Diffractive Dijet Production with a Leading Proton in ep Collisions at HERA

DIS 2015
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Results presented in this talk:
[arXiv:1502.01683], accepted by JHEP

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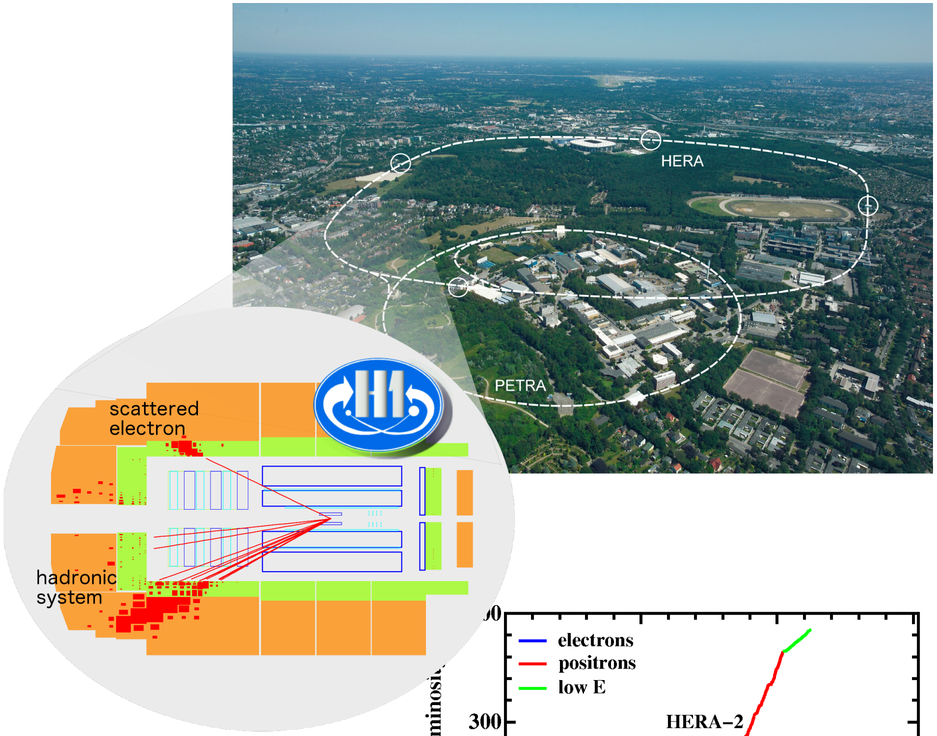
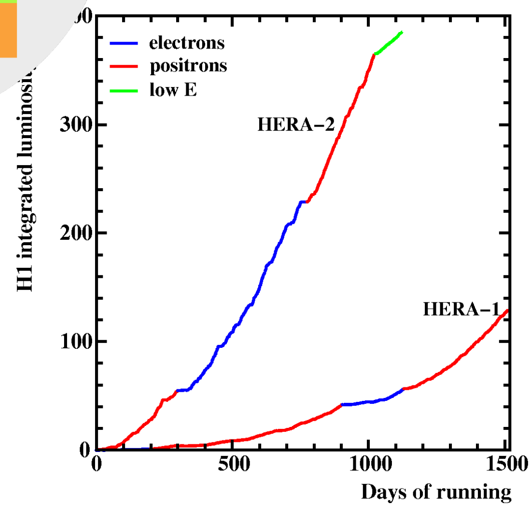
for the H1 Collaboration

The H1 experiment at HERA

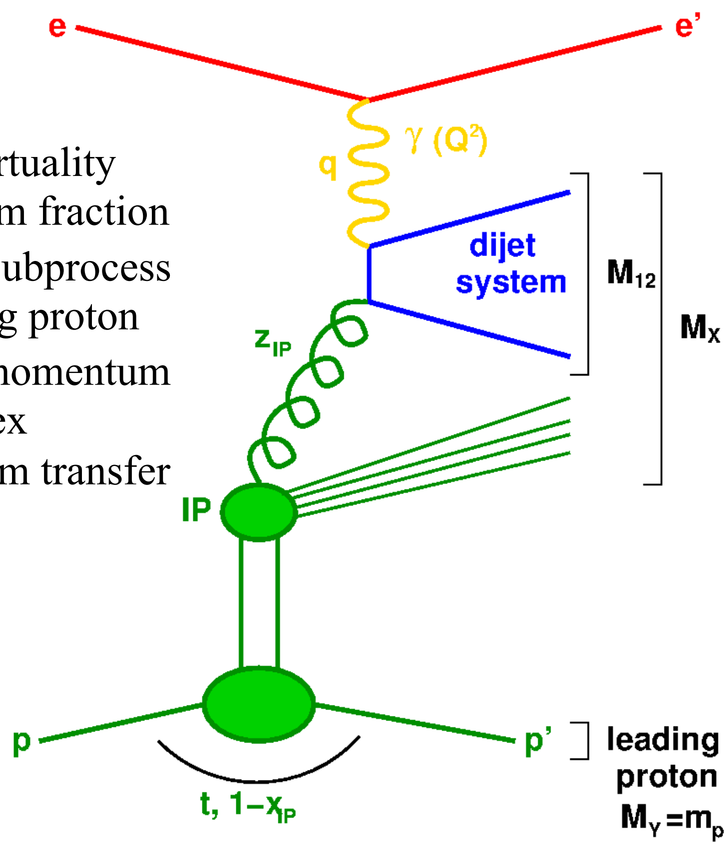
- World's only ep collider 1994-2007
- 920 x 27.6 GeV ($\sqrt{s}$=320 GeV)
- Two collider experiments, H1 and ZEUS
- Total integrated Luminosity:
  ~100 pb^{-1} (HERA-I)
  ~400 pb^{-1} (HERA-II)
- This analysis: HERA-II data, ~50 pb^{-1} with proton tagger





QCD Factorisation

Q^2: photon virtuality
z_{IP}: momentum fraction in hard subprocess
$1-x_{IP}$: leading proton long. momentum
t: proton vertex momentum transfer



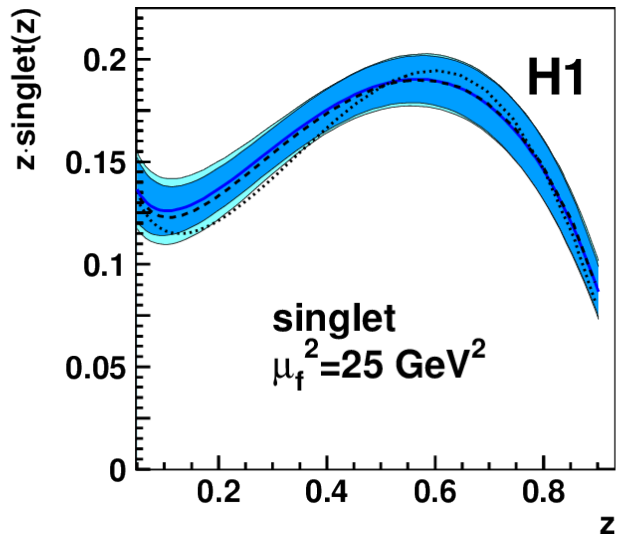
- QCD factorisation in diffractive DIS (Collins): proton structure can be described by DPDFs

