A new γ^*p/pp factorization test, valid for $Q^2 < 6$ GeV^2

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Abstract

One of the key experimental issues in $\mathcal{P}$omeron physics is the extent to which factorization of $\mathcal{P}$omeron emission and interaction is valid in diffractive processes. In the present paper, we present the results of a new test in diffractive $\gamma^* p$ and $\bar{p}p$ interactions, which does not rely on the assumption of universality of the $\mathcal{P}$omeron flux factor in the proton. The test is satisfied to within $\sim 20\%$ for $1 < Q^2 \sim 6$ GeV^2 and $\beta < 0.4$ in the $\gamma^* p$ interactions, suggesting that multi–$\mathcal{P}$omeron–exchange has a limited effect on factorization. However, a clear breakdown is observed at larger Q^2. Kharzeev and Levin suggest that this can be attributed to the onset of perturbative QCD effects due to the $\mathcal{P}$omeron's structure. The breakdown occurs in a Q^2 region which agrees with their estimates of a small $\mathcal{P}$omeron size.

$p\,p \rightarrow X\,p$ and $\gamma^*\,p \rightarrow X\,p$

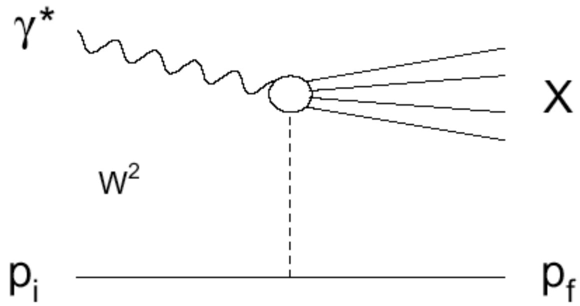
Available data from these inelastic diffraction reactions are well described by products of Pomeron emission and interaction factors:

$$\frac{d^2\sigma^{\rm diff}_{\bar{p}p}}{d\xi\, dt} = F^{\bar{p}p}_{\mathcal{P}/p}(t,\xi) \cdot \sigma^{\rm tot}_{p\mathcal{P}}(s')$$

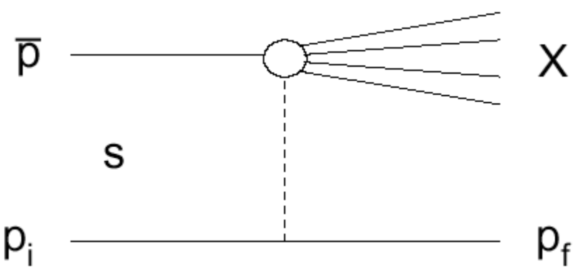
$$\frac{d^2\sigma^{\rm diff}_{\gamma^* p}}{d\xi\, dt} = F^{ep}_{\mathcal{P}/p}(t,\xi) \cdot \sigma^{\rm tot}_{\gamma^*\mathcal{P}}(s', Q^2)$$

However, it is found that the Pomeron flux factor is not universal, presumably a consequence of different non-perturbative Pomeron formation processes in the two cases (multi-Pom.-exchange).

