

# Summary of the ZEUS physics results



Monica Turcato  
Hamburg University



Federal Ministry  
of Education  
and Research

SPONSORED BY THE



on behalf of  
the ZEUS Collaboration

XVIII International Workshop on Deep-Inelastic Scattering  
and Related Subjects

Florence, Italy

April 19-23, 2010



Monica Turcato

DIS 2010



# Outline

- Inclusive NC and CC cross sections
- Heavy Flavours
- Jets cross sections,  $\alpha_s$
- Diffractive PDF fits





# ZEUS(+H1) results for DIS 2010

## Inclusive:

- High- $Q^2$  CC K. Oliver
- NC at high- $x$  R. Ingbir
- NC/CC and PDF fits S. Habib
- Combined  $F_L$  J. Grebenyuk
- QCD fits with low energy data V. Radescu

- QCD fits with charm data A. Cooper-Sarkar

## HFL:

- Incl. beauty in DIS P. Roloff
- Incl. beauty in PHP V. Aushev
- Charm mesons in DIS M. Lisovyi
- Inelastic  $J/\psi$  helicity A. Bertolin

## QCD:

- Jets with anti- $k_T$  and SIScone, (di)jets in NC DIS C. Glashan
- Three subjects J. Terron
- Jets in PHP D. Lontkowskyi
- Scaled momenta K. Olkiewicz
- Prompt photon D. Saxon

## Diffraction:

- Diffractive PDFs M. Wing
- $J/\psi$  at high  $t$  A. Bruni

## EW/searches:

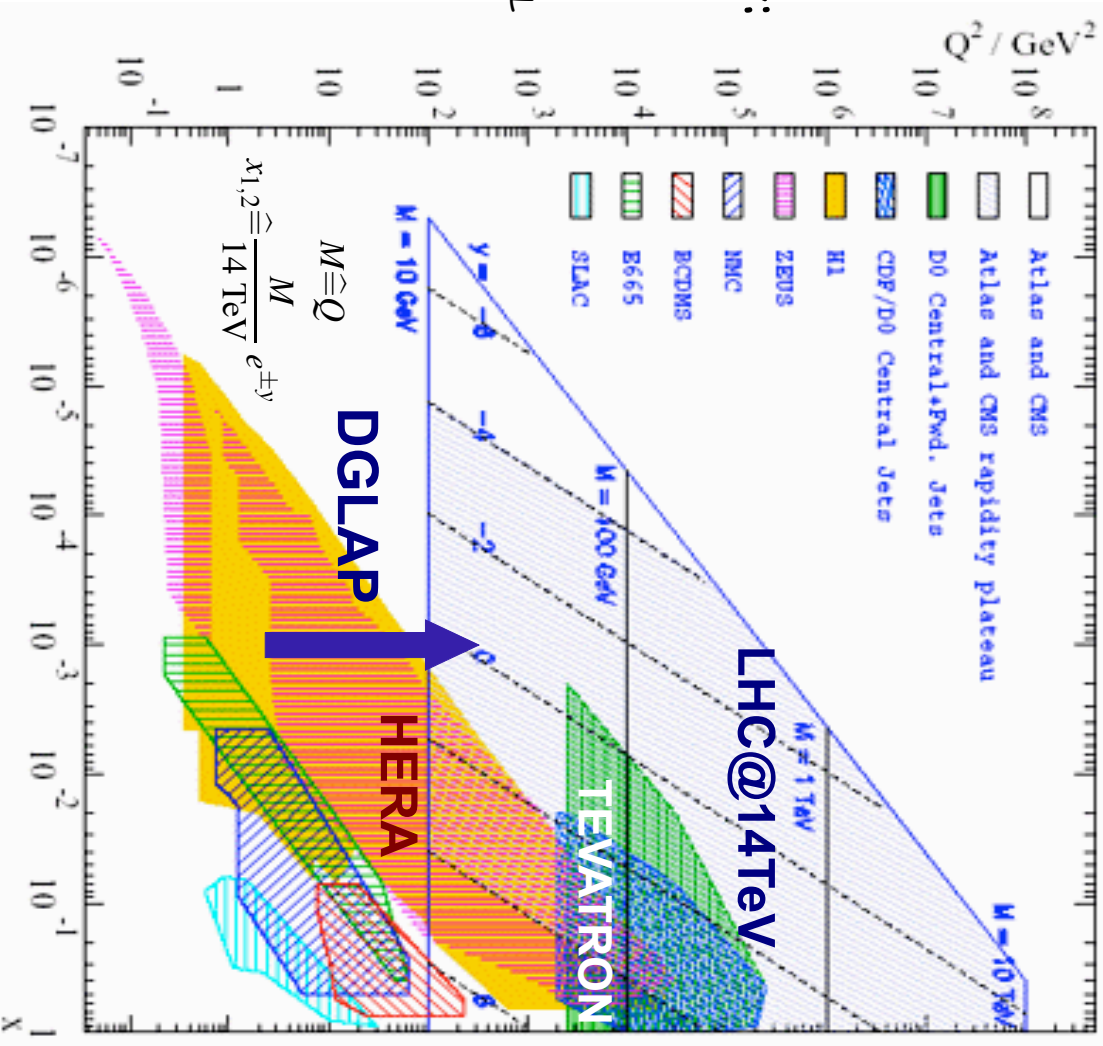
- Isolated leptons D. South
- Multi-leptons A. Parenti
- LQ and CI I. Panagoulas

# QCD at HERA

- NC and CC cross sections main input to QCD fits → **HERAPDF1.0**
- Extension to the high- $Q^2$  and x region
- Extension to the low- $Q^2$  region at high-y:
  - check of DGLAP evolution
  - check of QCD predictions for  $F_L$  (see K. Krueger)
- Inclusion of jet data and HFL data → sensitivity to the gluon



Provide precise input to QCD fits







# H1+ZEUS combined cross sections

see Shiraz Habib [169]



- NC and CC cross sections from H1 and ZEUS combined

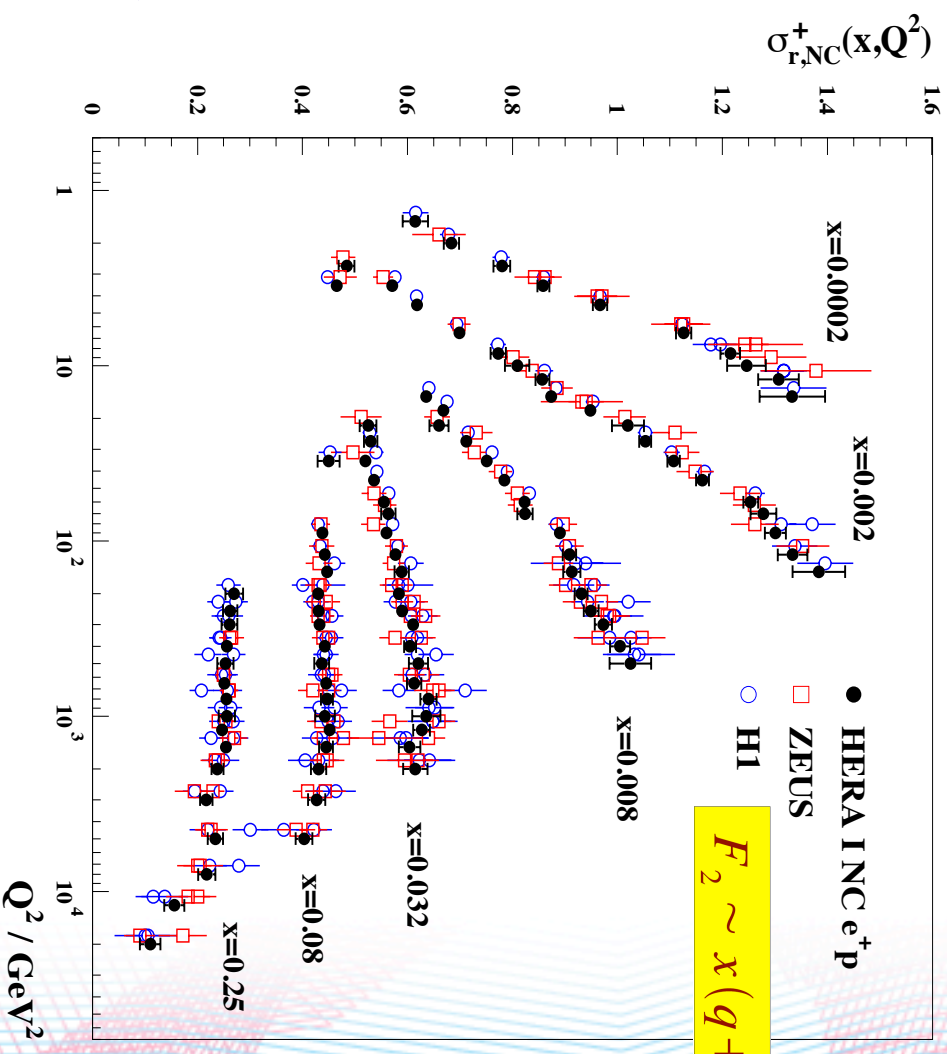
- **Data are now published**

- **Precision of 1-2%**

- Gluon density from **scaling violations**

$$\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_s(Q^2) x g(x, Q^2)$$

- **DGLAP** drives the evolution in  $Q^2$  at fixed  $x$

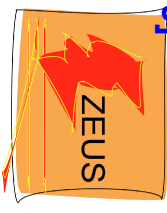


Data available to be used in PDF fits!

JHEP01(2010)109



# H1 and ZEUS



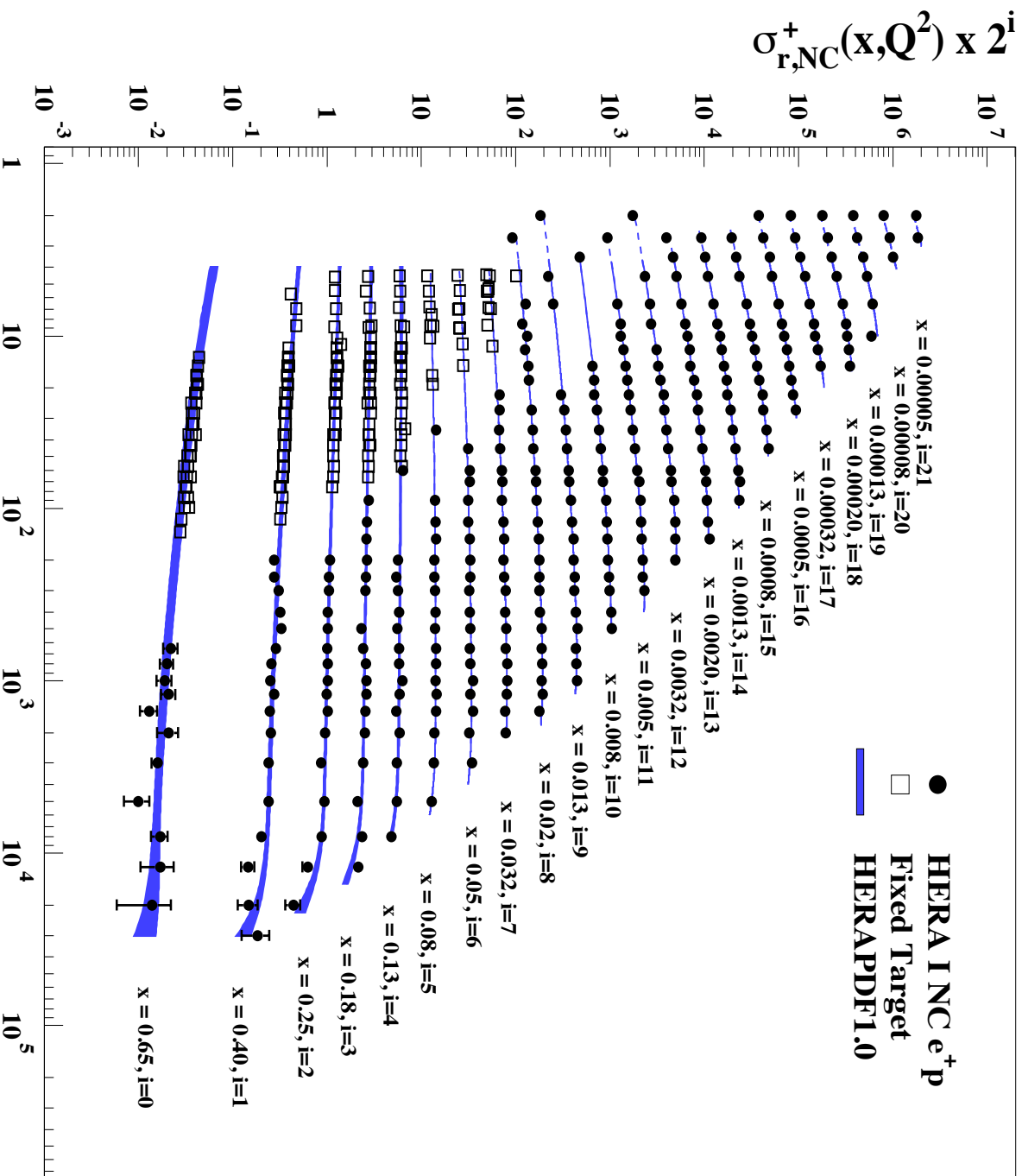
- NC and CC and ZEUS
- Data are r
- Precision
- Gluon densi

