Precision QCD and electroweak physics at the LheC

LHeC workshop 2009, 3 Sep 2009, Divonne Les Bains

Olaf Behnke, Claire Gwenlan,
Paolo Gambino, Thomas Gehrmann

Need for LHeC

27.5 GeV x 920 GeV ep HERA

with integrated L~0.5 fb^{-1} was a

- high precision machine for QCD
- modest precision machine for electroweak physics

Where could we go with a

20-150 GeV x 7 TeV ep LHeC

with integrated L~1-10 fb^{-1} ?

Precision QCD & electroweak physics at LHeC

Observables:	Targets:	Talks:
Incl. NC and CC	**u_v, d_v, Sea, gluon**	Max Klein
	Elweak: a_u, v_u, a_d, v_d , M_w	Claire Gwenlan, Paolo Gambino Soumitra Nandi
	Effect of LHeC pdfs on LHC Higgs	Alessandro Vicini
	α_s	Thomas Kluge
Jet production	**gluon; γ structure, α_s**	Joerg Behr, Claudia Glasman
Charm production	**gluon, intrinsic charm**	Goekhan Uenel
Beauty production	**effective b density in p**	O.B.
sW → c	**strange density in p**	
bW ->t	**Single top production**	

Theory development: SHERA Programme (e.g. bW->t) Stefan Hoeche

+ other final state topics not yet covered , e.g. prompt photons

Simulated Default Scenarios, April 2009

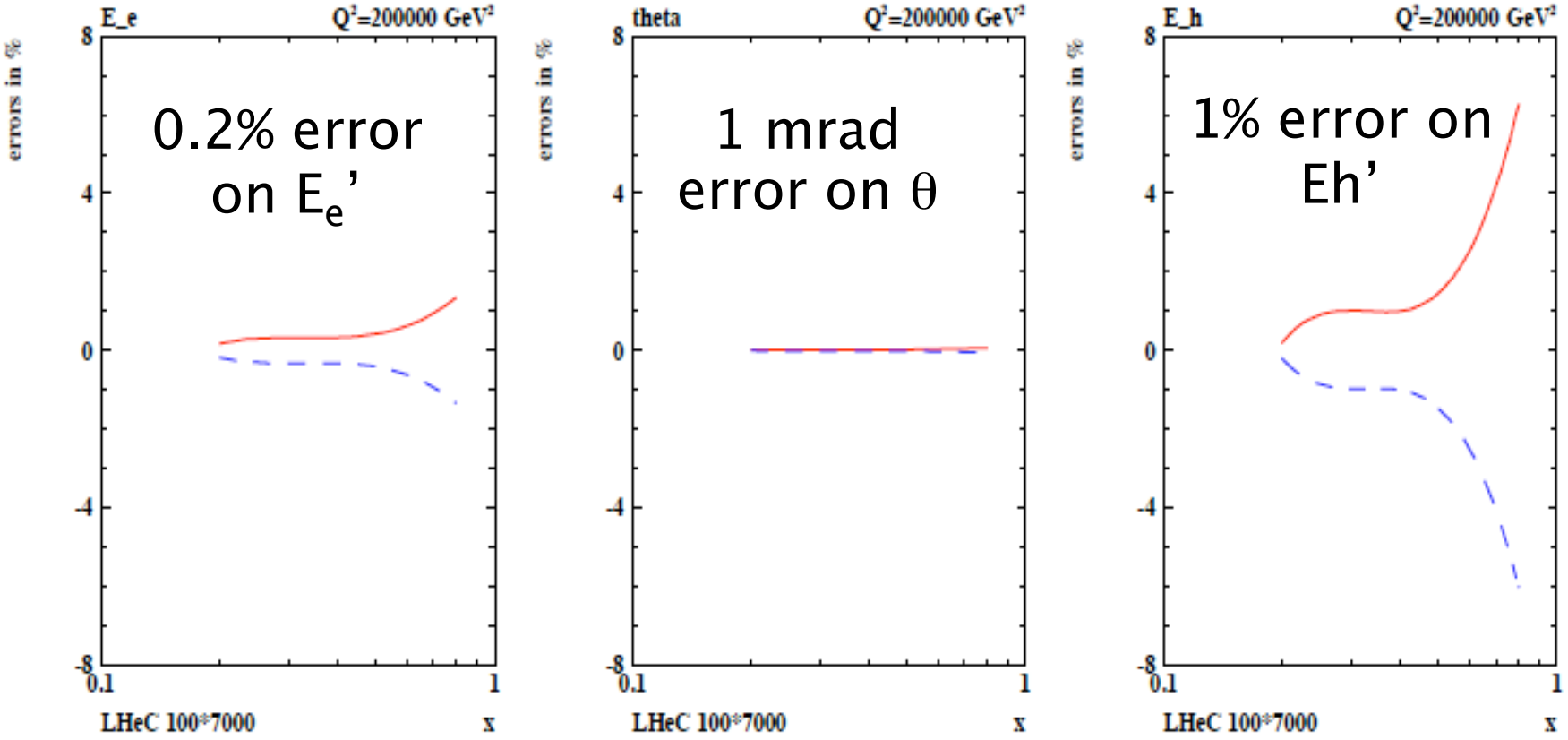
http://hep.ph.liv.ac.uk/~mklein/simdis09/lhecsim.Dmp.CC, readfirst

Max Klein, LHeC

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 hiQ^2
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

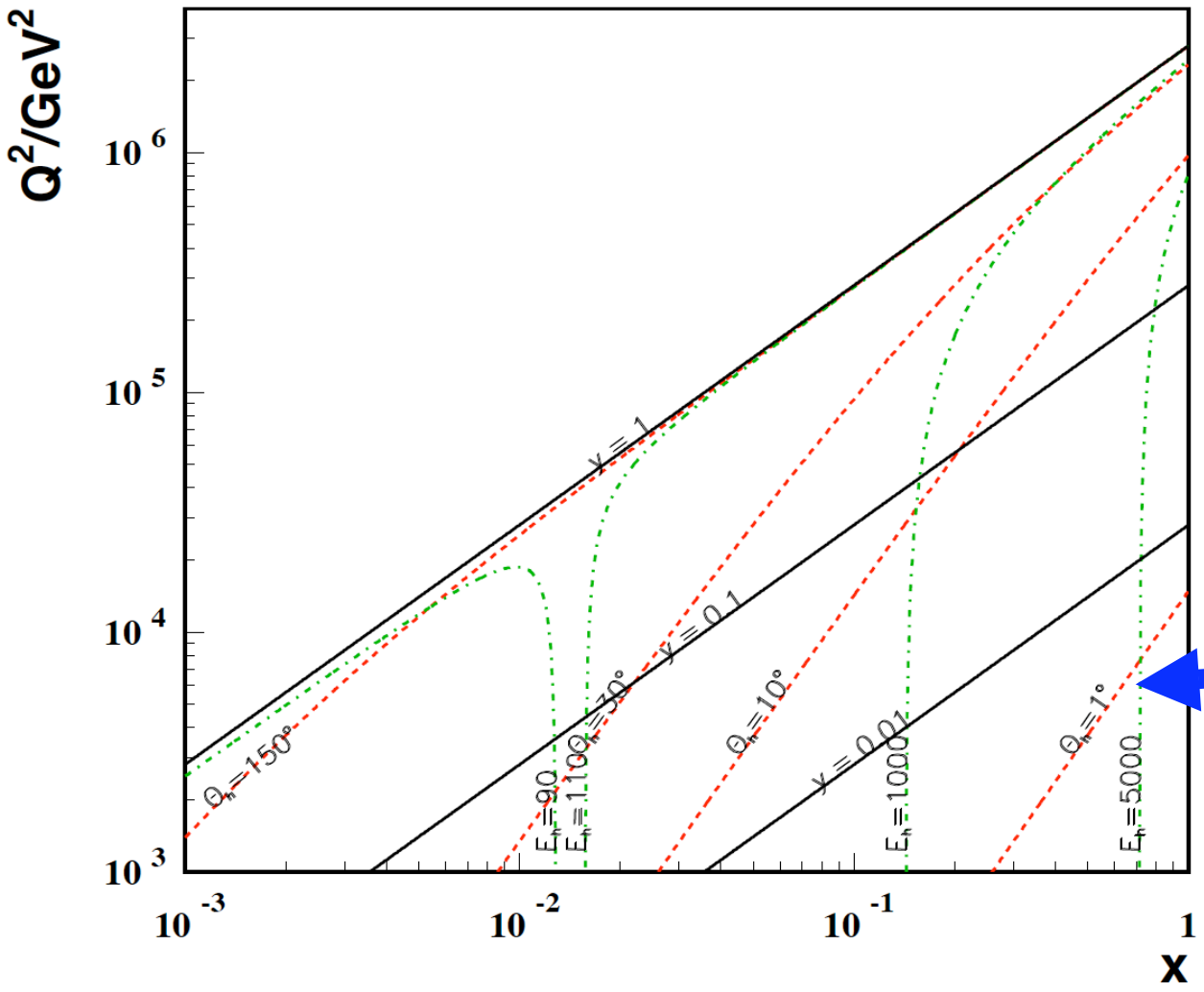
Not simulated

Systematic error calculation for inclusive NC & CC pseudodata: assumed uncertainties and effects on xsecs



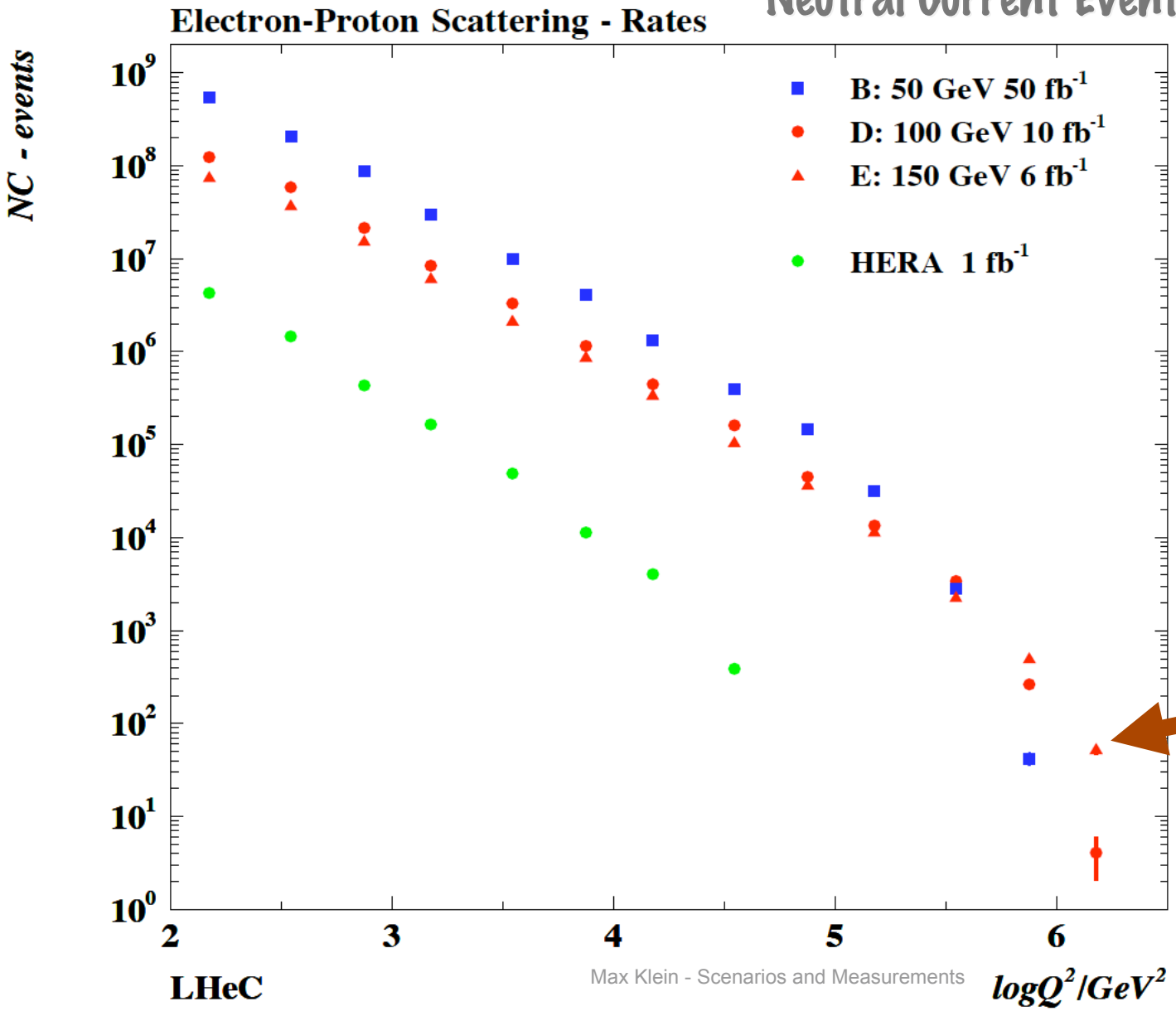
→ At high Q^2: Need <=1% hadronic energy scale uncertainty at very large E_h

