

ZEUS Highlights for ICHEP02

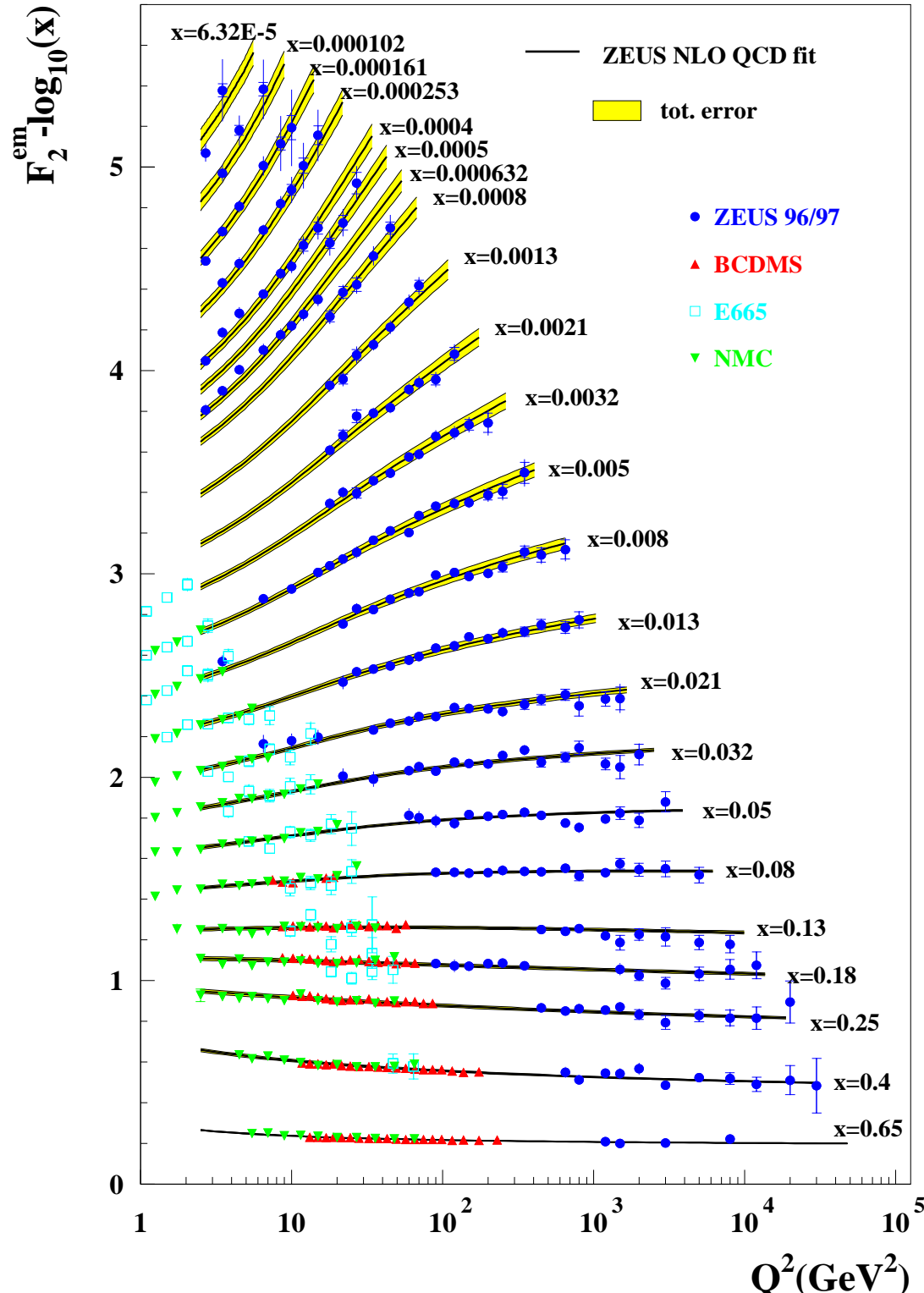
... a personal selection

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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 ?
 - How can we understand soft processes ?
 - More complex proton description : GPD ?
 - What drives colour singlet proton component ?
- Incl. DIS & PDF Fits
strange, charm, beauty
Tau
High Et: electrons&jets
DVCS/J/ Ψ & F_2^{D3}

ZEUS



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

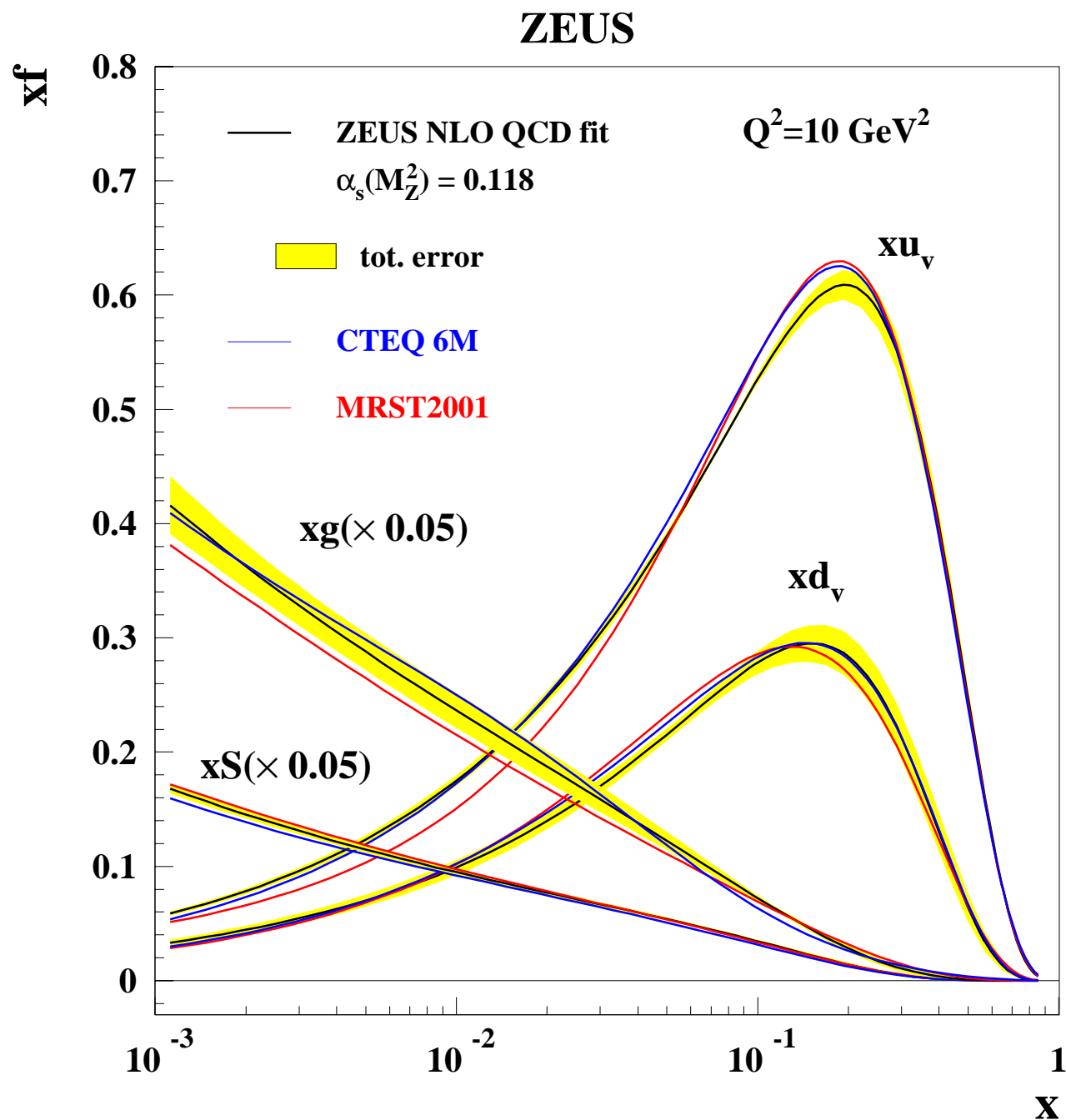
Not always Gaussian

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 ± 0.004 from ren. scale

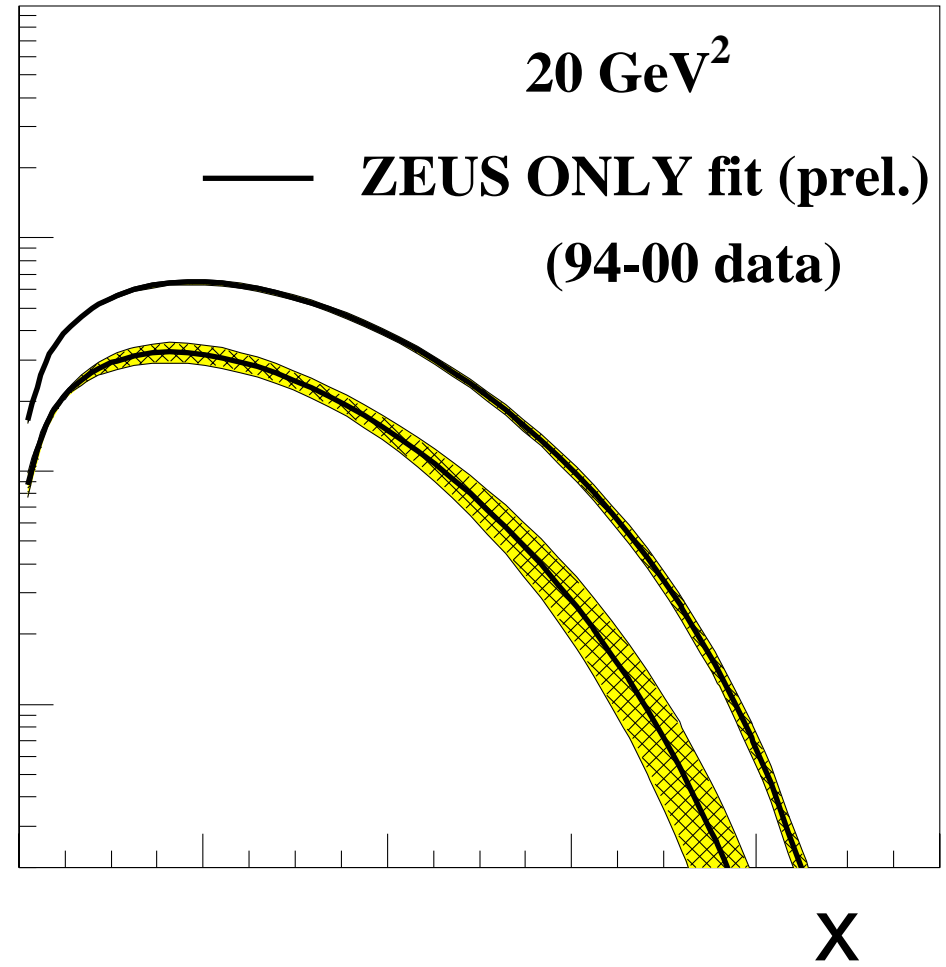
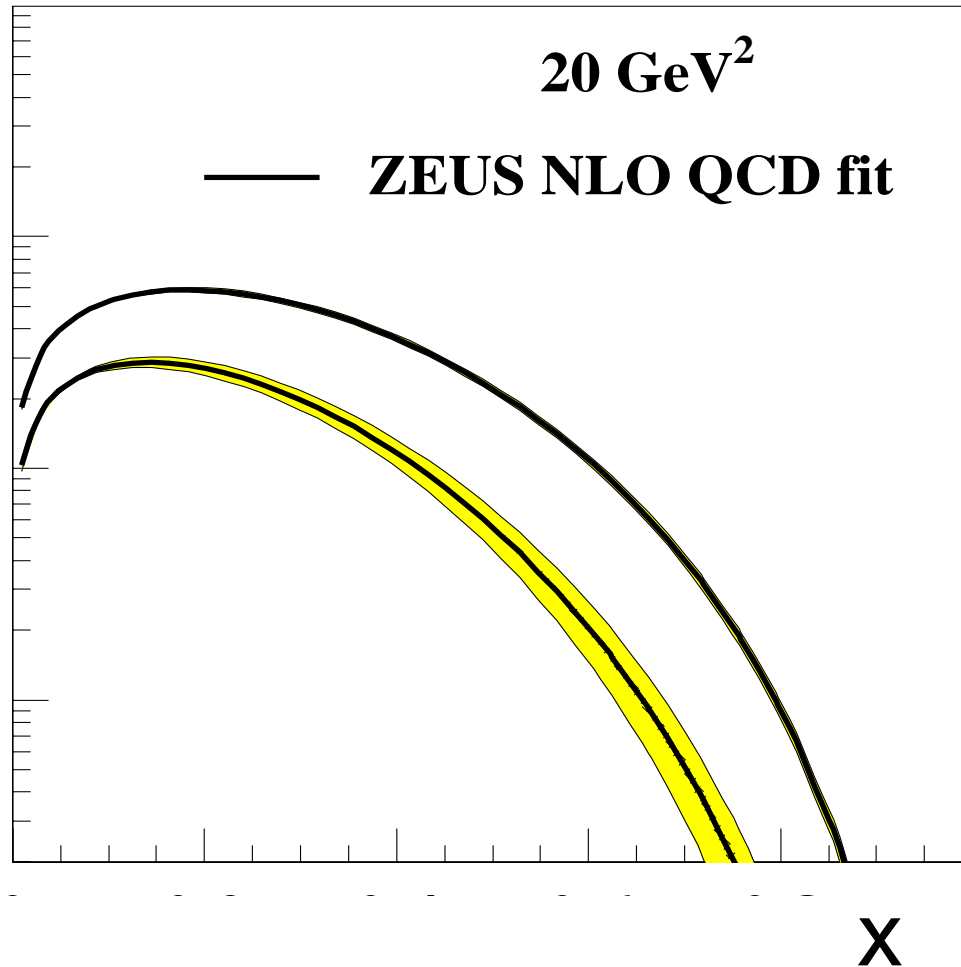


Valence Quarks from **One** Experiment:

ZEUS only, i.e. F_2

HERA-I: high- Q^2 NC/CC

ZEUS + fixed target



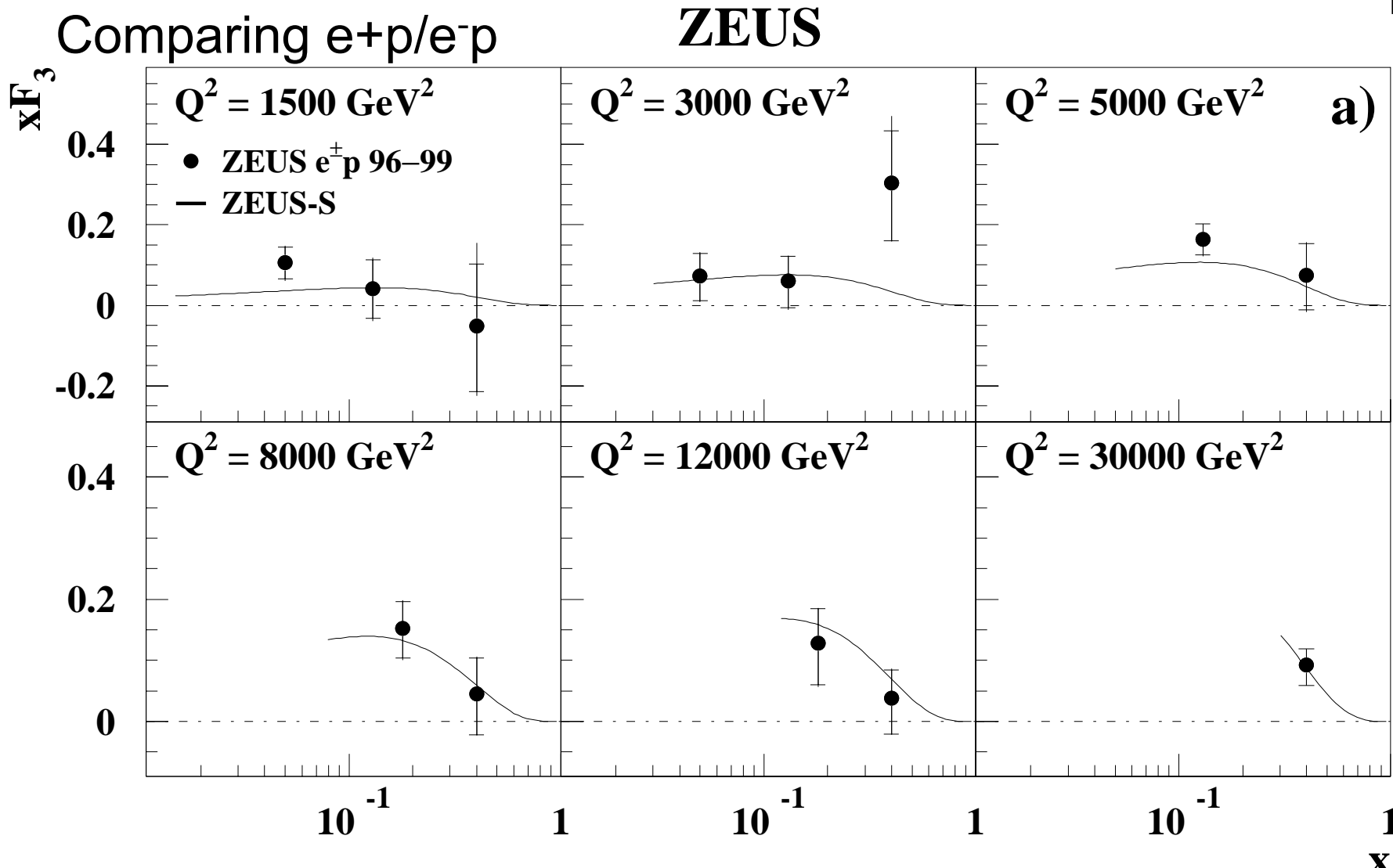
u better known than d , d can be fixed by high- Q^2 CC,
no need to discuss deuterium binding corrections in fixed target data
... hardly need fixed target data

Parity Violating Part of the Proton Structure Function

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

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

First measurement
Need more luminosity with **e-p**



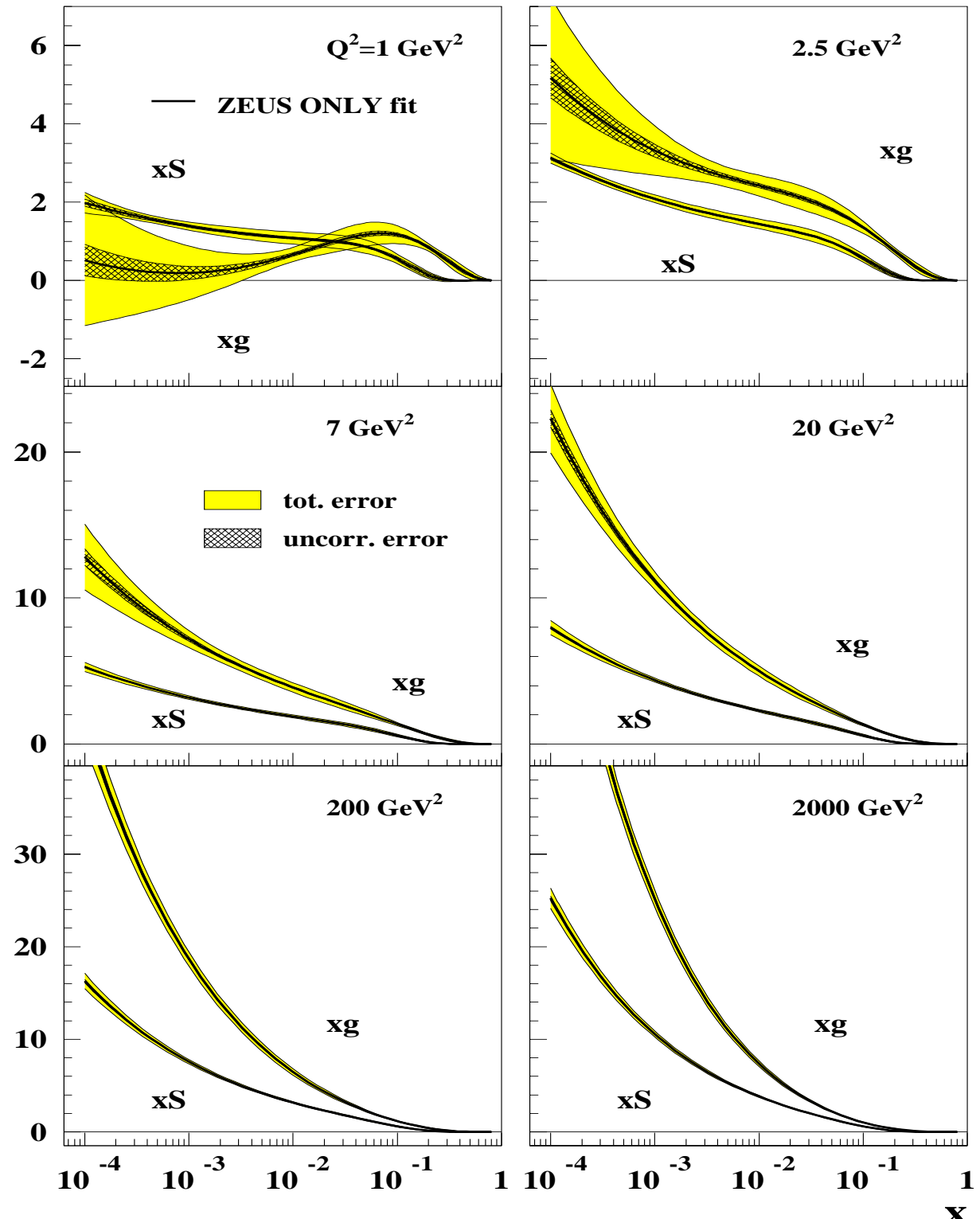
Gluon Density

Greatly improved precision !