violations

$$\frac{\partial F_2}{\partial \ln Q^2} \propto$$

- DGLAP driv
- at fixed x

Data a



$$c(q + \bar{q})$$

$$0.25$$

$$\text{GeV}^2$$



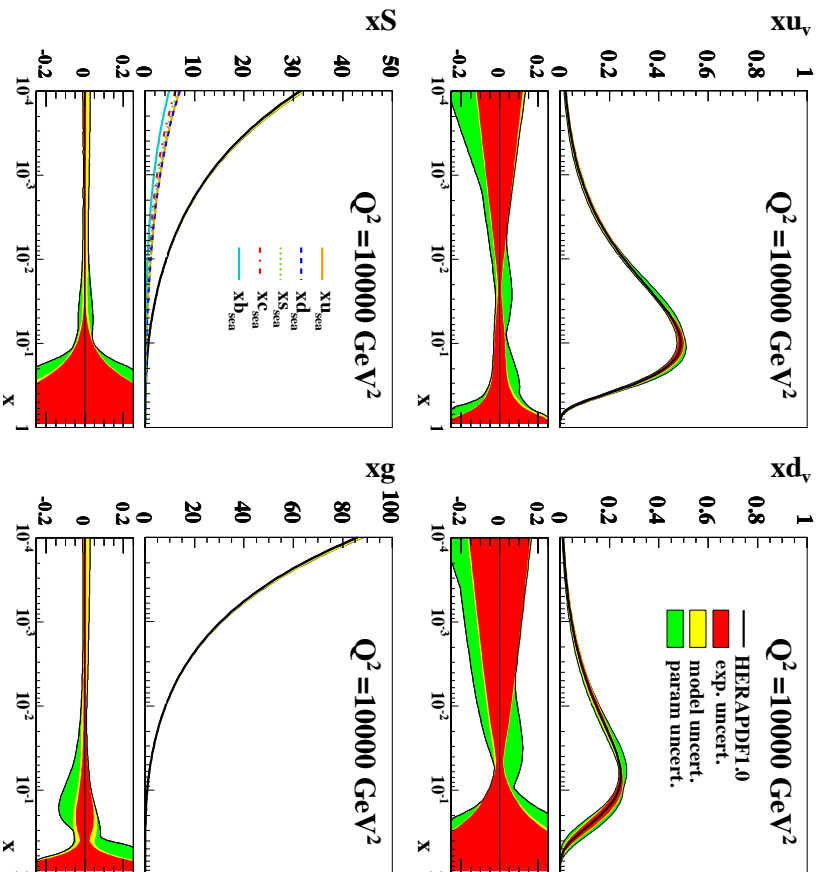


# HERAPDF1.0

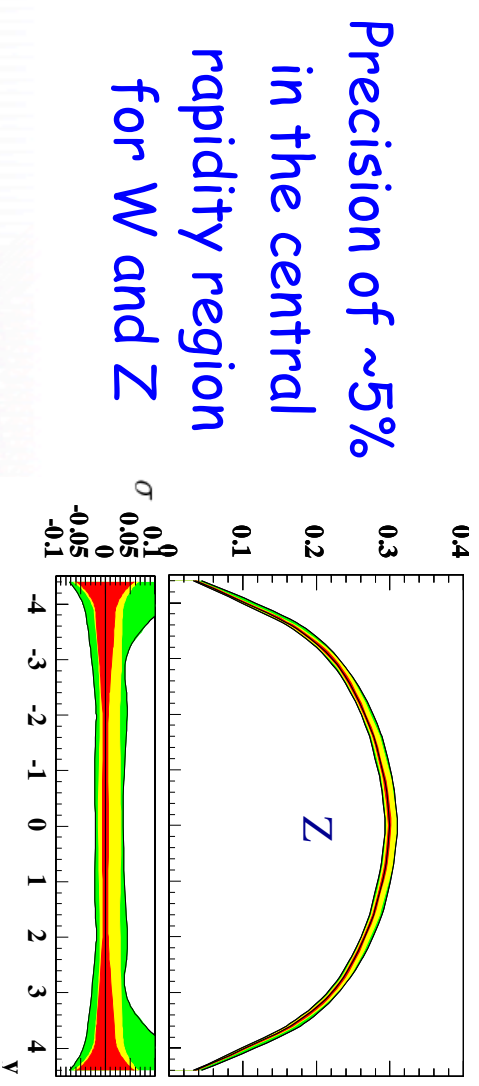
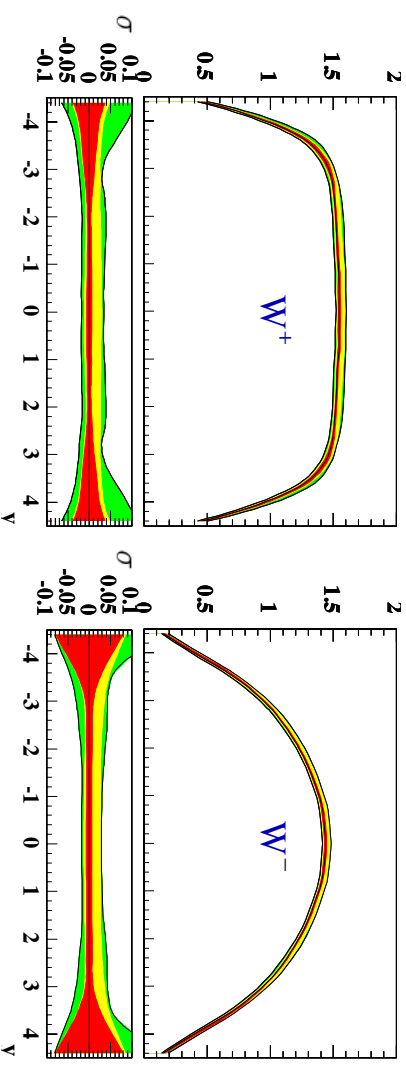
see Shiraz Habib [169]

The combined HERA data have been used as the sole input for the extraction of the HERAPDF1.0.

H1 and ZEUS

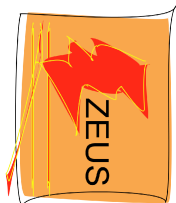


$W$  and  $Z$  rapidity distributions



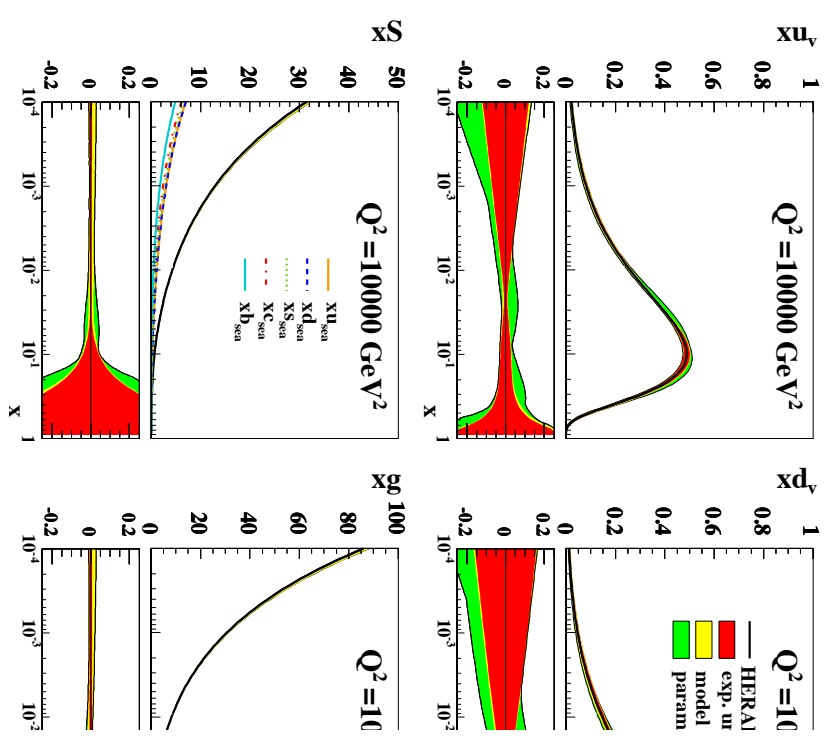
Precise picture of the proton

JHEP01(2010)109

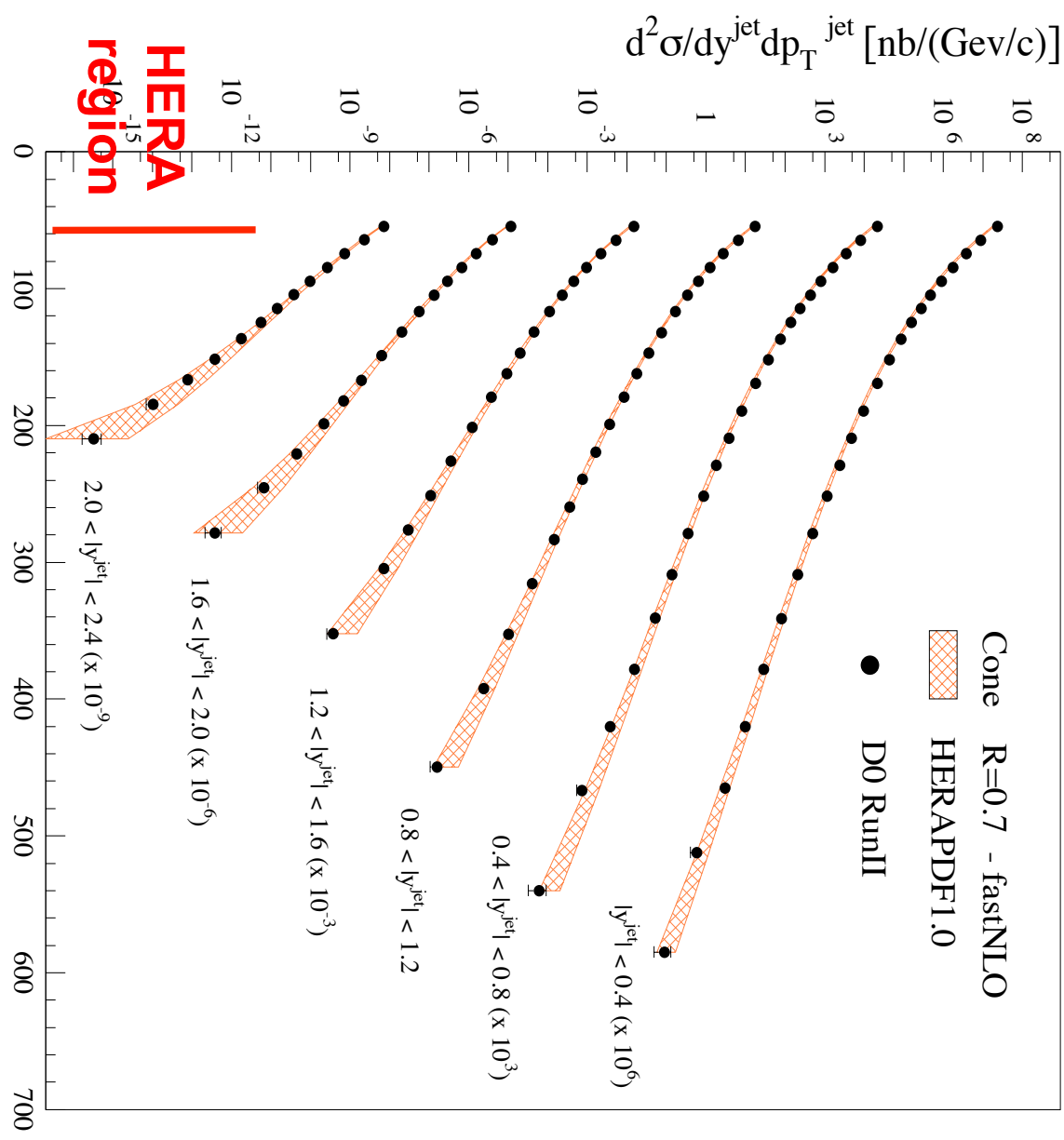


# The combined HERA data extraction of the HERAPL

H1 and ZEUS



## Tevatron Jet Cross Sections



sae Shiraz Habib r16a1



JHEP01(2010)109

Dns

HERAPDF1.0 able to describe high-x jet production

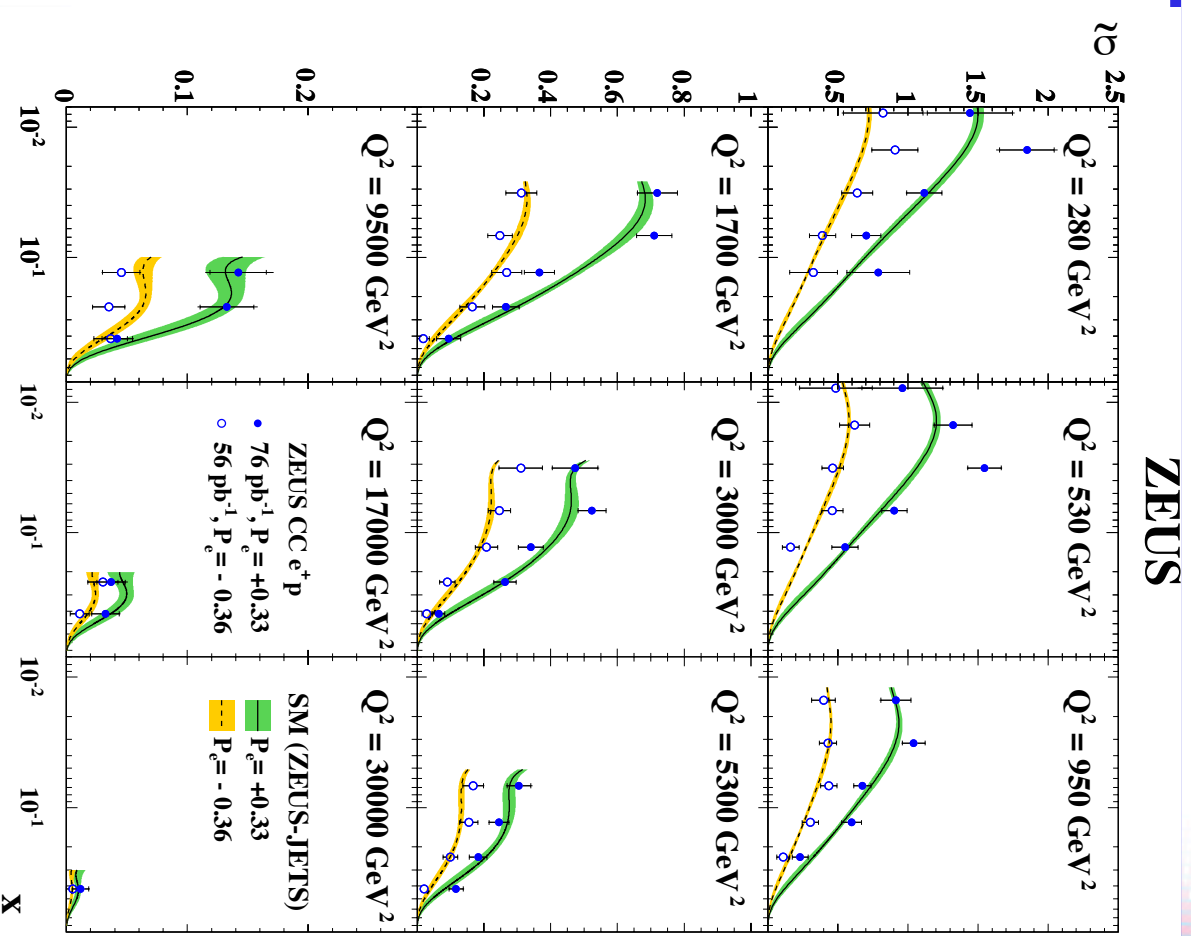
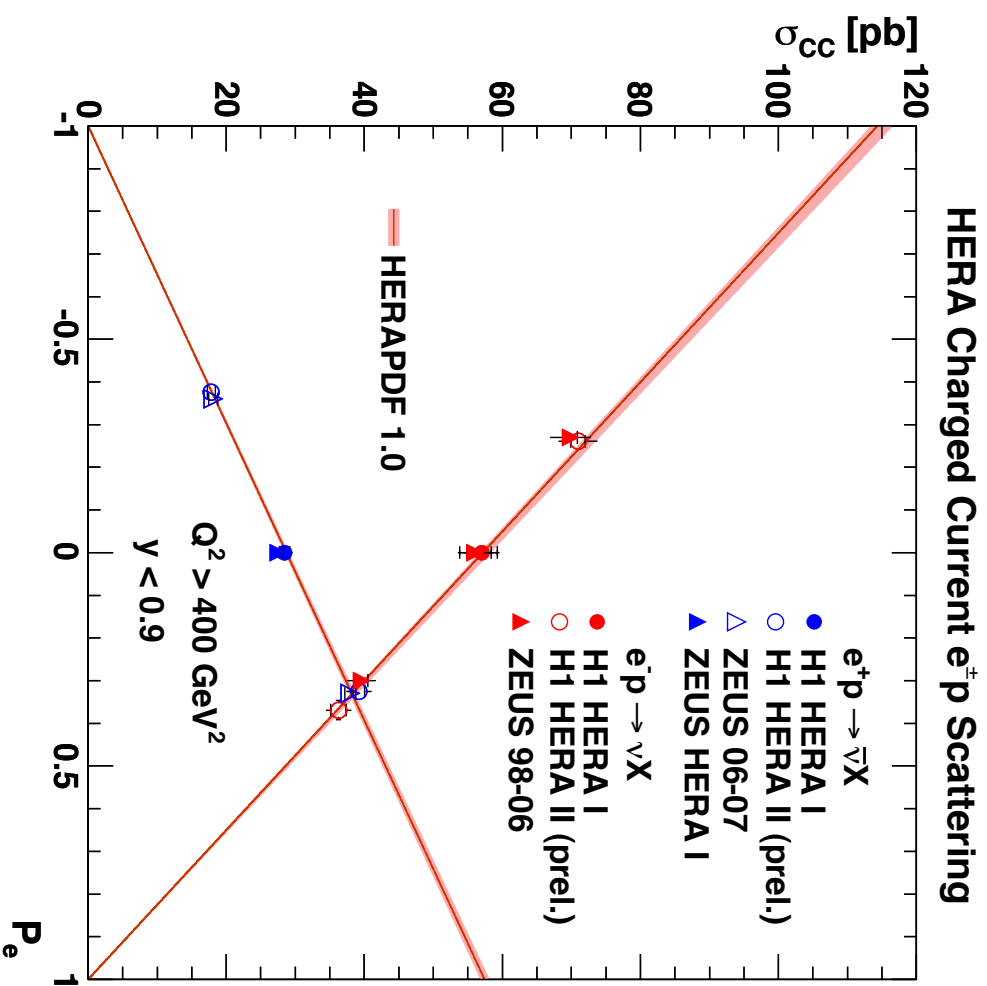


# High- $Q^2$ CC from $e^+p$ data

Final results on  $e^+p$  data,  $L=1332 \text{ pb}^{-1}$ .

