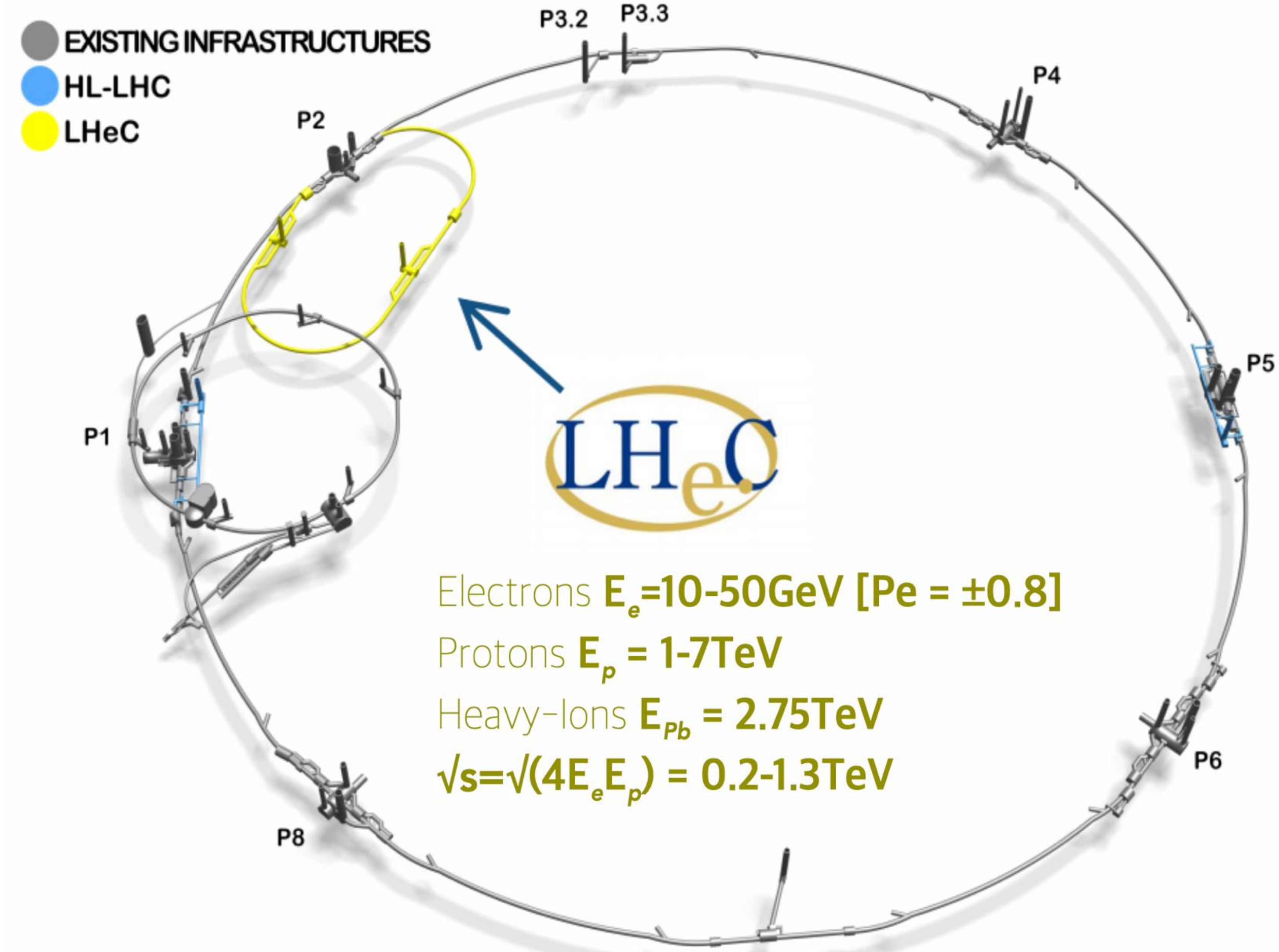
An experiment for *electron-hadron* scattering at the LHC

& ESPPU

Krzysztof PIOTRZKOWSKI (AGH University, Kraków)

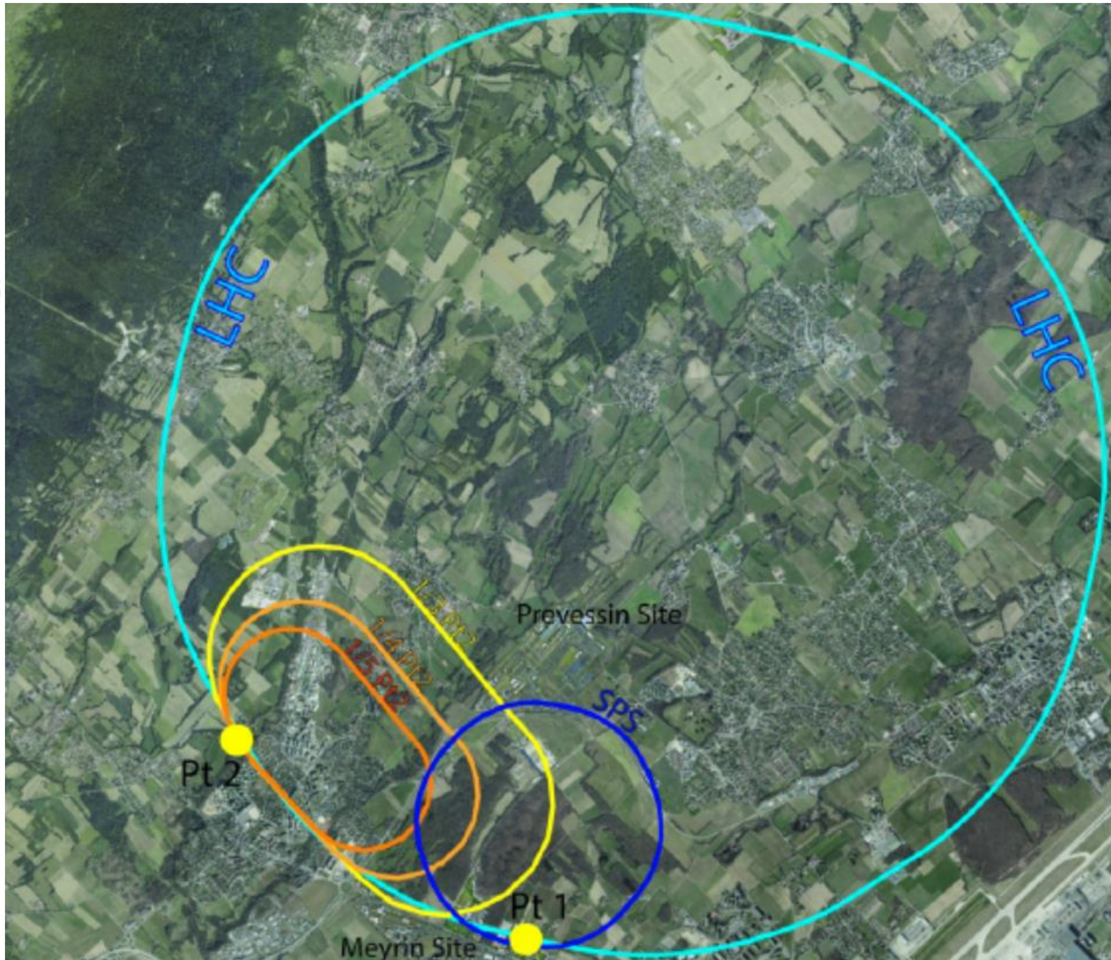


Electrons **E_e=10-50GeV [Pe = ±0.8]**

Protons **E_p = 1-7TeV**

Heavy-Ions **E_{Pb} = 2.75TeV**

$\sqrt{s}=\sqrt{(4E_eE_p)}$ = 0.2-1.3TeV



Before starting: Personal reflection

RAPID COMMUNICATIONS

PHYSICAL REVIEW D, VOLUME 63, 071502(R)

Tagging two-photon production at the CERN Large Hadron Collider

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and Institute of Nuclear Physics, Kawiory 26A, PL–30055 Kraków, Poland
(Received 17 October 2000; published 6 March 2001)

Tagging two-photon interactions offers a significant extension of the CERN LHC physics program. The effective luminosity of high-energy $\gamma\gamma$ collisions reaches 1% of the proton-proton luminosity. The standard detector techniques used for measuring very forward proton scattering will allow a reliable separation of interesting two-photon interactions. Particularly exciting is the possibility of detecting exclusive Higgs boson production via the $\gamma\gamma$ fusion.

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 179–180 (2008) August 2008

NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS

PHOTON-LHC-2008

Proceedings of the International Workshop on High-Energy Photon Collisions at the LHC
CERN, Geneva, Switzerland
22–28 April 2008

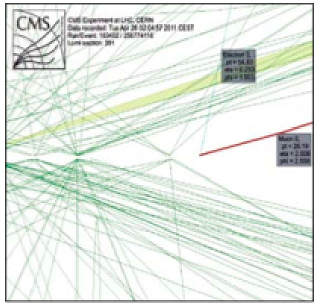
Edited by
D. d'Enterria
M. Klasen
K. Piotrzkowski

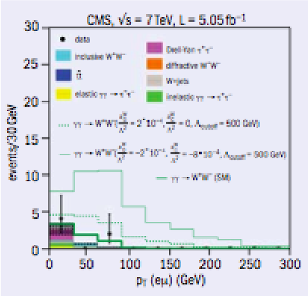
www.elsevierphysics.com

LHC PHYSICS

CMS sees first direct evidence for γγ→WW

In a small fraction of proton collisions at the LHC, the two colliding protons interact only electromagnetically, radiating high-energy photons that subsequently interact or "fuse" to produce a pair of heavy charged particles. Fully exclusive production of such pairs takes place when quasi-real photons are emitted coherently by the protons rather than by their quarks, which survive the interaction. The ability to select such events opens up the exciting possibility of transforming the LHC into a high-energy photon–photon collider and of performing complementary or unique studies of the Standard Model and





INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERNCOURIER

VOLUME 53 NUMBER 6 JULY/AUGUST 2013

collected at $\sqrt{s}$=7 TeV and to obtain the first direct evidence of the $\gamma\gamma\to WW$ process. Fully leptonic W-boson decays have been measured in final states characterized by opposite-sign and opposite-flavour lepton pairs where one W decays into an electron and a neutrino, the other into a muon and a neutrino (both neutrinos leave undetected). The leptons were required to have: transverse momenta p_T >20 GeV/c and pseudorapidity $|\eta|<2.1$; no extra track associated with their vertex; and for the pair, a total p_T>30 GeV/c. After applying all selection criteria, only two events remained – compared with an expectation of 3.2 events: 2.2 from $\gamma\gamma\to WW$ and 1 from background (figure 2).

The lack of events observed at large values of transverse momentum for the pair, which would be expected within the Standard Model, allows stringent limits on anomalous quartic $\gamma\gamma WW$ couplings to be derived. These surpass the previous best limits, set at the Large Electron–Positron collider and at the Tevatron, by up to two orders of magnitude (figure 3).

