Establishing Parton Saturation at a TeV scale ep Collider

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LHeC Workshop
Divonne

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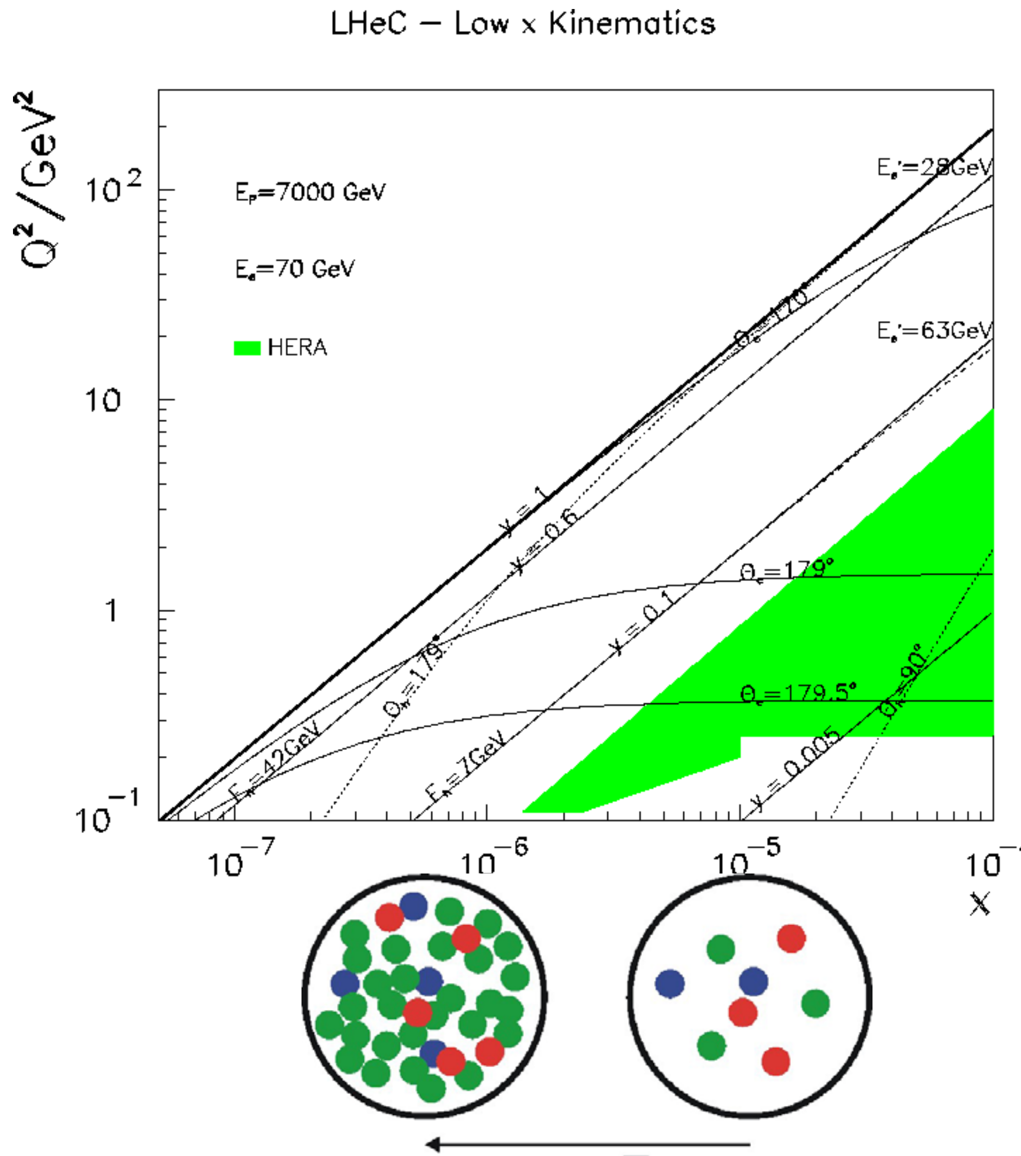
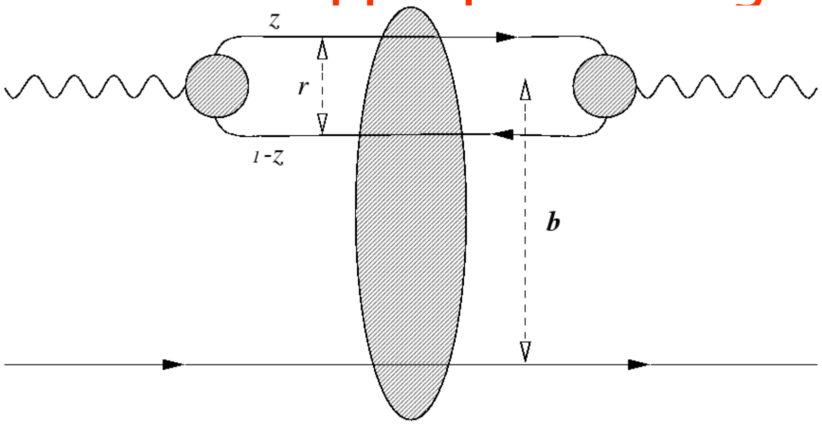


Thanks for additional predictions to C Marquet and G Soyez

Reminder : Dipole models

• Unified description of low x region, including region where Q^2 small and partons not appropriate degrees of freedom …



$$\sigma_{\gamma^* p}^{T,L}(x,Q^2) \sim \int \mathrm{dz}\ \mathrm{d}^2 r\ \left|\psi_{\gamma^*}^{T,L}(z,r,Q^2)\right|^2 \sigma_{dipole}(x,r,z)$$

• Simple unified picture of many inclusive and exclusive processes … F_2, F_2^c, F_2^b, F_L, high β F_2^D, DVCS, VMs
… strong interaction physics in (universal) dipole cross section σ_{dipole}.
… process dependence in wavefunction Ψ Factors
• In perturbative region, $\sigma_{dipole} \sim \alpha_s\, r^2\, xg(x,1/r^2)$

4 Dipole Models used for Illustration

1) `FS04 Regge' Non-saturating (Regge inspired) model
Dipoles with $r<r_0$ scatter with $\sigma \sim x^{-0.3}$
Dipoles with $r>r_0$ scatter with $\sigma \sim x^{-0.07}$
r_0 constant

Forshaw, Shaw: JHEP 0412:052 (2004)

2) `FS04 Sat' saturating model
Dipoles with $r<r_s$ scatter with $\sigma \sim x^{-0.3}$
Dipoles with $r>r_s$ scatter with $\sigma \sim x^{-0.06}$
r_s decreases with decreasing x

Forshaw, Shaw: JHEP 0412:052 (2004)

3,4) `CGC' saturating model
BFKL-like cross section for $r<r_s(x)$ constant for $r>r_s(x)$

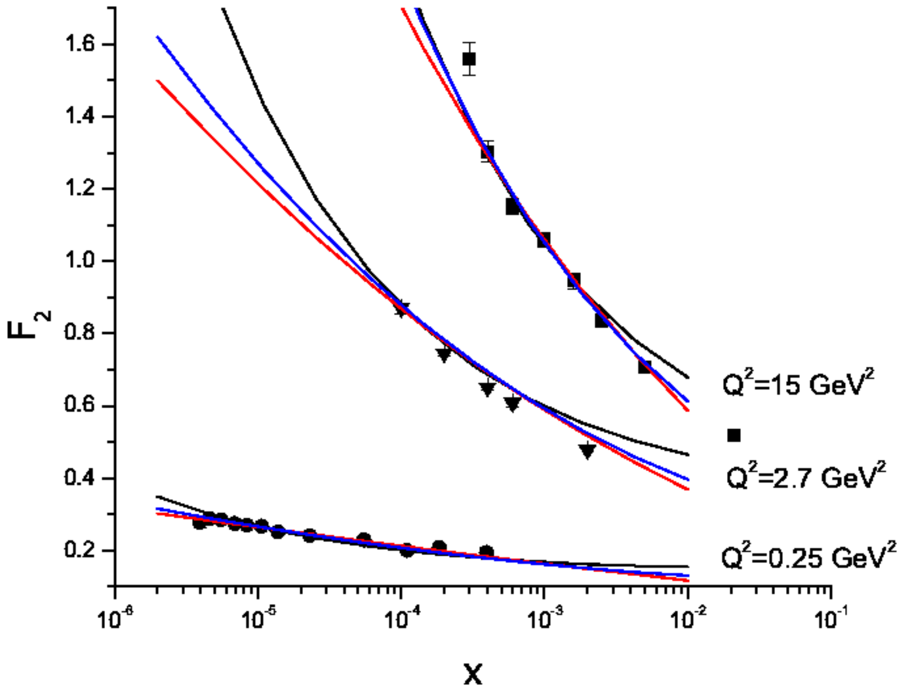
Iancu, Itakura, Munier: Phys Lett B590 (2004) 199
Kowalski, Motyka, Watt: Phys Rev D74 (2006) 074016

