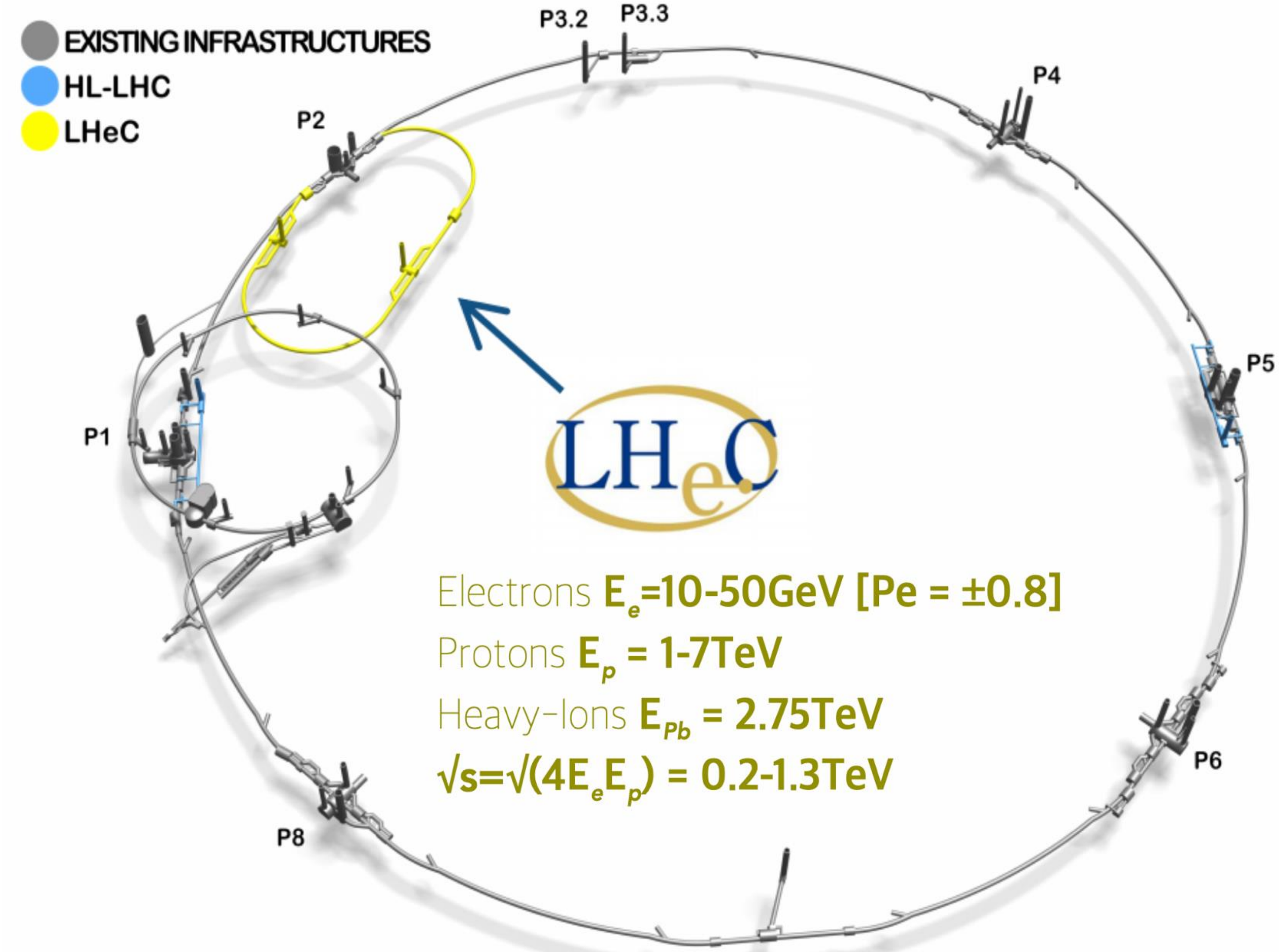
Experiment for *Electron-Hadron* Scattering at LHC

& ESPPU

Krzysztof PIOTRZKOWSKI (AGH)

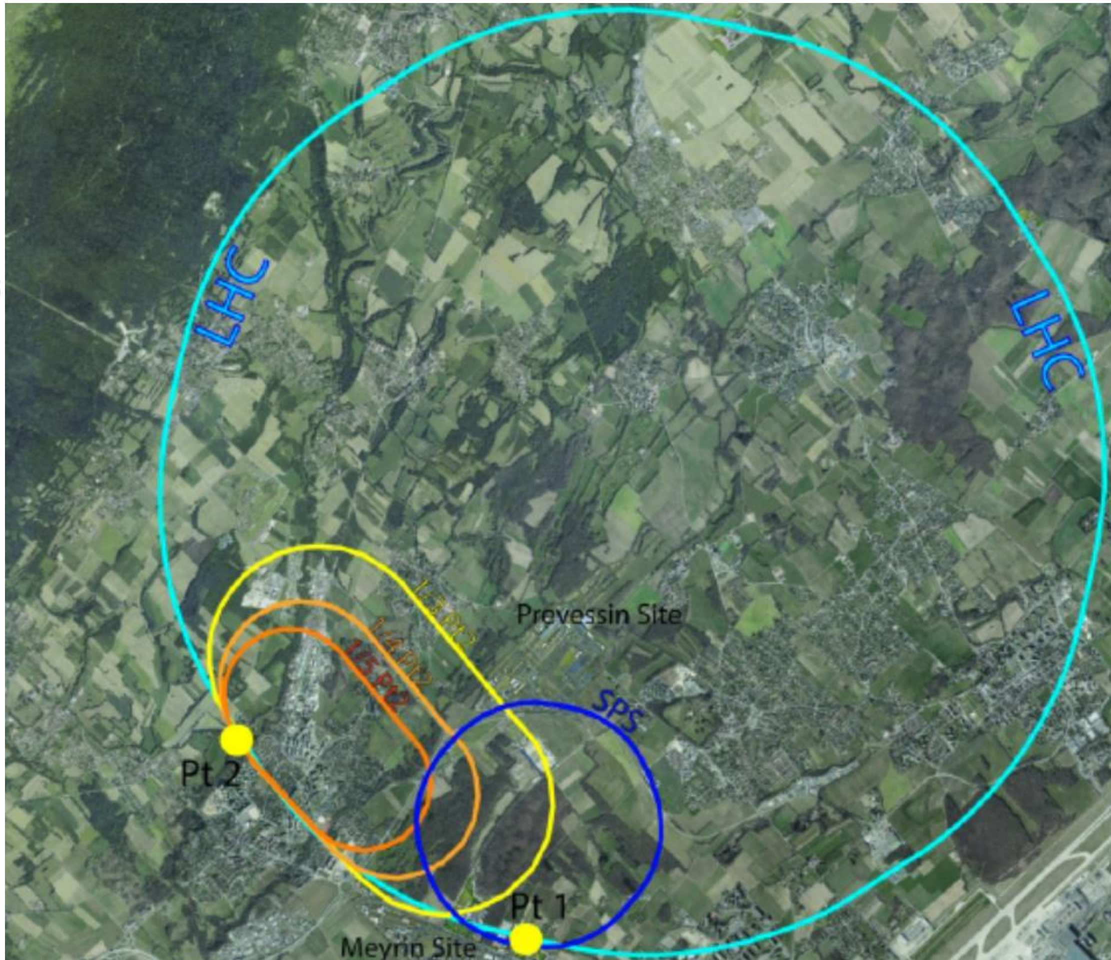


Electrons **E_e=10-50GeV [Pe = ±0.8]**

Protons **E_p = 1-7TeV**

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

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



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

Print | PDF | Full screen | Detailed view | Filter

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 • © 2021 The Author(s). Published by IOP Publishing Ltd
Journal of Physics G: Nuclear and Particle Physics, Volume 48, Number 11

Reminder:

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

New LHeC proposal in 2020 – 337 authors from 156 institutions

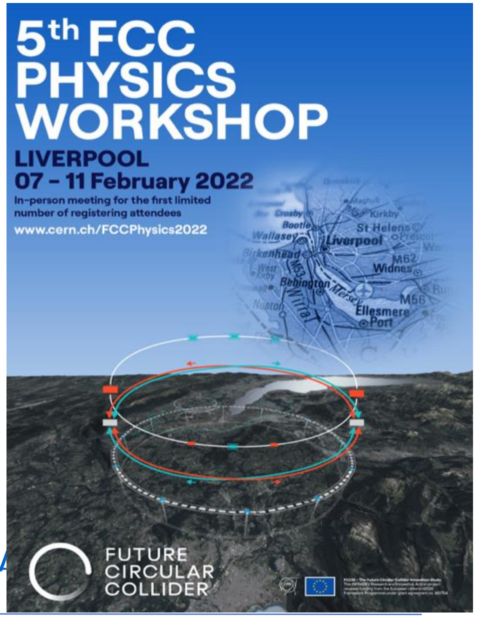
Includes discussion of FCC-*eh* physics (1.2 → 3.5 TeV)

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!

