Structure of Virtual Photons from HERA

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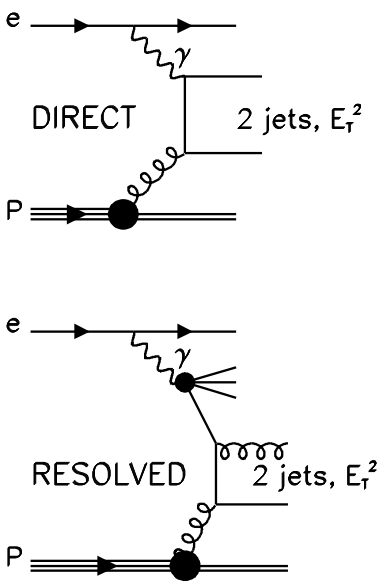
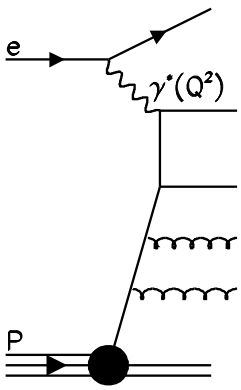
Representing

H1 and **ZEUS** Collaborations

- Di-jets at HERA
- DGLAP-like Concept, γ_L^*
- CCFM-like Concept
- Conclusions

Di-jet Production at HERA

PHOTOPRODUCTION $E_T^2 >> Q^2 \sim 0$	LOW Q^2 $E_T^2 > Q^2 > 0$	D.I.S. ON PROTON $Q^2 >> m_p^2$
		

Possible concepts in low Q^2 region:

- Direct and Resolved processes of standard DGLAP-like MC programs (HERWIG, RAPGAP).
- k_t unordered initial parton cascade processes based on CCFM or BFKL evolution (CASCADE).
- NLO calculations.

All the previous approaches include different higher order corrections.

γ^* Resolved Processes

- Cross-section of the resolved photon contributions to the di-jet production:

$$\sigma \sim \sum_{k=T,L} f_{\gamma^k/e} \otimes \mathrm{PDF}_{\gamma_k^*} \otimes \mathrm{PDF}_P \otimes |M_{ij}|^2$$

- Photon fluxes:

$$f_{\gamma^T/e}(y,Q^2) = \frac{\alpha}{2\pi}\left[\frac{2(1-y)+y^2}{y}\frac{1}{Q^2} - \frac{2m_e^2 y}{Q^4}\right]$$

$$f_{\gamma^L/e}(y,Q^2) = \frac{\alpha}{2\pi}\left[\frac{2(1-y)}{y}\frac{1}{Q^2}\right]$$

Note that for $Q^2 \gg m_e$:

$$y = 0 \implies f_{\gamma^L/e} = f_{\gamma^T/e}$$
$$y = 1 \implies f_{\gamma^L/e} = 0$$

- QED behavior of γ^* PDF in our kinematic region:

$$\left.\begin{aligned} \mathrm{PDF}_{\gamma_T^*} &\sim h_1(x)\cdot \ln\frac{E_t^2}{Q^2} \\ \mathrm{PDF}_{\gamma_L^*} &\sim h_2(x) \end{aligned}\right\} \text{ for } Q^2 \gg m_q^2$$