● **Further reading**
CMS collaboration 2013 arXiv:1305.5596 [hep-ex], submitted to *JHEP*.

This paper was first rejected by *Physics Letters B* and *Zeit. f. Physik C*…

and by now has 142 citations on *INSPIRE-HEP*

Lesson learned: it takes time, persistence and hard work to open new directions, but it is very much worth it!

https://indico.cern.ch/event/1423983/

- Overview
- Call for Abstracts
- Timetable
- Contribution List
- My Conference
  - My Contributions
- Registration
- Participant List
- Practical information
- Videoconference

Timetable

Thu 19/09 | **Fri 20/09** | All days

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Time	Contribution	Speaker	Location	Slot
09:00	**Introduction to the LHeC machine**	*Oliver Bruning*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	09:00 - 09:25
	Introduction to the machine-detector interface studies	*Bernhard Holzer*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	09:25 - 09:50
	Proton optics studies	*Tiziana Von Witzleben*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	09:50 - 10:15
10:00	**Electron optics studies**	*Kevin Daniel Joel Andre*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	10:15 - 10:40
	Coffee break		*D-10 D-czarna (3rd floor), AGH University of Kraków*	10:40 - 11:10
11:00	**Synchrotron radiations studies**	*Laurent Forthomme*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	11:10 - 11:35
	The HERA ep Interaction Regions - Learned Lessons	*Uwe Schneekloth*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	11:35 - 12:00
12:00	**EIC machine-detector interface experience**	*Andrii Natochii*	*D-10 D-czarna (3rd floor), AGH University of Kraków*	12:00 - 12:25

Electron-Hadron collisions at TeV scales

TOPICAL REVIEW • OPEN ACCESS

The Large Hadron–Electron Collider at the HL-LHC

P Agostini[1], H Aksakal[2], S Alekhin[3,4], P P Allport[5], N Andari[6], K D J Andre[7,8], D Angal-
S Antusch[11], L Aperio Bella[12], L Apolinario[13] + Show full author list

Published 20 December 2021 •

Journal of Physics G: Nuclear and Particle Physics, Volume 48, Number 11

Reminder:

LH*e*C CDR in 2012 – proposing **concurrent** *ep* collisions (above 1 TeV) at the LHC

New LH*e*C proposal in 2020 – 337 authors from 156 institutions

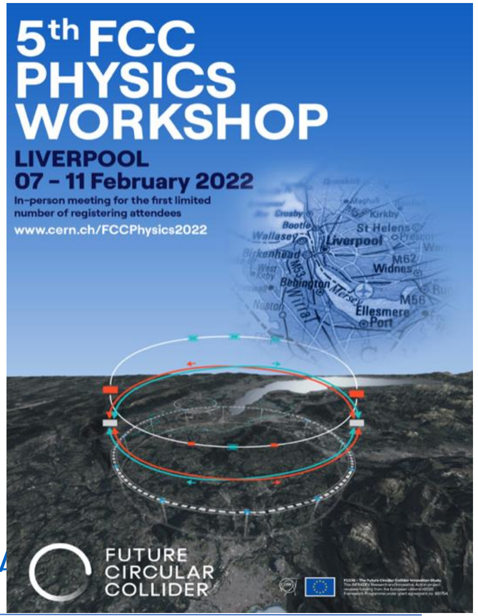
Includes discussion of FCC-*eh* physics (1.2 → 3.5 TeV)

Eur. Phys. J. C (2019) 79:474
https://doi.org/10.1140/epjc/s10052-019-6904-3

Review

FCC Physics Opportunities

https://indico.cern.ch/event/1066234/



Large Hadron *electron* Collider

LH*e*C is **NOT** simply super-HERA!

LHeC luminosity ≈ 1000 × HERA

LH*e*C is not just "super QCD machine" – it is much more:

Novel **powerful lab** for Electroweak & Higgs physics

+

Sensitivities to **new BSM signatures**

+

High energy *eA* collider (**very complementary** to EIC)

Large Hadron *electron* Collider

Energy Recovery Linac technology, or on-going revolution in high energy electron acceleration techniques

Machine Parameters and Operation - ep

arXiv:2007.14401

Parameter	Unit	LHeC			
		CDR	Run 5	Run 6	Dedicated
E_e	GeV	60	30	50	50
N_p	10^{11}	1.7	2.2	2.2	2.2
ϵ_p	μm	3.7	2.5	2.5	2.5
I_e	mA	6.4	15	20	50
N_e	10^9	1	2.3	3.1	7.8
β^*	cm	10	10	7	7
Luminosity	$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1	5	9	23

ERL technology resulted in major breakthrough for LH*e*C (at 100 MW):

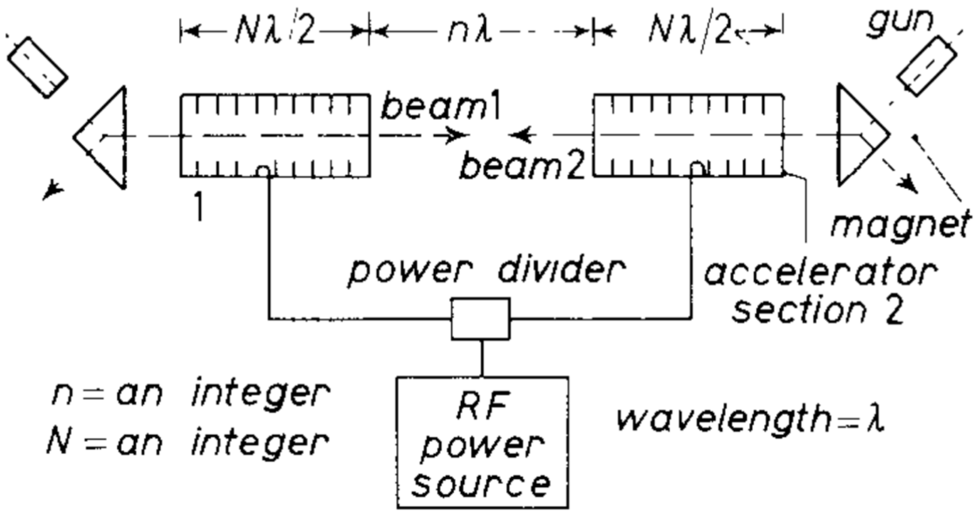
→ **10 × luminosity**

Energy Recovery Linac (green) technology

“Energy Recovery is at the threshold of becoming a key means for the advancement of accelerators. **Recycling the kinetic energy of a used beam for accelerating a newly injected beam**, i.e. **reducing the power consumption***, utilising the high injector brightness and dumping at injection energy: these are the key elements of a novel accelerator concept, invented half a century ago**. The potential of this technique may be compared with the finest innovations of accelerator technology such as by Widerøe, Lawrence, Veksler, Kerst, van der Meer and others during the past century. Innovations of such depth are rare, and their impact is only approximately predictable. **The fundamental principles of Energy-recovery linacs (ERLs) have now been successfully demonstrated across the globe**. There can no longer be any doubt that an ERL can be built and achieve its goals.” -- *European Strategy for Particle Physics – Accelerator R&D Roadmap* (CERN Yellow Report)
https://arxiv.org/abs/2201.07895

*) Even by an order of magnitude

**) M. Tigner – *A Possible Apparatus for Electron Clashing-Beam Experiments*, Nuovo Cimento 10 (1965) 1228 ⇒⇒

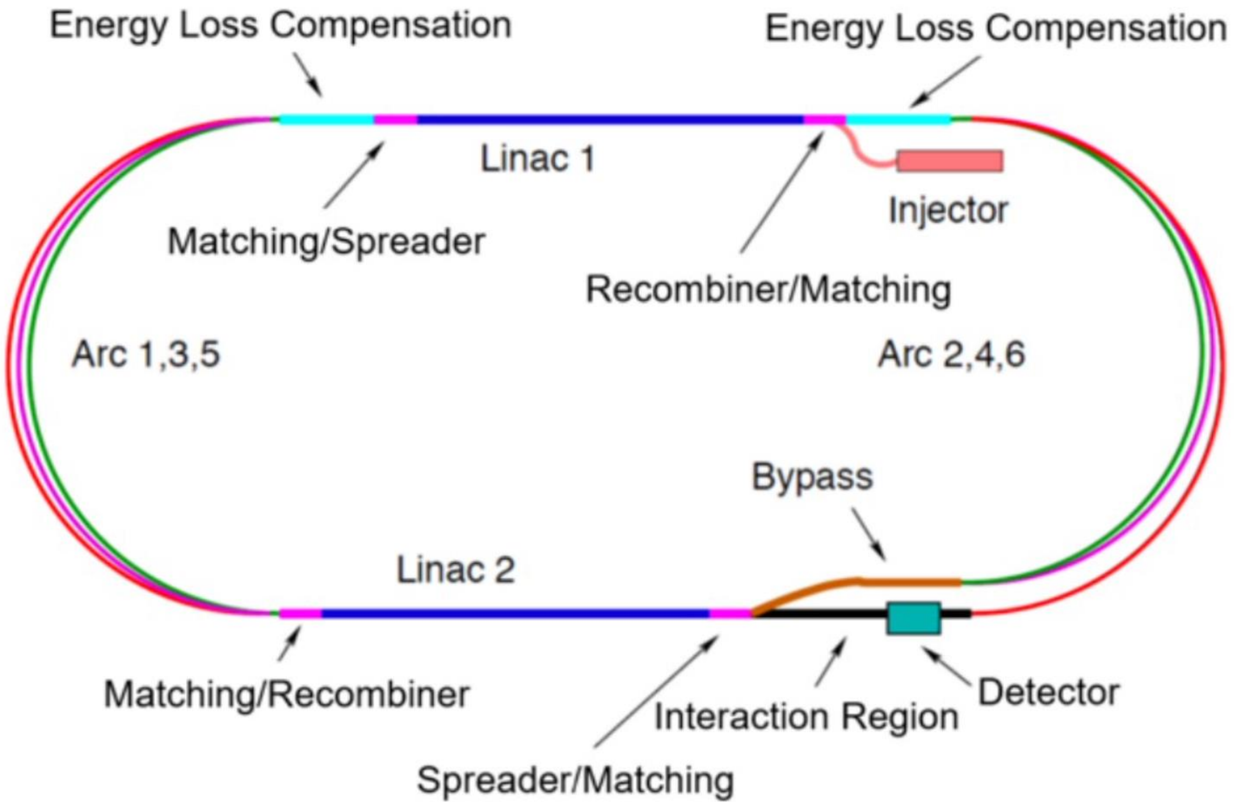


Quite surprising gravitational analogy – note 2036 date 🚀
https://www.youtube.com/watch?v=6RiYXI1Tfu4

