Precision QCD and electroweak physics at the LHeC

3rd LHeC workshop, 13 Nov 2010, Chavannes-De-Bogis

Paolo Gambino (Torino), Olaf Behnke (DESY), Thomas Gehrmann (Zurich)

What kind of QCD/EW physics can be done with a (20-150 GeV) x 7 TeV ep collider with integrated L~1-100 fb-1?

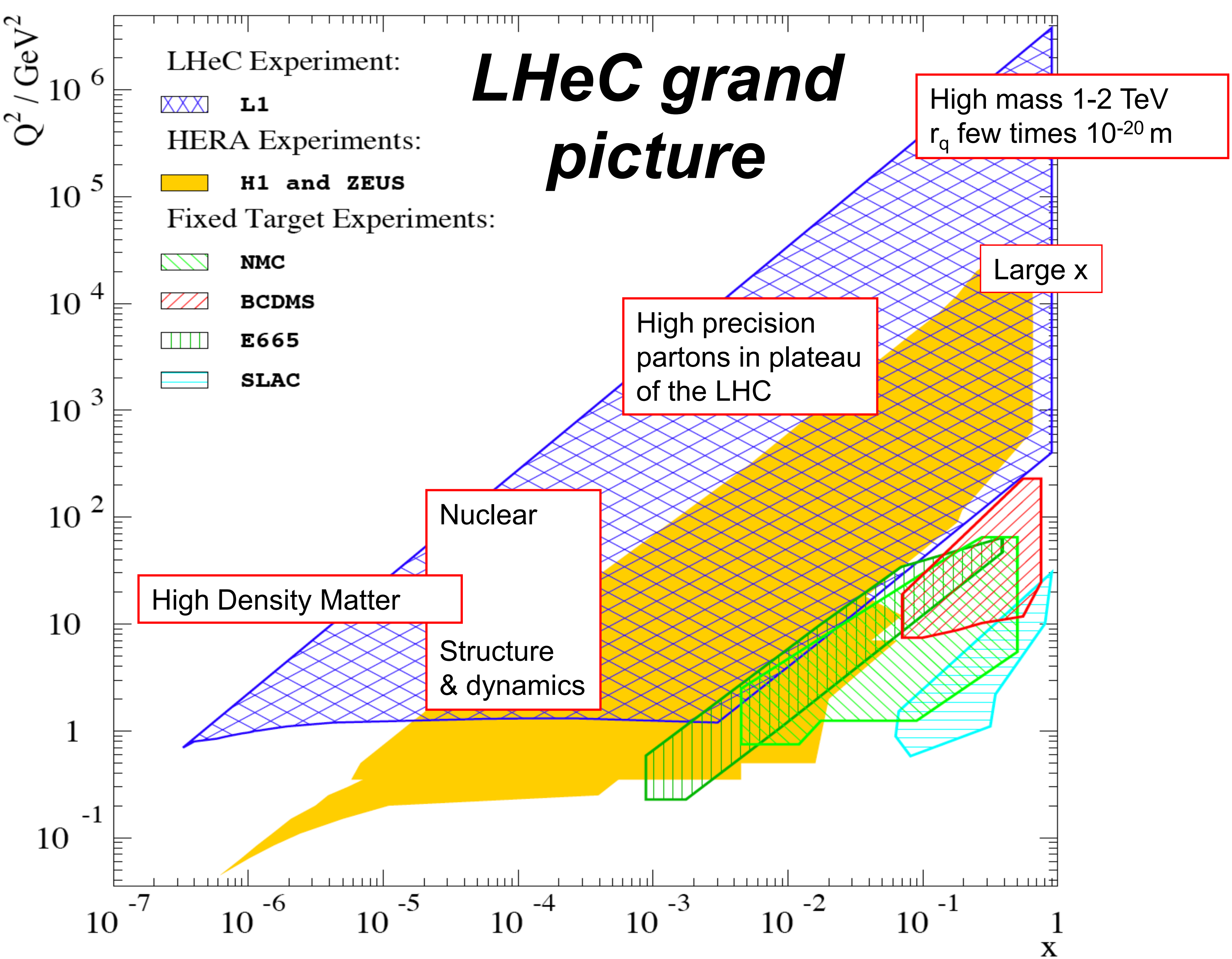
1. DIS
2. Jets
3. Heavy flavors
4. Electroweak physics

Most work completed, writing in progress

LHeC QCE Group CDR preparation status 12 nov 2010

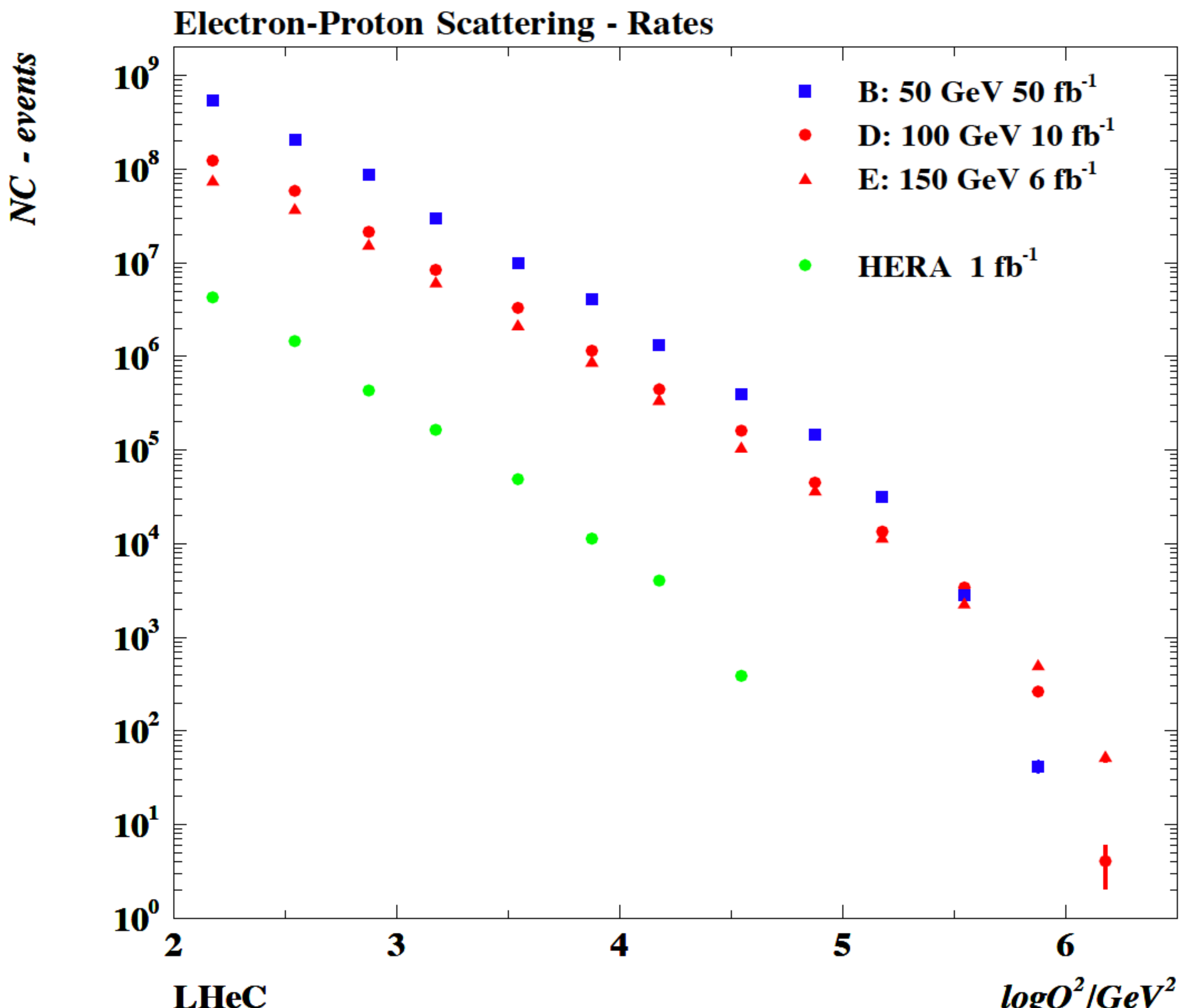
Topic	Authors	# Pages	Study status	CDR subarticle status	Chavanne talk
1. Inclusive ep cross sections and structure functions	Max Klein, Enrico Tassi	10	**Finished**	**Ongoing writing**	**yes**
2. QCD fits (PDF & α_s)	Claire Gwenlan, Alberto Guffanti, Max Klein Thomas Kluge, Voica Radescu	7+4	**Mostly finished**	**Ongoing writing**	**yes**
3. Electroweak physics	Paolo Gambino, Claire Gwenlan, Nandi Soumitra, Voica Radescu	5	**Mos**	**Ongoing writing**	**yes**
4. Single top production	**Vacant**	4	**Generator level studies, Sherpa plus Det. simulation??**		
5. Charm and beauty production	Gustav Kramer, Hubert Spiesberger, Gokhan Unel, O. B.	11	**Finished**	**Delivered 1st draft**	**yes**
6 High pt jets	Thomas Gehrmann, Claudia Glasman, Juan Terron, Thomas Schoerner, Joerg Behr	8	**Finished**	**Delivered 1st draft**	**yes**

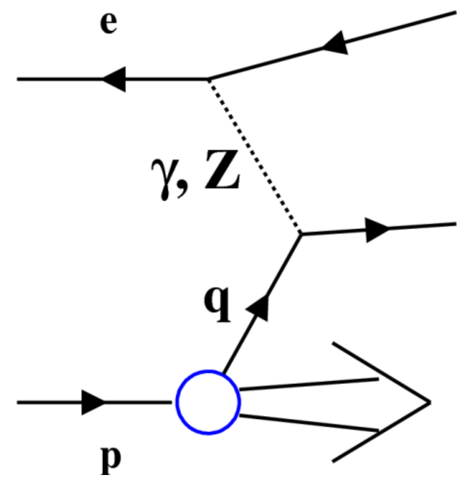
1. DIS at LHeC



LHeC grand picture
LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
High mass 1-2 TeV
r_q few times 10^{-20} m
Large x
High precision partons in plateau of the LHC
Nuclear
Structure & dynamics
High Density Matter
Q^2 / GeV^2
x

Pseudodata: Neutral Current Event Rates

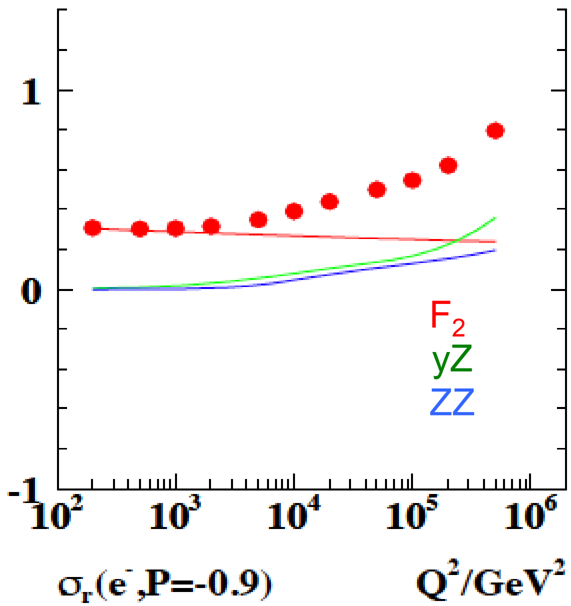




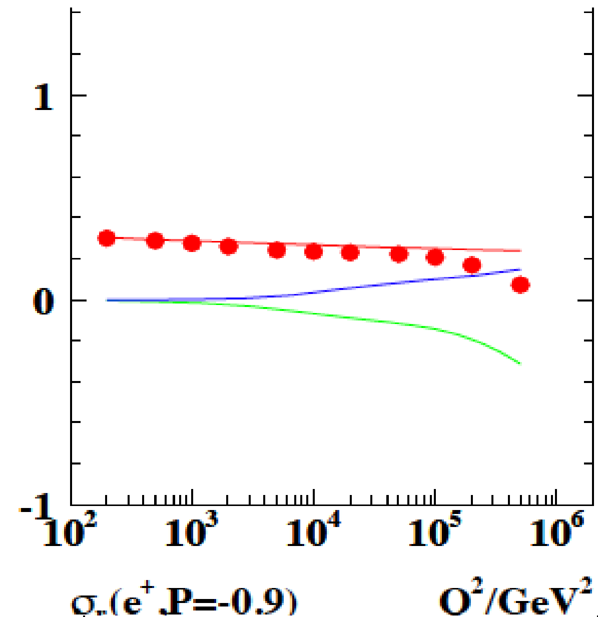
Vary charge, polarisation, and beam energy to disentangle contributions

