

News on the LHeC and the FCC_he

Max Klein
U Liverpool and CERN
For the LHeC Coordination Group



Physics
Updates
Schedule
Footprint
Executive Remarks
FCC
Two Options



Talk for Discussion - Meeting of the Advisory Committee, CERN, Geneva, 26. June 2014

<http://lhec.web.cern.ch>

← new web page since a few weeks

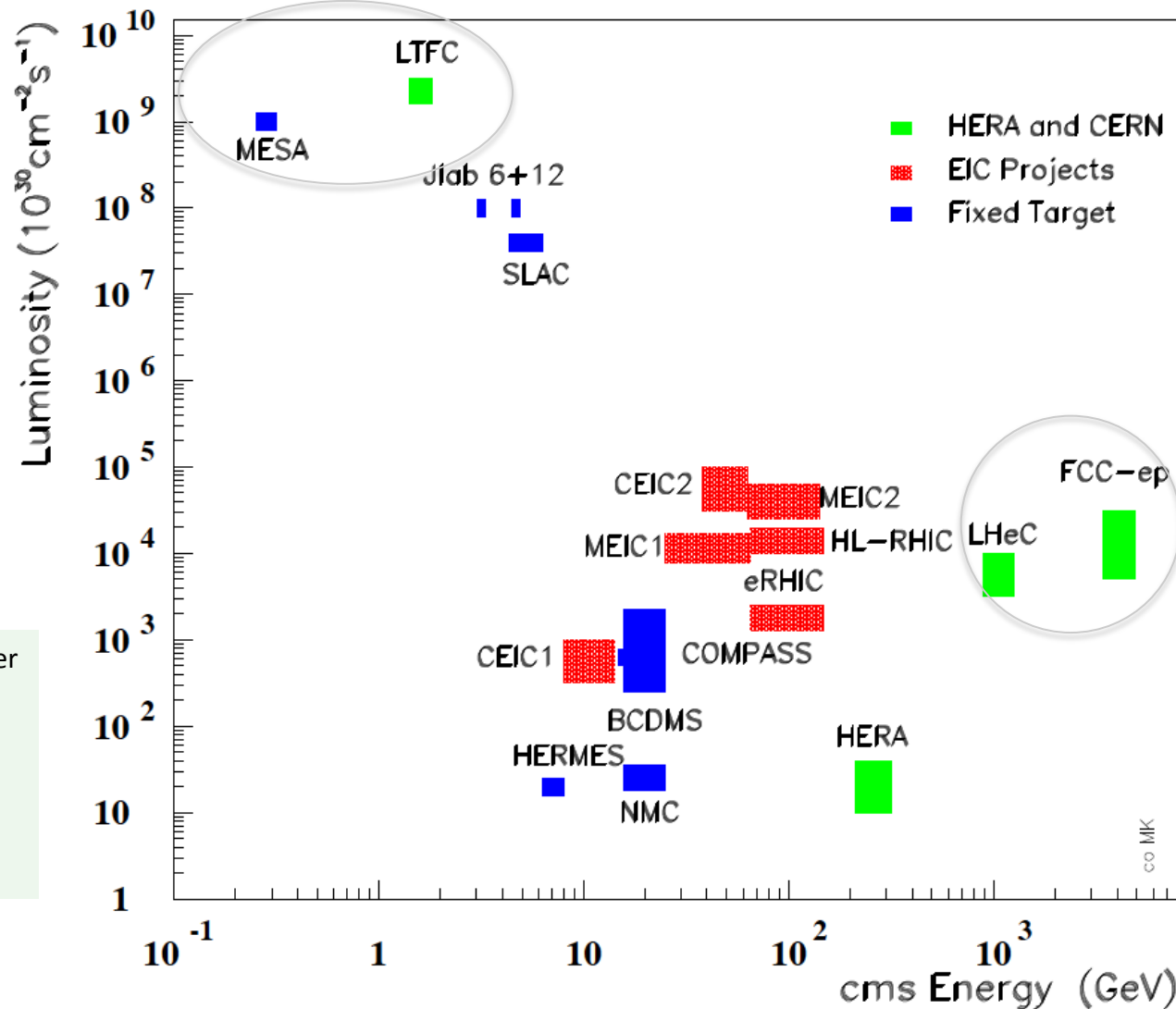
Today

| | | |
|-------|-------------------------------------|-----------------------------|
| 09:00 | 0 - Opening | <i>Prof. Herwig SCHOPPE</i> |
| | 1 - Recent Developments | <i>Max KLEIN</i> |
| | CERN | 09:15 - 10:00 |
| 10:00 | 2 - Higgs Physics in ep | <i>Bruce MELLADO GARCIA</i> |
| | CERN | 10:00 - 10:30 |
| | 4 - LHeC Performance | <i>Daniel SCHULTE</i> |
| | CERN | 10:30 - 11:00 |
| 11:00 | Coffee Break | 11:00 - 11:30 |
| | 6 - Civil Engineering | <i>John Andrew OSBORNE</i> |
| | 160-1-009, CERN | 11:30 - 12:00 |
| 12:00 | 7 - Testfacility Development | <i>Oliver BRUNING</i> |
| | 160-1-009, CERN | 12:00 - 12:30 |
| | 8 - RF Development | <i>Erk JENSEN</i> |
| | 160-1-009, CERN | 12:30 - 13:00 |
| 13:00 | Lunch | |

Please note the posters on
Testfacility (for today)
Higgs (Master thesis)
Detector (for ICHEP)
Interaction Region (from IPAC)

Lunch of IAC with Speakers and Coordination Group (in R1 “glassbox”)
Restart at 14.30 with closed session of IAC in this room.

