Parton Distribution Functions determination and Heavy Flavour production at the LHeC

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PDF fits, a brief Overview

	MSTW08	CTEQ6.6/CT10	NNPDF2.1/2.3	HERAPDF1.0/1.5	ABKM09/ABM11	GJR08/JR09
PDF order	LO, NLO, NNLO	LO, NLO, NNLO	LO, NLO, NNLO	NLO, NNLO	NLO, NNLO	NLO, NNLO
HERA DIS	✔ (old)	✔ (old/new)	✔ (new)	✔ (new/newest)	✔ (new)	✔ (new)
Fixed target DIS	✔	✔	✔	-	✔	✔
Fixed target DY	✔	✔	✔	-	✔	✔
Tevatron W, Z	✔	✔	some	-	some	some
Tevatron jets	✔	✔	✔	-	✔	✔
LHC	-	-	-/W, Z, jets	-	-	-
HF Scheme	RTGMVF	SACOT GMVFN	FONLL GMVFN	RT GMVFN	BMSN FFNS	FFNS
Alphas (NLO)	0.120	0.118(f)	0.119	0.1176(f)	0.1179	0.1145
Alphas (NNLO)	0.1171	0.118(f)	0.1174	0.1176(f)	0.1135	0.1124

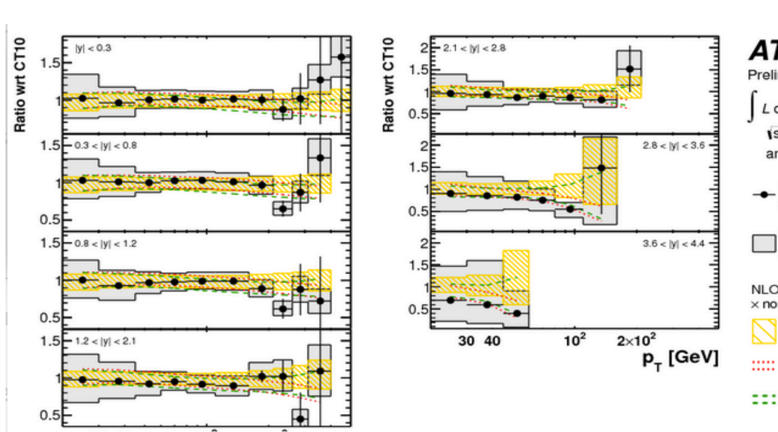
PDF fits - The LHC data charge

[V. Radescu, PDF4LHC - CERN]

- LHC data is introducing completely new observables to be used for PDF constraints:

  2010-2011 data:
  - o Inclusive jets and dijets, central and forward: high-x quarks and gluons
  - o Inclusive W and Z production and asymmetries: quark flavor separation, strangeness
  - o Off peak Drell-Yan production at low and high mass: quarks at low and high-x
  - o Isolated photons: medium-x gluons
  - o W production with charm quarks: direct handle on strangeness (to come)
  - o W,Z production with jets: medium and small-x gluon
  - o Single top production: gluon and bottom PDFs
  - o ttbar production: help to discriminate between different PDF sets - medium x
    - Also a direct handle on the strong coupling
  - o Top quark differential distributions: high-x gluon
  - o Z+b production sensitive to b-quark

  More stringent constraints are expected with the full 8 TeV and later 13TeV data



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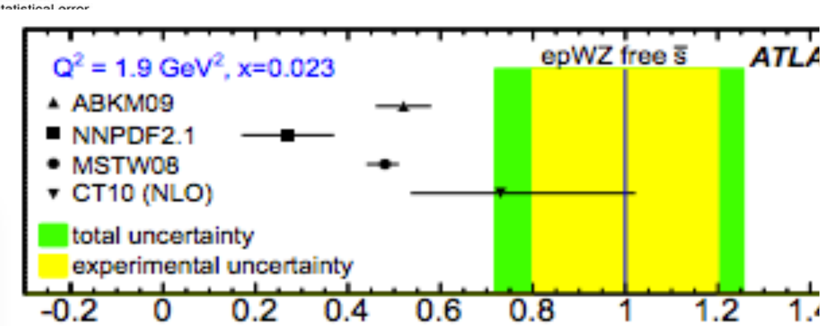

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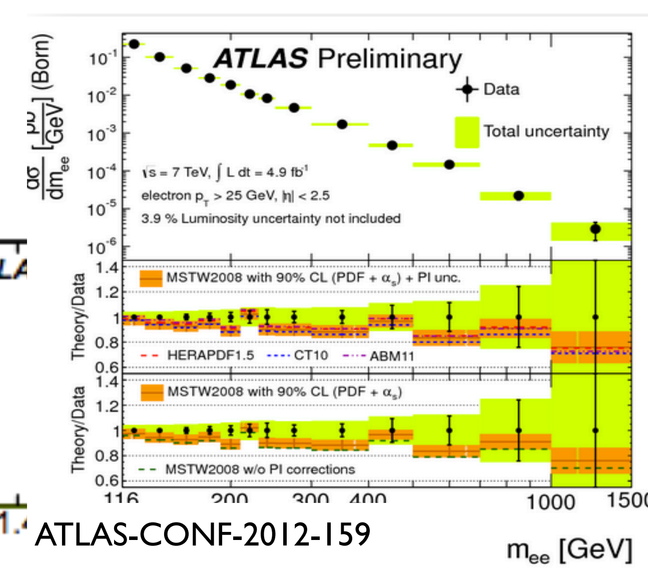

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The LHeC project


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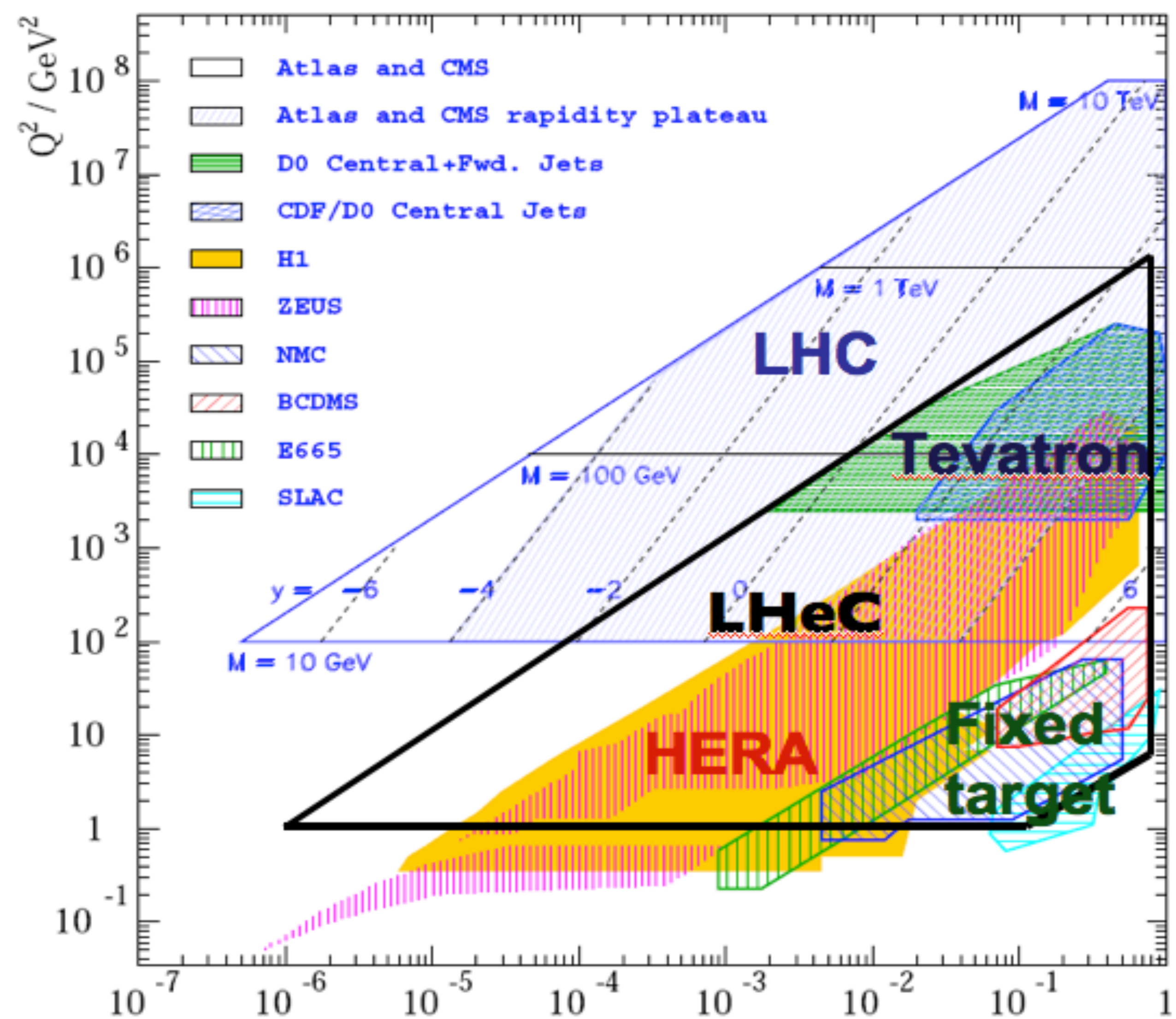
Present LHeC Study group and CDR authors