e.m. & hadronic inelastic diffract

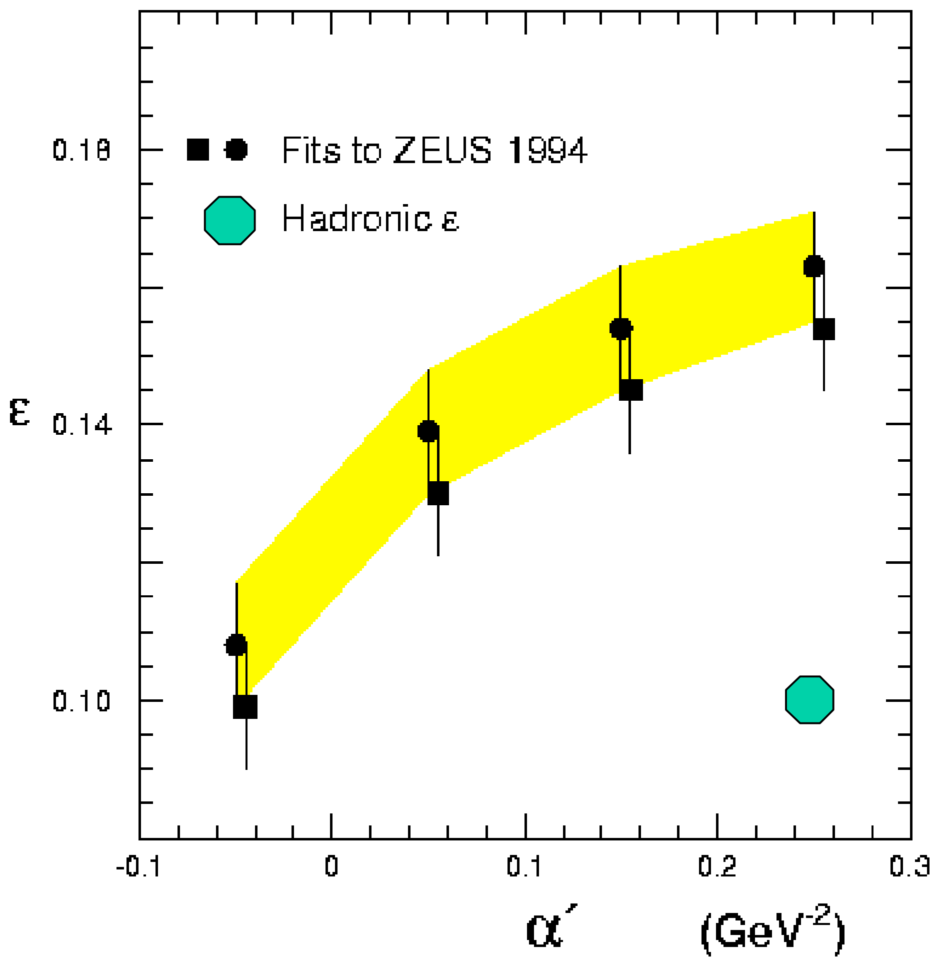


$s' = \square W^2 - Q^2$



$s' = \square s$

Effective Pomeron trajectories



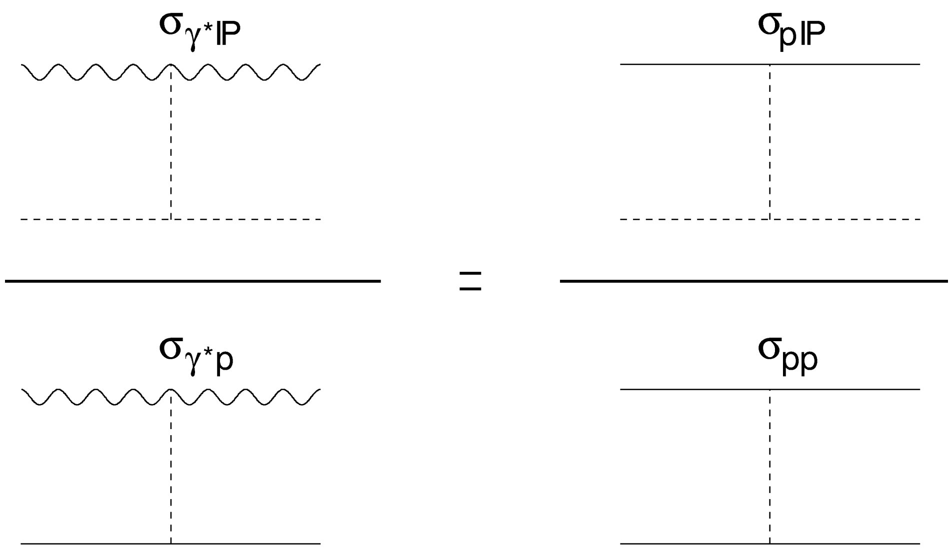
Damping complicates phenomology

Flux Factor, $F_{\mathbf{P}/p}(\square,t)$, is not universal.

Reason: Pomeron's existence is non-perturbative. Multi-Pomeron-exchange effects (a.k.a. "screening", "shadowing", "damping", "absorption") increase with energy and depend on particle types. Kaidalov, Ponomarev, Ter-Martirosyan (Sov. Jour. Nucl. Phys 44 [1986] 468) showed that, in hadronic int., these effects are phenomenologically equivalent to smaller effective Pomeron trajectory intercept with energy. Theoretical challenge is to calculate these effects to agree with data.

