Deep Inelastic Scattering and dipion electroproduction at HERA

Achim Geiser, DESY Hamburg

EDS Blois workshop

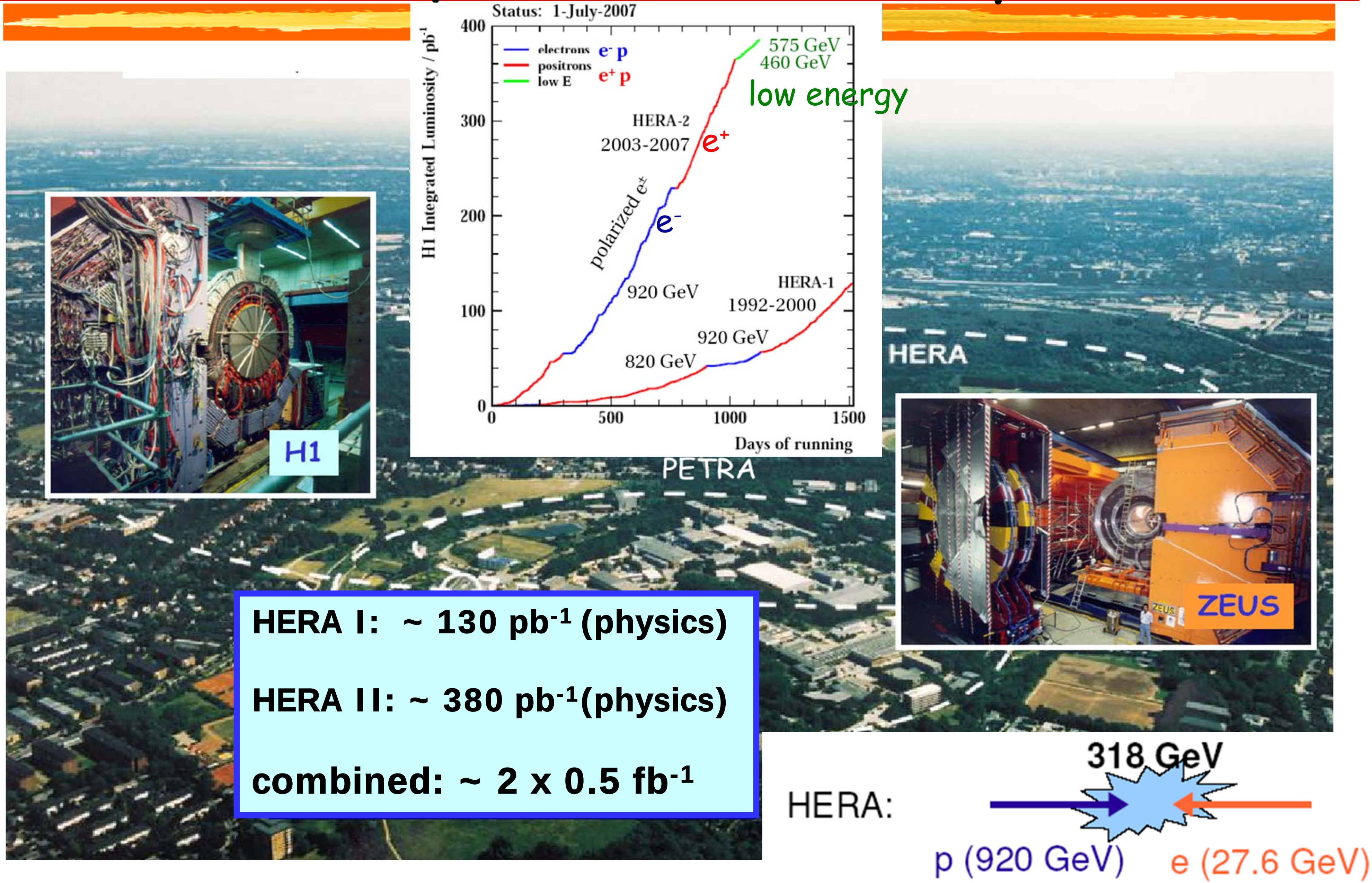
Qui Nhon, Vietnam, 2011

- Inclusive Deep Inelastic Scattering
- Jets and Heavy Flavours in DIS
- Exclusive dipion electroproduction

selection of recent results

inclusive diffraction + diffractive dijets + total cross section -> talk A. Valkarova
comparison of diffraction at HERA and Tevatron -> talks C. Royon & K. Giulianos
exclusive vector meson production -> talk L. Favart
HERA data and pomeron -> talk U. Maor

The HERA ep collider and experiments



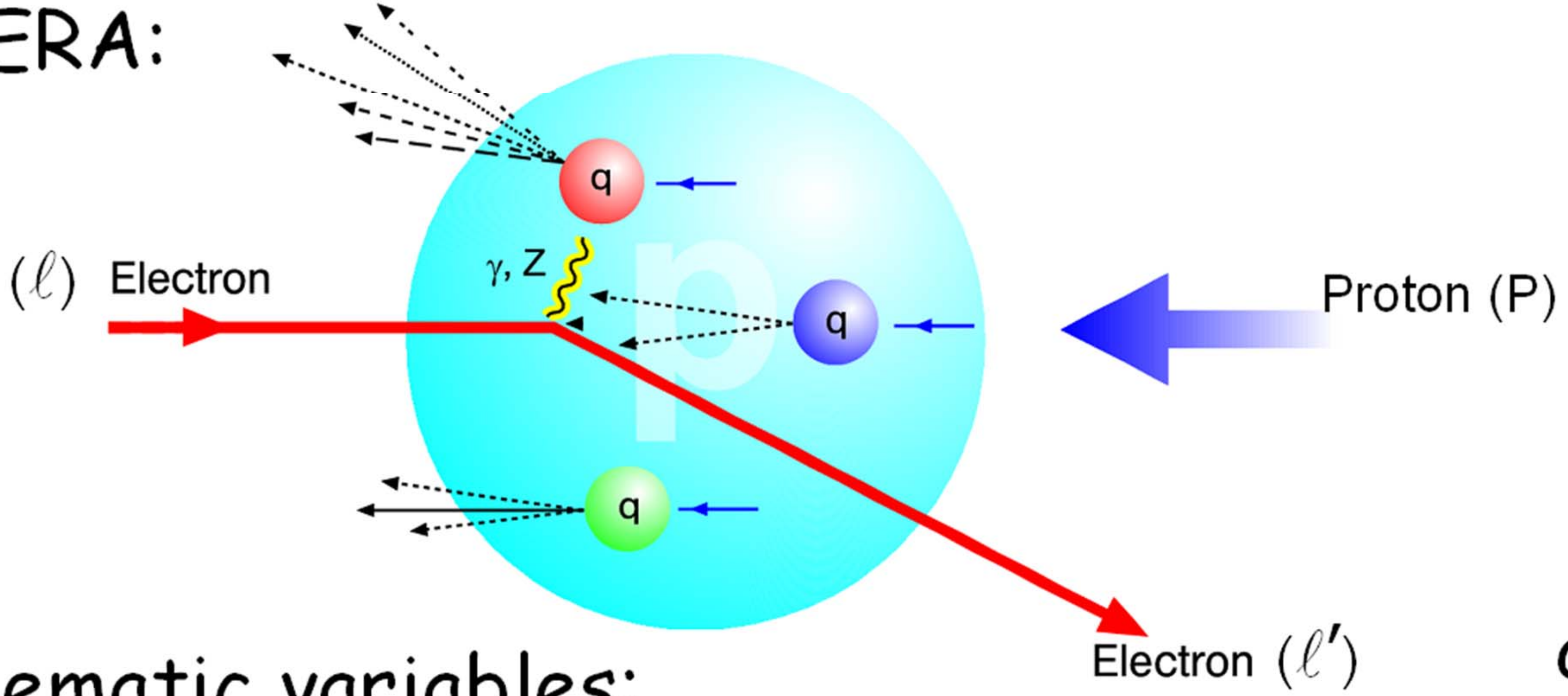
HERA I: ~ 130 pb^{-1} (physics)

HERA II: ~ 380 pb^{-1}(physics)

combined: ~ 2 x 0.5 fb^{-1}

Deep Inelastic ep Scattering at HERA

HERA:



$q = \ell - \ell'$

kinematic variables:

$Q^2 = -q^2$ photon (or Z) virtuality, squared momentum transfer

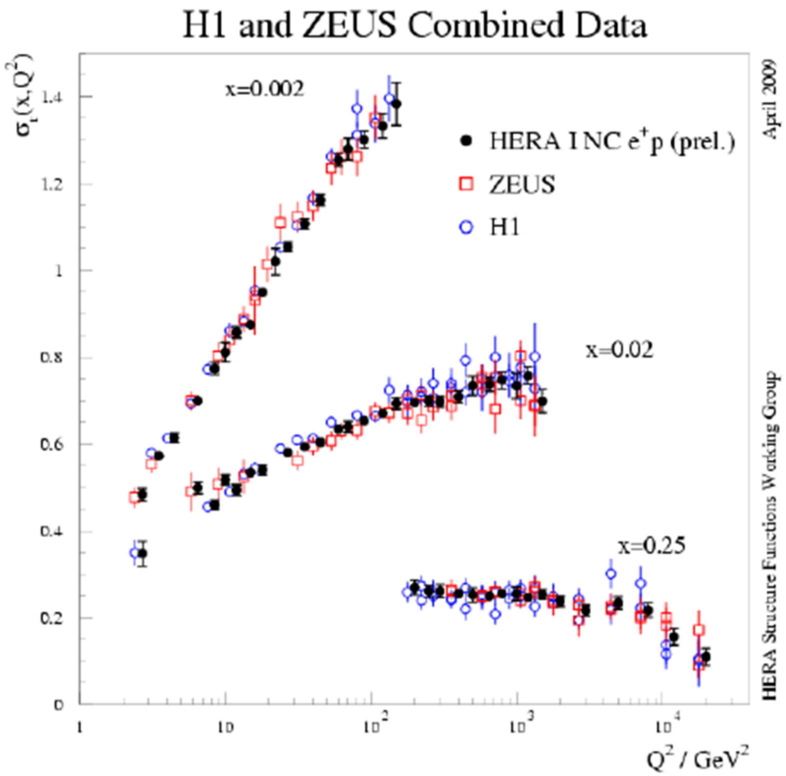
$x = \frac{Q^2}{2Pq}$ Bjorken scaling variable,
for $Q^2 \gg (2m_q)^2$: momentum fraction of p constituent

$y = \frac{qP}{\ell P}$ inelasticity,
γ momentum fraction (of e)

$Q^2 \lesssim 1\ GeV^2$:
photoproduction

$Q^2 \gtrsim 1\ GeV^2$:
DIS

Inclusive DIS



H1-ZEUS combinations & PDF fits:

full expert treatment of exp. syst. uncertainties and correlations

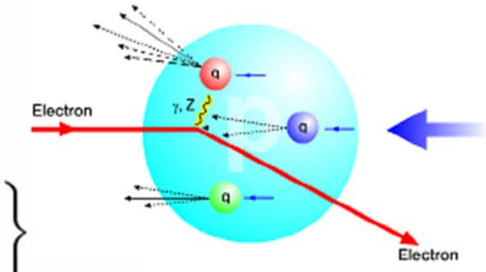
HERA data essential input to any PDF fit

The structure of the proton

- Measure cross section

special HERA run in 2007

small



$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right]F_2(x,Q^2) - y^2 F_L(x,Q^2) \;+\!-Y_-\; xF_3\right\}$$

at highQ^2

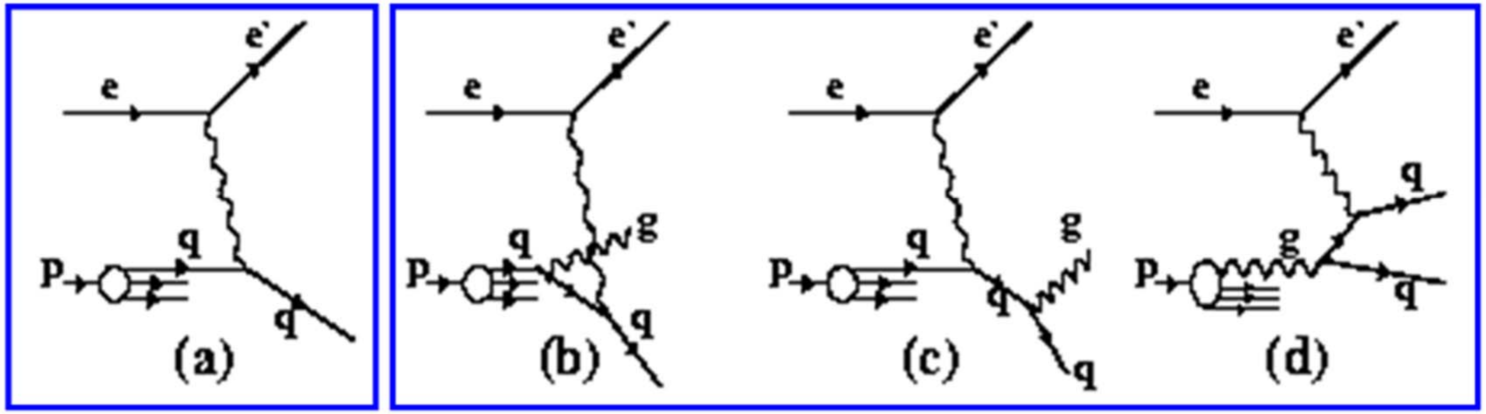
to 0th order QCD (Quark Parton Model, $Q^2 \gg m_q^2$):

