High P_T Jet Photoproduction

at

HERA

8th International Workshop on DIS and QCD

Liverpool, April 25-30, 2000

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On behalf of the H1 and ZEUS Collaborations

Introduction: Jets in γP

◇ **Photoproduction**

Real photons: $m_\gamma^2 = Q^2 \sim 0$ GeV^2

γP center of mass: $100 \lesssim W \lesssim 280$ GeV

◇ **Jets: theoretically** **e.g. dijets**

$$d\sigma(e^+p \to e^+ + j_1 + j_2 + X) =$$
$$\sum_{a,b} \int_0^1 dy f_{\gamma/e}(y) \int_0^1 dx_\gamma f_{a/\gamma}(x_\gamma, \mu_{F_\gamma}^2) \int_0^1 dx_p f_{b/p}(x_p, \mu_{F_p}^2) d\hat{\sigma}_{a,b\to j_1+j_2}(\mu_R^2)$$

$y = E_\gamma / E_e$ ... momentum fraction of γ in the e^+
x_γ ... momentum fraction of parton a in the γ
x_p ... momentum fraction of parton b in the P

- **$f_{\gamma/e}(y)$ ... flux of γ's from the e^+**

⇒ Calculated using Weizsäcker-Williams Approximation

- **$f_{a/\gamma}(x_\gamma, \mu_{F_\gamma}^2)$ ... PDF of γ for parton $a = q, g, \gamma$**

⇒ Constrained by 2γ data from e^+e^- for $\mu_F^2 \lesssim 100$ GeV^2
⇒ Obey (inhomogenous) QCD evolution equations
⇒ Direct process: $a = \gamma$: $f_{\gamma/\gamma} = \delta(1 - x_\gamma)$
⇒ Several parametrizations on the market: GRV, DG, LAC...
⇒ Uncertainties: – at larger scales $\gtrsim 100$ GeV^2
– gluon at small x
– quark at large x
– heavy quark content

- **$f_{b/P}(x_\gamma, \mu^2_{F_P})$ ... PDF of P for parton $b = q, g$**

  ⇒ Constrained by DIS data
  ⇒ Several parametrizations: CTEQ, MRS, GRV...
  ⇒ Relatively well known over large kinematic range of x and μ_F

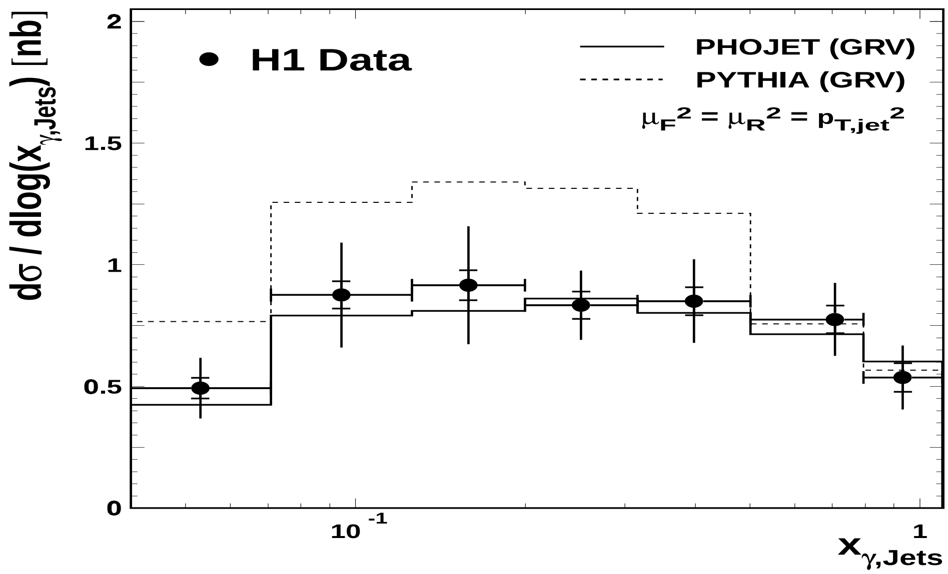
- **$d\hat{\sigma} = \frac{1}{2s'}|\overline{\mathcal{M}}|^2 dPS$ ... Subprocess cross section**

  ⇒ Calculable in pQCD
  ⇒ $\mathcal{M}$ dependent on Mandelstam variables s, t, u or m_{jj}, $\cos\theta^*$
  ⇒ Calculated to α_s^2: Dijet: NLO
  Trijet: LO

Complication I: Multiparton Interactions

Soft underlying event

H1 Dijets: $E_{T,jet} > 4$ **GeV,** $M_{JJ} > 12$ **GeV**



⇒ Comparison of x_γ distribution with LL PS MC's

⇒ Predictions differ by factor of ~ 2:

Different regularisation procedure
Different treatment of underlying event

⇒ Effects drastically reduced at higher $E_{T,jet} \gtrsim 10$ GeV

Complication II: Hadronisation corrections

⇒ Needed for comparison with parton level calculations

⇒ Can be estimated using LL PS MC:

Estimated to be large at low $E_{T,jet}$: $20 - 40$ %
Reduced at higher $E_{T,jet} \gtrsim 10$ GeV

⇒ Convention: No corrections applied!