★ Explore survival of factorization despite non-universality of $F_{P/p}(□,t)$

Find relationship between Pomeron components of the relevant total cross sections (optical theorem)



$$\frac{\sigma^{tot}_{\gamma^* \mathcal{P}}}{\sigma^{tot}_{\gamma^* p}} = \frac{\sigma^{tot}_{p\mathcal{P}}}{\sigma^{tot}_{pp}},$$

Evaluate all at same s.

Ryskin

Single Diffractive Parametrization

Triple-Regge parametrization fits all available single diffractive data at ISR, SPS (Tevatron consistent)

UA8: Nucl. Phys. B 514 (1998) 3.

Erhan & Schlein: Phys. Lett. B 481 (2000) 177.

$$d^2\sigma / d\xi dt = F_{P/p}(\xi, t) \; \sigma_{Pp}(s')$$

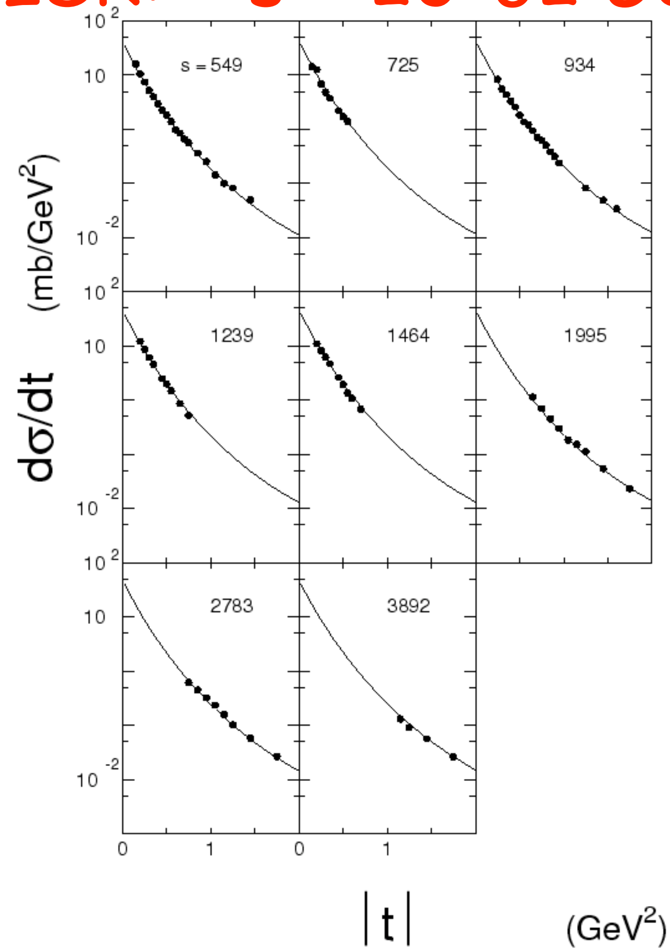
$$F_{\mathcal{P}/p}(t,\xi) = K \cdot |F_1(t)|^2 \cdot e^{(1.1 \pm 0.2)t} \cdot \xi^{1-2\alpha(t)}$$

$$\alpha(t) = 1 + \epsilon + \alpha' t + \alpha'' t^2 = 1.10 + 0.25t + (0.079 \pm 0.012)t^2$$

$$K_{pp}\, \sigma_{p\mathcal{P}}^{\rm tot}(s') \;=\; (0.72 \pm 0.10) \cdot [(s')^{0.10} + (4.0 \pm 0.6)(s')^{-0.32}] \quad {\rm mb\, GeV^{-2}}$$

s-dependent □ from fits to d□/dt

ISR: s = 23-62 GeV



$\square(t) = 1 + \square + \square' \, t + \square'' \, t^2$

6-parameter fit:

$\square = 0.10 - 0.02 \log(s/549)$

$\square' = 0.22 - 0.03 \log(s/549)$

$\square'' = 0.06 - 0.01 \log(s/549)$

s-dependent □ starts within ISR range.

□(t) flattens at high-|t|, but is s-independent there.