Trivial, but important: largest $\mathbf{E_{lep}}$ allows highest Q^2 scales

Photon and Z exchanges are 1:1



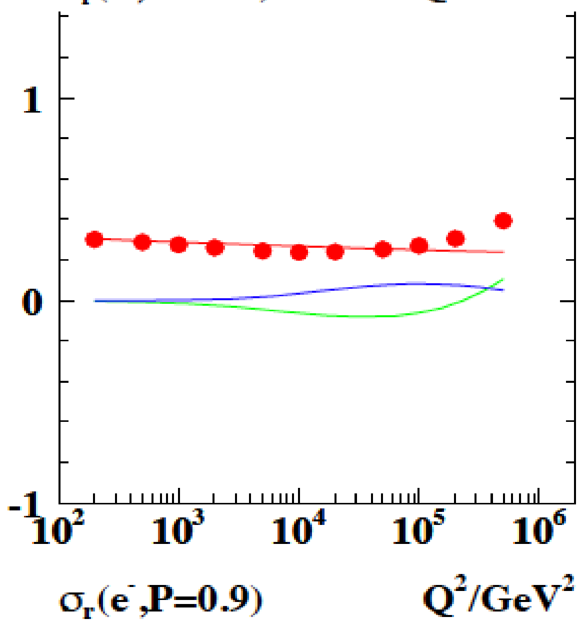
x=0.2
100 GeV
7000 GeV

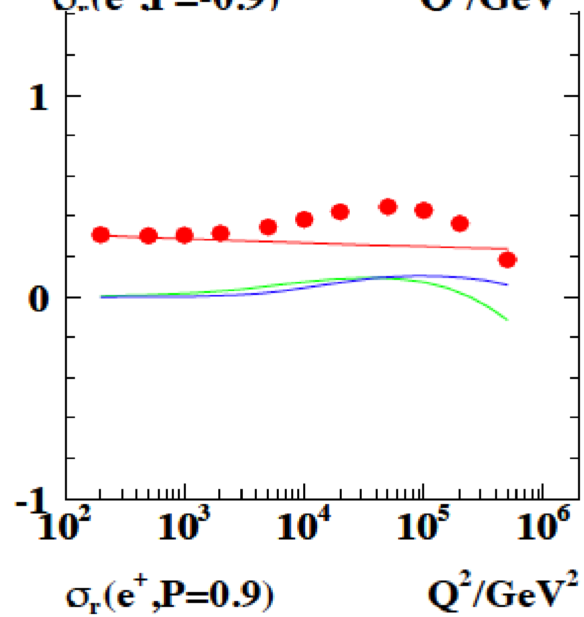


2 charges and
2 polarisations
very desirable

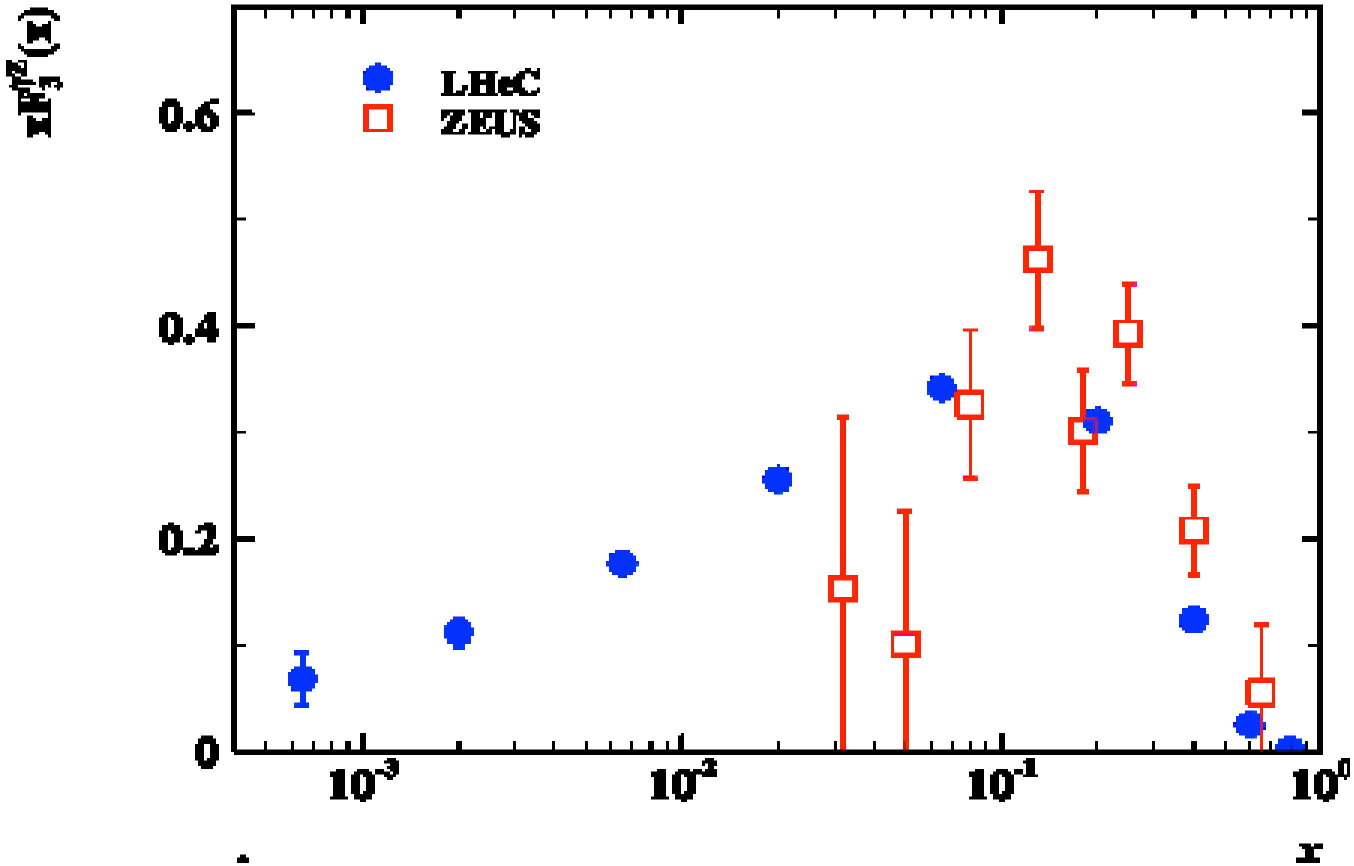
for electroweak
precision physics
and a
new spectroscopy
should that appear.

Z effects depend on lepton charge and polarisation.





Charge Asymmetry $xF_3^{\gamma Z}$



60x7000 GeV^2
P=0
10fb^{-1}

$$xF_3^{\gamma Z} = 2x[e_u a_u(u_v + \Delta_u) + e_d a_d(d_v + \Delta_d)]$$

$$\Delta_u = (u_{sea} - \overline{u} + c - \overline{c})$$

$$\Delta_d = (d_{sea} - \overline{d} + s - \overline{s})$$

Charged Currents

$$\sigma_{r,CC} = \frac{2\pi x}{Y_+ G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]^2 \frac{\mathrm{d}^2\sigma_{CC}}{\mathrm{d}x\mathrm{d}Q^2}$$

$$\sigma_{r,CC}^{\pm} = \frac{1\pm P}{2}\left(W_2^{\pm} \mp \frac{Y_-}{Y_+} xW_3^{\pm} - \frac{y^2}{Y_+} W_L^{\pm}\right)$$

$$W_2^+ = x(\overline{U}+D)\,,\, xW_3^+ = x(D-\overline{U})\,,\, W_2^- = x(U+\overline{D})\,,\, xW_3^- = x(U-\overline{D})$$

$$U = u + c \qquad \overline{U} = \overline{u} + \overline{c} \qquad D = d + s \qquad \overline{D} = \overline{d} + \overline{s}$$

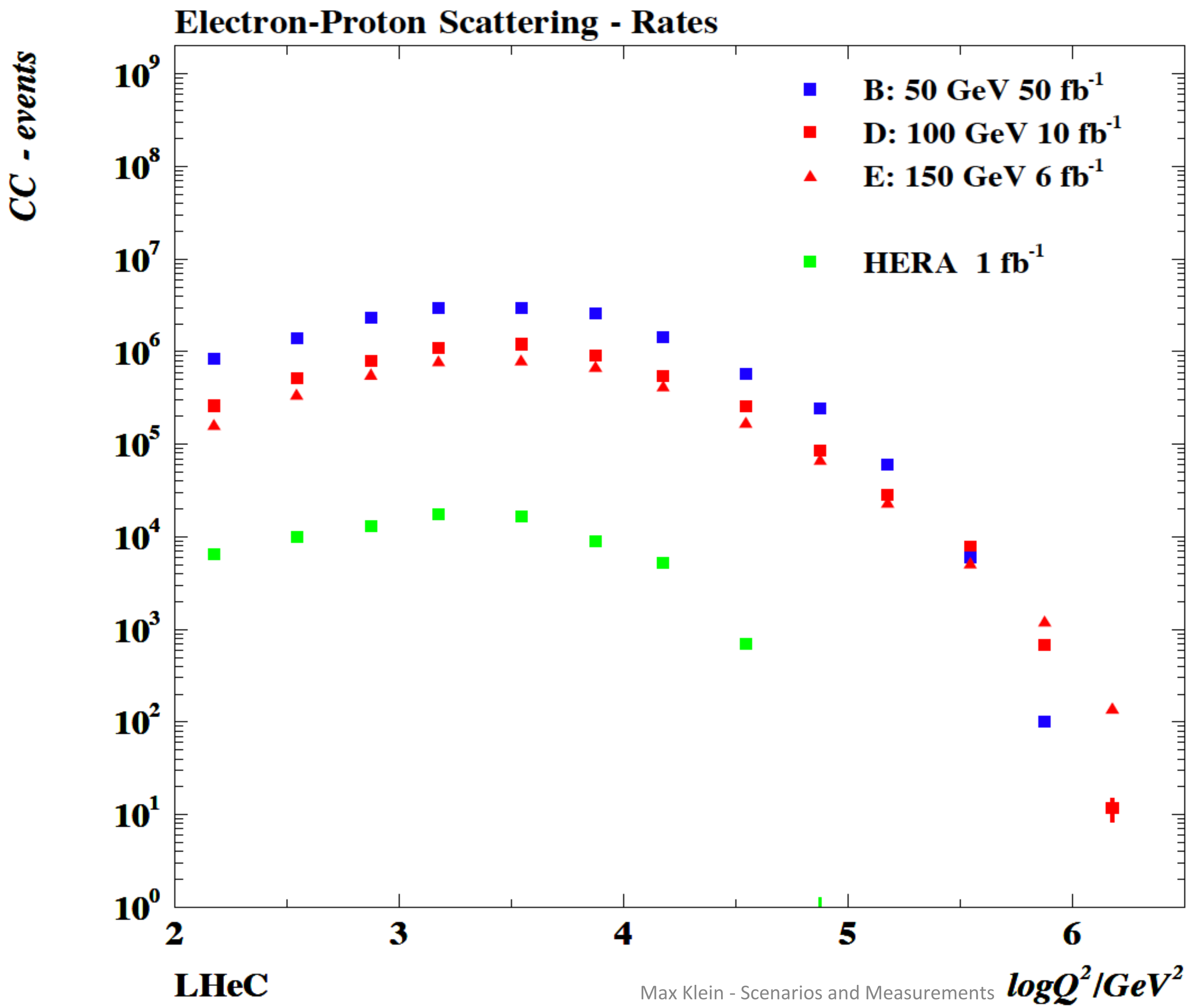
$$\sigma_{r,CC}^{+} \sim x\overline{U} + (1-y)^2 xD,$$
$$\sigma_{r,CC}^{-} \sim xU + (1-y)^2 x\overline{D}$$

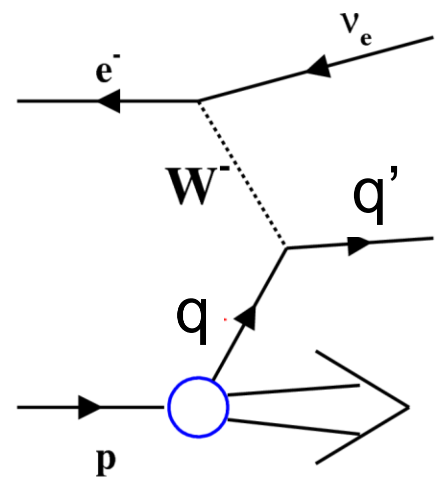
$$\sigma_{r,NC}^{\pm} \simeq [c_u(U+\overline{U}) + c_d(D+\overline{D})] + \kappa_Z[d_u(U-\overline{U}) + d_d(D-\overline{D})]$$

with $c_{u,d} = e_{u,d}^2 + \kappa_Z(-v_e \mp Pa_e)e_{u,d}v_{u,d}$ and $d_{u,d} = \pm a_e a_{u,d} e_{u,d},$

Complete unfolding of all parton distributions to unprecedented accuracy

Pseudodata: Charged Current Event Rates

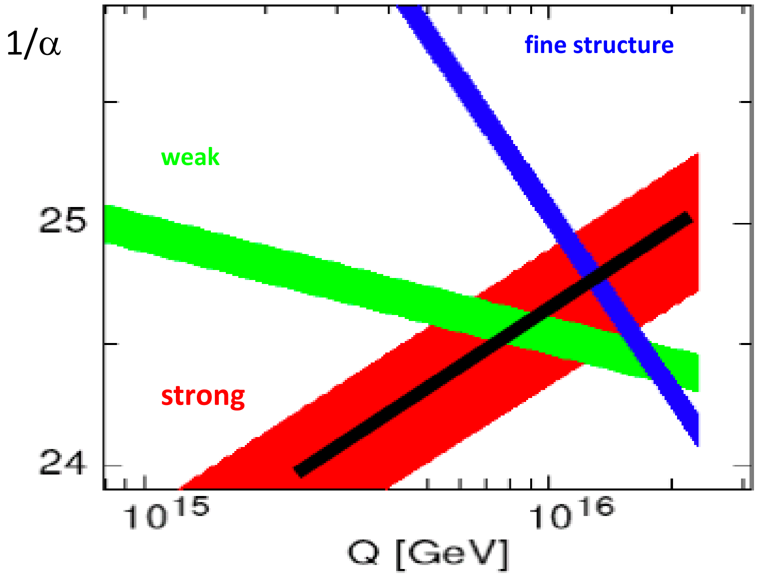




LHeC: expect ~ two orders of magnitude **more events** + better coverage for x>0.5

