# Heavy Flavour Production and the Hadronic Final State at High Energy ep Collisions

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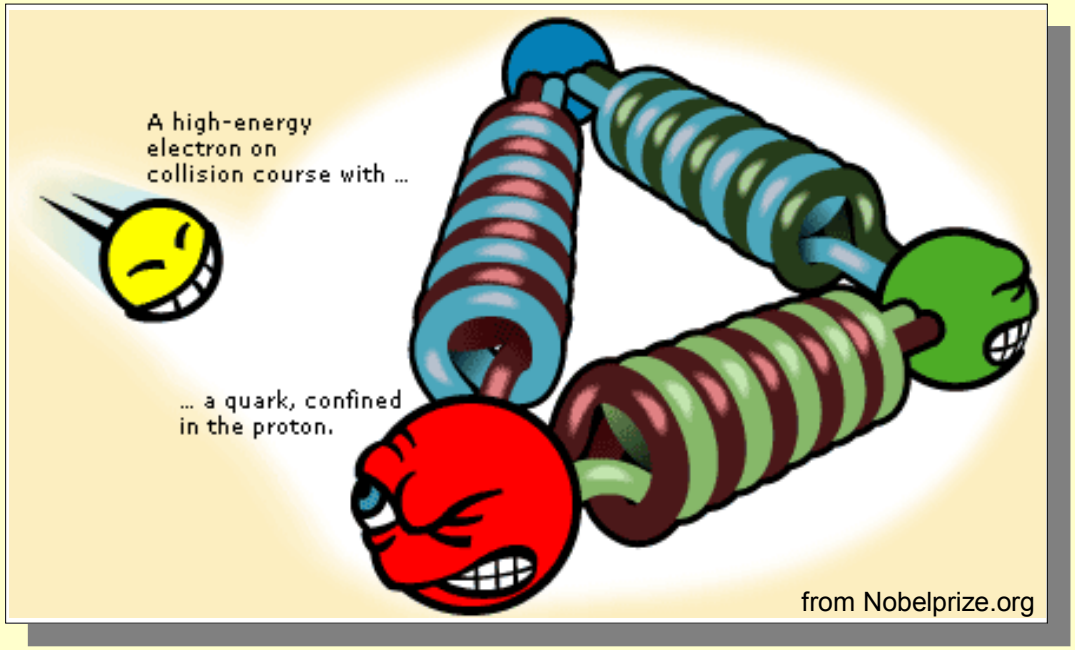
on behalf of the H1 and ZEUS Collaborations

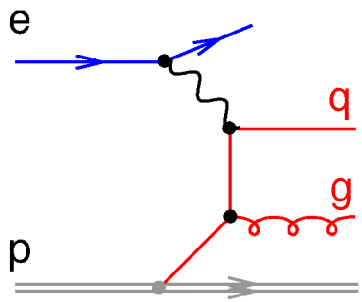
HADRON 2005, 23 August 2005

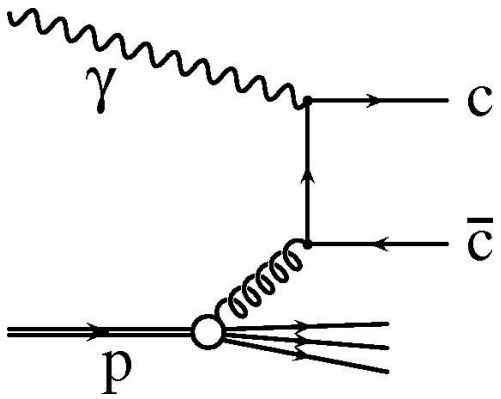


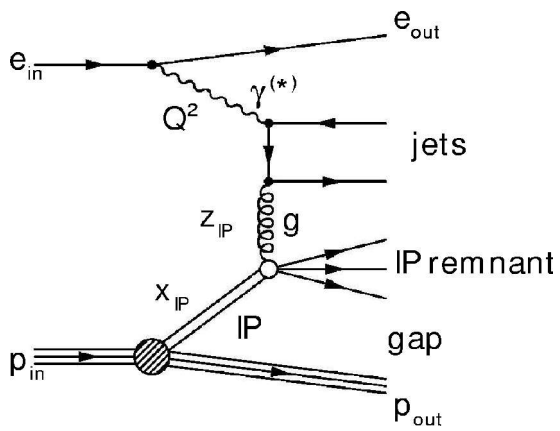
# Outline

Talk by Tobias Haas: Introduction to HERA, structure functions, searches for new phenomena

This talk: analyses which study details of the hadronic final state



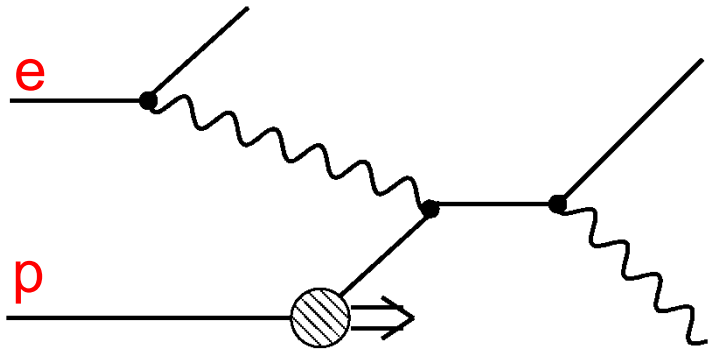

Inclusive → Exclusive

e.g. jet cross sections

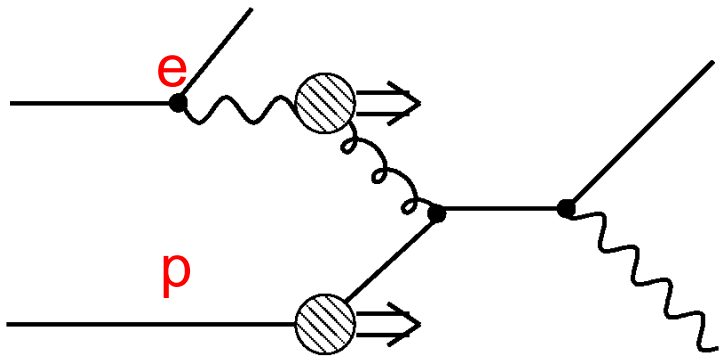
e.g. vector meson production

# Introduction

HERA phasespace: either DIS ($Q^2 \gtrsim 1$GeV) or photoproduction γp ($Q^2 \lesssim 1$GeV)




DIS: need proton parton densities

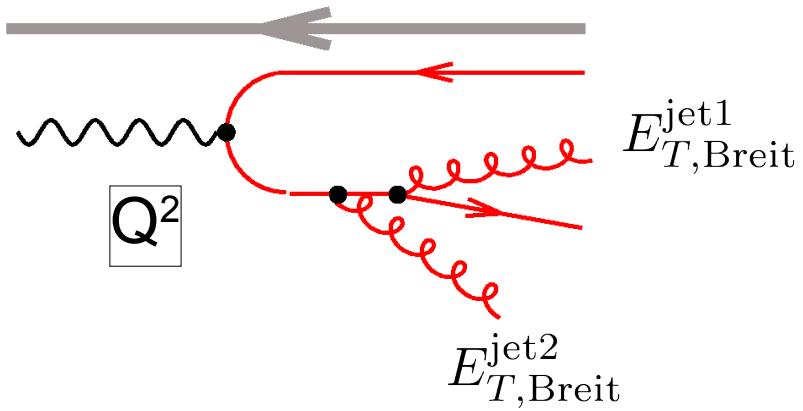



γp: resolved contributes, need also photon parton densities

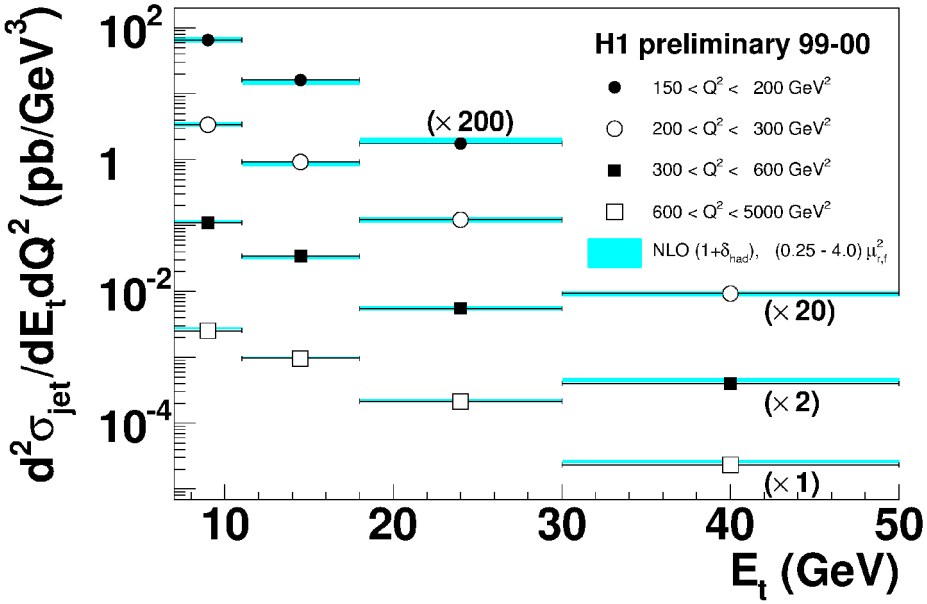
$$x_\gamma = \frac{1}{2yE_e} \sum_i^2 p_{t,i} e^{-\eta_i}$$