LH*e*C 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

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} cm^{-2}s^{-1}	1	5	9	23

ERL technology resulted in major breakthrough for LH*e*C:

→ >**10 × luminosity**

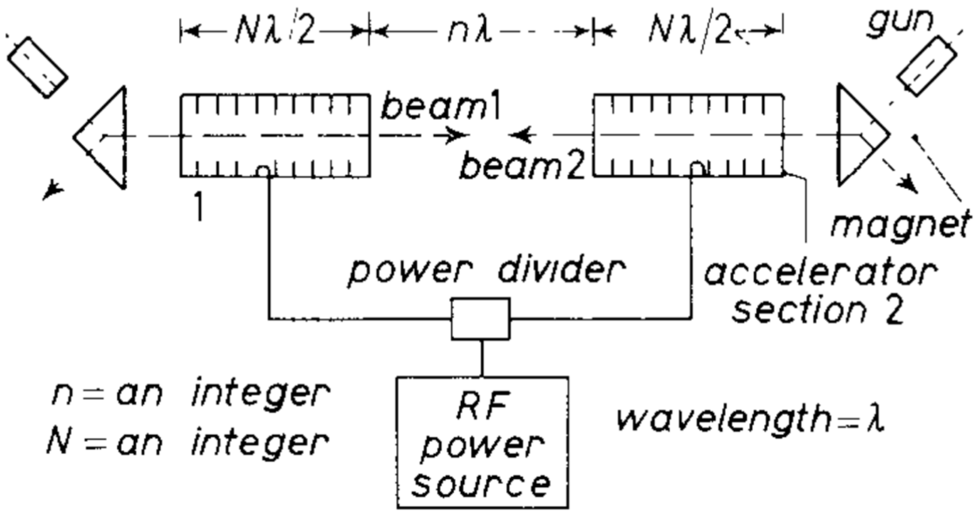
1 GW electron beam using only 100 MW !

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 ⇒⇒

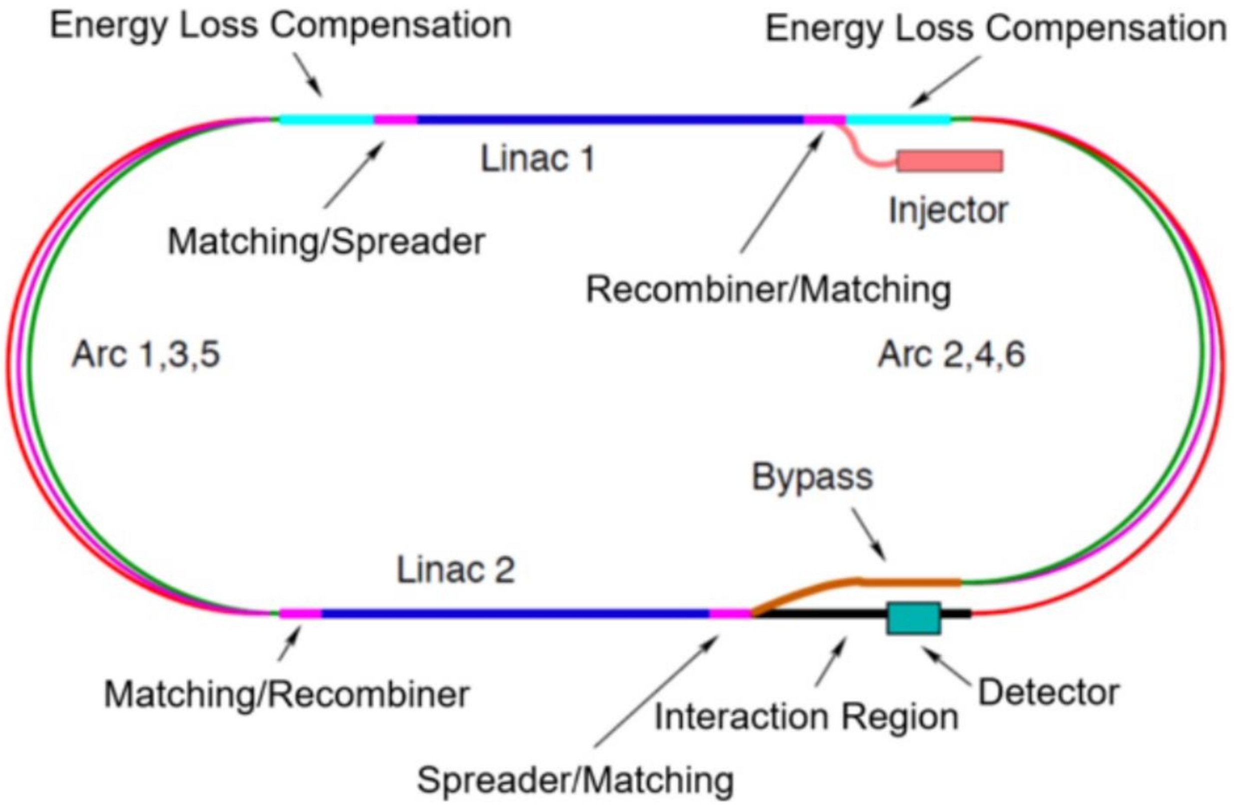


Quite surprising gravitational analogy – note 2036 date 🚀
https://www.youtube.com/watch?v=6RiYXI1Tfu4

ERL@LHeC as *Relay* Short Track Speed Skating

6×ERL@HL-LHC

ERL geometry

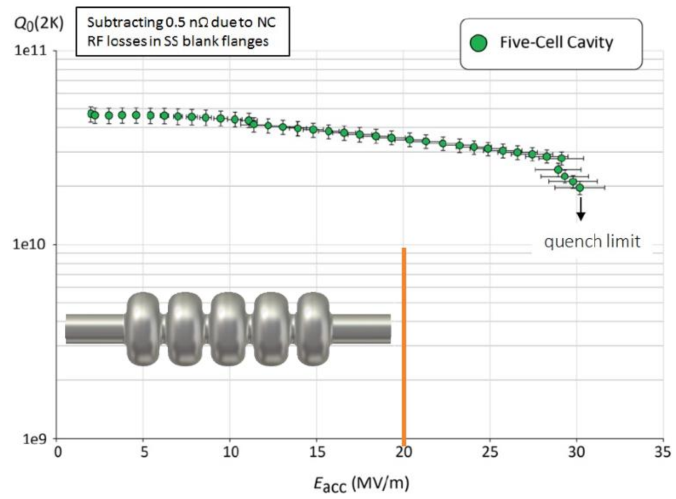


- Two SC linac accelerators
- three-pass return arcs

- ERL main parameters

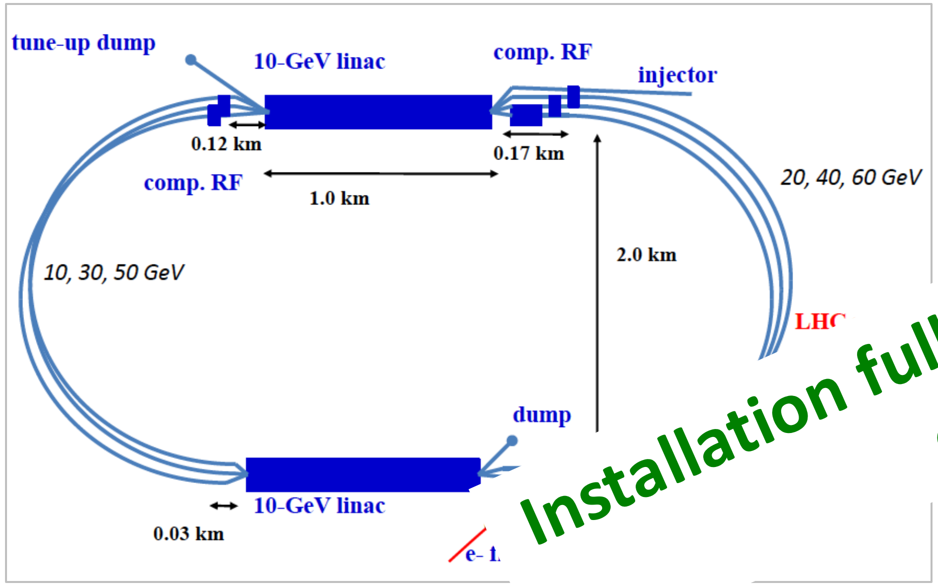
Parameter	Unit	Value
Beam energy	GeV	50
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
trans. norm. emittance	μm	30
RF frequency	MHz	801.58
Acceleration gradient	MV/m	20.06
Total length	m	6665

