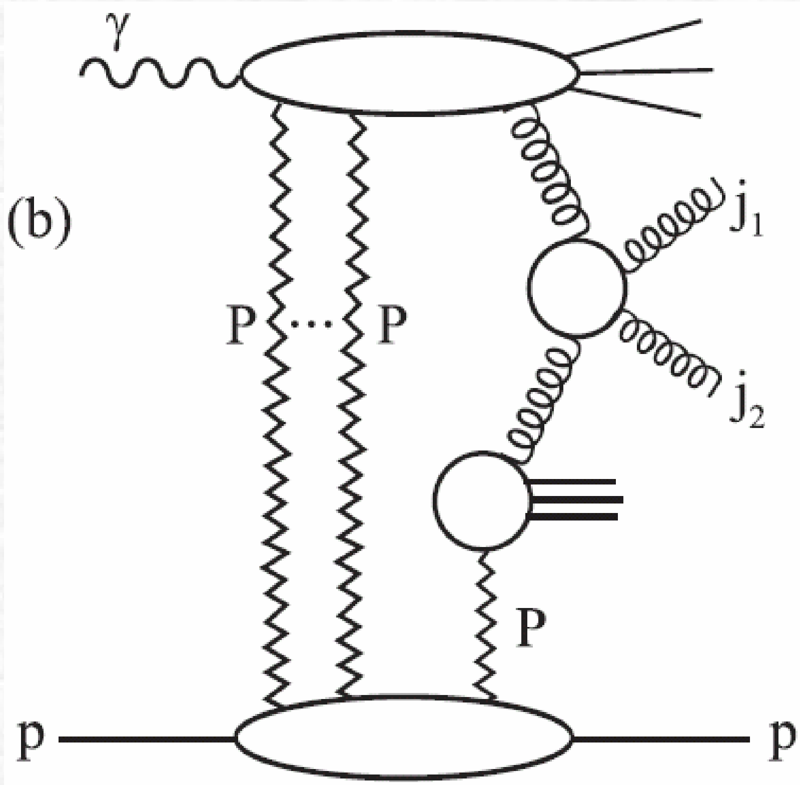
Multipomeron Exchanges

Direct photoproduction:



$\rightarrow$ Modify the Regge trajectory

Resolved photoproduction:



$\rightarrow$ Factorization breaking

Diffractive Photoproduction of Dijets

Cross section:

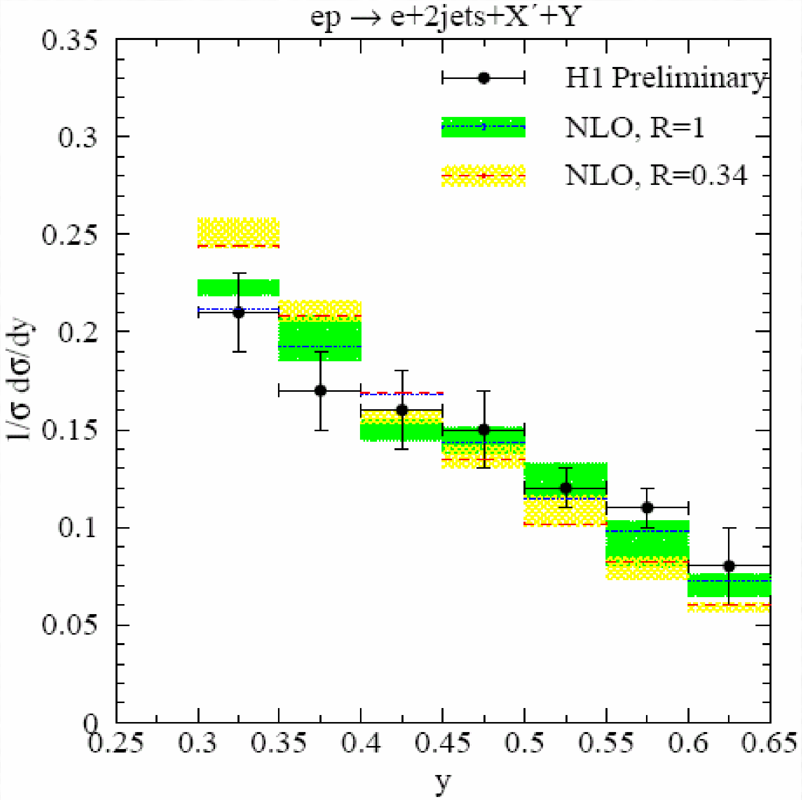
$$d\sigma^D(ep \to e + 2\text{ jets} + X' + Y) =$$
$$\sum_{a,b} \int_{t_{\rm cut}}^{t_{\rm min}} dt \int_{x_{I\!P}^{\rm min}}^{x_{I\!P}^{\rm max}} dx_{I\!P} \int_0^1 dz_{I\!P} \int_{y_{\rm min}}^{y_{\rm max}} dy \int_0^1 dx_\gamma$$
$$f_{\gamma/e}(y) f_{a/\gamma}(x_\gamma, M_\gamma^2) f_{I\!P/p}(x_{I\!P}, t) f_{b/I\!P}(z_{I\!P}, M_{I\!P}^2)$$
$$d\sigma^{(n)}(ab \to \text{jets}).$$

Photon flux: Weizsäcker-Williams approximation

$$f_{\gamma/e}(y) = \frac{\alpha}{2\pi}\left[\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{\rm max}(1-y)}{m_e^2 y^2} + 2m_e^2 y\left(\frac{1-y}{m_e^2 y^2} - \frac{1}{Q^2_{\rm max}}\right)\right]$$

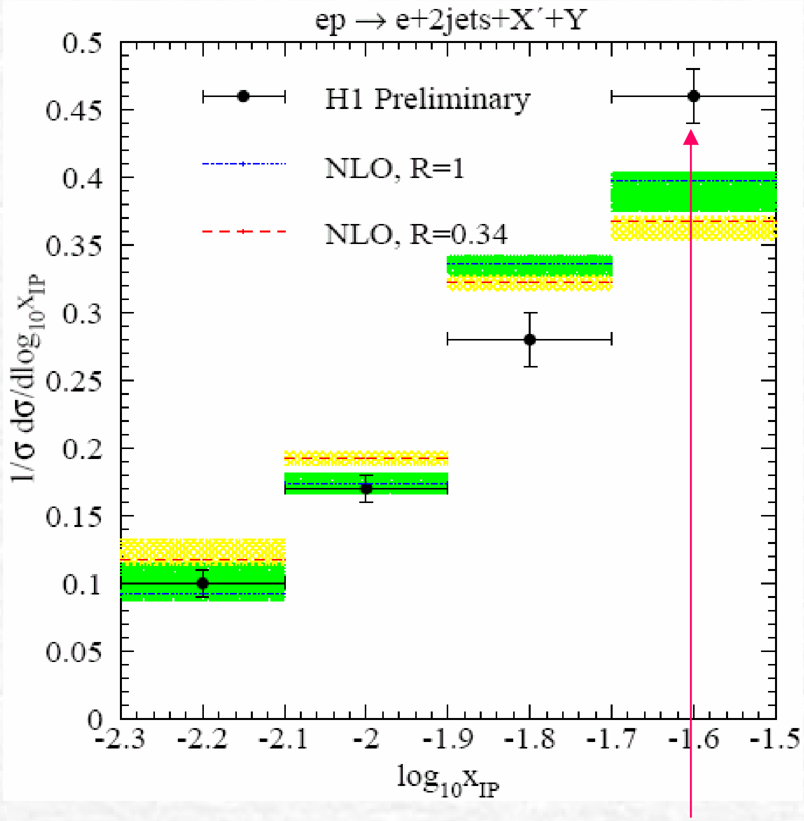
Factorizable Multipomeron Exchanges

y-dependence: Photon flux



→ Small correlations due to exp. cuts

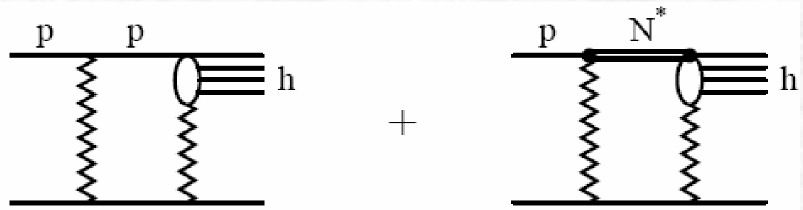
x_{IP}-dependence: Pomeron flux



→ Subleading Reggeon contribution

Two-Channel Eikonal Model

Hadronic collisions:



