The LHeC Project

QCD and low x physics

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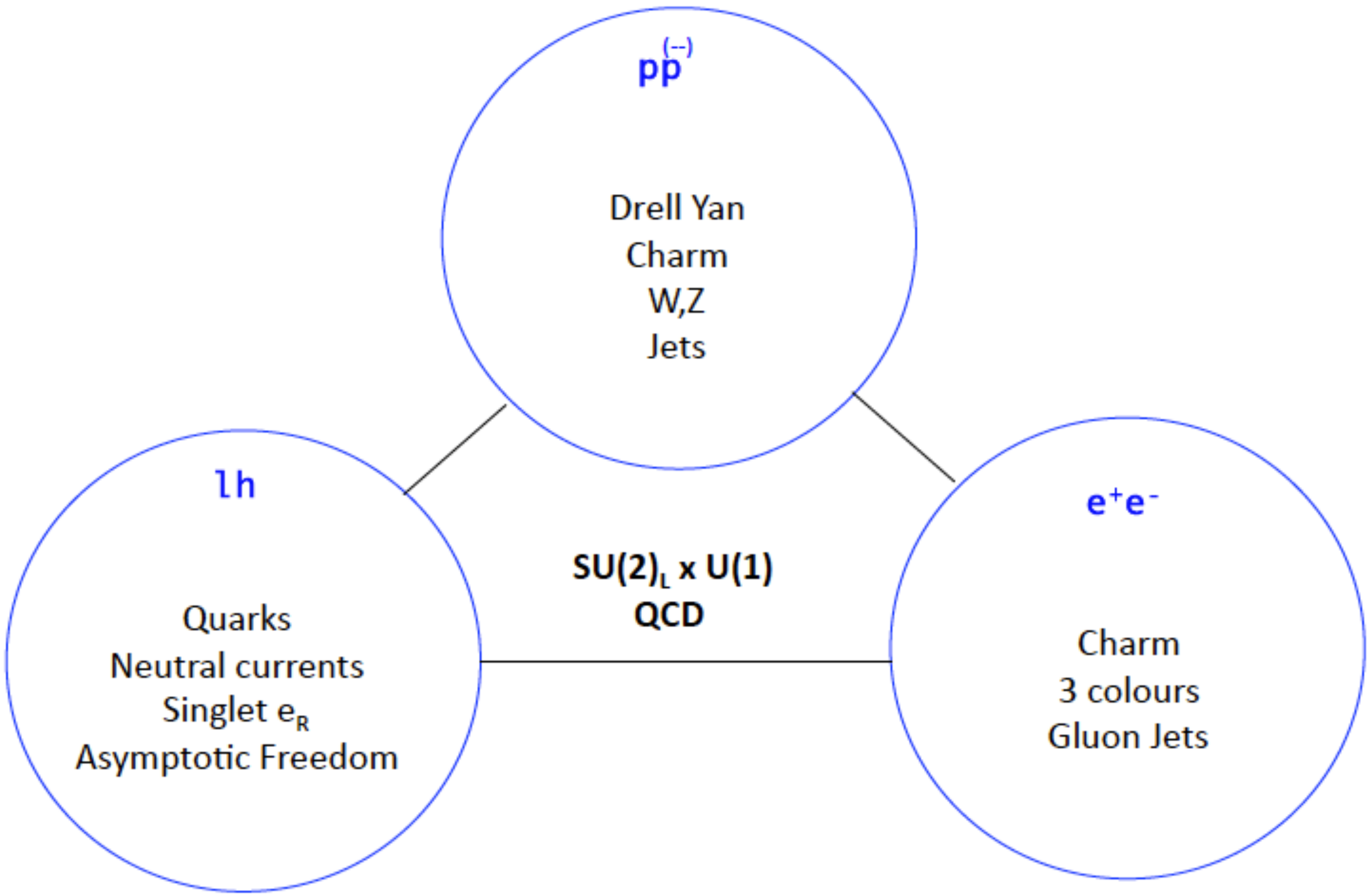
UNIVERSITY OF LIVERPOOL

for the *LHeC* Study Group *http://cern.ch/lhec*

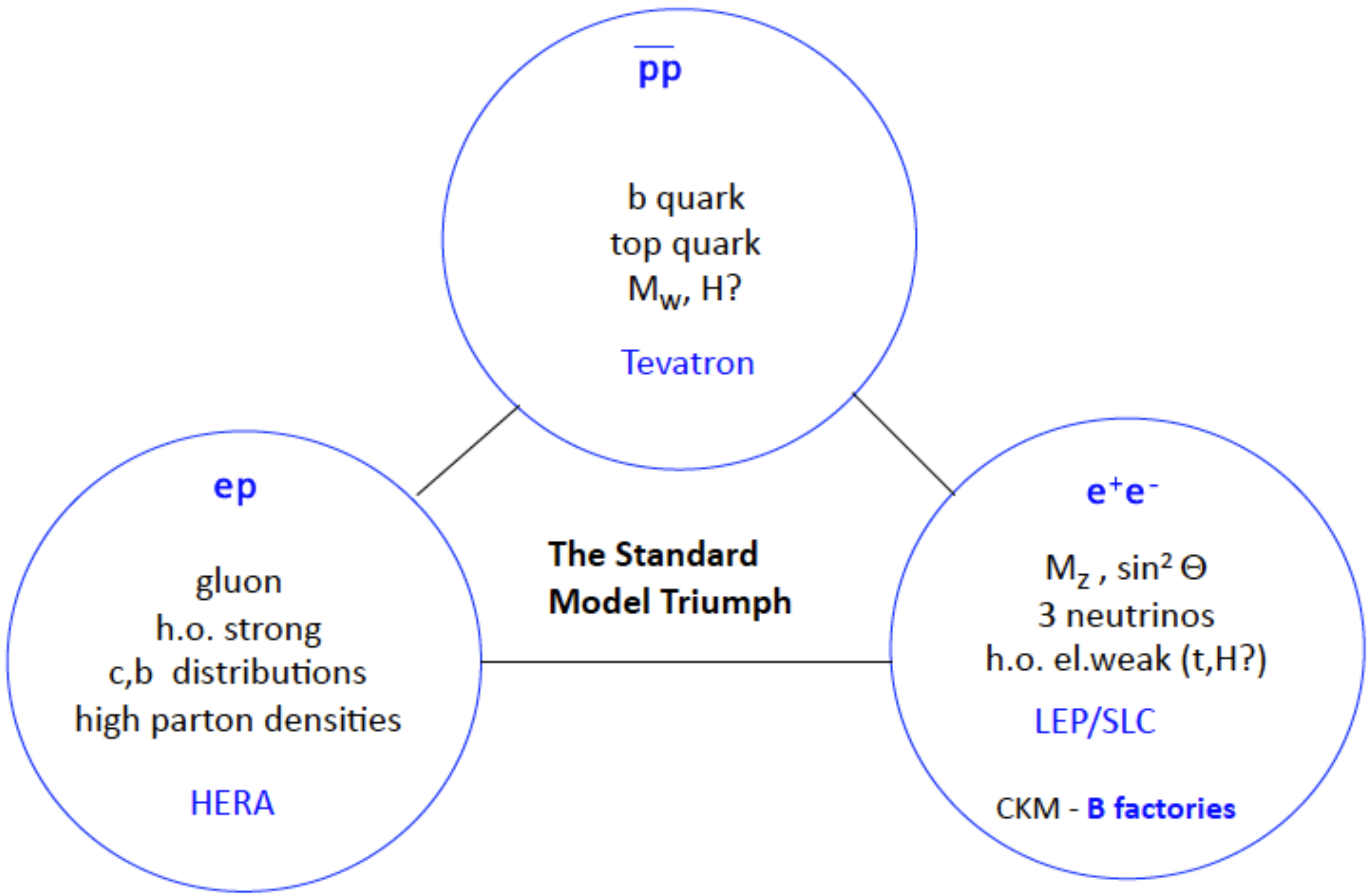
- Machine
- Physics
- Status

23rd July 2011 **HEP 2011, Grenoble, France**

The 10-100 GeV Energy Scale [1968-1986]



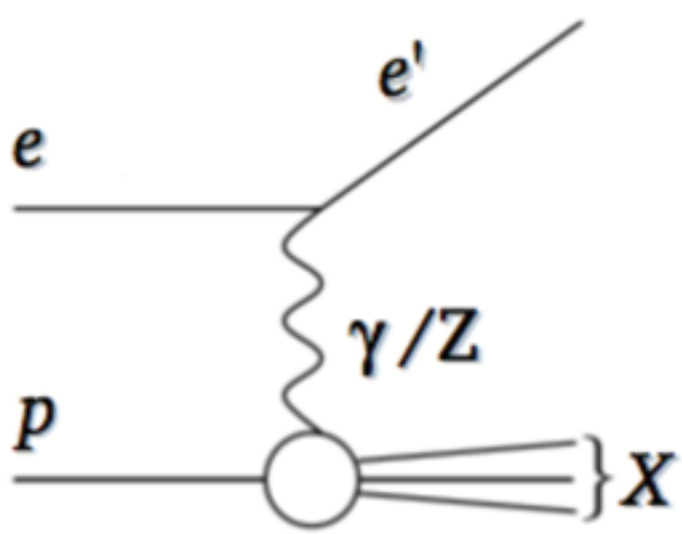
The Fermi Scale [1985-2010]



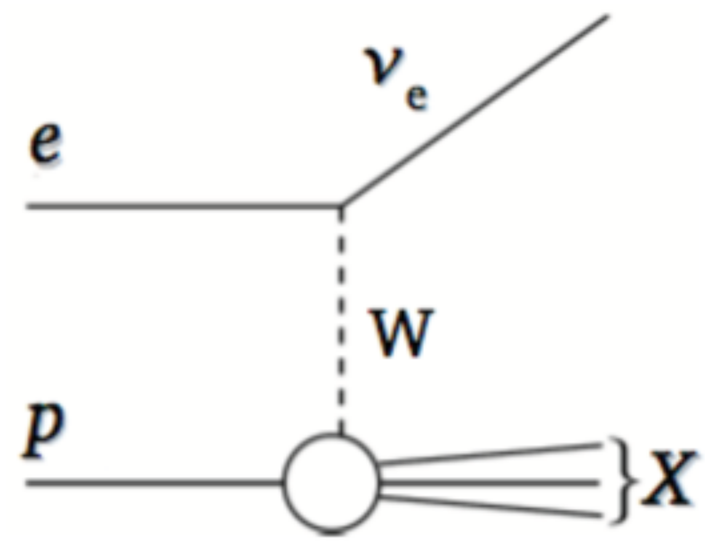
Colliders at the energy frontier

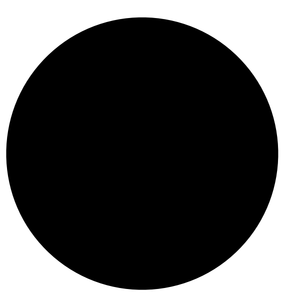
What is the proton?

