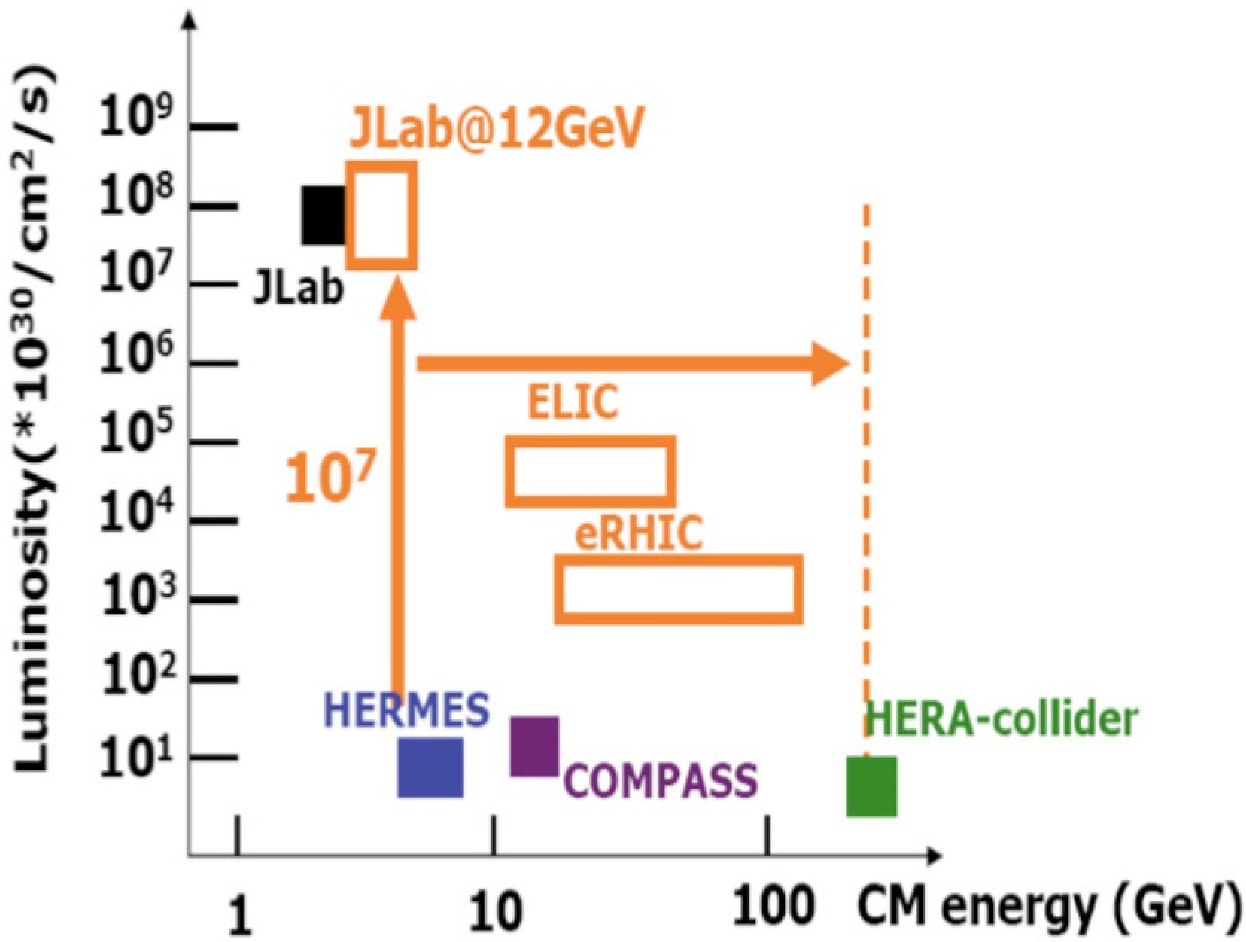
Electron-Ion collider
my personal perspective from Europe

- the international context
- LHeC accelerator
- status of the project and planned physics
- LHeC in the FCC
- some final remarks

NAS e-ion panel
Feb.1-2, 2017
Washington,D.C.

