Diffractive Dijet Photoproduction

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Publications

- With G. Kramer

- PLB 508 (2001) 259: $\gamma\, p \rightarrow 2$ jets+n
- EPJC 38 (2004) 39: $\gamma\, p \rightarrow 2$ jets+p
- PRL 93 (2004) 232002: $\gamma^{*} p \rightarrow 2$ jets+p

+ 1 paper in preparation

Motivation

Hard diffraction:

→ Does factorization hold?

Deep inelastic scattering: Yes

→ Direct photoproduction

Hadroproduction: No

→ Resolved photoproduction

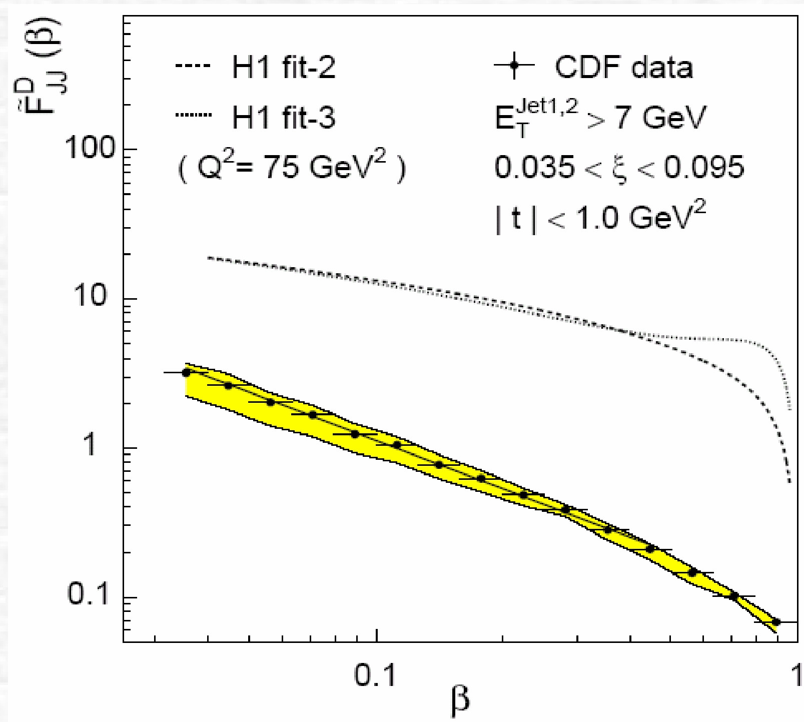
Why next-to-leading order?

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

→ 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

Higgs Production at the LHC

Higgs signal	number of events: signal	number of events: background	S/B	significance $S/\sqrt{S+B}$
a) $H \to \gamma\gamma$ CMS	313	5007	$0.06 \left(\frac{1\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	4.3σ
a) $H \to \gamma\gamma$ ATLAS	385	11820	$0.03 \left(\frac{2\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$, $H \to b\bar{b}$	26	31	$0.8 \left(\frac{10\,\text{GeV}}{\Delta M_{b\bar{b}}}\right)$	3σ
c) $gg^{PP} \to p + H + p$, $H \to b\bar{b}$	11	4	$3 \left(\frac{1\,\text{GeV}}{\Delta M_{\text{missing}}}\right)$	3σ
d) $gg^{PP} \to X + H + Y$, $H \to b\bar{b}$	190	21,000	$0.009 \left(\frac{10\,\text{GeV}}{\Delta M_{b\bar{b}}}\right)$	1.3σ
e) Weak Boson Fusion (WBF) $qWWq \to jHj \to j\gamma\gamma j$	17	9	CMS	3.3σ
	18	17	ATLAS	3σ
$\to j\tau\tau j$	25	8		4.4σ
$\to jW(l\nu)W^*(l\nu)j$	49	31		5.4σ
f) WBF with rapidity gaps $qWWq \to j + H(\text{high}\,q_t) + j$, $H \to b\bar{b}$	jet E_T cuts:			
	250	1800	$0.14 \left(\frac{10\,\text{GeV}}{\Delta M_{b\bar{b}}}\right)$	5.5σ
	Higgs q_t cut:			
	400	3700	$0.11 \left(\frac{10\,\text{GeV}}{\Delta M_{b\bar{b}}}\right)$	6.2σ
g) $gg \to ZZ^* \to 4l$	6	4	CMS	1.9σ
	3	1.5	ATLAS	1.4σ
h) $gg \to WW^* \to l\nu l\bar{\nu}$	44	272	CMS	2.5σ
i) $WH \to l\nu b\bar{b}$	161	7095	0.02	1.9σ

M_H = 120 GeV – V. Khoze, A. Martin, A. Roeck, M. Ryskin, EPJC 25 (2002) 391

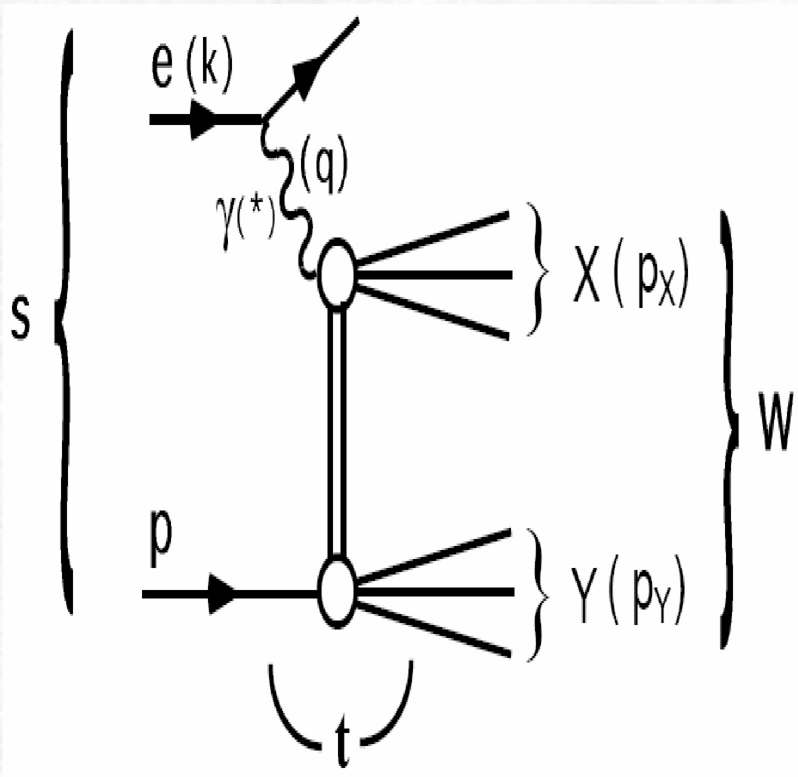
Diffractive Higgs Production

Reference	Process	Survival factor T^2	Survival factor S^2	Norm.	σ_{Higgs} (fb) Teva.	σ_{Higgs} (fb) LHC	Notes
Cudell, Hernandez [21]	excl incl	no	no	σ_{tot}	30 200	300 1200	Overshoots CDF dijets by 1000.
Levin [20]	excl incl	yes No DL	yes	σ_{tot}	20 70	–	Overshoots CDF dijets by 300.
Khoze, Martin, Ryskin [16]	excl incl C.incl	yes	yes	pdf pdf	0.2 1 ~ 0.03	3 40 50	Uses skewed gluons. CDF dijets OK.
Cox, Forshaw, Heinemann [5]	C.incl	$T \simeq 1$	norm	CDF dijet	0.02	6	No LO, only NLO, QCD i.e., no Fig.2(a), only 2(c).
Boonekamp, De Roeck, Peschanski, Royon [7]	C.incl	$T \simeq 1$	norm	CDF dijet	**1.9**	**180**	No LO, only NLO, QCD. Assume $S^2_{CDF} = S^2_{LHC}$.
Enberg, Ingelman, Kissavos, Timneanu [19]	incl C.incl	yes	yes	$F_2^{Diff.}$	< 0.01	0.2	No coherence.