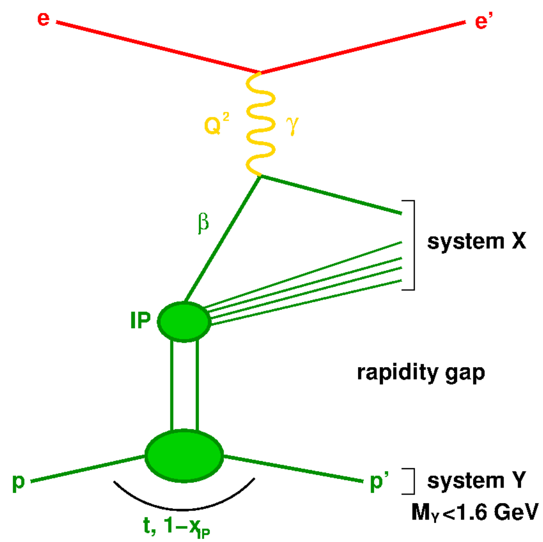
$$f_i(z_{IP},\mu_F^2,x_{IP},t)$$

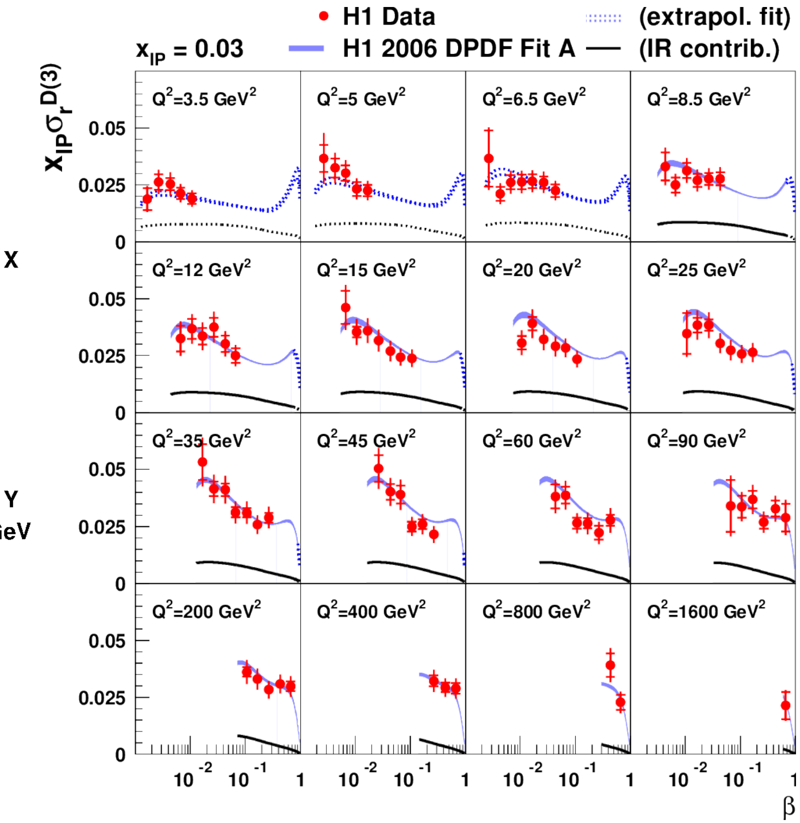
- Proton vertex factorisation: assume that DPDF factorizes into flux and pomeron PDF

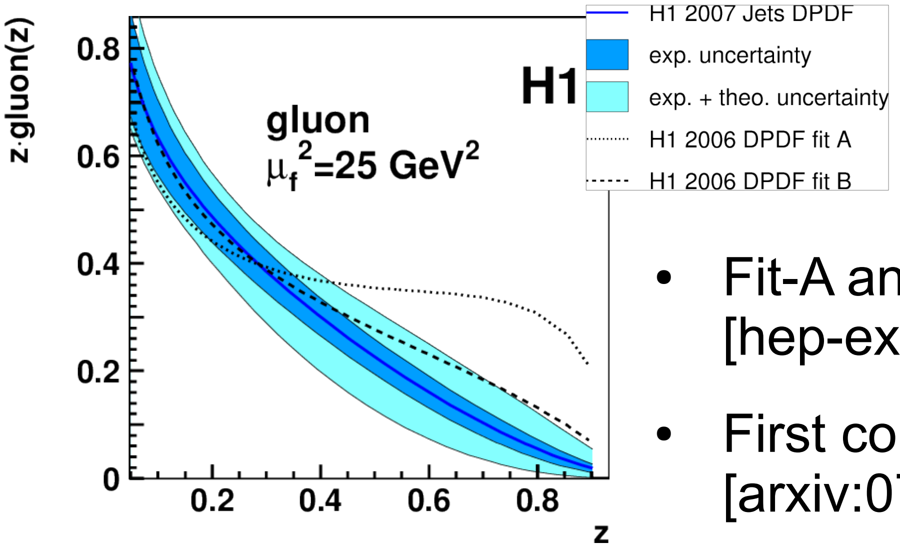
$$f_i(z_{IP},\mu_F^2,x_{IP},t)= f_{p/IP}(x_{IP},t)\times f_i(z_{IP},\mu_F^2)$$

H12006 DPDF Fit-A and Fit-B



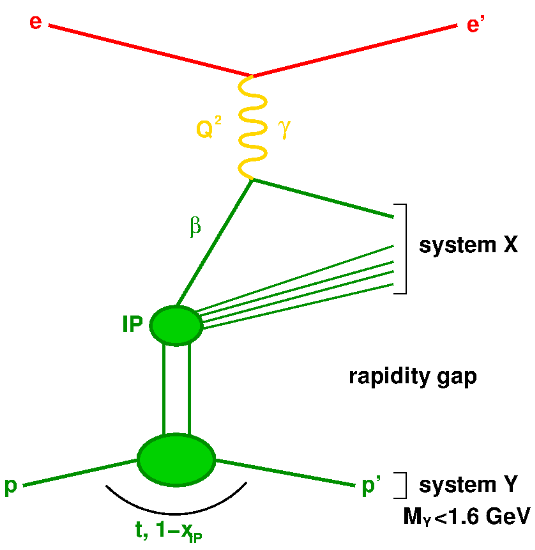






- Fit-A and Fit-B: Eur. Phys. J. C48 (2006) 715-748 [hep-ex/0606004]
- First comparison to jet data: JHEP 0710:042,2007. [arxiv:0708.3217]

Proton dissociation



- H12006 Fit-B is made using diffractive DIS data with large-rapidity gap selection
- Includes contribution from proton-dissociation M_Y<1.6 GeV
- This analysis: tagged forward proton, M_Y=m_p

→ Global correction factor applied to NLO predictions:

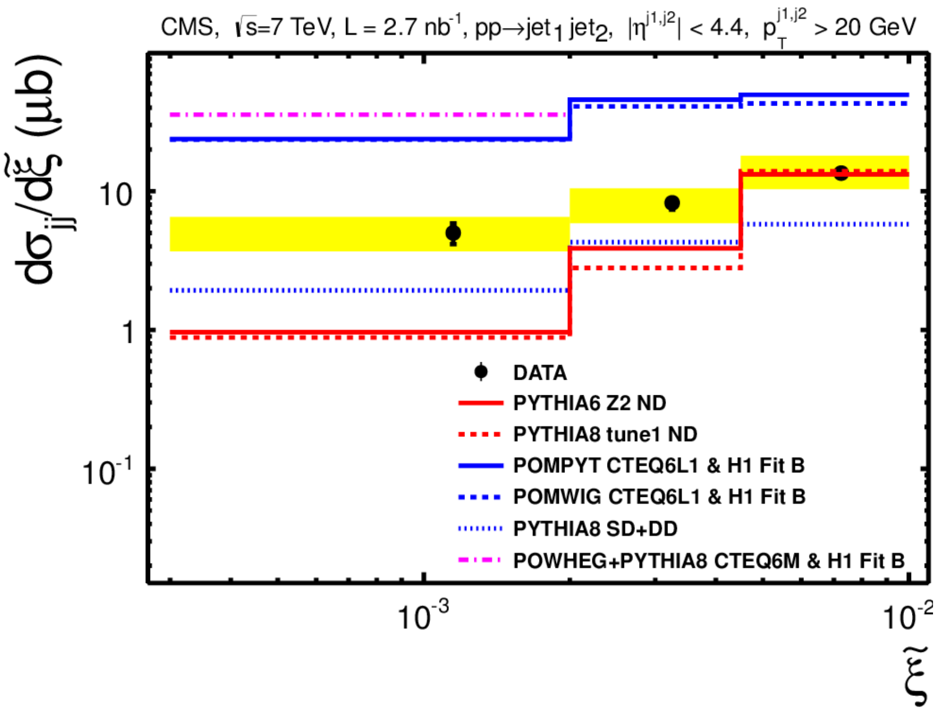
$$\frac{\sigma(M_Y=m_p)}{\sigma(M_Y<1.6\,GeV)}=\frac{1}{1.2}=0.83$$

Ratio has been measured by H1, see backup slides

EPJC71 (2011) 1578 [arxiv:1010.1476]

Factorisation breaking

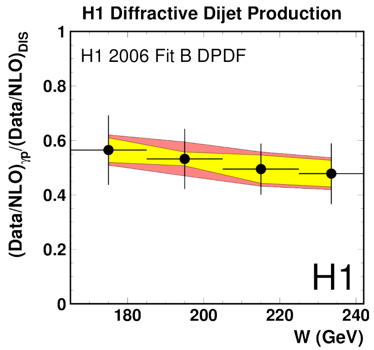
- NLO predictions based on HERA DPDFs fail to predict diffractive jet production at hadron colliders
- Suppression factor: data/NLO $S^2 \sim 0.2$
- At HERA: suppression observable in photoproduction?