- Parton distribution functions (PDF) in pQCD

$$F_2^{em}(x,Q^2) = x\sum_i e_i^2[q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$$

q_i – probability to find quark with flavour i in proton

"higher" order QCD corrections



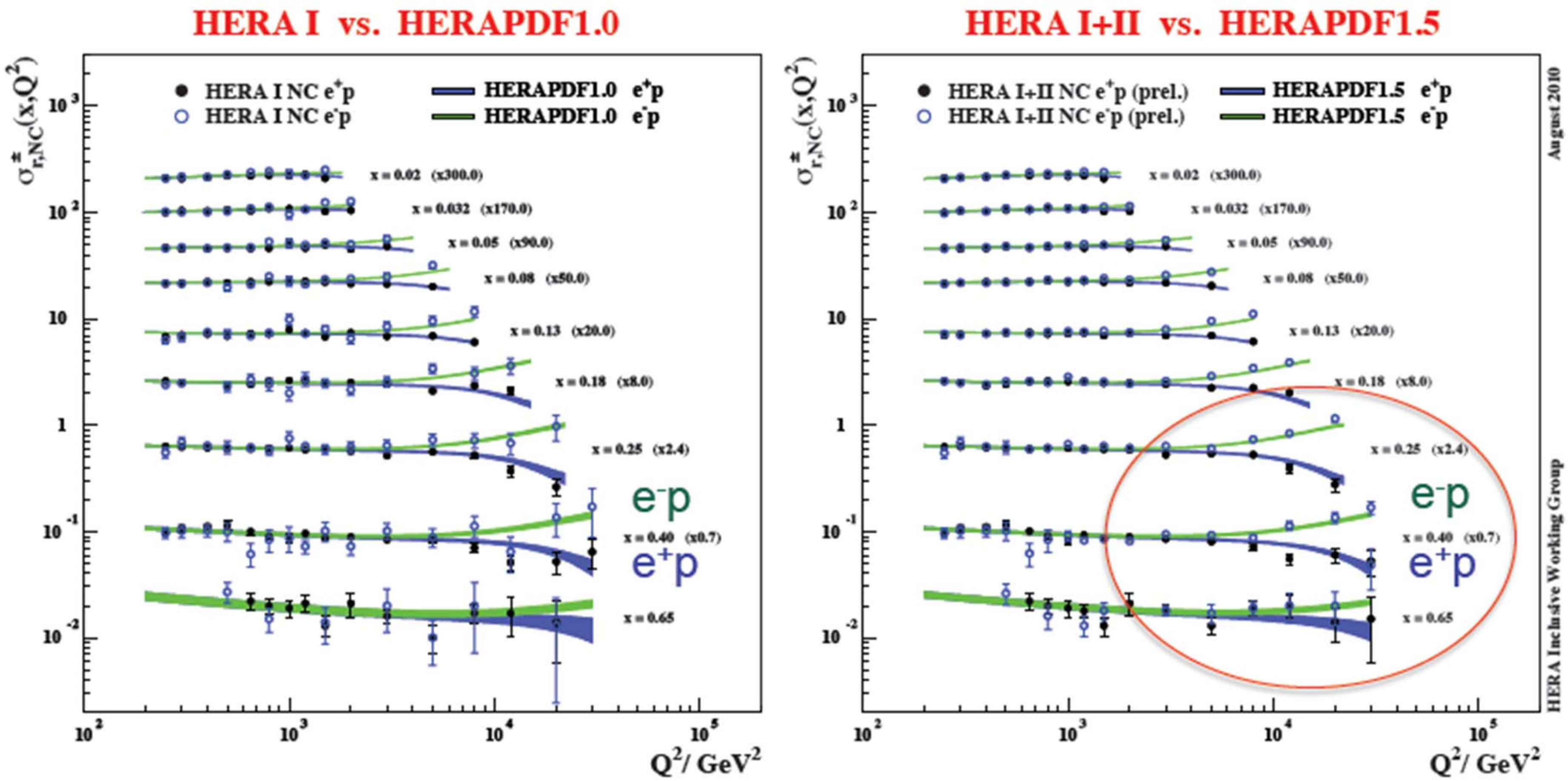
in general: F_2 structure function is **not** PDF

Combination of HERA data and PDF fit

e.g. high Q^2 neutral current:

JHEP 1001-109

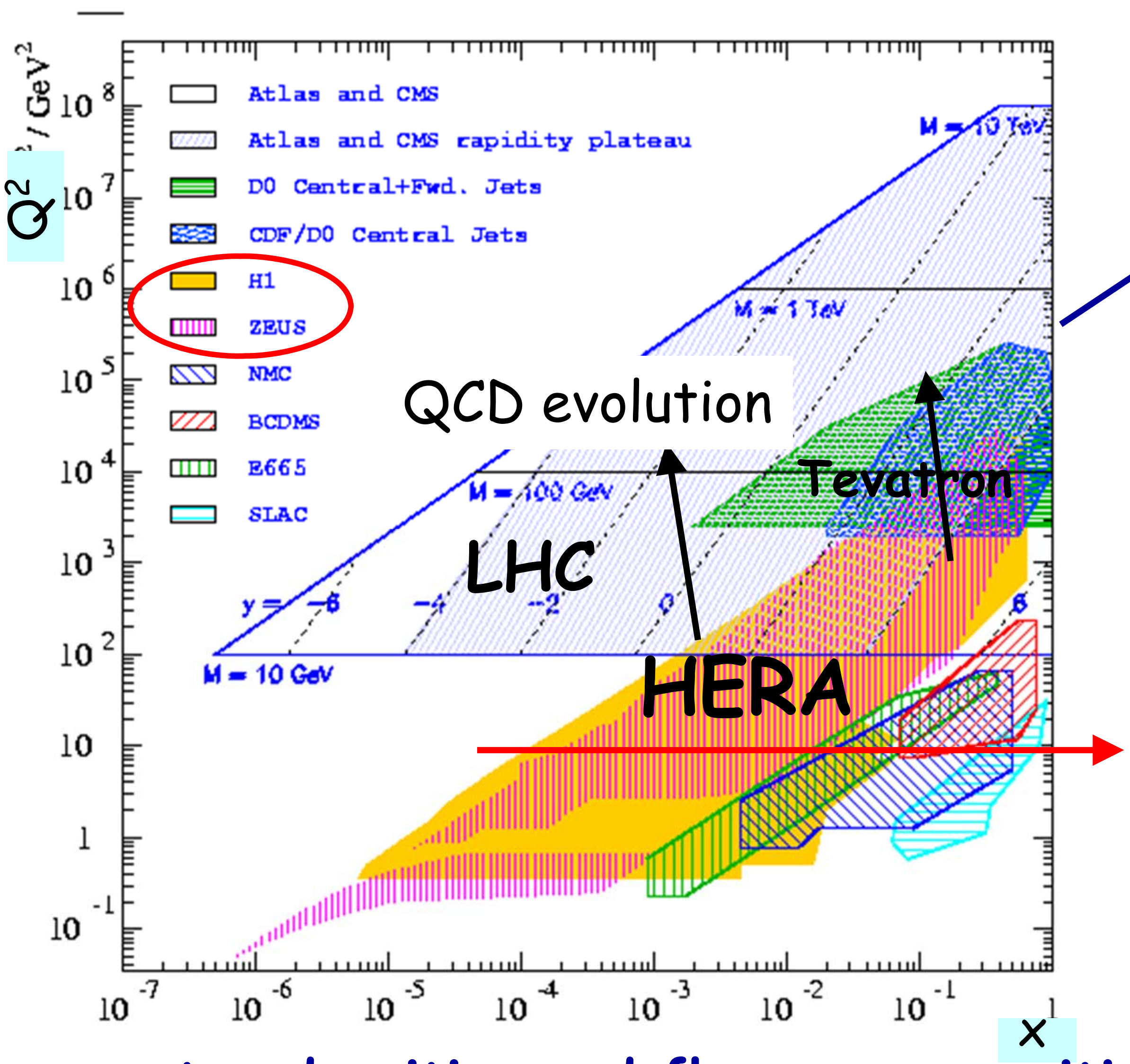
ZEUS-prel 10-018, 11-002, H1-prelim 10-042, 11-042

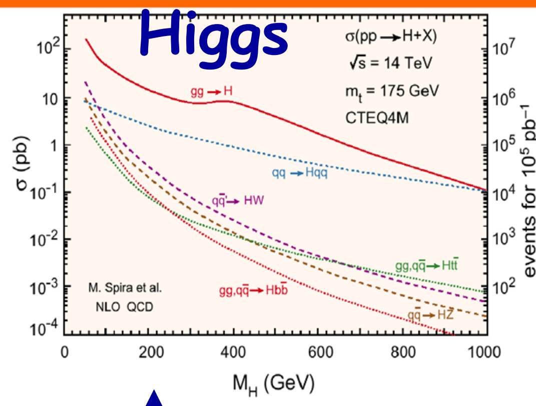


- inclusion of the HERA II high Q^2 data improves precision at high Q^2 and high x
- further new results (not yet included in average): ZEUS-prel 11-003, 11-004

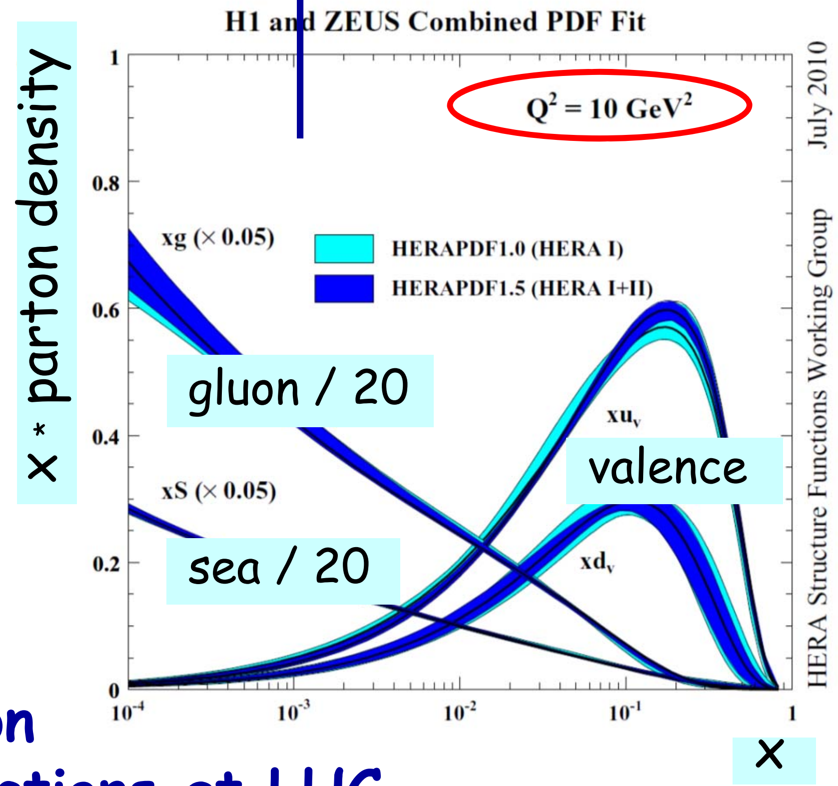
- NLO and NNLO versions of HERAPDF 1.5 available on LHAPDF

Parton density functions (PDF)





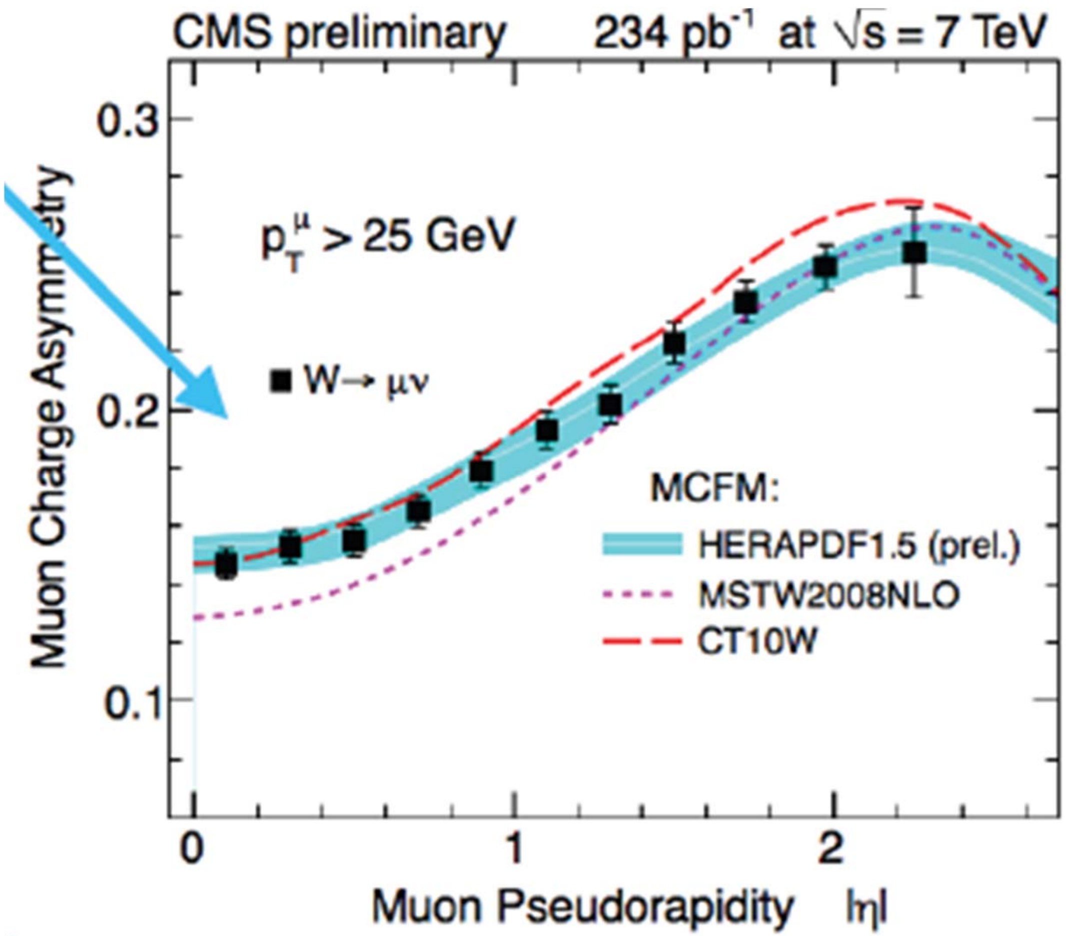
W,Z, top, jets, …



parton densities and flavour composition measured at HERA determine cross sections at LHC

