The LHeC as a Higgs Facility

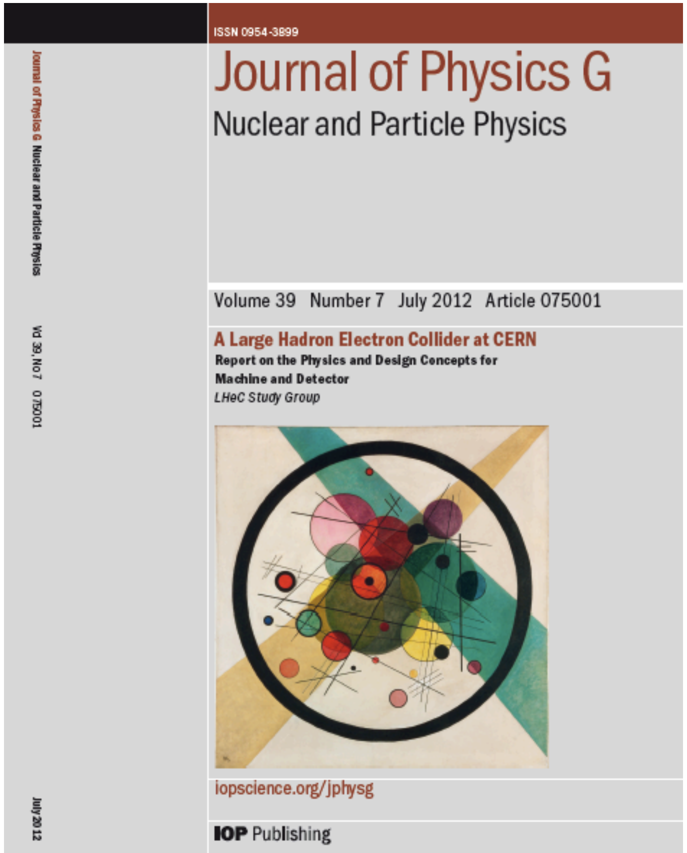
Max Klein
U Liverpool and CERN
For the LHeC Study Group

Introduction
Physics
LHeC Developments
Outlook

ICHEP, Valencia, 3rd of July, 2014

http://lhec.web.cern.ch

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)

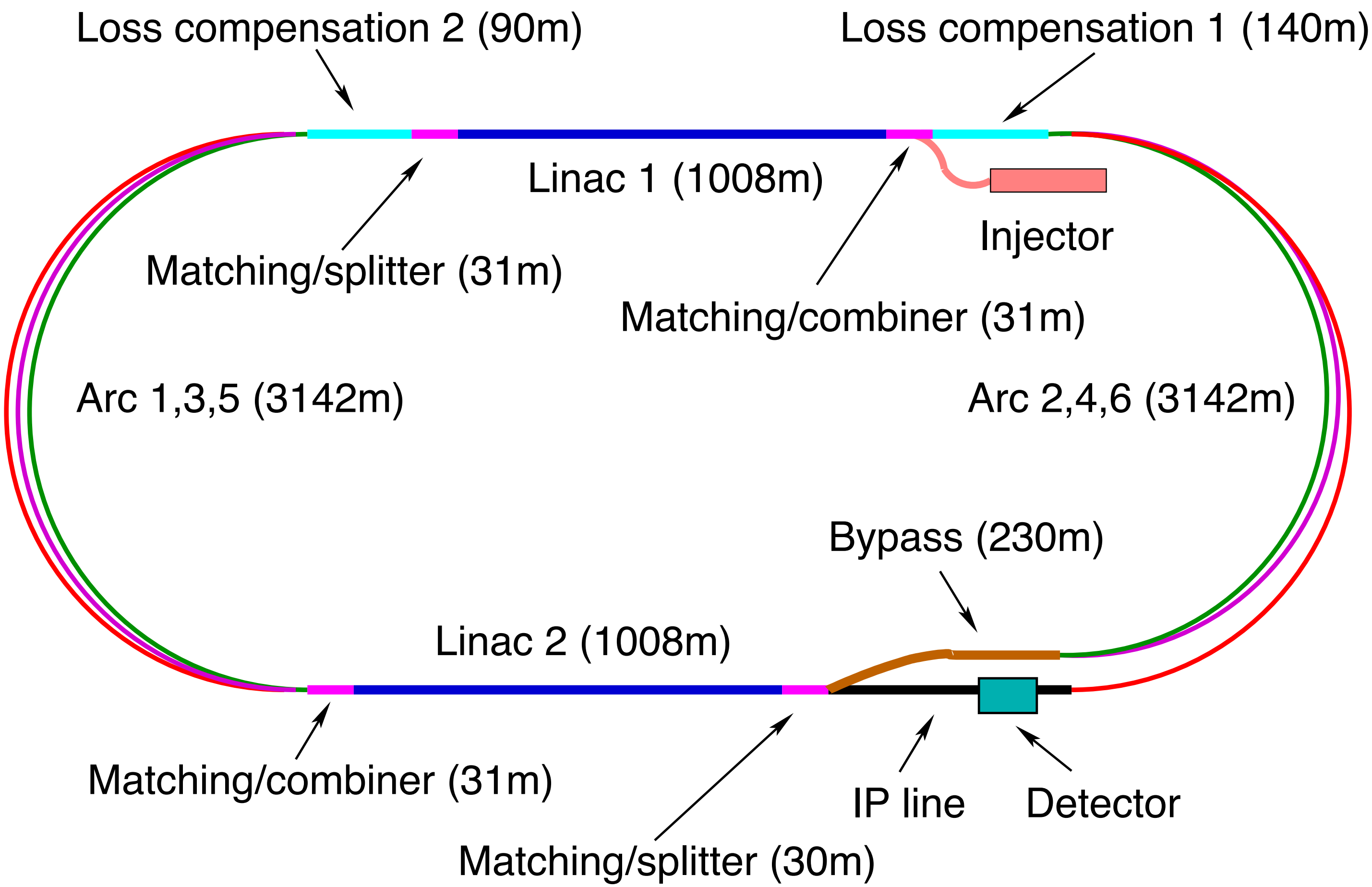
The theory of DIS has developed much further: J.Blümlein Prog.Part.Nucl.Phys. 69(2013)28
DIS is an important part of particle physics: G.Altarelli, 1303.2842, S.Forte, G.Watt 1301:6754

http://lhec.web.cern.ch

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]

LHeC Study group and CDR authors (May 13)

CDR Footprint of the LHeC ERL Electron Beam for synchronous ep and pp OP @ LHC



60 GeV electron beam energy, L= 10^{33} $cm^{-2}s^{-1}$, √s=1.3 TeV: Q^2_{max}= 10^6 GeV^2, 10^{-6} < x< 1
Recirculating linac (2 * 1km, 2*60 cavity cryo modules, 3 passes, energy recovery)
Ring-ring as fall back. “SAPHIRE” 4 pass 80 GeV option to do mainly: γγ→ H. CDR