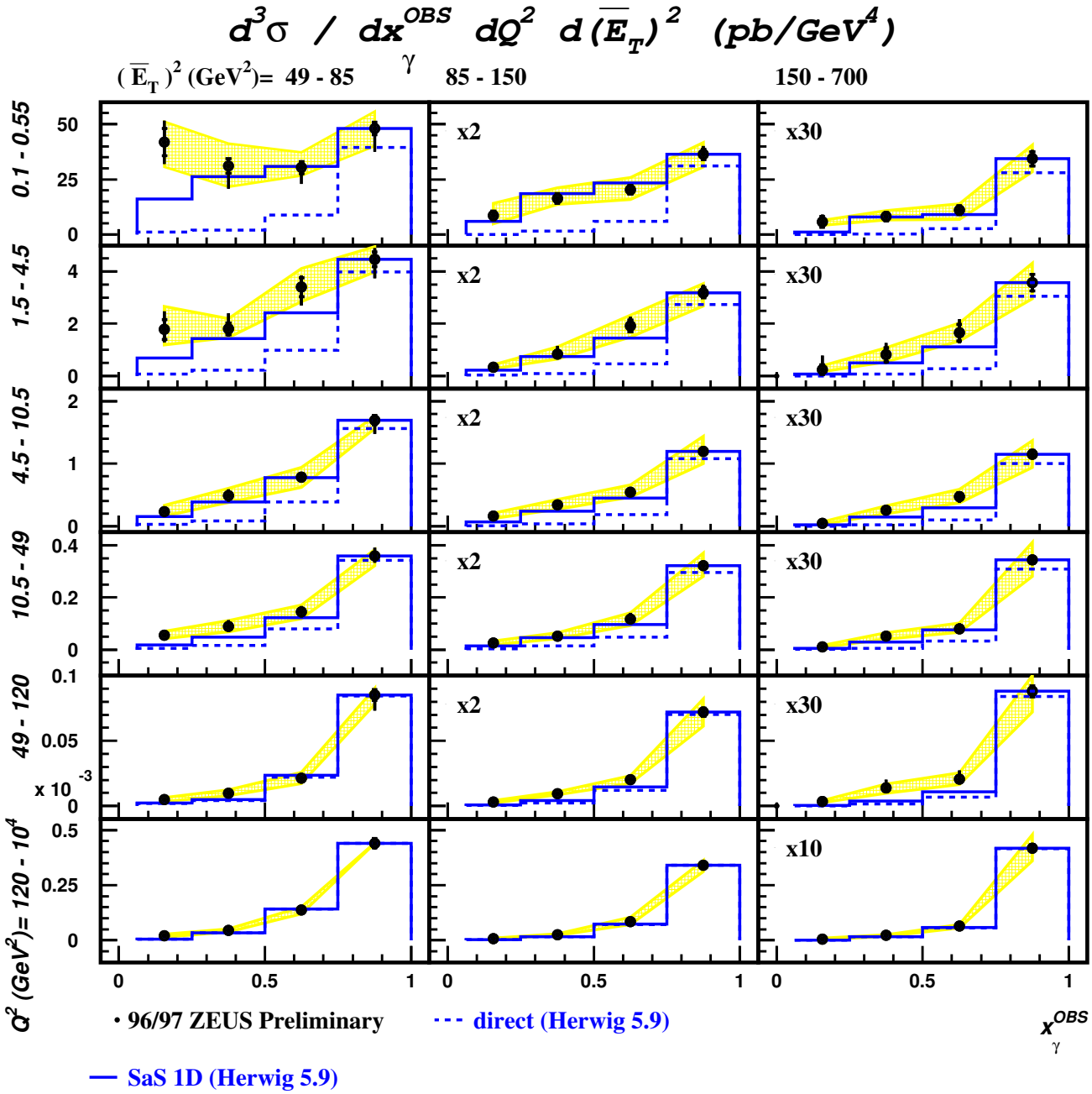
Kinematic Range of the Measurement

H1 (16.3 pb^{-1}, 1999)	**ZEUS** (38.2 pb^{-1}, 1996-97)
$\sqrt{s} = 318$ GeV	$\sqrt{s} = 300$ GeV
$2\ \mathrm{GeV}^2 < Q^2 < 80\ \mathrm{GeV}^2$	$0.1 < Q^2 < 10\,000\ \mathrm{GeV}^2$
$0.1 < y < 0.85$	$0.2 < y < 0.55$
$E_t^{jet\,1,2} > 5$ GeV $\overline{E}_t > 6$ GeV	$E_t^{jet\,1} > 7.5$ GeV $E_t^{jet\,2} > 6.5$ GeV
$-2.5 < \eta^{jet\,1,2} < 0$	$-3 < \eta^{jet\,1,2} < 0$

MC Models Used

H1	**ZEUS**
HERWIG 5.9, RAPGAP 2.8: proton PDF: GRV LO γ_T^* PDF: SaS1D γ_L^* PDF: J. Chýla s.u.e. in HERWIG: 10%	HERWIG 5.9: proton PDF: MRSA γ_T^* PDF: SaS1D s.u.e. in HERWIG: 0%
CASCADE 1.0: Default setting	

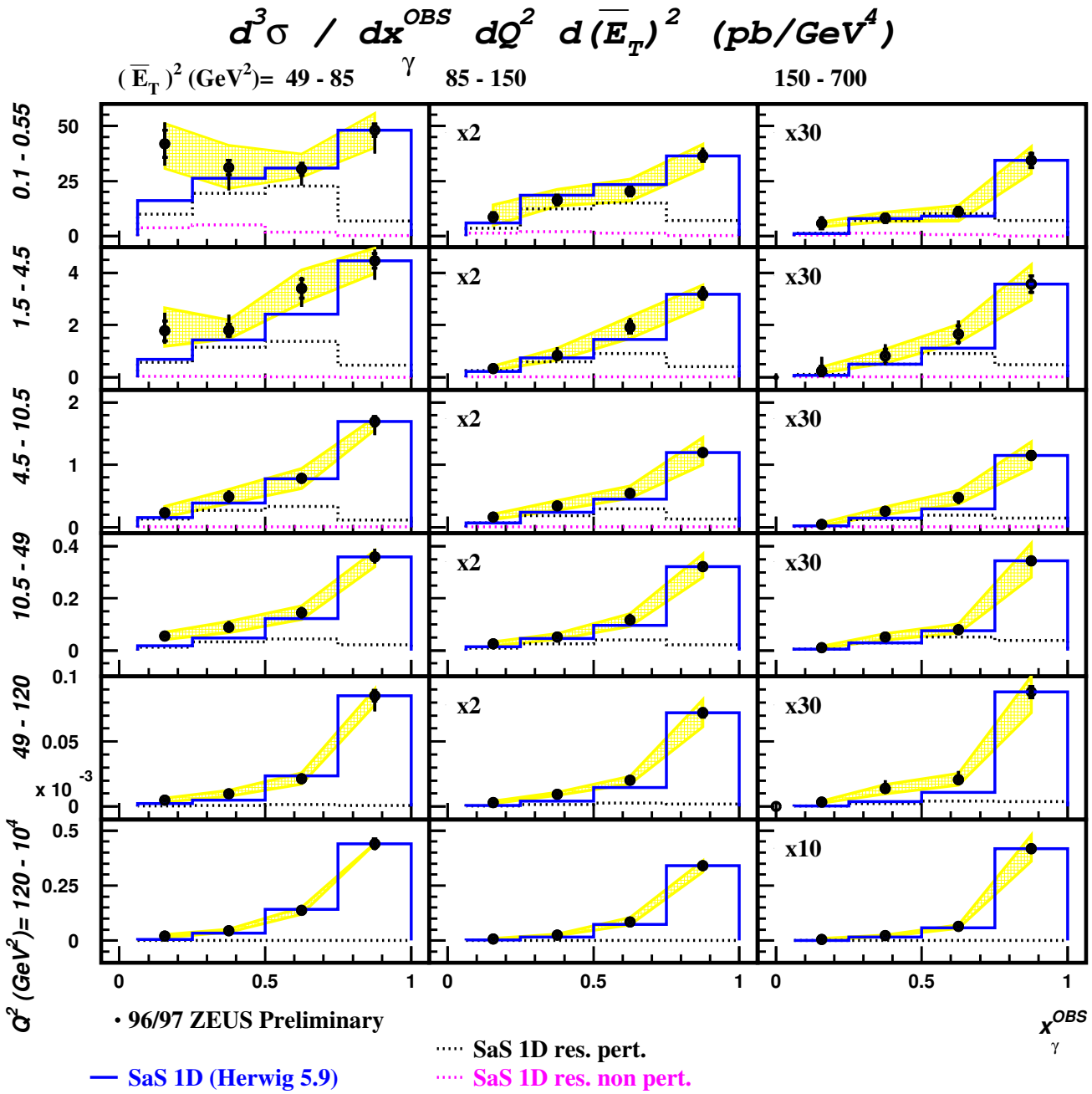
Triple Differential Cross Section from ZEUS