V. Khoze, A. Martin, M. Ryskin, EPJC 26 (2002) 229

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:

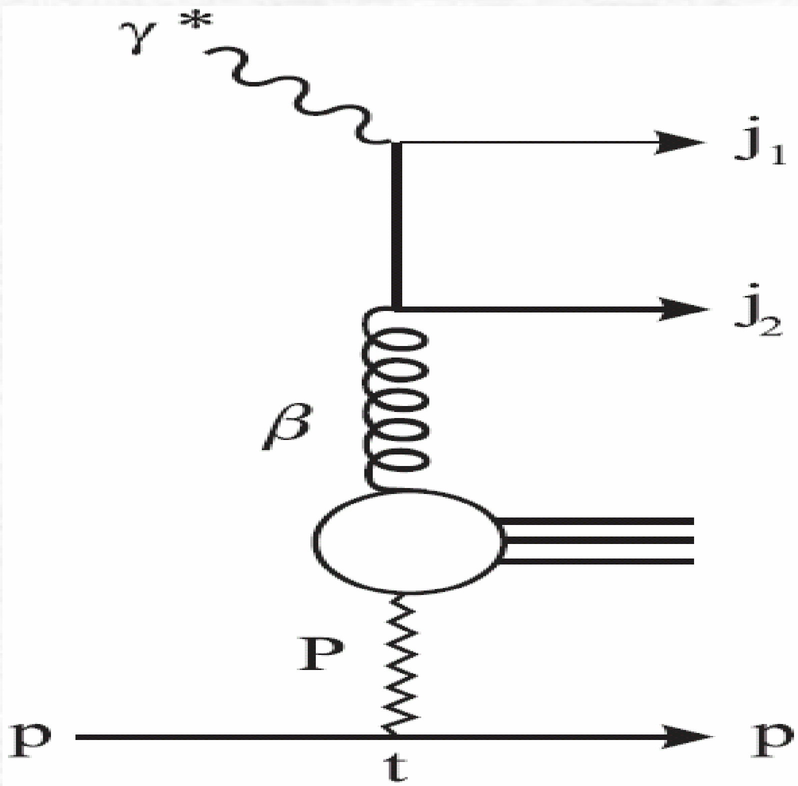
$$M_X^2 = p_X^2 \quad \text{and} \quad t = (p - p_Y)^2,$$
$$M_Y^2 = p_Y^2 \quad \text{and} \quad x_{I\!P} = \frac{q(p - p_Y)}{qp}$$

Experimental cuts:

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

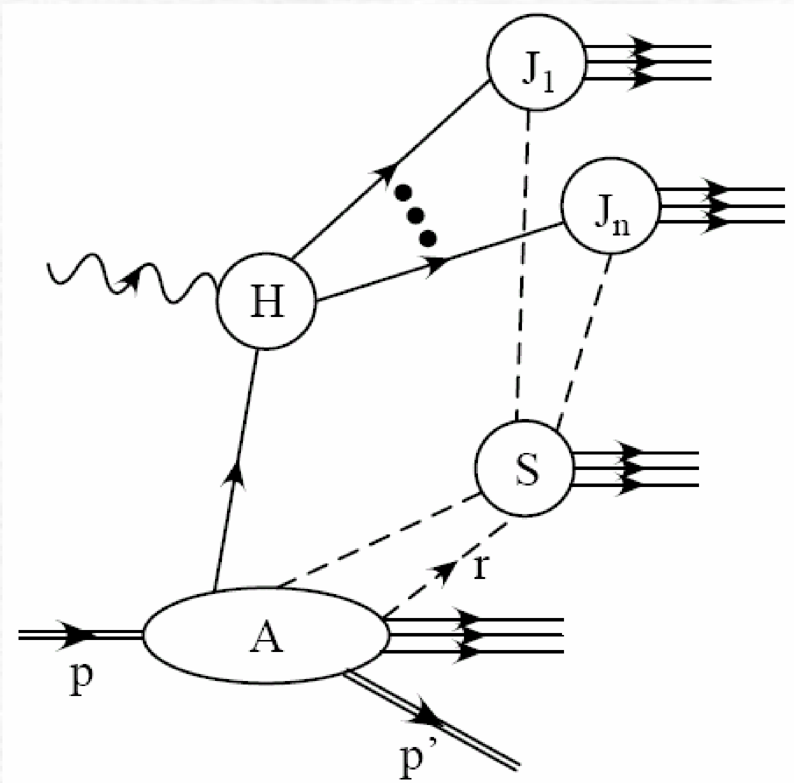
$$f_{I\!P/p}(x_{I\!P}, t) = x_{I\!P}^{1-2\alpha_{I\!P}(t)} \exp(B_{I\!P} t)$$

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

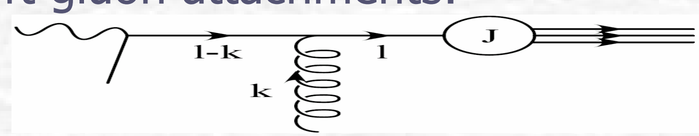
Light cone coordinates:

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

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:

- 

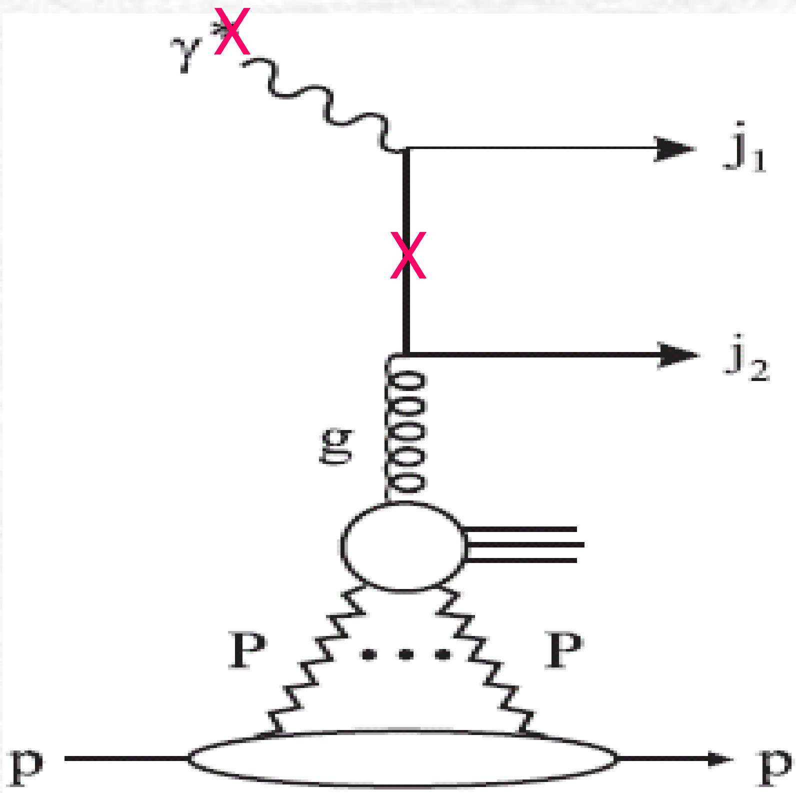
- $$\frac{1}{(l-k)^2 - m^2 + i\epsilon} \simeq \frac{1}{-2l^-k^+ + \text{transverse} + i\epsilon}$$

