UNIVERSITY
of
GLASGOW

PHOTOPRODUCED JETS AT HERA

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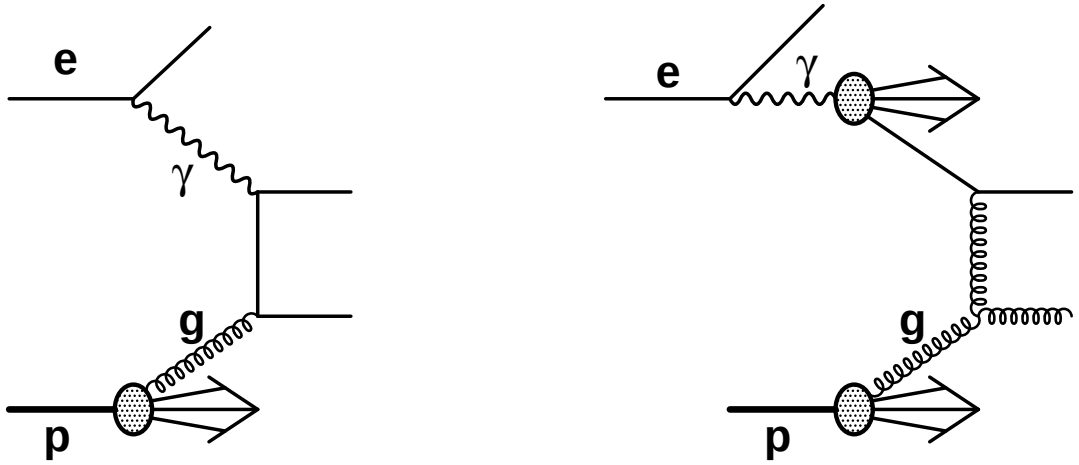
for the H1 and ZEUS Collaborations

Contents:

- **Formalism**
- **Results from H1**
- **Results from ZEUS**

FORMALISM (1)

To remind. . .



Direct processes: entire photon takes part in hard interaction

Resolved processes: parton with momentum fraction x_γ takes part.

Distinct at LO; in HO diagrams a separating cut is required.

The pQCD cross section for $\gamma p \longrightarrow$ two high-p_T jets is

$$\sum_{a,b} \int_{x_p} \int_{x_\gamma} dx_p dx_\gamma f_p(x_p, \mu_F^2)\, f_\gamma(x_\gamma, \mu_F^2) d\hat{\sigma}_{ab}(x_p, x_\gamma, \mu_F^2)$$

- summing over hard scatters, for proton and photon PDF's f_p, f_γ.

For direct processes, $f_\gamma(x_\gamma, \mu_F^2)$ is replaced by $\delta(x_\gamma - 1)$.

FORMALISM (2)

As experimentally measurable approximations to x_γ and x_p we have used:

$$x_\gamma^{\rm obs} = \frac{E_T^{(1)} e^{-\eta(1)} + E_T^{(2)} e^{-\eta(2)}}{2yE_e}$$

$$x_p^{\rm obs} = \frac{E_T^{(1)} e^{\eta(1)} + E_T^{(2)} e^{\eta(2)}}{2E_p}$$

where y = fractional photon energy = $\sum(E - p_z)/E_e$.

Only the calorimeter cells were used in the jet and y measurements.

$\overline{E}_T$, $\overline{\eta}$ = mean transverse energy and pseudorapidity of the two jets.

- **HERA –** $E_p = 920$ GeV, $E_e = 27.5$ GeV.
- Data taken 1998-2000
- Determine acceptance, detector response using PYTHIA6.221 (HERWIG6.505)
- Main detector component used was the calorimeter
- Remove DIS, background (standard cleaning cuts)
- Require $0.15 < y < 0.7$ for purest γp sample (use Jacquet-Blondel calculation)
- Find jets with k_T algorithm.

Select 2 highest E_T jets with :
$E_T^{(1)} > 20$ GeV, $E_T^{(2)} > 15$ GeV, $-1 < \eta < 3$, $-1 < \eta < 2.5$

Correct bins by a factor $N^{\rm had}/N^{\rm detector}$

ZEUS - SYSTEMATICS

- **Vary simulated jet energies by $\pm 1\%$ (calorimeter energy scale) (biggest systematic: 5%)**
- **PYTHIA $\longrightarrow$ HERWIG in acceptance corrections**
- **Vary cuts**
- **Vary fraction of direct process in MC**
- **Vary photon and proton PDFs**

H1 - EXPERIMENTAL METHOD

- **HERA –** $E_p = 920$ GeV, $E_e = 27.5$ GeV.
- Data taken 1999-2000
- Determine acceptance, detector response using PYTHIA6.1 (HERWIG)
- Used calorimeter, tracker to make energy objects
- Remove DIS, background (standard cleaning cuts)
- Require $0.1 < y < 0.9$ for purest γp sample
- Find jets with k_T algorithm.

Select 2 highest E_T jets with :

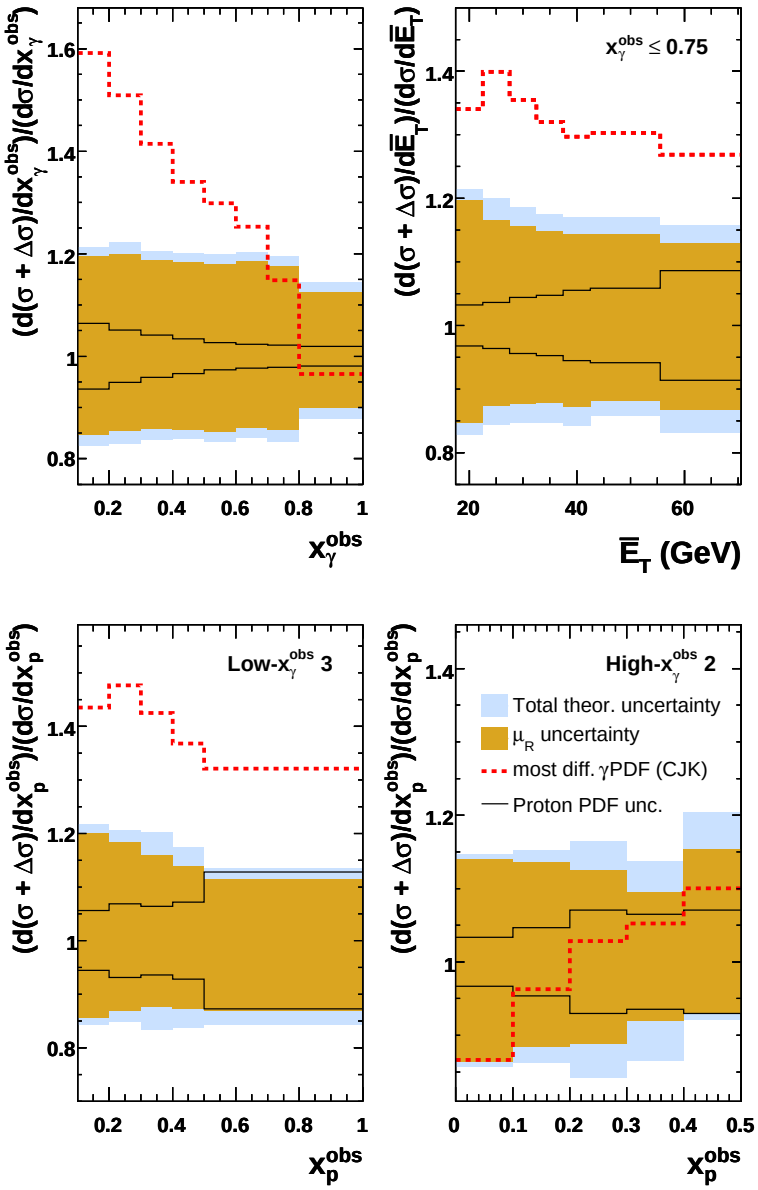
$$E_T^{(1)} > 25 \text{ GeV}, \quad E_T^{(2)} > 15 \text{ GeV}, \quad -0.5 < \eta < 2.75.$$

Correct bins by a factor $N^{\rm had}/N^{\rm detector}$

H1 - SYSTEMATICS

- Vary simulated jet energies by $\pm 1.5\%$ (calorimeter energy scale) (biggest systematic: 7-15%)
- PYTHIA $\longrightarrow$ HERWIG in acceptance corrections: 2-7%.
- Trigger efficiency
- Luminosity (1.5%)

THEORETICAL UNCERTAINTIES



Theoretical uncertainties:
(ZEUS context)

Bands indicate renormalisation scale uncertainty (sand-brown) and
total theory uncertainty (blue).