Note: HERWIG prediction normalized to the highest x_γ bin

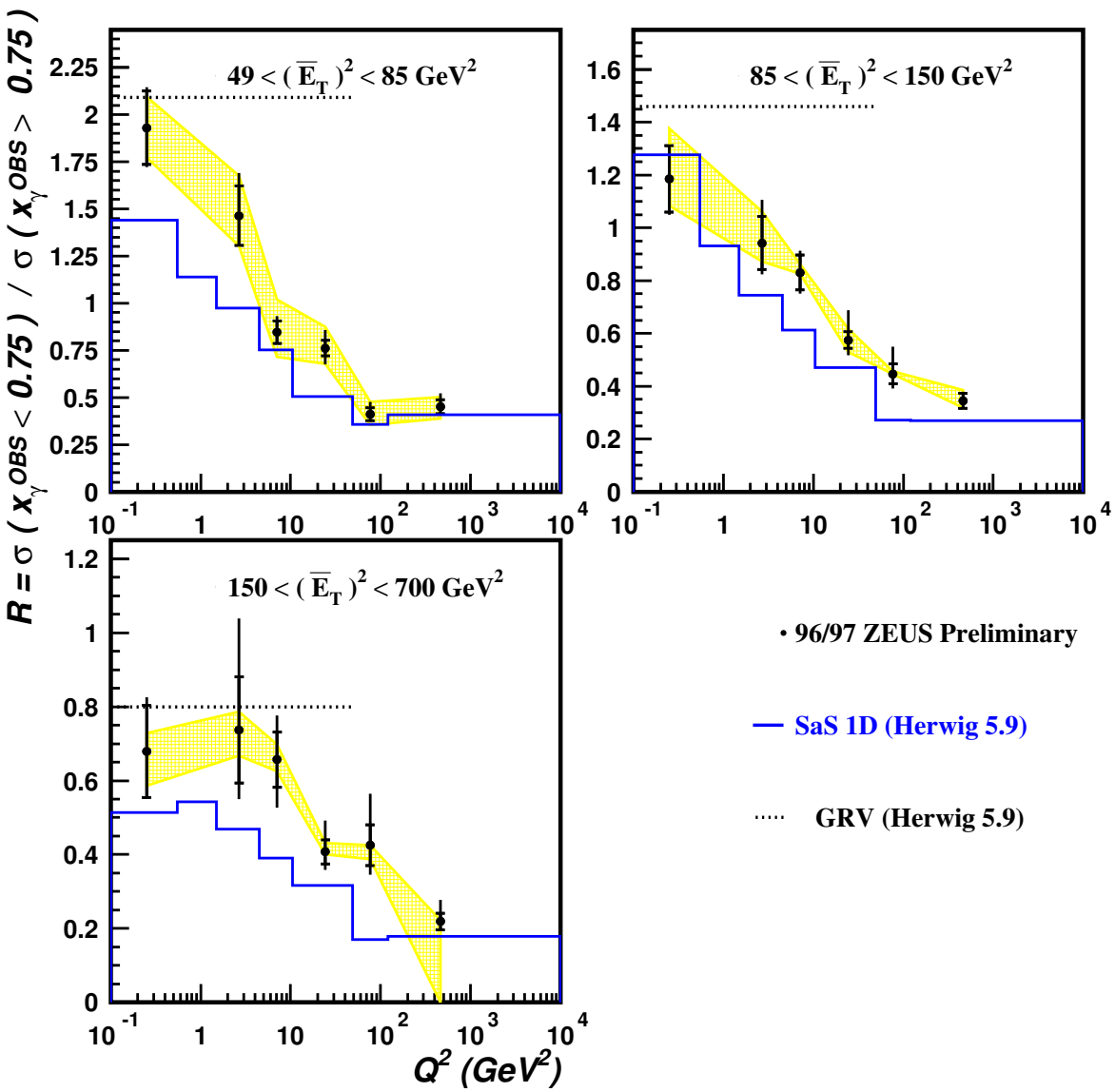
- Lower x_γ cross-section falls faster with Q^2 than higher x_γ.
- $Q^2 < \overline{E}_t^2$: direct-only not enough to describe the data,
  SaS1D slightly below the data in the low Q^2 , low x_γ.
- $Q^2 > \overline{E}_t^2$: resolved processes not needed.

