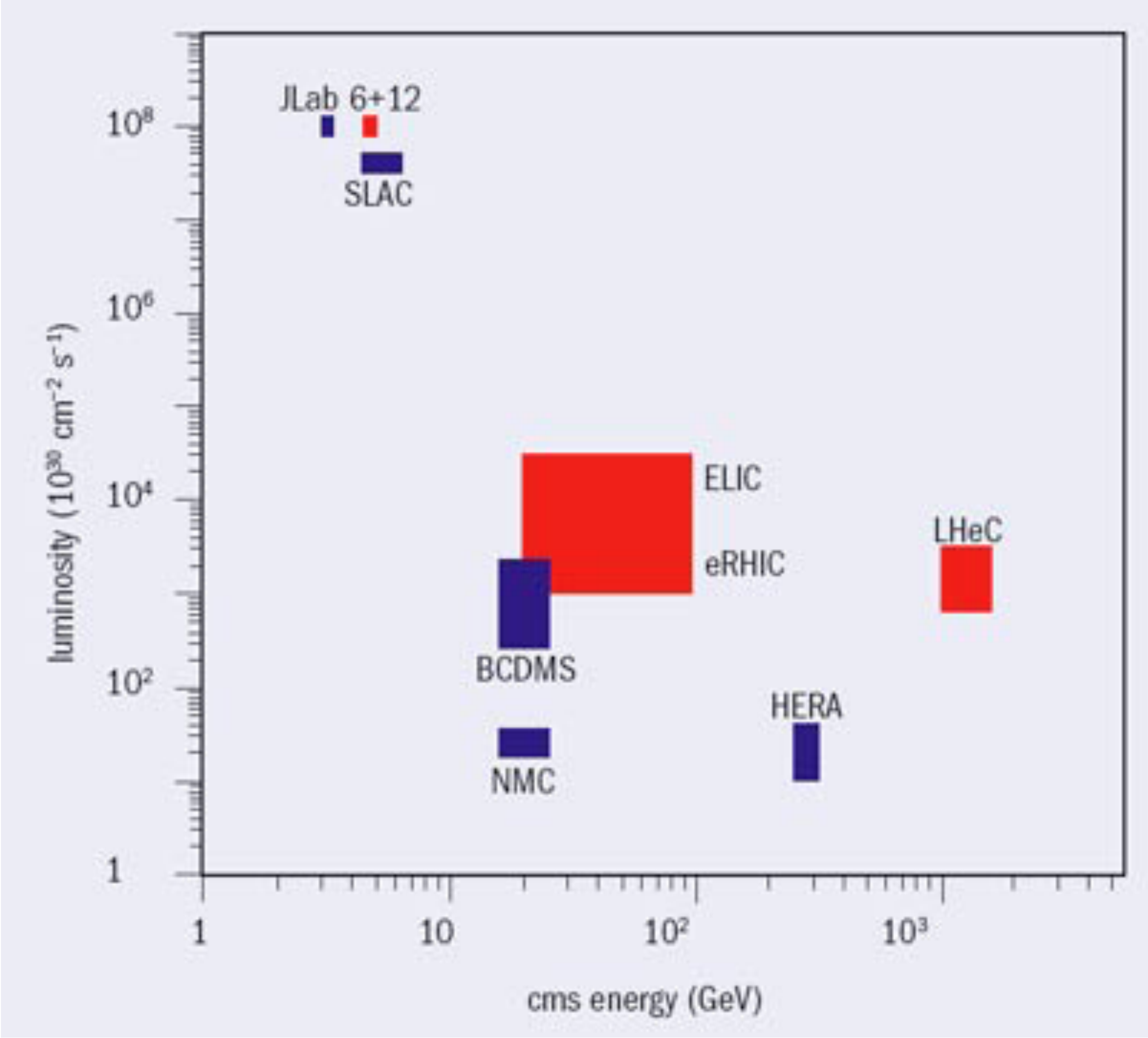
An Overview of the LHeC

Paul Laycock

UNIVERSITY OF LIVERPOOL

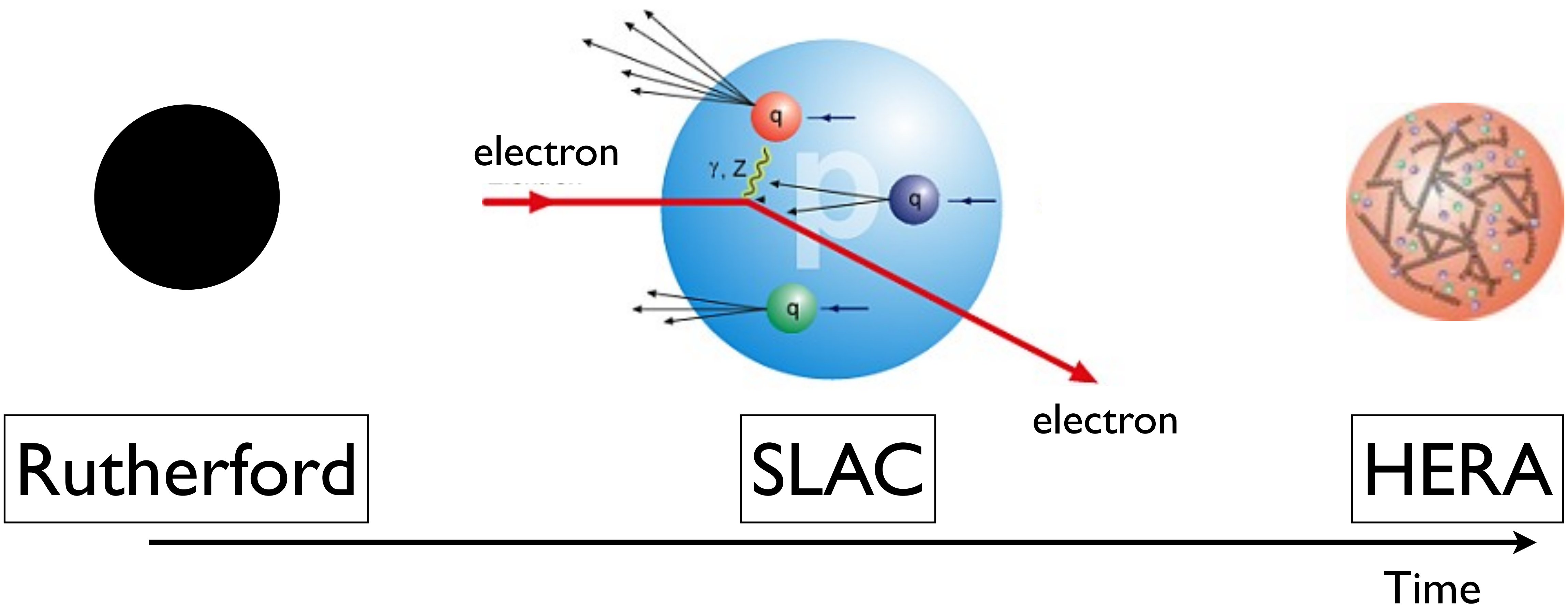
4th March 2013 Physics Opportunities at an Electron-Ion Collider, Valparaiso, Chile

Tools to unfold nuclear structure

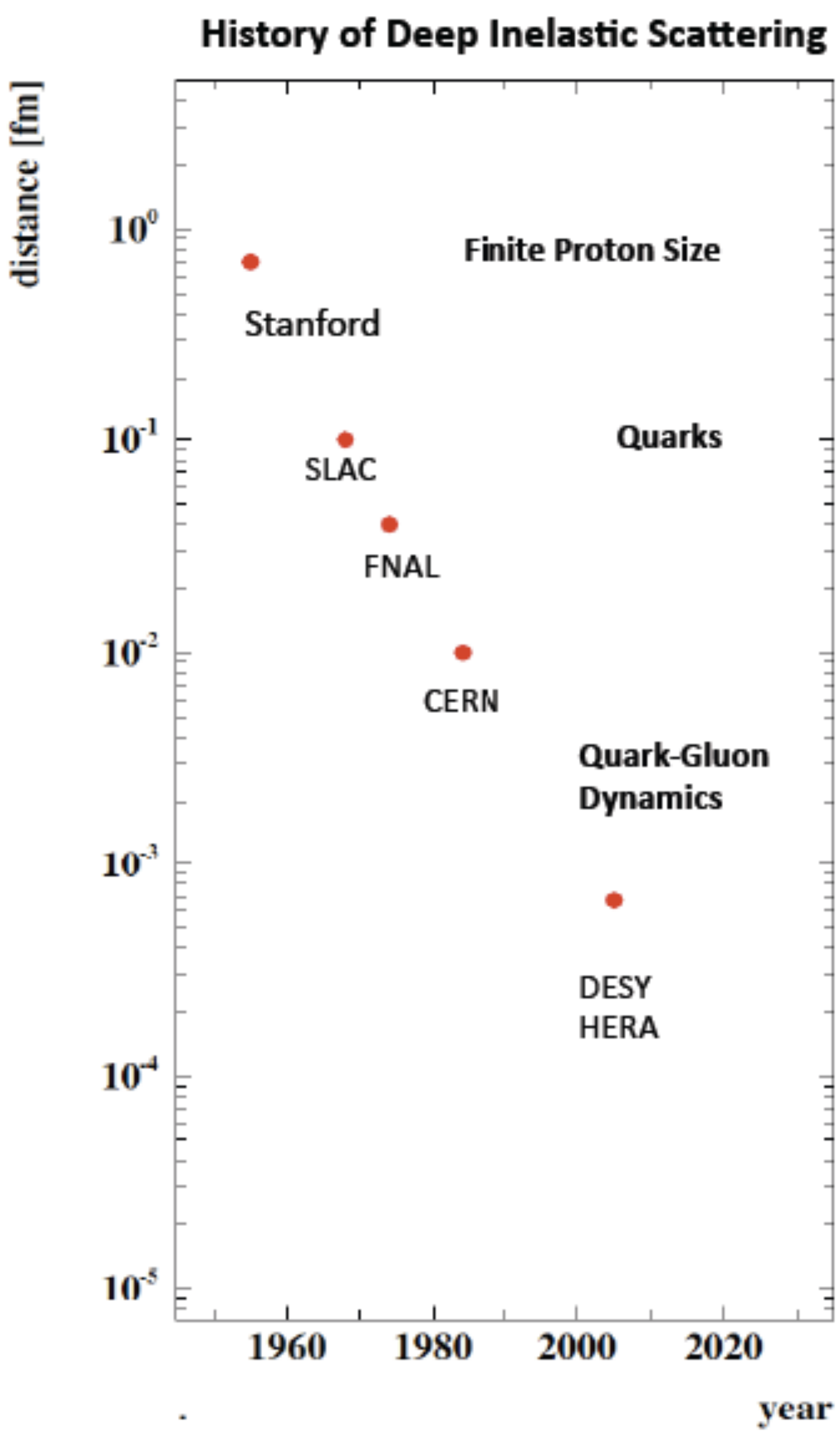


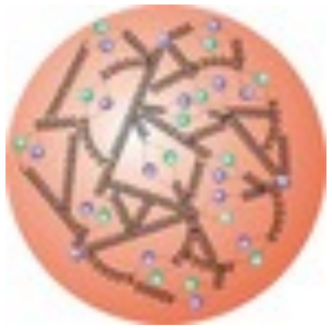
- Historically, we build tools which attack the luminosity and energy frontier
- Ideally we want the best tools possible

Unfolding nuclear structure



An incomplete history of deep-inelastic scattering





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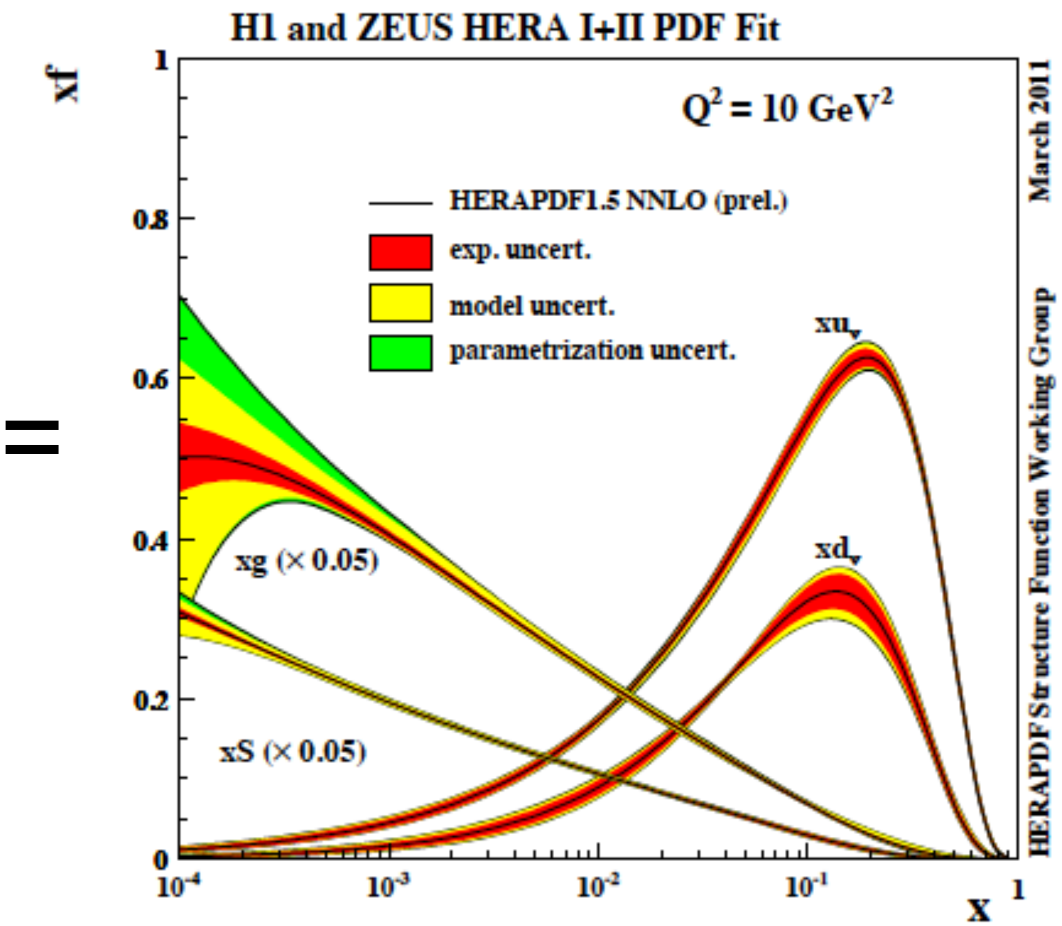
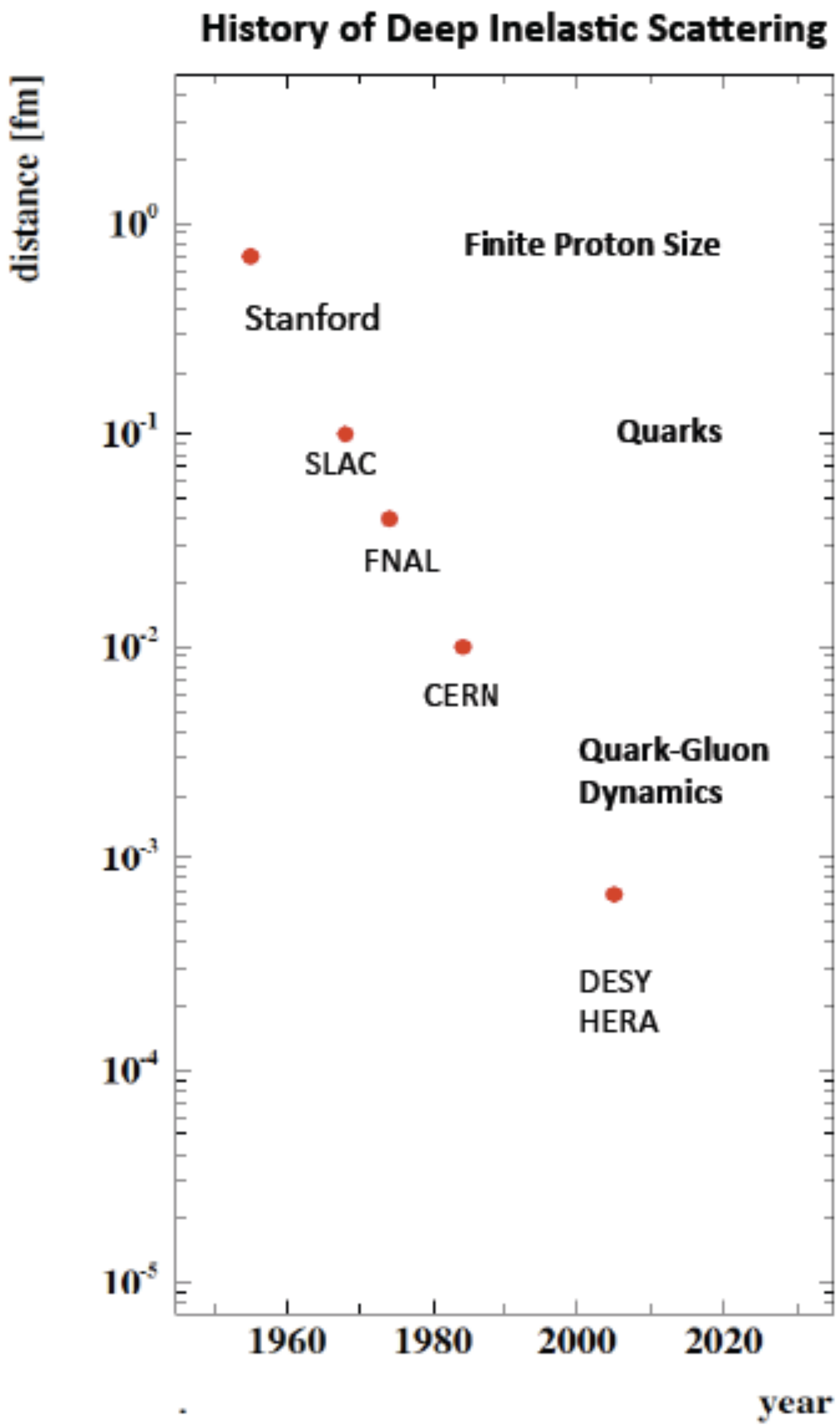
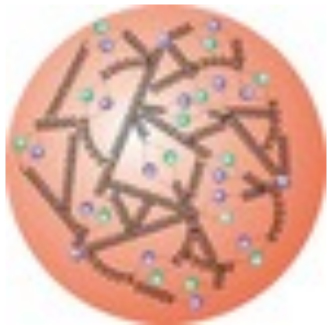


- A rich history of exploiting scattering experiments to study structure, culminating in the HERA electron-proton machine
- Confirmation of the QCD picture of the proton, structure mapped with high precision...

An incomplete history of deep-inelastic scattering





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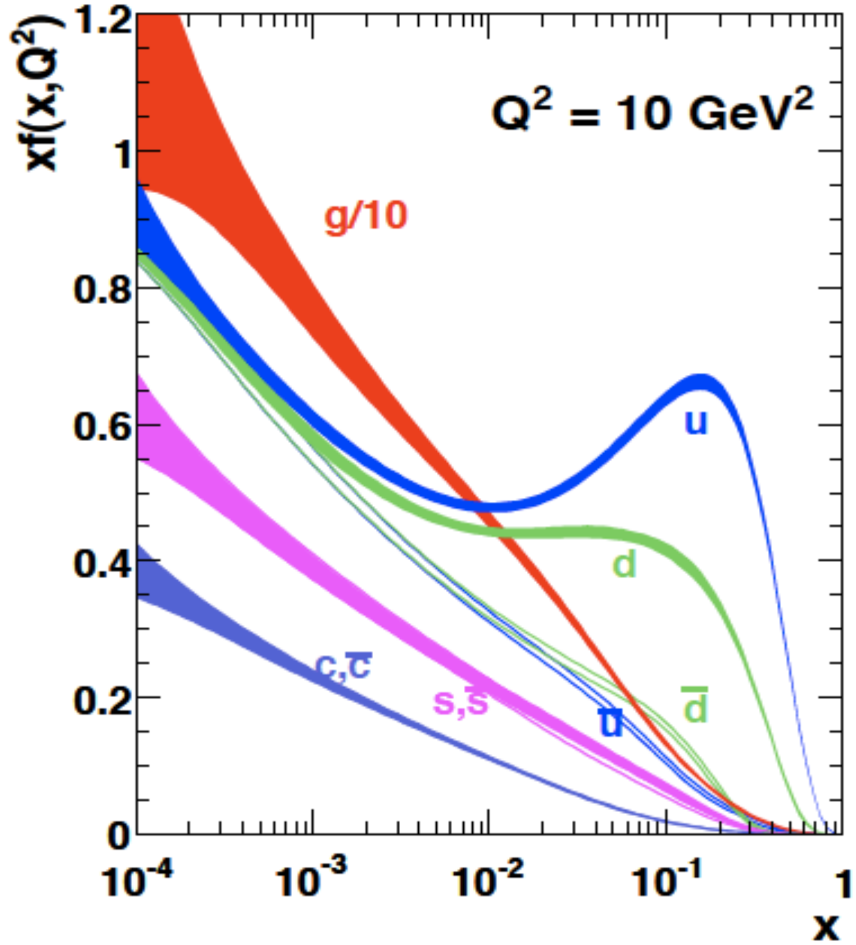

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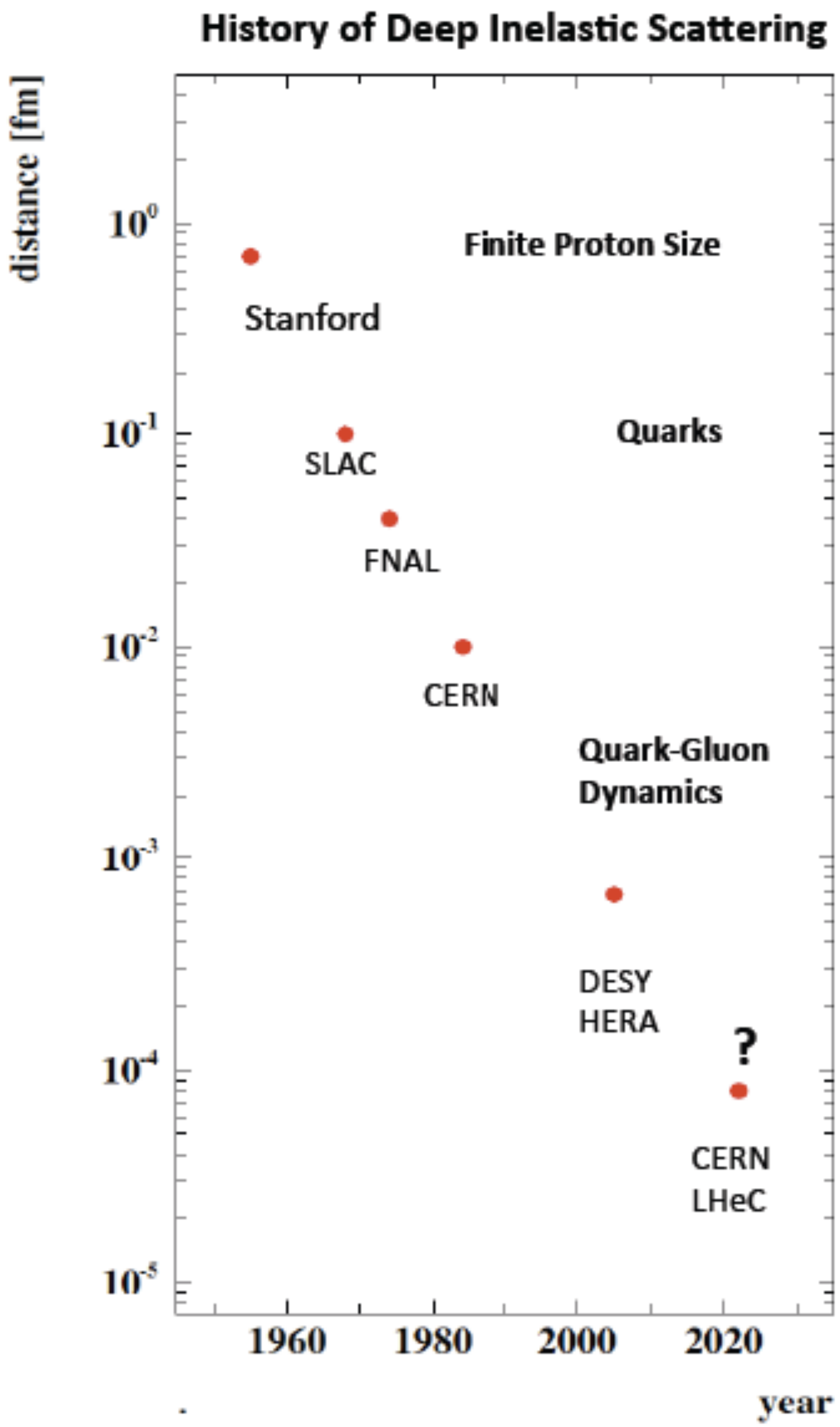
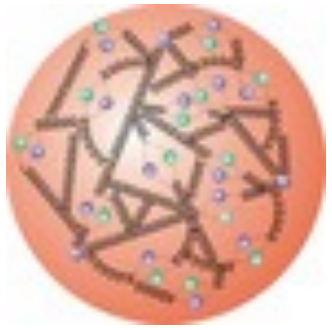
An incomplete history of deep-inelastic scattering