"Most different" photon PDF is **CJK**.

Lower two plots are two of the "sensitivity-optimised" regions.

Conclusions: the optimisation gains a little, and region 2 would be a good place to look for proton PDF sensitivities.

RESULTS TO BE PRESENTED

Will present:

- General cross sections to test NLO description
- Sensitivity-optimised cross sections, i.e. in kinematic regions where the sensitivity to gluons at high x_P in the proton is found to be greatest.

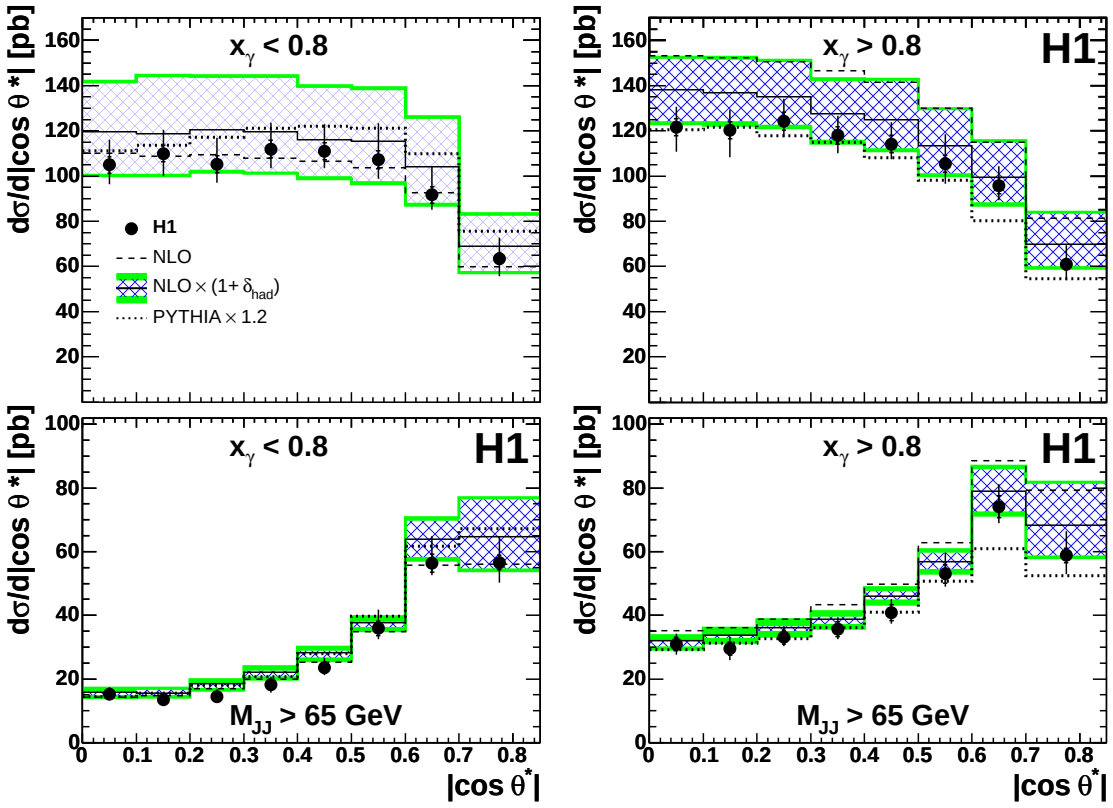
Proton structures used:

CTEQ5M1 [H Lai et al., Phys. Rev. D55, (1997) 1280]

Photon structures used:

CJK [F Cornet, P Jankowksi, M Krawczyk, Phys. Rev. D70, 093004 (2004)]
AFG04 [P Aurenche, M Fontannaz, J.P Guillet,Eur. Phys. J. C34, 395 (2005)]
SAL [W Slominski, H Abramowicz, A Levy,Eur. Phys. J. C45, 633 (2006)]
GRV [M Glück, E Reya, A Vogt, Phys. Rev. D45, 3986 (1992); D46, 1973 (1992)]
AGF-HO [P Aurenche, J.P Guillet, M Fontannaz, Z. Phys. C64, 621 (1994)]

PROPAGATOR STUDY



Resolved dominated Direct dominated

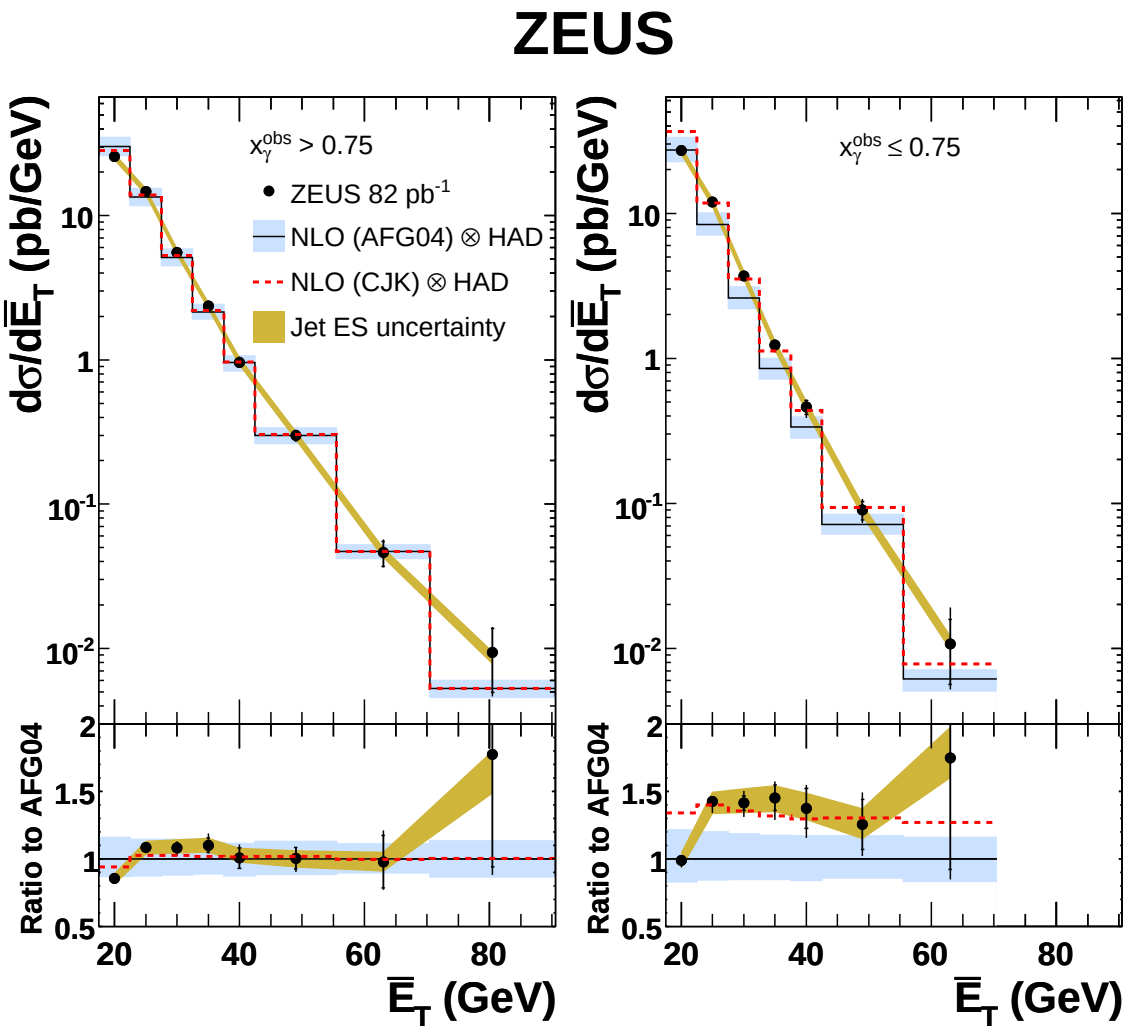
H1: $\cos\theta^*$ of jets in dijet system.