low $x_\gamma$: resolved contributes,
high $x_\gamma$: direct enriched

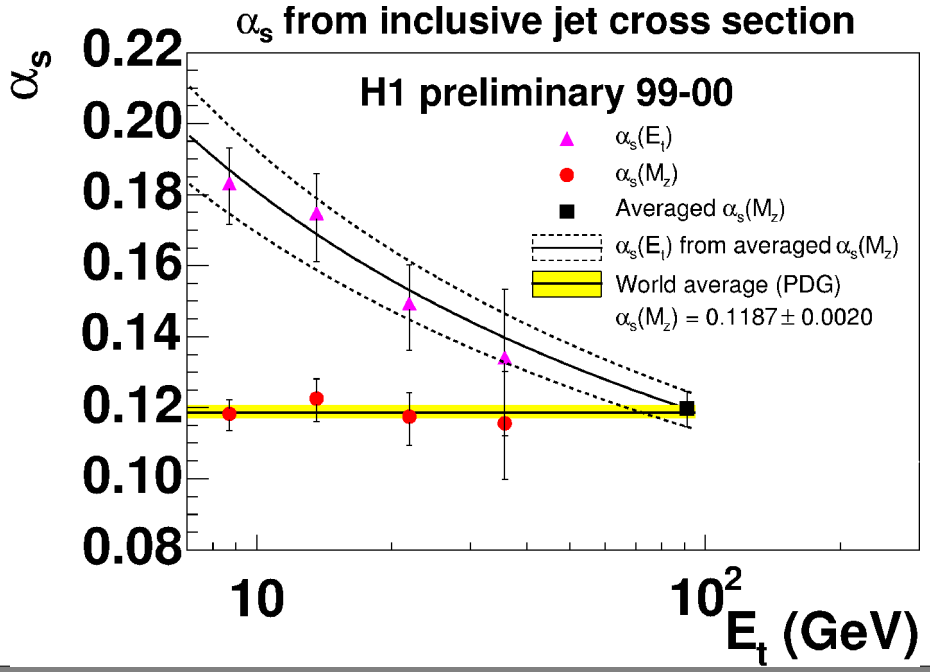
# Inclusive Jet Cross Sections in DIS




inclusive: each jet contributes at it's $E_T$




described by NLO pQCD (NLOJET++) + had. corrections




Fitted $\alpha_s(m_Z)$:

$0.1197 \pm 0.0016\,^{+0.0046}_{-0.0048}$ (exp.+theo.)

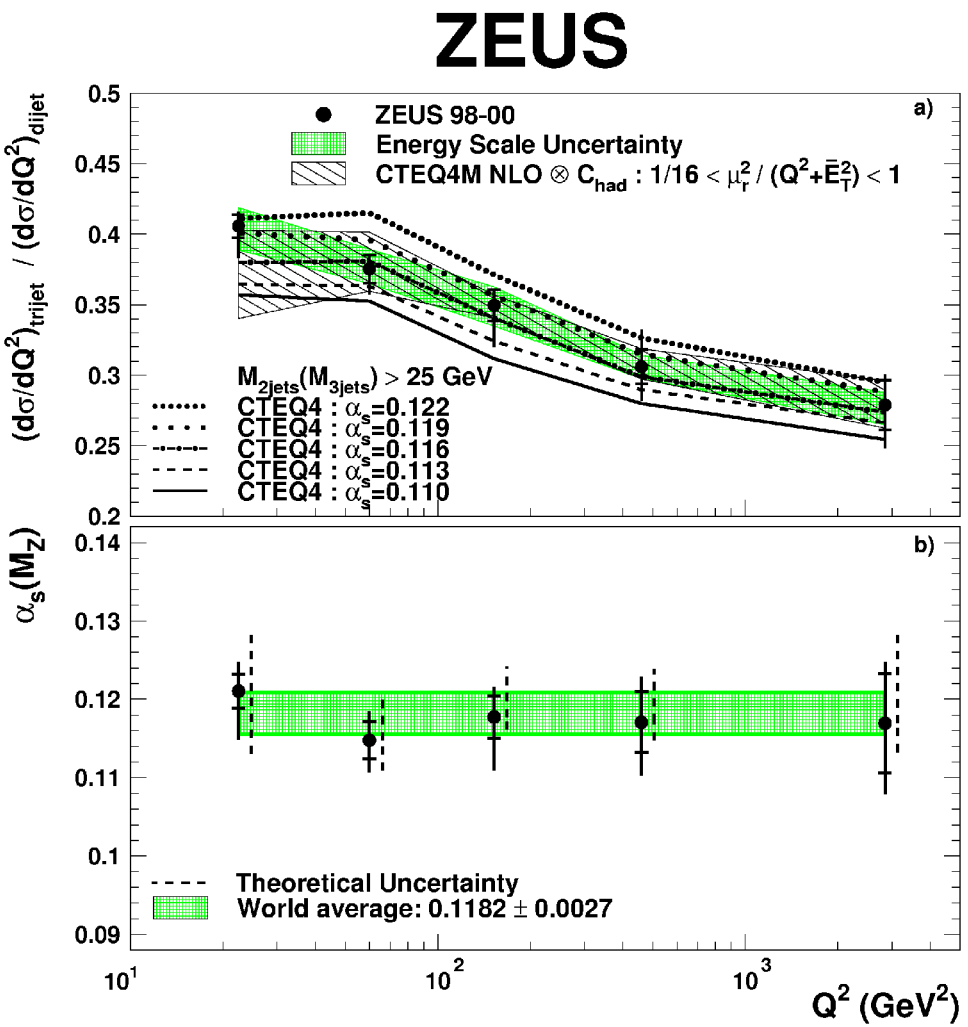
# 2-Jet and 3-Jet Cross Sections in DIS

multi jet: count events with $n_{jet} \geq 2$ and $n_{jet} \geq 3$

- lower statistics

Build ratio $\frac{\sigma_{3\text{jet}}}{\sigma_{2\text{jet}}}$

- cancellation of uncertainties extent to lower $Q^2$




Fitted $\alpha_s(m_Z)$:

$0.1179 \pm 0.0013\ ^{+0.0028\ +0.0064}_{-0.0046\ -0.0046}$ (stat.+syst.+theo.)

# Parton Dynamics

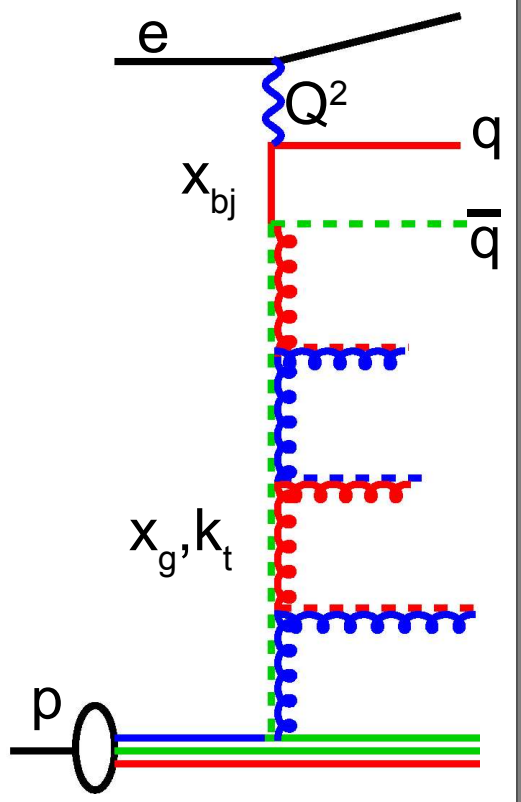
Between hard scattering ME and PDFs:

DGLAP: evolution in $Q^2$
- at small x strong $k_t$ ordering
- neglects log(1/x) terms, low x?

