# Measurement of dijet production at low $Q^2$ at HERA

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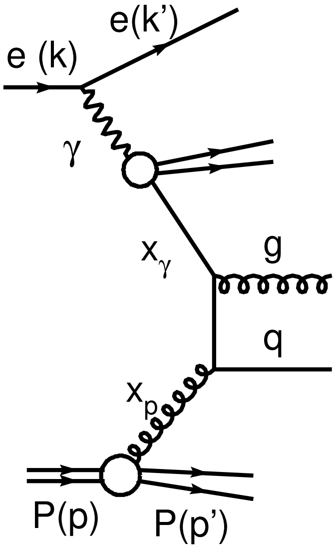
Representing **H1** Collaboration

- Dijet cross section vs. NLO QCD calculations
- Dijet cross section vs. LO MC predictions
- Dijet cross section vs. CCFM evolution eq.
- Conclusions

# Phase space of the measurement

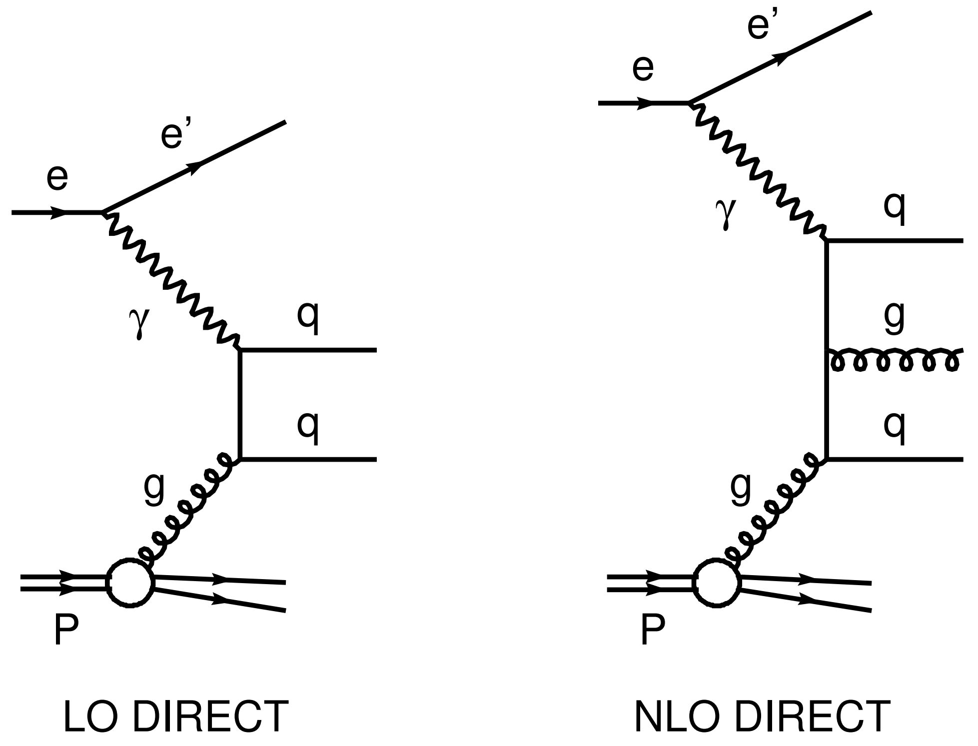
$e^+$ (27.6 GeV) $\longrightarrow$ $\longleftarrow$ $p$ (920 GeV)




- $Q^2$ – virtuality of $\gamma^*$
- $y$ – inelasticity
- $E_T^*$ – transverse energy of the jets
- $\eta^*$ – pseudorapidity of the jets
- $x_\gamma$ – fraction of the photon energy carried into the hard process

| |
|---|
| **H1** (57 pb$^{-1}$, 1999-2000) |
| $\sqrt{s} = 318$ GeV |
| $2 < Q^2 < 80$ GeV$^2$ |
| $0.1 < y < 0.85$ |
| $E_{T1}^* > 7$ GeV<br>$E_{T2}^* > 5$ GeV |
| $-2.5 < \eta_{1,2}^* < 0$ |
| longitudinally invariant $k_t$ jet algorithm, $\gamma^* p$ CMS |
| More details: [hep-ex/0401010] |