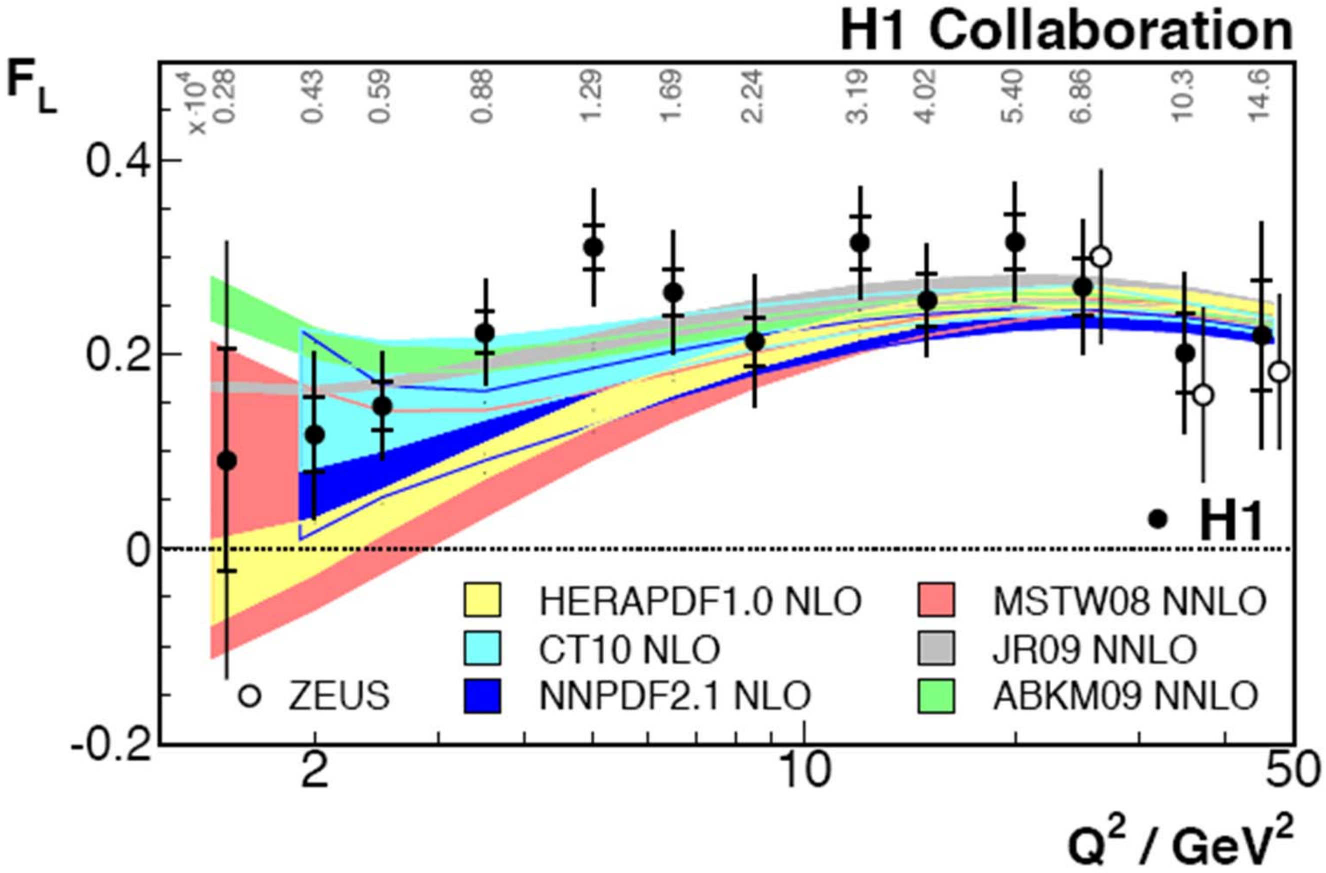
Example: W production in CMS

HERAPDF
prediction



probably more examples in LHC talks this afternoon

Longitudinal structure function F_L



EPJ C71(2011)1579

also H1-ZEUS combination:
ZEUS-prel 10-001
H1-prelim 10-043

ZEUS update:
ZEUS-prel 10-006

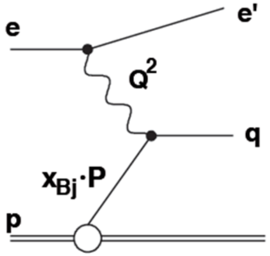
- perfect description of the F_L data by QCD at $Q^2 \geq 10$ GeV^2
- large spread/uncertainty of the QCD predictions at low Q^2

F_L data are valuable input to QCD fits

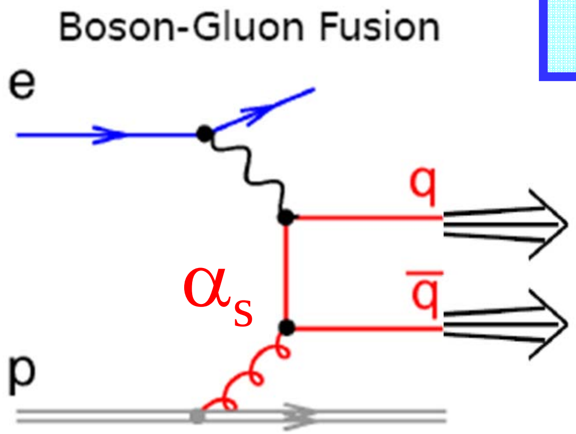
Jets and α_s

Jets in ep interactions (HERA)

QPM:



single (or no) jets in DIS: no QCD, measure quark densities

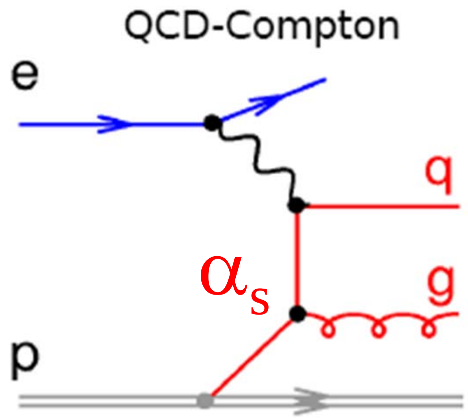


dijets in DIS or photoproduction:

measure both (**dijets**) or

integrate over 2nd jet (**inclusive jets**)

require high E_T w.r.t. photon axis

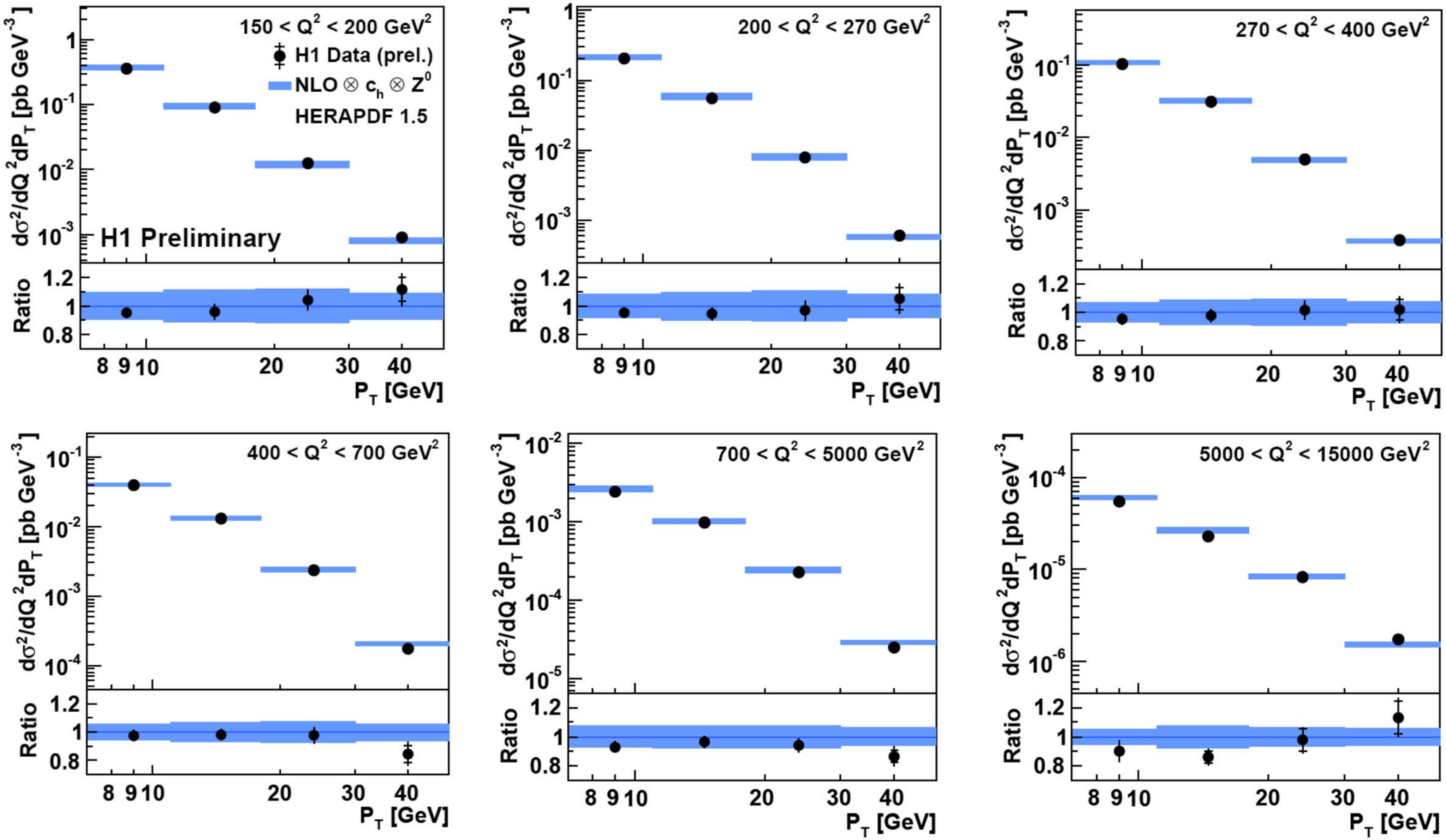


- check QCD
- study performance of jet algorithms
- measure α_s and its running
- measure gluon density

Inclusive jets in DIS

H1-prelim 11-032

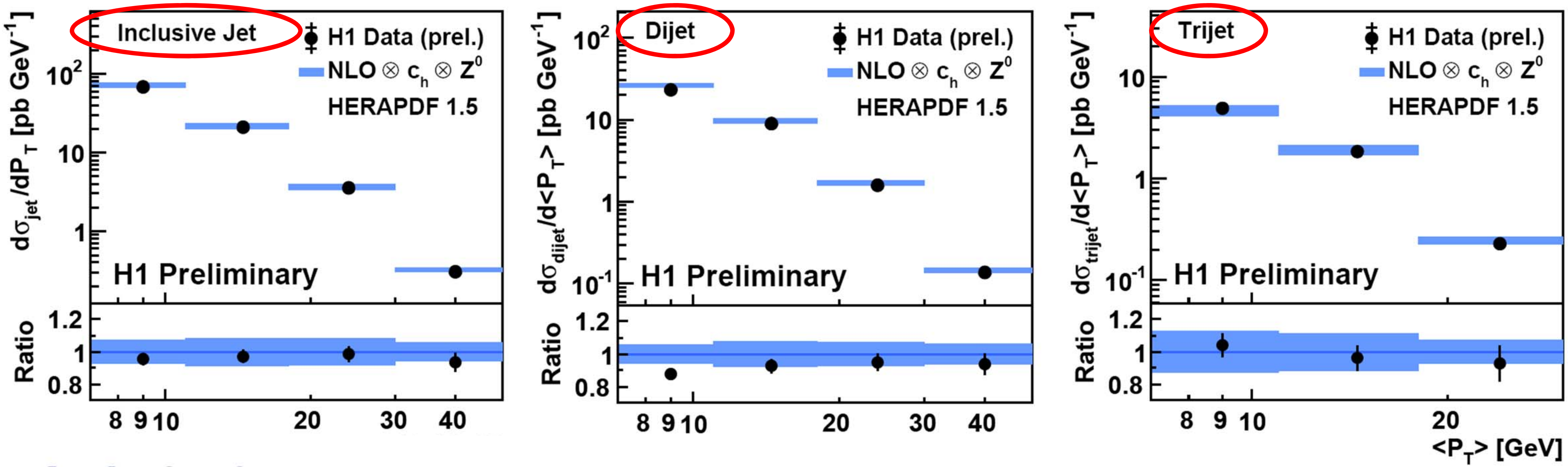
double differential in Q^2 and p_T



well described by NLO QCD + HERAPDF

Multijet production + α_s

H1-prelim 11-032



Inclusive jet:

$$\alpha_s(M_Z) = 0.1190 \pm 0.0021\ (\text{exp.}) \pm 0.0020\ (\text{pdf})\ ^{+0.0050}_{-0.0056}\ (\text{th.})$$

