Charm and the Virtual Photon

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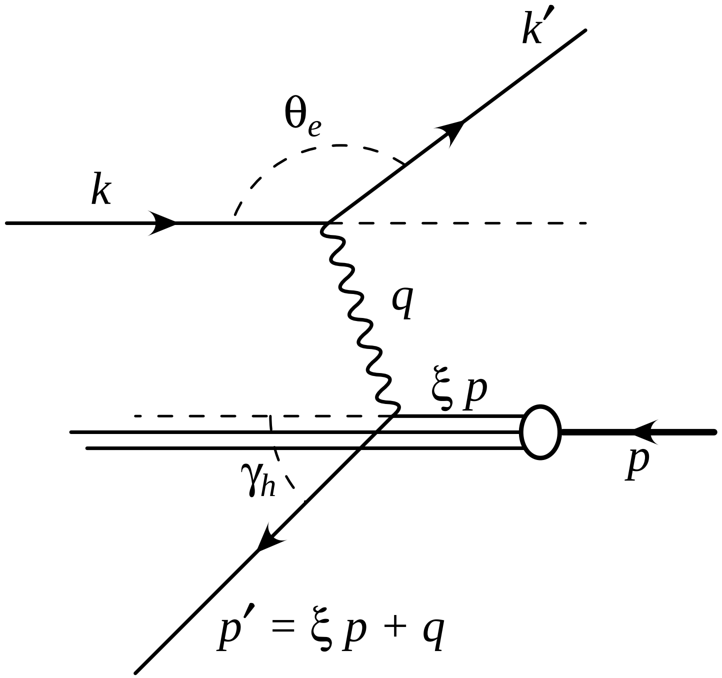
- Photon structure
- Charm in photoproduction
- Evolution schemes
- Charm and the virtual photon
- Leading-order pQCD predictions
- Summary

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) $Q^2<1\text{GeV}^2$; $<Q^2>\approx 3.10^{-4}$ GeV^2
  No scattered e in main detector ⇒quasi-real photon

Virtual photon structure

- Real photons have partonic structure:
  - Measurements of F_2^{γ} in **eγ** interactions and observation of single- and double- resolved processes in **γγ** 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 $Q^2 \rightarrow (E_T^{Jet})^2$]

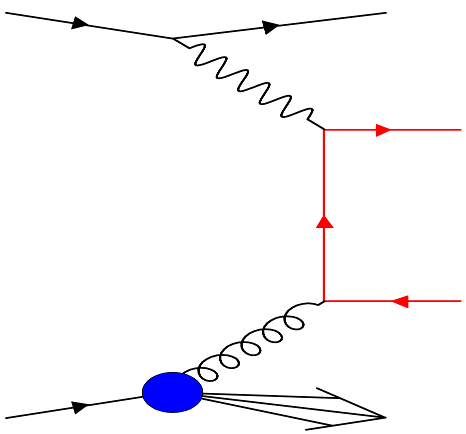
$$f_a^{\gamma^*}(x,Q^2,P^2) = \sum_V \frac{4\alpha_{em}}{f_V^2}\left(\frac{m_V^2}{m_V^2+P^2}\right)^2 f_a^{\gamma,V}(x,Q^2;\tilde{Q}_0^2) + \frac{\alpha_{em}}{2\pi}\sum_q 2e_q^2 \int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\left(\frac{k^2}{k^2+P^2}\right)^2 f_a^{\gamma,q\bar{q}}(x,Q^2;k^2)$$

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

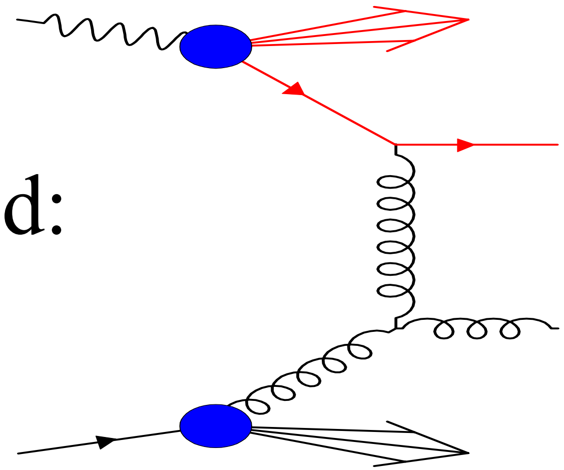
Virtual photon structure at HERA

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

direct:



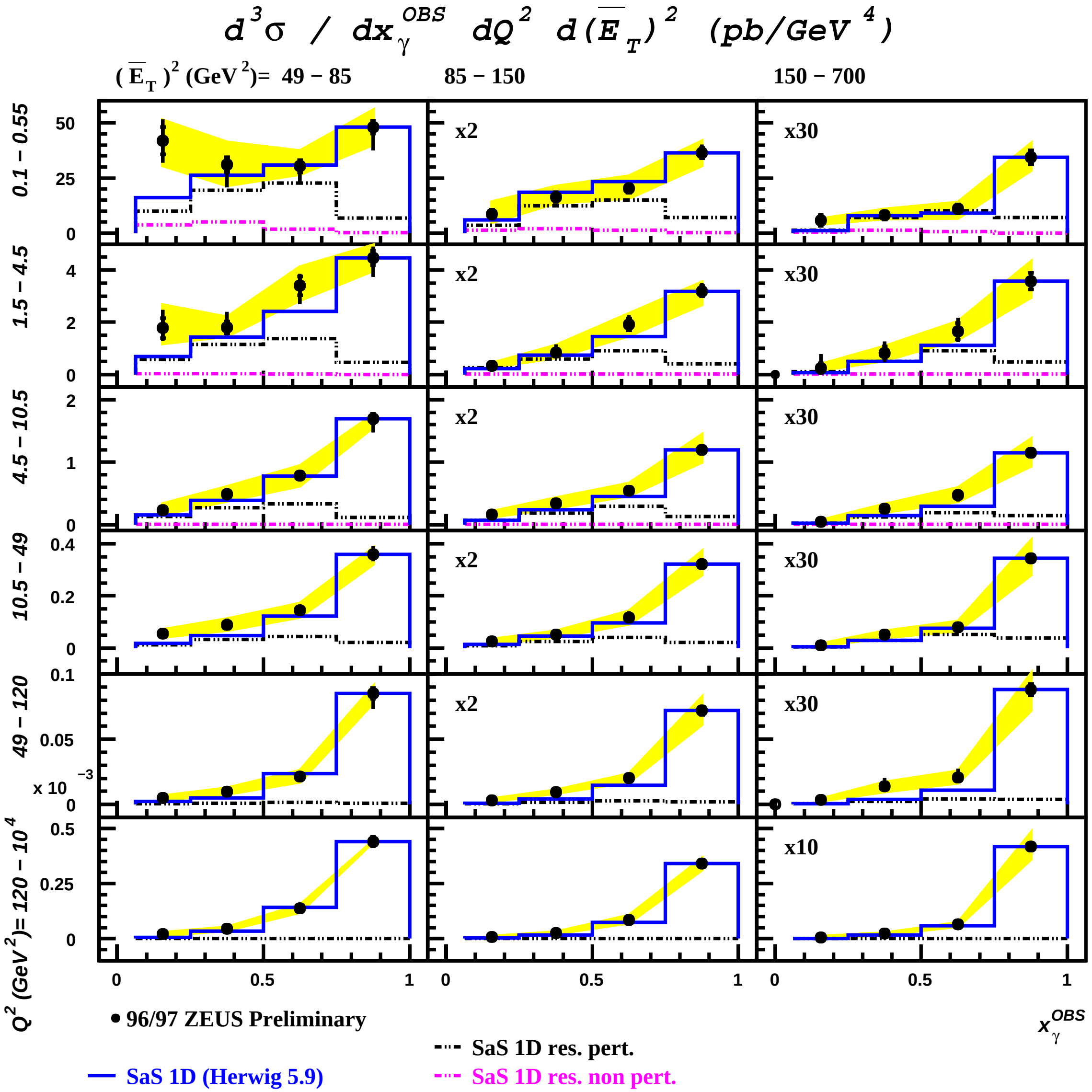
resolved:



- 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

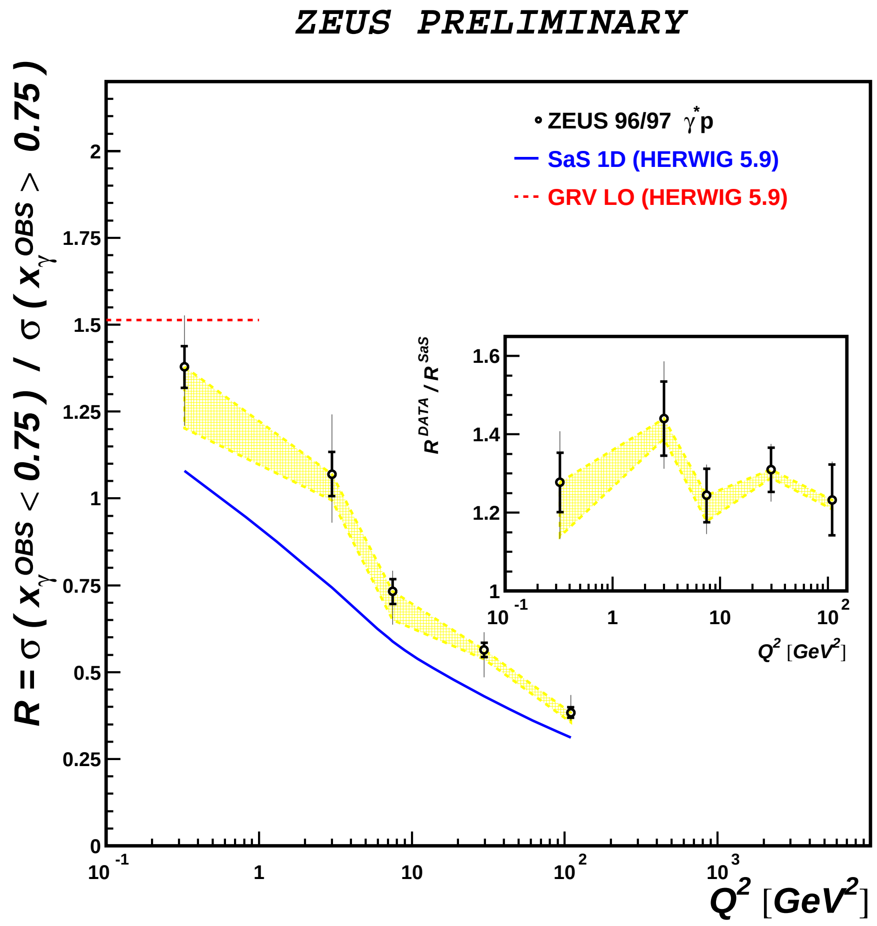


- Cross section measured as a function of Q^2, $\overline{E}_T^2$ and x_γ^{obs}.
- k_T algorithm in HCM frame: at least two jets with $E_T^{Jet} > 7.5$, 6.5 GeV and $-3.0 < \eta^{Jet} < 0.0$.
- LO prediction from **SaS1D**.

- Low x_γ^{obs} cross section falls faster than high x_γ^{obs} with increasing Q^2.
- Perturbative (anomalous photon) dominates LO resolved.
- For $Q^2 > \overline{E}_T^2$ data can be described by LO direct only.

