

# Diffraction PDF determination from HERA incl. and jet data at NNLO

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on behalf of the H1 Collaboration

*Torino*

**DIS 2019, April 9**

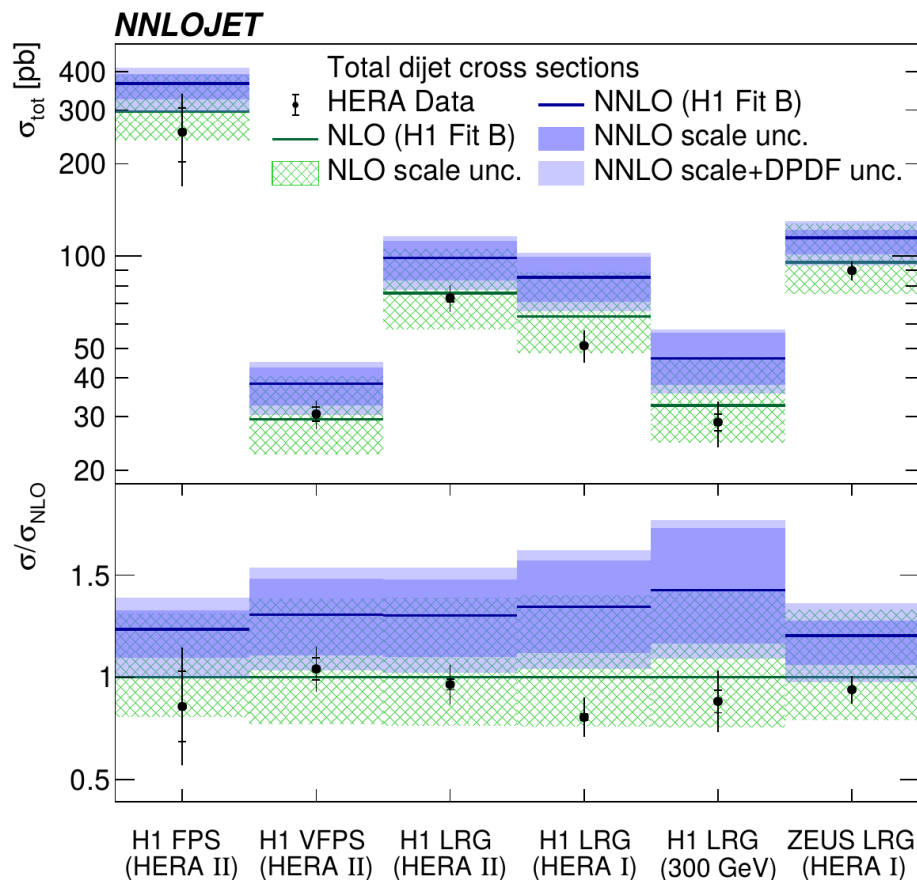


# Why new DPDFs?



# Motivation 1: Progress in theory

- Compared to 2006 or 2007 the NNLO predictions are currently available for both, the inclusive production and jet production
- Large NNLO/NLO k-factors observed for dijet production



The NNLO prediction based on H1 Fit2006B NLO DPDF overestimates the data **by ~30%** With much lower scale unc. for NNLO

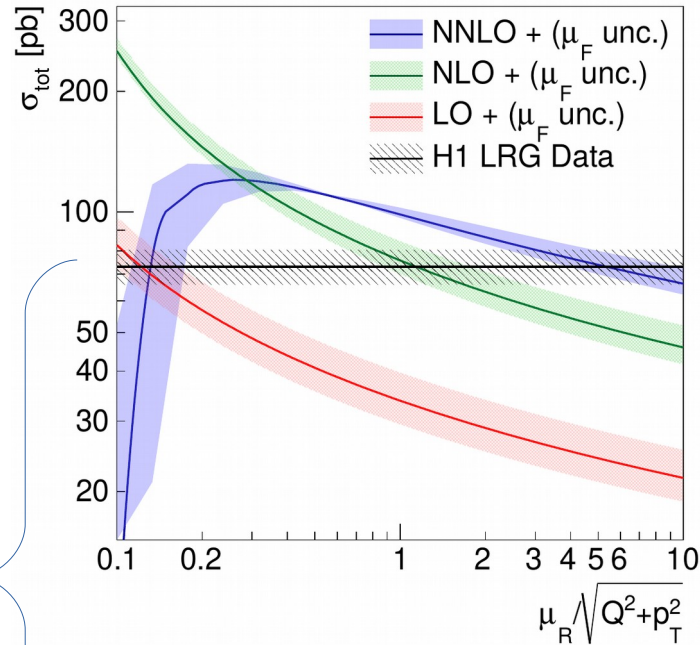
Eur.Phys.J. C78 (2018) no.7, 538  
[arXiv:1804.05663]

**Are inclusive and jet data compatible at NNLO?**

# Scale dependence of dijet cross section

Jets in DDIS ( $\sqrt{s} = 319$  GeV)

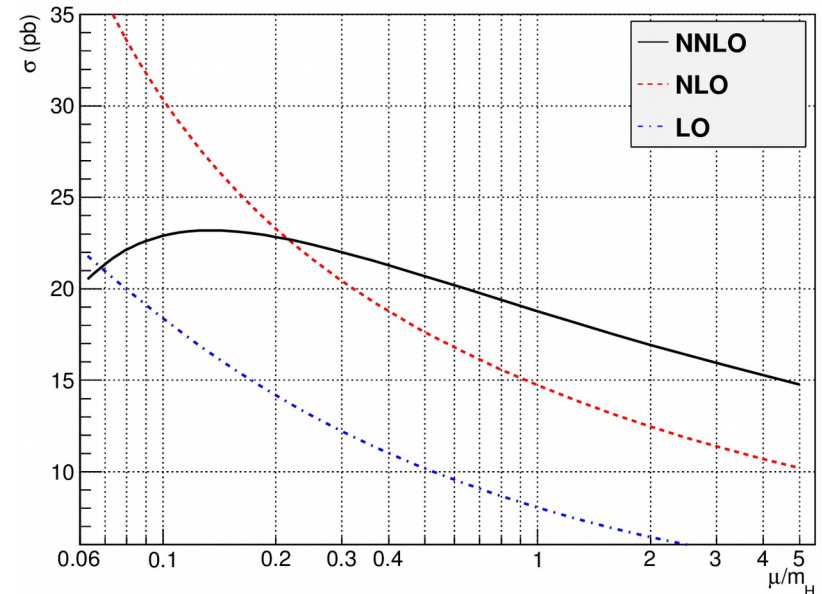
**NNLOJET**



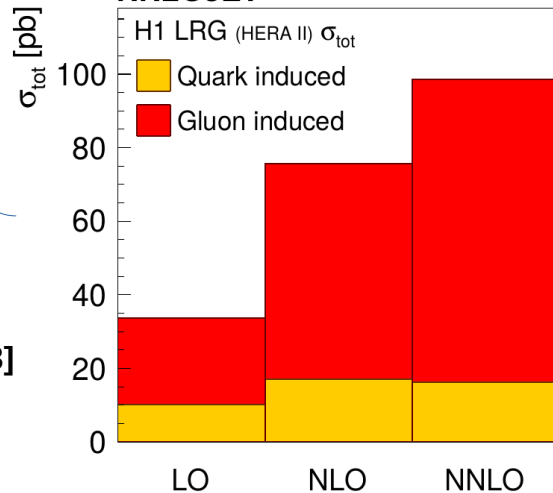
Based on  
**H1 2006B**  
DPDF

Higgs production in pp ( $\sqrt{s} = 8$  TeV)

JHEP 1204 (2012) 004



**NNLOJET**



Eur.Phys.J. C78  
(2018) no.7, 538  
[arXiv:1804.05663]

- The gluon-DPDF induced cross section rises gradually with order
- The quark-Induced cross section stagnates at NLO
- At NNLO 84% of the cross section is from gluon DPDF

# Motivation 2:

## Progress in data

- Compared to last diffractive fits from 2006 or 2007 the HERA II data of much higher luminosity available

### Inclusive DDIS data:

Data Set	$Q^2$ range (GeV <sup>2</sup> )	Proton Energy $E_p$ (GeV)	Luminosity (pb <sup>-1</sup> )
New data samples			
1999 MB	$3 < Q^2 < 25$	920	3.5
1999-2000	$10 < Q^2 < 105$	920	34.3
2004-2007	$10 < Q^2 < 105$	920	336.6
Previously published data samples			
1997 MB	$3 < Q^2 < 13.5$	820	2.0
1997	$13.5 < Q^2 < 105$	820	10.6
1999-2000	$133 < Q^2 < 1600$	920	61.6

*~40 times higher luminosity*

**Eur.Phys.J. C72 (2012) 2074**  
**[arXiv:1203.4495]**

**+ data at lower energies**  
**225, 252 GeV**

### The jet data:

<b>New data sample</b>		
2005-2007	920 + 27.6	290 pb <sup>-1</sup>
<b>Previously published</b>		
1999-2000	920 + 27.5	51.5 pb <sup>-1</sup>

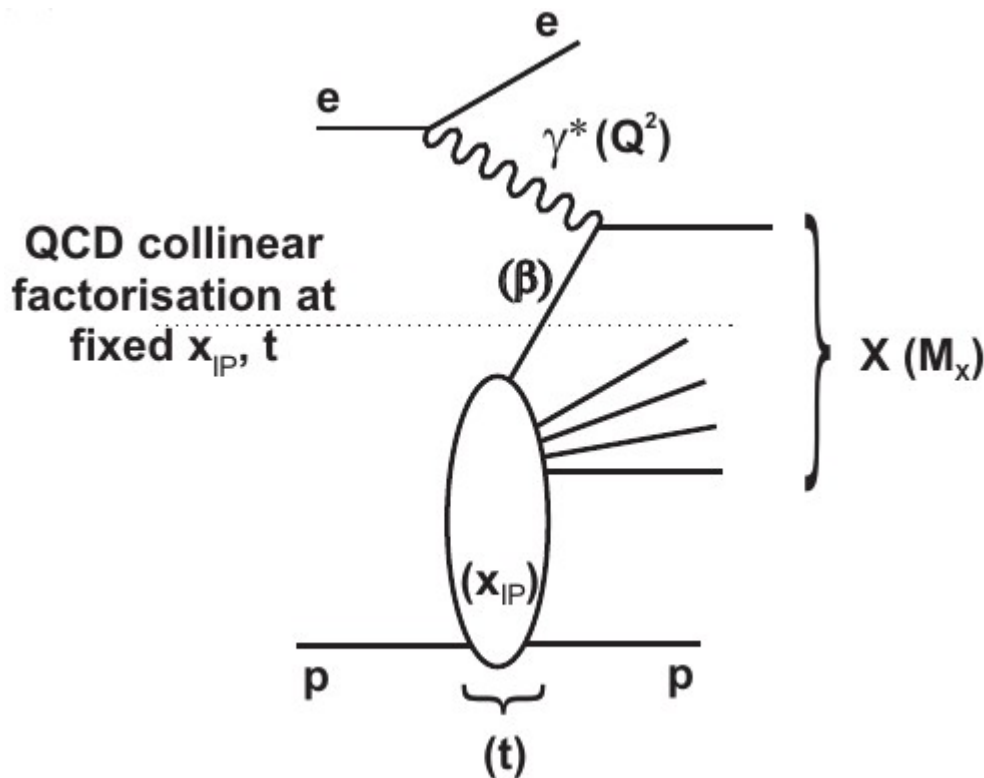
*~6 times higher luminosity*

**JHEP 1503 (2015) 092**  
**[arXiv:1412.0928]:**

**With proper treatment of correlations between bins** <sub>5</sub>

# Diffractive Production in ep

In diffractive events the beam proton stays intact or dissociates into low mass hadronic system Y