Survival probability:

$$|S|^2 = \frac{\int d^2b \left(|\mathcal{M}_{\rm v}|^2 \, e^{-\Omega_{\rm v}(s,b)} + |\mathcal{M}_{\rm sea}|^2 \, e^{-\Omega_{\rm sea}(s,b)} \right)}{\int d^2b \left(|\mathcal{M}_{\rm v}|^2 + |\mathcal{M}_{\rm sea}|^2 \right)}$$

Opacity / optical density: $K_i = 1 \pm \gamma$

$$\Omega_i = K_i \, \frac{(g_{pp}^{I\!P})^2 \, (s/s_0)^{\Delta}}{4\pi B} \, e^{-b^2/4B}$$

Kaidalov et al., EPJC 21 (2001) 521

Photoproduction:

Generalized vector meson dominance:

- $J^{PC} = 1^{--}$: $\gamma \to \rho, \omega, \ldots$

Fitted parameters (W = 200 GeV):

- Total cross section: $\sigma^{tot}(\rho p) = 34$ mb
- Pomeron slope: $B = 11.3$ GeV^{-2}
- Transition probability: $\gamma = 0.6$

→ ZEUS Coll., EPJ C2 (1998) 247
→ H1 Coll., EPJ C13 (2000) 371

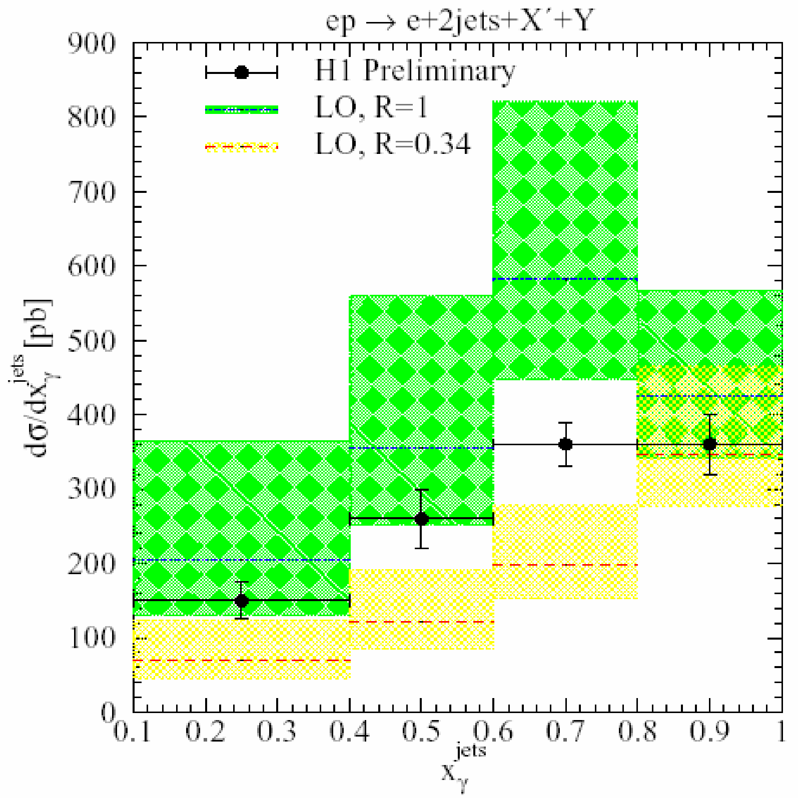
Survival probability:

- $R \equiv |S|^2 \approx 0.34$

Kaidalov et al., PLB 567 (2003) 61

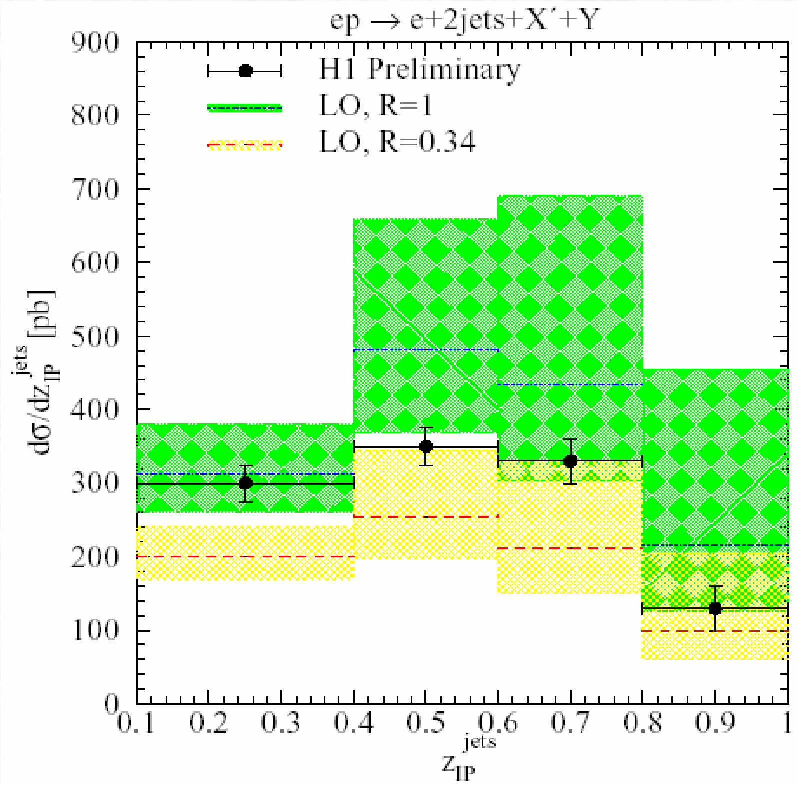
No Sign of Factorization Breaking at LO

x_γ-dependence: Direct/resolved photons



→ At LO, R = 1 agrees better with data!

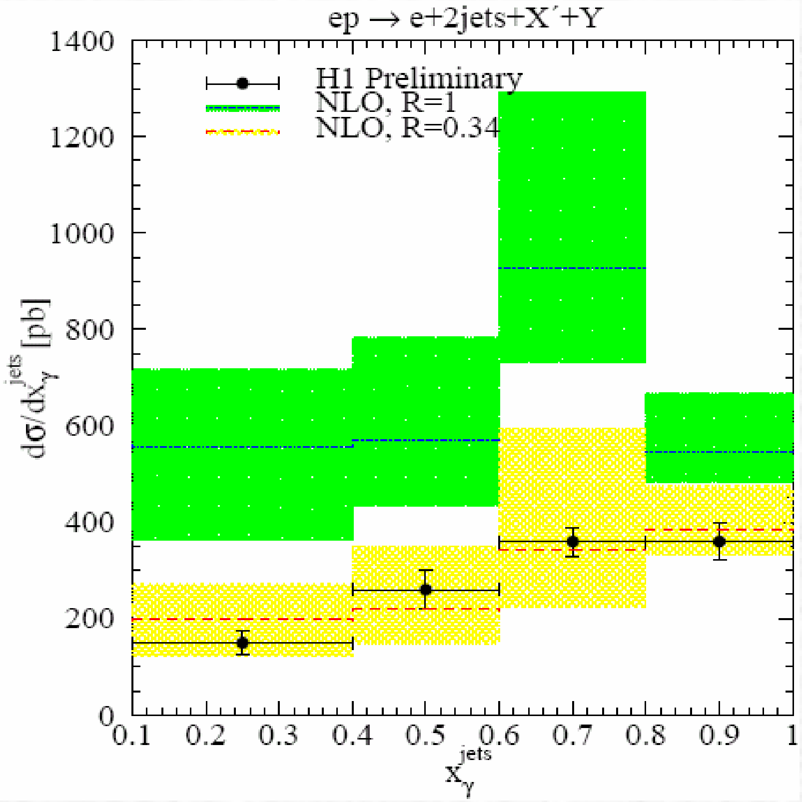
z_{IP}-dependence: Gluon density in pom.