Running and planned facilities in 2009

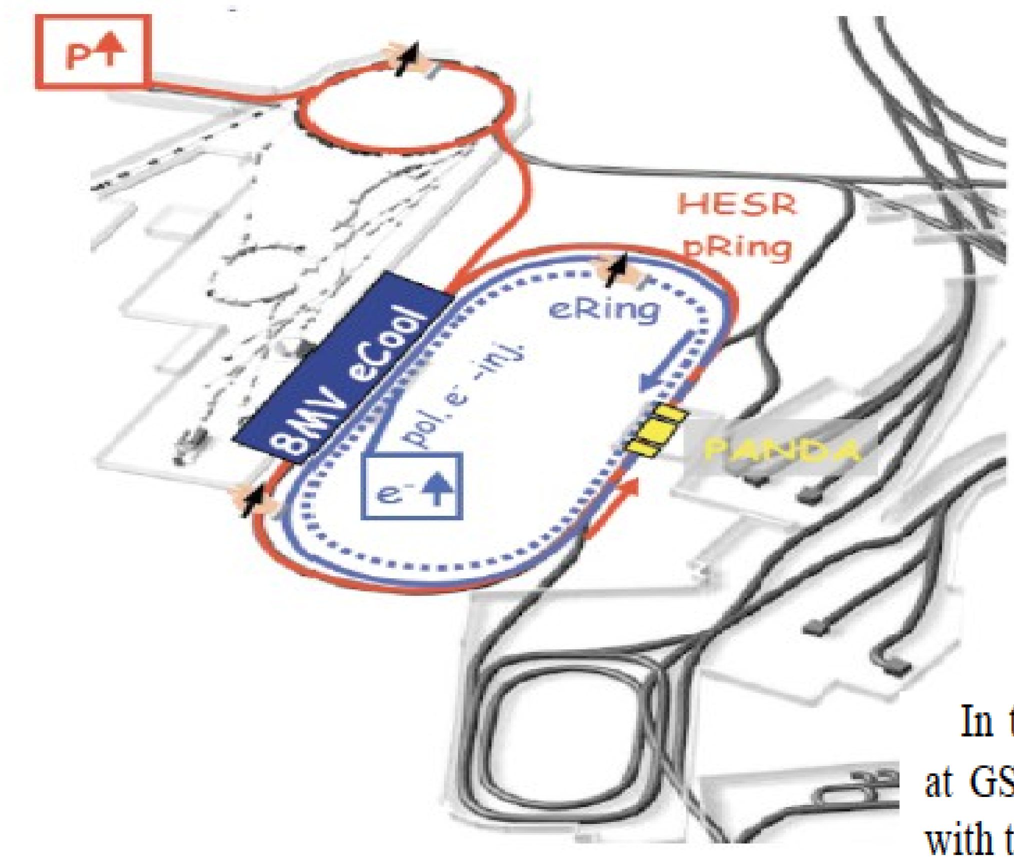


Proceedings of PAC09, Vancouver, BC, Canada FR1PBI02

OVERVIEW OF ELECTRON-ION COLLIDER INITIATIVES

Richard G. Milner, MIT, Cambridge, MA 02139

European plans 2008 - 2012



polarized e- proton collider
at HESR/FAIR

In the Electron-Nucleon Collider (ENC) considered at GSI [6], a 3 GeV electron ring would be collided with the planned 15 GeV HESR of FAIR. The 14 GeV center-of-mass energy with polarized electron and nucleon beams at a collision luminosity of 10^{33} cm^{-2} s^{-1} would allow access to the sea quarks and gluons of the nucleon. Nuclear beams are not envisaged for ENC at this time.

First ideas in 1996: put nuclear beams into HERA@DESY

Nuclear beams in HERA

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arXiv:hep-ph/9610423

- **Study of the x and Q^2 dependence of nuclear shadowing over a wide Q^2 range.** This will allow the processes limiting the growth of F_2 as x tends to zero to be studied in detail.