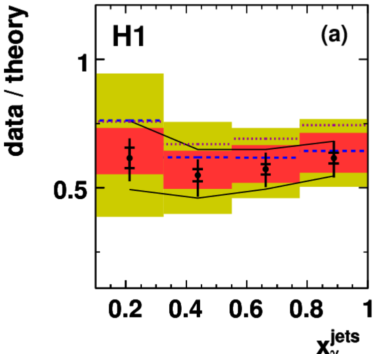
Example: CMS jet data are suppressed wrt blue line (POMPYT+H12006 Fit B)

Past results from HERA

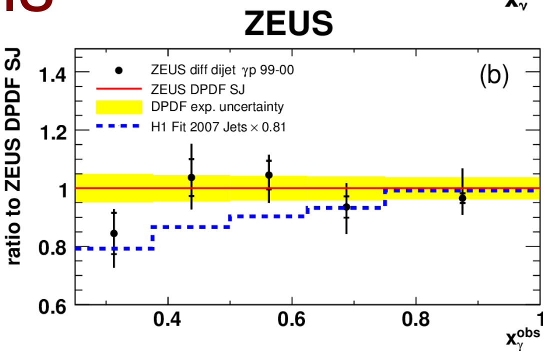
- Three independent analyses, results not fully consistent
- All based on large-rapidity gap method
- H1 tagged photoproduction (electron in zero-angle spectrometer)
- This talk: new analysis using tagged proton
- Measure both DIS and γp



EPJ C 51 (2007) 549
[hep-ex/0703022]
S^2=0.5±0.1 [γp/DIS]
Tagged photoproduction
E_T>5 (4) GeV, -1<η<2



EPJ C 70 (2010) 15
[arXiv:1006.0946]
S^2=0.58±0.21 [γp]
Tagged photoproduction
E_T>5 (4) GeV, -1<η<2



Nucl.Phys B 831 (2010) 1
[arXiv:0911.4119]
S^2~1 [γp]
Untagged photoproduction
E_T>7.5 (6.5) GeV, -1.5<η<1.5

NLO calculations

- DIS
  - NLOJET++, verified against DISENT NLO
  - Scale choice:

$$\mu_R^2 = \mu_F^2 = \langle E_T^{*\,jet} \rangle^2 + Q^2$$

$$\text{where: } \langle E_T^{*\,jet} \rangle = \frac{E_T^{*\,jet1} + E_T^{*\,jet2}}{2}$$

  - Scale variant:

$$\mu_R^2 = \mu_F^2 = (E_T^{*\,jet1})^2 + Q^2$$

- Photoproduction
  - FKS, verified against Klasen & Kramer
  - Scale choice:

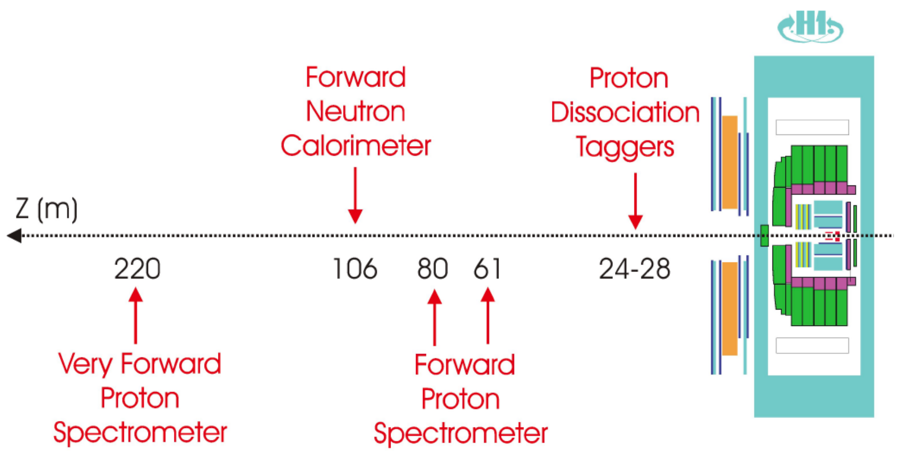
$$\mu_R^2 = \mu_F^2 = \langle E_T^{jet} \rangle^2$$

  - Photon PDF: GRV, alternative: AFG
  - Scale variant:

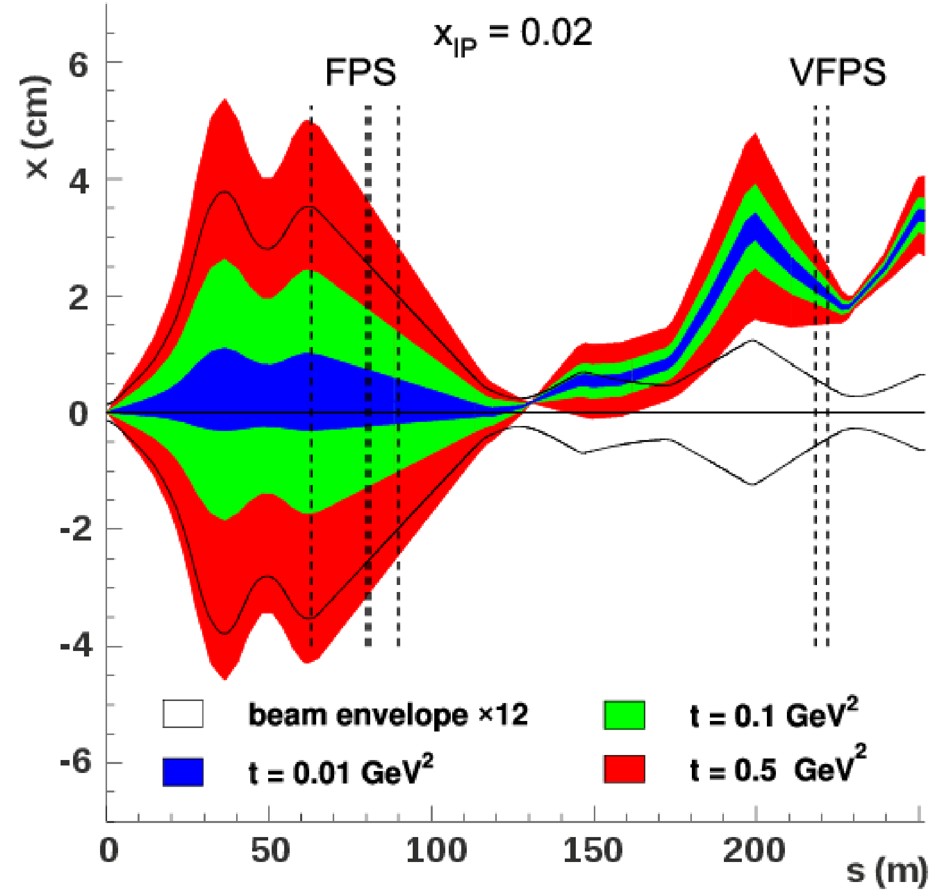
$$\mu_R^2 = \mu_F^2 = (E_T^{*\,jet1})^2$$

Scale variation: factor 2 up and down

Detecting the leading proton



- HERA-I: forward proton spectrometer (FPS)
- HERA-II: upgrade of FPS and new very forward spectrometer (VFPS), 220 m downstream main detector
- This talk: results from VFPS



- VFPS: full geometrical acceptance down to t=0

Event selection

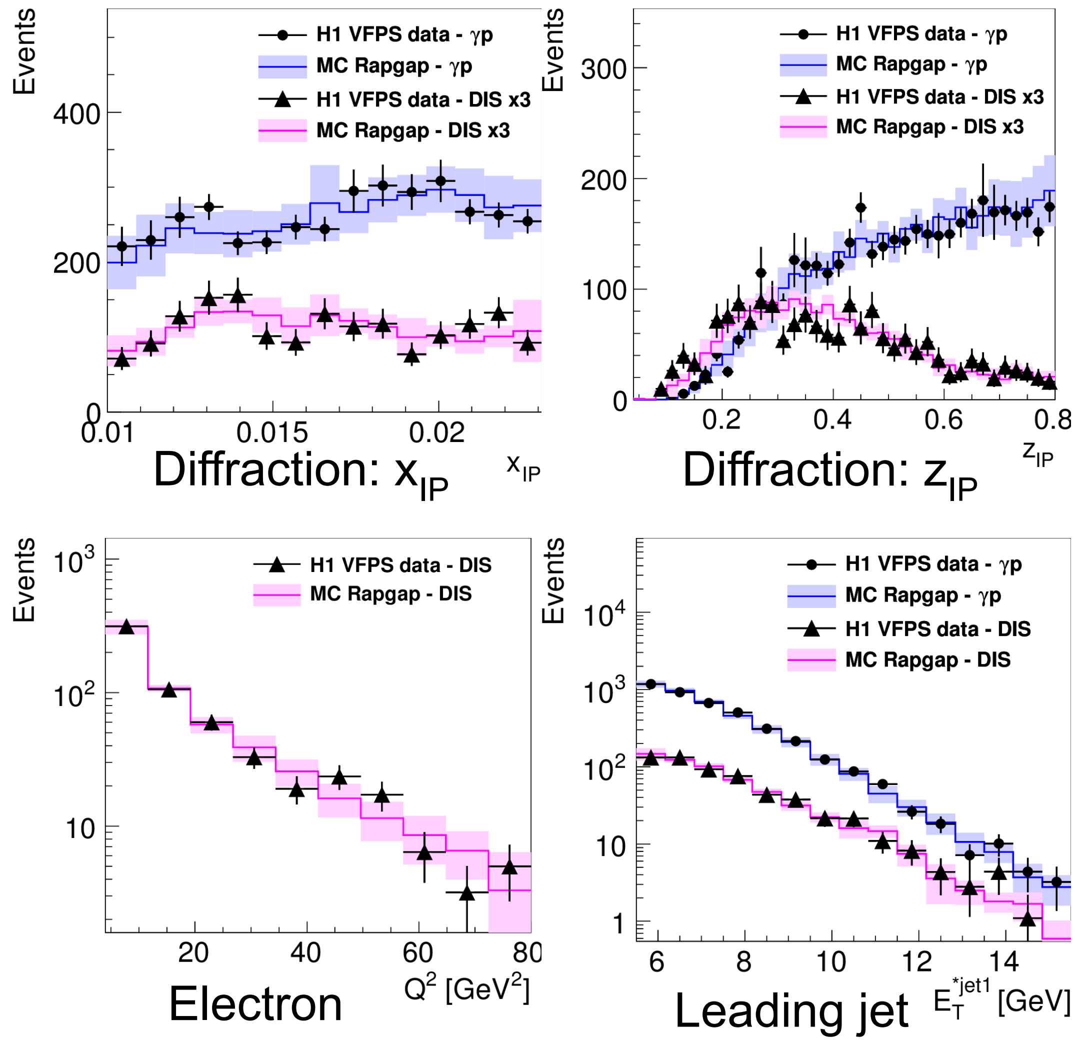
	Photoproduction	DIS
Event kinematics	$Q^2 < 2\,\mathrm{GeV}^2$	$4\,\mathrm{GeV}^2 < Q^2 < 80\,\mathrm{GeV}^2$
	$0.2 < y < 0.7$	
Diffractive phase space	$0.010 < x_{I\!P} < 0.024$	
	$\lvert t \rvert < 0.6\,\mathrm{GeV}^2$	
	$z_{I\!P} < 0.8$	
Jet phase space	$E_T^{*\mathrm{jet1}} > 5.5\,\mathrm{GeV}$	
	$E_T^{*\mathrm{jet2}} > 4.0\,\mathrm{GeV}$	
	$-1 < \eta^{\mathrm{jet1,2}} < 2.5$	