Poles in k^+-plane:

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

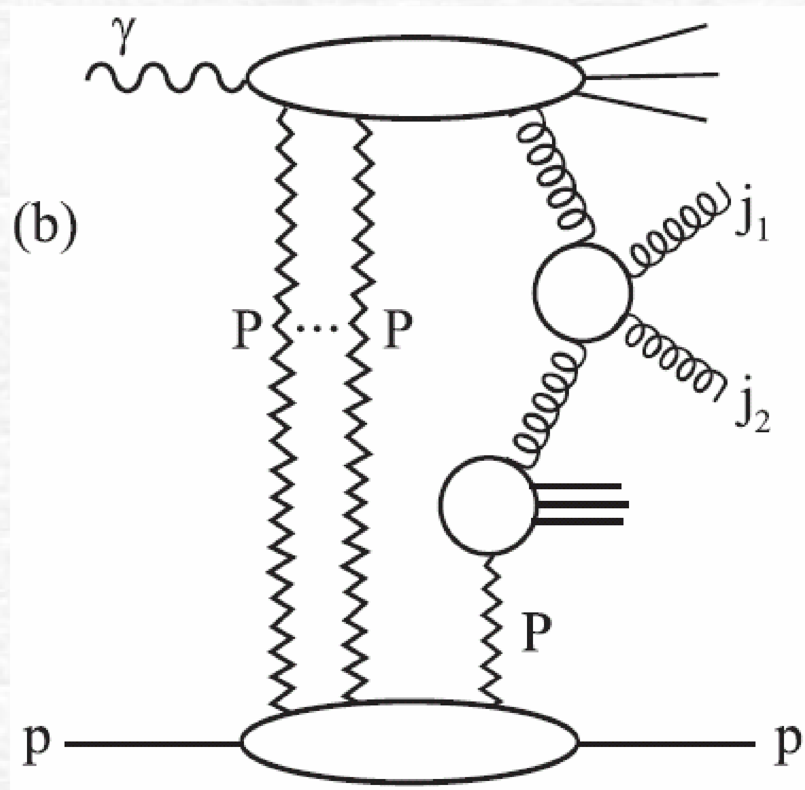
Multipomeron Exchanges

Direct photoproduction:



→ Modify the Regge trajectory

Resolved photoproduction:



→ Factorization breaking

Diffractive Photoproduction of Dijets

Cross section:

$$d\sigma^D(ep \to e + 2 \text{ jets} + X' + Y) =$$

$$\sum_{a,b} \int_{t_{\rm cut}}^{t_{\rm min}} dt \int_{x_{I\!P}^{\rm min}}^{x_{I\!P}^{\rm max}} dx_{I\!P} \int_0^1 dz_{I\!P} \int_{y_{\rm min}}^{y_{\rm max}} dy \int_0^1 dx_\gamma$$

$$f_{\gamma/e}(y) f_{a/\gamma}(x_\gamma, M_\gamma^2) f_{I\!P/p}(x_{I\!P}, t) f_{b/I\!P}(z_{I\!P}, M_{I\!P}^2)$$