LHeC Accelerator Design: Participating Institutes

CERN

SLAC NATIONAL ACCELERATOR LABORATORY

NTNU Norwegian University of Science and Technology

ECFA

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

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

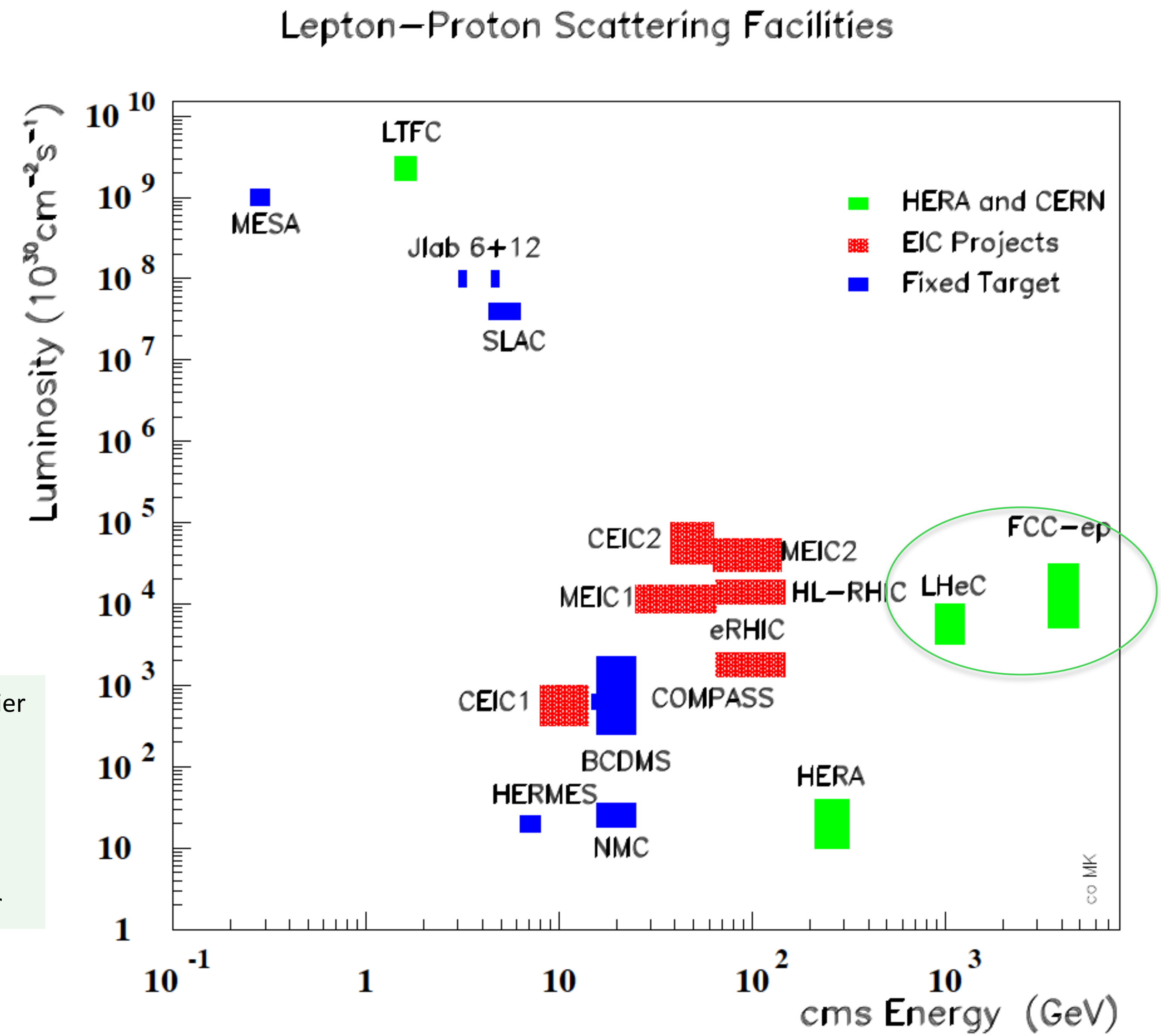
UNIVERSITY OF LIVERPOOL

KEK

BROOKHAVEN NATIONAL LABORATORY

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

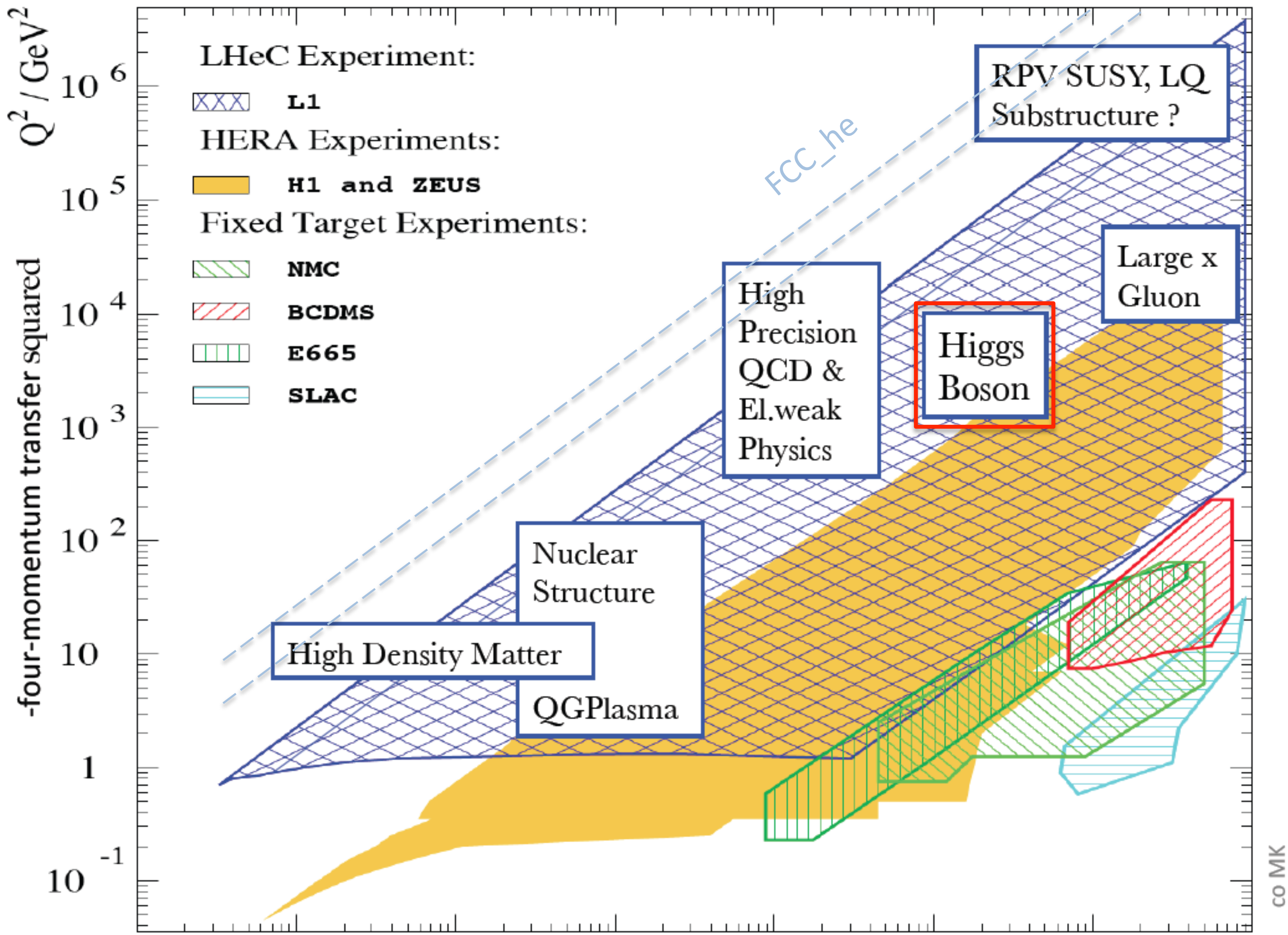
Source	Power [MW]
Cryogenics (linac)	21
Linac grid power	24
SR compensation	23
Extra RF cryopower	2
Injector	6
Arc magnets	3
Total	**78**



From CERN Courier
MK, H.Schopper
June 2014

With input from
A.Hutton, R.Ent,
F.Maas, T.Rosner

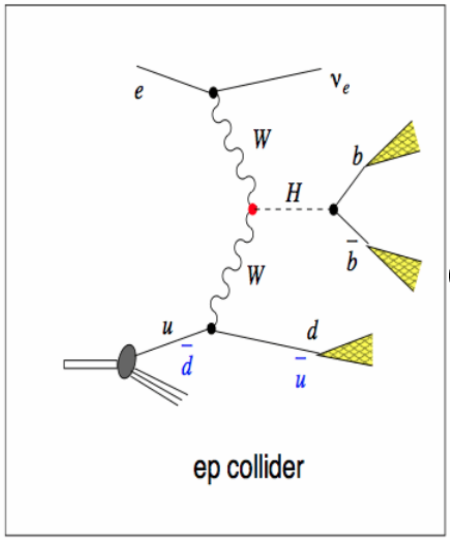
CERN: LHC+FCC: the only realistic opportunity for energy frontier deep inelastic scattering
Huge step in energy (Q^2,1/x) and 2-3 orders of magnitude higher luminosity than HERA



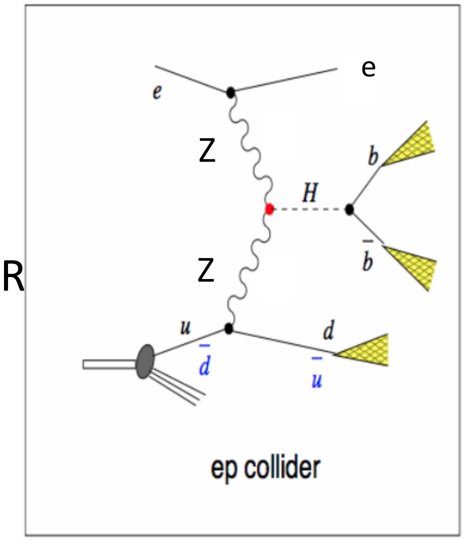
LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
FCC_he
RPV SUSY, LQ
Substructure ?
Large x
Gluon
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Nuclear
Structure
High Density Matter
QGPlasma
Q^2 / GeV^2
-four-momentum transfer squared
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x
co MK

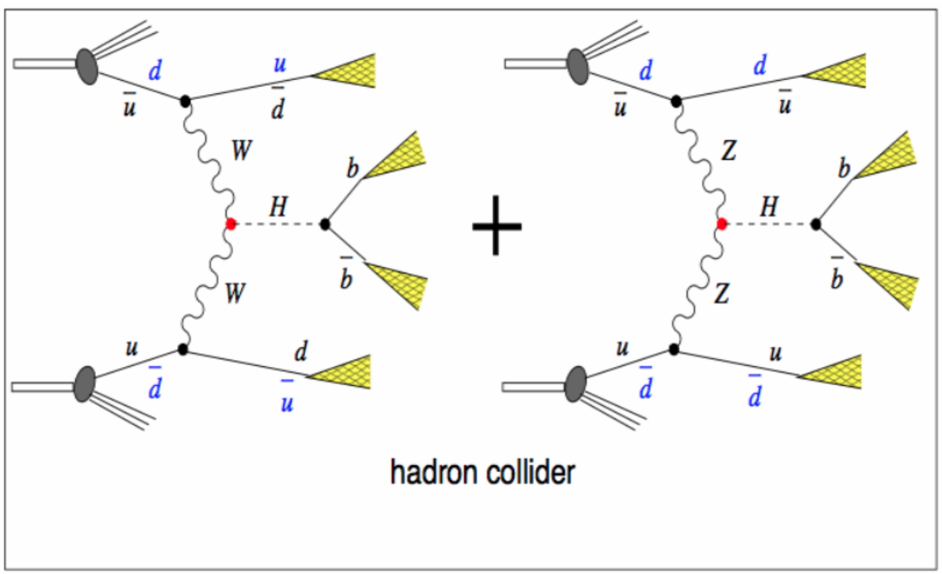
2. Remarks on Higgs ep and pp Physics

Higgs Production at the LH(e)C



OR





Higgs production in ep comes uniquely from either CC or NC

Cross section at LHeC ~200fb (about as at the ee colliders).

Pile-up in ep at 10^{34} is 0.1, 25ns

Clean(er) bb final state, S/B ~ 1

Higgs production in pp comes predominantly from gg→ H

VBF cross section about 200fb (about as at the ep colliders).

