ZEUS Highlights for ICHEP02
... a personal selection

Tancredi.Carli@desy.de

Main Questions at HERA:

- What is the structure of the proton ?
- Is DGLAP working at low-x ?
- How are heavy quarks produced ?

- Is the SM valid at high energies ?

Incl. DIS & PDF Fits

strange, charm, beauty

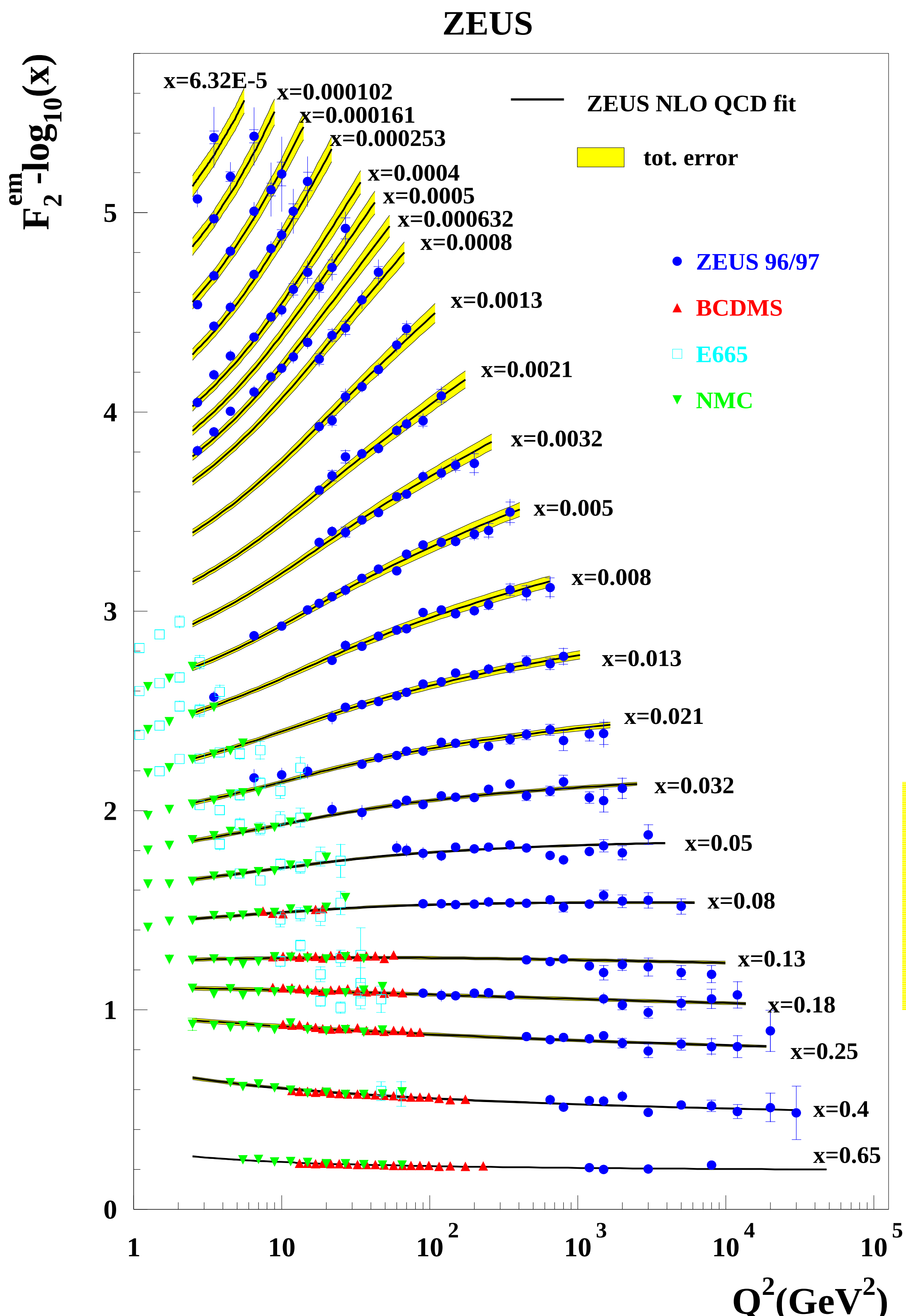
Tau

High Et: electrons&jets

- How can we understand soft processes ?
- More complex proton description : GPD ?
- What drives colour singlet proton component ?

DVCS/J/Ψ & F_2^{D3}

Final incl. DIS PDF-Fits



Proton structure function F_2:

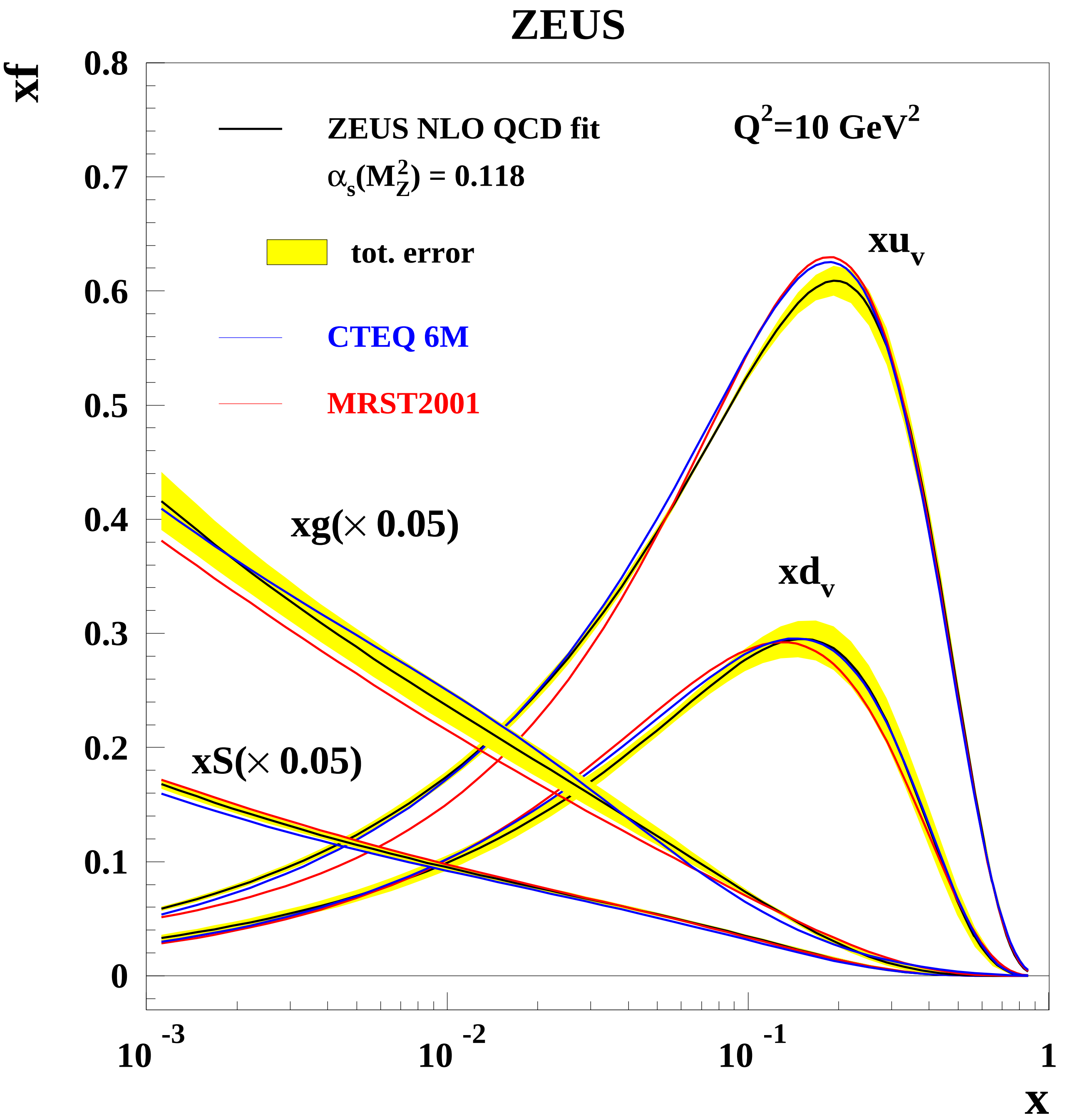
impressive precision
over wide x, Q^2 range

Final PDF-fits:

- Needs precise data and careful evaluation of exp. uncertainties
- much improved fit technique

Not always Gaussian

Extraction of parton densities **and** exp. uncertainties



- impressive precision
- agreement with global fits
- simultaneous fit: PDF & α_s:

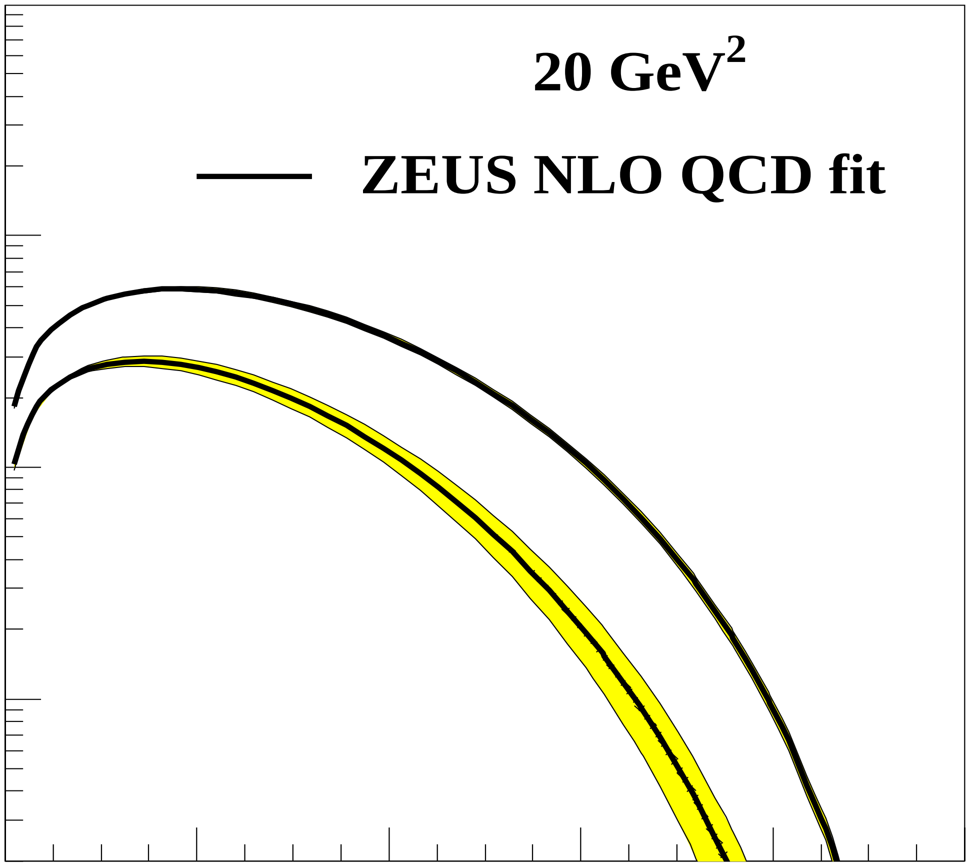
$$\alpha_s(M_Z) = 0.1166 \pm 0.0008\ (\text{uncorr}) \pm 0.0032\ (\text{corr}) \pm 0.0036\ (\text{norm}) \pm 0.0018\ (\text{model})$$

plus additional $\pm$ 0.004 from ren. scale

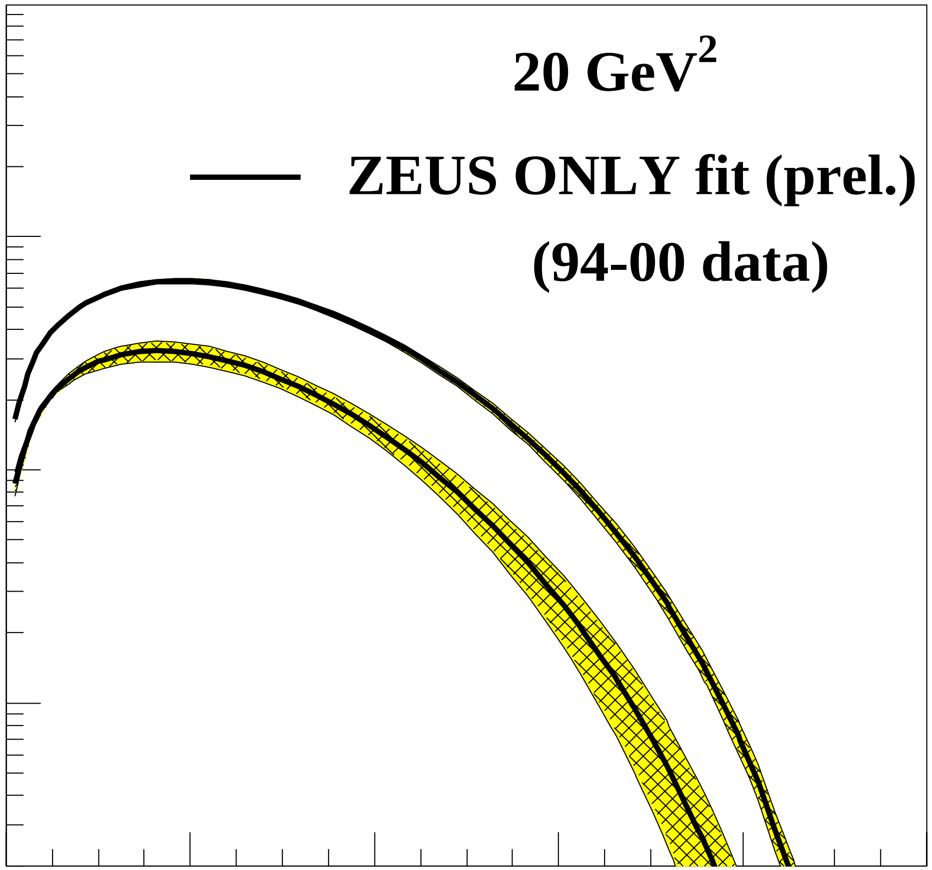
Valence Quarks from One Experiment:

ZEUS only, i.e. F_2
HERA-I: high-Q^2 NC/CC

ZEUS + fixed target



x



x

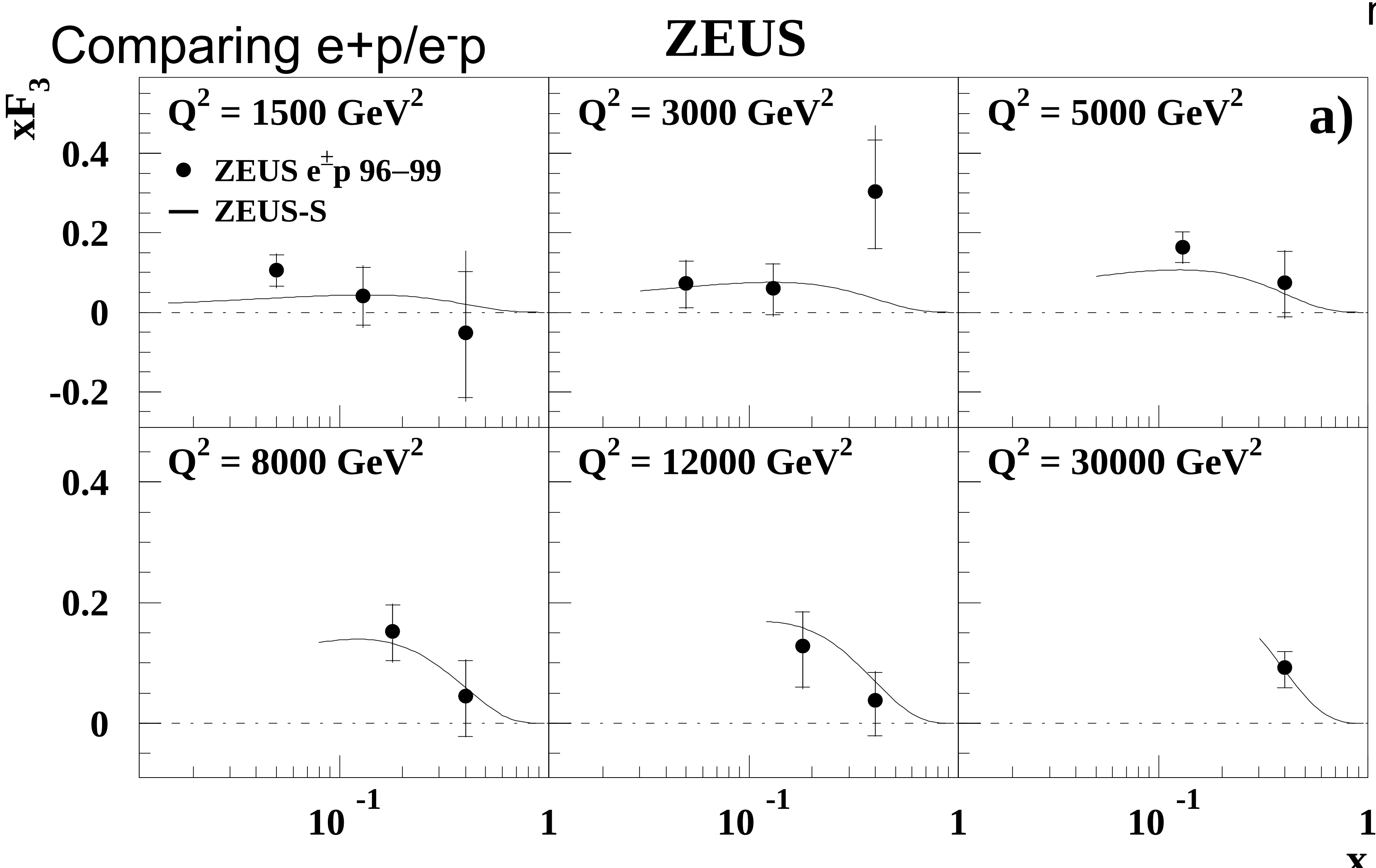
u better known than d, d can be fixed by high-Q^2 CC,
no need to discuss deuterium binding corrections in fixed target data
... hardly need fixed target data

Parity Violating Part of the Proton Structure Function

$$\frac{d^2\sigma^{NC}_{e^{\pm}_{L,R}}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[Y_+ F_2^{L,R} \mp Y_- \, x F_3^{L,R}\right] \quad \text{with } Y_\pm = 1 \pm (1-y)^2$$

$$x F_3^{L,R} \sim \left(x\,q(x) - x\,\bar{q}(x)\right) \quad \text{sensitive to valence quark}$$