3) Forshaw & Shaw and 4) Marquet & Soyez
implementations differ in heavy flavour treatment

A Search for Parton Saturation @ HERA

Forshaw, Sandapen, Shaw
hep-ph/0411337,0608161
… used for illustrations here

Fit inclusive HERA data using dipole models with and without parton saturation effects in σ_{dipole}



FS04 Regge — FS04 Sat — CGC

- All three models can describe data with $Q^2 > 1 GeV^2$, $x < 0.01$
- Only versions with saturation work for $0.045 < Q^2 < 1 GeV^2$
- All models adequately describe final state observables
- Similar conclusions from Kowalski, Motyka, Watt

… <u>any saturation at HERA not easily interpreted partonically</u>

Another way to look at it: Geometric Scaling

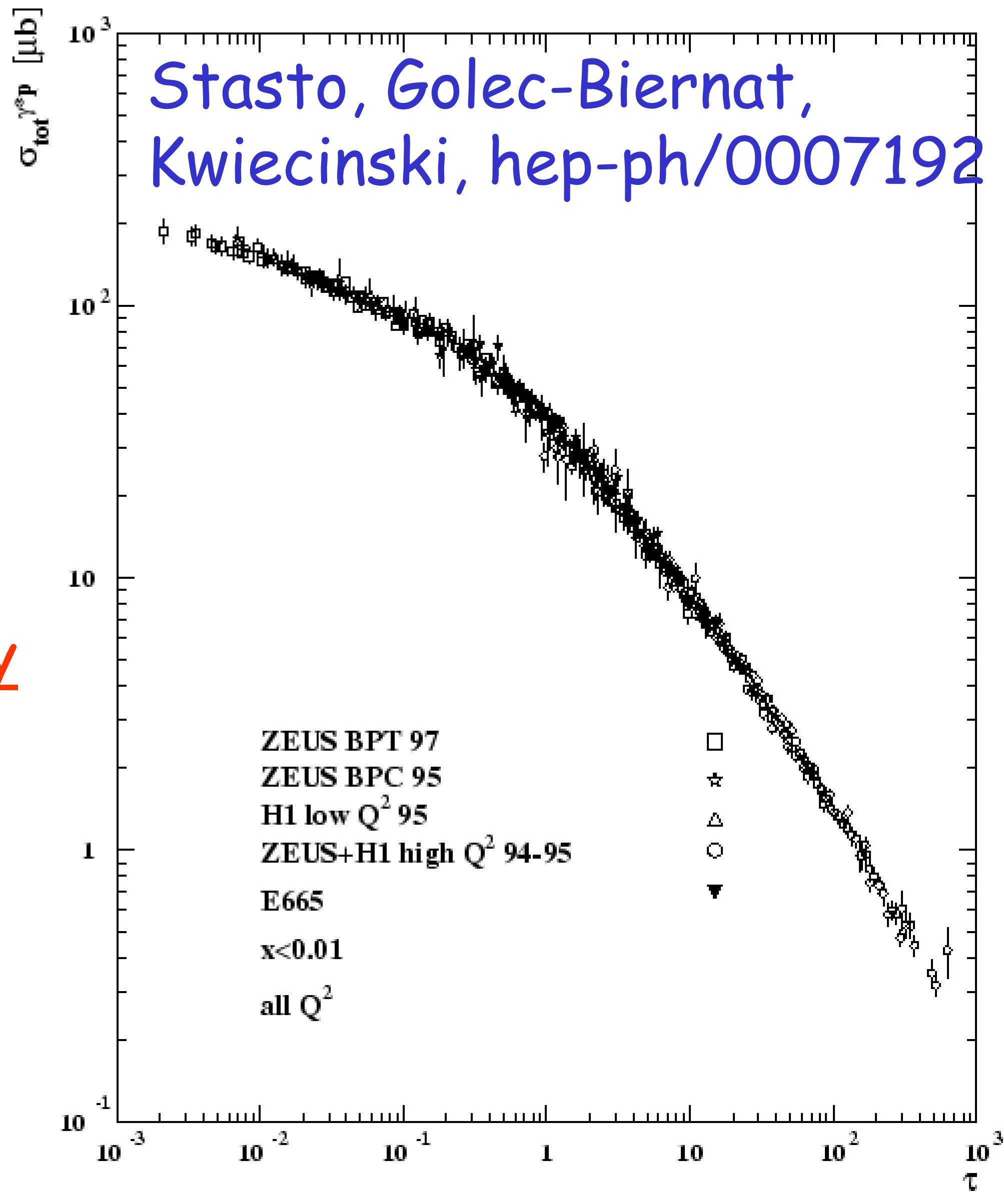
$\sigma_{\gamma^* p}(\tau \text{ only})$, $\tau = Q^2 R_0^2(x)$

$R_0^2(x)$ is "saturation radius"

Change of behaviour near τ=1 often cited as evidence for saturation

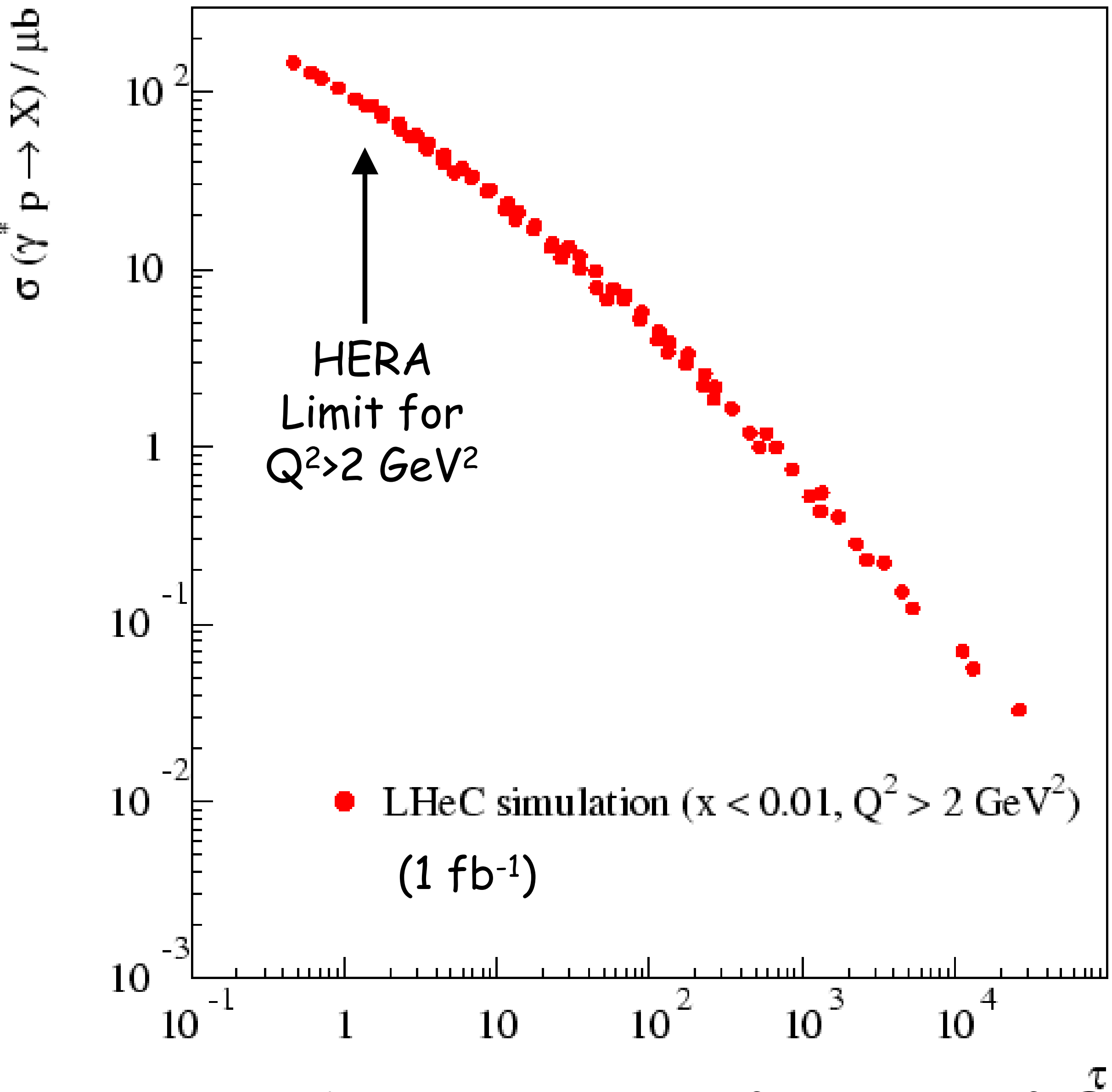
... but data below τ = 1 are <u>very</u> low Q^2 – below confinement change to hadronic dof's

