Exclusive photoproduction of vector mesons and Z/γ^*

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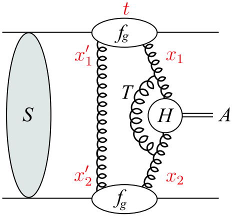
Talk based on work done in collaboration with L. Motyka:
Phys. Rev. D **78** (2008) 014023 [arXiv:0805.2113]

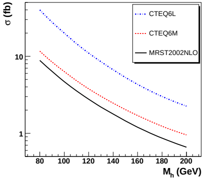
Motivation: central exclusive production at the LHC

Khoze, Martin, Ryskin [arXiv:0802.0177, and references therein]:

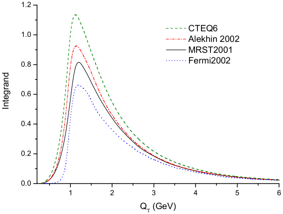
$$\sigma(pp \to p+A+p) \sim \frac{S^2}{B_D^2} \left| \frac{\pi}{8} \int \frac{\mathrm{d}Q_T^2}{Q_T^4}\, f_g(x_1, x_1', Q_T^2, \mu^2)\, f_g(x_2, x_2', Q_T^2, \mu^2) \right|^2 \hat{\sigma}(gg \to A)$$



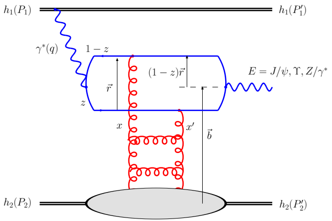
$$f_g(x, x', Q_T^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_T^2} \left[\sqrt{T_g(Q_T^2, \mu^2)}\, xg(x, Q_T^2) \right]$$



Integrand dominated by $Q_T \sim$ 1–2 GeV $\Rightarrow$ pQCD applicable (just).



Exclusive photoproduction at the LHC



Klein and Nystrand [hep-ph/0311164]

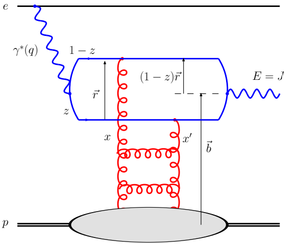
- Exclusive final state $E = J/\psi, \Upsilon, Z/\gamma^*$ with rapidity y.
- Flux $\mathrm{d}n/\mathrm{d}k$ of quasi-real photons with energy $k \simeq (M_E/2)\exp(y) \simeq W^2/(2\sqrt{s})$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y}(h_1 h_2 \to h_1 + E + h_2) = k\frac{\mathrm{d}n}{\mathrm{d}k}\sigma(\gamma p \to E + p) \quad + \quad (y \to -y)$$

Disclaimer

- Neglect interference between photon–Pomeron and Pomeron–photon fusion, and effect of absorptive corrections from soft rescattering.
- Only present cross sections integrated over final state momenta, then these effects will be largely washed out. (Rapidity gap survival factor $S^2 \sim 0.7$–0.9.)
- Detailed treatment of these effects by Khoze, Martin and Ryskin [hep-ph/0201301] and by Rybarska, Schäfer and Szczurek [arXiv:0705.2887, arXiv:0805.0717].

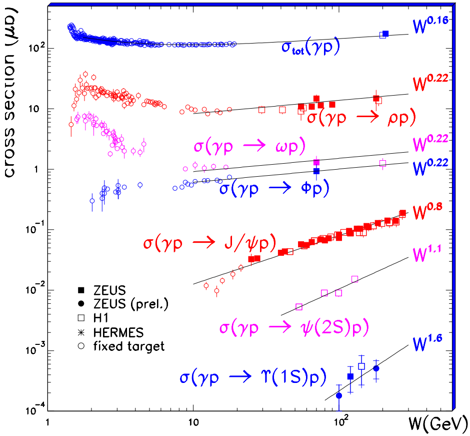
Exclusive photoproduction at HERA



- In LLA [Ryskin '93]:

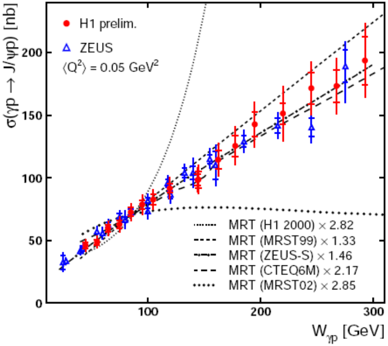
$$\sigma \propto \left[xg(x, M_V^2/4)\right]^2$$

- Beyond LLA, use k_T-factorization [Martin, Ryskin, Teubner].



