Latest results on diffraction at HERA

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(on behalf of the H1 and ZEUS Collaborations)

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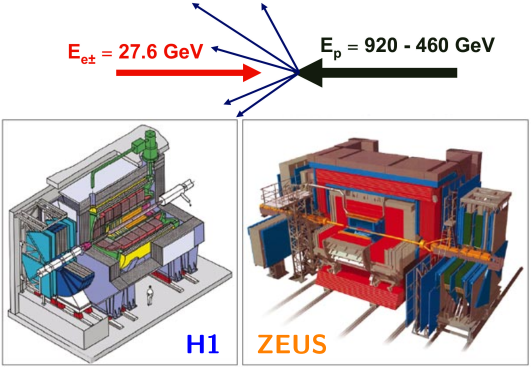
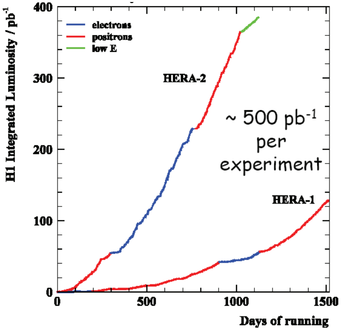
Outline

Recent results on diffraction from H1 and ZEUS experiments:

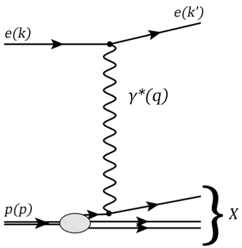
- Measurement of $D^\star$ production in diffractive deep inelastic scattering at HERA
  H1 Collaboration, Eur. Phys. J. C (2017) 77:340
- Measurement of the cross section ratio $\boldsymbol{\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}}$ in exclusive DIS
  ZEUS Collaboration, Nucl. Phys. B909 (2016) 934-953
- Studies of the diffractive photoproduction of isolated photons at HERA
  ZEUS Collaboration, DESY-17-077, Submitted to Phys. Rev. D

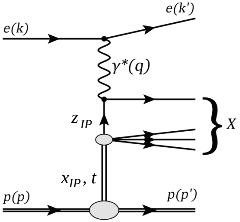




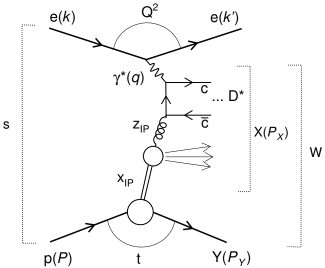
DIS, photoproduction and diffraction in ep collisions

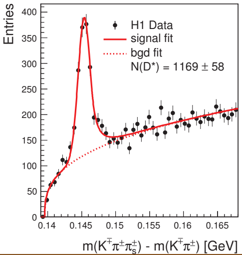
- Deep inelastic scattering (DIS):
  - Kinematics: $s = (k+p)^2, \quad W^2 = (q+p)^2$
  $$Q^2 = -q^2 = -(k-k')^2, \quad x = \frac{Q^2}{2q \cdot p}, \quad y = \frac{q \cdot p}{k \cdot p}$$
  - Charaterized by large photon virtualities Q^2.
  - Collinear factorisation allows to extract PDFs (with DGLAP evolution equations) from one process and use them to predict cross section for another process.
- Photoproduction: $Q^2 \approx 0$
- Diffractive deep inelastic scattering (DDIS):
  - Large rapidity gap between proton and hadronic system X,
  - pQCD description in terms of exchange of collective colorless partonic state (Pomeron) based on collinear factorisation and proton vertex factorisation theorems (diffractive PDFs).
  - Kinematics:
  $$x_{I\!P} = \frac{q \cdot (p-p')}{q \cdot p}, \quad z_{I\!P} = \frac{\hat{s} + Q^2}{M_X^2 + Q^2}, \quad t = (p-p')^2$$
  where $\hat{s}$ is the centre-of-mass energy of the hard process.
- Diffractive photoproduction: $Q^2 \approx 0$