Kinematics – high Q^2



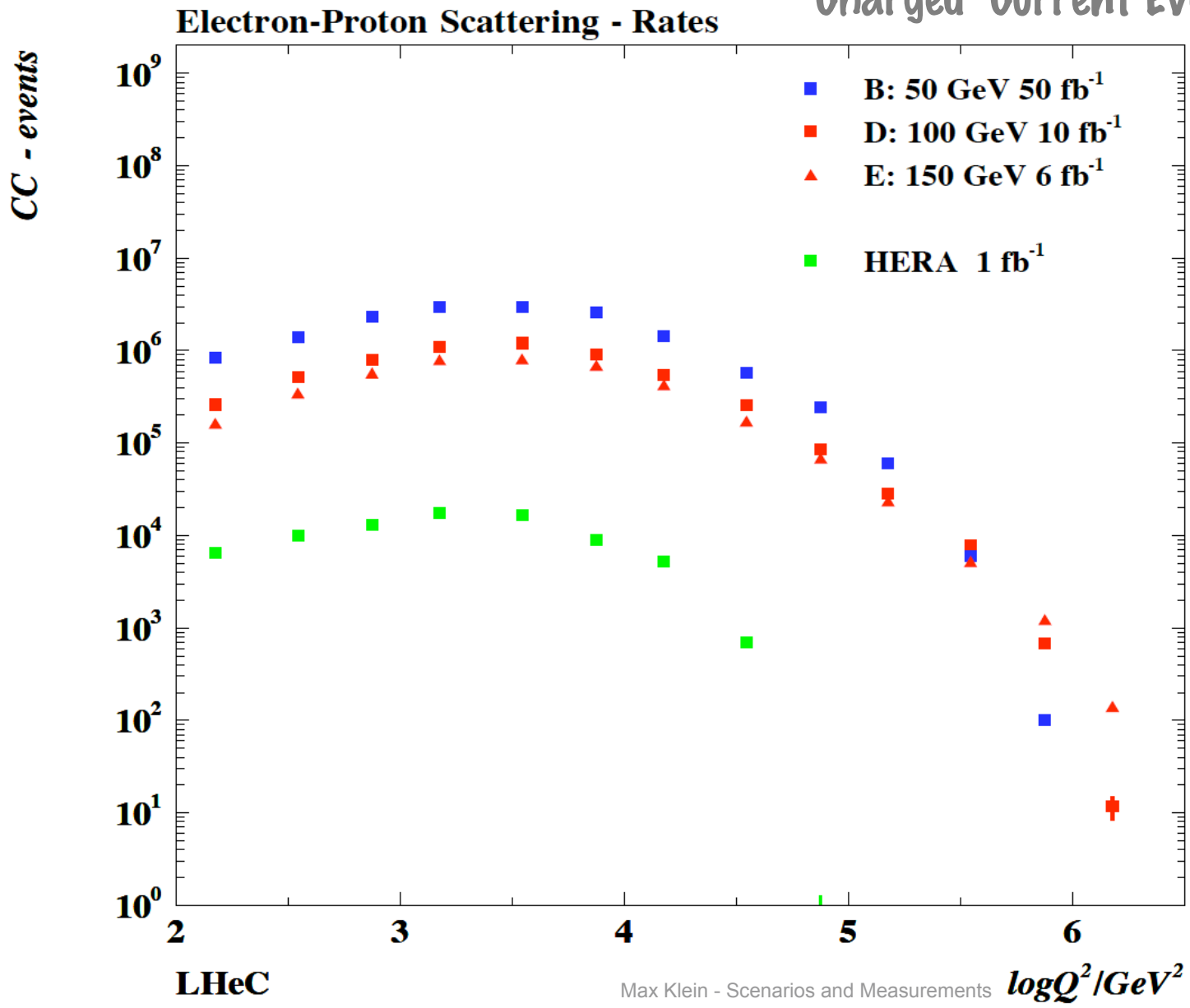
Need excellent forward hadron calorimetry & calibration

Neutral Current Event Rates



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

Charged Current Event Rates



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

NLO QCD and electroweak fit

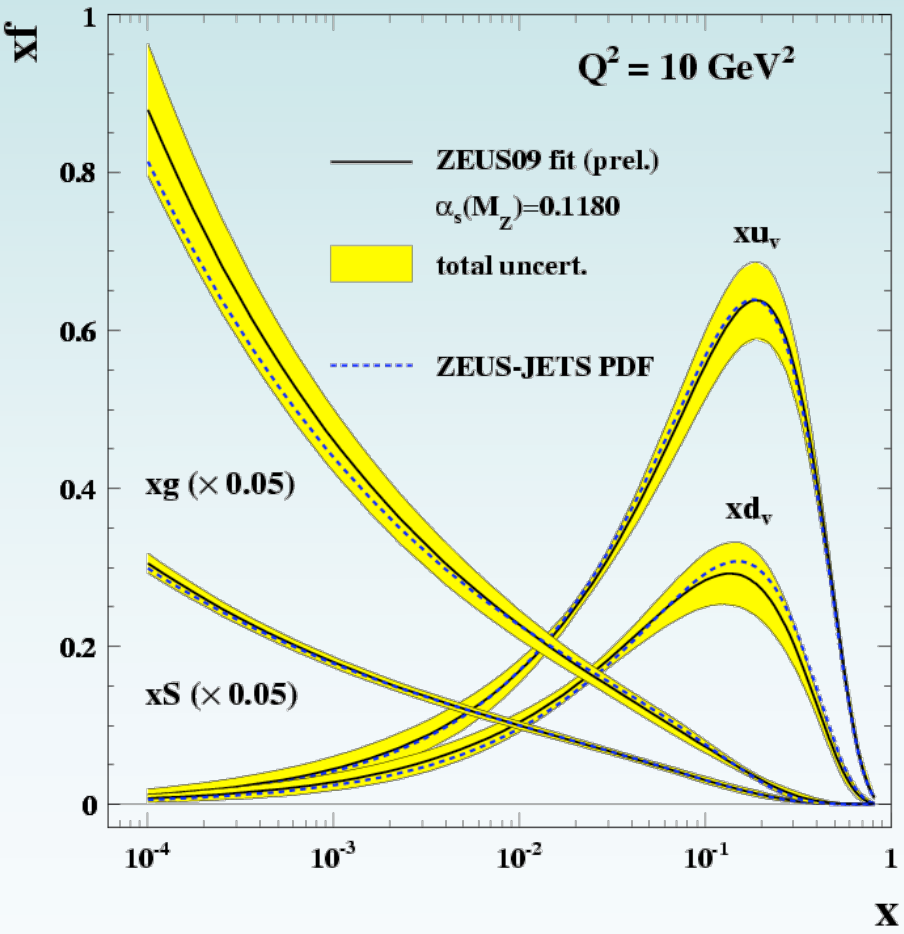
Claire Gwenlan

Study presented here is based on new **ZEUS NLO QCD fit** to HERA-I and HERA-II data

LHeC NC/CC simulated data added to this in a **combined fit** for the PDFs and electroweak parameters

Making use of Max pseudodata

ZEUS09 fit (c.f. central values of HERA-I fit)



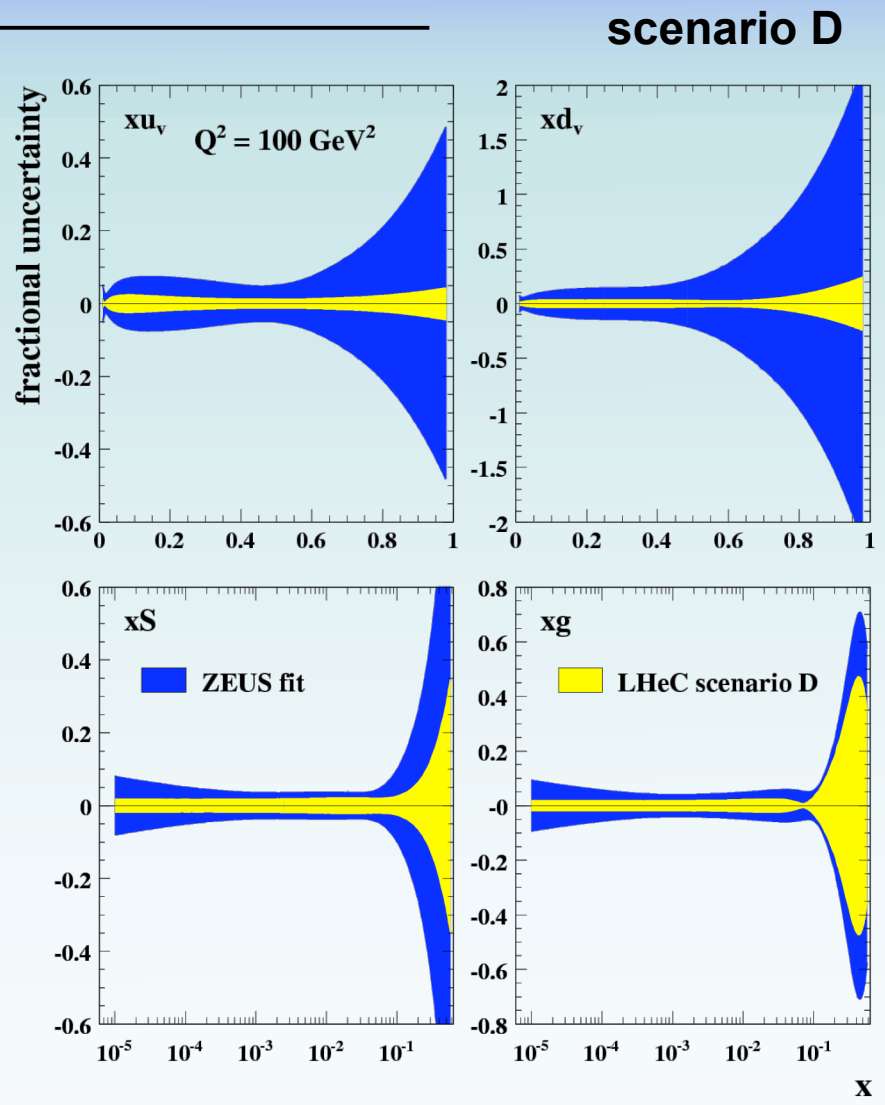
Proton PDFs

Claire Gwenlan

$Q^2 = 100\ GeV^2$

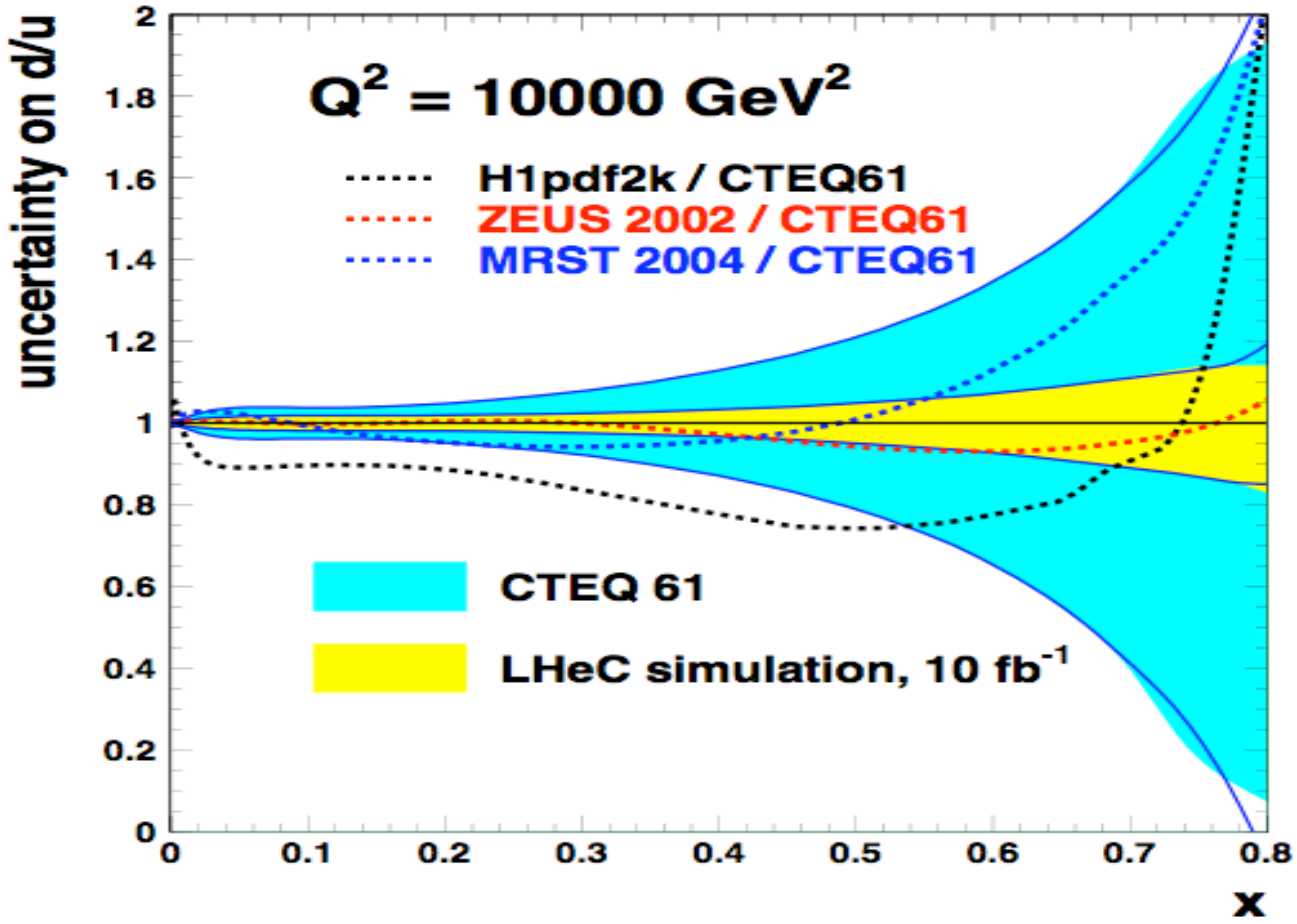
» only PDF parameters free (LHeC **NC** and **CC** $e^{\pm}p$ included)

