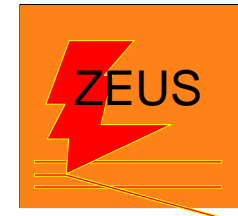


Charm and the Virtual Photon

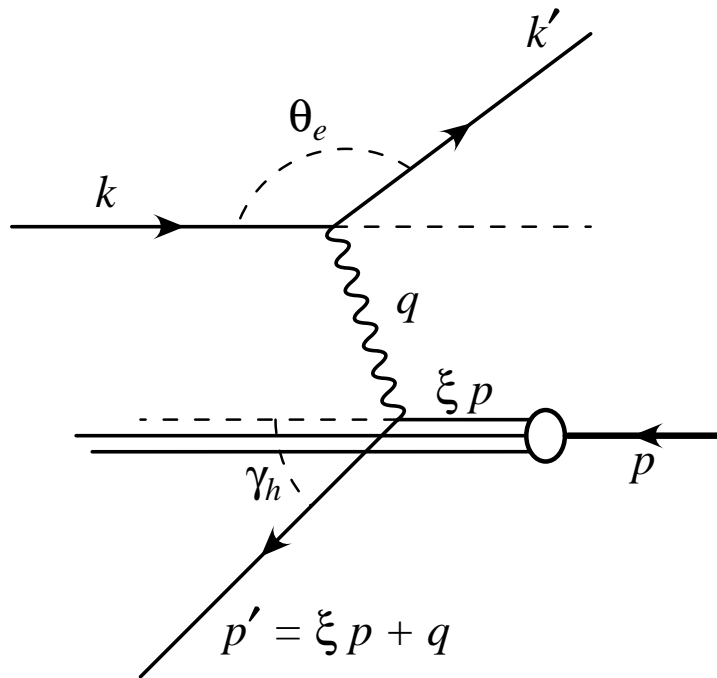


Ben West
Photon 2001, Ascona
3rd September



-
- Photon structure
 - Charm in photoproduction
 - Evolution schemes
 - Charm and the virtual photon
 - Leading-order pQCD predictions
 - Summary

Introduction



$$\sqrt{s} \approx 300 \text{ GeV}$$

$$\eta = -\ln(\tan \theta / 2)$$

$$y = \frac{q \cdot p}{k \cdot p}$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$Q^2 = -q^2$$

Two kinematic regimes:

- **Deep Inelastic Scattering (DIS)** $Q^2 > 1 \text{ GeV}^2$

Scattered e visible in main detector

- **Photoproduction (PHP)** $Q^2 < 1 \text{ GeV}^2$; $\langle Q^2 \rangle \approx 3 \cdot 10^{-4} \text{ GeV}^2$

No scattered e in main detector \Rightarrow quasi-real photon

Virtual photon structure

- Real photons have partonic structure:
 - Measurements of F_2^γ in $e\gamma$ interactions and observation of single- and double- resolved processes in $\gamma\gamma$ interactions at LEP.
 - Observation of resolved processes in γp interactions at HERA.
- Virtual photons should also have a partonic structure:
 - In DIS photon is a point-like probe of the proton - must be a continuum between PHP and DIS regimes in which resolved dies out.
 - QCD predicts that the parton densities of the virtual photons become **logarithmically suppressed** as P^2 (virtuality of the probed photon) increases at **fixed Q^2** (scale) [at HERA $P^2 \rightarrow Q^2$ and $Q^2 \rightarrow (E_T^{Jet})^2$]

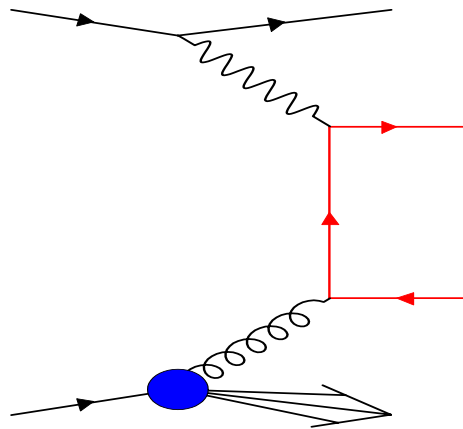
$$f_a^{\gamma^*}(x, Q^2, P^2) = \sum_V \frac{4\alpha_{em}}{f_V^2} \left(\frac{m_V^2}{m_V^2 + P^2} \right)^2 f_a^{\gamma, V}(x, Q^2; \tilde{Q}_0^2) + \frac{\alpha_{em}}{2\pi} \sum_q 2e_q^2 \int_{Q_0^2}^{Q^2} \frac{dk^2}{k^2} \left(\frac{k^2}{k^2 + P^2} \right)^2 f_a^{\gamma, q\bar{q}}(x, Q^2; k^2)$$

- These predictions are contained in the **SaS1D** virtual photon PDF

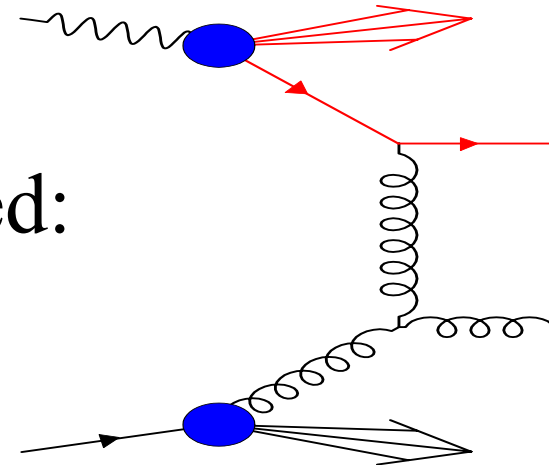
Virtual photon structure at HERA

- Studied at HERA in the production of dijets from a virtual photon.
- At LO two classes of events contribute to dijet production:

direct:



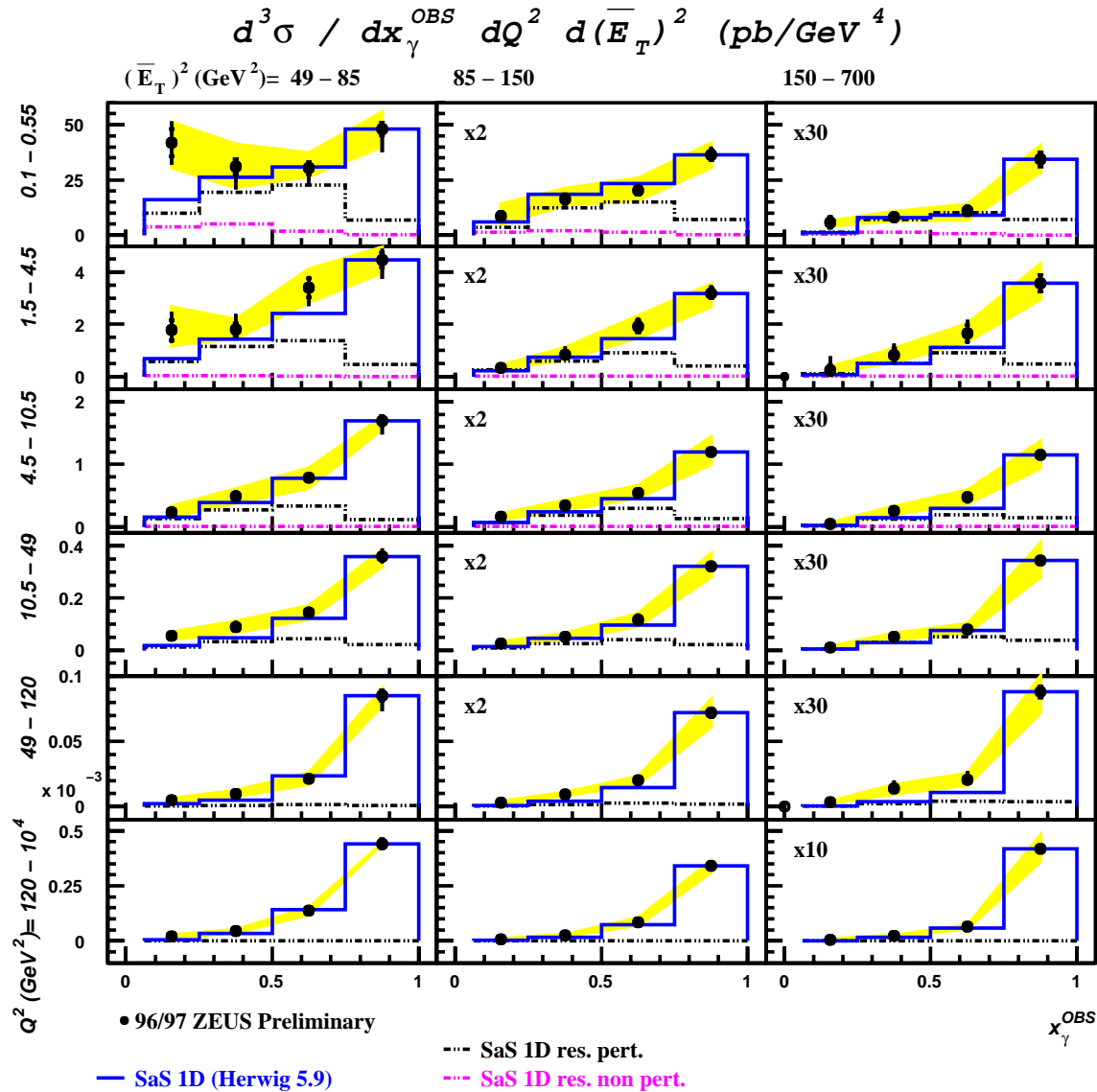
resolved:



- Separated by x_γ the fraction of the photon's momentum entering the hard scatter. Experimentally, and at all orders in theory, we define:

$$x_\gamma^{obs} = \frac{\sum_{jets} E_T e^{-\eta}}{2yE_e}$$

Differential dijet cross sections

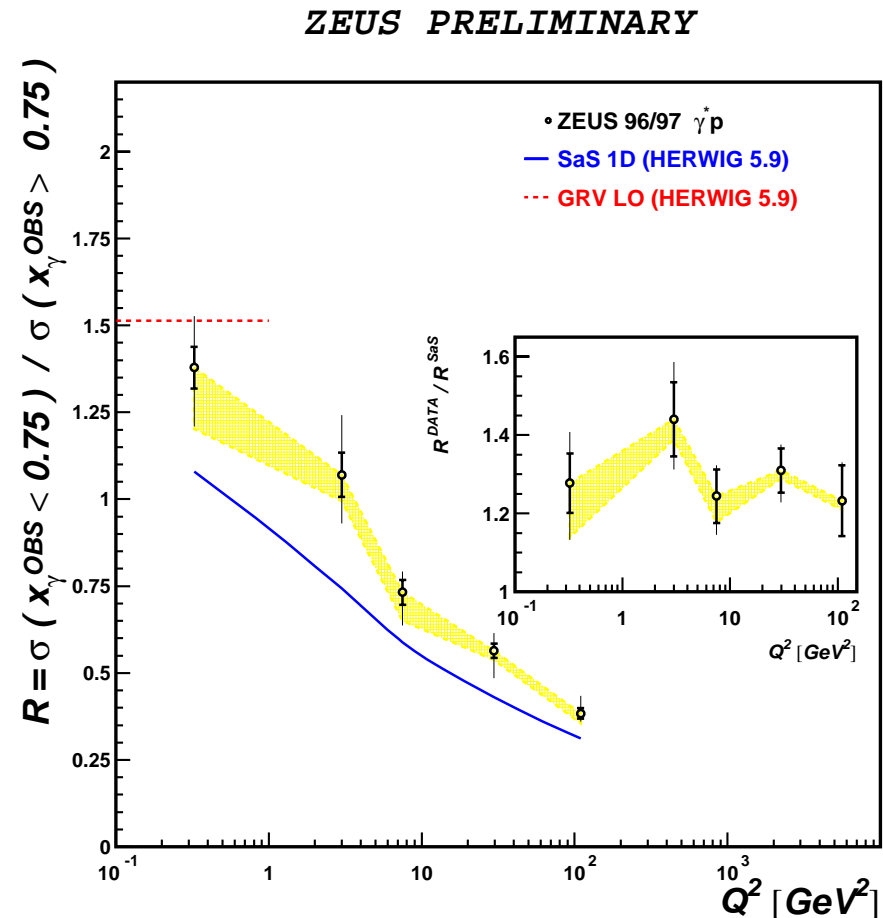


- Cross section measured as a function of Q^2 , \bar{E}_T^2 and x_γ^{obs} .
- k_T algorithm in HCM frame: at least two jets with $E_T^{Jet} > 7.5, 6.5$ GeV and $-3.0 < \eta^{Jet} < 0.0$.
- LO prediction from **SaS1D**.
- Low x_γ^{obs} cross section falls faster than high x_γ^{obs} with increasing Q^2 .
- Perturbative (anomalous photon) dominates LO resolved.
- For $Q^2 > \bar{E}_T^2$ data can be described by LO direct only.

Ratio of cross sections

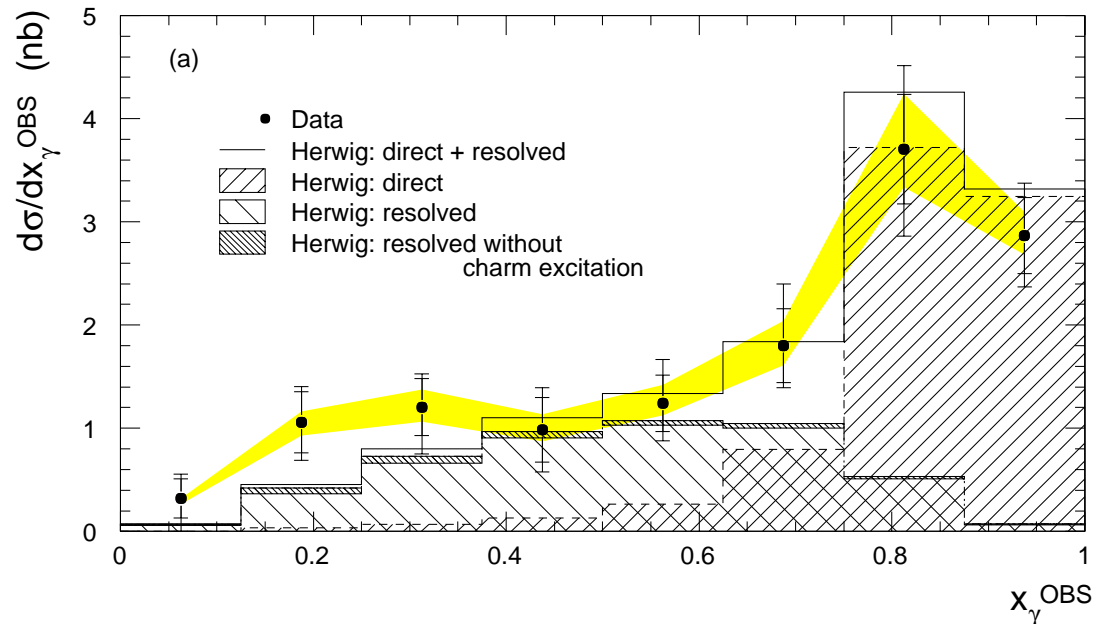
- Measure
$$\frac{\sigma(x_\gamma^{obs} < 0.75)}{\sigma(x_\gamma^{obs} > 0.75)}$$
 - Ratio falls steeply with Q^2
 - Interpreted as suppression of resolved component as the photon virtuality increases.
- SaS1D
 - Decreases with Q^2 but lies below the data for entire Q^2 range
 - Suppression included in SaS1D reproduces the shape but not the normalisation of the ratio

⇒ Suppression of resolved with Q^2



D^* s in dijet photoproduction

ZEUS 1996+97



$$E_T^{\text{Jet}} > 7, 6 \text{ GeV}$$

$$-2.4 < \eta^{\text{jet}} < 2.4$$

$$p_T(D^*) > 3 \text{ GeV}$$

$$|\eta(D^*)| < 1.5$$

$$0.2 < y < 0.8$$

$$Q^2 < 1 \text{ GeV}^2$$

- LO resolved contribution of 45% is necessary to describe the data compared to $\sim 90\%$ in similar analyses without D^* .