Strong Coupling Constant

Simulation of α_s measurement at LHeC



MSSM - B.Allnach et al, hep-ex/0403133

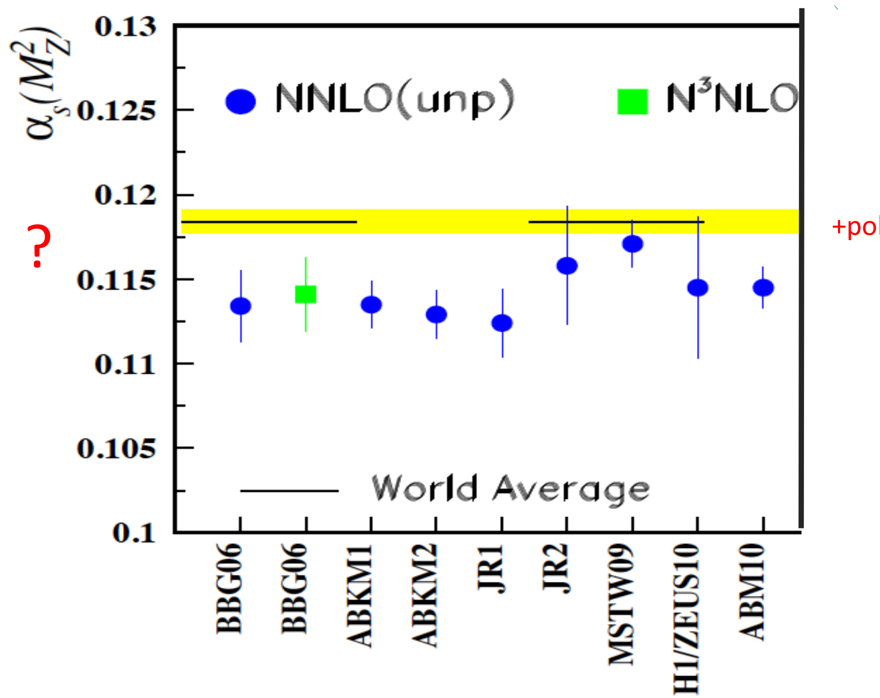
DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) θ_{lh} >5°	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

T.Kluge/M.Klein Divonne 09

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

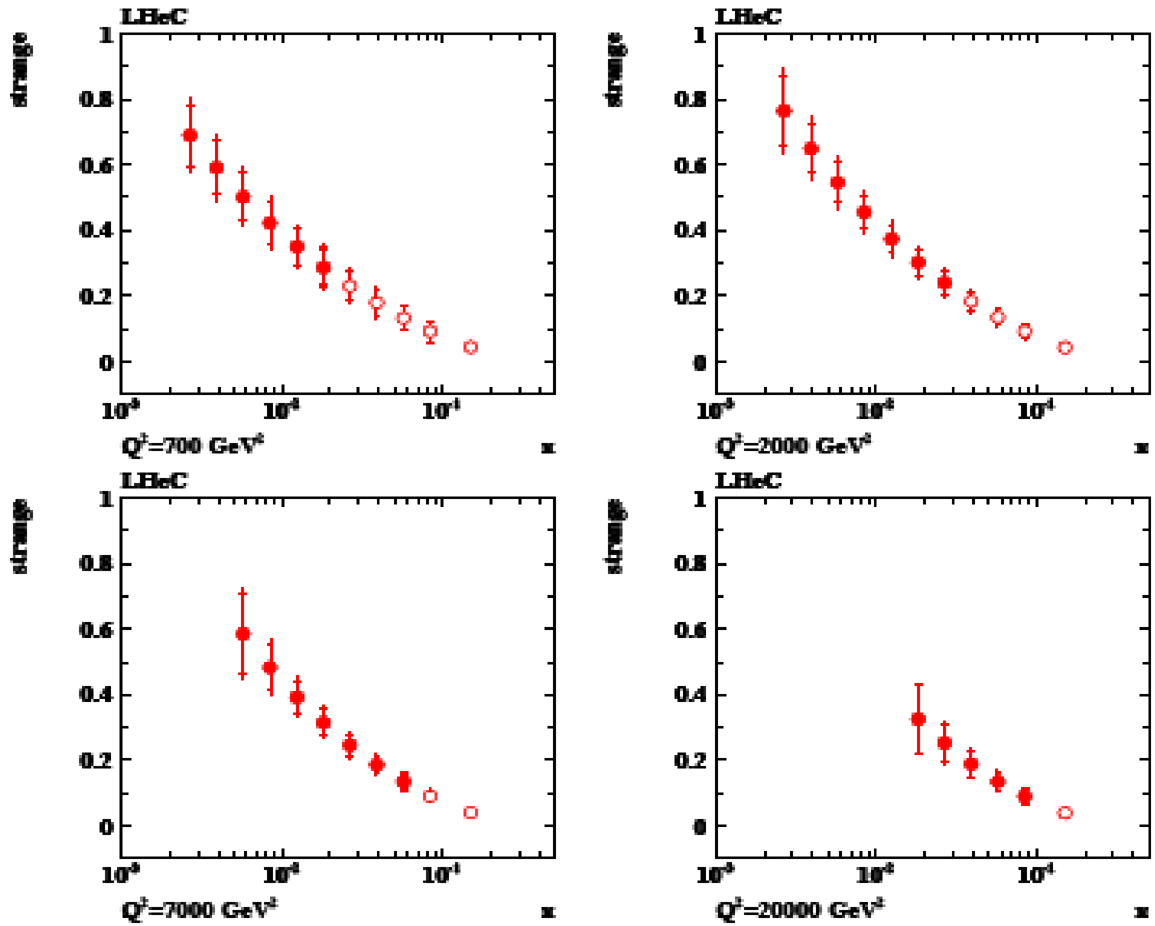
DIS tends to be lower than world average

LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD



J.Bluemlein and H. Boettcher, arXiv 1005.3013 (2010)

Strange (=? anti-strange) Quark



$W^+ s \rightarrow c$

$1\ fb^{-1}$

$\varepsilon_c = 0.1$

$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

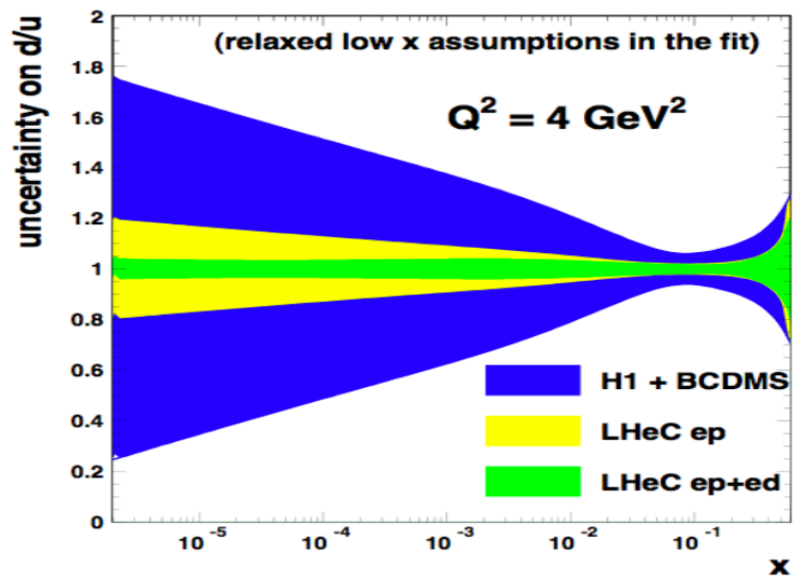
$\circ - \vartheta_h \geq 1^o$

$\bullet - \vartheta_h \geq 10^o$

Some dimuon and K data
never properly measured

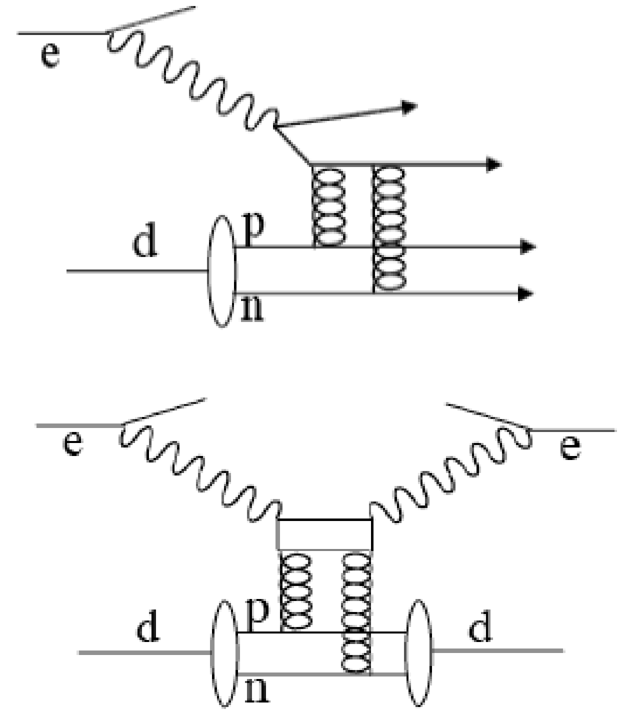
Neutron Structure (ed $\rightarrow$ eX)

d/u at low x from deuterons



(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

crucial constraint on evolution (S-NS), improved α_s



In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

Studied LHeC simulated scenarios

- Studied scenarios (produced by Max Klein)

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

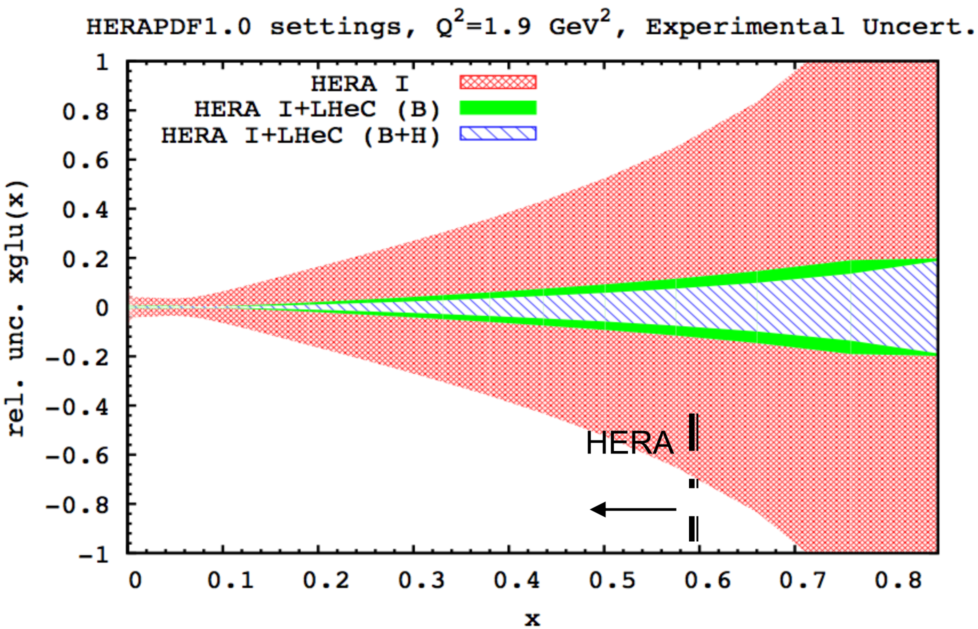
- Scenario B:
  - o $E(e^{\pm})$ = 50 GeV
  - o E(p) = 7 TeV
  - o Pol = $\pm$0.4
  - o Lumi e^+p = 50 fb^{-1}
  - o Lumi e^-p = 50 fb^{-1}
- Scenario H:
  - o $E(e^-)$ = 50 GeV
  - o E(p) = 1 TeV
  - o Pol=0
  - o Lumi e^-p = 1 fb^{-1}

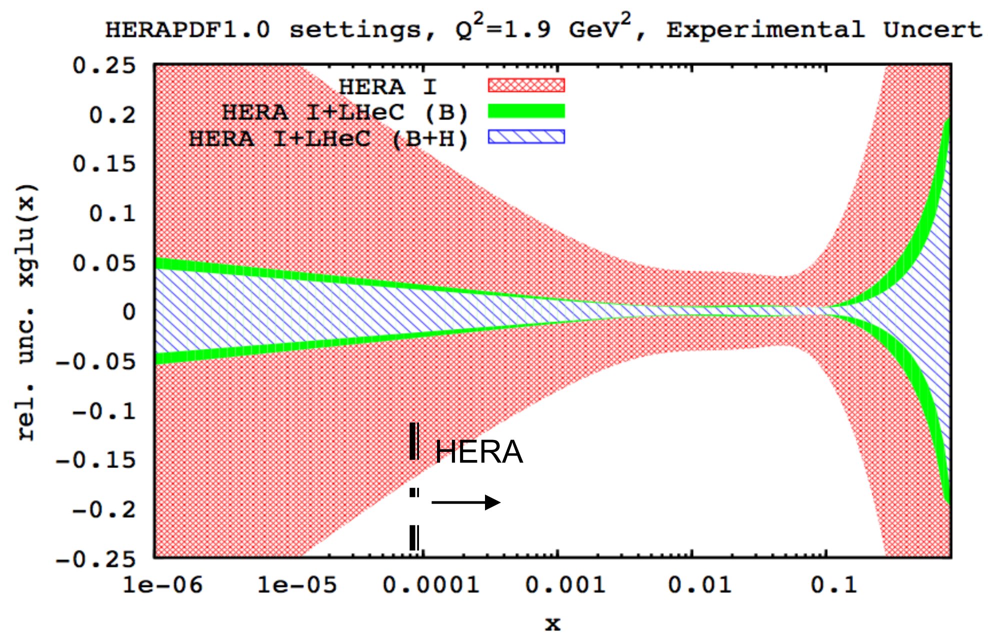
- The central values of the cross sections are based on the HERAPDF1.0 settings
- The uncertainties are taken from the simulated tables (Max Klein)

Same settings as for HERAPDF1.0 has been used

Impact of LHeC on PDFs: gluon

- Impressive impact of the LHeC simulated data on PDFs:
  - At high x (see linear plot) and at very low x (see log x plot)!