Different for resolved and direct processes.

Effect more visible at high dijet masses.

steeper behaviour at low x_γ reflects the different spins of the propagators (gluon, quark) that dominate the resolved, direct diagrams respectively.

TRANSVERSE JET ENERGIES



Direct dominated Resolved dominated

Distributions in $\overline{E}_T$

Blue band = total theoretical error.

Mustard = Jet Energy Scale

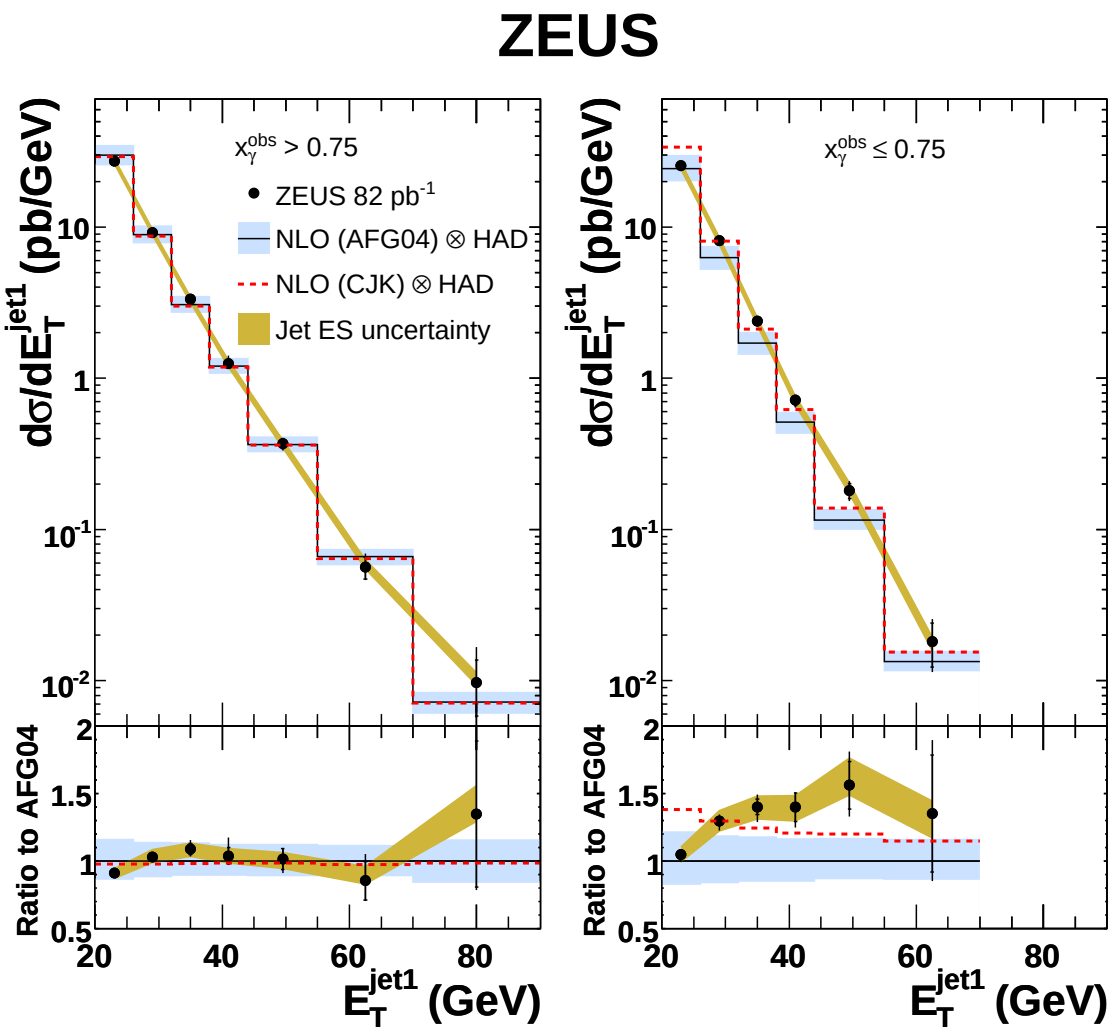
In resolved-dominated results

CJK seems better than AFG04.

except in first bin!

Overall NLO description good over many orders of magnitude.