BFKL: evolution in x
- strong x ordering, no $k_t$ ordering
- low x !

CCFM: small x -> BFKL, large x->DGLAP
- no $k_t$ ordering
- unintegrated PDFs

gluon ladder




Dijets at low x and low $Q^2$

low x: DGLAP evolution might fail

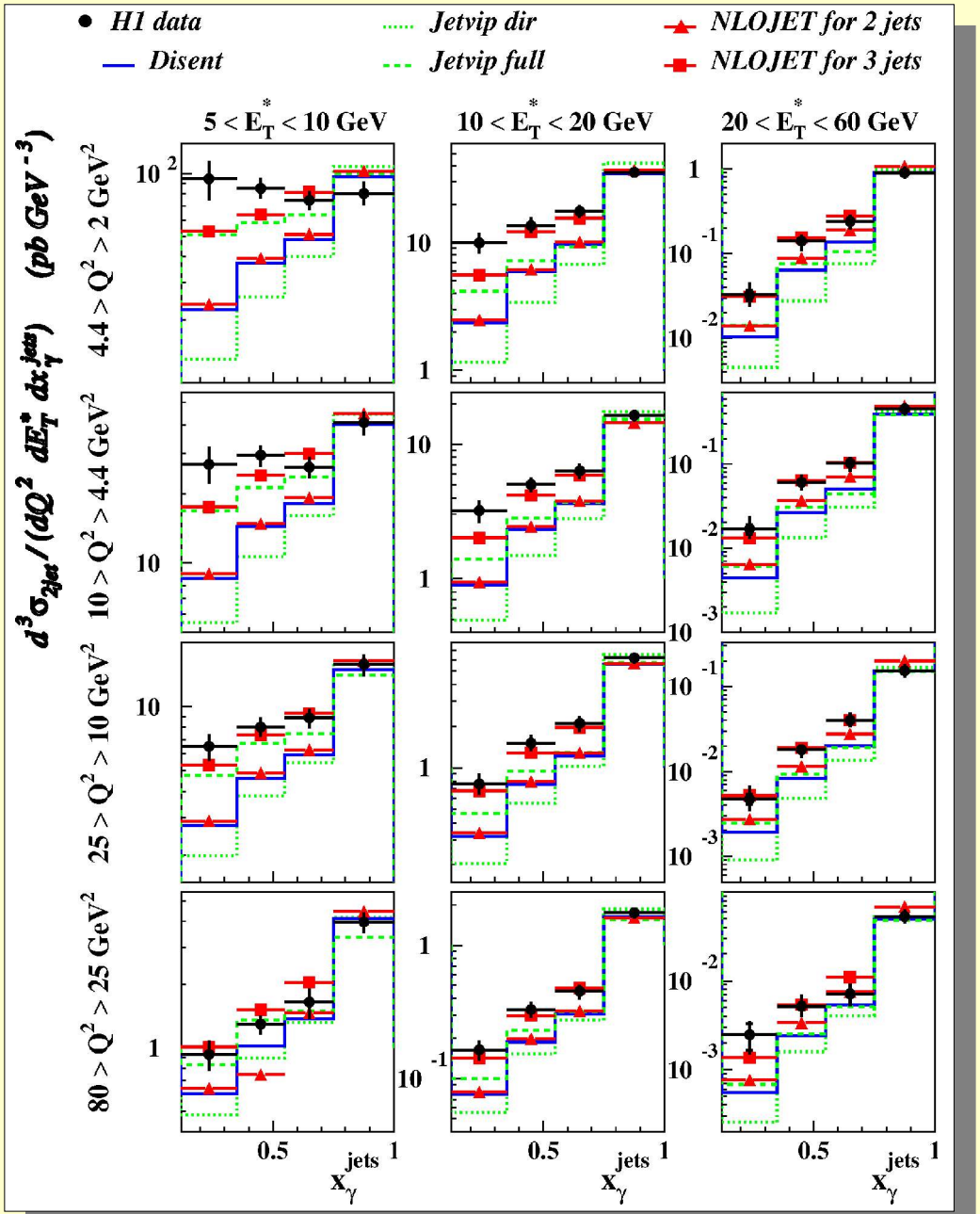
low $Q^2$: resolved photon important

# 2-Jet Cross Sections at low x and low $Q^2$

JETVIP (NLO,DGLAP)
- undershoots at low $Q^2$, low $x_\gamma$
- even with resolved photons

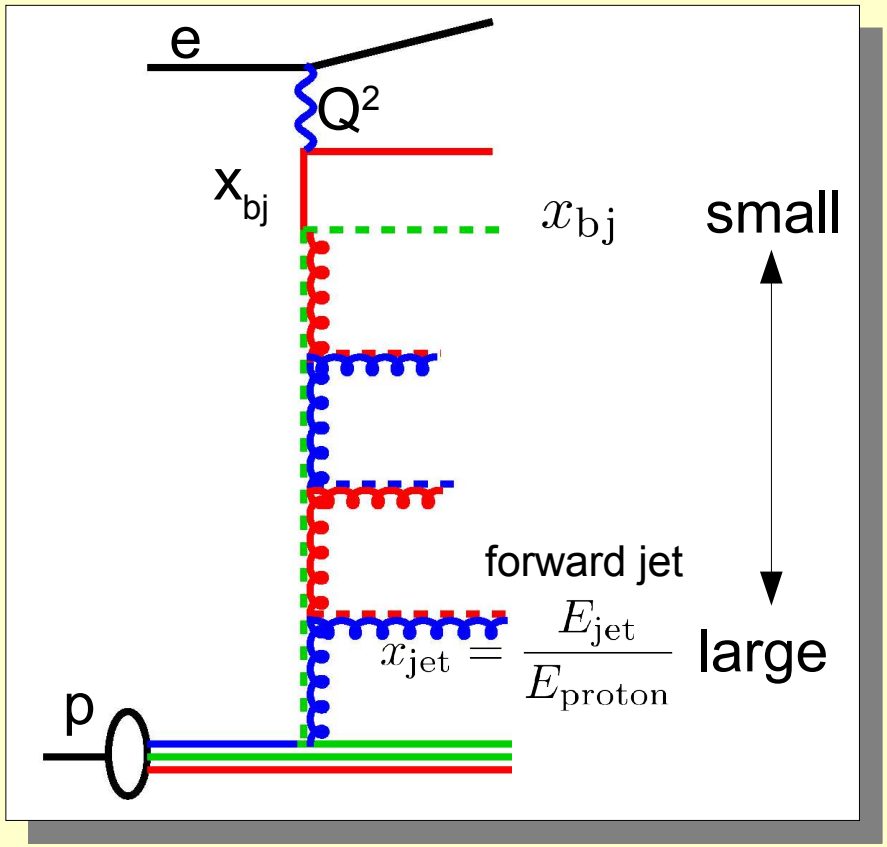
NLOJET (NLO,DGLAP)
- offers also 3-jet phasespace,
- enriches low $x_\gamma$ without resolved photon