ERL@LHeC as *Relay* Short Track Speed Skating

6×ERL@HL-LHC

ERL geometry

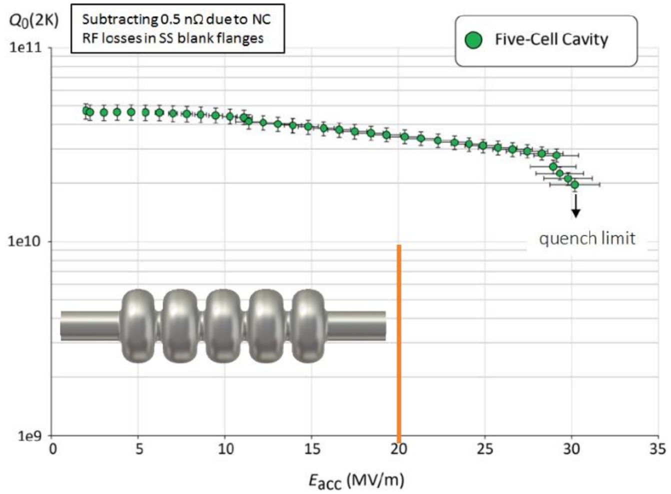


- Two SC linac accelerators
- three-pass return arcs

- ERL main parameters

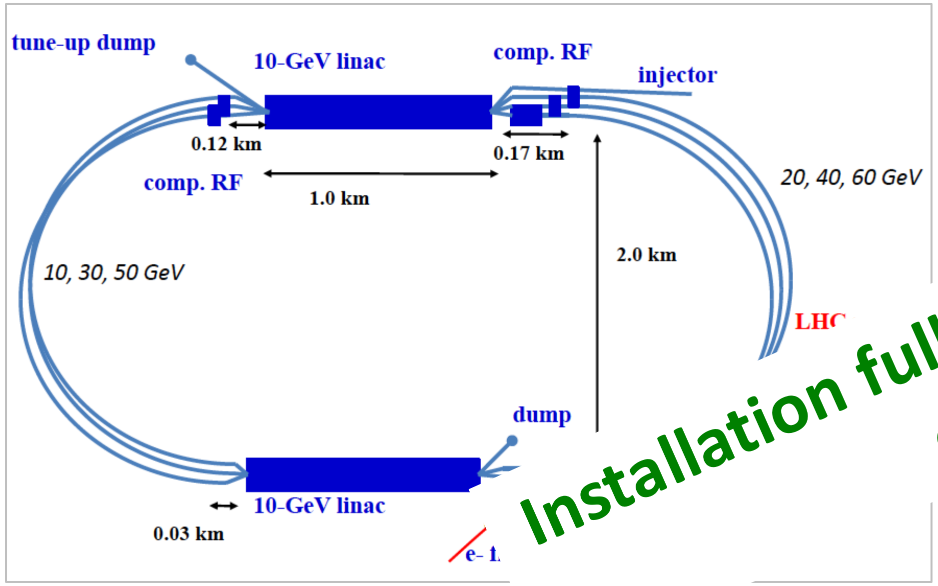
Parameter	Unit	Value
Beam energy	GeV	50
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
trans. norm. emittance	μm	30
RF frequency	MHz	801.58
Acceleration gradient	MV/m	20.06
Total length	m	6665

- Q-parameter of 5-cell prototype



LHeC Linac-Ring Option: Power & Cost considerations

- 2 Super Conducting Linacs with Energy Recovery & high current (> 6mA)



Installation fully decoupled from LHC operation!

Two 1 km lo… SC linacs … ration ($Q_0 > 10^{10}$)

…s Cryogenic system comparable to LHC system!

➔ ca. 9km underground tunnel infrastructure [SPS size]

- Efficient Concept

➔ re-circulation implies cost effective use of the SRF investment

➔ ERL implies efficient operation and higher performance reach

Experiment for *eh* and *hh* scattering @ IP2

Eur. Phys. J. C (2022) 82:40
https://doi.org/10.1140/epjc/s10052-021-09967-z

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

An experiment for electron-hadron scattering at the LHC

K. D. J. André[1,2], L. Aperio Bella[3], N. Armesto[4,a], S. A. Bogacz[5], D. Britzger[6], O. S. Brüning[1], M. D'Onofrio[2], E. G. Ferreiro[4], O. Fischer[2], C. Gwenlan[7], B. J. Holzer[1], M. Klein[2], U. Klein[2], F. Kocak[8], P. Kostka[2], M. Kumar[9], B. Mellado[9,10], J. G. Milhano[11,12], P. R. Newman[13], K. Piotrzkowski[14], A. Polini[15], X. Ruan[9], S. Russenschuk[1], C. Schwanenberger[3], E. Vilella-Figueras[2], Y. Yamazaki[16]

In 2019 proposal of Alice 3 at IP2 of HL-LHC was presented – our paper showed that it is feasible to make experiments of

ep* vs. *pp AND ***eA* vs. *AA***

with SAME (Alice 3*e*..:) detector !

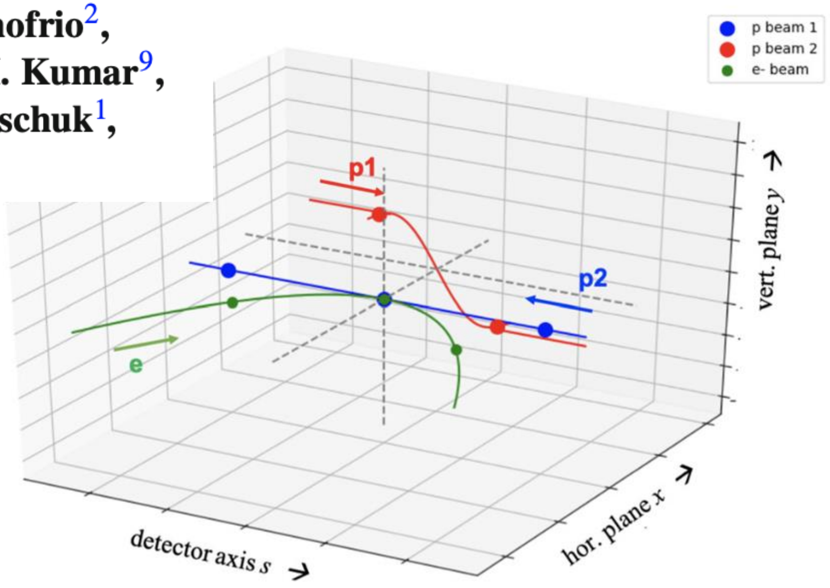
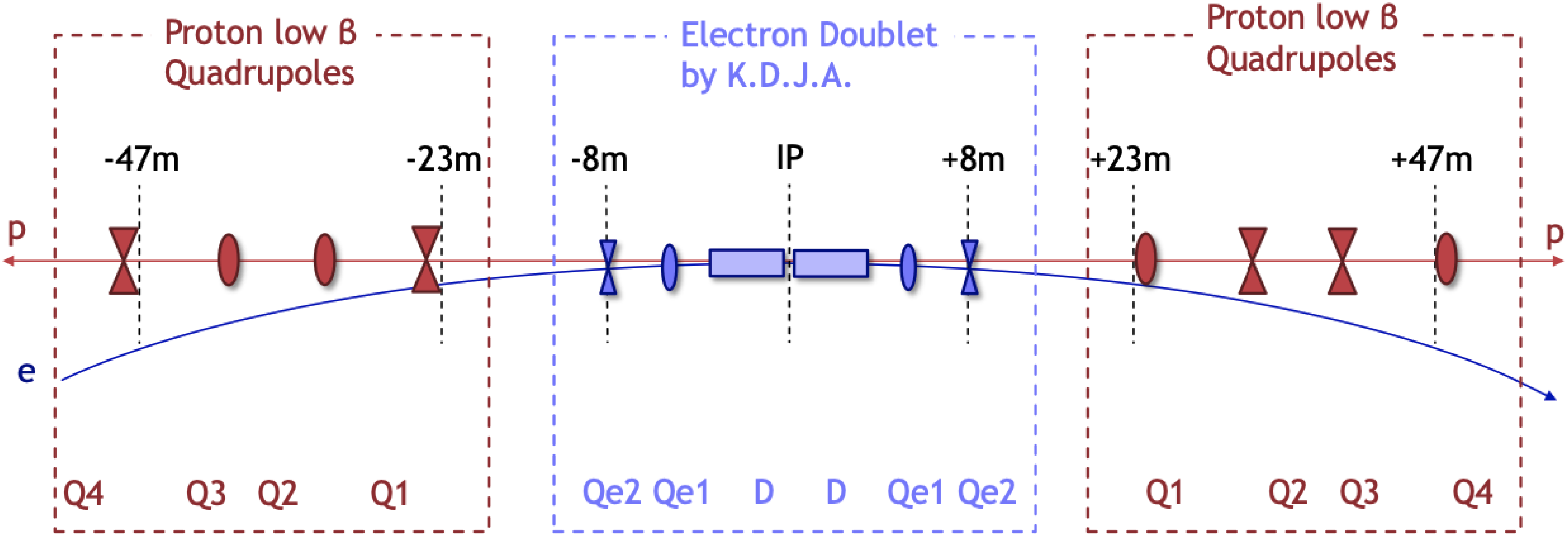


Fig. 17 Schematic view of the three beams in the interaction region. Collisions between electrons and proton beam 1 and a well separated proton beam 2

The LHeC interaction region:

Tiziana Von Witzleben @ Synergy Workshop ep/eA, CERN 1.3.2024



Create a three beam optics, with e-p collisions and one proton beam passing by

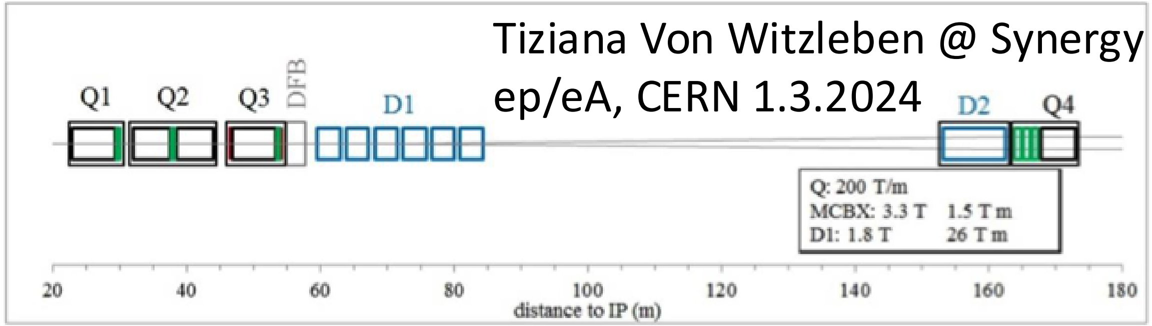
PhD thesis K.D. J. André

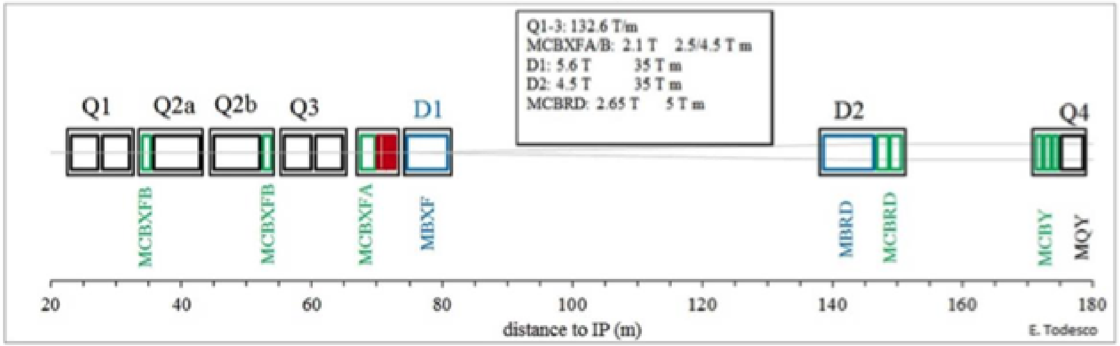
01/03/2024 3

Tiziana Von Witzleben @ Synergy Workshop ep/eA, CERN 1.3.2024

HL-LHC Upgrade

- Final focusing system is changed from NbTi to Nb3Sn
- D1 magnet superconducting
- crab cavities are inserted in IR 1 and IR 5
- Q4 is moved relative to the IP





