PHOTON 2000
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Virtual Photon Structure

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from

ZEUS Collab.

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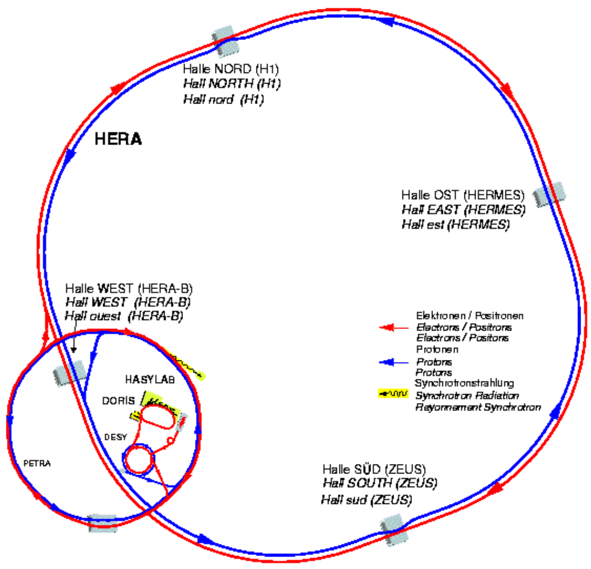
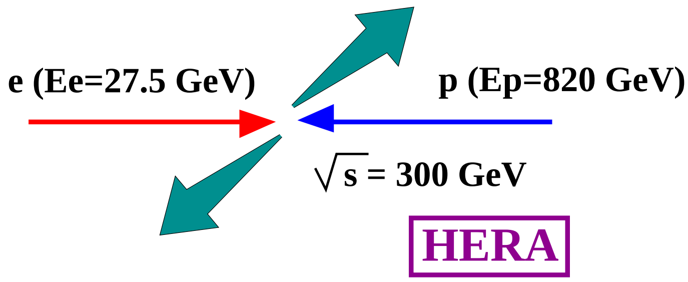




Virtual photon structure

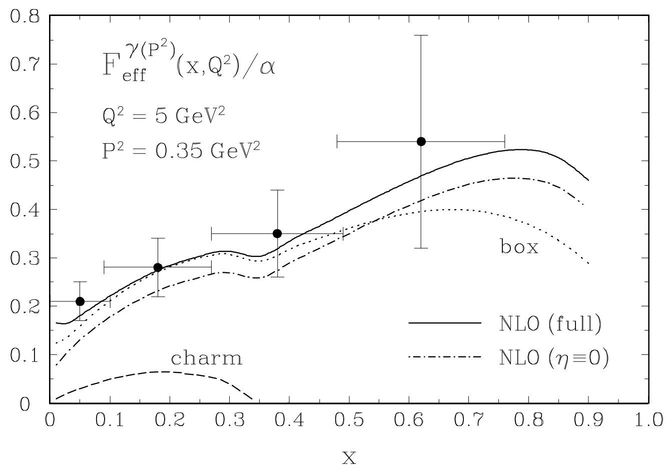
- Real photons have partonic structure: measurements of F_2^γ in $e\gamma$ interactions and observation of resolved processes in γp interactions and of single- and double-resolved processes in $\gamma\gamma$ interactions

- Virtual photons should also have a partonic structure: QCD predicts that the parton densities of virtual photons become logarithmically suppressed as P^2 (virtuality of the probed photon) increases at fixed μ^2 (scale of interaction: Q^2 in DIS $e\gamma$ and E_T^{jet} in jet production)

- The virtual photon structure function:
  $\rightarrow F_2^{\gamma^*}(x, P^2, \mu^2) = \sum_q x\, e_q^2 [f_{q/\gamma^*}(x, P^2, \mu^2) + f_{\bar{q}/\gamma^*}(x, P^2, \mu^2)]$

- The virtual photon parton densities contain two terms:
  $\rightarrow f_{i/\gamma^*}(x, P^2, \mu^2) = f_{i/\gamma^*}^{\mathrm{had}}(x, P^2, \mu^2) + f_{i/\gamma^*}^{\mathrm{anom}}(x, P^2, \mu^2)$

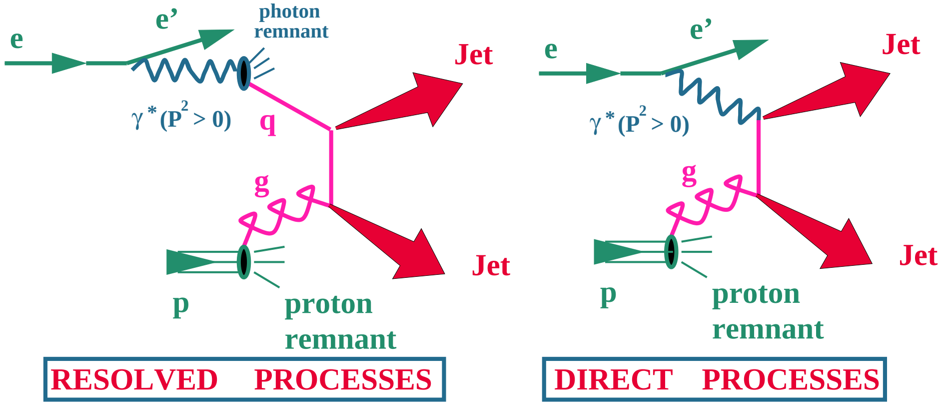
- First measurement of $F_{\mathrm{eff}}^{\gamma^*} \equiv F_2 + \frac{3}{2} F_L$ by PLUTO