Looks very promising, model and parameterisation uncertainties to be studied



PDF fits to expected LHeC data

previous assessment by Emmanuelle Perez



Example: u/d ratio

In general reasonable agreement between Claire's & Emmanuelle's PDF fits

electroweak parameters

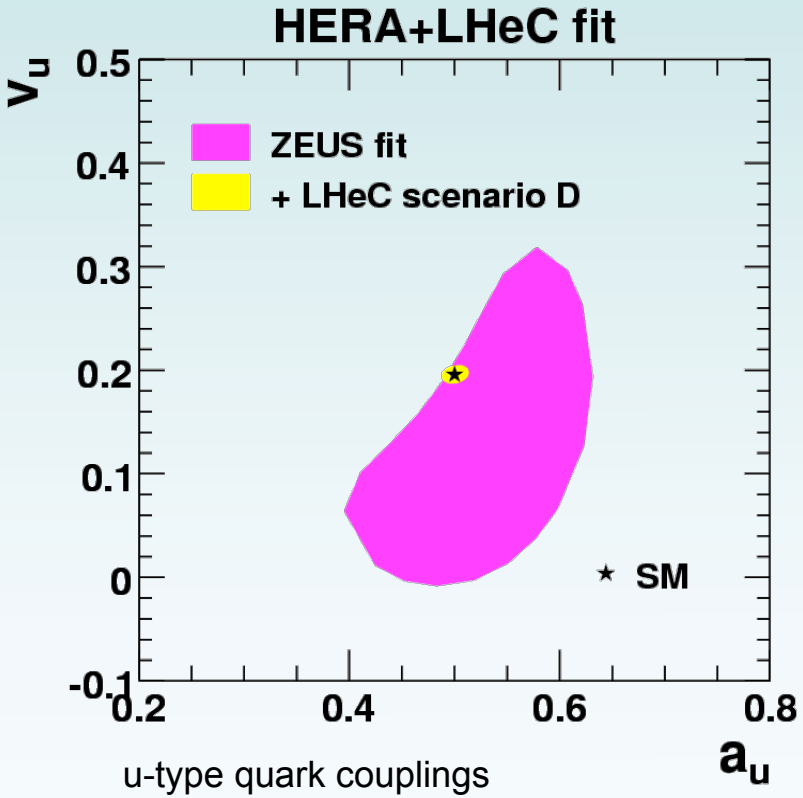
» fit with PDF and electroweak parameters simultaneously free

- neutral current axial and vector quark couplings (a_u, v_u, a_d, v_d)
- mass of the W boson

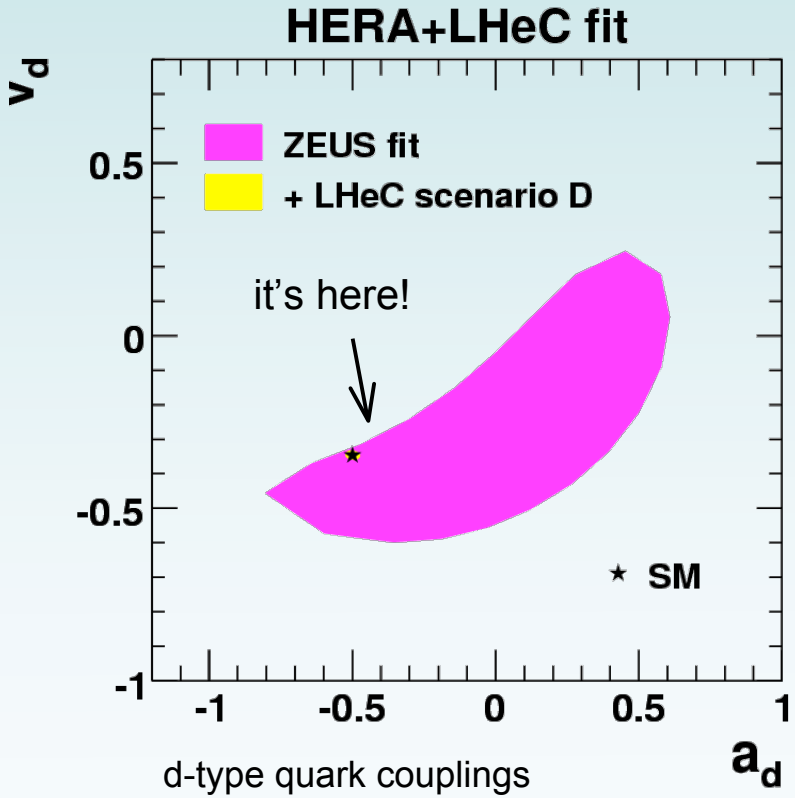
neutral current quark couplings

scenario D:
$P_e = \pm 0.9$

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



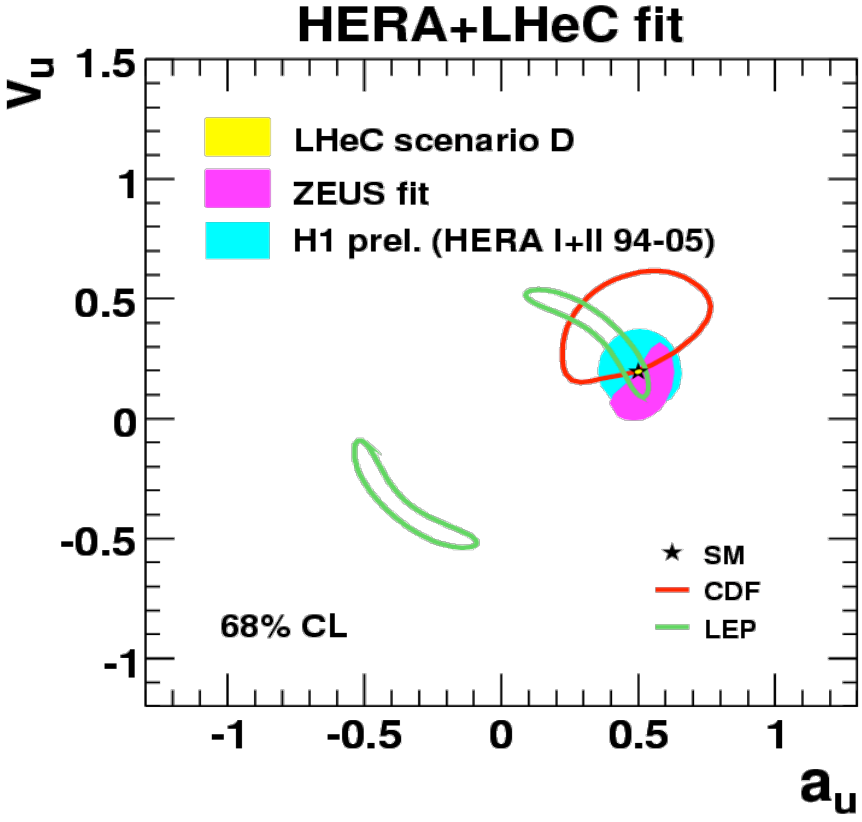
u-type quark couplings

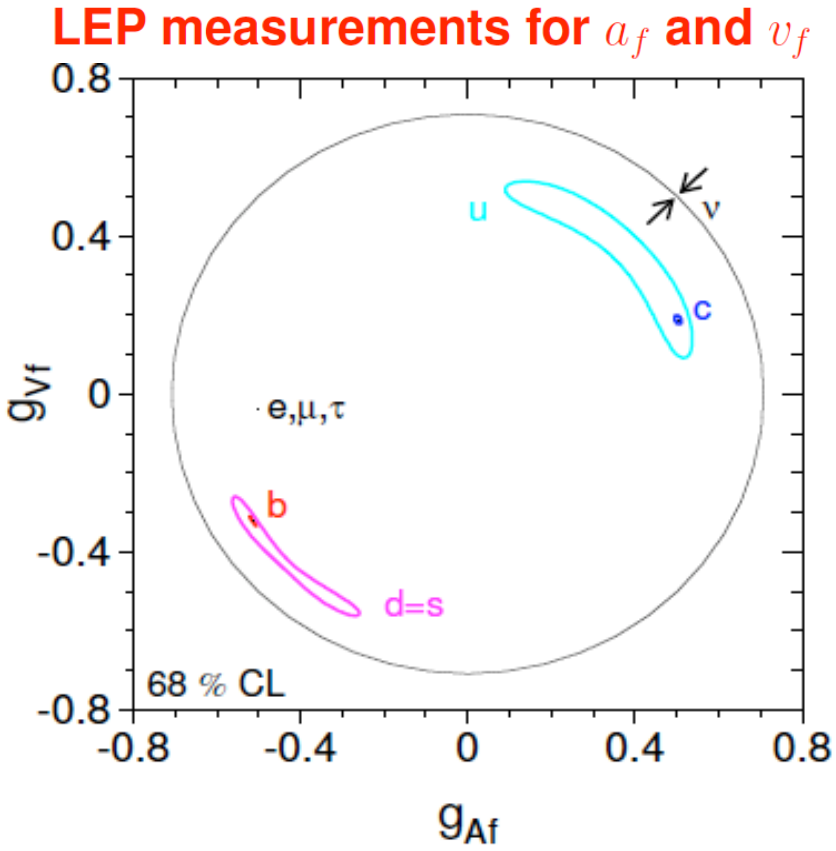


d-type quark couplings

Fermion couplings to Z boson

Soumitra Nandi.

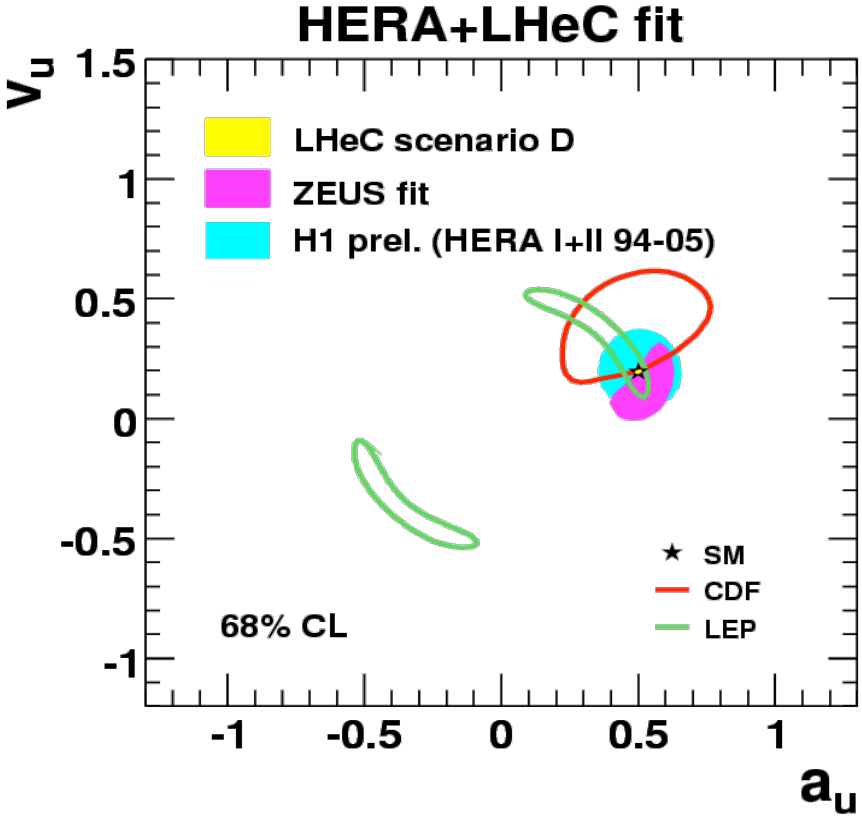


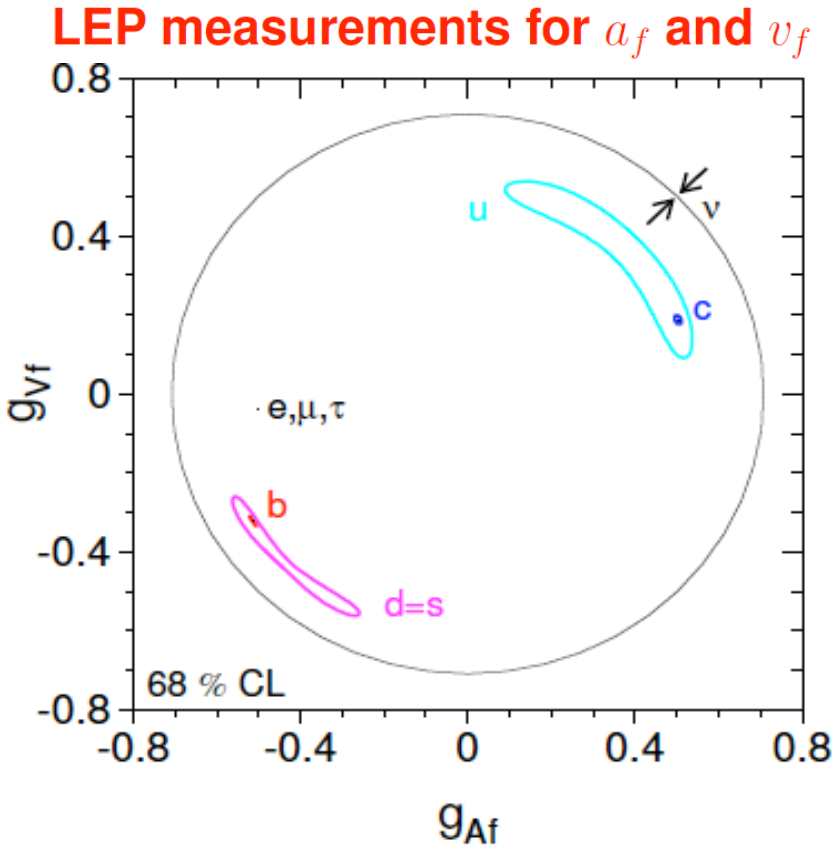


LHeC (and HERA) especially sensitive to u and d couplings: expect deviations from SM for these couplings e.g in Leptophobic Z' models

Fermion couplings to Z boson

Soumitra Nandi.