Comparing e+p/e-p



First measurement

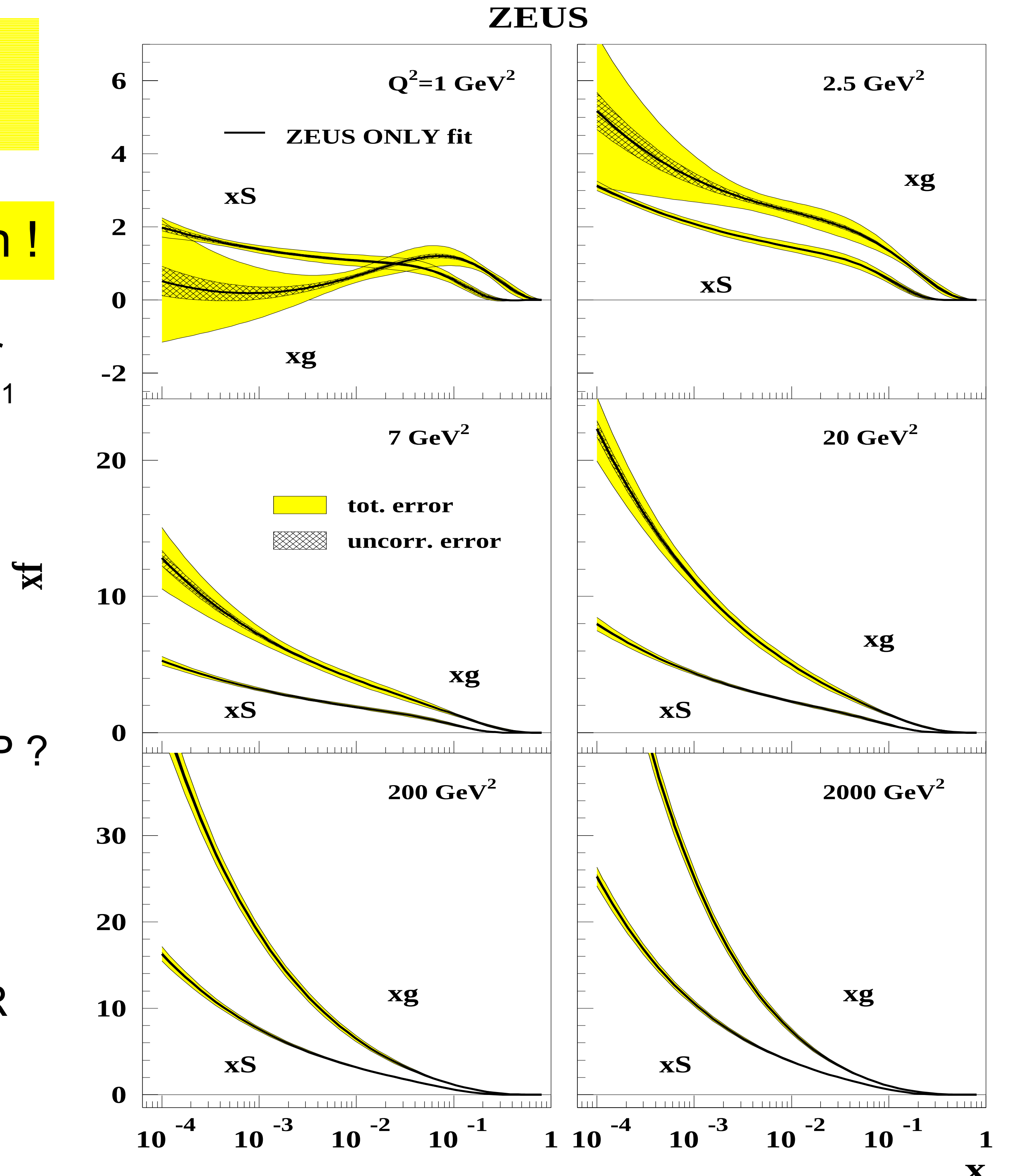
Need more luminosity with e-p

Gluon Density

Greatly improved precision !

- Gluon known within 20% for $Q^2>20$ GeV^2 and $10^{-4}<x<10^{-1}$ by ZEUS only
  considerable uncertainty for x>0.1 -> include jets !

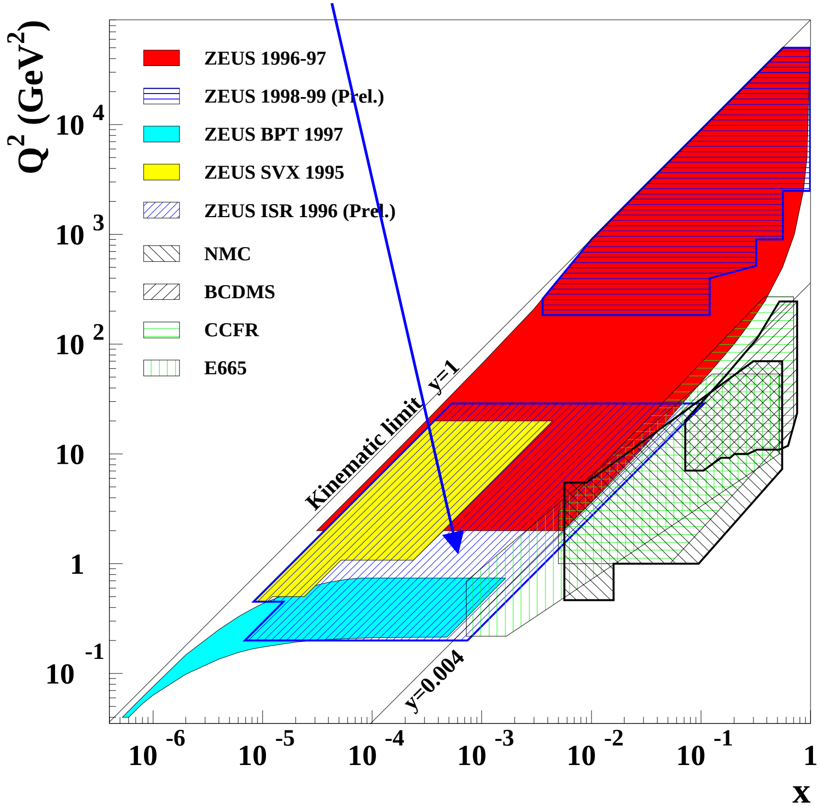
- Gluon valence-like or even negative for Q^2->0:
  end of applicability of DGLAP ?
  Fitted F_L also negative
  direct determination of F_L would provide additional independent information
  -> lower HERA E_p or use ISR

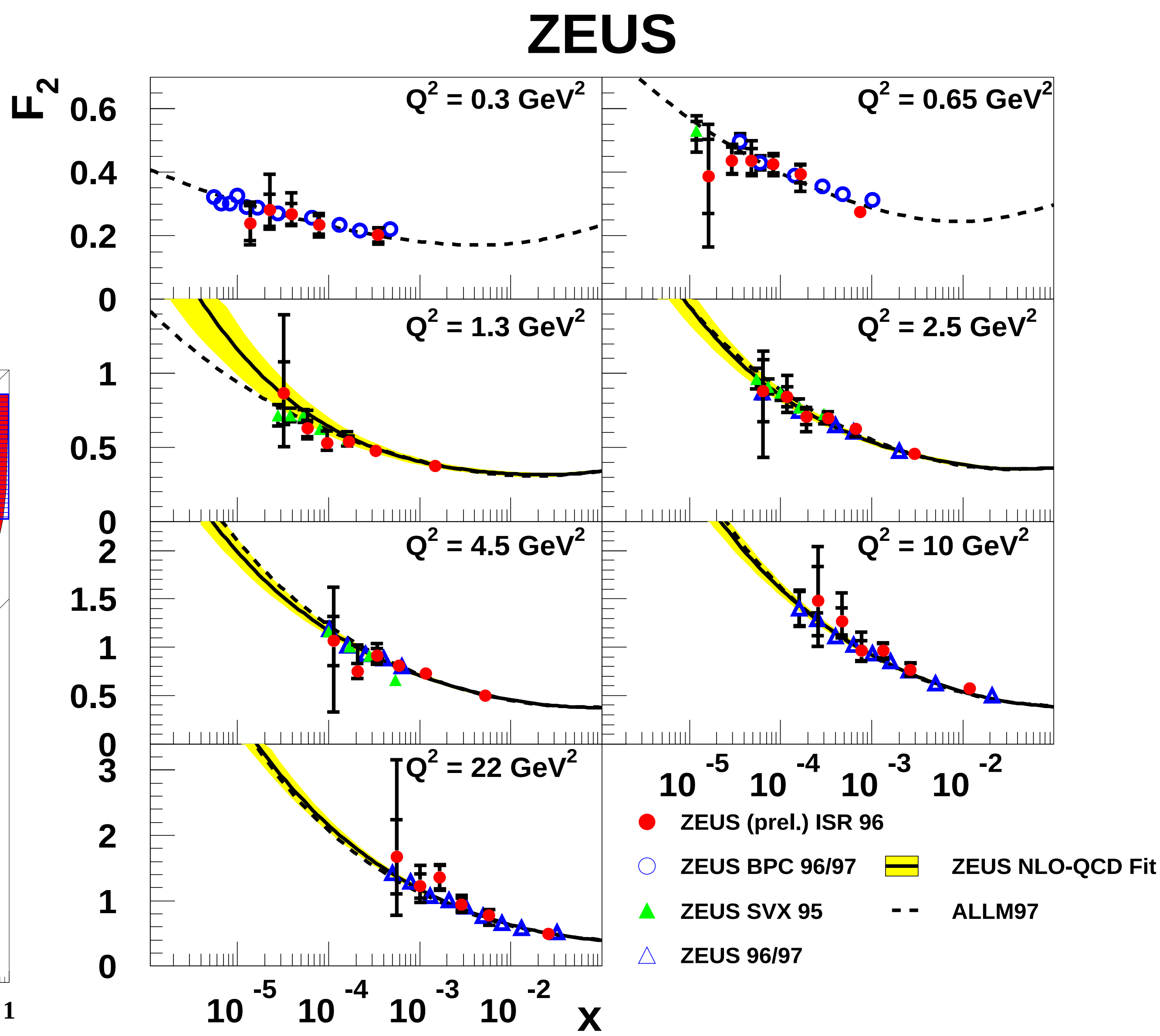


New F_2 Points at low Q^2: ISR Analysis

ISR lowers electron energy
difficult analysis: need
precise knowledge of
Bethe-Heitler overlays

previously unexplored !

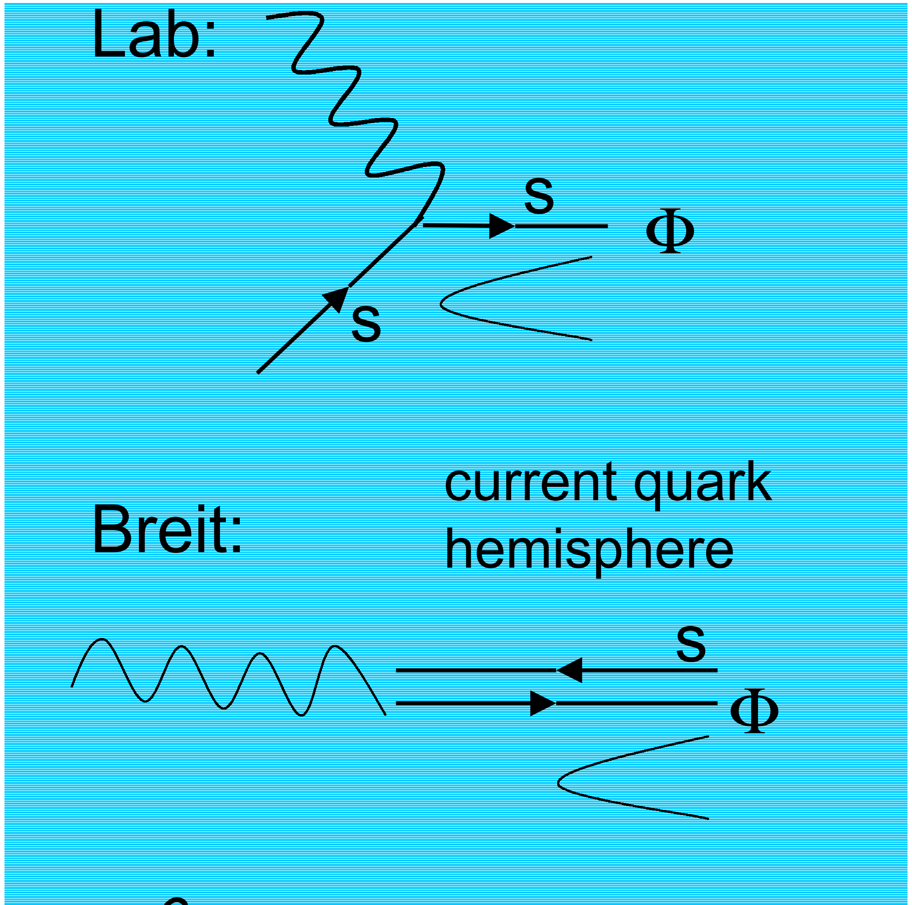




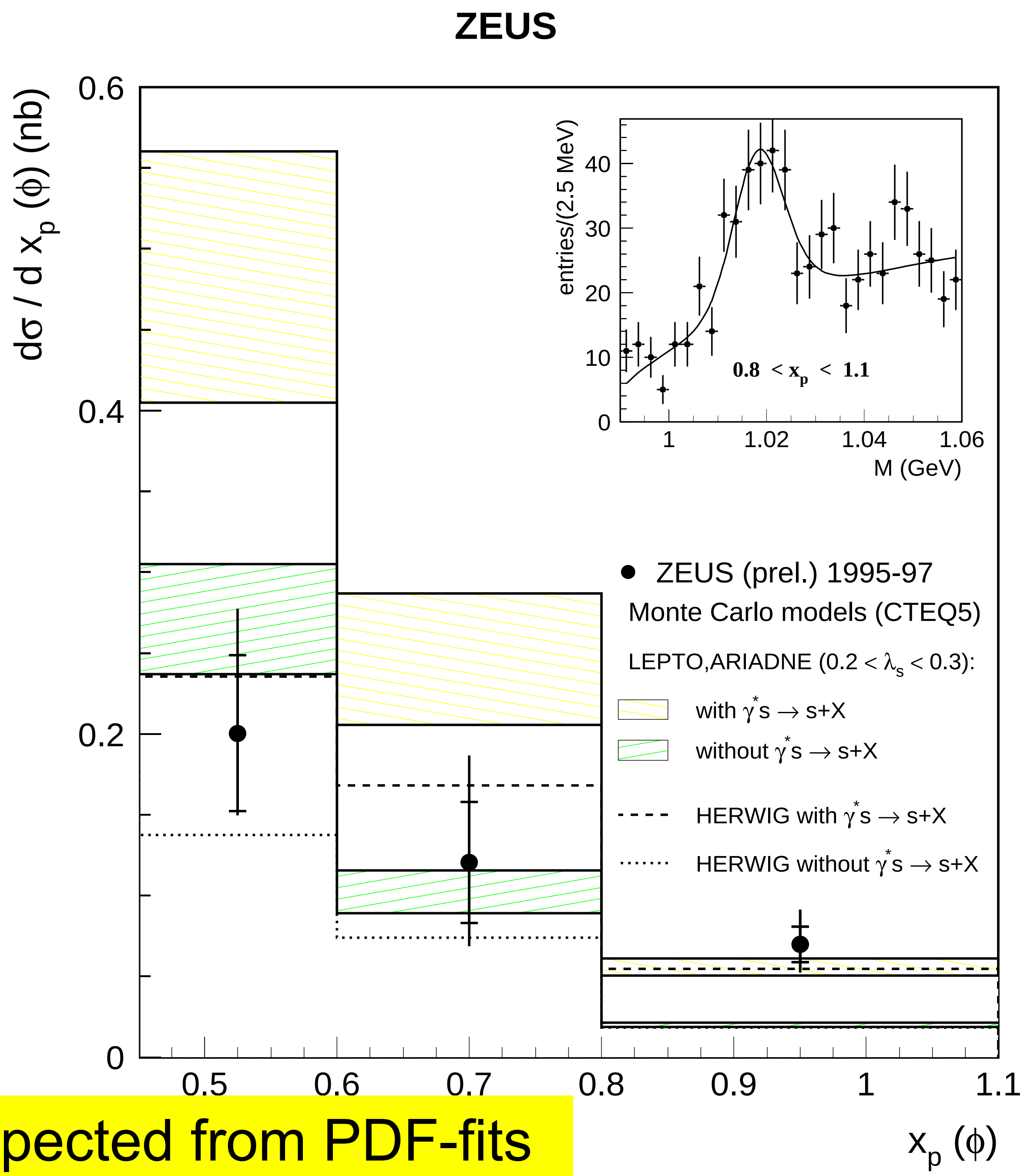
So far only small data set analysed

Consistency in overlap region:
prove of method -> direct F_L in reach ?

Φ–meson: Access to Strange Sea ?