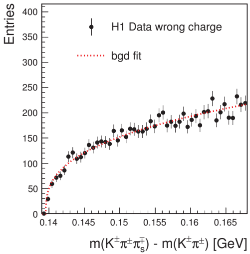


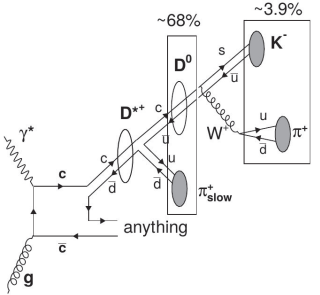


- DIS cuts: $5 < Q^2 < 100\,\text{GeV}^2,\ 0.02 < y < 0.65$
- DDIS: large rapidity gap method with $\eta_{\text{max}} < 3.2$
- $D^\star$ production in photon-gluon fusion $\gamma^\star g \to c\bar{c}$
- $D^\star$ signal reconstruction in the 'golden channel':
  $D^{\star +} \to D^0 \pi^+_{\text{slow}} \to (K^- \pi^+)\pi^+_{\text{slow}} \quad (+C.C.)$
  - tracks: $p_{t,K}, p_{t,\pi} > 0.3\,\text{GeV}, \quad p_{t,\pi_{\text{slow}}} > 0.12\,\text{GeV}$
  - signal in: $\Delta m = m(K^\mp \pi^\pm \pi^\pm_{\text{slow}}) - m(K^\mp \pi^\pm)$
  - no signal in: $\Delta m = m(K^\pm \pi^\pm \pi^\mp_{\text{slow}}) - m(K^\pm \pi^\pm)$
  - background suppresion by D^0 mass cut:
    $|m(K^\mp \pi^\pm) - m(D^0_{\text{DPG}})| < 80\,\text{MeV}$







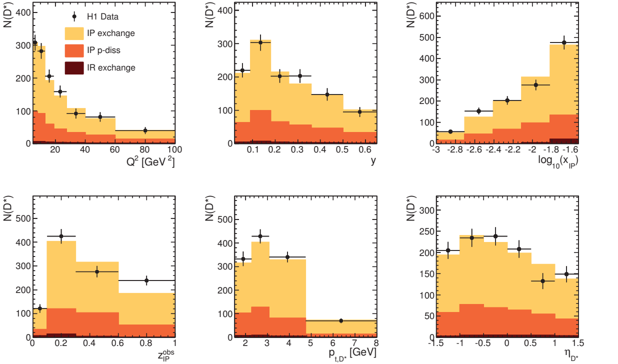


$D^\star$ production in diffractive deep inelastic scattering

- H1 data: 287 pb^{-1} at $\sqrt{s} = 319$ GeV
- Signal MC: RAPGAP with H1 2006 DPDF Fit B (elastic + proton dissociative)

  relative normalisation: $\sigma(M_Y < 1.6\,\text{GeV})/\sigma(M_Y = m_p) = 1.20 \pm 0.11$
- Background MC: RAPGAP with CTEQ6L PDF (non-diffractive, $< 1\%$)
- Good description of data by simulation.
- Cross section measurement in the phase space:

DIS phase space
$5 < Q^2 < 100$ GeV^2
$0.02 < y < 0.65$
Fiducial cuts on $D^\star$
$p_{t,D^\star} > 1.5$ GeV
$-1.5 < \eta_{D^\star} < 1.5$
Diffractive phase space
$x_{I\!P} < 0.03$
$M_Y < 1.6$ GeV
$\|t\| < 1$ GeV^2

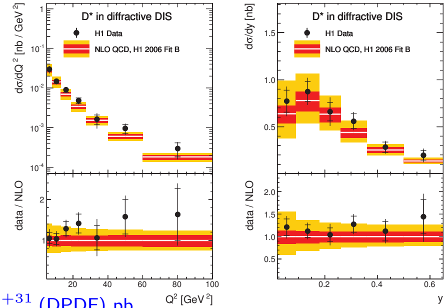


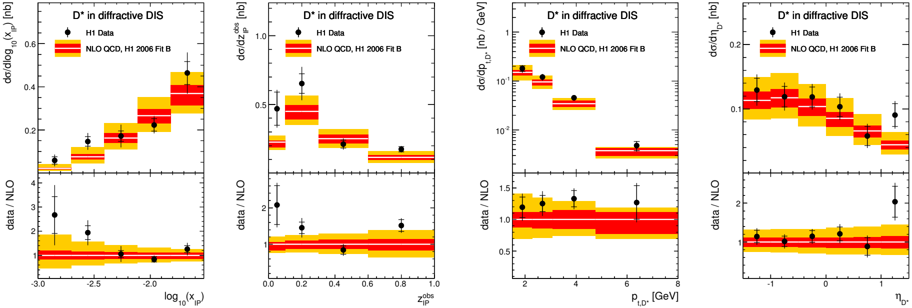
$D^\star$ production in diffractive deep inelastic scattering

- Differential and total cross sections have been measured in phase space defined on the previous slide.
- The shapes of all variables are well described by NLO QCD (HVQDIS).
- Total cross section:

$$\sigma_{ep\to eYX(D^\star)} = 314 \pm 23\,(\text{stat}) \pm 35\,(\text{sys})\ \text{pb}$$

$$\sigma^{\text{theory}}_{ep\to eYX(D^\star)} = 265^{+54}_{-40}\,(\text{scale})\ {}^{+68}_{-54}\,(m_c)\ {}^{+7.0}_{-8.2}\,(\text{frag})\ {}^{+31}_{-35}\,(\text{DPDF})\ \text{pb}$$





$D^\star$ production in diffractive deep inelastic scattering

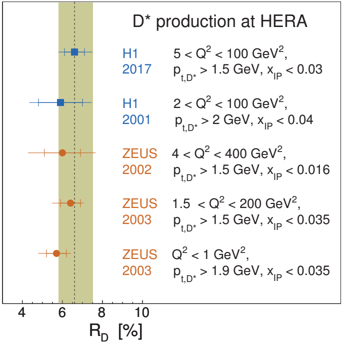
Diffractive to non-diffractive ratio $R_D = \sigma^{\text{diff}}_{D^\star} / \sigma^{\text{non-diff}}_{D^\star}$