- 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

O. Bruning – Kraków'24

From drawings to reality with PERLE

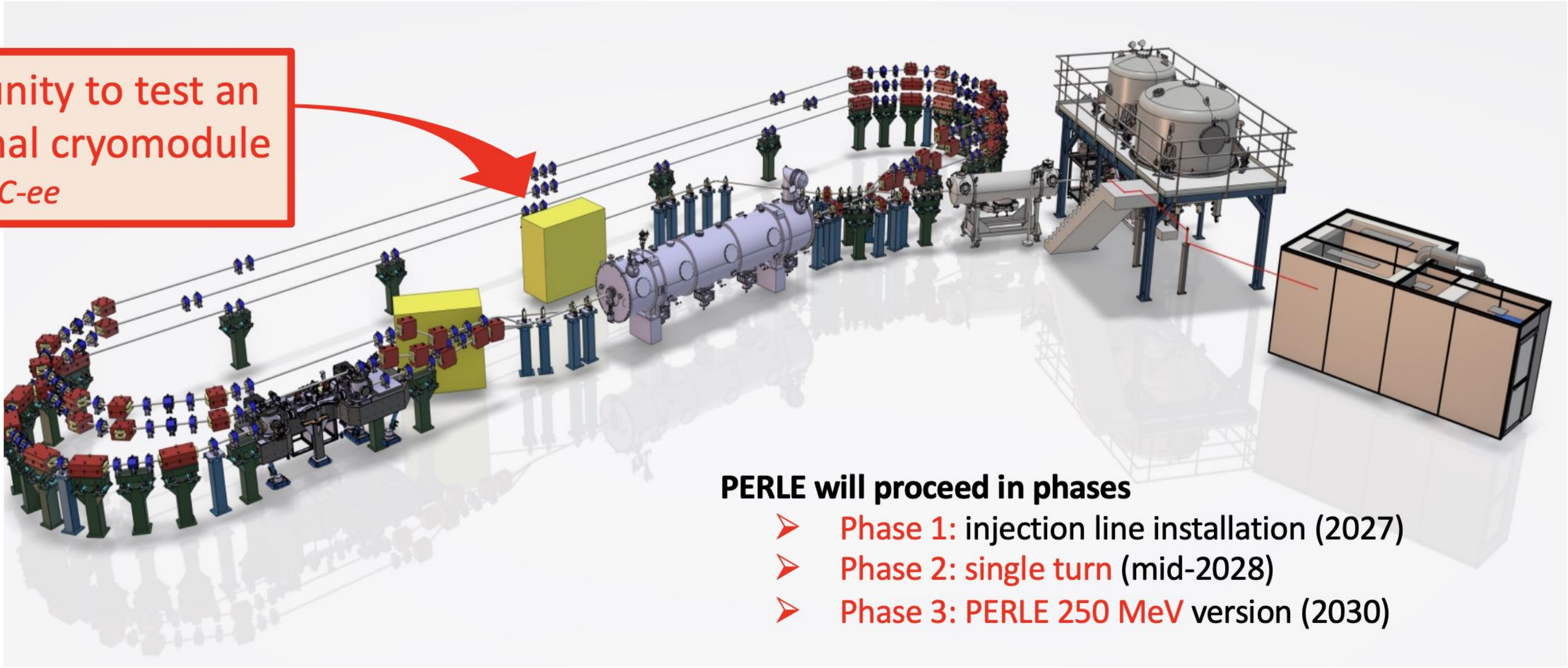
+ Contributions through iSAS of

Various (in-kind) contributions

e.g. cryoplant from HZB

opportunity to test an additional cryomodule

e.g. for FCC-ee



PERLE will proceed in phases

- Phase 1: injection line installation (2027)
- Phase 2: single turn (mid-2028)
- Phase 3: PERLE 250 MeV version (2030)

JDH

Experiment for *eh* and *hh* scattering @ P2

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 2022 *LoI* of ALICE 3 at HL-LHC was released – our paper showed that it is feasible to make experiments of

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

with SAME ("ALICE 3*e*") detector!

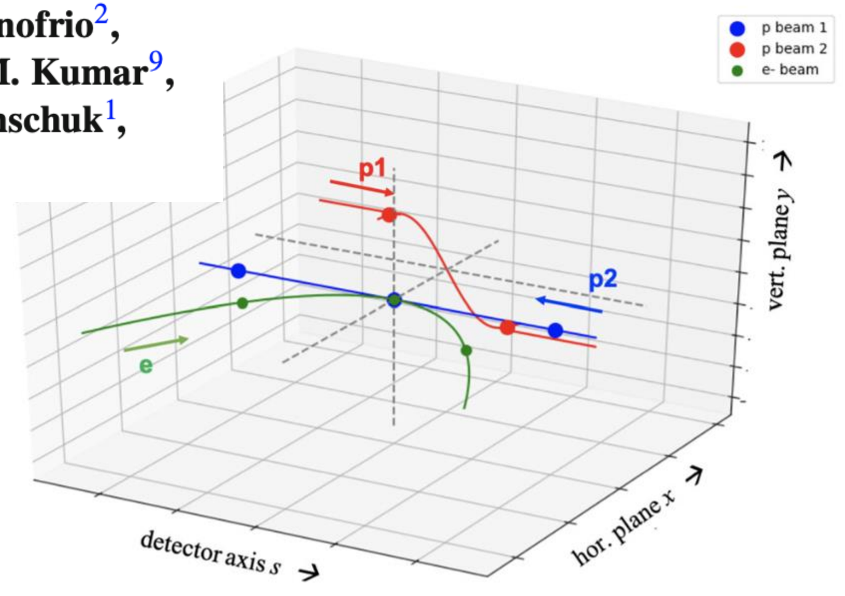


Fig. 17 Schematic view of the three beams in the interaction region. Collisions between electrons and proton beam 1 and a well separated proton beam 2

Experiment for electron-hadron scattering @ P2

– 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 @ P2

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 and **ALICE!**)

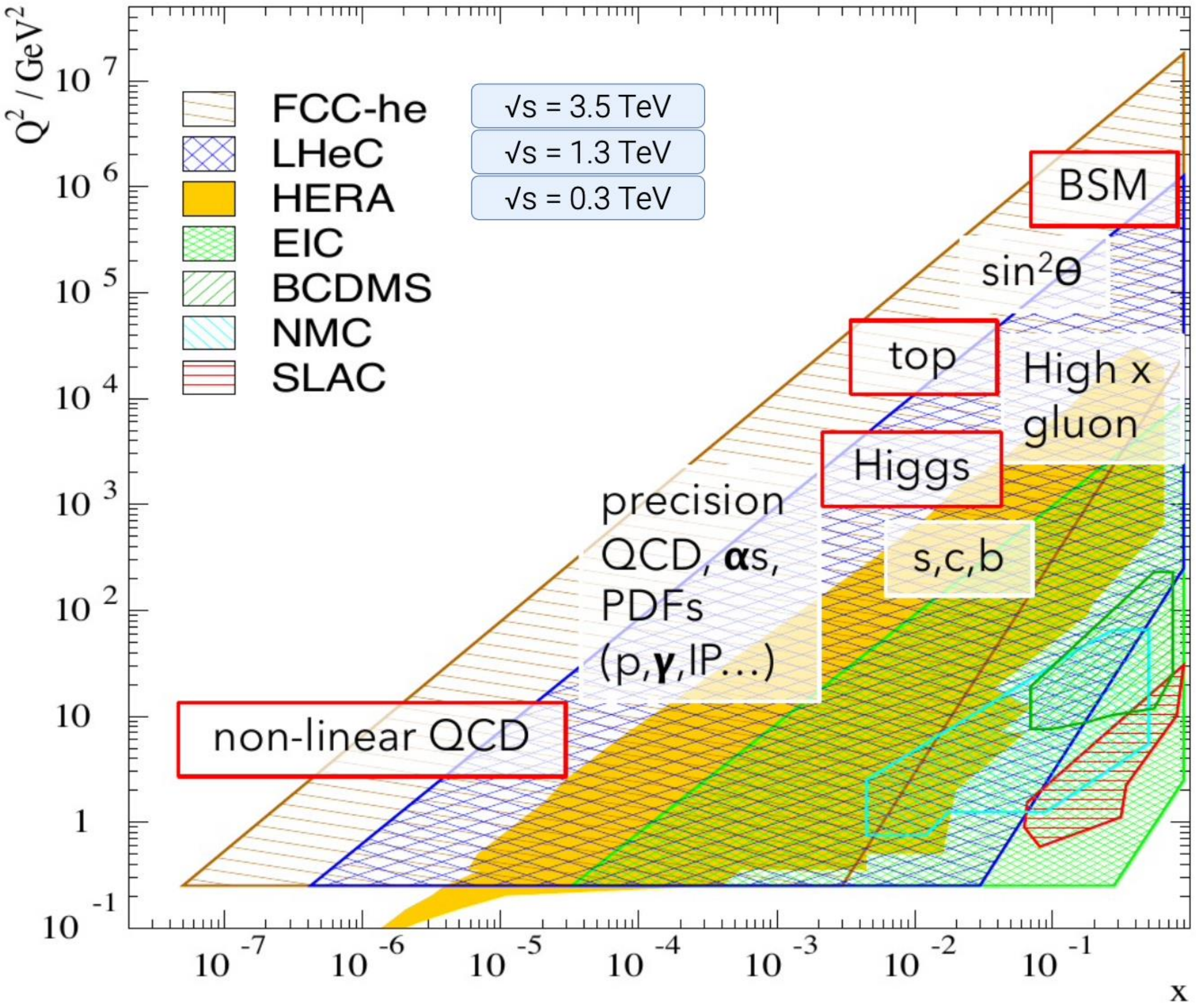
↓

Much broader class of final states/decay channels is feasible!