At HERA about 10% of low- $x$  events are diffractive

**DIS variables:**

$$Q^2 = -(k - k')^2 \quad y = \frac{p \cdot q}{p \cdot k}$$

**Diffractive variables:**

$$x_{IP} = 1 - \frac{E'_p}{E_p} \quad t = (p - p')^2$$

$$\text{Mass: } M_X^2 = Q^2 \left( \frac{1}{\beta} - 1 \right)$$

At LO: The momentum fraction entering the hard subprocess with respect to the diffractive exchange

$$\beta = \frac{x_{Bj}}{x_{IP}} = \frac{Q^2}{syx_{IP}}$$



# Collinear QCD factorization theorem in hard diffraction

- For diffractive events with a **hard scale** (e.g  $Q^2$  or jets  $p_T$ )
- Factorization of the diffractive cross section into **process independent DPDFs** and **partonic cross sections**

$$d\sigma(ep \rightarrow epX) = \sum_i f_i^D(x, Q^2, x_{IP}, t) \otimes d\sigma^{ie}(x, Q^2)$$

- For diffractive processes (including dijets) with high enough  $Q^2$  factorization proven by Collins within perturbative QCD, for low  $Q^2$  factorization breaking suggested

## Factorization of Hard Processes in QCD

John C. Collins (IIT, Chicago & SUNY, Stony Brook), Davison E. Soper (Oregon U.), George F. Sterman (SUNY, Stony Brook). May 30, 1989. 91 pp.  
Published in *Adv.Ser.Direct.High Energy Phys.* 5 (1989) 1-91  
ITP-SB-89-31

DOI: [10.1142/9789814503266\\_0001](https://doi.org/10.1142/9789814503266_0001)

e-Print: [hep-ph/0409313](https://arxiv.org/abs/hep-ph/0409313) | [PDF](#)

[References](#) | [BibTeX](#) | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [EndNote](#)  
[ADS Abstract Service](#)

[Detailed record](#) - [Cited by 812 records](#) 500+

## Proof of factorization for diffractive hard scattering

John C. Collins (Penn State U.). Sep 1997. 12 pp.  
Published in *Phys.Rev. D57 (1998) 3051-3056*, Erratum: *Phys.Rev. D61 (2000) 019902*

PSU-TH-189

DOI: [10.1103/PhysRevD.57.3051](https://doi.org/10.1103/PhysRevD.57.3051), [10.1103/PhysRevD.61.019902](https://doi.org/10.1103/PhysRevD.61.019902)

e-Print: [hep-ph/9709499](https://arxiv.org/abs/hep-ph/9709499) | [PDF](#)

[References](#) | [BibTeX](#) | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [EndNote](#)  
[ADS Abstract Service](#); [OSTI.gov Server](#)

[Detailed record](#) - [Cited by 404 records](#) 250+

# NLO DPDFs

- DPDF sets differ mainly in gluon component which is weakly constrained from inclusive diffractive data
- For gluon dominated diffractive dijet production we have sizable DPDF uncertainty
- DPDFs obey standard DGLAP evolution equation

## Fits of inclusive data

H1 2006 Fit A  
**H1 2006 Fit B**  
 MRW DPDF  
 GKG18

## Combined inclusive + dijets data fits

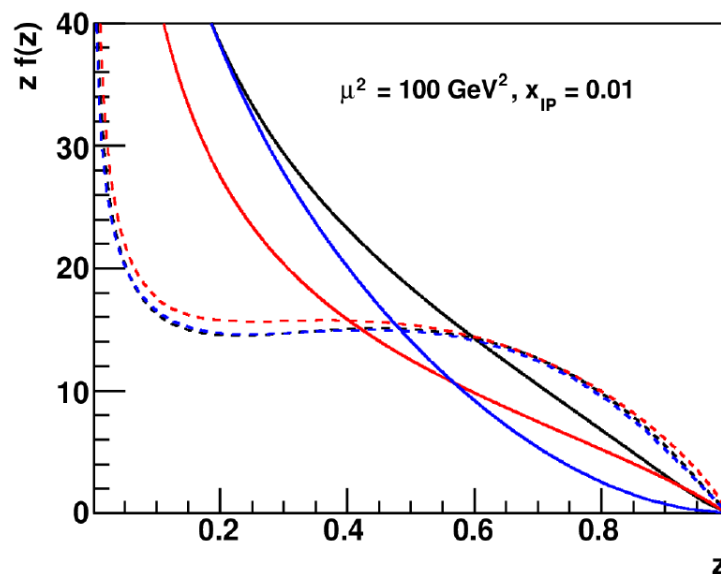
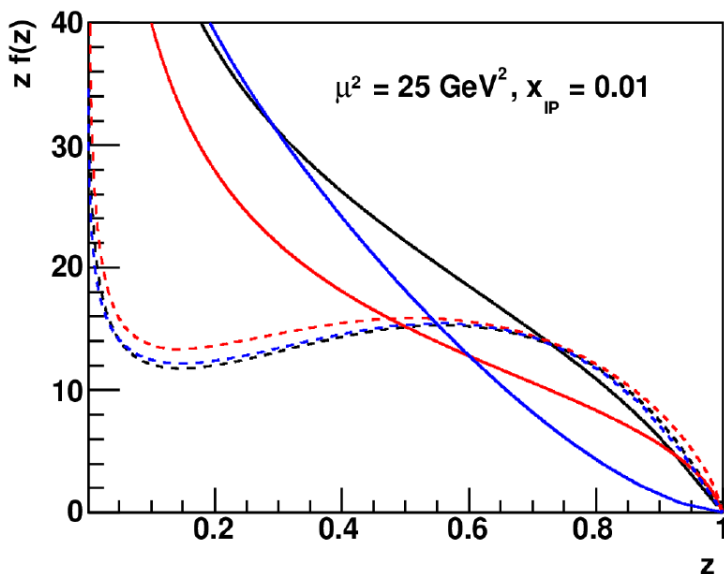
H1 2007 Fit Jets  
 ZEUS 2009 Fit SJ

### Quark Singlet Densities

- H1 Fit B -  $z \Sigma(z)$
- H1 Fit Jets -  $z \Sigma(z)$
- ZEUS SJ -  $z \Sigma(z) \times 1.2$

### Gluon Densities

- H1 Fit B -  $z G(z)$
- H1 Fit Jets -  $z G(z)$
- ZEUS SJ -  $z G(z) \times 1.2$



70% of diffractive exchange momentum carried by gluons

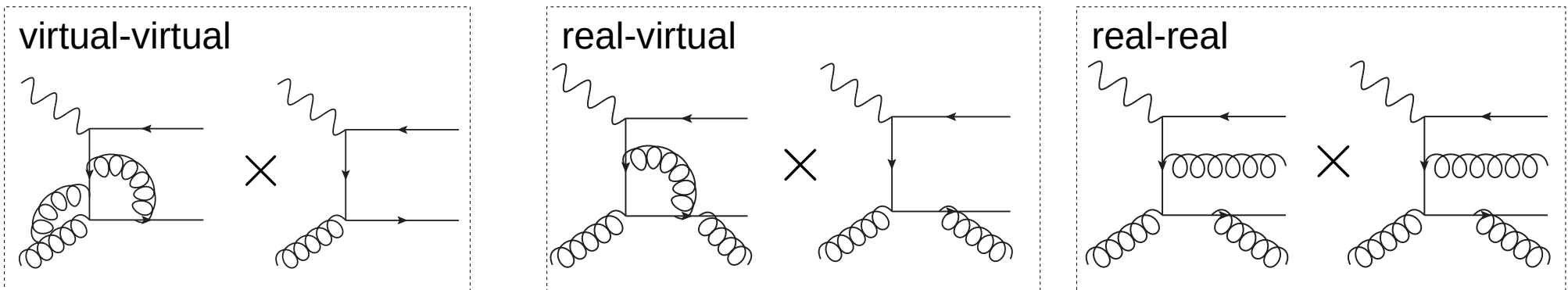


# Overview of the new fit

## Theory

- NNLO accuracy for both inclusive and jet production
- Using FONLL-C GM-VFNS (by APFEL) for inclusive production,  
→ default QCD scale for inc. production:  $\mu_R^2 = \mu_F^2 = Q^2$
- Using NNLOJET (massless quarks) + fastNLO for dijets,  
→ default QCD scale for dijets:  $\mu_R^2 = \mu_F^2 = Q^2 + \langle p_T^{*jets} \rangle^2$
- Scale unc. by simultaneous (for all processes)  
 $\mu_F = \mu_R \times 2, \times 0.5$  variation

Examples of  $\alpha_S^3$  diagrams contributing to dijet production



# DPDF Parametrization

- Regge factorisation ansatz

$$f_i^D(z, \mu^2, x_{\mathbb{P}}, t) = f_{\mathbb{P}/p}(x_{\mathbb{P}}, t) f_{i/\mathbb{P}}(z, \mu^2) + n_{\mathbb{R}} f_{\mathbb{R}/p}(x_{\mathbb{P}}, t) f_{i/\mathbb{R}}(z, \mu^2)$$

- **Pomeron PDF**  $f_{i/\mathbb{P}}(z, \mu^2)$  times  $z=1$  regulator:  $\exp\left(-\frac{0.01}{1-z}\right)$

	Gluon	Singlet ( $u=d=s=\bar{u}=\bar{d}=\bar{s}$ )
H1 Fit2006A	$A_g (1-z)^{C_g}$	$A_q z^{B_q} (1-z)^{C_q}$
H1 Fit2006B	$A_g$	
H1 Fit2007Jets ZEUS SJ <b>H1 Fit2019 NNLO</b>	$A_g z^{B_g} (1-z)^{C_g}$	

- **Reggeon PDF**  $f_{i/\mathbb{R}}(z, \mu^2)$

→ only few % at  $x_{\mathbb{P}} = 0.03$

→ Fixed to the pion PDF (GRV NLO as default)

→ The overall normalization  $n_{\mathbb{R}}$  taken as free parameter

# Collinear QCD factorization in inclusive DDIS

$$\alpha_{em} \stackrel{\text{def}}{=} \frac{1}{137}$$

- The reduced diffractive cross section:

$$\frac{d^3\sigma^{ep \rightarrow eXY}}{dQ^2 d\beta dx_{\mathbb{P}}} = \frac{4\pi\alpha_{em}^2}{\beta Q^4} \left(1 - y + \frac{y^2}{2}\right) \underbrace{\left(F_2 - \frac{y^2}{1 + (1-y)^2} F_L\right)}_{\sigma_r^{D(3)}(\beta, Q^2, x_{\mathbb{P}})}$$

