The LHeC – Science and Status

LHeC:
E_e=60 GeV
E_p= 7 TeV

Introduction

Five Themes

Important Steps

For references,
please consult
lhec.web.cern.ch

LHeC CDR
arXiv:1206.2913
J.Phys. G39 (2012) 075001

Max Klein
University of Liverpool

for the LHeC+FCC-eh Study Group

FCC_eh:
E_e =60 GeV
E_p =50 TeV

HE LHC:
E_p=12.5 TeV

DIS Workshop at Birmingham, 7th of April 2017

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) ?)

Framework of the Development

Following the CDR in 2012: Mandate issued by CERN:2014 (RH), confirmed in 2016 (FG)

Mandate to the International Advisory Committee

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.

Chair: Herwig Schopper, em. DG of CERN

LHeC has been a development for and initiated by ECFA and NuPECC

Organisation*)

International Advisory Committee

"..Direction for ep/A both at LHC+FCC"

Sergio Bertolucci (CERN/Bologna)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Eckhard Elsen (CERN)
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 (ESS)

We miss Guido Altarelli.

*)February 2017

Coordination Group

Accelerator+Detector+Physics

Nestor Armesto
Oliver Brüning – Co-Chair
Stefano Forte
Andrea Gaddi
Erk Jensen
Max Klein – Co-Chair
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

5(11) are members of the FCC coordination team

OB+MK: FCC-eh responsibles
MDO: physics co-convenor

Working Groups

PDFs, QCD
Fred Olness,
Voica Radescu
Higgs
Uta Klein,
Masahiro Kuze
BSM
Georges Azuelos,
Monica D'Onofrio
Top
Olaf Behnke,
Christian
Schwanenberger
eA Physics
Nestor Armesto
Small x
Paul Newman,
Anna Stasto
Detector
Alessandro Polini
Peter Kostka

Five Major Themes of LHeC PHysics

The Cleanest High Resolution Microscope of the World

The Electron Beam Upgrade of the LHC

The First High Precision Higgs Facility

Discovery Beyond the Standard Model

A Unique Nuclear Physics Facility

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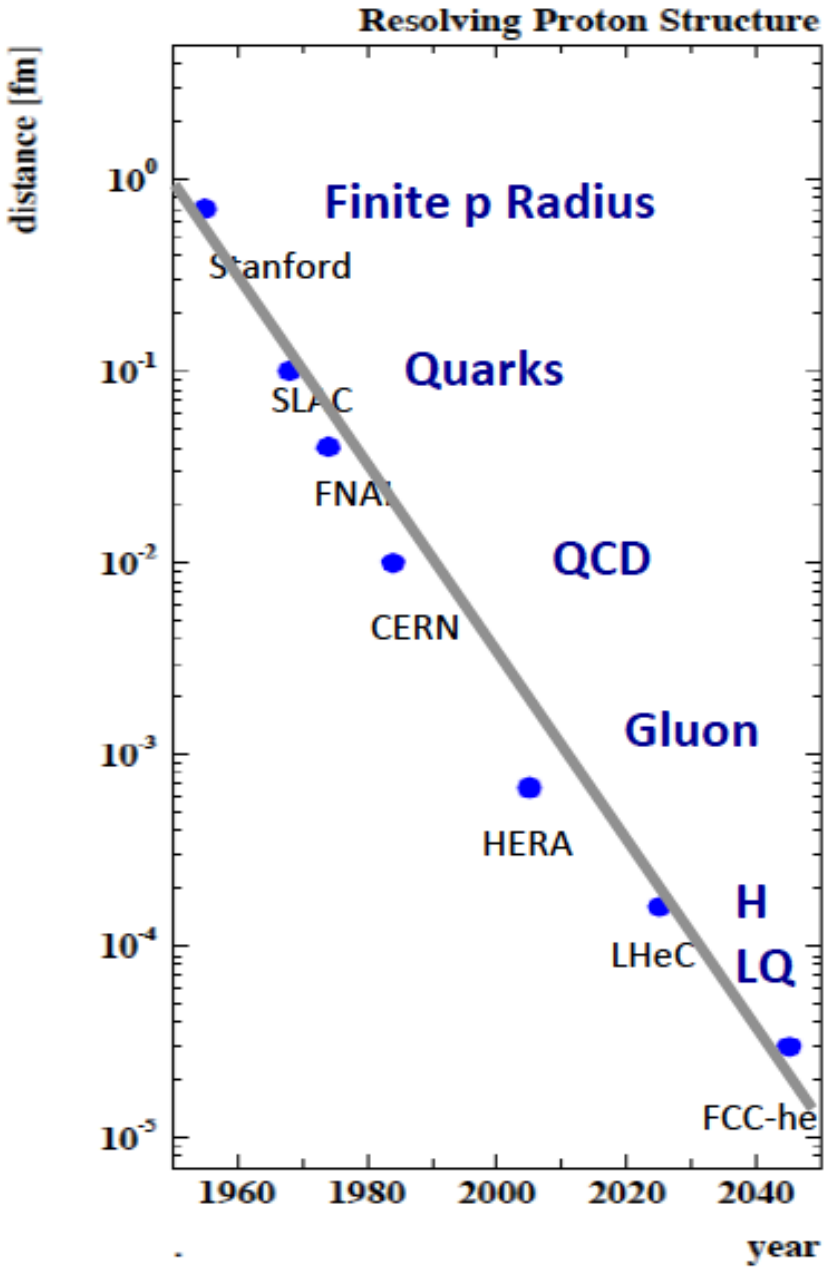


Microscope

Resolve with spectacular range (each high energy ep collider probes range down to SLAC's 0.1fm as Q^2 varies) and precision:

Structure and Dynamics of

Proton, neutron, photon, pomeron, jets..

in Momentum and Transverse Space

PDFs, TMDs, DVCS, generalised PDFs, ..

presented in the LHeC CDR 1206.2913
Short version see arXiv:1211.4831

Can we continue the pass begun 60 years ago for the coming decades?