Would like to see transition in a Q^2 region where partonic interpretation unquestionable



c.f. Bartels yesterday: $Q^2_s \sim 0.8\ \text{GeV}^2$ @ $x=10^{-4}$

Geometric Scaling at the LHeC



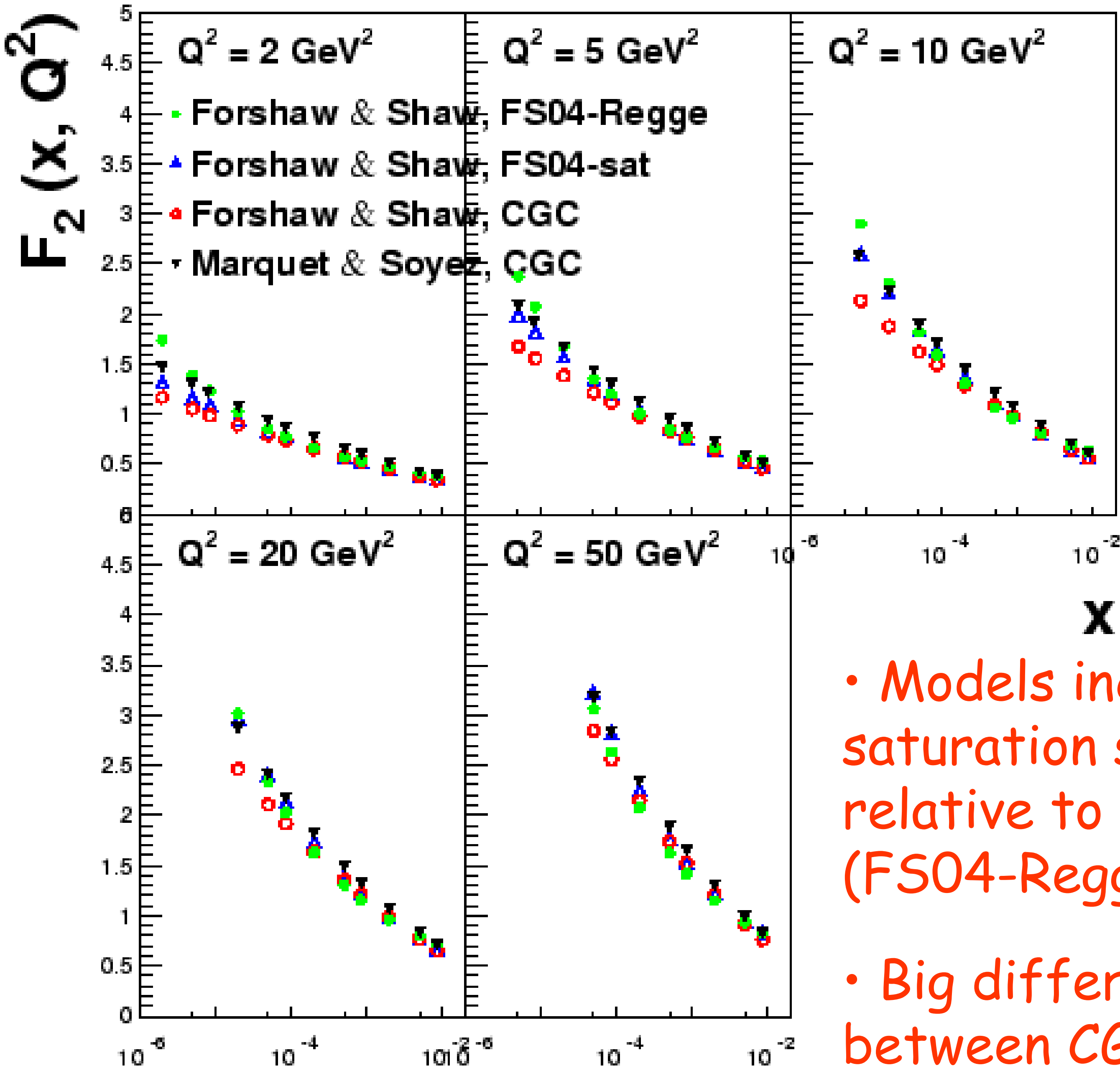
LHeC reaches $\tau \sim 0.15$ for Q^2=1 GeV^2 and $\tau \sim 0.4$ for Q^2=2 GeV^2

Acceptance for $Q^2 < Q^2_s$ with Q^2 "perturbative" still limited, but:

- There is some!
- Enhance with nuclei?
- $Q^2 < 1$ GeV^2 accessible in special runs?

c.f. Bartels yesterday: $Q^2_s \sim 3$ GeV^2 @ $x=10^{-6}$

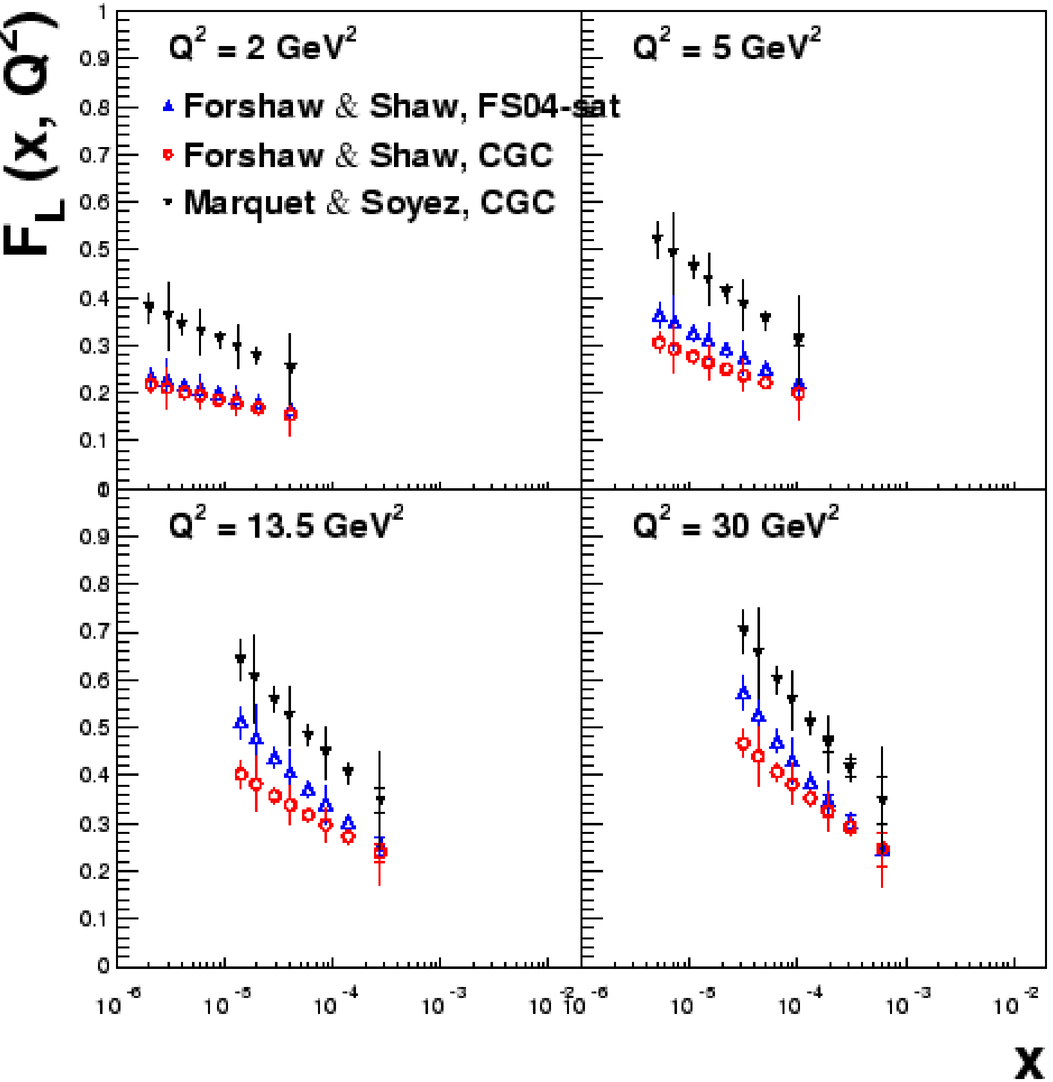
Range of F_2 Predictions for LHeC



… pure low-x extrapolation of fits to data in HERA region

- Models including saturation suppressed relative to that without (FS04-Regge) at low x, Q^2
- Big differences even between CGC-based models