↓

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

Electron-Hadron Scattering @ LHC



LHeC

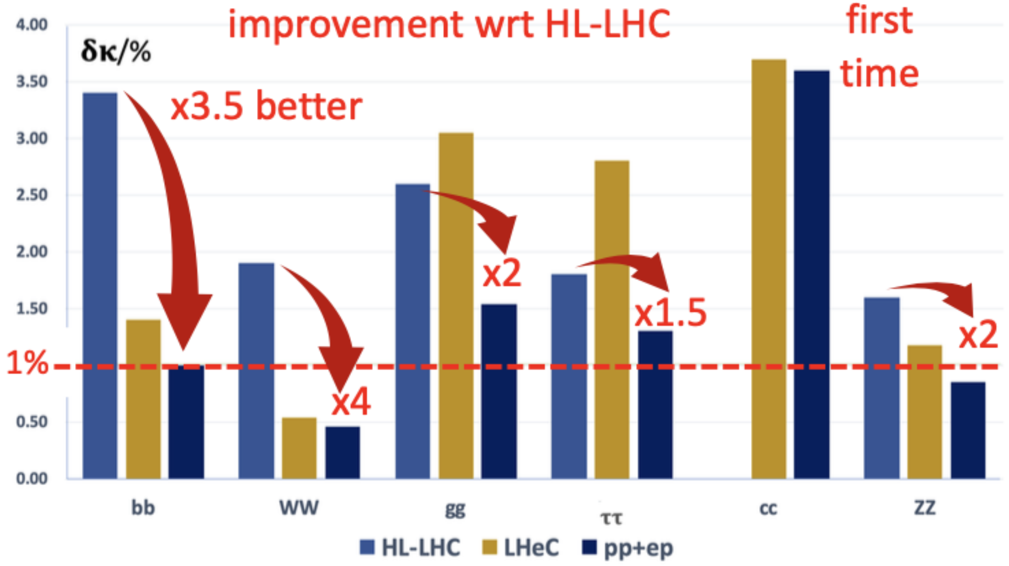
- Rich physics program at all scales
  - Higgs physics in NC and CC DIS
  - Top quark production
  - BSM physics and searches
  - Precision QCD
    Proton structure, substructure, strong coupling constant, jet physics, heavy quarks, ...
  - Electroweak physics
  - Heavy ion programme

Several highlights ⇒⇒

Some physics highlights of the LHeC (ep/eA@LHC)

on several fronts comparable improvements between LHC → HL-LHC as for HL-LHC → LHeC

Higgs physics - pp+ep comb



EW physics – pp & ep

- Δm_W to 2 MeV (today at ~10 MeV) **pp with ep input**
- $\Delta \sin^2\theta_W^{eff}$ to 0.00015 (same as LEP + scale dep) **ep only**

Top quark physics – ep only

- $|V_{tb}|$ precision better than 1% (today ~5%)
- top quark FCNC and γ, W, Z couplings

DIS scattering cross sections - ep 1y

- complete unfolding of PDFs extended in (Q^2,x) by orders of magnitude

Strong interaction physics - ep 1y

- α_s precision of 0.2%
- low-x: a new discovery frontier

The Large Hadron-Electron Collider at the HL-LHC, J. Phys. G 48 (2021) 110501, 364p (updated CDR)

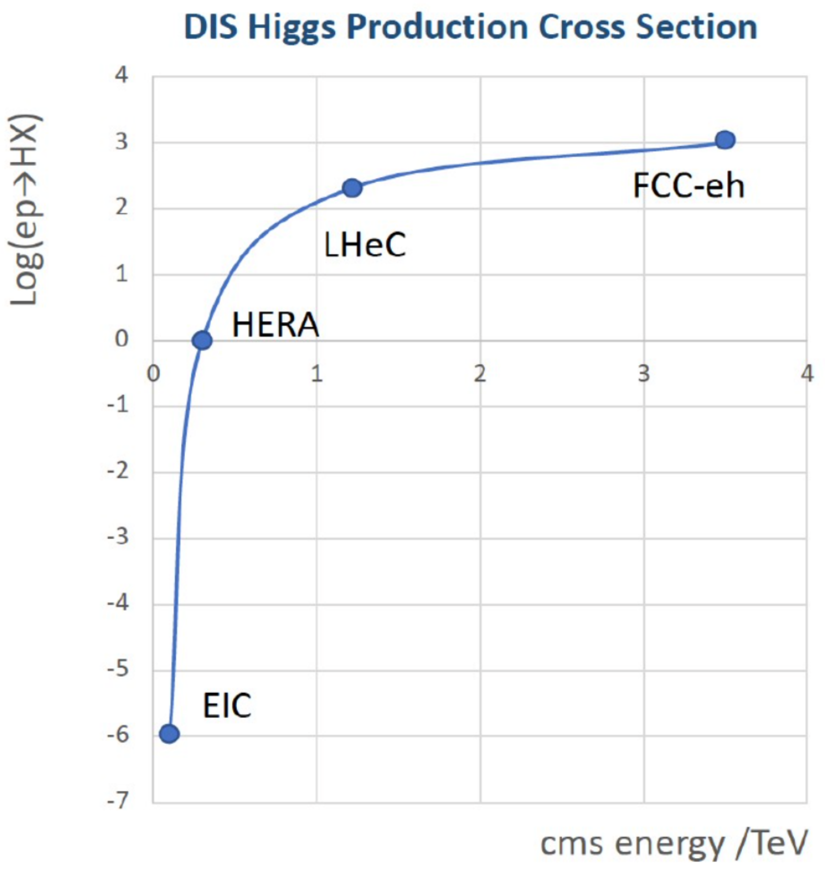
JDH

LHeC as Gauge Boson Collider

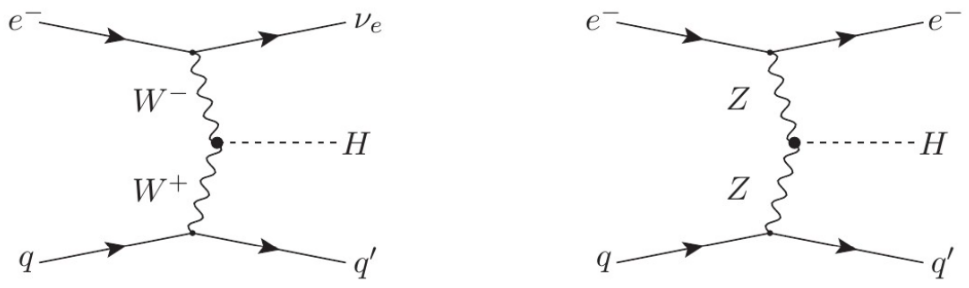
WW, *ZZ* and $\gamma\gamma$ fusion

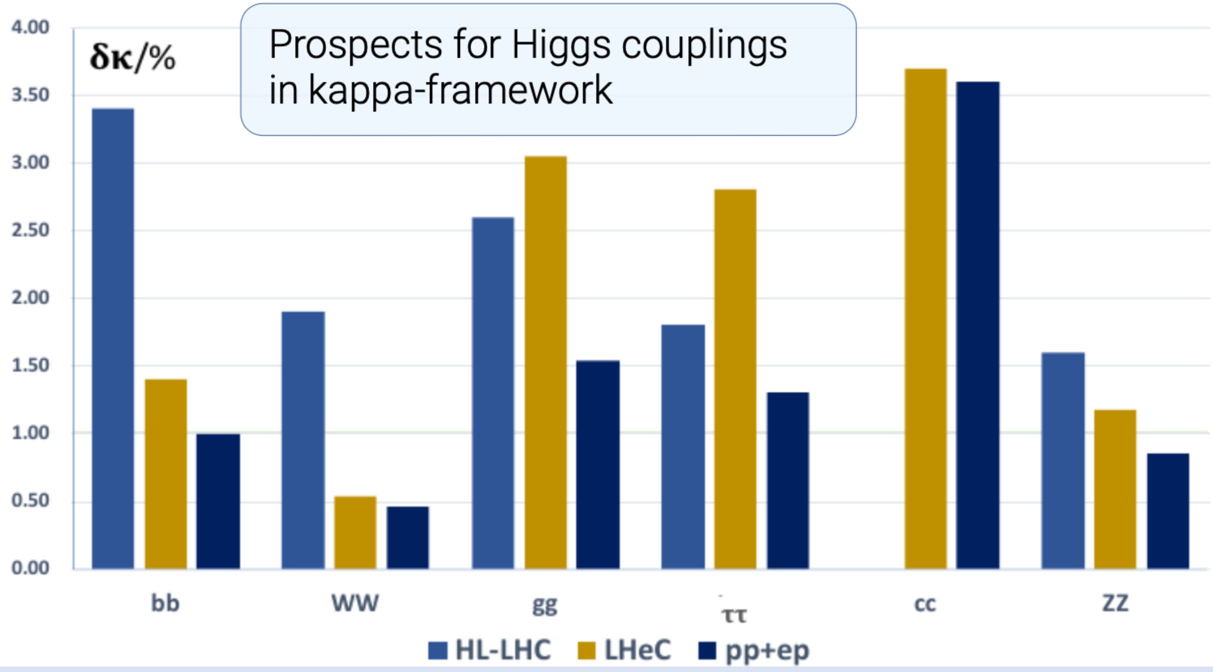
(in clean environment)