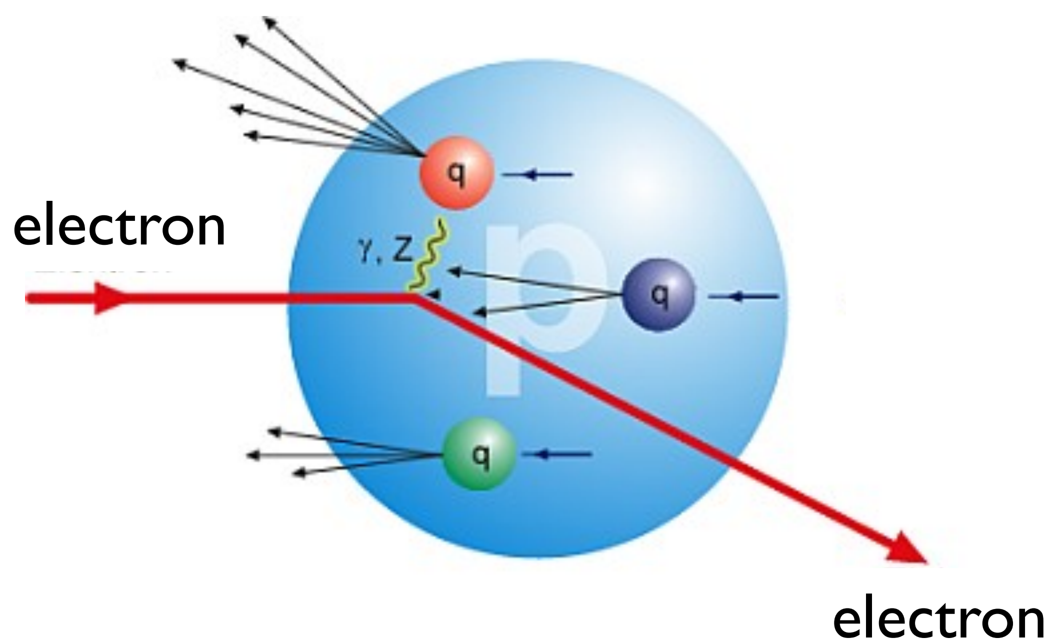
NC : $e\,p \rightarrow e'\,X$



CC : $e\,p \rightarrow \nu_e\,X$

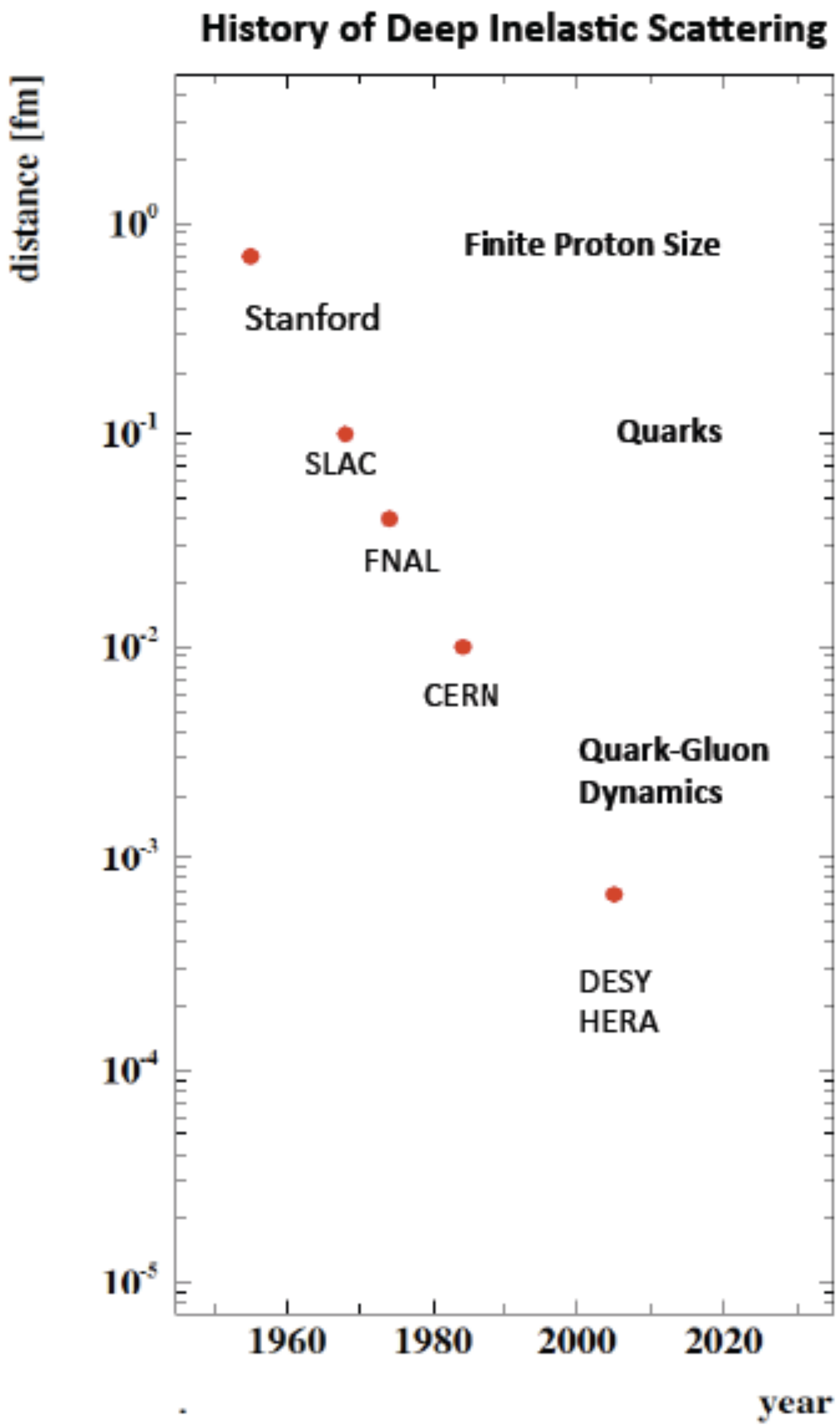


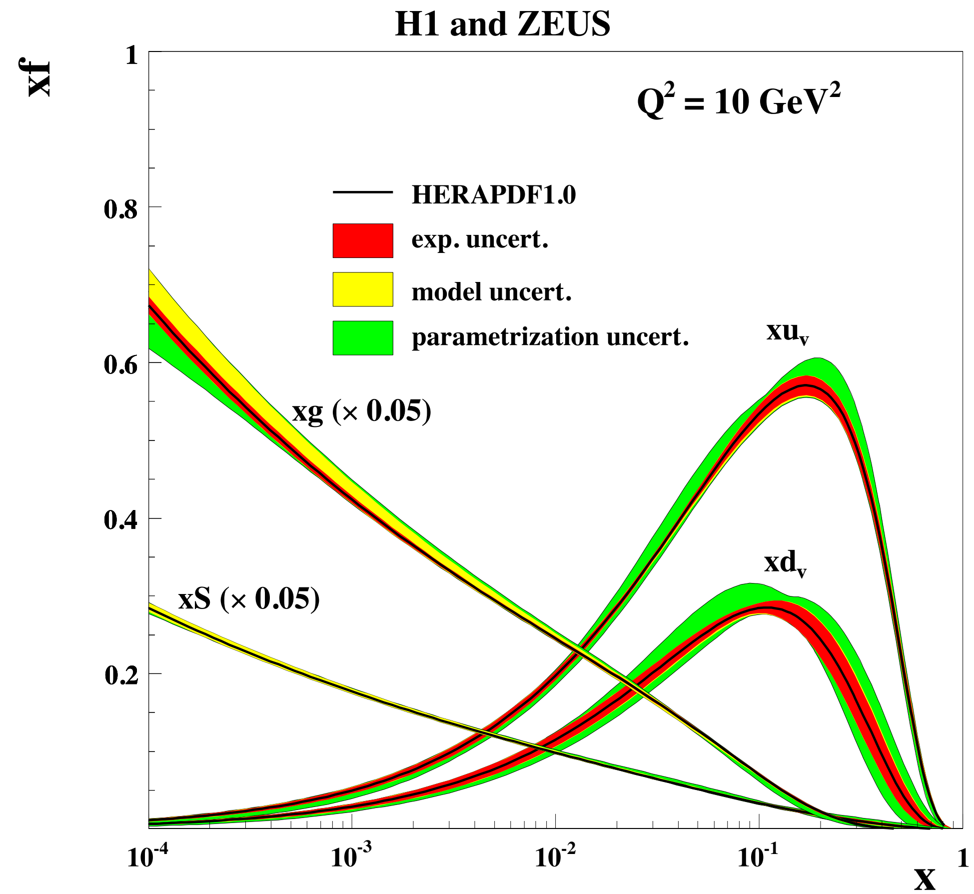




Time

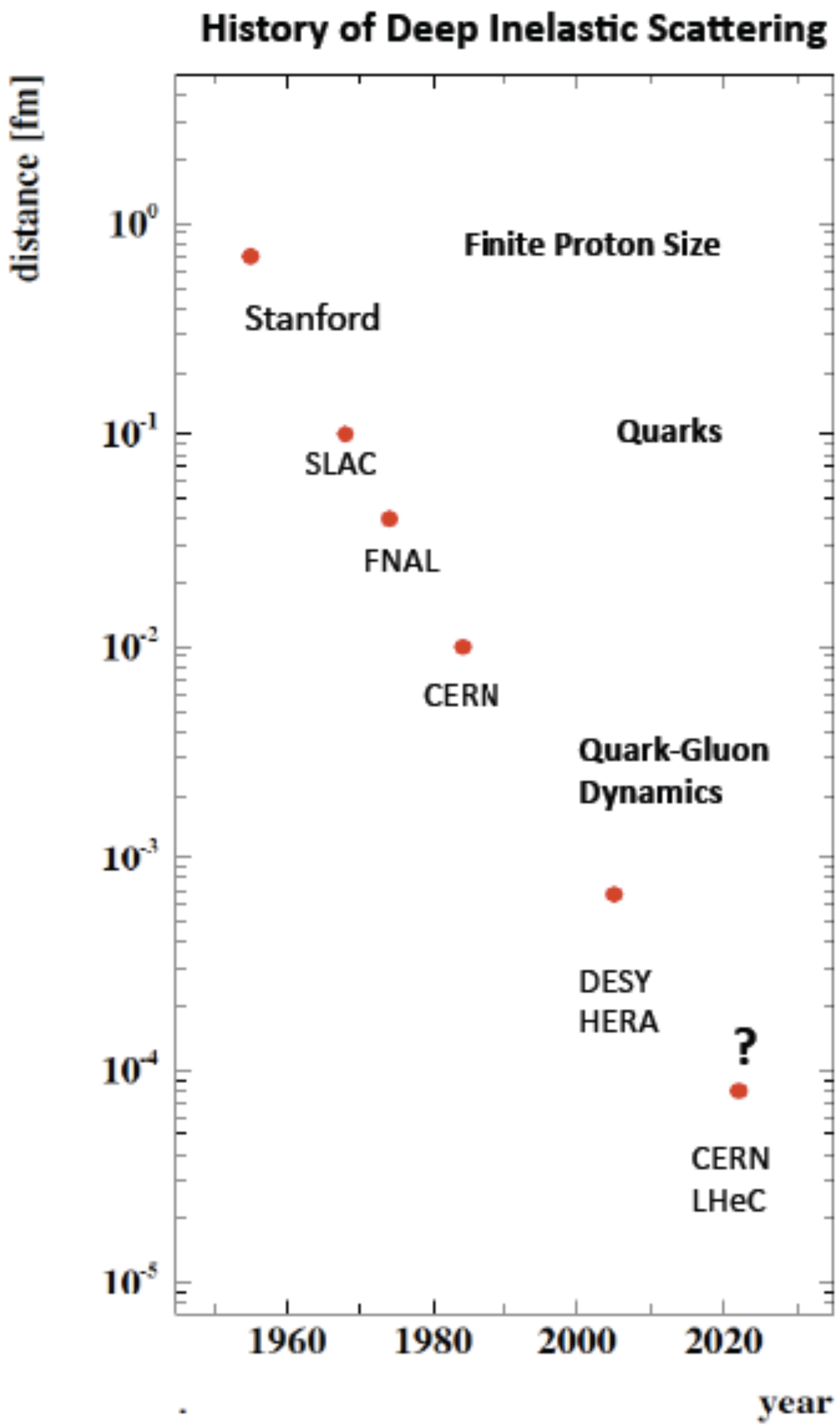
An incomplete history of deep-inelastic scattering

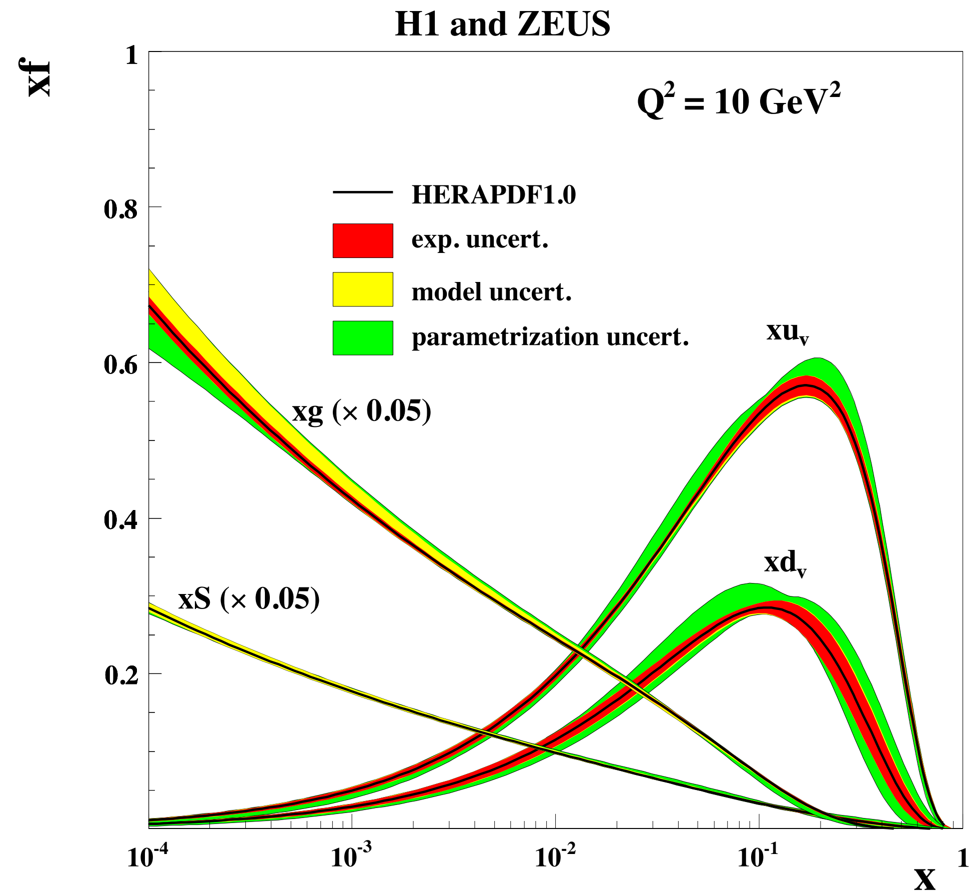




- A rich history of exploiting scattering experiments to study structure, culminating in the HERA electron-proton machine
- Confirmation of the QCD picture of the proton, structure mapped with high precision...
- ... But QCD is a harsh mistress, many questions remain... if only we had a machine which could collide very high energy protons with electrons...

An incomplete history of deep-inelastic scattering





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LHeC Accelerator Institutes

CERN

SLAC
NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

CLIC

The Cockcroft Institute
of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

ANKARA ÜNİVERSİTESİ

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

DESY

LAL
Physique des accélérateurs

ECFA

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

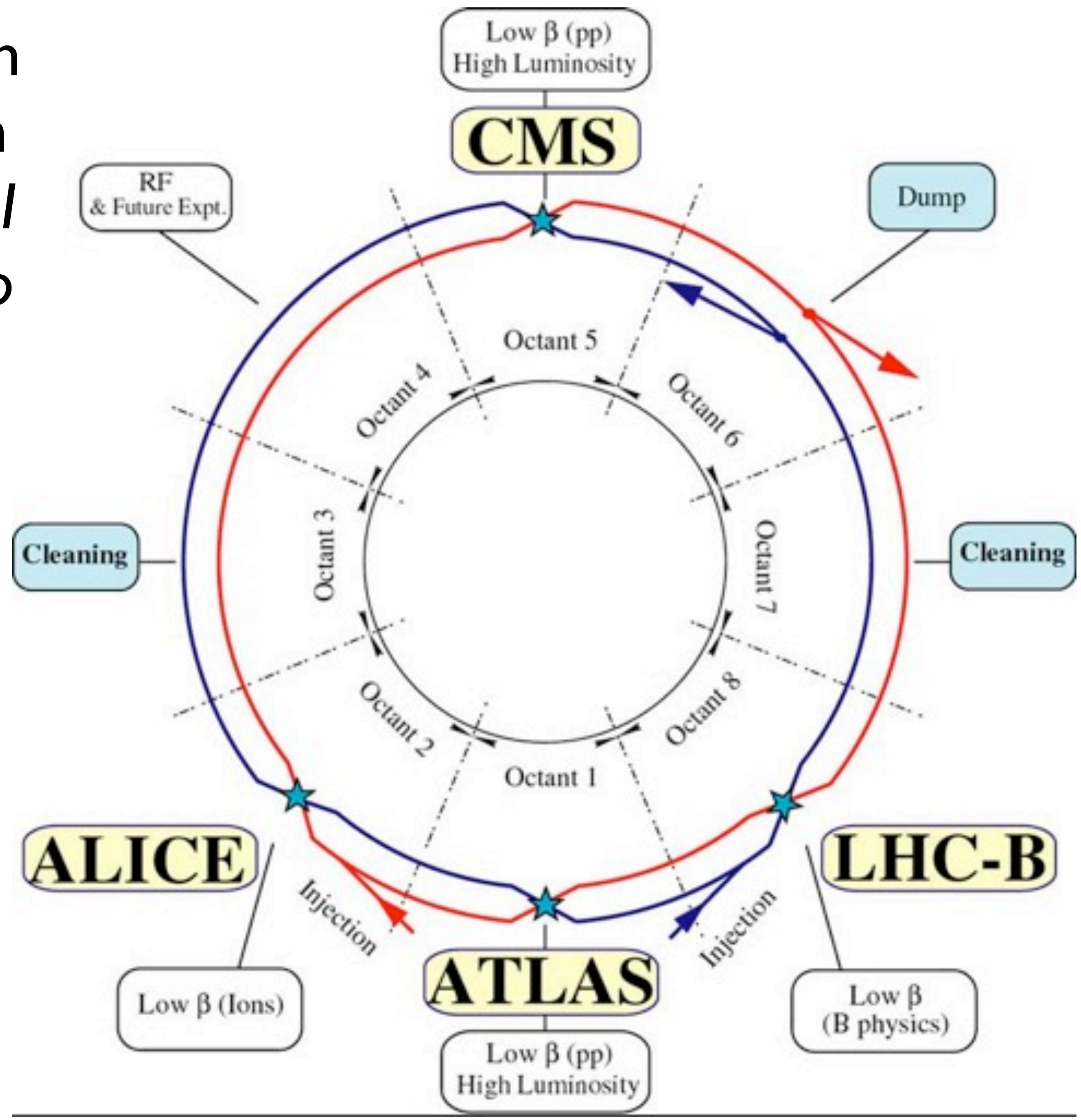
BROOKHAVEN
NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера
630090 Новосибирск

KEK

The LHeC Concept

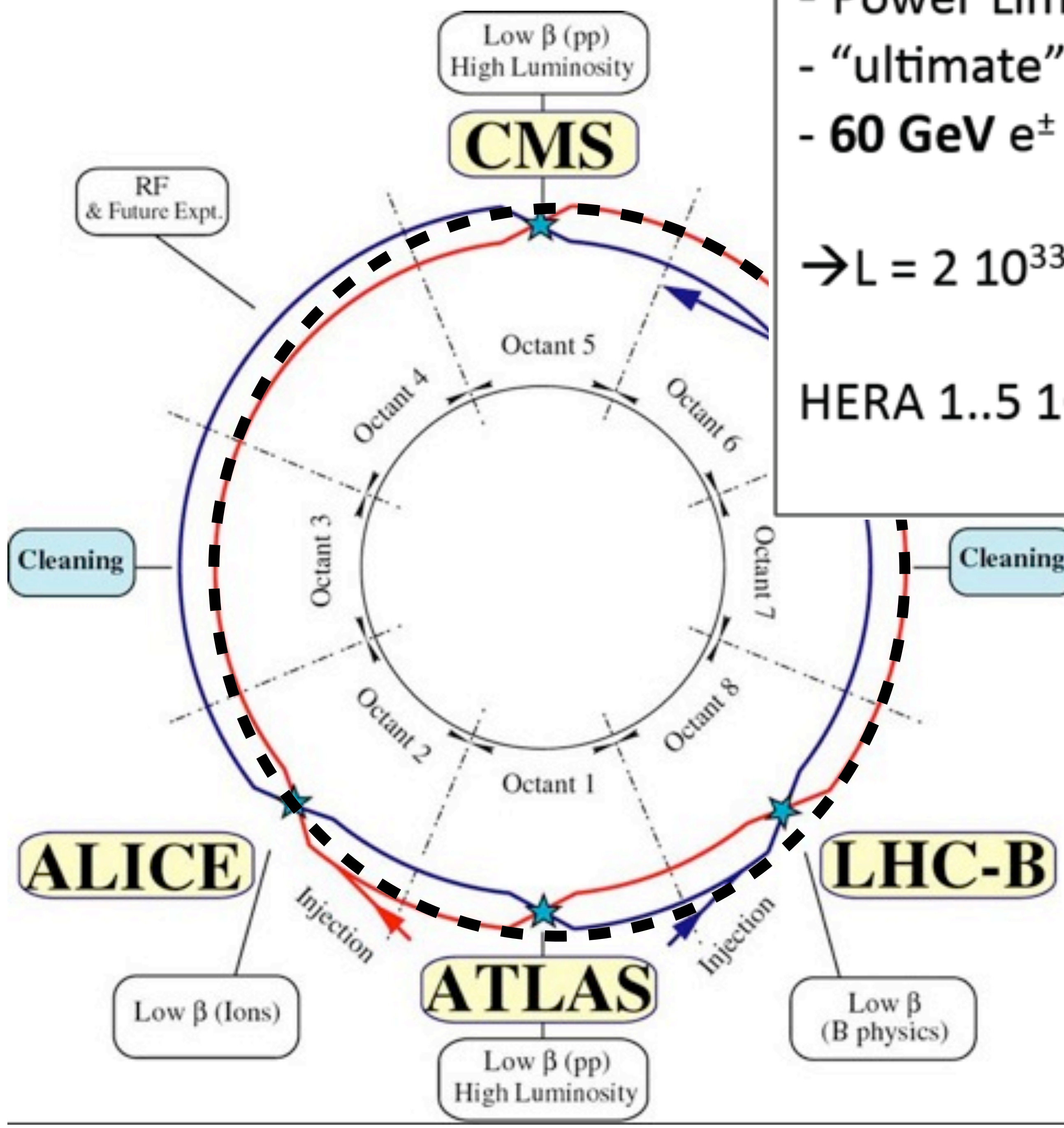
The LHeC *ep* program would run *simultaneously* with the LHC *pp* and *HI* programs (small *ep* tuneshifts)



- Collide a new polarised electron beam E~60 GeV with a proton/HI beam of the LHC

The LHeC - Ring-Ring

To develop the concept, an IP is needed and Alice has been used



- Power Limit of **100 MW wall plug**
- "ultimate" LHC proton beam
- **60 GeV** $e^{\pm}$ beam

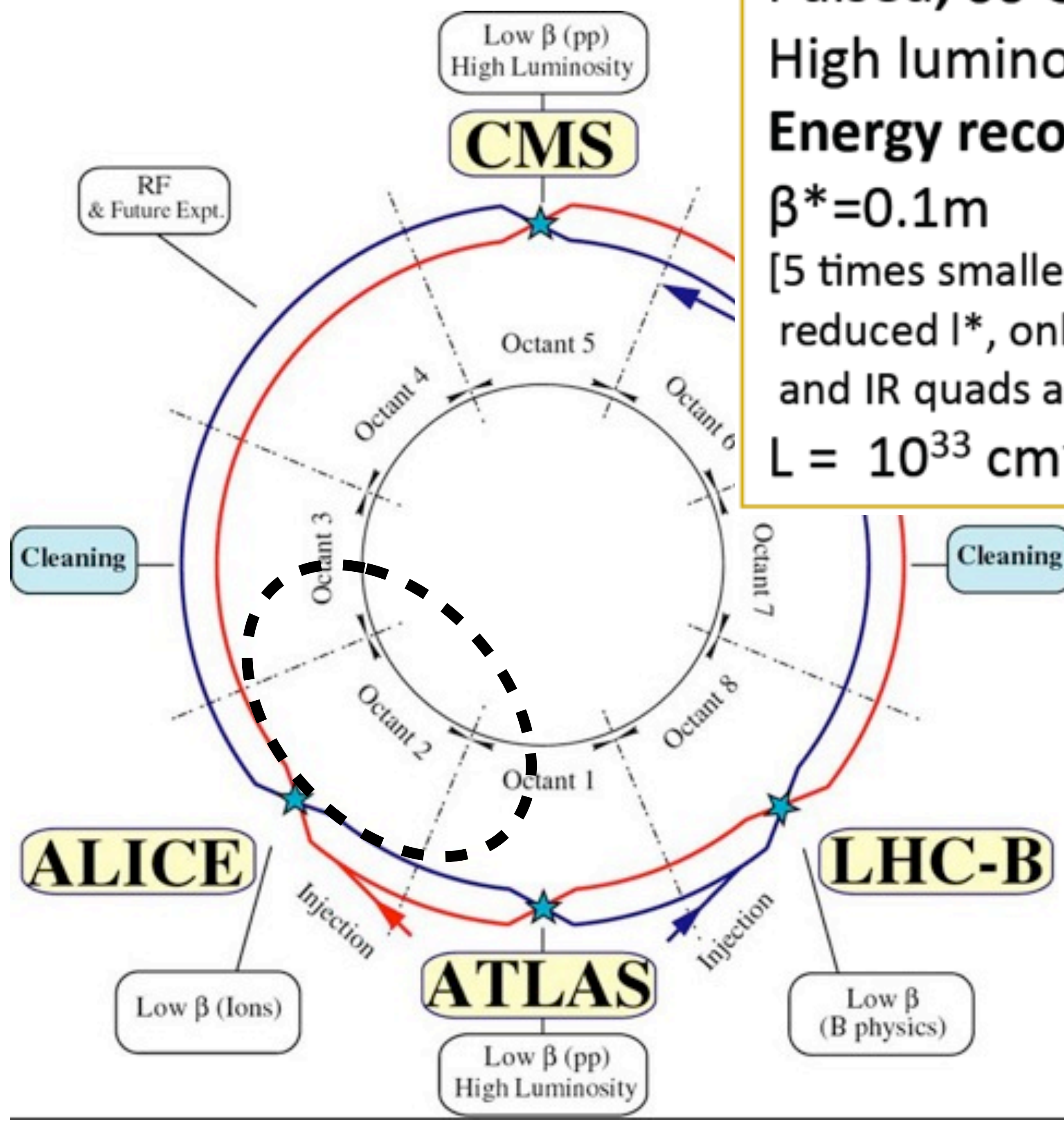
→ $L = 2\ 10^{33}\ cm^{-2}s^{-1}$ → $O(100)\ fb^{-1}$