General suggestion (Paolo Gambino) for LHeC electroweak studies: Try fit with $\sin^2(\theta_w)$ as only free parameter; determination as function of hard scale also interesting

W boson mass

M_W enters the fit through the **propagator** in the CC cross sections:

$$\frac{G_F^2 M_W^4}{(Q^2 + M_W^2)^2}$$

➔ also performed fit including LHeC CC, **with M_W free**, together with the PDFs (NC quark couplings fixed to SM)

M_W (= 80.4 SM)

Scenario D

M_W = 80.40 ± 0.04 (uncorr.) ± 0.15 (corr.) GeV (total exp. 0.2%)

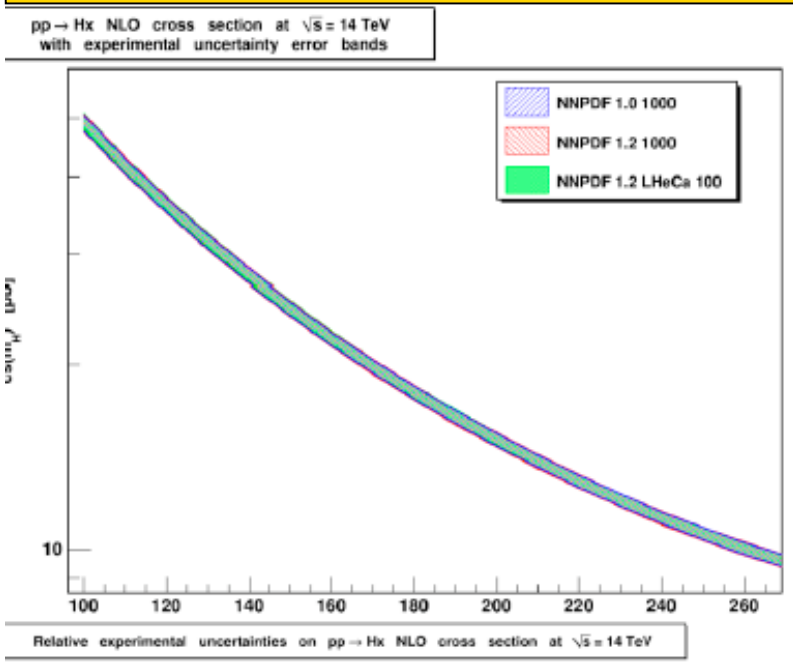
Improved (wrt HERA) but not competitive

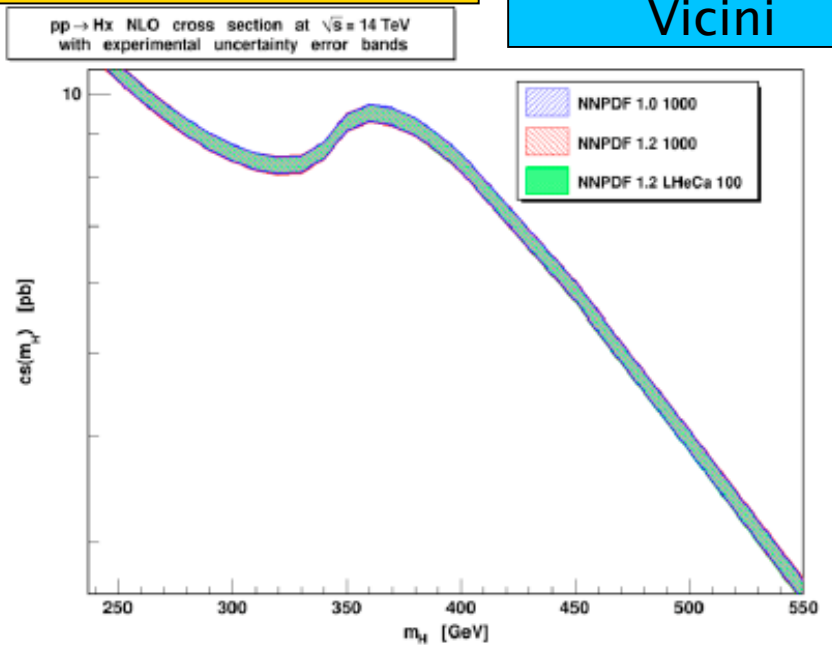
(although still interesting as a cross-check; space-like regime)

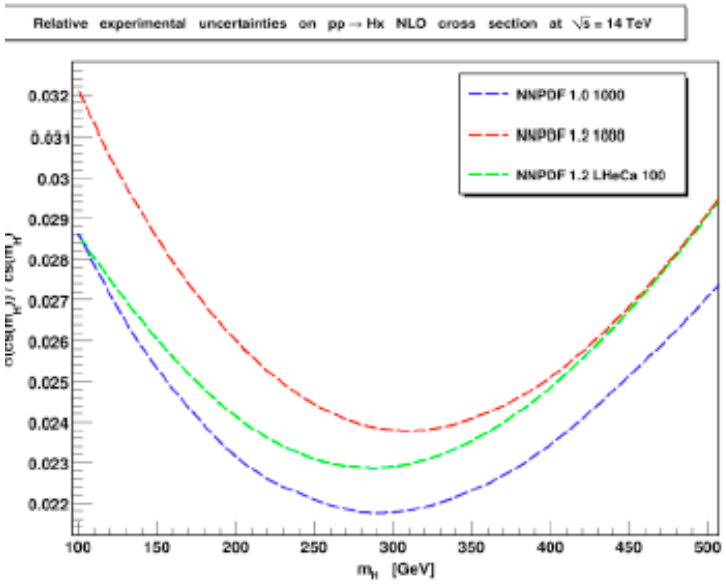
current world average (PDG 2008): M_W = 80.398 ± 0.025 GeV **(0.03% total)**

LHC Higgs production and improvement due to LHeC pdfs

Alessandro Vicini







Comparison of

NNPDF1.2 vs NNPDF1.2LHeC

Tiny improvement (0.3 %)

for small values of mH

Divonne, September 2nd 2009

Conclusions

Alessandro Vicini

- Tiny sensitivity of the inclusive gluon-fusion Higgs cross-section to the LHeC *pdf*s improvement in the small-*x* region

➔ the inclusion of all the LHeC pseudo-data (DIS-jets, F2c) reducing the uncertainty of the gluon density for medium-large *x* might lead to a more significant reduction of the cross-section uncertainty

- Lepton distributions in the charged-current Drell-Yan are sensitive to a larger range of *x* values

➔ they might benefit of the small-*x* LHeC improvement because of the important role of the sea quarks

To do:

- Include all the available LHeC pseudodata to repeat in a more complete form this exercise
- Study more exclusive Higgs distributions and/or include Higgs decay products
- Repeat the Drell-Yan analyses including QCD corrections consider e.g. the impact on the W mass measurement
- Repeat the analyses when NNPDF2.0 will become available

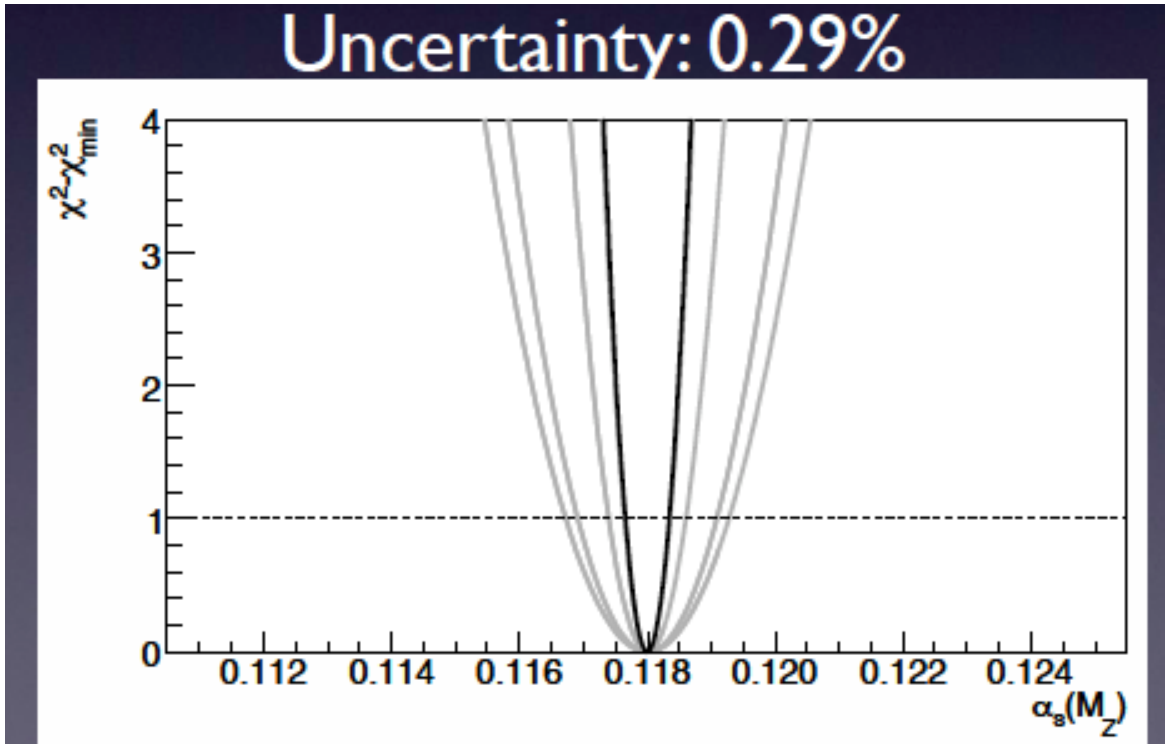
α_s from inclusive NC+CC

Thomas Kluge

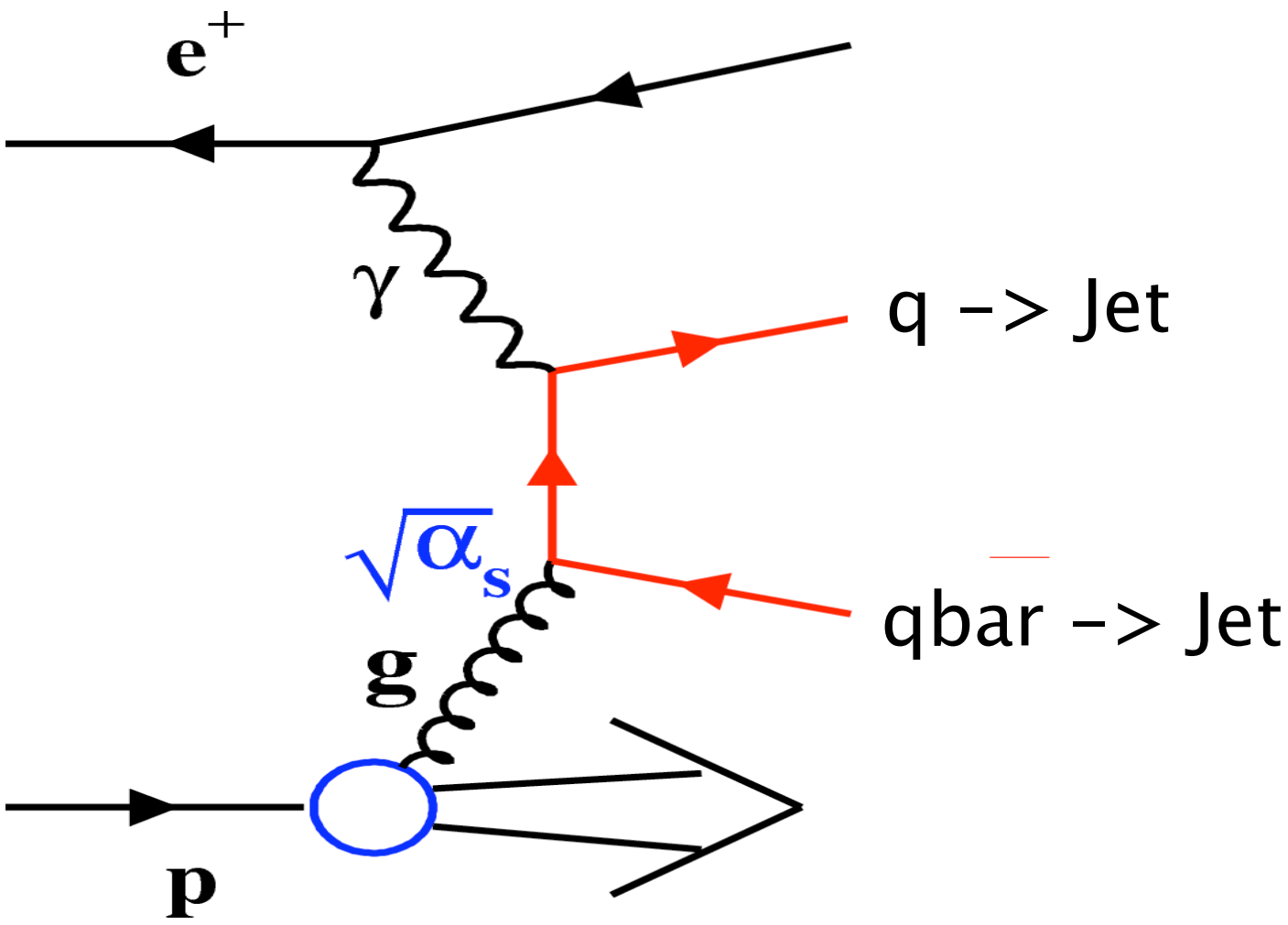
Sensitivity mainly from scaling violations of F2

config.	E(e)	E(N)	N	|L(e⁺)|	|L(e⁻)|	|Pol|	L/10³² 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 hiQ²
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