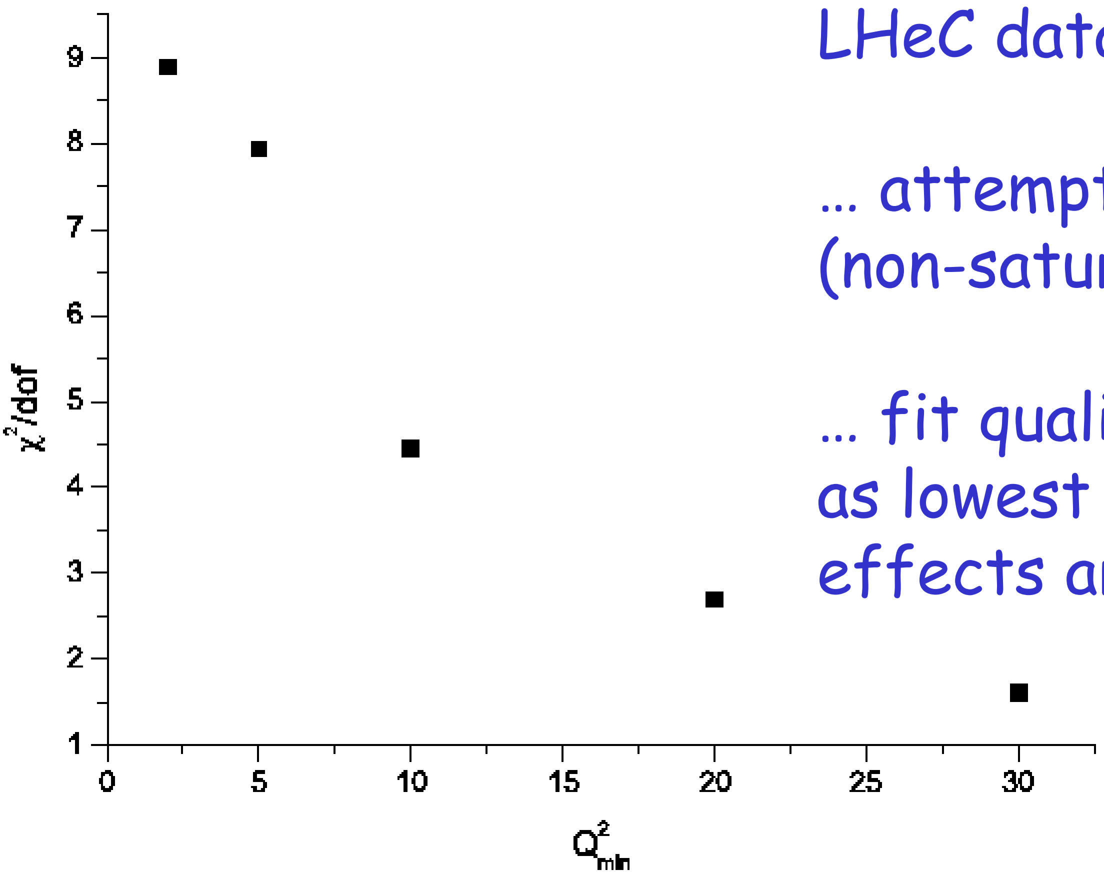
Range of F_L Predictions for LHeC



- Low x F_L reflects differences between gluon densities.
- Significant differences between all models.
- F_2 (quarks) and F_L (gluons) together are a powerful combination

Can we see Saturation unambiguously at LHeC?

- Can saturated dipole model data be fitted using a dipole model not containing saturation?

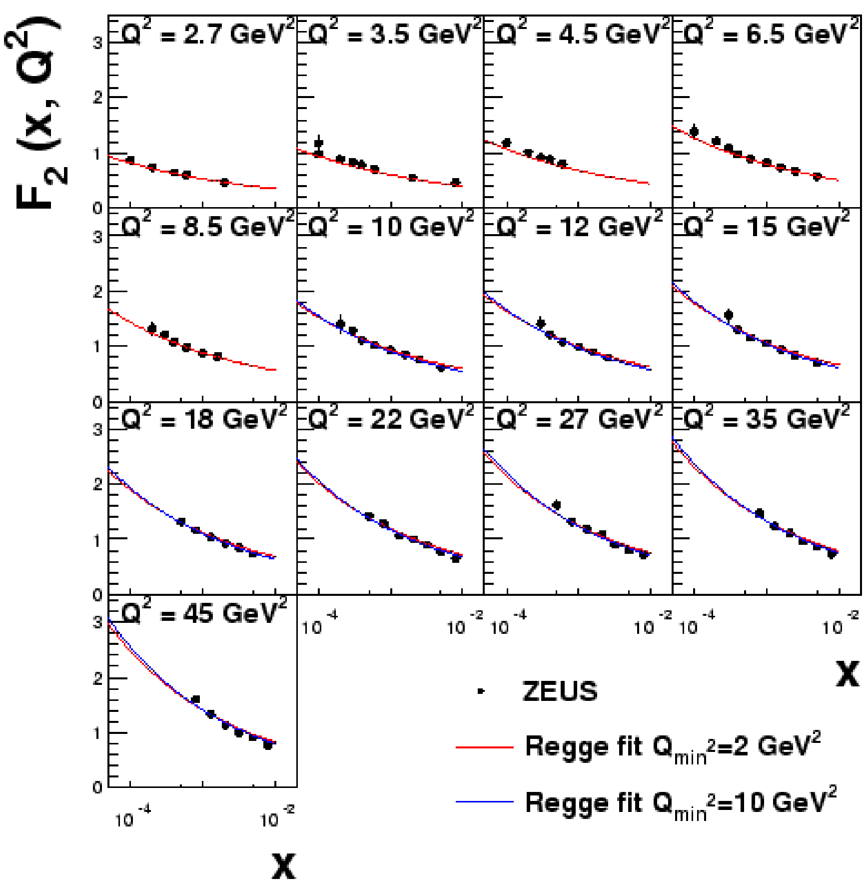


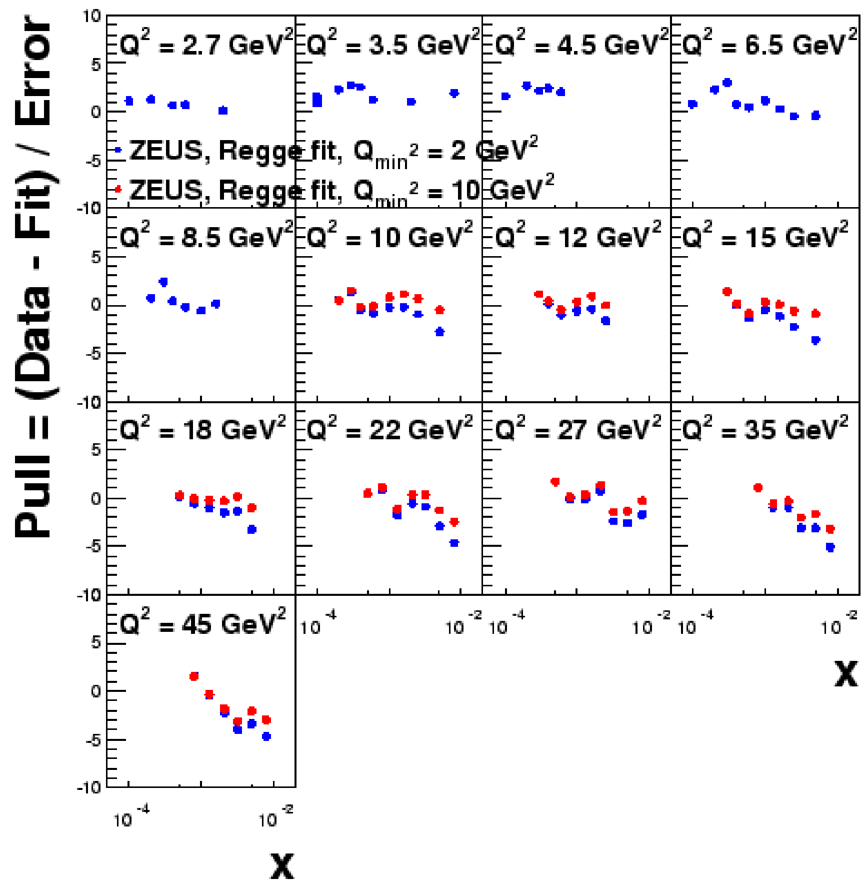
Take ZEUS and FS04 simulated LHeC data

… attempt to fit using FS-Regge (non-saturating) model

… fit quality improves progressively as lowest Q^2 data containing sat^n effects are removed