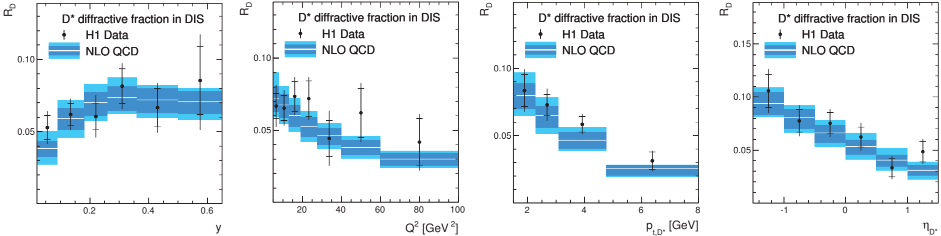
- using non-diffractive $D^\star$ cross section:
  H1 Collab., Eur. Phys. J. C71 (2011) 1769
- correction to common PS by HVQDIS $(1\% - 3.5\%)$
- partial cancellation of systematic uncerainties,
- theoretical predictions by HVQDIS in NLO QCD,
- good agreement with previous results,
- compatible ratios in DIS and photoproduction.

$$R_D = 6.6 \pm 0.5\,\text{(stat)}\,^{+0.9}_{-0.8}\,\text{(sys)}\ \%$$

$$R_D^{\text{theory}} = 6.0^{+1.0}_{-0.7}\,\text{(scale)}\,^{+0.5}_{-0.4}\,(m_c)\,^{+0.7}_{-0.8}\,\text{(DPDF)}\,^{+0.02}_{-0.04}\,\text{(frag)}\ \%$$

Diffractive fraction

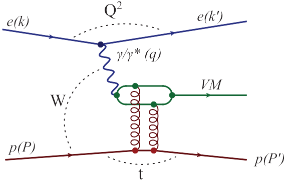


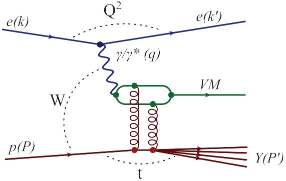


Cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in exclusive DIS

Exclusive diffractive vector meson (VM) production:

- photon fluctuates into $q\bar{q}$ pair which interacts with the proton via colourless exchange, e.g. two-gluon ladder, and then hadronises into the vector meson (VM),
- proton can dissociate into a low mass system.





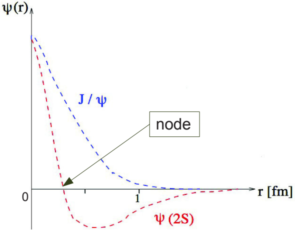
Measure the ratio of the cross sections:

$$R = \frac{\sigma(\gamma^\star p \to \psi(2S)p)}{\sigma(\gamma^\star p \to J/\psi(1S)p)}$$

which is insensitive to many systematic uncertainties.

$\psi(2S)$ and $J/\psi(1S)$ have the same quark content, but different radial wave functions, which means that R is sensitive to the radial wave function of charmonium and provides insight into the dynamics of hard process.

- $\psi(2S)$ has a node at 0.35 fm (typical transverse separation of virtual $c\bar{c}$ pair),
- $\langle r^2_{\psi(2S)}\rangle \approx 2\langle r^2_{J/\psi(1S)}\rangle$
- pQCD predicts rise of R with Q^2 starting from $R(Q^2 = 0) \approx 0.17$

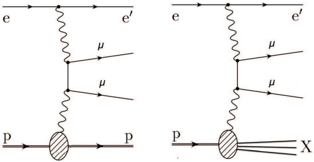


Cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in exclusive DIS

ZEUS data: 468 pb^{-1} ($5 < Q^2 < 80$ GeV^2)
+ 114 pb^{-1} ($2 < Q^2 < 5$ GeV^2)

Signal MC: DIFFVM (exclusive VM production)

Background MC: GRAPE (Bethe-Heitler elastic and proton dissociative $\mu^+\mu^-$ production)



Event selection:

$E' > 10$ GeV, $|z_{\text{vtx}}| < 30$ cm,

$5\ (2) < Q^2 < 80$ GeV^2, $30 < W < 210$ GeV, $|t| < 1$ GeV^2

Investigated decay channels and their selection:

$\left.\begin{array}{l}\psi(2S) \to \mu^+\mu^- \\ J/\psi(1S) \to \mu^+\mu^-\end{array}\right\}$ two tracks identified as muons and nothing else in the detector above noise level are required

$\psi(2S) \to J/\psi(1S)\pi^+\pi^- \to \mu^+\mu^-\,\pi^+\pi^-$ } in addition two pion tracks from the $\mu^+\mu^-$ vertex are required

