



New results on proton structure from HERA

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HERA and luminosity



HERA (DESY, Hamburg): 1992 - 2007
Total lumi H1, ZEUS: 0.5 fb⁻¹ each
HERA-I 1992-2000 ~120 pb⁻¹
HERA-II 2003-2007 ~380 pb⁻¹

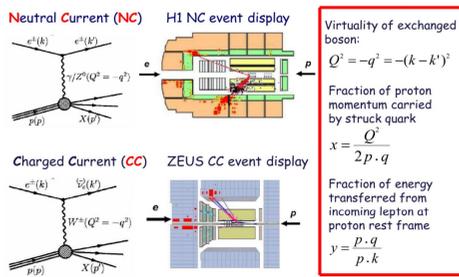
E_{e/p.e.} = 27.6 GeV

HERA-I (E_p = 820, 920 GeV) upgraded to HERA-II (E_p = 920 GeV)

Since April 2007 until the end of June
Low energy run - LER - (E_p = 460 GeV)
Medium energy run - MER - (E_p = 575 GeV) } Measurement of F₂

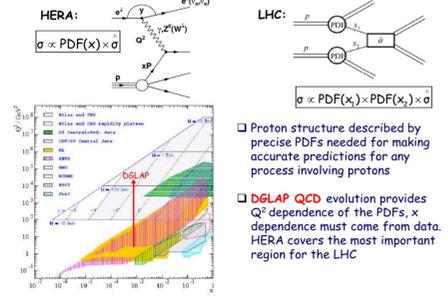
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Inclusive Deep Inelastic Scattering (DIS)



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HERA Parton Density Functions (PDFs) and the LHC



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NC and CC cross sections

Neutral current cross section
 $\frac{d^2\sigma_{NC}(e^+p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \sum_f Y_f^2 [F_2 - Y_f F_L + \frac{Y_f}{2} xF_3]$
Contribution from valence and sea quarks. Directly related to gluon in pQCD. Contribution from valence quarks at high Q².

Charged current cross section
 $\frac{d^2\sigma_{CC}^{ep}}{dx dQ^2} = \frac{G_F^2 M_p^4}{2\pi x(Q^2 + M_W^2)^2} \sigma_{CC}^{ep}$
 $\sigma_{CC}^{ep} \sim (x\bar{u} + x\bar{c}) + (1-\gamma)^2(xd + xs)$
Sensitivity to the flavor of the valence distributions at high x.

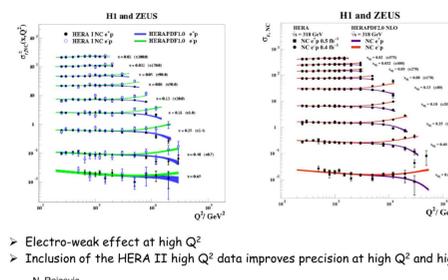
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H1 and ZEUS NC and CC cross sections and PDFs

H1 and ZEUS published high precision measurements of NC and CC cross sections. Q² from 0.045 GeV² to 40000 GeV², x from 6 · 10⁻⁷ to 0.65.
Allow PDFs to be extracted solely from these data.
To get high precision measurements of PDFs H1 and ZEUS results are combined → HERAPDF sets.
HERAPDF1.0 NLO: based on published NC+CC HERA-I data - published (JHEP01 (2010) 109).
HERAPDF1.5 NLO, NNLO and LO: based on preliminary NC+CC HERA-I + HERA-II data - preliminaries.
Here: new published QCD fit from HERA based on the latest combinations of complete HERA data.
HERAPDF2.0 (at NLO, NNLO and LO), arXiv:1506.06042
QCD fits are performed using HERAFitter package (www.herafitter.org)

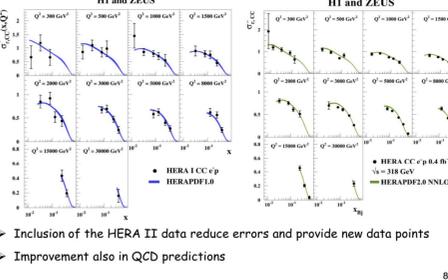
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Combined data - HERA-I vs HERA-II (NC)



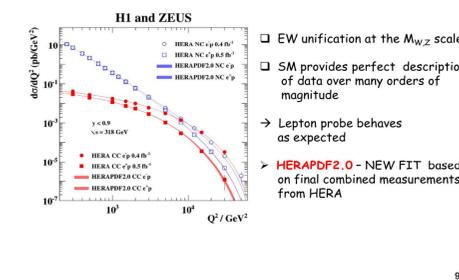
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Combined data - HERA-I vs HERA-II (CC)



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Final measurements from HERA at high Q²



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QCD analysis

General approach for PDF determination:
1. Parametrise the parton density functions at low starting scale μ₀² = Q₀² = 1.9 by smooth analytical functions as Ax^b(1-x)^c(1+Dx+Ex²...)
2. Express the strange-quark distribution as an x-independent fraction, f_s, of the d-type sea at μ₀² (xs = f_sxD = f_s(xd+xs))
3. Evolve these functions using the DGLAP equations to higher Q² and calculate x-sections
4. Compare the calculation to experimental data
5. Minimisation of χ² adjusting the free parameters
6. To safely remain in the kinematic region where pQCD is expected to be applicable, only cross sections for Q² starting from Q²_{min} = 3.5 GeV² are used