Triple Differential Cross Section from ZEUS



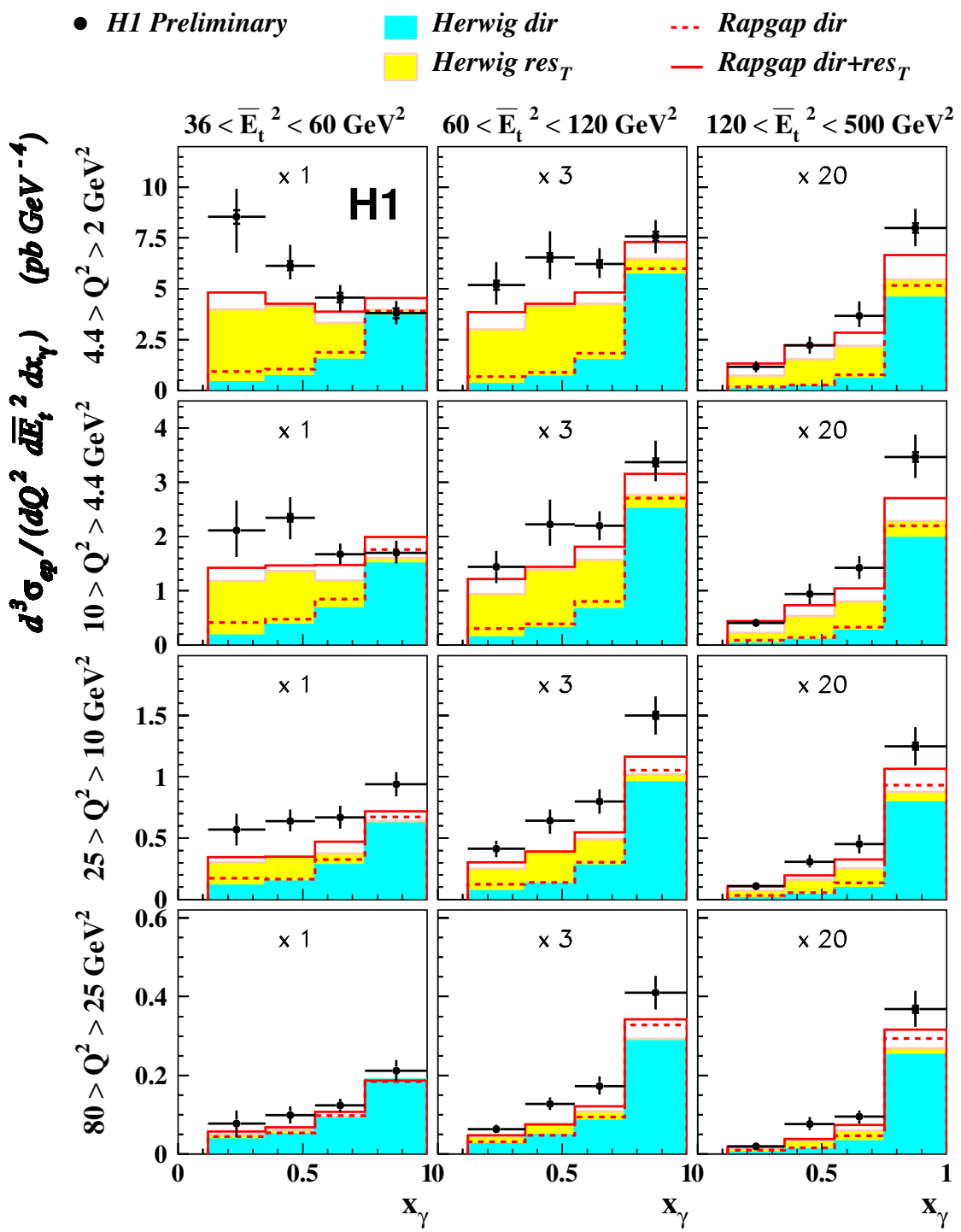
- Within the SaS1D parameterization, only the perturbative component of γ^* PDF matters in our kinematic region.

Resolved to Direct Ratio from ZEUS



- Ratios $(x_\gamma < 0.75 / x_\gamma > 0.75)$ demonstrate suppression of the photon structure with Q^2 .
- HERWIG with SaS1D γ_T^* below the data ratio.

