Precision QCD and electroweak physics

at the LheC

DIS 2009, 28 April 2009, Madrid

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} ?

LHeC precision QCD & electroweak expected gain areas- examples

Area:	Tools:
u_v, d_v	NC and CC at high Q^2
strange sea	$sW \rightarrow c$, $sbarW \rightarrow cbar$
g(x) for $x<10^{-3}$, $x>0.1$	$dF_2/d(\ln Q^2)$, jets, F_2^{cc}
Intrinsic charm	F_2^{cc} at $x>0.1$
beauty sea	F_2^{bb}
α_s at 0.0001 precision	QCD analysis of incl. data
Top production:	$bW \rightarrow t$
Electroweak:	
a_u, v_u, a_d, v_d	polarised NC
M_W (propagator mass)	CC

LHeC precision QCD & elweak areas - covered in this talk

Area:	Tools:
u_v, d_v	NC and CC at high Q^2
strange sea	$sW \rightarrow c$, $sbarW \rightarrow cbar$
g(x) for $x<10^{-3}$, $x>0.1$	$dF_2/d(\ln Q^2)$, jets, F_2^{cc}
Intrinsic charm	F_2^{cc} at $x>0.1$
beauty sea	F_2^{bb}
α_s at 0.0001 precision	QCD analysis of incl. data
Top production:	$bW \rightarrow t$
Electroweak:	
a_u, v_u, a_d, v_d	(polarised) NC
M_W (propagator mass)	CC

← *See e.g. talks by Kluge, Klein DIS 08*

← For the very first time

New April 09: NC and CC **Pseudodata** available for different LHeC scenarios -> Thanks to Max

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

Can be used by interested people to do their own LHeC studies at their convenience

Note: Most of the material in the following was taken from the talks by Max Klein, Claire Gwenlan and O.B.
at the LHeC DIS2009 premeeting, 25 apr 2009, Madrid,
which are available at

http://indico.cern.ch/conferenceOtherViews.py?view=cdsagenda&confId=55684

Simulated Default Scenarios, April 2009

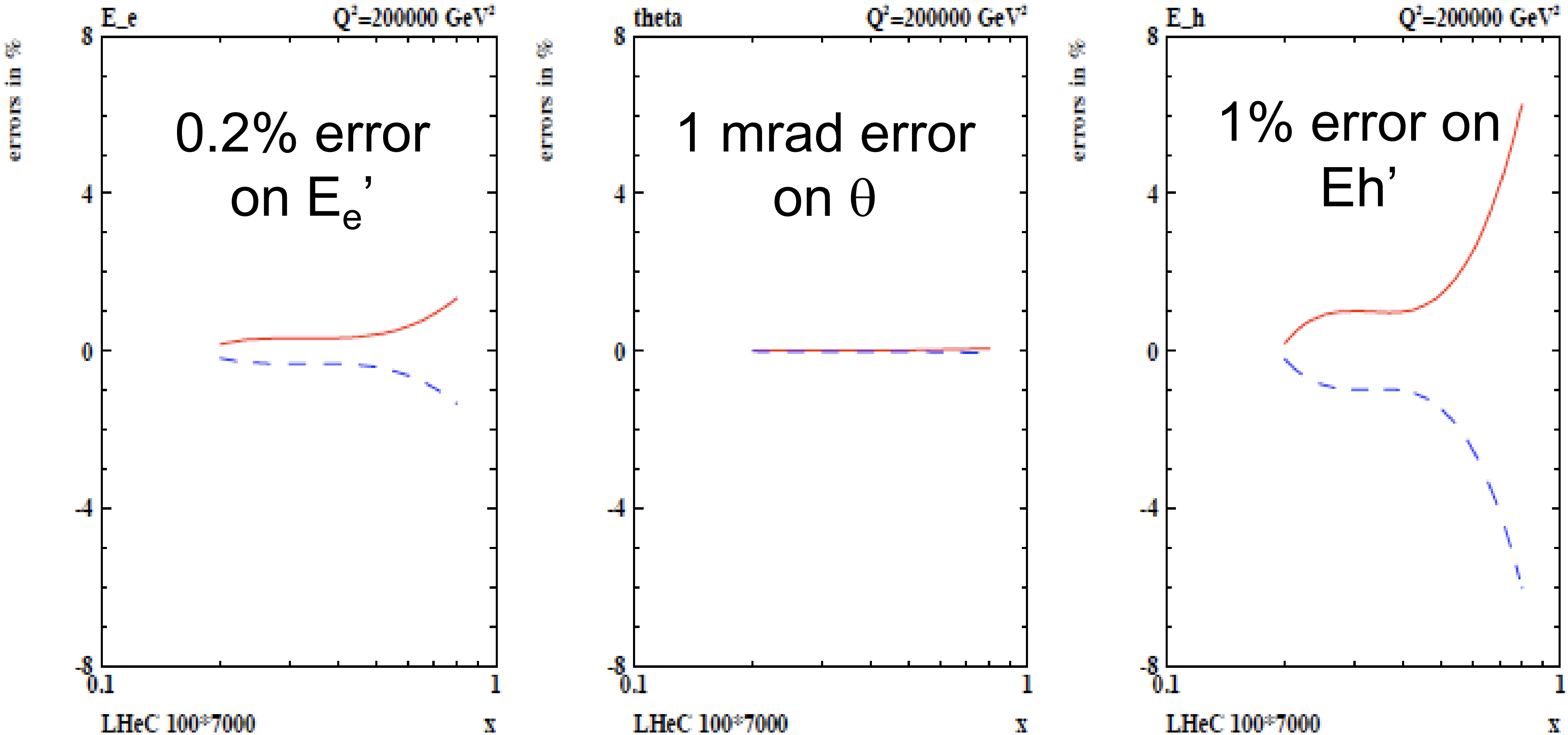
http://hep.ph.liv.ac.uk/~mklein/simdis09/lhecsim.Dmp.CC, readfirst

Max Klein, LHeC

config.	E(e)	E(N)	N	∫L(e⁺)	∫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

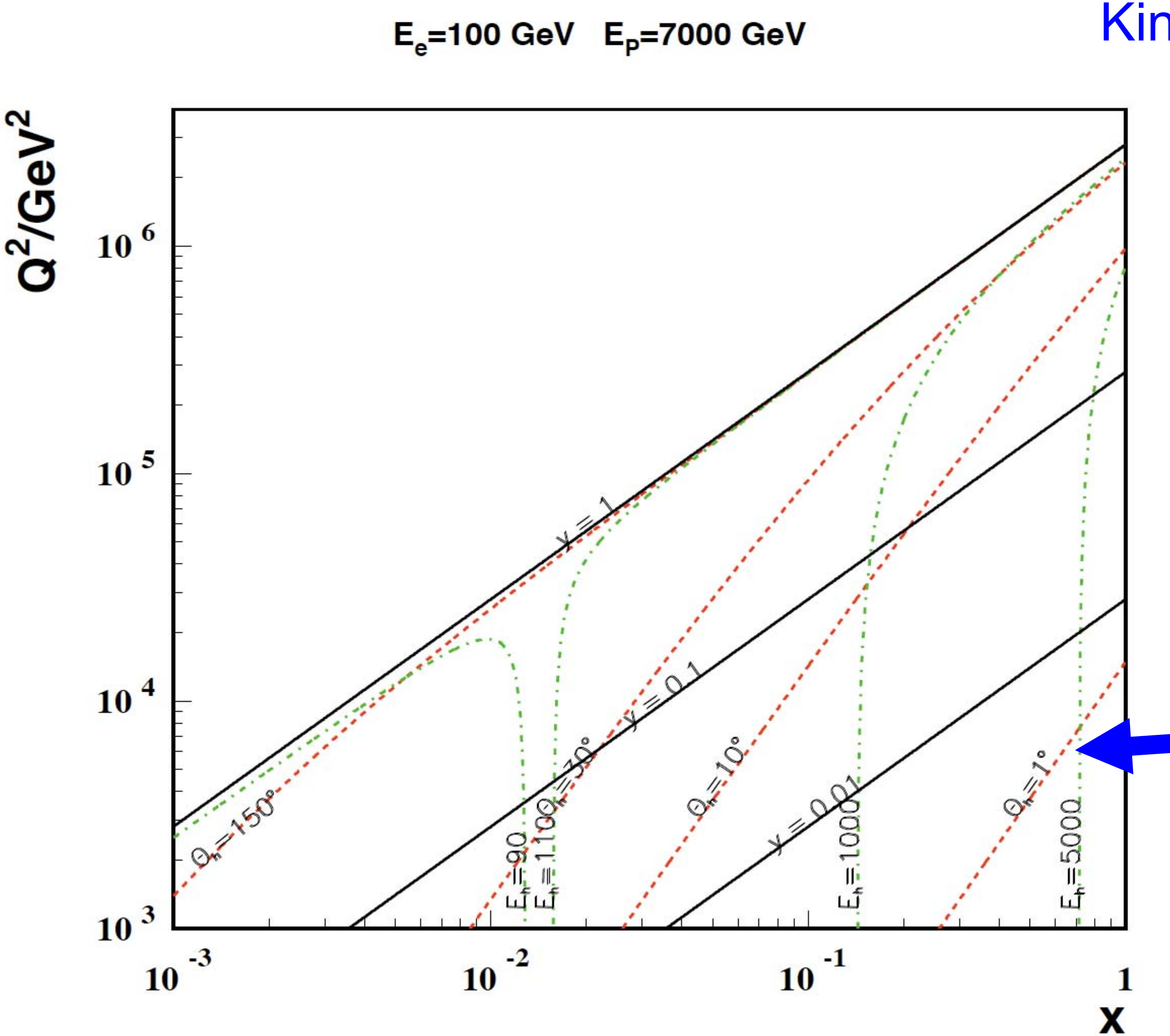
Not simulated (G)

Systematic error calculation for pseudodata: assumed uncertainties and effects on xsecs



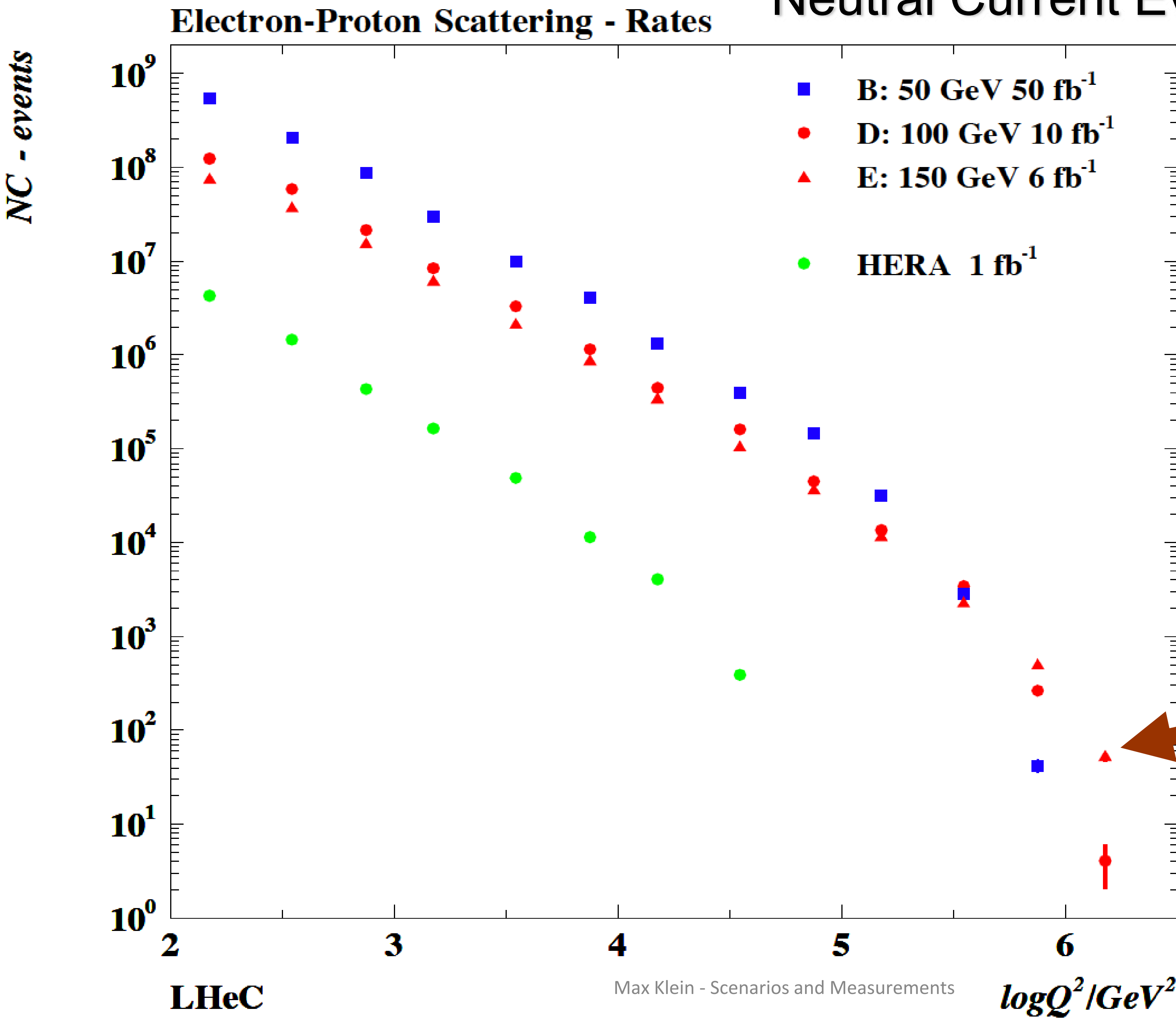
→ At high Q^2: Need <=1% hadronic energy scale uncertainty at very large E_h

