

# Hard pomeron and DGLAP

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- $pp$  and  $p\bar{p}$  total cross sections
- $pp$  elastic scattering
- $\gamma$  and  $\gamma^*$ -induced processes

Puzzles from data:

ISR — Tevatron — HERA — LEP

# Pomerons

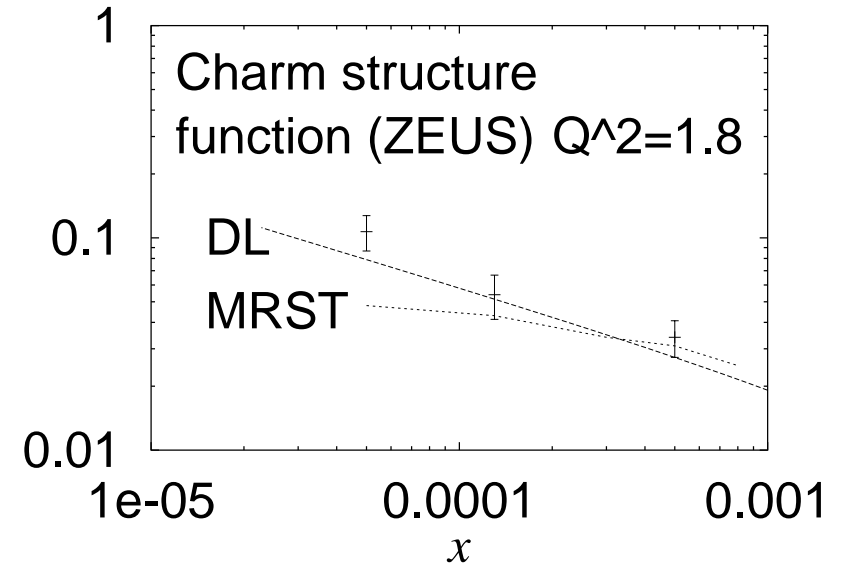
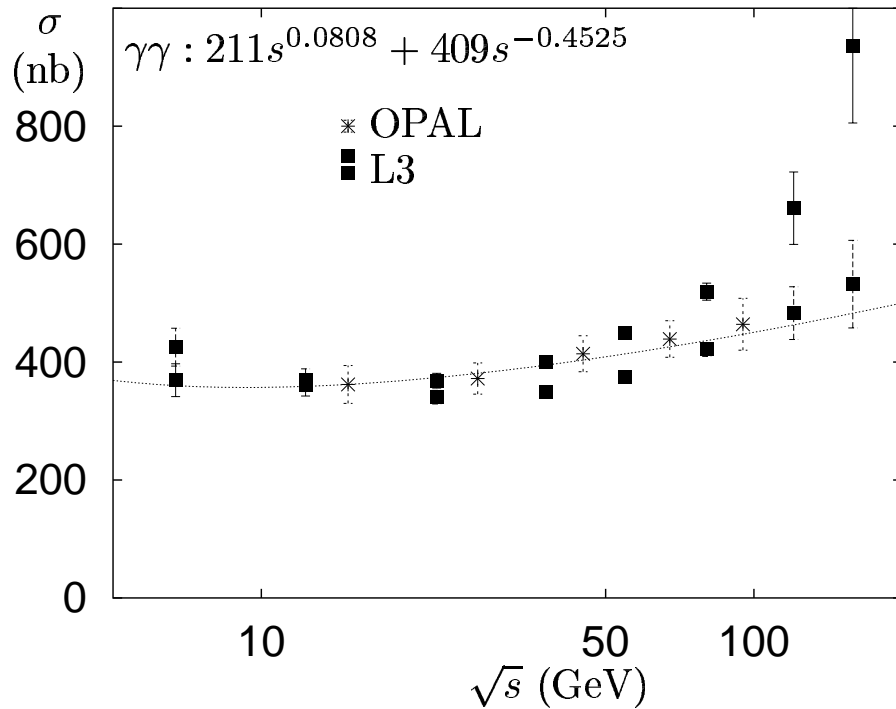
1984: soft pomeron

Fit high-energy  $\sigma(pp), \sigma(p\bar{p})$  with simple power  $s^{\epsilon_1}$   
 $\epsilon_1 \approx 0.08$

1998: hard pomeron

HERA data for  $F_2(x, Q^2)$  at small  $x$  need also a term with  
 $\epsilon_1 \approx 0.4$

## Do soft cross sections have a hard term?



**Important question:** Is there a hard term already at  $Q^2 = 0$ ?

That is, does perturbative evolution merely make the hard term grow with  $Q^2$ ?

Or does evolution make the soft pomeron progressively become harder?

## 2004 fit

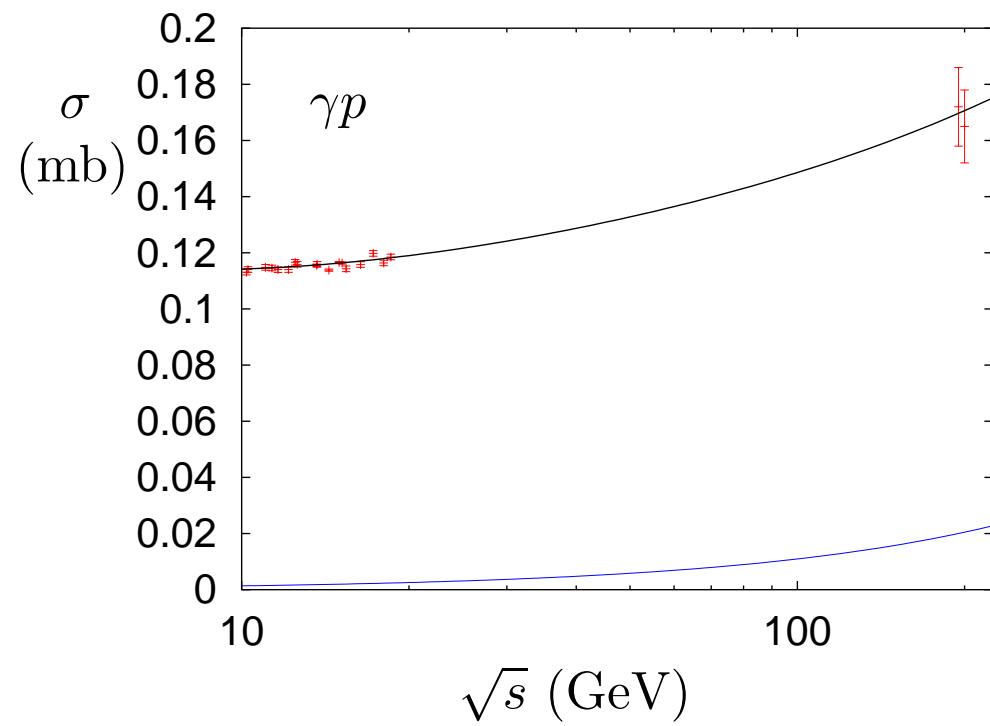
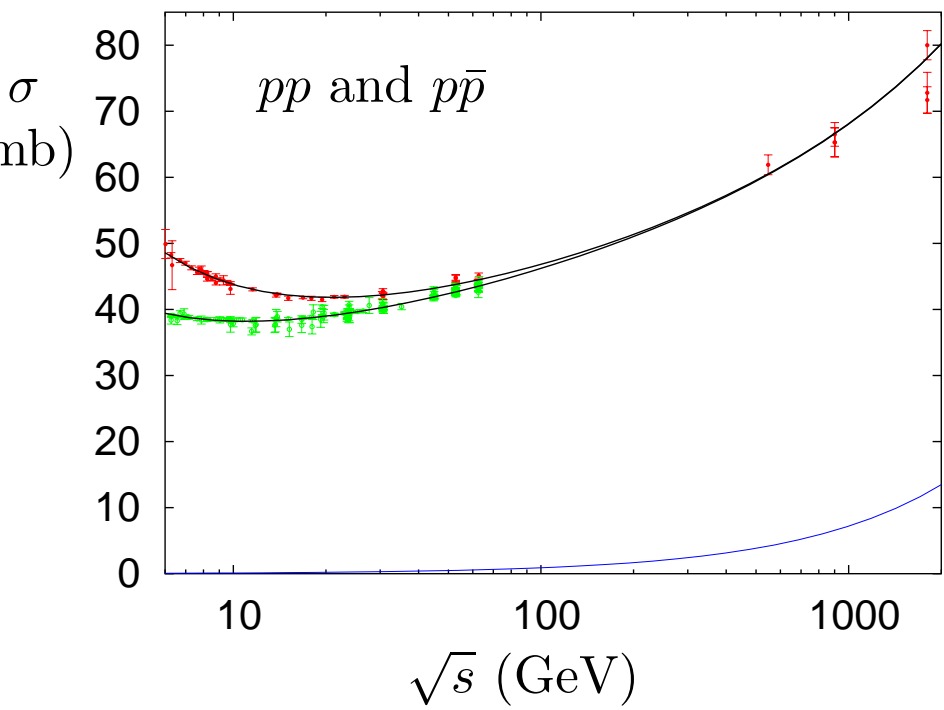
Use hardpom, softpom and reggeon exchange