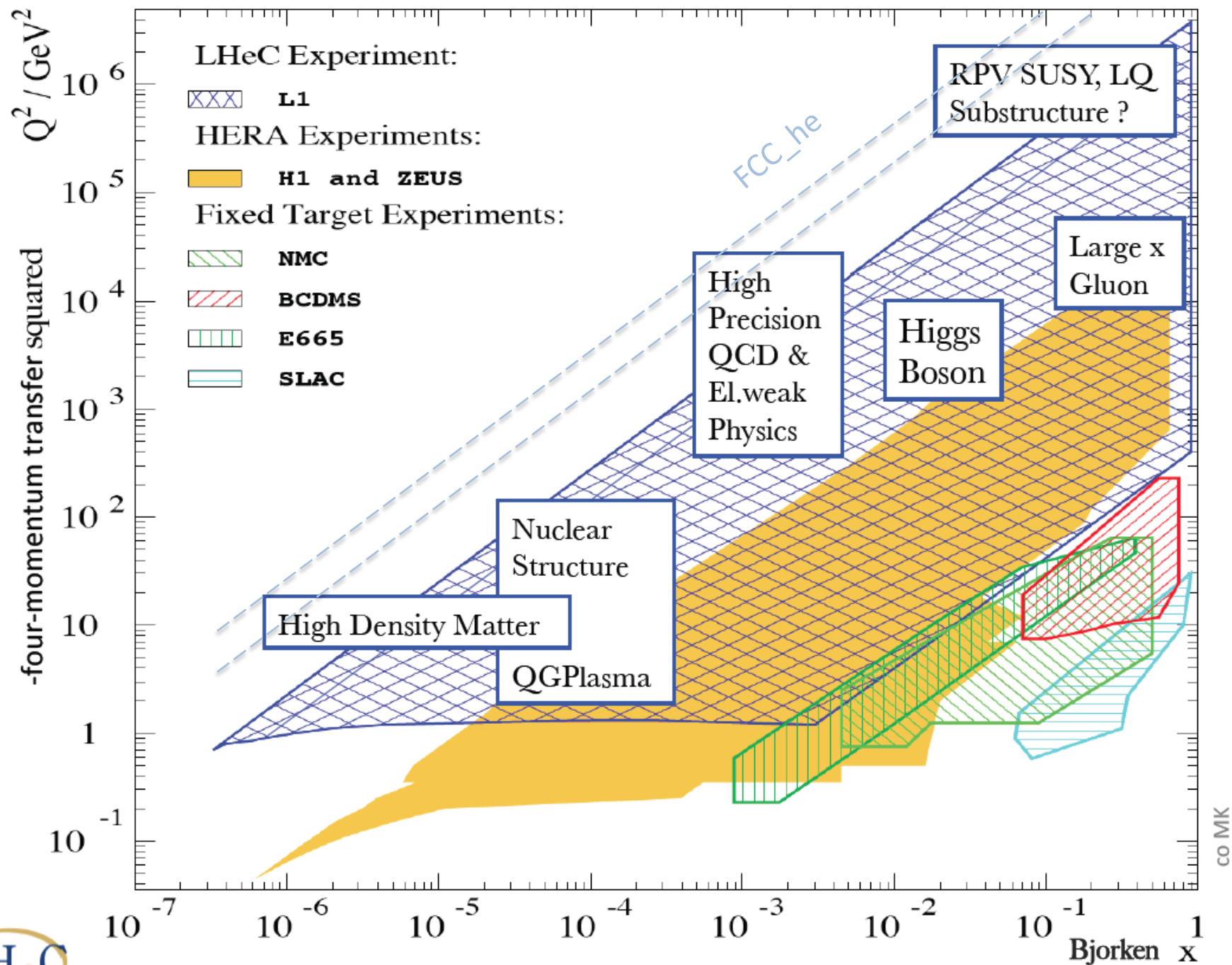
Lepton-Proton Scattering Facilities



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



$ep \rightarrow \nu H(bb)X$

charged currents

$\sigma_{BR} \sim 120 \text{ fb}$

$S/B \sim 1-2 \rightarrow$ crucial for QCD of H

$\mu = 0.1$

1% coupling at 1 ab^{-1}

$H \rightarrow b\bar{b}$

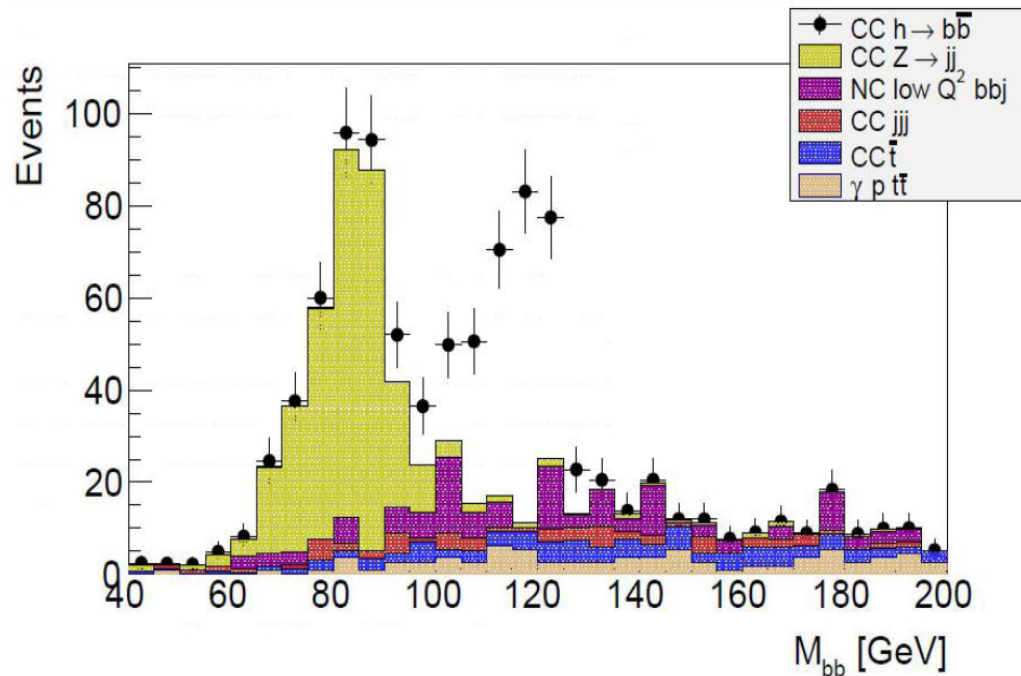
$pp \rightarrow X_1 W(l\nu) H(bb) X_2$

associated VH

$\sigma_{BR} \sim 130 \text{ fb}$

$S/B < \sim 0.01$

$\mu \sim 40$

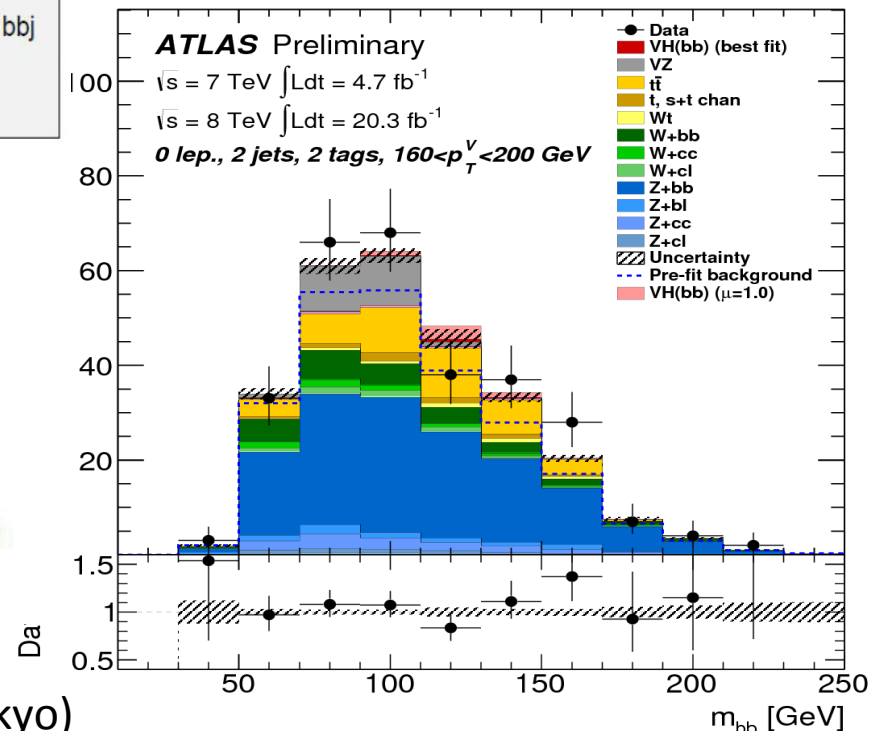


ep (new) Simulation 100 fb^{-1}

Ellis Kay (U Liverpool) ~ ok with M.Tanaka (Tokyo)

Master Thesis 5/14 with U.Klein

Next: PGS \rightarrow LHeC detector + optimisation

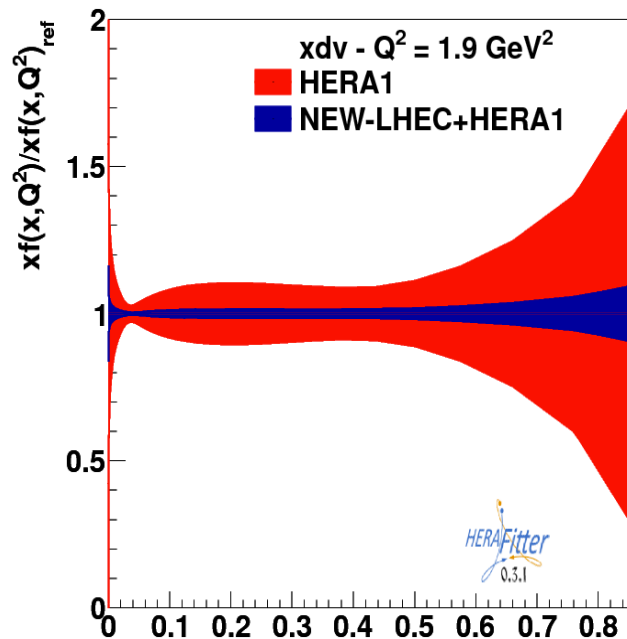
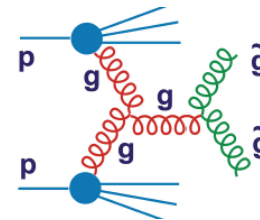


pp 2013: Measurement

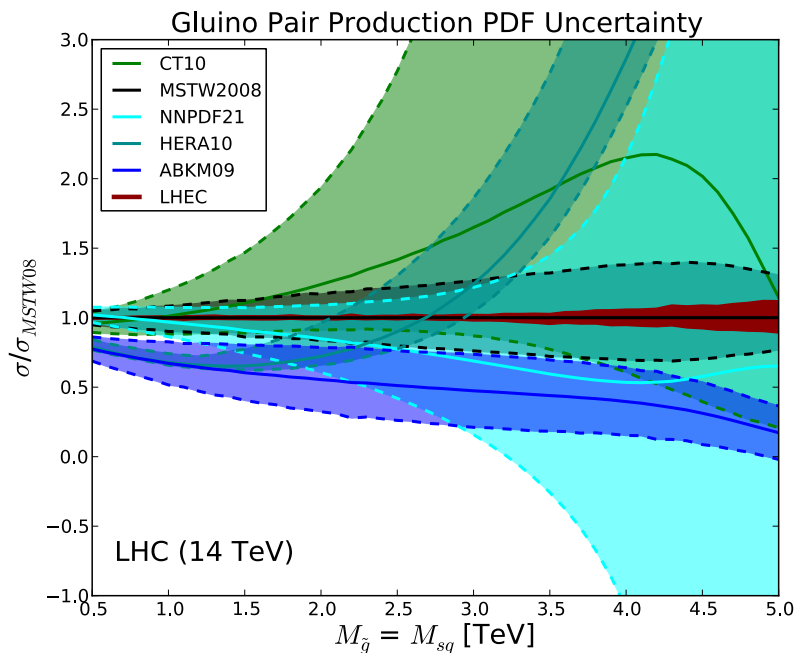
ATLAS CONF-2013-079

down valence

Parton Distributions



V Radescu, MK [pdf set on LHAPDF]



M D'Onofrio, R.Kleiss et al

LHeC: arXiv:1211.5102

Why important: Low x: nonlinear evolution?, 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, N³LO (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..

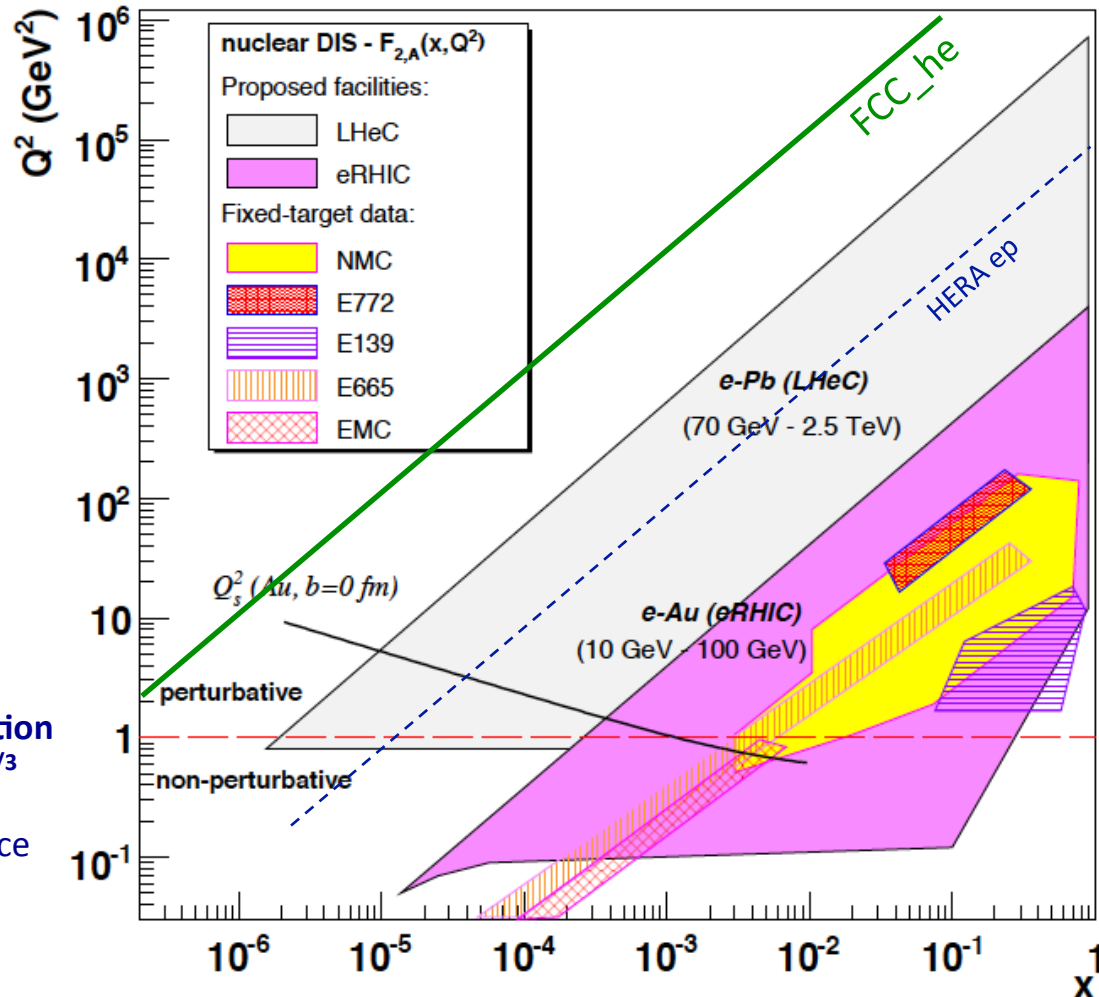
There are MANY more PDFs than some may want: nuclear, diffractive, photonic, unintegrated, generalised

Remarks on the EIC(s)

LHeC is part of NuPECCs long range plan since 2010

$$L_{eN} > 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$$

- No saturation of xg ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?
- **Nuclear PDFs for the first time**
- Initial state of QGP
- ...



Suppose there had been no HERA...

Some expect saturation
 $Q_s^2 \approx xg \alpha_s \approx c x^{-\lambda} A^{1/3}$

Note that xg is valence like at low Q^2 !

