Nuclear Parton Distributions with the LHeC

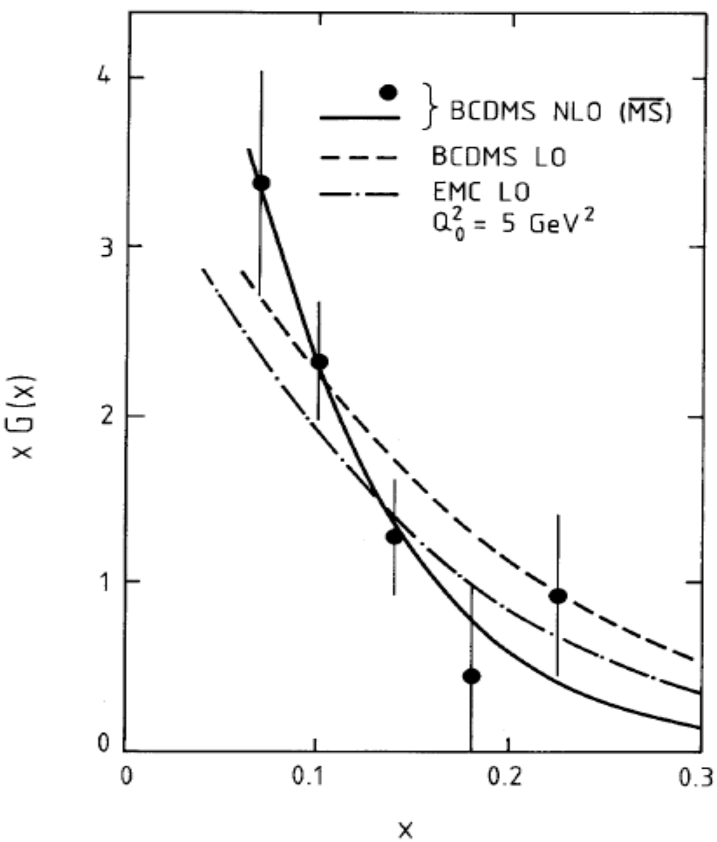
Max Klein
CERN and U Liverpool

(n)PDFs without an eh collider
The potential and simulations of the LHeC
The LHeC Detector
Saturation without nuclei
Deuterons
The non-universality of (anti)shadowing effects
Heavy Flavours in eA
An EPS type study of the LHeC

Presentation at POETIC 2015, Paris, 10.9.2015
For the LHeC Study Group, in Collaboration with
Nestor Armesto, Peter Kostka, Hannu Paukkuunen, Voica Radescu

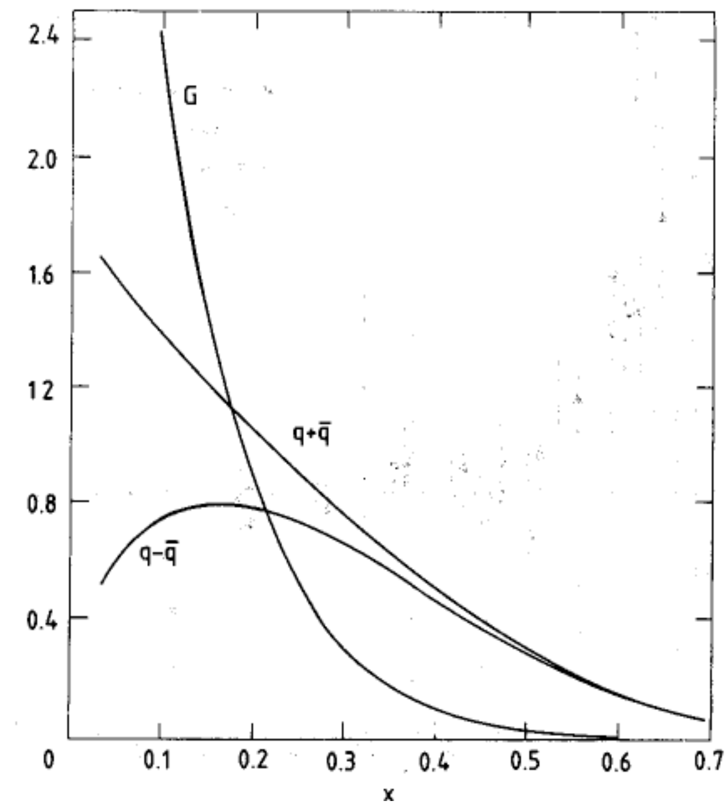
Proton PDFs before HERA

BCDMS muon-proton, also -carbon



CERN-EP/89-07
January 17th, 1989

CDHS neutrino-iron scattering



CERN-EP/89-103
15 August 1989

Parton Distributions from a Global QCD Analysis of Deep Inelastic Scattering and Lepton-Pair Production*

Jorge G. Morfin[1,3] and Wu-Ki Tung[1,2]

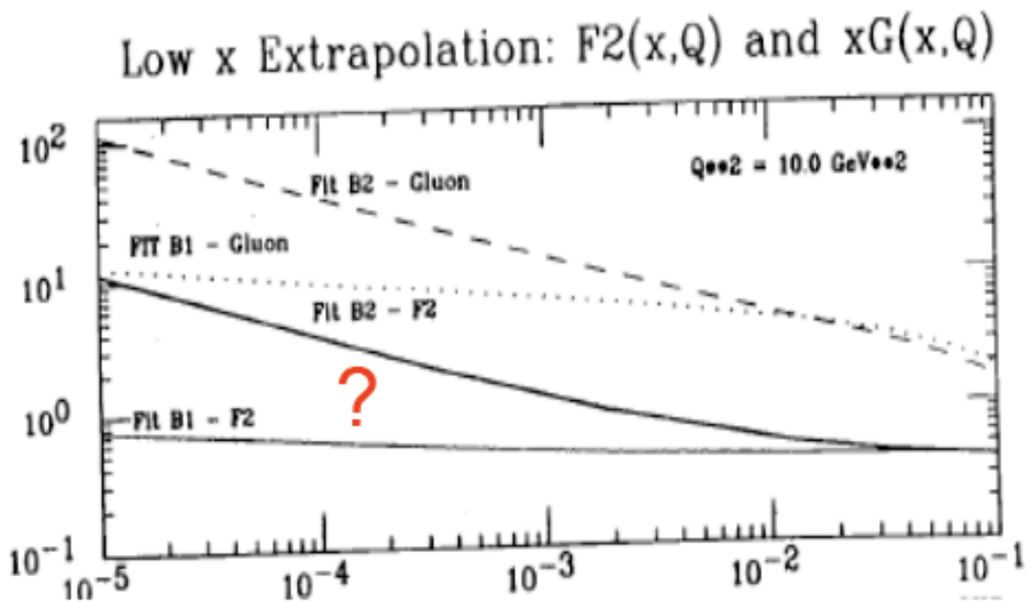
FERMILAB-Pub-90/74

April 1990

* Submitted to Z. Phys. C.

$$f(x,Q) = e^{A_0} x^{A_1} (1-x)^{A_2} \ln^{A_3} x \, \cancel{\ln^{A_4}(1-x)}$$

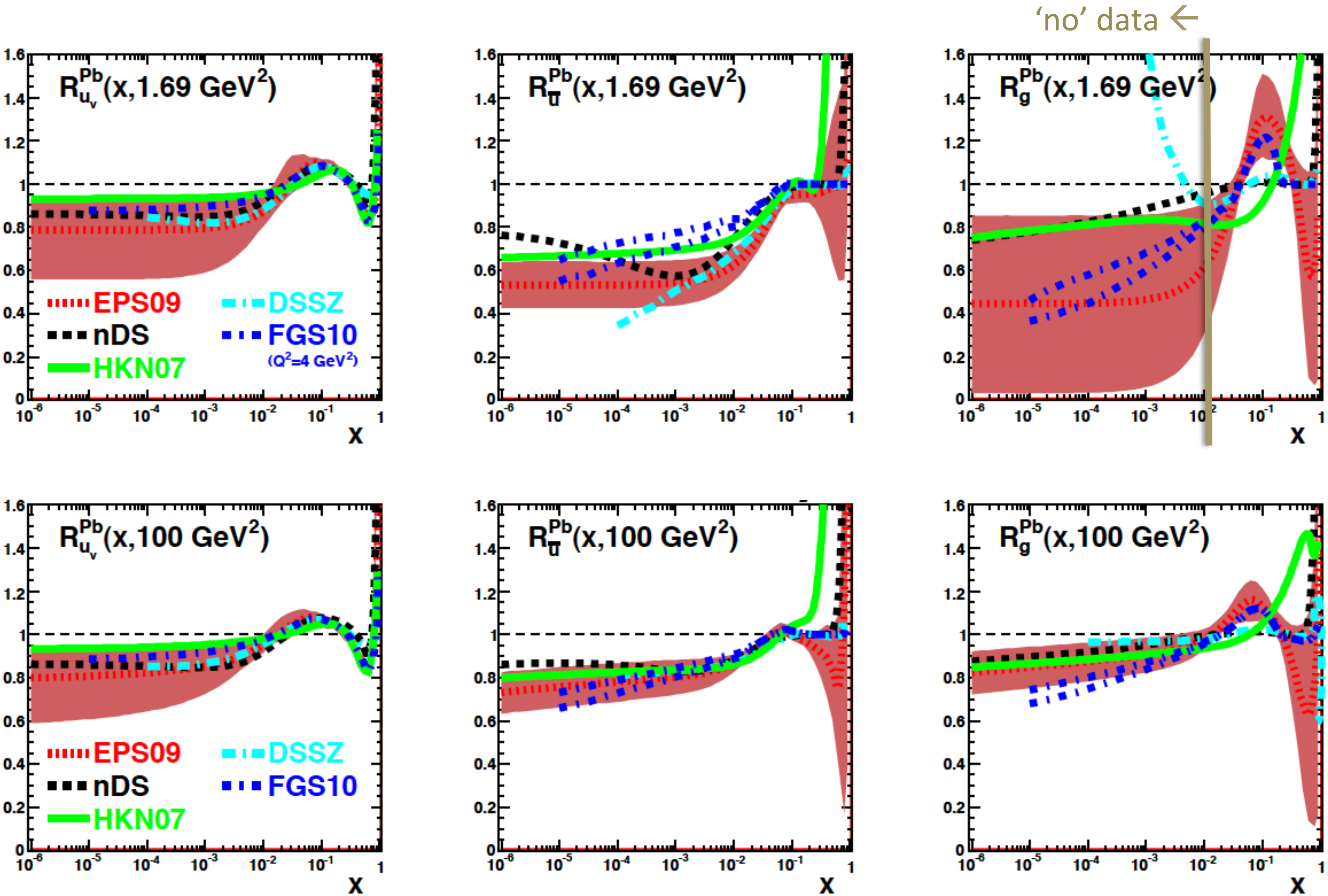
"A_1 changes rapidly with Q^2" ICHEP Singapore 1990