(*Clean*) Higgs factory @ LHeC



Higgs in CC and NC DIS





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

LHeC updates in Praha @ ICHEP2024

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

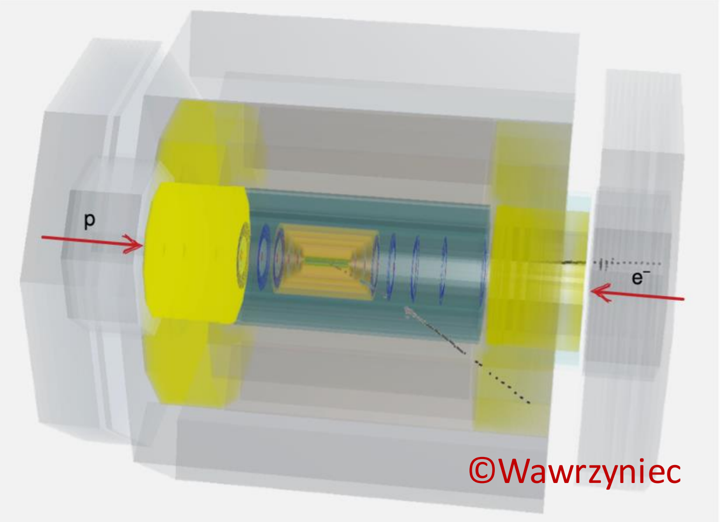
A detector for future DIS at the energy frontier, Laurent Forthomme
https://indico.cern.ch/event/1291157/contributions/5888179/

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: staging proposal

[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** ~~very~~ **big project at CERN**

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* (or *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: staging proposal

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* (or *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/Warsaw

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

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

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))
  ep-eA-workshop-No...
- 09:10 **Staged approach to LHeC**
  Speaker: Krzysztof Piotrzkowski (AGH University (Kraków, PL))
  CERN_KP.pdf
- 09:30 **News from the IR workshop**
  Speakers: Bernhard Holzer (CERN), Laurent Forthomme (AGH University of Krakow (PL))
  LHeC_summary_Kr... offline_sw_status-fo...
- 10:00 **PDFs and alphas**
  Speaker: Katarzyna Wichmann (Deutsches Elektronen-Synchrotron (DE))
  ultimate-dis-151124...
- 10:20 **Small x**
  Speaker: Mirja Tevio
  Mirja_LHeC_whitep...
- 10:40 **PDFs and SMEFT**
  Speaker: Elie Hammou
  LHeC_SMEFT_PDFs...

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

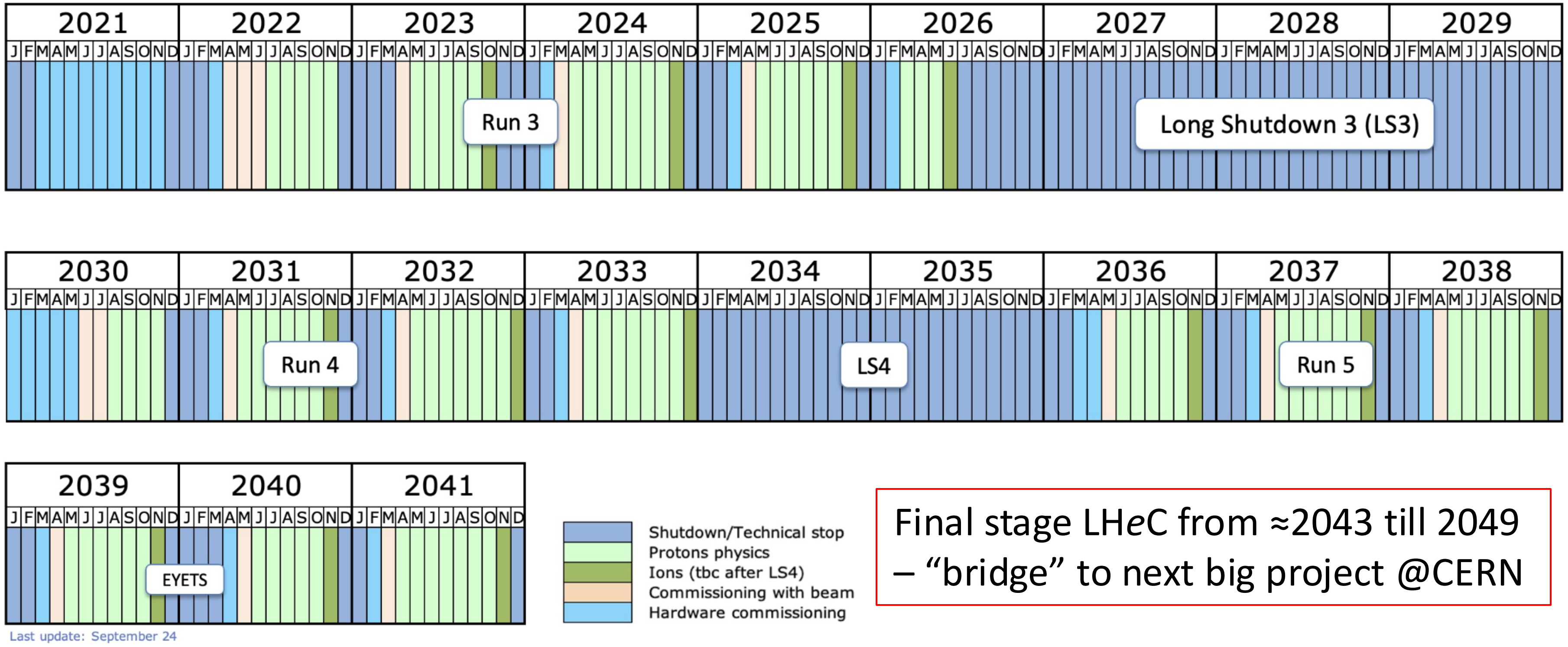
11:30 → 13:00 **Part II**

- 11:30 **I: The LHeC at the frontline of particle and nuclear physics**
  Speaker: Christian Schwanenberger (Deutsches Elektronen-Synchrotron (DE))
  LHeC_White_Paper_...
- 11:45 **II: LHeC physics enabling HL-LHC & high-energy proton collider physics**
  Speakers: Claire Gwenlan (University of Oxford (GB)), Maarten Boonekamp (Université Paris-Saclay (FR))
  lhec_whitepaper_15...
- 12:00 **III: LHeC technology enabling a Higgs factory**
  Speakers: Paul Richard Newman (University of Birmingham (GB)), Yannis Papaphilippou (CERN)
  Detectors.pdf LHeC_AT_ESPP_whi... LHeC_AT_ESPP_whi...
- 12:15 **IV: Technical feasibility of the LHeC**
  Speakers: Yannis Papaphilippou (CERN), Yuji Yamazaki (Kobe University (JP)), Prof. achille stocchi (IJCLab ,
  ESPP_section4_Det...
- 12:30 **V: The LHeC Cost and Resource Estimates**
  Speaker: Oliver Bruning (CERN)
- 12:45 **VI: The LHeC implementation plan**
  Speakers: Oliver Bruning (CERN), Yuji Yamazaki (Kobe University (JP))
  ESPP_section7_Opt...

Last week

LHeC in Run 5

LH*e*C was conceived to provide *eh* collisions **concurrently** to *hh* collisions at HL-LHC (at other IPs) ⇒ its schedule defines time constraints



Final stage LH*e*C from ≈2043 till 2049 – "bridge" to next big project @CERN

Question:

It is possible to commission *eh* collisions at P2 in 2036?

Proposed answer: yes!

1. By staging LH*e*C project
2. By accommodating *eh* experiment in "ALICE 3e"

LHeC: Staging Proposal

If one targets LH*e*C commissioning **in 2036 then staging is necessary**

⇒ **20 GeV electron beam offers significant simplifications in design & running:**

- Center-of-mass energy of **0.75 TeV** ensures excellent science
- Only **one-pass ERL** is required with significantly lower power use
- **Synchrotron Radiation is much softer** and simplifies MDI design
- Electron beam **separation is easier**
- Very high luminosity might be **easier** to achieve

ALICE 3 requires rather minor adaptations to accommodate *eh* physics:

- ALICE is already using data streaming
- Beneficial dipole field at IP2 was considered in ALICE 3 proposal

Luminosity (and Polarization) Expectations

Electron emittance at 20 GeV is larger by 5/2

with careful emittance tuning and smaller start emittances we should be able to stay within emittance regime that allows for compensation of beam optics and unchanged luminosity values.

Electron beam current for 1-pass ERL should reach 60 mA – *for total current in ERL cavities of* 120 mA – and luminosity of 10^{34} $cm^{-2}s^{-1}$ may be achieved [→ 500 fb^{-1} of data in Run 5?]