Kinematics – high Q^2



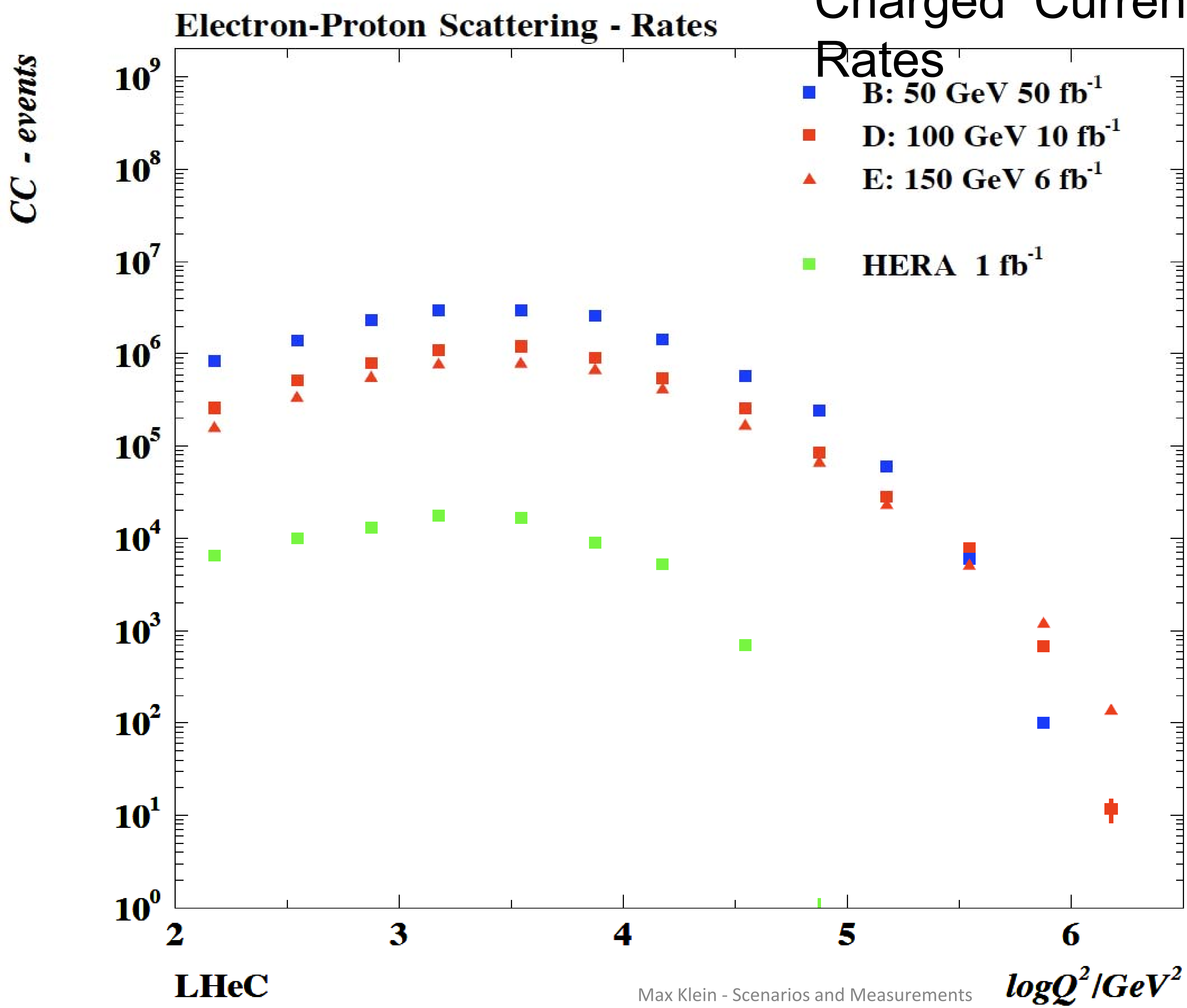
Need excellent forward hadron calorimetry & calibration

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

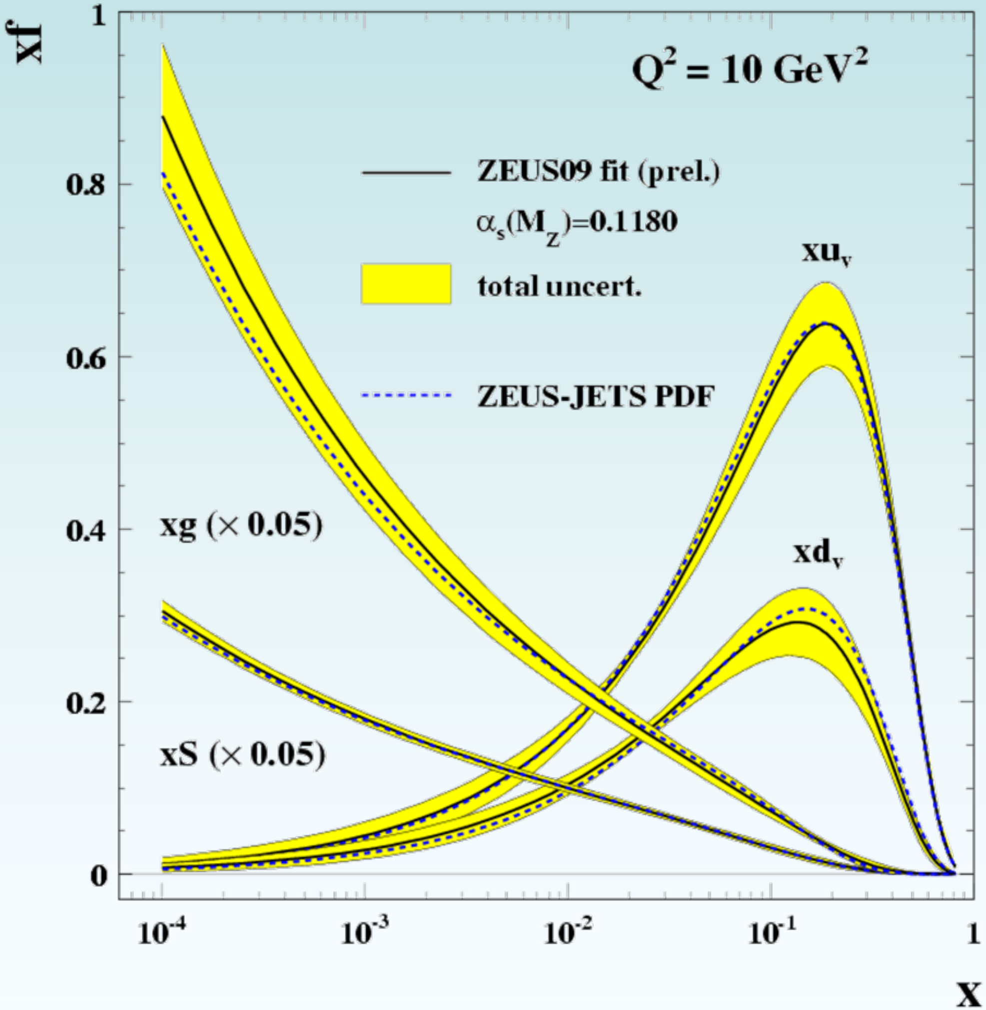
Claire Gwenlan

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

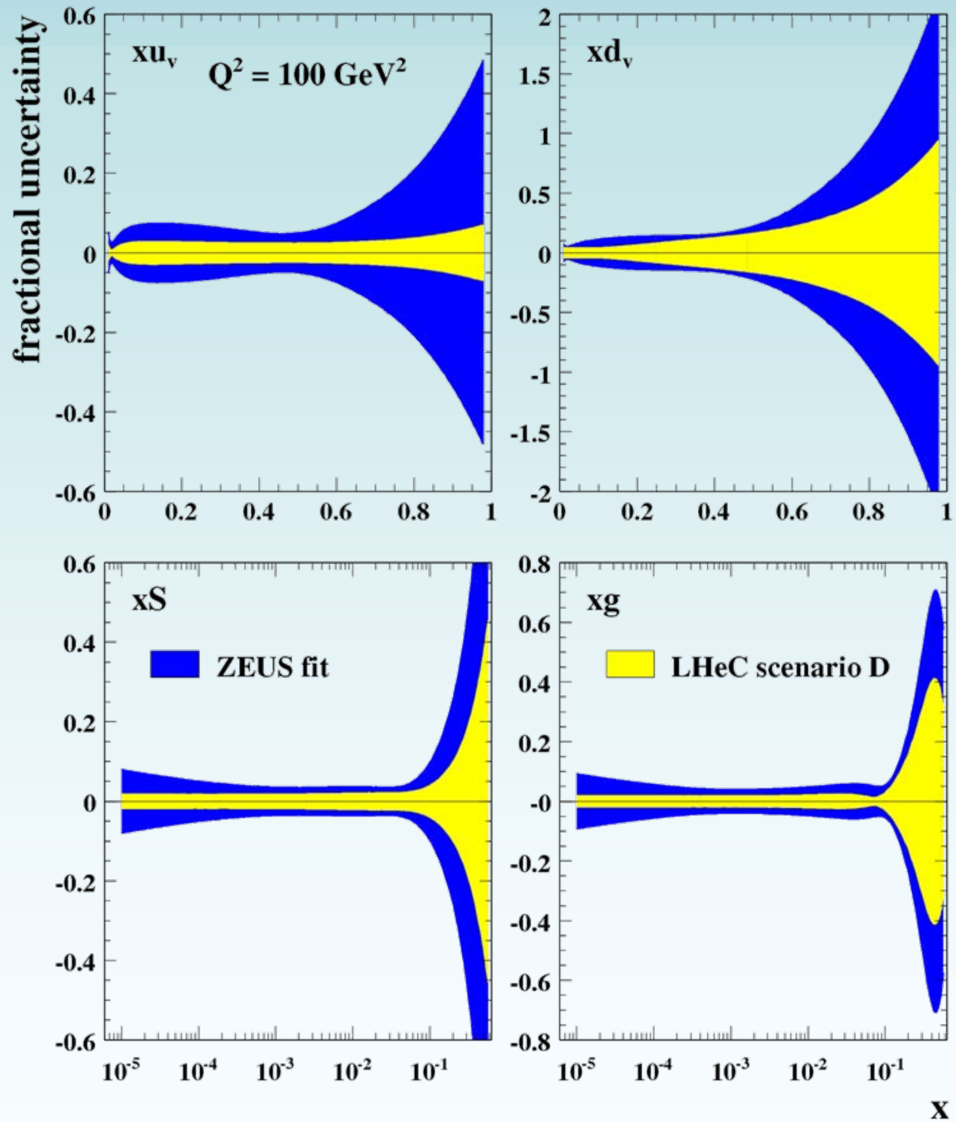
$Q^2 = 100\ GeV^2$

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

PDF uncertainties:

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

scenario D



Proton PDFs

Claire Gwenlan

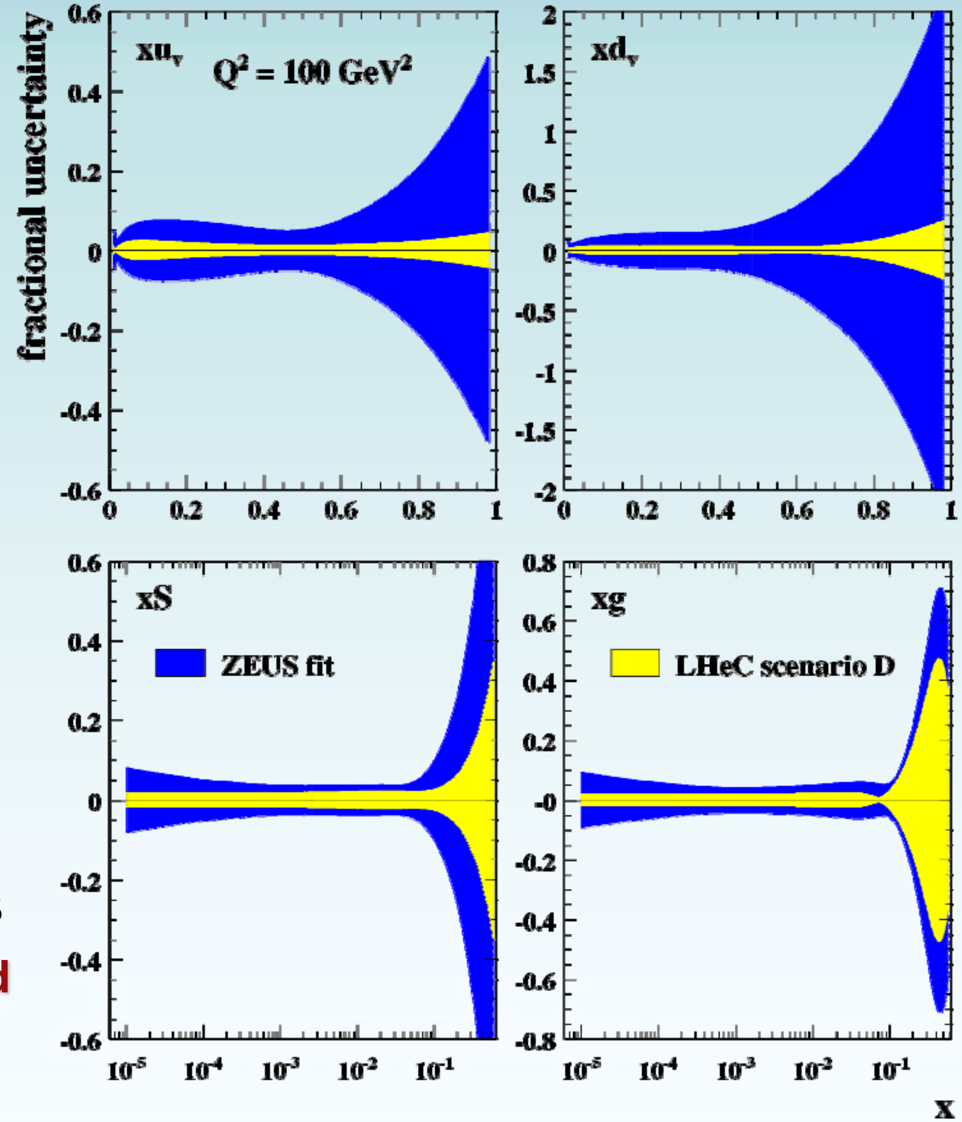
$Q^2 = 100\ GeV^2$

scenario D

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

<u>PDF uncertainties:</u>

- **NC $e^{\pm}p$**: direct constraints on **quark densities**; indirect on **gluon** via scaling violations
- **CC $e^{\pm}p$**: constraints on quarks
  ➔ **flavour decomposition**
  (e^-: mostly u; e^+: mostly d)



Looks very promising ☺ model and parameterisation uncertainties to be studied, **also to be compared in detail to Emmanuelle Perez QCD-fit results**

Claire Gwenlan

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

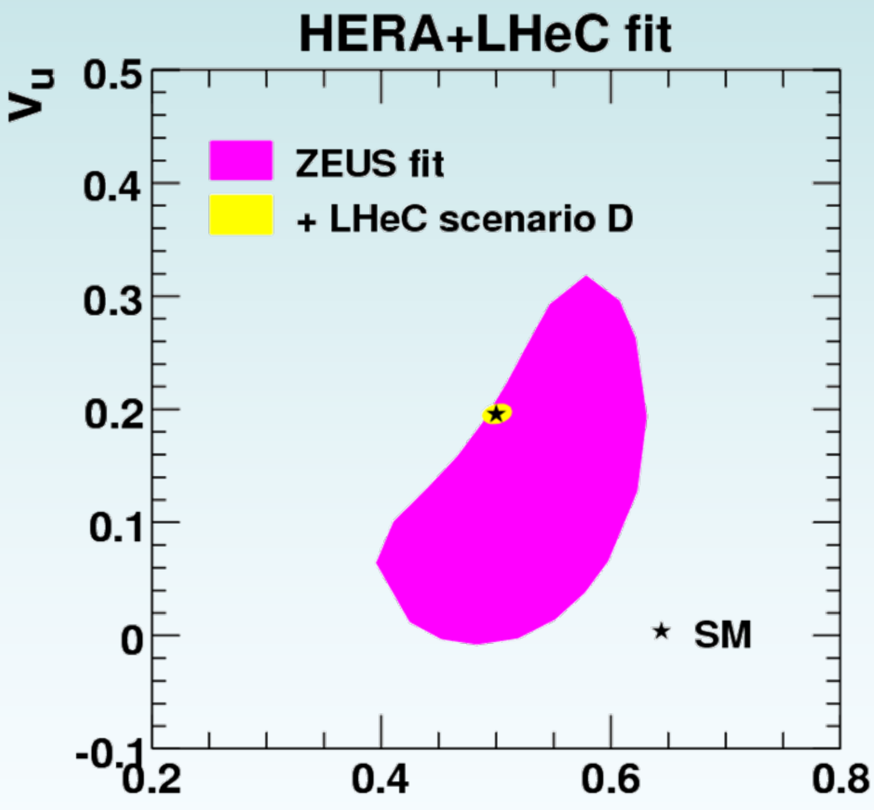
* the following results currently have only the LHeC NC (CC will not change things by much)