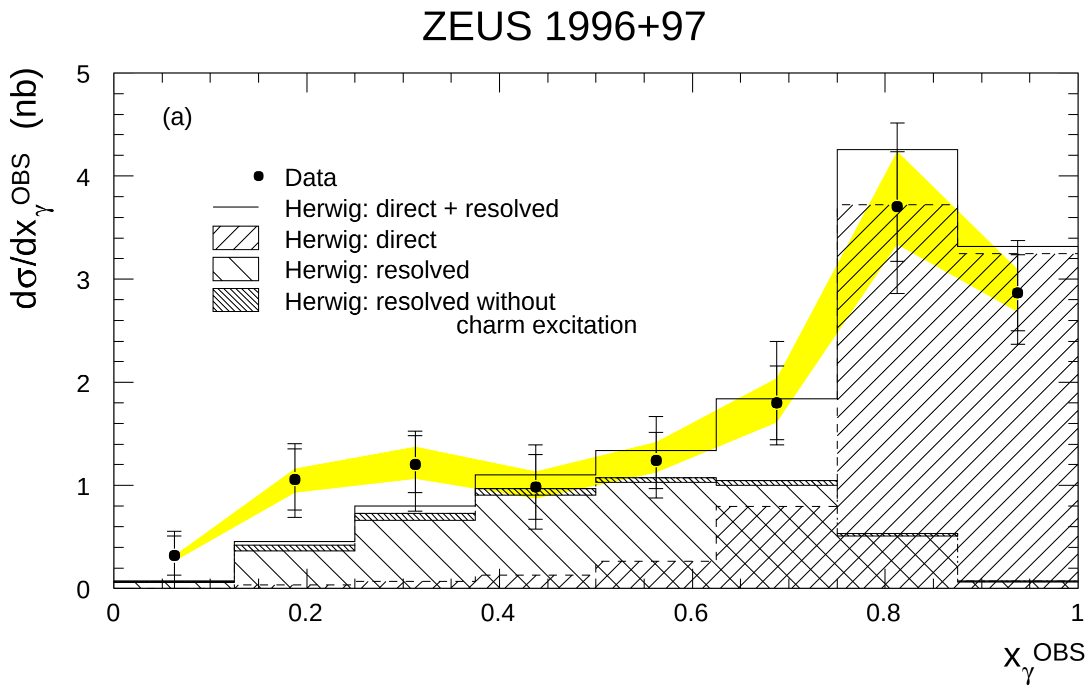
Ratio of cross sections

- 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



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

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

$p_T(D^*) > 3$ GeV

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

$0.2 < y < 0.8$

$Q^2 < 1$ GeV^2

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

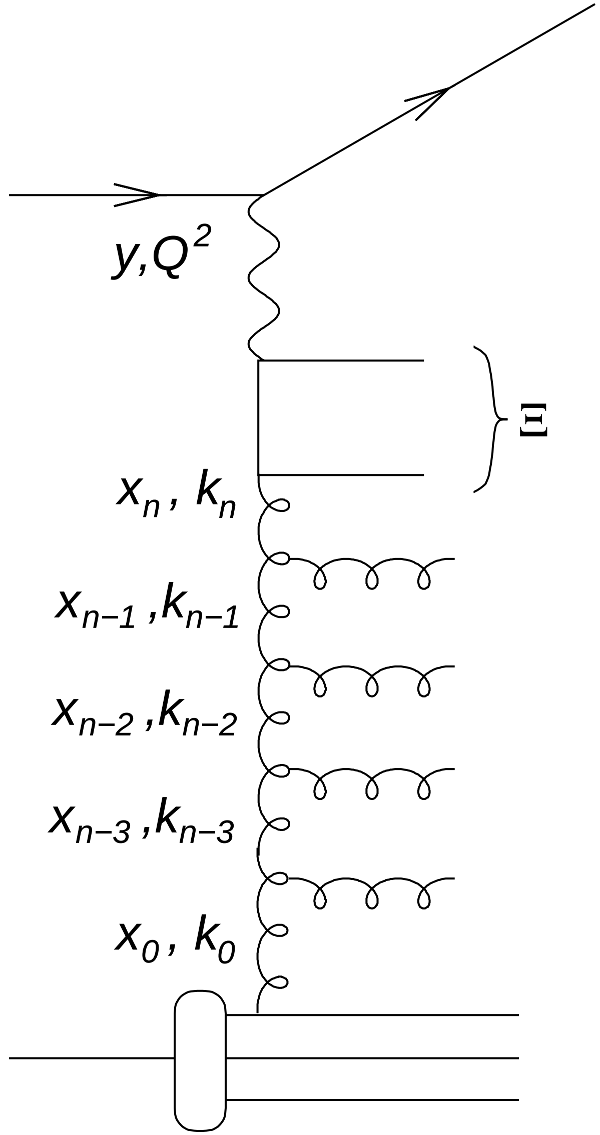
  $\Rightarrow$ suppression of resolved due to charm
- How does this effect the suppression of resolved evolve with Q^2?
- Are the charm and Q^2 suppressions related?

  $\Rightarrow$ 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.

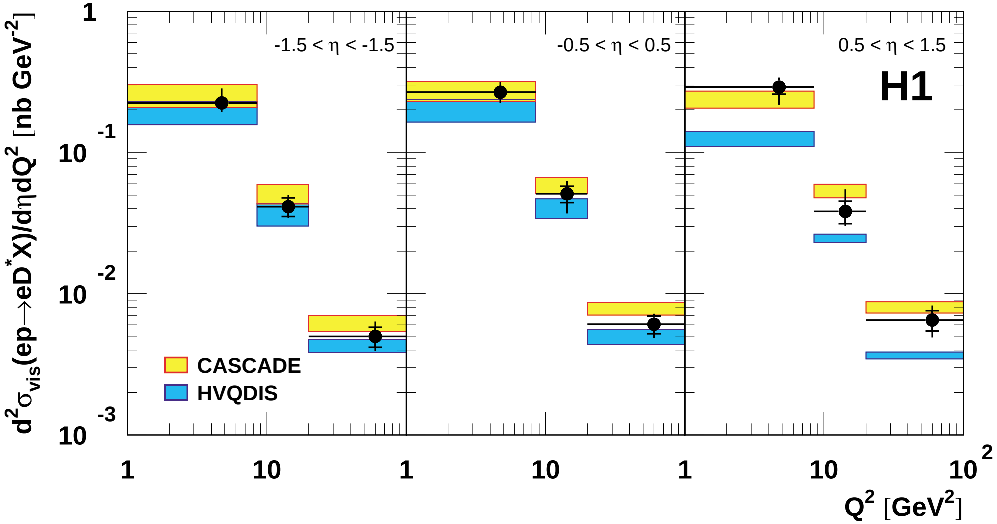


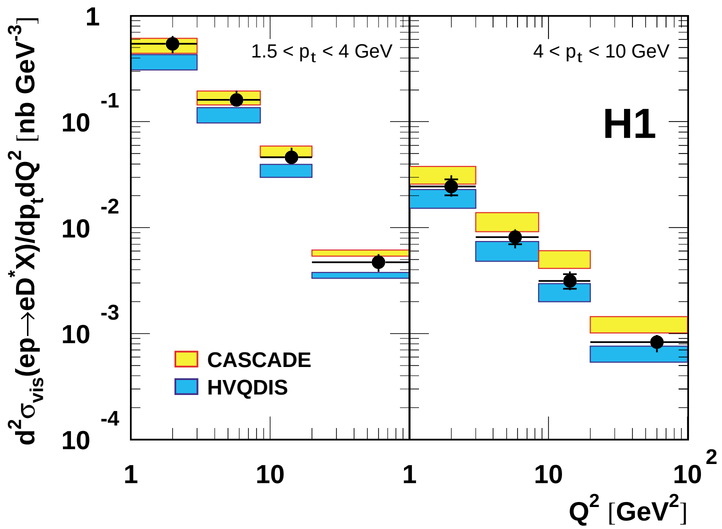
Charm in DIS

- Cross section for production of D^*s in DIS measured for
  $p_T(D^*) > 3$ GeV, $|\eta(D^*)| < 1.5$
  $0.2 < y < 0.8$, $1 < Q^2 < 100$ GeV^2