Rather: non-linear evolution of PDFs
 → Crucial for FCC_hh

EIC: nuclear holography at medium x and p spin
LHeC: saturation and weak nuclear interactions
 → The machines are NOT at all the same but genuinely and positively complementary

D.D'Enterria
 arXiv:0706.4182

For EIC cf R.Ent
 at DIS2014

Update on Events 2014

since first IAC meeting in January

January – Workshop at Chavannes [cf lhec.web.cern.ch]
February – FCC Kickoff [2 plenary talks, 8 in parallel session(s)]
March – EIC Workshop at Jefferson Laboratory [6 talks]
April – DIS Workshop at Warsaw [5 talks]
May – FCC_hh Workshop, 2nd Meeting of Coordination Group (LCG)
June – IPAC14 at Dresden, Endorsement of the MTP (SCRF 802 MHz)
July – ICHEP [3 talks, 3 posters]
August – QCD at LHC [1h plenary invited]
September – POETIC
October – ICFA at Beijing (tbc)

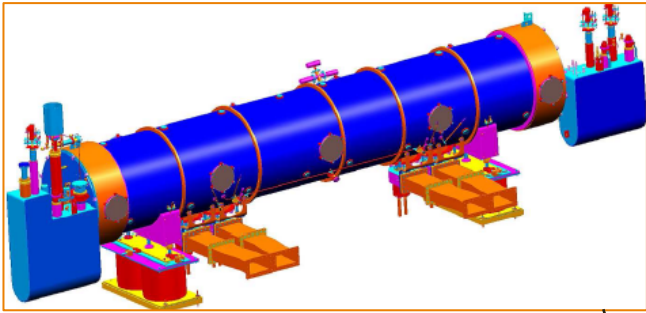
Need to carefully select conferences we attend

Started joint EIC workshops besides DIS (Accelerator and POETIC)

Conference organisation by Nestor Armesto

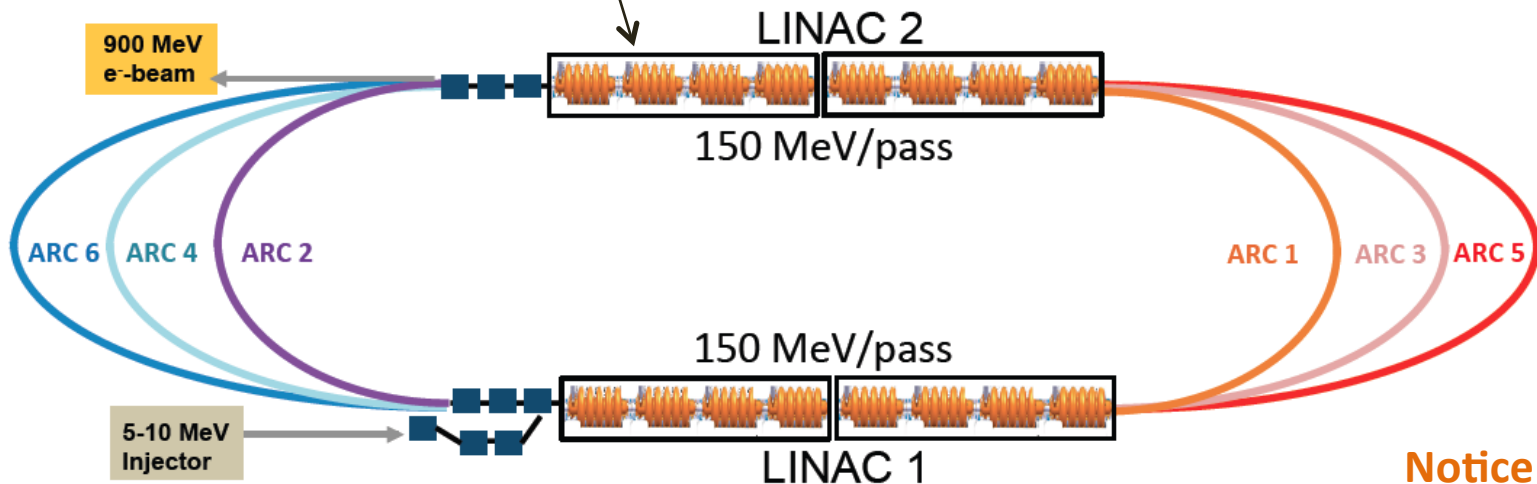
SCRF and LTFC

superconducting RF and ERL Test Facility at CERN



A.Hutton, B. Rimmer, E.Jensen et al.
MoU between CERN and Jlab - signed

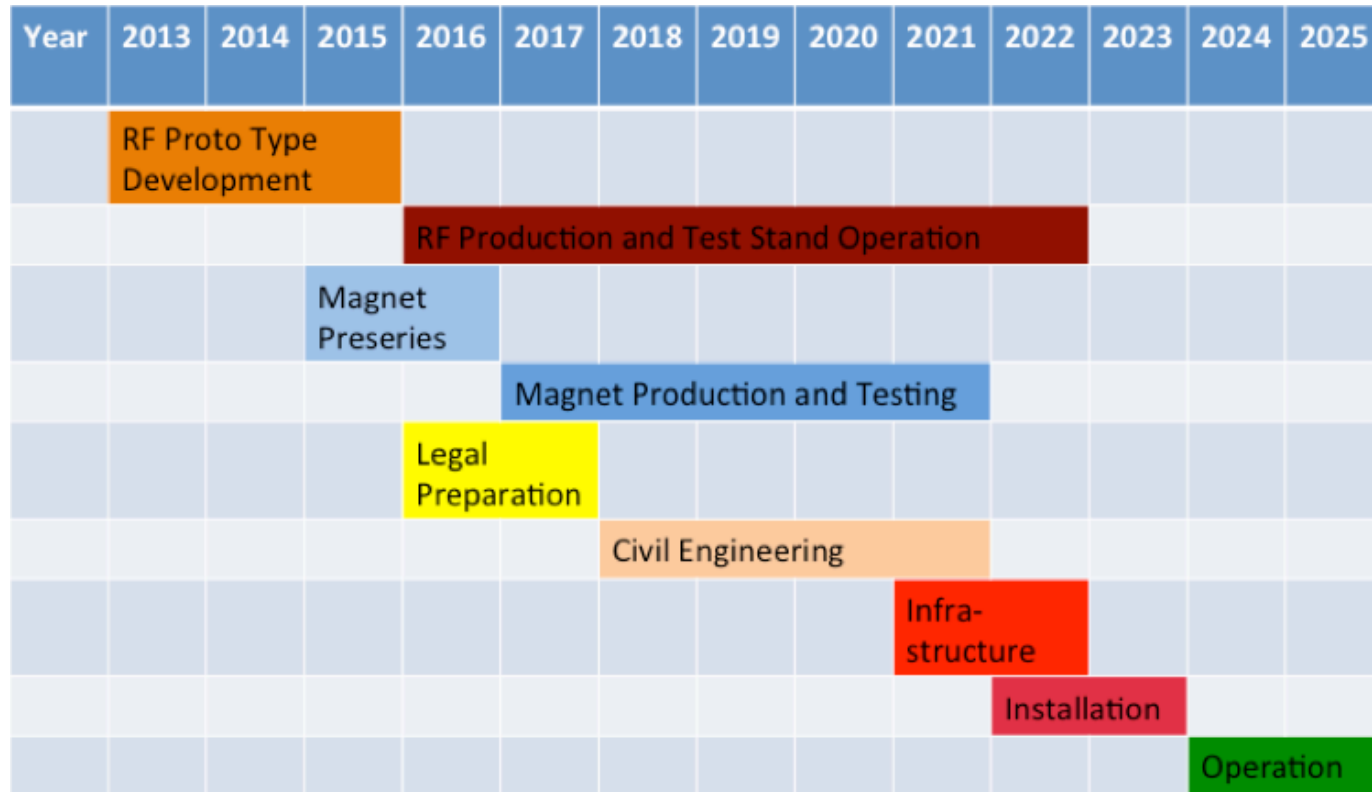
Frequency 802 MHz
Design and built of 2 Modules (CERN+Jlab+?)
Tentative Design of the LTFC – end of 2014:
Collaborations for Source (Cornell, CI,?),
Magnets (BINP, IHEP Beijing?), Operation
(AsTEC), Applications (TU Darmstadt, CERN
Users, ..) – **look for guidance from IAC**
cf Talks today by Erk Jensen + Oliver Brüning



Notice Poster

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

Time Schedule – 1 – Electron Beam



Schedule
from the
CDR 7/2012

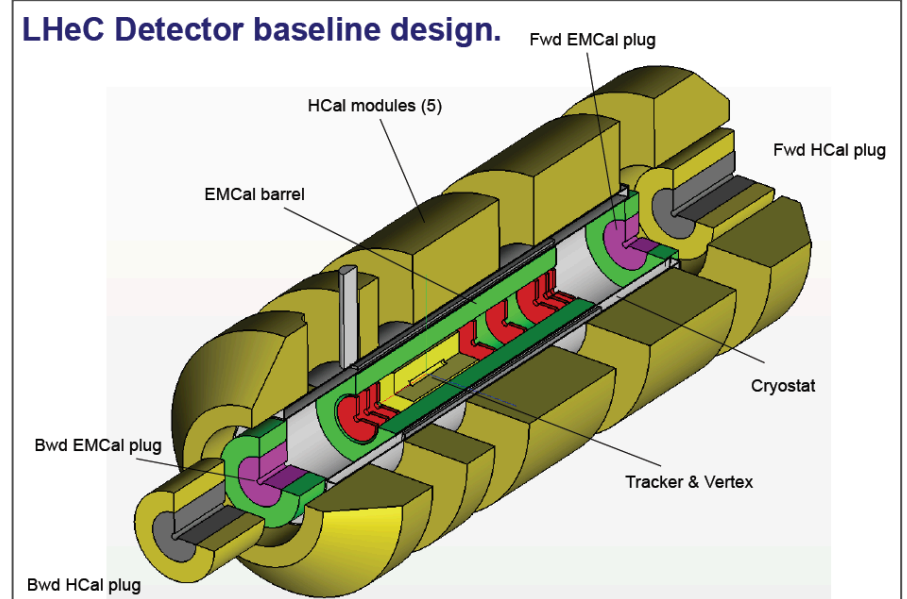
LHeC – is an about 10 years project from approval to start.

HERA (e and p beams) : proposal 1984 – beam 1992. DESY XFEL: 8 years (RB)

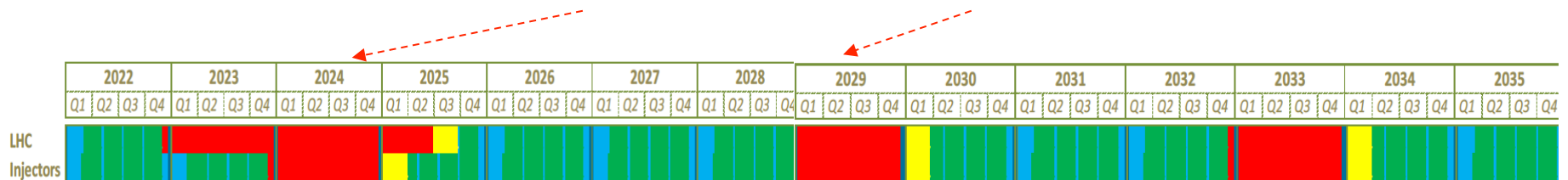
The real installation plan will need to be agreed upon in the process of endorsing the project, it also depends on the LHC physics and time schedule. The design is made for synchronous ep and pp (eA and AA) LHeC and LHC operation for that is cost, time and luminosity effective. Would be easier in dedicated phase.