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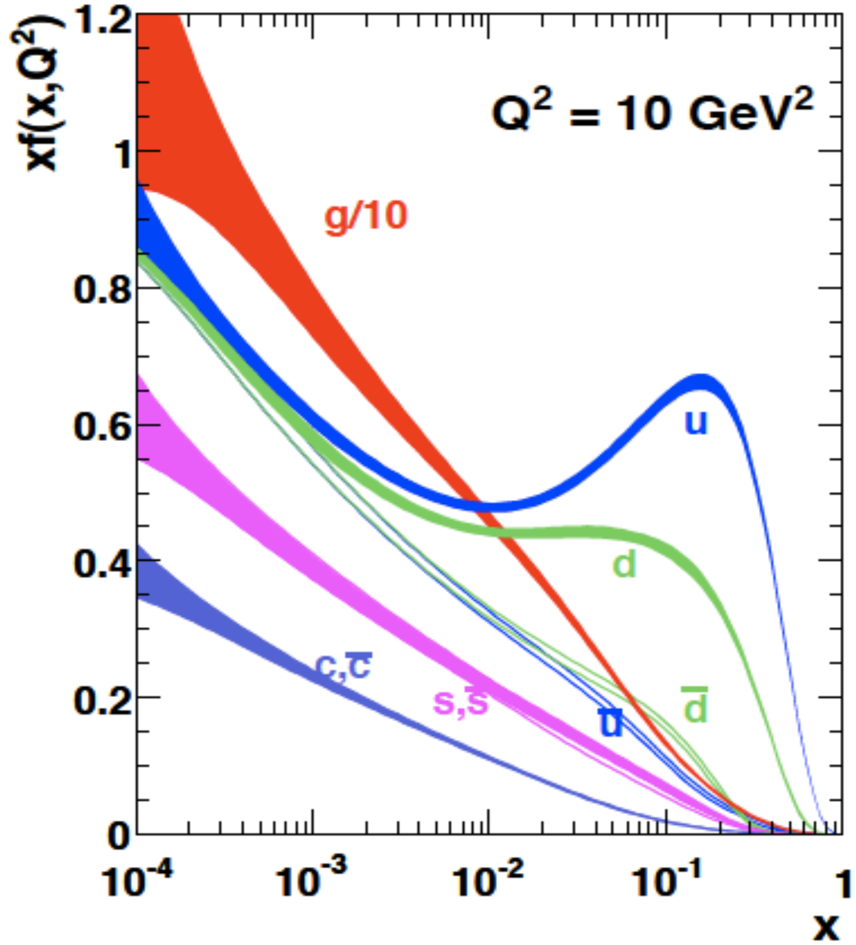

- A rich history of exploiting scattering experiments to study structure, culminating in the HERA electron-proton machine
- Confirmation of the QCD picture of the proton, structure mapped with high precision...
- But QCD is a very subtle theory and not easily mastered, it has not given up all of its secrets

What HERA didn't or couldn't do

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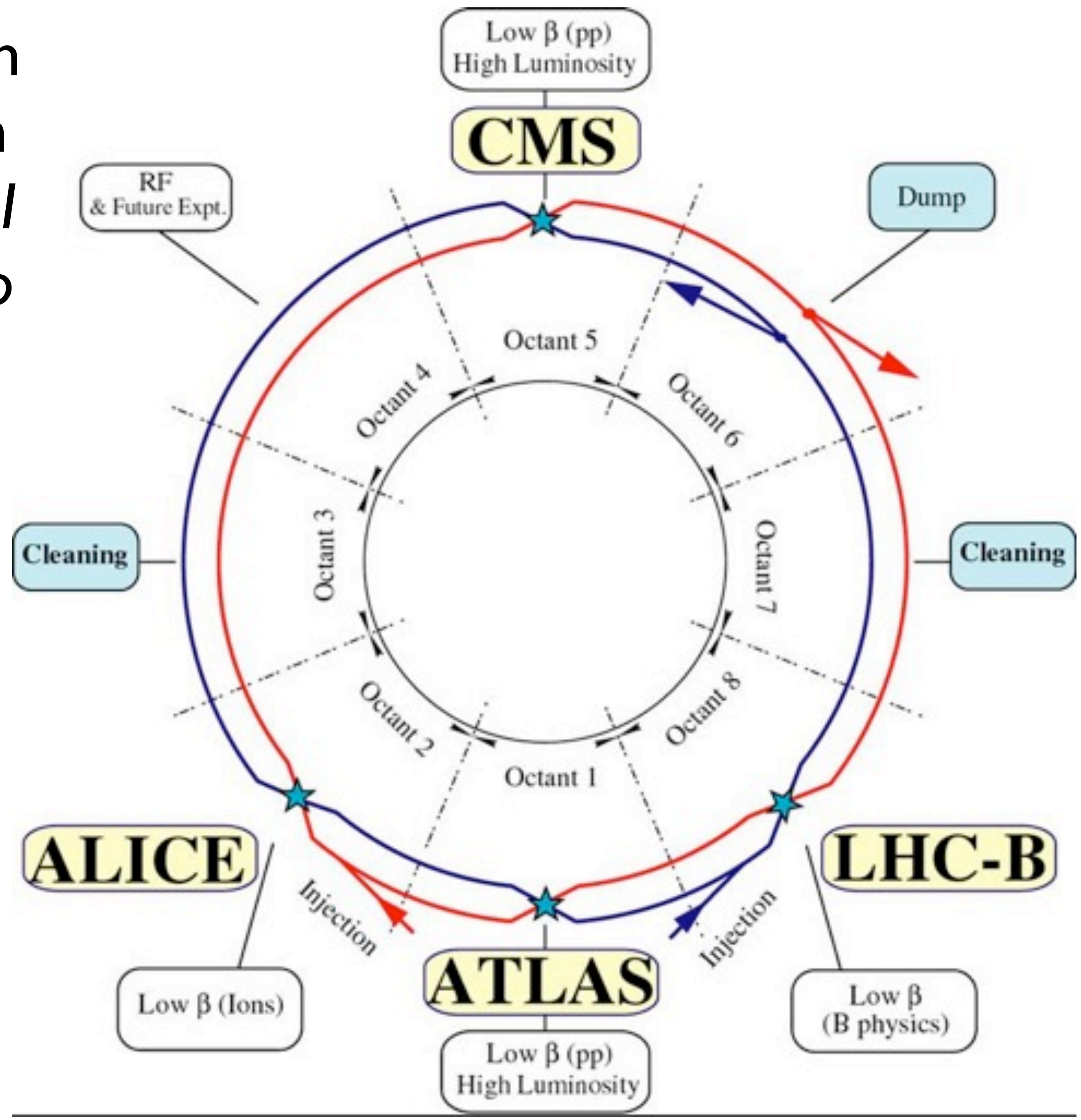
- There was no electron-ion program at HERA
    - Nuclear parton densities are largely unknown
    - No deuterons - no test of isospin symmetry comparing protons with neutrons
    - How does nuclear matter affect partons and their dynamics?
    - Saturation
- The kinematic reach and luminosity were too low
    - Saturation
    - The proton parton densities can not be fully unfolded without making assumptions
    - Charm and beauty are poorly know, strange is unknown
    - The gluon is poorly known at low and high x
    - There is no precision measurement of αs
    - No instantons or odderons? Why not?
- To make progress, we need a successor to HERA that includes ions
- Thankfully half of that machine has already been built in Geneva

The LHeC Concept

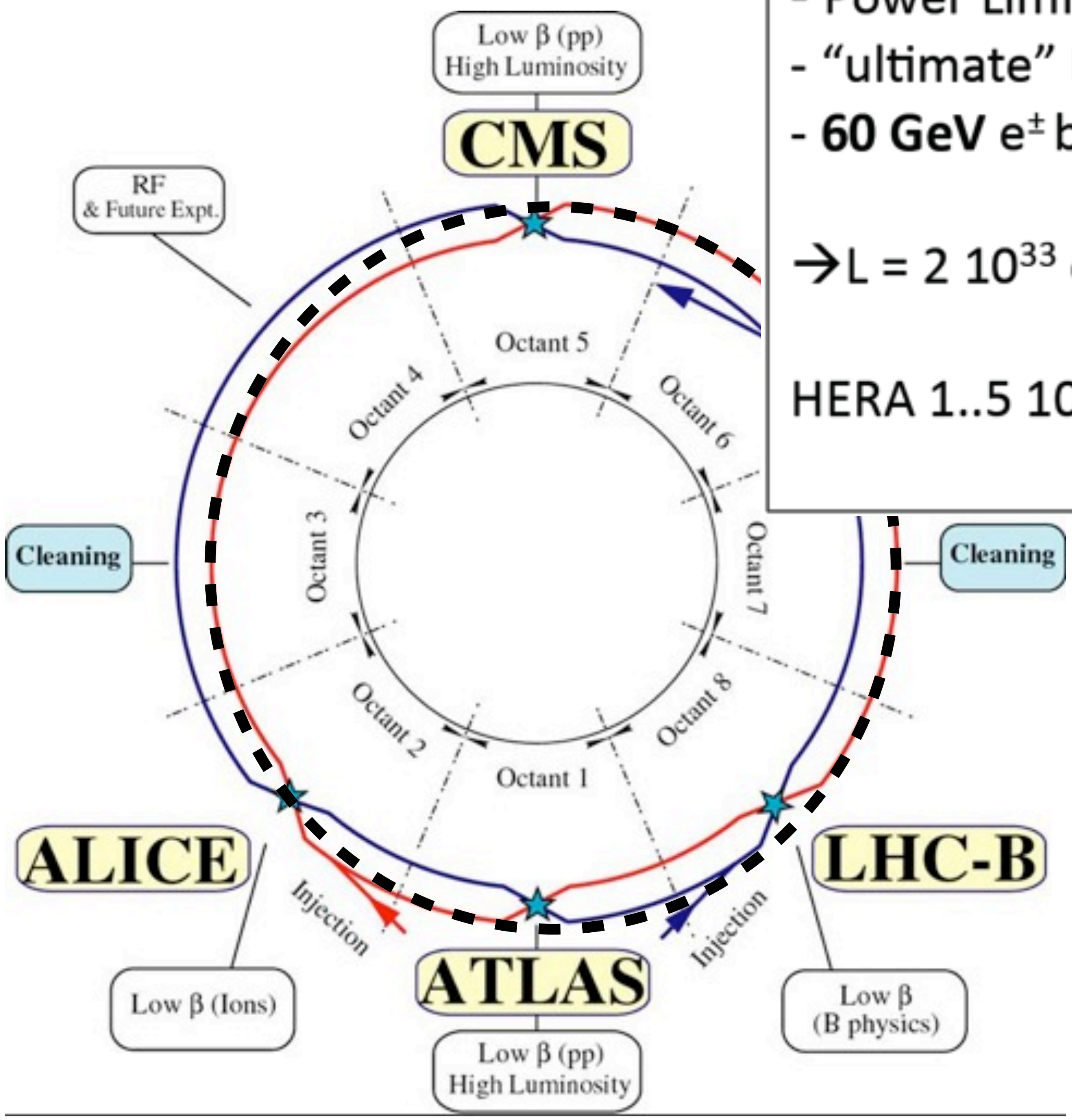
The LHeC *ep* program would run *simultaneously* with the LHC *pp* and *HI* programs (small *ep* tuneshifts)



- 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

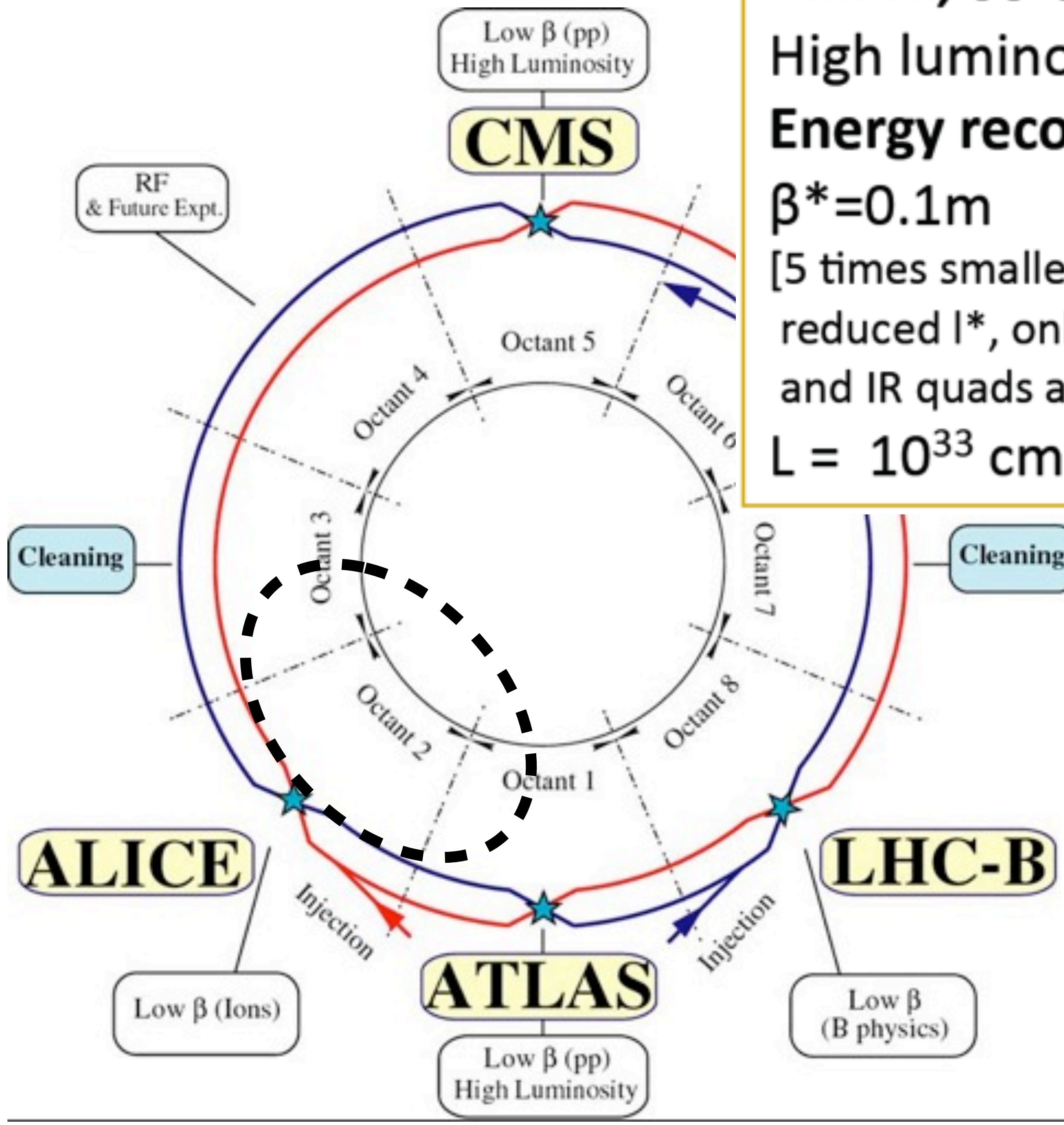
→ $L = 2\ 10^{33}\ cm^{-2}s^{-1}$ → $O(100)\ fb^{-1}$

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

- Either by installing a new electron storage ring in the LHC tunnel (Pol~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: $P=P_0/(1-\eta)$
$\beta^*=0.1m$
[5 times smaller than LHC by reduced l*, only one p squeezed and IR quads as for HL-LHC]
$L = 10^{33}\ cm^{-2}s^{-1} \rightarrow O(100)\ fb^{-1}$

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

LHeC development

2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

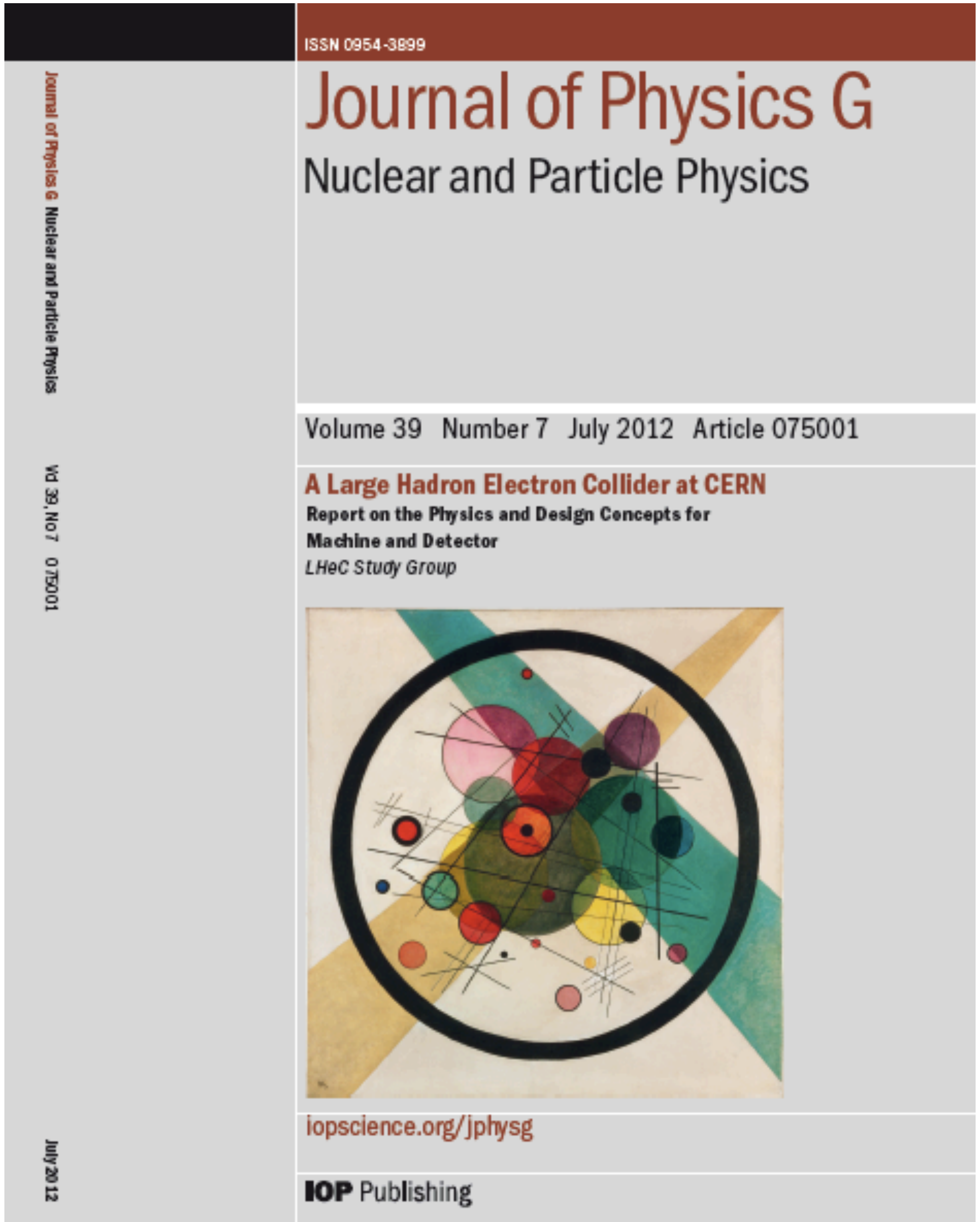
2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)
3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)
NuPECC: LHeC on Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
refereed and being updated

2012: Discussion of LHeC at LHC Machine Workshop (Chamonix)
Publication of CDR + 2 Contributions to European Strategy [arXiv]
Chavannes workshop (June14-15, 2012) – **CERN**: **Linac+TDR Mandate**
ECFA final endorsement of CDR

Conceptual Design Report



CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

- 600 page report published on the conceptual design, 200 authors from 60 institutes
- Refereed by 23 world-leading experts invited by CERN

LHeC mandate from CERN

The mandate for the technology development **includes studies and prototyping of the following key technical components:**

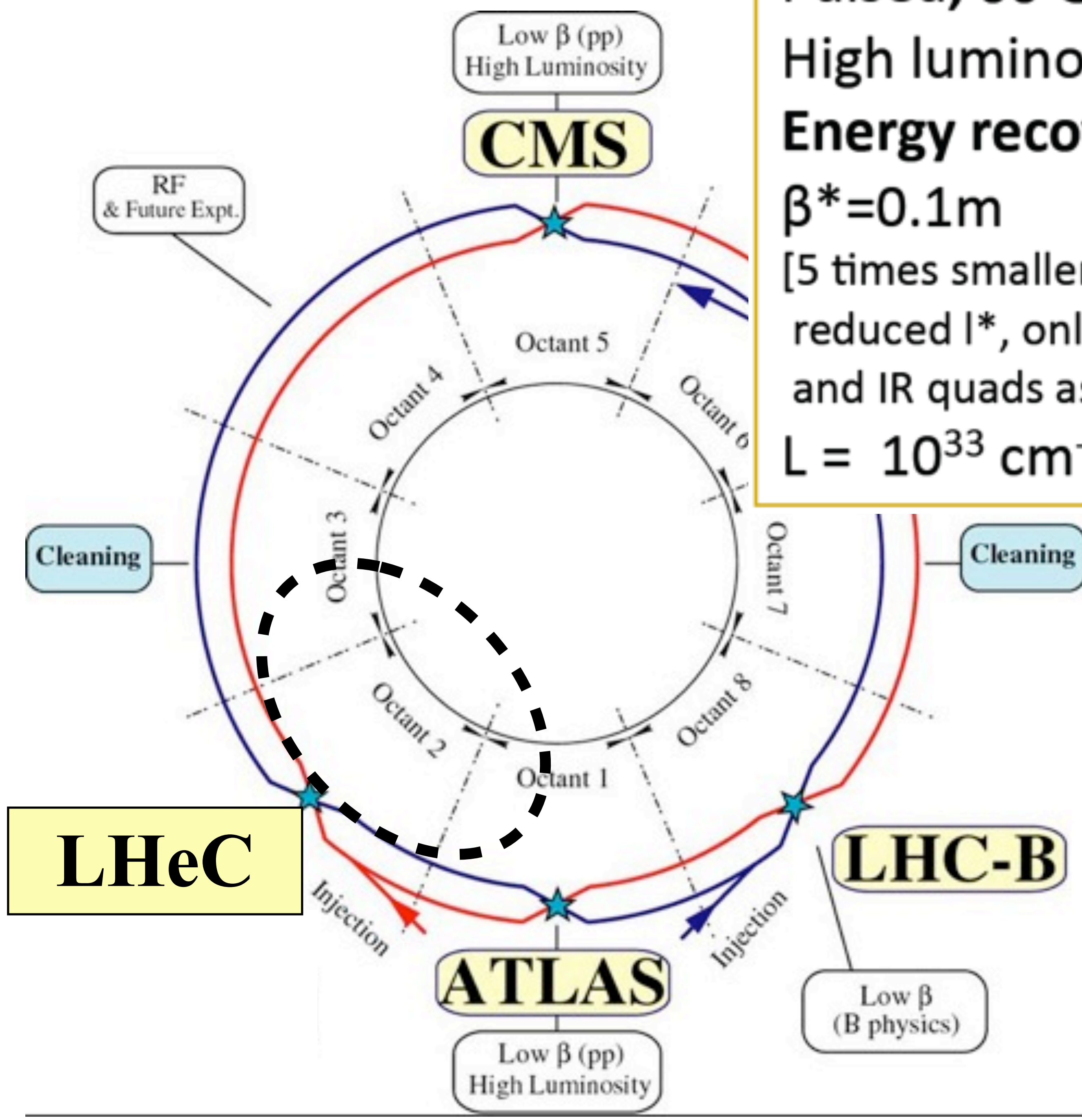
- Superconducting RF system for CW operation in an Energy Recovery Linac, (high Q0 for efficient energy recovery). The studies require design and prototyping of the cavity, couplers and cryostat.
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models.
- Studies related to the experimental beam pipes with large beam acceptance in a high synchrotron radiation environment.
- The design and specification of an ERL test facility for the LHeC.
- The finalization of the ERL design for the LHeC including a finalization of the optics design, beam dynamic studies and identification of potential performance limitations.

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators.

Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies within existing CERN studies** (e.g. SPL and ESS SC RF, HL-LHC triplet magnet development and collaboration with ERL test facility outside CERN).

