Forward Detector Physics

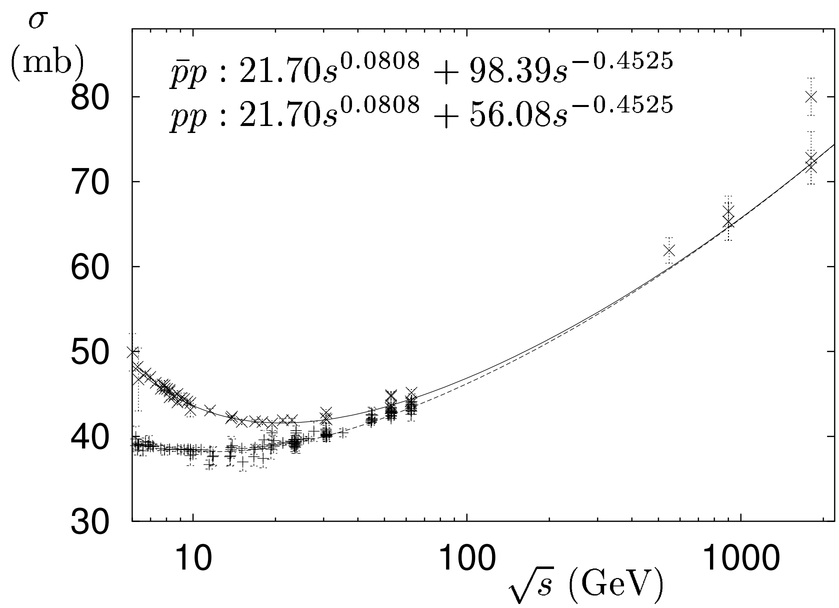
A Donnachie and P V Landshoff

- Total cross sections
- Elastic scattering
- Soft diffraction dissociation
- $p\ p \to p$ Higgs p

Puzzles from data:

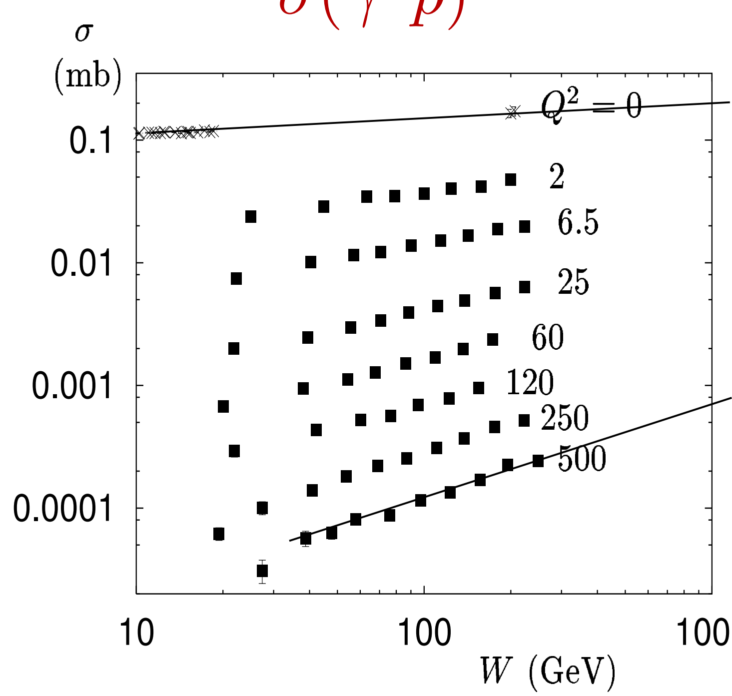
ISR — Tevatron — HERA — LEP

HERA's striking discovery



Note disagreement between E710/E811 and CDF

$\sigma(\gamma^* p)$



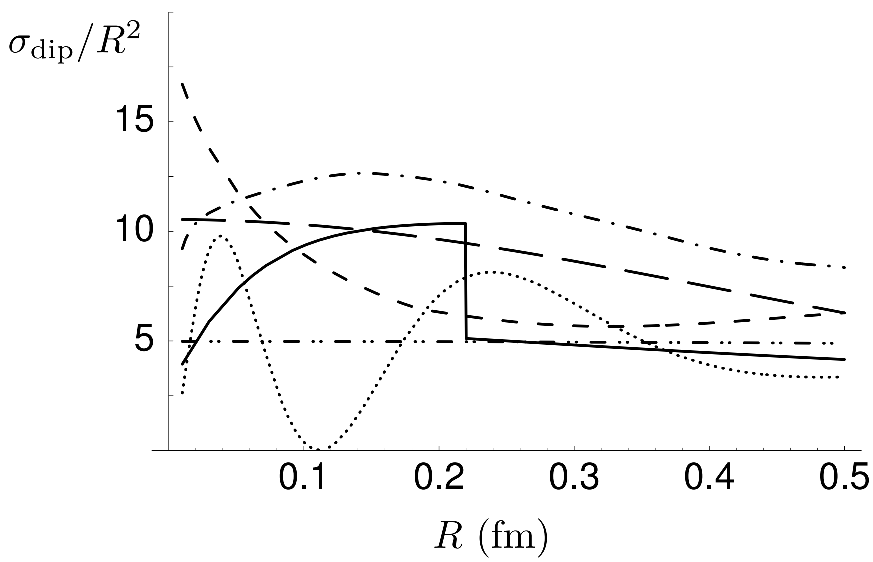
At very low Q^2, $\sigma(\gamma^* p) \sim (W^2)^{0.08}$
At high Q^2, $\sigma(\gamma^* p) \sim (W^2)^{0.4}$

Many theoretical models:

- Regge theory
- dipole models
- DGLAP
- BFKL
- stochastic vacuum models
- saturation models
- semiclassical approach

They all use different language, but there are many links between them.
All are just models.

Different dipole potentials:



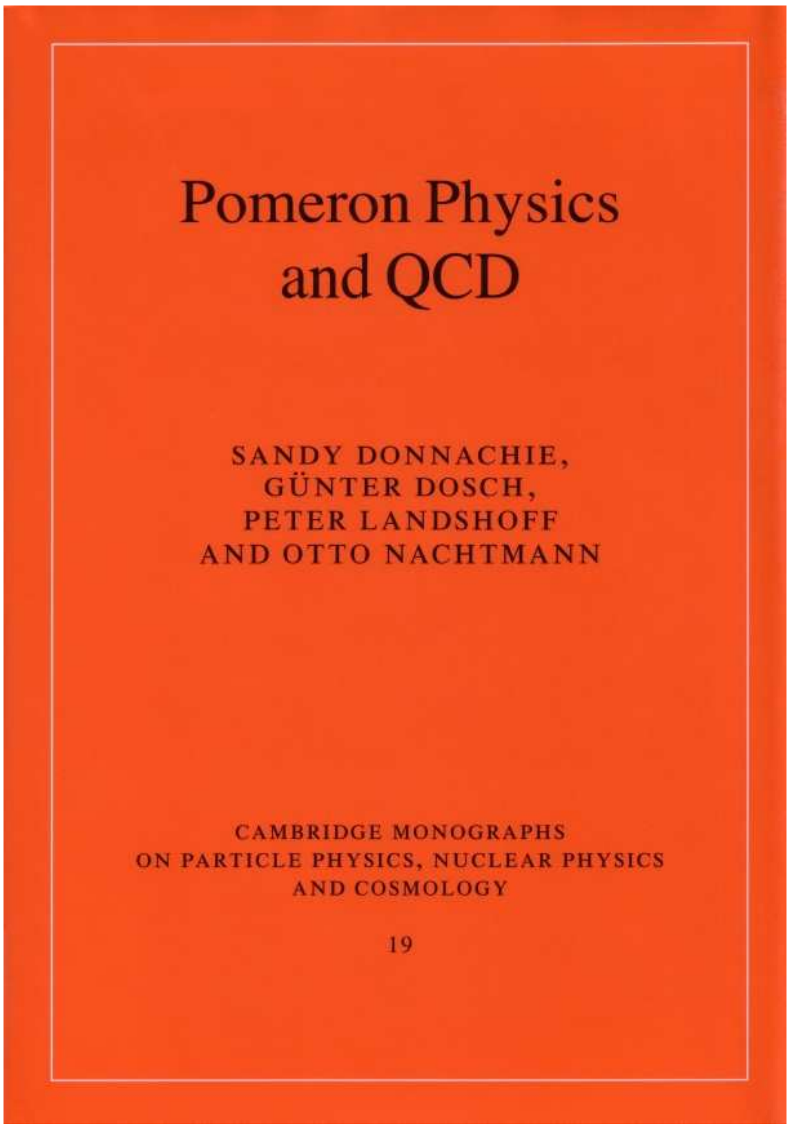
DGLAP: expansion of splitting matrix in powers of α_s invalid for $x < 0.005$ (MRST)

Regge: how to make contact with QCD?

BFKL: NLO correction wrecks the whole thing

John Bell:

"I'm not impressed when a theorist tells me he can fit the data.
If he had not been able to, he would not have told me."



Pomerons

1984: soft pomeron

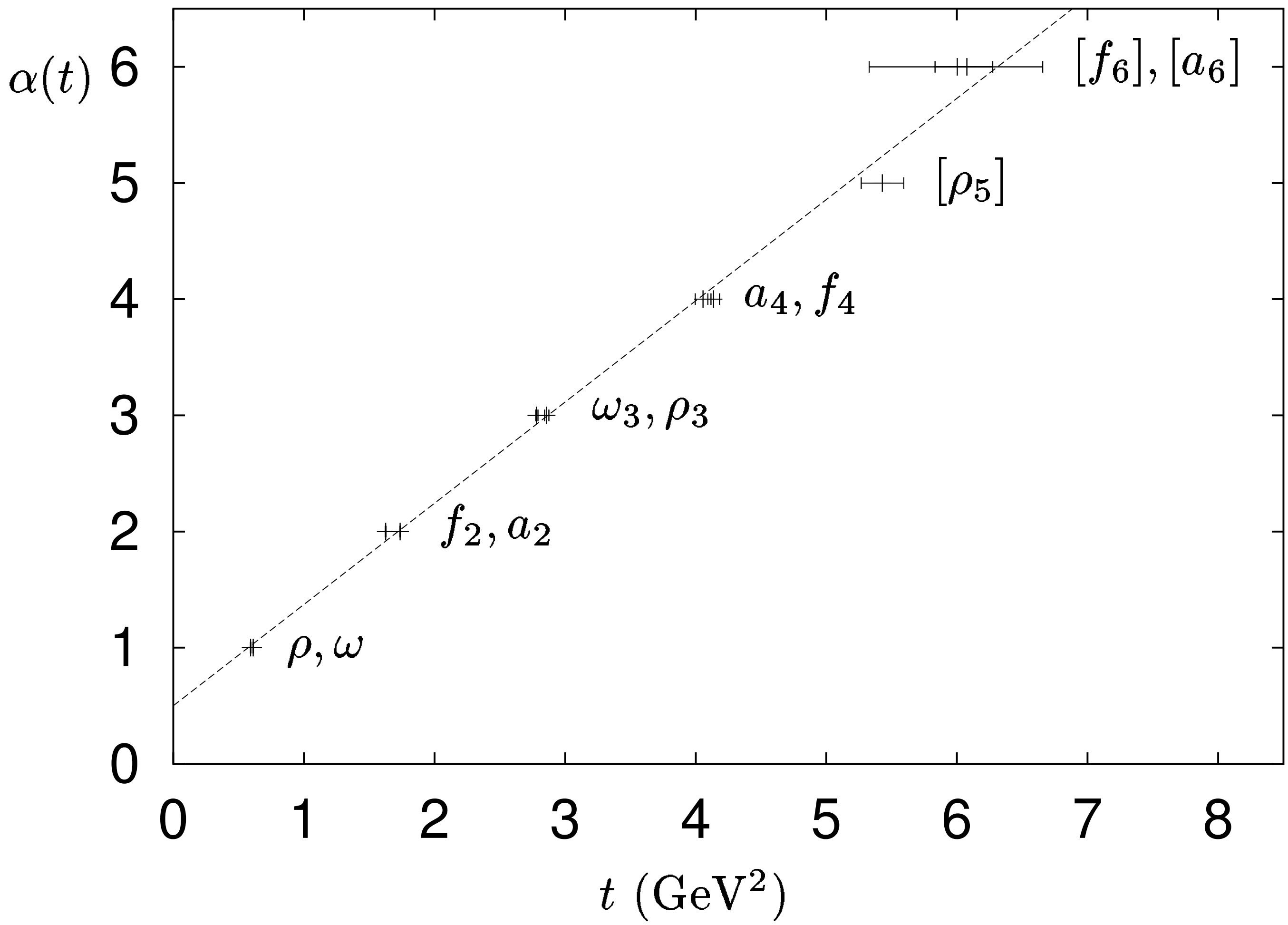
Fit high-energy $\sigma(pp), \sigma(p\bar{p})$ with simple power s^{ϵ_1}
$\epsilon_1 \approx 0.08$

