Searching for the Odderon in exclusive vector meson hadroproduction

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Overview

Motivation

QCD calculation

Phenomenological improvements

Results and Discussion

Based on results obtained with A. Bzdak, J-R. Cudell and L. Szymanowski

Puzzle of Odderon

High energy scattering in QCD $\longrightarrow$ 2 color neutral reggeons with intercepts around 1:

Pomeron $(C = +1)$ and Odderon $(C = -1)$

Pomeron: Total cross sections and diffraction

Odderon: Difference between cross sections for AB and $A\bar{B}$ and exclusive processes

Searches for Odderon at HERA: $\gamma p \to p\pi^0$, $\gamma p \to \eta_c$, $\gamma p \to \eta_c X$,
asymmetries in diffractive charm and pion pair production $\longrightarrow$ no signal found

Some weak evidence for Odderon in elastic pp and $p\bar{p}$ scattering at CERN-ISR at $\sqrt{s} = 53$ GeV in the dip region $|t| \sim 1.5$ GeV^2

Odderon is important element of the theory

The first reggeon beyond Pomeron that fulfills BKP equation; **[J. Bartels, J. Kwieciński, M. Praszalowicz]**;

relevant for considerations of integrability in QCD **[L. Lipatov]**

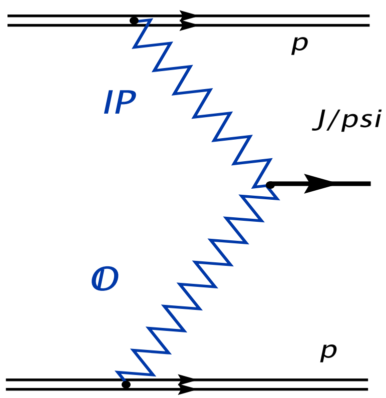
Proposal of measurement

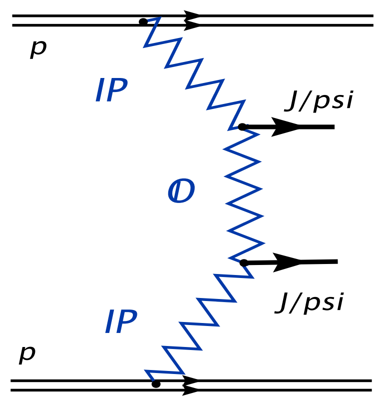
Exclusive production of vector mesons: **[A. Schäfer, L. Mankiewicz, O. Nachtmann 1991]**, **[C. Ewerz]**

$pp \to pp\, V$ (or $p\bar{p} \to p\bar{p}\, V$) with $V = J/\Psi, \Upsilon$

C-parity conservation requires the Odderon exchange (or the photon)

Alternatively: $pp \to p$ gap V gap V gap p



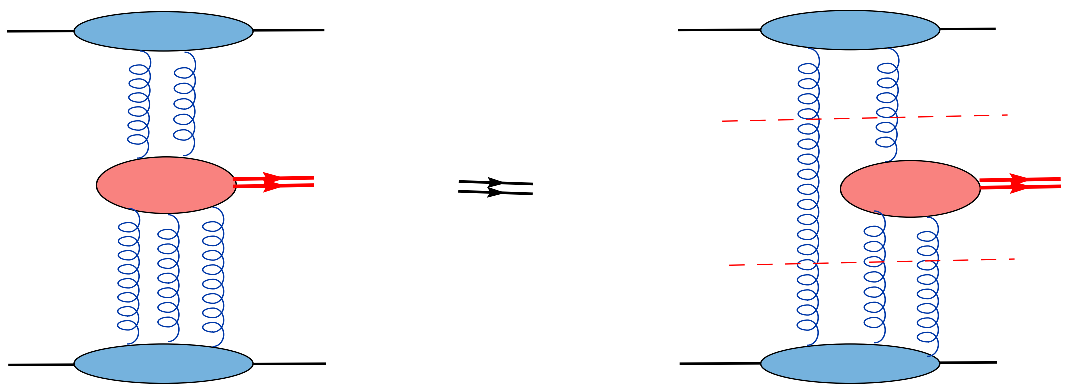


Formalism

Basic tool – QCD at high energy $\longrightarrow$ eikonal couplings, discontinuities