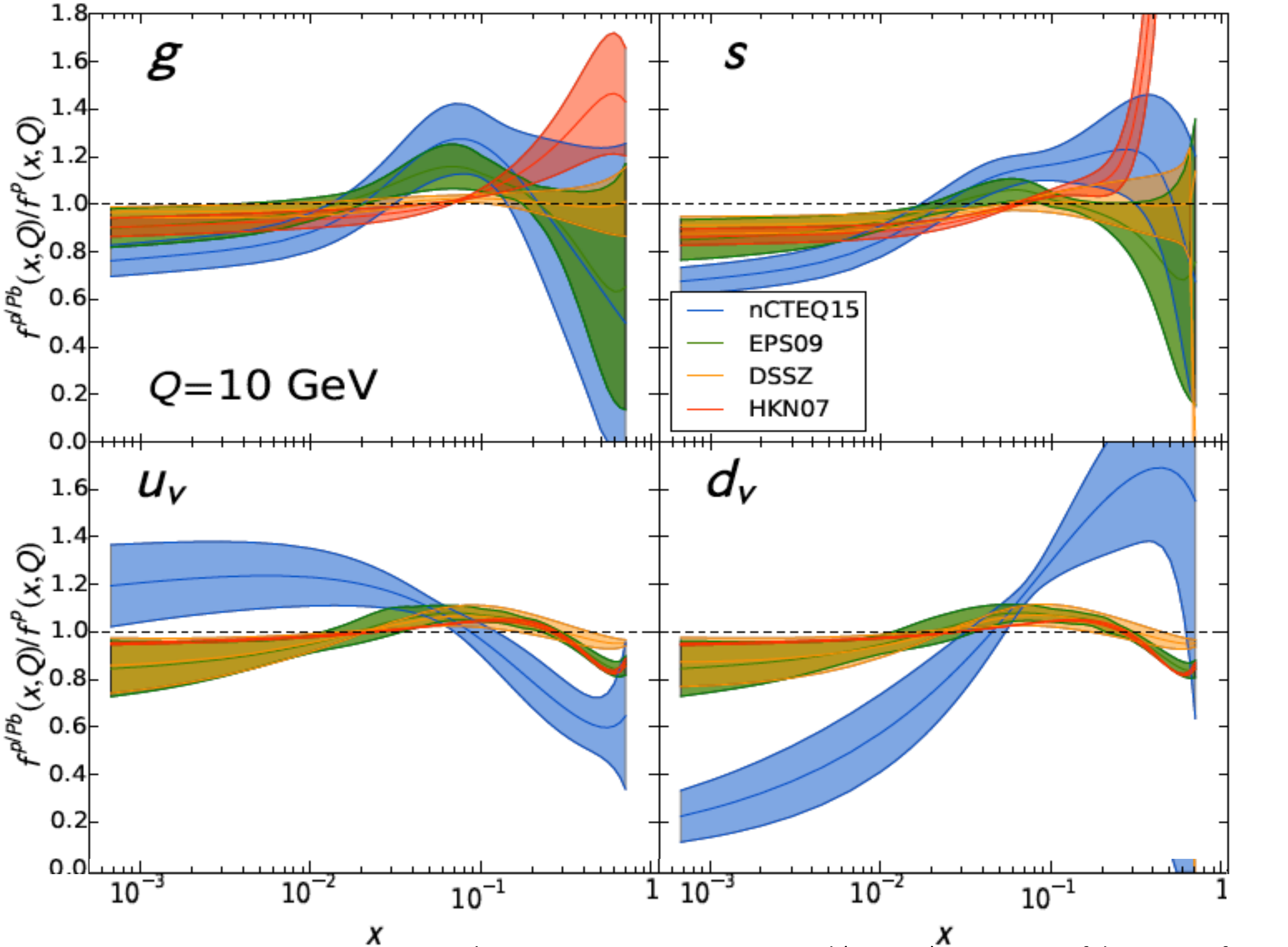


Global
Functional forms
Systematic errors
Kinematic ranges
Heavy target corr's
LO-NLO
Renorm. Schemes

No HERA
No heavy quarks
No error bands
No NNLO

In lively dispute with MRS (T)
A.D. Martin, R.G. Roberts & W.J. Stirling, Mod. Phys. Lett. A4 1135 (1989)


'no' data
$R_{u_v}^{Pb}(x,1.69\ GeV^2)$
$R_{\bar{u}}^{Pb}(x,1.69\ GeV^2)$
$R_{g}^{Pb}(x,1.69\ GeV^2)$
$R_{u_v}^{Pb}(x,100\ GeV^2)$
$R_{\bar{u}}^{Pb}(x,100\ GeV^2)$
$R_{g}^{Pb}(x,100\ GeV^2)$
EPS09
nDS
HKN07
DSSZ
FGS10
(Q^2=4 GeV^2)
x

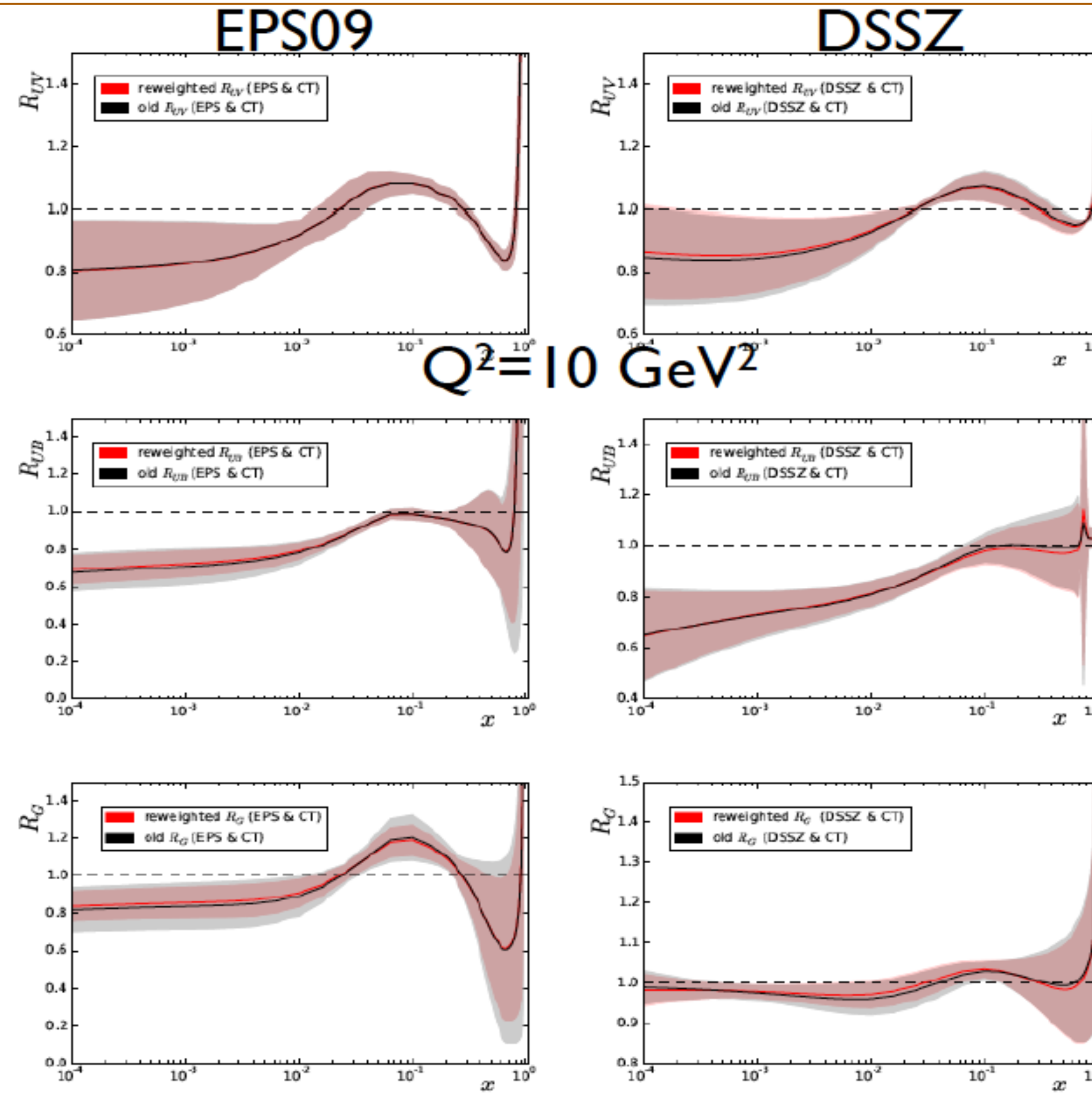


nCTEQ15: cf remarks in conclusions Extrapolation. Assumptions, unmeasured (strange), treatment of data, pions for xg..

- All in all, the effect of LHC data is rather mild.

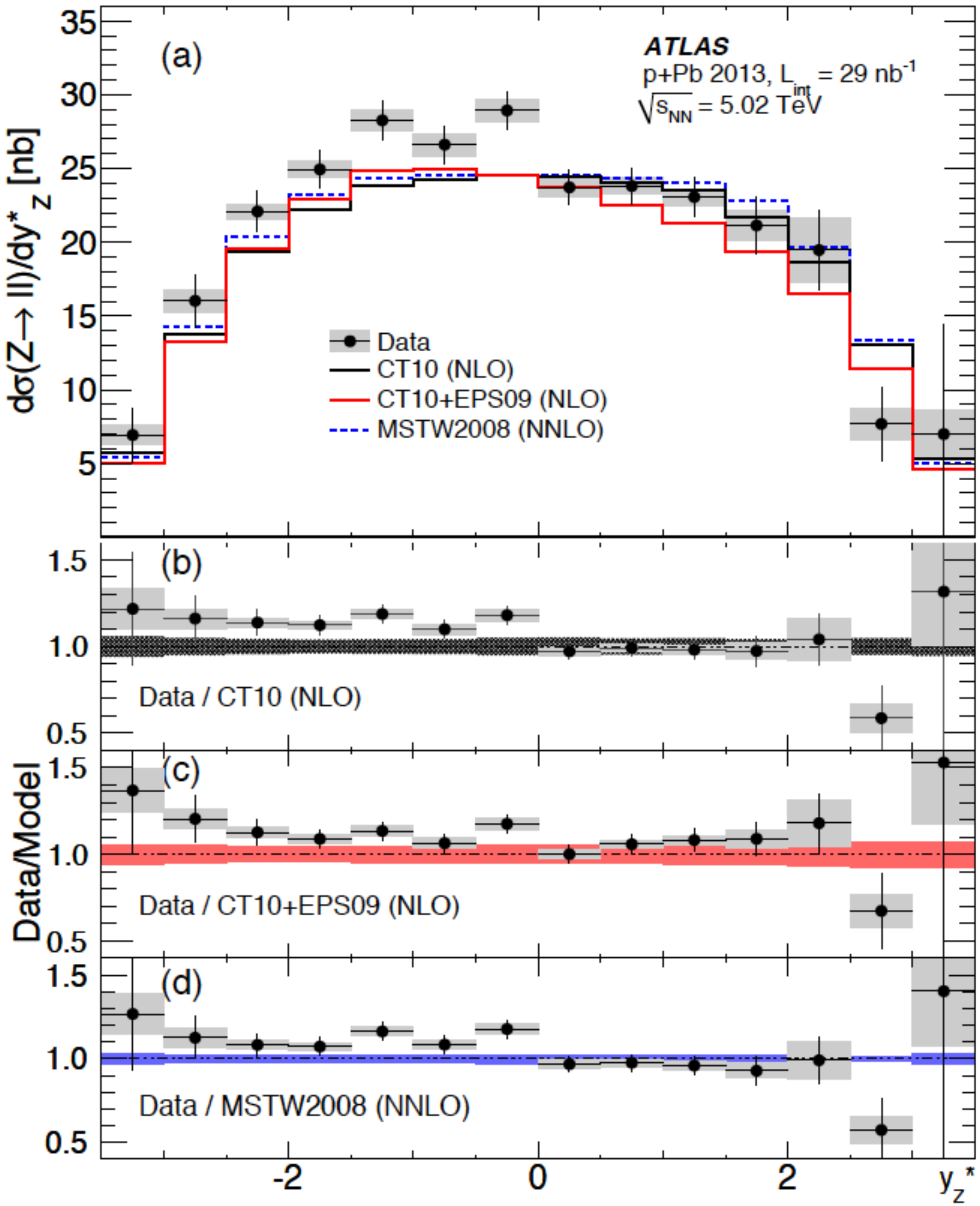
- Dijets are the most constraining, EW bosons the most promising to relax the initial condition $R_u=R_d$.

- Link PDF - nPDF clearly visible.



N. Armesto - Nuclear PDFs in eA at the LHeC

See NA's Talk at QCD at LHC, London 2.9.2015, for a detailed discussion of LHC and nPDFs
Field will develop more but there remains the principal difference between eA and p/AA..