Virtual Photon Structure at HERA

Studied in γp: $ep \to e + \text{jet} + \text{jet} + X$

At LO QCD:



direct: $\sigma_{LO}^{ep\to 2\,\text{jet}} = \int d\Omega\ f_{\gamma^*/e}(y,P^2)\ f_{j/p}(x_p,\mu^2)\ d\sigma(\gamma^* j \to \text{jet jet})$

resolved: $\sigma_{LO}^{ep\to 2\,\text{jet}} = \int d\Omega\ f_{\gamma^*/e}(y,P^2)\ f_{j/p}(x_p,\mu^2) \times$
$f_{i/\gamma^*}(x_{\gamma^*},P^2,\mu^2)\ d\sigma(ij \to \text{jet jet})$

$\to f_{\gamma^*/e}(y,P^2)$: flux of virtual photons in e

$\to f_{j/p}(x_p,\mu^2)$: parton j density in p (determined from e.g. global fits)

$\to f_{i/\gamma^*}(x_{\gamma^*},P^2,\mu^2)$: parton i density in γ^* (very little information from measurements of $F_2^{\gamma^*}$ in $e\gamma$) $\to \delta(1-x_i)$ for direct

$\to d\sigma(i(\gamma^*)j \to \text{jet jet})$: subprocess cross section (calculable in pQCD)

Resolved vs Direct

- The contribution to the dijet cross section from resolved processes is expected to decrease relative to the contribution from direct processes as $P^2 \to \mu^2$
  $\to$ the partonic content of the photon becomes suppressed

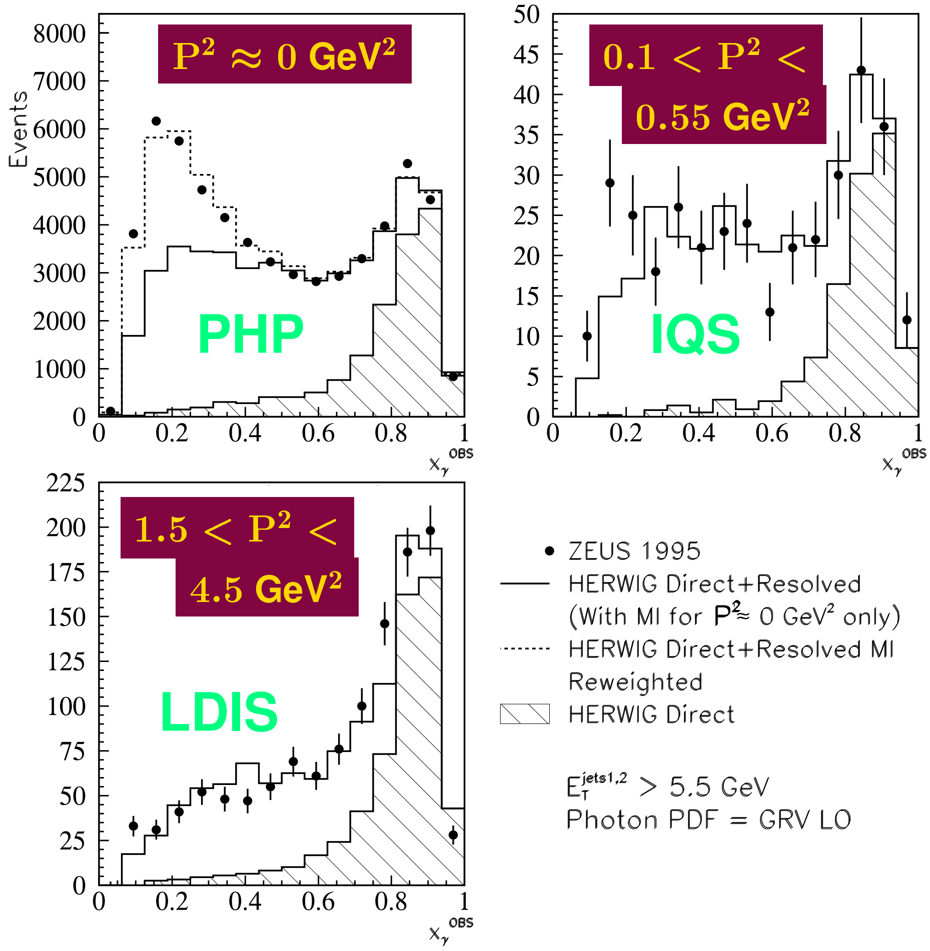
- Resolved and direct processes can be separated using the variable x_γ^{OBS}:

$$\boxed{x_\gamma^{OBS} = \frac{1}{2yE_e}(E_T^{jet1}e^{-\eta^{jet1}} + E_T^{jet2}e^{-\eta^{jet2}})}$$

  * Resolved processes $\to$ low x_γ^{OBS}
  * Direct processes $\to$ high x_γ^{OBS}

- Three P^2 regions studied

- Need a significant resolved photon component in MC to describe data for $x_\gamma^{OBS} < 0.75$
  $\to$ sensitivity to virtual photon structure