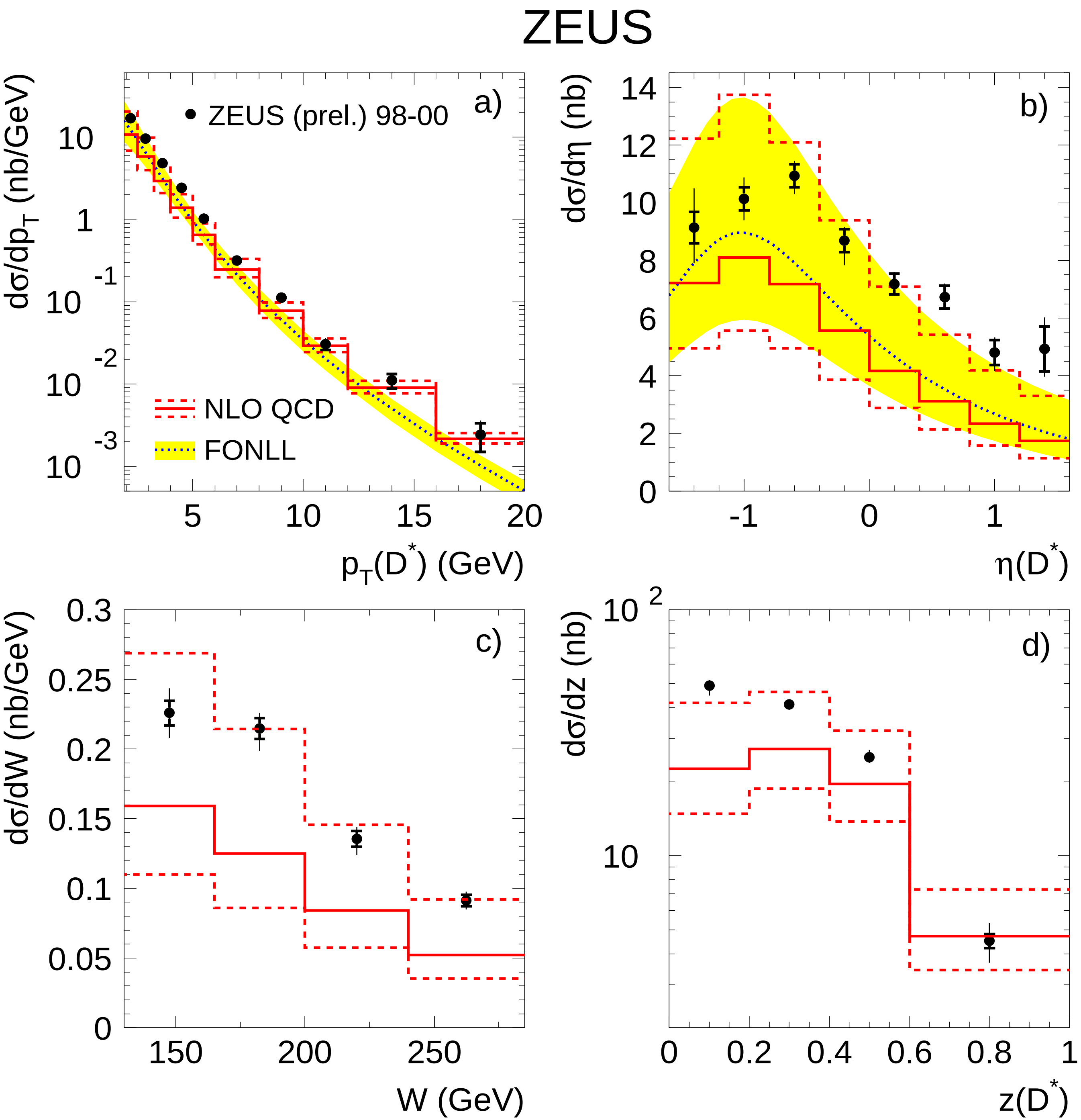


$x_p = \frac{2p}{Q} \rightarrow 1 : \Phi$ leading particle



x_p -> 1: need strange sea as expected from PDF-fits
low x_p : better understanding of Φ formation needed !

Charm: D^* Cross Sections in γp Collisions



central NLO significantly below data

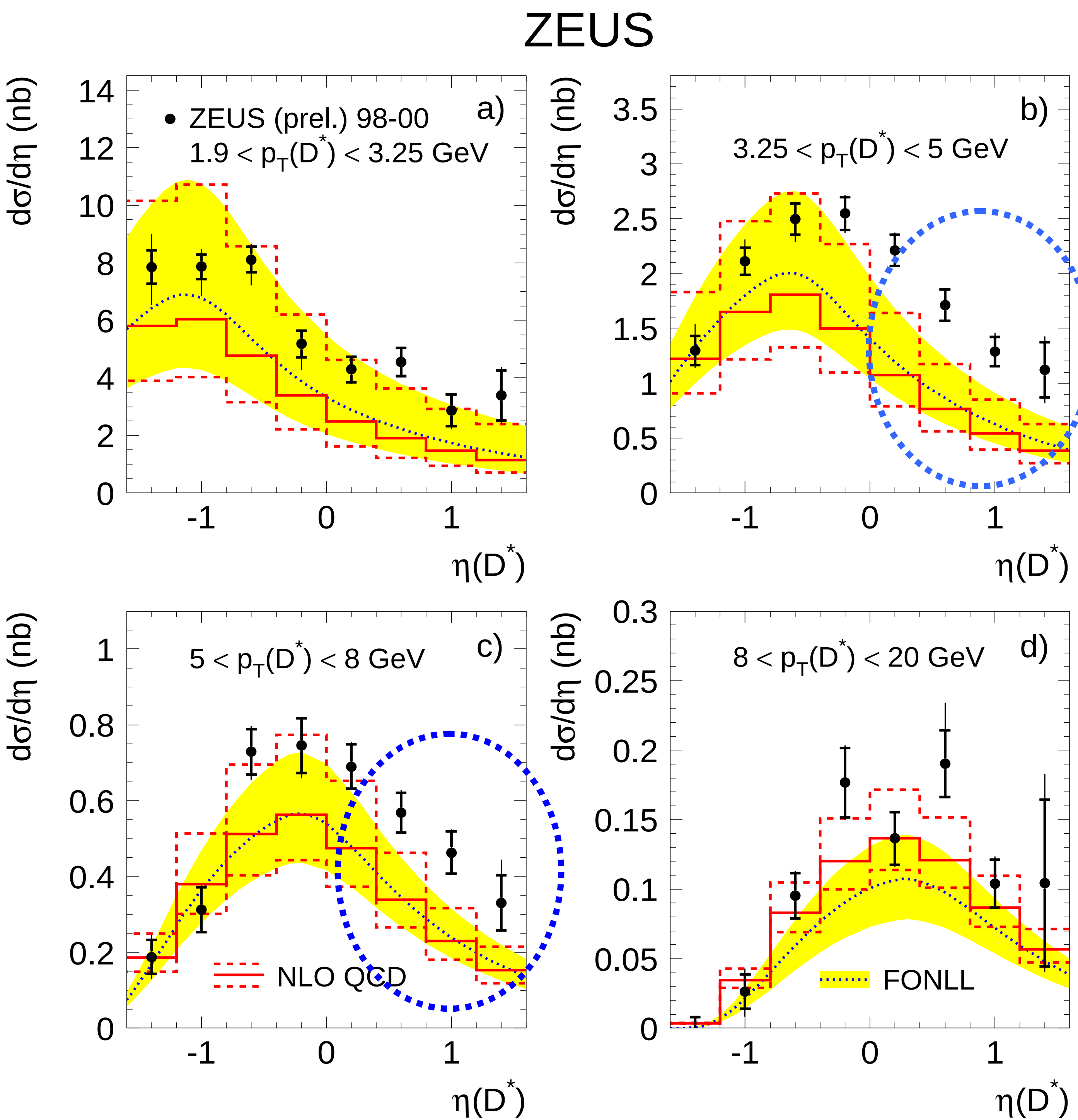
largest disagreement:

- medium $p_{T,D}$
- forward η
- low $z=(E-P_z)^D/(E-P_z)^{all}$

major exp. progress: data errors smaller than theory errors !

FONLL: massive NLO QCD plus resummation of NLO logs not better

Need better theory



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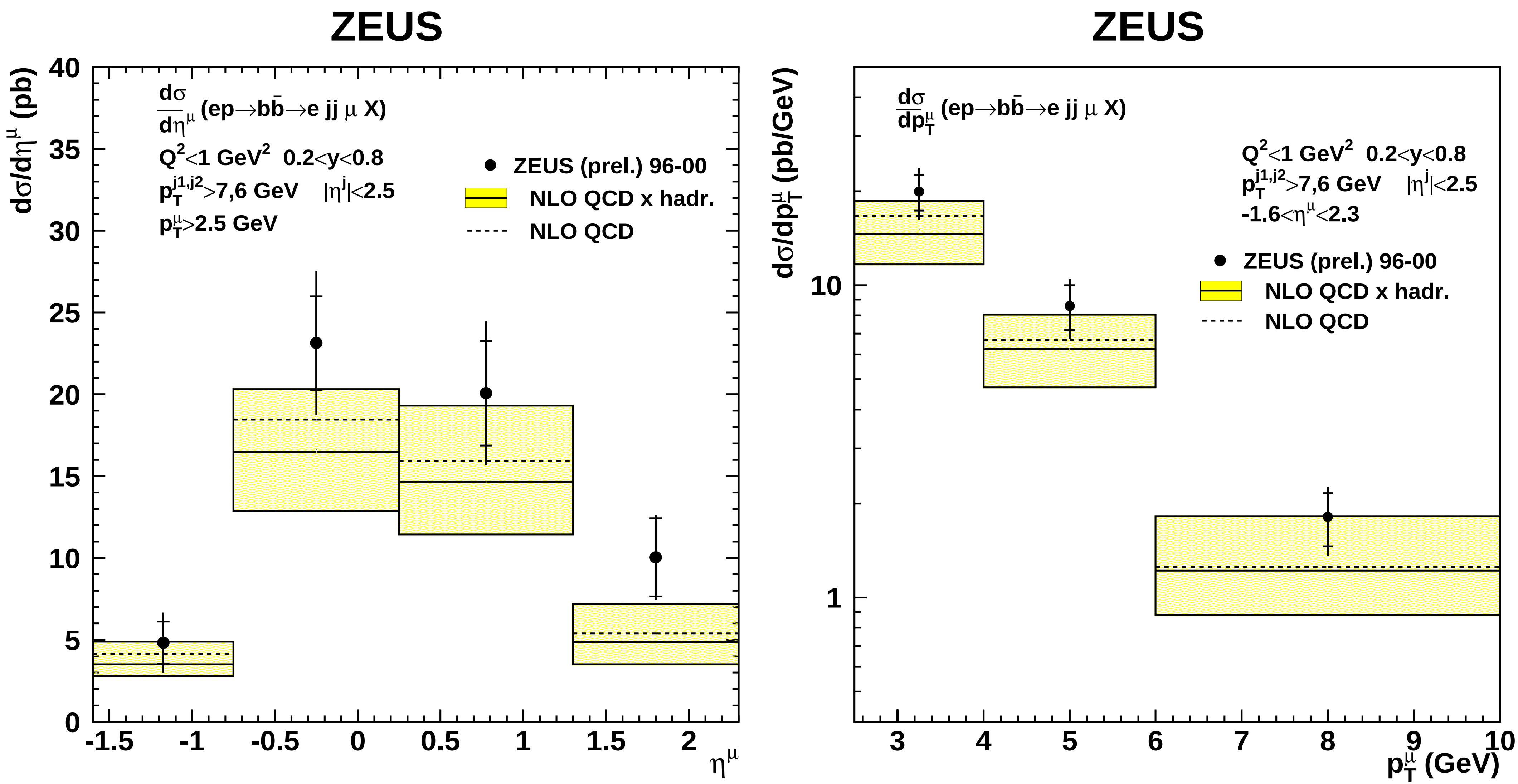
FONLL:
massive NLO QCD plus resummation of NLO logs not better

Beauty in γp Collisions - semi-leptonic μ–decay

Full HERA-I data set -> data error ~ theory errors

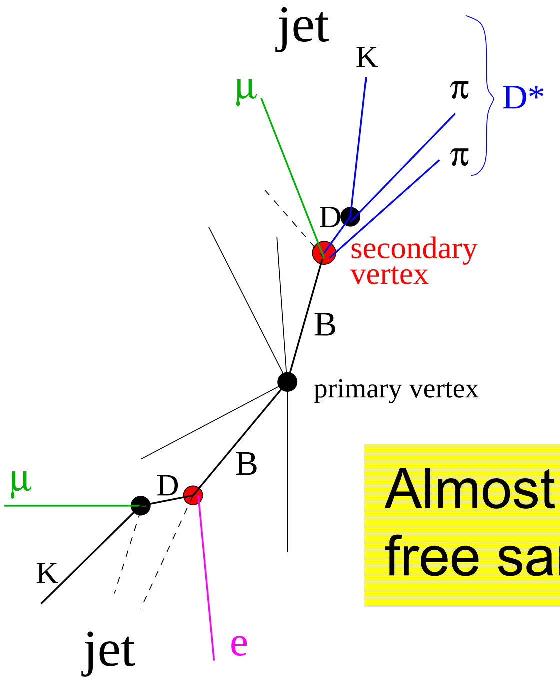
Visible beauty cross-section: ep -> e + jet + jet + μ+X



data/theory ~ 1.4, but compatible within exp/theo uncertainty !

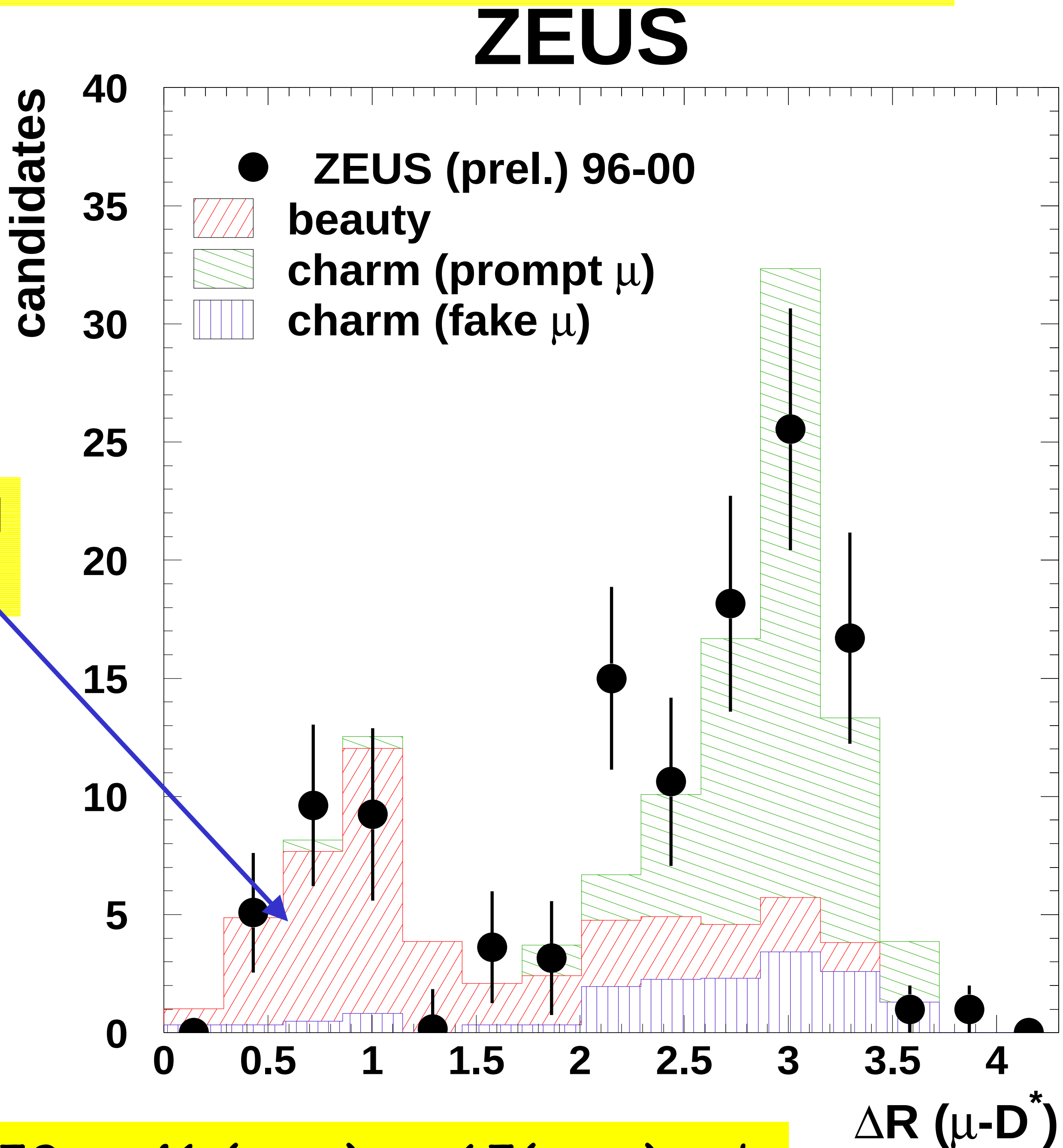
Beauty in γp Collisions - via μ and D*-decay

Full HERA-I data set:



Almost background free sample !