- CDR summarised at a final workshop in June 2012 after the CDR publication
- Above taken from slides of S. Bertolucci as he concluded the workshop
- Choose the linac-ring - CERN will build an ERL test facility

The LHeC



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- Build a new super-conducting RF electron linac (Pol~90%)

LHeC Accelerator Design: Participating Institutes

CERN

SLAC NATIONAL ACCELERATOR LABORATORY

The Cockcroft Institute of Accelerator Science and Technology

NTNU Norwegian University of Science and Technology

Jefferson Lab Thomas Jefferson National Accelerator Facility

CLIC

ANKARA ÜNİVERSİTESİ 1946

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

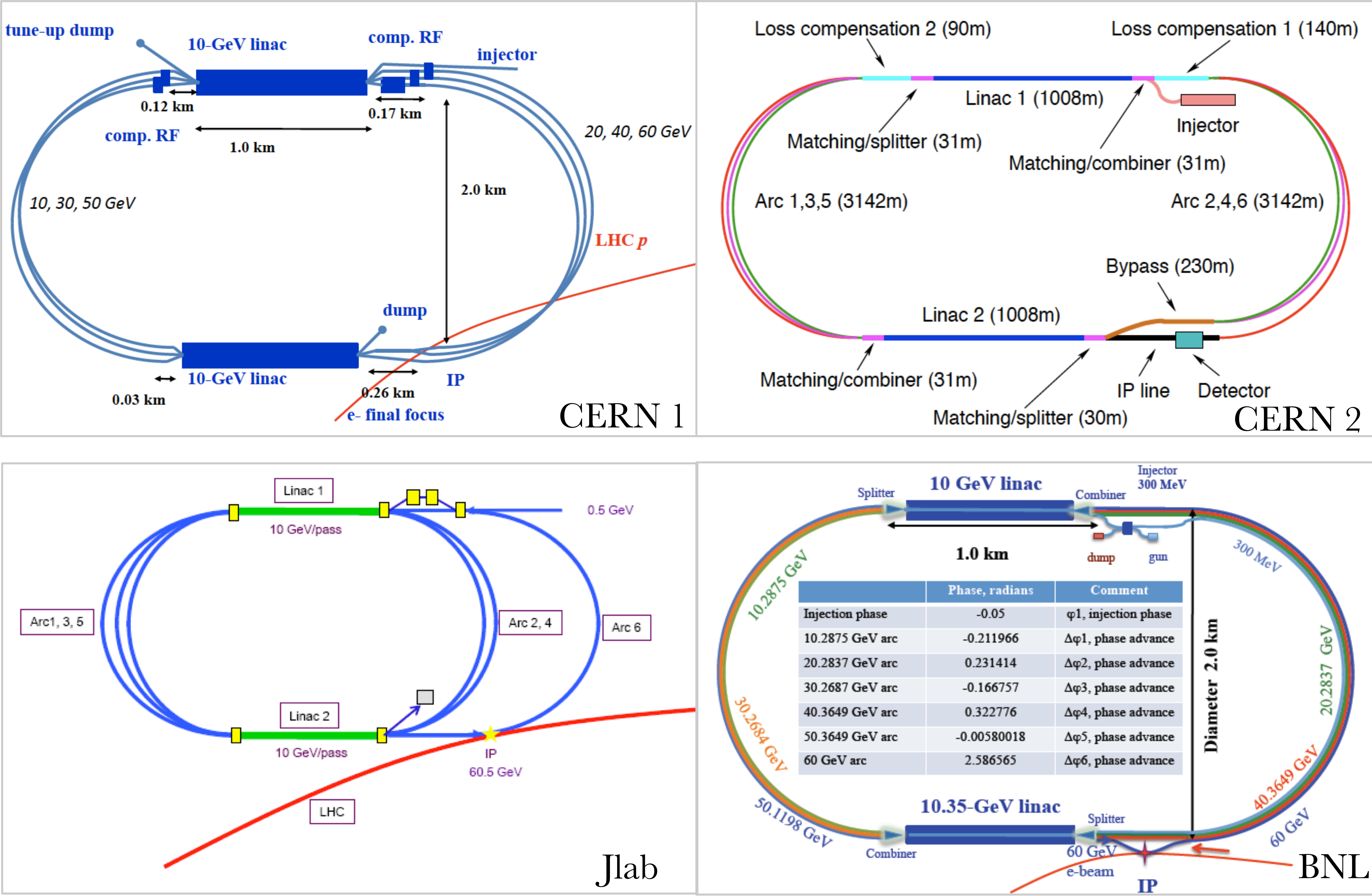
UNIVERSITY OF LIVERPOOL

BROOKHAVEN NATIONAL LABORATORY

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

KEK

60 GeV Energy Recovery Linac



	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

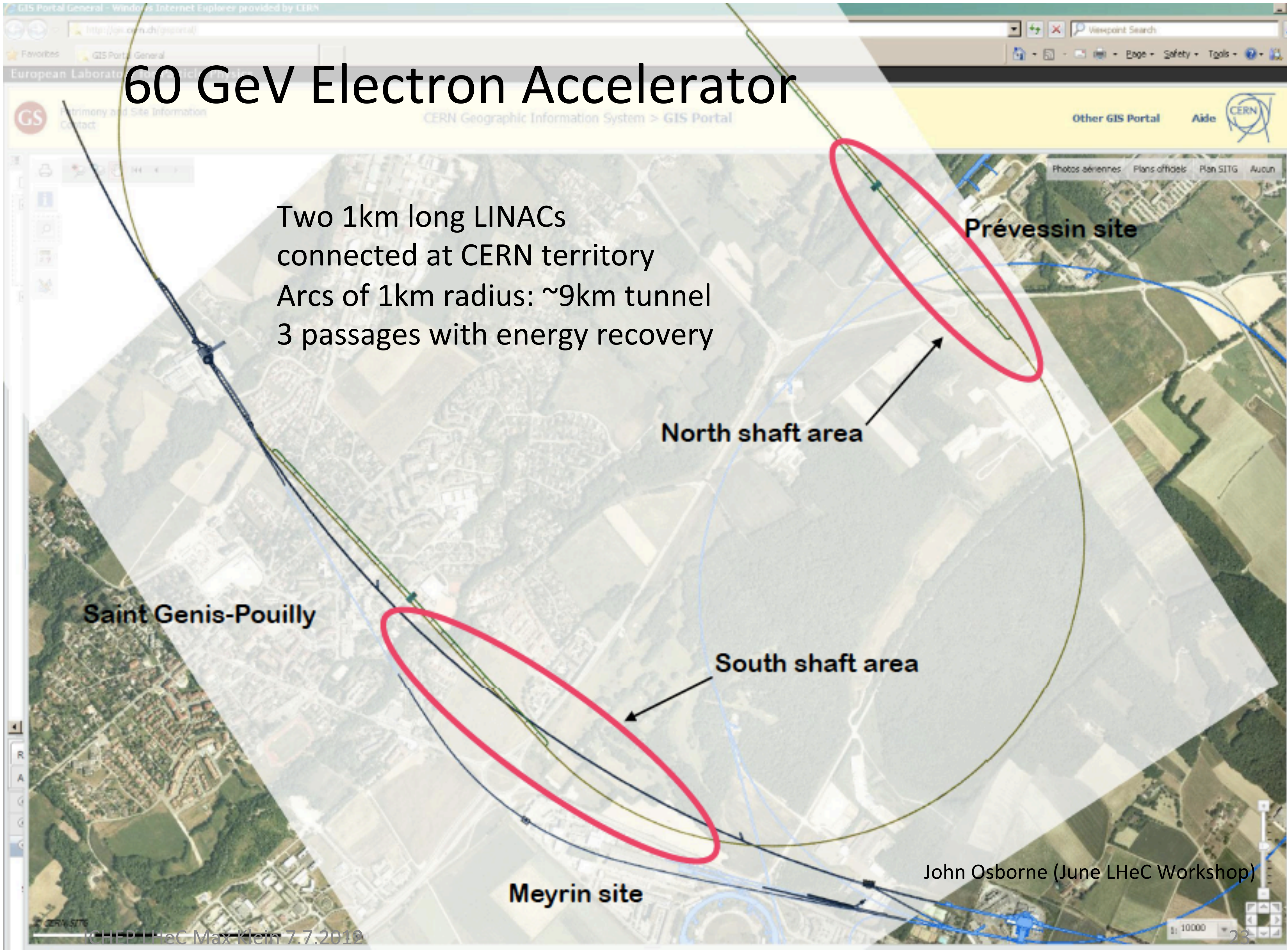
Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities

LHeC machine parameters

parameter [unit]	LHeC	
species	e	p, $^{208}Pb^{82+}$
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarisation [%]	90 (e^+ none)	none, none
normalised rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP spot size [μm]	7.2 (3.7)	7.2 (3.7)
synchrotron tune Q_s	—	1.9×10^{-3}
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
crossing angle	0 (detector-integrated dipole)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35 (0.3 for e^+)	
CM energy [TeV]	1.3, 0.81	
luminosity / nucleon [10^{33} cm^{-2}s^{-1}]	1 (10), 0.2	

- ep luminosities of 10^{33} shown in the CDR, up to 10^{34} possible in an update sent to the European Strategy debate
- eA luminosities of 10^{32} for lead, 10^{31} for eD
- See talk of Vladimir Litvinenko

The Linac Ring design in situ @LHC



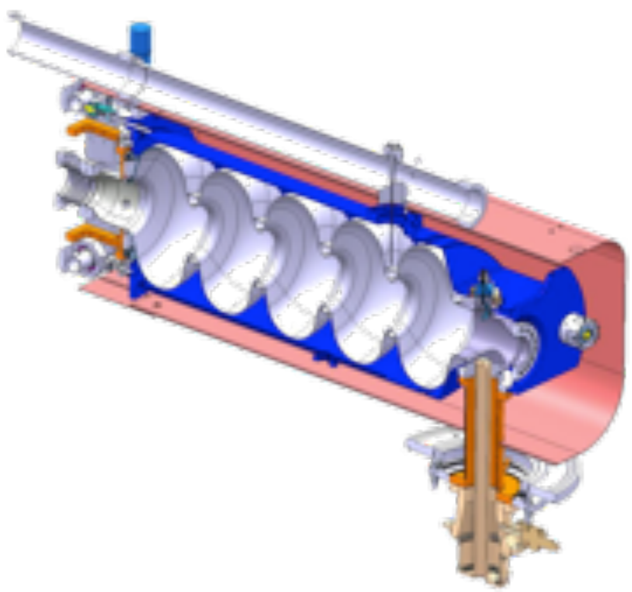
RF Development

Frequency choice: *n* * 120.237 MHz
N=6: 721 MHz, n=11: 1.3GHz (XFEL)

Detailed comparison (threshold current, cryo power, Rf power, size, cost, collaboration, synergy..)

ALICE 1.3 GHz, not CW – only EU ERL facility operational
Daresbury develops cryomodule for ESS (700 MHz)
CERN: in house collaboration with SPL, and eRHIC/BNL

SPL cryomodule 704 MHz

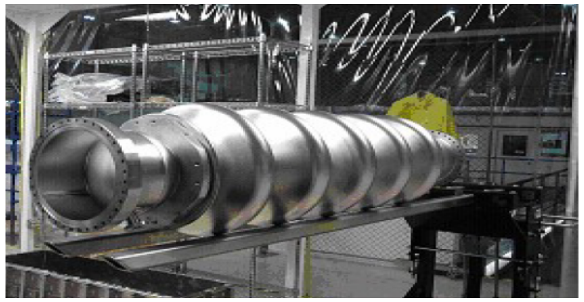


Accelerator physics motivation:
- ERL demonstration, FEL, γ-ray source, e-cooling demo!
- Ultra-short electron bunches

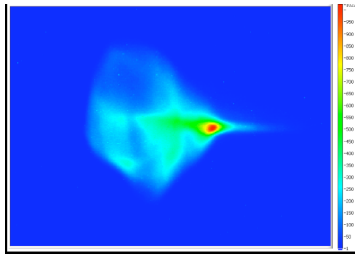
One of the 1st low-frequency, multi-pass SC-ERL
- synergy with SPL/ESS and BNL activities

High energies (200 … 400 MeV) & CW
Multi-cavity cryomodule layout – validation and gymnastics
Two-Linac layout (similar to LHeC)
MW class power coupler tests in non-ER mode
Complete HOM characterization and instability studies!
Cryogenics & instrumentation test bed … E.Jensen

BNL 704 MHz cavity (20 MV/m with high Q0 demonstrated)



Steps: Design of LHeC ERL TF, cavity-cryo module (hi Q), lattice, optics, magnets, source, ….
Watch out for surprises as humming bird:
Building international collaboration (CERN,Daresbury, Jlab, others?)

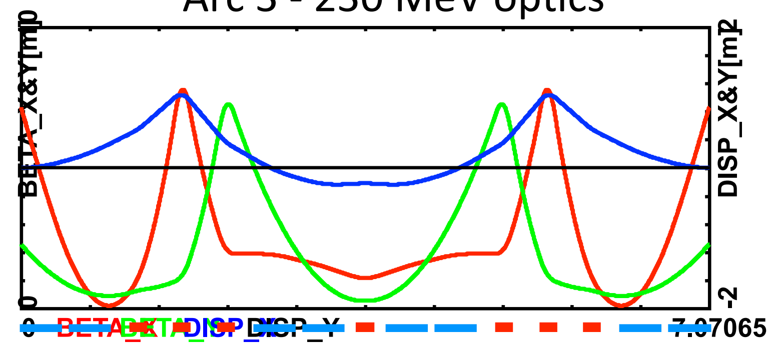


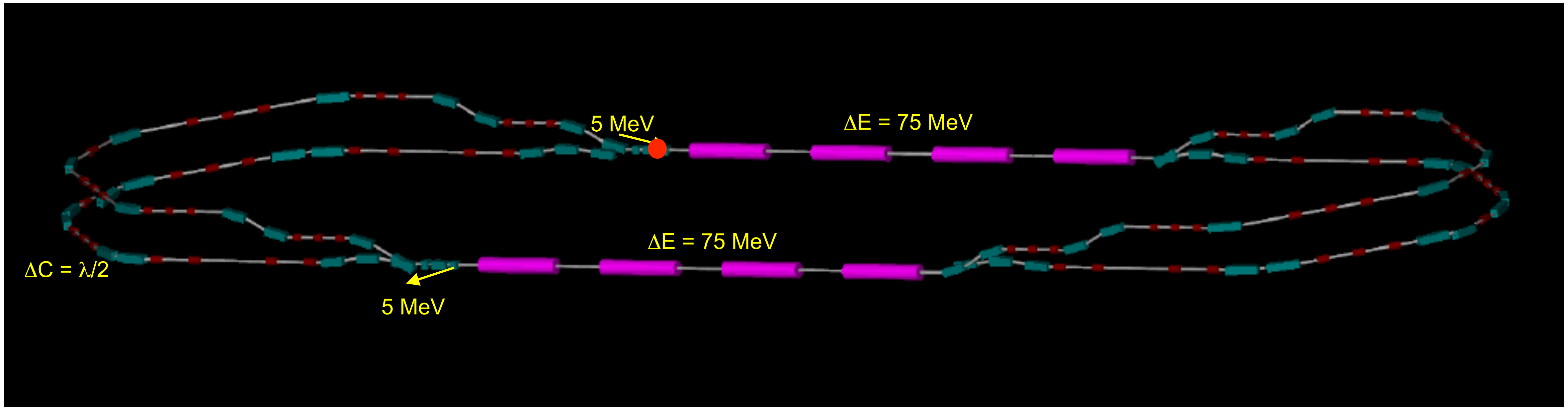
beam structure at ALICE with 230-kV DC gun voltage

LHeC - ERL-TF

Tentative study of multipass optics and lattice

Arc 3 - 230 MeV optics



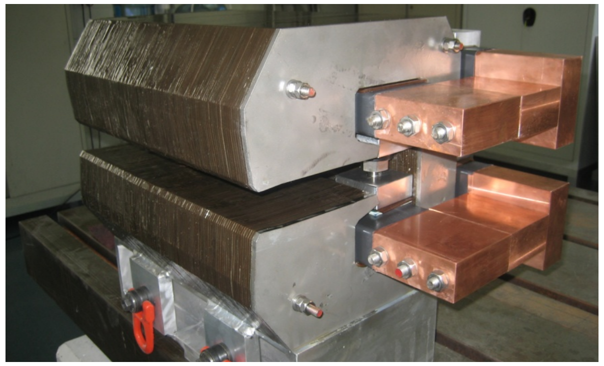


Development of LHeC Testfacility at CERN in international collaboration

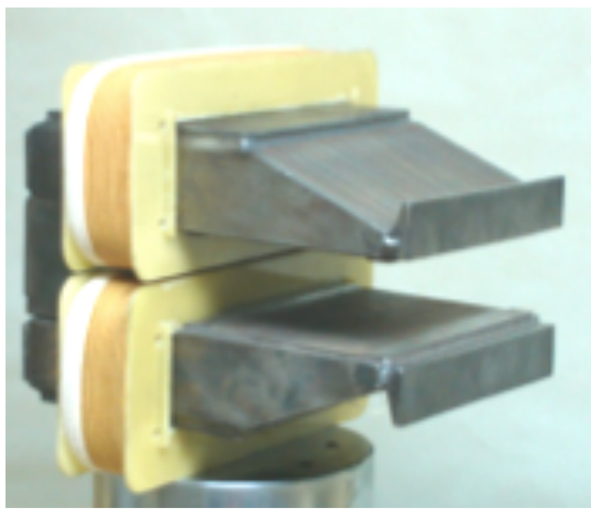
(Jlab, BNL, Mainz, AsTEC...)

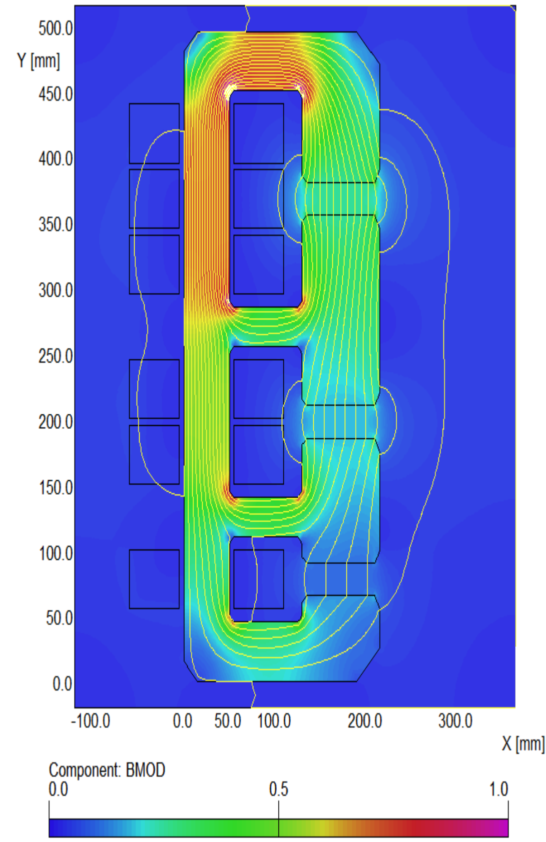
Alex Bogacz, JLab, August 21, 2012

Magnets Developments



Prototypes for Ring dipoles
Fabricated and tested by
CERN (top) and Novosibirsk





flux density in the gaps	0.264 T 0.176 T 0.088 T
magnetic length	4.0 m
vertical aperture	25 mm
pole width	85 mm
number of magnets	584
current	1750 A
number of turns per aperture	1 / 2 / 3
current density	0.7 A/ mm^2
conductor material	copper
resistance	0.36 mΩ
power	1.1 kW
total power 20 / 40 / 60 GeV	642 kW
cooling	air

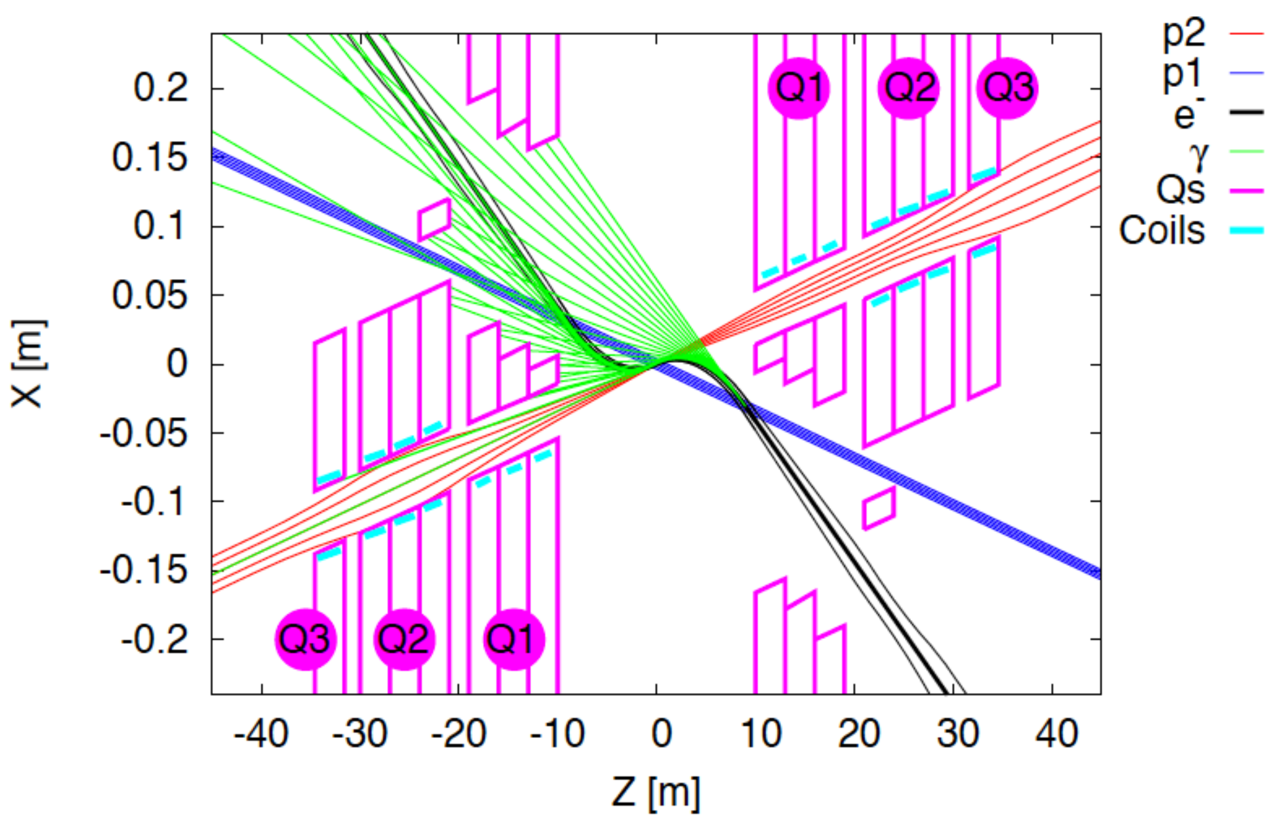
LR recirculator dipoles and quadrupoles
New requirements (aperture, field)?
Combined apertures?
Combined functions (for example, dipole + quad)?
LR linac quadrupoles and correctors
New requirements (aperture, field)?
More compact magnets, maybe with at least two families for quadrupoles?
Permanent magnets / superconducting for quads?
A.Milanese, Chavannes workshop

1/2m dipole model
Full scale prototype
Quadrupole for Linac

Magnets for ERL test stand

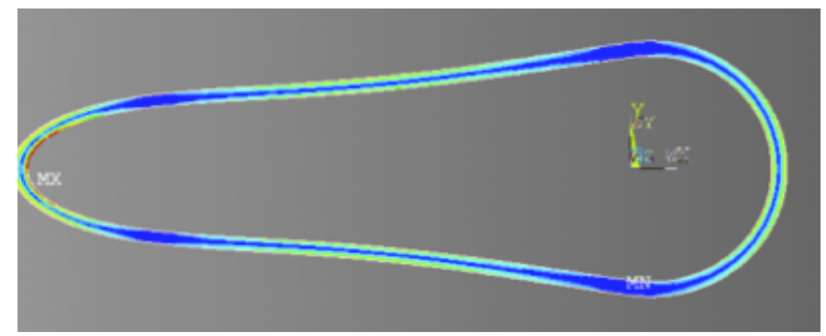
Collaboration of CERN, Daresbury and Budker (Novosibirsk)

Interaction Region Developments



Beam pipe: in CDR 6m, Be, ANSYS calculations

Composite material R+D, prototype, support..
→ Essential for tracking, acceptance and Higgs



Have optics compatible with LHC and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector

Specification of Q1 – NbTi prototype (with KEK?)
Revisit SR (direct and backscattered),
Masks+collimators
Beam-beam dynamics and 3 beam operation studies

Optimisation: HL-LHC uses IR2 quads to squeeze IR1
("ATS" achromatic telescopic squeeze) Start in IR3.? R.Tomas et al.

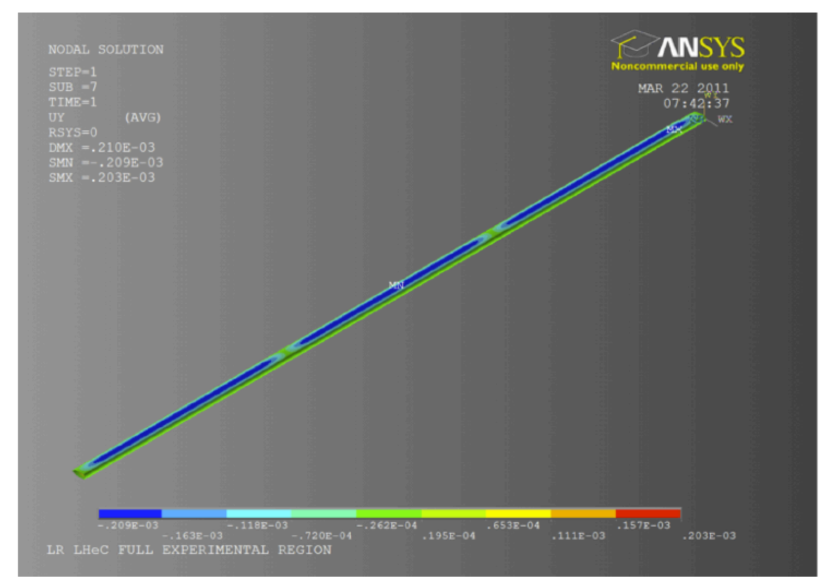
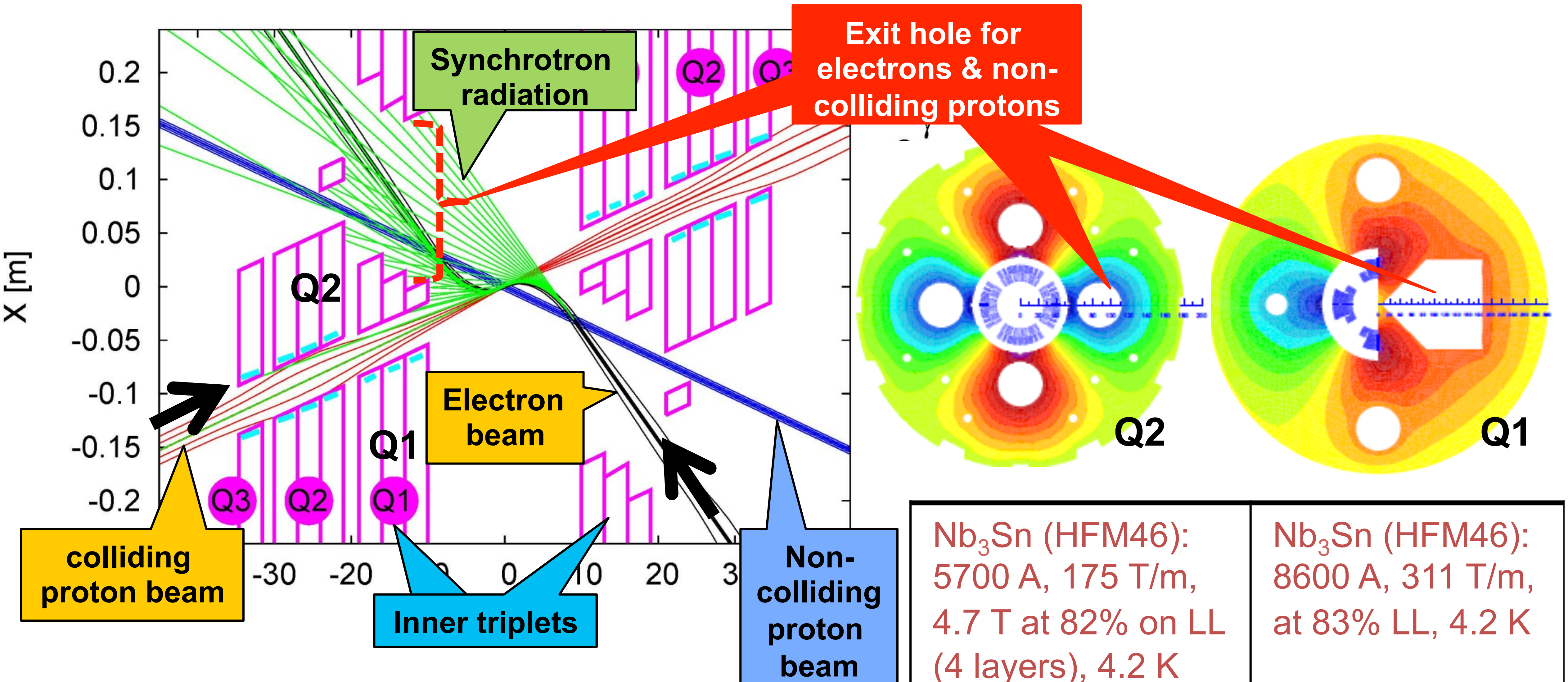


Figure 9.32: 3-D view of the LR geometry showing contours of bending displacement [m].

