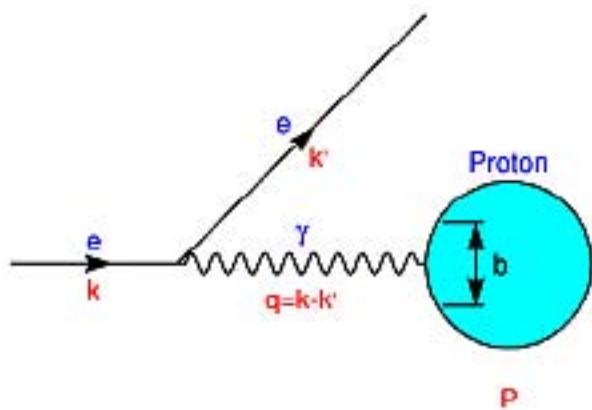
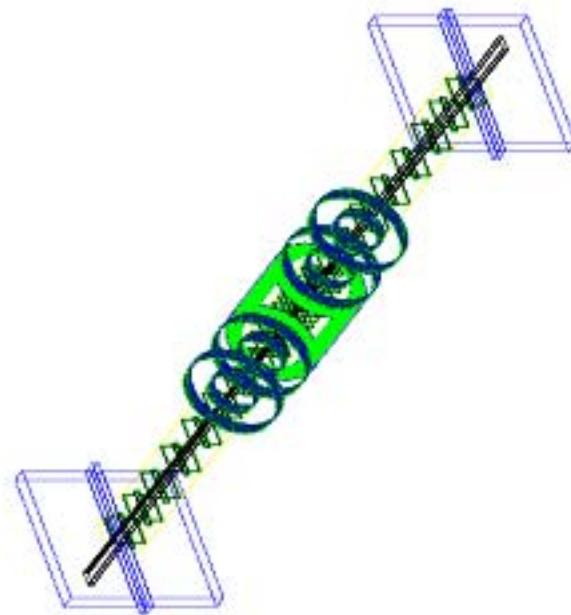


F_2/F_L with HERA III/eRHIC

A. Caldwell, Max-Planck-Institut f. Physik



New Detector for HERA/eRHIC

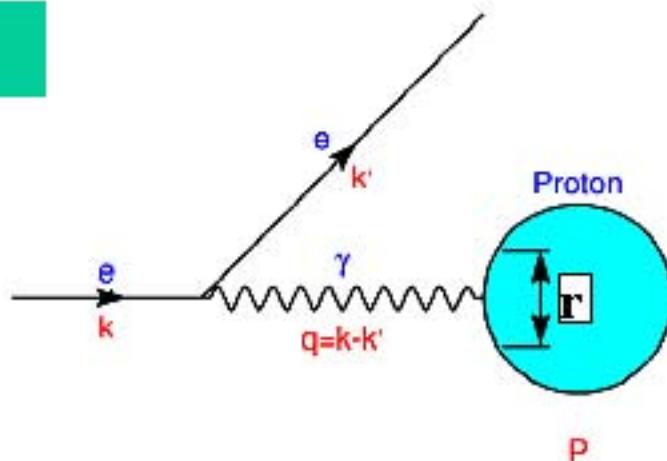


**Physics - QCD in the
high energy limit**

Kinematics

$E_e = 10 - 27.5 \text{ GeV}$

$E_P = 250 - 920 \text{ GeV}$



$$s = (k+P)^2 = (100-320 \text{ GeV})^2$$

$$Q^2 = -(k-k')^2$$

$$W^2 = (q+P)^2$$

CM energy squared

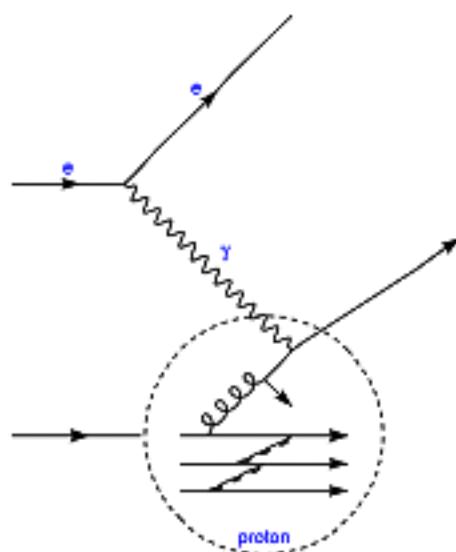
virtually

$\gamma^* P$ CM energy squared

Transverse distance scale probed: $r \approx hc/Q$

McAllister, Hofstadter	$E_e = 188 \text{ MeV}$	$r_{\min} = 0.4 \text{ fm}$
Bloom et al.	10 GeV	0.05 fm
CERN, FNAL fixed target	500 GeV	0.007 fm
EIC	5 TeV	0.002 fm
HERA	50 TeV	0.0007 fm

Proton \propto momentum frame



Rutherford

$$\frac{d^2\sigma}{dx dQ^2} = 2\pi\alpha^2/x Q^4 [(1+(1-y)^2) F_2 - y^2 F_L]$$

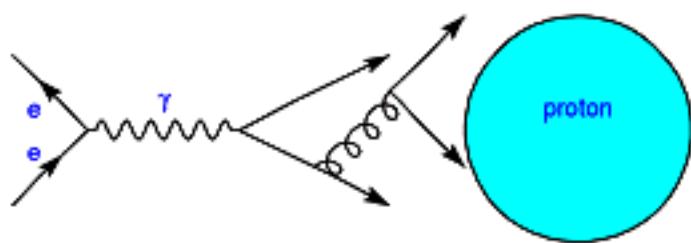
$$F_2 = \sum_f e_f^2 x \{ q(x, Q^2) + \bar{q}(x, Q^2) \}$$

e_f is quark charge

$q(x, Q^2)$ is quark density

$F_L = 0$ in LO (QPM), non-zero after gluon radiation. Key test of our understanding

Proton rest frame



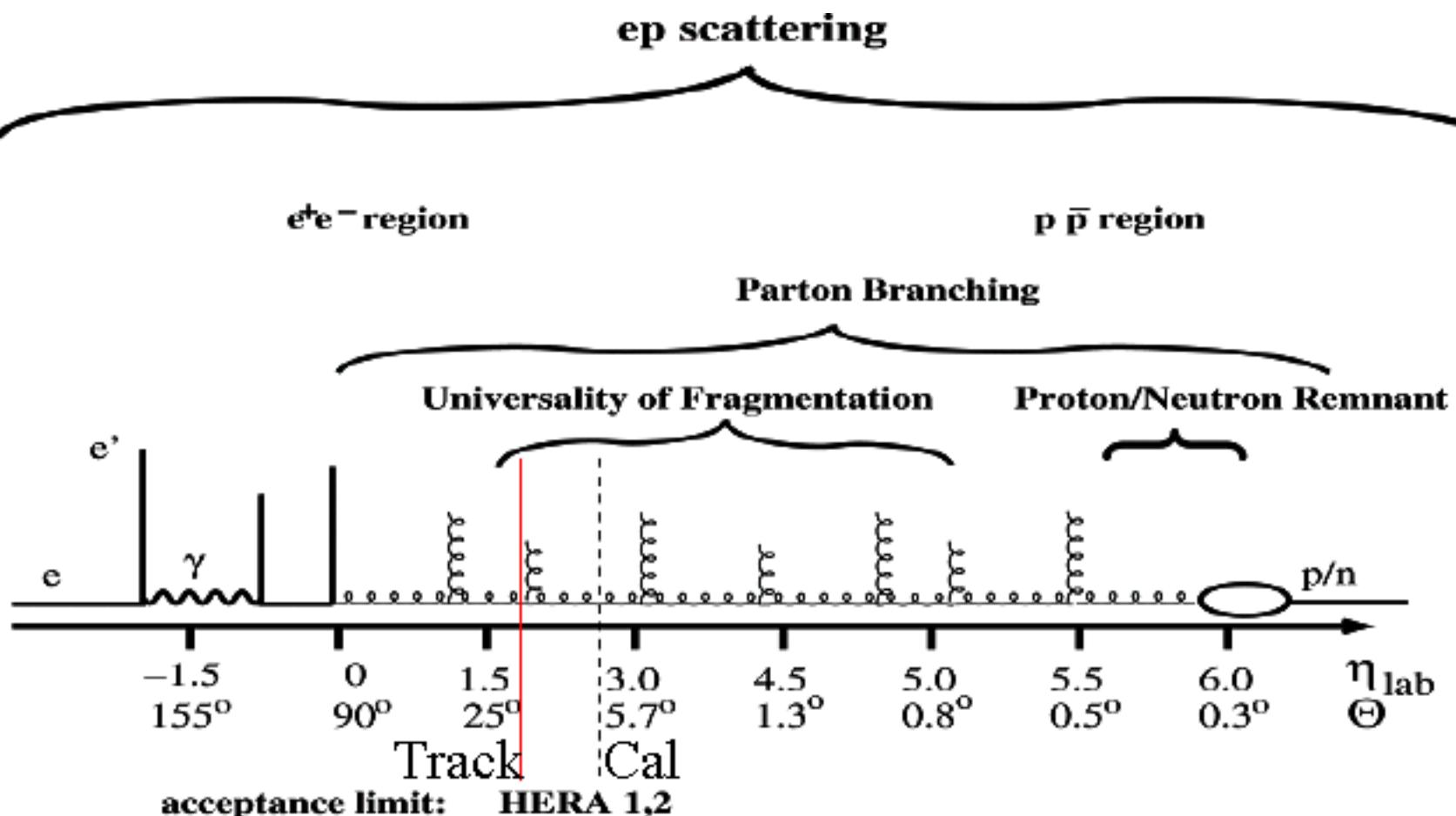
$$\frac{d^2\sigma}{dW dQ^2} = \Gamma (\sigma_T + \epsilon \sigma_L)$$