- Regge factorization ansatz

$$F_{2/L}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) = f_{\mathbb{P}/p}(x_{\mathbb{P}}) F_{2/L}^{\mathbb{P}}(\beta, Q^2) + n_{\mathbb{R}} \underbrace{f_{\mathbb{R}/p}(x_{\mathbb{P}}) F_{2/L}^{\mathbb{R}}(\beta, Q^2)}_{\text{Fixed}}$$

$$F_{2/L}^{\mathbb{P}}(\beta, Q^2) = C_{2/L}^i(\beta/z, Q^2, \mu^2) \otimes f_{i/\mathbb{P}}(z, \mu^2)$$

Up to NNLO

Standard DIS  
coef. functions

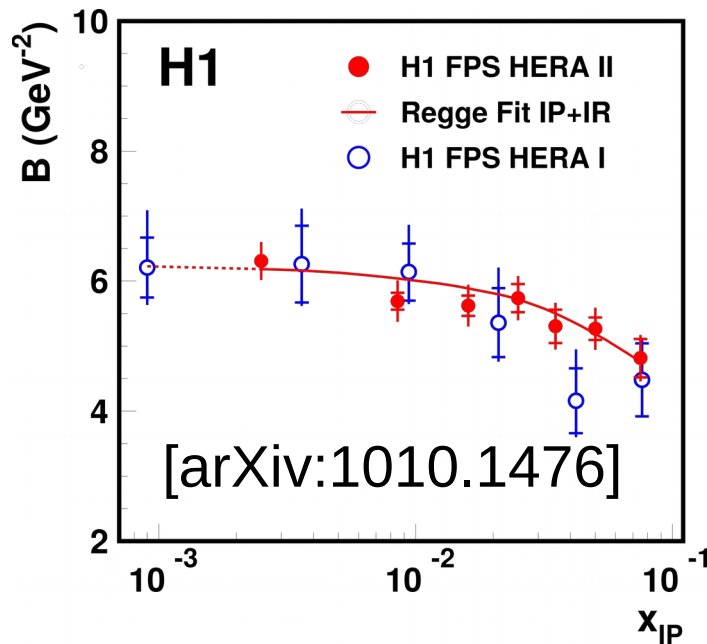
Obeys DGLAP

**Both coef. functions and DGLAP evolution depend on  $\alpha_s$  and  $m_c, m_b$**

# Flux Parametrization

- Param. inspired by Regge theory (Streng and Berger):

$$f_{IP/p}(x_{IP}, t) \propto \left( \frac{1}{x_{IP}} \right)^{2[\alpha_{IP}(0) + \alpha'_{IP}t] - 1} e^{B_{IP}^0 t} \quad \Rightarrow \quad \frac{d\sigma}{dt} \propto e^{-B|t|}$$



B-slope dependence:

$$B = B_{IP}^0 + 2\alpha'_{IP} \left( \log \frac{1}{x_{IP}} \right)$$

$$\alpha'_{IP} = 0.04^{+0.08}_{-0.06} \text{ GeV}^{-2}$$

$$B_{IP}^0 = 5.73^{+0.84}_{-0.93} \text{ GeV}^{-2}$$

Uncertainties anti-correlated

- t-integrated version:

$$f_{IP/p}(x_{IP}) \propto \left( \frac{1}{x_{IP}} \right)^{2\alpha_{IP}(0) - 1} \frac{1}{1 + 2 \frac{\alpha'_{IP}}{B_{IP}^0} \log \frac{1}{x_{IP}}} \doteq \left( \frac{1}{x_{IP}} \right)^{2\alpha_{IP}(0) - 1 - 2 \frac{\alpha'_{IP}}{B_{IP}^0} \log \frac{1}{x_{IP}}}$$

Annotations:   
 -  $2\alpha_{IP}(0) - 1$  is circled in blue with a callout bubble containing  $\sim -1.2$ .   
 -  $2 \frac{\alpha'_{IP}}{B_{IP}^0} \log \frac{1}{x_{IP}}$  is circled in blue with a callout bubble containing  $\sim -0.01$ .   
 - A green speech bubble labeled "Fitted" points to the  $\alpha'_{IP}$  term in the denominator.   
 - An orange speech bubble labeled "Fixed" points to the  $B_{IP}^0$  term in the denominator.

# Parameters & Model Unc.

- Fixed params. mostly identical with H1 2006 & 2007 fits

	Parameter	Value	Source
Pomeron slope	$\alpha'_{\mathbb{P}}$	$0.04^{+0.08}_{-0.06} \text{ GeV}^{-2}$	H1 FPS HII [arXiv:1010.1476]
Pomeron B-slope	$B_{\mathbb{P}}^0$	$5.73^{+0.84}_{-0.93} \text{ GeV}^{-2}$	H1 FPS HII [arXiv:1010.1476]
Reggeon intercept	$\alpha_{\mathbb{R}}(0)$	$0.5 \pm 0.1$	H1 LRG HI [hep-ex/9708016]
Reggeon slope	$\alpha'_{\mathbb{R}}$	$0.3^{+0.6}_{-0.3} \text{ GeV}^{-2}$	H1 FPS HI [hep-ex/0606003]
Reggeon B-slope	$B_{\mathbb{R}}^0$	$1.6^{+0.4}_{-1.6} \text{ GeV}^{-2}$	H1 FPS HI [hep-ex/0606003]
charm mass	$m_c$	$1.4 \pm 0.2 \text{ GeV}$	PDG2004
bottom mass	$m_b$	$4.5 \pm 0.5 \text{ GeV}$	PDG2004
strong coupling	$\alpha_S(M_Z^2)$	$0.118 \pm 0.002$	PDG2004
starting scale of ev.	$\mu_0$	$1.15^{+0.24}_{-0.15} \text{ GeV}$	

- Parameters  $\alpha'_{\mathbb{P}}, B_{\mathbb{P}}$  (  $\alpha'_{\mathbb{P}}, B_{\mathbb{P}}$  ) strongly anti-correlated  
 $\rightarrow$  Varied simultaneously as (up,down) & (down,up)
- The QCD scale varied by a factor of 2  
 (dominant unc. together with  $\mu_0$  variation)
- 8 parameters fitted:** 6 of pomeron PDF +  $\alpha_{\mathbb{P}}(0)$  &  $n_{\mathbb{R}}$

# Fitted data sets

## Data

- Combined H1 HERA-I + HERA-II LRG inc. data [[arXiv:1203.4495](#)]
- H1 LowE HERA-II LRG inc. data  $\sqrt{s} = 225$  GeV,  $\sqrt{s} = 252$  GeV [[arXiv:1107.3420](#)]
- H1 HERA-II dijets LRG data,  $p_T^{\text{jet1}}$  vs  $Q^2$  dist. [[arXiv:1412.0928](#)]

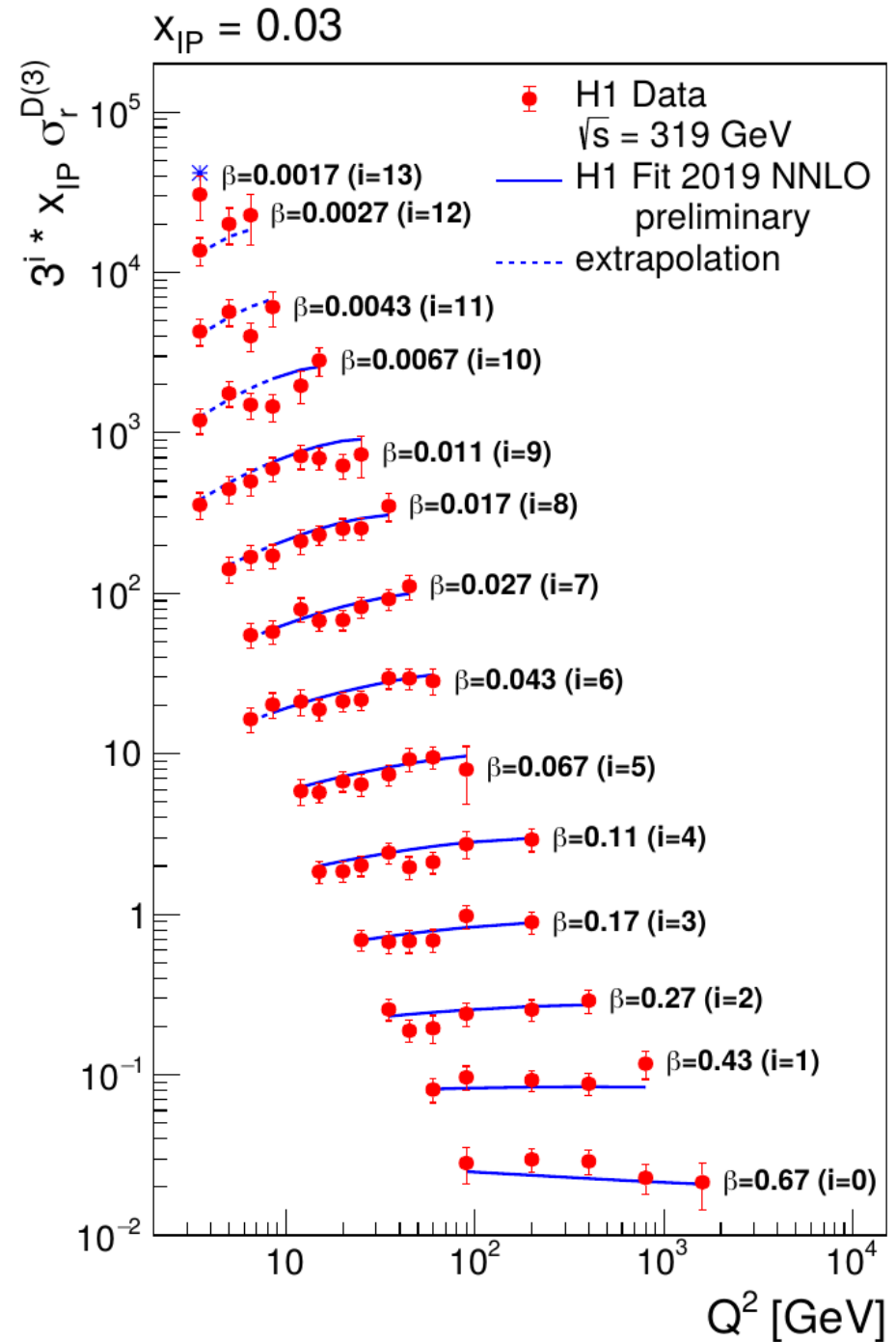
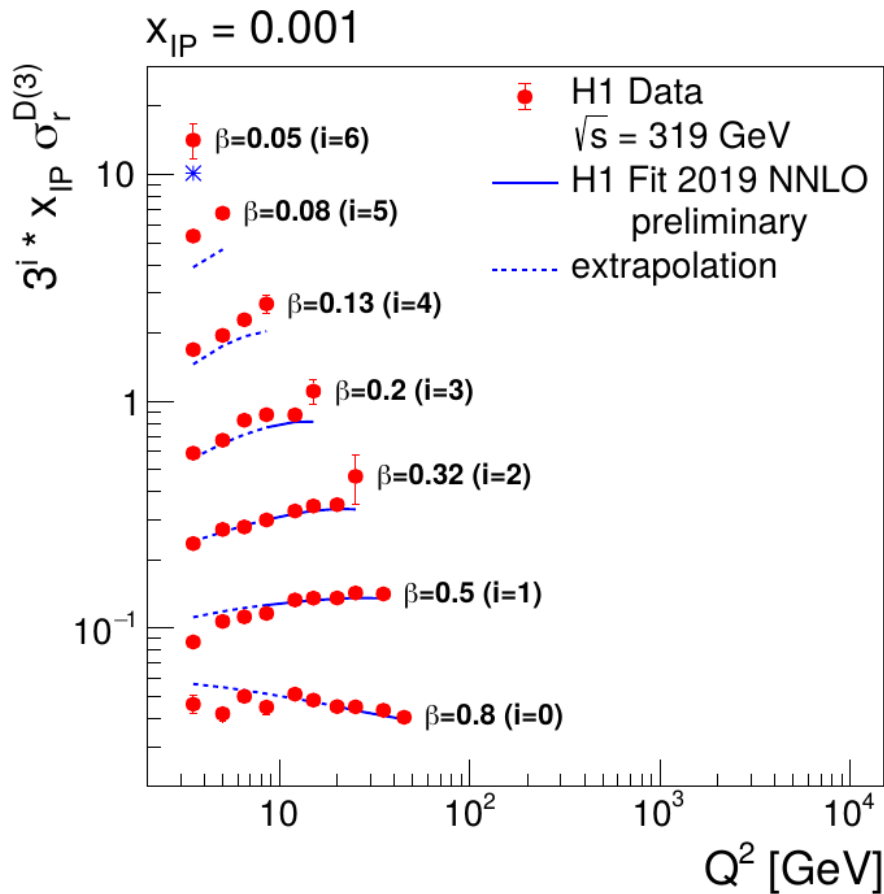
Data Set	Phase-Space	$\sqrt{s}$ [GeV]	Lumi [ $\text{pb}^{-1}$ ]	$\chi^2/N_{\text{pts}}$
H1 LRG HERA-I+II inc. combined	$8.5 < Q^2 < 1600 \text{ GeV}^2$ $0.0003 < x_{\mathcal{P}} < 0.03$	319 + 300	up to 336.6	192/191
H1 LRG HERA-II inc. lowE252	$8.5 < Q^2 < 44 \text{ GeV}^2$	252	5.2	19/12
H1 LRG HERA-II inc. lowE225	$0.0005 < x_{\mathcal{P}} < 0.003$	225	8.5	10/13
H1 LRG HERA-II dijets $p_T^{\text{jet1}}$ vs $Q^2$ distr.	$4 < Q^2 < 100 \text{ GeV}^2$ $p_T^{\text{jet1(2)}} > 5.5(4) \text{ GeV}$ $x_{\mathcal{P}} < 0.03$	319	290	12/15
+ always: $ t  < 1 \text{ GeV}^2, M_Y < 1.6 \text{ GeV}$				235/231 ndf = 223