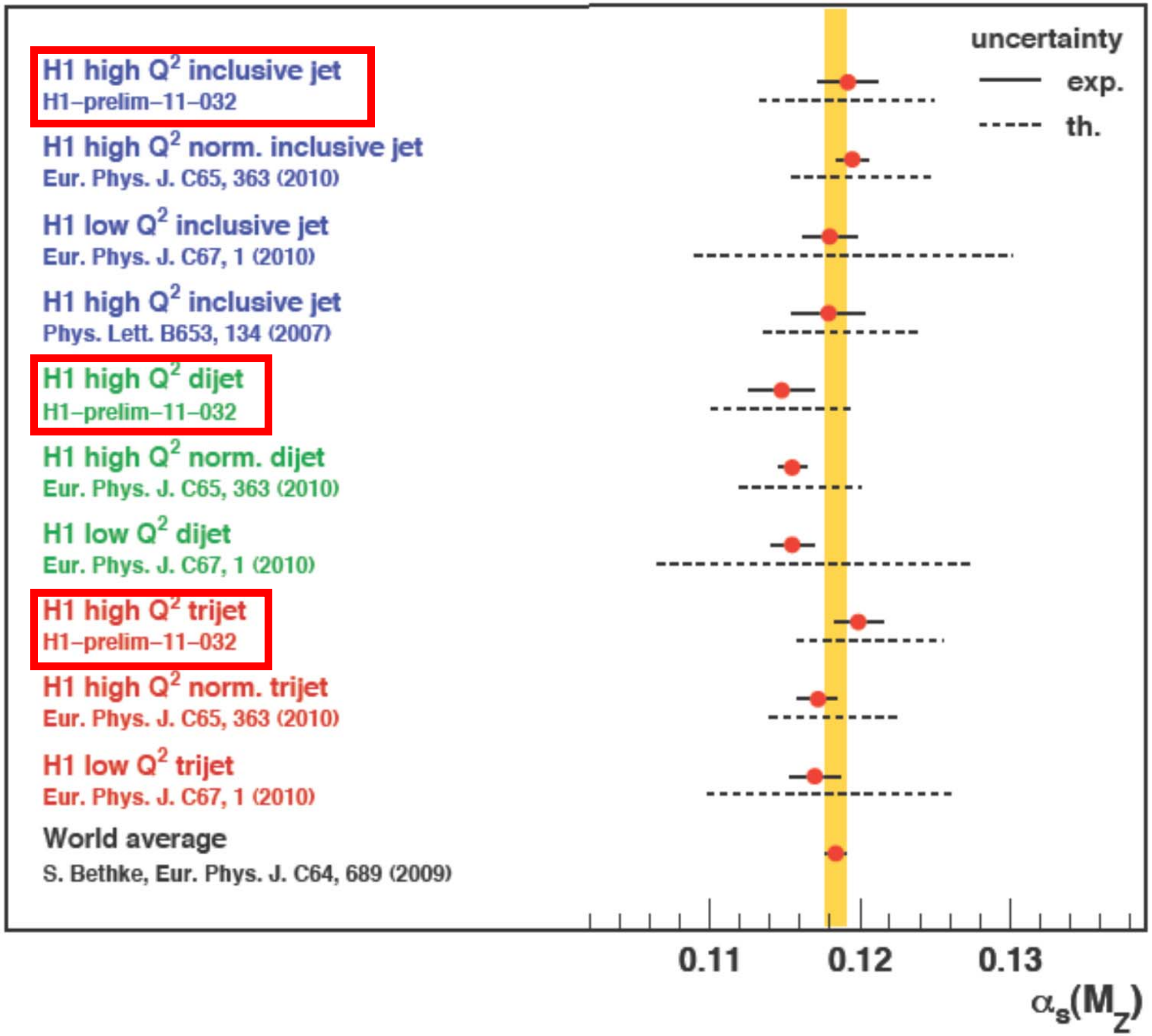
Dijet:

$$\alpha_s(M_Z) = 0.1146 \pm 0.0022\ (\text{exp.}) \pm 0.0021\ (\text{pdf})\ ^{+0.0044}_{-0.0045}\ (\text{th.})$$

Trijet: most precise ($\sim\alpha_s^2$)

$$\alpha_s(M_Z) = 0.1196 \pm 0.0016\ (\text{exp.}) \pm 0.0010\ (\text{pdf})\ ^{+0.0055}_{-0.0039}\ (\text{th.})$$

H1 summary of α_s measurements



optimised for minimization of experimental uncertainties

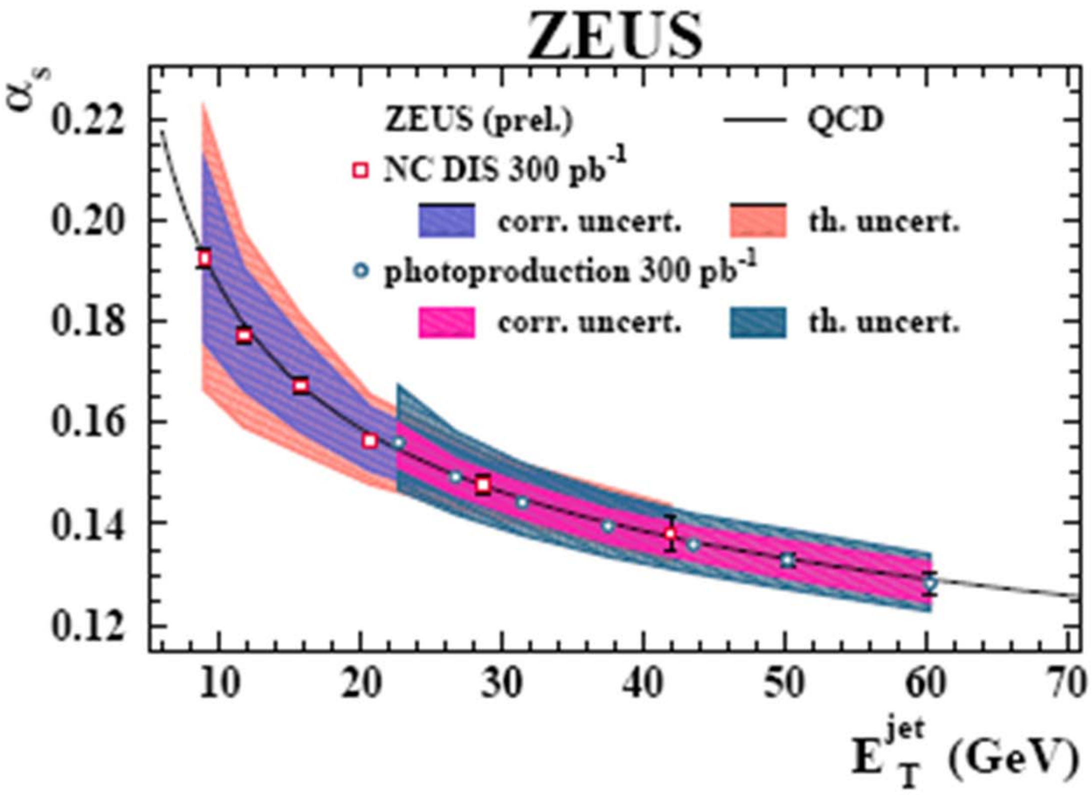
good agreement with previous measurements and world average

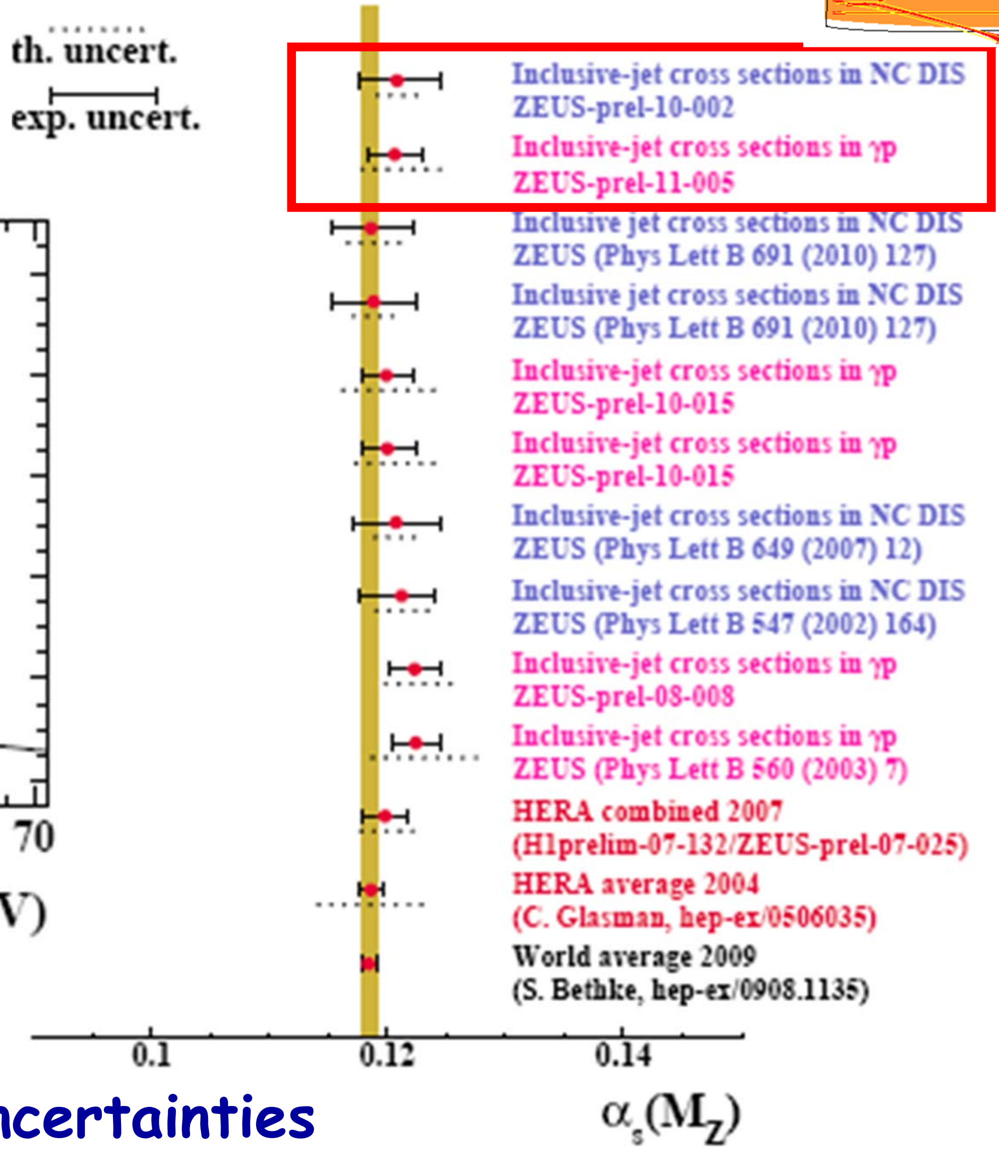
uncertainties dominated by NLO theory

Summary of ZEUS α_s measurements

ZEUS-prel
11-005

α_s running



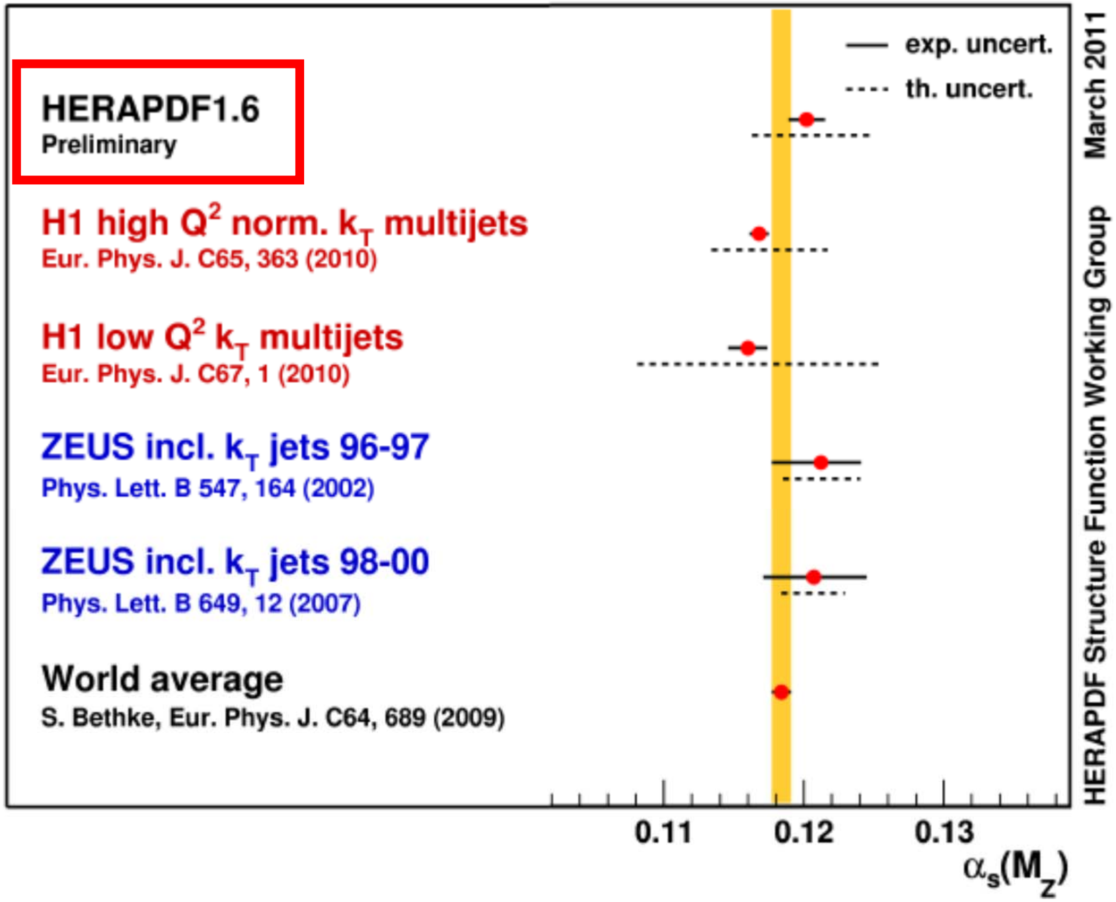


analyses optimized for
minimization of theoretical uncertainties

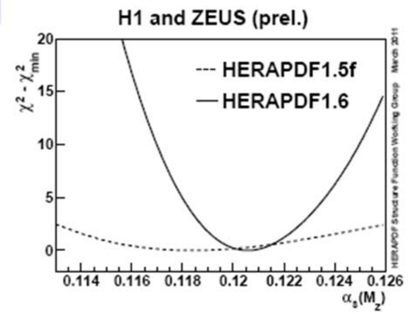
PDF fit including Jets + free α_s

ZEUS-prel 11-001
H1-prelim 11-034

H1 and ZEUS (prel.)



$$\alpha_s = 0.1202 \pm 0.0013\,(exp) \pm 0.0007\,(mod/par) \pm 0.0012\,(hadr) {}^{+0.0045}_{-0.0036}\,(scale)$$

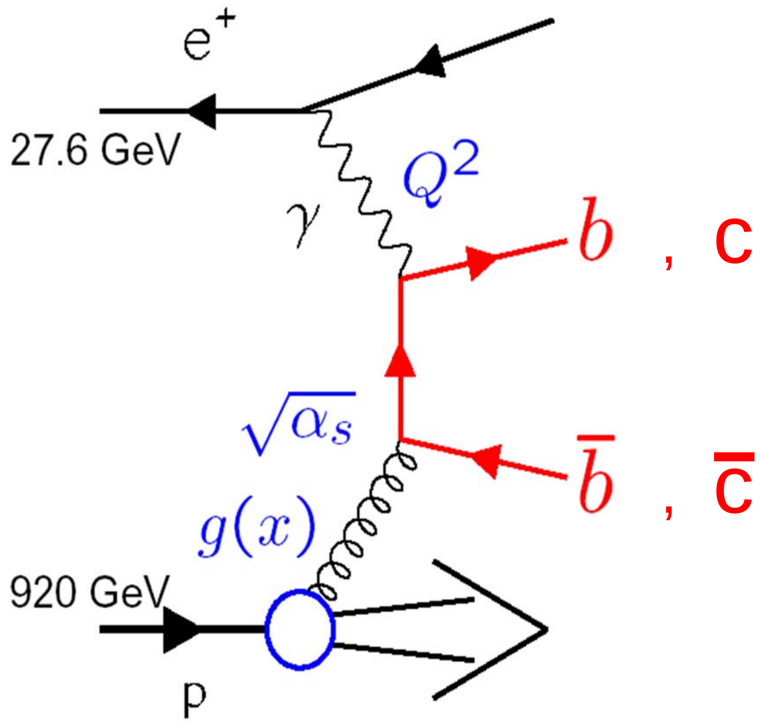


decorrelates α_s and gluon

agrees well with world average

uncertainty dominated by NLO theory, need NNLO !