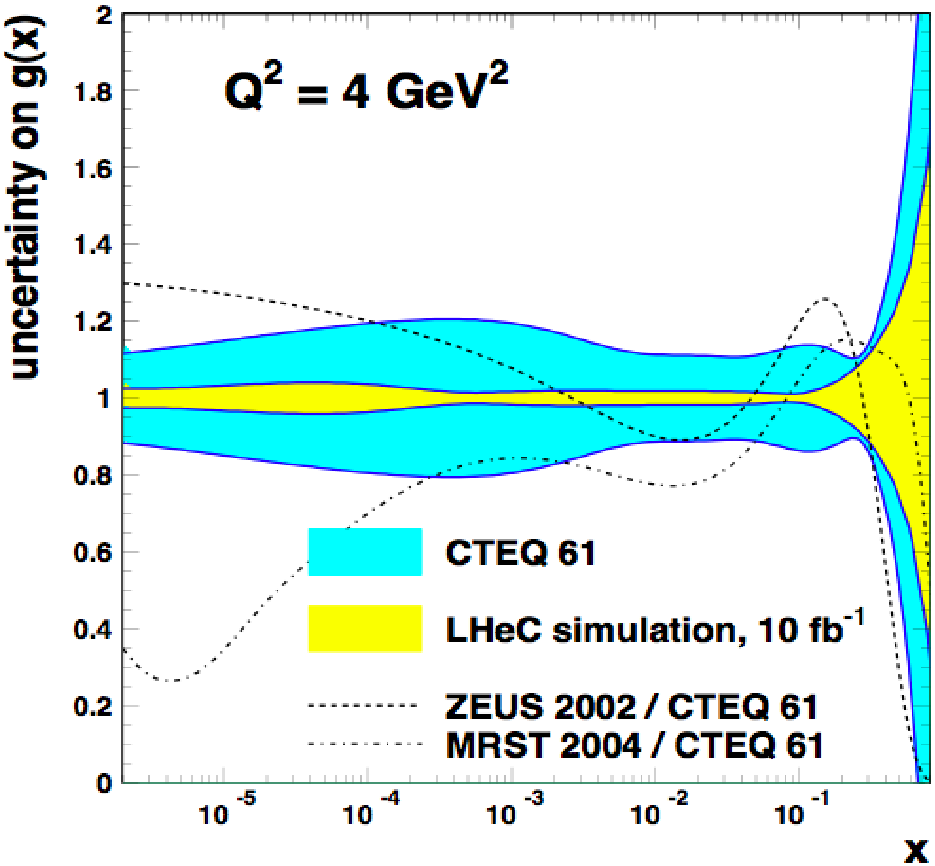


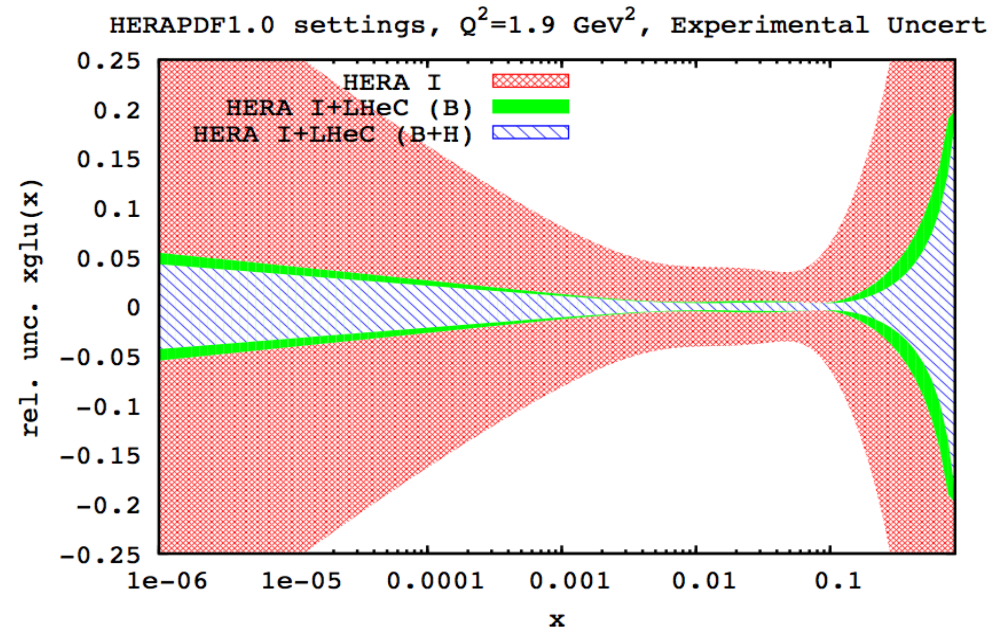


* All uncertainties are shown at the starting scale Q^2=1.9 GeV^2

Impact of LHeC on PDFs: gluon

- Impressive impact of the LHeC simulated data on PDFs:
  - At very low x (see log x plot) and at high x (see linear plot) too!

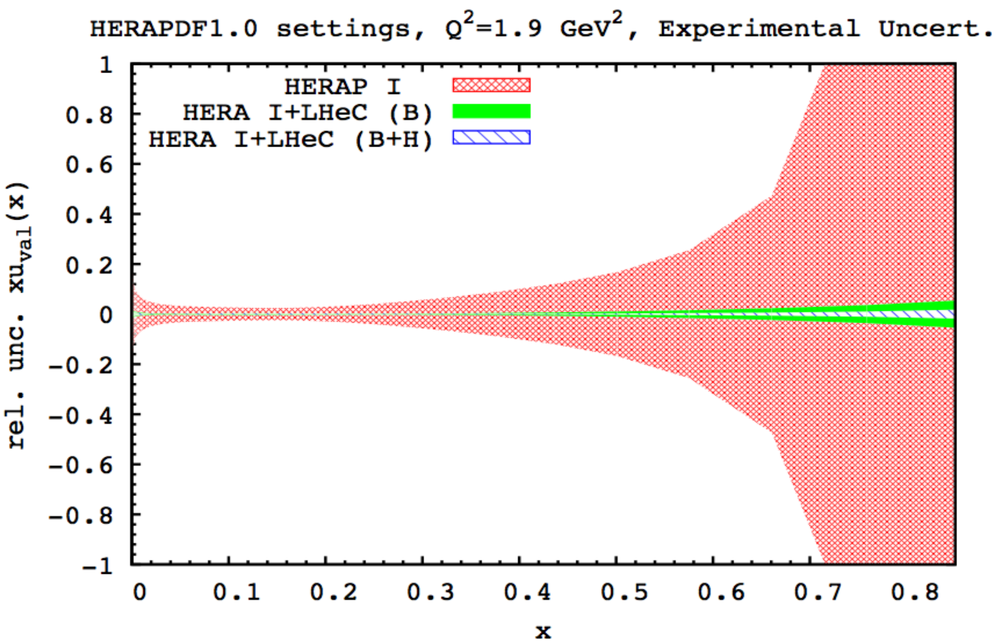


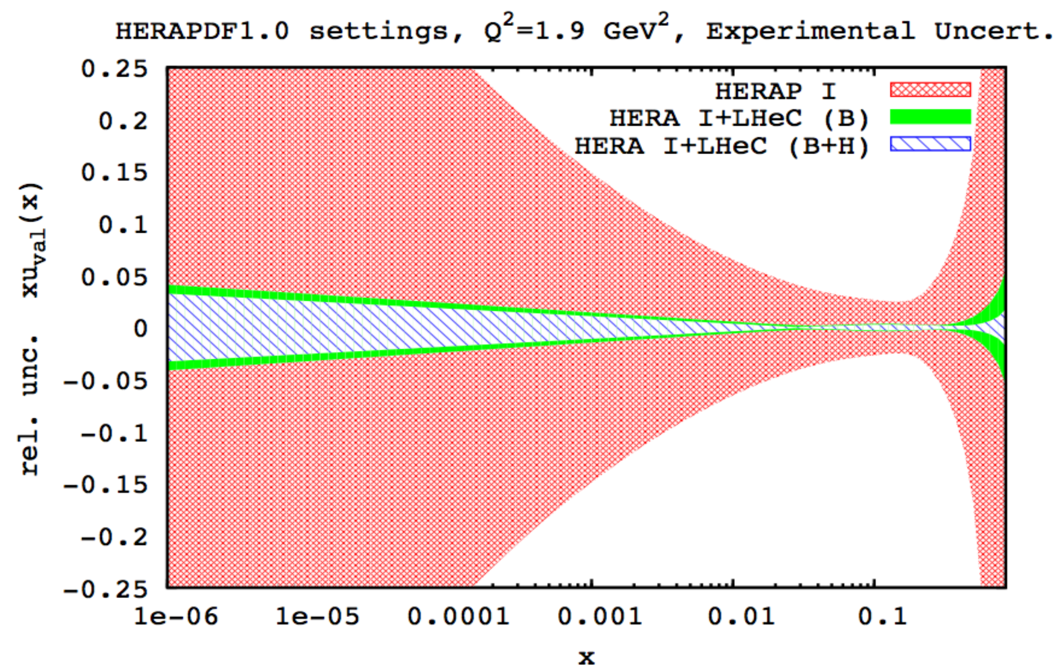


[Consistent with E.Perez]

Impact of LHeC on PDFs: u valence

- Similarly for u valence (linear and log plots are shown)

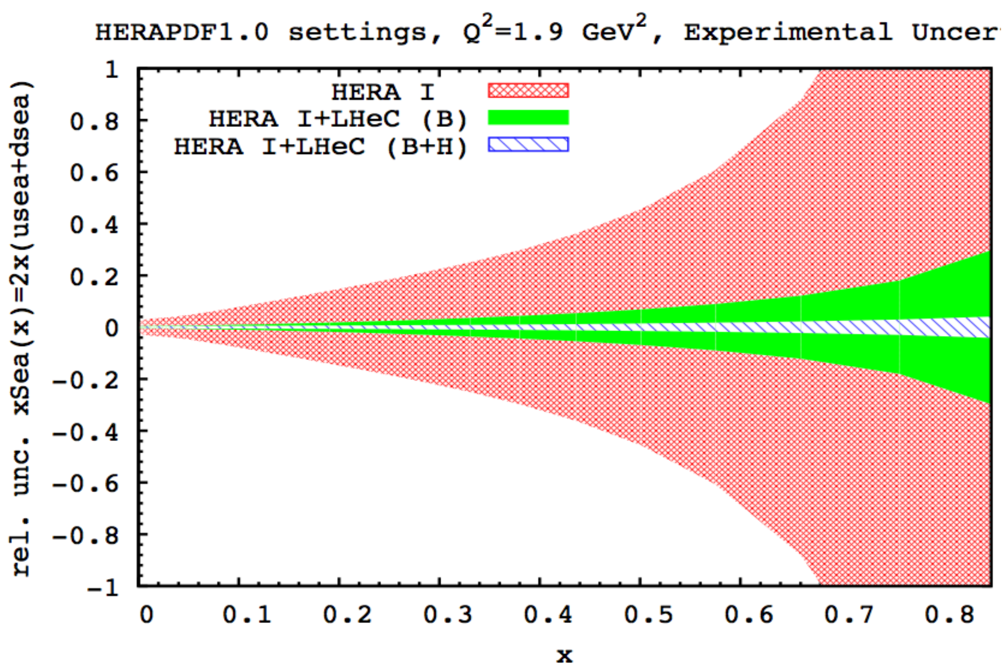


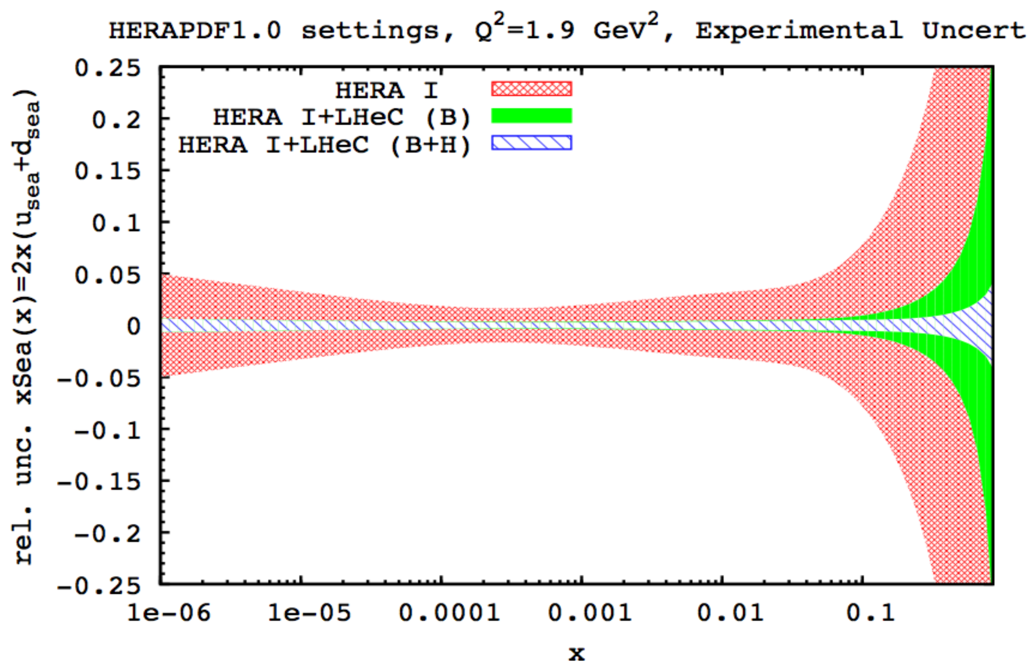


Similar but a bit less precise for d valence

Impact of LHeC on PDFs: sea = 2(usea+dsea)

- Beautiful reduction of the uncertainties given the precision and kinematic span of the LHeC simulation.