HERA 1..5 10^{31} → $1\ fb^{-1}$ (H1+ZEUS)

- Either by installing a new electron storage ring in the LHC tunnel (P~40%)

The LHeC - Linac-Ring

To develop the concept, an IP is needed and Alice has been used



Pulsed, **60 GeV**: ~10^{32}cm^{-2}s^{-1}

High luminosity:

Energy recovery: $P=P_0/(1-\eta)$

$\beta^*=0.1$m

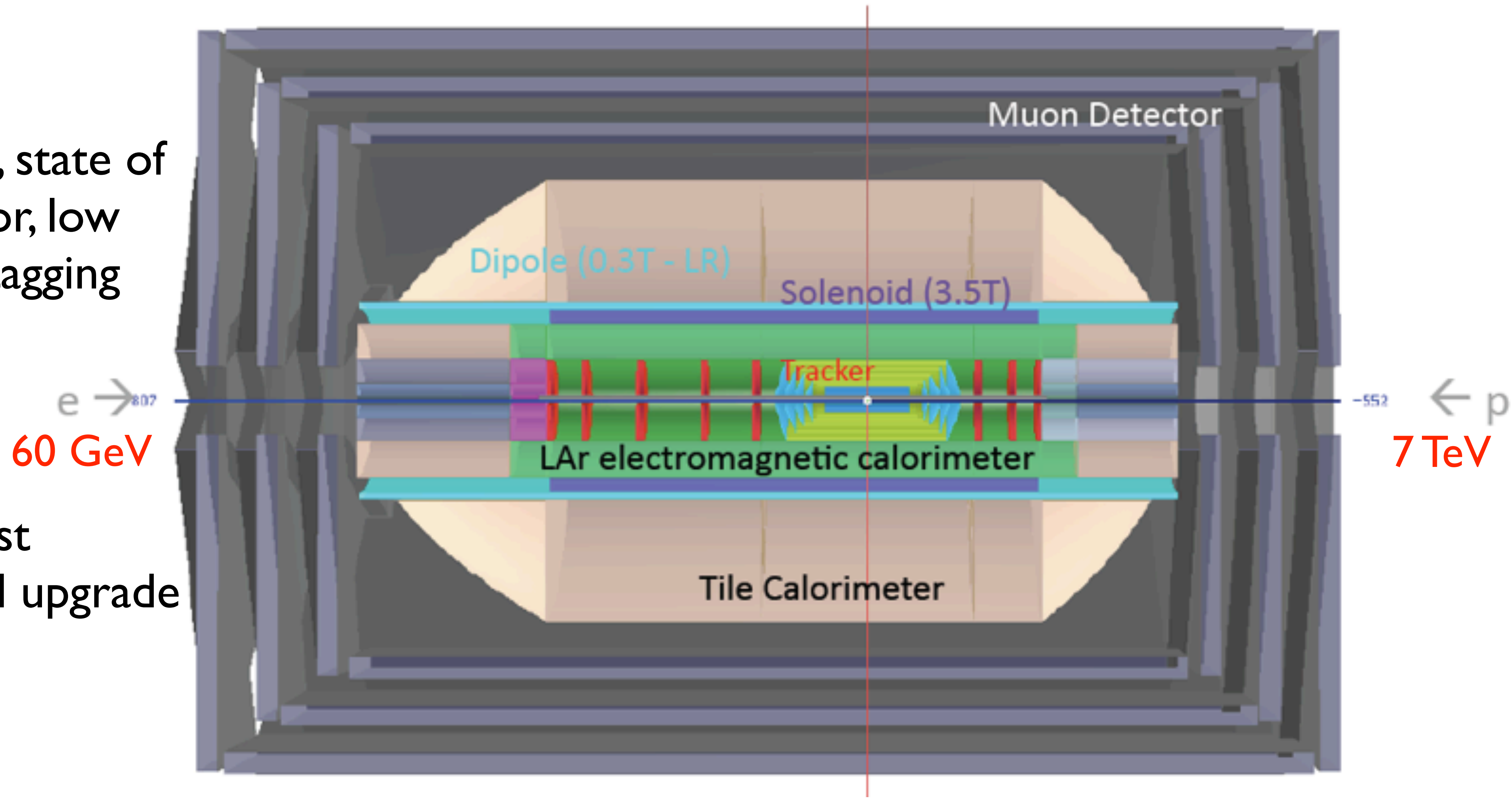
[5 times smaller than LHC by reduced l*, only one p squeezed and IR quads as for HL-LHC]

L = 10^{33} cm^{-2}s^{-1} → O(100) fb^{-1}

- Or by building a new super-conducting RF electron linac (P~90%)

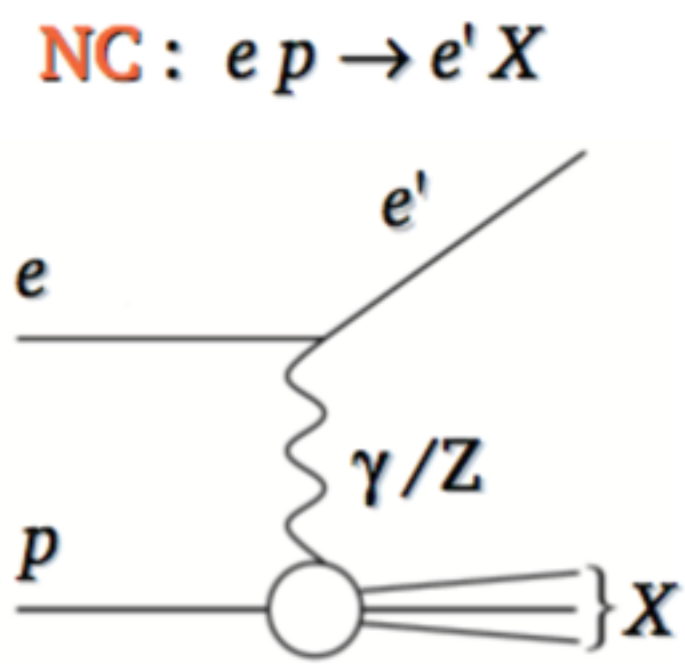
The LHeC Detector

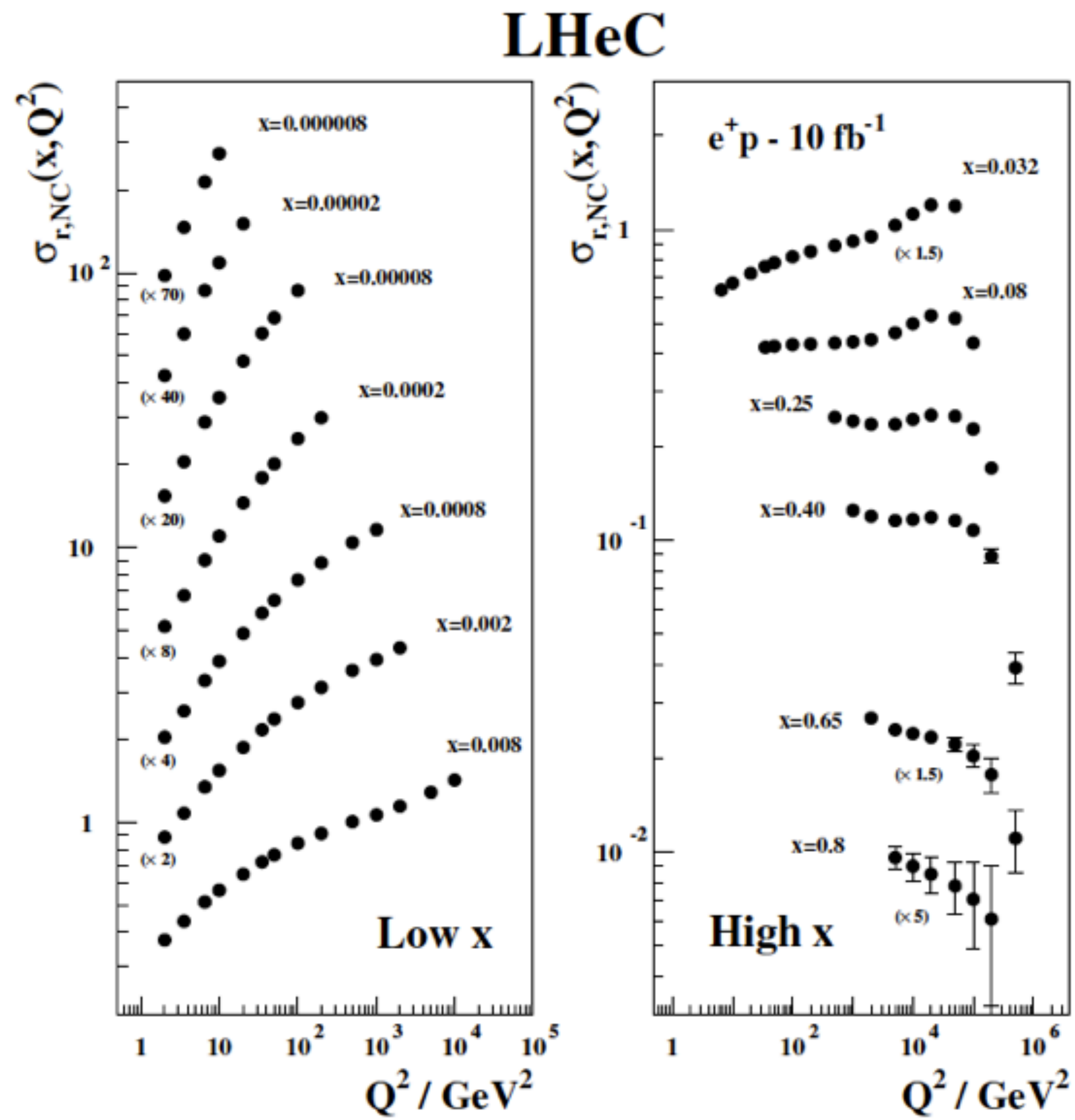
- High precision, state of the art detector, low noise, flavour tagging down to 1°
- No R&D
- Modular for fast installation and upgrade
- Affordable



- Asymmetric beams, a new large acceptance (1° < θ < 179°) detector is required
- Current dimensions LxD: $13 \times 9 m^2$ (cf. Atlas [45x25] and CMS[21x15])
- Dedicated electron, photon, proton and neutron taggers downstream