Reggeon =  $\rho, \omega, f_2, a_2$

$$\sigma(pp), \sigma(p\bar{p}), \sigma(\gamma p): \quad \sigma = X_0 s^{\epsilon_0} + X_1 s^{\epsilon_1} + Y s^{\epsilon_R}$$

$$F_2(x, Q^2): \quad x^{-\epsilon_0} f_0(Q^2) + x^{-\epsilon_1} f_1(Q^2) + x^{-\epsilon_R} f_R(Q^2)$$

$$\epsilon_0 \approx 0.4 \quad \epsilon_1 \approx 0.08 \quad \epsilon_R \approx -0.5$$



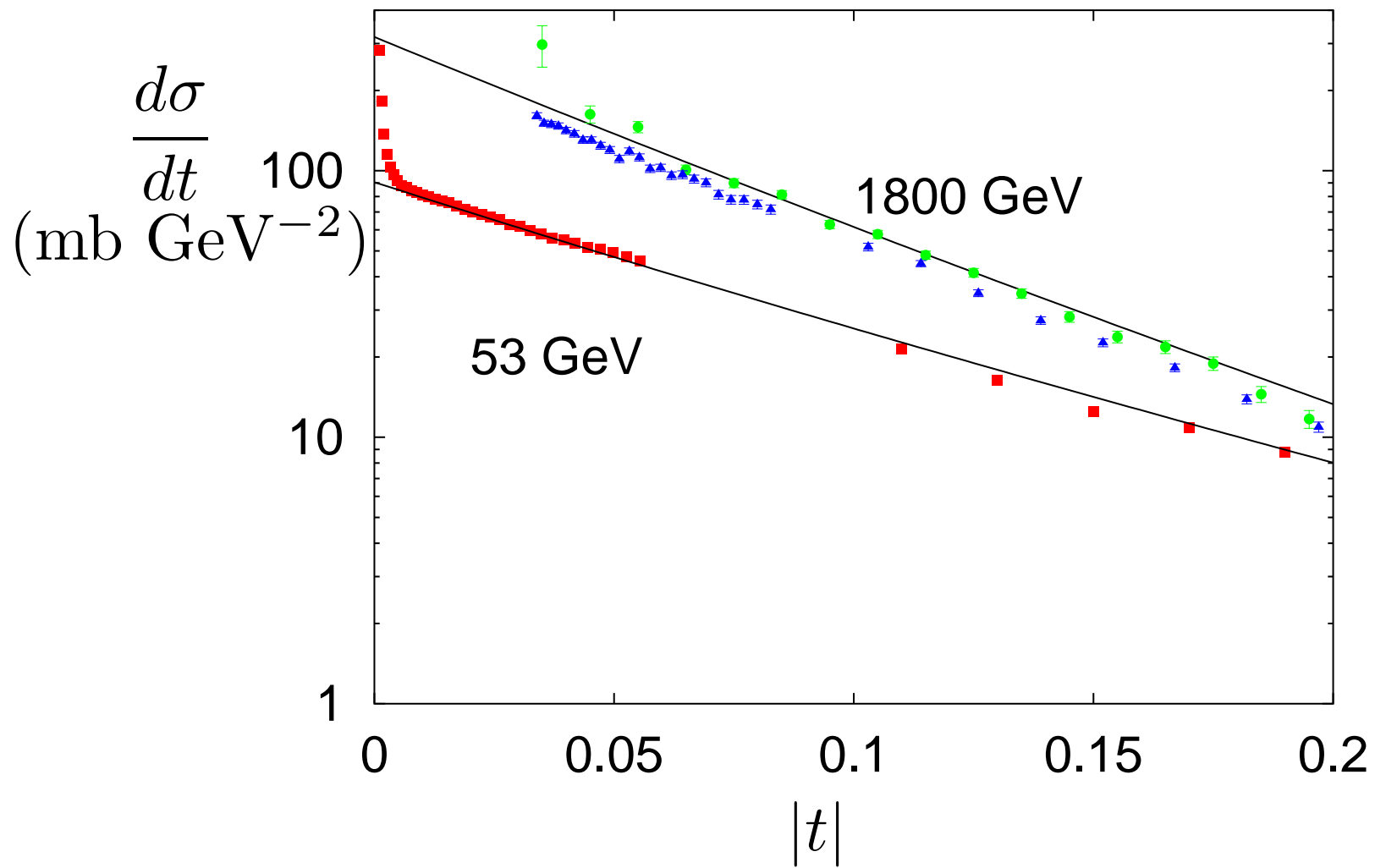
## $pp$ and $p\bar{p}$ elastic scattering

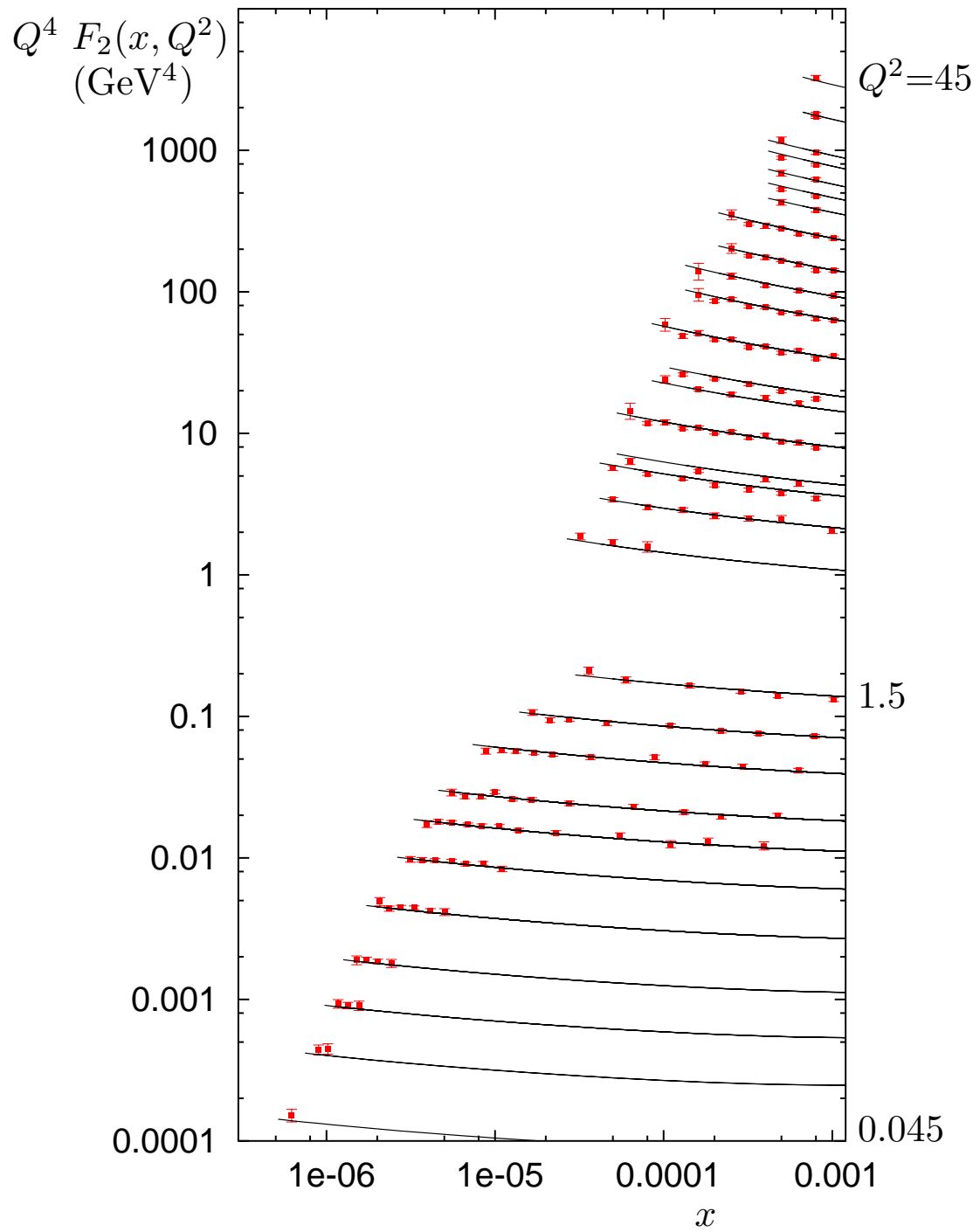
Old fit:

$$\alpha(t) = 1 + \epsilon + \alpha' t \quad \epsilon = 0.08 \quad \alpha' = 0.25$$