Measure the ratios:

$$R_{\mu\mu} = \frac{\sigma_{\psi(2S)\to\mu\mu}}{\sigma_{J/\psi(1S)\to\mu\mu}} = \left(\frac{N_{\mu\mu}^{\psi(2S)}}{B(\psi(2S)\to\mu\mu)\cdot A_{\mu\mu}^{\psi(2S)}}\right) \Big/ \left(\frac{N_{\mu\mu}^{J/\psi(1S)}}{B(J/\psi(1S)\to\mu\mu)\cdot A_{\mu\mu}^{J/\psi(1S)}}\right)$$

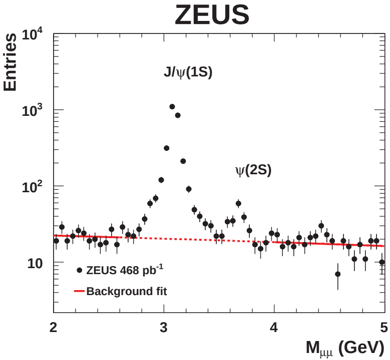
$$R_{J/\psi\pi\pi} = \frac{\sigma_{\psi(2S)\to J/\psi\,\pi\pi}}{\sigma_{J/\psi(1S)\to\mu\mu}} = \left(\frac{N_{J/\psi\,\pi\pi}^{\psi(2S)}}{B(\psi(2S)\to J/\psi(1S)\,\pi\pi)\cdot A_{J/\psi\,\pi\pi}^{\psi(2S)}}\right) \Big/ \left(\frac{N_{\mu\mu}^{J/\psi(1S)}}{A_{\mu\mu}^{J/\psi(1S)}}\right)$$

Cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in exclusive DIS

Background subtraction in $J/\psi \to \mu^+\mu^-$ and $\psi \to \mu^+\mu^-$:

BH dimuon background fit to straight line for $2 < M_{\mu\mu} < 2.62$ GeV and $4.05 < M_{\mu\mu} < 5$ GeV.

J/ψ and ψ signals: numbers of events above background in the range $3.02 < M_{\mu\mu} < 3.17$ GeV and $3.59 < M_{\mu\mu} < 3.79$ GeV, respectively.



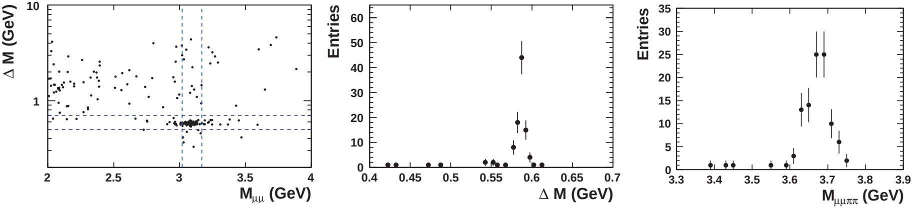
Background subtraction in $\psi(2S) \to J/\psi\, \pi^+\pi^-$:

Data show a clear peak on the scatterplot $\Delta M = M_{\mu\mu\pi\pi} - M_{\mu\mu}$ vs. $M_{\mu\mu}$

Applied cuts:

$3.02 < M_{\mu\mu} < 3.17$ GeV and $0.5 < \Delta M < 0.7$ GeV

No background (upper limit 3 ev. at 90% CL)



Cross section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in exclusive DIS

R is measured in the kinematic range:

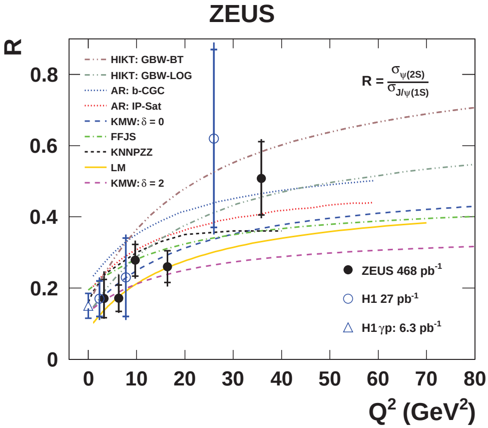
$5\ (2) < Q^2 < 80$ GeV^2
$30 < W < 210$ GeV, $|t| < 1$ GeV^2

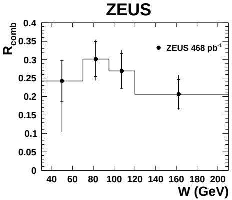
- Data contain proton dissociative background with masses $M_Y < 4$ GeV.
- Assuming that cross section ratio does not vary with M_Y, the results are not affected by proton dissociation backgr.
- Combined ratio R obtained as weighted average of the cross sections determined for the two $\psi(2S)$ decay channels.