neutral current quark couplings

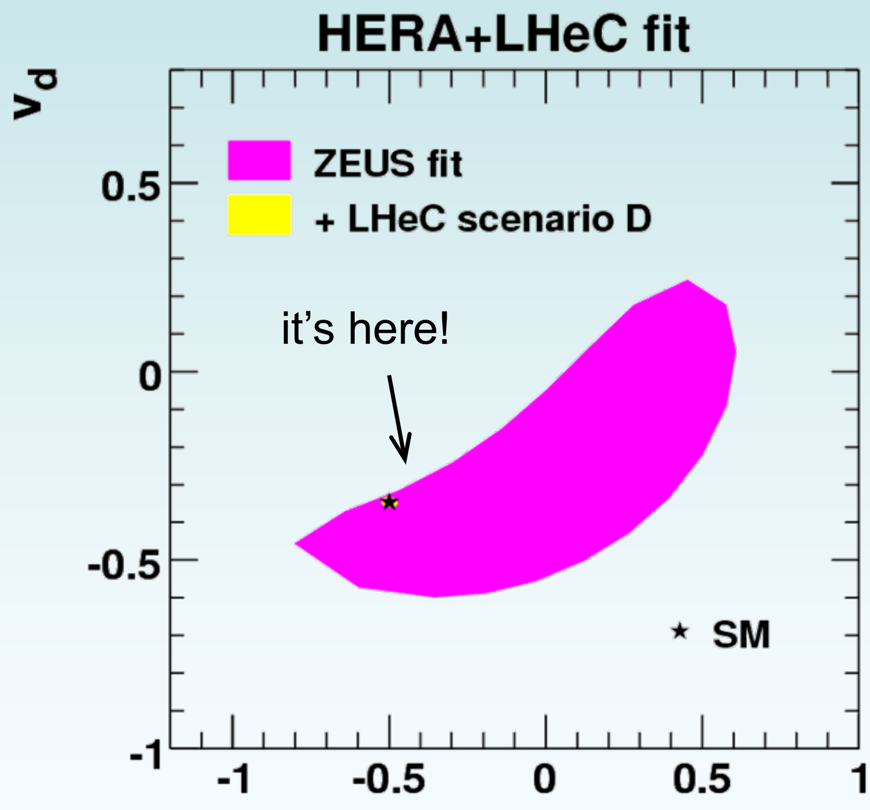
scenario D:
$P_e = \pm 0.9$

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

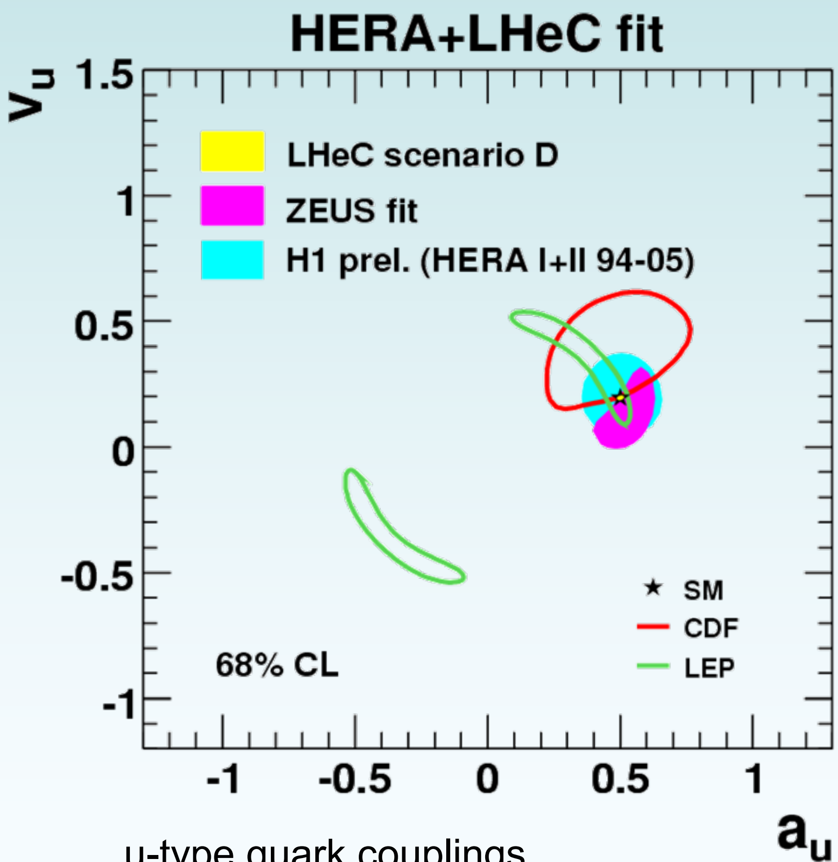
Claire Gwenlan

neutral current quark couplings

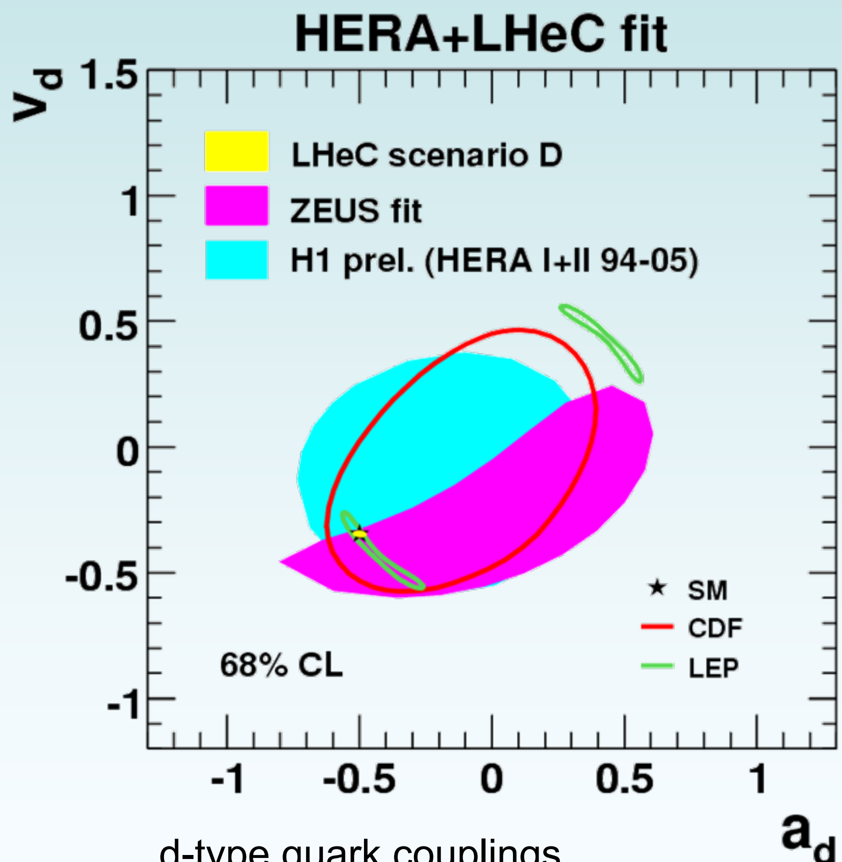
scenario D:
$P_e = \pm 0.9$

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

Claire Gwenlan

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%)

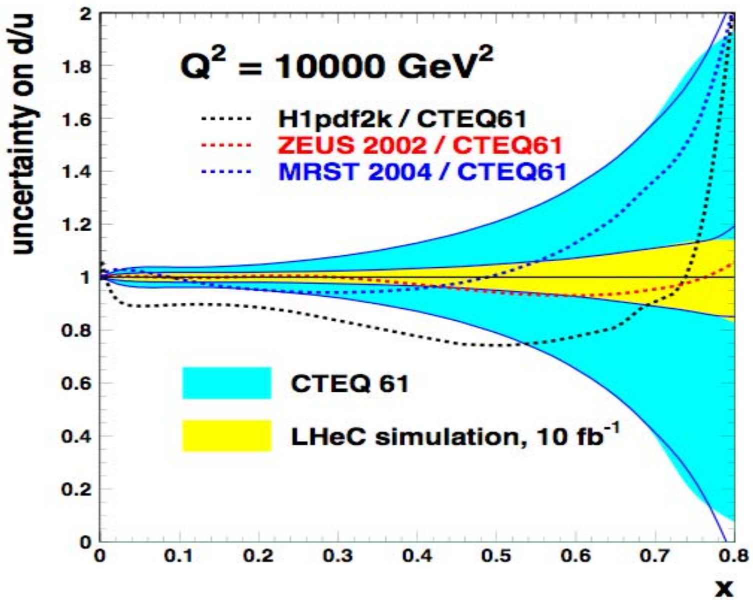
c.f. same method using only HERA data currently giving uncertainties of order **1 GeV** (total experimental; no accounting for model uncertainties in the fit)

improved but not competitive ↓ (although still interesting as a cross-check; space-like regime)

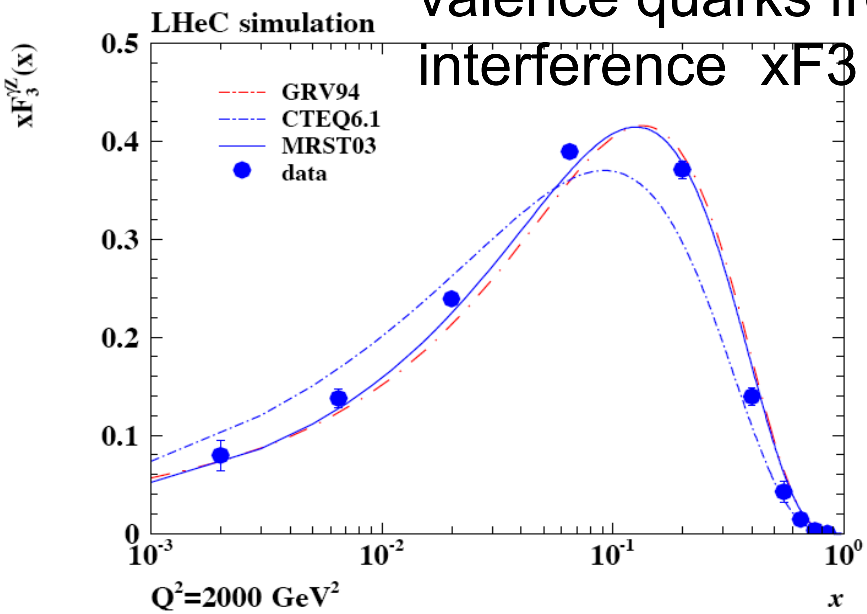
current world average (PDG 2008): M_W = 80.398 ± 0.025 GeV **(0.03% total)**

Back to proton structure: examples of previous 70 GeV x 7 TeV LHeC studies on unfolding of quark content of nucleon

