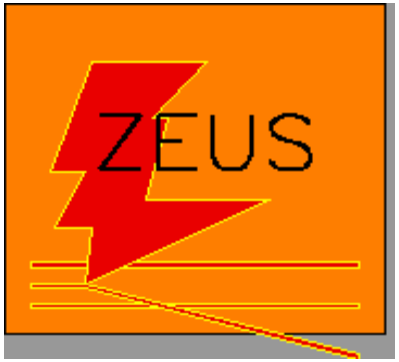
Structure Functions and the Transition Region from Photoproduction to DIS

Ringberg Workshop: New Trends in HERA Physics 2003

Dorian Kcira

University of Wisconsin



Outline

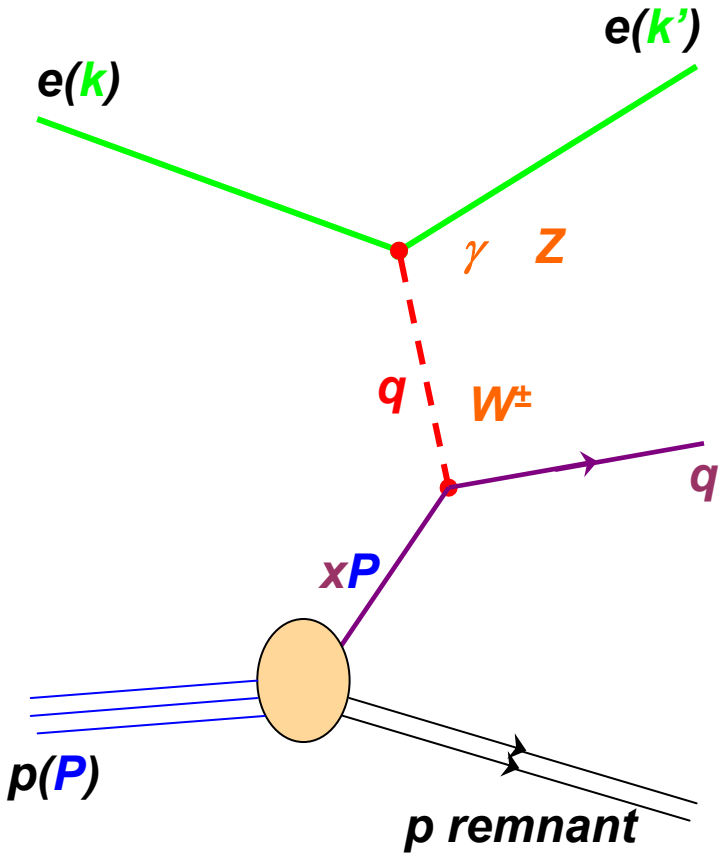
- New H1 and ZEUS inclusive measurements in the transition region
- Dijet measurements in the transition region.

Transition Region from DIS to PHP
The hard and soft regimes of QCD

At HERA: probe proton with photon of virtuality: $Q^2 = -q^2 = -(k-k')^2$

Hard scale = Q^2. Three regions:

- DIS/ high Q^2 – hard regime, α_s small, pQCD reliable and very succesful in describing hard scattering
- PHP/low Q^2 (≈ 0) – soft regime, αs large, pQCD breaks down, non-perturbative region. Use phenomenological models (Regge, etc.)
- Transition region – between low and high Q^2, in this case between perturbative and non-perturbative regimes. Can we merge them into a unified QCD picture ? HERA plays important role.



New measurements in transition region

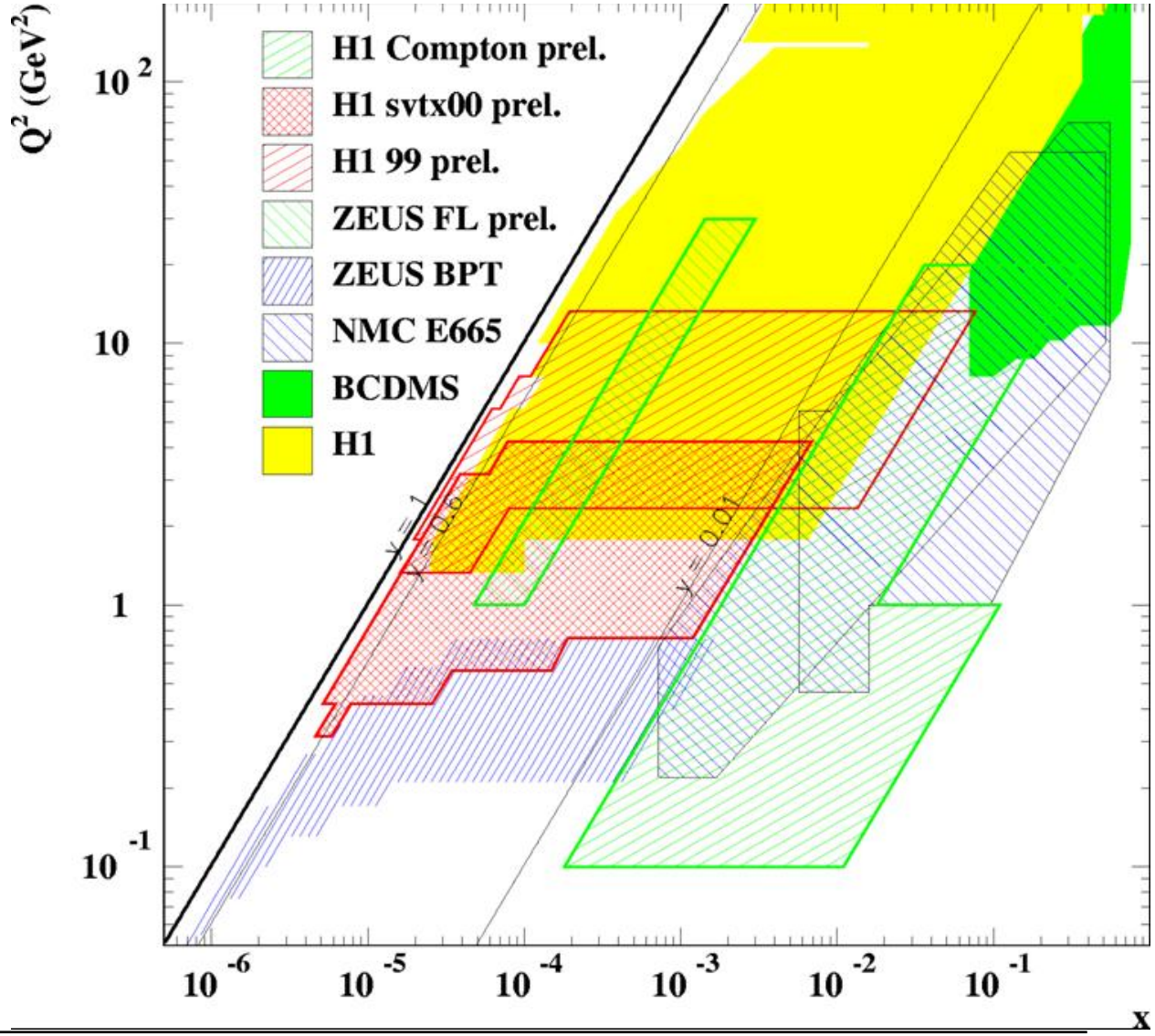
Precise measurements cover transition region around Q^2 = 1GeV^2 in a wide range of x

Previous measurement:

- ZEUS BPC/BPT

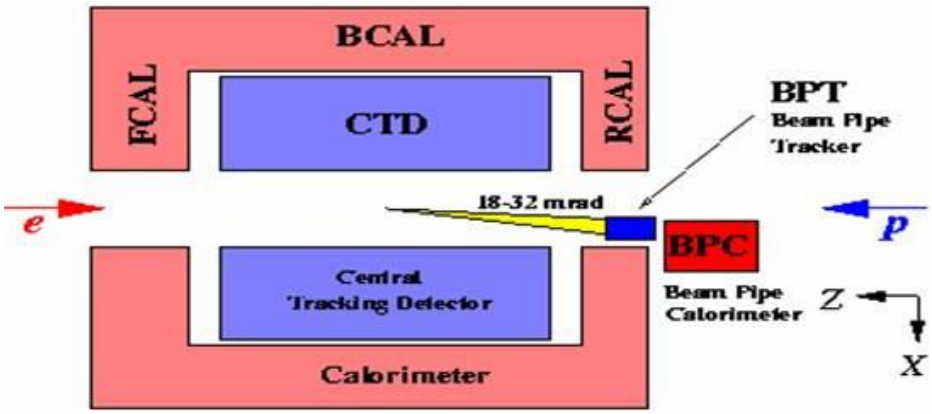
This talk:

- H1 1999 (minimum bias)
- H1 2000 shifted vertex
- H1 1997 QED Compton
- ZEUS ISR (F_L part: see talk from V.Chekelian)