ATLAS Z in pPB
CERN-PH-2015-146
September 6th, 2015

Z to di-lepton final state

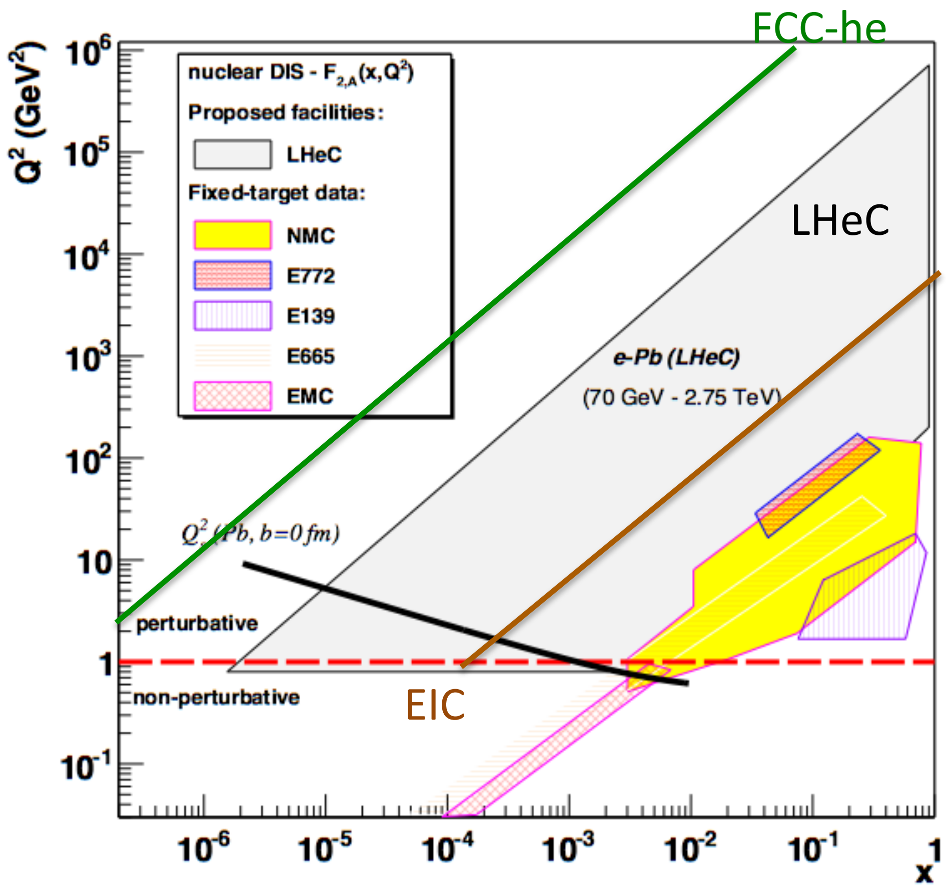
trend with nuclear corrections as are in EPS09 to better describe the y shape than without.

Z not affected by collective effects, a nice probe,
x between 0.001 and 0.2
at 5 TeV cms
but at $Q^2=10^4$ GeV^2

Surprise that pPb showed collective features as PbPb

item	HKN07	EPS09	DSSZ	nCTEQ	LHeC
Reference	Phys. Rev. C76 (2007) 065207	JHEP 0904 (2009) 065	Phys.Rev. D85 (2012) 074028	arXiv: 1509.00792	Workshops + this talk PRD(2030+)
Order pQCD	LO & NLO	LO & NLO	NLO	NLO	NNLO
NC e+A / e+d DIS	√	√	√	√	NC
Drell-Yan ll in p+A / p+d	√	√	√	√	--
RHIC pions in d+Au / p+p		√	√	√	--
Neutrino-nucleus DIS			√		CC
$\sqrt{Q^2}$ cut in DIS	1 GeV	1.3 GeV	1 GeV	2 GeV	free
# of data points	1241	929	1579	740	many
Free parameters	12	15	25	17	O(20)
Error sets available		√	√	√	(y)
Error tolerance $\Delta\chi^2$	13.7	50	30	35	1
Baseline	MRST98	CTEQ6.1	MSTW08	CTEQ6M?	None – or ep+eD+eA
Heavy quark treatment	ZM_VFNS	ZM_VFNS	GM_VFNS	GM_VFNS	s,c,b data

LHeC-FCC-he as Electron Ion Collider(s)



LHeC is part of NuPECCs long range plan since 2010
$L_{eN} \sim 10^{32}\ cm^{-2}\ s^{-1}$

Extension of kinematic range in lA by 4-5 orders of magnitude will change QCD view on nuclear structure and parton dynamics

May lead to genuine surprises…

- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

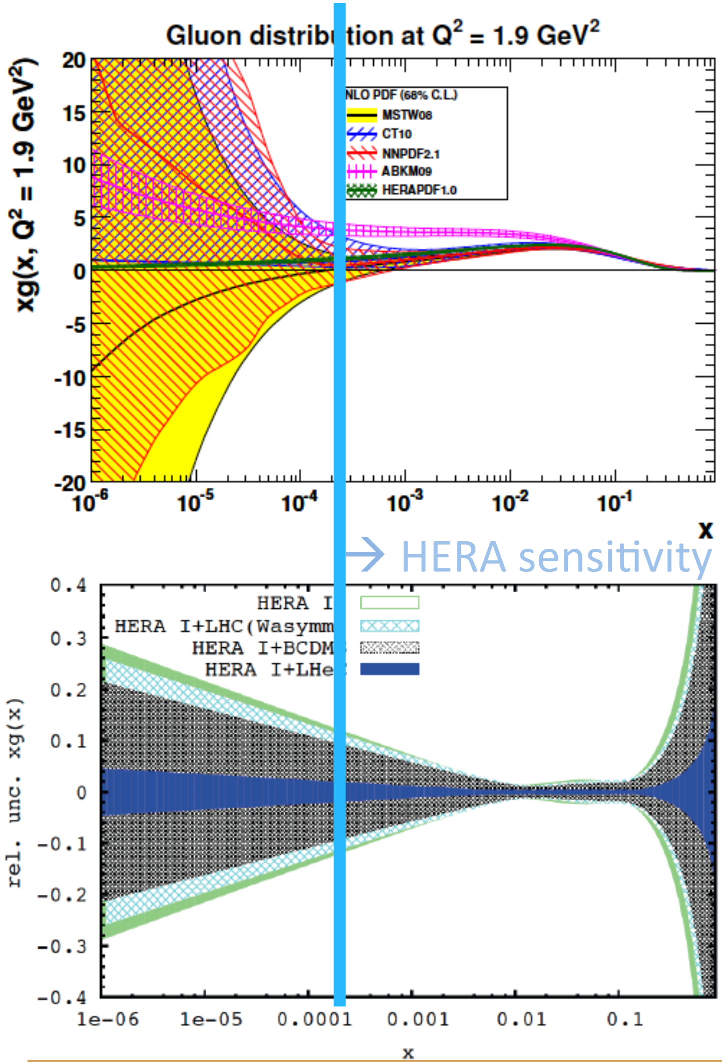
Expect saturation of rise at

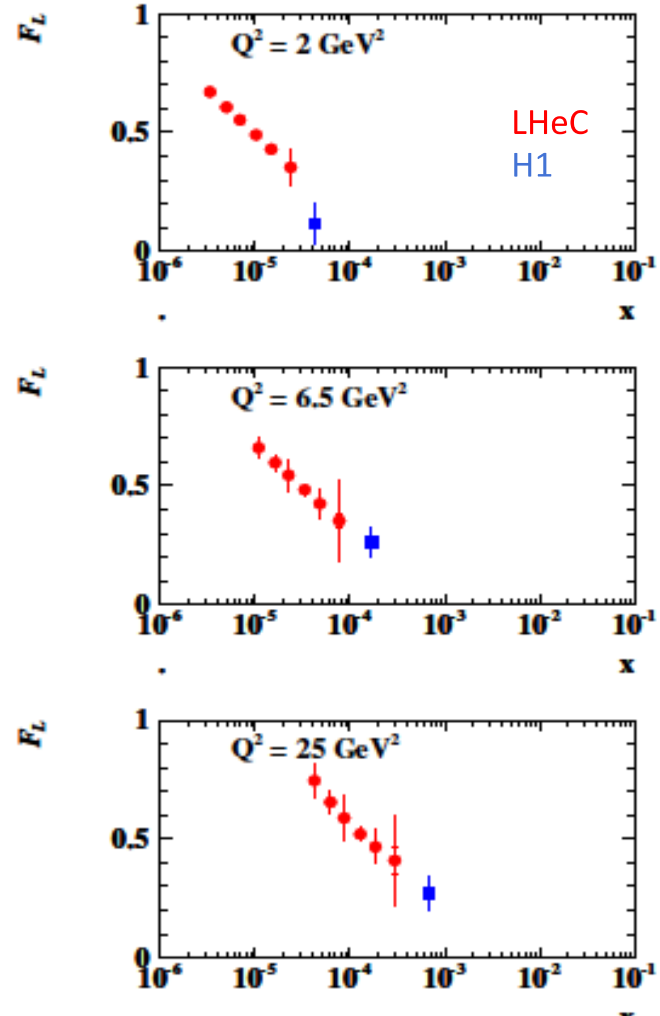
$$Q^2_s \approx xg\,\alpha_s \approx c\, x^{-\lambda} A^{1/3}$$

Note that the gluon is valence like at low Q^2

Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

Gluon Saturation at Low x? using only ep



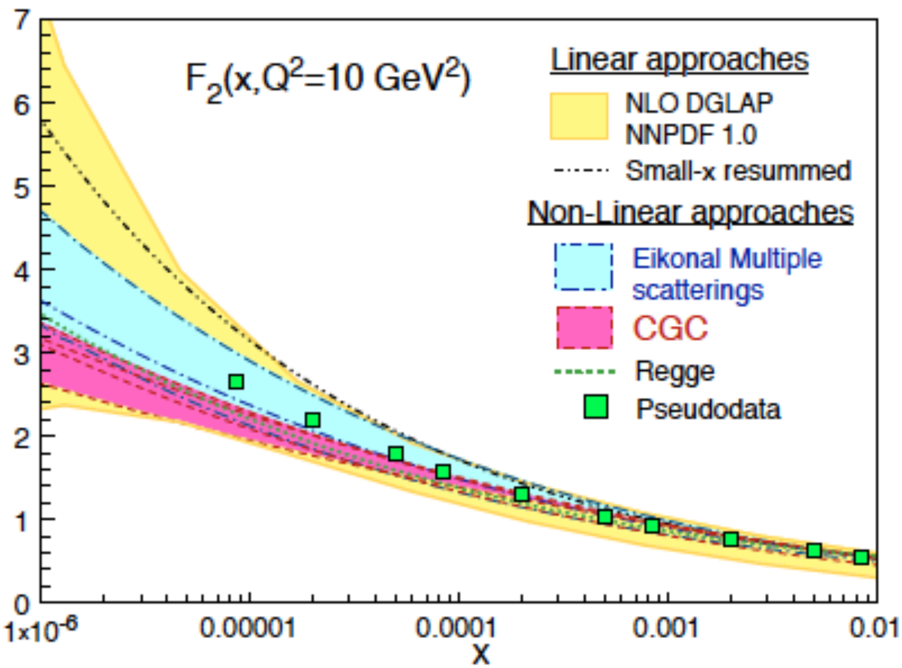


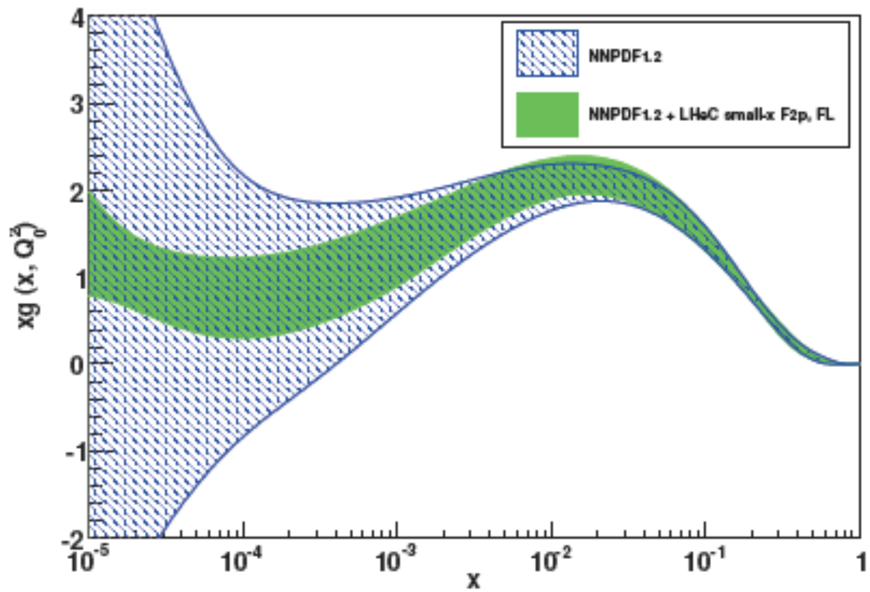
Gluon measurement down to $x=10^{-5}$, **Saturation or no saturation** (F_2 and precise F_L)
Non-linear evolution equations? Relations to string theory, and **SUSY at ~10 TeV**?