Gives access to low p_T
study b close to kin limit

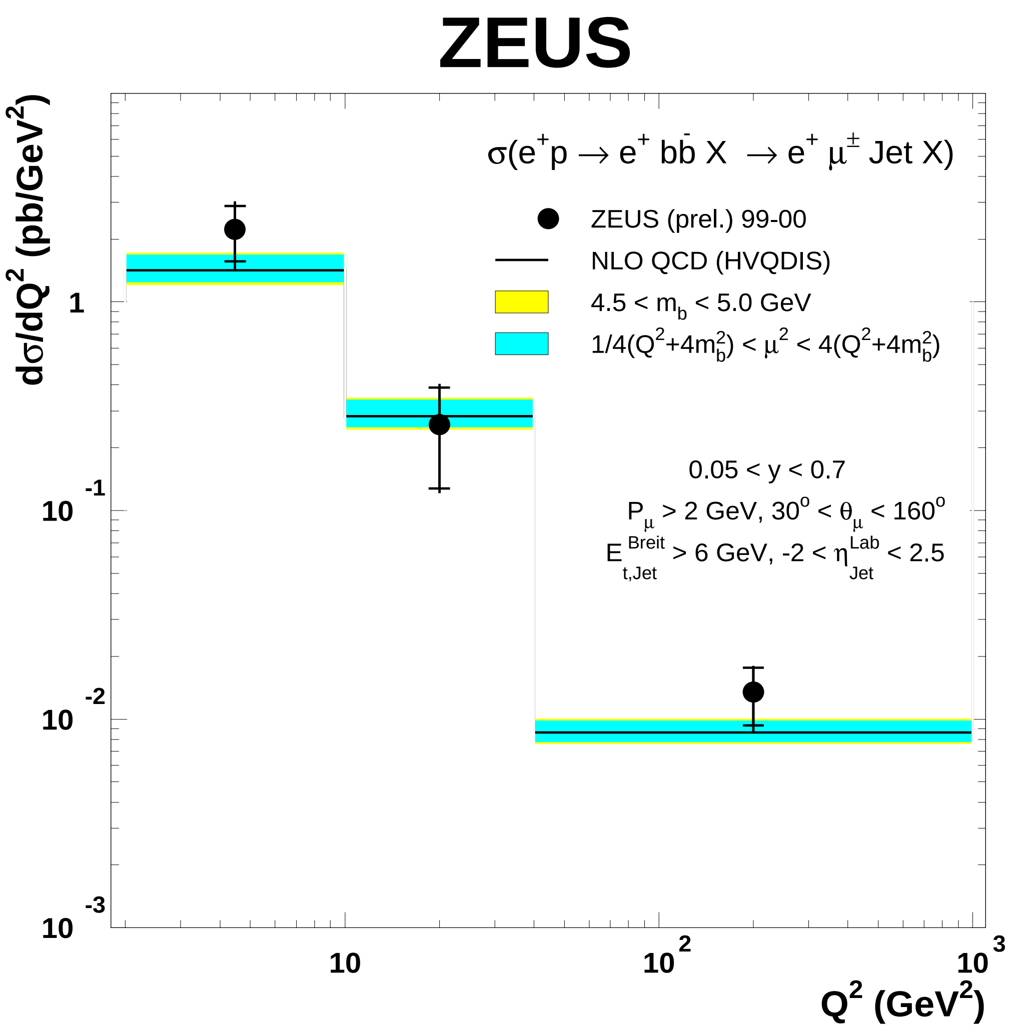


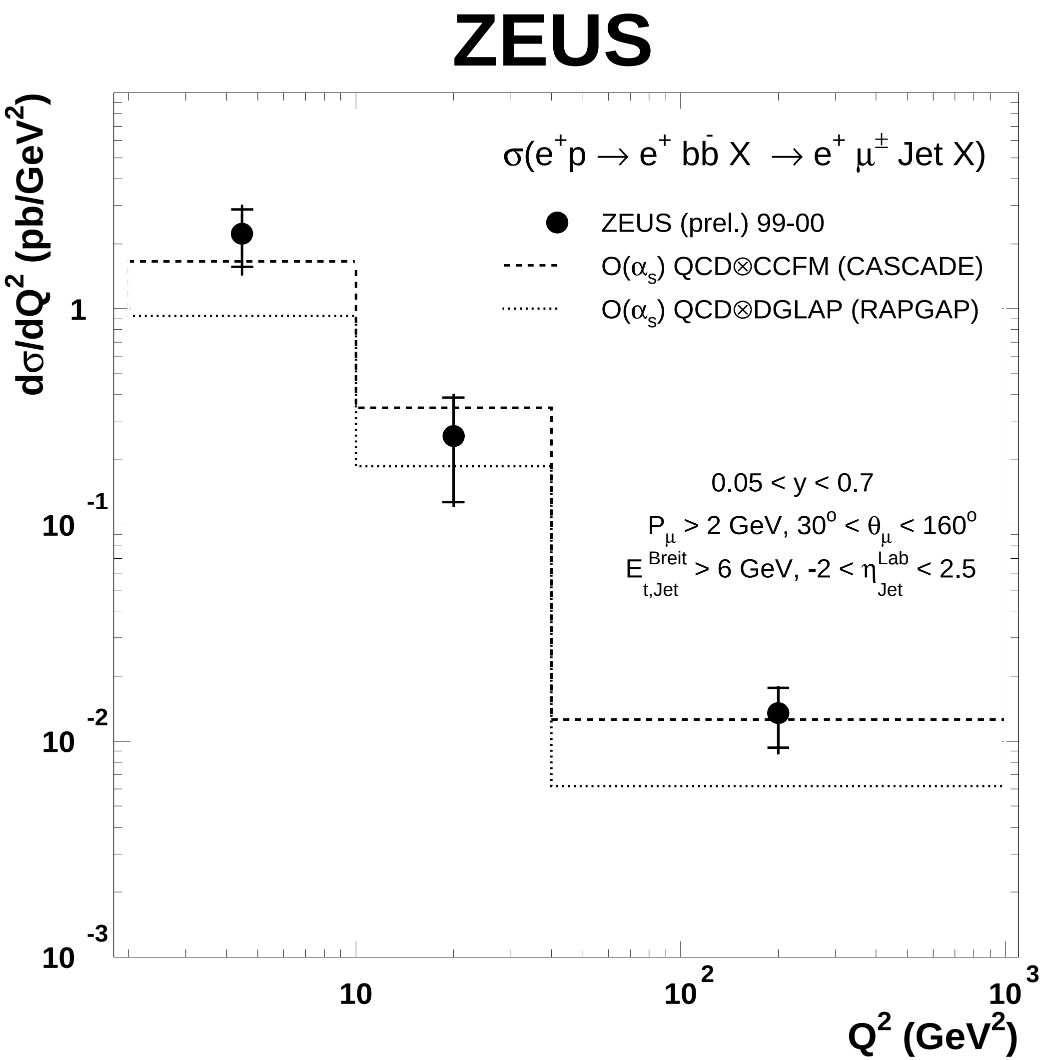
$$\sigma(\gamma\, p \to b\bar{b}\, X \to D^{*}\mu\, X) = 159 \pm 41\ (stat) \pm 65(syst)\ \ pb$$

Beauty in DIS - semi-leptonic μ-decay

First time differential distributions ($L \sim 60\ pb^{-1}$)

In Breit frame: Visible beauty cross-section: ep -> e + jet + μ+X



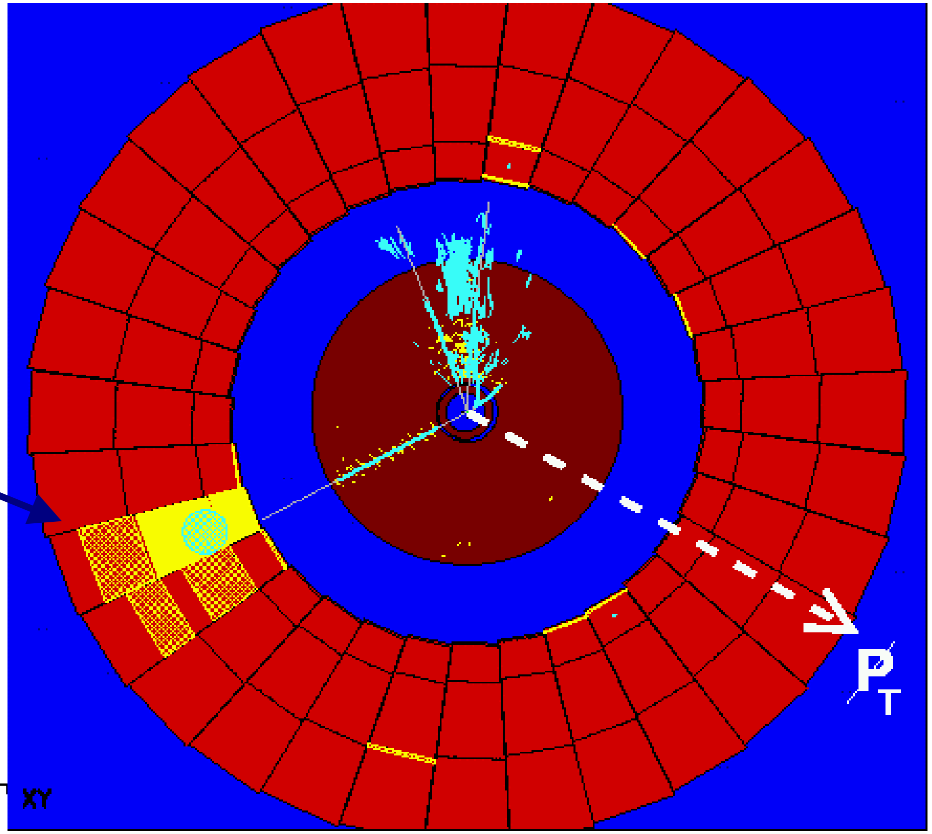


NLO agrees within uncertainties, LO+CCFM perfect

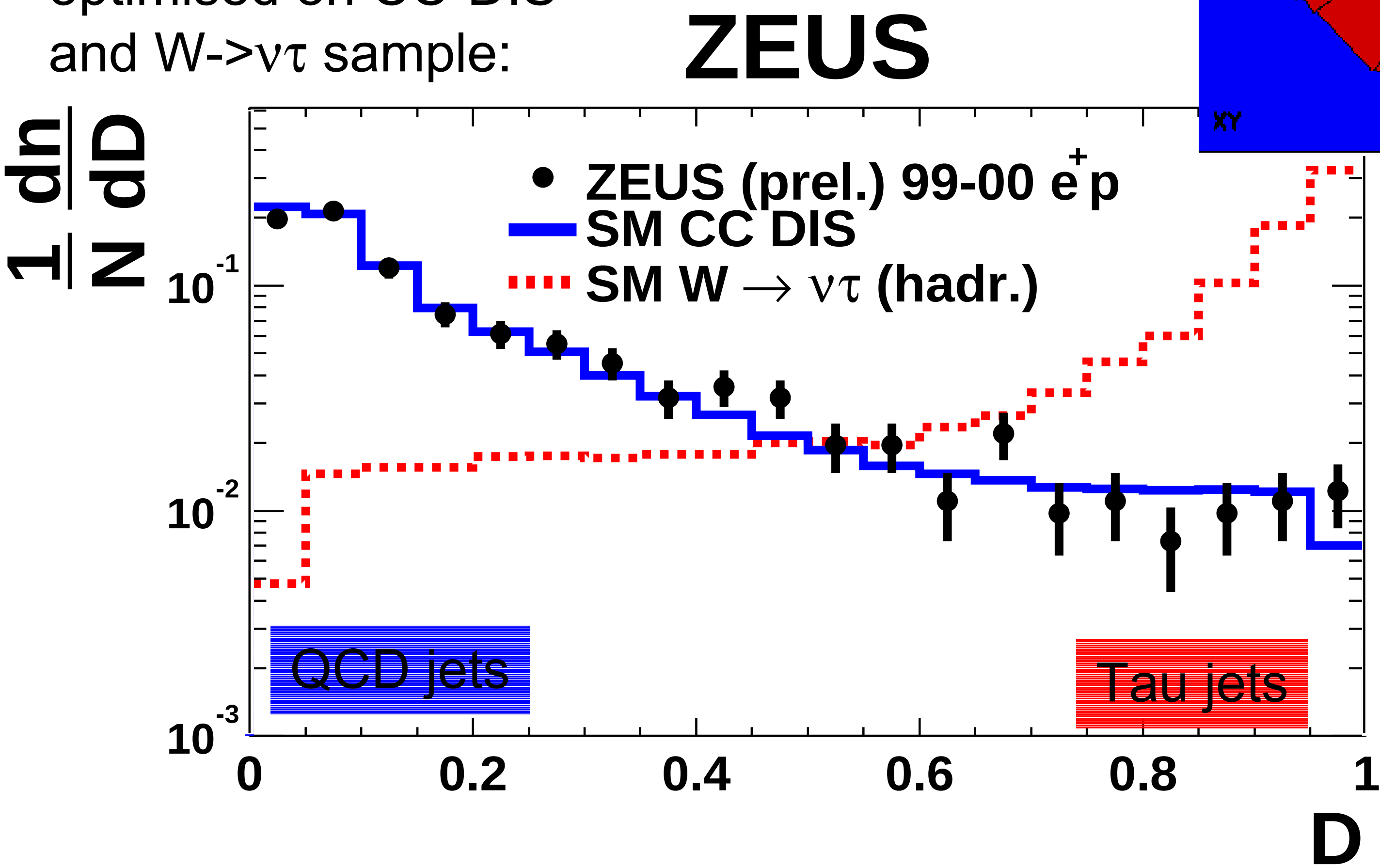
B-puzzle solved !?

Tau-Identification:

consider hadronic tau -decay
based on internal jet structure:
collimated (pencil-like) jets,
mostly only 1 track



Multi-variate Discriminant (hep-ph/0011224)
based on range searching
optimised on CC-DIS
and W->ντ sample:



Good separation
tau efficiency ~25%
bg rejection ~550

Search for Isolated Tau-Leptons and Missing Pt

Event selection:

- $p_T^{miss} > 20\ GeV$
- isolated track with $p_T > 5\ GeV$
  $(D_{track,track} > 0.5, D_{track,jet} > 1.8)$
- not electron or muon
- not acoplanar

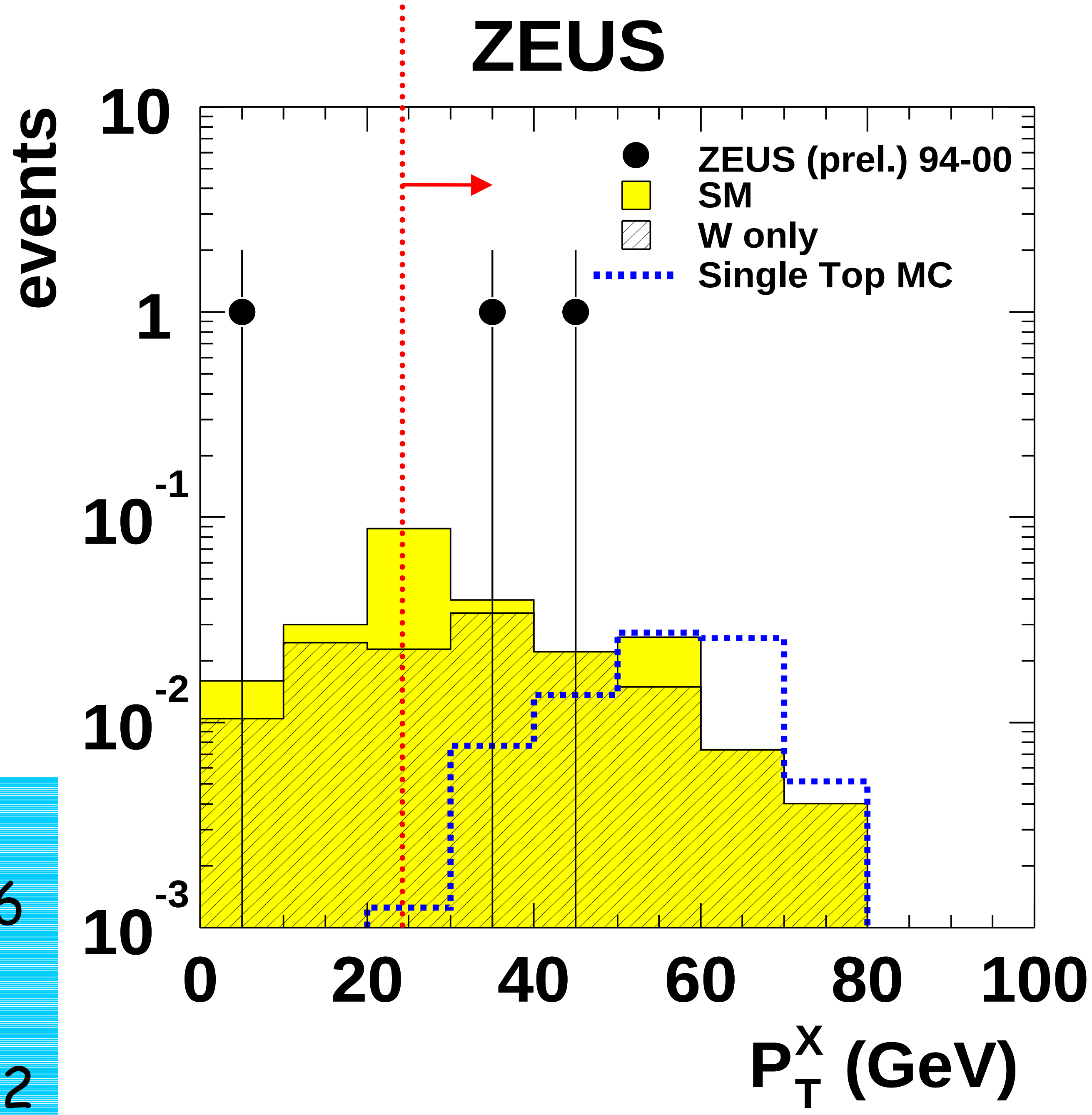
4 events found !
3 are compatible with
tau hypothesis, i.e.
Discriminant D > 0.95

$D > 0.95$:

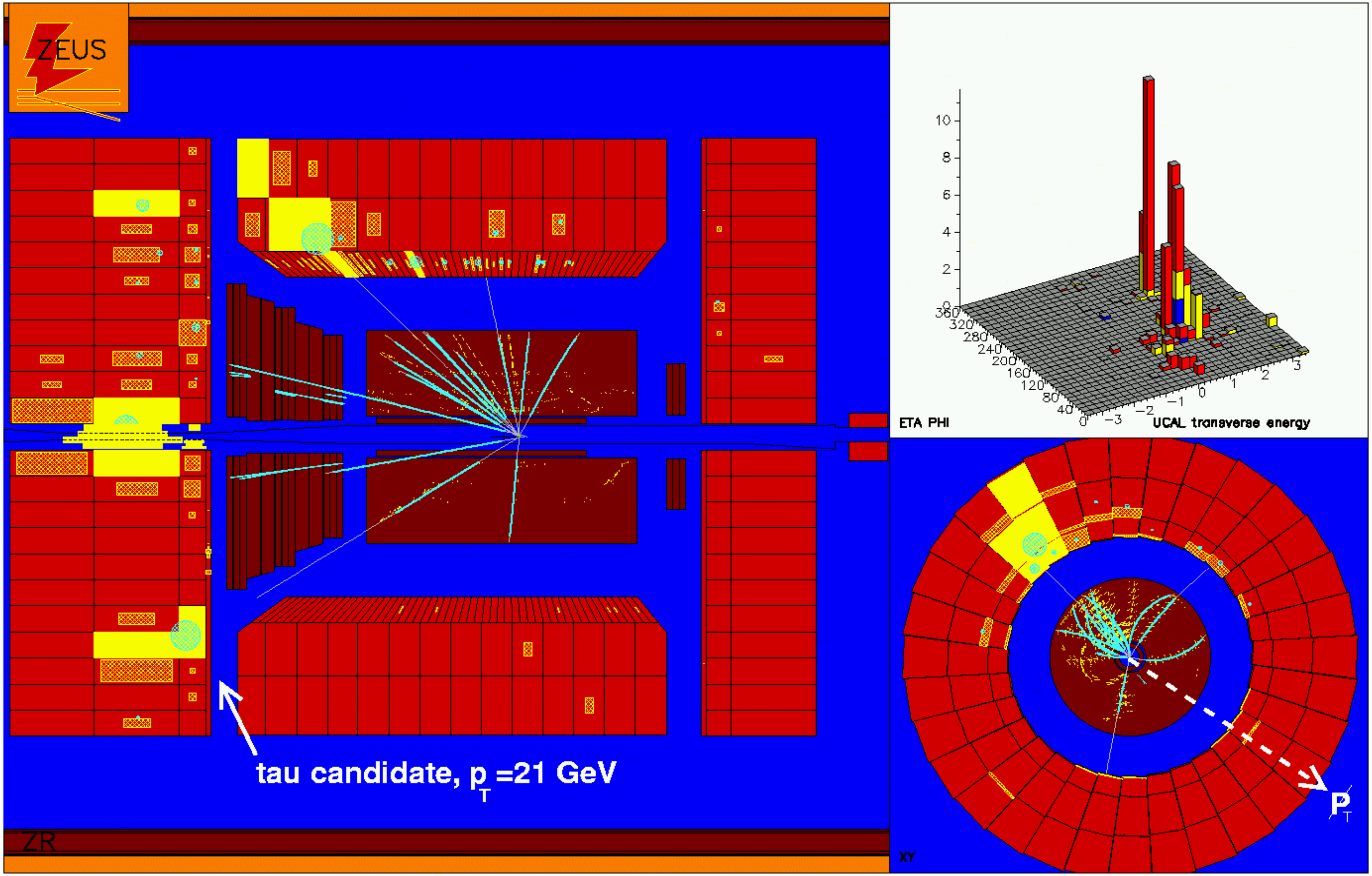
data : 3 SM : 0.23 ± 0.06

$P_T^X > 25\ GeV$:

data : 2 SM : 0.12 ± 0.02

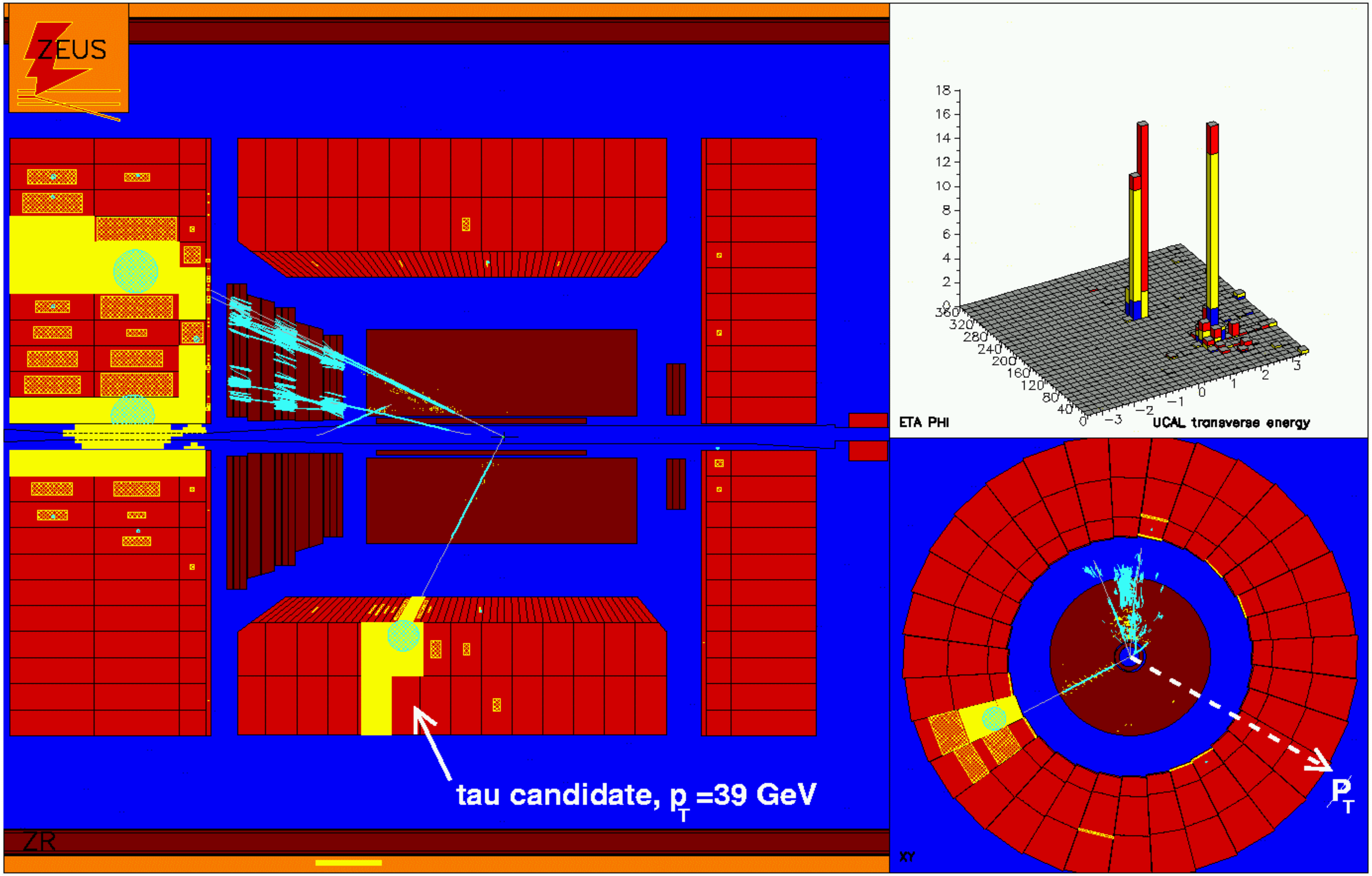


Tau-1 Candidate



$P_T^{CAL} = 37\ GeV$ $P_T^{X} = 48\ GeV$ $M_T = 32\ GeV$

Tau-2 Candidate



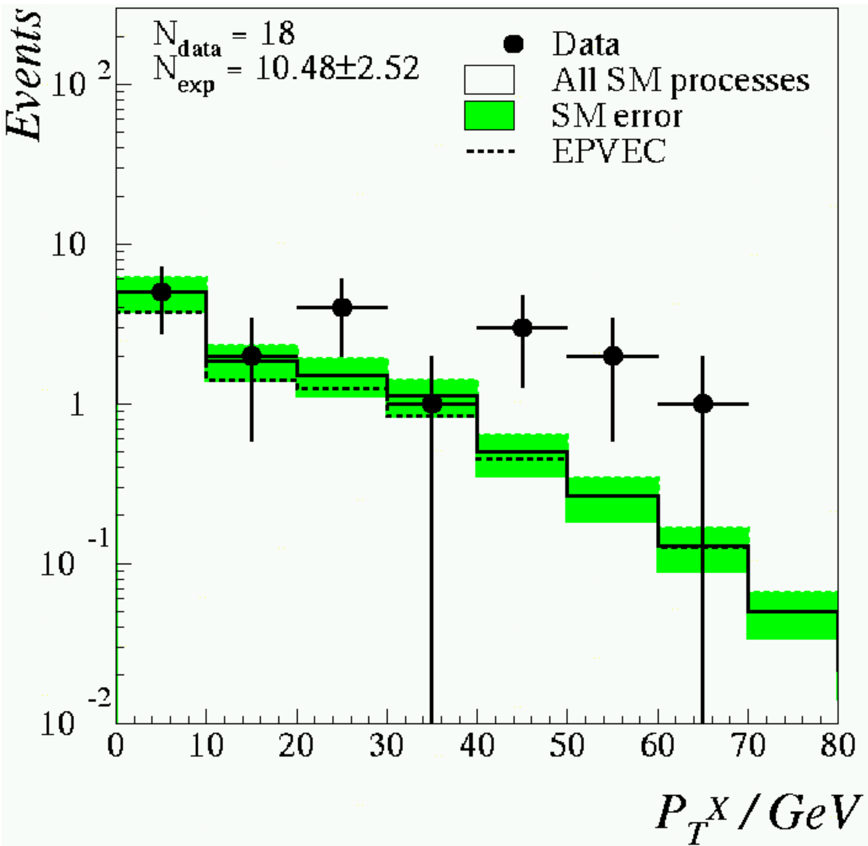
$P_T^{CAL} = 39\,GeV \quad P_T^X = 37\,GeV \quad M_T = 68\,GeV$

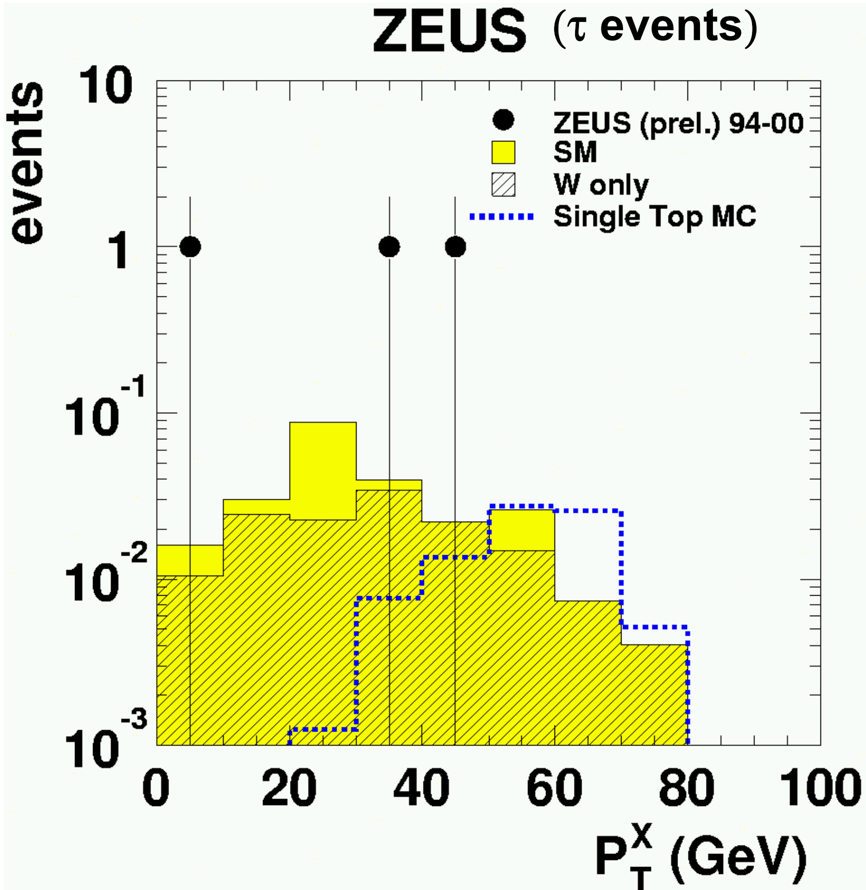
Status: Isolated Lepton Events at HERA I

H1 preliminary 94-00 e^+p (101.6 pb^{-1})	Electron obs./exp. (W)	Muon obs./exp. (W)
P_T^X > 25 GeV	4 / 1.29 ± 0.33 (1.05)	6 / 1.54 ± 0.41 (1.29)
P_T^X > 40 GeV	2 / 0.41 ± 0.12 (0.40)	4 / 0.58 ± 0.16 (0.53)

ZEUS preliminary 94-00 $e^{\pm}p$ (130.5 pb^{-1})	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau obs./exp. (W)
P_T^X > 25 GeV	1 / 1.14 ± 0.06 (1.10)	1 / 1.29 ± 0.16 (0.95)	2 / 0.12 ± 0.02 (0.10)
P_T^X > 40 GeV	0 / 0.46 ± 0.03 (0.46)	0 / 0.50 ± 0.08 (0.41)	1 / 0.06 ± 0.01 (0.05)

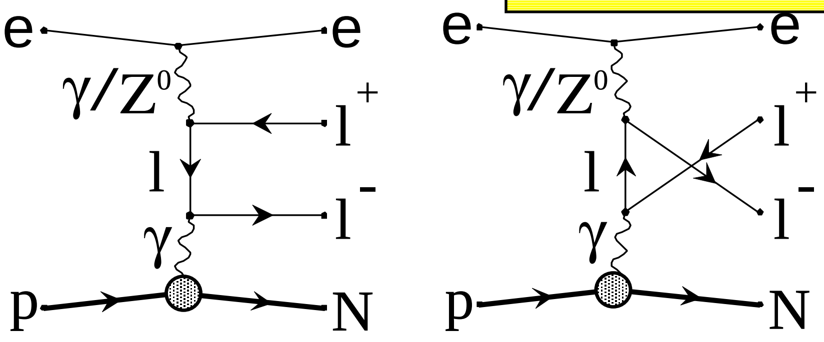
H1 (e and μ events)



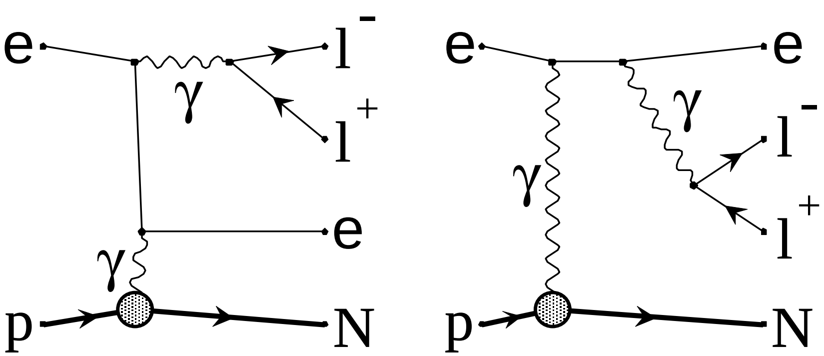


Multi-Electron Events

Grape:



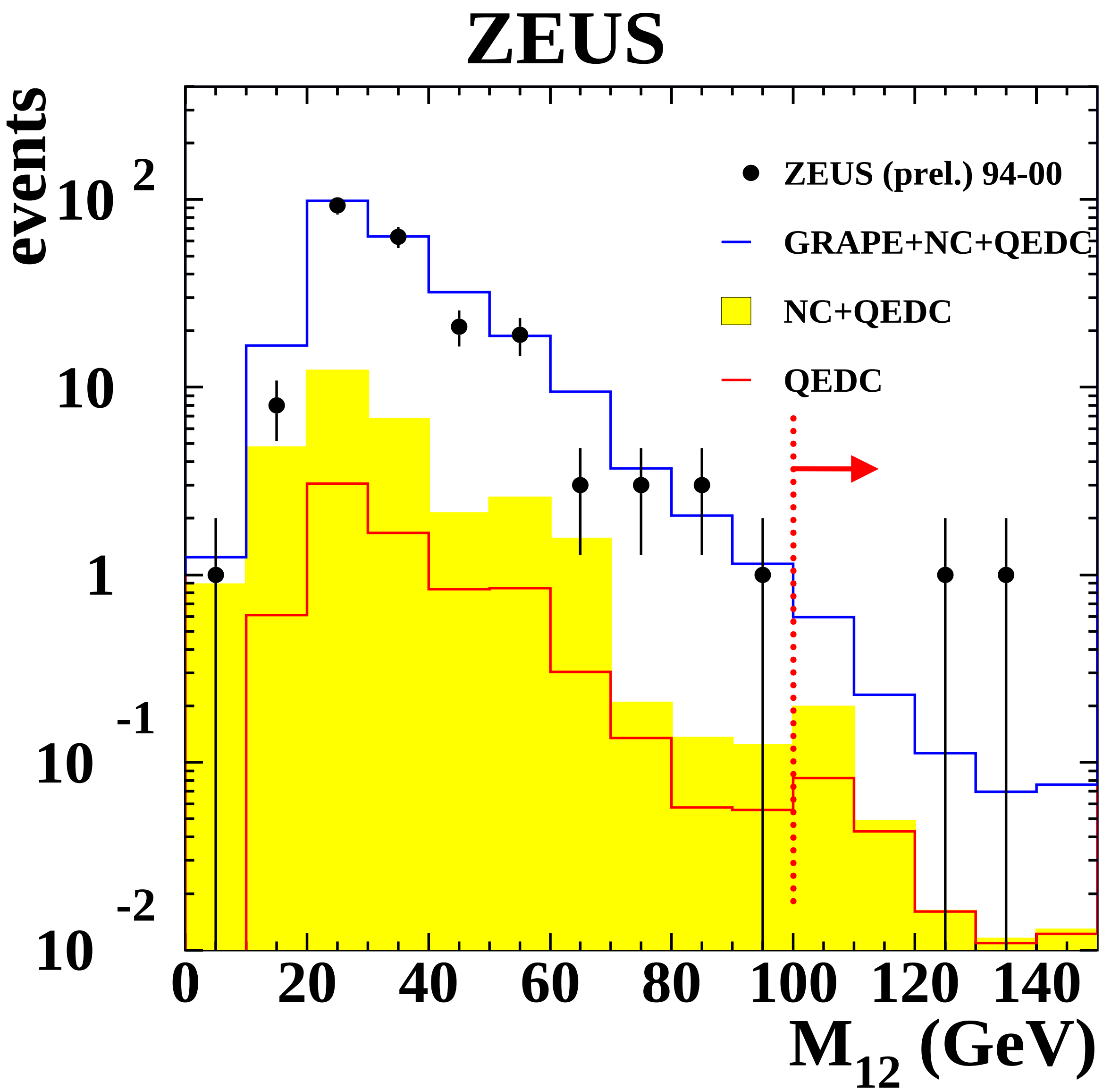
(a) Bethe-Heitler type diagrams



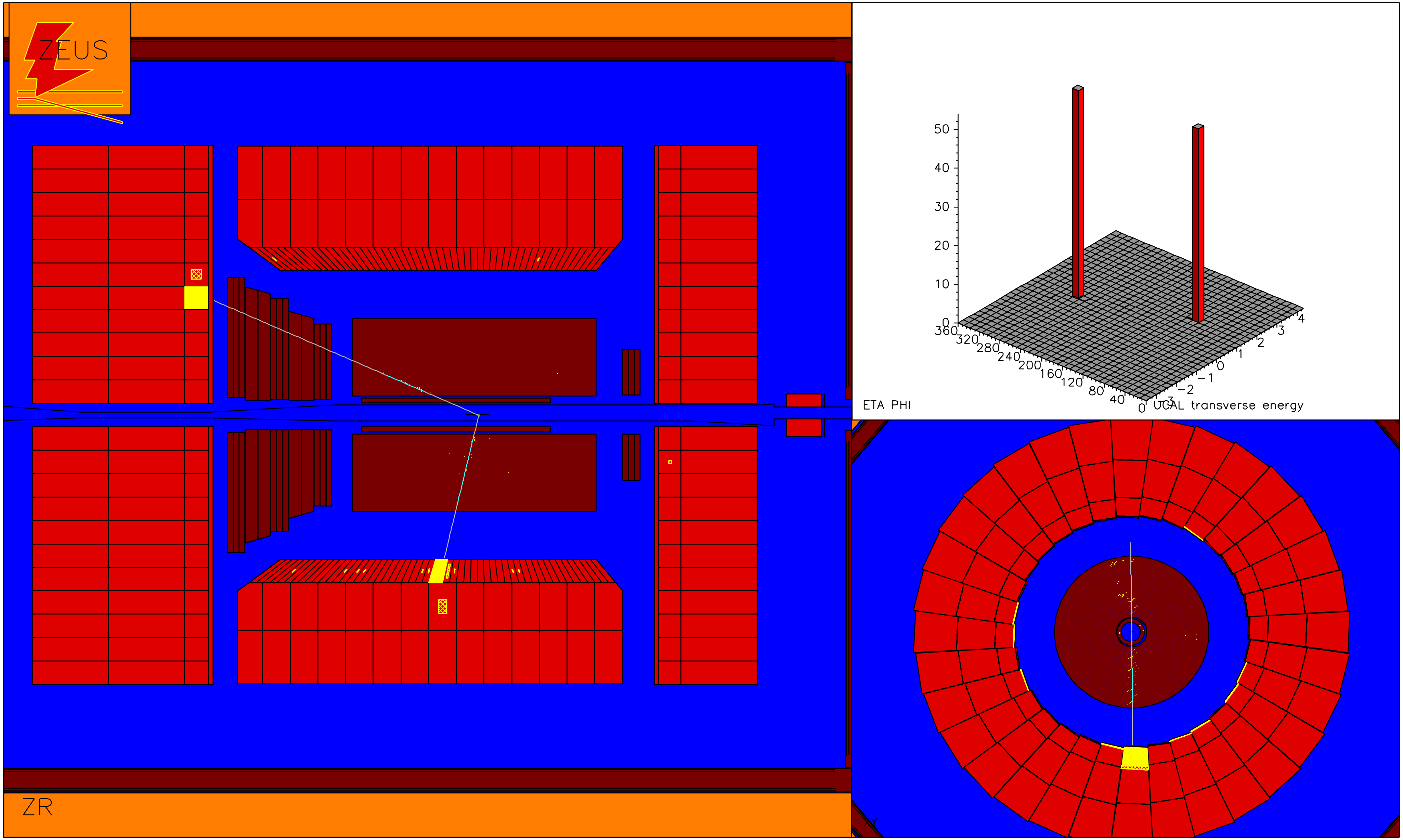
(b) QED-Compton type diagrams

+ electroweak diagrams

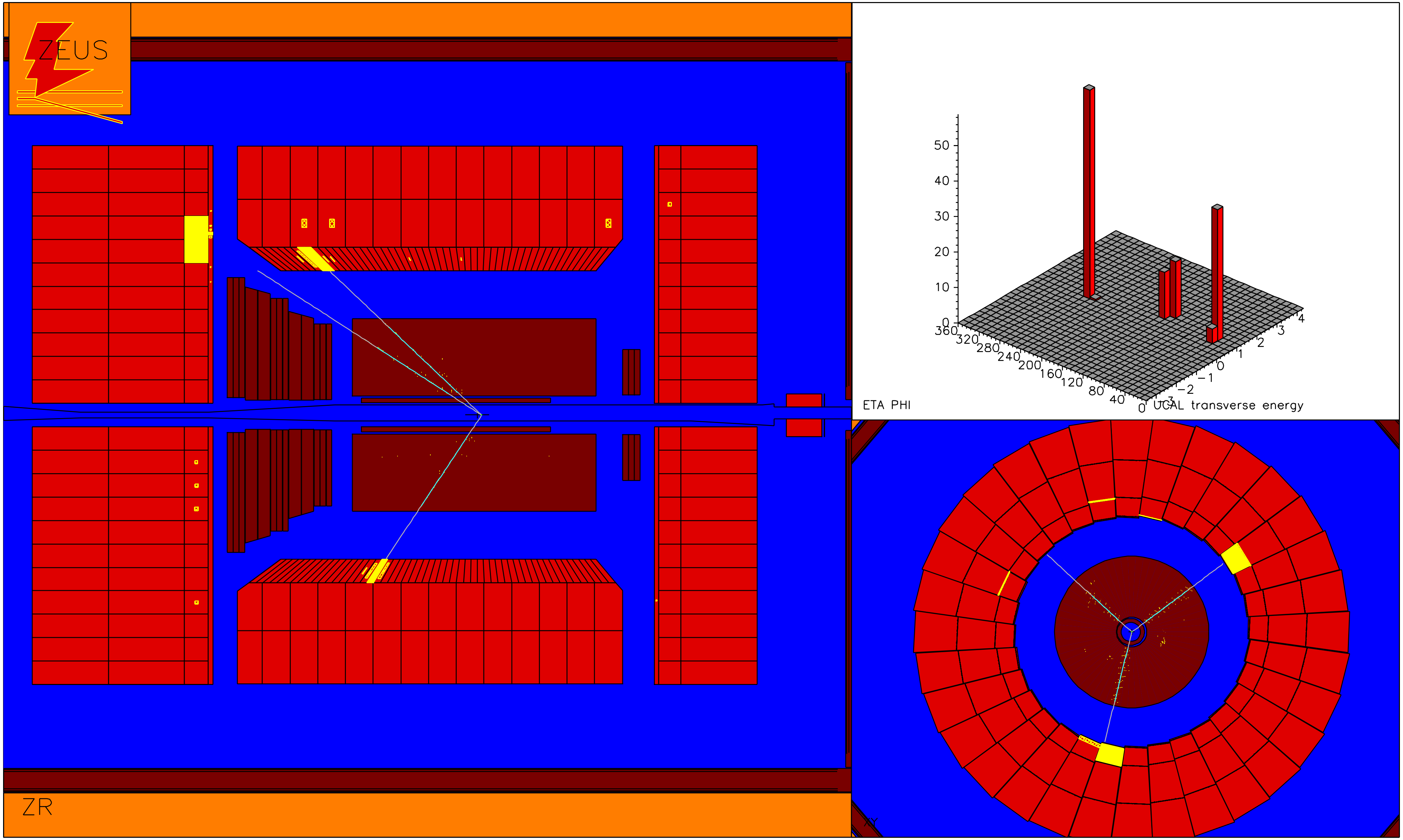
Two electrons : $M_{1,2} > 100$ GeV :		
Data	SM	GRAPE
2	0.8 ± 0.1	0.5 ± 0.1
Three electrons : $E_{T,1} > 30$ GeV		
Data	SM	GRAPE
2	1.4 ± 0.1	1.4 ± 0.1



Overall good agreement
no excess at high mass
in μ–channel no event M>100 GeV



$E_{T1} = 56\ GeV \quad E_{T2} = 53\ GeV \quad M = 134\ GeV$



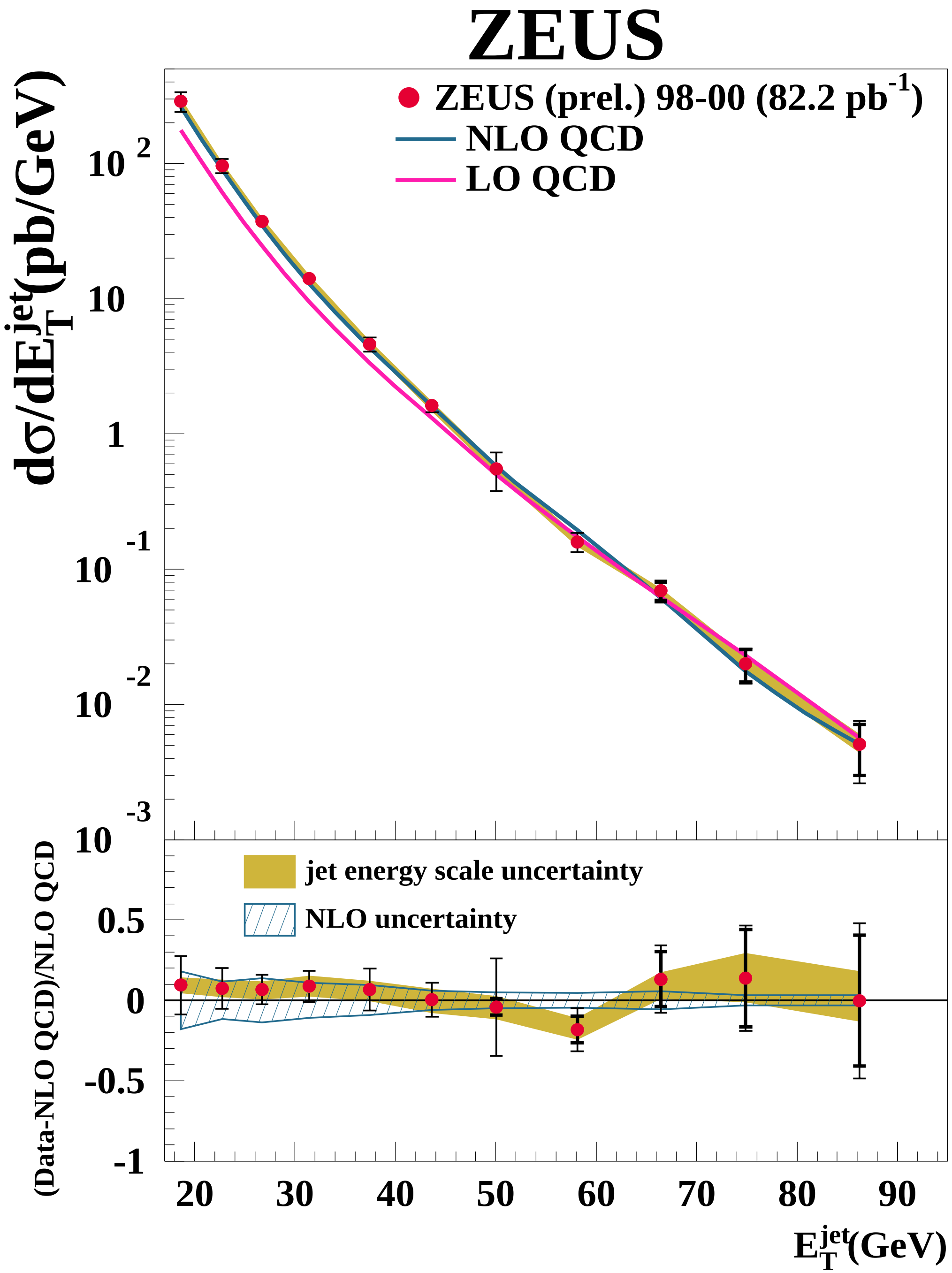
$E_{T1} = 52\ GeV \quad \theta_1 = 1.0\ rad$

$E_{T2} = 47\ GeV \quad \theta_2 = 0.76\ rad$

$E_{T3} = 36\ GeV \quad \theta_3 = 0.58\ rad$

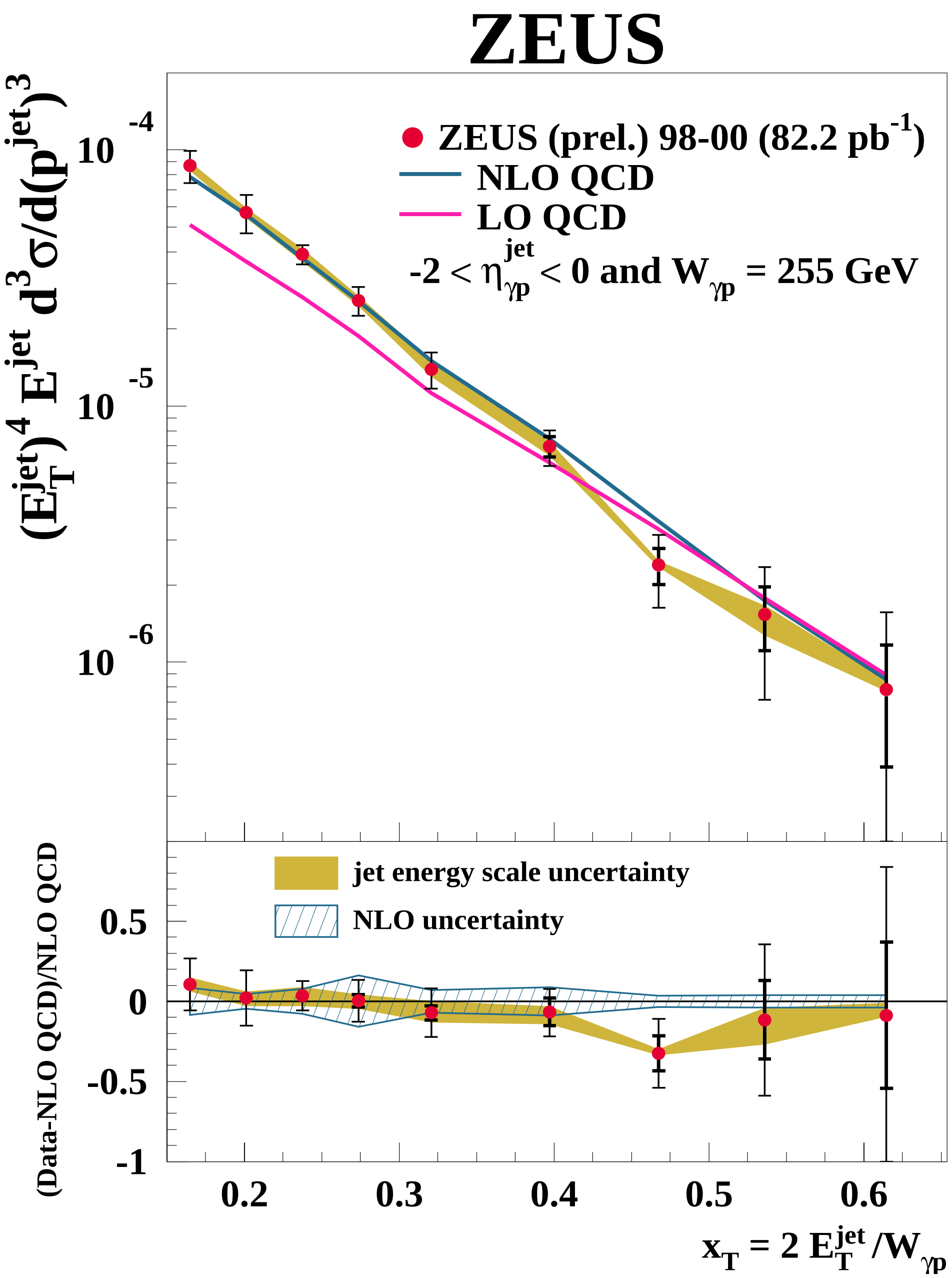
$M_2 = 94\ GeV$

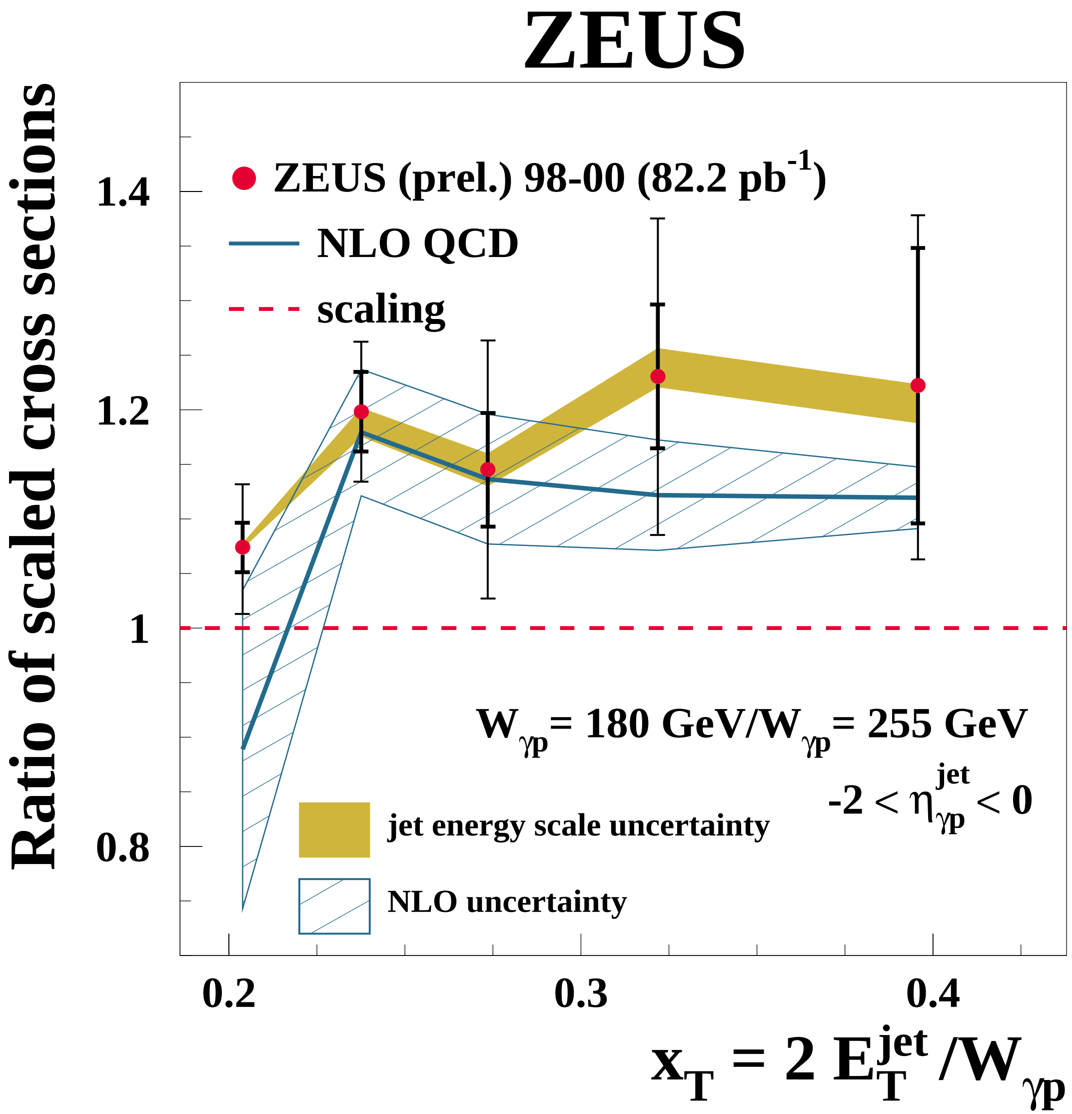
Inclusive Jet-Cross Sections in γp



High precision data
Excellent agreement over
4 orders of magnitude
no excess at high E_T