No rapidity gap requirement: enlarged jet angular acceptance compared to earlier analyses

- Parallel selection of DIS (detect electron) and photoproduction (absence of electron)
- Otherwise, identical phase-space

Control distributions

- Simulation: RAPGAP+DPDF fit B, reweighted to describe data
- Reconstructed quantities are well described by reweighted LO MC → can be used for unfolding detector effects
- Regularized unfolding (TUnfold) to correct for migrations



Integrated cross section

	PHP	DIS
Data [pb]	237 ± 14 (stat) ± 31 (syst)	30.5 ± 1.6 (stat) ± 2.8 (syst)
NLO QCD [pb]	$430\,^{+172}_{-98}$ (scale) $^{+48}_{-61}$ (DPDF) ± 13 (hadr)	$28.3\,^{+11.4}_{-6.4}$ (scale) $^{+3.0}_{-4.0}$ (DPDF) ± 0.8 (hadr)
RAPGAP [pb]	180	18.0
Data/NLO	0.551 ± 0.078 (data)$^{+0.230}_{-0.149}$ (theory)	1.08 ± 0.11 (data)$^{+0.45}_{-0.29}$ (theory)

- DIS cross section is consistent with NLO
- γp cross section is off by ~ factor of two
- Suppression is there – not related to proton dissociation
- Numerically consistent with earlier H1 measurements

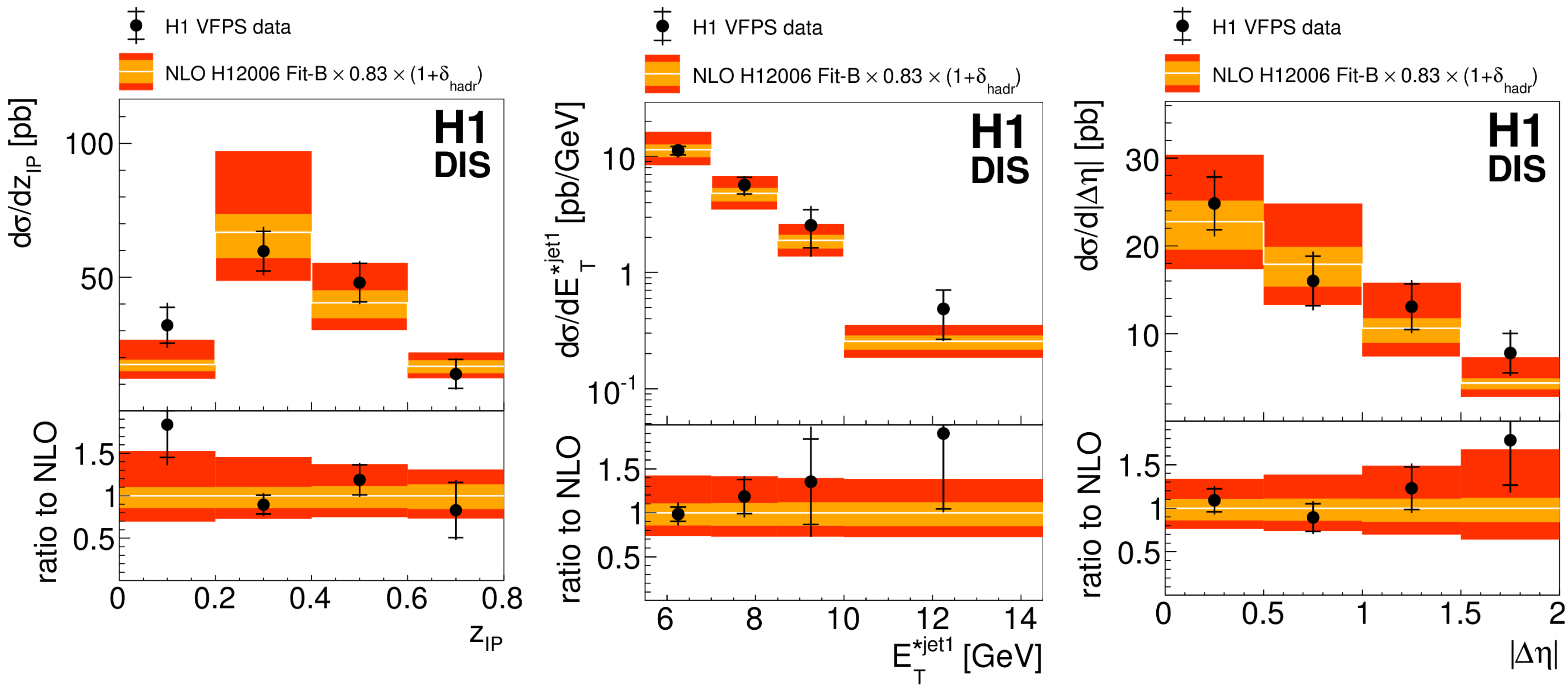
Systematic uncertainties

- All sources contribute about equally

	DIS	γp
VFPS detector	3.0%	5.3%
hadr energy scale	4.4%	7.2%
model uncertainties	4.3%	6.9%
Normalisation	6.0%	6.0%
Total	**9.1%**	**12.8%**

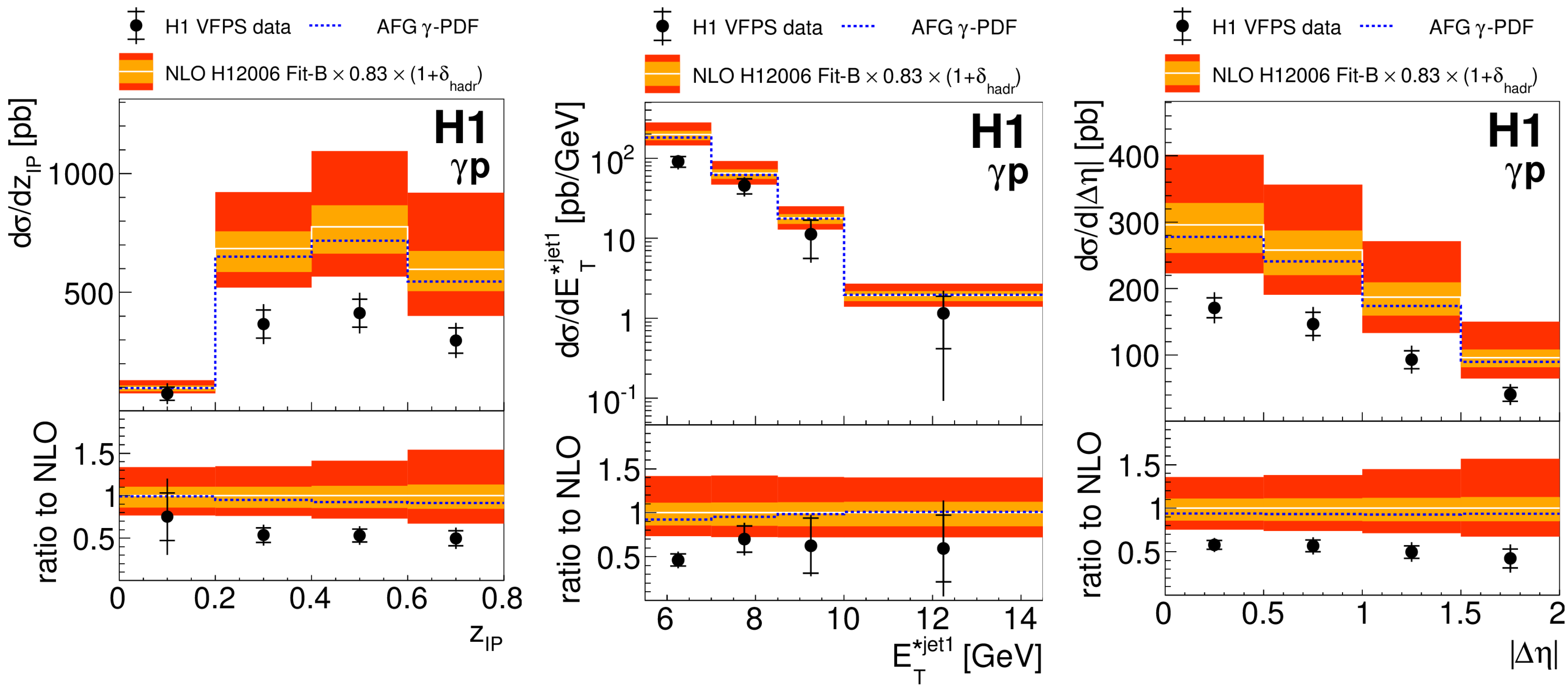
- Model uncertainty is uncorrelated between DIS and γp, so there is no cancellation in cross section ratios