Single Diffractive continued

At low |t| effective Pomeron trajectory continues to drop with increasing s. At s = 630 GeV:
$\alpha(t) = 1 + \epsilon + \alpha' t + \alpha'' t^2 = 1.035 + 0.165\, t + 0.059\, t^2$.
However, there is no s-dependence for |t| >1 GeV^2 and ISR-SPS data sets used are in region of small damping.

To prepare for factorization test, we need:

$$\sigma_{pp}^{\rm tot} = 18\, s^{0.10} - 27\, s^{-0.50} + 55\, s^{-0.32} \quad {\rm mb}$$

Cudell et al.
Covolan et al.

$$\frac{K_{pp}\, \sigma_{p\mathcal{P}}^{\rm tot}}{\sigma_{pp}^{\rm tot}} = 0.041 \pm 0.007\ {\rm GeV}^{-2}.$$

Analysis of diffractive γ^*p data

For t-integrated data, we have:

$$\frac{d\sigma^{diff}_{\gamma^* p}}{d\xi} = \frac{4\pi^2\alpha}{Q^2} \cdot F_2^{D(3)}(\beta, Q^2, \xi)$$

$$F_2^{D(3)}(\beta, Q^2, \xi) = \int F^{ep}_{\mathcal{P}/p}(t,\xi)dt \cdot F_2^{D(2)}(\beta, Q^2) \approx \frac{K_{ep}}{\xi^{1+2\epsilon} \cdot (3.9 - 2\alpha' \, ln \, \xi)} \cdot F_2^{D(2)}(\beta, Q^2).$$

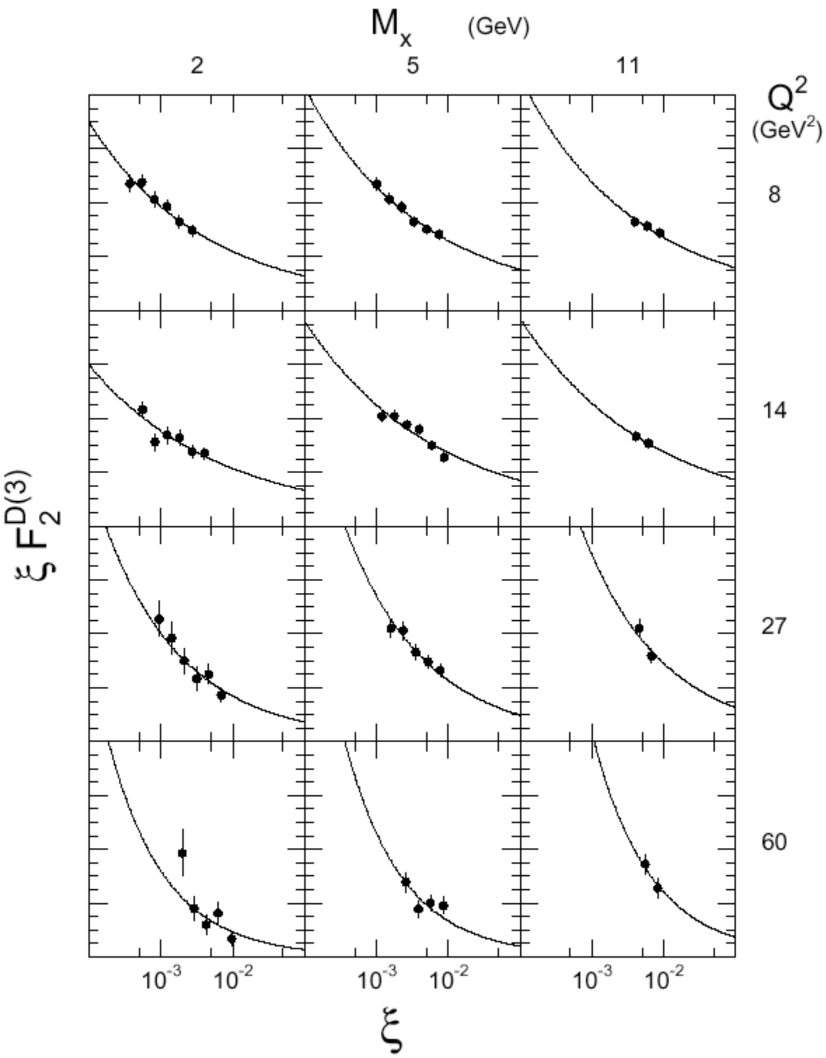
$$K_{ep}\, \sigma^{\text{tot}}_{\gamma^* \mathcal{P}}(s', Q^2) = \frac{4\pi^2\alpha}{Q^2} \cdot K_{ep}\, F_2^{D(2)}(\beta, Q^2) \qquad s' = Q^2(1-\beta)/\beta$$