High E_T Jets in γP

- **Reduced uncertainty from MPI**
- **Reduced hadronisation corrections/uncertainties**
- **Proton PDF: small uncertainty (also at low $E_{T,jet}$)**
- **x_γ reconstruction:**

$$x_\gamma^{obs} = \frac{\sum_{jets} E_{T,jet} e^{-\eta^{jet}}}{2yE_e}$$

⇒ Selection of direct or resolved γP enhanced samples

Direct:	$d\sigma$ has no x_γ dependence
	normalisation of $d\sigma$ dependent on PDF$_\gamma$
Resolved:	$d\sigma$ dependent on x_γ and PDF$_\gamma$

⇒ Test ground of perturbative QCD

Topics

I **Dijets**

II **Trijets**

III **Subjets**

Calculations to $\mathcal{O}(\alpha_s^2)$

- **Parton level calculations** (no hadronization)
- **Singularities dealt with**
  - Subtraction method

    or

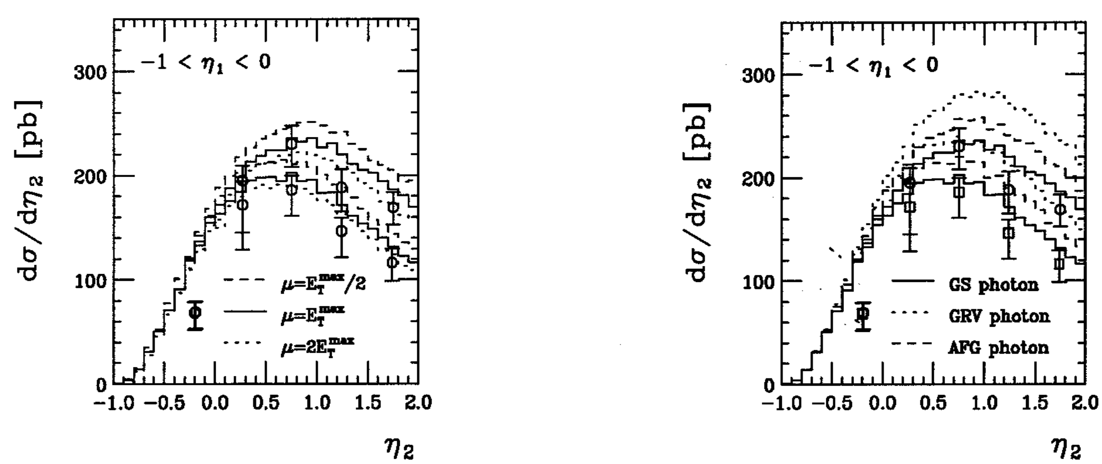
  - Phase space slicing method
- **Calculations by several groups**
  - Frixione and Ridolfi
  - Harris and Owens
  - Klasen, Kleinwort and Kramer
  - Aurenche et al.
  - Kramer and Pötter