- Gluon known within 20% for $Q^2 > 20 \text{ GeV}^2$ and $10^{-4} < x < 10^{-1}$ by ZEUS only
considerable uncertainty for $x > 0.1 \rightarrow$ include jets !
- Gluon valence-like or even negative for $Q^2 \rightarrow 0$:
end of applicability of DGLAP ?
Fitted F_L also negative
direct determination of F_L would provide additional independent information
 \rightarrow lower HERA E_p or use ISR

xf

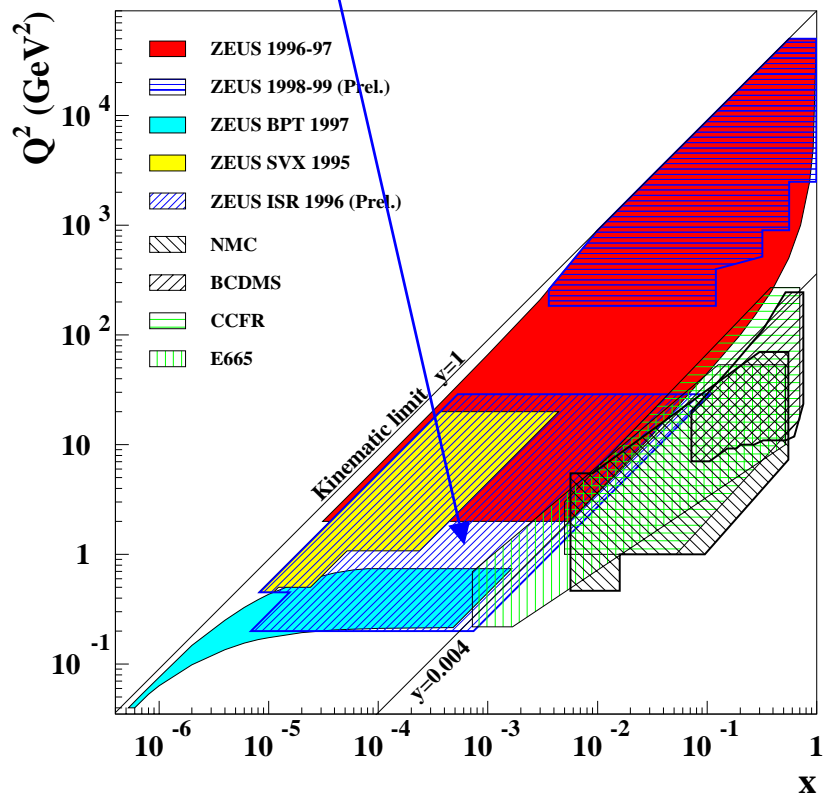
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New F_2 Points at low Q^2 : ISR Analysis

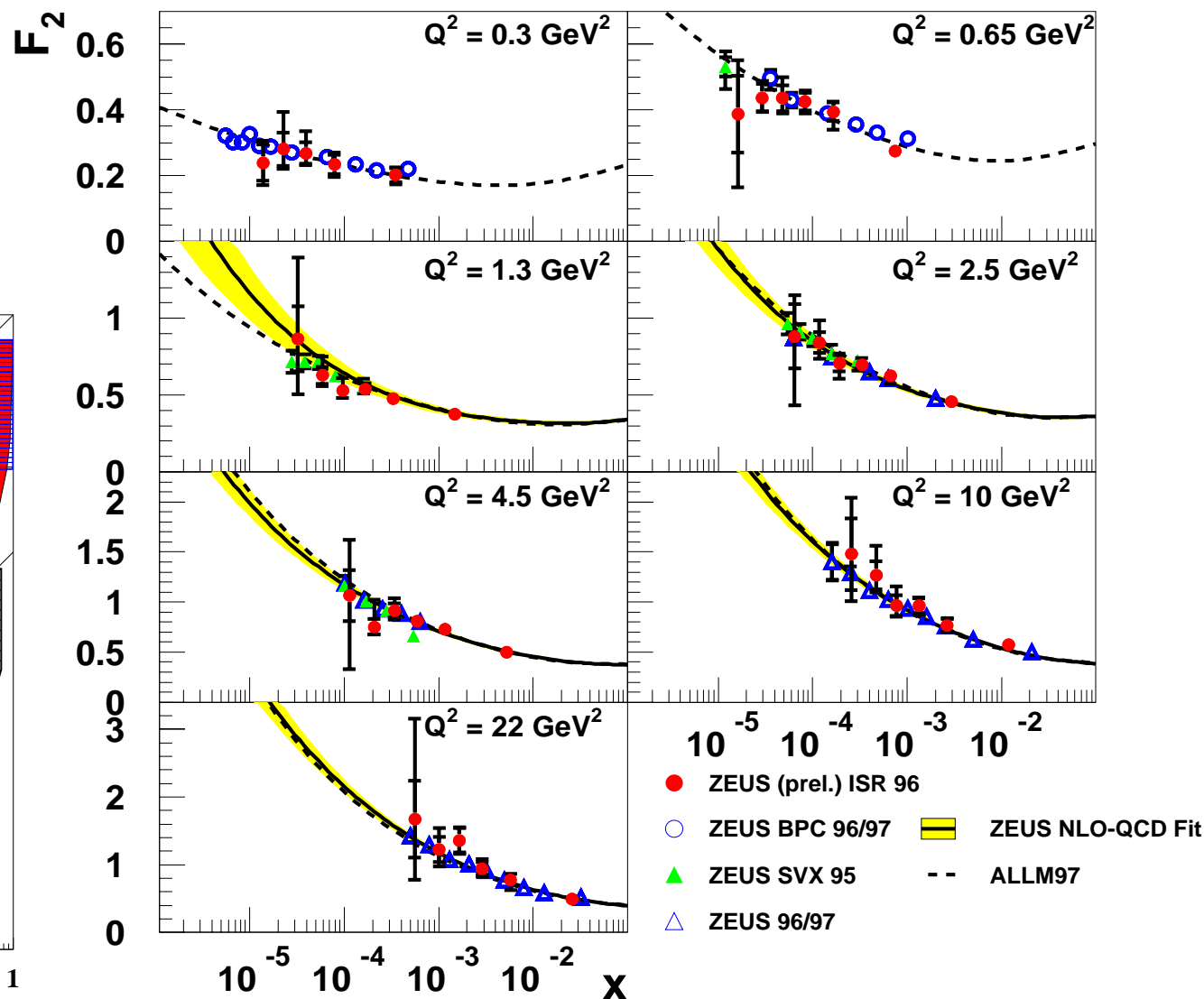
ISR lowers electron energy
difficult analysis: need
precise knowledge of
Bethe-Heitler overlays

previously unexplored !



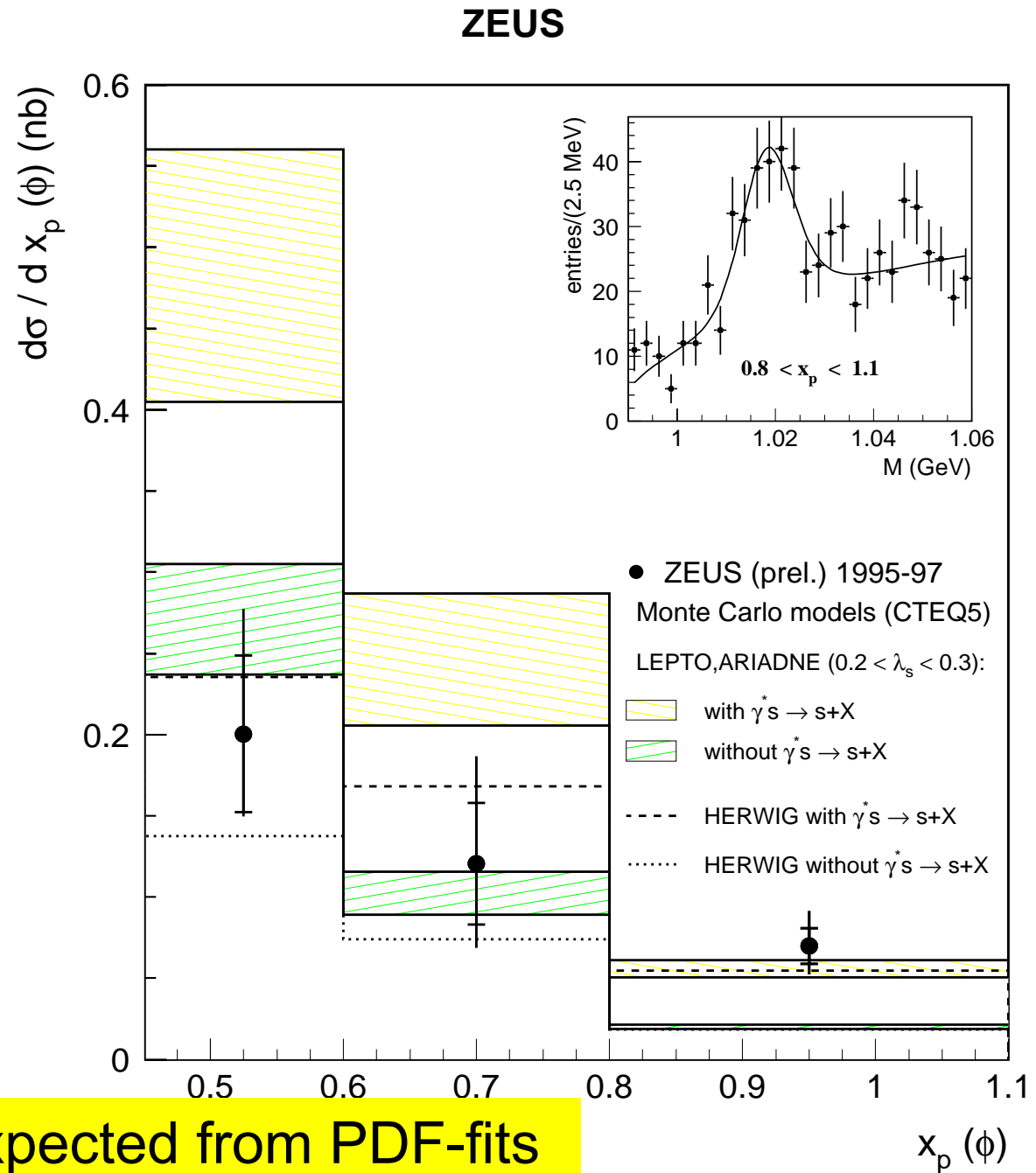
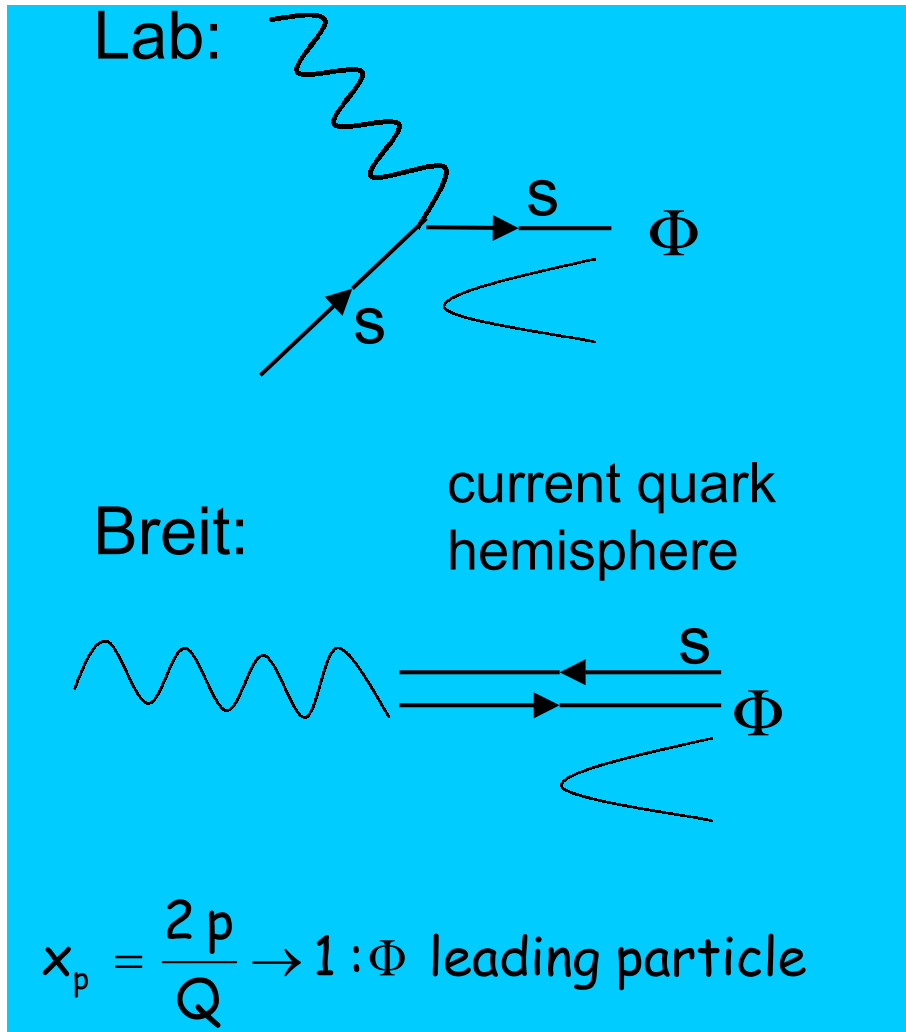
So far only small data set
analysed

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

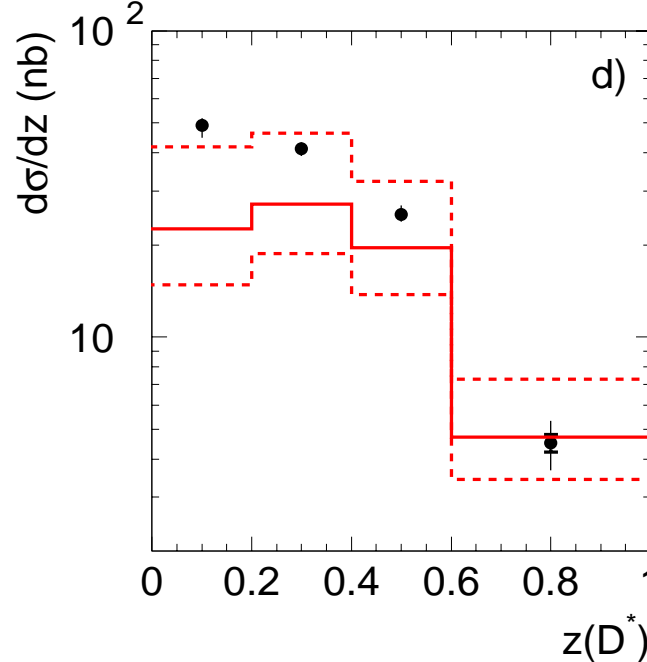
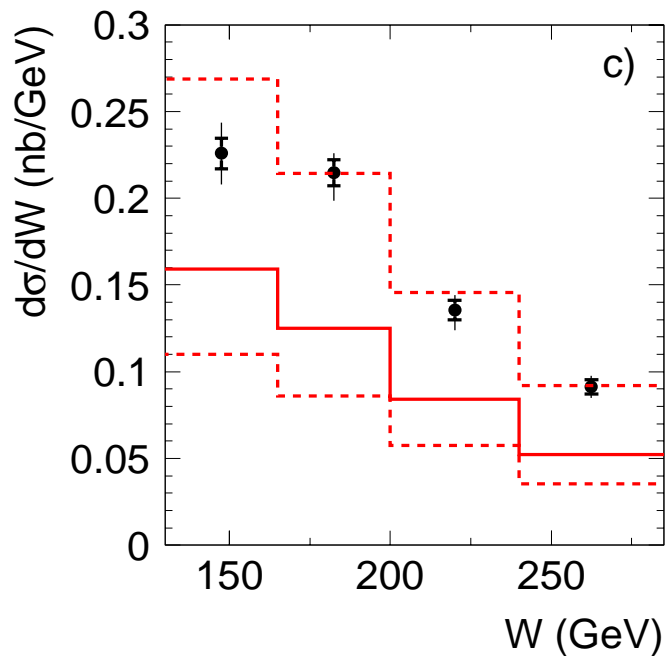
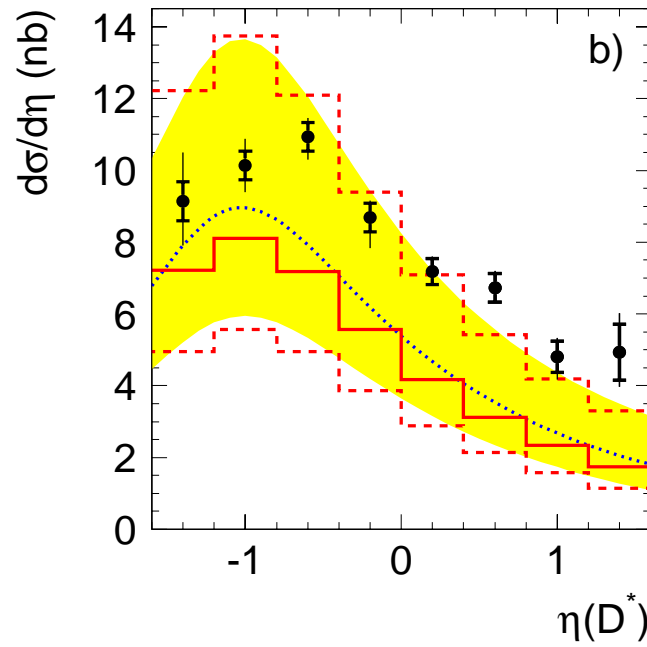
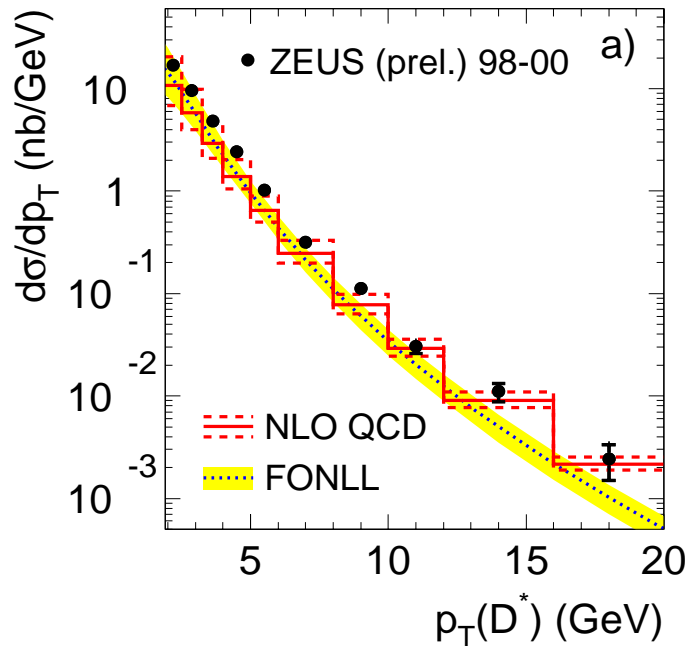
Φ -meson: Access to Strange Sea ?