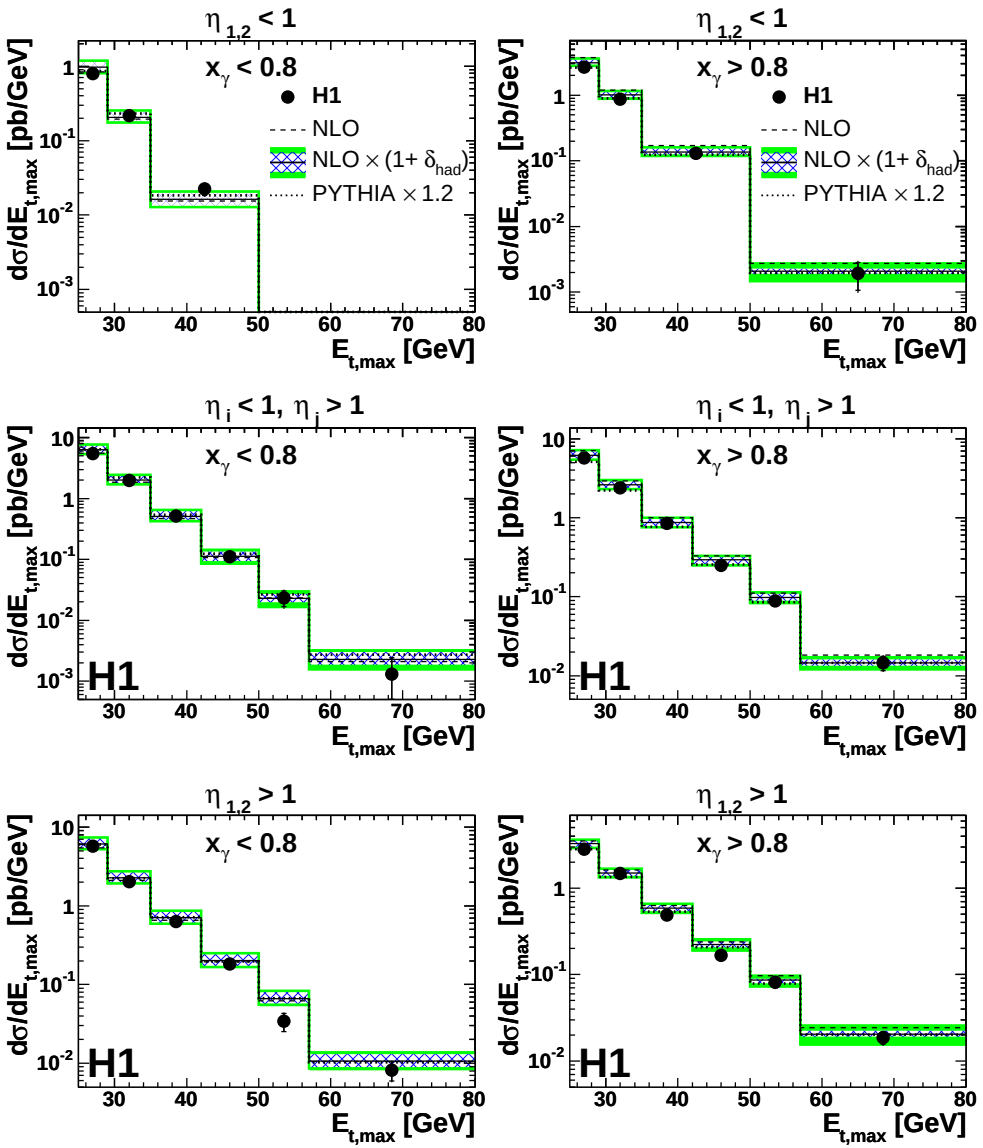
TRANSVERSE JET ENERGIES



Direct dominated **Resolved dominated**

Similar when just the higher jet E_T is plotted

TRANSVERSE JET ENERGIES



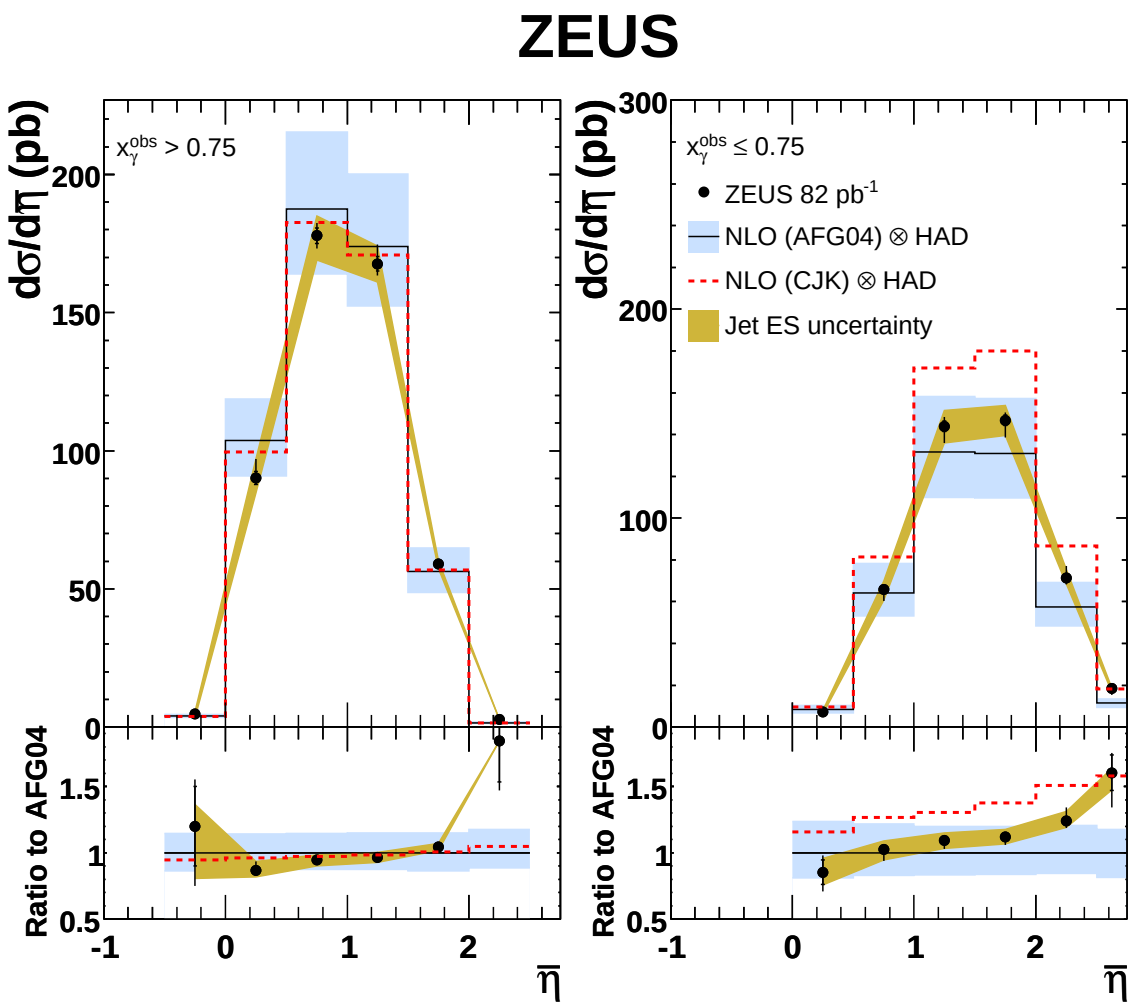
H1: Distributions in $E_T^{\max}$ for different jet configurations

Resolved, direct dominated regions

Green band = total theoretical error.

Overall NLO description good over many orders of magnitude.

PSEUDO-RAPIDITIES



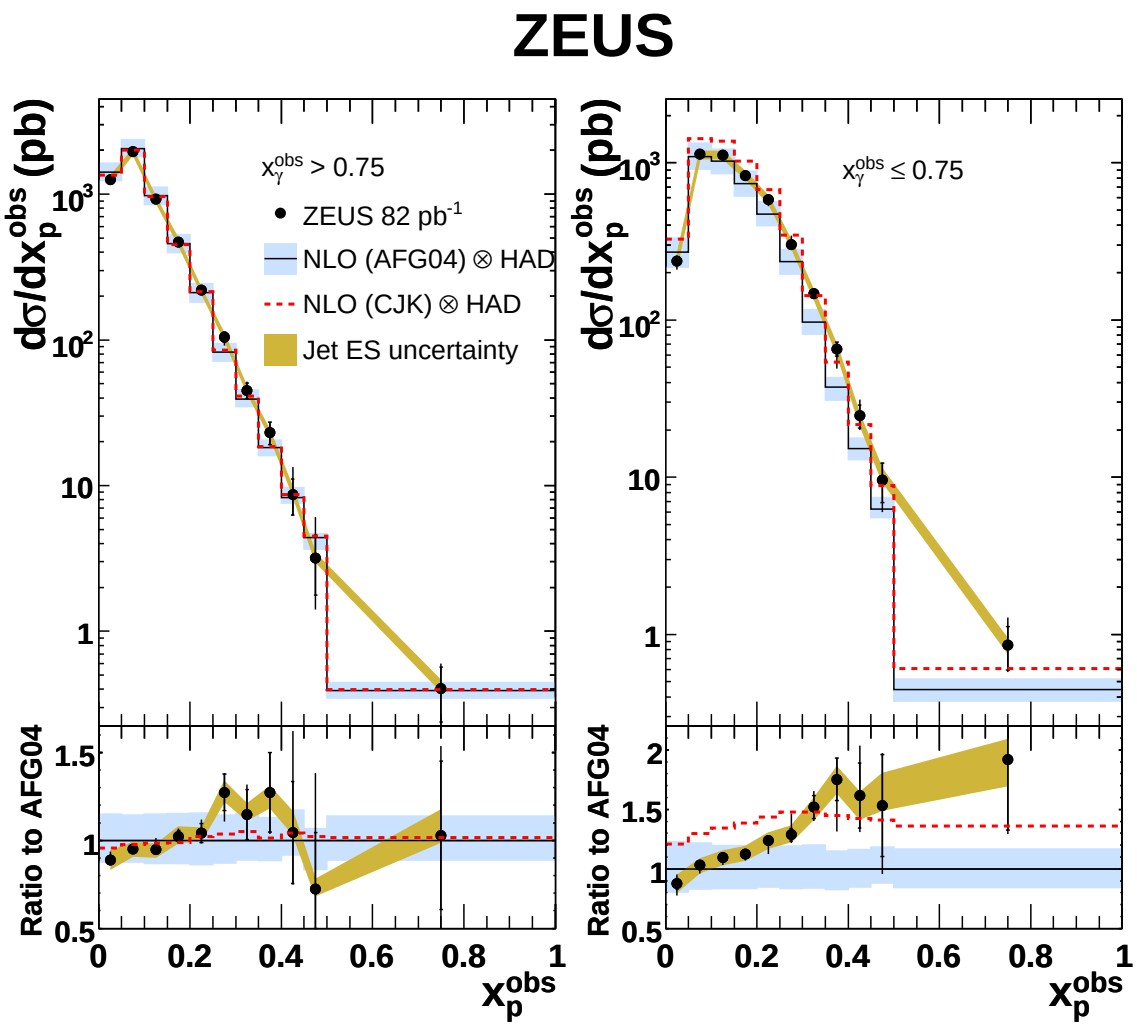
Direct dominated **Resolved dominated**

Distributions in $\overline{\eta}$

N.B. lowest E_T bin dominates statistics.

In resolved-dominated CJK too high.