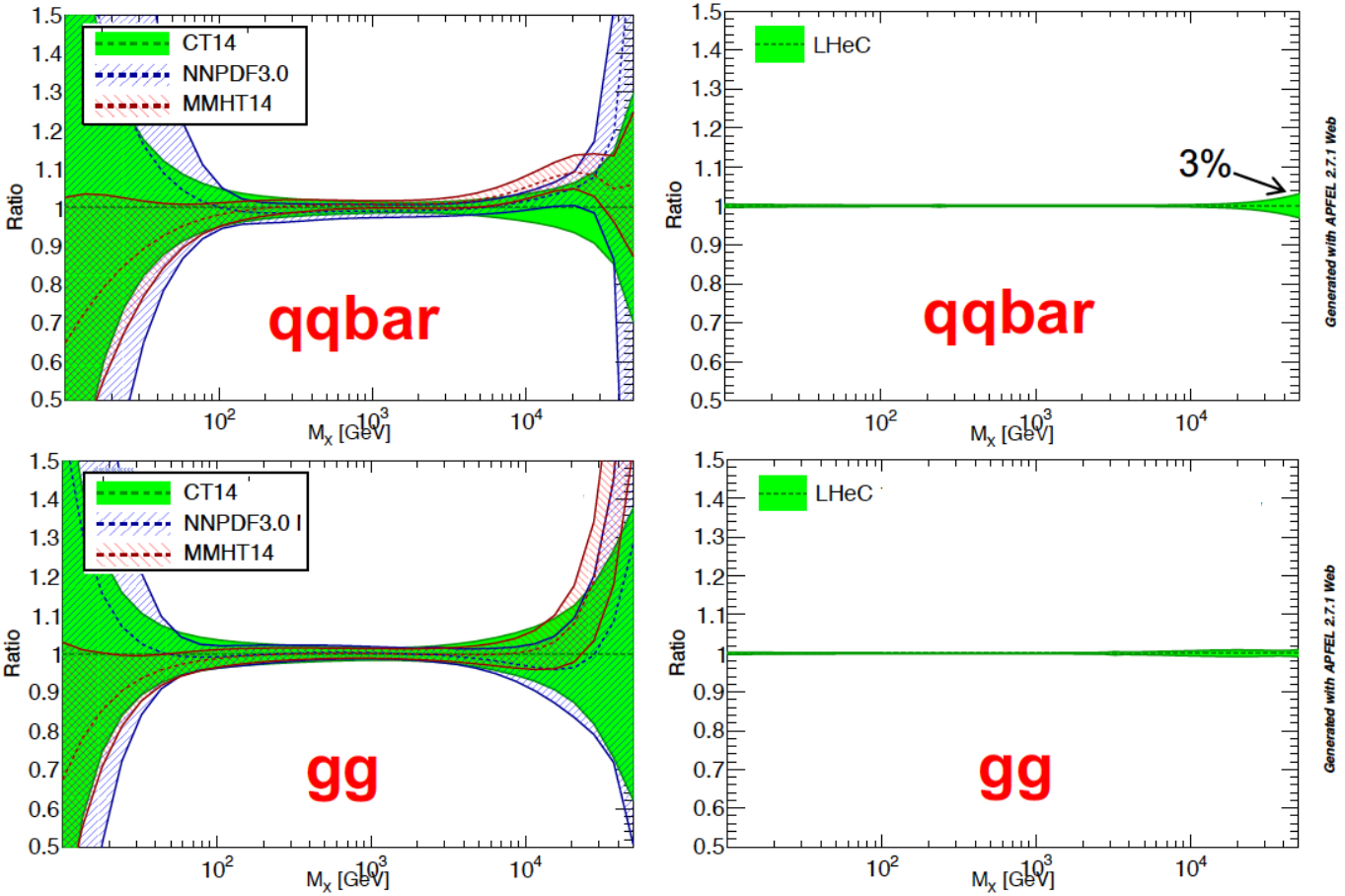
Prospect and challenge:
5 orders of magnitude in 100 years

The LHeC PDF Programme

Resolve parton structure of the proton completely: u_v,d_v,s_v?,u,d,s,c,b,t and xg
Unprecedented range, sub% precision, free of parameterisation assumptions,
Resolve p structure, solve non linear and saturation issues, test QCD, N^{3}LO…

Strong Coupling in inclusive DIS at LHeC to 0.1%

Lattice??
Jets??
BCDMS??
GUTs?
Higgs in pp



Note that LHC is about to reach its own limits on PDFs. pp is NOT DIS, cf ATLAS W,Z to 0.5%

Top Physics

Top electric charge

EDM and MDM

Anomalous t-q-y and t-g-Z

V_{tb}

Top spin

W-t-b

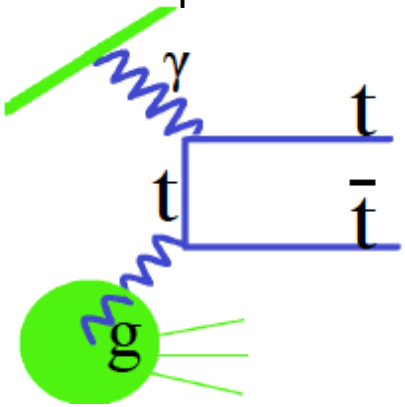
Top PDF

Top mass

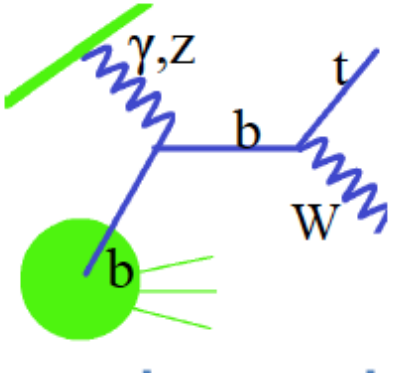
Top-Higgs (1602.04670)

CP nature of ttH (1702.03426)

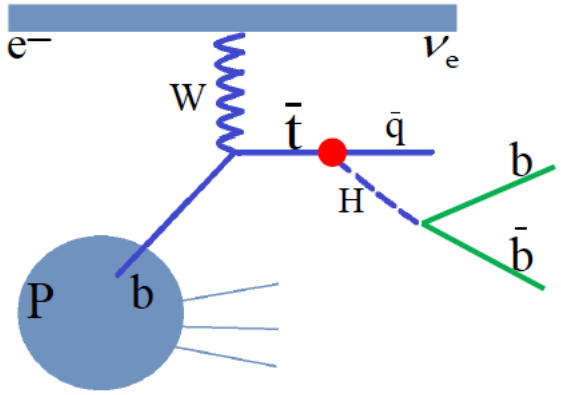
Pair production



Single production



FCNC top Higgs CC interaction



Just started to fully see the huge potential of top physics in ep at high energies

Five Major Themes of LHeC PHysics

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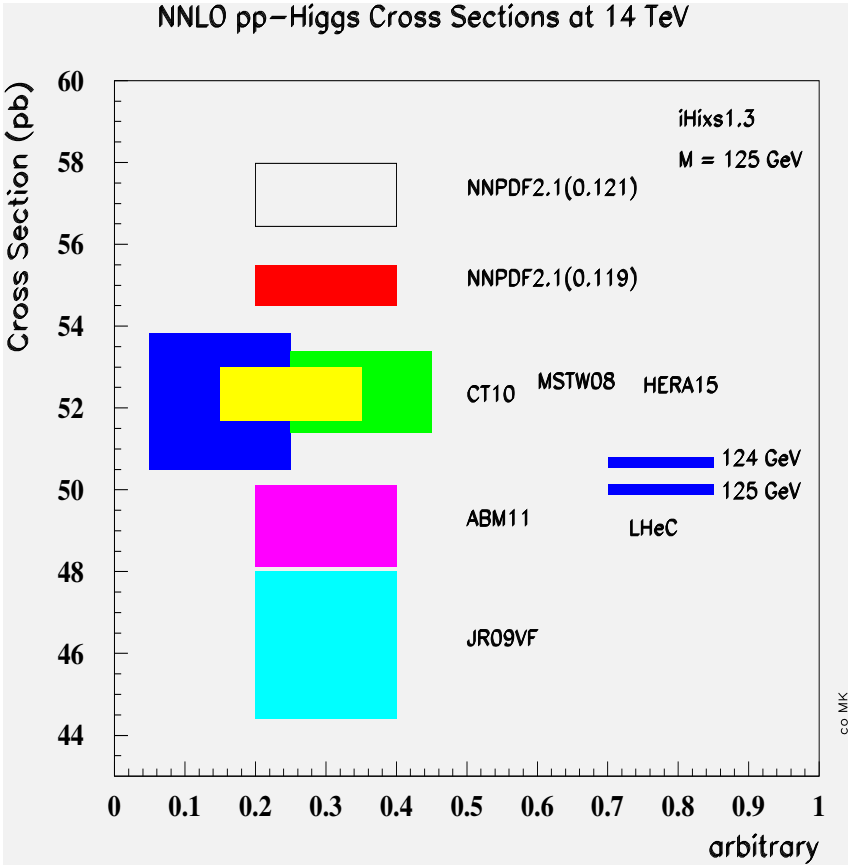
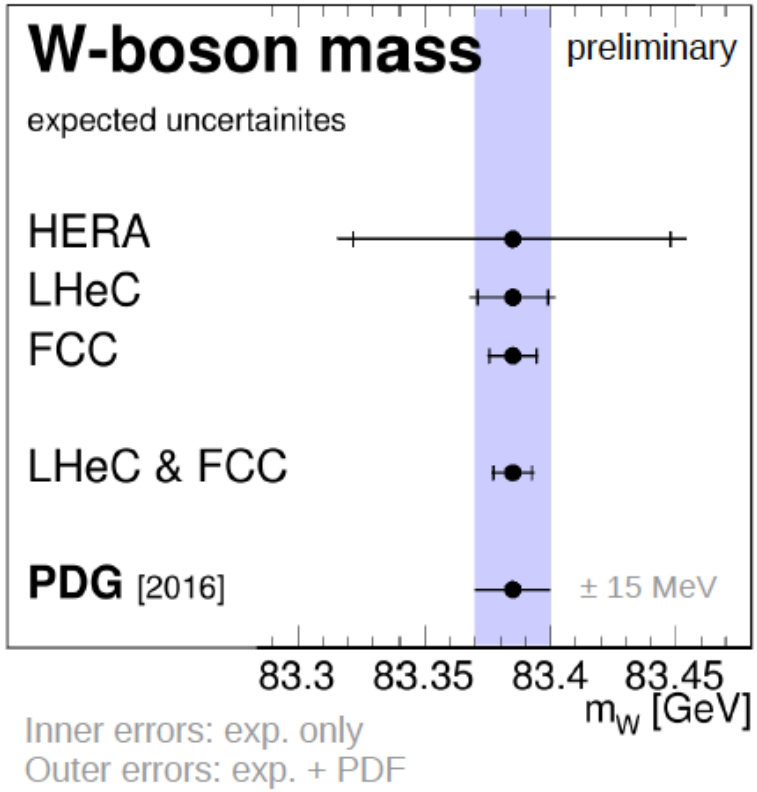
High Precision for the LHC