⇒ **Consistent within 5 – 10 %**

⇒ **Major uncertainties:**

Scales: μ_F^2, μ_R^2 PDF$_\gamma$

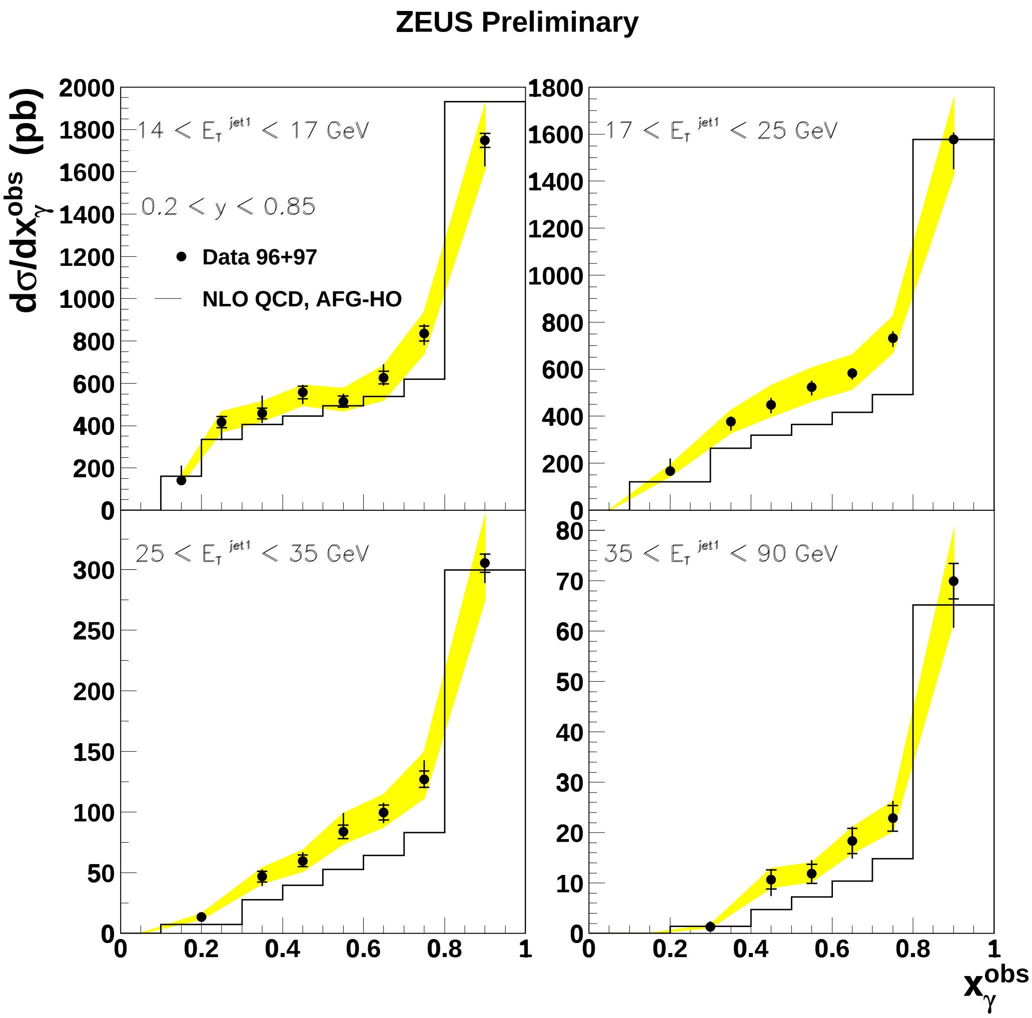
From B.W.Harris and J.F.Owens, hep-ph/9712299



Dijets I

ZEUS: $d\sigma/dx_\gamma^{obs}$ **for different** $E_{T,jet}$ **bins**

$\int \mathcal{L}dt = 38$ **pb** $^{-1}$
γP **with** $Q^2 < 1$ **GeV**$^{-2}$
Inclusive dijets: $E_{T1,2} > 14, 11$ GeV
Longitudinally invariant k_T algorithm



$\Rightarrow$ **Comparison with NLO calculations (F+R)**

- Using AFG-HO PDF$_\gamma$
- Agreement for $x_\gamma > 0.8$(direct)
- Data systematically above at $x_\gamma < 0.8$(resolved)

Uncertainty in $f_{g/\gamma}$ at low x_γ
Uncertainty in $f_{q/\gamma}$ at high x_γ