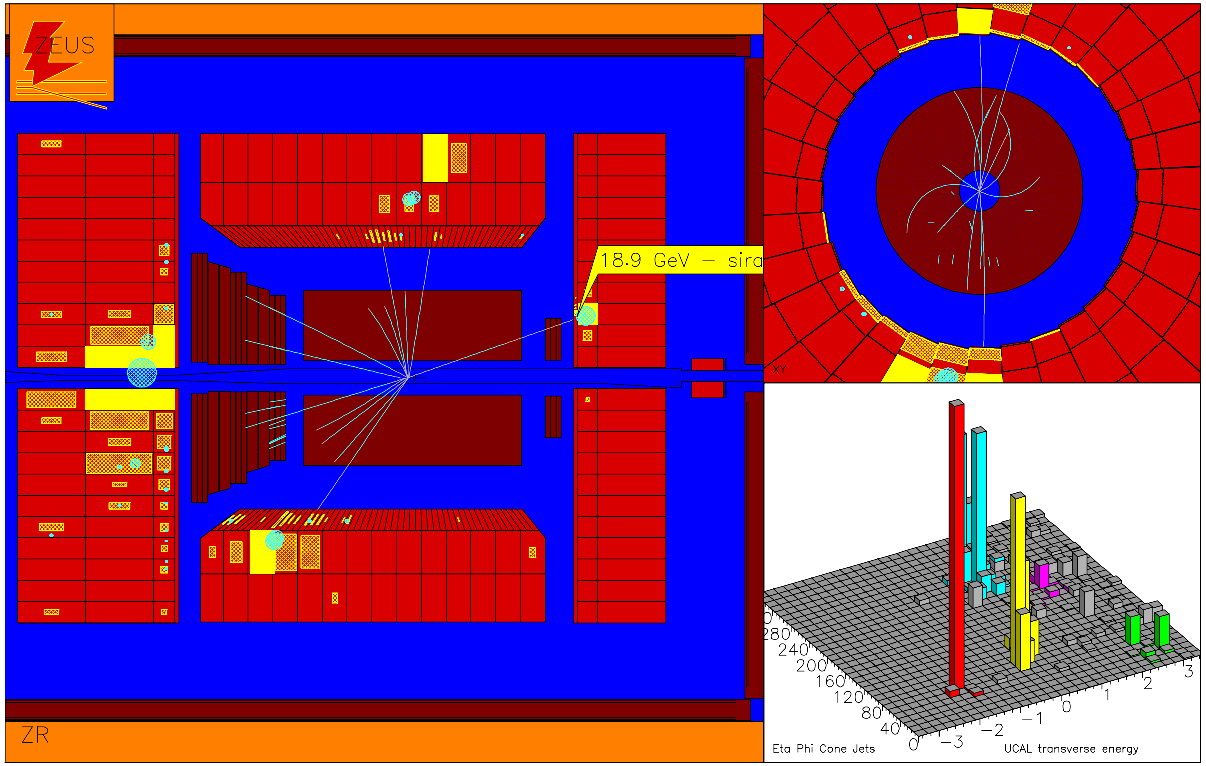
- Data compared to:
  - CASCADE - LO CCFM.
  - HVQDIS - NLO DGLAP.