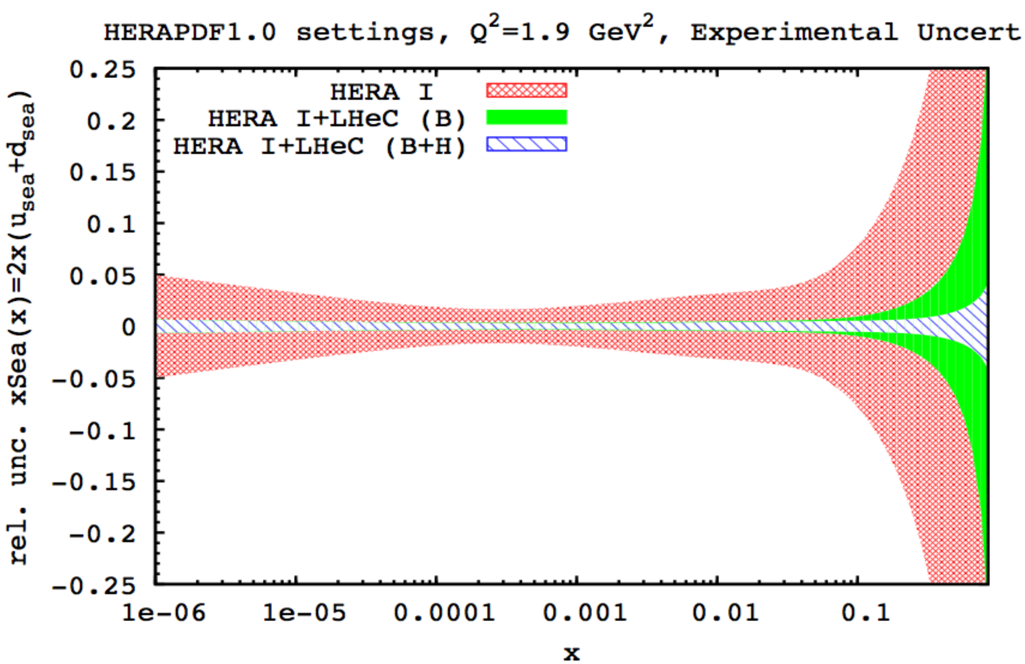


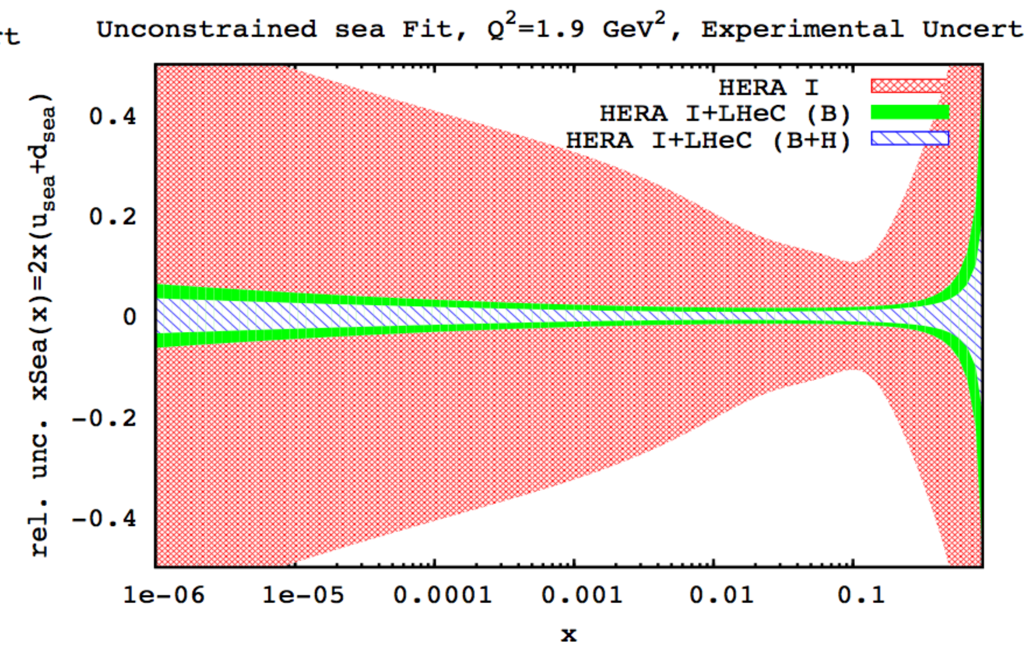


Accurate high x sea is important to study production of heavy particles at the LHC, e.g. Z'

Unconstrained setting

- Usual assumptions for light quark decomposition at low x may not necessary hold.
- Relaxing the assumption at low x u=d , we observe that uncertainties escalate, this has been shown that would impact considerably the size of uncertainties which could propagate further to Ws at the LHC up to 5% in the plateau region!
  - One can see that for HERA data, if we relax the low x constraint on u and d, the errors are increased tremendously!
  - However, when adding the LHeC simulated data, we observe that uncertainties are visbly improved even without this assumption.





Proton PDFs

Claire Gwenlan

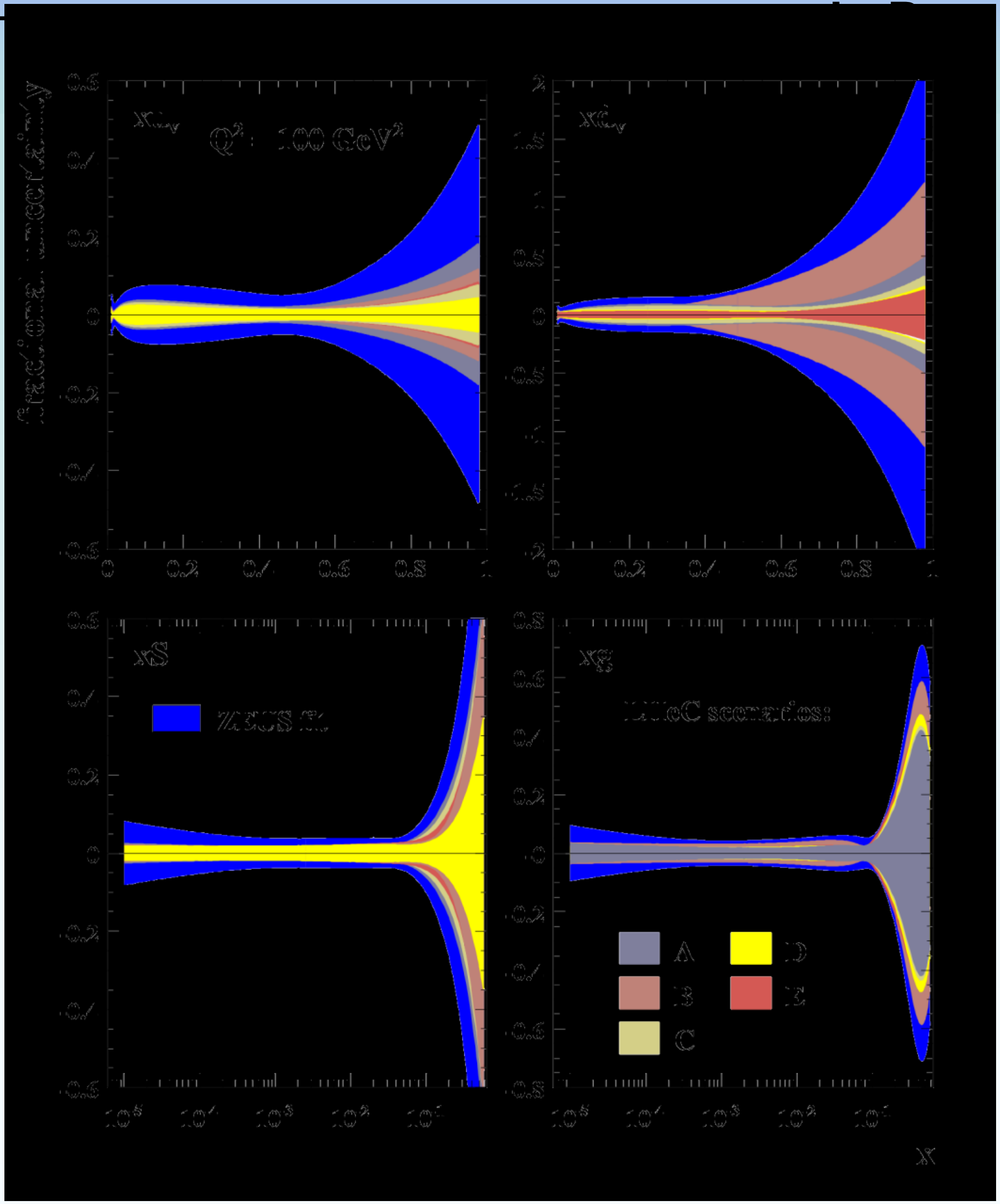
$Q^2 = 100\ GeV^2$

» only PDF parameters free
(LHeC **NC** and **CC** $e^{\pm}p$ included)

scenarios: **A**, **B**, **C**, **D** and **E**

	E_e (GeV)	P	L (e-:e+)
A	20	0	2 (1:1)
B	50	0.4	200 (1:1)
C	50	0.4	4 (1:1)
D	100	0.9	30 (2:1)
E	150	0.9	18 (2:1)

(examples with several different Q^2 values are shown in backups)



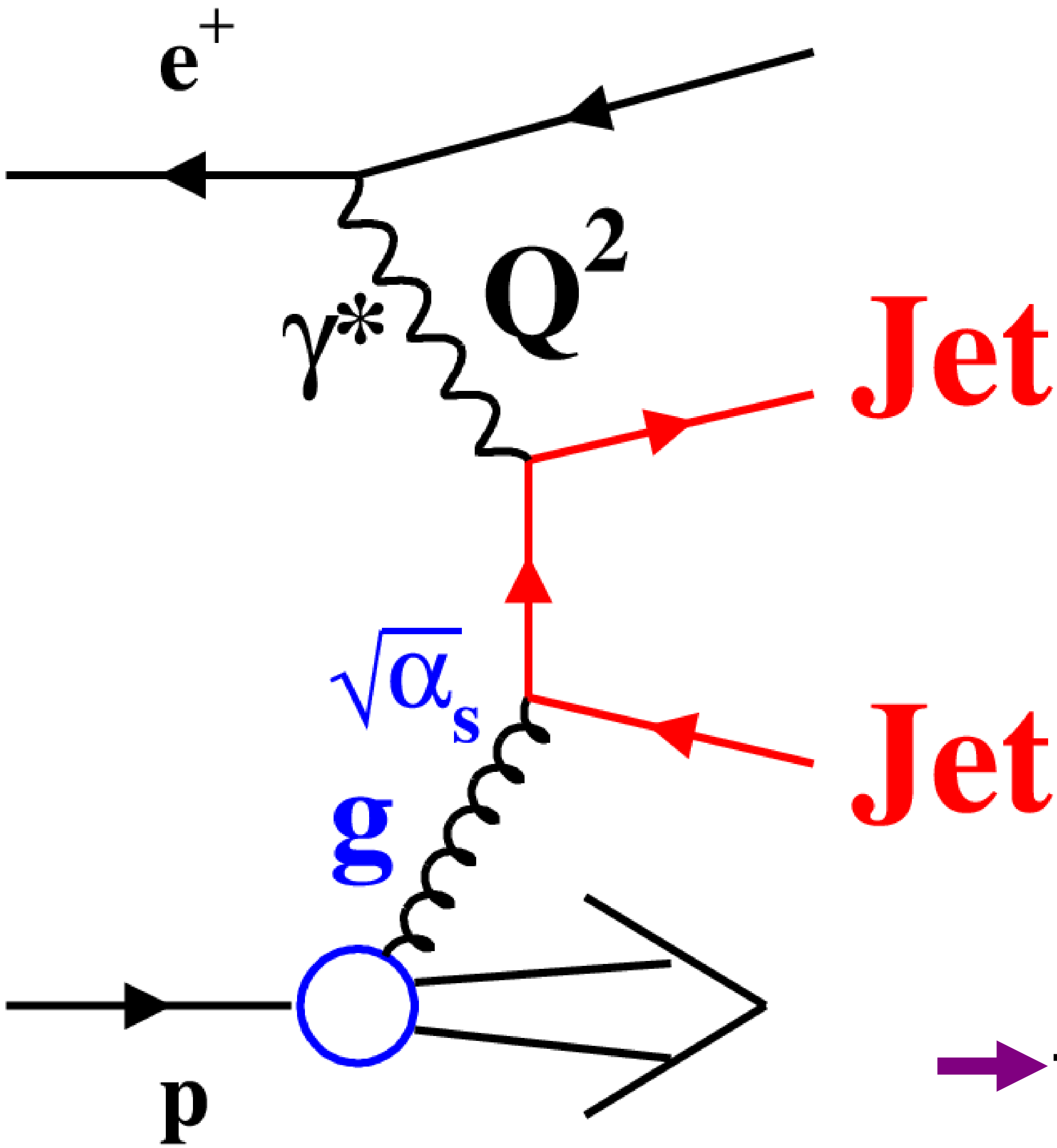
* acceptance for scenario B has been taken to be: $10 < \theta < 170^{o}$