Differential cross sections (DIS)



- DIS data compatible with NLO predictions, both in shape and in normalisation
- Jet E_T somewhat harder than predicted

Differential cross sections (γp)



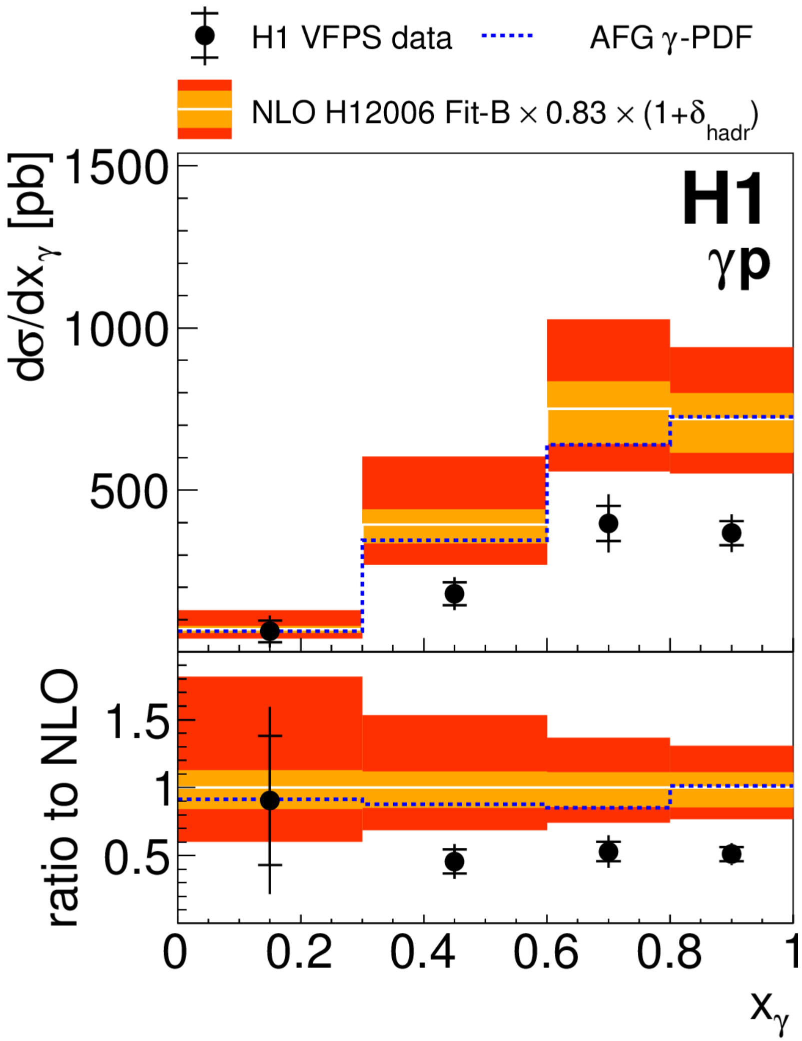
- Photoproduction data compatible in shape with NLO predictions, normalisation is off
- Jet E_T somewhat harder than predicted

Dependence on x_γ

- Suppression related to resolved photon? Expect to see dependence on x_γ
- No dependence observed, confirms earlier measurements

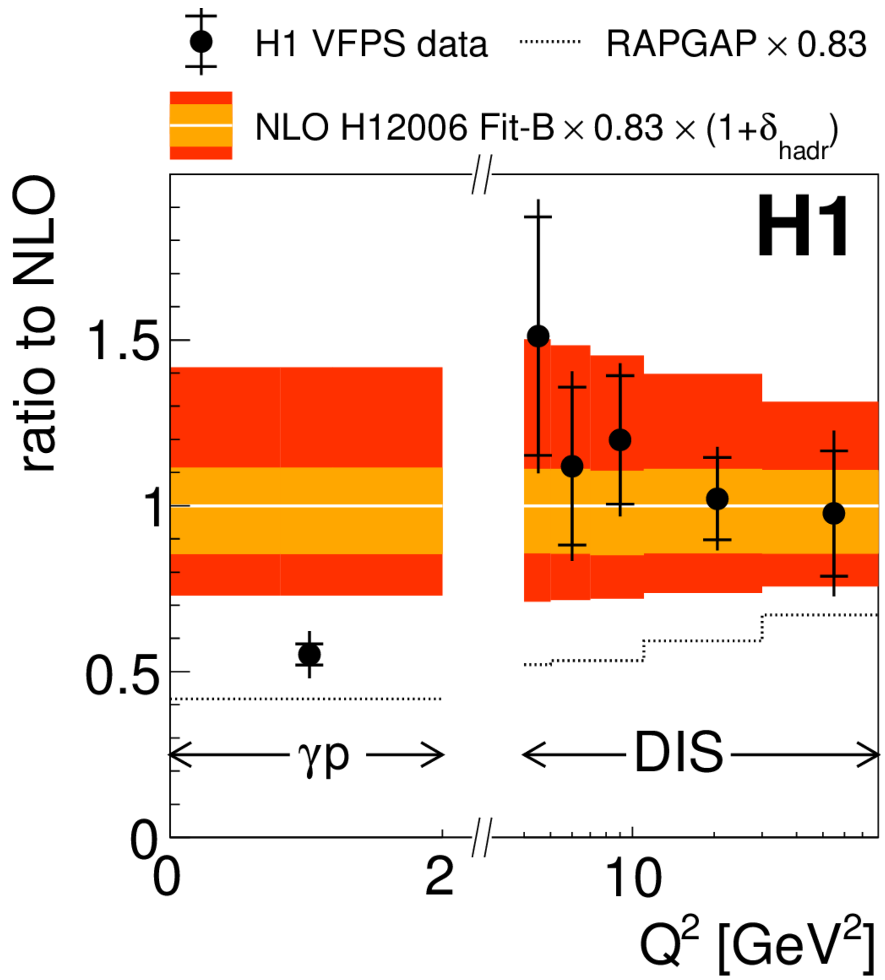
$$x_\gamma = \frac{(E-p_z)_{\text{jets}}}{(E-p_z)_X}$$