High electron longitudinal polarization **seems possible as couple of on-going low energy experiments are demonstrating**

Detector for Electron-Hadron Scattering @ P2

Measurements of *eh* scattering require very good detectors for scattered electrons AND for jets (⇒ HCAL)

Bending power for electron separation of about 1 Tm is needed, but can be also done with off-axis/combined function electron quadrupoles

Precise electron-hadron luminosity measurements will directly follow EIC design

“Triggerless” data streaming is essential

To be released very soon ⇒

A proposal for an electron-hadron collider at the high-luminosity LHC

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(Dated: November 19, 2024)

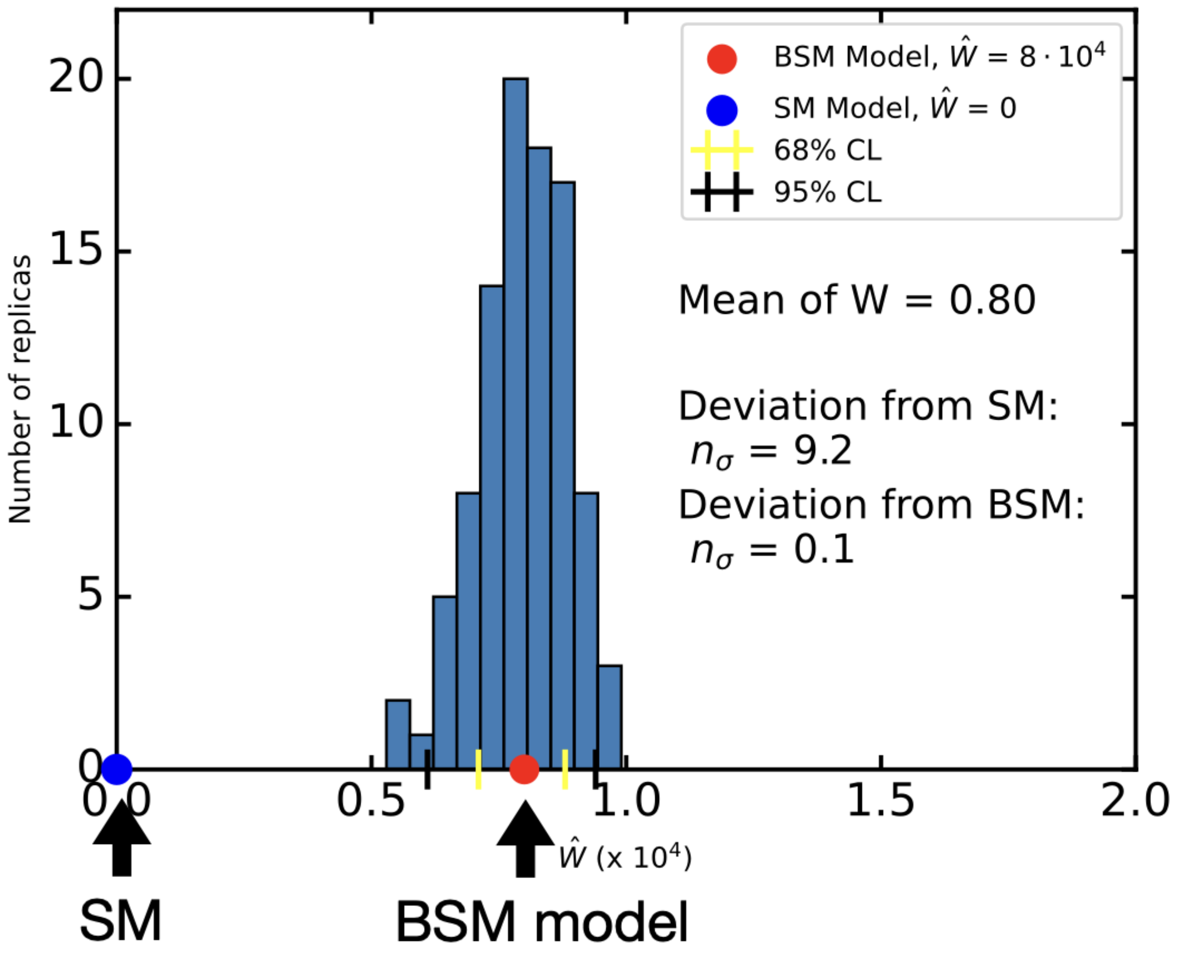
We discuss a concept of lower-energy version of the Large Hadron-electron Collider (LHeC), providing *eh* collisions concurrently to the hadron-hadron collisions at the high-luminosity LHC at CERN. Assuming use of a 20 GeV electron Energy Recovery Linac (ERL), we describe the optimised beam dynamics, accelerator technologies and detector constraints required for such a ”stage-one” LHeC. Finally, we also discuss the ERL configurations and outline the scientific potential of this proposal.

Missing new physics

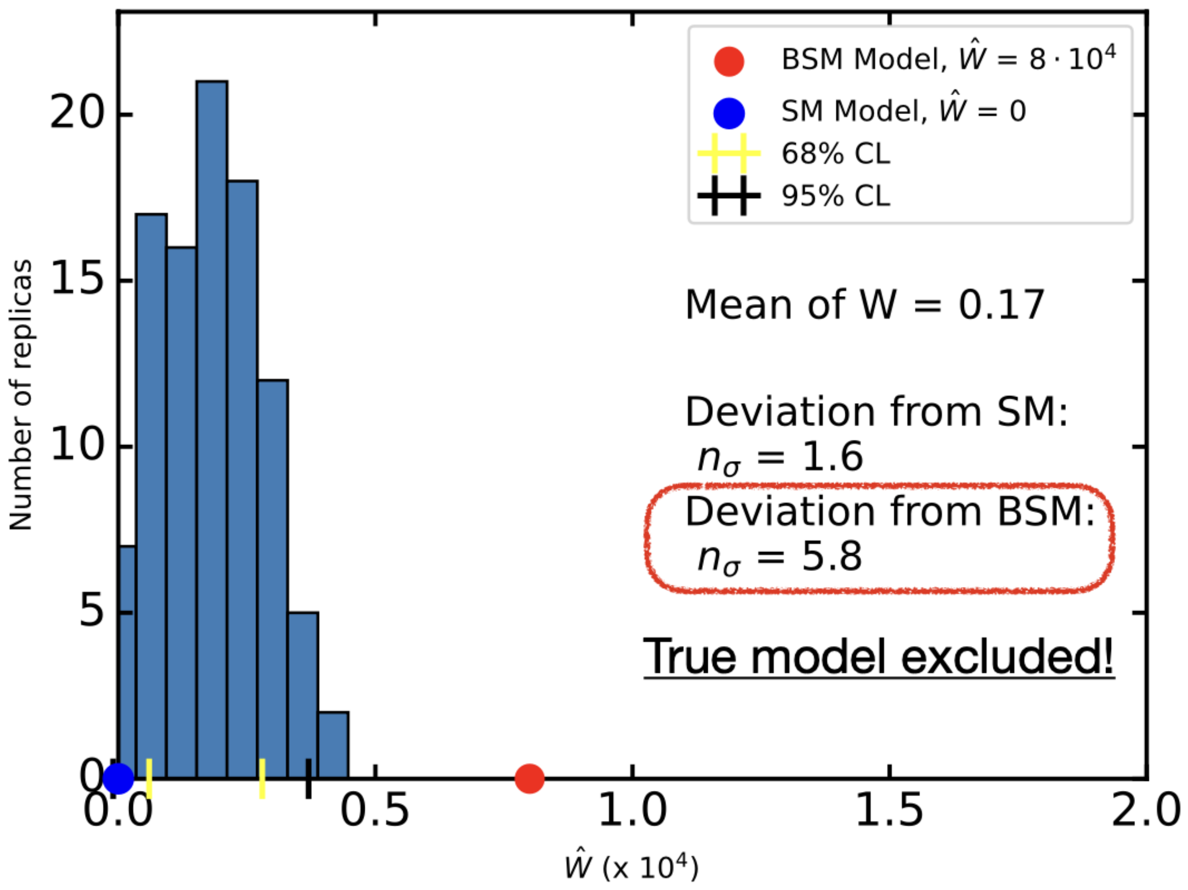
Impact of the choice of PDF on SMEFT fits

Talk by E. Hammou

SMEFT Fit with true PDF



SMEFT Fit with SMEFT PDF



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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 P2, accommodating both *eh* and *hh* collisions (⇒ stage 1 LH*e*C "includes" ALICE 3)

LHeC: personal outlook

Extracting best science at LHC is our **duty** – LH*e*C will open vast fields of research <u>and</u> significantly strengthen **concurrent** hadron-hadron research **at cost of HL-LHC!**

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 and **Poland is contributing to CERN budget H40M CHF each year!**

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

End September 2024
Council appointment of the members of the **PPG** and decision on the venue for the **Open Symposium**

December 2024
Council decision on the venue for the **ESG Strategy Drafting Session**

31 March 2025
Deadline for the submission of main input from the community

26 May 2025
Deadline for the submission of additional national input in advance of the **Open Symposium**

23-27 June 2025
Open Symposium

End September 2025
Submission of the “Briefing Book” to the **ESG**

14 November 2025
Deadline for the submission of final national input in advance of the **ESG Strategy Drafting Session**

1-5 December 2025
ESG Strategy Drafting Session

End January 2026
Submission of the draft strategy document to the Council

March and June 2026
Discussion of the draft strategy document by the Council and **updating of the Strategy**

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

Experiment for *eh* and *hh* scattering @ P2

"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**."