Heavy Flavours



Why are heavy flavours important?

- charm contribution to HERA data up to 30%! (beauty ~1-3%)
- **kinematic effect of mass**
- **competing scales for perturbative expansion**

  e.g. m, Q^2, p_T -> terms $\log Q^2/m^2$

  $\log p_T{}^2/m^2$ etc.

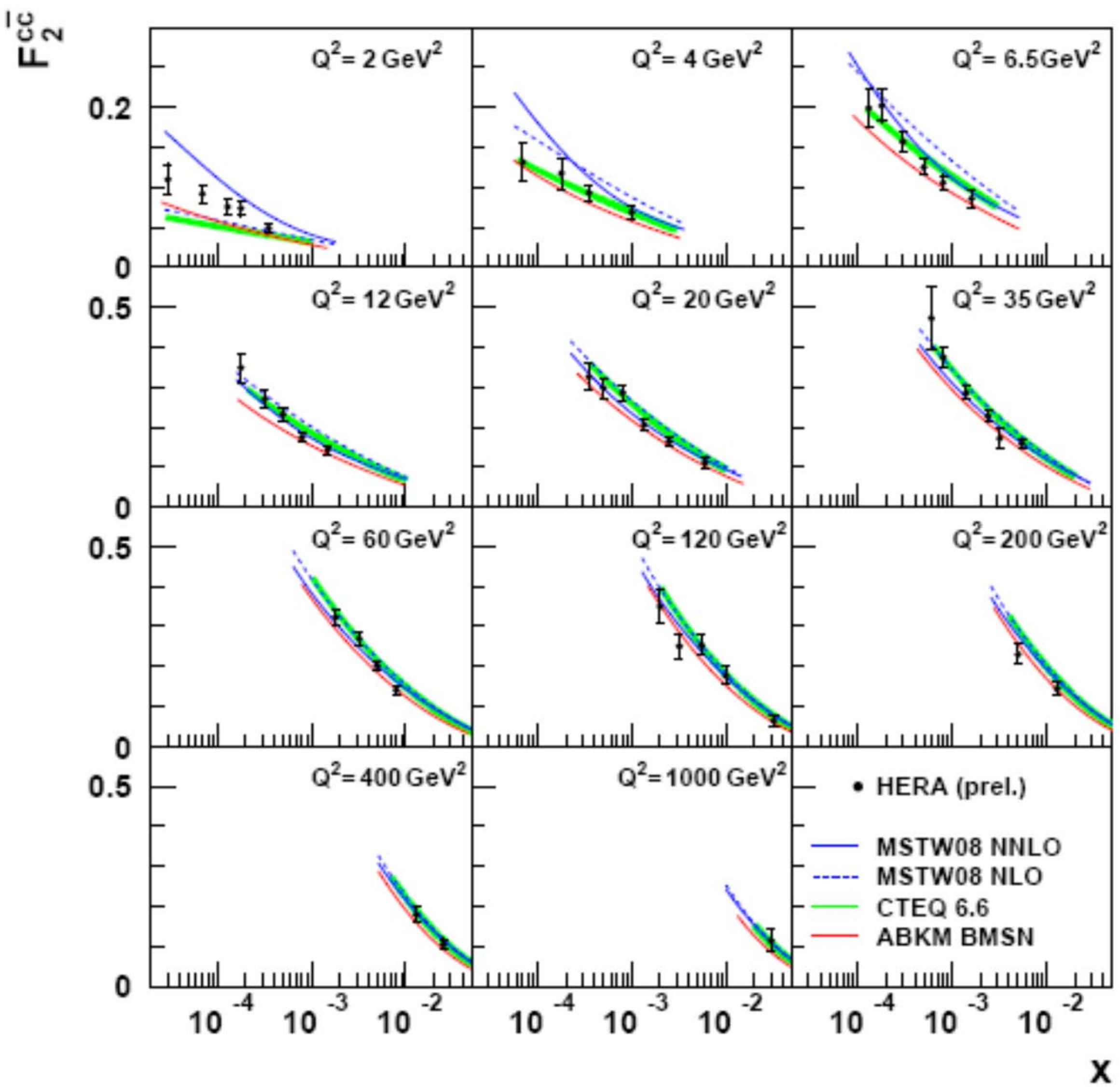
=> "**massless**" treatment (ZM-VFNS) allows resummation, but fails near "mass threshold" -> avoid !

=> "**massive**" treatment gets kinematics right, but does not allow resummation (fixed flavour number schemes, FFNS) or induces ambiguities in QCD corrections near flavour threshold (variable flavour number schemes, GM-VFNS)

check different schemes against HERA data

charm contribution to F_2

combined HERA (H1 and ZEUS) charm data:



sensitive to m_c
and to differences in
Heavy Flavour schemes

here: massive
VFNS schemes

fit to these data
-> u/c flavour separation
-> reduced uncertainties on
W/Z cross sections at LHC

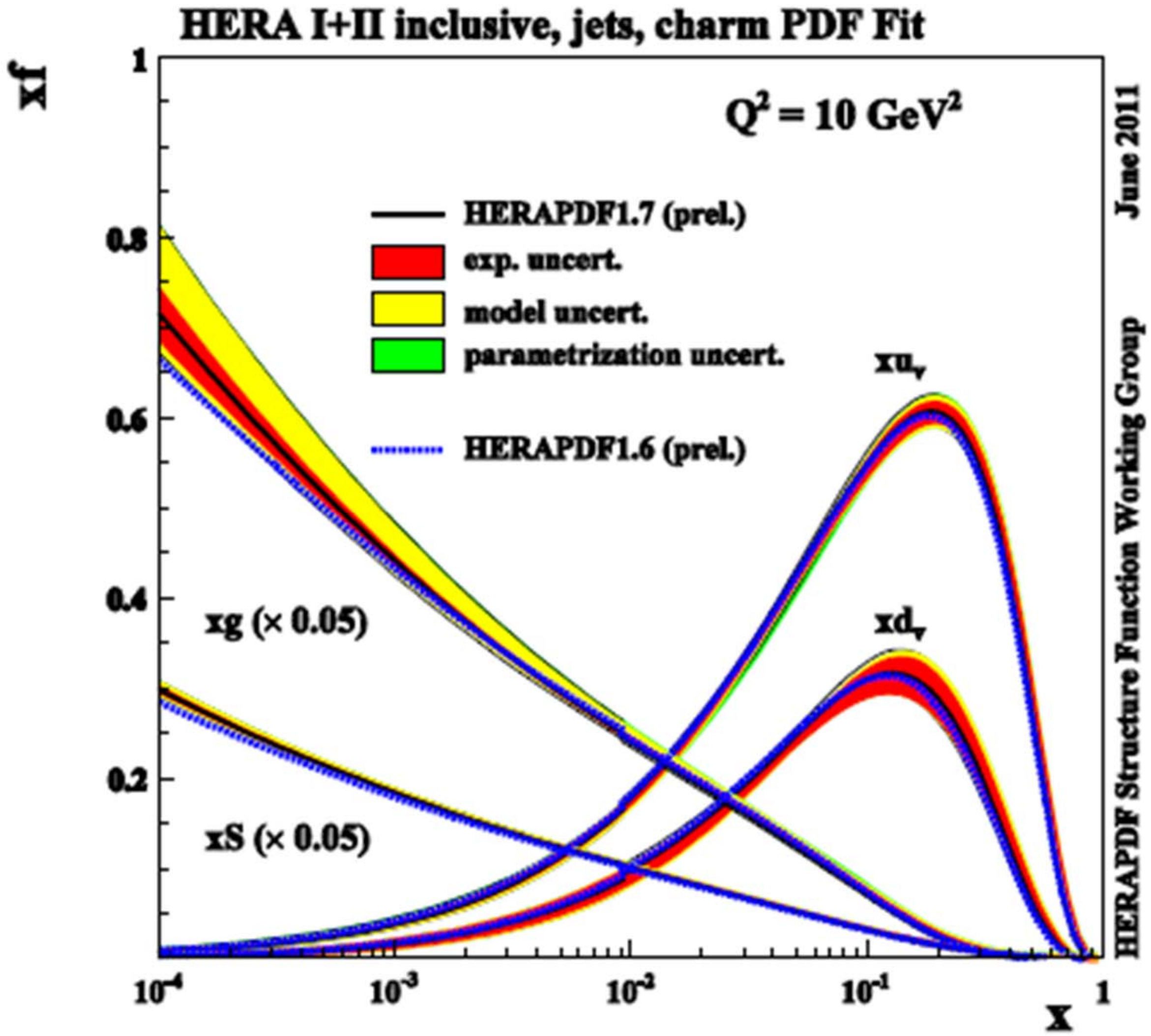
H1-prelim 10-045
ZEUS-prel 10-009

also updated/new results
(not yet included)

ZEUS-prel 10-005, 11-012
H1, DESY 11-066

PDF fit to "all" HERA data

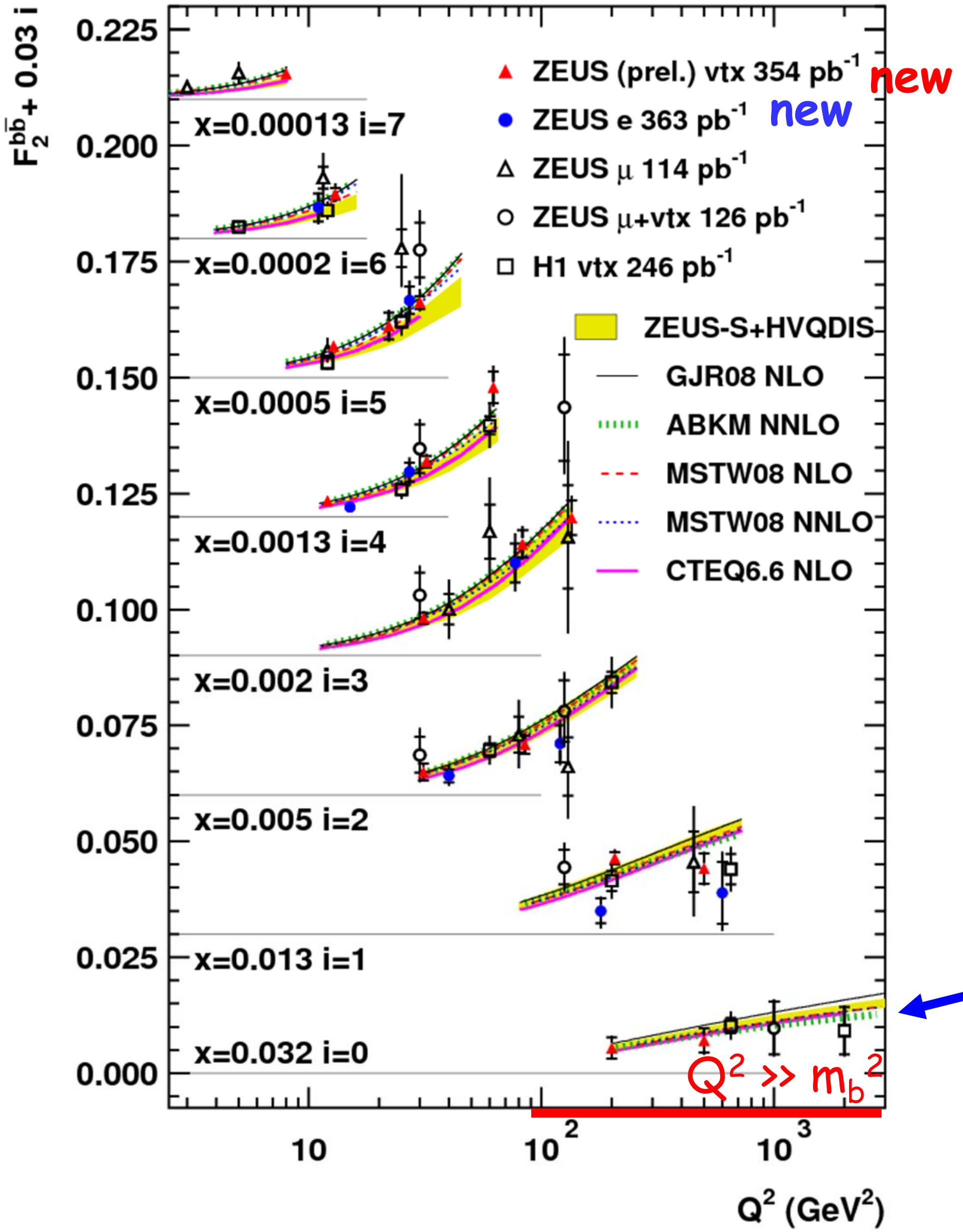
combined inclusive data, F_L, jets, charm:



all data consistent
(good fit)
-> QCD works

ongoing work,
future public release
will further reduce
model uncertainties
(e.g. m_c,
gluon/α_s correlations)

beauty contribution to F_2



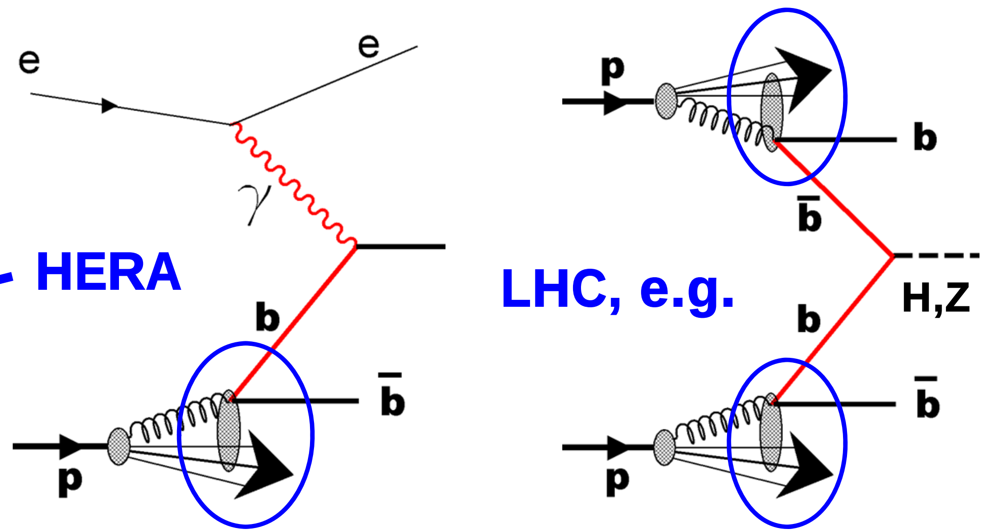
ZEUS-prel-10-004

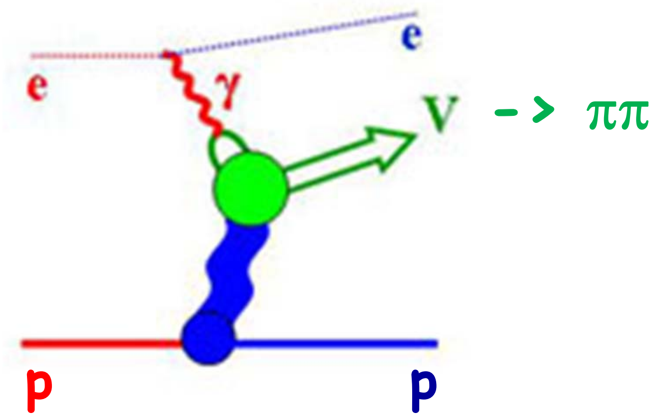
DESY-11-005, arXiv:1101.3692

NLO and partial NNLO QCD in agreement with data,

NNLO slightly better

check b PDF for LHC:

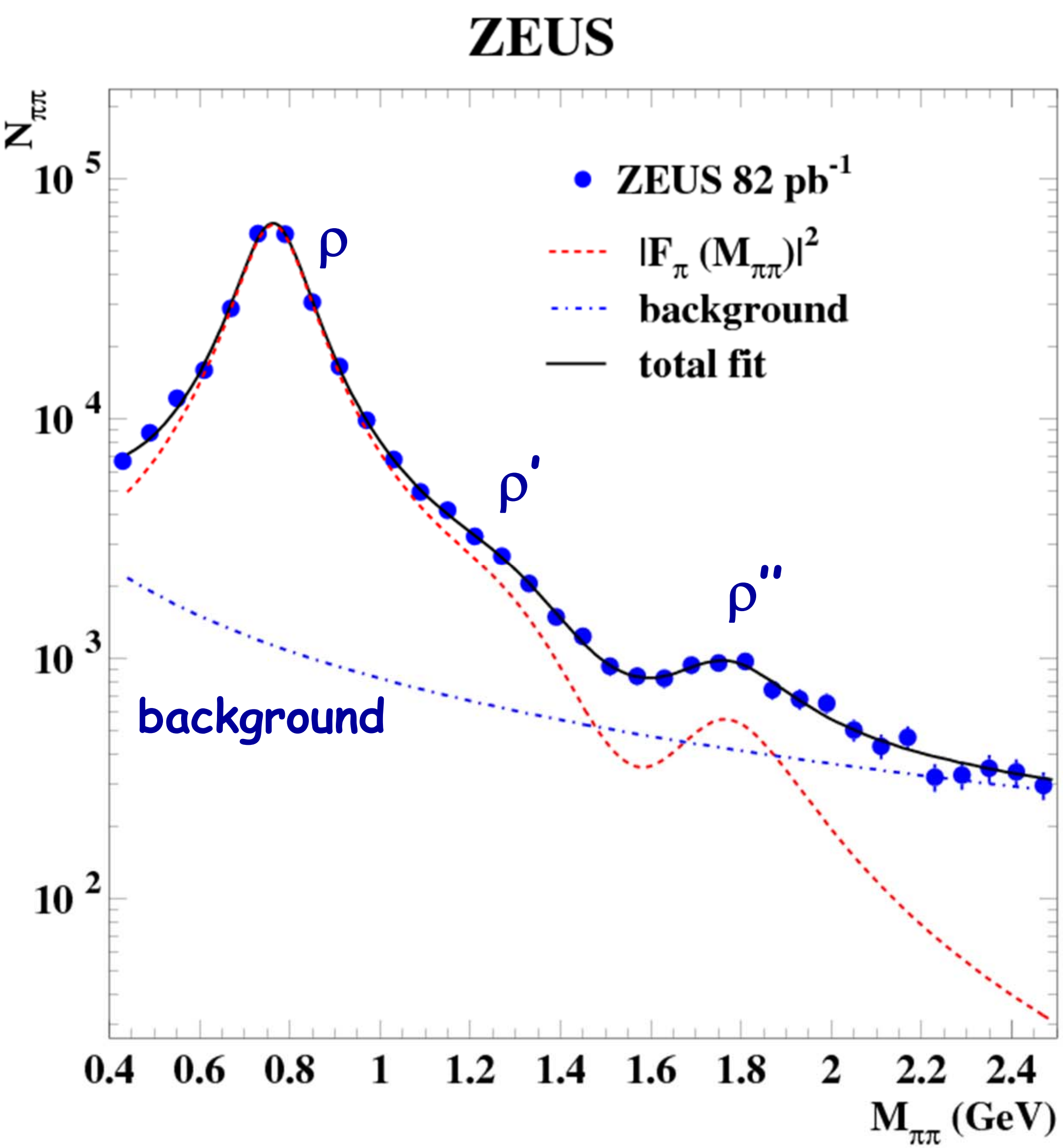


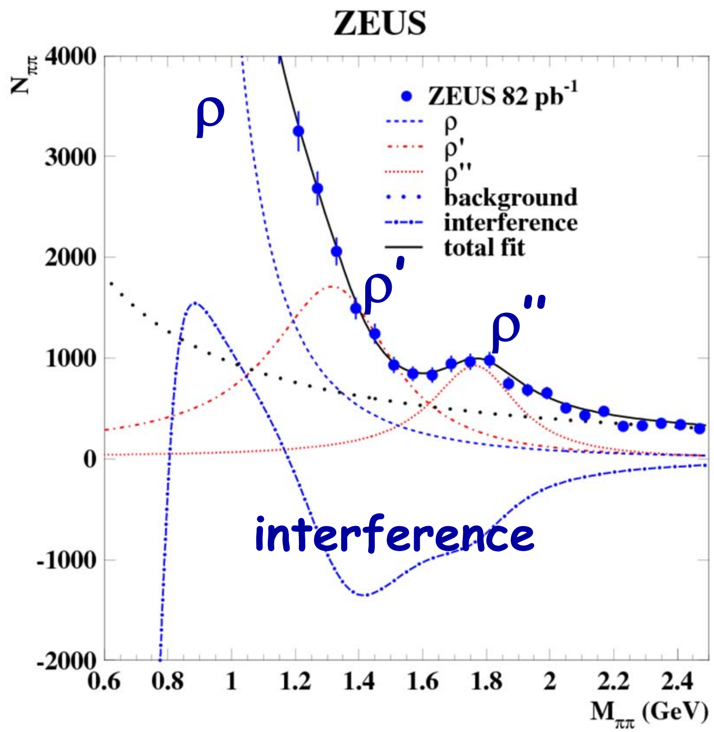


Exclusive dipion electroproduction

(other results on exclusive vector meson production see talk L. Favart)

$\pi\pi$ mass distribution, fit of F_π





Santamaria parametrization:

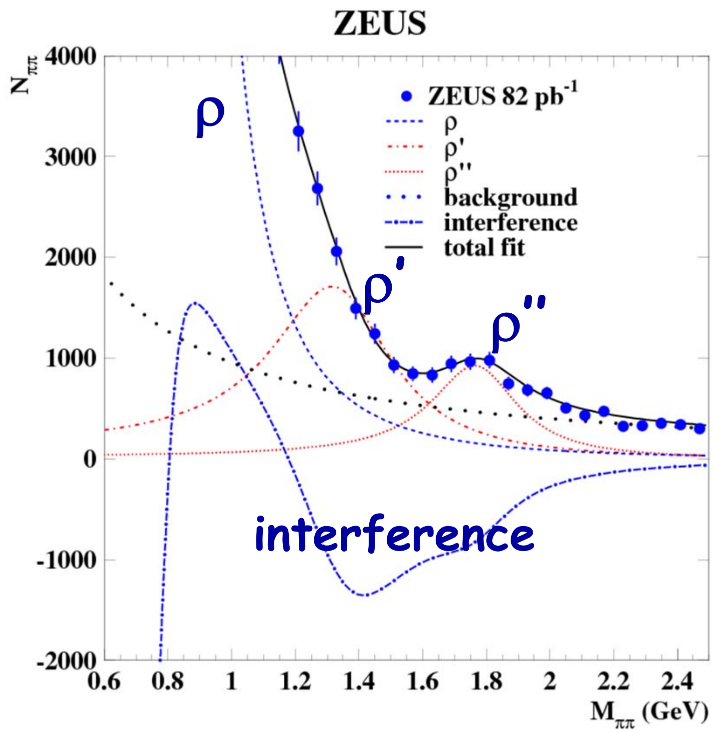
$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1+\beta+\gamma}.$$

with Breit-Wigner

$$BW_V(M_{\pi\pi}) = \frac{M_V^2}{M_V^2 - M_{\pi\pi}^2 - iM_V\Gamma_V(M_{\pi\pi})},$$

$\pi\pi$ mass distribution, fit of F_π

Parameter	ZEUS	PDG
M_ρ (MeV)	$771 \pm 2^{+2}_{-1}$	775.49±0.34
Γ_ρ (MeV)	$155 \pm 5 \pm 2$	149.1±0.8
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho'}$ (MeV)	$1350 \pm 20^{+20}_{-30}$	1465±25
$\Gamma_{\rho'}$ (MeV)	$460 \pm 30^{+40}_{-45}$	400±60
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	
$M_{\rho''}$ (MeV)	$1780 \pm 20^{+15}_{-20}$	1720±20
$\Gamma_{\rho''}$ (MeV)	$310 \pm 30^{+25}_{-35}$	250±100
B	$0.41 \pm 0.03 \pm 0.07$	
n	$1.30 \pm 0.06^{+0.18}_{-0.13}$	



masses and widths consistent with expectations (but ρ' mass lower than PDG)

Interference important !