At LO: fraction of photon momemtum entering hard subprocess



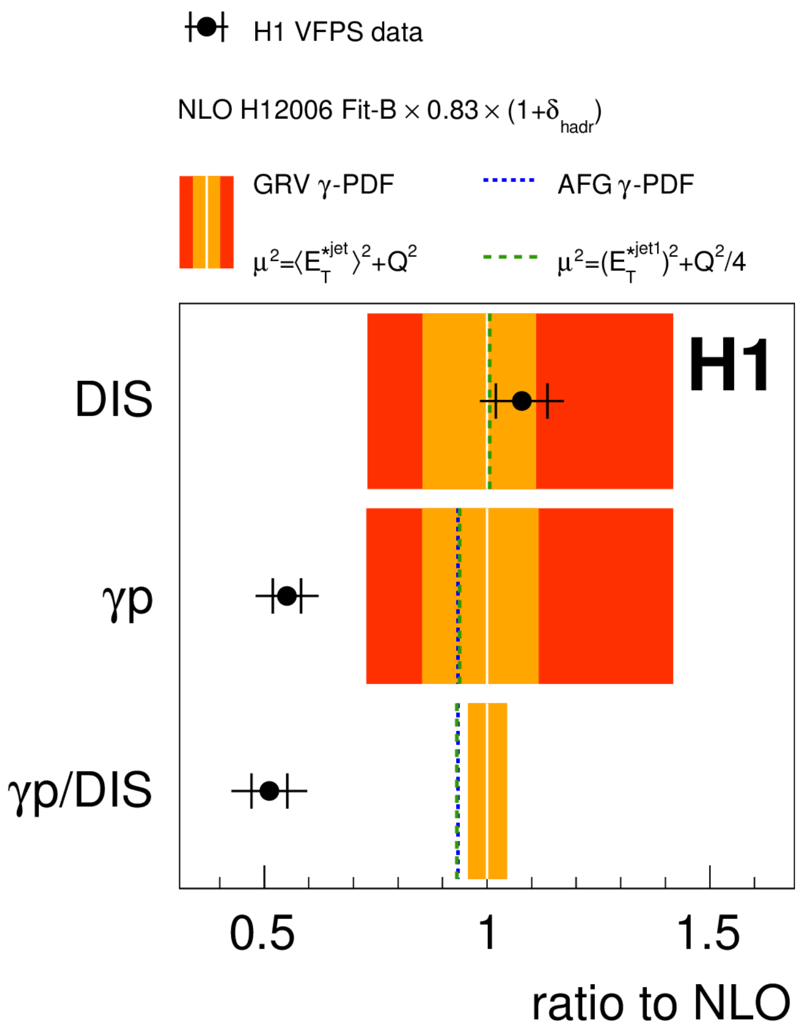
Dependence on Q^2

- Same phase-space for DIS and γp: measure Q^2 dependence data/NLO
- No significant Q^2 dependence down to 4 GeV². Suppression only in photoproduction
- Leading order MC RAPGAP fails in shape and normalisation

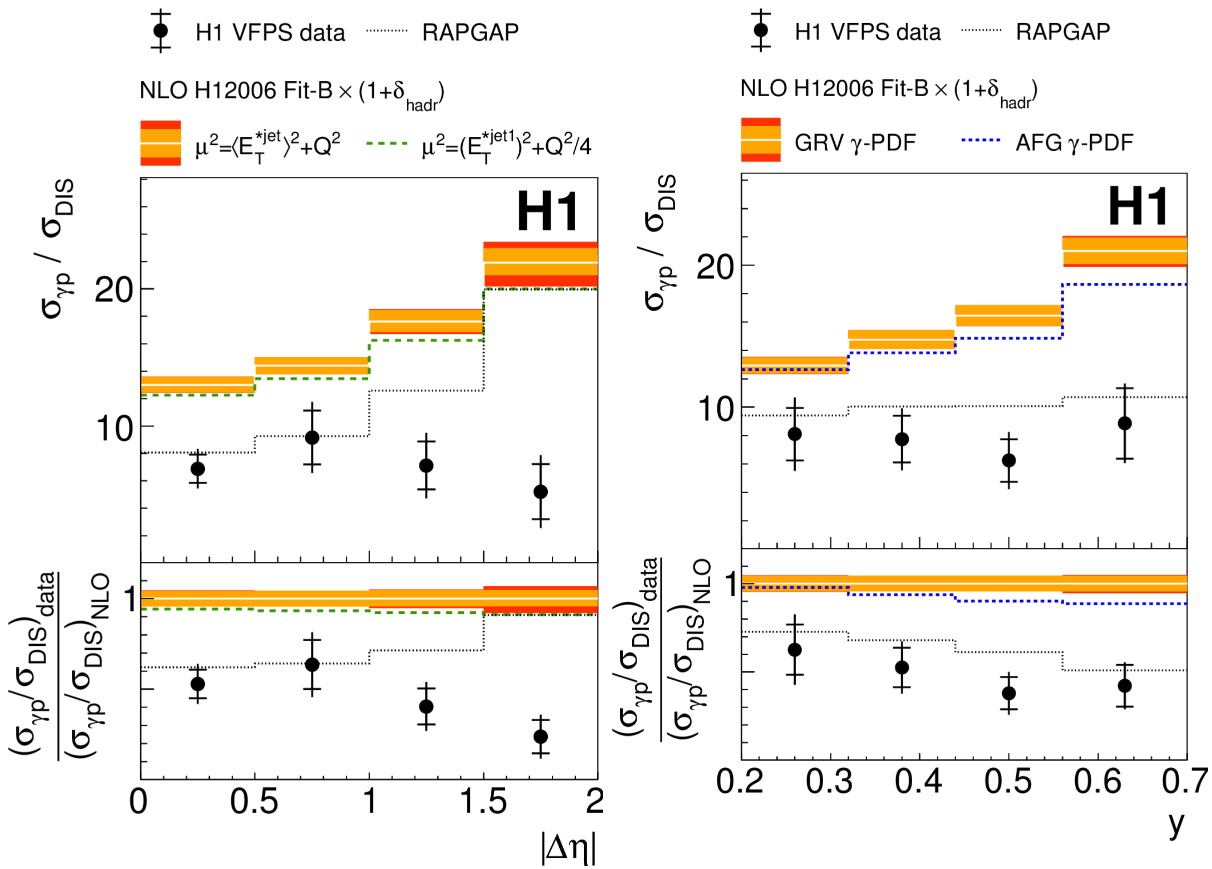


Ratio photoproduction to DIS

- Systematic uncertainties may cancel in the ratio of cross sections γp/DIS
- No significant cancellation observed in data (model uncertainties dominate ratio)
- NLO scale uncertainties cancel in ratio IF scales are varied simultaneously in DIS and γp



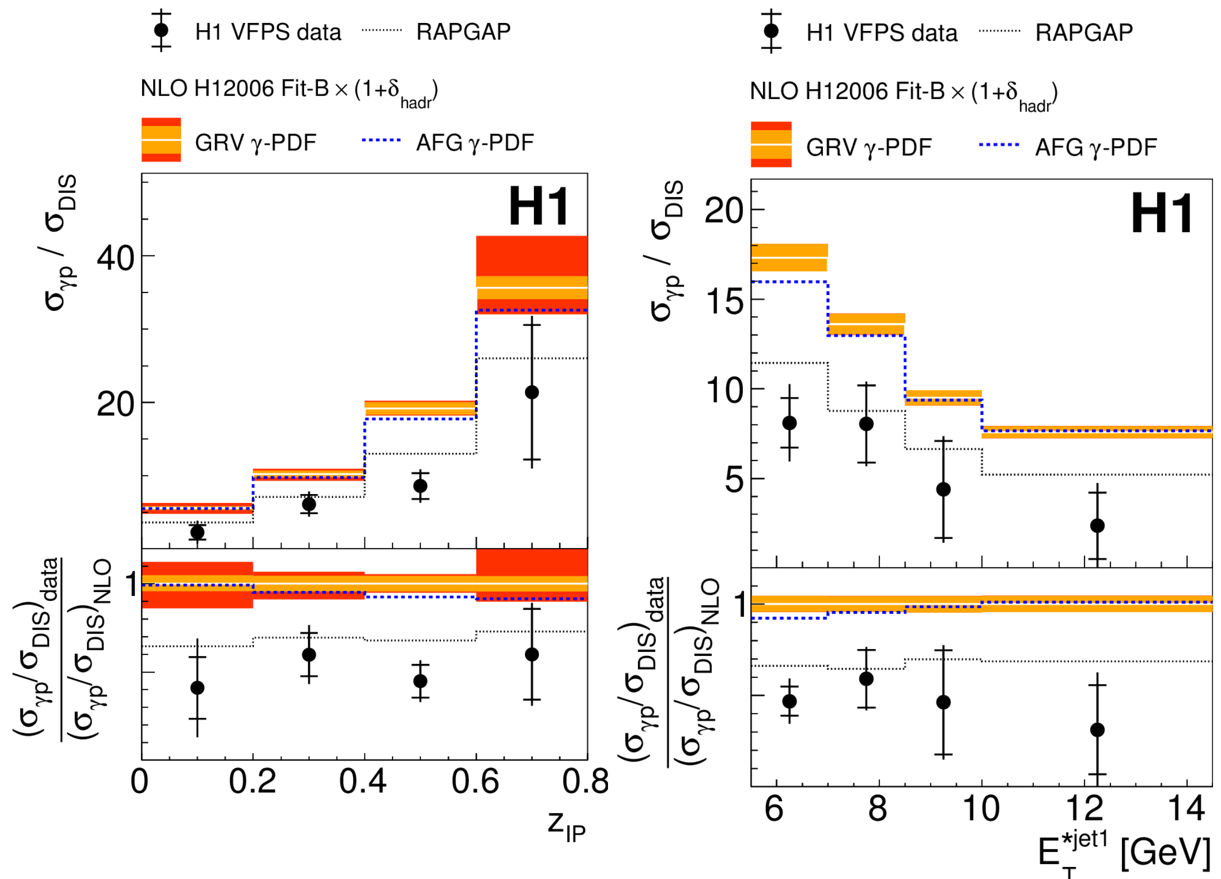
Double ratios (1)