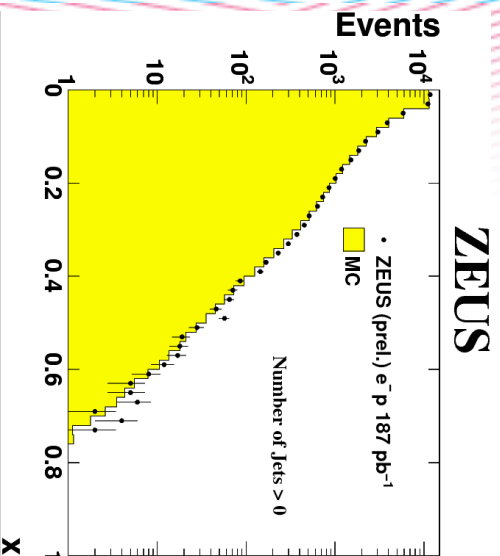
$200 < Q^2 < 60000 \text{ GeV}^2$

Precise input to QCD fits  $\rightarrow$  high  $x$

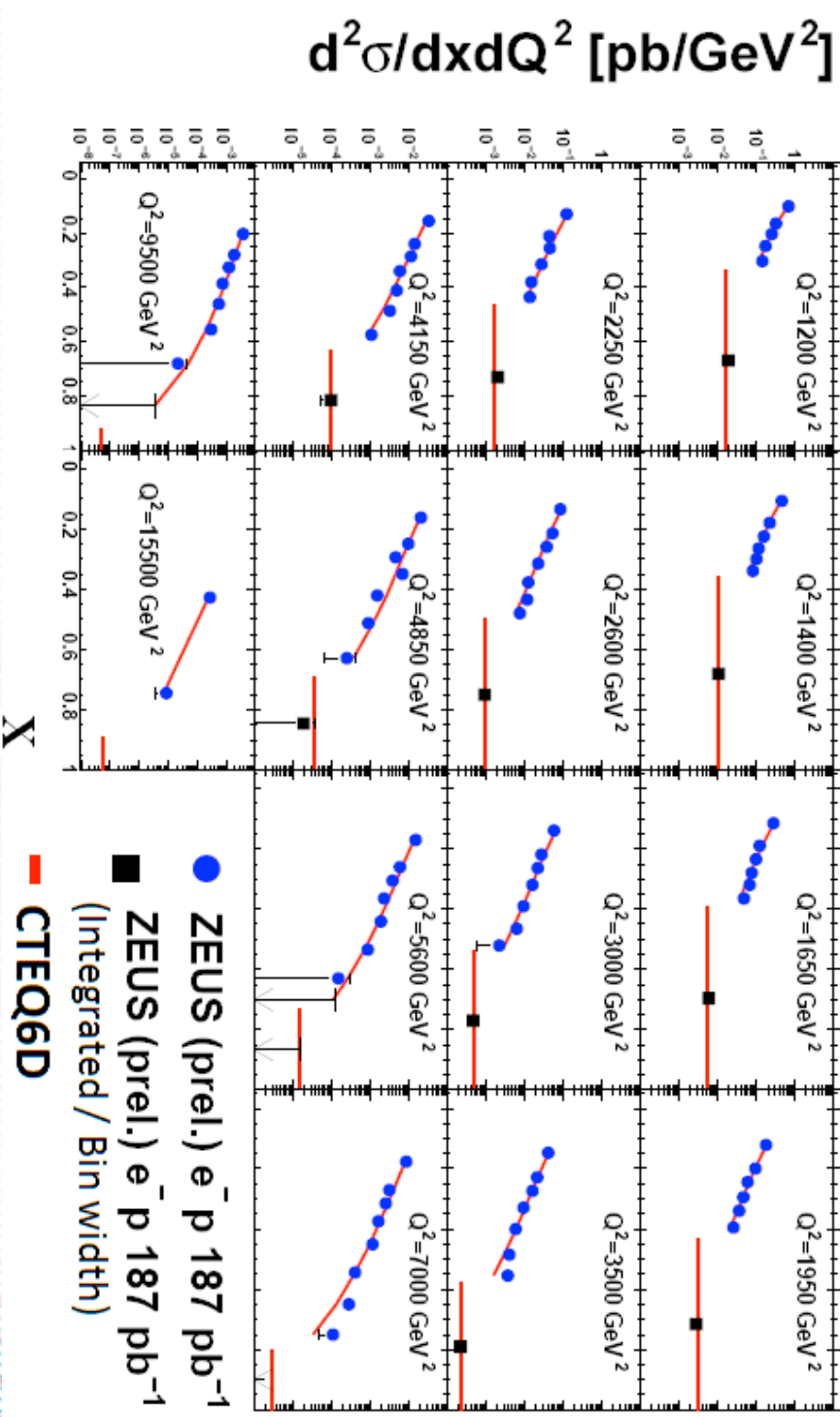


# NC cross sections at high-x

$Q^2 > 450 \text{ GeV}^2$ , 0-, 1-  
and multi-jet events  
reconstructed



Sensitivity to the  
high-x region.





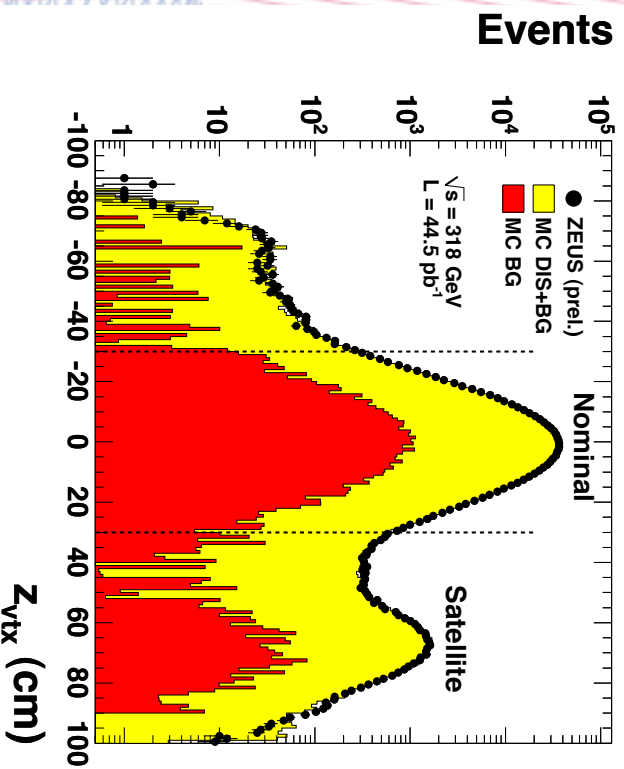
# High, medium and low energy cross section at high $\gamma$

HERA NC cross sections from data collected at  $E_p=920$ , 460 and 575 GeV for

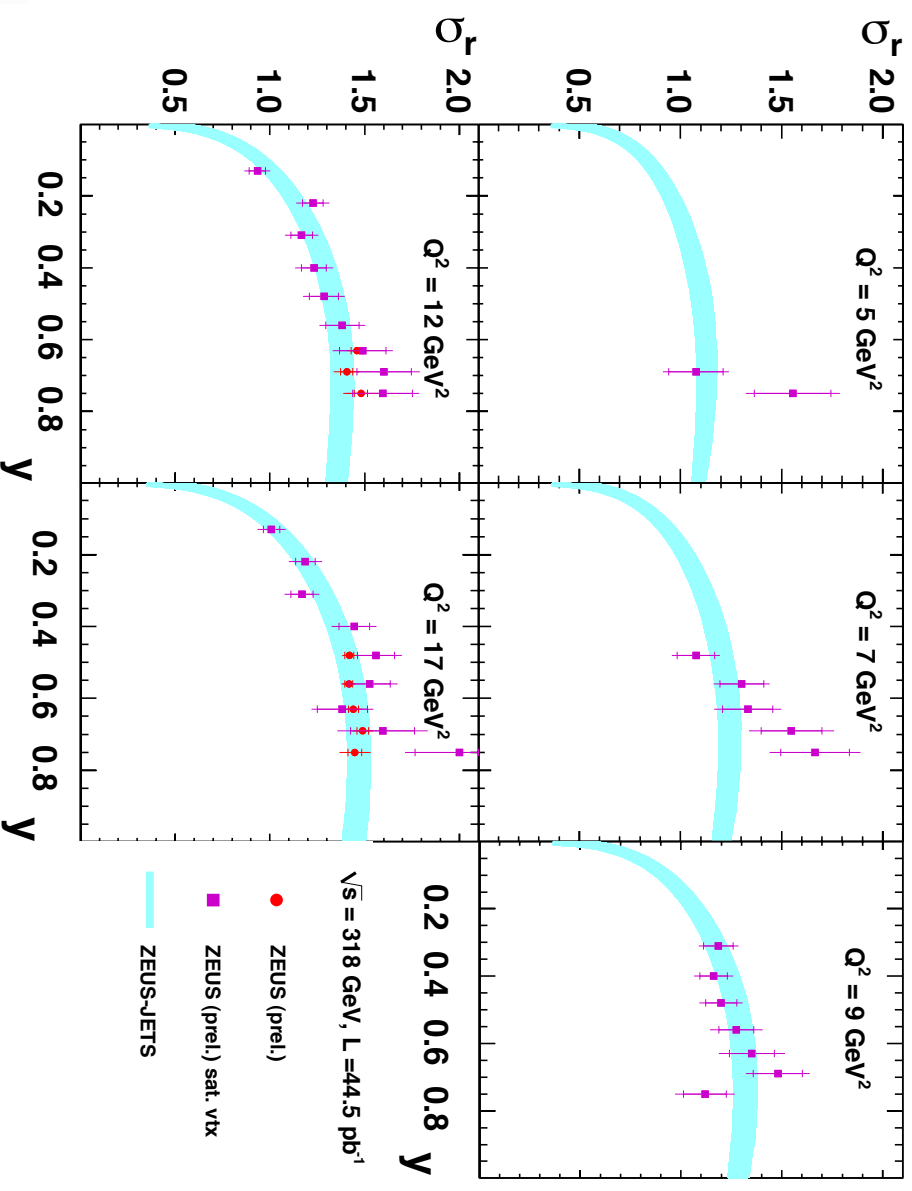
the  $F_L$  determination used in PDF

**ZEUS** extends its  $Q^2$  region for all energies, down to 5 GeV<sup>2</sup> for HER also using shifted vertex data.

## ZEUS

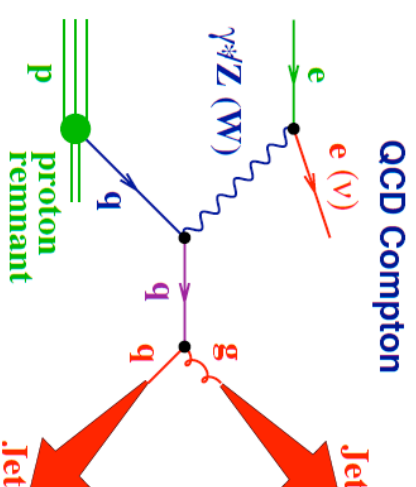
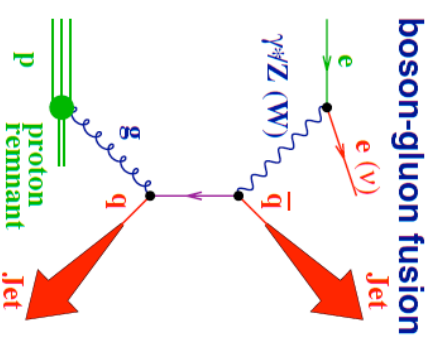


## ZEUS



# Jet cross sections

- Stringent test of perturbative QCD
- Sensitivity to the gluon in the proton, precise input to QCD fits.



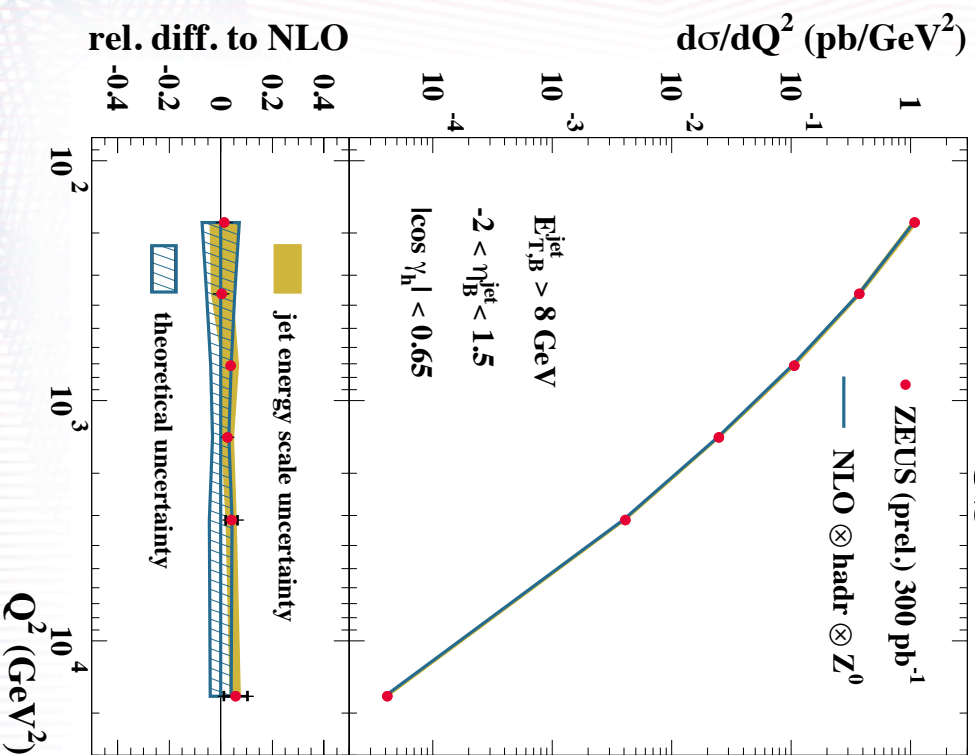
- Extract  $\alpha_s$  with high precision, check the scale dependence within a single experiment and in different regimes.