Γ is flux of photons

$\sigma_{T,L}$ are cross sections for transversely, longitudinally polarized photons to scatter from proton

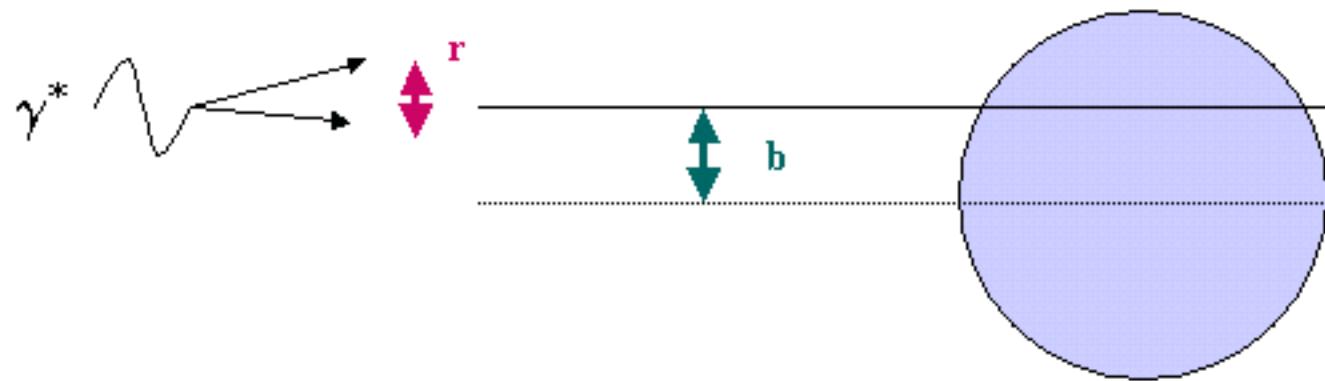
ϵ is the relative flux

$$F_2 = Q^2/4\pi^2\alpha (\sigma_T + \epsilon \sigma_L)$$



Structure function measurements – measure distribution of quarks at the end of the radiation chain. Try to understand result with various QCD based evolution approaches.

Physics Picture in Proton Rest Frame



$r \sim 0.2 \text{ fm}/Q$ ($0.02 - 2 \text{ fm}$ for $100 > Q^2 > 0.01 \text{ GeV}^2$) transverse size of probe

$ct \sim 0.2 \text{ fm} (W^2/2M_p Q^2)$ (<1 fm to 1000's fm) – scale over which photon fluctuations survive

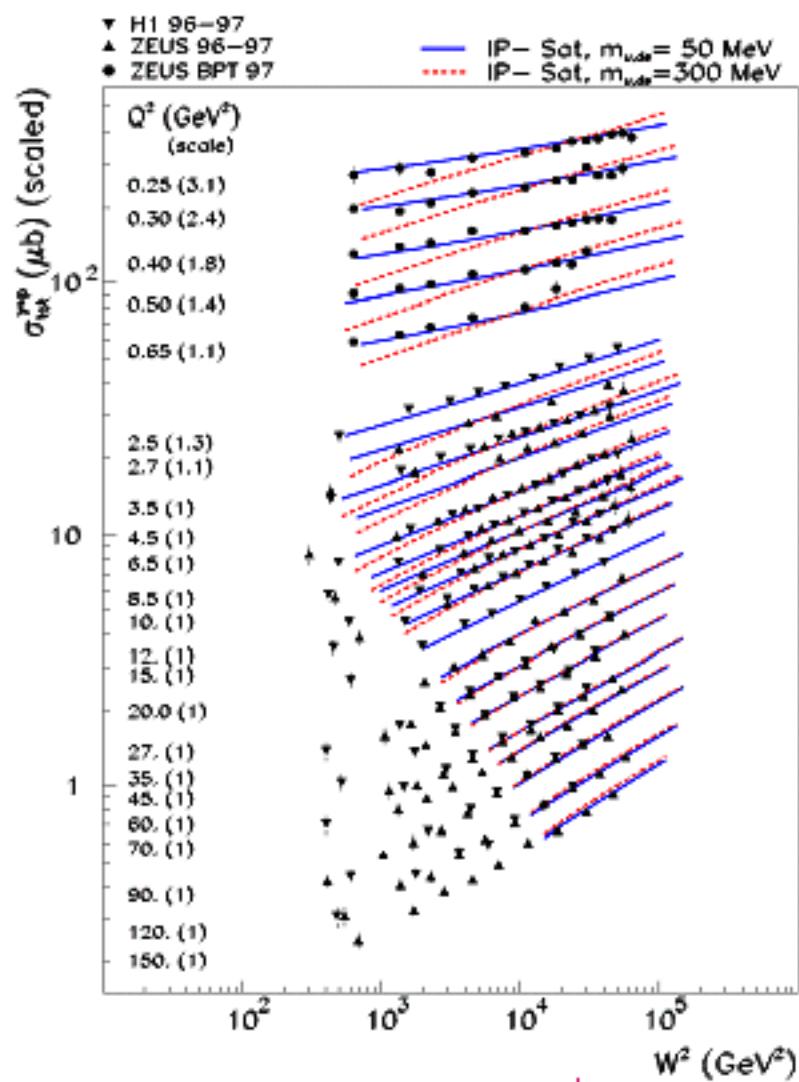
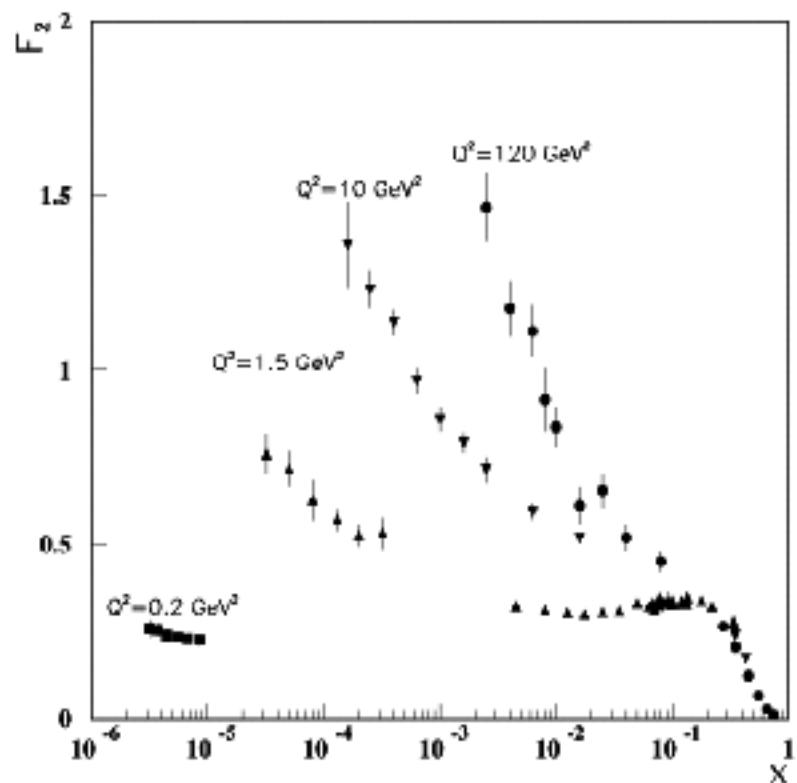
And, in exclusive processes, can vary the impact parameter

$$\mathbf{b} \sim 0.2 \text{ fm/sqrt}(t) \quad t = (\mathbf{p} - \mathbf{p}')^2$$

Can control these parameters experimentally !