\Rightarrow suppression of resolved due to charm

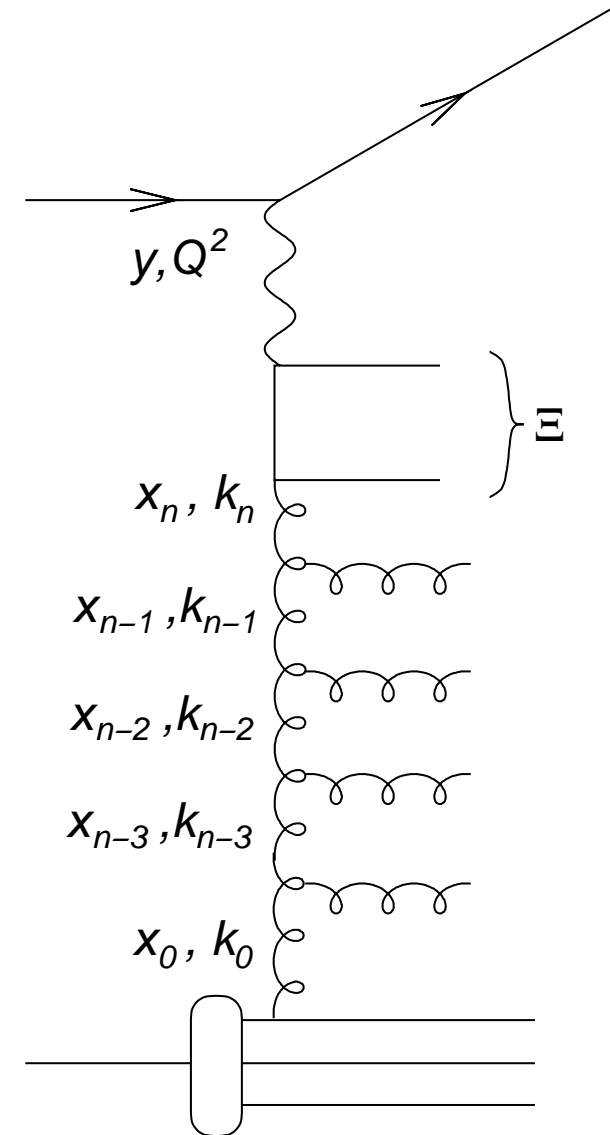
- How does this effect the suppression of resolved evolve with Q^2 ?
- Are the charm and Q^2 suppressions related?

\Rightarrow measure charm ratio of low to high x_γ^{obs} as a function of Q^2 .

QCD evolution schemes

	BFKL	CCFM	DGLAP
Ordering	x	η	k_T^2

- **DGLAP** evolution describes inclusive data over full range measured at HERA but may be inadequate at low x (c.f. $\ln x$).
- **BFKL** describes **low x** but not Q^2 evolution.
- **CCFM** attempts to be applicable across the **whole kinematical plane**:
 - At **small x** approximated by **BFKL**.
 - At **moderate x** **DGLAP** recovered.
- Due to angular ordering the evolution includes resolved γ^* -like terms - anomalous photon.



Charm in DIS

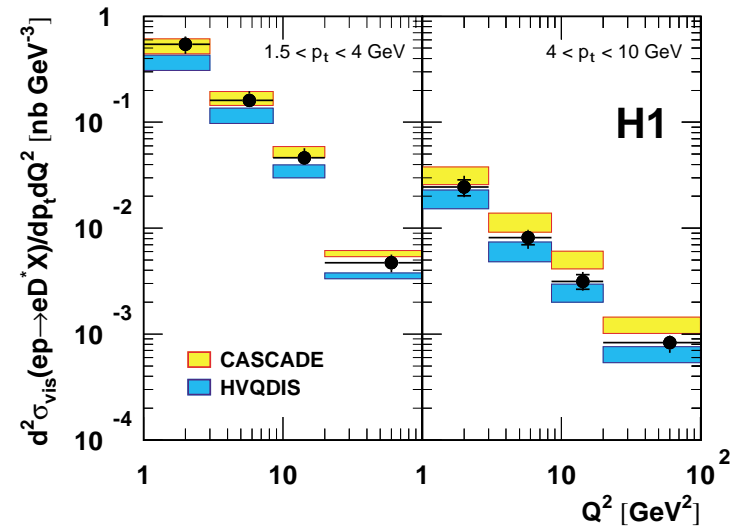
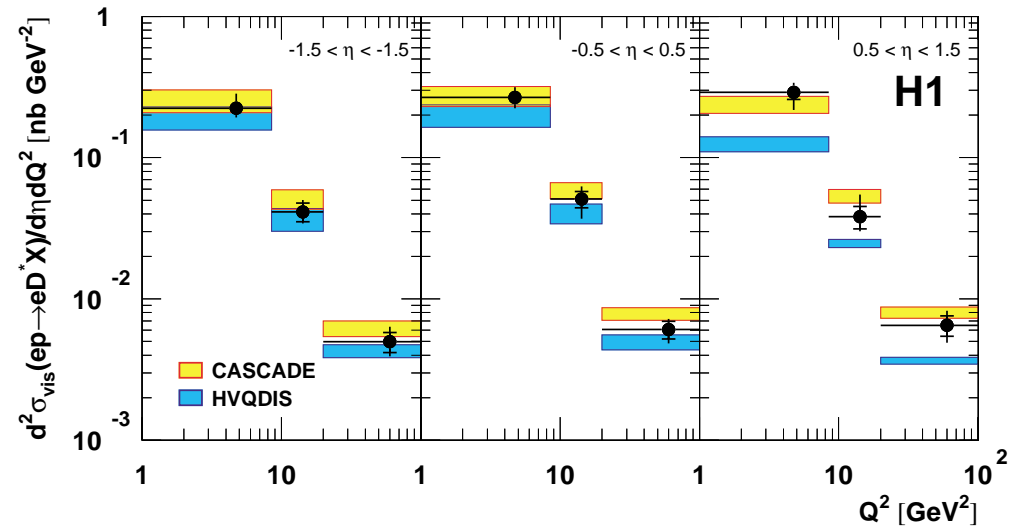
- Cross section for production of D^* s in DIS measured for