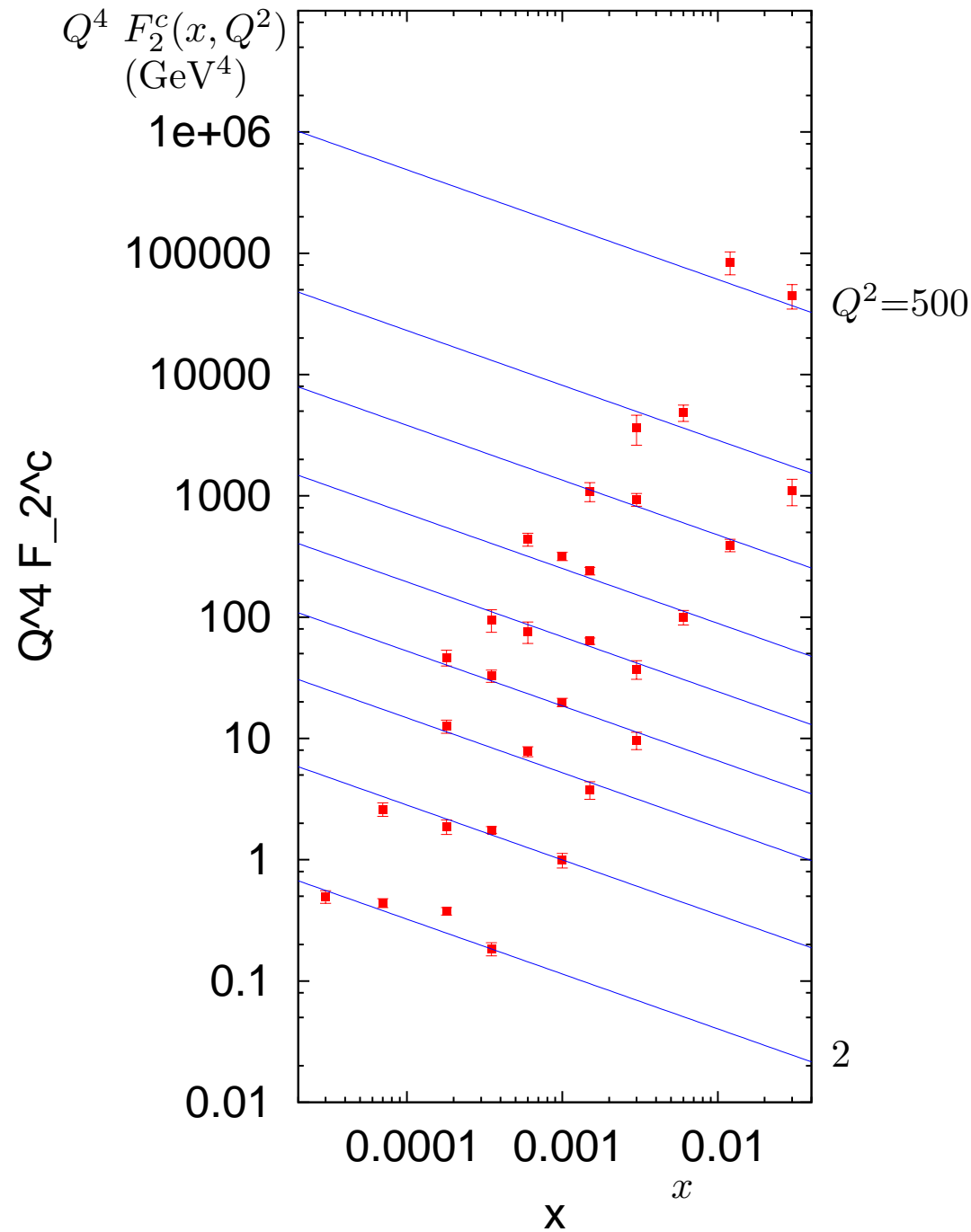
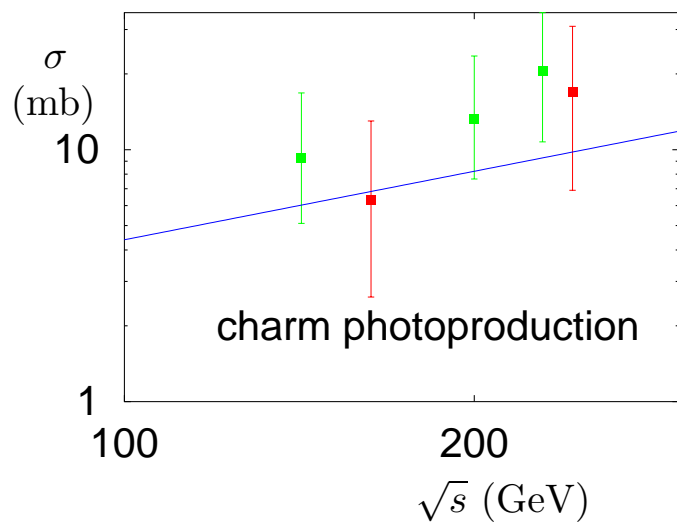
Replace with two trajectories:

$$\epsilon_0 = 0.45 \quad \alpha'_0 \approx 0.1 \quad \epsilon_1 = 0.067 \quad \alpha'_1 \approx 0.3$$





$F_2^{c\bar{c}}$  needs **only** the hard pomeron  
 Fits well to 2/5 the hard-  
 pomeron part of  $F_2$



## DGLAP

$$\mathbf{u}(x, t) = \begin{pmatrix} x \sum_f (q_f + \bar{q}_f) \\ xg(x, t) \end{pmatrix} \quad t = \log(Q^2/\Lambda^2)$$

$$\mathbf{u}(N, Q^2) = \int_0^1 dx x^N \mathbf{u}(x, Q^2)$$

$$\frac{\partial}{\partial t} \mathbf{u}(N, Q^2) = \mathbf{P}(N, \alpha_s(Q^2)) \mathbf{u}(N, Q^2)$$

Usually  $\mathbf{P}(N, \alpha_s(Q^2))$  is expanded in powers of  $\alpha_s$ .

This is illegal at small  $N$ .

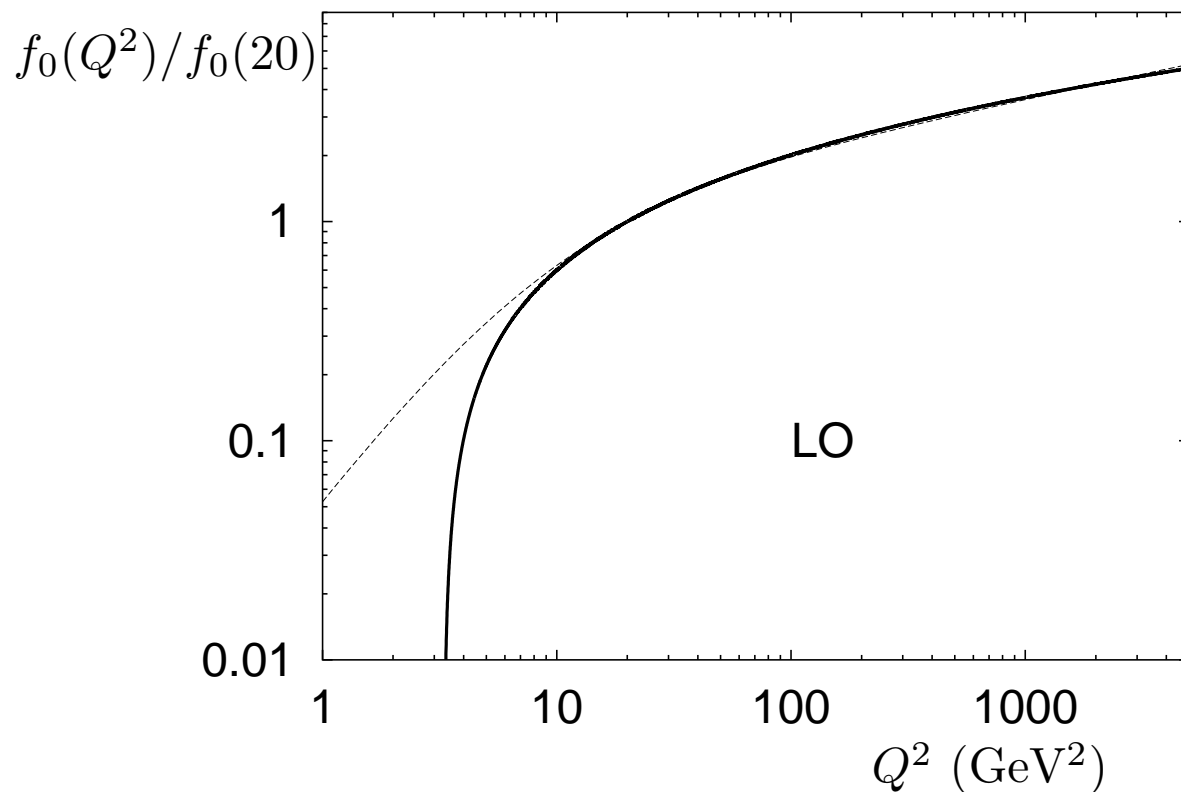
Compare

$$\sqrt{N^2 + \alpha_s} - N = \alpha_s/2N - \alpha_s^2/8N^3 + \dots$$

A power contribution  $f(Q^2)x^{-\epsilon}$  to  $F_2(x, Q^2) \leftrightarrow$  a pole in  $\mathbf{u}(N, Q^2)$ :

$$\frac{\mathbf{f}(Q^2)}{N - \epsilon} \quad \mathbf{f}(Q^2) = \begin{pmatrix} f_q(Q^2) \\ f_g(Q^2) \end{pmatrix}$$

$$\text{DGLAP: } \frac{\partial}{\partial t} \mathbf{f}(Q^2) = \mathbf{P}(N = \epsilon, \alpha_s(Q^2)) \mathbf{f}(Q^2)$$