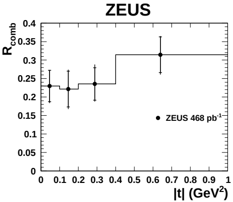
- All models predict rise of R with Q^2:

  HIKT, Hufner et al.:
  dipole model, dipole-proton constrained by inclusive DIS data
  AR, Armesto and Rezaeian:
  impact parameter dependent CGC and IP-Sat model
  KMW, Kowalski, Motyka and Watt:
  QCD description and universality of quarkonia production
  FFJS, Fazio et al.: two component Pomeron model
  KNNPZZ, Nemchik et al.:
  color-dipol cross section derived from BFKL generalised equation
  LM, Lappi and Mäntysaari: dipole picture in IP-Sat model

- Good agreement with earlier H1 mesurements (EPJ C10 (1999) 373)
- R is independent of W and $|t|$

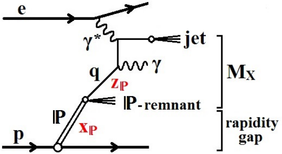




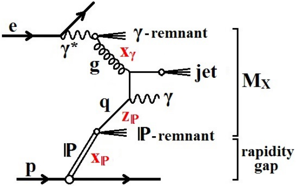


Diffractive photoproduction of isolated photons

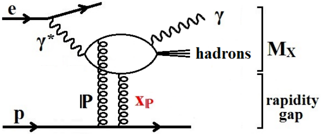
- High p_T photons can be:
  - produced in a hard partonic interaction (prompt photons),
  - radiated from the incoming or outgoing lepton,
  - radiated from a quark within a jet or be decay product of a hadron within a jet.
- Prompt photons arising from hard diffractive photoproduction:
  - are relatively well isolated from other final state particles,
  - demonstrate presence of either a quark in the Pomeron or of higher-order process in which both the Pomeron and the exchanged photon couple to quarks.
- In contrast, diffractive dijet production is mainly sensitive to the gluon content of the Pomeron.



direct-resolved
($x_\gamma \approx 1,\ z_{\mathbb{P}} < 1$)



resolved-resolved
($x_\gamma < 1,\ z_{\mathbb{P}} < 1$)



direct-direct
($x_\gamma \approx 1,\ z_{\mathbb{P}} \approx 1$)

$x_\gamma \,/\, z_{\mathbb{P}}$ are the fractions of the $\gamma^\star \,/\, \mathbb{P}$ momenta taking part in hard scattering:

$$z_{\mathbb{P}}^{\text{meas}} = \frac{(E+p_z)^\gamma + (E+p_z)^{\text{jet}}}{(E+p_z)^{\text{all}}} \qquad x_\gamma^{\text{meas}} = \frac{(E-p_z)^\gamma + (E-p_z)^{\text{jet}}}{(E-p_z)^{\text{all}}} \qquad x_{\mathbb{P}}^{\text{meas}} = \frac{(E+p_z)^{\text{all}}}{2E_p}$$

Diffractive photoproduction of isolated photons

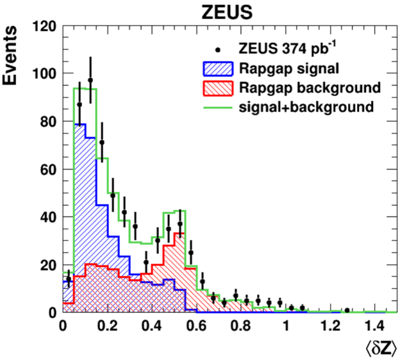
- ZEUS data HERA I+II: $82 + 374$ pb^{-1}
- Signal MC: RAPGAP with H1 2006 DPDF Fit B (no direct Pomeron) and SASGAM-2D

Photoproduction	Diffraction
no electron with $E > 3.5$ GeV $0.02 < (E - p_z)^{\text{all}}/2E_e < 0.7$	$E_{\text{FPC}} < 1$ GeV or $\eta_{\text{max}} < 2.5$ $x_{I\!P} < 0.03$
Hard photons	**Jets**
$E_{\text{EMC}}/(E_{\text{EMC}} + E_{\text{HAC}}) > 0.9$ $5 < E_T^\gamma < 15$ GeV $-0.7 < \eta^\gamma < 0.9$ in jet: $E_T^\gamma > 0.9 E_T^{\text{jet}}$	k_T-cluster algorithm $(R = 1)$ $4 < E_T^{\text{jet}} < 35$ GeV $-1.5 < \eta^{\text{jet}} < 1.8$

- Background from events in which one or more neutral mesons (π^0, η) have decayed to photons is subracted statisticaly using

$$\langle \delta Z \rangle = \Sigma_i E_i |Z_i - Z_{\text{cluster}}| / (w_{\text{cell}} \Sigma_i E_i)$$

fitted for each measured cross section interval using signal and background histograms templates obtained from MC.