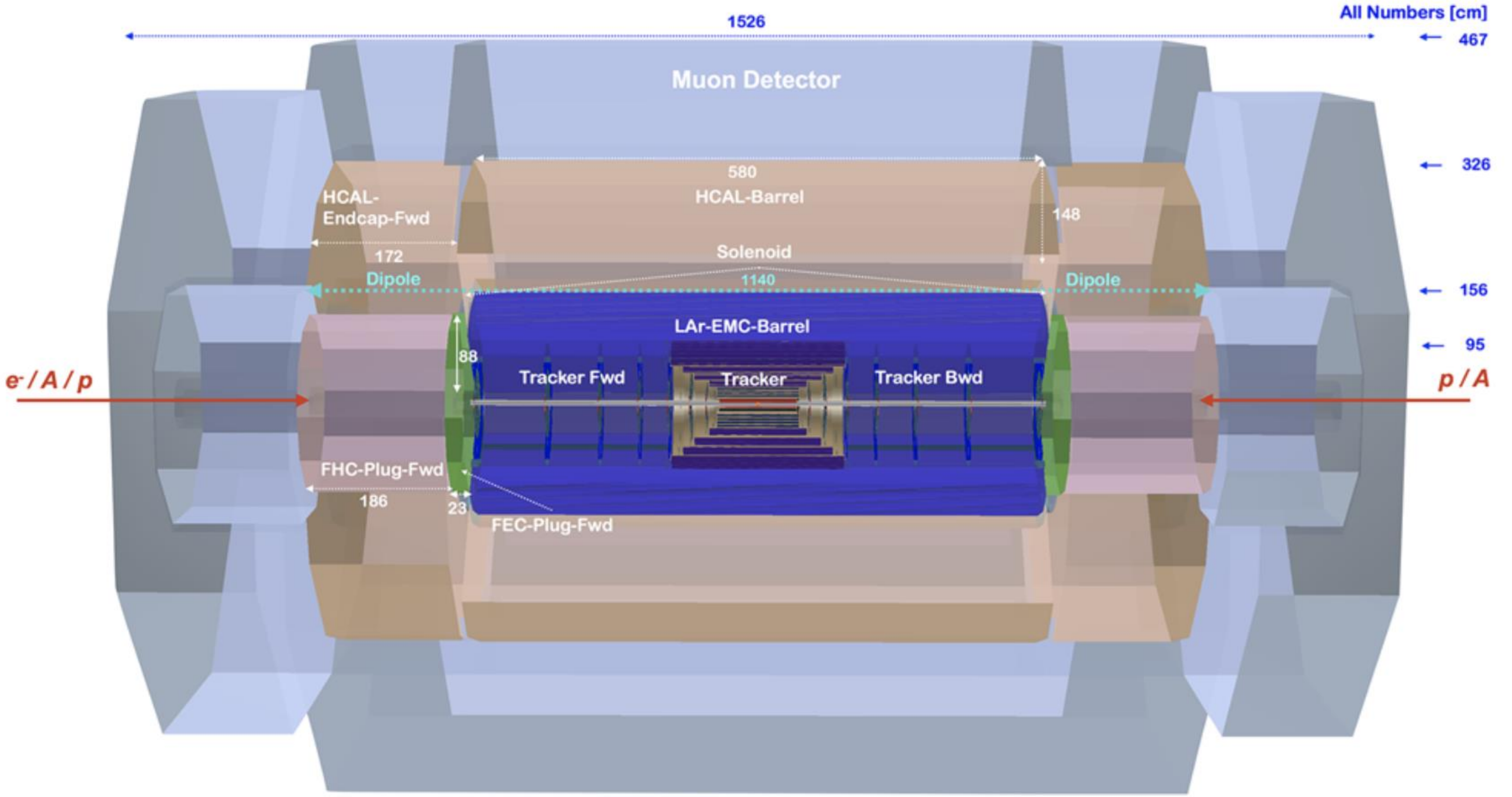
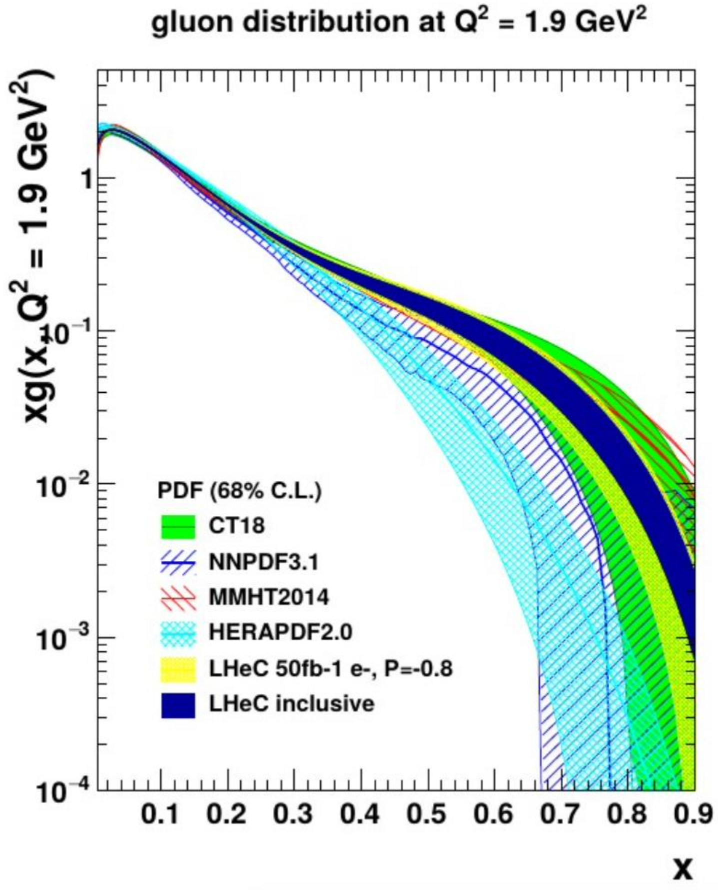
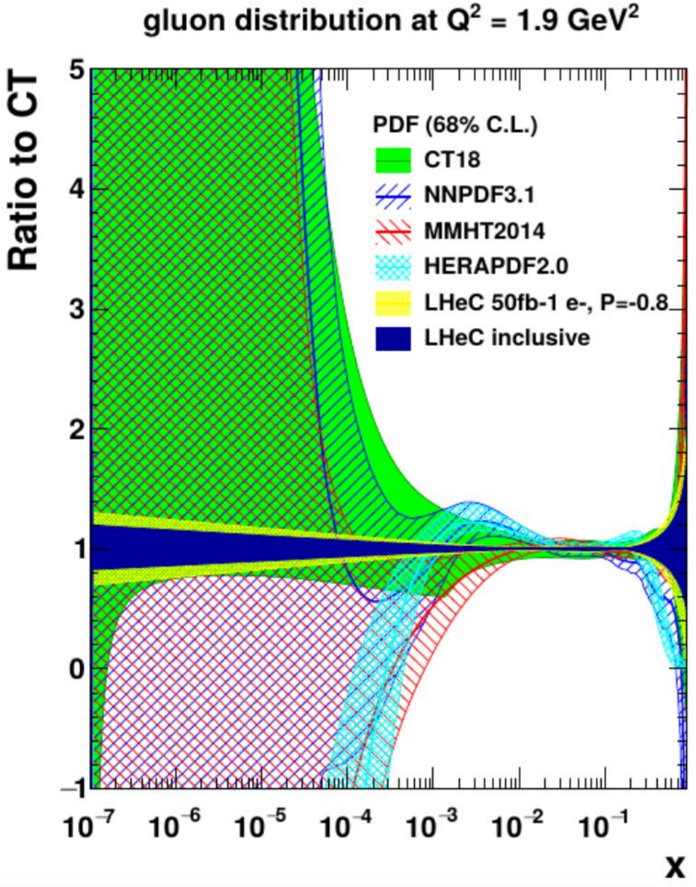


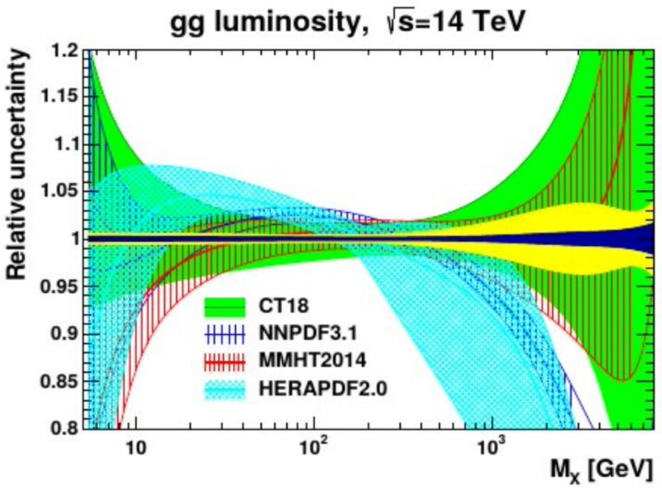
Fig. 24 Side view of a first design of the LHeC detector for both *eh* and *hh* collisions, where the detector coverage of the backward (electron) direction is extended to match that for the forward (hadron) direction.