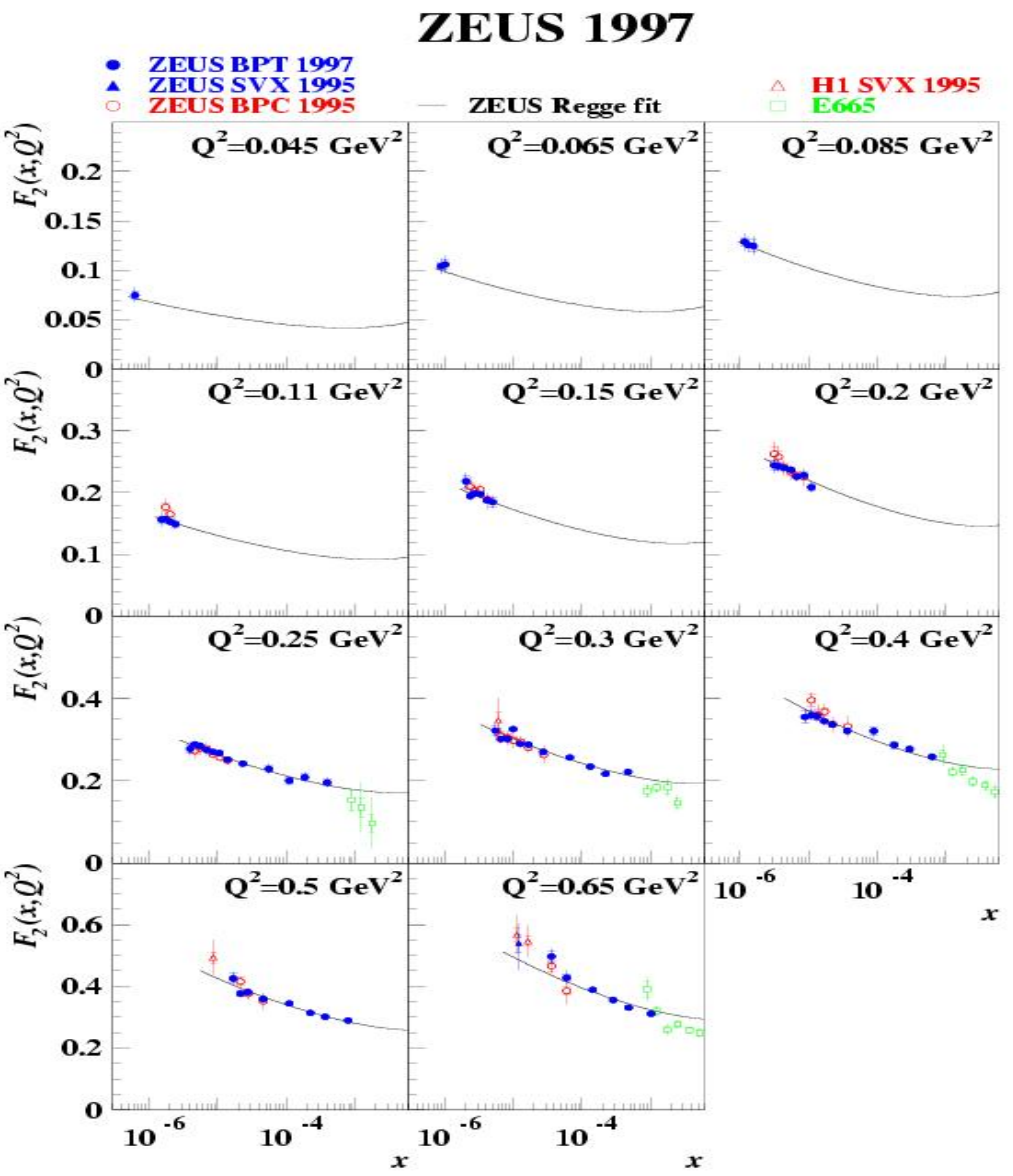
Previous results – ZEUS BPC/BPT

$Q^2 \approx 2\, E_e\, E_{e'}\, (1 + \cos(\theta_{e'}))$



3.9 pb^{-1} at very low Q^2 and x:

- $0.045 < Q^2 < 0.65\ GeV^2$
- $10^{-7} < x < 10^{-3}$



- Rise of F_2 at low x continues at low Q^2 but is shallower.
- Good description from Regge fit:

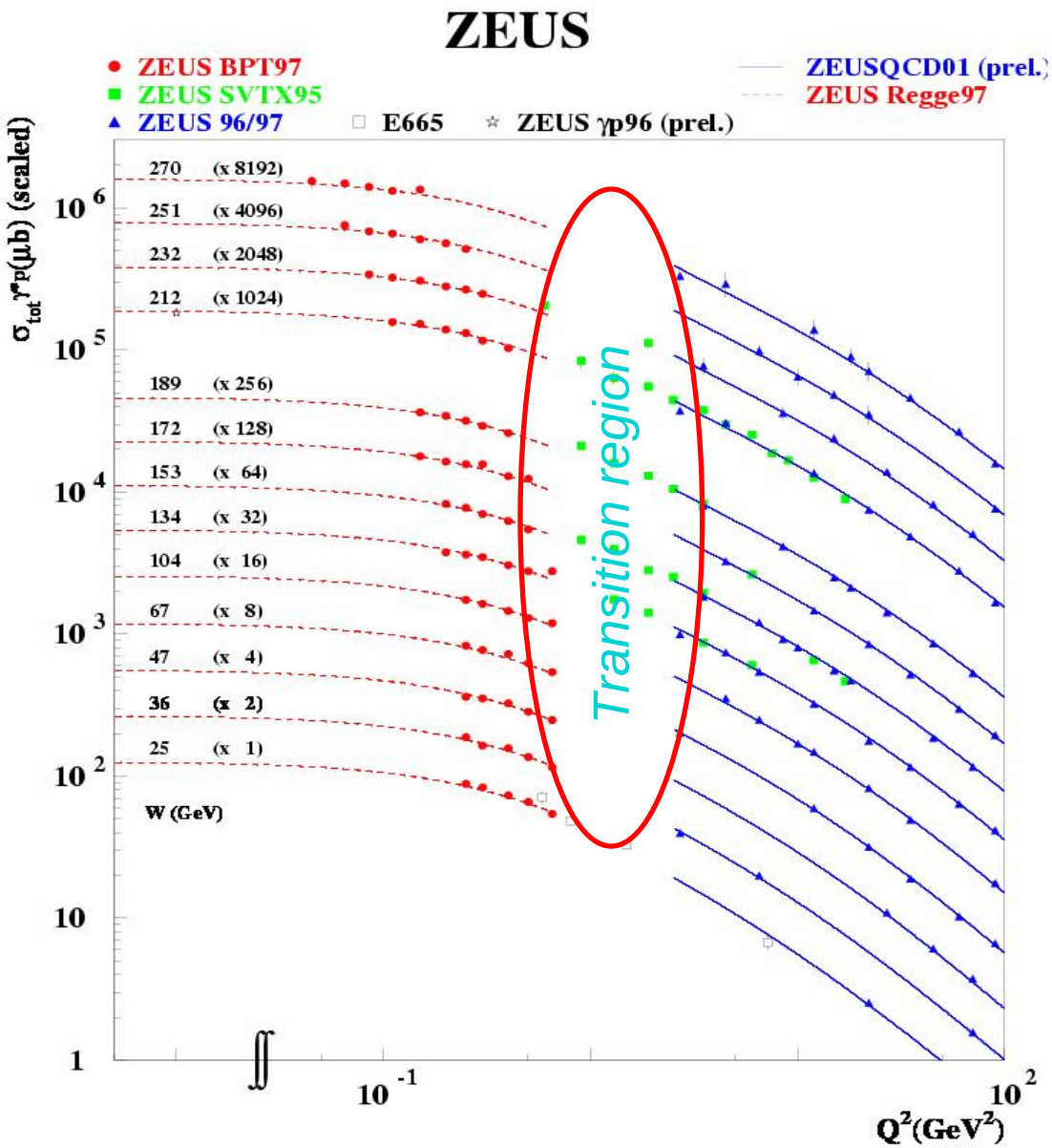
$$F_2(x,Q^2) = \left(\frac{Q^2}{4\pi^2\alpha}\right) \cdot \left(\frac{M_0^2}{M_0^2+Q^2}\right) \cdot \left(A_{I\!R} \cdot \left(\frac{Q^2}{x}\right)^{\alpha_{I\!R}-1} + A_{I\!P} \cdot \left(\frac{Q^2}{x}\right)^{\alpha_{I\!P}-1}\right)$$

Structure functions at low Q2,

Previous results – ZEUS BPC/BPT

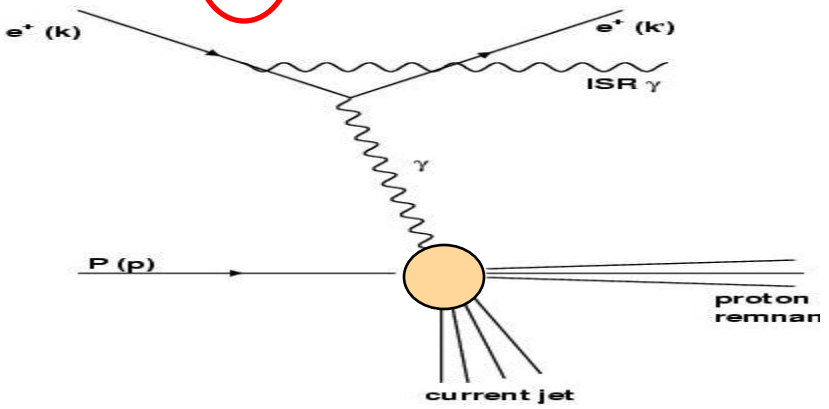
$\sigma_{tot} \sim F_2/Q^2$ vs. Q^2, fixed W

- low Q^2 REGGE fit ($Q^2_{max} = 0.65\ GeV^2$)
- high Q^2 NLO QCD fit ($Q^2min = 2.5GeV^2$)
- low Q^2: $F_2 \sim Q^2$
- Transition region: few shifted vertex data with large errors.