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





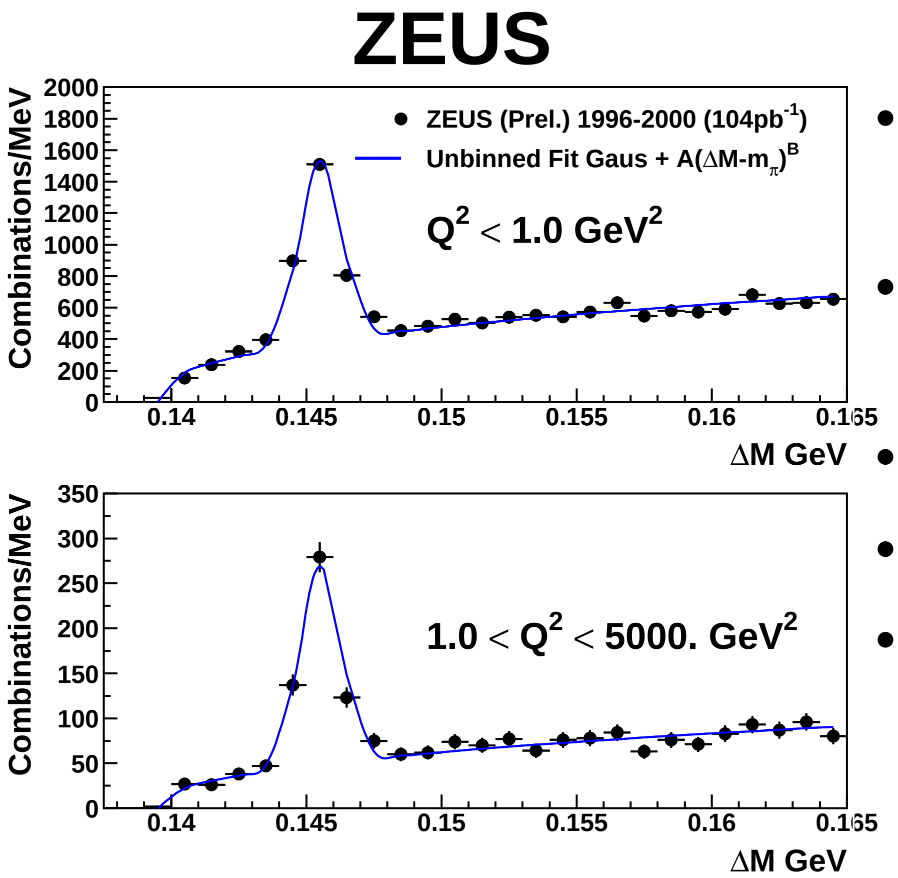
Event selection



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

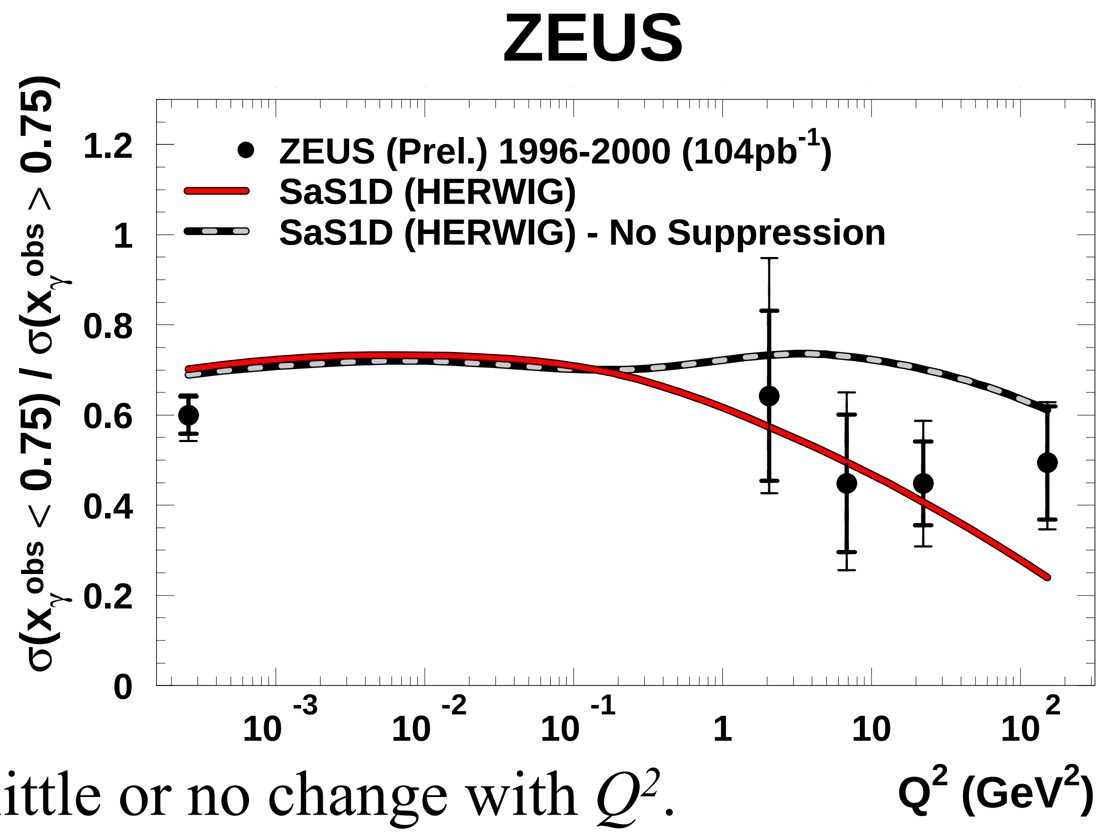
- Kinematic selection: $0.2 < y < 0.65$
  Q^2 Bins: $Q^2 < 1.0$, $1.0 < Q^2 < 4.5$, $4.5 < Q^2 < 10.5$, $10.5 < Q^2 < 49.$
  and $49. < Q^2 < 5000.$ GeV^2