cf H.Kowalski, L.Lipatov, D.Ross, arXiv:1205.6713

Partons at low x

Studies within NNPDF (CDR 8/12)





High precision F_2 and F_L pin down low x phenomenology and determine the gluon distribution down to $x \sim 10^{-5}$

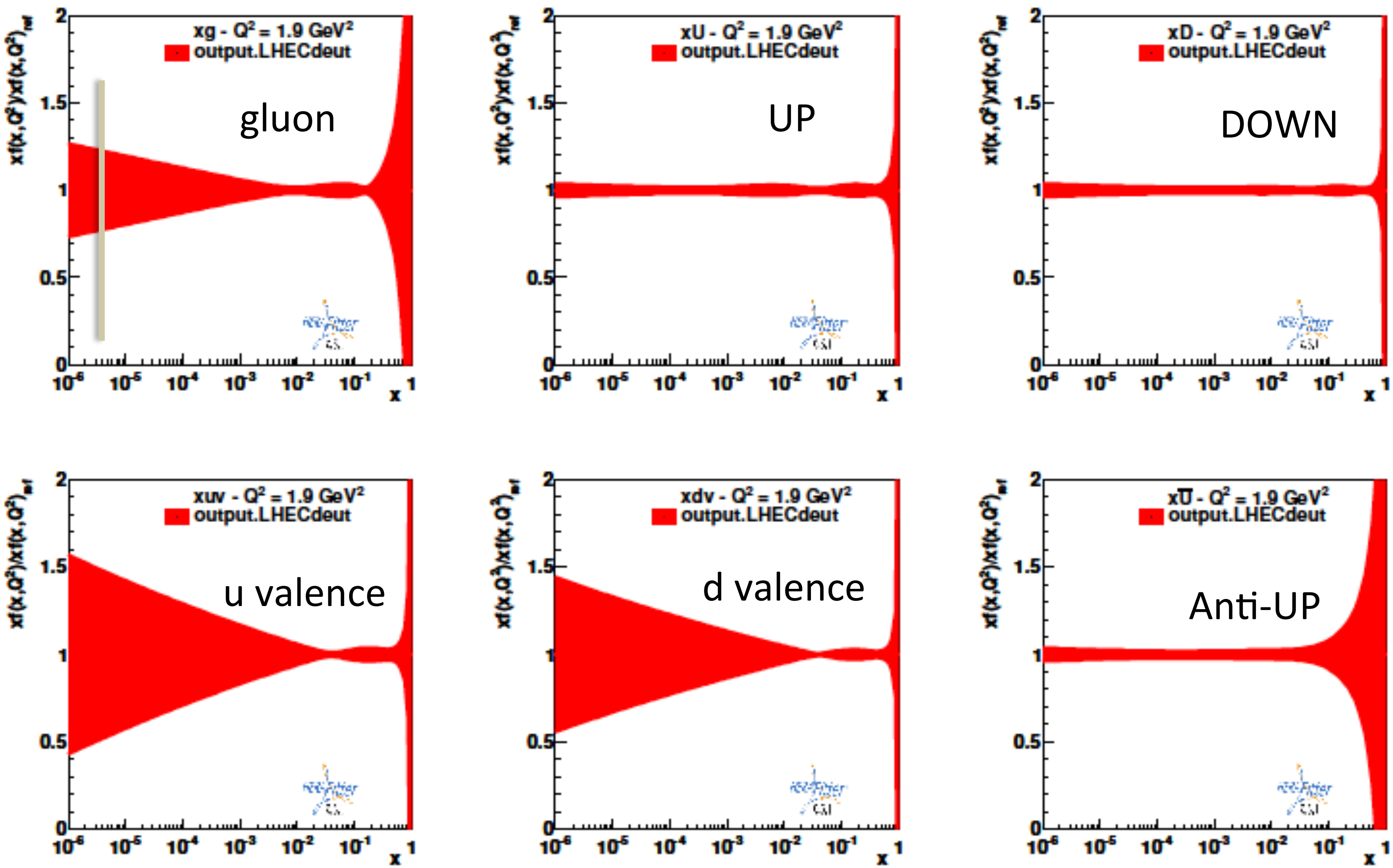
Simulation

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 %

Full simulation of NC and CC with correlated systematic errors and optimum kinematic reconstruction method (electron at large y and 'mixed' at low y).
Numerical program, gauged/compared to H1 Monte Carlo simulation.
→ **All results have statistical and systematic uncertainty (corr+unc)**
The so-called model uncertainties at the LHeC will be much reduced as it provides precision data (CC for flavours, mc to 3 MeV, extended range, high x with high statistics etc.)
RC in eA is large source of uncertainty, needs photon tagger, still E-pz : 2%
For the simulation of the s,c,b data, background and tag efficiencies are considered

Standalone eD analysis – the forgotten neutron..

3.5 TeV x 60 GeV, e-, P=-0.8, 1fb-1 Neutral and Charged Current, exp uncertainties

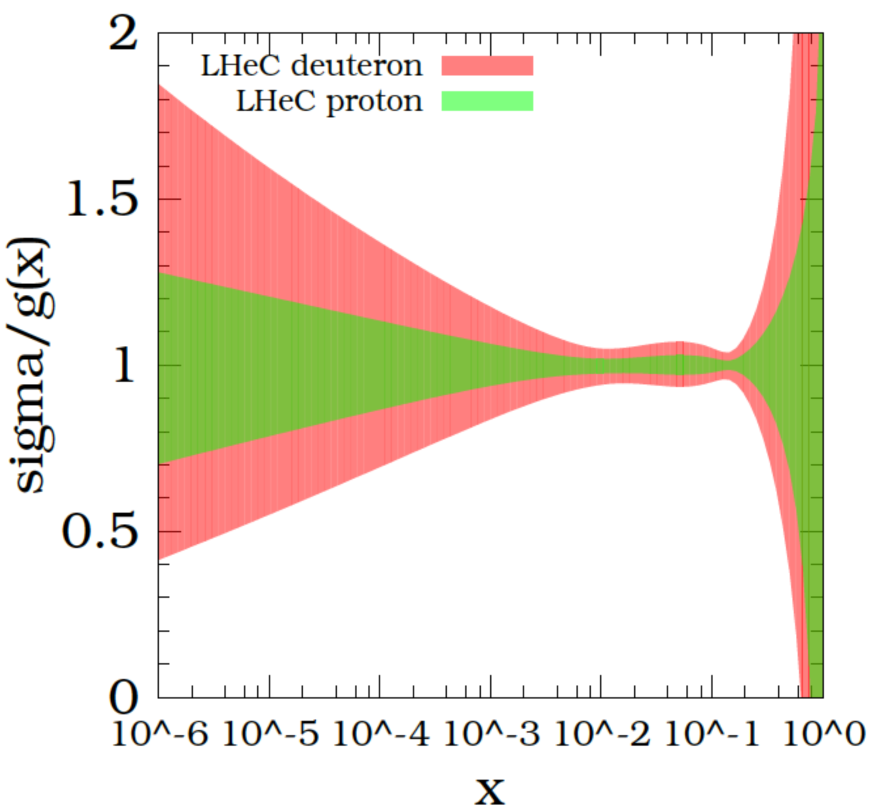


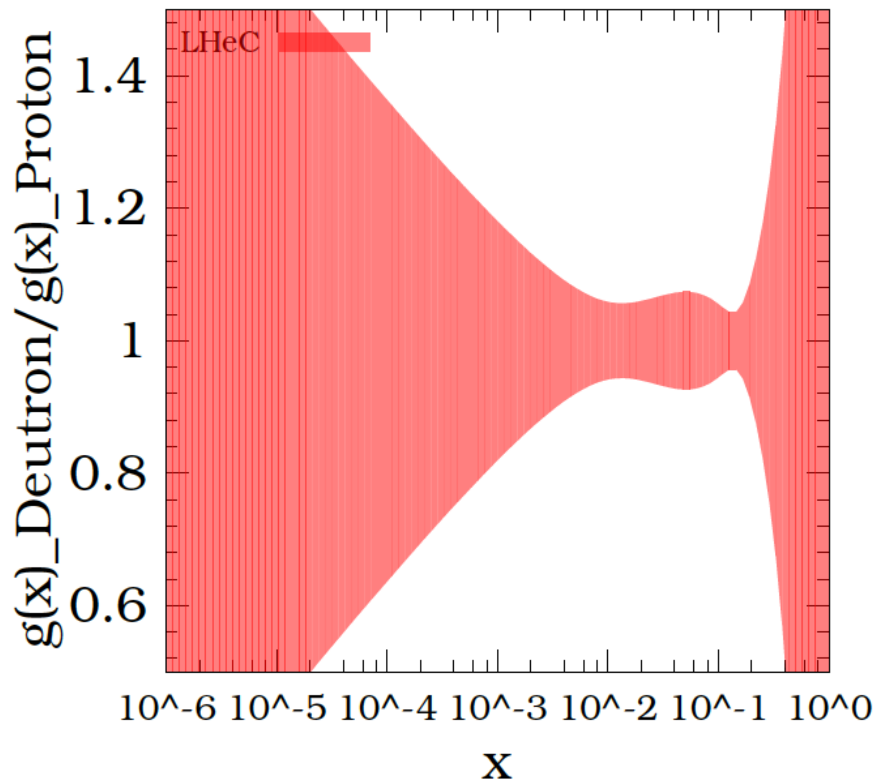
Future fit of jointly ep and eD data will lead to precise unfolding of u-d

Parton dependent nuclear effects

gluon

preliminary





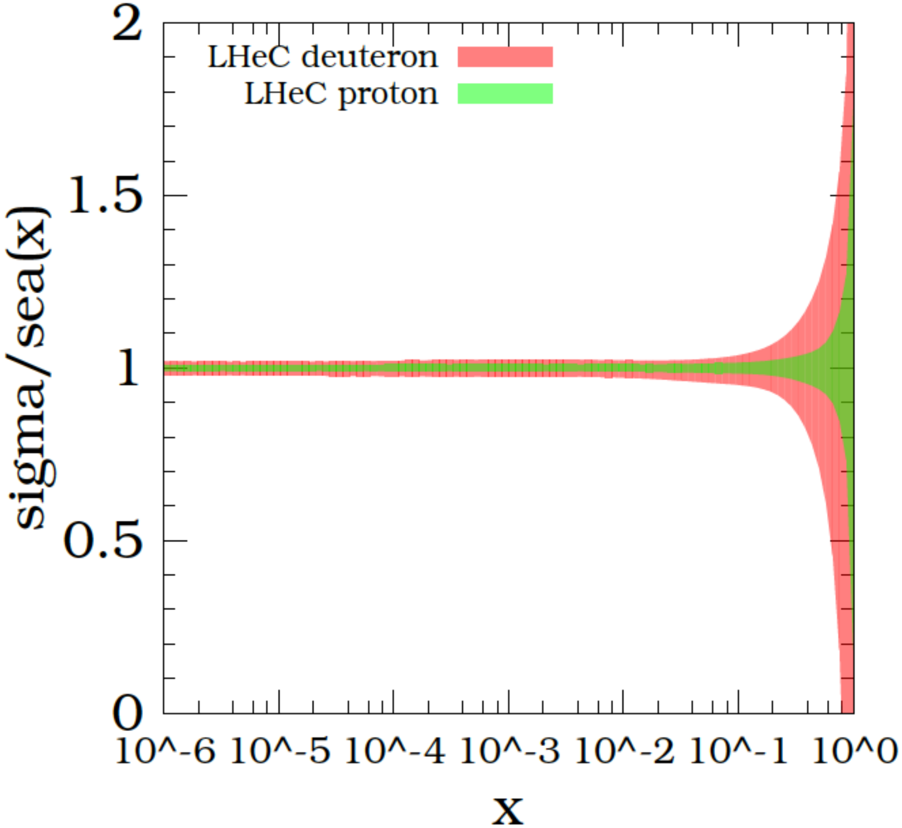
Measure gluon in proton and nucleus (here used deuteron simulation).