relative amplitudes measured, found to be real

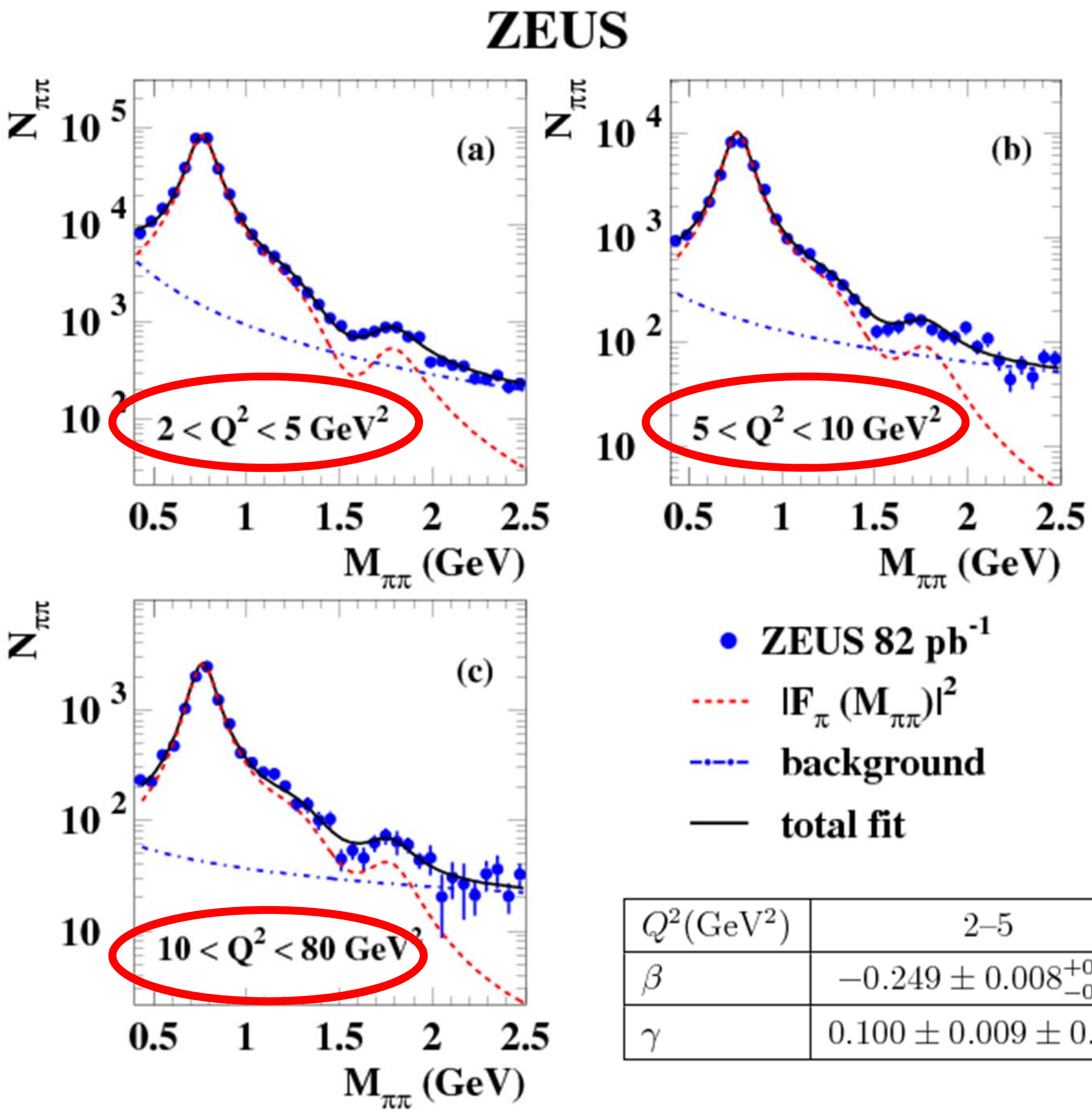
Santamaria parametrization:

$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1+\beta+\gamma}.$$

with Breit-Wigner

$$BW_V(M_{\pi\pi}) = \frac{M_V^2}{M_V^2 - M_{\pi\pi}^2 - iM_V\Gamma_V(M_{\pi\pi})},$$

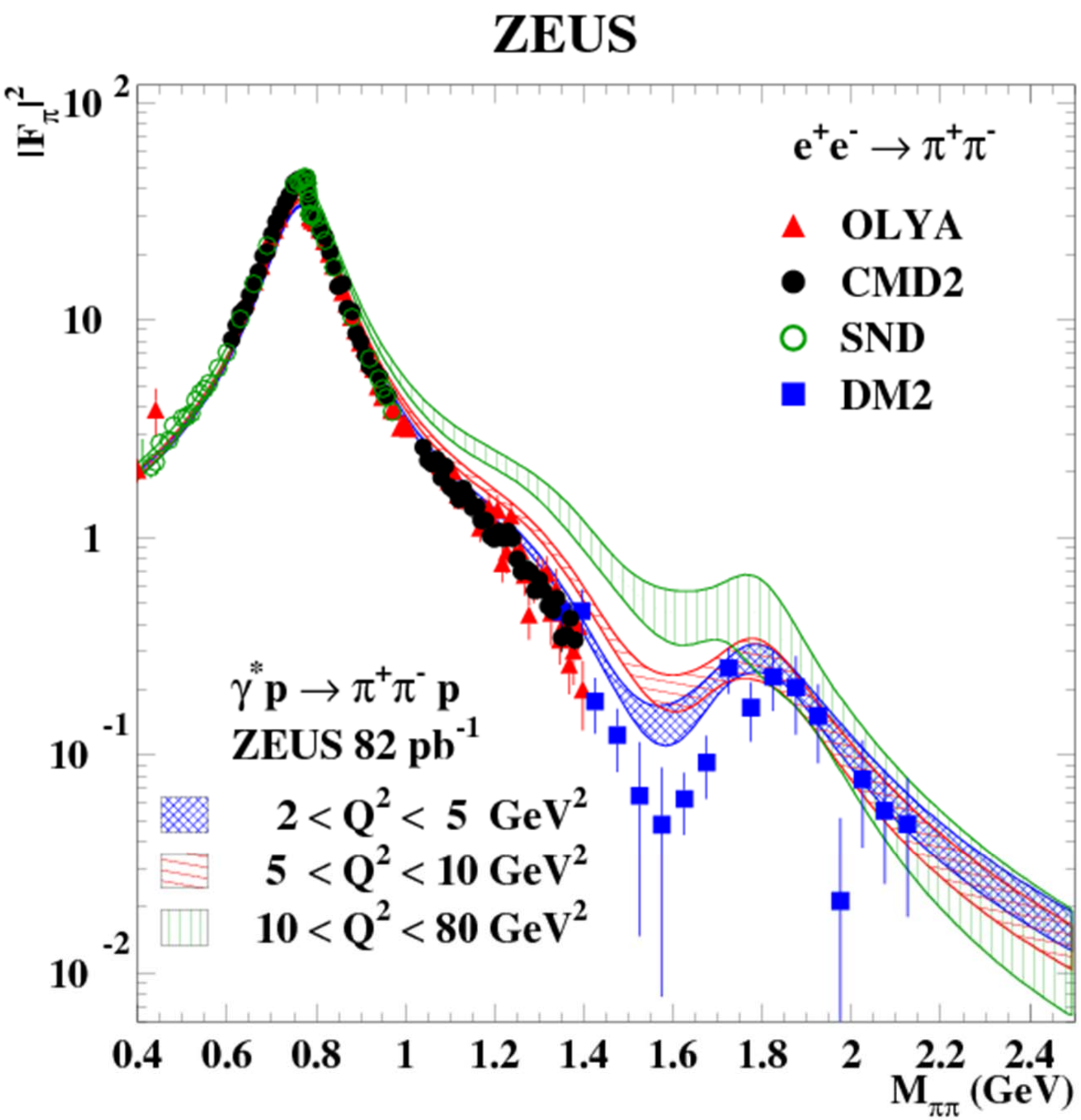
ππ mass distribution, F_π fit vs Q^2

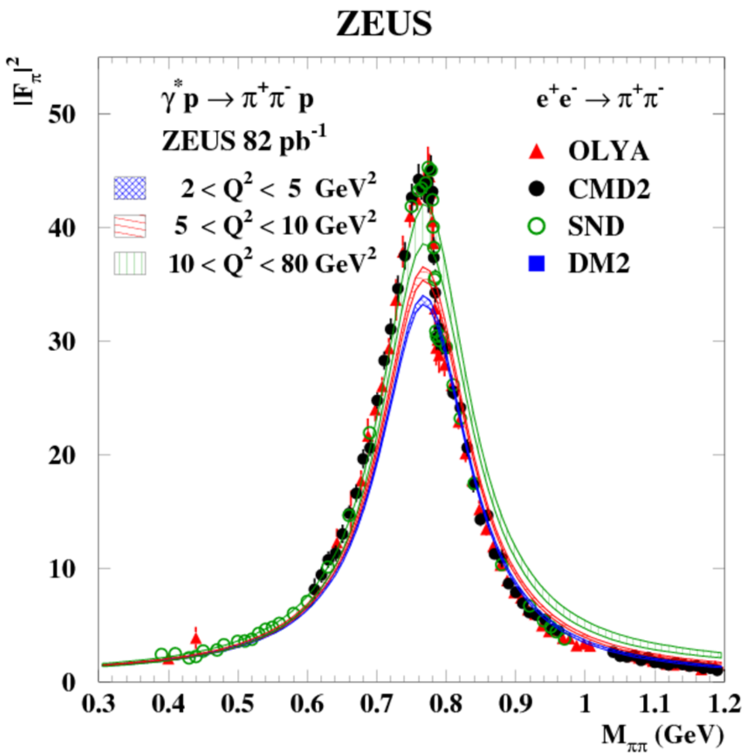


similar results,
but some Q^2 dependence

$Q^2(\mathrm{GeV}^2)$	2–5	5–10	10–80
β	$-0.249 \pm 0.008^{+0.005}_{-0.003}$	$-0.282 \pm 0.008^{+0.005}_{-0.008}$	$-0.35 \pm 0.02 \pm 0.01$
γ	$0.100 \pm 0.009 \pm 0.003$	$0.098 \pm 0.012^{+0.005}_{-0.003}$	$0.118 \pm 0.022^{+0.008}_{-0.006}$

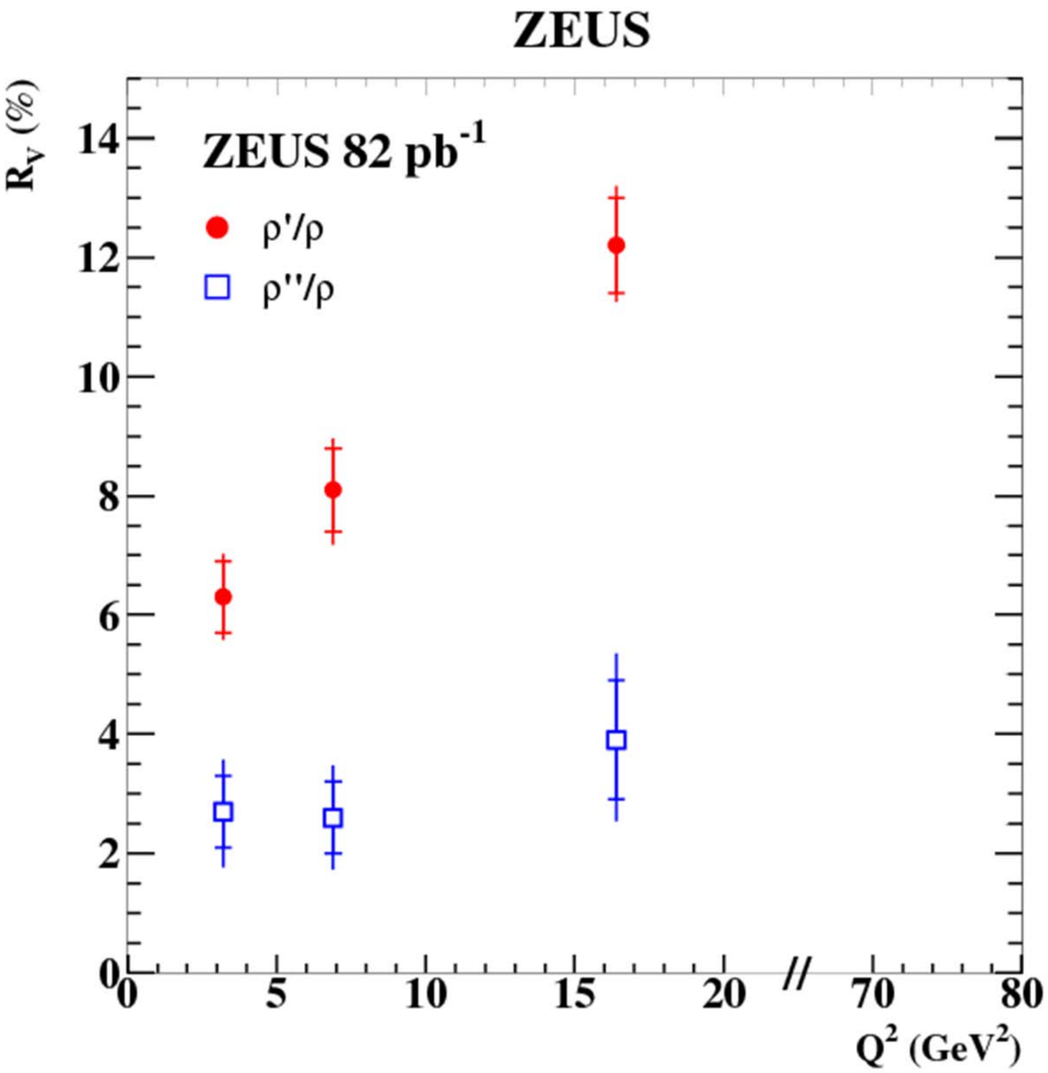
comparison to e⁺e⁻





form factor in ep DIS very similar to e+e- despite different production mechanism ($gg\gamma^*$ vs γ^*)

Q^2 dependence of ratios ρ'/ρ, ρ''/ρ



ρ'/ρ ratio rises with increasing Q^2
- qualitatively expected due to node in ρ' wave function (suppression at low Q^2)

ρ''/ρ ratio inconclusive

Summary and conclusions

- **DIS measurements at HERA successfully test QCD** and provide unique input to **determination of parton densities**
  HERAPDF 1.5 NLO/NNLO available on LHAPDF

- **HERA jet and heavy flavour measurements successfully test and constrain QCD parameters, improve PDFs**
  -> **potential to yield competitive measurements of α_s**
  (need NNLO calculations ! partially in progress).
  -> **further improve cross section predictions for LHC**