→ Smaller uncertainties in $1/\sigma\ d\sigma/dz_{IP}$

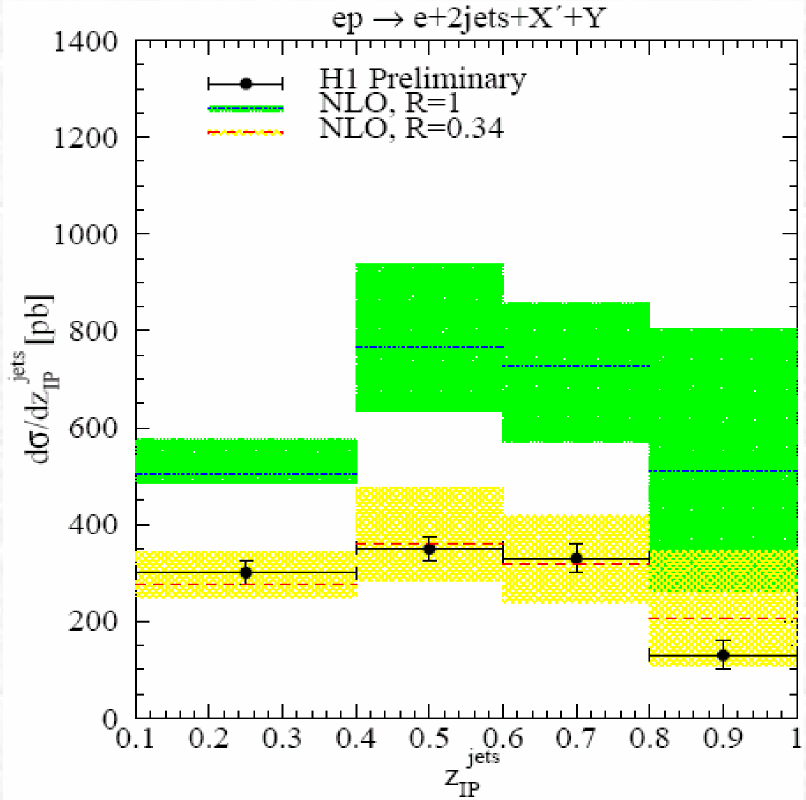
Non-Factorizable Multipomeron Exchanges

x_γ-dependence: Direct/resolved photons



→ Large K-Factor ↔ Survival probability

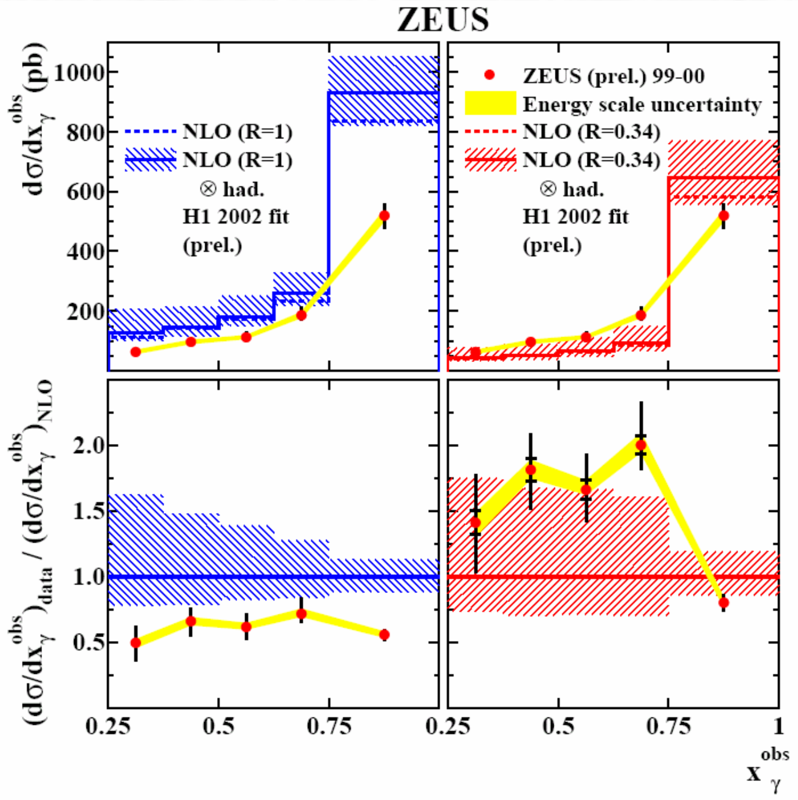
z_{IP}-dependence: Gluon density in pom.



→ Reduced scale uncertainties at NLO

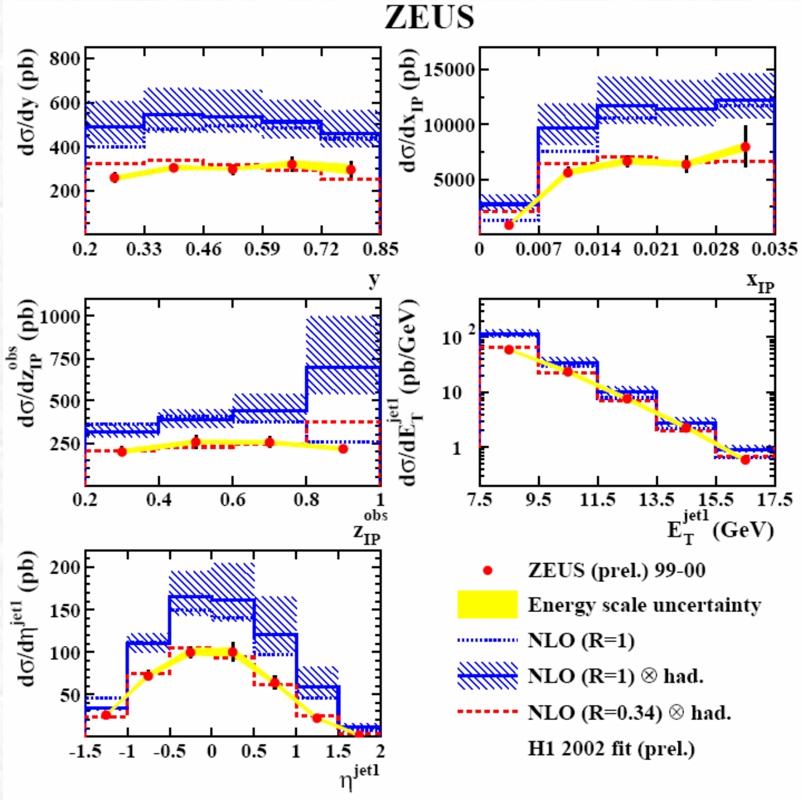
ZEUS Analysis

x_γ-dependence: Direct/resolved photons



$\rightarrow$ At LO, R = 1 agrees better with data!

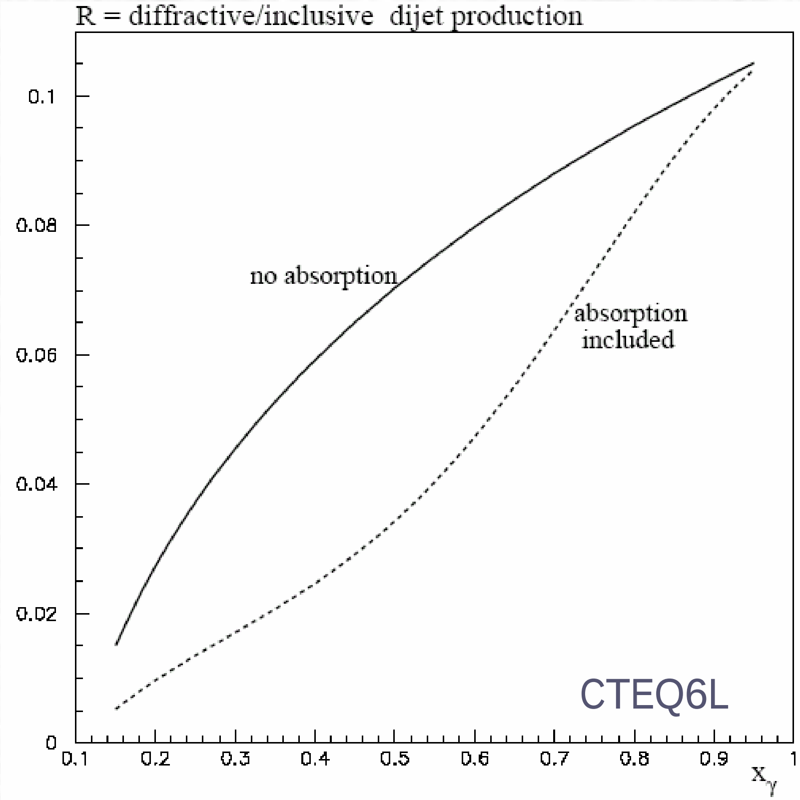
Other observables:



$\rightarrow$ Excellent agreement for absolute σ's!