DGLAP ok
Resolved photon<->higher orders



# Forward Jet Cross Sections

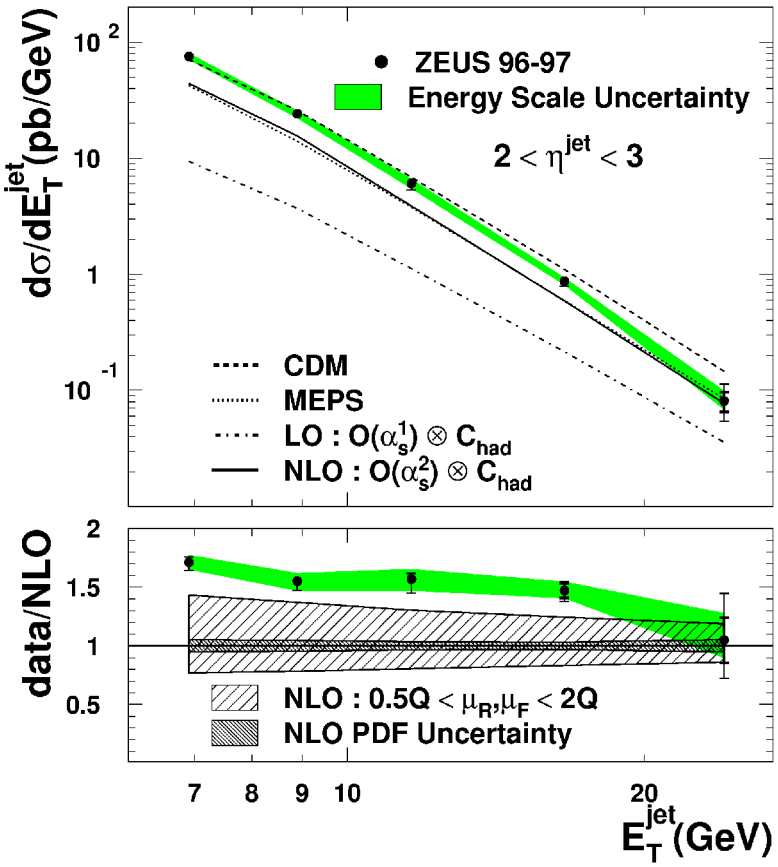
Parton dynamics beyond DGLAP?

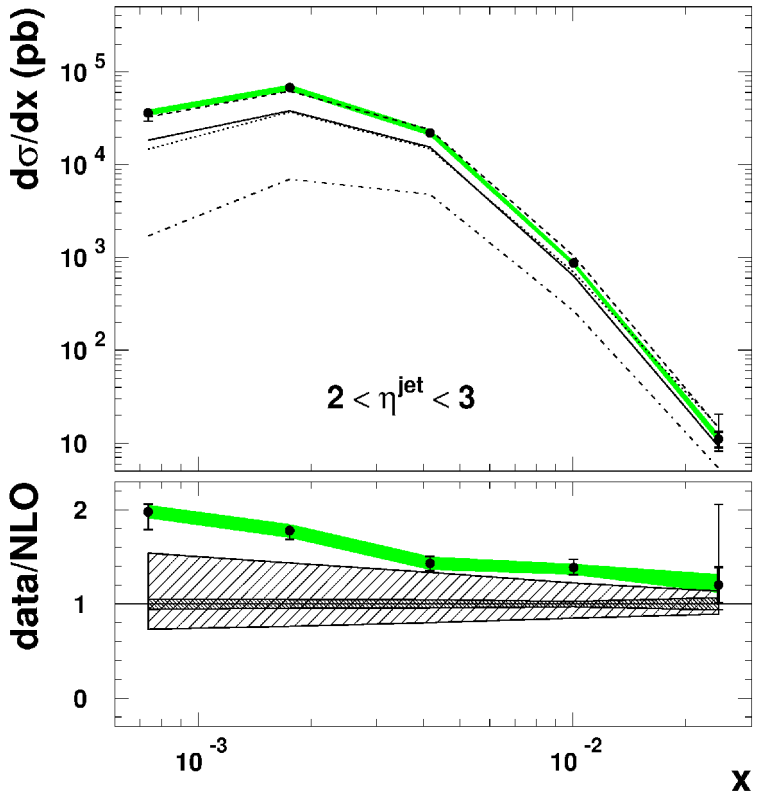



Enrich phasespace for x evolution (BFKL)
$x_{jet} >> x_{bj}$ , forward jet

Suppress phasespace for $Q^2$ evolution (DGLAP)
$p_t^2 \sim Q^2$

# Forward Jet Cross Sections




MEPS: LEPTO(LO+PS,DGLAP)
undershoots the data

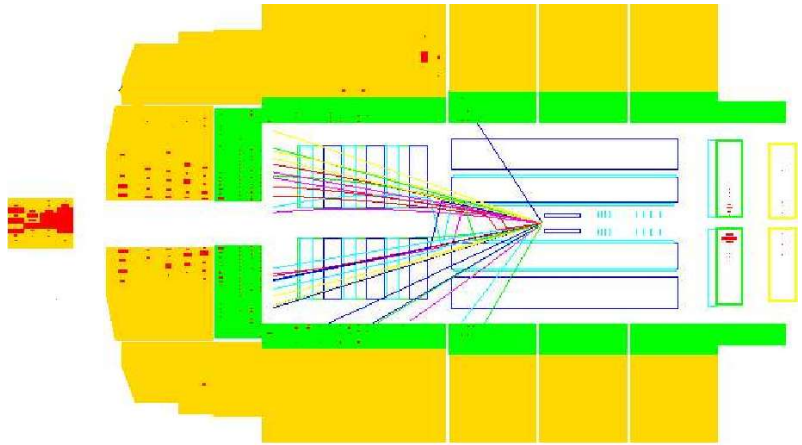
CDM: ARIADNE(LO+PS,BFKL like)
describes forward jets well

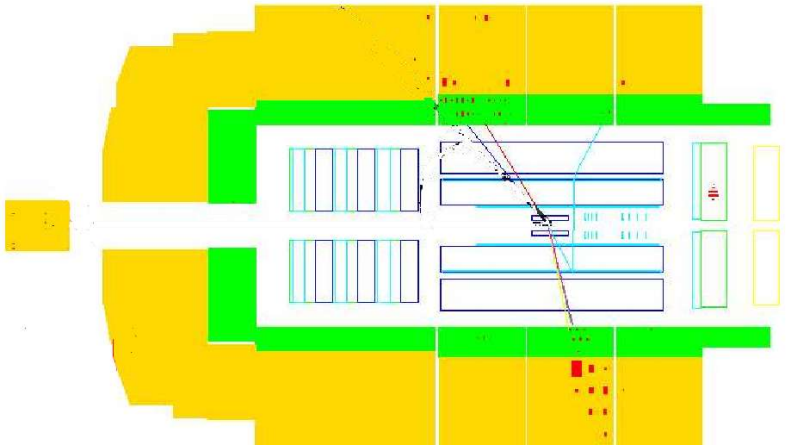
NLO: DISENT(DGLAP) + had.corr.
undershoots the data

NLO corrections and uncertainty large!
need higher orders

# Diffractive 2-Jet Cross Sections in DIS and γp

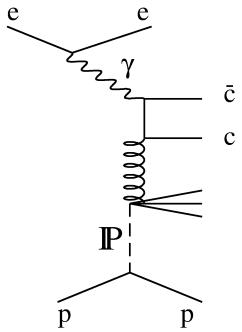
Diffractive: colorless exchange with proton,
no forward activity



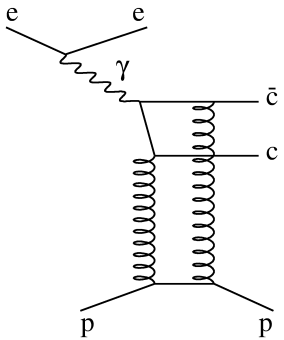


## Models

Regge picture




QCD: gluon dipole

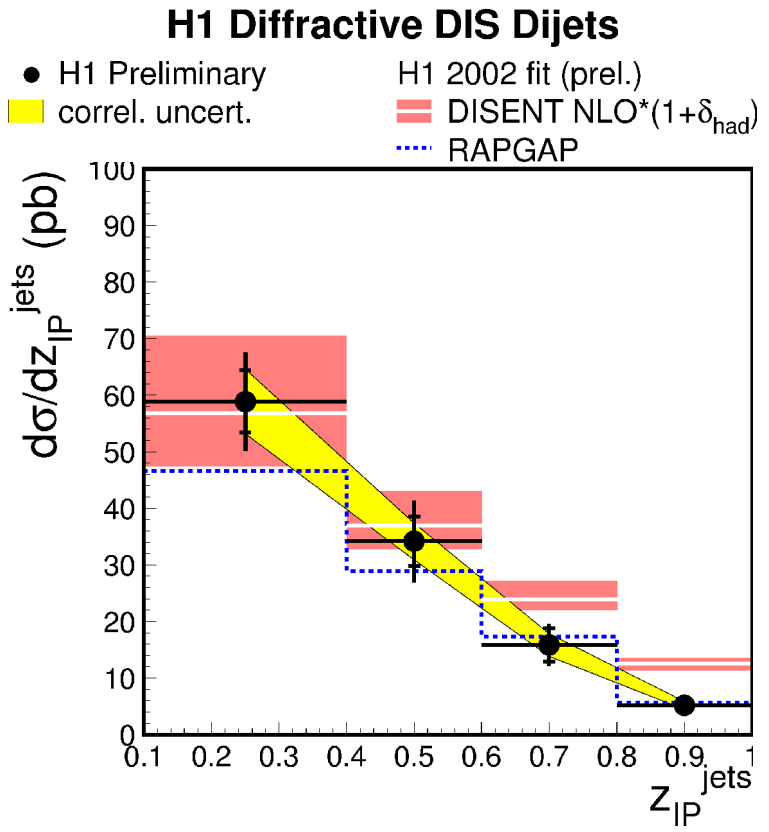



Does QCD factorisation hold?