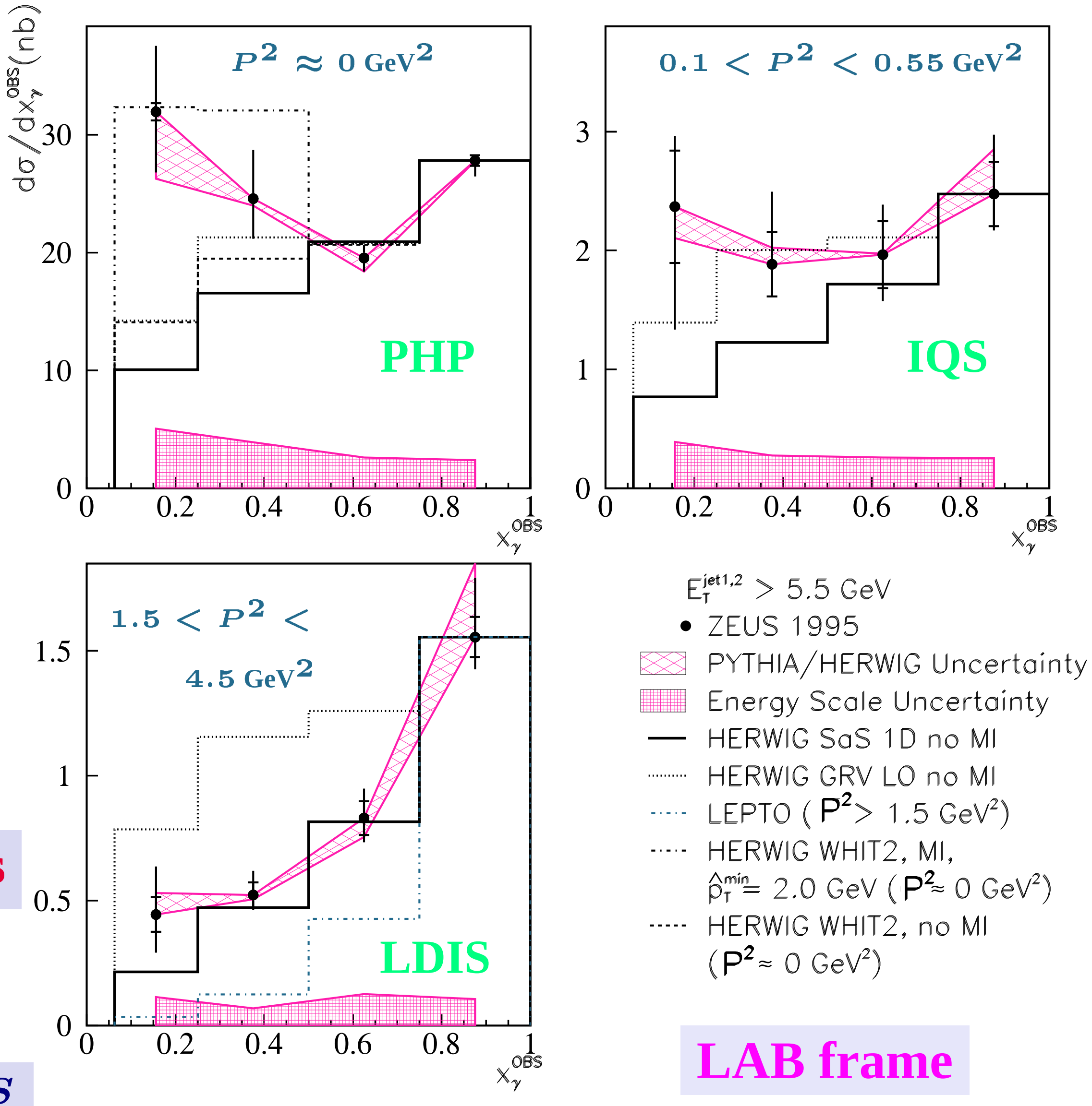


Measurement of $d\sigma/dx_\gamma^{OBS}$

MC normalised to data for $x_\gamma^{OBS} > 0.75$

* **Low E_T^{jet} region:**

- Jets searched using the longitudinally invariant k_T cluster algorithm in the inclusive mode in the LAB frame
- Kinematic region: $0.2 < y < 0.55$ and $0 \lesssim P^2 < 4.5$ GeV^2
- At least two jets with $E_T^{jet} > 5.5$ GeV and $-1.125 < \eta^{jet} < 2.2$