1998: hard pomeron

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

2004 fit

Use hardpom, softpom and reggeon exchange
Reggeon = ρ, ω, f_2, a_2



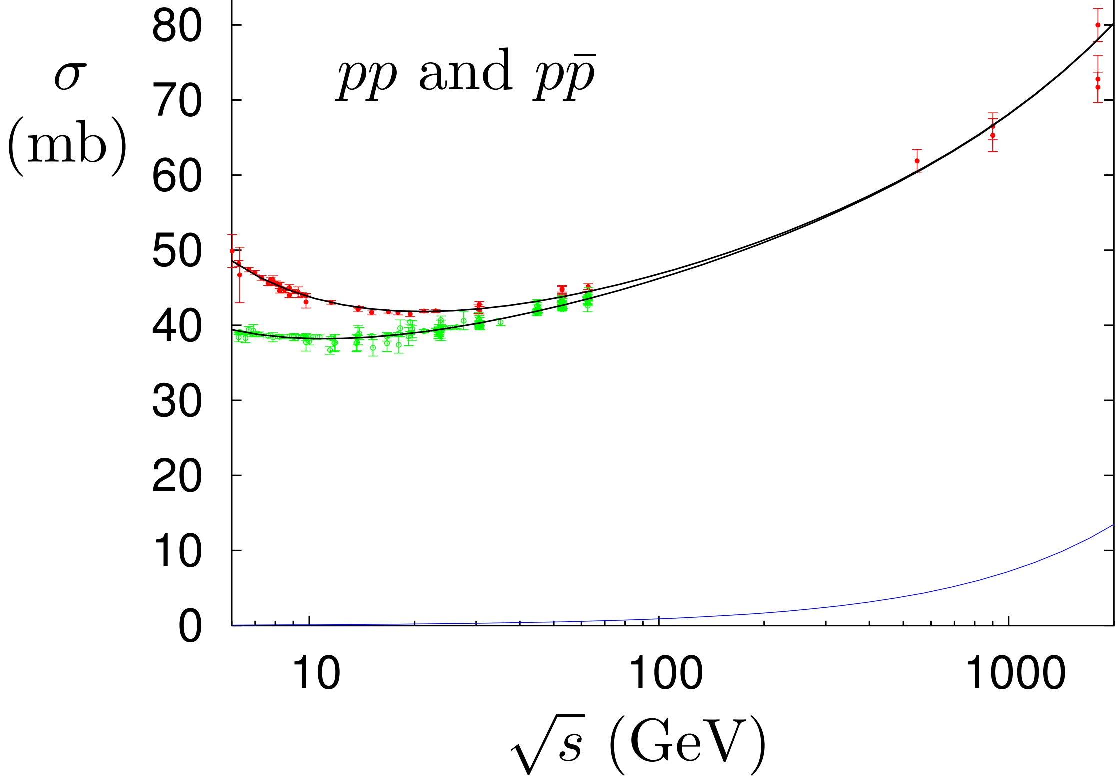
Approximate with a single term $\epsilon_R \approx 0.5$

$\sigma(pp), \sigma(p\bar{p}), \sigma(\gamma p)$:

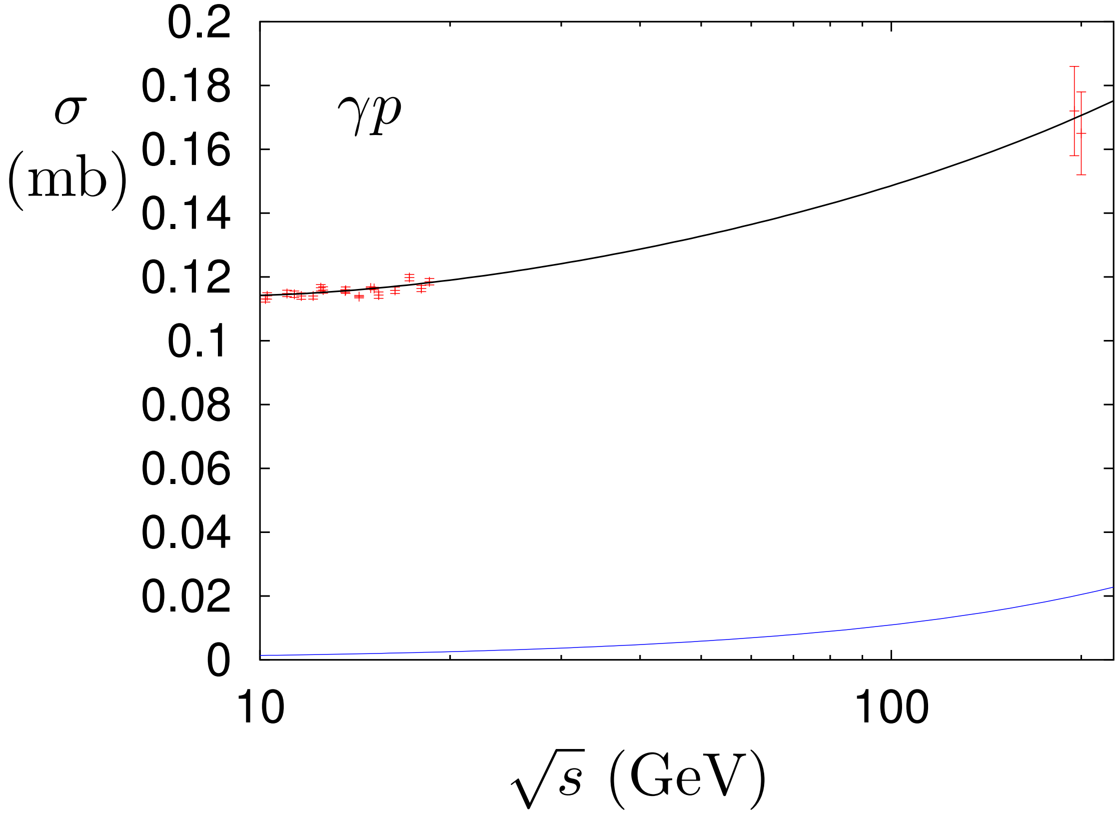
$$\sigma = X_0 s^{\epsilon_0} + X_1 s^{\epsilon_1} + Y s^{\epsilon_R}$$

$F_2(x, Q^2)$:

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



σ
(mb)
pp and p$\bar{p}$
80
70
60
50
40
30
20
10
0
10
100
1000
$\sqrt{s}$ (GeV)



σ
(mb)
γp
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10
100
$\sqrt{s}$ (GeV)

Differential cross section

Elastic scattering:

$$\frac{d\sigma^{pp}}{dt} \sim \frac{d\sigma^{\bar{p}p}}{dt} \sim \frac{(3\beta_{I\!P} F_1(t))^4}{4\pi} \left(\frac{s}{s_0}\right)^{2\alpha_{I\!P}(t)-2}$$

$$\alpha_{I\!P}(t) = 1.08 + \alpha' t \qquad s_0 = 1/\alpha'$$

$F_1(t)$=Dirac form factor

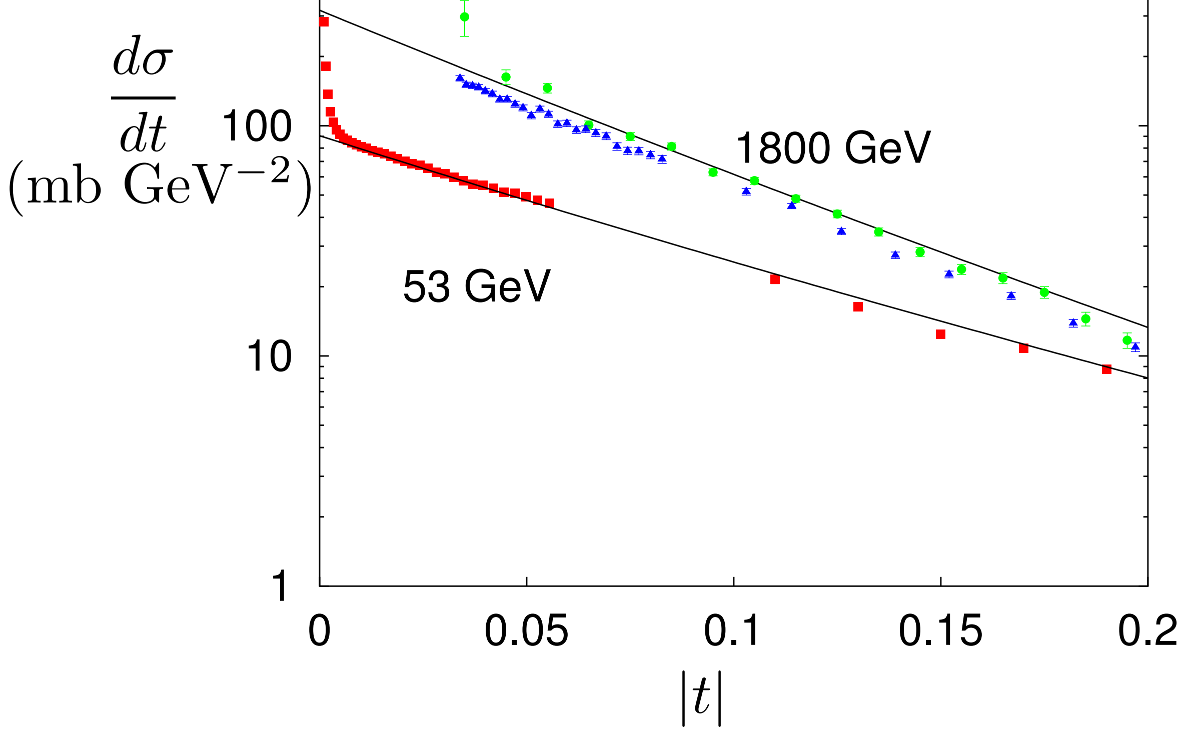
Old fit:

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

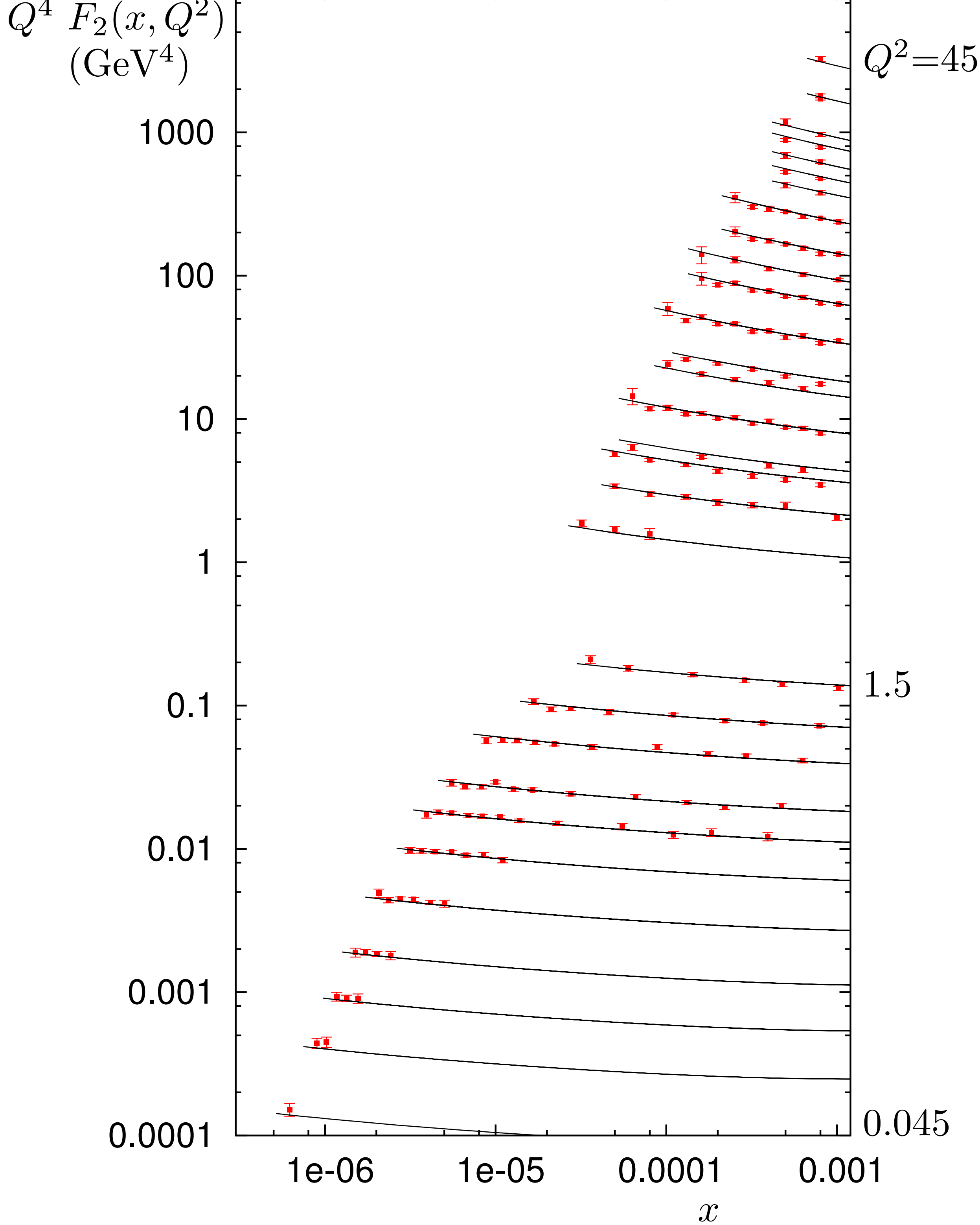
Replace with two trajectories:

$$\epsilon_0 = 0.45 \qquad \alpha'_0 \approx 0.1$$

$$\epsilon_1 = 0.067 \qquad \alpha'_1 \approx 0.3$$

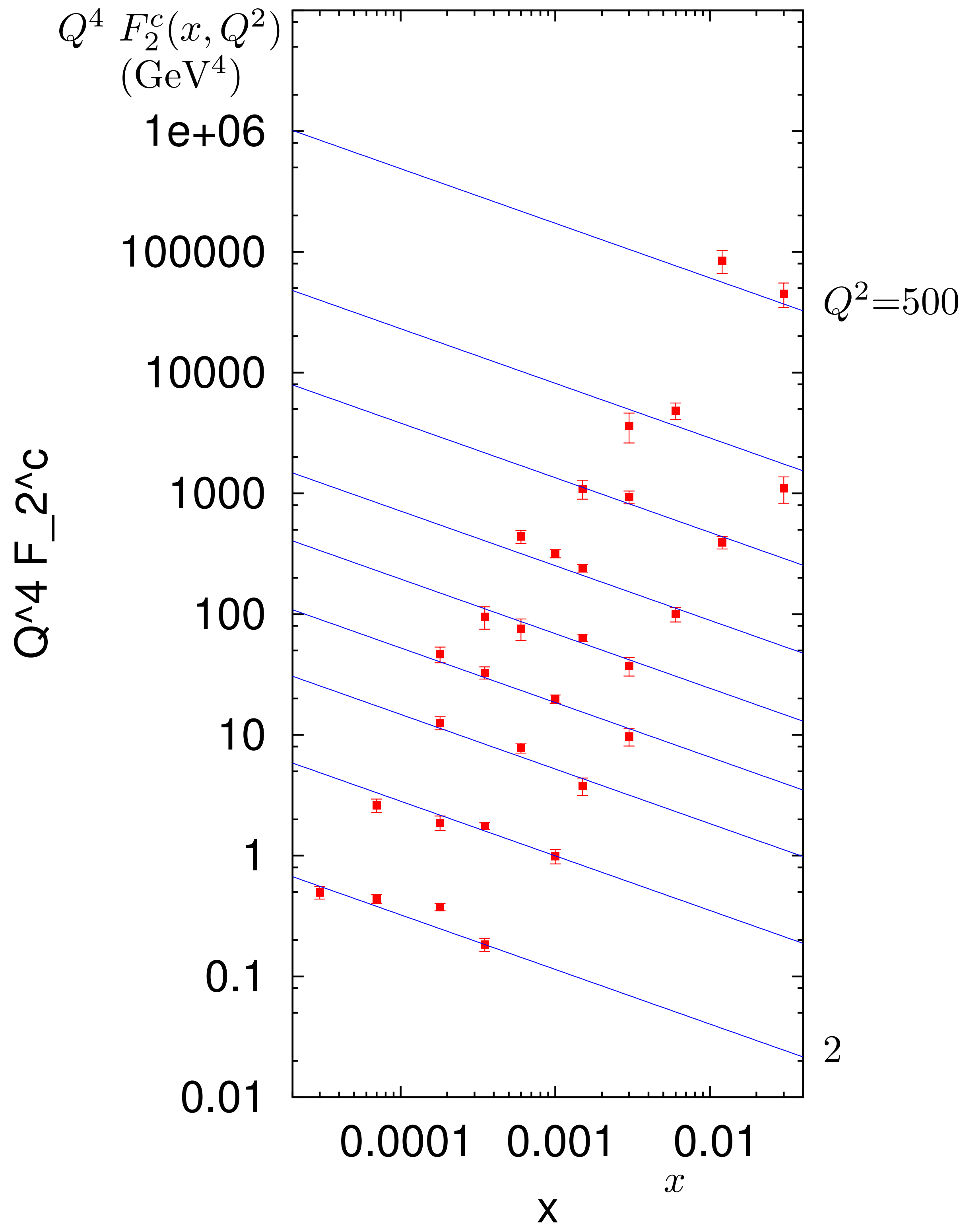


$\frac{d\sigma}{dt}$
(mb GeV^{-2})
100
10
1
1800 GeV
53 GeV
0
0.05
0.1
0.15
0.2
$|t|$



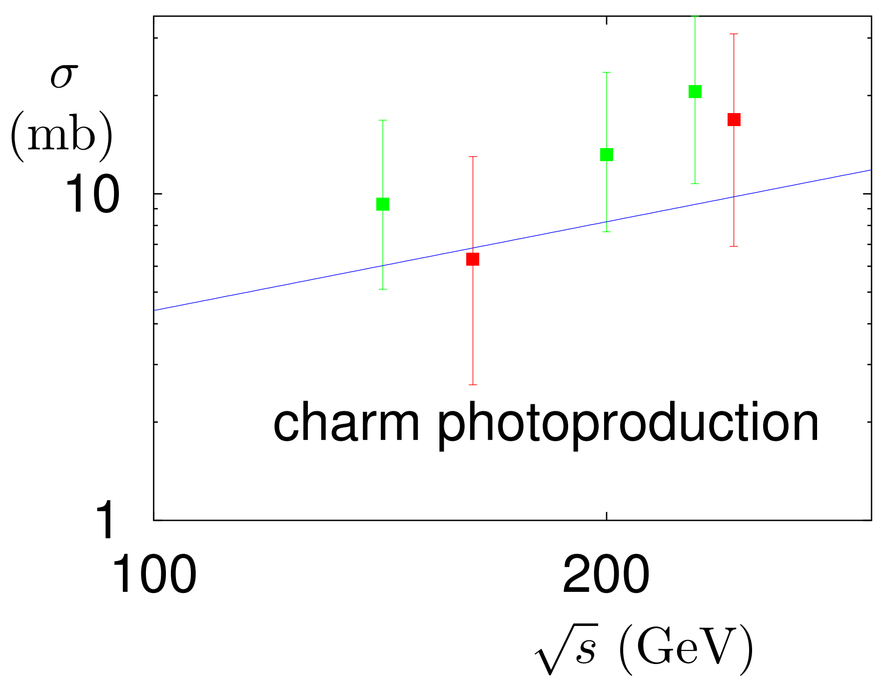
$Q^4\ F_2(x,Q^2)$ (GeV^4)
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-06
1e-05
0.0001
0.001
x
Q^2=45
1.5
0.045

