Quark Asymmetries in the Proton
from a model for parton densities

Johan Alwall and Gunnar Ingelman, hep-ph/0503099

Problem: non-perturbative x-shape of parton distributions $f_i(x, Q_0^2)$

- Conventional parameterisations of pdf's:
  - $+$ good fit of data on structure functions etc
  - $-$ many parameters required
  - $-$ no understanding of non-pQCD dynamics

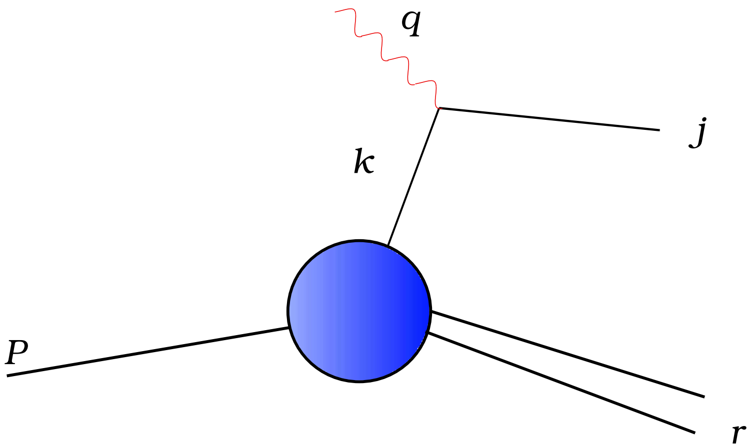
- Our model for pdf's:
  - $\pm$ reasonable fit to data
  - $+$ few parameters
  - $+$ insights on non-pQCD dynamics

Our Model: Valence distributions

In hadron rest frame: Parton momenta spherically symmetric

Typical momentum from Heisenberg uncertainty $\langle k \rangle \sim \Delta p = \hbar/\Delta x \sim 200 \text{ MeV}$

Gaussian momentum fluctuations $f_i(k) = N(\sigma_i, m_i) \exp\left(-\frac{(k_0-m_i)^2+k_x^2+k_y^2+k_z^2}{2\sigma_i^2}\right)$



$$x = \frac{k_+}{P_+} = \frac{E_k + k_z}{E_P + P_z}$$ z-boost invariant

Kinematic constraints:

$$m_i^2 < j^2 < W^2 = (P+q)^2$$
$$r^2 = (P-k)^2 > 0$$

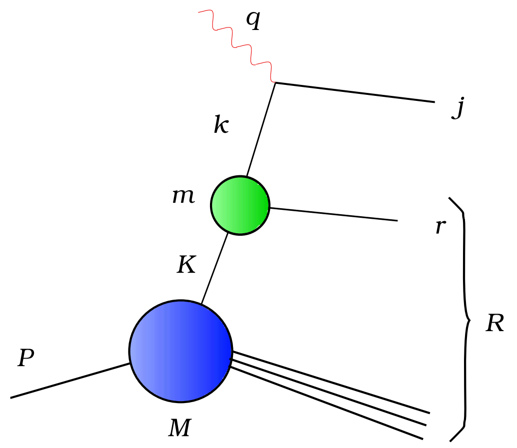
$\Longrightarrow 0 \leq x \leq 1$ and $f_i(x) \to 0$ as $x \to 1$

Monte Carlo-simulate to get x distribution.

$\int_0^1 dx\, u_v(x) = 2$ and $\int_0^1 dx\, d_v(x) = 1$ gives u_v and d_v normalisation

Momentum sum rule $\sum_i \int_0^1 dx\, x f_i(x) = 1$ gives $xg(x)$ normalisation

Our Model: Sea distributions



- Hadronic quantum fluctuations:

$$|p\rangle = \alpha_0 |p_0\rangle + \alpha_{p\pi^0} |p_0 \pi^0\rangle + \alpha_{n\pi^+} |n\pi^+\rangle$$

$$+ \ldots + \alpha_{\Lambda K} |\Lambda K^+\rangle + \ldots$$

- Gaussian momentum distribution of meson and baryon (in p rest frame)

- Photon probes parton in meson or baryon

- Normalization: fit effective α^2_{MB} instead of unknown mass suppression and mixing of states (also Clebsch-Gordan coefficients)

$$x_H = K_+/(K + K_{\text{partner}})_+$$

$$x_i = k_+/K_+$$

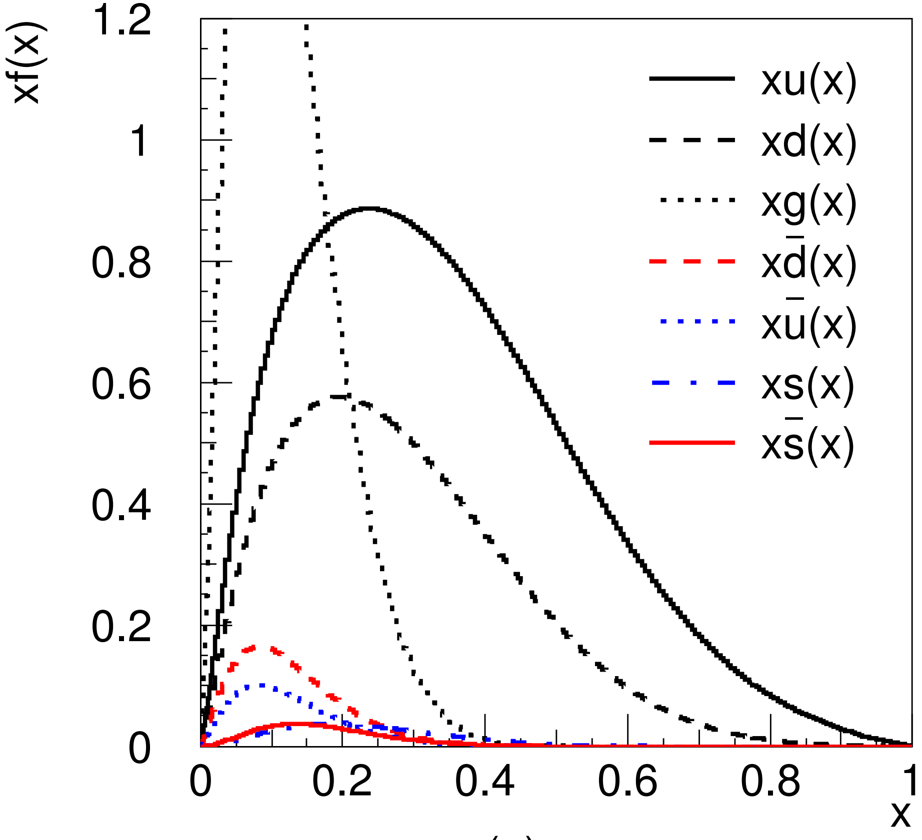
$$x = x_H \cdot x_i$$

Kinematic constraints:

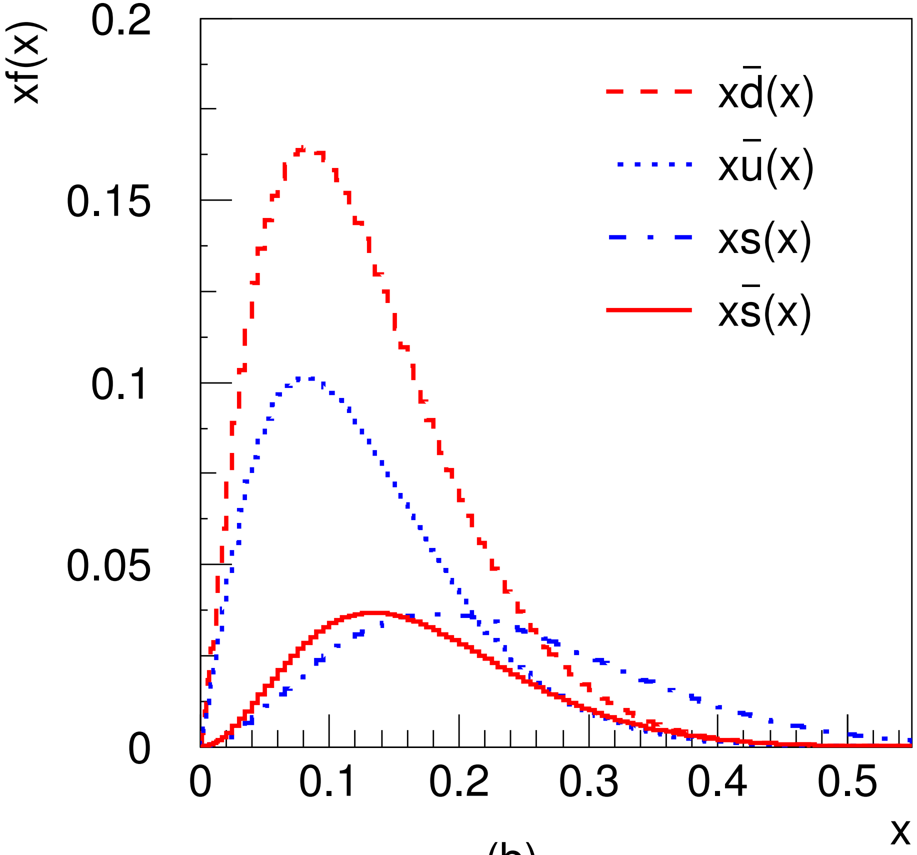
$$0 < j^2 < W_H^2 = (K+q)^2$$

$$r^2 > 0 \, , \; R^2 > 0$$

Resulting distributions



(a)



(b)

Shapes as expected, agree with parametrizations (shown below)

Add standard DGLAP Q^2 evolution (using QCDNUM16) $\rightarrow xf_i(x, Q^2)$

Parameters and experimental data

Parameters:

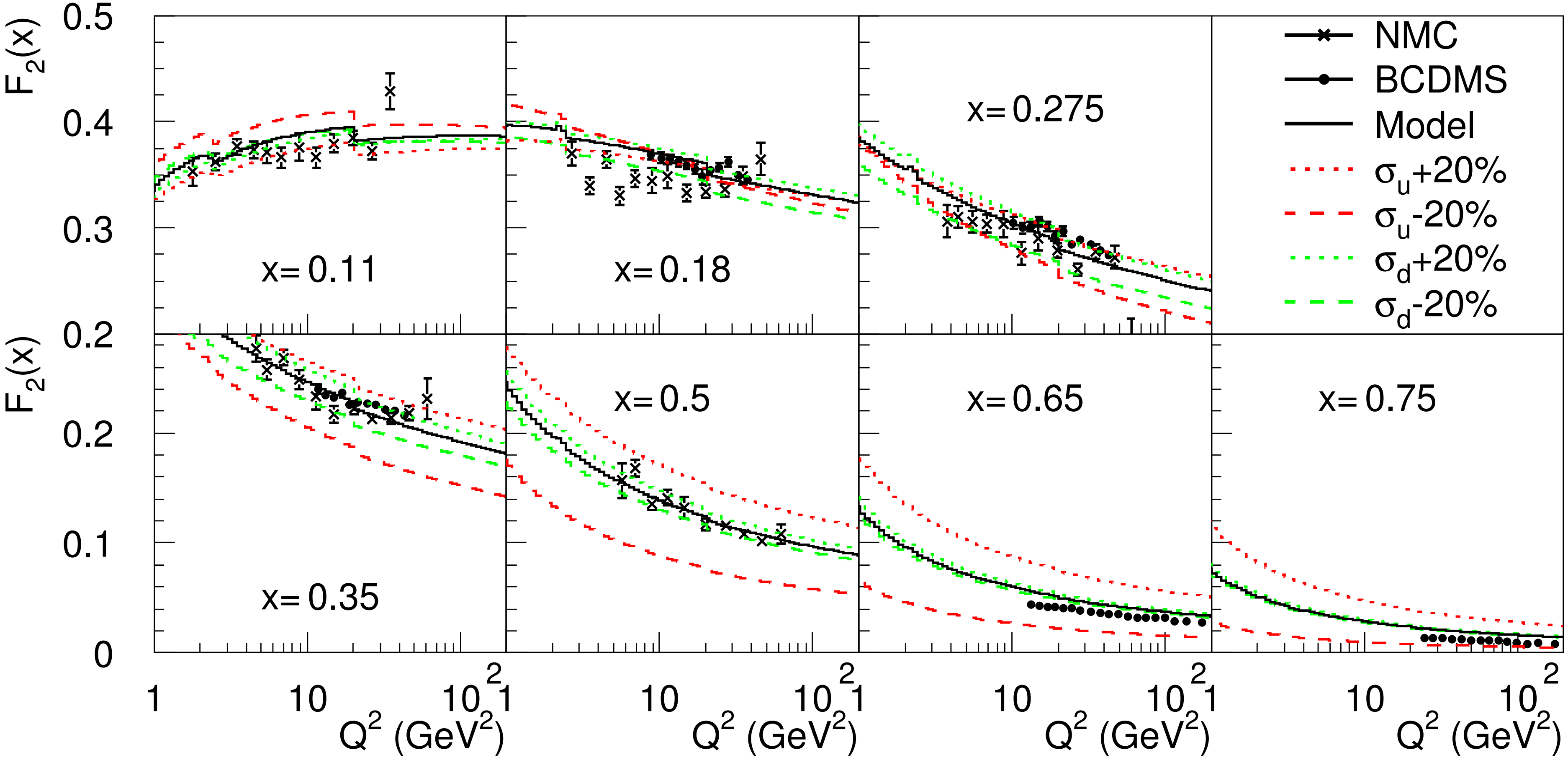
$$\sigma_u = 230 \text{ MeV} \quad \sigma_d = 170 \text{ MeV} \quad \sigma_g = 77 \text{ MeV}$$
$$Q_0 = 0.75 \text{ GeV} \quad \sigma_H = 100 \text{ MeV}$$
$$\alpha^2_{p\pi^0} = 0.45 \quad \alpha^2_{n\pi^+} = 0.14 \quad \alpha^2_{\Lambda K} = 0.05$$