LR LHeC IR layout & SC IR quadrupoles



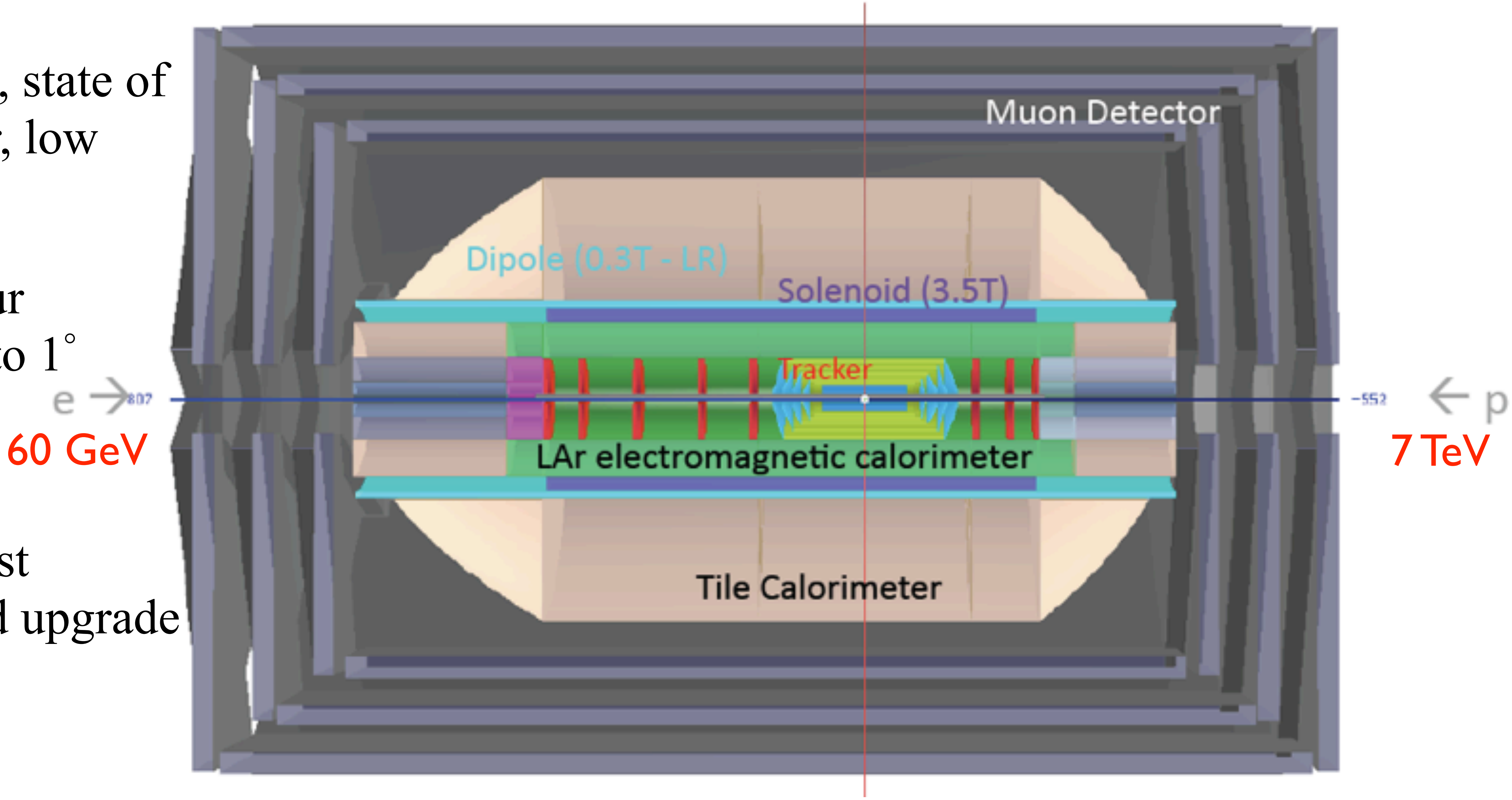
Nb_3Sn (HFM46): 5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K	Nb_3Sn (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K
46 mm (half) ap., 63 mm beam sep.	23 mm ap.. 87 mm beam sep.
0.5 T, 25 T/m	0.09 T, 9 T/m

High-gradient SC IR quadrupoles based on Nb_3Sn for colliding proton beam with common low-field

As shown by F. Zimmermann at Chamonix12

The LHeC Detector (see talk of Alessandro Polini)

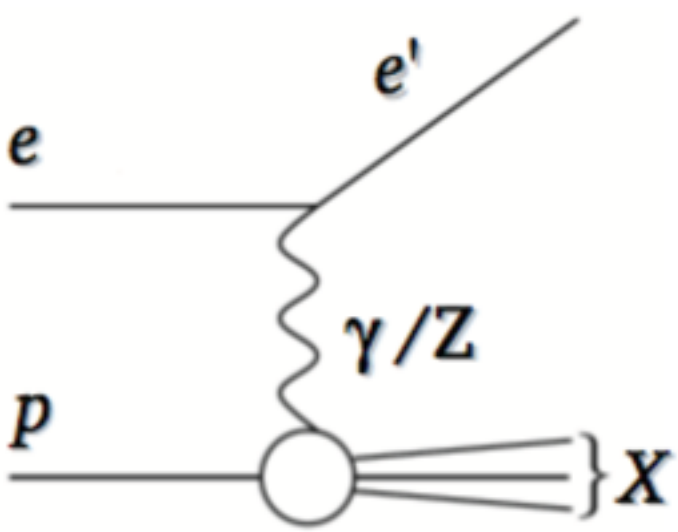
- High precision, state of the art detector, low noise
- efficient flavour tagging down to 1°
- No R&D
- Modular for fast installation and upgrade
- Affordable



So what could we do with this?

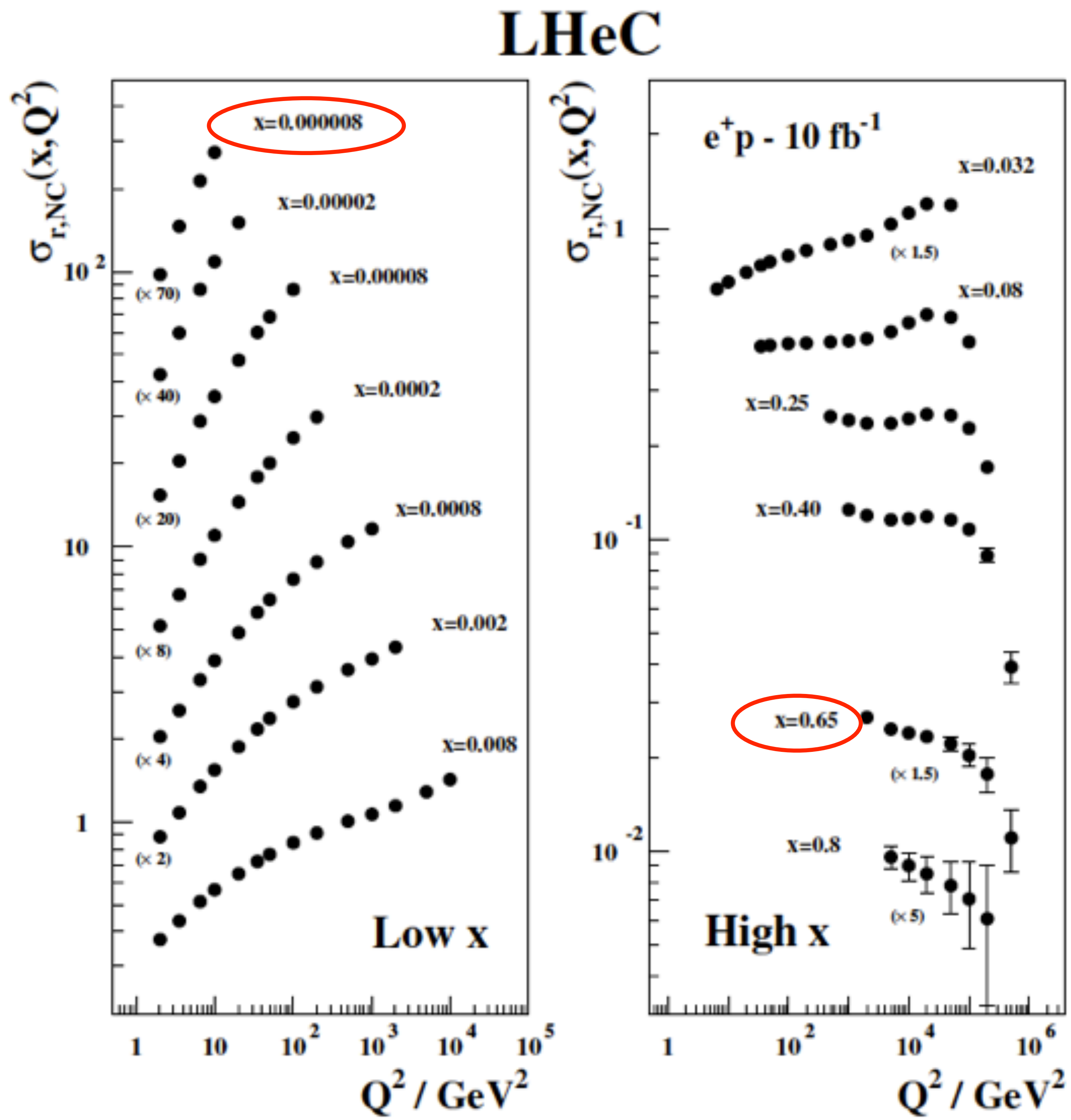
Studying proton structure

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



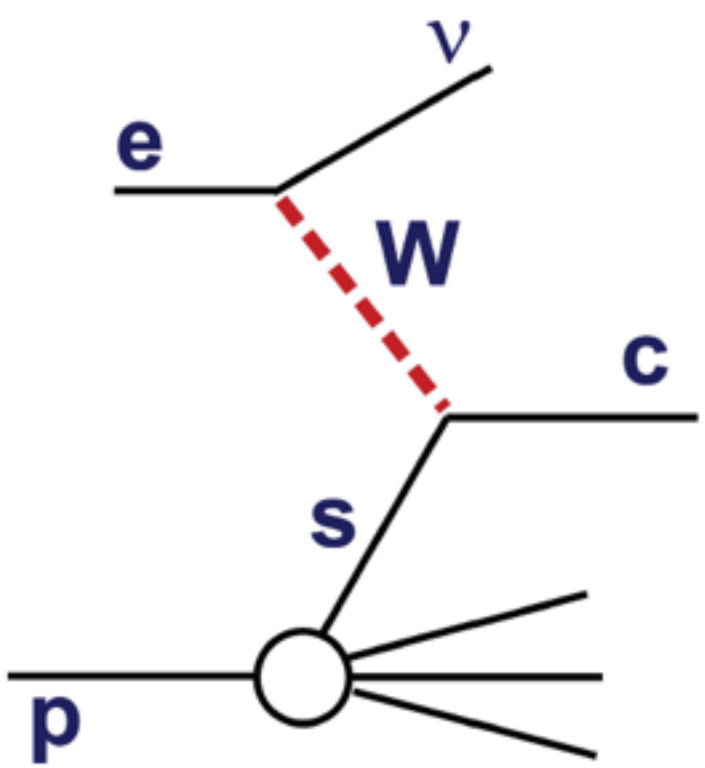
$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x} \cdot \sigma_{r,NC}$$

$$\sigma_{r,NC} = \mathbf{F_2} + \frac{Y_-}{Y_+}\mathbf{xF_3} - \frac{y^2}{Y_+}\mathbf{F_L},$$

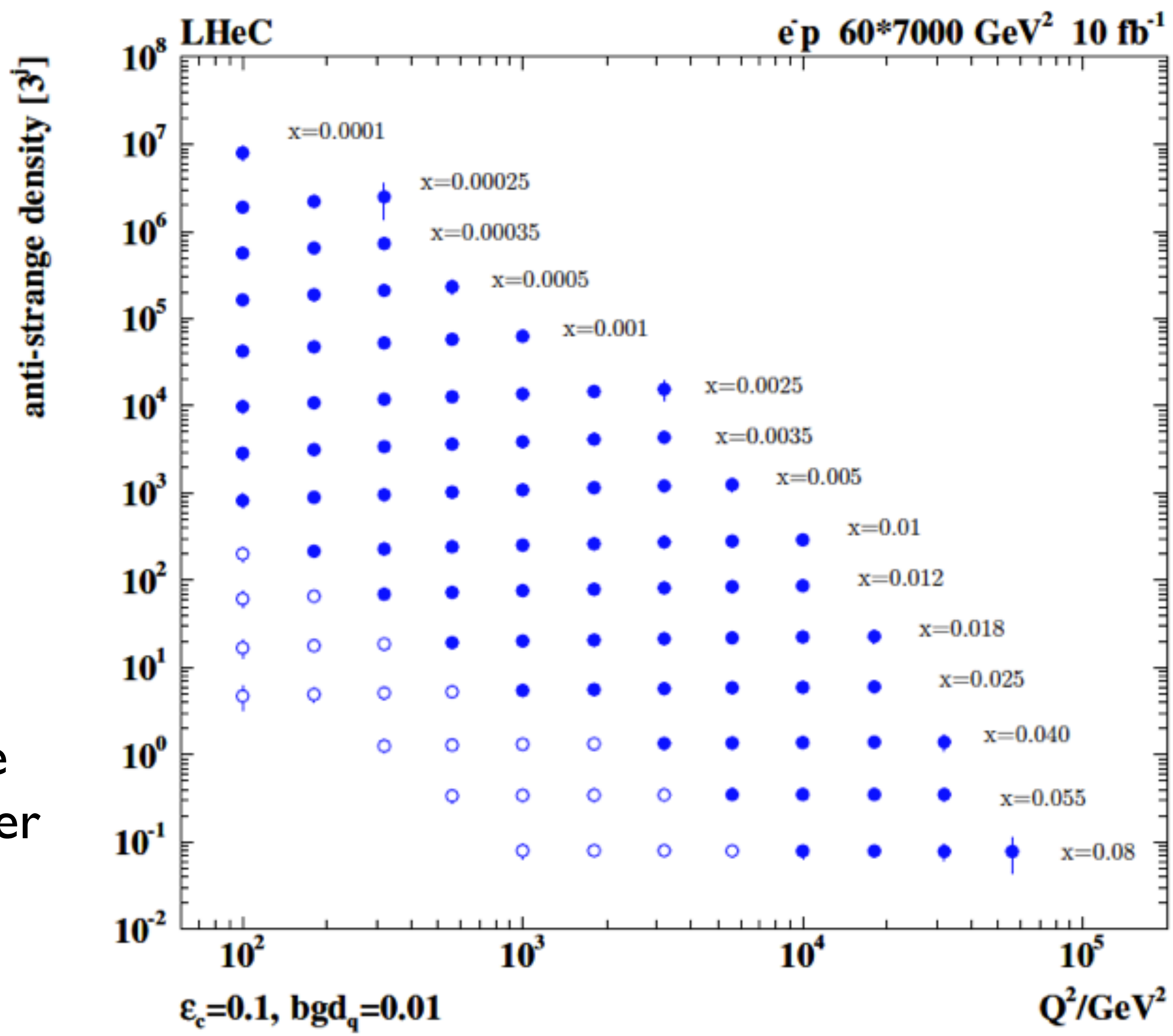


- The optics of the LHeC means no pile-up, a clean unfolding of the proton structure with 100 times the HERA luminosity over a huge kinematic range
- Thanks to the large acceptance, precision data at even the lowest and highest x

How strange is the proton?

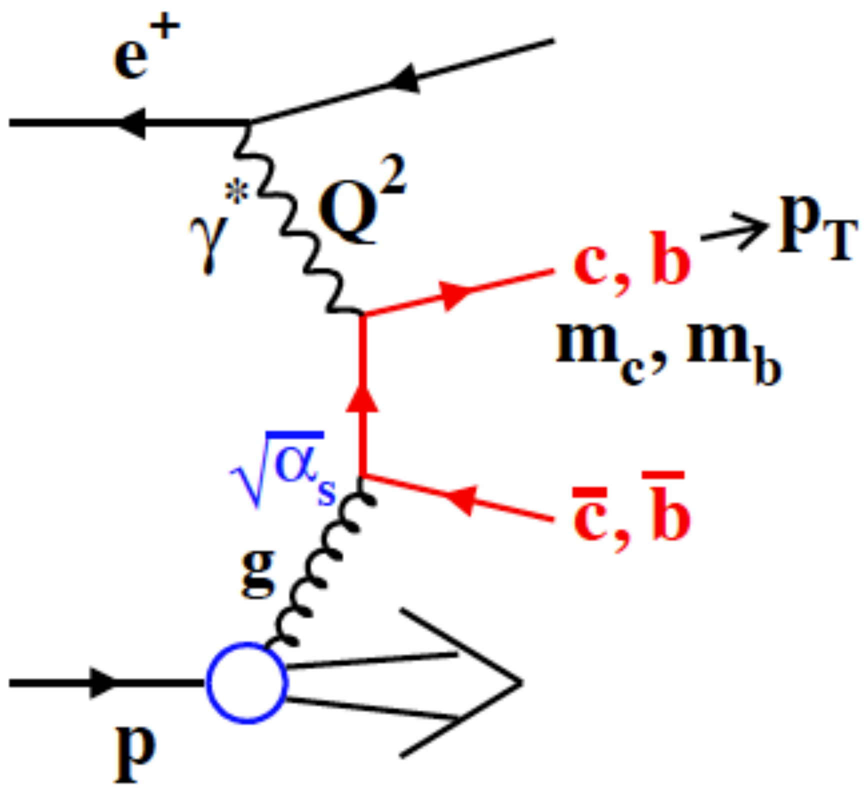


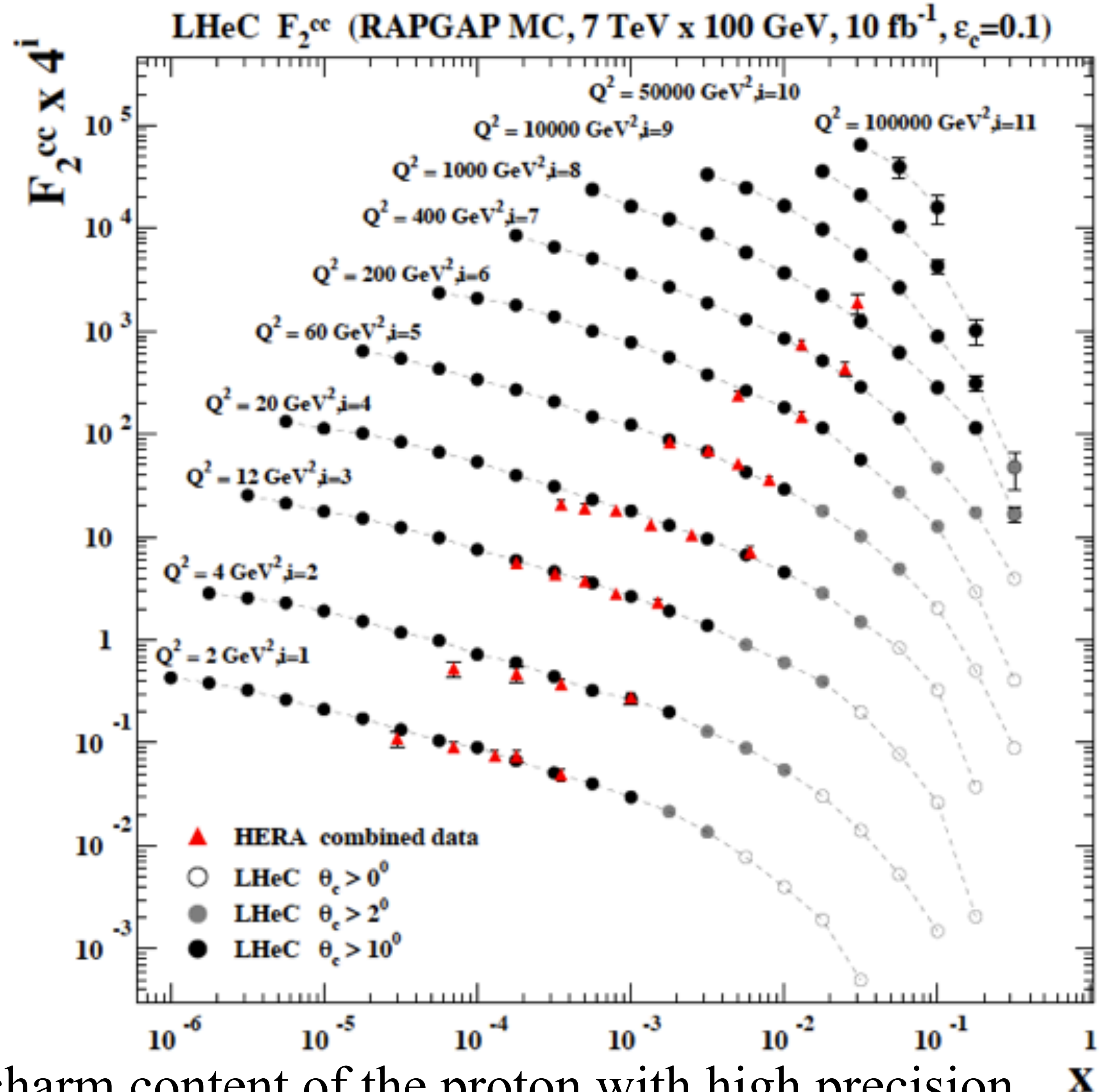
Charm tagging employing the high acceptance silicon tracker



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

How charming is the proton?

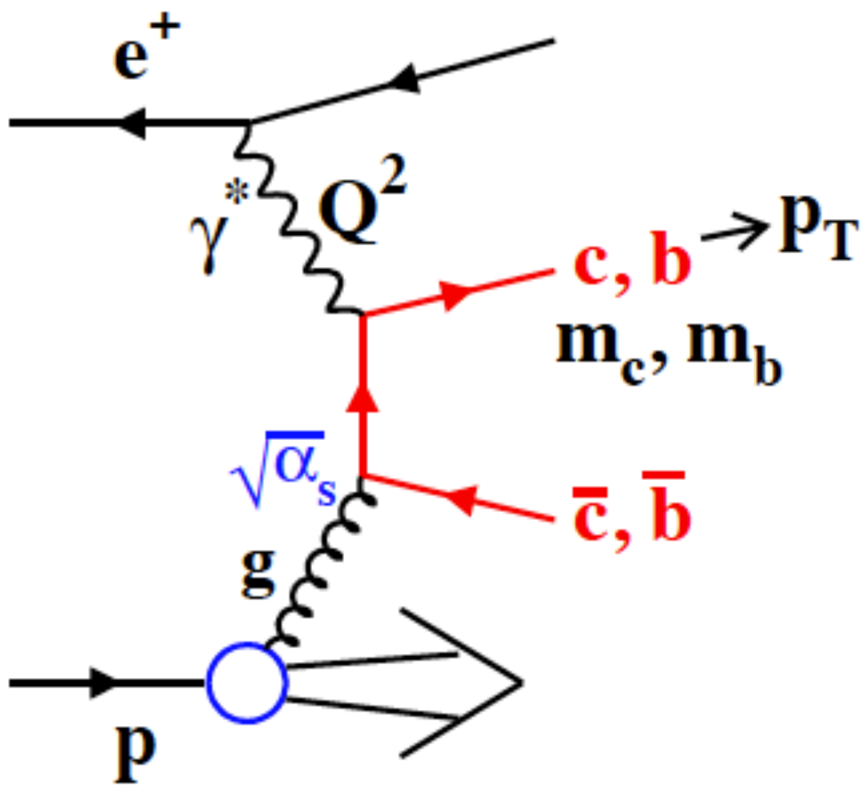




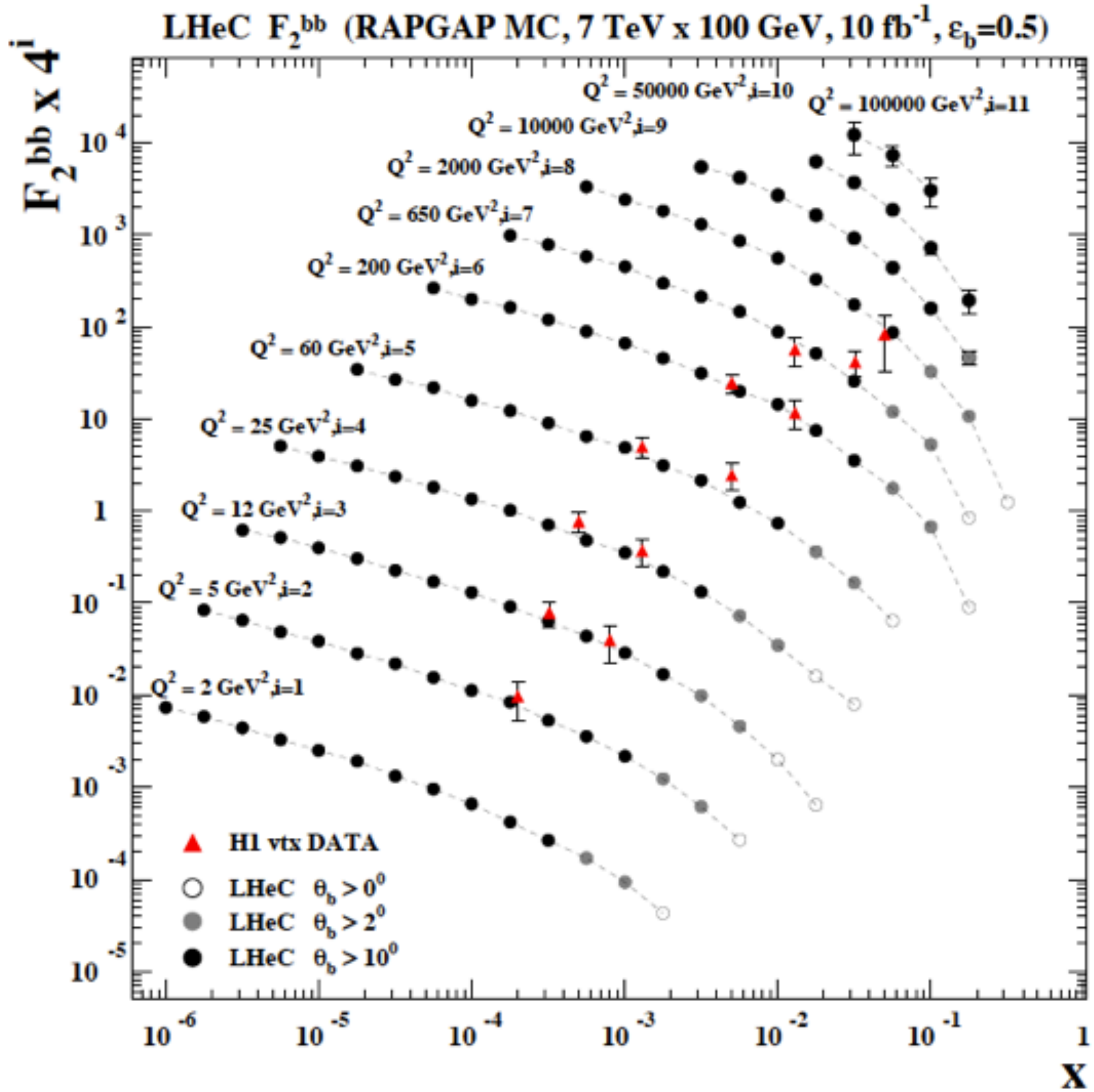
Charm tagging employing the high acceptance silicon tracker

- The LHeC would measure the charm content of the proton with high precision across more than 5 decades in x and Q^2
- These data could determine the charm mass to ~3 MeV
- It will finally measure the charm content at high x - is there intrinsic charm?