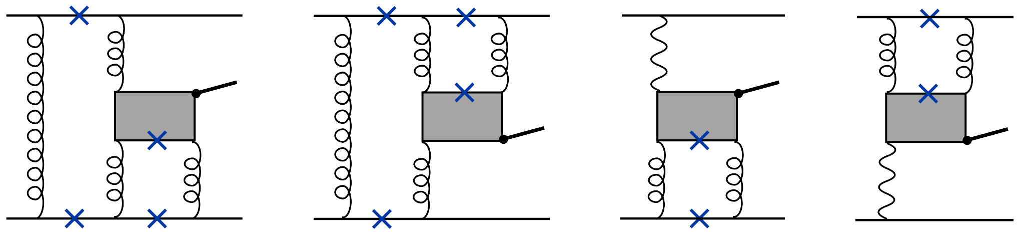
Lowest order diagrams for the Odderon and Pomeron exchange

Amplitude and impact factors



Derivation of the amplitude

Diagrams that contribute to exclusive prodution of C-odd meson



$$M = M_{PO}^{(1)} + M_{PO}^{(2)} + M_{\gamma P}^{(1)} + M_{\gamma P}^{(2)}$$

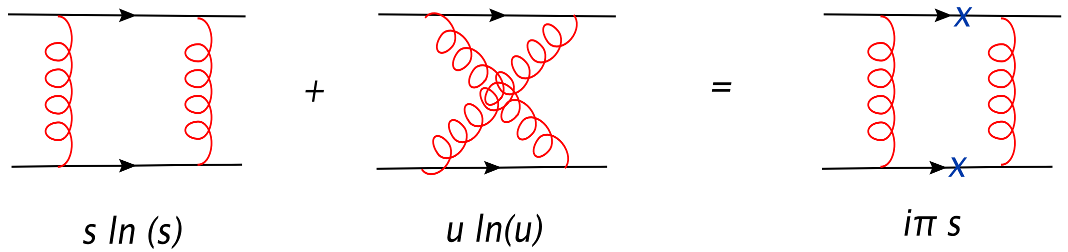
Diagrams evaluated using k_T-factorisation

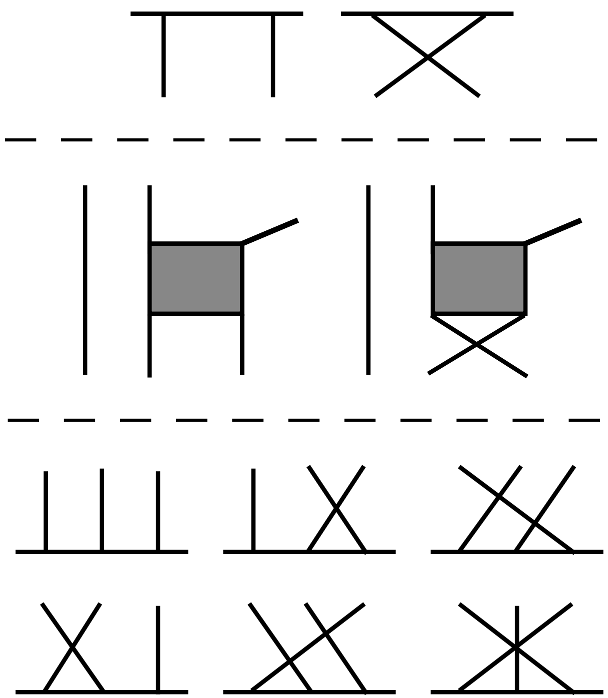
$$M_{PO}^{(1)} = \frac{N}{sx'} \int \frac{d^2 q_\perp d^2 l_\perp}{Q_\perp^2 q_\perp^2 l_\perp^2 h_\perp^2} \Phi_{2g}(-Q_\perp, q_\perp) \Phi_{3g}^{J/\Psi}(q_\perp, h_\perp, l_\perp) \Phi_{3g}(Q_\perp, h_\perp, l_\perp).$$

$$M_{\gamma P}^{(1)} = \frac{N}{sx'} \int \frac{d^2 l_\perp}{q_\perp^2 l_\perp^2 h_\perp^2} \Phi_\gamma(q_\perp) \Phi_{3g}^{J/\Psi}(q_\perp, h_\perp, l_\perp) \Phi_{2g}(h_\perp, l_\perp).$$