→ **The shape of the cross section changes markedly with increasing P^2:**

→ **the cross section at low x_γ^{OBS} decreases faster than at high x_γ^{OBS}**

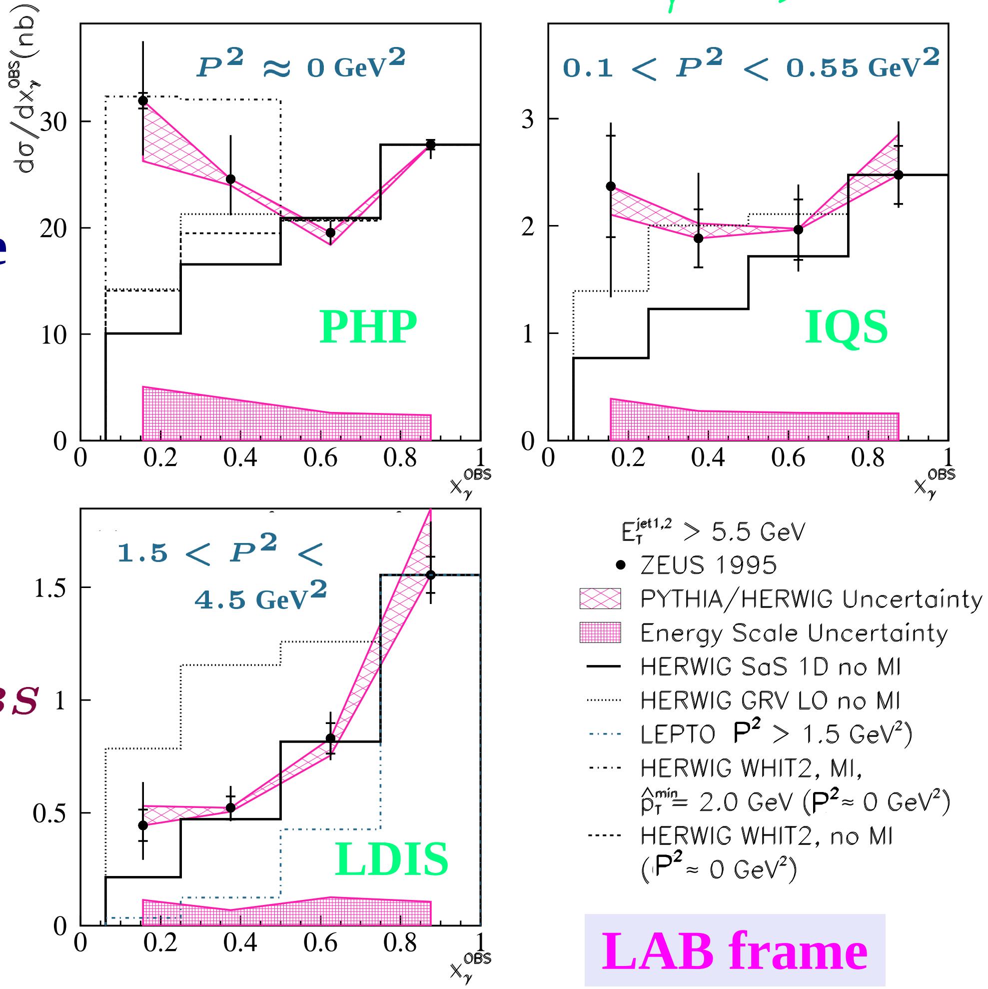
- **γPDFs:**
  - $\rightarrow$ **GRV and WHIT2 PDFs valid for real photons only, no P^2 dependence**
  - $\rightarrow$ **SaS 1D consists of two components with different P^2 dependence: the hadronic decreases $\approx (m_\rho^2/(m_\rho^2 + P^2))^2$ and the anomalous decreases $\sim \log(\mu^2/P^2)$**
- **Comparison to HERWIG MC:**
  - $\rightarrow$ **GRV: does not describe the data**
  - $\rightarrow$ **WHIT2: reasonable agreement with the data in PHP and IQS**
  - $\rightarrow$ **SaS 1D: agrees with the data at high x_γ^{OBS}**
- **Comparison to DIS LEPTO MC:**