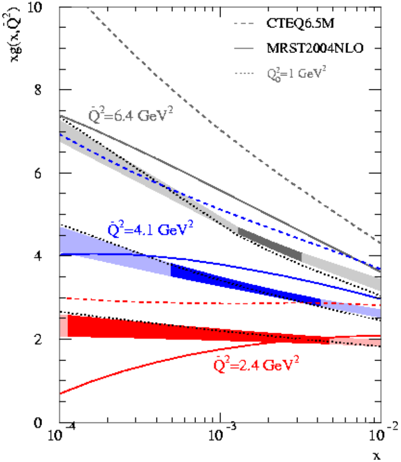
Small-x gluon density from exclusive J/ψ at HERA

Plot by P. Fleischmann (H1).

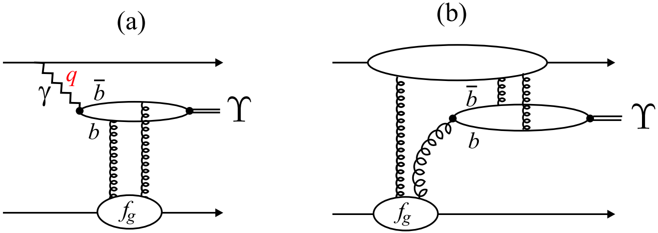


- J/ψ data can discriminate.
- $\Rightarrow$ Fit gluon directly.

MRT+Nockles [arXiv:0709.4406]



Potential for odderon discovery at the Tevatron and LHC



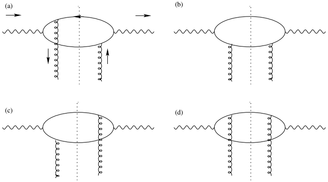
- **Pomeron** is colour singlet exchange with **even** charge parity.
- Hypothetical partner with **odd** charge parity is the **odderon**.
- Bdzak, Motyka, Szymanowski, Cudell [hep-ph/0702134] calculated odderon-to-photon ratio using k_T-factorisation:

	J/ψ	Υ
Tevatron	0.3–0.6	0.8–1.7
LHC	0.06–0.15	0.16–0.38

- Odderon exchange also leads to different p_T-distribution.

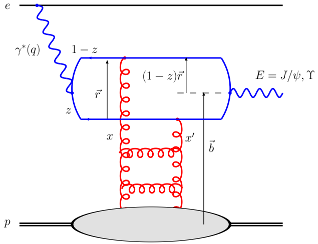
Dipole model approach for exclusive diffractive processes

Bartels, Golec-Biernat, Peters [hep-ph/0301192]



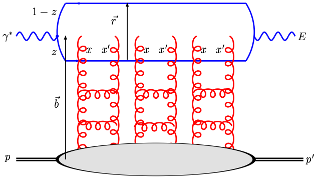
- Non-forward photon impact factor calculated in the high-energy limit.

- Fourier transform from momentum space to coordinate space ($\mathbf{k} \to \mathbf{r}$), then to impact parameter space ($\mathbf{\Delta} \to \mathbf{b}$), with $t = -\Delta^2$.



- Amplitude factorises into:
  (wave function)·(dipole cross section)·(wave function).

Impact parameter dependent saturation (b-Sat) model



Kowalski, Teaney [hep-ph/0304189]
Kowalski, Motyka, G.W. [hep-ph/0606272]
G.W., Kowalski [arXiv:0712.2670]

