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

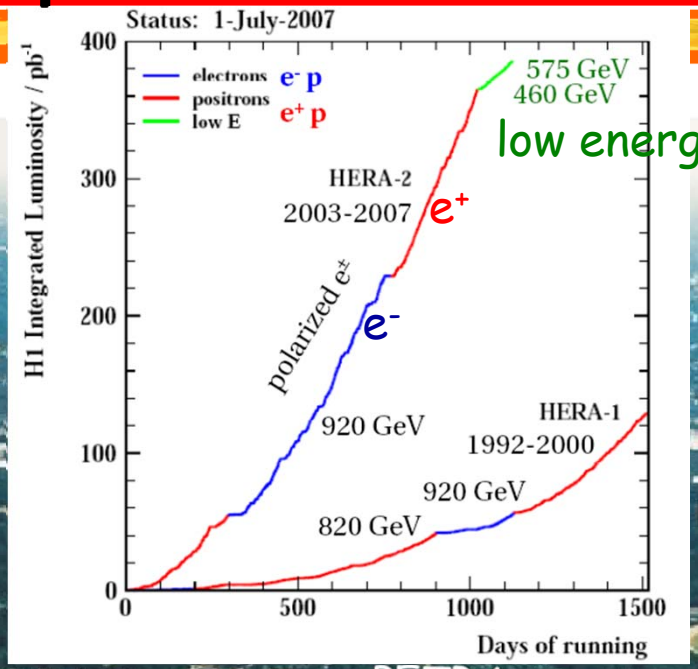
inclusive diffraction + diffractive dijets + total cross section -> talk A. Valkarova

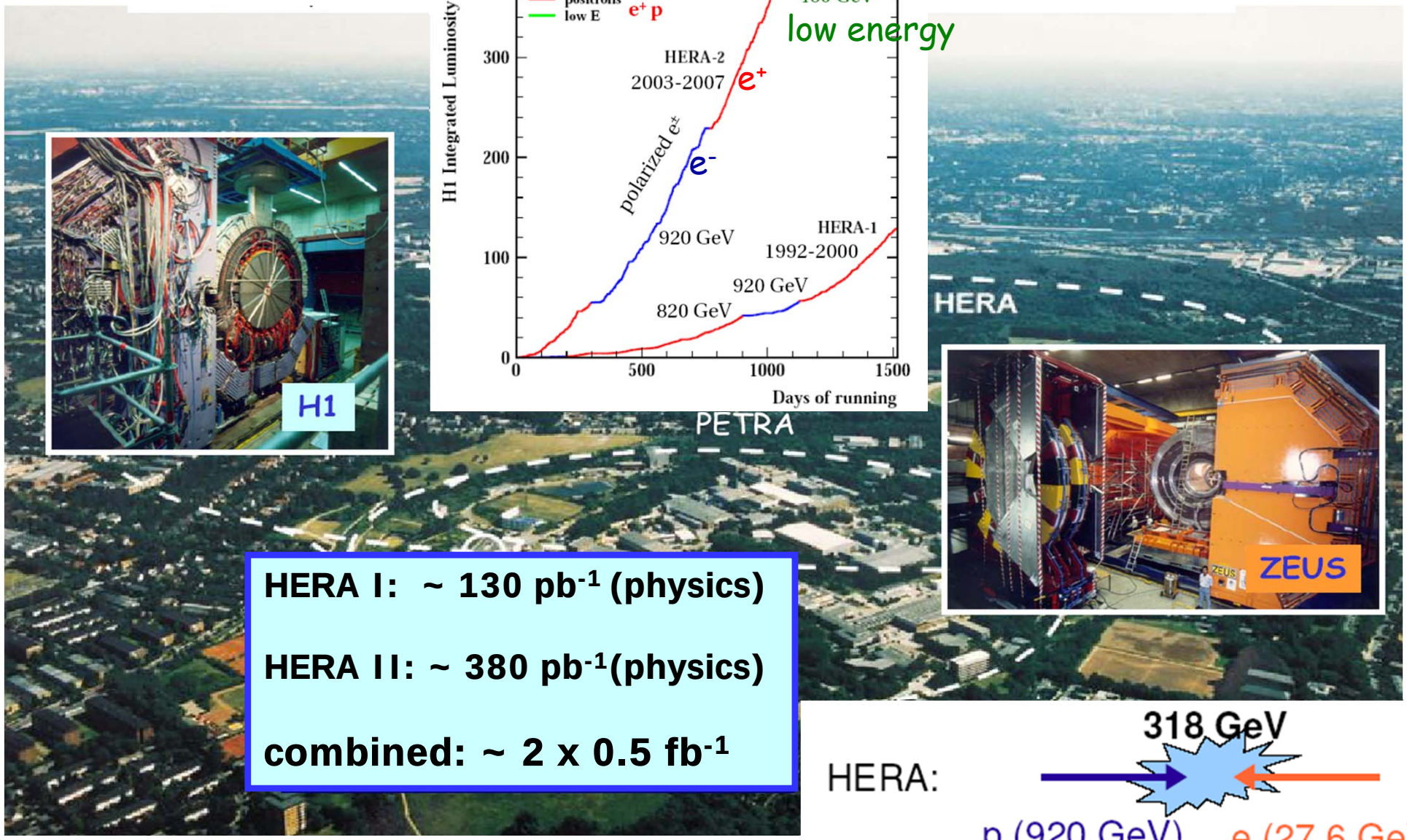
comparison of diffraction at HERA and Tevatron -> talks C. Royon & K. Giulianos

exclusive vector meson production -> talk L. Favart

HERA data and pomeron -> talk U. Maor

The HERA ep collider and experiments

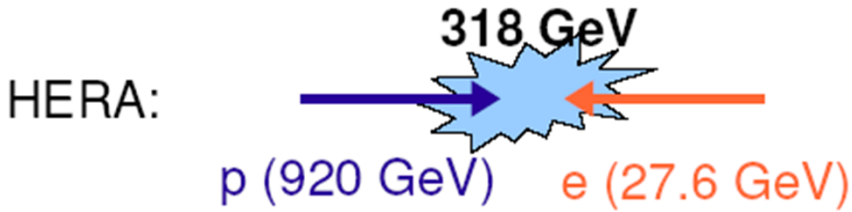




HERA I: ~ 130 pb^{-1} (physics)

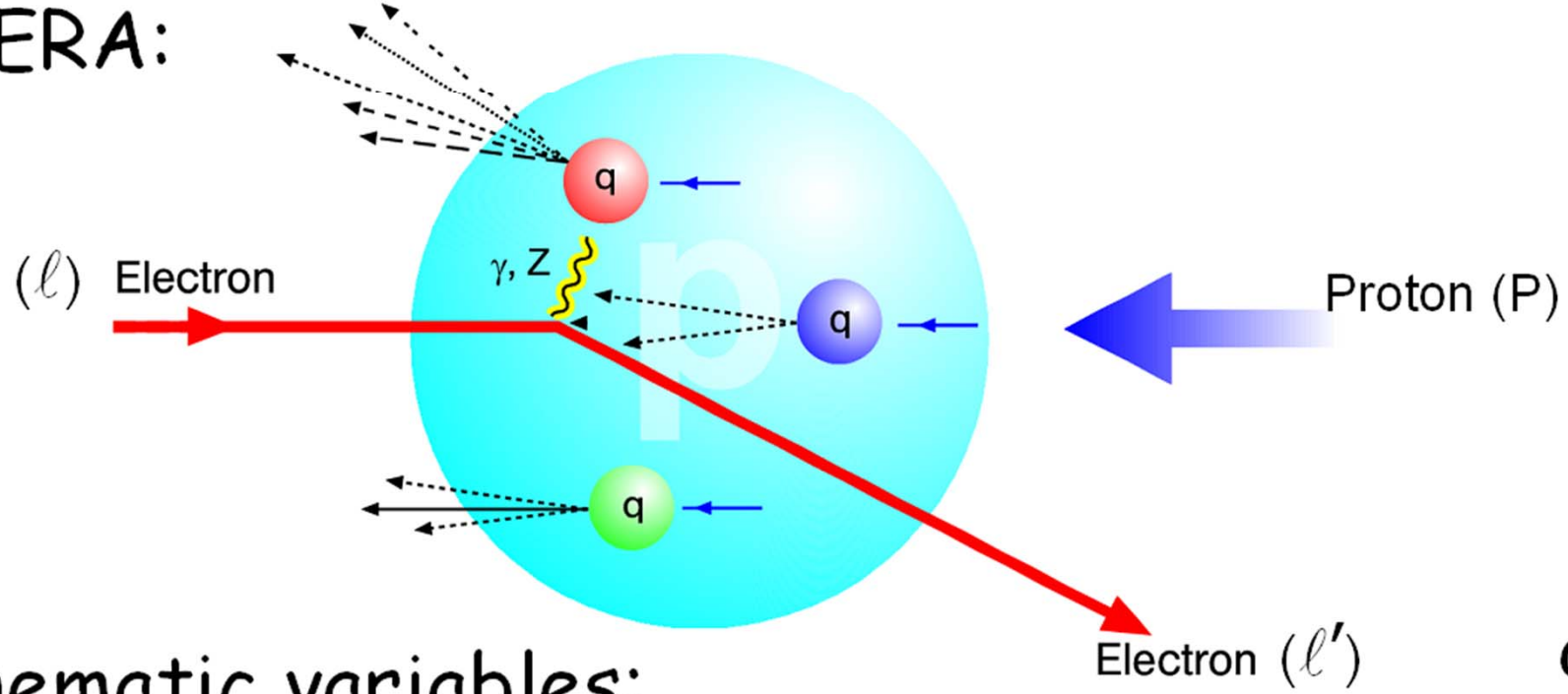
HERA II: ~ 380 pb^{-1}(physics)

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

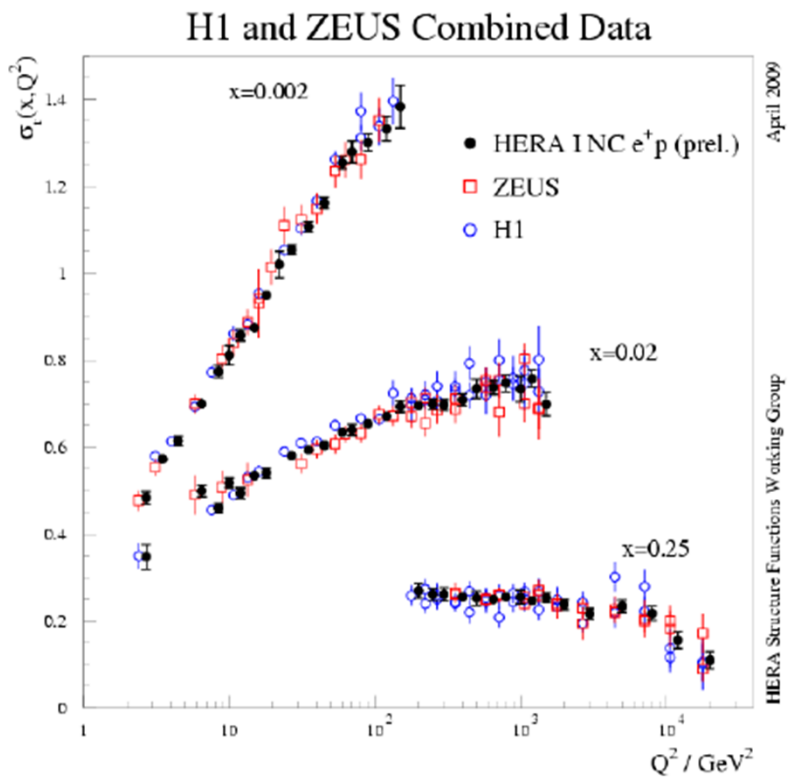
$x = \frac{Q^2}{2Pq}$ Bjorken scaling variable,
for $Q^2 \gg (2m_q)^2$: momentum fraction of p constituent

$y = \frac{qP}{\ell P}$ 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:

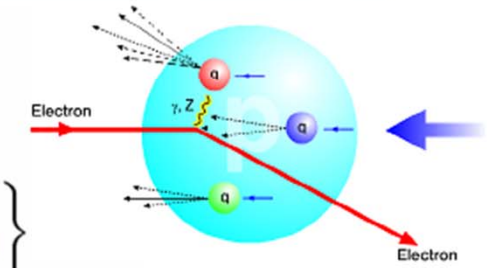
full expert treatment of

exp. syst. uncertainties and correlations

HERA data essential input to any PDF fit

The structure of the proton

special HERA run in 2007



- Measure cross section

small

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

at high Q^2

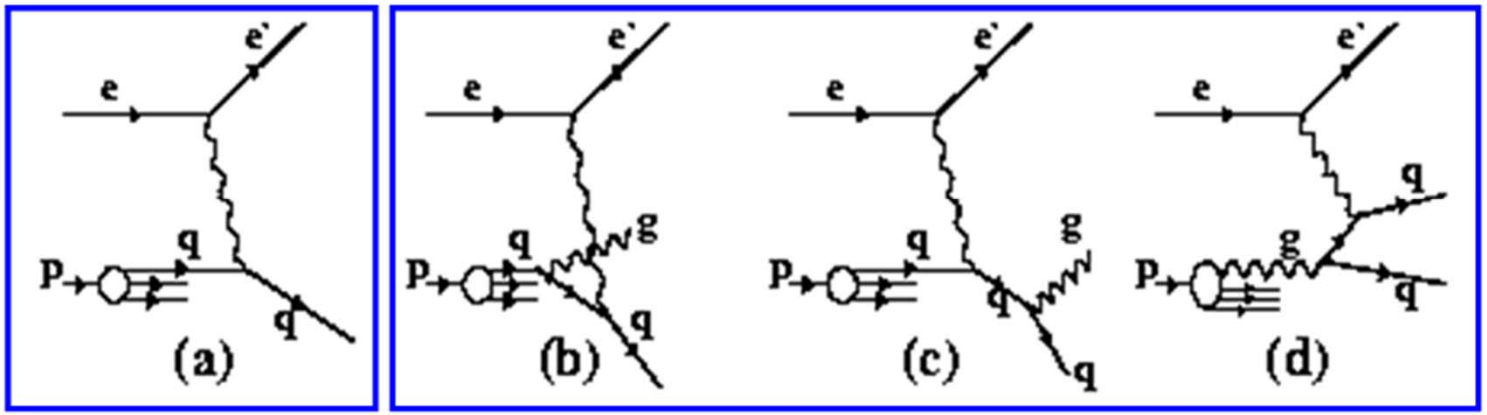
to 0th order QCD (Quark Parton Model, $Q^2 \gg m_q^2$):