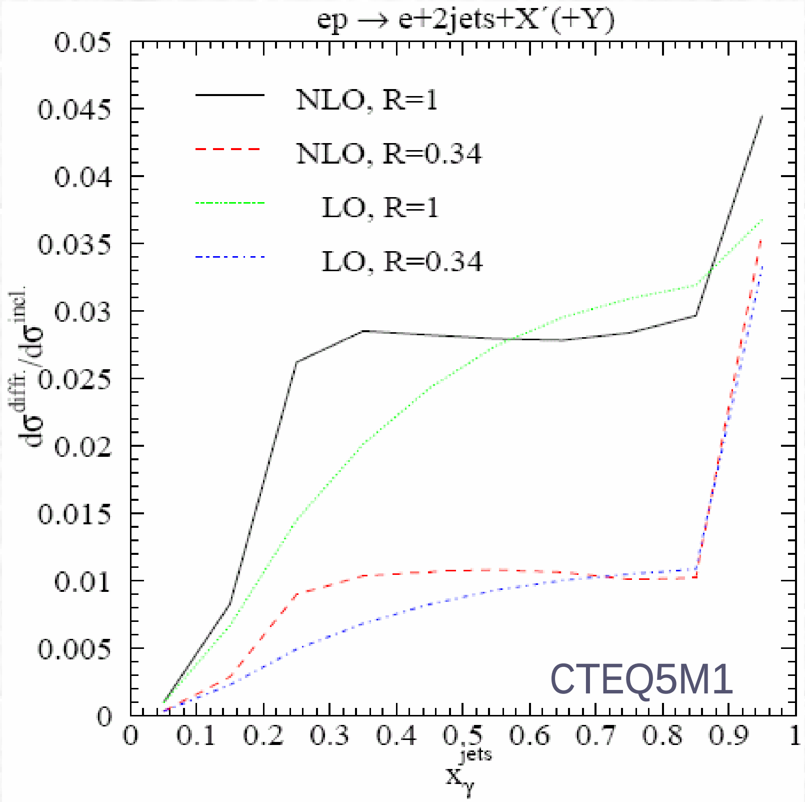
Diffractive / Inclusive Production

$R = f_{g/IP} \otimes f_{IP/p} \,/\, f_{g/p}$ with $M_{12} = x_\gamma z_{IP} x_{IP} W$:



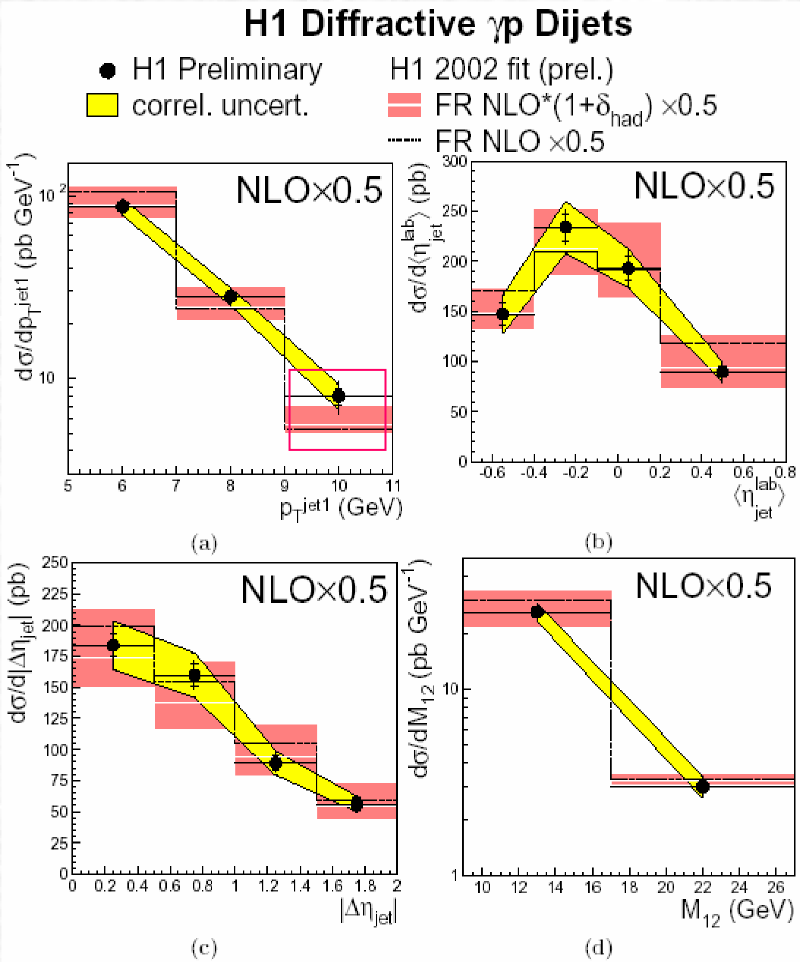
A. Kaidalov et al., PLB 567 (2003) 61

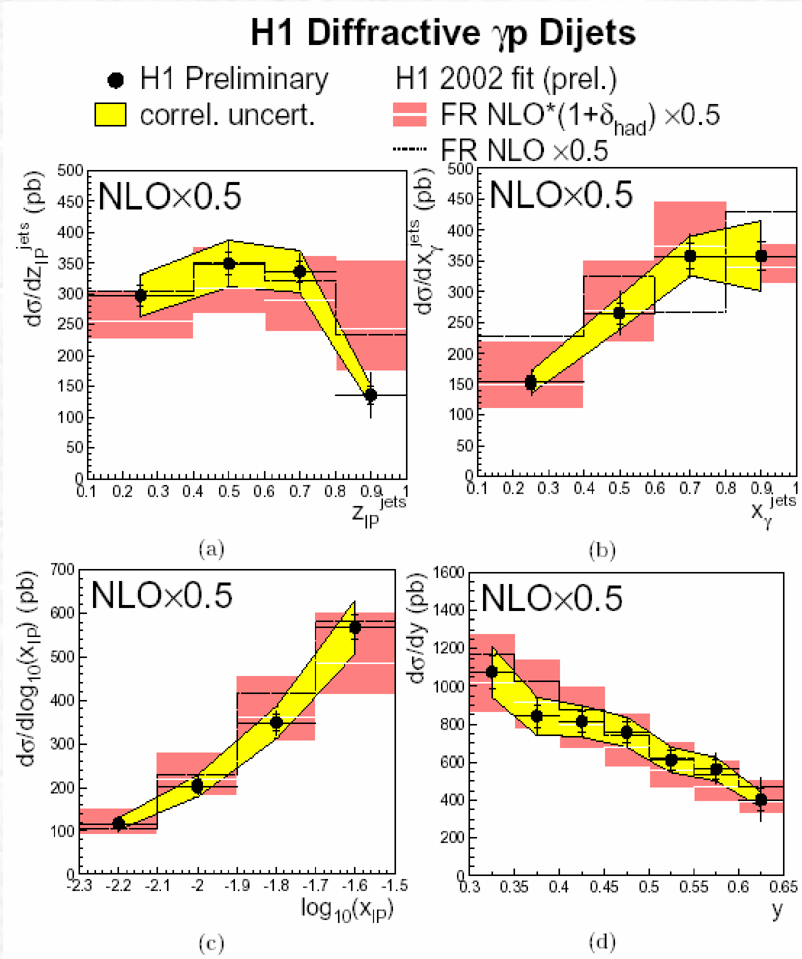
$R = \sigma^{diffr.} \,/\, \sigma^{incl.}$ with full kinematics:



MK, G. Kramer, EPJC 38 (2004) 39

But: Data also support direct suppression!