Discontinuities and Combinatorics

In the high energy limit the amplitudes are dominated by discontinuities:





All crossings are needed to provide the impact factor with correct analytic properties

⟶ The definition of impact factors leads to over-counting of diagrams in the amplitude

⟶ To correct for multiple counting we multiply by $1/2! \times 1/3!$

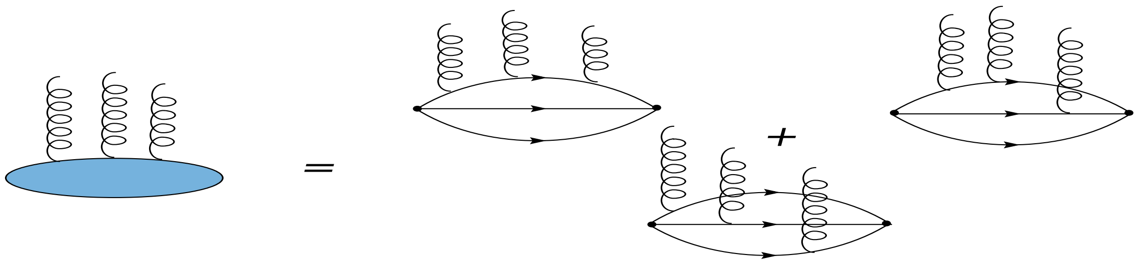
⟶ The intermediate diagram may be connected in 2×3 ways

⟶ The combinatorial factor 1/2 is obtained

Impact factors

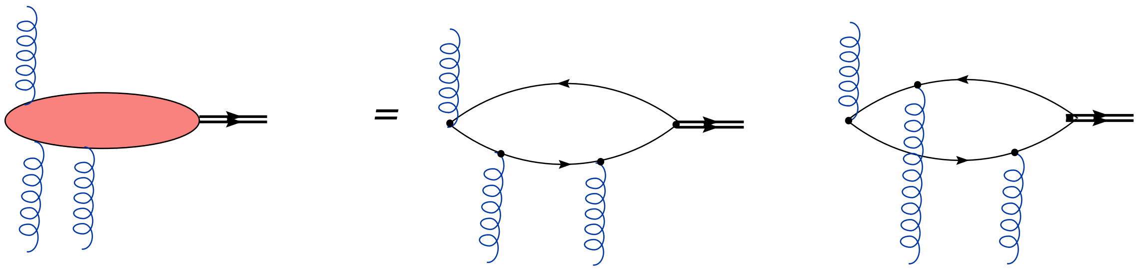
Proton impact factor – Fukugita-Kwieciński model

⟶ Antisymmetric wave function in color indices + scale $m_\rho/2$



$3g \to J/\Psi$ impact factor

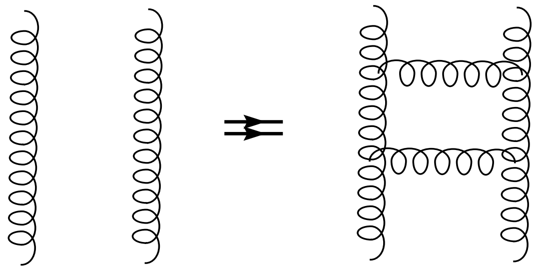
⟶ standard QCD calculation (with non-relativistic wave function)



Evolution & gap survival

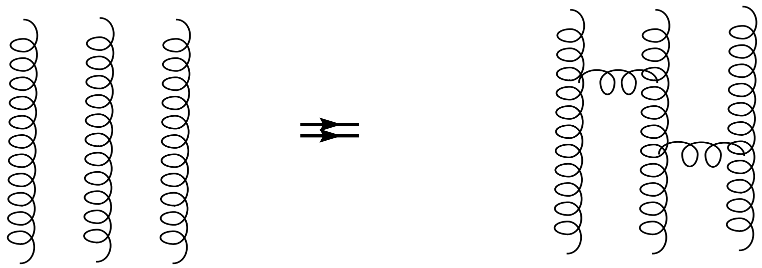
Higher order corrections $\longrightarrow$ ladder diagrams for the Pomeron