About 200 Experimentalists and Theorists from 76 Institutes

Supported by
CERN, ECFA, NuPECC

The LHeC project

- The **LHeC kinematics** represents a **substantial extension** to the **coverage** of the data which are used today in **PDF fits**
- Increase in the precision of PDF in regions which are now extrapolation regions
- **Unique opportunity** to study the **small-x** region ($x \sim 10^{-6}$) and look for evidence of **deviations from DGLAP evolution** (resummation/ saturation effects)



LHeC simulated dataset

- **Scenario B**
  - Integrated Luminosity: $e^{\pm}p$=50 fb^{-1}
  - E_p = 7 TeV, E_e = 50 GeV, Pol = ± 0.4
  - Kinematic coverage: $2 < Q^2 < 5\cdot10^5$ GeV^2; $2\cdot10^{-6} < x < 0.8$
- **Uncertainties**
  - Full simulation of Neutral and Charged current measurements
  - Including Statistical, Uncorrelated and Correlated Systematic uncertaities
  - Based on H1 best values
- **Typical uncertainties**
  - **Stat.**: from ~0.1% (low Q^2, NC) to ~10% (CC, x = 0.7)
  - **Uncorr. Syst.**: 0.7 %
  - **Corr. Syst.**: typically 1-3% (up to 9% for high-x CC)

source of uncertainty	error on the source or cross section
scattered electron energy scale $\Delta E'_e/E'_e$	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale $\Delta E_h/E_h$	0.5 %
calorimeter noise (only $y < 0.01$)	1-3 %
radiative corrections	0.5%
photoproduction background (only $y > 0.5$)	1 %
global efficiency error	0.7 %

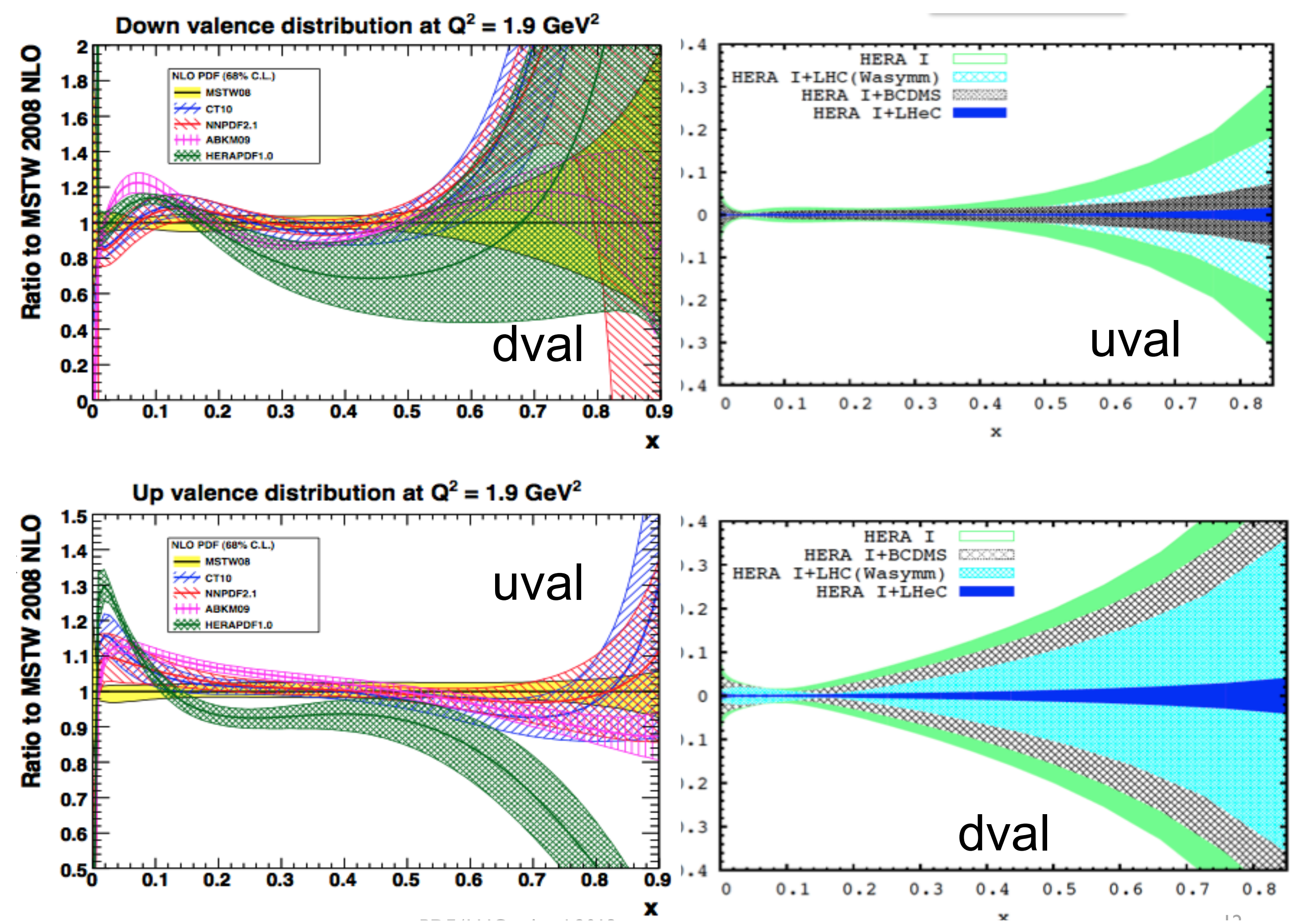
PDF determination setup

- **Data**
  - Hera I combined dataset
  - BCDMS fixed target proton/duteron DIS
  - ATLAS W asymmetry data (adjusted uncertainties: stat/unc. syst: 0.5%, total:1%)
  - LHeC simulated data Scenario B ($e^{\pm}p$ NC/CC red. cross sections, pol = ± 0.4)
- **Theory setup**
  - HERAPDF1.0 settings
  - NLO DGLAP, Thorne-Roberts scheme for HQ treatment
  - Fitted PDFs
    - u_v, d_v, g, U = u+c, D = d+b
    - f
  - One small-x exp. for sea and one valence
  - Valence and Momentum sum rules imposed

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}(1+D_g x)\,, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)\,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}\,, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\,, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}\,.
\end{aligned}
$$

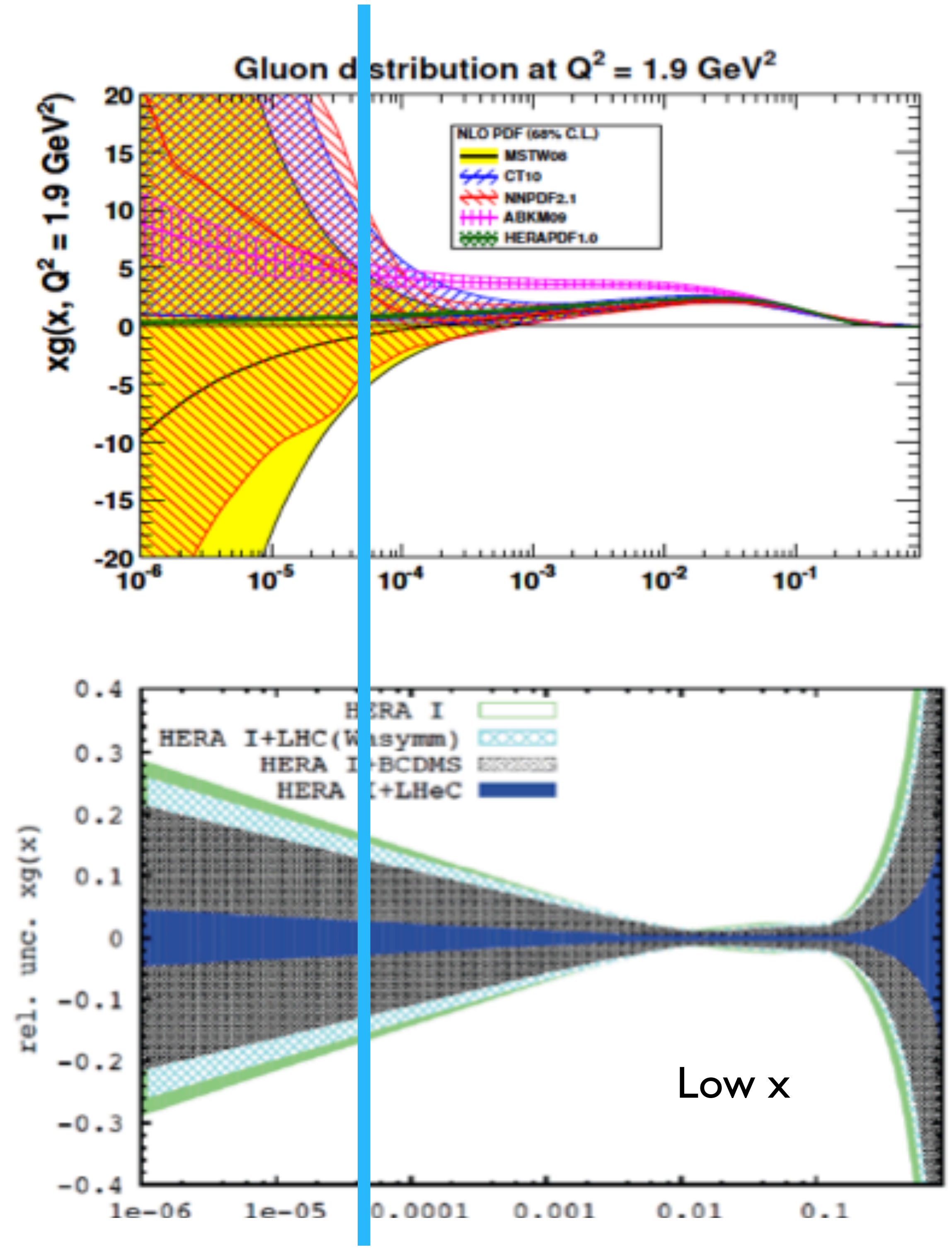
PDF constraints from LHeC - valence sector