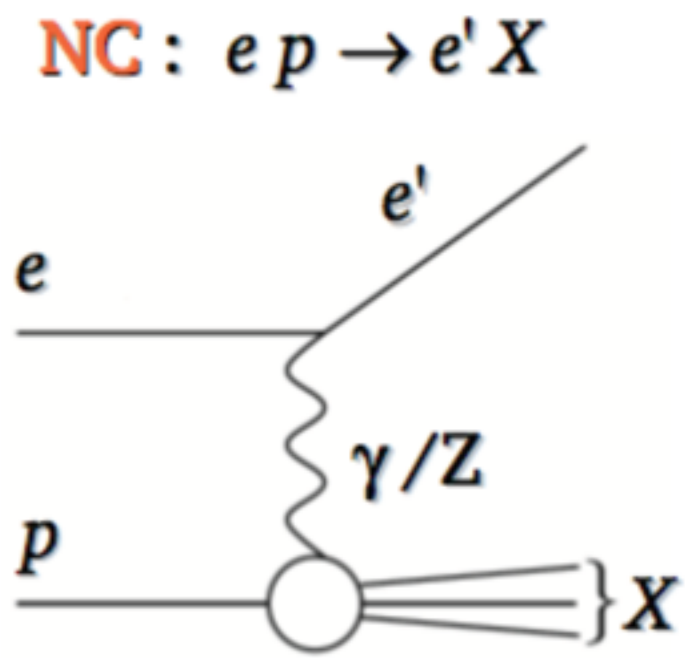
Studying proton structure

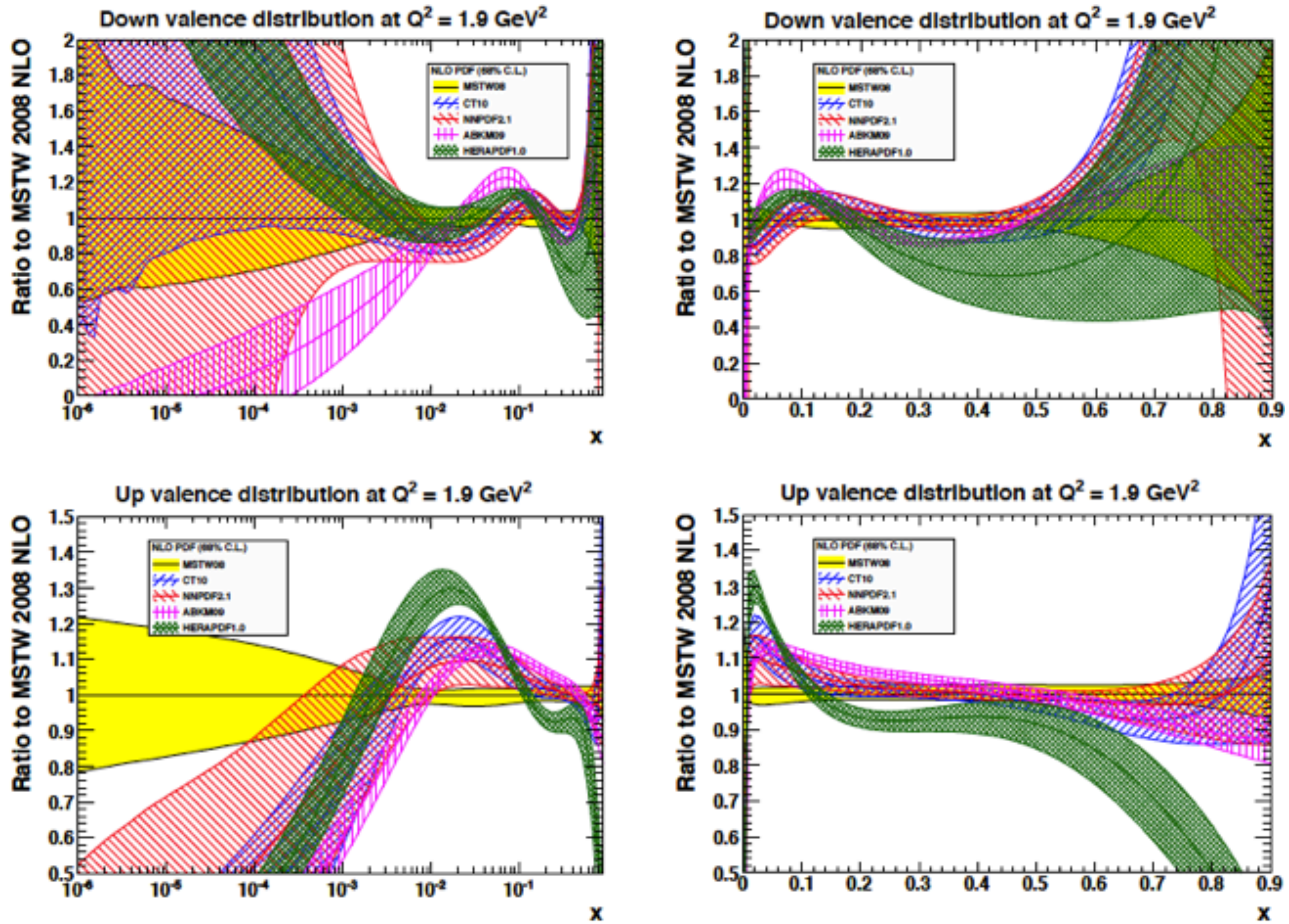




- The optics of the LHeC mean no pile-up, a clean unfolding of proton structure

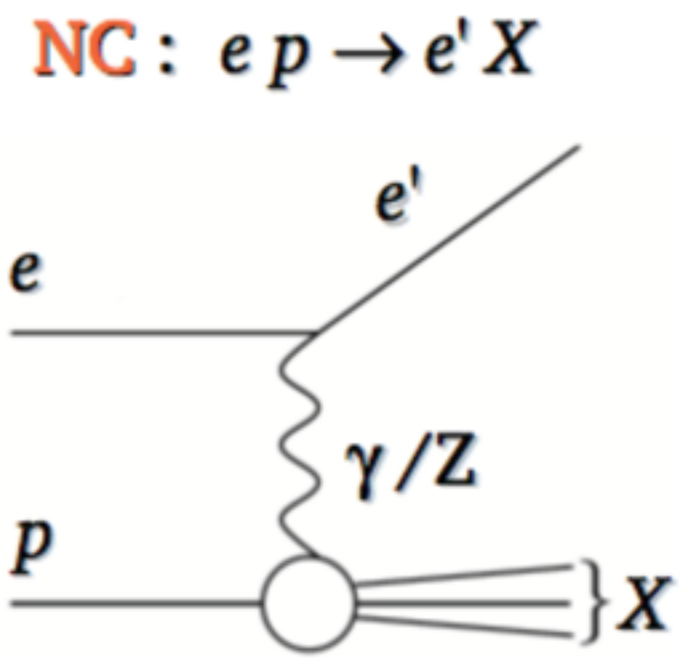
The proton has its ups and downs

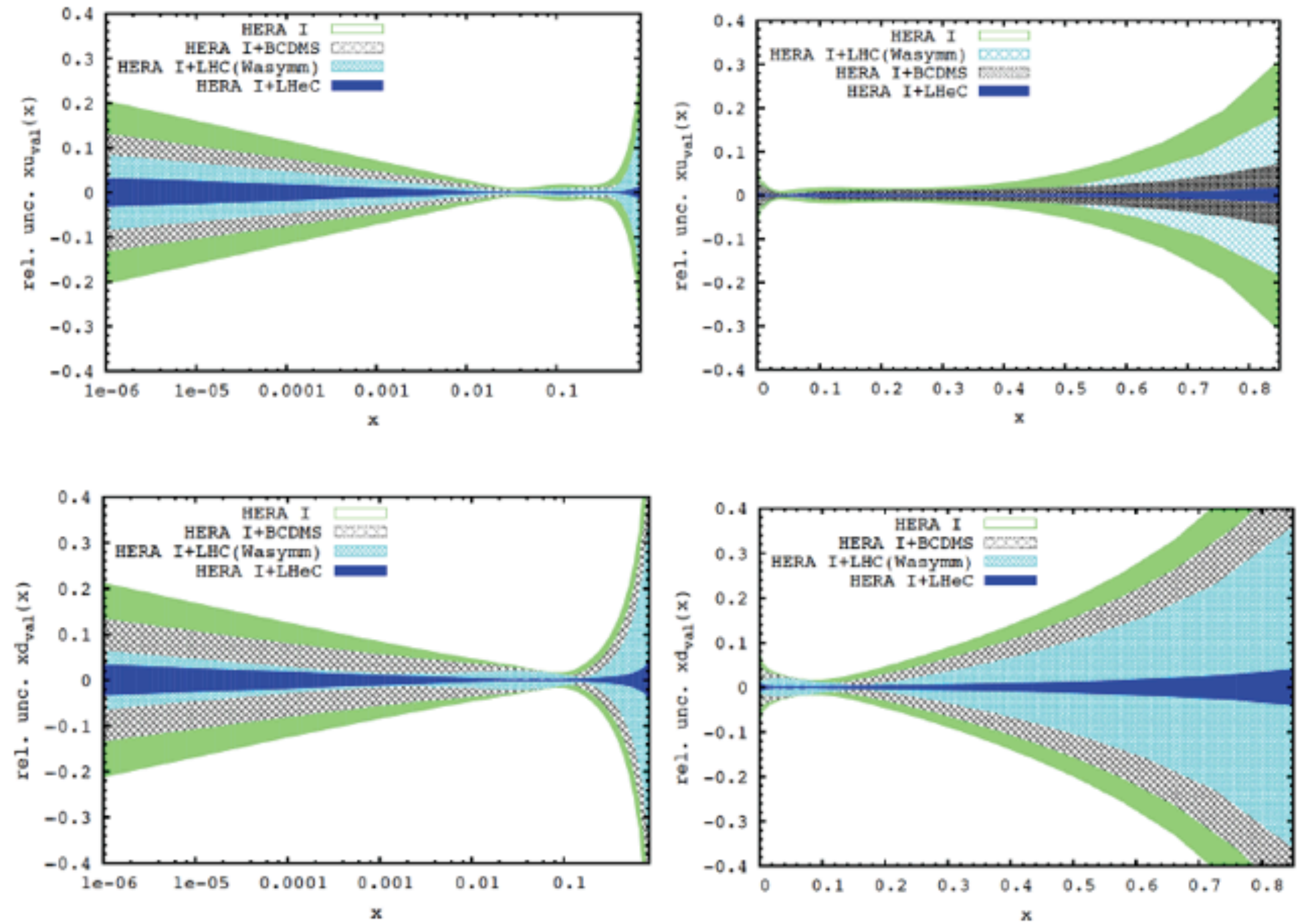




- The valence structure of the proton may be known, the details are not
- The range of answers offered by the latest and greatest is surprisingly varied

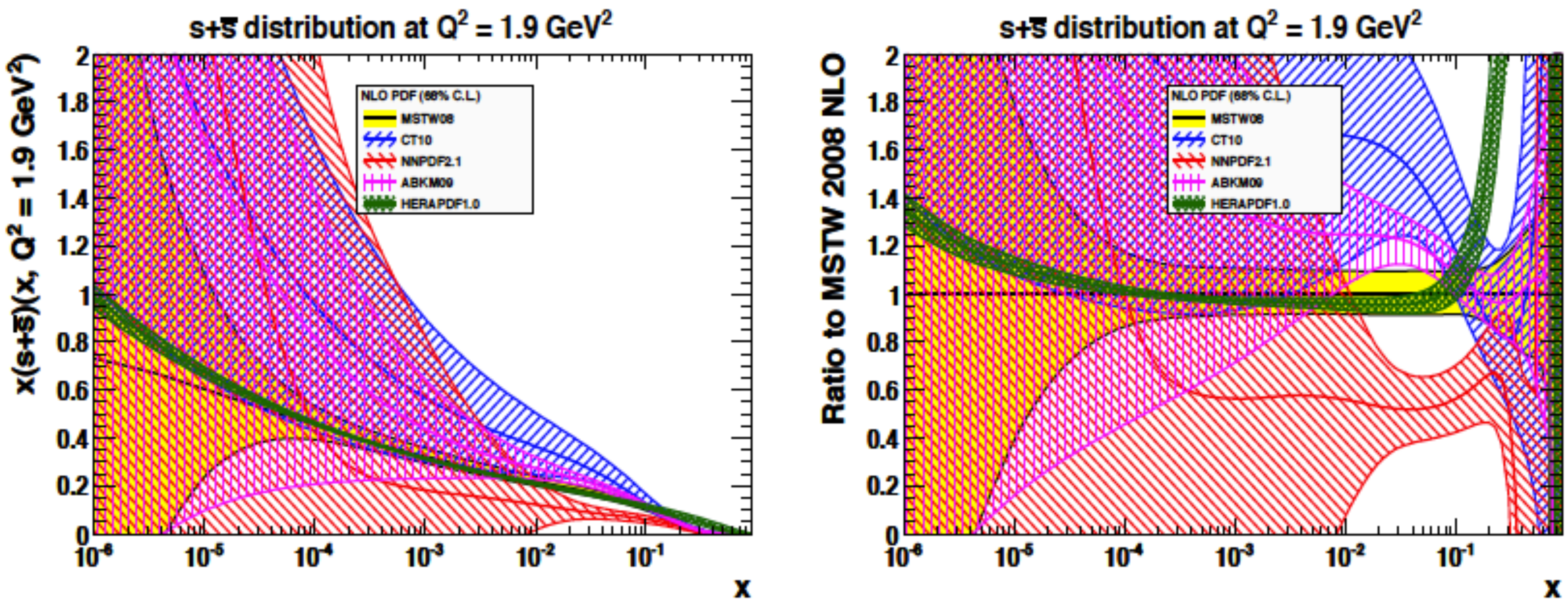
The proton has its ups and downs





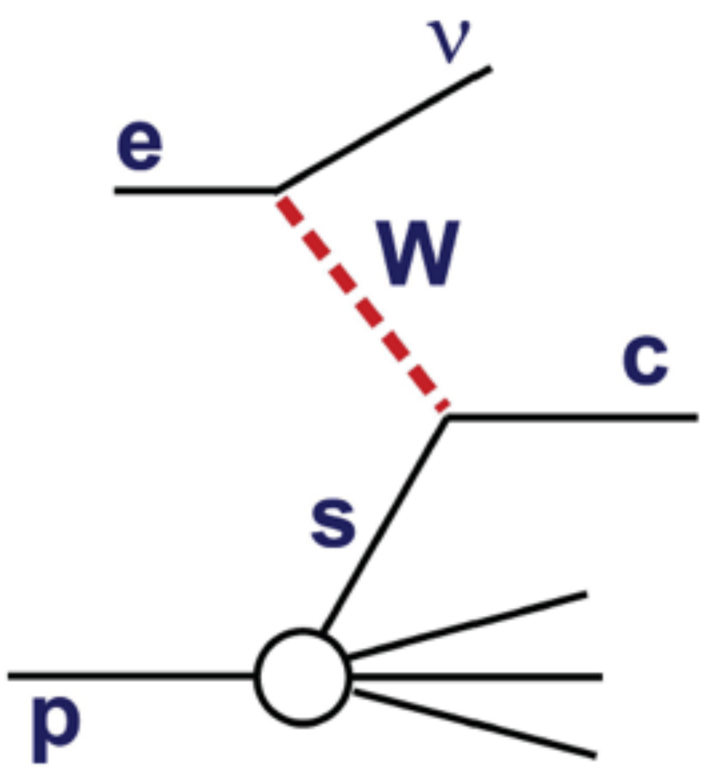
- The LHeC would be able to constrain the valence quarks across the whole kinematic range to better than ~2% precision

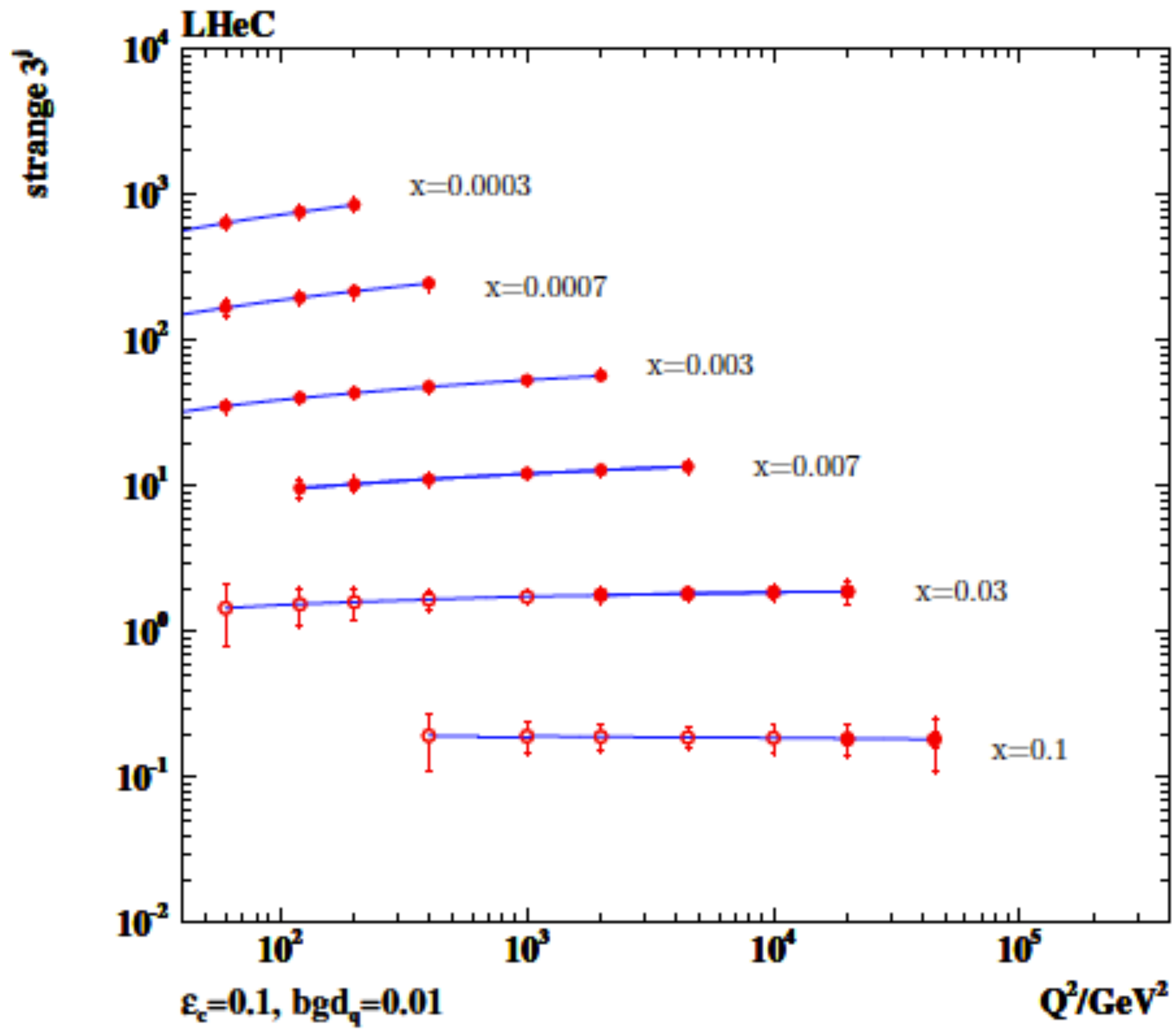
How strange is the proton



- The current constraints from data are very poor and consequently the strange content of the proton is very poorly known

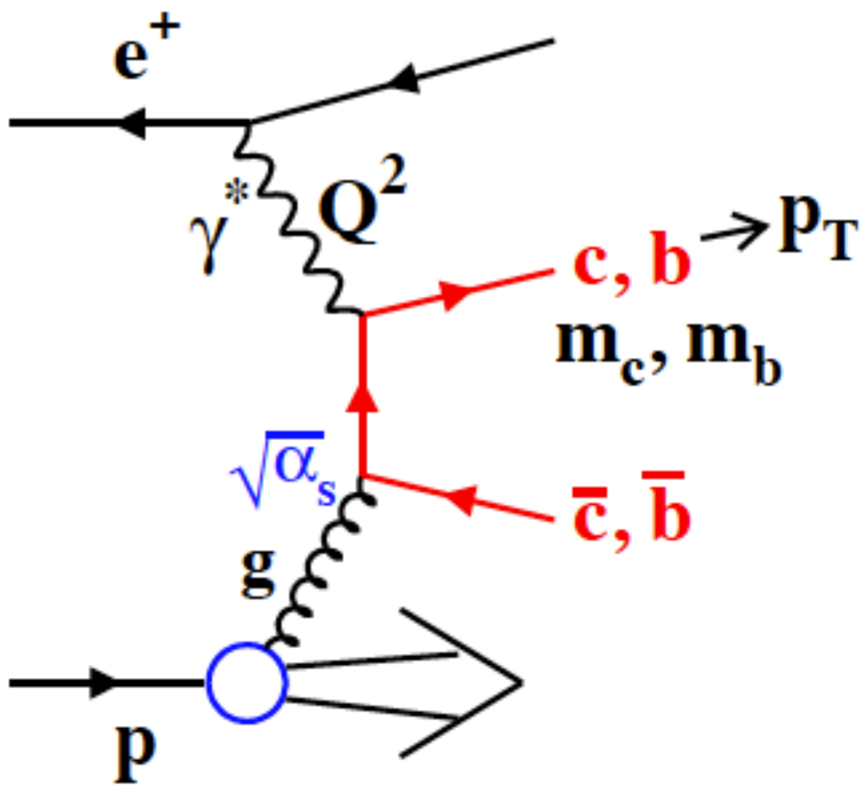
How strange is the proton

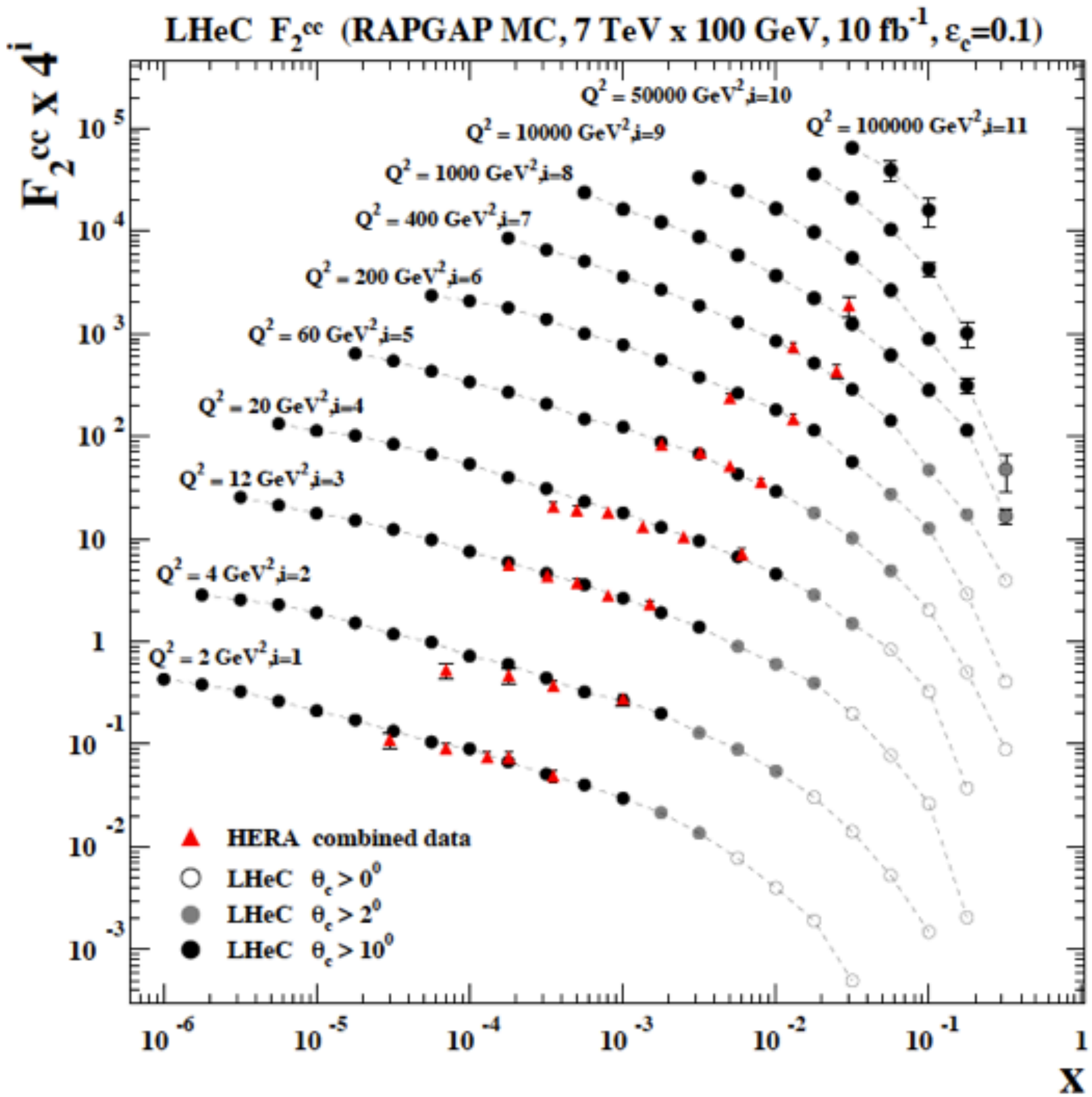




- The LHeC would measure the strangeness of the proton with high precision
- Positrons and electrons would disentangle strange from anti-strange