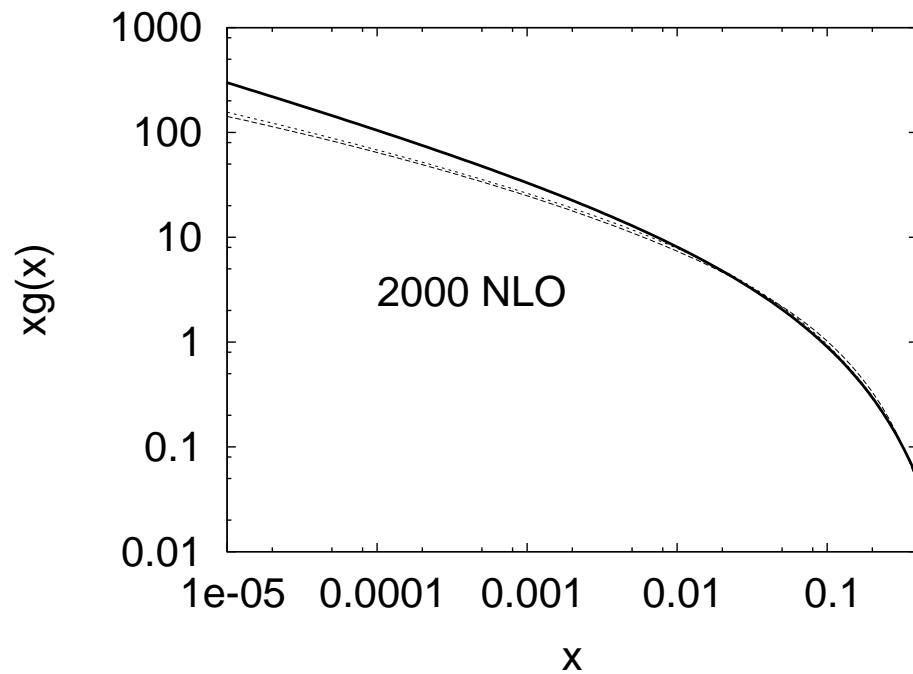
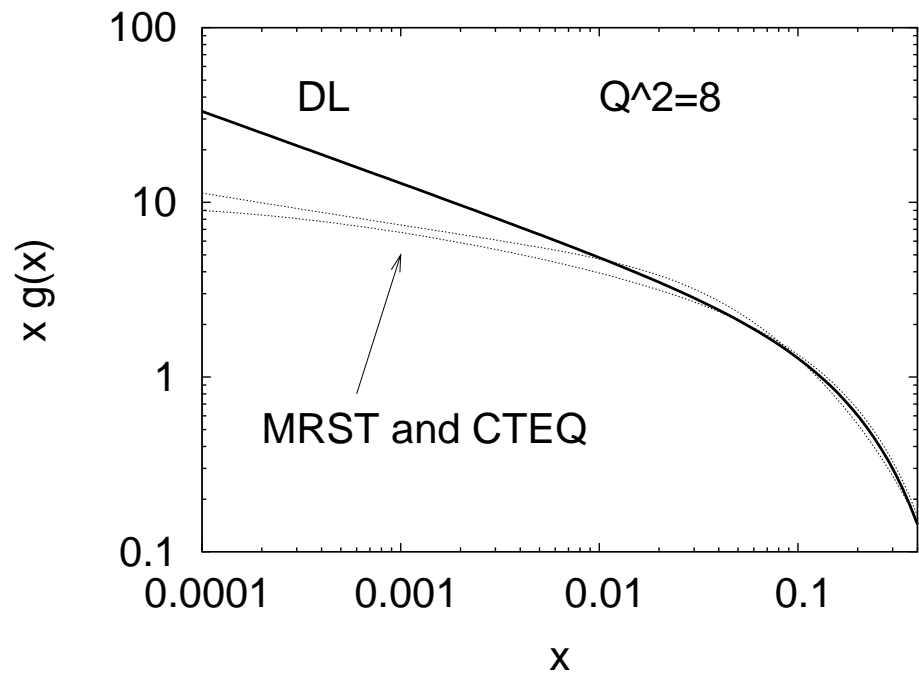


For the **hard** pomeron it is safe to use the expansion of  $\mathbf{P}(N)$  in powers of  $\alpha_s$ . **Not** for the soft.

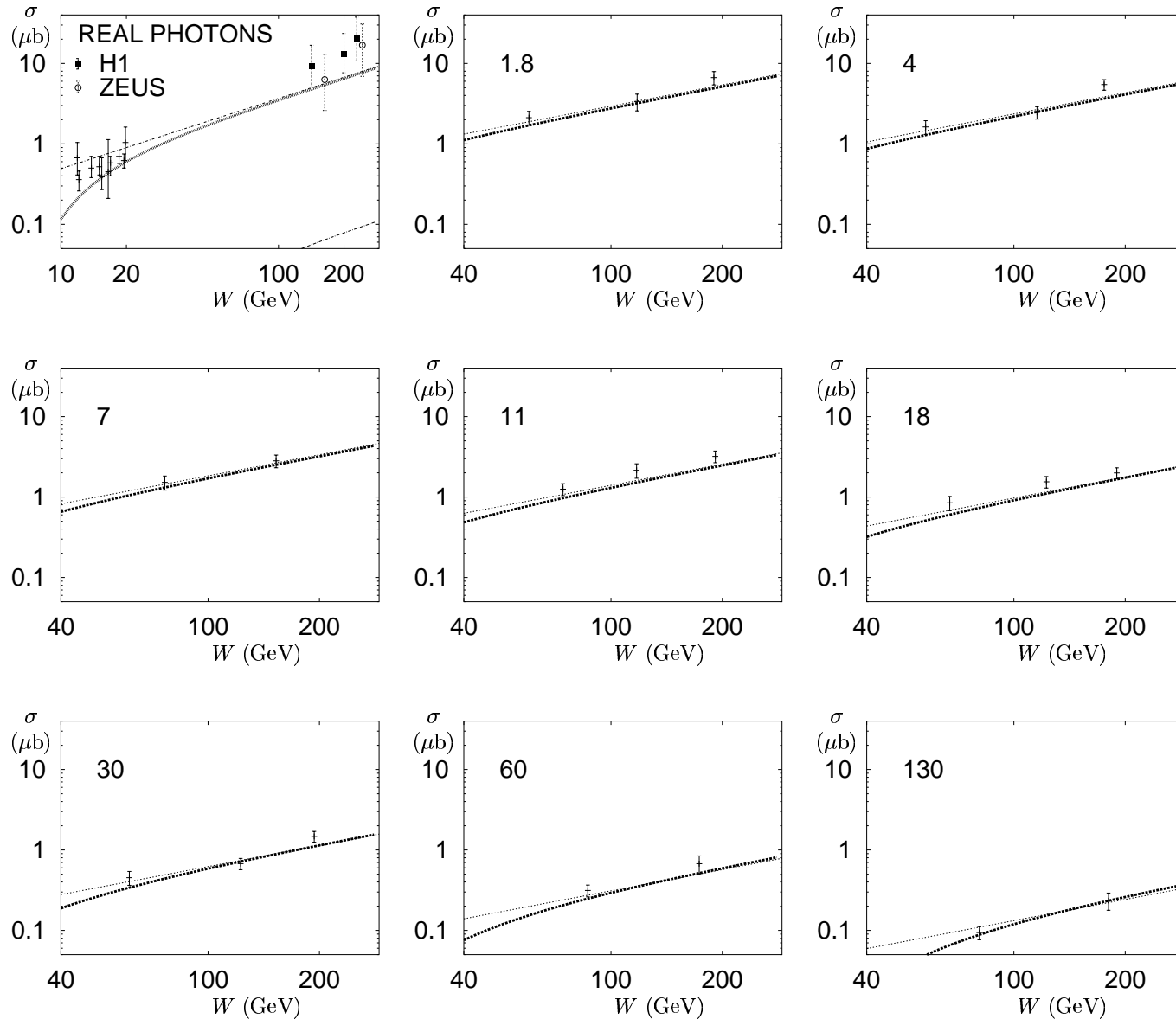
The conventional application of DGLAP is valid only to part of  $F_2(x, Q^2)$  and only for  $Q^2$  greater than about  $5 \text{ GeV}^2$ .

*cf* MRST: things go wrong at small  $x$  and small  $Q^2$

$xg(x, Q^2)$  is purely hard already at small  $Q^2$



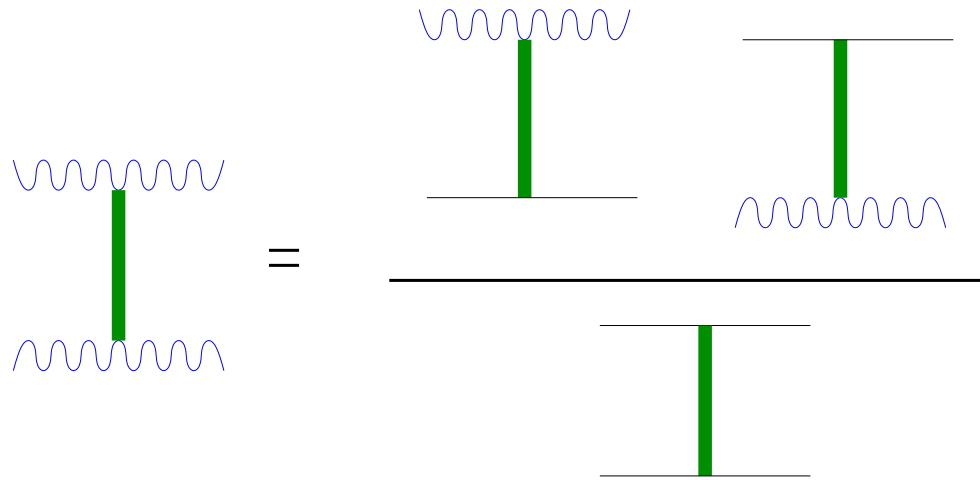
# Charm production



$gg \rightarrow c\bar{c}$  — contribution from photon's structure neglected.