Fitting to Pseudodata B+C+F+H ->



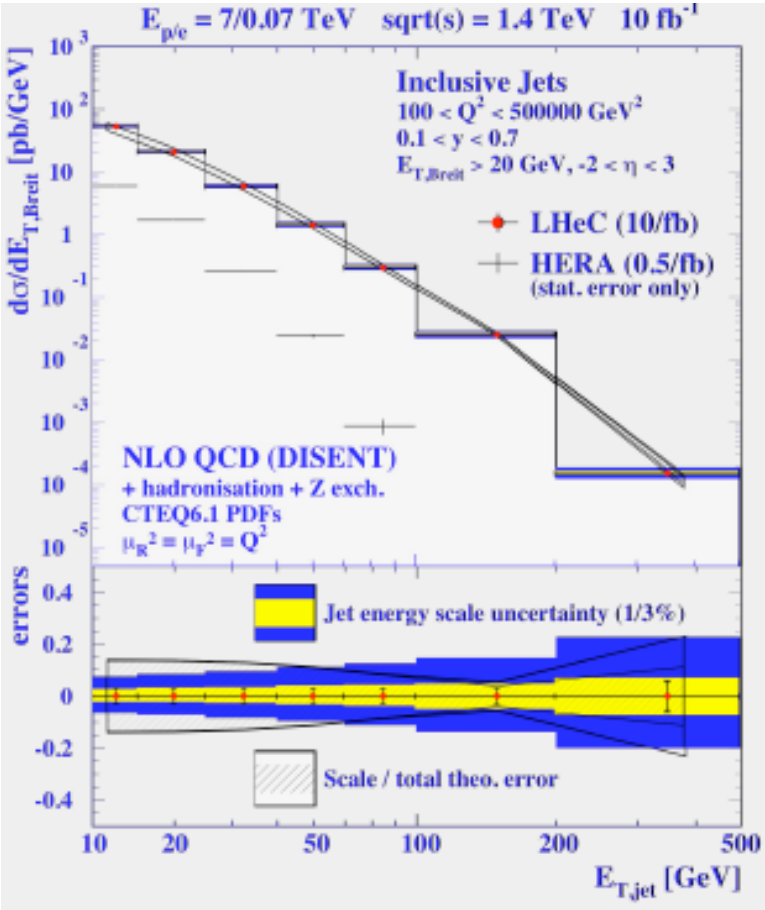
$O(\alpha_s)$ processes



Jet production

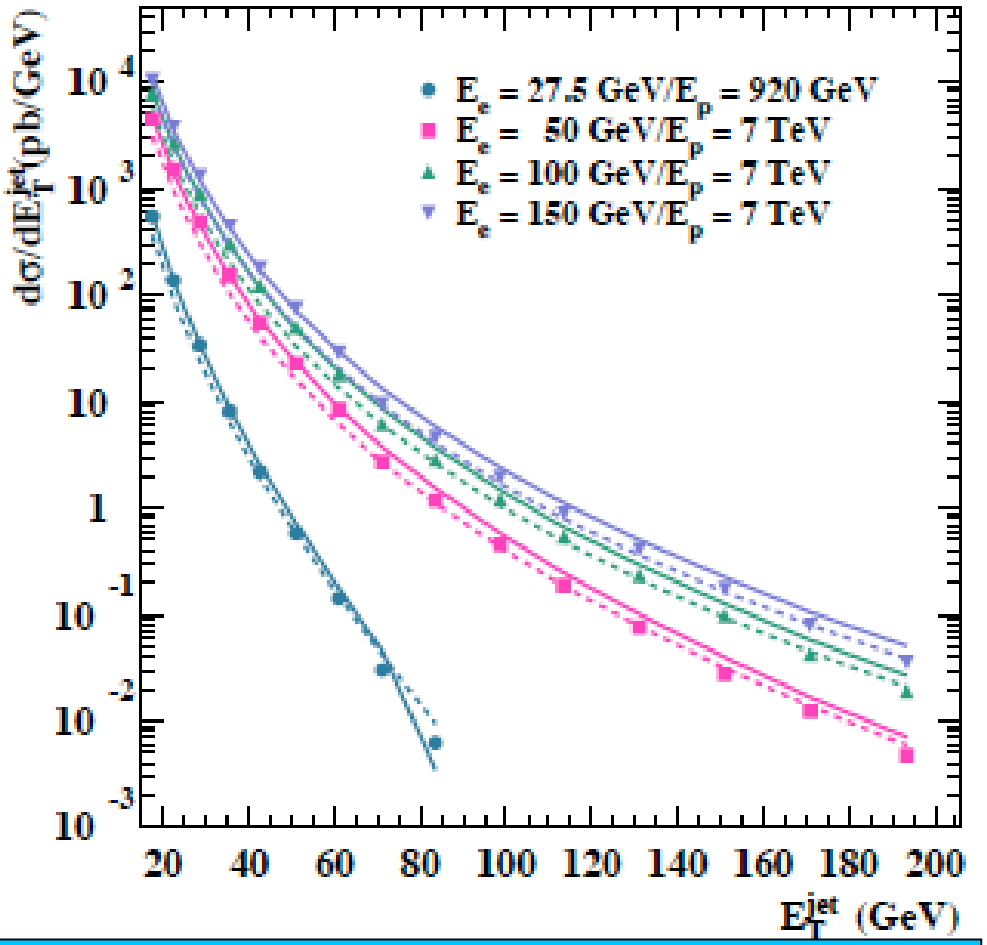
DIS

Joerg Behr



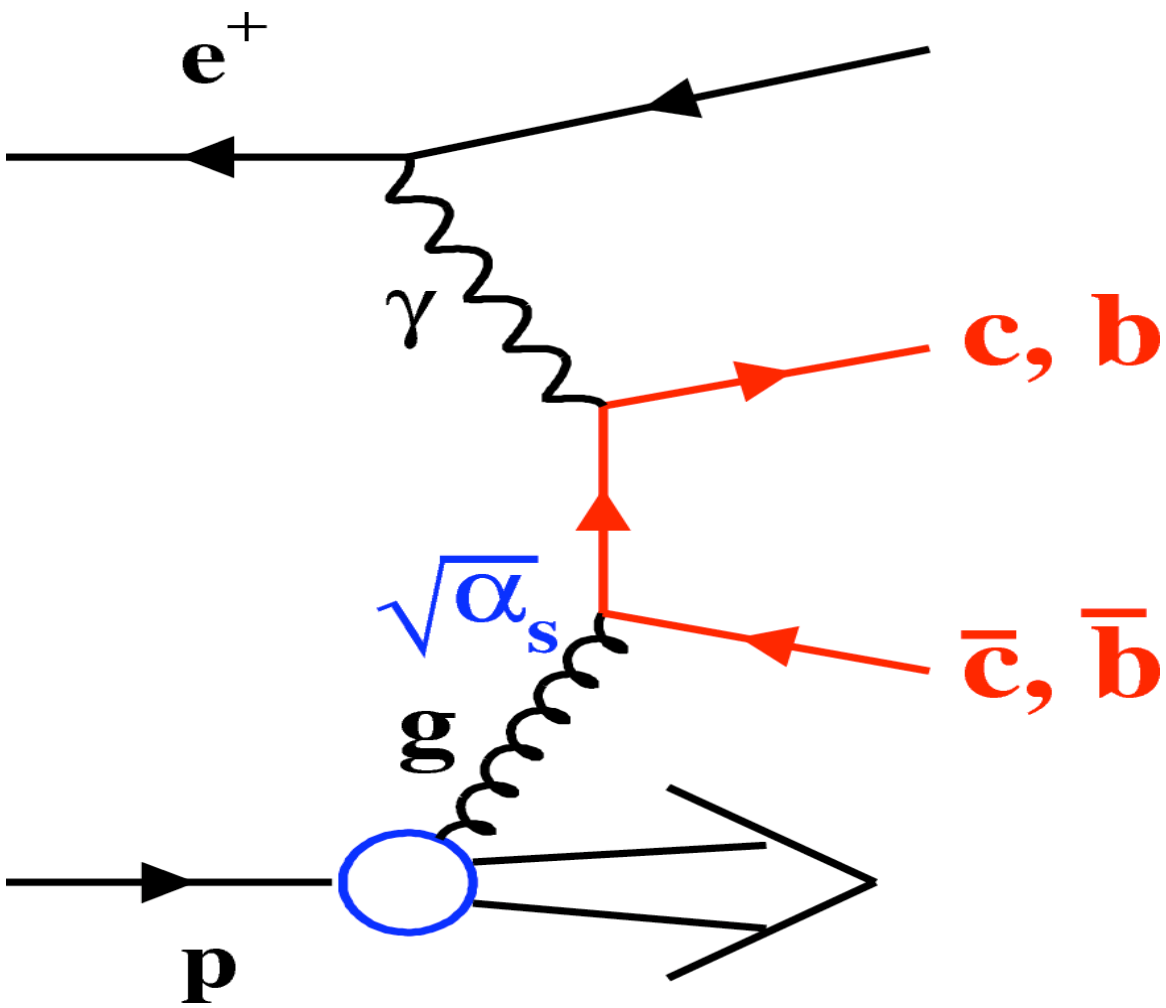
Photoproduction

Claudia Glasman



Reach scales up to 2m_t where change of $1/\alpha_s$ slope is expected

$O(\alpha_s)$ processes



Charm eg-> ecc vs γg->cc

Gökhan Ünel

- Comphep 4.5.1/ Calchep 2.5.4

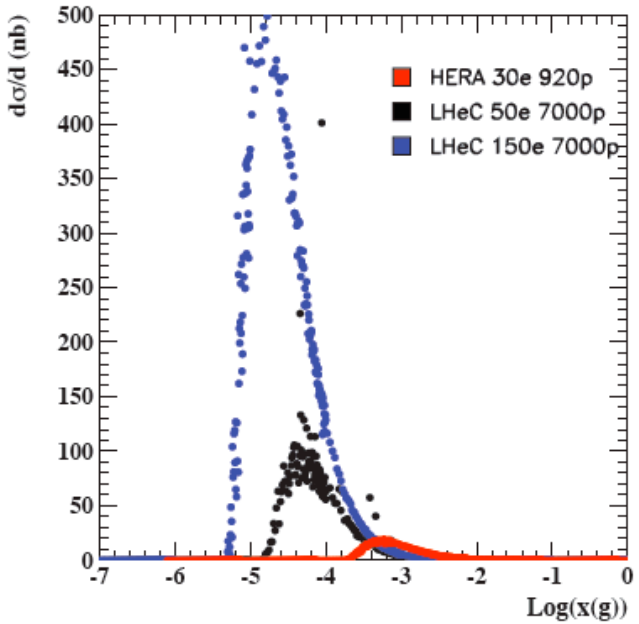
x(g) with Heavy Flavours in ep & γp collisions at LHeC 4