PROTON X



Direct dominated Resolved dominated

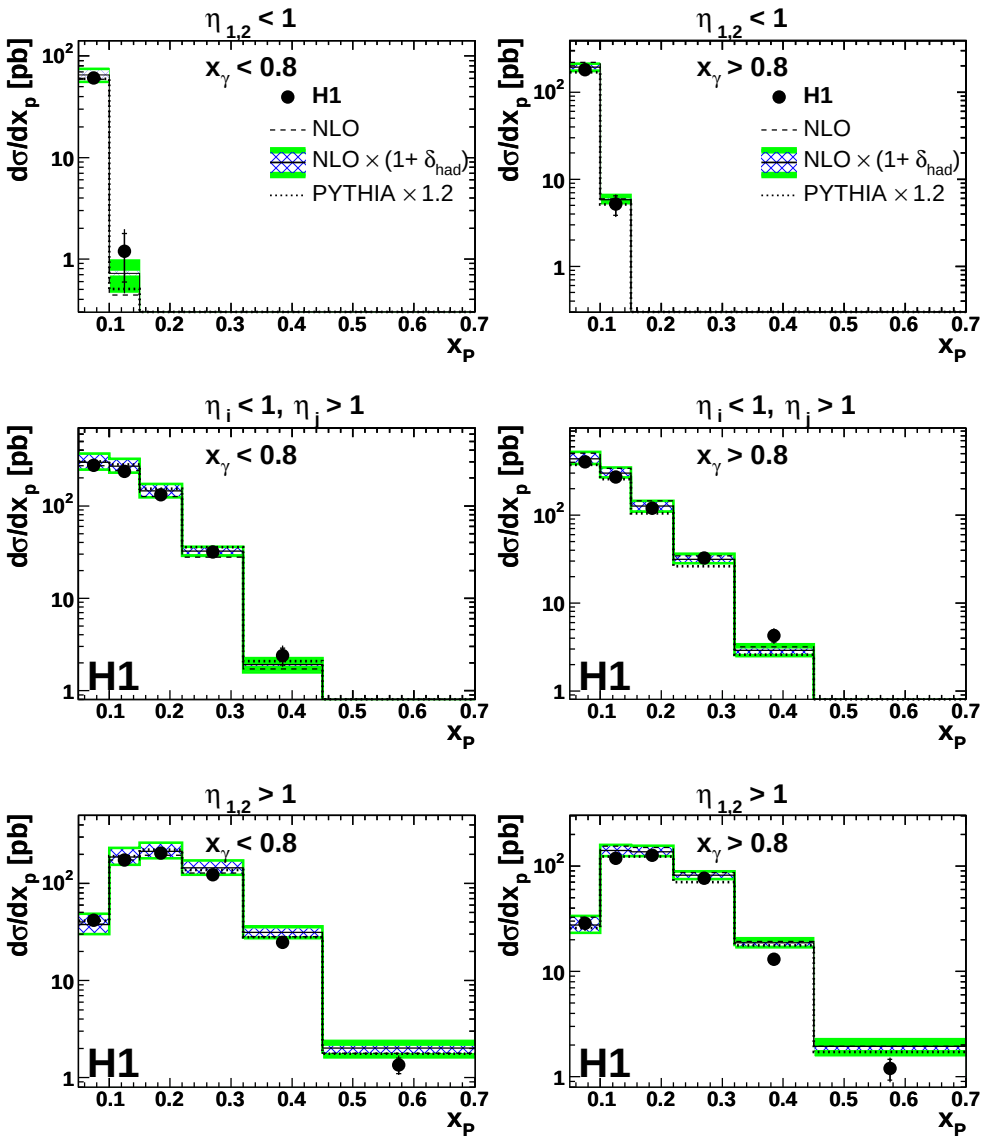
Distributions in x_P

In direct-dominated, excellent agreement.

In resolved-dominated data rise above theory with x_P

Apparently different.

PROTON X

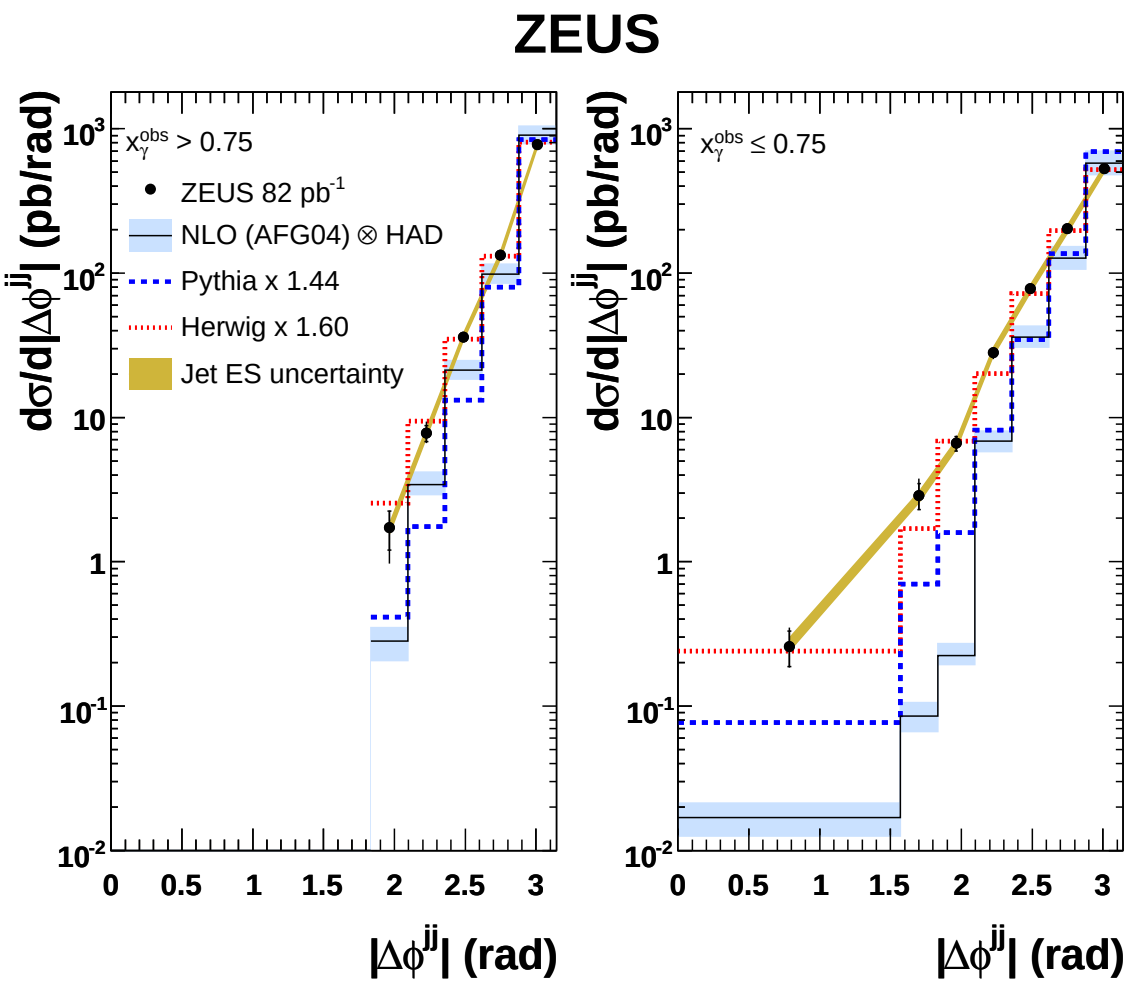


H1: Distributions in x_p for different jet configurations

Resolved, direct dominated regions

Overall NLO description good over many orders of magnitude, apart perhaps from large-x_p in direct enhanced events with both jets forward.

AZIMUTHAL SEPARATION



Direct dominated

Resolved dominated

Distributions in $\Delta\phi$ (jet azimuth separation)