$\rightarrow$ **LEPTO underestimates low x_γ^{OBS} in LDIS**

$\rightarrow$ **parton shower contributions alone cannot describe the data**

Measurement of $d\sigma/dx_\gamma^{OBS}$

MC normalised to data for $x_\gamma^{OBS} > 0.75$



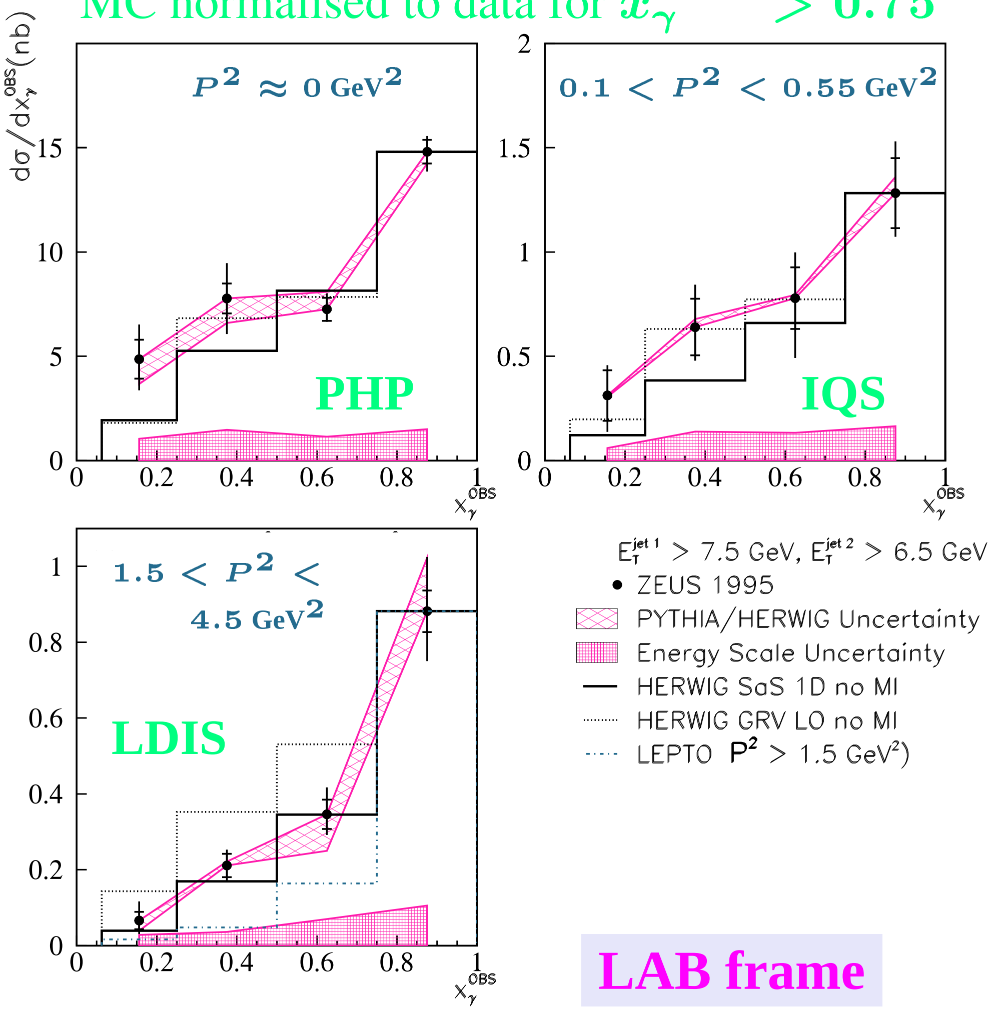
LAB frame

Measurement of $d\sigma/dx_\gamma^{OBS}$

- **High E_T^{jet} region:** At least two jets with $E_T^{jet1(2)} > 7.5(6.5)$ GeV and $-1.125 < \eta^{jet1,2} < 1.875$

→ **the cross section at low x_γ^{OBS} decreases faster than at high x_γ^{OBS}**

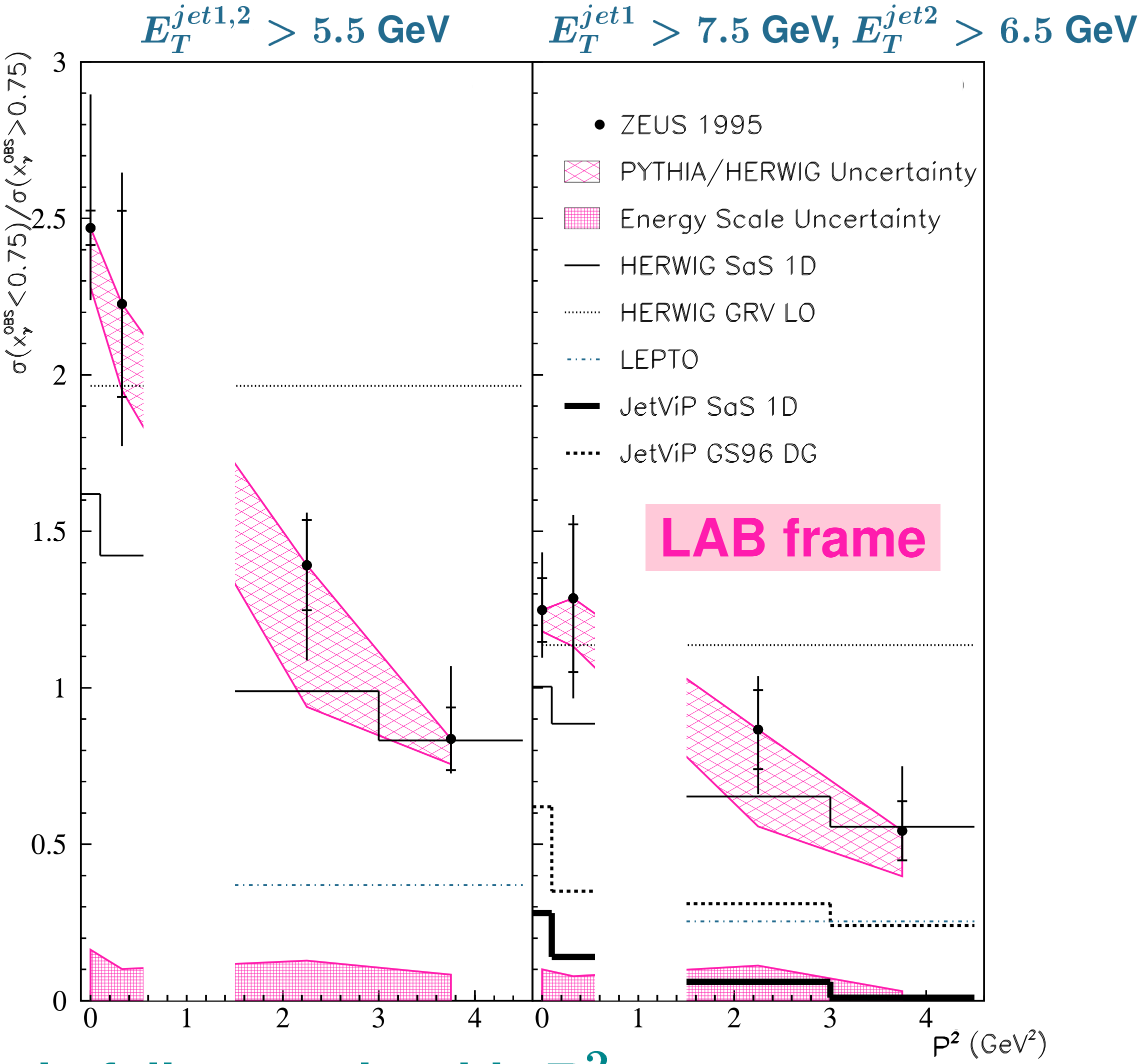
MC normalised to data for $x_\gamma^{OBS} > 0.75$