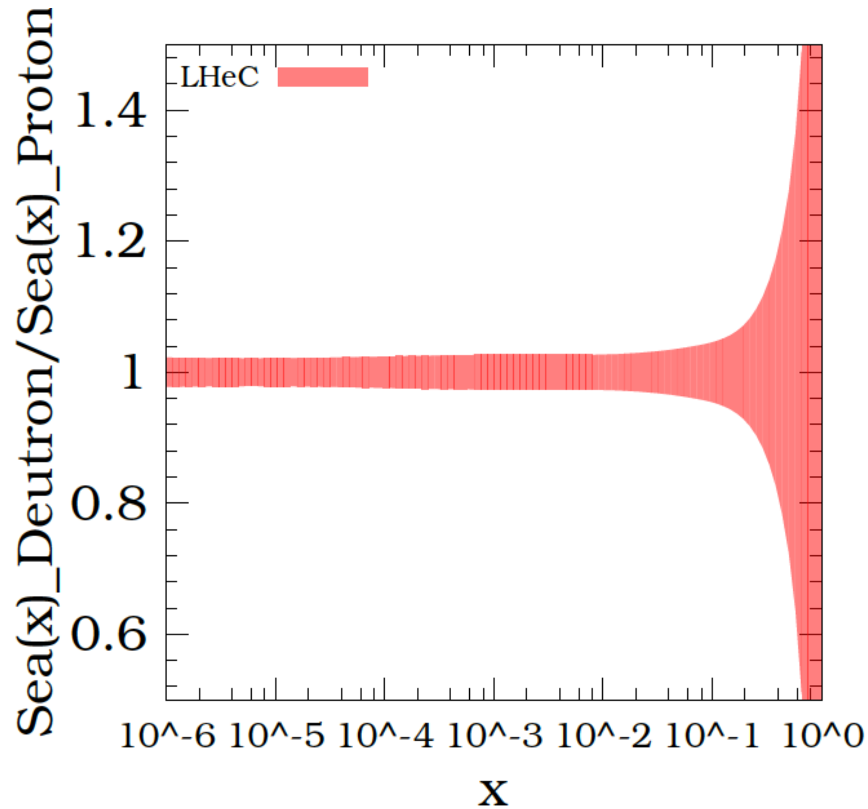
Ratio should provide nuclear correction and its uncertainty, for each parton fitted

Parton dependent nuclear effects

sea

preliminary

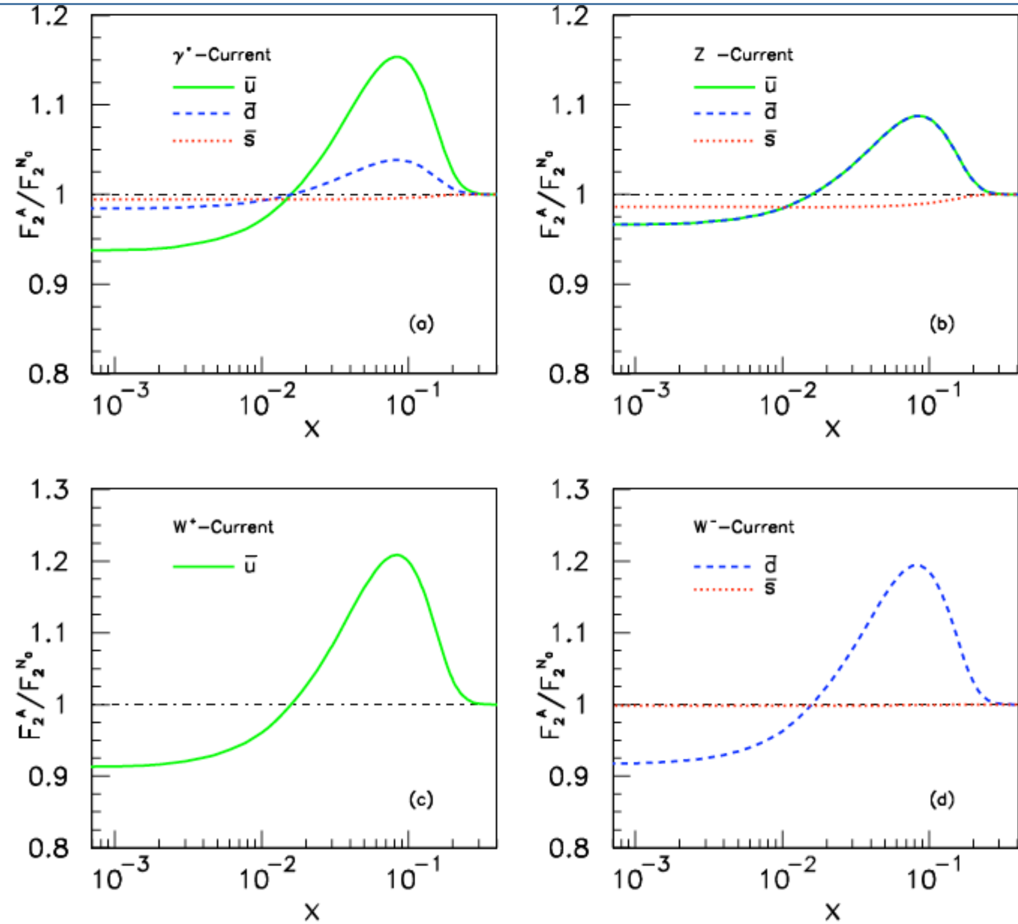




Measure sea in proton and nucleus (here used deuteron simulation).

Ratio should provide nuclear correction and its uncertainty, for each parton fitted

In progress valence and sea quarks..



Nuclear Distributions are not Universal !

LHeC Workshop
June 25, 2015

LHeC Physics Highlights

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Stan Brodsky

SLAC NATIONAL ACCELERATOR LABORATORY

Dependence on flavour and on probe (electromagnetic or weak (NC or CC)) – high L+E
A further important handle on shadowing is its relation (Gribov) to diffraction

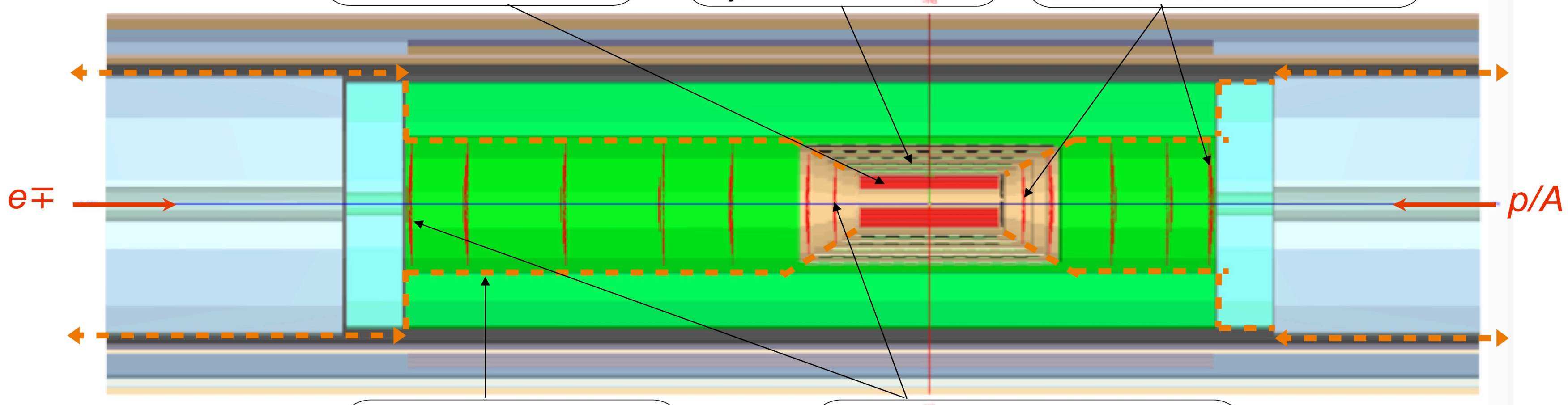
The central Silicon tracker of the LHeC detector – tagging c and b

Performance figures used in simulation and gauged to ATLAS. Much work ahead for real reconstruction and simulation (cf the June 2015 workshop detector session)

Central Pixel Tracker - CPT
4 double-layers
min-inner-R = 4.51 cm
max-inner-R = 17.13 cm
z_{length} = ±50cm

Central Silicon Tracker – CST
5x(double-layers)
1. layer: inner R = 25.1 cm
2. layer: = 30.0 cm
3. layer: = 34.9 cm
4. layer: = 39.9 cm
5. layer: = 44.7 cm

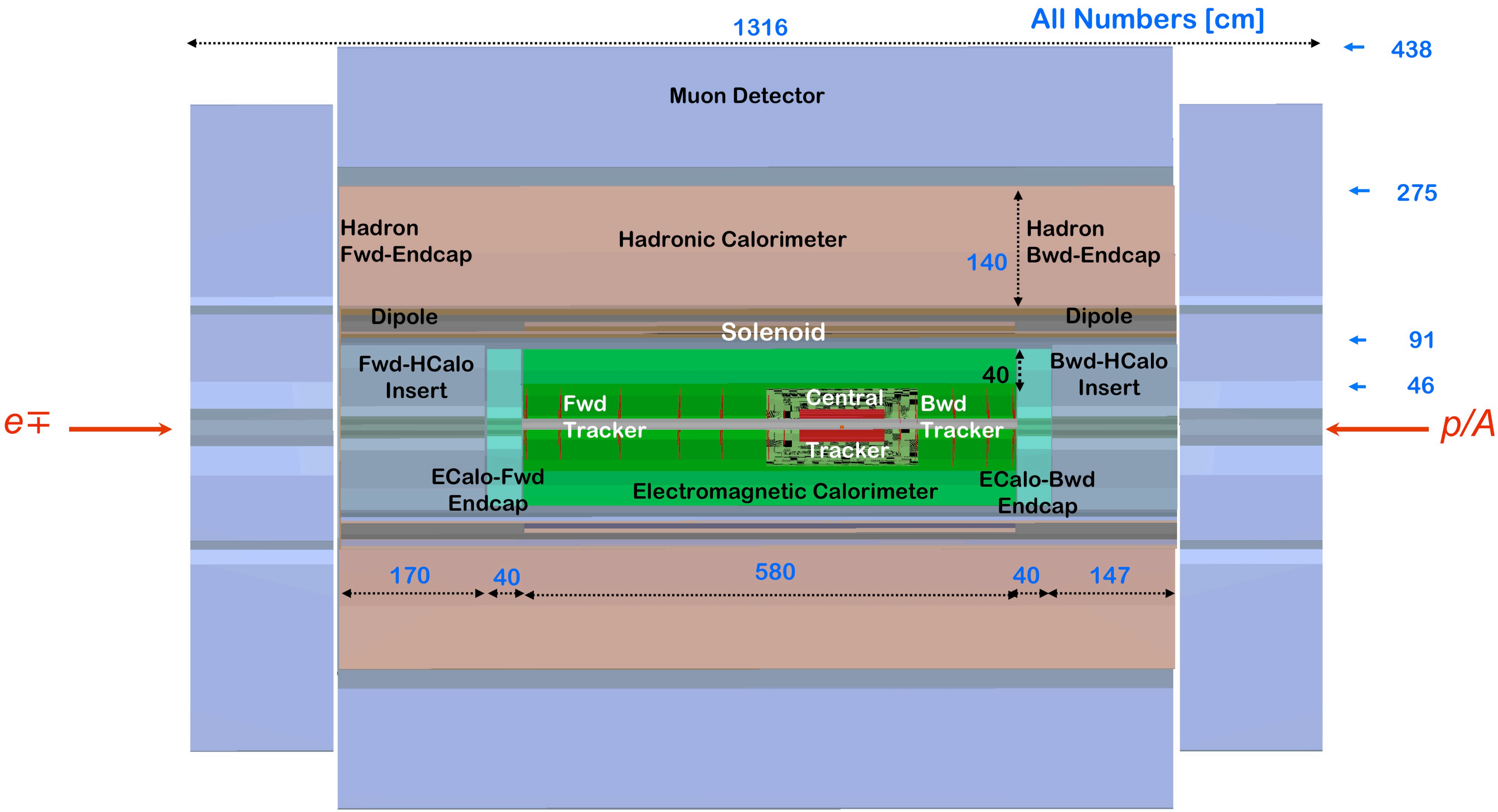
Backward Silicon Tracker – BST
5x(double layers pix / strix)
min-inner-R = 4.3 cm;
max-inner-R= 16.2 cm
max-outer R = 45.1 cm
Planes 1 - 5:
z_{1-5} = -67. / -87. / -132. / -172. / -202. cm



Path of services for all tracking. The detector services (shown in dark orange) shall be integrated into support structures whenever possible. Optimum of costs and detector acceptance. Design of services and infrastructure crucial for material budget.