# Cross section of dijet events (DIRECT photon part)

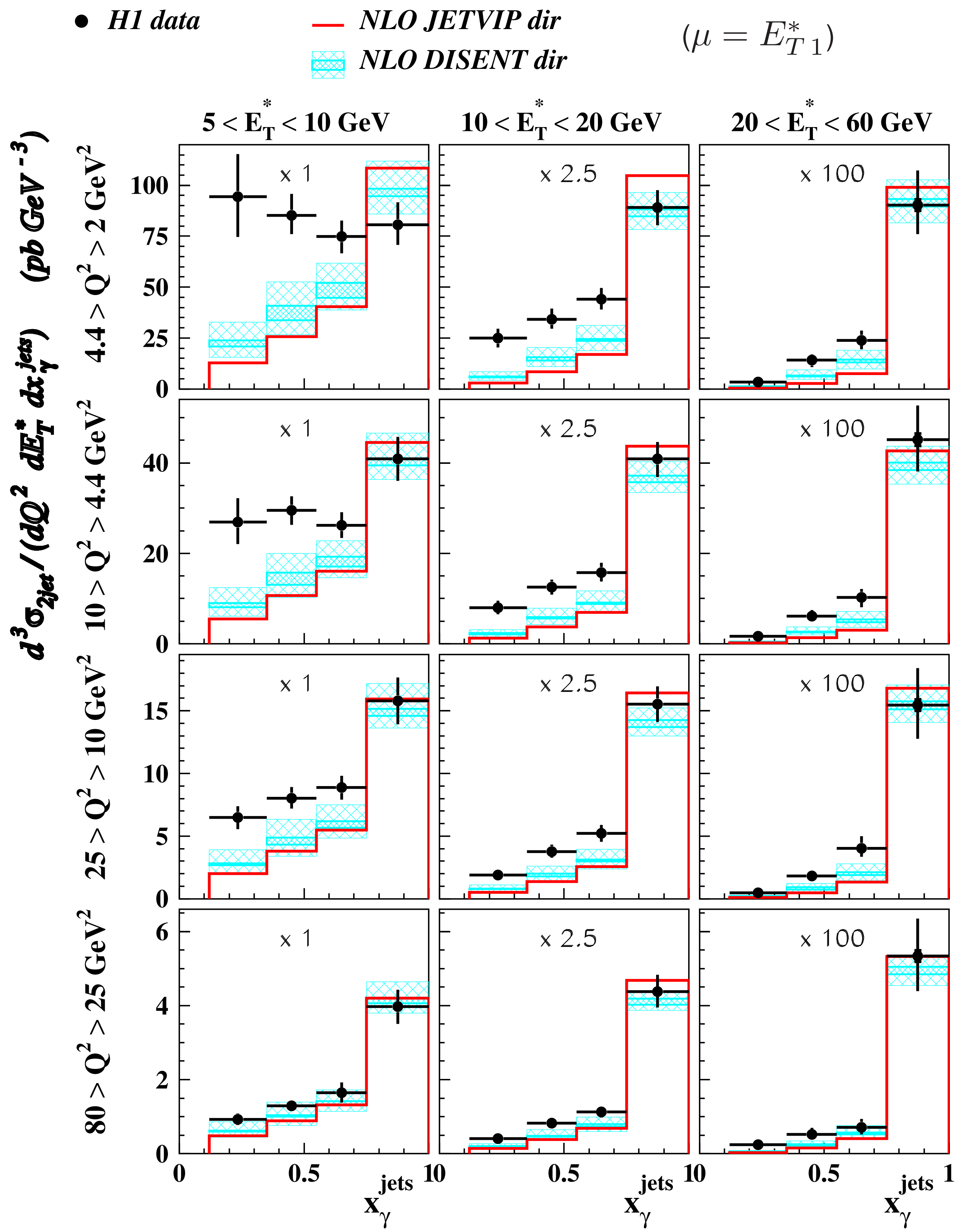



$$\sigma^{\mathrm{DIR}} \sim \sum_{\mathbf{j}} \mathbf{D_{j/p}} \otimes \sigma_{\mathbf{ej}}$$

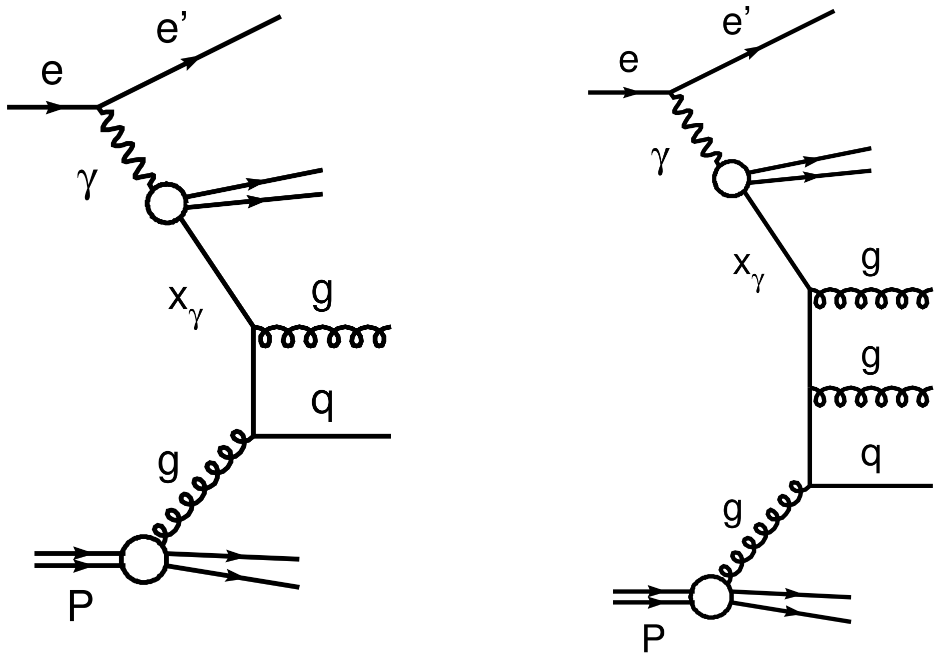
where $$\sigma_{\mathbf{ej}} = \mathbf{c}^{(1)}_{\mathbf{ej}} \alpha_{\mathbf{s}} + \mathbf{c}^{(2)}_{\mathbf{ej}} \alpha^{\mathbf{2}}_{\mathbf{s}} + \cdots$$