Experimental data sets:

- Fixed-target F_2 data
- HERA F_2 data
- $W^\pm$ charge asymmetry data
- $\bar{d}/\bar{u}$-asymmetry data
- Strange sea data

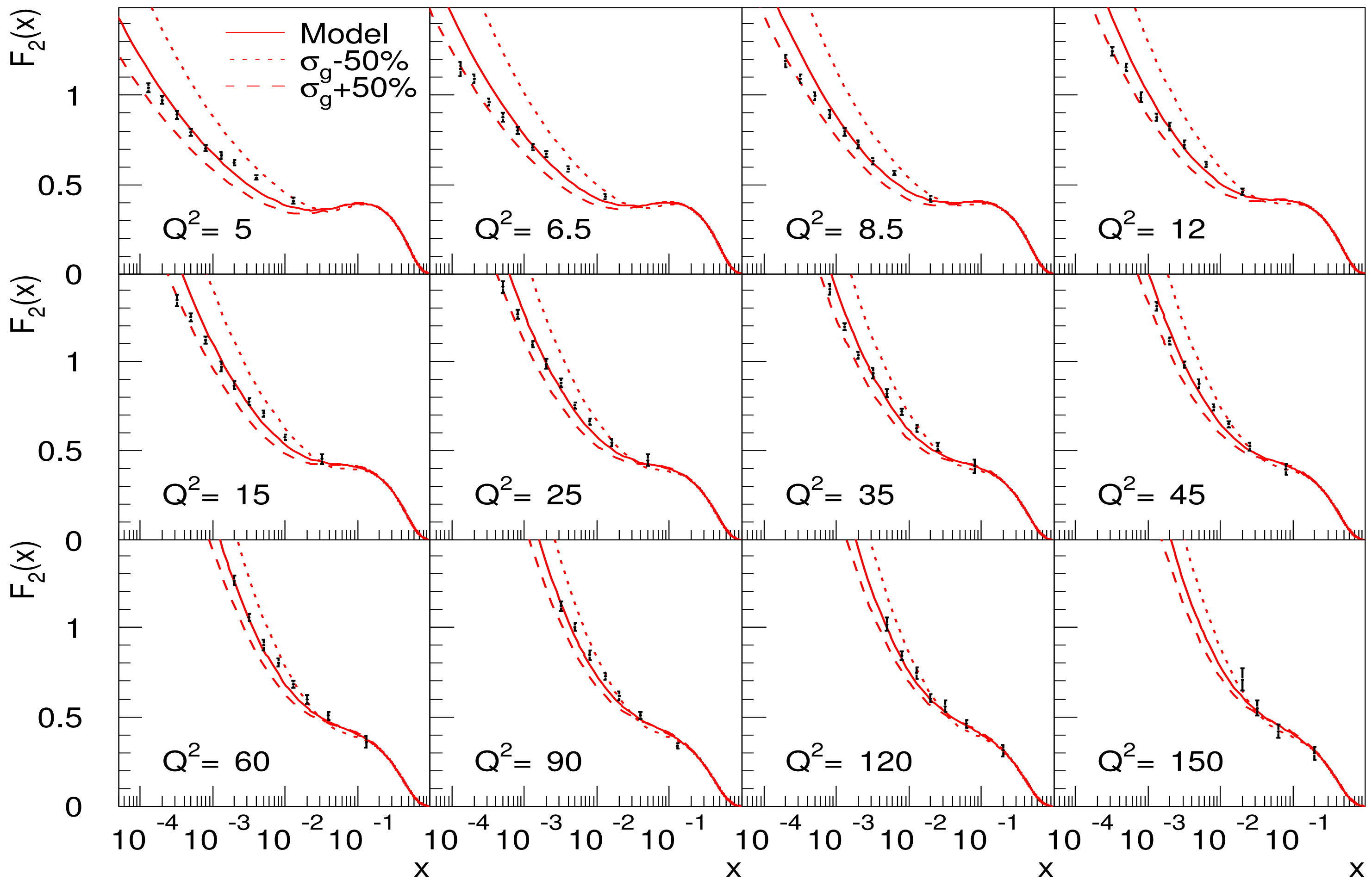
Fixed-target DIS data

NMC and BCDMS F_2 data fix large-x valence distributions (σ_u, σ_d)



HERA DIS data

HERA small-x F_2 data fix gluon distribution (σ_g) and starting scale Q_0



$W^{\pm}$ asymmetry data

In $p\bar{p}$-collisions at Tevatron:

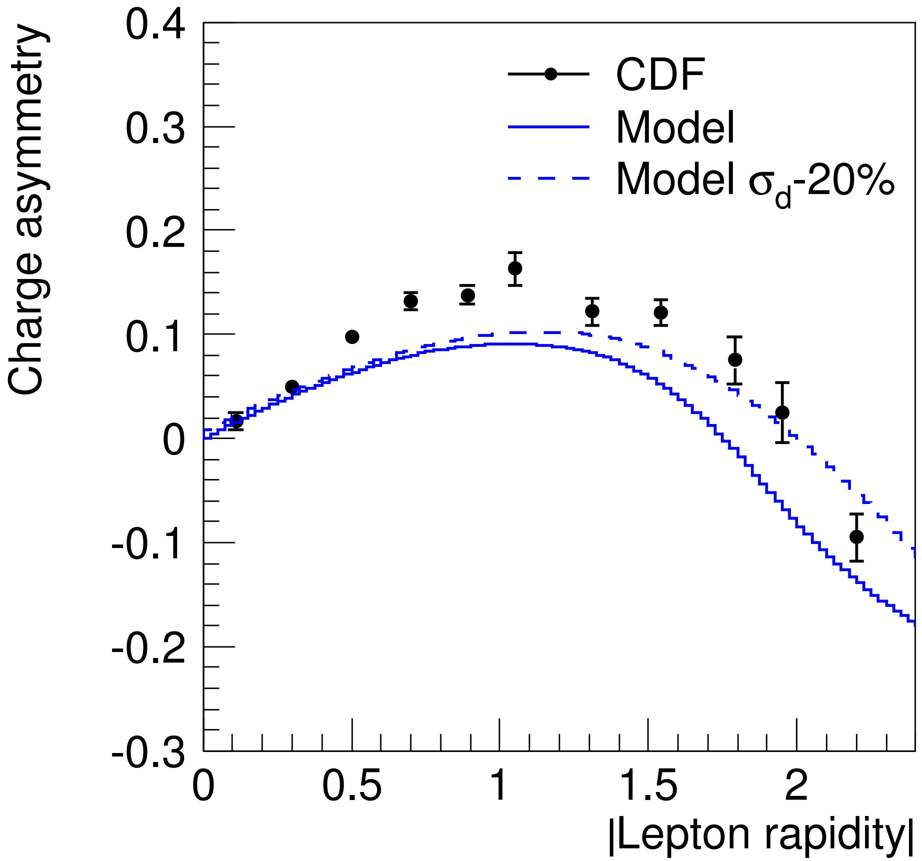
$$\left.\begin{array}{l} u\bar{d} \to W^+ \to l^+\nu_l \\ d\bar{u} \to W^- \to l^-\bar{\nu}_l \end{array}\right\} \Longrightarrow$$