How beautiful is the proton?

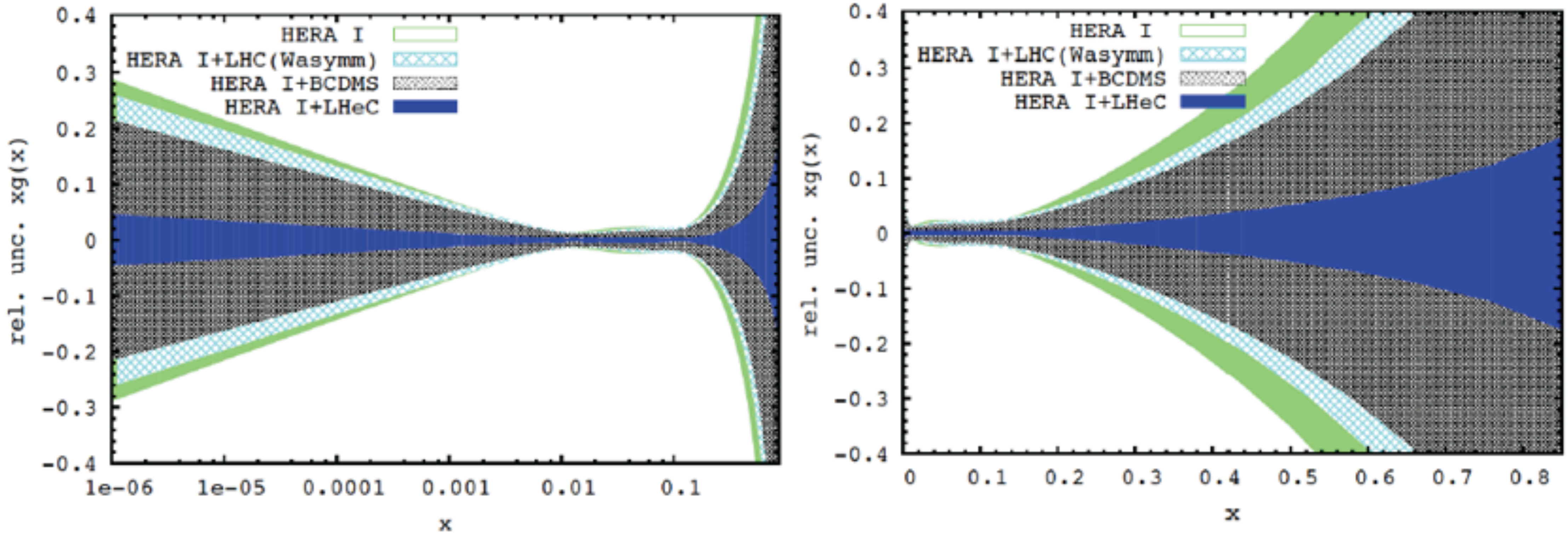


Beauty tagging employing the high acceptance silicon tracker



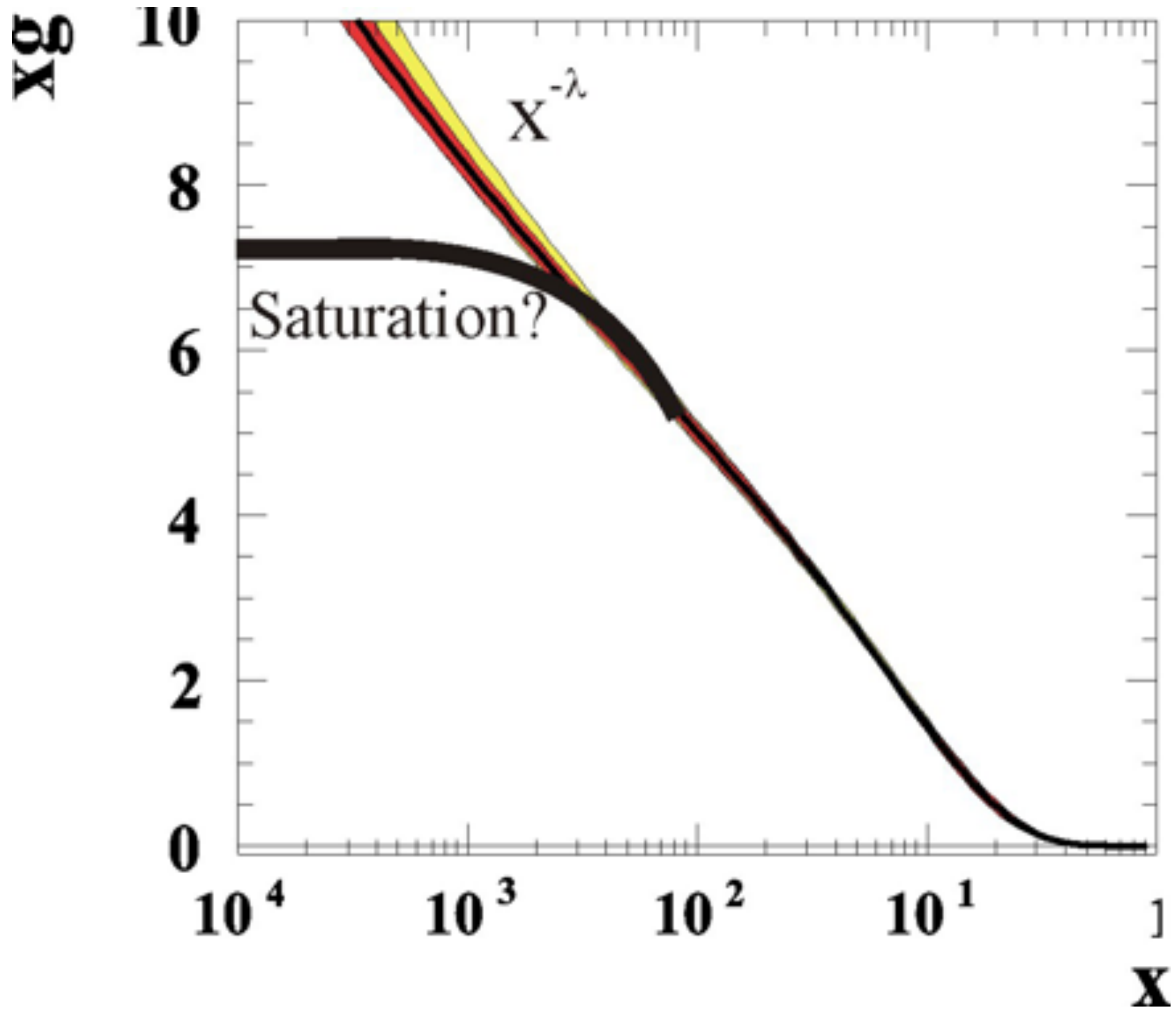
- Thanks to the vastly superior tracking detector, the beauty of the proton will be fully appreciated, finally measuring this precisely across the complete kinematic range
- Of high importance for very many searches at the LHC

The new era in proton PDFs



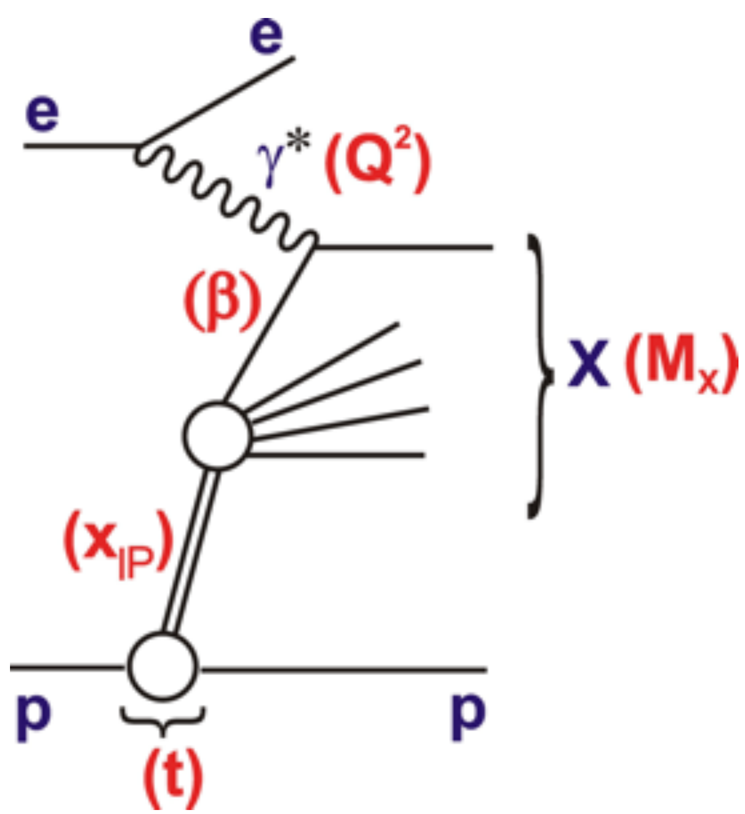
- The LHeC completely unfolds the gluon field in the proton
- Not to mention the expected improvements from adding deuteron data
  - Test whether the neutron d is equivalent to the proton u
  - Have another handle on singlet / non-singlet evolution
- Assumptions will be replaced by data, leading to a new era in proton PDFs
- See talk by Voica Radescu
- Especially important at high x for new particle searches, and at low x...

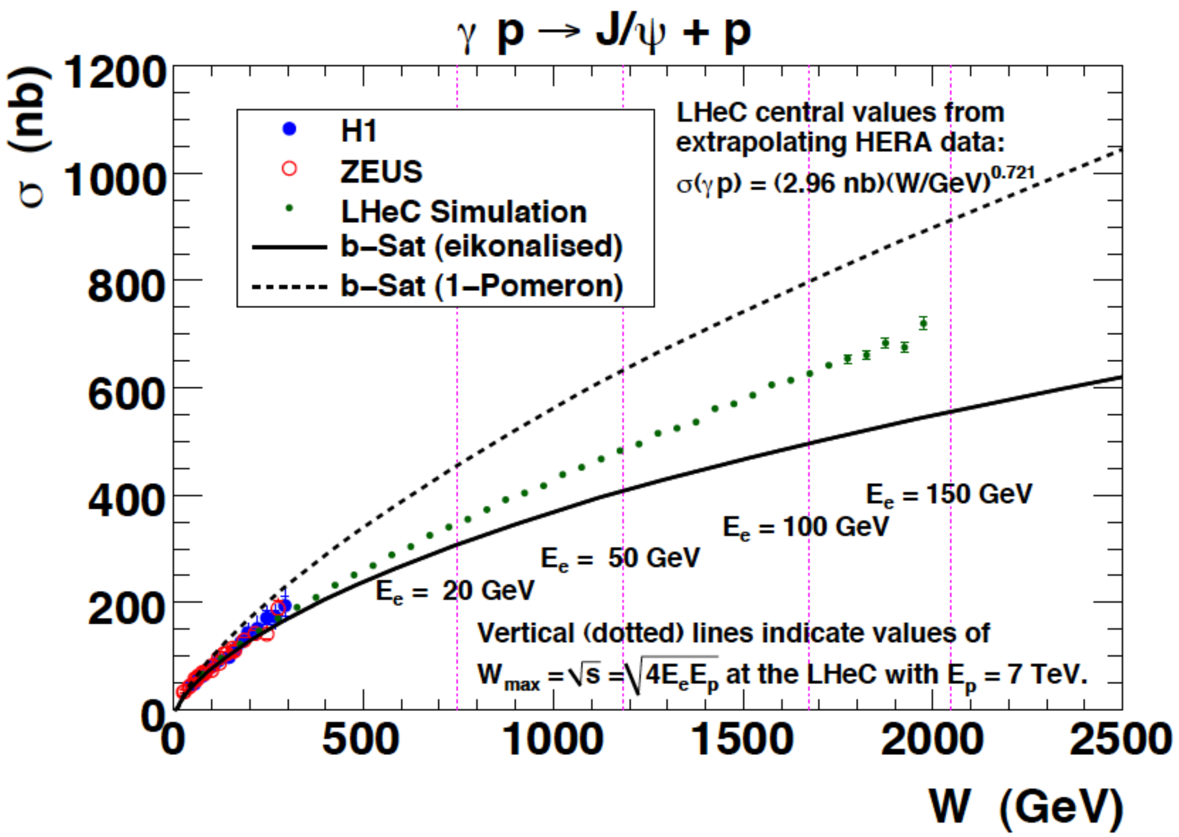
What happens at low x?



- The rise of the gluon can’t continue forever
- Recombination (gg →g) / saturation
- LHeC has the correct kinematic configuration to access low x to study this process with a hard probe
- Understand saturation in perturbative QCD

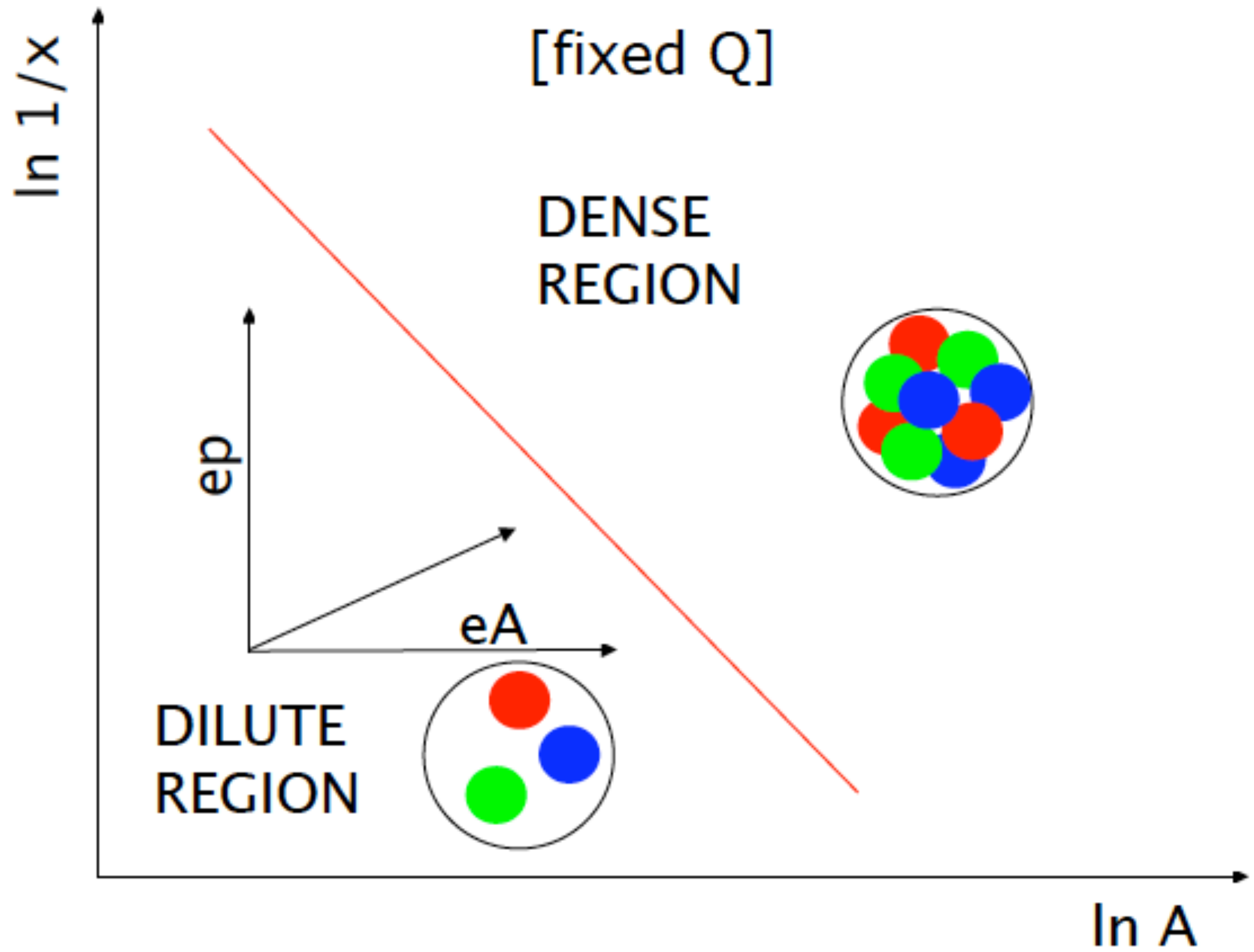
Low x and diffraction





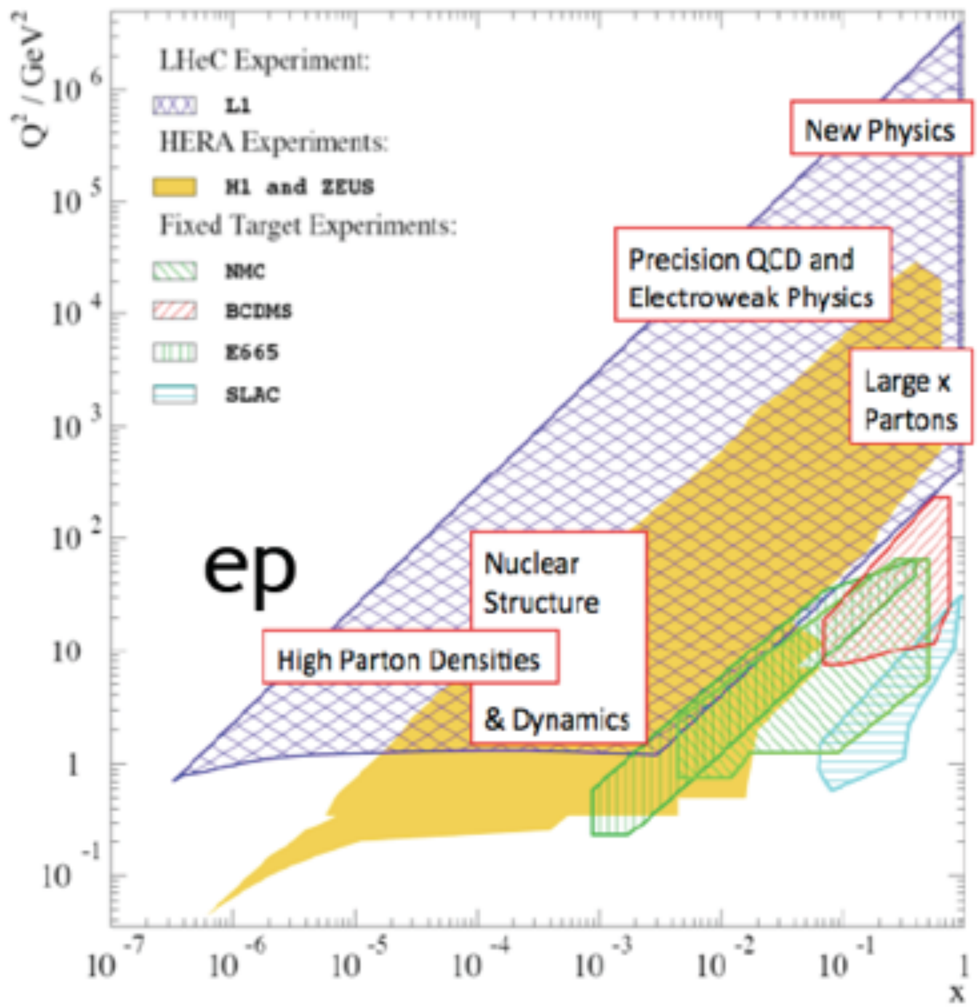
- Inclusive and exclusive diffraction will be studied at LHeC over a hugely expanded kinematic range, also using dedicated detectors
- See talk of Pierre Van Mechelen
- Of particular interest - the sensitivity of exclusive vector meson production to saturation

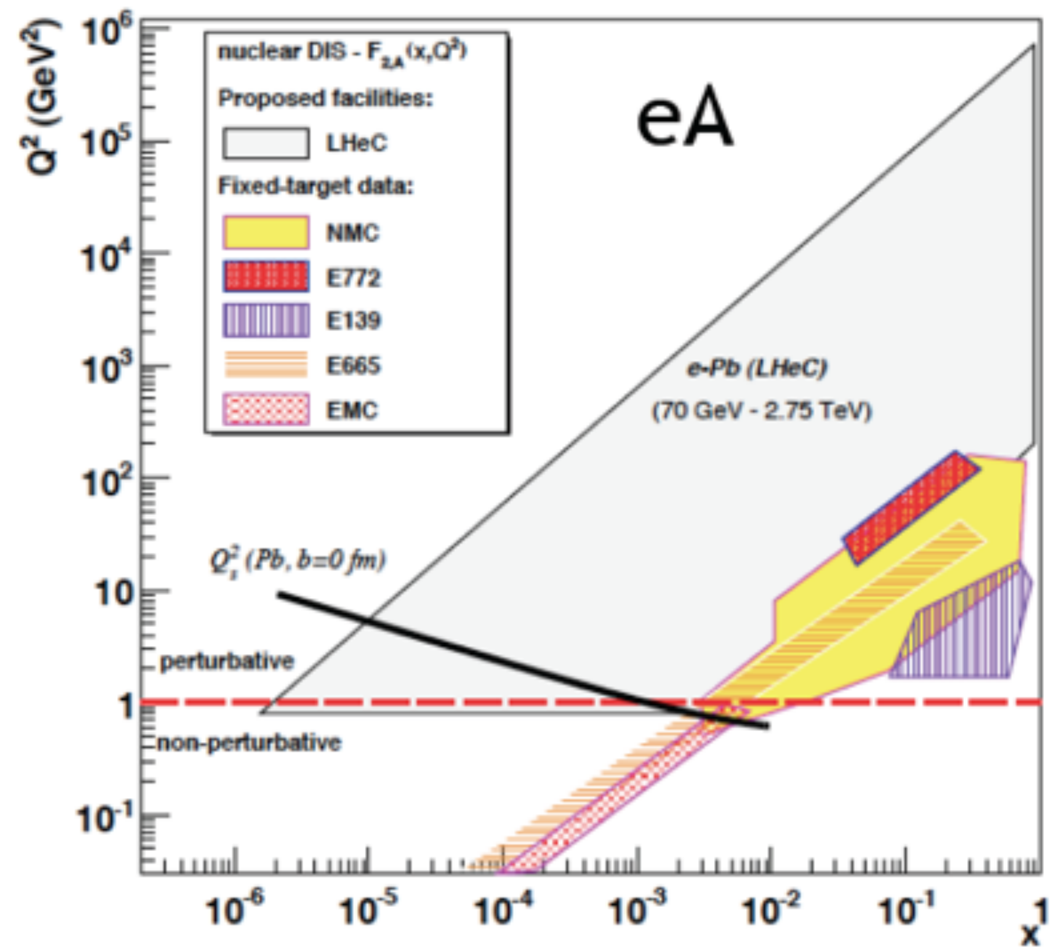
Paint it black



- Two ways to make the target blacker at LHeC:
  - go to low x in ep
  - increase A

Kinematic coverage of ep and eA



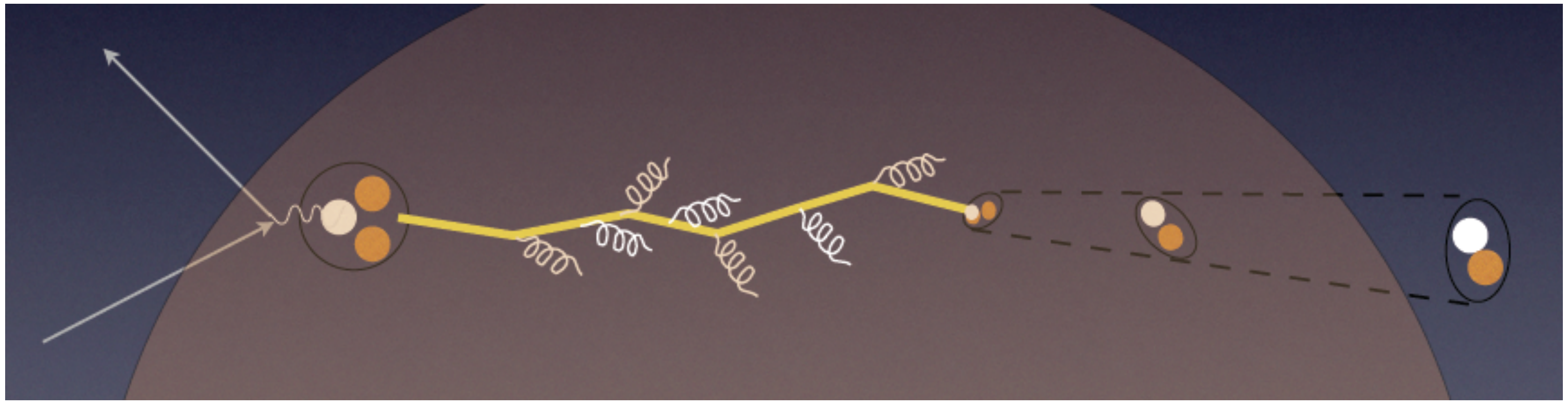


- The understanding of nuclear PDFs would undergo a revolution given the ~4 orders of magnitude increase in kinematic range
- Pin down the initial conditions of nuclei to better understand pA and AA
- Thanks to the LHeC detector, measure charm and beauty in nPDFs for the first time

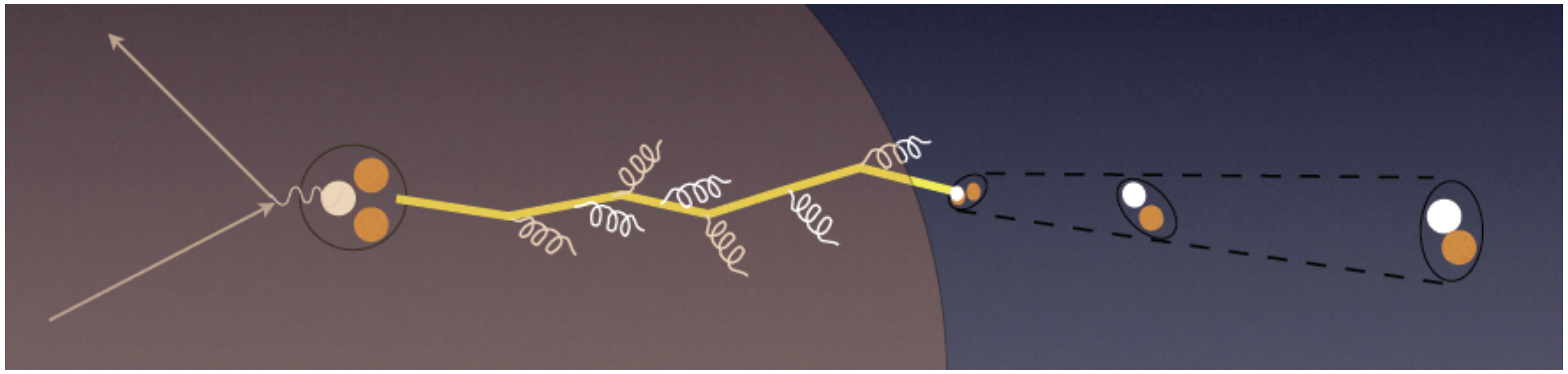
In-medium Hadronisation

The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).