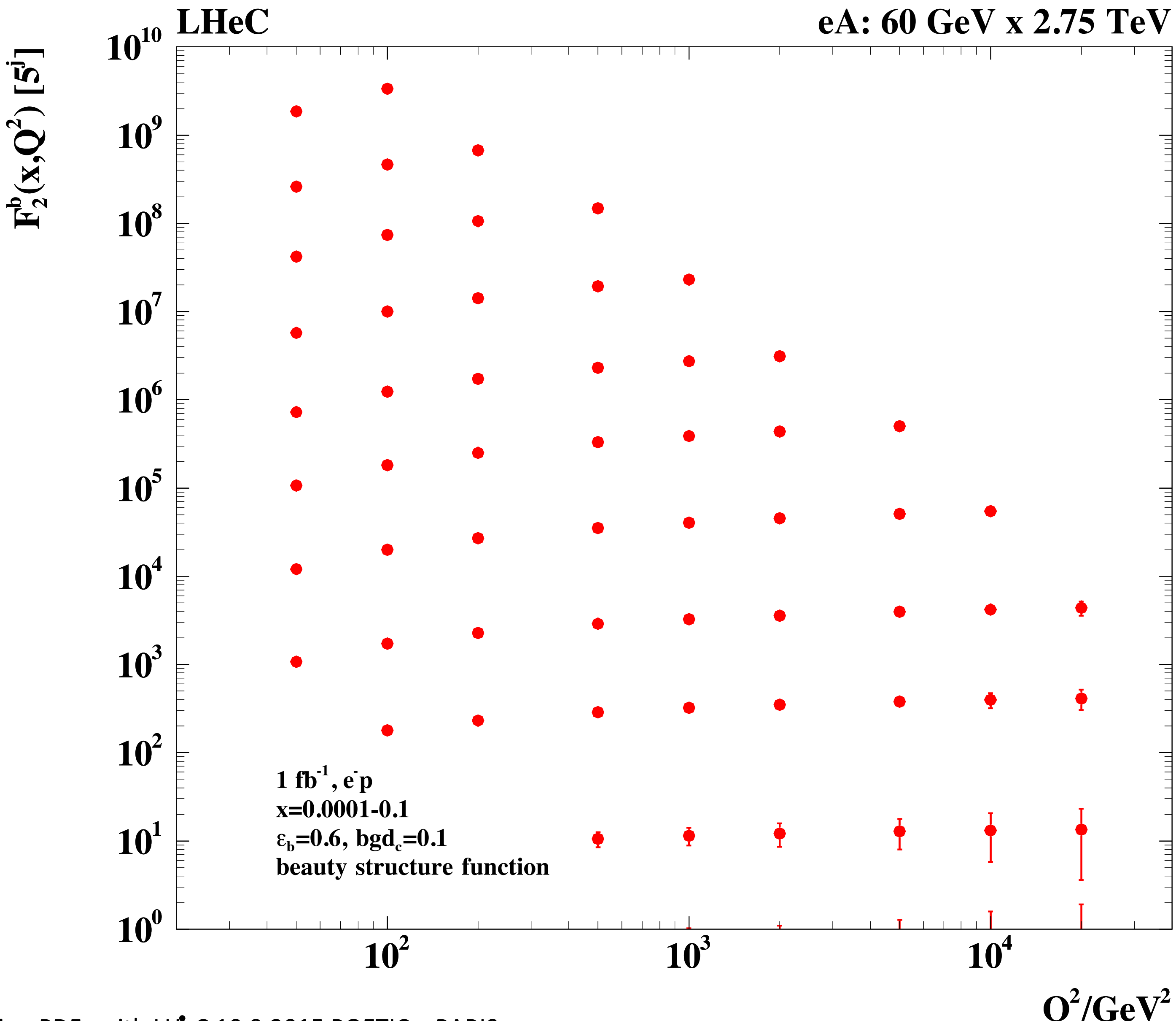
Forward Silicon Tracker - FST
7x(double layer pix/ strix)
min-inner-R = 4.3 cm;
max-inner-R= 16.2 cm
max-outer R = 45.1 cm
Planes 1 - 7:
z_{1-7} = 67. / 87. / 142. / 230. / 292. / 332. / 372. cm

Modular design for installation (cf talk by Andrea Gaddi at the opening of the LHeC June 15 WS)
The LHeC Silicon detector is much smaller than new pp trackers. Much less radiation. No pileup
For ep/D/A have considered photon, electron, proton, neutron, deuteron taggers



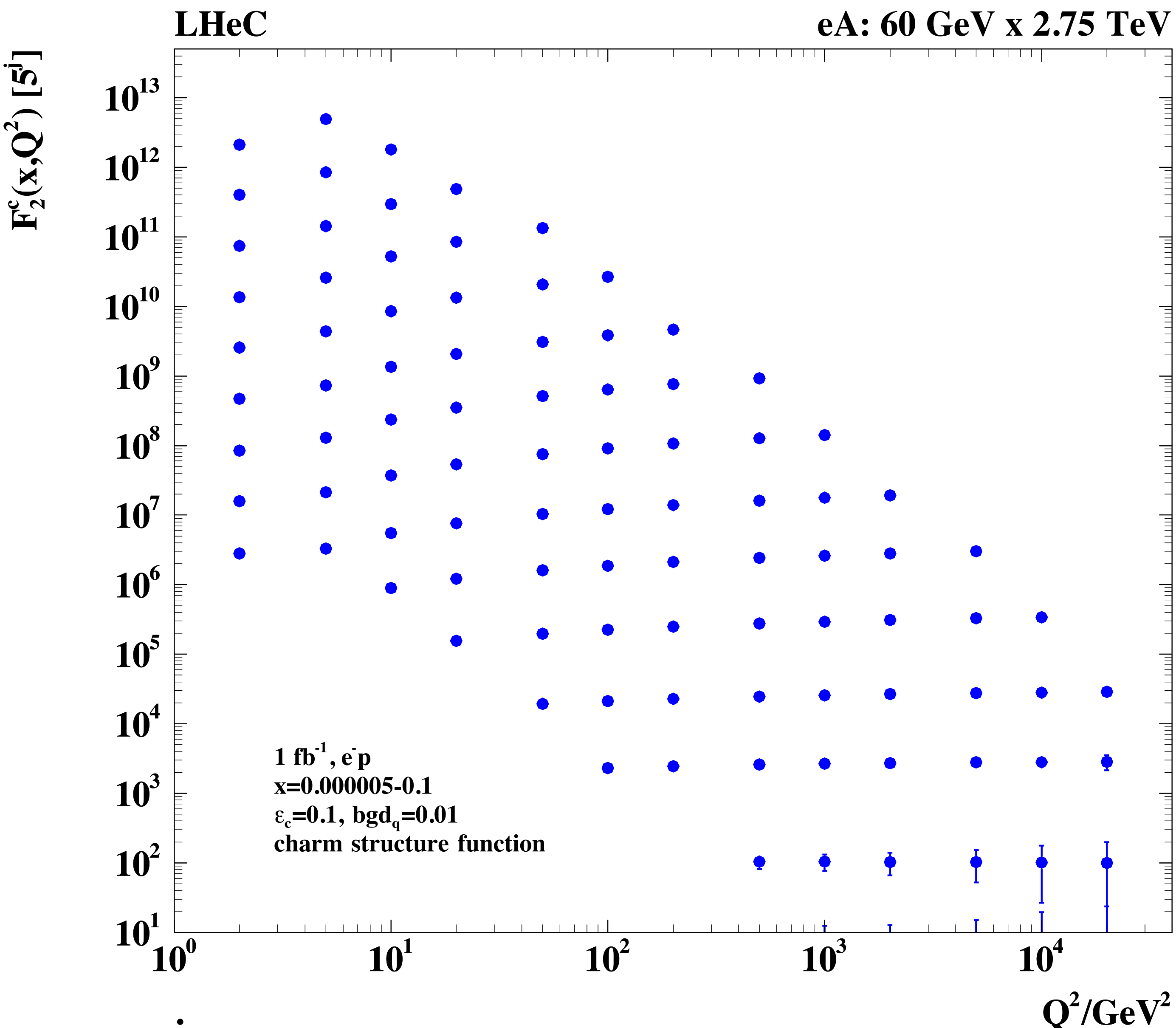
Current (7/15) LHeC detector design (14 * 9 m^2, taggers (not shown), 3.5T solenoid Silicon tracker, LAr elm calorimeter, fwd Si-W, Tile hadronic calo, muon tagger)