Pile-up in pp at 5 10^{34} is 150, 25ns

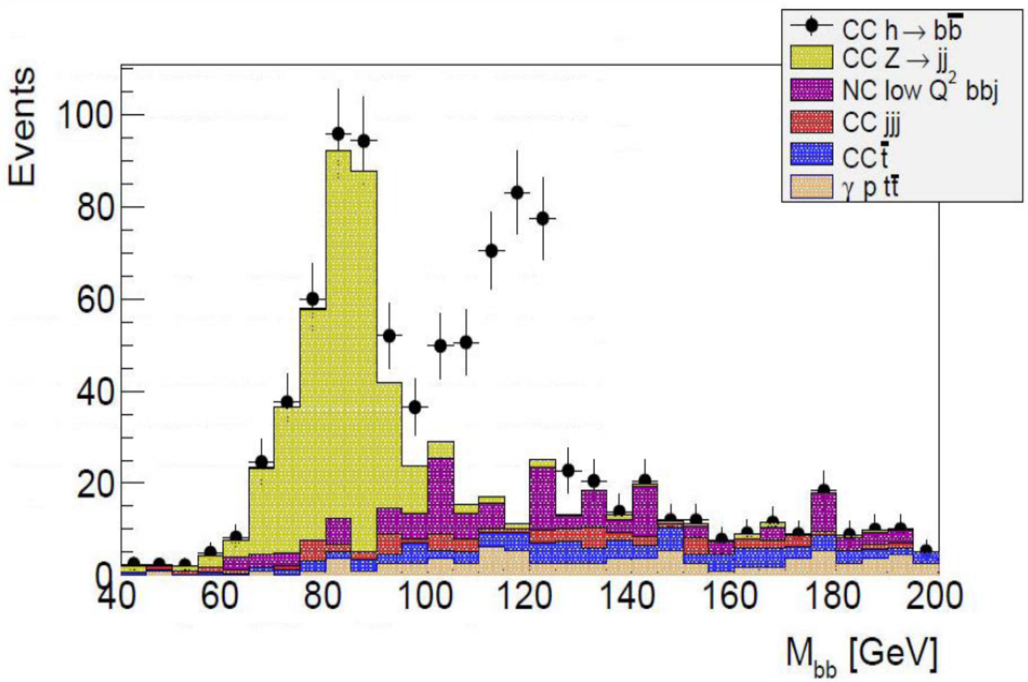
S/B very small for bb

ep→ vH(bb)X
charged currents
σBR~120 fb
S/B ~1-2 → crucial for QCD of H
Pile up 0.1

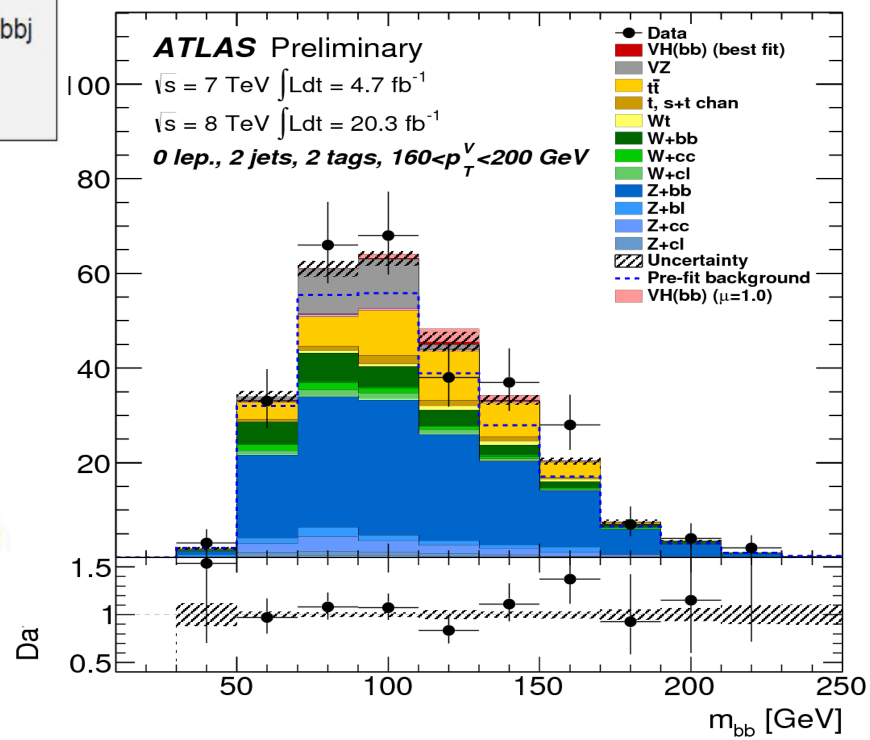
1% coupling precision at 1 ab^{-1}

H → bbar

pp→ X_1W(lv)H(bb)X_2
associated VH
σBR~130 fb
S/B <~0.01
<Pile up> ~20

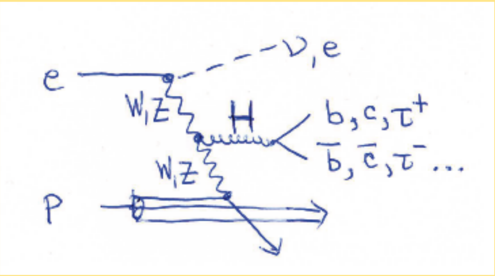


ep (new) Simulation 100 fb^{-1}
Confirming CDR initial studies
See Poster U. Klein Higgs in ep – this conference



pp 2013: Measurement
ATLAS CONF-2013-079

Rates of Higgs Production in e^-p



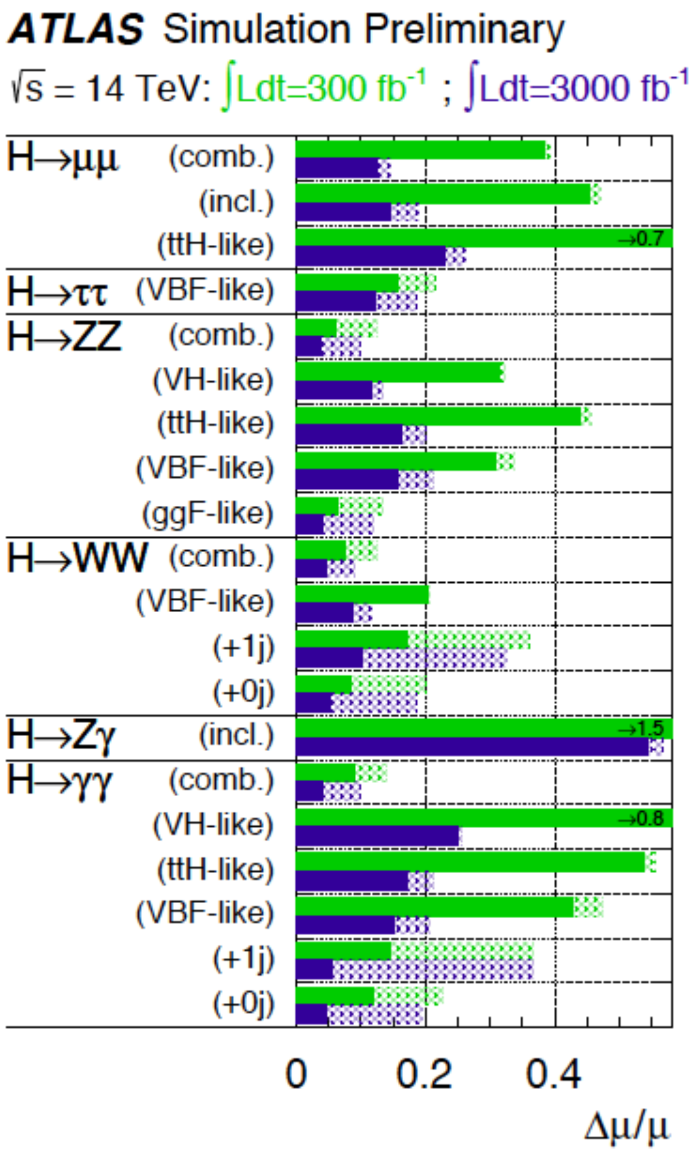
Higgs in e^-p		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N^H_{CC}	N^H_{NC}	N^H_{CC}
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	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

Clean VV production and high S/B in reconstruction are base for unique further program as on CP
Biswal et al, PRL109(12)261801
+differential measurements

There is a huge potential for Higgs physics in ep.

High rates for bb but also WW,gg,ττ,cc → desire for maximum luminosity O(10^{34}) $cm^{-2}s^{-1}$
Note that 10^{33} is 100 times HERA (I) and a huge step more than adequate for DIS
Each of the channels requires dedicated simulation study, as has been done for bb
Ahead is use of ep detector and its design optimisation for H and general fwd physics.
For the detector design – see poster 'A New Detector for ep Scattering' – this conference

Prospects for H **at HL-LHC**



Prospects for signal strength measurements at the **LHC** and the **HL-LHC**

Dashed: Theoretical uncertainties from PDFs, strong coupling and scales

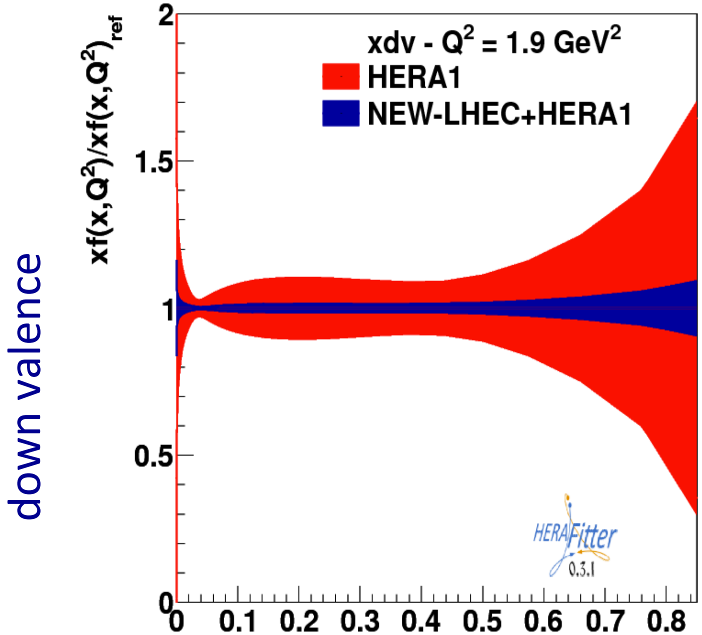
To make the LHC a precision Higgs factory, one needs: much better PDFs
much more precise α_s ,
all determined to a next order pQCD: N^3LO

The LHeC provides a unique data basis and theoretical framework for H physics in pp while N^3LO Higgs calculations have begun
(Anastasio et al)

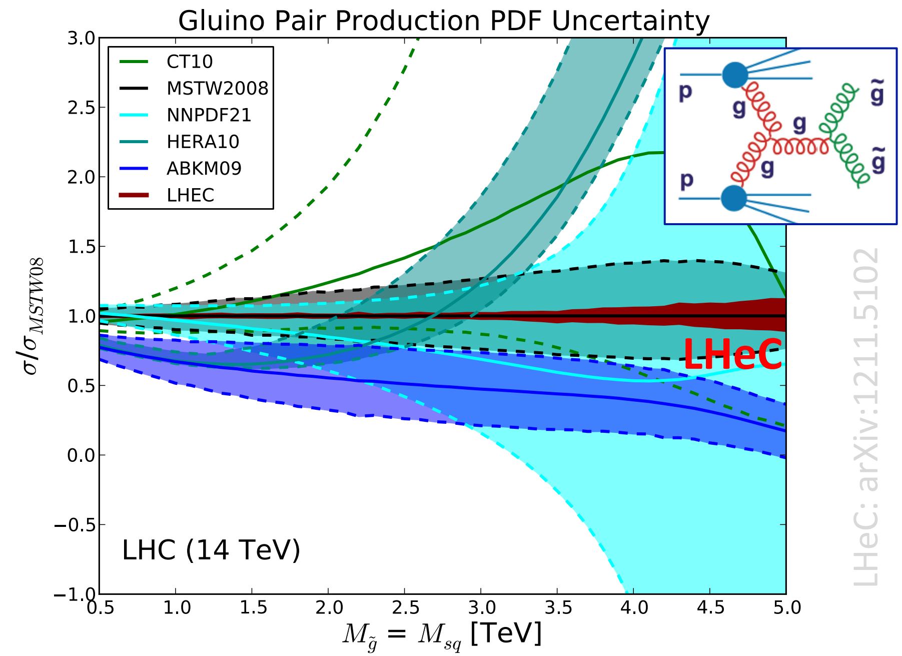
Note we do not know yet the bb prospect as it is notoriously difficult in pp, and there is no cc nor gg prospect for pp either.

ATLAS-PHYS-PUB-2013-014 (10/13) - see also CMS prospects with two assumptions on theory uncertainties

Precision Parton Distributions from ep



V Radescu, MK [pdf set on LHAPDF]



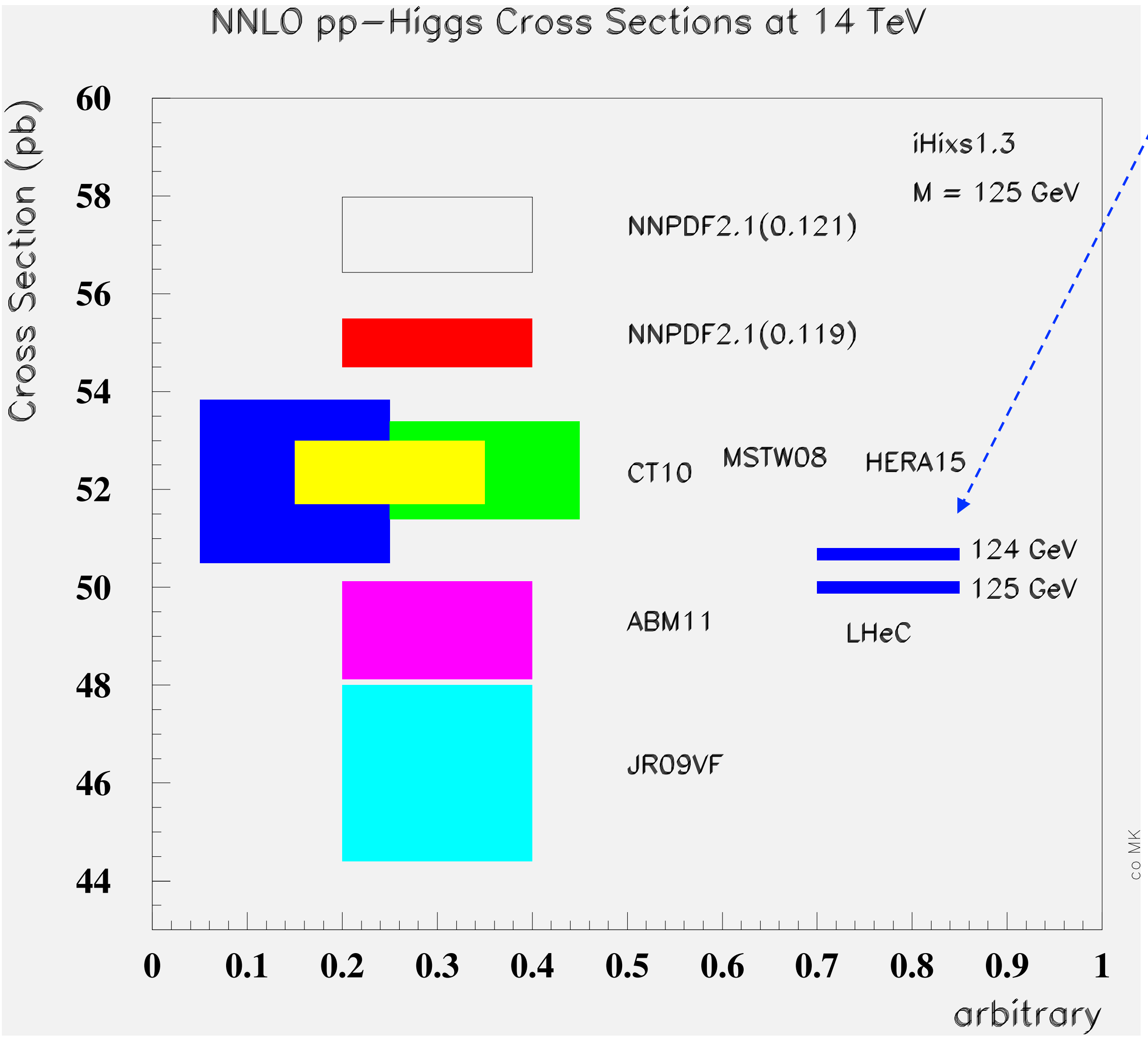
M D'Onofrio, R.Kleiss et al

Why important: qg dynamics determines the mass of the visible universe.
Low x: nonlinear evolution?, Medium x: Higgs High x: d/u… Searches at HL-LHC – hi Mass

Why ep: Because it is the only way to measure/derive these and they will be needed for HL-LHC
For testing QCD: Factorisation, Resummation, N^{3}LO (Higgs), α_s – lattice, HF, intrinsic PDFs, ..

Why LHeC: the only base for fully unfolding PDFs, free of symmetry assumptions (need precision CC), bDF, tDF..

Precision PDFs for Higgs at the LHC



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

LHeC:

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 …

3. Recent Machine and Developments

CDR Parameters - LHeC

10^{33} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.1	0.12
rms Beam size $\sigma^*_{x,y}$ [μm]	7	7
rms Beam divergence $\sigma'_{x,y}$ [μrad]	70	58
Beam Current [mA]	430 (860)	6.6
Bunch Spacing [ns]	25 (50)	25 (50)
Bunch Population	$1.7*10^{11}$	$(1*10^9)$ $2*10^9$
Bunch charge [nC]	27	(0.16) 0.32

"Ultimate" proton beam parameters

100 times HERA Luminosity and 4 times cms Energy

Advanced Luminosity Parameters*) - LHeC

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [$10^{33}cm^{-2}s^{-1}$]	16	16
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20
Beta Function $\beta^*_{x,y}$ [m]	0.05	0.10
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4
rms Beam divergence $\sigma'_{x,y}$ [μrad]	80	40
Beam Current [mA]	1112	25
Bunch Spacing [ns]	25	25
Bunch Population	$2.2*10^{11}$	$4*10^{9}$
Bunch charge [nC]	35	0.64

HL-LHC proton beam parameters

*) under study now

1000 times HERA Luminosity and 4 times cms Energy

Areas of Study Post-CDR *)

More realistic with dedicated tools and evaluation of high luminosity prospect

Choice of RF Frequency – 802 MHz
Optimisation of IR Design [L*(e) < L*(p), inner triplet half? quad…]
Integration of p optics into HL-LHC
Integration of e optics into HL-LHC
Beam-beam effects (phase space deformation)
Multi-bunch beam break up
Wakefield effects on multi-bunch instability at IP
Emittance growth
Coherent synchrotron radiation
Fast beam-ion instability (1/3 gap compensated by 1.3 from pinch effect)
Arc optics FODO vs FMC (flexible momentum compaction)
Lattice design
Spreader and combiner
Civil engineering
…

So far no showstopper found for O(10^{34})cm^{-2} s^{-1}: it requires further serious study and the development of SCRF within a Testfacility

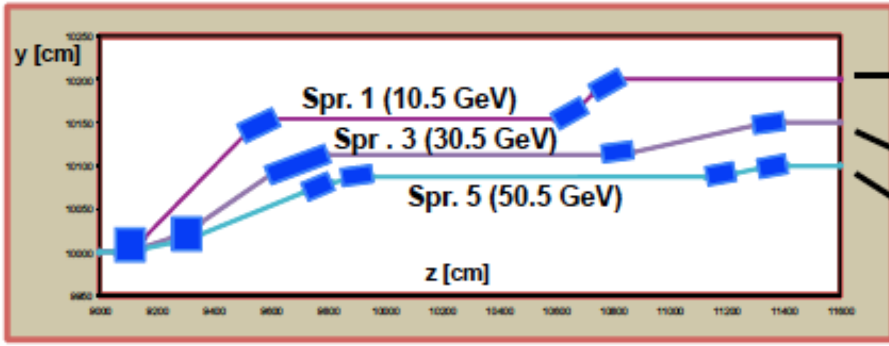
*) Recent presentations by A.Bogacz, O.Bruening, E.Cruz, E.Jensen, D.Schulte, A.Valloni – see Webpage
Work by E.Cruz, M.Korostelev, E.Nissen, J.Osborne, D.Pellegrini, A.Letina, A.Milanese, A.Valloni and others

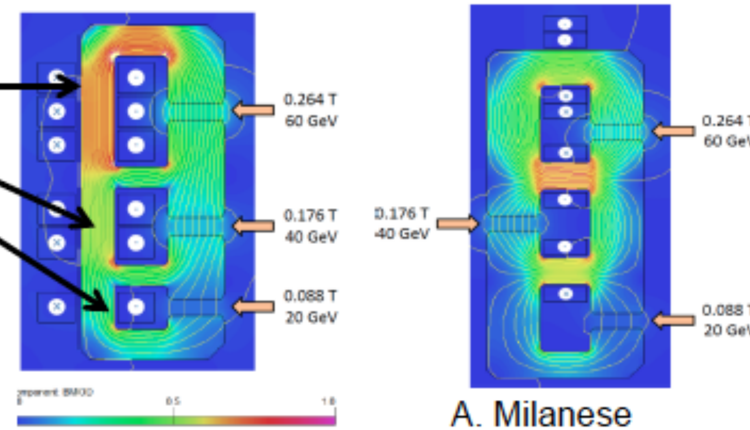
Optics Design Study

- High luminosity Linac-Ring option – ERL
  - RF power nearly independent of beam current.
- Multi-pass linac Optics in ER mode
  - Choice of linac RF and Optics – 802 MHz SRF and 130^0 FODO
  - Linear lattice: 3-pass 'up' + 3-pass 'down'
- Arc Optics Choice – Emittance preserving lattices
  - Quasi-isochronous lattices
  - Flexible Momentum Compaction Optics
  - Balanced emittance dilution & momentum compaction
- Complete Arc Architecture
  - Vertical switchyard
  - Matching sections & path-length correcting 'doglegs'
- Alternative ERL Topology – 'Dogbone' Option?

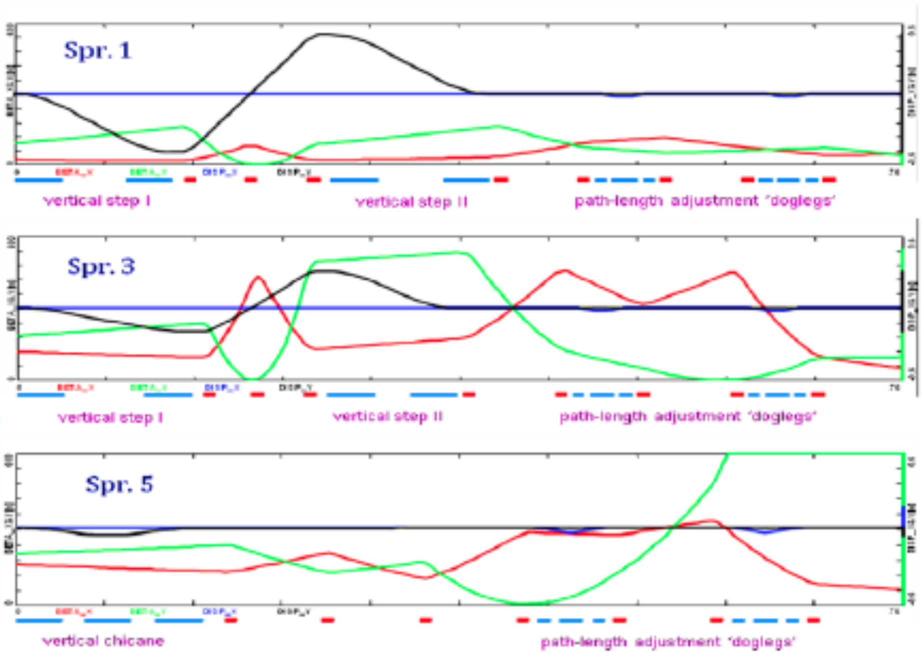
Summary of Presentation by Alex Bogacz at EIC14, Jlab, March 20, 2014

Switchyards





A. Milanese

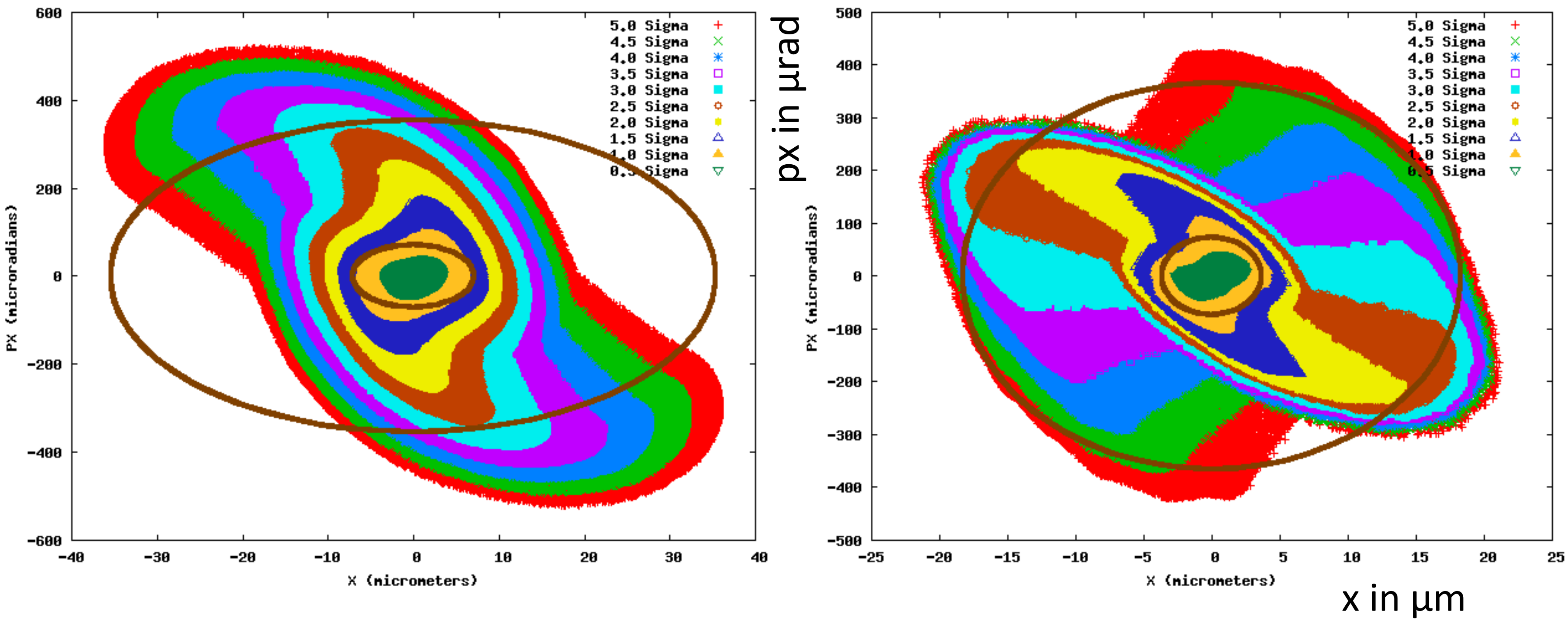


- Two-step-achromat spreaders and mirror symmetric recombiners
- Arcs are separated into 1m high vertical stack
- Very compact switchyard system (~20 m long)
- Horizontal doglegs used for path-length adjustment