➢Use diffractive PDFs from inclusive for jet cross sections

Important application: diffractive Higgs at LHC

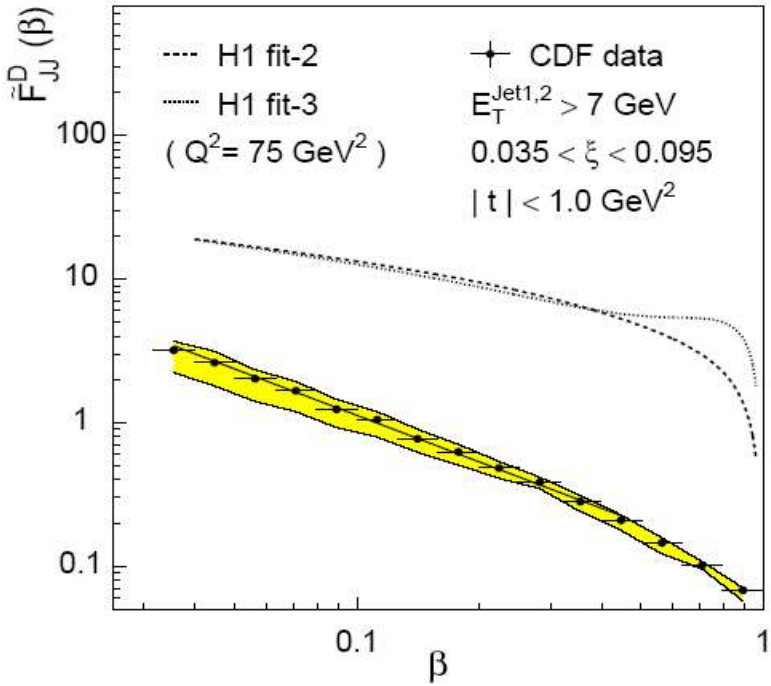
# Diffractive 2-Jet Cross Sections in DIS




Use diffractive PDF H1 2002 (inclusive data) for prediction of 2-jets

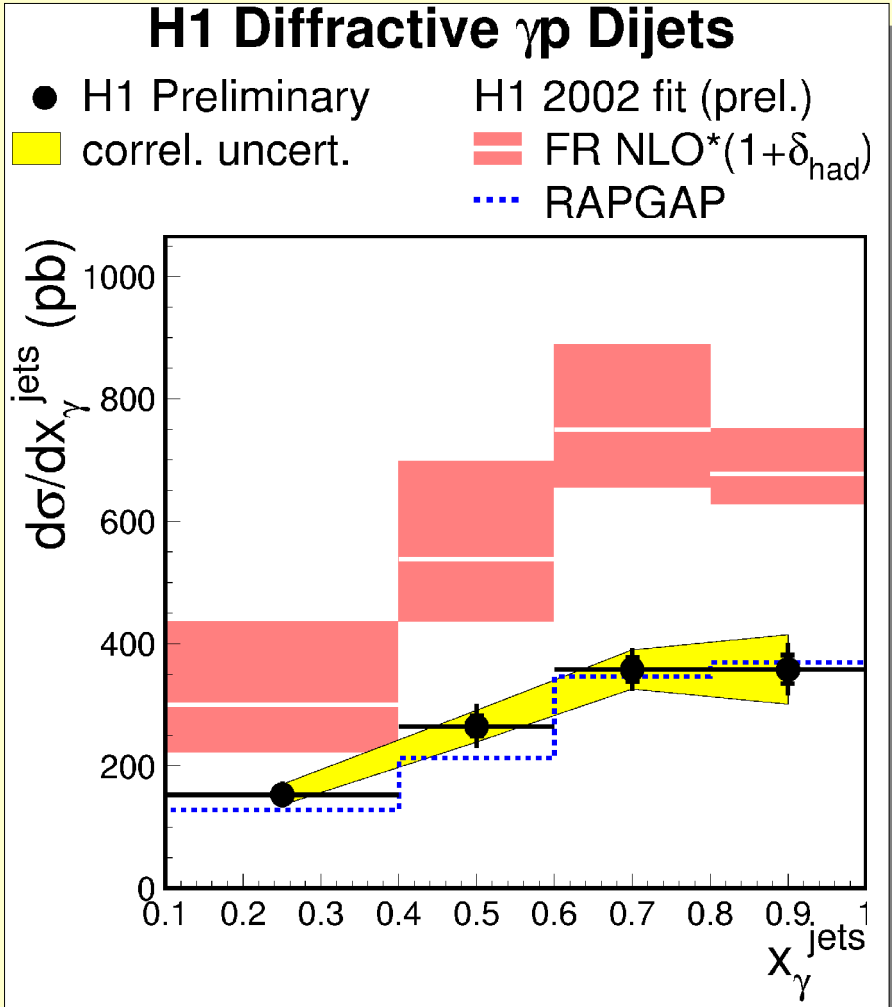
➢factorisation holds in DIS!

But not able to predict diffractive 2-jets in $p\bar{p}$



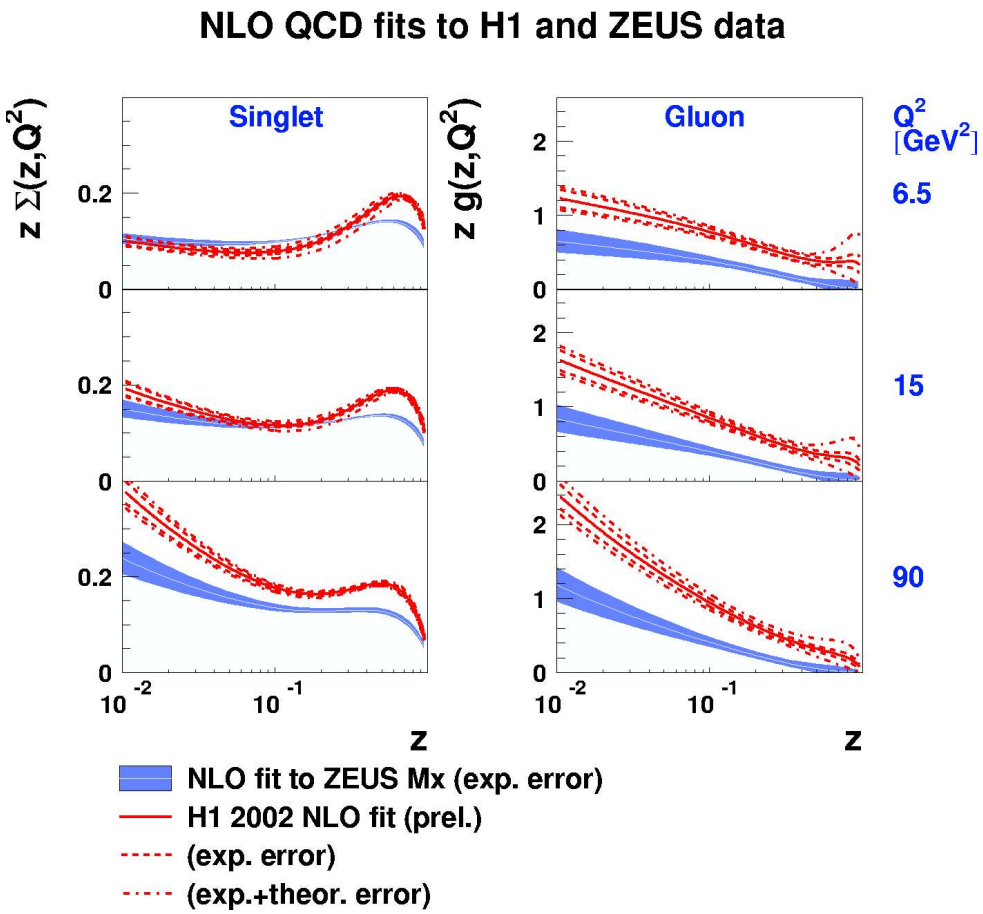

➢Compare to γp at HERA!