NLO - not great

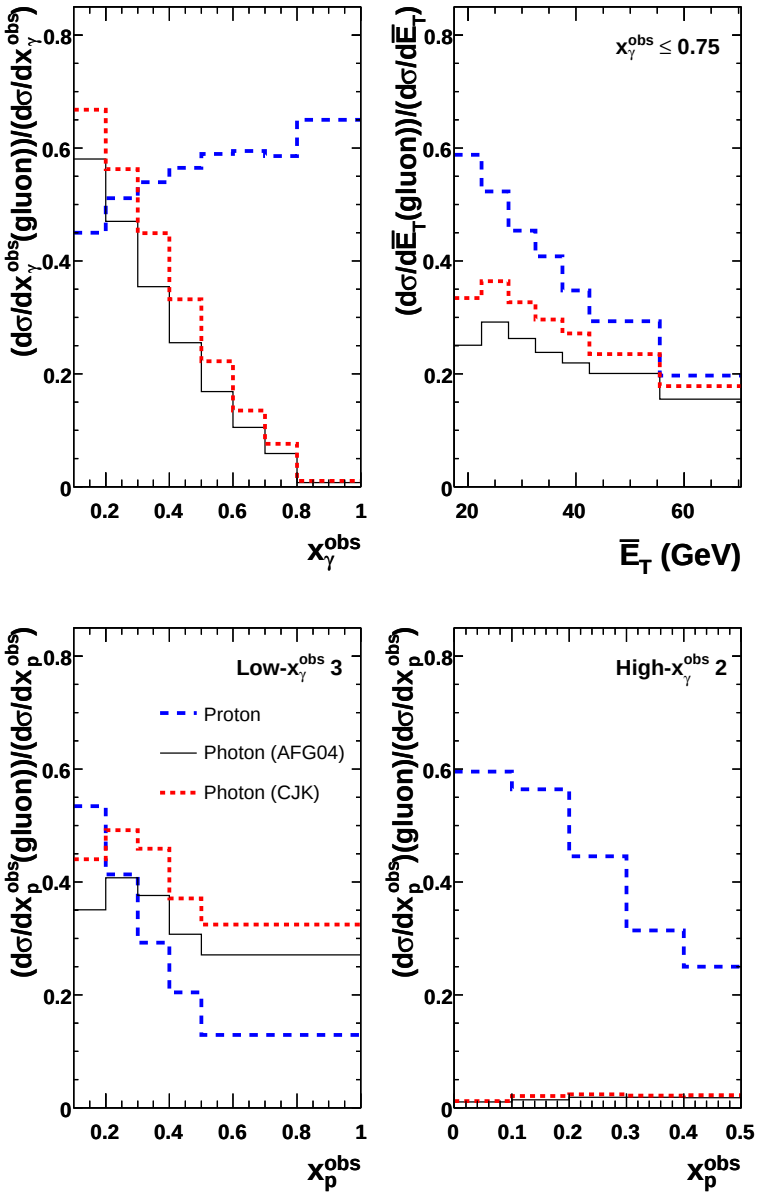
PYTHIA - still poor

HERWIG - better!

Conclude that HERWIG shower treatment gives a better description of these HO effects.

C.f. ZEUS prompt photon + jet in Physics Letters B 511 (2001) 19-32

GLUON DENSITIES



Calculated gluon densities:

Lines indicate fraction of cross section initiated by gluons.

Proton CTEQ5M1

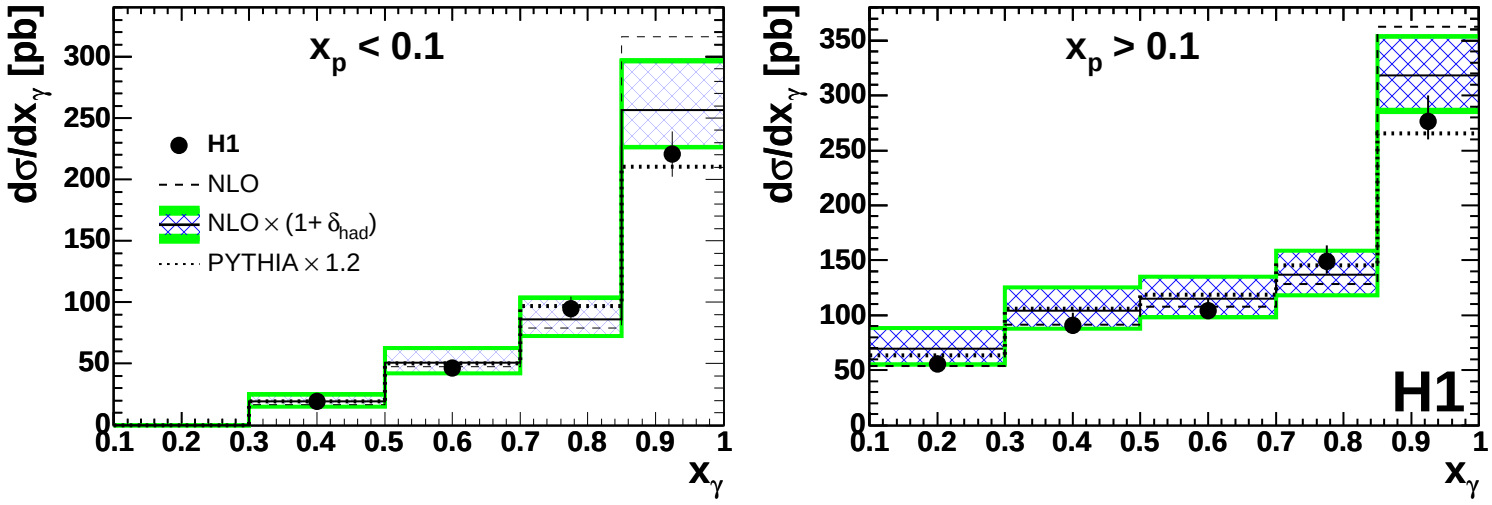
Photon AFG04

Photon CJK

Lower two plots are same two "sensitivity-optimised" regions.

Conclusions: direct events, of course, have no photon-gluon dependence. Softer jets depend more on gluons in both particles.

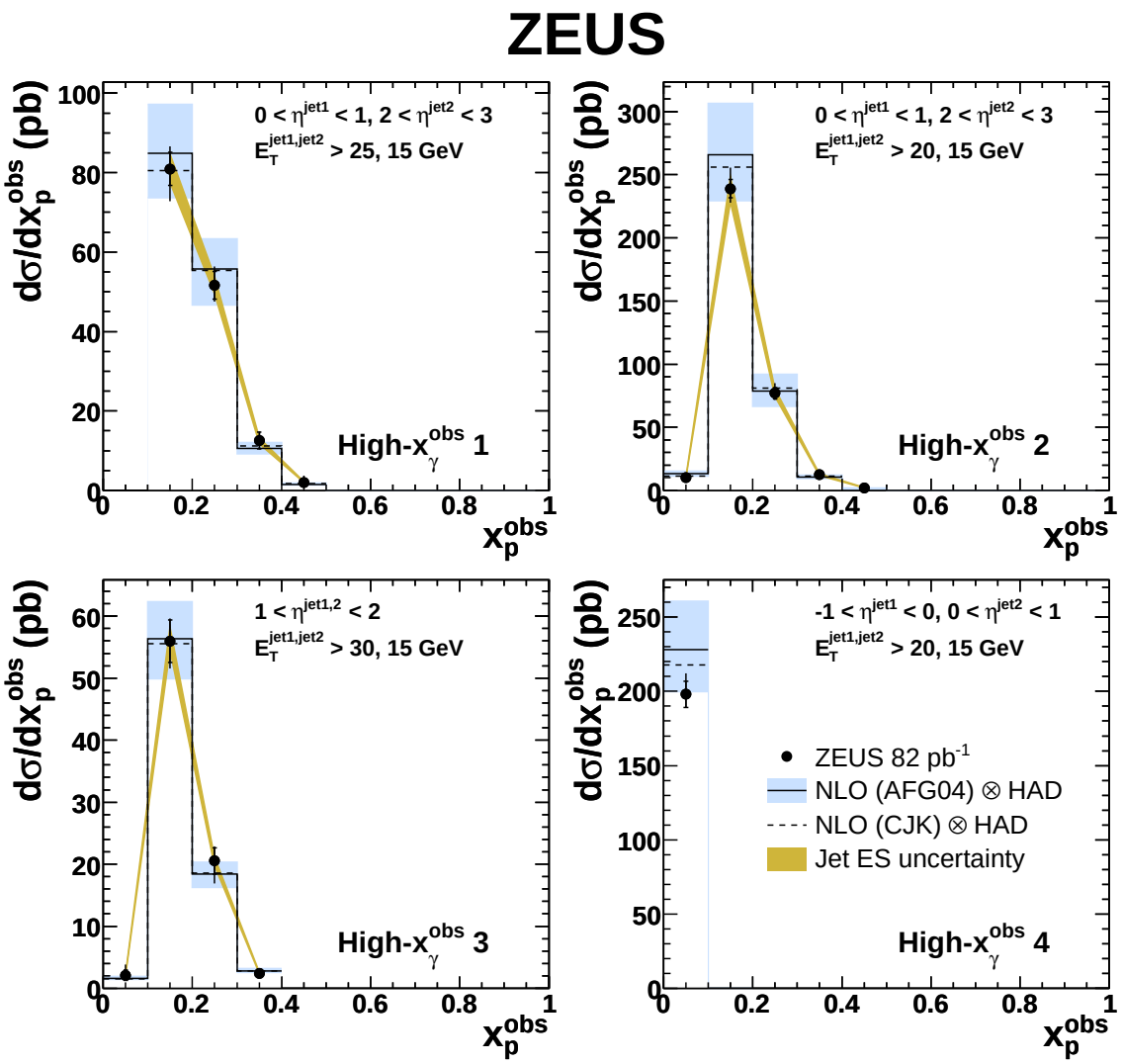
PHOTON BEHAVIOUR



H1: Distributions in x_γ for different x_p ranges

Shape of resolved-dominated region is OK.