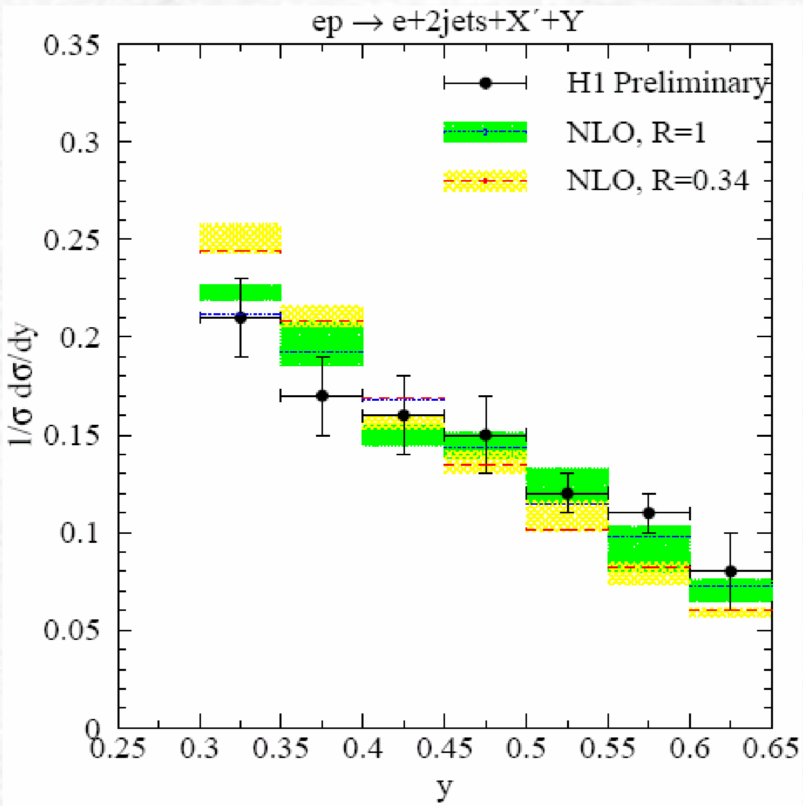
$$d\sigma^{(n)}(ab \to \text{jets}).$$

Photon flux: Weizsäcker-Williams approximation

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

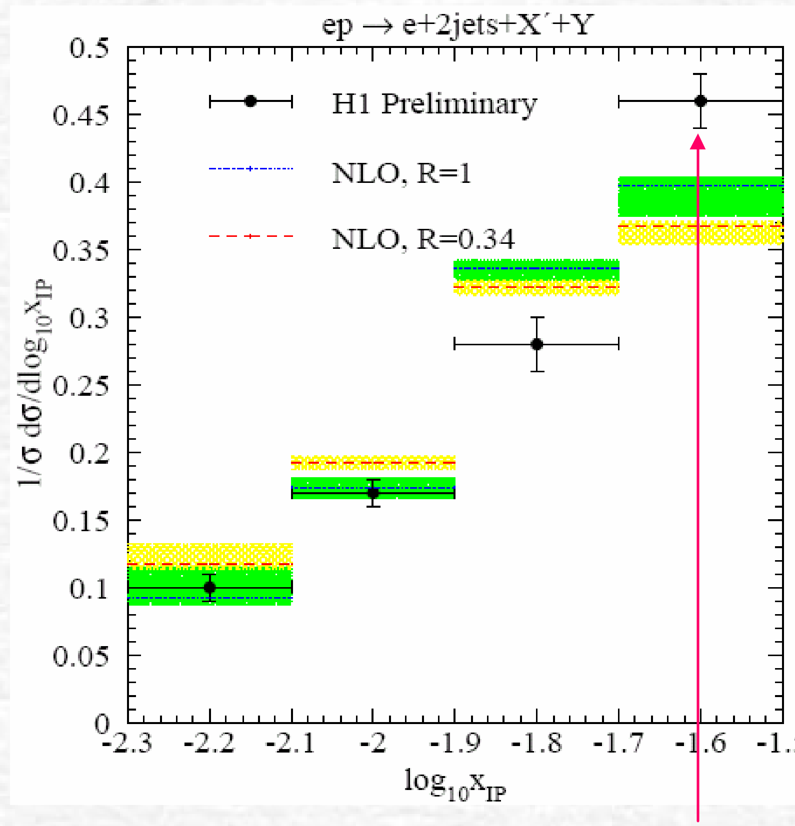
Factorizable Multipomeron Exchanges

y-dependence: Photon flux



$\rightarrow$ Small correlations due to exp. cuts

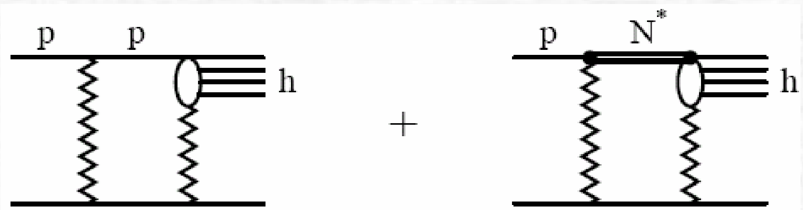
x_{IP}-dependence: Pomeron flux



$\rightarrow$ 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: γ = 0.6

$\to$ ZEUS Coll., EPJ C2 (1998) 247
$\to$ H1 Coll., EPJ C13 (2000) 371

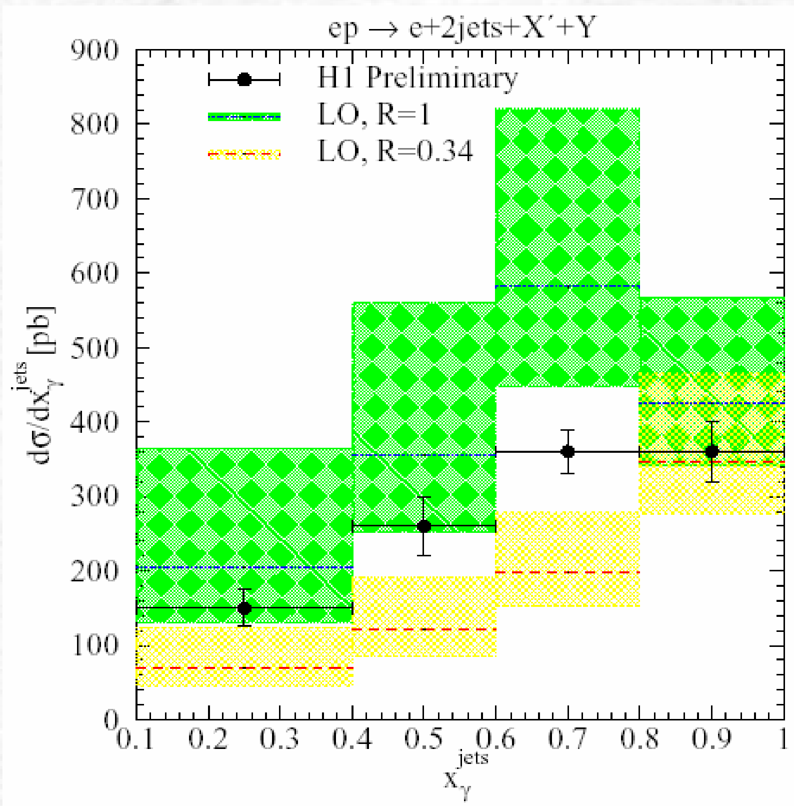
Survival probability:

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

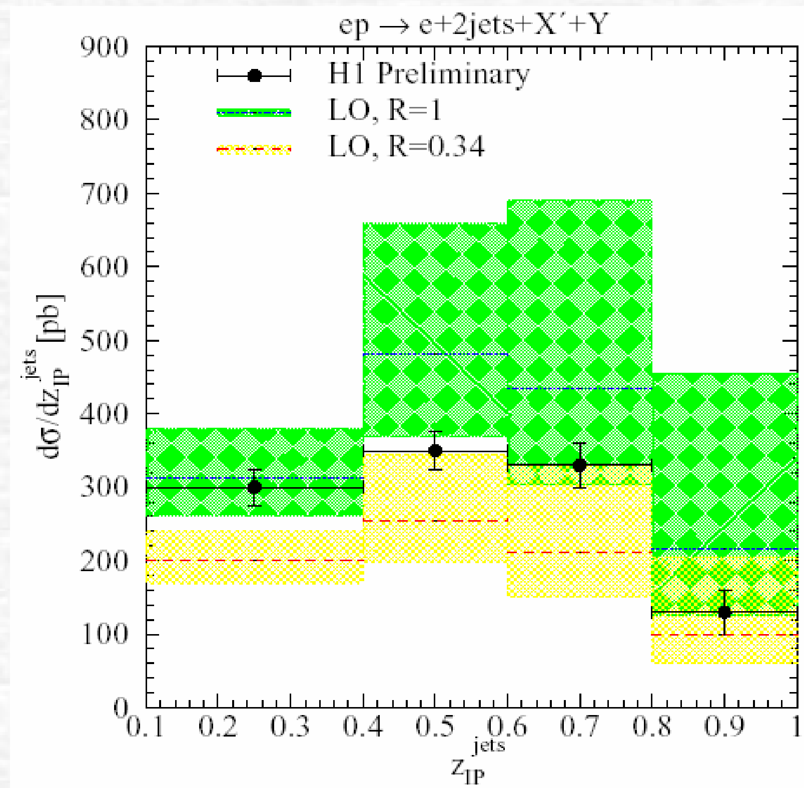
Kaidalov et al., PLB 567 (2003) 61

No Sign of Factorization Breaking at LO

x_γ-dependence: Direct/resolved photons



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

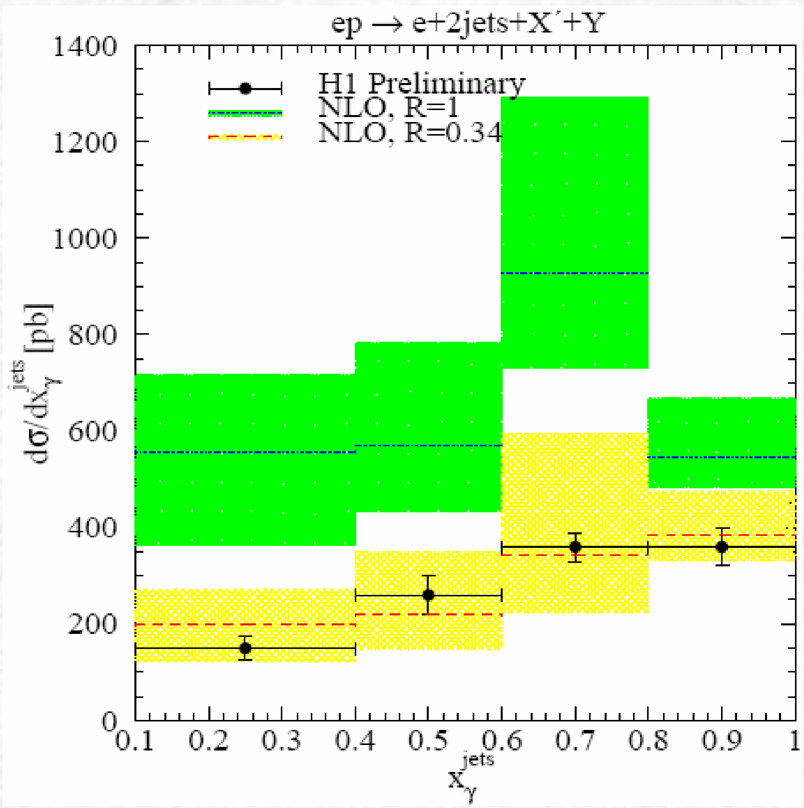


→ At LO, R = 1 agrees better with data!