- $\mathbf{D_{j/p}}$ $\cdots$ PDF of the proton
- $\sigma_{\mathbf{ej}}$ $\cdots$ electron-parton cross section
- $\mathbf{c}^{(1)}_{\mathbf{ej}}, \mathbf{c}^{(2)}_{\mathbf{ej}}$ $\cdots$ coefficients of an expansion of $\sigma_{\mathbf{ej}}$ in $\alpha_{\mathbf{s}}$.

# Dijet cross sections – comparison with NLO



# Cross section of dijet events (RESOLVED photon)



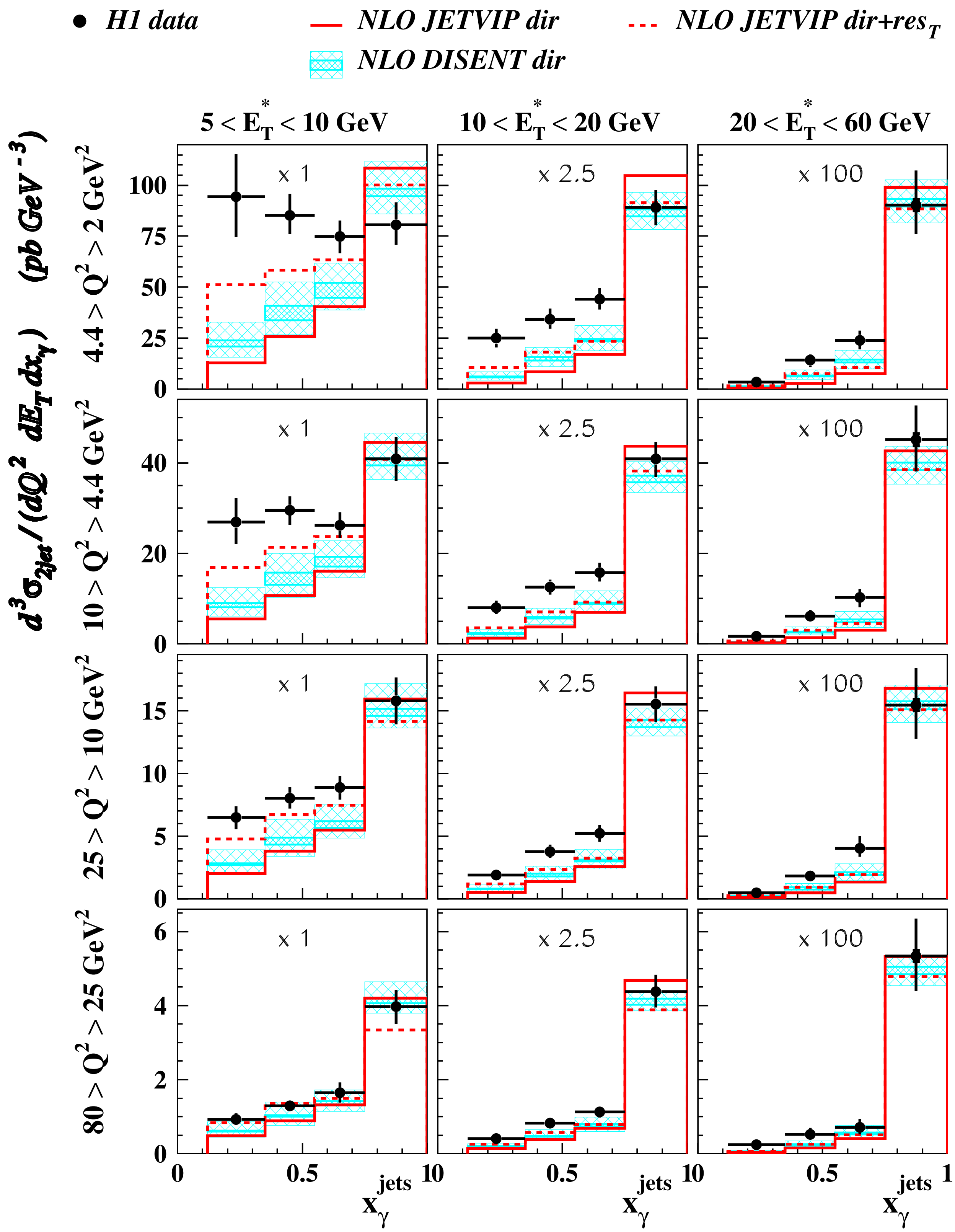