Low energy (ν): need of hadronization inside.
Parton propagation: pt broadening
Hadron formation: attenuation



High energy (ν): partonic evolution altered in the nuclear medium.

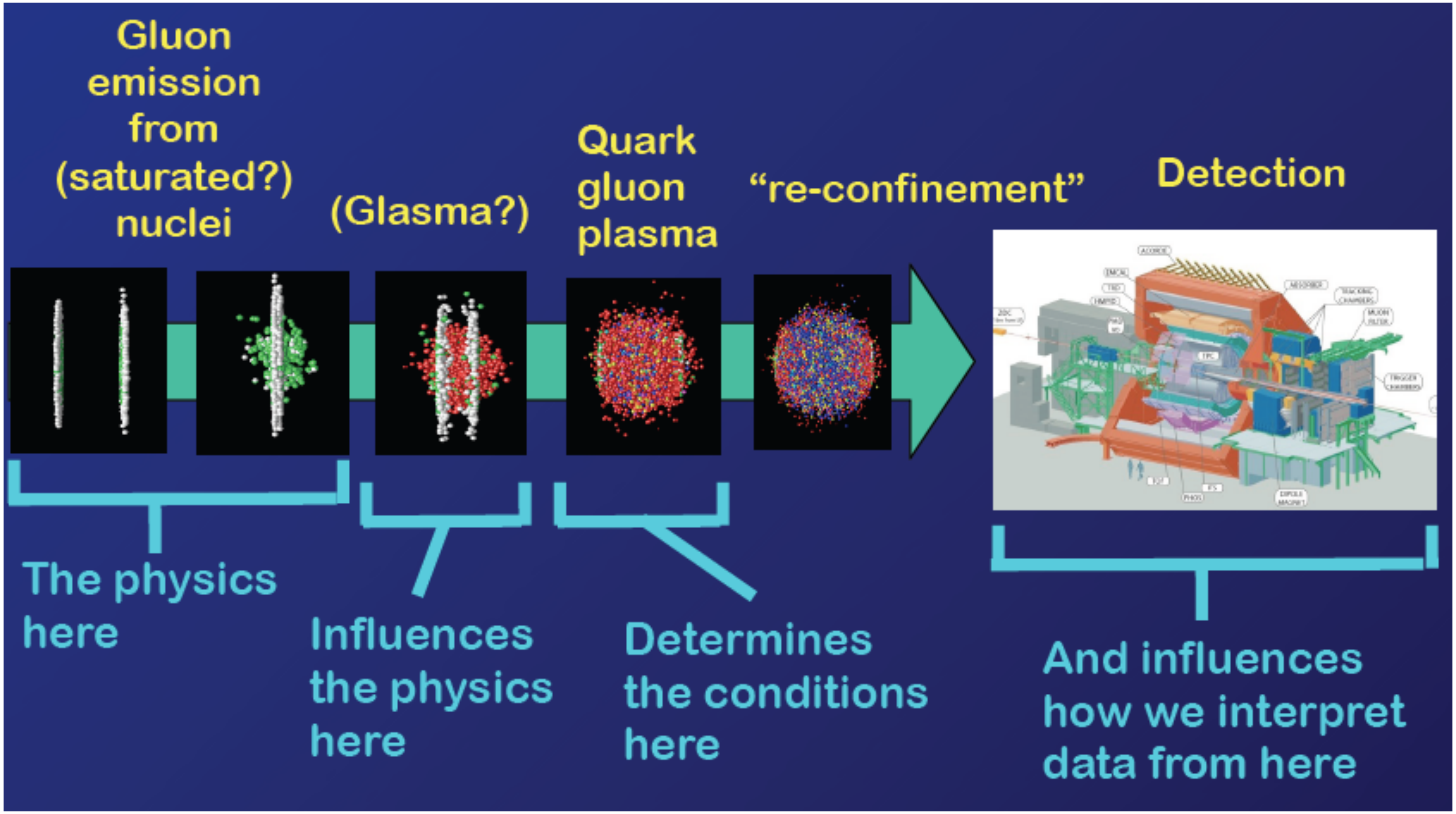


W.Brooks, Divonne09

LHeC :

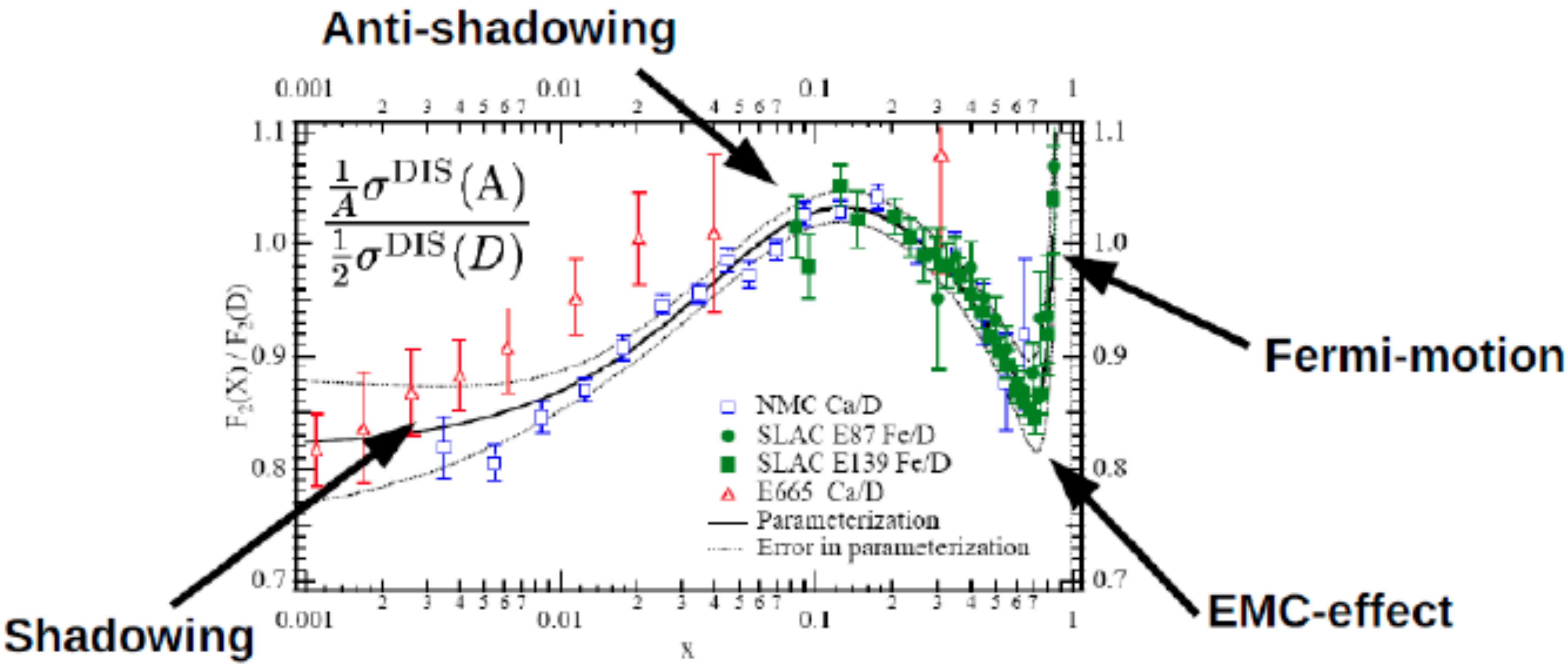
+ study the transition from small to high energies in much extended range wrt. fixed target data
+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC
+ detailed study of heavy quark hadronisation ...

LHeC and heavy ion physics



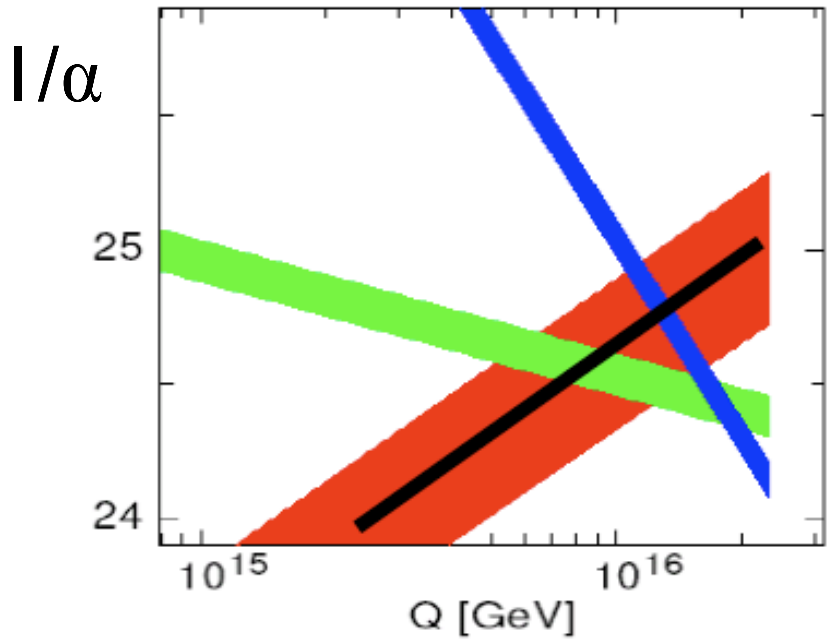
- The key experimental advantage with LHeC - the kinematics of the struck parton are known with high precision
- Precision measurements for a precise understanding
- See talk of Anna Stasto

eA vs ep



- File under "things I don't understand very well about QCD"
- More from Anna

Precision α_s measurement - Grand Unification?



α_s scenarios

case	cut [Q^2 in GeV^2]	relative precision in %
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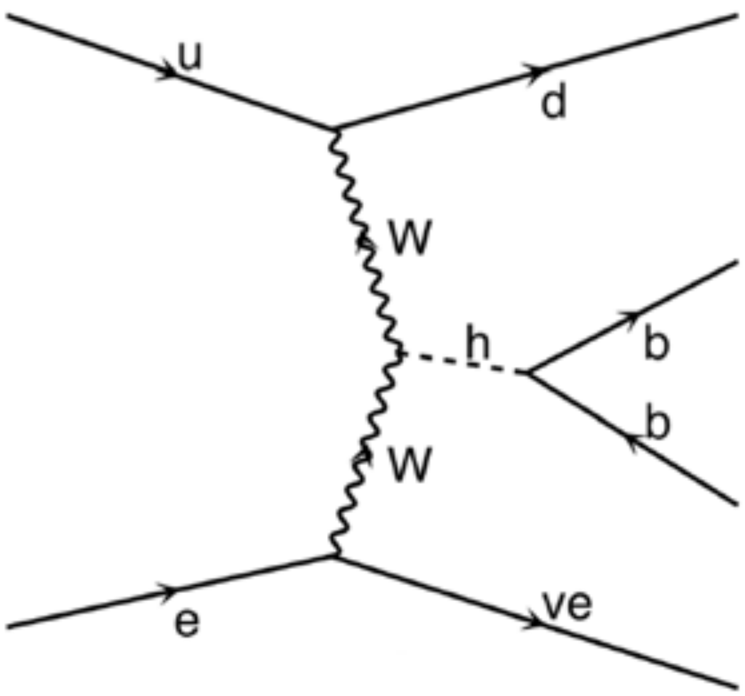
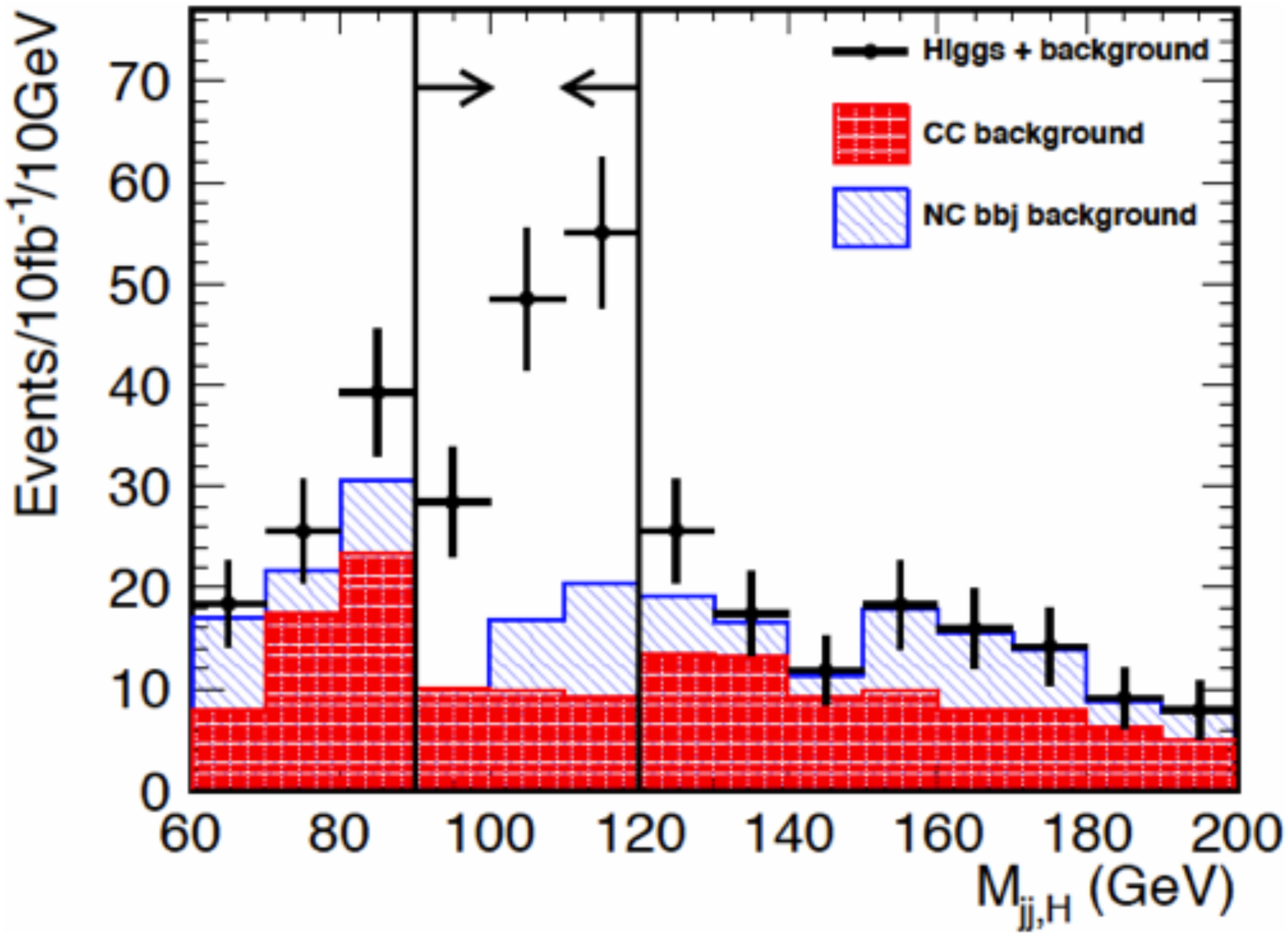
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

- It may be that the forces unify, i.e. have the same strength, at high energy
- Verifying that demands improvements in our knowledge of α_s which is by far the least well known of the fundamental couplings
- Presently known to ~1% precision, it would be determined at the per mille level..
- ..and at a couple per mille for Q^2>20 GeV^2, i.e. no non-perturbative effects

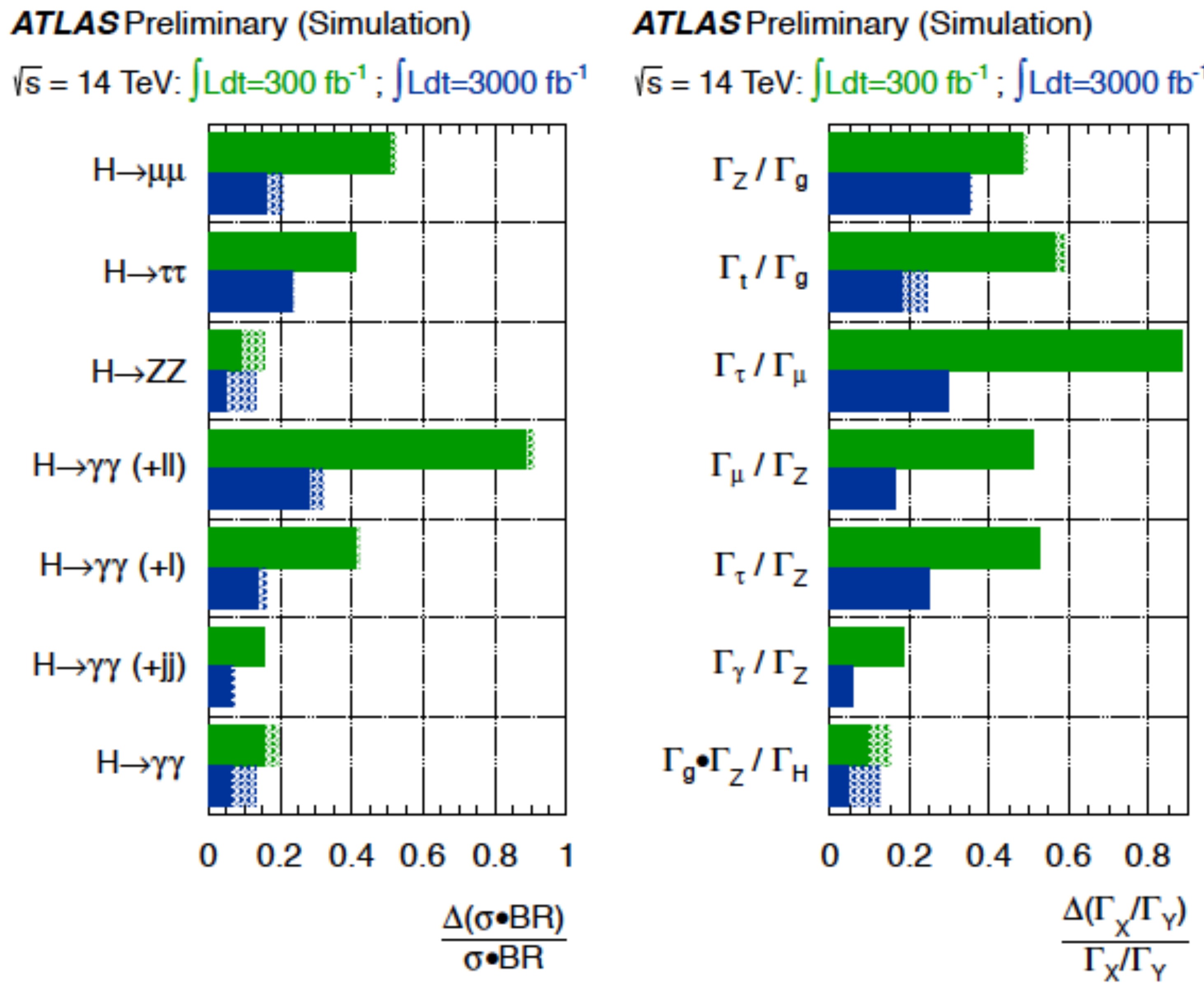
Higgs@ LHeC





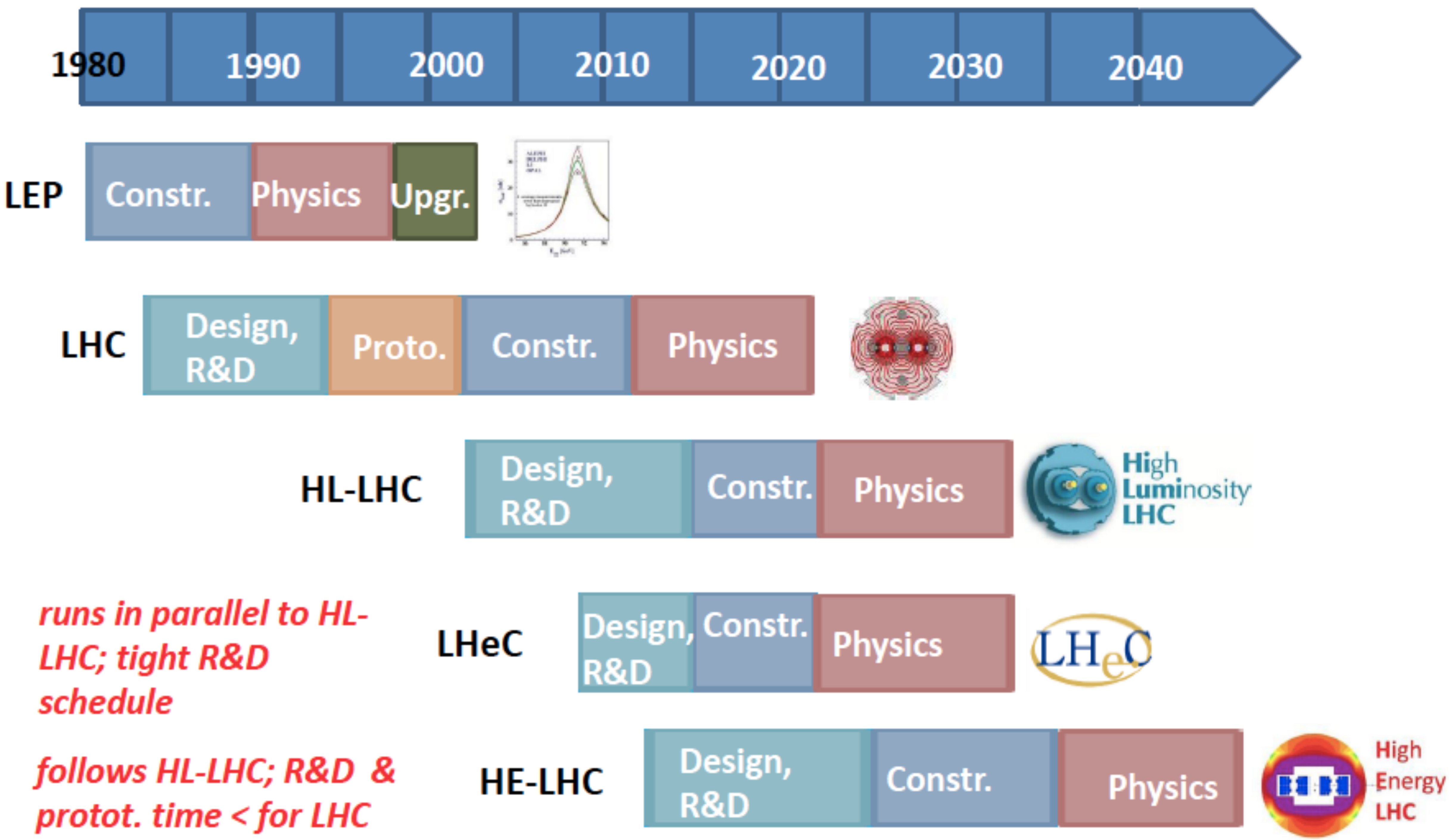
- Higgs cleanly produced in CC reactions, ~hundred reconstructed events
- Studied with the Higgs decaying to bb, possible with LHeC tracking detector
- Signal significance of ~16 found, clearly worthy of further study!
- See talk of Voica for more details