$$p_T(D^*) > 3 \text{ GeV}, |\eta(D^*)| < 1.5$$

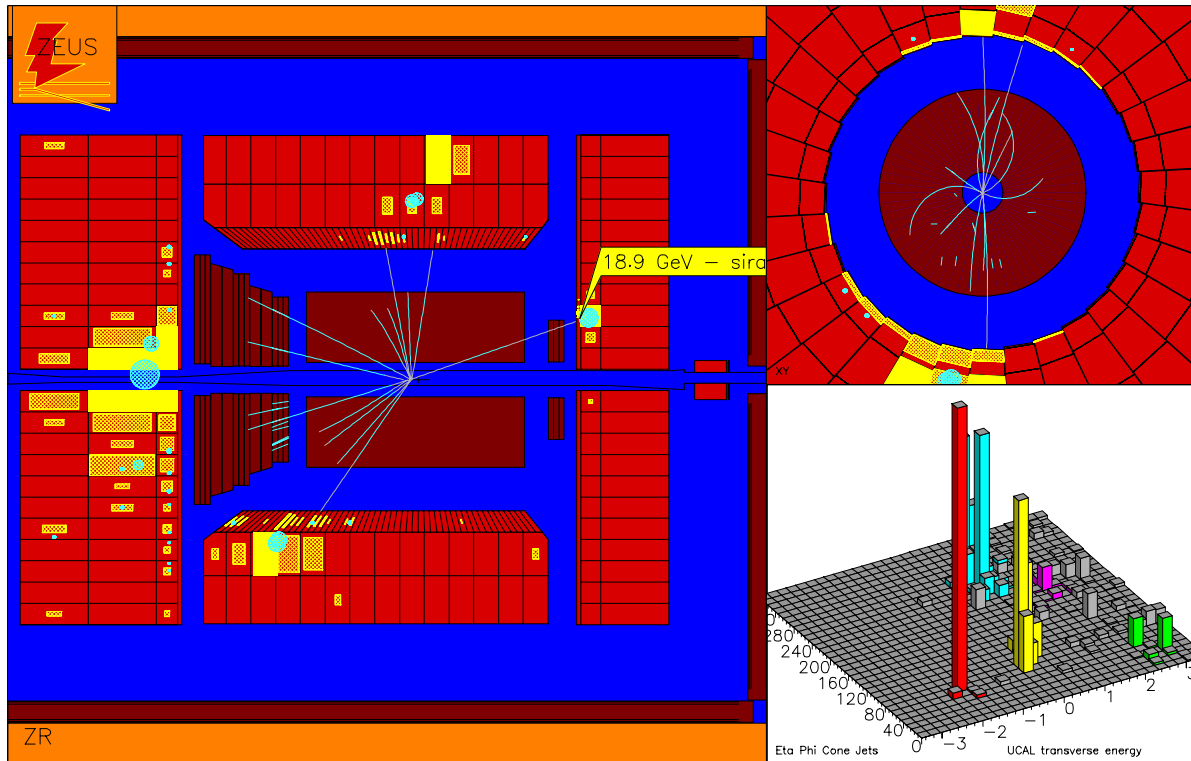
$$0.2 < y < 0.8, 1 < Q^2 < 100 \text{ GeV}^2$$

- Data compared to:
 - CASCADE - LO CCFM.
 - HVQDIS - NLO DGLAP.

• At low $p_T(D^*)$ and forward $\eta(D^*)$ CASCADE gives a better description of the data.