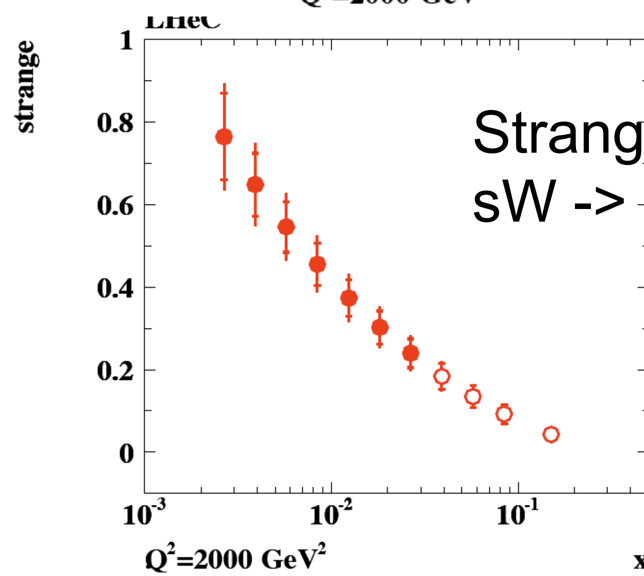
d/u for x ->1



valence quarks from γZ interference xF3



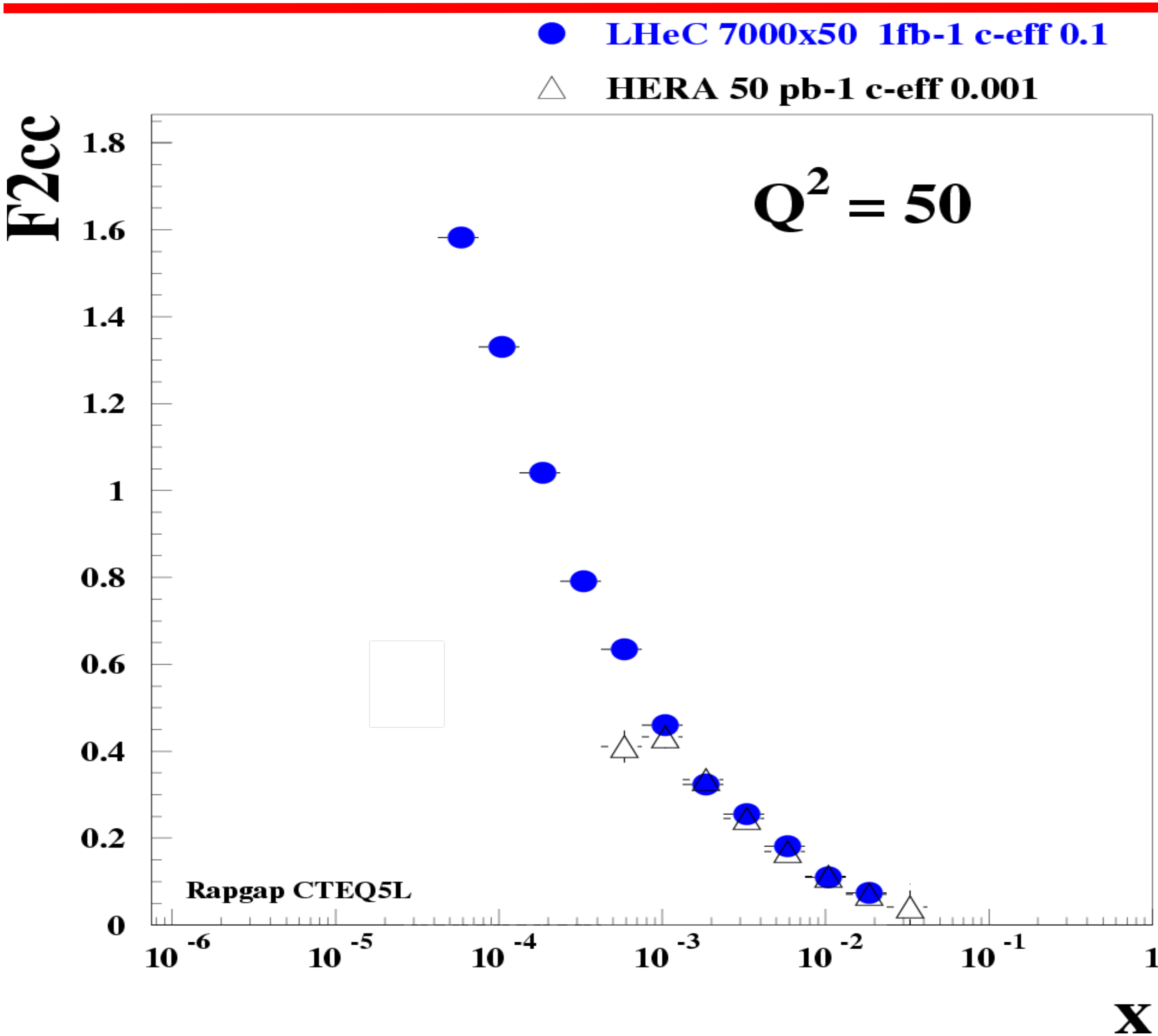
Strange sea from sW -> c

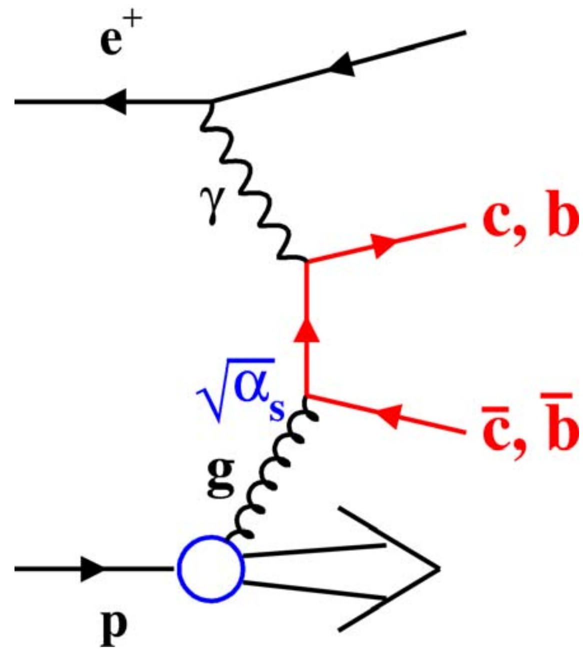


E. Perez, M. Klein, A. Mehta

See backup for results on F2cc And F2bb

New rapgap simulation results on F2cc: LheC vs HERA

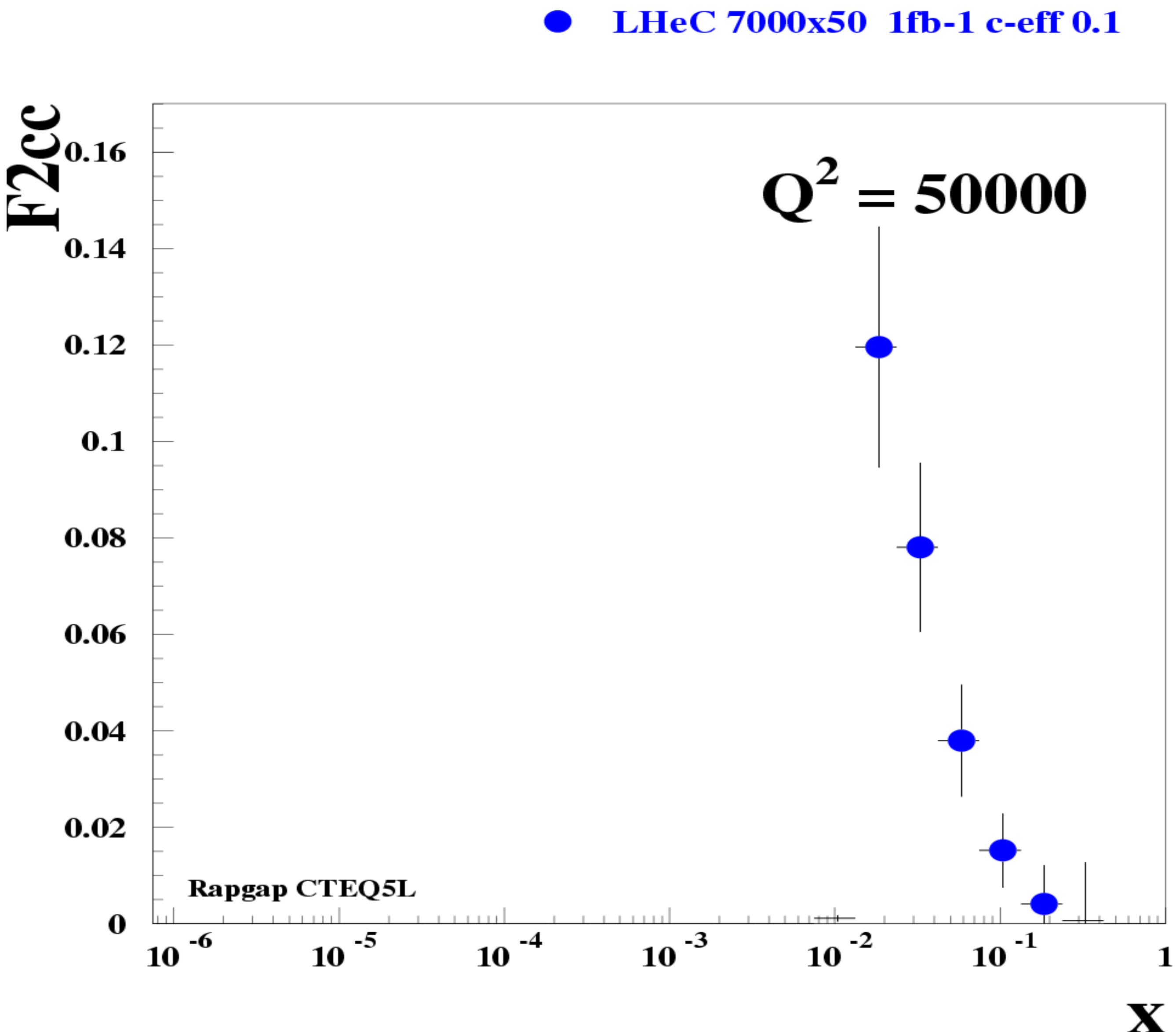




→ For same Q2 LHeC extends to much lower x

Olaf Behnke

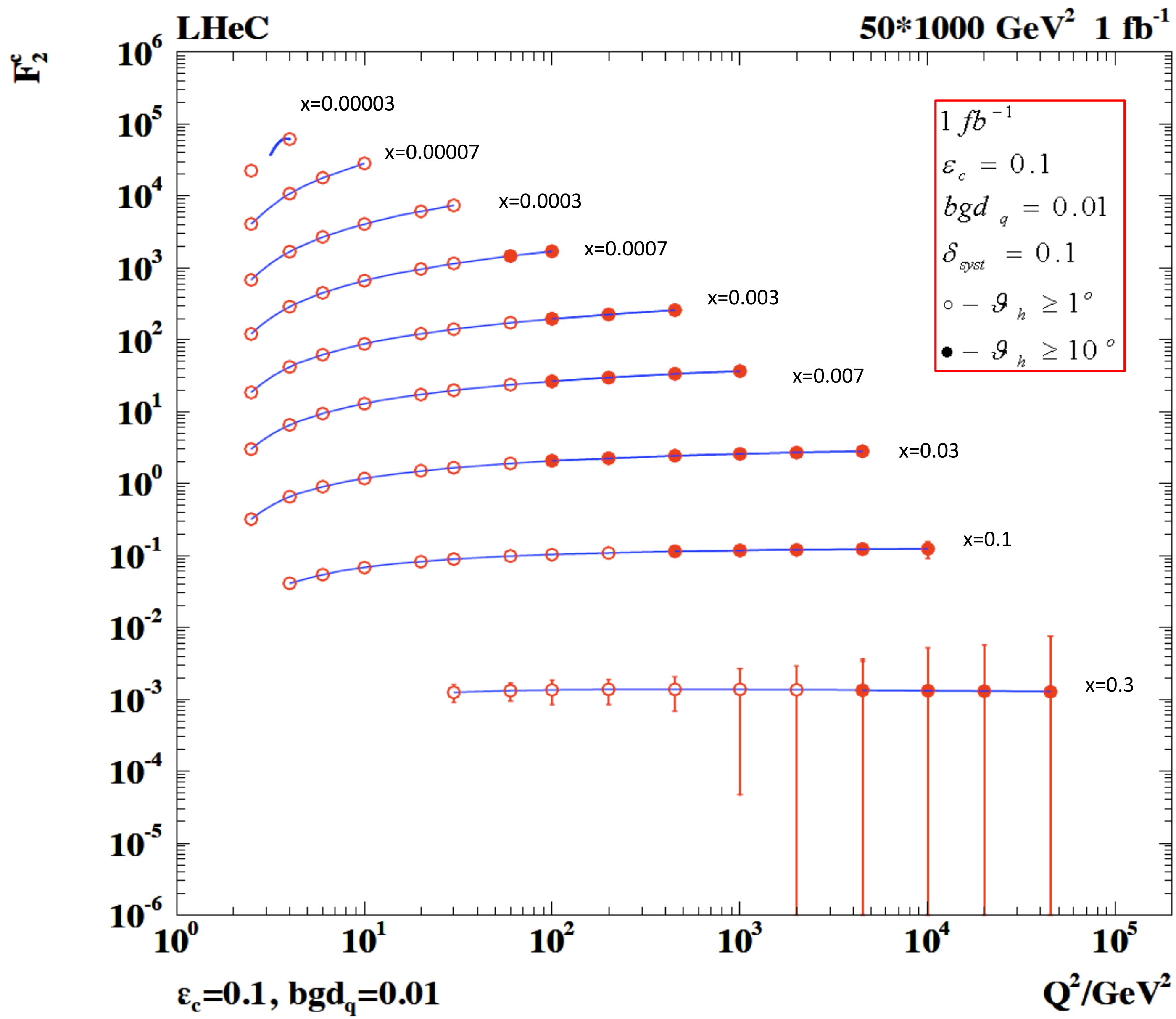
Simulation results F2cc: LheC vs HERA



➔ Up to where we can go…

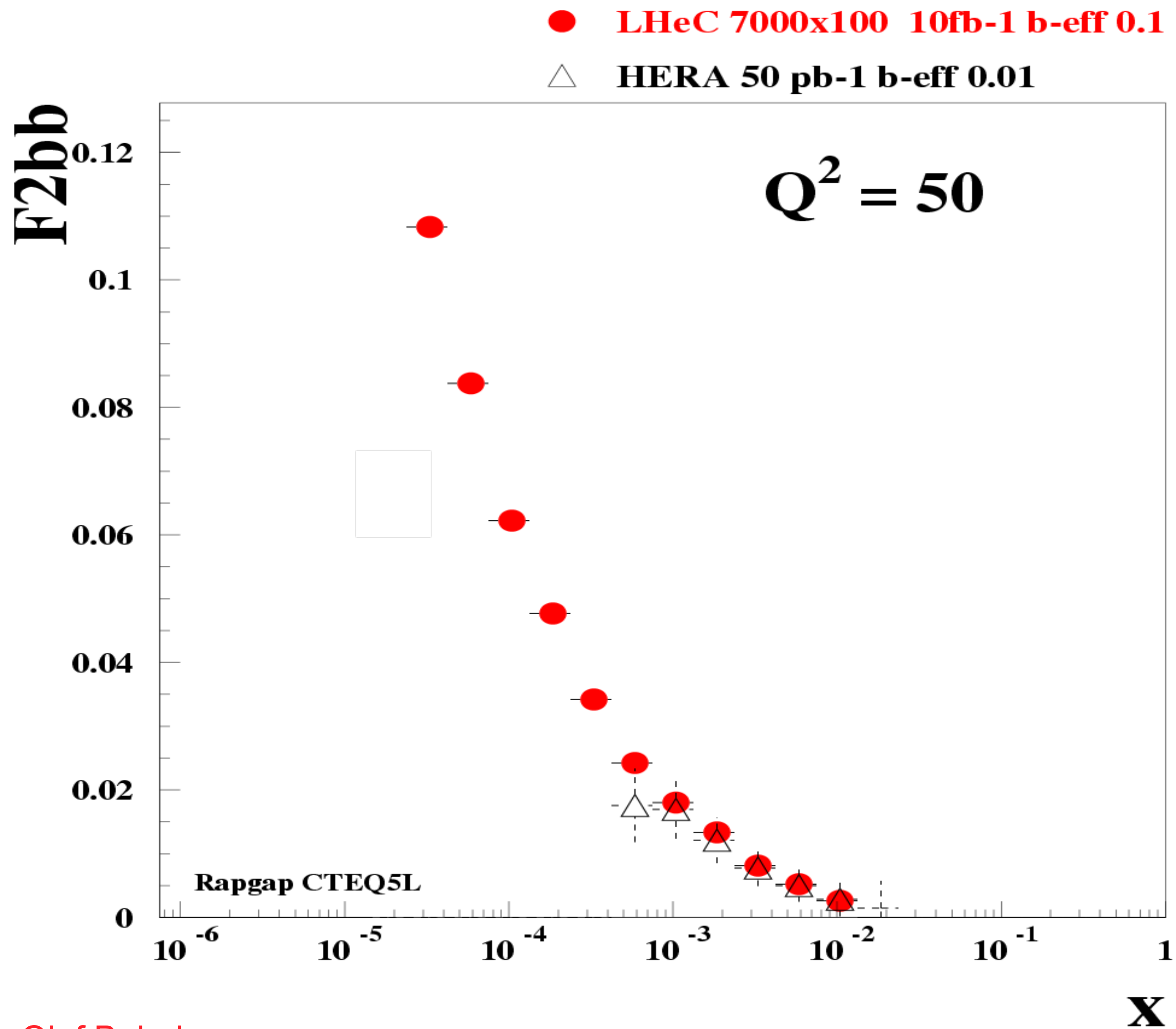
New study: Try to see charm at large x

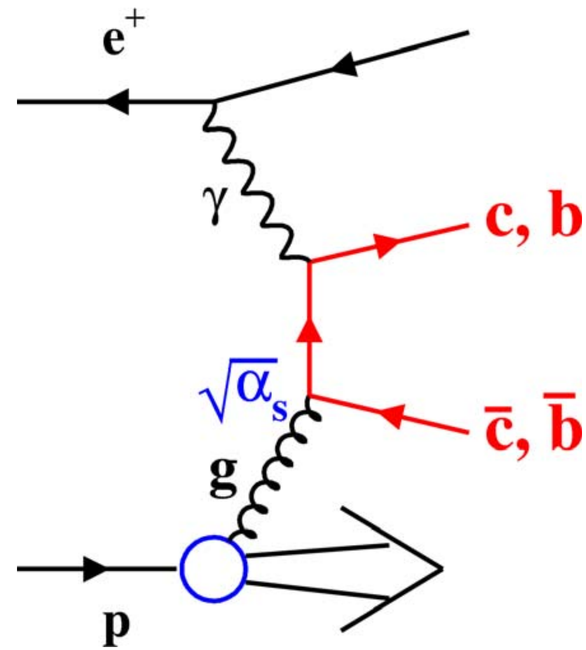
Max Klein



➔ Even in the most favourable beam energy scenario it will be quite a challenge to measure F2cc for x>0.1, where intrinsic charm would be expected