# Diffractive 2-Jet Cross Sections in γp




prediction again too high,
factorisation broken?
global suppression?

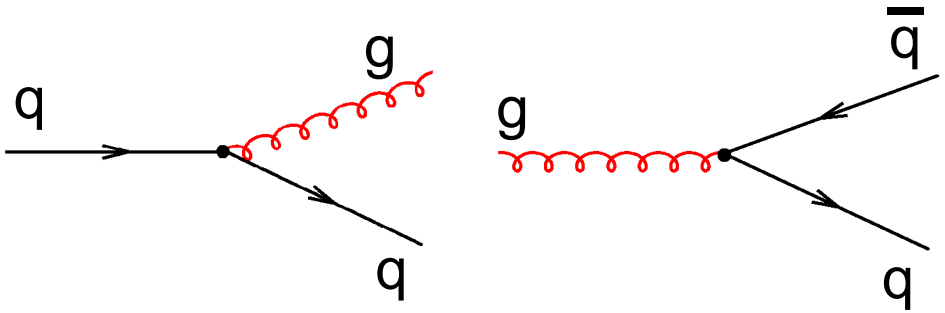
ZEUS fits different from H1, especially gluon!



# Subjet Distributions in DIS

Study internal structure of jets by running jet algo. again with finer resolution

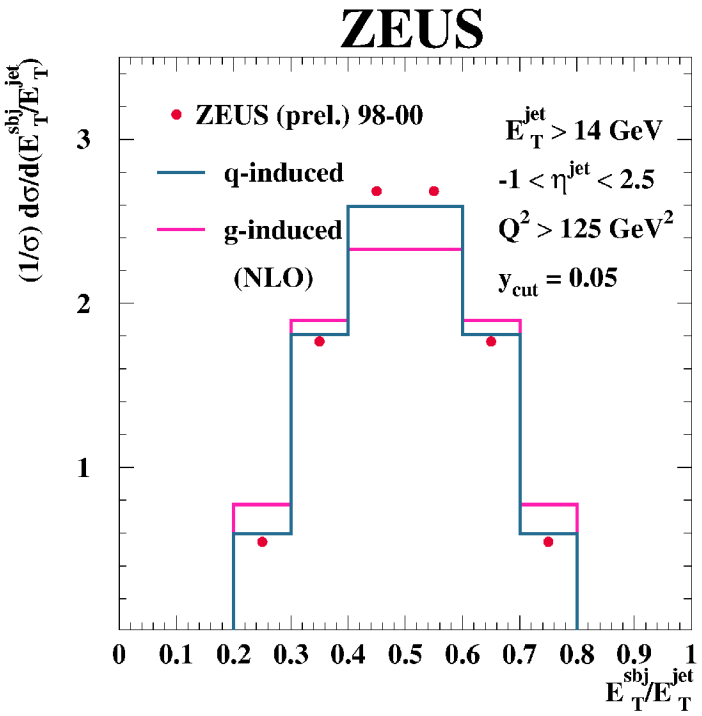
Sensitive to parton radiation




NLO QCD:

82% contribution

18% contribution

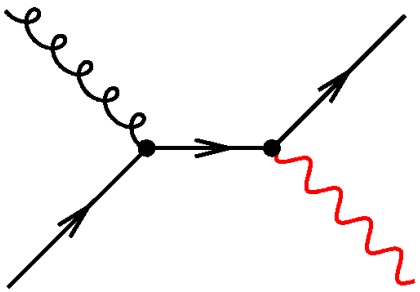



NLO describes data, jets from q->qg dominate

# Prompt Photon Cross Sections in γp

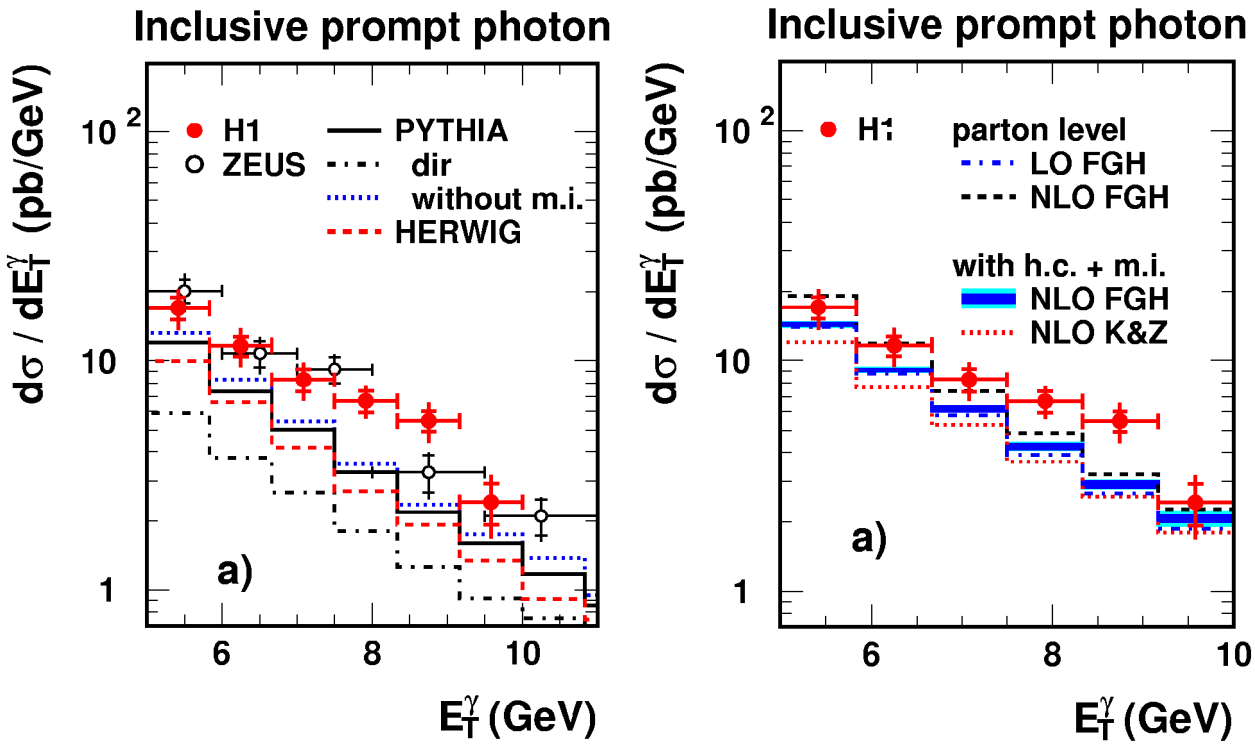
pQCD: deals with partons:
use jet algorithm

Alternative:
detect γ radiated off quarks
"prompt photons"