**Fit gives reasonable  $\chi^2/\text{ndf}$ , both the “total” and partial data set**



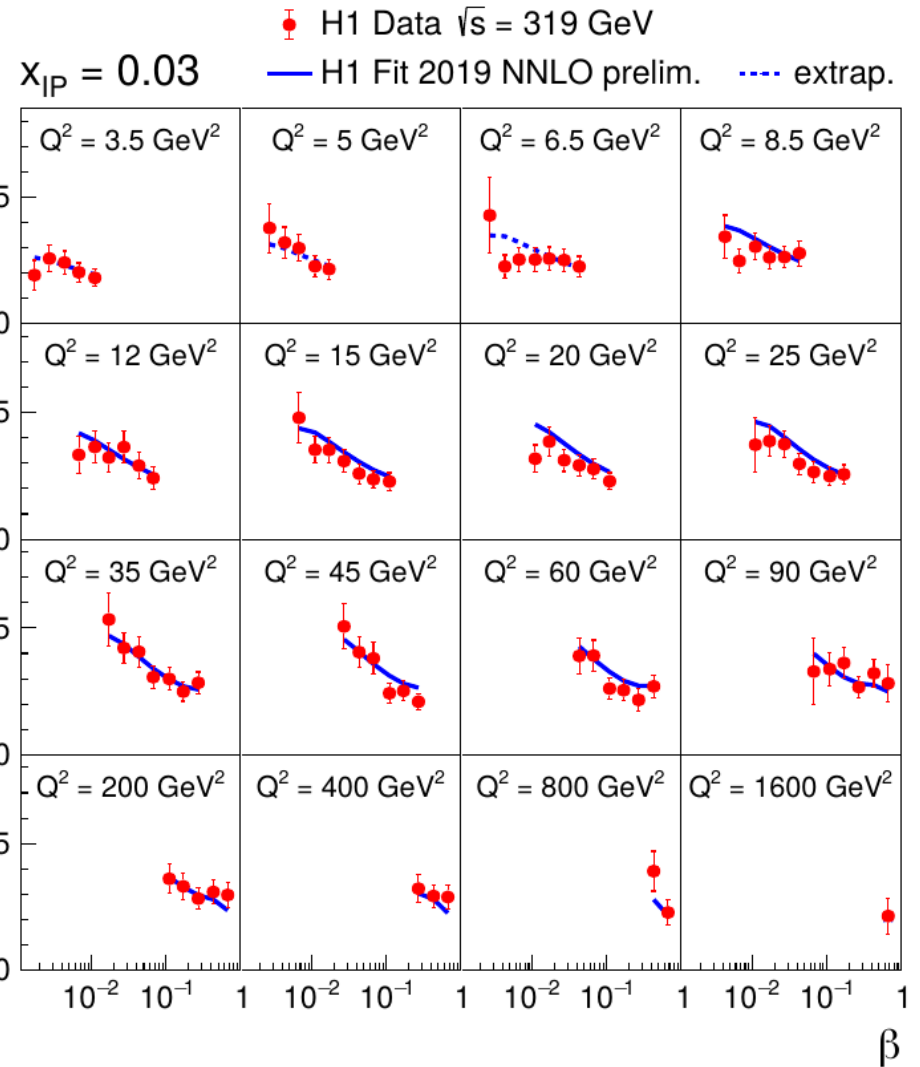
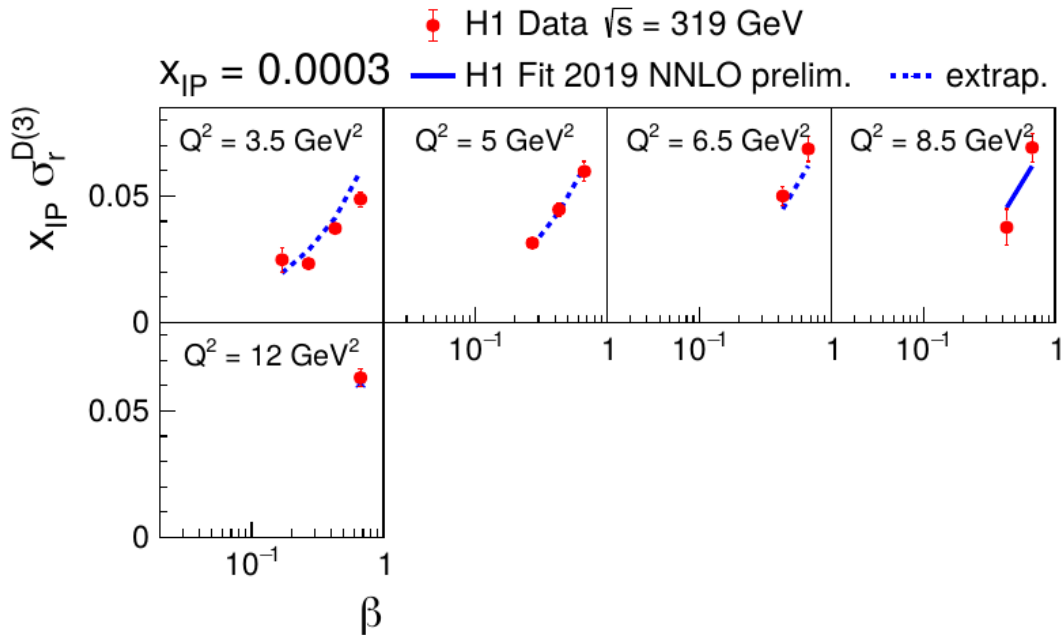
# Fitted data – Inclusive Sample ( $Q^2$ dep.)

- At the nominal HERA energy ( $\sqrt{s}=319\text{GeV}$ ) fitted combined H1 HERA I+HERA-II data  
 $x_{\text{IP}}=0.0003, 0.001, 0.003, 0.01, 0.03$
- Description in “extrapolated” region  $Q^2 < 8.5$  sometimes worse



# Fitted data – Inclusive Sample ( $\beta$ dep.)

- Good description by NNLO QCD predictions over wide range of  $x_{\text{IP}}$  and  $\beta$
- At LO  $\beta$  is the momentum fraction parton entering hard process wrt pomeron (argument of DPDF)