Triple Differential Cross Section from H1

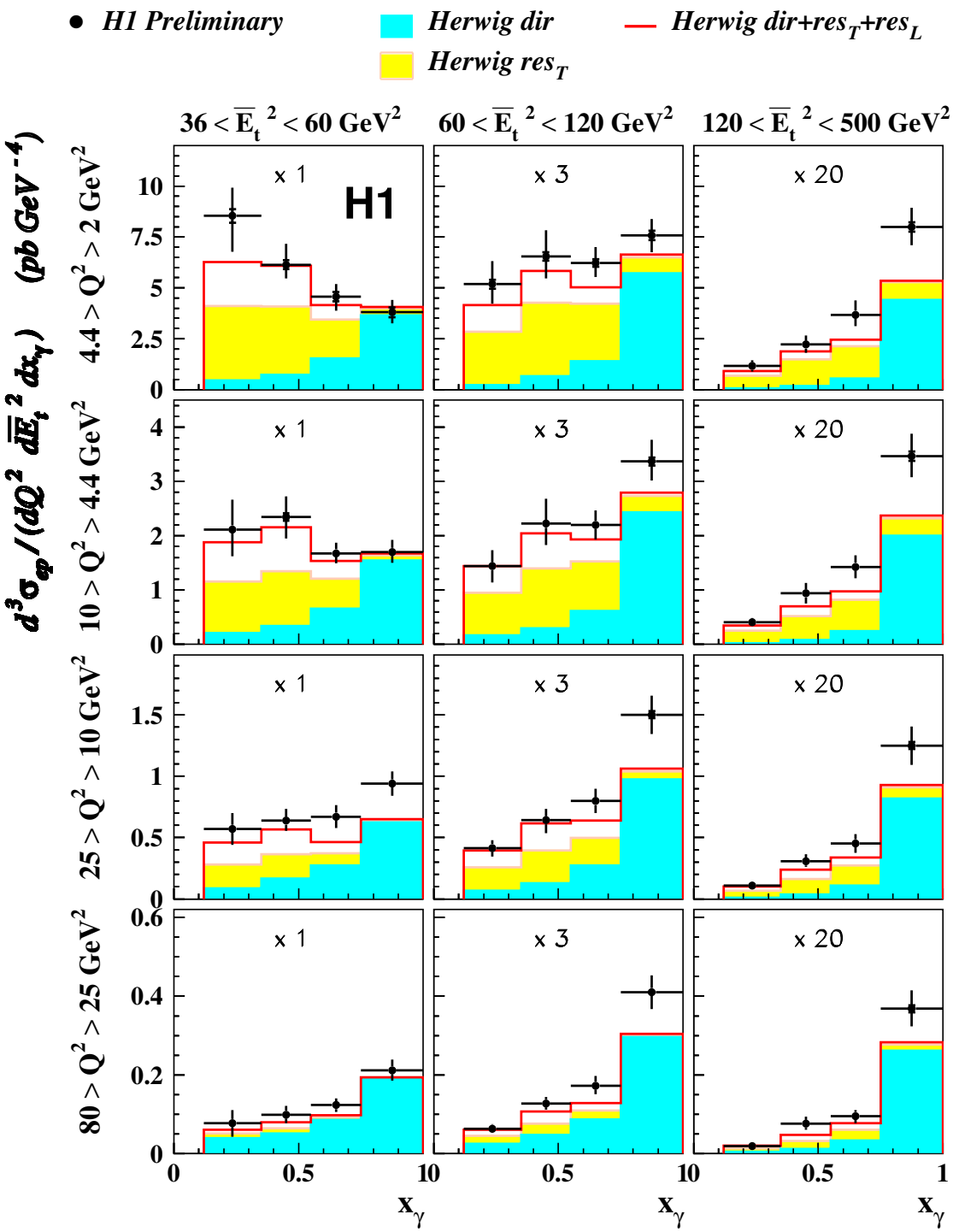


- Both HERWIG and RAPGAP under the data.

$\Rightarrow$ Is something missing in the MC predictions ?

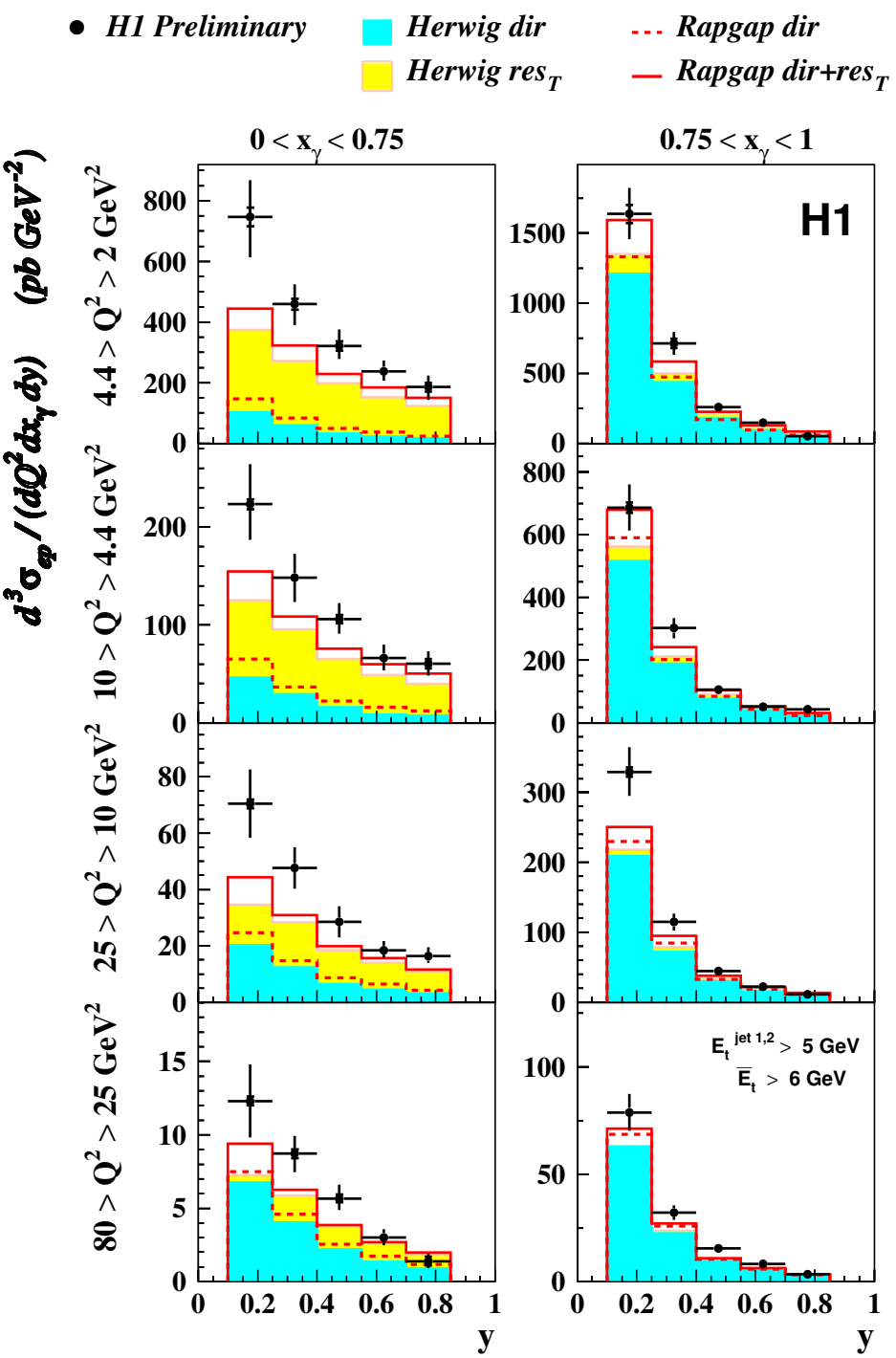
- Absolute normalization of LO MC is uncertain.