$\longrightarrow$ enhancement $\sim x^{-\lambda}$



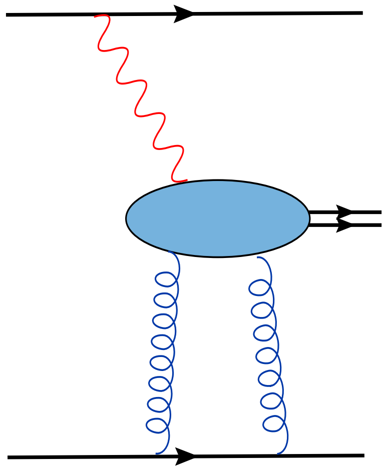
Bartels-Kwieciński-Praszałowicz (BKP) equation for the Odderon

$\longrightarrow$ broadening of the t-dependence, possible pre-asymptotic enhancement



Soft rescattering corrections: impact parameter profile of $\mathbb{O} - \mathbb{P}$ fusion similar to $\mathbb{P} - \mathbb{P}$ fusion.
Khoze-Martin-Ryskin estimates of soft gap survival factor S^2 for χ_c may be used

Photon exchange



Instead of the Odderon – the photon may be exchanged

Weizsäcker-Williams approximation:
[Khoze,Martin,Ryskin],[Klein,Nystrand]

$$dn_{\gamma/p} \propto \alpha_{em} \frac{dx}{x} \frac{dq^2}{q^2} F(q^2)$$

$$d\sigma(pp \to pp\,V) \simeq 2\,dn_{\gamma/p}\,\sigma(\gamma p \to V p)$$

$\sigma(\gamma p \to V p) \sim W^{4\delta}$ was measured at HERA

Weizsäcker-Williams spectrum and proton form-factor – upper cut-off: $q^2_{max} \sim 0.2$ GeV^2

and lower cut-off $q^2_{min} \sim M_P^2 M_\Psi^2 / s \sim 2.5 \cdot 10^{-6}$ [Tevatron] to $5 \cdot 10^{-8}$ GeV^2 [LHC]

$\longrightarrow$ dominated by small q^2 $\longrightarrow$ peripheral collisions $\longrightarrow$ little rescattering

$\longrightarrow$ soft gap survival $S^2 \sim 0.8 - 1$

Sudakov form-factor at $3g \to V$ vertex – not important for J/Ψ, possibly relevant for Υ

Interference

The photon and the Odderon contributions do not interfere due to a phase shift

The γP and $P\gamma$ interference occurs at very low p_T-s of the outgoing protons

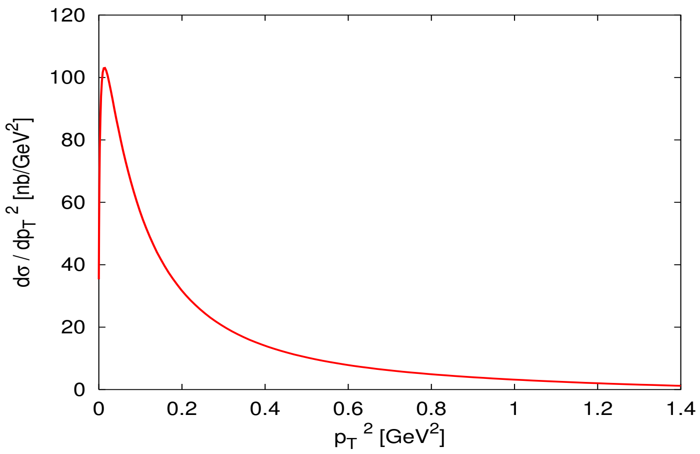
Photon emitter and the target are transformed into each other by a parity transformation

P-parity of vector mesons is negative
$\longrightarrow$ the interference is destructive for pp collisions and constructive for $p\bar{p}$ collisions