ZEUS: Initial State Radiation

$Q^2 \approx 2\, E_e\, E_{e'}\, (1 + \cos(\theta_{e'}))$



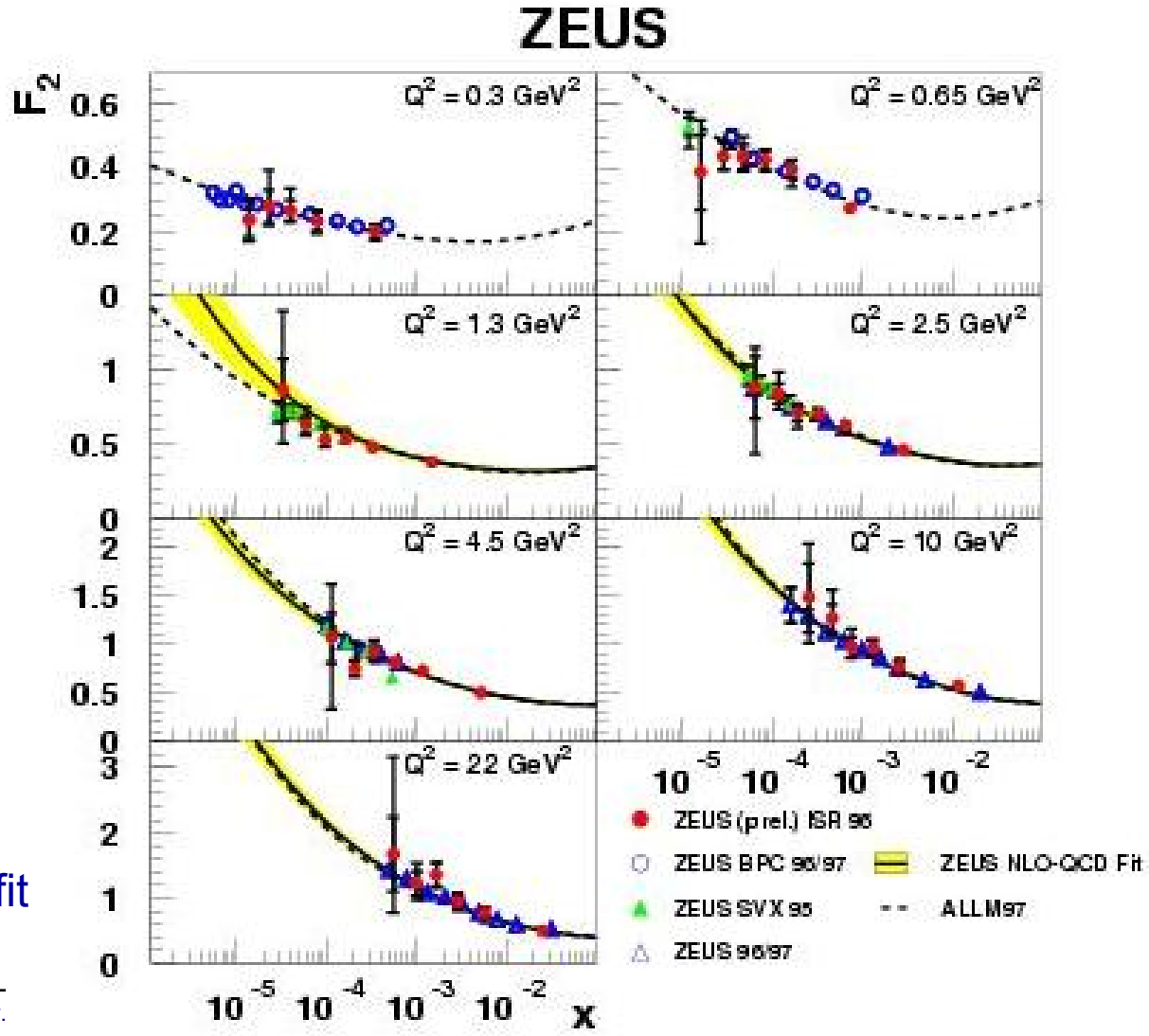
ISR γ : reduction of E_e : lower Q^2.

•e‘ identified in main detector. ISR γ in the luminosity monitor

•96: 3.9 pb^{-1} complete kinem. region:

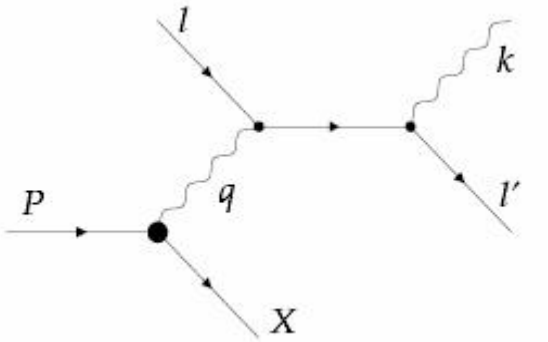
- •$0.3 < Q^2 < 22\ GeV^2$
- •$8 \cdot 10^{-6} < x < 1.8 \cdot 10^{-1}$

•Agreement with previous measurements and ZEUS NLO-QCD fit



H1: F2 from QEDCompton analysis

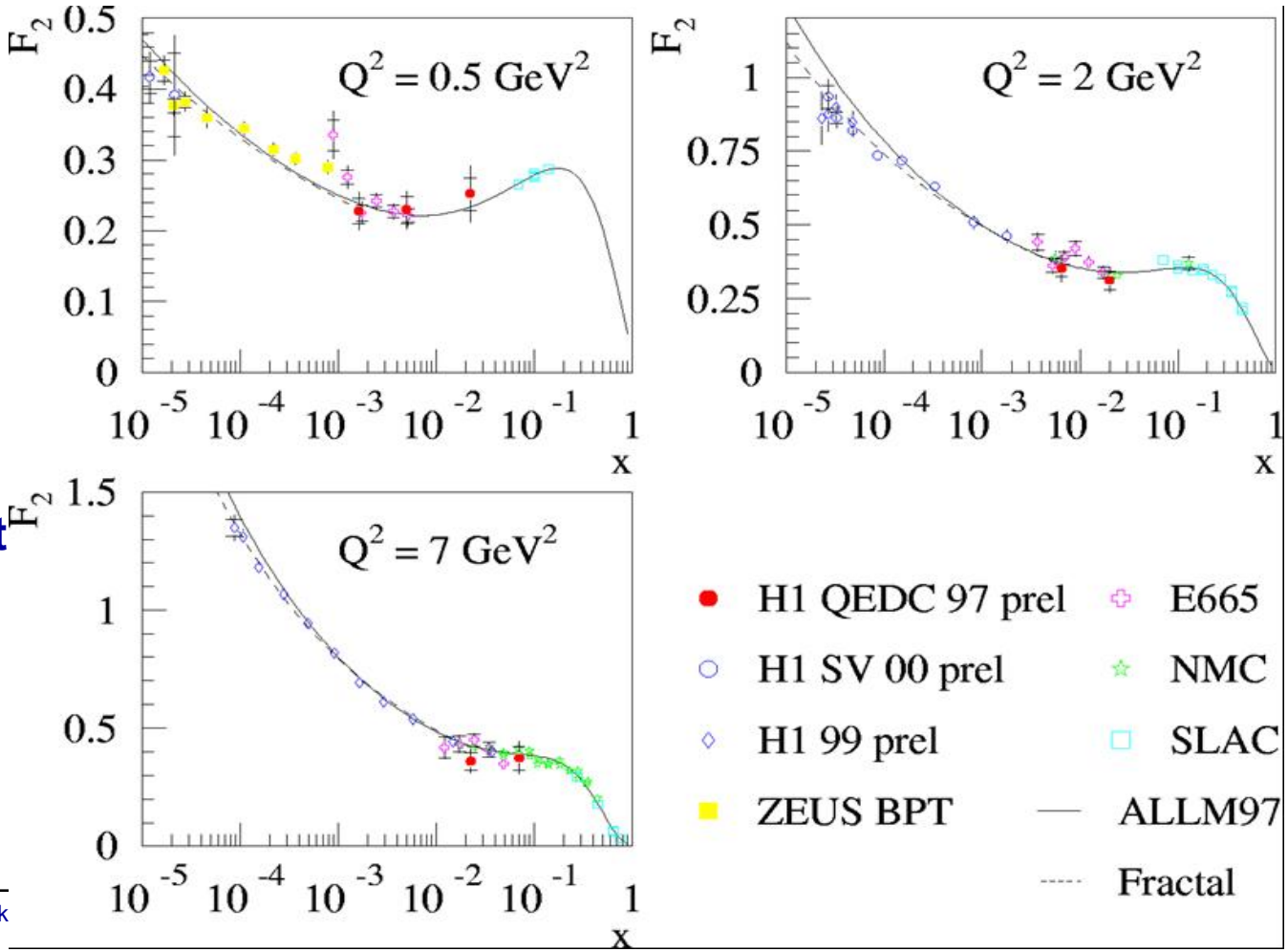
QEDC: $q^2 \sim 0$, Compton scattering of a quasi-real photon off an electron:



Tag electron and photon. Reconstruct kinematics from hadrons.