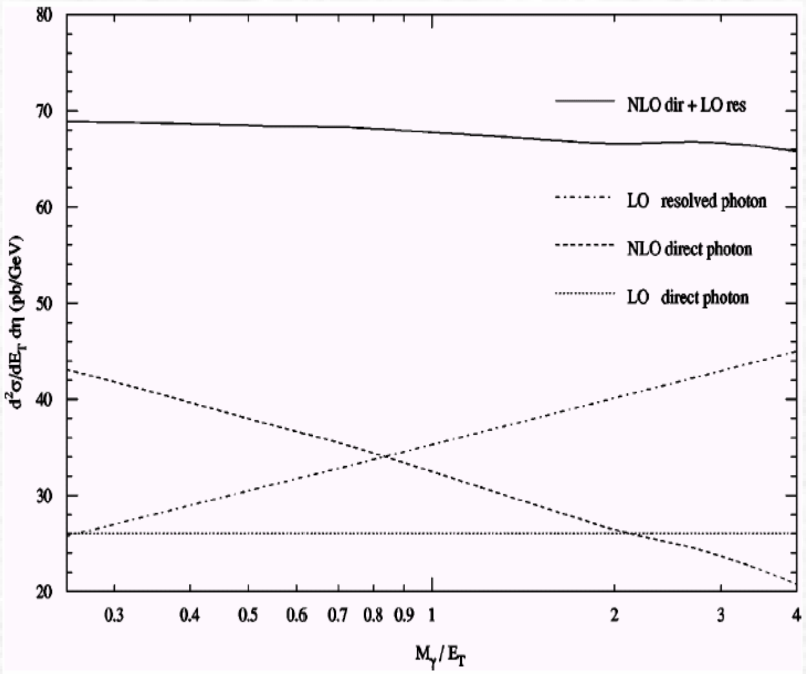




Factorization Scale Dependence

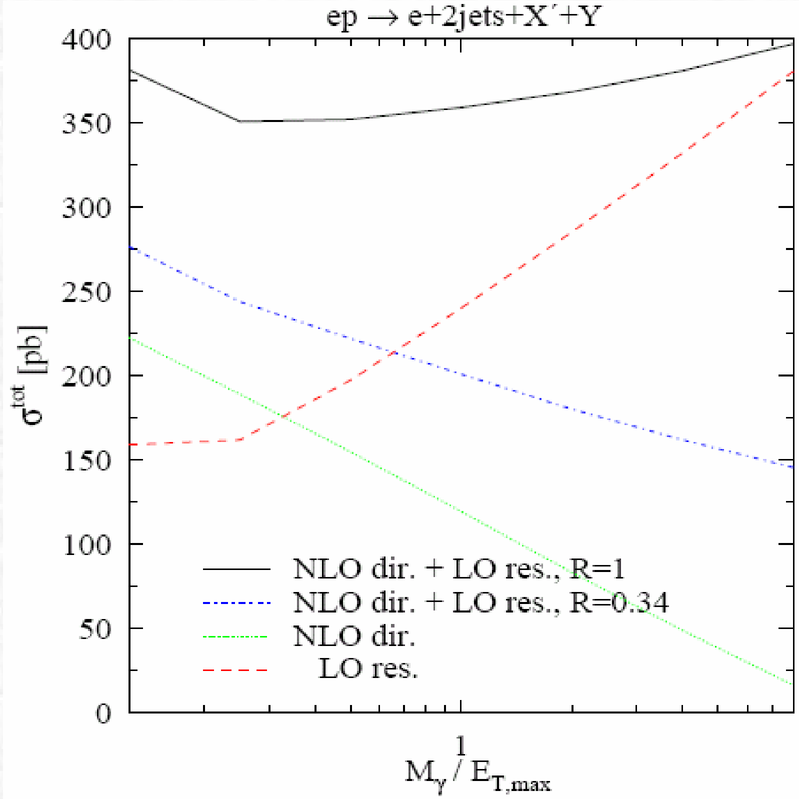
Inclusive photoproduction:

$$|\mathcal{M}^I|^2_{ab\to 123} = \ln\left(\frac{M^2}{Q^2}\right)|\mathcal{M}^B|^2_{cb\to 12} P_{c\leftarrow a}(x) + \cdots$$



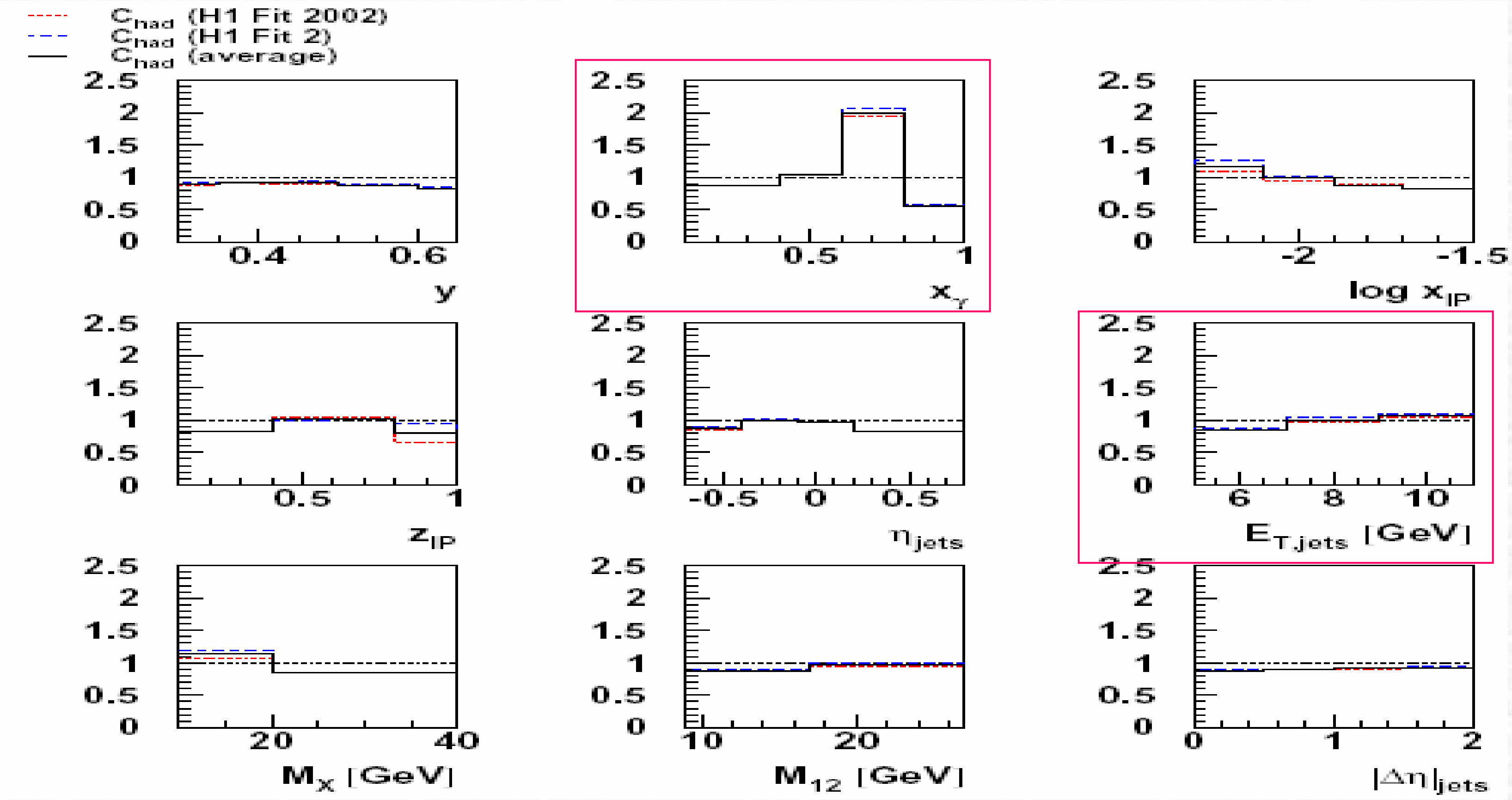
MK, Rev. Mod. Phys. 74 (2002) 1221

Diffractive photoproduction:



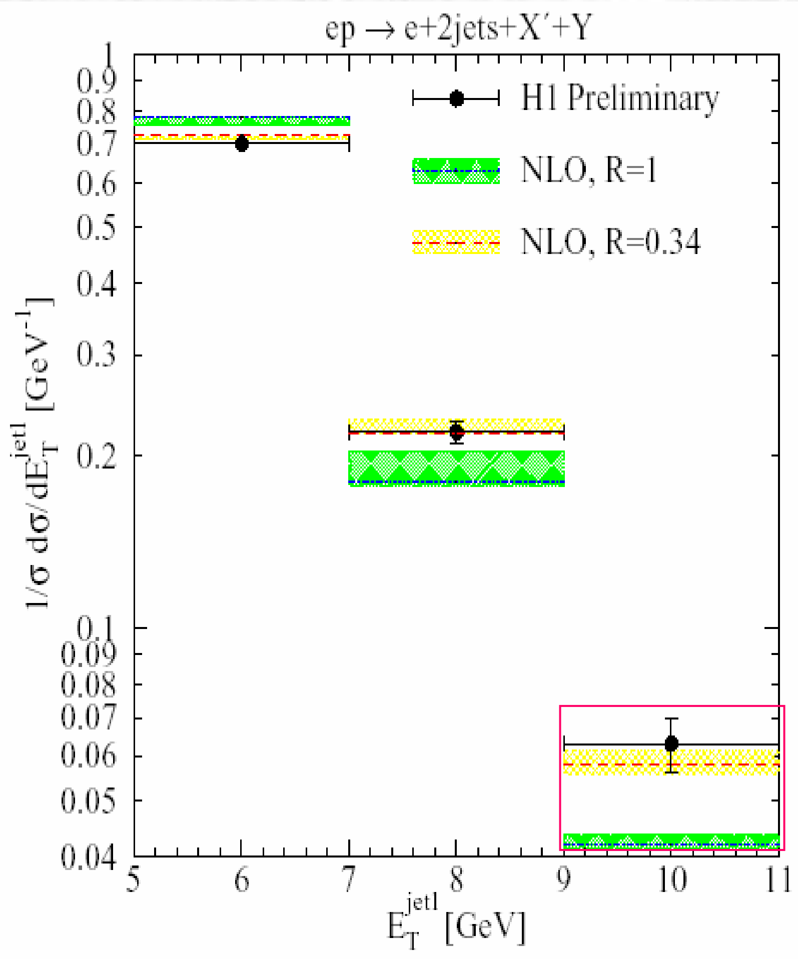
MK, G. Kramer, EPJC 38 (2004) 39

Hadronization Corrections



→ Observable and model dependent!