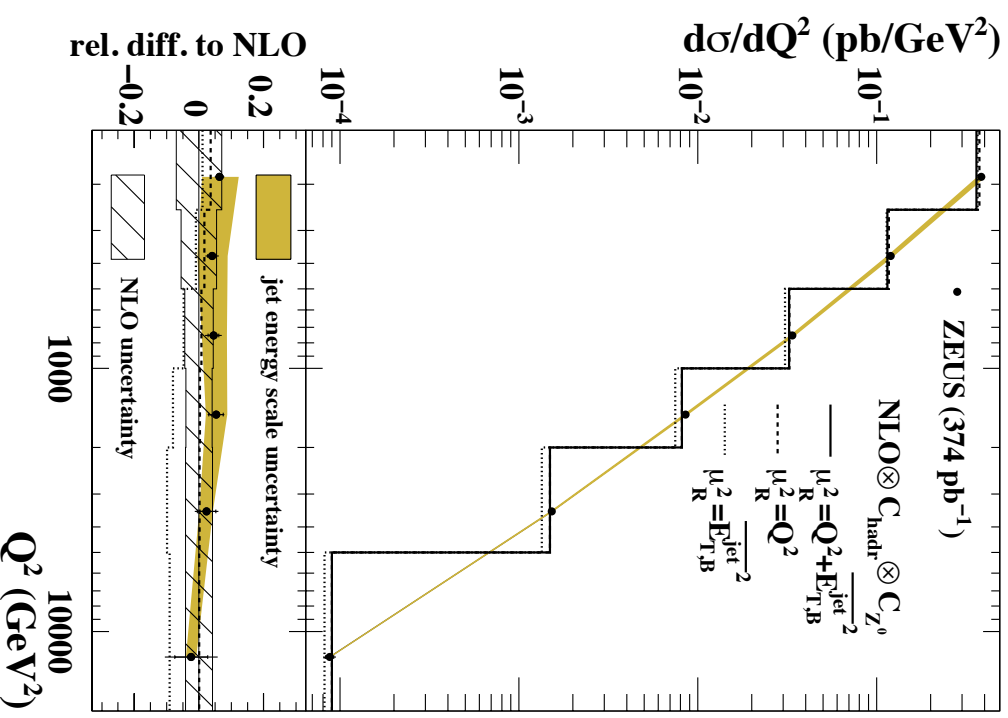
# Inclusive jets and dijets in NC DIS

Kinematic range  $Q^2 > 125 \text{ GeV}^2$ . Good agreement with QCD at NLO.

## ZEUS



## Inclusive dijets, $L=374 \text{ pb}^{-1}$

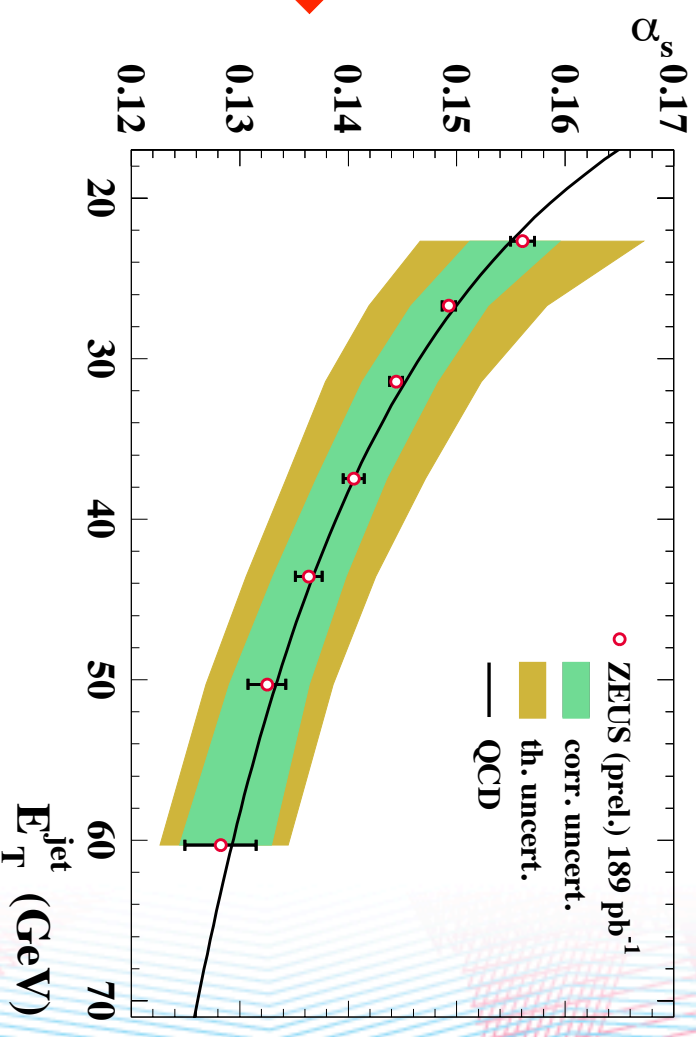
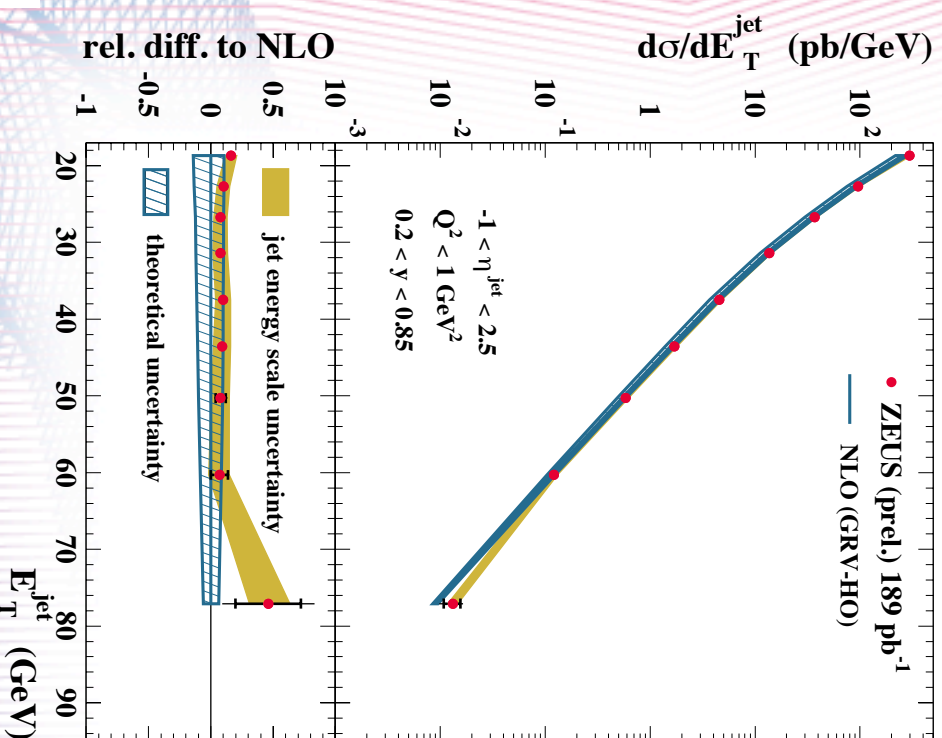


# Inclusive jets in PHP

$Q^2 < 1 \text{ GeV}^2$ ,  $0.2 < \gamma < 0.85$

At least one jet with

$E_T^{\text{jet}} > 17 \text{ GeV}$ ,  $-1 < \eta_{\text{jet}} < 2.5$



$\alpha_s$  extracted from the dependence of the cross section on  $E_T$ . Jets in PHP gave the most precise  $\alpha_s$  measurement at ZEUS, **now extended to HERAII**

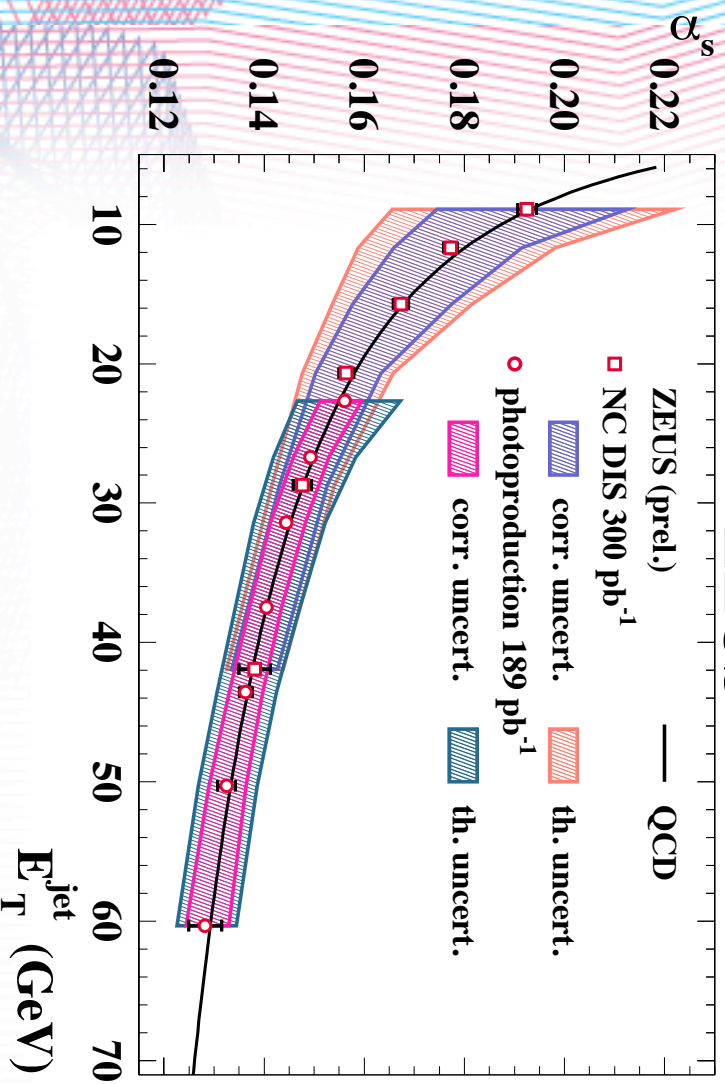
Test of the running of  $\alpha_s$ .



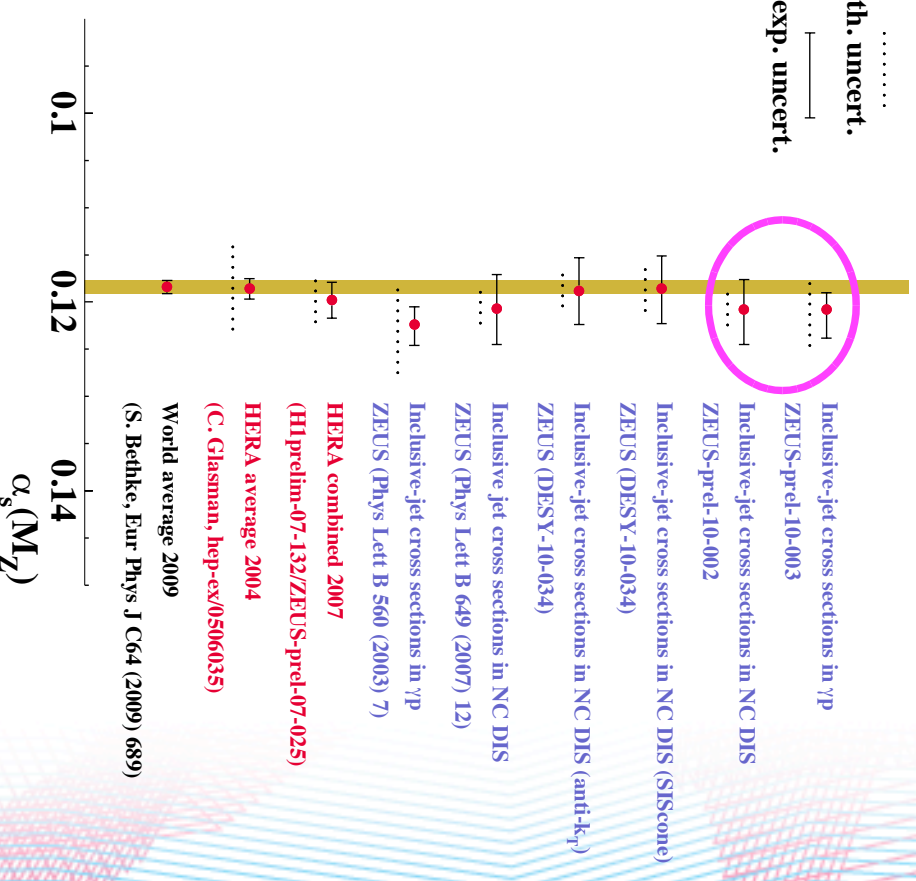
# $\alpha_s$ running from PHP to DIS

Running of the coupling constant with the scale tested from the low to the high  $Q^2$  regime.

## ZEUS



th. uncert.  
exp. uncert.

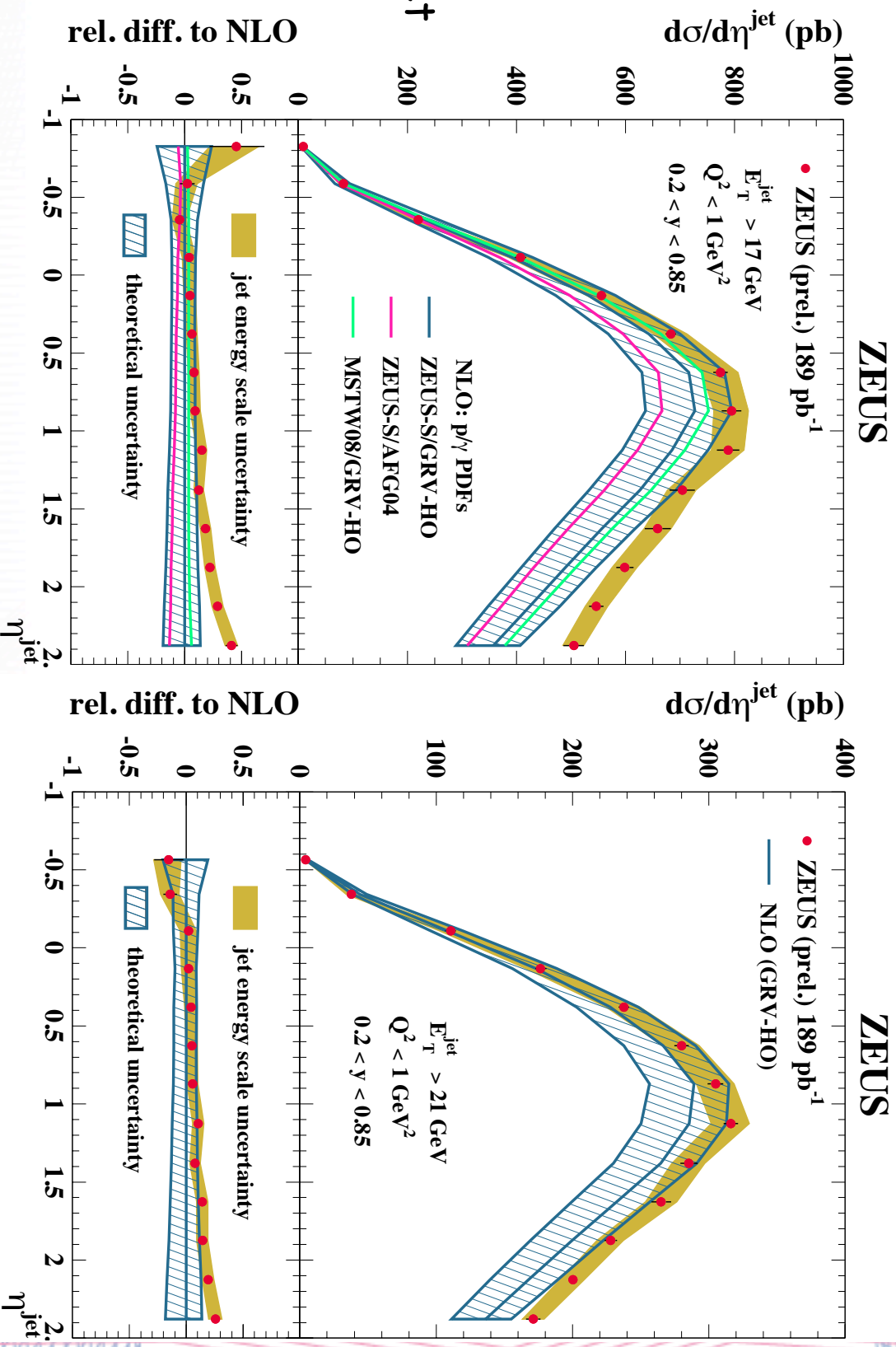


Two new precise  $\alpha_s$  measurements from DIS and PHP in agreement with the world average.