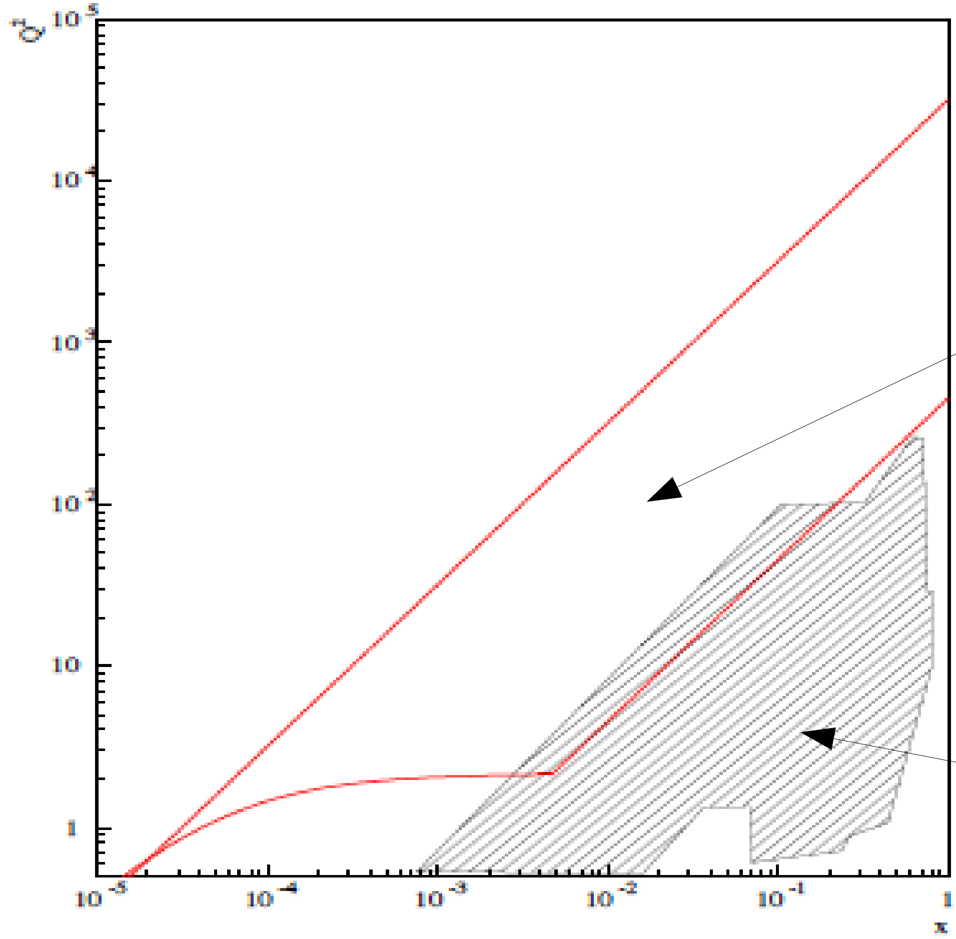
- **To establish the difference between the gluon distributions of bound and free nucleons.** This will allow the part played by gluon fusion in the shadowing process to be studied directly.

- **Study of diffractive processes:** to see if the pomeron generated by nuclei shows any difference from that generated by free nucleons. Processes such as vector meson production can also be used to search for colour transparency.

- **Study of hadronic final states.** This allows the propagation of partons in the nuclear medium to be studied as well as the multiplicity fluctuations discussed later.

Kinematical coverage for N=Z nuclei at HERA (HERA3)

Q^2 (GeV^2)



collider coverage

fixed target experiments

x

HERA2: s = 100000 GeV^2

HERA3: s = 50000 GeV (N=Z)

Luminosity: about 10^{31} /(cm2 s)