Discussion on pdfs

- LHeC is clearly a wonderful toy for such physics
- Comparisons here with Hera only, better to compare with fits including present non-DIS data as well
- More flexible parameterization shown by Voica, may need further investigation
- NNPDF might cover the last two topics to give us even more confidence (a last effort, please!)
- LHC will have important effects on pdfs, but depth and uniqueness of LHeC are undisputable

2. Jets

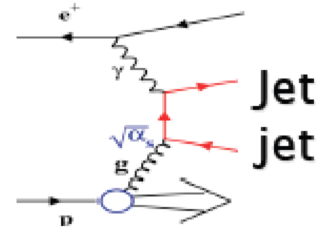
$O(\alpha_s)$ processes: Jets



sensitive to g(x) and α_s

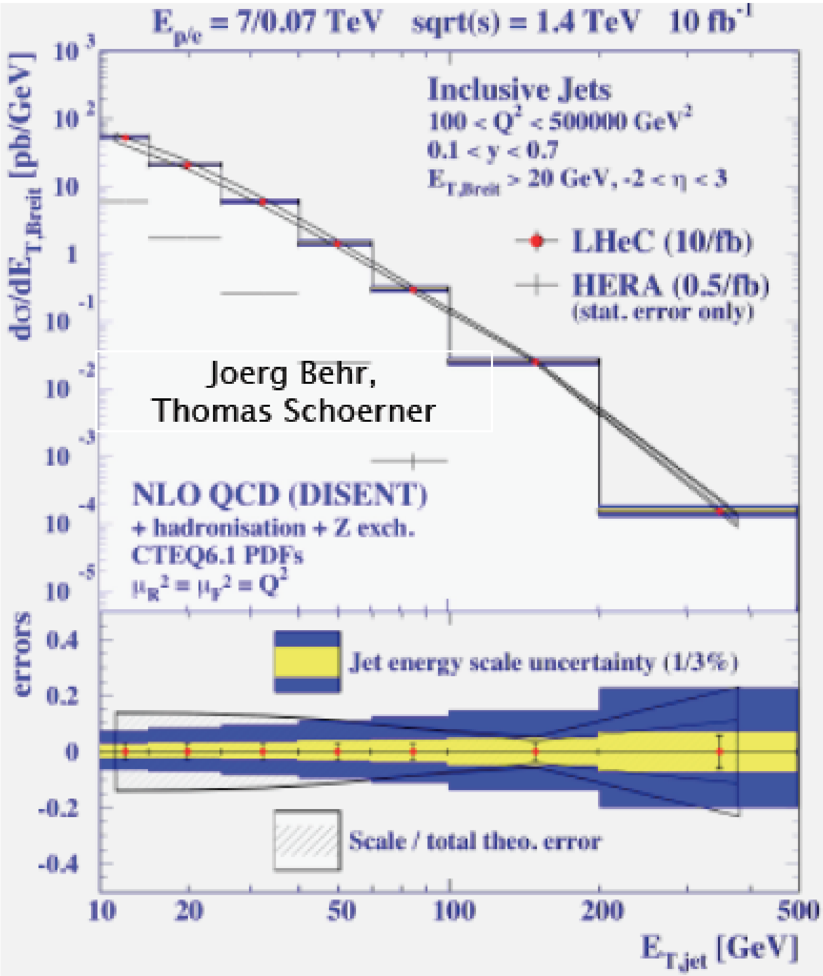
→ fundamental test of pQCD

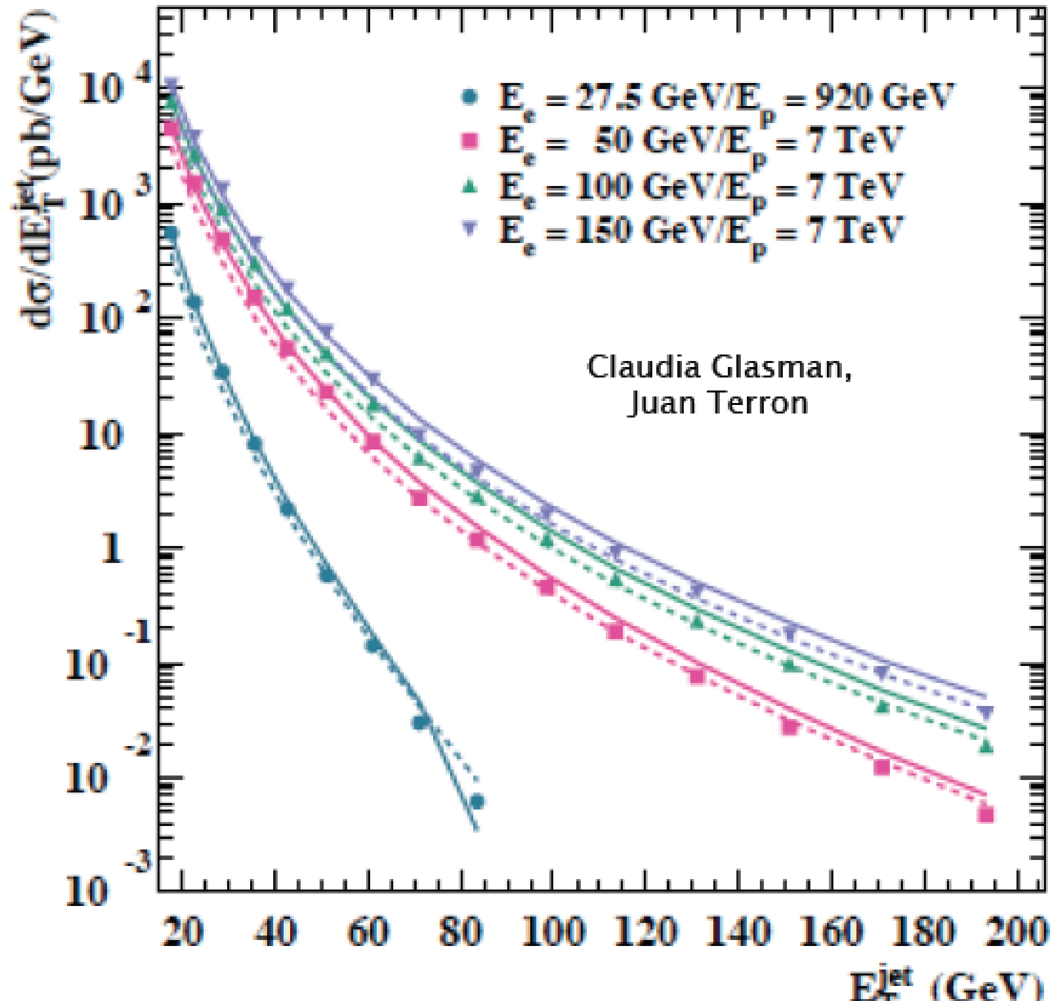
Jet production



DIS

Photoproduction





Reach scales up to $2m_{top}$ where change of $1/\alpha_s$ slope is expected

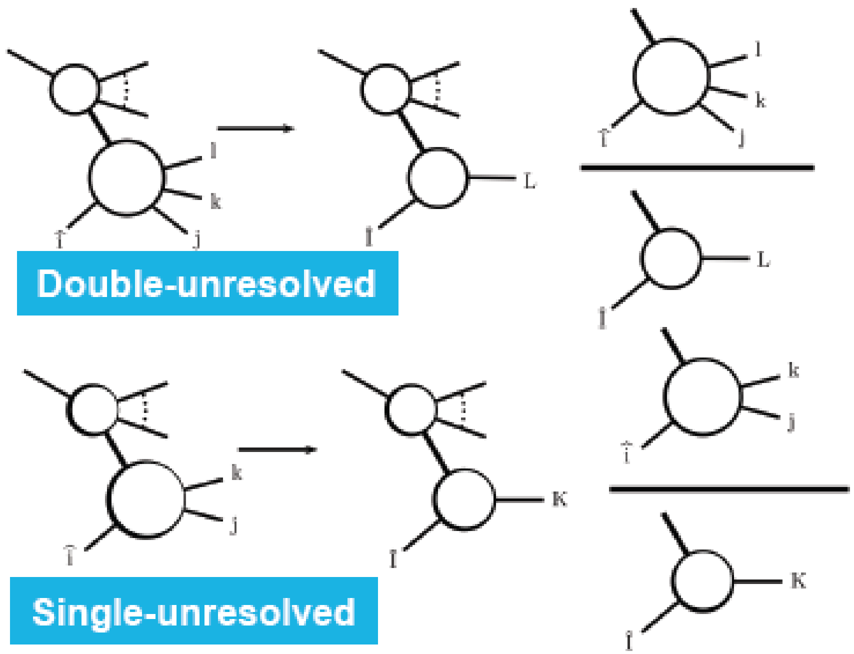
NNLO THEORY (T. Gehrmann et al.)

- NNLO calculations are ongoing. Matrix elements are either
  - already derived (NLO corrections to 3-jet production in DIS, Z. Nagy, NLOJET++) or
  - Contained in work by Gehrmann/Glover (for the two-loop 2-parton final state).

PLB676(2009)146

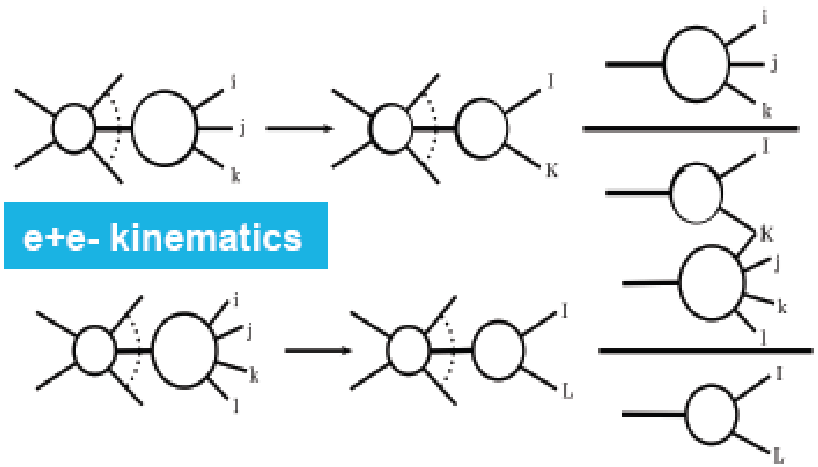
- Required: subtraction method!
  - Gehrmann et al.: antenna subtraction method (for DIS).