Predict the Higg cross section in pp to 0.2% precision which matches the M_H measurement and removes the PDF error

Spacelike M_W to 10 MeV from ep
→ Electroweak thy test at 0.01% !

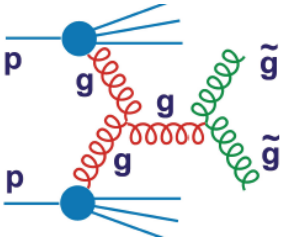
Predict M_W in pp to 2.8 MeV →
Remove PDF uncertainty on M_W LHC

Search Range Extension - worth the Lumi Upgrade

External, reliable input (PDFs, factorisation..) is crucial for range extension + CI interpretation

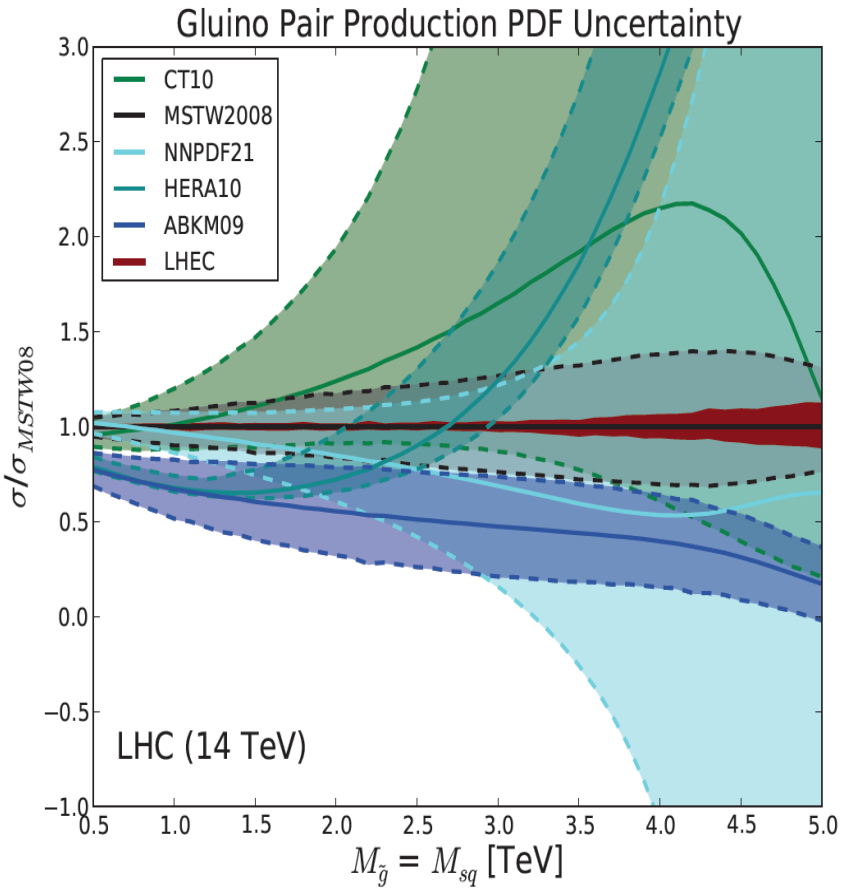
GLUON

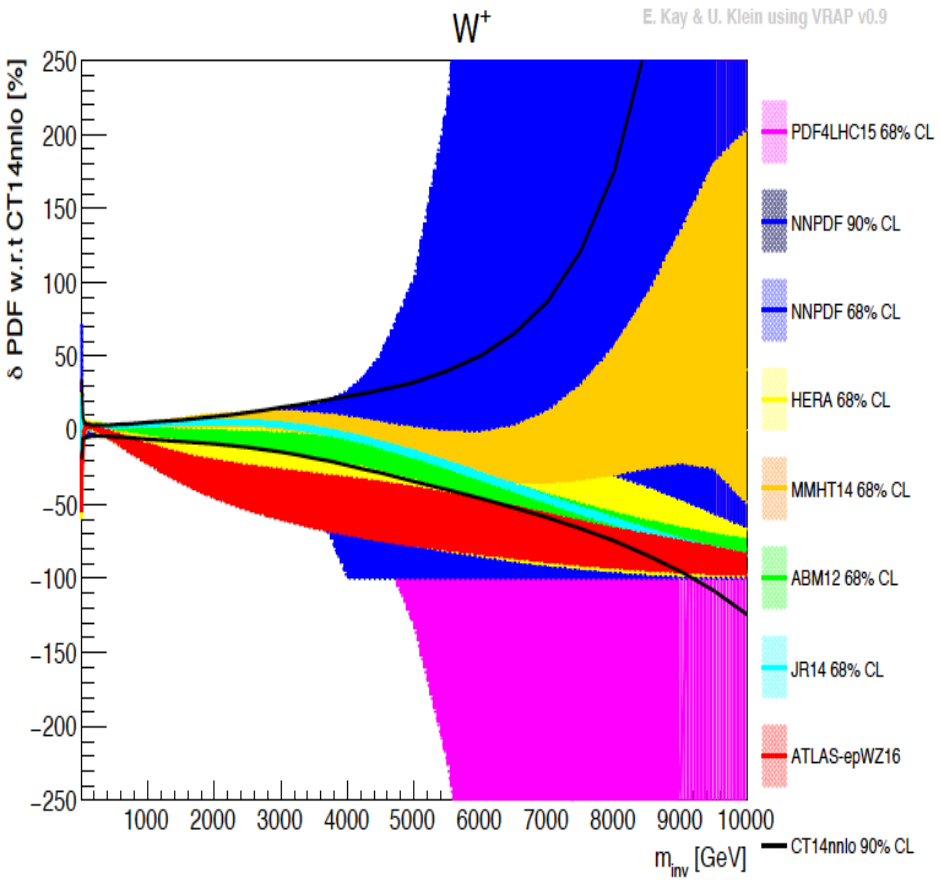
SUSY, RPC, RPV, LQS..