From F_2:

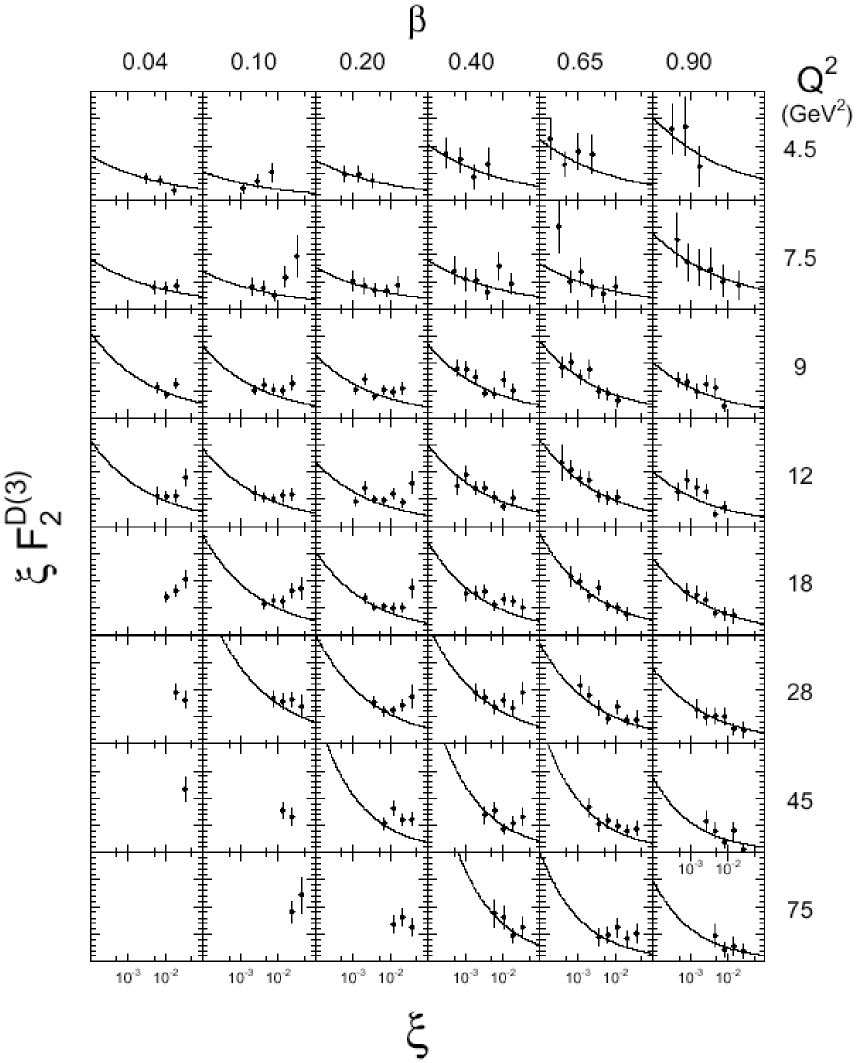
$$\sigma^{\text{tot}}_{\gamma^* p}(W^2, Q^2) = \frac{4\pi^2\alpha}{Q^2} \cdot \frac{Q^2 + 4m_p^2 x^2}{Q^2(1-x)} \cdot F_2(W^2, Q^2)$$

$$Ratio \equiv \frac{K_{ep}\, \sigma^{\text{tot}}_{\gamma^* \mathcal{P}}}{\sigma^{\text{tot}}_{\gamma^* p}} = \frac{Q^2(1-x)}{Q^2 + 4m_p^2 x^2} \cdot \frac{K_{ep}\, F_2^{D(2)}(\beta, Q^2)}{F_2(x, Q^2)}$$