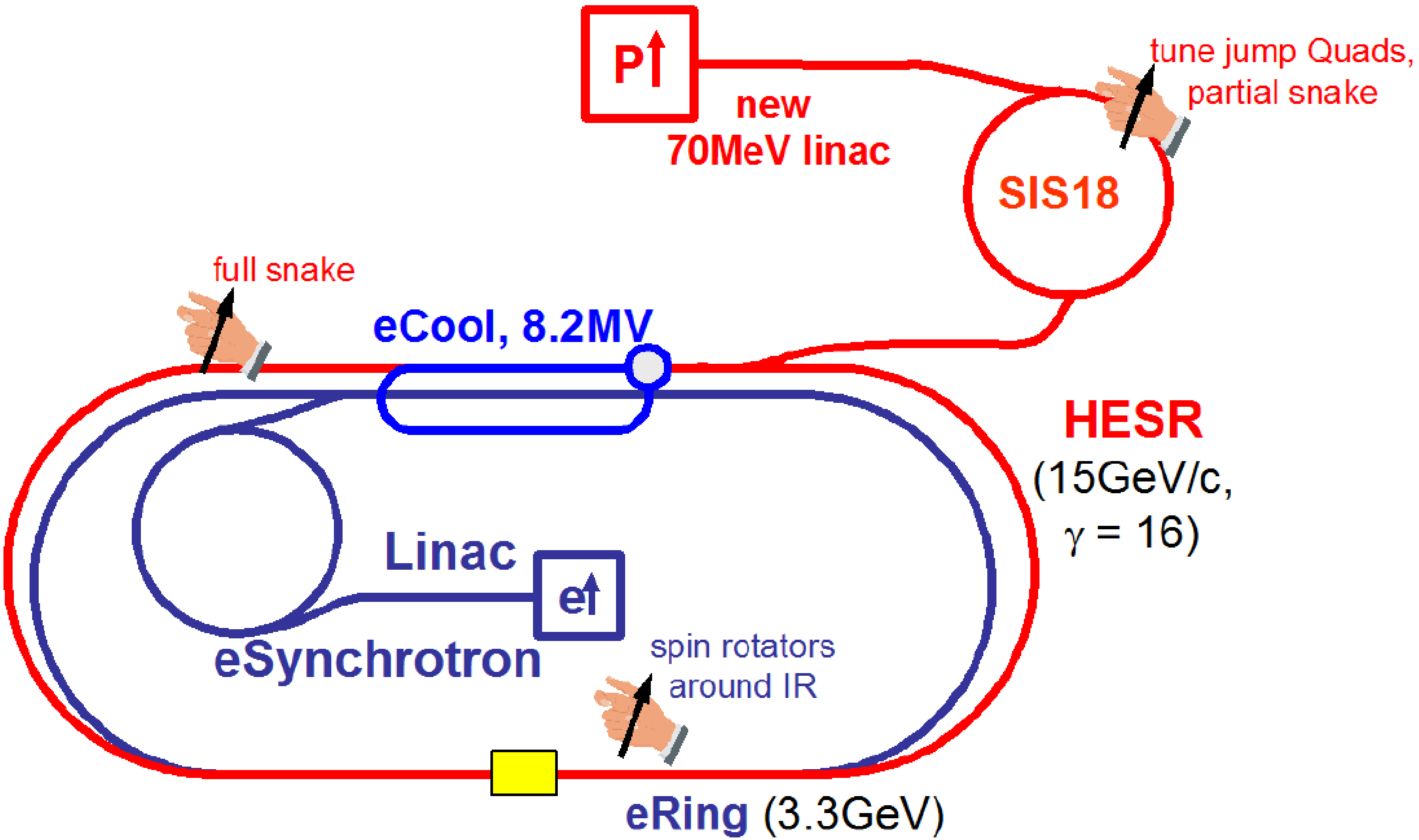
personal comment: HERA3 never materialized because DESY wanted to concentrate on the Tesla linear collider

The polarized electron-nucleon collider project ENC at GSI/FAIR

A Lehrach[1], K Aulenbacher[2], O Boldt[3], R Heine[2], W Hillert[3], C Montag[4], P Schnizer[5] and T Weis[6]

Abstract. The ENC project attempts to realize an electron-nucleon collider at the upcoming Facility for Antiproton and Ion Research FAIR at GSI Darmstadt by utilizing the antiproton high-energy storage ring HESR for polarized proton and deuteron beams. The addition of a 3.3 GeV storage ring for polarized electrons will enable electron-nucleon collisions up to a center-of-mass energy of $\sqrt{s} \approx 14\,\mathrm{GeV}$. In such a configuration peak luminosities in the range of $L = 10^{32}$ to $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ are feasible. Beam-beam effects in a space-charge dominated regimes in conjunction with high-energy electron cooling represents one of the main challenges for this project. In this paper beam- and spin dynamics simulations are presented, together with the required modifications and extensions for a collision mode of the HESR storage ring and the conceptual design of this new collider complex.

Layout of accelerator configuration at FAIR



personal comment: this option not further pursued. Not part of FAIR physics priorities and not fundable in foreseeable future.