Event selection



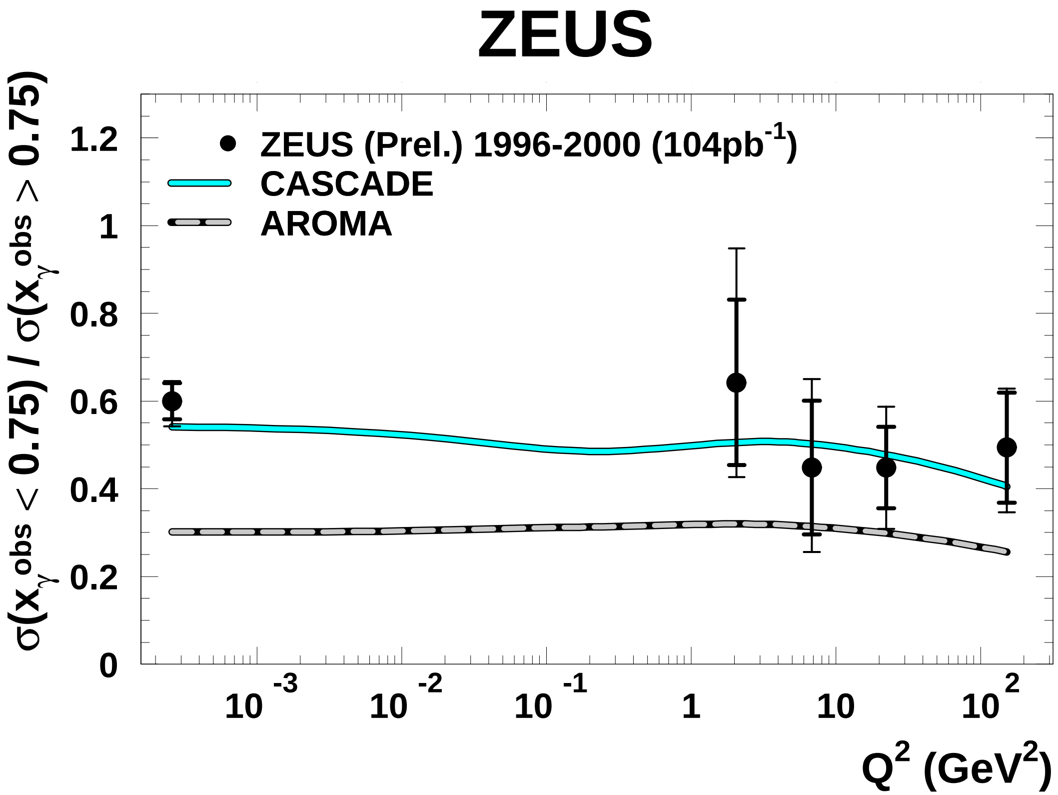
- D^*s found using combinatorial mass difference method.
- 3 parameter unbinned fit used for background estimation.
- 2200 ± 61 dijet events in PHP region.
- 421 ± 25 dijet events in DIS region.
- Statistics too low for highly differential plots
  $\Rightarrow$ study x_γ^{obs} ratio as a function of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

Leading-order predictions with SaS1D γ PDF



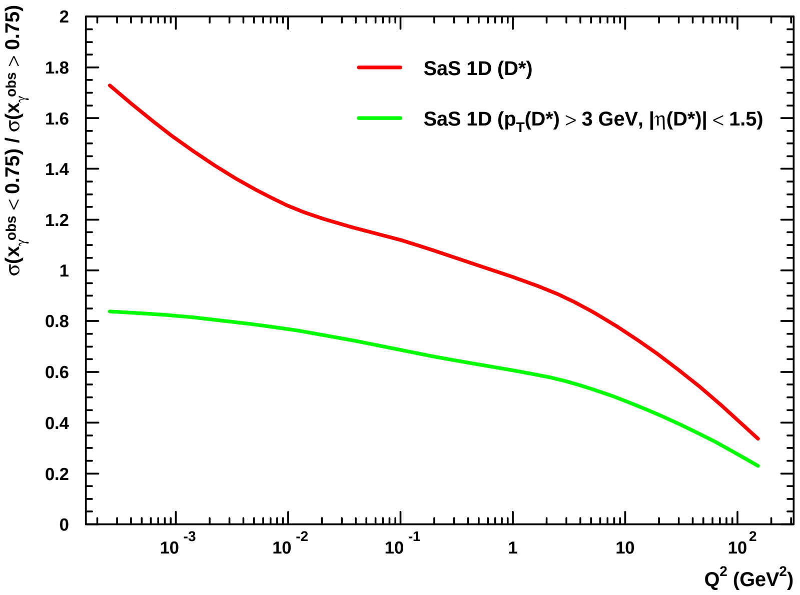
- Ratio shows little or no change with Q^2.
- Prediction of SaS1D virtual photon structure function shown:
    - ratio flat when no suppression in structure function.
    - ratio with suppression gives a reasonable description of the data.

Leading-order predictions with no γ PDF



- 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.