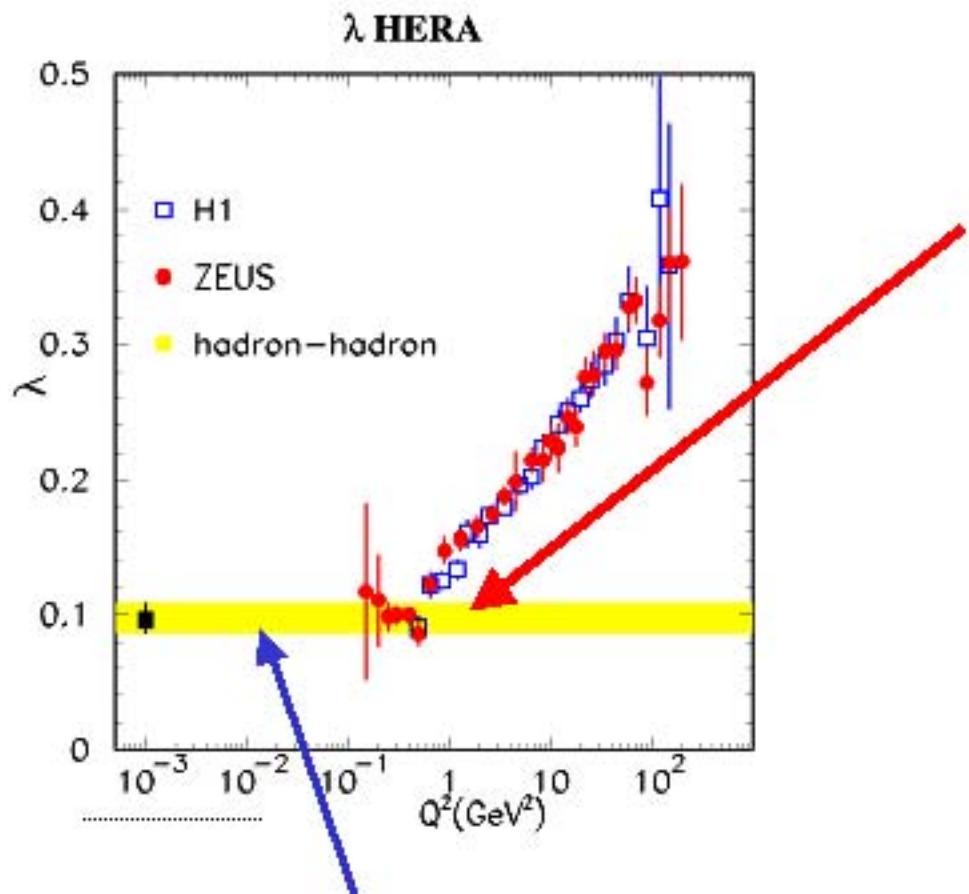
Cross sections as a function of Q^2

The rise of F_2 with decreasing x observed at HERA is strongly dependent on Q^2



Equivalently, strongly rising $\gamma^+ p$ cross section with W at high Q^2

The behavior of the rise with Q^2

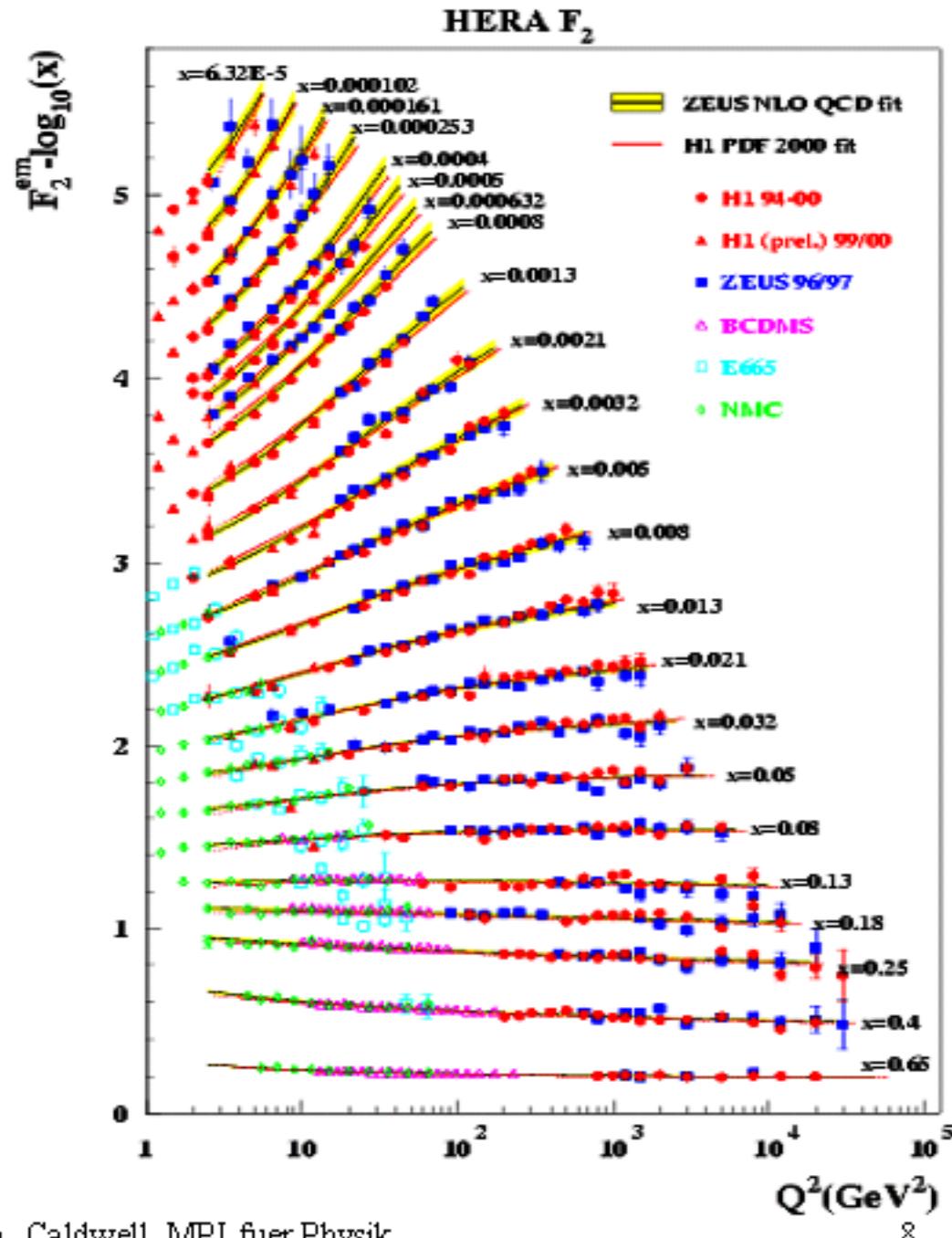


Below $Q^2 \approx 0.5 \text{ GeV}^2$, see same energy dependence as observed in hadron-hadron interactions.
Observe transition from partons to hadrons (constituent quarks) in data. Distance scale $\approx 0.3 \text{ fm} ??$

What physics causes this transition ?

Hadron-hadron scattering energy dependence (Donnachie-Landshoff)

In general, NLO pQCD (DGLAP) fits do a good job of reproducing the data over the full measurement range.



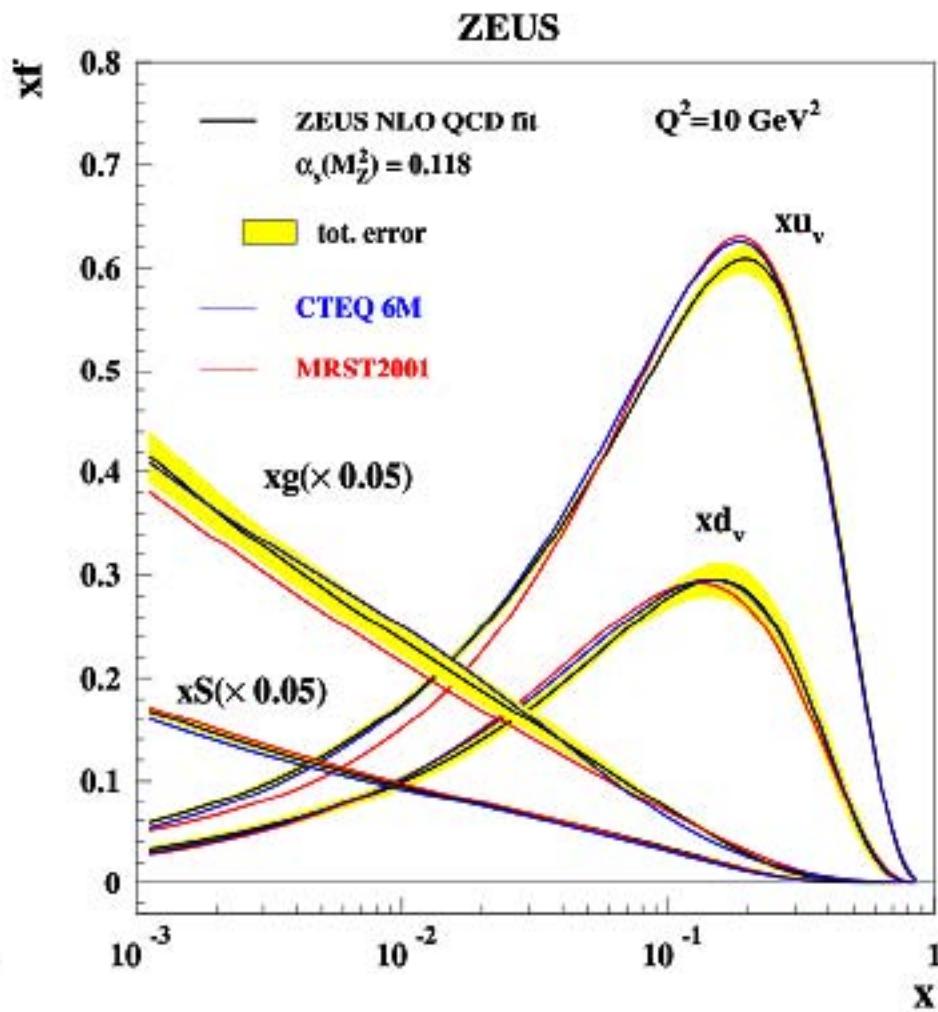
Analysis of F_2 in terms of parton densities (quarks and gluons)

NLO DGLAP fits can follow the data accurately, yield parton densities.