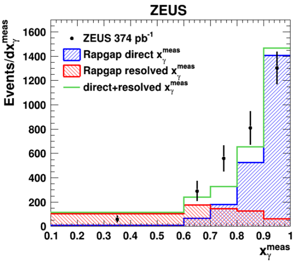
- Proton dissociation effects (not subtracted):

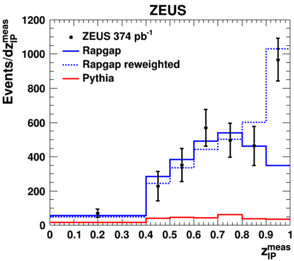
HERA I: $16 \pm 4\%$, $M_Y < 3$ GeV

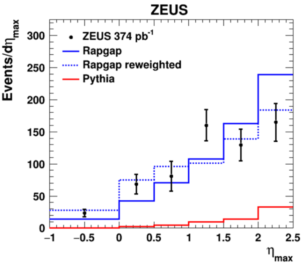
HERA II: $45 \pm 15\%$, $M_Y < 6$ GeV

Diffractive photoproduction of isolated photons

- A 70:30 mixture of direct:resolved photon events generated with Rapgap gives a reasonable description of the $x_\gamma^{\rm meas}$ distribution in data and is employed in the following distributions.
- However, the shape of $z_{I\!P}^{\rm meas}$ still differes for $z_{I\!P}^{\rm meas} > 0.9$ – additional reweighting by factor 7 of direct photon contribution for $z_{I\!P} > 0.9$ at the hadron level is necessary.
- Reweighting Rapgap to the shape of $z_{I\!P}^{\rm meas}$ in data, provides also better description of $\eta_{\rm max}$ distribution, but has little effect on other variables.
- Non-diffractive background (simulated with Pythia) up to 10%, although not necessary to give correct description of data, can not be excluded. It is included in asymmetric systematic uncertainty.



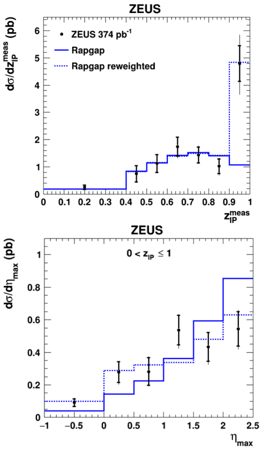




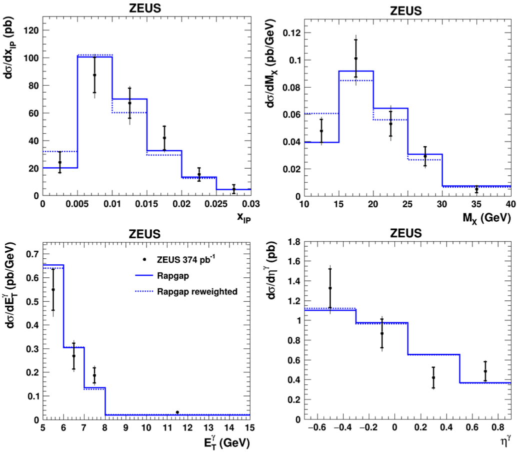
Diffractive photoproduction of isolated photons

- Many differential cross sections for, inclusive and accompanied by at least one jet, production of isolated photon have been measured and compared to the reweighted Rapgap.
- Data suggest significant contribution from direct Pomeron interactions.

Production accompanied by jets



Inclusive production



Summary

Experiments H1 and ZEUS at HERA provided new results on diffraction:

- (H1) Diffractive $D^\star$ production cross sections in DIS agree in both, shapes and normalisation, with NLO QCD predictions using H1 2006 DPDF Fit B.
- (H1) Data provide support for collinear factorisation in DDIS.
- (H1) Diffractive to non-diffractive ratios are also in agreement with NLO calculations. No sign for different rapidity gap probability in DIS and photoproduction.
- (ZEUS) Measurement of the cross sections ratio $R = \sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in exclusive DIS is in agreement with pQCD predictions regarding its rise with Q^2 and being independent of W and $|t|$.
- (ZEUS) In spite of significantly improved accuracy compared to previous H1 result, only very rough discrimination of models of exclusive VM production is possible.
- (ZEUS) First measurement of diffractive photoproduction of isolated photons, inclusively and accompanied by at least one jet.
- (ZEUS) Data provide evidence for direct Pomeron interactions, dominantly in the direct photon channel.

Thank you for your attention!

Backup slides

H1 - $D^\star$ production in DDIS - systematic checks

The following sources of systematic uncertainties were considered:

- Energy scale (polar angle) of the scattered lepton is known to the 1% (1 mrad) level resulting in a 0.5% (1.5%), uncertainty.
- Relative energy scale of the hadronic final state, known up to 1%, has an 0.06% effect.
- Uncertainty in energy losses at high η results in 2.7% uncertainty.
- Ambiguity in describing the tails of the Δm signal distribution has 3.8% effect.
- Normalisation of the proton dissociative contribution introduces an uncertainty of 7.1%
- A 10% uncertainty on the large rapidity gap selection inefficiency determined in a dedicated study, translates to a 2.4% uncertainty.
- Uncertainties on the data correction procedure stemming from the shapes of $Q^2, y, x_{I\!P}$, $p_{t,D^\star}$ and t in MC model have uncertainties: 0.5, 0.9, 0.4, 3.7 and 1.1%, respectively.
- Integrated luminosity is known to 2.7% and the golden channel branching ratio to 1.1%
- Uncertainty on the trigger efficiency (98% on average) is covered by a 2% variation.
- A systematic uncertainty of 2% covers the observed difference in yields of $D^\star$ between data and simulation due to 80 MeV mass cut window on D^0.
- Branching fractions of $D^\star$ decaying to reflections are not precisely reproduced in the simulation; integrated cross section increases by about 1.2% if recent BR are used.
- Track reconstruction efficiency is known with 1% uncertainty resulting in 3% per $D^\star$.
- Contribution of non-diffractive processes is suppressed by the diffractive selection to a level of less than 1%; a conservative uncertainty of 1% is assigned.

H1 - $D^\star$ production in DDIS - additional information

- Cross section measurements:

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}x}\right)_i = \frac{N_i^{\text{data}} - N_i^{\text{sim, bgr}}}{\mathcal{L}_{\text{int}}\,\Delta_i^x\,B_r\,\varepsilon_{\text{trig}}\,A_i}\,C_{\text{corr},i}^{\text{QED}}, \qquad A_i = \frac{N_i^{\text{sim}} - N_i^{\text{sim, bgr}}}{n_i^{\text{sim}}}$$

- Predictions for $D^\star$ cross sections in NLO QCD are obtained from HVQDIS:
  - Based on B.W. Harris and J. Smith, Nucl. Phys. B452 (1995) 109; Phys. Rev. D57 (1998) 2806.
  - Modified for diffraction - collinear factorization with H1 2006 DPDF Fit B NLO PDF.
  - Massive charm quarks are produced via photon-gluon fusion.
  - Charm quarks are fragmented independently into $D^\star$ mesons in the $\gamma^\star p$ rest frame using $f(c \to D^\star) = 0.235 \pm 0.007$ and the Kartvelishvili parametrisation for reweighting of longitudinal part.
  - Factorization and renormalization scales set to $\mu_r = \mu_f = \sqrt{Q^2 + 4m_c^2}$ with $m_c = 1.5$ GeV.
- Probability distribution functions used in fits to Δm distributions:
  - Signal: Crystal Ball function - Gaussian core with power-law low-end tail, below a certain threshold.
  - Combinatorial background: Granet function, Nucl. Phys. B 140, 389 (1978)

$$f(\Delta m - m_{\pi^\pm}) = (\Delta m - m_{\pi^\pm})^{p_1} \cdot \exp\left[-p_2(\Delta m - m_{\pi^\pm})\right]$$

ZEUS - $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ - systematic checks

The following sources of systematic uncertainties were considered:

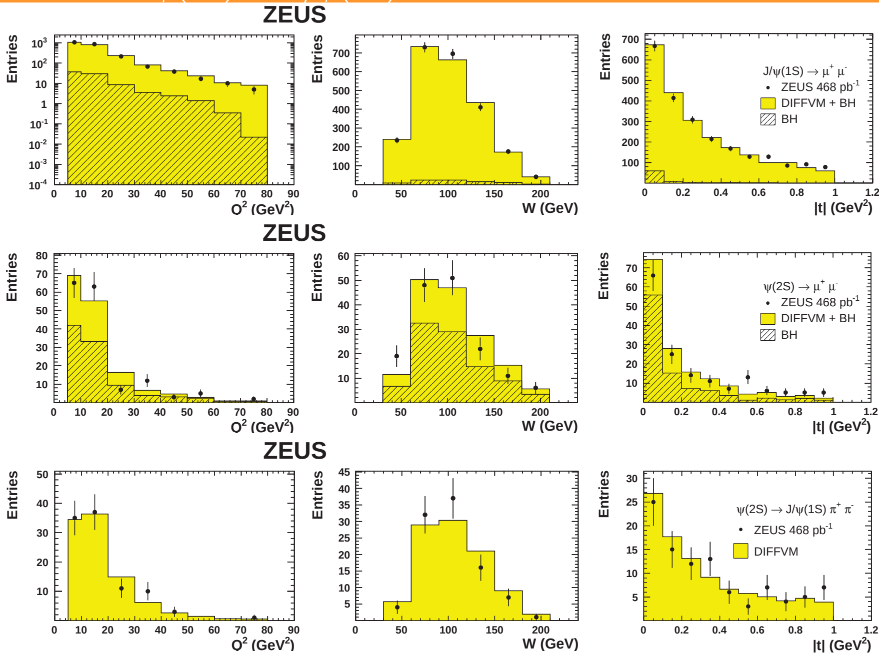
- varying the nominal $M_{\mu\mu}$ window for counting signal events:
  - for $J/\psi(1S)$: from $3.02 - 3.17$ GeV to $3.05 - 3.15$ GeV and $2.97 - 3.22$ GeV
  - for $\psi(2S)$: from $3.59 - 3.79$ GeV to $3.62 - 3.75$ GeV and $3.55 - 3.80$ GeV