## Regge factorisation

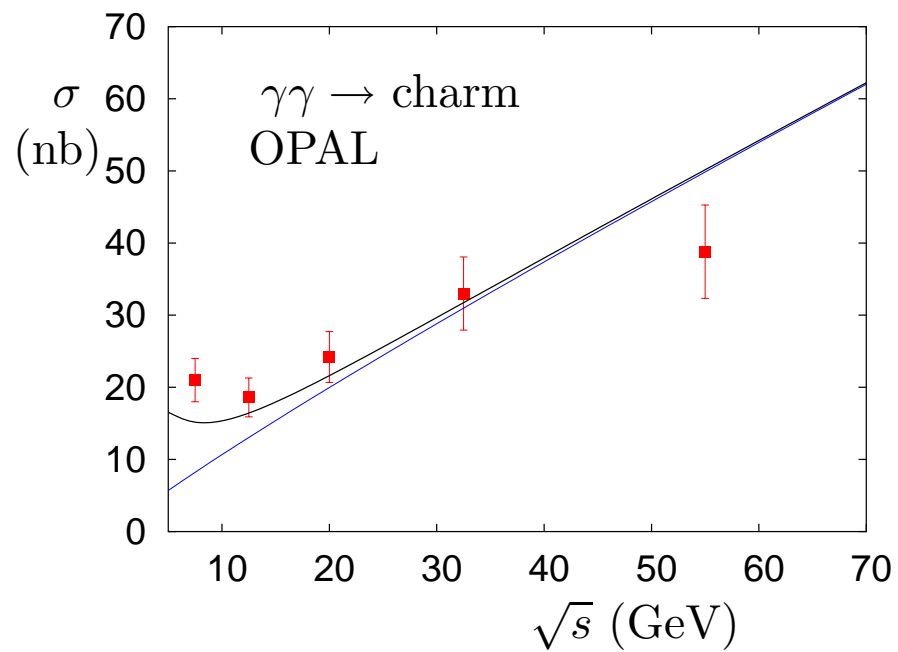
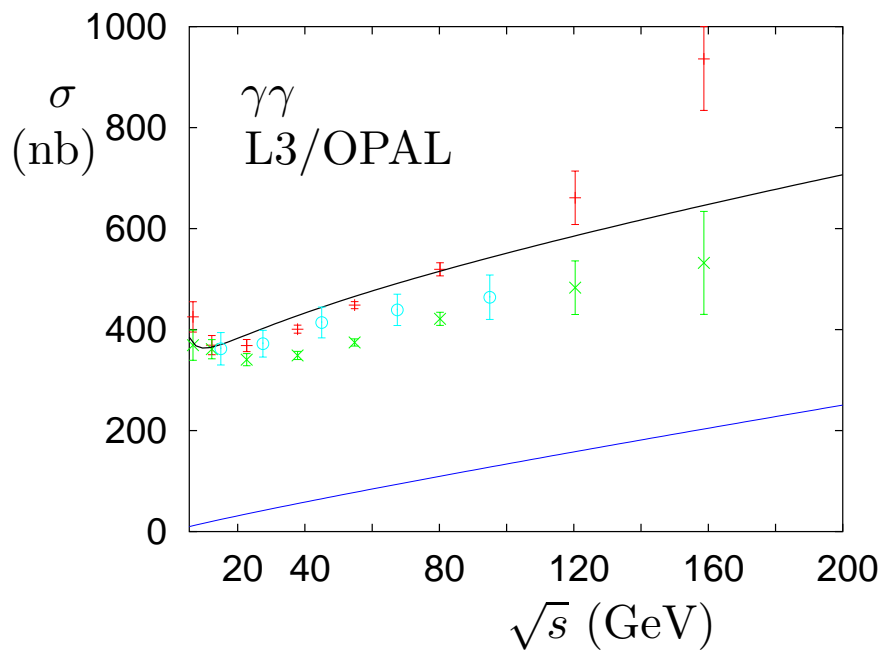
For each of hardpom, softpom and reggeon exchange



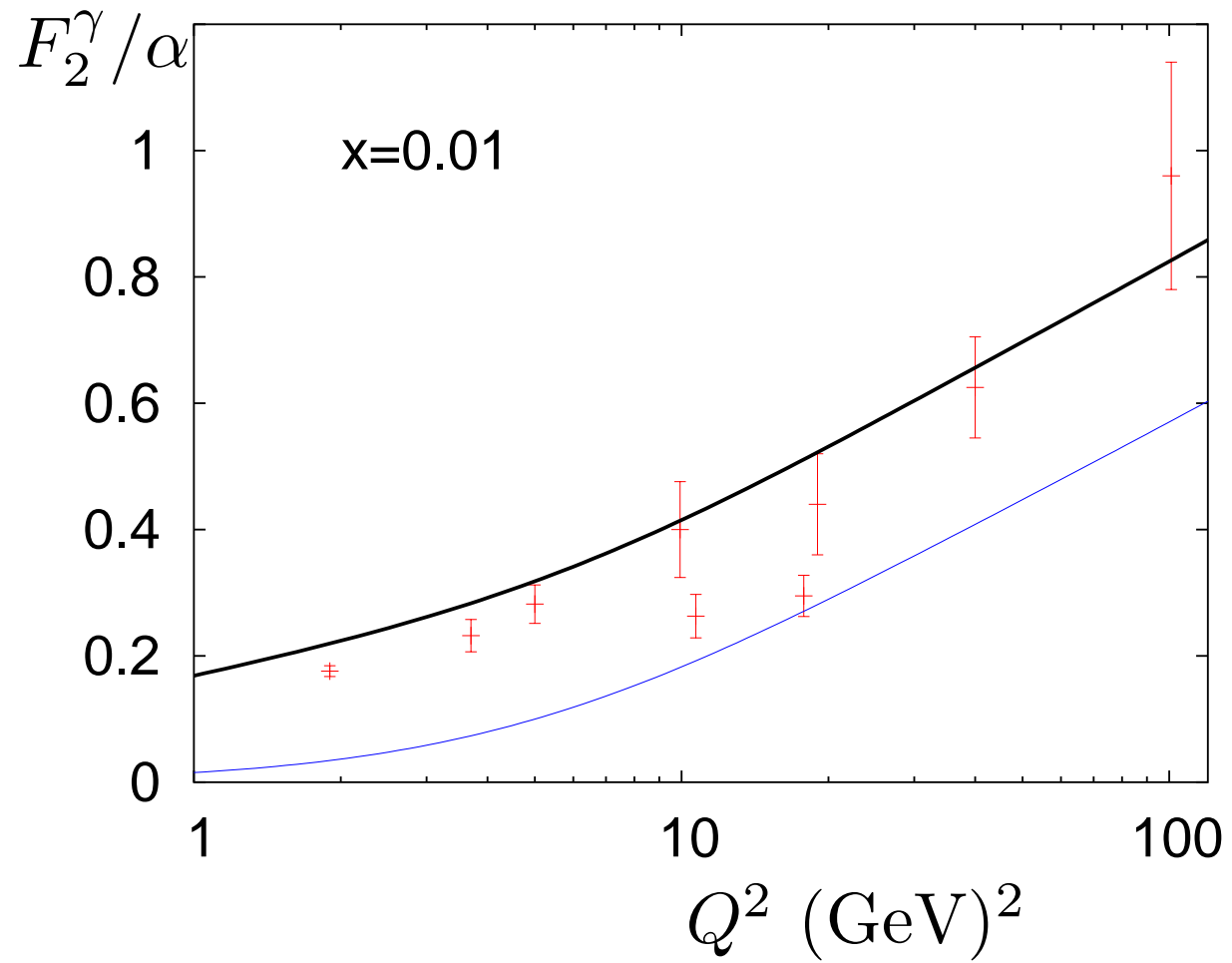
That is, for each term,

$$\sigma(\gamma\gamma) = \frac{\sigma(\gamma p)\sigma(\gamma p)}{\sigma(pp)} \text{ for all } Q_1^2, Q_2^2$$