JHEP0704*2007)016
JEHP1001(2010)118



Double-unresolved

Single-unresolved

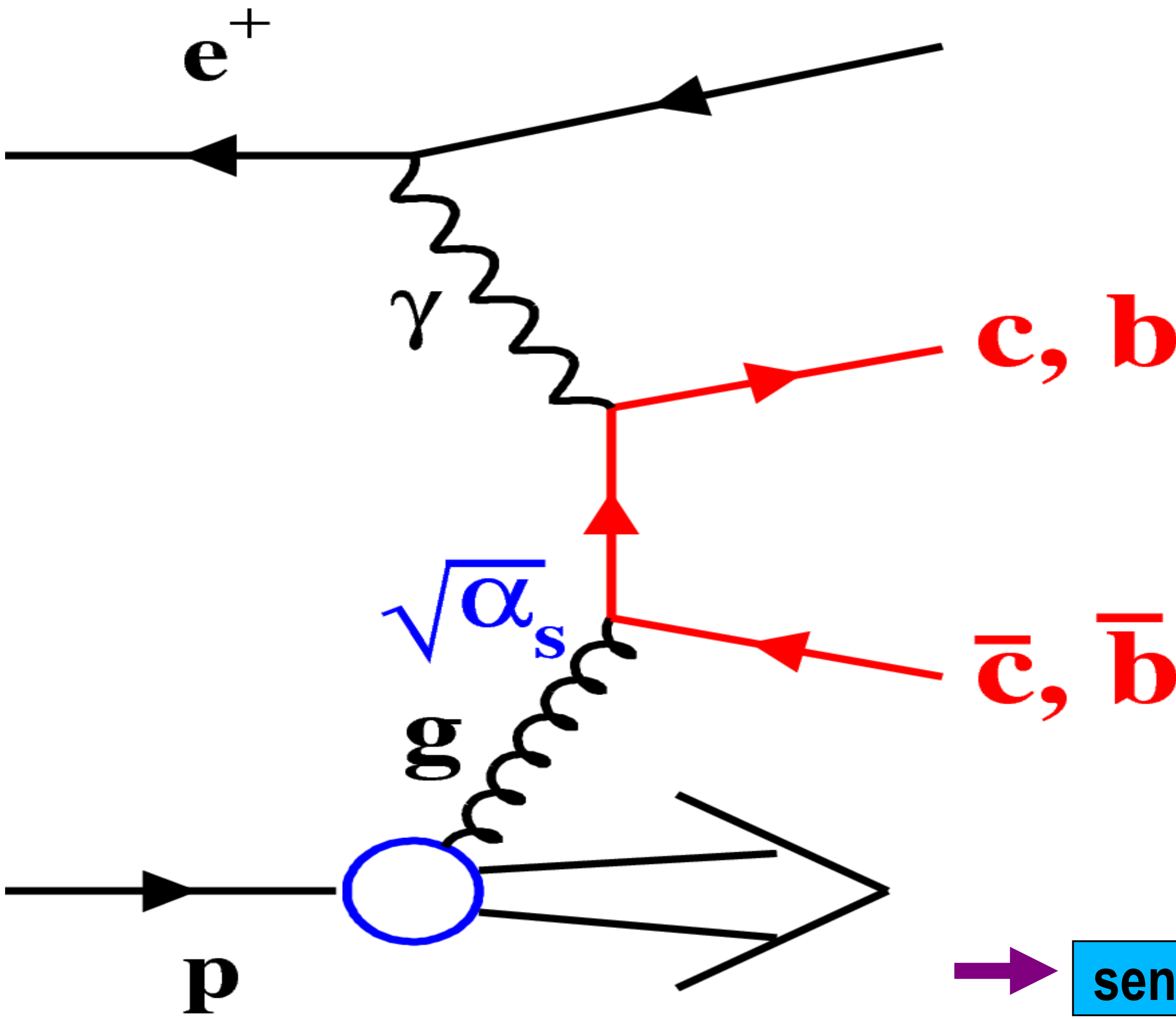


e+e- kinematics

- Currently implementing method into program for DIS jet production.

3. Heavy flavors

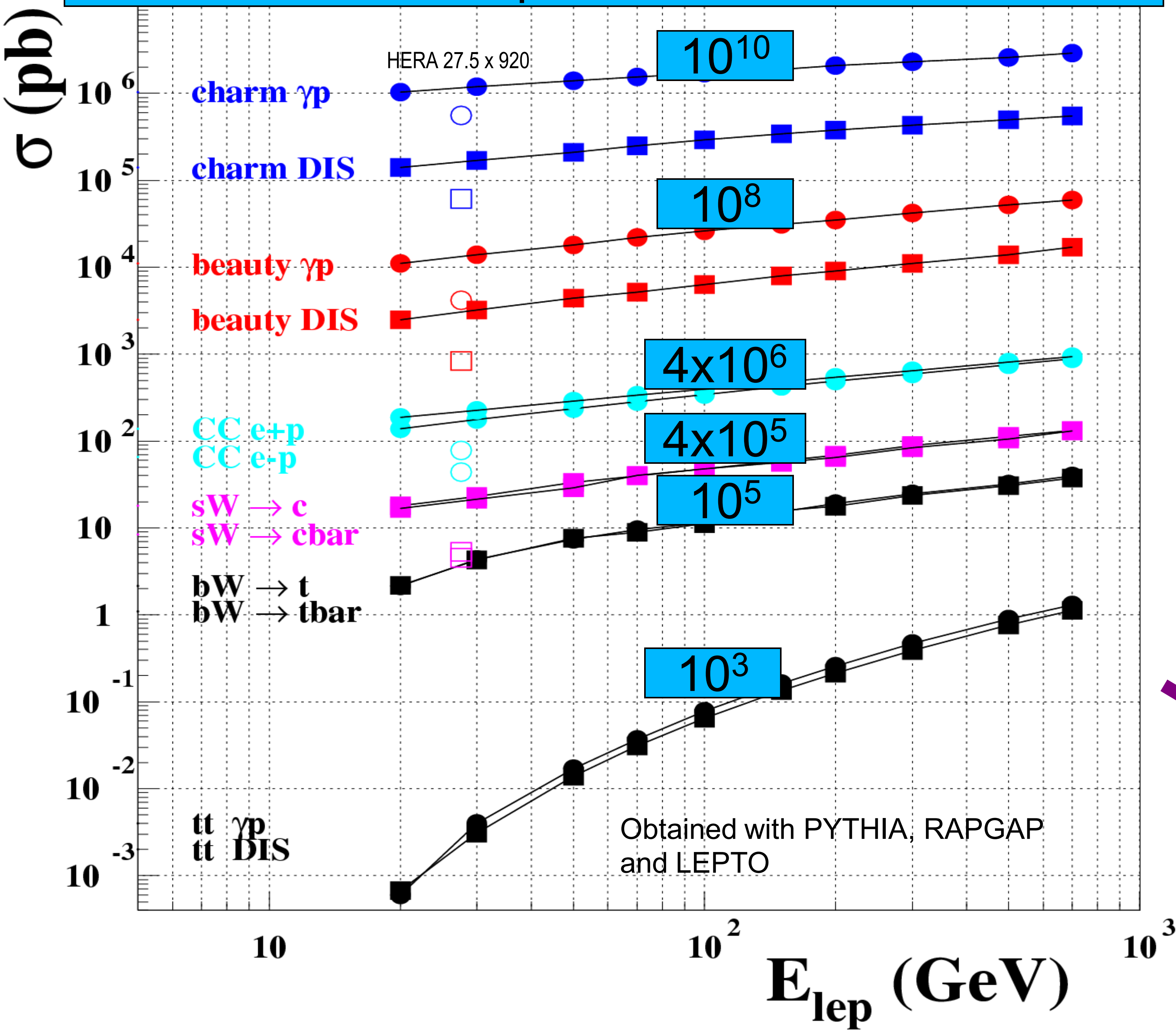
$O(\alpha_s)$ processes: charm & beauty



sensitive to g(x) and α_s

Events per 10 fb-1 Lumi

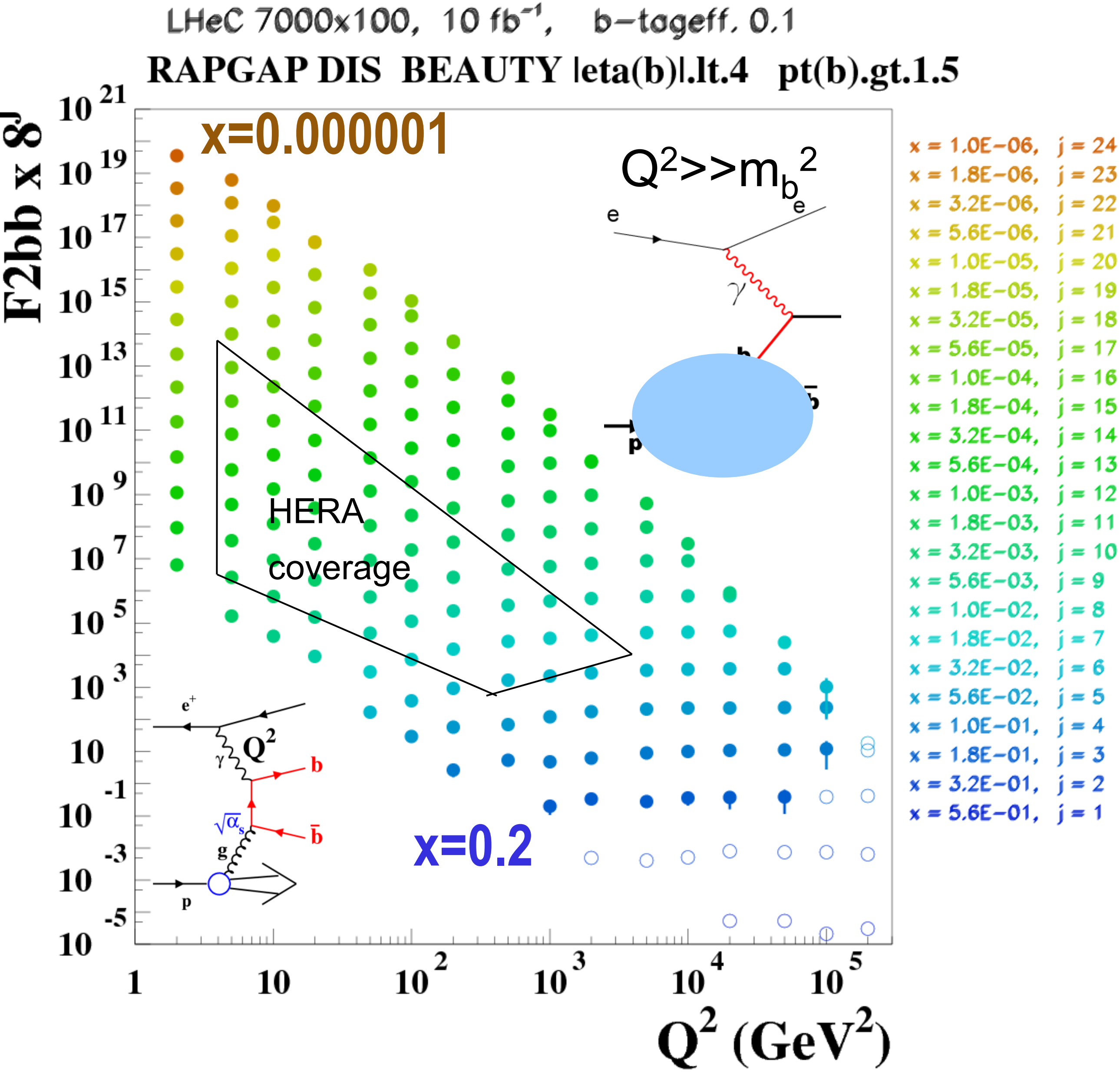
O.B.

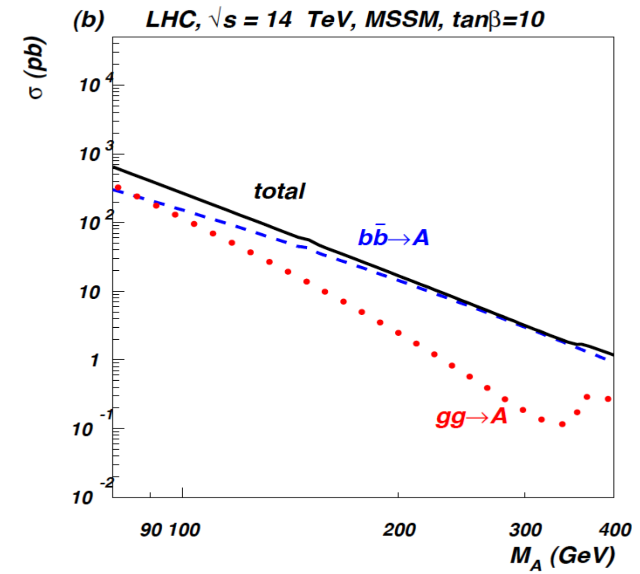


LHeC is a flavour factory

O.Behnke

Beauty in DIS





In MSSM Higgs production is b dominated

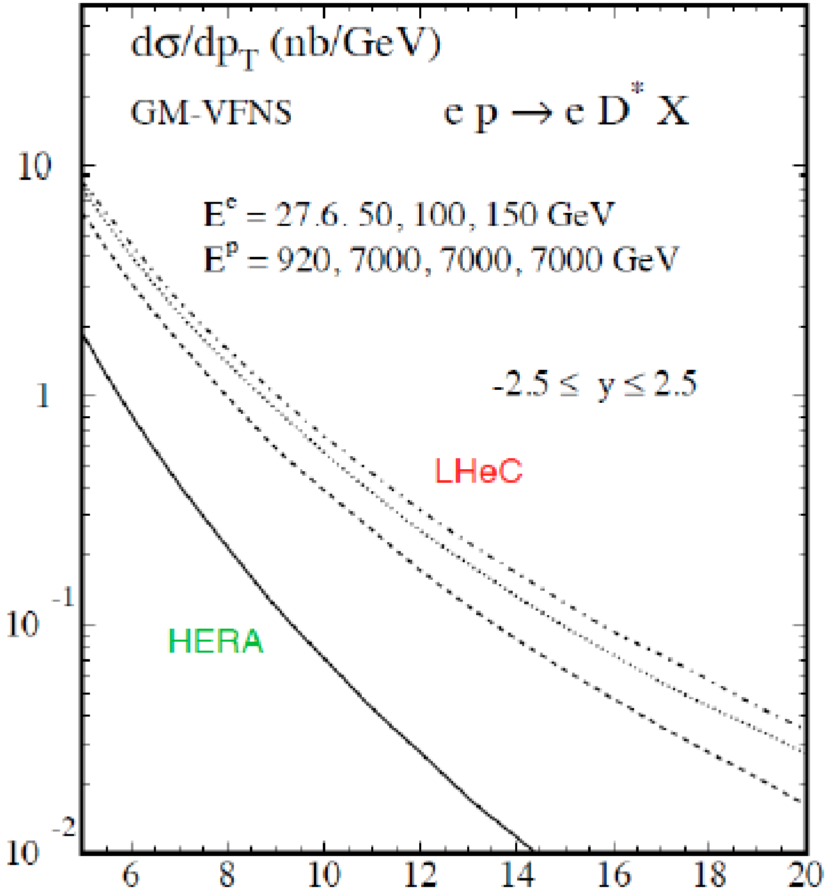
LHeC F2bb measurements can be used to determine precise b density in the proton