Parameter	Unit	Value HL-LHC	LHC IR1/5 Q1/Q2/Q3
Magnetic field gradient	T/m	132.6	200/205
Magnetic length	m	4.20/7.15	6.3/5.5/6.3
Aperture radius	mm	75	22.2/28.95
Number of turns per pole		50	
Conductor material		Nb_3Sn	NbTi

Implement this triplet in IR2 -> Gain of aperture!

01/03/2024 8

Experiment for electron-hadron scattering @ IP2

– The detector is required to have a magnet system consisting of **a central solenoid along with a dipole system** to steer the electron beam allowing for head-on *eh* collisions at the interaction point;

– The **non-interacting proton/ion beam** has to bypass the *ep* interaction yet to be guided through the same beam pipe housing the interacting electron and proton/ion beams;

– The shape of the beam pipe has to allow for the electron beam generated **synchrotron fan** to leave the interaction region unaffected and with minimal back-scattering;

– Good vertex resolution implies a small radius and thin beam pipe optimised in view of synchrotron radiation and background effects;

– The tracking and calorimetry in the forward and backward directions are set up to take into account the extreme asymmetry of the DIS production kinematics, see [1], with multi-TeV energies emitted in the forward, proton beam direction while the electromagnetic and hadron energies emitted backwards are limited by the electron beam energy.

– Very forward and backward detectors have to be set up to access diffractive produced events and to tag photo-production processes besides measuring the luminosity with high precision in Bether–Heitler scattering, respectively.

https://link.springer.com/article/10.1140/epjc/s10052-021-09967-z

Experiment for *eh* and *hh* scattering @ IP2

"As described above in Sect. 4.6, the **new accelerator optics is able to provide collisions for *eh* and *hh* configurations in the same interaction point**. As a consequence and if confirmed by further study, IP2 could indeed house one, common multi-purpose detector serving for all of these, mostly related physics programs, of *ep*, *pp*, *eA*, *pA* and *AA* interactions, with high precision and large acceptance, and the **unique advantage for cross-calibration of performance and physics**."

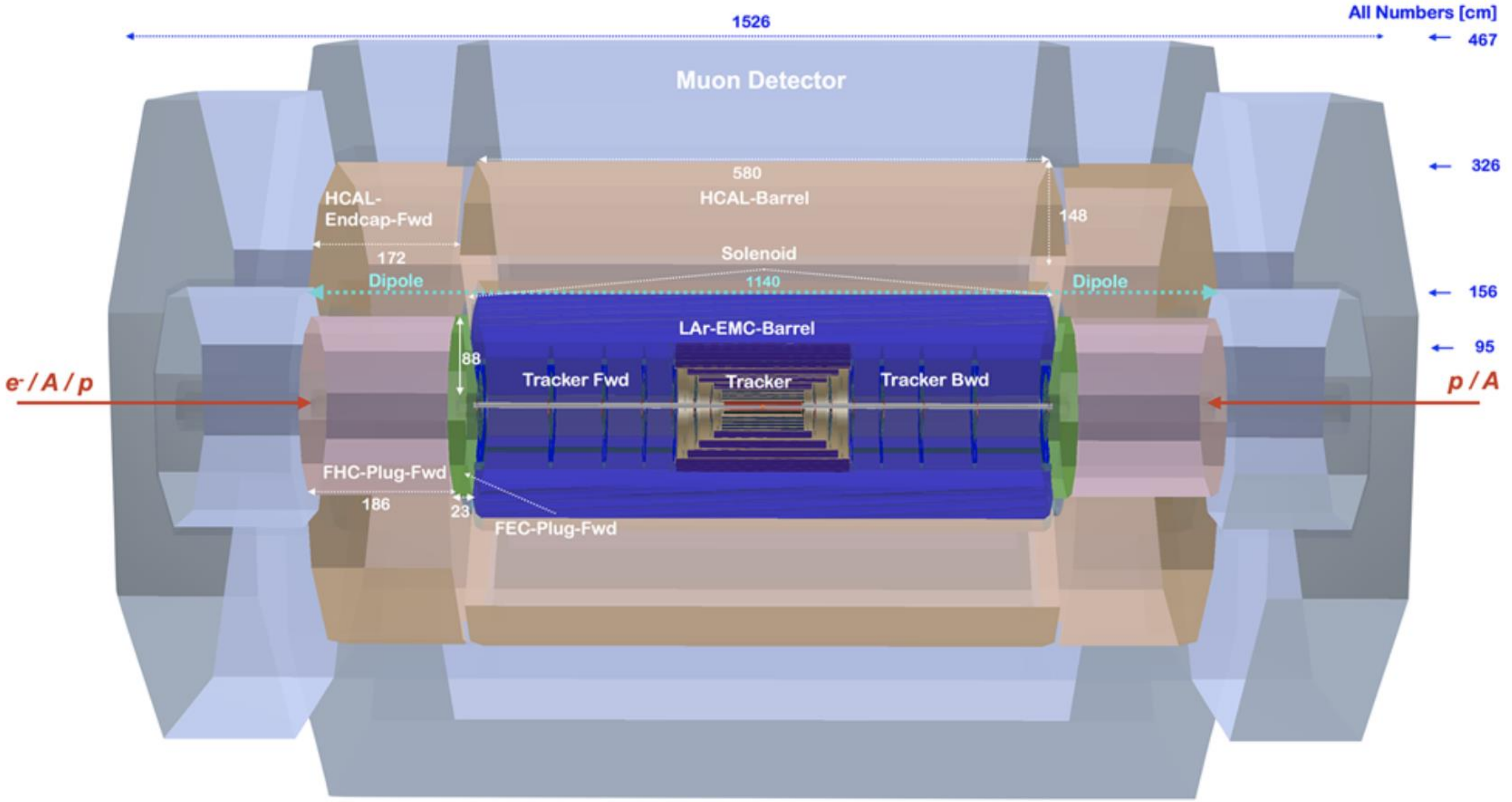


Fig. 24 Side view of a first design of the LHeC detector for both *eh* and *hh* collisions, where the detector coverage of the backward (electron) direction is extended to match that for the forward (hadron) direction.

Experiment for *eh* (and *hh*) scattering @ IP2

Huge advantage for *eh* experiments ⇒ **total inelastic cross-section:**

$$\sigma_{ep} \ll \sigma_{pp}$$

Event pileup is very small/negligible at LH*e*C

⬇

Data streaming *aka* "no triggering" is possible (as at EIC)

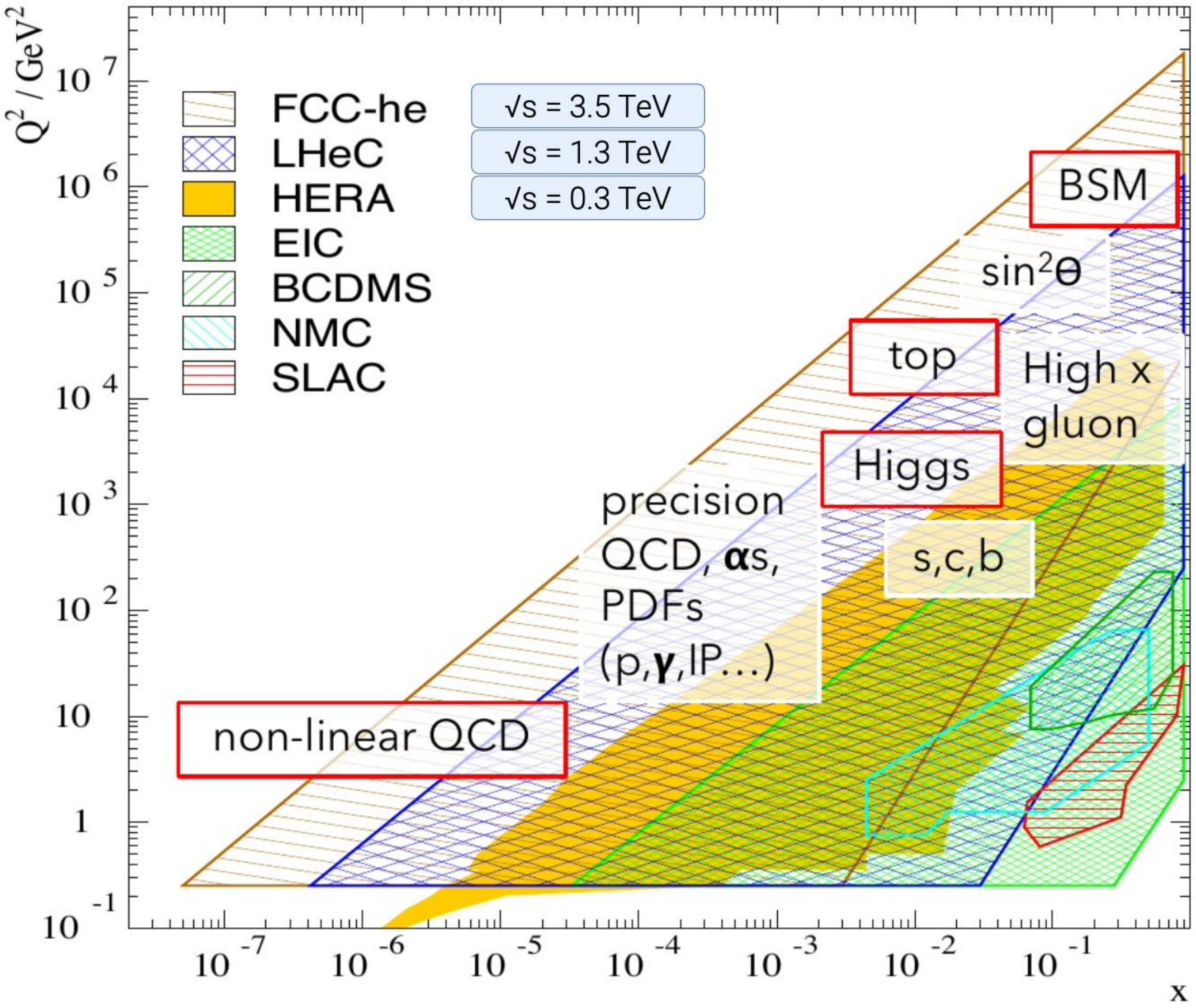
⬇

Much broader types of final states/decay channels are feasible!