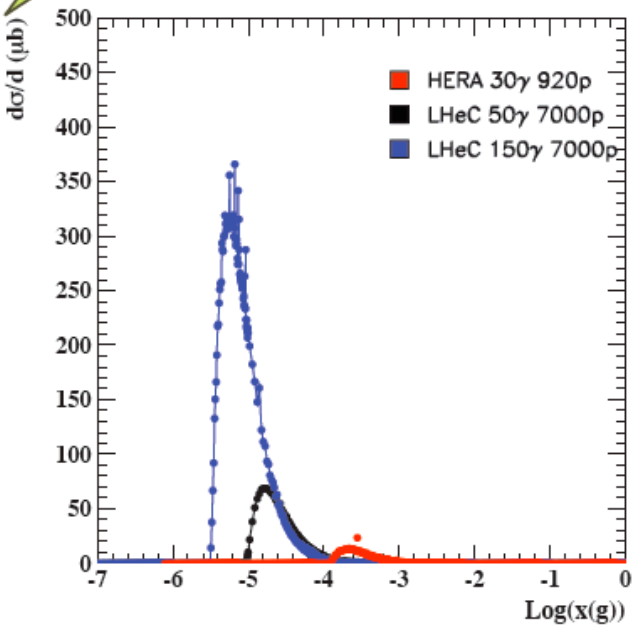
x(g) cc reach

- PDF=CTEQ 6L1 mc=1.65GeV
  - ➡ eg->ecc

~x700 gain in σ for the γ mode

γg->cc

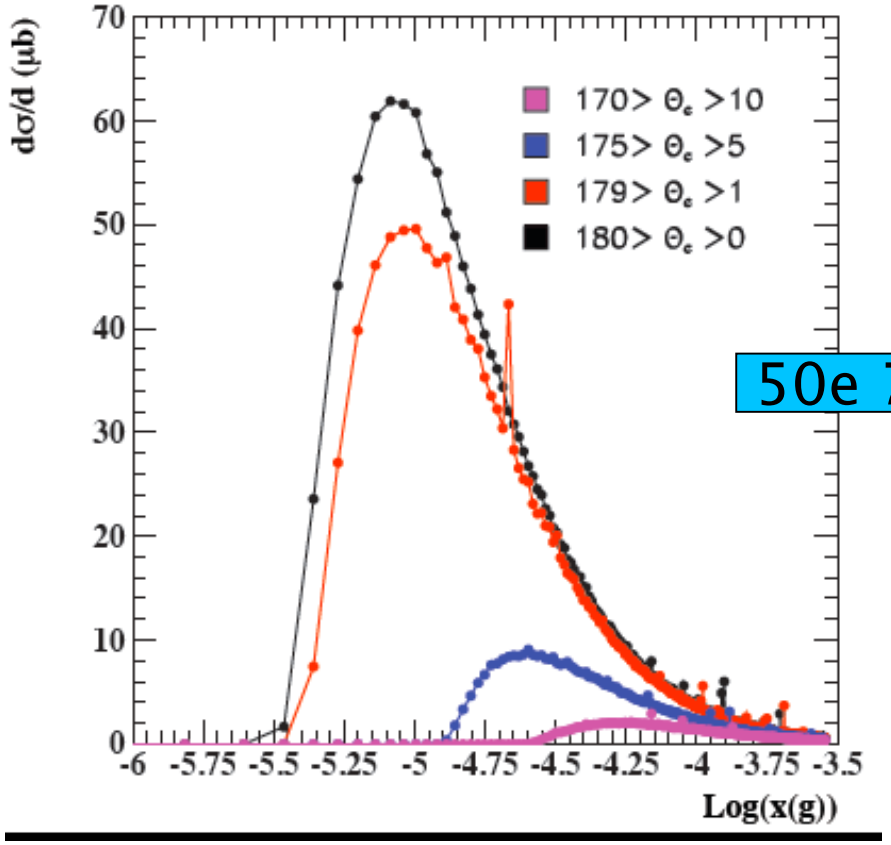




Cross sections much higher for photon proton collider

Charm γp cross sections vs detector acceptance

Gökhan Ünel

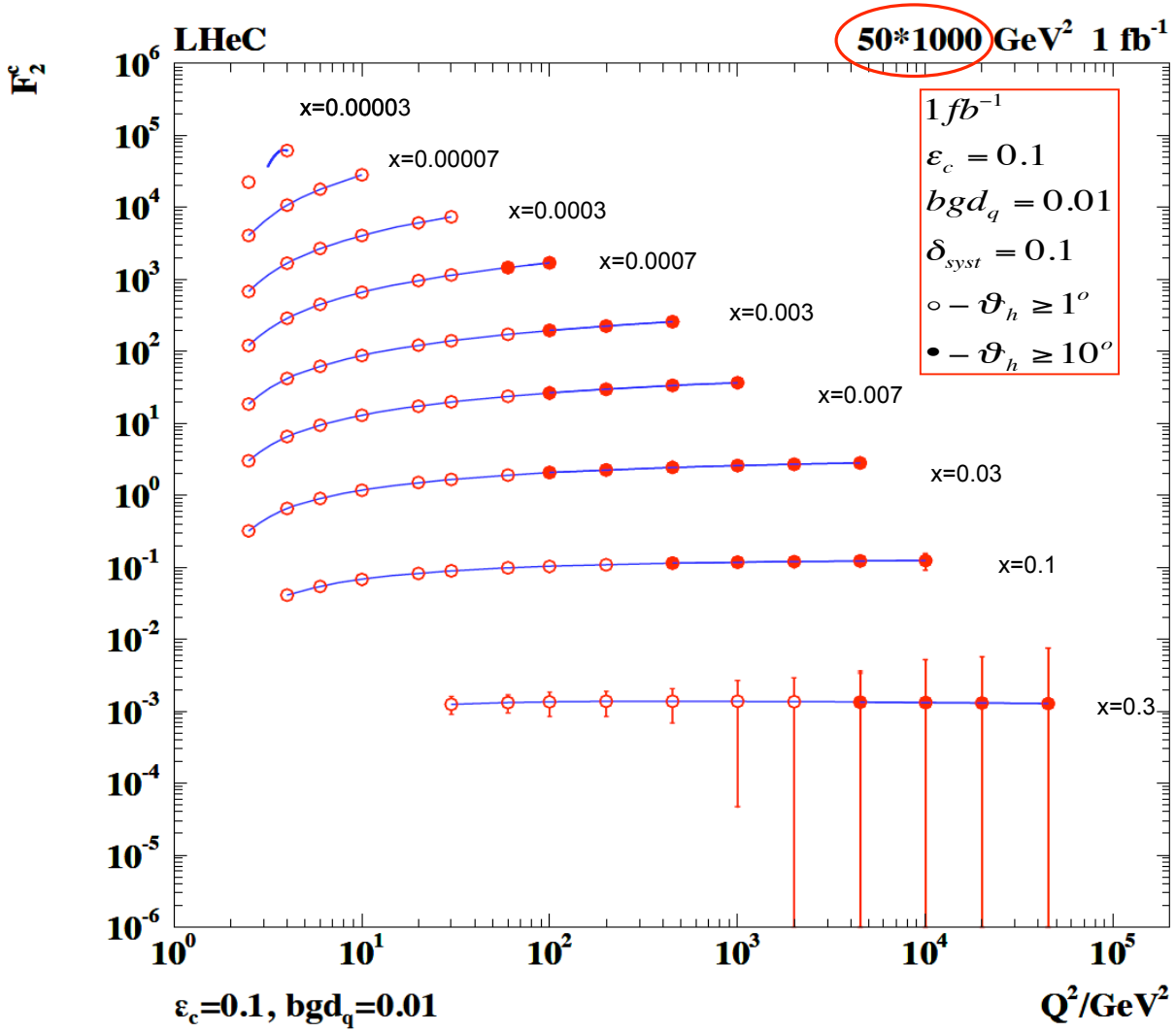


50e 7000 p

Detector polar angular coverage from 1^0–179^0 highly desirable

Charm in DIS

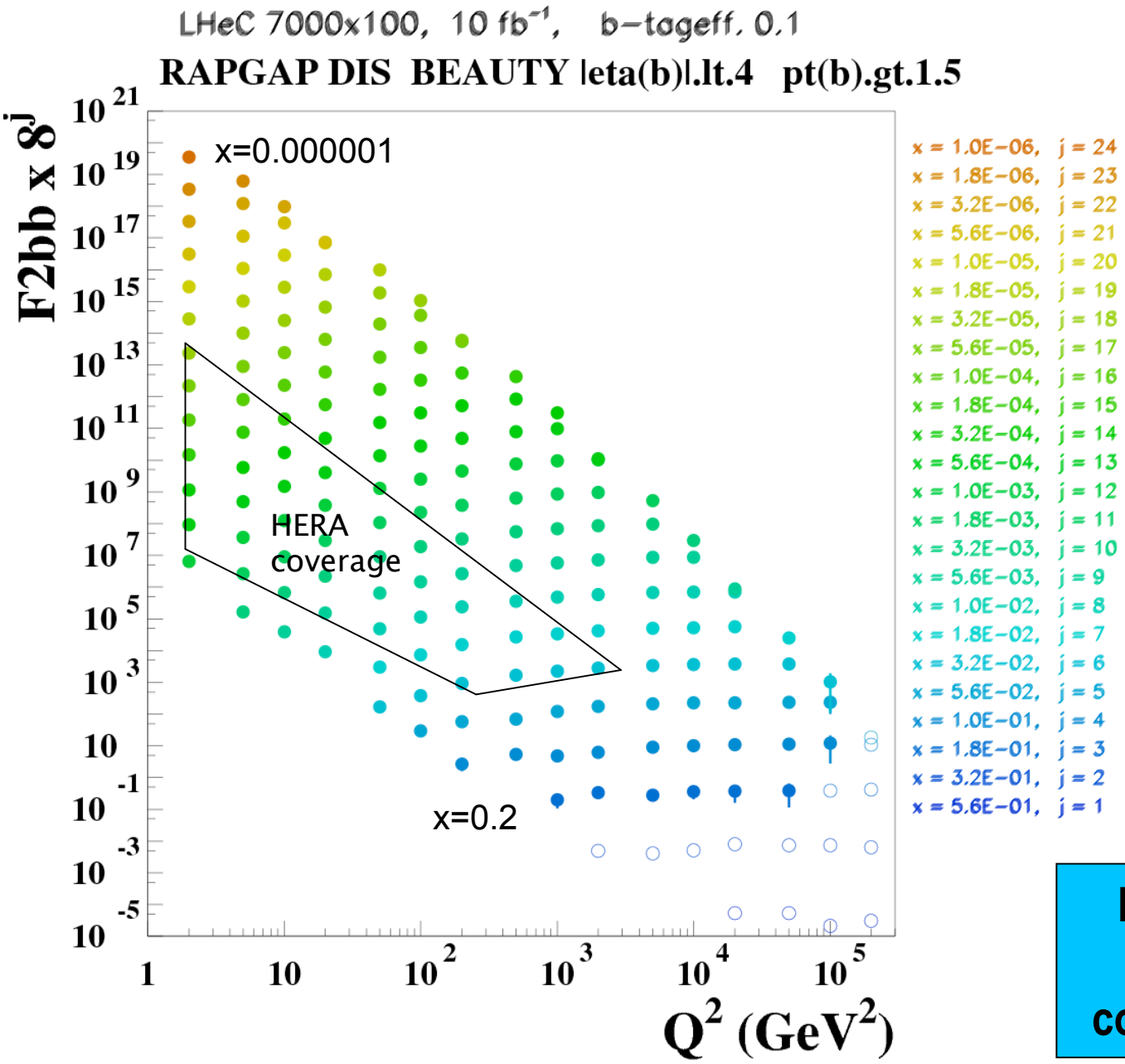
Max Klein



Charm at at large x will be an interesting challenge

Beauty in DIS

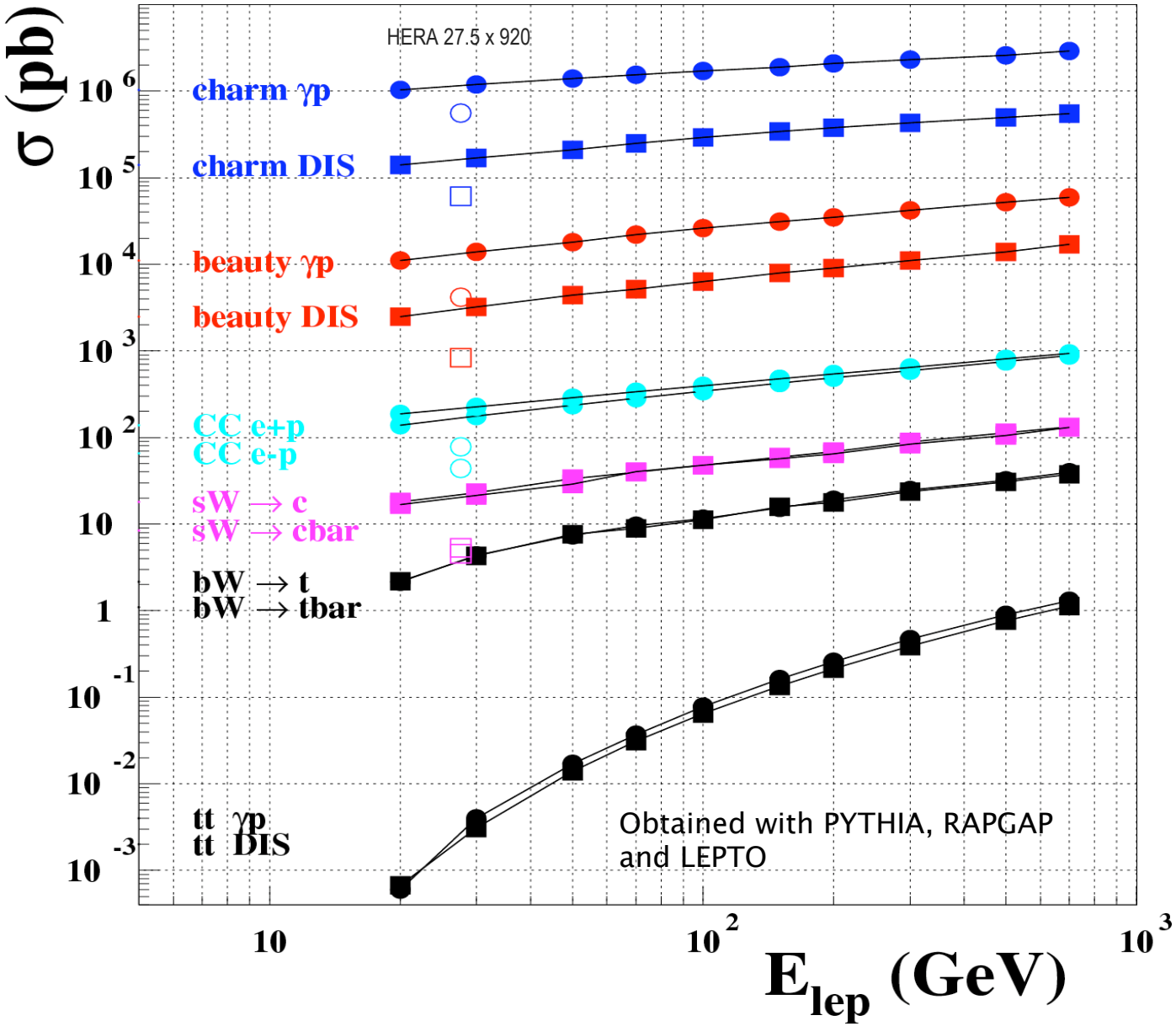
O.B.