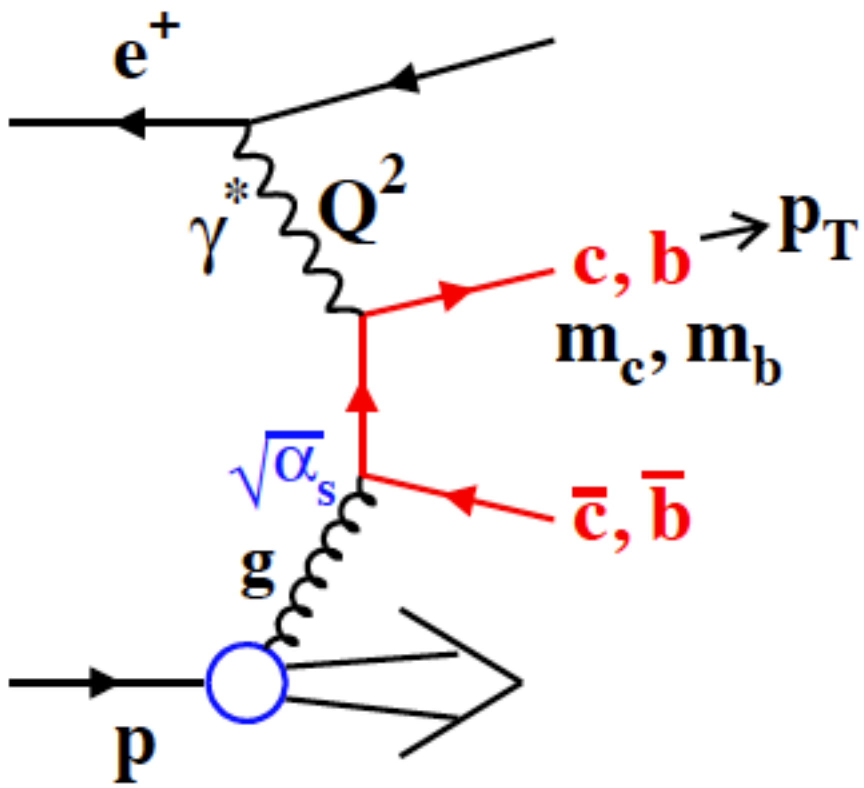
How charming is the proton

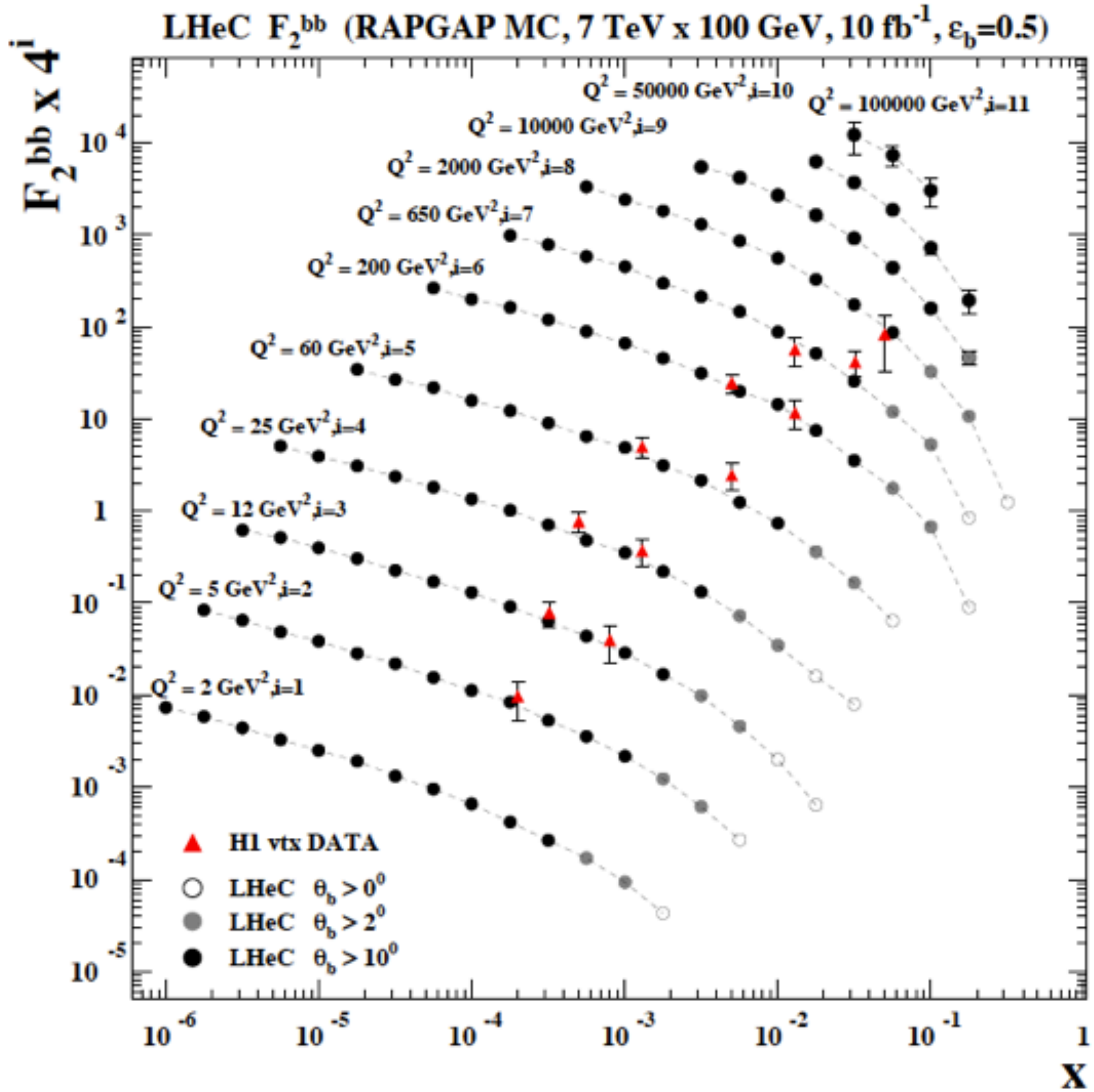




- The LHeC would measure the charm content of the proton with high precision across more than 5 decades in x and Q^2
- It will finally measure the charm content at high x - intrinsic charm

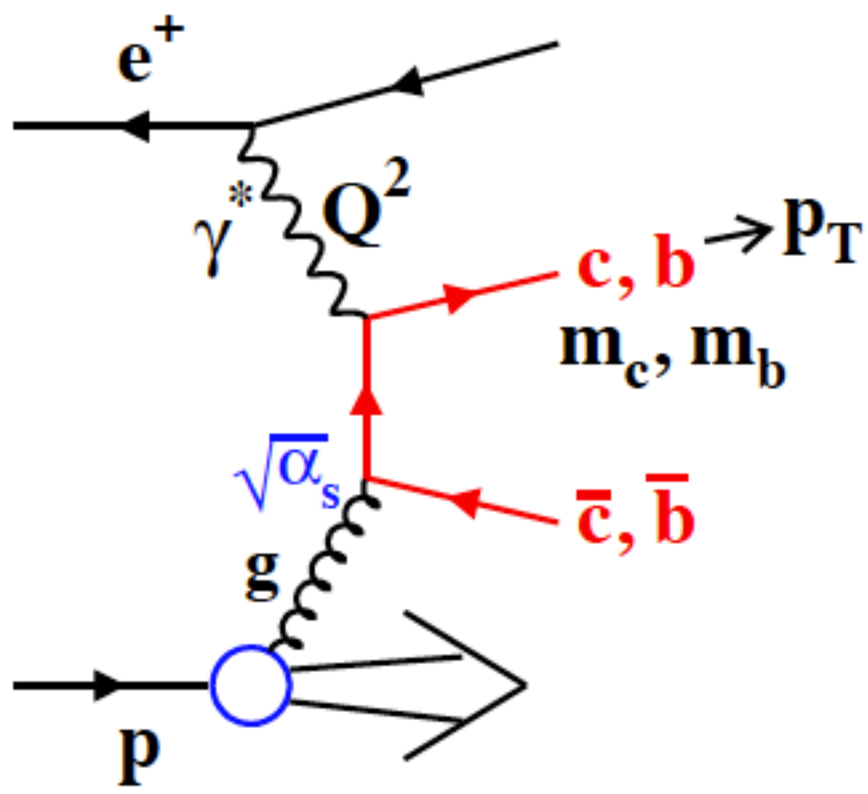
How beautiful is the proton

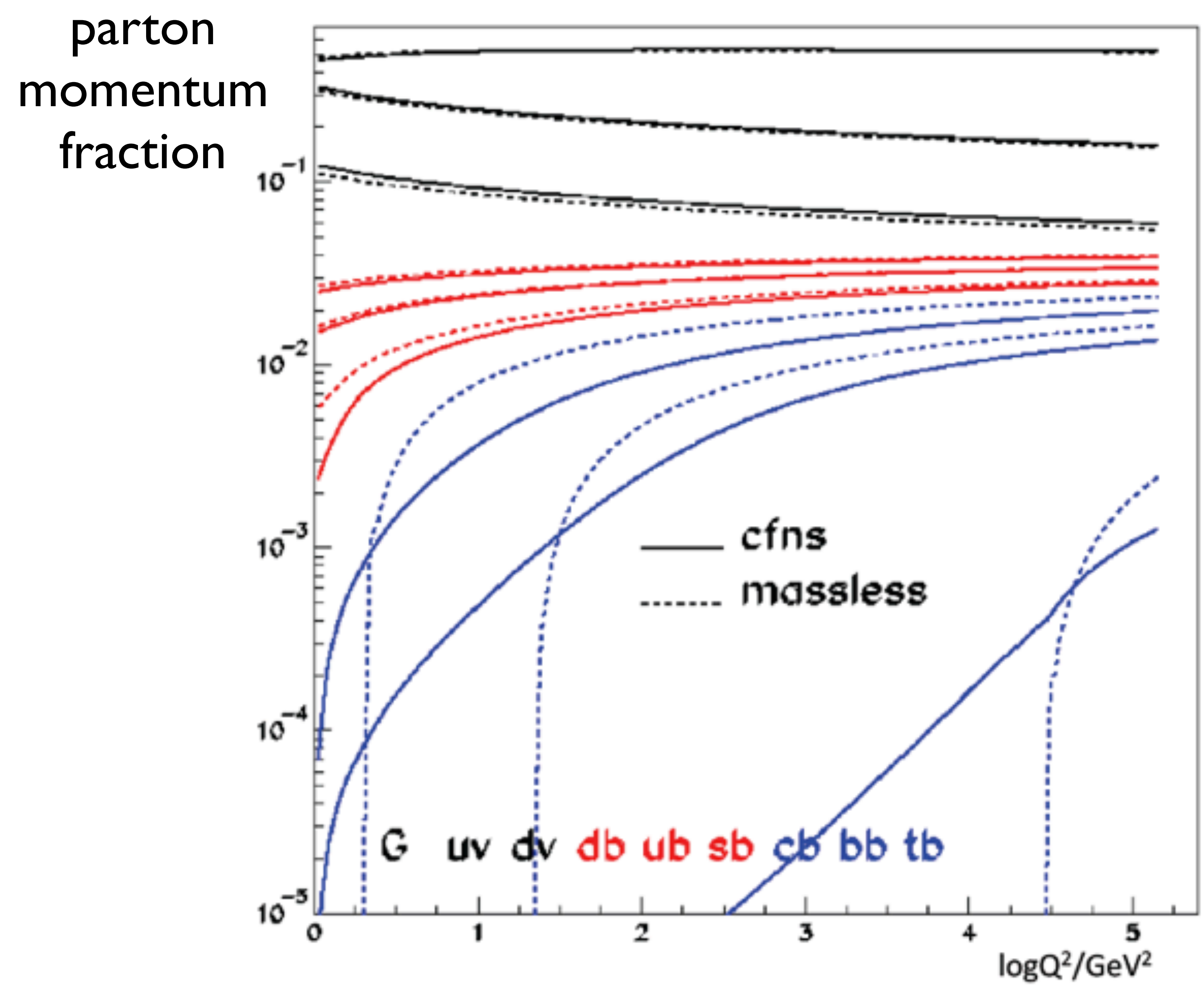




- The LHeC would measure the beauty content of the proton with high precision
- Interesting in order to predict initial states with beauty, e.g. Higgs

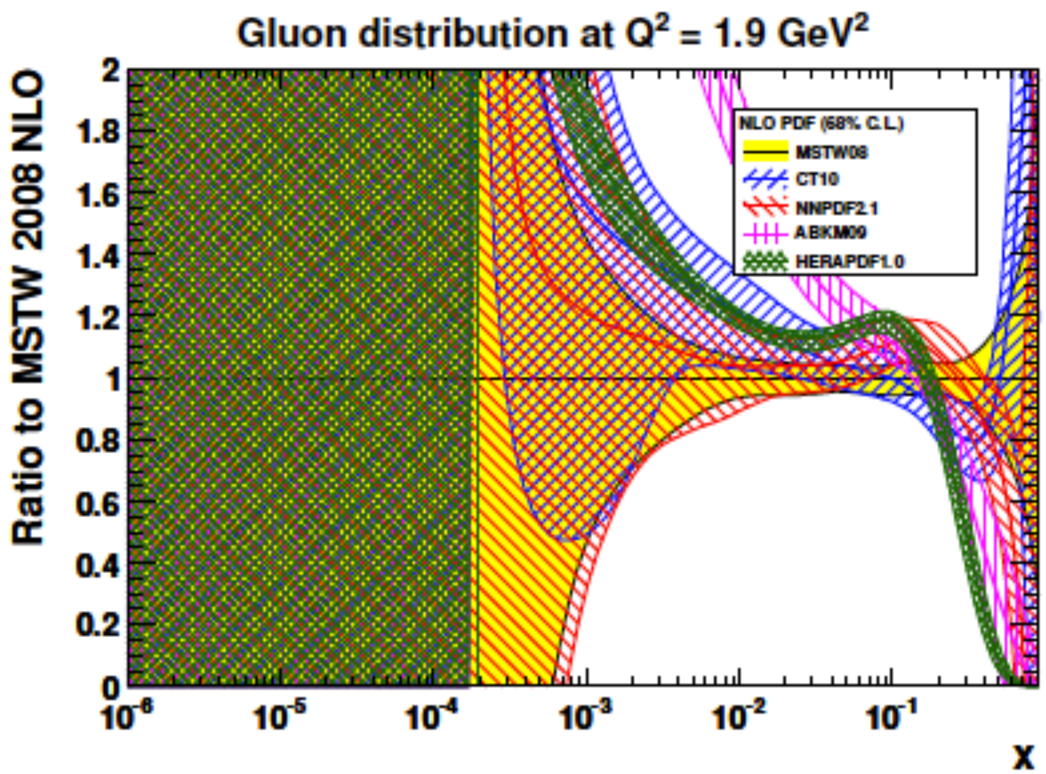
How to treat heavy flavours?