⬇

Unique capabilities (with about 1000 fb^{-1} of collected data in total)

Electron-Hadron Scattering @ LHC



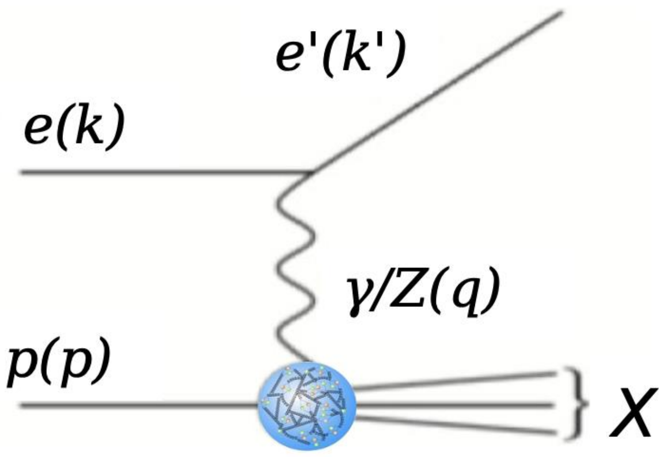
LHeC

- Rich physics program at all scales
  - Higgs physics in NC and CC DIS
  - Top quark production
  - BSM physics and searches
  - Precision QCD
    Proton structure, substructure, strong coupling constant, jet physics, heavy quarks, ...
  - Electroweak physics
  - Heavy ion programme

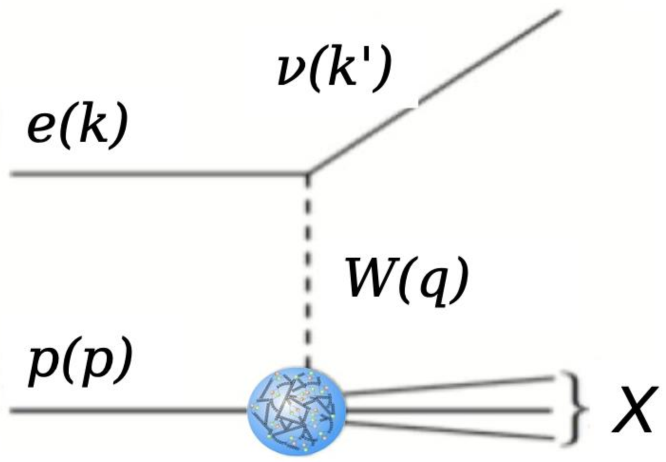
Several highlights ⇒⇒

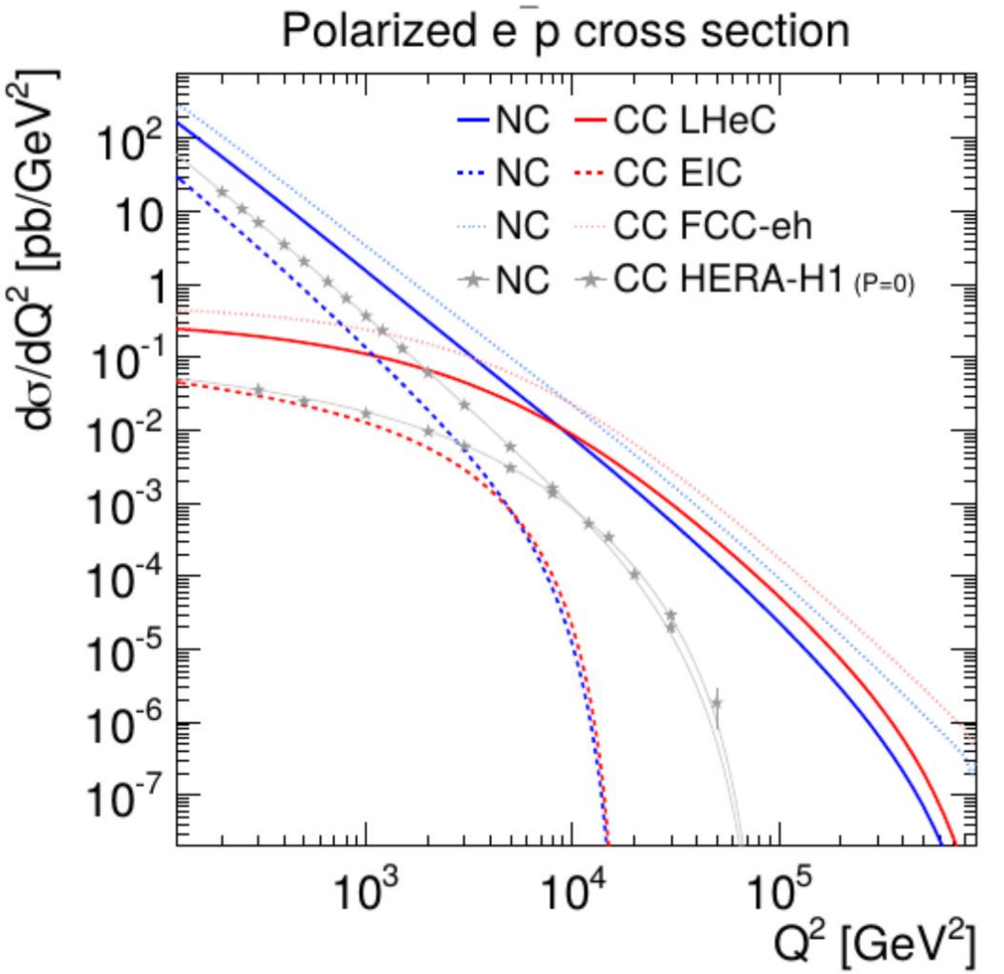
DIS @ LHeC

Neutral current scattering
$ep \to e'X$



Charged current scattering
$ep \to \nu_e X$





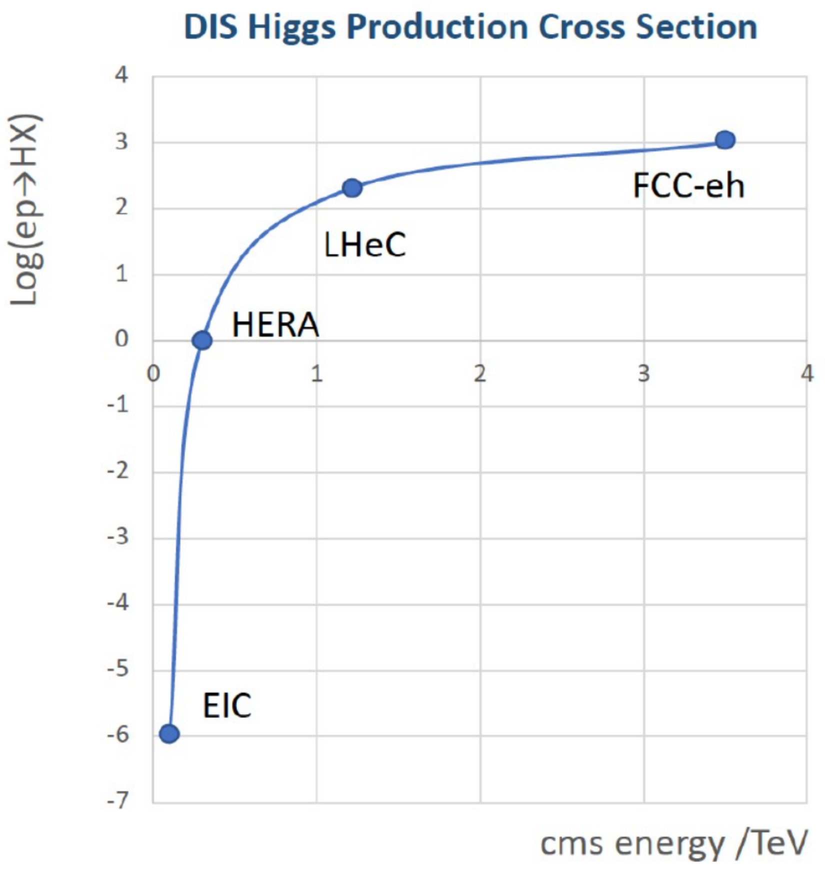
Deep-inelastic electron-proton scattering mediated in spacelike regime, by γ, γZ, Z or W-boson exchange

LHeC as Gauge Boson Collider

WW, *ZZ* and $\gamma\gamma$ fusion

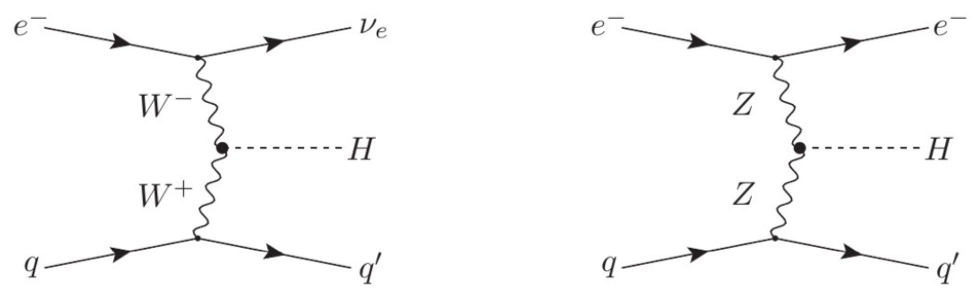
(in clean environment)