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

Charm: D^* Cross Sections in γp Collisions

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central NLO

significantly below data
largest disagreement:

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

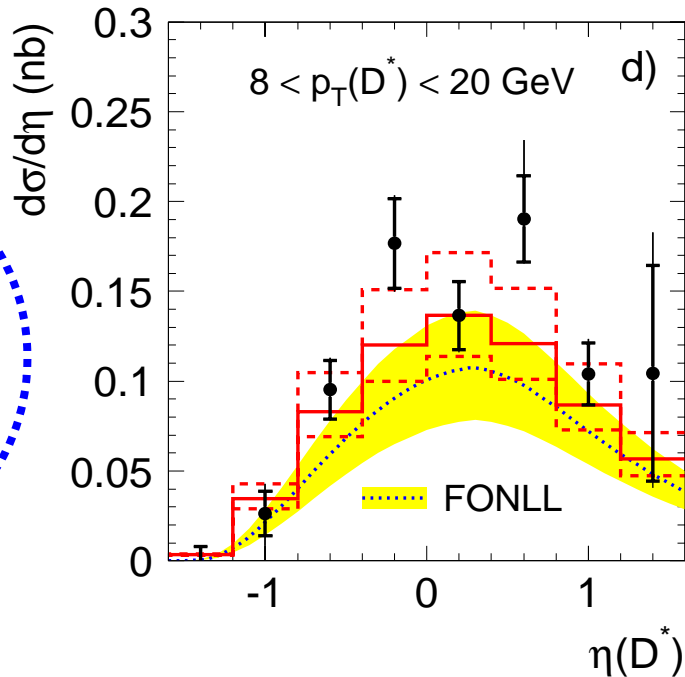
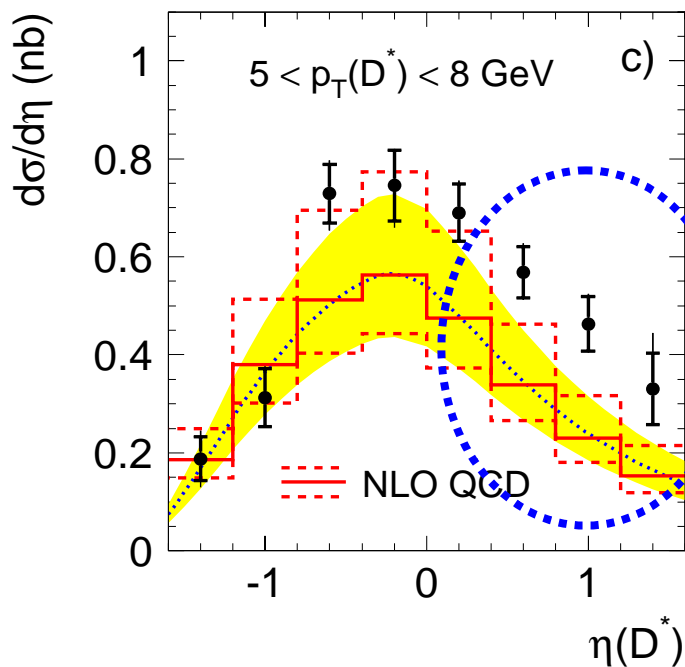
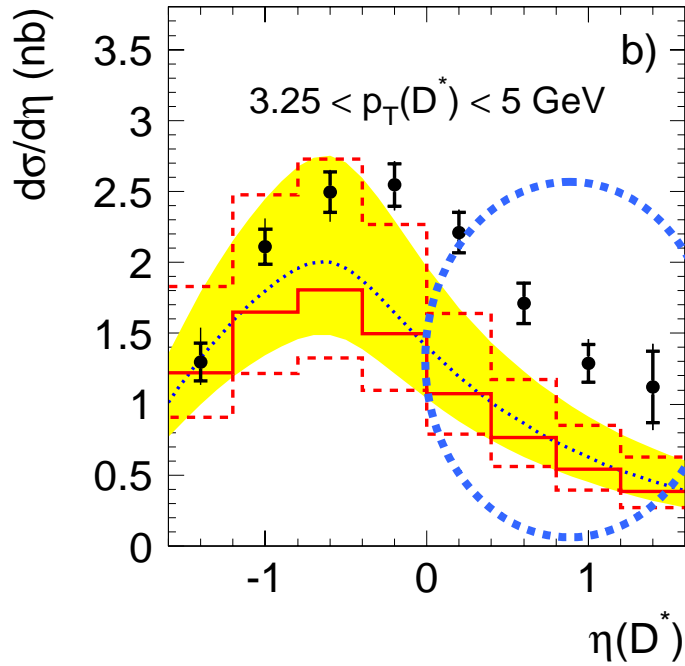
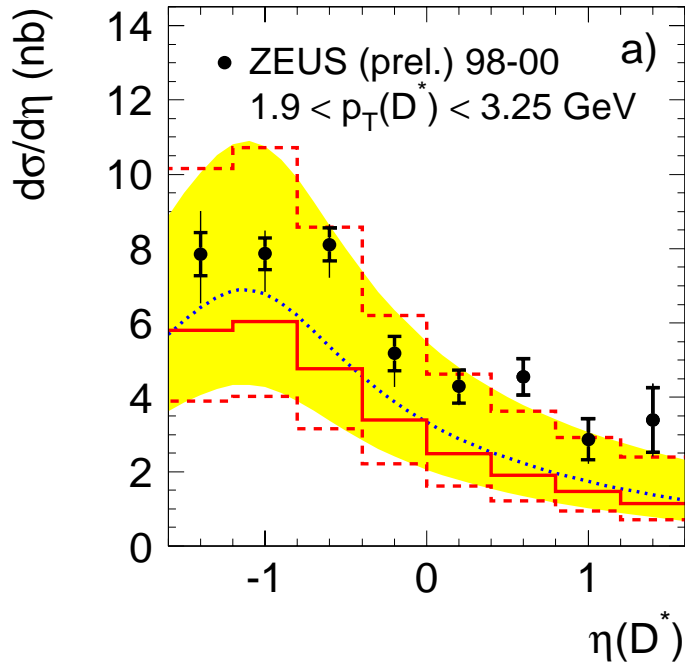
major exp. progress:
data errors smaller
than theory errors !

FONLL:

massive NLO QCD
plus resummation
of NLO logs not better

Need better theory

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Central NLO

significantly below data
 largest disagreement:

- medium $p_{T,D}$
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major exp. progress:
 data errors smaller
 than theory errors !

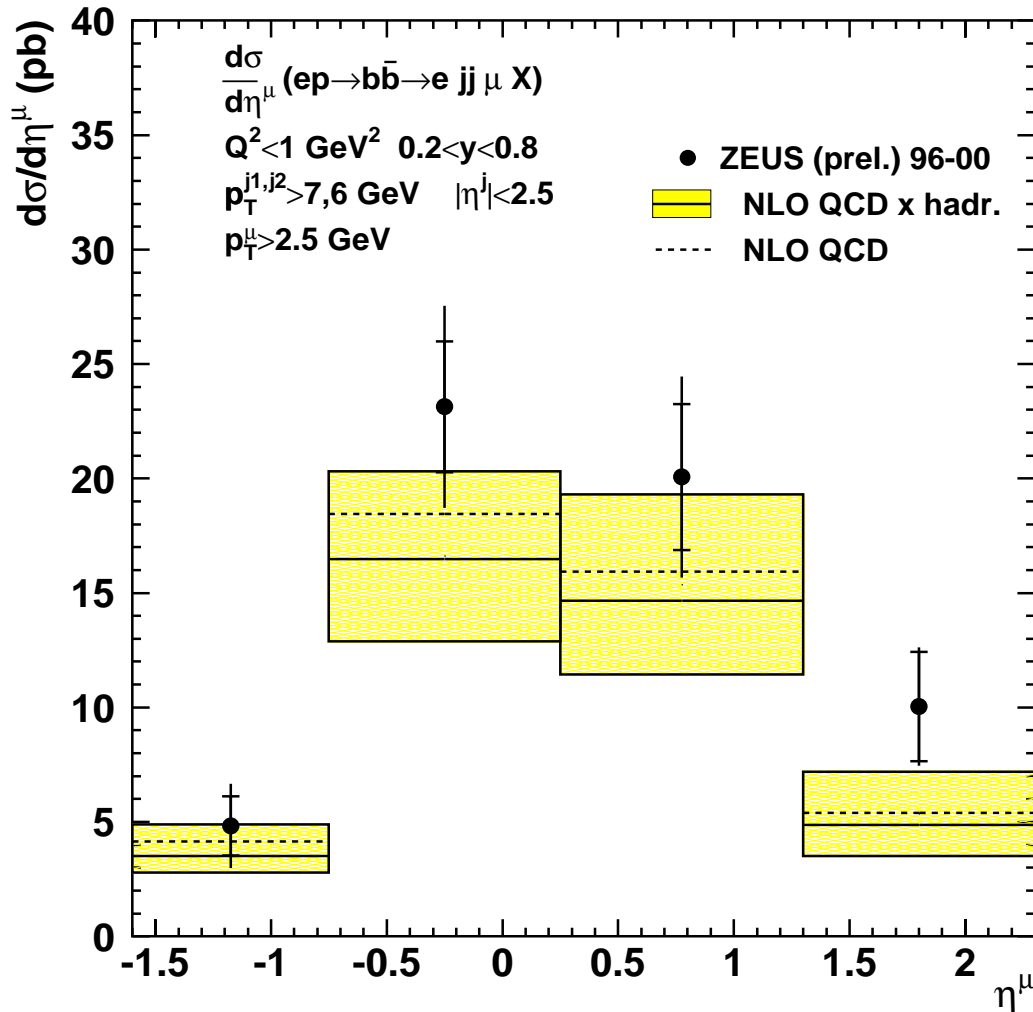
FONLL:
 massive NLO QCD
 plus resummation
 of NLO logs
 not better

Beauty in γp Collisions - semi-leptonic μ -decay

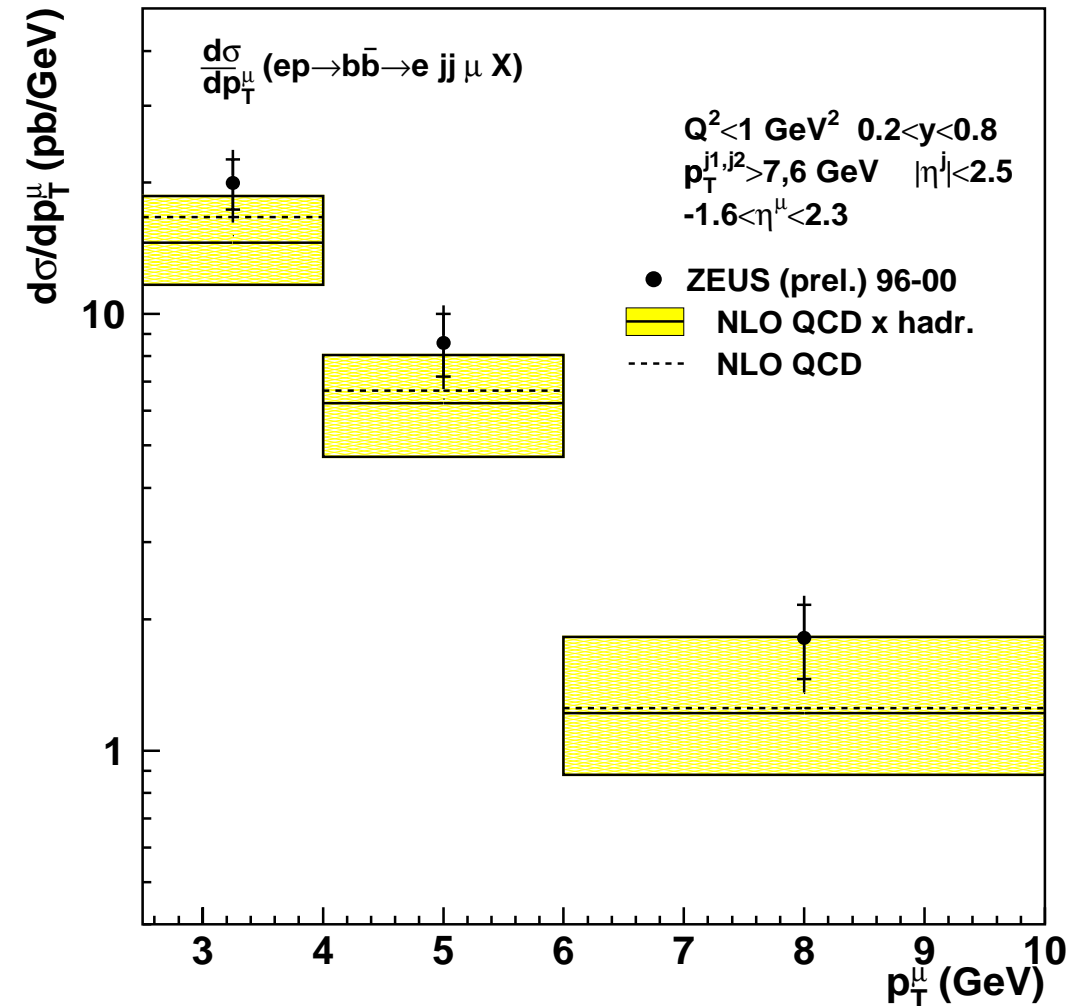
Full HERA-I data set -> data error \sim theory errors

Visible beauty cross-section: $ep \rightarrow e + \text{jet} + \text{jet} + \mu + X$

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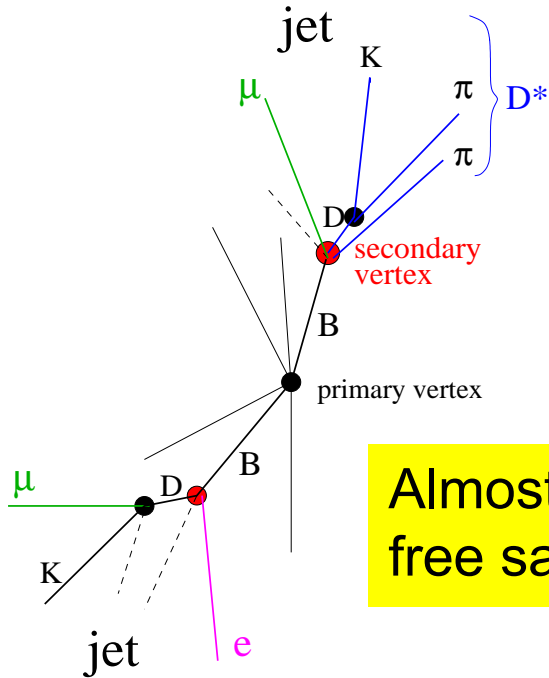


data/theory ~ 1.4 , but compatible within exp/theo uncertainty !

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

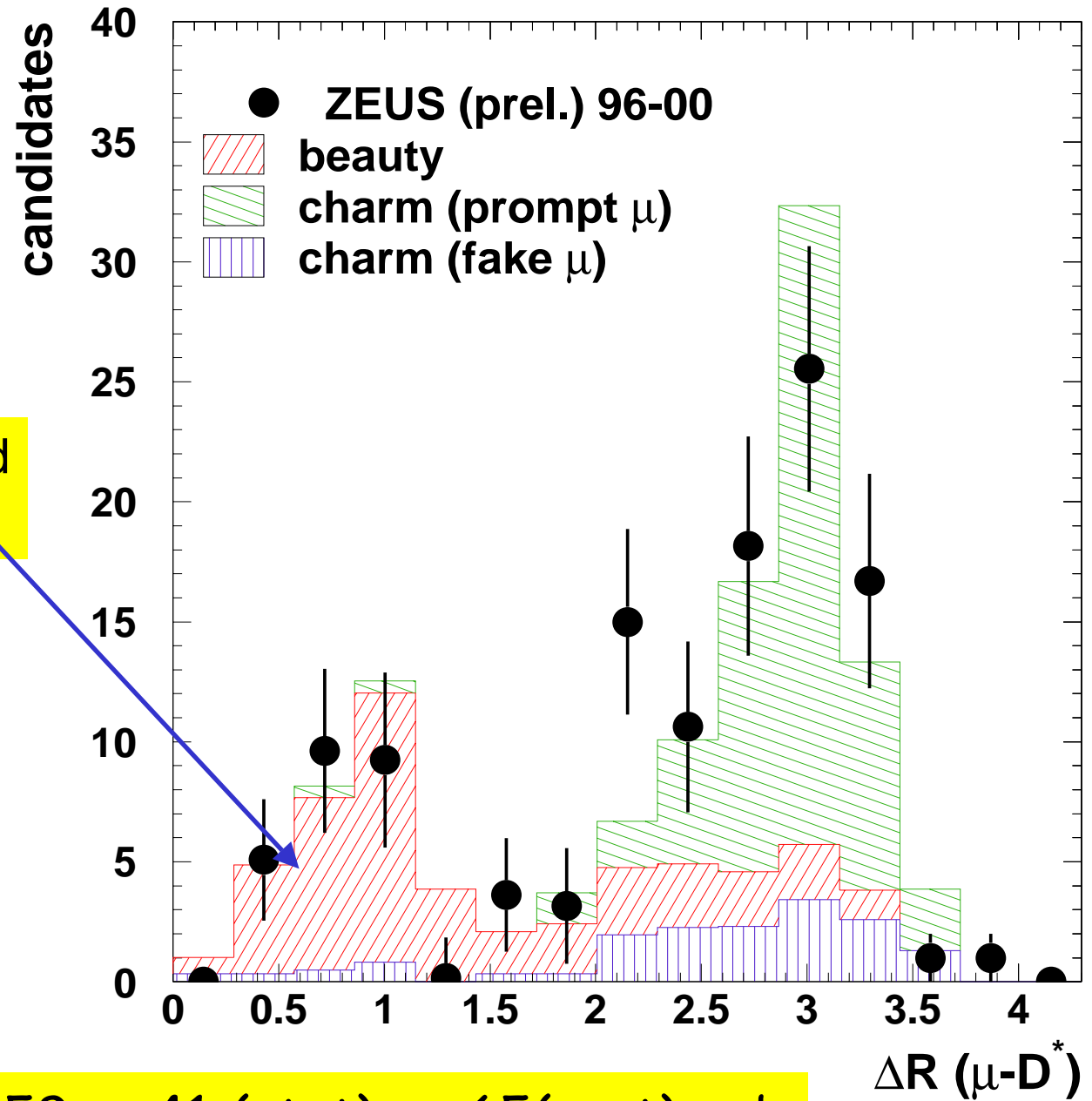
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Full HERA-I data set:



Almost background free sample !