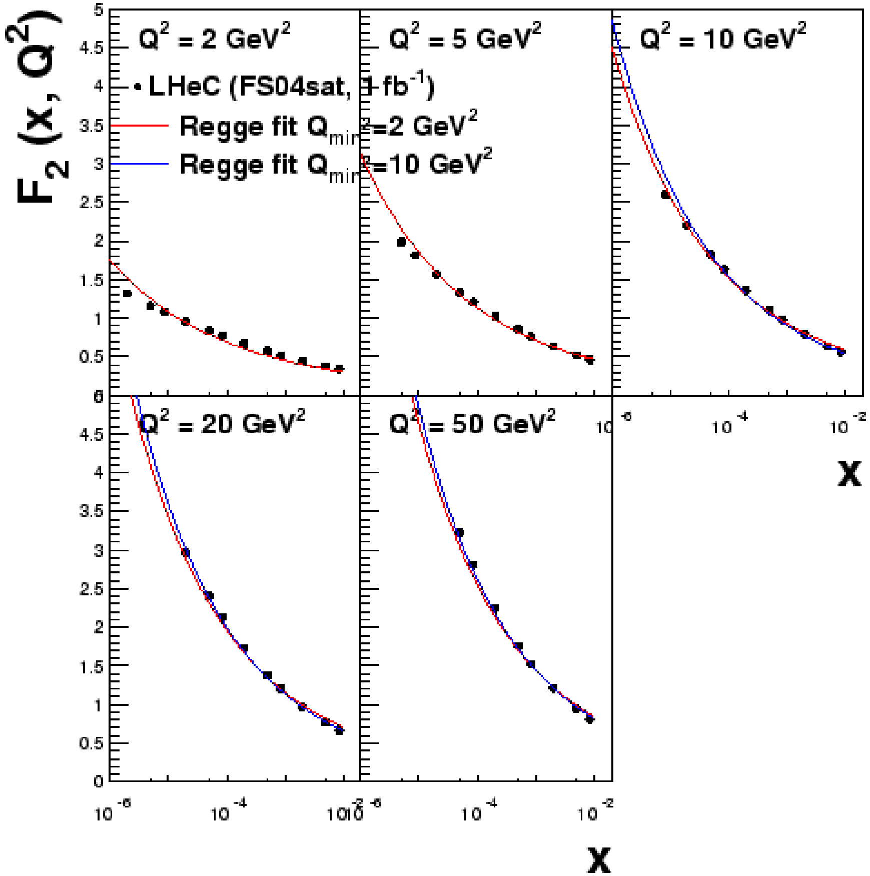
Regge model fit compared with ZEUS data

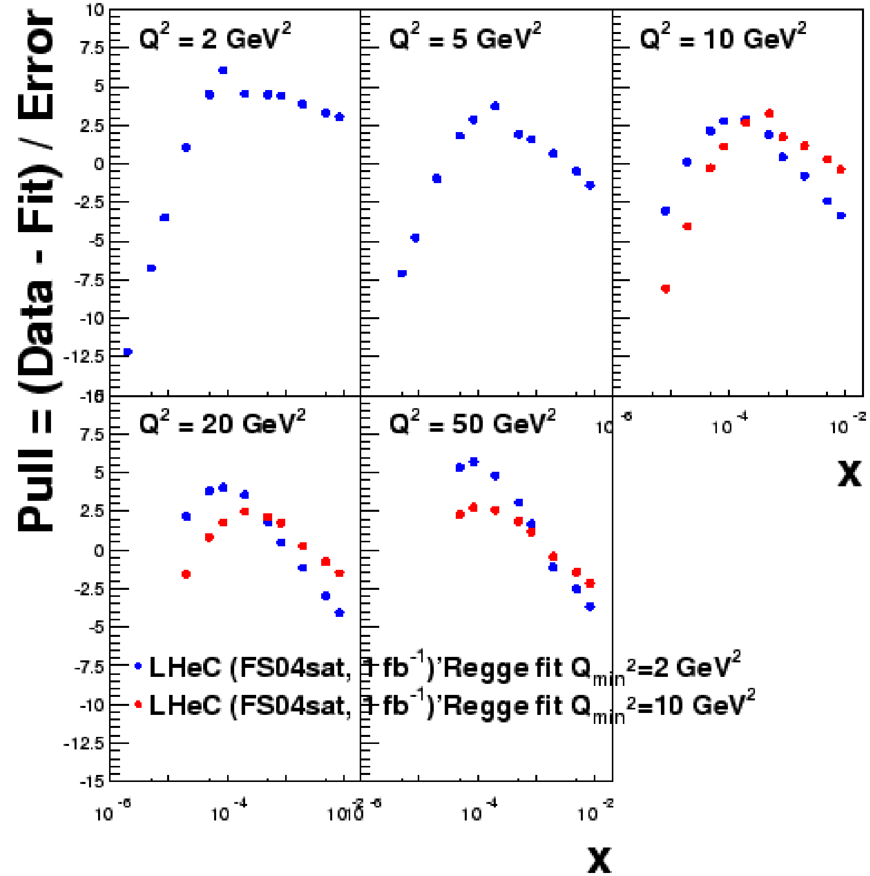




… reasonable fits to ZEUS data

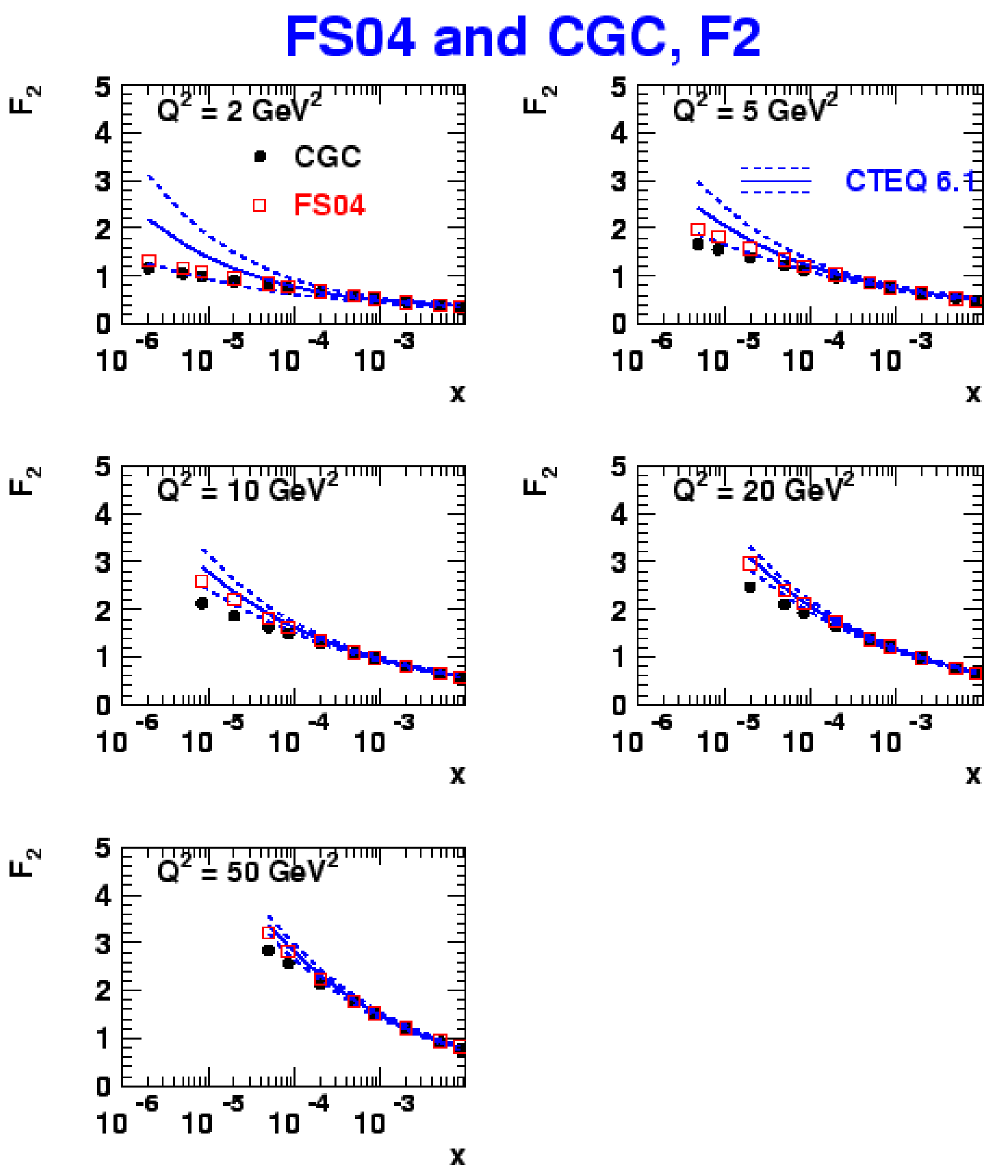
Regge model fit v FS04 LHeC data





… origin of poor χ^2 for Q^2_{min} = 2 GeV^2 is low x, low Q^2 region, but arises from only a handful of data points.

What about Extrapolating a DGLAP model?



CTeQ 6.1 starting scale distributions beyond HERA x range are pure extrapolation of parameterisation, but …

- it lies above saturation models at low x

-its Q^2 evolution follows DGLAP expectations

Question:

Can we see DGLAP fail in Q^2 dependence?…

… or can DGLAP be made to fit data which include saturation effects?

FS04 / CGC (satn) data as `straw men': can DGLAP fit them?

Can DGLAP adjust to fit LHeC sat models?