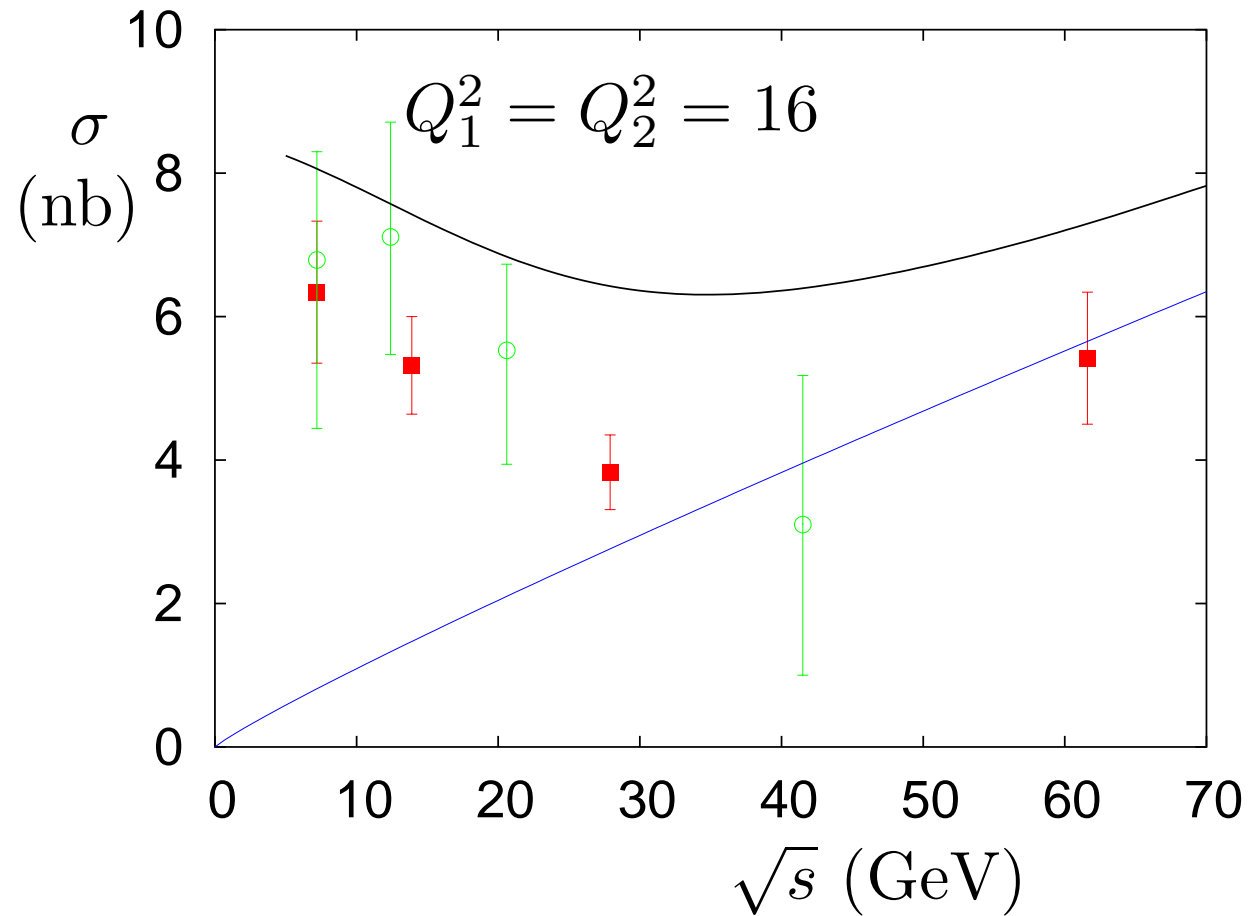
For  $\gamma\gamma$  we must add in the box graph.



# Photon structure function



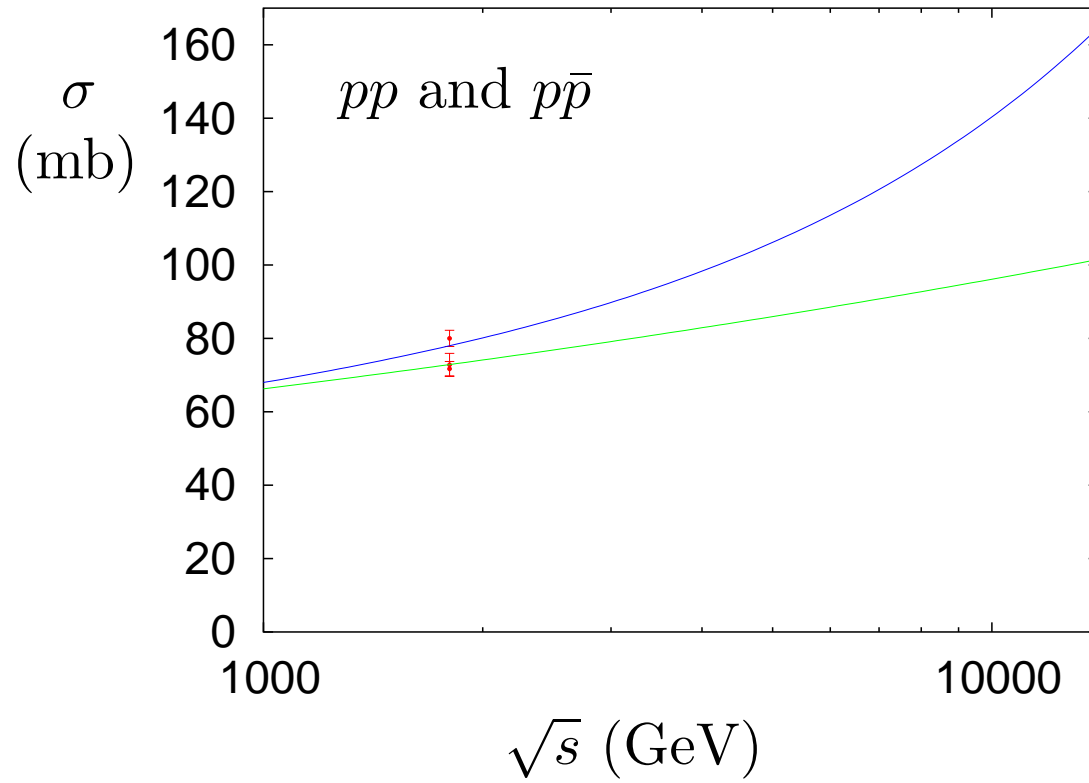
## Both photons off shell



Conclusion about Regge factorisation:

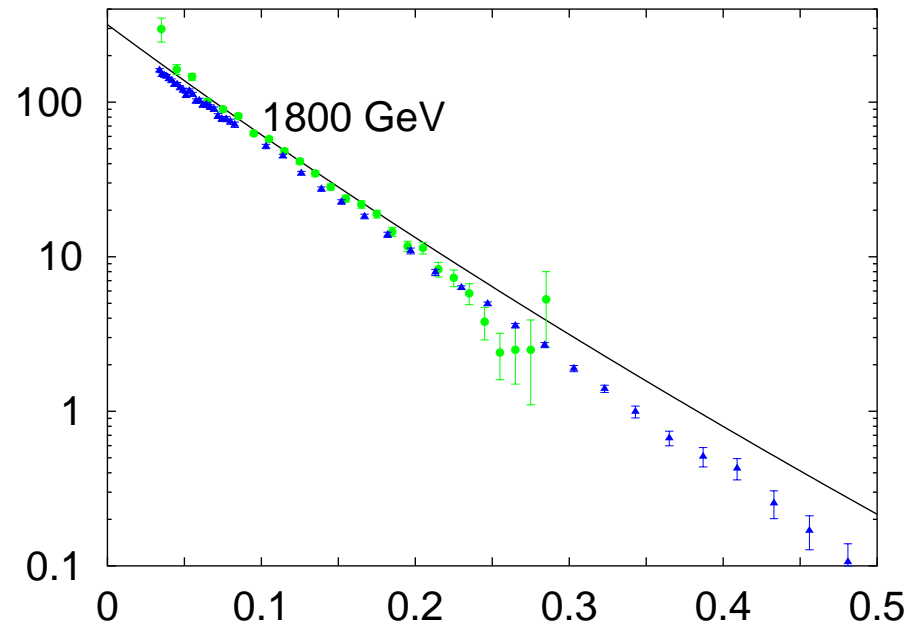
I'm not sure!

# LHC total cross section



Add **PP** exchange to **P** exchange

**PP** exchange pulls  $d\sigma/dt$  down at larger  $t$ .



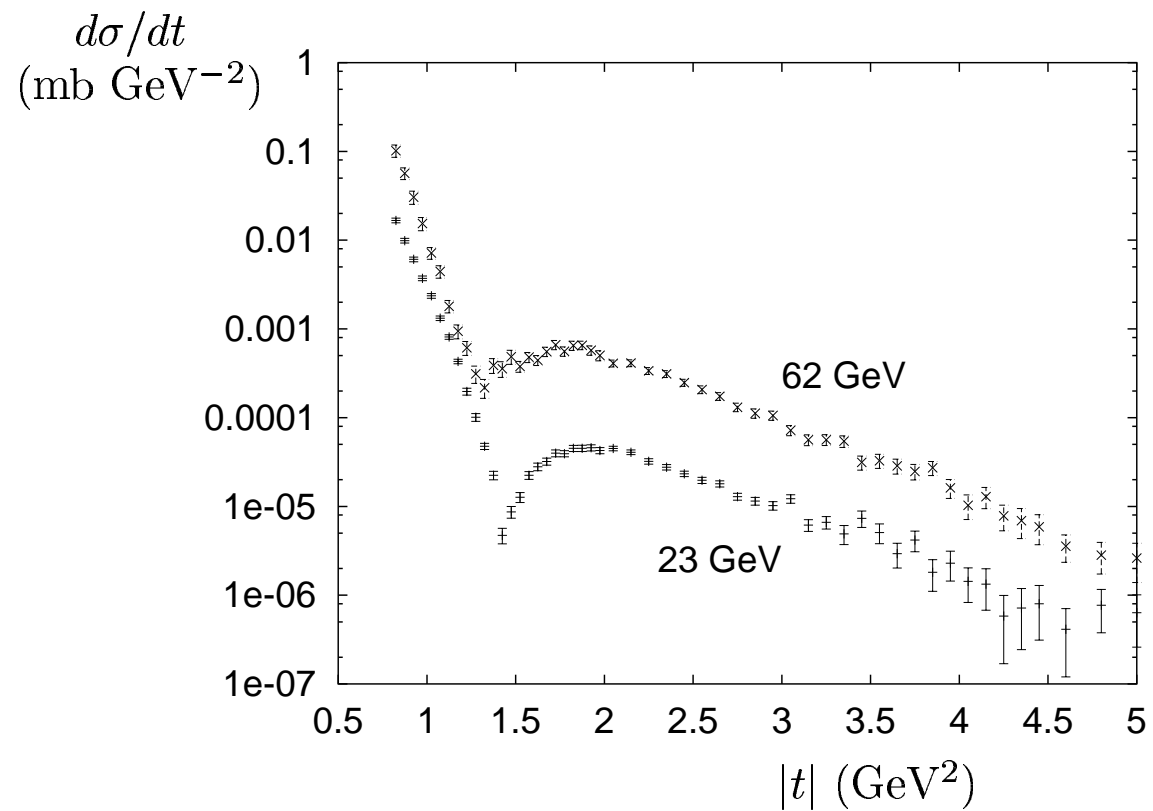
But nobody knows how to calculate it!