QUARKS

Exotic+ Extra boson searches at high mass





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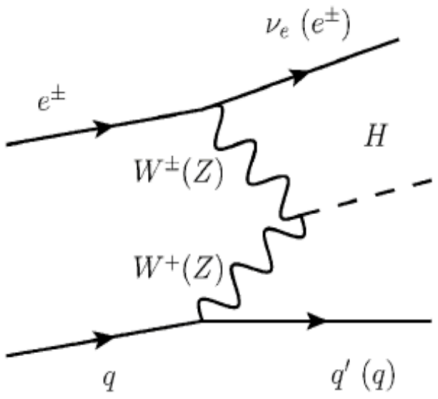

Higgs Physics with ep

κ in %	HL LHC	LHeC HL	LHeC HE	FCC-eh
H → bb	10	0.5	0.3	0.2
H → cc	50?	4	2.8	1.8

- Higgs is produced via an EW process in ep collisions
  - **No contamination from ggF and no pile-up**
  - **Precise theoretical control of the cross-section**
- Superior sensitivity of ep with respect to pp in various aspects:
  - **h → bb,cc,tautau couplings, unique access to WW-H-WW**
    - **Access to h → gg?**
  - **Structure of hVV and top Yukawa couplings**
- Access to hh and invisible decays (dark matter) in ep collisions
- Removal of QCD uncertainties to gg → H calculation for LHC
- **LHC can be transformed into a high precision Higgs facility.**

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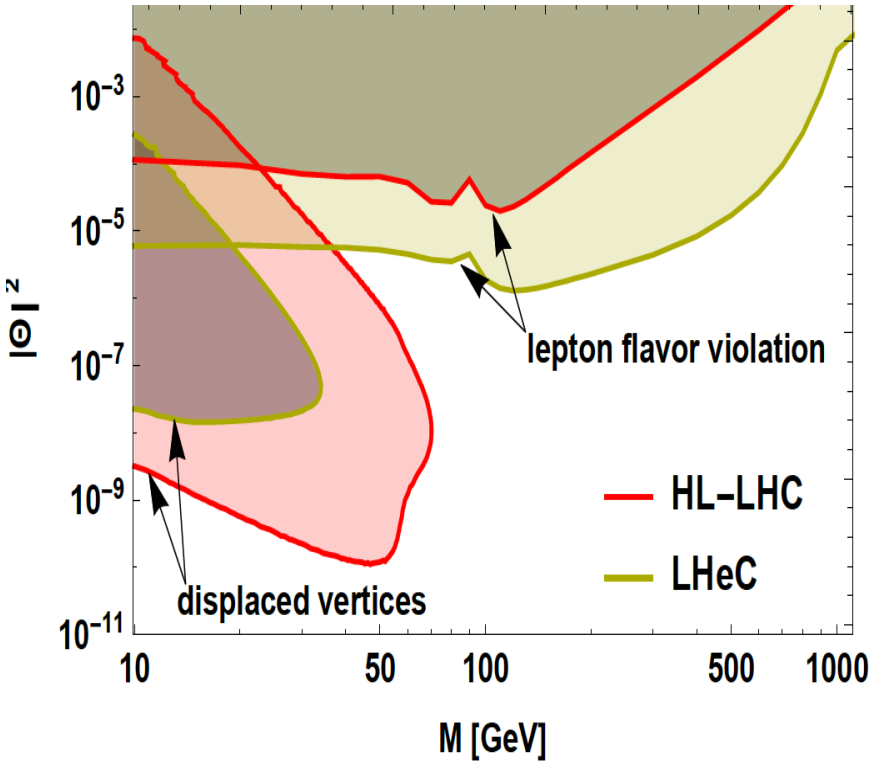
Possible Discoveries Beyond SM with LHeC

Search for Sterile Neutrinos (LHC LHeC)



It is a wasted p that does NOT collide with an e beam
(Oliver Fischer - 2017)

QCD:

No saturation

BFKL

Instantons

Higher symmetry embedding QCD

Electroweak:

EFTs

Exotic Higgs Decays

Extension of Higgs Sector

Sterile Neutrinos …

It would be a waste not to exploit the 7 TeV beams for ep and eA physics at some stage during the LHC time (Guido Altarelli − 2008)

Five Major Themes of LHeC PHysics

The Cleanest High Resolution Microscope of the World

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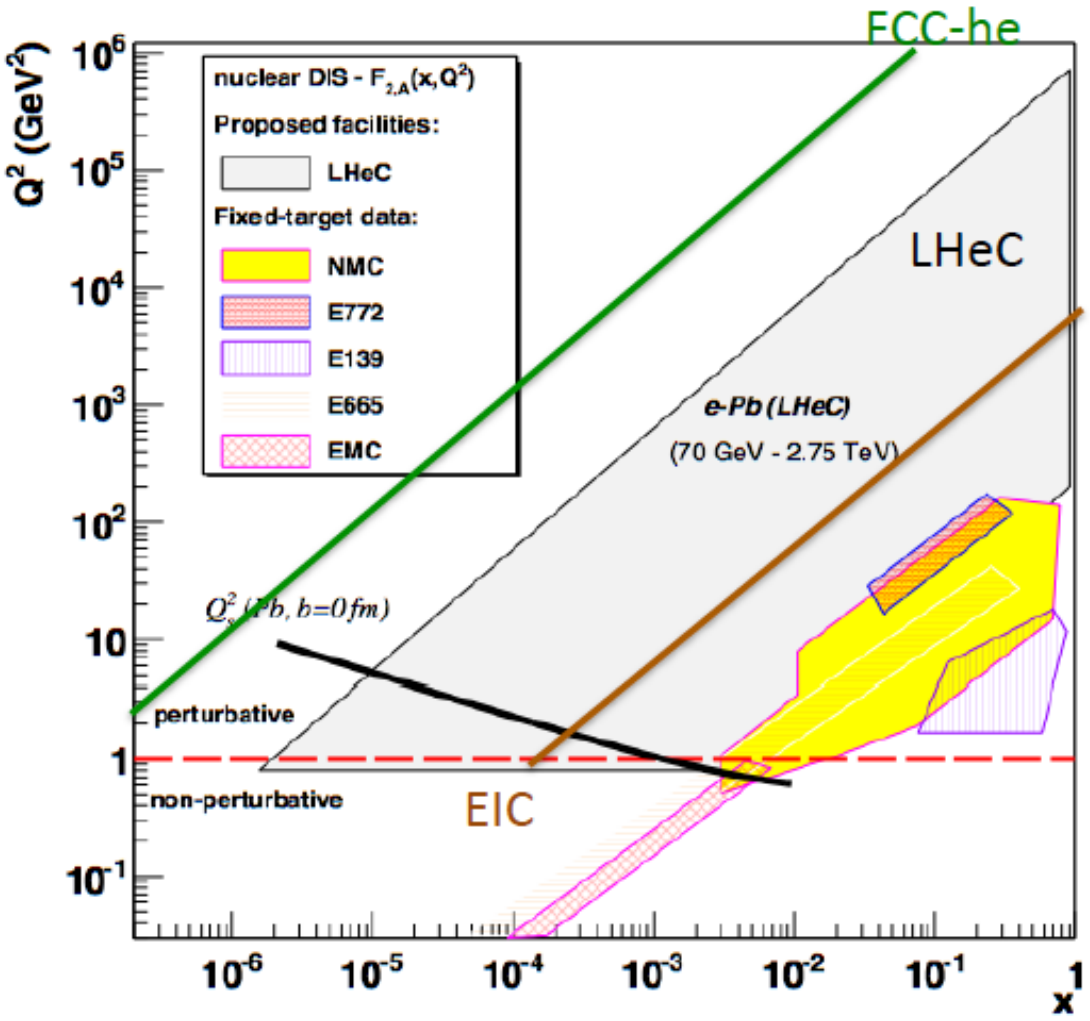
Electron-Ion Nuclear and Particle Physics