Time Schedule – 2 – Detector

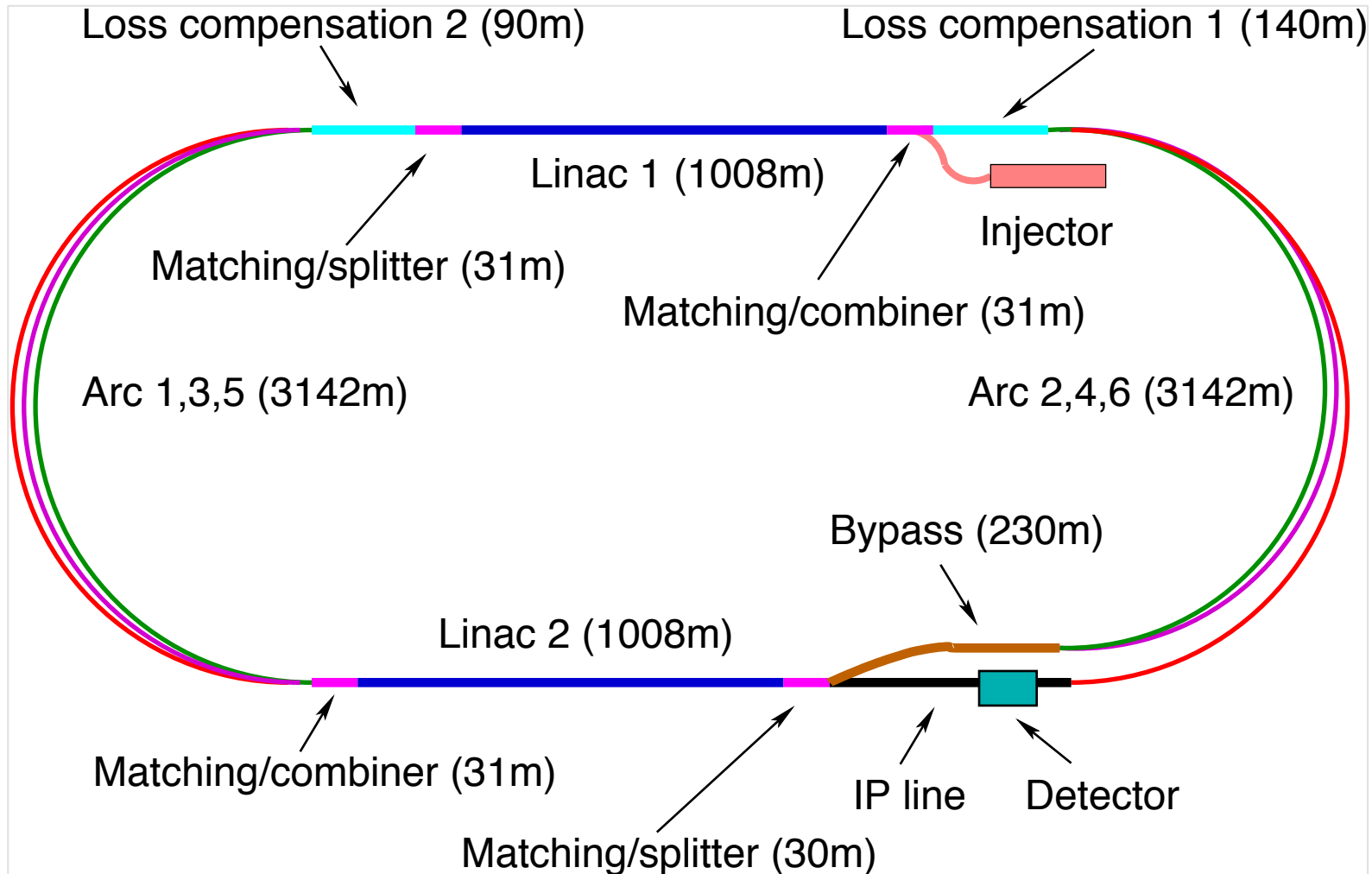
A.Gaddi Chavannes 1/14



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



CDR Footprint: $U=U(\text{LHC})/3$



1km arc radius, 1km linac, 300m auxiliary, linear structure: $2\pi + 2.6 = 8.9\text{km}$

Electron Beam Energy - Physics and Cost

3 main components, cost per km in relative units

| | |
|--|--------------------|
| Tunnel (input from Amberg): | 40/km |
| Linac (input from XFEL and Friedrich Haug) | 200/km |
| Magnets (input from Davide Tommassini) | 10/km – single arc |

Scaling the CDR design to obtain dependence of circumference on $E=E(e)$

$$U(E) = 2\pi (E/60)^4 + 2.62 (E/60)$$

| | $U/U(\text{LHC})$ | $E(e)/\text{GeV}$ | U/km | Arc-R/km | Linac/km | |
|-------|-------------------|-------------------|---------------|----------|----------|-------|
| | 1/2 | 68 | 13.3 | 1.65 | 1.13 | |
| | 1/3 | 60 | 8.9 | 1 | 1 | ← CDR |
| SPS → | 1/4 | 54.6 | 6.7 | 0.69 | 0.91 | |
| | 1/5 | 50.4 | 5.3 | 0.50 | 0.84 | |
| | 1/6 | 47.1 | 4.45 | 0.38 | 0.78 | |

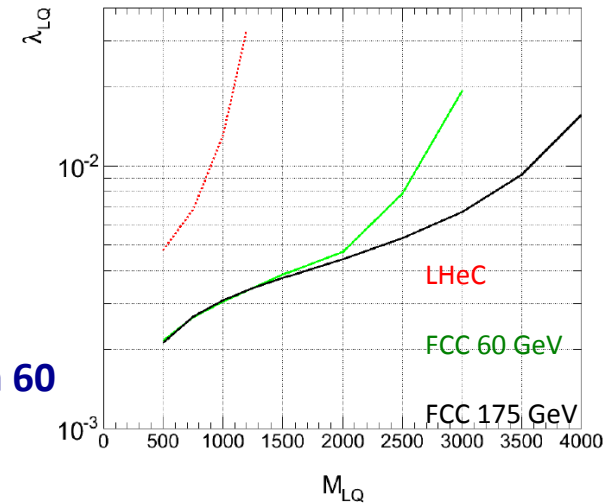
Physics (E_e)

Higgs and top in ep: $E_e > 50$ GeV required for precision measurements
 Saturation: high Q^2 and $\ln Q^2$ range; $F_L: \gamma = 0.9: E_{\min} > 5$ GeV: $E_e \geq 50$ GeV

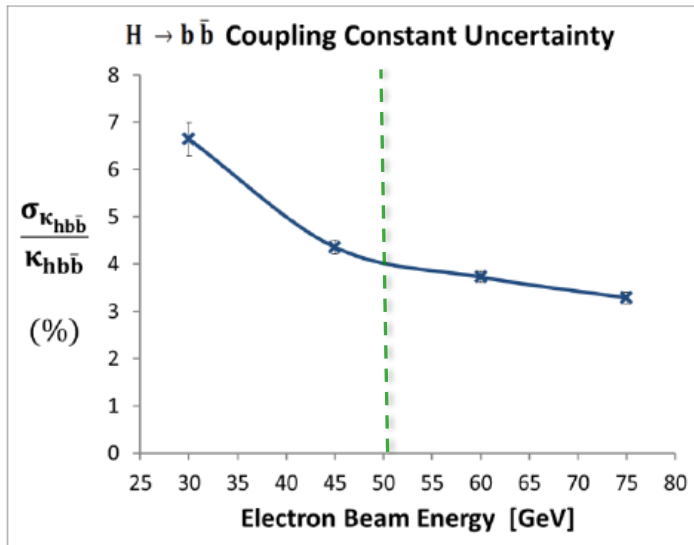
Current LQ limits: ATLAS [534,685,660GeV, scalar]



50 GeV may be tolerable but wait for Run 2 before moving away from 60

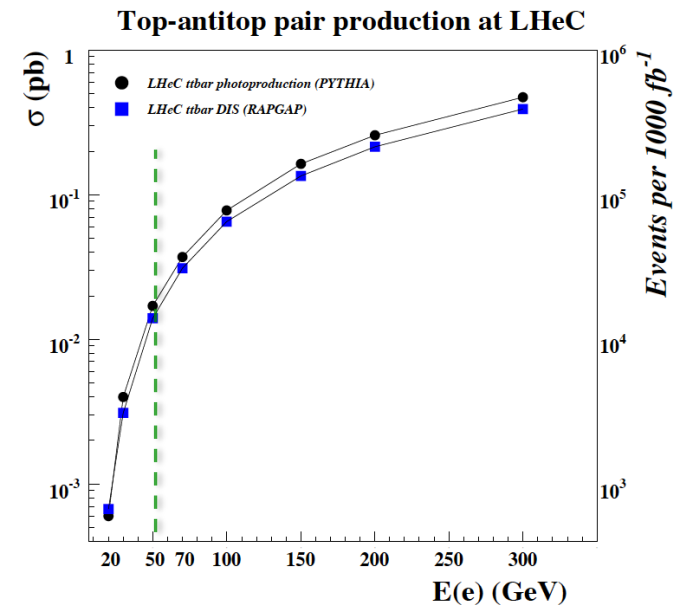


G Azuelos 5/14



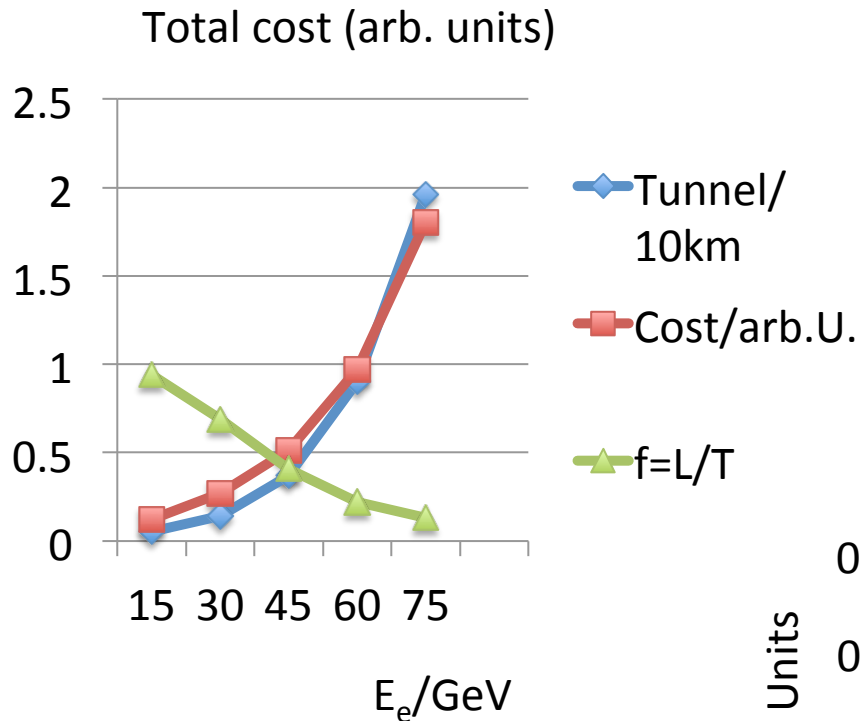
U Klein, E Kay 5/14

Fixed luminosity of 100fb^{-1} : reach 1% with 1ab^{-1}
Precision Higgs as a “window to new physics” P5



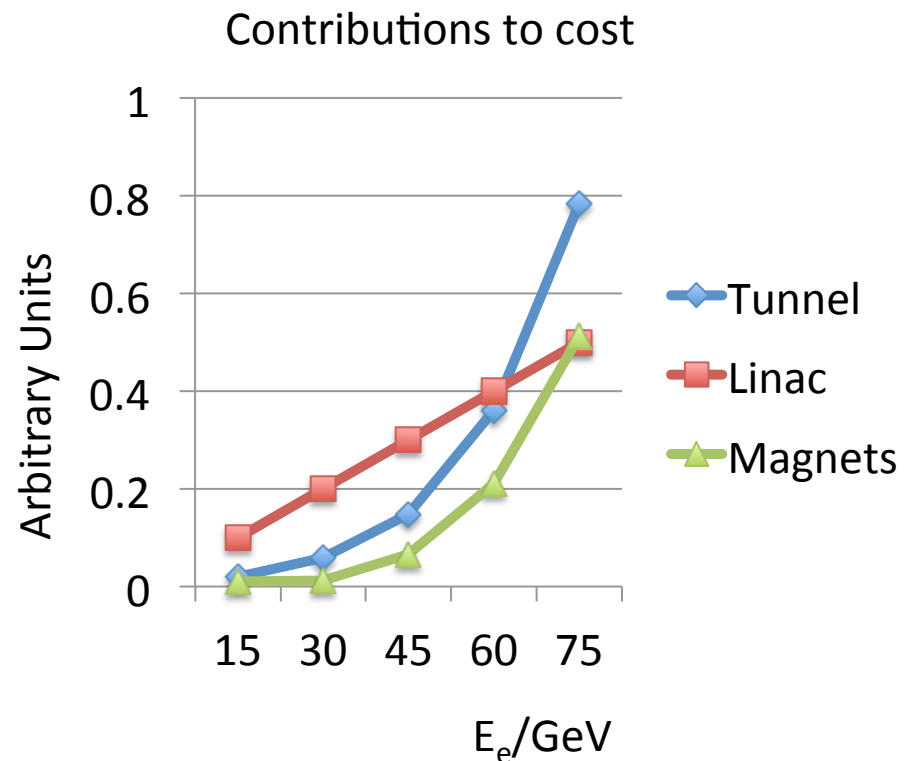
Top provides the $gg \rightarrow H$ and may be anomalous (cf DIS14, Y.Sirois, C.Schwanenberger)

