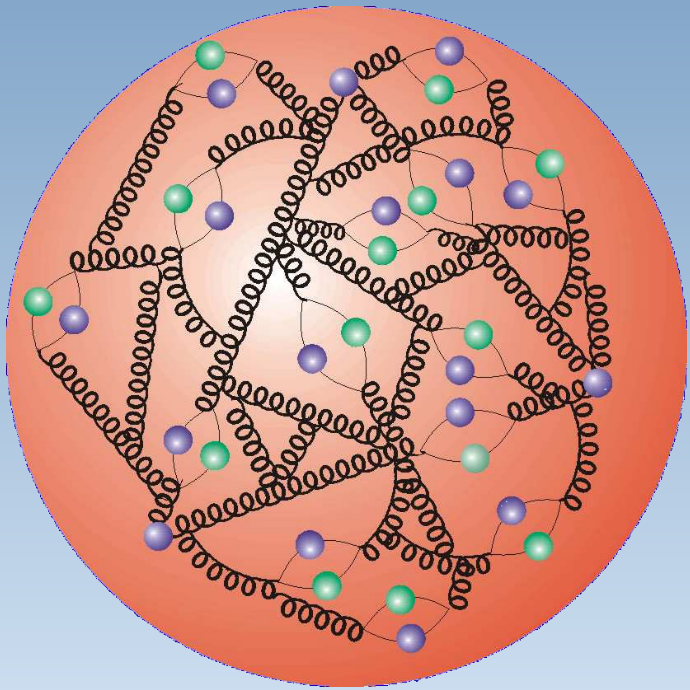
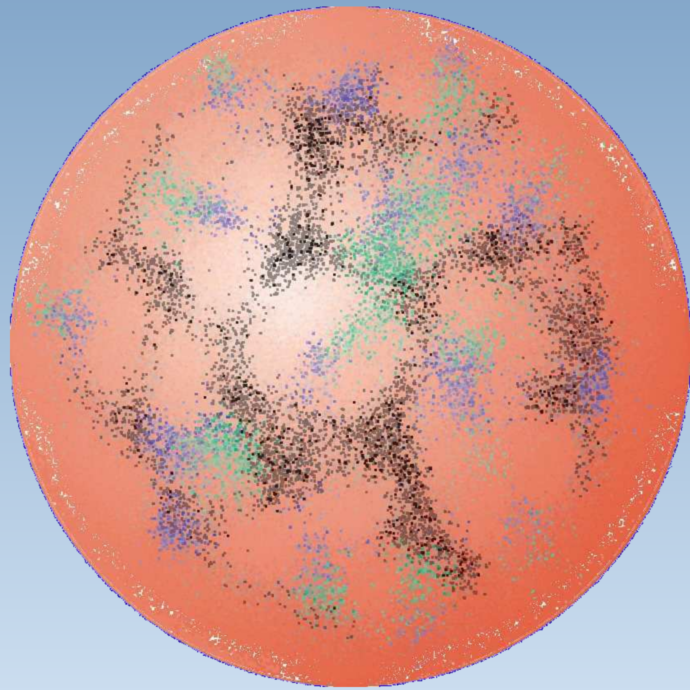
Measurements of Proton Structure at low Q^2 at HERA

- Deep Inelastic Scattering
- Experimental techniques
- F_2 measurements
- F_L determination
- Summary

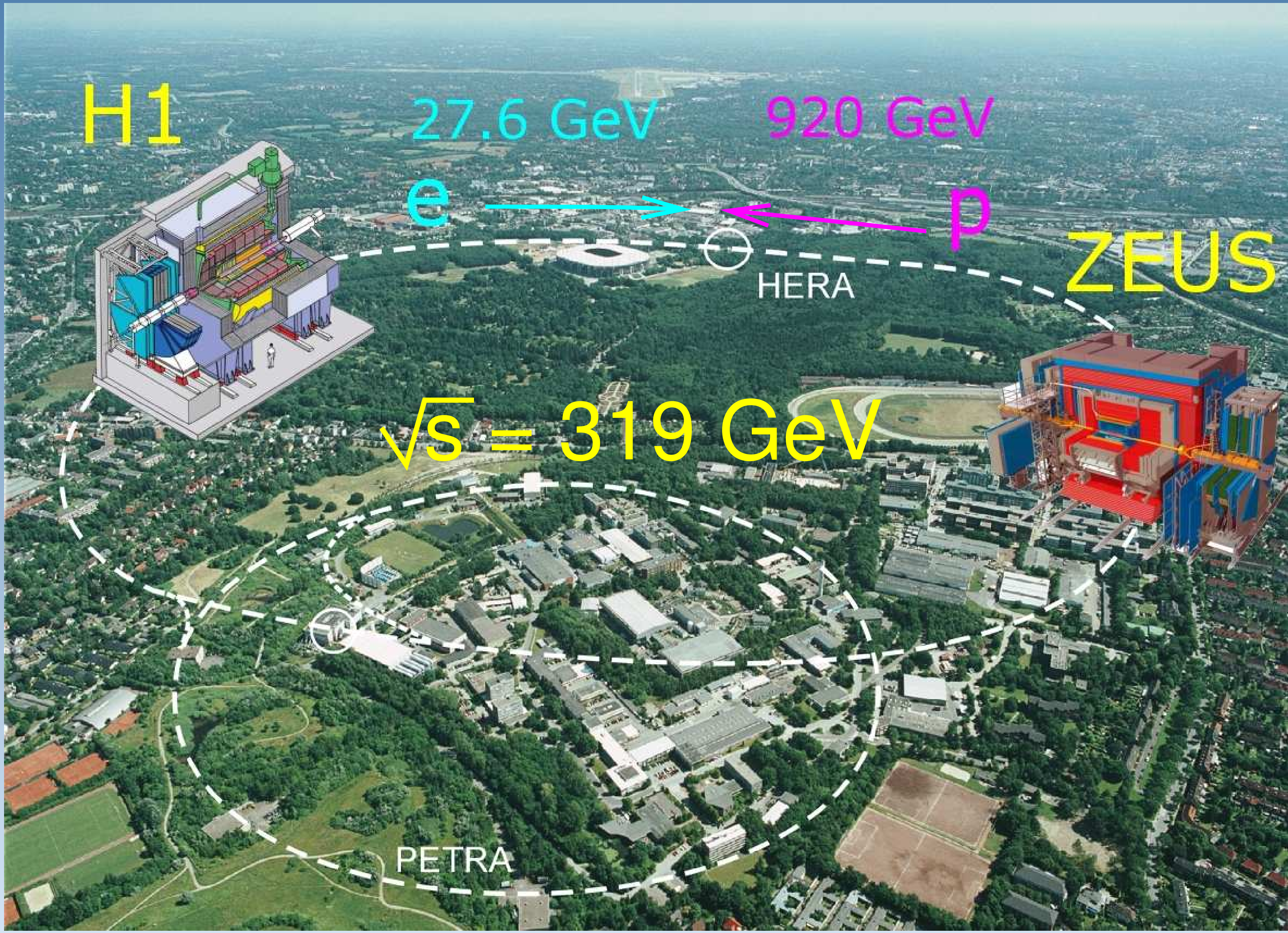




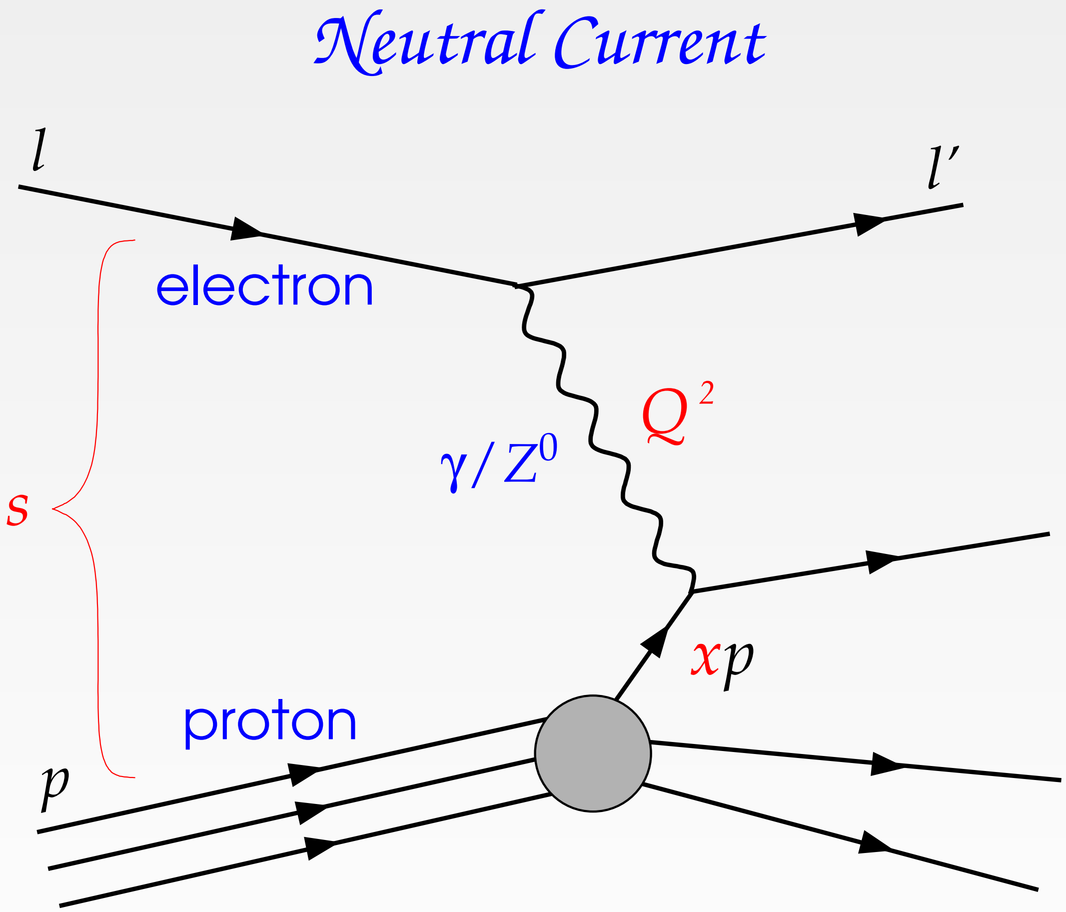
Victor Lendermann
University of Heidelberg

CIPANP 2006
Puerto Rico, 29.05 – 03.06.2006

HERA ep Collider at DESY, Hamburg



Inclusive DIS Kinematics



2 d.o.f. at fixed $s = (l+p)^2$

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

fractional momentum
of struck quark $\quad x = \dfrac{Q^2}{2p\cdot(l-l')}$

inelasticity $\quad y = \dfrac{p\cdot(l-l')}{p\cdot l}$

$$Q^2 = x\,y\,s$$

low $x \Longleftrightarrow$ high y

Inclusive DIS at Low Q^2

- Measure NC cross section

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x} Y_+ \left\{ F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2) \right\} \qquad Y_\pm = 1 \pm (1-y)^2$$

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

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- Parton distribution functions (PDF) in pQCD

$$F_2^{em}(x,Q^2) = x \sum_i e_i^2 [q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$$

q_i – probability to find quark with flavour i in proton

Inclusive DIS at Low Q^2

- Measure NC cross section

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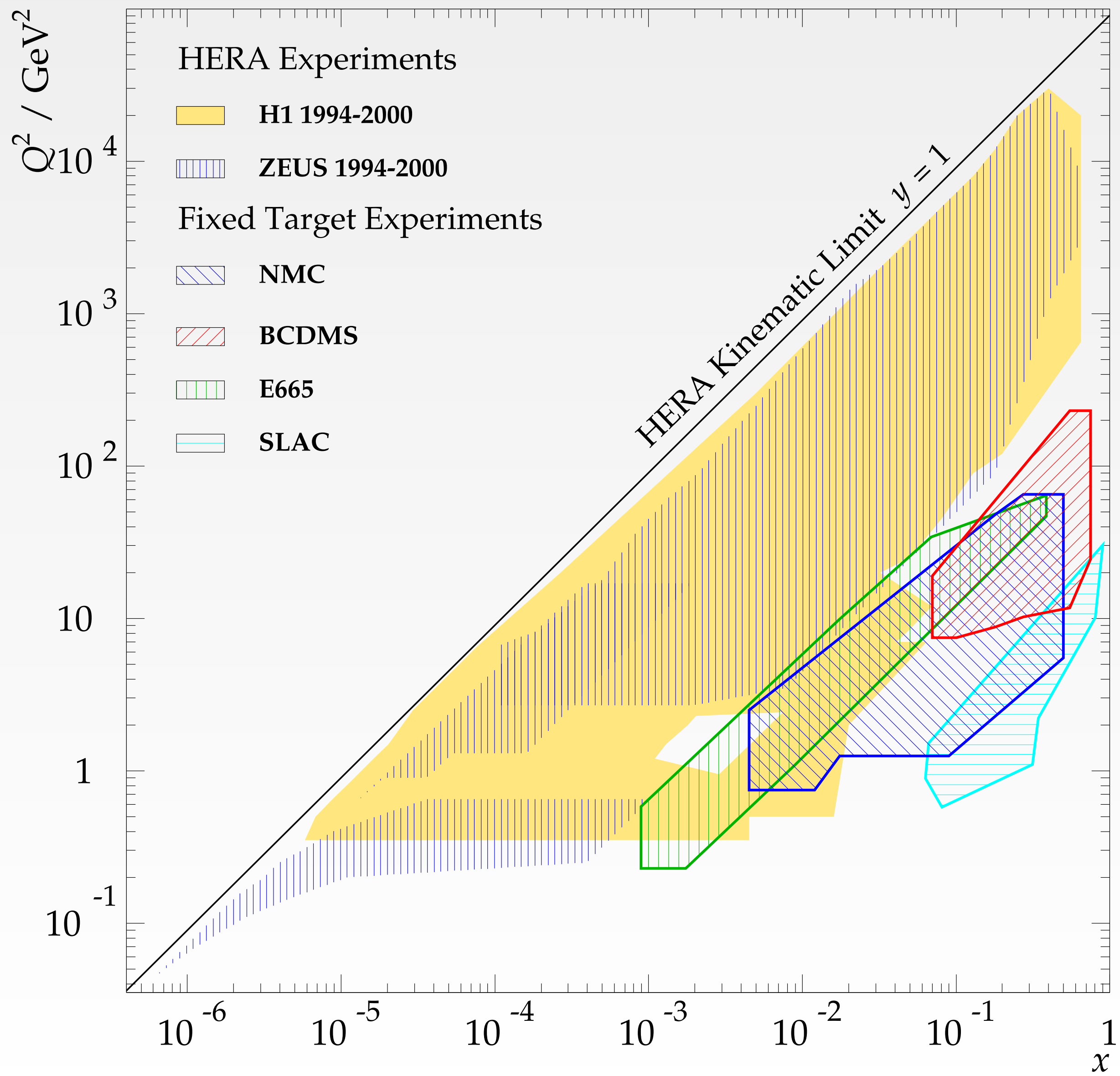
- $F_L(x,Q^2)$ – longitudinally polarised photons
  - Contribution only at high y
  - Sensitive to QCD higher orders (gluon emission)

    $F_L \sim \alpha_s g$ — constrains gluon density

Q^2 Determines QCD Regime



→ *High Q^2*

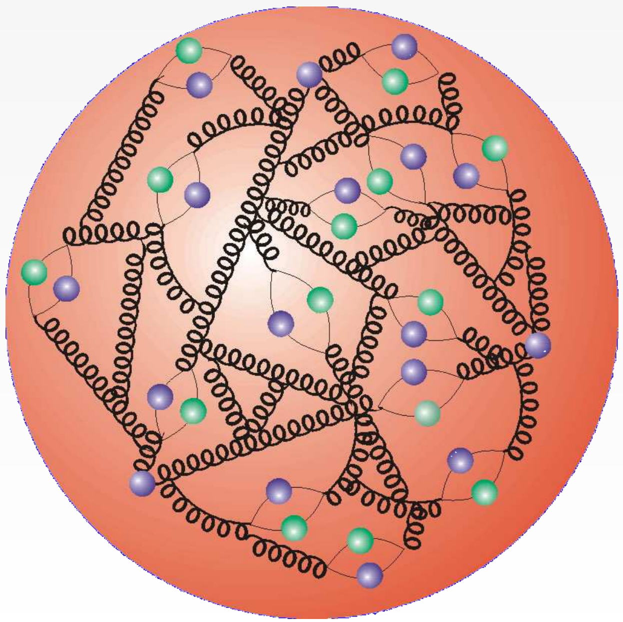
asymptotic freedom

perturbative QCD (DGLAP)