charged lepton forward-backward asymmetry

$$A(y_l) = \frac{d\sigma^+/dy_l - d\sigma^-/dy_l}{d\sigma^+/dy_l + d\sigma^-/dy_l}$$

if different u and d spectrum

In our model: Different Gaussian widths σ_u and σ_d (due to "Pauli blocking" ?)

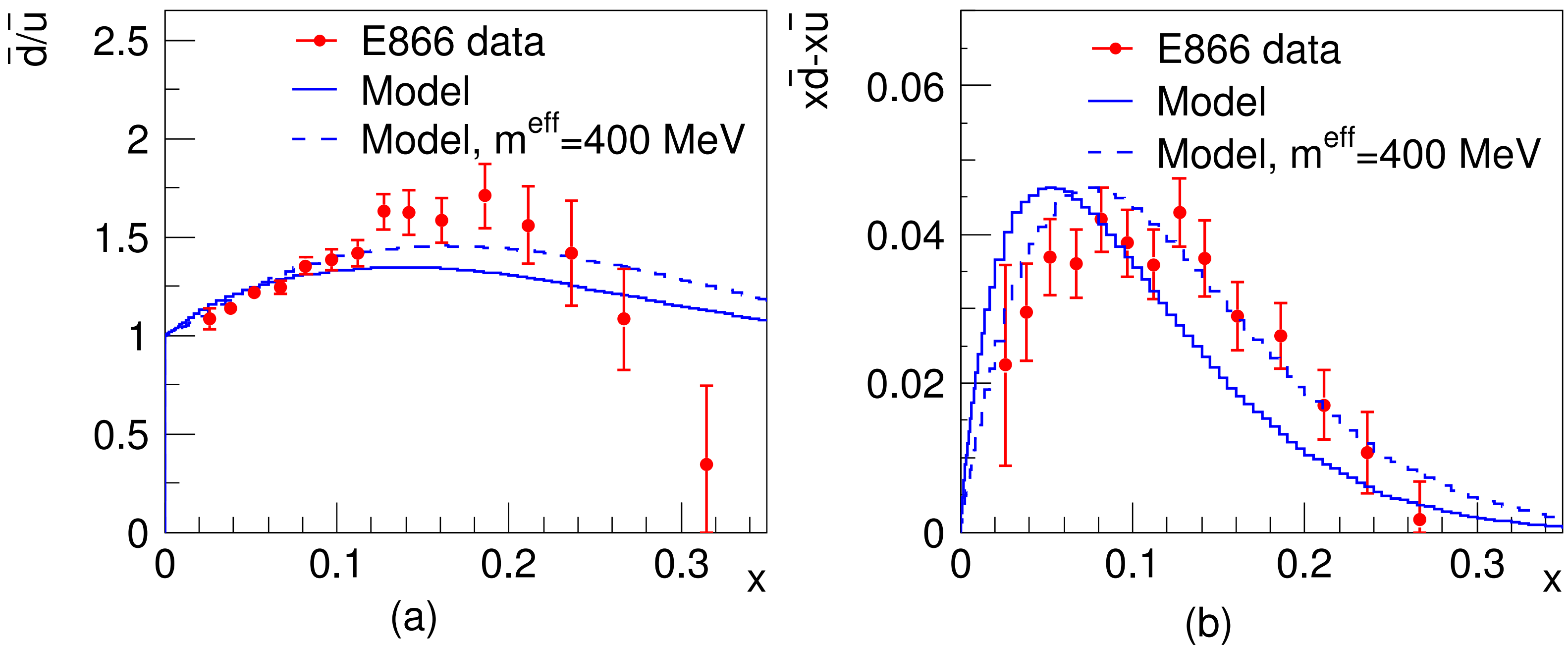


The $\bar{d} - \bar{u}$ asymmetry

pert. QCD $g \to q\bar{q}$ gives $\bar{d}$ - $\bar{u}$ symmetry, but no symmetry forbids $d\bar{d} \neq u\bar{u}$

Fluctuations $p \to p\pi^0$, $p \to n\pi^+$, but no $p \to N\pi^-$ $\Longrightarrow$ excess of $\bar{d}$ over $\bar{u}$

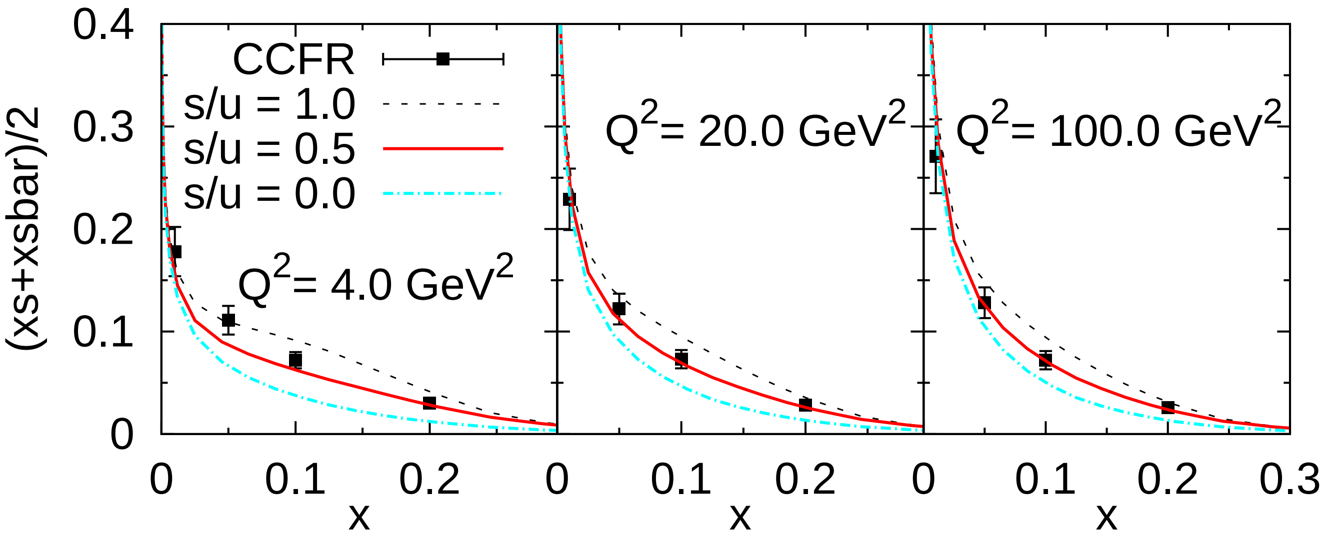
Fitted parameters: $\alpha^2_{p\pi^0}$ and $\alpha^2_{n\pi^+}$