Adding Longitudinal Photon



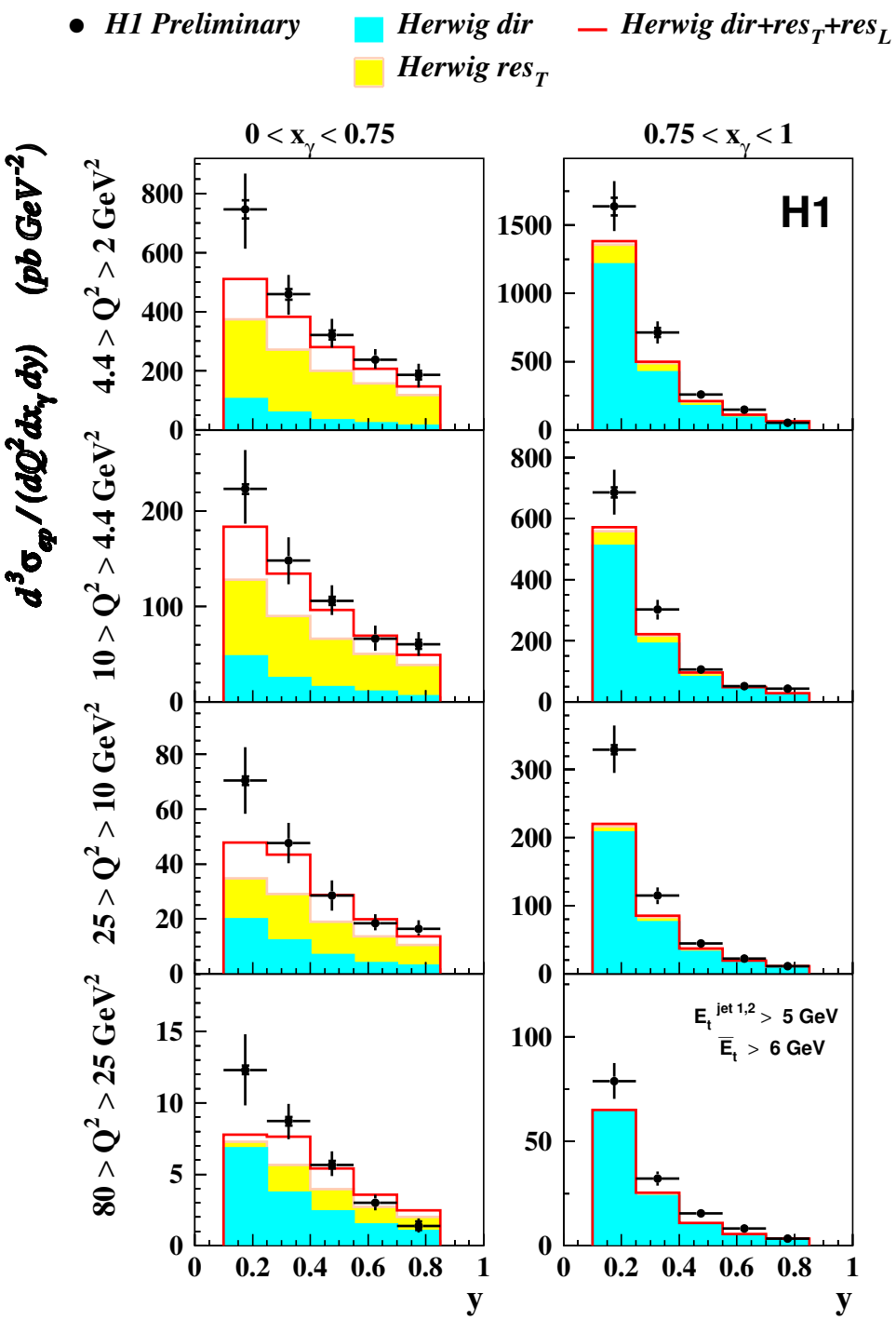
- Addition of γ_L^* helps to describe the data.
- Are there other possibilities ?

y Dependence of Di-jet Cross-Section



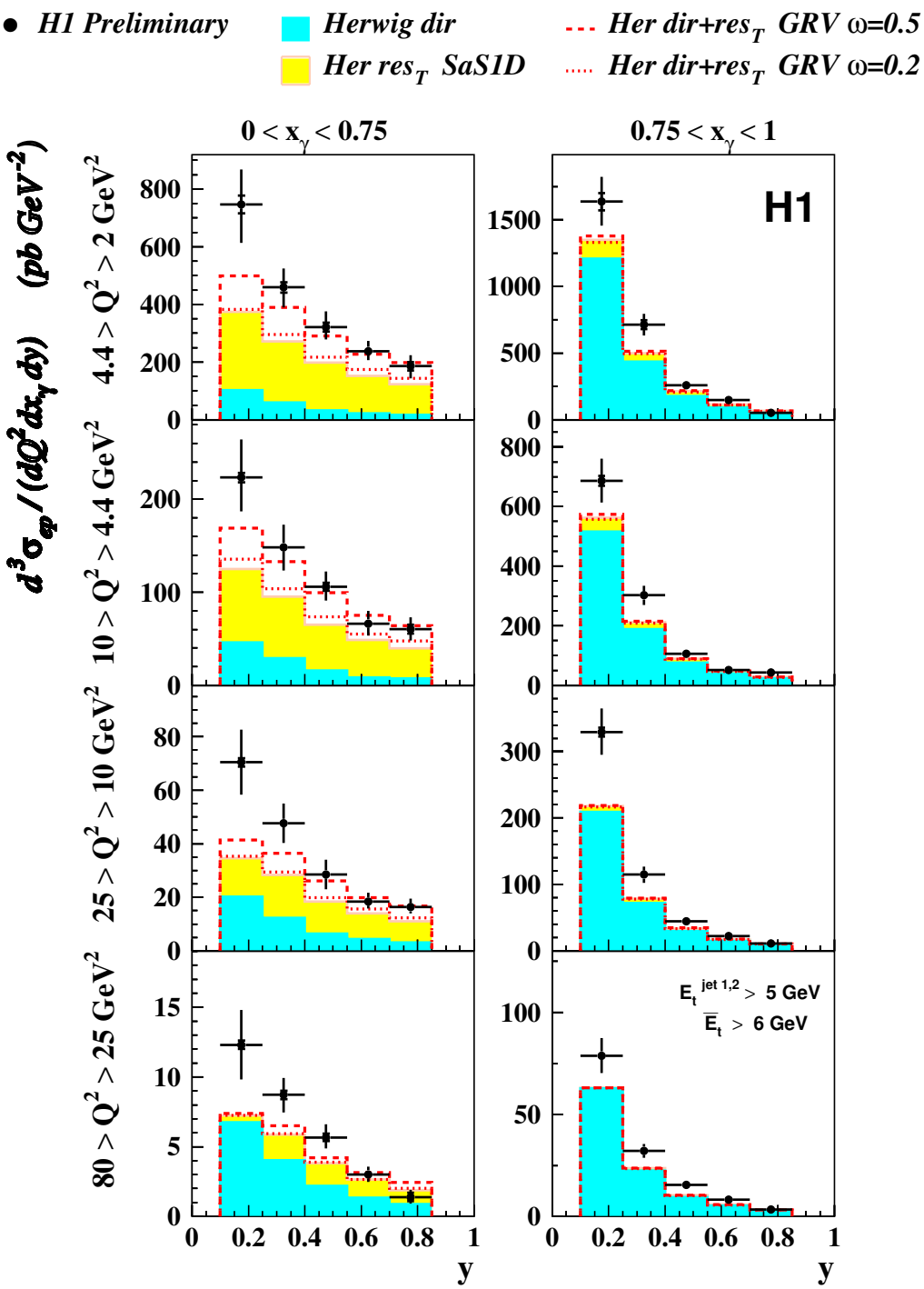
- The slope of y dependence is different in data compared to HERWIG or RAPGAP.