➥ *next talk by Y. Ning*

el.-weak effects

➥ *talk by J. Bracinik yesterday*



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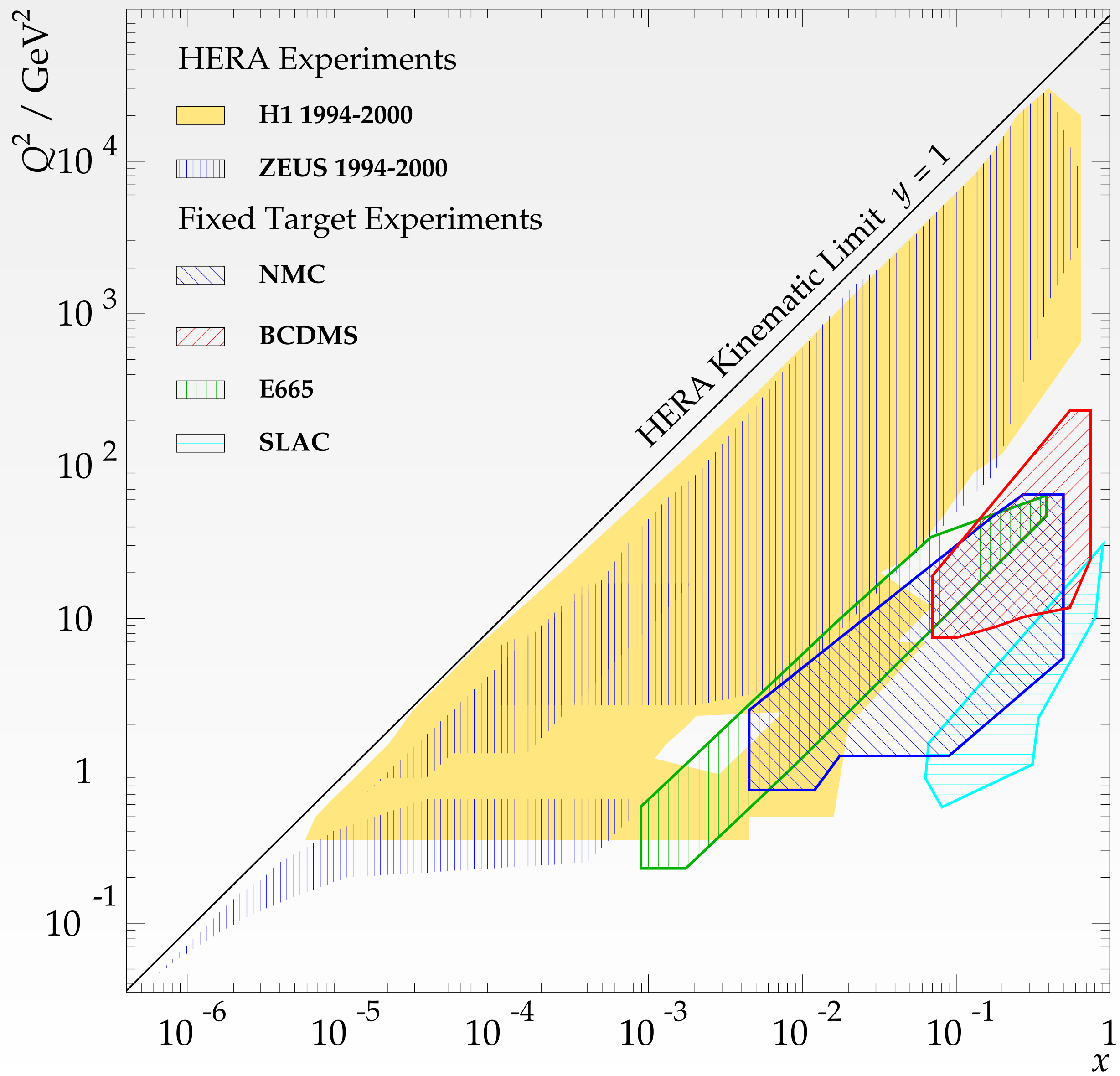
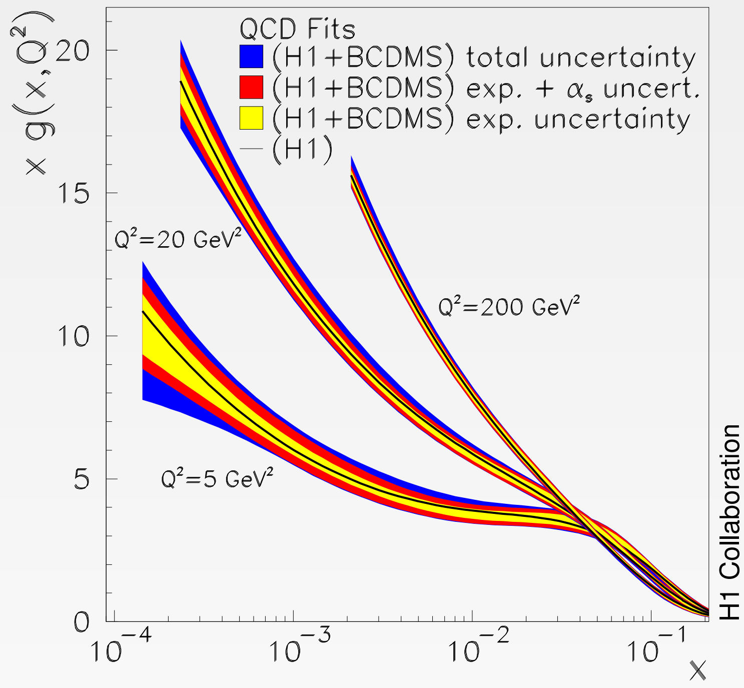