Note: Position of peak better described with effective pion mass $m^{\text{eff}} \approx 400$ MeV
may account for heavier mesons, *e.g.* $|N\rho\rangle$

The strange sea

Lightest strange fluctuation $p \to \Lambda K^+$:
Normalization $\alpha^2_{\Lambda K}$ given by comparison to CCFR $\nu_\mu N \to \mu + c + X$ data

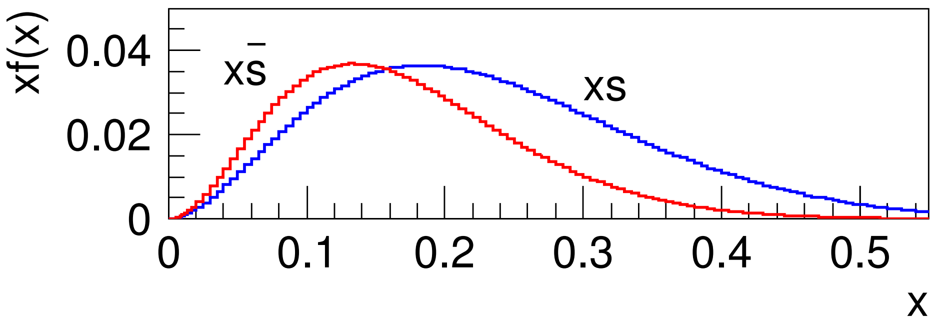


$s/u \approx 0.5$ as in
- pdf parameterisations
- hadronisation models
  e.g. Lund $\frac{P(s\bar{s})}{P(u\bar{u})} \simeq \frac{1}{3}$

Non-pert. $s\bar{s}$ production in colour field

- s quark in (heavier) baryon Λ
- $\bar{s}$ quark in (lighter) meson K^+

$\Longrightarrow$



s distribution harder than $\bar{s}$ distribution

Strange sea asymmetry and the NuTeV anomaly

Based on $R^- = \frac{\sigma(\nu_\mu N \to \nu_\mu X) - \sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \to \mu^- X) - \sigma(\bar{\nu}_\mu N \to \mu^+ X)} = g_L^2 - g_R^2 = \frac{1}{2} - \sin^2\theta_W$

NuTeV obtains $\sin^2\theta_W^{\rm NuTeV} = 0.2277 \pm 0.0016$, 3σ deviation from previous fits of Standard Model $\sin^2\theta_W^{\rm SM} = 0.2227 \pm 0.0004$, *i.e.* an anomaly!

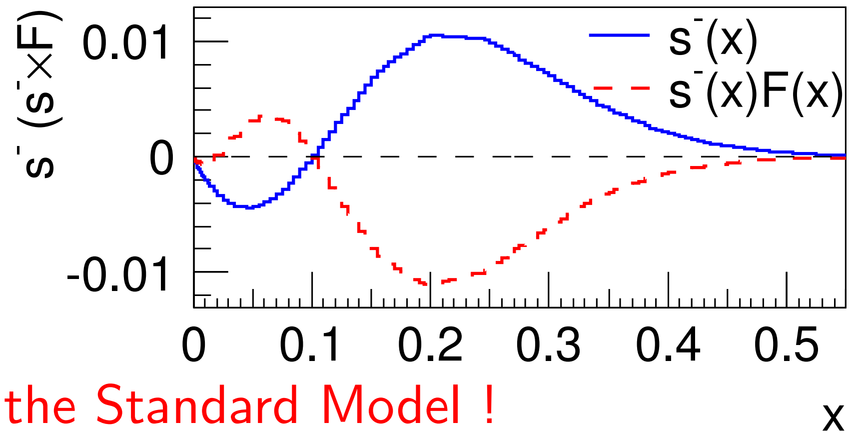
But, shift $\Delta\sin^2\theta_W = \int_0^1 dx[xs(x) - x\bar{s}(x)]F(x)$ ($F(x)$ is NuTeV folding function)

if $xs(x) \neq x\bar{s}(x)$ since $\nu s \to \mu^- c$ and $\bar{\nu}\bar{s} \to \mu^+\bar{c}$ then give different σ's

Our model: $0.0010 \leq S^- = \int_0^1 dx[xs(x) - x\bar{s}(x)] \leq 0.0023$ (varying details, σ_d)