To give DGLAP best chance, use dipole-like (GBW) Q_0^2 gluon.

$$x\bar{q}(x,Q_0^2) = A_q x^{B_q}(1-x)^{C_q} \qquad xg(x,Q_0^2) = A_g\left(1-\exp\left[-B_g \log^2\left(\frac{x}{x_0}\right)^{\lambda}\right]\right)(1-x)^{C_g}$$

Free parameters: A_q, B_q, A_g, B_g, x_0, λ, C_g

u_v, d_v and high x parameter C_q from H1PDF2K

NLO DGLAP in MSbar scheme

Fixed flavour number scheme with m_c = 1.4 GeV, m_b = 4.5 GeV

[massless scheme similar]

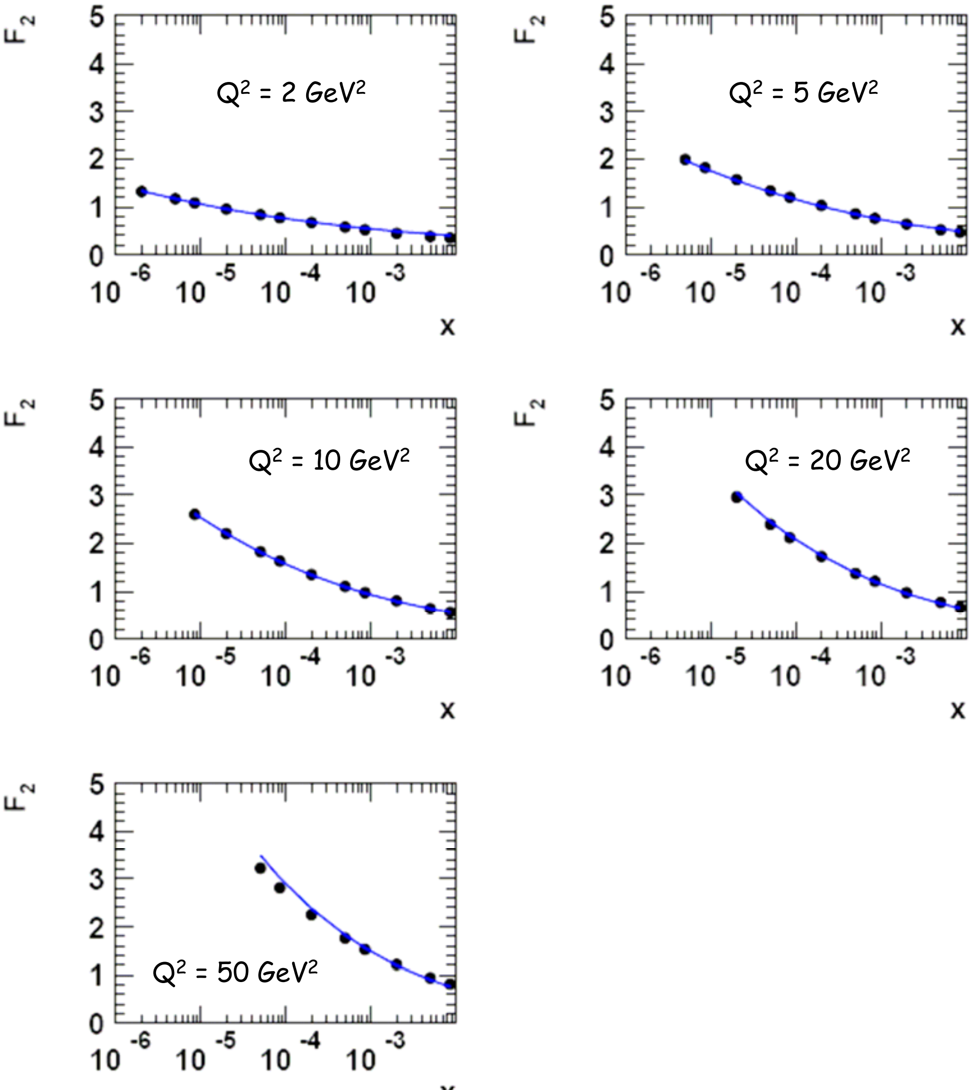
$\alpha_s(Mz)$ = 0.1185, Q_0^2 = 1.9 GeV^2 [just below charm threshold]

Philosophy: fit ZEUS and LHeC saturation model data in increasingly narrow (low) Q^2 region until good fit obtained

Fitting ZEUS + FS04 data with DGLAP

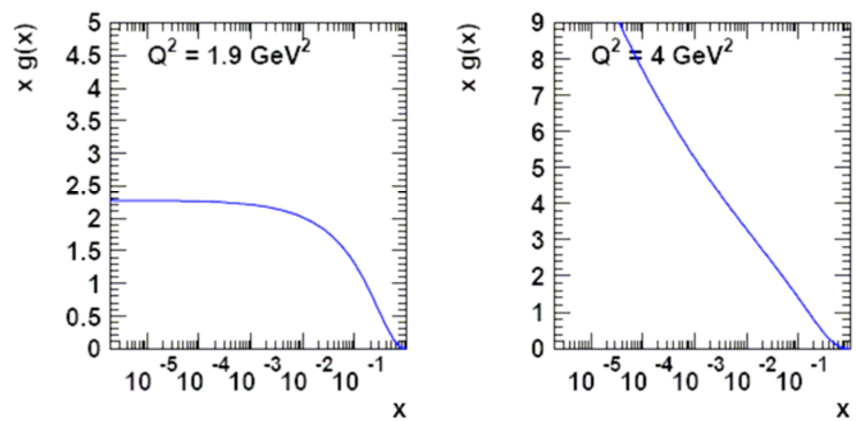
Acceptable fit when all data with Q^2 <= 20 GeV^2 included.

FS04 dataset, F2

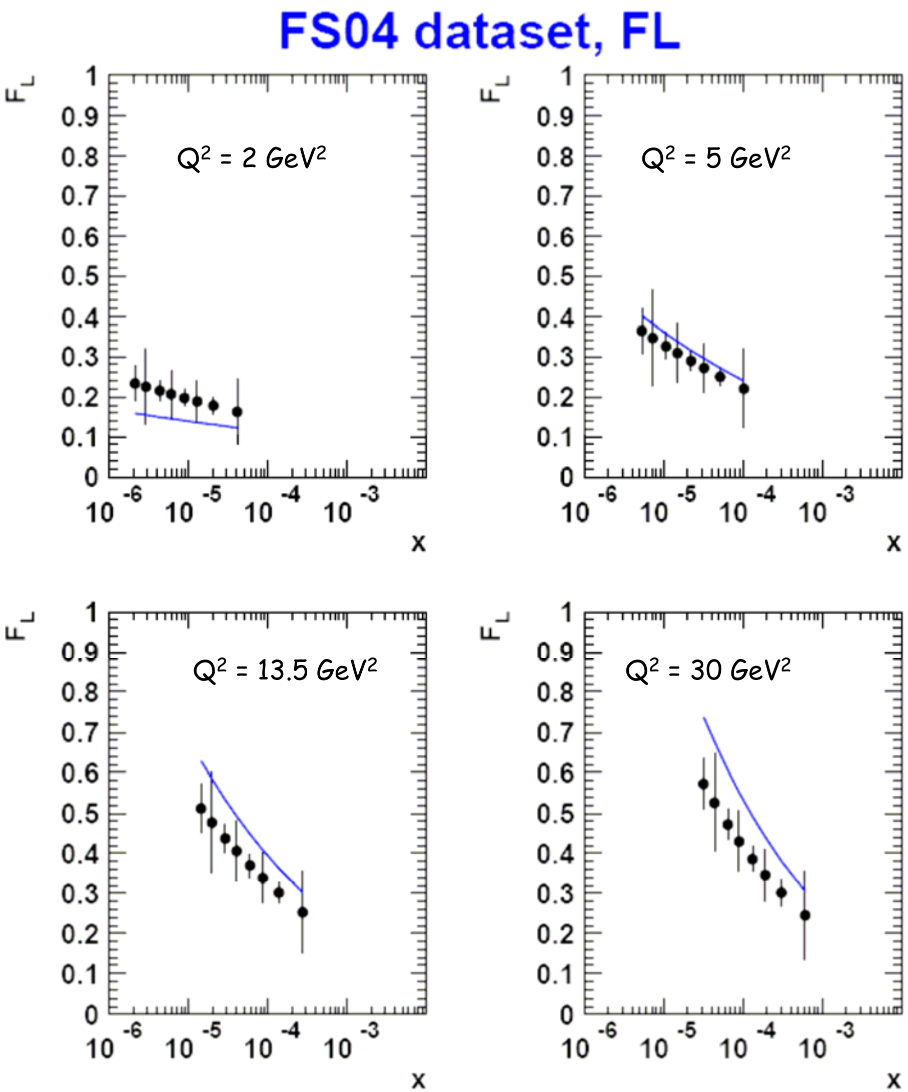


χ^2 = 56.8 for 62 ZEUS points
χ^2 = 35.1 for 30 FS04 points
χ^2 / ndf = 1.07

- Extrapolation to Q^2=50 GeV^2 fails with lowest x points
- Gluon looks saturated @ Q_0^2