- Ratio γp/DIS
- Variables studied: $|\Delta\eta|$ and y
- Ratio is shape dependent in $|\Delta\eta|$?
- Fit of $|\Delta\eta|$ with constant has probability 15% → not significant

Double ratios (2)

- Ratio γp/DIS
- Variables studied: z_{IP} and E_T
- No shape dependence observed



- Possible small E_T dependence of DIS and γp cross sections cancels in ratio

Summary

- New measurement of dijet production with a leading proton detected in the H1 VFPS
- Simultaneous measurement of DIS and photoproduction
- DIS well described by NLO
- Photoproduction suppressed by S^2~0.5
- Tagged leading proton: suppression is not related to proton dissociation
- Earlier measurements of S^2 by H1 with rapidity-gap method are confirmed

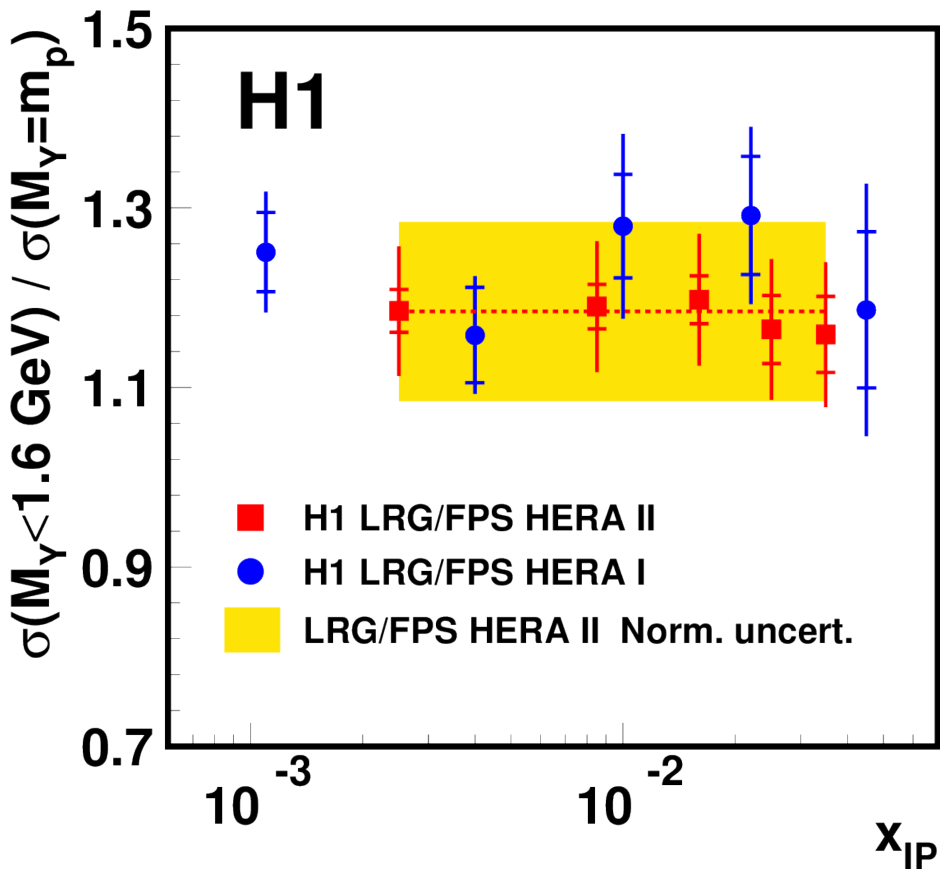
Backup

Correction for proton dissociation

- Proton dissociation is present in inclusive diffractive data, hence also in the DPDFs
- Comparison to leading proton data showed

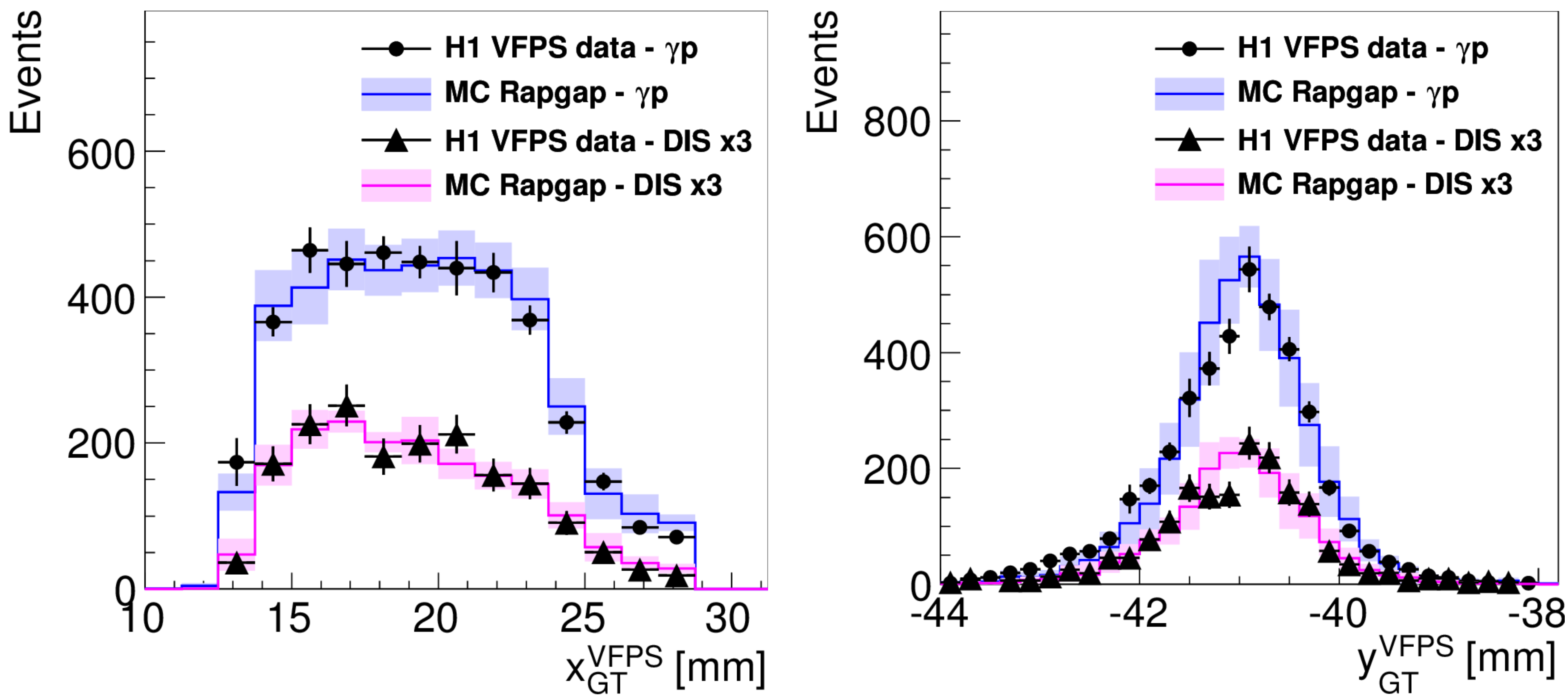
$$\frac{\sigma(M_Y = m_p)}{\sigma(M_Y < 1.6\,GeV)} = \frac{1}{1.2} = 0.83$$