The Large Hadron electron Collider LHeC

Bits of LHeC History (1984-2007)

Lausanne 1984: ep at CERN: Altarelli, Rueckl

Aachen 1990: LEP x LHC Study Group
Rubbia DG@ICHEP: pp in 1996, ep in 1998 …

HERA ($s=10^5$ GeV^2 at L= 1-4 10^{31}) 1992-2007 [F_L]

1997 E. Keil: ep at the LHC 10^{32} – LHC Report 93

HERA III (eD and eA, EIC@DESY) no - TESLA yes

THERA 2001 (1 x 0.5 TeV^2) with 10^{31} Luminosity..

Snowmass 2001 Interaction with EIC (AD et al)..

QCD explorer (CLIC x LHC', L ~ 10^{30}), ep with SPS?

DIS2005 at Madison: LHeC for the first time

Jinst

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Deep inelastic electron-nucleon scattering at the LHC

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ABSTRACT: The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, 10^{33}cm^{-2}s^{-1}, and high energy, $\sqrt{s}$ = 1.4 TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (*ep*, *eD* and *eA*) scattering for momentum transfers Q^2 beyond 10^6 GeV^2 and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

→ Initialisation of the CERN-ECFA-NuPECC LHeC Study (2008-2012) → CDR arXiv:1206.2913

The LHeC Physics Programme

arXiv:1206.2913 (CDR) 1211.4831 and 5102

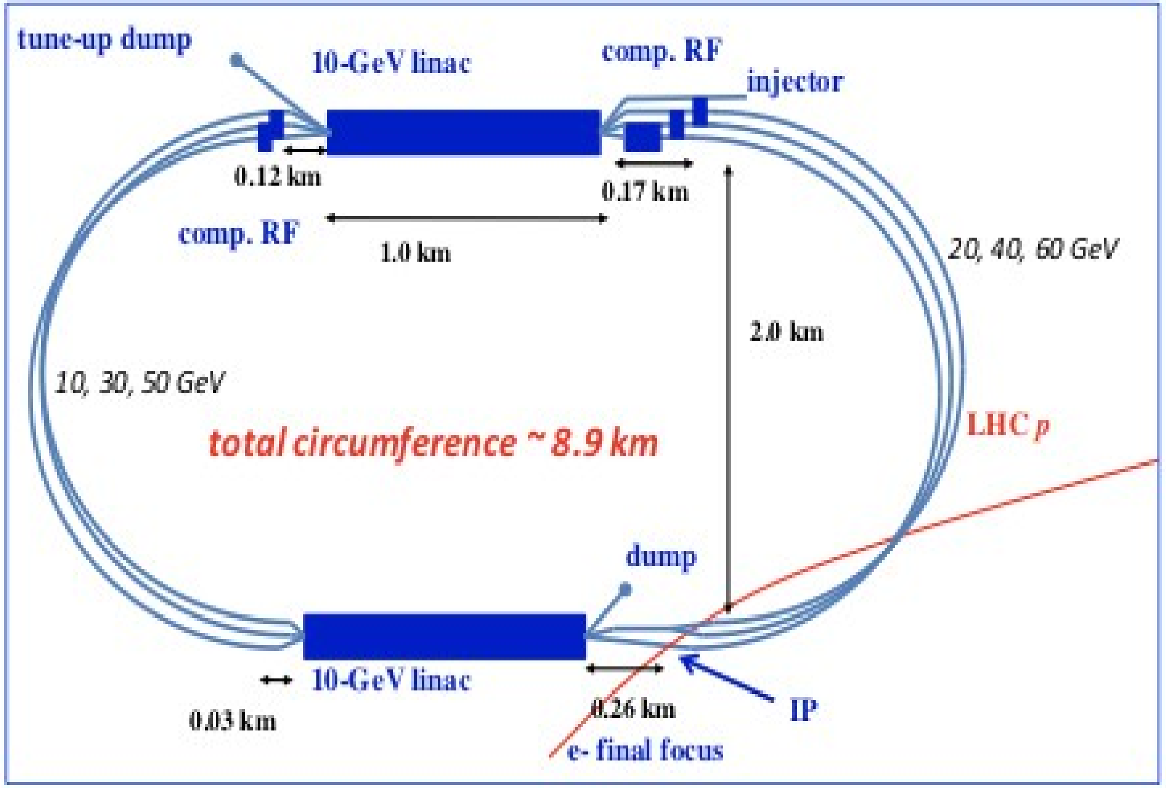
QCD Discoveries	$\alpha_s < 0.12$, $q_{sea} \neq \bar{q}$, instanton, odderon, low x: (n0) saturation, $\bar{u} \neq \bar{d}$
Higgs	WW and ZZ production, $H \to b\bar{b}$, $H \to 4l$, CP eigenstate
Substructure	electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H?
New and BSM Physics	leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s
Top Quark	top PDF, $xt = x\bar{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c
Precision DIS	$\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure	Proton, Deuteron, Neutron, Ions, Photon
Quark Distributions	valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \bar{s}$?, charm, beauty, top
QCD	N^{3}LO, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing
Heavy Ions	initial QGP, nPDFs, hadronization inside media, black limit, saturation
Modified Partons	PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Ultra high precision (detector, e-h redundancy) - new insight
Maximum luminosity and much extended range - rare, new effects
Deep relation to (HL-) LHC (precision+range) - complementarity