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

May lead to genuine surprises…

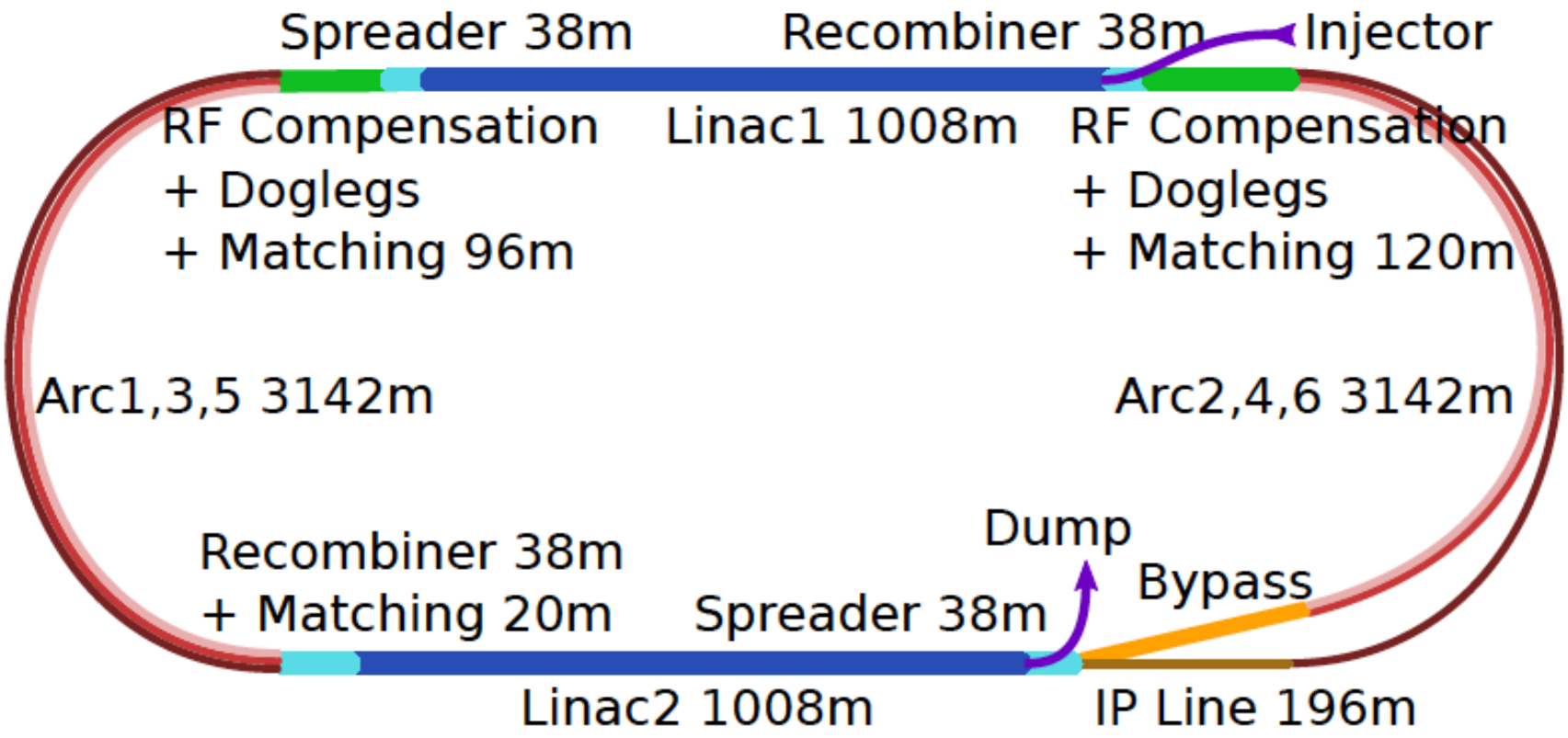
- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

Relates to LHC Heavy Ion Physics
- Quark Gluon Plasma
- Collectivity of small nuclei (p)?
- ..

Saturation: needs large xg at small x
ep and eA

Design and Preparations

LHeC ERL Baseline Design



Concurrent operation to pp, LHC becomes a 3 beam faclity. P < 100 MW. CW

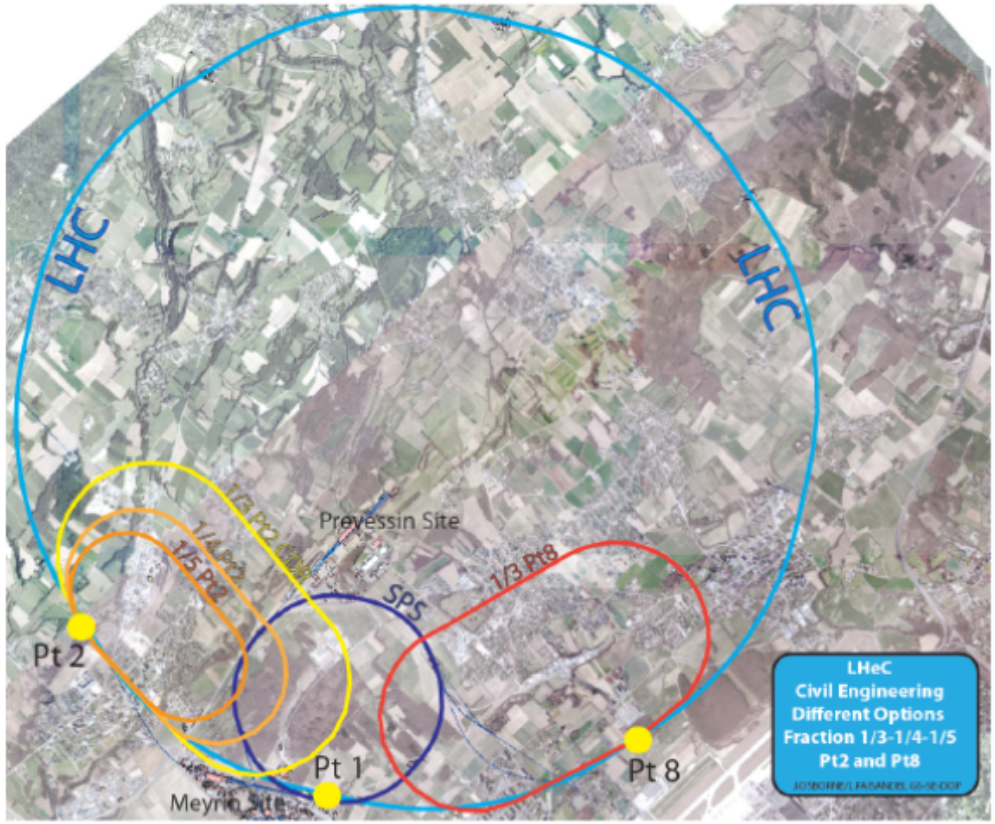
Luminosity for LHeC, HE-LHeC and FCC

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
electrons per bunch [10^9]	1	2.3	3.0	3.0
electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	1	8	12	15

