Deep Inelastic Scattering at High Energy

Max Klein
University of Liverpool

For the ep/eA study group

FCC Meeting. 14.2.2014
University of Geneva

http://cern.ch/lhec

60 GeV x 7 TeV (LHC)

60 … 175 GeV x 50 TeV (FCC-h)

M.Froissart ICHEP ("Rochester") 1966

THEORY

H.Murayama – ICFA11

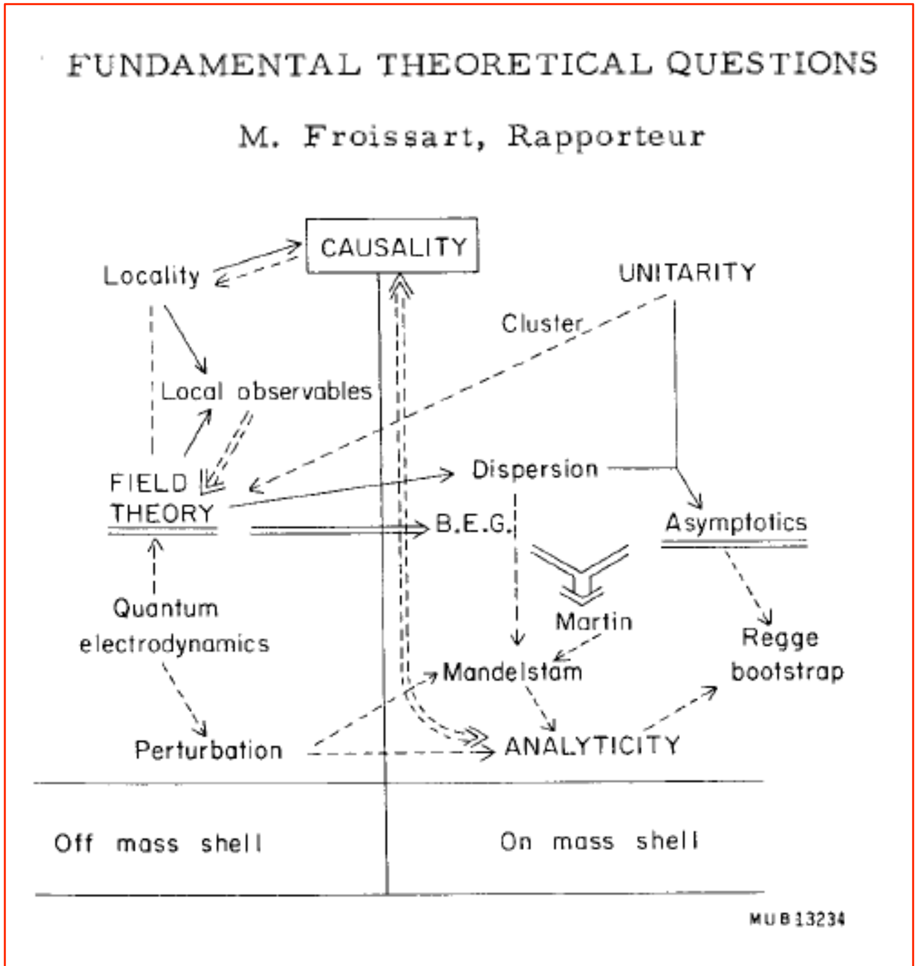
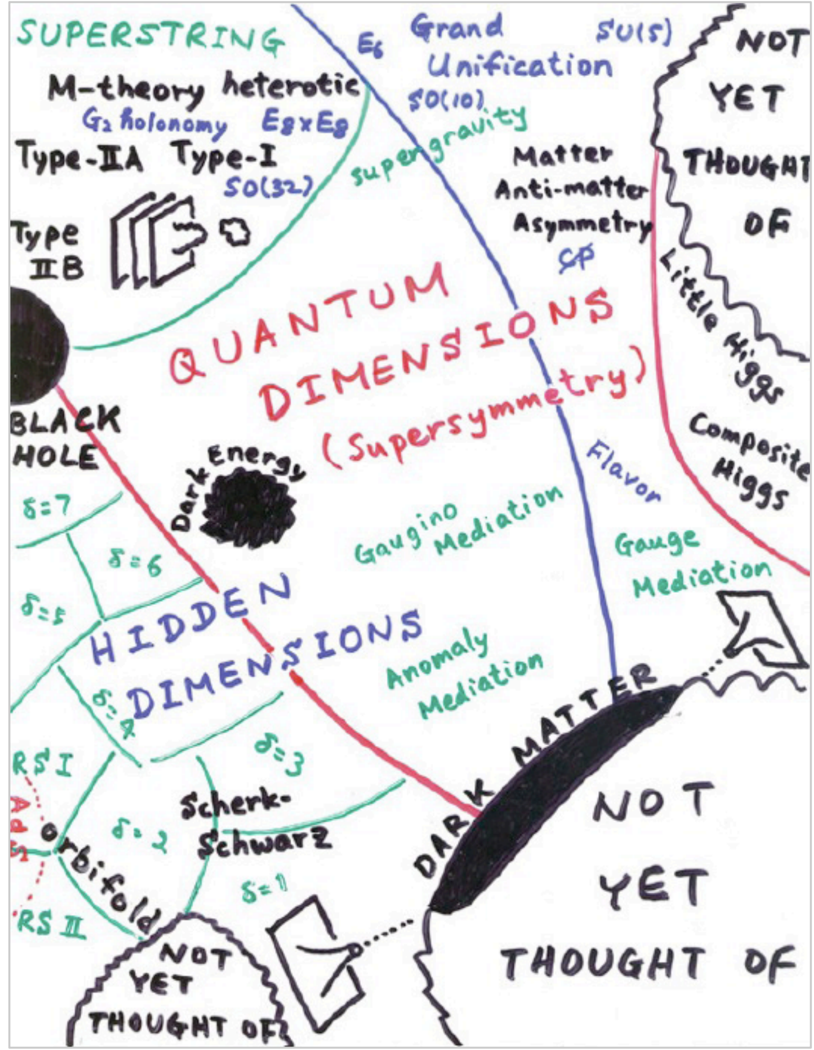


Fig. 1-1. Logical map of "Fundamental" concepts.

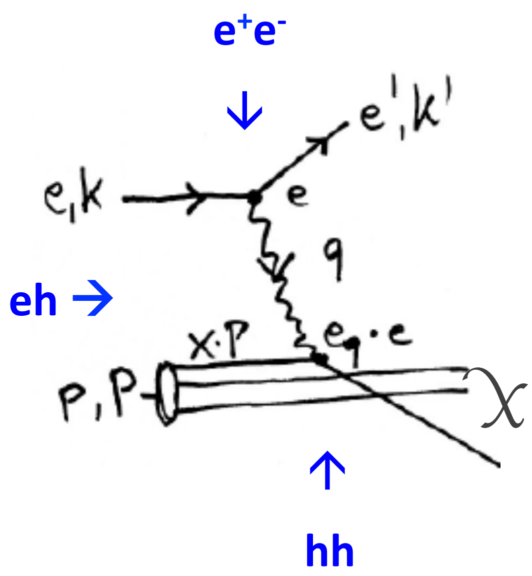


→ Quarks in 1969

→ ?in 2015+?

We like to see particle physics as driven by experiment … Burt Richter

Deep Inelastic Scattering [eh → e'X]



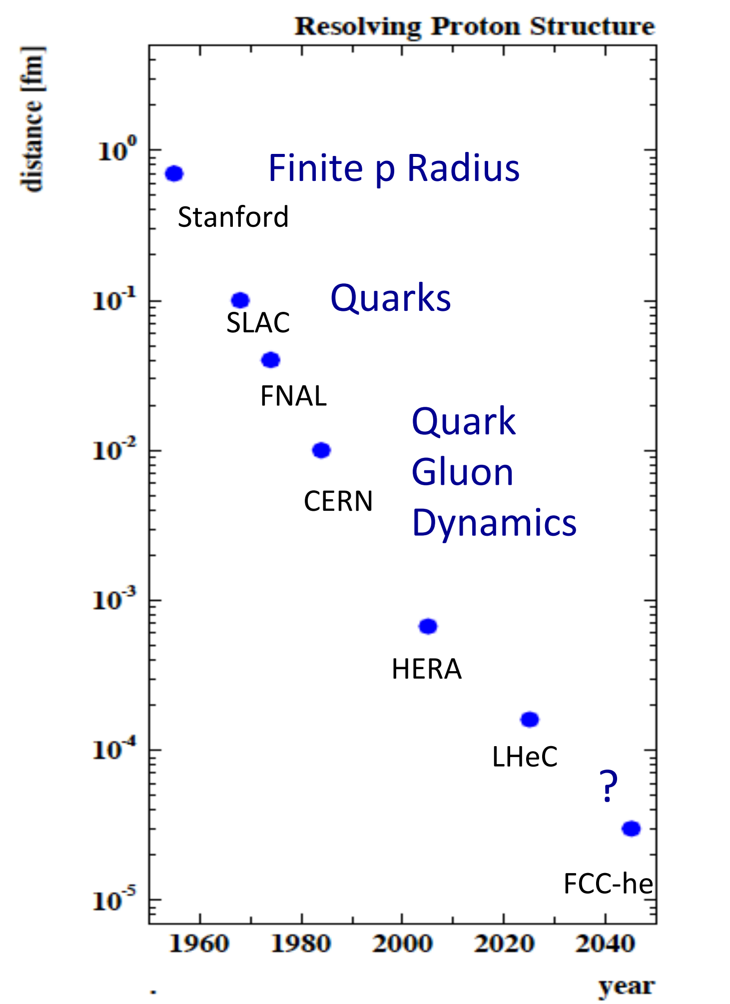
$$x = \frac{Q^2}{sy}$$

$$Q^2 = -(k - k')^2$$

$$y_{lab} = 1 - \frac{E_e'}{E_e}$$

$$s = 4E_e E_p$$

HERA-LHeC-FCC-eh: finest microscopes with resolution varying like $1/\sqrt{Q^2}$



electromagnetic radius

Parton momentum fixed by electron kinematics

Incl. NC (γ,Z) and CC ($W^{\pm}$) independent of hadronisation

Rigorous theory: Operator expansion (lightcone)

Parton momentum distributions to be measured in DIS

Collider- HERA: y_h=y_e : Redundant kinematics

THE UNCONFINED QUARKS AND GLUONS

Abdus Salam

International Centre for Theoretical Physics,
Trieste, Italy and Imperical College, London,
England

1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

Tbilissi →
1976

Dogmas are absolutely essential for the progress of Science but they become tragic if they succeed in stopping experimentation designed to prove them wrong.

Possible QCD Developments and Discoveries

AdS/CFT

Instantons

Odderons

Non pQCD

QGP and Nuclei

N^kLO

Resummation

Saturation and BFKL

Non-conventional PDFs …

Breaking of Factorisation

Free Quarks

Unconfined Color

New kind of coloured matter

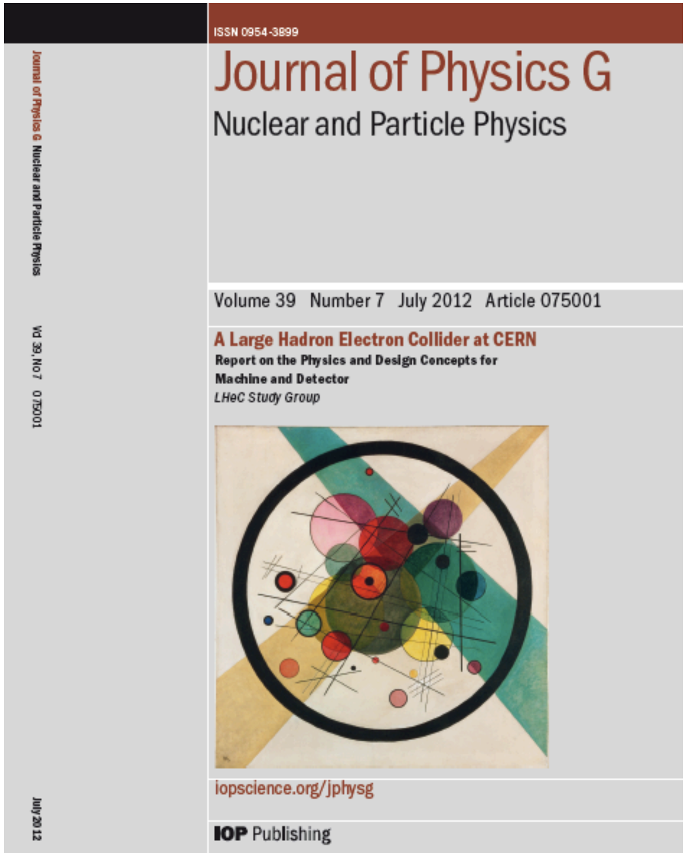
Quark substructure

New symmetry embedding QCD

QCD may break .. (Quigg DIS13)

QCD is the richest part of the Standard Model Gauge Field Theory and will (have to) be developed much further, for its own and as background

Design Report 2012

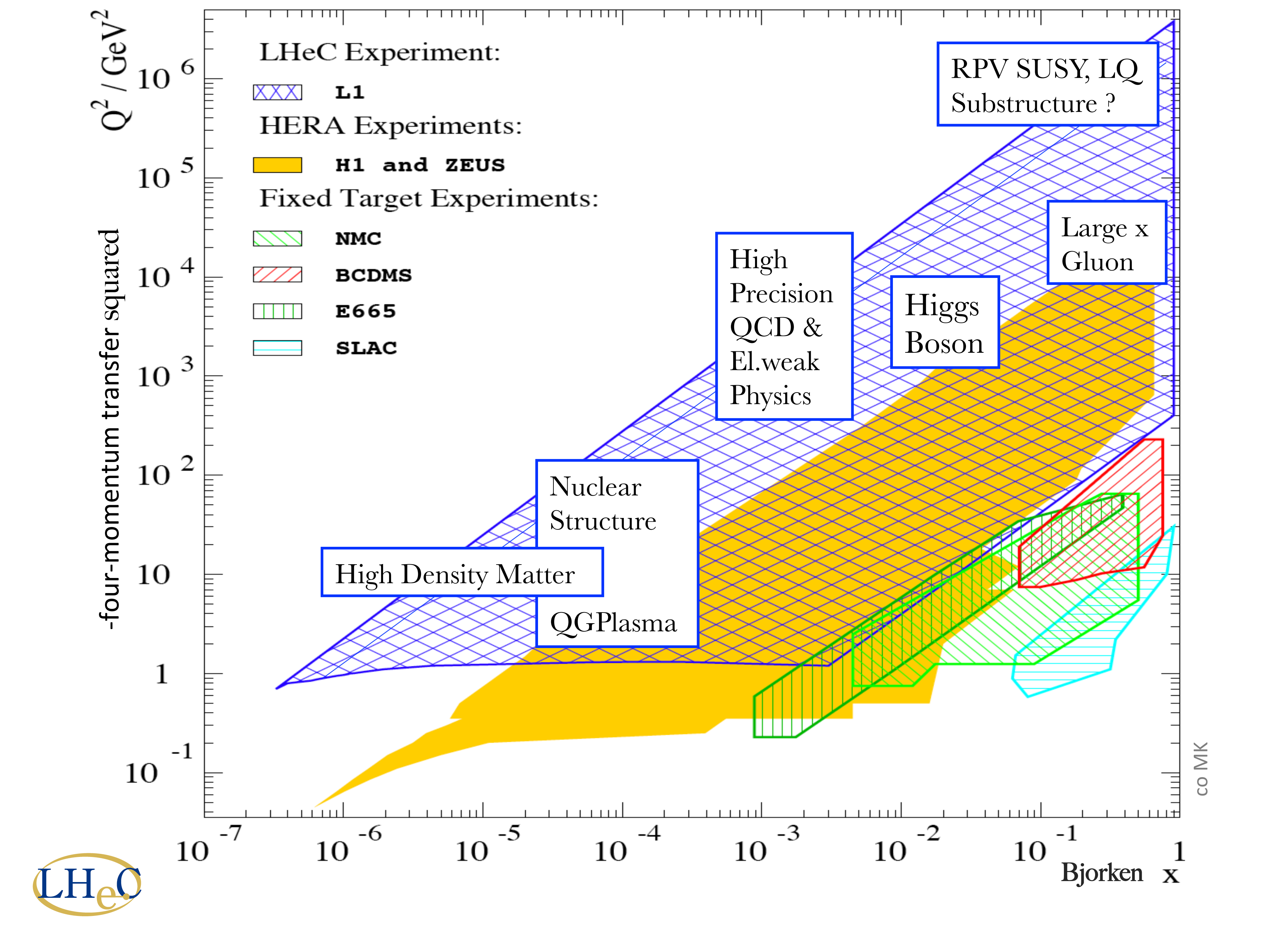


arXiv:1206.2913 http://cern.ch/lhec

CERN Referees

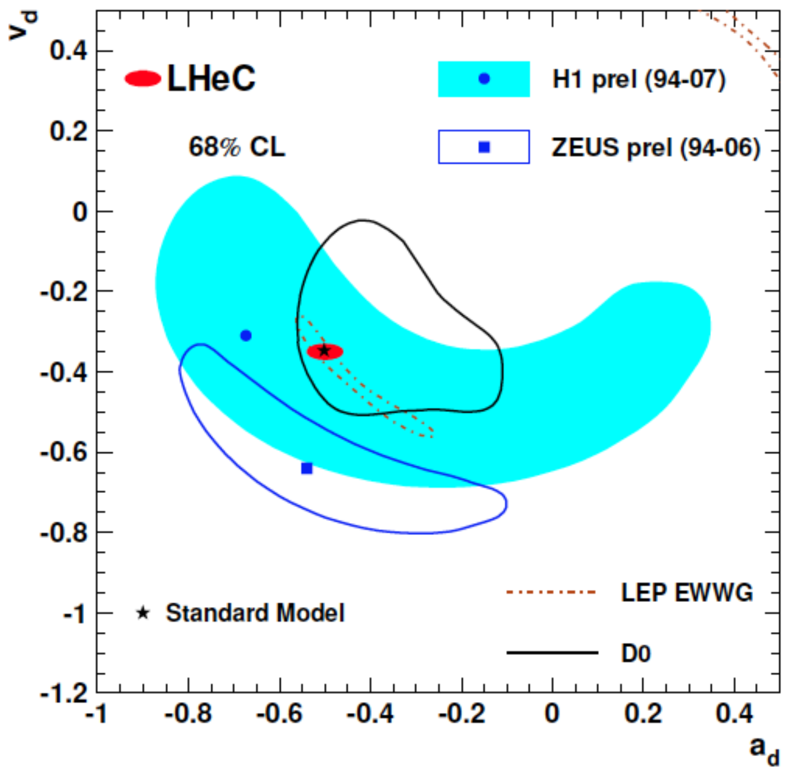
Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
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)

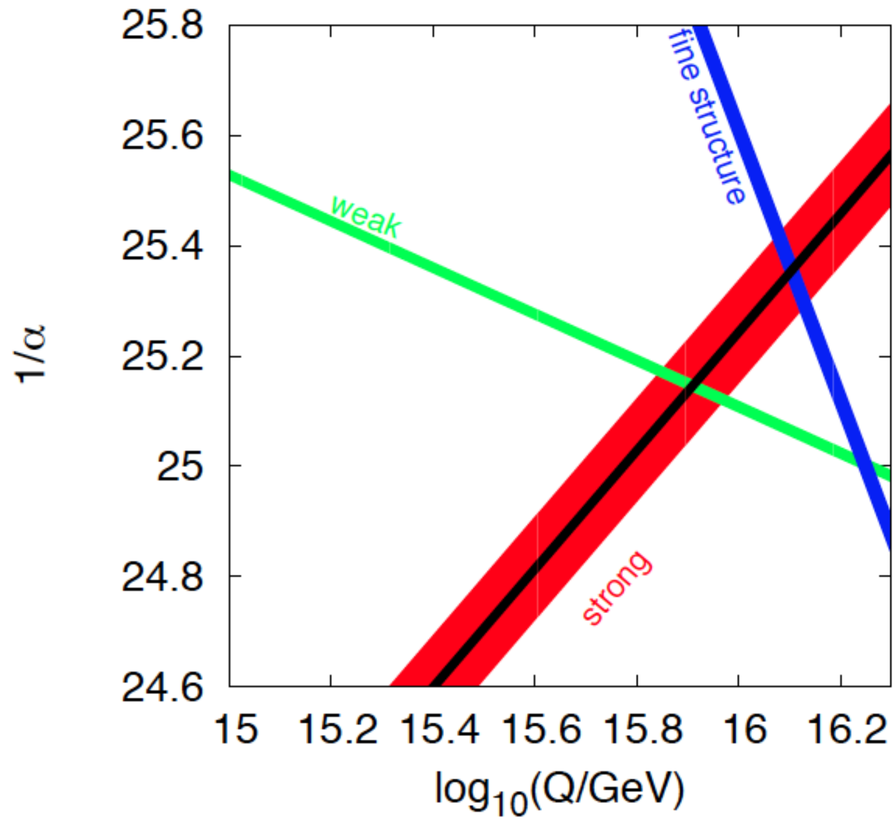
The theory of DIS has developed much further: J.Blümlein Prog.Part.Nucl.Phys. 69(2013)28
DIS is an important part of particle physics: G.Altarelli, 1303.2842, S.Forte, G.Watt 1301:6754



LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
RPV SUSY, LQ
Substructure ?
Large x
Gluon
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Nuclear
Structure
High Density Matter
QGPlasma
Q^2 / GeV^2
-four-momentum transfer squared
Bjorken x
co MK
LHeC

High Precision DIS



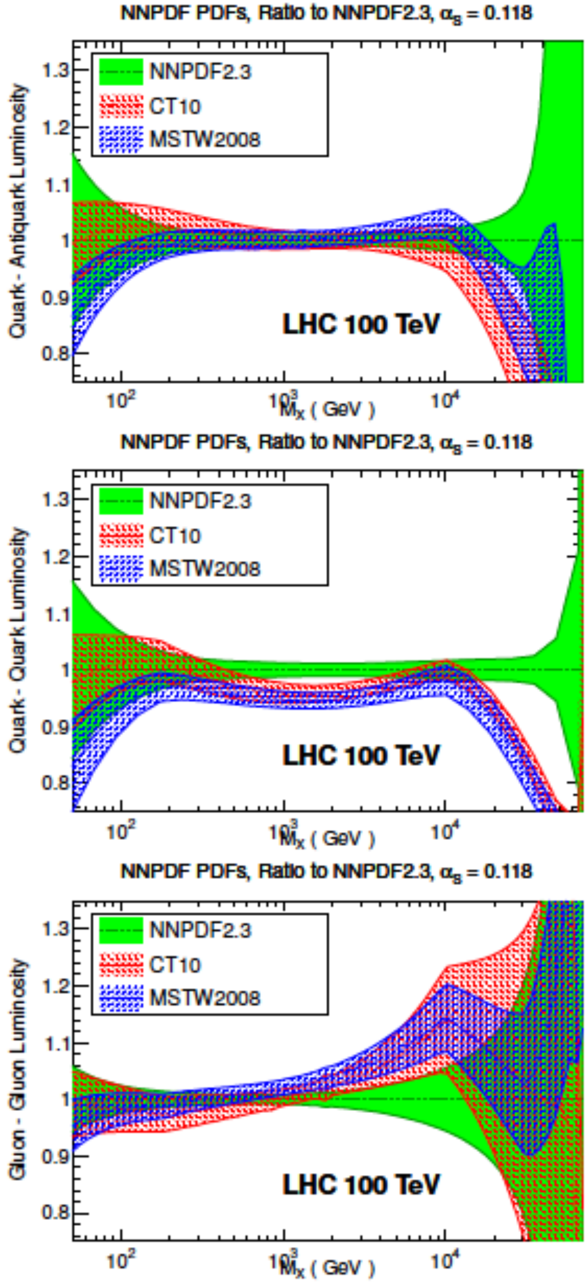


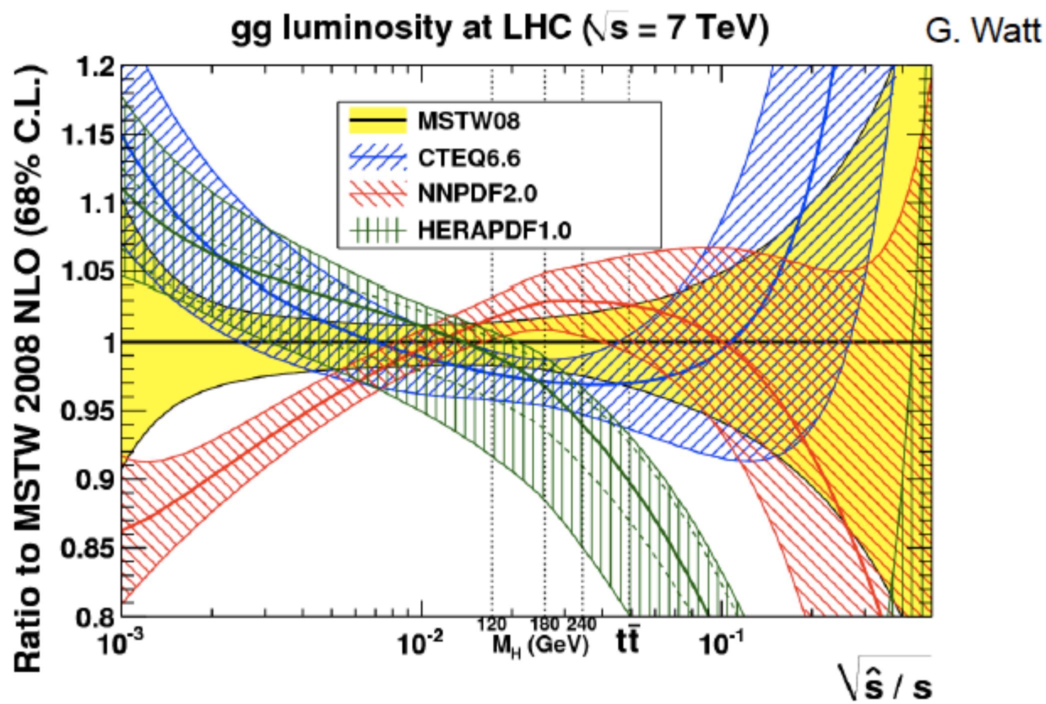
$Q^2 >> M_{Z,W}^2$, high luminosity, large acceptance
Unprecedented precision in NC and CC
Contact interactions probed to 50 TeV
Scale dependence of $\sin^2\theta$ left and right to Z

→ A renaissance of deep inelastic scattering ←

Solving a 30 year old puzzle:
α_s small in DIS or high with jets?
Per mille measurement accuracy
Testing QCD lattice calculations
Constraining GUT (CMSSM40.2.5)
Charm mass to 3MeV, N^3LO

Parton Distributions



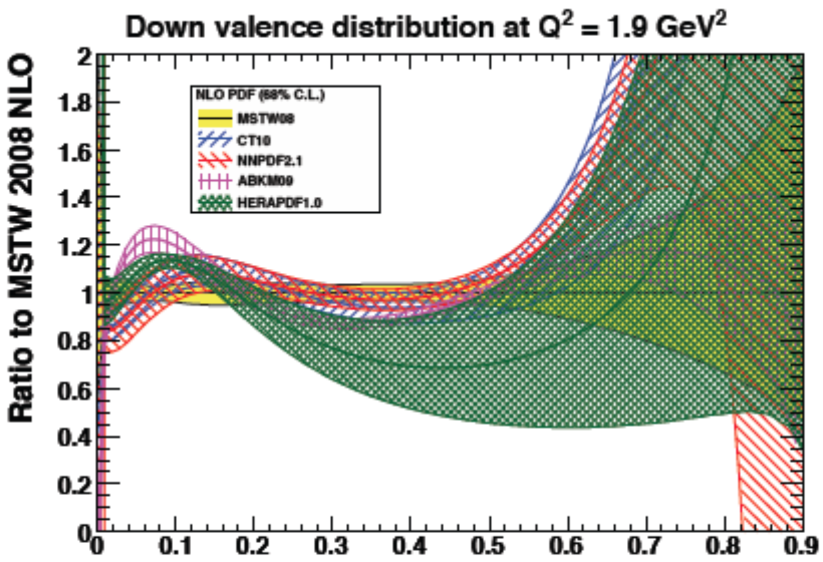


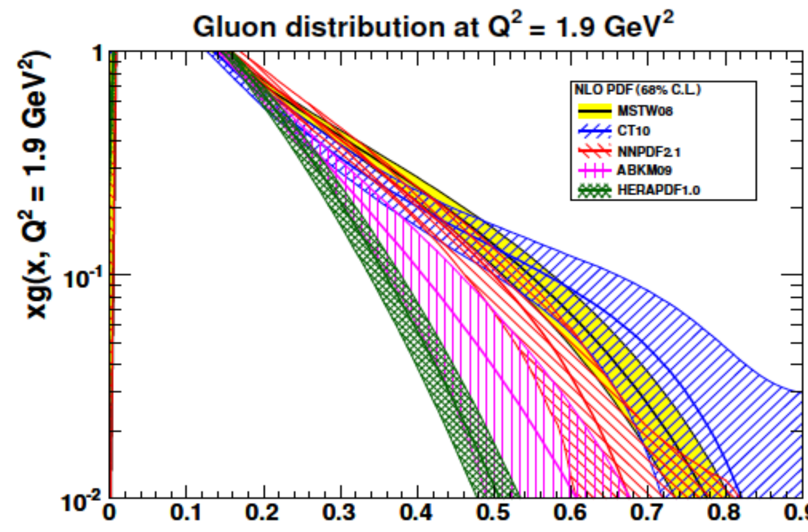
Need to know the PDFs much better than so far, for nucleon structure, q-g dynamics, Higgs, searches, future colliders FCC-hh, and for the development of QCD.

The LHC will provide further constraints too but cannot resolve them precisely (MCS).

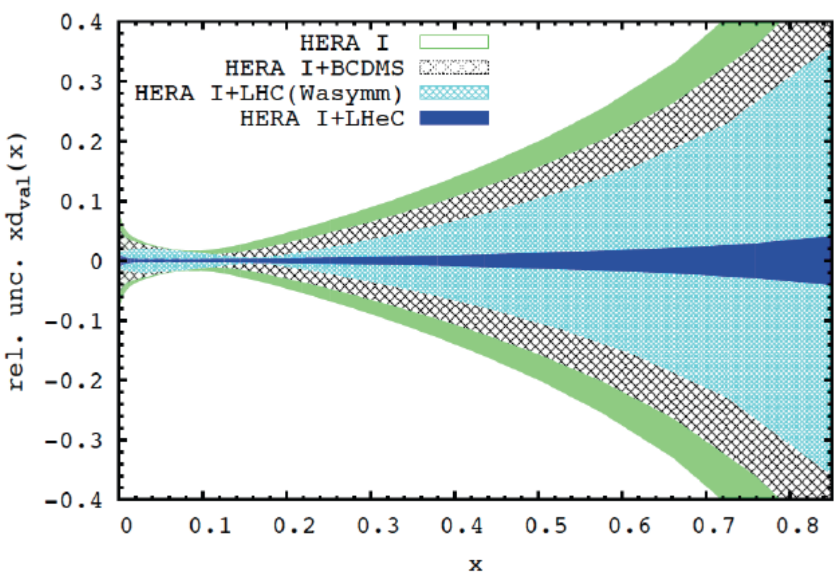
Snowmass13 QCD WG report J.Rojo

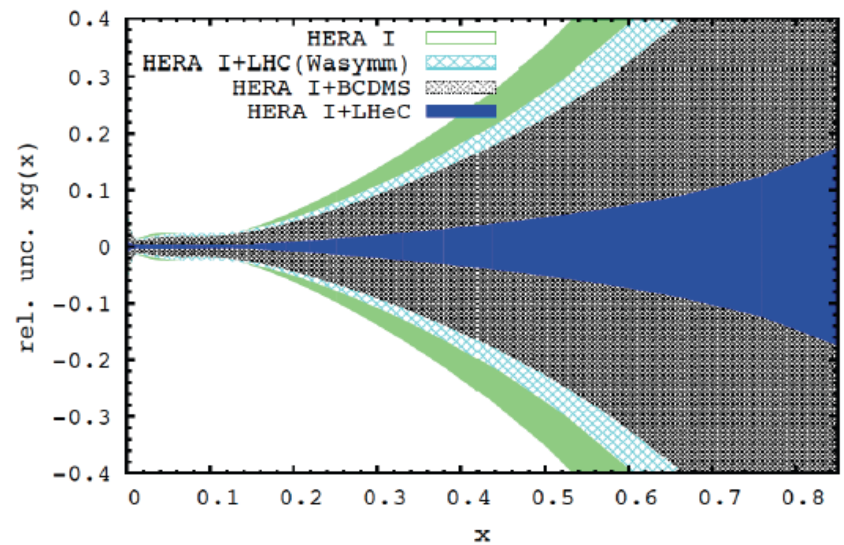
PDFs at Large x



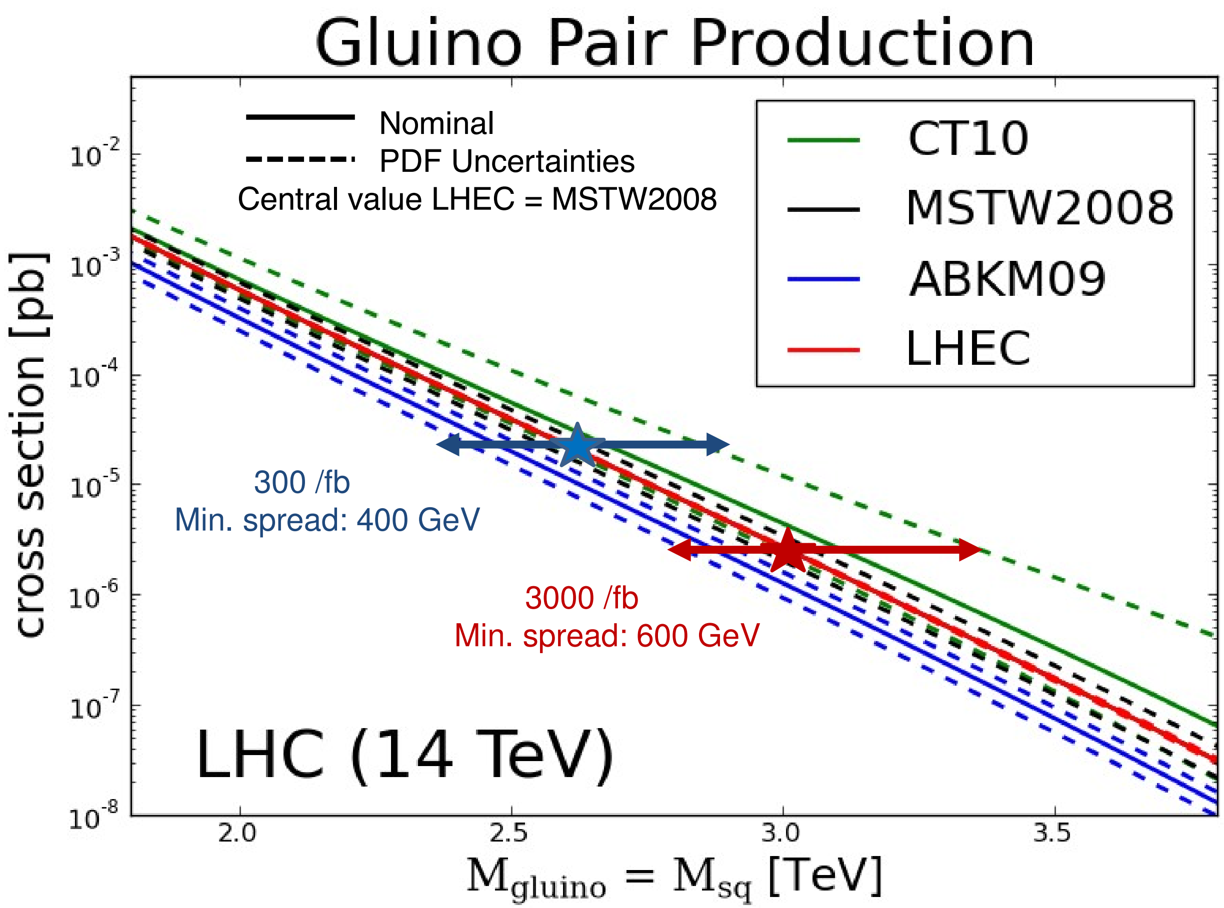


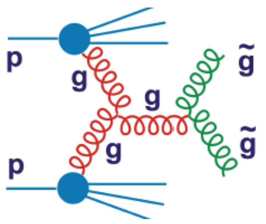
No higher twist corrections, free of nuclear uncertainties, high precision test of factorisation





HL-LHC - Searches

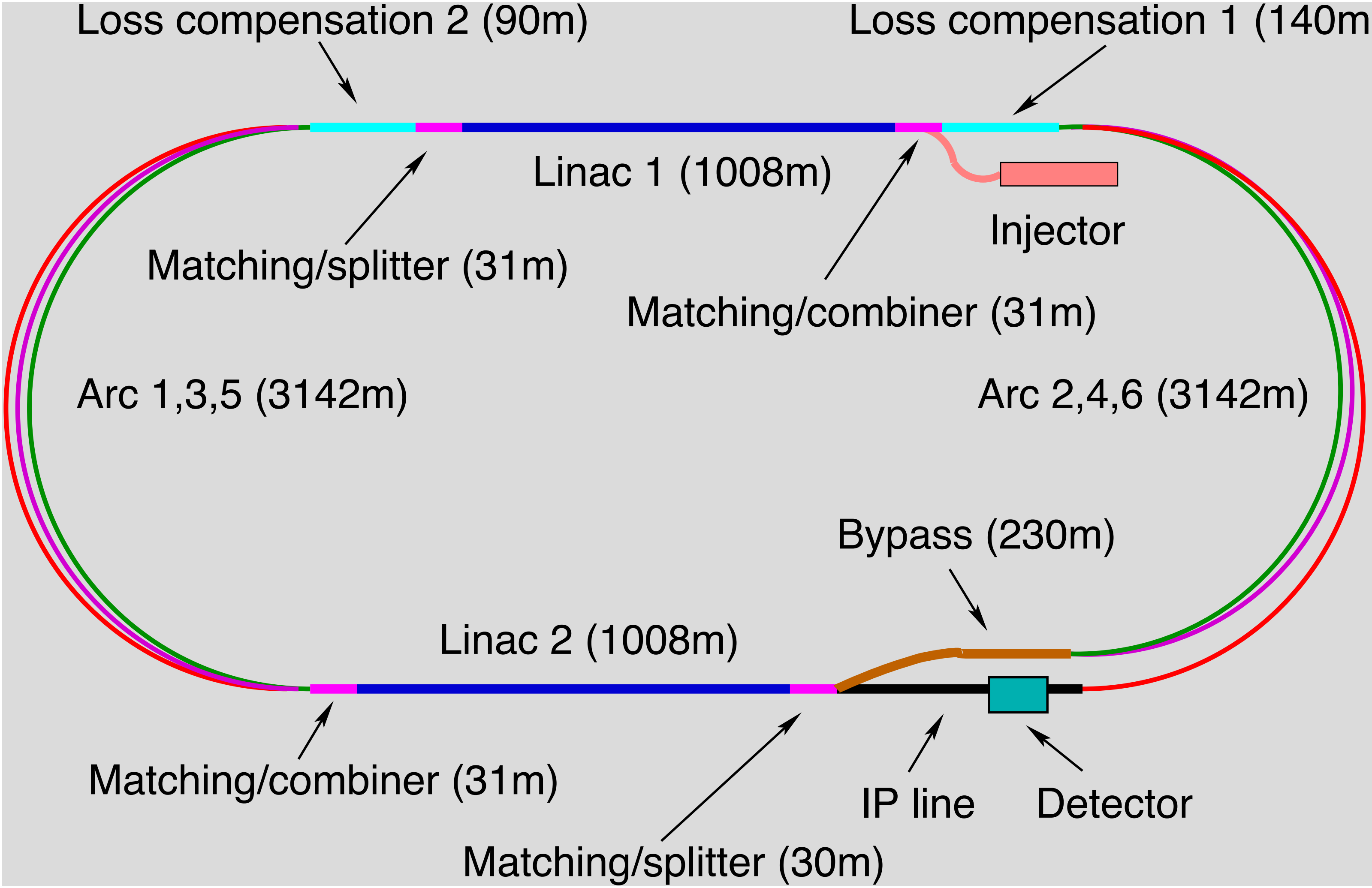




High precision PDFs are needed for the HL-LHC searches in order to probe into the range opened by the luminosity increase and to interprete possibly intriguing effects based on external information.

LHeC BSM poster at EPS13 M.D'Onofrio et al. see also arXiv:1211:5102 Relation LHeC-LHC
Simulated PDFs from LHeC are on LHAPDF (Partons from LHeC, MK, V.Radescu LHeC-Note-2013-002 PHY)

Electron accelerator - basic concept



JPhysG:39(2012)075001, arXiv:1206.2913 http://cern.ch/lhec

CDR: default design. 60 GeV. L=$10^{33}cm^{-2}s^{-1}$, P< 100 MW → ERL, synchronous ep/pp http://cern.ch/lhec

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], P.Adzic[74], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], B.Allanach[73], 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], J.Bracinik[06], 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], M.D'Onofrio[24], 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], R.Klees[75], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], M.Kraemer[75], 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], J.G.Milhano[76], 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], M.Schaefer[75], 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], D.South[17], 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], T.Ullrich[37], 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[69], 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]

Present (May 13) - LHeC Study group and CDR authors

Thanks to all above, to CERN and the IAC, and for the rush to this kickoff special thanks to Alessandra Valoni, Monica D'Onofrio, Uta Klein, Voica Radescu and a similar number of men

FCC-he   Context of These Days

Thursday: Overview Monica D'O

Yesterday: outbreak:

Introduction - Max K

LHeC – Oliver B

Testfacility – Alessandra V

Interaction Region – Rogelio T

Detector – Alessandro P

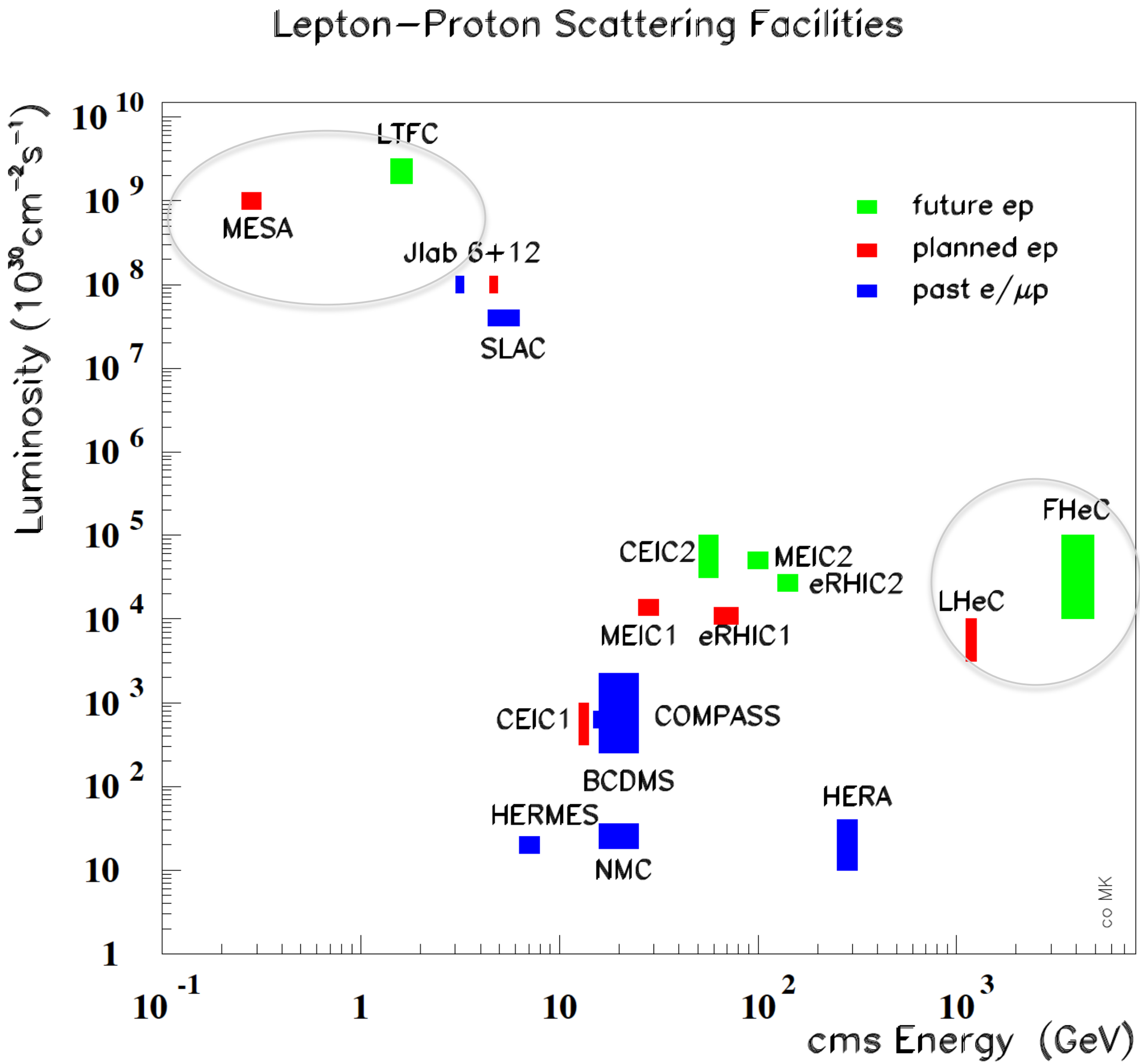
FCC-he - Frank Z

DIS - Max K

Heavy Ions – Brian C

Transition to pheno-session

Higgs – Uta K



CERN: LHC+FCC: the only realistic opportunity for energy frontier deep inelastic scattering
Huge step in energy (Q^2,1/x) and 3 orders of magnitude higher luminosity than HERA

Workshop at Chavannes 20/21.1.2014

My clarifying remark:

Any ep/eA project **cannot be a major CERN flagship project**
Essentially only one experiment,
cannot satisfy > 8000 users

not in competition with main projects (HL-LHC, HE-LHC, CLIC, FCC)
complementary (in time, resources)

International collaboration will be essential

- **for experiments (detectors, intersections)**
- **accelerator design (parameters, optimisation)**
- **preparing necessary technology (SC rf cavities, possibly ERL test facility)**

As in the tradition of CERN

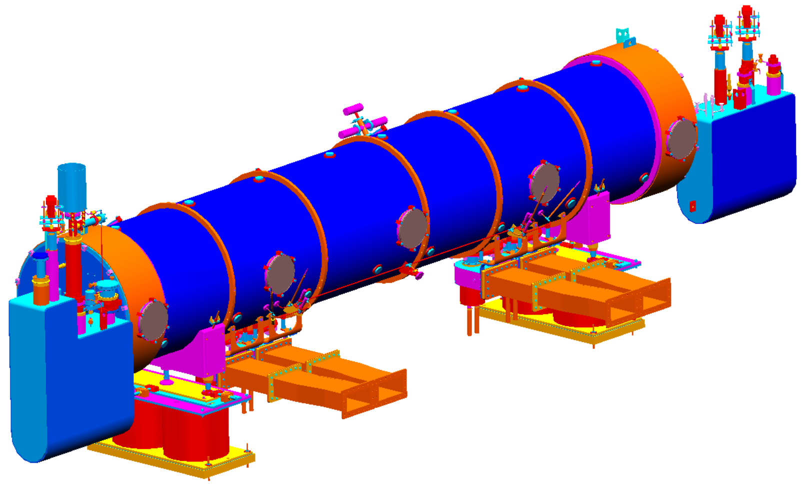
Herwig Schopper (Chair IAC) at Chavannes in the Panel Discussion with the CERN Directorate

Truth is stranger than fiction, but it is because fiction is obliged to stick to possibilities
Mark Twain, cited by Stan Brodsky at Chavannes

ERL Test-Facility

Purpose

Test facility for SCRF cavities and modules
- Test facility for multi-pass multiple cavity ERL
- Test facility for controlled SC magnet quench tests
- Injector studies: DC gun or SRF gun
- Study reliability issues, operational issues!
- Could be foreseen as the injector to LHeC ERL
- LHeC may serve as injector to FCC-ee
- Experimental Facility (electron and photon exp's)
- …



E. Daly, J. Henry, A. Hutton, J. Preble and R. Rimmer
JLab Accelerator Division 20-JAN-2014
4 cavity SNS style – design for 802 MHz

TARGET PARAMETER*	VALUE
Injection Energy [MeV]	5
Final Beam Energy [MeV]	900
Normalized emittance $\gamma\epsilon_{x,y}$ [μm]	50
Beam Current [mA]	10
Bunch Spacing [ns]	25 (50)
Passes	3

A.Valloni

First endorsed step: 802 MHz Cavity-cryo module in collaboration with partners.

Important goal: Design of LTF: End of 2015 (open to wide international collaboration)

Collaborations and International Activities:

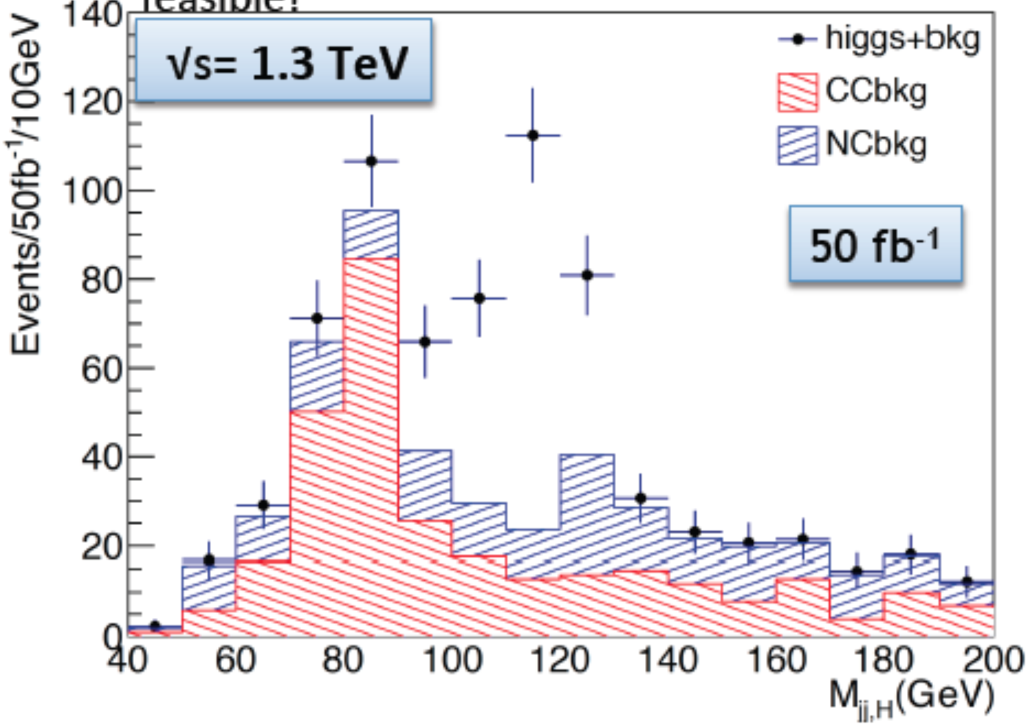
- -MESA @ University Mainz
  - ➔ SC RF cavity and cryostat prototypes
  - ➔ includes collaboration with JLab
- -JLab ERL (‘LHeC like’, injector, halo, op. experience)
- -BNL SC RF activities & ERL
  (HOM, eRHIC, applications, frequency choice,
  cost and complexity)
- -Cornell ERL (frequency choice, high Q_0, errors, HOM)
- -ALICE ERL and UK (operational experience)

O.Bruening

H→$b\bar{b}$ results updated

[after Higgs discovery M_H=125 GeV, E_p=7 TeV]

- Case study for electron beam energy of 60 GeV using same analysis strategy
  - luminosity values of 50 fb^{-1} → with high luminosity LHeC 100 fb^{-1}/year would be feasible!



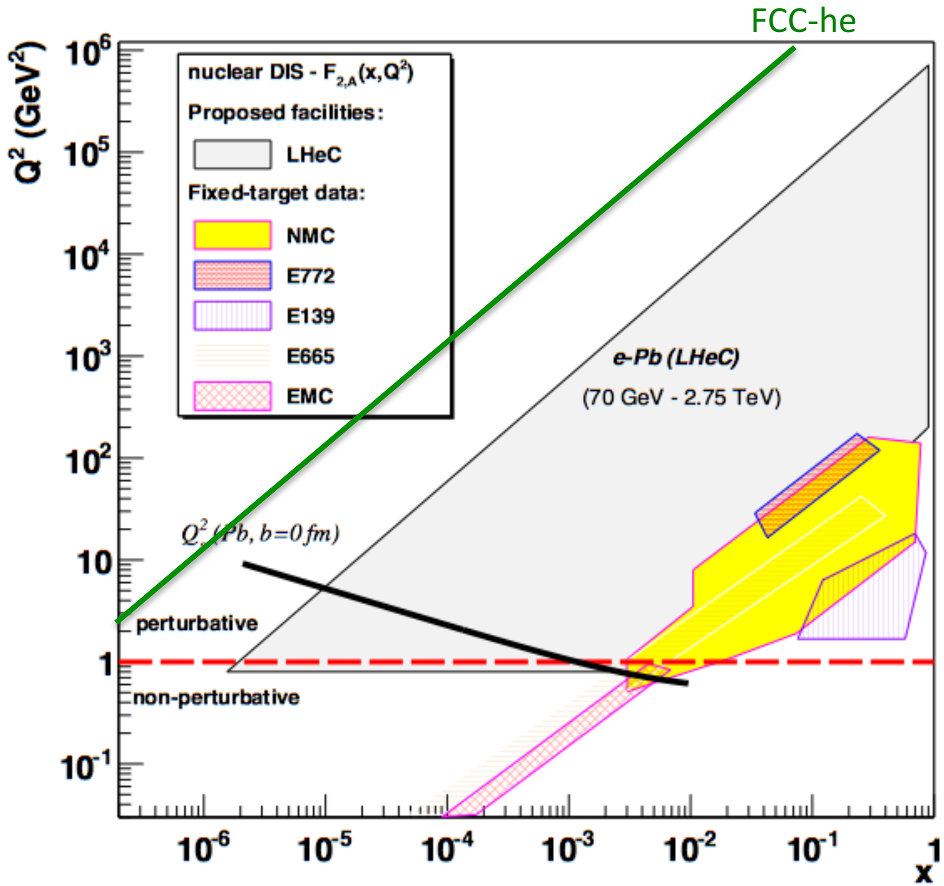
Masahiro Tanaka, BSc thesis, Tokyo Tech 2014

M_H selection [100-130 GeV]	E_e = 60 GeV ($50\ fb^{-1}$, P=0)
H → bb signal	175
S/N	1.9
S/√N	18.1

- Electron energy recovery LINAC with **high electron polarisation of 80% and $10^{34}\ cm^{-2}\ s^{-1}$** → enhancement by factor 20*1.8 feasible, i.e. around 6300 Higgs candidates for E_e=60 GeV allowing to measure Hbb coupling with ~ **0.5 % - 1%** statistical precision.

- Very promising estimate of S/N → more sophisticated analysis and detector optimisations, may enhance those prospects further

LHeC-FCC-he: Electron Ion Collider



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…

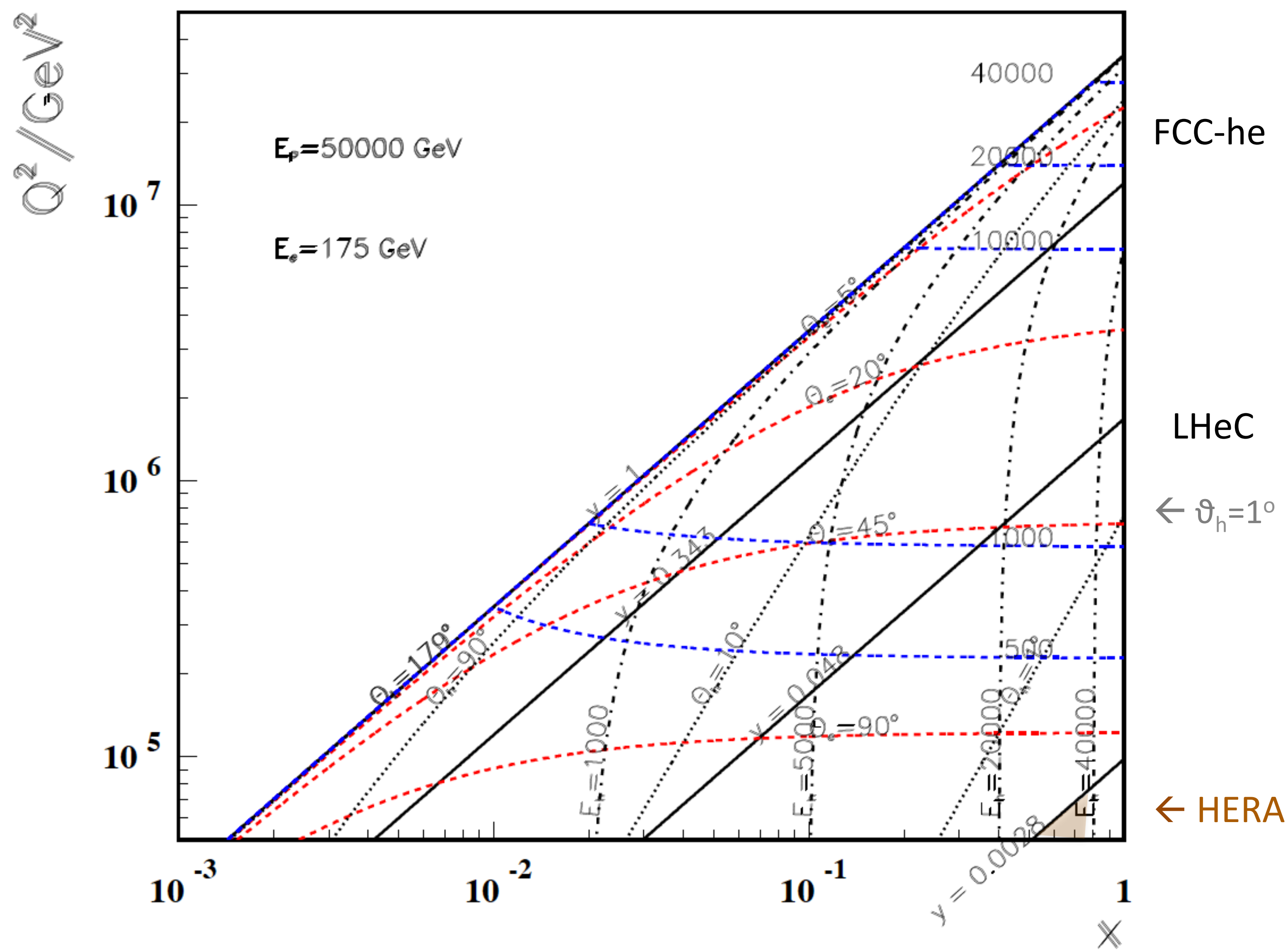
- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

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

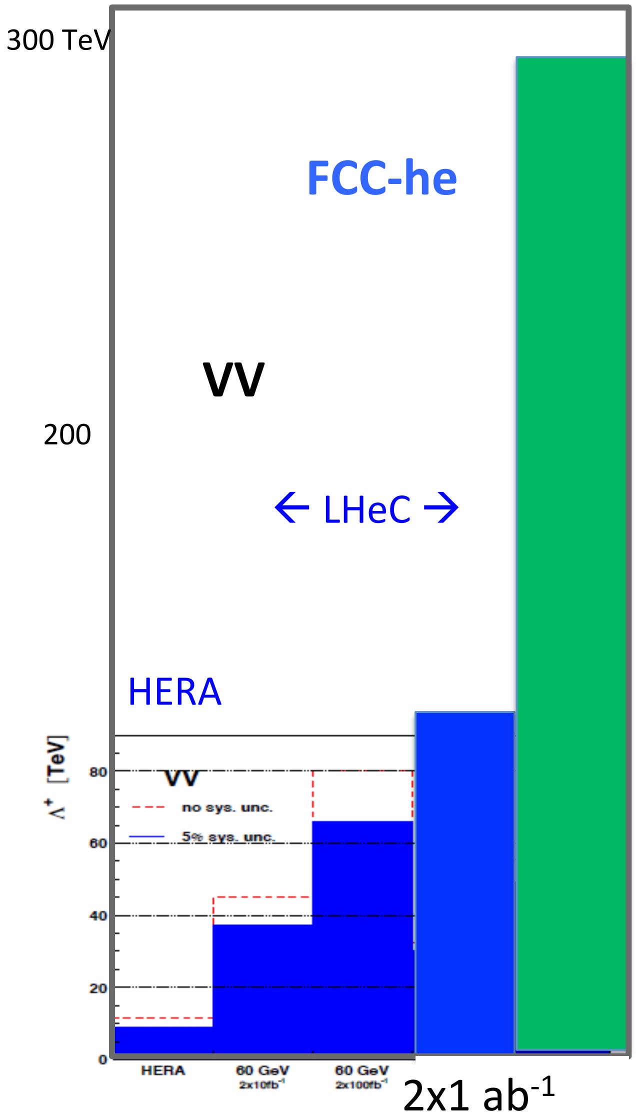
Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

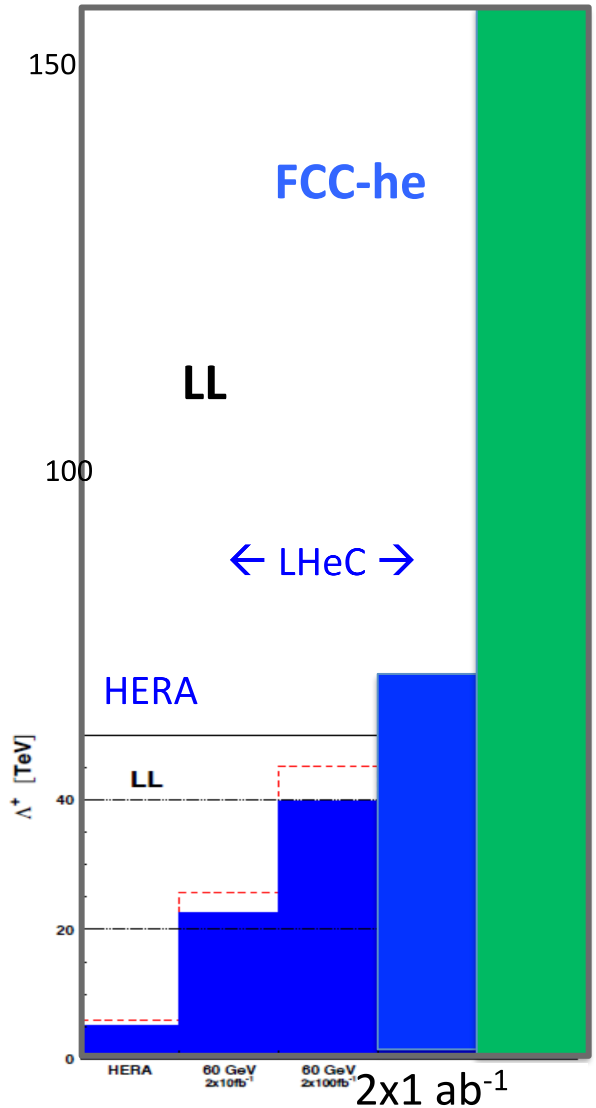
High Q^2

Rutherford backscattering of dozens of TeV e- energy



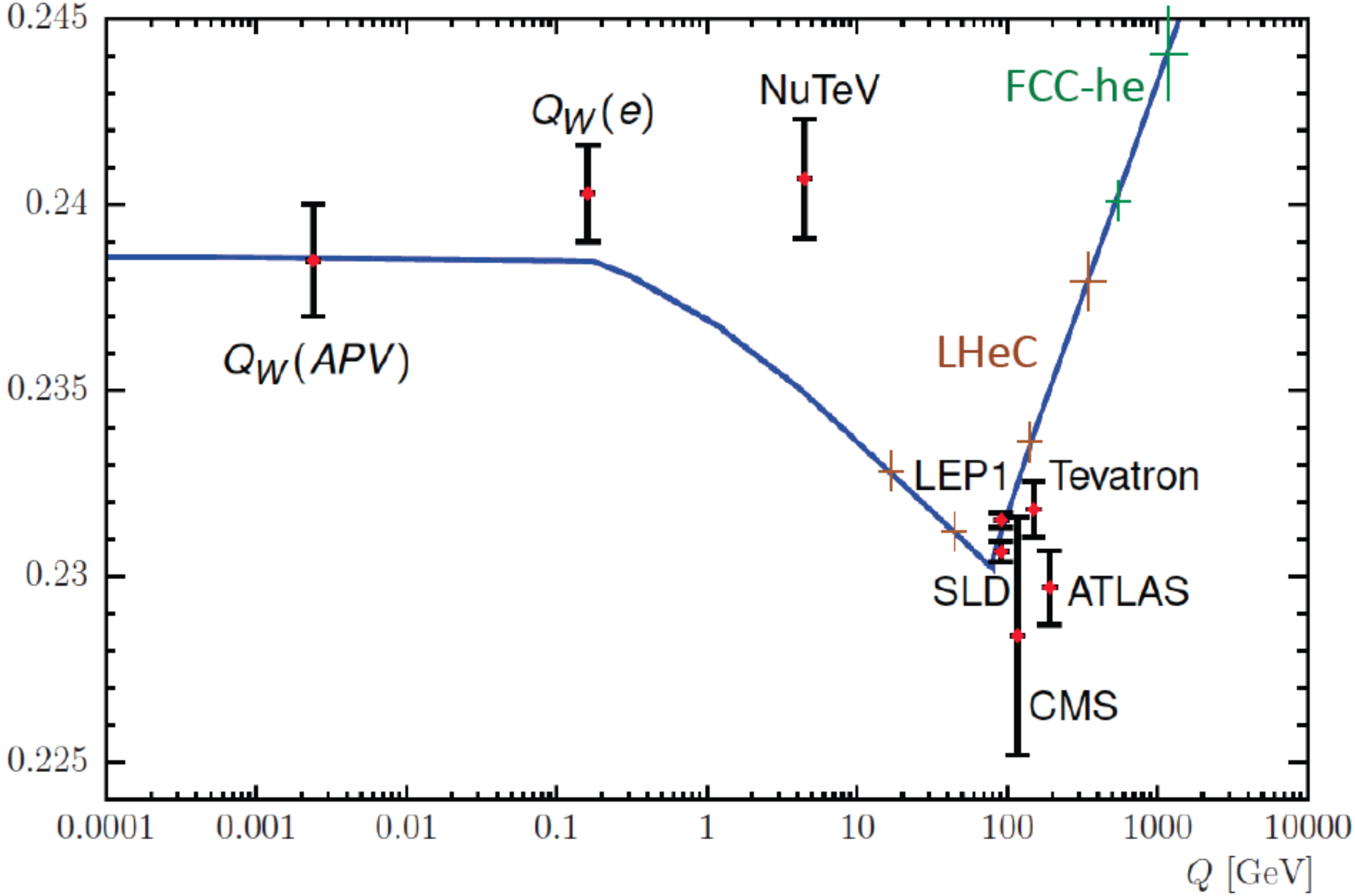
Reach for CI (eeqq) at FCC-he





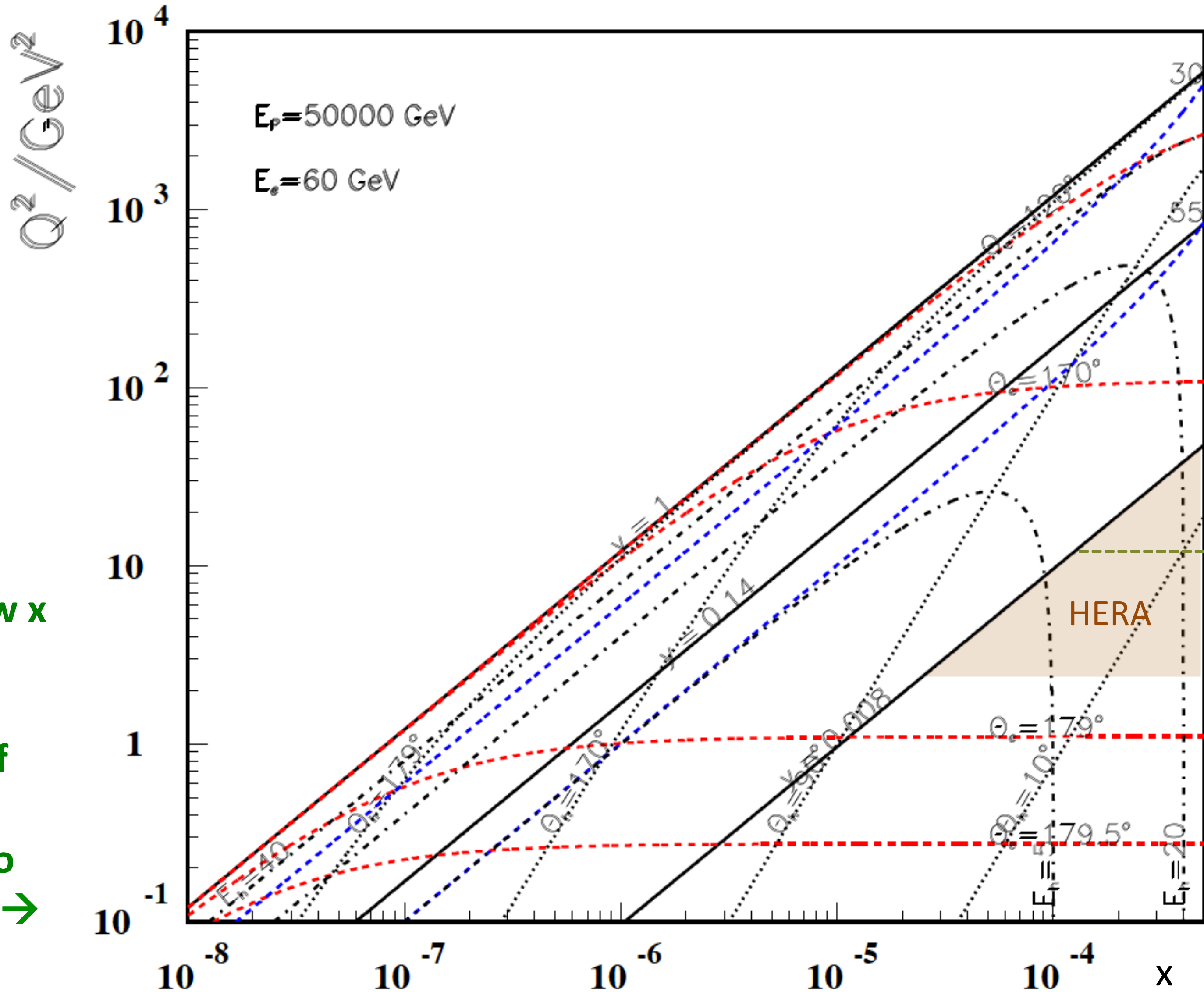
- Very preliminary scaling from LHeC
- Reach about **O(100) TeV**, expected to be competitive with FHC

Scale dependence of $\sin^2\theta_W$



Preliminary illustration

Low x



FHeC

LHeC

← 179° @ 180 GeV .. very low x requires not the maximum of E_e

Very low x reaches direct range of UHE neutrino physics →

For x < 10^{-3} no (average) energy deposition exceeding the electron beam energy

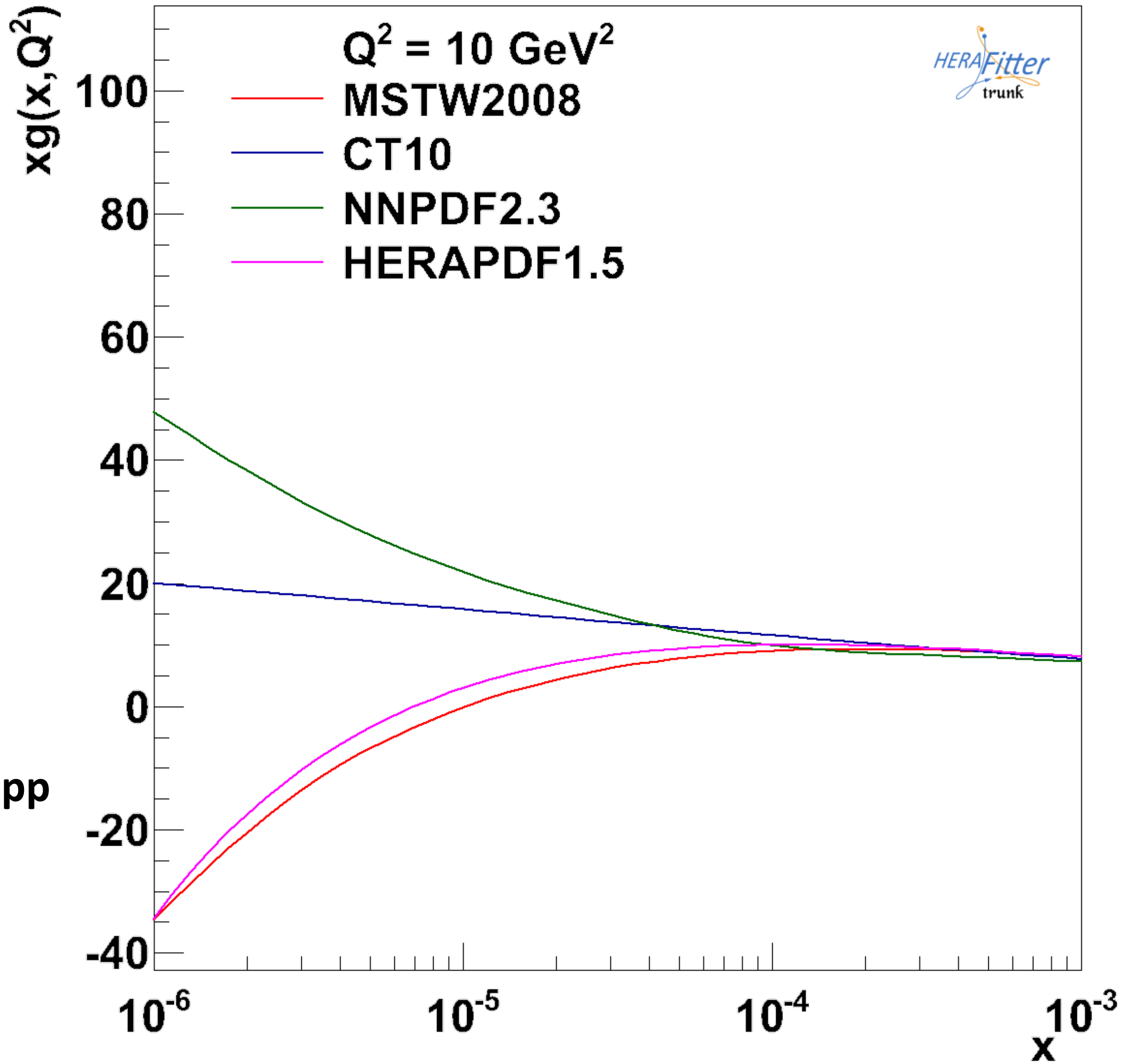
xg at low x

No clue about xg for $x < 10^{-4}$

Evolution law may not be DGLAP

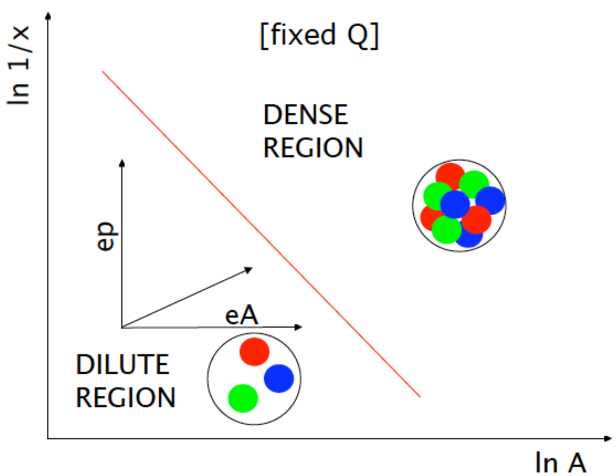
Affects FCC-pp rates because $x=M/\sqrt{s}\exp(\pm y)$

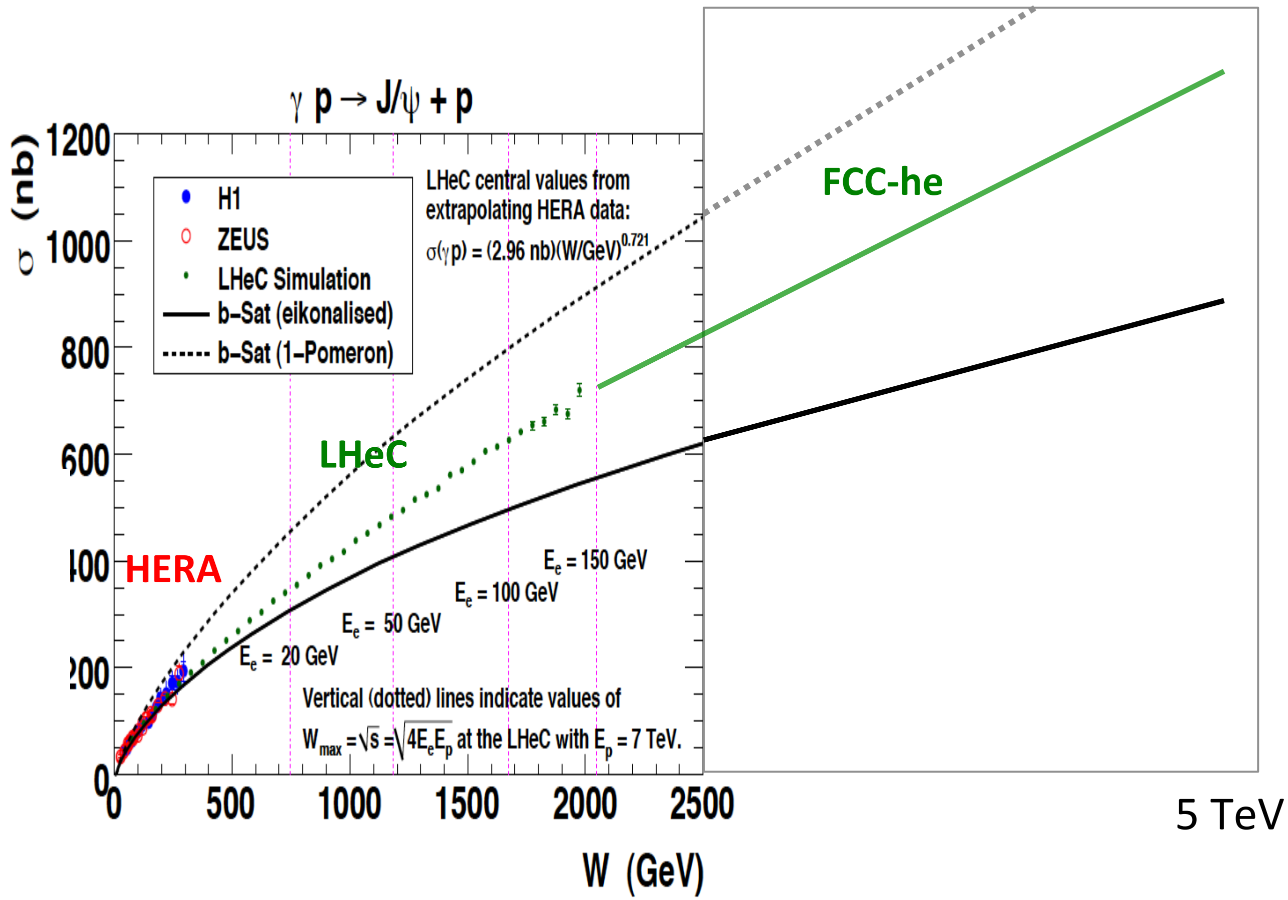
note x(Higgs) at FCC-pp for y=0 is 10^{-3} ..



Vector Mesons

Precision Measurements of vector mesons and diffraction to very high $M_X \sim xg^2$





Higher energy (1/x), higher A

W = √ (ys) extends to ~ 5 TeV at FCC-he

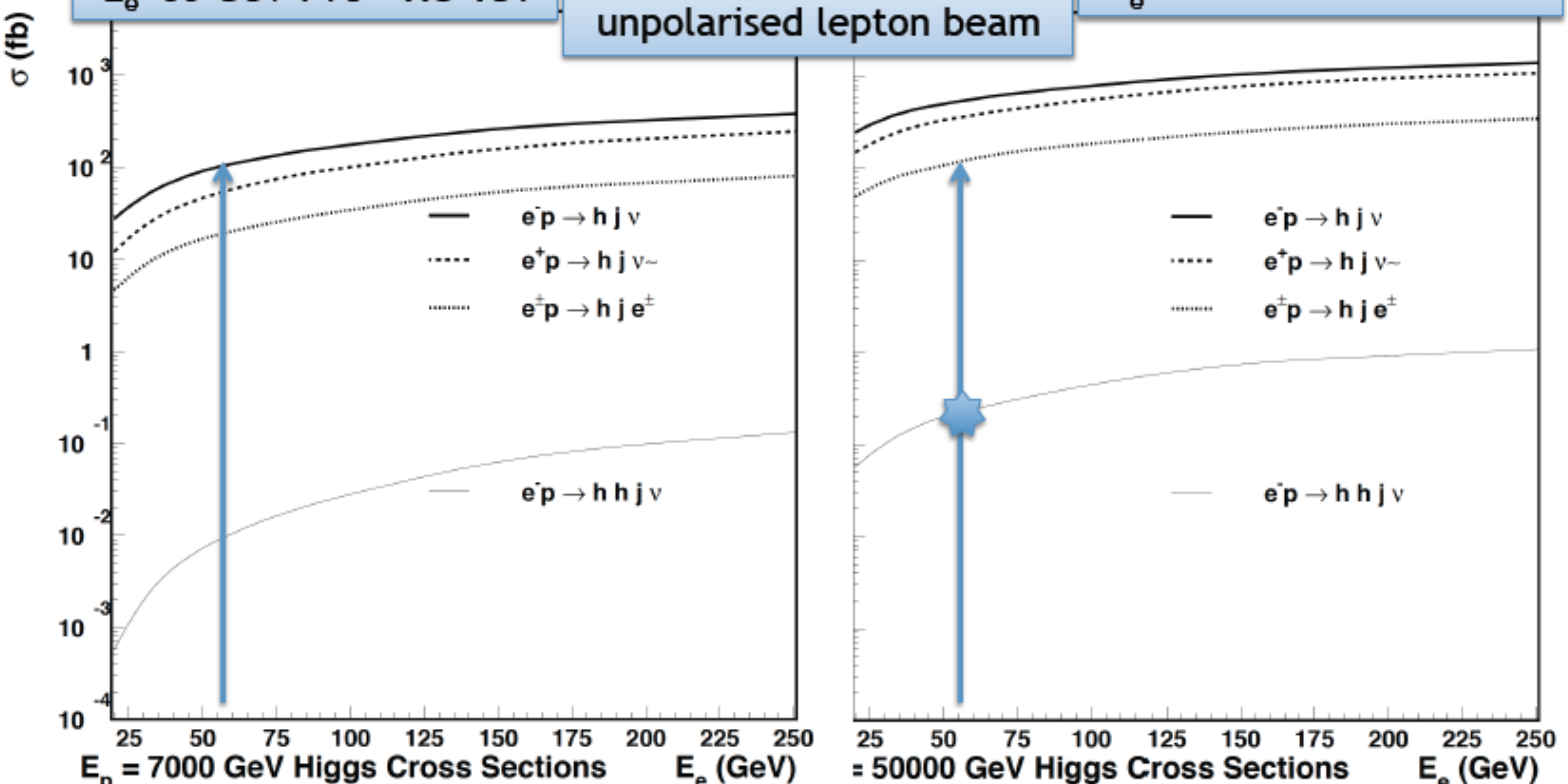
Black body limit, interference pattern of σ

Total Higgs cross sections

E_e=60 GeV : $\sqrt{s}$= 1.3 TeV

M_h=125 GeV
unpolarised lepton beam

E_e=60 GeV : $\sqrt{s}$=3.5 TeV



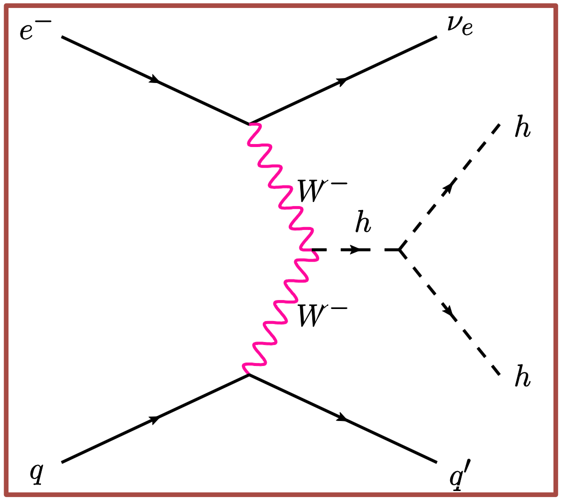
7 TeV LHC protons

50 TeV FCC protons

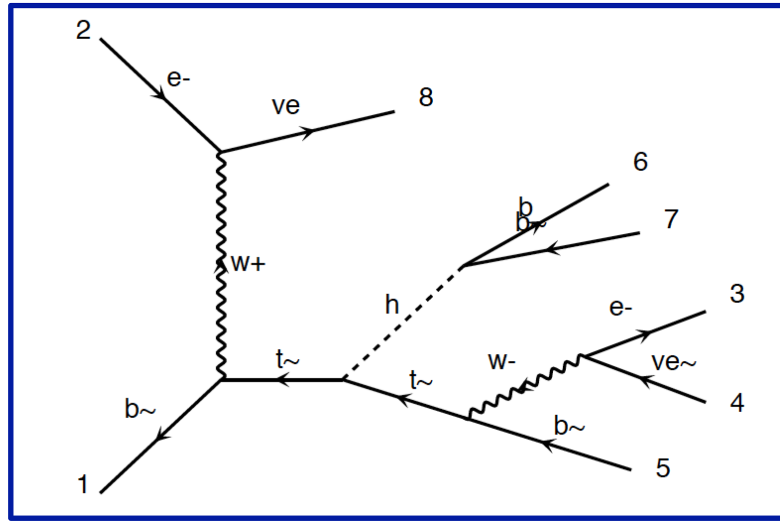
and

electrons from a 60 GeV energy recovery LINAC

HH and tHt in ep



New
Tentative
Studies



FCC-he unpolarised
Cross section at 3.5 TeV:

total : 0.7 fb
fiducial : 0.2 fb
using pt(b,j)>20 GeV
ΔR(j.b)>0.4
η(j) <5
η(b) < 3

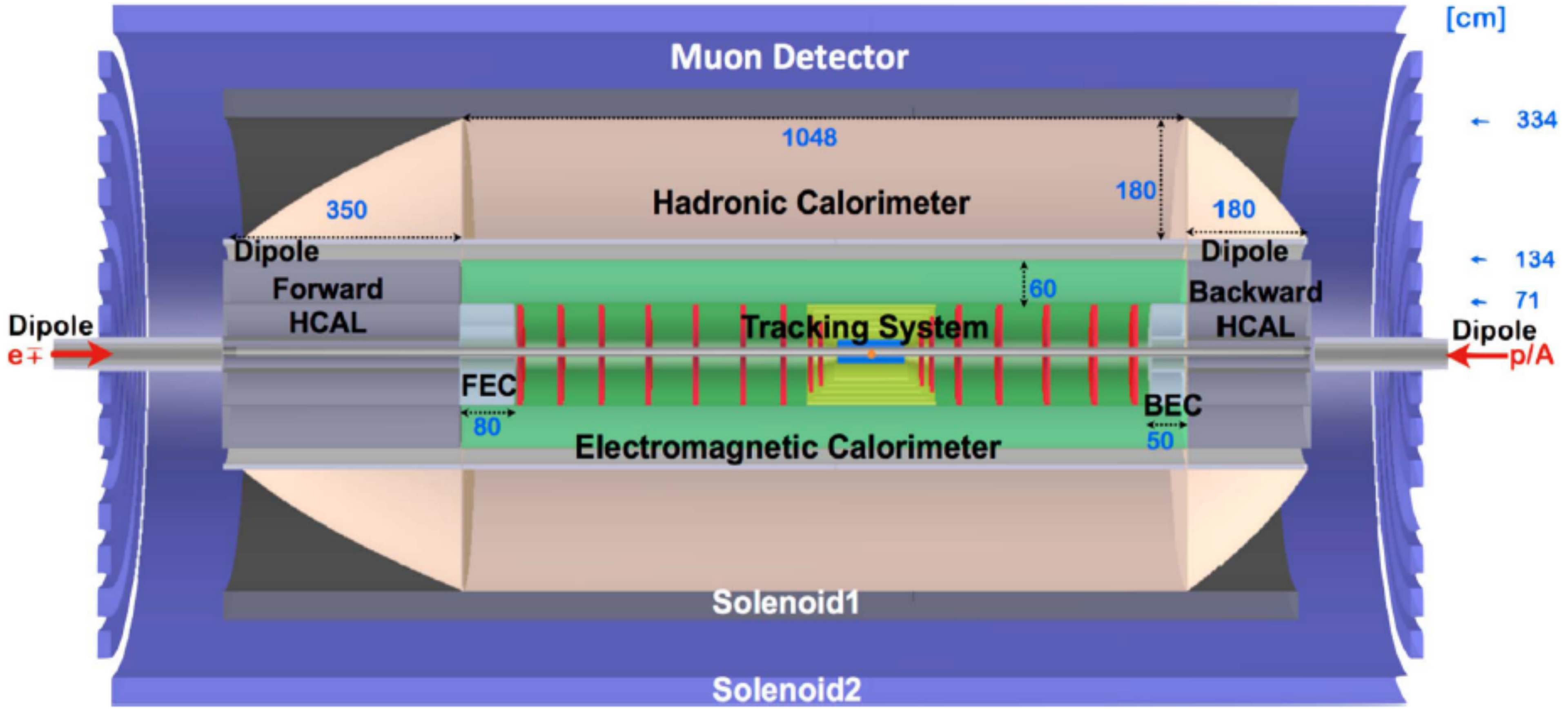
Processes	E_e (GeV)	σ(fb)	σ_{eff}(fb)
$e^-p \to \nu_e hhj, h \to b\bar{b}$	60	0.04	0.01
	120	0.10	0.024
	150	0.14	0.034

Polarisation, max lumi, tuning cuts, bb and WW decays may provide O(10%) precision - tentative

Require time for reliable result (detector, analysis, backgrounds..)

Bruce Mellado, Uta Klein, Masahiro Khuze et al

FCC-he Detector (B) – 0.1



Crab cavities for p instead of dipole magnet for e bend to ensure head on collisions
1000 H → μμ may call for better muon momentum measurement
H→ HH → 4b (and large/low x) call for large acceptance and optimum hadr. E resolution
Detector for FCC scales by about ln(50/7) ~2 in fwd, and ~1.3 in bwd direction
Full simulation of LHeC and FCC-he detectors vital for H and H-HH analysis

P.Kostka et al.

DRAFT - Structure of further work

Physics	Detector	Testfacility	Accelerator	Infrastructure
Higgs Top LHC-LHeC eA Low x Theory	Simulation Design Taggers Collaboration	Cavcryo module Magnets Source Optics Operation Coordination	Optimisation Optics IR Q1,2 Pipe+Vacuum Positrons Deuterons	Installation CE Resources Conferences Outreach Relations

Last December, CERN called a **coordination group** with a 4 years mandate:

The group has the task to coordinate the study of the scientific potential and possible technical realisation of an ep/eA collider and the associated detectors at CERN, with the LHC and the FCC, over the next four years. It also should coordinate the design of an ERL test facility at CERN as part of the preparations for a larger energy electron accelerator employing ERL techniques.

The group will cooperate with CERN and an International Advisory Committee, chaired by the emeritus DG of CERN, Professor Herwig Schopper, who also advises the CERN directorate. The Coordination Group is asked to represent the ep/eA collider development towards CERN, its committees and the international community. The currently tentative composition is listed *left*. CERN has asked Max Klein to chair and Oliver Brüning to co-chair this activity

Important Milestones for the first FCC Phase

2014: Higgs, … Physics → Validate Configuration of LHeC for 10^{34}, Footprint

- Front-end simulation of the ERL
- Detailed p beam dynamics studies with complete integration into HL LHC
- Detector-IR integration for 10^{34}
- Detector Simulation for more realistic physics simulation studies
- Collaboration agreements, for RF: 802 MHz Cavity-Cryo Module, warm magnets..

2015: March: FCC Workshop

- ‘he’ Physics in the ‘hh’ (LHC/FCC) and ‘ee’ (FCC, LC) context
- ERL integration with HL-LHC and FCC-hh
- ERL Testfacility as FCC-ee injector
- Detector design and IR (LR and RR)

Design of the Testfacility, including its applications

Further development of International Detector Collaboration …

Your input and collaboration is vital – please contact us (Physics, Detector, Accelerator)

Draft as discussed in yesterdays breakout session and to be further developed. Demanding program

Summary

LHeC and FCC-he will be the worlds cleanest, high resolution microscopes.

They have a huge potential for discovery (QCD, BSM, Higgs), for novel phenomena (non-standard partons, neutron, nuclear, photon, pomeron structure..) and for measurements of unprecedented reach and precision (couplings..)

Only the LHeC and subsequently the FCC-he will be able to completely resolve the partonic structure of the nucleon and map xg for 6 orders of magnitude in x. This eventually will break DGLAP and affect the physics of the FCC-hh.

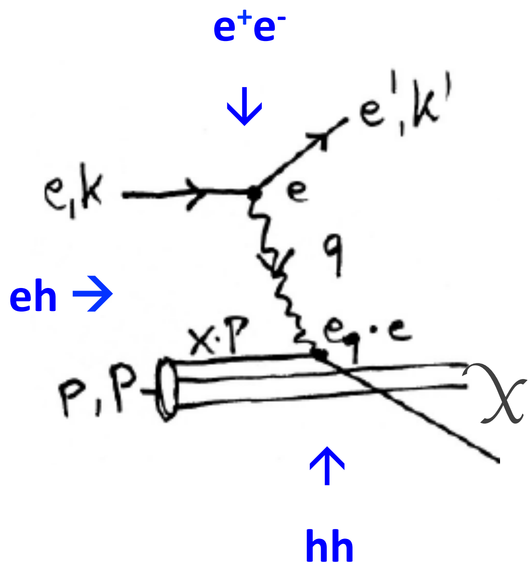
TeV energy, high luminosity, polarised ep scattering has a unique potential for precision Higgs physics (200-1000 fb) and to access rare H processes.

By its size and ambition, ep is not in competition with the HEP flagship projects, but compliments these, as is evident from the PDF-H and -BSM relation.

Understanding the multi-TeV energy scale and the development of DIS require a TeV energy he-collider, for which the LHC and FCC at CERN provide unique bases.

For the electron beam, there are two options under consideration, and for both the ERL is vital to develop. A crucial next step is related to the ERL testfacility at CERN which has a multitude of possible applications of international interest.

Deep Inelastic Scattering [eh → e'X]



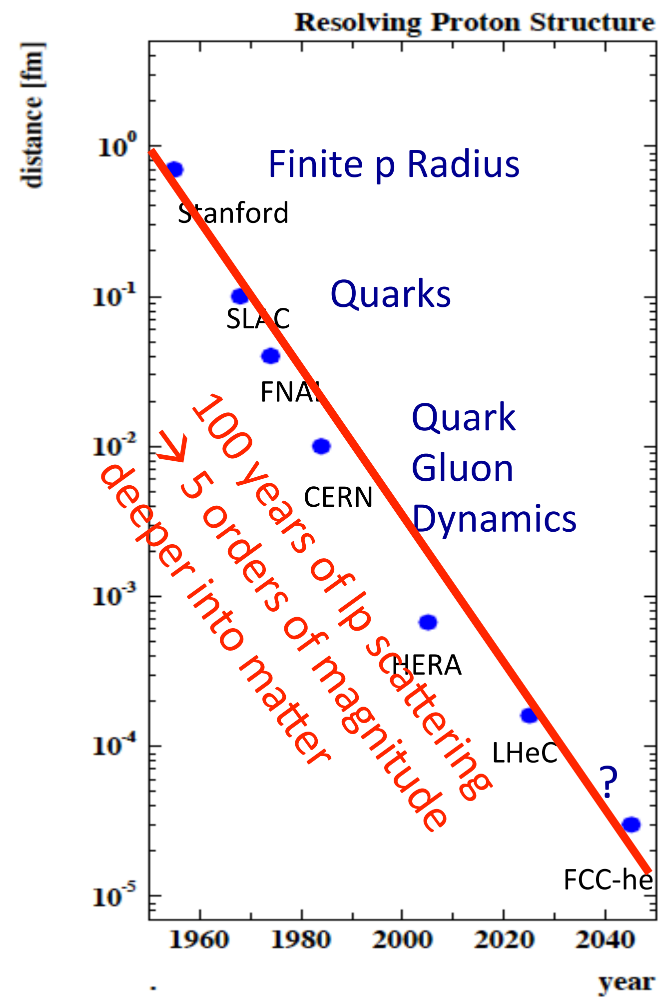
$$x = \frac{Q^2}{sy}$$

$$Q^2 = -(k-k')^2$$

$$y_{lab} = 1 - \frac{E_e'}{E_e}$$

$$s = 4E_eE_p$$

HERA-LHeC-FCC-eh: finest microscopes with resolution varying like $1/\sqrt{Q^2}$

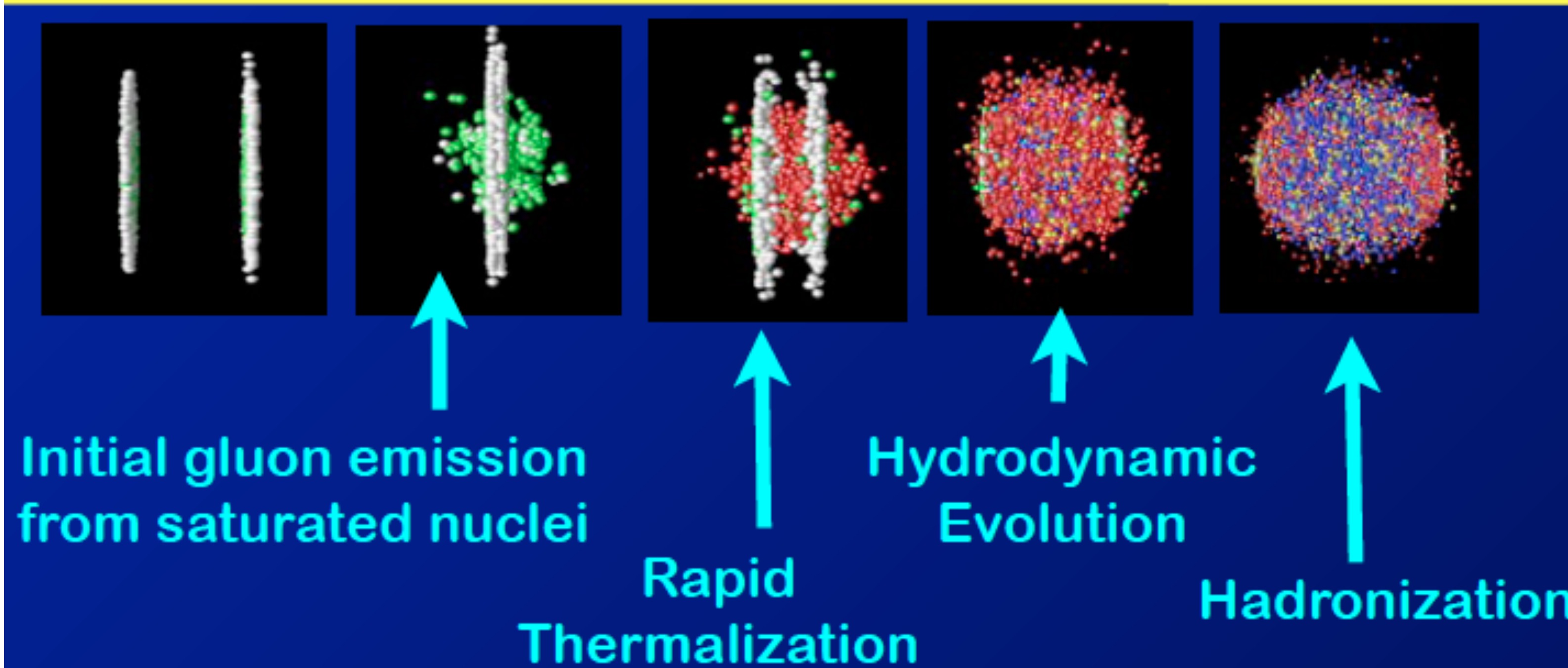


electromagnetic radius

- Parton momentum fixed by electron kinematics
- Incl. NC (γ,Z) and CC ($W^{\pm}$) independent of hadronisation
- Rigorous theory: Operator expansion (lightcone)
- Parton momentum distributions to be measured in DIS
- Collider- HERA: $y_h = y_e$: Redundant kinematics

backup

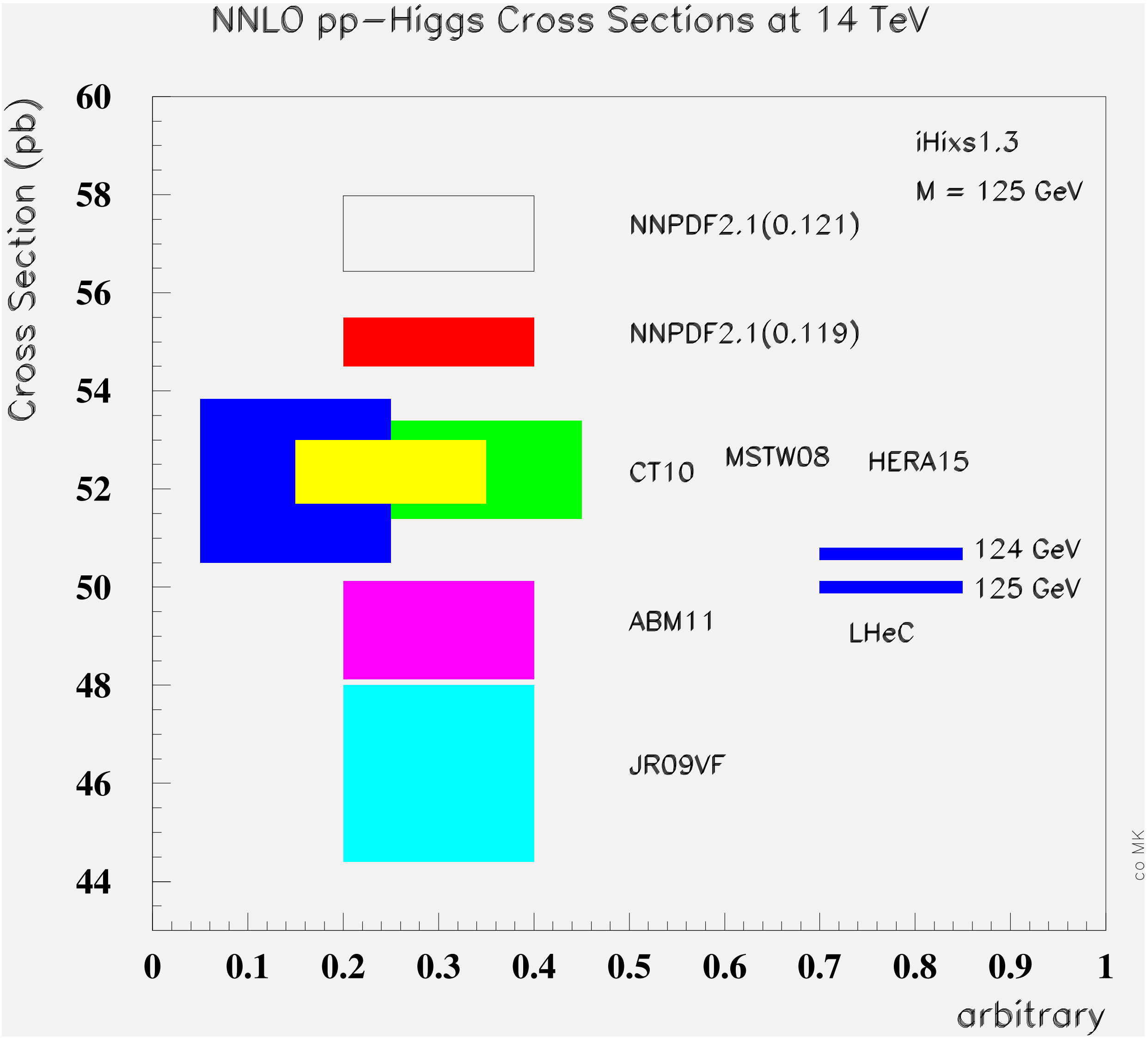
Heavy ion "concordance model"



- Initial particle production from strong gluon fields (saturated) in the incident nuclei.
- Created particles rapidly ($\tau < 0.5$-1 fm/c!) thermalize into a strongly coupled QGP.
- QGP evolves hydrodynamically with an η/s ratio close to conjectured lower bound.

Brian Cole

Reducing the thy uncertainties in pp → H



Exp uncertainty of predicted H cross section is 0.25% (sys+sta), using LHeC only.

Leads to H mass sensitivity.

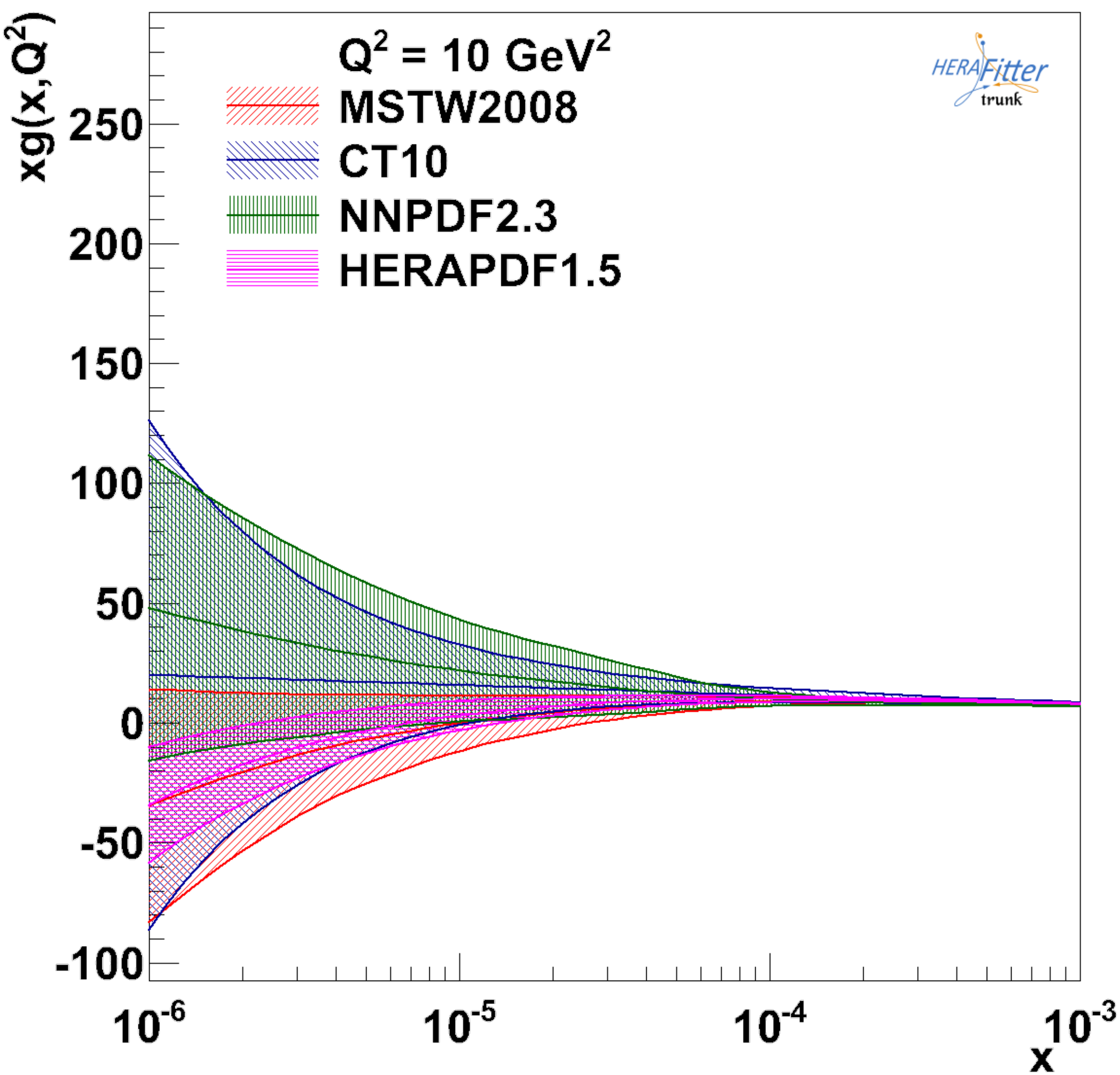
Strong coupling underlying parameter (0.005 → 10%). LHeC: 0.0002 !

Needs N^3LO

HQ treatment important ...

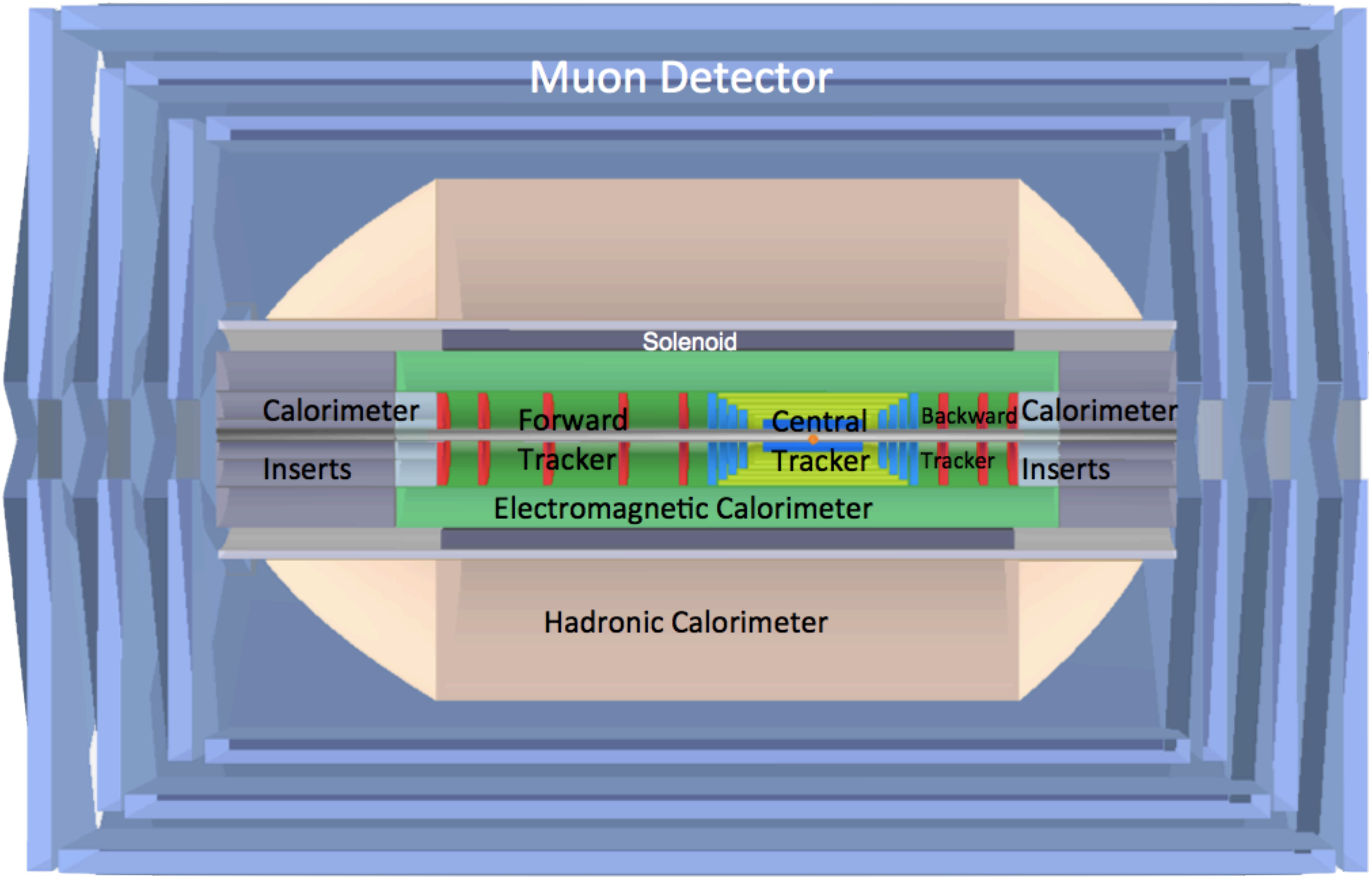
O.Brüning and M.Klein arXiv:1305.2090, MPLA 2013

xg at low x



Q^2 = 10 GeV^2
MSTW2008
CT10
NNPDF2.3
HERAPDF1.5
HERAFitter
trunk
xg(x,Q^2)
250
200
150
100
50
0
-50
-100
10^{-6}
10^{-5}
10^{-4}
10^{-3}
x

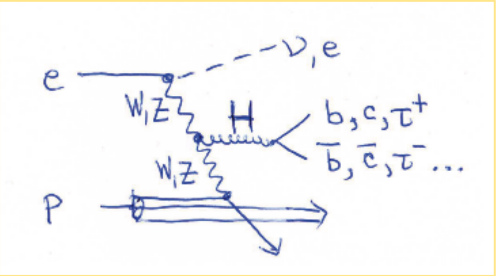
LHeC Detector Overview



Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

From Higgs facility (LHeC) to Higgs 'factory' (FCC-he)



Higgs in e^-p		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N^H_{CC}	N^H_{NC}	N^H_{CC}
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	270 000
$H \to \mu\mu$	0.00022	50	5	1 000
$H \to 4l$	0.00013	30	3	550
$H \to 2l2\nu$	0.0106	2 080	250	45 000
$H \to gg$	0.086	16 850	2 050	365 000
$H \to WW$	0.215	42 100	5 150	915 000
$H \to ZZ$	0.0264	5 200	600	110 000
$H \to \gamma\gamma$	0.00228	450	60	10 000
$H \to Z\gamma$	0.00154	300	40	6 500

Cross section
1pb ep→ vHX

Luminosity
> 10^{34} crucial
for H → HH
0.5 fb
and rare decays

First sets of
Parameters for
LR and RR
cf F.Z yesterday

Tuesday Afternoon: Accelerator Physics, R. F. Bacher presiding.

Hofstadter opened the discussion with a presentation of some of the extremely elegant electron-scattering work being done by a large group consisting of himself and J. Fregeau, B. Hahn, R. Helm, A. Knudsen, R. McAllister, and J. McIntyre.

Rochester Conf 1955

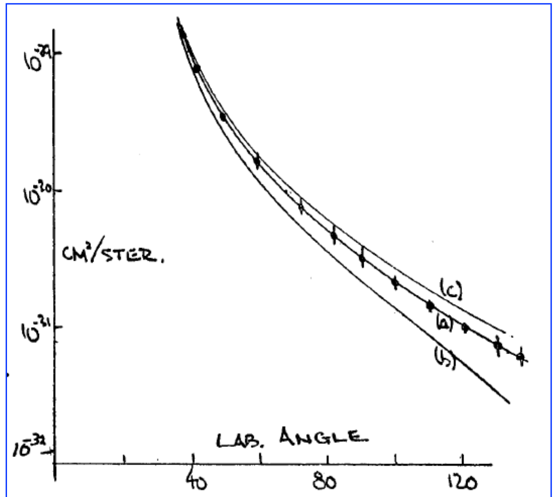


Fig. 2

of the moment is considerably larger. The deviation of the experimental curve from the Rosenbluth cross section (c) suggests that there is a finite size to the proton. $\lambda\!\!\!^{-}$ at this energy is about 10^{-13} cm. so that we expect, roughly speaking, a proton radius of this order to be significant in giving deviations. The experimental curve can, in fact, be analyzed a little more closely by inserting form factors into the Rosenbluth expression. An estimate of the proton radius from such an attempt is the value $(7.0 \pm 2.4) \times 10^{-14}$ cm., if one assumes that both the charge and the moment are diffused over the same volume. There is not enough experimental information to separate the two finite-size effects; in principle, however, the separation can be effected experimentally from work of this kind done at a variety of energies.

A New Era of Particle Physics

4.7.2012 greeting Melbourne from CERN

“The Higgs: So simple and yet so unnatural” G.Altarelli,arXiv:1308.0545

Further Path Determined with IAC Mandate

Guido Altarelli (Rome) *)
Sergio Bertolucci (CERN)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – **Chair**
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)

The IAC was invited in 12/13 by the DG with the following

Mandate 2014-2017

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.

Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

*) IAC Composition End of January 2014 +
Oliver Brüning Max Klein ex officio

Coordination Group for Future DIS at CERN

LCG (2014-2017) *)

Nestor Armesto
Oliver Brüning
Stefano Forte
Andrea Gaddi
Bruce Mellado
Max Klein
Peter Kostka
Daniel Schulte
Frank Zimmermann

Directors (ex-officio)
Sergio Bertolucci, Frederick Bordry

The coordination group was invited end of December 2013 by the CERN directorate with the following mandate (2014-2017)

The group has the task to coordinate the study of the scientific potential and possible technical realisation of an ep/eA collider and the associated detectors at CERN, with the LHC and the FCC, over the next four years. It also should coordinate the design of an ERL test facility at CERN as part of the preparations for a larger energy electron accelerator employing ERL techniques.

The group will cooperate with CERN and an International Advisory Committee, chaired by the emeritus DG of CERN, Professor Herwig Schopper, who also advises the CERN directorate. The Coordination Group is asked to represent the ep/eA collider development towards CERN, its committees and the international community. The currently tentative composition is listed *left*. CERN has asked Max Klein to chair and Oliver Brüning to co-chair this activity

*) LCG Composition early January 14

CURRENT TOPICS IN PARTICLE PHYSICS

Murray Gell-Mann

What can we look forward to hearing? Something which we can certainly look forward to hearing, although not necessarily with pleasure, is a lot of discussion among the different kinds of theorists about whether one should work with "S-matrix theory" or "field theory" or "Lagrangian field theory" or "abstract field theory," and I would like to suggest,

...

if all the efforts that we expend on the discussions on which form of field theory one should use were devoted to arguing for a higher-energy accelerator so that we can do more experiments over the next generation and really learn more about the basic structure of matter.

Rochester 1966

Early ep Scattering

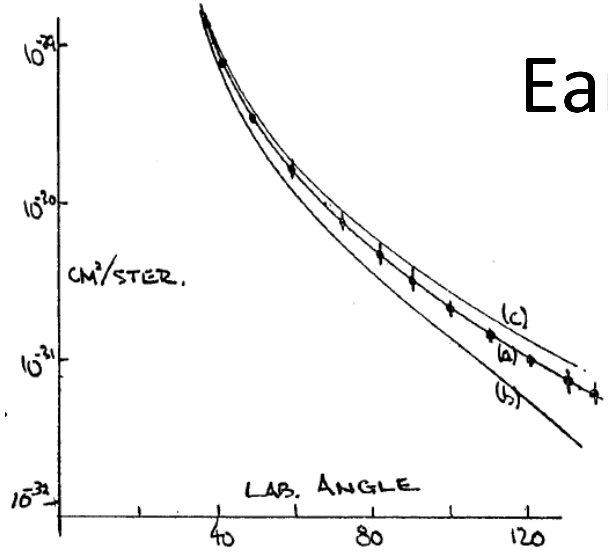
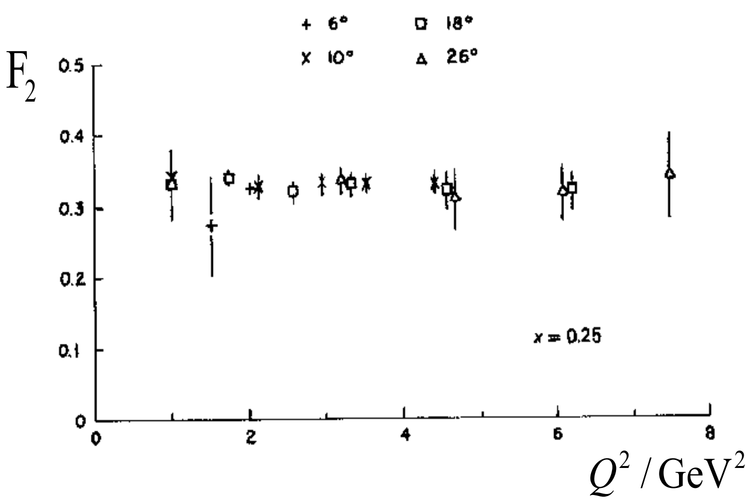
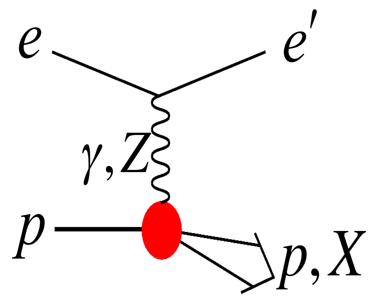


Fig. 2

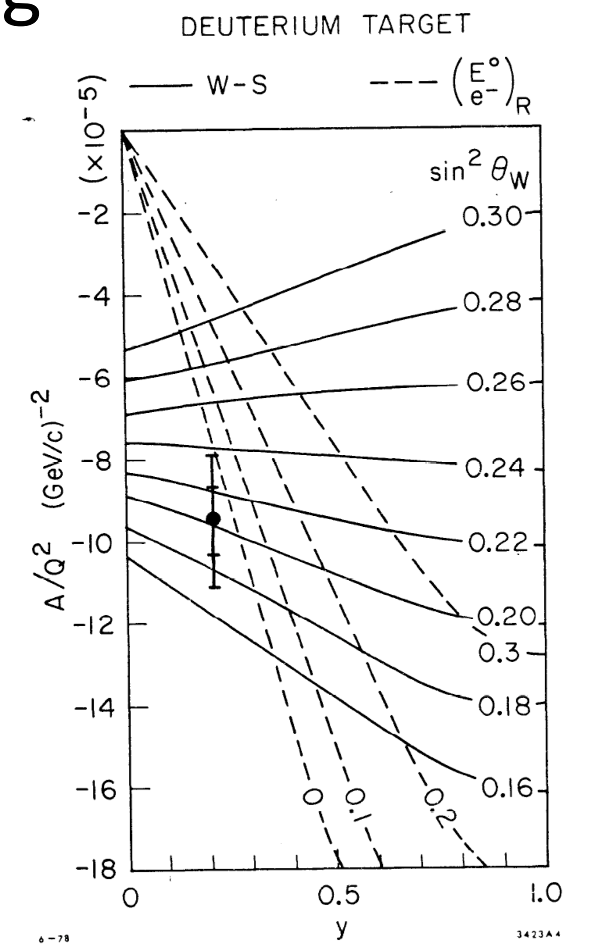
Hofstadter et al, 1955, r_p=0.74±0.20fm



SLAC-MIT 1968 Bj Scaling → Partons



In DIS the x and Q^2 scales are prescribed by the electron kinematics



$$A^{\pm} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

SLAC-PUB-2148
July 1978

Prescott et al, 1978, $I_{3,R}^{e}$=0

Exploit the Higgs Potential in ep

Four fermion operators with leptons and quark fields:

$8:(\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$

$8:(\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$

$8:(\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{d}_s \gamma^\mu T^A d_t)$

$8:(\bar{L}R)(\bar{R}L) + \text{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8:(\bar{L}R)(\bar{L}R) + \text{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$

Number of 4 fermion parameters with lepton-quark: $13\, n_g^4$ *or* 1053 *of* 2499

M.Trott at Chavannes 20.1.2014

What HERA could not do or has not done

HERA in one box
the first ep collider

$E_p * E_e =$
$920 * 27.6 GeV^2$
$\sqrt{s} = 2\sqrt{E_e E_p} = 320$ GeV

$L = 1..4\ 10^{31} cm^{-2} s^{-1}$
→ $\Sigma L = 0.5 fb^{-1}$
1992-2000 & 2003-2007

$Q^2 = [0.1 -- 3 * 10^4]\ GeV^2$
-4-momentum transfer^2

$x = Q^2/(sy) \cong 10^{-4}$ .. 0.7
Bjorken x

$y \cong 0.005$ .. 0.9
inelasticity

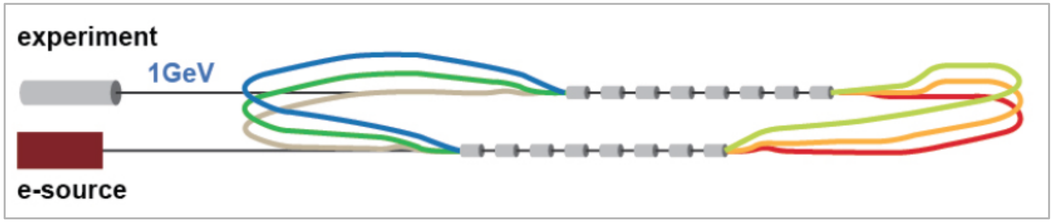
Test of the isospin symmetry (u-d) with eD - no deuterons
Investigation of the q-g dynamics in nuclei - no time for eA
Verification of saturation prediction at low x – too low s
Measurement of the strange quark distribution – too low L
Discovery of Higgs in WW fusion in CC – too low cross section
Study of top quark distribution in the proton – too low s
Precise measurement of F_L – too short running time left
Resolving d/u question at large Bjorken x – too low L
Determination of gluon distribution at hi/lo x – too small range
High precision measurement of α_s – overall not precise enough
Discovering instantons, odderons – don't know why not
Finding RPV SUSY and/or leptoquarks – may reside higher up
…

The H1 and ZEUS apparatus were basically well suited
The machine had too low luminosity and running time

HEP needs a TeV energy scale machine with 100 times higher luminosity than HERA to develop DIS physics further and to complement the physics at the LHC. The Large Hadron Collider p and A beams offer a unique opportunity to build a second ep and first eA collider at the energy frontier.

SC RF and ERL Test Facility at CERN

ERL Workshop at Daresbury: January 2013. f=801.54 MHz, I=10mA, $Q_0 > 2\ 10^{10}$



Applications

Development of SuperConducting RF technology at CERN (November 13 – ok)

Operation and experience with S.C energy recovery linac

Injector to LHeC → injector to a future e+/e- machine

Testbed for SC magnets, cables, stacks – in high dose, non-radiative environment

Experiments with **electron beam**: PV at $Q^2 \sim 1\ GeV^2$, proton radius

Experiments with **photon beam**: much higher intensity than ELI-NP