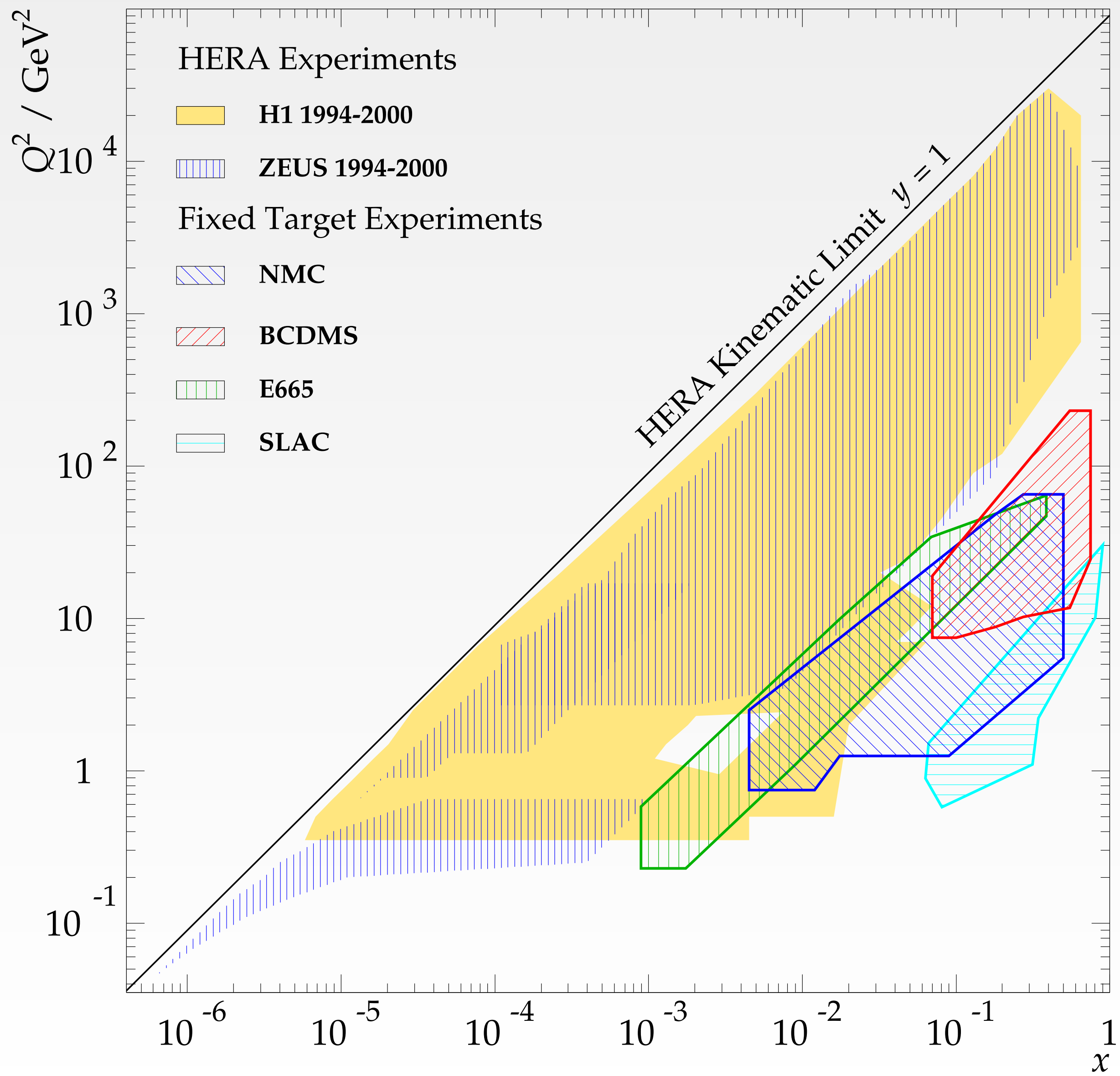


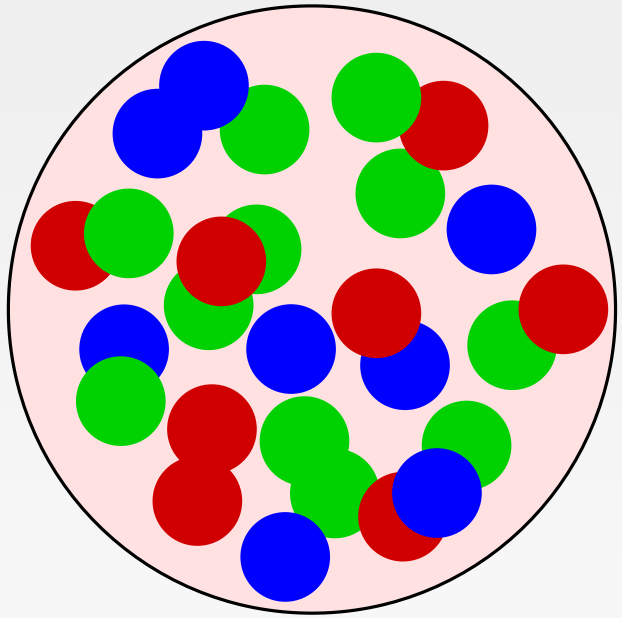
⟶ *Low* Q^2 $\Longrightarrow$ *Low* x

strongly rising gluon

testing validitity of DGLAP

Q^2 Determines QCD Regime



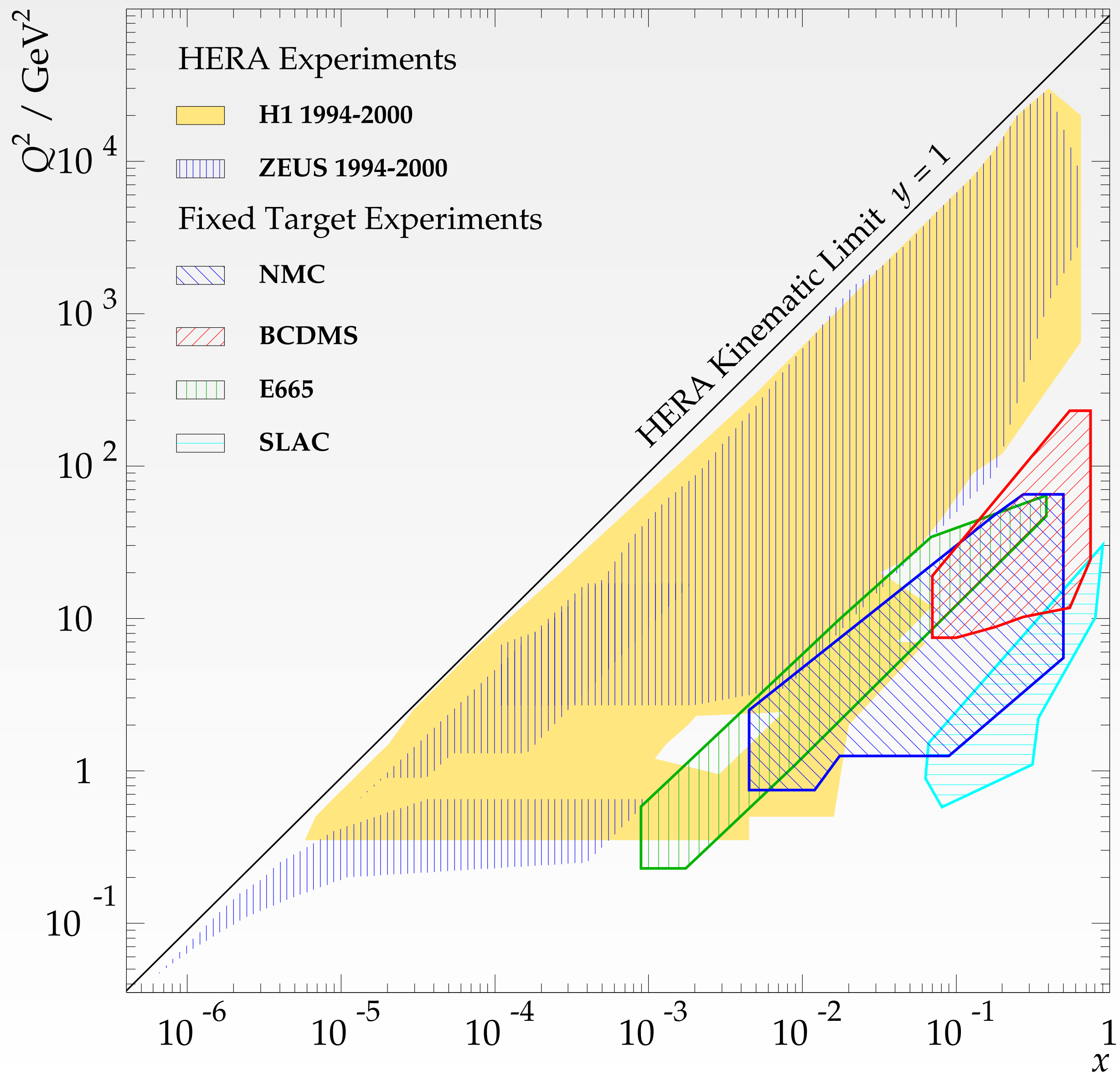


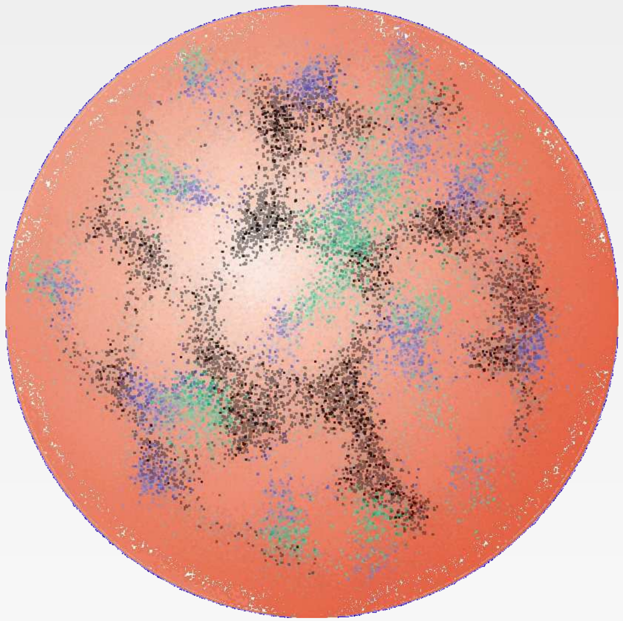
→ *Low* $Q^2 \Longrightarrow$ *Low* x

dense gluon states

search for saturation

Q^2 Determines QCD Regime

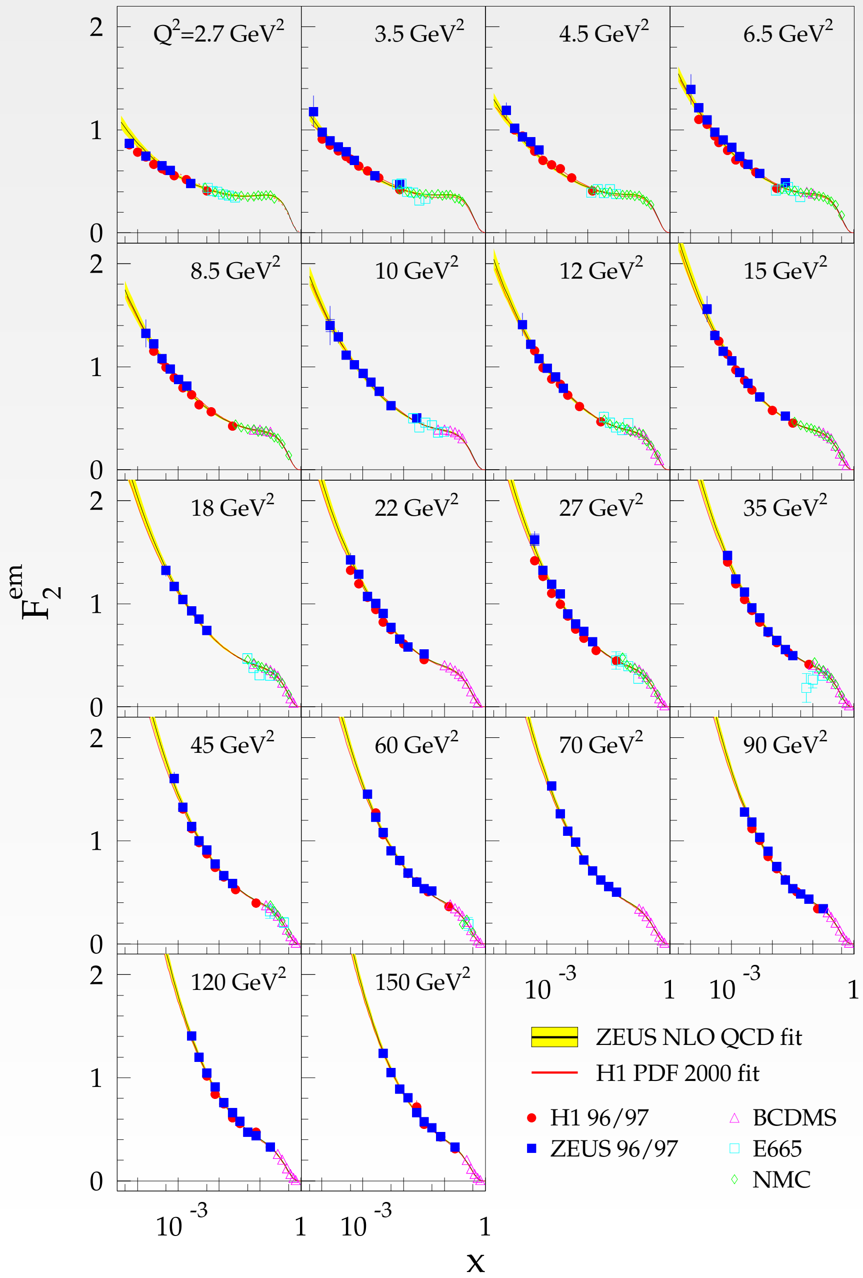




⟶ *Very low Q^2*

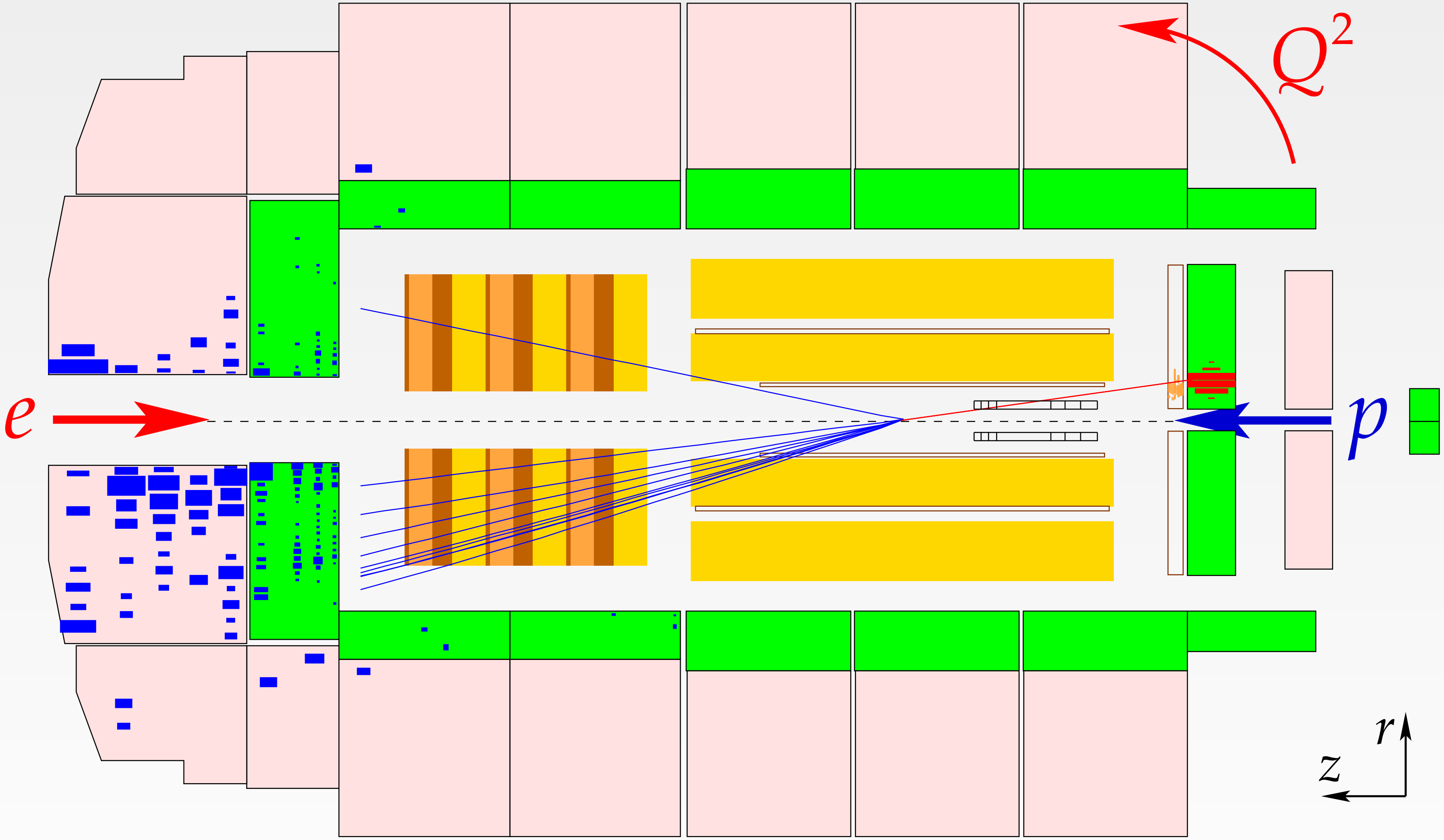
$\alpha_s(Q^2)$ becomes large $\Longrightarrow$
quark confinement
transition from quarks to hadrons
➨ phenomenological models

F_2 in pQCD Region



- Scaling violations are well described by NLO QCD DGLAP fits
- Strong rise of F_2 towards low x
- No evidence for new dynamics at low x in inclusive data
- Precision: 2 – 3% in bulk region
- Also very important for LHC

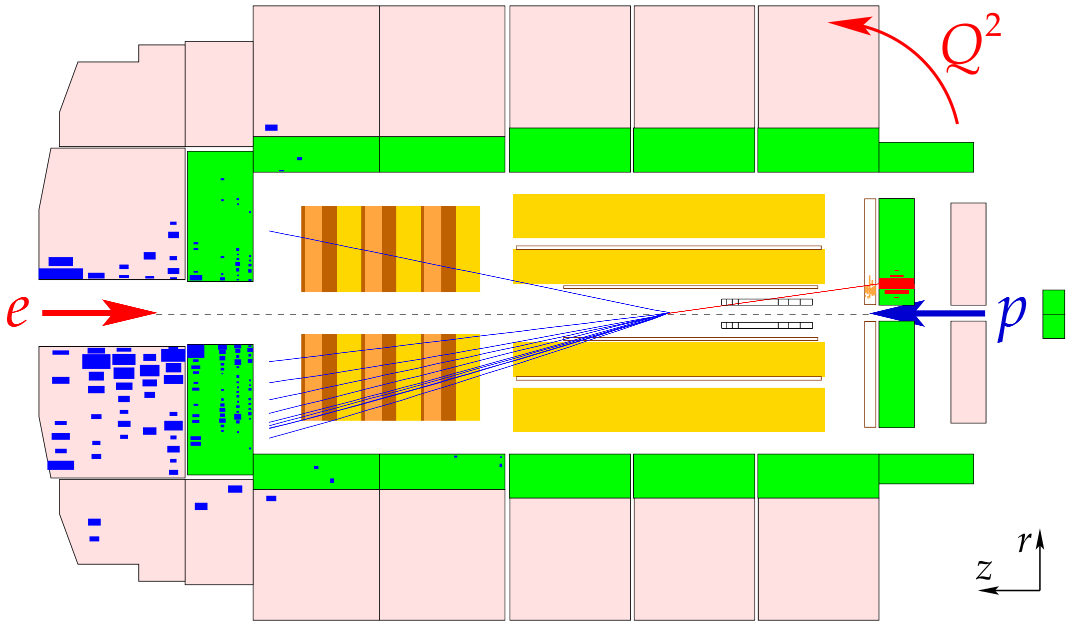
Low Q^2 DIS Event



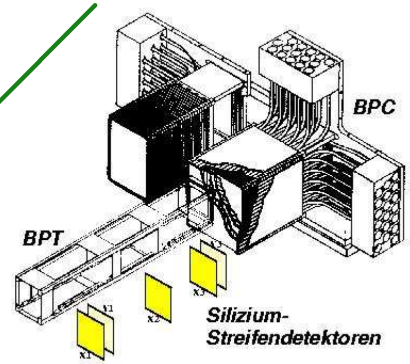
$Q^2 \sim p_{t,e}^2$ $\Longrightarrow$ *experimental challenge*

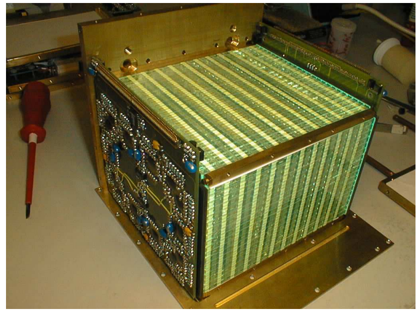
For main detector: $Q^2 \gtrsim 2\,\text{GeV}^2$

Experimental Techniques at Low Q^2

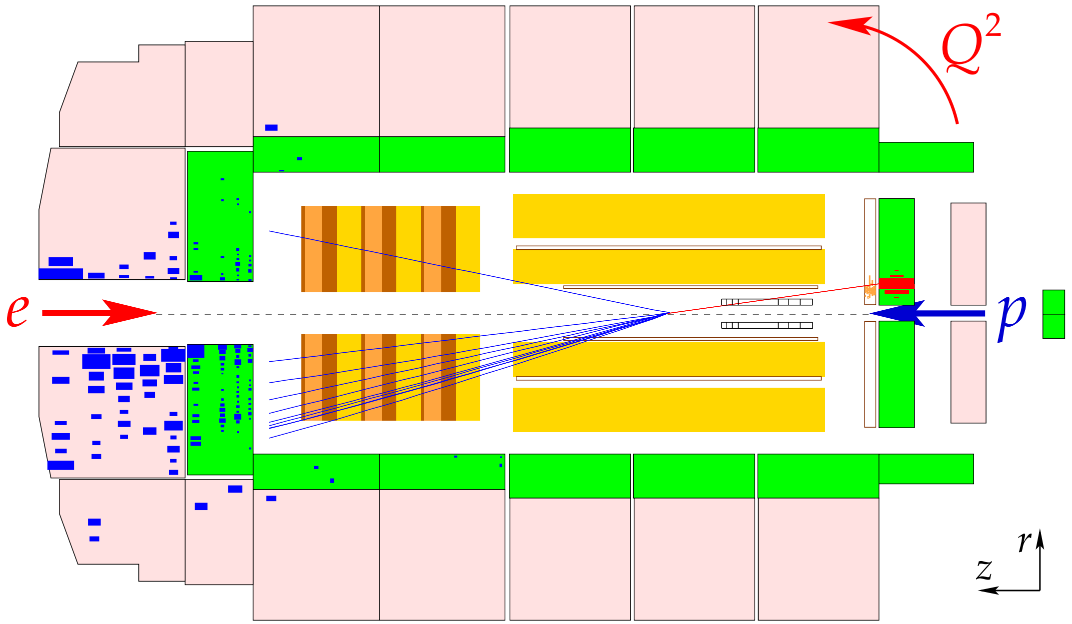


1) Very low Q^2 devices





Experimental Techniques at Low Q^2



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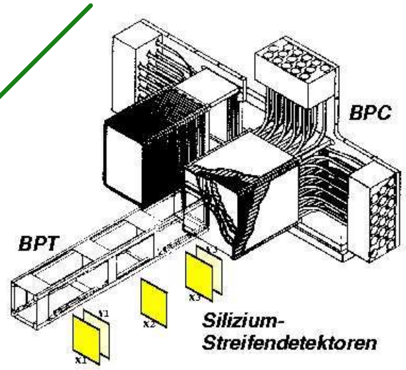
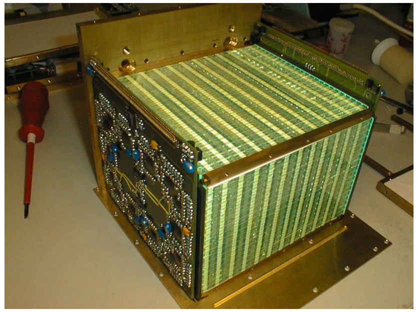
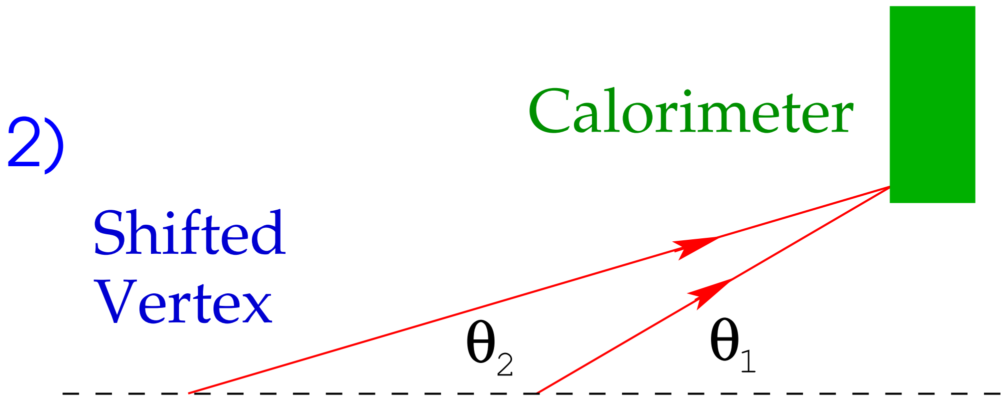
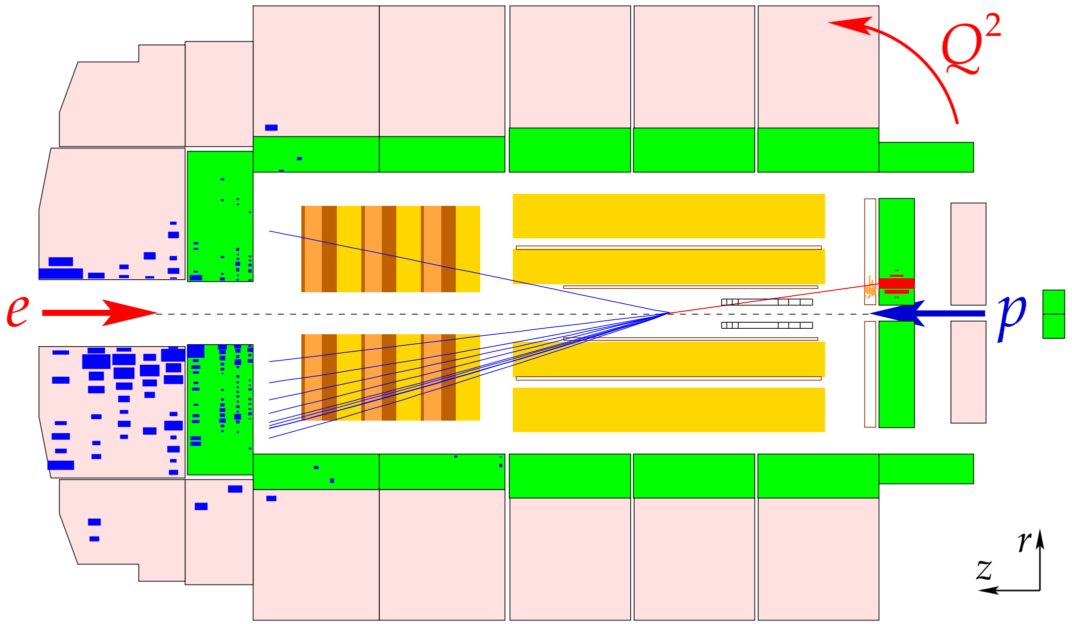




2)



Experimental Techniques at Low Q^2



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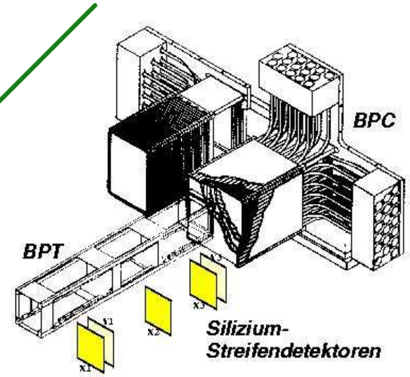
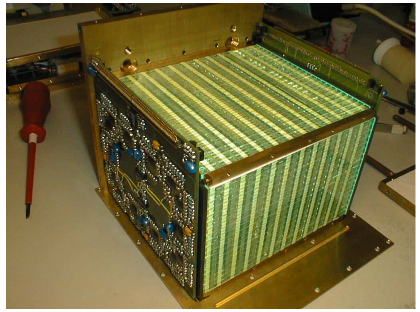
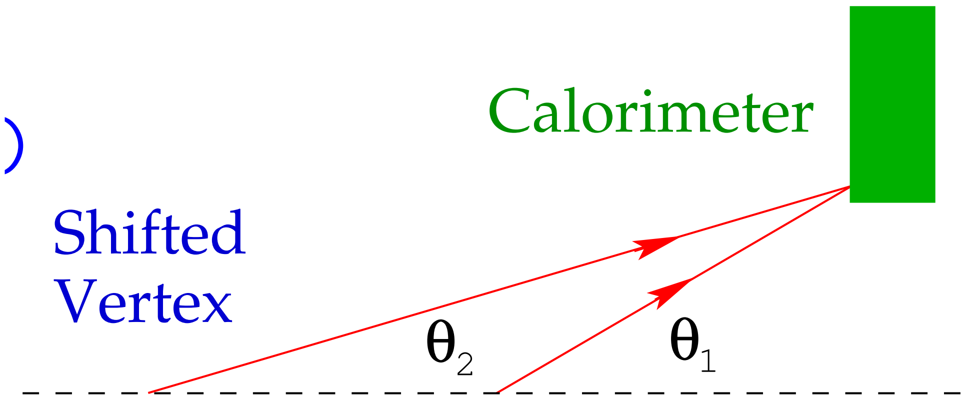