LO RESOLVED NLO RESOLVED

$$\sigma^{\mathrm{RES}} \sim \sum_{\mathbf{k=T,L}} \mathbf{f_k} \otimes \sum_{\mathbf{i,j}} \mathbf{D_{i/\gamma^*_k}} \otimes \mathbf{D_{j/p}} \otimes \sigma_{\mathbf{ij}}$$

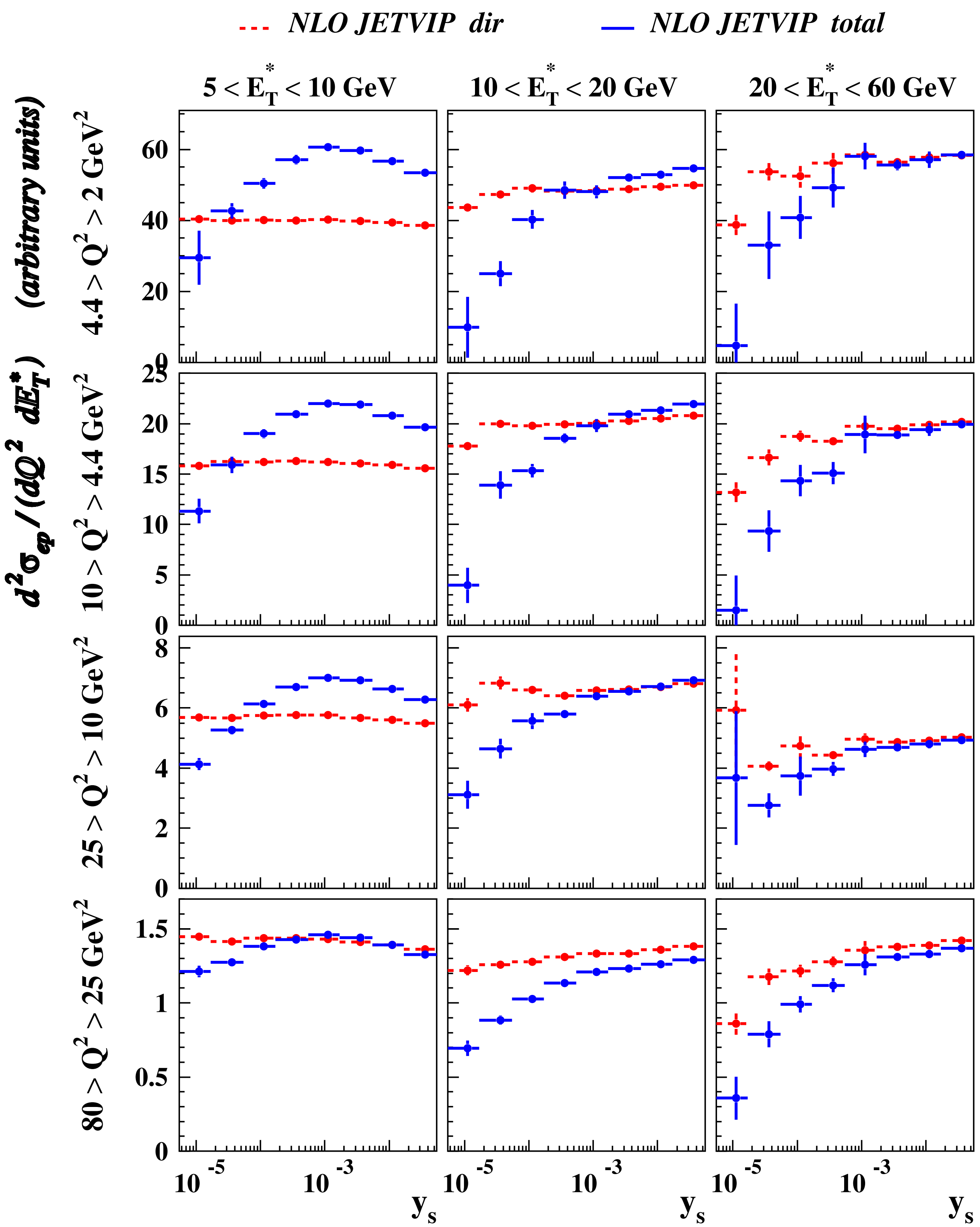
where $$\sigma_{\mathbf{ij}} = \mathbf{c^{(1)}_{ij}} \alpha_{\mathbf{s}}^{\mathbf{2}} + \mathbf{c^{(2)}_{ij}} \alpha_{\mathbf{s}}^{\mathbf{3}} + \cdots$$