Charm structure function



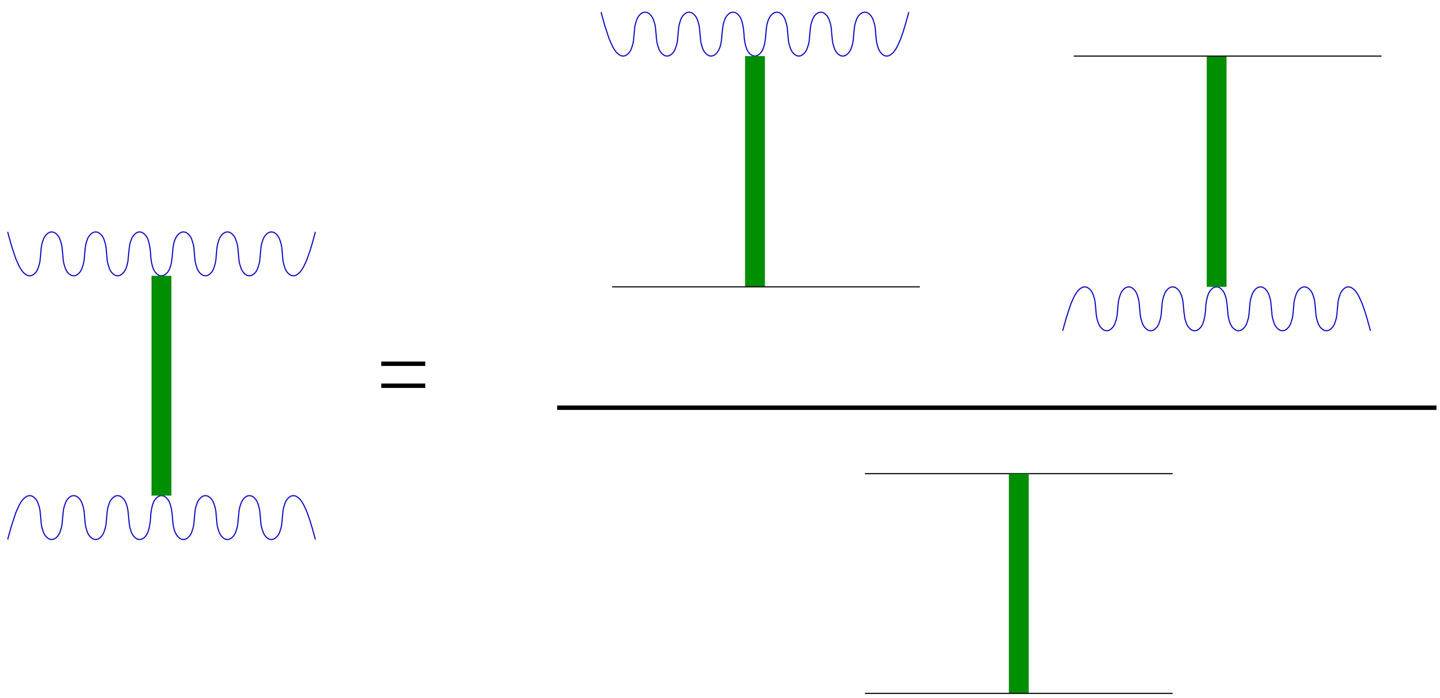
- F_2^c is purely hardpom exchange
- The hardpom is flavour-blind:

$$F_2^c(x,Q^2) = \frac{\frac{4}{9}}{\frac{4}{9}+\frac{1}{9}+\frac{1}{9}+\frac{4}{9}}\ F_2(x,Q^2)\Big|_{\text{HARDPOM}}$$
$$= 0.4\ F_2(x,Q^2)\Big|_{\text{HARDPOM}}$$



Regge factorisation

For each of hardpom, softpom and reggeon exchange

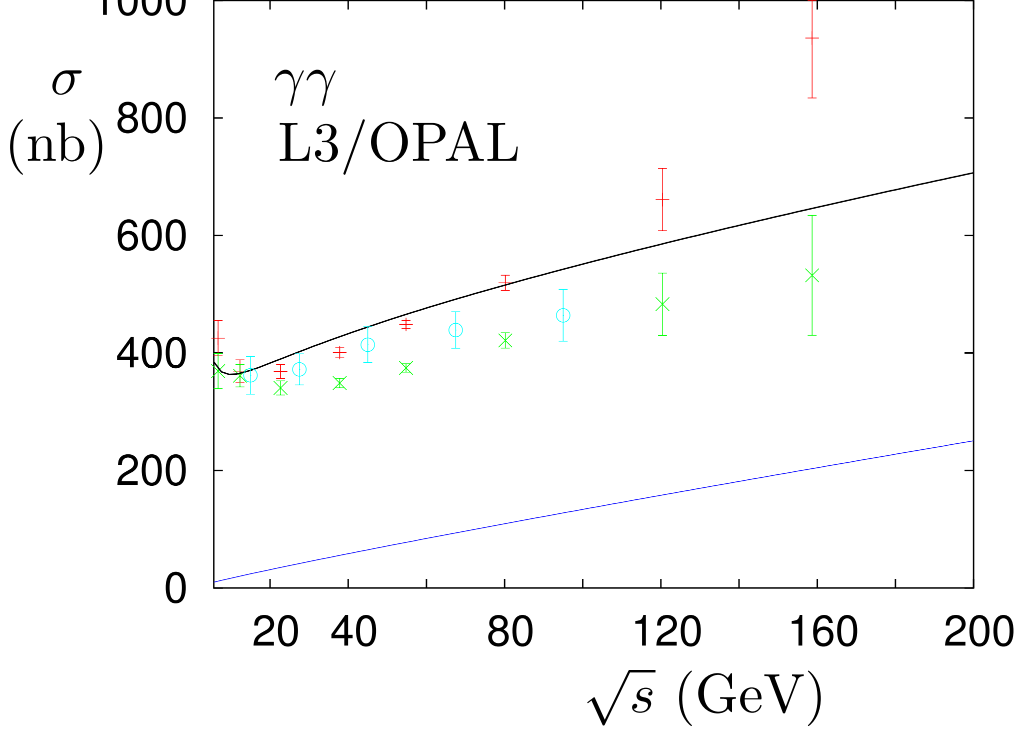


That is, for each term,

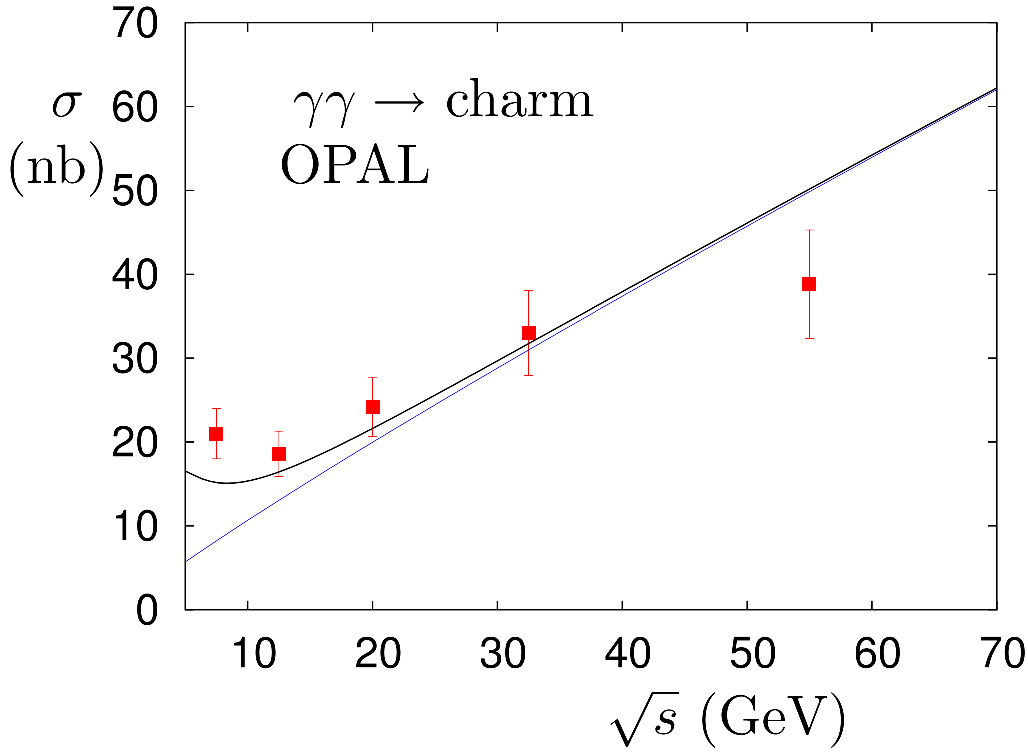
$$\sigma(\gamma\gamma) = \frac{\sigma(\gamma p)\sigma(\gamma p)}{\sigma(pp)}$$

for all Q_1^2, Q_2^2.