**Model:**

Calculate  $b$ -space amplitude for **P** exchange, square it:

$$A(s, b) = a(s, b) + \lambda[a(s, b)]^2$$

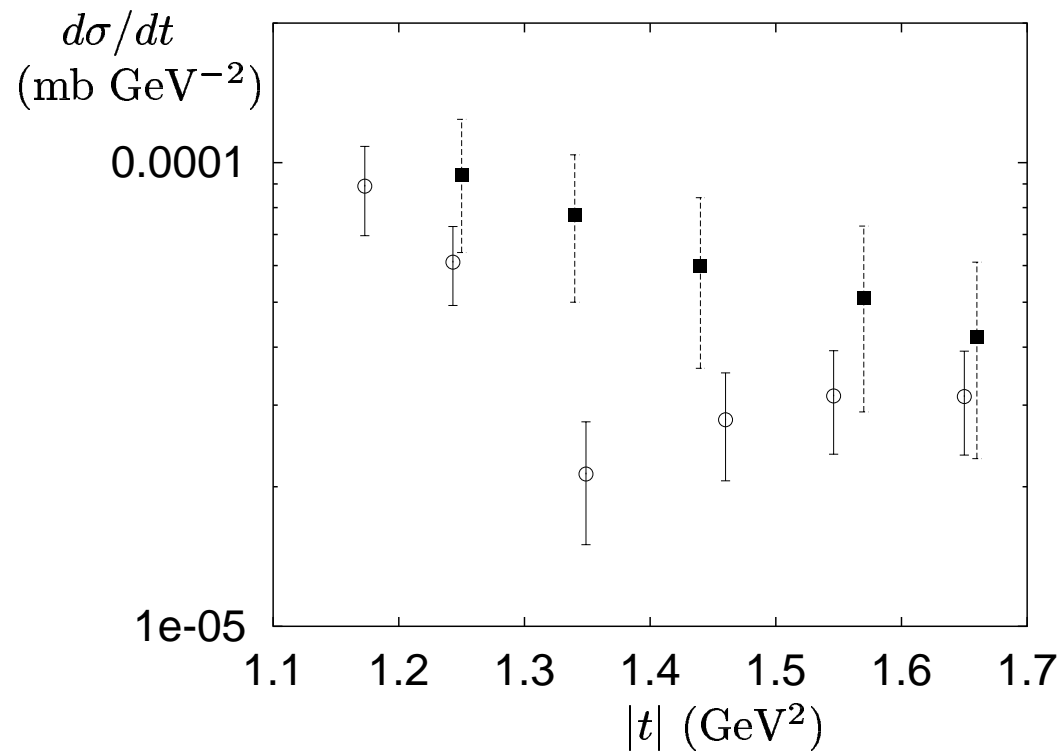
Choose  $\lambda$  to get  $pp$  dips at the right  $t$

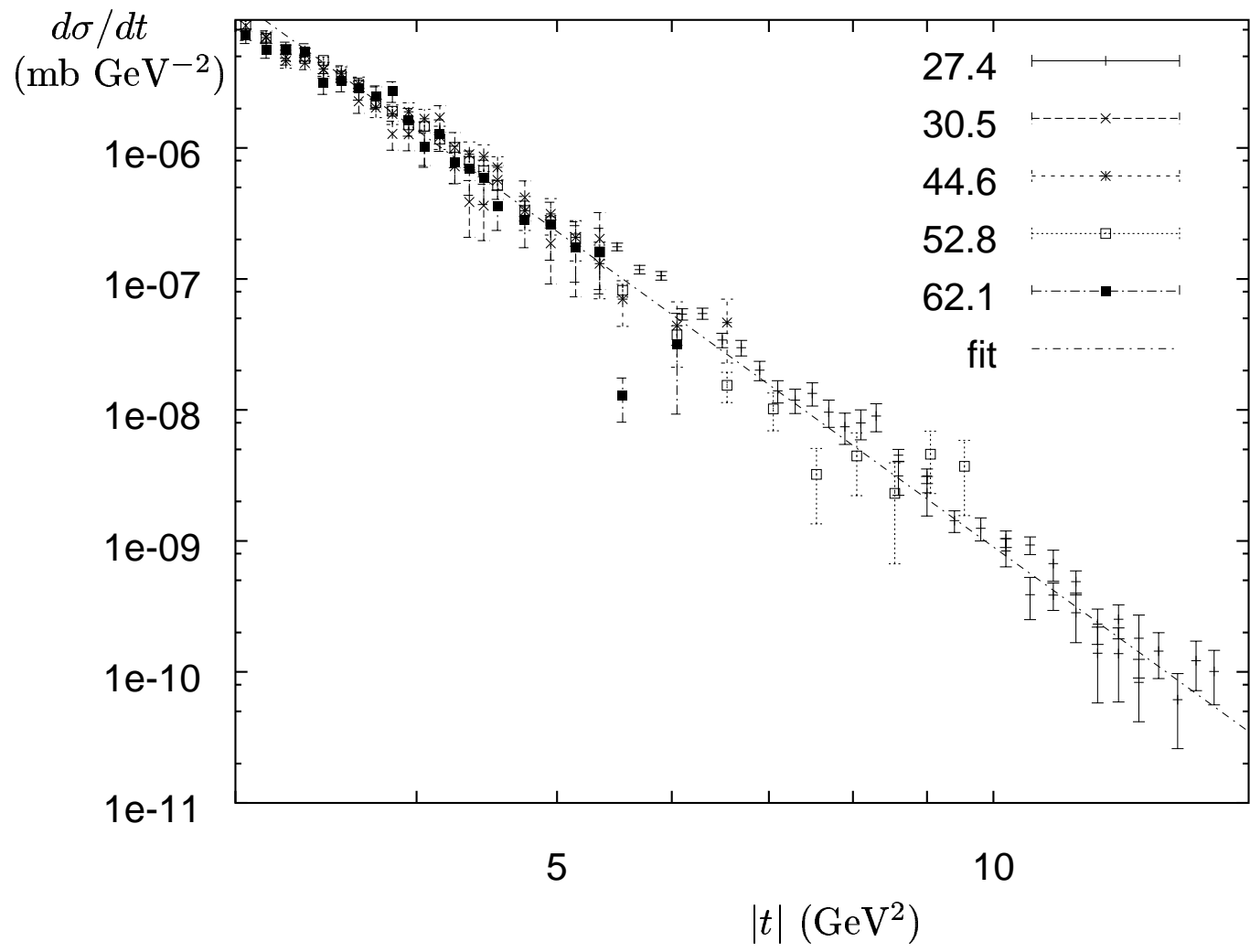


*pp* elastic data (CHHAV)

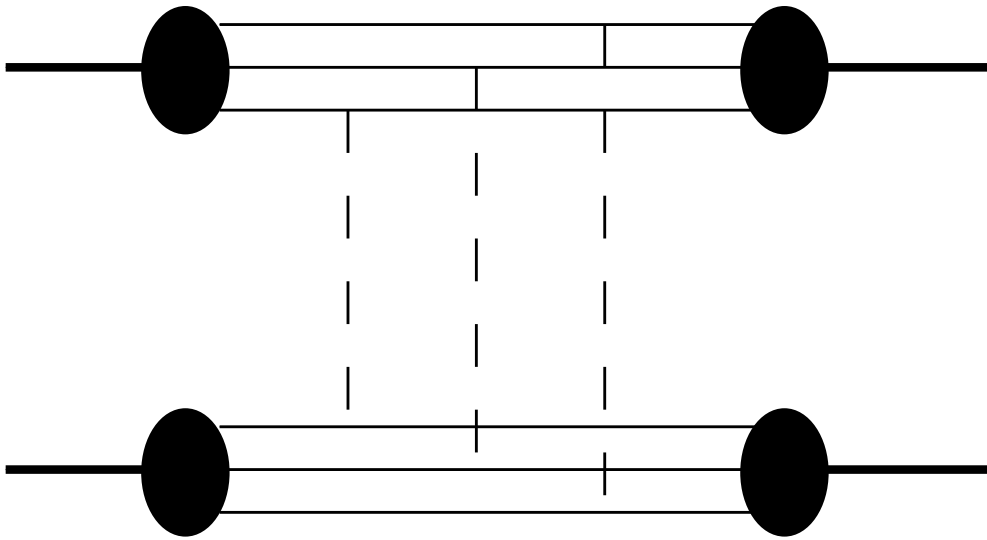
# Large $t$

$\bar{p}p$  and  $pp$  data (ISR):