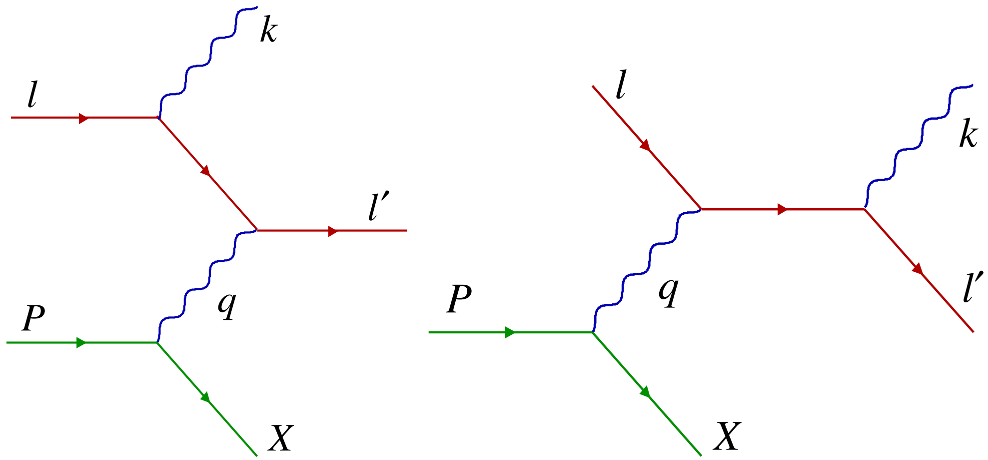


2)

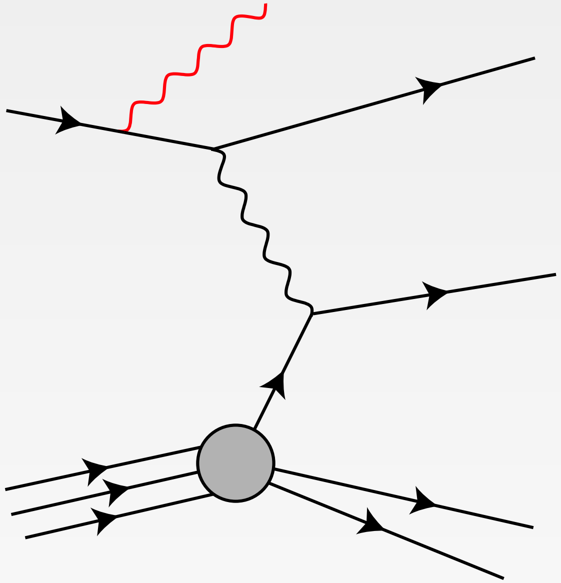
Shifted
Vertex

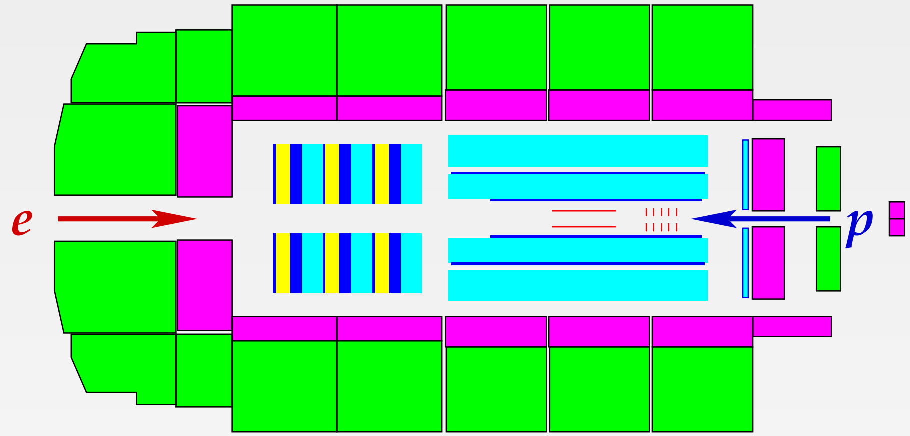


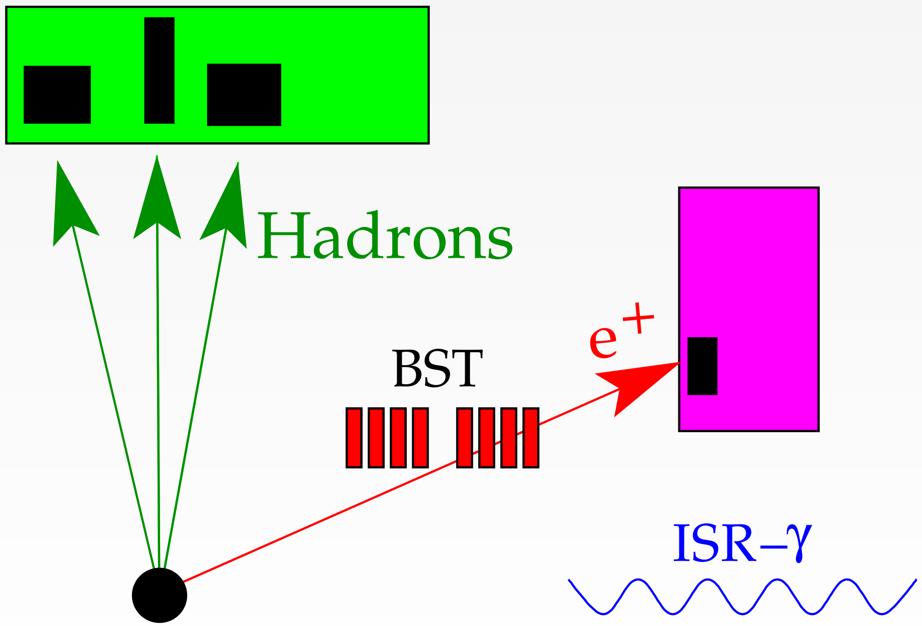
3) Radiative events



Initial State Radiation – Untagged







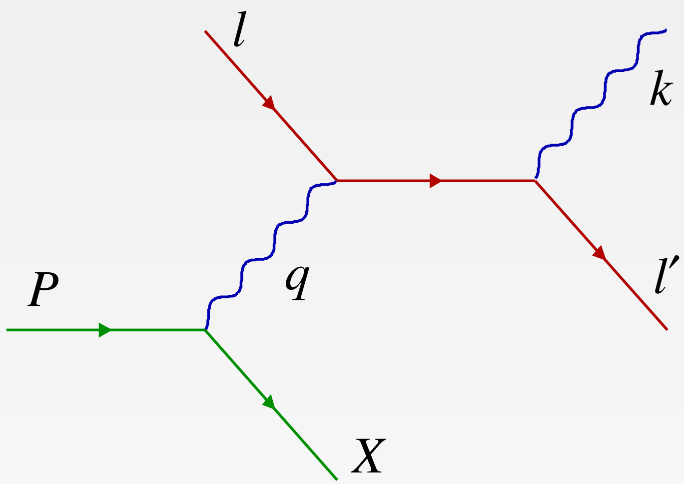
Equivalent to inclusive ep scattering at reduced s

$$Q^2 = xys$$

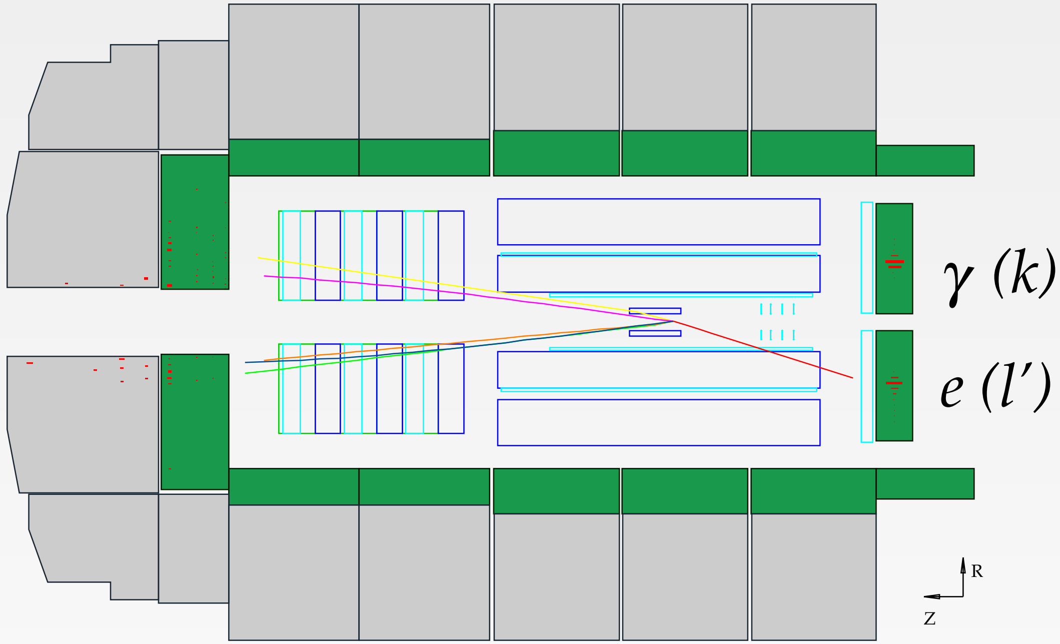
$\Rightarrow$ *Access higher* x

γp background rejected by BST

Inelastic QED Compton Scattering

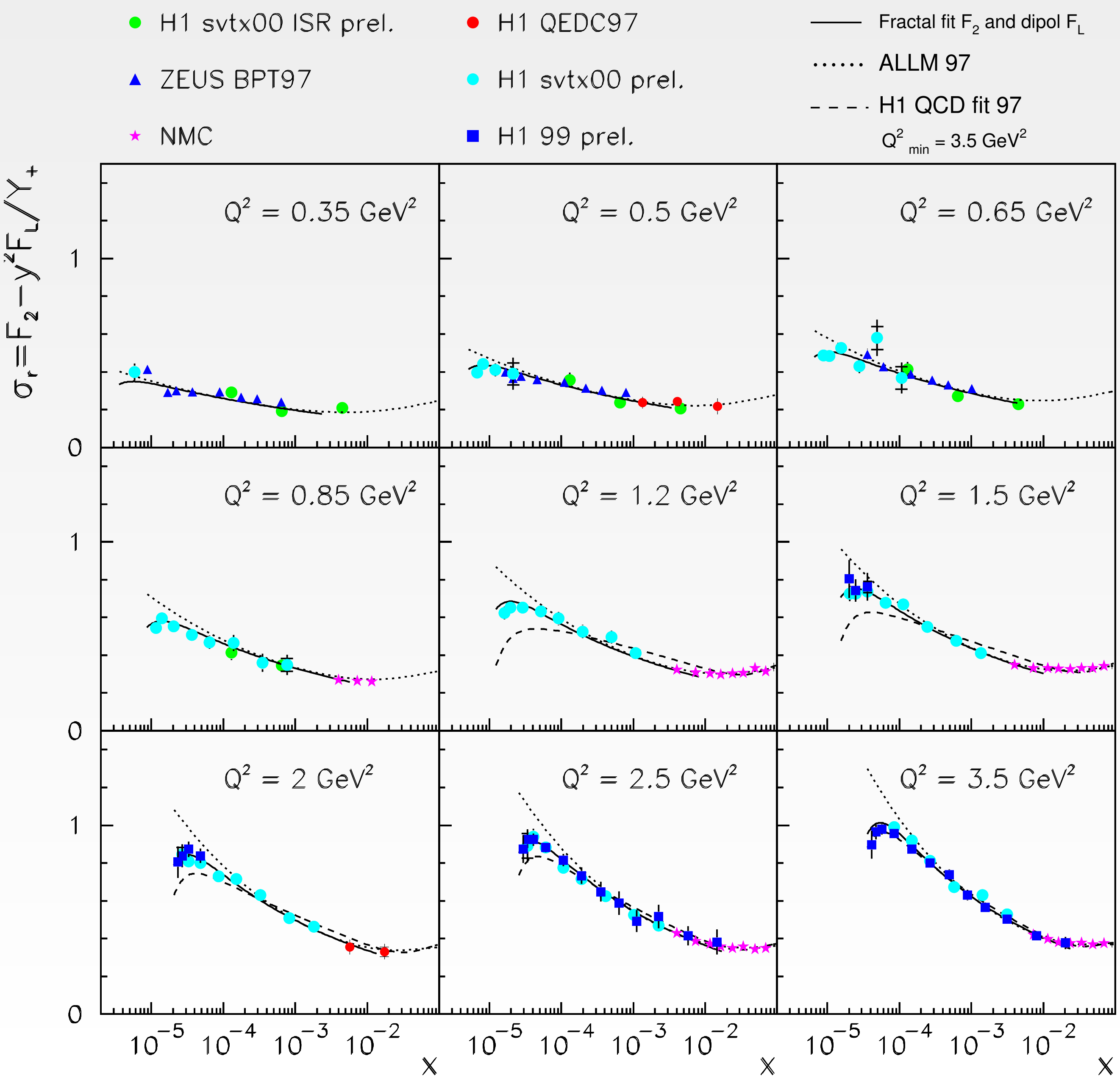


QEDC Event in H1 Detector



- Equivalent to inclusive ep scattering at low $\theta \Longrightarrow$ low Q^2
- DIS background at low x: π^0 fakes γ
- *Medium – high x are measured*
- Understanding of HFS at low masses = at low y

Current Results for Transition Region



Precision ∼2–4%
reached for inclusive data

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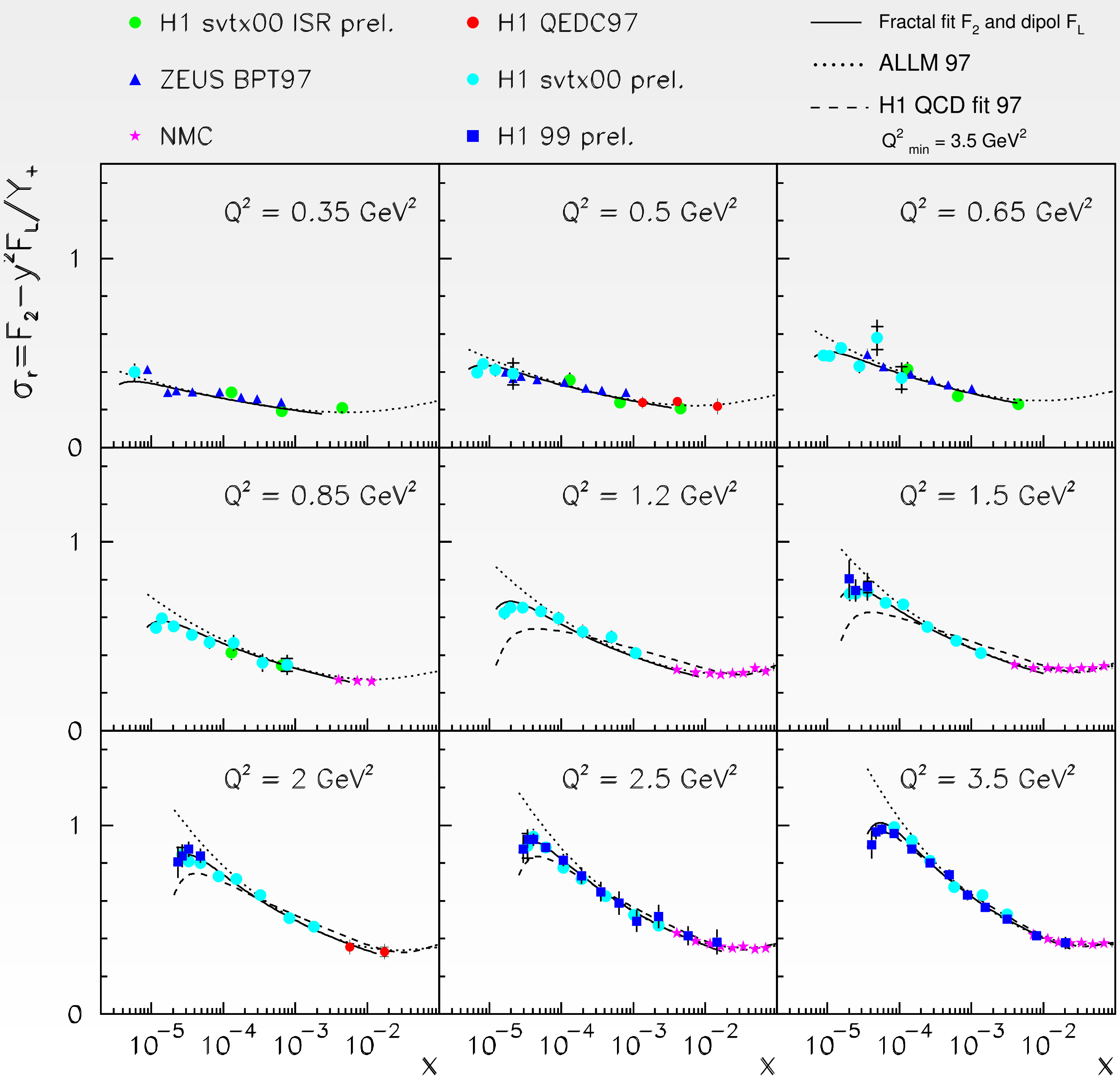