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

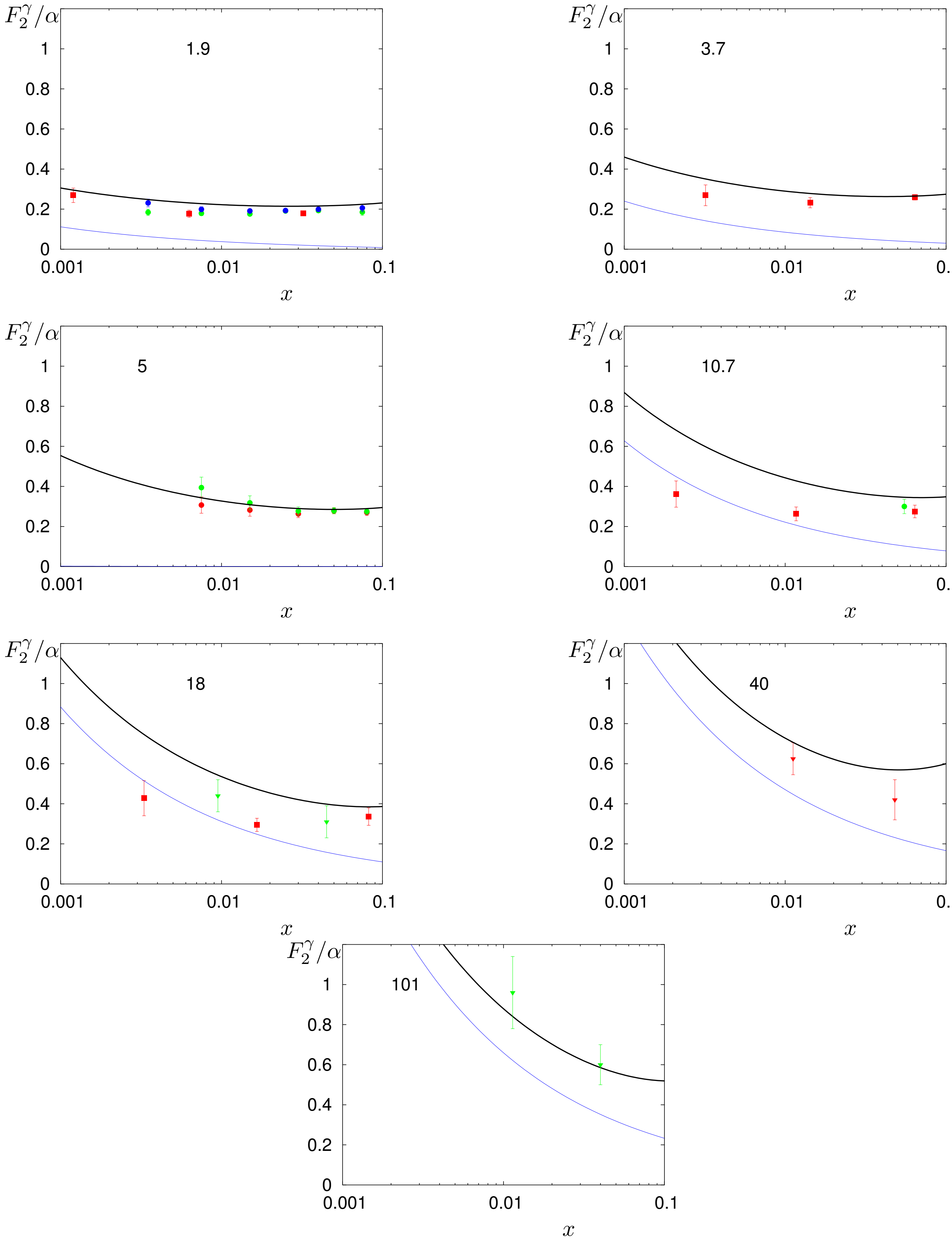


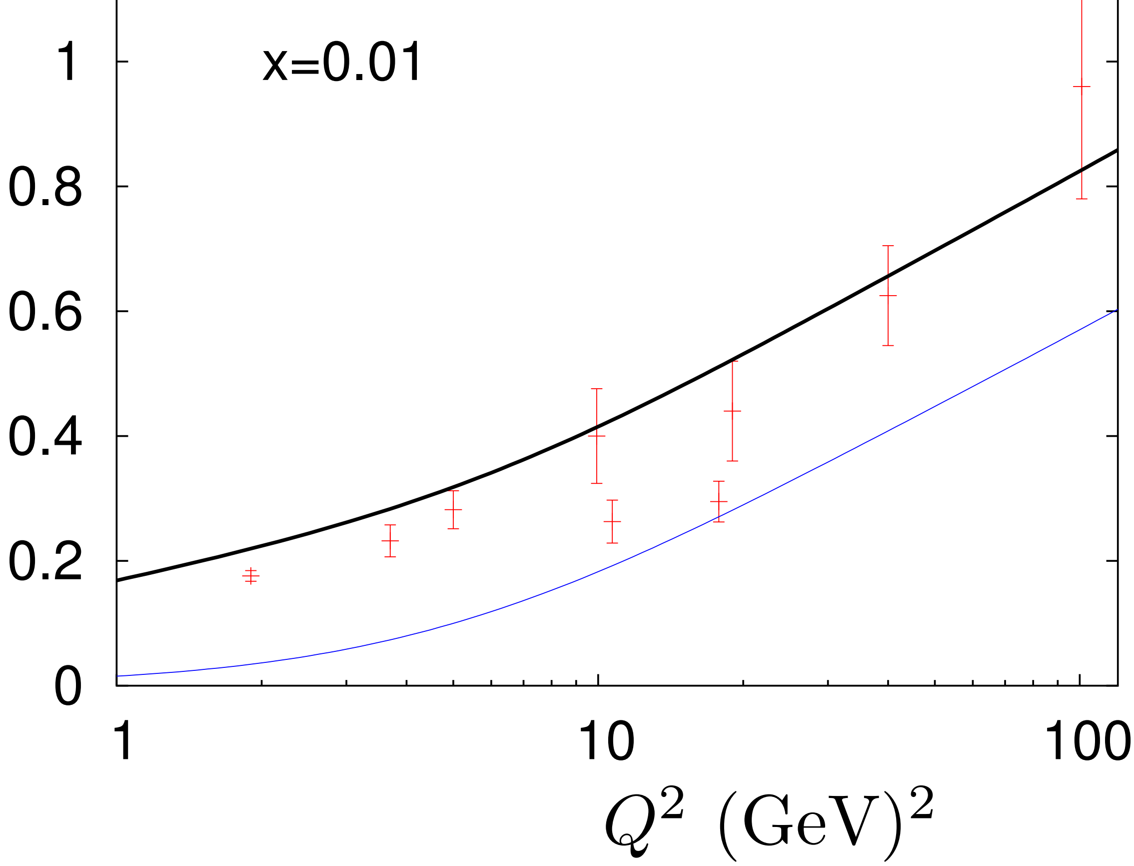
σ (nb)
γγ
L3/OPAL
0
200
400
600
800
1000
20
40
80
120
160
200
√s (GeV)



σ (nb)
γγ → charm
OPAL
0
10
20
30
40
50
60
70
10
20
30
40
50
60
70
√s (GeV)

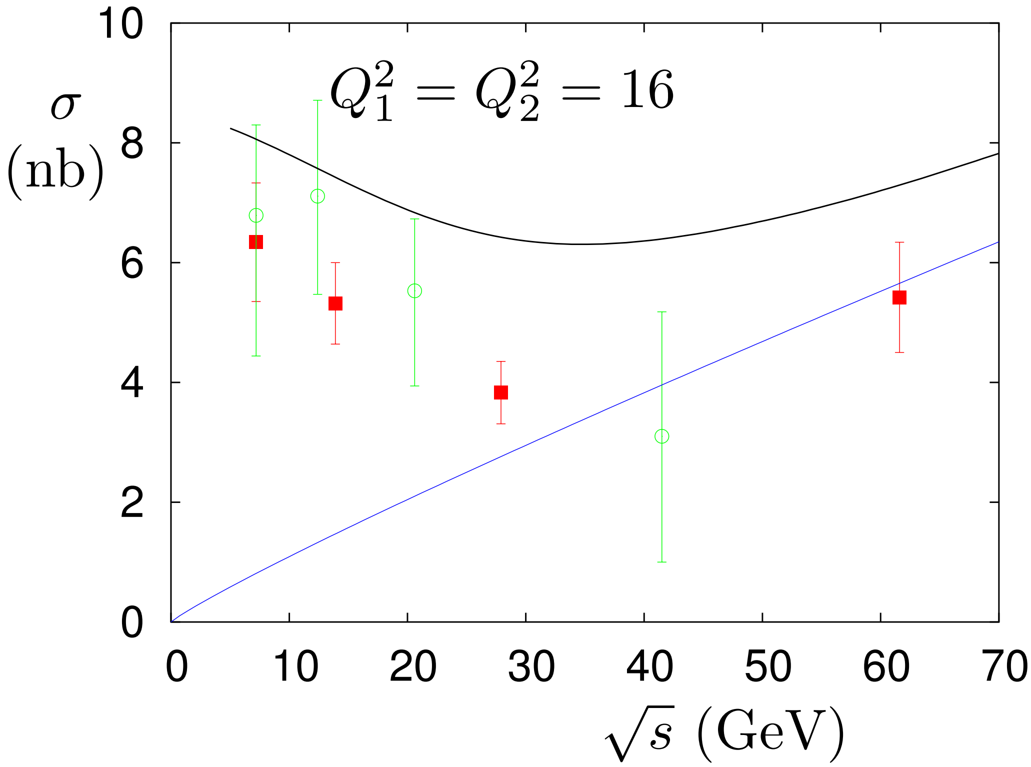
Photon structure function





x=0.01
1
0.8
0.6
0.4
0.2
0
1
10
100
Q^2 (GeV)^2

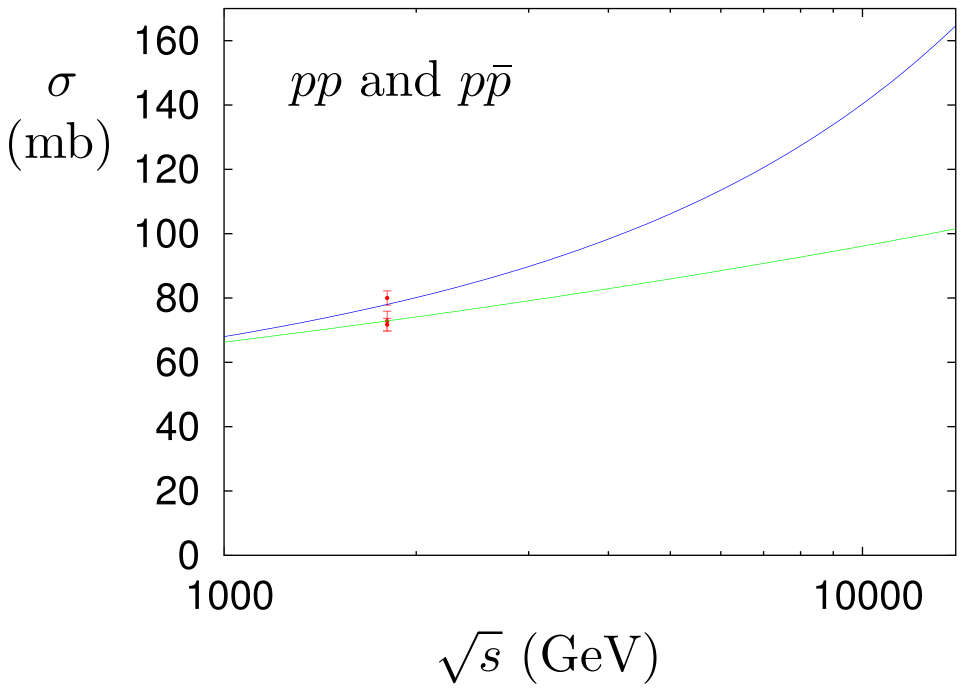
Both photons off shell



Conclusion about Regge factorisation:

I'm not sure!

LHC energies: unitarity



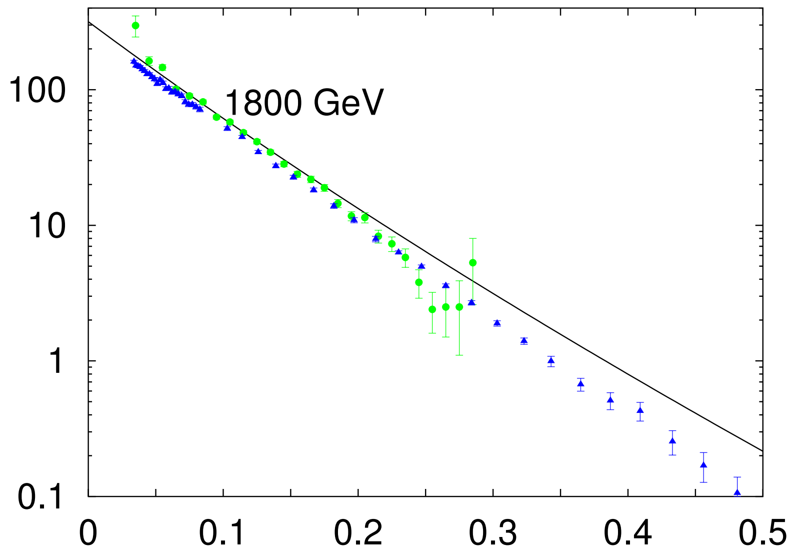
Froissart-Lukaszuk-Martin bound:

$$\sigma < \frac{\pi}{m_\pi^2} \log^2\left(\frac{s}{s_0}\right) \approx 22 \textbf{ barns}$$

$$A(s,b) = \frac{1}{16\pi^2} \int d^2q \; e^{i\mathbf{q}.\mathbf{b}} A(s, t = -\mathbf{q}^2)$$