- Knowledge of **PDFs** at **large-x** currently limited by
  - Luminosity barrier
  - Challenging systematics
  - Nuclear/higher twist effects
- LHeC data could help reduce the uncertainties on large-x valence distributions to
  - **2%** for **u_v** at x=0.8
  - **4%** for **d_v** at x=0.8
- Crucial to study the **d/u ratio** at large-x



PDF constraints from LHeC - small-x gluon

- **Sensitivity** of **HERA** data stops at **$x \sim 5 \cdot 10^{-4}$**
- **Uncertainties** on **small-x gluon** driven by the **parametrization**
- **LHeC** data extend down to **$x \sim 10^{-6}$**, allowing for detailed studies of possible **deviation from DGLAP** evolution and **evidence** for **BFKL** resummation or **saturation** effects
- **LHeC sensitivity** to small-x gluon **improved** by use of **F_L data** (not considered in the present study)



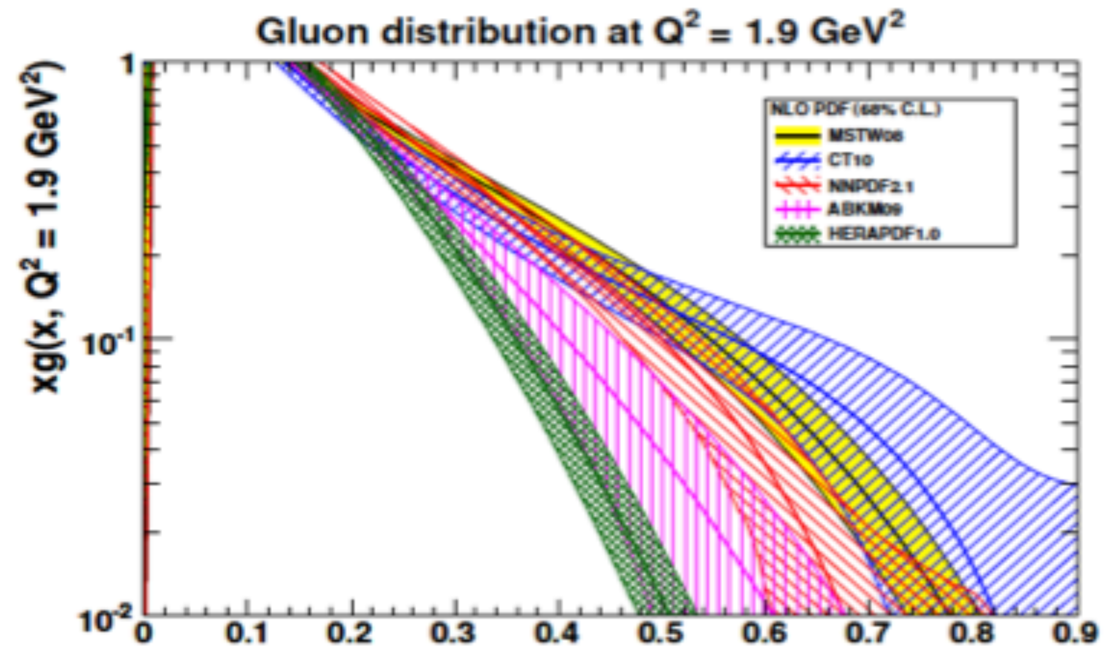
PDF constraints from LHeC - large-x gluon

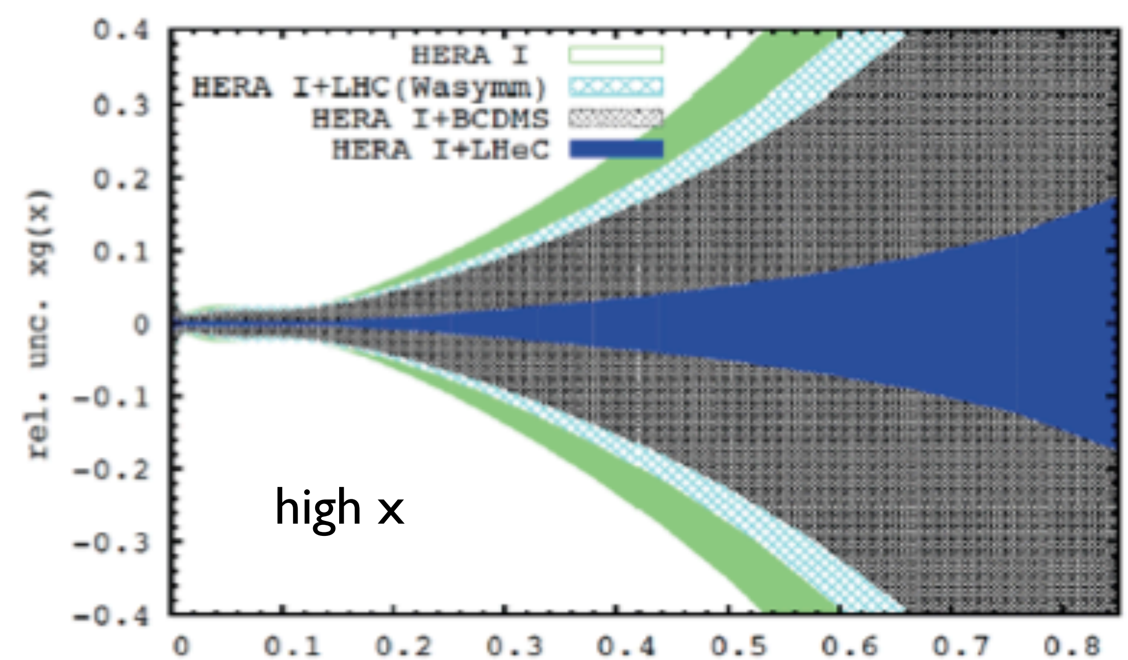
- **Large-x gluon uncertainty** in PDF fits **quite large**, mostly due to **limited statistics** (constrained by inclusive jet data)

- **Related** by evolution to **large-x sea quarks** (DGLAP evolution of valence distribution decouples)

- **LHeC** can **disentangle** the **sea** from the **valence** at **large-x** through measurements of **CC** reduced cross sections, **F_2**, **$F_2^{\gamma Z}$**, **xF_3**

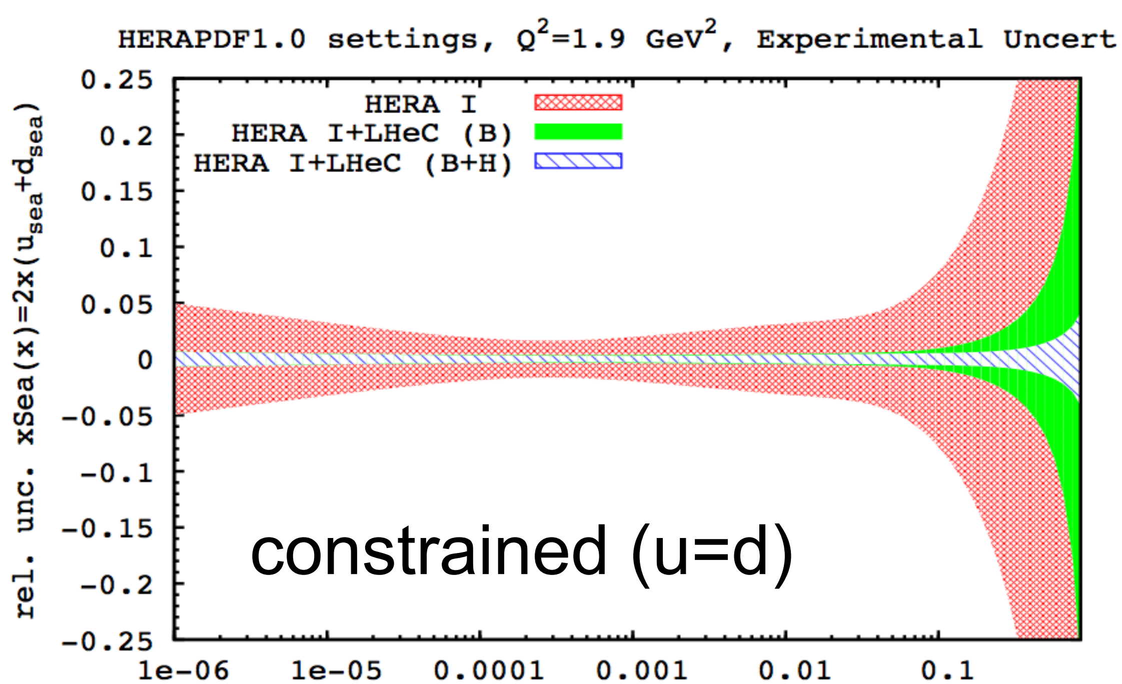
- **Crucial** for searches of **high-mass resonances** in **BSM** scenarios (gluino pair production)