F_L Prediction from ZEUS + FS04 DGLAP fit



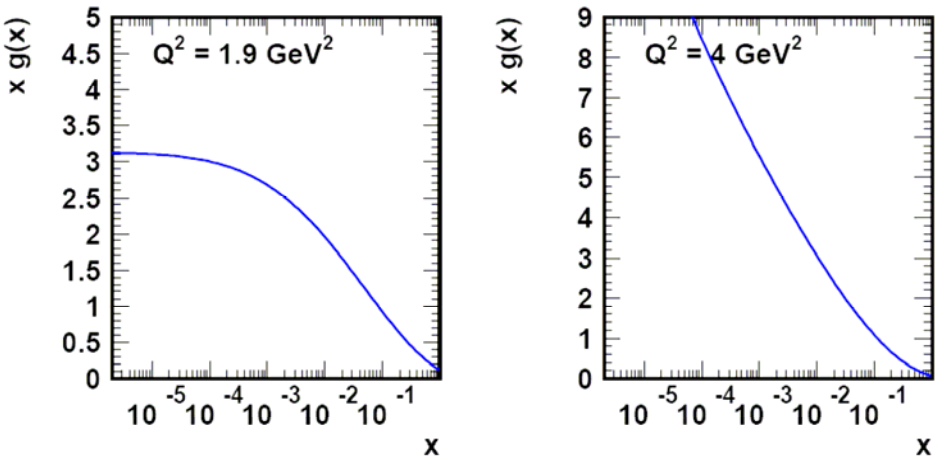
Q^2 dependence of F_L FS04 data not well Described

F_2 and F_L together are powerful!

Fitting ZEUS + CGC F_2 data with DGLAP

- No successful fits to F_2 over any significant Q^2 range: e.g. χ^2/ndf ~ 3 when including all $Q^2 <= 5$ GeV^2 data.

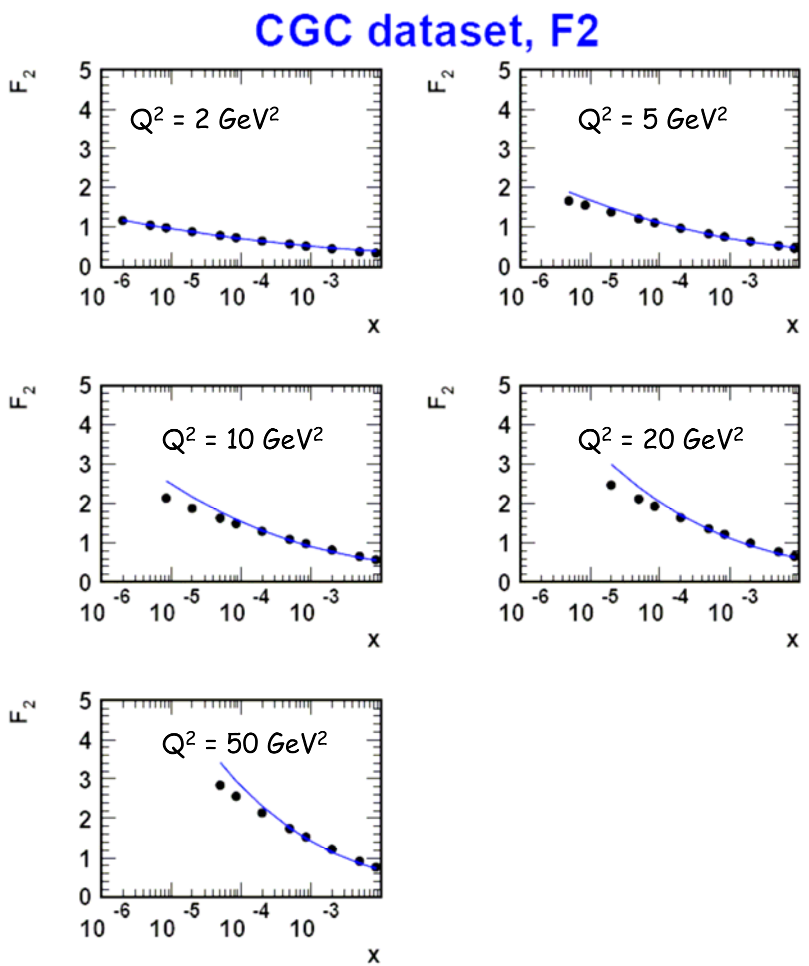
- Can fit $Q^2 = 2$ GeV^2 (LHeC) and $Q^2 = 2.7$ GeV^2 (ZEUS), but then not much constrains the gluon.

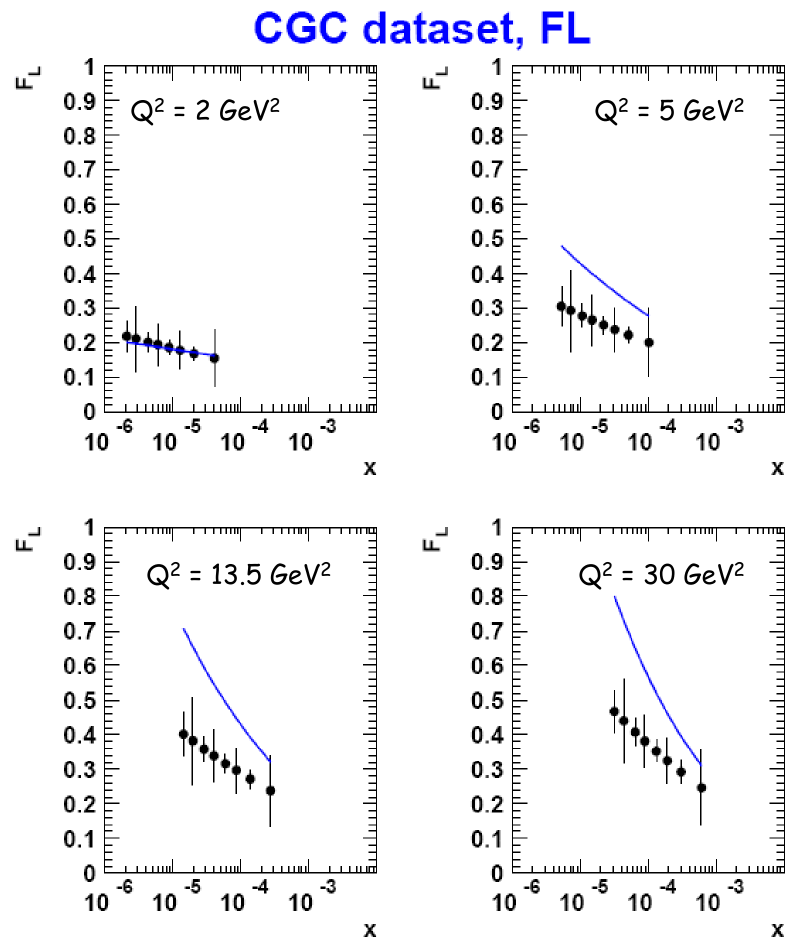


... exhibits saturation type behaviour nonetheless

- Another approach: fit for $Q^2 < 3$ GeV^2 to both
  F2 (LHeC and ZEUS) to constrain quarks
  FL (LHeC) to constrain gluons

Fitting ZEUS + FS-CGC F_2 and F_L data





- Fits $Q^2 = 2$ GeV^2 only.
- Extrapolation of fit to higher Q^2 describes neither $dF_2/d\ln Q^2$ nor F_L. → DGLAP clearly not coping.

Conclusions

- Saturation effects may be present in HERA data, but there is no compelling evidence within the perturbative domain … strong motivation for lower x measurements.

- Study so far is by no means definitive, but …

… Saturation models which fit very low Q^2 HERA data lead to F_2 predictions at LHeC which cannot be easily be `faked' by pure DGLAP evolution.

  - Somewhat dependent on details of saturation model.
  - Low x resummations etc not yet considered

… If fitting F_2 alone is insufficient to establish an effect, tension between F_2 and other observables, (F_L in particular) could be a very powerful tool.