- Disagreement up to highest $E_{T,jet}$

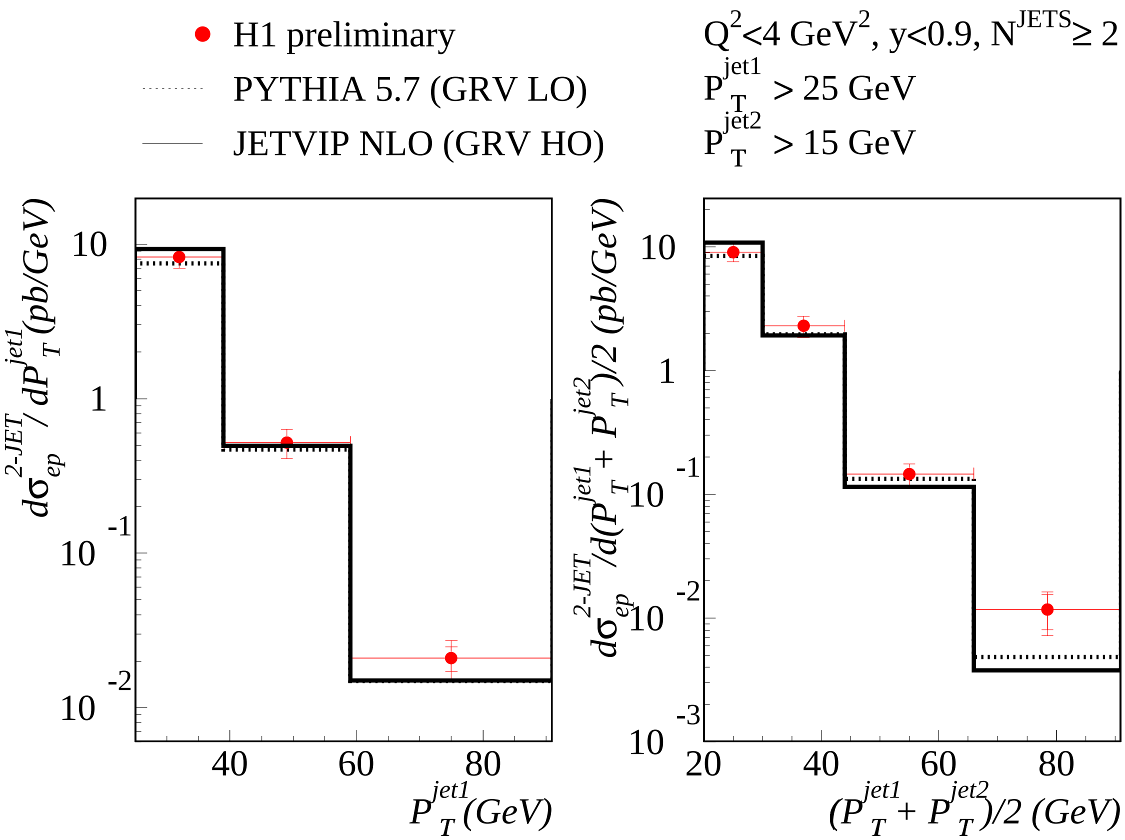
Dijets II

H1: $d\sigma/dp_{T1}$ and $d\sigma/d < p_{T,jet} >$

$\int \mathcal{L}dt = 36$ pb $^{-1}$

γP with $Q^2 < 4$ GeV^{-2}

Inclusive dijets



⇒ **Comparison with LL PS MC (PYTHIA)**

- Using GRV-LO PDF$_\gamma$
- Reasonable agreement

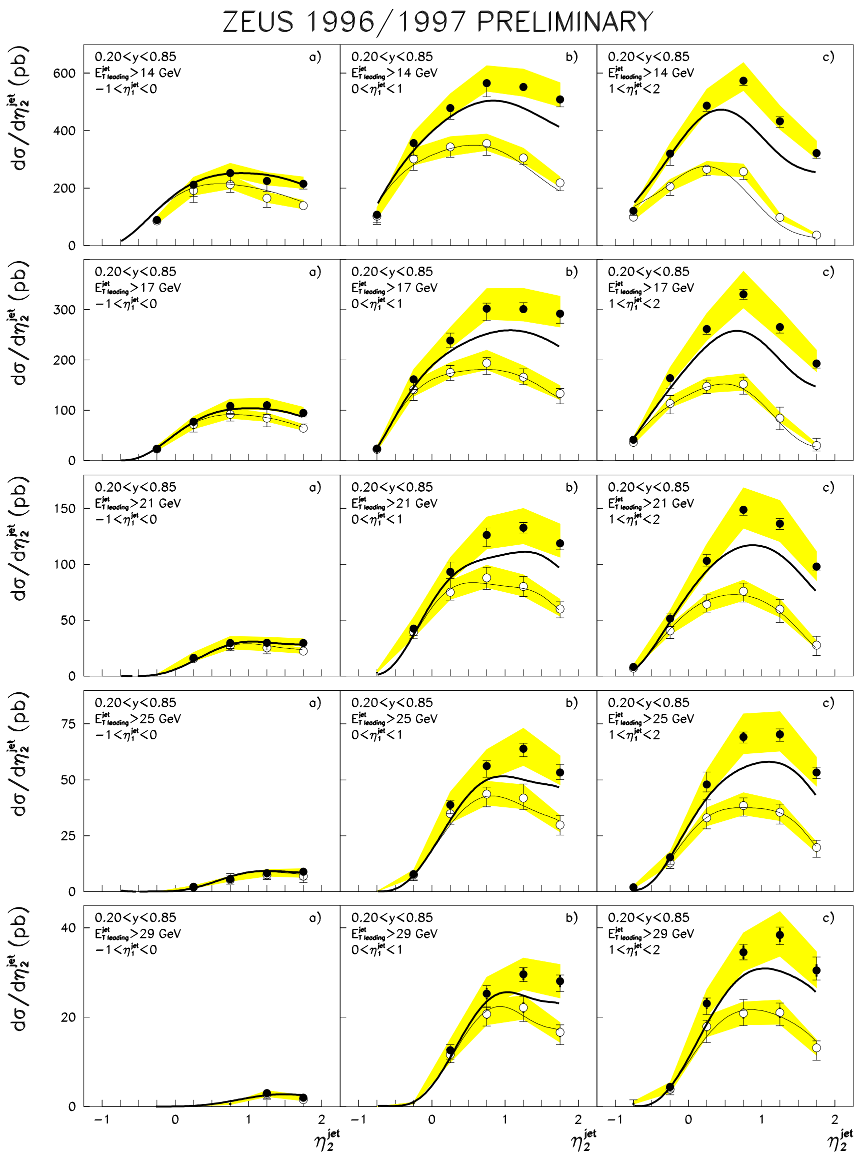
⇒ **Comparison with NLO calculations (K+P)**