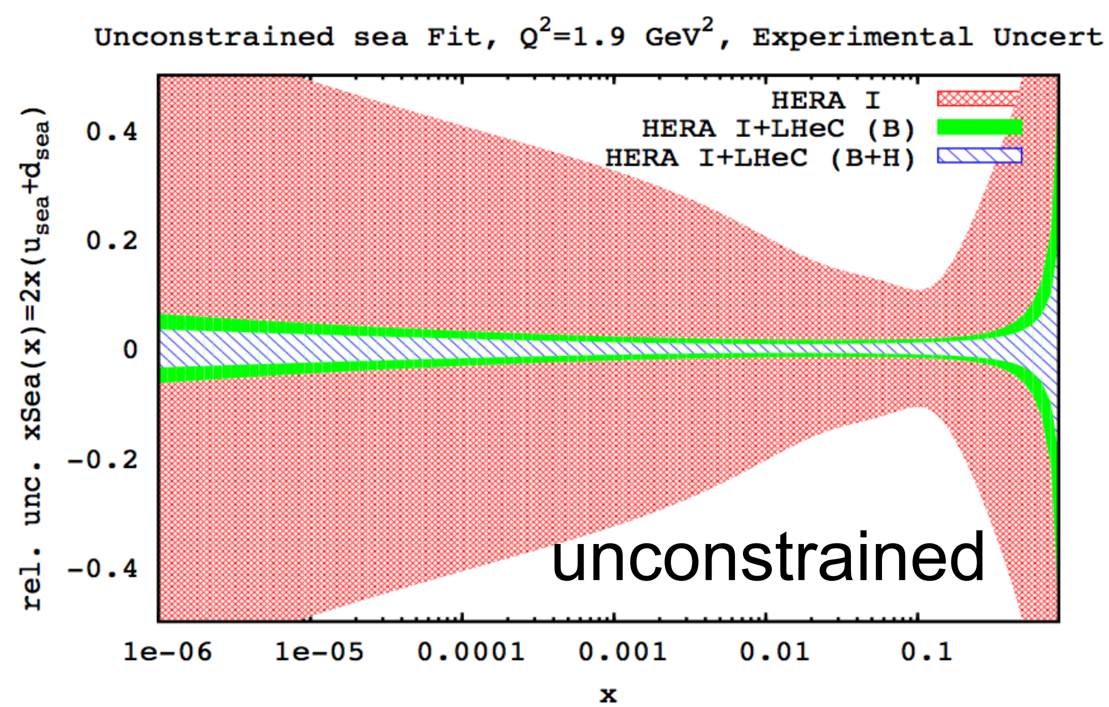




Releasing standard assumptions - u=d at small-x

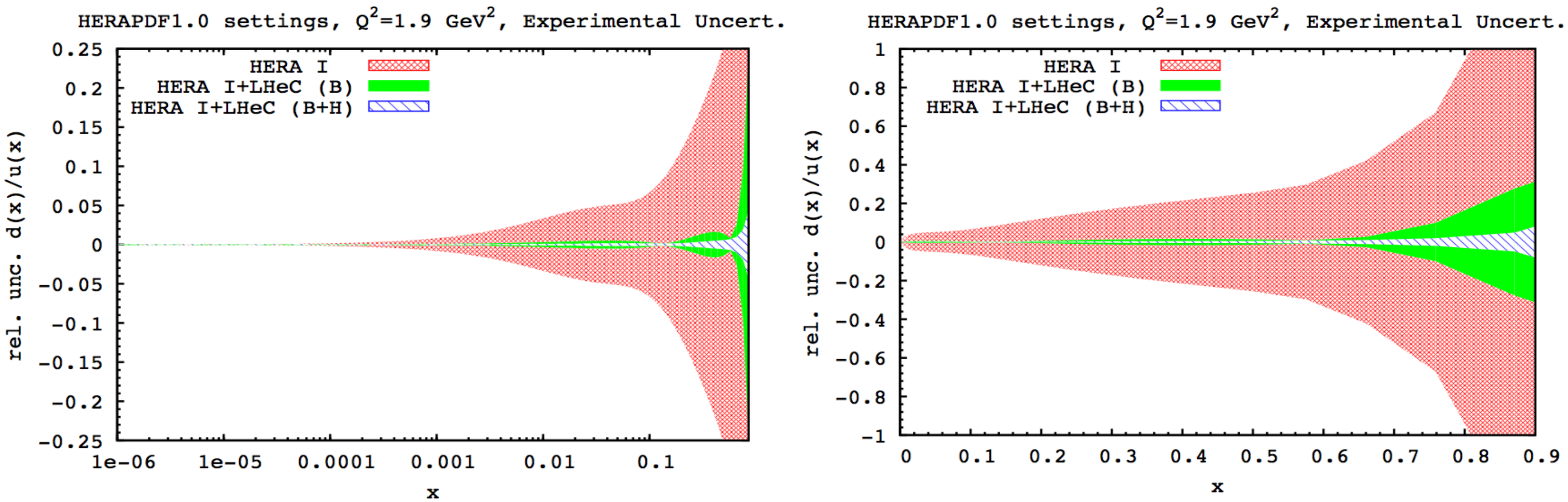
- Due to lack of constraining data standard PDF fits assume d=u at small-x
- HERA data do not constrain flavour separation at small-x, uncertainties grow substantially when theoretical assumptions are released
- LHeC data provide enough experimental constraints to keep uncertainties on small-x light flavour under control



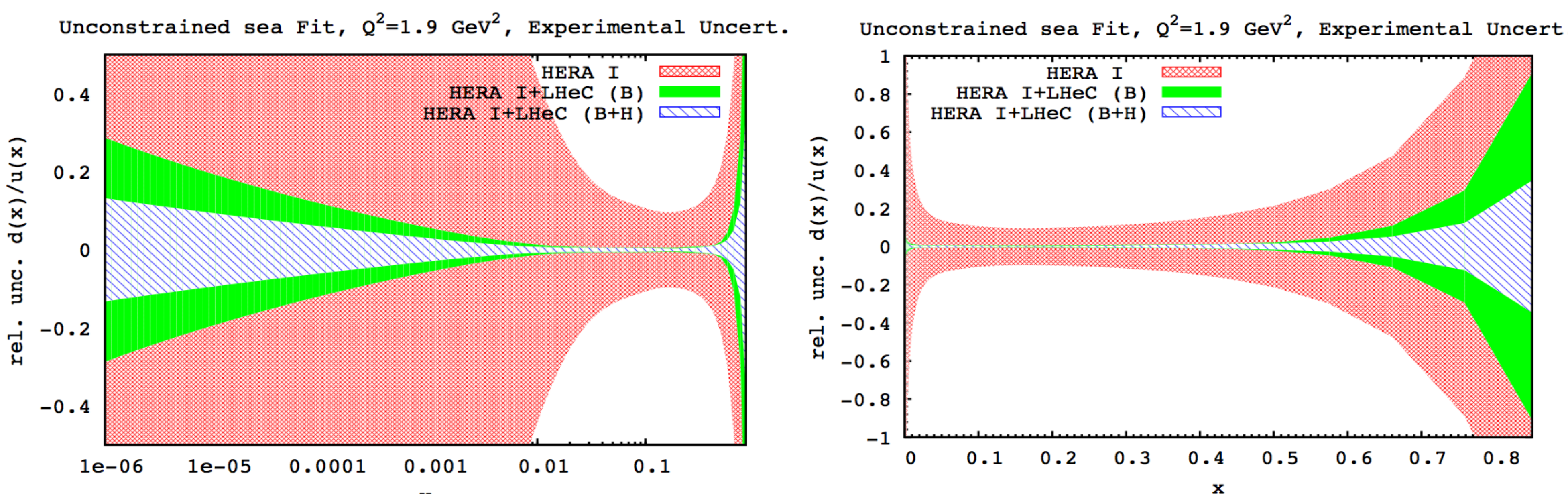


Releasing standard assumptions - d/u ratio

- Constrained decomposition:



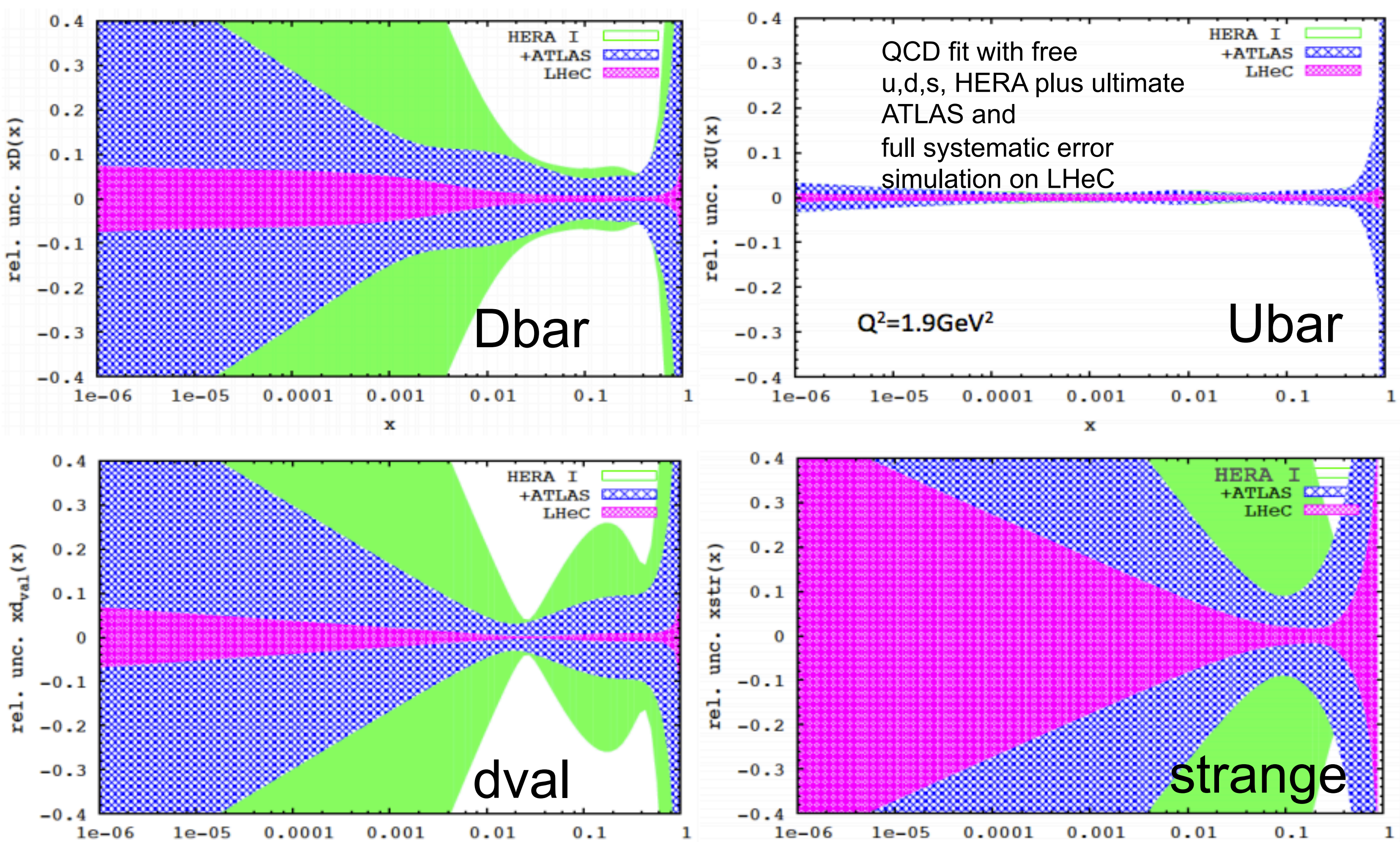
- Unconstrained sea decomposition:



Releasing standard assumptions - Ultimate fit

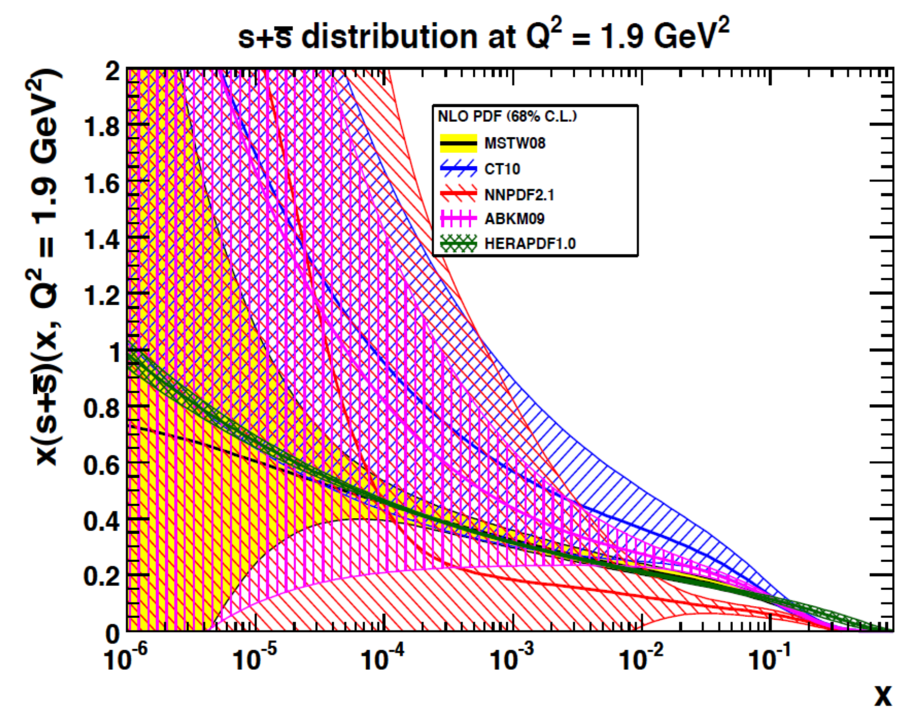
- **Combined fit** to **HERA**, **LHC** and **LHeC** data has the **potential** to deliver a **PDF set** with **very small, reliable, uncertainties** even when releasing most of the standard assumptions (u=d at small-x, free strange parametrization)

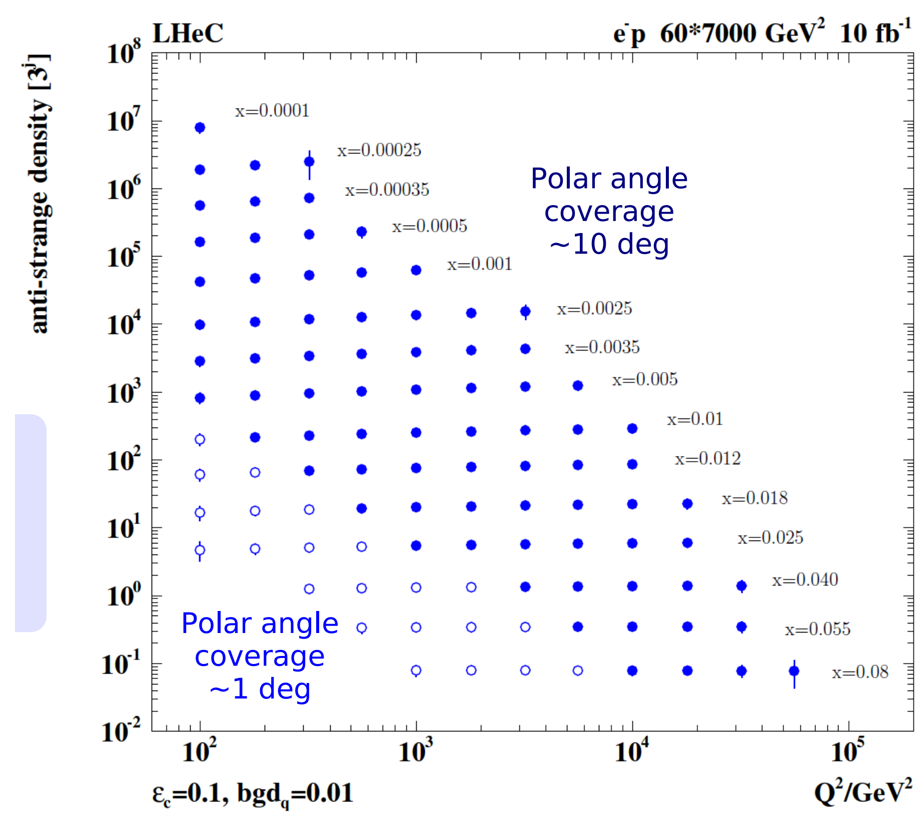
- Only on **high-energy**, **proton data**: **no higher-twist** or **nuclear corrections**