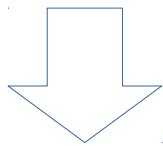


# Fitted data – LowE Inclusive Sample

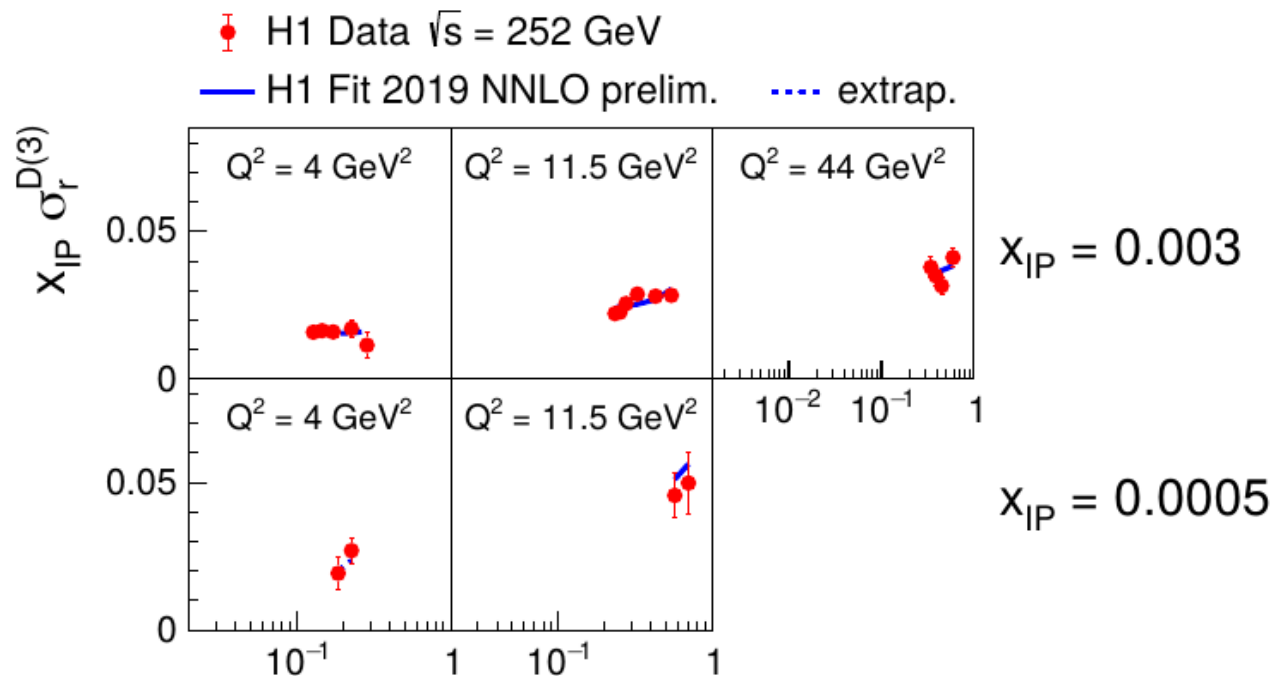
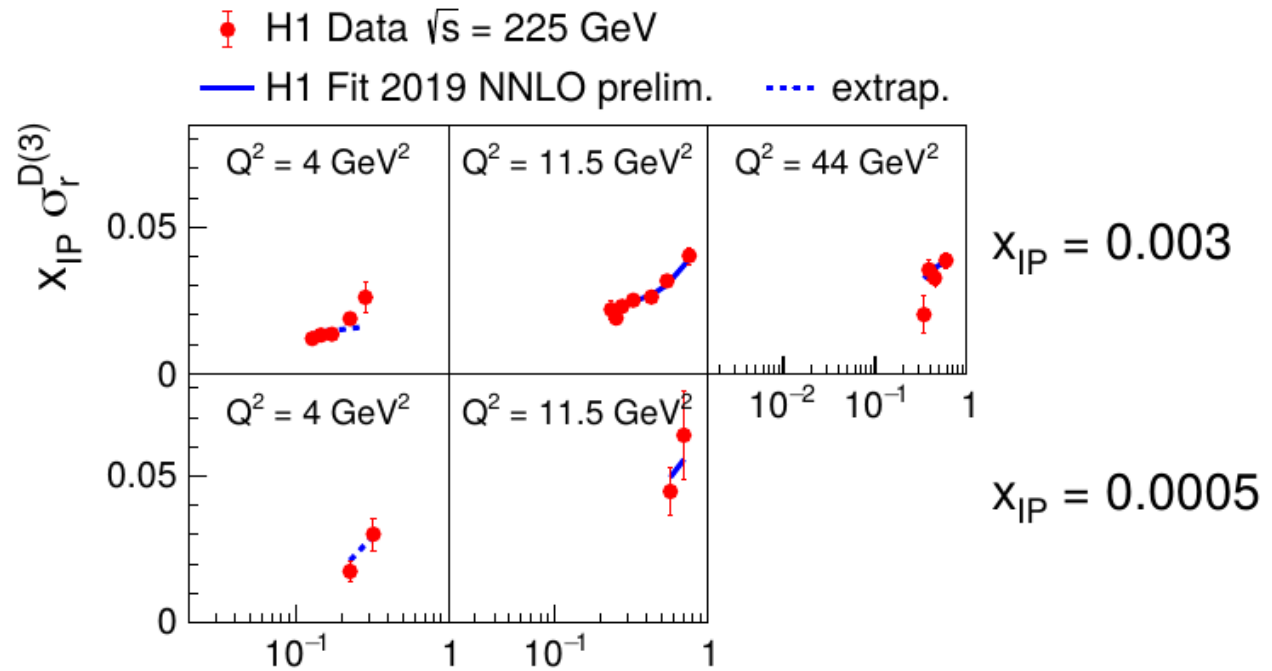
- The  $F_2$  &  $F_L$  beam energy independent
- The reduced cross section predicted to be energy dependent:

$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = F_2 - \frac{y^2}{1 + (1 - y)^2} F_L$$

since:  $y = \frac{Q^2}{\beta x_{IP} s}$

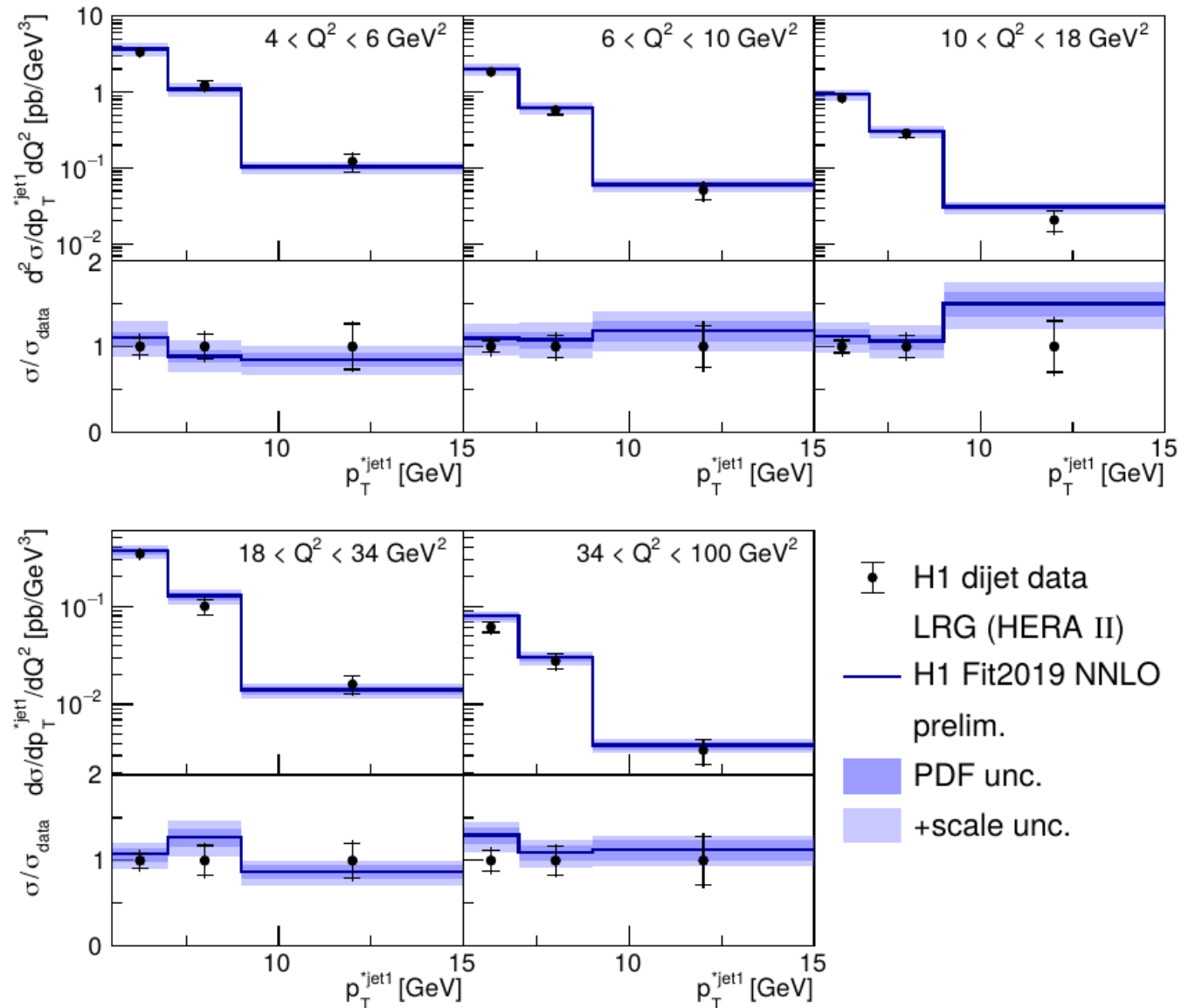


To disentangle  $F_2$  &  $F_L$  the  $\sigma_r$  must be measured for several beam energies



# Fitted data – Jet Data

- Currently only the 2D  $p_T^{\text{jet1}}$  vs  $Q^2$  H1 HERA-II cross sections fitted
- Shown PDF & scale uncertainty of the fit
- Good fit quality  $\chi^2/ndf = 12/15$

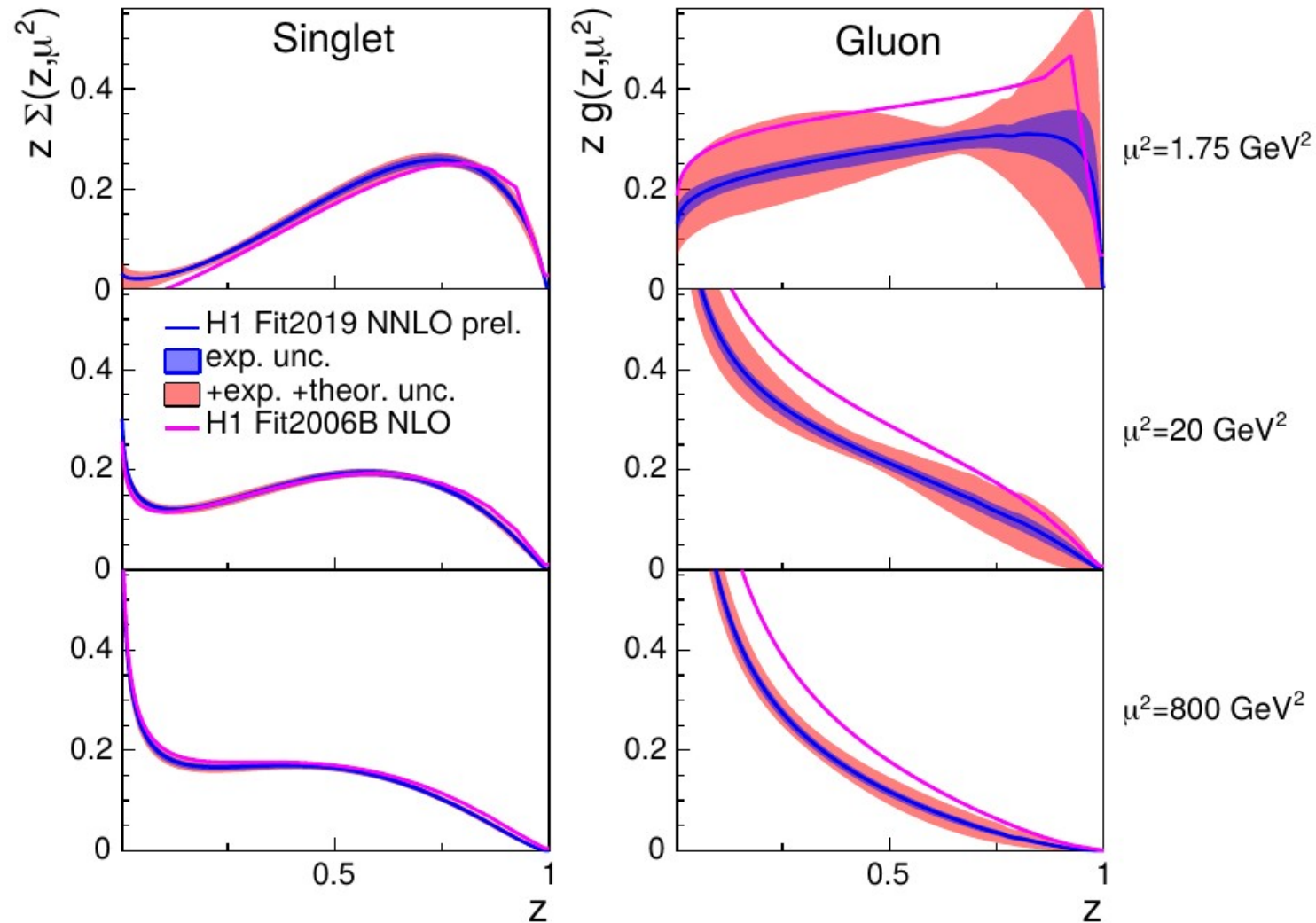


# The DPDF Comparison (H1 Fit2019 NNLO vs H1 Fit2006B NLO)

- The old and new DPDFs in different QCD order & flavour scheme  
→ comparison problematic!