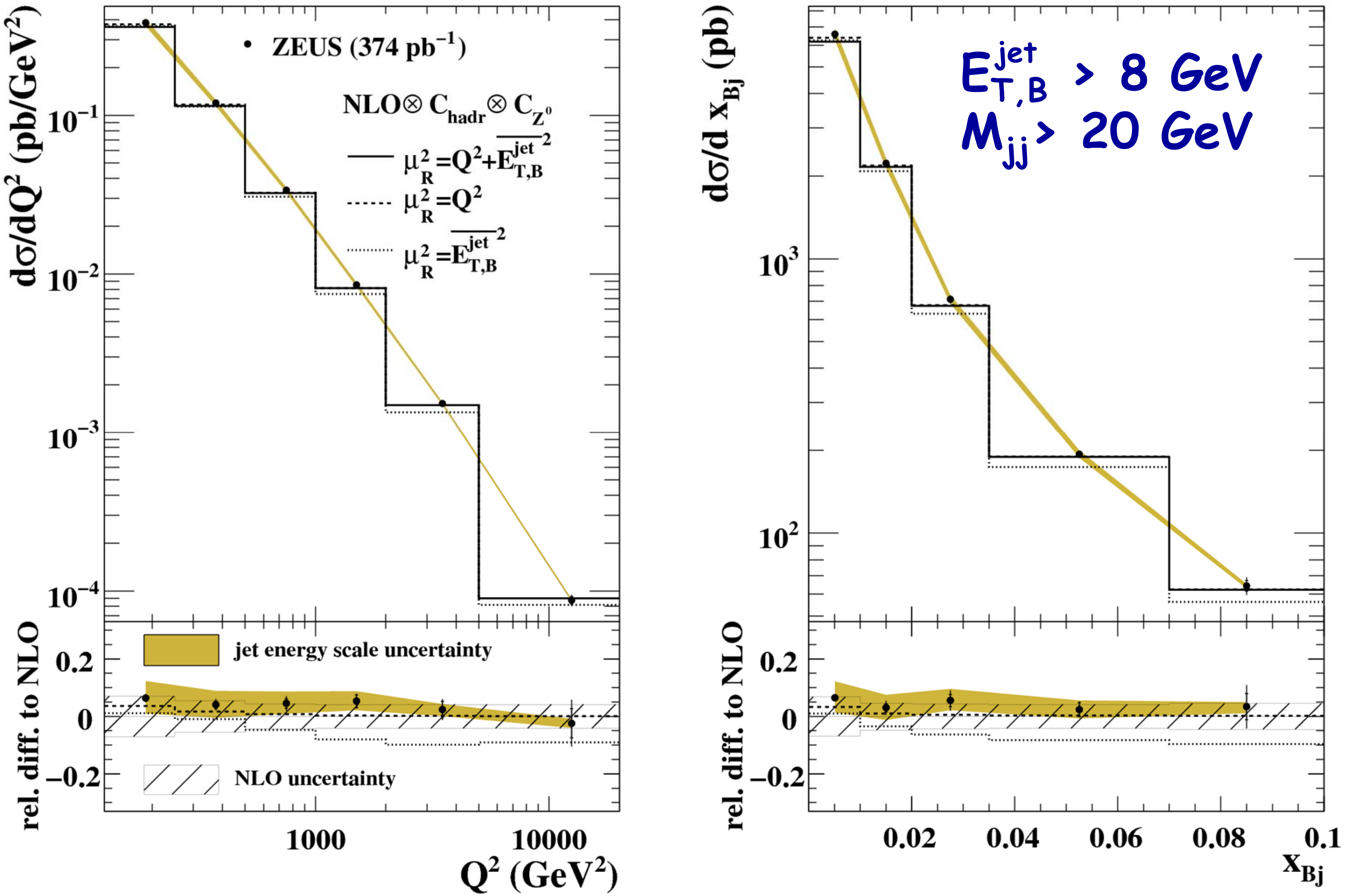
- combination of H1/ZEUS results ongoing
  -> **towards full 1 fb^{-1} results (H1+ZEUS, HERA1+2)**.
  -> expect **significant further improvements** over next few years

- **exclusive dipion electroproduction allows measurement of ρ, ρ' and ρ'' production and their interference**
  -> relative production amplitudes are real and similar to e+e-
  -> ρ'/ρ ratio rising with Q^2 as expected

Backup

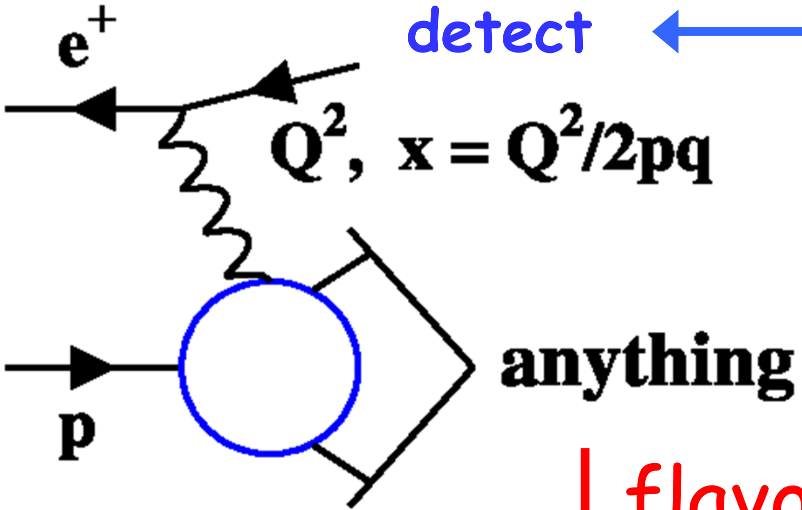
Dijets in DIS

DESY-10-170, Eur. Phys. J. C70 (2010) 965



QCD works!

Heavy flavour contributions to F_2

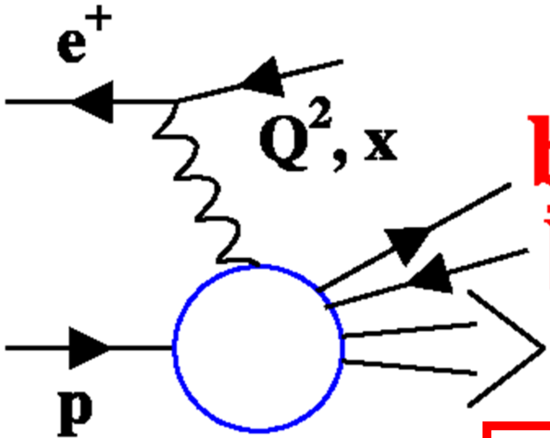


detect ↔

Measure cross section

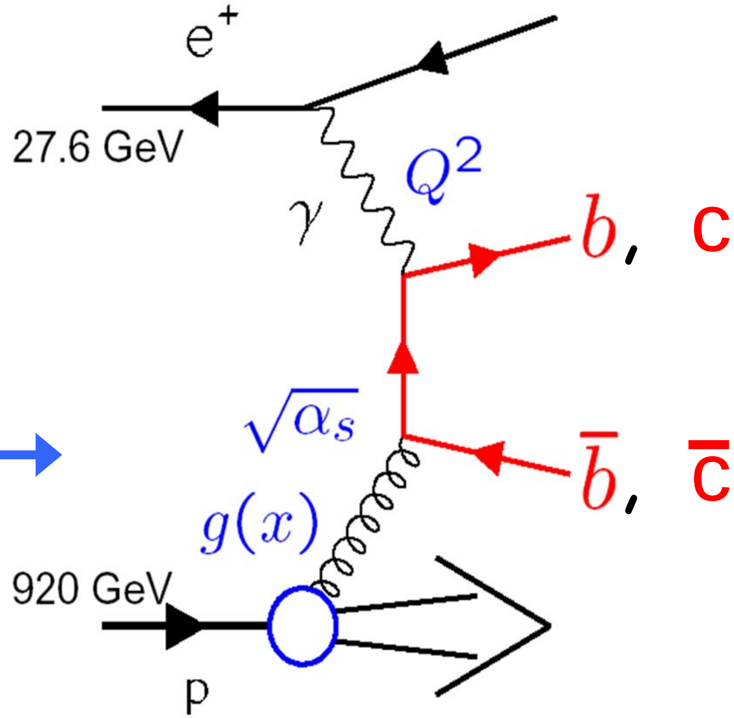
$$\frac{d^2\sigma}{dx\,dQ^2} \cong \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right] F_2(x,Q^2)\right.$$

flavour tagging



$b\,\bar{b}$ or $c\,\bar{c}$

QCD ↔



-> $F_2^{b\bar{b}}$, $F_2^{c\bar{c}}$

ππ control distributions

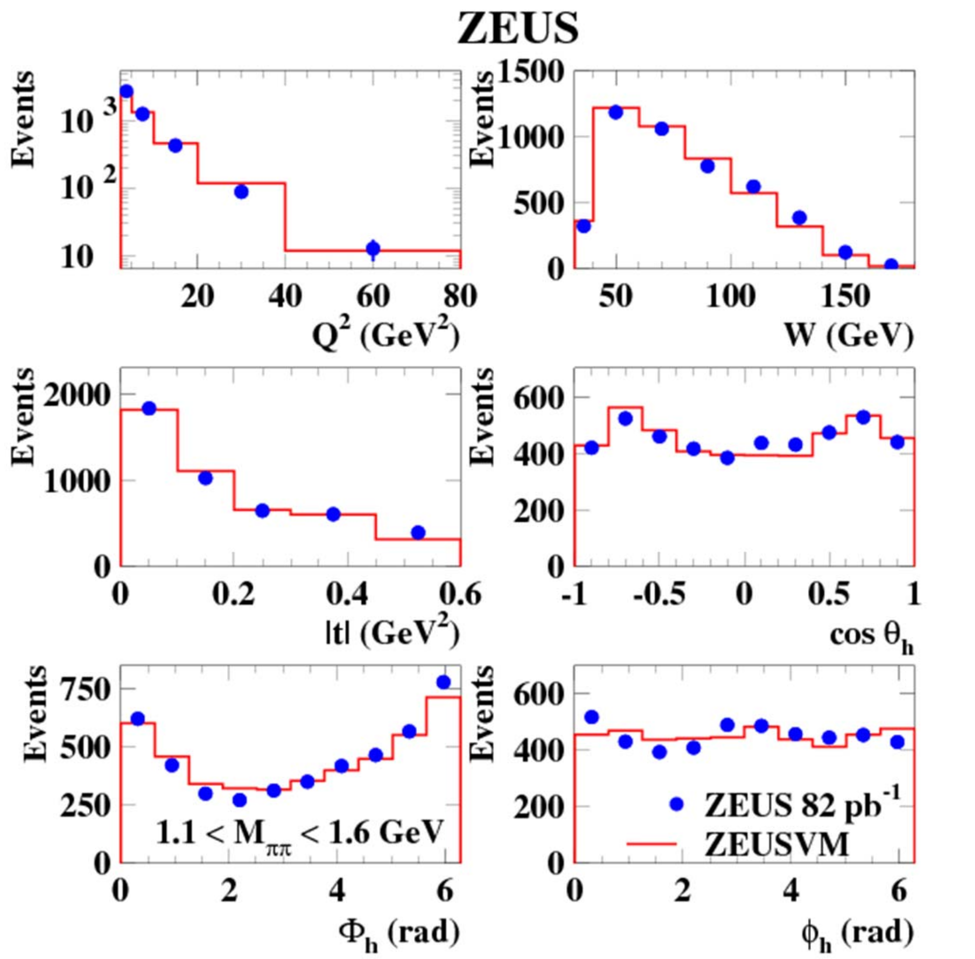


Figure 2: *Comparison between the data and the* ZEUSVM *MC distributions for* Q^2, W, $|t|$, $\cos\theta_h$, Φ_h *and* ϕ_h *for events within mass range* $1.1 < M_{\pi\pi} < 1.6$ *GeV. The MC distributions are normalized to the data.*

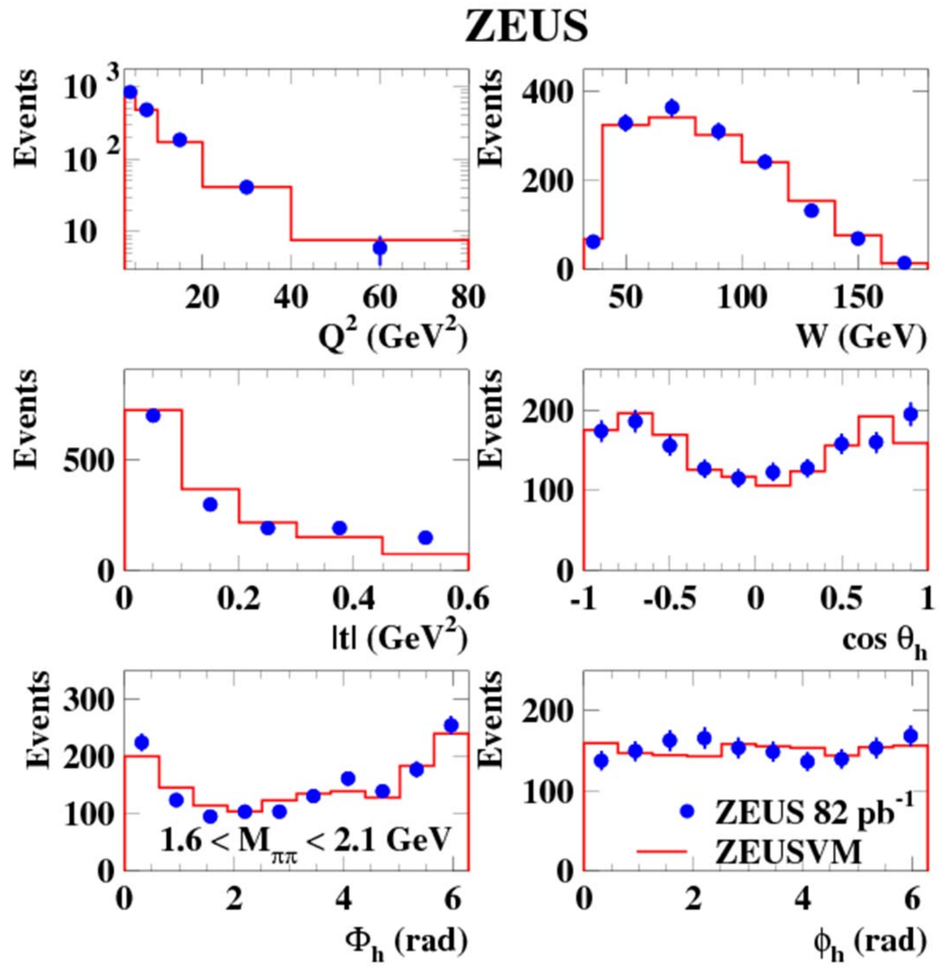


Figure 3: *Comparison between the data and the* ZEUSVM *MC distributions for* Q^2, W, $|t|$, $\cos\theta_h$, Φ_h *and* ϕ_h *for events within mass range* $1.6 < M_{\pi\pi} < 2.1$ *GeV. The MC distributions are normalized to the data.*