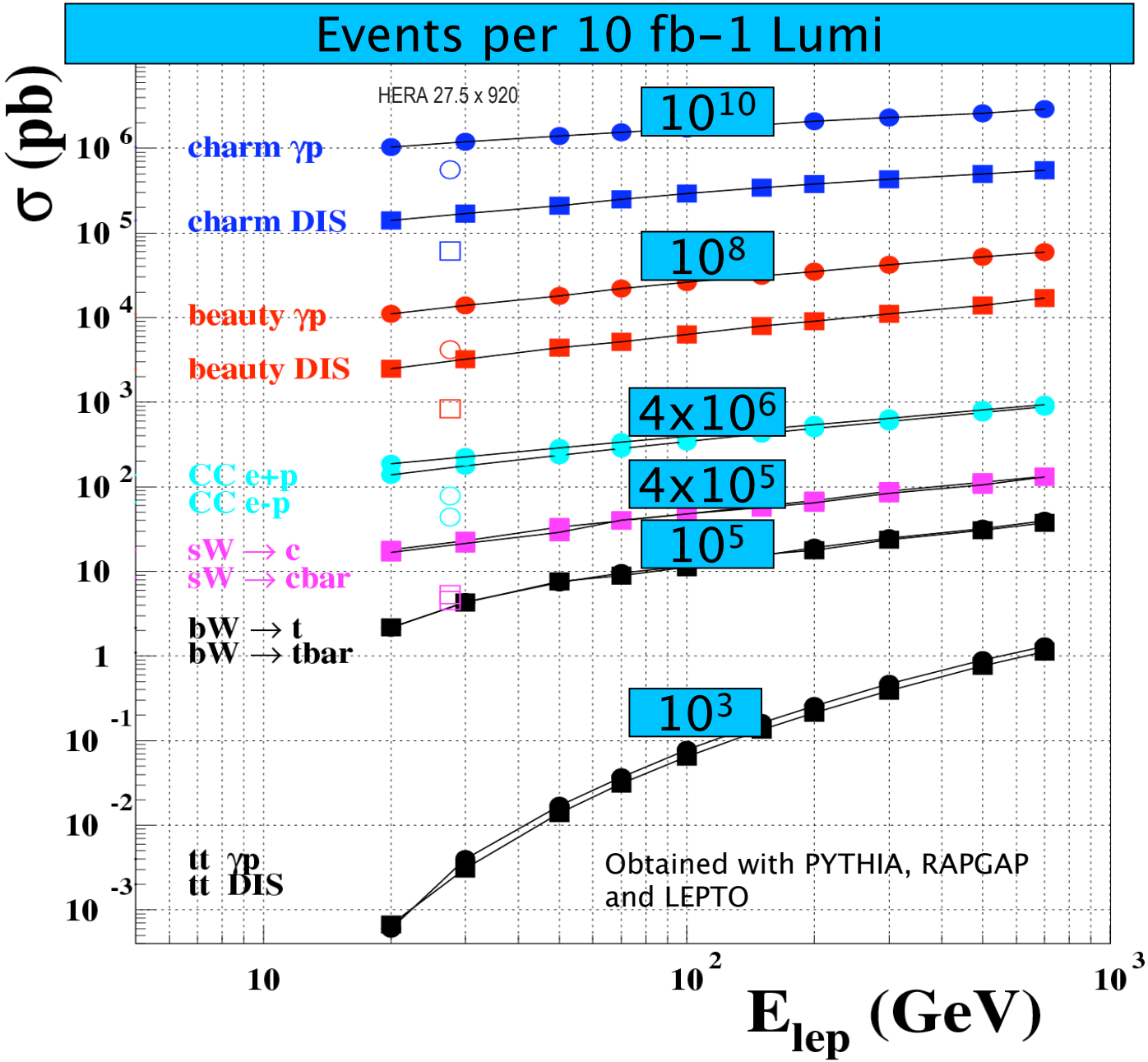
Largely extended phasespace compared to HERA

LHeC total cross sections (MC simulated)

O.B.



LHeC is a flavour factory



O.B.

LHeC is a flavour factory

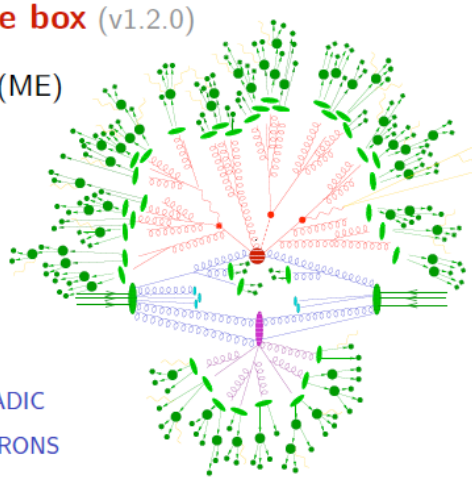
SHERPA

Stefan Hoeche

Sherpa's event generation framework JHEP02(2009)007

Things that are currently in the box (v1.2.0)

- Two multi-purpose Matrix Element (ME) generators AMEGIC++ JHEP02(2002)044 and Comix JHEP12(2008)039
- A standard Parton Shower (PS) APACIC++ CPC174(2006)876 and the dipole-like PS CSS JHEP03(2008)038
- A multiple interaction simulation à la Pythia AMISIC++ hep-ph/0601012
- A cluster fragmentation module AHADIC
- A hadron and τ decay package HADRONS
- A photon radiation generator à la YFS PHOTONS JHEP12(2008)018



Sherpa's traditional strength is the perturbative part of the event
NLO real ME's consistently combined with PS à la JHEP05(2009)053

Summary

Things already done ...

- SHERPA including ME⊗PS set up for DIS framework stable, promising first results
- HZTool steering included in SHERPA
  → "any" existing HZTool analysis can be done

Things to be done ...

- More tests and validations
  forward jets, 4-jets, ...
- Resolved photons
- Multiparton events

Looking forward to meet the challenge !

Lets make use of it for LHeC predictions, e.g. for bW-> t

Summary

The LHeC has potential to completely unfold the partonic content of the proton: u,d, c,s, t,b for the first time and in an unprecedent kinematic range. This is based on inclusive NC, CC cross sections complemented by heavy quark identification.

Puzzles as u/d at large x or a strange-antistrange asymmetry will be solved.

Precision measurements are possible of xg (up to large x) and the beauty density which are of particular relevance for the LHC. The (almost) whole p structure which the LHC assumes to know will become accurately known.

Large x>0.1 programme necessiates excellent forward hadronic calorimetry and control of hadronic energy scale to <= 1 %.

First fits to LHeC pseudodata: demonstrate a high precision potential for electroweak physics, e.g. for the light quark couplings to the Z boson and for the W propagator mass, Should be continued, e.g. fits of sin(θw)

The working group made substantial progess on the way towards the conceptional design report; several new simulated predictions have been obtained for the agreed machine scenarios; try to complete the studies and add some (most important) missing pieces….

Backup slides

Proton PDFs

Claire Gwenlan

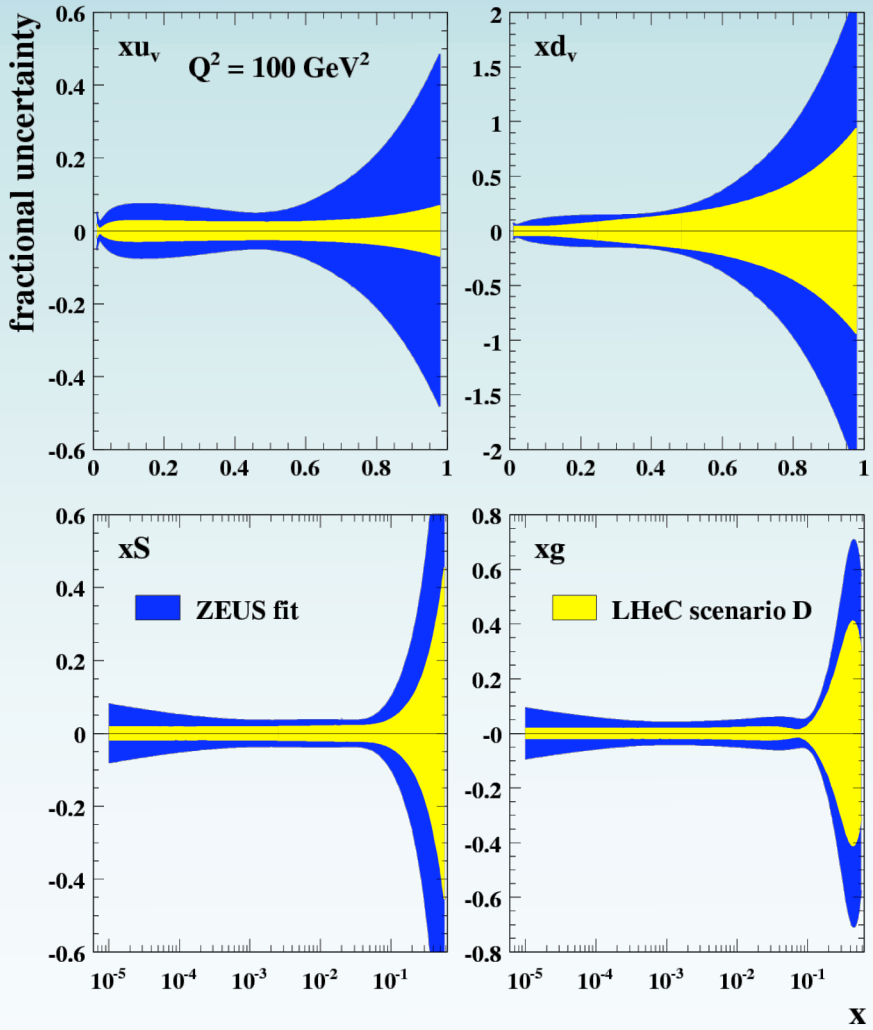
$Q^2 = 100\ GeV^2$

scenario D

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

PDF uncertainties:

- **NC $e^{\pm}p$**: direct constraints on **quark densities**; indirect on **gluon** via scaling violations



Proton PDFs

Claire Gwenlan

$Q^2 = 100\ GeV^2$

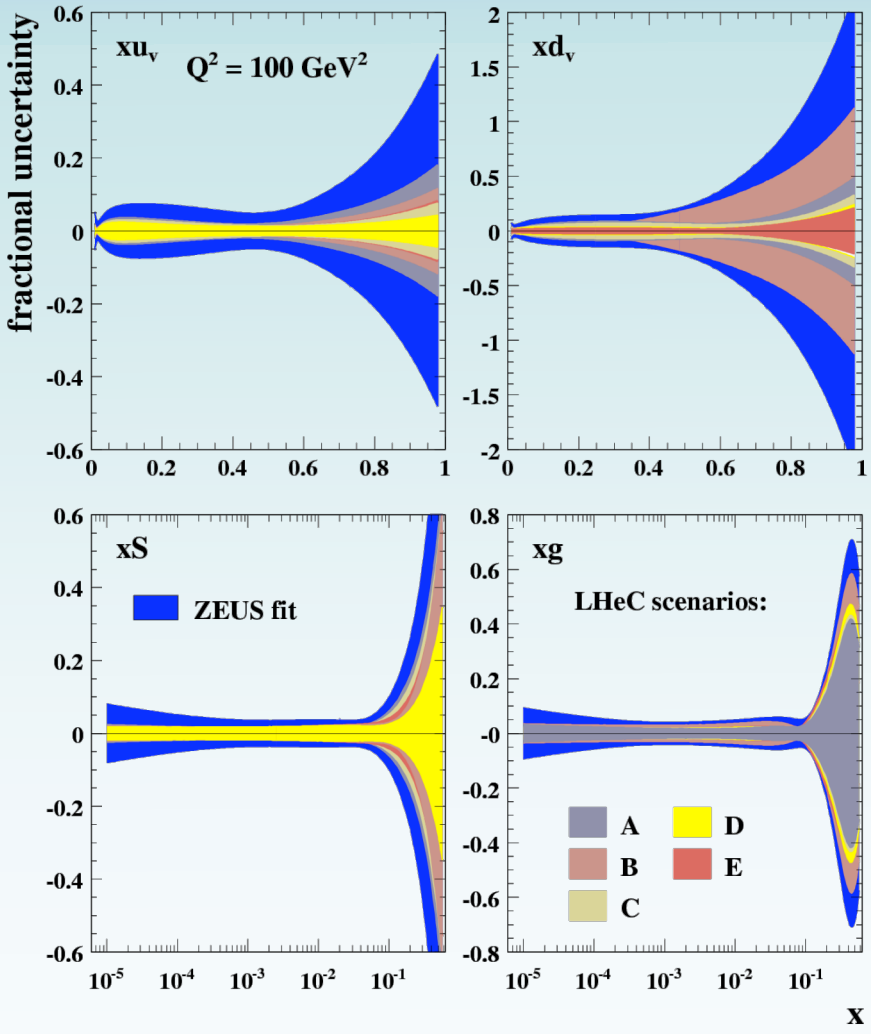
» only PDF parameters free
(LHeC **NC** and **CC** $e^{\pm}p$ included)