Note: LHeC physics focus is mainly on Higgs, substructure of partons, BSM physics etc

Default Electron Accelerator Concept

Conceptual Design Report: arXiv:1206.2913



LHeC: 60 GeV off 7 TeV, L(ep) =10^{34} cm^{-2} s^{-1} (1000 x HERA) in synchronous ep+pp operation

LHeC Conceptual Design Report: a very detailed and widely read document

A Large Hadron Electron Collider at CERN: Report on the Physics and Design Concepts for Machine and Detector

LHeC Study Group (J.L. Abelleira Fernandez (Ecole Polytechnique, Lausanne & CERN) et al.). Jun 2012. 633 pp.

Published in J.Phys. G39 (2012) 075001

SLAC-R-999, CERN-OPEN-2012-015, LHEC-NOTE-2012-001-GEN

DOI: 10.1088/0954-3899/39/7/075001

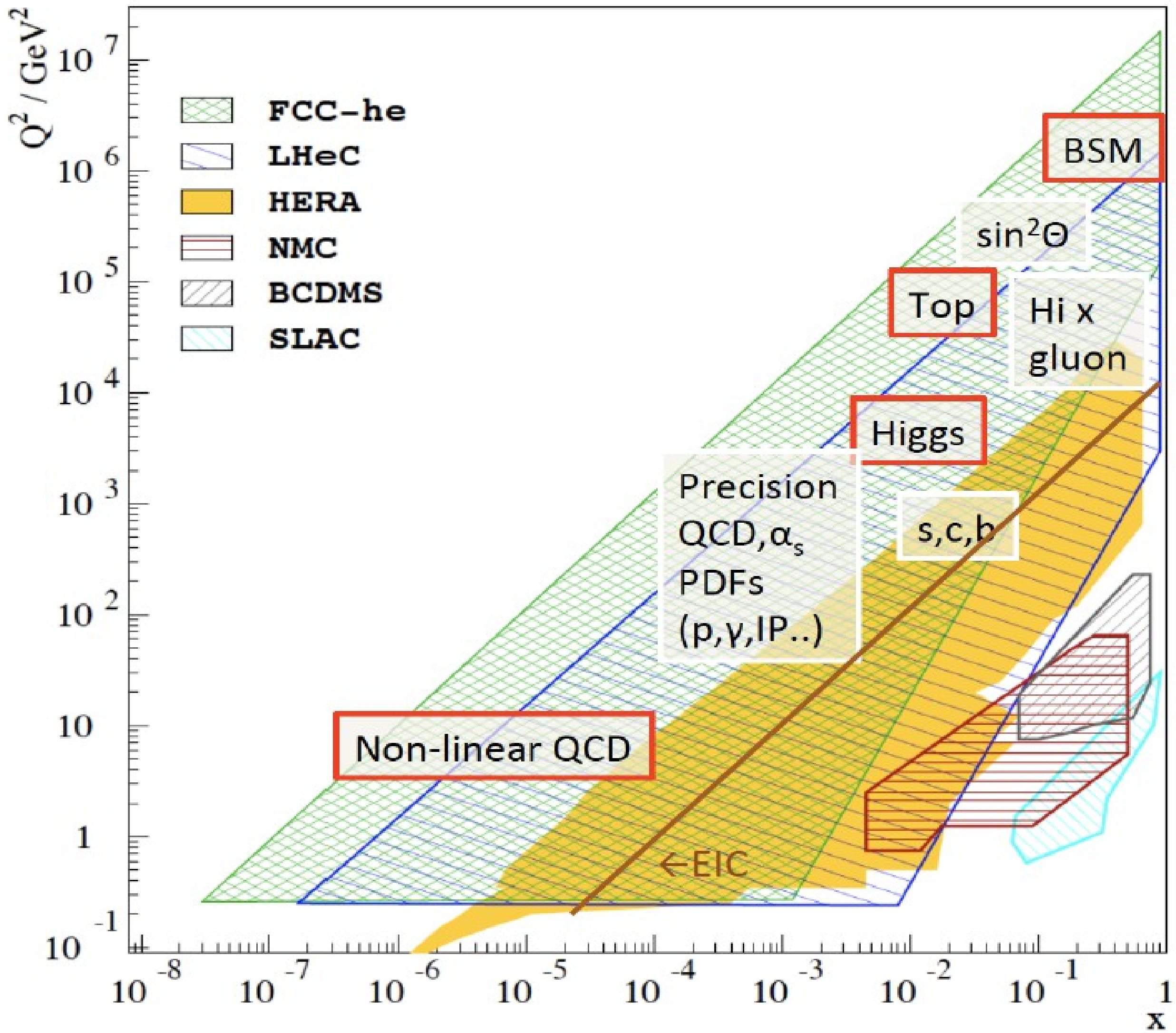
e-Print: arXiv:1206.2913 [physics.acc-ph] | PDF