Higgs@LHC and PDF uncertainties



- Many of the channels at LHC will be limited by PDF uncertainties
- With the LHeC, the huge improvements in knowledge of PDFs, precision of α_s will remove this, allowing the full exploitation of the LHC data for Higgs physics

time line of CERN HEP projects



Summary

LHeC represents a fantastic opportunity to understand nuclear structure and QCD with high precision

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], A.Caldwell[70], V.Cetinkaya[01], V.Chekelian[70], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], P.DiNezza[72], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], A.Glazov[17], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], E.Jensen[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], E.Rizvi[71], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], P.Thompson[06], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

Support material

The LHeC Conceptual Design Report - http://arxiv.org/abs/1206.2913

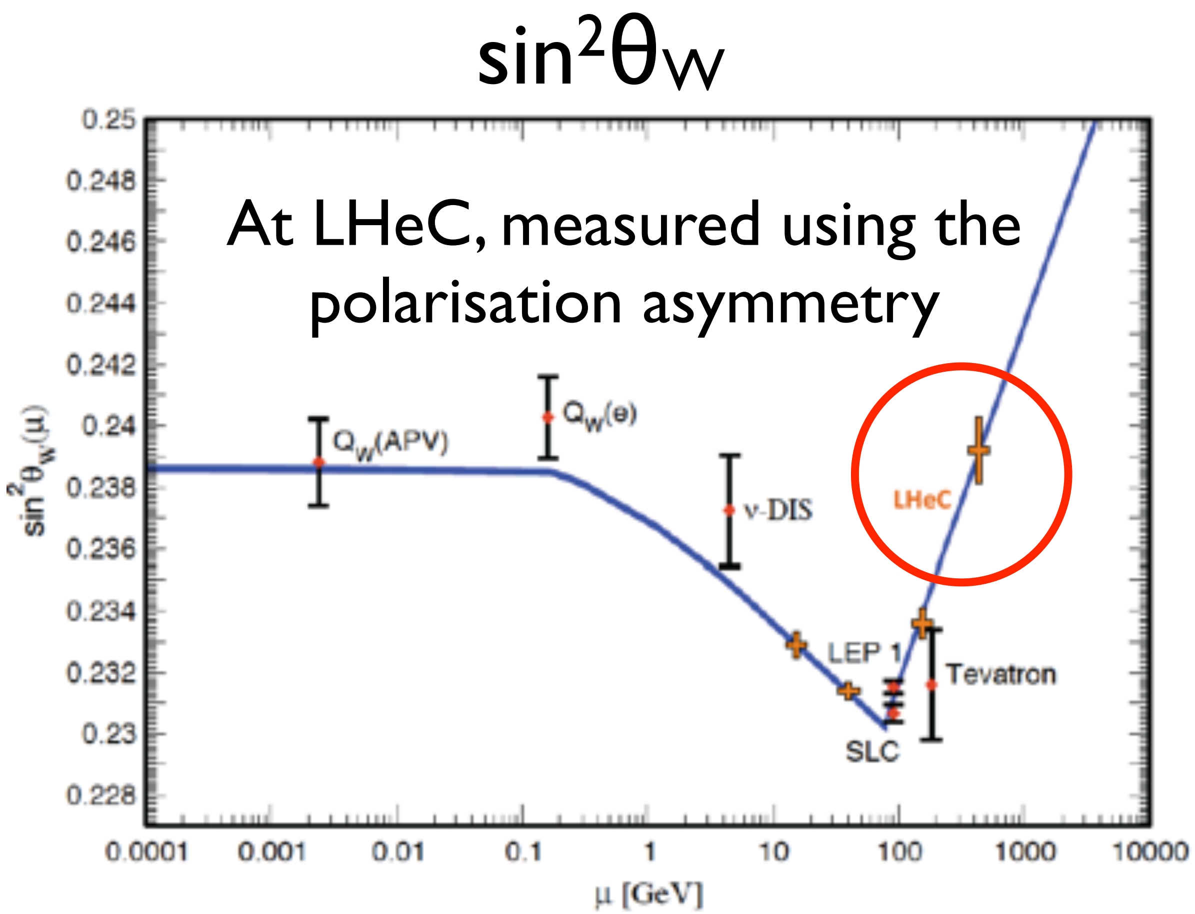
The LHeC Summary for the European Strategy - http://arxiv.org/abs/1211.4831

On the Relation of LHeC to the LHC - http://arxiv.org/abs/1211.5102

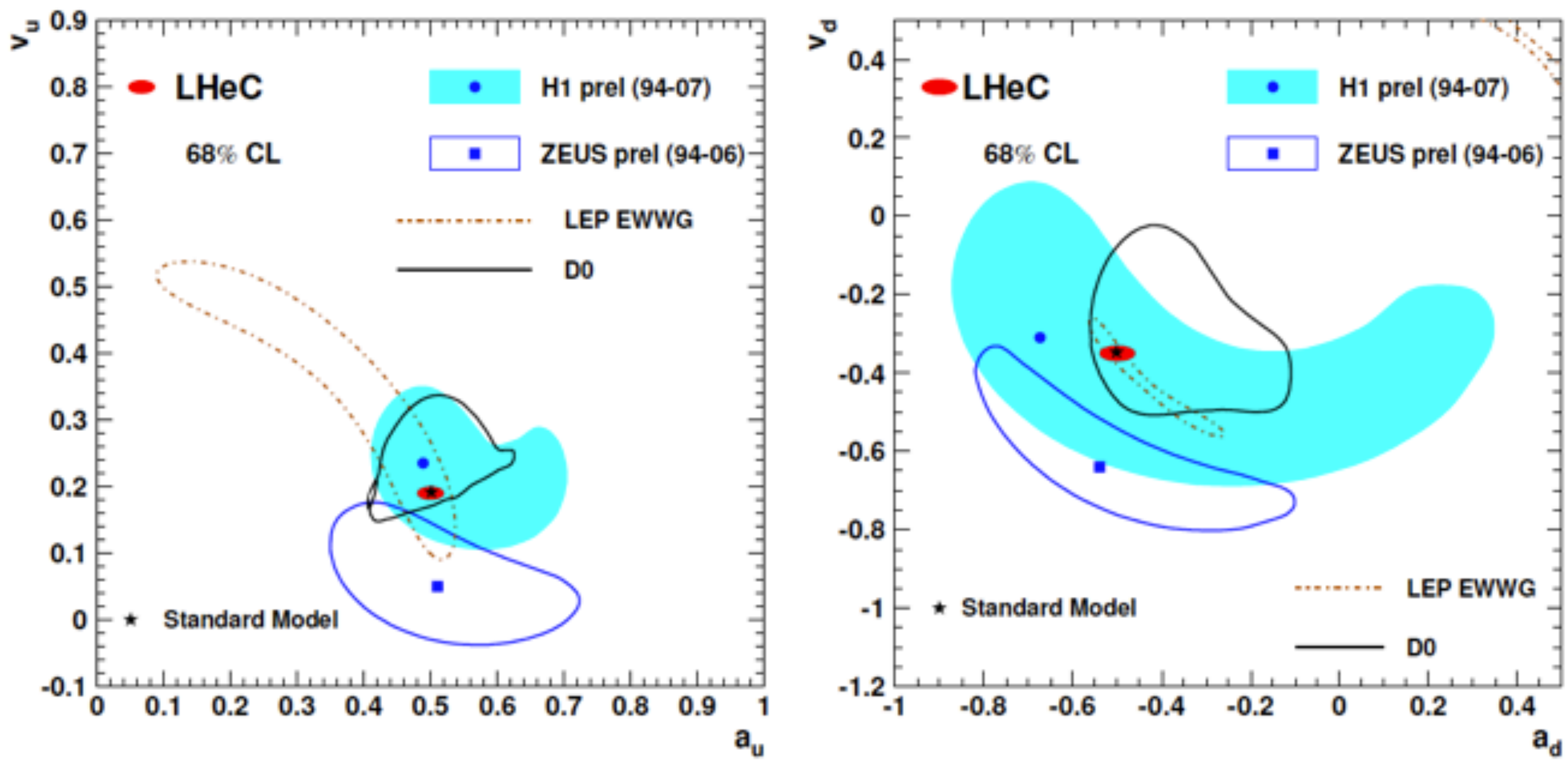
Web page with much more information: cern.ch/lhec

Backup

Precision electroweak measurements



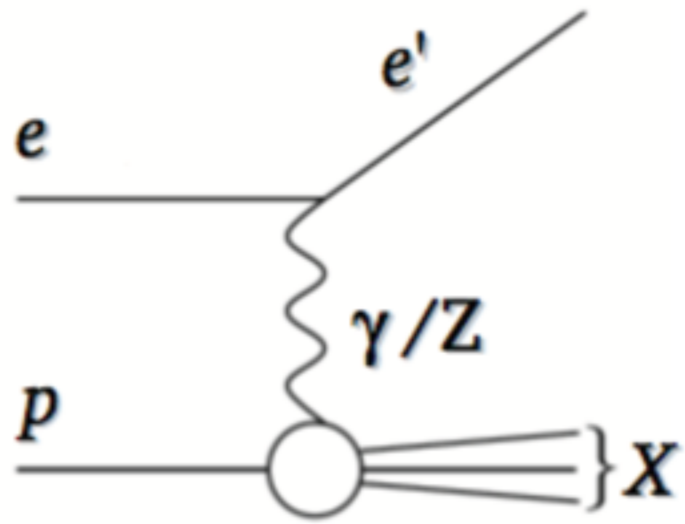
- An interesting proposal to measure the electroweak mixing angle using polarisation asymmetry measurements
- Good precision and the scale dependence measured in one experiment
- To be pursued further

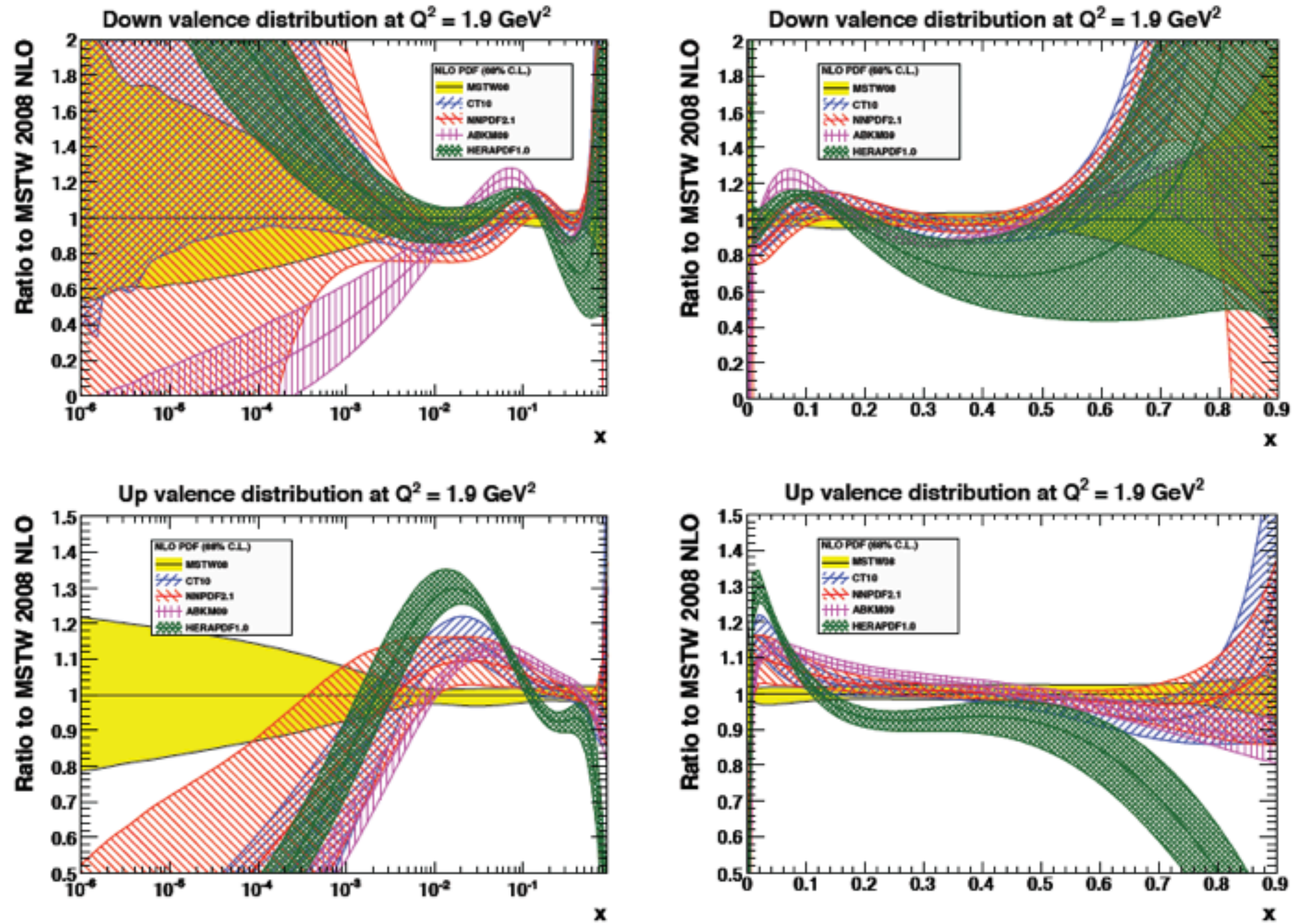


The vector and axial-vector weak NC couplings to the u and d quarks would be measured to very high precision (look closely!)

Current knowledge of the valence quarks

$\mathrm{NC}: \; e\,p \rightarrow e'\,X$

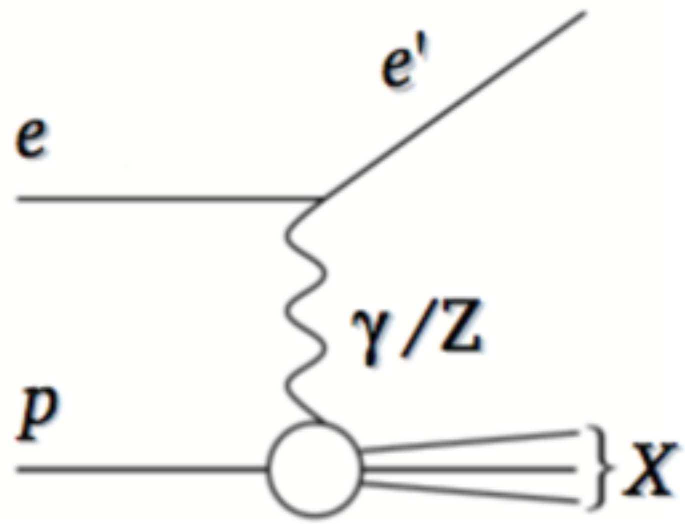


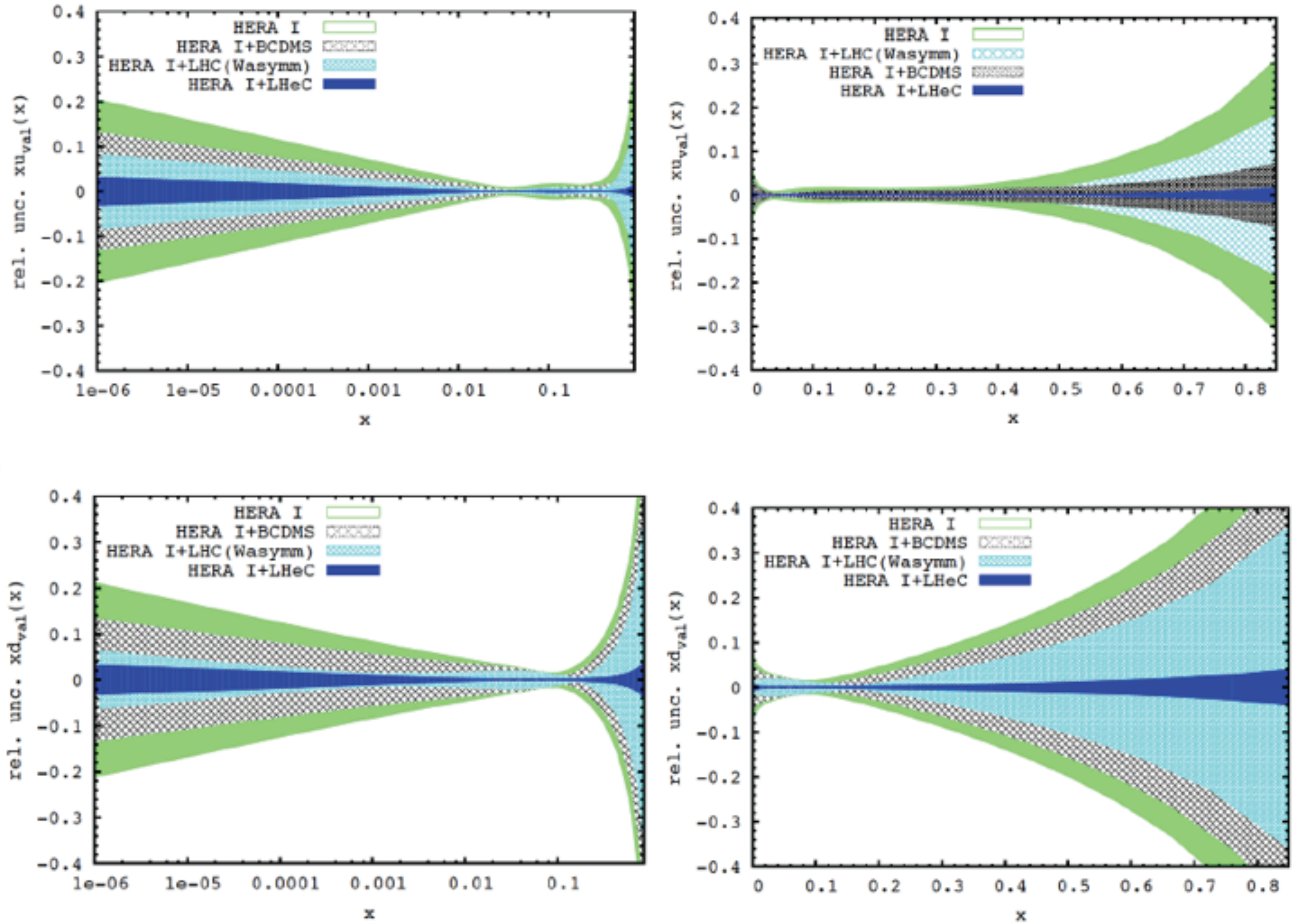


- The valence structure of the proton may be known, the details are not
- The range of answers offered by the latest and greatest is surprisingly varied

The proton has its ups and downs

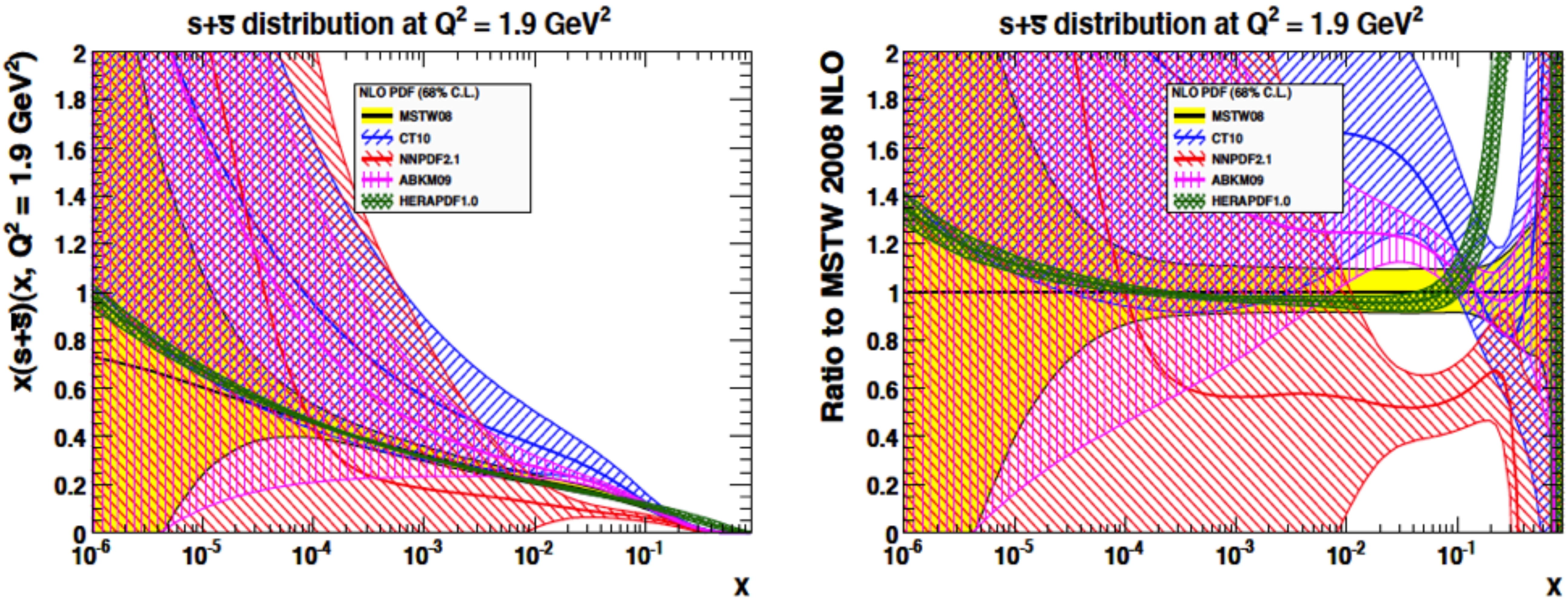
NC : $ep \rightarrow e'X$





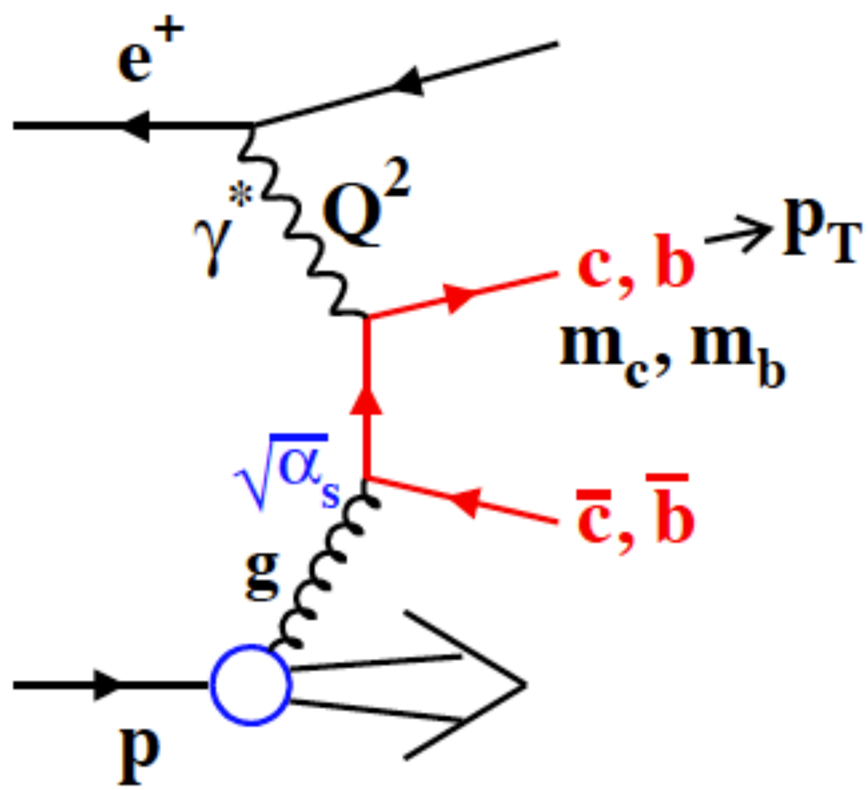
- The LHeC would be able to constrain the valence quarks across the whole kinematic range to better than ~2% precision
- c.f. LHC searches continue to push towards higher masses, i.e. higher x

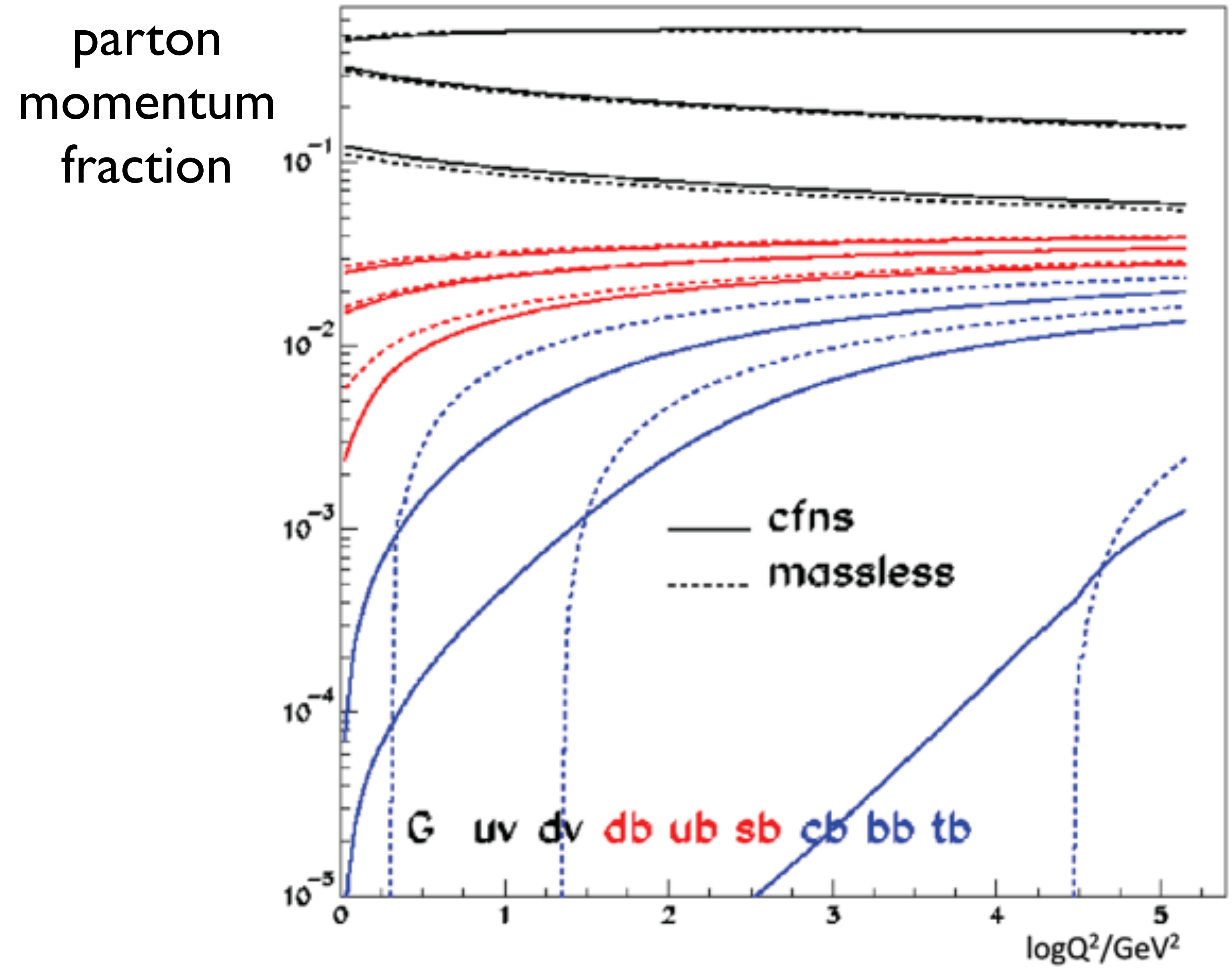
How strange is the proton?