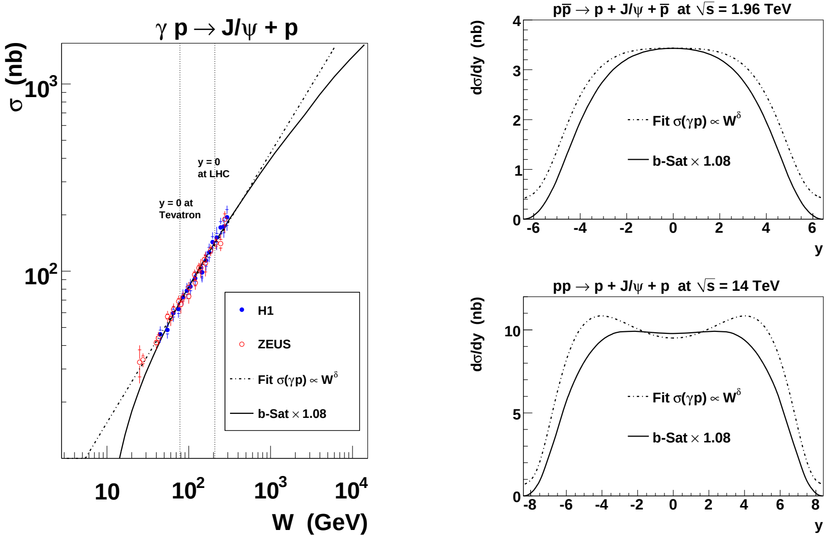
- DGLAP-evolved gluon density with Gaussian b dependence:

$$\mathcal{N}(x,r,b) = 1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_S(\mu^2)\, xg(x,\mu^2)\, T(b)\right)$$

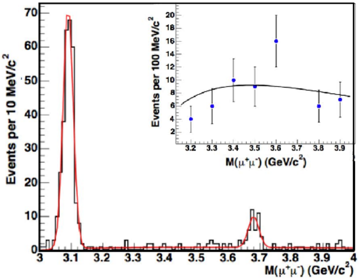
$$xg(x,\mu_0^2) = A_g\, x^{-\lambda_g}\,(1-x)^{5.6}, \quad T(b) = \frac{1}{2\pi B_G} \mathrm{e}^{-\frac{b^2}{2B_G}}$$

- $B_G = 4$ GeV^{-2} from t-slope of exclusive J/ψ photoproduction.
- Fit input gluon parameters (μ_0^2, A_g, λ_g) to small-x F_2 data.
- Good (parameter-free) description of exclusive $\gamma^* p \to V + p$ ($V = \rho, \phi, J/\psi, \gamma$) and inclusive $F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$, F_L, F_2^{D}.

Exclusive J/ψ photoproduction at Tevatron and LHC



Exclusive charmonium production [arXiv:0902.1271]



- CDF measure J/ψ:

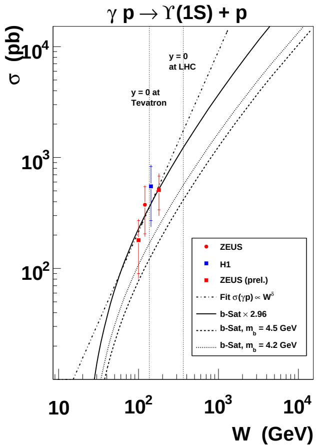
$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}y}\right|_{y=0} = (3.92 \pm 0.62)\text{ nb.}$$

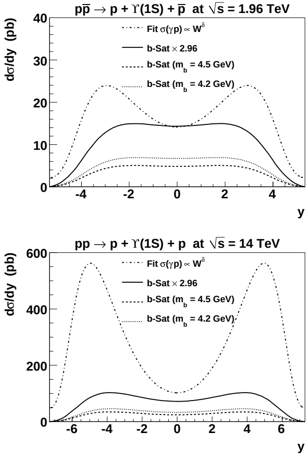
- Photoproduction contrib.: 3.4 nb $\times(S^2 \simeq 0.9)$
- Odderon-to-photon ratio: 0.3–0.6
- $\Rightarrow$ Total theory prediction: (4.0–4.9) nb.

Prospects for J/ψ measurements at the LHC

ATLAS/CMS unlikely to measure exclusive J/ψ due to lack of low p_T trigger on leptons, but should be possible with ALICE/LHCb.