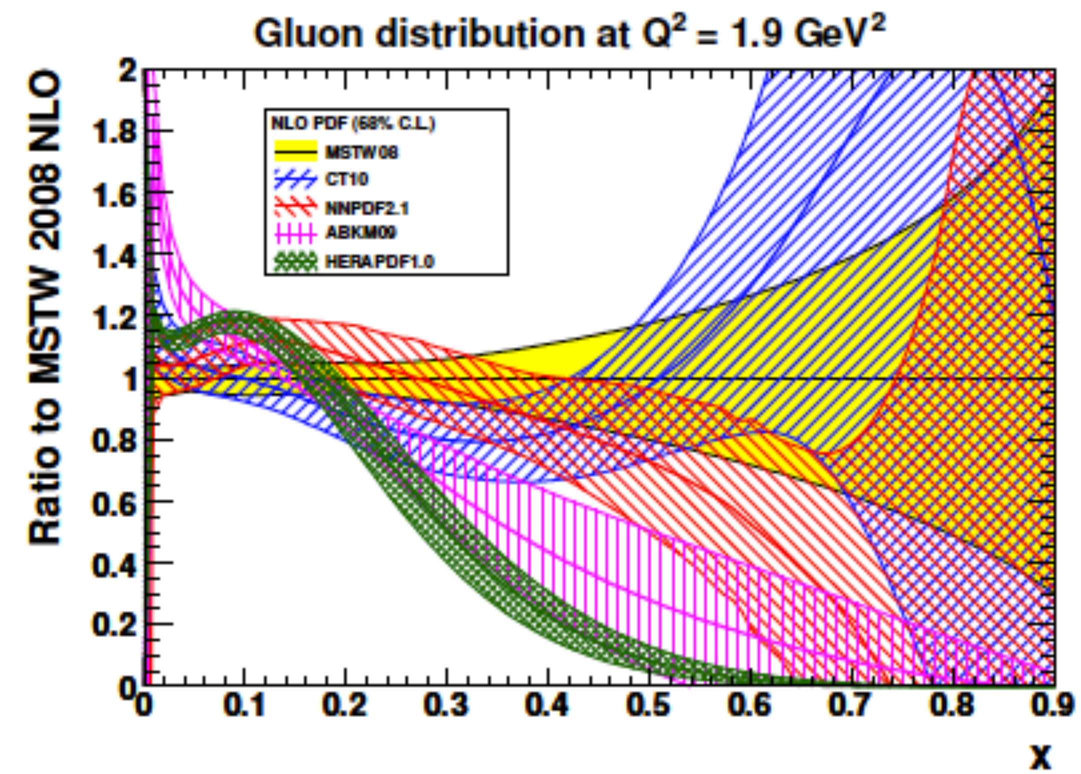




- The LHeC would distinguish between the massive and massless approaches, precision heavy flavour data invaluable for theory
- We expect to see top quarks in the proton before threshold (100,000 events)
- Through Boson-Gluon Fusion, access the gluon down to $x \sim 10^{-5}$

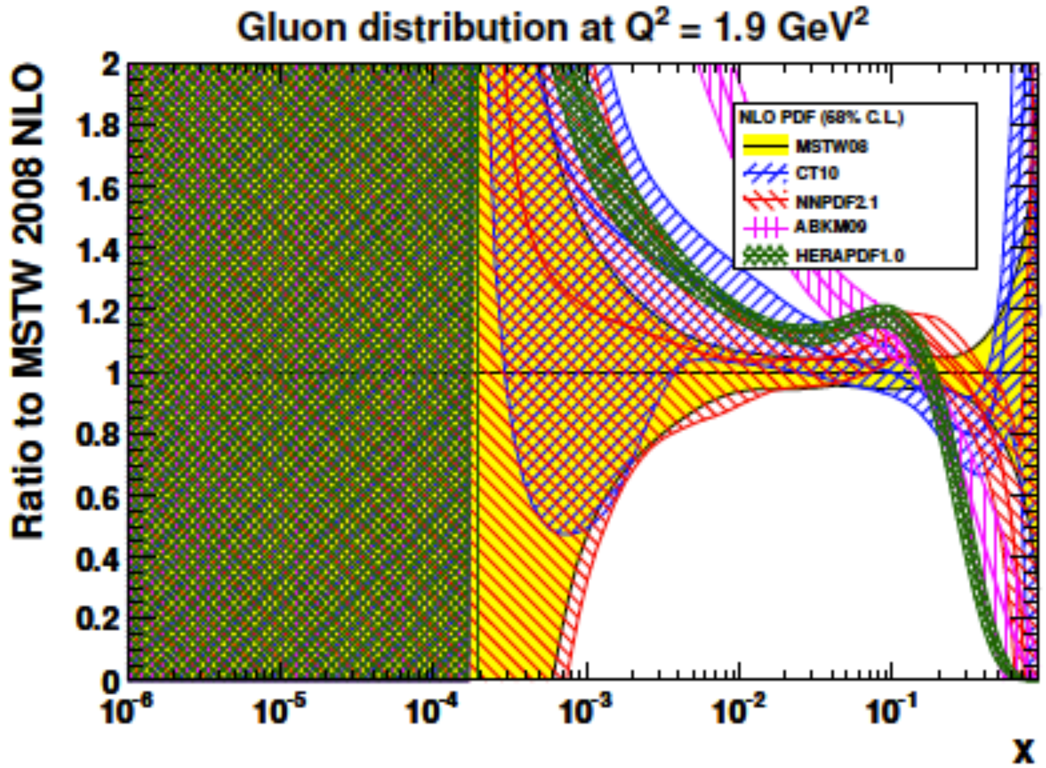
The gluon - a big unknown

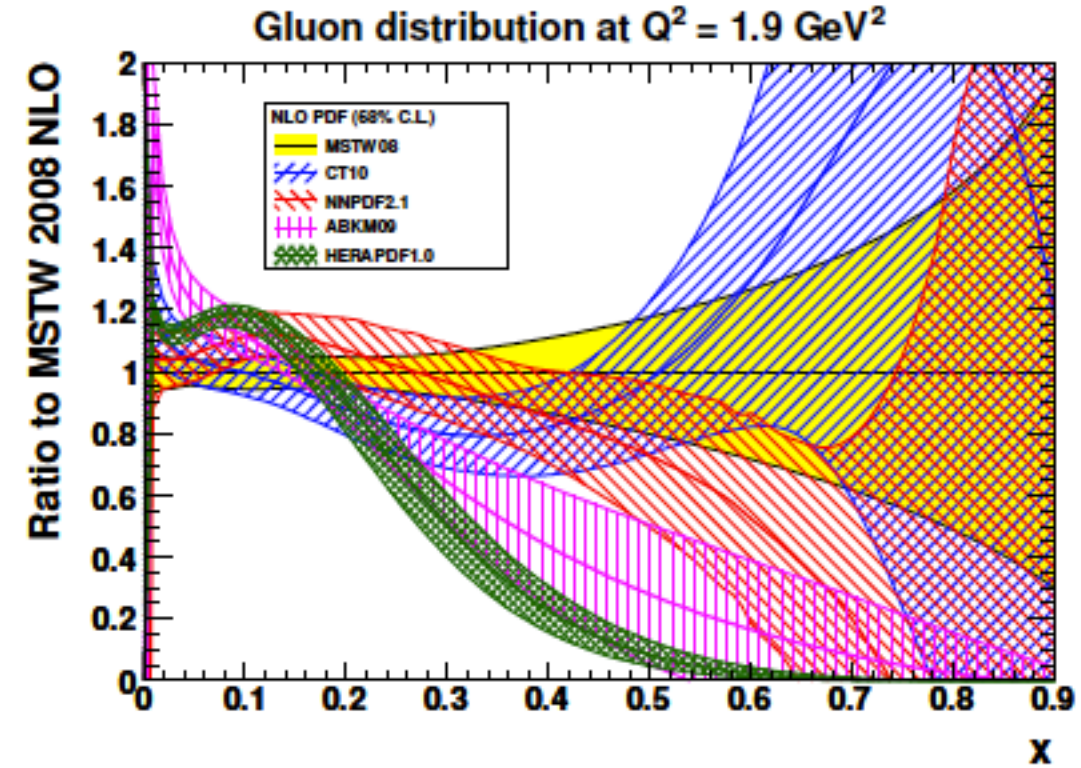


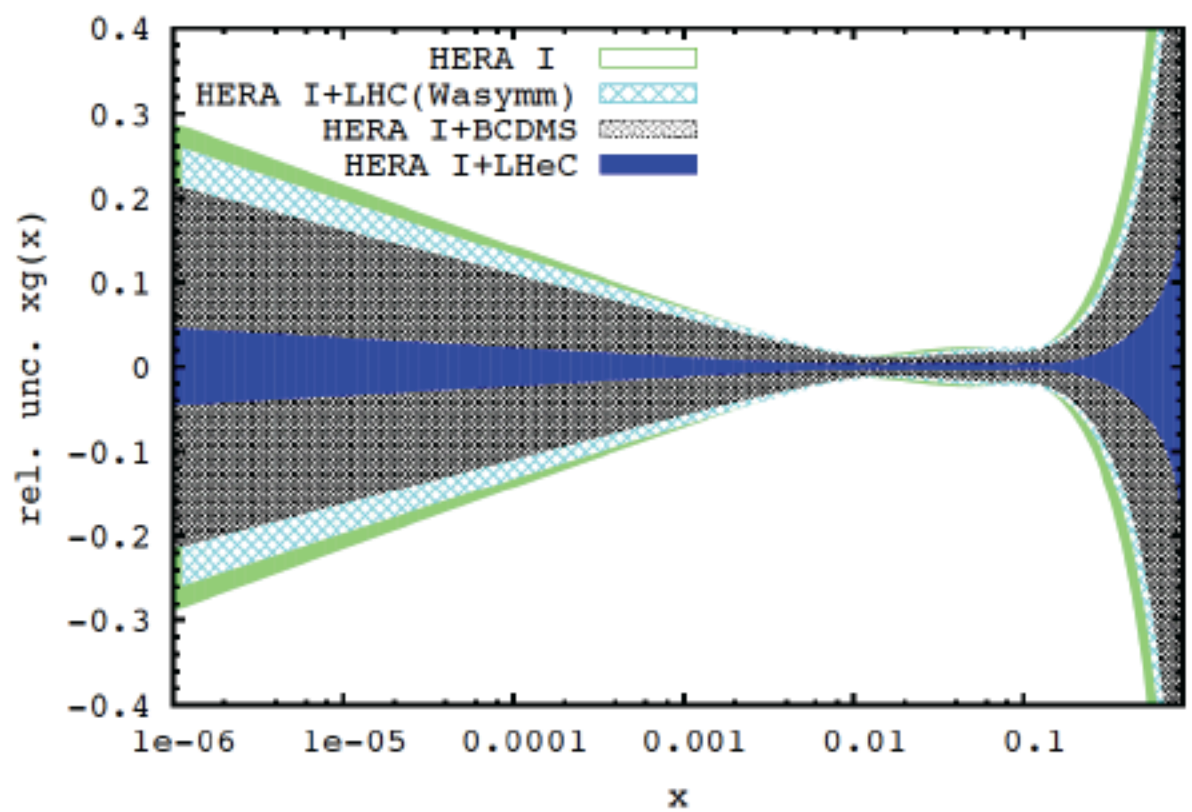


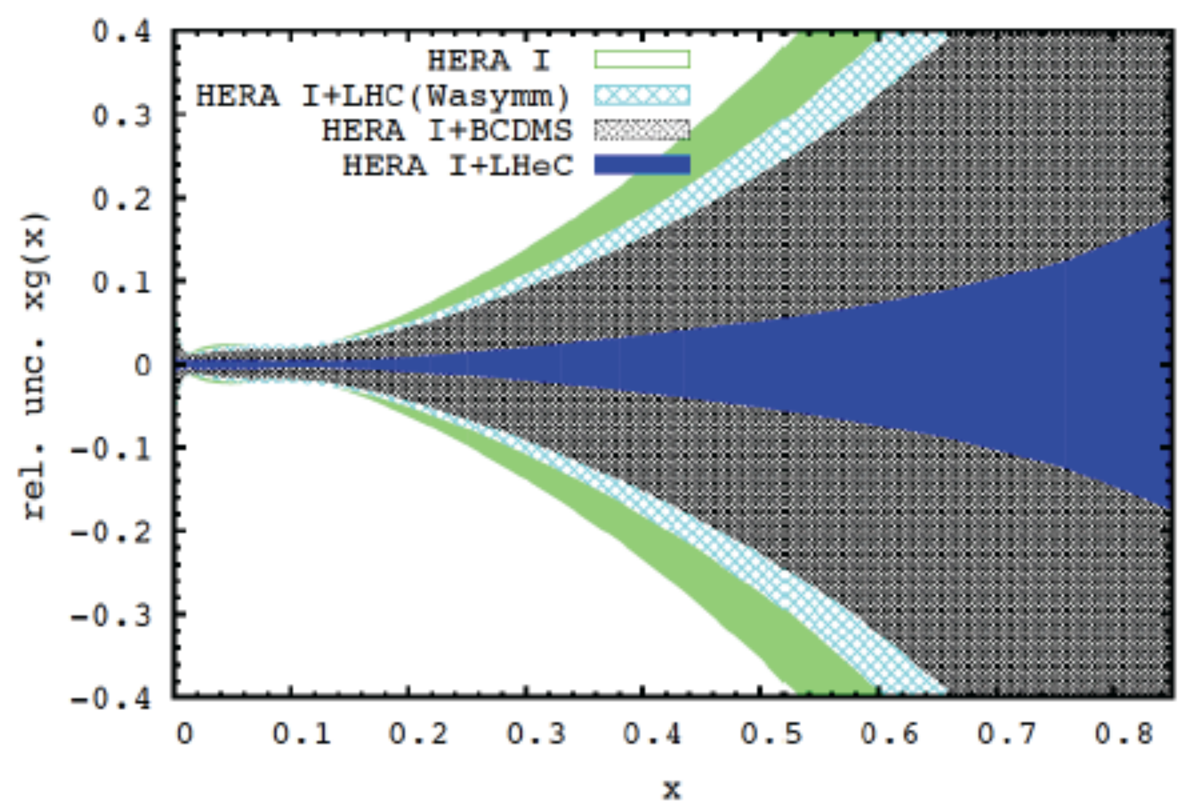
- The gluon dominates proton structure at low x, but is not well known
- It's all but unknown at high x - are there even "cold spots" with g=0?