- Very strange? The spread of distributions looks appropriately strange
- But not really strange, the current constraints from data are very poor and consequently the strange content of the proton is very poorly known

How to treat heavy flavours?

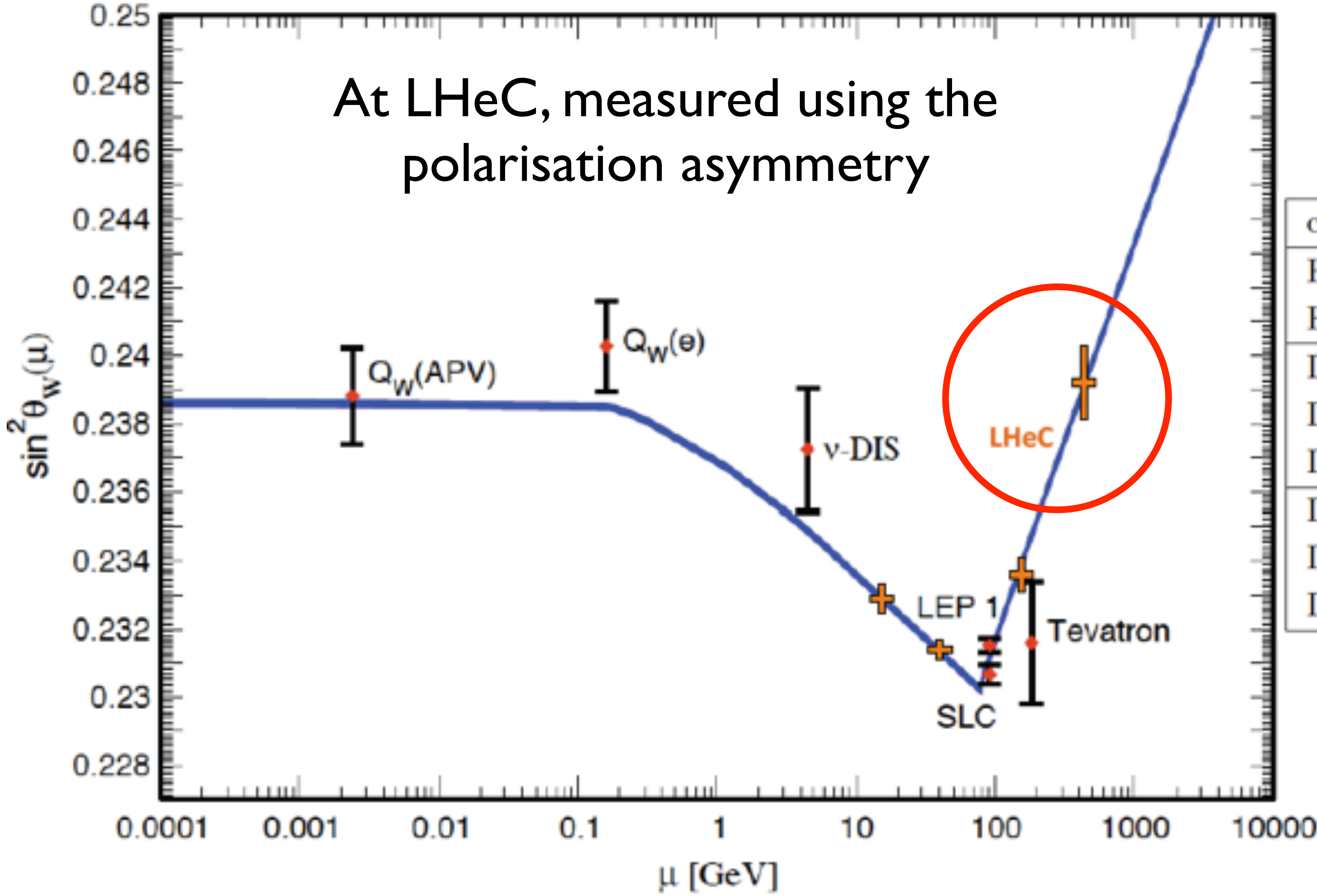




- We expect to see many top quarks (100,000 events) at the LHeC, opening up the field of top PDFs
- Need to have 6 flavour-number scheme (see talk of Pascaud)
- The LHeC would map the transition between the massive and massless approaches, precision heavy flavour data invaluable for theory

Measuring fundamentals

$\sin^2\theta_W$



α_s scenarios

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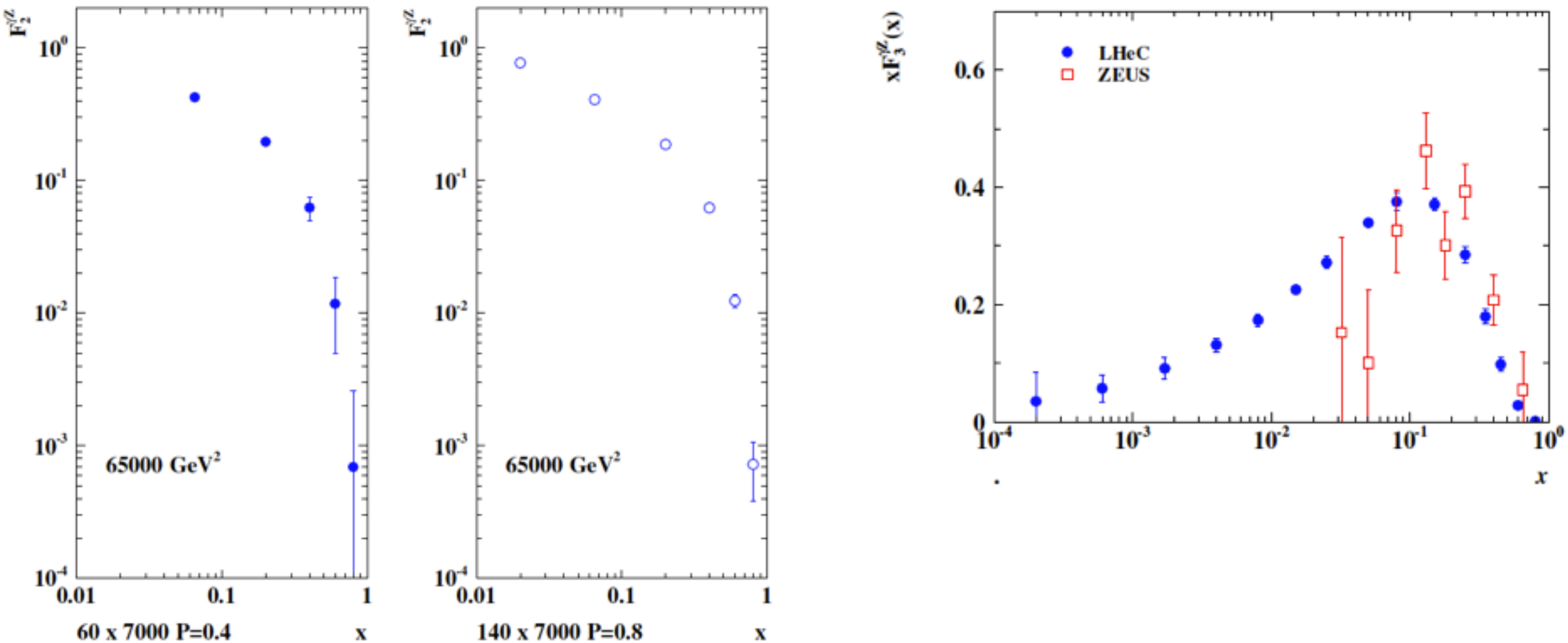
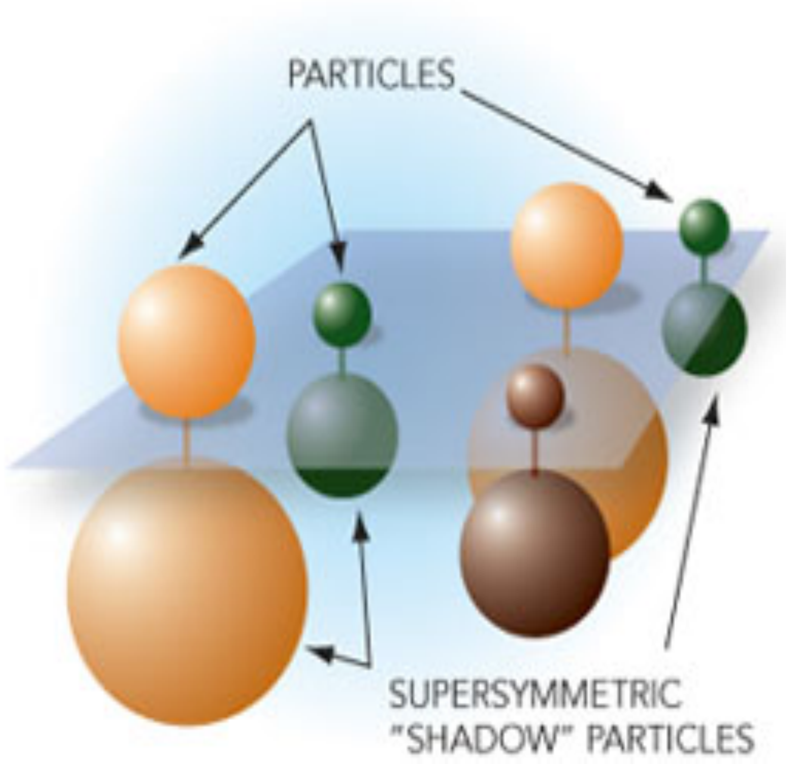
- The LHeC would be able to measure the value of $\sin^2\theta_W$ at different $\mu(Q^2)$
- The strong coupling constant, presently known to ~1% precision, would be determined at the per mille level
- At a couple per mille for Q^2>20 GeV^2, i.e. no non-perturbative effects

Neutral Current Boson Interference



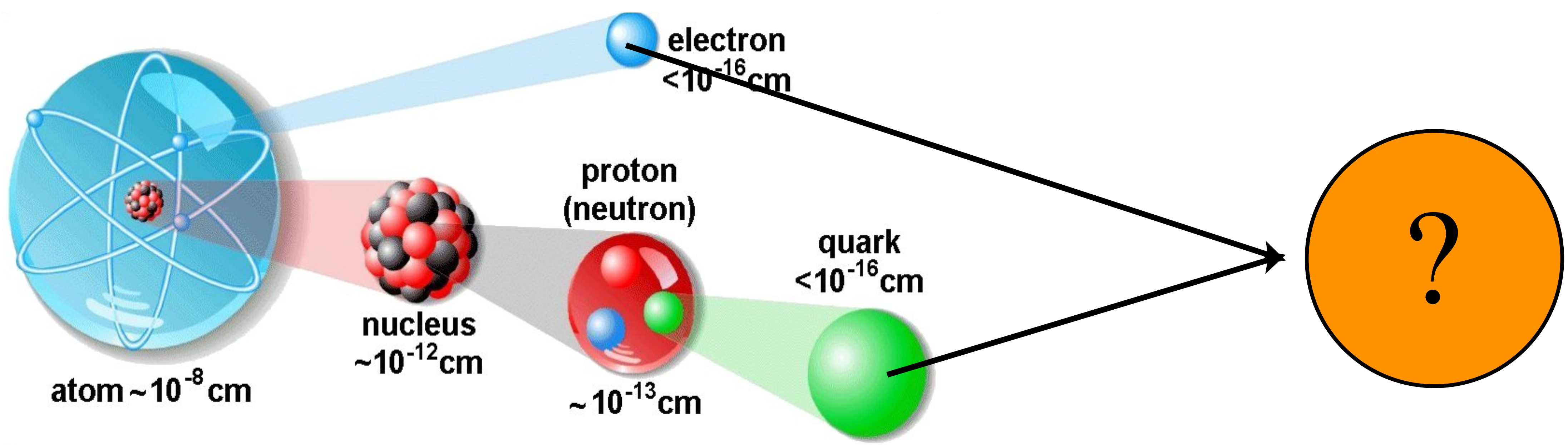
- Limited measurements of the interference terms contributing to proton structure
- LHeC measures $F_2^{\gamma Z}$ for the first time - probing parity violation at small distances
- Also measures $xF_3^{\gamma Z}$ with good precision - probing the valence at $x < 10^{-3}$

What lies beyond?



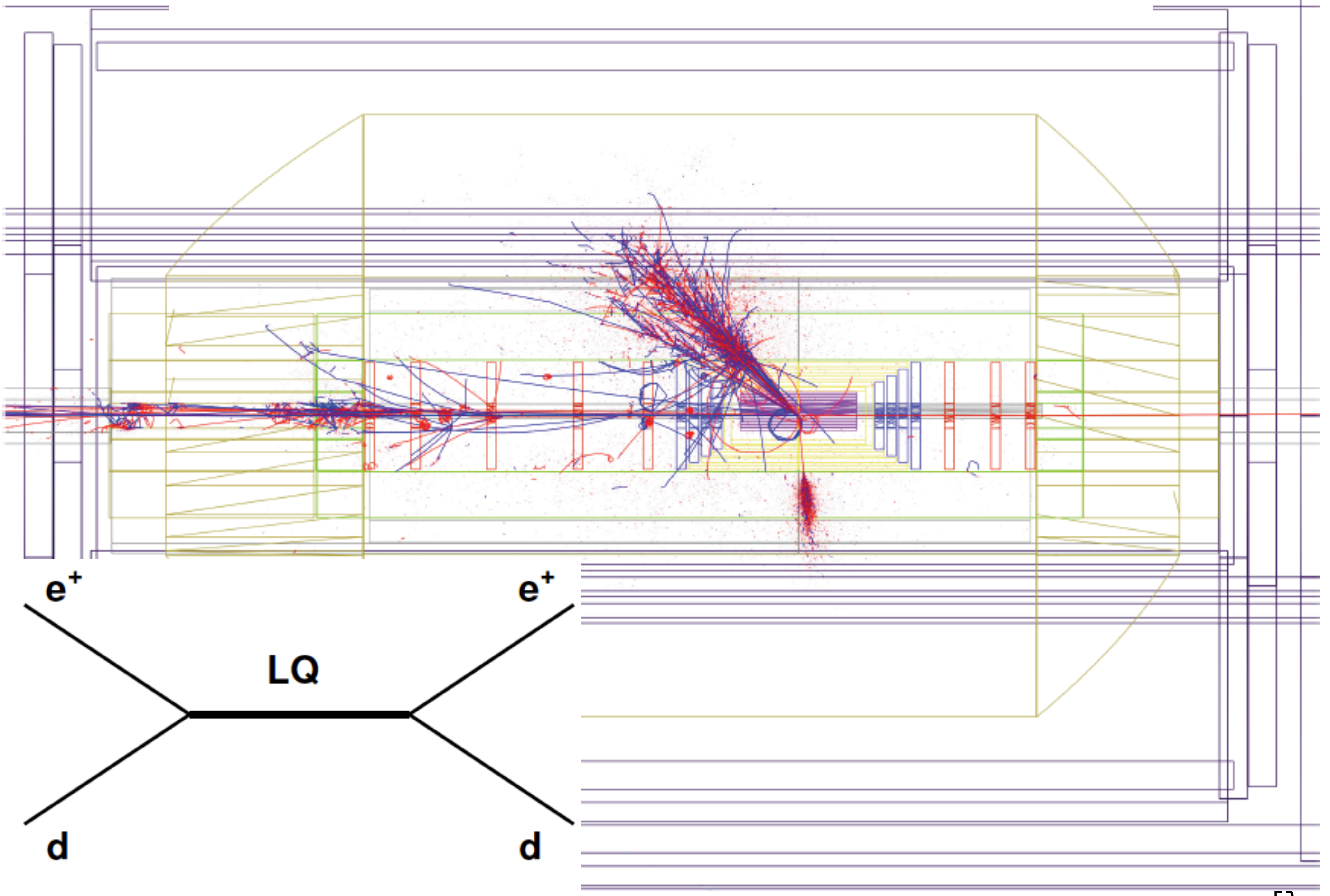
- Is nature supersymmetric?
- Normally consider pair-production of SUSY particles at the LHC which decay into the lightest SUSY particle, they can't decay if R-parity is conserved
  - Striking missing energy signatures in the detector as the LSP escapes
- But if R-parity isn't conserved?
- More on SUSY and LHeC in Monica's talk tomorrow

What lies beyond?

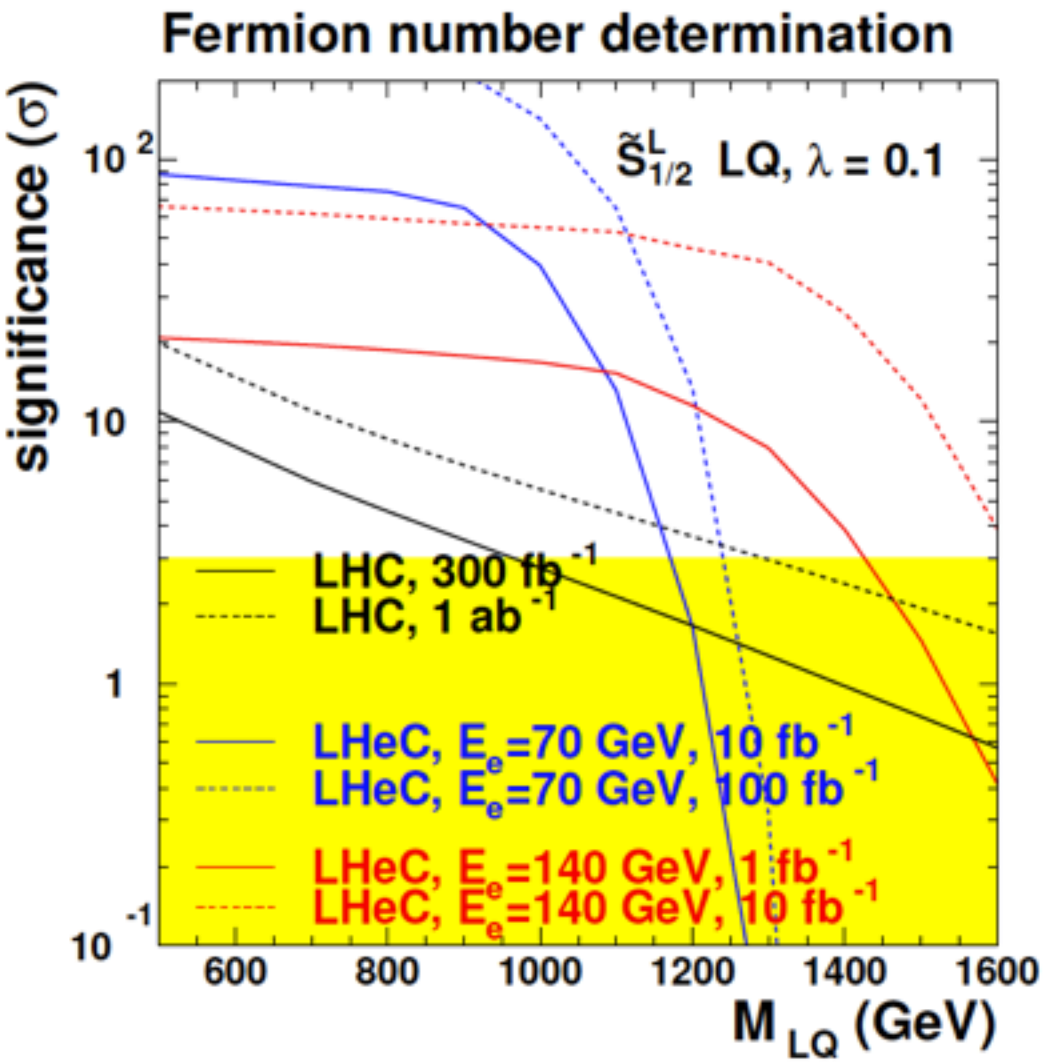


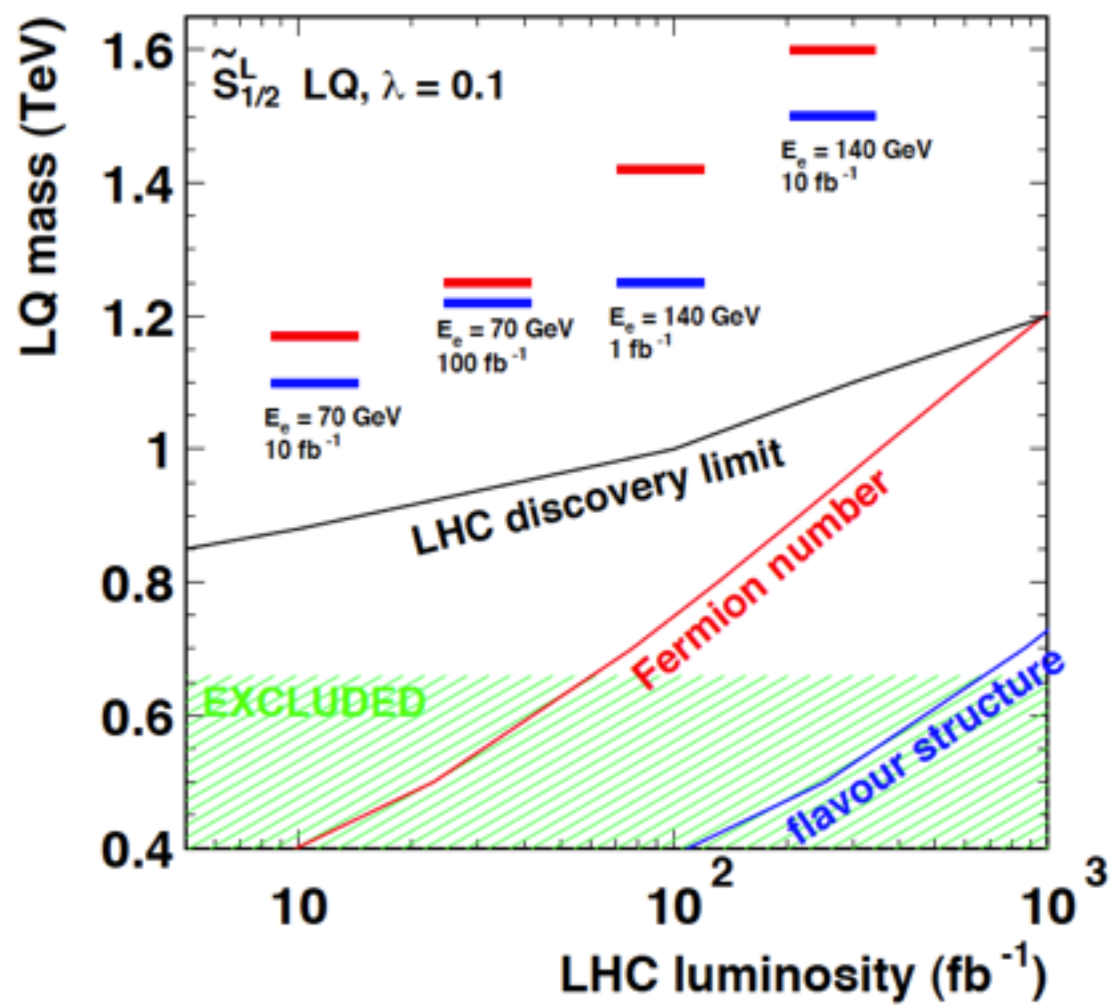
- Why are there quarks and leptons?
- They both experience the electromagnetic and weak forces, but only quarks feel the strong force, why??
- Perhaps quarks and leptons are composites of more fundamental particles, many theories, predict leptoquarks (may also be squarks in RPV SUSY)
- The LHeC provides lepton and baryon number in the initial state, a good leptoquark factory if such things exist

Clean signatures of new physics - leptoquarks



Leptoquarks





- Similar or better sensitivity than LHC
- The key difference is that, if they exist, the LHeC can characterise them, measuring their quantum numbers
- Similar story for other new physics, e.g. excited electrons (see talk by Azuelos)