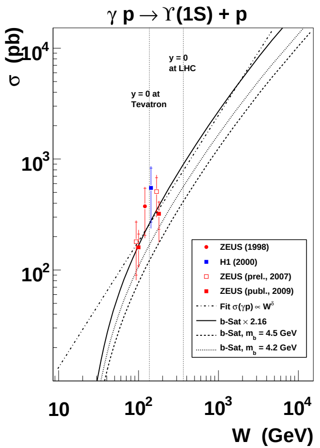
Exclusive Υ photoproduction at Tevatron and LHC

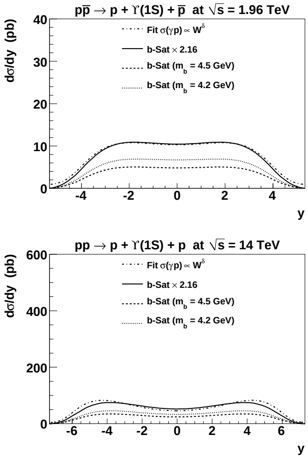




- Uncertainty in m_b and Ψ_Υ $\Rightarrow$ Scale to HERA data.
- Sensitive to W dependence of γp cross section.

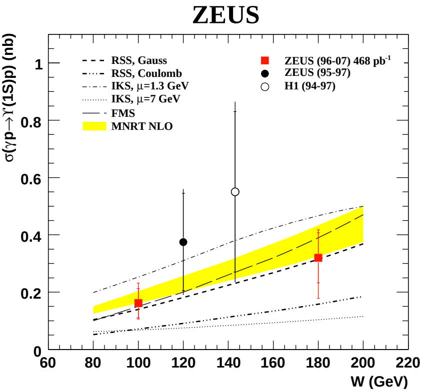
Update: publication of ZEUS data [arXiv:0903.4205]





- ZEUS 2009 points move down cf. 2007 (prel.) points.
- Fit to HERA data more compatible with model.

Other theory predictions compared to HERA Υ data



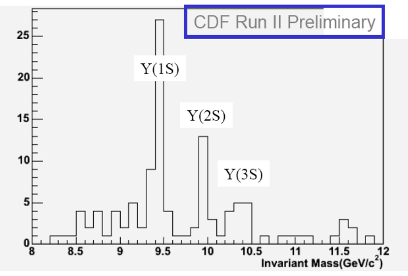
[ZEUS, arXiv:0903.4205]

- **RSS** = **R**ybarska, **S**chäfer, **S**zczurek [arXiv:0805.0717]
- **IKS** = **I**vanov, **K**rasnikov, **S**zymanowski [hep-ph/0412235]
- **FMS** = **F**rankfurt, **M**cDermott, **S**trikman [hep-ph/9812316]
- **MNRT** = **M**artin, **N**ockles, **R**yskin, **T**eubner [arXiv:0709.4406]

Prospects for exclusive Υ at Tevatron and LHC

Tevatron

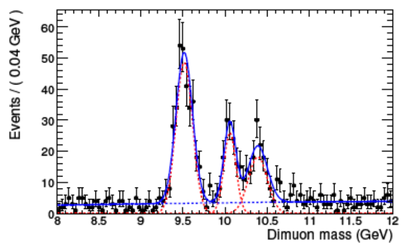
- Candidate events found by CDF.



- Cross section measurements eagerly awaited.

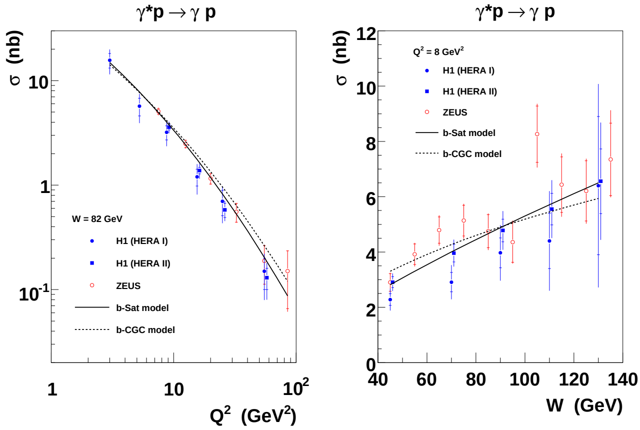
LHC

- Study by CMS [CMS PAS DIF-07-001] for 100 pb^{-1} and using STARLIGHT to generate signal sample.