Gives access to low p_T study b close to kin limit



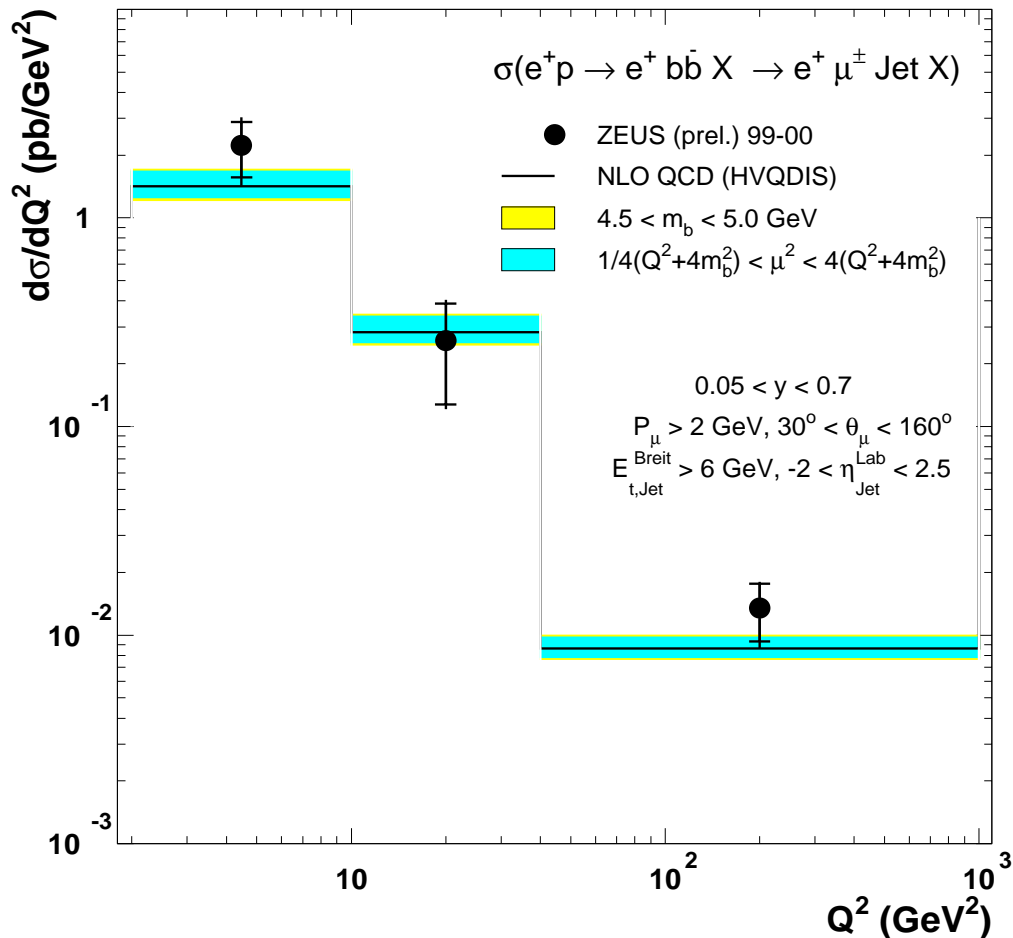
$$\sigma(\gamma p \rightarrow b\bar{b} X \rightarrow D^* \mu X) = 159 \pm 41 (\text{stat}) \pm 65 (\text{syst}) \text{ pb}$$

Beauty in DIS - semi-leptonic μ -decay

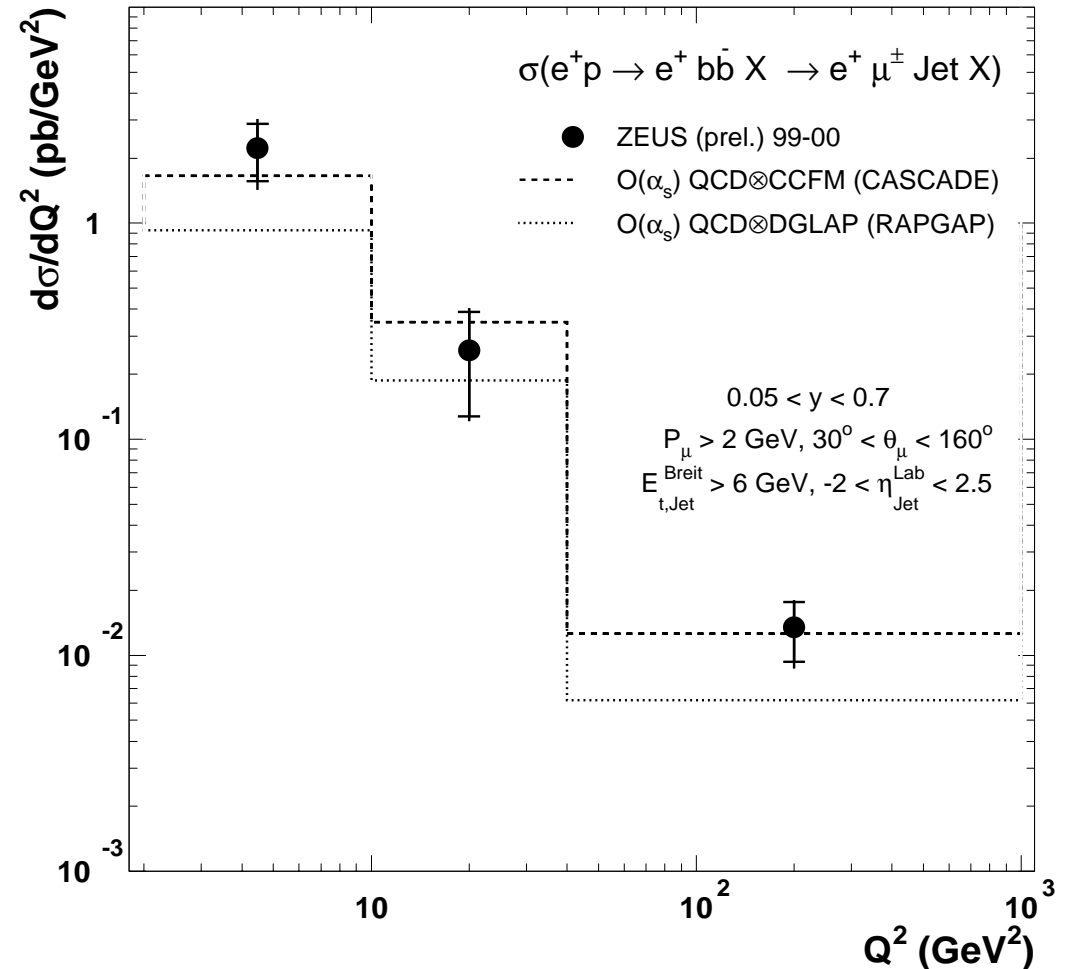
First time differential distributions ($L \sim 60 \text{ pb}^{-1}$)

In Breit frame: **Visible** beauty cross-section: $ep \rightarrow e + \text{jet} + \mu + X$

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NLO agrees within uncertainties, LO+CCFM perfect

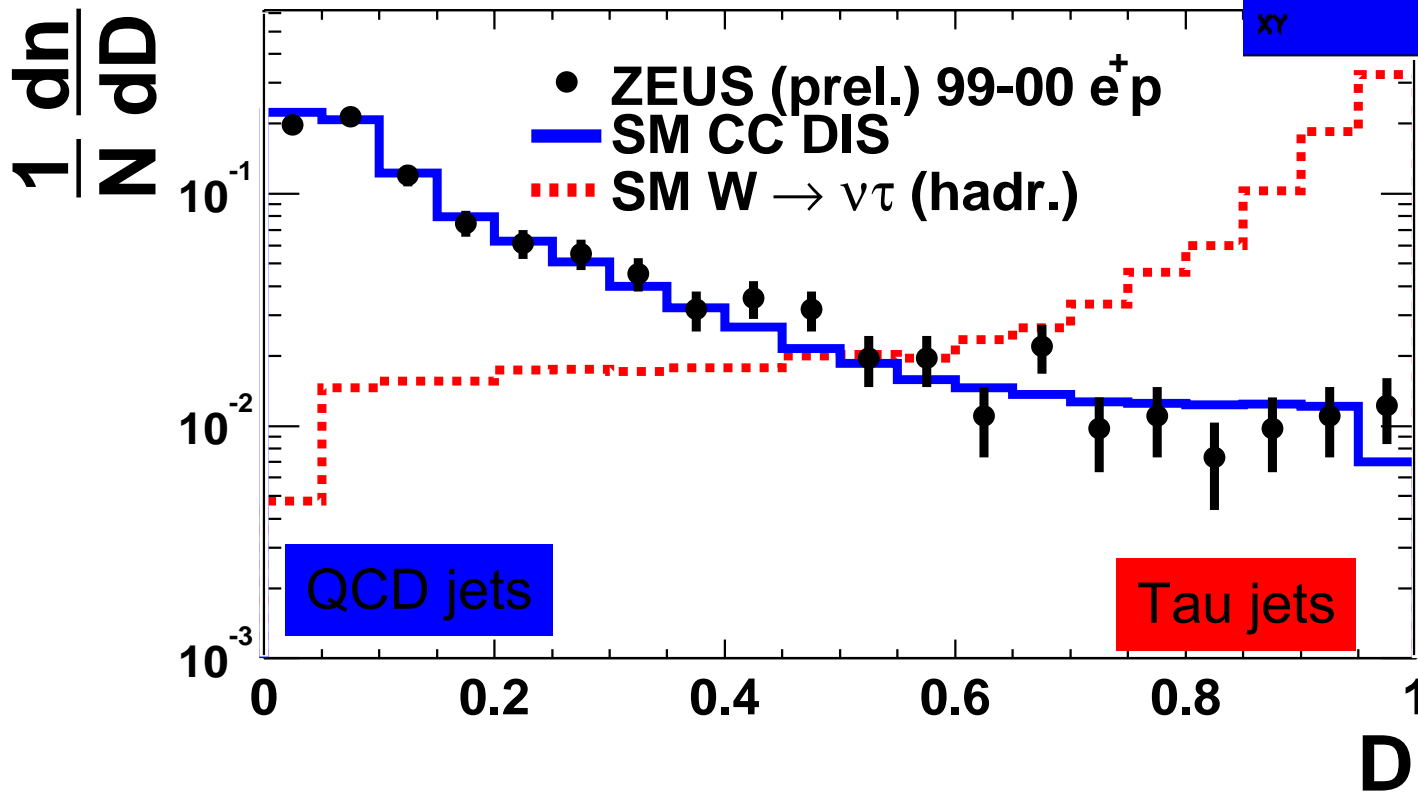
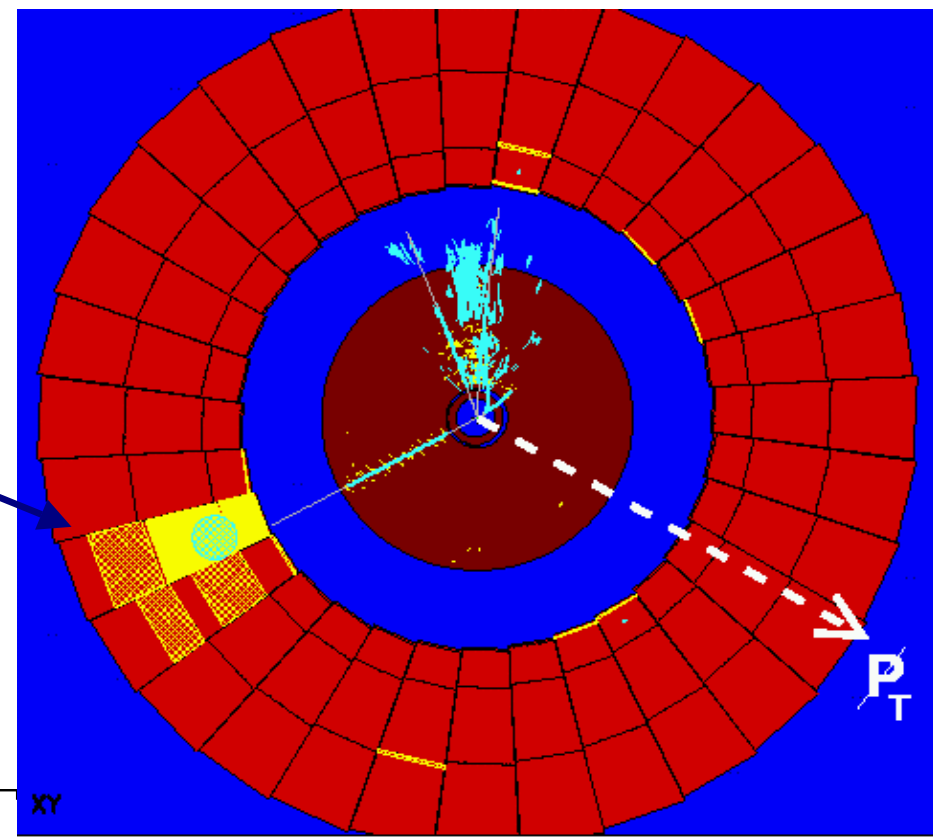
B-puzzle solved !?

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 $W \rightarrow \nu\tau$ sample:

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Good separation
tau efficiency $\sim 25\%$
bg rejection ~ 550

Search for Isolated Tau-Leptons and Missing Pt

Event selection:

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

4 events found !

3 are compatible with
tau hypothesis, i.e.

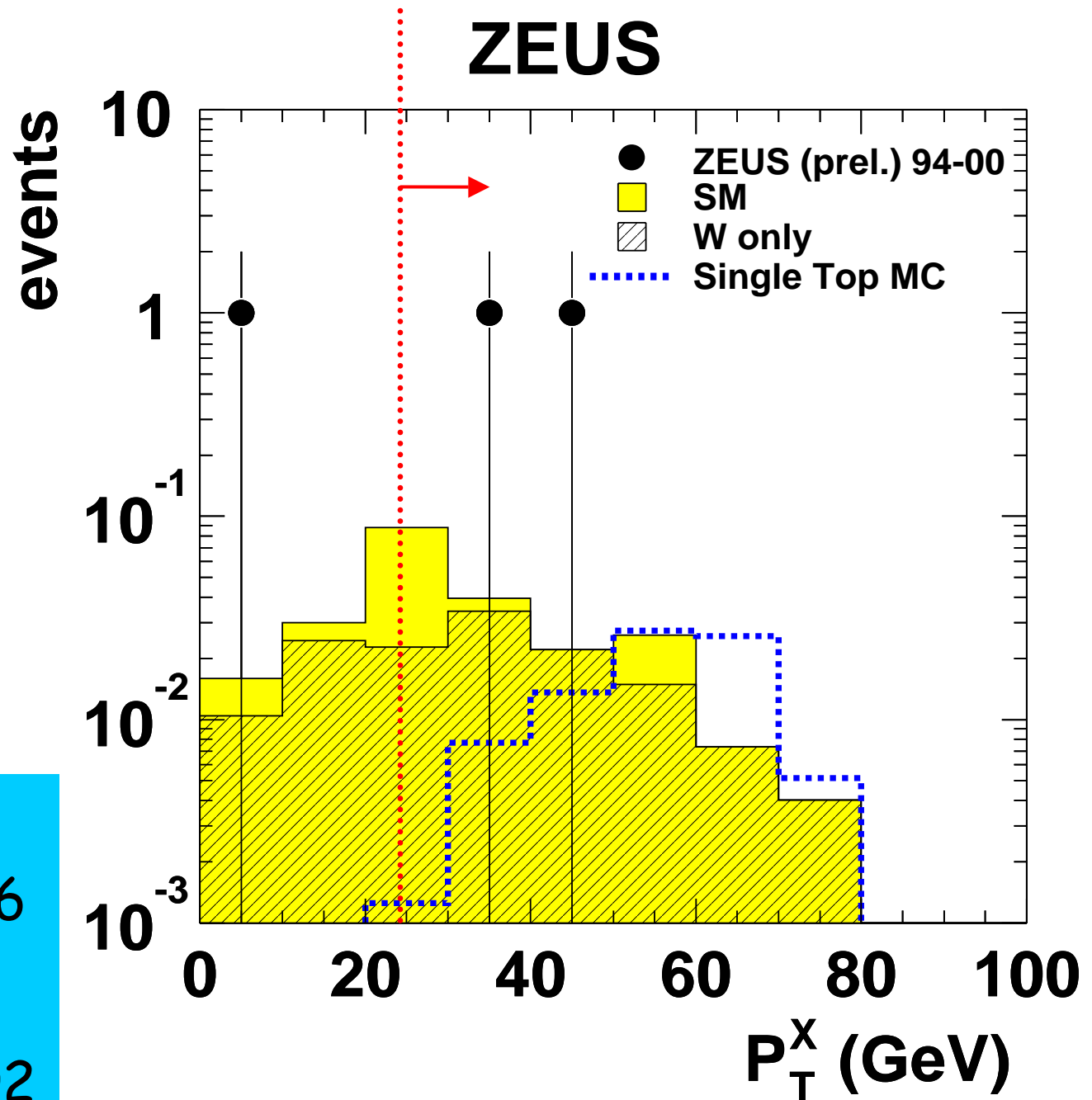
Discriminant $D > 0.95$

$D > 0.95$:

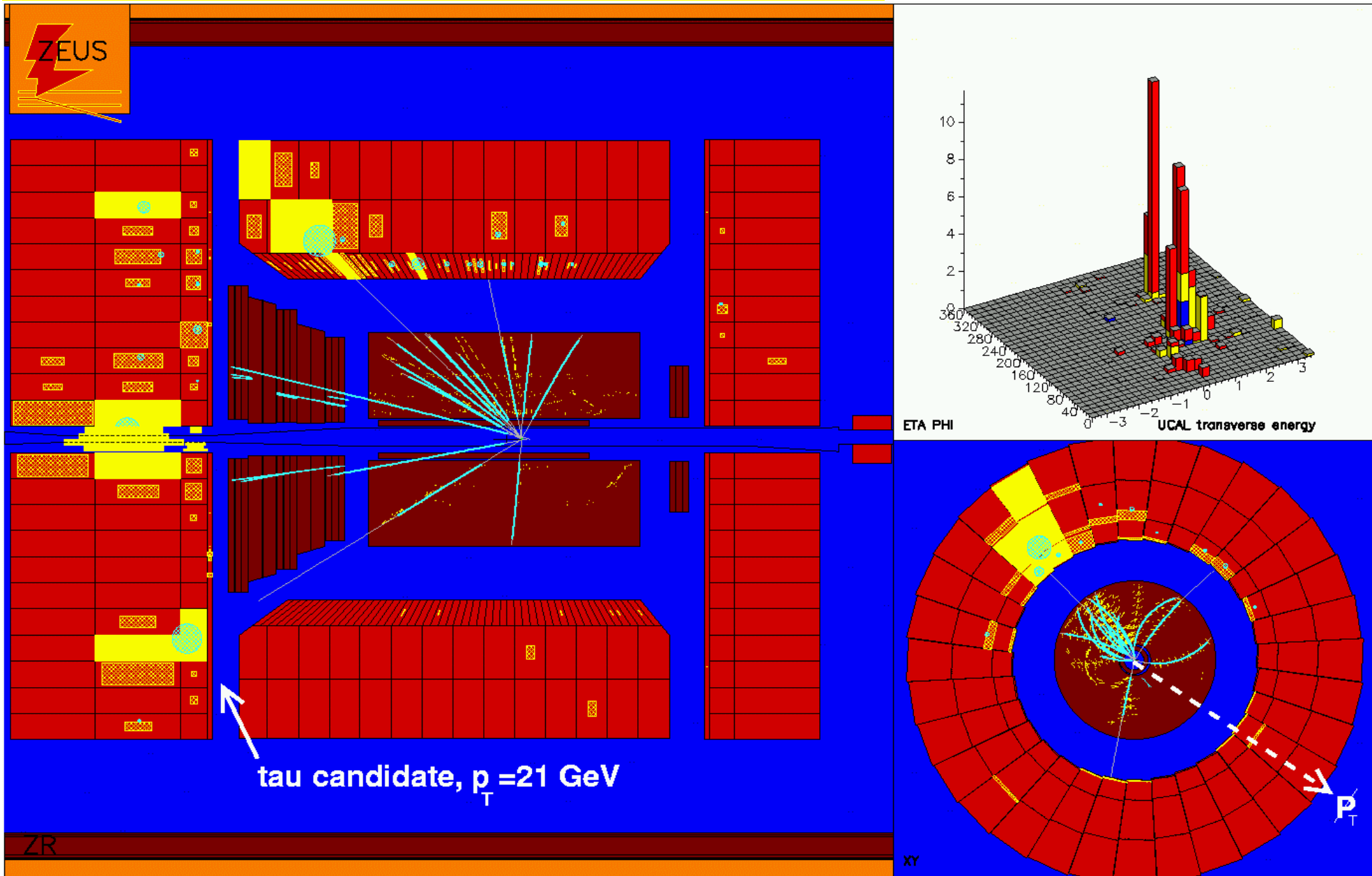
data : 3 SM : 0.23 ± 0.06

$P_T^X > 25 \text{ GeV}$:

data : 2 SM : 0.12 ± 0.02

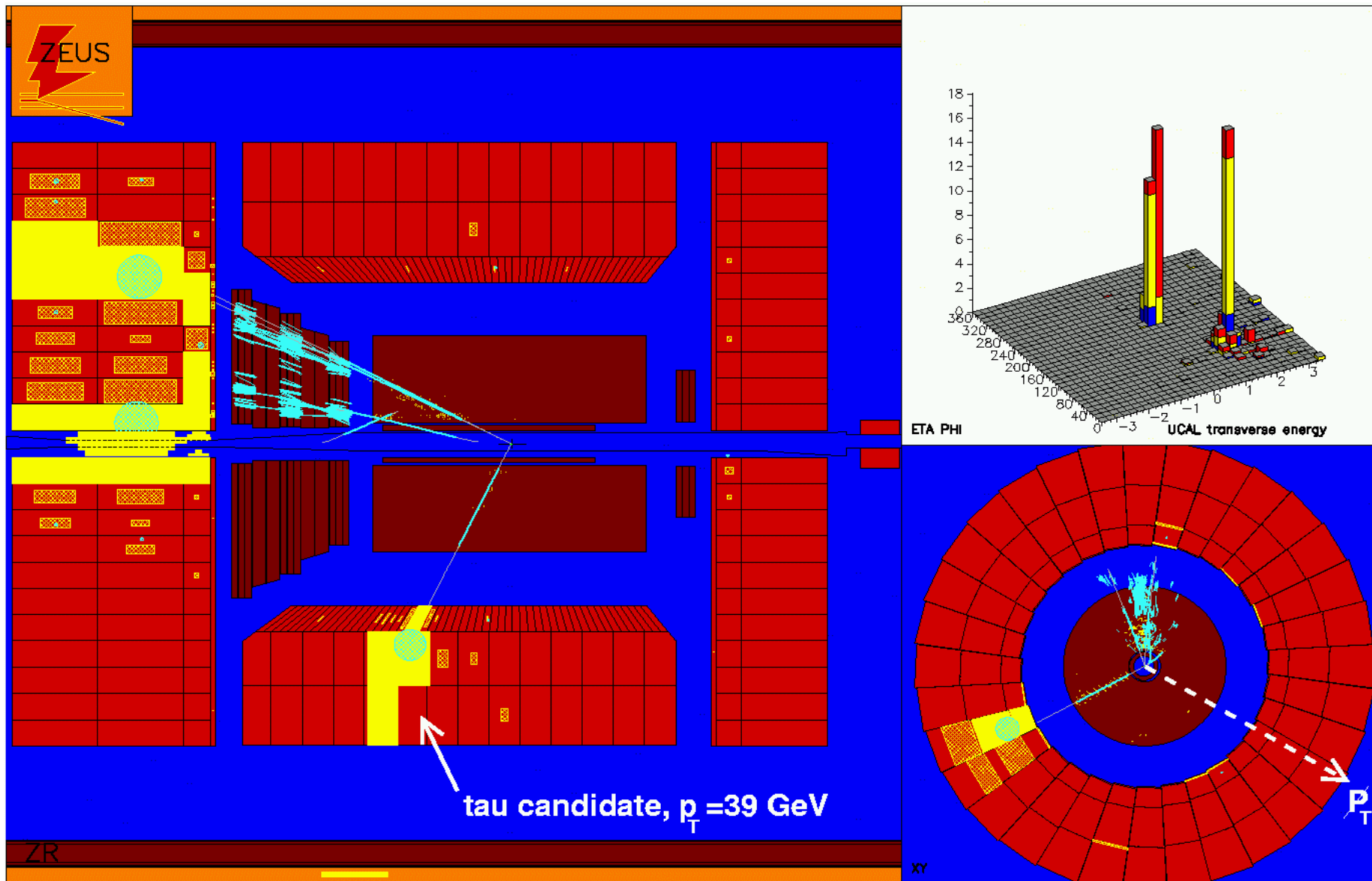


Tau-1 Candidate



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

Tau-2 Candidate



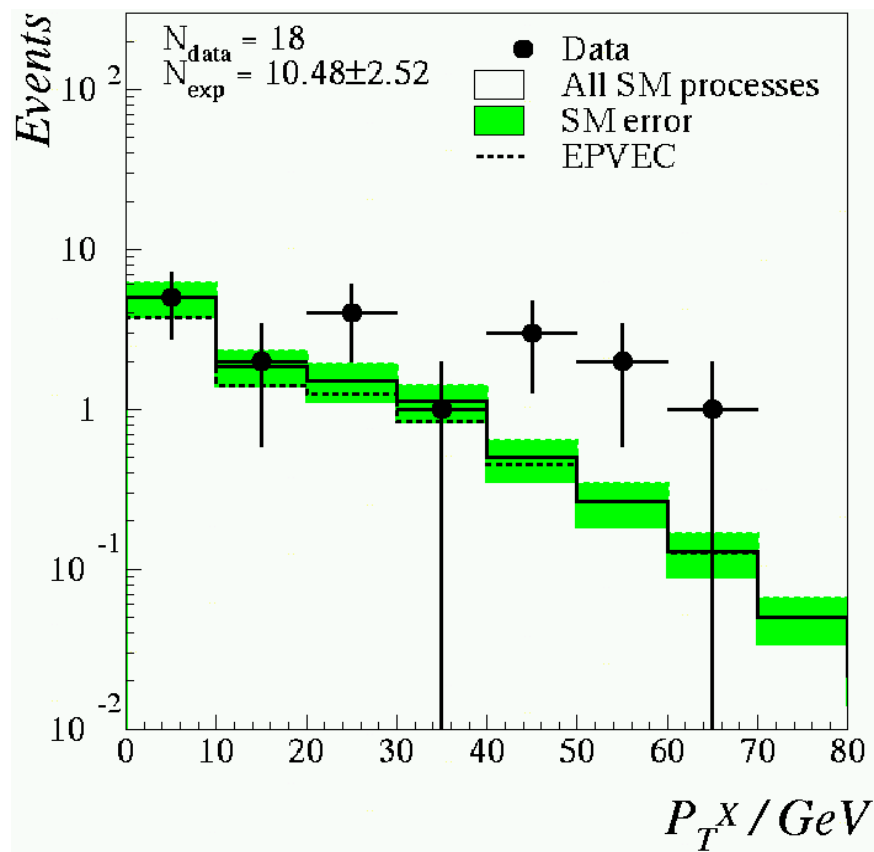
$$P_T^{CAL} = 39 \text{ GeV} \quad P_T^X = 37 \text{ GeV} \quad M_T = 68 \text{ GeV}$$

Status: Isolated Lepton Events at HERA I

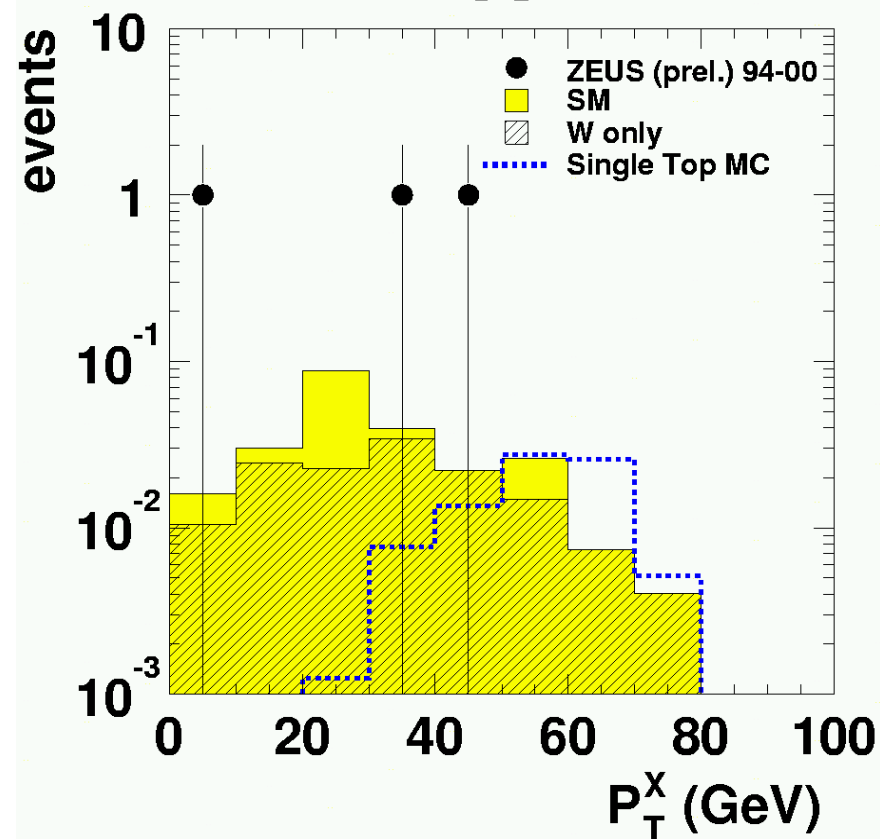
H1 preliminary 94-00 e^+p (101.6 pb $^{-1}$)	Electron obs./exp. (W)	Muon obs./exp. (W)
$P_T^X > 25$ GeV	4 / 1.29 ± 0.33 (1.05)	6 / 1.54 ± 0.41 (1.29)
$P_T^X > 40$ GeV	2 / 0.41 ± 0.12 (0.40)	4 / 0.58 ± 0.16 (0.53)

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)

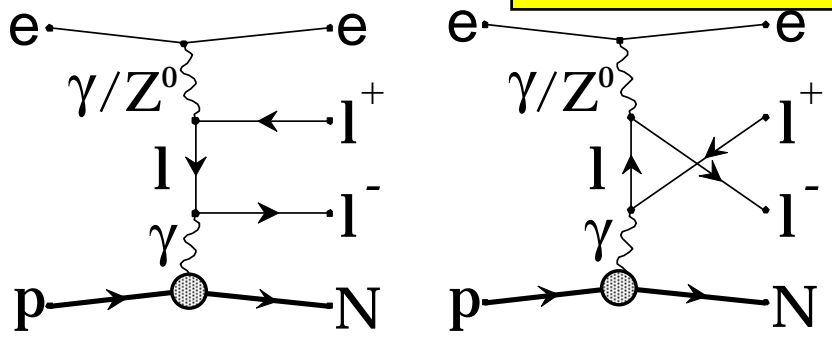


ZEUS (τ events)

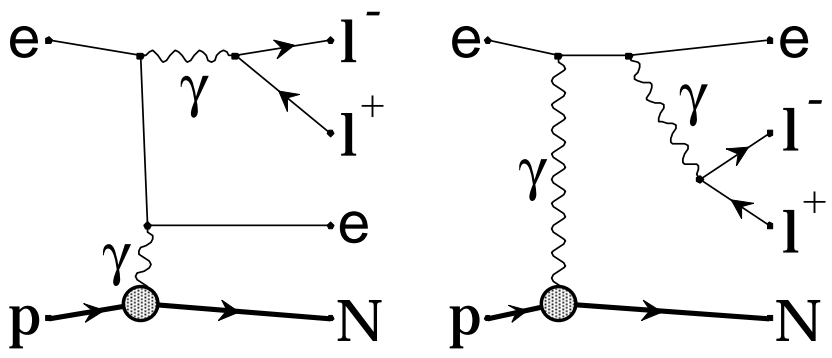


Multi-Electron Events

Grape:



(a) Bethe-Heitler type diagrams



(b) QED-Compton type diagrams + electroweak diagrams

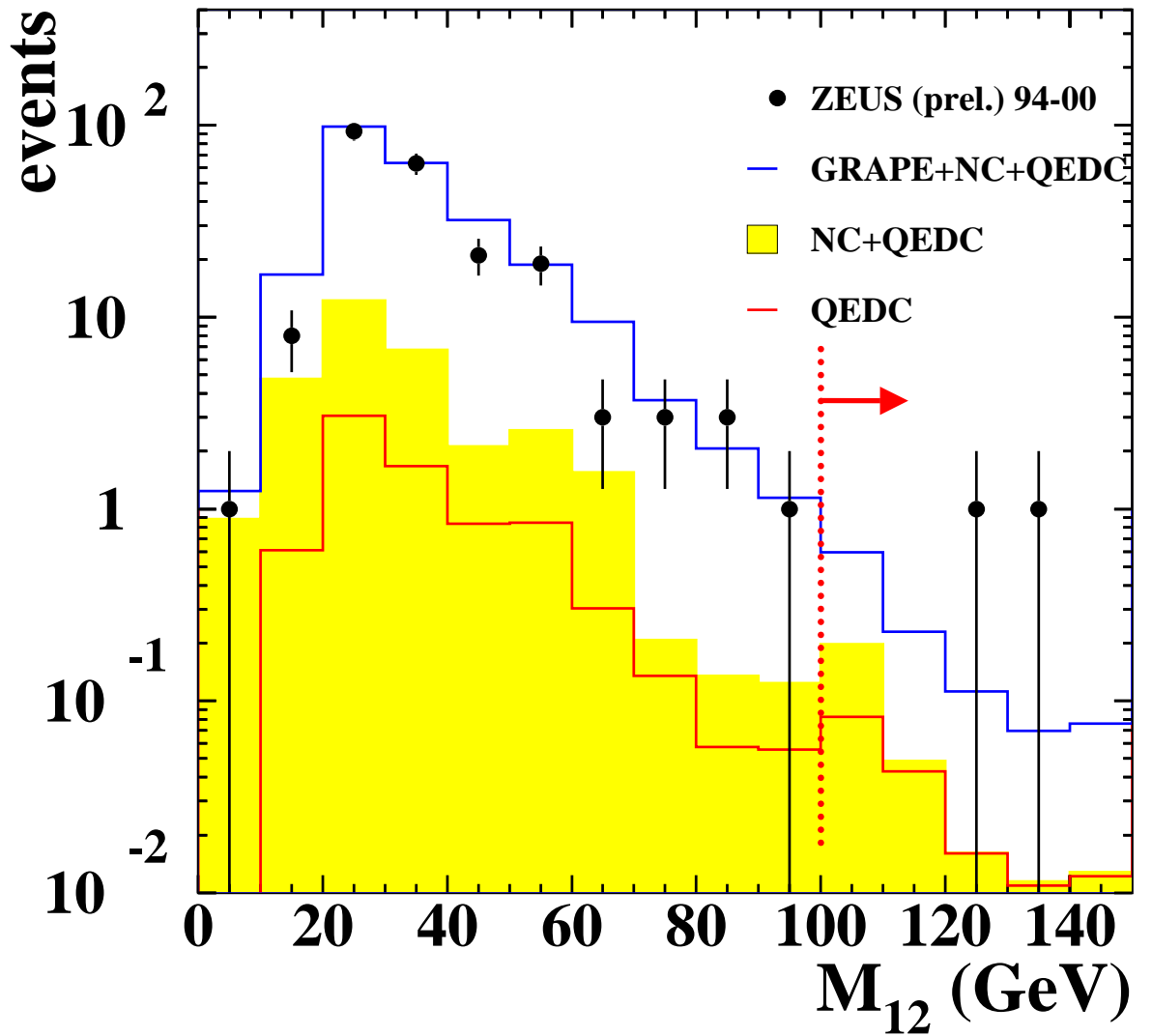
Two electrons : $M_{1,2} > 100 \text{ GeV}$:

Data	SM	GRAPE
2	0.8 ± 0.1	0.5 ± 0.1

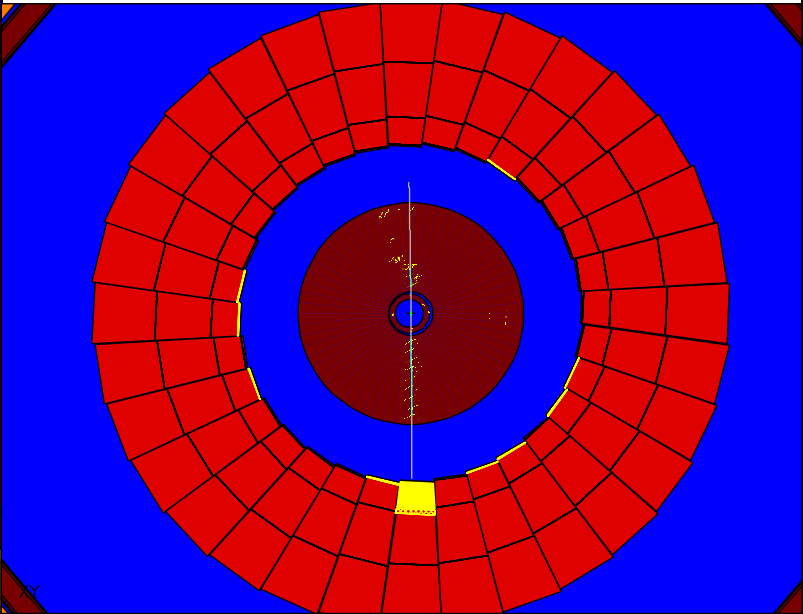
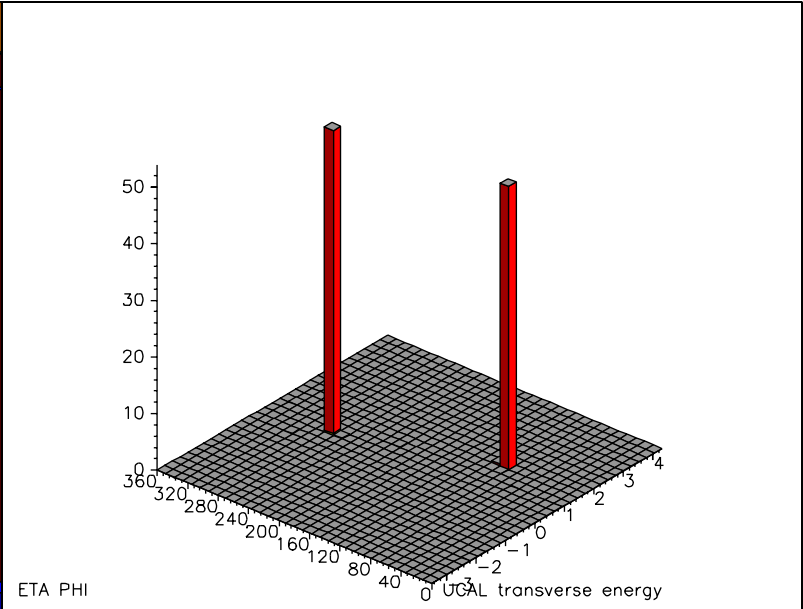
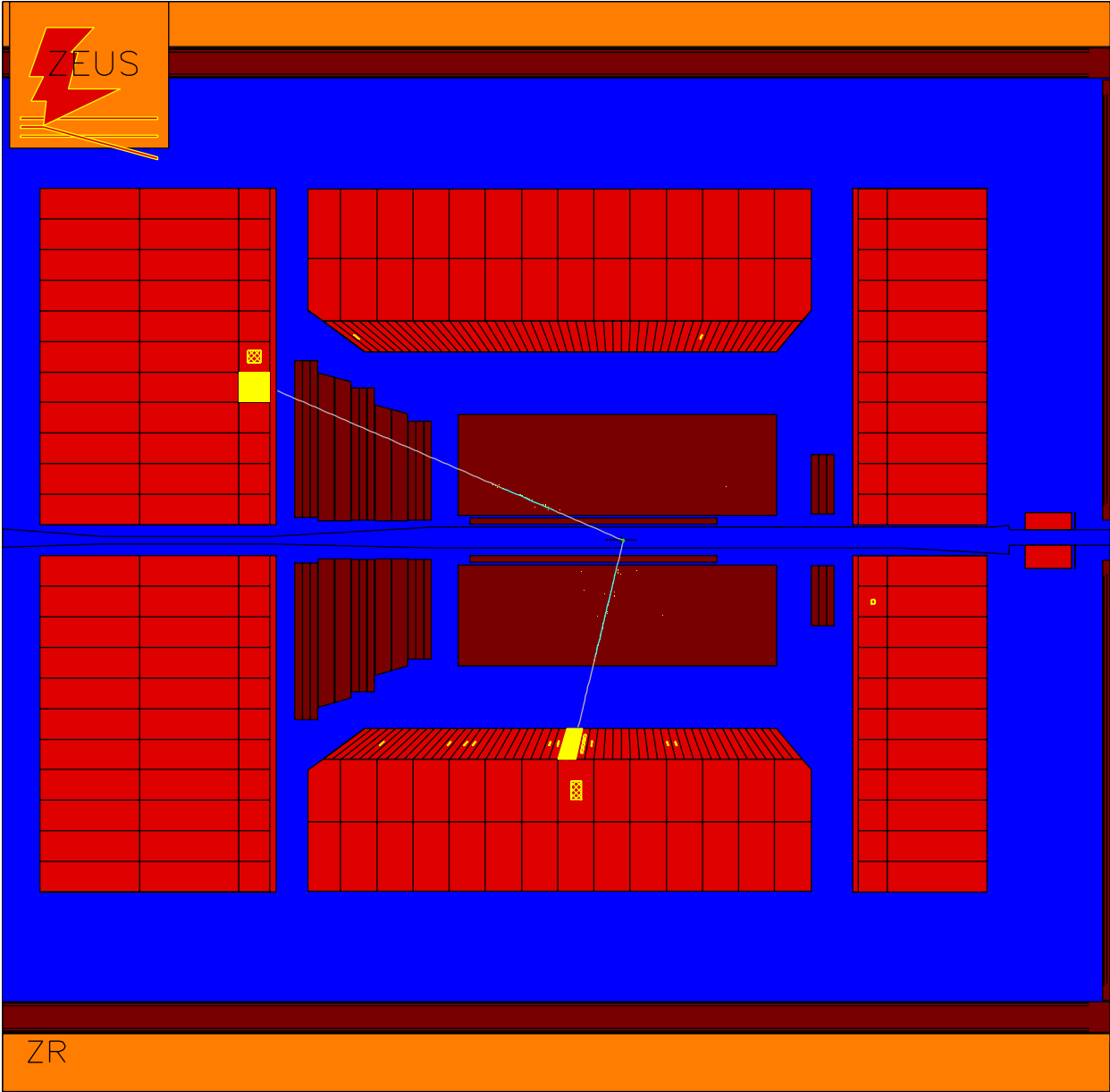
Three electrons : $E_{T,1} > 30 \text{ GeV}$

Data	SM	GRAPE
2	1.4 ± 0.1	1.4 ± 0.1

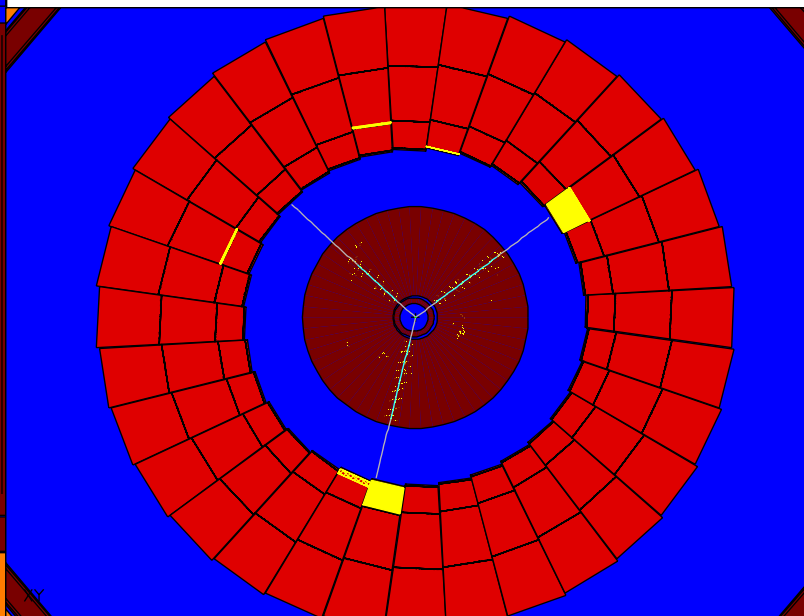
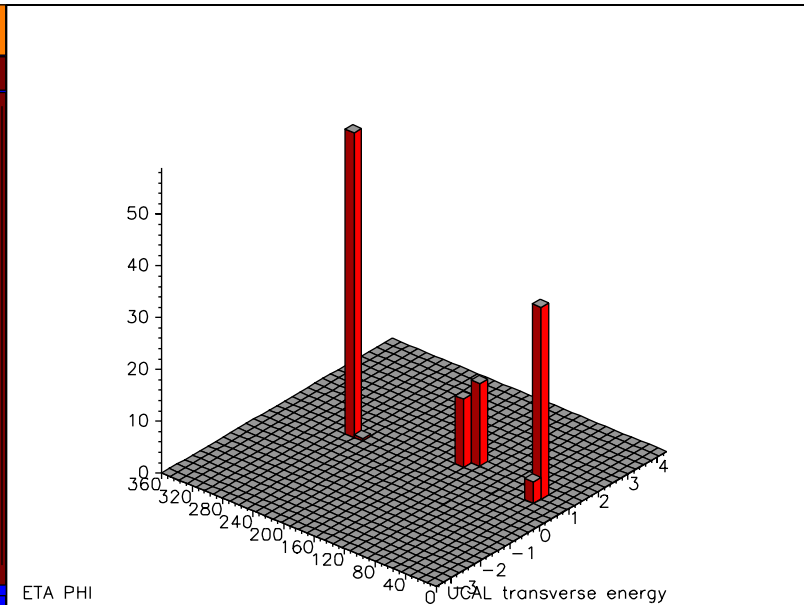
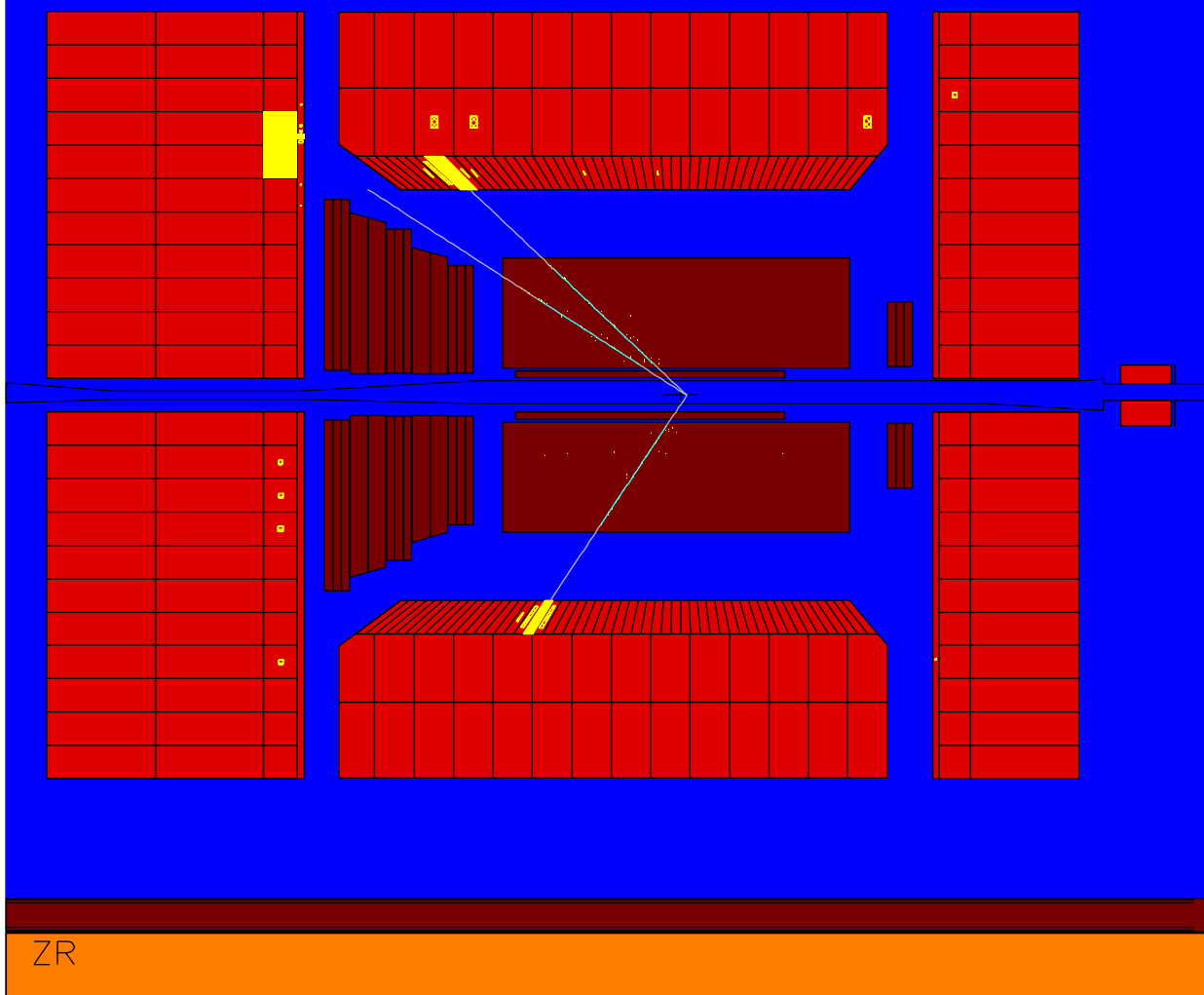
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Overall good agreement
no excess at high mass
in μ -channel no event $M > 100 \text{ GeV}$



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



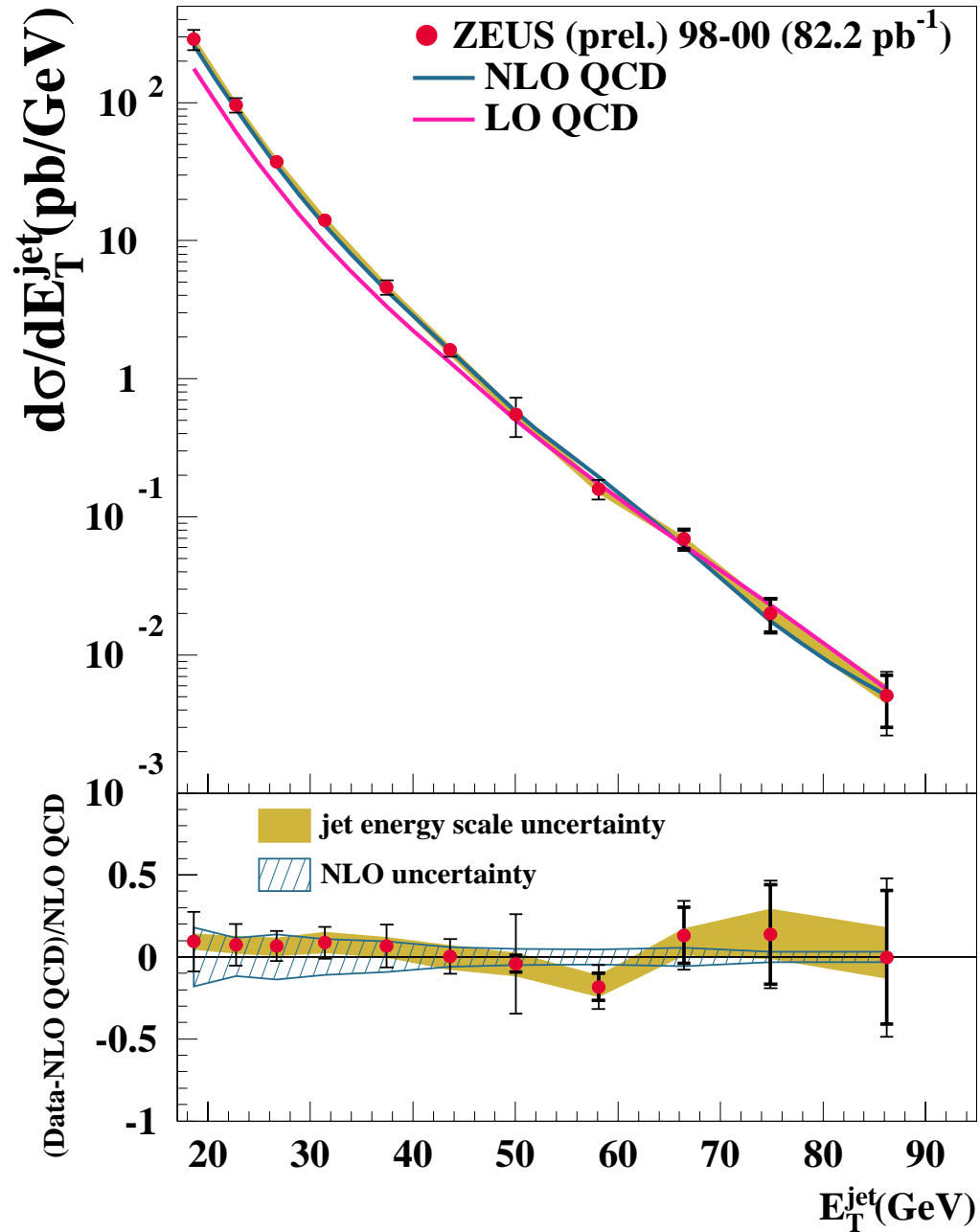
$E_{T1} = 52 \text{ GeV}$ $\theta_1 = 1.0 \text{ rad}$
 $E_{T2} = 47 \text{ GeV}$ $\theta_2 = 0.76 \text{ rad}$
 $E_{T3} = 36 \text{ GeV}$ $\theta_3 = 0.58 \text{ rad}$

$M_2 = 94 \text{ GeV}$

ZR

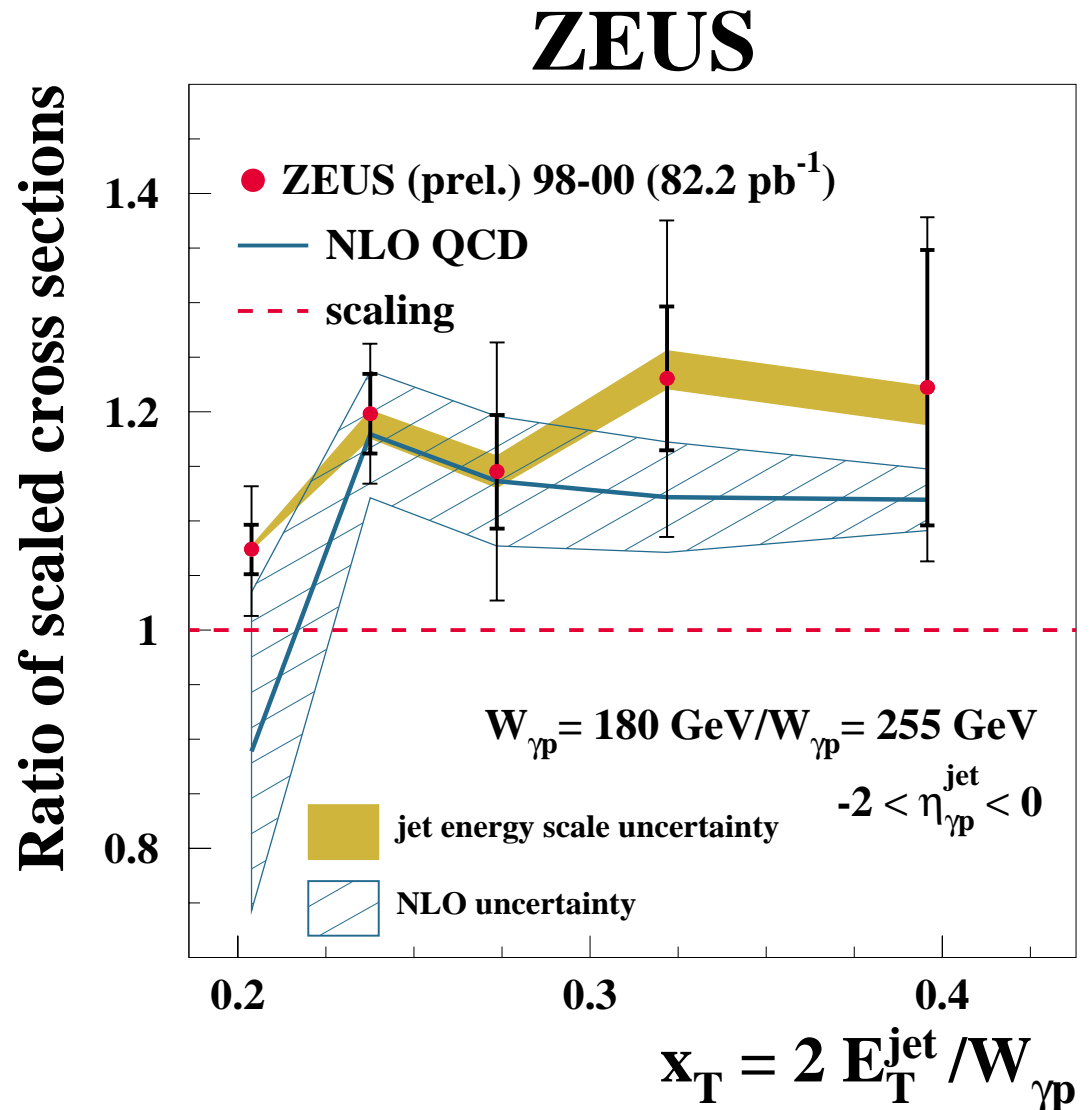
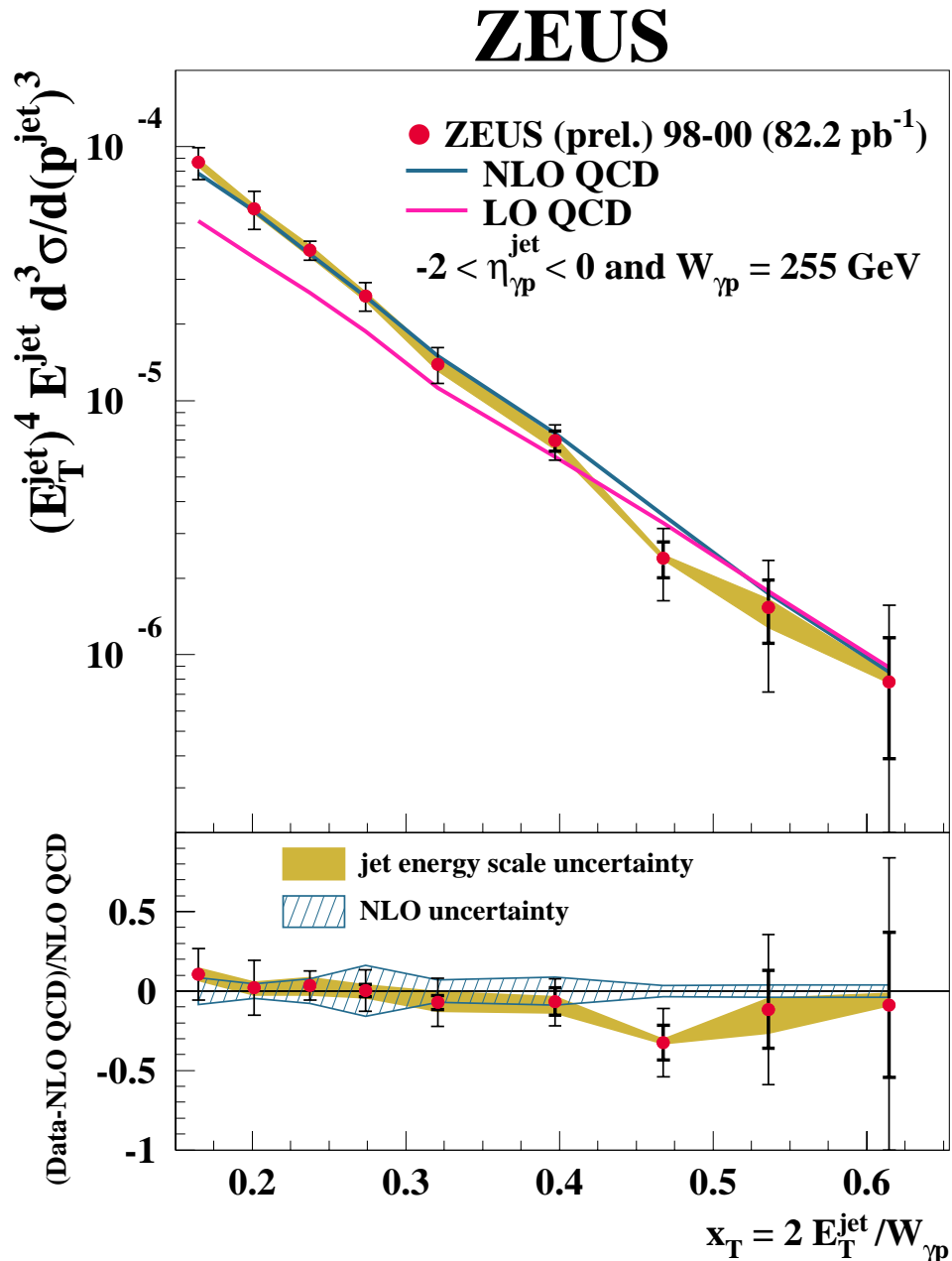
Inclusive Jet-Cross Sections in γp