Cost versus Electron Beam Energy



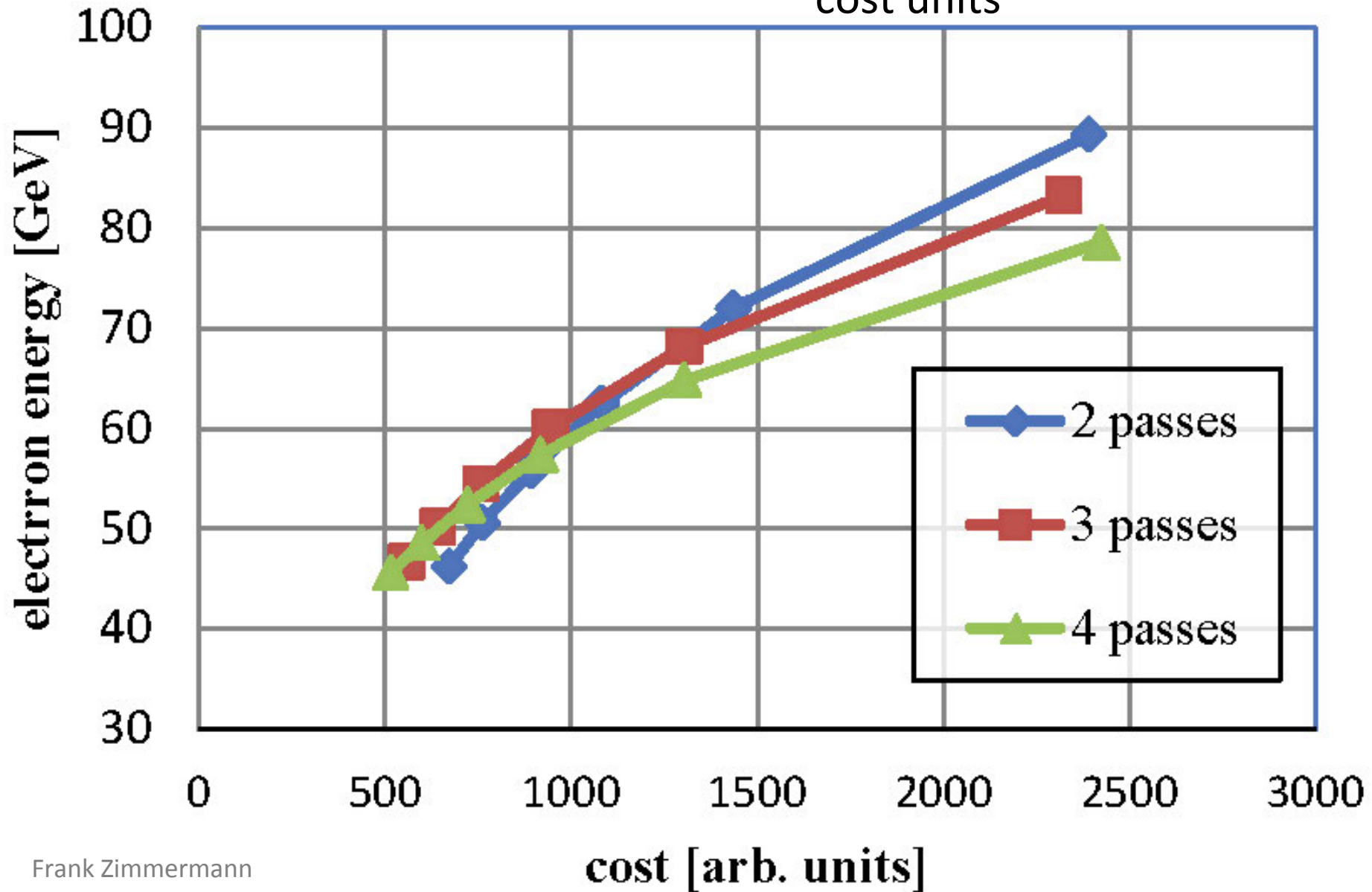
Cost reduced by 1/3 when E_e is 50 instead of 60 GeV

Cost reviews:
Core CDR detector: 106 MSF
Tunnel: 250*1.4 MSF
No accelerator cost review yet,
beyond common sense
which hardly applies here..
Consider also power and operation

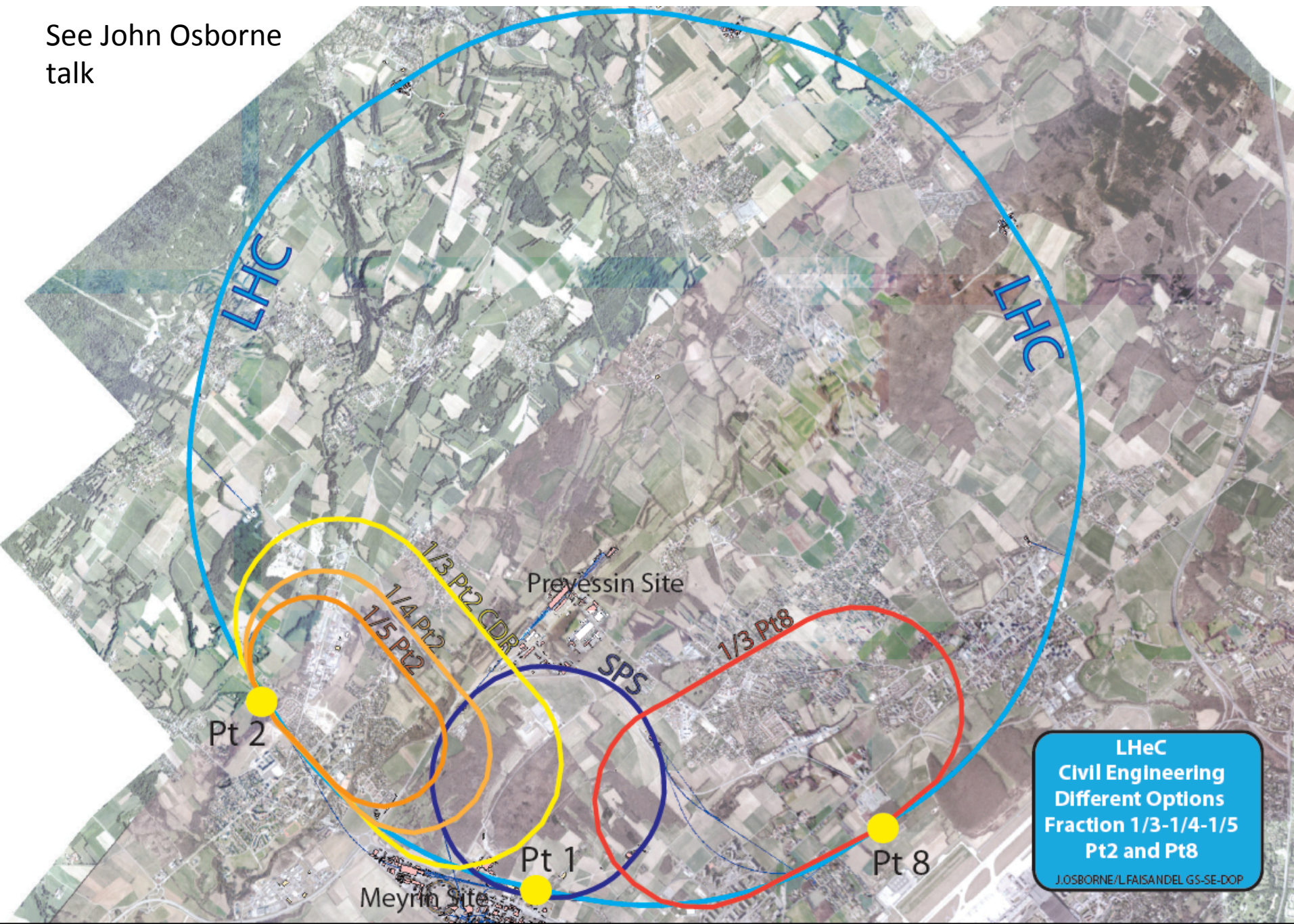


maximum energy vs. cost

3 passes yield highest energy
between 600 and 1000 (M)
cost units

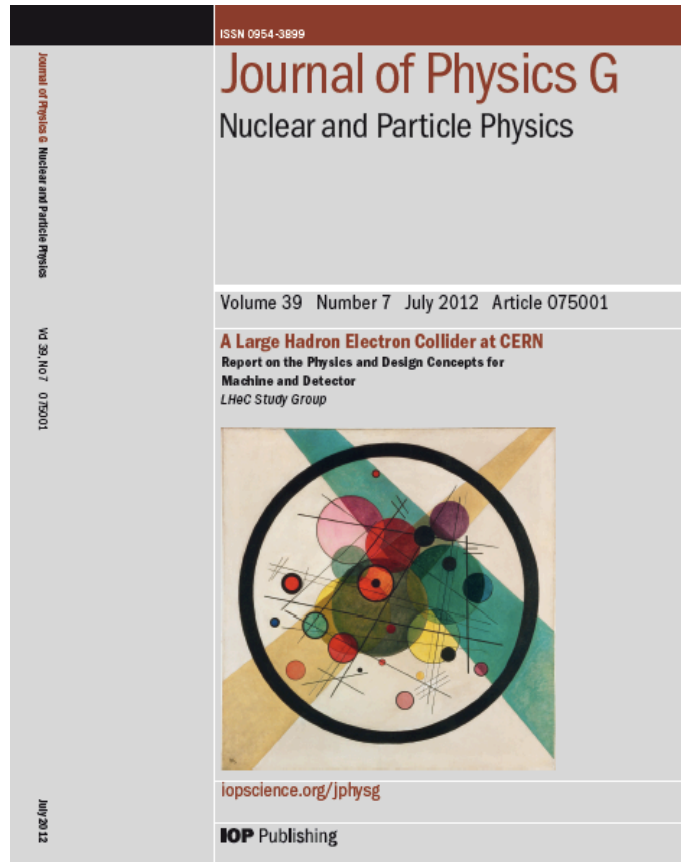


See John Osborne
talk



LHeC
Civil Engineering
Different Options
Fraction 1/3-1/4-1/5
Pt2 and Pt8
J.OSBORNE/L.FAISANDEL GS-SE-DOP

Design Report 2012



[arXiv:1206.2913](https://arxiv.org/abs/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

A bit of history

Lausanne 1984, Aachen 1990, ... SPC September 2007 → (r)ECFA, CERN Mandate

HERA stops operation in 2007. Final NC/CC data come out now(ish).

NuPECC 2010 includes LHeC into its Long Range Plan

Annual LHeC Workshops (Chavannes 2014 was the fifth)

Conceptual Design Report 2012 [a move towards the “real axis” (SB)]

Discovery of the Higgs Boson [200fb in polarised e-p at LHeC → 10^{34} : Daniel Schulte]

Cracow/Erice: Higgs, LHC upgrade, High Gradients, CERN energy frontier (FCC) ..