Heavy Flavour – Beauty in ePb - from NC



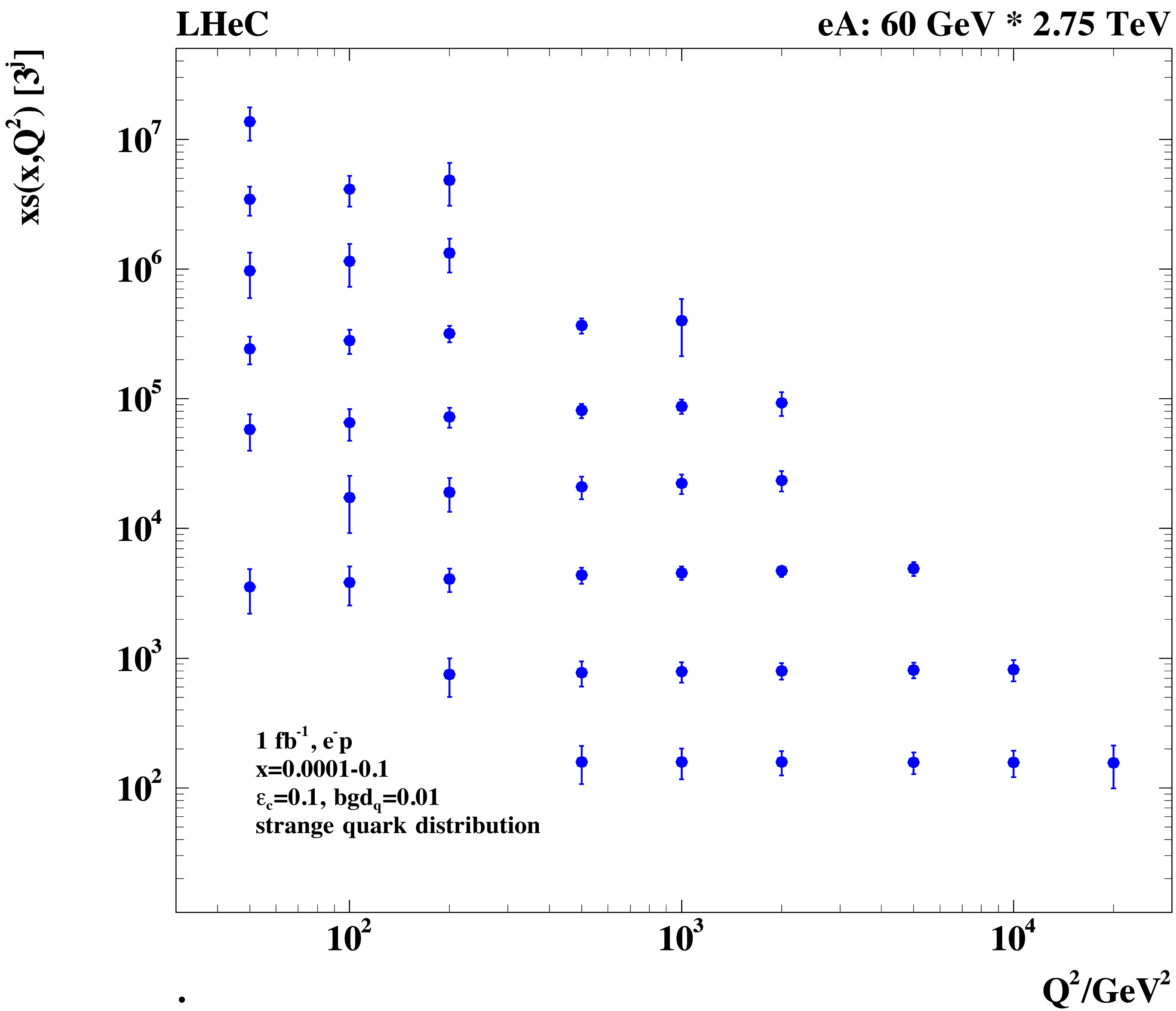
3-5%

Heavy Flavour – Charm in eA - from NC



3-5%

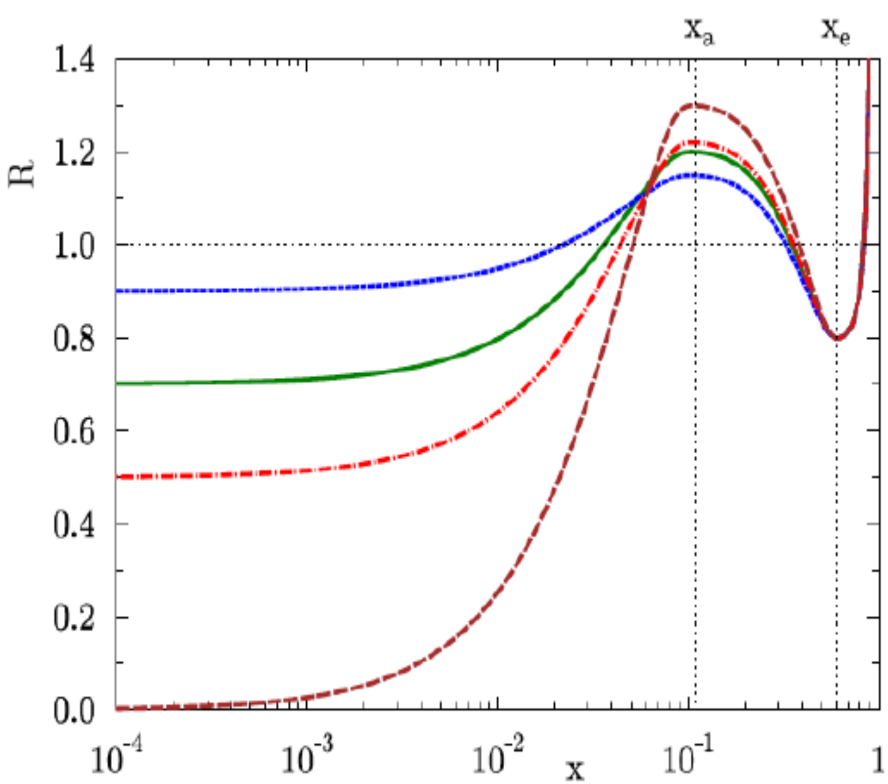
Heavy Flavour – Strange in ePb - from CC



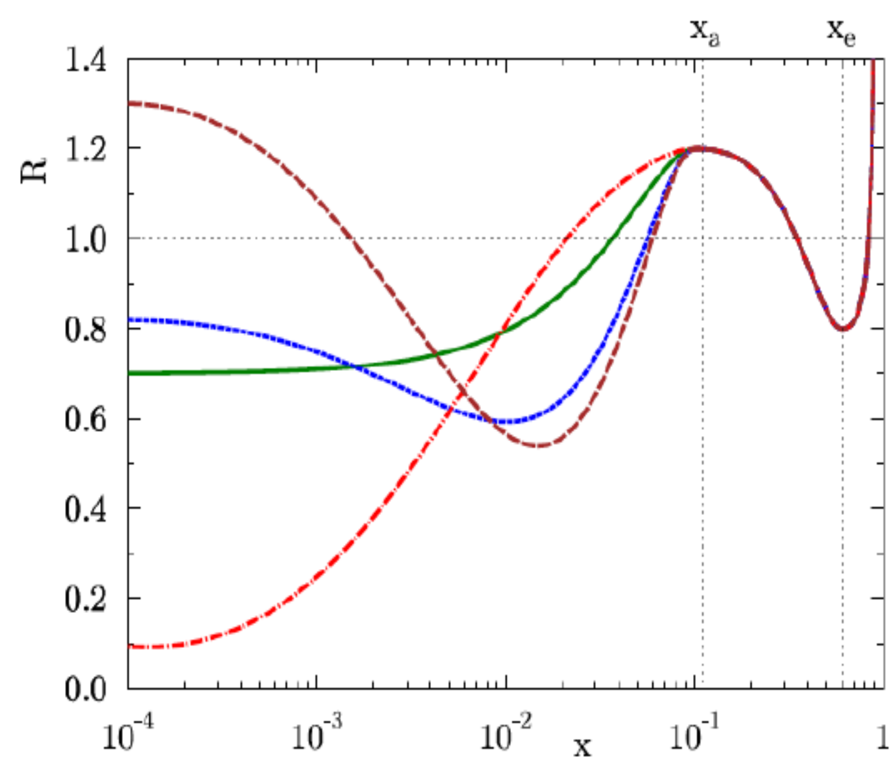
10-20%

A first EPS09 +LHeC (NC ONLY) Analysis

First step: introduction of more flexibility to (unconstrained) low x shape



Prejudice: shadowing at low x going to a constant with x → 0

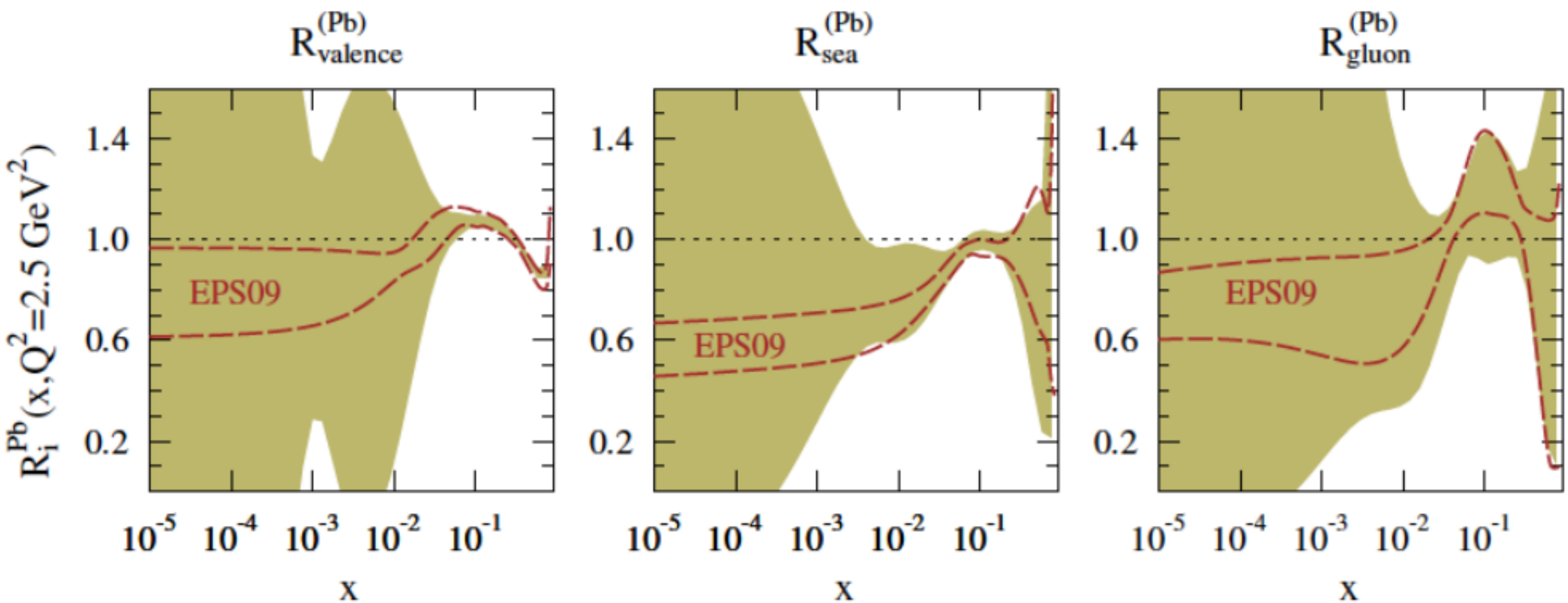


Freedom: simulated with a set of 3 parameters a1,a2,a3

Parameterisations see N Armesto at QCD at LHC London last week

A first EPS09 +LHeC (NC ONLY) Analysis

First step: introduction of more flexibility to (unconstrained) low x shape



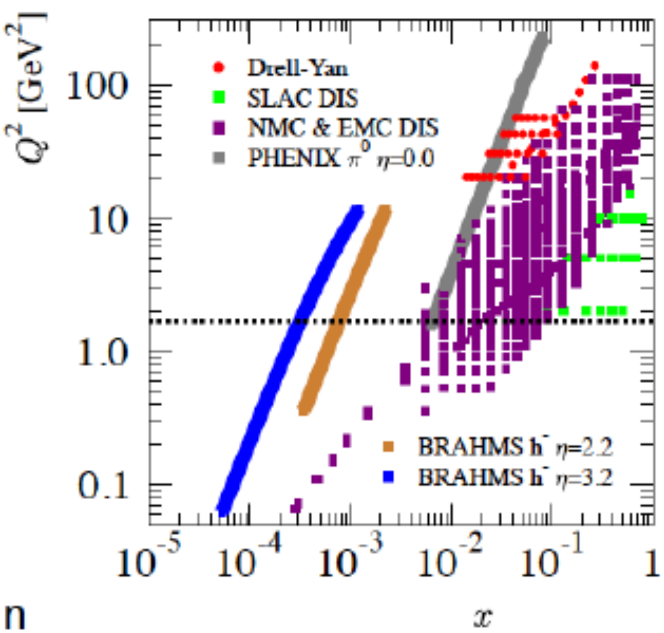
Prejudice: shadowing at low x going to a constant with x → 0

Freedom: simulated with a set of 3 parameters

A first EPS09 +LHeC (NC ONLY) Analysis

- Include the same data (DIS, Drell-Yan, inclusive π^0) as in EPS09 (no LHC data yet) plus LHeC (neutral current) pseudo data.
- CTEQ6.6 as baseline (doesn't really matter which one)
- Flavour-independent nuclear modifications at $Q_0 = 1.3\,\mathrm{GeV}$