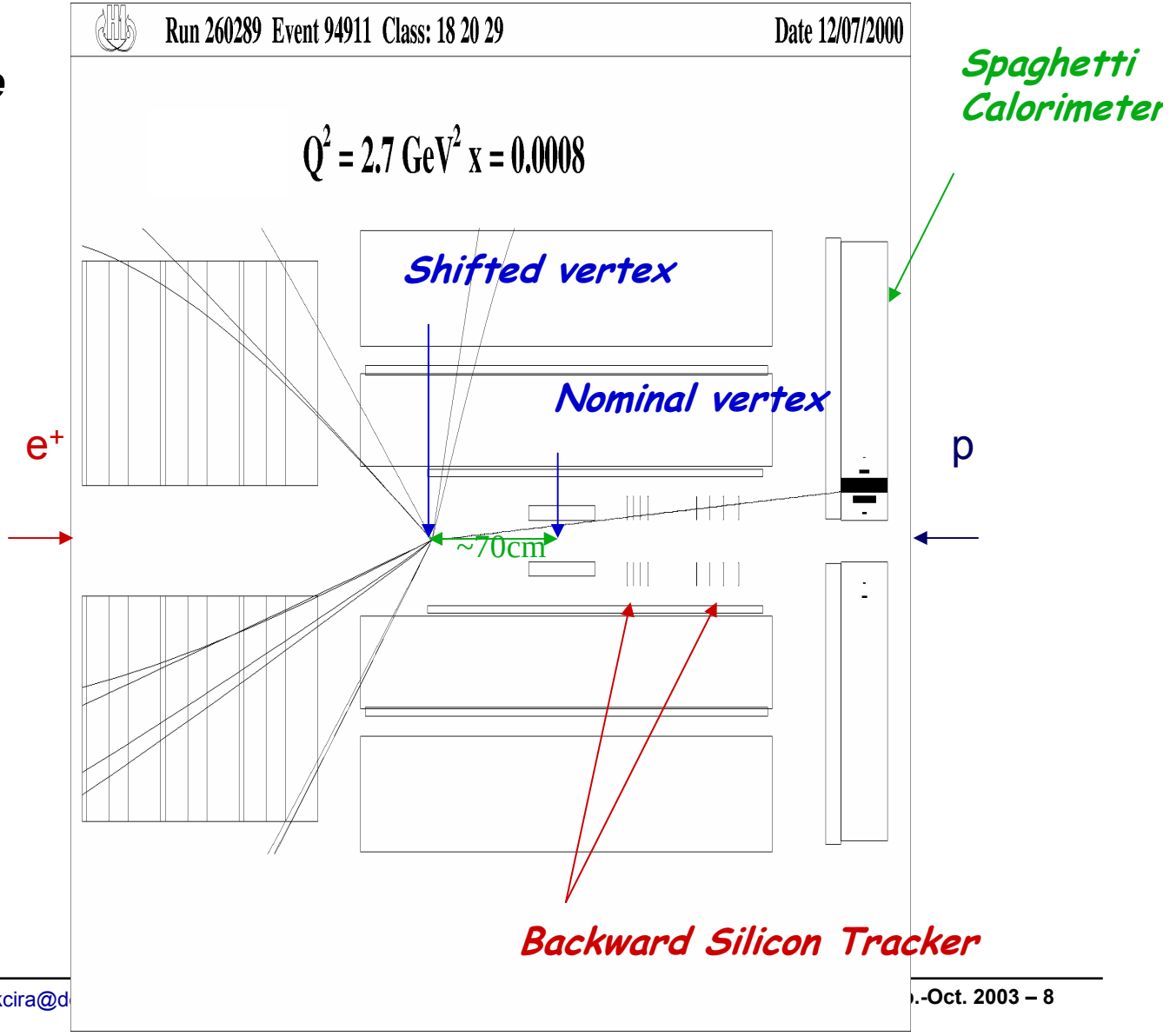
***F_2* at large *x* – good agreement with fixed target experiments.**

Complementary to standard inclusive DIS measurement



H1: Shifted Vertex Measurement

- *Shifting vertex by 70cm allows access to lower angle electrons, hence to lower Q^2*
- *Precise reconstruction of the scattered positron: ($\Delta\theta$ = 0.3 mrad, $\Delta E_{e'}$ = 0.3%)*
- *Measure very low positron energy (~3GeV) → high-y*