The gluon



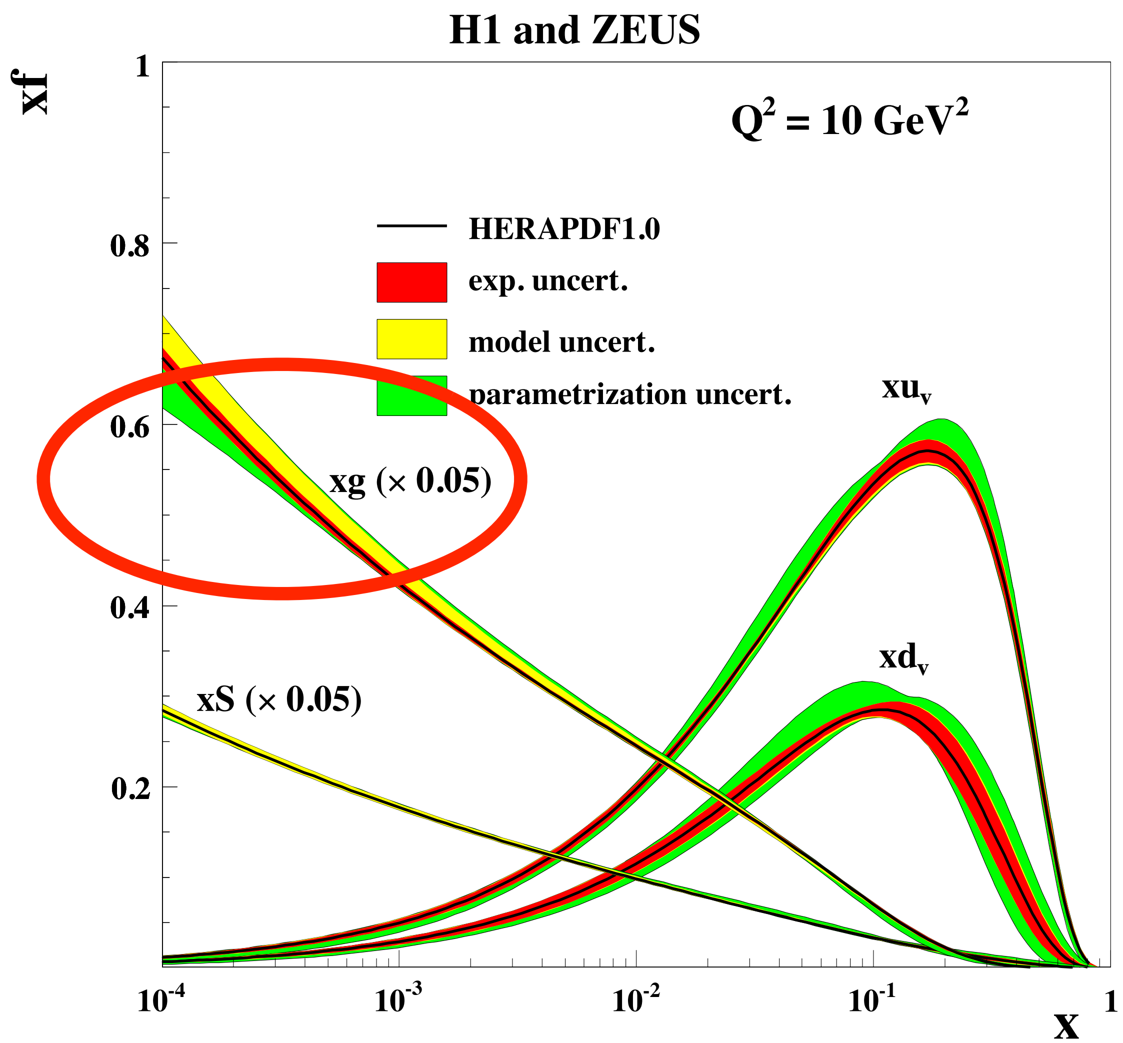


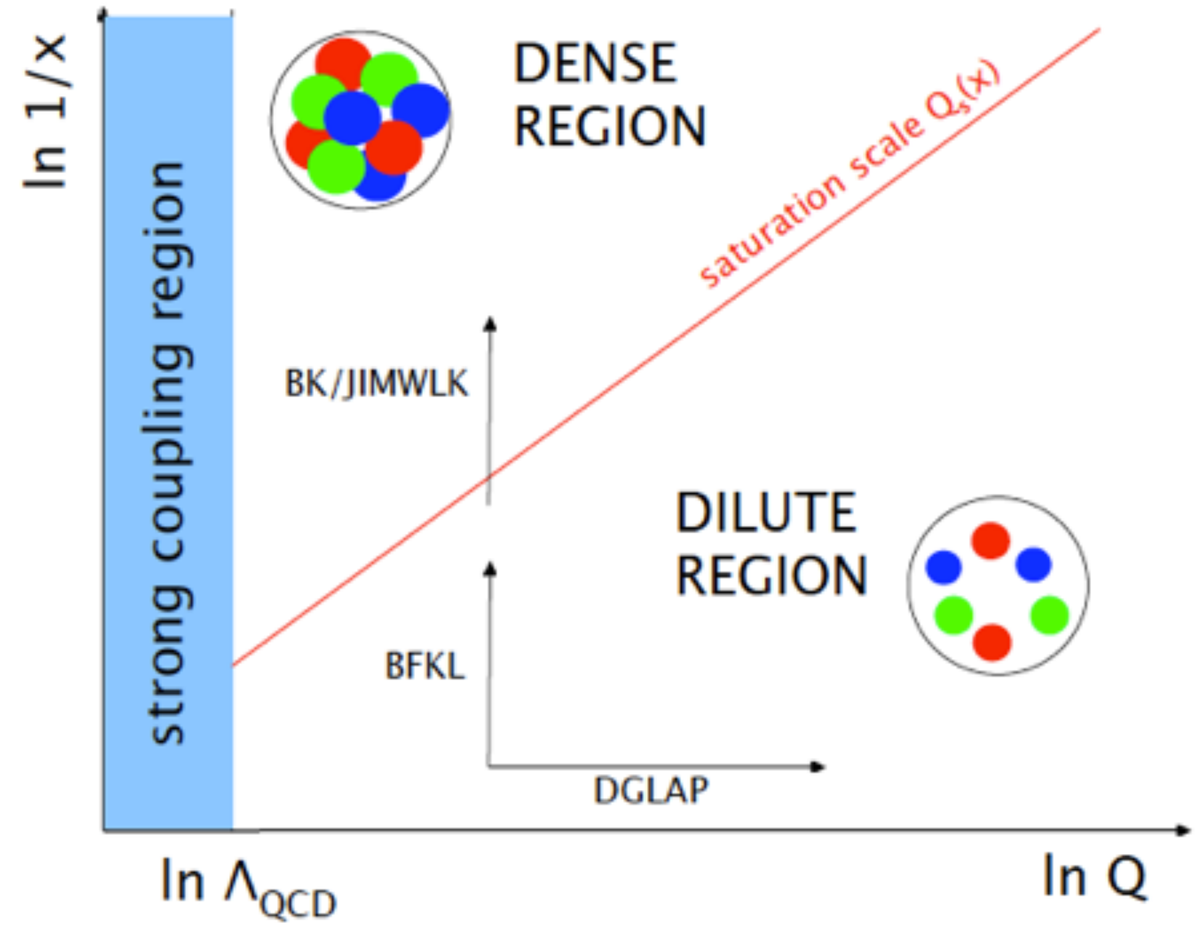




- Adding the LHeC data leads to very good precision across the kinematic range

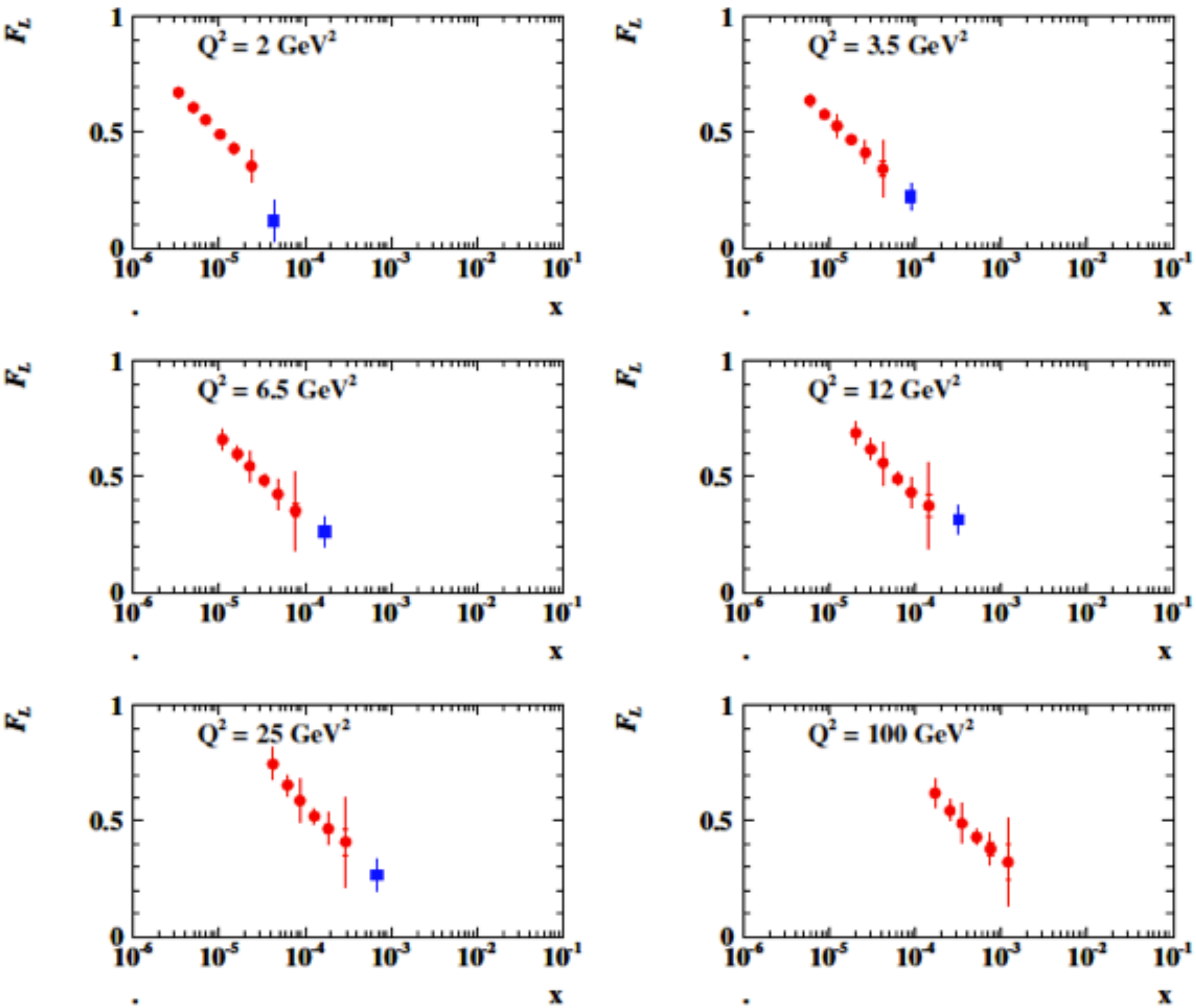
Saturation of parton densities

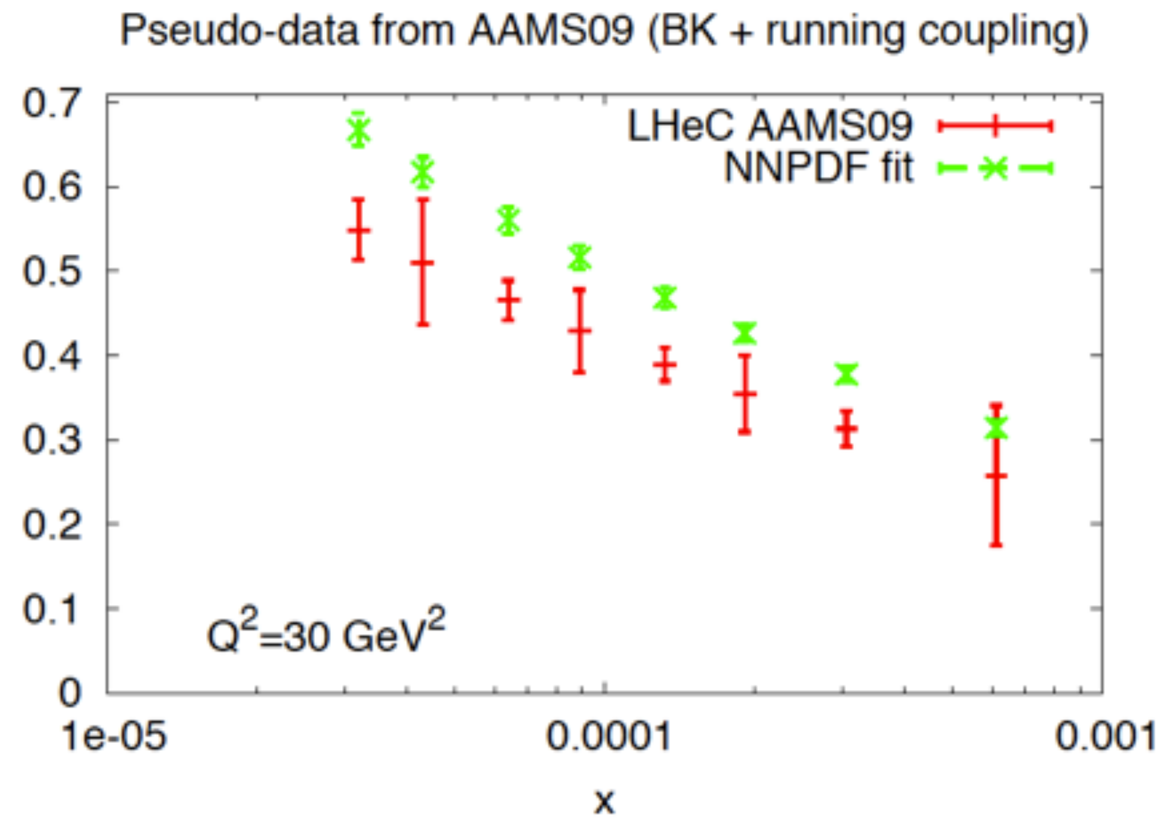




- The growth of the gluon density must be tamed at some point, non-linear effects
- Can still think in parton language if Q^2 large enough, recombination $gg \rightarrow g$ becomes important below the x-dependent saturation scale $Q_s(x)$
- Hints of breakdown of DGLAP at HERA but impossible to disentangle from fit treatment, e.g. heavy flavour treatment

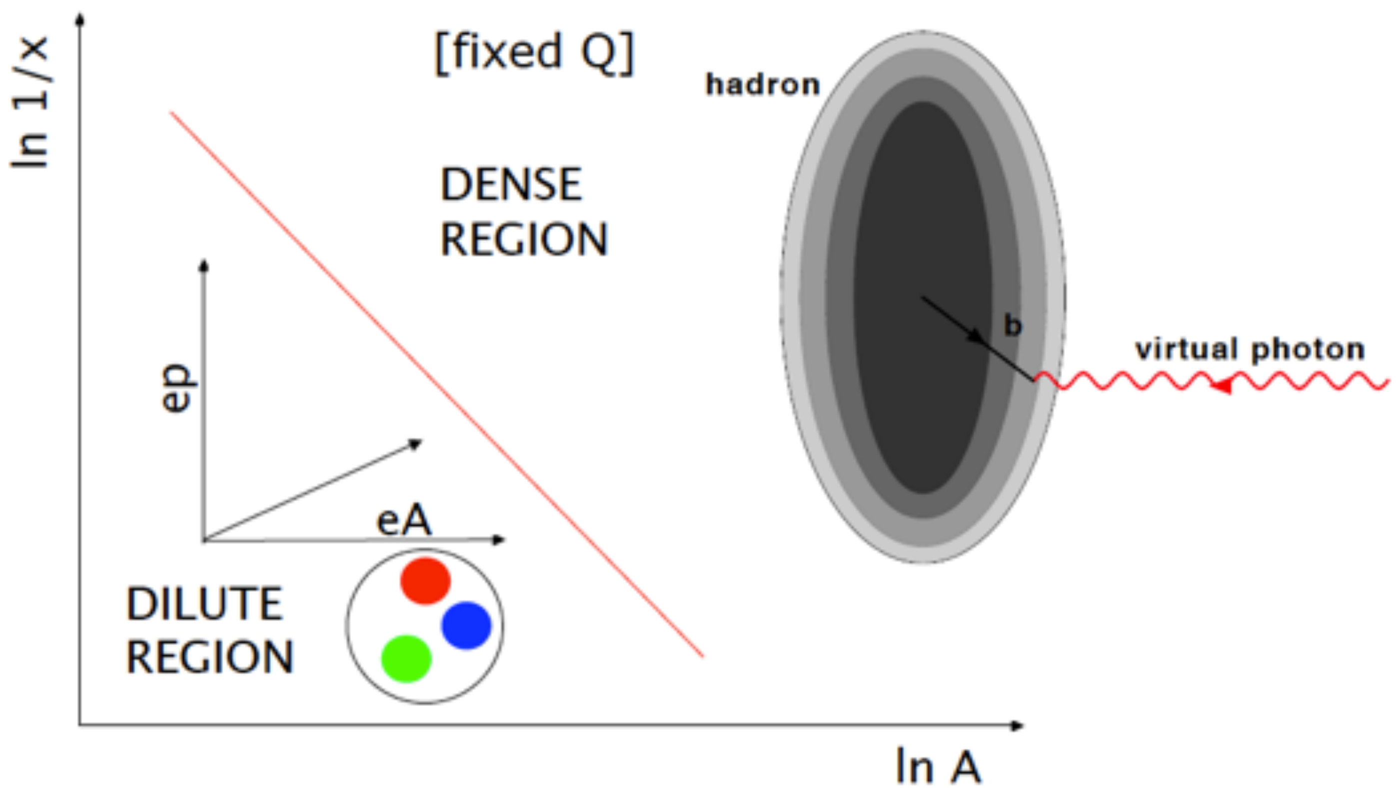
Finding saturation

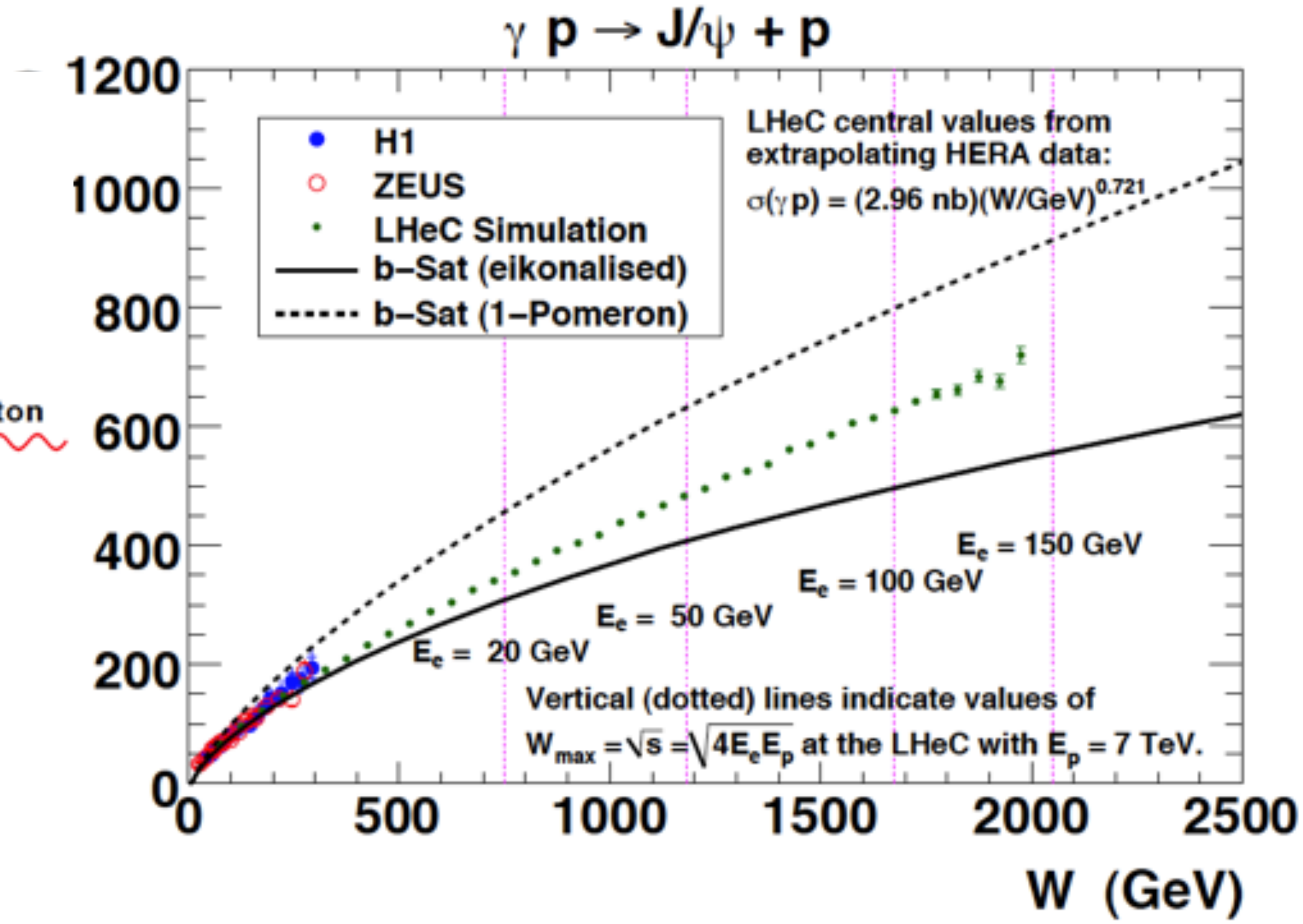




- Including a precision measurement of F_L in addition to F_2 into a DGLAP fit will fail if there are saturation effects in the gluon density
- F_2 data alone are not enough, F_2^c could also work

Characterising saturation





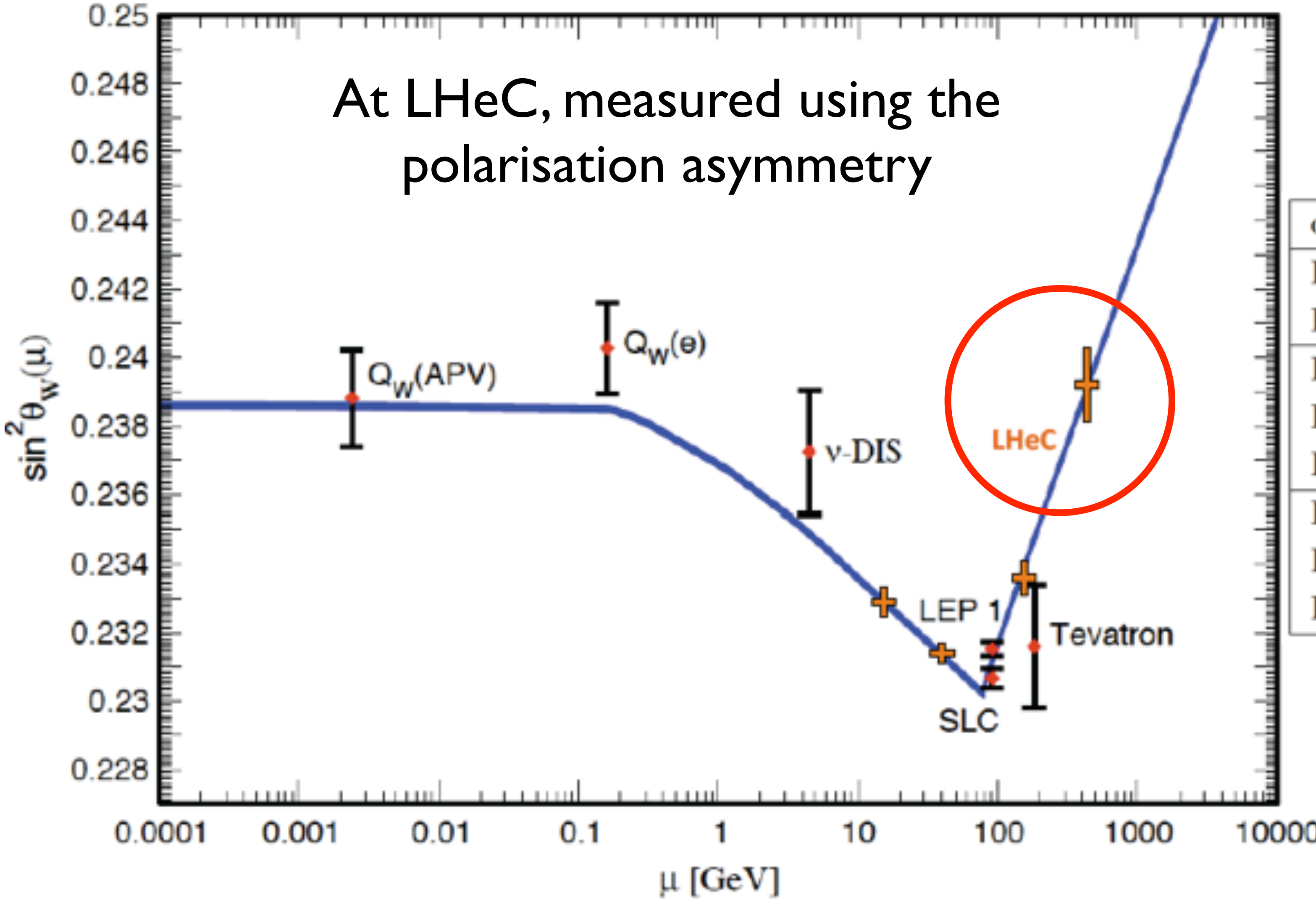
- Two ways of attacking the saturation scale at the LHeC, either by decreasing x, or alternatively by increasing the mass number A of the nucleus