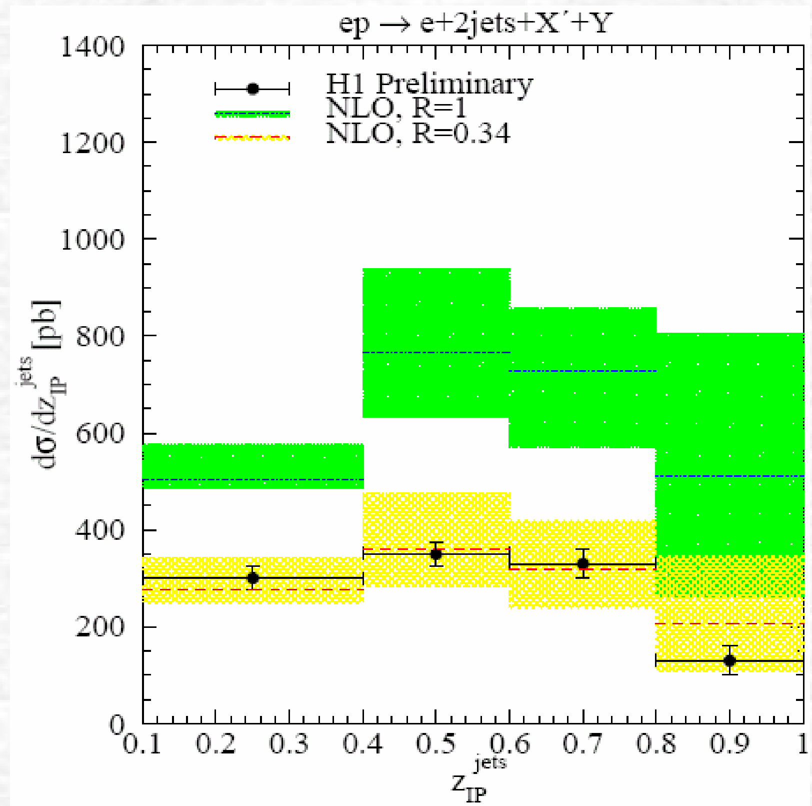
→ Smaller uncertainties in $1/\sigma\, d\sigma/dz_{IP}$

Non-Factorizable Multipomeron Exchanges

x_γ-dependence: Direct/resolved photons



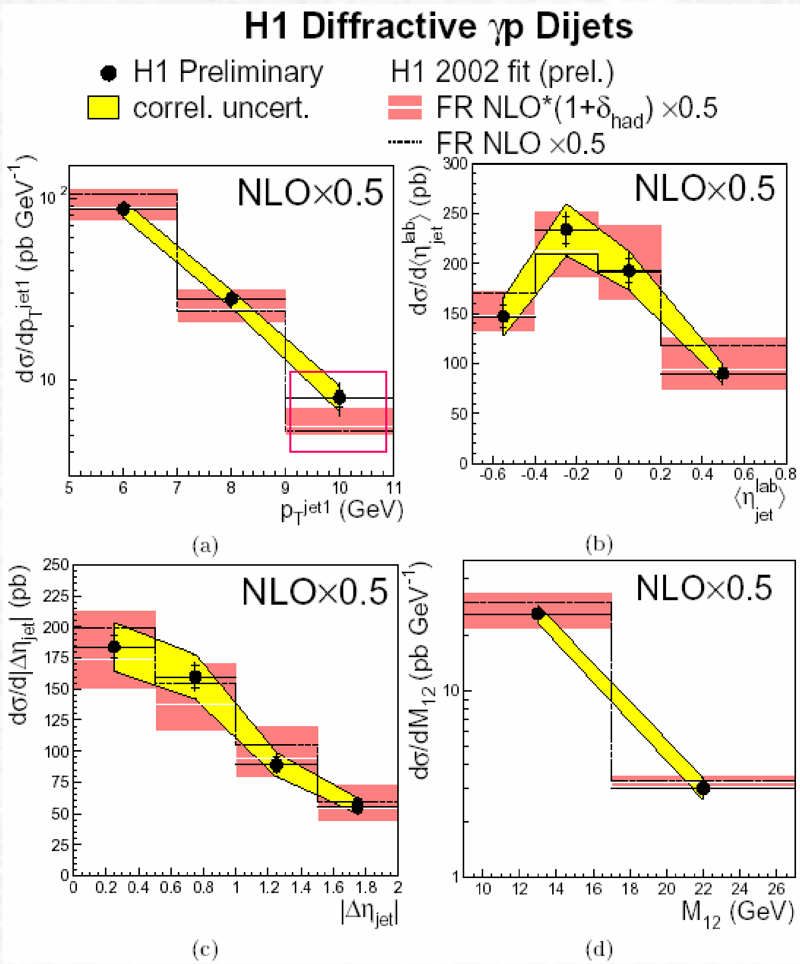
z_{IP}-dependence: Gluon density in pom.

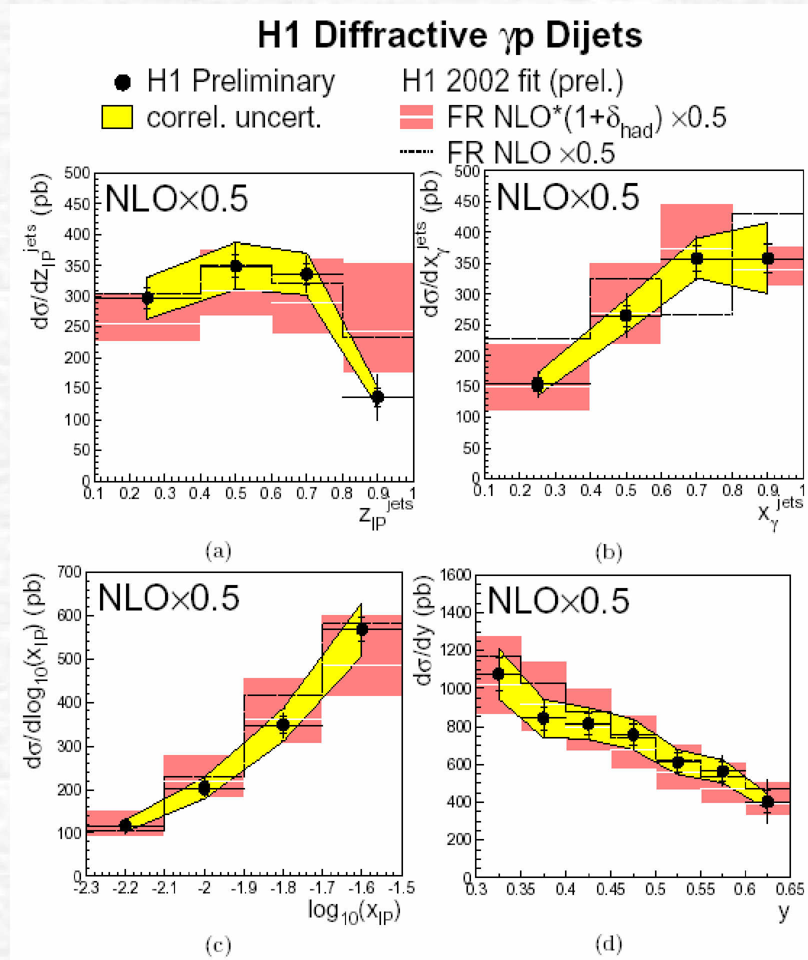


→ Large K-Factor ↔ Survival probability

→ Reduced scale uncertainties at NLO

But: Data also support direct suppression!