Invariant Inclusive Jet-Cross Sections

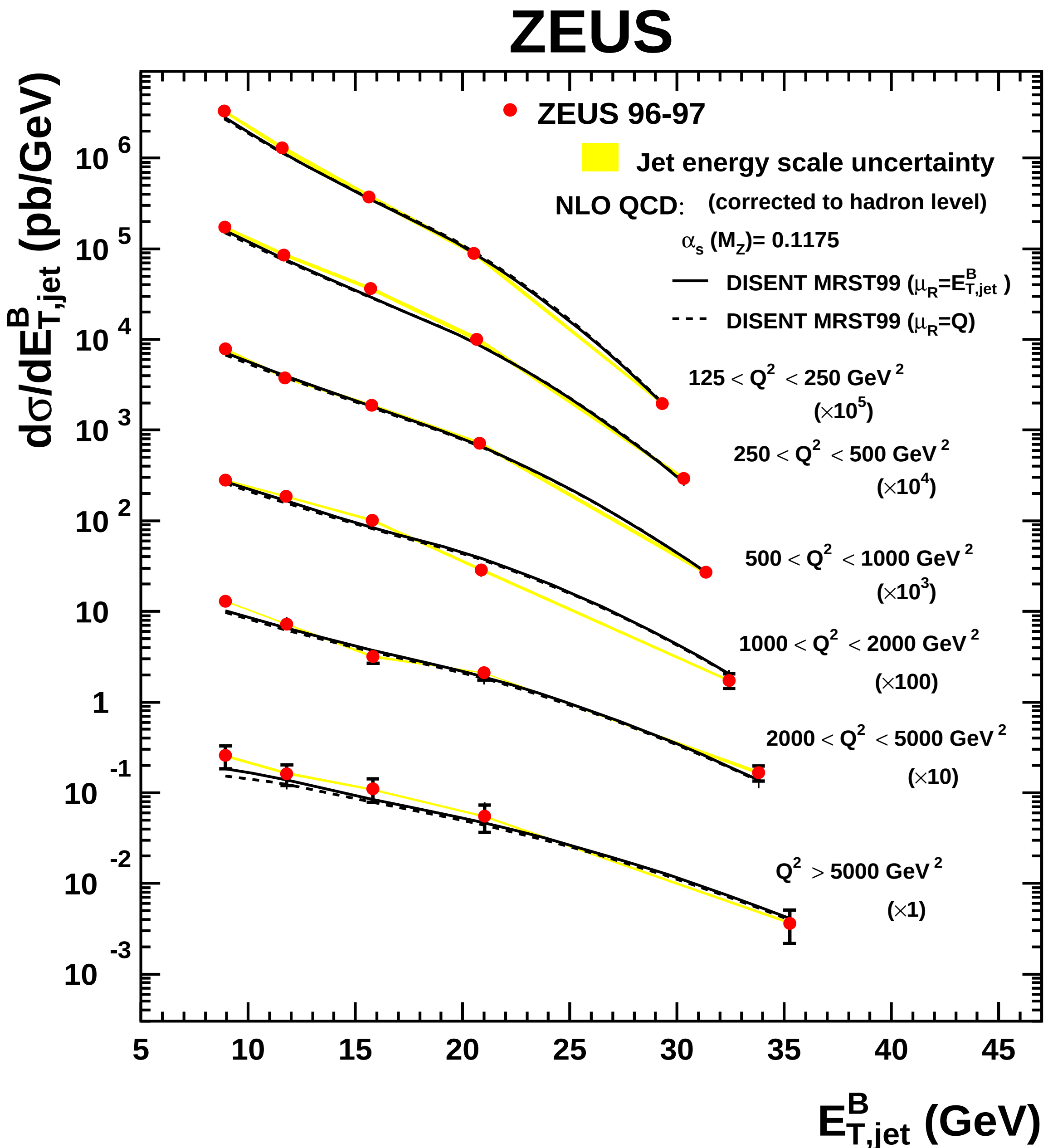


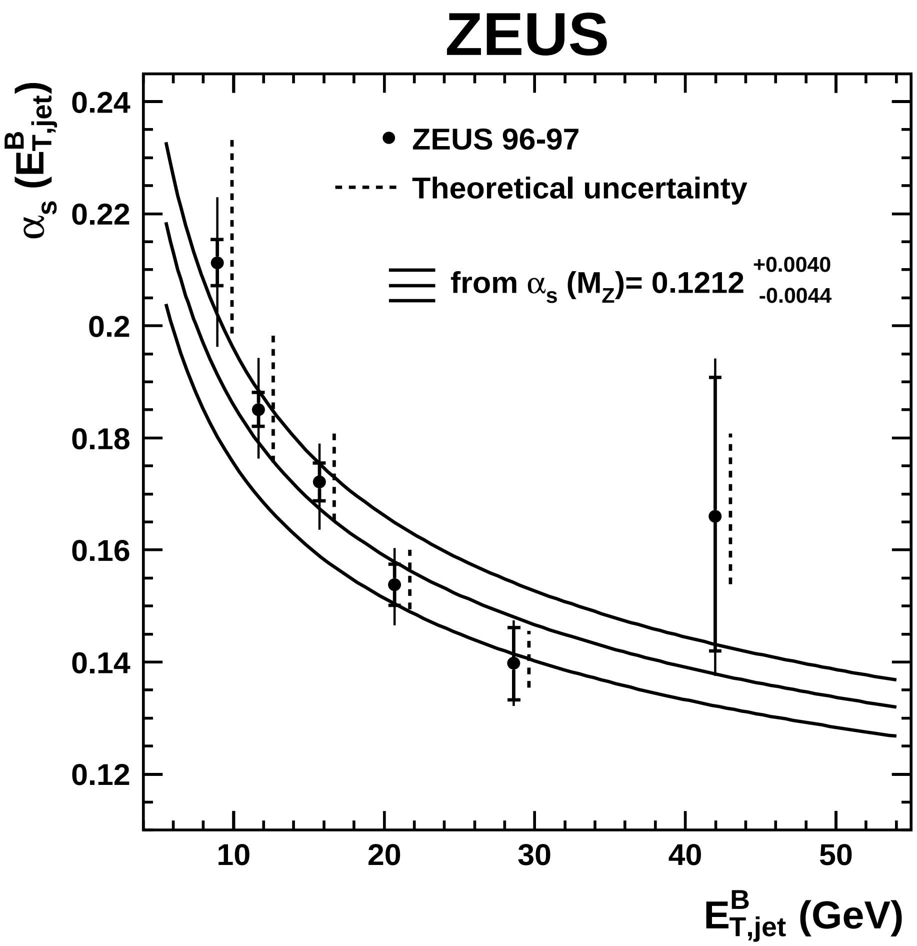


Evidence for scaling violations in γp collisions

Inclusive Jet Production in DIS

Impressive description of NLO QCD
of these precise data:





for $Q^2 > 500$ GeV^2:

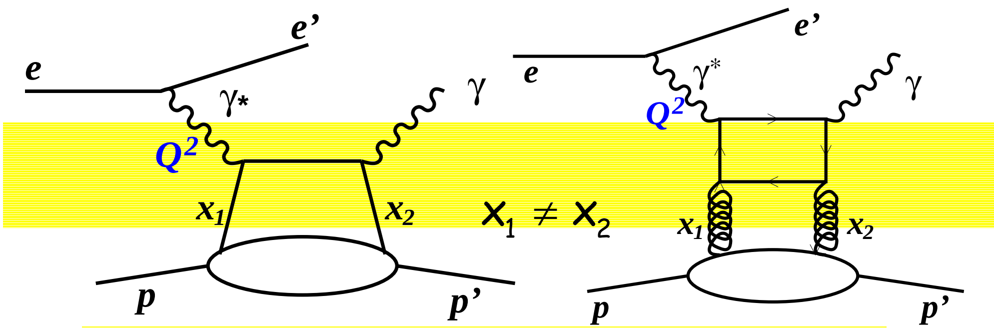
$$\alpha_s(M_Z) = 0.1212 \pm 0.0017\ (\text{stat})\ {}^{+0.0023}_{-0.0031}\ (\text{syst})\ {}^{+0.0028}_{-0.0027}\ (\text{theo})$$

Very precise measurement !

Deeply Virtual Compton Scattering

GPD-based Model (FFS)

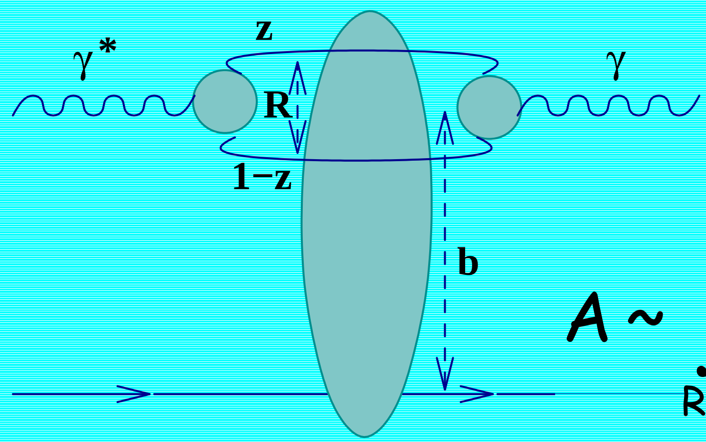
High-x (HERMES) Low-x (ZEUS)



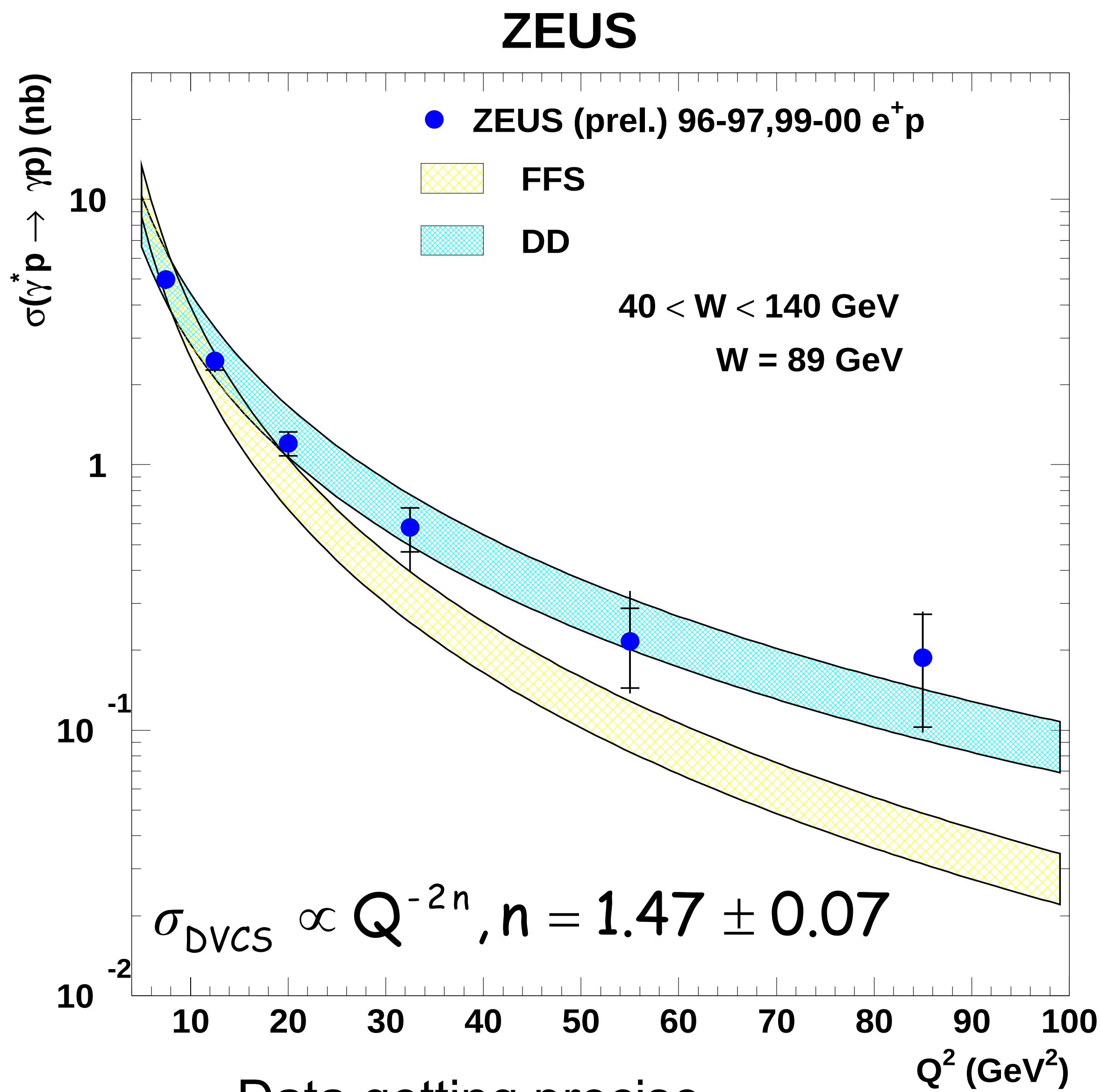
$$A \sim \int \frac{dx}{x} C(\xi/x, Q^2)\ H(x, \xi, Q^2)$$

H: Off-diagonal PDF

Colour Dipole Model (DD)



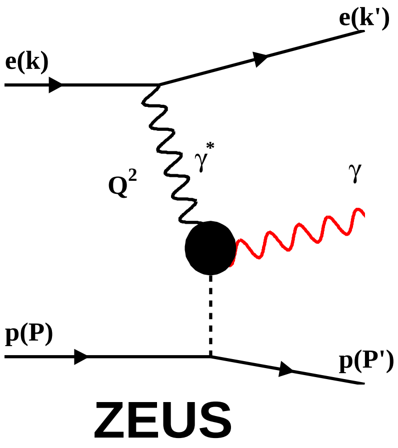
$$A \sim \int_{R,z} \Psi_{ini}^{\gamma^*}\ \sigma_{dipole}\ \Psi_{out}^{\gamma}$$