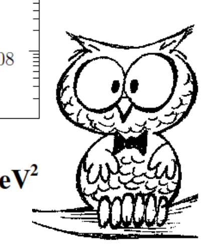


Strangeness at the LHeC

- Strange is one of the least constrained PDFs in global fits (NuTeV, CCFR)
- Recent ATLAS measurement hints to "unsuppressed" strange with respect to non-strange sea
- Further constraints from LHC (W+c, DY)
- LHeC allows for precision measurements of s and $\bar{s}$ distributions in CC $e^{\pm}p$ with tagged charm
- Independent measurements of s and s ($W^{+}s \rightarrow c$ and $W^{-}\bar{s} \rightarrow \bar{c}$)

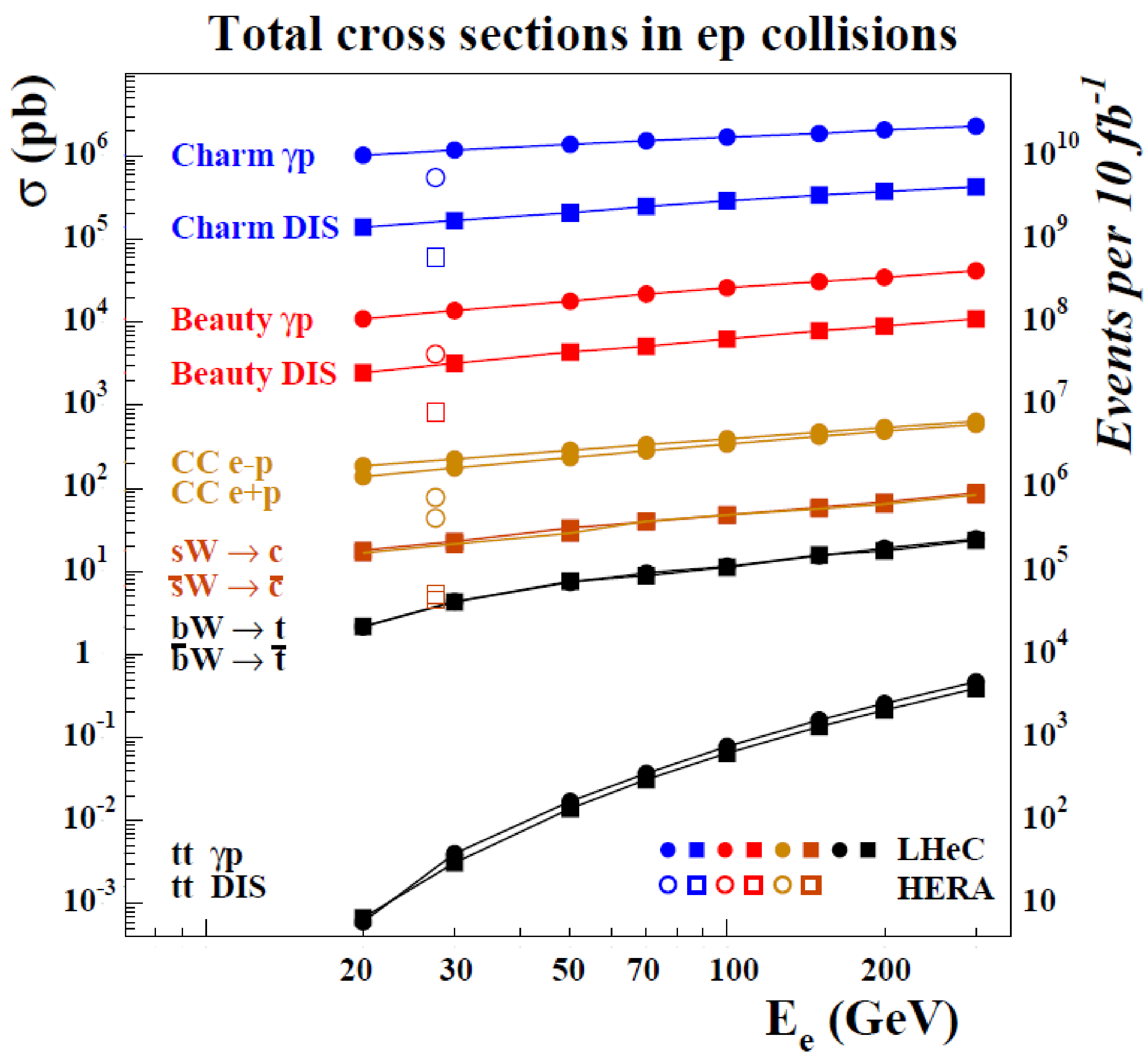






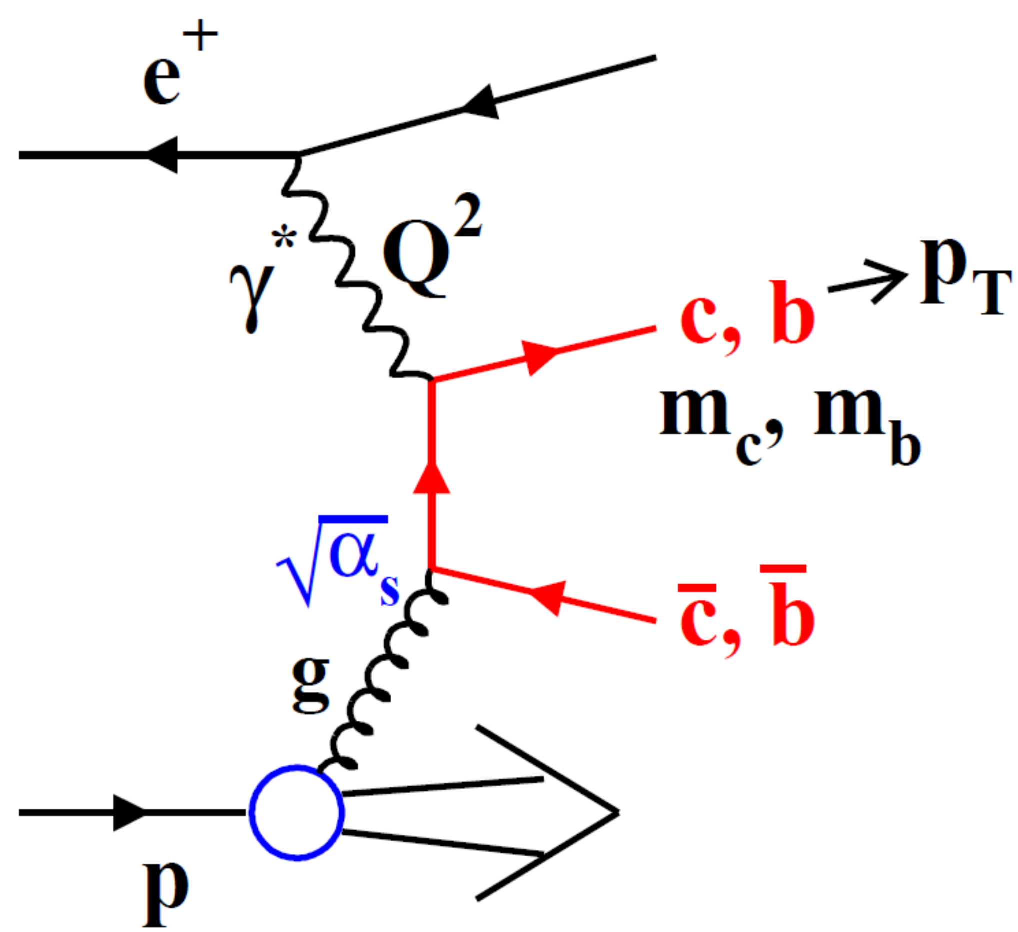
Heavy Quark production - Overview

- Access to **all quark flavours** with **high statistics**
- Study **heavy quark densities** in the proton
- **Intrinsic charm** component
- Measurement of **electroweak parameters** (CKM matrix elem.)
- Better understanding of Heavy Flavours treatment in PDF fits