- Using GRV-HO PDF$_\gamma$
- Reasonable agreement

Dijets III

ZEUS: $d\sigma/d\eta_2$ for different bins in η_1 and E_{T1} cuts

Same conditions as above



⇒ Comparison with NLO

- Good agreement for $x_\gamma > 0.75$ (direct)
- Data above for entire x_γ range

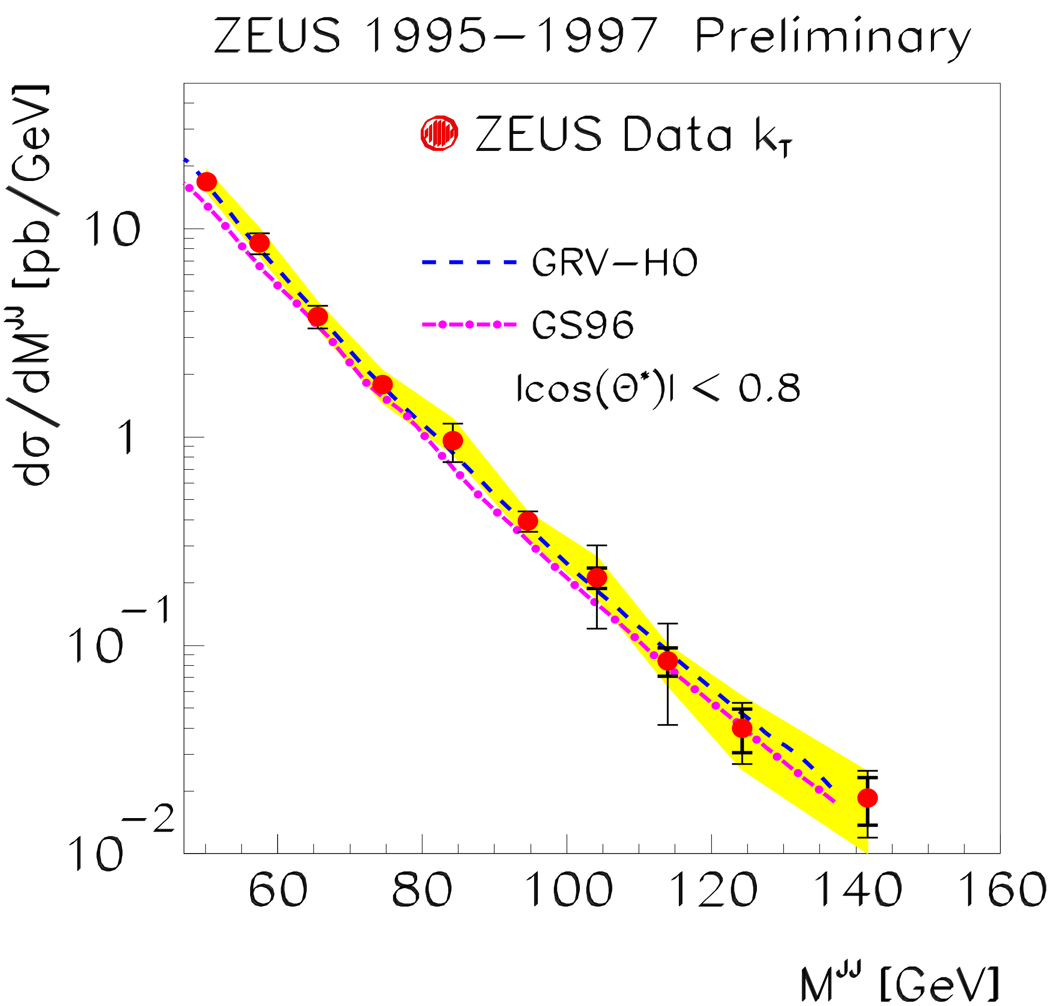
Excess in forward region where resolved component large