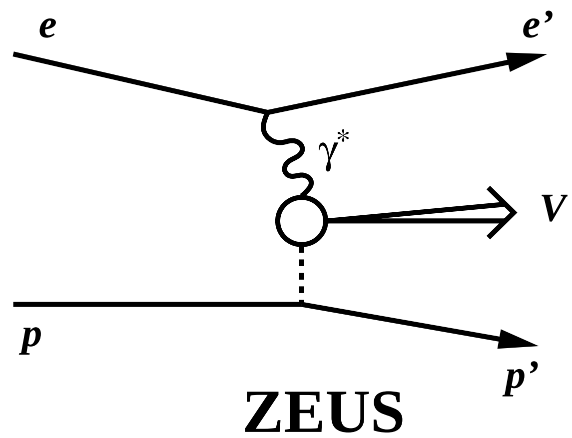


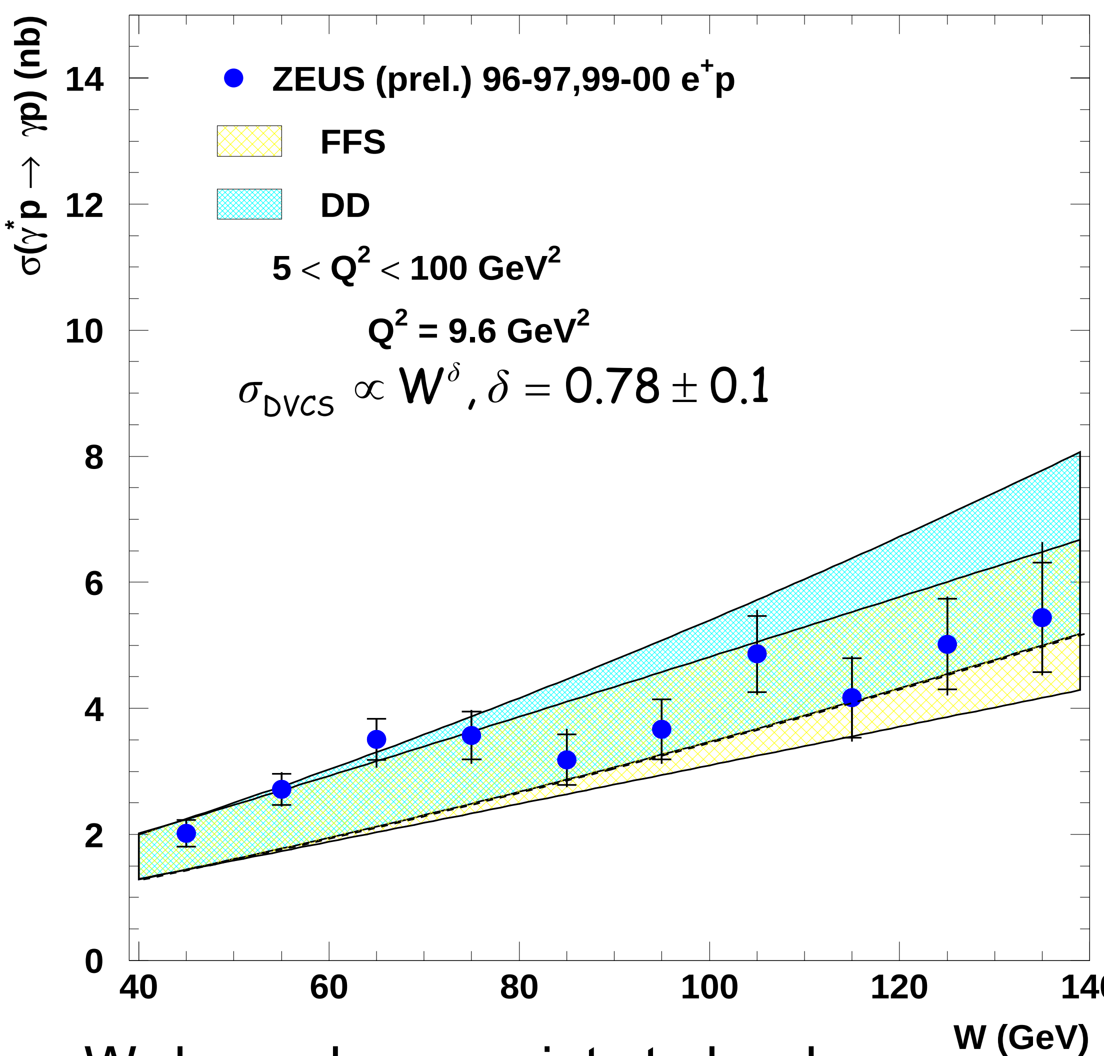
Data getting precise

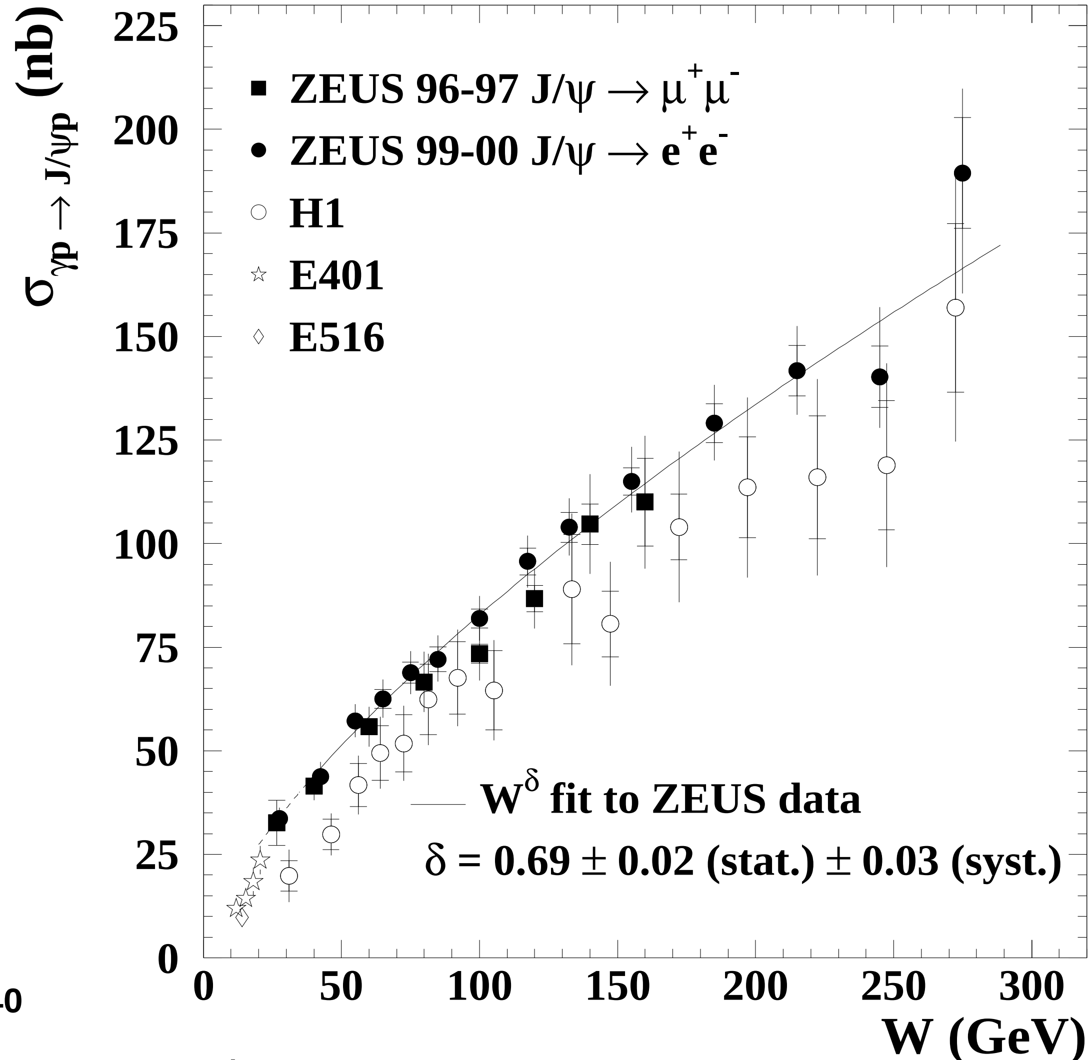
Q^2 spectrum seems harder than predicted by FFS

HERA-II: e^+/e^- and polarisation !







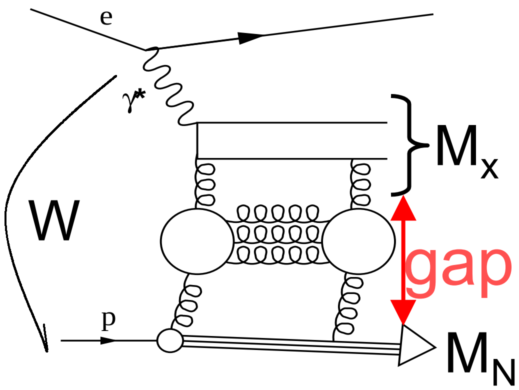


W-dependence points to hard process as e.g. in J/Ψ production

New: F_2^{D3} Data

$$x_{IP} = x\,(1 + M_X^2 / Q^2)$$

$$\beta = \frac{x}{x_p}$$



Analysis using FPC (L=4 pb^{-1}):

- coverage $4.0 < \eta < 5.0$
- increased M_X range
- reduced bias from nucleon dissociation

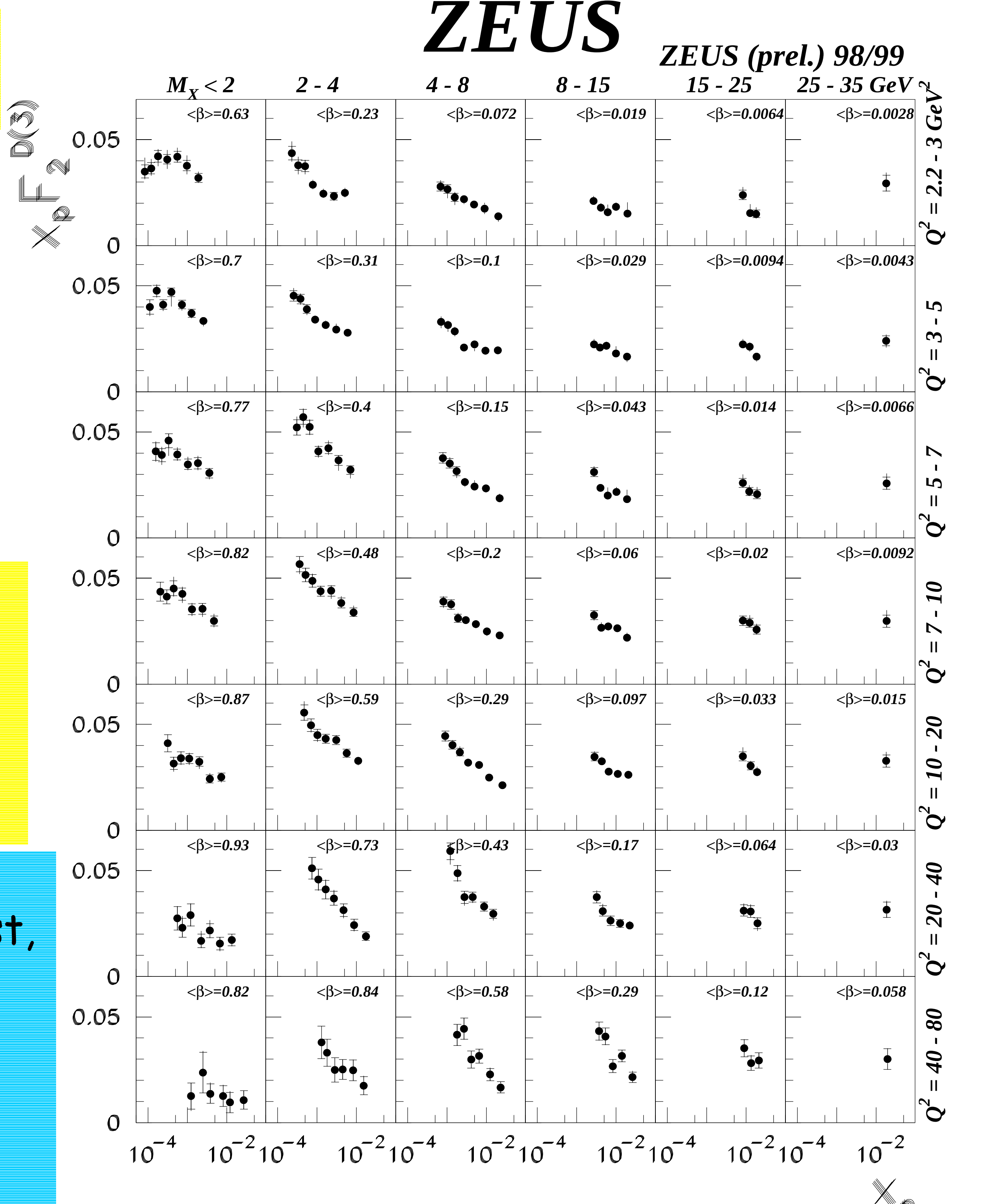
+extension to lower Q^2

if $F_2^{D3} \sim \left(\frac{1}{x_{IP}}\right)^{\lambda}$ expect $x_{IP} F_2^{D3} \sim$ const,

if diffraction is soft ($\lambda \approx 1$)

from data:

diffraction has hard component!



What happens here ?

Much improved precision !

Same energy dependence in inclusive and diffractive scattering !

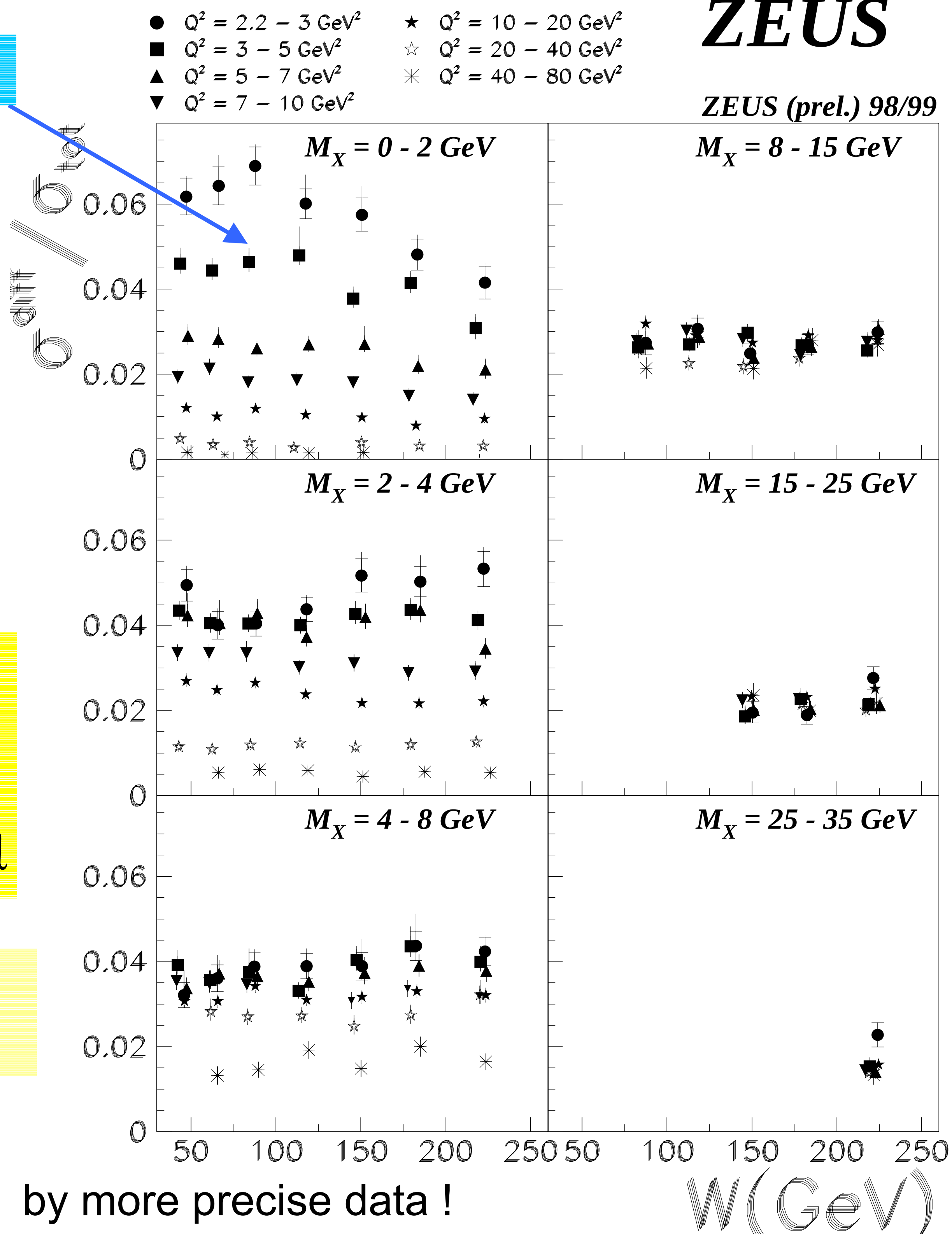
Naive expectation:

$$\sigma_{tot} \sim g(x,Q^2) \sim x^{-\lambda}$$

$$\text{Hard}: \sigma_{diff} \sim g(x,Q^2)^2 \sim x^{-2\lambda}$$

$$\text{Soft}: \sigma_{diff} \sim x^{-\varepsilon}, \varepsilon = 0.08 << \lambda$$

Diffraction contains soft and hard pieces even at large Q^2

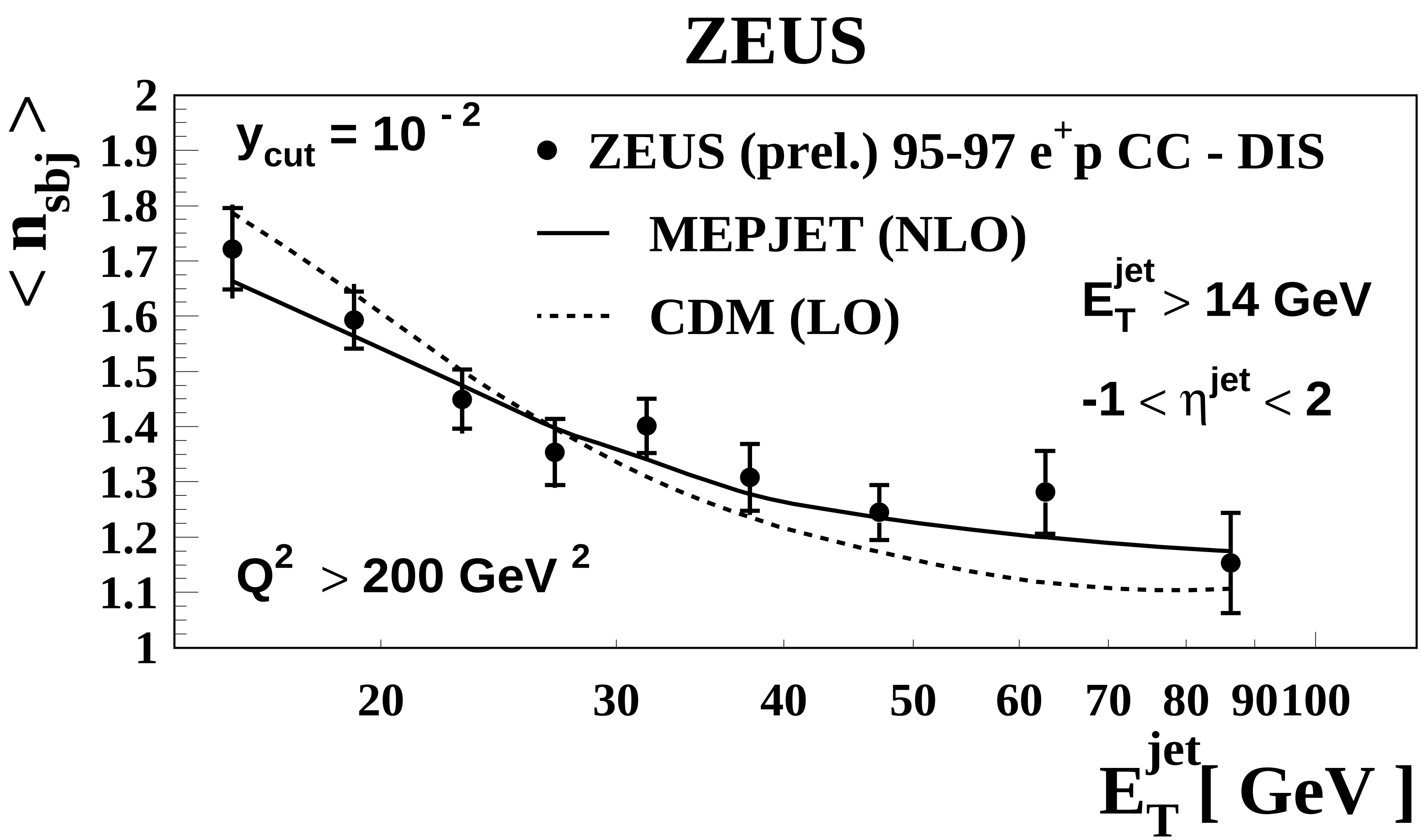


Recently models (like CDM) tried to explain this -> new challenge by more precise data !

Conclusions

- New level of extraction of parton density and α_s
  and their experimental uncertainties reached
  ...hardly need fixed target data
  HERA-II: e^+/ e^- program ahead of us ! (also for xF_3 !)
- Direct F_L measurement seems in reach via ISR analysis
  HERA-II: dedicated run with lower beam energy ?
- Analysis of hadronic final state enters new stage:
  many interesting results from jets -> combine with incl. DIS
  particle ID: strange, charm, bottom, ...tau
  HERA holds the key for production mechanism of heavy quarks
- Isolated Lepton story continues: wait for answer at HERA-II
  Can the SM hold the strength ?
- DVCS: towards determination of off-diagonal PDF
  HERA-II: e^+/ e^- and polarisation
- new precise F_2^{D3} new challenge for models

Internal Jet structure



Internal jet structure well described by NLO and MC

Isolated high-pt lepton selection:

$p_T^{miss} > 20$ GeV

isolated track with $p_T > 5$ GeV

$(D_{track,track} > 0.5, D_{track,jet} > 1.8)$

not electron or muon, not acoplanar

4 events found

3 are compatible with tau hypothesis