- $\mathbf{D_{i/\gamma^*_k}}, \mathbf{D_{j/p}} \cdots$ PDF of the photon
- $\sigma_{\mathbf{ij}} \cdots$ parton-parton cross section
- $\mathbf{c^{(1)}_{ij}}, \mathbf{c^{(2)}_{ij}} \cdots$ coefficients of an expansion of $\sigma_{\mathbf{ij}}$ in $\alpha_{\mathbf{s}}$
- $\mathbf{f_k} \cdots$ photon flux

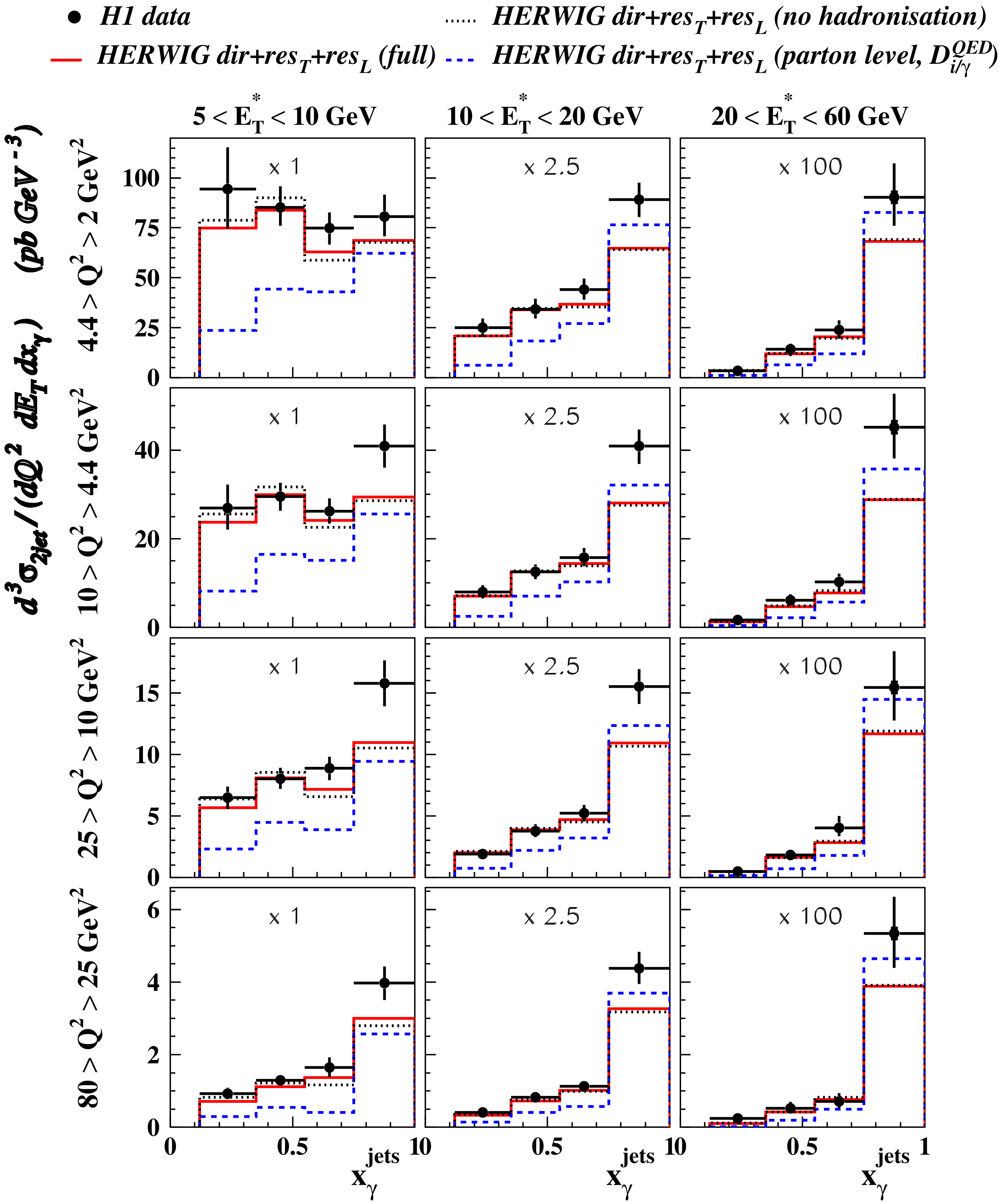
# Dijet cross sections – comparison with NLO