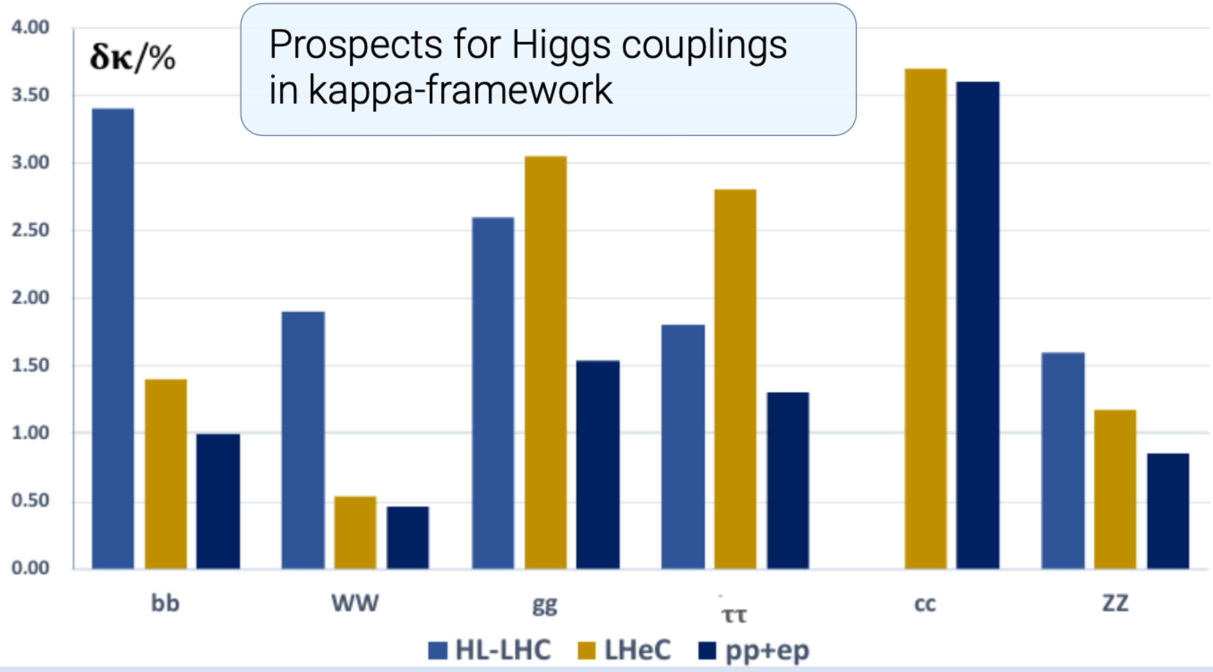
(*Clean*) Higgs factory @ LHeC



- Higgs-production cross section ~ 200pb
- Sensitivity to six decay channels
  bb, WW, gg, ττ, cc, ZZ

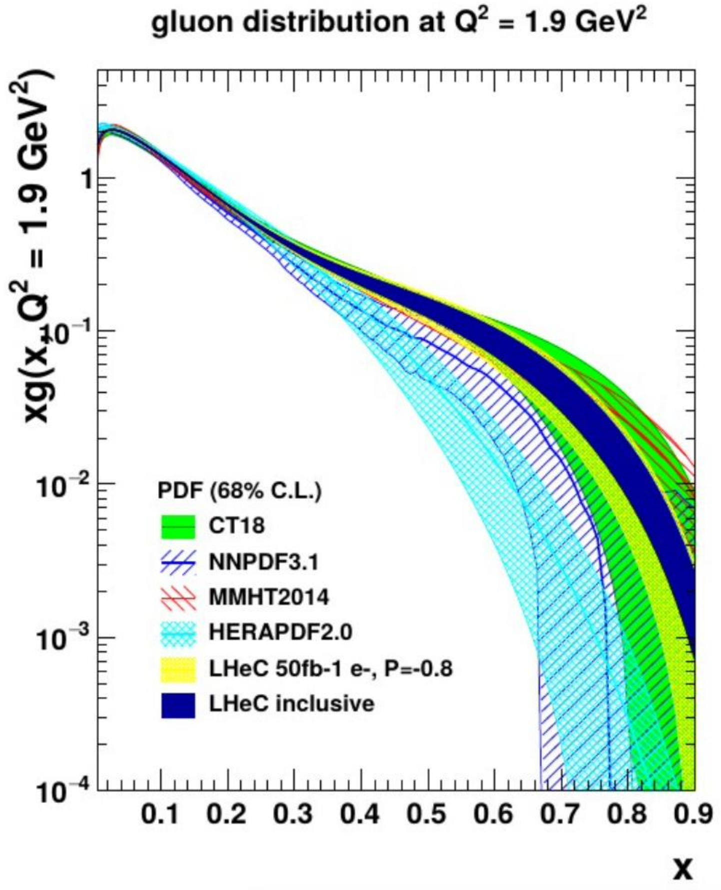
Higgs in CC and NC DIS

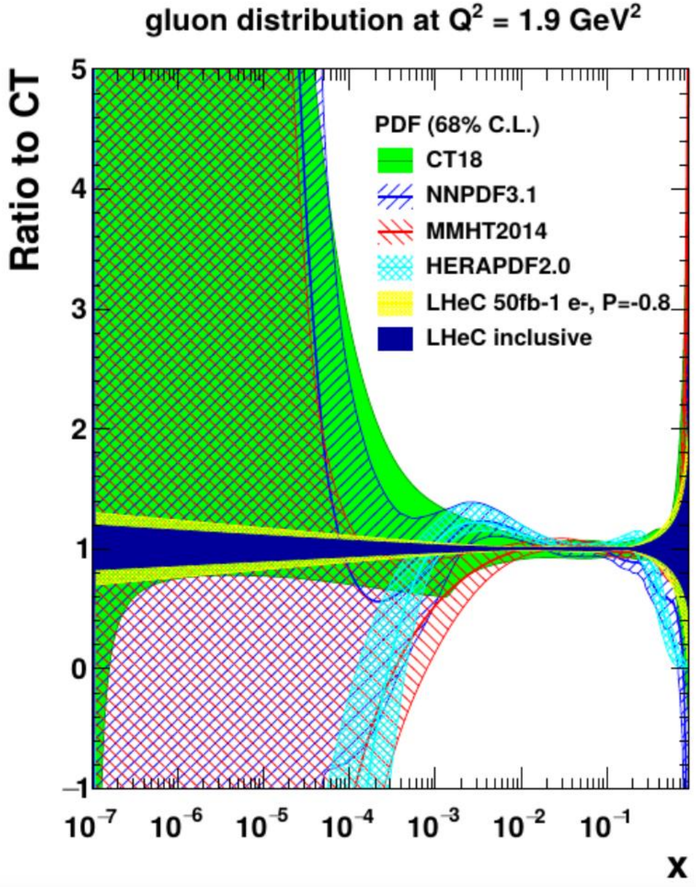


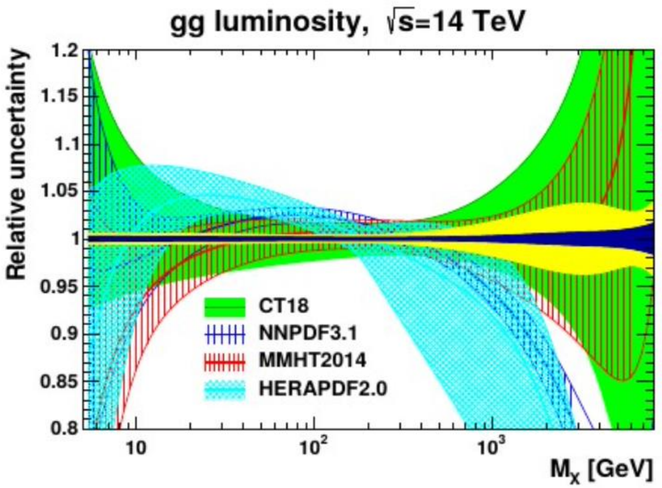


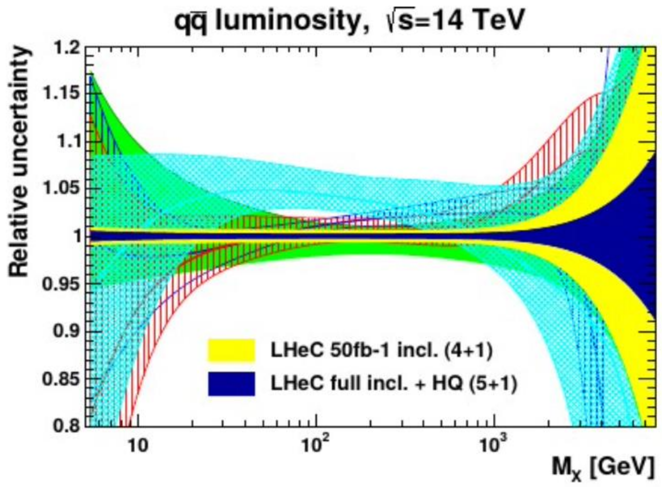
Electron-Hadron Scattering @ LHC

- Parton distribution functions (PDFs) of the proton with unprecedented precision
- Full determination of all flavors







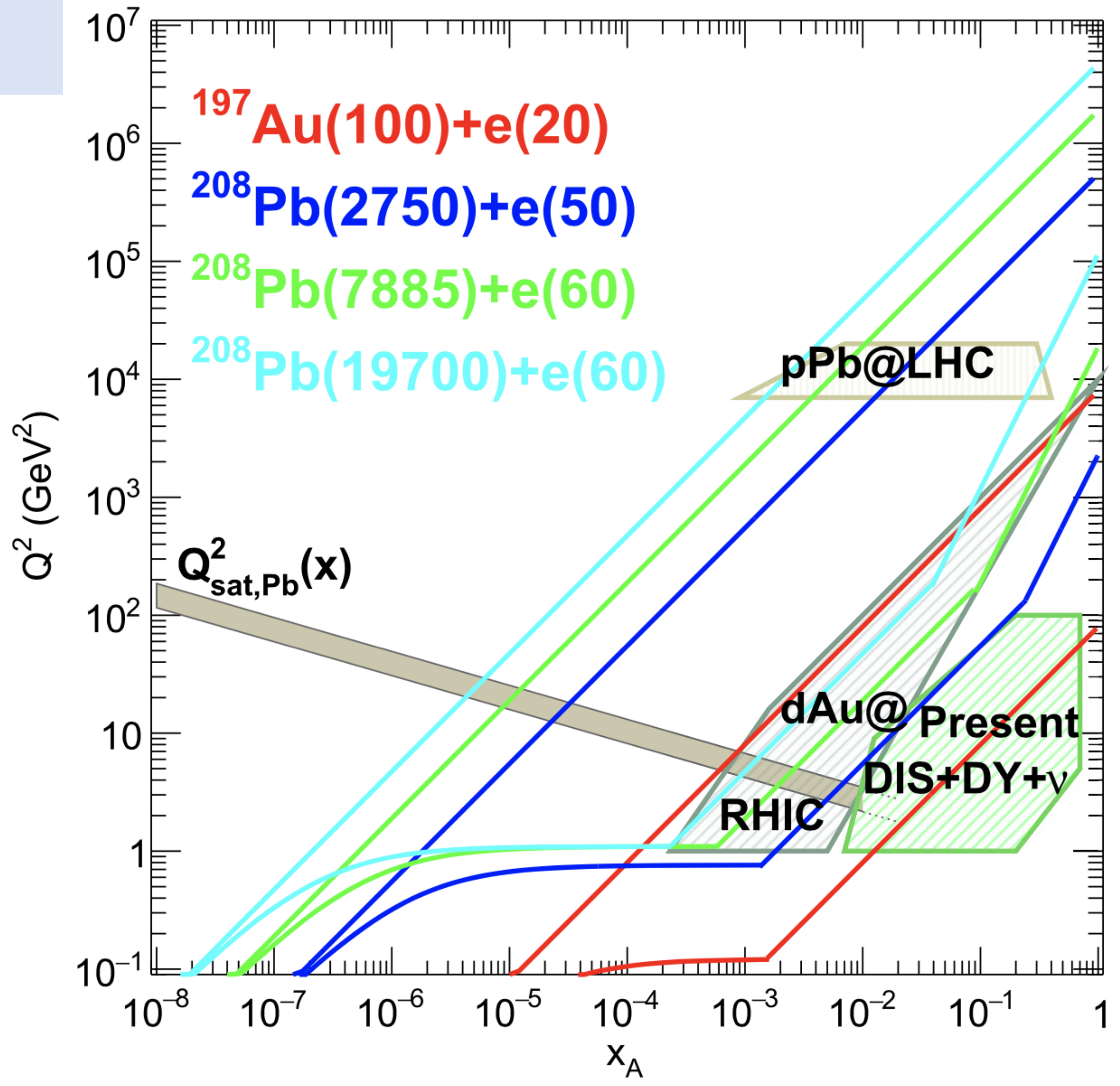


eA scattering at LHeC

Unprecedented access to (x,Q^2) kinematic plane in *eA*:

• coverage extended with respect to EIC by up to **2 orders of magnitude**

• DIS with nuclei down to and below $x = 10^{-5}$ in **perturbative** regime ⇒ ⇒ saturation scale (non-linearities) in fully perturbative regime



LHeC updates in Praha @ ICHEP2024

The LHeC and FCC-eh experimental program, Jorgen D'Hondt
https://indico.cern.ch/event/1291157/contributions/5890135/

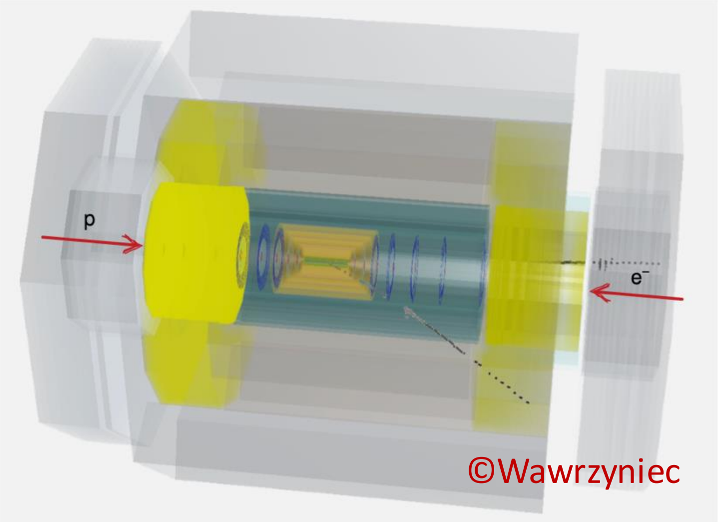
A detector for future DIS at the energy frontier, Laurent Forthomme
https://indico.cern.ch/event/1291157/contributions/5888179/

The general-purpose LHeC and FCC-eh high-energy precision programme: Top and EW measurements, Daniel Britzger https://indico.cern.ch/event/1291157/contributions/5896101/

Higgs precision physics in electron–proton scattering at CERN, Uta Klein
https://indico.cern.ch/event/1291157/contributions/5876815/

Proton and nuclear structure from EIC and HERA to LHeC and FCC-eh, Claire Gwenlan https://indico.cern.ch/event/1291157/contributions/5876815/

High energy $\gamma\gamma$ interactions at the LHeC, Krzysztof Piotrzkowski
https://indico.cern.ch/event/1291157/contributions/5905430/



Event display of a DDG4/Geant4 simulation of a central exclusive $ep \to e(\gamma\gamma \to \mu^+\mu^-)p$ event as generated by CepGen inside the LHeC detector.

Aftermath of two "earthquakes" last winter…

CERN SUPERCOLLIDER IN QUESTION AS TOP FUNDER CRITICIZES COST

Germany has raised doubts about the affordability of the Large Hadron Collider's planned successor.

By Davide Castelvecchi

Plans for a 91-kilometre European particle accelerator are facing a challenge after the German government said that the project was unaffordable.

CERN, the European particle-physics laboratory outside Geneva, Switzerland, has embarked on a feasibility study for the first stage of its Future Circular Collider (FCC). This stage, known as FCC-ee, would involve a machine to smash electrons together with antielectrons, and could cost 15 billion Swiss francs (US$17 billion) by the time it is completed in the mid-2040s. The initial phase of that study, focusing on the technical aspects, had a positive outcome, CERN said in February.

But Germany, which already contributes €267 million (US$290 million) annually to CERN – some 20% of the lab's budget – cannot afford to spend more, said Eckart Lilienthal of the country's Federal Ministry of Education and Research (BMBF) on 23 May, at a workshop for particle physicists in Bonn, Germany.

The preliminary cost estimates for the FCC-ee "are subject to a large number of uncertainties, the effects of which are still largely unknown", a BMBF spokesperson told *Nature*. "The financing plan is extremely vague and requires a high level of commitment from external partners, which is neither assured nor even in prospect at the present time. Given these conditions, Germany cannot support funding of the project at this point."

The German government had already made its position known to CERN at a closed meeting in February. But Lilienthal's remarks surprised some researchers, says Jenny List, a particle physicist at the German Electron Synchrotron (DESY) in Hamburg, who presented alternatives to the FCC-ee at the Bonn workshop. "Clearly, this is still sinking in with the German particle-physics community," she says.

CERN's research director, Joachim Mnich, played down the implications of Lilienthal's remarks. "The questions and concerns he raised about the FCC are not new to us and they are all being addressed in the FCC feasibility study," he says.

"All comments and feedback received from our member states will be taken into account in the preparation for the final report," says CERN spokesperson Arnaud Marsollier.

Future Higgs factory

The main goal of the FCC-ee would be to mass-produce the Higgs boson, the particle that was discovered in 2012 at CERN's

Bottom line

FCC-ee (in 2048)

vs.

CEPC (in 2037)

"issue" to be resolved by **end of 2025**

CHINA HOPES TO BUILD WORLD'S BIGGEST PARTICLE COLLIDER

The facility would be cheaper, bigger and faster to construct than one proposed by European scientists.

By Gemma Conroy

China hopes to build a US$5-billion particle smasher in the next three years, beating Europe's proposed mega-collider to the punch. The 100-kilometre Circular Electron Positron Collider (CEPC) would aim to measure the Higgs boson – a mysterious particle that gives everything mass – in exquisite detail. Such information could answer fundamental questions about how the Universe evolved and why particles interact in the way that they do.

Next year, the proposal for the CEPC will go before the Chinese government for possible inclusion in the country's next five-year plan. If it can win government support, construction could begin in 2027 and would take around a decade, according to a technical-design report published on 3 June (J. Gao *Radiat. Detect. Technol. Methods* https://doi.org/m4kg; 2024). The report estimates that the supersized collider would cost 36.4 billion yuan (US$5.2 billion), making it considerably cheaper to build and run than Europe's US$17-billion Future Circular Collider (FCC). Construction on the European facility will begin in the 2030s if it receives government approval.

Inside its enormous underground tunnel, the CEPC would smash together electrons and their antiparticles, positrons, at extraordinarily high energies to generate millions of Higgs bosons. The sheer number of these would allow researchers to study the particle in greater detail than ever before, says Andrew Cohen, a theoretical physicist at the Hong Kong University of Science and Technology. By measuring the Higgs more precisely, researchers will be able to explore questions that reach beyond the Standard Model – the leading but incomplete theory of what the cosmos is made of – such as the nature of dark matter and why there is more ordinary matter than antimatter in the Universe.

The latest report includes a detailed blueprint of the accelerator's layout design and component prototypes, says physicist Wang Yifang, director of the Chinese Academy of Science's Institute of High Energy Physics (IHEP) in Beijing. It also includes assessments of three potential sites: Qinhuangdao, Changsha and Huzhou. "We are now confident this is a real machine that we can build," says Wang.

Many of the components that are planned for China's mega machine are already being tested at other facilities in the country, says

LHeC: very personal outlook

[It is likely CEPC funding will be approved in 2025]

LH*e*C concept is fully developed and is ready to be thoroughly considered by ESPP Update as next big project at CERN

If by 2027 CERN/Europe decide to make LHeC, it seems feasible by 2036 to get 20 GeV electron beam at IP2 for concurrent *ep* (and *eA*) collisions at 0.75 TeV, and final "stand-alone" LH*e*C at 1.2 TeV in 2040s

In parallel, novel acceleration techniques can be vigorously pursued, as acceleration in plasma, or/and concept of **multi-TeV muon collider**

LHeC: very personal outlook

If by 2027 CERN/Europe decide to make LH*e*C, it seems feasible by 2036 to get 20 GeV electron beam at IP2 for **concurrent** *ep* (and *eA*) collisions at **0.75 TeV**, providing also perfect LH*e*C staging

↓

win-win-win for LHC science programme

↓

making unique LH*e*C science + improving precision of *pp* experiments + enhancing HI research with Alice 3*e* [data streaming already in use in Alice!]

ESPP white paper preparation meeting for LHeC

Friday 15 Nov 2024, 08:00 → 18:30 Europe/Zurich

6/2-024 - BE Auditorium Meyrin (CERN)

Jorgen D'Hondt (Vrije Universiteit Brussel (BE)), Nestor Armesto Perez (Universidade de Santiago
Yannis Papaphilippou (CERN)

https://indico.cern.ch/event/1456583/

zoom ESPP white paper preparation meeting for ep/eA

09:00 → 11:00 **Part I**

- 09:00 **Introduction**
  Speaker: Jorgen D'Hondt (Vrije Universiteit Brussel (BE))
- 09:10 **Staged approach to LHeC**
  Speaker: Krzysztof Piotrzkowski (AGH University (Kraków, PL))
- 09:30 **News from the IR workshop**
  Speakers: Bernhard Holzer (CERN), Laurent Forthomme (AGH University
- 10:00 **PDFs and alphas**
  Speaker: Katarzyna Wichmann (Deutsches Elektronen-Synchrotron (DE))
- 10:20 **Small x**
  Speaker: Mirja Tevio
- 10:40 **PDFs and SMEFT**

11:30 → 13:00 **Part II**

- 11:30 **I: The LHeC at the frontline of particle and nuclear physics**
- 11:45 **II: LHeC physics enabling HL-LHC & high-energy proton collider physics**
- 12:00 **III: LHeC technology enabling a Higgs factory**
- 12:15 **IV: Technical feasibility of the LHeC**
- 12:30 **V: The LHeC Cost and Resource Estimates**
- 12:45 **VI: The LHeC implementation plan**

Next week

LHeC: Summary

LH*e*C will complete the HL-LHC science in profound & relevant ways – in **QCD**, HF, top, **Higgs** & Electroweak sectors

In addition, PDF determined at LH*e*C will **significantly decrease systematic uncertainties** of *pp* experiments at HL-LHC

LH*e*C offers practically ideal conditions for studying high energy $\gamma\gamma$ interactions (and other exclusive processes) and will open new era in *eA* studies

NEW detector and beamline designs have been developed for IP2, accommodating both *eh* and *hh* collisions (⇒ stage 1 LH*e*C "includes" ALICE 3)

LHeC: Final personal remarks

Extracting best science at LHC is our **duty** – LH*e*C will open vast new fields of research and significantly strengthen **concurrent** hadron-hadron research at **cost below that of EIC!**

Join us! For example, by checking how much **your** HL-LHC research would profit from LH*e*C!