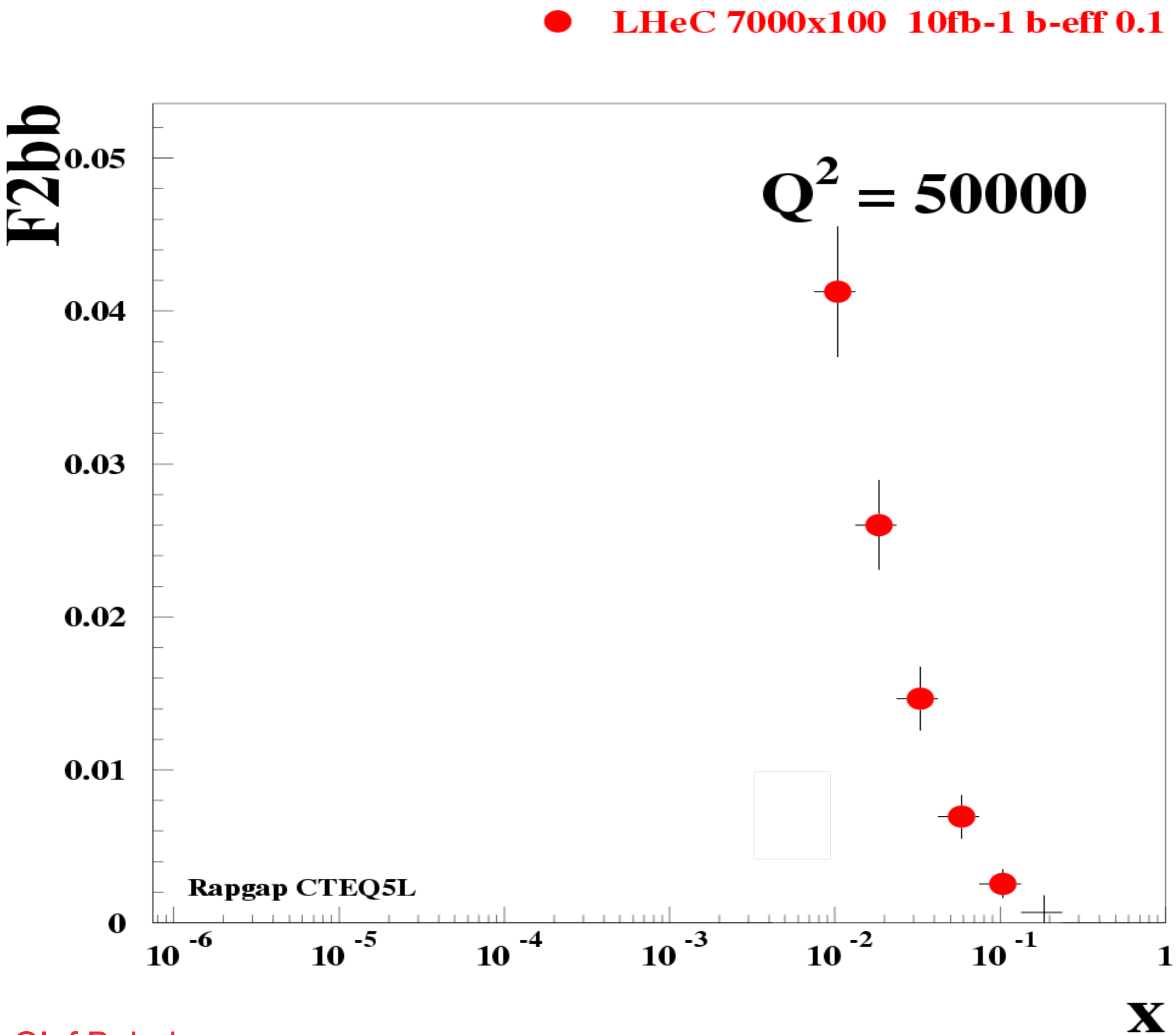
Rapgap 31 simulation results F2bb: LheC vs HERA





➔ For same Q2 LHeC extends to much lower x

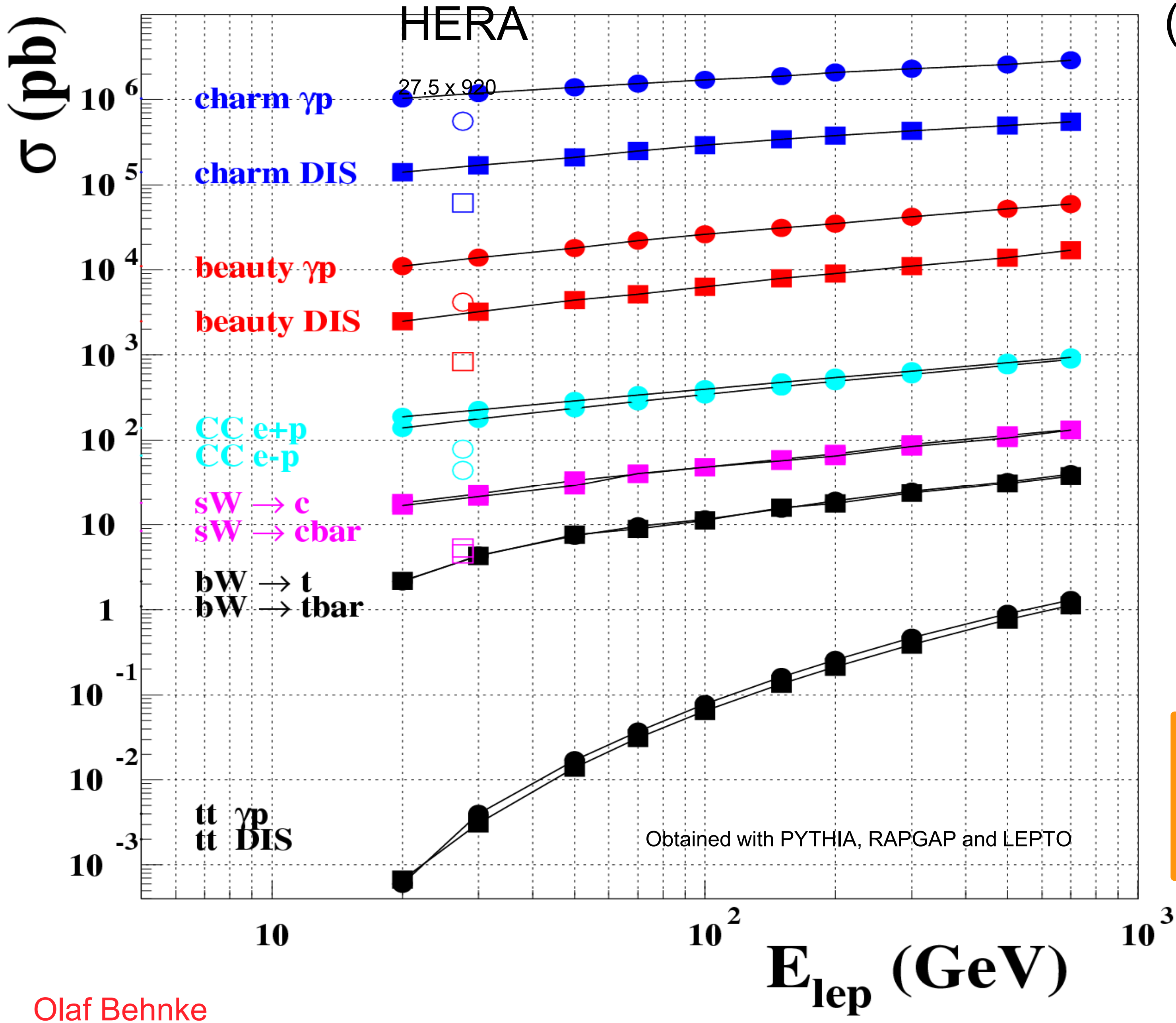
Simulation results F2bb: LheC vs HERA



➔ Up to where we can go…

Olaf Behnke

LHeC total cross sections (MC simulated)



vs lepton energy
(Ep = 7 TeV)

Charm

Beauty

cc

sW-> c

bW->top

ttbar

➔Expect many unique samples at an LHeC

Olaf Behnke

Summary

Quote Max Klein (talk sep 02, 2008 at LHeC workshop in Divonne):
“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.”

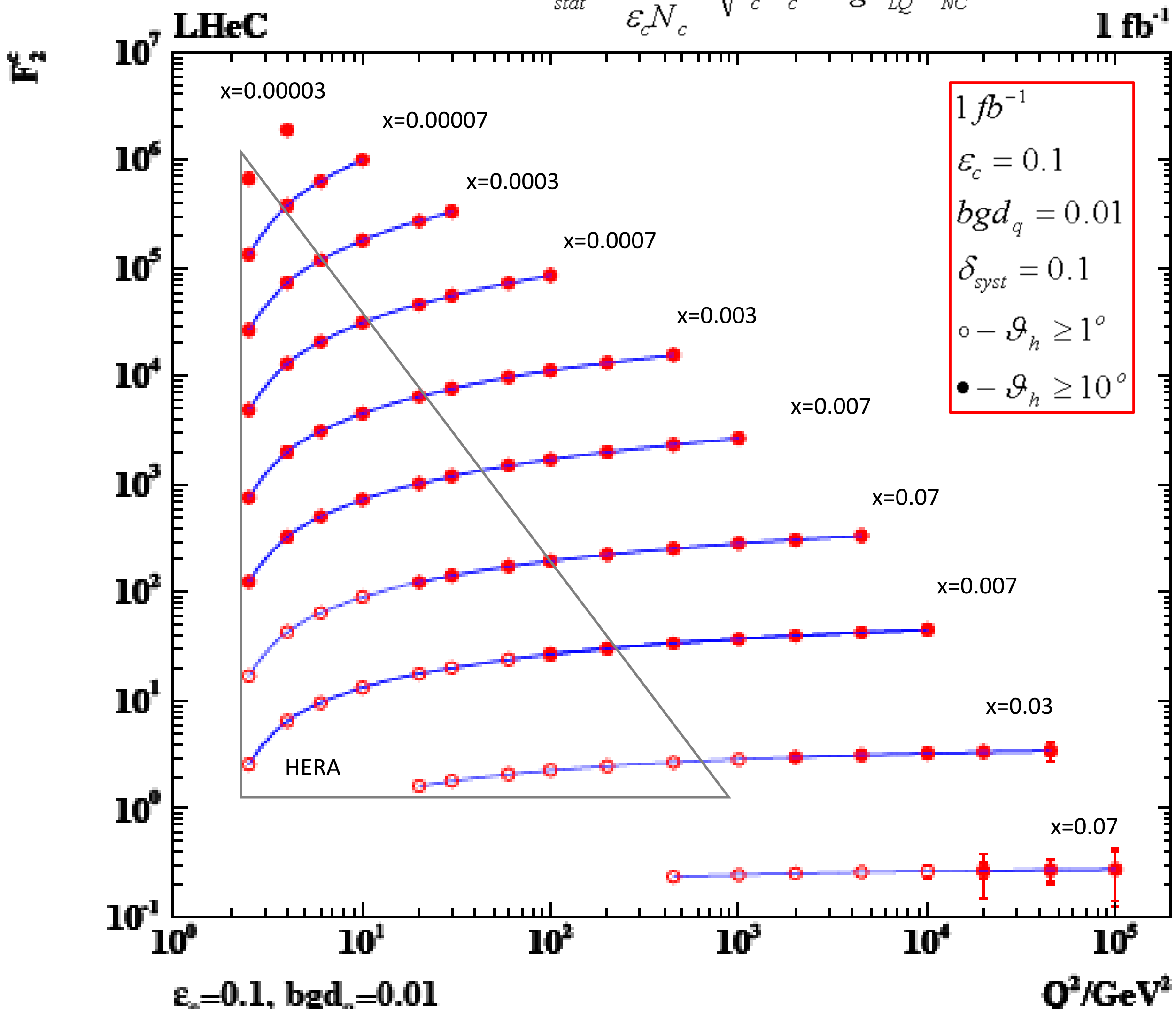
Large x>0.1 programme necessiates excellent forward hadronic calorimetry and control of hadronic energy scale to <= 1 %.