Event selection

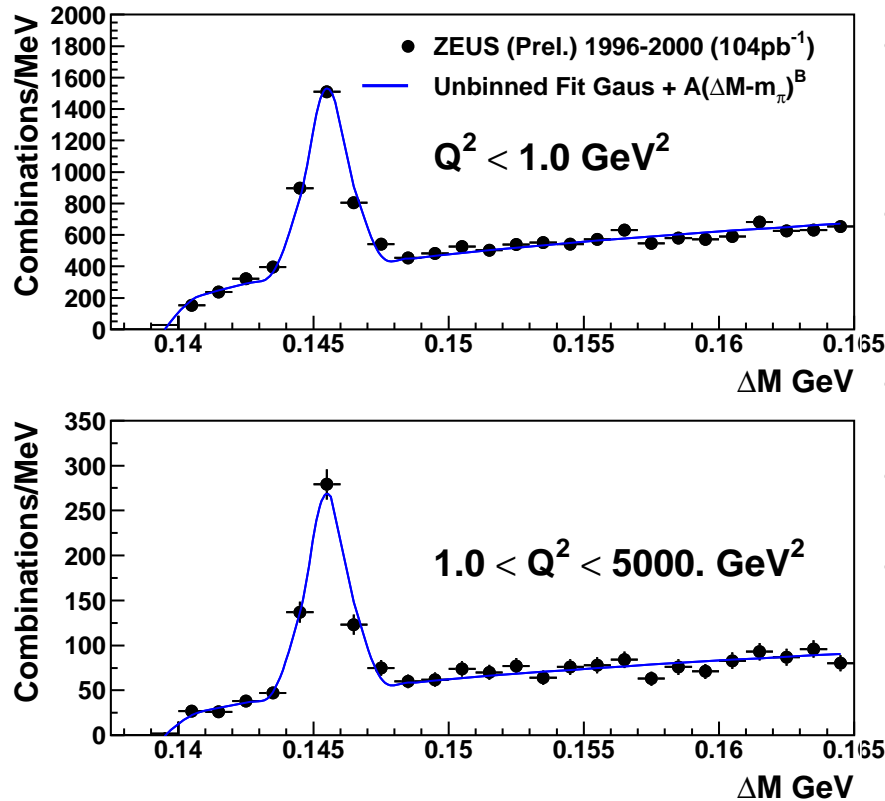


- Use $\approx 100\text{pb}^{-1}$ from 96-00
- D^* 's selection: $k\pi\pi_s$ decay channel - $p_T(D^*) > 3 \text{ GeV}$, $|\eta(D^*)| < 1.5$
- dijet selection: define jets using KTCLUS clustering algorithm in LAB frame - $E_T^{\text{Jet}} > 7.5, 6.5 \text{ GeV}$
 $-2.4 < \eta^{\text{jet}} < 2.4$;

- Kinematic selection: $0.2 < y < 0.65$
 Q^2 Bins: $Q^2 < 1.0$, $1.0 < Q^2 < 4.5$, $4.5 < Q^2 < 10.5$, $10.5 < Q^2 < 49$.
 and $49. < Q^2 < 5000. \text{ GeV}^2$

Event selection

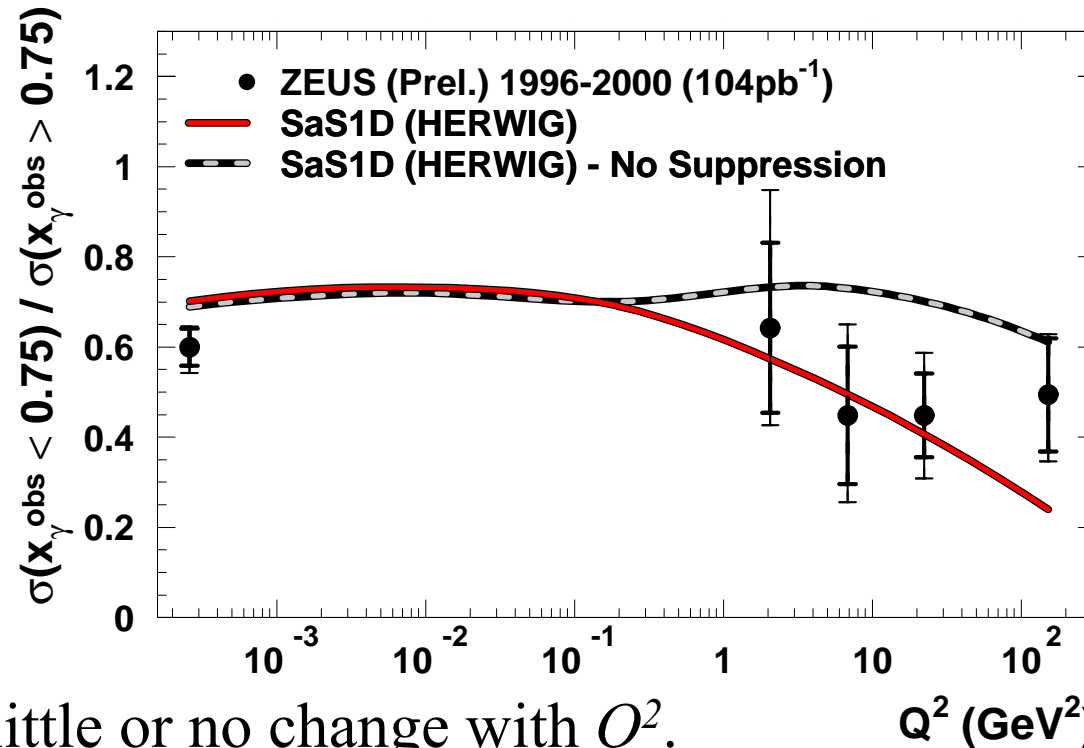
ZEUS



- D^* s found using combinatorial mass difference method.
- 3 parameter unbinned fit used for background estimation.
- 2200 ± 61 dijet events in PHP region.
- 421 ± 25 dijet events in DIS region.
- Statistics too low for highly differential plots
 \Rightarrow study χ_γ^{obs} ratio as a function of Q^2