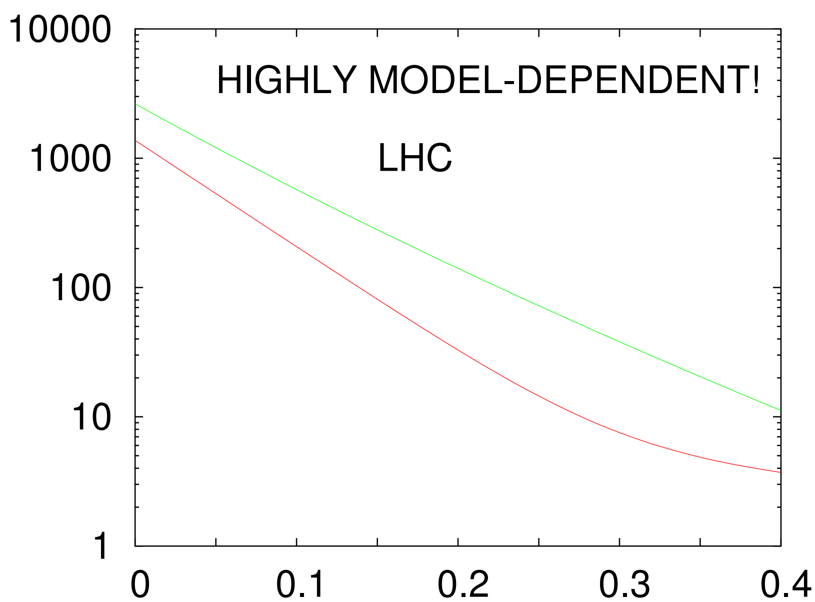
$$\mathrm{Im}\; A(s,b) = 1.1$$

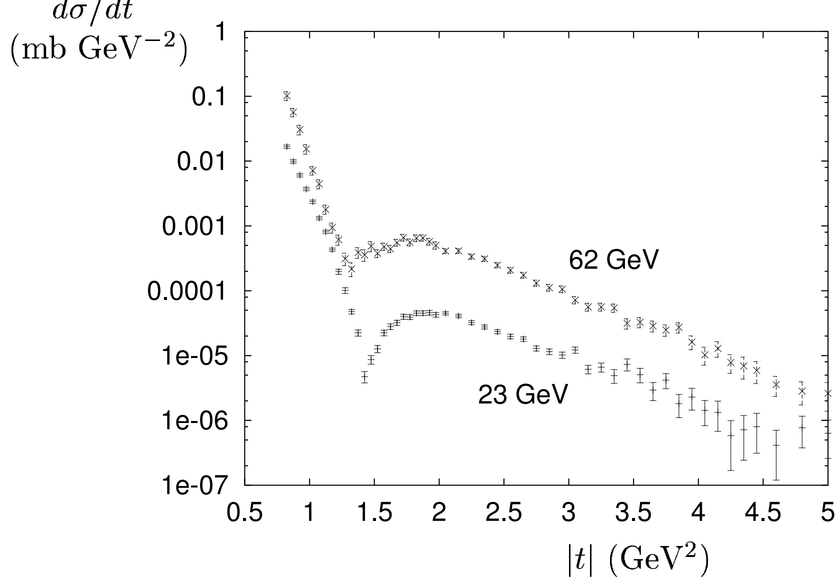
It should be < 1 **but** ...



$I\!\!P I\!\!P$ exchange pulls $d\sigma/dt$ down at larger t.
But nobody knows how to calculate it!
Eikonal: a popular model, not a theory.

At 14 TeV:

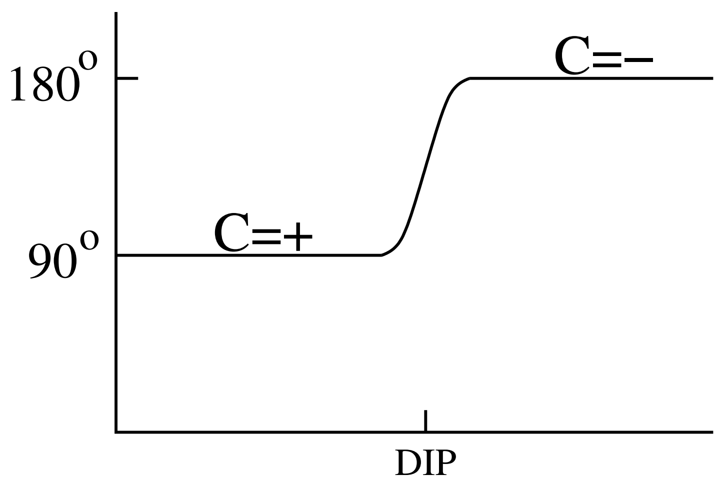




pp elastic data (CHHAV)

If $A(s,t) \sim s^{\alpha_{\rm EFF}(t)}$,
its phase is

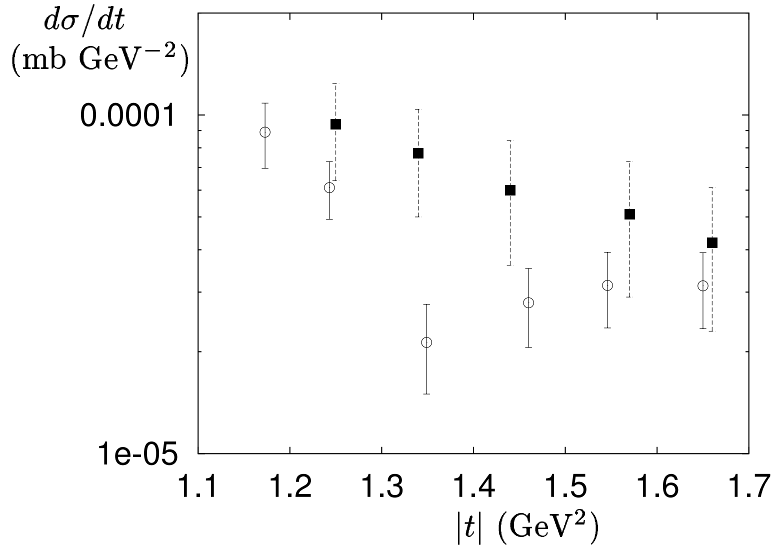
$$\begin{array}{ll} \exp(\frac{1}{2}i\pi\alpha_{\rm EFF}(t)) & C = +\text{ exchange} \\ i\exp(\frac{1}{2}i\pi\alpha_{\rm EFF}(t)) & C = -\text{ exchange} \end{array}$$



Rapid energy variation only near the dip

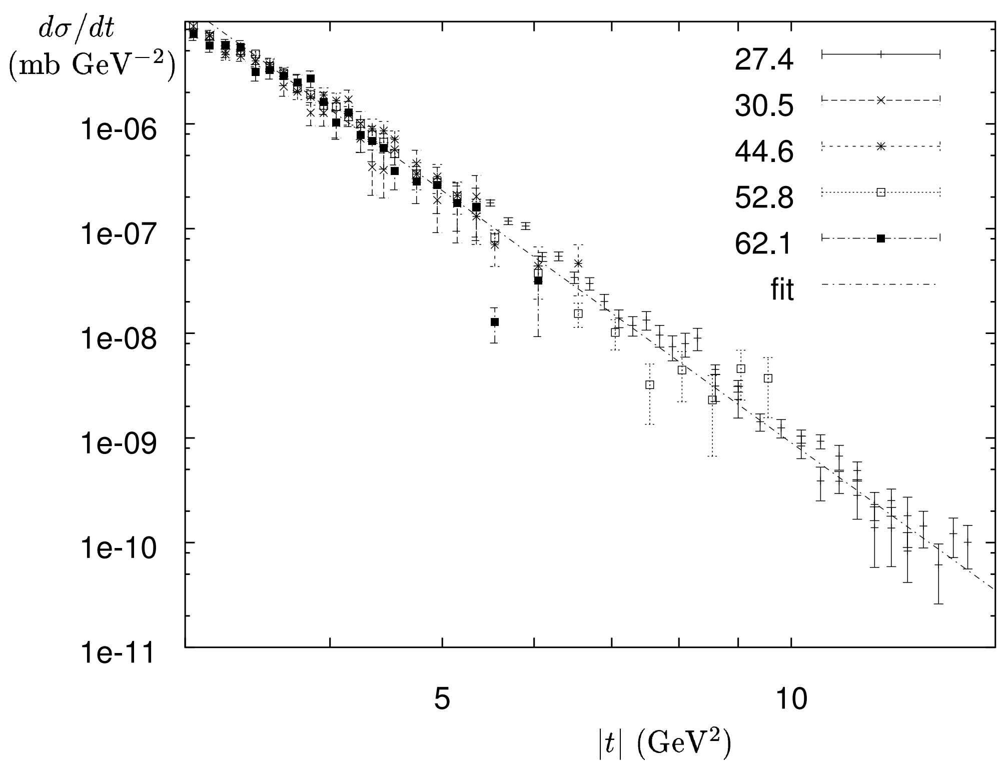
Note: It is *difficult* to get a dip when there are contributions with different phases!

Large t

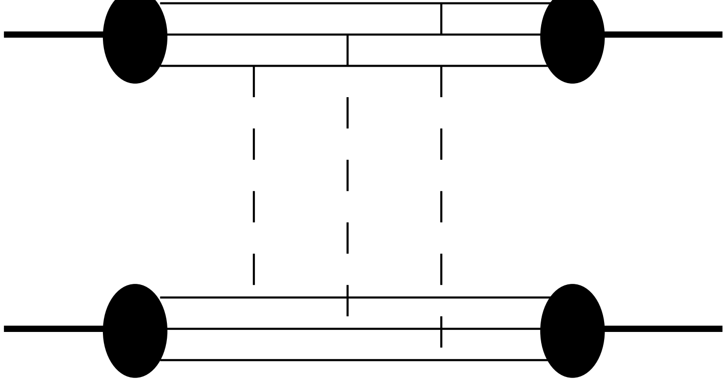


$\bar{p}p$ and pp data (ISR)

Why do we see no odderon at small t?