pros:no hadronisation,
good E measurement

cons: low cross section,
difficult γ identification

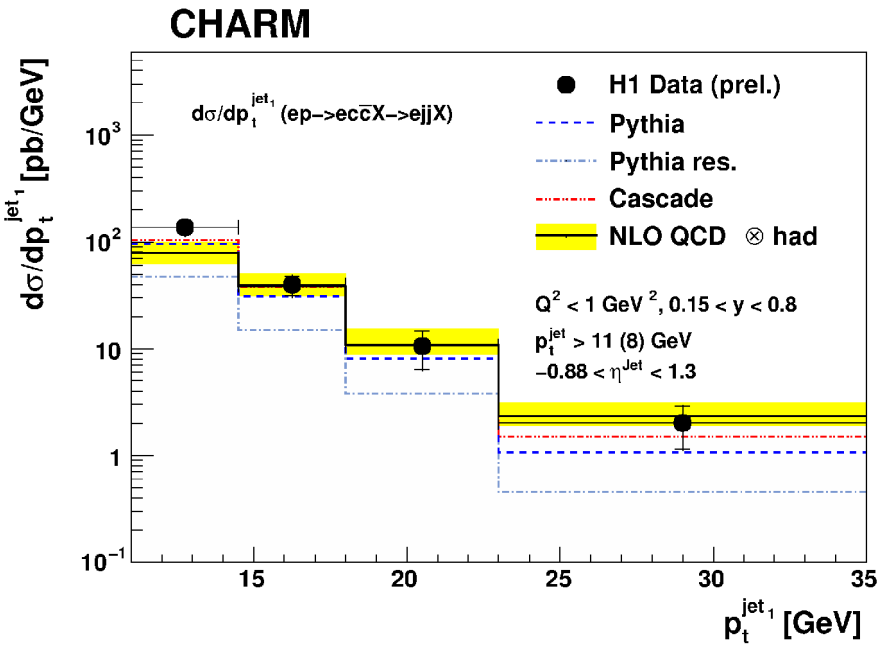


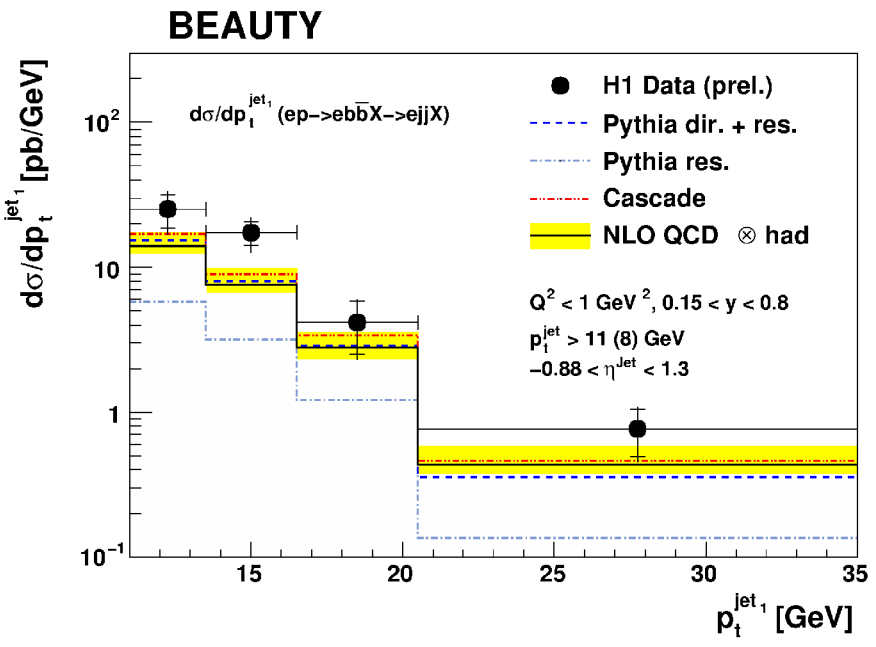

Shape: good description by NLO,
normalistion too low

# Charm and Beauty Jet Cross Sections in γp

Cross section for ep->e'$c\bar{c}$X->e'jjX'
and ep->e'$b\bar{b}$X->e'jjX'

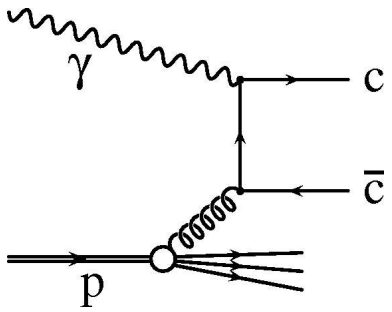
NLO: Frixione et al.
pPDF: CTEQ5D
γPDF: GRV-G HO
hadr. corrections




PYTHIA (LO+PS, direct + resolved) and FNMR(NLO, direct+resolved) agree well
Both describe charm by shape and normalisation, but undershoot beauty

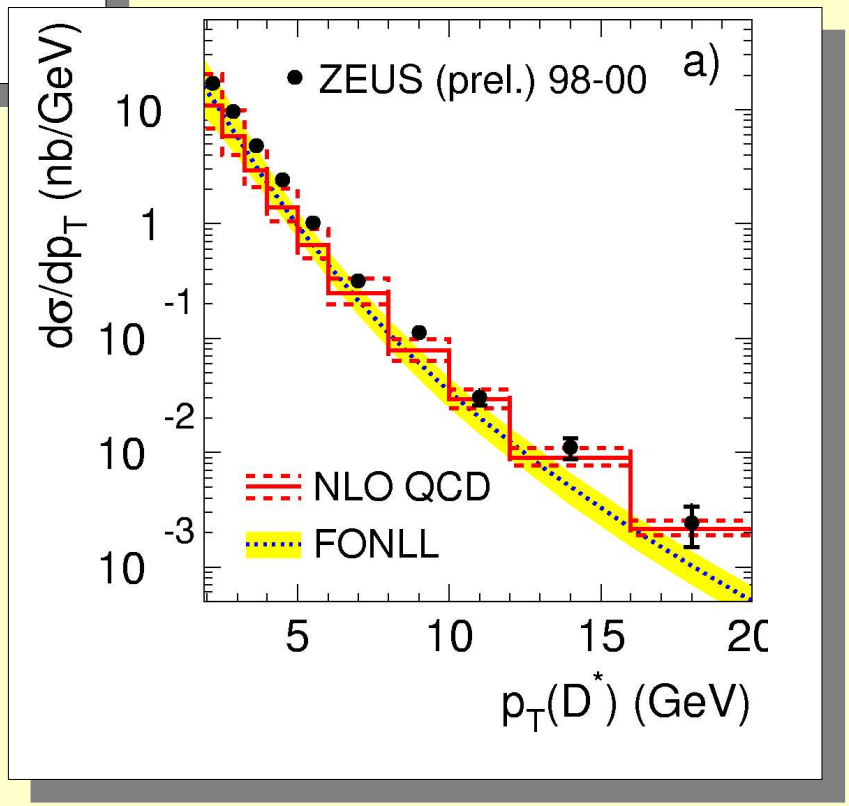
# D* Cross Sections in γp




Identify charmed events by reconstructing D* mesons through $D^{*+} \to D^0 \pi_s^+$ with $D^0 \to K^- \pi^+$

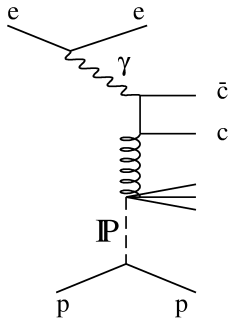
NLO QCD: Frixione et al.
FONLL: Cacciari et al.
pPDF: CTEQ5M1
γPDF: AFG
charm fragmentation: Peterson param.