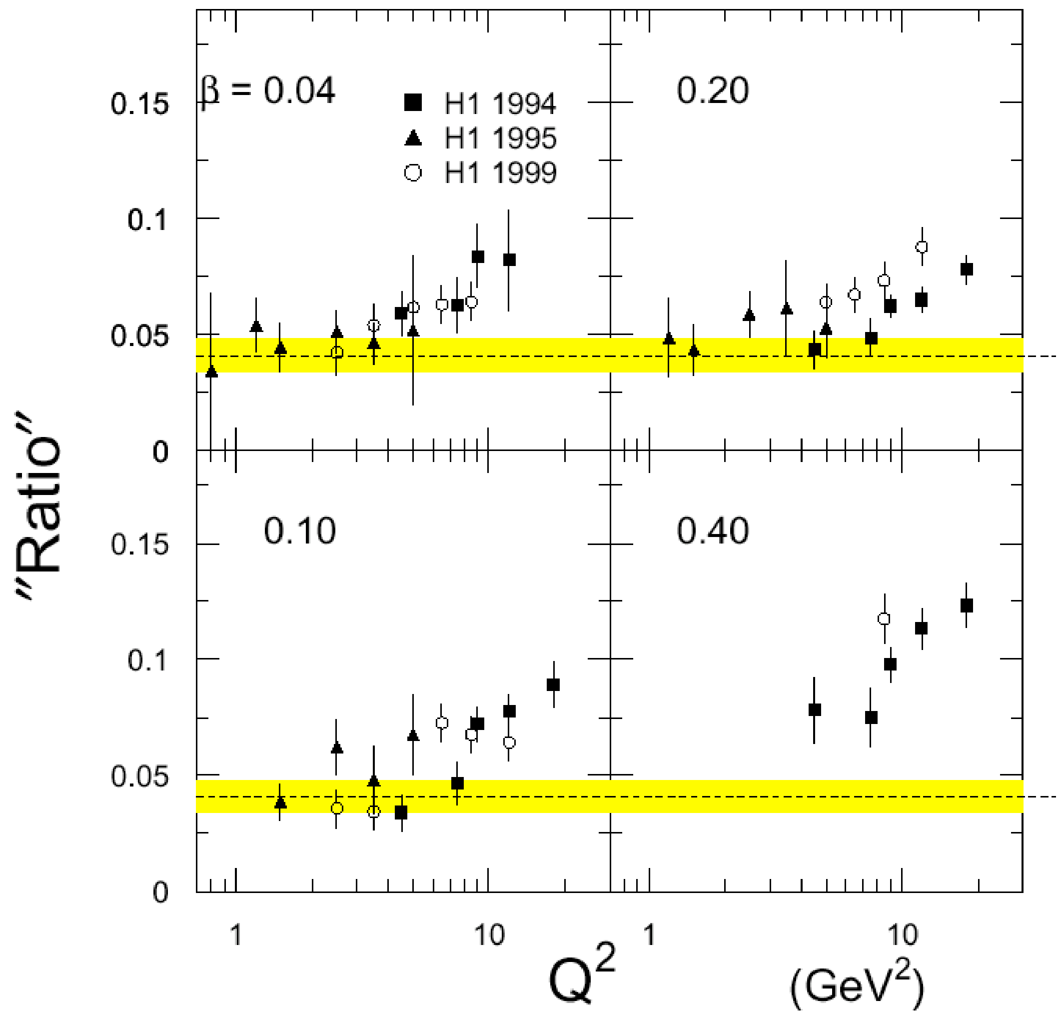
1994 ZEUS data: factorization fits



1994 H1: factorization fits



New Factorization Test (H1 data)



$$\frac{K_{ep}\,\sigma^{\text{tot}}_{\gamma^*\mathcal{P}}}{\sigma^{\text{tot}}_{\gamma^* p}} = \frac{K_{pp}\,\sigma^{\text{tot}}_{p\mathcal{P}}}{\sigma^{\text{tot}}_{pp}}$$

- Reasonably good for $Q^2 < 6$ GeV^2
- Breakdown above

Caveats

1. Factorization test should be performed only with Pomeron-exchange components of "*Ratio*". Continued work with improved data necessary.