Precision ~2–4%
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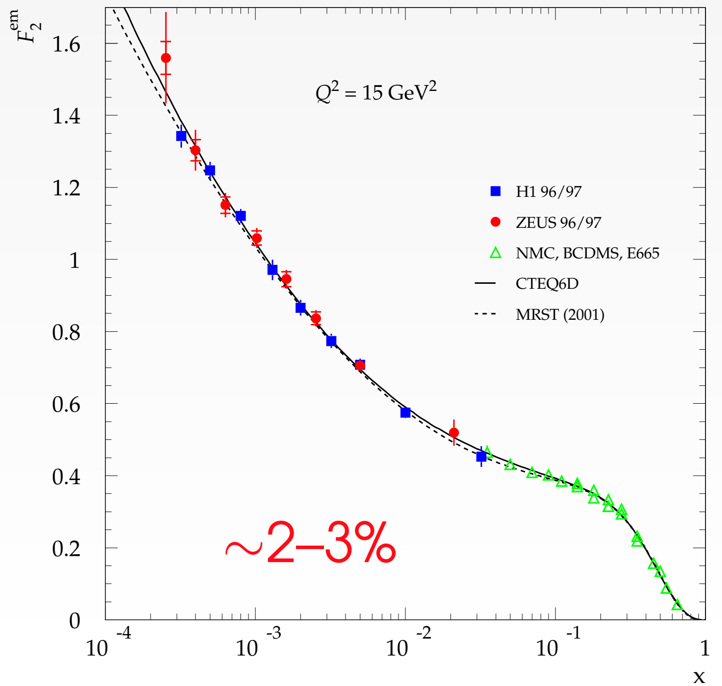
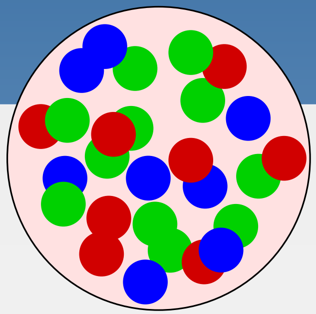


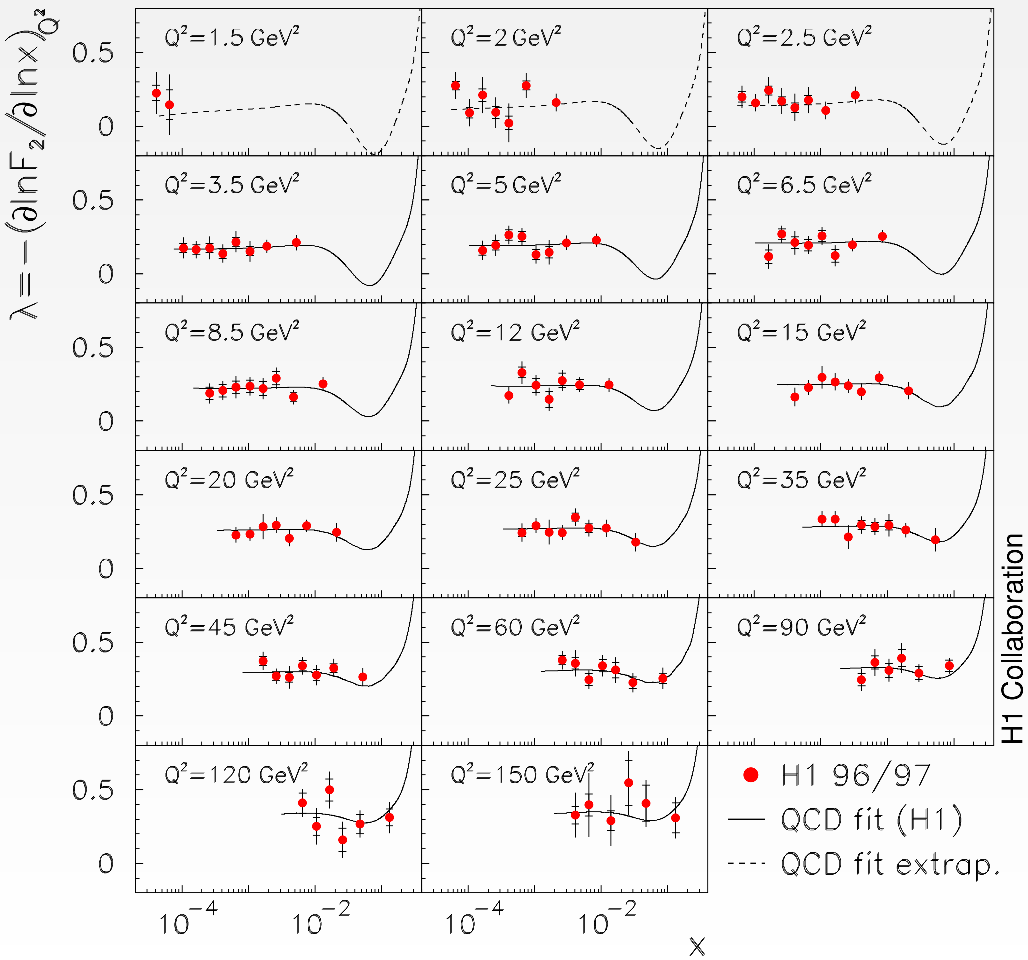
x Dependence of F_2 at Low Q^2



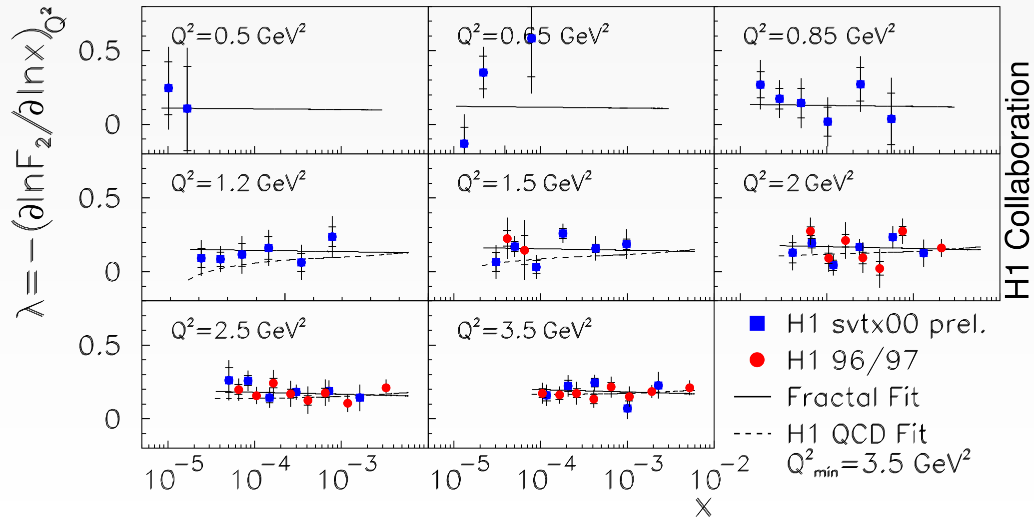
- If saturation effects present, expect taming of rise of F_2 at low x
- Extract $\lambda = \dfrac{\partial \ln F_2}{\partial \ln x}$ at fixed Q^2
- Derivative independent of x for $x < 10^{-2}$

  no evidence for saturation

pQCD region

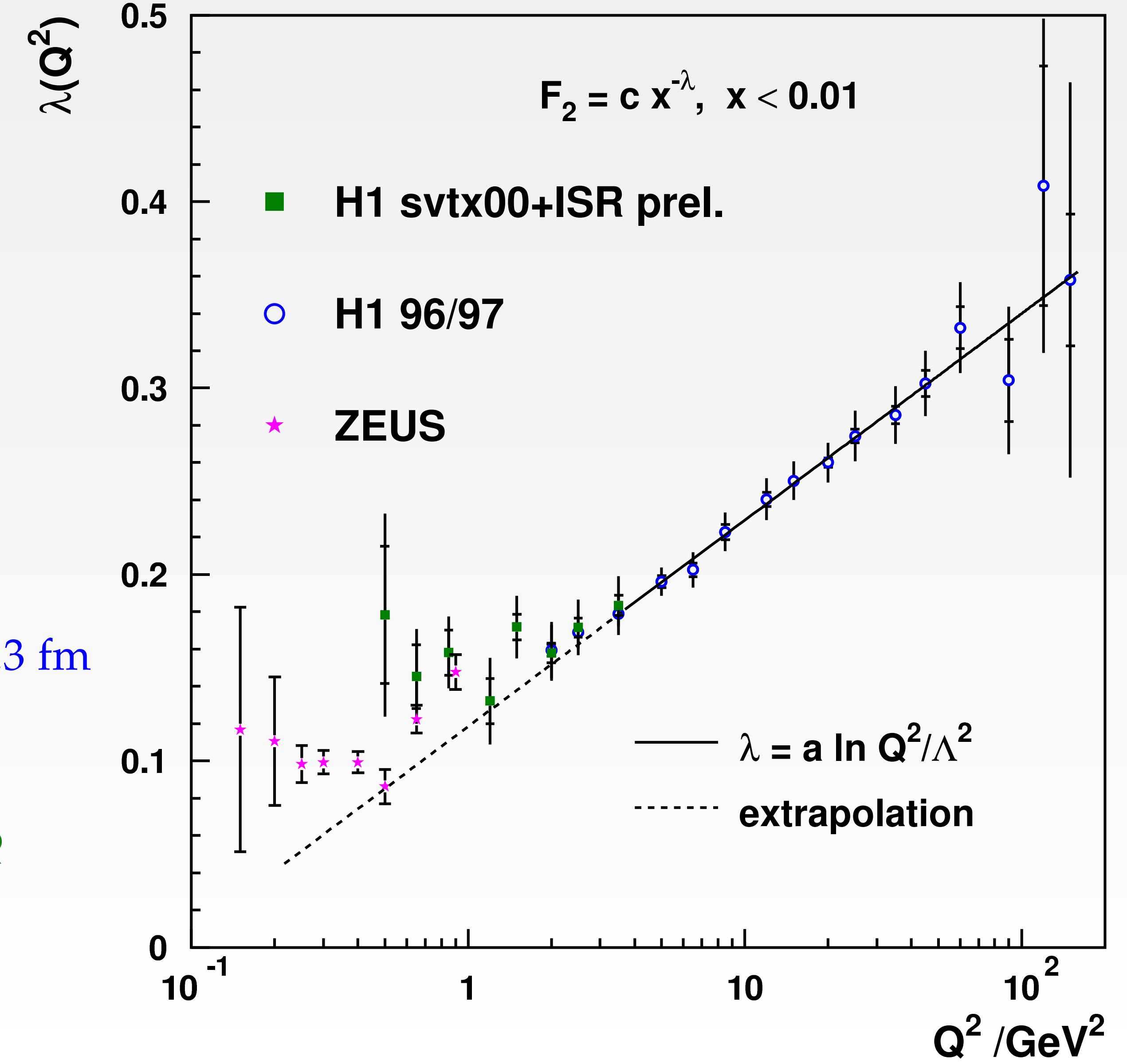


transition region



Extraction of $\lambda(Q^2)$

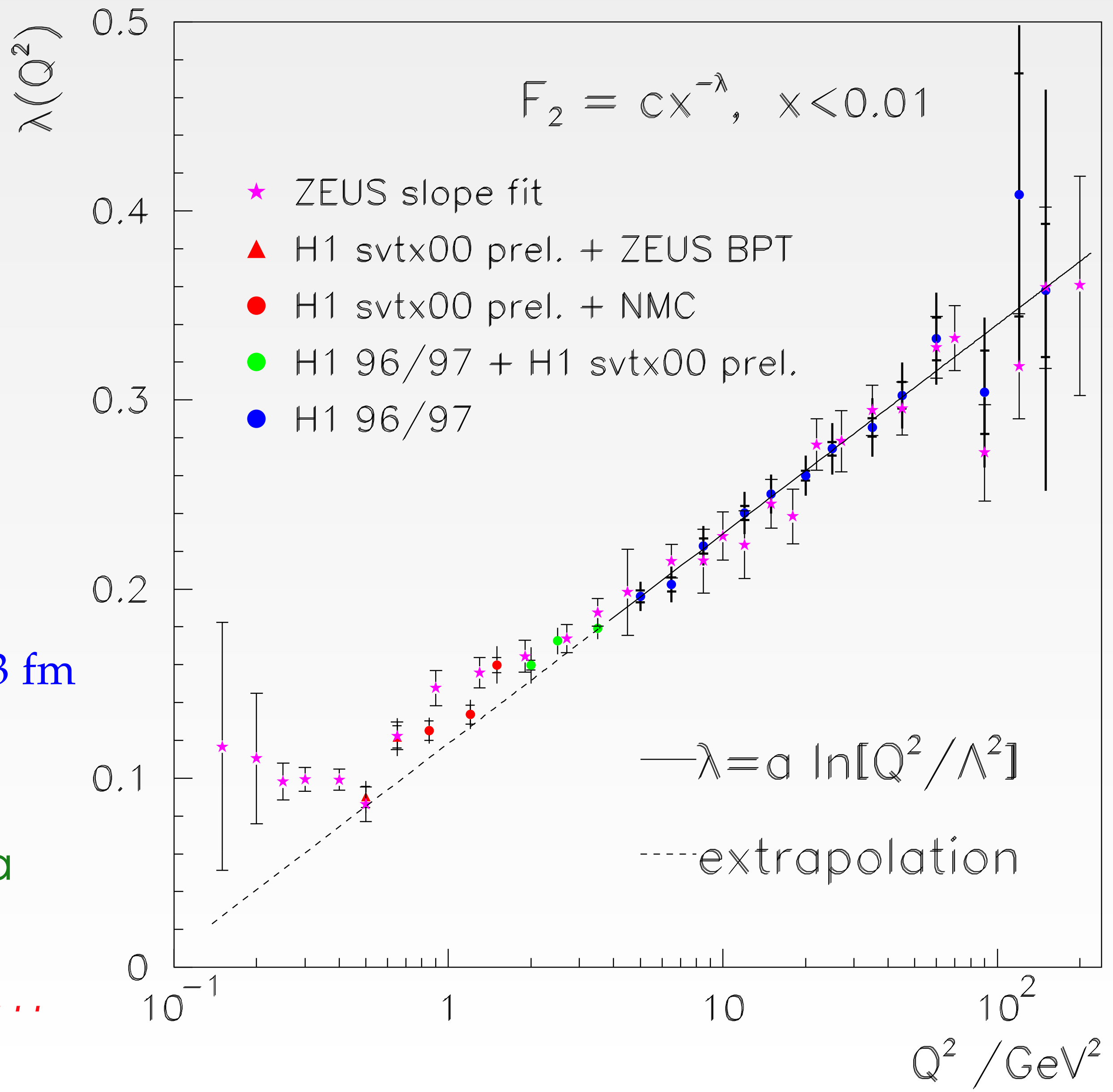
- Rise of F_2 at $x < 10^{-2}$ is well parameterised by
  $$F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$$
- At $Q^2 \gtrsim 3\,\mathrm{GeV}^2$:
  $$\lambda \sim \ln Q^2 \;,\; c \sim \mathrm{const}$$
  Partonic degrees of freedom
- At $Q^2 \lesssim 2\,\mathrm{GeV}^2$:
  Transition to hadronic d.o.f. at ~ 0.3 fm
  $Q^2 \to 0$: $\lambda \to 0.08$ (Regge model)
- H1 improved its λ extraction by ISR