E_T-Distribution



Importance of large E_T:

- Direct process dominates
- IS singularity less important
- Hadronization corrections small
- Experimentally directly accessible
- Less sensitive than x_γ

Result:

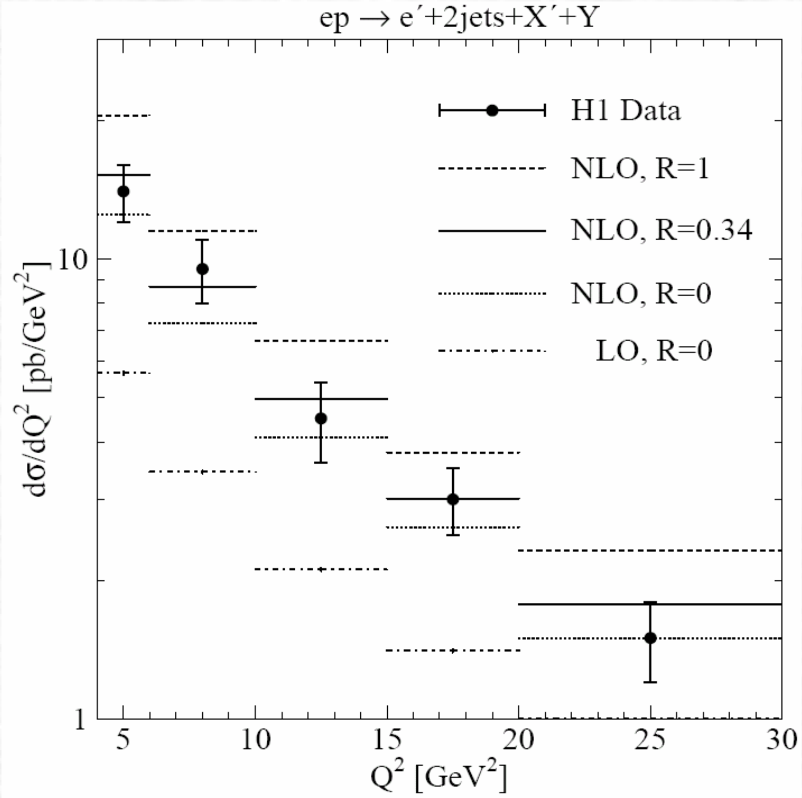
- Suppressed result agrees
- Unsuppressed 50% too low

How can we learn more?

- Critical role of IS singularity
- Transition from γp to DIS

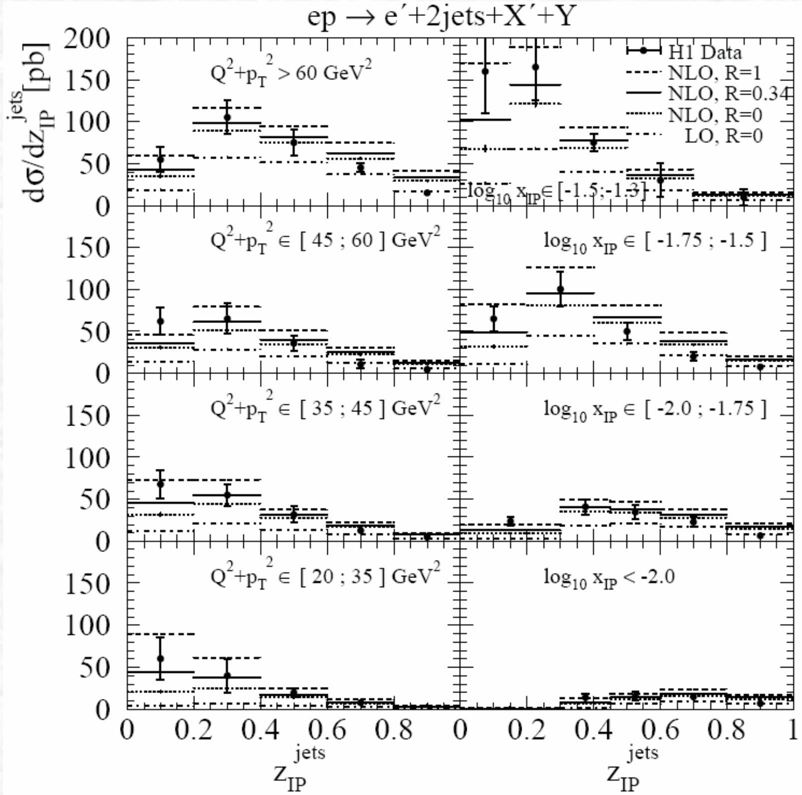
High- to Low-Q^2 Transition in DIS

Q^2-dependence:



MK, G. Kramer, PRL 93 (2004) 232002

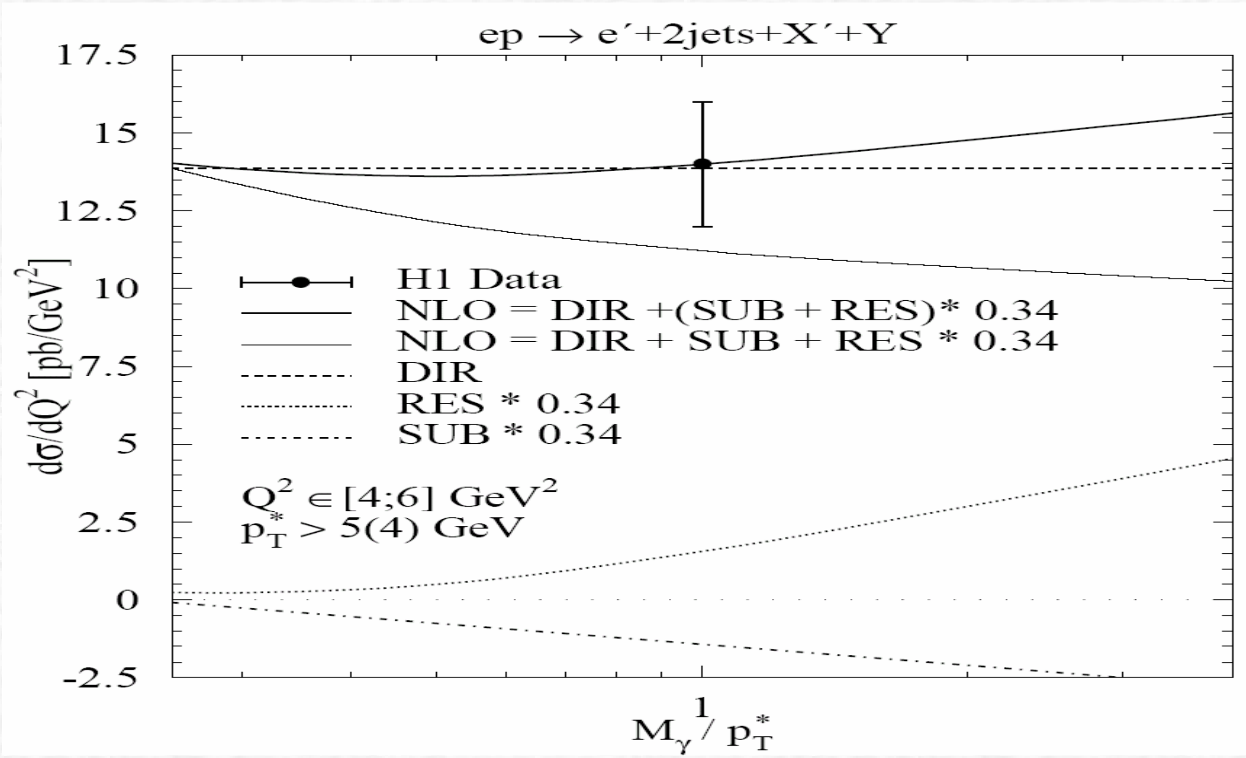
z_{IP}-dependence:



MK, G. Kramer, PRL 93 (2004) 232002

Factorization Scale Dependence (1)

$$M(P^2)_{\overline{MS}} = -\frac{1}{2N_c} P_{q_i \leftarrow \gamma}(z_a) \ln \left(\frac{M_\gamma^2 z_a}{(z_a P^2 + y_s s)(1 - z_a)} \right) + \frac{Q_i^2}{2}$$