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c and b quark mass parameters

Charm contribution to the inclusive DIS cross section is up to 30% (sizeable part), beauty ~3%.
The F₂^{cc} and F₂^{bb} from the combined data allow to determine the optimal mass parameters (using GM-VFNS RTOPT scheme).
HERA I and ZEUS: M_c = 1.47 GeV, M_b = 4.5 GeV
NNLO: M_c = 1.43 GeV, M_b = 4.5 GeV

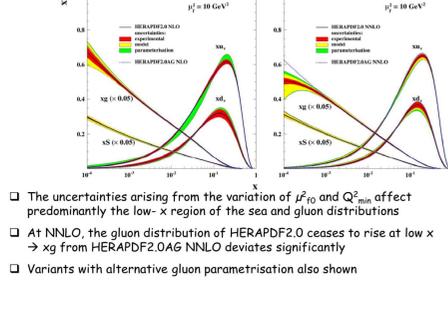
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Uncertainties estimation

Experimental uncertainties were determined using the Hessian method with the criterion Δχ² = 1 (68% CL).
Model uncertainties were evaluated by varying the assumptions (all variations are added in quadratures).
Parameterisation uncertainties: two kinds considered, the variation in μ₀ = Q₀ (from 1.6 to 2.2 GeV²) and the addition of parameters D and E (added separately for each PDF).

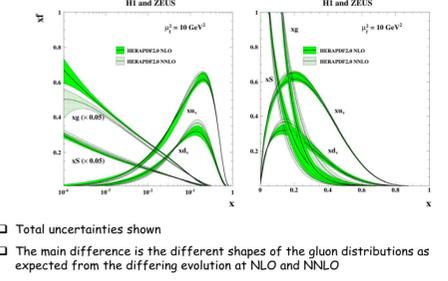
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HERAPDF2.0 at NLO and NNLO



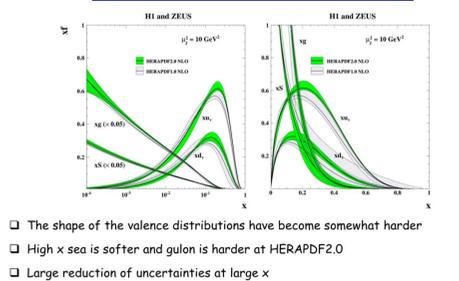
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HERAPDF2.0 NLO vs NNLO



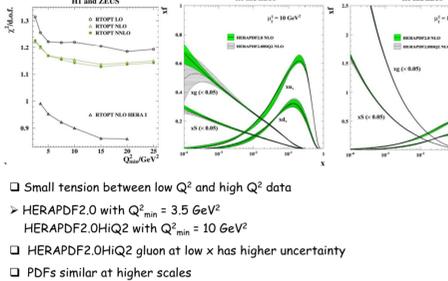
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HERAPDF2.0 NLO vs HERAPDF1.0 NLO



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Q²_{min} dependence



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Inclusion of charm and jet data and α_s(M_Z) determination

QCD fit of inclusive, charm and jet data at NLO with α_s(M_Z) as a free parameter.
Result of the fit: α_s(M_Z) = 0.118 (value used in HERAPDF2.0 at NLO and NNLO) → does not depend on Q²_{min}.
Fits based only on inclusive data can not constrain α_s(M_Z) → dependent on Q²_{min}.
Inclusion of jet data → HERAPDF2.0jets

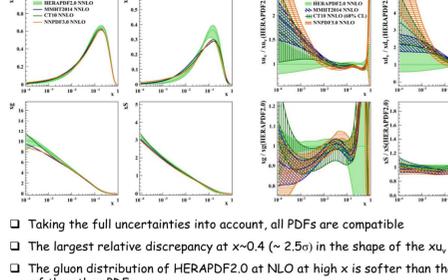
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HERAPDF2.0JETS

Full treatment of uncertainties in both cases (with fixed and free parameters).
In free fit, gluon uncertainty only slightly larger.
α_s(M_Z) = 0.1183 ± 0.0009(exp) ± 0.0005(model/parameterisation) ± 0.0012(hadronisation) ± 0.0017(scale) ± 0.0020(α_s)
Comparison of HERAPDF2.0 and HERAPDF2.0JETS with fixed α_s(M_Z) = 0.118.
The fits differ only slightly in uncertainty on gluon distribution.

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Comparison to other sets of PDFs



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- Set of HERAPDF2.0 is obtained the latest and most comprehensive combinations of HERA data of a total integrated luminosity of about 1 Fb⁻¹
- Small experimental uncertainties due to the high precision and coherence of the input data
- HERAPDF2.0 are available at LO, NLO and NNLO
- HERAPDF2.0 NNLO and NLO of a similar fit quality
- Large reduction of uncertainties at large x in HERAPDF2.0 compared to HERAPDF1.0
- A measurement of α_s(M_Z²) was made using a perturbative QCD fit for which the inclusive cross sections were augmented with selected jet and charm production cross sections as measured by both the H1 and ZEUS → excellent agreement with the value of the world average
- HERAPDF2.0 compatible with available PDFs