  changes the values of $R_{\mu\mu}$ by 2% and 6%, and $R_{J/\psi\pi\pi}$ by 1.5% and -0.5%, respectively;
- changing the cut on the transverse momenta of pion tracks from the nominal value of 0.12 GeV to 0.15 GeV changes the value of $R_{J/\psi\pi\pi}$ by -4.5%;
- changing the background fit function from linear to quadratic changes the values of $R_{\mu\mu}$ by -11% and of $R_{J/\psi\pi\pi}$ by 0.5%;
- changing the reconstruction of kinematic variables from the *constrained* to *electron* method changes the values of both $R_{\mu\mu}$ and $R_{J/\psi\pi\pi}$ by 1.5%;
- not applying the reweighting of the Monte Carlo events changes the values of $R_{\mu\mu}$ by -3% and of $R_{J/\psi\pi\pi}$ by -1%;
- applying different cuts on the total number of tracks, including tracks not associated with the event vertex, changes $R_{\mu\mu}$ by -5% and $R_{J/\psi\pi\pi}$ by 3%.

Total systematic uncertainties obtained by separate quadratic sums of the positive and negative changes read:

$$\delta R_{\mu\mu} = ^{+7}_{-14}\,\%, \quad \delta R_{J/\psi\pi\pi} = ^{+4}_{-5}\,\%, \quad \delta R_{\text{comb}} = ^{+3}_{-5}\,\%$$

ZEUS - $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ - comparison of data with MC

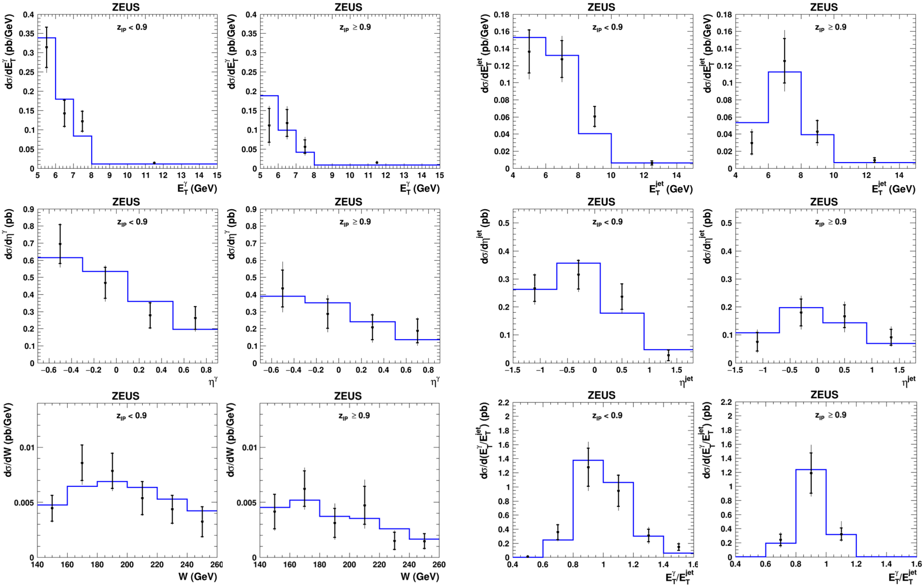


The following sources of systematic uncertainties were considered:

- Energy scale uncertainty: the energy of the photon candidate and independently the energy of the accompanying jet were varied by $\pm 2\%$ in the MC at the detector. Each of them gave variations in the measured cross sections of typically $\pm 5\%$.
- Uncertainty in the acceptance due to the estimation of the relative fractions of direct and resolved photon events in the Rapgap sample was estimated by varying the fraction of direct photon events between 60% and 80%; this gave a $\pm 2\%$ uncertainty.
- Dependence of the result on the modelling by the MC of the hadronic background in the $\langle \delta Z \rangle$ distribution was investigated by varying the upper limit for the $\langle \delta Z \rangle$ fit in the range $[0.6, 1.0]$; this gave a $\pm 2\%$ uncertainty.
- The non-diffractive photoproduction background was estimated by fitting a number of experimental variables to mixtures of Rapgap and Pythia samples. The Pythia samples were treated in the same way as the data, using an appropriate mixture of resolved and direct photoproduction events. It was found that a satisfactory description of the data was obtained with no non-diffractive background, but that up to 10% of background could not be excluded. This is included as an asymmetric systematic uncertainty.
- A possible contamination of DIS events was investigated using the programs Grape-Compton and Djangoh, and a possible contribution from photon–photon interactions was investigated using Grape-Compton. Both of these were found to be negligible.
- The uncertainties of 2% on the trigger efficiency and 1.9% on the luminosity measurement are included in the uncertainties on the visible cross sections.

ZEUS - DPHP of isolated photons - cross sections

Cross sections for isolated photon production accompanied by at least one jet:



Cross sections for isolated photon production accompanied by at least one jet: