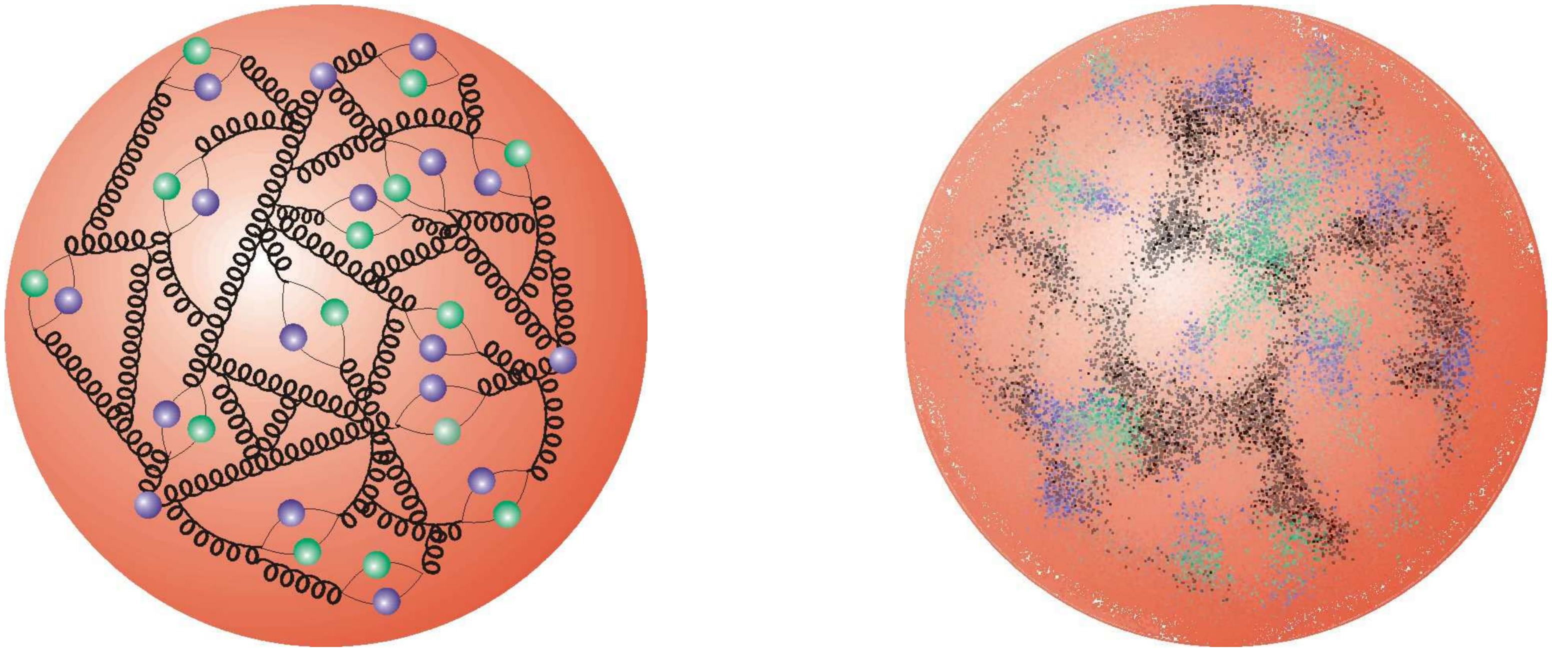
Inclusive Measurements at low Q^2

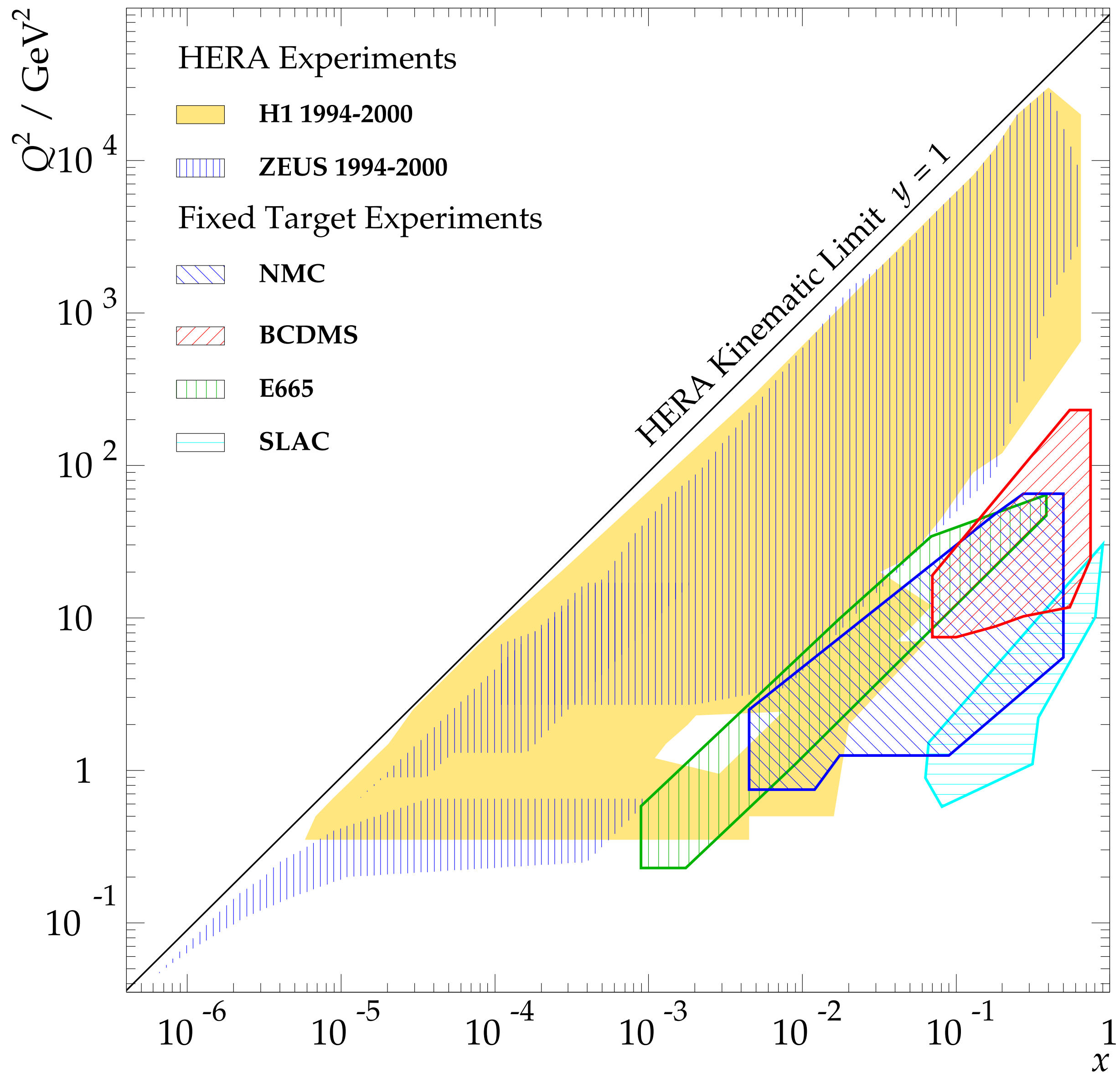
- Introduction
- Low x dynamics
- Soft QCD region
- Experimental techniques
- F_L determination
- Summary



Victor Lendermann
KIP, Universität Heidelberg

New Trends in HERA Physics
Ringberg Castle, 02–07.10.2005

Q^2 Determines QCD Regime



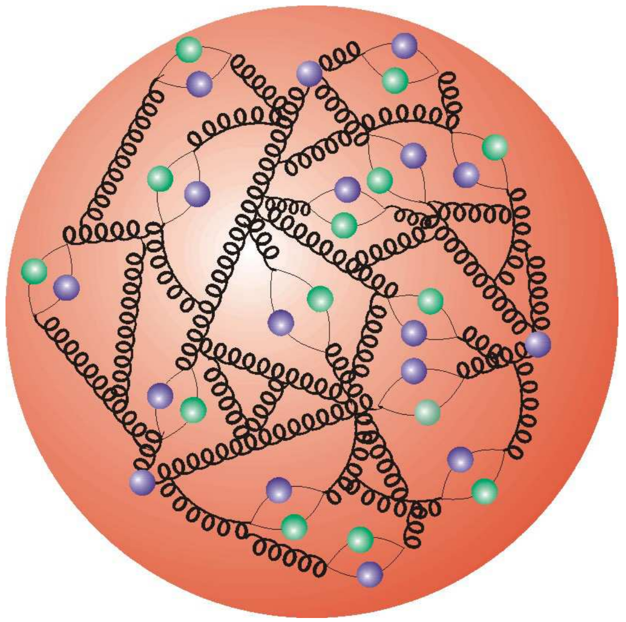
→ ***High Q^2***

asymptotic freedom

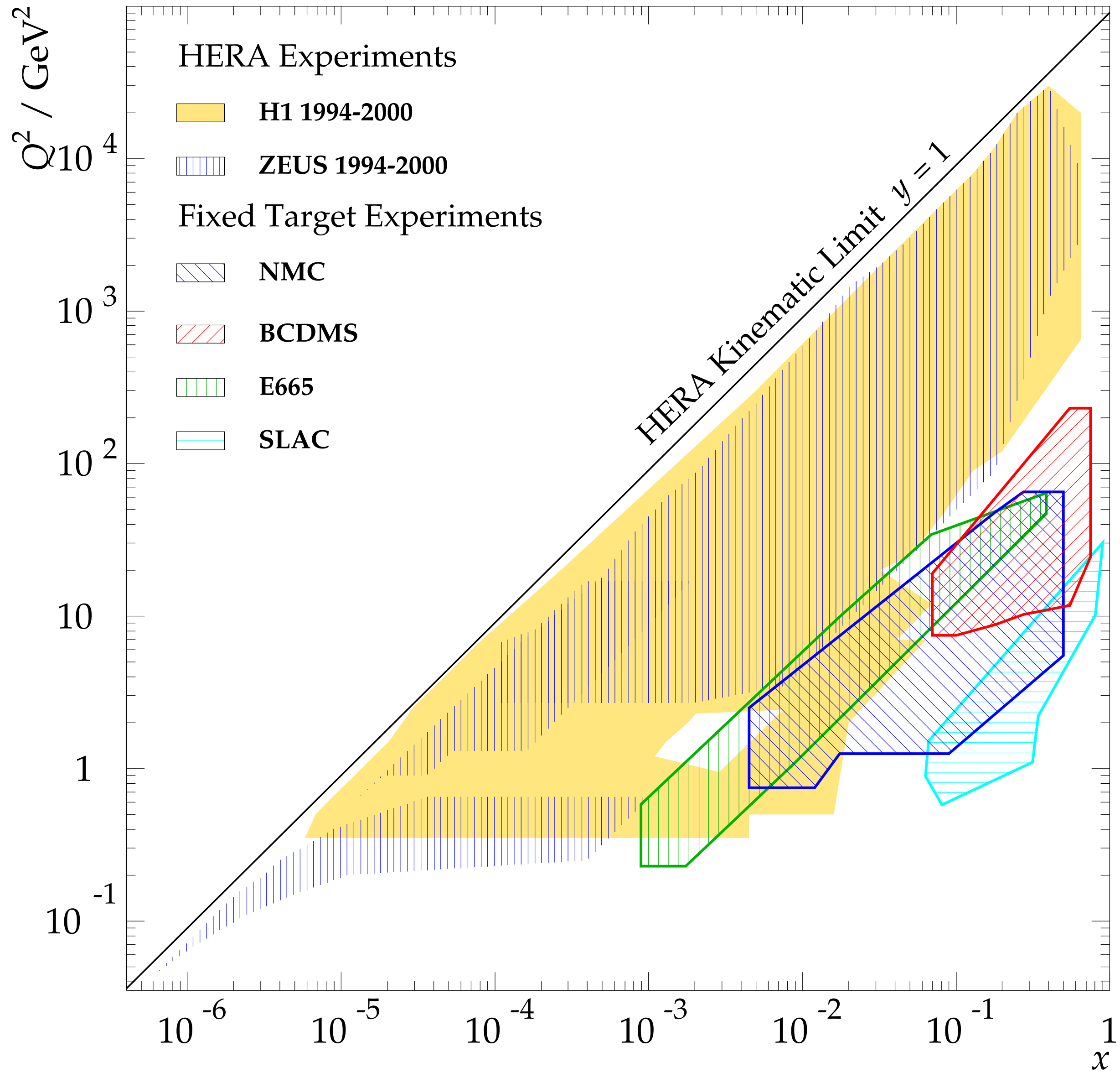
perturbative QCD (DGLAP)

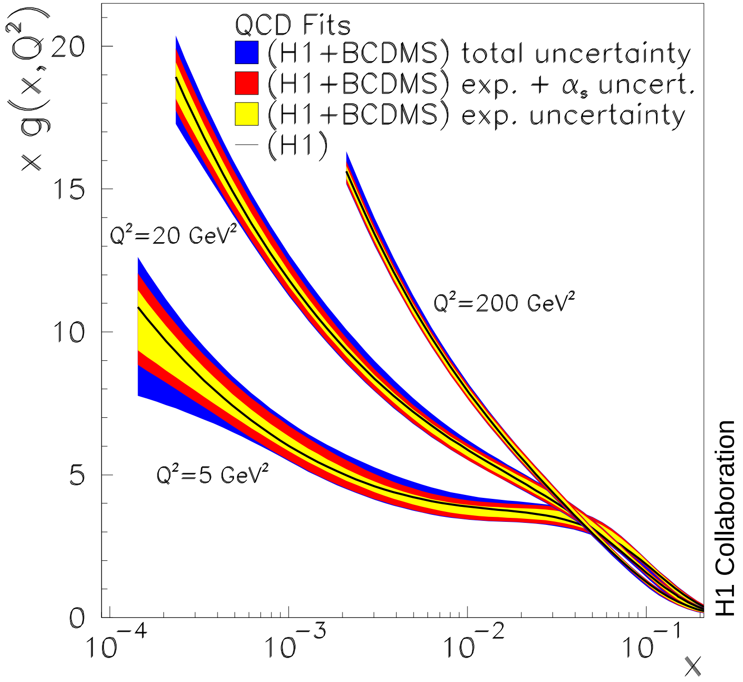
el.-weak effects

➥ *talks by K. Wichmann and J. Meyer*



Q^2 Determines QCD Regime



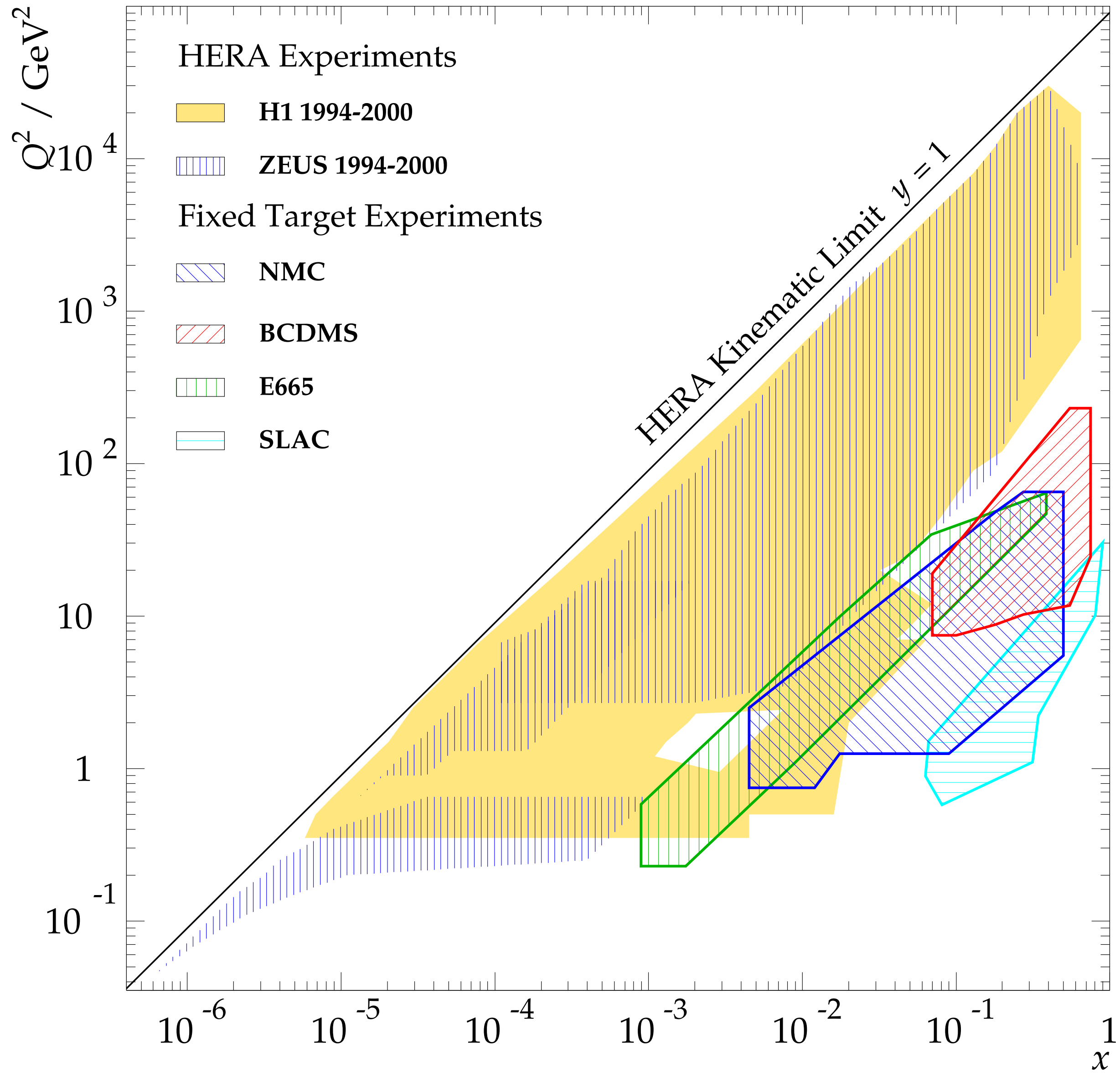


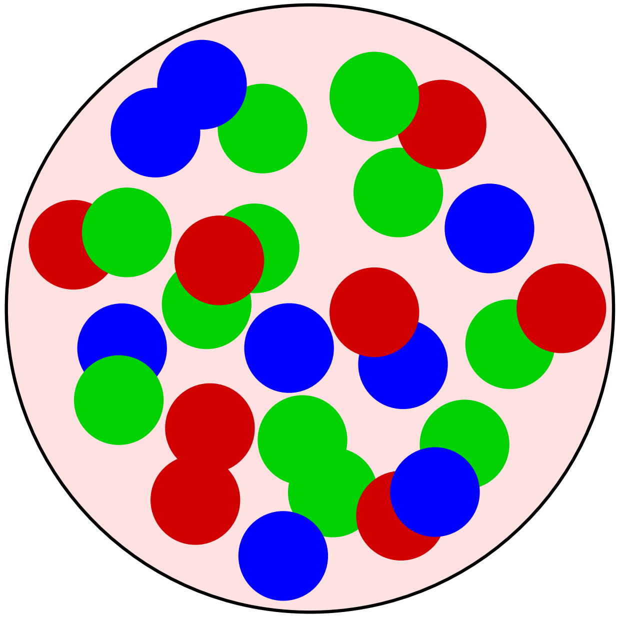
$\longrightarrow$ *Low* $Q^2 \Longrightarrow$ *Low* x

strongly rising gluon

testing validitity of DGLAP

Q^2 Determines QCD Regime





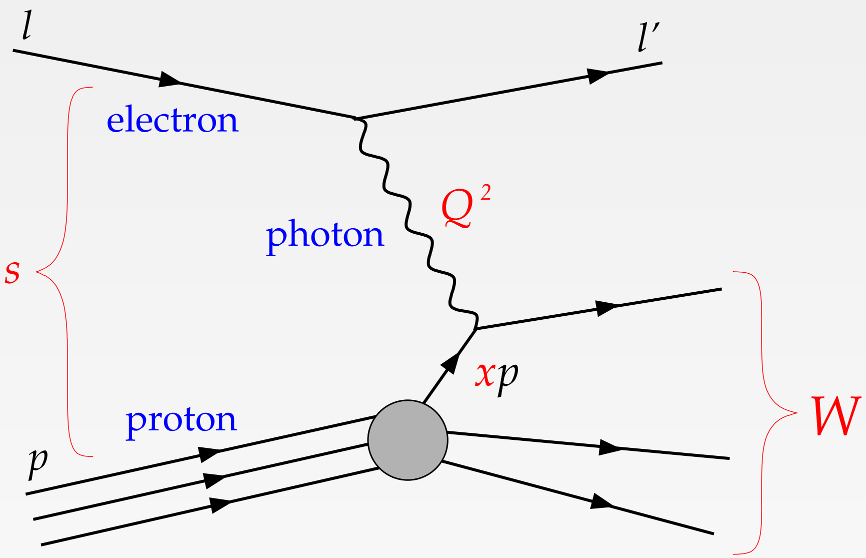
→ *Low* Q^2 $\Longrightarrow$ *Low* x

dense gluon states

search for saturation

Inclusive DIS at Low Q^2

photon exchange



boson virtuality = resolution scale $Q^2 = -(l - l')^2$

fractional momentum of struck quark $x = \dfrac{Q^2}{2p \cdot q}$

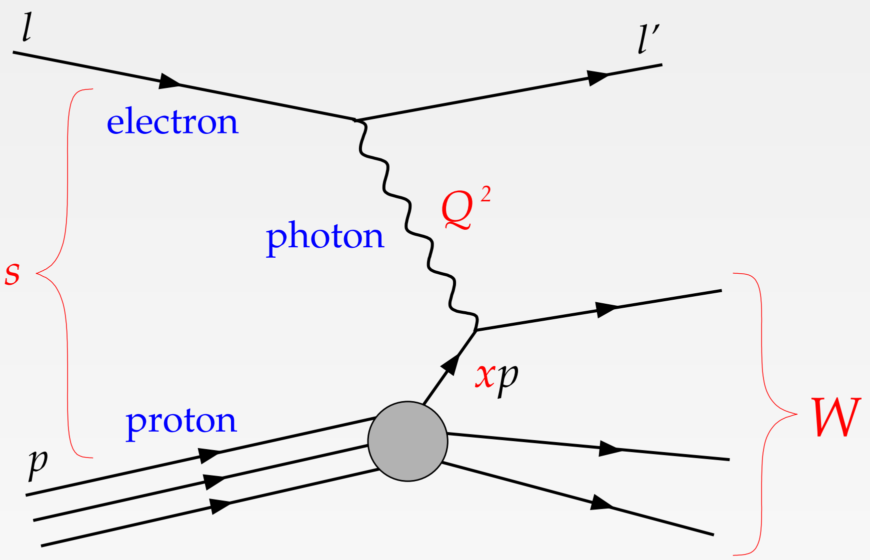
inelasticity $y = \dfrac{p \cdot q}{p \cdot l} \approx \dfrac{Q^2}{xs}$

boson–proton cms energy $W = \sqrt{ys - Q^2 + m_p^2}$

low $x \Longleftrightarrow$ high y, high W

Inclusive DIS at Low Q^2

photon exchange



boson virtuality = resolution scale $\quad Q^2 = -(l - l')^2$

fractional momentum of struck quark $\quad x = \dfrac{Q^2}{2p \cdot q}$

inelasticity $\quad y = \dfrac{p \cdot q}{p \cdot l} \approx \dfrac{Q^2}{xs}$

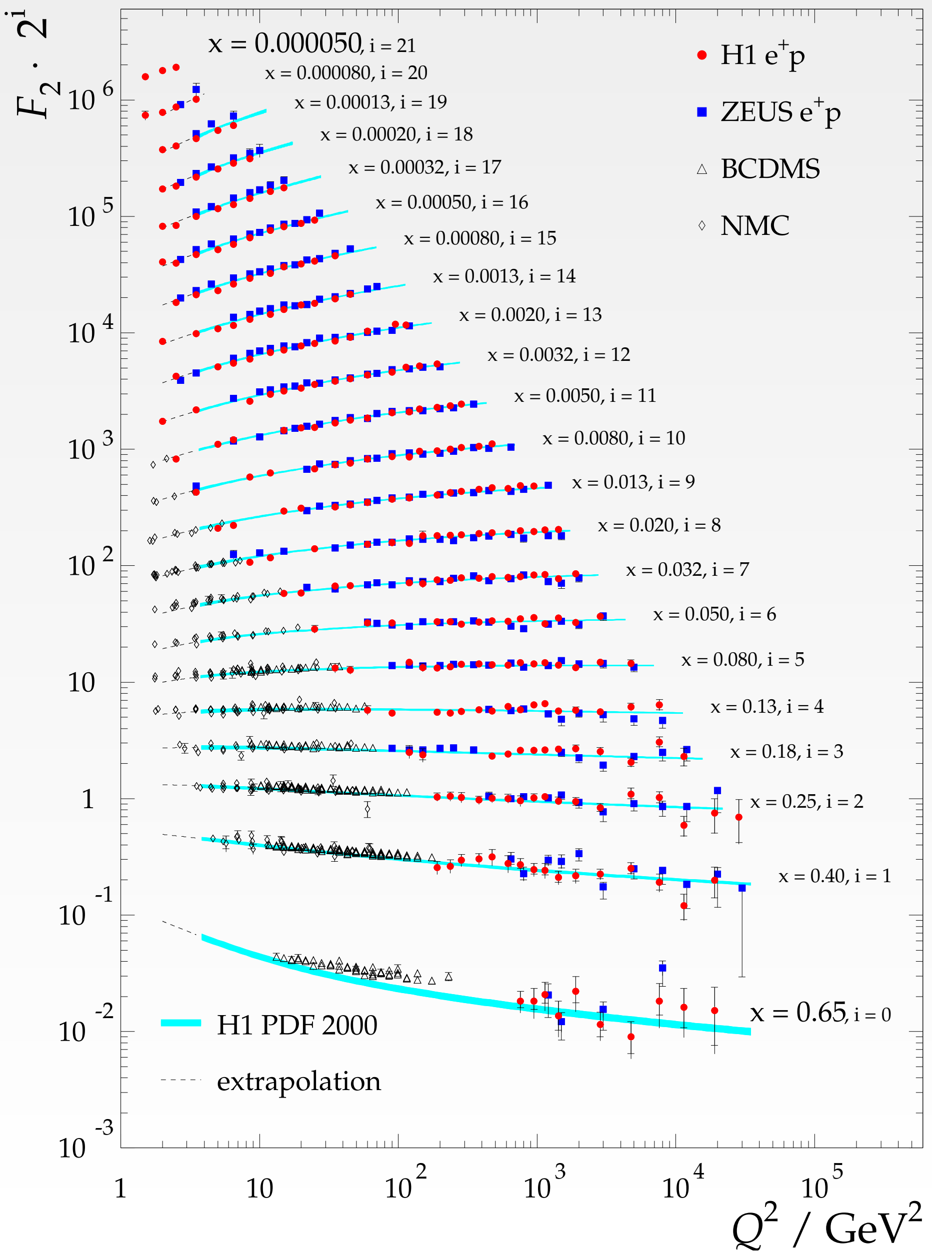
boson–proton cms energy $\quad W = \sqrt{ys - Q^2 + m_p^2}$

Cross section: $\quad \dfrac{d^2\sigma}{dx\,dQ^2} = \dfrac{2\pi\alpha^2}{Q^4 x}\left\{Y_+ F_2(x,Q^2) - \underset{\text{at high } y}{y^2 F_L(x,Q^2)}\right\} \qquad Y_+ = 1 + (1-y)^2$

Reduced cross section: $\quad \sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$

Only in pQCD: $\quad F_2^{\mathrm{em}}(x,Q^2) = x \sum_i e_i^2 [q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$

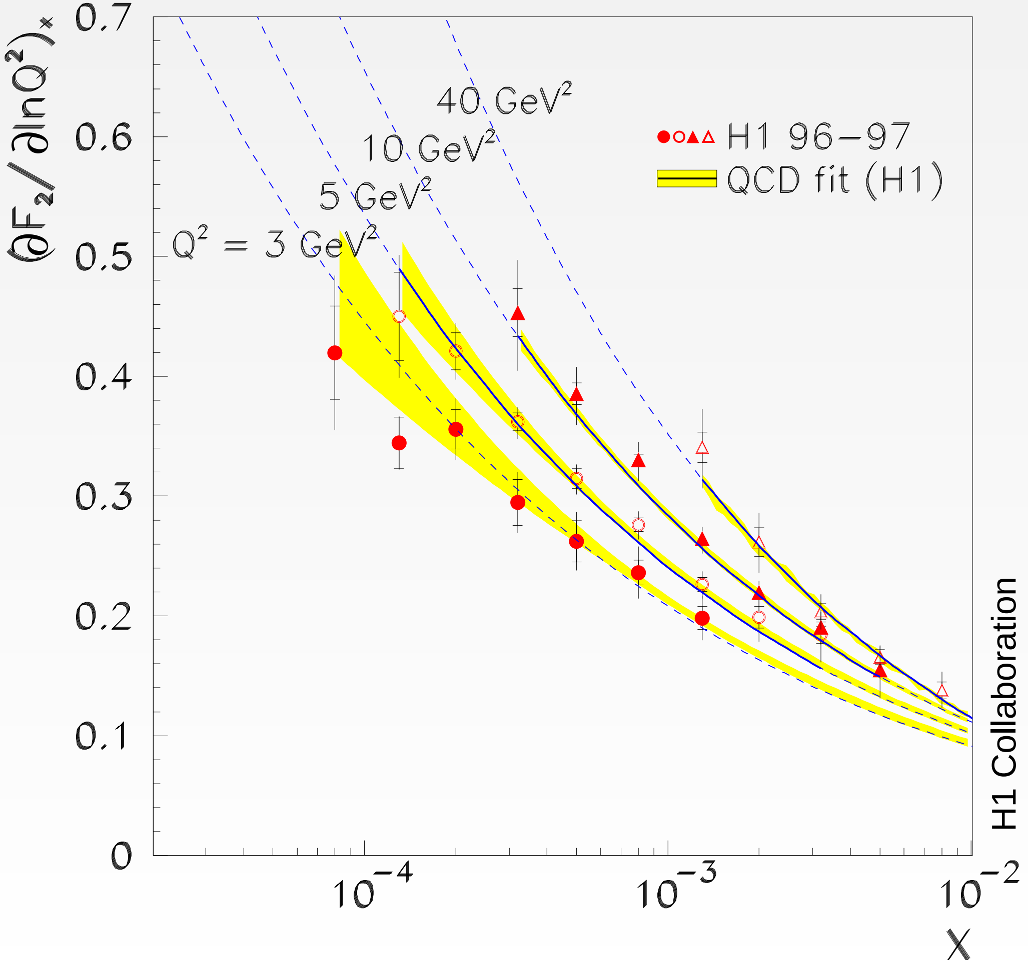
F_2 Measurements in pQCD Region



- Scaling violations are well described by NLO DGLAP QCD fits
- No evidence for new dynamics at low x in inclusive data
- Precision: 2 – 3% in bulk region

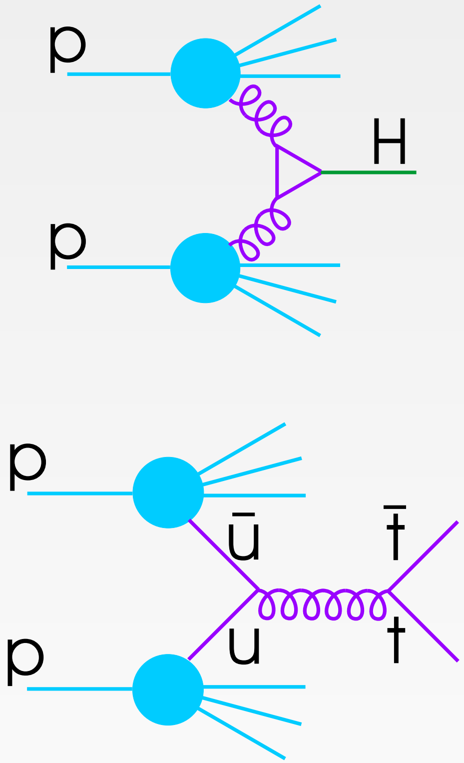
Scaling Violations at Low x

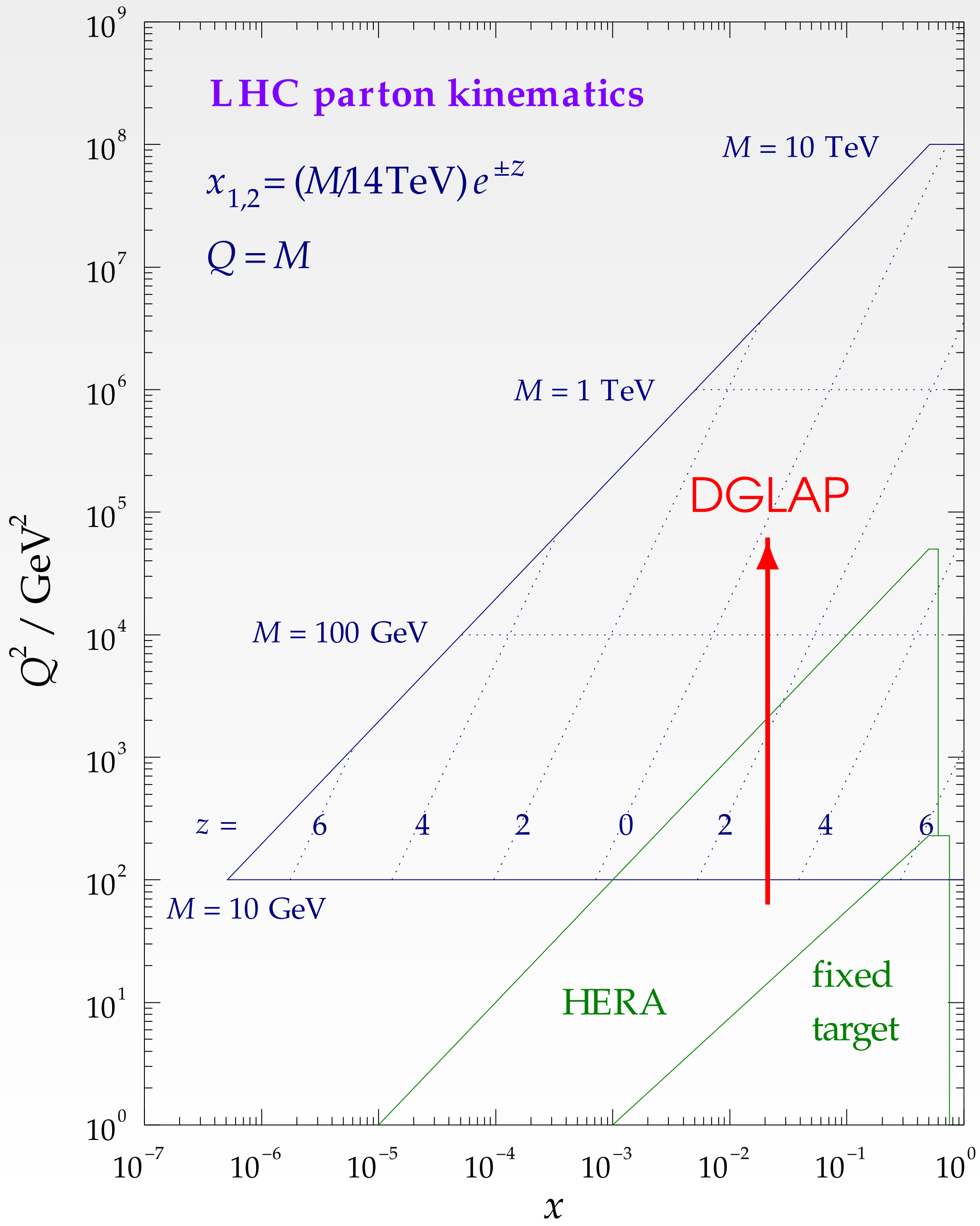
Local derivatives $$\left.\frac{\partial F_2}{\partial \ln Q^2}\right|_x \propto \alpha_s(Q^2)xg(x,Q^2)$$



- Consistent with DGLAP QCD fits for $Q^2 \gtrsim 3\,\mathrm{GeV}^2$
- No sign of new dynamics
- More precision desirable

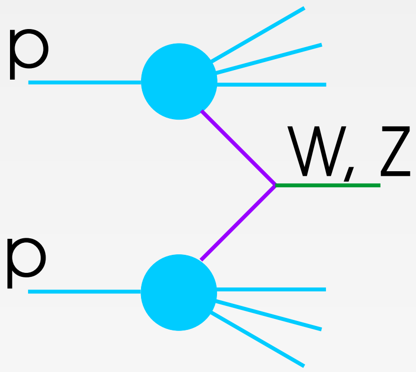
PDFs for LHC



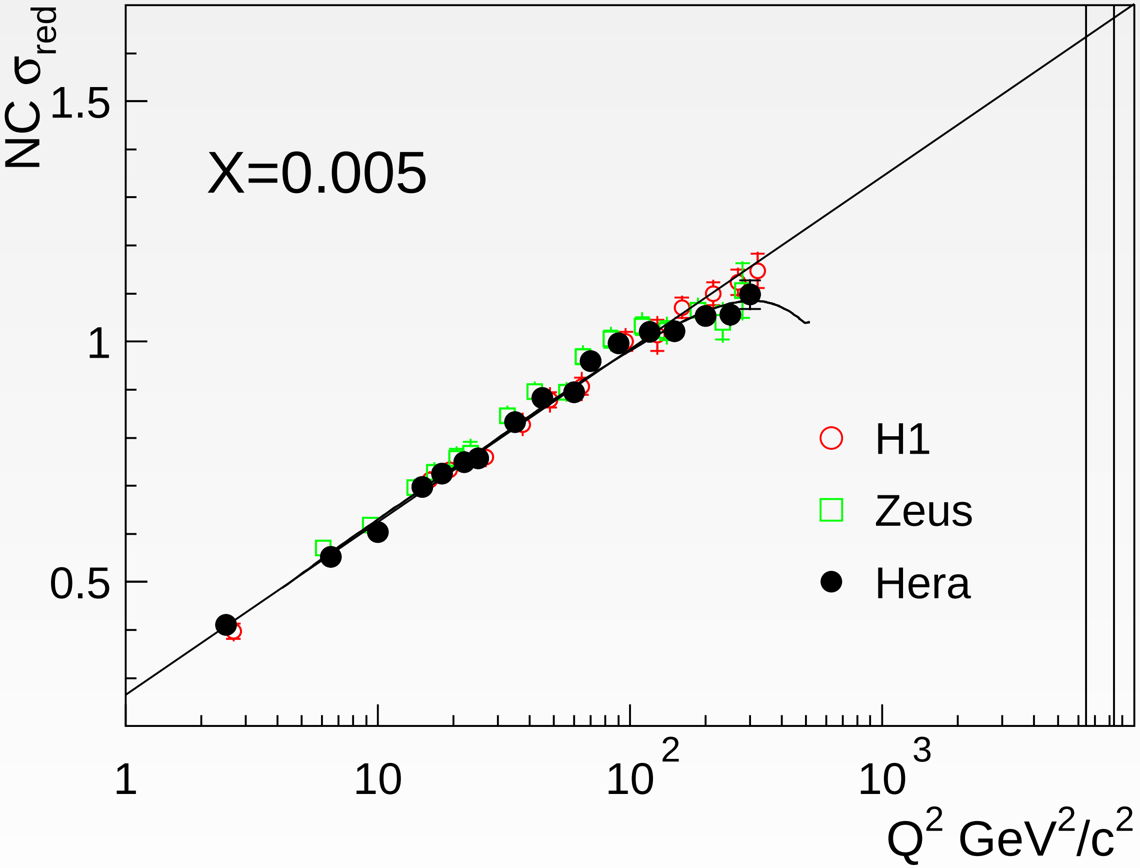


Precise quark and gluon densities are required in the whole x range to understand signal and background