Dijets IV

ZEUS: $d\sigma/dm_{JJ}$ **Resolution $\sigma_{m_{JJ}} \sim 8\%$**

$\int \mathcal{L}dt = 43$ **pb** $^{-1}$

Inclusive dijets: $E_{T,jet} > 14$ GeV
$|\cos\theta^*| < 0.8$



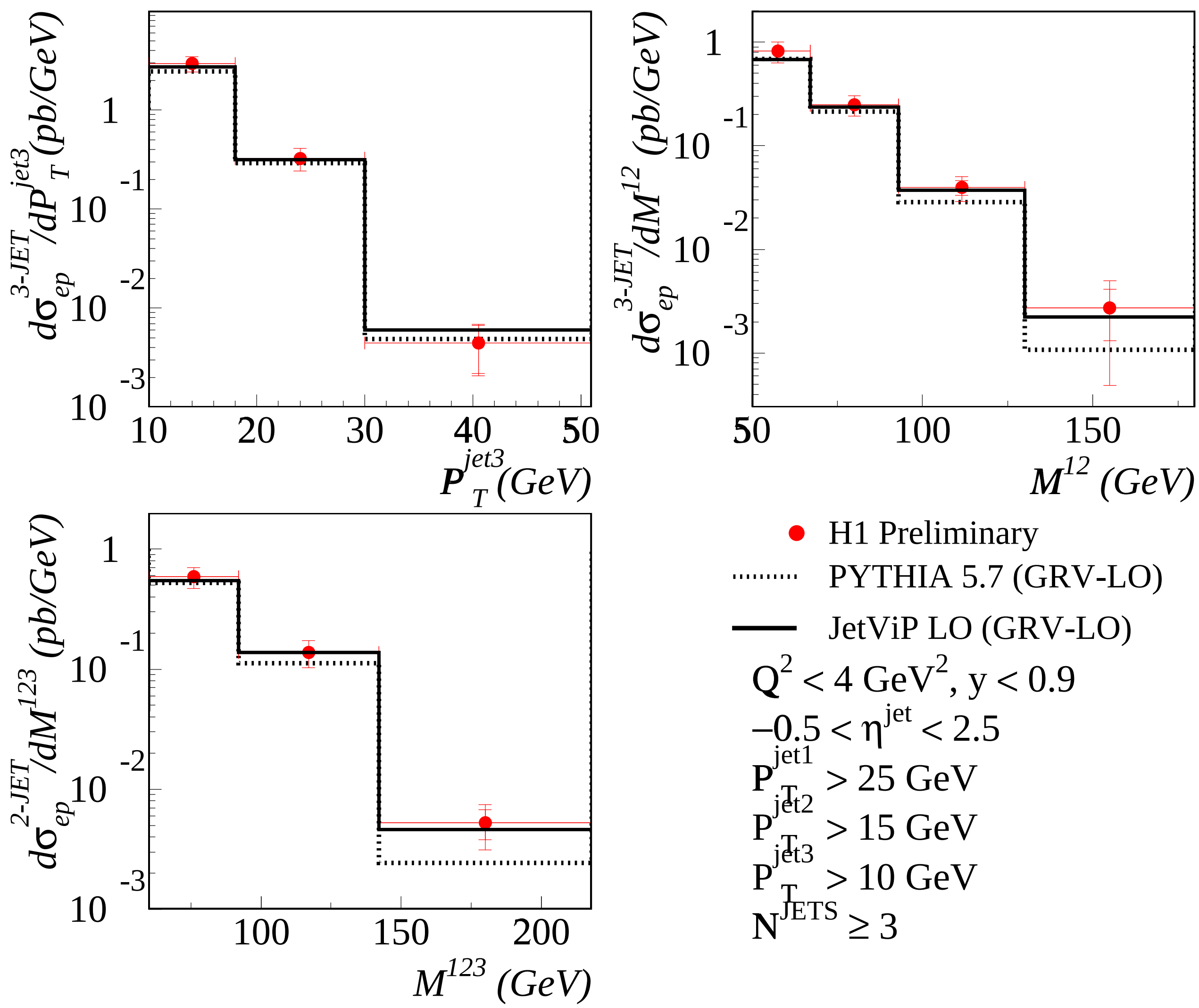
⇒ **Comparison with NLO calculations (K,K+K)**