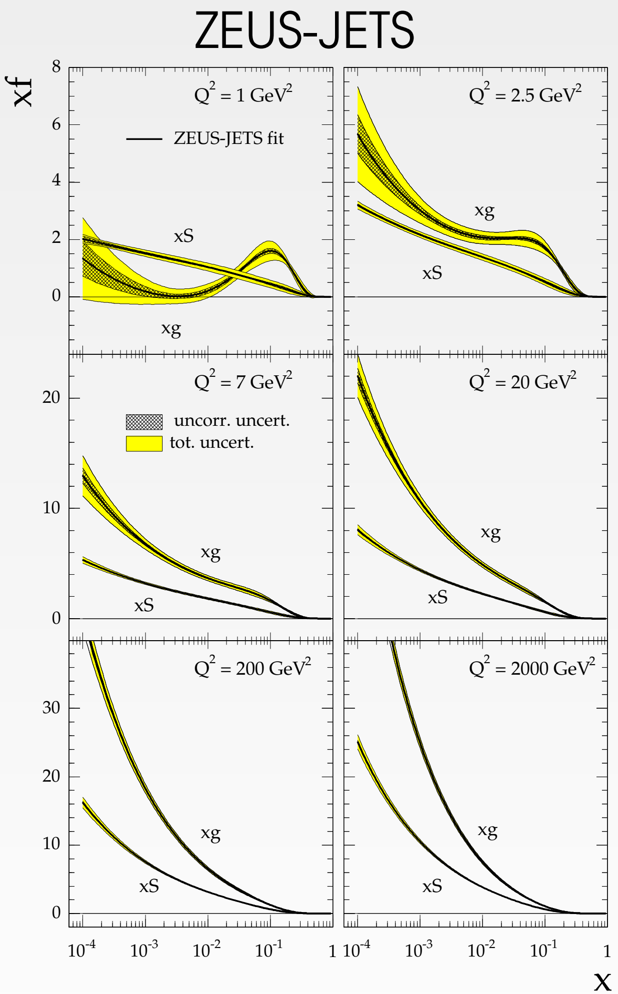
Combined Extraction of $\lambda(Q^2)$

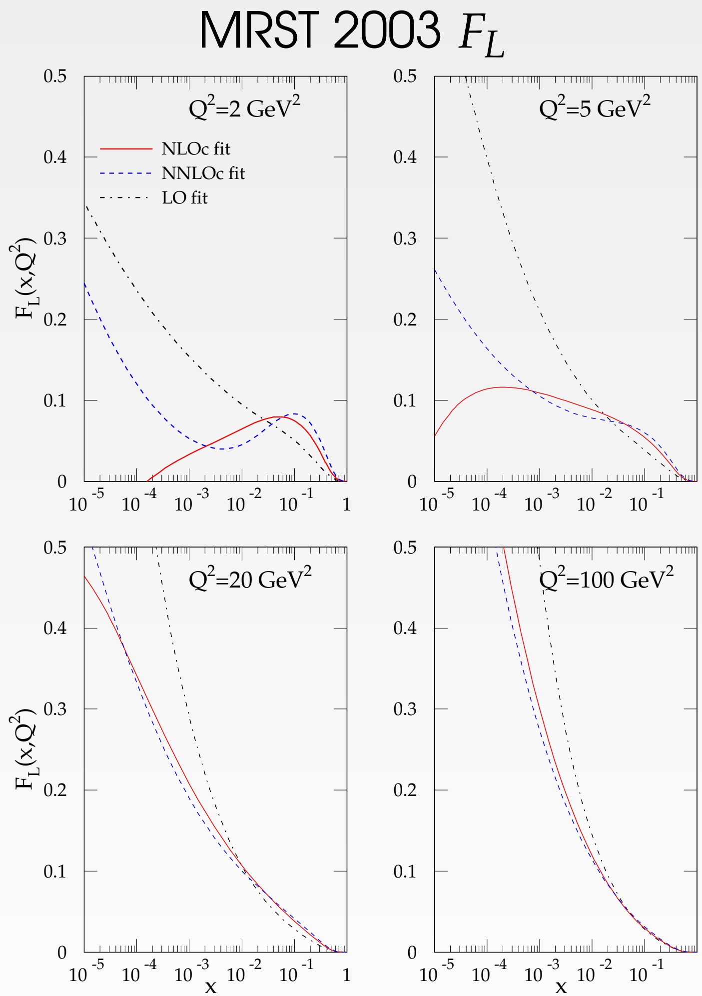
- Rise of F_2 at $x < 10^{-2}$ is well parameterised by
  $F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$
- At $Q^2 \gtrsim 3\,\mathrm{GeV}^2$:
  $\lambda \sim \ln Q^2$, $c \sim \mathrm{const}$
  Partonic degrees of freedom
- At $Q^2 \lesssim 2\,\mathrm{GeV}^2$:
  Transition to hadronic d.o.f. at ~ 0.3 fm
  $Q^2 \to 0$: $\lambda \to 0.08$ (Regge model)
- Best precision from combined data

Looking forward to the final results . . .



Gluon and F_L



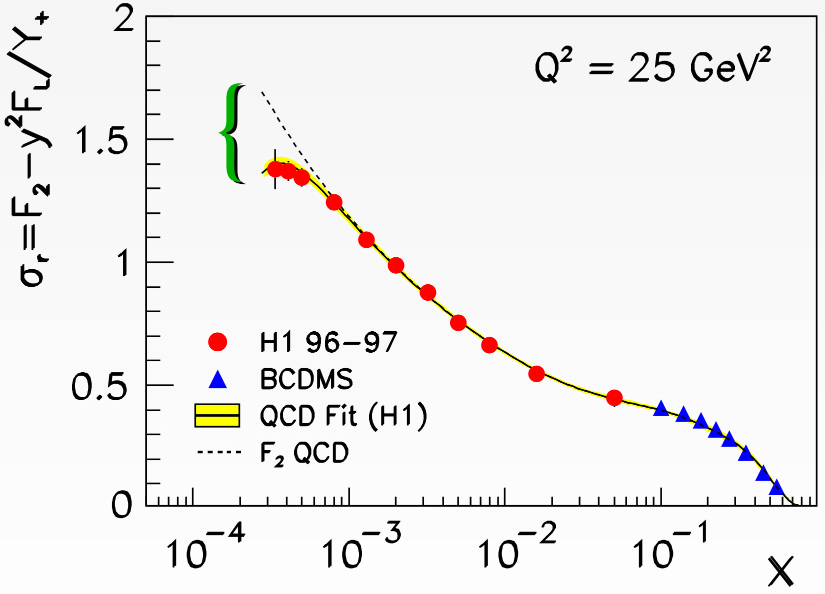


- Critical corner – low Q^2 and low x
  Gluon becomes valence-like or even negative
- Large spread of calculations for gluon and F_L

Determination of F_L

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

Reduced Cross Section



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

  $Q^2 = x\,y\,s$

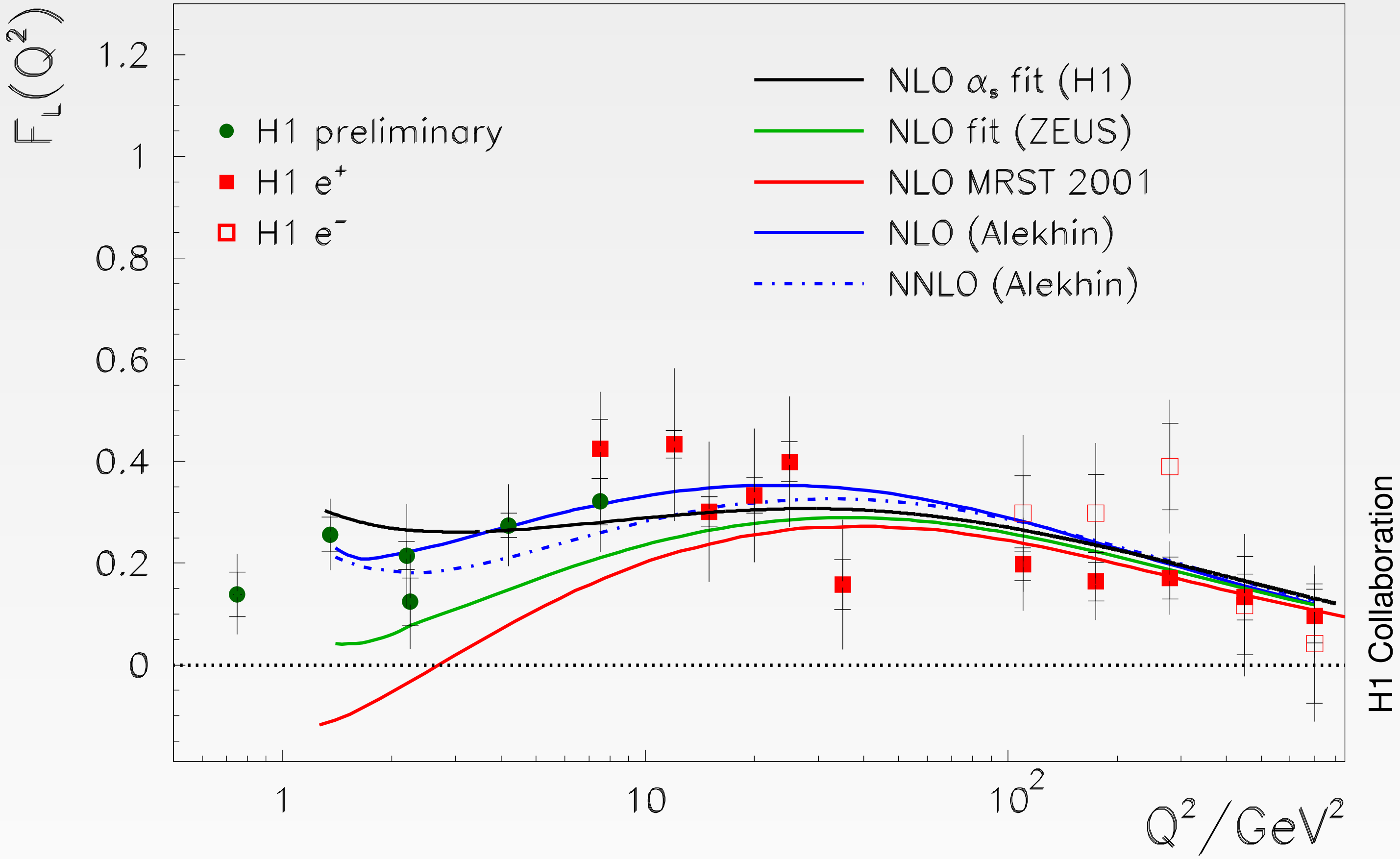
- Indirect determination at high y
  - Newest approach – Shape method

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

Shape driven by kin. factor rathen than F_L

Model dependent

F_L at Fixed $y = 0.75$

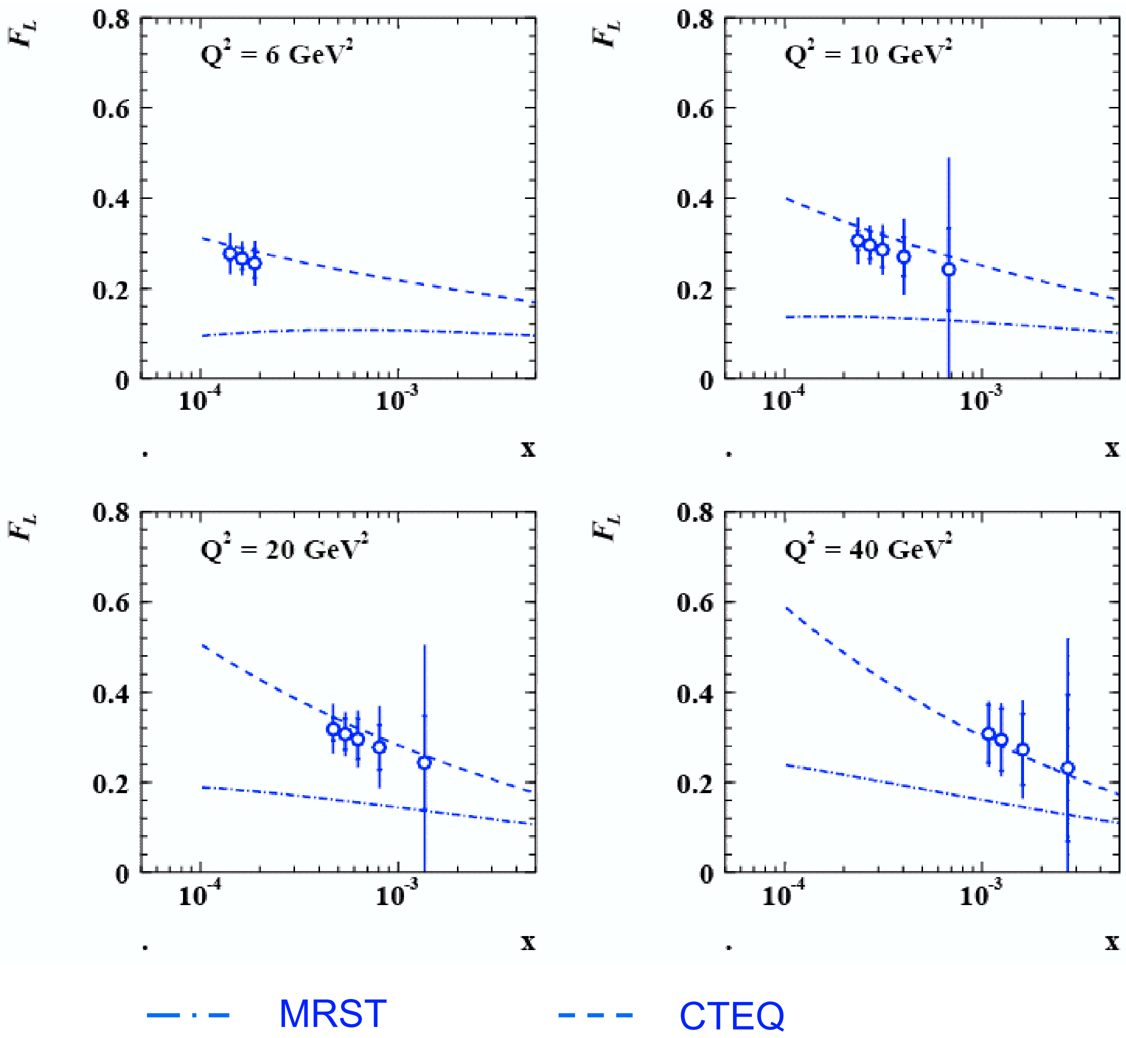


- New constraints from low Q^2 data
- F_L spans 3 orders of magnitude in Q^2
- Basic agreement with NLO pQCD fits
- Non-negligible F_L at low Q^2
- x dependence is still missing $\longrightarrow$ *need low E_p run*

Future Low Energy Run

H1 and ZEUS expressed interest to perform low E_p run

DESY Physics Research Committee recommended a run of 3 months $\approx 10\,\mathrm{pb}^{-1}$



Simulation

$30\,\mathrm{pb}^{-1}$ at $E_p = 920\,\mathrm{GeV}$

$10\,\mathrm{pb}^{-1}$ at $E_p = 460\,\mathrm{GeV}$

Abs. error $\sim 0.05 - 0.1$

Summary

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

- DIS–γp transition region is described by phenomenological models
  Accessed using special experimental techniques
  Transition occurs at ~ 0.3 fm
  Looking forward to final results

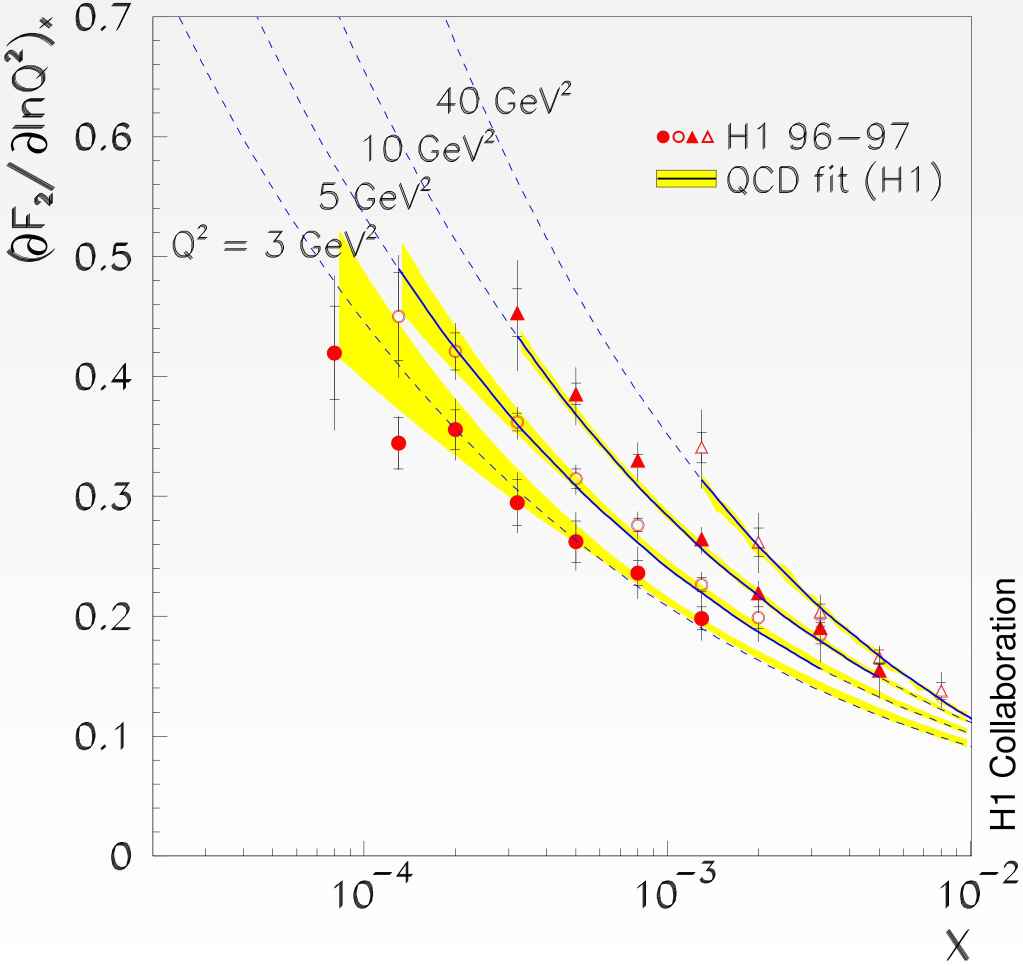
- F_L is important to pin down gluon at low Q^2 and low x
  So far determined only indirectly
  F_L is described by pQCD fits at $Q^2 > 2$ GeV^2
  $F_L > 0$ also at $Q^2 < 1$ GeV^2
  Planning low energy run at the end of HERA II