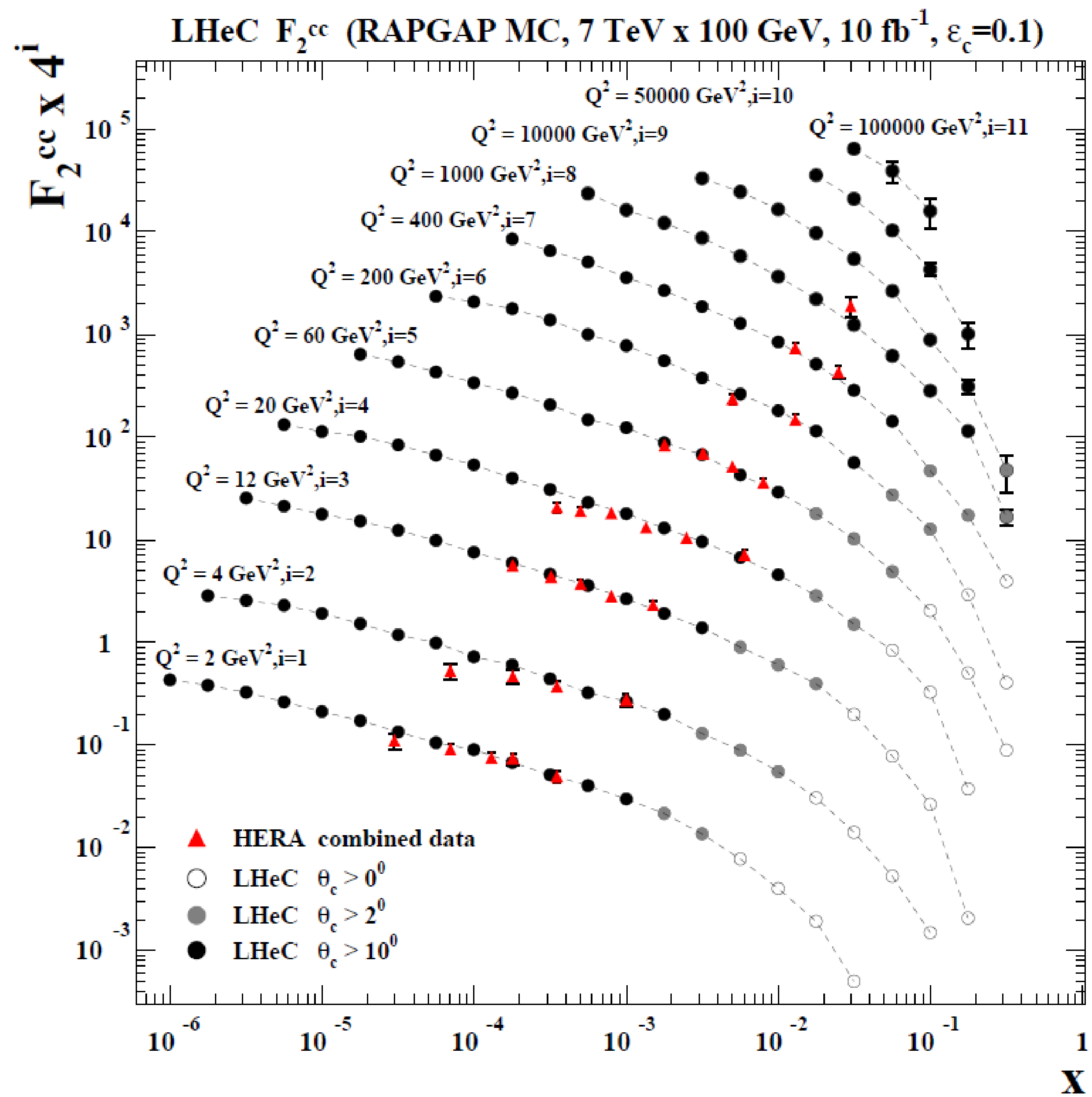
Heavy Quark production - Ocerview

- LO **charm & bottom** production in **DIS** through boson-gluon-fusion (**BGF**)
- **Direct probe** of the **gluon** distribution
- Predictions from **different PDF sets differ** because of **treatment of Heavy Flavour contributions** in fits
  - Fixed Flavour Number Scheme (**FFN**)
  - Zero-Mass Variable Flavour Number Scheme (**ZM-VFNS**)
  - General-Mass Variable Flavour Number Scheme (**GM-VFNS**)



Heavy Quark production - Charm

- F_2^{cc} simulation obtained with RAPGAP & CTEQ5L
- To be compared to the **combined H1-ZEUS** measurement (**5-10% uncertainty**)
- Hugely **enlarged phase space** accessible at the **LHeC**
- Substantially **improved tagging** efficiency, much **larger luminosity**



Heavy Quark production - Charm mass

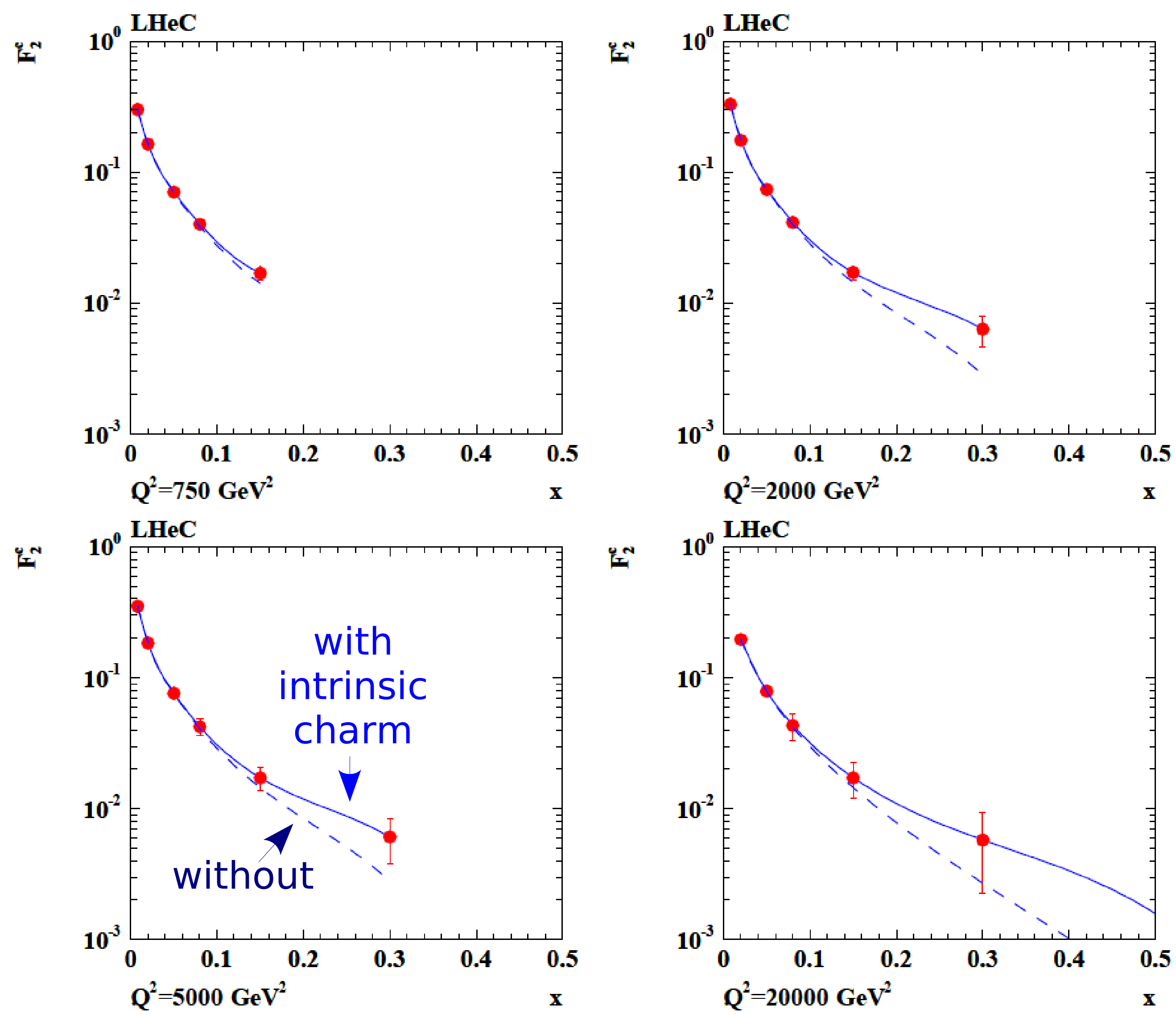
- **High precision** determination of the **charm mass** from **inclusive and F_2^{cc}** data

Data input	Experimental uncertainty on m_c [MeV]
HERA: NC+CC	100
HERA: NC+CC+ F_2^{cc}	60
LHeC: NC+CC	25
LHeC: NC+CC+ F_2^{cc}	3

- LHeC inclusive data alone have the potential to reduce the uncertainty on m_c determination from HERA data by a factor of 4
- Combination with **F_2^{cc}** allows to aim for **ultimate precision** of **3 MeV**
- **Similar precision** achievable in measurements involving **b quarks**