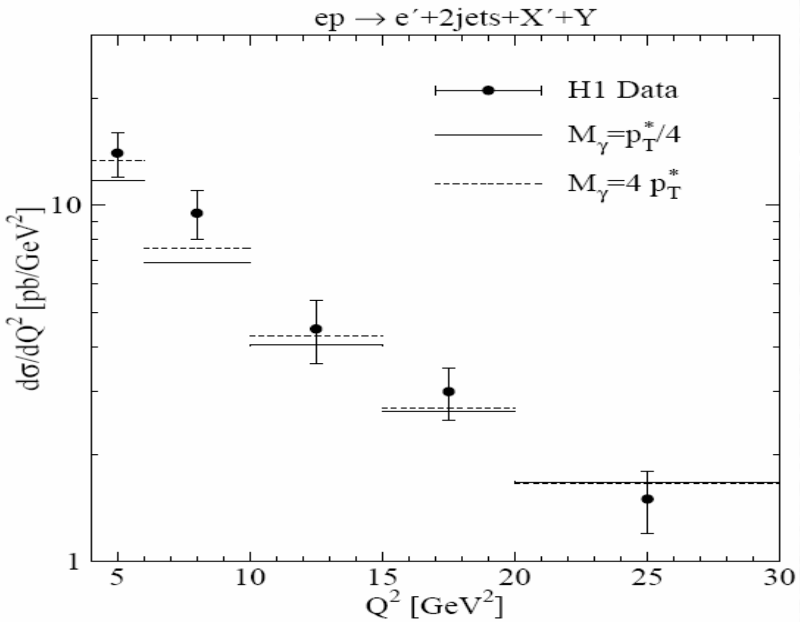


MK, G. Kramer, JPG 31 (2005) 1391

Factorization Scale Dependence (2)

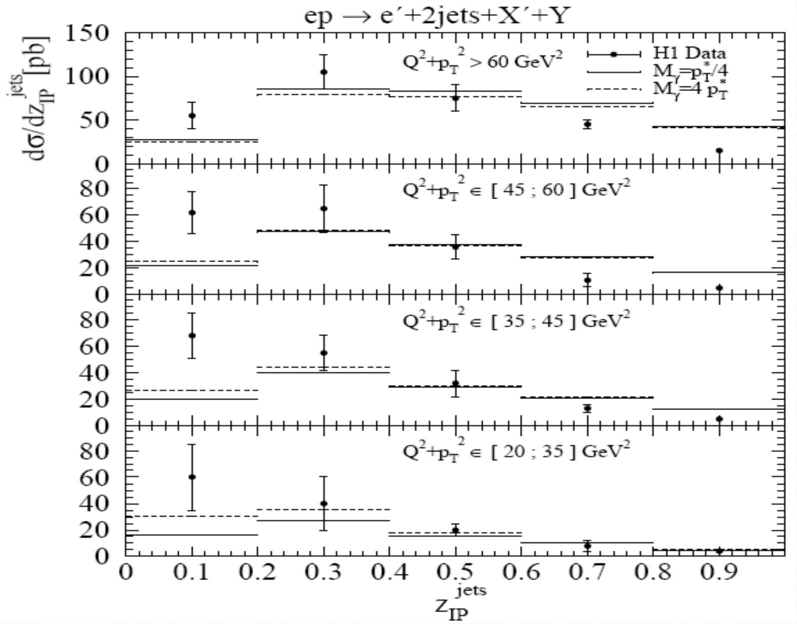
$$M(P^2)_{\overline{MS}} = -\frac{1}{2N_c} P_{q_i\leftarrow\gamma}(z_a) \ln\left(\frac{M_\gamma^2 z_a}{(z_a P^2 + y_s s)(1-z_a)}\right) + \frac{Q_i^2}{2}$$

Q^2-dependence:



MK, G. Kramer, JPG 31 (2005) 1391

z_{IP}-dependence:



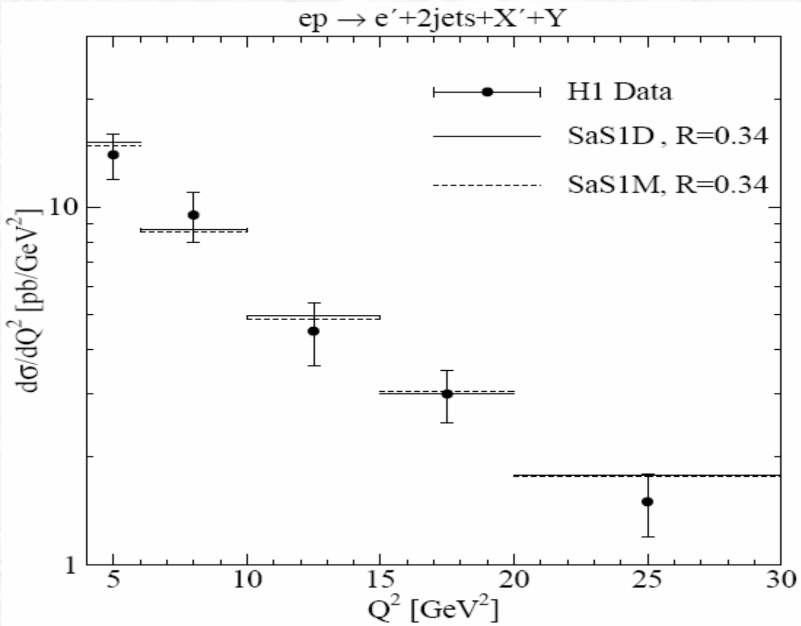
MK, G. Kramer, JPG 31 (2005) 1391

Factorization Scheme Dependence

$$F_2^\gamma(Q^2) = \sum_q 2xe_q^2 \left\{ f_{q/\gamma}(Q^2) + \frac{\alpha_s(Q^2)}{2\pi} \left[C_q \otimes f_{q/\gamma}(Q^2) \right.\right.$$
$$\left.\left. + \, C_g \otimes f_{g/\gamma}(Q^2) \right] + \frac{\alpha}{2\pi} e_q^2 C_\gamma \right\}.$$

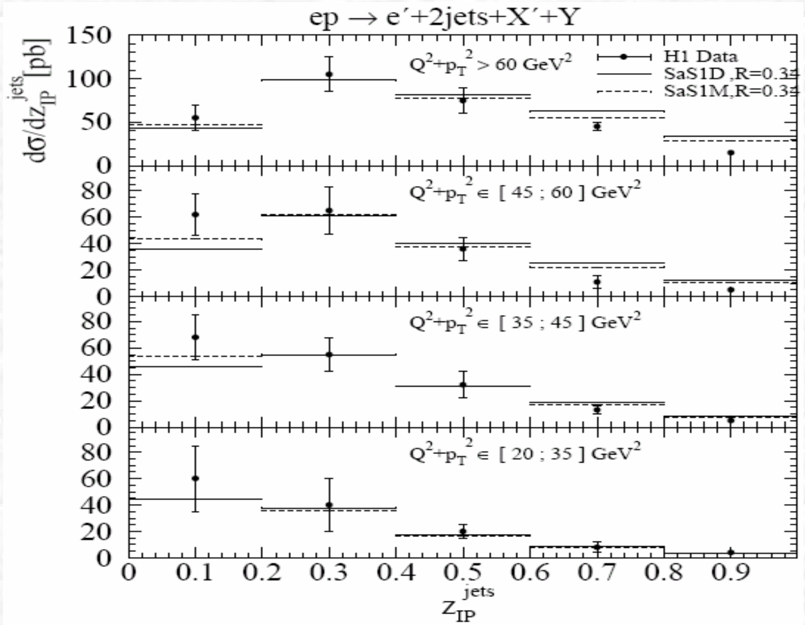
$$C_\gamma(x) = 2N_C \, C_g(x) = 3 \left[\left(x^2 + (1-x)^2 \right) \ln \frac{1-x}{x} \right.$$
$$\left. + \, 8x(1-x) - 1 \right],$$

Q^2-dependence:



MK, G. Kramer, JPG 31 (2005) 1391

z_{IP}-dependence:



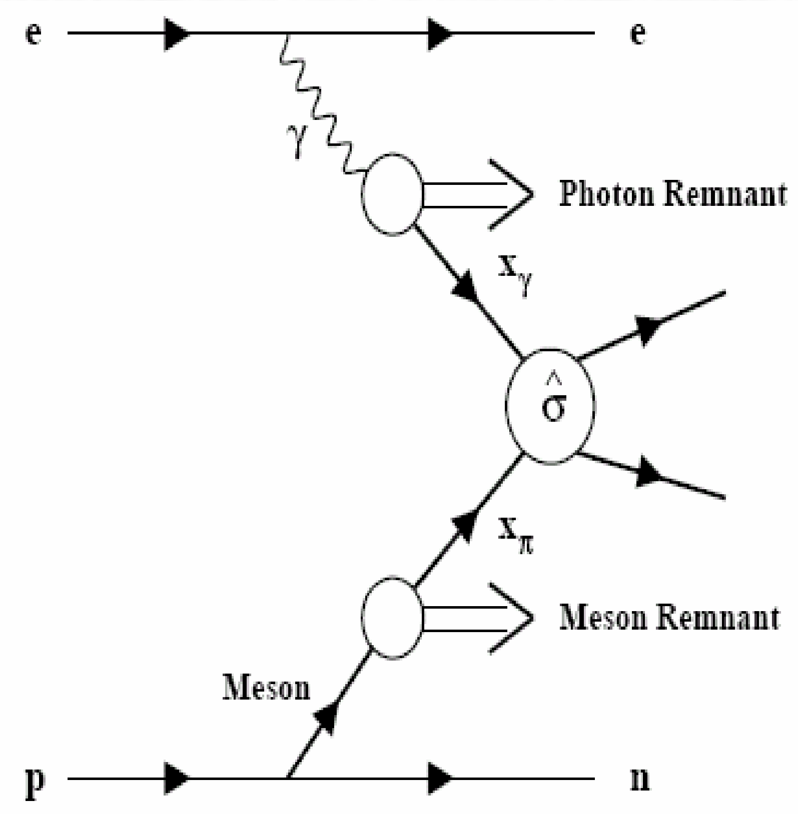
MK, G. Kramer, JPG 31 (2005) 1391

Components of Parton Densities in Photon

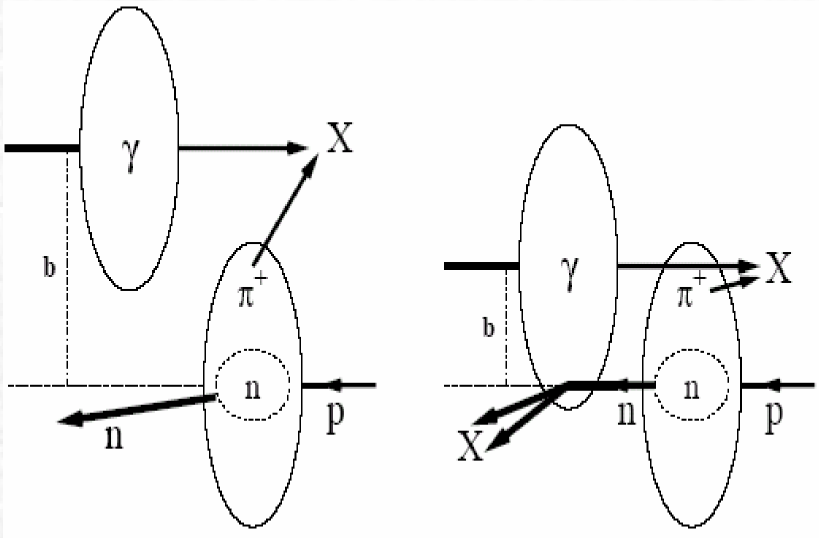
- SaS parameterizations allow for separation:
  - Anomalous component: Resummation of IS singularity
  - Hadronic component: Vector meson dominance model
- VMD component suppressed:
  - 10^{-4} for $Q^2 \approx 70$ GeV^2
  - 10^{-2} for $Q^2 \approx 5$ GeV^2
- Anomalous component dominates:
  - Direct higher order contributions
- Known from inclusive low-Q^2 production

Leading Neutron Production (1)

Scattering process:



Meson cloud model:



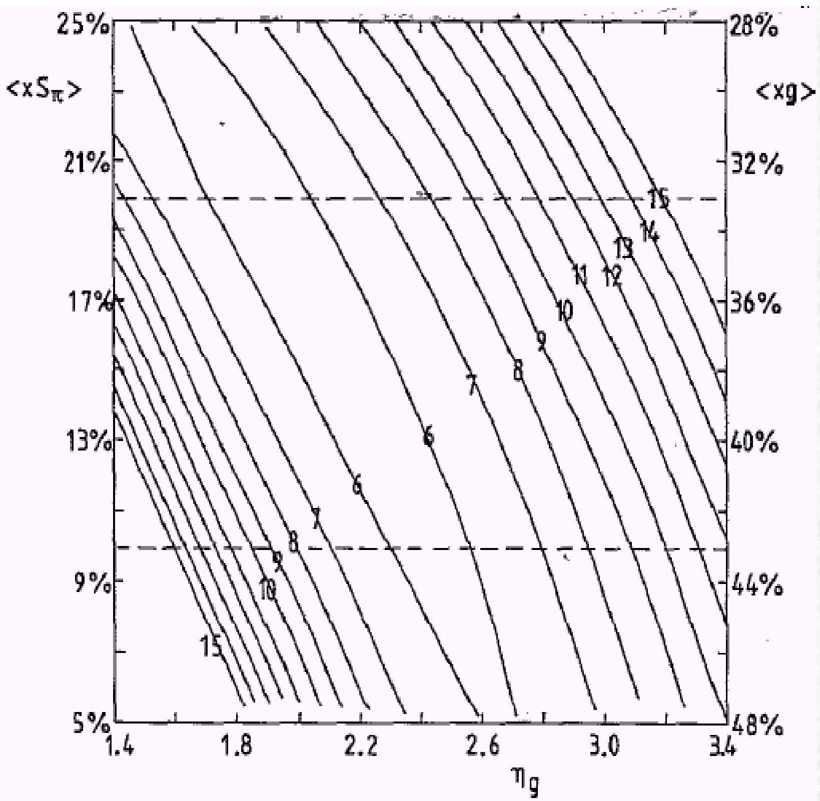
Pion flux factor:

$$f_{\pi/p}(1-x_n,t') = \int \mathrm{d}^2\mathbf{p_T} |\phi_{\pi/p}(x_n,\mathbf{p_T})|^2 \delta(t'-f(p_T))$$

$$= \frac{3C_n}{4\pi}\frac{g^2_{n\pi p}}{4\pi}\frac{-t'}{(m_\pi^2-t')^2}(1-x_n)^{1-2\alpha'_\pi(t'-m_\pi^2)}[F(x_n,t')]^2$$

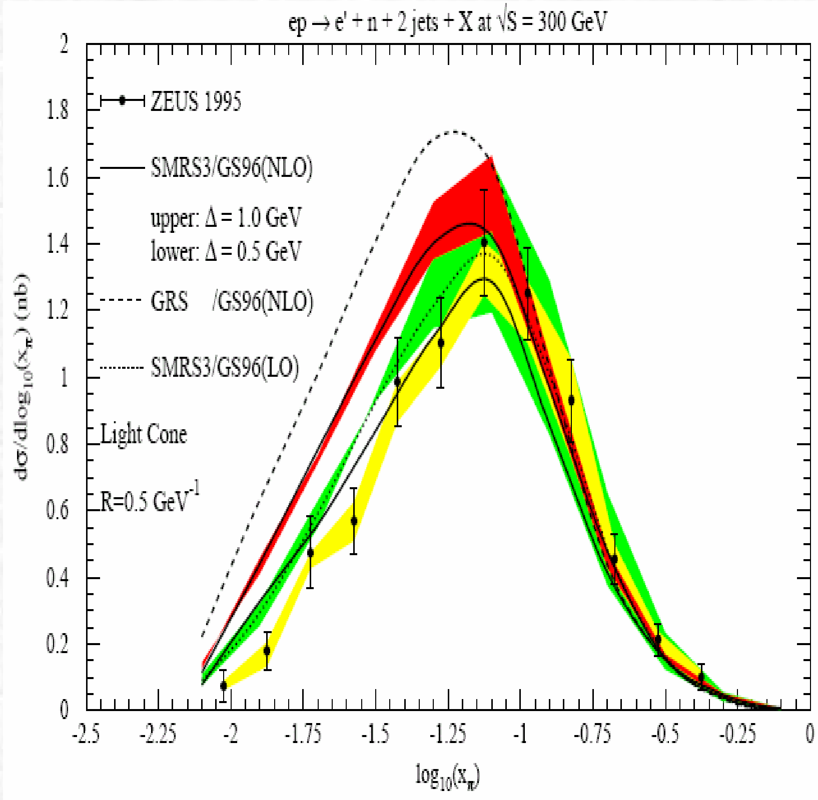
Leading Neutron Production (2)

Sea-quark and gluon density in pions:



Sutton, Martin, Roberts, Stirling, PRD 45

Dijet production with a leading neutron:



MK, G. Kramer, PLB 508 (2001) 259

Conclusions

Hard diffraction: Factorizable or not?

- Deep inelastic scattering: Yes $\rightarrow$ Diffractive parton densities
- Hadronic scattering: No $\rightarrow$ Multipomeron exchanges
- Important application: Diffractive Higgs production at LHC

Diffractive photoproduction of dijets: Initial state singularity at NLO

- Direct / resolved photoproduction: x_γ and M_γ dependence
- (Non-) factorizable multipomeron exchanges

Two-channel eikonal model:

- Generalized vector meson dominance: $\gamma \rightarrow \rho, \omega, \ldots$
- Rapidity gap survival probability: $R = 0.34$

Related process:

- Leading neutron with π-exchange (NB: $f_{q/\pi}$, not $f_{g/IP}$!)