"OPTIMISED" CROSS SECTIONS

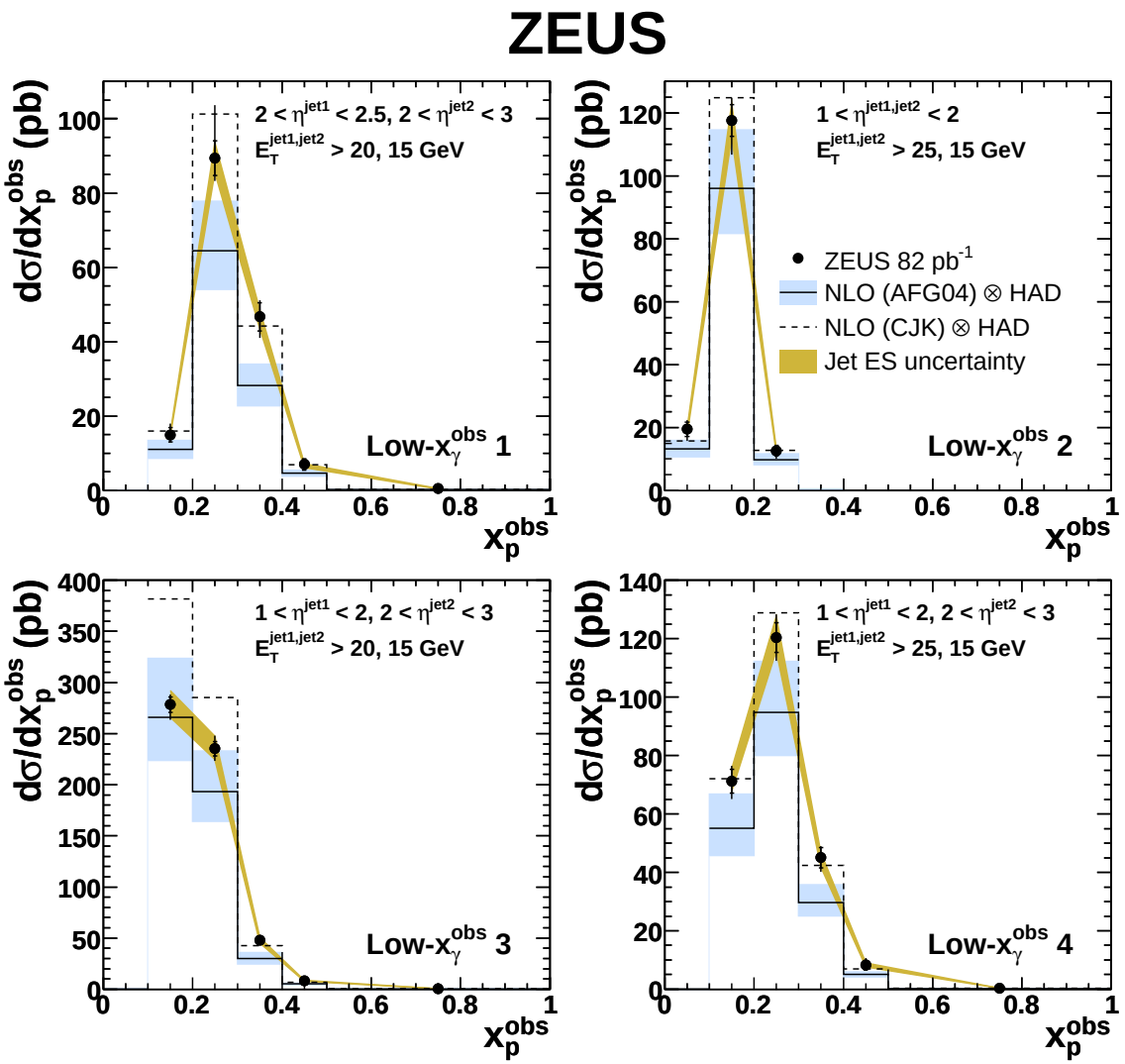


Direct dominated ($x_\gamma^{\rm obs} > 0.75$)

Sensitivity-optimised cross sections: kinematic regions chosen for greatest sensitivity to proton gluon density.

(a) direct-dominated regions; sensitivity to photon structure is small.

"OPTIMISED" CROSS SECTIONS



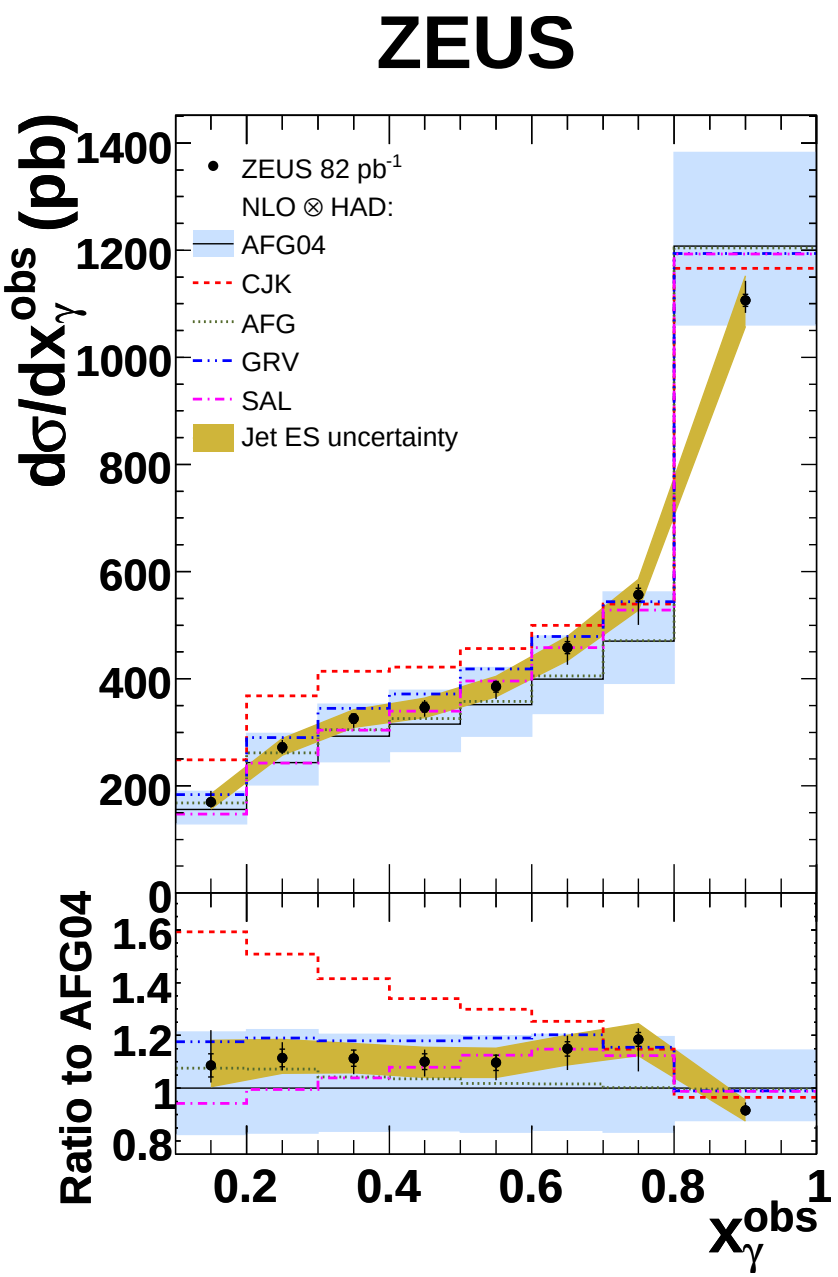
Resolved dominated ($x_\gamma^{\rm obs} < 0.75$)

Sensitivity-optimised cross sections: kinematic regions chosen for greatest sensitivity to proton gluon density.