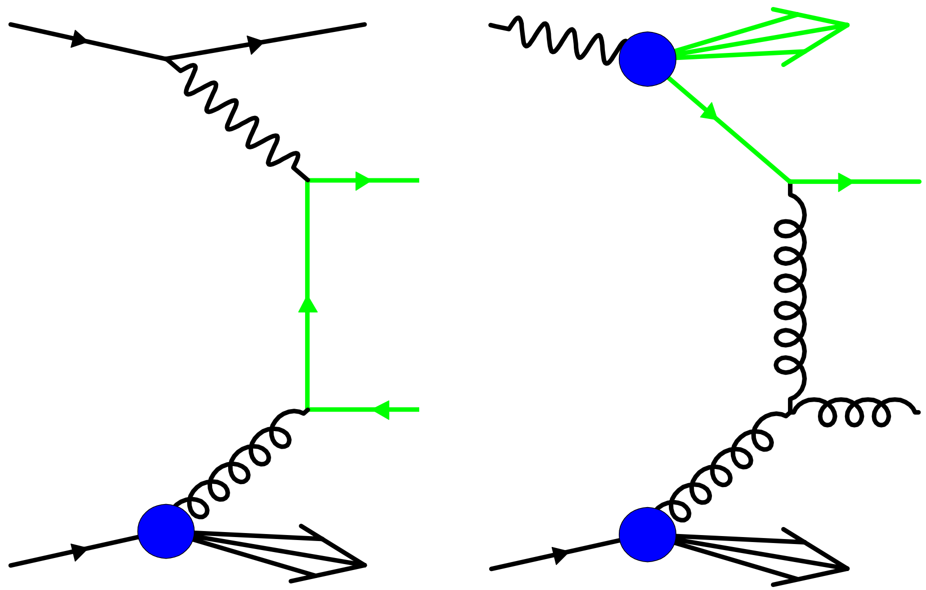
Comparison to “all flavours” ratio



• 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.

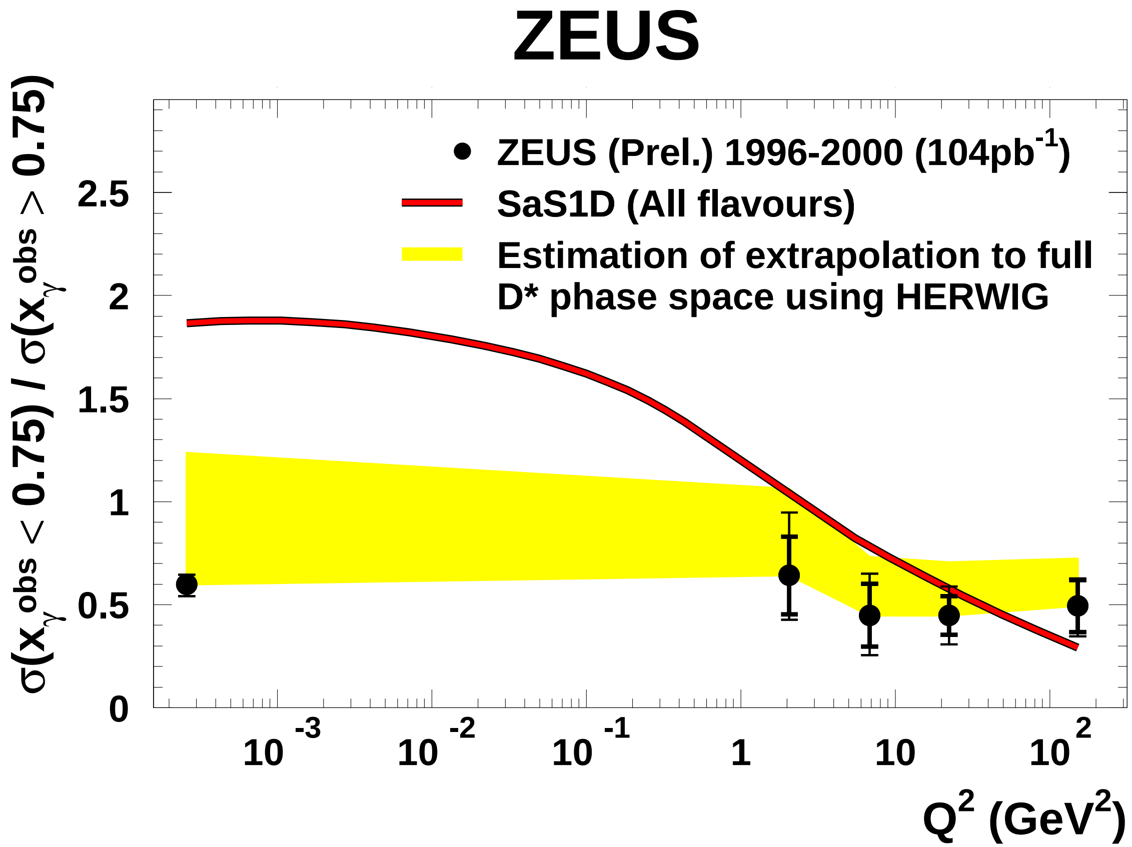
•Some suppression due to D* kinematics is seen.

•Estimate the change in the ratio due to this using Herwig/SaS1D events.

Comparison to "all flavours" ratio

- 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.