$\Rightarrow -0.0024 \leq \Delta\sin^2\theta_W \leq -0.00097$

i.e. discrepancy reduced to $1.6 - 2.4\sigma$

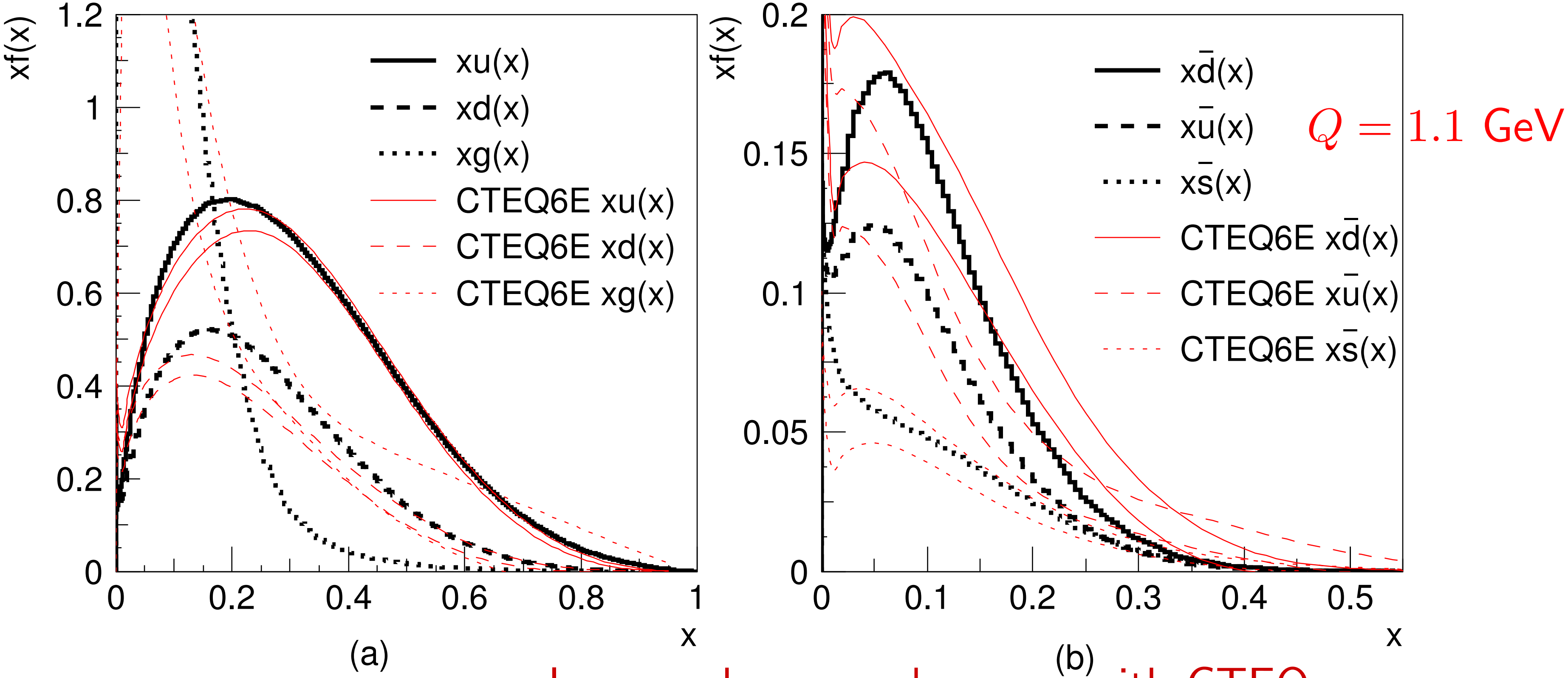


No significant indication for physics beyond the Standard Model !

Comparison with CTEQ6 distributions

CTEQ: "arbitrary" parametrization, 20 x-shape-parameters (+ normalisation)

Our model: physically motivated, 4 x-shape-parameters with reasonable values



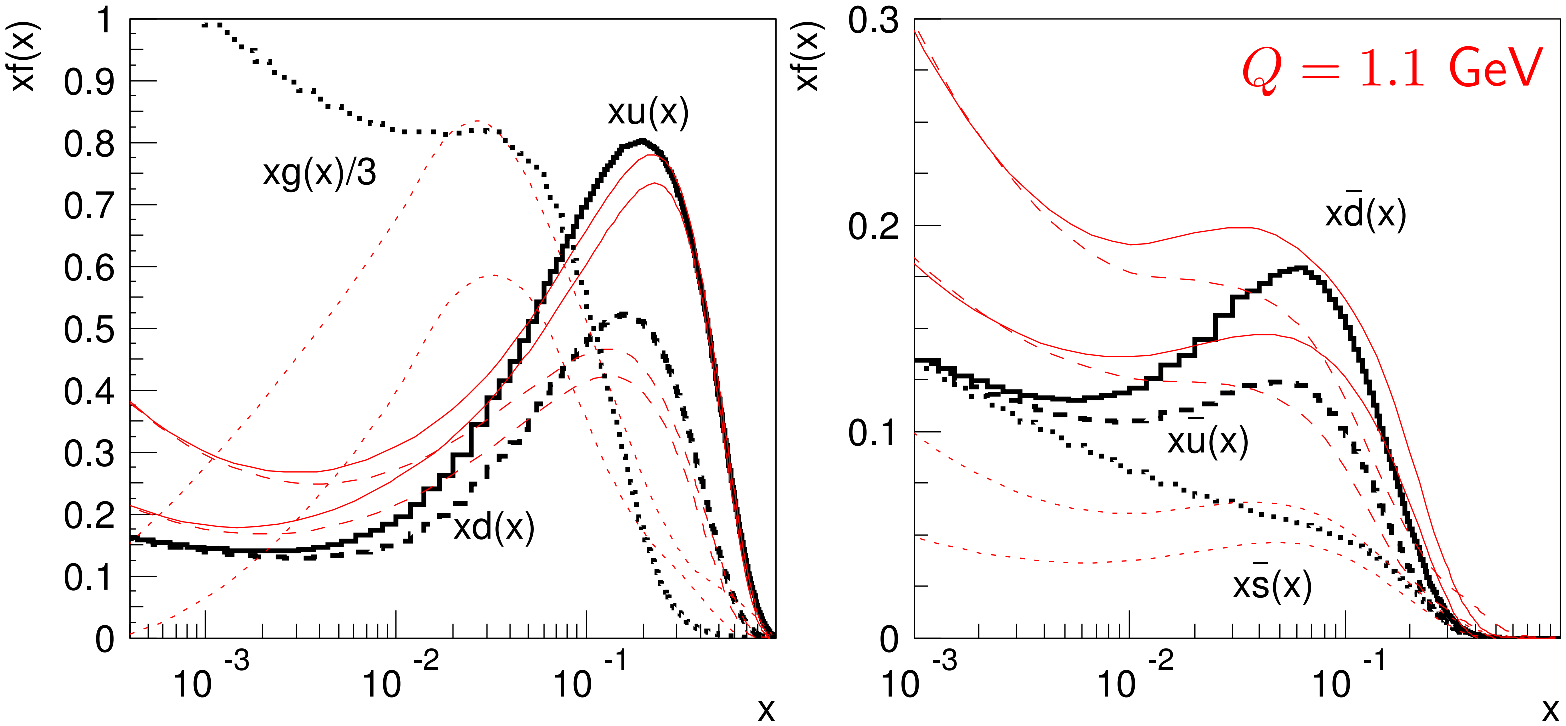
For $x \gtrsim 10^{-2}$

- valence and sea quarks agree with CTEQ
- gluon lower than CTEQ at large x

Comparison with CTEQ6 cont.