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote

CERN Document Server; ADS Abstract Service; SLAC Document Server

Detailed record - Cited by 275 records

kinematical reach of LHeC and FCC-he deep into the possible 'saturation region'



'2013 European Strategy for Particle Physics' recommendations

General issues

a) The success of the LHC is proof of the effectiveness of the European organisational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN. *Europe should preserve this model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to the wider society.*

b) The scale of the facilities required by particle physics is resulting in the globalisation of the field. *The European Strategy takes into account the worldwide particle physics landscape and developments in related fields and should continue to do so.*

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

LHeC not part of major recommendations

Next steps

DG: Mandate to the International Advisory Committee 2015-2018

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

Two major next goals:

-Design and build an LHeC ERL demonstrator (10mA, 3 turn, 802 MHz)

-Update of the CDR by 2018: LHC physics, 10^{34} lumi, detector and accelerator updates

Currently the LHeC community is working on an update of the CDR to take into account LHC running and current results as well as to prepare for the “next European Strategy for Particle Physics' long range plan in 2019

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)

LHeC CDR update because:

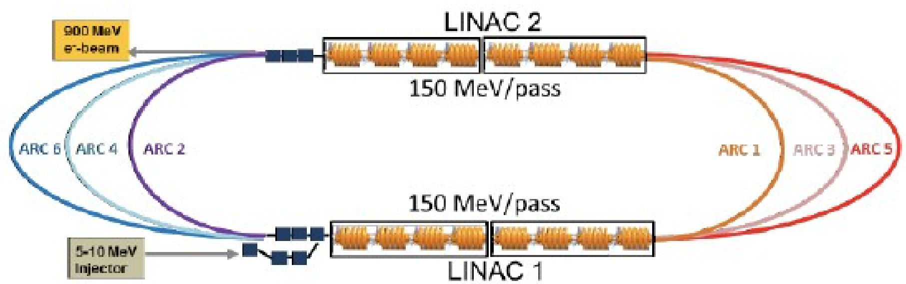
- Lumi * 10
- LHC results
- Technology progress