$0.09\ t^{-8}$



3-gluon exchange at large t:

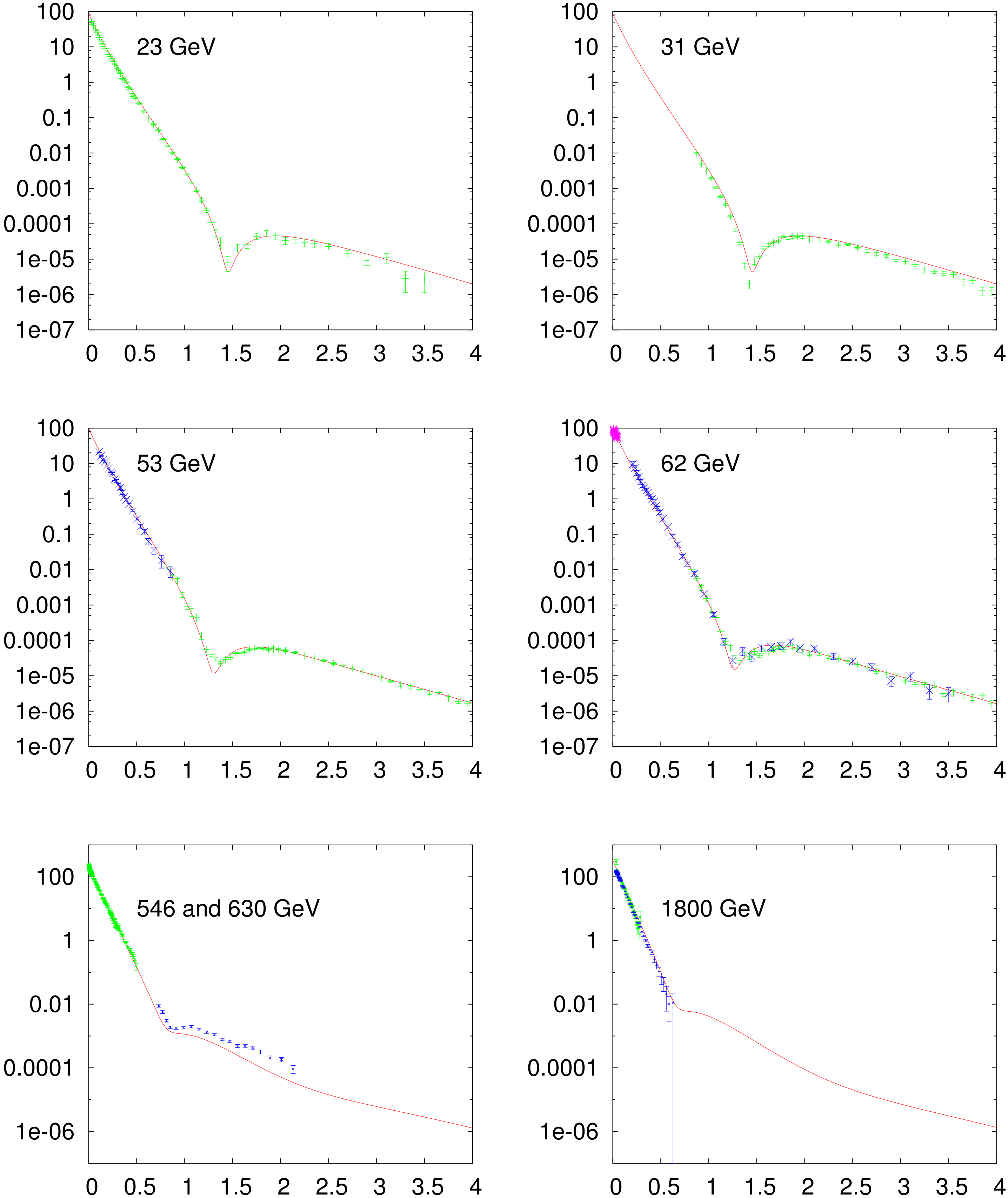
$$\frac{d\sigma}{dt} \sim C t^{-8} \qquad \text{independent of } s$$

Data: $C = 0.09$ in mb–GeV units

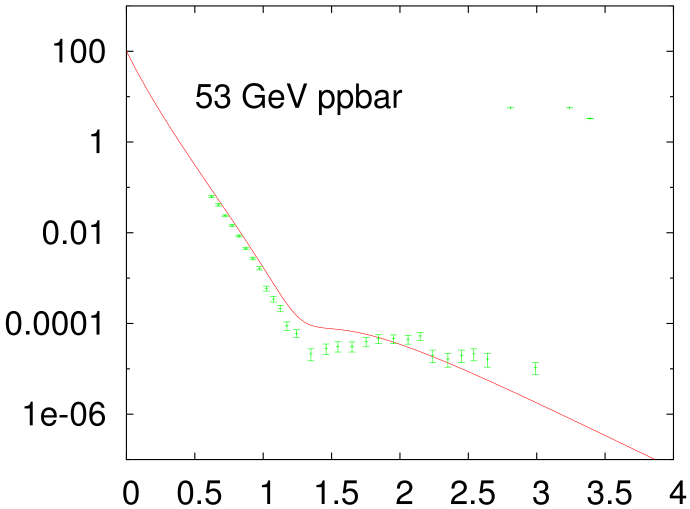
Fit pp and $\bar{p}p$ elastic data with

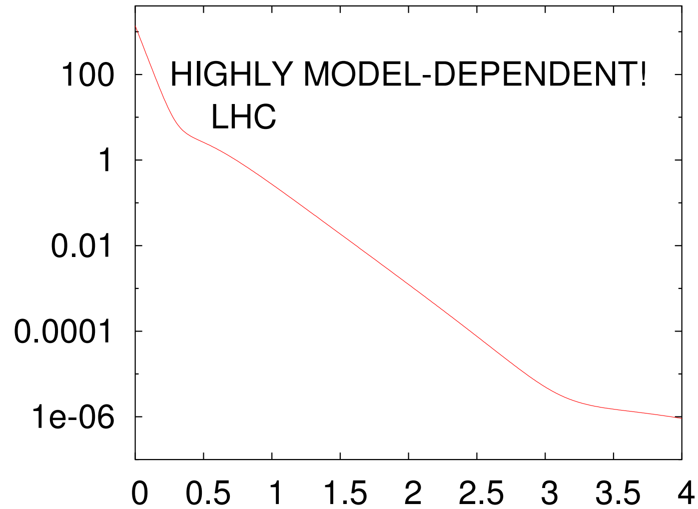
$$I\!\!P + I\!\!P I\!\!P + ggg$$

with 2 additional parameters

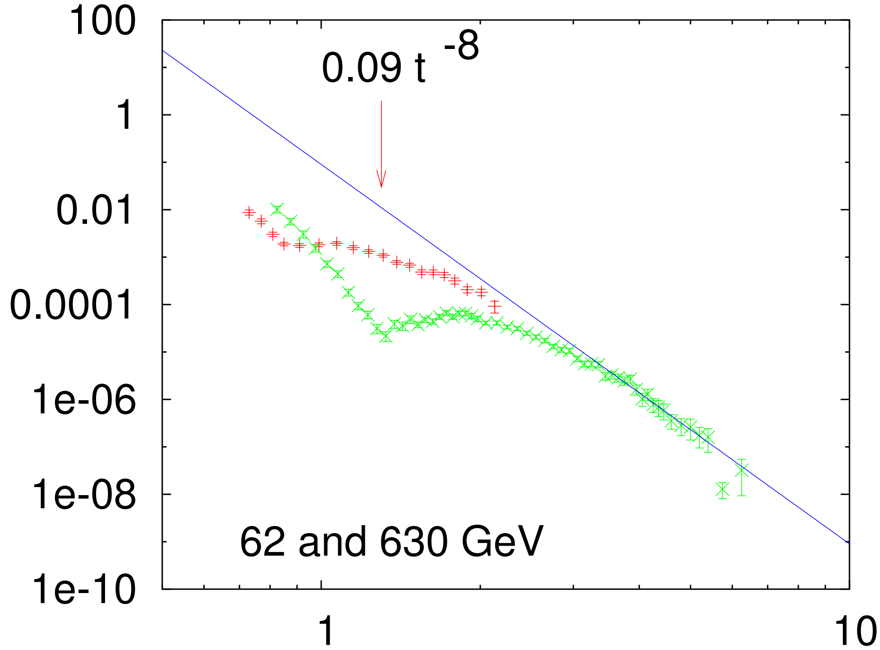


23 GeV
31 GeV
53 GeV
62 GeV
546 and 630 GeV
1800 GeV
100
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
0
0.5
1
1.5
2
2.5
3
3.5
4

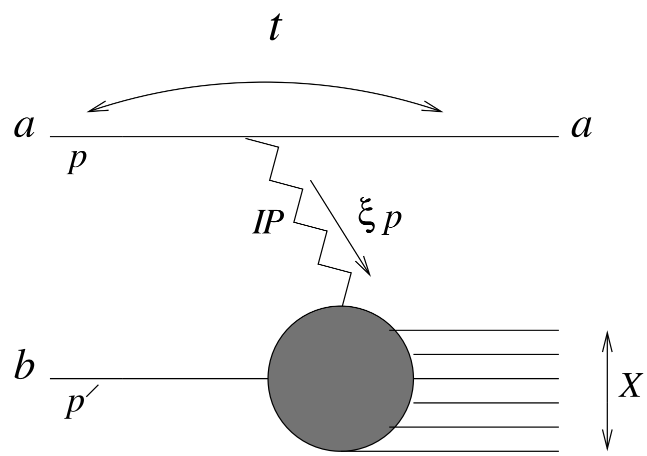

53 GeV ppbar
100
1
0.01
0.0001
1e-06
0
0.5
1
1.5
2
2.5
3
3.5
4


HIGHLY MODEL-DEPENDENT!
LHC
100
1
0.01
0.0001
1e-06
0
0.5
1
1.5
2
2.5
3
3.5
4

What if we replace one or all three gluons with a hard pomeron?



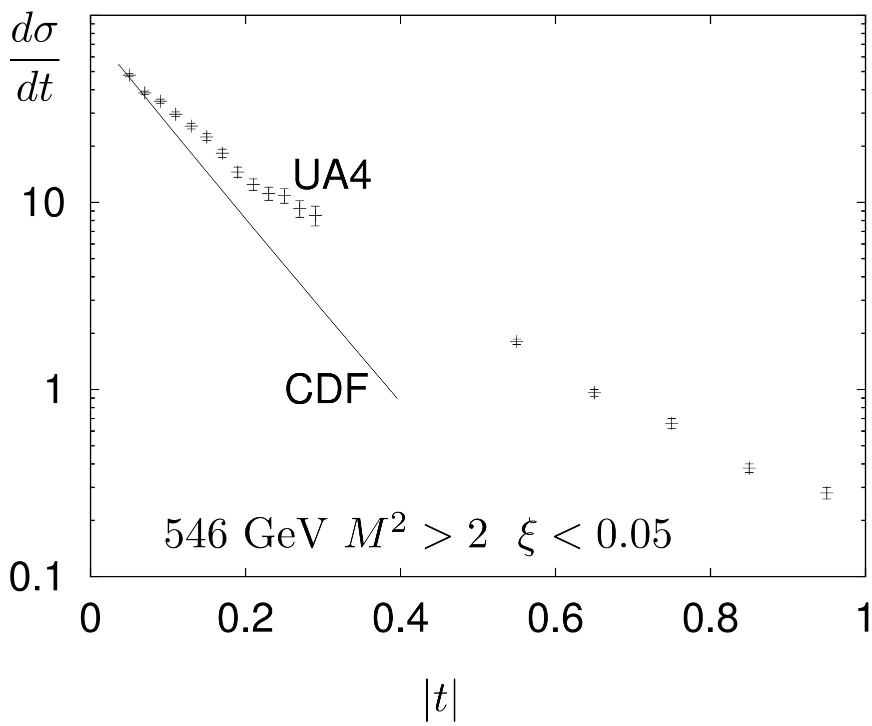
Soft diffraction dissociation



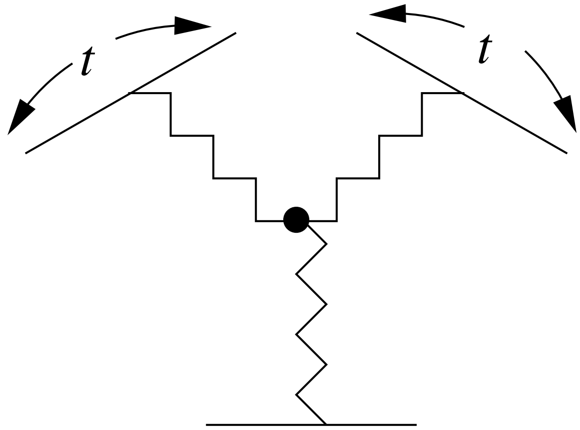
Unfortunate situation with the high-energy data:

- CDF only give a formula to fit their data for $d^2\sigma/dtd\xi$

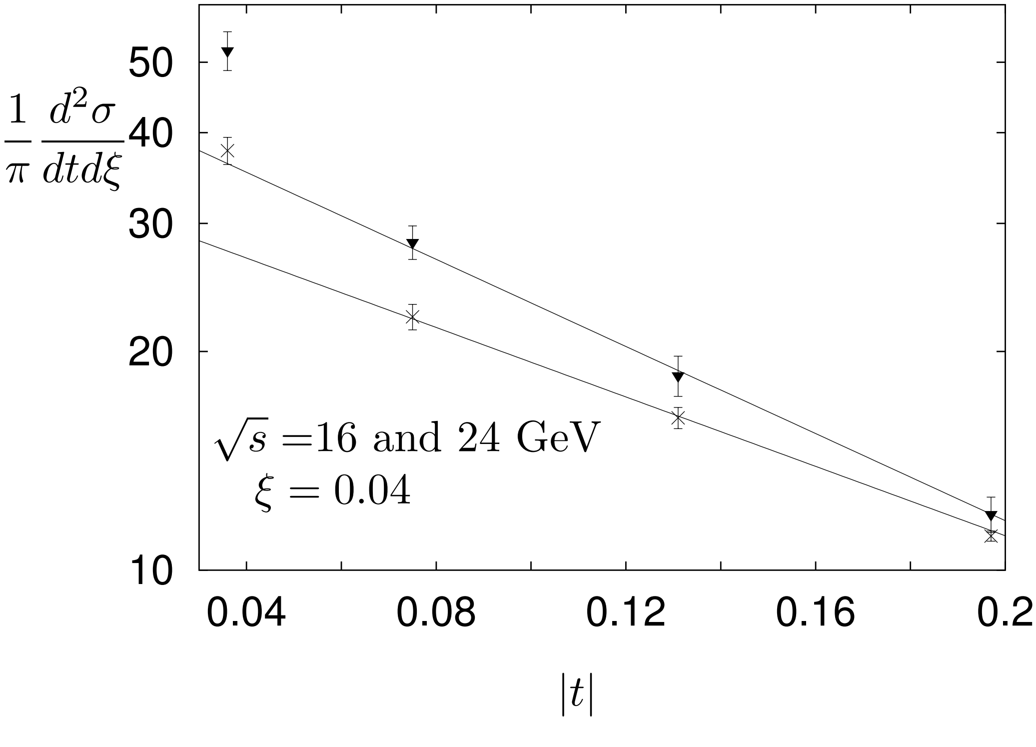
- UA4 data for $d^2\sigma/dtd\xi$ no longer available



Triple Regge



$I\!P I\!P$	$I\!P I\!P$	$f_2 I\!P$	$I\!P f_2$	$f_2 I\!P$	$\omega I\!P$	
$I\!P$	f_2	$I\!P$	$I\!P$	f_2	ω	$\dots$



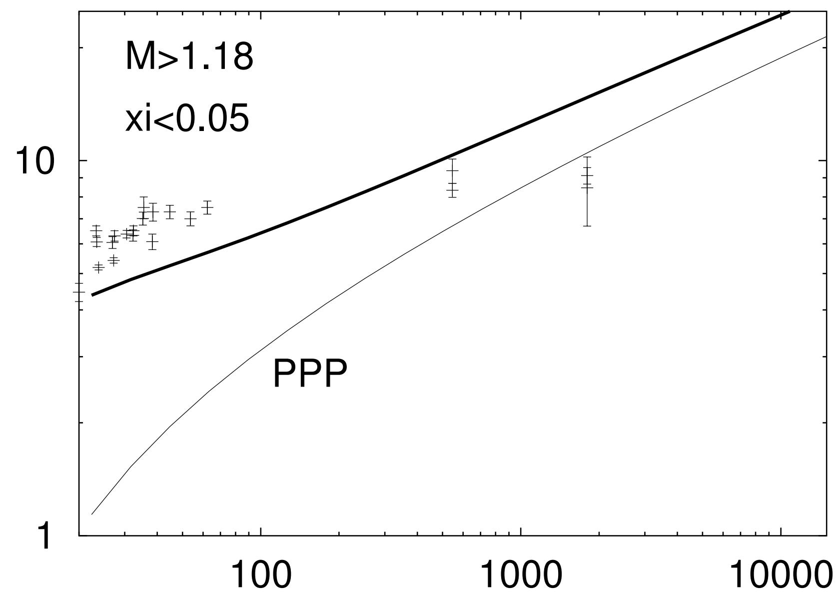
Complicated!

Total diffractive cross section

Most of it comes from small M — no theory!

Most of it from small ξ — resolution problems

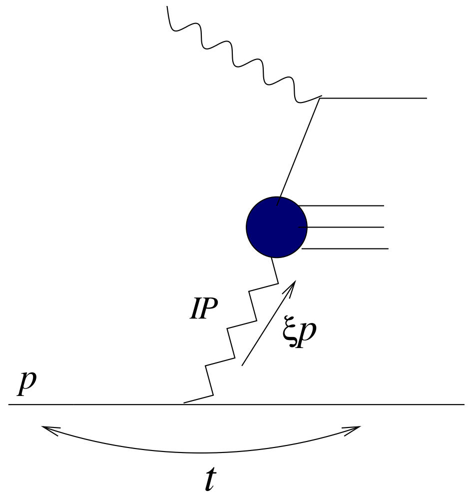
Different data integrate over different ranges of M and ξ



Not to be taken seriously – we have no theory at small M.

Hard diffraction

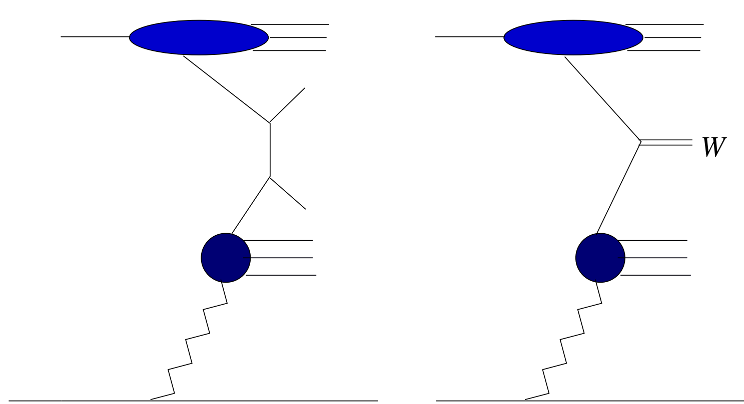
$ep \to epX$ with fast final-state proton



$$\frac{d^2}{dtd\xi}F_2(x,Q^2) = D^{\mathbf{P}/a}(t,\xi)F_2^{\mathrm{pom}}(x/\xi,t,Q^2)$$

$$D^{\mathbf{P}/a}(t,\xi) = \frac{9\beta_{\mathbf{P}}^2}{4\pi^2}\,(F_1(t))^2\,\xi^{1-2\alpha_{\mathbf{P}}(t)}$$

(Regge factorisation: the pomeron is not a particle!)



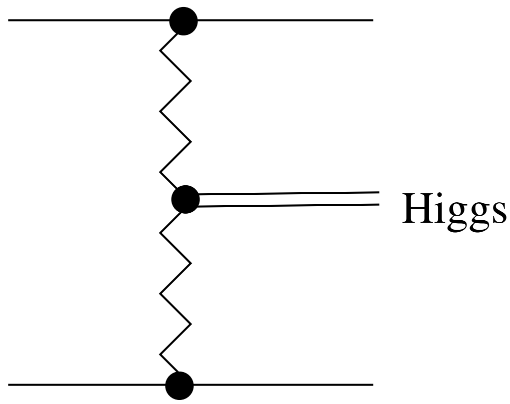
(a) (b)

Puzzle: at HERA 10% of small-x events are diffractive

at Tevatron only 1%

But mixture of soft and hard pomerons: no factorisation.

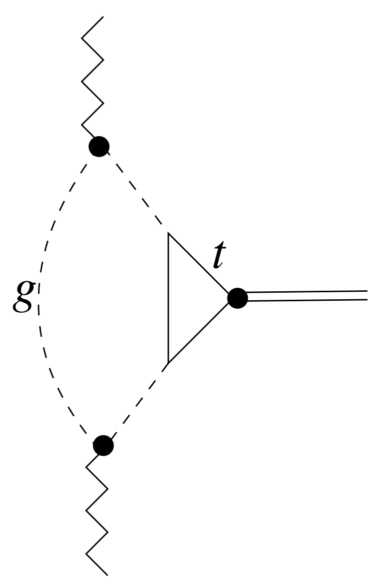
$pp \to pHp$



A good way to discover the Higgs: the background is relatively small - Albrow

Big disagreement about size of cross section

Bialas + PVL (1991):



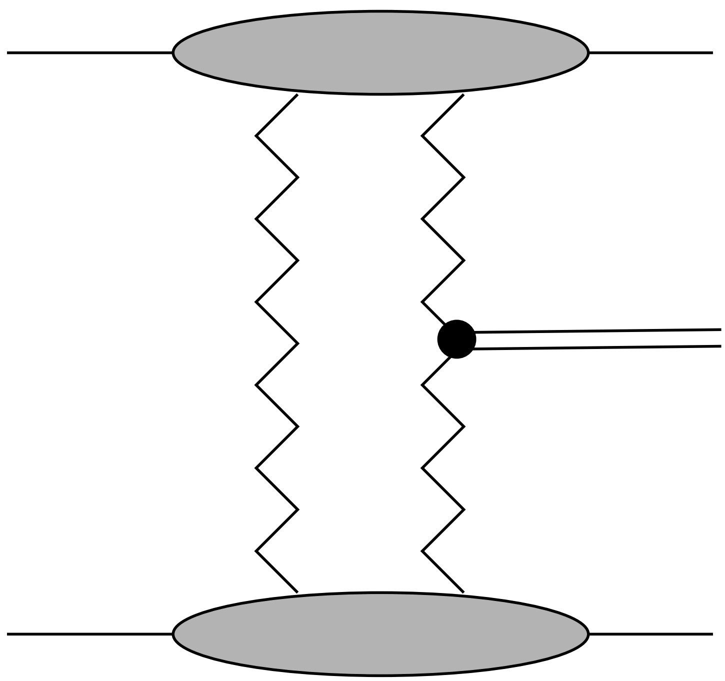
Predictions vary between a few fb and a few hundred fb!

Screening

People talk about *survival probability*

This is incorrect: the probability for an exclusive process depends only on the amplitude for that process.

Issue: how large is the screening correction?



Khoze, Martin &Ryskin: it gives suppression of an order of magnitude?

Summary

- $\sigma(pp)$ anywhere between 100 and 150 mb

- $d\sigma/dt$ shape unpredictable at small t

- $d\sigma/dt$ could be large at large t

- soft diffraction dissociation unpredictable

- $pp \rightarrow p$ Higgs p anywhere between 3 and 300 fb

LHC should teach us a lot