$$0.09 t^{-8}$$

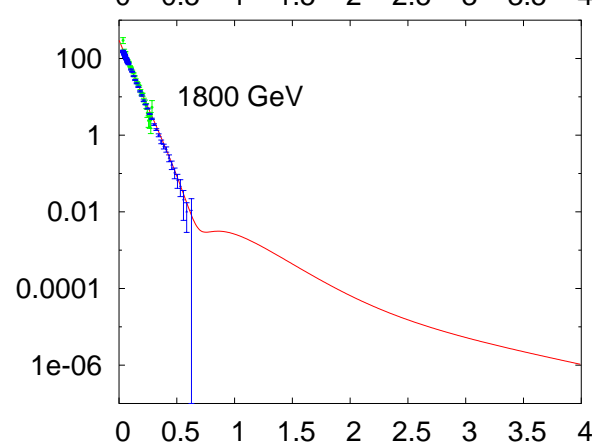
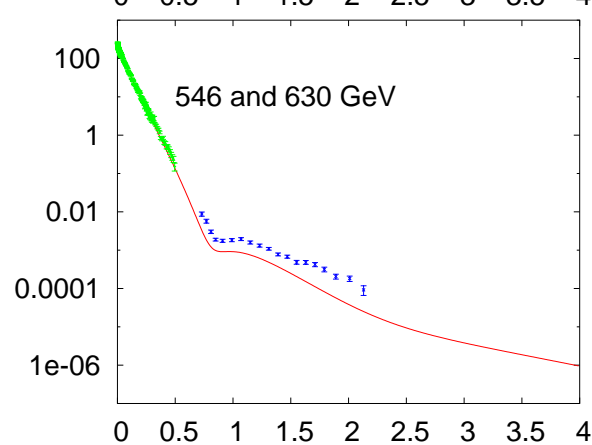
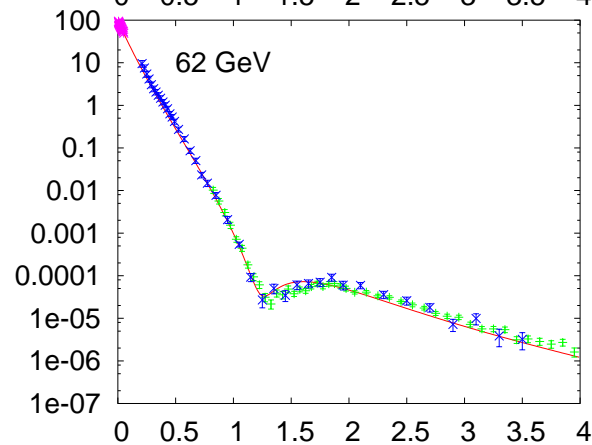
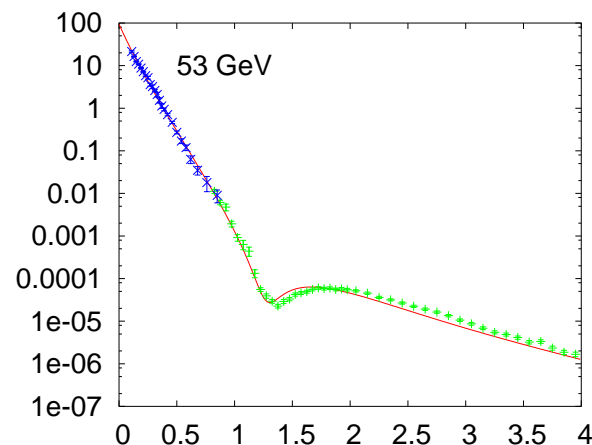
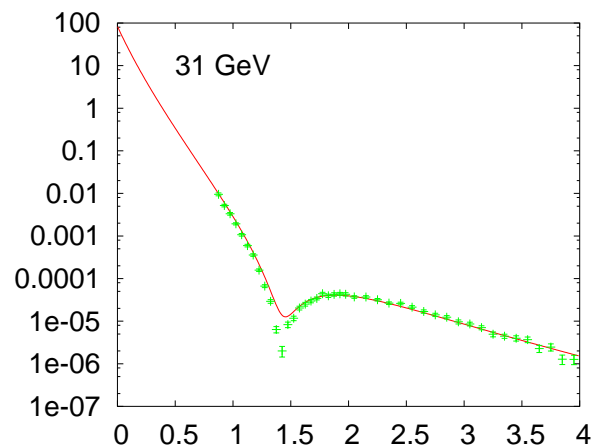
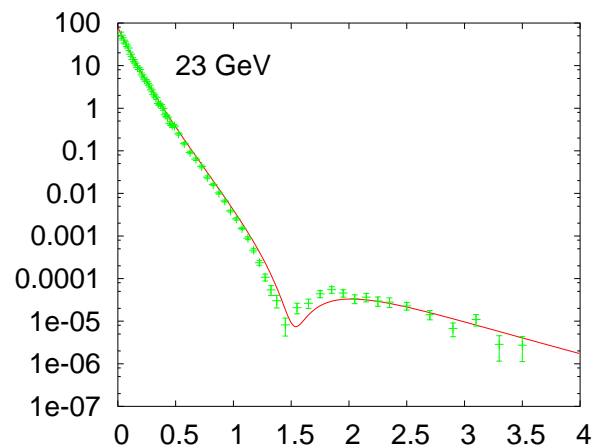


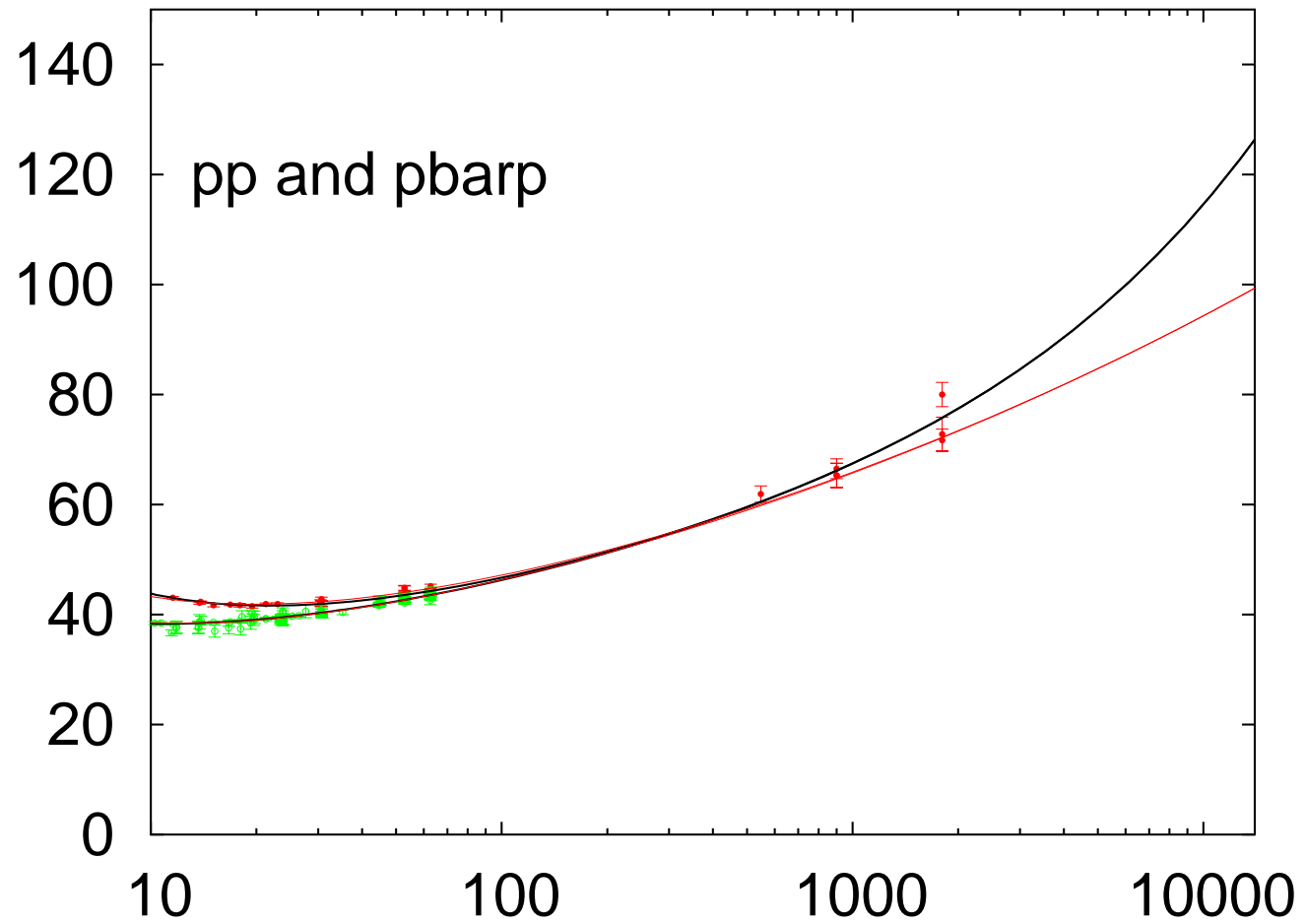
3-gluon exchange at large  $t$ :

$$\frac{d\sigma}{dt} \sim Ct^{-8} \quad \text{independent of } s$$

$$C = -1$$

# Fit $pp$ and $\bar{p}p$ elastic data with $\mathbf{P} + \mathbf{PP} + ggg$





$$\sigma(\text{LHC}) = 125 \pm 25 \text{ mb}$$

## Summary

- $\sigma(pp)$  anywhere between 100 and 150 mb
- $xg(x, Q^2)$  is likely to be large at small  $x$
- Not sure whether hardpom reggefactorises

*LHC should teach us a lot*