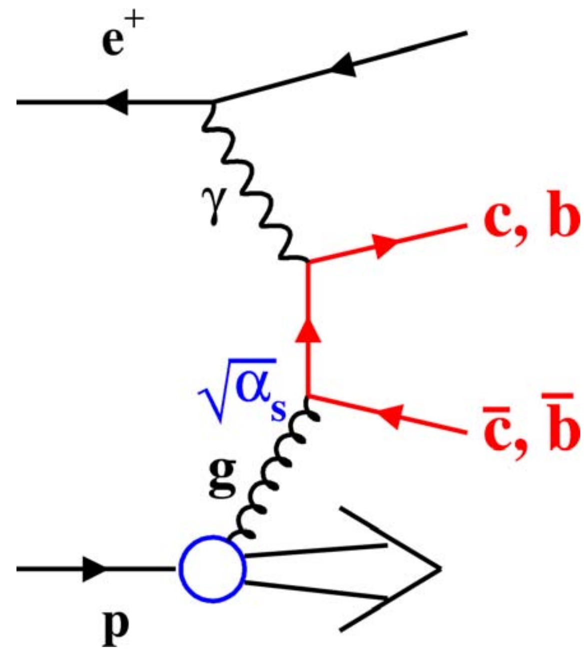
First fits to LHeC pseudodata: demonstrate a high precision potential for electroweak physics, e.g. for the light quark couplings to the Z boson and for the W propagator mass. ***What can we do else, e.g. using heavy quark identifcation? Further inspirational ideas and studies are welcome!***

Backup slides

70 GeV x 7 TeV: Charm contribution to inclusive DIS: F_2^{cc}

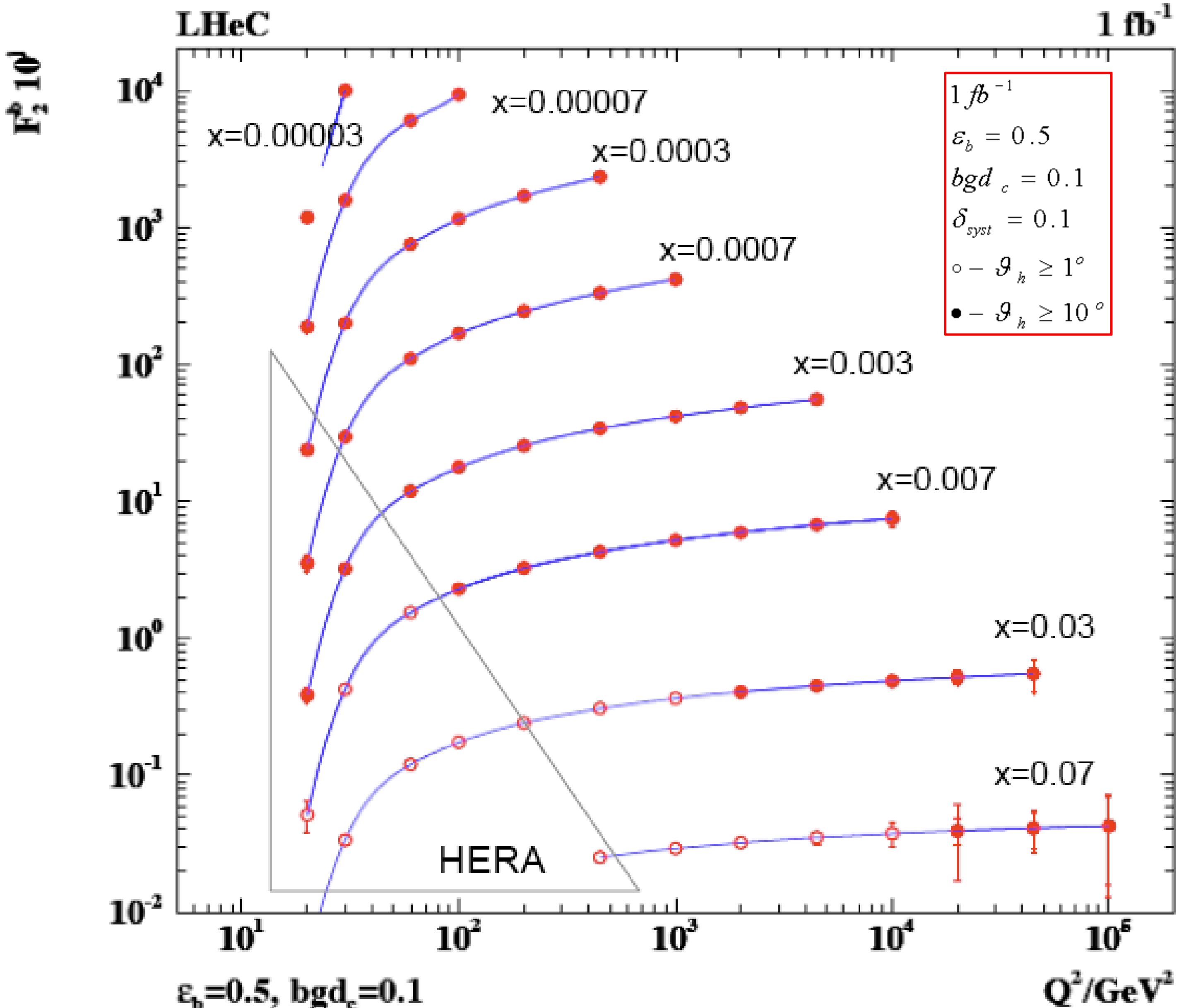
$$\delta_{stat} = \frac{1}{\varepsilon_c N_c} \cdot \sqrt{\varepsilon_c N_c + bgd_{LQ} N_{NC}}$$





M. Klein, A. Mehta

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



M. Klein,
A. Mehta

Proton PDFs

Claire Gwenlan

$Q^2 = 100$ GeV^2

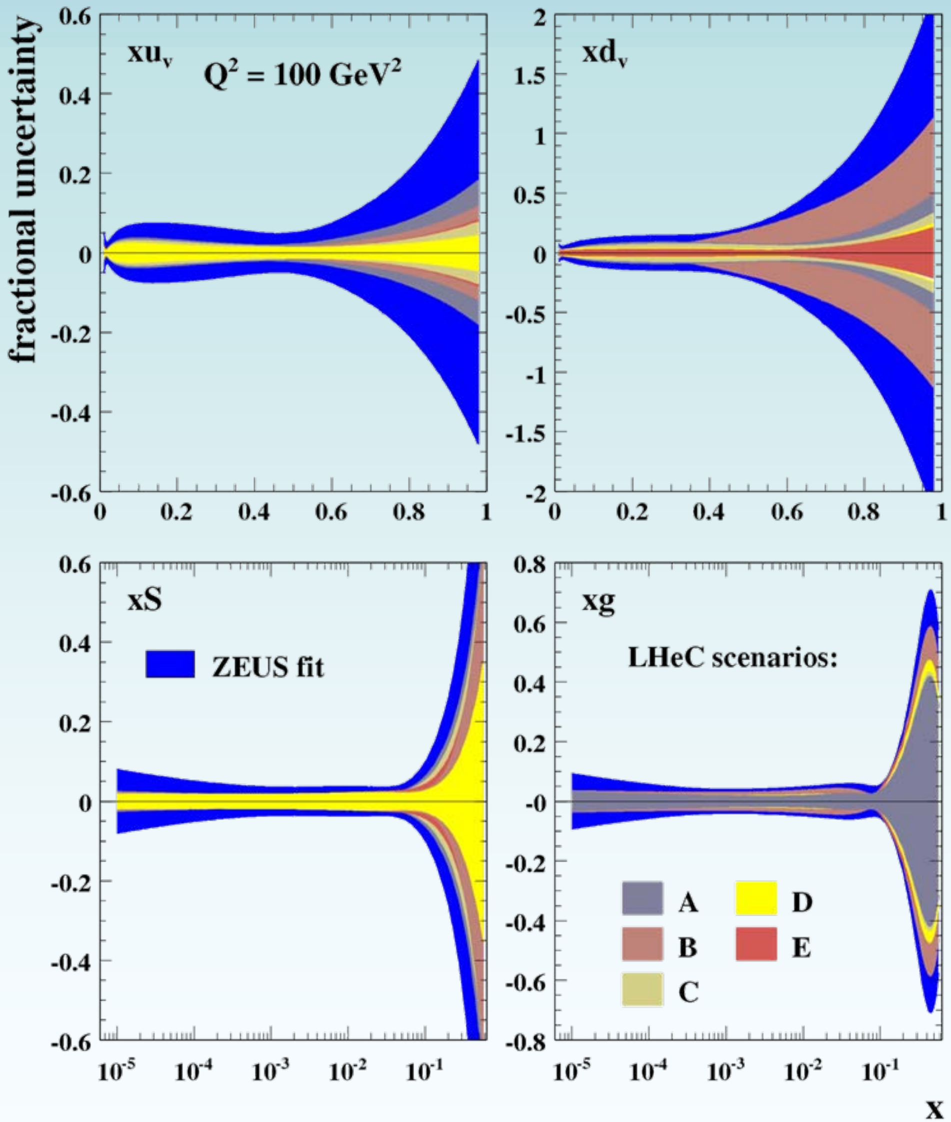
scenario D

» <u>only</u> 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)