# Jets in PHP: non perturbative effects

Check non perturbative effects (low  $E_T^{\text{jet}}$ ), important for the LHC

This can also be influenced by the jet algorithm, new developments being tested for the LHC (anti- $k_T$ , *SIScone*...)

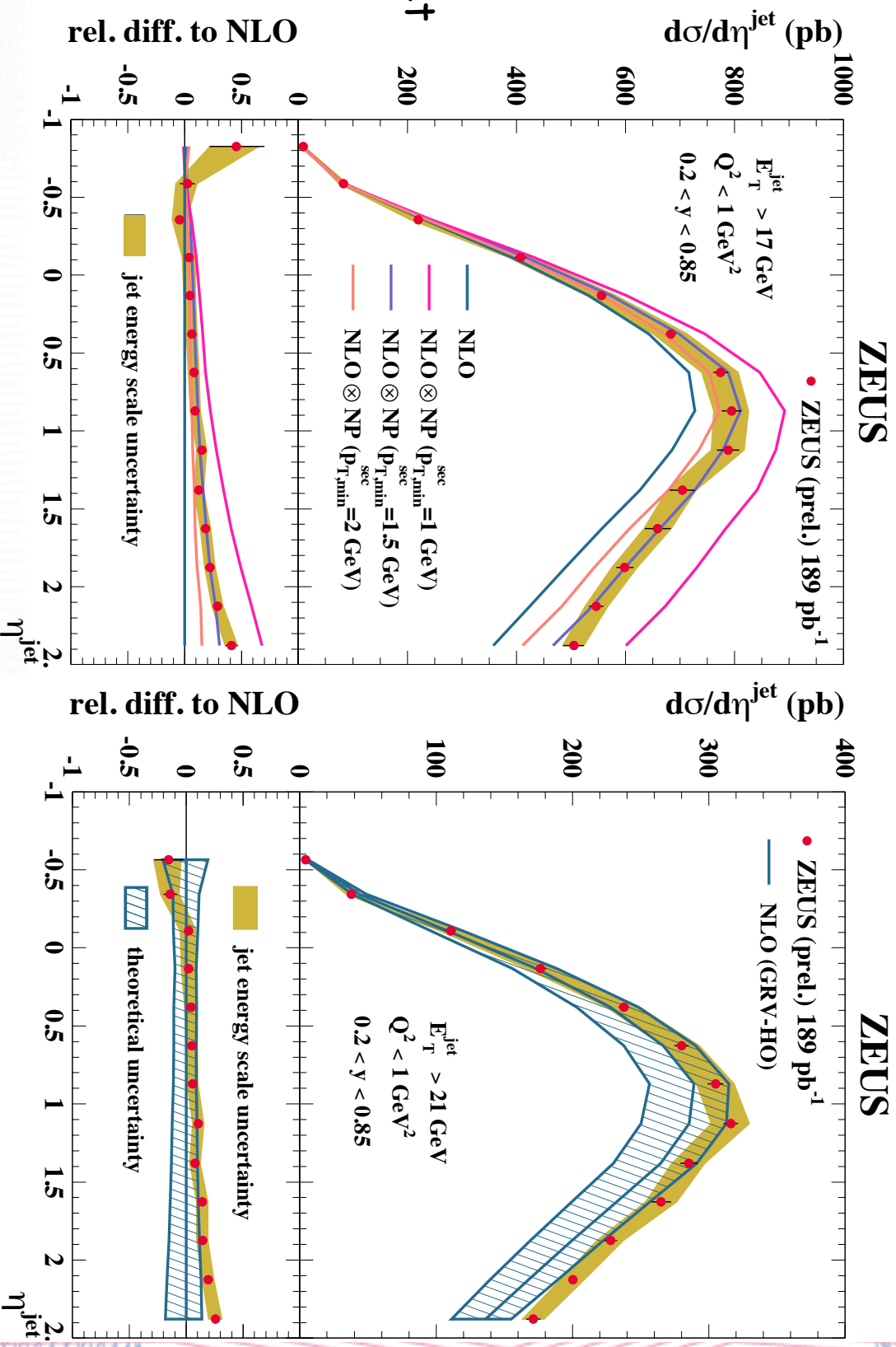




# Jets in PHP: non perturbative effects

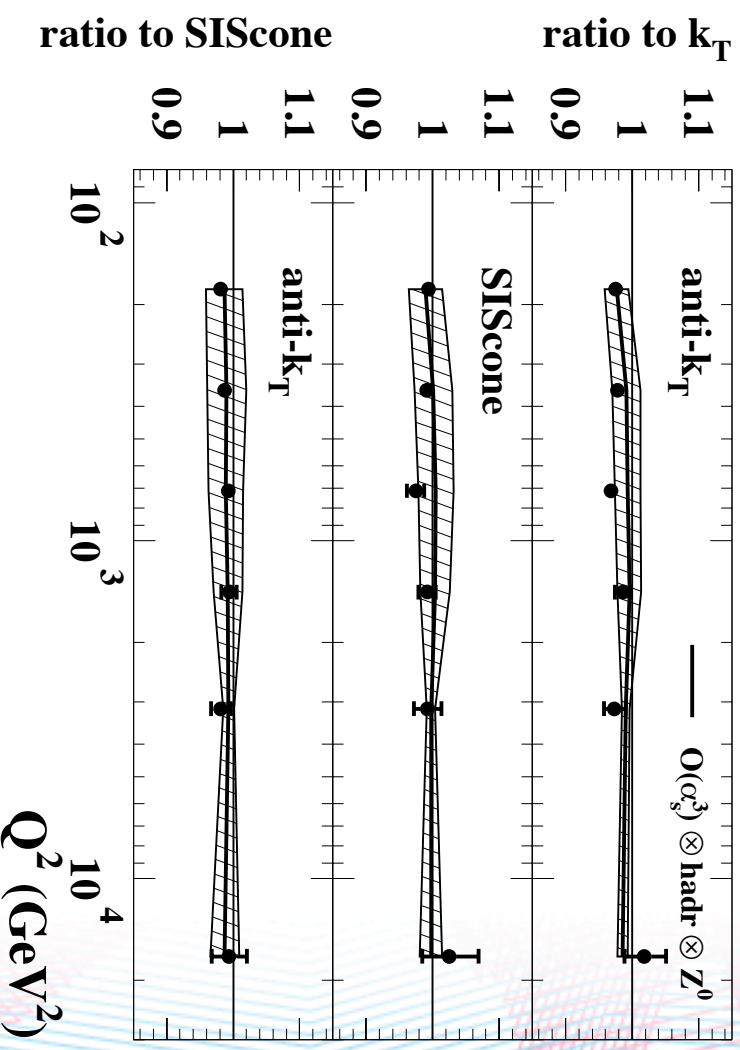
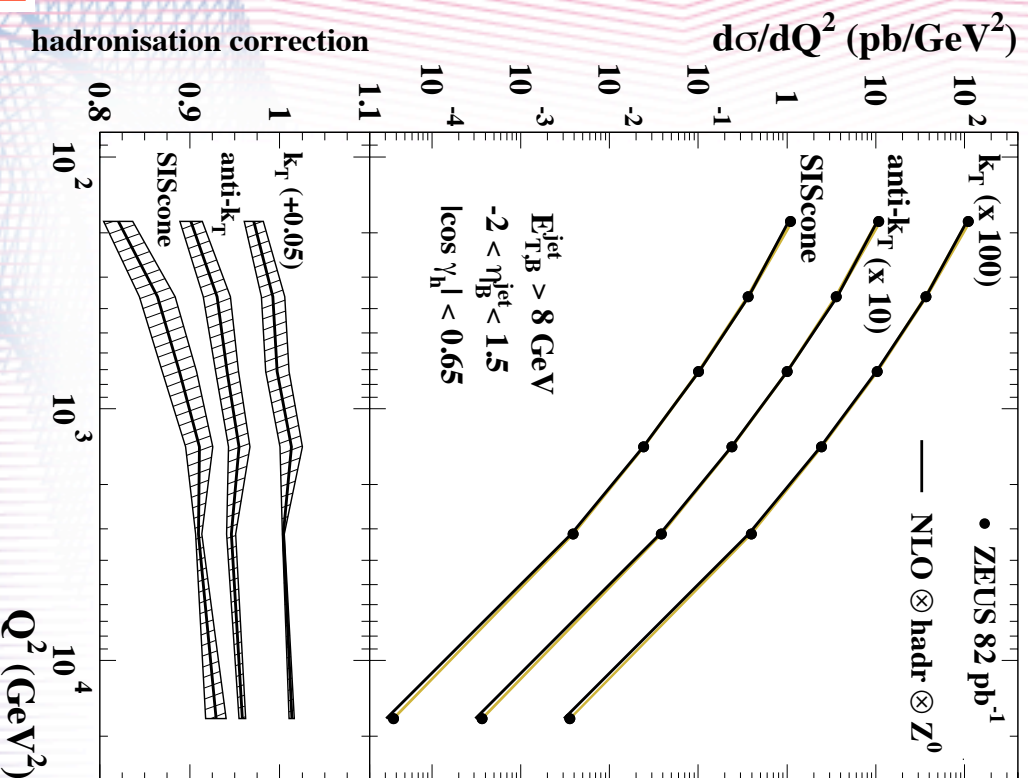
Check non perturbative effects (low  $E_T^{\text{jet}}$ ), important for the LHC

This can also be influenced by the jet algorithm, new developments being tested for the LHC (anti- $k_T$ , *SIScone*...)



# Anti- $k_T$ and SIScone jet algorithms

Reanalysis of inclusive jets in DIS  
( $k_T$  used originally)



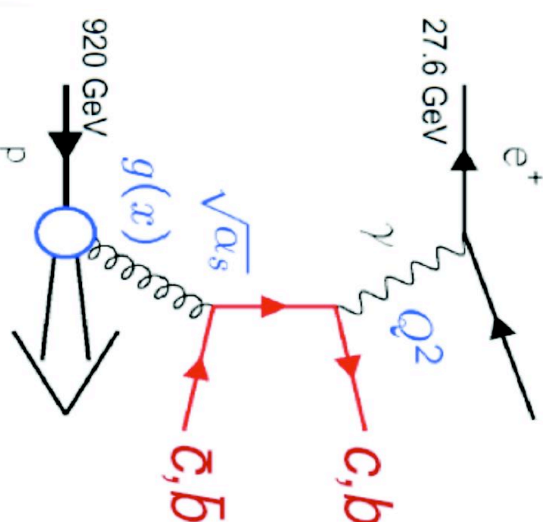
Data very well described by NLO and all the algorithms.  
Similar precision (slightly worse for SIScone)  
Ratios evaluated up to order  $\alpha_s^3$

First test on data,  
important for LHC



# Charm and beauty production

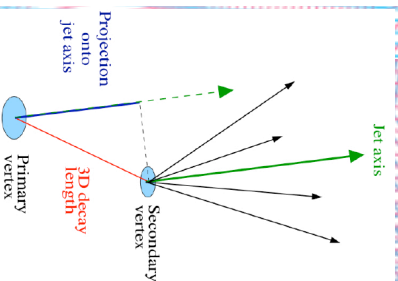
- Stringent test of perturbative QCD, sensitivity to the gluon in the proton.
- Multi-scale problem (mass,  $p_T$ ,  $Q^2$ )
- Check of the QCD fits dependence on the heavy flavour treatment



# Beauty in DIS

**$L=354 \text{ pb}^{-1}$**

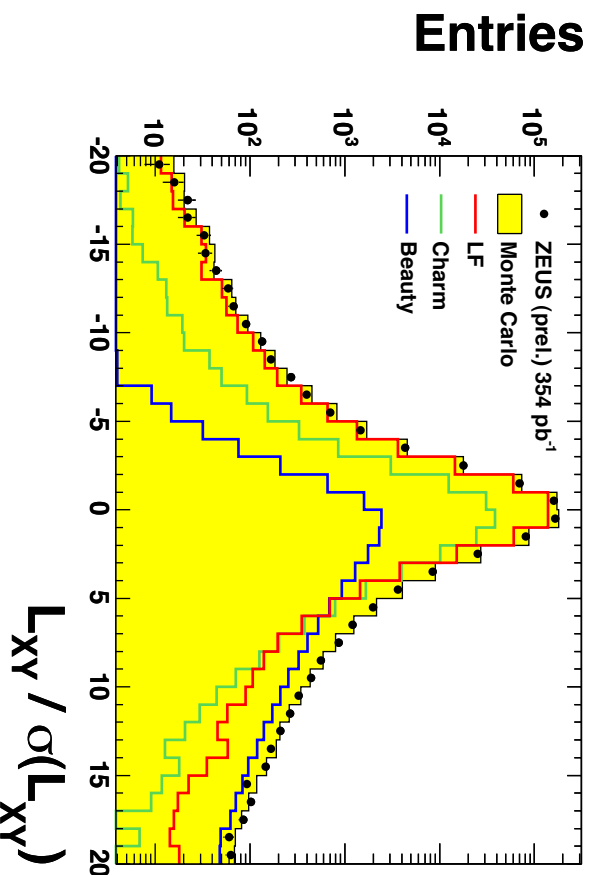
Beauty reconstructed from jets with secondary vertices.