“A new beginning” with [Mandates to Advisory Committee](#) and Coordination Group

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.

Physics Study Groups

| | | |
|----------------|--|-----------------------------|
| PDFs (and QCD) | Voica Radescu (DESY) +1 (tba) | |
| Higgs | Uta Klein (Liverpool) + Masahiro Khuze (Tokyo) | |
| Top | Olaf Behnke (DESY) + Christian Schwanenberger (Manchester) | |
| BSM | Monica D'Onofrio (Liverpool) + Georges Azuelos (Montreal) | |
| eA | Nestor Armesto (Santiago..) + 1 (tba) | } In close collaboration |
| Low x | Paul Newman (Birmingham) + Anna Stasto (PennState) | |

More regular studies in between workshops, conferences, papers, topical events. **Singularity and complementarity to LHC program!**
Depends on support as with master theses, PhDs and fellows.

Common base and problem: detector simulation- fellow request.

Funding

NP2020: in February no big LHeC proposal, no hope

Joint EIC proposal, hope for 1 PhD for Nestor and Paul

H2020 FCC status?

Fall: PI for Higgs – again?

ERL: joint CERN, Mainz, Darmstadt, Berlin for BMBF

UK accelerator review 14/15

CERN MTP and FCC fellow program

Cannot replace resources from contributing institutes!

The problem number 1 – effort considerable not to be late

Outreach

Electrons at the LHC: a new beginning

A new committee is providing direction on the case for an electron-hadron collider, both at the LHC and at a Future Circular Collider complex.

From time to time, great experimental progress in particle physics suddenly reveals a crisis in theoretical physics. This happened in the early 1960s when a plethora of hadrons had been discovered, while strong-interaction theory dealt with analytical properties of the S matrix and a number of phenomenological models. At that time, Murray Gell-Mann, who had just introduced the notion of quarks, seconded by Georg Zweig, argued for focusing on "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" (Gell-Mann 1967). The current situation is not so different.

At the LHC, the Standard Model is being subjected to a thorough confirmation, including the remarkable completion of its particle contents with the discovery of a Higgs boson. Important as these results are, however, there is still no indication of the existence of the long-predicted supersymmetric particles or of Kaluza-Klein resonances below a mass scale of about a tera-electron-volt, or of other new phenomena. Of course, the hope is that in the coming years the LHC will discover new physics in exploring the next higher-energy domain with increased luminosity. Yet, to discover all hidden treasures when entering unknown territory, it is a wise strategy to prepare for all possibilities and not to rely on a few choices only.

In this spirit, investigations of electron-proton (ep) and electron-ion (eA) collisions at high energies offer an important prospect, complementary to proton-proton (pp) and electron-positron (ee) collisions. So far, the only collider to exploit the ep configuration was HERA at DESY, where results from the H1 and ZEUS experiments provided much of the base of current LHC physics and also led to surprising results, for example on the momentum distributions of partons inside the proton. Building on the conceptual design study for the Large Hadron Electron Collider (LHeC) – an electron-beam upgrade to the LHC (CERN Courier May 2012 p25) – CERN's management decided recently to investigate these possibilities more deeply. It has established an International Advisory Committee (IAC) to report to the director-general, with the mandate to provide "...scientific and technical direction for the physics potential of the ep/eA collider, both at the LHC and FCC [the proposed Future

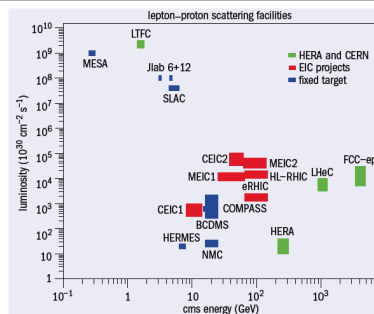
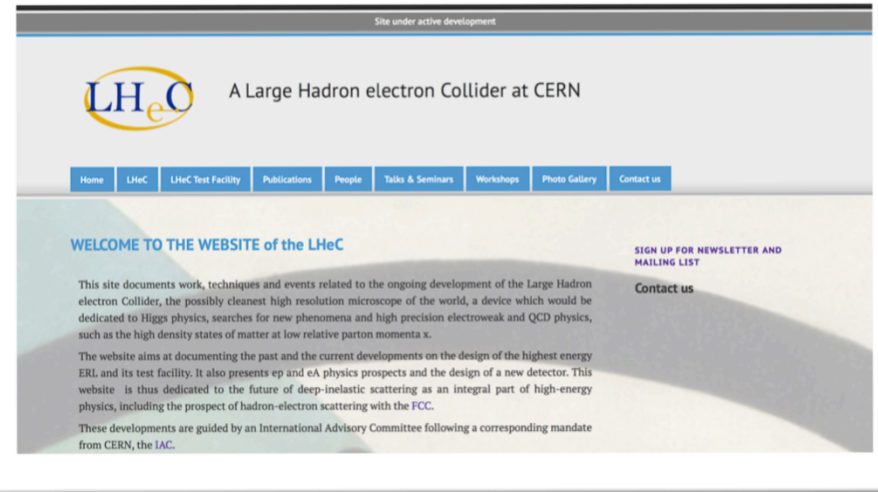


Fig. 1. Lepton-proton scattering projects – using fixed targets (blue), future medium-energy electron-ion collider projects (red), HERA and CERN's electron-proton concepts (green) – in terms of luminosity and centre-of-mass energy.

Circular Collider complex], as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an energy recovery linac (ERL) test facility at CERN...". Furthermore, the advisory committee should offer "assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects...". Chaired by Herwig Schopper, the IAC comprises 12 eminent scientists from three continents, together with CERN's director for research and computing, Sergio Bertolucci, and the director for accelerators and technology, Frederick Bordry, as well as the co-chairs of the newly established LHeC Co-ordination Group, Oliver Brüning and Max Klein.

To discover all hidden treasures, it is a wise strategy to prepare for all possibilities.

One of the IAC's first major activities was to hold a well-attended workshop on the LHeC, its physics, and the accelerator and detector development, at Chavannes-de-Bogis in January this year. ▷



New web page realised by Alessandra Valoni

A new web page
(...Wikipedia, Interviews, Newsletter)
A new beginning
(articles, P.Newman/A.Stasto, ..)
Many ideas: ep back to CERN School,
"LHeC days" in a few countries
Next LHeC workshop – spring 2015

Home made PR
(ILC has sizeable annual budget for PR)

Article in June CERN Courier H.Schopper+MK
following IAC suggestion from January 14

Remarks

... “I just opened the latest issue of the CERN Courier and was pleased to read the article by you and Schopper. Congratulations on a very nice piece of work. It touches all the bases at just the right level - from the Higgs capability, through the ERL test facility, as well as the historical setting. **The program itself is very well thought out. With enough collaborator support it will be hard to resist.**”

The accelerator, detector and physics work has reached a stage where it needs more and dedicated person power to proceed in a convincing way. This may only be achieved with (realistic and accepted) goals and support.

specifically we are working on
SCRF – mid term plan (Jlab, Mainz?)
Testfacility – tentative design by end of 2014, CDR with MoUs by 2015
Accelerator – 10^{34} , Interaction Region, IP at LHC and FCC_he
Detector – dedicated simulation now needed for physics optimisation
Physics studies – H, t, eA, .. closer contact to LHC and theorists

A far horizon has been opened with the “triangular” pp-pe-ee FCC study:

Future Circular Collider (FCC) study ; goals: CDR and cost review for the next European Strategy Update (2018)

International collaboration :

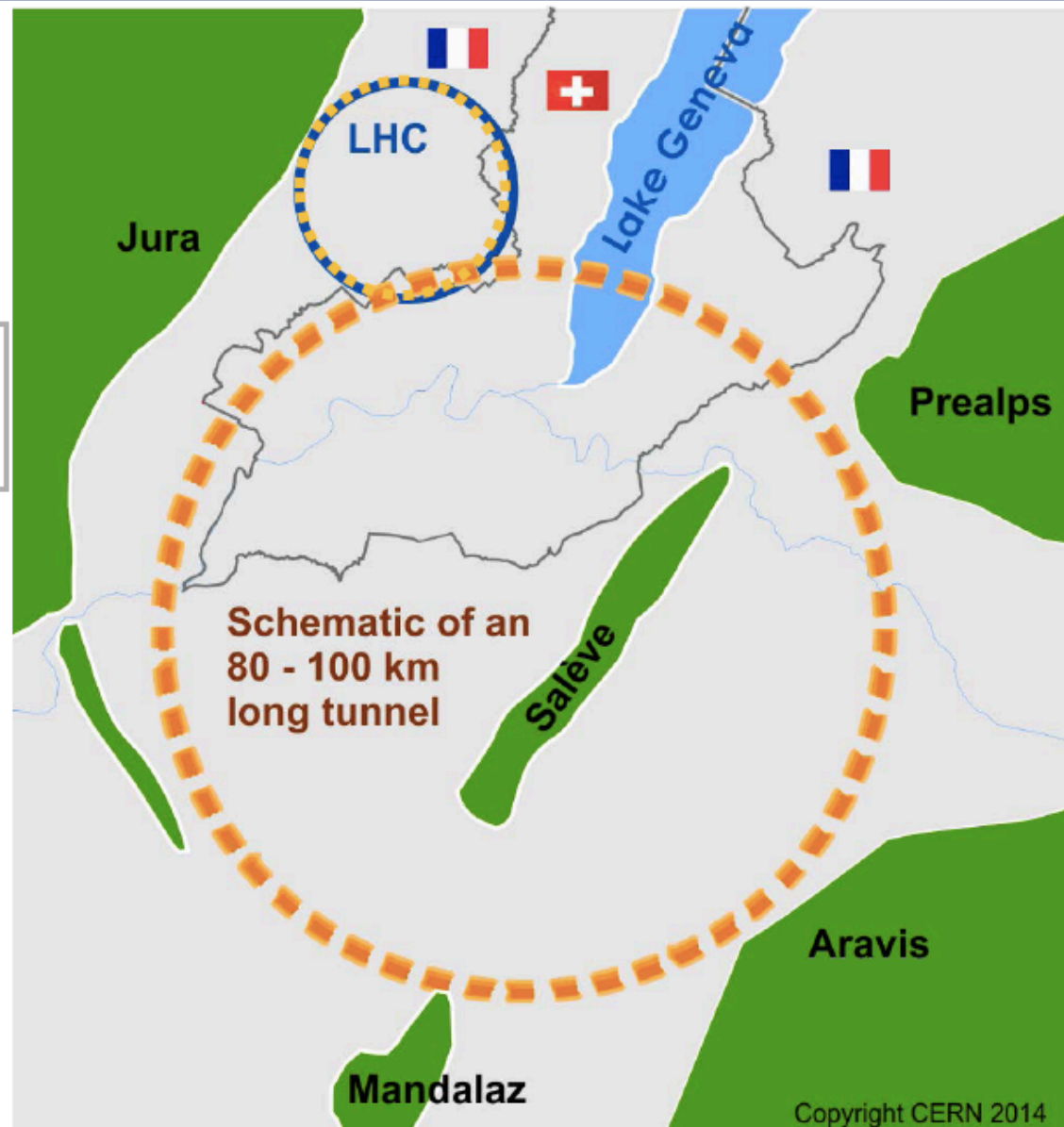
- pp -collider (*FCC-hh*)
→ defining infrastructure requirements