Or, just help it happen…remember – ESPP update will shape HEP for next >25 years

Reminder: LH*e*C has been driving developments of **green** ERL technology for future colliders [**very appropriate response to demands of our time**] ⇒ strong hadron cooling at EIC, new designs of Next Linear Collider & **electron beam injector for FCC-*ee*** + electron beam for FCC-*eh*

Timeline for the update of the European Strategy for Particle Physics

Thank you for attention!

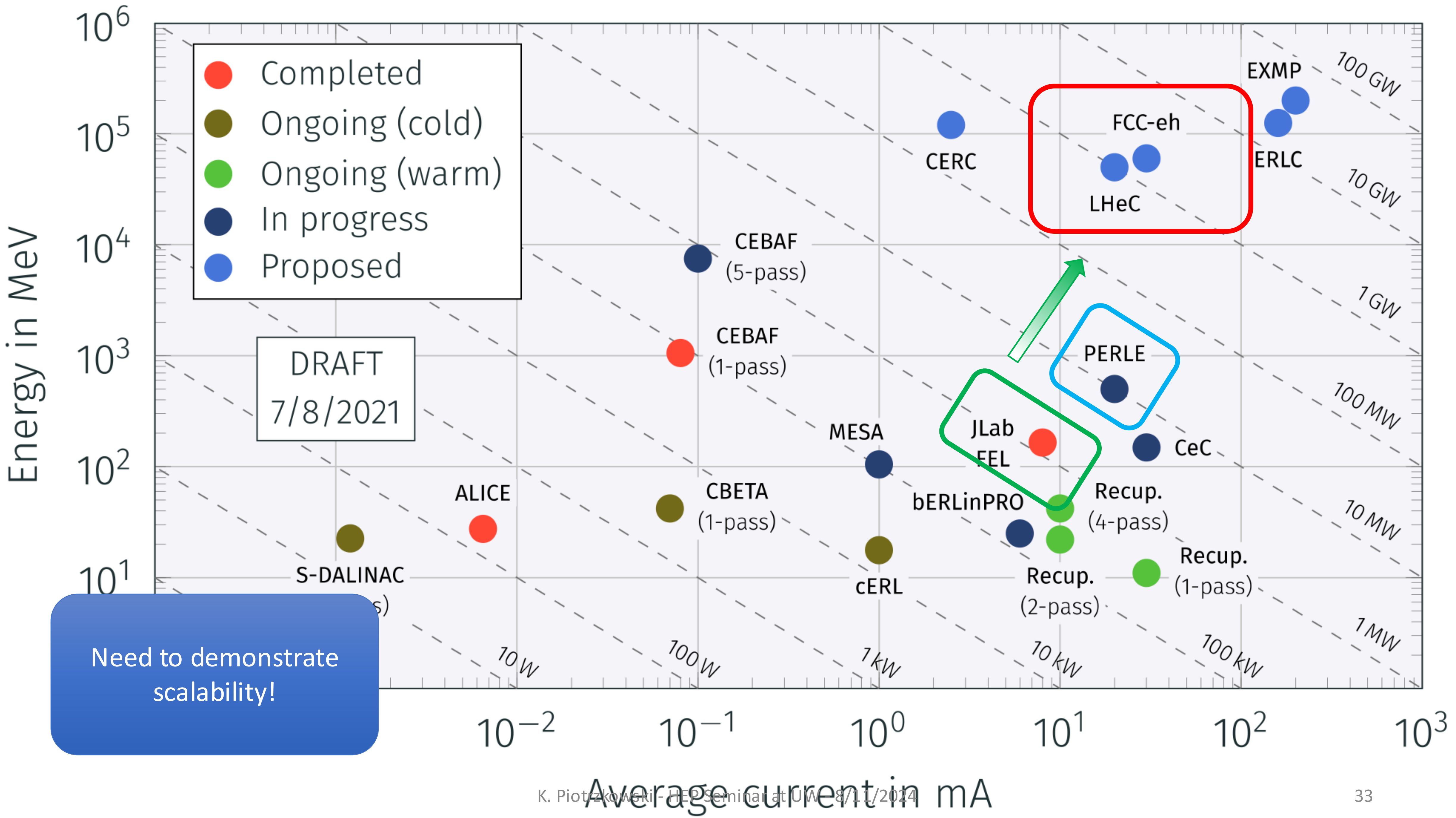
For interested…

Two very well financed four-year scholarships for doctoral students are available at AGH from October 2025, dedicated to the LH*e*C (and CMS) research – one more phenomenology- and one more detector-oriented

Contact: piotrzkowski@agh.edu.pl

In addition, **up to six-months LH*e*C project positions** (including extended stays at CERN) can be offered to both undergraduate and graduate candidates – starting from January 2025!

Backup slides



Need to demonstrate scalability!

Summary LHeC / FCC-eh

- Unique machine for exploring the TeV Center of Mass region of HEP with ep
- Maximum Infrastructure exploitation of the LHC and FCC!
- Moderate cost – [compared to ILC, CLIC or FCC]
- Unique oportunity – no other machine can provide ep @ TeV CME
- Technology driver with many spin off benefits – ERL & SRF

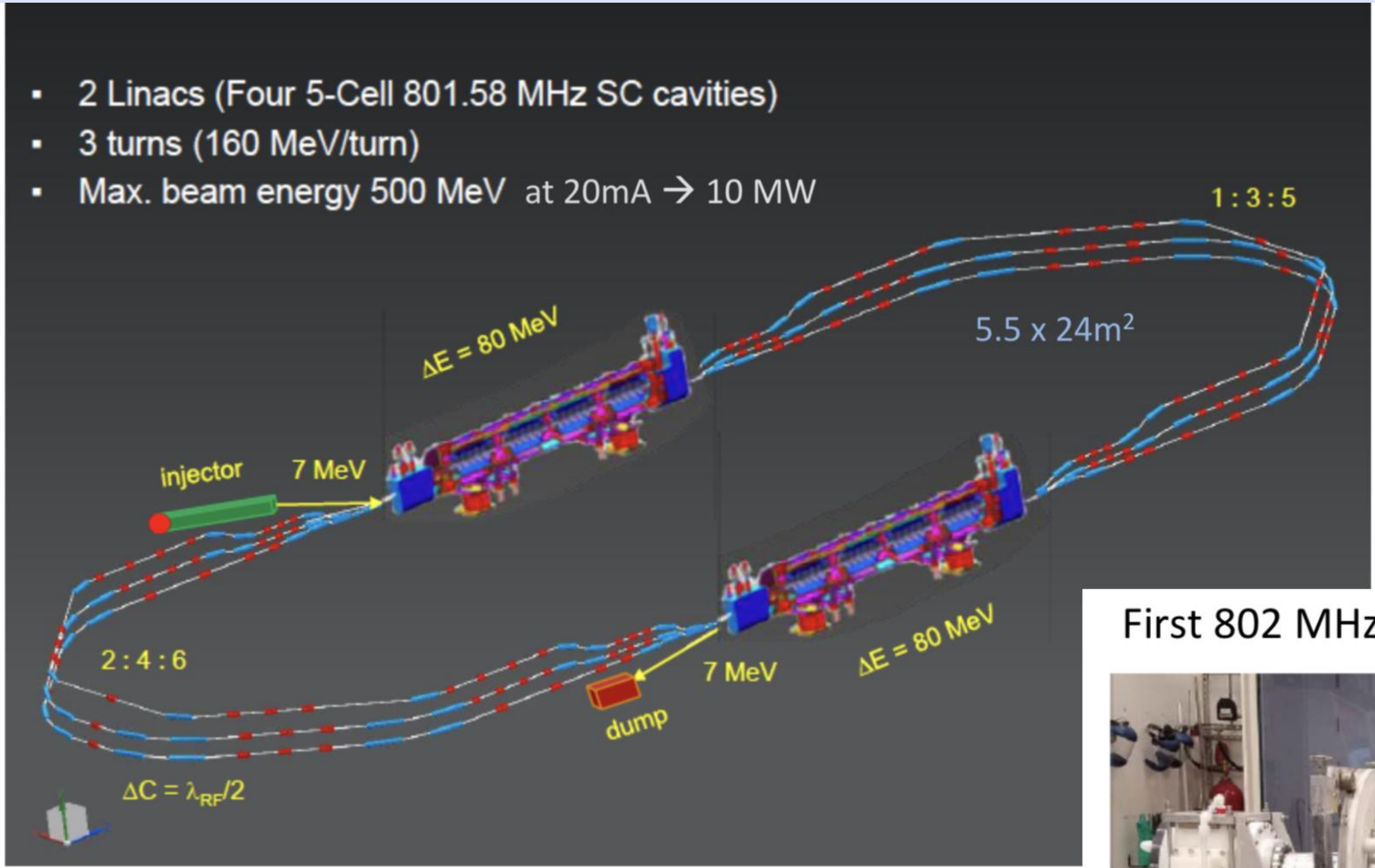
  ➔ Sustainable accelerator operation!

- Unique physics program
- Modular design with several operation phases!

  ➔ LHeC, FCC-ee injector, FCC-eh

O. Bruning – Kraków'24

LHeC demonstrator: Powerful ERL for Experiments (PERLE)



cf Walid Kaabi at Amsterdam FCC

in <u>Orsay</u>

- **BINP**
- **CERN**
- **Daresbury/Liverpool**
- **Jlab**
- **Orsay**

→ CDR 1705.08783 [J. Phys G]
→ TDR in 2019

First 802 MHz cavity successfully built (Jlab)

→ ERL demonstrator
→ O(10 MeV) physics

Nuclear particle physics with electron–ion scattering at the LHeC

- “The LHeC will be able to test and establish or exclude the phenomenon of parton saturation at low *x* in protons and nuclei. […] The LHeC will be a unique machine with which to address both of their variations, such that the saturation concepts can be precisely tested.”
- “LHeC machine in *eA* mode will have a huge impact on physics explored in *pA* and *AA* collisions, see section 9.7, where it will provide vital input and constraints on the ‘baseline’ initial state in nuclear collisions and measurements of the impact of a cold nuclear medium on hard probes and the effects of hadronisation. It will also explore the effect of the initial-state correlations on the final-state observables, which are relevant in order to understand collectivity in small systems explored in *pp* or *pA* collisions.”
- “The measurements of diffraction of protons and nuclei as well as the inclusive structure functions in the nuclear case will allow us to explore the very important relation between nuclear shadowing and diffraction […]
- Similarly to the proton case, DVCS and exclusive vector-meson production will provide unique insight into 3D nuclear structure.”

https://iopscience.iop.org/article/10.1088/1361-6471/abf3ba