Adding γ_L^*



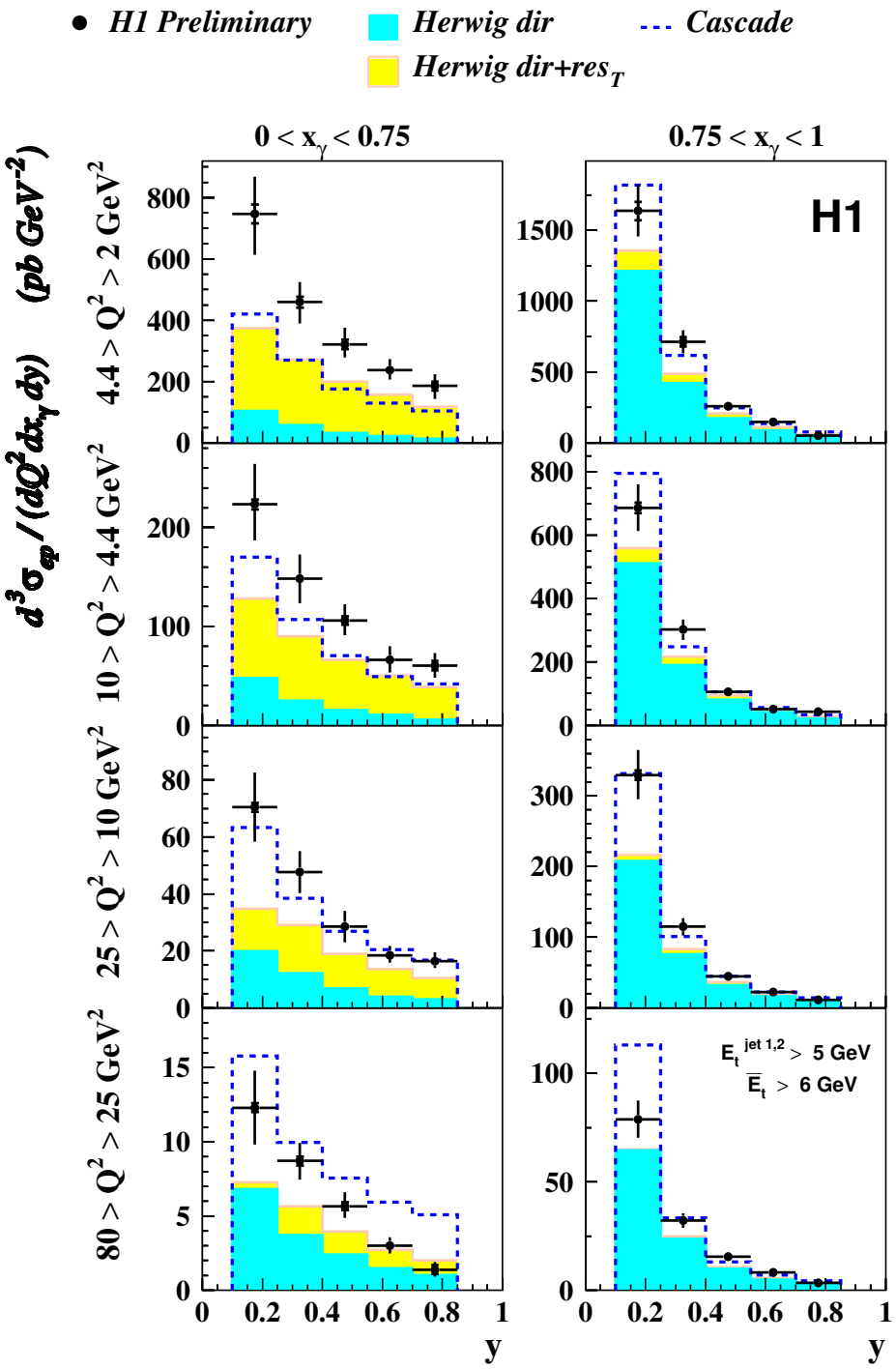
- Additional γ_L^* resolved contribution brings slope of HERWIG prediction closer to data in $x_\gamma < 0.75$ region.