$\sim 16\text{ T} \Rightarrow 100\text{ TeV in } 100\text{ km}$

$\sim 20\text{ T} \Rightarrow 100\text{ TeV in } 80\text{ km}$

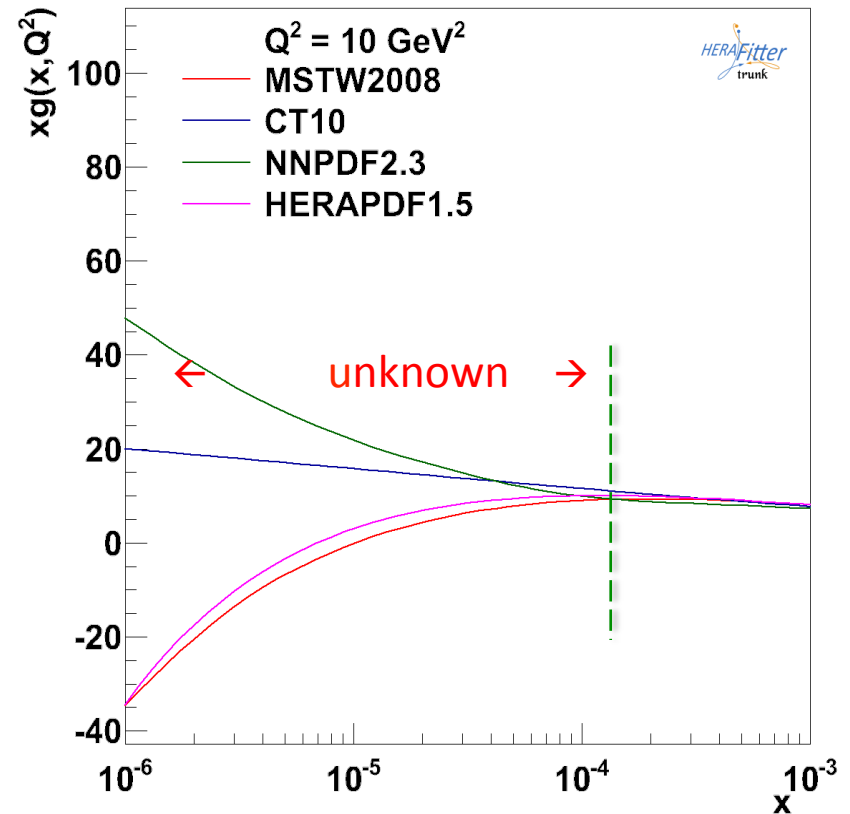
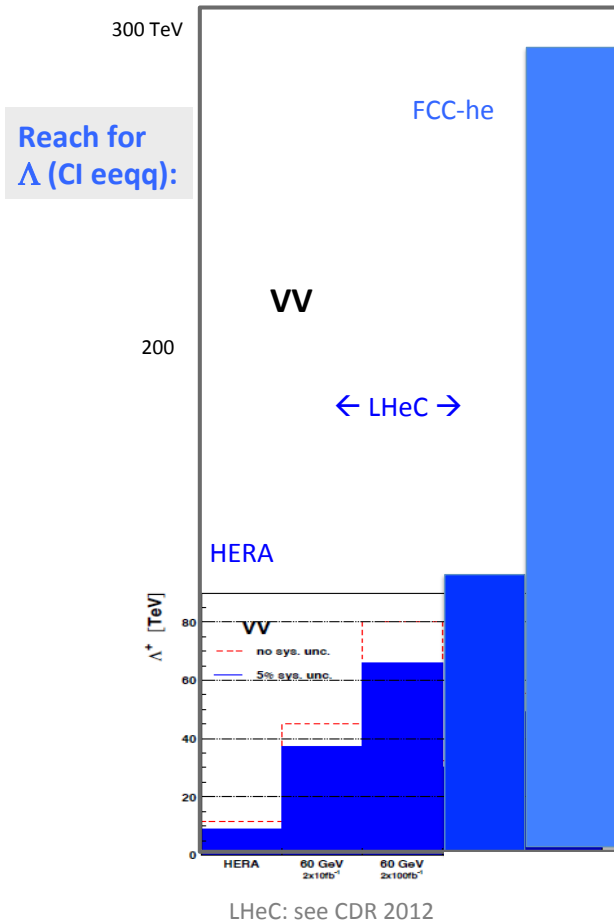
- including *HE-LHC* option:
16-20 T in LHC tunnel
- e^+e^- collider (*FCC-ee/TLEP*) as potential intermediate step
- $p-e$ (*FCC-he*) option
- 100 km infrastructure in Geneva area

M. Benedikt



| collider parameters | FCC ERL | FCC-ee ring | | protons |
|---|------------------------|--------------|-------------|------------------------------|
| species | $e^- (e^+?)$ | e^\pm | e^\pm | p |
| beam energy [GeV] | 60 | 80 | 120 | 50000 |
| bunches / beam | - | 4490 | 1360 | 10600 |
| bunch intensity [10^{11}] | 0.04 | 0.7 | 0.46 | 1.0 |
| beam current [mA] | 25.6 | 152 | 30 | 500 |
| rms bunch length [cm] | 0.02 | 0.11 | 0.12 | 8 |
| rms emittance [nm] | 0.17 | 3.3 (x) | 0.94 (x) | 0.04 [0.02 y] |
| $\beta_{x,y}^*$ [mm] | 1000 | 6.0, 3.0 | 22, 11 | 500 [250 y] |
| $\sigma_{x,y}^*$ [μm] | 4.0 | 4.5, 2.3 | | equal |
| beam-b. parameter ξ | ($D=32$) | 0.05 | 0.13 | 0.017 (0.0002) |
| hourglass reduction | 0.94 ($H_D=1.35$) | ~0.24 | ~0.60 | |
| CM energy [TeV] | 3.5 | 4.0 | 4.9 | F.Zimmermann IPAC14, June |
| luminosity [$10^{34}\text{cm}^{-2}\text{s}^{-1}$] | 1.0 | 2.3 | 1.2 | |

FCC – physics



Huge extension of reach for new physics

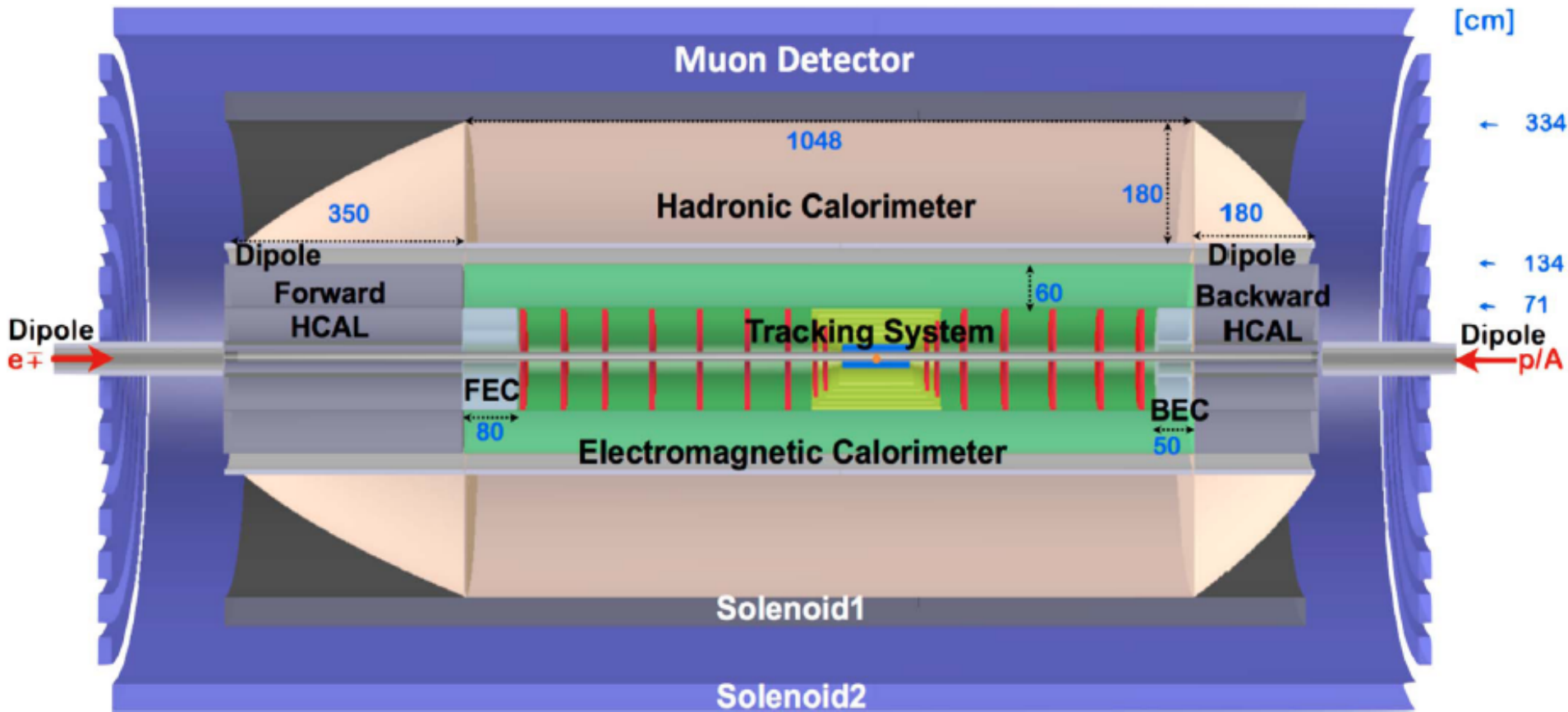
Leptoquark reach to $\sqrt{s} \approx 4 \text{ TeV}$

H-HH??

Program to be further investigated, Collaboration with hh and ee, Joint Software Group

Very low x – close to UHEv region, BFKL?

FCC-he Detector (B) – 0.1



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

The future of the LHeC project has these two options,
we hope for advice and support towards the left one.

“BFKL evolution and Saturation in DIS”