CTEQ: $xf(x) \to x^{-0.3}$ for $x \to 0$ at $Q_0 = 1.3$ GeV

Our model: $xf(x) \to 0$ for $x \to 0$ at $Q_0 = 0.75$ GeV



For $x \lesssim 10^{-2}$: Gluon larger than CTEQ, but $u\bar{u}$ and $d\bar{d}$ sea lower than CTEQ

Large $xg(x, Q_0^2)$ and low Q_0^2 needed to give low-x quark sea via DGLAP

$\Rightarrow$ Need for additional souce of $q\bar{q}$ without accompanying gluons !?

Conclusions

- Physically motivated model, based on Gaussian momentum fluctuations, gives the x-shape of parton distribution functions in hadrons, $i.e.\ f_i(x, Q_0^2)$
- Sea quark distributions from hadronic quantum fluctuations, $e.g.\ |N\pi\rangle$, $|\Lambda K\rangle$
- Nice description of large-x valence quark data
  $\hookrightarrow$ Gaussians OK $\rightarrow$ statistical description of non-perturbative dynamics
- $\bar{u} - \bar{d}$ asymmetry in agreement with data
  $\hookrightarrow$ Meson-baryon fluctuations explain non-perturbative sea
- $s - \bar{s}$ asymmetry reduces NuTeV anomaly to $\sim 2\sigma$
  $\hookrightarrow$ No hint of new physics
- Valence and sea quarks $\sim$ CTEQ, but gluon differs !?

NEGATIVE GLUON DENSITY AND GVDM AT LOW Q^2

Johan Alwall and Gunnar Ingelman, hep-ph/0402248

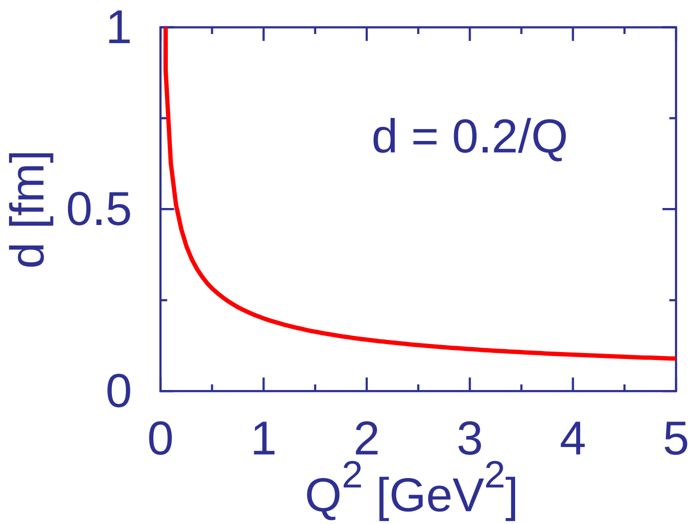
Problem:

DIS formalism and parton pdf's applied at very low Q^2

$$\frac{d\sigma}{dx dQ^2} \sim F_2(x,Q^2) \sim xq(x,Q^2)$$
$$\Downarrow$$

need quark densities, but no or negative gluon density to avoid too much DGLAP evolution

Solution: Low Q^2 does not resolve partons!



Generalised vector meson dominance model accounts for cross-section at $Q^2 \lesssim 1$ GeV^2

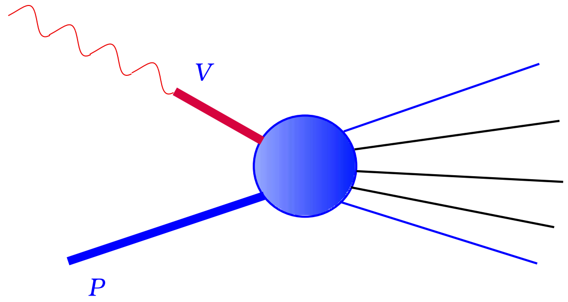
$\hookrightarrow$ parton pdf's work well for $Q^2 \gtrsim 1$ GeV^2

Generalised Vector Meson Dominance Model in ep at low Q^2

Quantum fluctuations $|\gamma\rangle = C_0|\gamma_0\rangle + \sum_V \frac{e}{f_V}|V\rangle + \int_{m_0} dm_V(\ldots)|V\rangle$

i.e. photon $\rightarrow$ vector mesons $V = \rho^0, \omega, \phi \ldots +$ continuum

followed by $Vp \rightarrow X$ with soft hadronic cross-section



$\sigma_{T,L}^{\mathrm{GVDM}} = P(\gamma \rightarrow V)\sigma_{Vp}$; $\sigma_{Vp} = A_V s^{\epsilon} + B_V s^{-\eta}$; $\epsilon \approx 0.08$