- eA scattering program finally realised, nuclear PDFs, deuteron scattering with a tagged proton to understand neutron structure without nuclear corrections

- Exclusive diffractive processes can be used to probe the spatial distribution of the partons via the impact parameter (t) dependence

Measuring fundamentals

$\sin^2\theta_W$

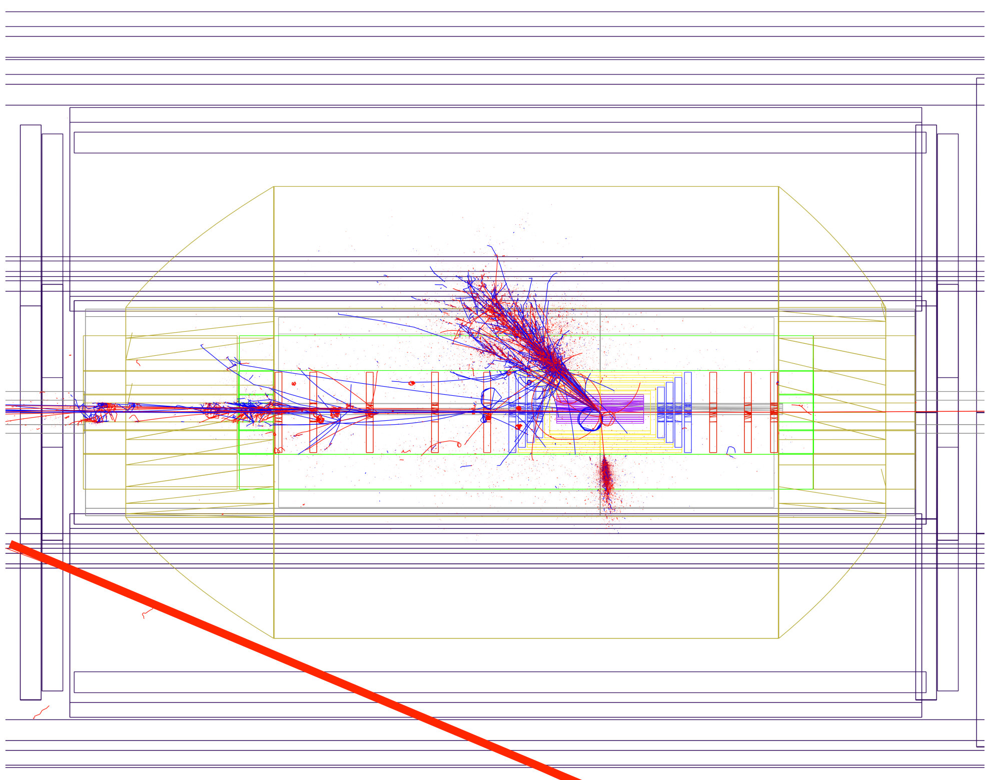


α_s scenarios

case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

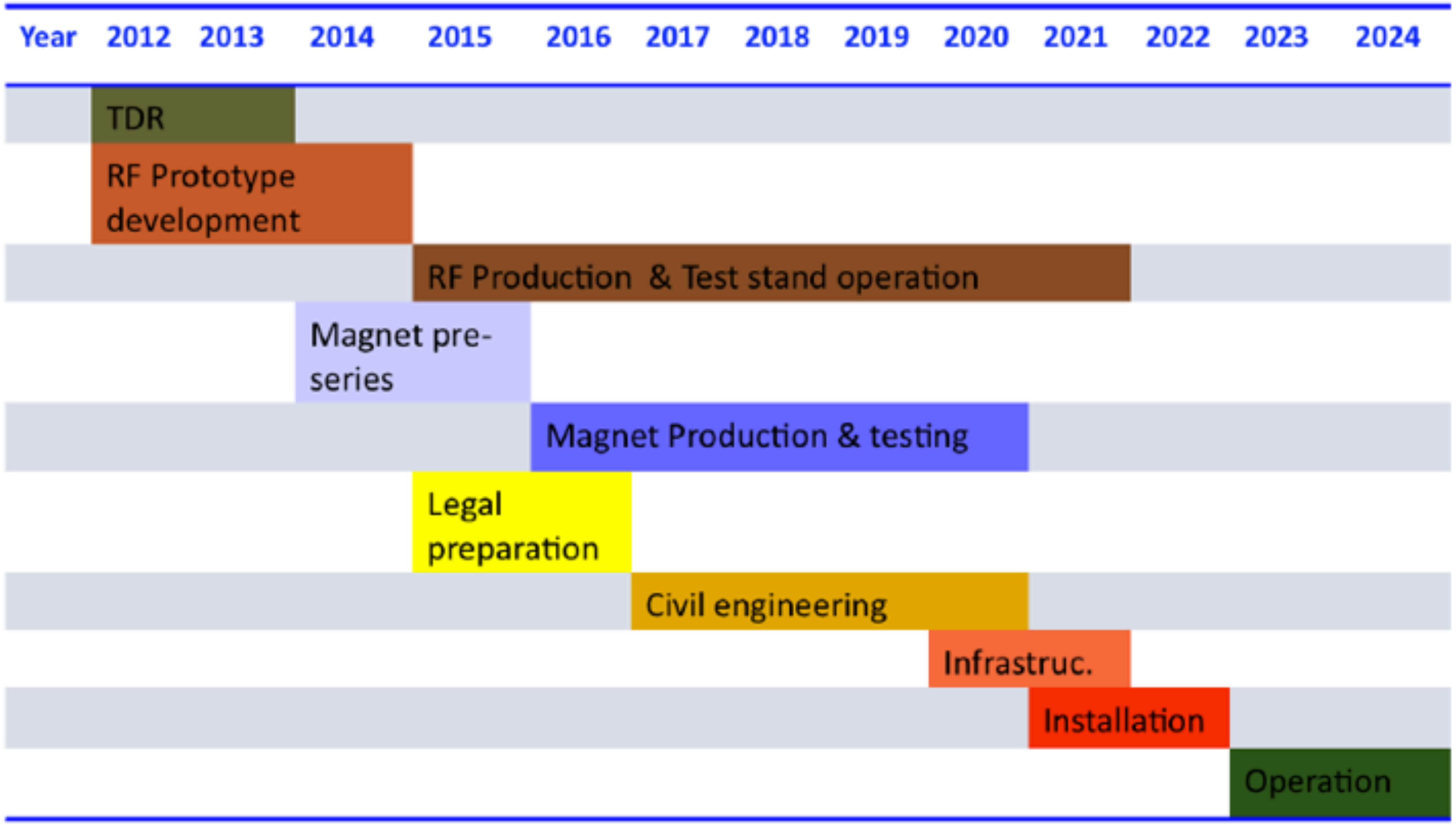
- The LHeC would be able to measure the value of $\sin^2\theta_W$ at different $\mu(Q^2)$
- The strong coupling constant, presently known to ~1% precision, would be determined at the per mille level
- At a couple per mille for Q^2>20 GeV^2, i.e. no non-perturbative effects

Physics highlights



- α_s measured to per mille
  - Grand unification of the couplings
- Complete unfolding of proton structure
  - Maximise the potential of LHC
- Saturation at low x
  - Study in pQCD regime
- eA - nuclear structure functions
  - Complementary to e.g. EIC
- Heavy flavour factory, precision tests of the treatment of mass in pQCD
  - Understand the fits
- Leptoquarks, excited electrons, Higgs
  - Complementary to LHC searches

Timeline



- The actual timeline will of course be constrained by the LHC, with the installation taking place during the pre-SLHC shutdown around 2021
- The CDR is being finalised now, for referees this month, then finalise and hand CDR to ECFA/NuPECC/CERN
- Workshop to decide on Ring vs Linac in Fall 2011
- Participate in 2011/2012 European Strategy Process, starting at EPS 2011
- Predicting the future is difficult, but the LHeC realises DIS at the TeV scale

Summary

- The LHeC could be built on a timescale that appears feasible and complements the LHC program very well
- It's difficult to completely quantify the effect that it will have on our understanding of the proton as it will change the way we look at it and how we perform our analyses
- Assumptions will be replaced by measurements
- QCD will be placed under the electron microscope as never before, unfolding the proton to maximise the physics potential of the LHC and exploring a new state of strongly interacting matter beyond the saturation scale with a perturbative probe

A Large Hadron Electron Collider at CERN

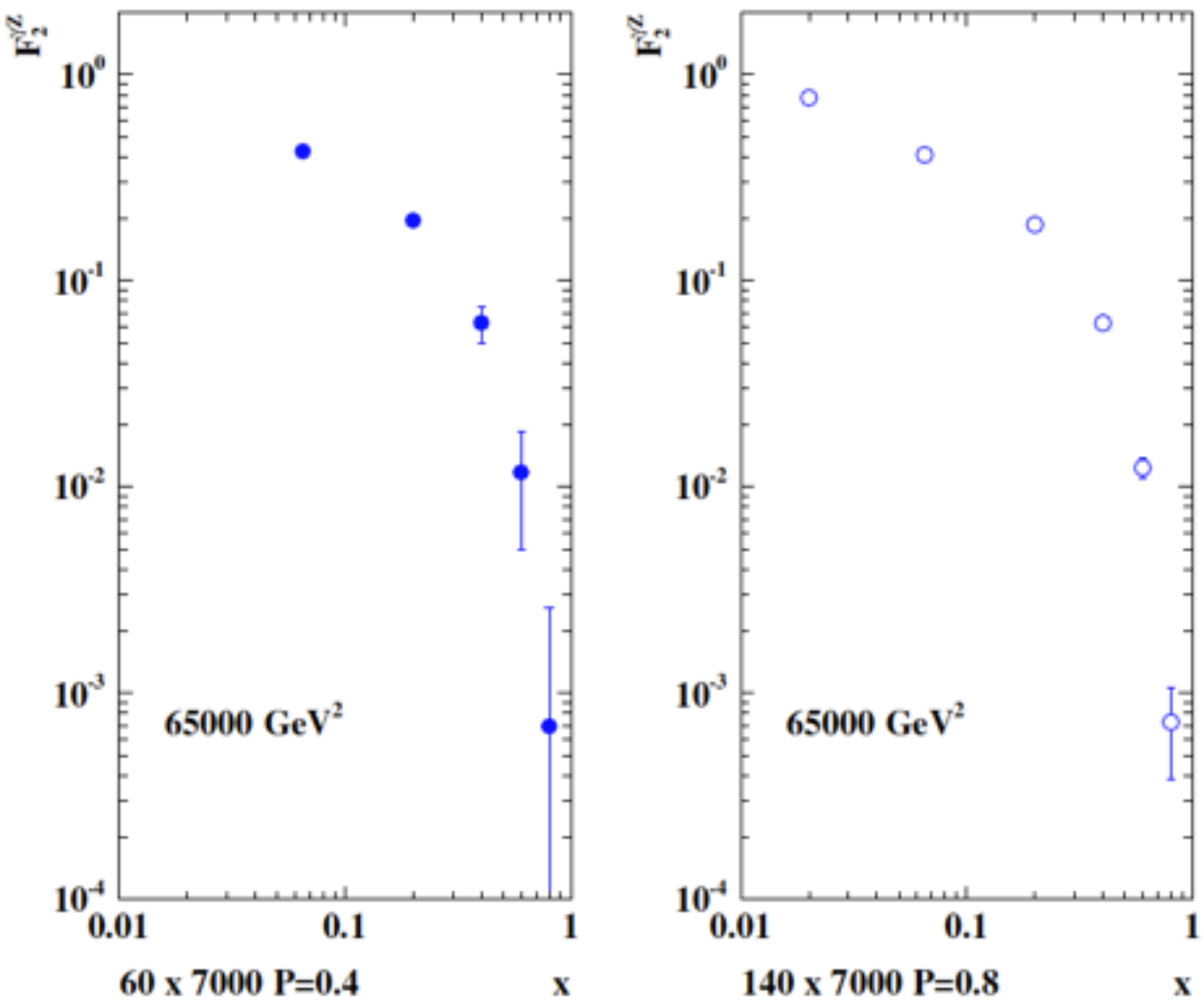
Report on the Physics and Design
Concepts for Machine and Detector

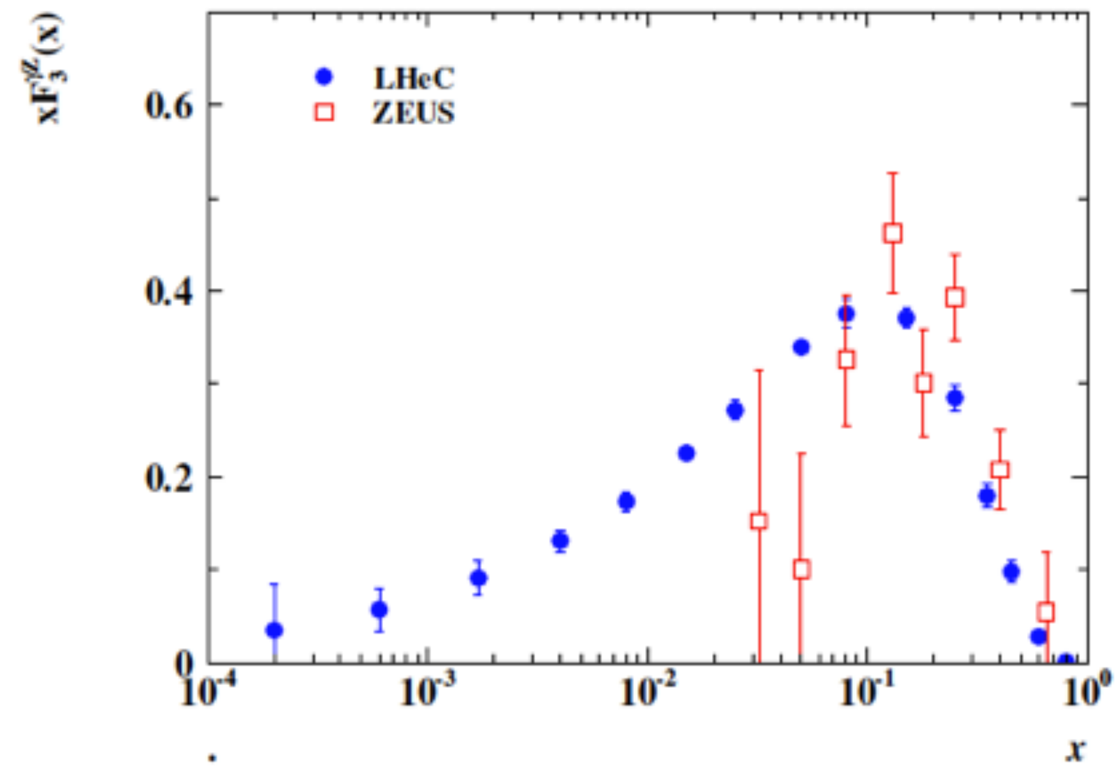
LHeC Study Group

"Exploring a new territory with a precision instrument is the key to discovery" - Professor Ting, Erice 2011

Backup

Neutral Current Boson Interference





- Limited measurements of the interference terms contributing to proton structure
- LHeC measures $F_2^{\gamma Z}$ for the first time - probing parity violation at small distances
- Also measures $xF_3^{\gamma Z}$ with good precision - probing the valence at $x < 10^{-3}$

The Conceptual Design Report

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

- 160 pages on Physics
  - Precision QCD and electroweak, New Physics at Large Scales, Physics at High Parton Densities
- 210 pages on Machine
  - Ring-Ring, Linac-Ring, Components and Civil Engineering
- 105 pages on Detector
- 700 references and counting...
- To be given to the CERN-appointed referees this month

LHeC Study Group

Not Final!

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LHeC Organisation

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Linac-Ring Design
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Energy Recovery
Georg Hoffstatter, Ilan Ben Zvi

Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz

Baseline Parameters

electron beam	RR	LR	LR
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} cm^{-2}s^{-1}]	17	10	0.44
polarization [%]	40	90	90
bunch population [10^9]	26	2.0	1.6
e- bunch length [mm]	10	0.3	0.3
bunch interval [ns]	25	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.58, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	30, 16	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.18, 0.10	0.12	0.14
full crossing angle [mrad]	0.93	0	0
geometric reduction H_{hg}	0.77	0.91	0.94
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	131	6.6	5.4
tot. wall plug power[MW]	100	100	100

High E_e Linac option (ERL?) if physics demands, HE-LHC?

proton beam	RR	LR
bunch pop. [10^{11}]	1.7	1.7
tr.emit.$\gamma\varepsilon_{x,y}$ [μm]	3.75	3.75
spot size $\sigma_{x,y}$ [μm]	30, 16	7
$\beta^*_{x,y}$ [m]	1.8,0.5	0.1
bunch spacing [ns]	25	25

"ultimate p beam"
1.7 probably conservative

Design also for
D and A ($L_{eN} = 10^{31}$ cm^{-2}s^{-1})

RR= Ring – Ring
LR =Linac –Ring

Parameters from 8.7.2010
New: Ring: use 1° as baseline : L/2
Linac: clearing gap: L*2/3