LAB frame

- **Comparison to HERWIG MC:**
  - → **GRV: in good agreement with the data in PHP and IQS, but fails in LDIS**
  - → **SaS 1D: agrees with the data in LDIS but underestimates the PHP and IQS data at low x_γ^{OBS}**
- **Comparison to DIS LEPTO MC:**
  - → **LEPTO underestimates low x_γ^{OBS} in LDIS**

$\sigma(x_\gamma^{OBS} < 0.75)/\sigma(x_\gamma^{OBS} > 0.75)$ vs P^2



- The ratio falls steeply with P^2
  $\rightarrow$ interpreted as suppression of resolved photon component as the photon virtuality increases
- **Comparison to HERWIG MC:**
  $\rightarrow$ GRV: constant $\rightarrow$ expected for a γ without P^2 dependence
  $\rightarrow$ SaS 1D: decreases with P^2 but lies below the data at low P^2
- **Comparison to DIS LEPTO MC:** the contribution to the ratio from parton shower effects underestimates the data
- **Comparison to QCD calculations (JetViP):** predictions sensitive to the choice of γPDF but lie well below the data

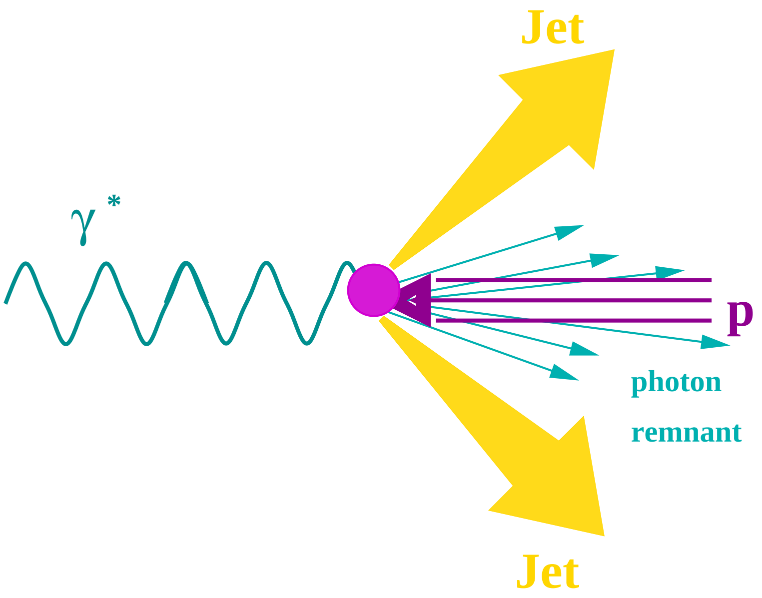
Measurements at high P^2: the $\gamma^* p$ frame

- For high P^2, the x_γ^{OBS} definition

$$\boxed{x_\gamma^{OBS} = \frac{1}{2yE_e}(E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}})}$$

is still valid

- However, at high P^2, the photon remnant may have high transverse energy in the LAB frame
- In order to avoid this problem $\rightarrow$ transform to the $\gamma^* p$ frame