- Parton distribution functions (PDF) in pQCD

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

q_i – probability to find quark with flavour i in proton

"higher" order QCD corrections



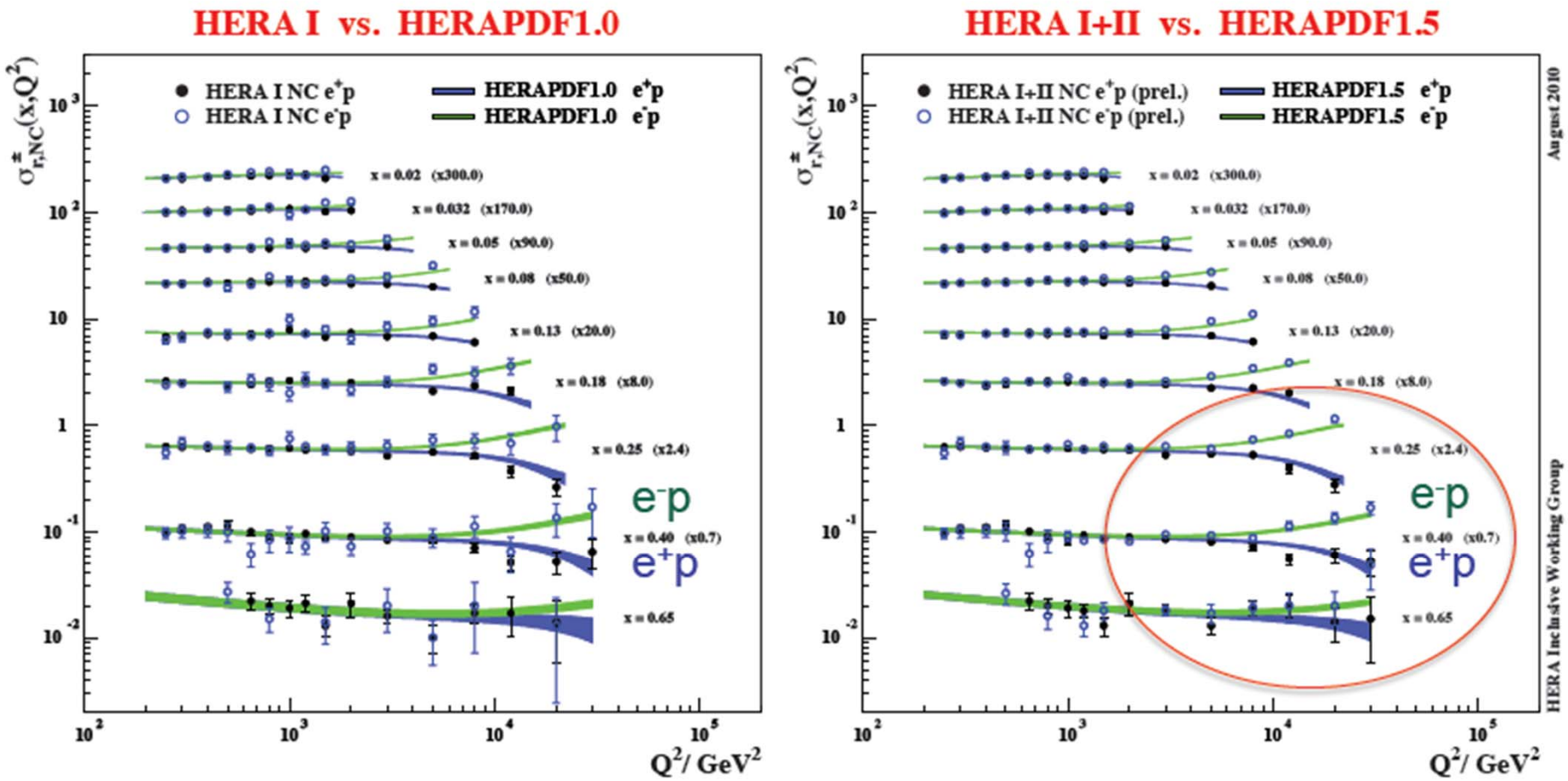
in general: F_2 structure function is **not** PDF

Combination of HERA data and PDF fit

e.g. high Q^2 neutral current:

JHEP 1001-109

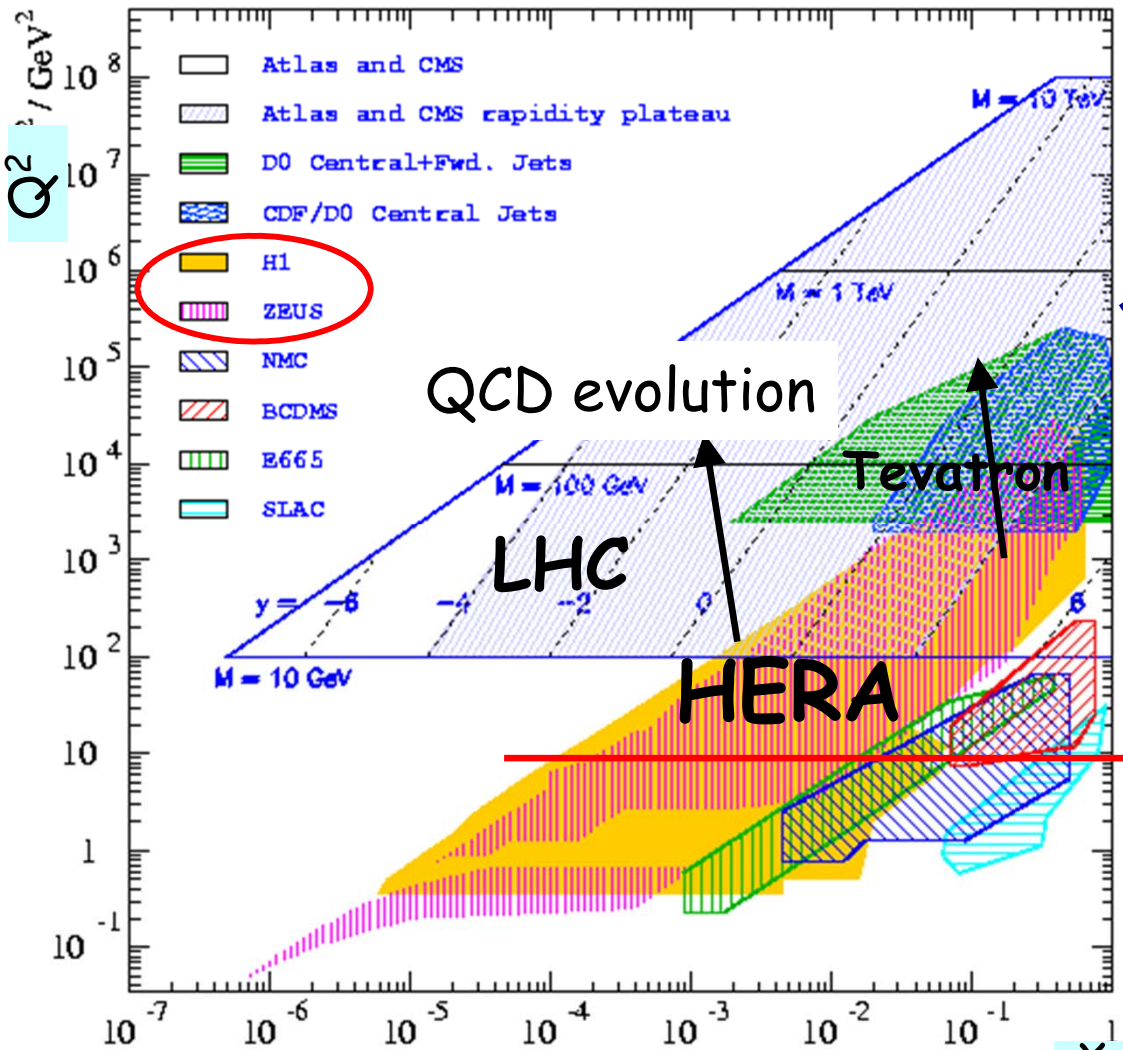
ZEUS-prel 10-018, 11-002, H1-prelim 10-042, 11-042



- 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)

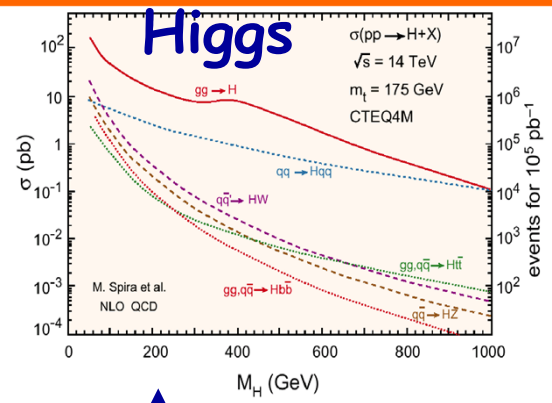


QCD evolution

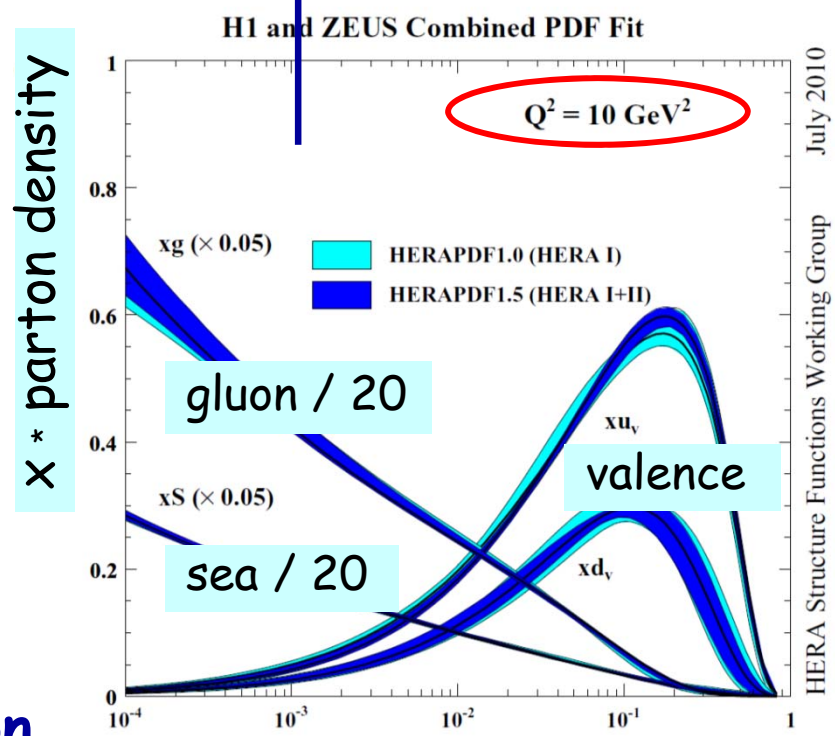
LHC

Tevatron

HERA



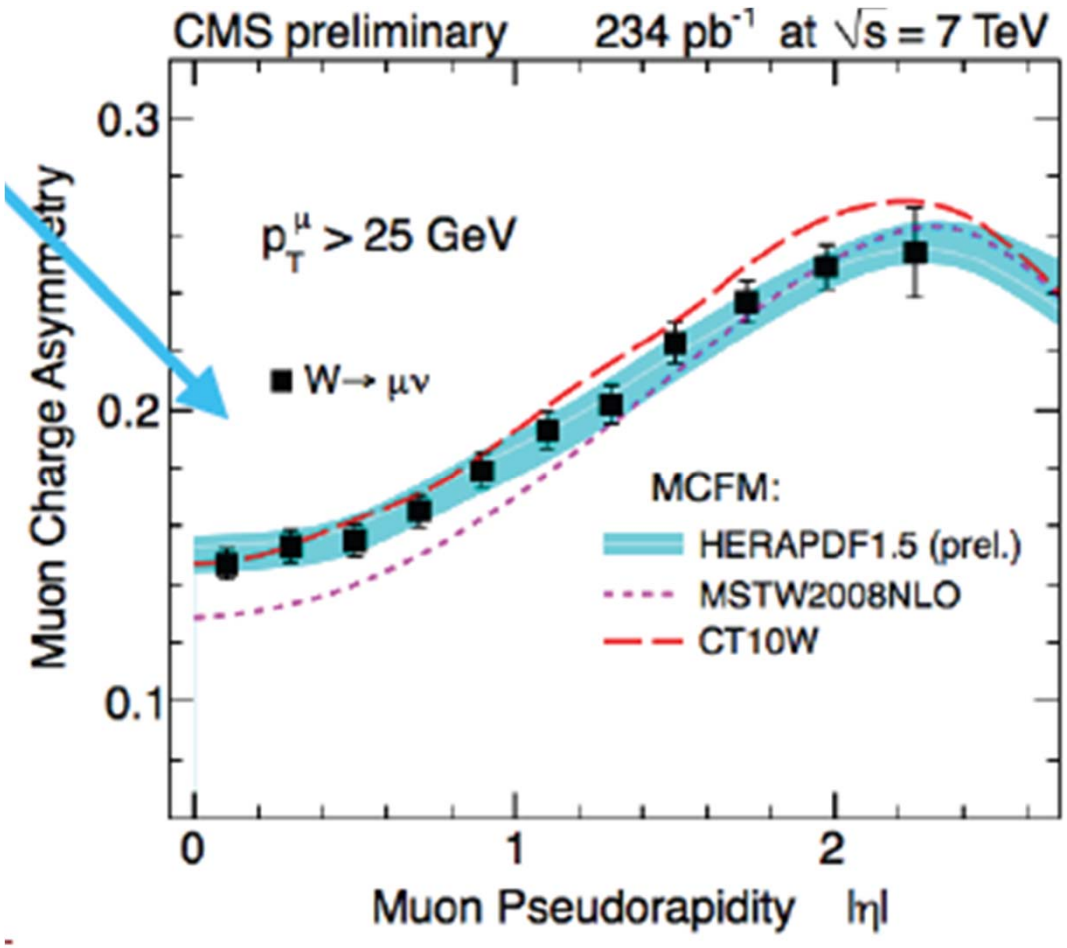
W,Z, top, jets, ...