Leading-order predictions with SaS1D γ PDF

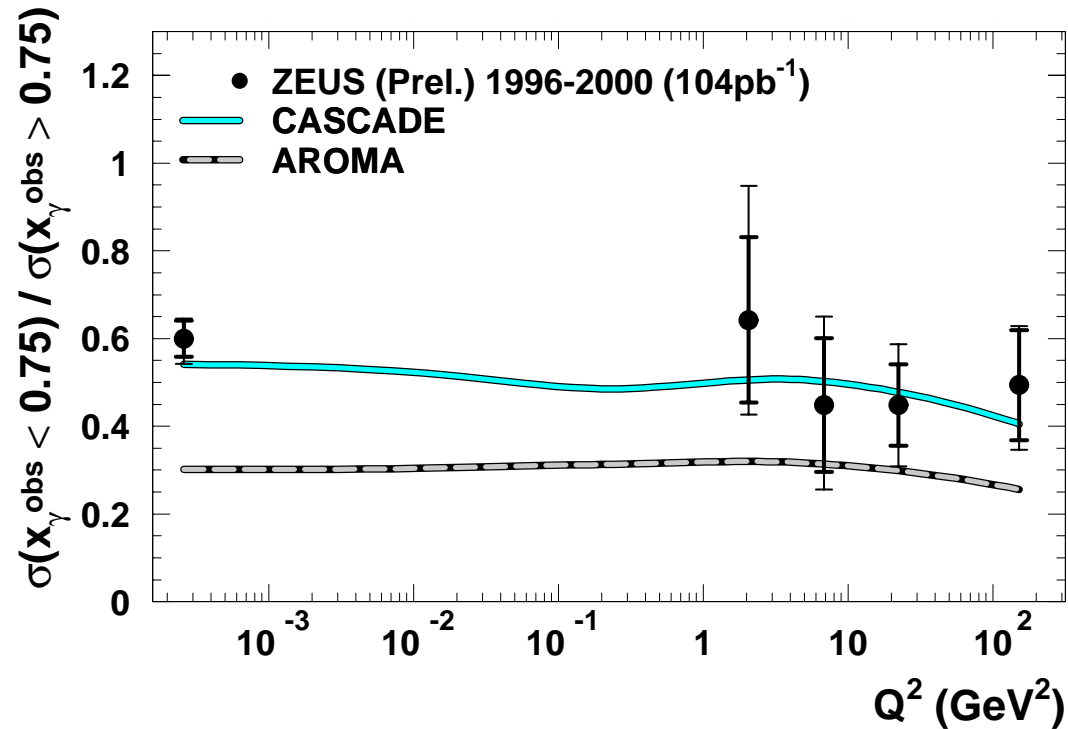
ZEUS



- Ratio shows little or no change with Q^2 .
- Prediction of SaS1D virtual photon structure function shown:
 - ratio flat when no suppression in structure function.
 - ratio with suppression gives a reasonable description of the data.

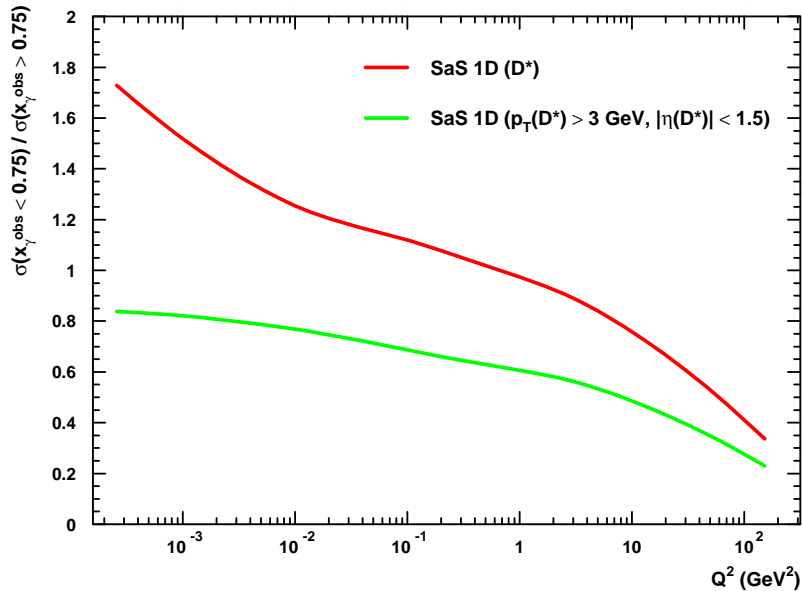
Leading-order predictions with no γ PDF

ZEUS



- No photon PDF
- Low x_γ^{obs} comes from evolution of parton showers.
- **AROMA**, using **DGLAP** evolution, lies below the data.
- **CASCADE**, using **CCFM** evolution, is closer to the data.