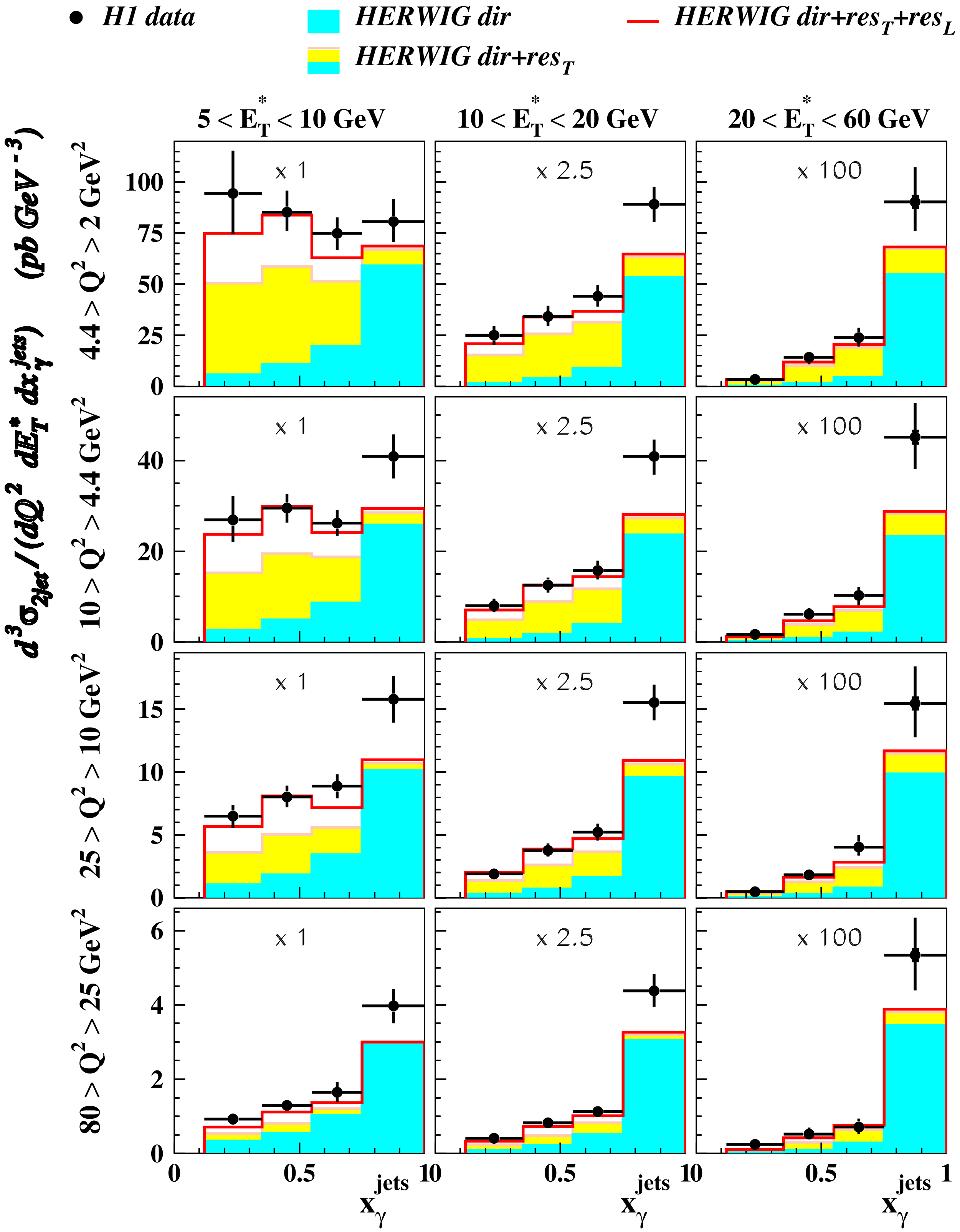
# $y_s$ dependence of the JETVIP prediction



# Higher order effects studied using LO MC



# Dijet cross section – comparison with LO MC



# Differences between $\gamma^*_T$ and $\gamma^*_L$

- QED prediction of $\gamma^*$ PDF in our kinematic region:

$$\mathbf{D_{i/\gamma^*_T}} \sim \frac{\alpha}{2\pi}\sum_{\mathbf{i}} \mathbf{3e_i^2}\left(\mathbf{x}_\gamma^2 + (\mathbf{1}-\mathbf{x}_\gamma)^2\right)\ln\frac{\mathbf{E_T^2}}{\mathbf{Q^2}}$$

$$\mathbf{D_{i/\gamma^*_L}} \sim \frac{\alpha}{2\pi}\sum_{\mathbf{i}} \mathbf{3e_i^2 4x_\gamma(1-x_\gamma)}$$