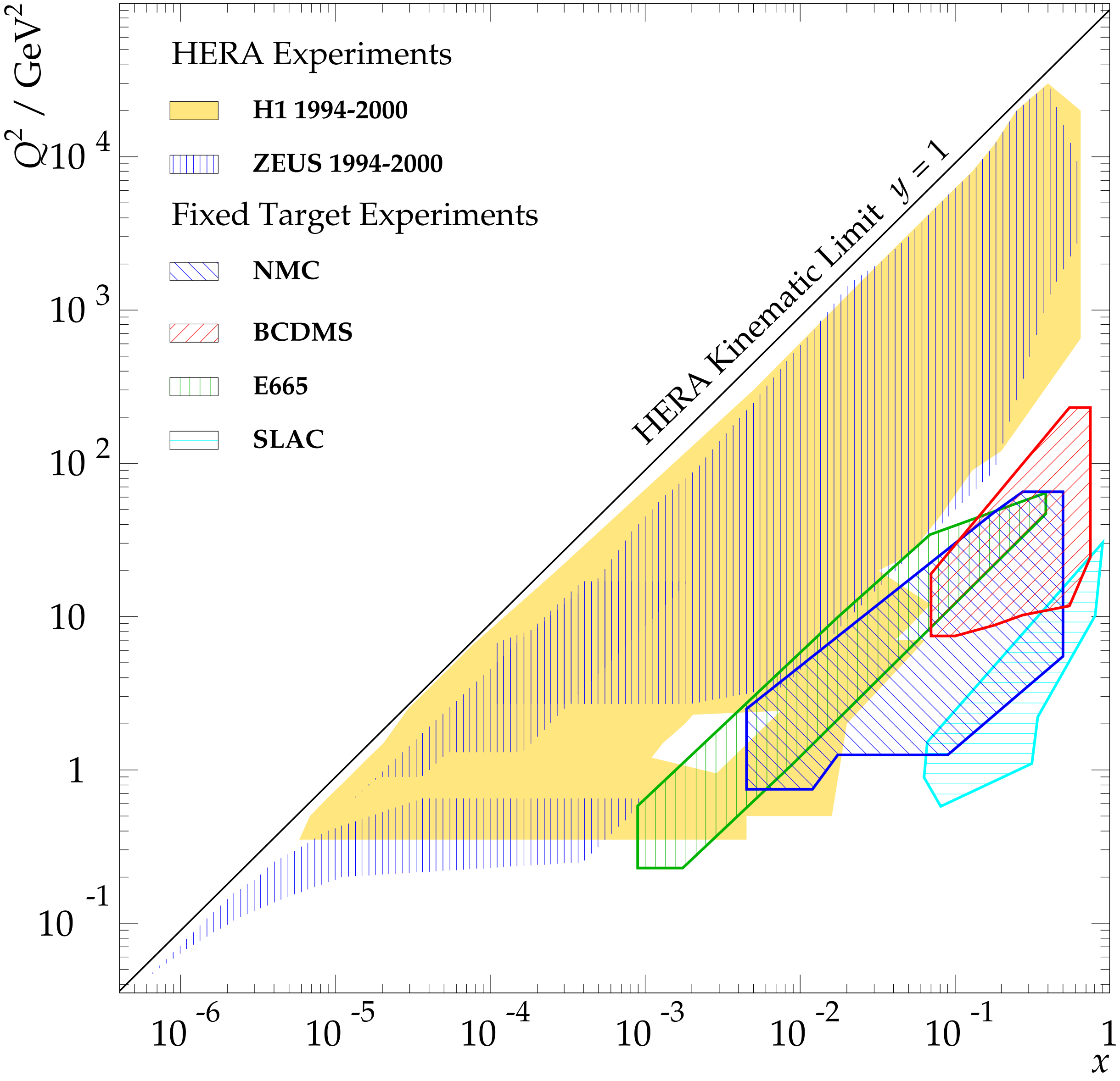
PDFs for LHC

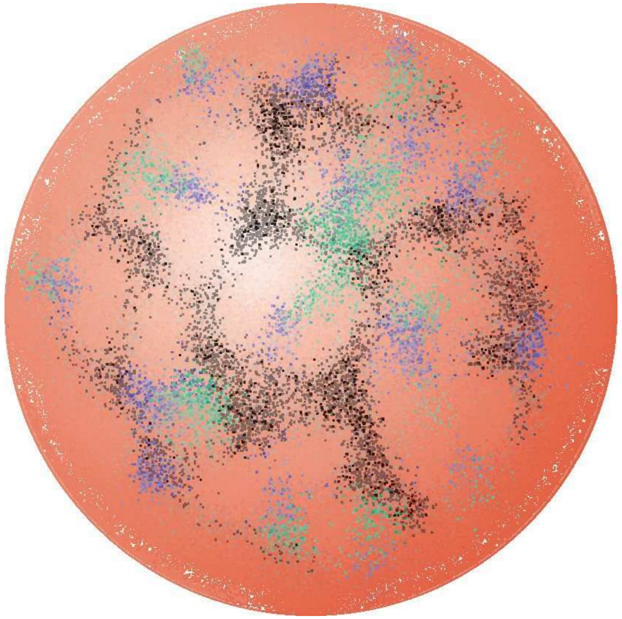


One can use W and Z production as a luminosity monitor



Q^2 Determines QCD Regime





⟶ *Low* Q^2

$\alpha_s(Q^2)$ becomes large $\Longrightarrow$

quark confinment

transition from quarks to hadrons

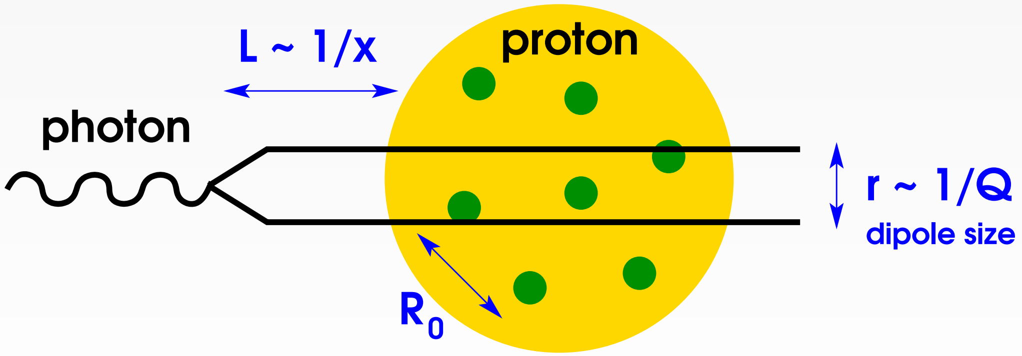
⟶ *phenomenological models*

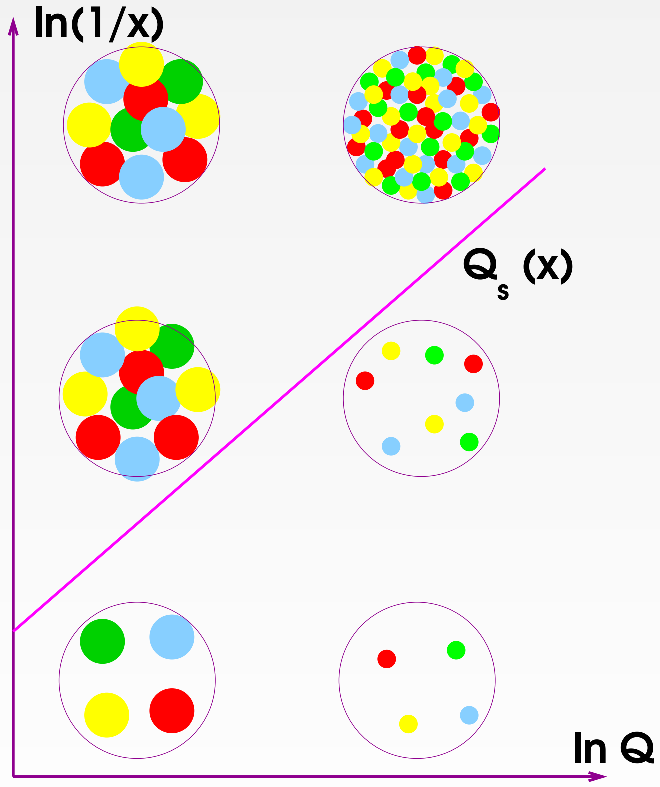
Models for Low Q^2 Region

- Inspired by Regge approach — Pomeron + Reggeon exchange
  Several models available

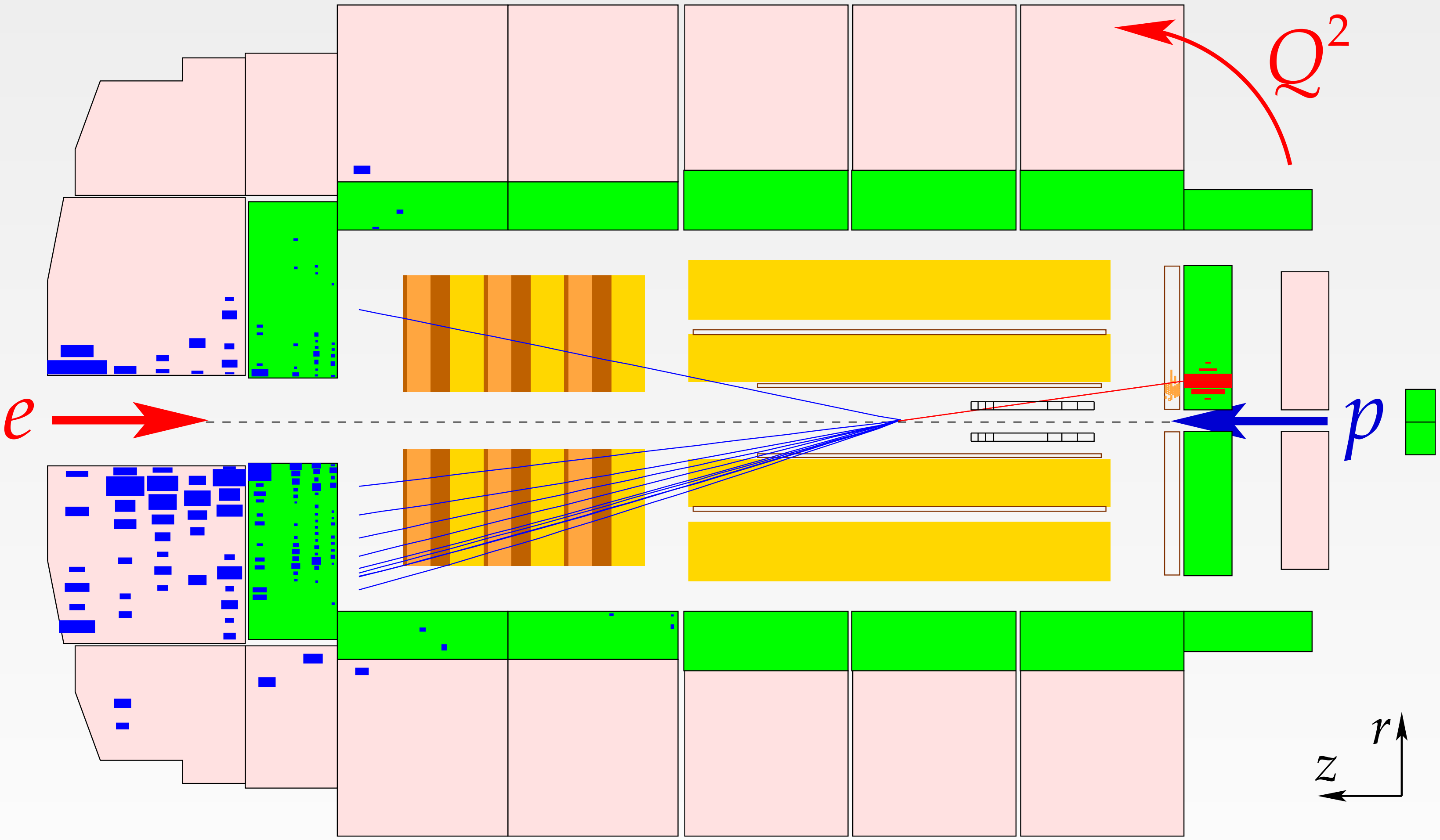
- Dipole models for low x region

  Example: saturation model (Golec-Biernat, Wüsthoff)
  using $R_0(x)$ – x-dependent saturation scale
  = average gluon distance





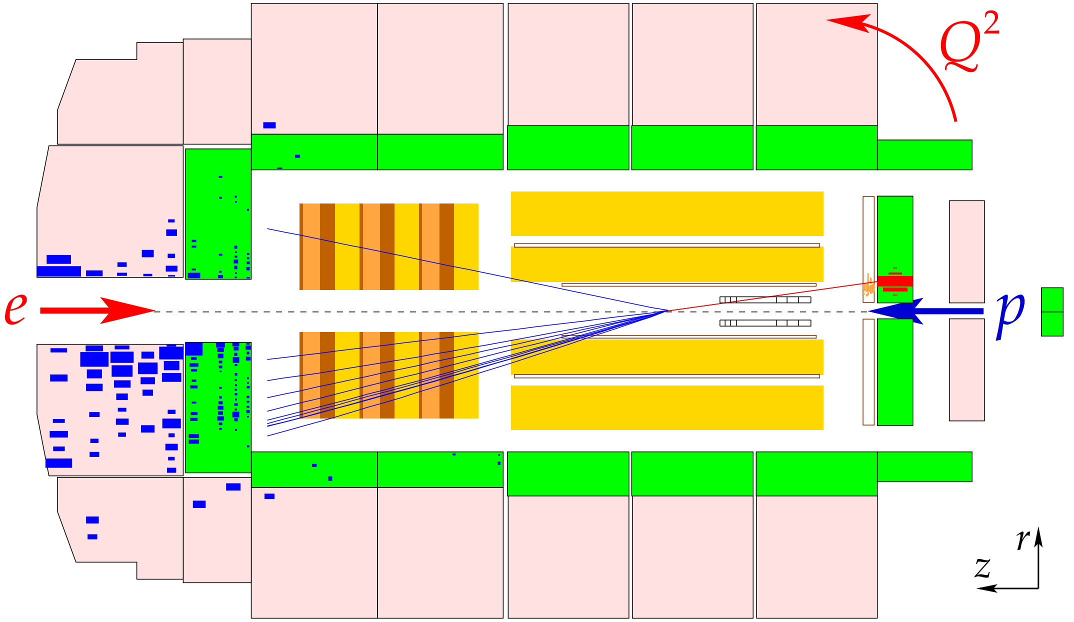
Low Q^2 DIS Event



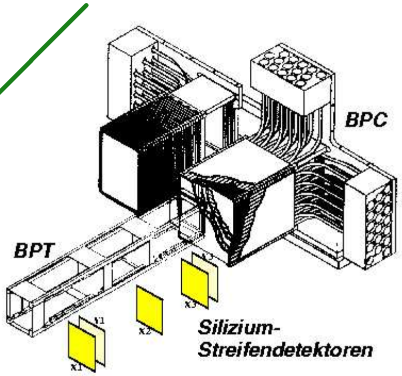
$Q^2 \sim p_{t,e}^2$ $\Longrightarrow$ *experimental challenge*

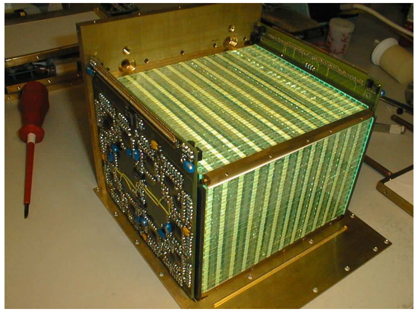
For main detector: $Q^2 \gtrsim 2\,\mathrm{GeV}^2$

Experimental Techniques at Low Q^2

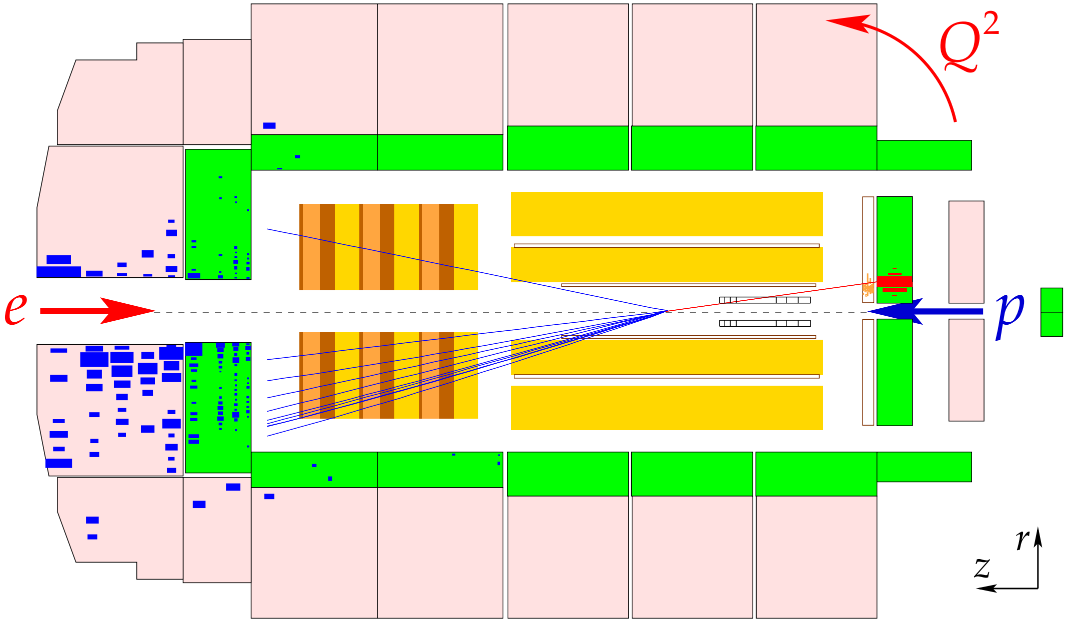


1) Very low Q^2 devices

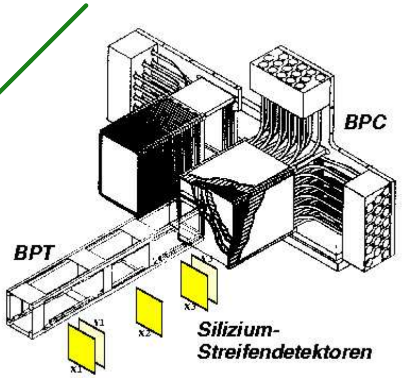


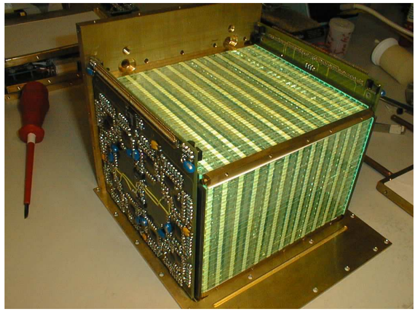


Experimental Techniques at Low Q^2



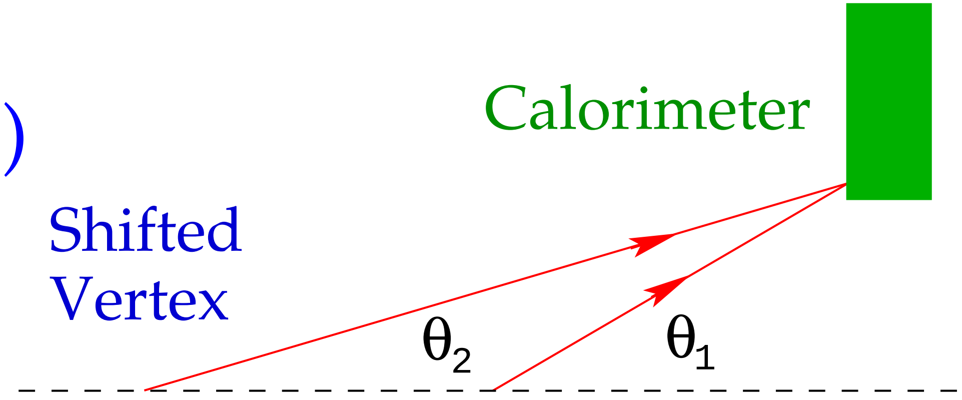
1) Very low Q^2 devices



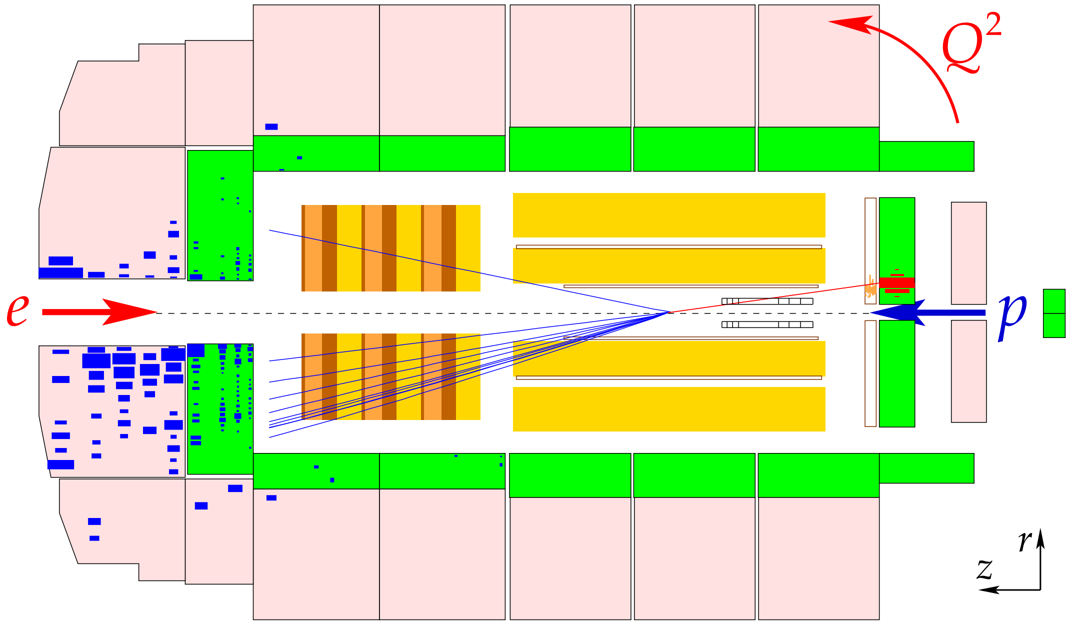


2)

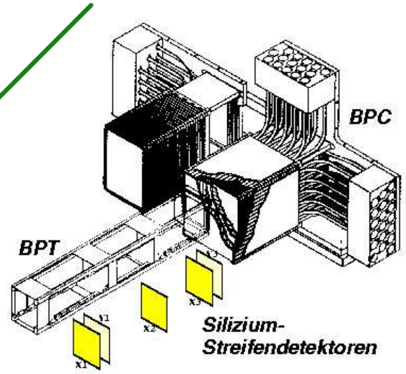
Shifted Vertex

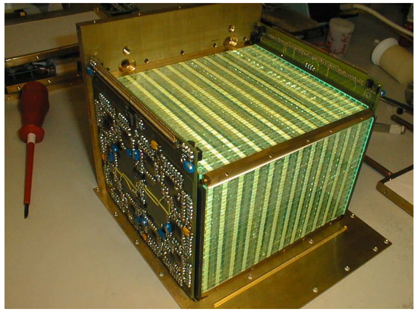


Experimental Techniques at Low Q^2



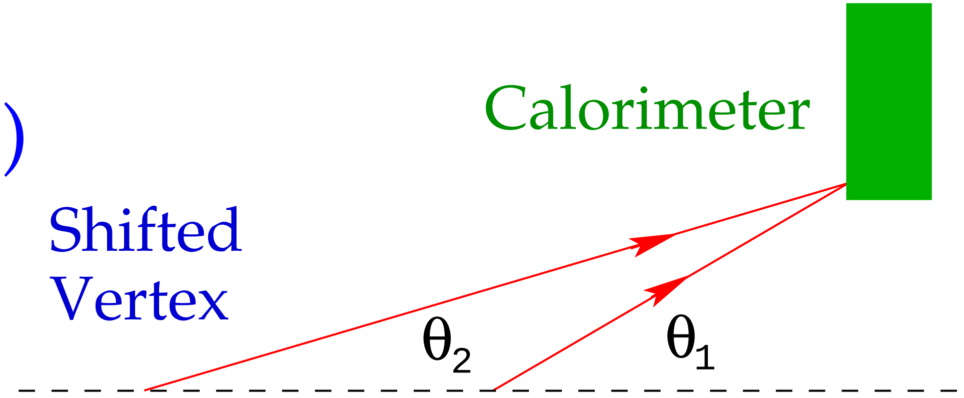
1) Very low Q^2 devices



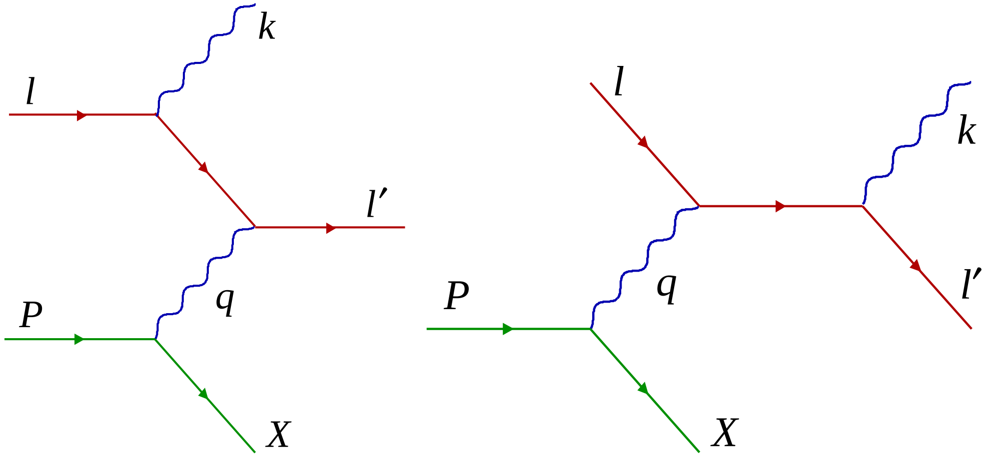


2)

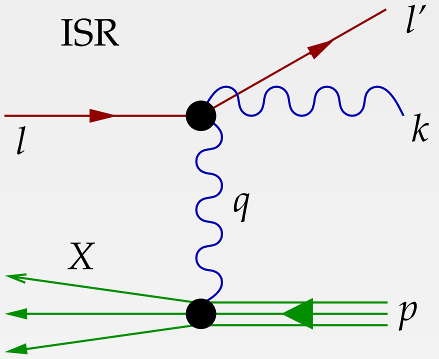
Shifted Vertex

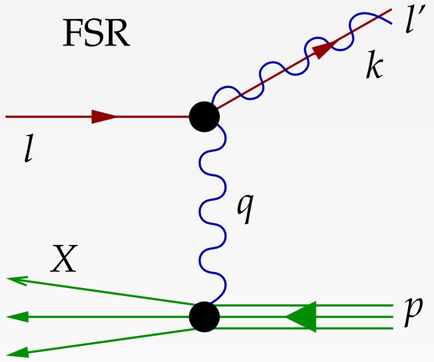


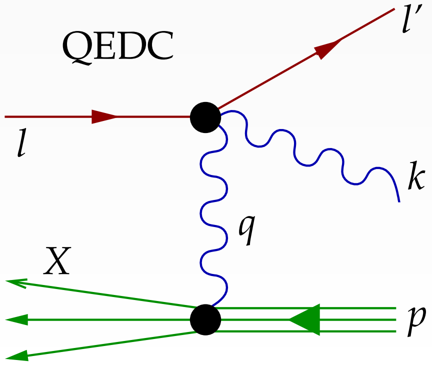
3) Radiative events



Photon Radiation from Lepton Line







$$q = l - l' - k$$

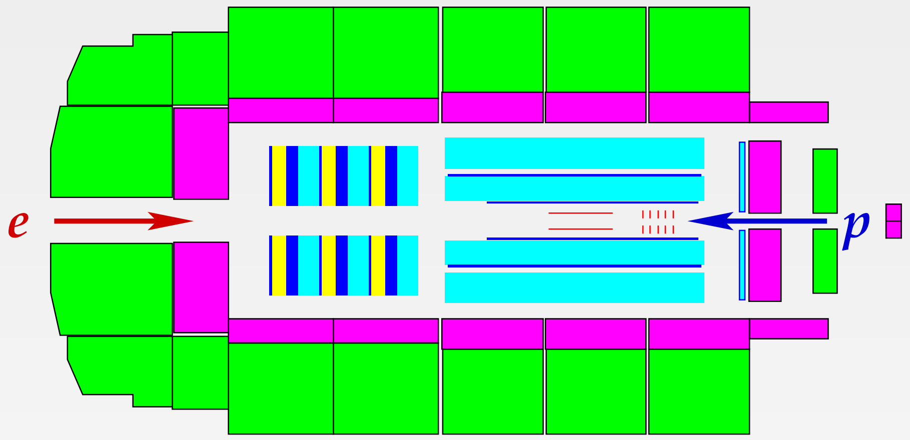
Modified kinematics

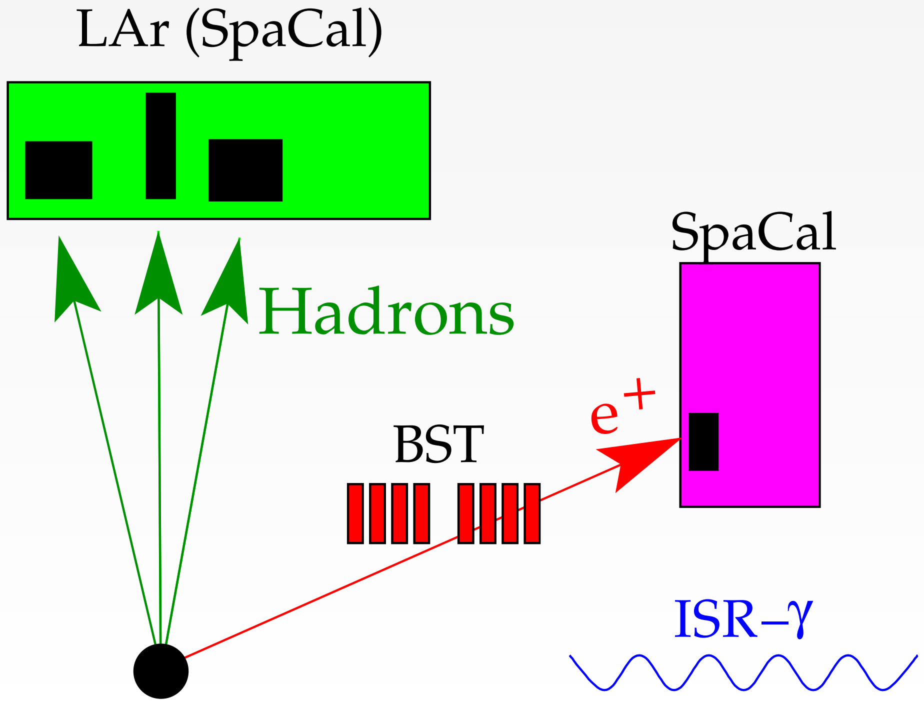
Access lower Q^2 and higher x

Distinct topologies:

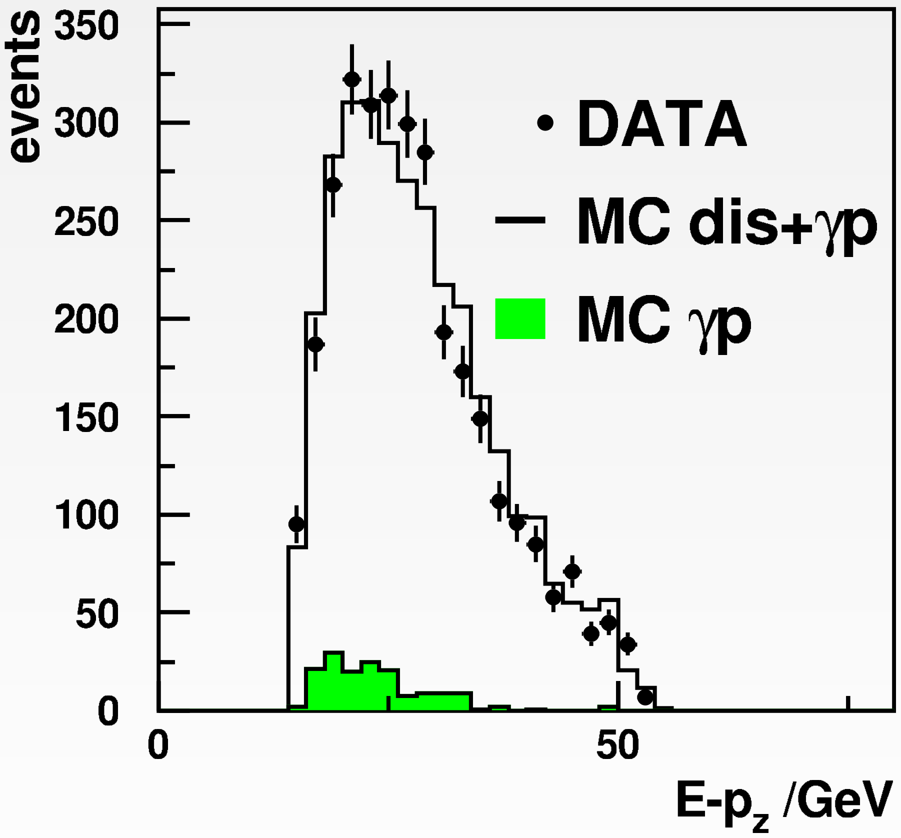
- Initial State Radiation (ISR) : $\vec{k} \parallel \vec{l}$
- Final State Radiation (FSR) : $\vec{k} \parallel \vec{l}'$
- QED Compton (QEDC) : $\vec{q} \parallel \vec{l}$

Untagged ISR Signature



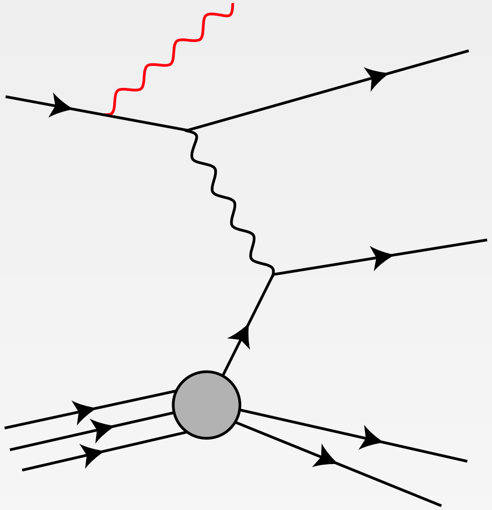


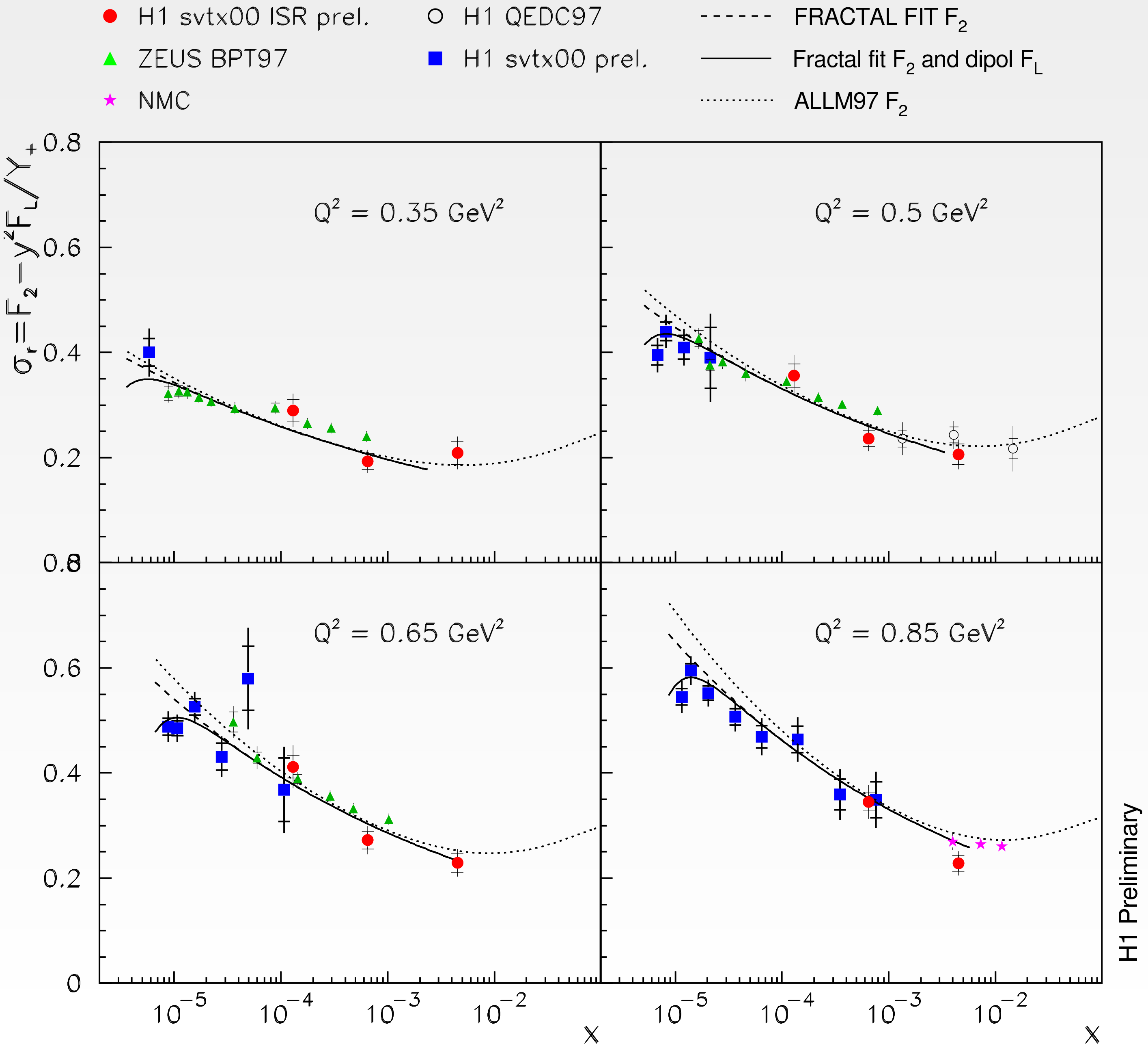
$$\sum (E - P_z)_i < 2E_{e-\mathrm{beam}}$$



γp *background rejected by BST*

F_2 in Shifted Vertex ISR



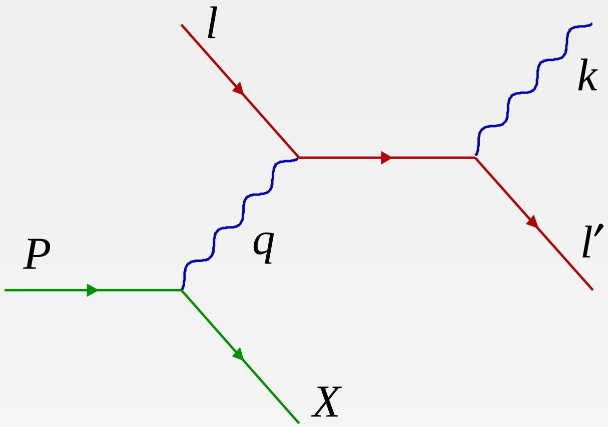


Equivalent to inclusive DIS at reduced s

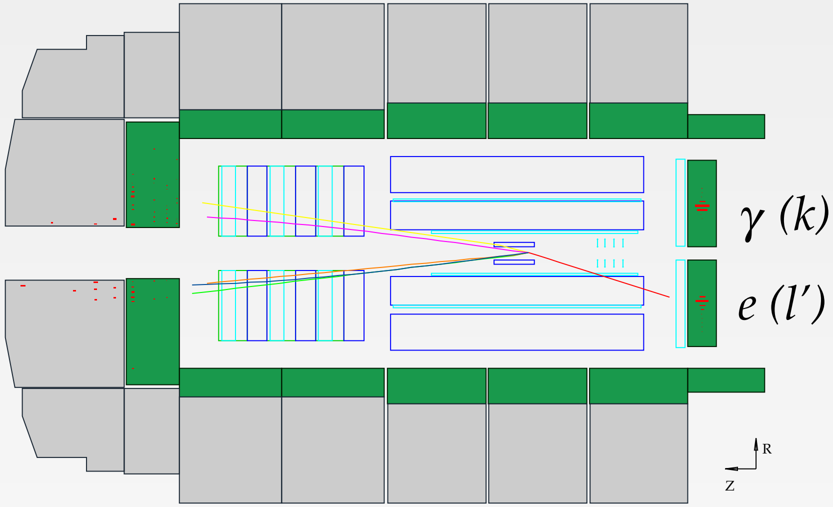
$$Q^2 = xys$$

Access higher x

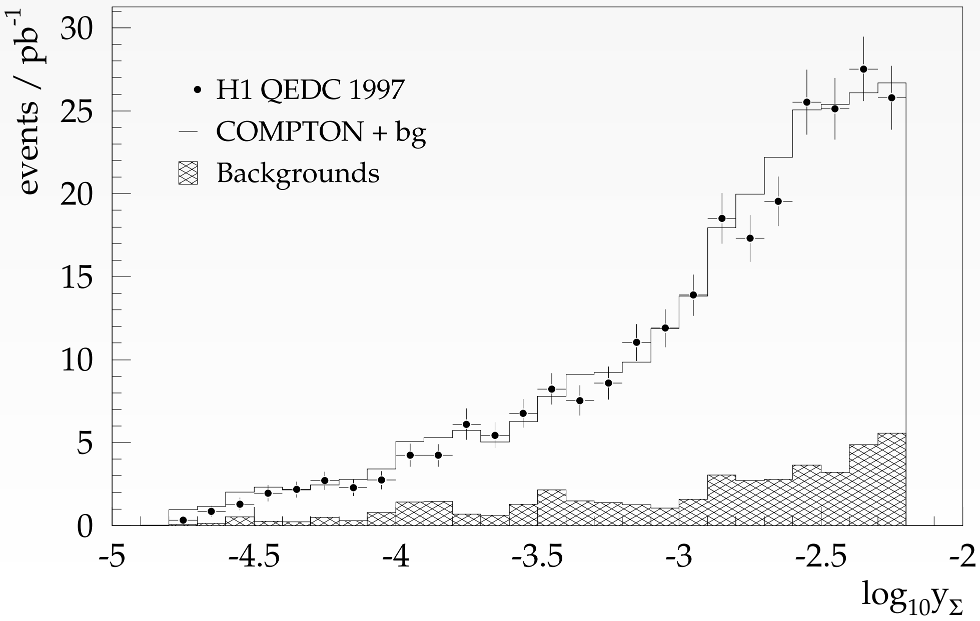
Inelastic QED Compton Events



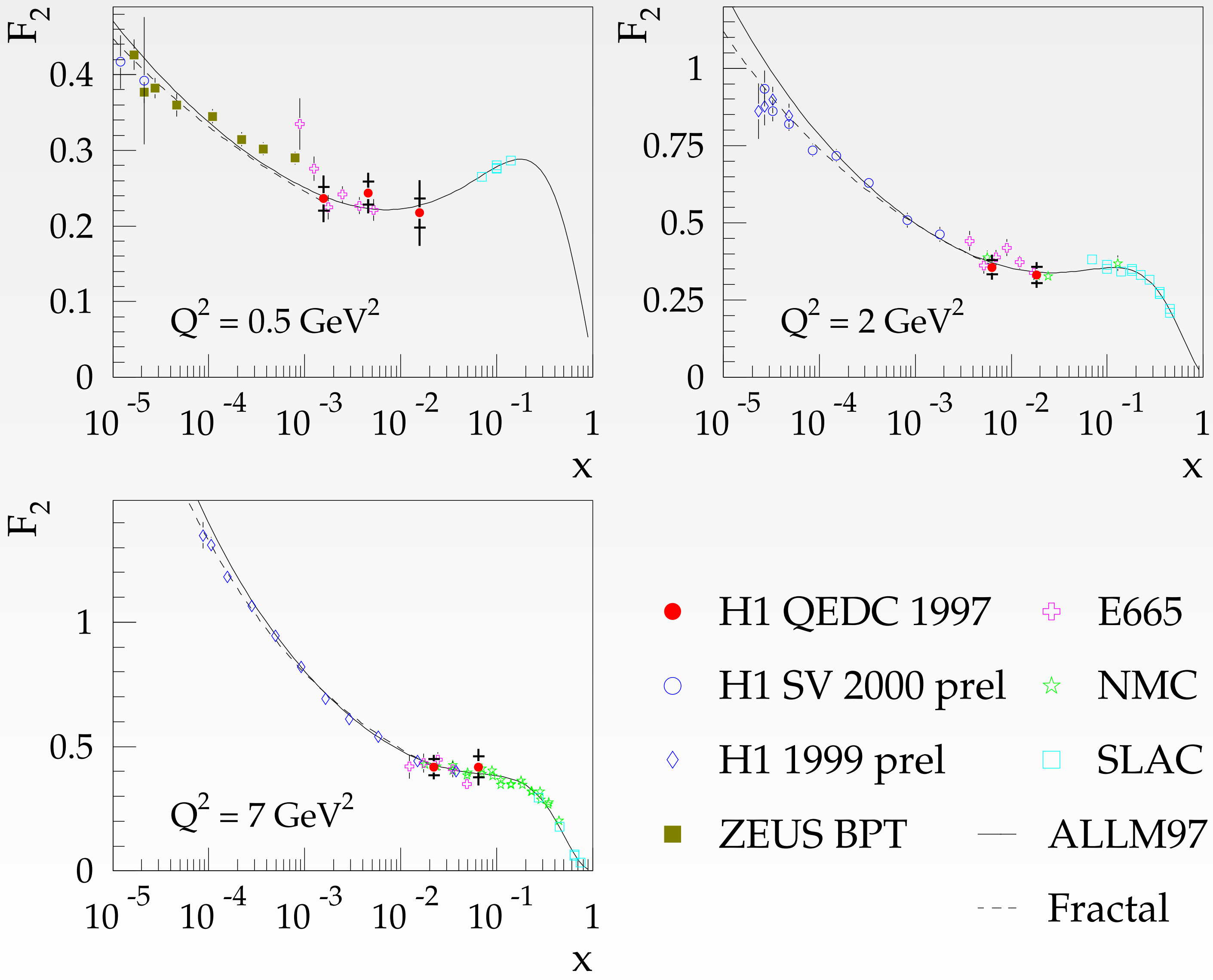
QEDC Event in H1 Detector



- DIS background at low x: π^0 fakes γ
- Medium – high x are measured
- Understanding of HFS at low W
  Use SOPHIA MC model



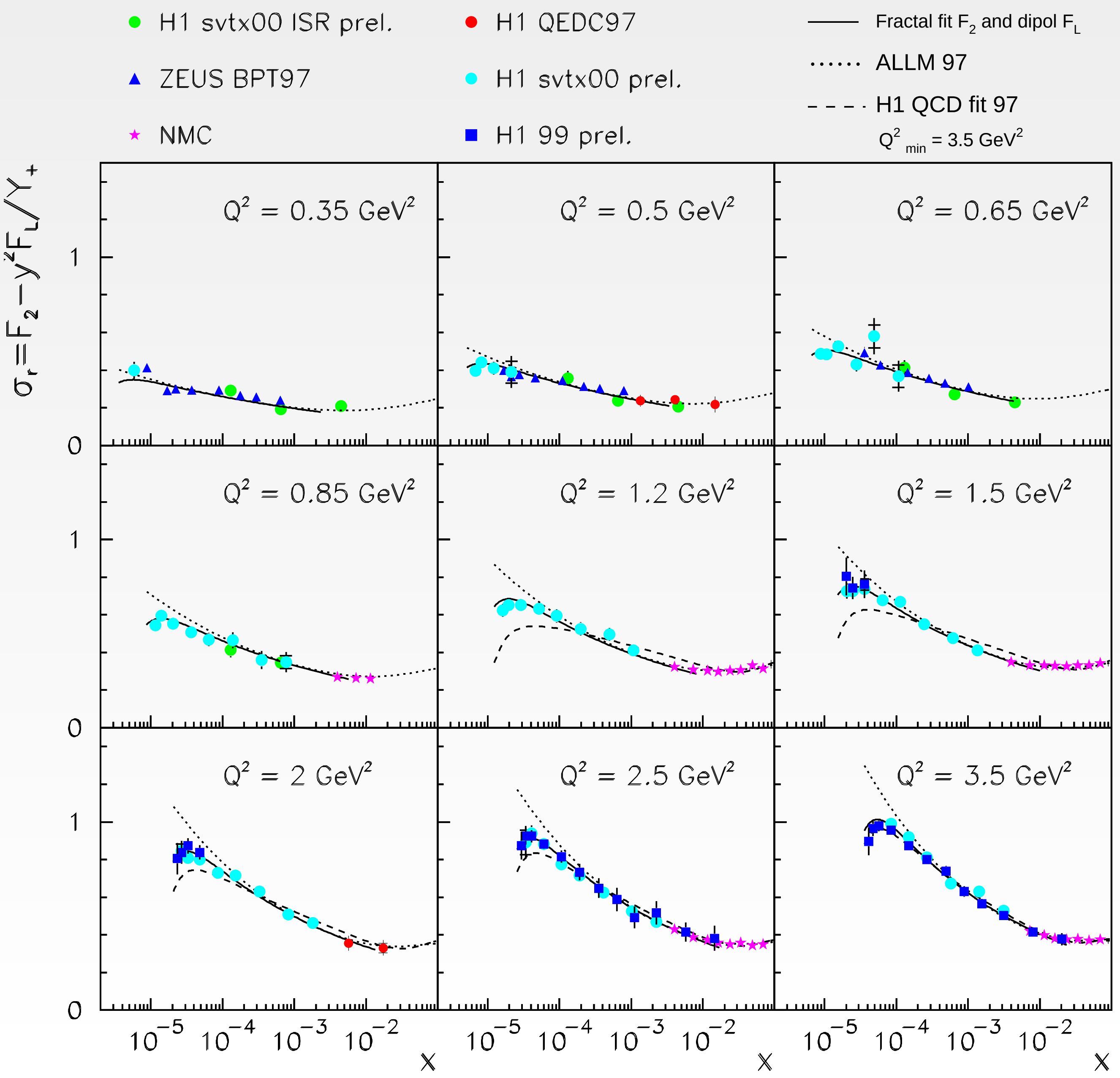
F_2 Measurement in QEDC by H1



Good agreement with fixed target experiments

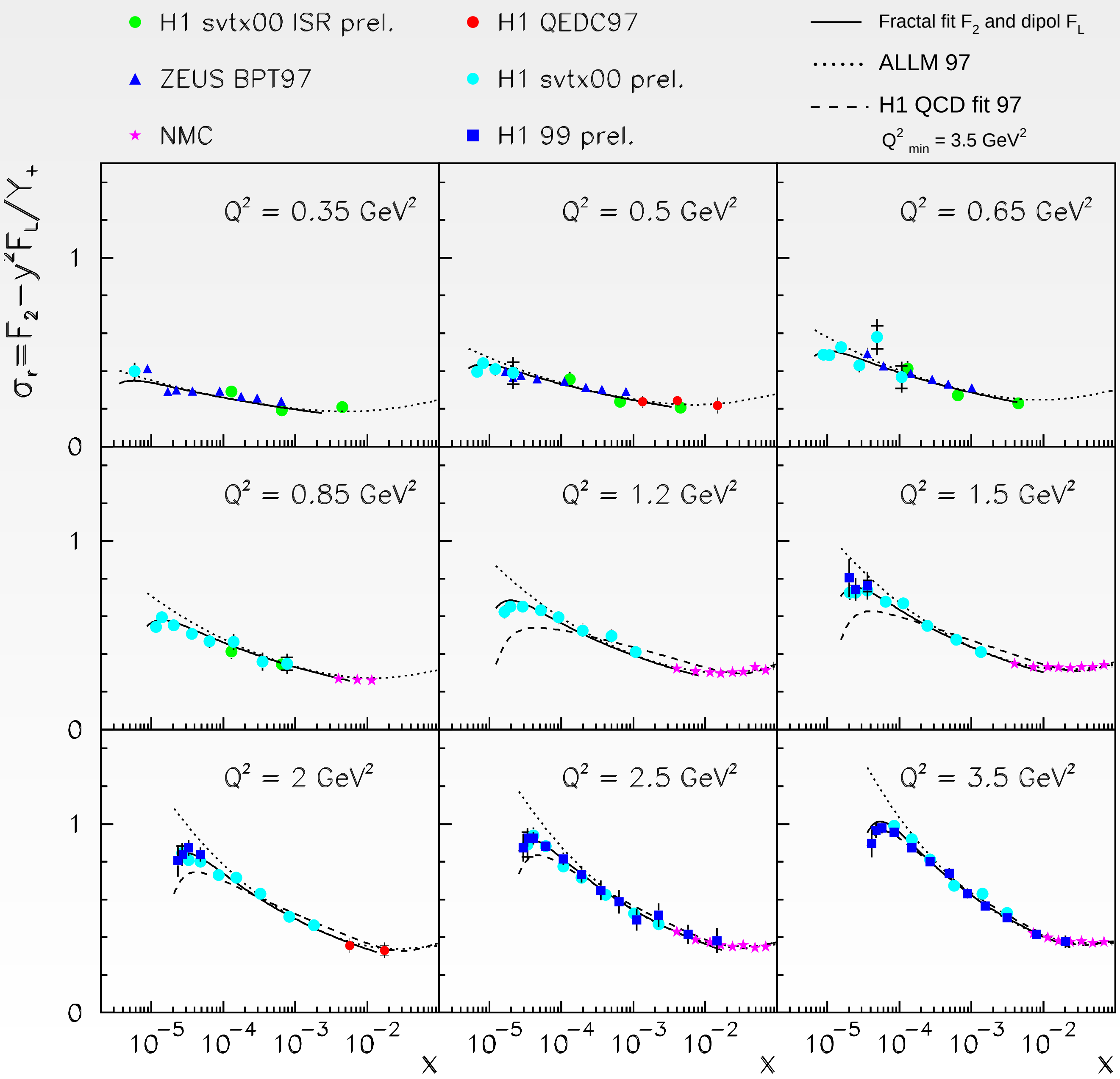
$\mathcal{L} = 9.25\,\mathrm{pb}^{-1}$ used

Current Results for Transition Region

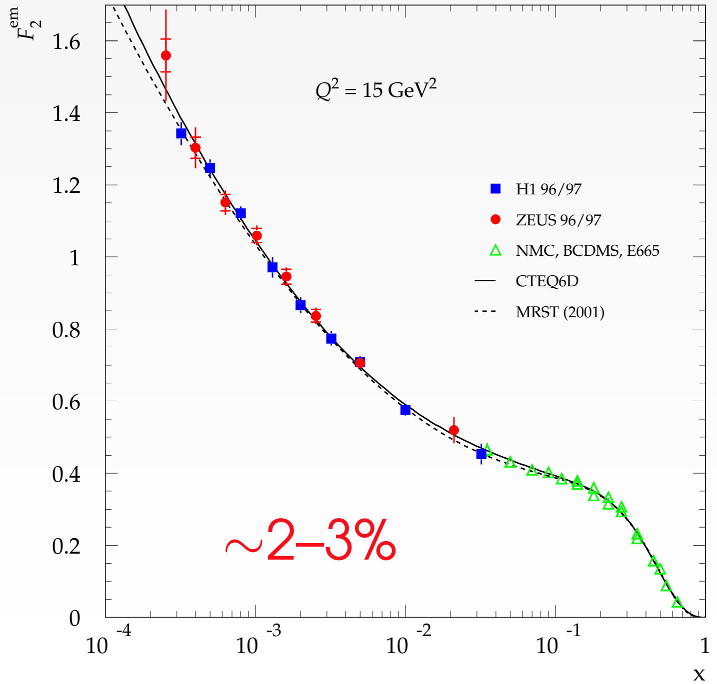


Precision ∼2–3%
reached for inclusive data

Current Results for Transition Region

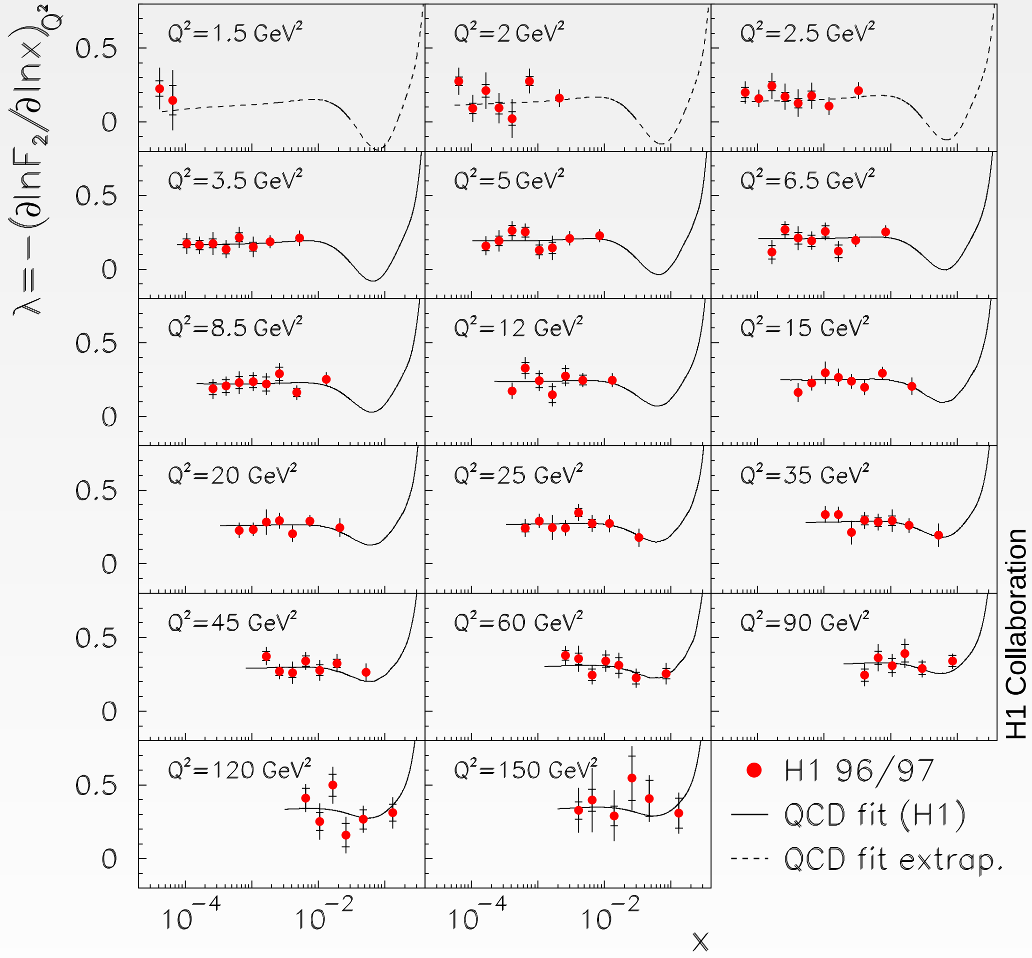


Precision ~2–3%
reached for inclusive data

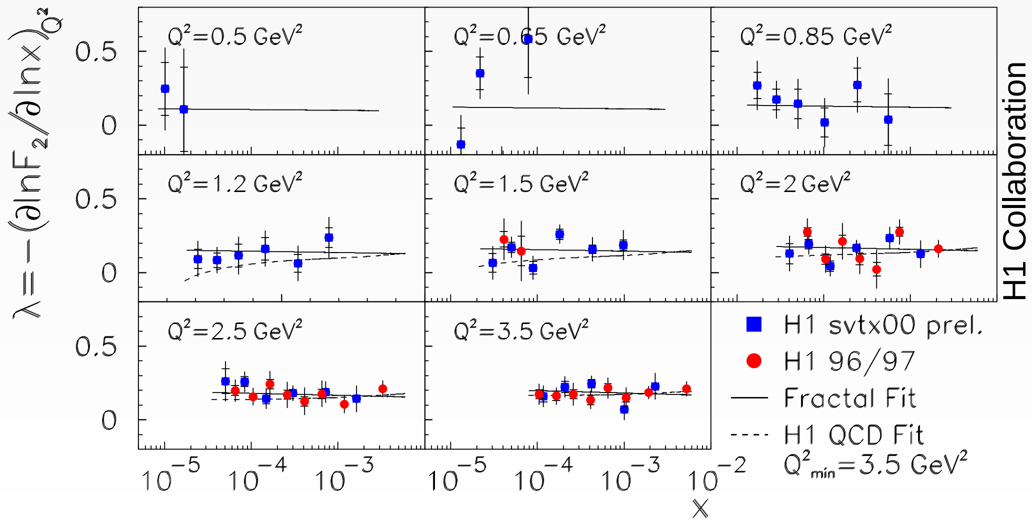


~2–3%

x Dependence of F_2 at Low Q^2

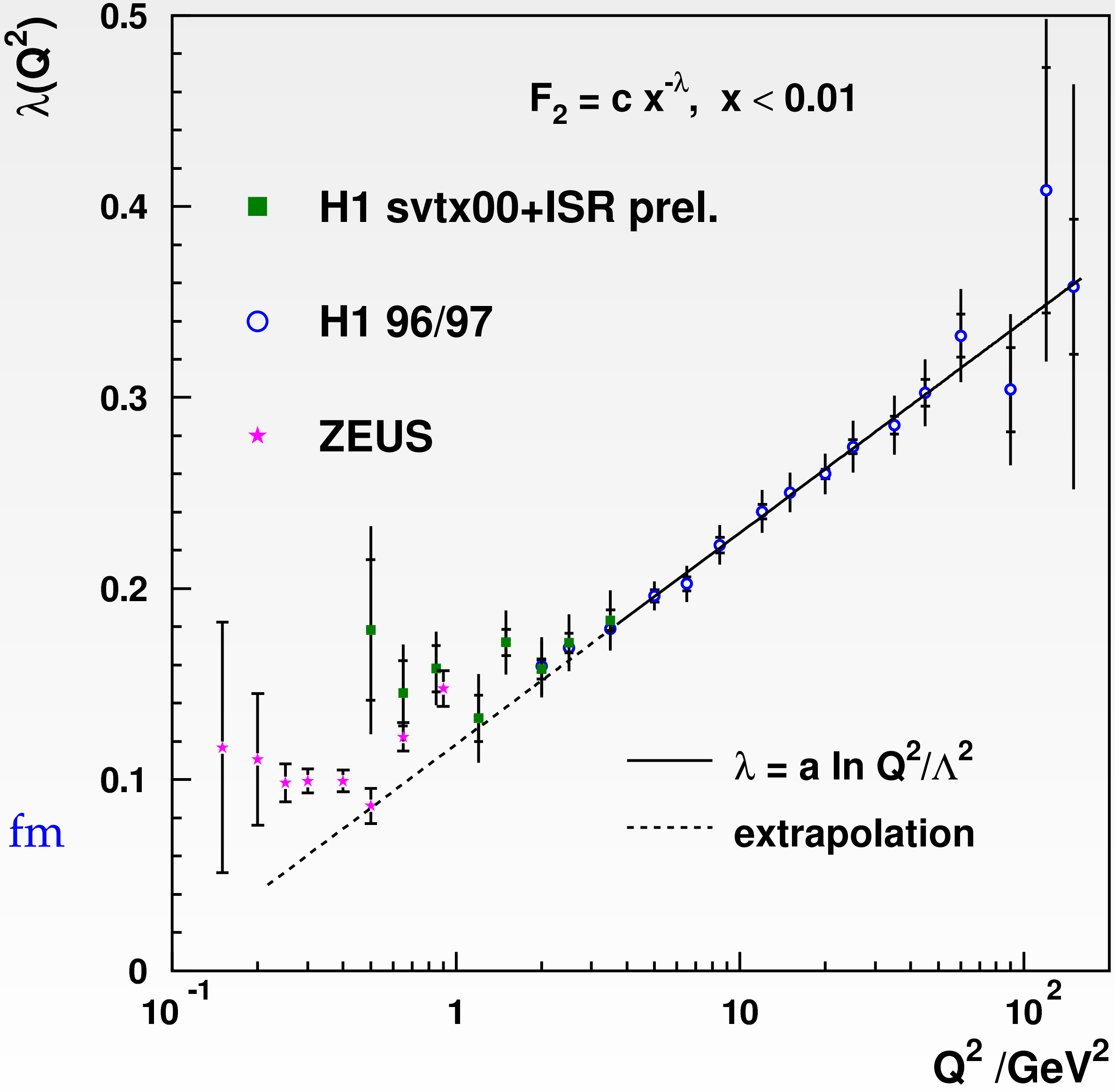


- If saturation effects present, expect taming of rise of F_2 at low x
- Extract $\lambda = \dfrac{\partial \ln F_2}{\partial \ln x}$ at fixed Q^2
- Derivative independent of x for $x < 10^{-2}$
  no evidence for saturation



Extraction of $\lambda(Q^2)$

- Rise of F_2 at $x < 10^{-2}$ is well parameterised by
  $F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$
- At $Q^2 \gtrsim 3\,\mathrm{GeV}^2$:
  $\lambda \sim \ln Q^2$, $c \sim \mathrm{const}$
  Partonic degrees of freedom
- At $Q^2 \lesssim 2\,\mathrm{GeV}^2$:
  $\lambda(Q^2) \to 0.08$ (Donnachie, Landshoff)
  Transition to hadronic d.o.f. at ~ 0.3 fm
- H1 improved its λ extraction by ISR



Combined Extraction of $\lambda(Q^2)$

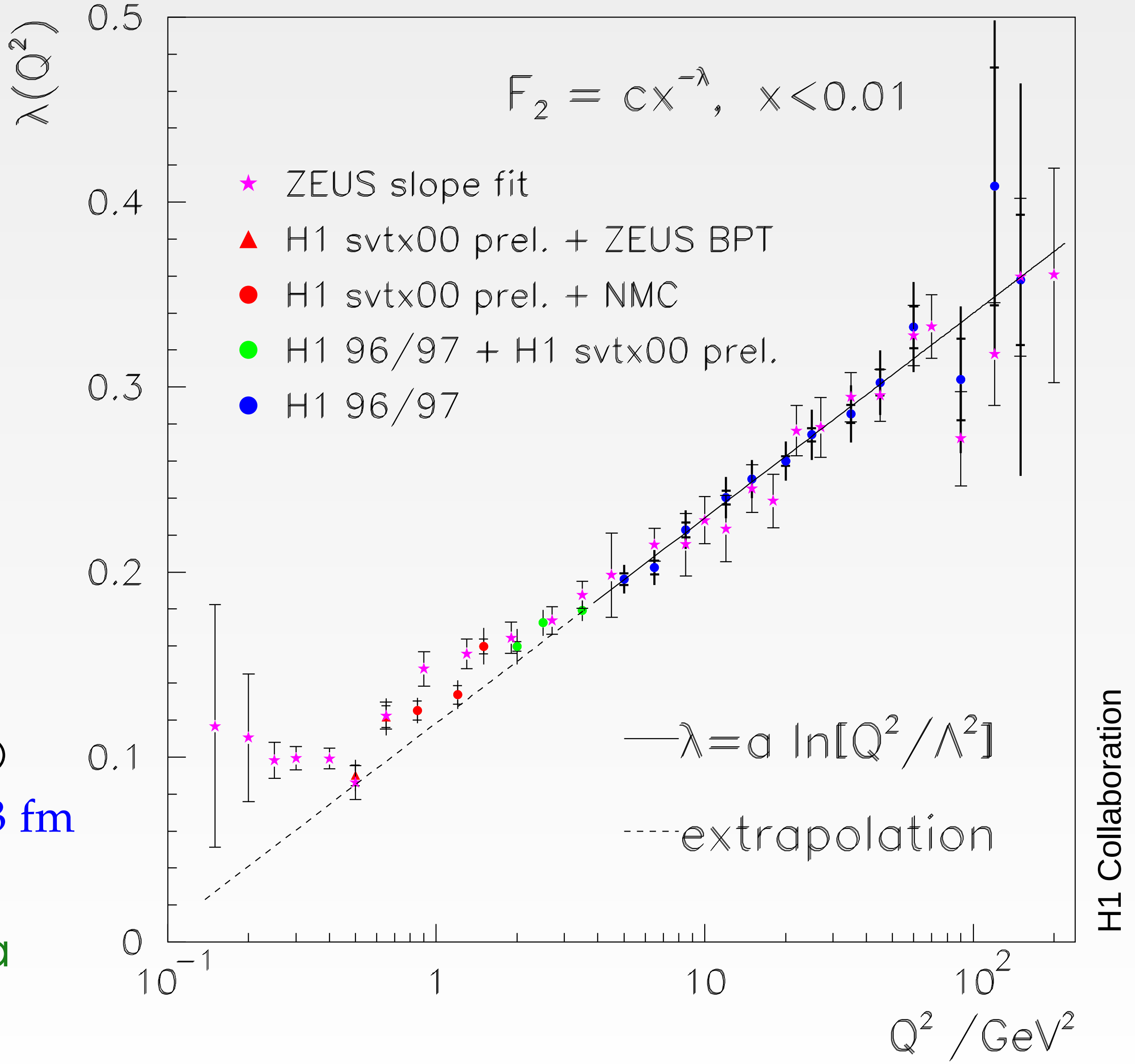
- Rise of F_2 at $x < 10^{-2}$ is well parameterised by
  $F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$

- At $Q^2 \gtrsim 3\,\text{GeV}^2$:
  $\lambda \sim \ln Q^2$, $c \sim \text{const}$
  Partonic degrees of freedom

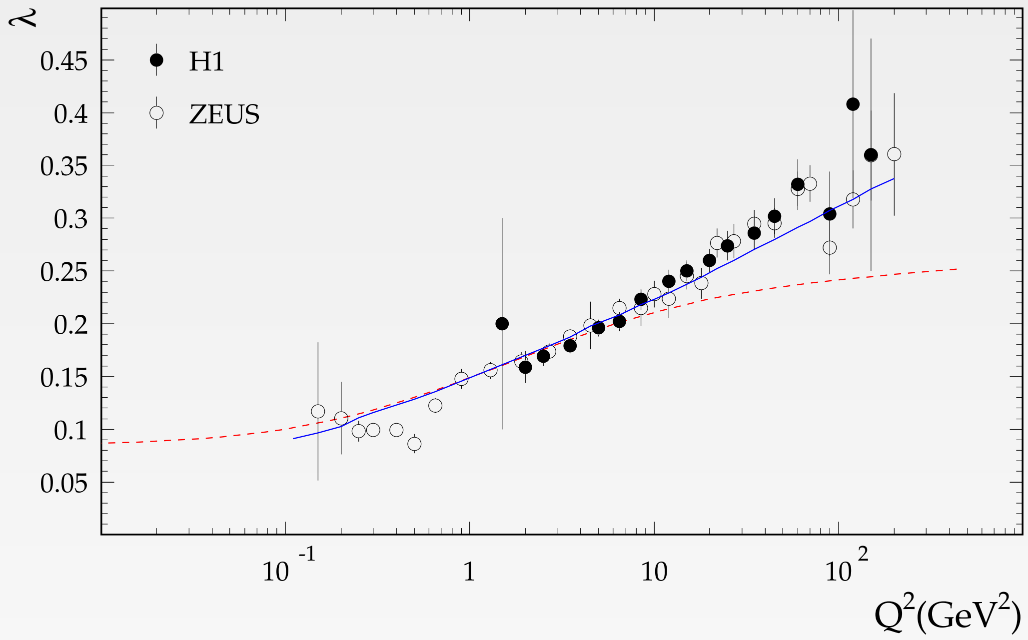
- At $Q^2 \lesssim 2\,\text{GeV}^2$:
  $\lambda(Q^2) \to 0.08$ (Donnachie, Landshoff)
  Transition to hadronic d.o.f. at ~ 0.3 fm

- Best precision from combined data

Looking forward to the final results . . .



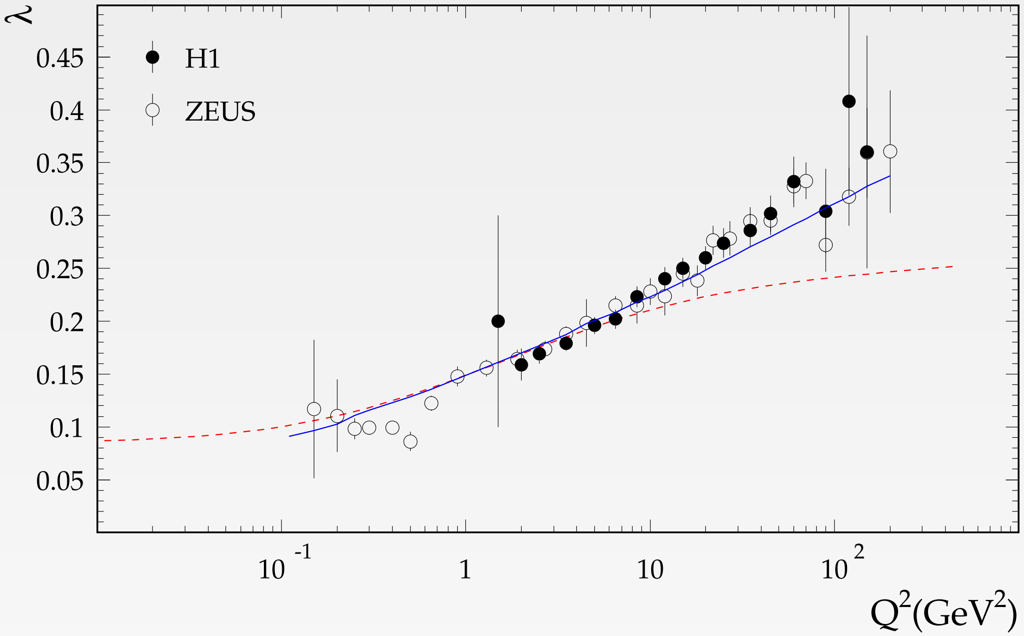
Data Are Described by Saturation Model



- Fitted using 5 parameters GBW + DGLAP evolution

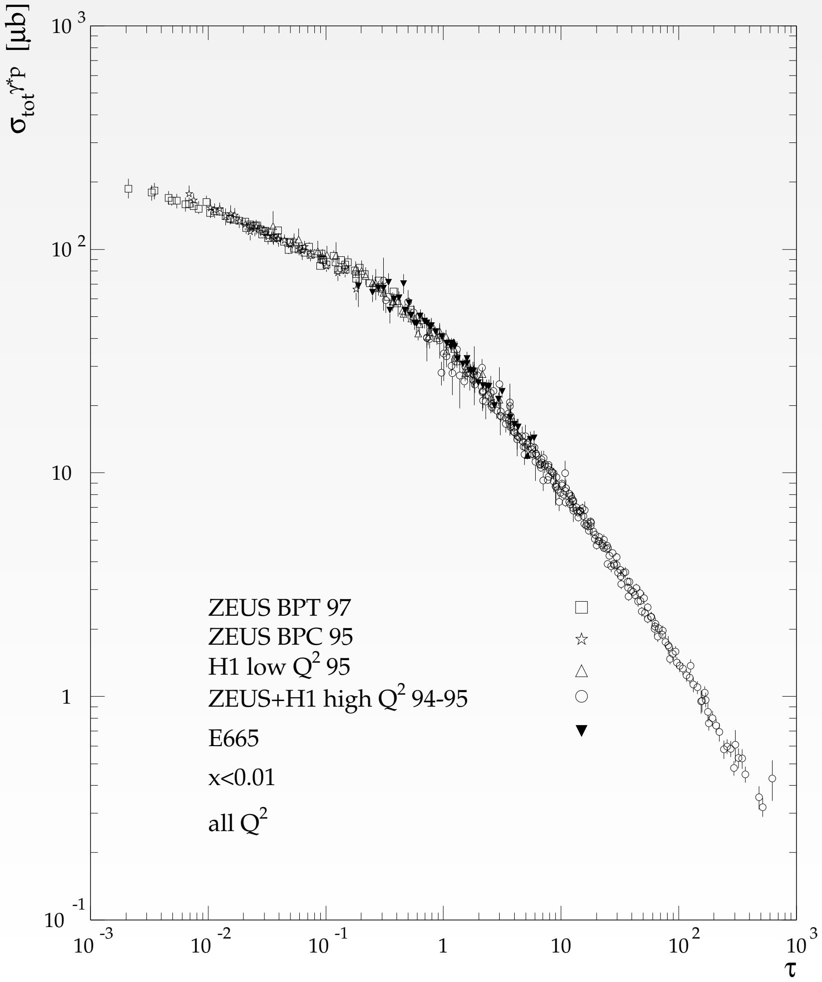
(J. Bartels, K. Golec-Biernat, H. Kowalski)

Data Are Described by Saturation Model



- Fitted using 5 parameters GBW + DGLAP evolution

  (J. Bartels, K. Golec-Biernat, H. Kowalski)

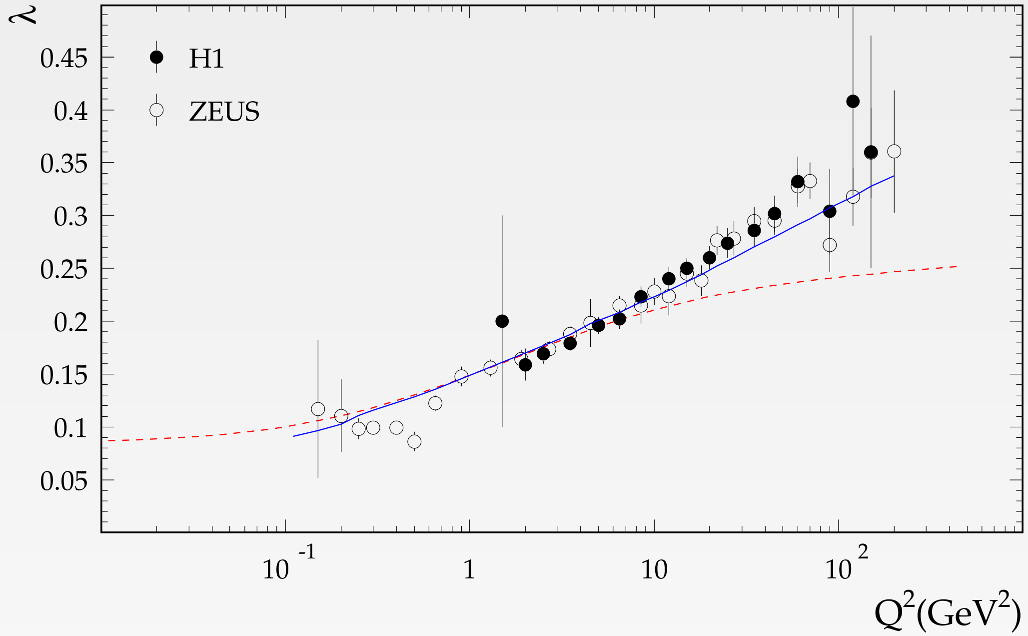


- $F_2 = F_2(\tau),\ \tau = Q^2 R_0^2(x)$ – *Geometric scaling*

  (A.M. Stasto, K. Golec-Biernat, J. Kwieciński)

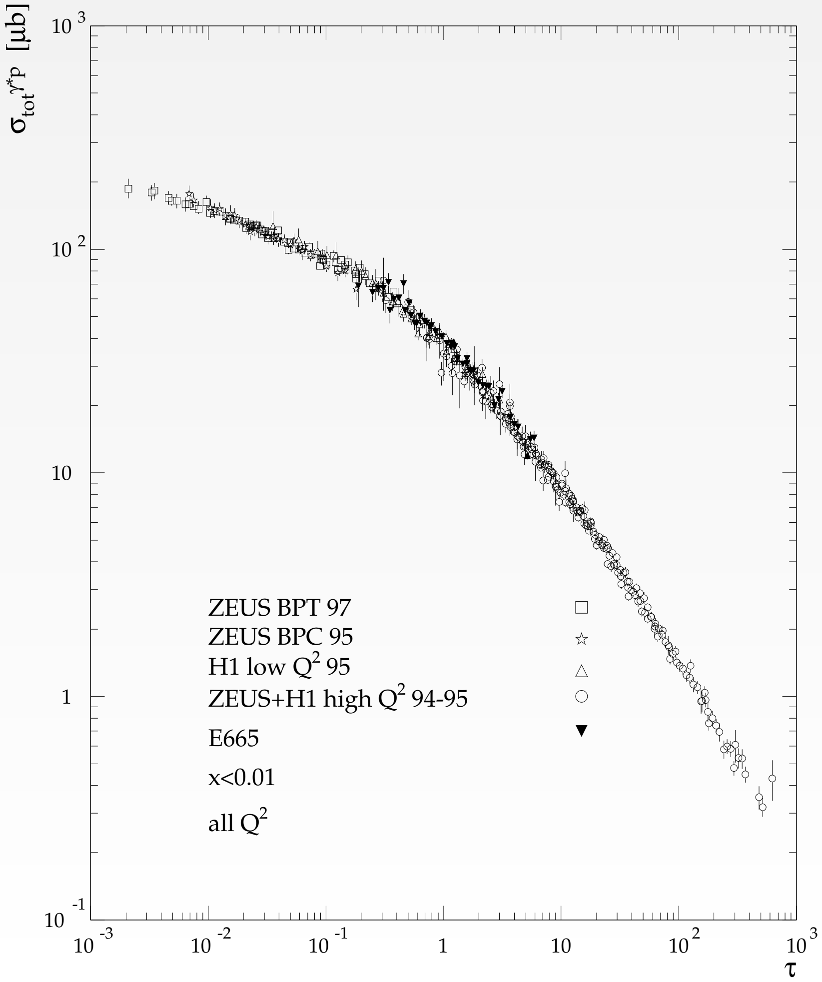
  Data manifest existence of saturation scale as used in saturation model

Data Are Described by Saturation Model



- Fitted using 5 parameters GBW + DGLAP evolution

  (J. Bartels, K. Golec-Biernat, H. Kowalski)



- $F_2 = F_2(\tau),\ \tau = Q^2 R_0^2(x)$ – *Geometric scaling*

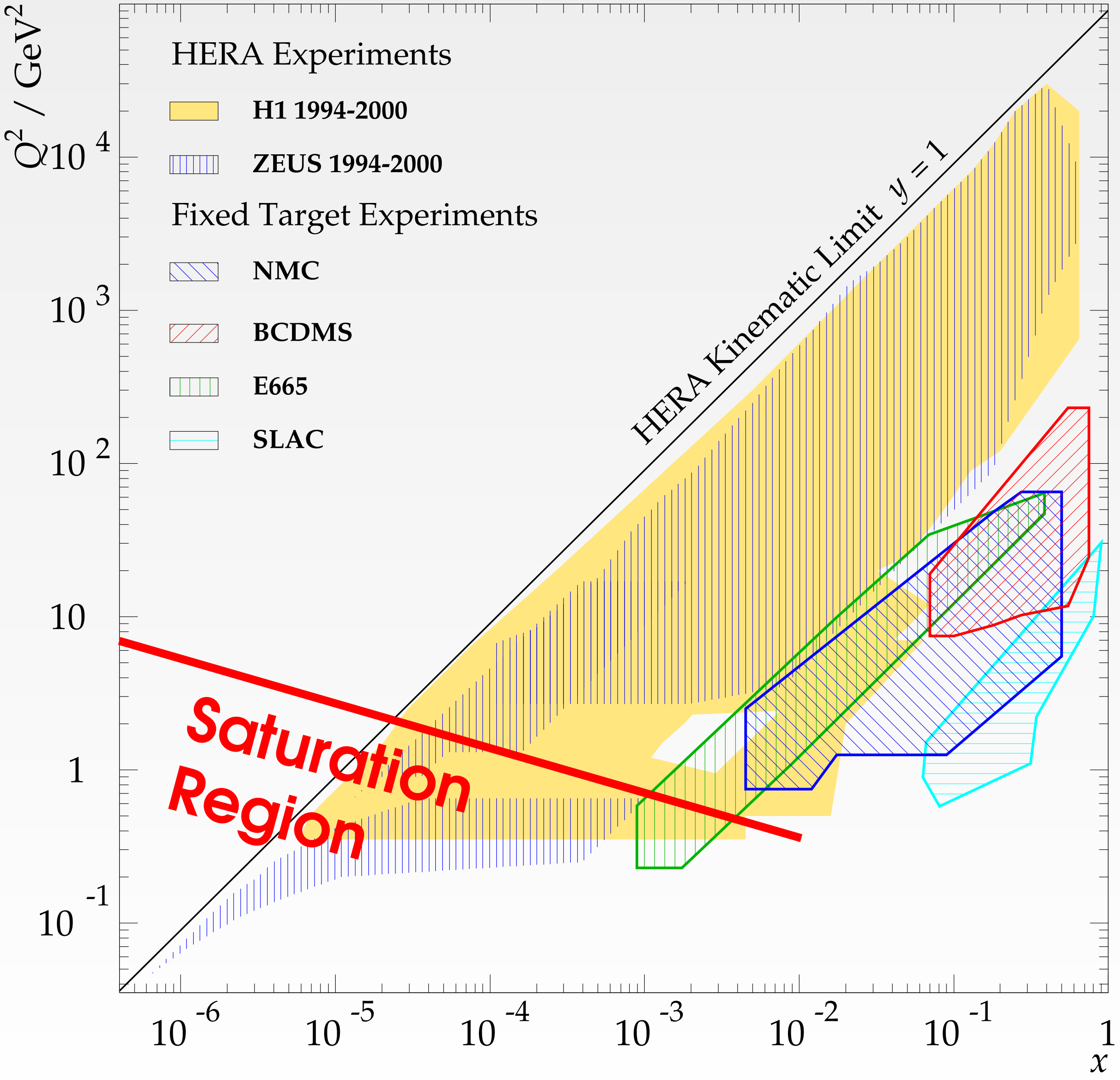
  (A.M. Stasto, K. Golec-Biernat, J. Kwieciński)

  Data manifest existence of saturation scale as used in saturation model

- Also describes $\frac{\sigma_{\mathrm{diffDIS}}}{\sigma_{\mathrm{DIS}}} = \mathrm{const}$

Very appealing

Saturation Region in Dipole Model

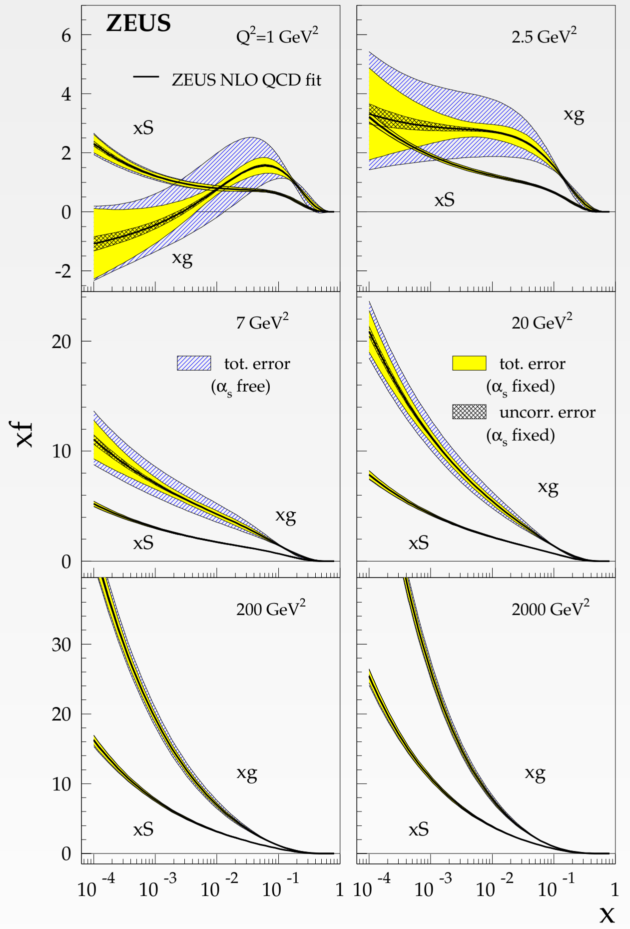


- For pQCD Q^2 scales saturation region is beyond HERA reach
- For $Q^2 \lesssim 1 - 2\,\mathrm{GeV}^2$ saturation model claims we see saturation

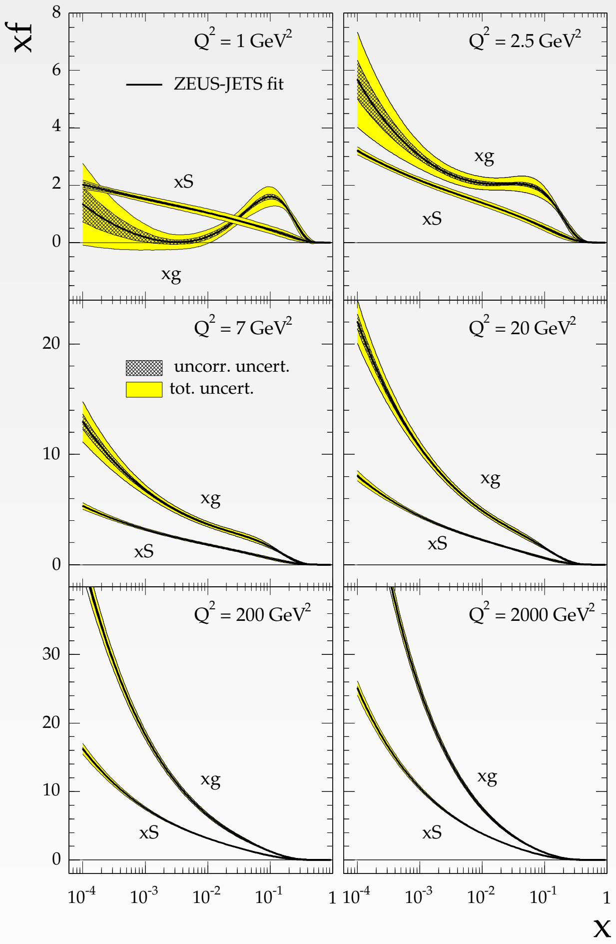
Appealing but not compelling

Gluon and F_L

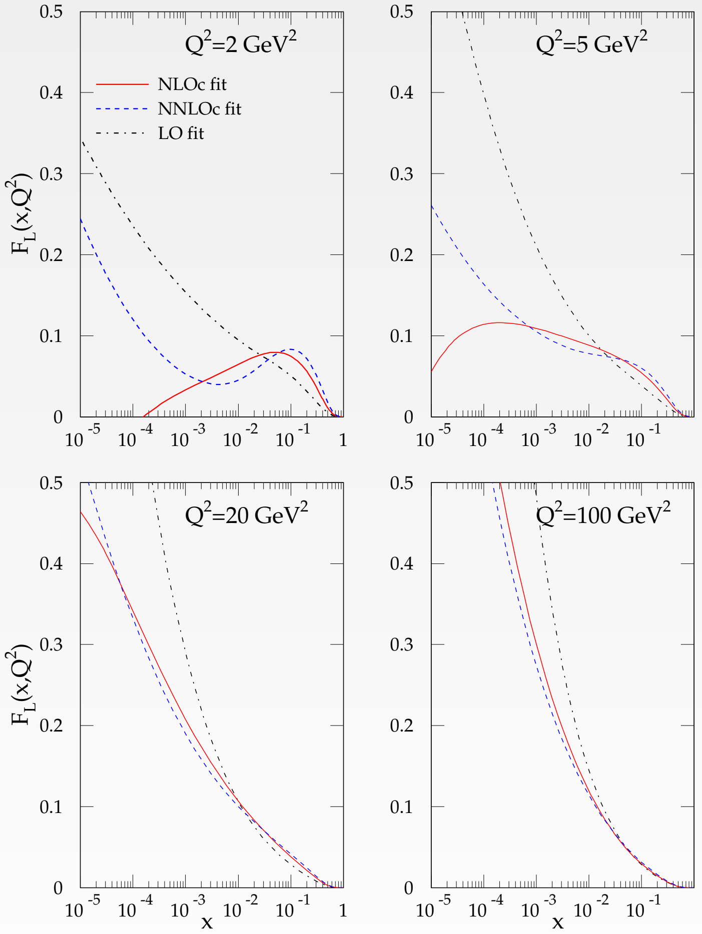
ZEUS NLO



ZEUS-JETS



MRST 2003 F_L



- Critical corner – low Q^2 and low x
  Gluon becomes valence-like or even negative
- Large spread of calculations for gluon and F_L

Determination of F_L

$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

- Data sensitive at highest y only
- Direct measurement requires data at different $s \longrightarrow$ *lower E_p runs*
- Indirect determination at high y
  - Derivative method

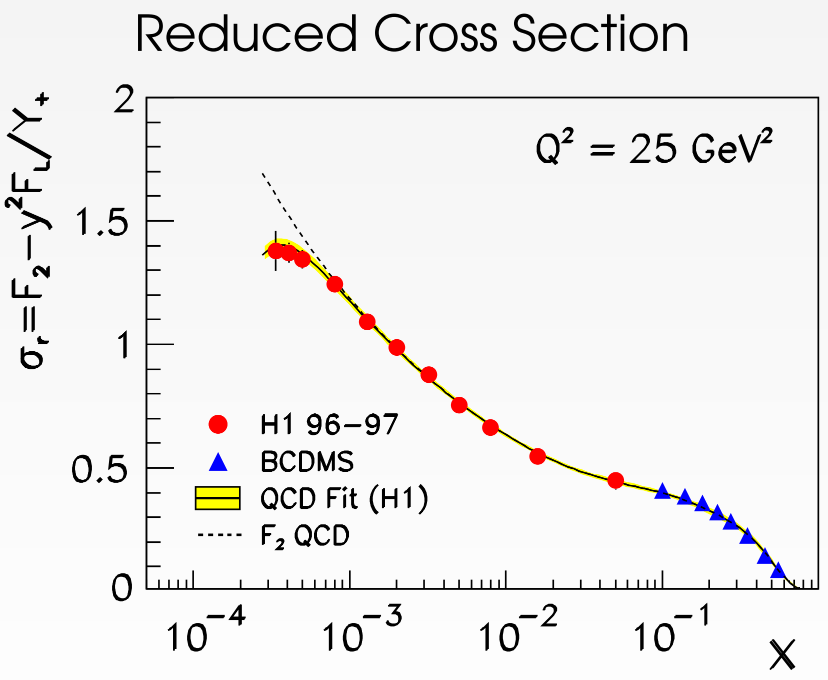
$$\left.\frac{\partial \sigma_r}{\partial \ln y}\right|_{Q^2} \approx \left.\frac{\partial F_2}{\partial \ln y}\right|_{Q^2} - \frac{2y^2(2-y)}{Y_+^2} F_L$$

Derivative dominated by F_L term at high y

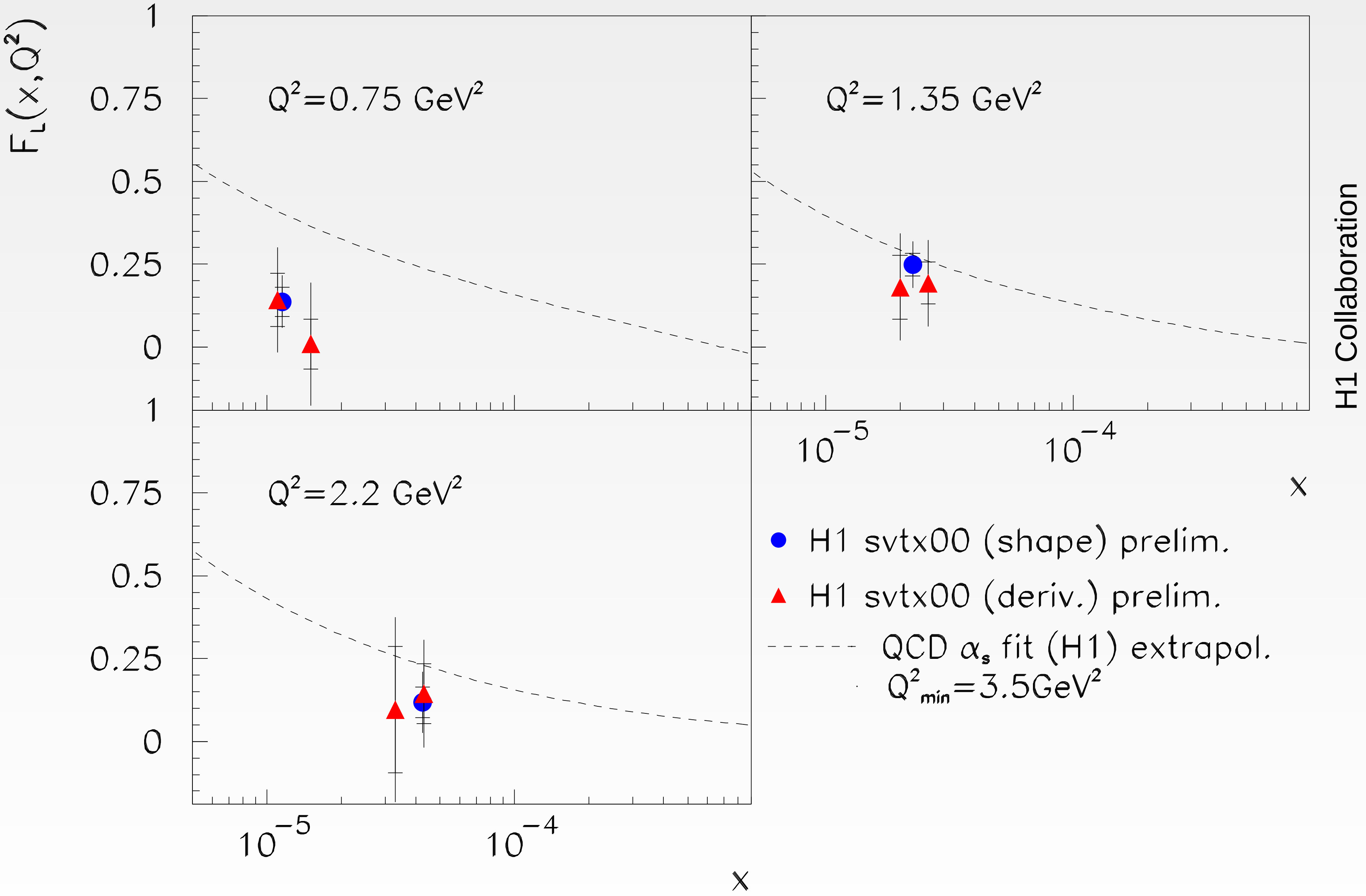
  - Shape method

$$\sigma_{\text{fit}} = c x^{-\lambda} - \frac{y^2}{Y_+} F_L$$

Shape driven by kin. factor rathen than F_L

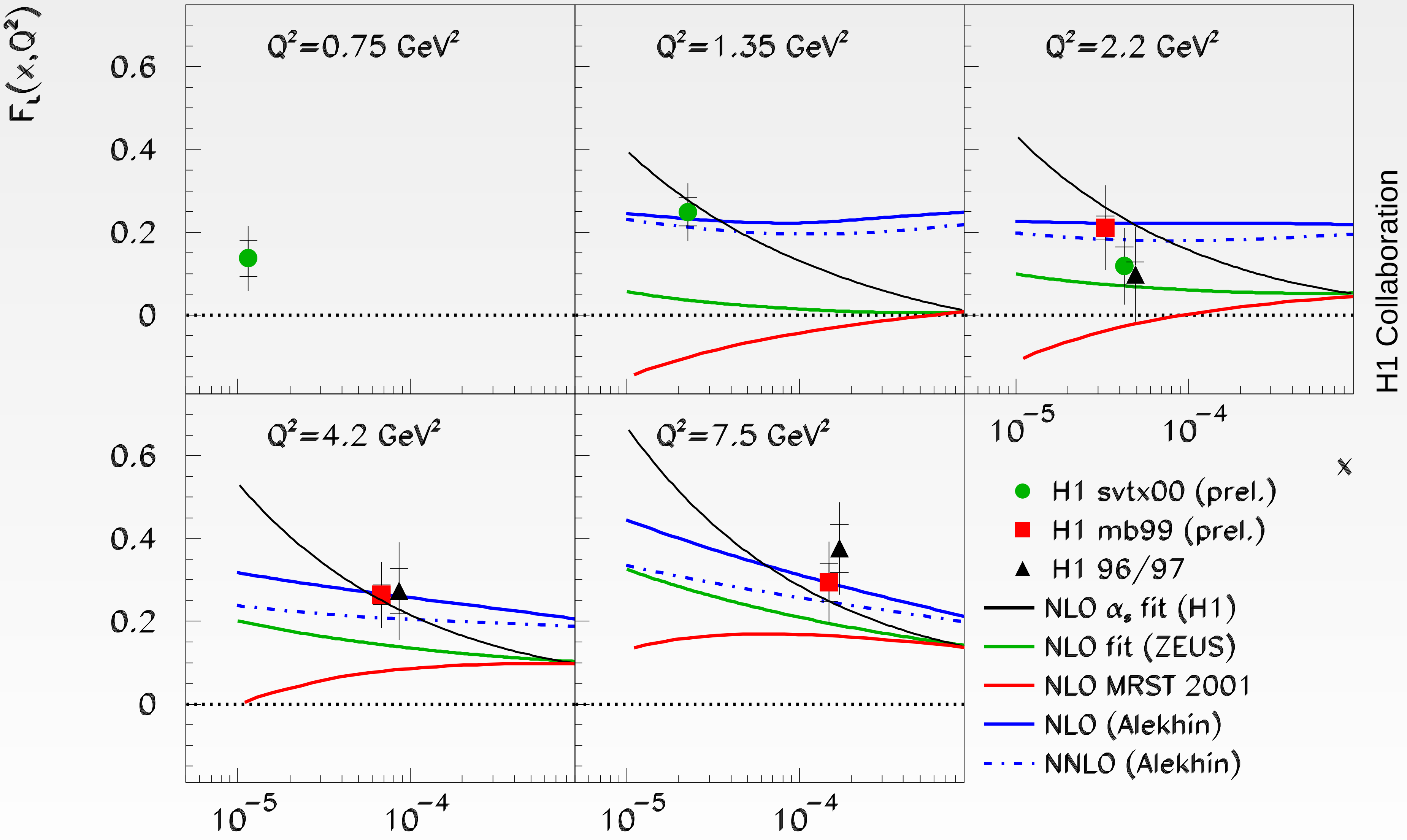


Shape Method vs. Derivative Method



Shape method provides higher precision

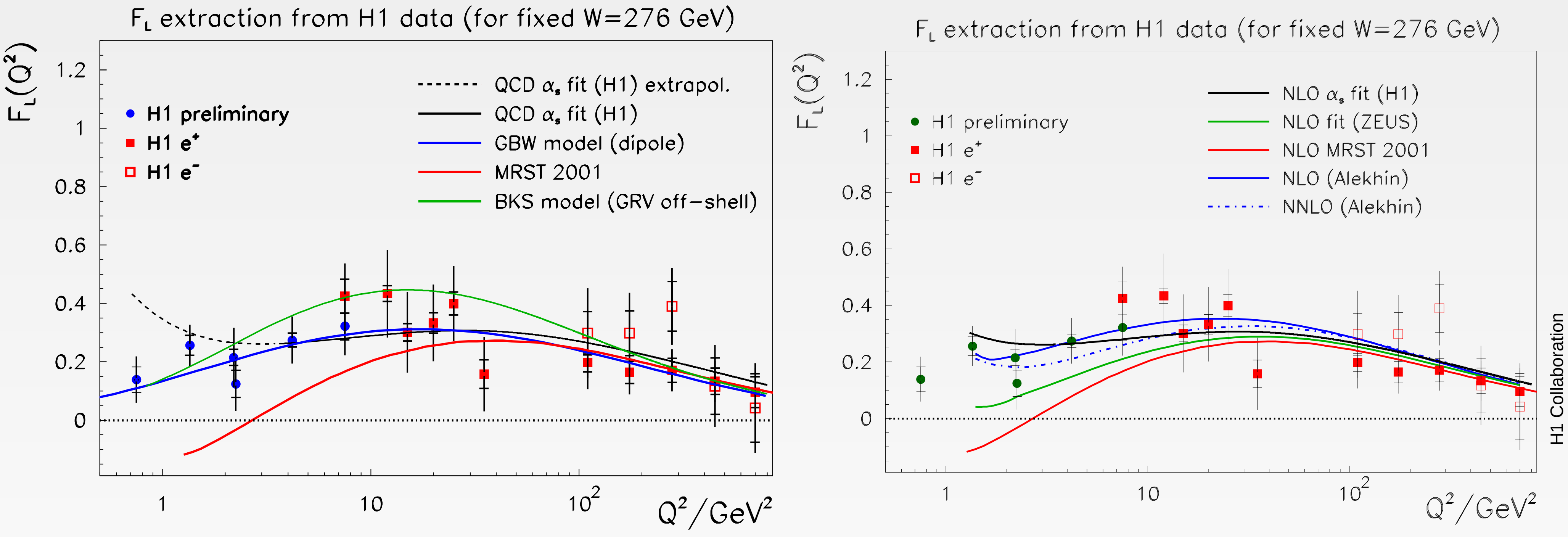
F_L for Fixed Q^2



Determination of x-dependence impossible $\Longrightarrow$ *Need low E_p runs*

➥ *talk by J. Feltesse*

F_L at Fixed $y = 0.75$



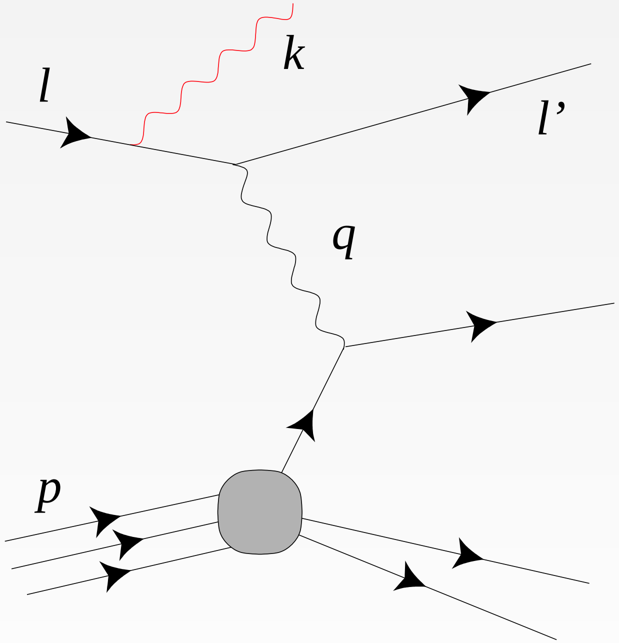
- New constraints from low Q^2 data
- F_L spans 3 orders of magnitude in Q^2
- Basic agreement with NLO pQCD fits
- Good description by dipole model in the whole Q^2 range
- H1 non-negligible F_L at low $Q^2 \Longrightarrow$ *positive g*

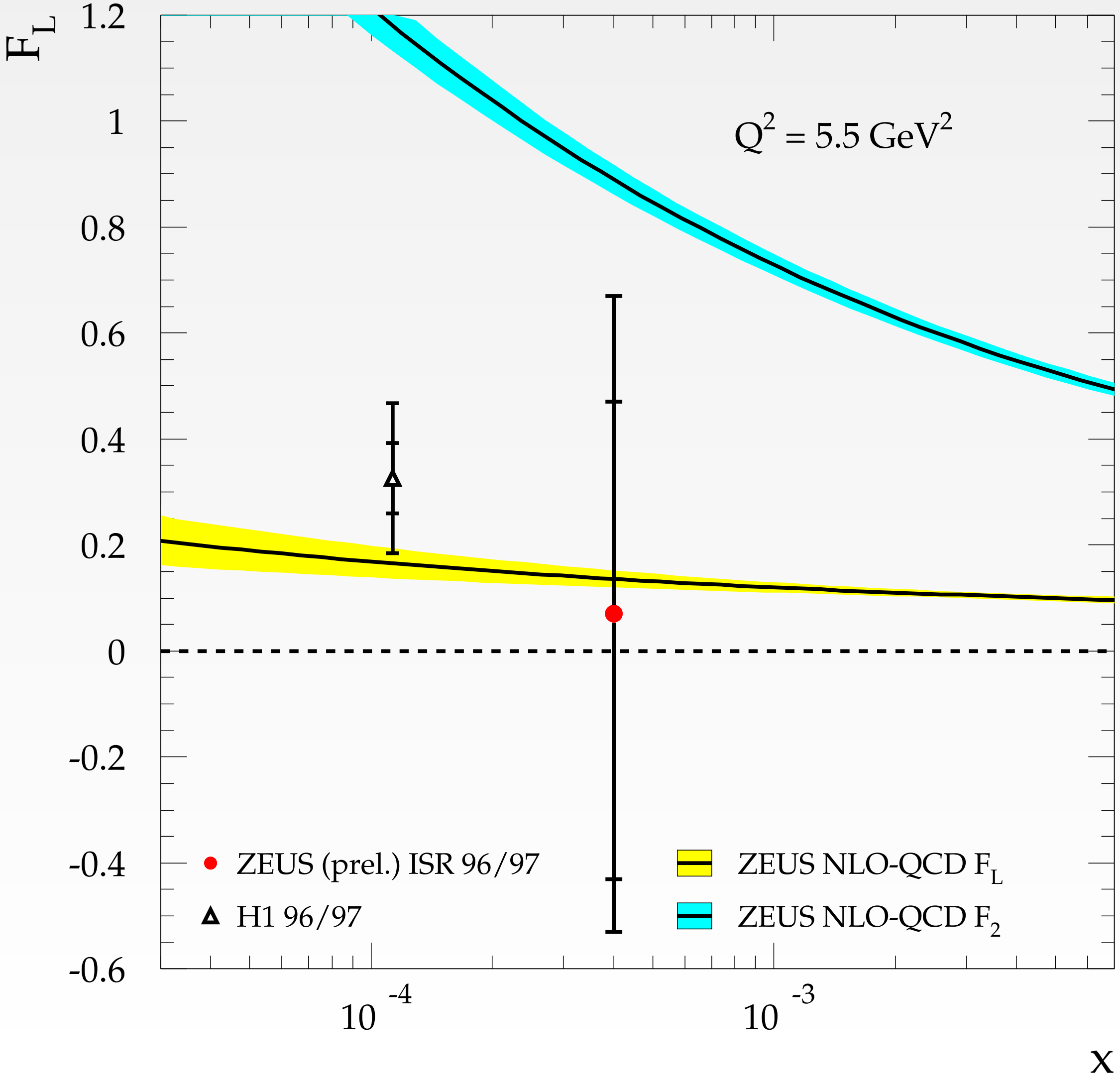
Direct Determination of F_L

Modified kinematics:

interpret as incident $E = E_{e-\mathrm{beam}} - E_{\gamma}$ $\Longrightarrow$ variation of y :

$$y = \frac{p \cdot q}{p \cdot (l - k)}$$





Need much more ISR statistics

Summary

- Inclusive data in pQCD region are well described by DGLAP
  Strongly rising gluon towards low x
  No clear sign for different dynamics, saturation . . .

- Precision 2–3% reached at low–medium Q^2
  Precise data in the whole x range are also important for the LHC

- $F_2 = c \cdot x^{-\lambda(Q^2)}$ at $x < 10^{-2}$ for all Q^2
  $\lambda(Q^2)$ compatible with pQCD at $Q^2 \gtrsim 3\,\mathrm{GeV}^2$
  At lower Q^2 transition to hadronic d.o.f. occurs, $\lambda \to 0.08$

- $F_2 = F_2(\tau)$, $\tau = Q^2 R_0^2(x)$ – Geometric scaling at $x < 10^{-2}$ for all Q^2

- F_L is important to pin down gluon at low Q^2 and low x
  F_L is described by pQCD fits at $Q^2 > 2\,\mathrm{GeV}^2$
  $F_L > 0$ also at $Q^2 < 1\,\mathrm{GeV}^2$

- DIS–γp transition region is described by phenomenological models
  Dipole model describes both transition and pQCD region at low x:
  F_2 (incl. $F_2(\tau)$, $\lambda(Q^2)$), F_L, $\frac{\sigma_{\mathrm{diffDIS}}}{\sigma_{\mathrm{DIS}}} = $ const using a few parameters

Summary of Experimental Methods

- Special experimental approaches are required for low Q^2
  - Low Q^2 devices
  - Shifted vertex
  - Radiative events (ISR, QEDC)

  extend low Q^2 measurements towards higher x

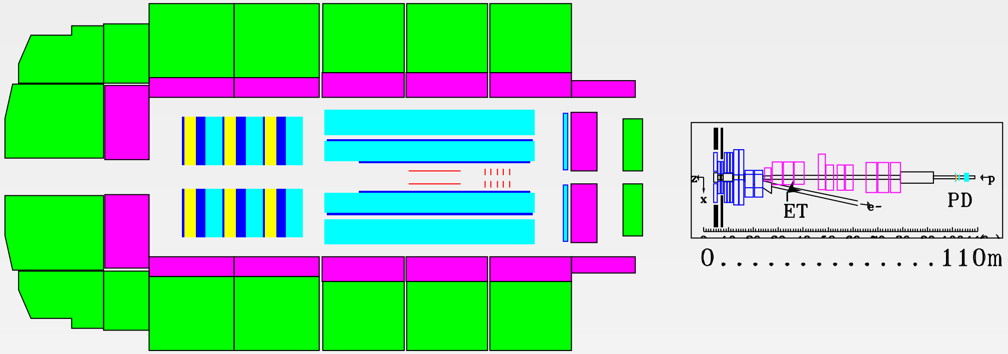
- F_L – large uncertainty at low Q^2 and low x
  - Direct extraction from ISR lacks statistics
  - Indirect methods at fixed high $y = 0.75$:
    - Derivative method
    - Shape method – more precise
  - Best solution would be low E_p runs

- Looking forward to final data and combined results

Backup

Additional Information

ISR Event in H1 Detector

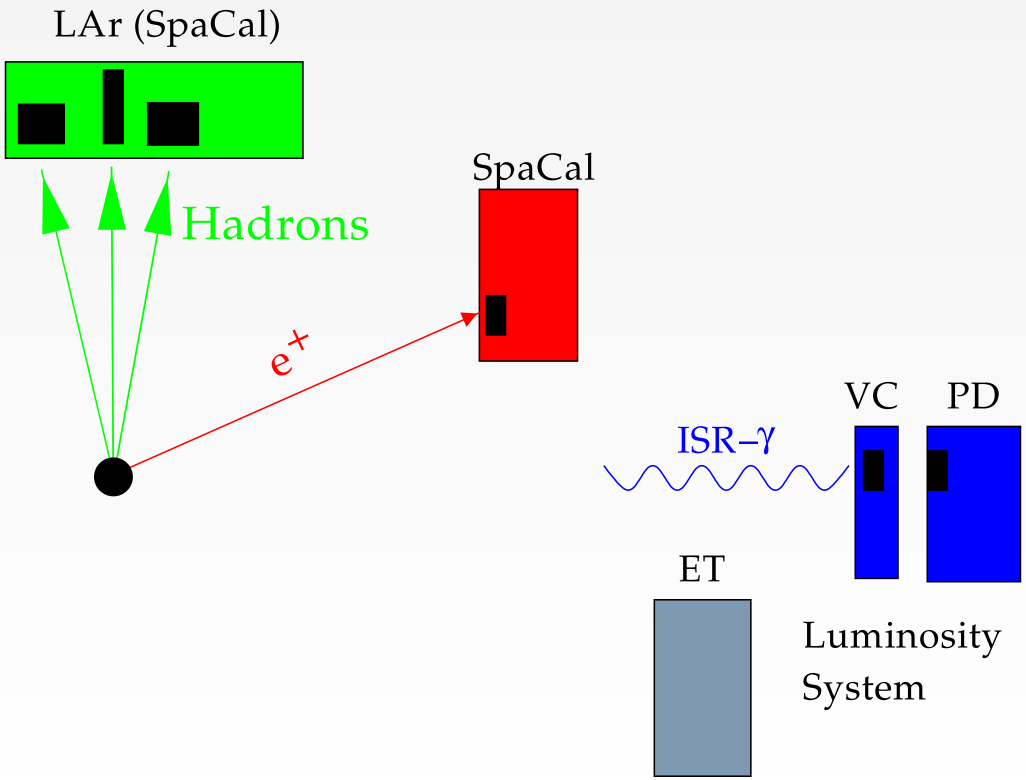


Access lower Q^2

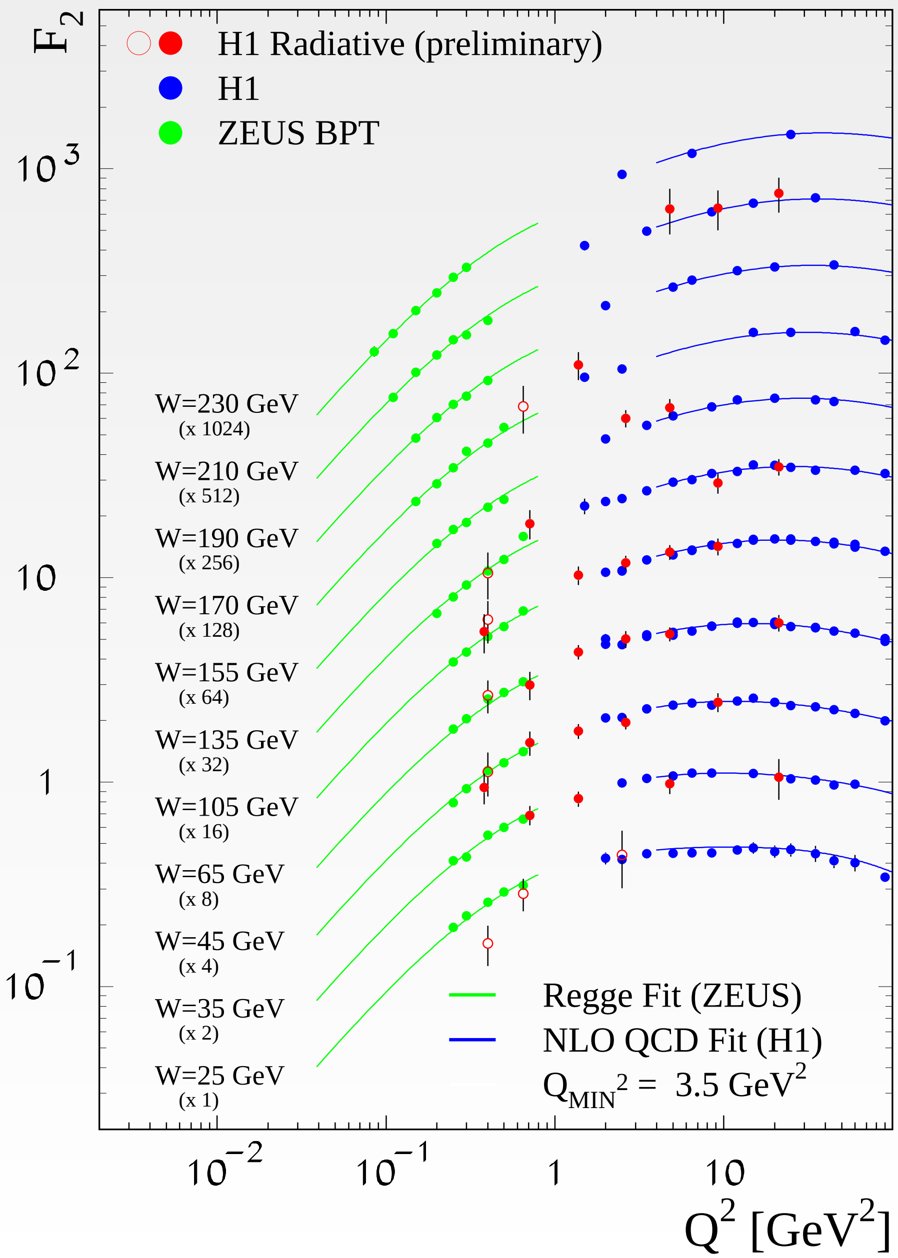
Additional experimental challenges

- Detector acceptance and calibration
- Backgrounds from event overlaps

(DIS + BH, γp + BH, ISR + BH)



Preliminary Results: F_2 in ISR



Access both perturbative and non-perturbative domain