Comparison to “all flavours” ratio

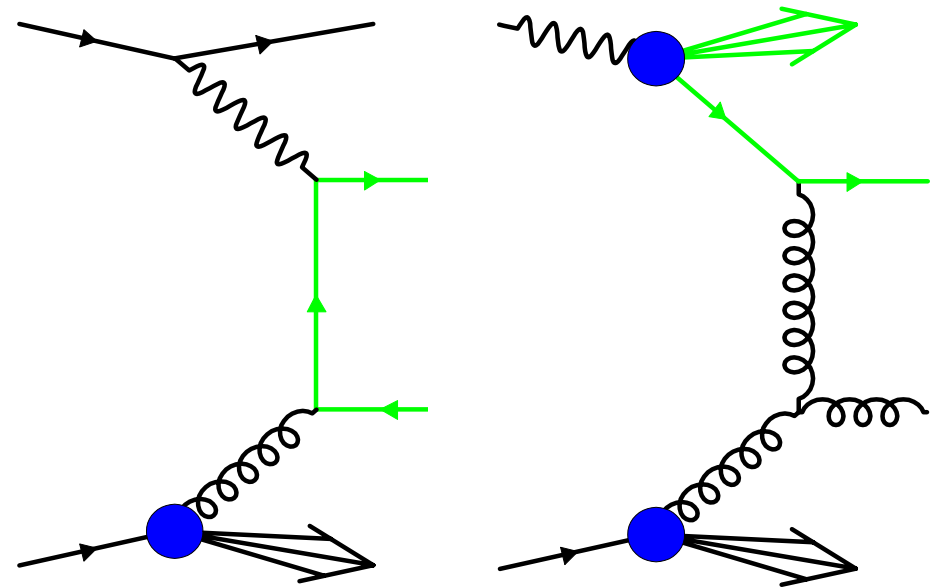


- Ratio's flatness with Q^2 is in marked contrast to case when D^* requirement is not made.

- Suppression due to charm and Q^2 not independent?

⇒ Compare to previous results without tag.

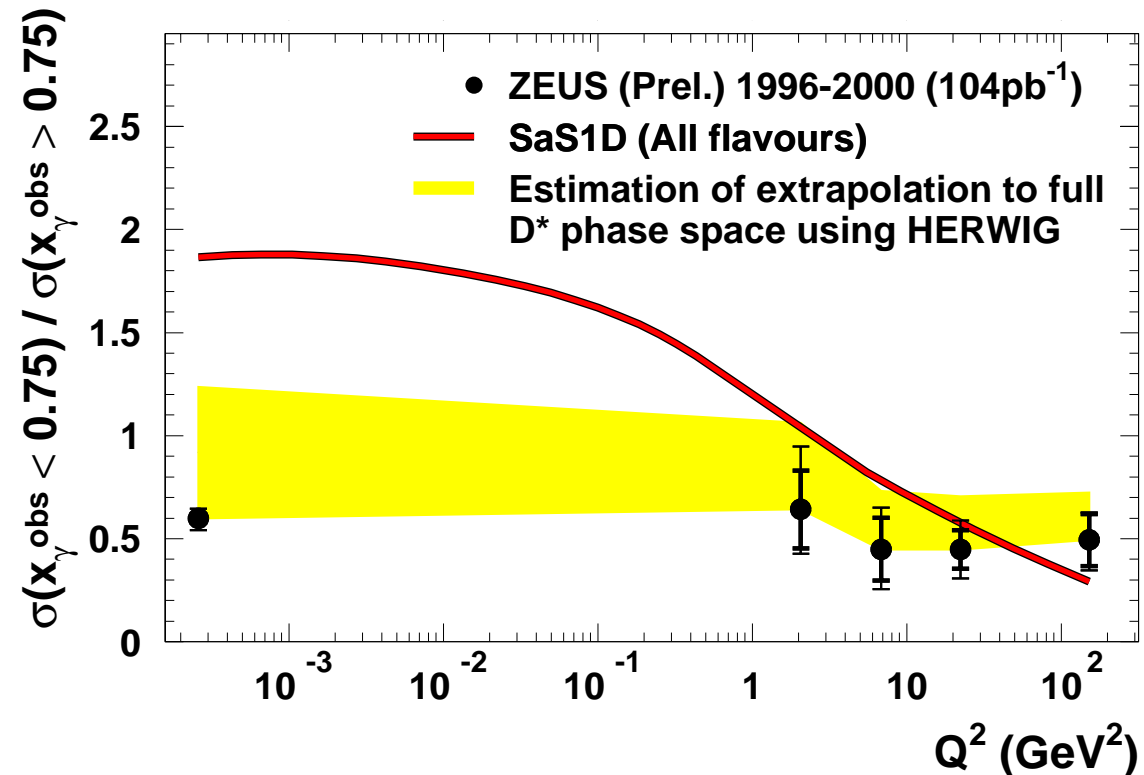
- Must first check that suppression is coming from presence of charm and not D^* kinematics.
- Some suppression due to D^* kinematics is seen.
- Estimate the change in the ratio due to this using Herwig/SaS1D events.



Comparison to “all flavours” ratio

ZEUS

- Ratio without a tag was measured in different kinematic region.
- **SaS1D** was shown to describe the shape, but not normalisation.
⇒ use to estimate “all flavours” ratio in correct kinematic region.



- Low x_γ^{obs} cross section of the photon falls off much less rapidly in the presence of charm.
- Q^2 and charm suppressions are not independent.

Summary

- x_γ^{obs} ratio has been measured for dijet events with a D^* for first time.
- Comparison to several pQCD predictions
 - **AROMA** (LO DGLAP, no photon structure) is unable to describe the data.
 - **SaS1D** (LO DGLAP, virtual photon PDF) describes the ratio.
 - **CASCADE** (LO CCFM, no photon structure) also describes the ratio.
- In order to describe the data at LO an anomalous photon contribution is required (either in PDF when using DGLAP evolution or in CCFM evolution).
- Next step, compare to **NLO** - clearer message?
- Ratio has also been compared to **SaS1D** predictions for “all flavours” ratio:
 - Low x_γ^{obs} falls off much less rapidly in the presence of charm.
 - Charm and Q^2 suppression not independent.