Heavy Quark production - Intrinsic charm

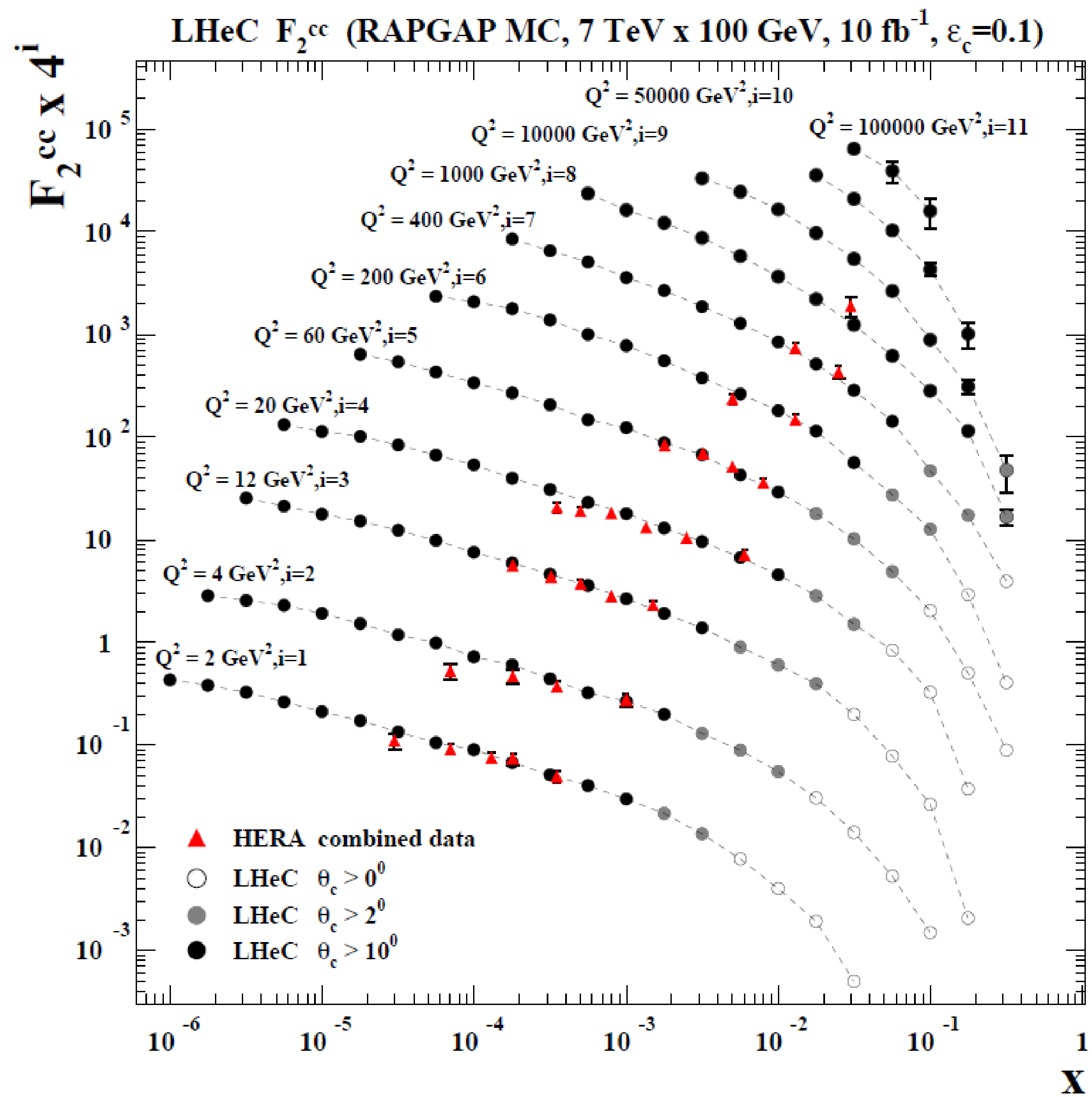
- **Present data** do **not exclude** a sizable (~1-5%) **intrinsic charm** component of the proton
- Possibly relevant for **Higgs production** in some **BSM scenarios**
- **Precise measurement** in the **large-x** region require very good **forward tagging acceptance** (possible in a **reduced E_p run**)
- Reliable determination of **intrinsic charm** is **challenging** but **possible**



Heavy Quark production - Beauty

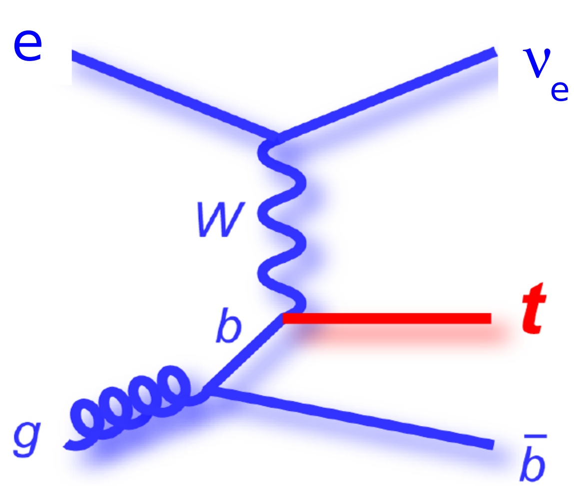
- F_2^{bb} simulation obtained with RAPGAP & CTEQ5L
- To be compared to the **combined H1** measurement (**20-50% unc.**)
- Hugely **enlarged phase space** accessible at the **LHeC**
- Precision measurement possible thanks to improved tagging
- Potentially important for Higgs production in the MSSM

[JHEP0601:069, 2006]

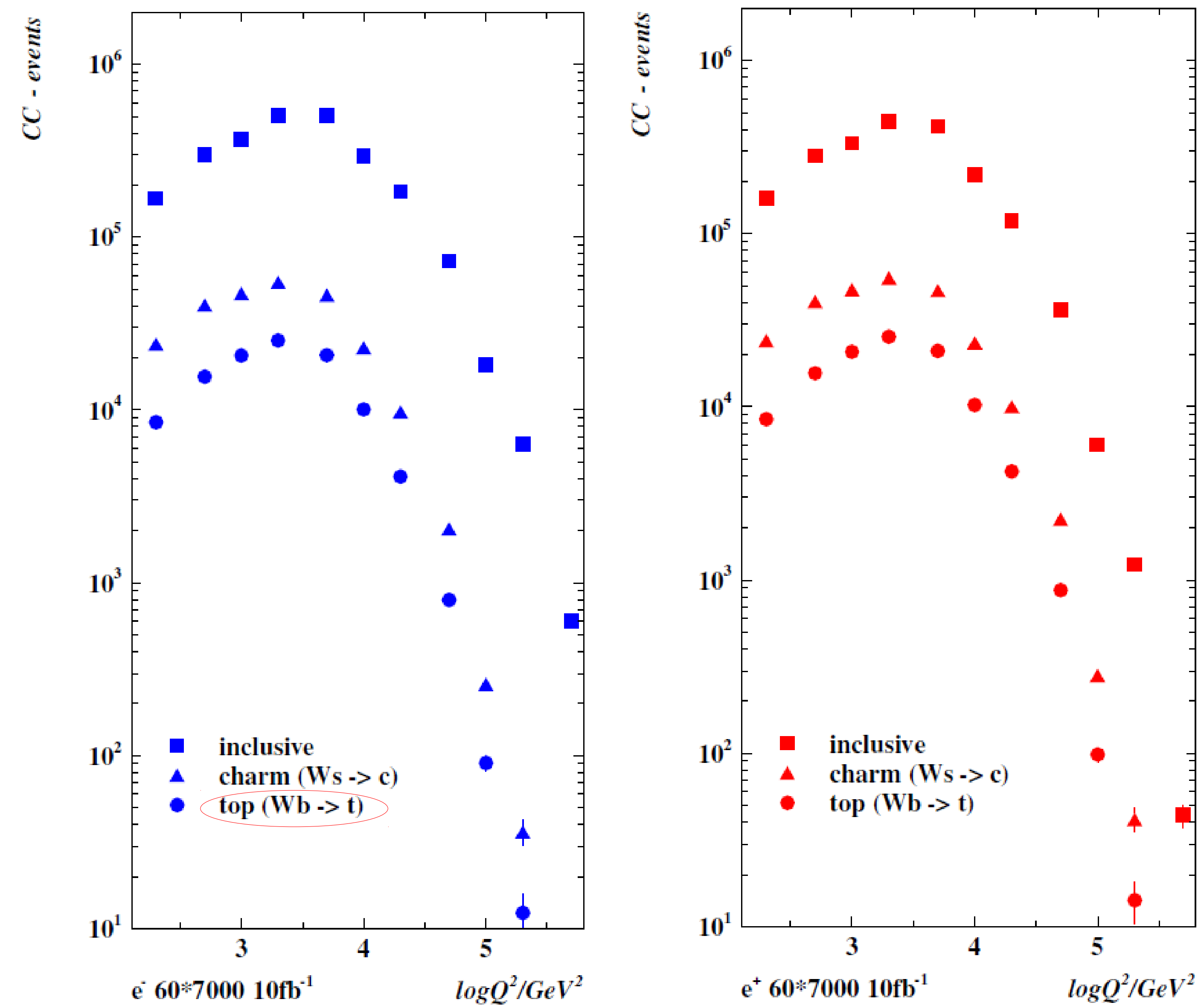


Heavy Quark production - Top

- **First opportunity** to study **top** quark in **DIS**
  (negligible cross-section at HERA)
- **CC**: Wb → t production
  (cross section: O(10 pb))



- **NC**: $t\bar{t}$ pair production
- **Details** of **top physics** at the **LHeC** still **under investigation**



Conclusions & Outlook

- **LHeC** is the **ideal machine** to resolve the (unpolarized) **flavour content** of the **proton**
- It can provide a powerful **handle** on **light flavour** quark and antiquark **separation**, both in the valence and the sea sector
- Can help us constraining the **gluon** distribution both at **small-** and **large-x**
- Will significantly **extend** the **HERA kinematic coverage** for production of **charm** and **bottom** quarks
- Will allow us for the **first** time to **study top quark** production **in DIS**
- It is a **challenging** but **realistic** project and a **natural extension to the LHC**