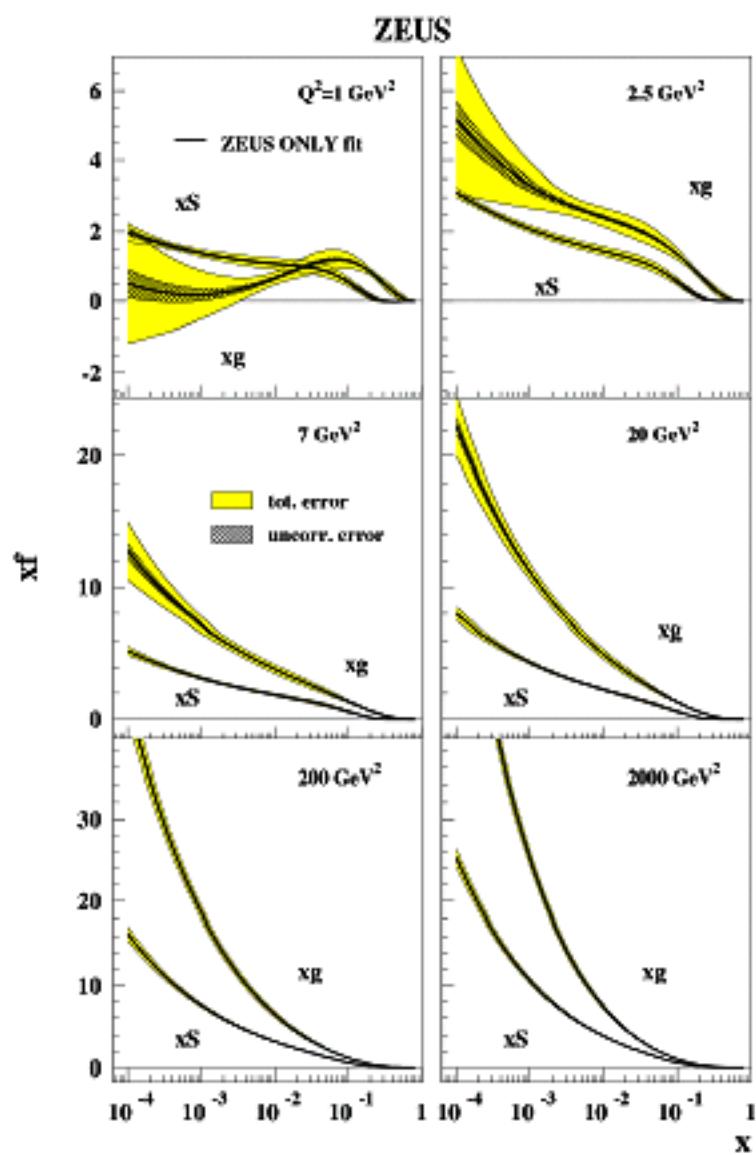
BUT:

- many free parameters (18-30)
- form of parametrization fixed (not given by theory)

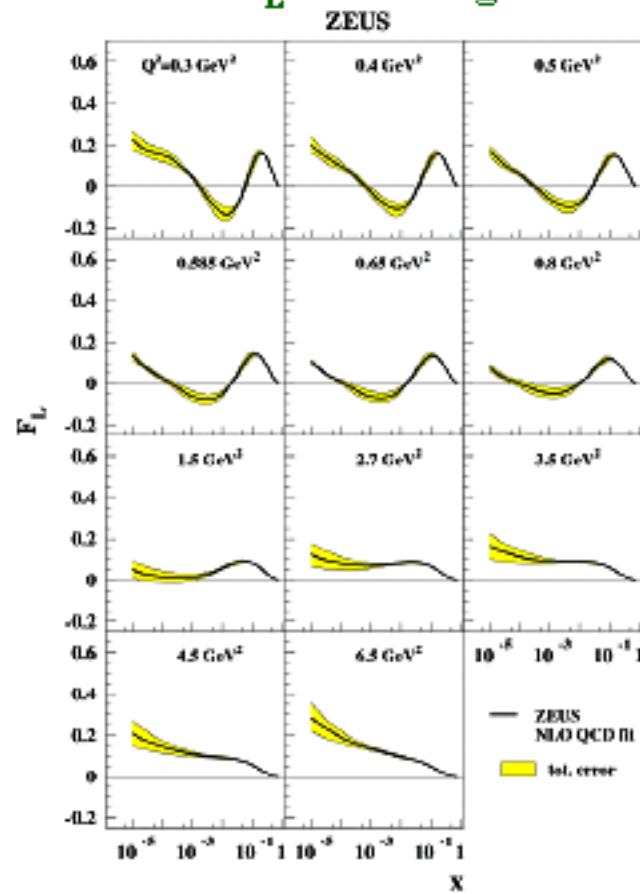
Constraints, e.g., $d_{\text{sea}} = u_{\text{sea}}$ put in by hand. Is this correct ? Need more constraints to untangle parton densities (deuterons, F_L).



See breakdown of NLO DGLAP approach ...

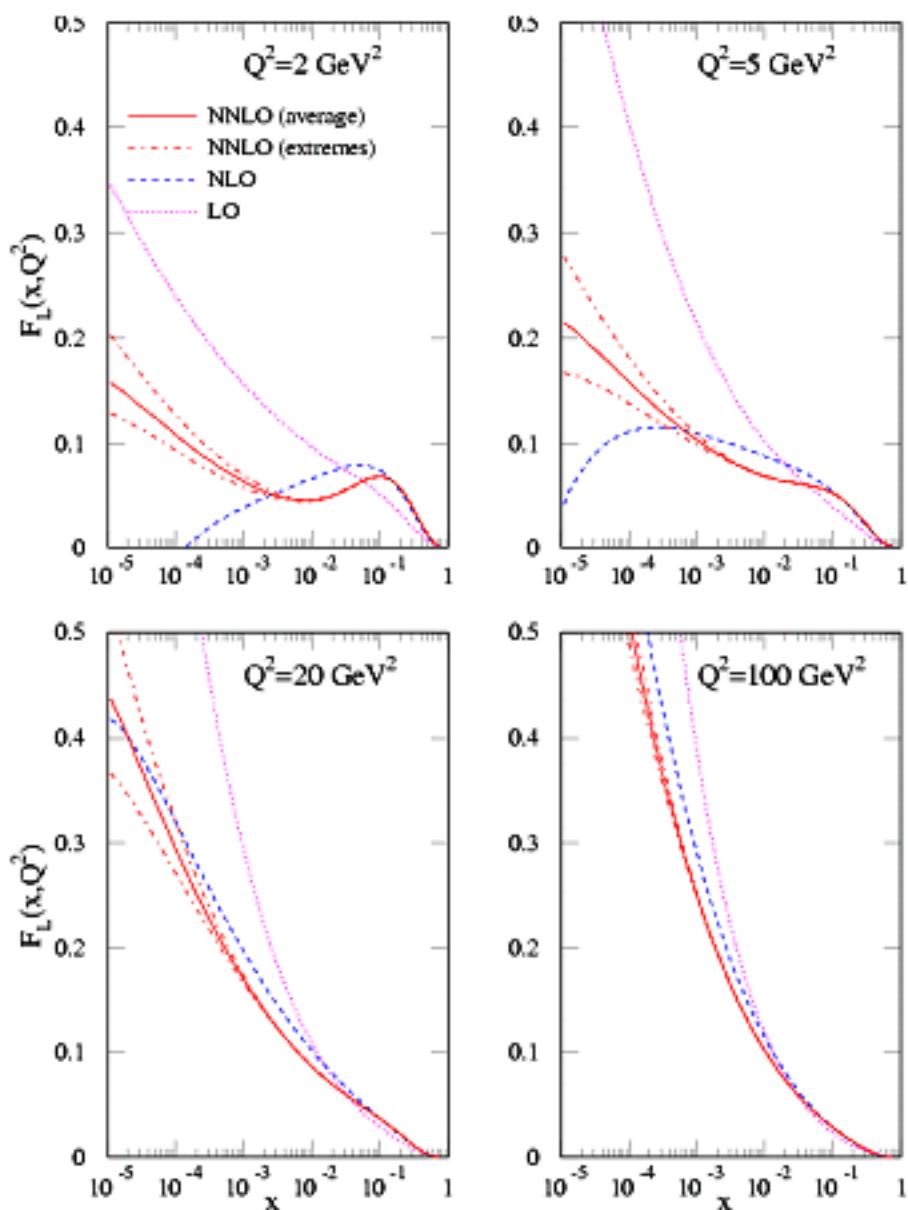
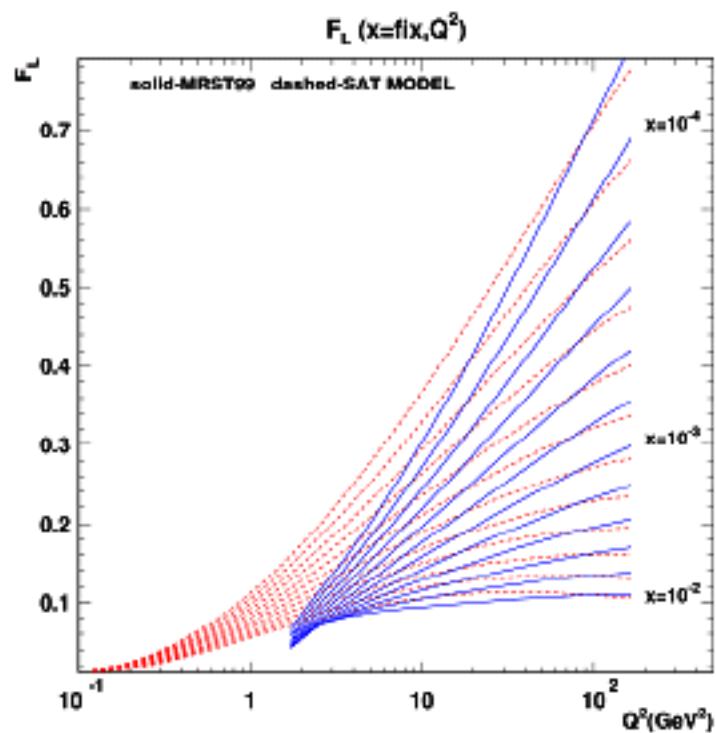


Gluon density known with good precision at larger Q^2 . For $Q^2=1$, gluons go negative. NLO, so not impossible, BUT – cross sections such as σ_L also negative !



F_L shows tremendous variations when attempt to calculate at different orders. But F_L is an observable – unique result.

F_L is hard to measure but a very sensitive test. Should be measured.



Large-x

Motivation:

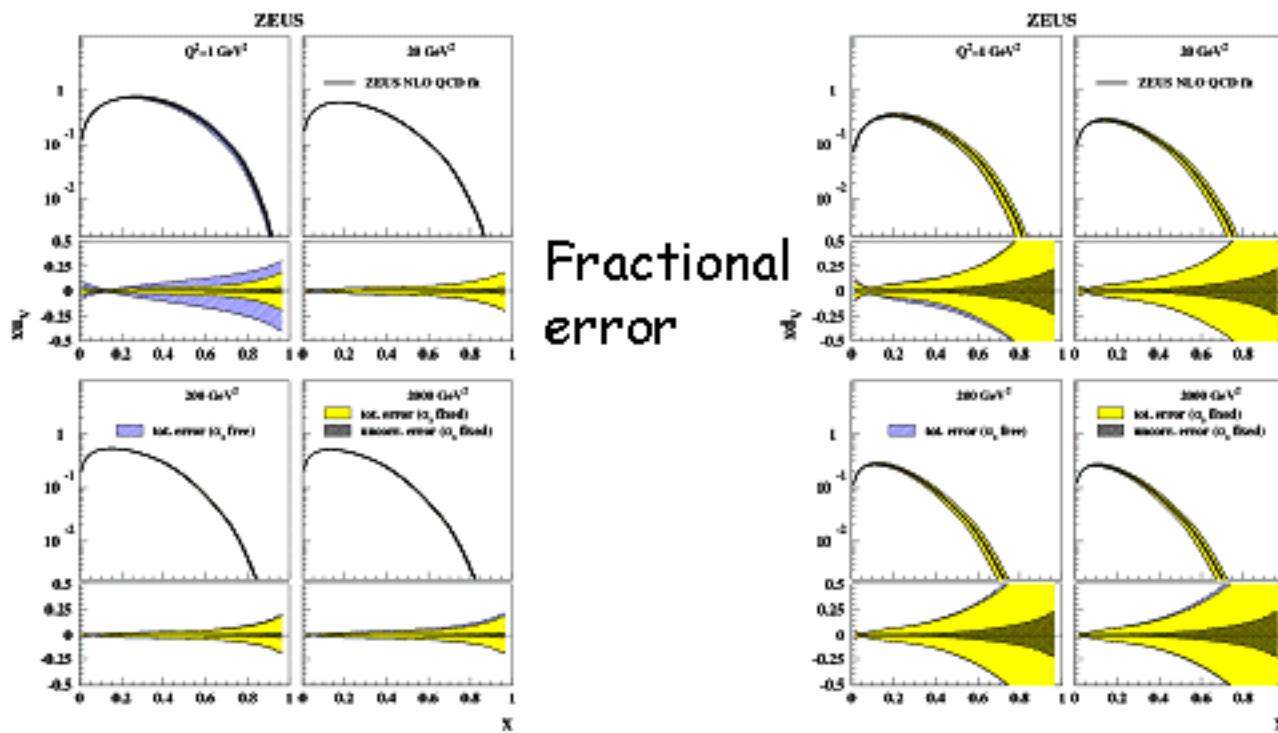
- No data on parton densities for $x > 0.75$ in DIS regime.
- Phenomenology uses standard parametrizations for large x , $q(x) \propto (1-x)^b$, but not well motivated. Could have surprises at large- x . At very high- x , novel QCD effects expected (ends in 'on').
- Parton densities need to be well understood for searches for new physics.

Requirements:

- Max possible luminosity
- e^+, e^- for valence quark flavor separation
- low E_T running for added sensitivity to large- x

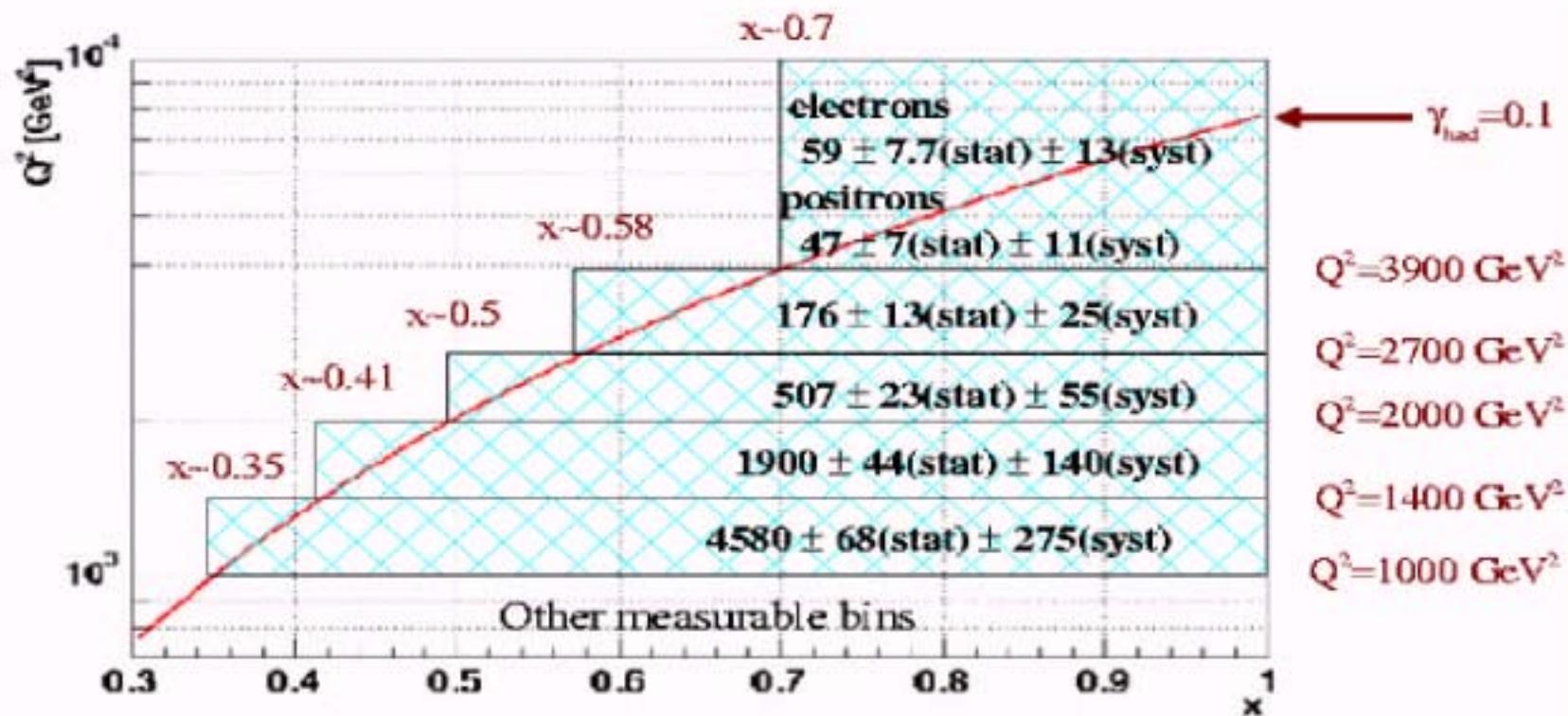
Large-x

Uncertainties in parton densities from ZEUS NLO fit: includes available fixed target data. Parametrization uncertainty not included.



Fractional
error

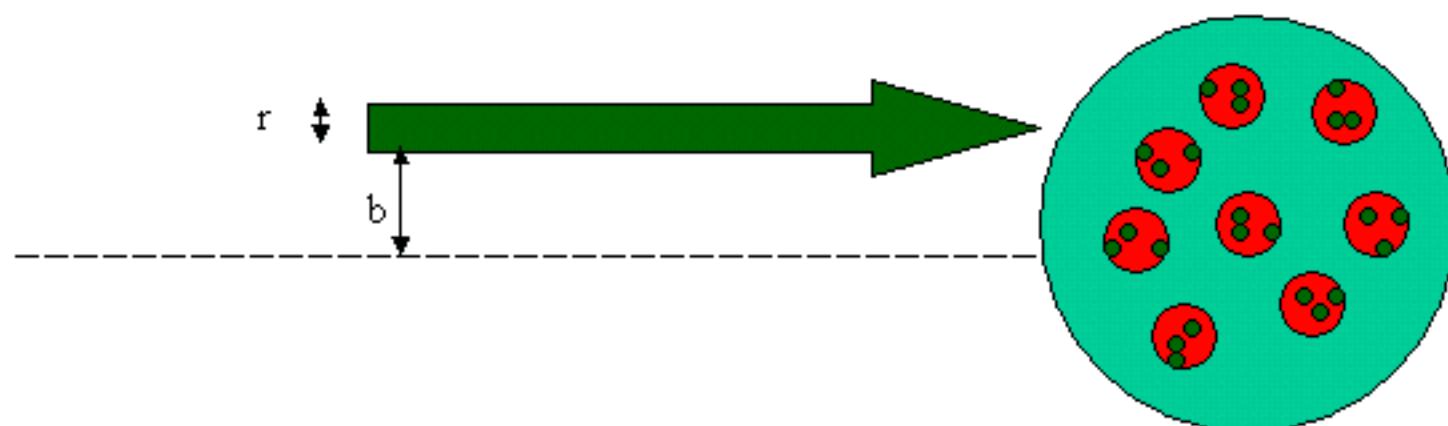
Statistics at large- x (HERA II):



From 1 fb^{-1} with $E_p = 920 \text{ GeV}$. 15% measurement at $x > 0.7$.
Will be a first measurement of this quantity.

Precision eA measurements

- Enhancement of possible nonlinear effects (saturation)



At small x , the scattering is coherent over nucleus, so the diquark sees much larger # of partons: $xg(x_{\text{eff}}, Q^2) \rightarrow A^{1/3} xg(x, Q^2)$

This should enhance the chances to see saturated gluon state (CGC) in nuclei. Need quantitative predictions for behavior of structure functions with x in heavy nuclei.

HERA-III Initiative

Two letters of intent were submitted to the DESY PRC (May 7,8 2002)

- **H1 Collaboration**

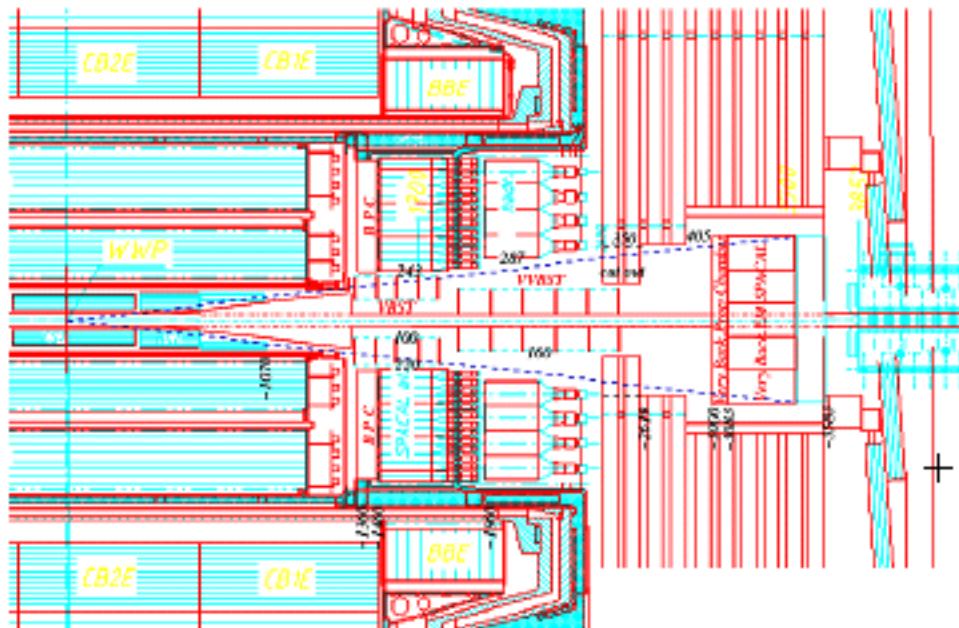
**Focus initially on eD: isospin symmetry of sea at small-x
 u_v/d_v at large-x
diffraction on n, D**

**Discuss also interest in: eA, F_2, F_L at small Q^2 , forward jets,
spin structure**

- **New Collaboration**

**Optimized detector for precision structure function measurements,
forward jets and particle production over a
large rapidity interval (eP, eD, eA)**

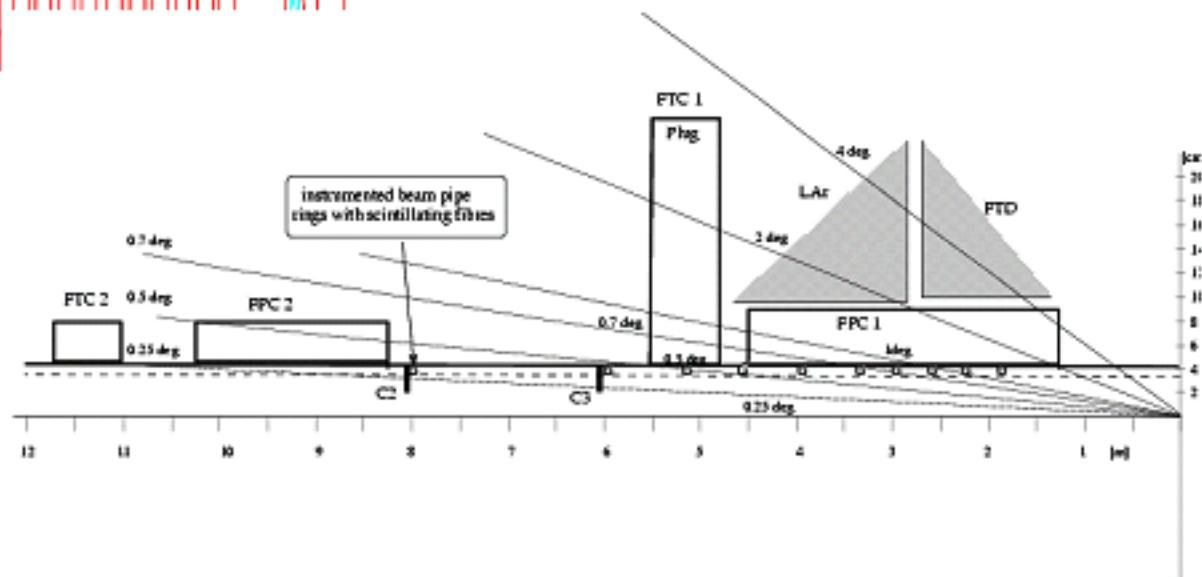
Possible upgrades of H1 detector



Upgrade in proton direction for forward particle, jets measurements

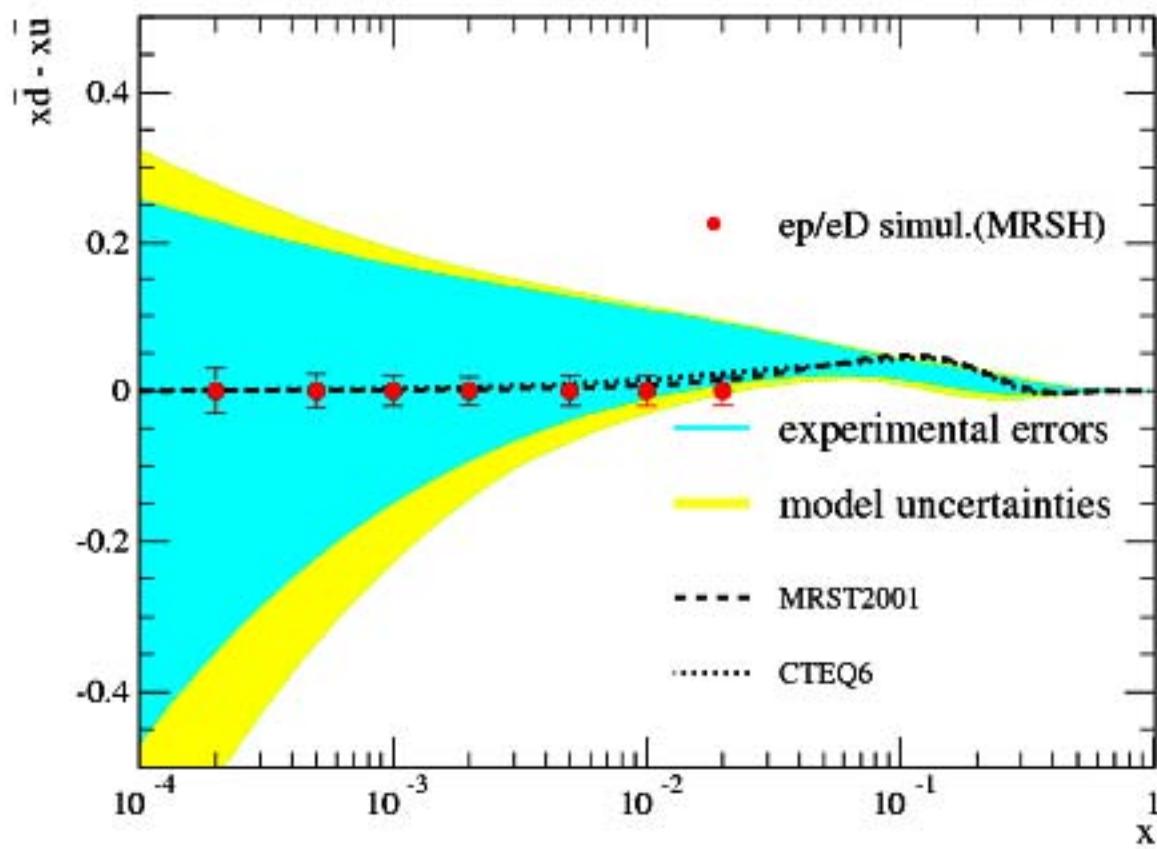
Upgrade in electron direction for low Q^2 F_2 and F_L measurements

+ very forward proton, neutron detectors



Precision eD measurements

- Universality of PDF's at small-x, isospin symmetry



Can measure $F_2^p - F_2^n$ w/o nuclear corrections if can tag scattered nucleon

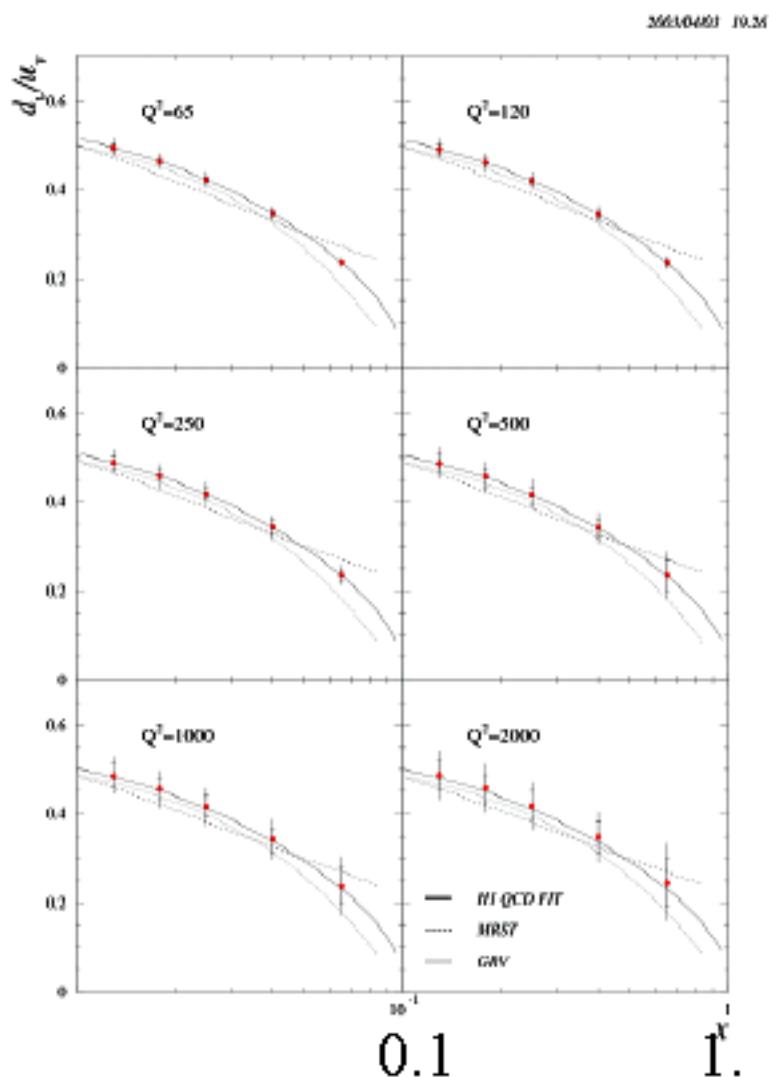
- Flavor dependence at high-x

Behavior of F_2^p/F_2^n as $x \rightarrow 1$

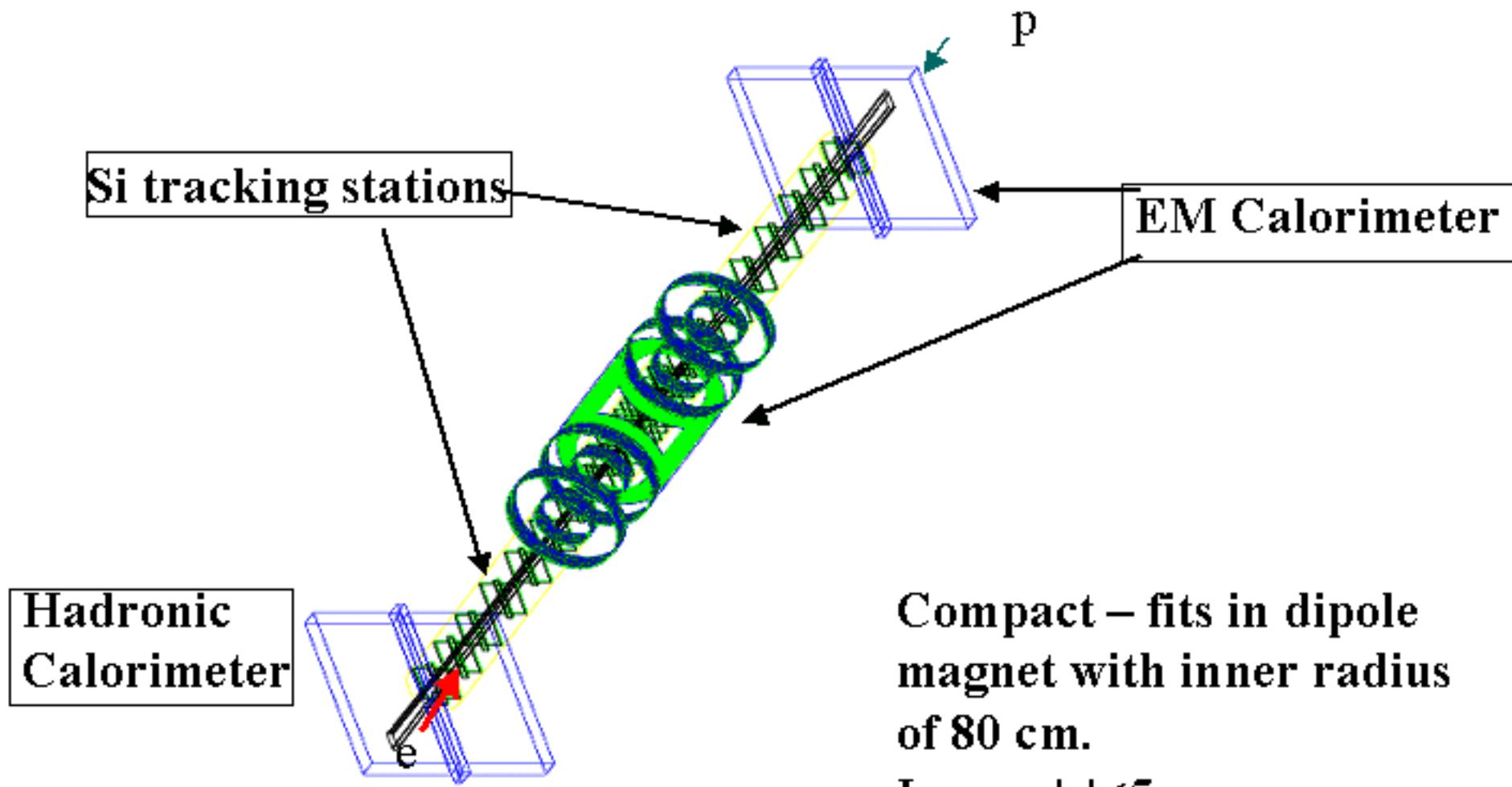
$$\begin{array}{ll} \text{SU(6) symmetry} & F_2^p/F_2^n = 2/3 \\ \text{Dominant scalar diquark} & F_2^p/F_2^n = 1/4 \end{array}$$

Can measure this ratio w/o need to correct for nuclear effects if can tag scattered nucleon.

Simulation with H1 based on 50 pb⁻¹



A new detector to study strong interaction physics



March 16, 2004

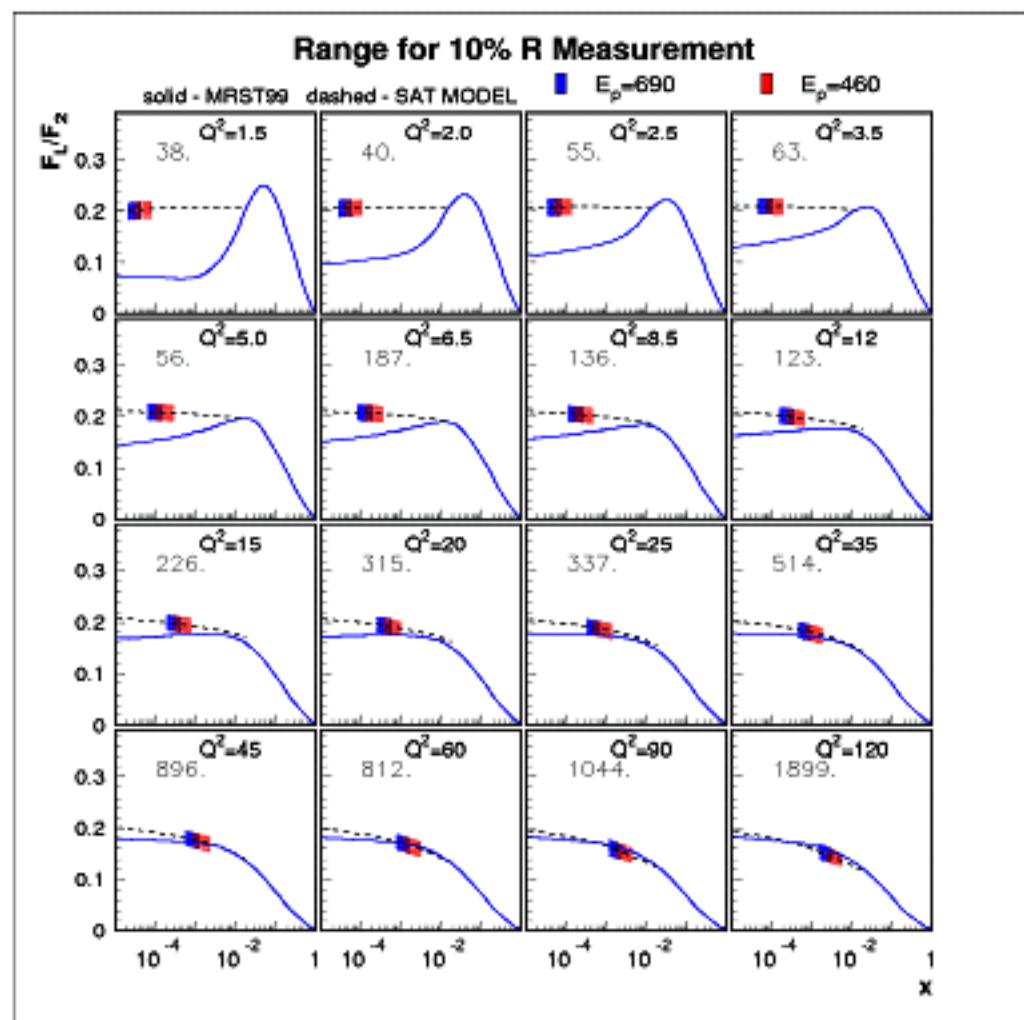
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F_L Measurement Range

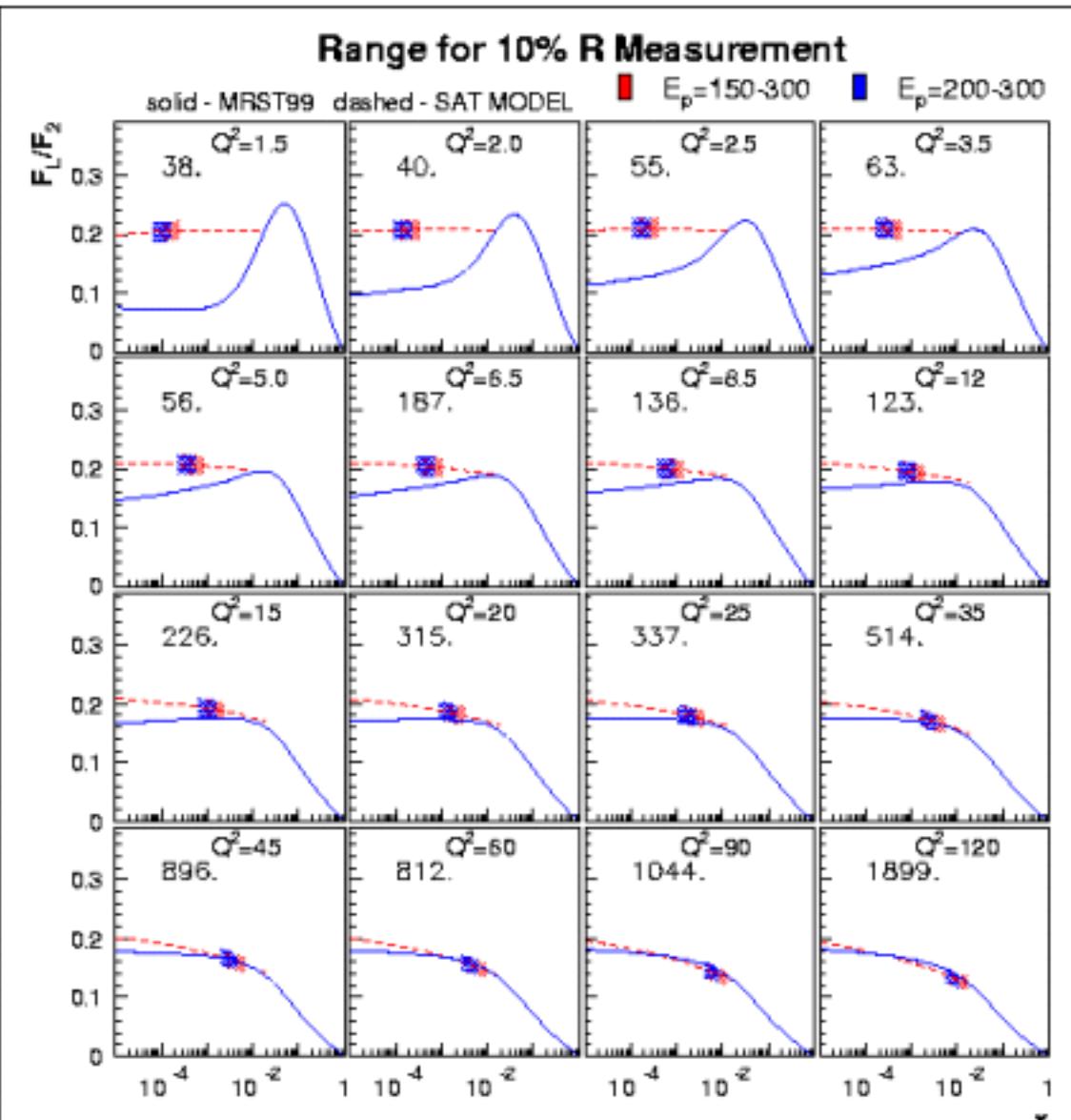
$$d^2\sigma/dxdQ^2 = 2\pi\alpha^2/xQ^4 [(1+(1-y)^2)F_2(x,Q^2) - y^2F_L(x,Q^2)]$$

Fix x , Q^2 . Use different beam energies to vary y . Critical issue: e/ π separation

F_L can be measured precisely in the region of maximum interest. This will be a strong test of our understanding of QCD radiation.



EIC kinematics



Summary

- Existing data (F_2 fits, forward jets,...) show limitations of pQCD calculations. Transition region observed.
- Exciting theoretical developments over the past few years. We are approaching a much deeper understanding of the high energy limit of QCD.
 - ⇒ Measure with more precision, over wider kinematical range, to see where/how breakdown takes place (high rapidities, high-t exclusive processes, expanded W , M_X range for diffraction, full coverage of transition region)
 - ⇒ Precision F_L measurement: key observable for pinning down pQCD. Large differences in predictions at LO, NLO, NNLO, dipole model.
 - ⇒ eD, eA measurements to probe high density gluon state, parton densities for nuclei.
- Additional benefits: parton densities for particle, astroparticle and nuclear high energy physics experiments. Crucial for cross section calculations.