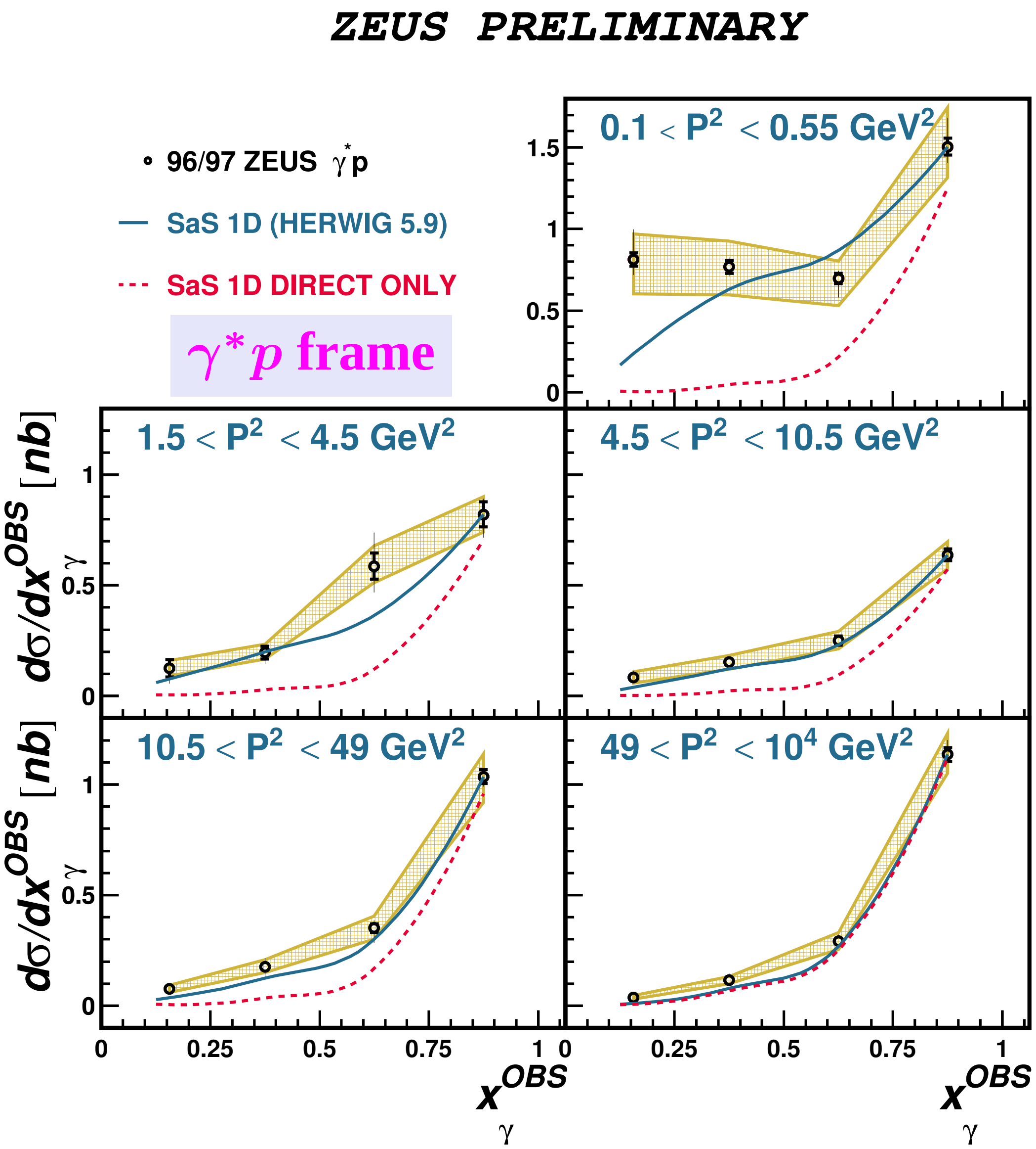


- In the $\gamma^* p$ frame the photon remnant has very low transverse energy $\rightarrow$ will not be considered as a jet

Measurement of $d\sigma/dx_\gamma^{OBS}$

MC normalised to data for $x_\gamma^{OBS} > 0.75$

- Jets searched using the longitudinally invariant k_T cluster algorithm in the inclusive mode in the $\gamma^* p$ frame
- Kinematic region: $0.2 < y < 0.55$ and $0.1 < P^2 < 10^4$ GeV^2
- Two jets with $E_{T,\gamma^* p}^{jet1(2)} > 7.5(6.5)$ GeV and $-3 < \eta_{\gamma^* p}^{jet1,2} < 0$



→ The shape of the cross section changes dramatically with increasing P^2:

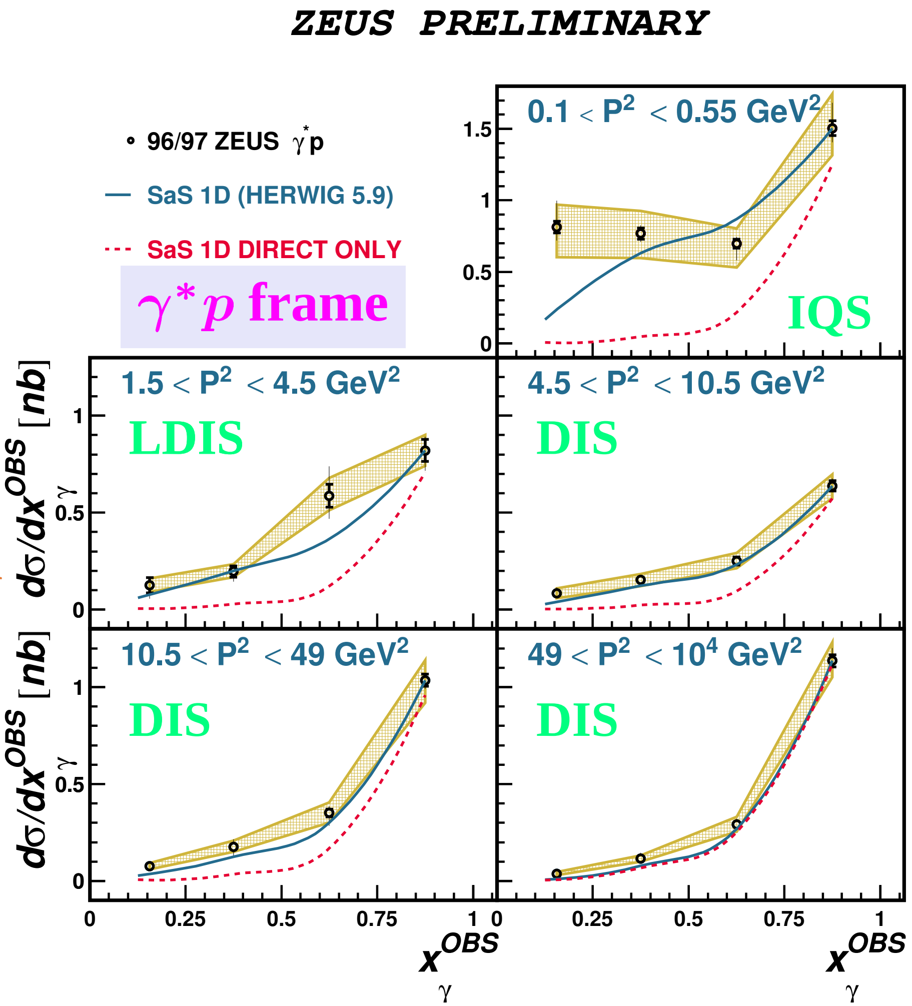
→ the cross section at low x_γ^{OBS} values falls rapidly with P^2