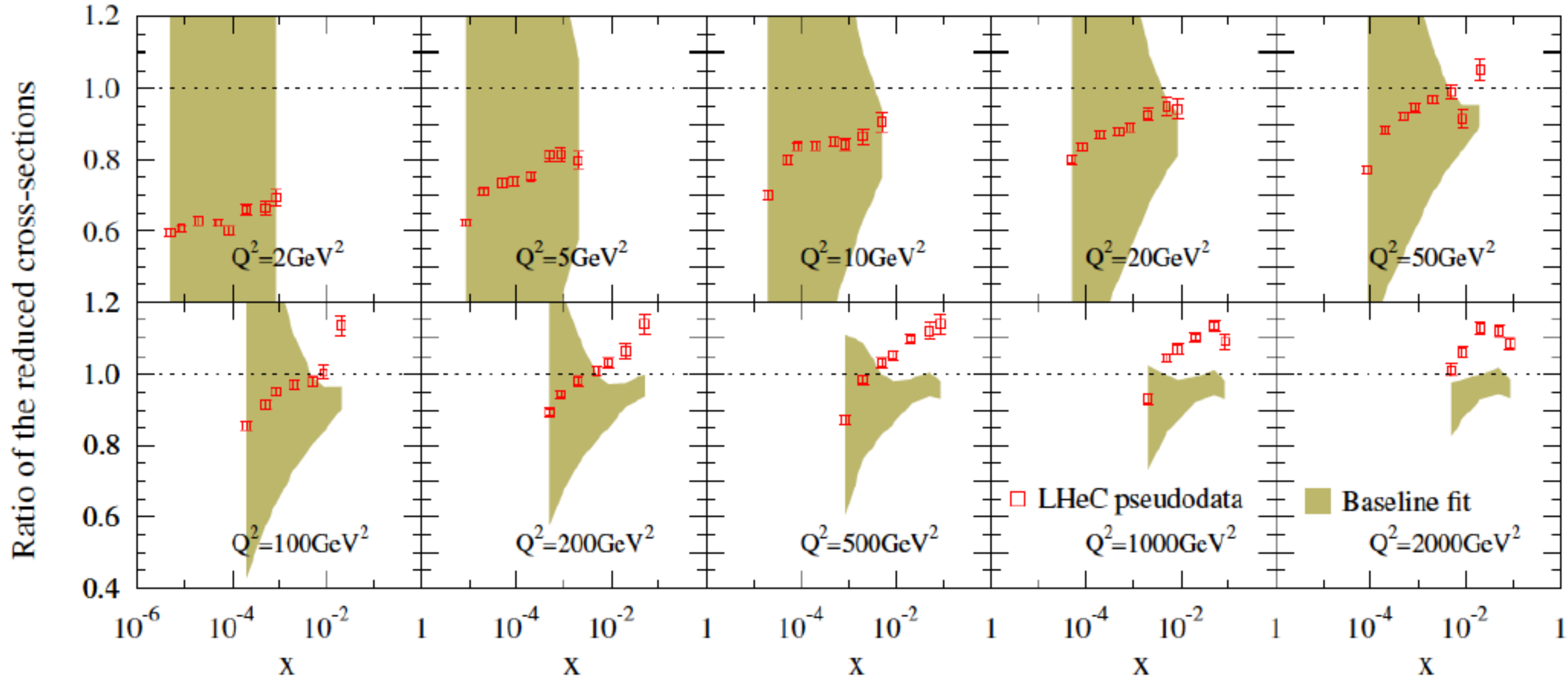
$R_{\mathrm{V}}(x, Q_0)$	for both valence quarks
$R_{\mathrm{S}}(x, Q_0)$	for light sea quarks
$R_{\mathrm{G}}(x, Q_0)$	for gluons



- Charged-current data will be added later on to study the flavour dependence
- Cross-sections at NLO in the SACOT heavy-quark scheme (as CTEQ6.6)
- Robust Levenberg-Marquardt minimization method

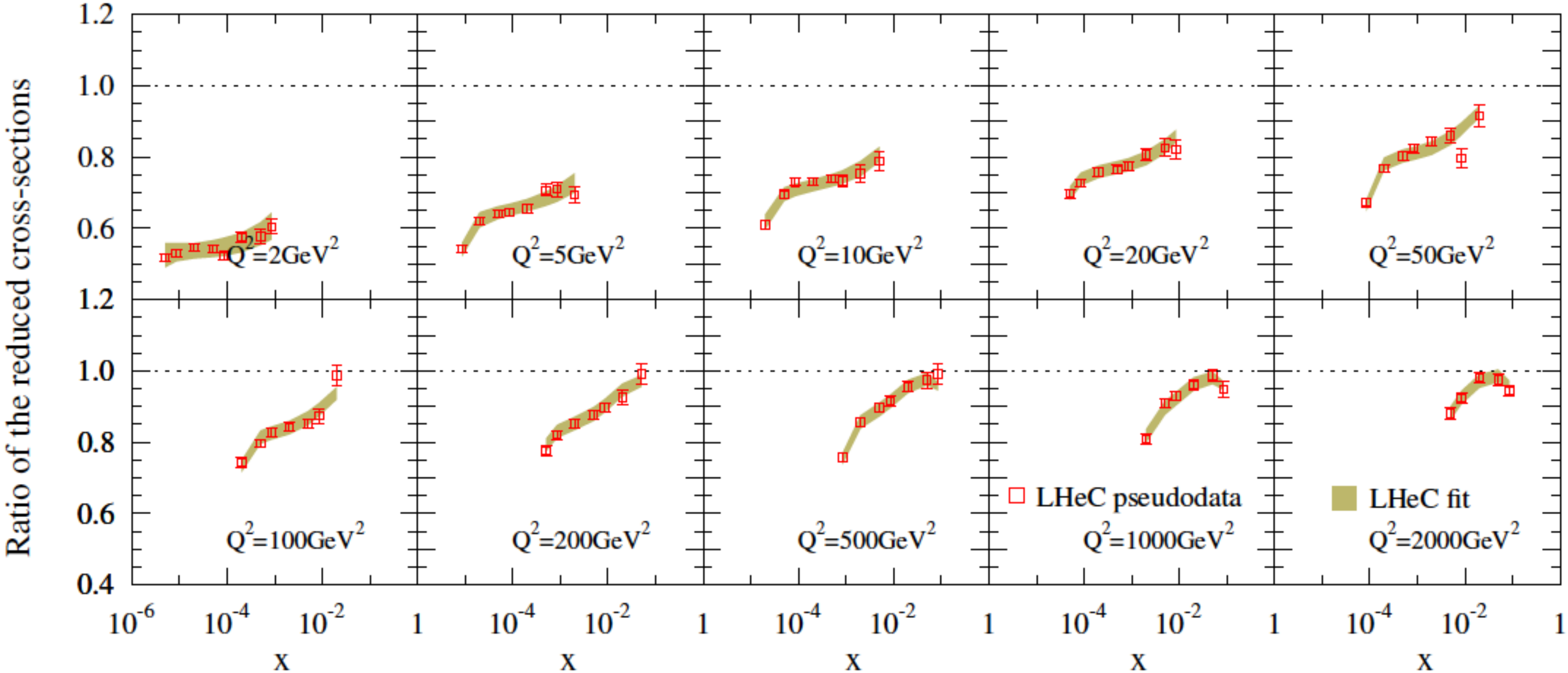
N. Armesto - Nuclear PDFs in eA at the LHeC

A first EPS09 +LHeC (NC ONLY) Analysis



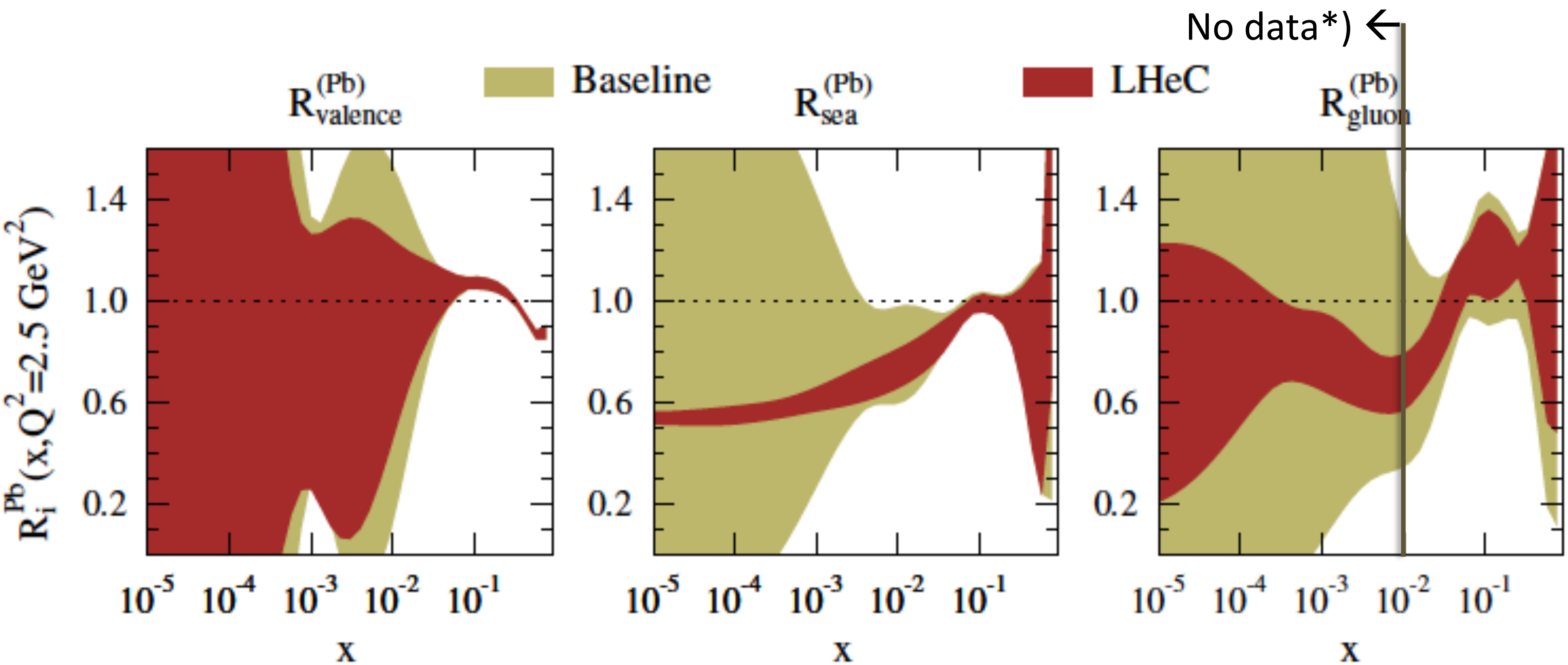
LHeC provides precision data where they do not exist

A first EPS09 +LHeC (NC ONLY) Analysis



No surprise the fit follows..

A first EPS09 +LHeC (NC ONLY) Analysis



*) some LHC di-jet pPb data go below

This is only a first glimpse: CC, Deuterons, s,c,b – data may all be added → A new world

See also talk by Hannu Paukkunen at the January 14 LHeC Workshop on more details!

Summary

The constraints without an eh collider on PDFs are weak and uncertain.

First complete and detailed ep, eD and eA LHeC simulations are done and
a suitable detector is under further design (software, technology, installation).

Saturation if it exists shall be discovered in ep at the LHeC (or FCC-he..)

Deuterons for the LHeC are of high interest (n, D, alphas…). Neutron structure?

The high Q^2 and luminosity provides a complete resolution of PDFs
→ **A revolution probably deeper than with HERA for lp as the kinematic range in lA DIS is extended by 3-4 orders of magnitude with the LHeC.**

Shadowing can be measured for each flavour by comparing ep and eA fits.

Strange, charm and beauty may be measured directly in eA (and ep..)

A first EPS type study (using NC for LHeC only) demonstrates huge potential

The LHeC (and FCC-eh) eA programme has a far reaching impact on the LHC HI programme, QCD, QGP, UHE of unprecedented range and precision. It leads much further than to nPDFs (VM, diffraction, jets, y*A, …)