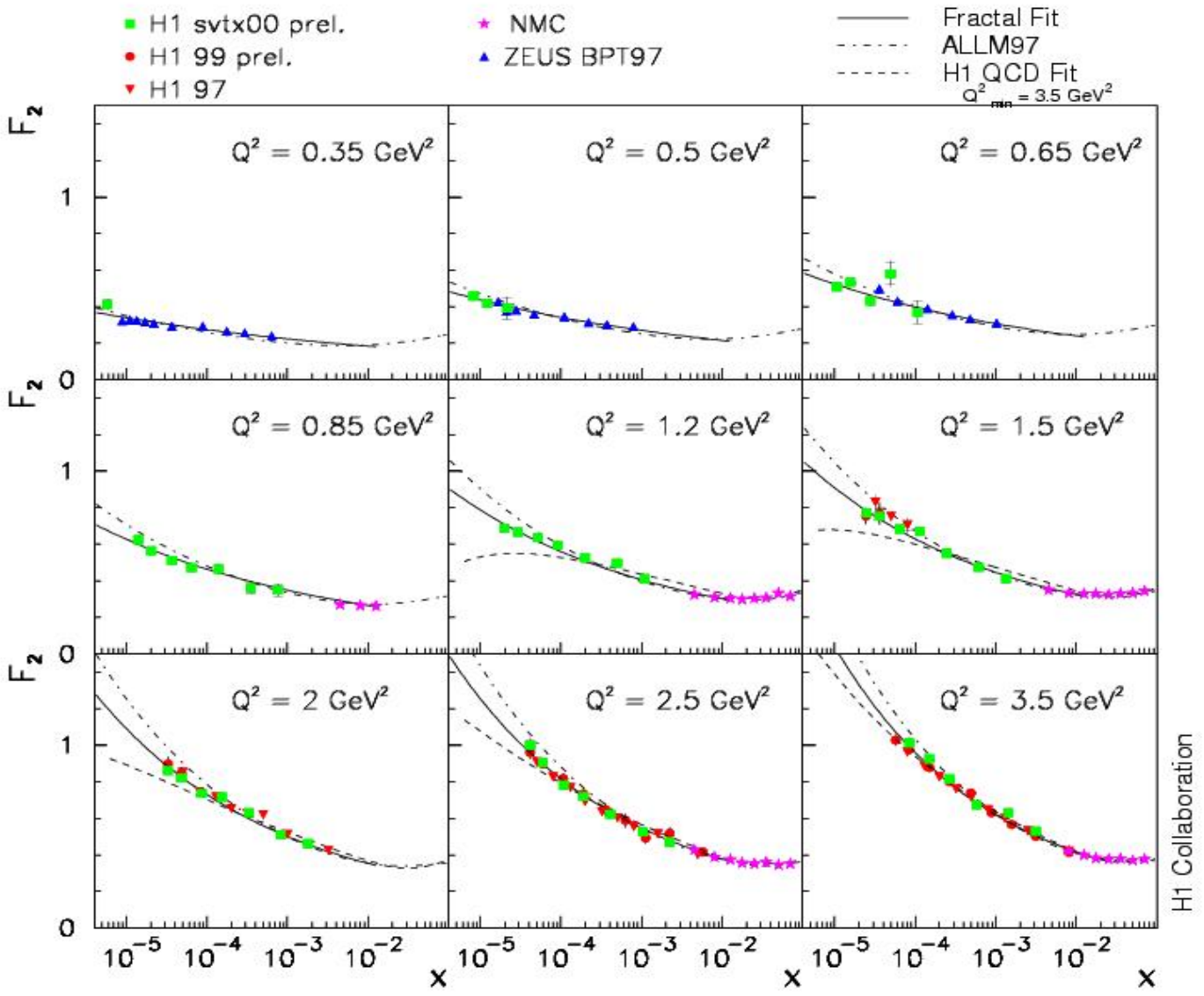


H1: Shifted Vertex Measurement

2000 measurement with 0.6pb^{-1} in special shifted-vertex run

Factor of 4 increase in statistics w.r.t. 95 shifted vertex run

Rise at low x observed also at lower Q^2 but rate is smaller with decreasing Q^2



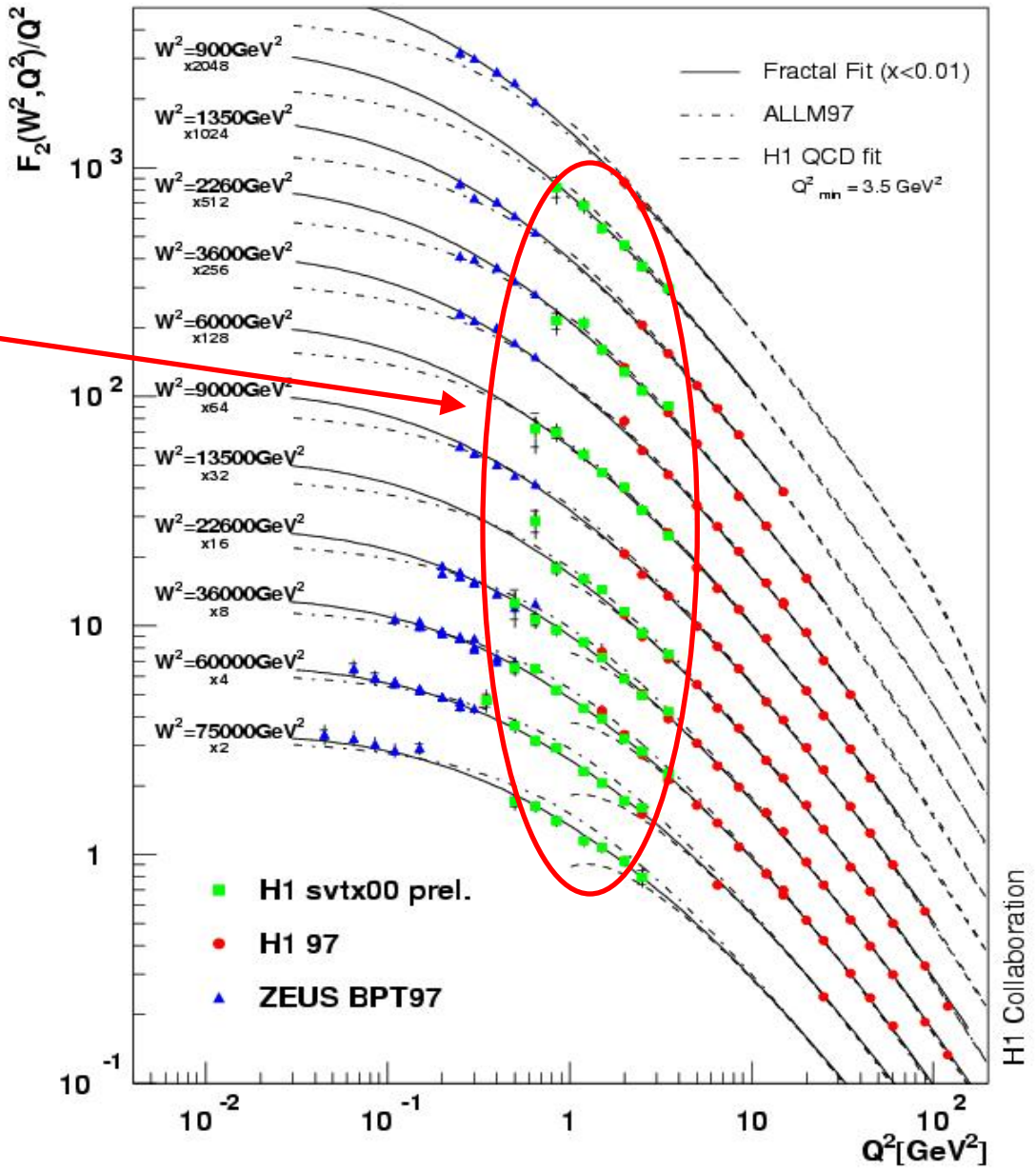
H1: Shifted Vertex Measurement

Php cross section in the limit $Q^2 \rightarrow 0$.

New precise data cover transition region.

Phenomenological parameterisation based on fractal dimension concept.

Fit describes data.



Rise of F_2 towards low x

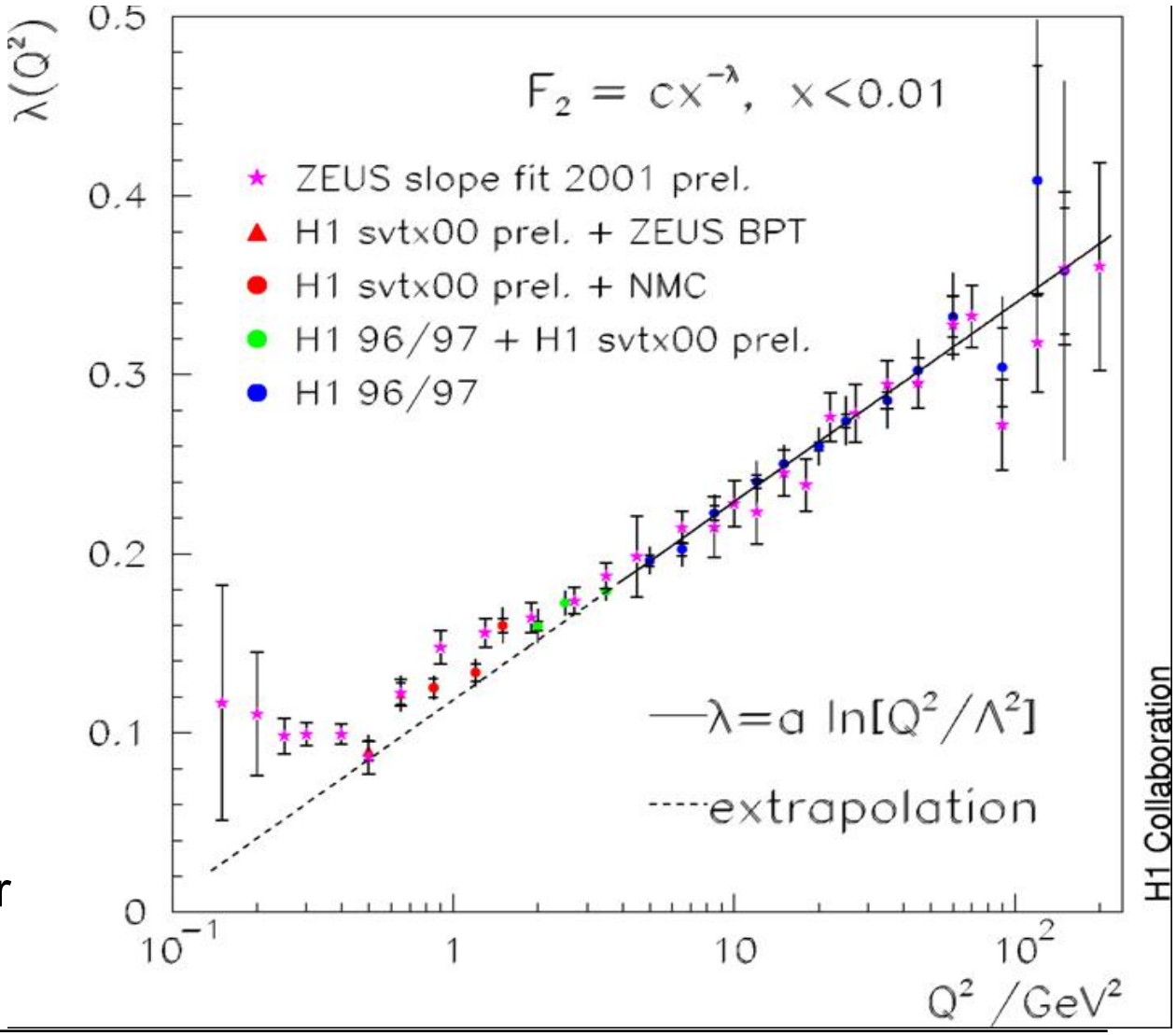
- H1 / ZEUS / NMC data used to fit Q^2 dependence for $x < 0.01$:

$$F_2 = C(Q^2)\, x^{-\lambda(Q^2)}$$

- $\lambda(Q^2) \sim \ln[Q^2/\Lambda^2]$ and $C(Q^2) \sim$ const. for $Q^2 > 3.5$ GeV^2

- Behaviour is changing at around $Q^2 \sim 1$ GeV^2

- From soft hadronic interactions it is expected that $\lambda \rightarrow \sim 0.08$ for $Q^2 \rightarrow 0$



Summary inclusive

- New precision data provide full coverage of important transition region of $Q^2 \sim 1 GeV^2$ between the perturbative and non-perturbative domains.

- The dependence of F_2 on Q^2 is stronger at lower Q^2 values approaching a region of linear dependence. Data show smooth transition between the two regions.

- The rise of F_2 at low x persists at low Q^2 but it is slower than observed at HERA at higher Q^2.

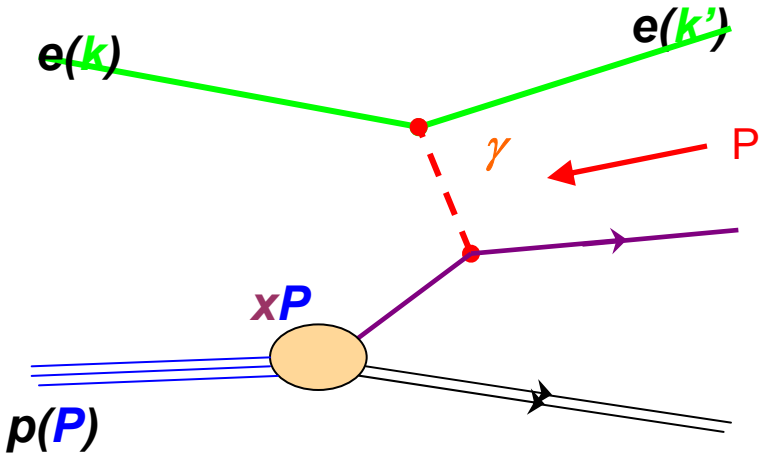
Two alternative ways of studying the transition region

Inclusive sample

•Probe proton structure with photon of virtuality Q^2.

•Transition from perturbative (DIS) to non-perturbative (PHP) regimes.

$$f_P(x, \mu^2 = Q^2)$$



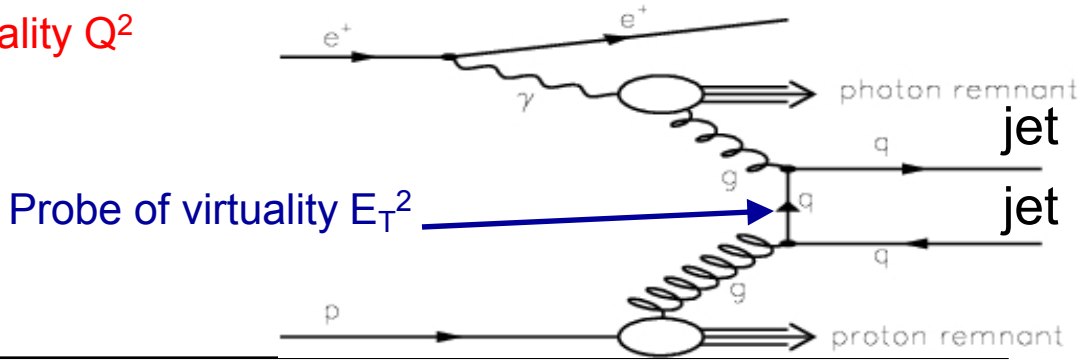
Subsample of dijet-events

•E_T of jets provides hard scale – pQCD applicable in the transition region.