In ep: $F_2(x, Q^2) = \frac{(1-x)Q^2}{4\pi^2\alpha}(\sigma_T + \sigma_L)$

$s_{\gamma p} = Q^2\,\frac{1-x}{x} + m_p^2 \approx Q^2/x$ at small-x

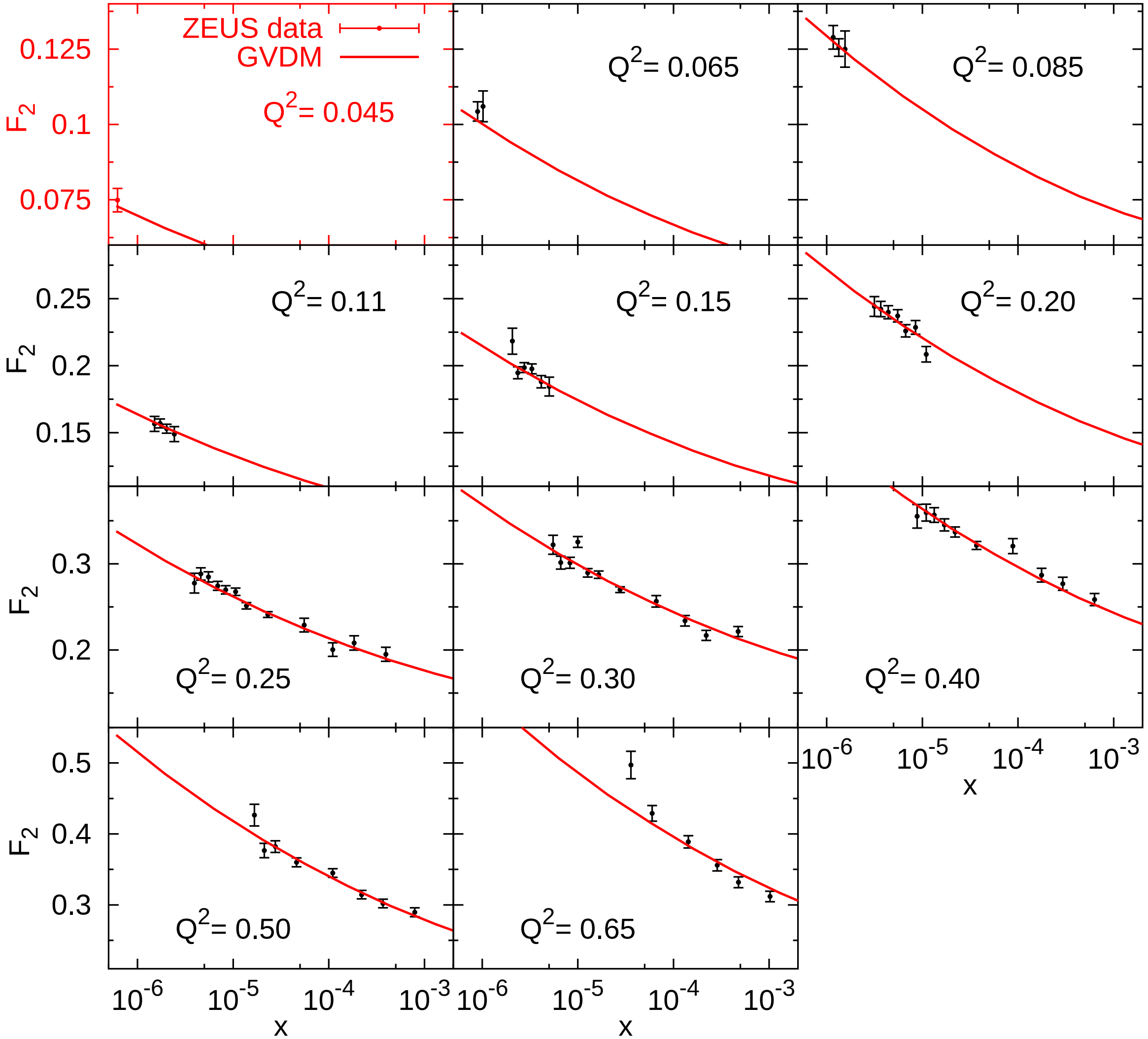
$$\Rightarrow F_2^{\mathrm{GVDM}}(x, Q^2) = \frac{(1-x)Q^2}{4\pi^2\alpha}\left\{\sum_V r_V \left(\frac{m_V^2}{Q^2+m_V^2}\right)^2 \left(1 + \xi\frac{Q^2}{m_V^2}\right) + r_C \frac{m_0^2}{Q^2+m_0^2}\right\} A\left(\frac{Q^2}{x}\right)^{\epsilon}$$

More complex Q^2-dependence from σ_L and continuum than simple VDM

Parameters 'known' from GVDM: $r_V = \frac{4\pi\alpha}{f_V^2}\frac{A_V}{A}$, $r_C = 1 - \sum_V r_V$

$m_0 \approx 1$ GeV, $r_{V=\rho,\omega,\phi,C} = 0.67, 0.062, 0.059, 0.21$; $\xi \approx 0.25$

HERA F_2 at low Q^2



ZEUS 1997 data

GVDM model fits well

$\chi^2 = 87/(70-4) = 1.3$

with parameter values

$\epsilon = 0.091$

$m_0 = 1.5$ GeV

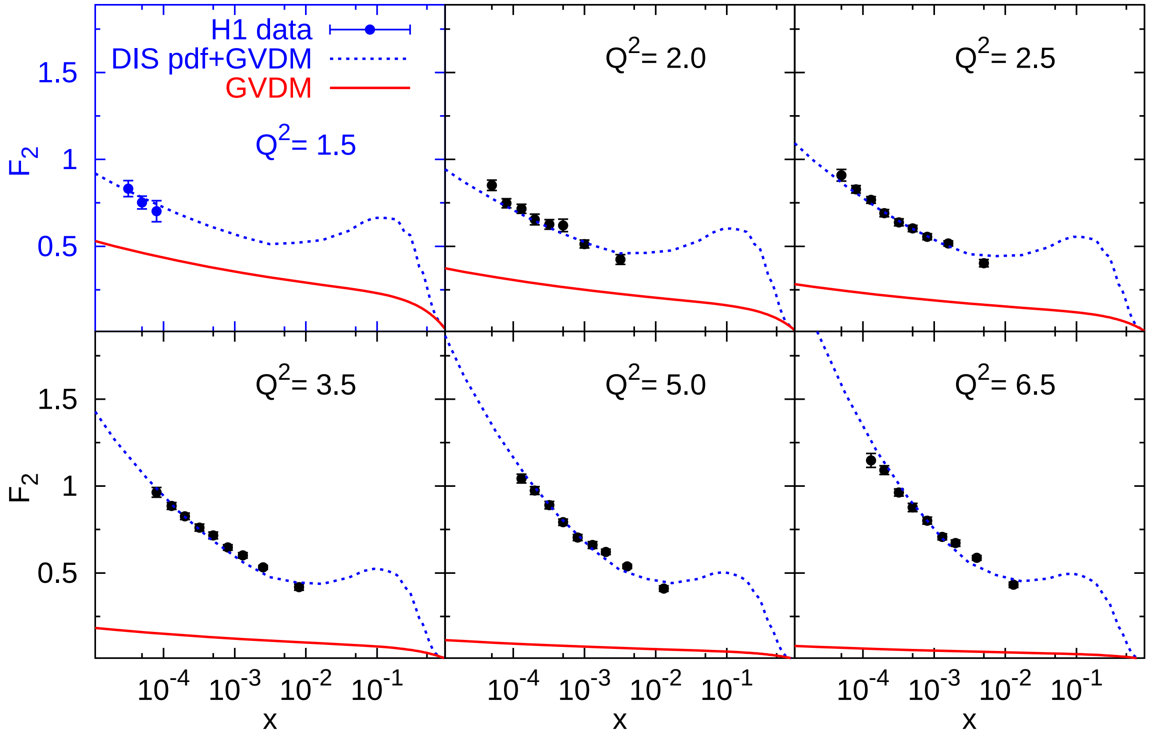
$A = 71\,\mu\text{b}$

$\xi = 0.34$

as expected

HERA F_2 at intermediate Q^2

In DIS-region: GVDM needs scale-down (form factor) with Q^2



GVDM $\times \left(\frac{Q_0^2}{Q^2}\right)^a$ with $a = 1.8$

for $Q^2 > Q_0^2 = 1.26$ (fitted)

$\rightarrow$ GVDM negligible for $Q^2 \gtrsim 3$

Adding parton densities,

here Alwall-Edin-Ingelman model,

gives good description of data

without negative gluon density

Consequences for pdf's at HERA and LHC

- Parameterisations OK within x, Q^2 region of fit, but extrapolations outside may go wrong

  Remember pdf's at small-x before HERA data

  Need to extend pdf's to even smaller x at LHC

- New observables may be sensitive to finer details not provided by fit to inclusive data

  Example: asymmetries

- Large-x pdf's important for production of new heavy particles