- Using GRV-HO or GS96 PDF$_\gamma$
- Theoretical uncertainties: scales and PDF$_\gamma$
- Shape adequately reproduced by NLO
- No significant deviations up to 140 GeV

Trijets I

H1: $d\sigma/dp_{T3}$, $d\sigma/dm_{12}$, $d\sigma/dm_{123}$

Same conditions as above



⇒ Comparison with LL PS MC (PYTHIA)

- Good agreement, no (big) deviations

⇒ Comparison with NLO (K+P)

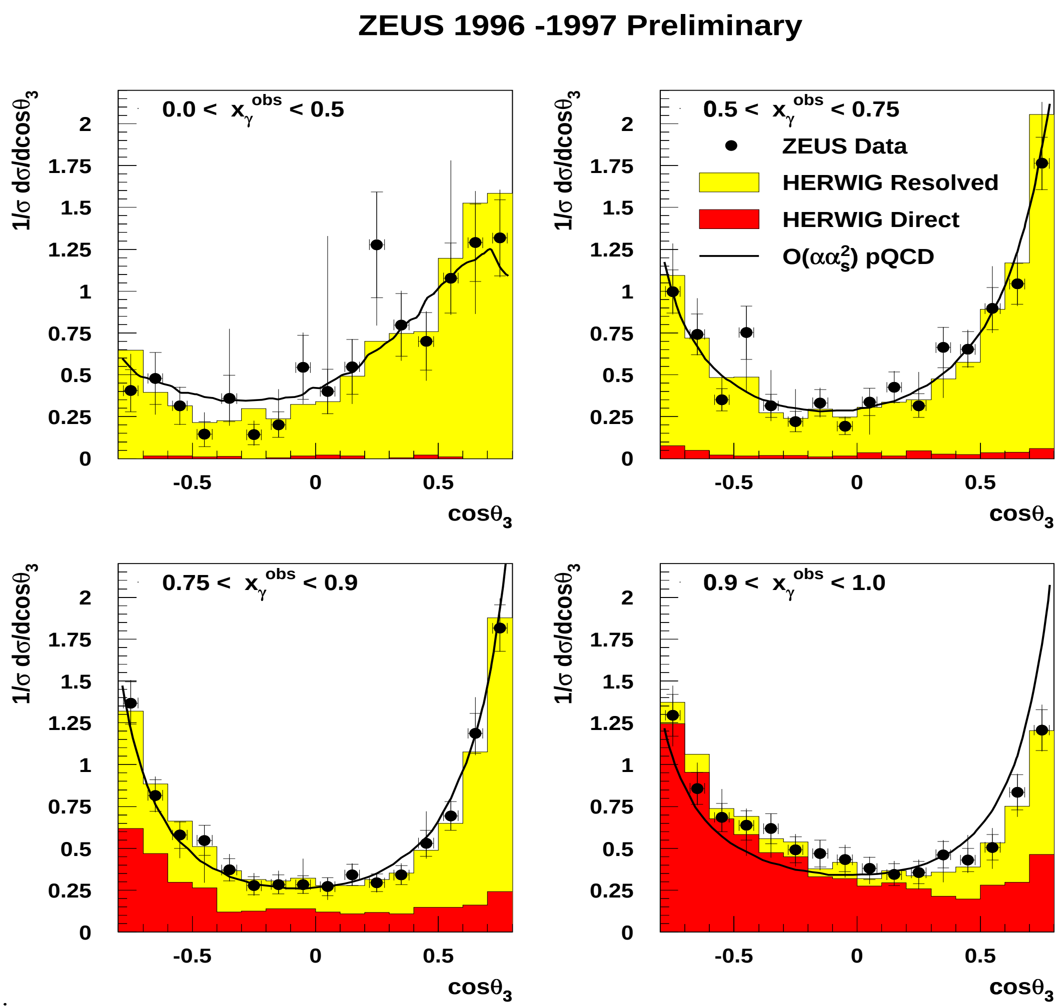
- Good agreement, no deviations

Trijets II

ZEUS: $d\sigma/d\cos\theta_3$ in different bins of x_γ

$\int \mathcal{L}dt = 38$ pb $^{-1}$

$m_{123} > 50$ GeV (minimize bias on $\cos\theta_3$ due to $E_{T,jet}$ cuts)



⇒ Comparison with LL PS MC (HERWIG)

⇒ Comparison with $\mathcal{O}(\alpha_s^2)$ calculations (H+O, K)