$$\text{Singlet} = u + d + s \quad (+\text{anti-}q)$$

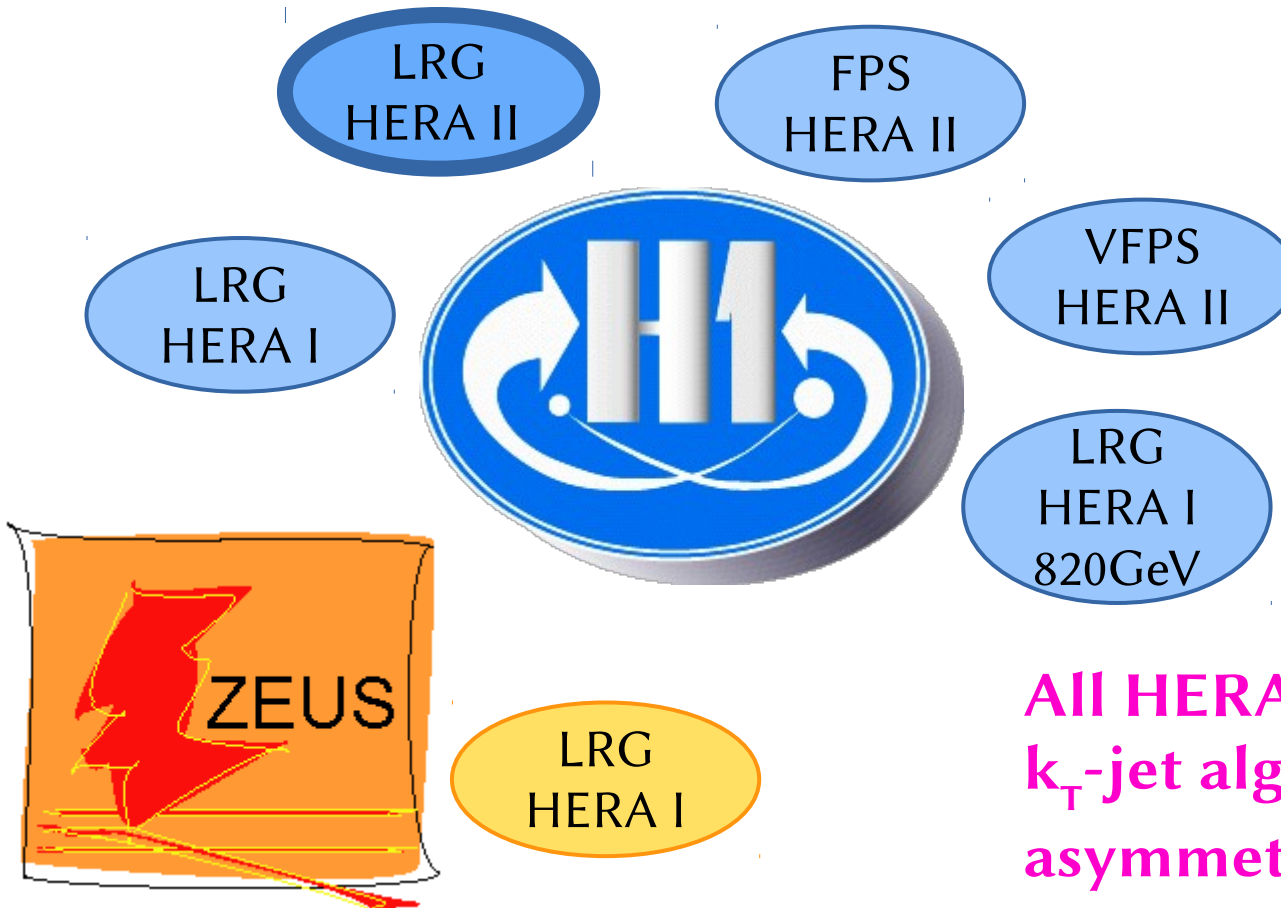
- The quark single component comparable for both fits
- Gluon component of the newer fit ~25% lower



# The DDIS HERA dijets measurements

- 5times e+p 27.6 GeV + 920 GeV  
1times e+p 27.5 GeV + 820 GeV
- 4times Large Rapidity Gap selection (LRG)  
2times Proton Spectrometer (FPS, VFPS)

H1 LRG HERA II Phase Space
$4 < Q^2 < 100 \text{ GeV}^2$ $0.1 < y < 0.7$
$x_P < 0.03$ $ t  < 1 \text{ GeV}^2$ $M_Y < 1.6 \text{ GeV}$
$p_{T,1}^* > 5.5 \text{ GeV}$ $p_{T,2}^* > 4.0 \text{ GeV}$ $-1 < \eta_{1,2}^{\text{lab}} < 2$



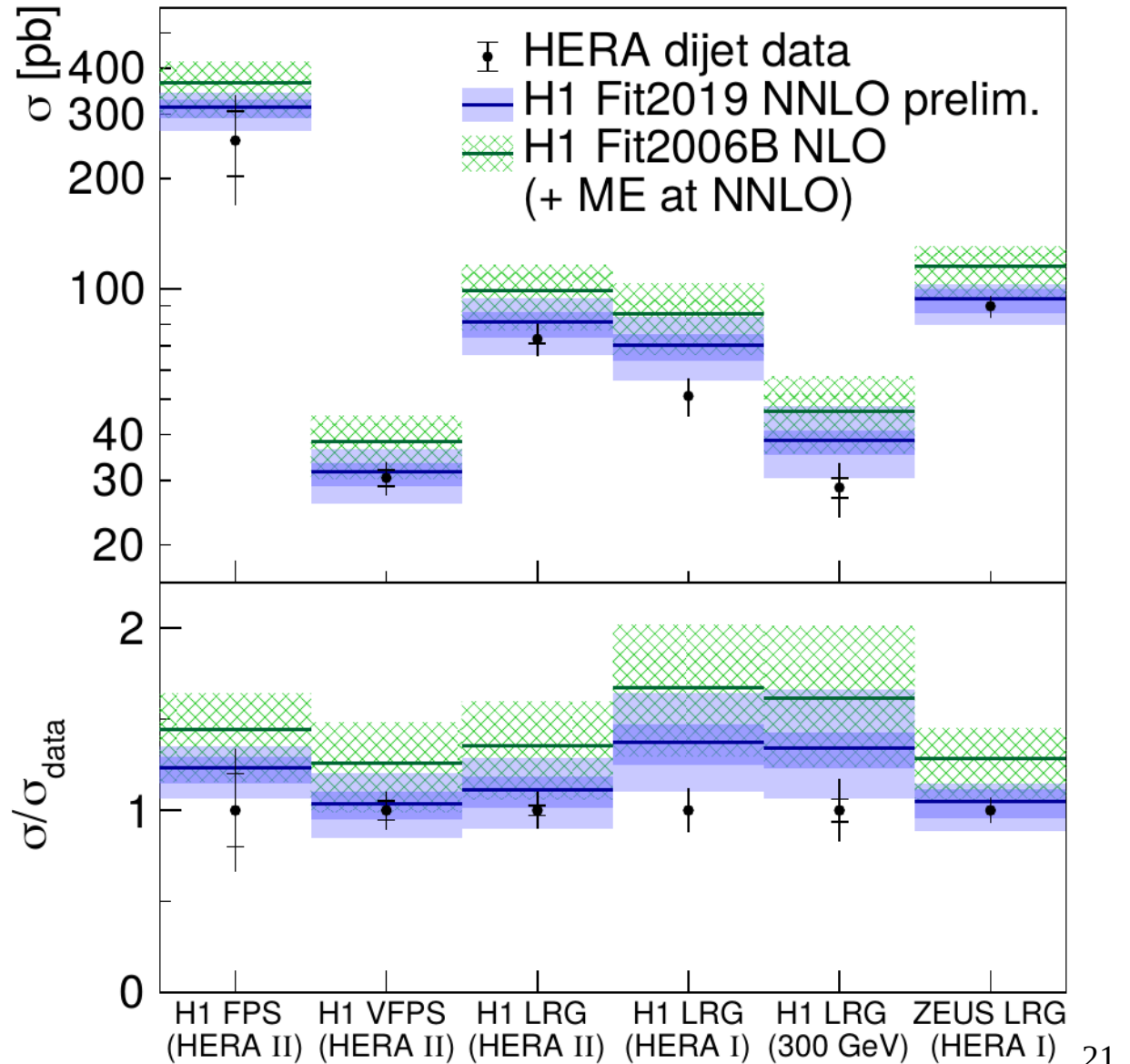
All HERA analyses are using  $k_T$ -jet algorithm ( $R=1$ ) and asymmetric jet  $p_T$  cuts



# Total Dijet Cross Sections

- **H1 Fit2019 NNLO**  
 → describes well  
 the H1 HERA-II data  
 + ZEUS HERA-I  
 → H1 HERA-I data  
 slightly below
- **H1 Fit2006B NLO**  
 with NNLO ME  
 overestimates all the  
 cross sections

In addition to the total cross sections we analyzed  
 39 single-differential  
 and  
 4 double-differential  
 distributions