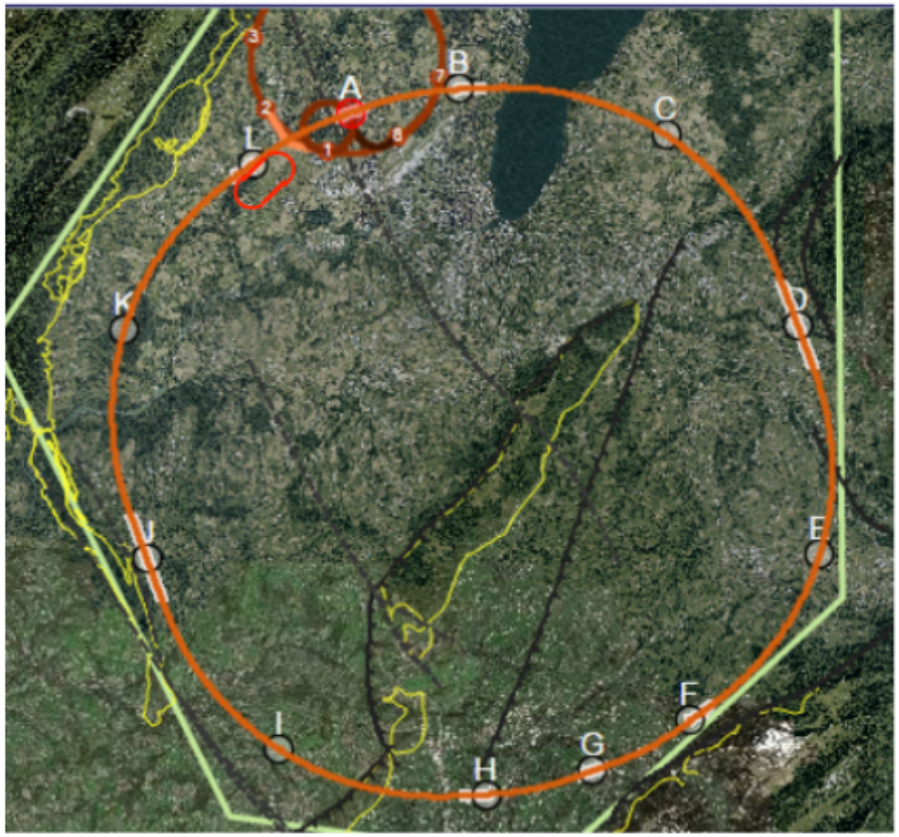
Oliver Brüning[1], John Jowett[1], Max Klein[1,2],
Dario Pellegrini[1], Daniel Schulte[1], Frank Zimmermann[1]
[1] CERN, [2] University of Liverpool
April 6th, 2017

Location + Footprint of the electron ERL

LHC



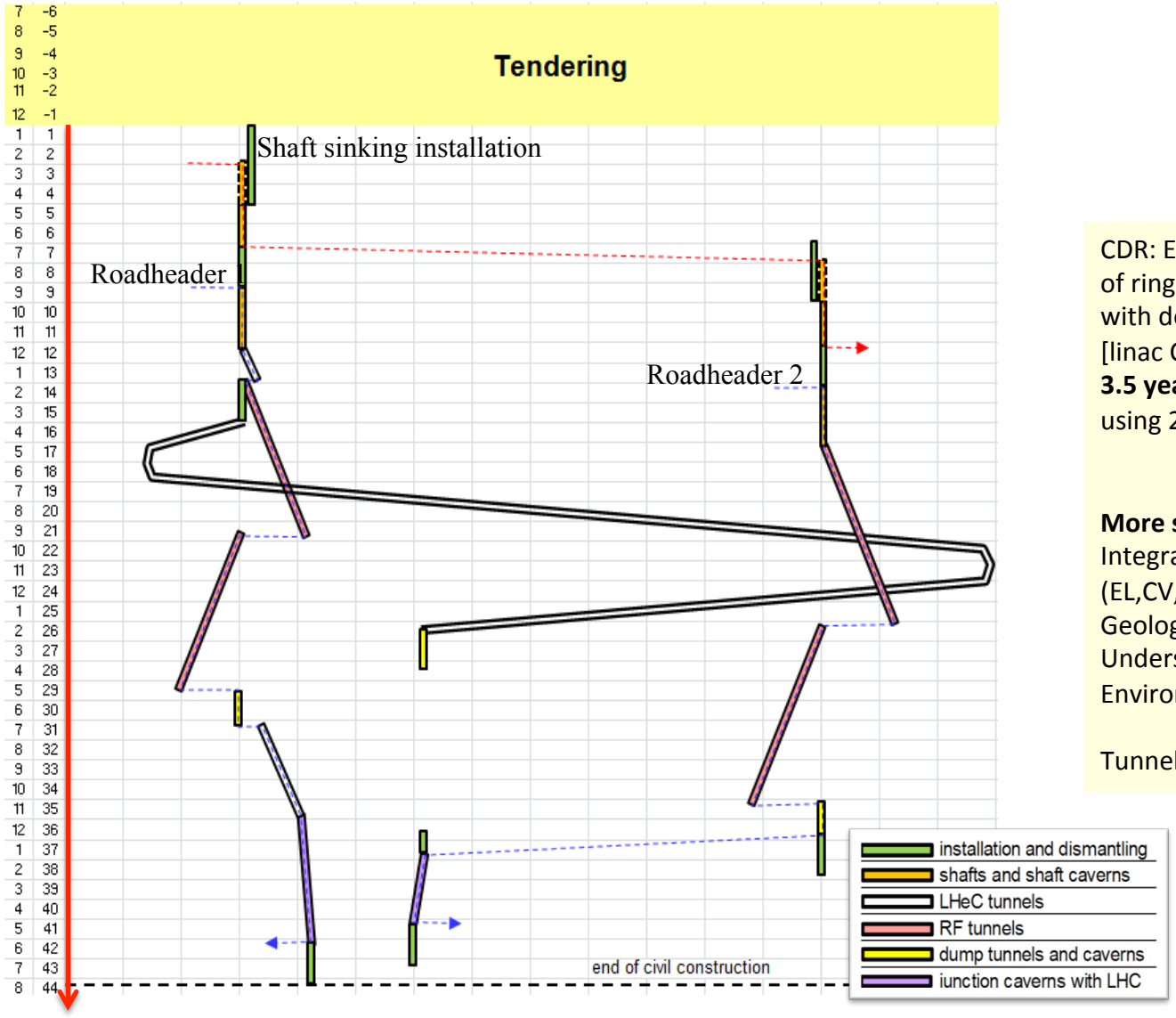
FCC



Energy – Cost – Physics – Footprint
are being reinvestigated

A 9km ERL is a small add-on for the FCC
Doubling the energy to 120 GeV hugely
Increases cost and effort.

Civil Engineering – full design made



CDR: Evaluation of CE, analysis of ring and linac by Amber Zurich with detailed cost estimate [linac CE: 249,928 kSF..] and time: **3.5 years for underground works** using 2 roadheaders and 1 TBM

More studies needed for
Integration with all services (EL,CV, transport, survey etc).
Geology
Understanding vibration risks
Environmental impact assessment

Tunnel connection in IP2

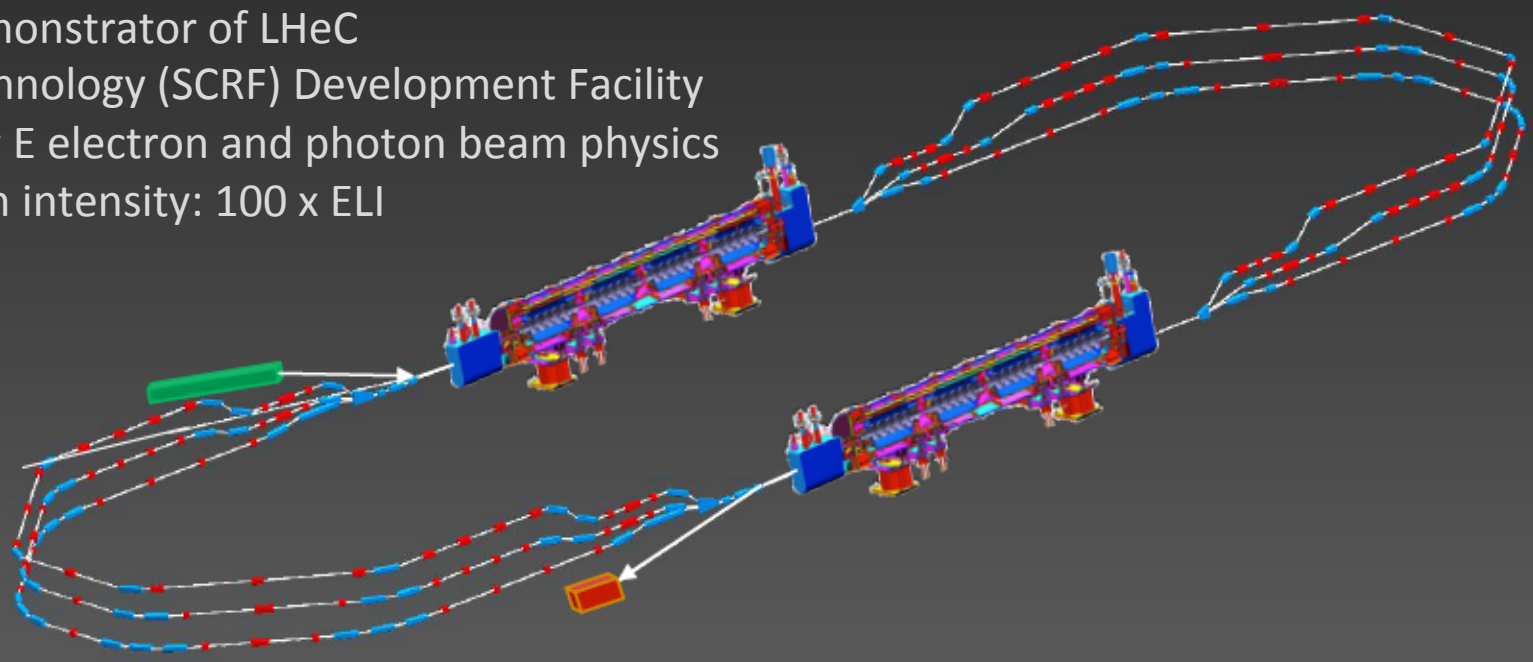
J.Osborne et al.

PERLE TDR Kickoff Meeting, Orsay, February 22-24, 2017. PERLE CDR subm to JPhysG

Powerful ERL for Experiments (ep.yp): PERLE at Orsay

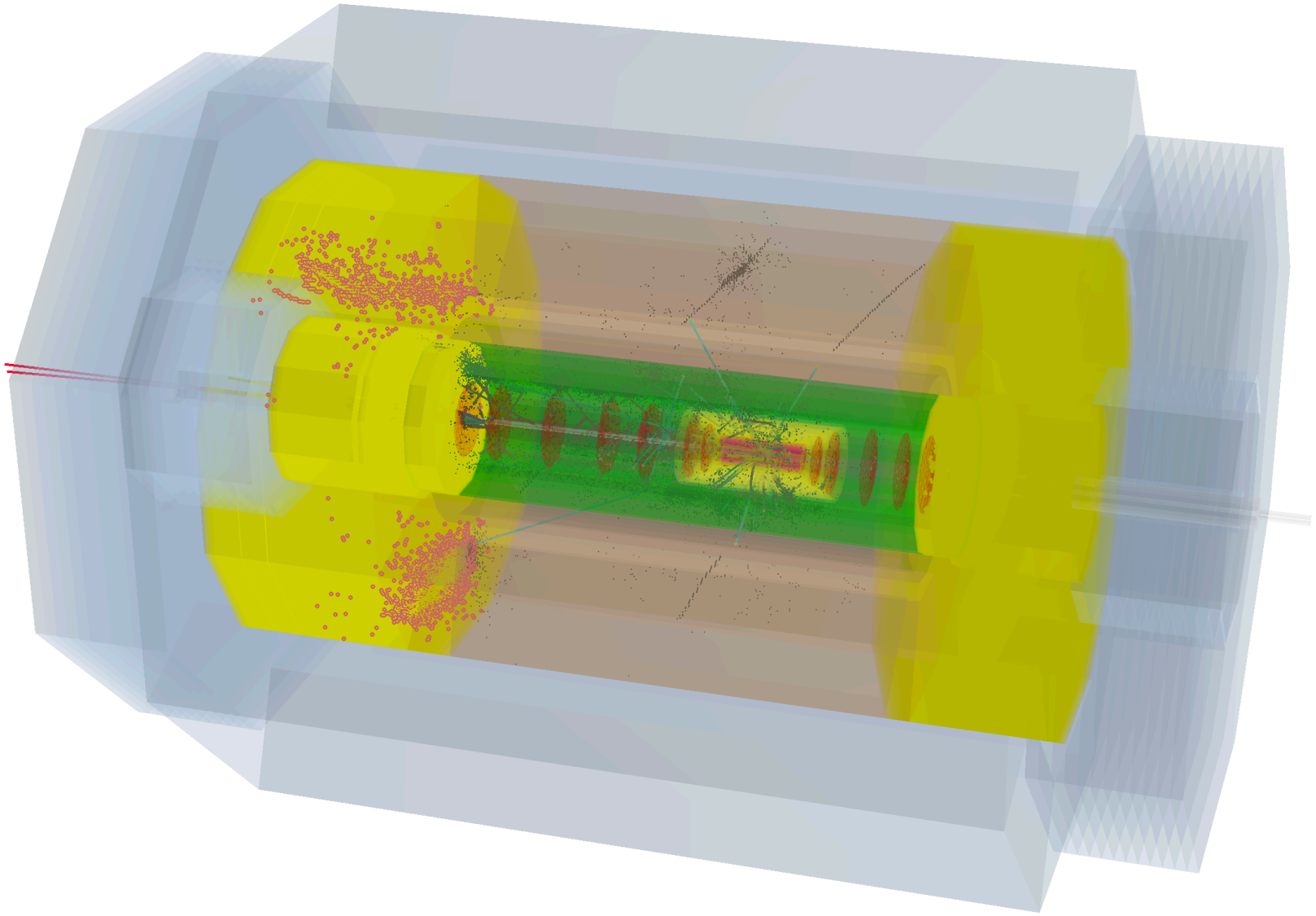
PERLE at Orsay: New Collaboration: BINP, CERN, Daresbury/Liverpool, Jlab, Orsay +