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

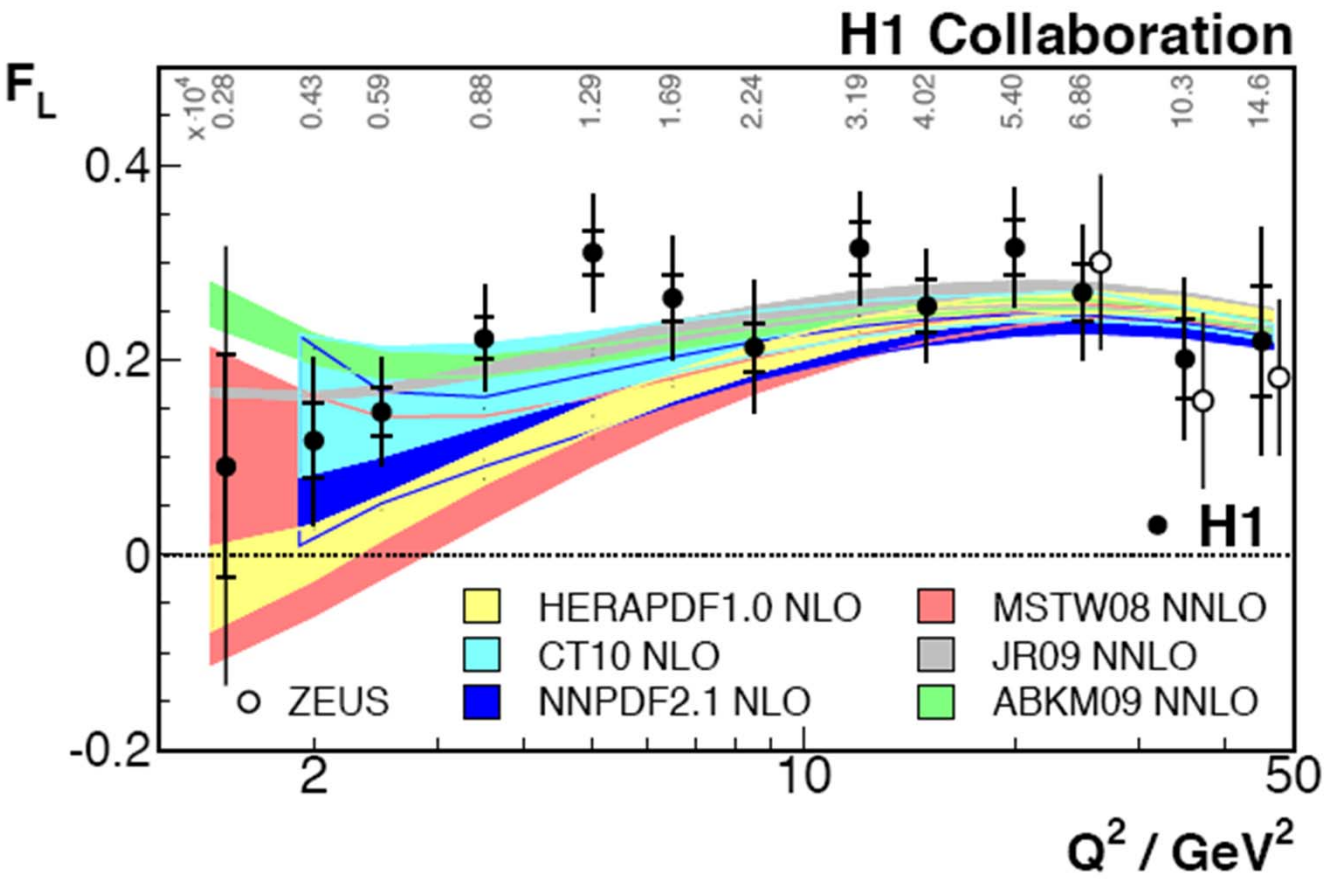
Example: W production in CMS

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

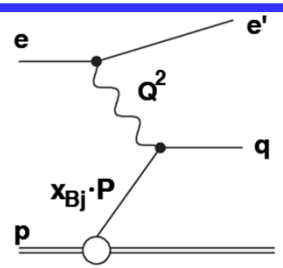
- perfect description of the F_L data by QCD at $Q^2 \geq 10$ GeV^2
- large spread/uncertainty of the QCD predictions at low Q^2

F_L data are valuable input to QCD fits

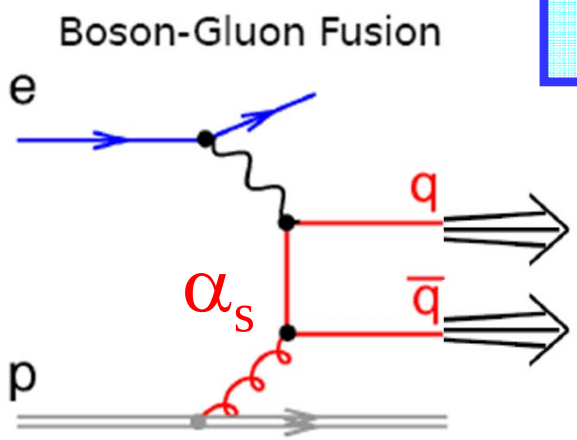
Jets and α_s

Jets in ep interactions (HERA)

QPM:



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

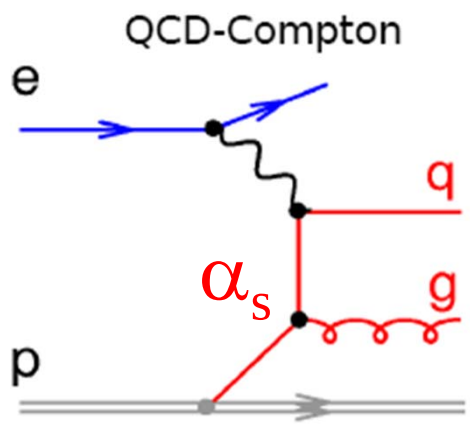


dijets in DIS or photoproduction:

measure both (**dijets**) or

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

require high E_T w.r.t. photon axis

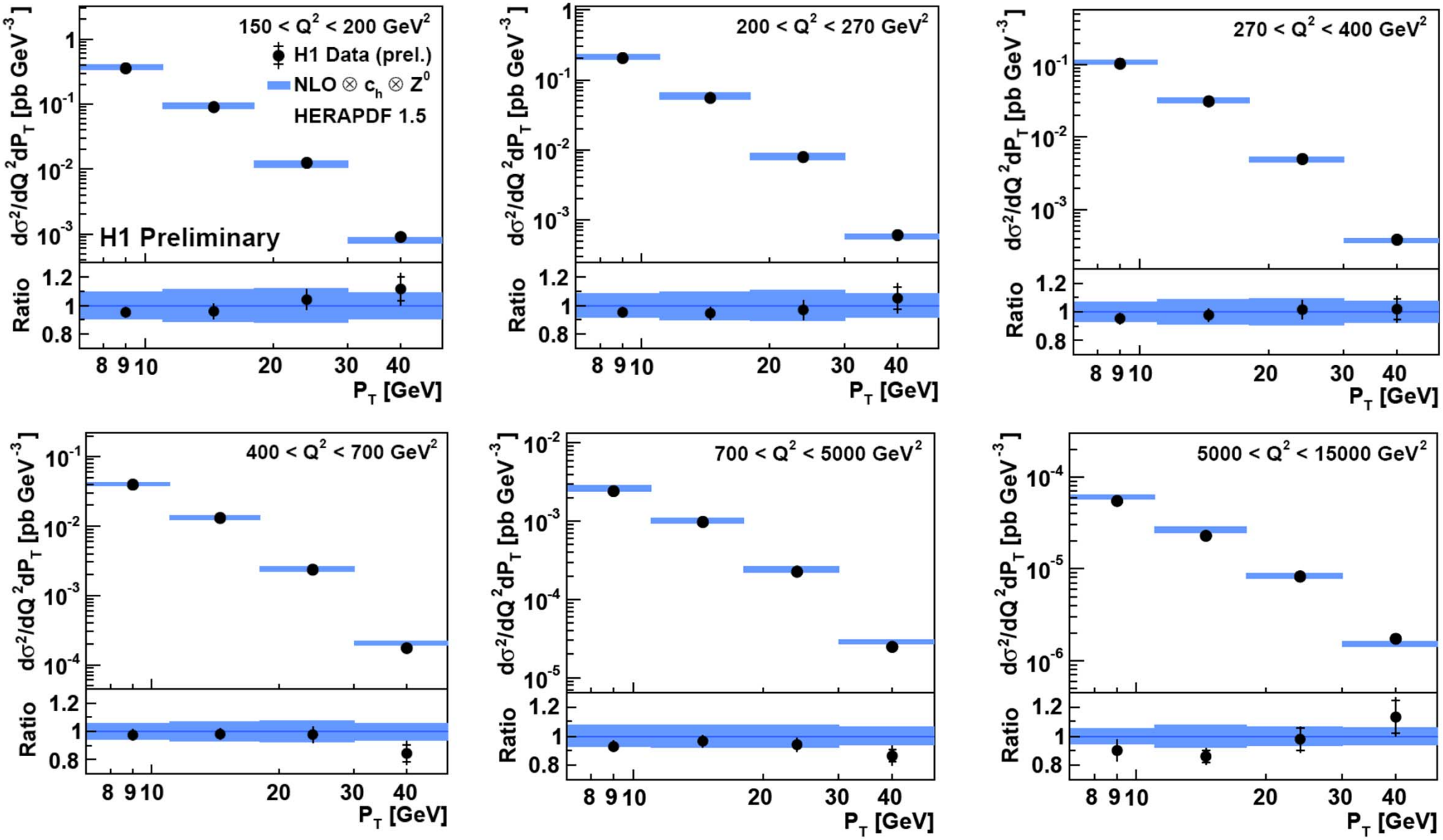


- check QCD
- study performance of jet algorithms
- measure α_s and its running
- measure gluon density

Inclusive jets in DIS

H1-prelim 11-032

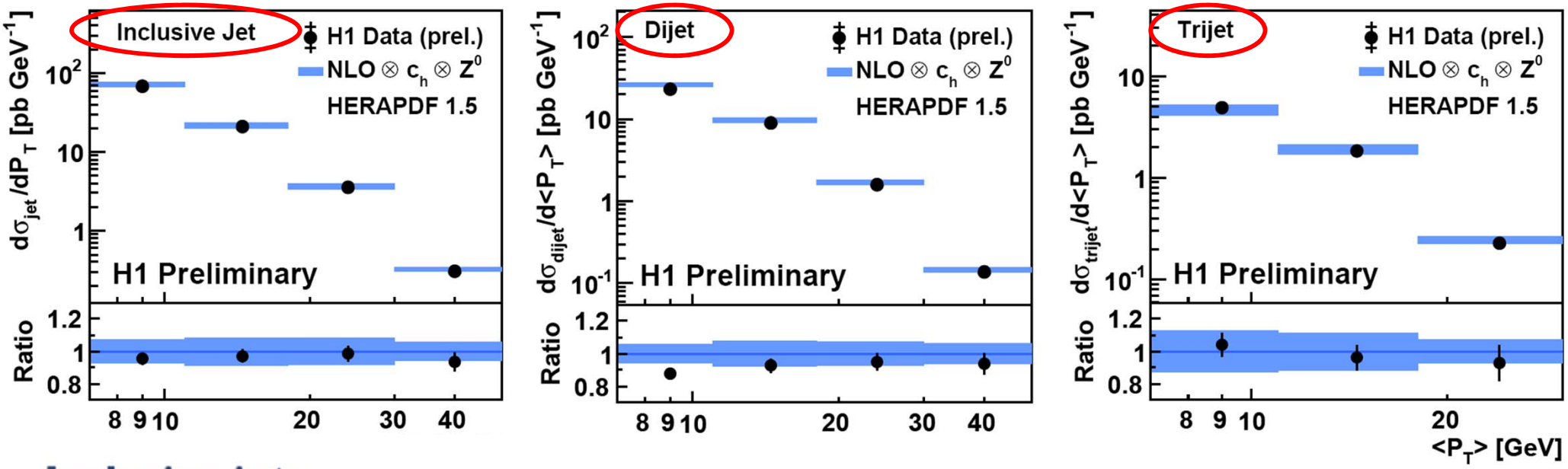
double differential in Q^2 and p_T



well described by NLO QCD + HERAPDF

Multijet production + α_s

H1-prelim 11-032



Inclusive jet:

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

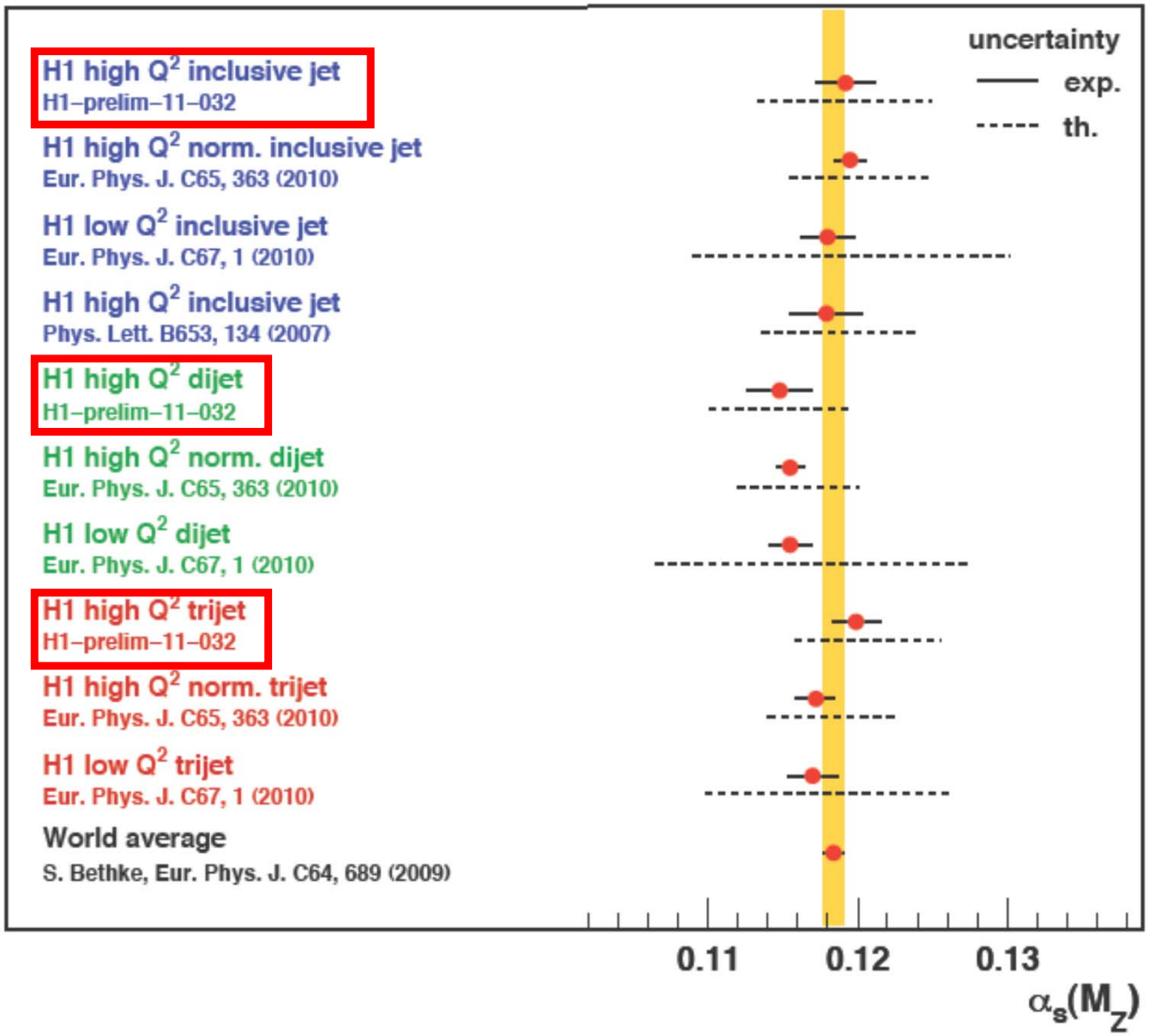
Dijet:

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

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

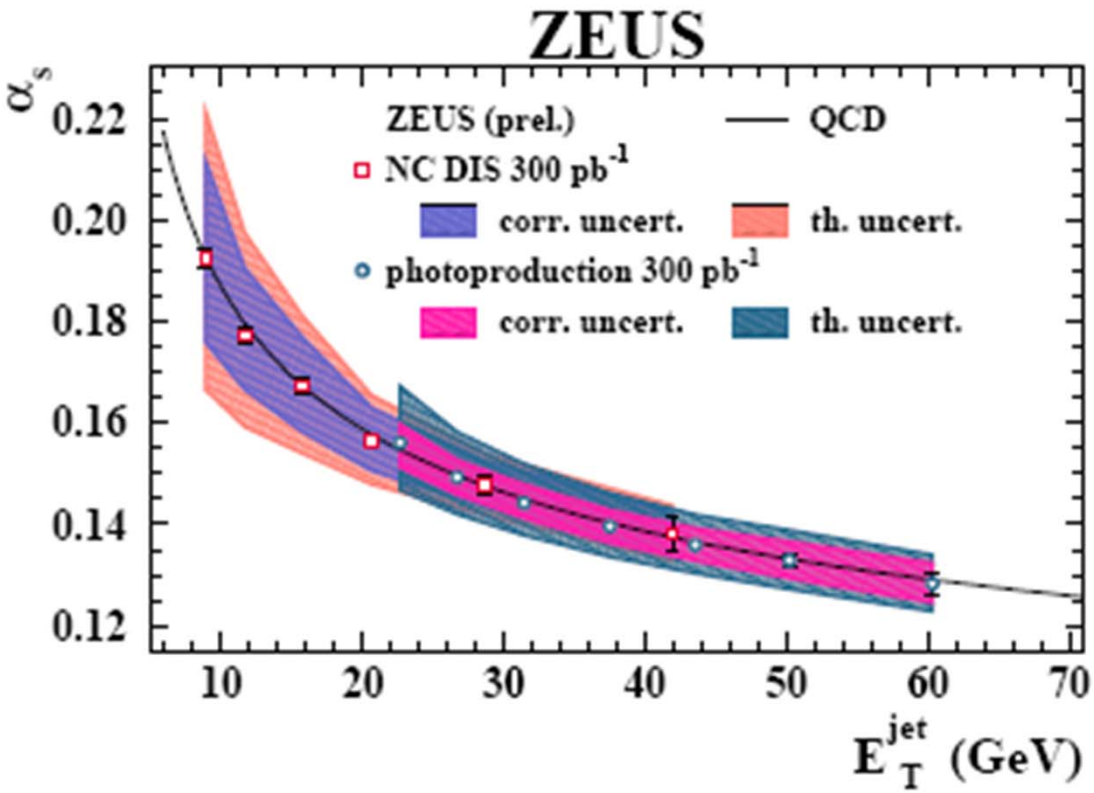
good agreement with previous measurements and world average

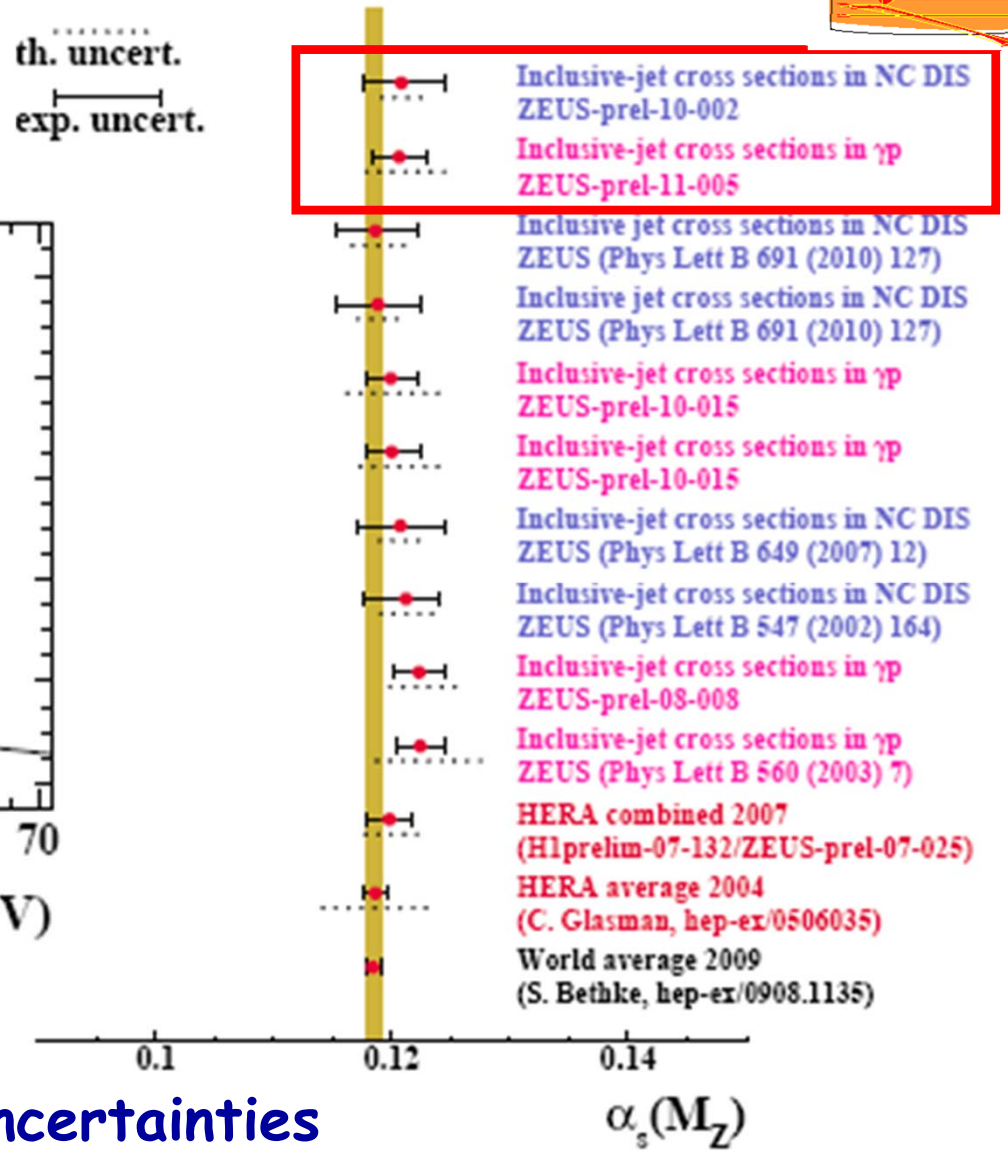
uncertainties dominated by NLO theory

Summary of ZEUS α_s measurements

ZEUS-prel 11-005

α_s running

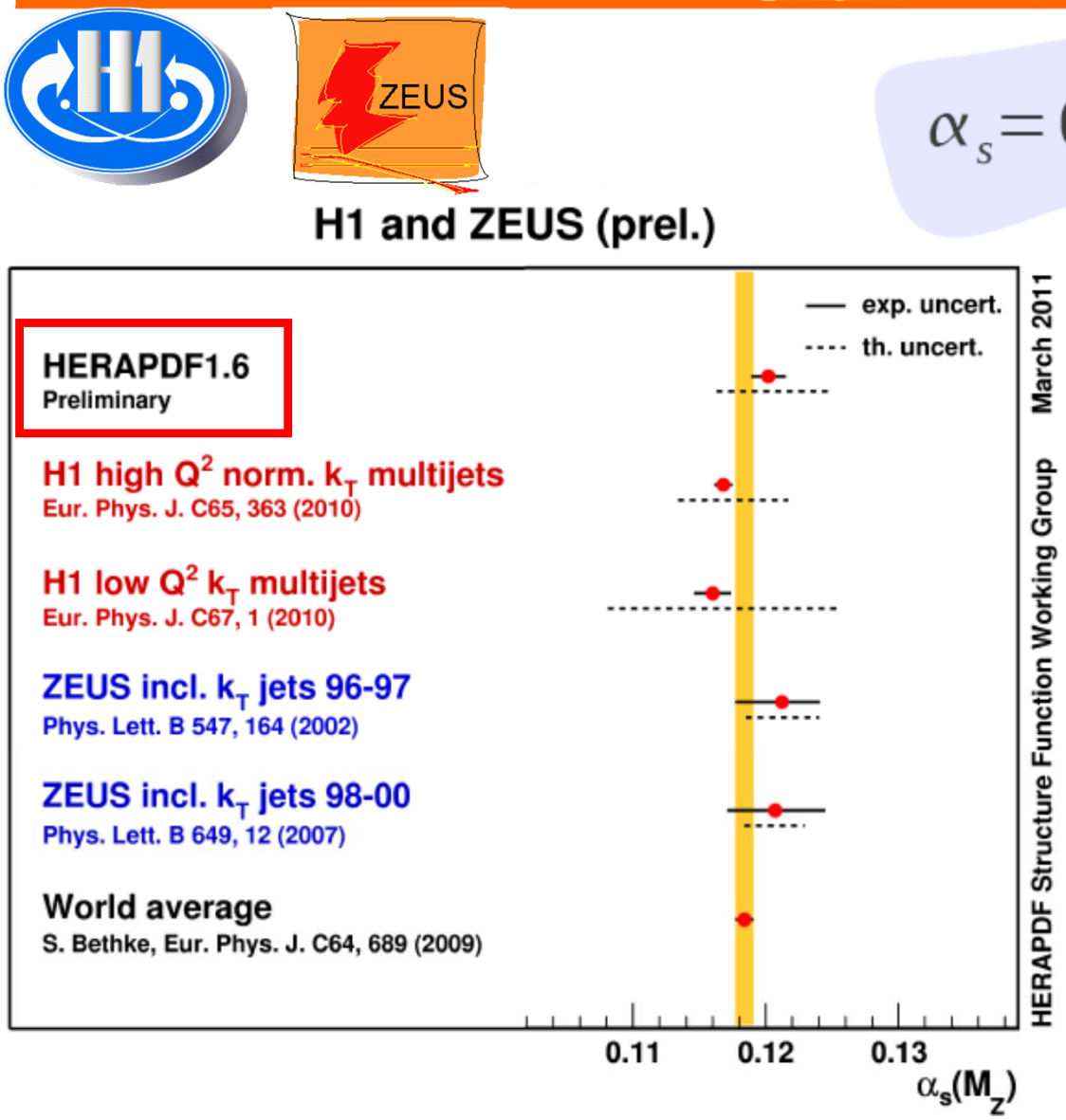




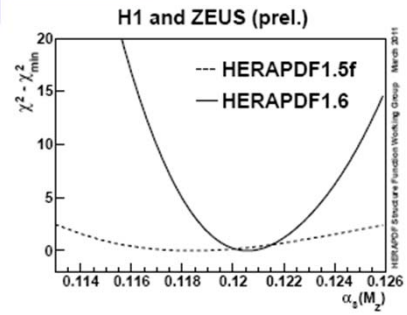
analyses optimized for minimization of theoretical uncertainties