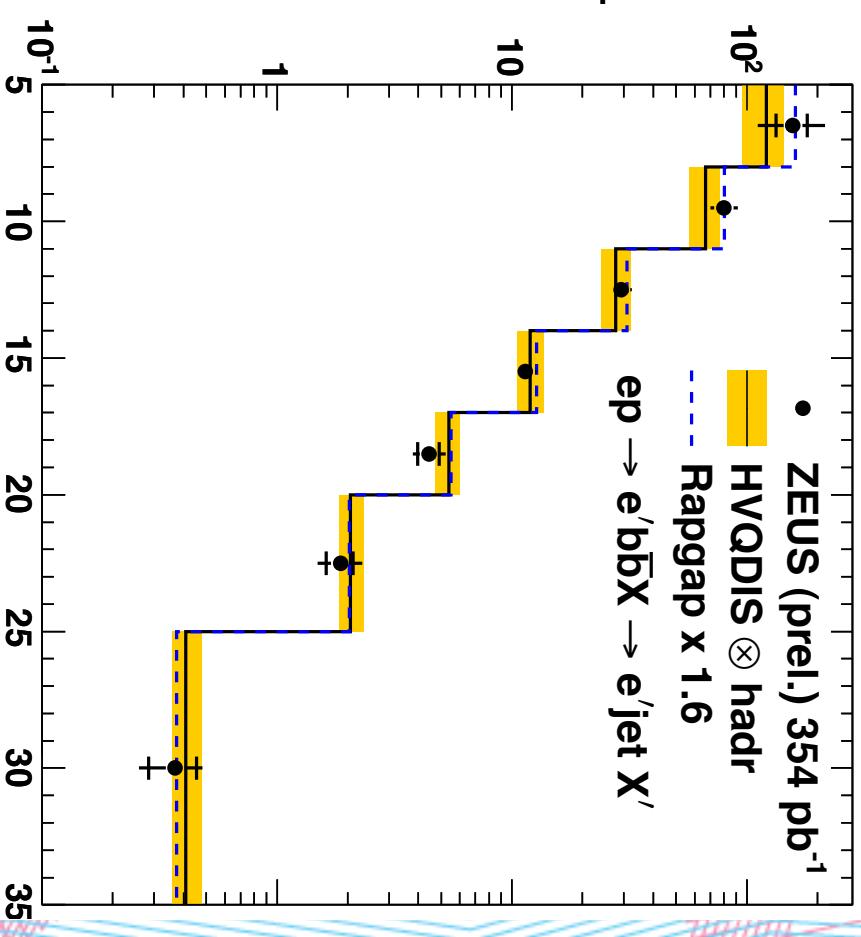
$$5.0 \text{ GeV}^2 < Q^2 < 1000.0 \text{ GeV}^2, 0.02 < y < 0.7$$

$$E_T(\text{Jet}) > 5.0 \text{ GeV}, -1.6 < \eta(\text{Jet}) < 2.2$$

## ZEUS



$d\sigma / dE_T^{\text{jet}} \text{ (pb / GeV)}$



Data will be used for the extraction of  $F_2^{bb}$   $E_T^{\text{jet}} \text{ (GeV)}$

90000 beauty events available

Monica Turcato



DIS 2010

ZEUS-prel-10-004

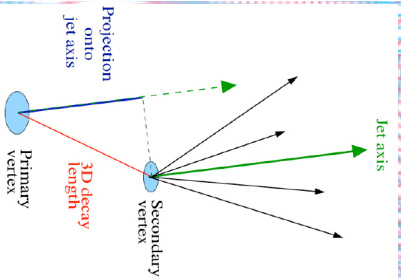
20



# Beauty in DIS

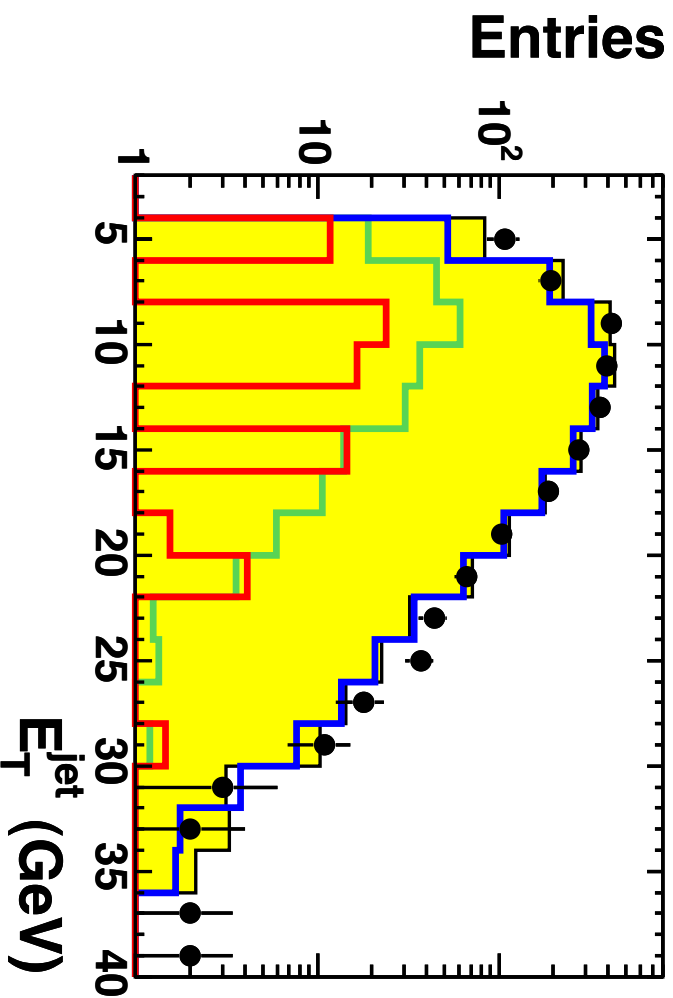
**$L=354 \text{ pb}^{-1}$**

Beauty reconstructed from jets with secondary vertices.

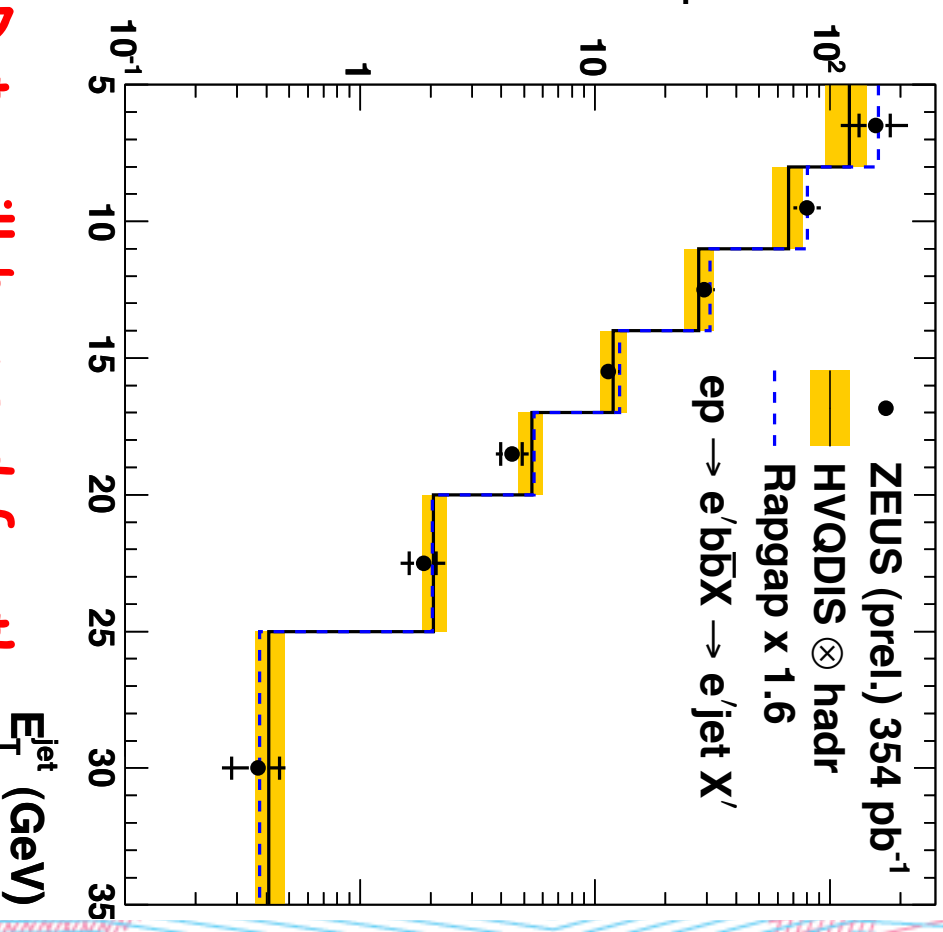


$$5.0 \text{ GeV}^2 < Q^2 < 1000.0 \text{ GeV}^2, 0.02 < y < 0.7$$

$$E_T(\text{Jet}) > 5.0 \text{ GeV}, -1.6 < \eta(\text{Jet}) < 2.2$$



$d\sigma / dE_T^{\text{jet}}$  (pb / GeV)



Data will be used for the extraction of  $F_2^{b\bar{b}}$

Very high purity at high mass

and significance

Monica Turcato

DIS 2010

ZEUS-prel-10-004

# $D^+$ in DIS

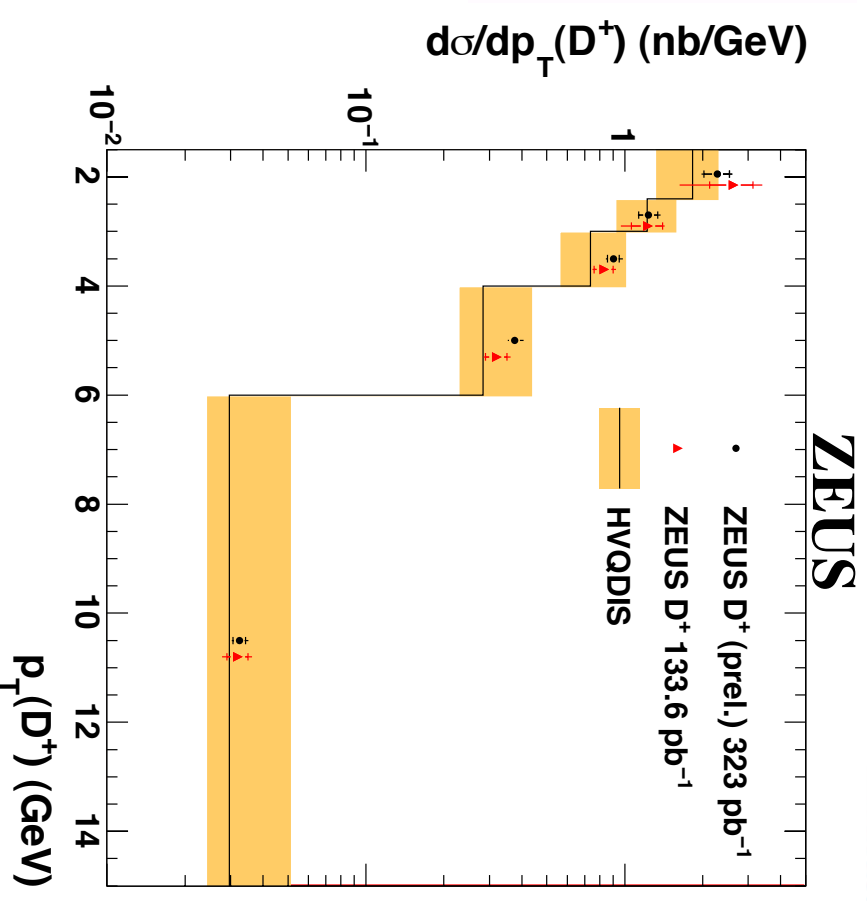
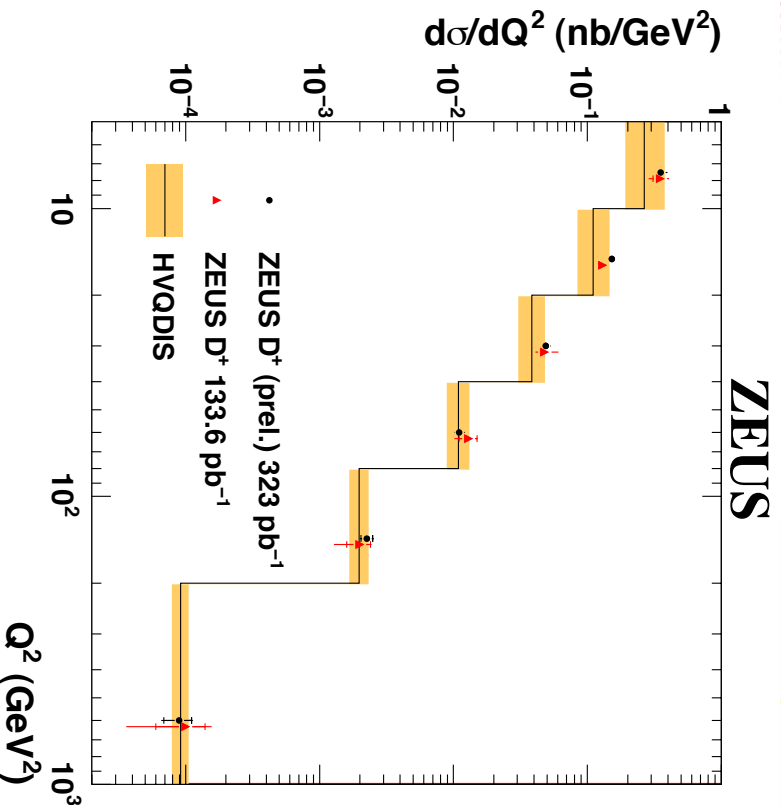
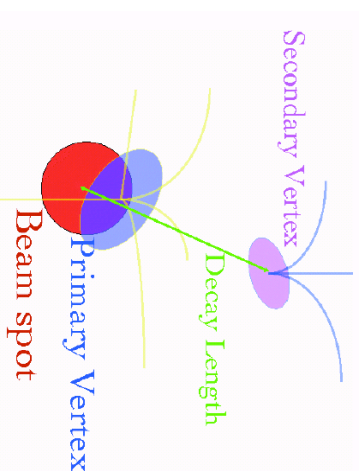
$D^+$  reconstructed using lifetime information.  $L=323 \text{ pb}^{-1}$ .

$$5 < Q^2_{DA} < 1000 \text{ GeV}^2$$

$$0.02 < \gamma_{DA} < 0.7$$

$$1.5 < p_T(D^+) < 15 \text{ GeV}$$

$$|\ln(D^+)| < 1.6$$



$\sim 7200 D^+$  events available

Precision comparable to  $D^*$  in HERAI

DIS 2010

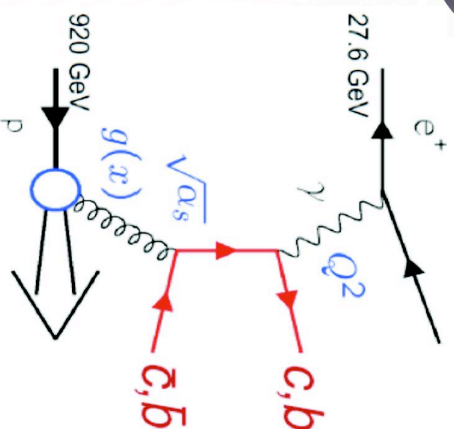
ZEUS-prel-10-005





# H1+ZEUS $F_2^{cc}$

see Mikhaylo Lisovsky [29]