Backup

Additional Information

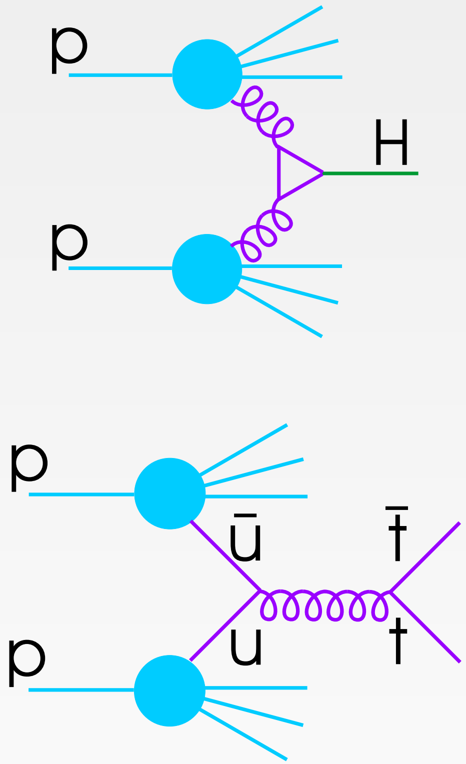
Scaling Violations at Low x

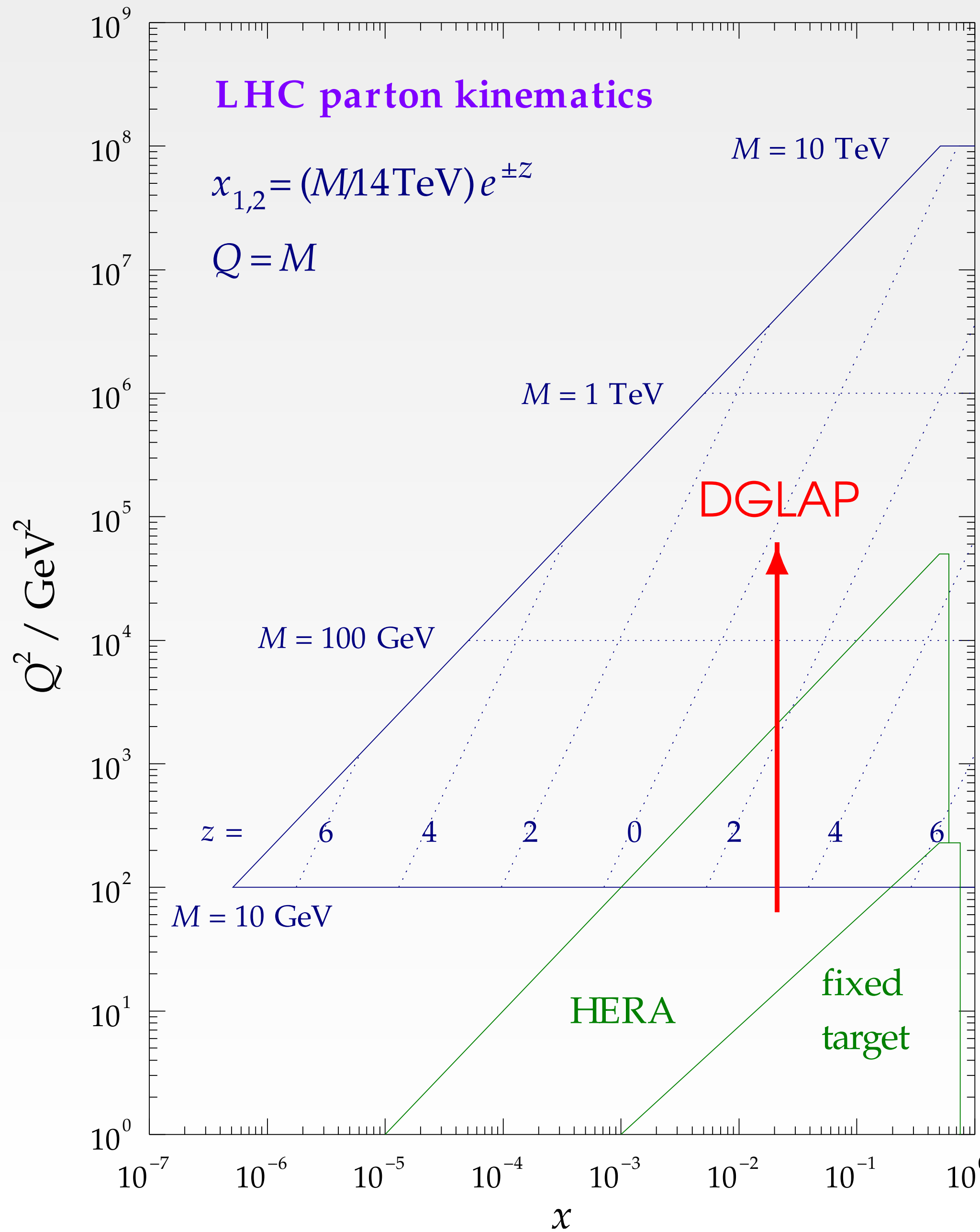
Local derivatives $$\left.\frac{\partial F_2}{\partial \ln Q^2}\right|_x \propto \alpha_s(Q^2)\, x g(x, Q^2)$$



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

PDFs for LHC





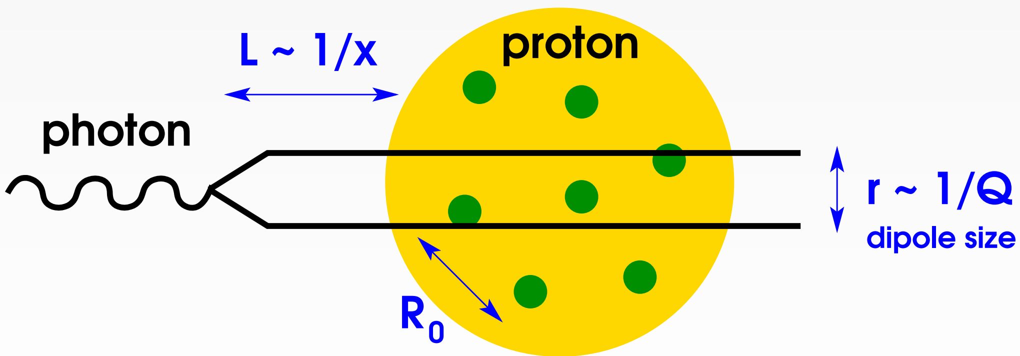
Precise quark and gluon densities are required in the whole x range to understand signal and background

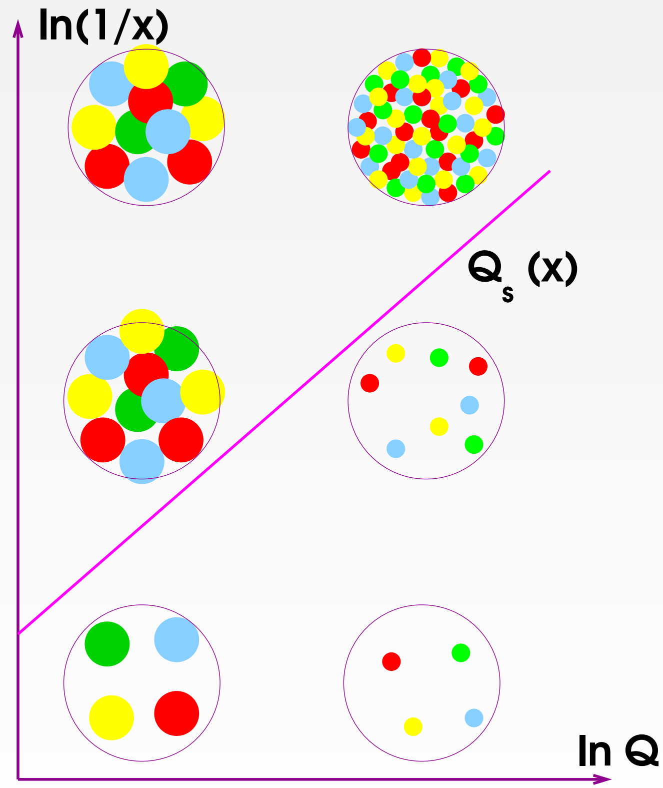
Models for Low Q^2 Region

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

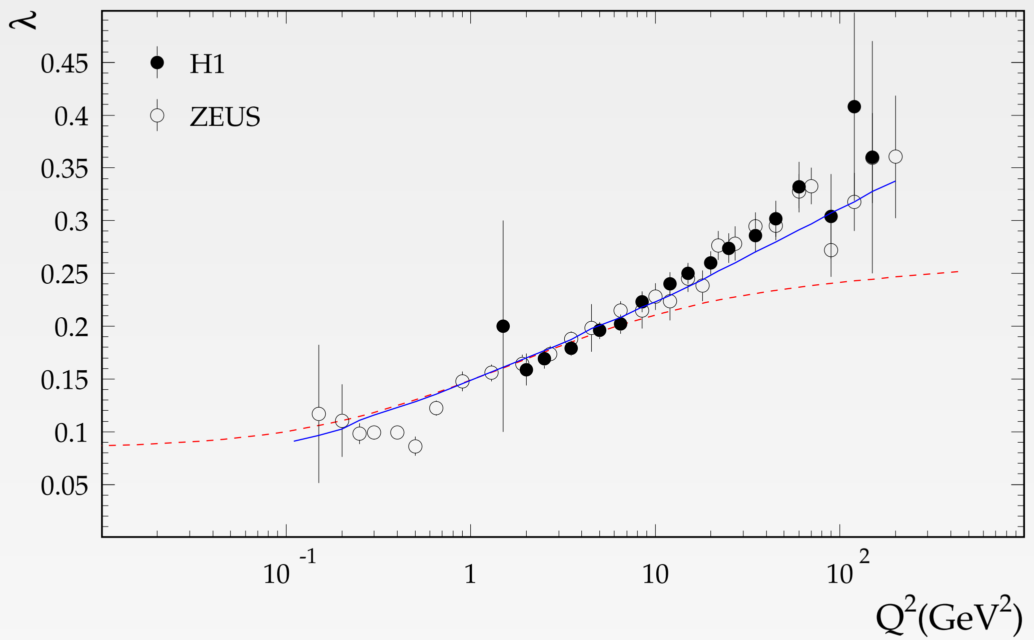
- Dipole models for low x region

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



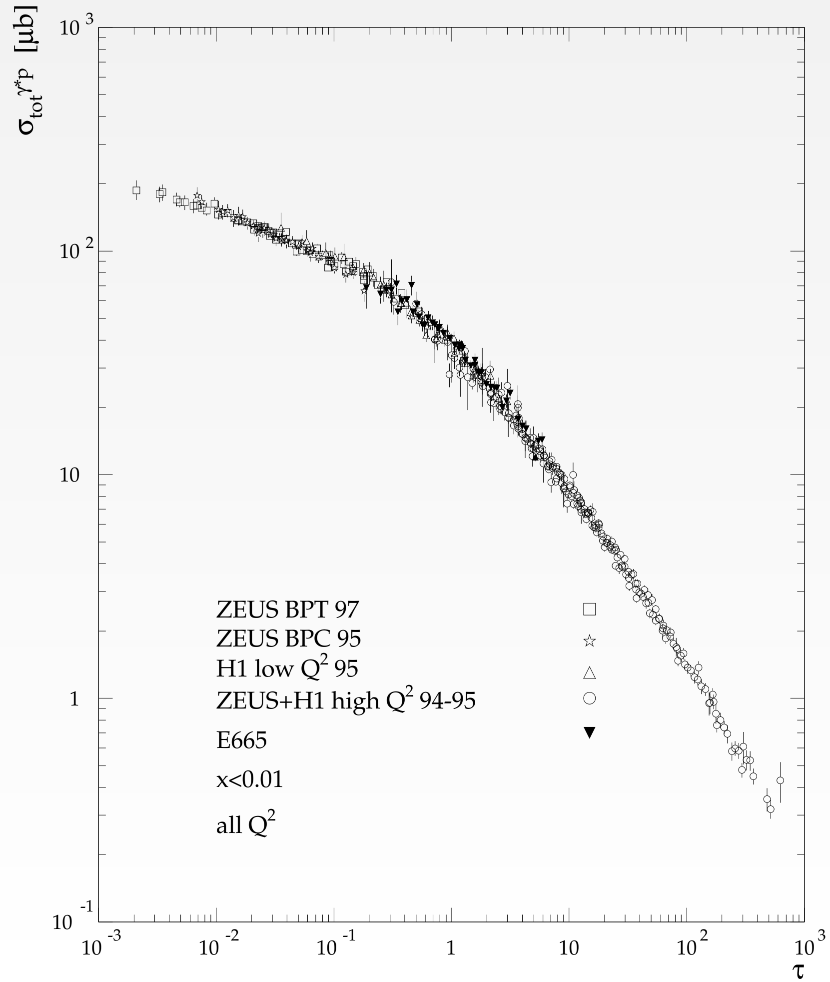


Data Are Described by Saturation Model



- 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*

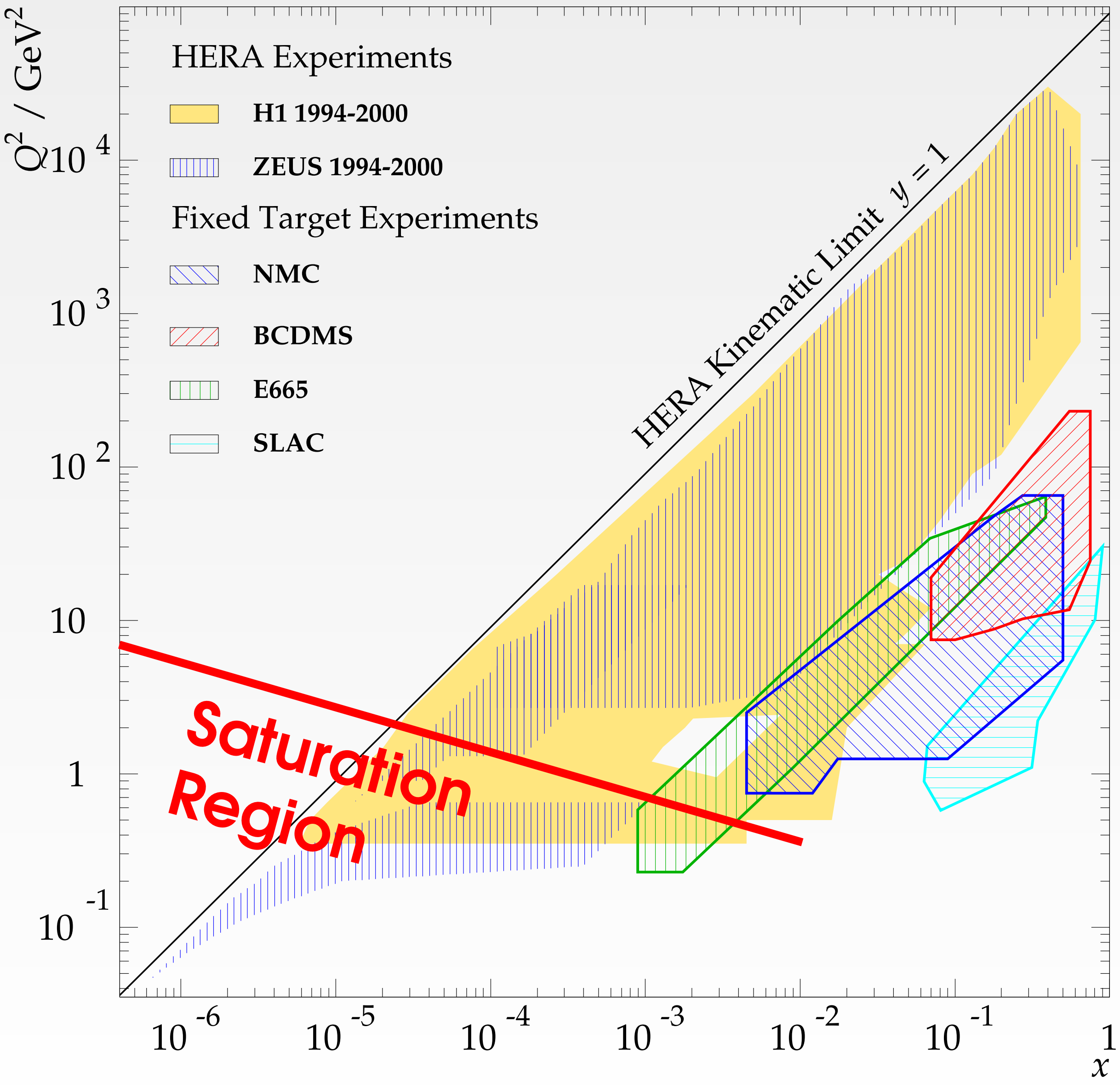
  (A.M. Stasto, K. Golec-Biernat, J. Kwieciński)