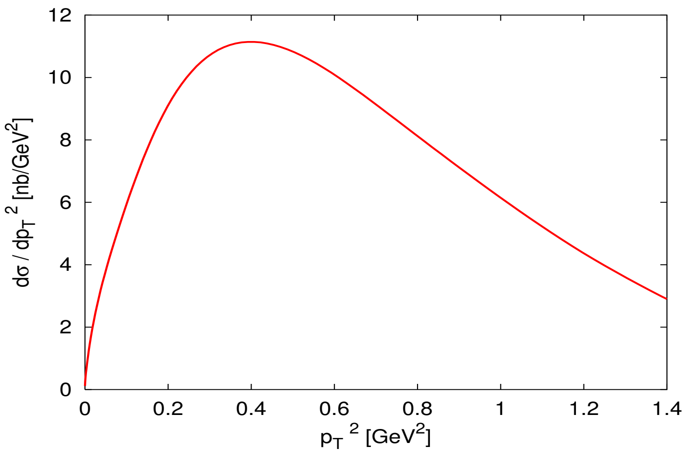
Similarly for Odderon – but broader p_T distribution

$\longrightarrow$ interference – quite important for the Odderon:

$p\bar{p} \to p\bar{p}V$



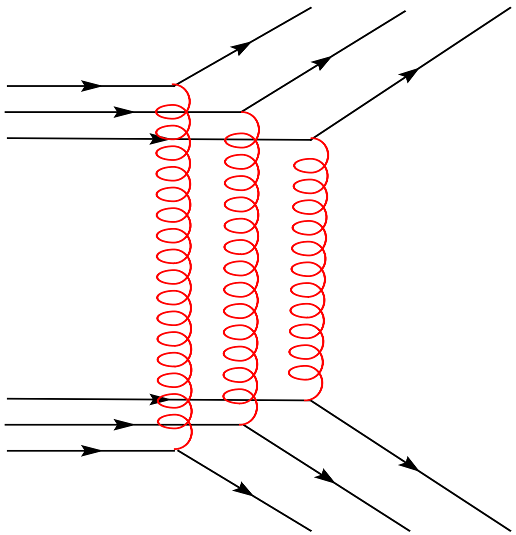
$pp \to ppV$

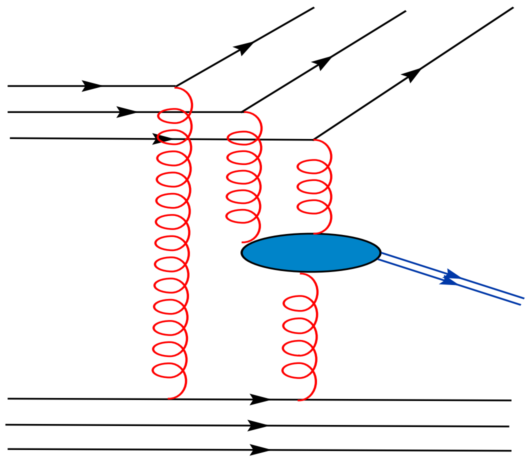


Production at larger p_T: Landshoff mechanism

Photoproduction contribution is characterized by a Pomeron driven p_T-dependence $d\sigma/dp_T^2 \sim \exp(-Bp_T^2)$ with $B \simeq 4.5$ GeV^{-2}

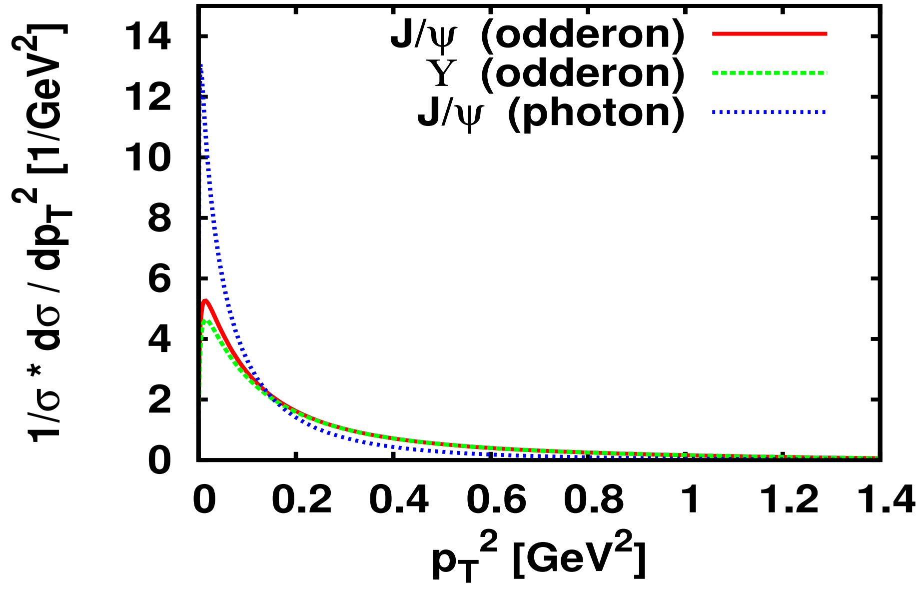
Tail of large p_T of vector mesons may emerge due to an analogue of the Landshoff mechanism for elastic pp scattering at large $|t|$