- **Comparison to HERWIG MC:**
  - → SaS 1D: good description of the data in whole DIS region but fails in the IQS region
  - → The LO resolved component is needed to describe the data up to $P^2 < 49$ GeV^2
  - → For $P^2 > 49$ GeV^2, HERWIG prediction is mainly due to direct component and describes well the data

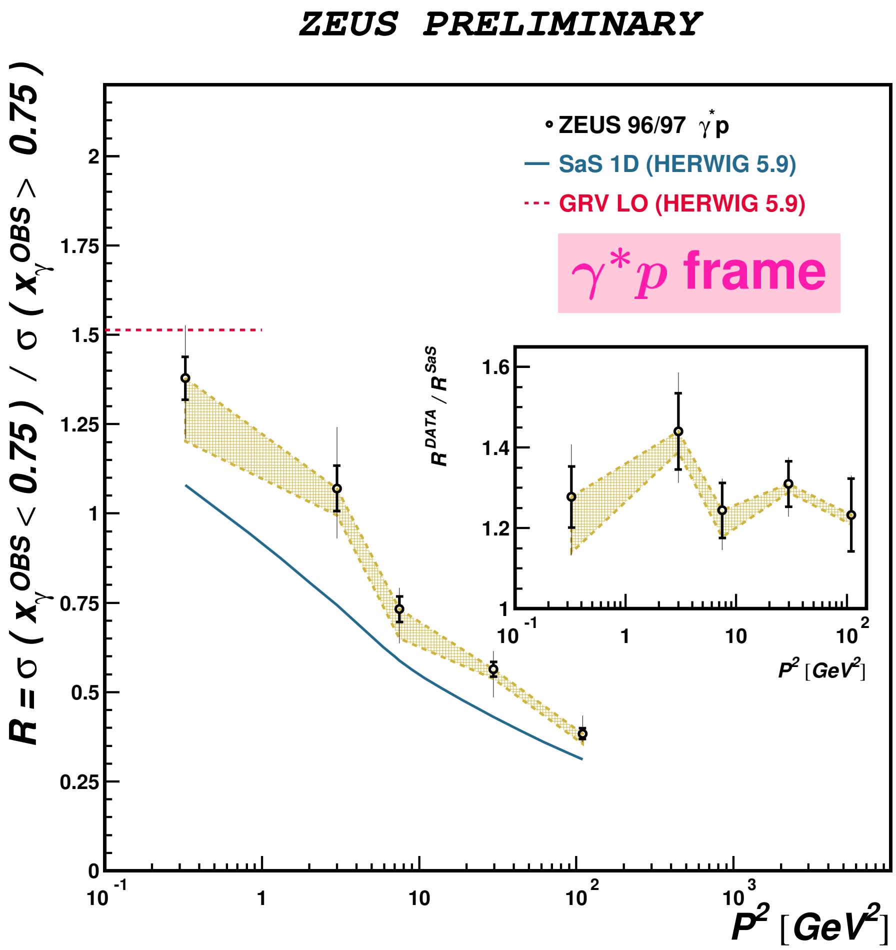
→ For $P^2 \geq (E_T^{jet})^2$ only direct photon processes are needed to describe the data

Measurement of $d\sigma/dx_\gamma^{OBS}$

MC normalised to data for $x_\gamma^{OBS} > 0.75$



$\sigma(x_\gamma^{OBS} < 0.75)/\sigma(x_\gamma^{OBS} > 0.75)$ vs P^2



→ The measured ratio falls steeply with P^2

- Comparison to HERWIG MC:
  → GRV: constant
  → SaS 1D: decreases with P^2 but lies below the data for the entire P^2 range measured

- The ratio $R^{DATA}/R^{SaS} \approx 1.3$ independent of P^2
  → the suppression included in SaS 1D is in agreement with the data, but it underestimates the resolved component by $\sim 30\%$

CONCLUSIONS

- Dijet cross sections as a function of x_γ^{OBS} have been measured in the $\gamma^* p$ frame in the kinematic region given by $0.2 < y < 0.55$ and $0.1 < P^2 < 10^4$ and $E_{T,\gamma^* p}^{jet1(2)} > 7.5(6.5)$ GeV and $-3 < \eta_{\gamma^* p}^{jet1,2} < 0$
- The x_γ^{OBS} dependence of the measured cross sections changes with increasing $P^2 \rightarrow$ the low x_γ^{OBS} cross section decreases more rapidly than high x_γ^{OBS}
- The predictions of HERWIG with SaS 1D describe the data for $1.5 < P^2 < 10^4$ GeV^2 but fail in the region $0.1 < P^2 < 0.55$ GeV^2
- The LO resolved photon component is needed to describe the data up to $P^2 = 49$ GeV^2, when the photon is probed at a scale comparable to $(E_T^{jet})^2$ (scale of the interaction)
- The ratio $\sigma(x_\gamma^{OBS} < 0.75)/\sigma(x_\gamma^{OBS} > 0.75)$ decreases as P^2 increases
- The predicted (HERWIG SaS 1D) rate of suppression of $x_\gamma^{OBS} < 0.75$ agrees with the data

$\rightarrow$ The data may be interpreted in terms of a resolved photon component which is suppressed as the photon virtuality increases