  Data manifest existence of saturation scale as used in saturation model

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

- Also describes F_L

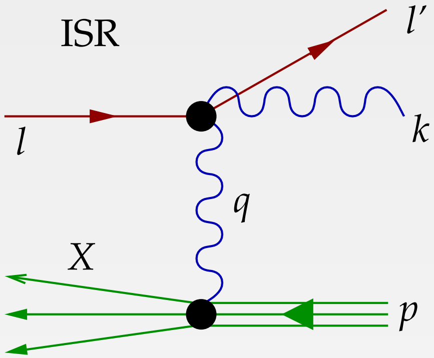
Saturation Region in Dipole Model

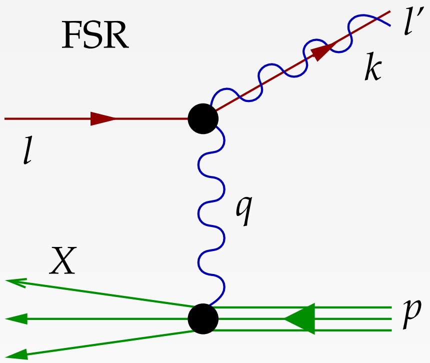


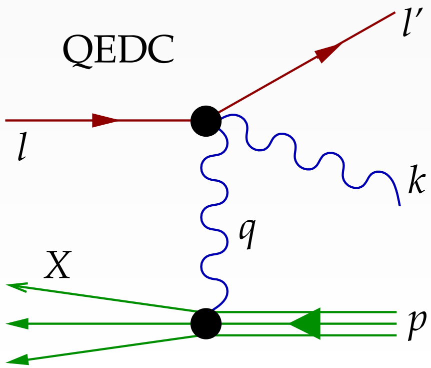
- For pQCD Q^2 scales saturation region is beyond HERA reach
- For $Q^2 \lesssim 1 - 2\,\mathrm{GeV}^2$ saturation model claims we see saturation

Appealing but not compelling

Photon Radiation from Lepton Line







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

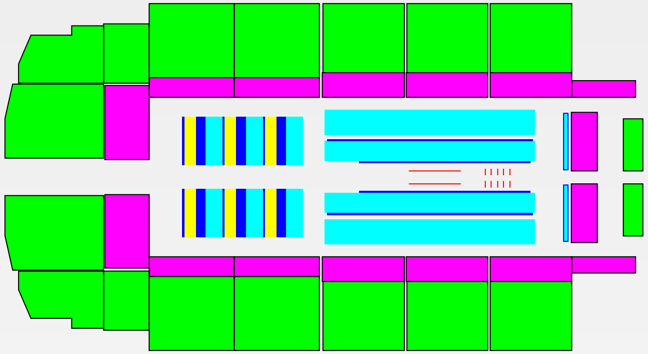
Modified kinematics

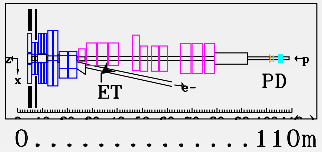
Access lower Q^2 and higher x

Distinct topologies:

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

ISR Event in H1 Detector



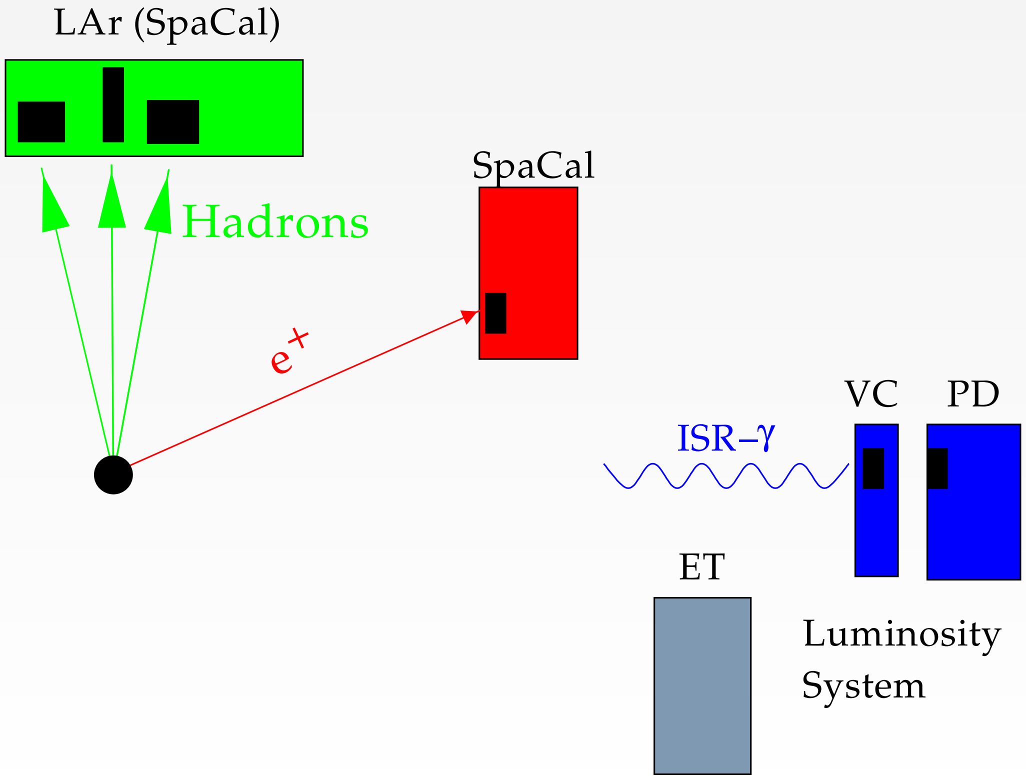


Access lower Q^2

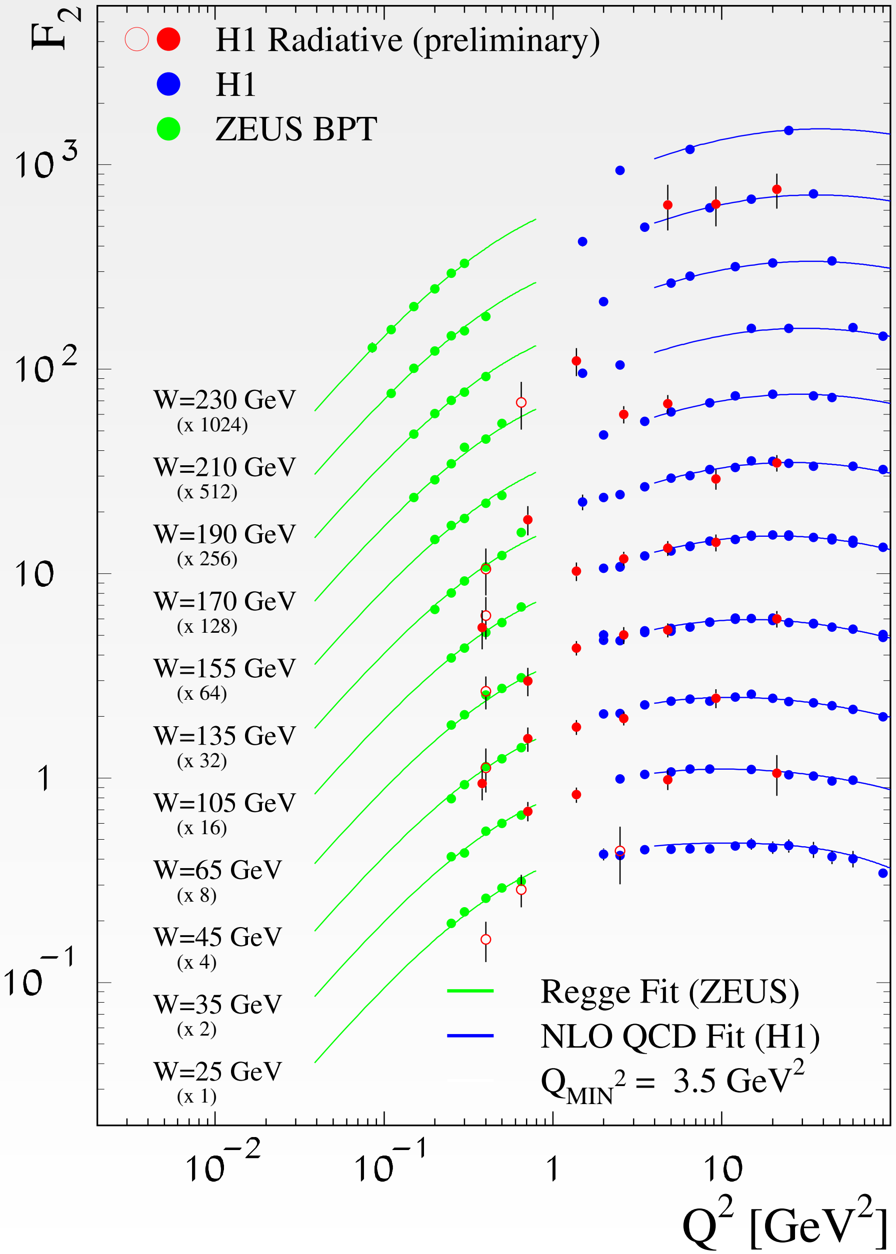
Additional experimental challenges

- Detector acceptance and calibration
- Backgrounds from event overlaps

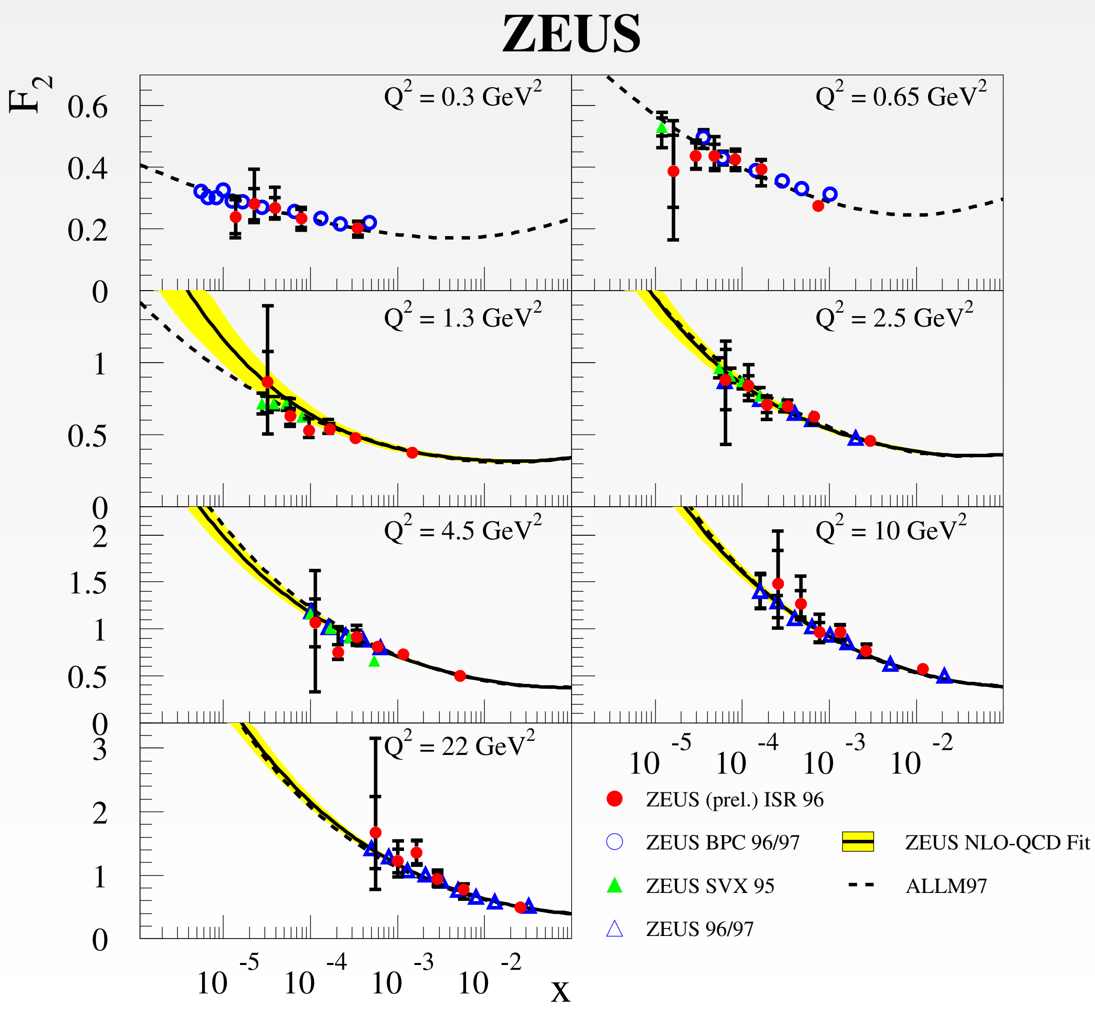
(DIS + BH, γp + BH, ISR + BH)



Preliminary Results: F_2 in ISR

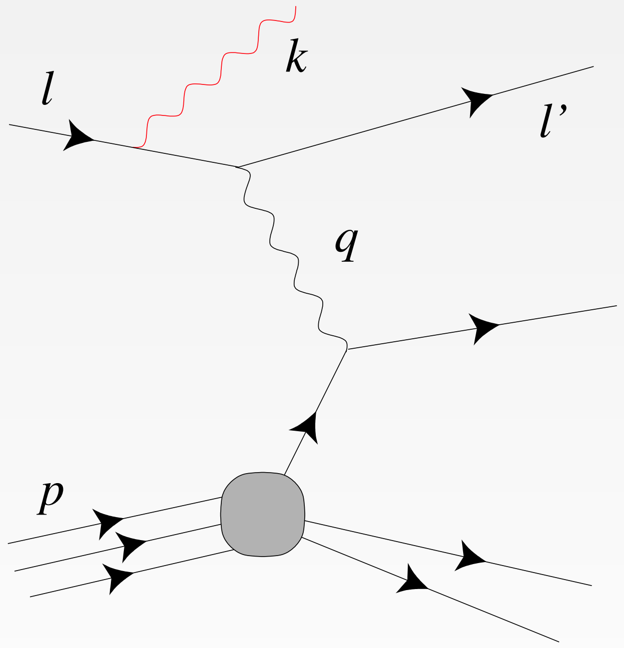


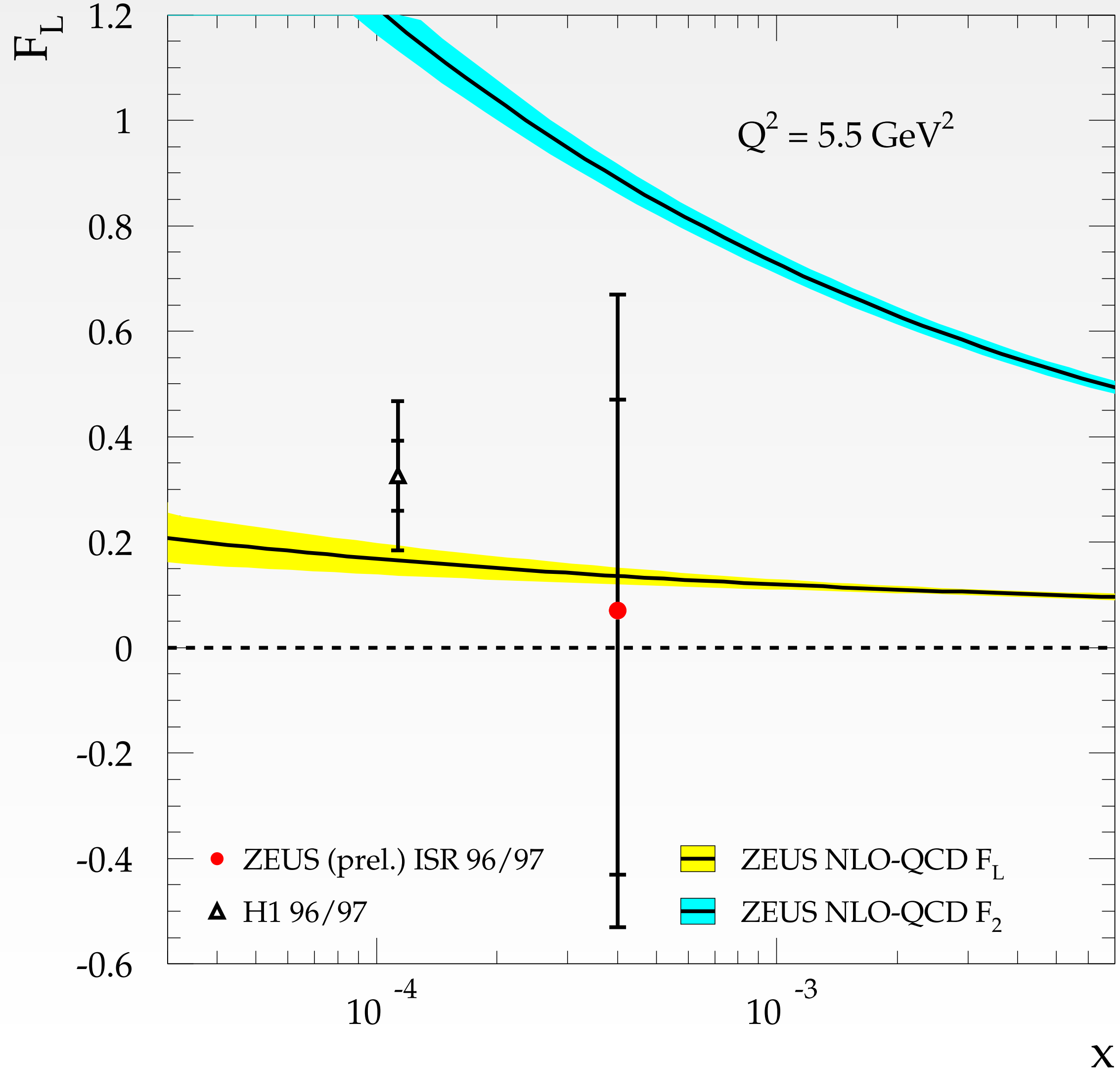
Access both perturbative and non-perturbative domain



Direct Determination of F_L

Modified kinematics:
interpret as incident $E = E_{e-\text{beam}} - E_\gamma$





Need much more ISR statistics