(b) resolved-dominated regions.

These measurements need to be followed up.

PHOTON STRUCTURE (1)

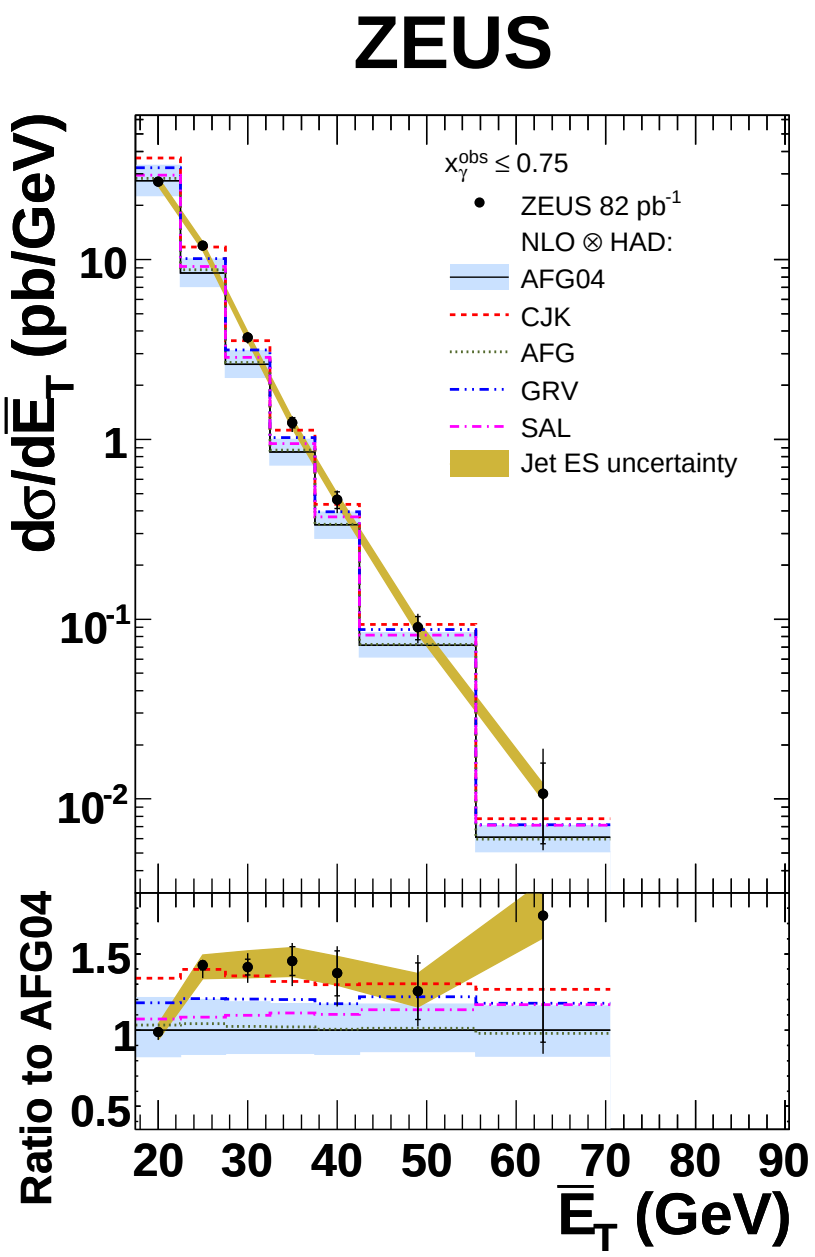


Closer look at photon structure.
(Using all data again)

All the photon PDF sets are in reasonable agreement except CJK.

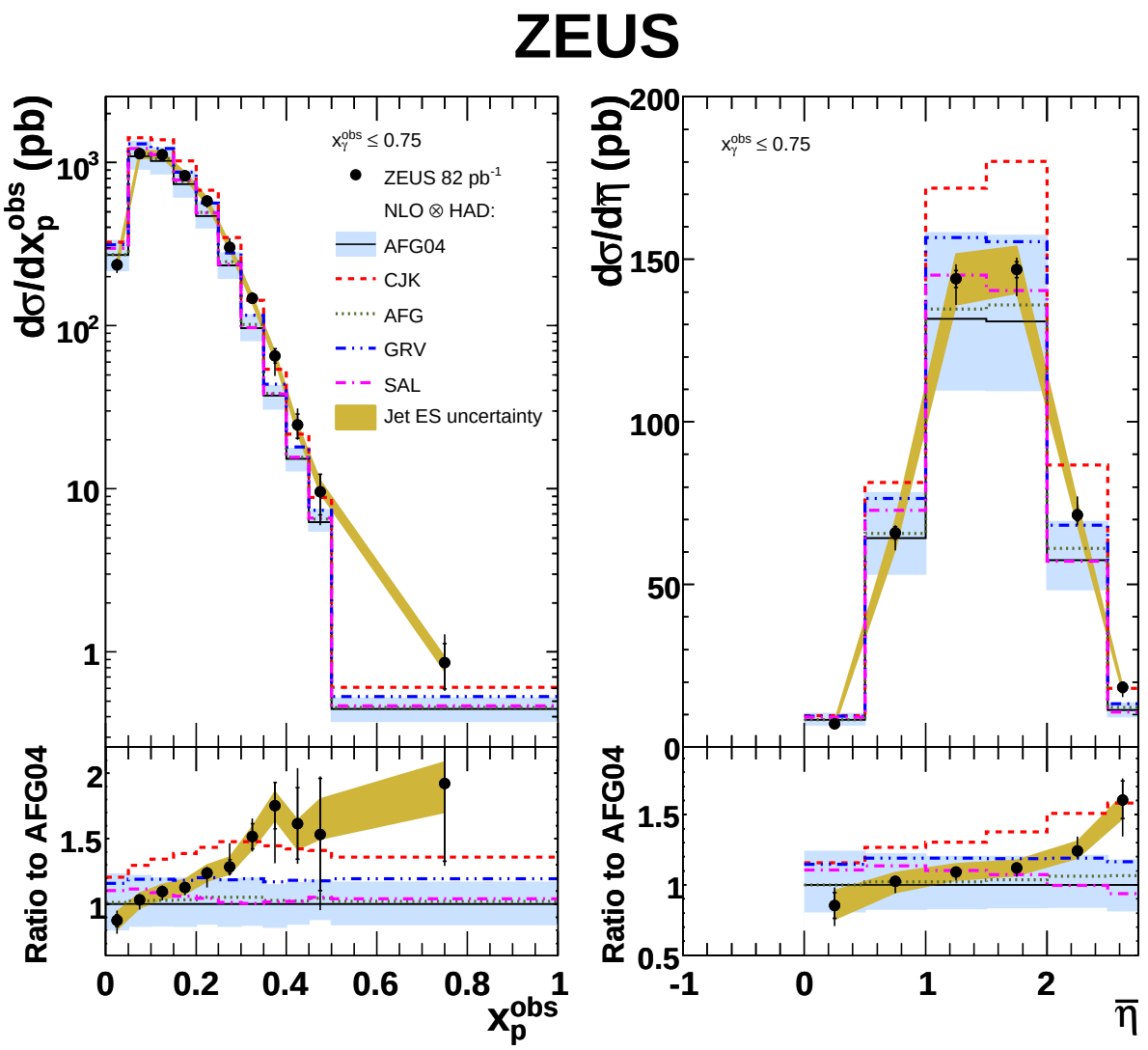
GRV possibly ahead marginally if one normalises up within theory band. But these data are dominated by the lowest E_T bin.

PHOTON STRUCTURE (2)



At higher $\overline{E}_T$ the picture changes. CJK wins here (as noted before).

PHOTON STRUCTURE (3)



CJK wins at high x_p and forward jets

CONCLUSIONS

- Both H1 and ZEUS have produced major new measurements of high- E_T jets in photoproduction since PHOTON05.
- NLO QCD gives a good basic description.
- The proton PDFs appear to be fine
- However the photon PDFs, although pretty good, still have to be tuned a little more.