PDF fit including Jets + free α_s

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



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

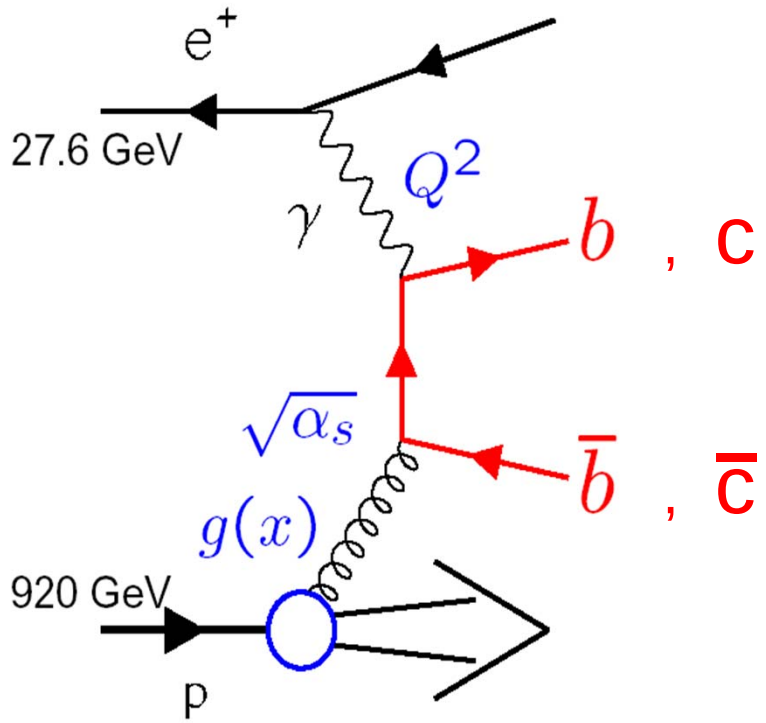


decorrelates α_s and gluon

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.

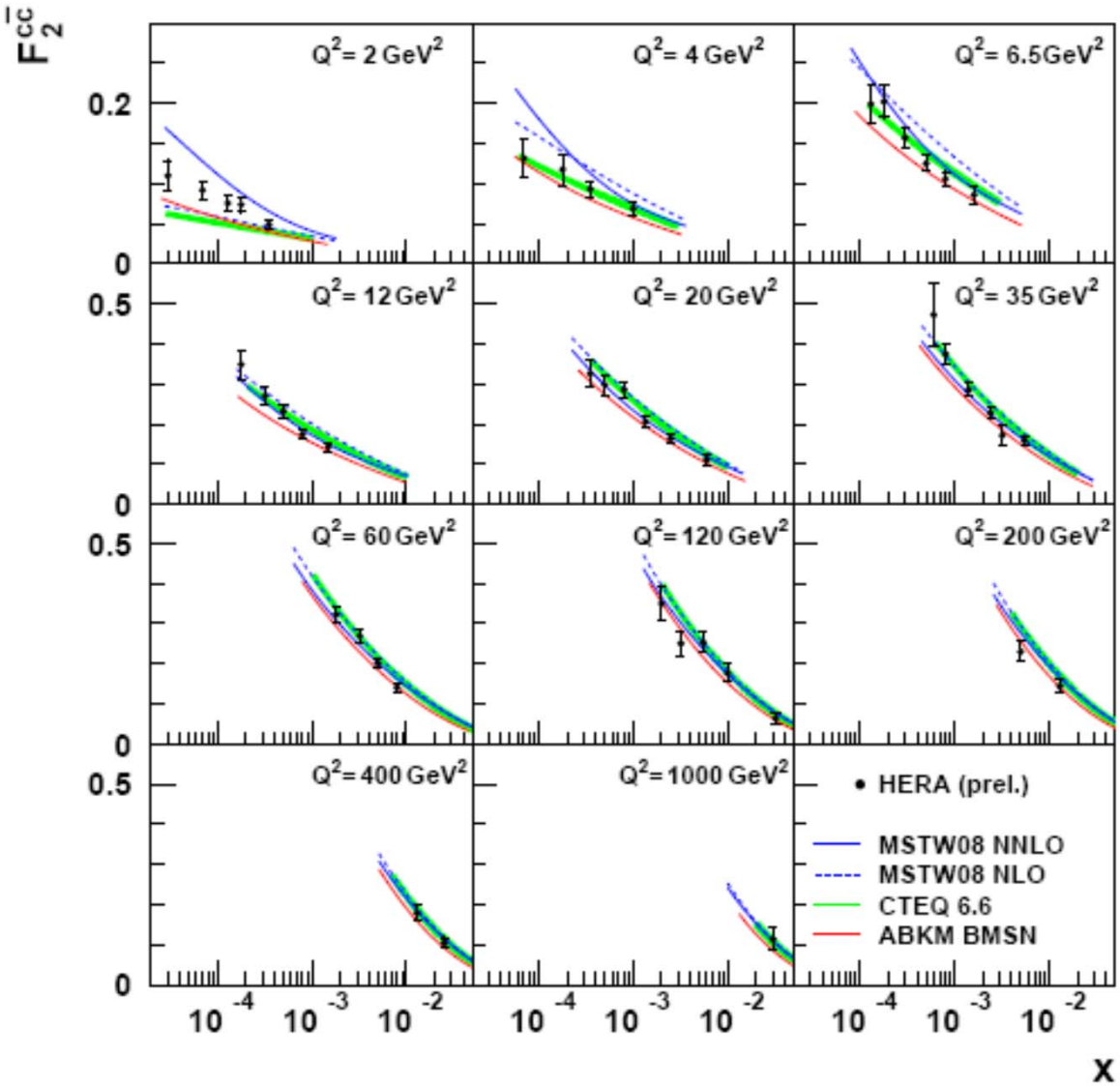
=> "**massless**" treatment (ZM-VFNS) allows resummation, but fails near "mass threshold" -> avoid !

=> "**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

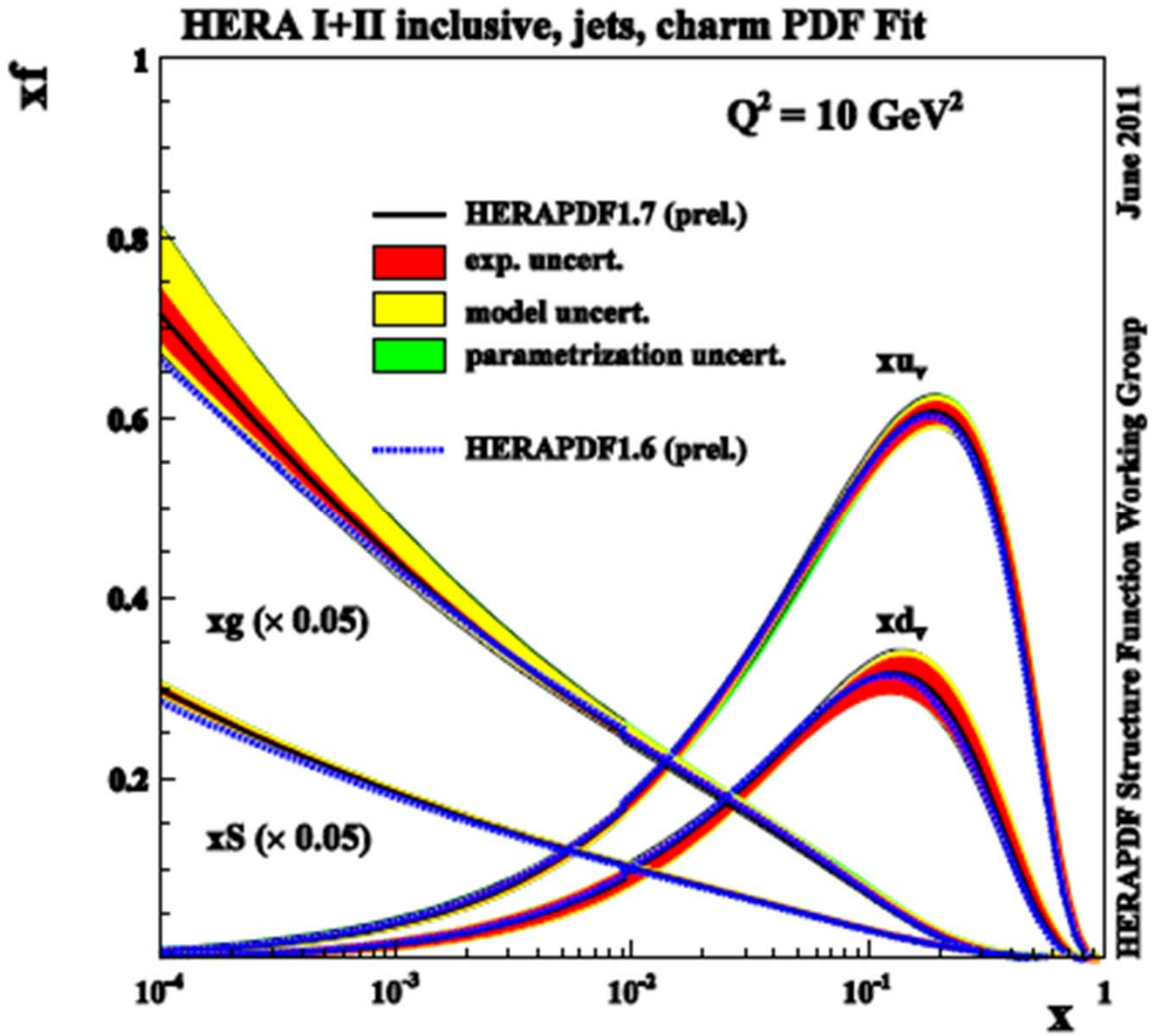
H1-prelim 10-045
ZEUS-prel 10-009

also updated/new results (not yet included)

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

PDF fit to "all" HERA data

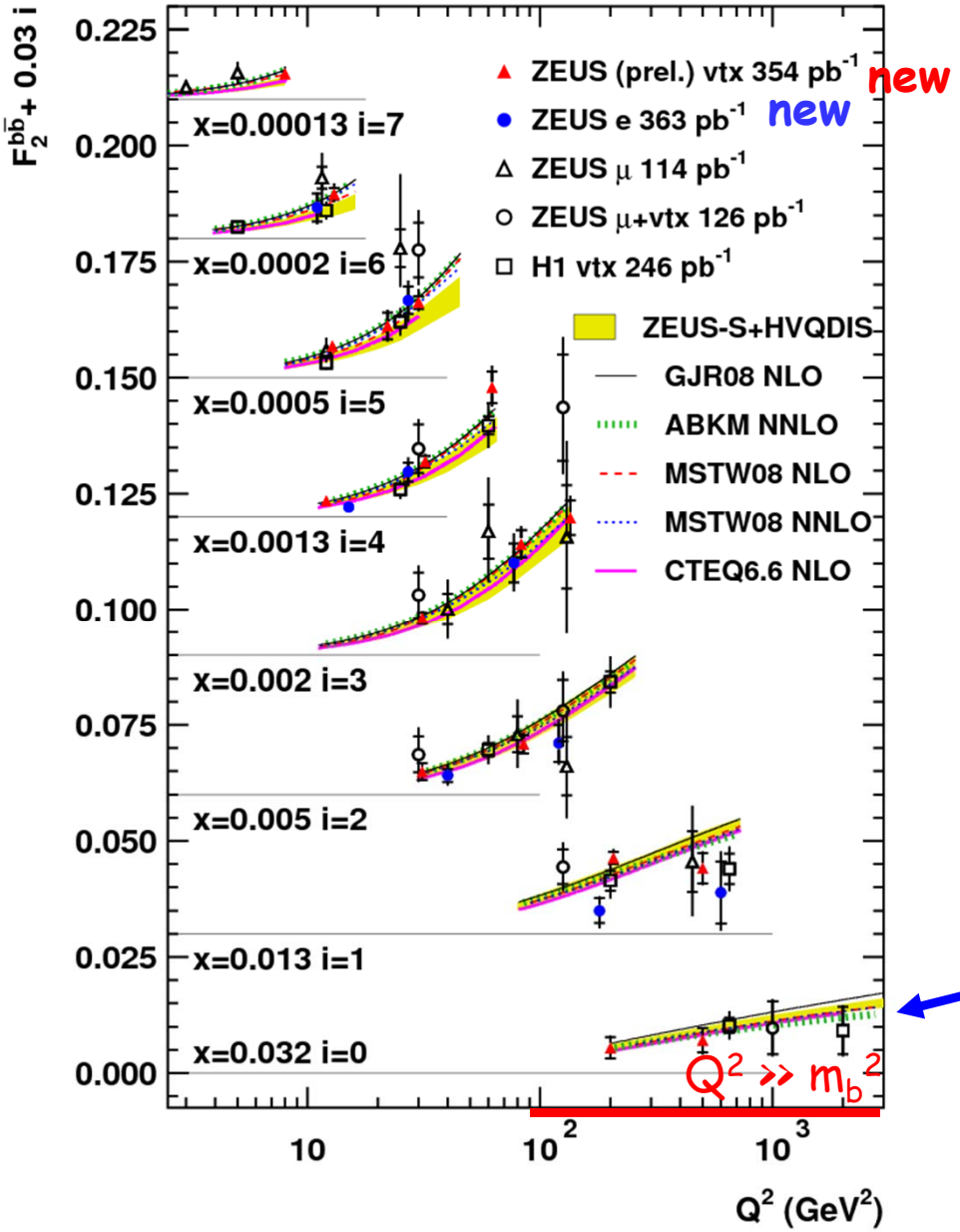
combined inclusive data, F_L, jets, charm:



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



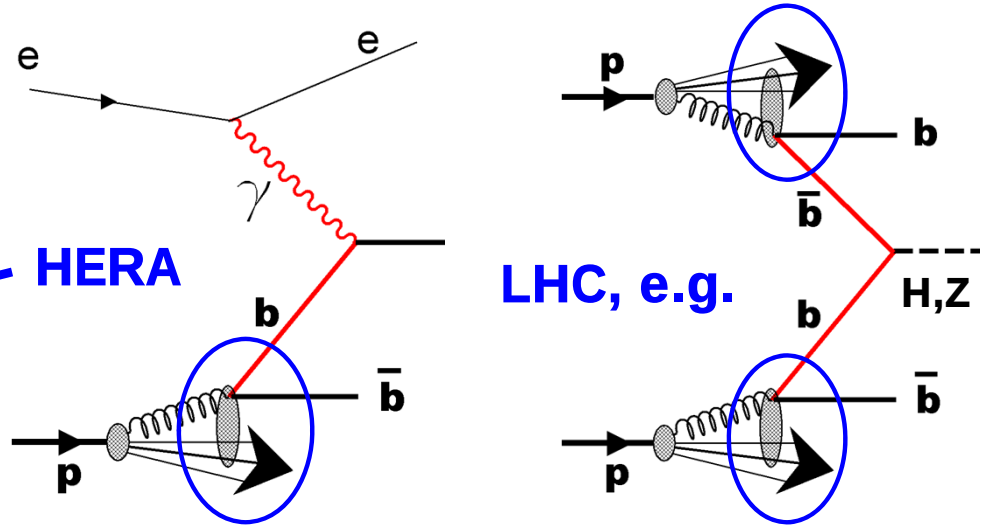
ZEUS-prel-10-004

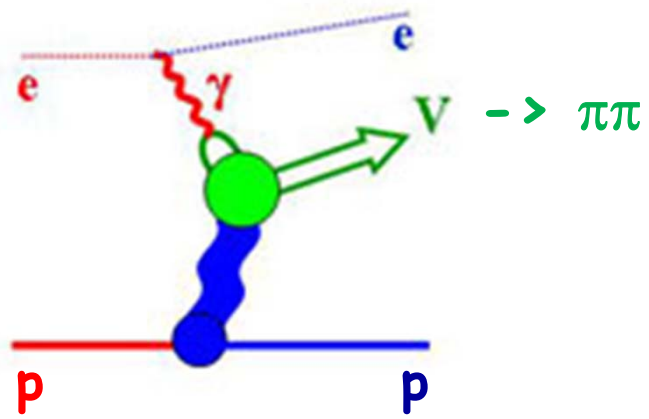
DESY-11-005, arXiv:1101.3692

NLO and partial NNLO QCD in agreement with data,

NNLO slightly better

check b PDF for LHC:

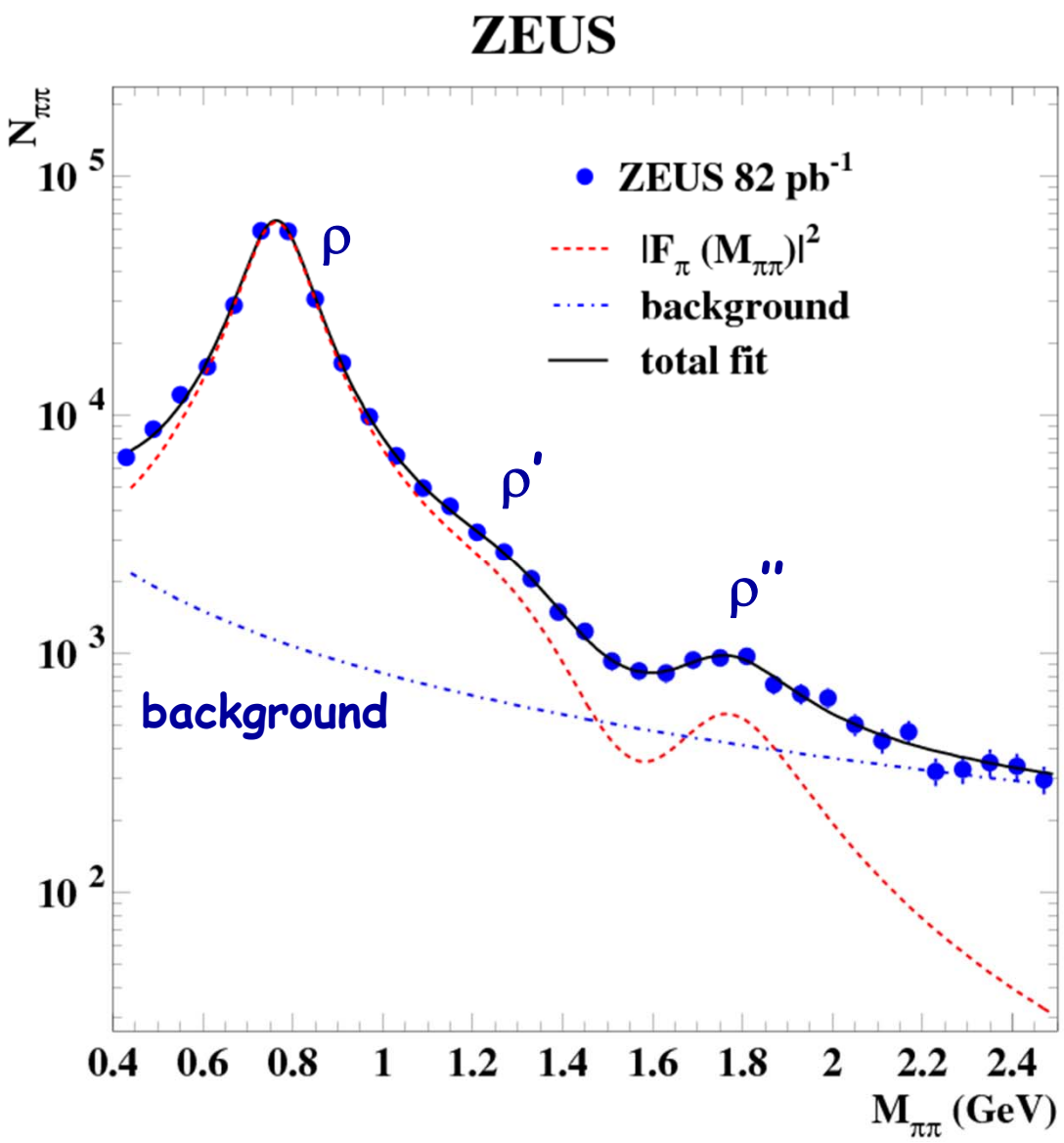


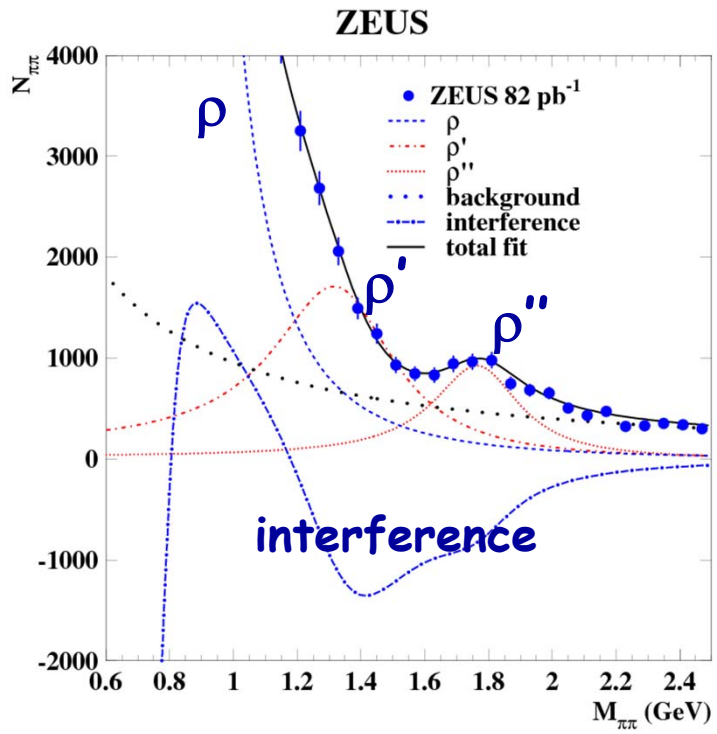


Exclusive dipion electroproduction

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

ππ mass distribution, fit of F_π





Santamaria parametrization:

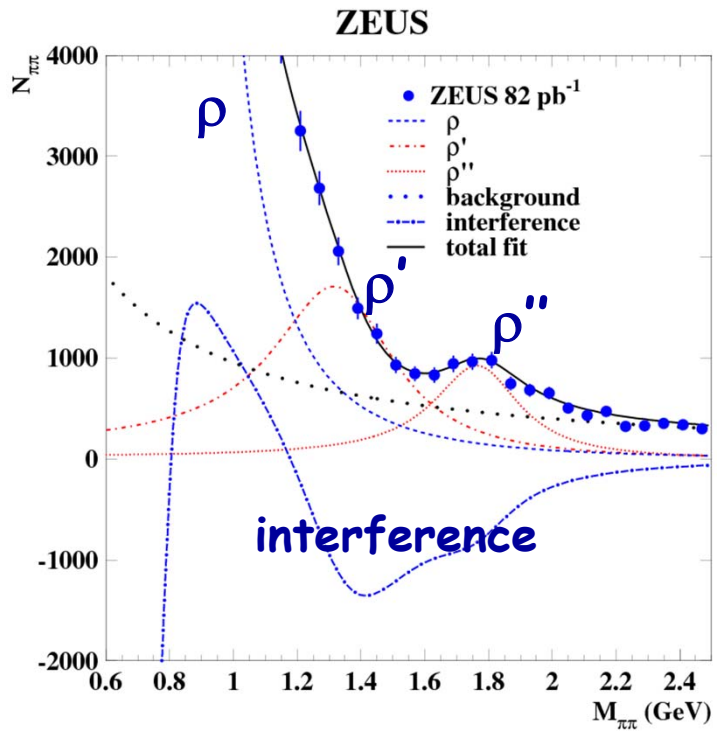
$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1+\beta+\gamma}.$$

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

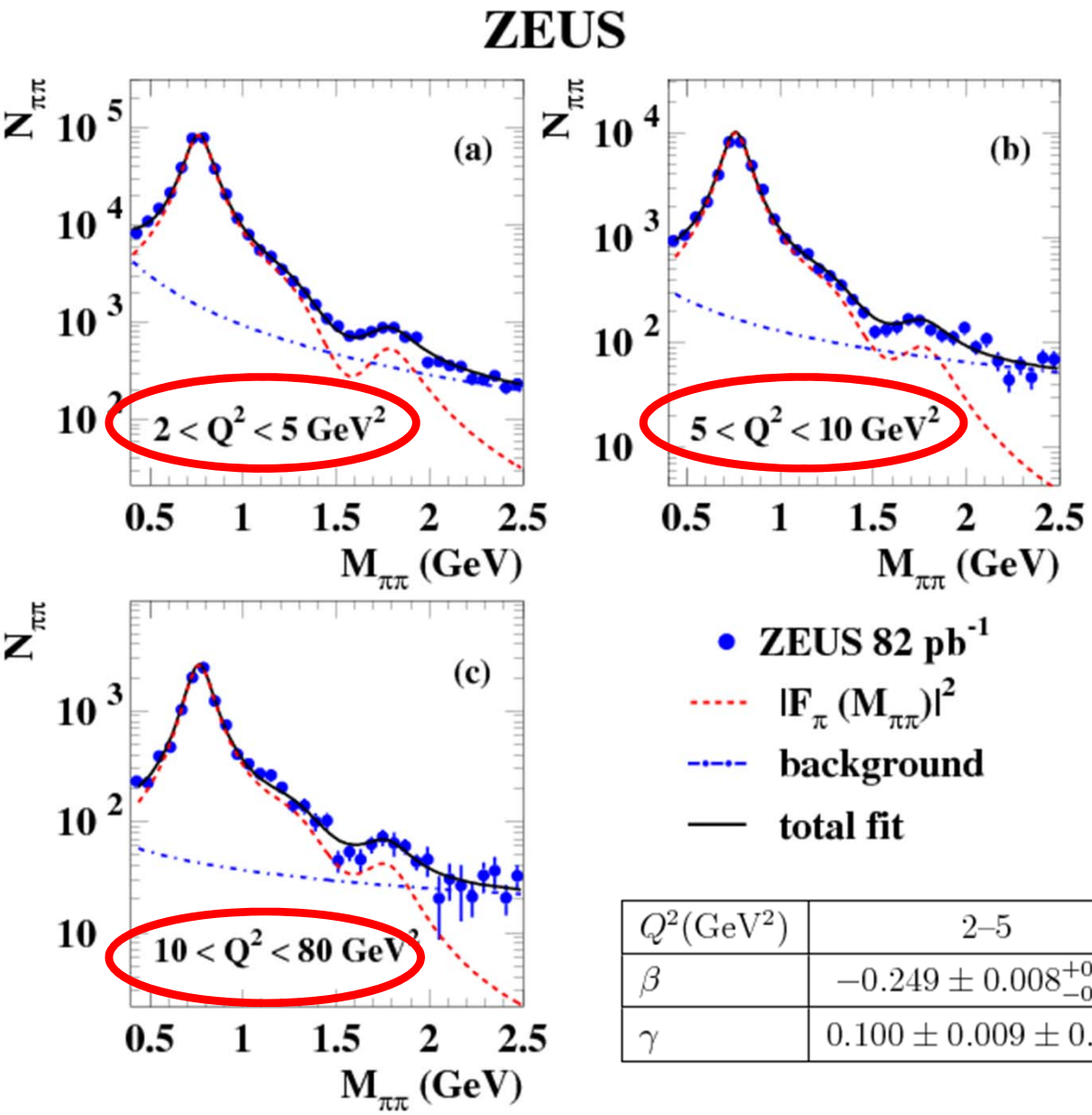
Santamaria parametrization:

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

with Breit-Wigner

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

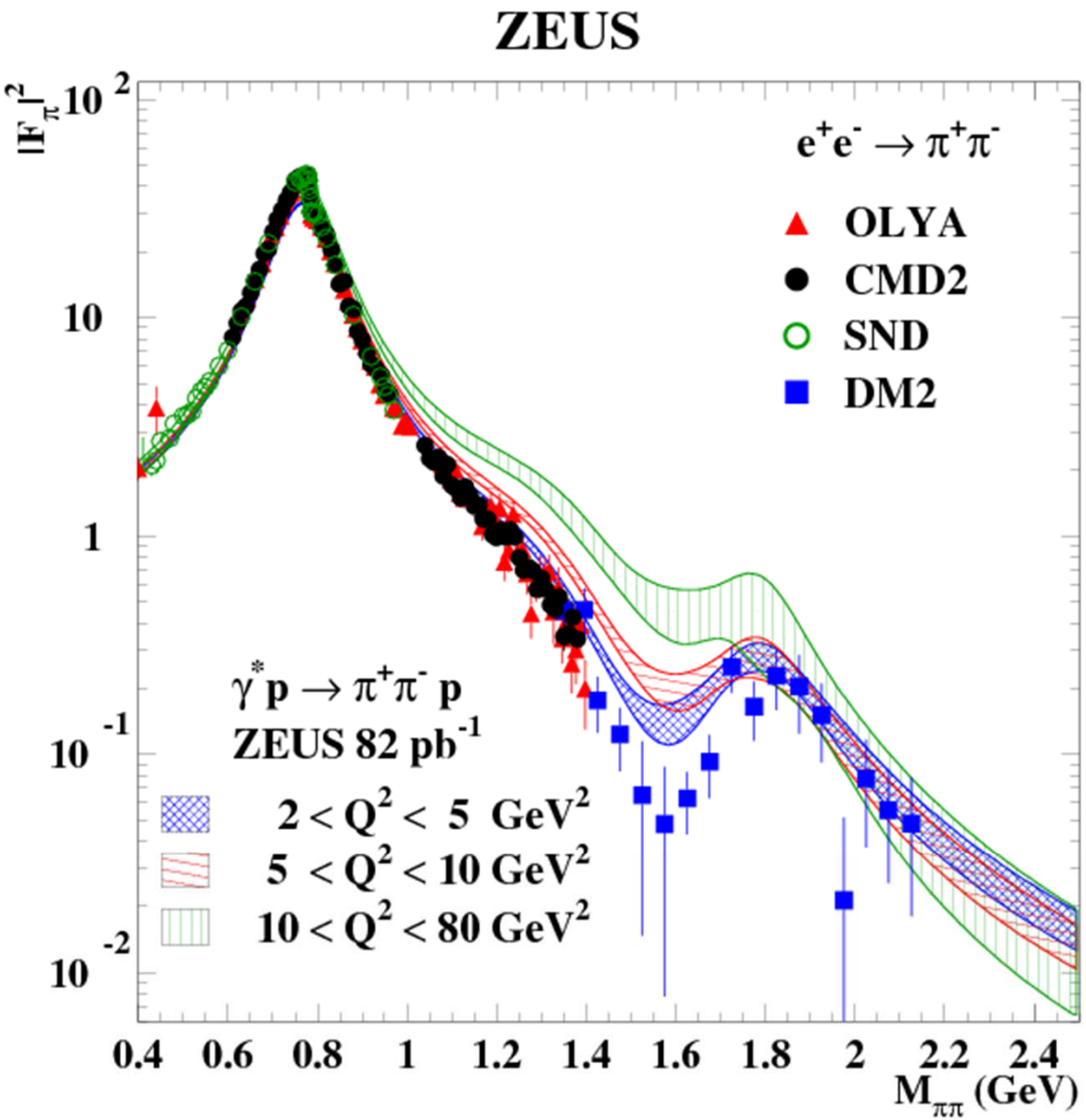
$\pi\pi$ mass distribution, F_π fit vs Q^2

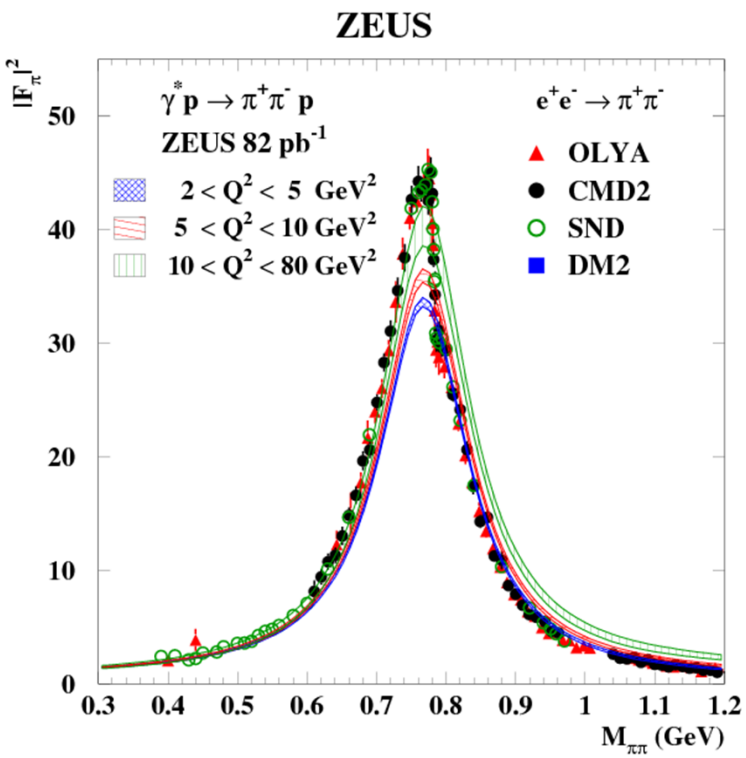


similar results,
but some Q^2 dependence

Q^2(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	$0.100 \pm 0.009 \pm 0.003$	$0.098 \pm 0.012^{+0.005}_{-0.003}$	$0.118 \pm 0.022^{+0.008}_{-0.006}$

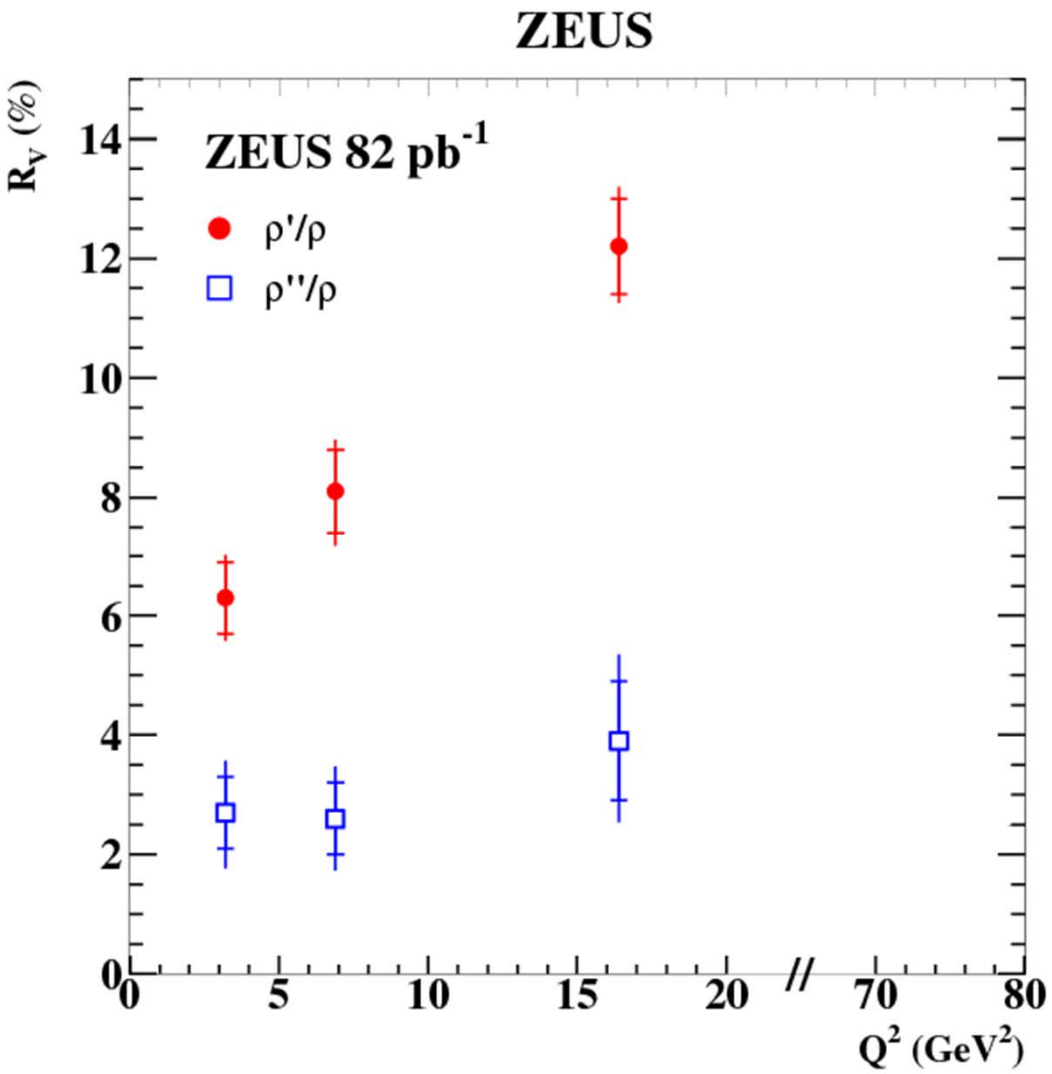
comparison to e^+e^-





form factor in ep DIS very similar to e+e- despite different production mechanism (ggγ* 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

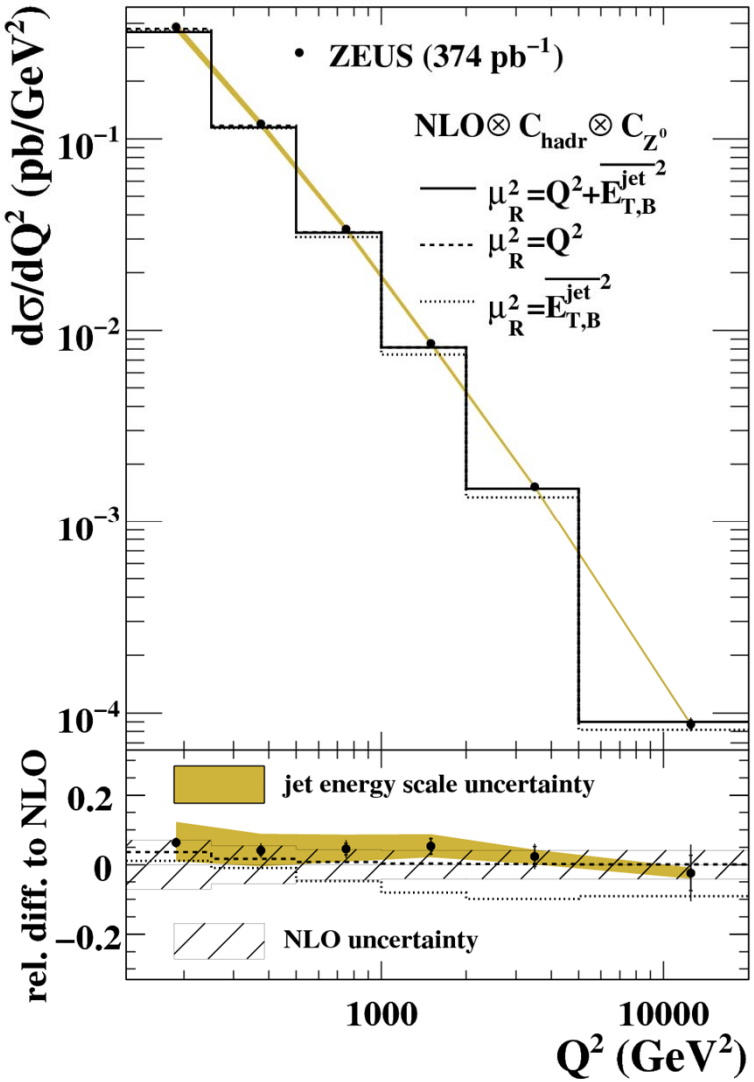
- combination of H1/ZEUS results ongoing
  -> **towards full 1 fb^{-1} results (H1+ZEUS, HERA1+2)**.
  -> expect **significant further improvements** over next few years