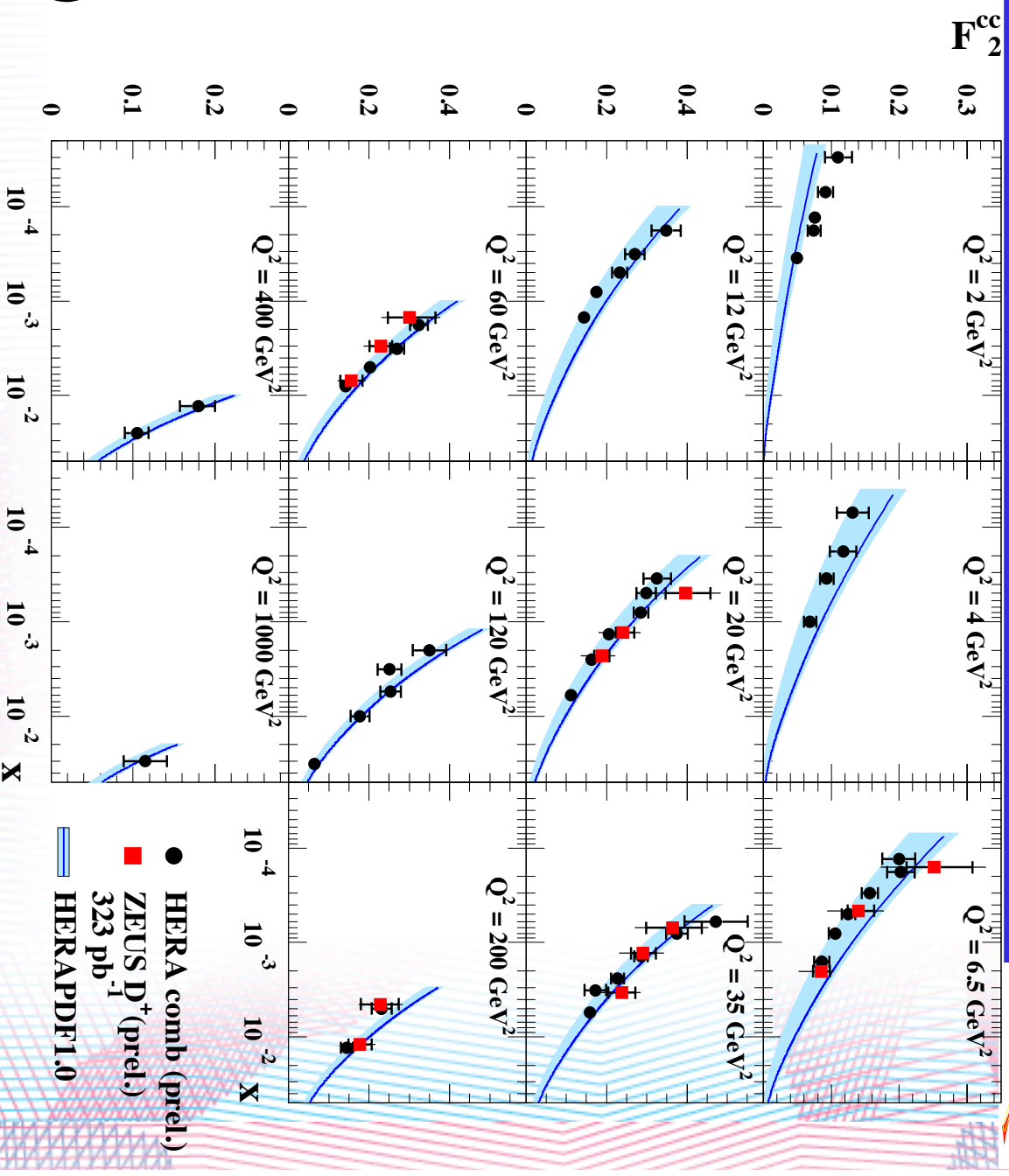


**Sensitivity to the gluon.**

Data from H1 and ZEUS combined.

Precision is now 5-10%.

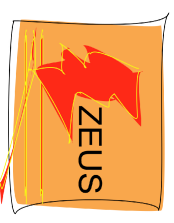
Can be improved by adding new measurements (see comparison with new  $D^+$  data)



● HERA comb (prel.)  
■ ZEUS  $D^+$  (prel.)  
323 pb  
HERAPDF1.0



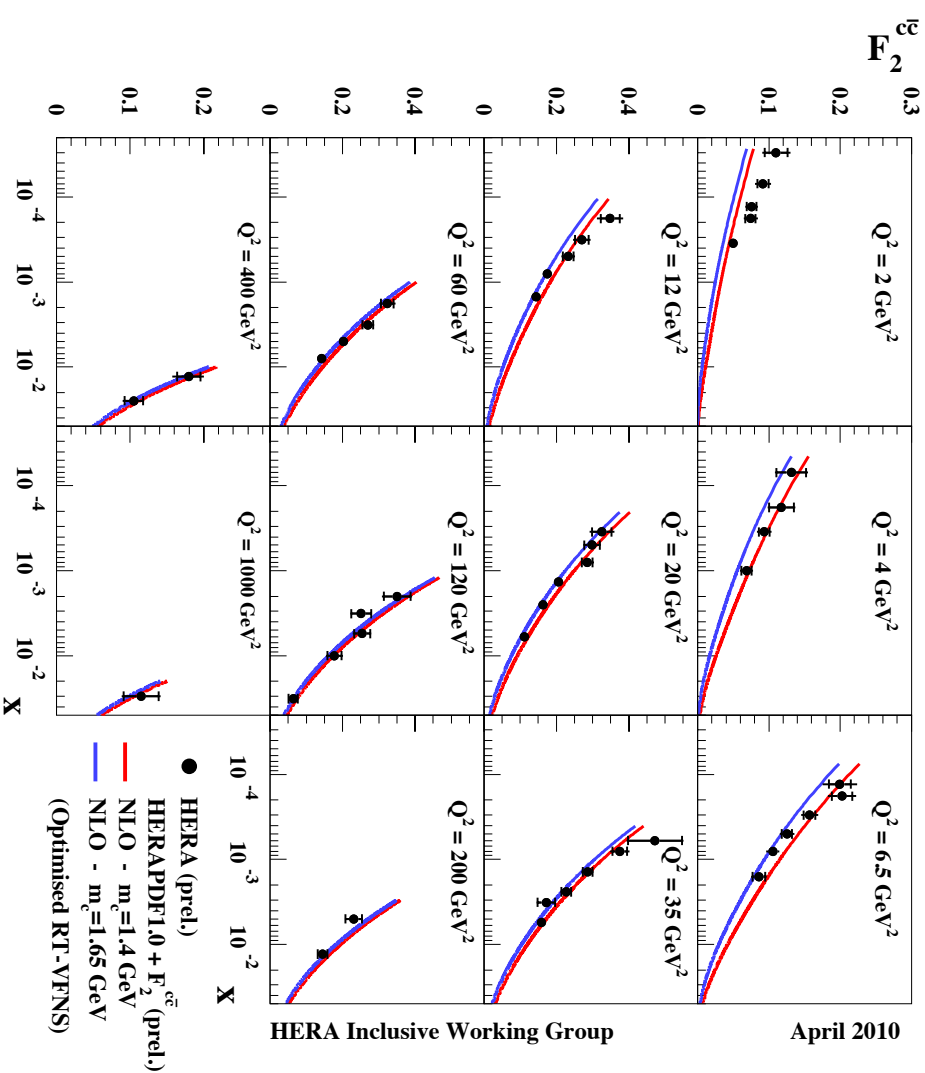
see Amanda Cooper-Sarkar [31]



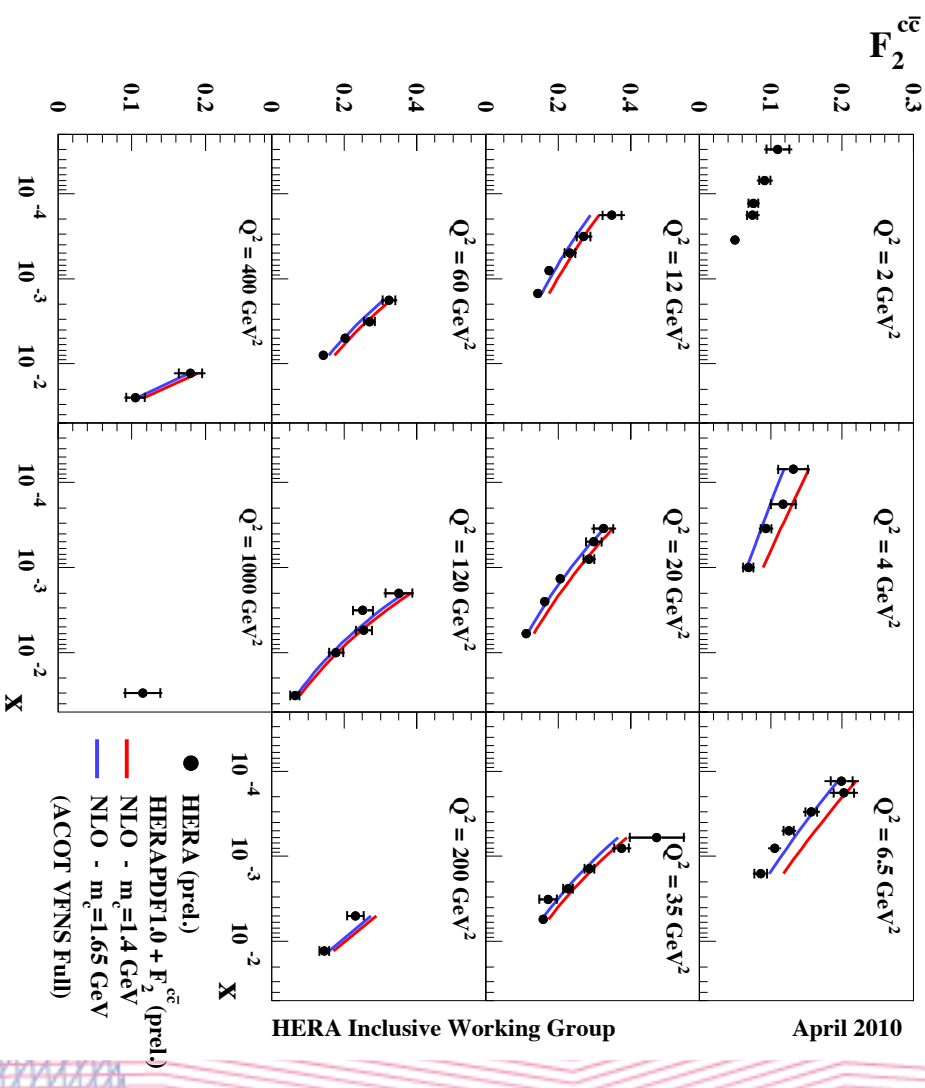
# QCD fits with charm data

$F_2^c$  data in HERAPDF1.0 fit. DGLAP evolution sensitive to the HF treatment.

H1 and ZEUS



H1 and ZEUS



The choice of the mass plays an important role for predictions at LHC!

ZEUS-prel-10-009

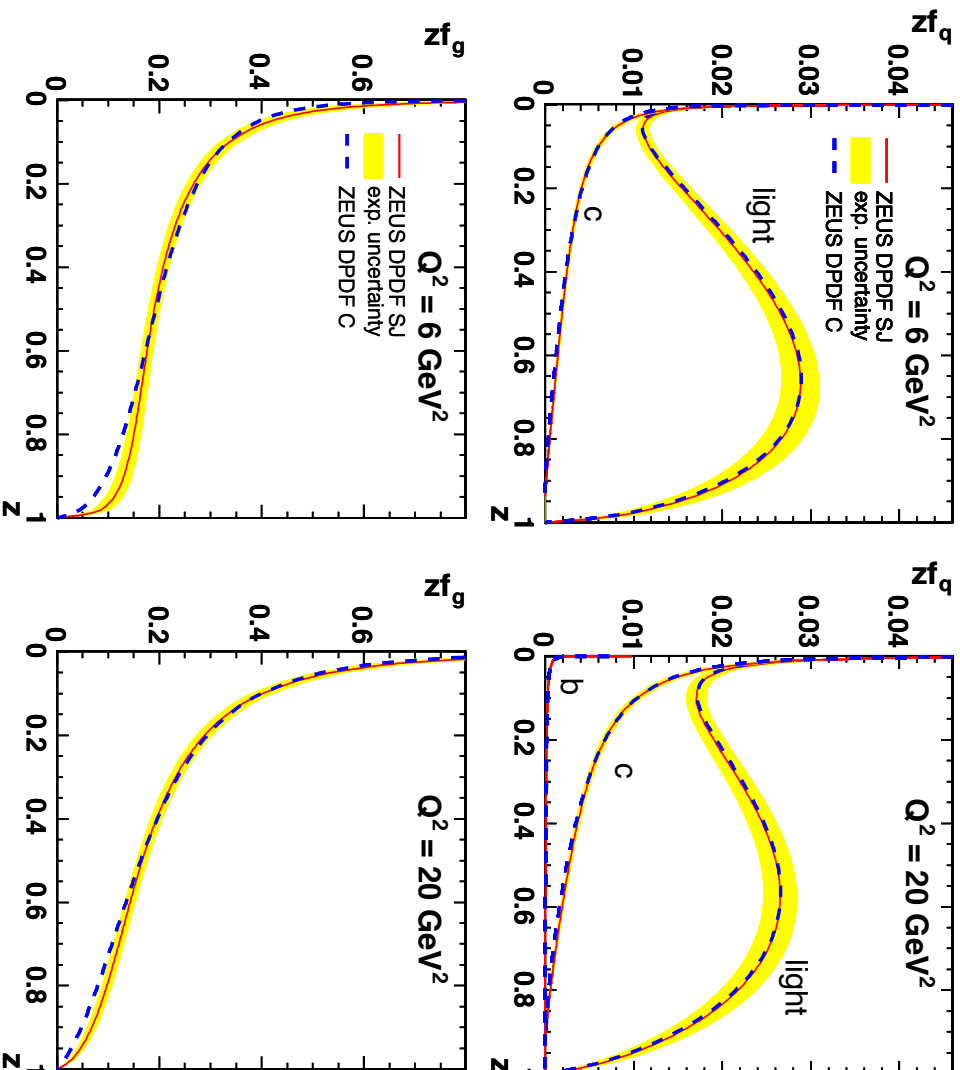




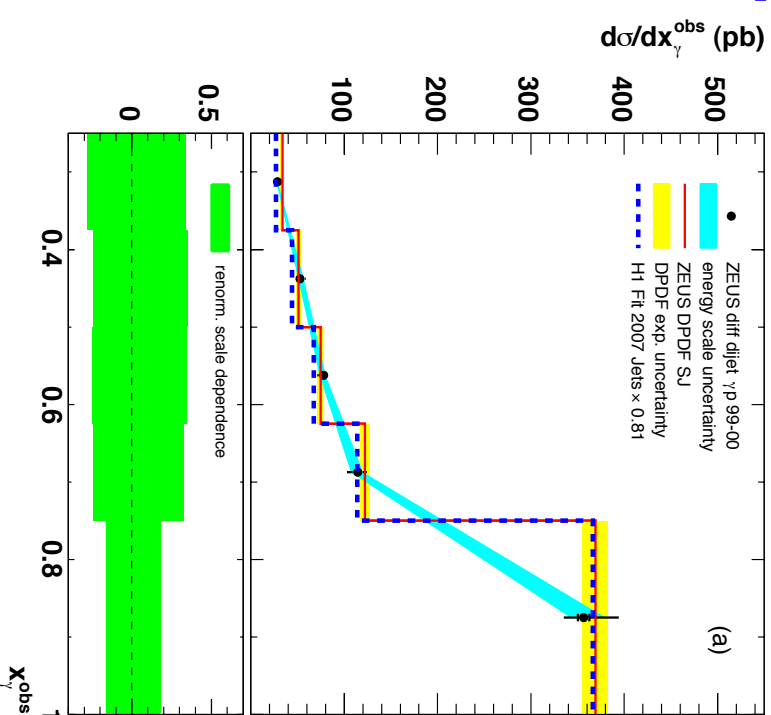
# Diffractive PDF fits

Diffractive PDFs extracted from inclusive and jets cross sections in diffractive DIS.

ZEUS



ZEUS



Good description of the data obtained also for data not included in the fit (here dijets in PHP, also in the low  $x_T^{\text{obs}}$  region). No suppression or factorisation breaking.

# Conclusions

---

- New ZEUS+H1 combination measurements are providing precision data used as input in QCD fits.
- The analyses of the HERAII on NC, CC, jets and heavy flavour processes are extended to the full data statistics allowing improved precision of the results.
- The new inclusive, jets and heavy flavour data are now investigated in the context of QCD fits, allowing more stringent test on the fit formalism.
- More to come from combination also for diffraction...