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)

scenario D



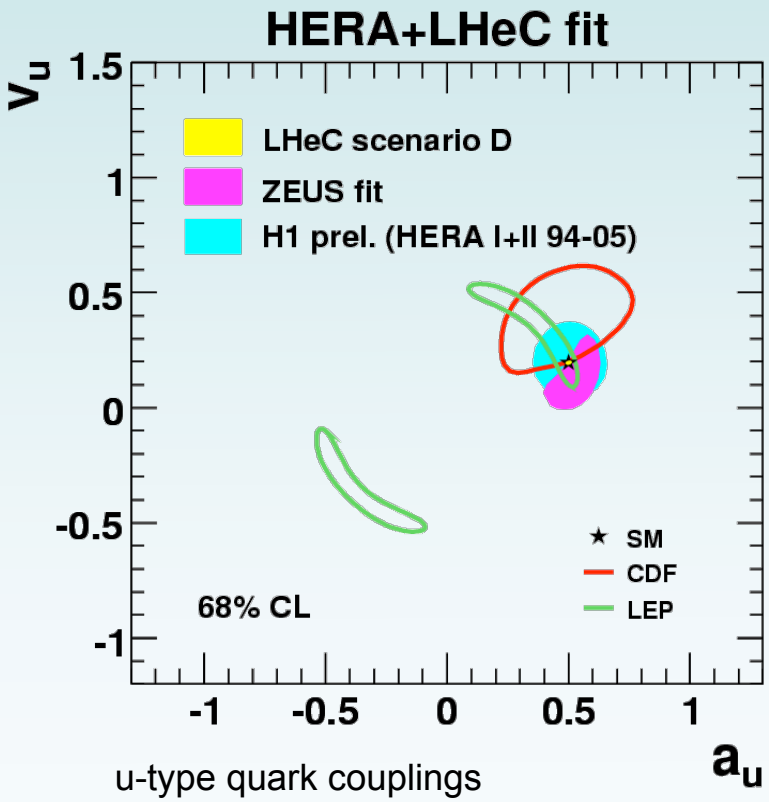
* acceptance for scenario B has been taken to be: $10 < \theta < 170^o$

neutral current quark couplings

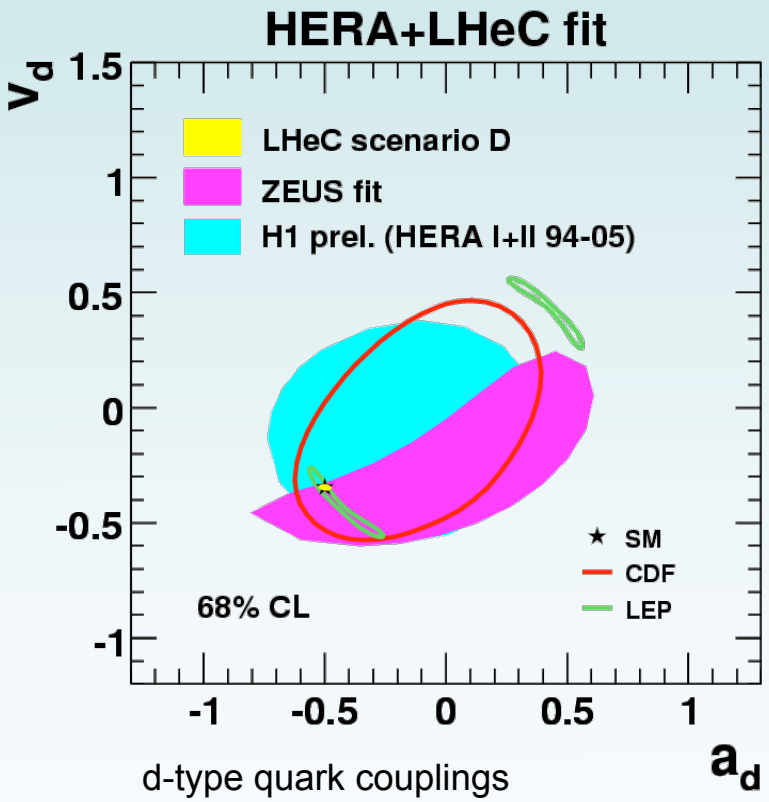
scenario D:
$P_e = \pm 0.9$

comparison with **other experiments**

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



u-type quark couplings



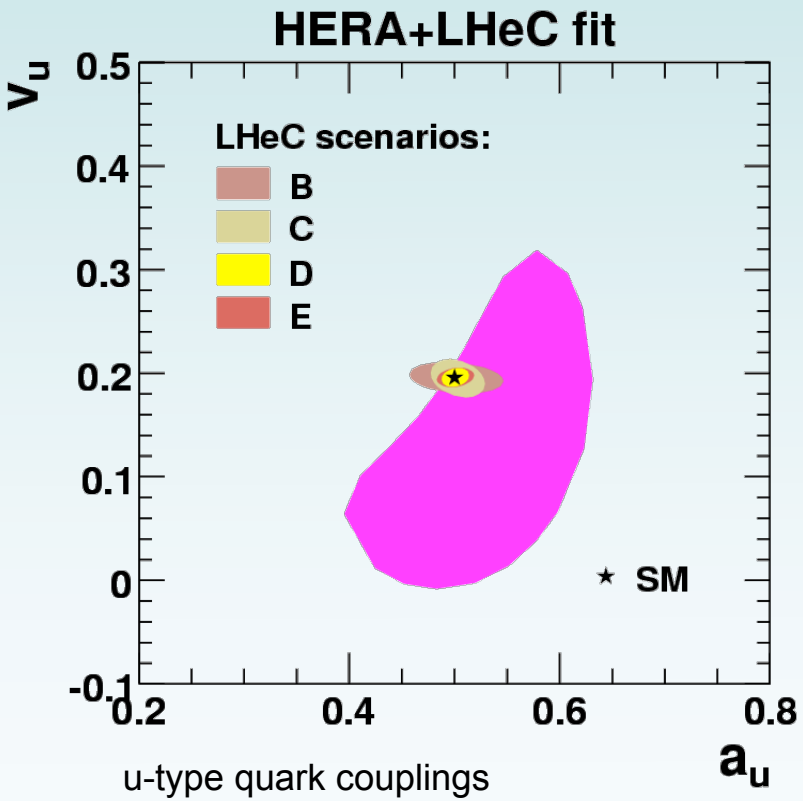
d-type quark couplings

neutral current quark couplings

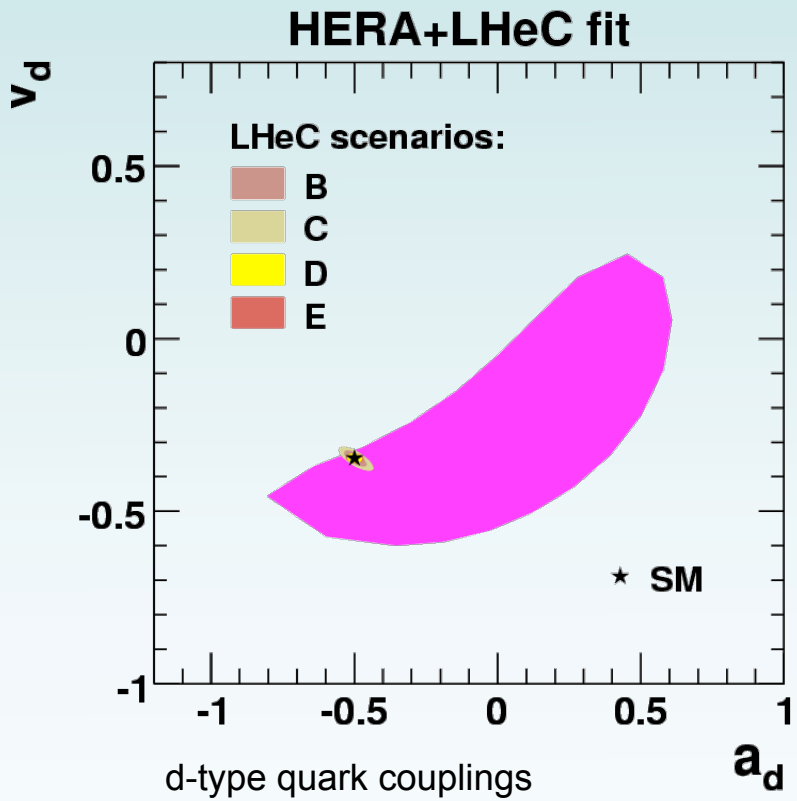
polarisations:
$P_e = \pm 0.4$ **(B,C)**
$P_e = \pm 0.9$ **(D,E)**

other scenarios: **B**, **C**, **(D)** and **E** (versus ZEUS base fit)

➔ factors of **×10−40 improvement** (depending on exact coupling and scenario)

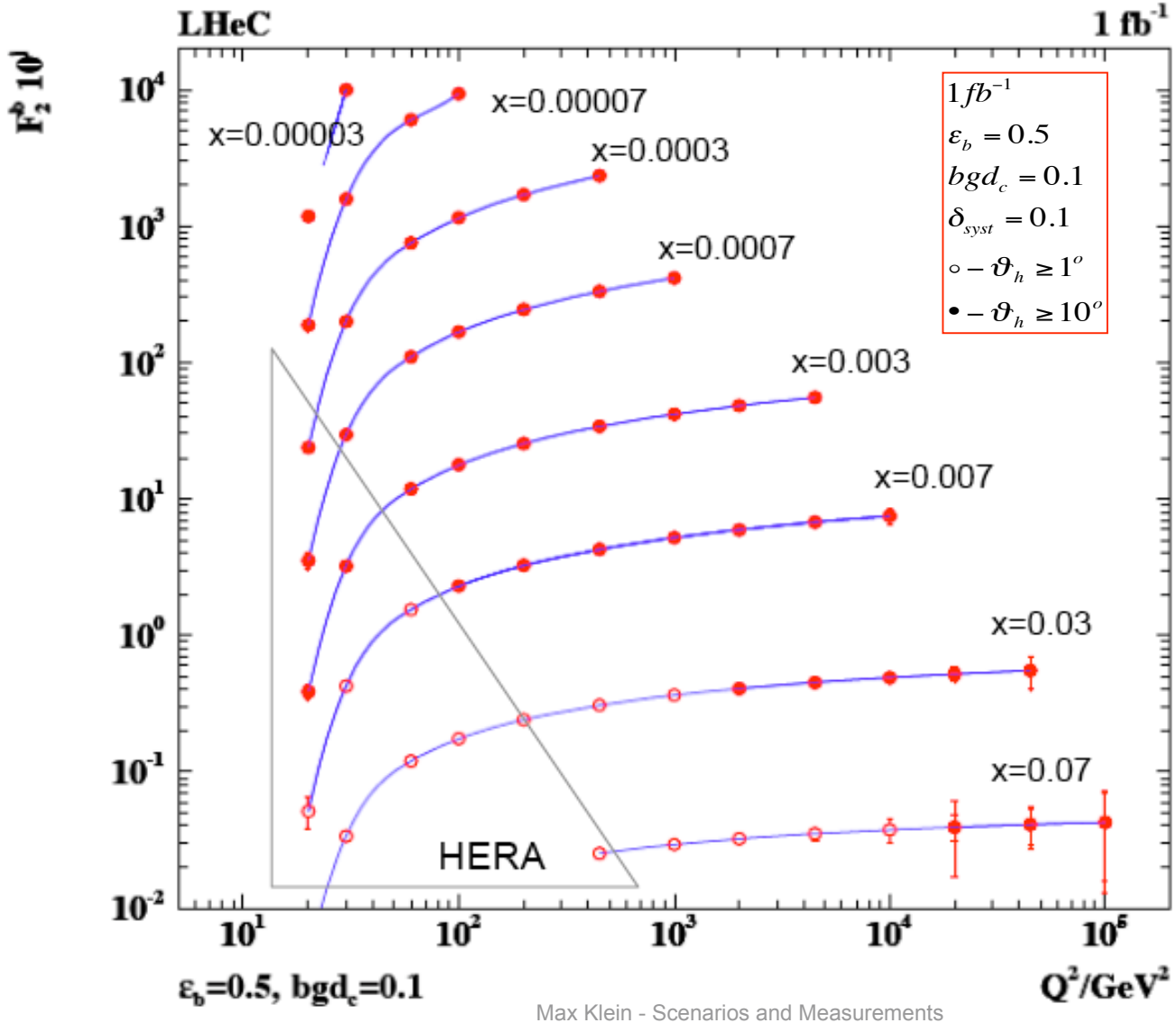


u-type quark couplings



d-type quark couplings

70 GeV x 7 TeV: F2bb in bins of x vs Q2 at the LHeC



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