Different γ_T^* PDFs



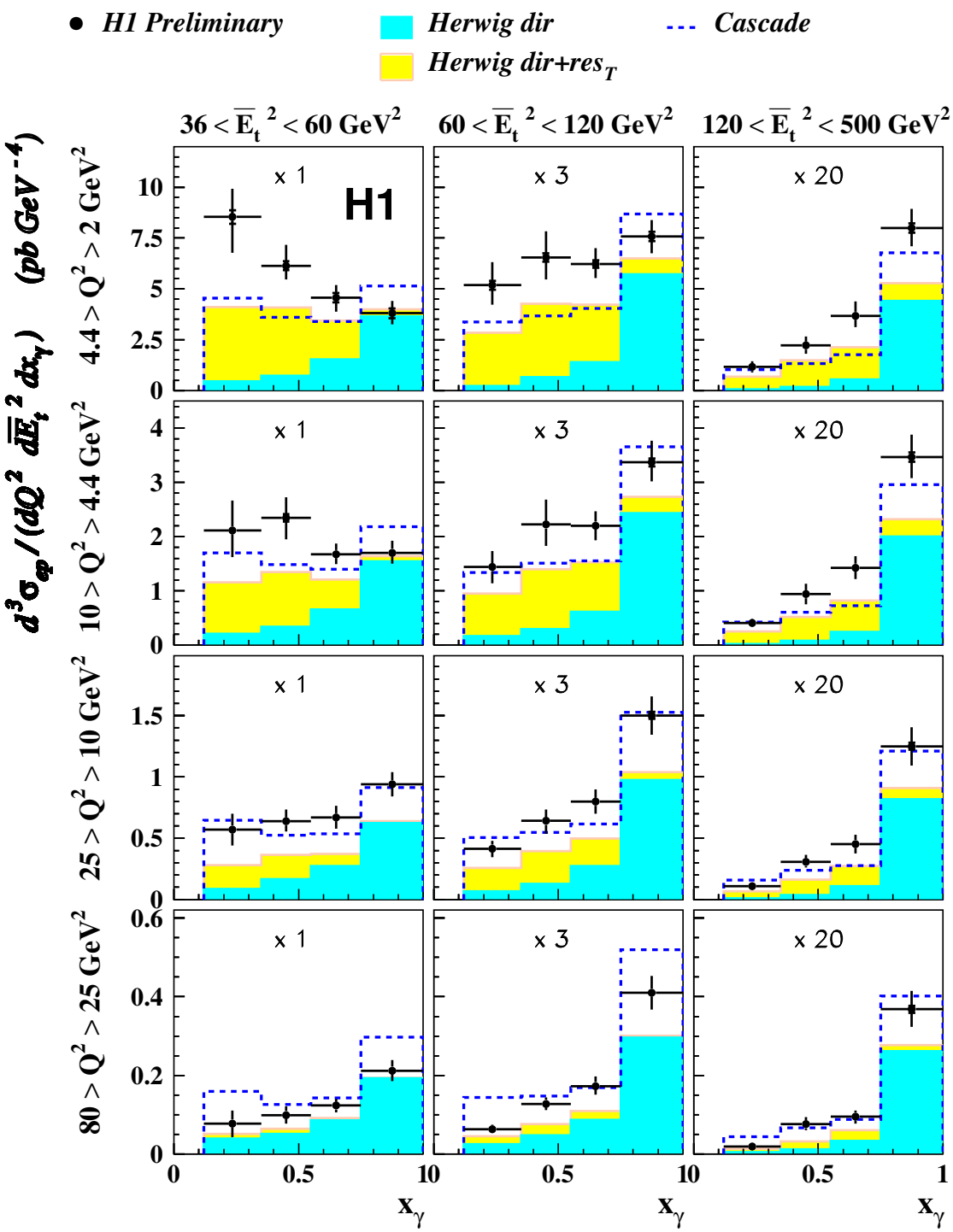
- Increase of γ_T^* PDFs can not describe the shape of y distribution in $x_\gamma < 0.75$ region.

Prediction of CASCADE MC



- CASCADE MC (with k_T unordered parton evolution and no concept of photon structure) much closer to data than standard DGLAP direct.

Prediction of CASCADE MC



References

Literatur

[1] γ_L^* PDF parameterization:
J. Chýla, “QCD improved parton distribution functions of gamma*(L)”, Phys. Lett. **B488** (2000), 289, hep-ph/0006232.

[2] HERWIG:
G. Marchesini et al., Comp. Phys. Comm. **67** (1992) 465

[3] RAPGAP:
H. Jung, “The RAPGAP Monte Carlo for Deep Inelastic Scattering”, *http://www-h1.desy.de/ jung/rapgap.html*

[4] CASCADE:
H. Jung, G. P. Salam, “Hadronic final state predictions from CCFM: the hadron-level Monte Carlo generator CASCADE”, Eur. Phys. J. **C19** (2001), 351-360

[5] DGLAP:
Y. Dokshitser, V. Gribov, L. Lipatov, G. Altarelli, G. Parisi

[6] CCFM:
M. Ciafaloni, S. Catani, F. Fiorani, G. Marchesini

Conclusions

- Triple differential di-jet cross-sections $d\sigma/dQ^2 d\overline{E}_t^2 dx_\gamma$ and $d\sigma/dQ^2 dx_\gamma dy$ were measured at HERA in the region of low Q^2.
- DGLAP (Direct + Resolved LO approach:)
  - Direct parts of RAPGAP and HERWIG describe the data in $Q^2 > E_t^2$ region only.
  - In $Q^2 < E_t^2$ range, γ_T^* resolved contributions needed, but not sufficient to describe the data completely in low x_γ region.
  - γ_L^* resolved contribution helps to describe the shape of y and x_γ distributions of di-jet cross-sections.
- CCFM - CASCADE (unordered k_t approach)
  - Similar qualitative description of jet cross-section as direct + resolved in HERWIG and RAPGAP.
  - Q^2 dependence of di-jet cross-sections less well described.
- NLO calculations are envisaged.