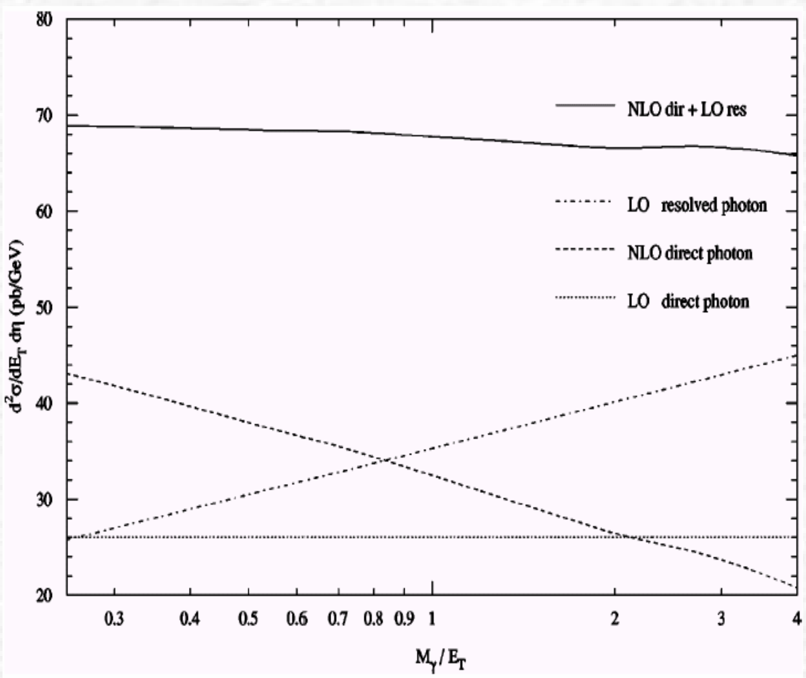




Factorization Scale Dependence

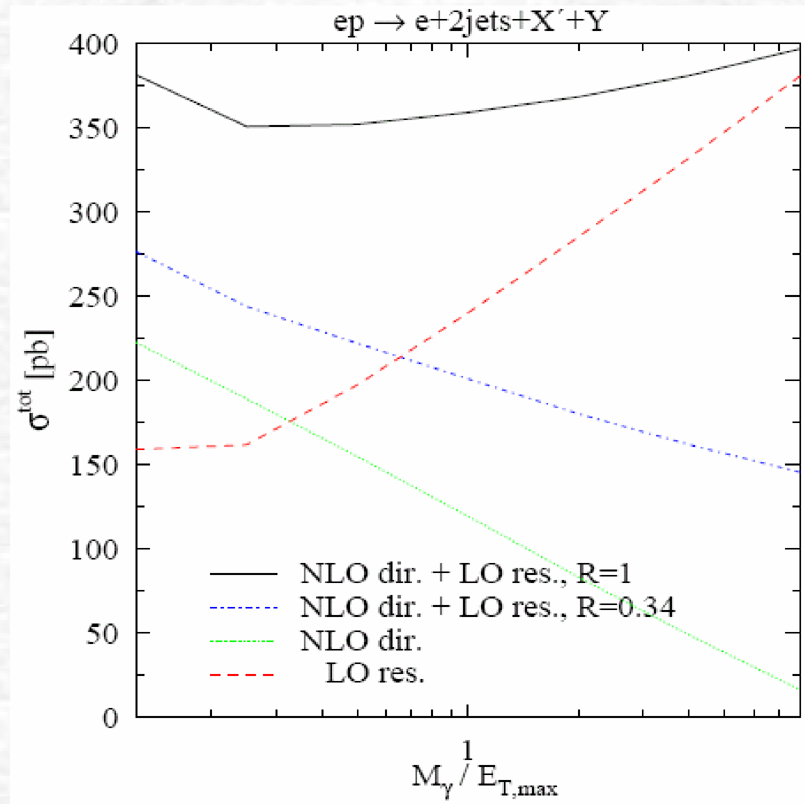
Inclusive photoproduction:

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



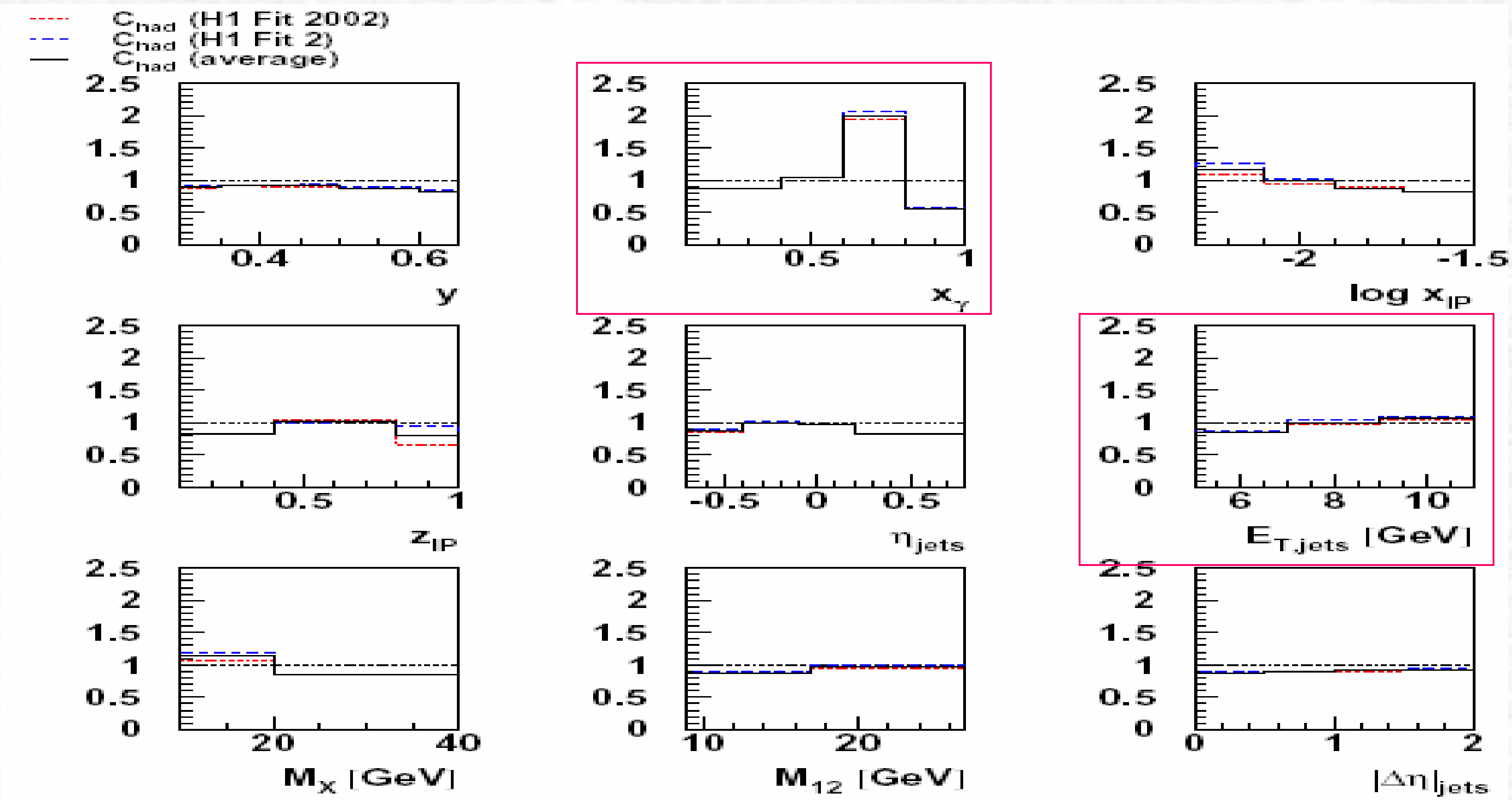
MK, Rev. Mod. Phys. 74 (2002) 1221

Diffractive photoproduction:



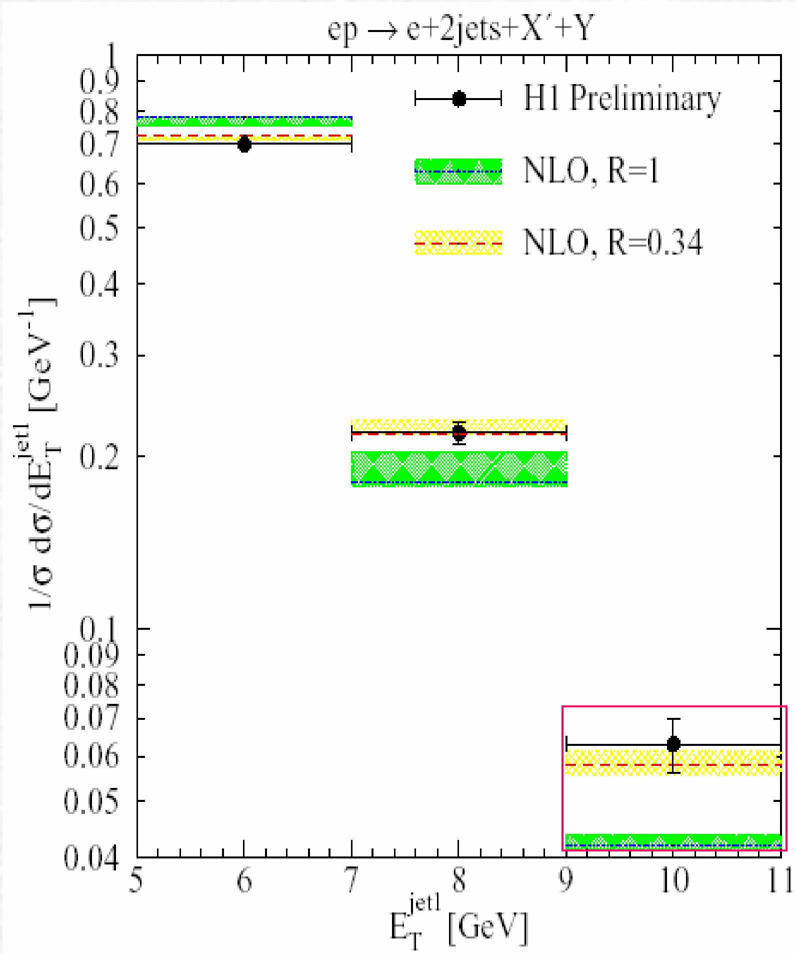
MK, G. Kramer, EPJC 38 (2004) 39

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:

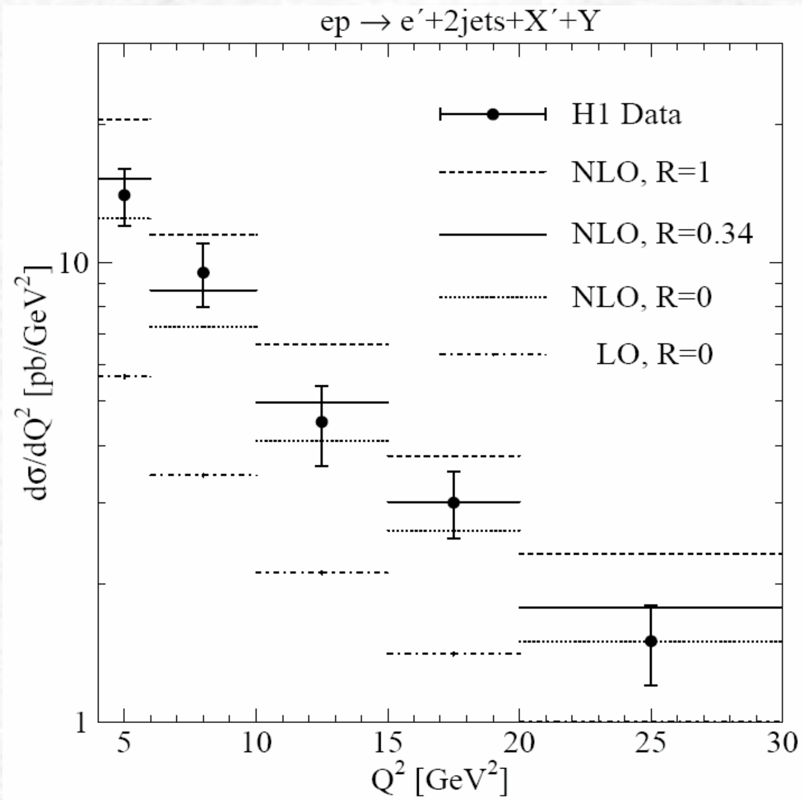
- Suppressed result agrees
- Unsuppressed 50% too low

How can we learn more?

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

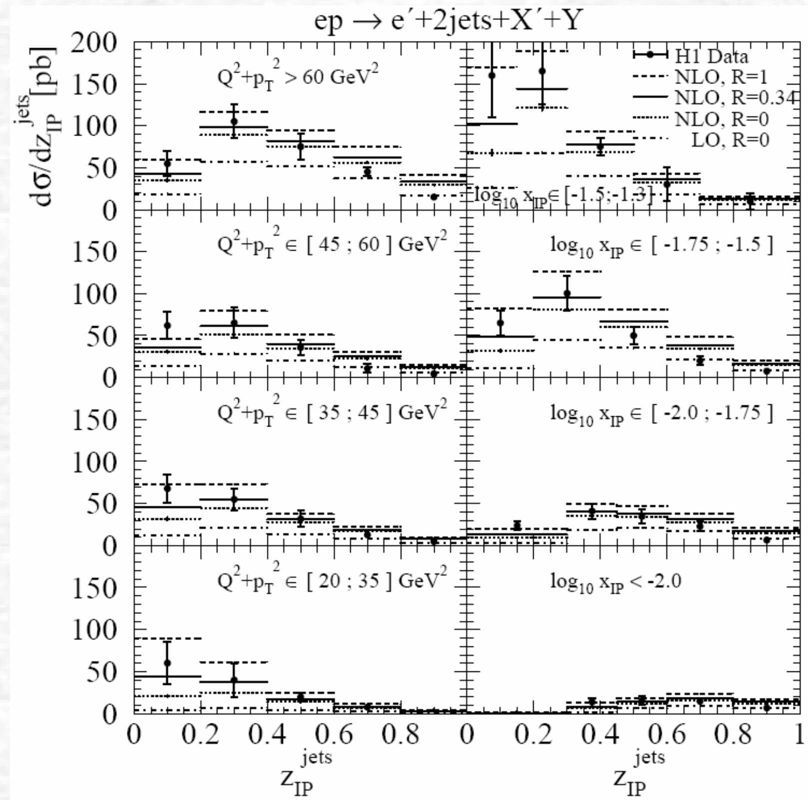
High- to Low-Q^2 Transition in DIS

Q^2-dependence:



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

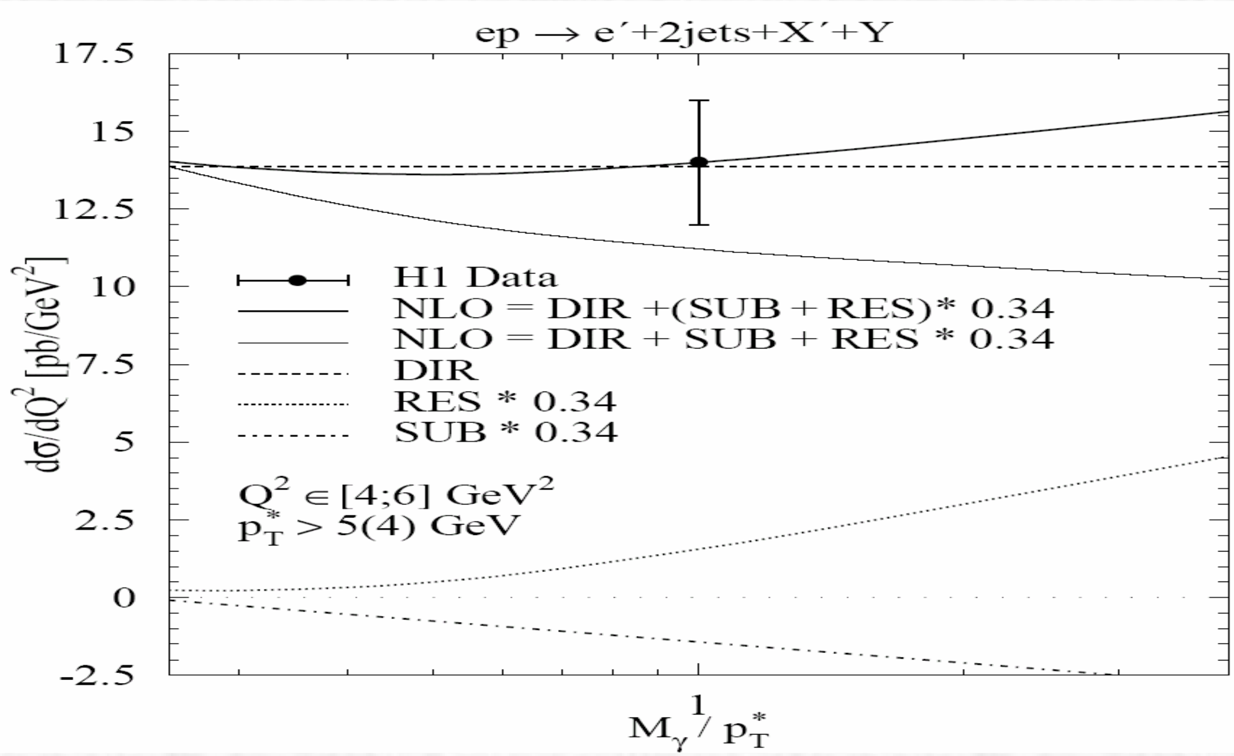
z_{IP}-dependence:



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

Factorization Scale Dependence

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



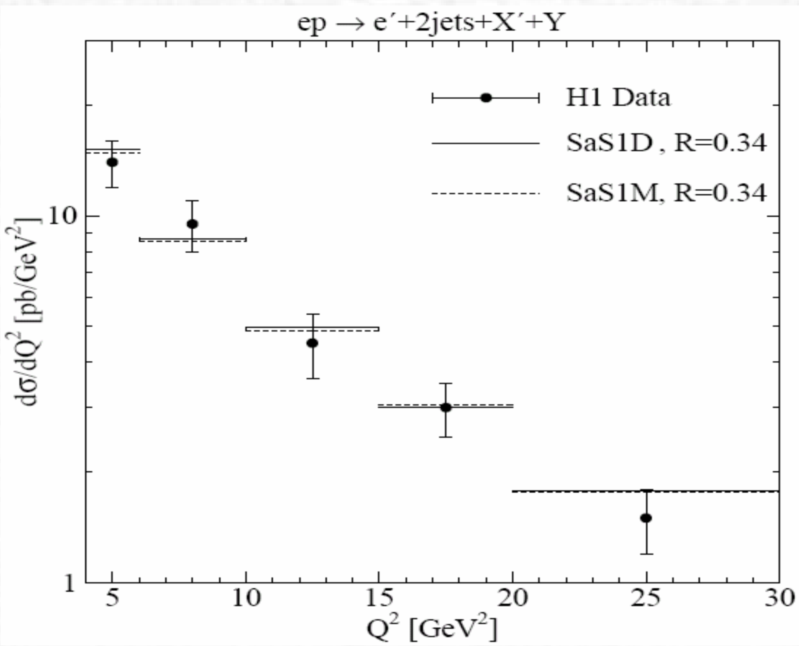
MK, G. Kramer, to appear

Factorization Scheme Dependence

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

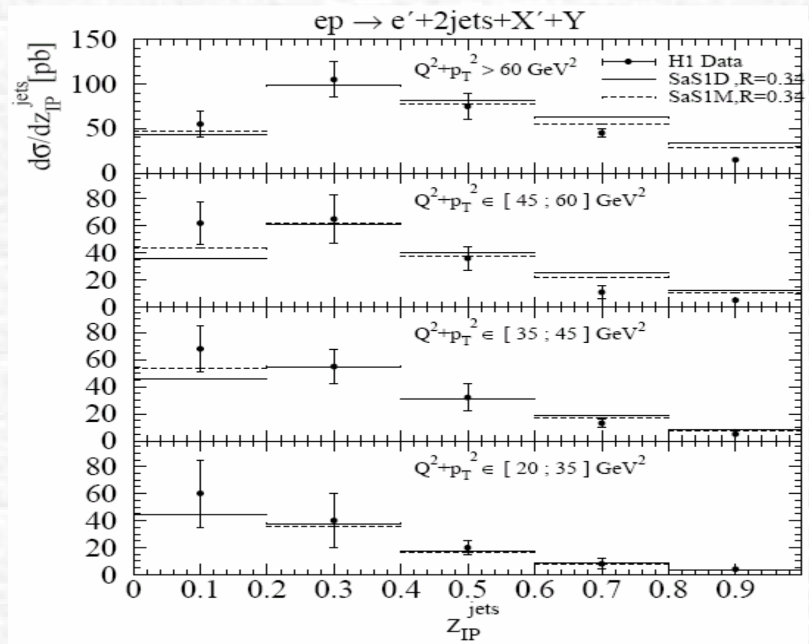
$$C_\gamma(x) = 2N_C\, C_g(x) = 3\left[\left(x^2 + (1-x)^2 \right) \ln \frac{1-x}{x} + 8x(1-x) - 1 \right],$$

Q^2-dependence:



MK, G. Kramer, to appear

z_{IP}-dependence:



MK, G. Kramer, to appear

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

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 $f_{g/IP}$!)