- Factor 0.83 is applied to all NLO calculations shown in this talk

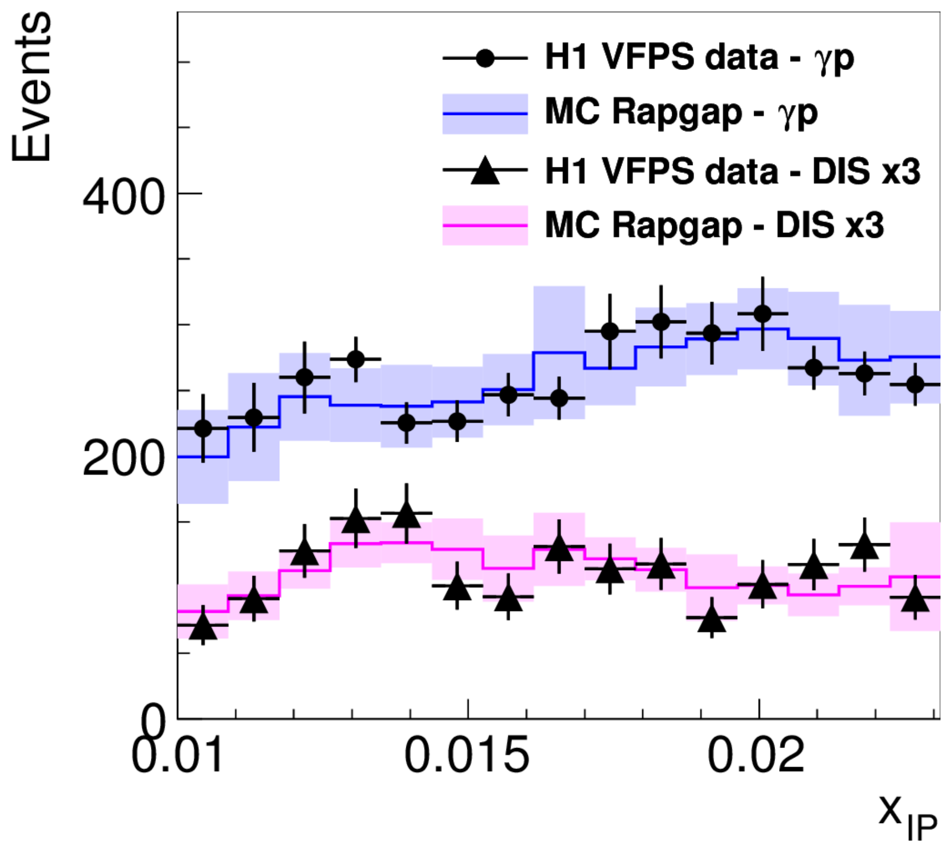


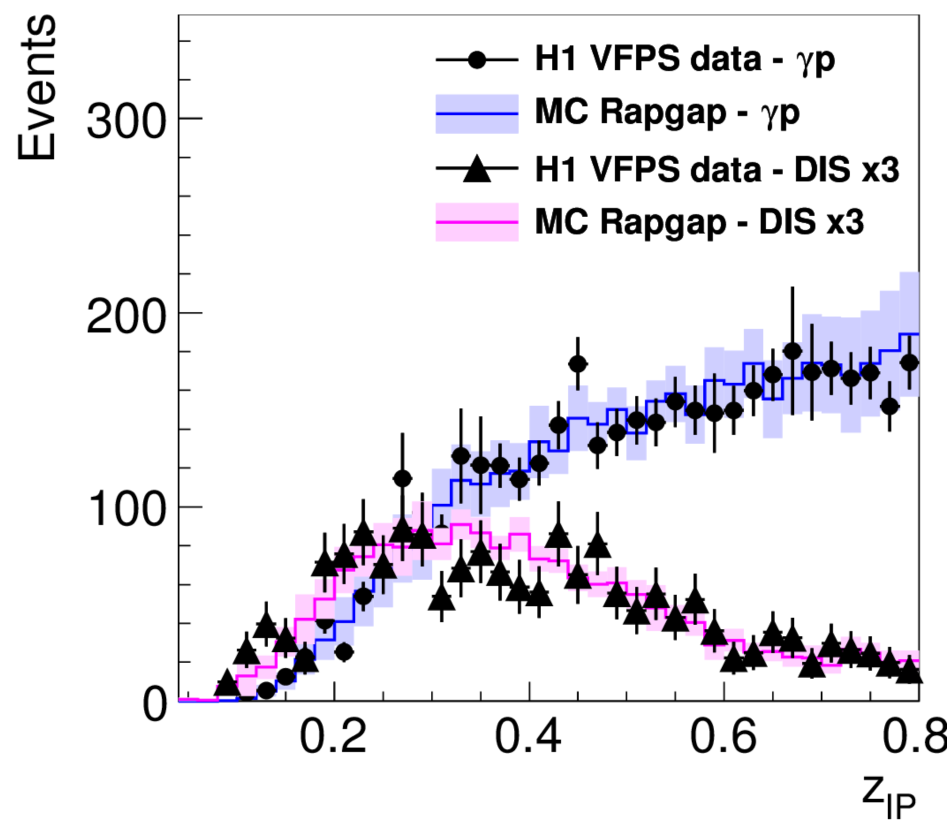
EPJC71 (2011) 1578
[arxiv:1010.1476]

Control distributions VFPS

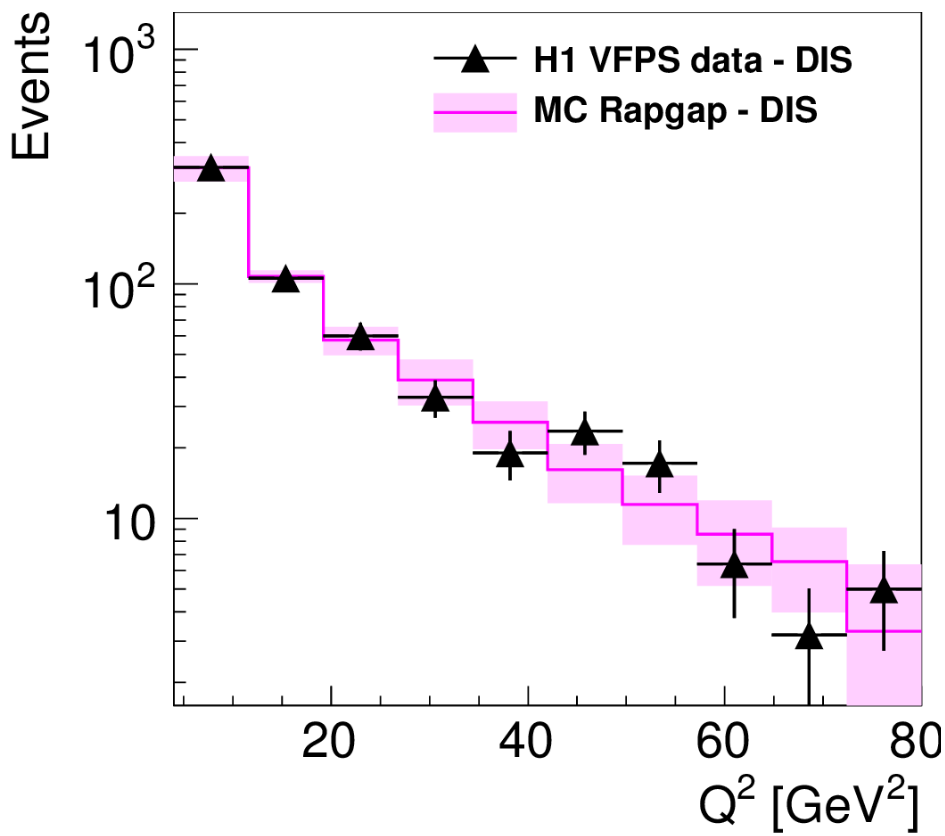


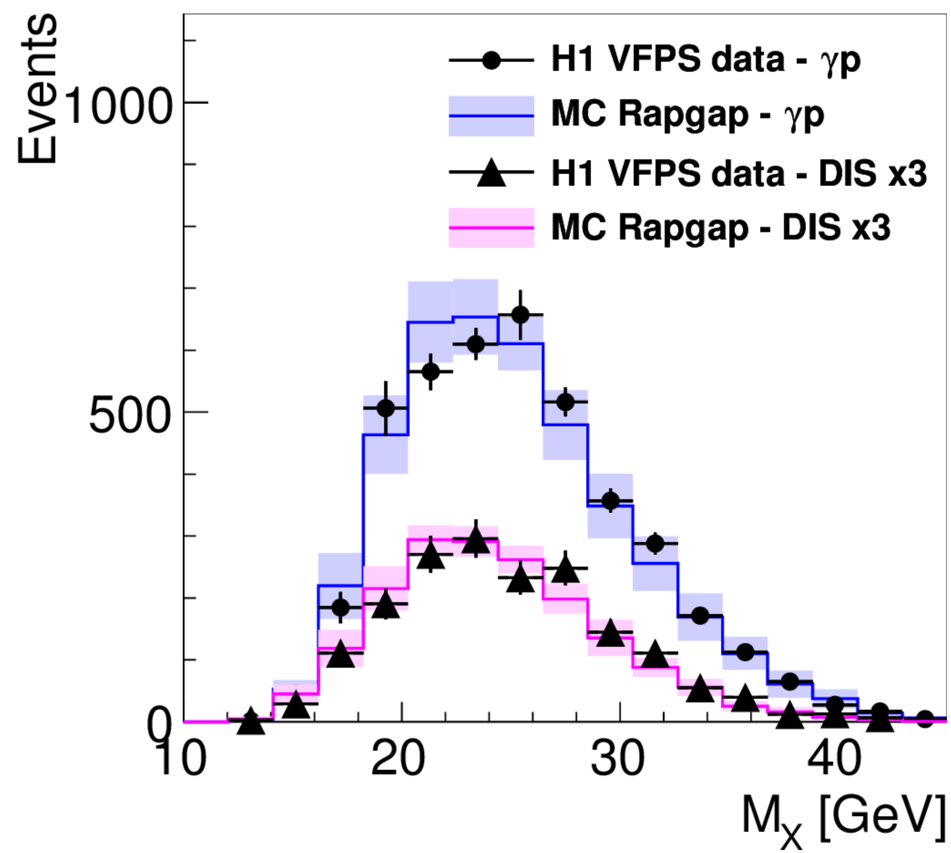
Control distributions diffraction





Control distributions Q^2 and M_X





Control distributions jet angles