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

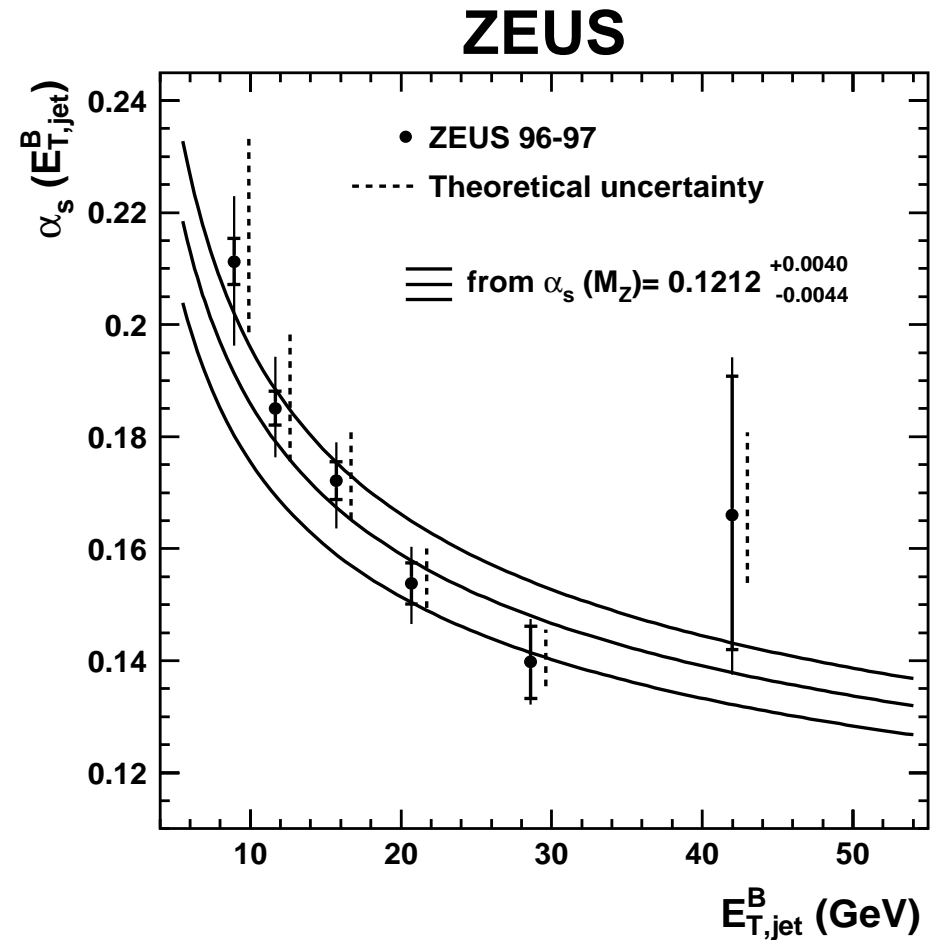
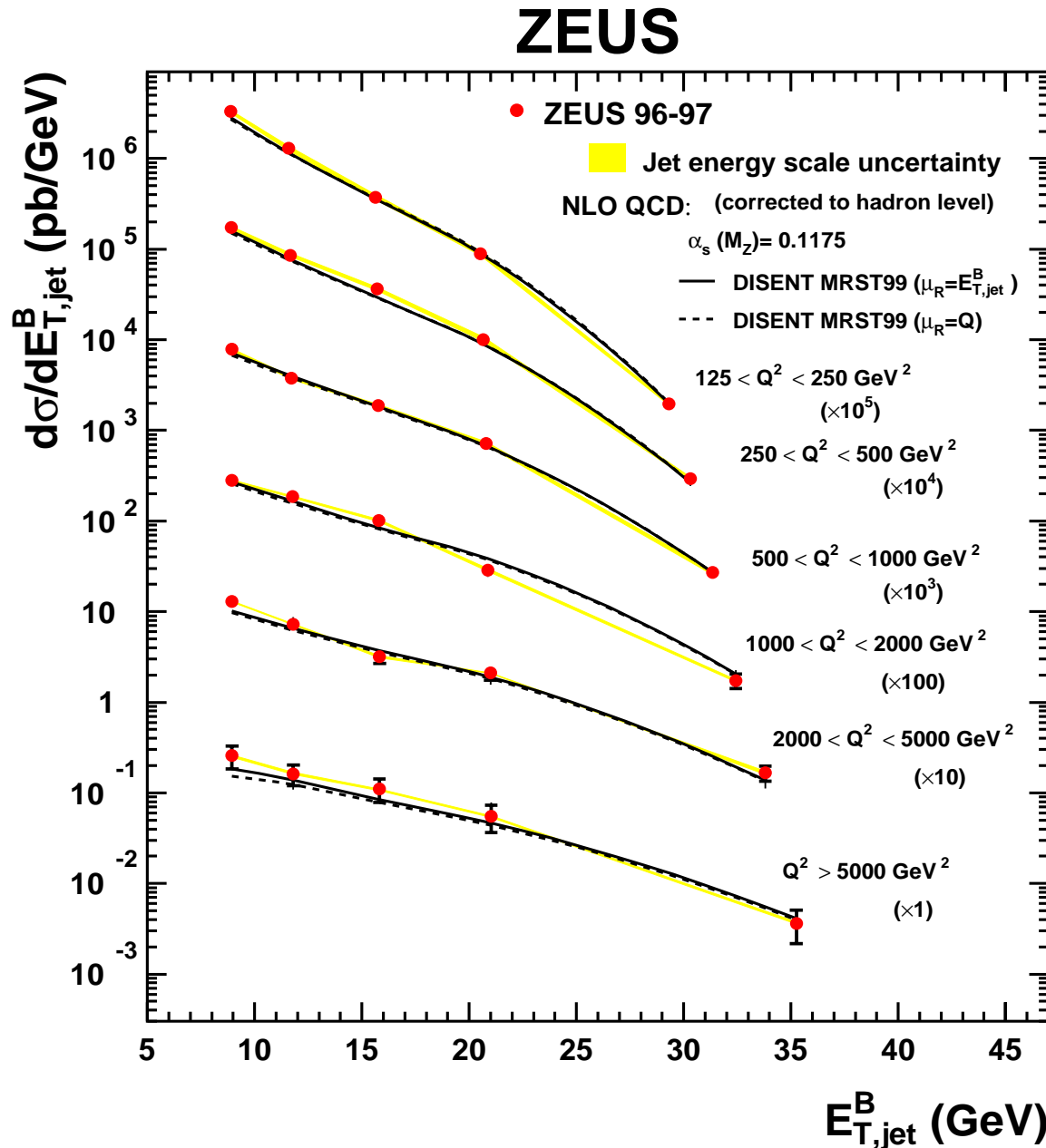
Invariant Inclusive Jet-Cross Sections



Evidence for scaling violations
in γp collisions

Inclusive Jet Production in DIS

Impressive description of NLO QCD
of these precise data:



for $Q^2 > 500 \text{ GeV}^2$:

$$\alpha_s(M_Z) = 0.1212 \pm 0.0017 \text{ (stat)}$$

$$+ 0.0023 \text{ (syst)} \quad + 0.0028 \text{ (theo)}$$

$$- 0.0031 \text{ (syst)} \quad - 0.0027 \text{ (theo)}$$

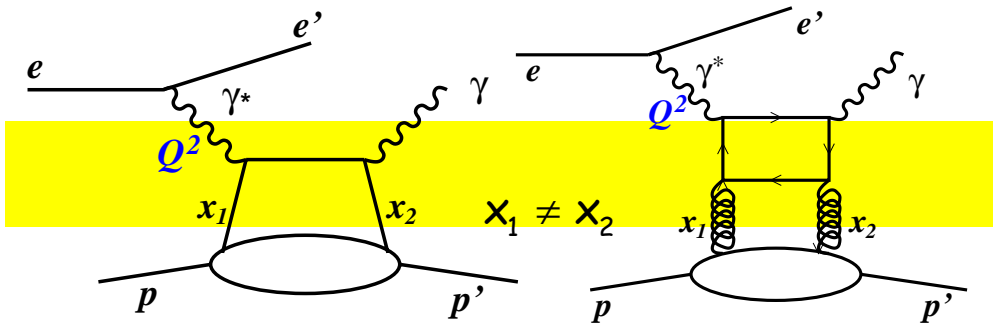
Very precise measurement !

Deeply Virtual Compton Scattering

GPD-based Model (FFS)

High-x (HERMES)

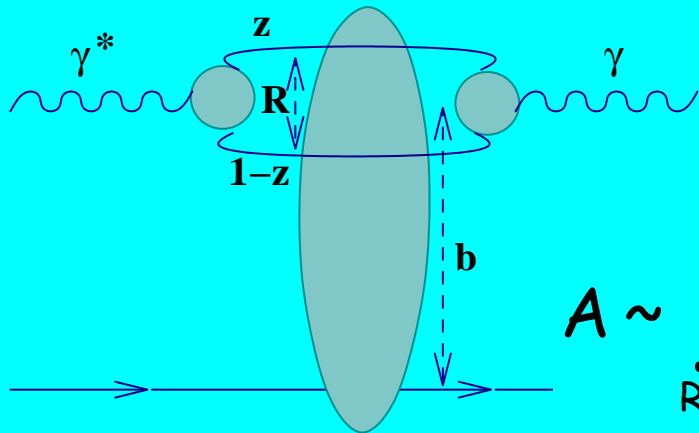
Low-x (ZEUS)



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

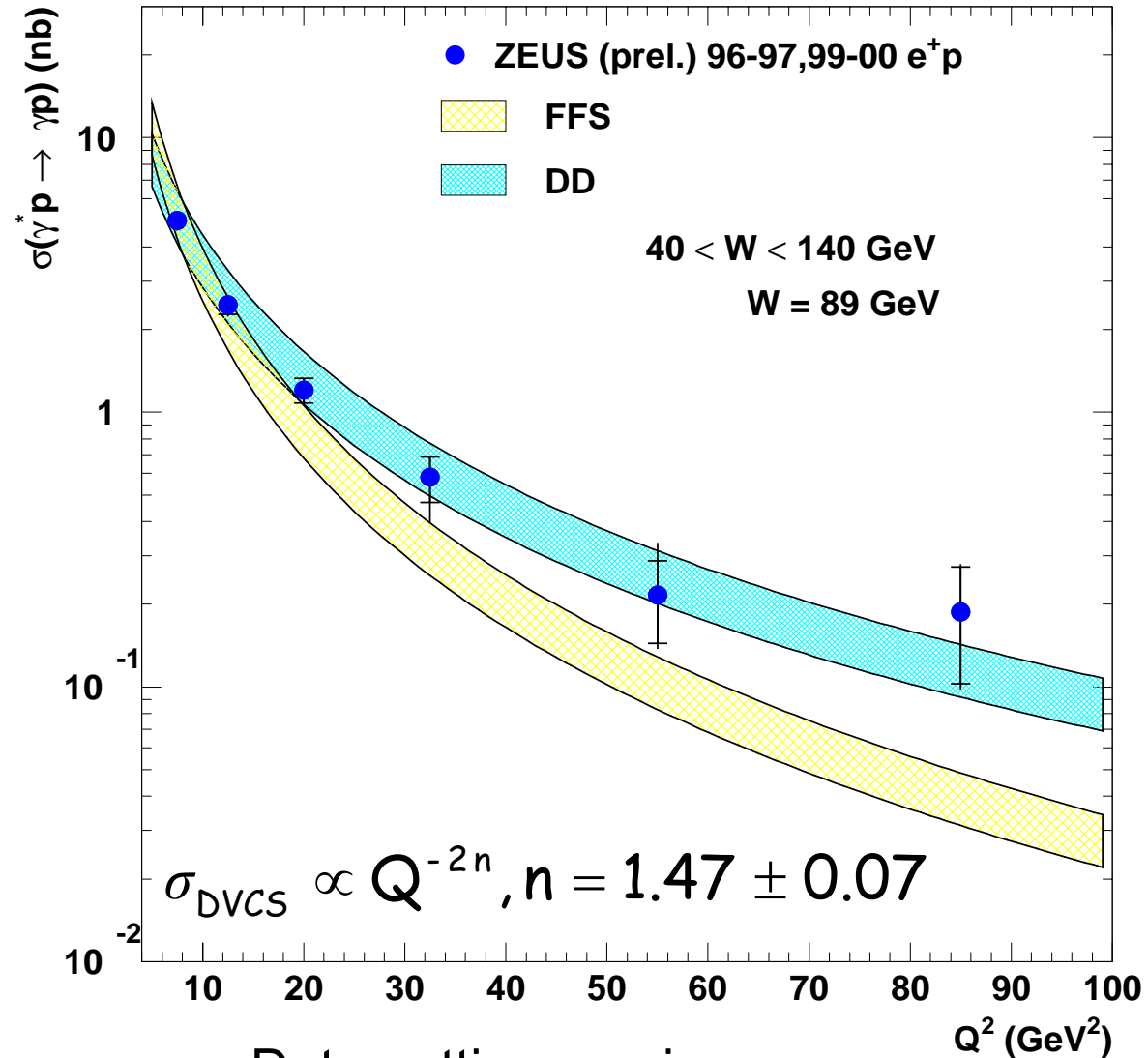
H: Off-diagonal PDF

Colour Dipole Model (DD)