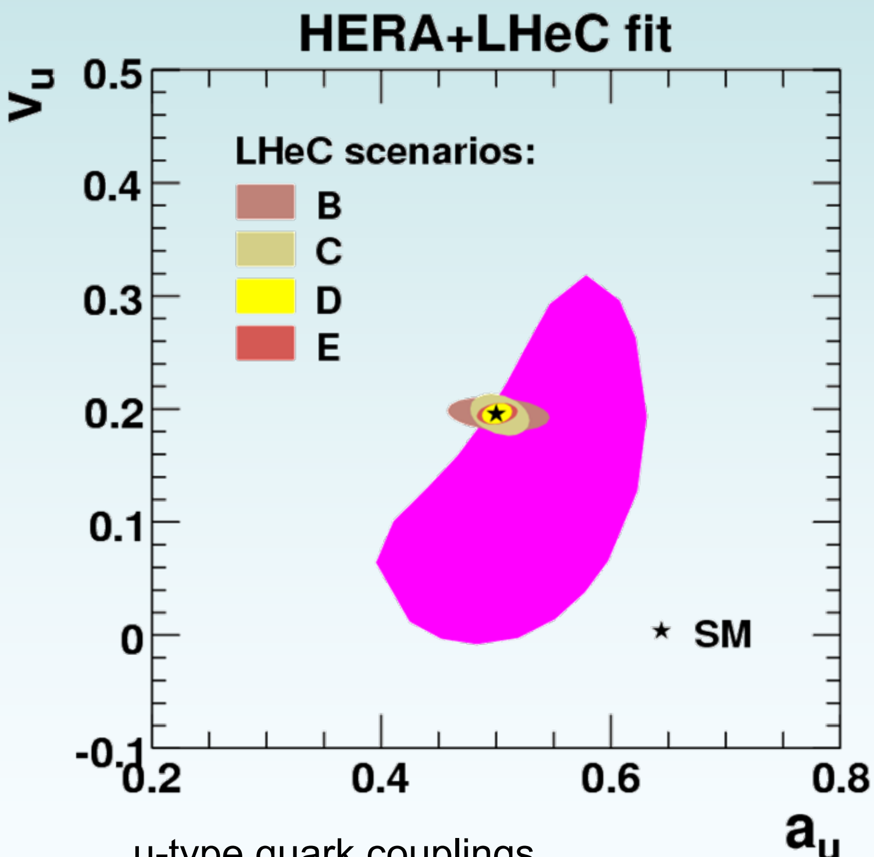
* acceptance for scenario B has been taken to be: 10 < θ < 170°

neutral current quark couplings

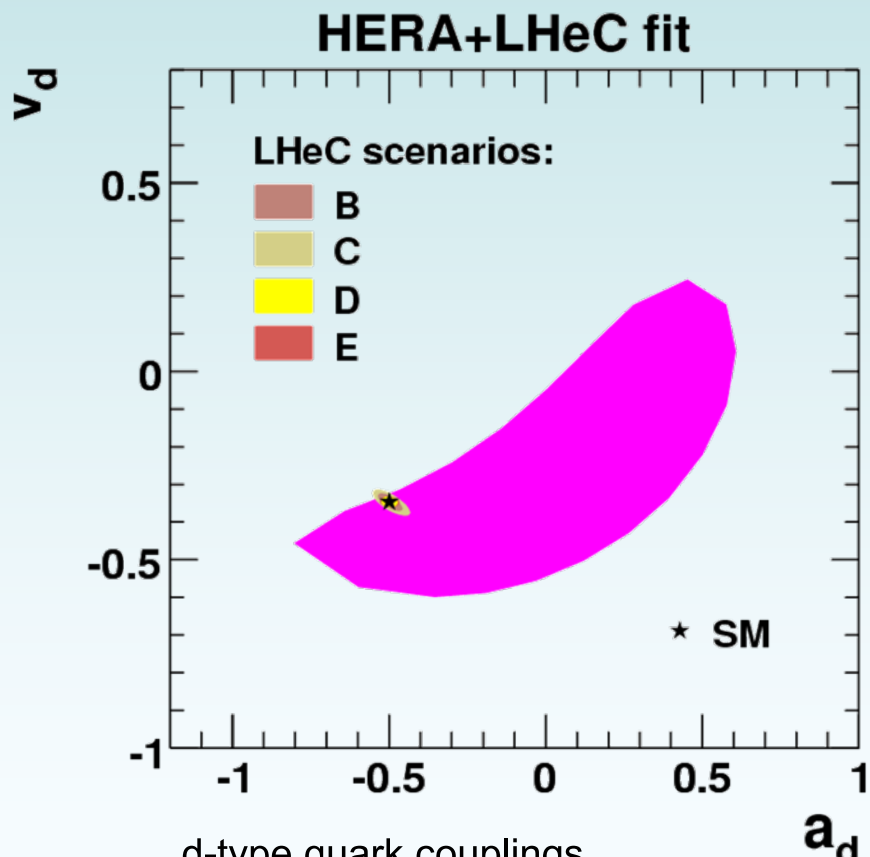
polarisations:
$P_e = \pm 0.4$ **(B,C)**
$P_e = \pm 0.9$ **(D,E)**

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

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



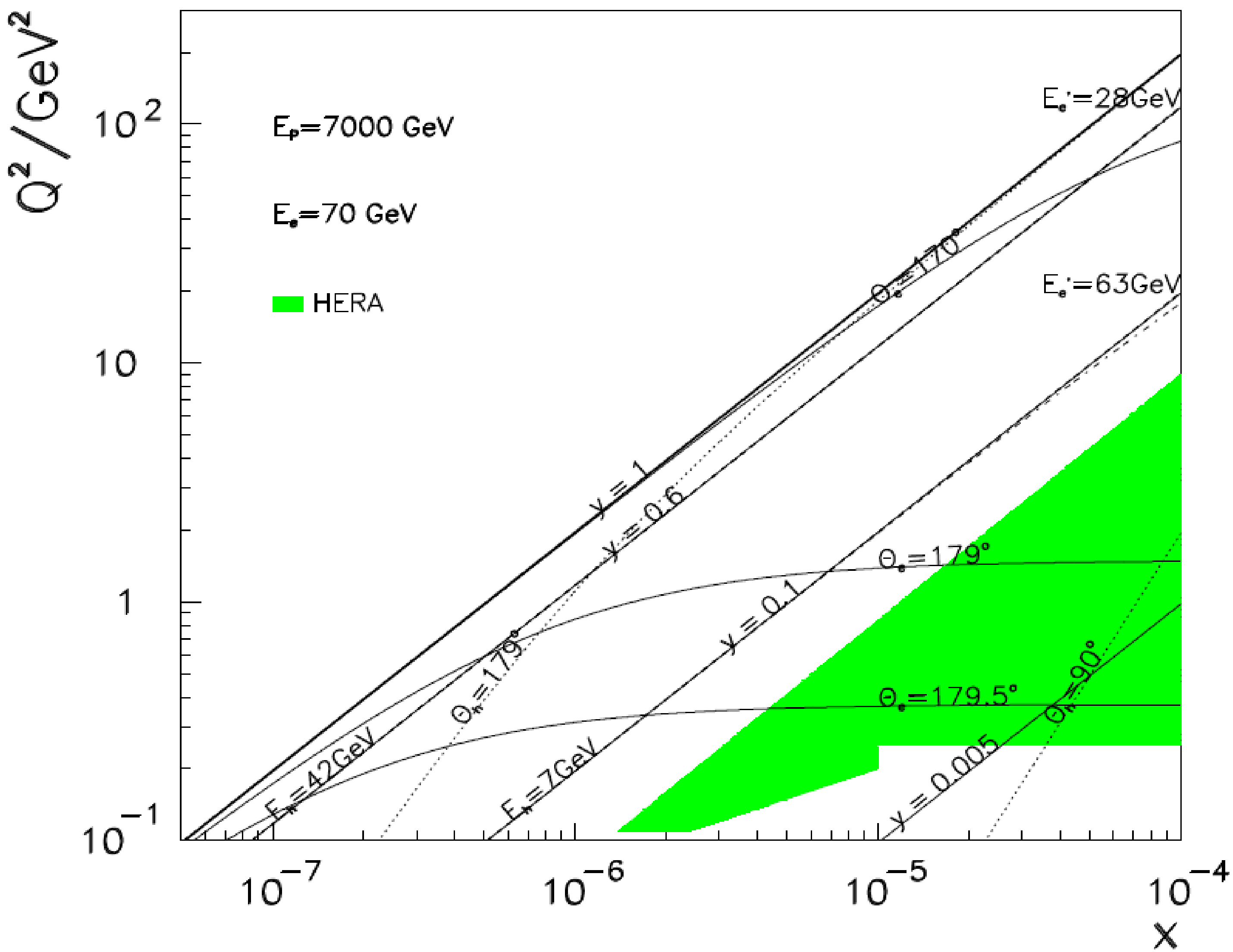
u-type quark couplings



d-type quark couplings

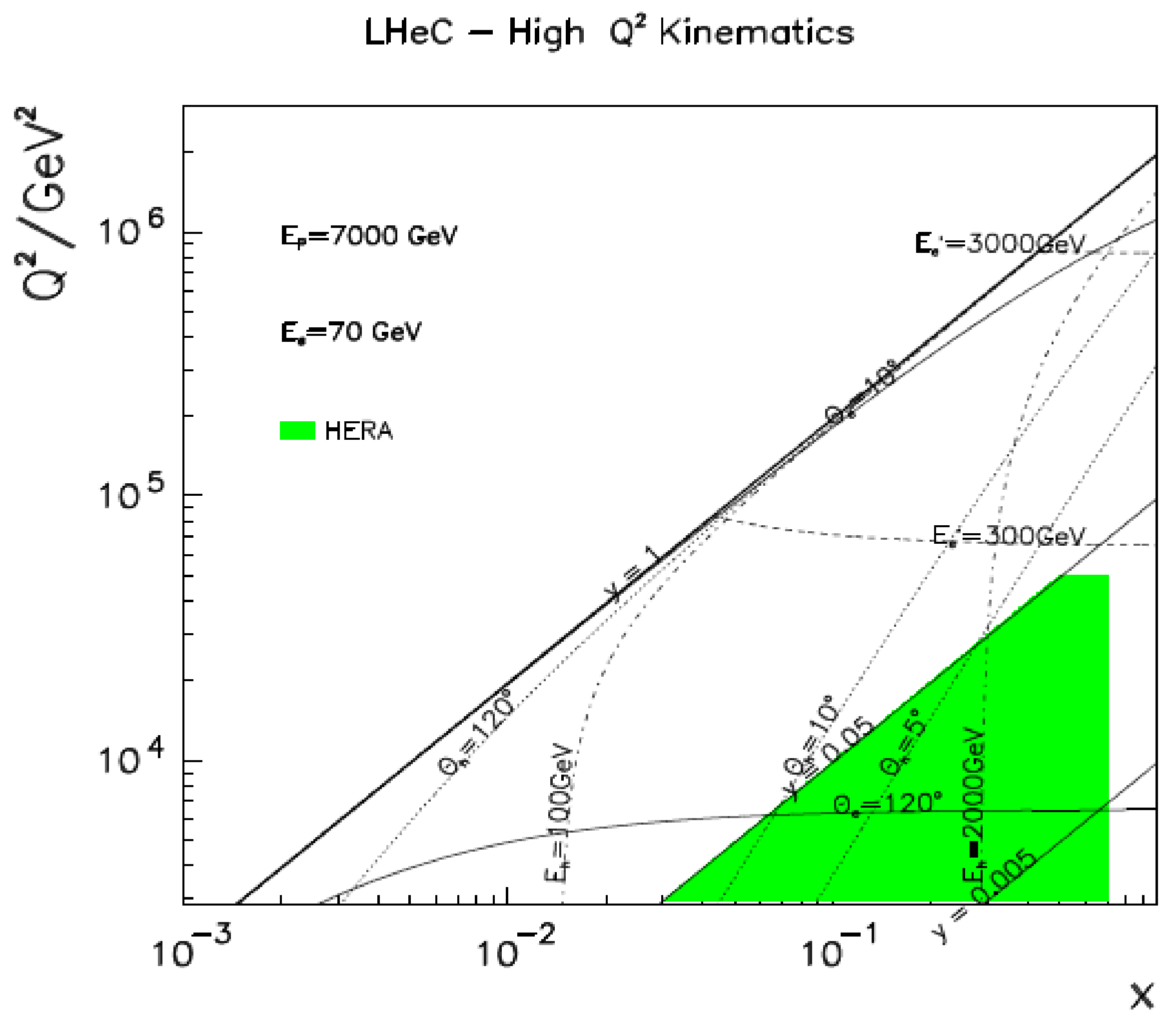
Claire Gwenlan

LHeC – Low x Kinematics



10^5 events per pb^{-1} for $Q^2>100$
Lumi 'easy'

Dramatic extension of low x kinematic range



Maximum luminosity in JINST06 design achieved with focusing magnets close to IP (9^o cut) two detectors or detector versions required
Low x with 10^{32} , high Q^2 with 10^{33} , about

LHeC, HERA and EIC