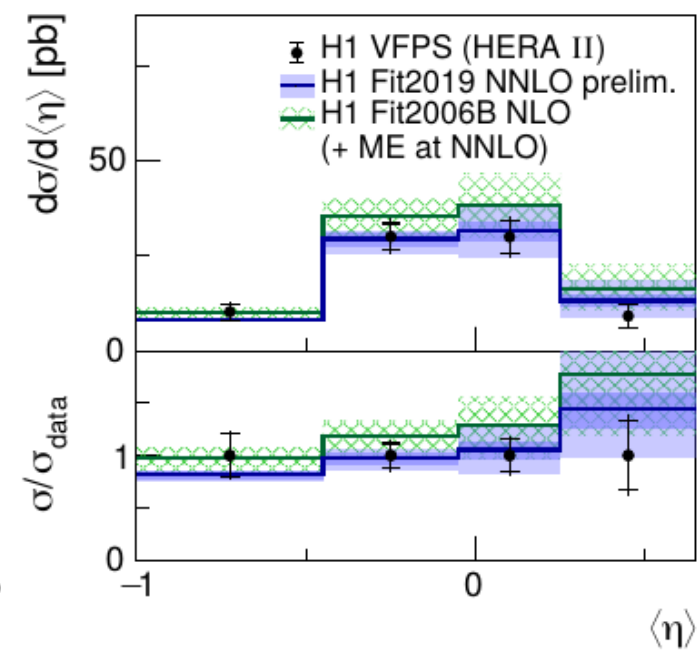
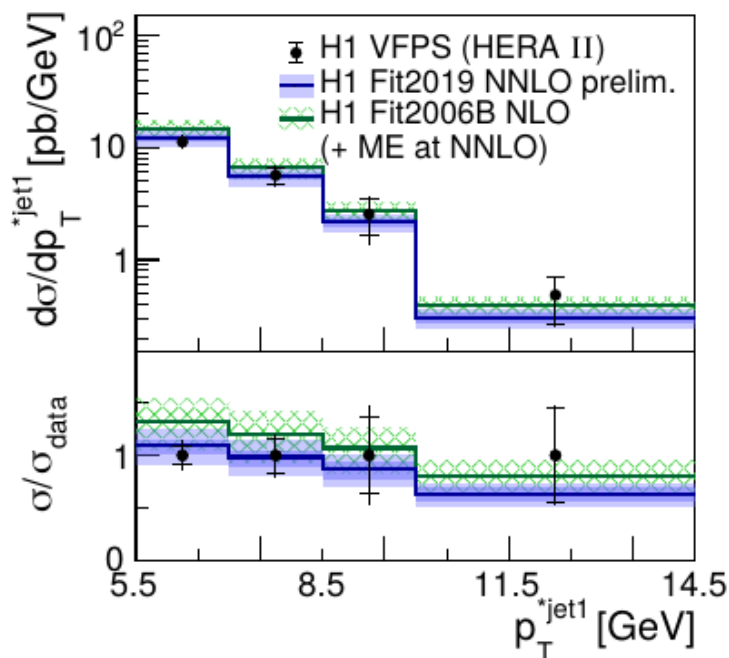
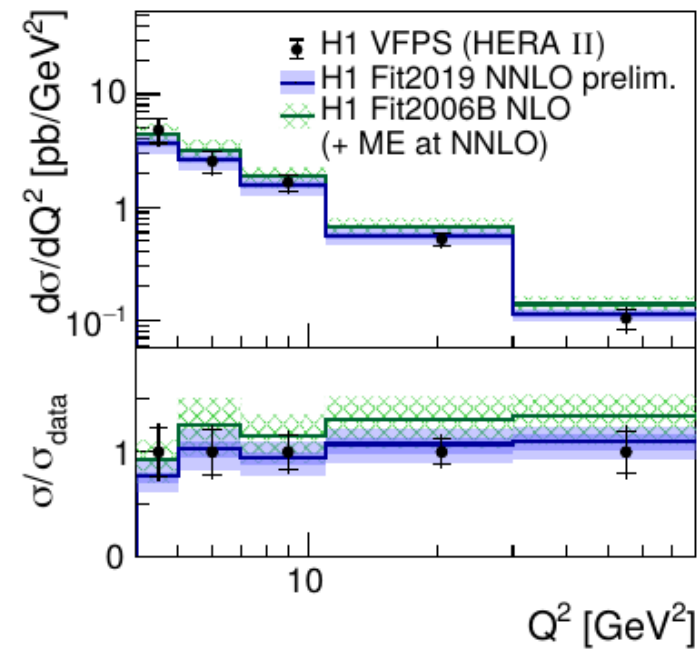
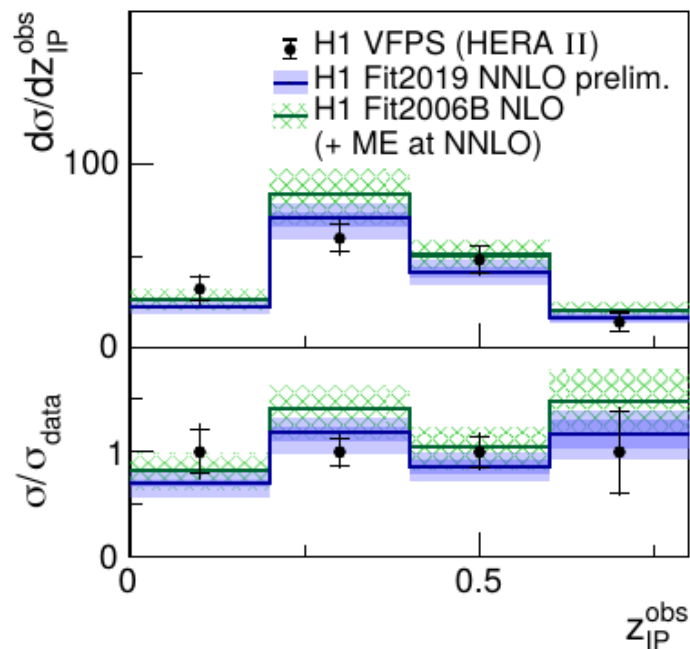


# Dijet cross sections (H1 VFPS)

- The data based on Very Forward Proton Spectrometer (VFPS) do not contain any proton dissociation and are in many ways systematically independent to the LRG-based data

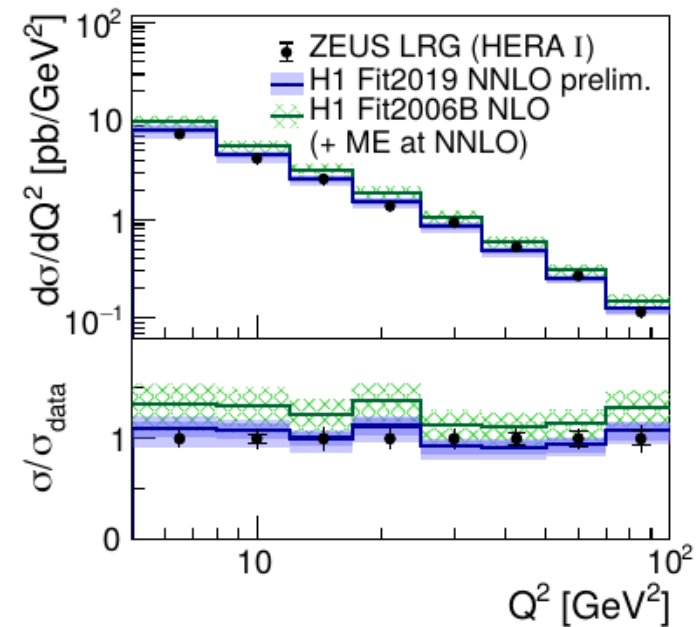
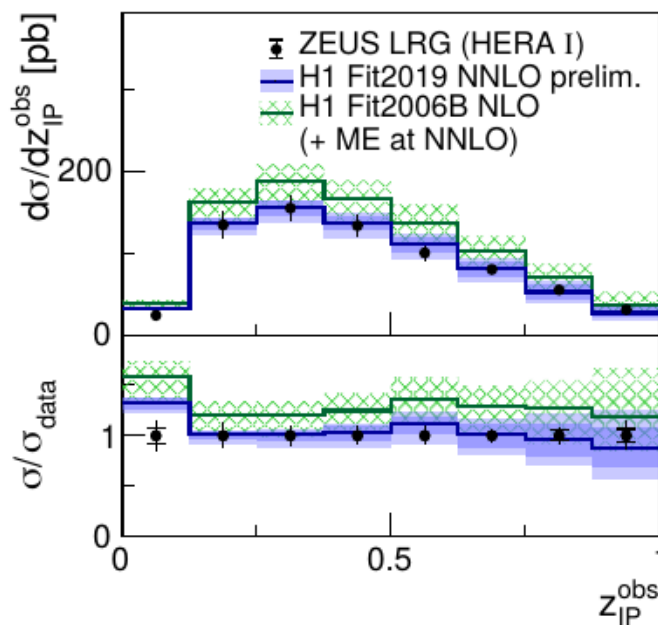
- Good description of the kinematic variables

$z_{IP}$ ,  $Q^2$ ,  $p_T^{jet1}$ ,  $\langle\eta\rangle$



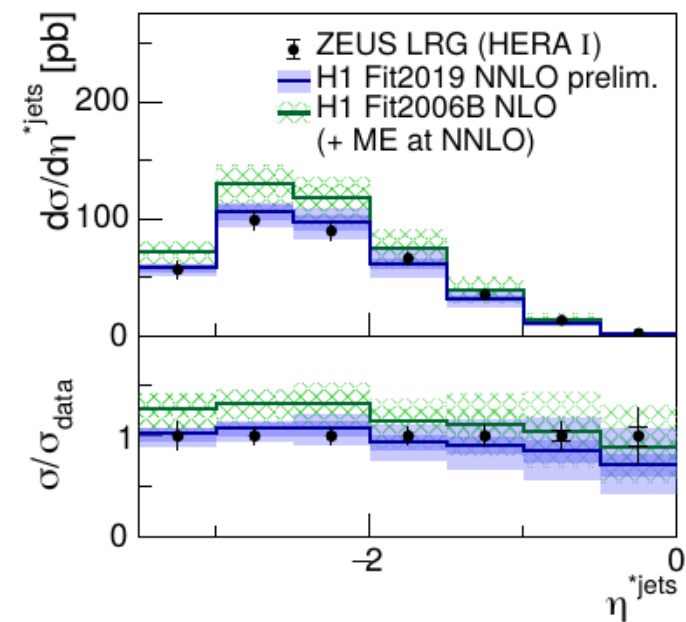
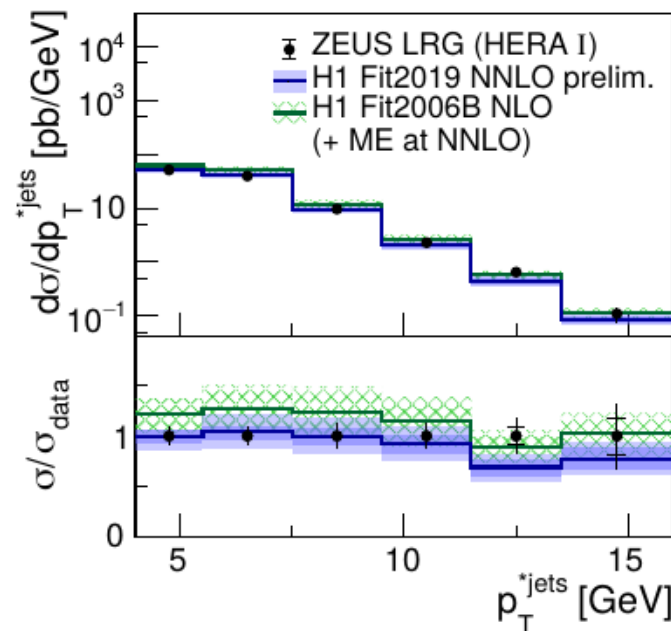
# Dijet cross sections (ZEUS LRG)

- The H1 Fit2019 NNLO based predictions agree well with the ZEUS dijet data [arXiv:0708.1415]



- At LO the  $z_{IP}^{obs}$  directly related to the pomeron momentum fraction entering ME

$$z_{IP}^{obs} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2}$$



# Conclusions

- First combined fit to the inclusive+jet DDiS DATA at NNLO
- The NNLO DPDF has lower gluon contribution compared to NLO version
- The jet data compatible with new inclusive data (at both NNLO and NLO)  
→ *Factorization in diffractive DDIS up to NNLO established*

## **Outlook:**

- Release the fit at LO, NLO & NNLO
- Include possible extra jet observables to the fit
- FPS data?