•Probe of virtuality E_T^2. Proton structure contained at these scales. Sensitivity to photon structure.

•Transition from real to virtual photons.

$$f_P(x, \mu^2 = E_T^2) \times f_{\gamma^*}(x_\gamma, \mu^2 = E_T^2, Q^2)$$



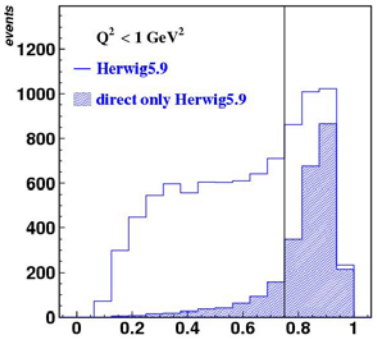
Dijet Production at HERA

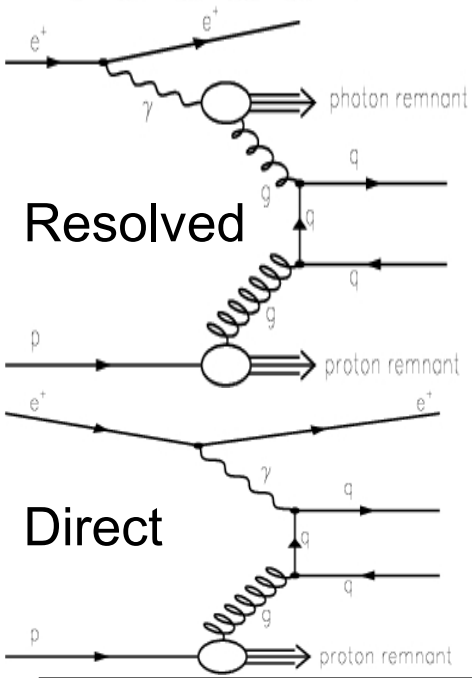
Photoproduction

Real photons

$$x_\gamma^{(obs)} = \frac{\sum_{jet1,2}(E^{jet} - p_z^{jet})}{\sum_{hadrons}(E - p_z)}$$

Note: No F_2^γ at HERA but sensitivity to γ^* structure at high scales.





Transition

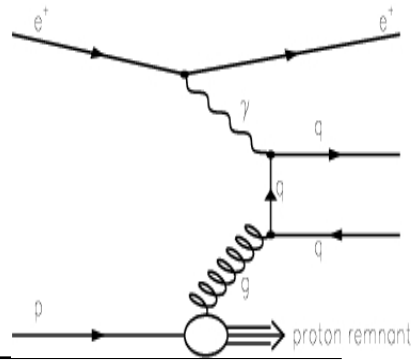
Understand how photon structure is suppressed

Test different approaches using HERA data

Increasing Q^2

DIS

Pointlike virtual photons



H1: dijet cross sections

$\gamma^* P - c.m.f.$

$2 < Q^2 < 80 GeV^2$

$0.1 < y < 0.85$

$E_T^{jet1,2} > 5 GeV$

$\overline{E_T} > 6 GeV$

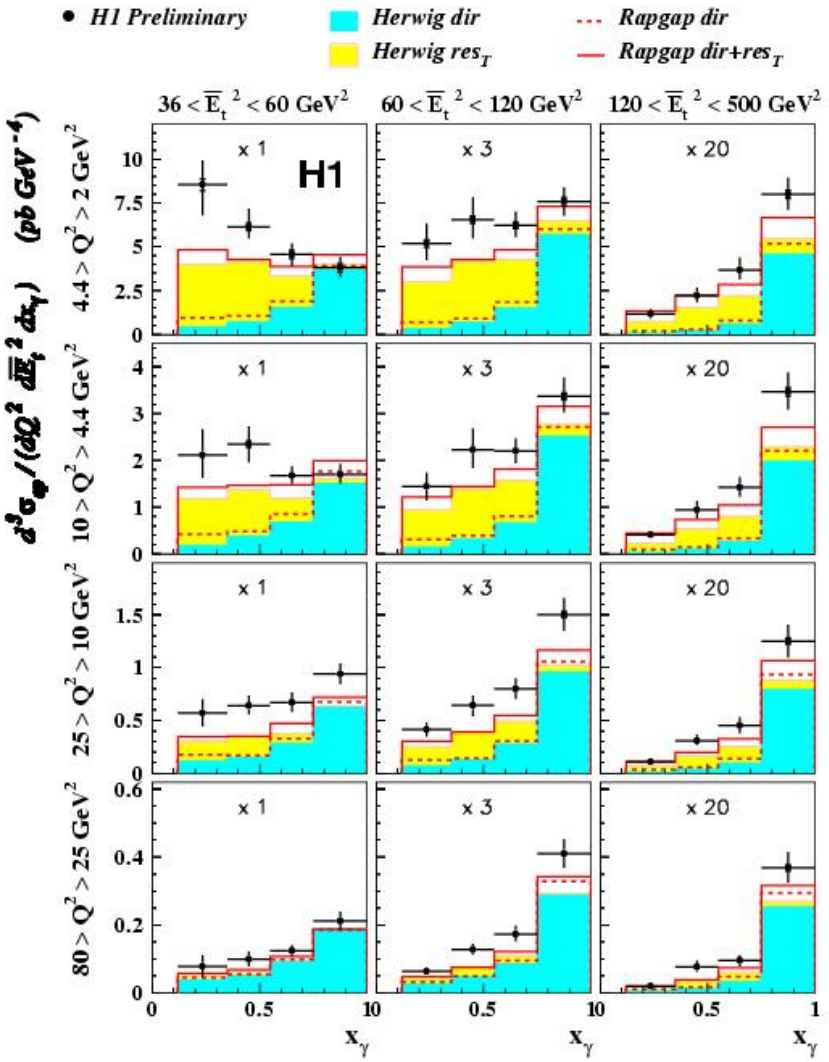
$-2.5 < \eta^{jet1,2} < 0$

Compare to LO MCs Herwig (cluster hadronization) and Rapgap (Lund hadronization) + parametr. of γ^* PDFs.

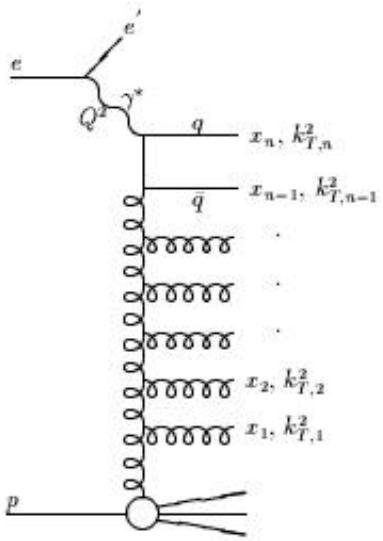
Interplay of scales:

- Resolved significant at low Q^2 or higher E_T^2
- Direct photon contribution almost describes data at higher Q^2 (lower E_T^2).

LO-MC predictions underestimate data (both Herwig and Rapgap)



$$d^3\sigma_{ep}/(dQ^2 d\overline{E_T}^2 dx_\gamma)$$

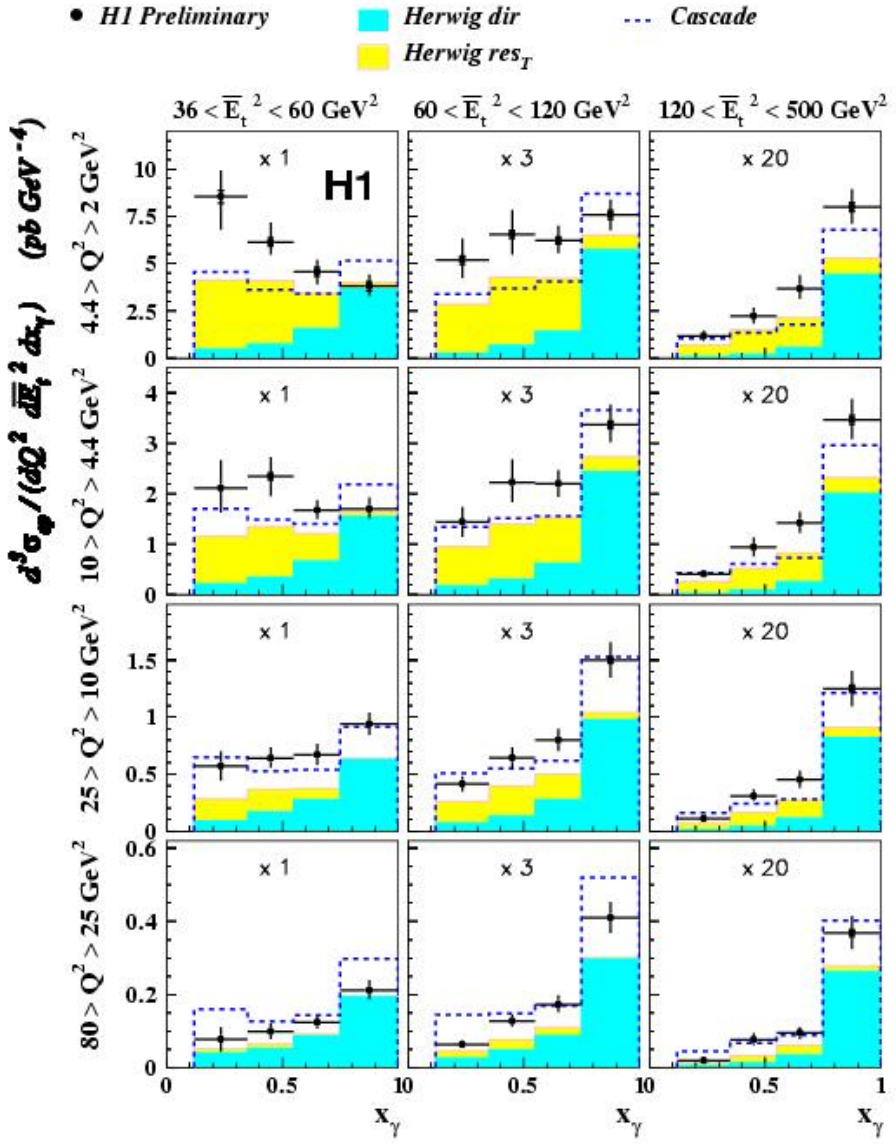


H1: CCFM (Cascade)

CCFM

- k_T unordered parton evolution
- no concept of photon structure

Better description than DGLAP LO direct but not perfect.