2. Although we do not presently know both □ and □' from □*p data, it is reassuring to know, for example, that "*Ratio*" changes by only 10% if □' = 0.15 is used.

3. Although K-factor might be different in □*p and pp, factorization agreement implies they are similar.

Conclusions on Fact. Agreement

Both γ^*p and pp data are well described by a product of Pomeron flux factor and $\sigma(\gamma^*/p + P)$ despite strong evidence for damping effects.

Factorization tests using the extracted cross sections presented here expand this view and now connect γ^*p and pp data. This suggests, perhaps surprisingly, that the multi-Pomeron-exchange effects are of such a nature that factorization is not very much disturbed.

Conclusions on Breakdown of Fact.

Kharzeev & Levin [NP B578 (2000) 351] argue that this evidence for the onset of QCD evolution effects at such large Q^2 gives us a large non-perturbative scale in QCD which relates to a small Pomeron size:

$$R_P{}^2 = 1/Q^2 = 0.39\ GeV^2 mb/6\ GeV^2 = 0.065 mb$$

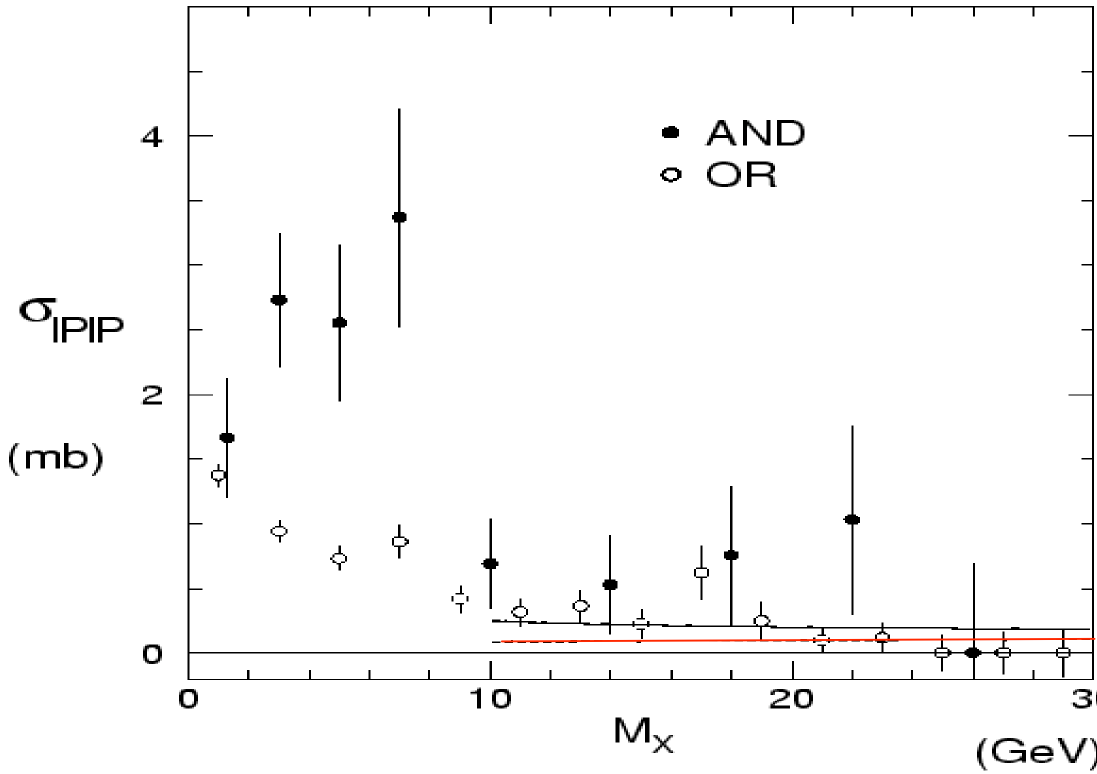
which agrees well with the recent Pomeron-Pomeron total cross section presented by our UA8 Collaboration [EPJ C25 (2002) 361].

Pomeron-Pomeron Total Sigma

Red line is factorization prediction.

➔ High mass points appear to agree with prediction

➔ σ_{PP} low mass enhancements in both data sets.



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EPJ C25 (2002) 361.