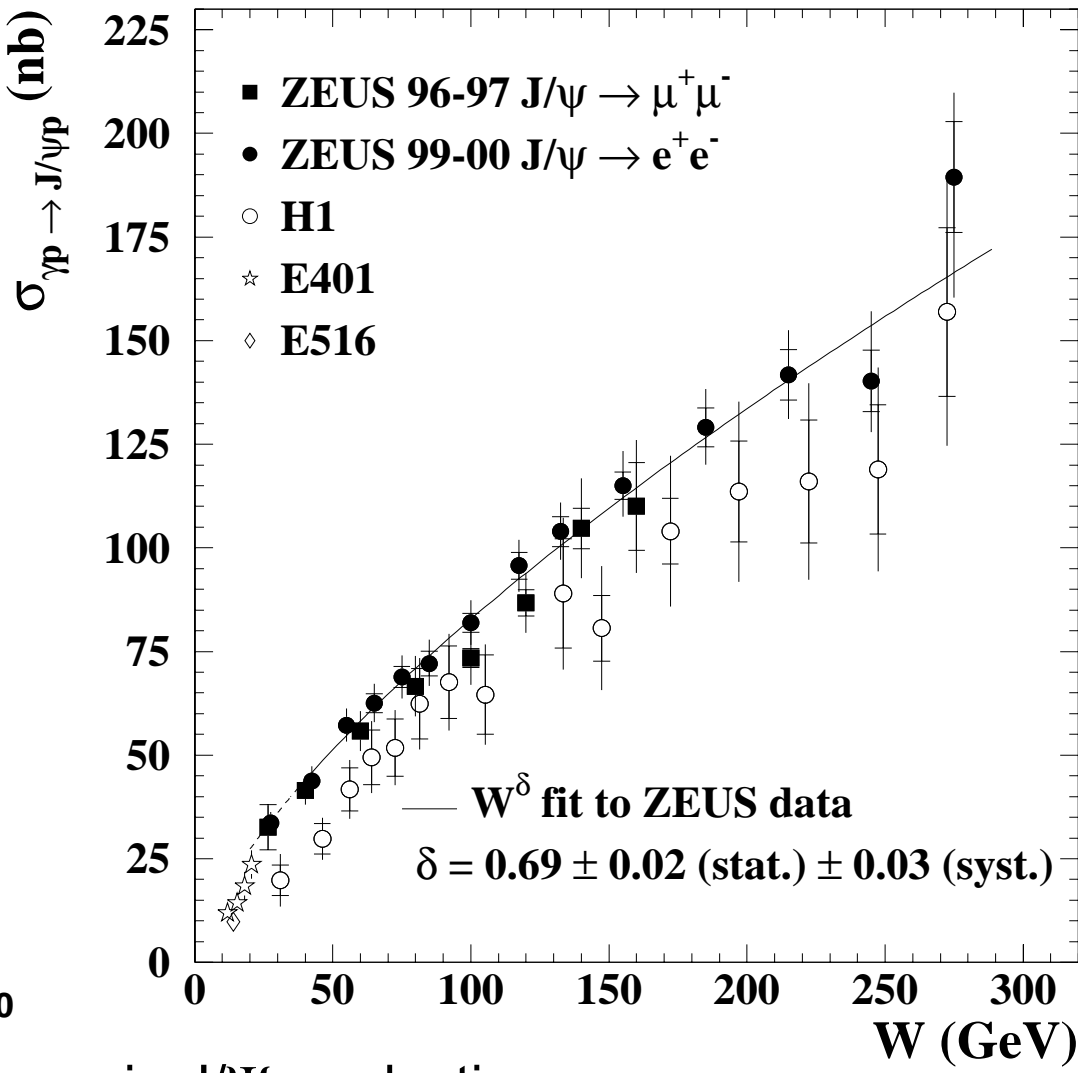
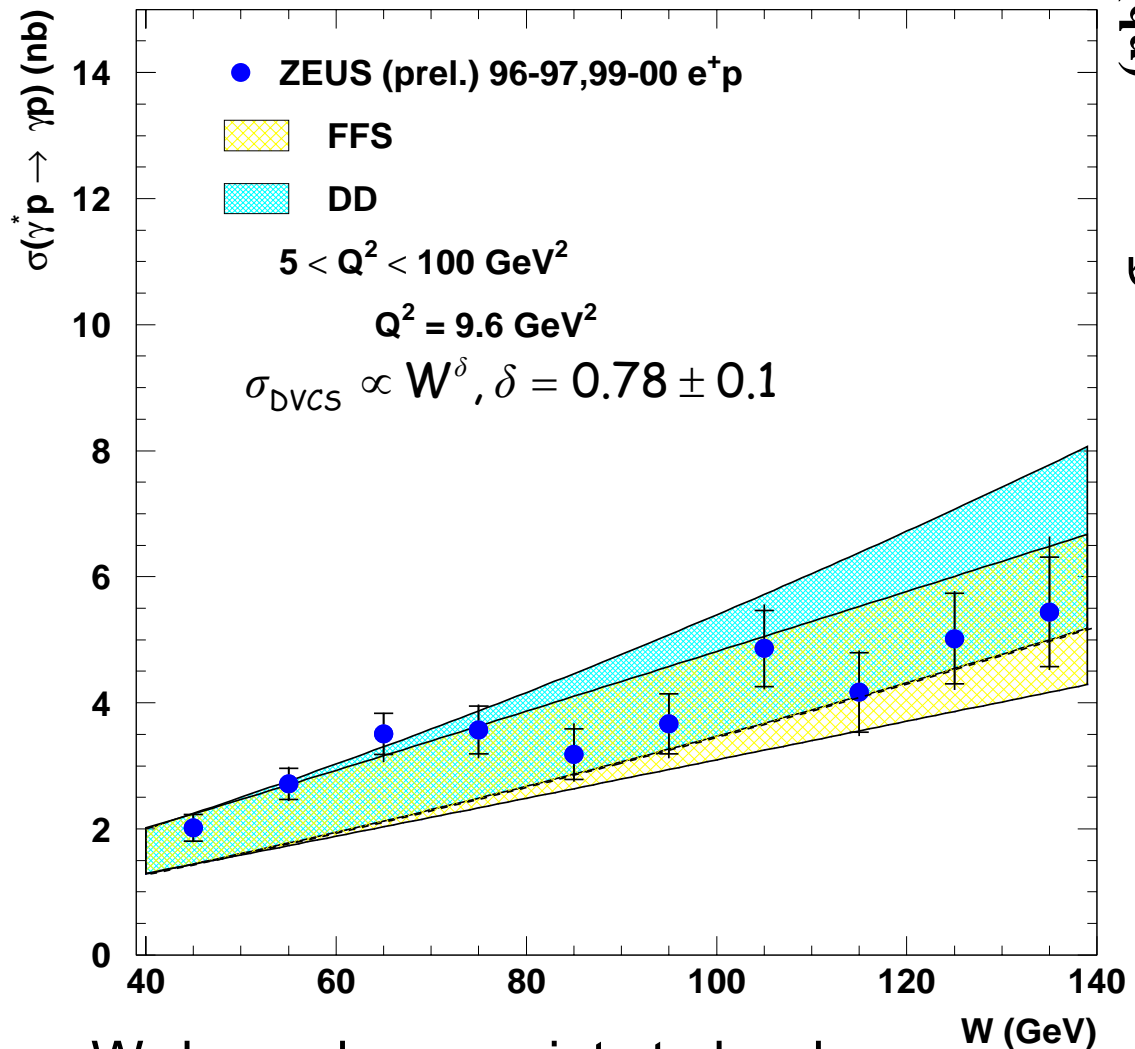
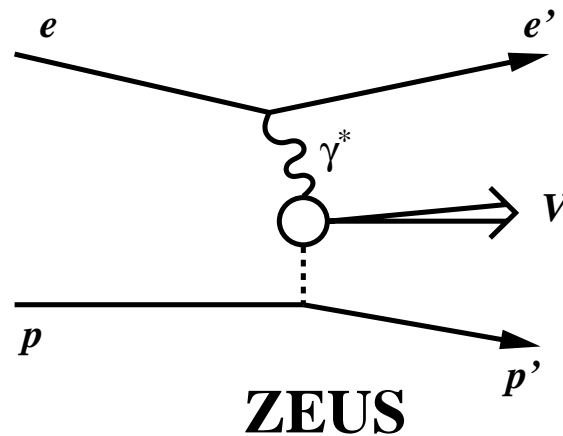
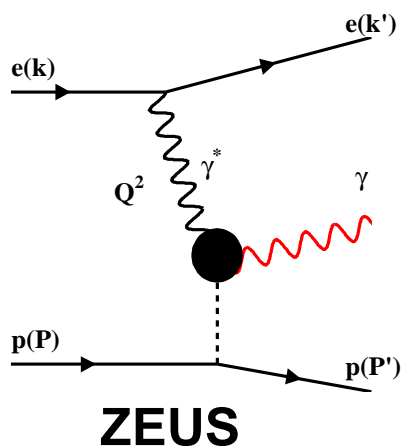
$$A \sim \int_{R,z} \Psi_{ini}^{\gamma} \sigma_{dipole} \Psi_{out}^{\gamma}$$

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Data getting precise
 Q^2 spectrum seems harder
 than predicted by FFS

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

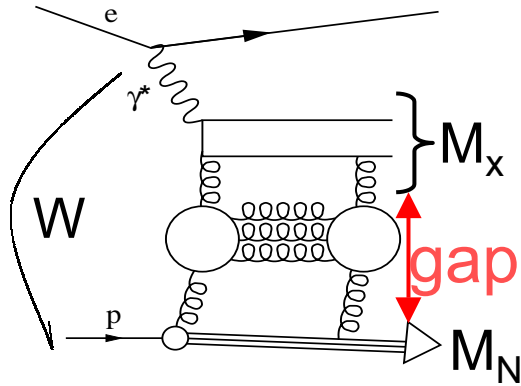


W -dependence points to hard process as e.g. in J/Ψ production

New: F_2^{D3} Data

$$x_p = x (1 + M_X^2 / Q^2)$$

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



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

- coverage $4.0 < \eta < 5.0$
- increased M_X range +extension
- reduced bias from nucleon dissociation to lower Q^2

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

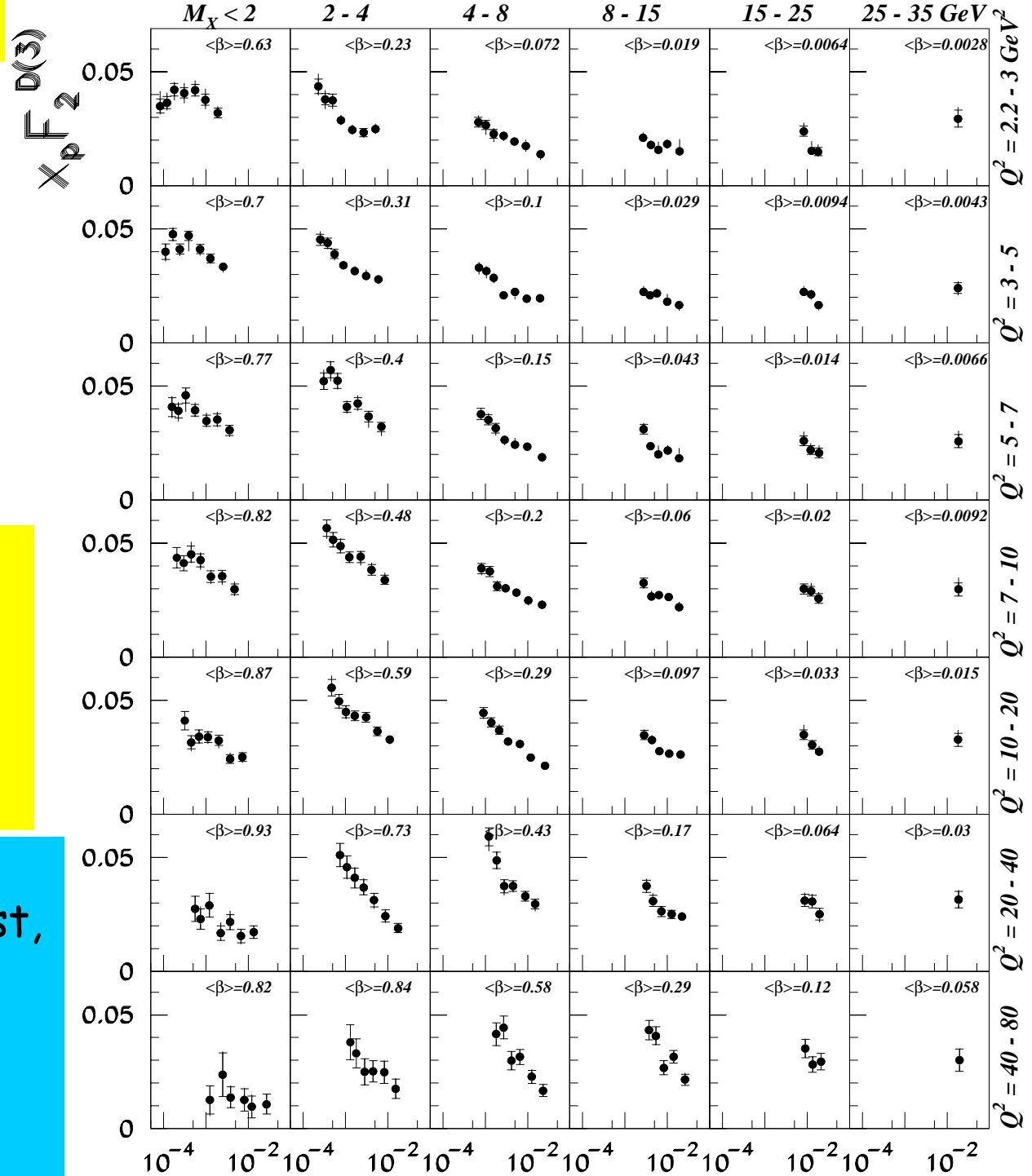
if diffraction is soft ($\lambda \approx 1$)

from data:

diffraction has hard component!

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ZEUS (prel.) 98/99



What happens here ?

- $Q^2 = 2.2 - 3 \text{ GeV}^2$ ★ $Q^2 = 10 - 20 \text{ GeV}^2$
- $Q^2 = 3 - 5 \text{ GeV}^2$ ☆ $Q^2 = 20 - 40 \text{ GeV}^2$
- ▲ $Q^2 = 5 - 7 \text{ GeV}^2$ * $Q^2 = 40 - 80 \text{ GeV}^2$
- ▼ $Q^2 = 7 - 10 \text{ GeV}^2$

Much improved precision !

Same energy dependence in inclusive and diffractive scattering !

Naive expectation:

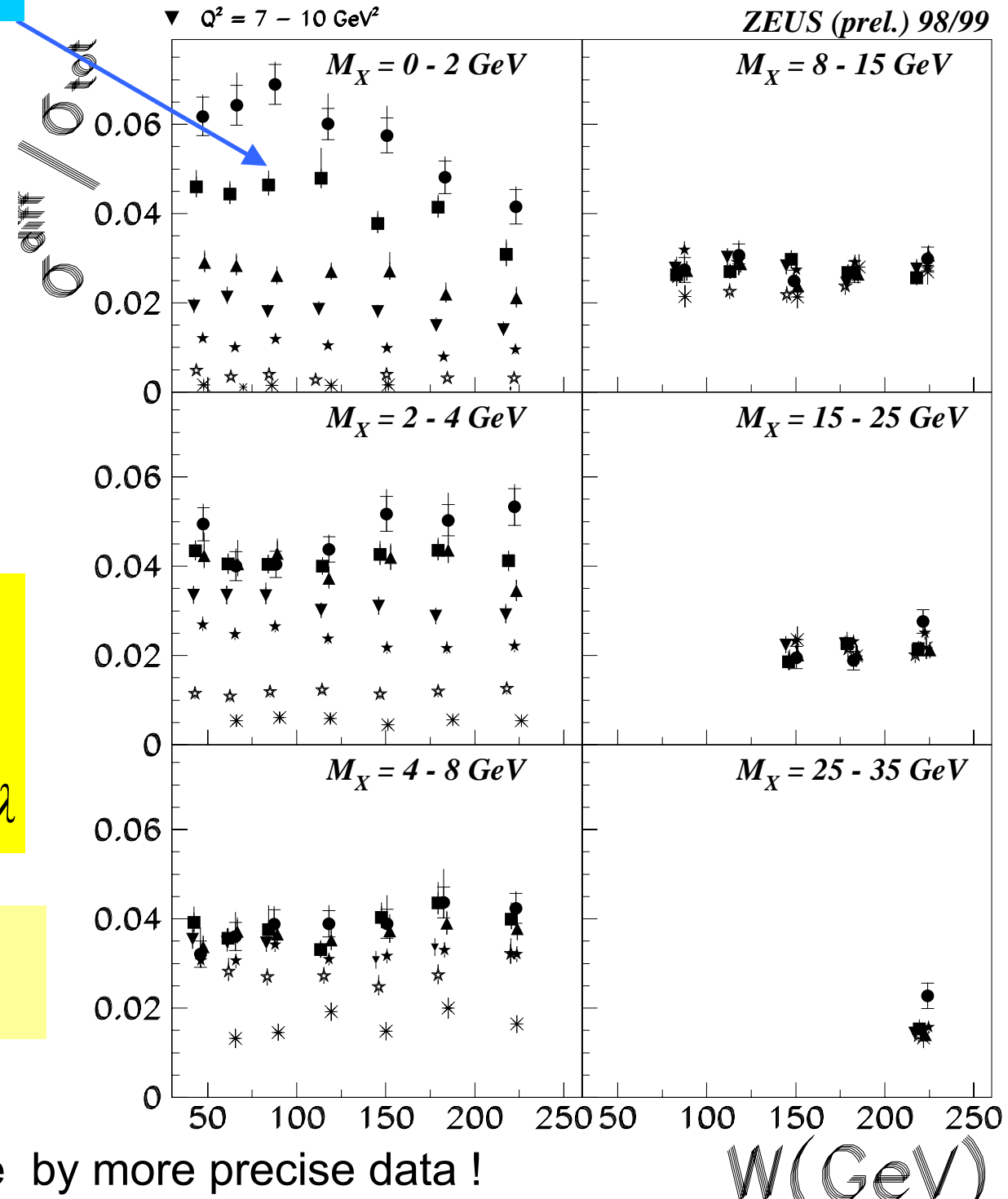
$$\sigma_{\text{tot}} \sim g(x, Q^2) \sim x^{-\lambda}$$

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

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

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 !



ZEUS (prel.) 98/99

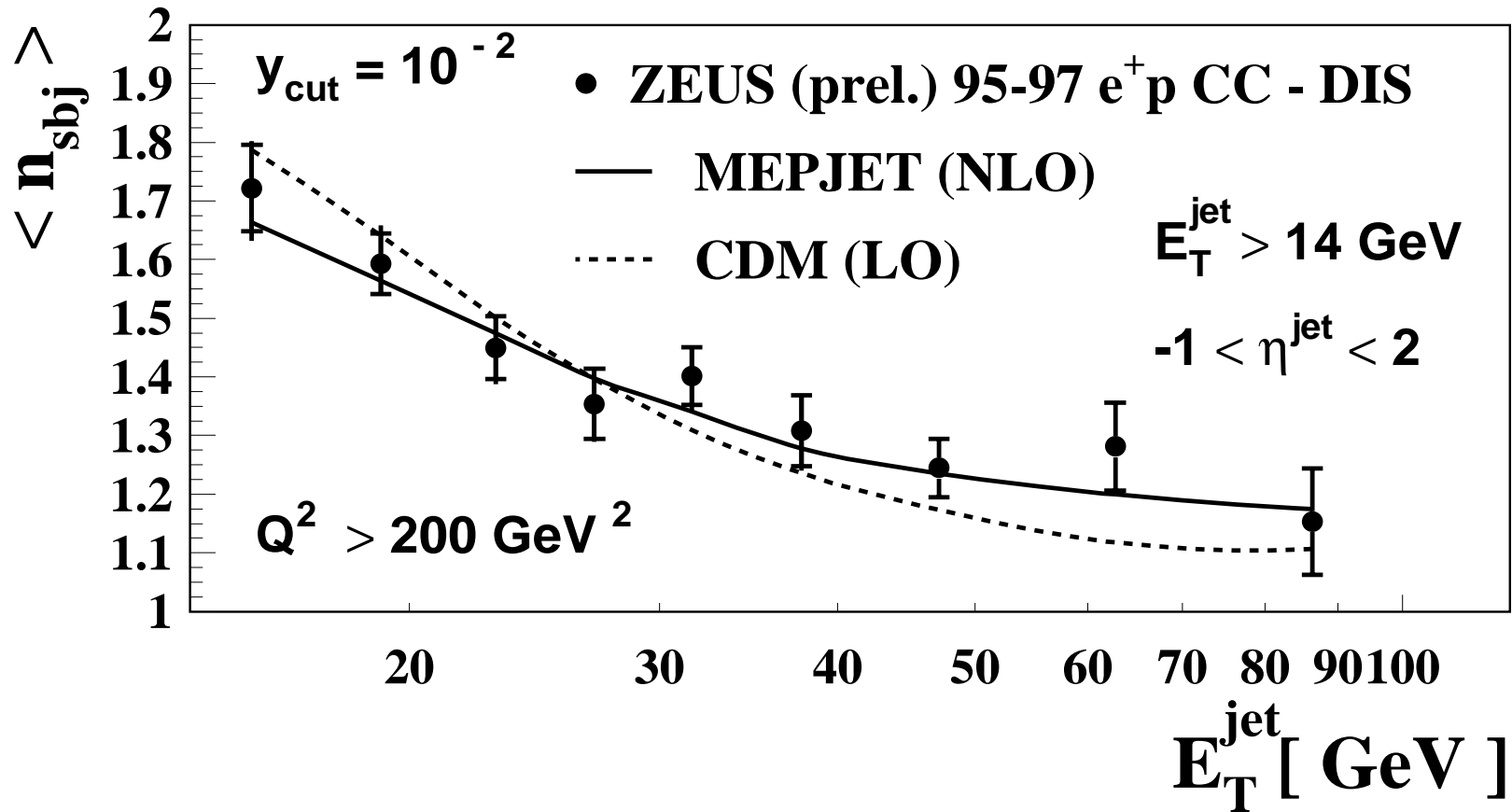
$W(\text{GeV})$

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

ZEUS



Internal jet structure well described by NLO and MC

Isolated high-pt lepton selection:

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

4 events found
3 are compatible with
tau hypothesis