Deeply virtual Compton scattering (DVCS) at HERA

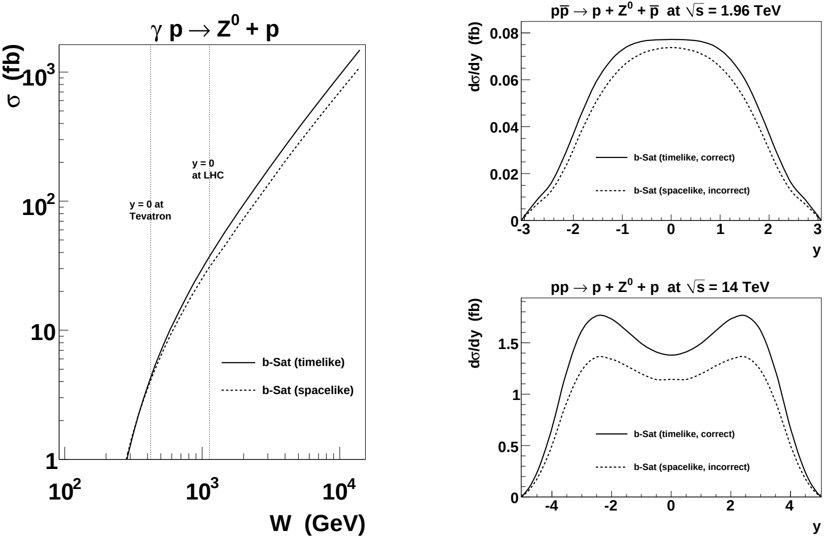
- DVCS theoretically cleaner than exclusive vector meson production since no uncertainty from wave function.



Timelike Compton scattering (TCS) and $\gamma p \to Z + p$

- Analogous processes to DVCS at hadron–hadron colliders are TCS ($\gamma p \to \gamma^* + p$) and exclusive Z photoproduction.
- Wave functions for an incoming Z/γ^* with **spacelike** virtuality $q^2 = -Q^2 < 0$ are already known.
- Wave functions for an outgoing Z/γ^* with **timelike** $q^2 = M^2 > 0$ worked out by Motyka and G.W. [arXiv:0805.2113].
- Amplitude for $\gamma p \to \gamma^* + p$ is **not** simply the DVCS amplitude at $Q^2 = M^2$: pick up **real** contribution to the amplitude.
- TCS interferes at amplitude level with the pure QED subprocess ($\gamma\gamma \to \ell^+\ell^-$), but the latter can be precisely calculated and suppressed by a cut on the polar angle [Pire, Szymanowski, Wagner, arXiv:0811.0321]. (This is similar to the measurement of DVCS at HERA, which interferes with the Bethe–Heitler process.)

Exclusive Z photoproduction at Tevatron and LHC



Search for exclusive Z by CDF [arXiv:0902.2816]

- Eight candidate events found in 2.20 (2.03) fb^{-1} of data in the electron (muon) channel with $M_{\ell\ell} > 40$ GeV and $\eta_\ell < 4$, consistent with prediction for $\gamma\gamma \to \ell^+\ell^-$ (LPAIR).
- No candidate events in Z mass window $\Rightarrow$ upper limit placed for exclusive Z cross section of $\sigma < 0.96$ pb at 95% confidence-level.
- Theory prediction: 0.3 fb, i.e. 3000 times lower than experimental limit.
- Certain BSM theory [A. White, hep-ph/0412062] predicts a much larger cross section, but without a quantitative estimate.
- Slightly more promising SM prediction at LHC: $\sigma = 13$ fb.

Summary of predictions for J/ψ, Υ and Z^0 production

J/ψ	$\mathrm{d}\sigma/\mathrm{d}y\vert_{y=0}$ (nb)	σ (nb)	Event rate (s^{-1})
Tevatron	3.4	28	0.33
LHC	9.8	120	71

$\Upsilon(1S)$	$\mathrm{d}\sigma/\mathrm{d}y\vert_{y=0}$ (pb)	σ (pb)	Event rate (hr^{-1})
Tevatron	10	83	1.5
LHC	53	772	690

Z^0	$\mathrm{d}\sigma/\mathrm{d}y\vert_{y=0}$ (fb)	σ (fb)	Event rate (yr^{-1})
Tevatron	0.077	0.30	0.065
LHC	1.4	13	135

- Event rates include leptonic branching ratio and assume a luminosity $\mathcal{L} = 2 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (Tevatron) and $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (LHC). No gap survival factor included.