- Photon flux:

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

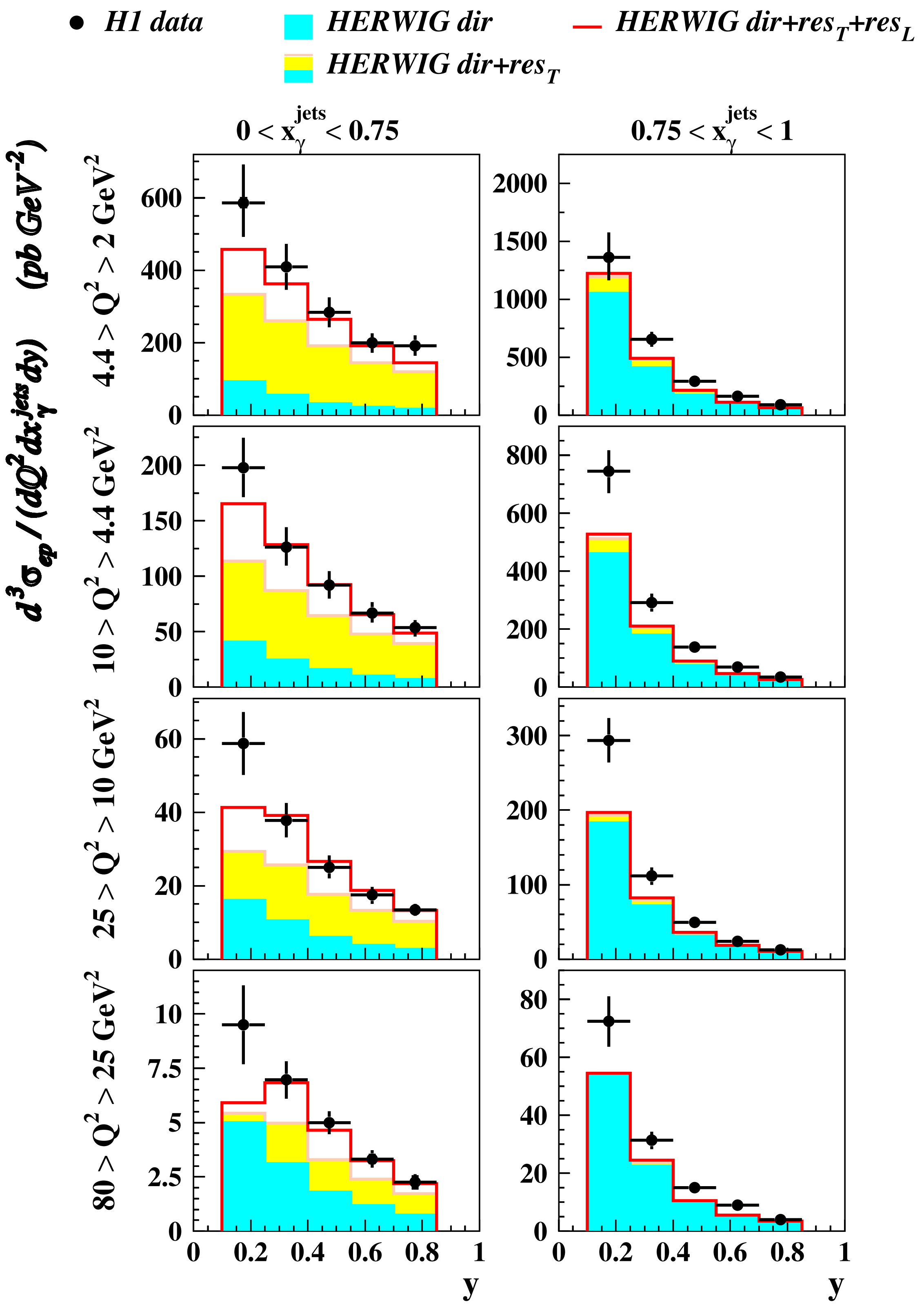
$$\mathbf{f_{\gamma^*_L/e}} = \frac{\alpha}{2\pi}\left[\frac{\mathbf{2(1-y)}}{\mathbf{y}}\frac{\mathbf{1}}{\mathbf{Q^2}}\right]$$

In the region $Q^2 \gg m_e$:

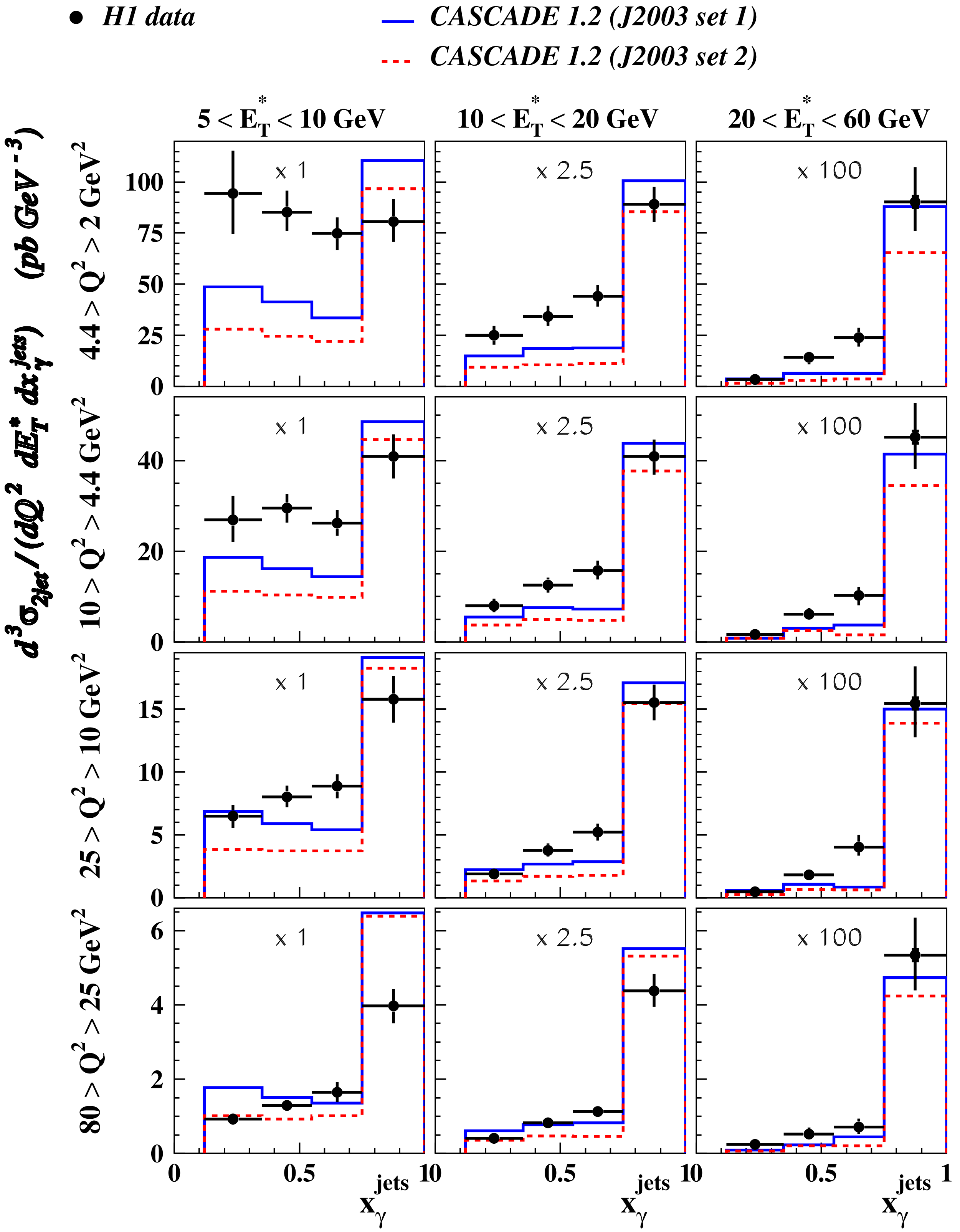
$$\mathbf{y=0} \implies \mathbf{f_{\gamma^L/e} = f_{\gamma^T/e}}$$

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

# Dijet cross section – comparison with LO MC



# CASCADE, a MC model based on CCFM eq.



# Conclusions

- Dijet cross sections were measured triple differentially as functions of $\mathbf{Q^2}$, $\mathbf{y}$, $\mathbf{x_\gamma}$, $\mathbf{E_T^*}$ and $\eta^*$ in the region of low $\mathbf{Q^2}$.
- NLO QCD calculations: NLO predictions do not reproduce the data in the region of low $\mathbf{Q^2}$, $\mathbf{E_T^*}$ and $\mathbf{x_\gamma}$. The disagreement indicates the need for orders beyond the NLO.
- LO MC predictions: The contribution of the resolved photon with the longitudinal polarisation improves the description of the data by the LO MC models.
- CCFM evolution: MC model CASCADE, based on the CCFM evolution equations, does not fully reproduce the data, however predicts significant cross section at low $\mathbf{x_\gamma}$ even without explicitly including resolved photon structure.

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# Dijet cross sections – comparison with NLO