➢Calculations describe shape, norm. a bit low

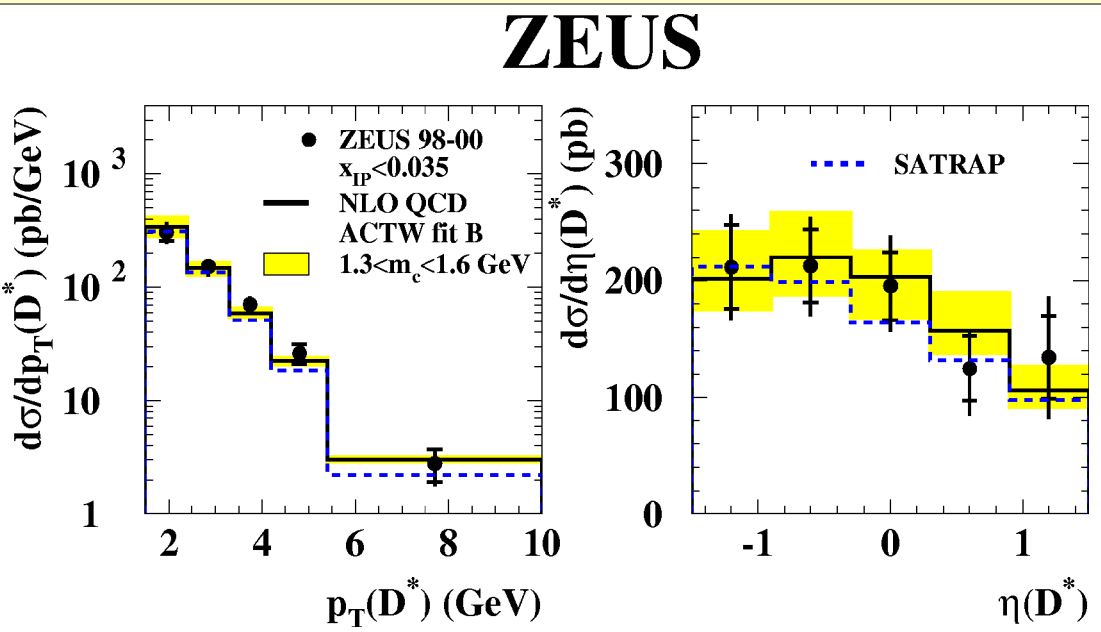


# Diffractive D* Cross Sections in DIS

Test of factorisation in diffractive DIS for heavy flavour production




NLO QCD (pomeron)
pomPDF: ACTW fit B
Peterson fragmentation



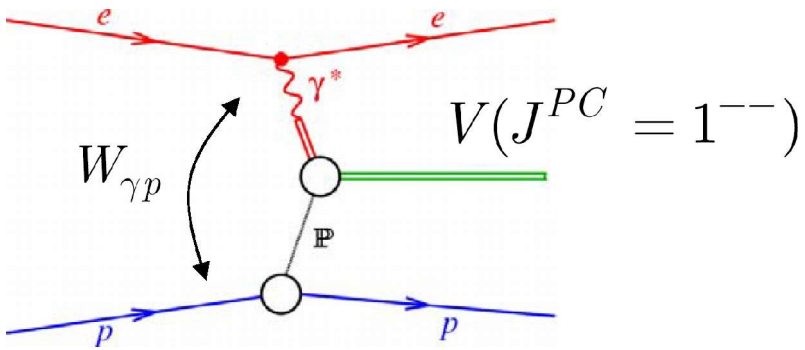

➢predictions describe data well -> validity of QCD factorisation in DIS

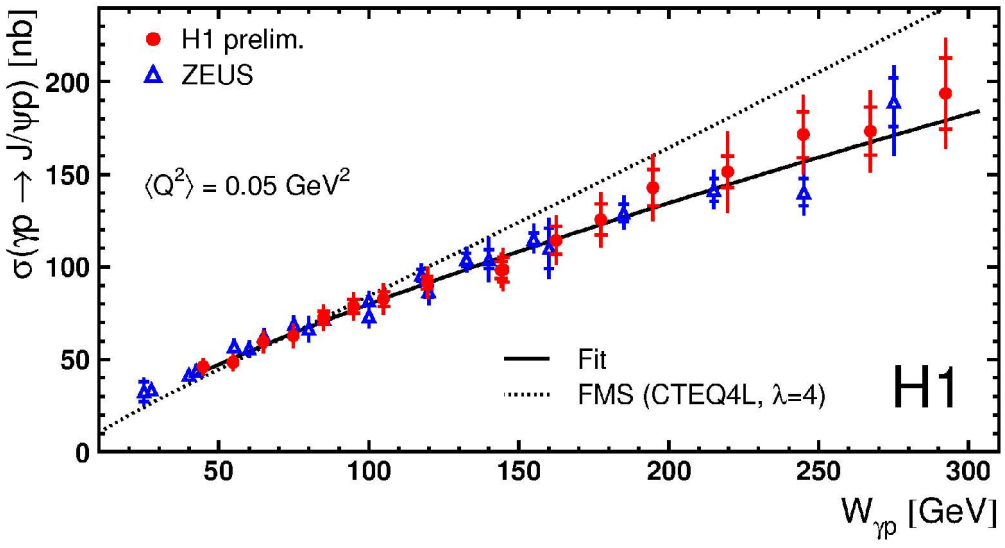
# Elastic J/Ψ Production in γp

Vector meson production in Regge picture

Prediction: $\sigma(\gamma p \to Vp) \propto W^{0.22}$

OK for ρ, ω, φ



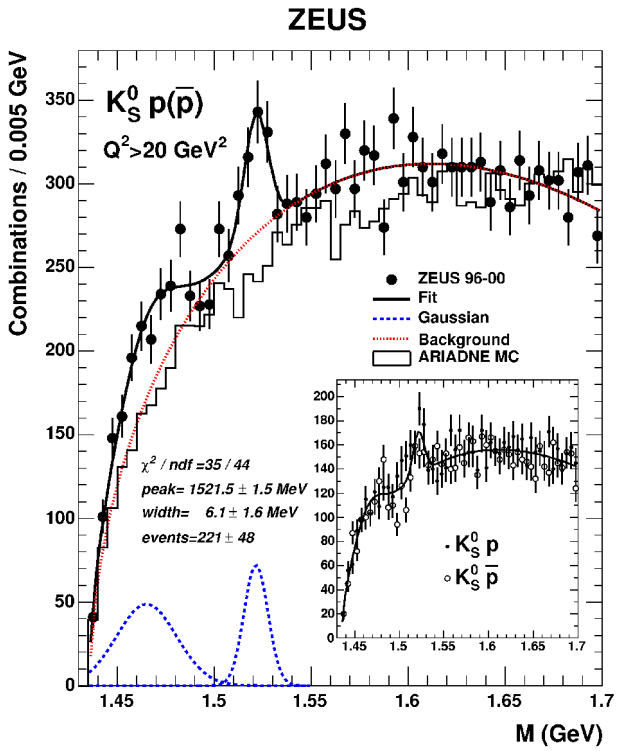




J/Ψ: $\sigma(\gamma p \to J/\psi p) \propto W^{0.8}$ from fit -> break down of pomeron universality

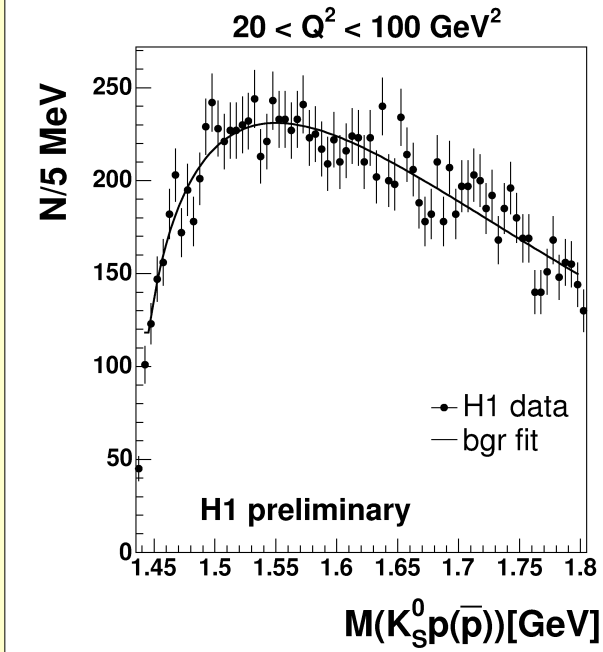
# Search for Strange Pentaquarks in DIS

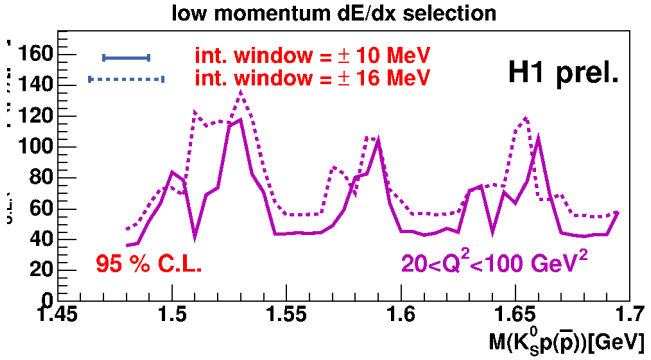
Many observations and non-obervations of $\theta^+$ ($uudd\bar{s}$)
Look for $\theta^+ \rightarrow K^0_s p$, can be well reconstructed, $K^0_s \rightarrow \pi^+\pi^-$ secondary vertex, proton dE/dx

ZEUS: 4.6σ signal near 1522MeV
Fit double gaussian+ threshold bgr.
DIS $20\text{GeV}^2<Q^2$, $0.01<y<0.95$
$\sigma(\theta^+)\sim 120$pb




H1: no signal
DIS $20\text{GeV}^2<Q^2$, $0.1<y<0.6$
Upper limit does not contradict ZEUS observation




➢Need more data

Charmed pentaquarks: talk by Yehuda Eisenberg

# Summary

- Hadronic final states at HERA are a rich field with many high precision measurements available
- Ideal testing ground for many properties of QCD
- Perturbative QCD(+corrections) gives precise description for large x, large $Q^2$
- low x, low $Q^2$ more difficult, higher order calculations desirable
- Diffraction still a difficult topic
- More data from HERA II will improve many analyses which are yet statistically limited (e.g. high $E_t$ jets, beauty)