- Reasonable agreement with both
- Direct component more backward
- Resolved component more forward

} simple kinematics

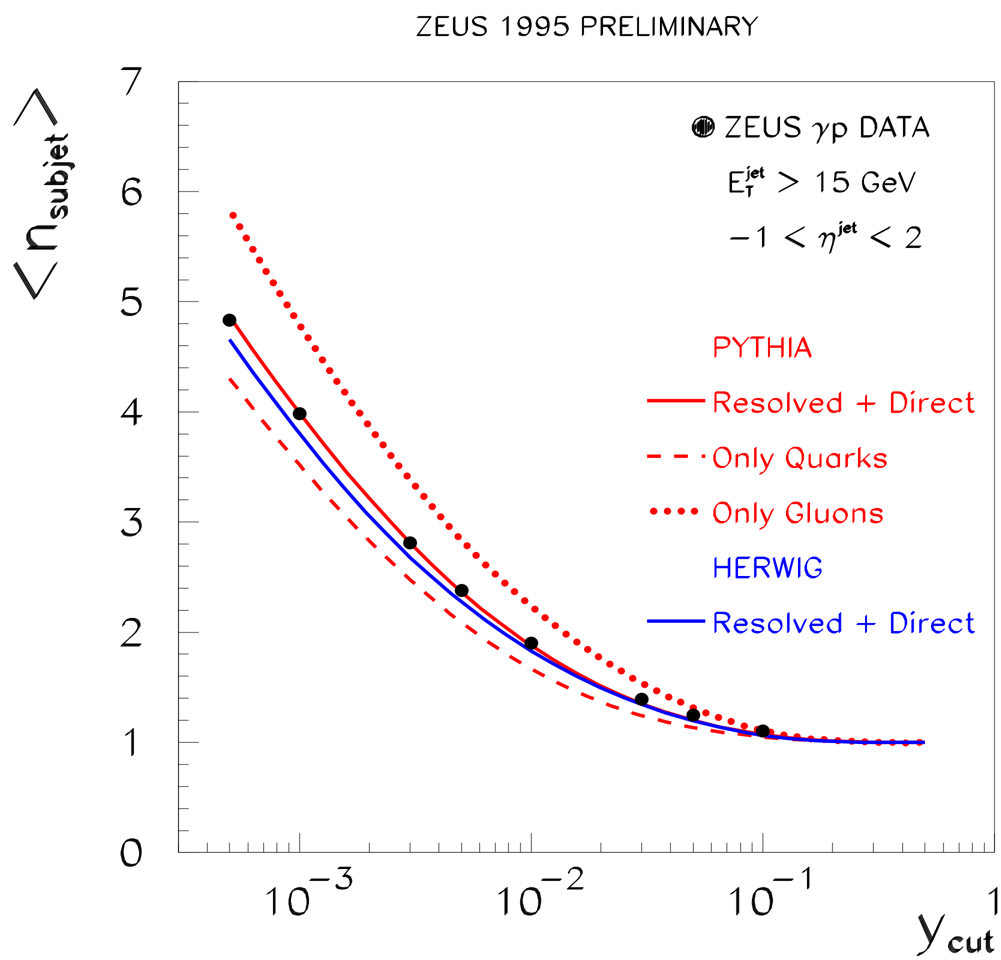
Subjets I

Resolve subjets within jets using

$$d_{cut} = y_{cut}(E_{T,jet})^2$$

ZEUS: $< n_{subjet} >$ **vs.** y_{cut}

$\int \mathcal{L} dt = 6.3$ pb $^{-1}$



⇒ **Comparison with LL PS MC**

- $< n_{subjet} >$ increases with decreasing y_{cut}
- Excellent/reasonable agreement
- No (exact) $\mathcal{O}\alpha_s^2$ calculation available

Conclusions and Outlook

◇ **Test of pQCD at $\mu^2 \gtrsim 200$ GeV^2**

- **Studied dijets, trijets, subjets**
- **pQCD works well**
- **No surprises**
- **PDF$_\gamma$ might need tuning**

◇ **After $\mathcal{L}$ upgrade:** assume 1 fb^{-1}

- **Extend reach:** $E_{T,jet} \sim 80 \rightarrow \sim 100$ GeV
  $m_{JJ} \sim 150 \rightarrow \sim 200$ GeV
- **Major progress IF**

  Experiment: reduced systematics (E-scale)

  Theory: reduced uncertainties:

  Hadronisation: NLO MC with PS and hadronisation
  Retuned PDF$_\gamma$
  Scale uncertainties: difficult