Circles in a circle
V. Kandinsky, 1923
Philadelphia Museum of Art



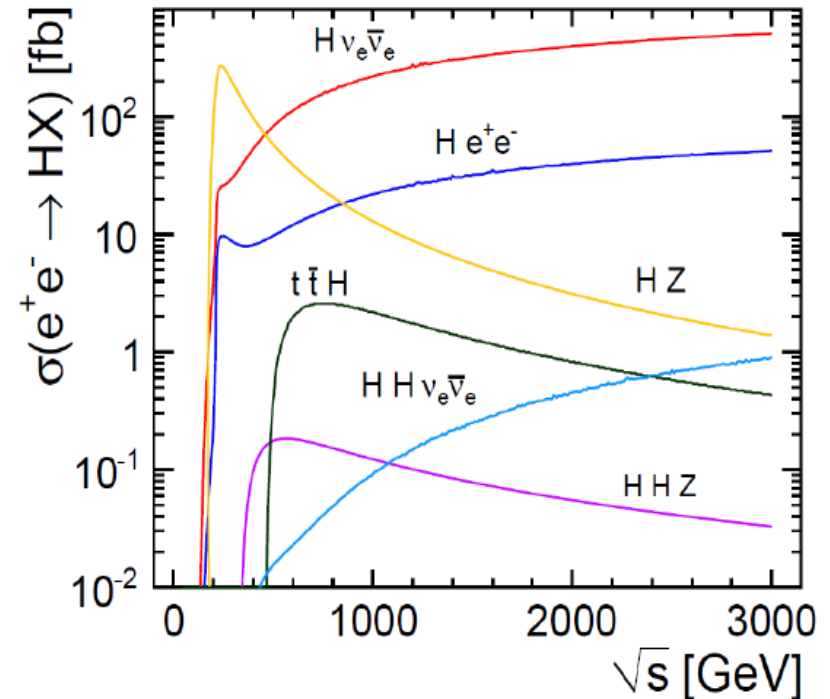
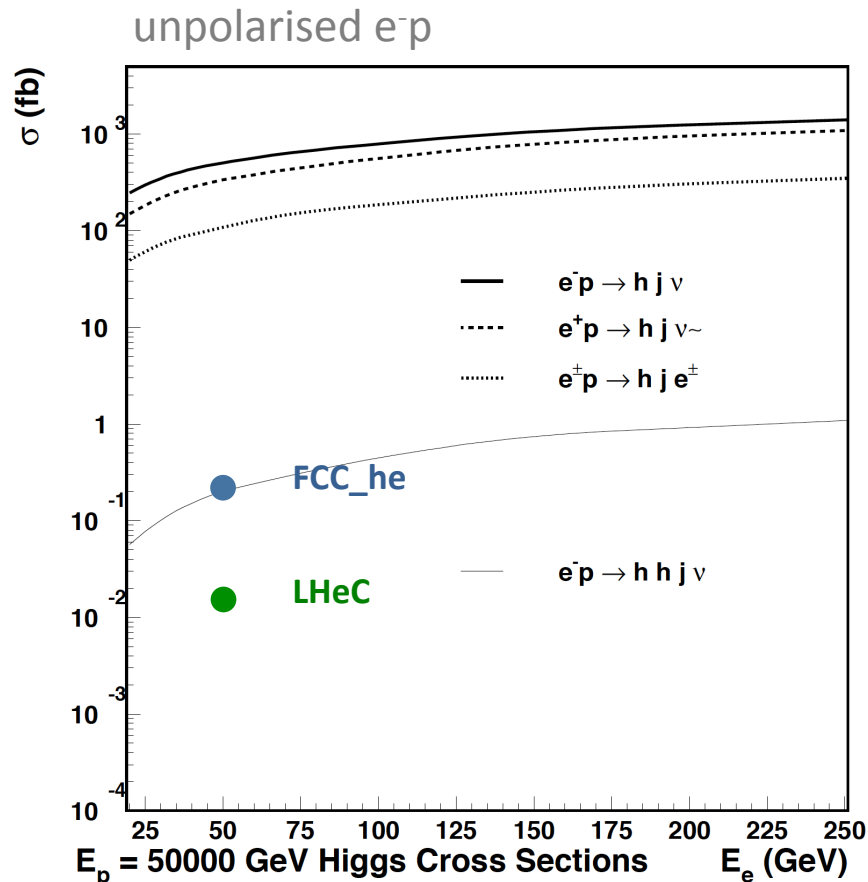
“Critical gravitational collapse”



5d tiny black holes and perturbative saturation
Talk by A.S.Vera at LHeC Workshop 2008

backup

FCC – H selfcoupling



LC has the same challenge, CLIC 3TeV

$\sigma(e^-p \rightarrow HHj\nu) = 0.4 \text{ fb}$ ($P = -0.8$) – gain of factor 10 with FCC vs LHC, still:
 $\varepsilon(HH \rightarrow 4b) = \text{br}^2(H \rightarrow bb) \varepsilon_b^2 A \approx (0.6)^2 (0.7)^2 A \approx 0.1 A \approx 10^{-2} \rightarrow N/\text{ab}^{-1} \approx 4$

Maximise b tag efficiency and acceptance – detector simulation!
 Luminosity crucial: can one reach 10^{35} at the FCC_he?

LeptoQuarks

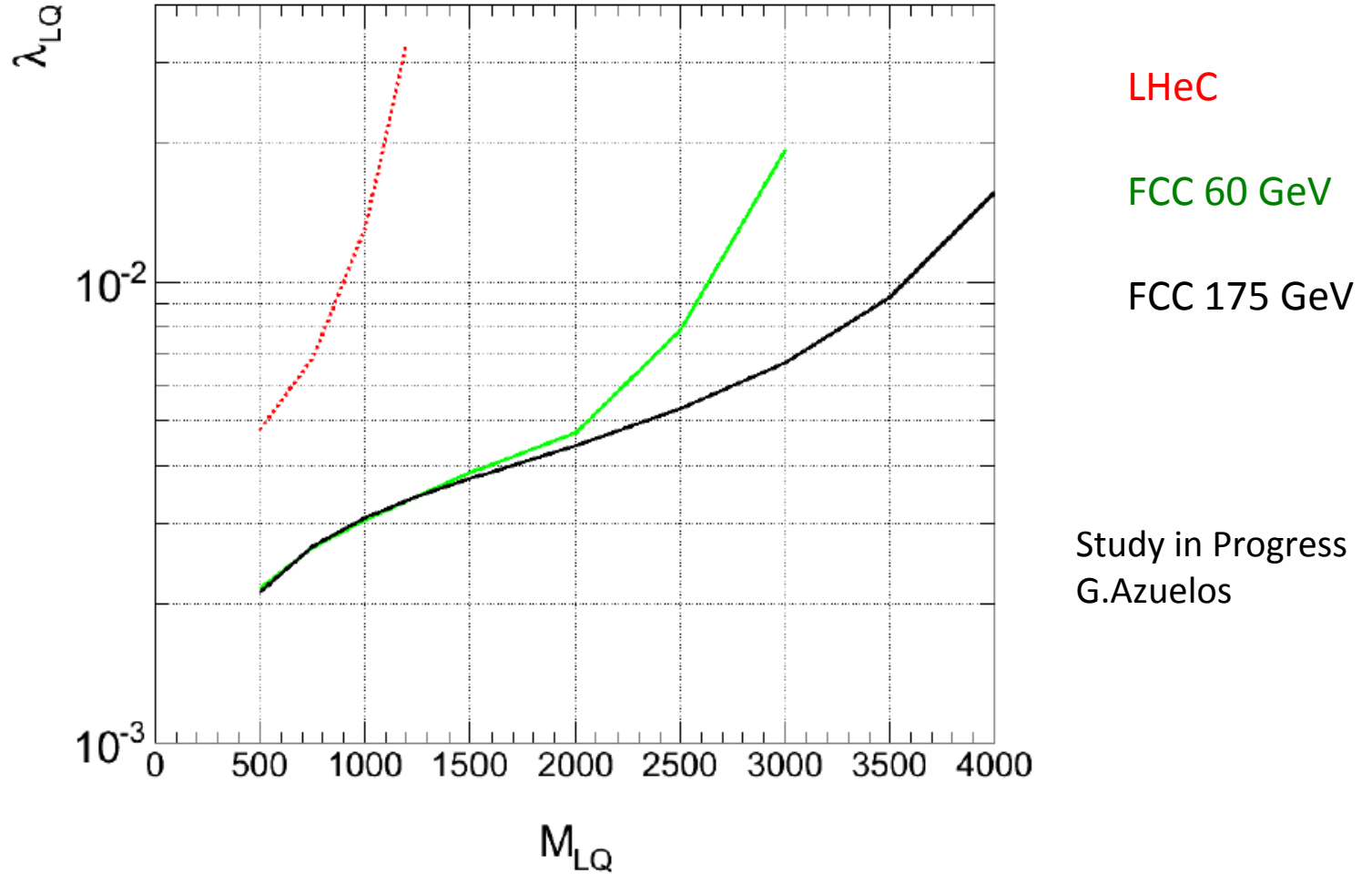
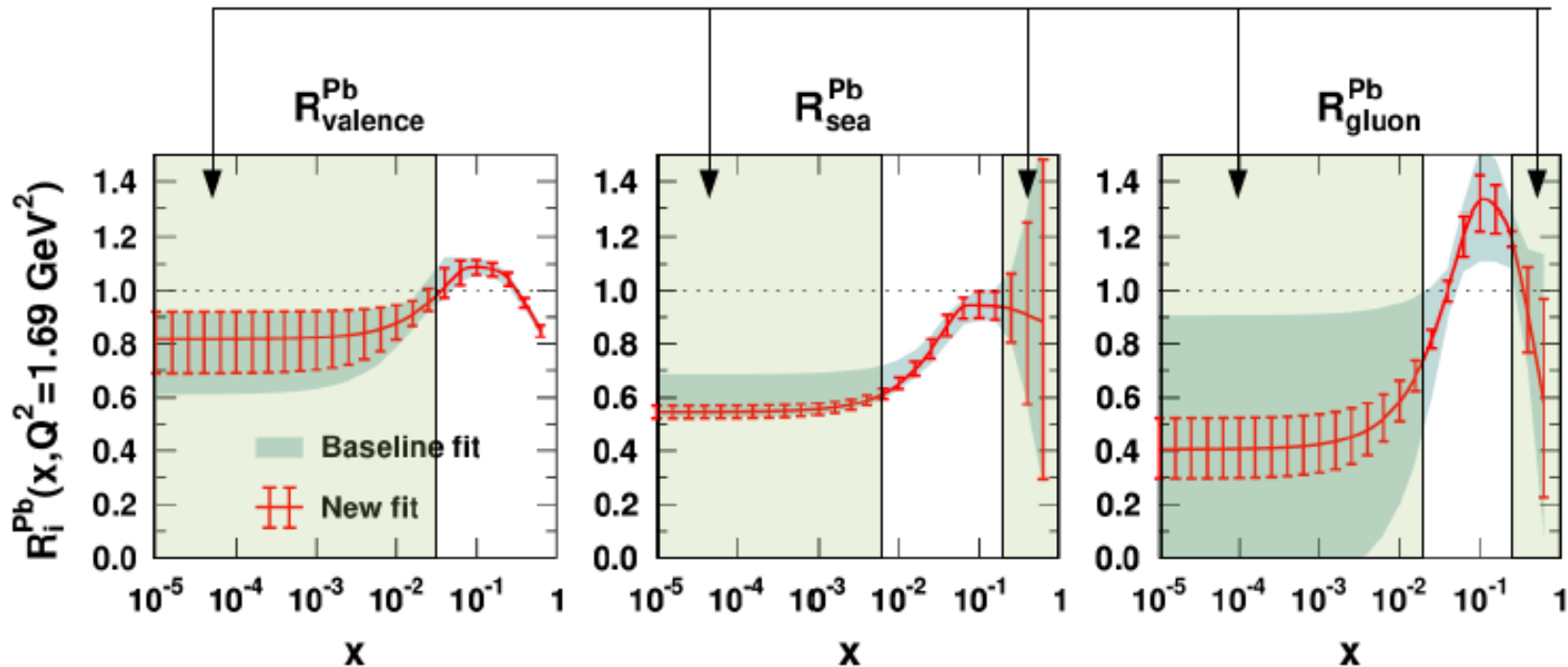


FIGURE 2. Mass-dependent upper bounds (2σ CL) on the LQ coupling λ as expected at LHeC for a luminosity of 20 fb^{-1} and at FHeC₁ and FHeC₂ for integrated luminosities of 500 fb^{-1} . These are shown for an example scalar LQ coupling to e^-u .

Effects in nPDFs, LHeC

Currently no real data constraints!



- **A drastic reduction in the small- x gluon and sea quark uncertainties**
- **More freedom in the fit function should be allowed – the baseline uncertainty probably underestimated**
- **Addition of charged-current data should give a handle on the flavor dependence, which is currently (practically) unconstrained**

Principal Goals

ep into HEP by 2017/18 (LHCC Lol before.?)
 CDR for Testfacility by the end of 2015 +
 Design+test of critical acc elements (Q1, IR..) by 2018
 Operation of Testfacility by 2018/19

Aim for synchronous ep and pp operations by 2025+
Consider very long term future – integration into FCC

Structure

| Physics | Detector | Testfacility | Accelerator | Infrastructure |
|--|--|--|---|---|
| Higgs Top pp-ep 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 |