A.Bogacz, A.Milanese, A.Valloni

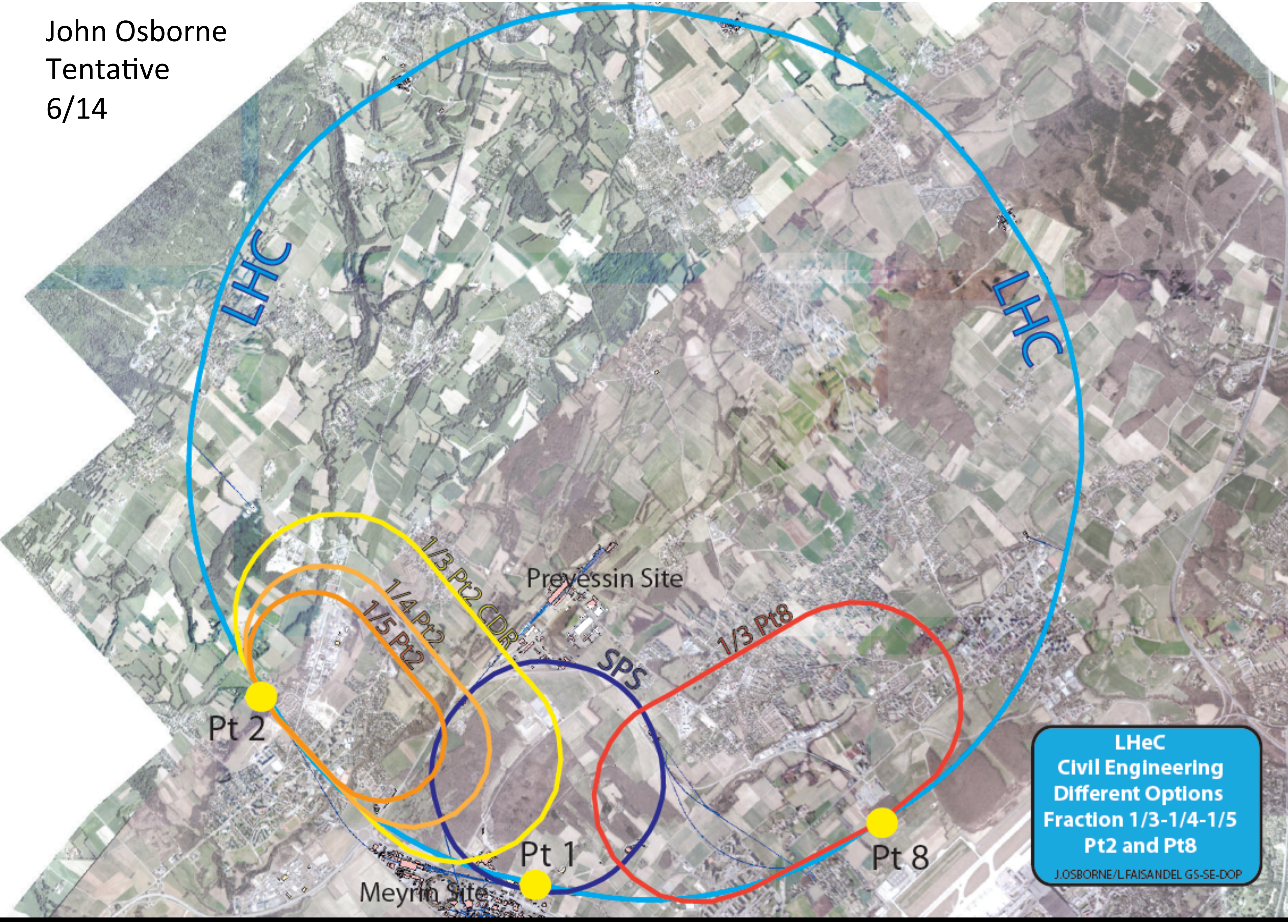
Phase Space Deformation from Beam Beam

CDR H-LHeC E.Nissen



Hypersphere phase space is significantly deformed by beam-beam interactions.
In the case of the high luminosity configuration, the (5σ) tails are folded back..

John Osborne
Tentative
6/14

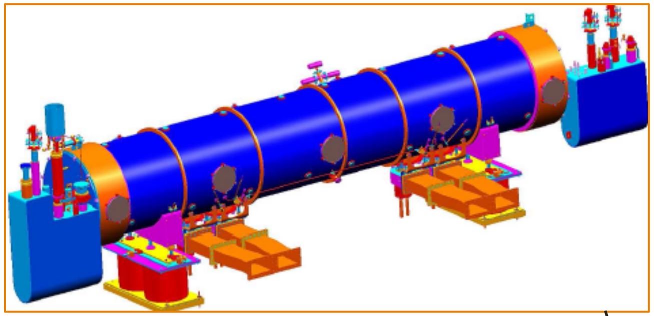


Goals of a CERN ERL-Test Facility

- Main goal: **Study real SRF Cavities with beam** – not interfering with HEP!
  - citing W. Funk ("Jefferson Lab: Lessons Learned from SNS Production", ILC Workshop 2004 http://ilc.kek.jp/ILCWS/):
    - **All problems will not be experienced until the complete subsystem is tested under realistic conditions. Be prepared to test, with full rf power systems and beam, all of the pre-production prototypes.**
- In addition, it would allow to study **beam dynamics** & **operational aspects** of the advanced concept ERL (recovery of otherwise wasted beam energy)!
- Exploration of the ERL concept with multiple re-circulations and high beam current operation
- Additional goals:
  - Gun and injector studies
  - Test beams for detector R&D,
  - Beam induced quench test of SC magnets
  - … later possibly user facility: $e^{\uparrow -}$ test beams, CW FEL, Compton γ-ray source …
- At the same time, it will be fostering international collaboration (JG|U Mainz and TJNAF collaborations being formalized)

SCRF and LTFC

superconducting RF and ERL Test Facility at CERN

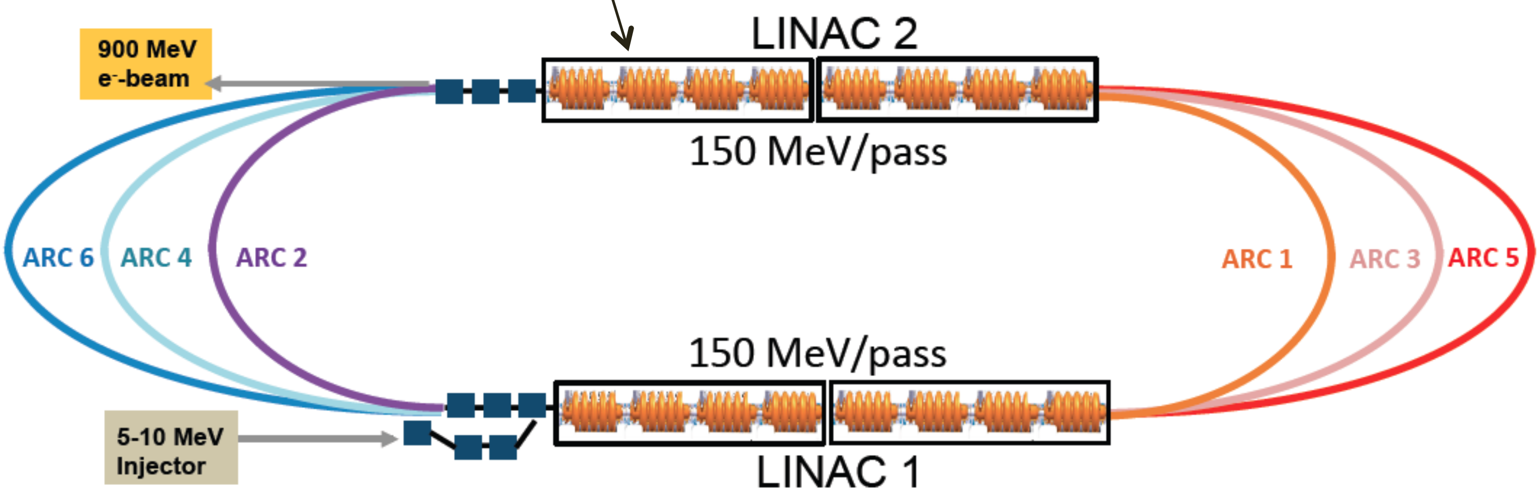


A.Hutton, B. Rimmer, E.Jensen et al.

MoU between CERN and Jlab - signed

Frequency 802 MHz
Design and built of 2 Modules (CERN+Jlab+?)
Tentative Design of the LTFC – end of 2014:

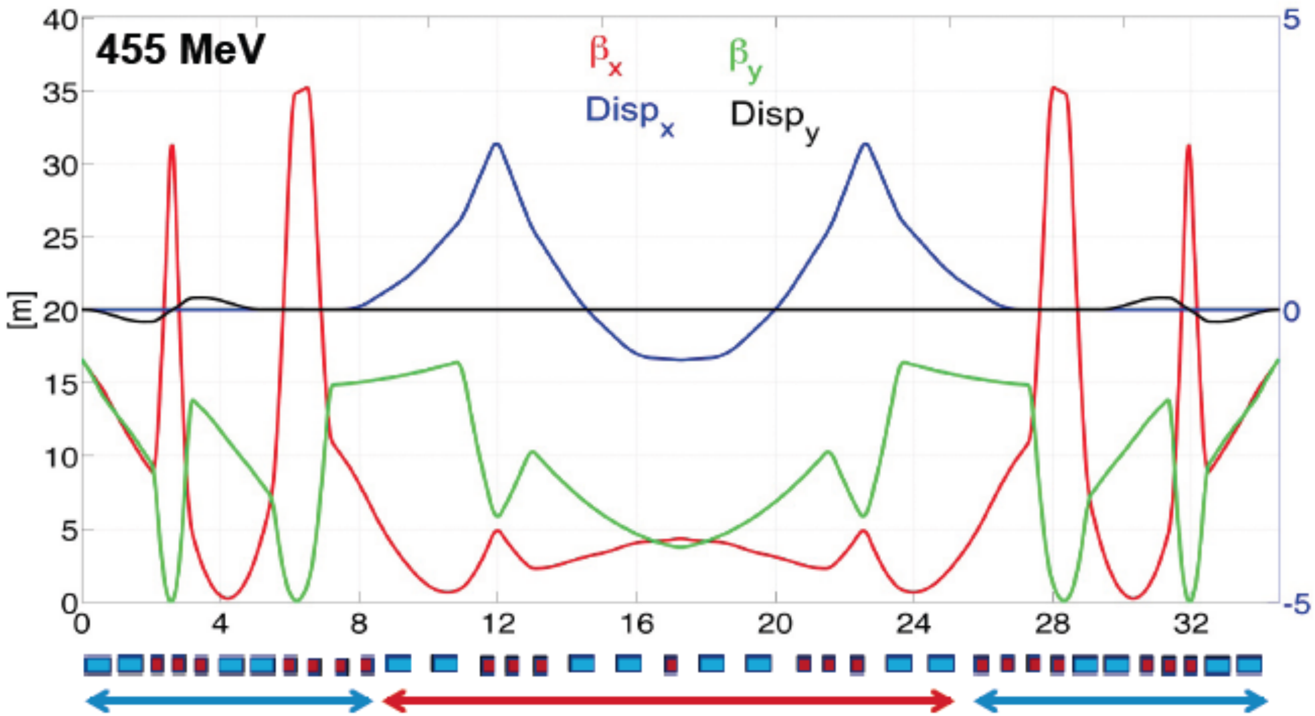
Collaborations being established on
Source, Magnets, Operation, Applications



A. Bogazc, A.Valloni et al. presented at IPAC14 at Dresden by Erk Jensen

Testfacility Design

Arc 3 optics



9.8° bends
(1 rec. + 3 sec.)