# Backup

# NNLO QCD Predictions

- **NNLOJET** program based on antenna subtraction

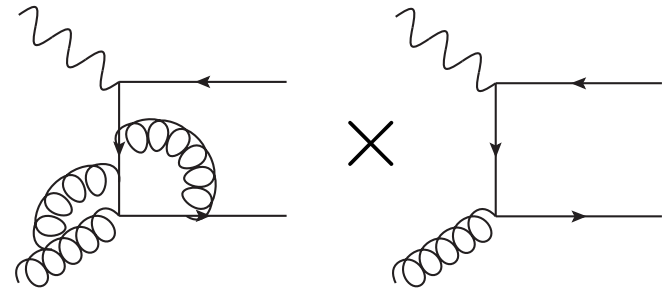
*J. Currie, T. Gehrmann, A. Huss and J. Niehues,  
JHEP 07 (2017) 018, [1703.05977]*

$$d\sigma(ep \rightarrow epX) = \sum_{i,n} d\sigma^{ie(n)}(x, Q^2) \otimes \alpha_S^n \otimes f_i^D(x, Q^2, x_{IP}, t)$$

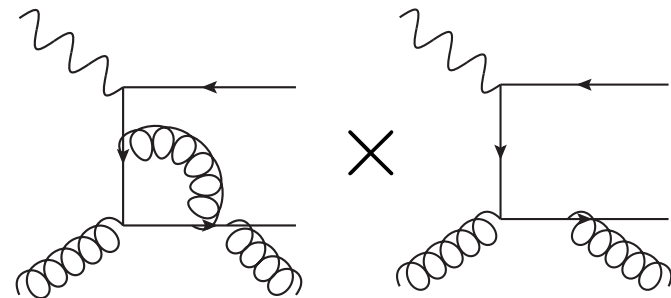
## Cookbook

- 1) The **matrix element** tables precalculated by **NNLOJET** program (~1M CPU hours)
  - 2) Then convoluted with **DPDFs** and  $\alpha_S$  using **fastNLO** (<1s)
- ✓ The NLO 2jet and 3jet contributions verified against Sherpa and NLOJET++

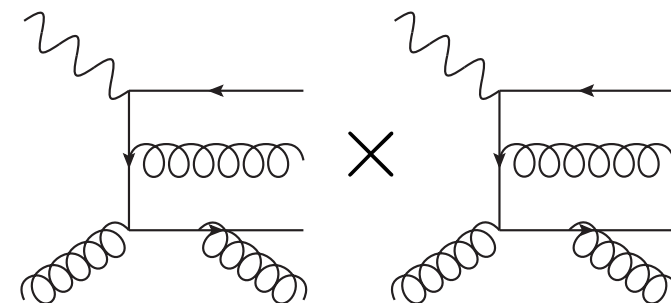
virtual-virtual



real-virtual



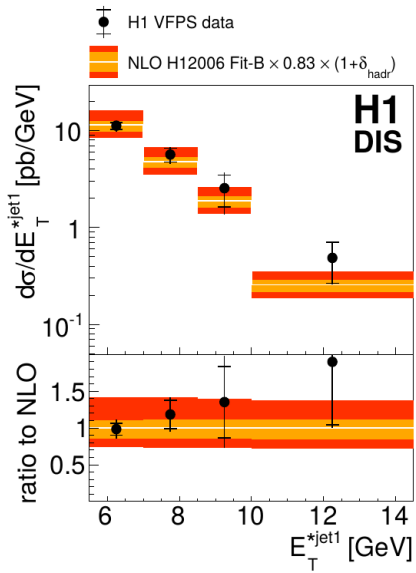
real-real



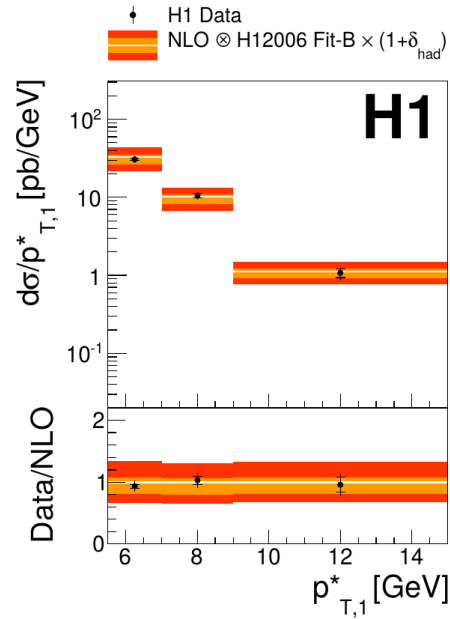


# The HERA DIS jets Legacy

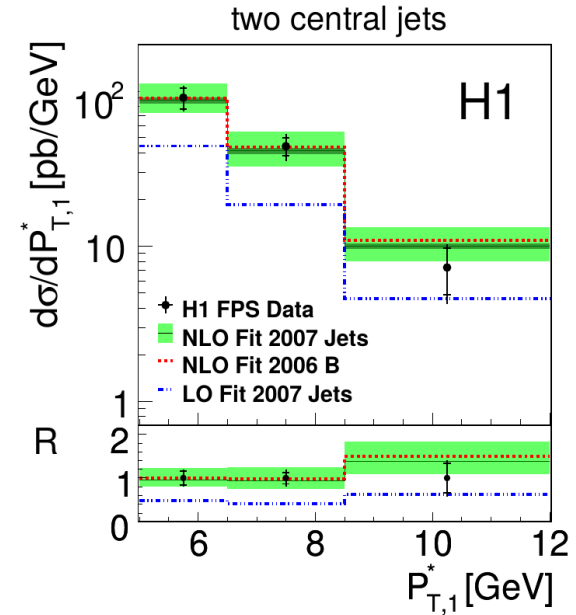
JHEP 1505 (2015) 056



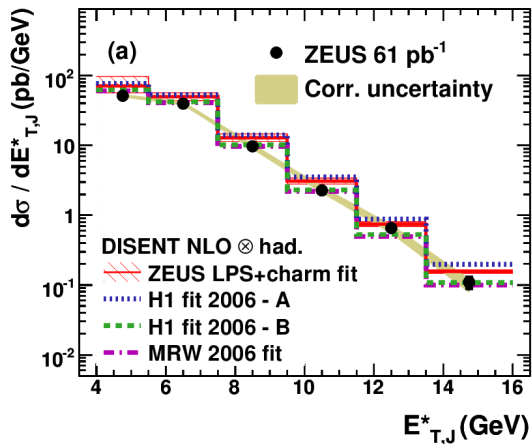
JHEP 1503 (2015) 092



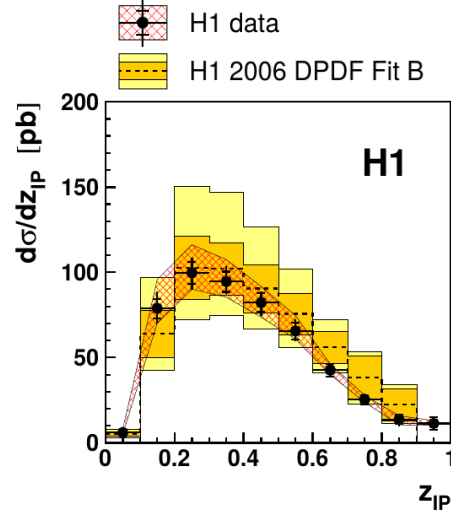
Eur.Phys.J.C72 (2012) 1970



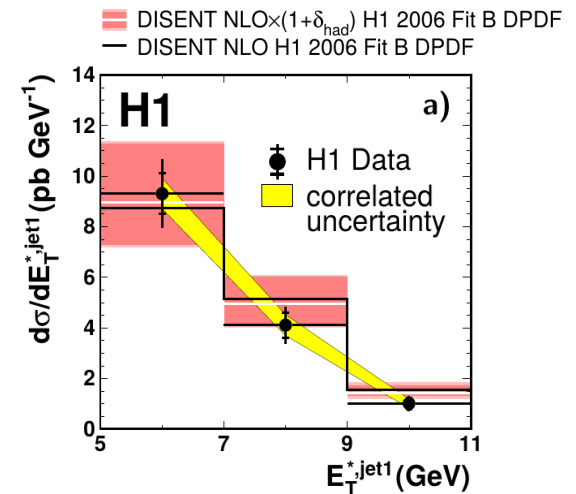
Eur. Phys. J. C 52 (2007) 813-832



JHEP 0710:042,2007



Eur.Phys.J.C 51 (2007) 549



# Backup

Data Set	$\mathcal{L}$ [ $\text{pb}^{-1}$ ]	DIS range	Dijet range	Diffractive range
H1 FPS (HERA II) [53]	156.6 (581ev)	$4 < Q^2 < 110 \text{ GeV}^2$ $0.05 < y < 0.7$	$p_{\text{T}}^{*,\text{jet}1} > 5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-1 < \eta_{\text{lab}}^{\text{jet}} < 2.5$	$x_{\text{P}} < 0.1$ $ t  < 1 \text{ GeV}^2$ $M_{\text{Y}} = m_{\text{P}}$
H1 VFPS (HERA II) [54]	50 (550ev)	$4 < Q^2 < 80 \text{ GeV}^2$ $0.2 < y < 0.7$	$p_{\text{T}}^{*,\text{jet}1} > 5.5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-1 < \eta_{\text{lab}}^{\text{jet}} < 2.5$	$0.010 < x_{\text{P}} < 0.024$ $ t  < 0.6 \text{ GeV}^2$ $M_{\text{Y}} = m_{\text{P}}$
H1 LRG (HERA II) [3]	290 ( $\sim 15000\text{ev}$ )	$4 < Q^2 < 100 \text{ GeV}^2$ $0.1 < y < 0.7$	$p_{\text{T}}^{*,\text{jet}1} > 5.5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-1 < \eta_{\text{lab}}^{\text{jet}} < 2$	$x_{\text{P}} < 0.03$ $ t  < 1 \text{ GeV}^2$ $M_{\text{Y}} < 1.6 \text{ GeV}$
H1 LRG (HERA I) [37]	51.5 (2723ev)	$4 < Q^2 < 80 \text{ GeV}^2$ $0.1 < y < 0.7$	$p_{\text{T}}^{*,\text{jet}1} > 5.5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-3 < \eta^{*\text{jet}} < 0$	$x_{\text{P}} < 0.03$ $ t  < 1 \text{ GeV}^2$ $M_{\text{Y}} < 1.6 \text{ GeV}$
H1 LRG (300 GeV) [55]	18 (322ev)	$4 < Q^2 < 80 \text{ GeV}^2$ $165 < W < 242 \text{ GeV}$ ( $0.30 < y < 0.65$ )	$p_{\text{T}}^{*,\text{jet}1} > 5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-1 < \eta_{\text{lab}}^{\text{jet}} < 2$ $-3 < \eta^{*\text{jet}} < 0$	$x_{\text{P}} < 0.03$ $ t  < 1 \text{ GeV}^2$ $M_{\text{Y}} < 1.6 \text{ GeV}$
ZEUS LRG (HERA I) [56]	61 (5539ev)	$5 < Q^2 < 100 \text{ GeV}^2$ $100 < W < 250 \text{ GeV}$ ( $0.10 < y < 0.62$ )	$p_{\text{T}}^{*,\text{jet}1} > 5 \text{ GeV}$ $p_{\text{T}}^{*,\text{jet}2} > 4.0 \text{ GeV}$ $-3.5 < \eta^{*\text{jet}} < 0$	$x_{\text{P}} < 0.03$ $ t  < 1 \text{ GeV}^2$ $M_{\text{Y}} = m_{\text{P}}$