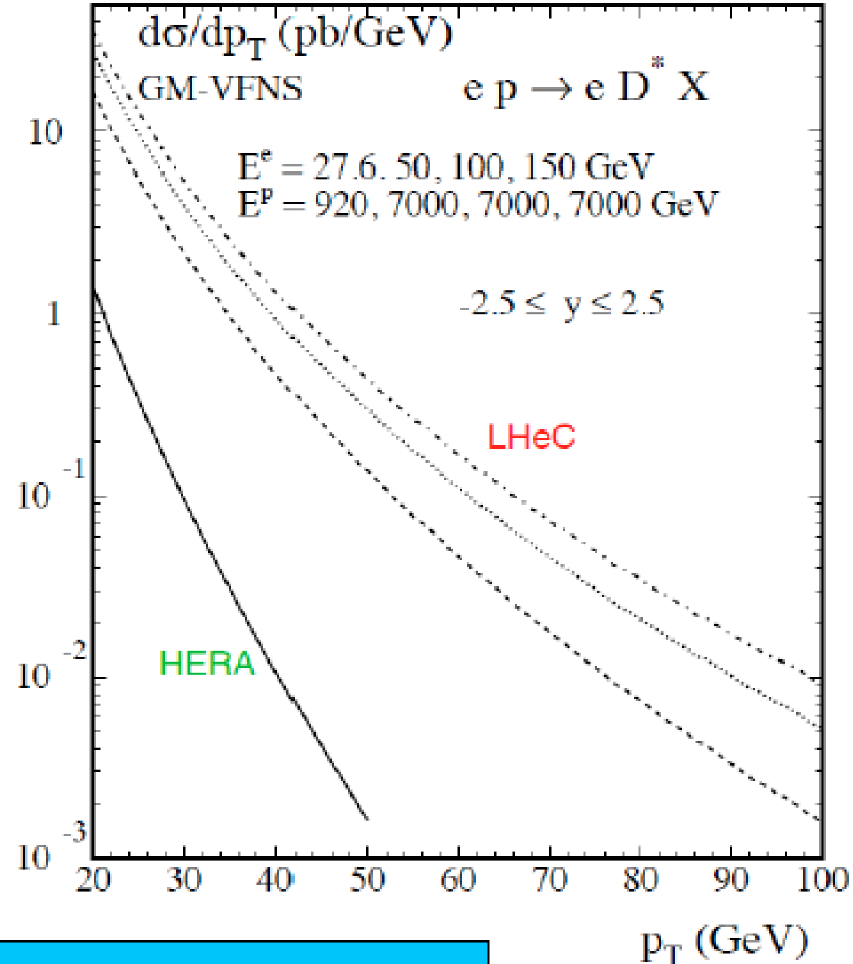
Competition from LHC: b+Z production also sensitive to b(x,Q2)

Also for **charm**: F_2^{cc} will become precision testing ground for QCD and proton structure

Inclusive photoproduction of D* mesons at LHeC

Gustav Kramer,
Hubert Spiesberger





→ **Can be studied at LHeC over very large pt range**

Test of applicability of different mass schemes for charm production

4. Electroweak physics

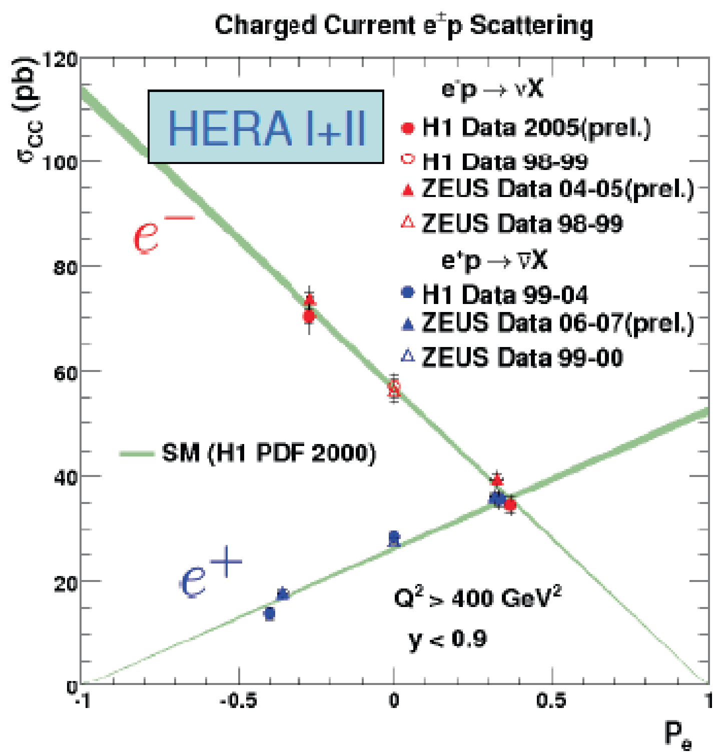
Electroweak physics @ HERA

Polarized CC cross section

In the SM the charged current is purely LH

$$P_e = \frac{N_R - N_L}{N_R + N_L} \qquad \sigma^{\pm}_{CC}(P_e) = (1 \pm P_e)\sigma^{\pm}_{CC}(P_e = 0)$$

linear dependence on P_e



Limits on W_R

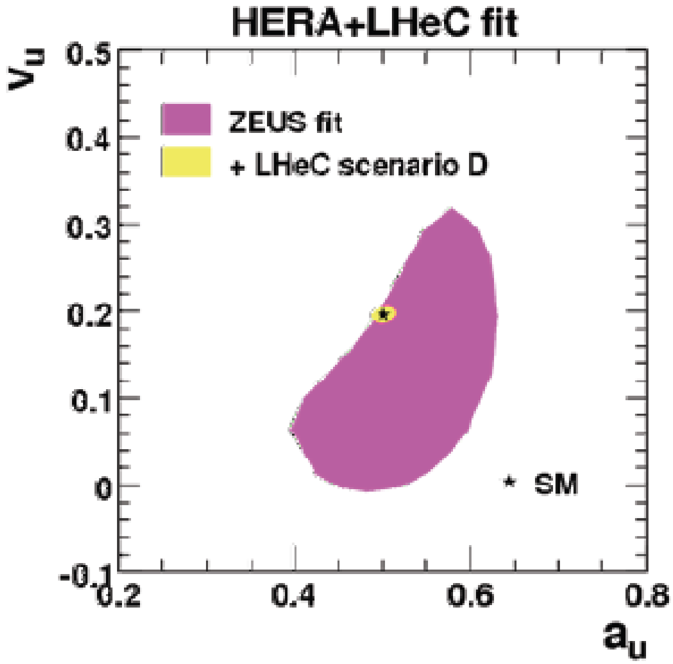
$$M_{W_R} > 208 \ @ \ 95\ \%\ \text{C.L.}$$

These constraints on RH currents will become much stronger at LHeC, and start competing with low energy ones. *They are independent of PDFs*

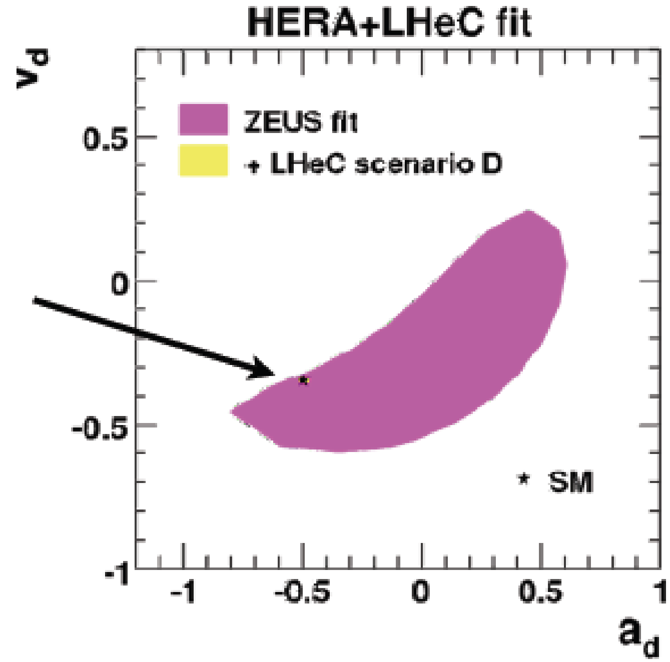
LHeC scenario D

comparison with **ZEUS fit** (base to which LHeC pseudo-data added)

» still to come: HERA-II NC e^+p data in ZEUS fit; **H1+ZEUS combined HERA-II** results



u-type quark couplings

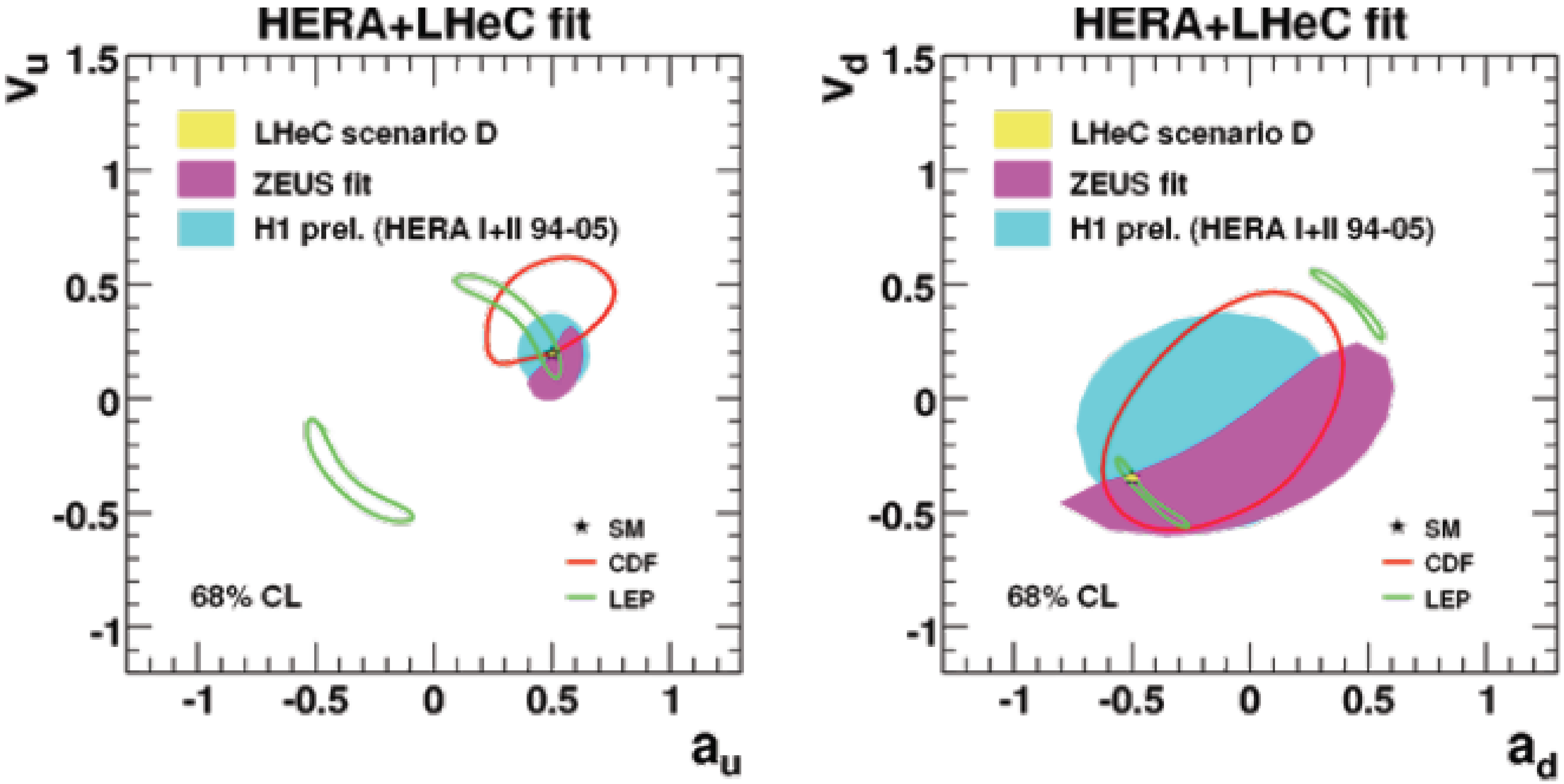


d-type quark couplings

LHeC scenario D

comparison with other experiments

» still to come: HERA-II NC $e^{+}p$ data in **ZEUS fit**; **H1+ZEUS combined HERA-II** results



By itself, a better determination of quark NC couplings will constrain some exotic scenarios that modify *only* light quark couplings (non-universal Z', R-parity violating susy) After LHC?

Summary

DIS: great opportunities for higher precision in gluon, flavor decomposition, s/sbar, α_s

Jets: very interesting pQCD tests, theoretical developments (NNLO closer) will allow precise α_s

Electroweak physics: NC couplings of the quarks can be measured to ~1%.