Arc dipoles :
Ldip = 90.58 cm
B = 6.58 kGauss
ρ = 230.66 cm

9.8° bends
(1 rec. + 3 sec.)

also: multi-pass linac optics

New LHeC International Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Nichola Bianchi (Frascati)
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)
John Womersley (STFC)

*) IAC Composition June 2014, and
Oliver Brüning Max Klein ex officio

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.

Workshop at Chavannes 20/21.1.2014

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

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

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

Next decades

Rolf Heuer at
Aix Les Bains
1. 10. 2013

Road beyond Standard Model

LHC results vital to guide the way at the energy frontier

At the energy frontier through synergy of

hadron - hadron colliders (LHC, (V)HE-LHC?)

lepton - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (**ILC** or CLIC) ?)

Outlook and Summary

Following the publication of the CDR and the Higgs boson discovery, there has been a renewed interest in the LHeC, because of the interest in genuine DIS and also for *Higgs, LHC Upgrade and Use, High Gradient Cavity and the Energy Frontier*

CERN has called for a new phase of the LHeC development and its consideration in the FCC [hh,he,ee] context by appointing a new advisory committee and a coordination group.

The next important steps regard
Physics: H, t, BSM, low x, eA, PDF studies especially with regard to the HL LHC
Detector: Simulation and optimised design for H and forward physics
Accelerator: Study of the prospects and consequences for high luminosity ep
SCRF: Development of two cavity-cryo modules with 802 MHz
Testfacility: Design and collaboration (tentative by 14 and CDR by 15)

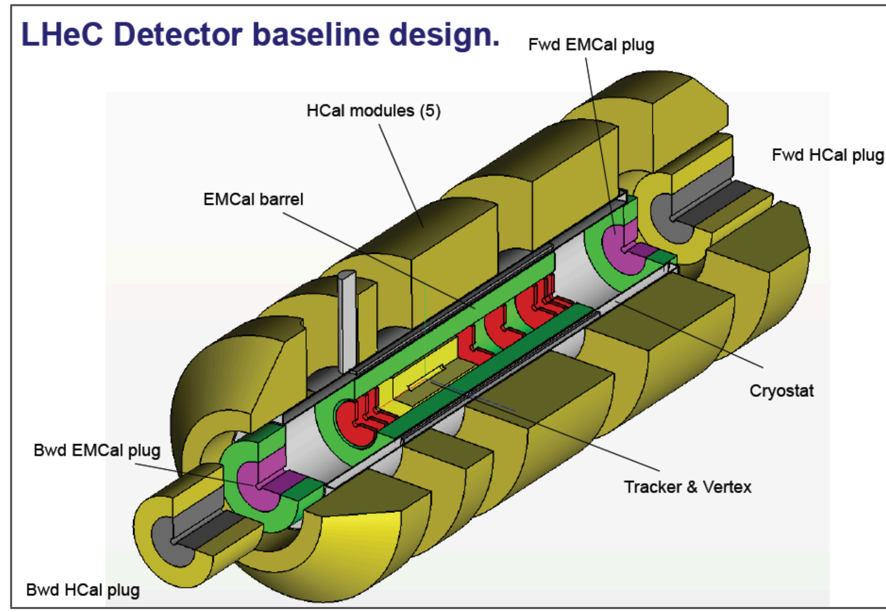
This is indeed a continuation and 'A New Beginning' H.Schopper, MK Ccourier 6/14

The ERL electron beam is a very economic option to realise ep (and eA) with FCC
(see presentation tomorrow)

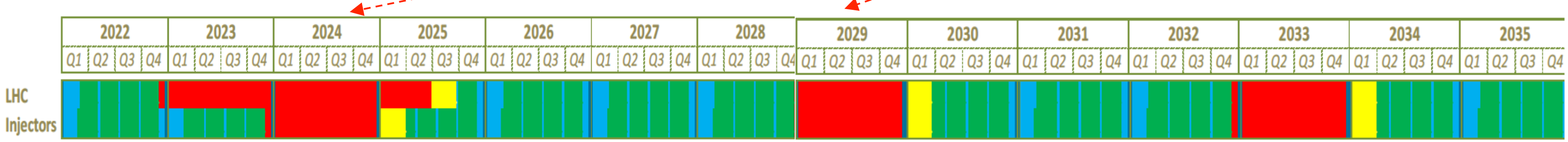
backup

Time Schedule – 2 – Detector

A.Gaddi Chavannes 1/14



Pre-mounting at the surface of a modular detector – independent of LHC
Lowering (7), Installation (2), Connection (6), Field Map (1), Pipe (1) … min of 15 Month
which would be compliant with LS3 and may be with LS4 – depends on the LHC

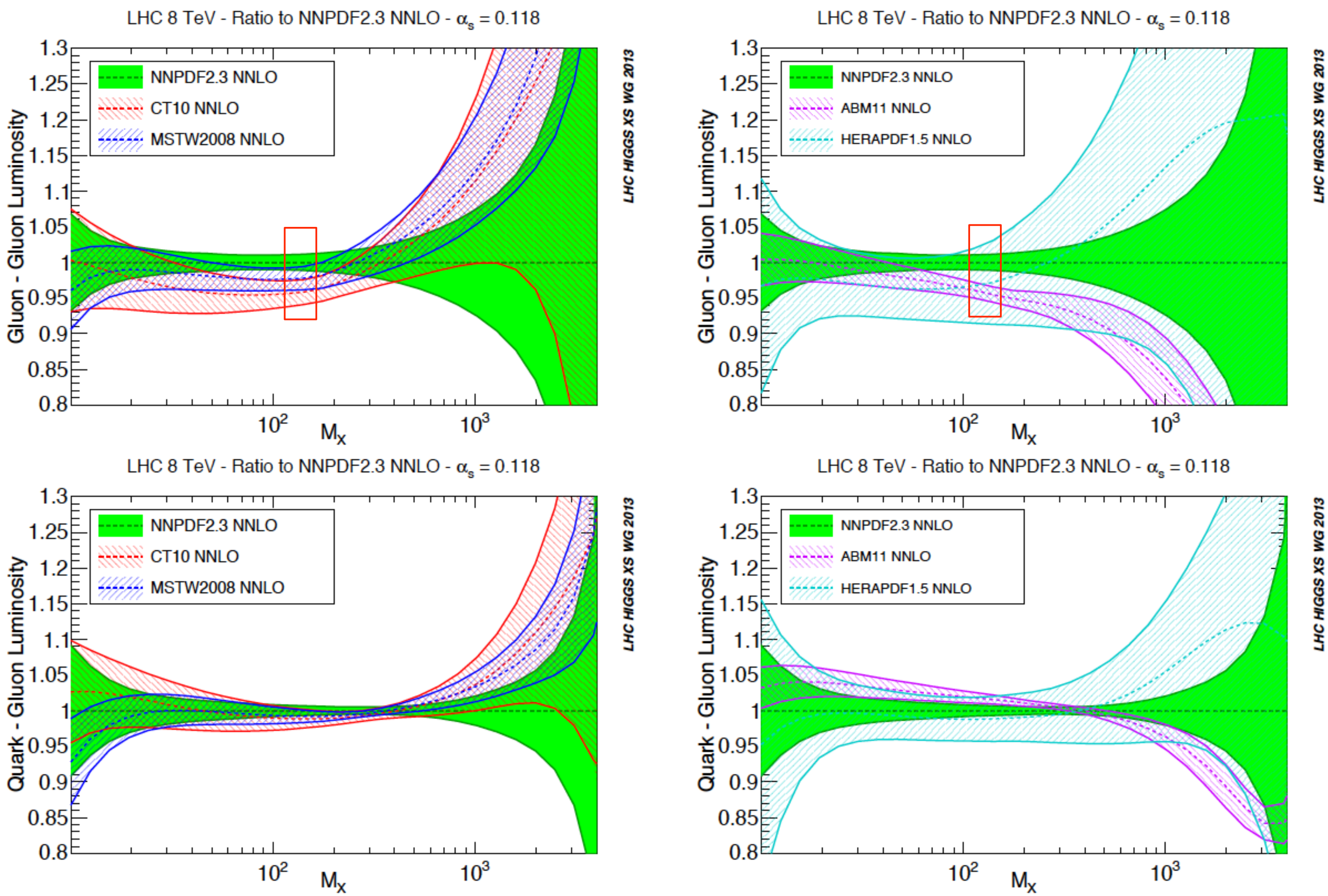


NNLO - PDF Uncertainties vs Mass in Drell-Yan

The mass of the visible universe is provided by the gluon selfinteraction and the gg interaction dominates the production of the Higgs boson in pp interactions.