CDR publication imminent.
3 turns, 2 Linacs, 15mA, 802 MHz ERL facility
-Demonstrator of LHeC
-Technology (SCRF) Development Facility
-Low E electron and photon beam physics
-High intensity: 100 x ELI

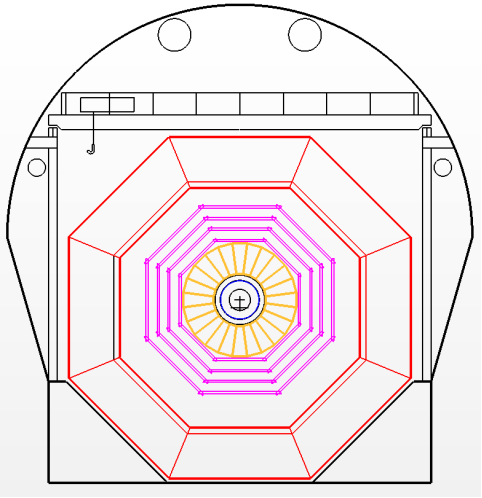


See https://indico.lal.in2p3.fr/event/3428/

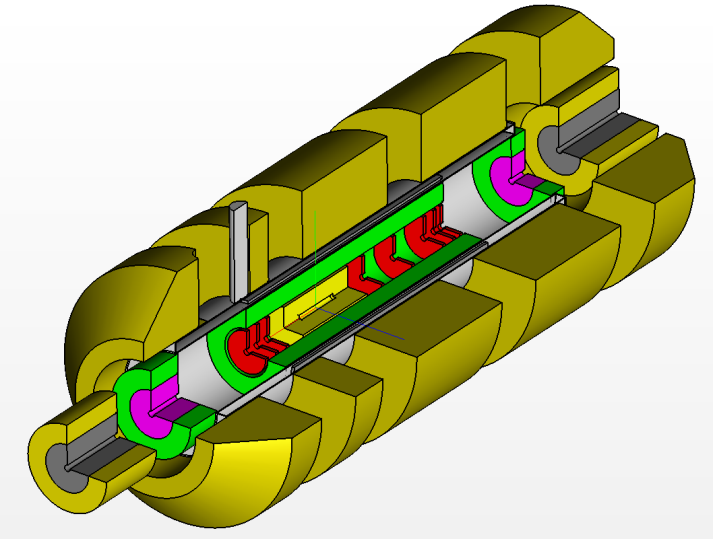
H→ bb in LHeC Detector



Installation Study
2 years (in LS4)



Detector fits in L3 magnet support



Modular structure

LHeC INSTALLATION SCHEDULE

ACTIVITY	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
DETECTOR CONTRUCTION ON SITE TO START BEFORE LHC LONG SHUT-DOWN								
LHC LONG SHUTDOWN START (T0)								
COIL COMMISSIONING ON SURFACE								
ACTUAL DETECTOR DISMANTLING								
PREPARATION FOR LOWERING								
LOWERING TO CAVERN								
HCAL MODULES & CRYOSTAT								
CABLES & SERVICES								
BARREL MUON CHAMBERS								
ENDCAPS MUON CHAMBERS								
TRACKER & CALORIMETER PLUGS								
BEAMPIPE & MACHINE								
DETECTOR CHECK-OUT								
LHC LONG SHUTDOWN END (T0+24m)								

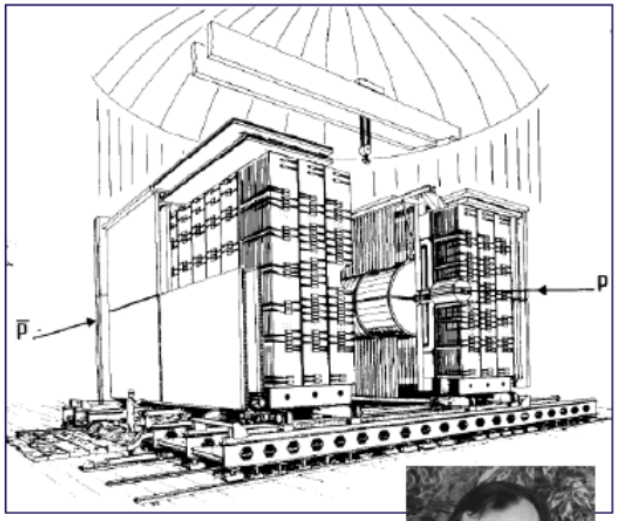
"The future belongs to those who believe in the beauty of their dreams."

Anna Eleanor Roosevelt
(1884-1962)

Universal Declaration of Human Rights (1948)

cited by Frank Zimmermann at the FCC Meeting at Washington DC, March 2015

CERN can do pp and lp: in the 80ies it successfully did



UA1

" We have two tasks: kill Weinberg Salam, kill QCD"
Carlo Rubbia: 1978 BCDMS meeting at Dubna.
The failure to fulfill his task made Carlo famous…

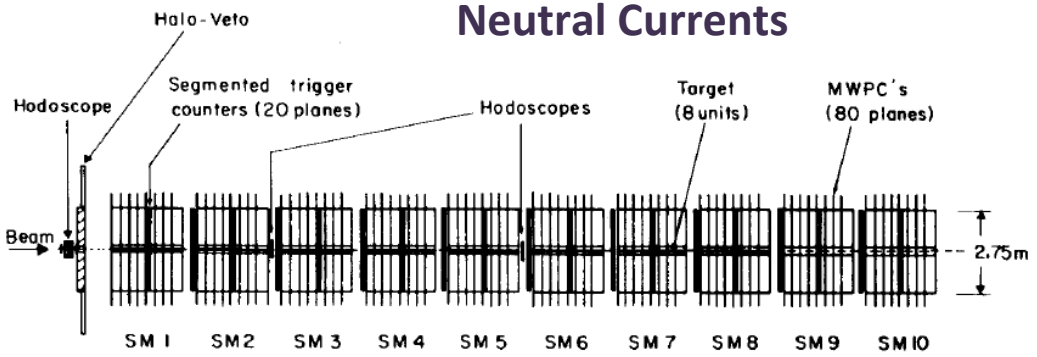
UA2

Pierre Darriulat
now in Vietnam

Charged Currents

BEBC, **CDHS(W)**, CHARM, CHORUS

Neutral Currents



BCDMS, EMC, SMC, COMPASS

Electron-Hadron Scattering at the Energy Frontier – A Higgs Physics Facility Resolving the Substructure of Matter

Draft Table of Contents (9. June 2016)

1. Introduction: The LHC, Modern Particle Physics and the Rôle of ep/eA
2. Physics: QCD/PDFs, Higgs, top, BSM, small x, eA at the LHeC; key items at 1.9/3.4 TeV
3. ERL electron beam: Design, Components, Injector, Dump, Civil Engineering ..
4. LHeC Performance: Collider Parameters, Luminosity, Joint Operation, Infrastructure..
5. Detector: Machine Interface (IR), Design and Performance, Components, Software
6. Installation of the Machine and Detector
7. Summary

Appendix:

- Status of the LHeC Demonstrator and ERL Developments
- Cost-Energy Relation and Cost Estimate for LHeC
- Detector Cost Estimate
- Extensions into the HE LHC Phase
- Electron-Hadron Scattering with the FCC (link to FCC CDR)

In agreement with DG we Work on an update of the LHeC CDR as input to Euro Strategy. We find it is worth it the deeper we look.

We'd be glad to have many of you with us.

Update of the LHeC CDR*) and input to EU Particle and Nuclear Physics Strategy

*) arXiv:1206.2913

The LHeC − Science + Status