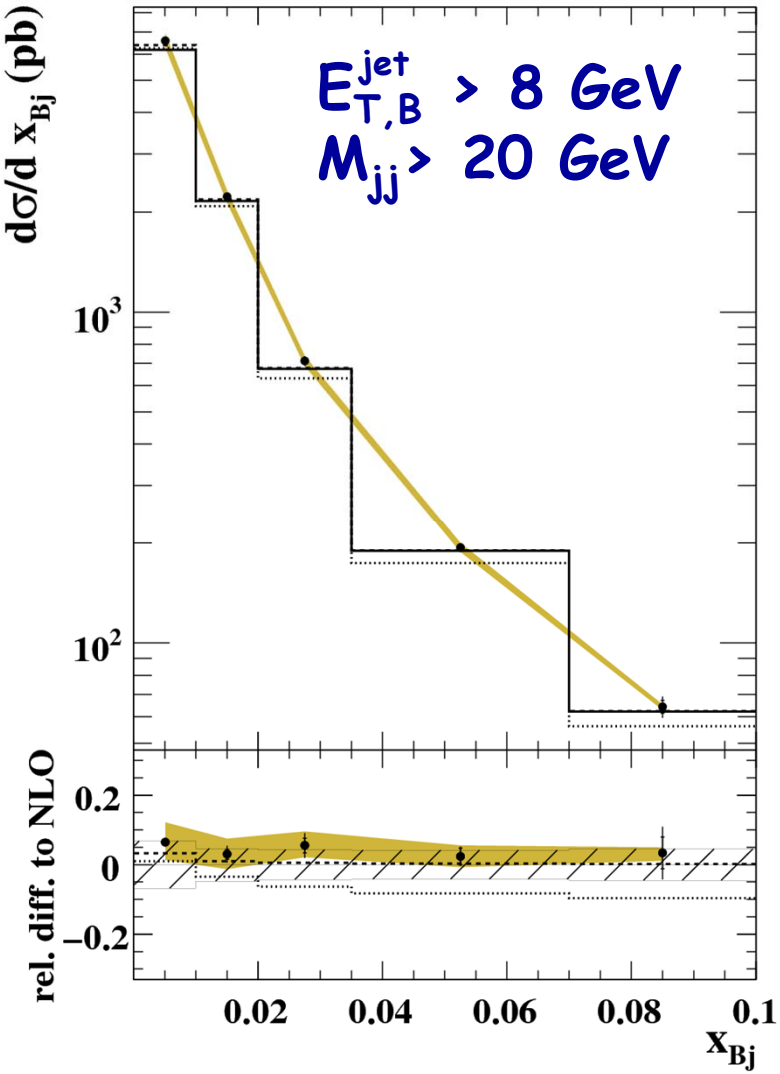
- **exclusive dipion electroproduction allows measurement of ρ, ρ' and ρ'' production and their interference**
  -> relative production amplitudes are real and similar to e+e-
  -> ρ'/ρ ratio rising with Q^2 as expected

Backup

Dijets in DIS

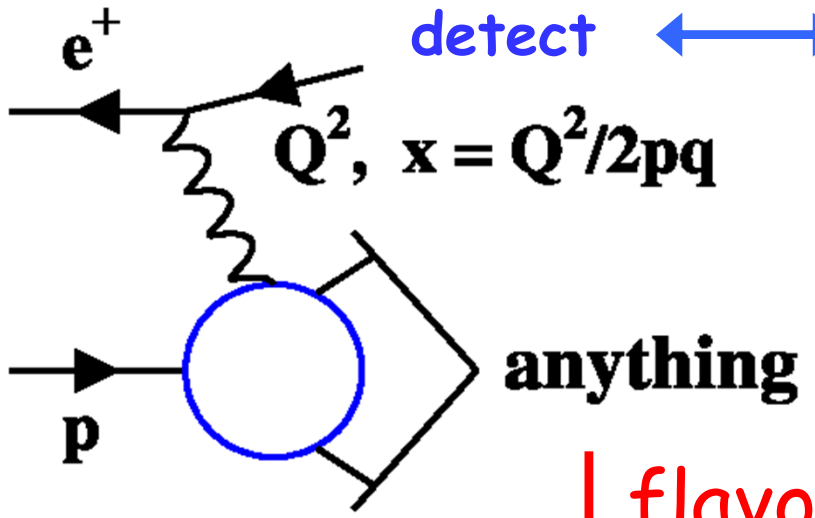
DESY-10-170, Eur. Phys. J. C70 (2010) 965





QCD works!

Heavy flavour contributions to F_2

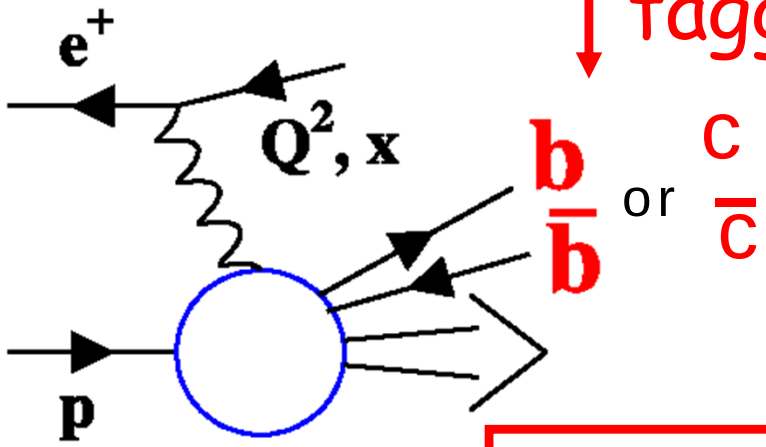


detect

Measure cross section

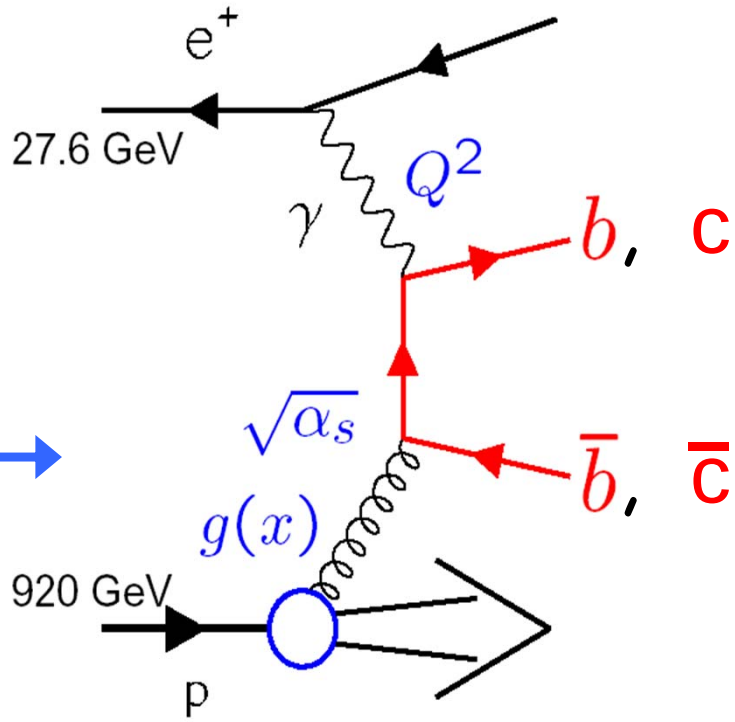
$$\frac{d^2\sigma}{dx\,dQ^2} \cong \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right] F_2(x,Q^2)\right.$$

flavour tagging



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

QCD



ππ control distributions

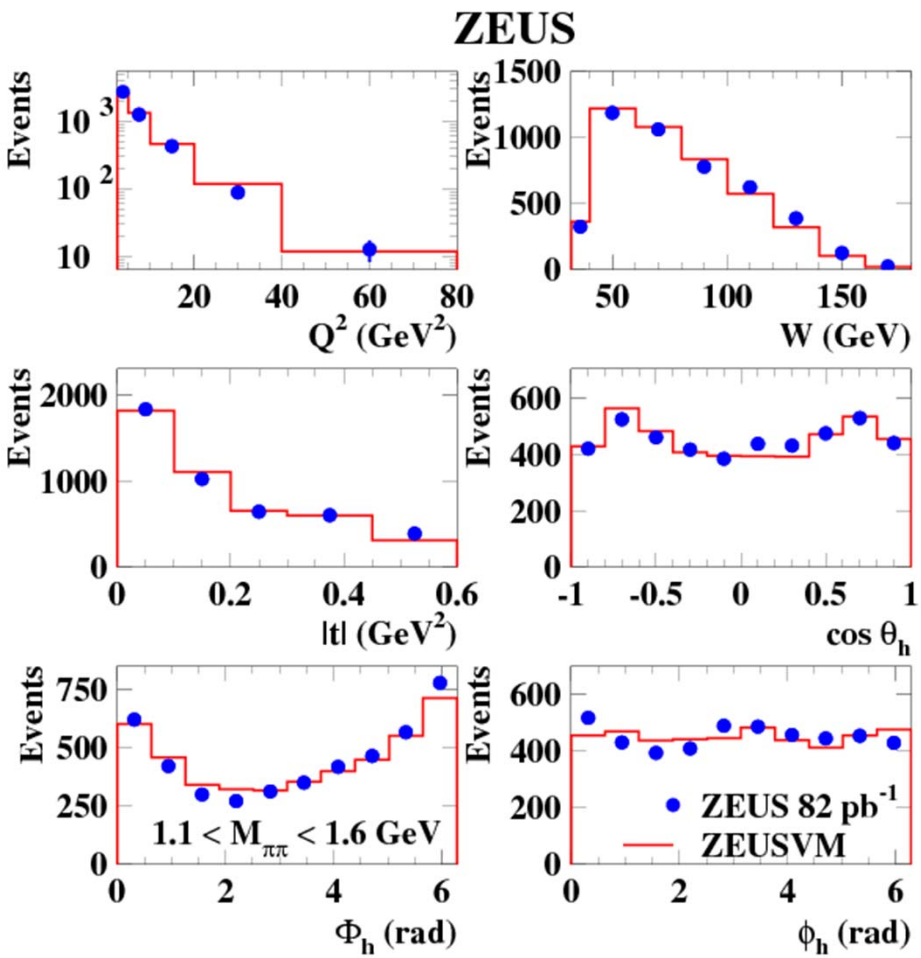


Figure 2: *Comparison between the data and the* ZEUSVM *MC distributions for* Q^2, W, $|t|$, $\cos\theta_h$, Φ_h *and* ϕ_h *for events within mass range* $1.1 < M_{\pi\pi} < 1.6$ *GeV. The MC distributions are normalized to the data.*

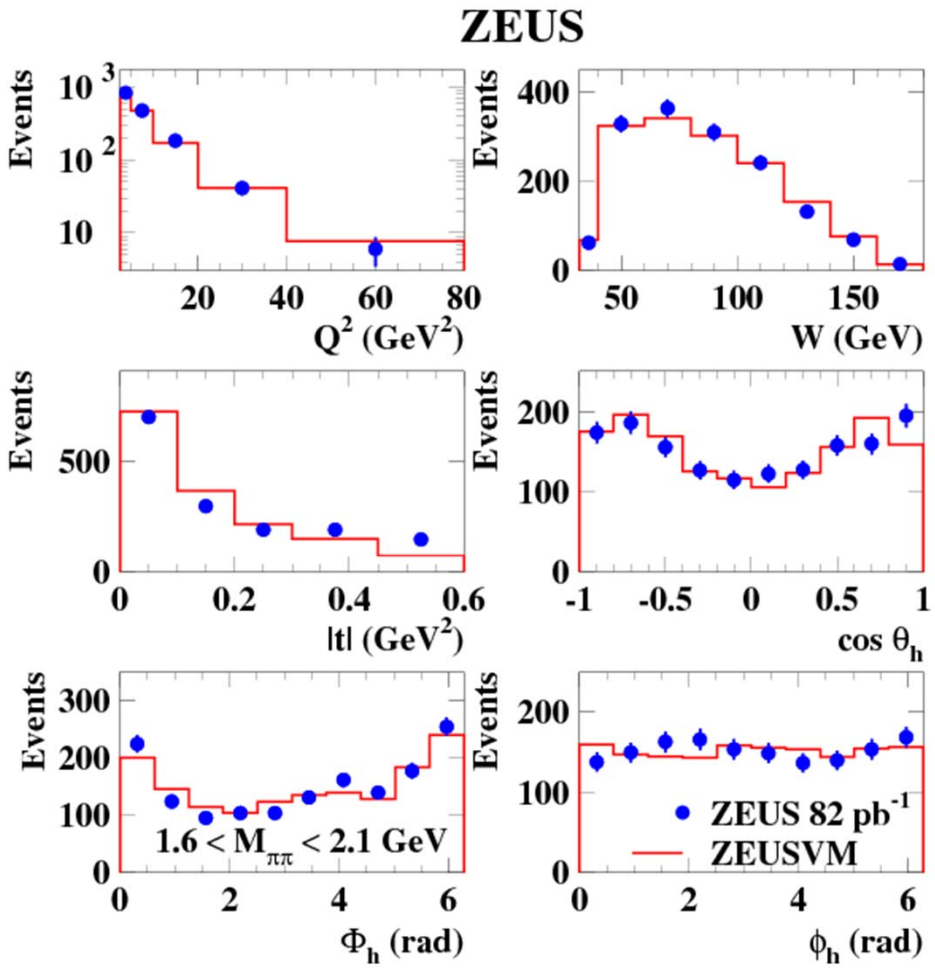


Figure 3: *Comparison between the data and the* ZEUSVM *MC distributions for* Q^2, W, $|t|$, $\cos\theta_h$, Φ_h *and* ϕ_h *for events within mass range* $1.6 < M_{\pi\pi} < 2.1$ *GeV. The MC distributions are normalized to the data.*