**The HERA data are a valuable input to understand  
QCD and therefore for the LHC physics**



# Backup

# Jet algorithms

$k_T$  (Catani et al.)

Jet reconstruction relies on **jet algorithms**.

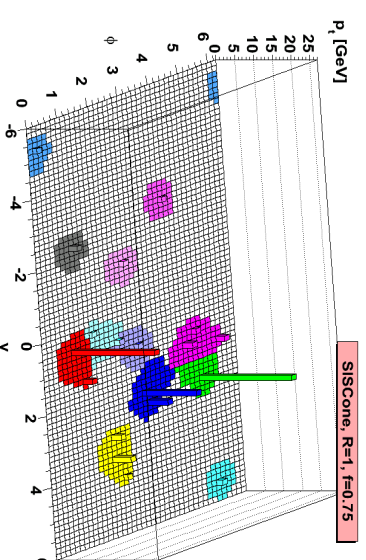
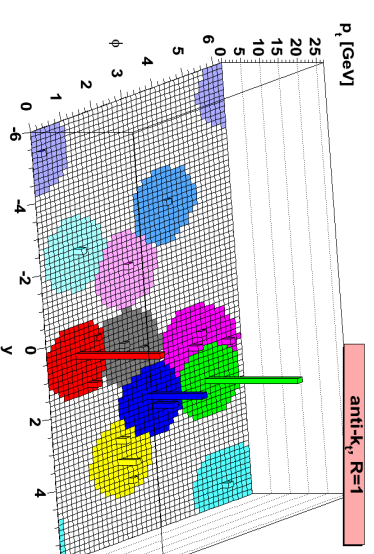
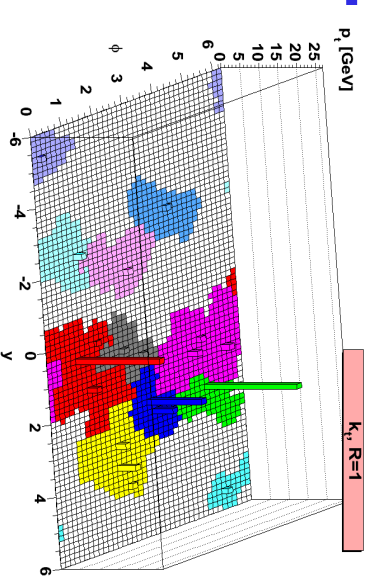
Jet algorithms should not be sensitive to soft particle emission (**infrared safe**) and collinear particle splitting (**collinear safe**).

Cone algorithms normally used in hadron-hadron collisions are **not safe at all order in QCD**.

Example test on the same MC event:

Anti- $k_T$  is similar to  $k_T$  but gives jets of regular shape, as SIScone (good i.e. for detector calibration).

Tested on data for the first time at ZEUS...



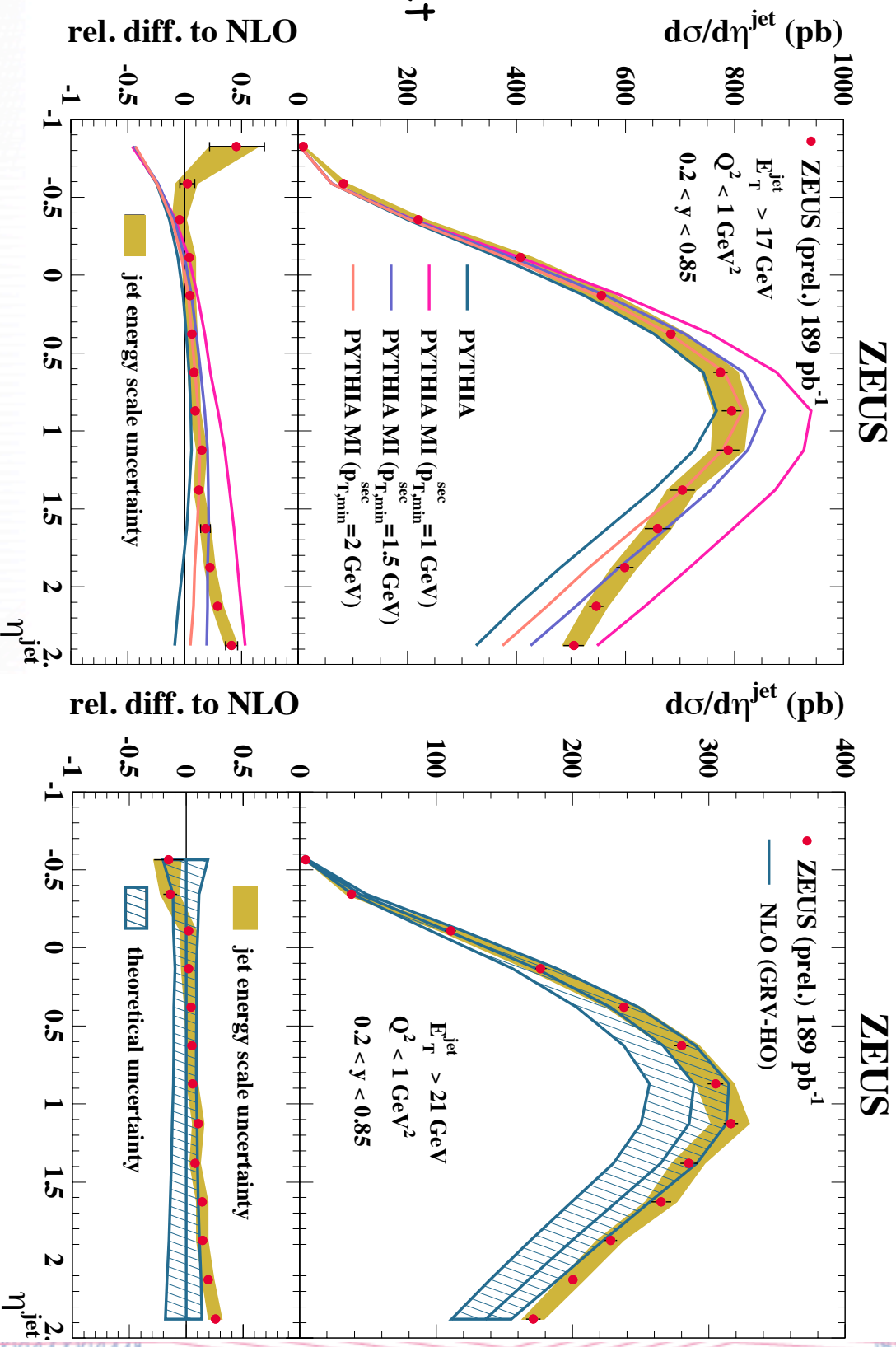
New developments:  
anti- $k_T$  (Cacciari,  
Salam, Soyez 08)  
SIScone  
(Salam, Soyez 07)  
both safe at all  
orders



# Jets in PHP: non perturbative effects

Check non perturbative effects (low  $E_T^{\text{jet}}$ ), important for the LHC

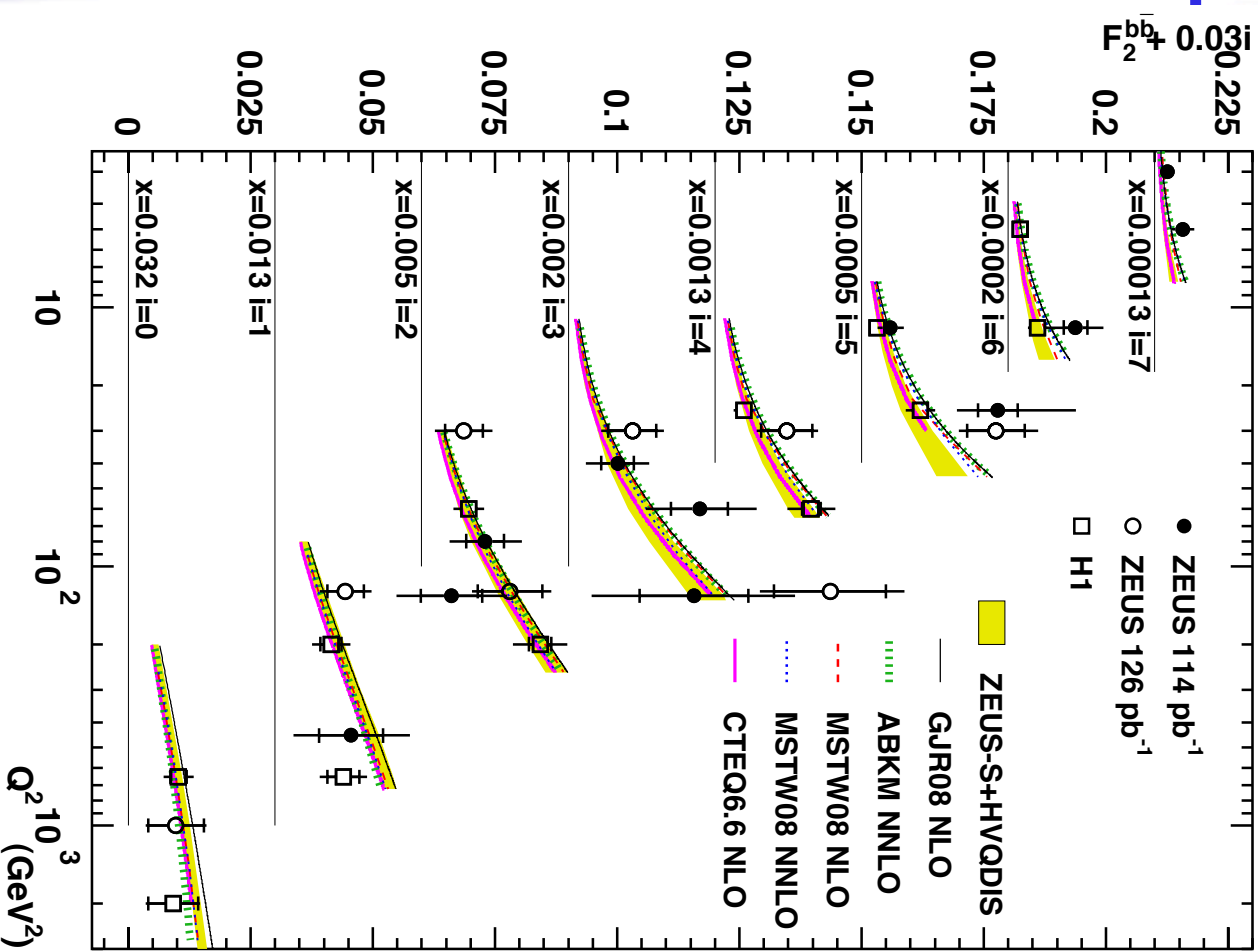
This can also be influenced by the jet algorithm, new developments being tested for the LHC (anti- $k_T$ , *SIScone*...)



# ZEUS $F_2^b$

- Present measurements based on events with muon and jets
- Precision of the data is limited
- Will dramatically improved using jets from secondary vertices.
- Fair agreement between the various theory predictions

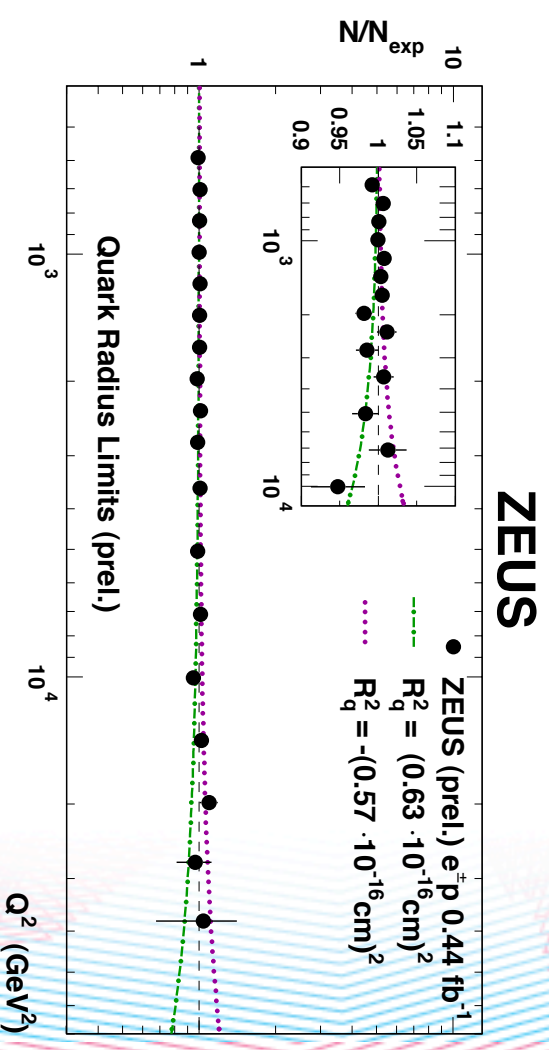
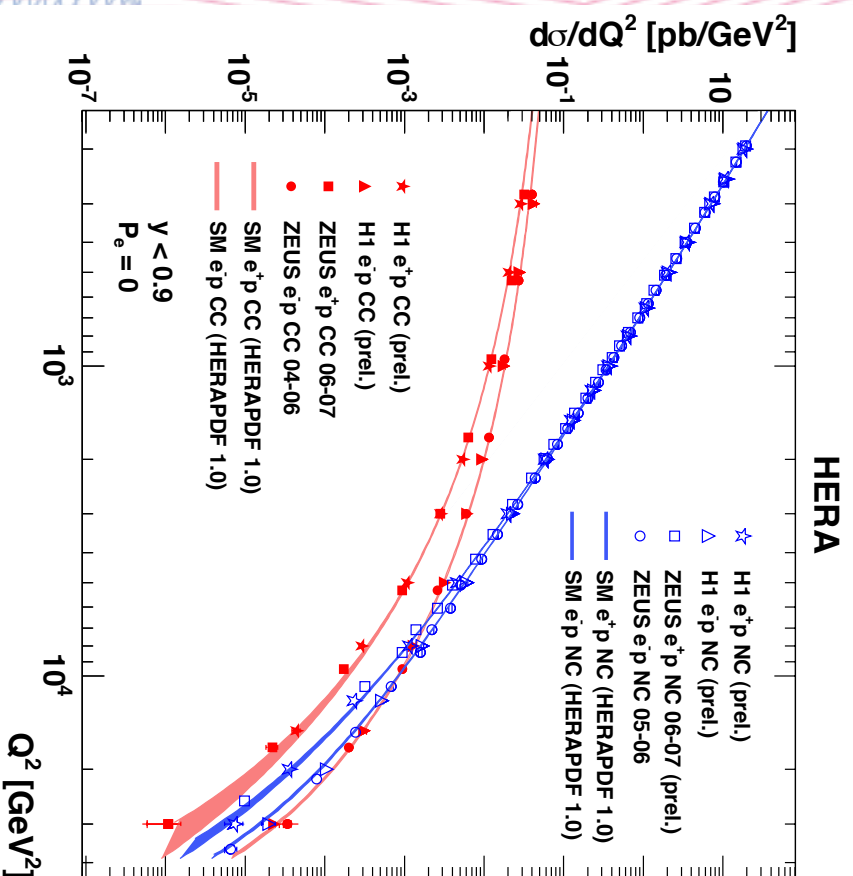
## ZEUS





# Quark radius, contact interactions

Full ZEUS NC statistics used to investigate quark radius, CI models, heavy leptoquarks, large extra dimensions. **Strong limits extracted.**



**Limit on the quark radius:**  
 **$R < 0.63 \cdot 10^{-3} \text{ fm}$  @ 95% CL**