Open for any participation

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

LHeC project closely linked to accelerator development

PERLE | Powerful energy recovery linac experiments



Conceptual Design Report

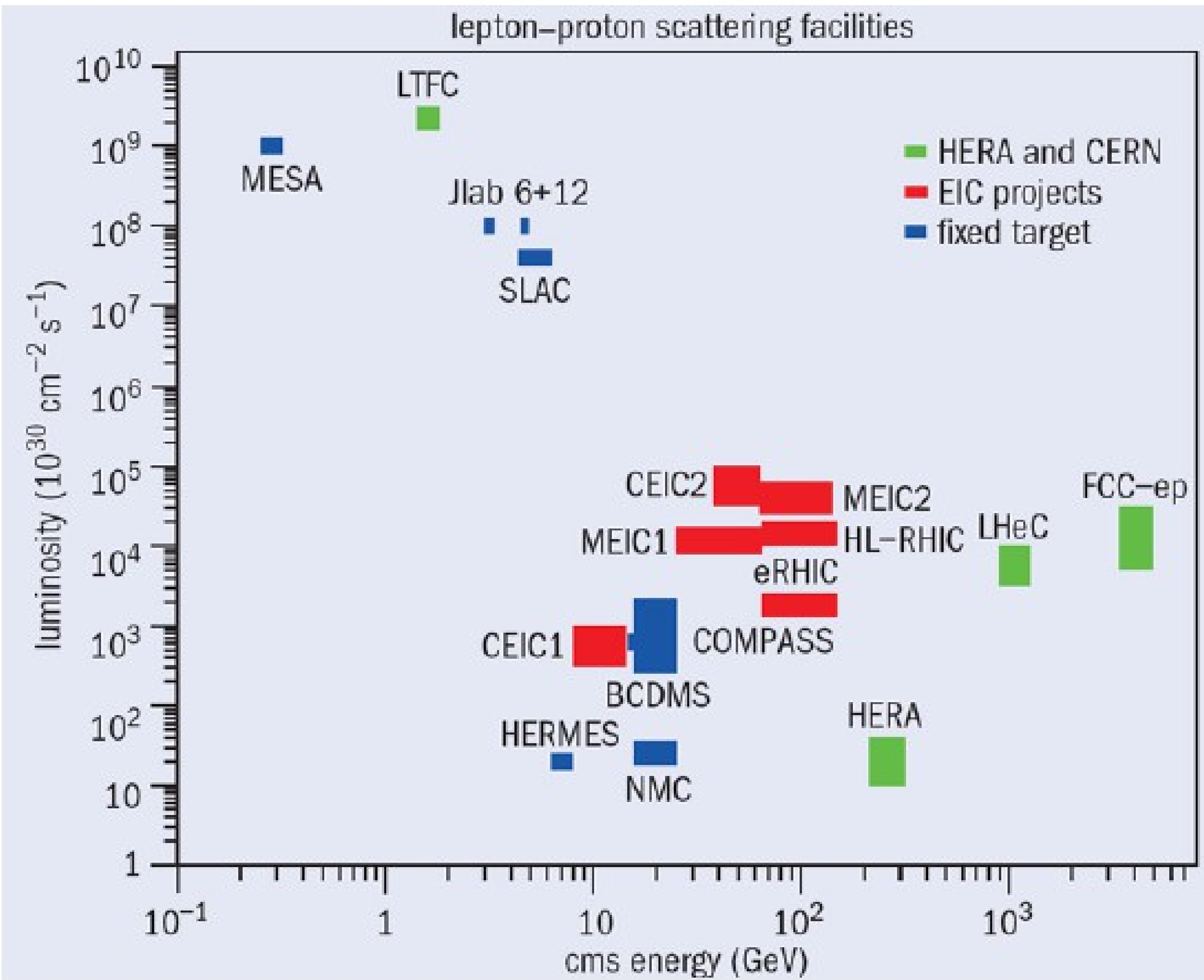
Draft 1.3 November 10^{th}, 2016

CELIA Bordeaux, MIT Boston, CERN, Cockcroft and Astec
Daresbury, TU Darmstadt, U Liverpool, Jefferson Lab
Newport News, BINP Novosibirsk, IPNO and LAL Orsay

Update on LHeC strategy in 2019

summary of e-p and e-ion facilities – completed, running and planned

plot courtesy H. Abramowicz
arXiv:1610.04109



Final thoughts (I)

- currently no electron-ion project ready for construction in Europe
- LHeC project is moving ahead to develop new CDR by 2018
- LHC high luminosity phase to run well into the 2030ties
- LHeC project has a sizable community with close ties to international HEP, NP, and accelerator community

Final thoughts (II)

- FAIR project to start full physics program around 2025
- LHC heavy ion program to run until (at least) 2028
- the US electron-ion collider project may well the only new major facility in HEP/NP in the foreseeable future