ZEUS: 2jets from PHP to DIS

$\gamma^* P - c.m.f$

$0 < Q^2 < 2000 GeV^2$

$0.2 < y < 0.55$

$E_T^{jet1,2} > 7.5, 6.5 GeV$

$-3.0 < \eta^{jet} < 0$

Measure:

$d\sigma / dQ^2$

$d^2\sigma / dQ^2 dE_T^{jet1}$

$d^2\sigma / dQ^2 d\eta^F$

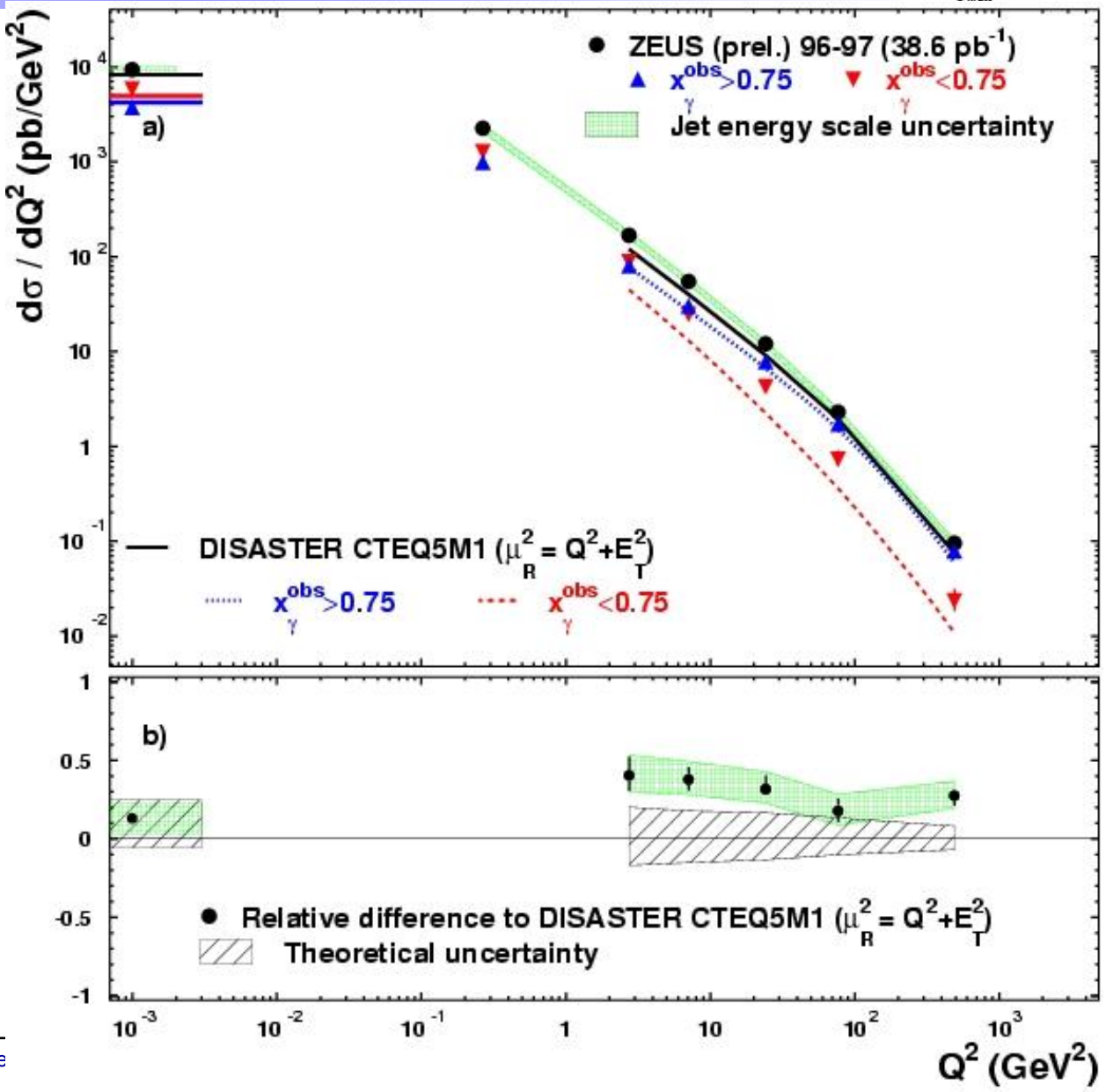
$R = \sigma(x_\gamma^{obs} < 0.75) / \sigma(x_\gamma^{obs} > 0.75)$

Compare results to LO and NLO predictions:

- Herwig MC with real photon GRV and SaS1D parametrization of γ*PDFs
- Frixione-Rindolfi-NLO for PHP: real photon PDFs GRV / AFG
- Disaster++ for DIS: higly virtual pointlike photon

ZEUS 2jets comparison to NLO

- Precise data from PHP to DIS including transition region
- Data and NLOs split in low and high x_γ^{obs} components
- Disaster scale: $\mu_R^2 = Q^2 + E_T^2$
- Low x_γ^{obs} dominant in PHP - still non-negligible up to order of 100GeV^2
- PHP: NLO describes data
- DIS: Shape of data described. NLO underestimates cross section
- High x_γ^{obs} component is better described from NLO than low one