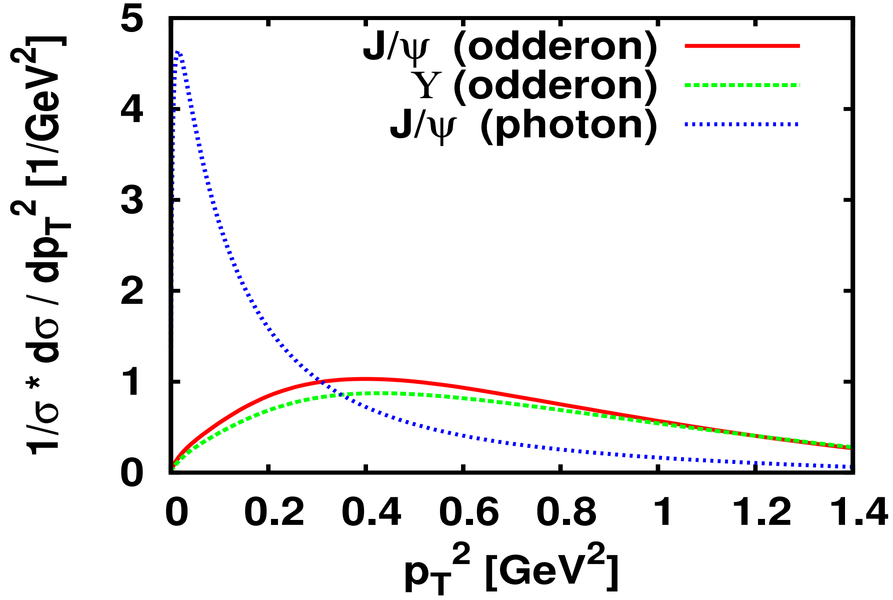


$\longrightarrow$ Enhanced sensitivity to the Odderon exchange at larger p_T

Meson p_T distributions: photon / Odderon



Tevatron



LHC

$\longrightarrow$ Cut on meson $p_T > 0.6$ GeV should enhance the relative Odderon contribution, especially in pp collisions

Improvements & Uncertainties

Photon contribution is well understood $\sim 30\%$ of uncertainty

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Cross-section mediated by Odderon exchange beyond the lowest order:

$$\sigma(pp \to ppV) \;\simeq\; \bar{\alpha}_s^5 \times \left(\frac{\sqrt{s}x_0}{M_V}\right)^{2\lambda(M_V^2)} \times S^2 \times \sigma_0(pp \to ppV)$$

High power of coupling constant $\sigma \sim \bar{\alpha}_s^5\, \alpha_s^3(M_Q)$

Evolution of the Pomeron (DGLAP/BFKL): standard and well understood

$\longrightarrow \lambda(M_{J/\Psi}^2) \simeq 0.2$, $\lambda(M_{\Upsilon}^2) \simeq 0.35 - 0.4$