Spares

Systematic Precision Requirements

e.g. Requirements based on reaching per-mil α_s (c.f. 1-2% now)

The new collider …

- should be 100 times more luminous than HERA …

… achievable using low β focusing quad's (acceptance → 170°)

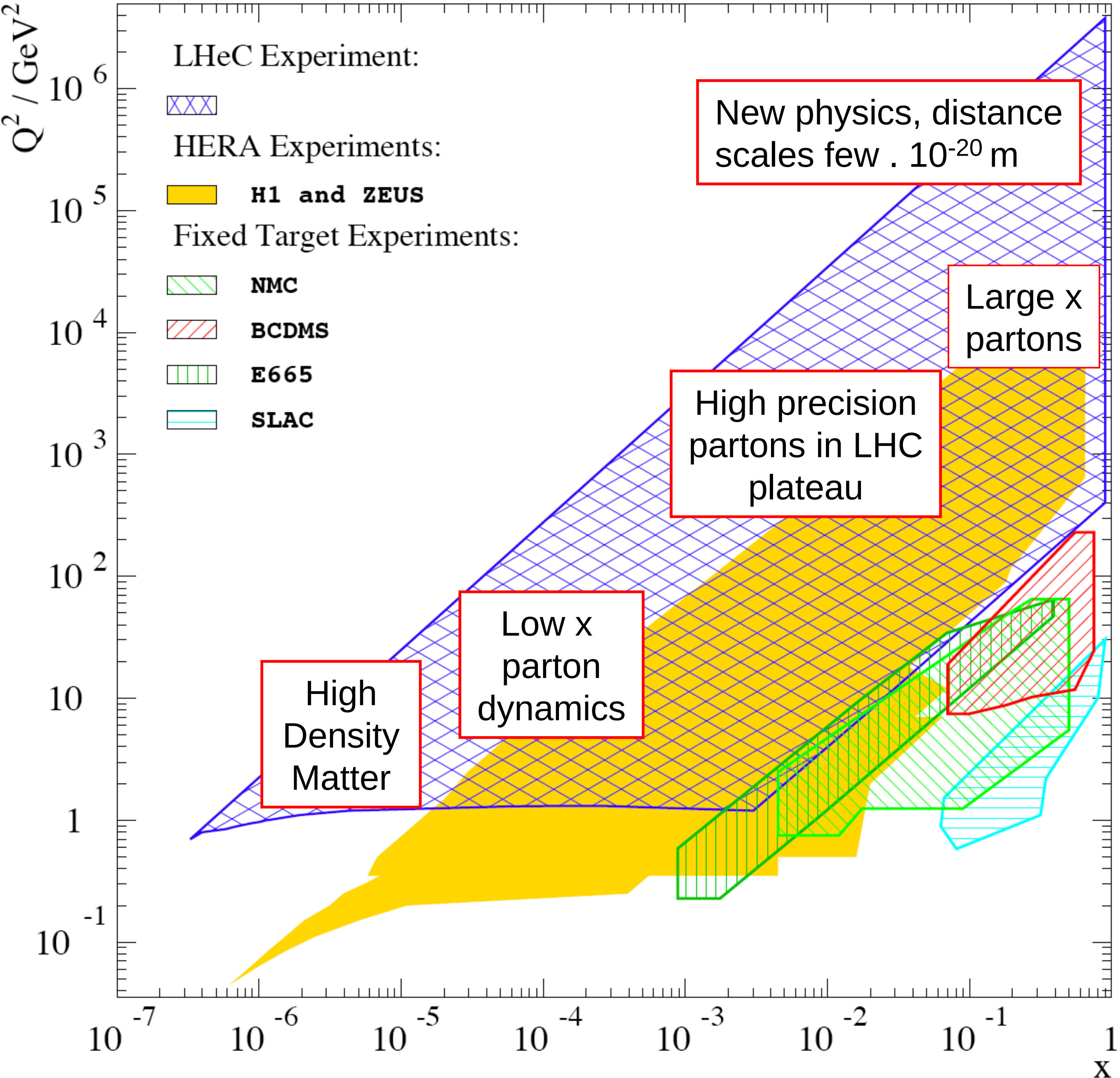
The new detector

- should be at least 2 times better than H1 / ZEUS

Redundant determination of kinematics from e and X is a huge help in calibration etc!

Lumi = 10^{33} cm^{-2} s^{-1}	(HERA 1-5 x 10^{31} cm^{-2} s^{-1})
Acceptance 10-170° (→179°?)	(HERA 7-177°)
Tracking to 0.1 mrad	(HERA 0.2 – 1 mrad)
EM Calorimetry to 0.1%	(HERA 0.2-0.5%)
Had calorimtry to 0.5%	(HERA 1%)
Luminosity to 0.5%	(HERA 1%)

Inclusive Kinematics for 70 GeV x 7 TeV



$\sqrt{s} = 1.4$ TeV

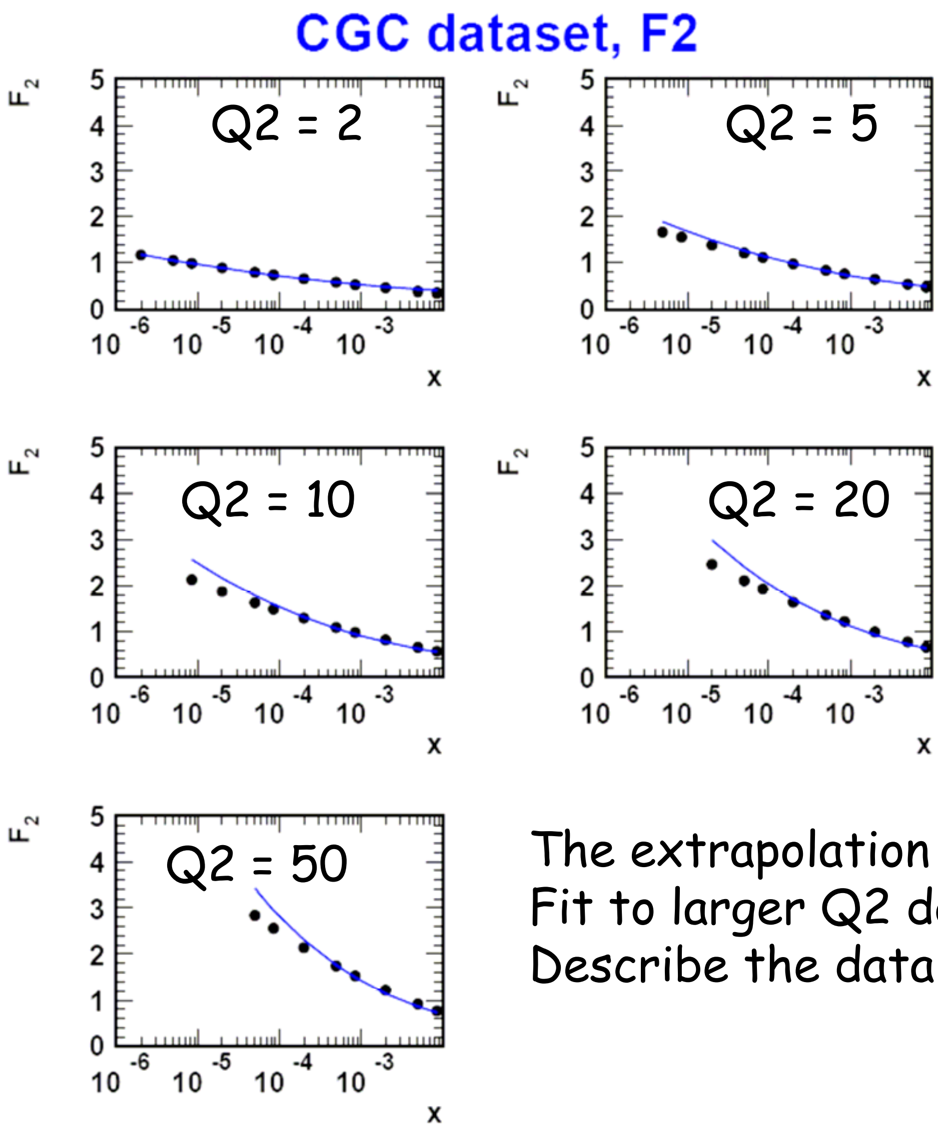
$W \leq 1.4$ TeV

$x \geq 5.10^{-7}$ at $Q^2 \leq 1$ GeV^2

- High mass (Q^2) frontier
- Q^2 lever-arm at moderate x
- Low x (high W) frontier

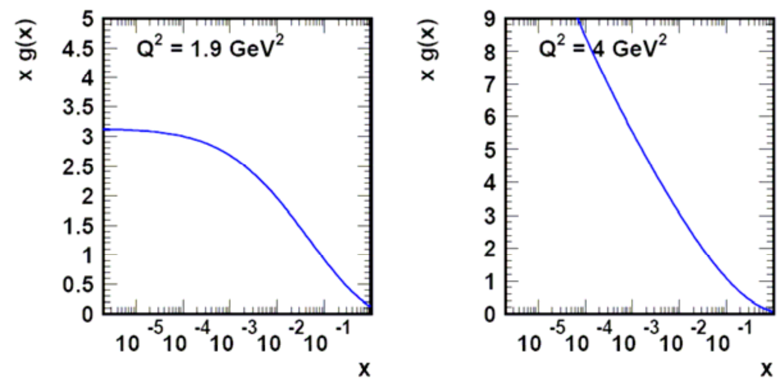
Fit to ZEUS + CGC, $Q2 \leq 3$ GeV2, and $x < 1e\text{-}3$ for the LHeC dataset

Leads to a "better" fit – but of course on much less data points…



$\chi 2$ / ndf = 1.31
($\sqrt{2/\text{ndf}} \sim 0.5$)

$\chi 2$ = 7 for 5 pts ZEUS
$\chi 2$ = 3.5 for 9 pts FS04



The extrapolation of this Fit to larger Q2 does not Describe the data well.

λ = + 0.9, B = 0.04, C = 2.3, β and D consistent with 0.

How this fit does describe FL