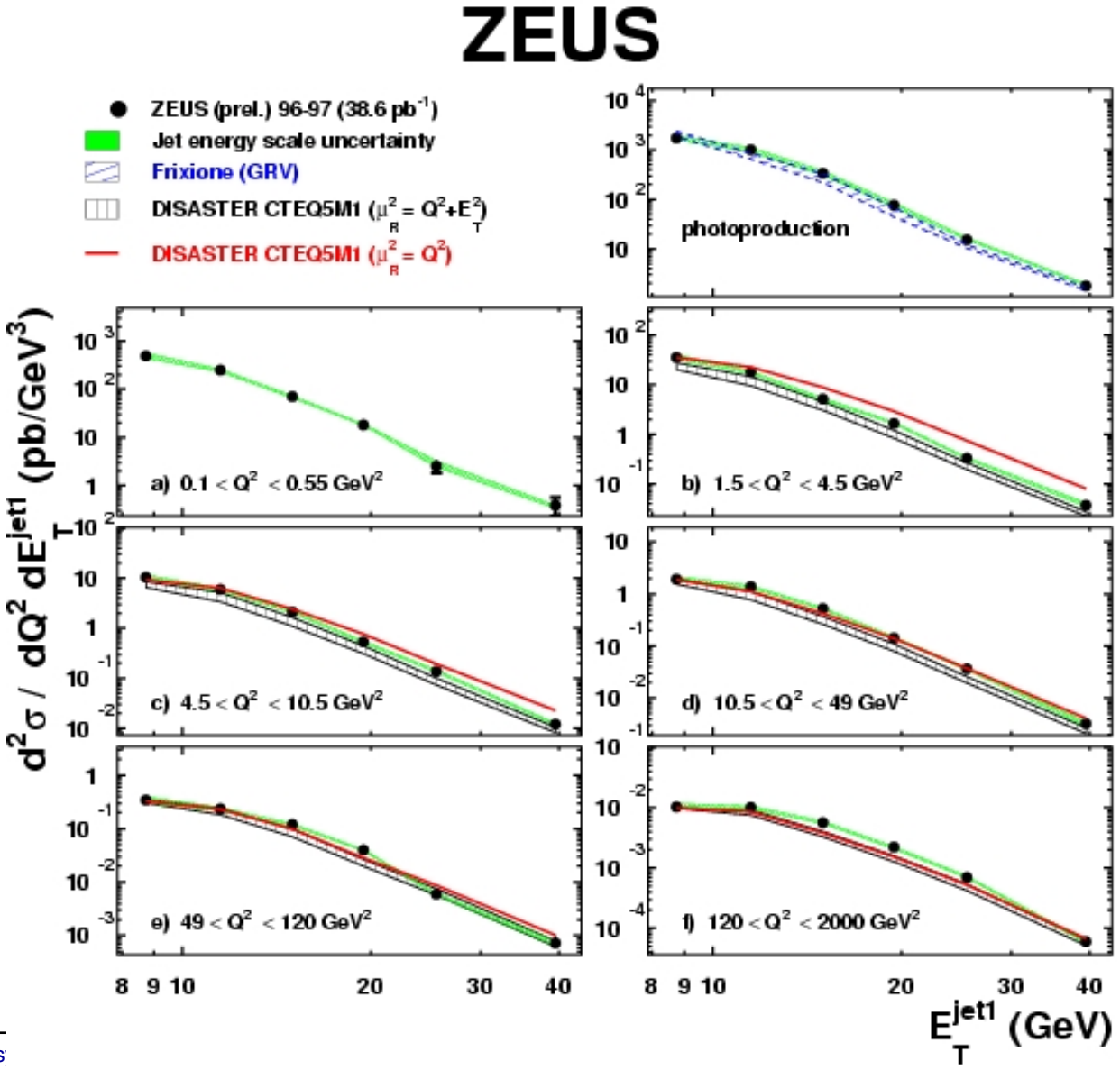


ZEUS 2jets comparison to NLO

The cross section falls less steeply as the Q^2 increases

PHP: DIS describes data within r.s.uncertainty

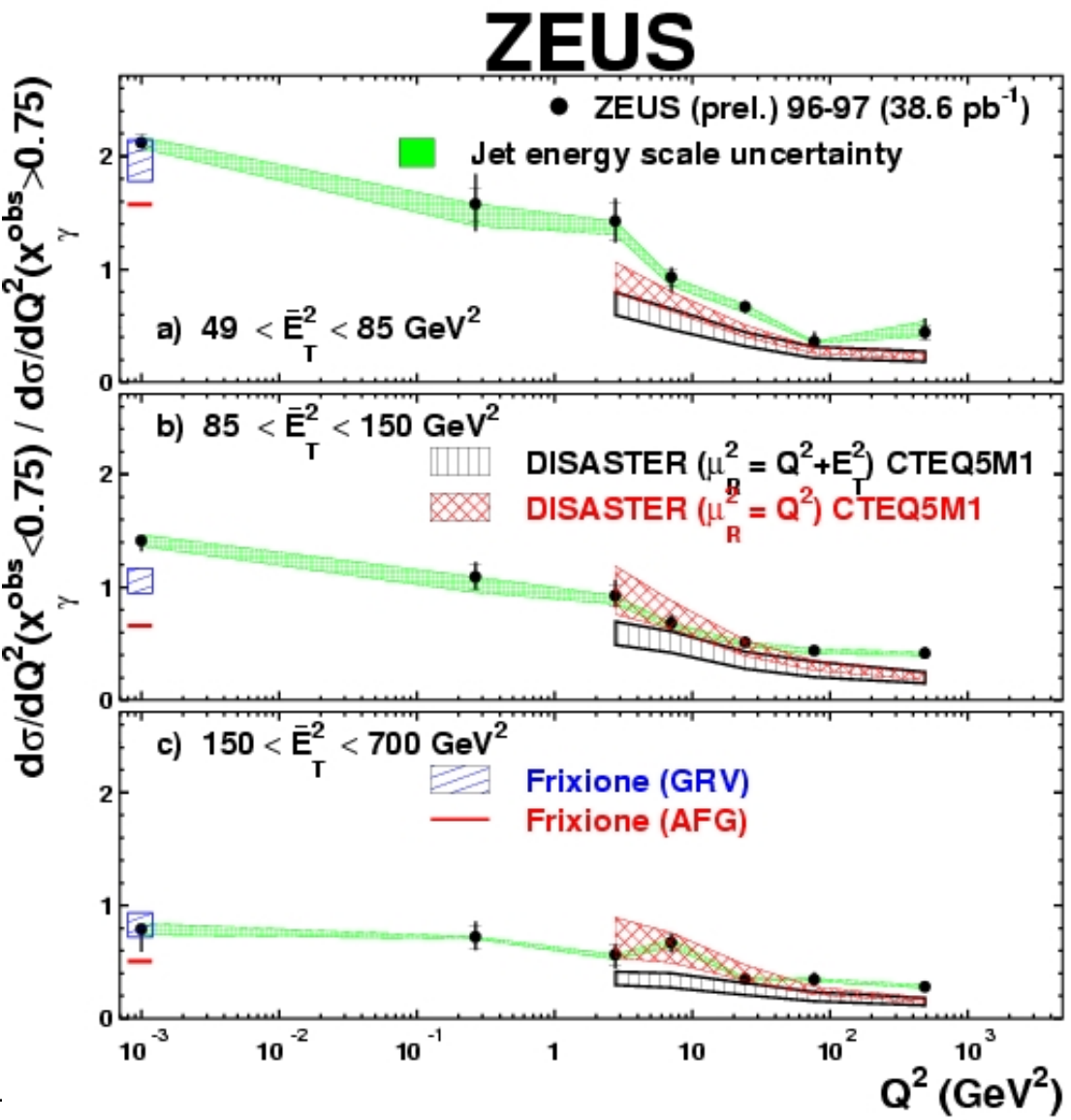
DIS: scale $Q^2+E_T^2$ does better in the description of the data than scale Q^2



ZEUS ratio of xsecs: NLO

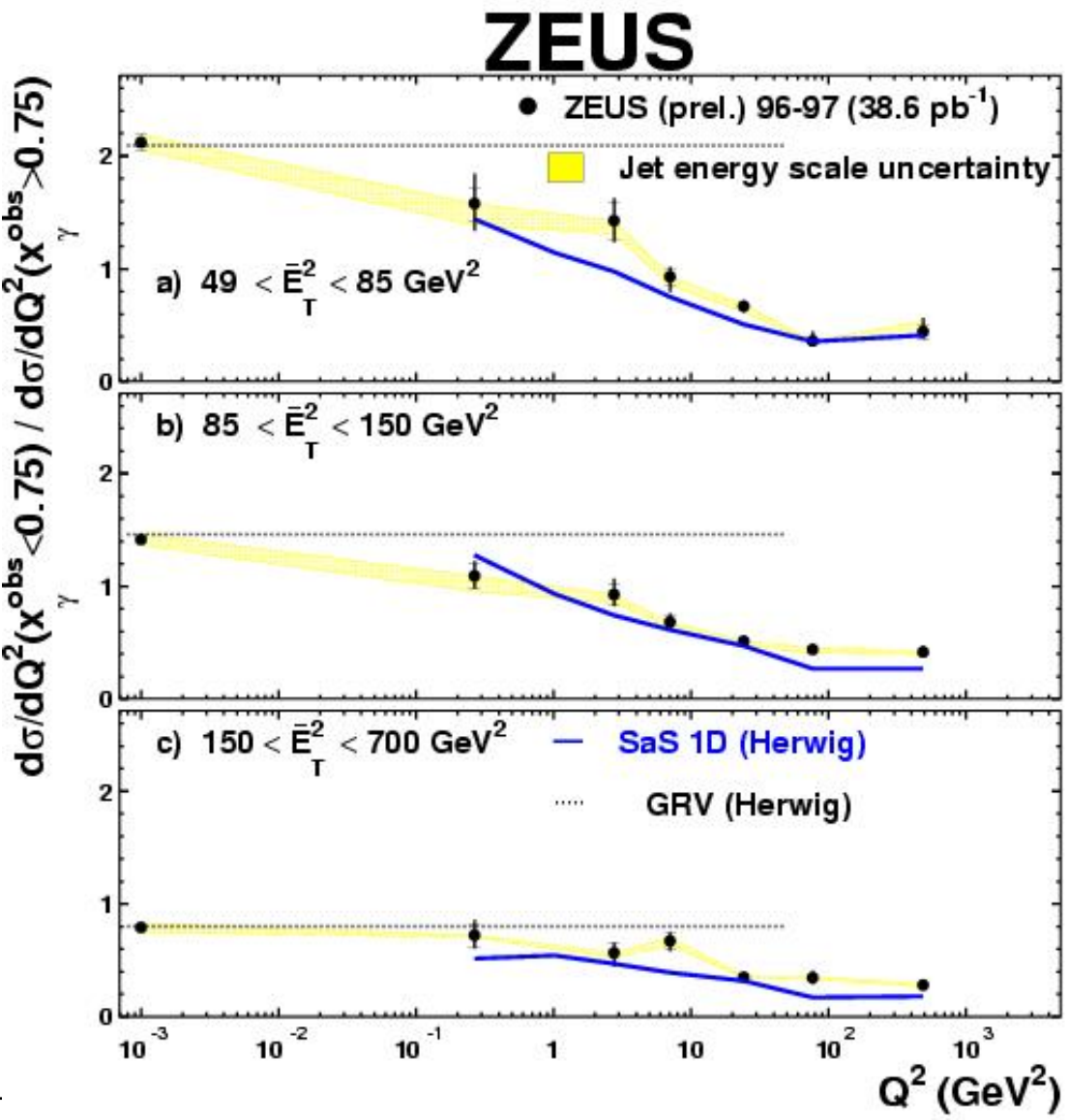
- **R** sensitive to res. photon structure suppression and cancellation of uncertainties
- Data fall with increasing photon virtuality. Steeper fall at lower E_T^2
- Ratio compared to NLO

- PHP: Frixione+GRV closer to measured ratio than Frixione+AFG
- DIS: Disaster scale $Q^2+E_T^2$ describes shape of fall of ratio but not enough low x_γ^{obs} in proportion to high x_γ^{obs}.



ZEUS ratio LO

- Herwig+GRV-LO describes PHP ratio
- Herwig+SaS1D seems to describe the shape of the data and slightly underestimate ratio
- Consistent picture across transition region



Summary Dijet measurements

- Precise dijet measurements in PHP/DIS and accross transition region. Measurements can significantly constrain PDFs of virtual photon.
- Different concepts tested in the low Q^2 region.
- LO consistent picture of transition from PHP to DIS with suppression of virtual photon structure.
- NLO calculations show large uncertainties and fail to describe transition region. High x_γ^{obs} component better described.

Conclusions

- Precise inclusive inclusive and dijet measurements cover the transition region from low to high photon virtualities.

- Rise of F_2 at low x persists but is slower at low Q^2

- Dijet measurements can significantly contrain PDFs of virtual photon.

- No consistent QCD picture yet for the transition region.