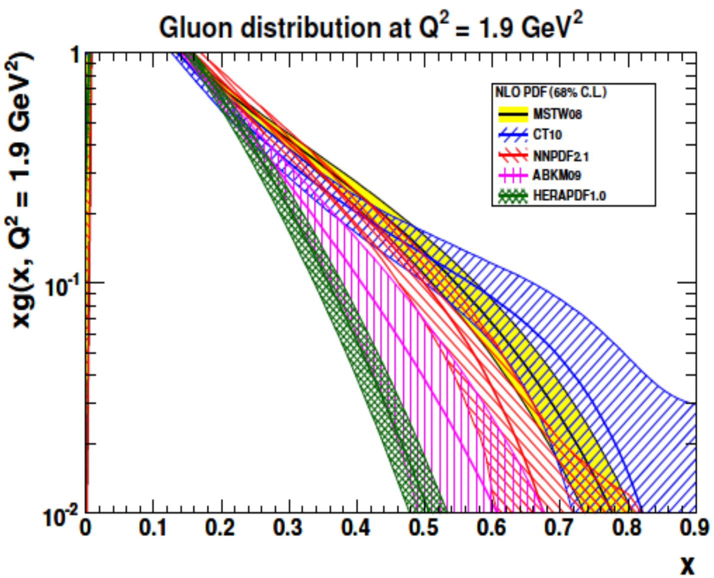
gg

qg

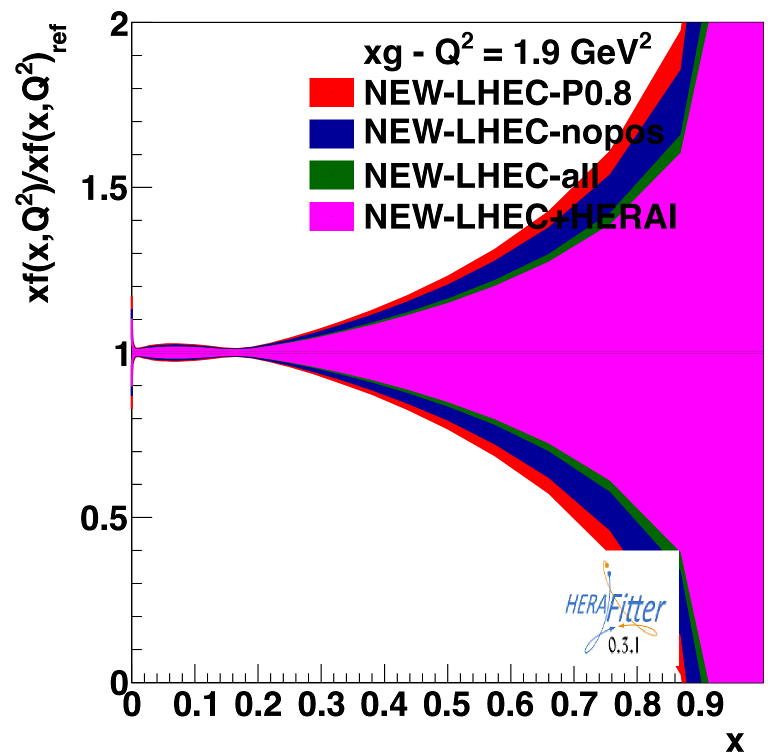


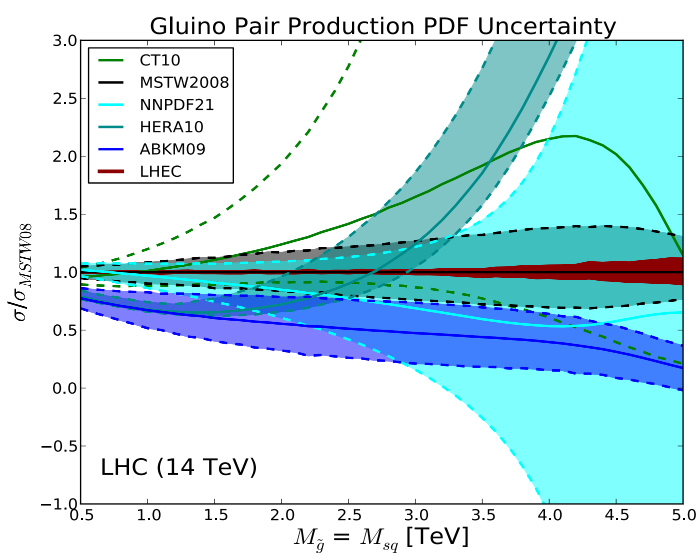
Higgs Handbook 7/2013, arXiv:1307.1347 S.Forte, J.Huston, R.Thorne

Determination of the Gluon Density at Large x



High(er) precision at x ~ 0.01 for Higgs and independent accurate PDF input at x > 0.4 for searches at HL-LHC





MK, V.Radescu, LHeC Note 2013-002 and Workshop on LHeC, Chavannes, January 14

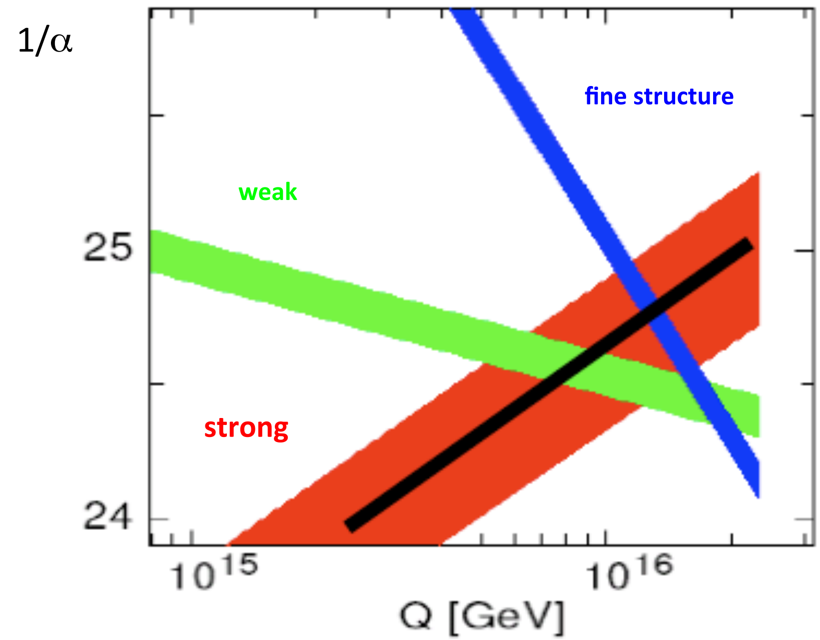
Strong Coupling Constant

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

DIS tends to be lower than world average (?)

LHeC: per mille - independent of BCDMS.

Challenge to experiment and to h.o. QCD →
A genuine DIS research programme rather than
one outstanding measurement only.

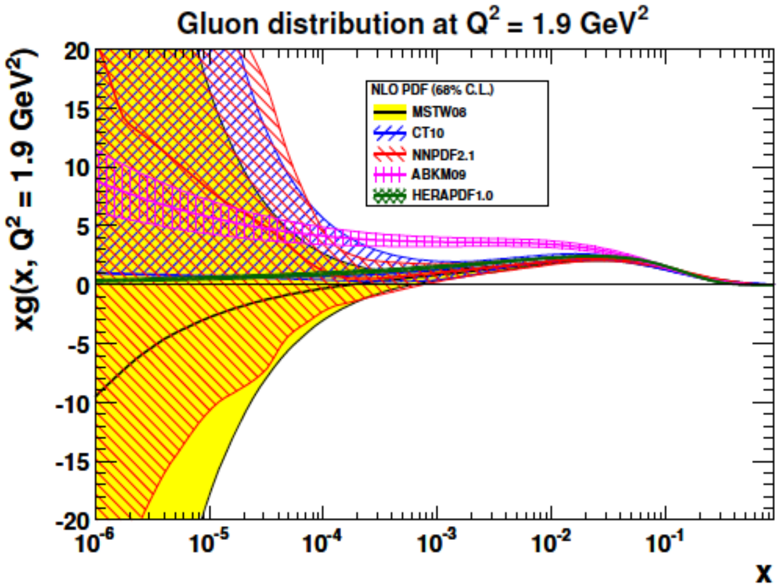


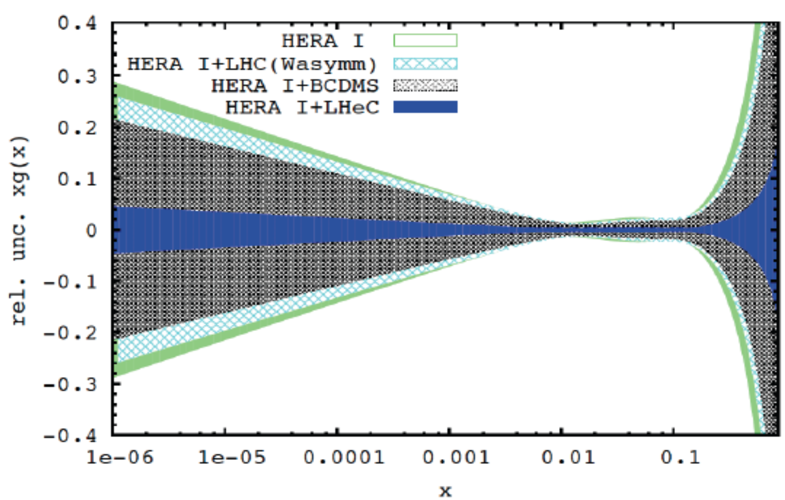
case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 >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

Two independent QCD analyses using LHeC+HERA/BCDMS

DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

Determination of the Gluon Density at Small x





Small x is related to large x in DY production

x = M/√s exp(±y) = 0.009 … 0.015 (8 … 13 TeV)

HERA constraints end at x ~ 10^{-3} in DIS region

DGLAP may break at small x and the conventional gluon determinations, linking also low and large x, will then be inadequate.

The LHeC is the only configuration where this can be tested with enough confidence.

Measure $dF_2/dlnQ^2$ and F_L precisely!

MK, V.Radescu, LHeC Note 2013-002 and
Workshop on LHeC, Chavannes, January 14

Possible QCD Developments and Discoveries

AdS/CFT

Instantons

Odderons

Non pQCD

QGP

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, on its own and as background