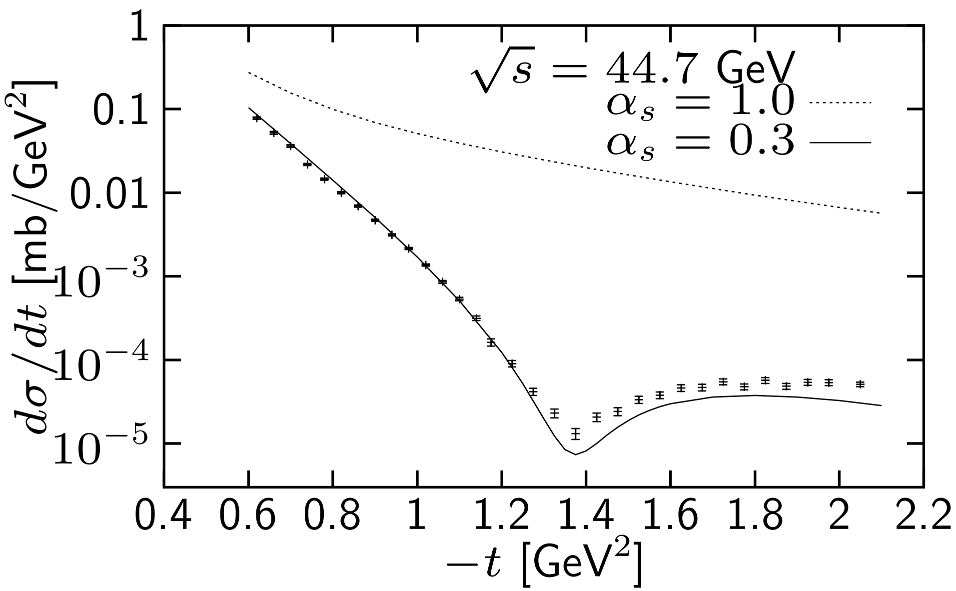
Evolution and absorption of the Odderon – not taken into account yet

Soft gap survival factor $S^2 \simeq 0.05$ for Tevatron and $S^2 \simeq 0.025$ for LHC

Constraining Odderon coupling to proton

[G. Dosch, C. Ewerz, V. Schatz]

$\bar{\alpha}_s$ in Fukugita-Kwieciński impact factor for 3 gluons was constrained by fitting elastic pp and $p\bar{p}$ cross sections: $\bar{\alpha}_s \sim 0.3$ was found



Alternatively: total cross section and J/Ψ photoproduction data indicate $\bar{\alpha}_s \sim 0.7 — 0.9$

Possible explanations of discrepancy could be e.g. rescattering or absorption of the Odderon

Pessimistic scenario: $\bar{\alpha}_s = 0.3$, $S^2 = 1$

Optimistic scenario: $\bar{\alpha}_s = 1$, $S^2 = 0.05 – 0.025$

Results

Photon: t-integrated $\frac{d\sigma}{dy}|_{y=0}$:

$p\bar{p} \to p\bar{p}\ J/\Psi$ at Tevatron: $\sim$ 2.5 nb

$pp \to pp\ J/\Psi$ at LHC: ~ 12 nb

$pp \to pp\ \Upsilon$ at LHC: 0.1 — 0.3 nb

Odderon: t-integrated $\frac{d\sigma}{dy}|_{y=0}$:

$p\bar{p} \to p\bar{p}\ J/\Psi$ at Tevatron: 0.2 — 3 nb

$pp \to pp\ J/\Psi$ at LHC: 0.3 — 3 nb

$pp \to pp\ \Upsilon$ at LHC: 0.002 — 0.02 nb

Enhancing the Odderon by p_T-cut

Photon Weizsäcker-Williams spectrum: $\sim \frac{dp_T^2}{p_T^2}$ — dominated by $p_T^2 \ll 0.1$ GeV^2

Odderon contribution tends to be much broader in p_T — characteristic $p_T^2 \sim 0.25$ GeV^2 and a power-like tail due to Landshoff mechanism

Pomeron–Odderon fusion gives p_T-distributions of both outgoing proton transverse momenta characterised by a scale $t_0 \sim 0.25$ GeV^2

Pomeron-Photon fusion gives one proton with very small p_T

Sensitivity to Odderon may be improved by measuring protons' p_T:
with both $|t_1| > 0.25$ GeV^2 and $|t_2| > 0.25$ GeV^2 photon contribution decreases ~ 200 times and Odderon – only ~ 10 times

Recipe for the Odderon

1. Measure exclusive $pp \longrightarrow pp\ J/\Psi$ or $pp \longrightarrow pp\Upsilon$ and compare to photon contribution
2. Cut on transverse momentum of VM and compare to photon
3. Cut on transverse momenta of two outgoing protons and compare to photon
4. Try to find the excess