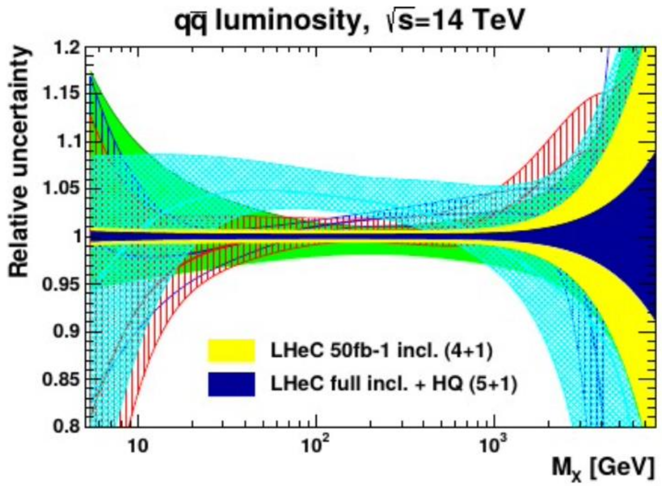
Electron-Hadron Scattering @ LHC

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







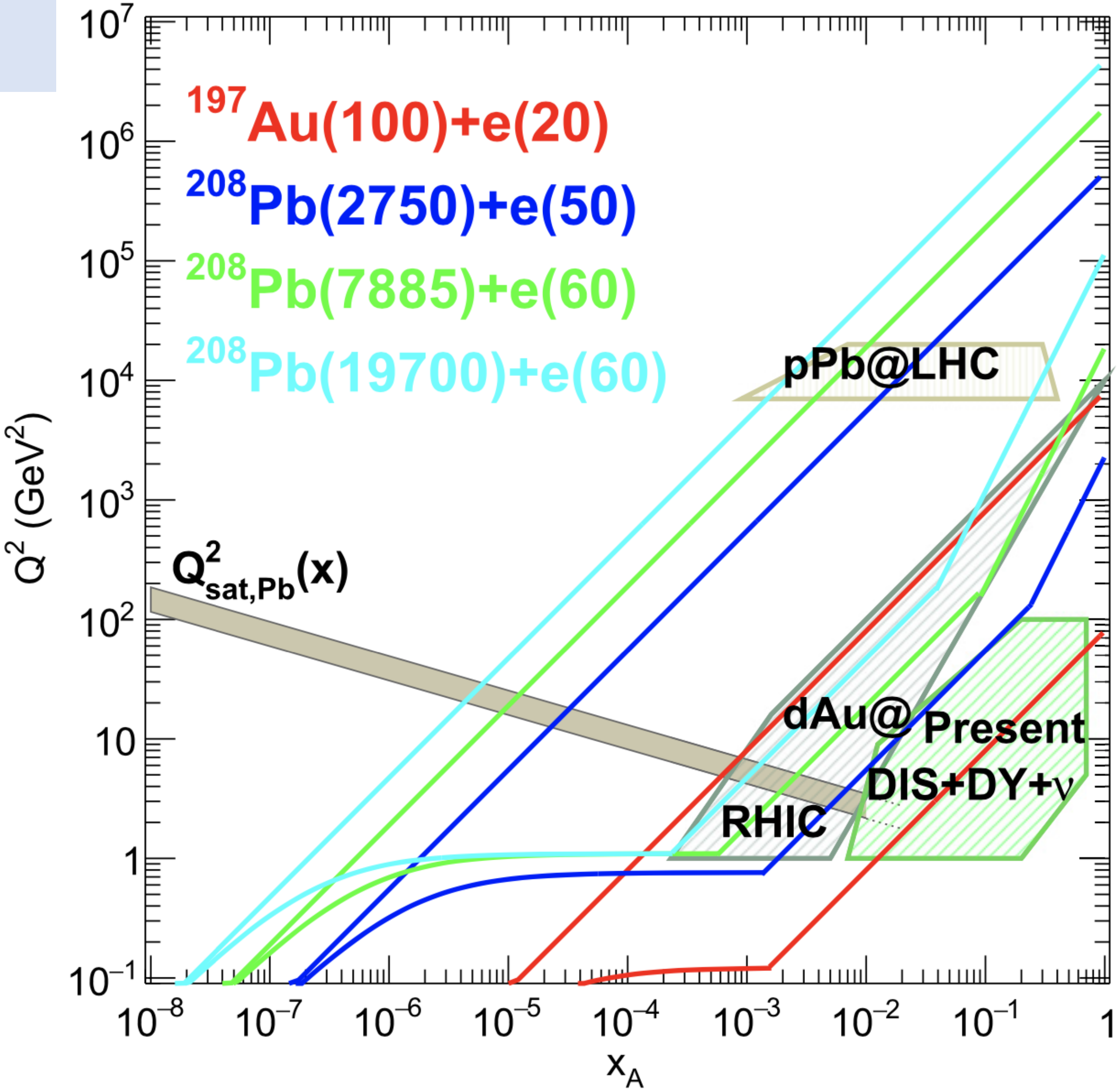


eA scattering at LHeC

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

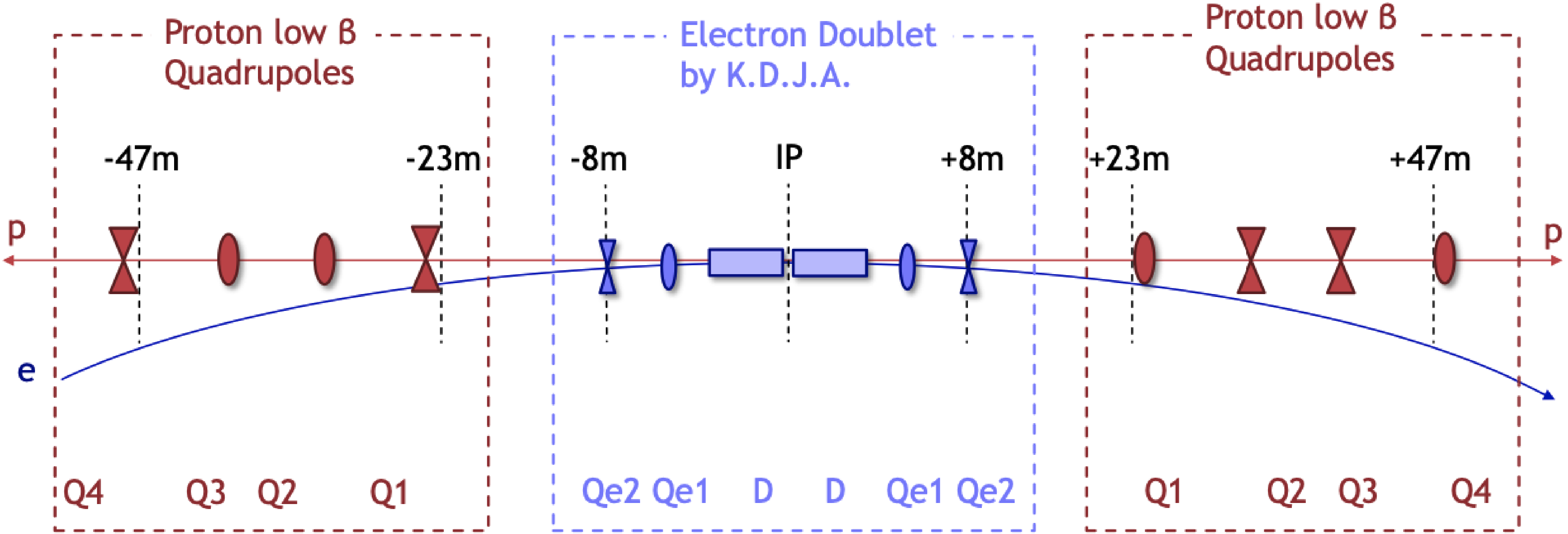
• coverage extended with respect to EIC by up to **2 orders of magnitude**

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



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

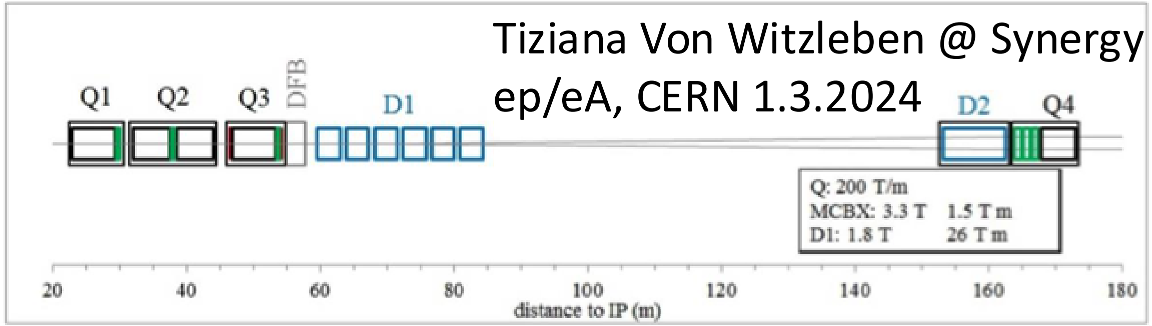
PhD thesis K.D. J. André

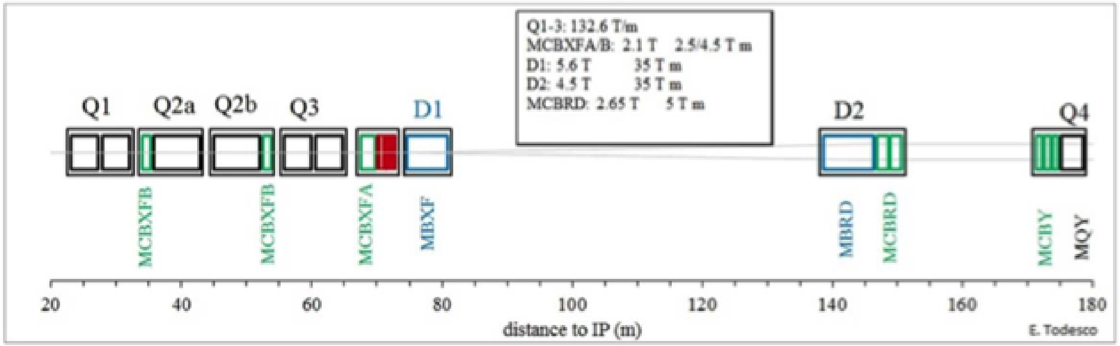
01/03/2024 3

HL-LHC Upgrade

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

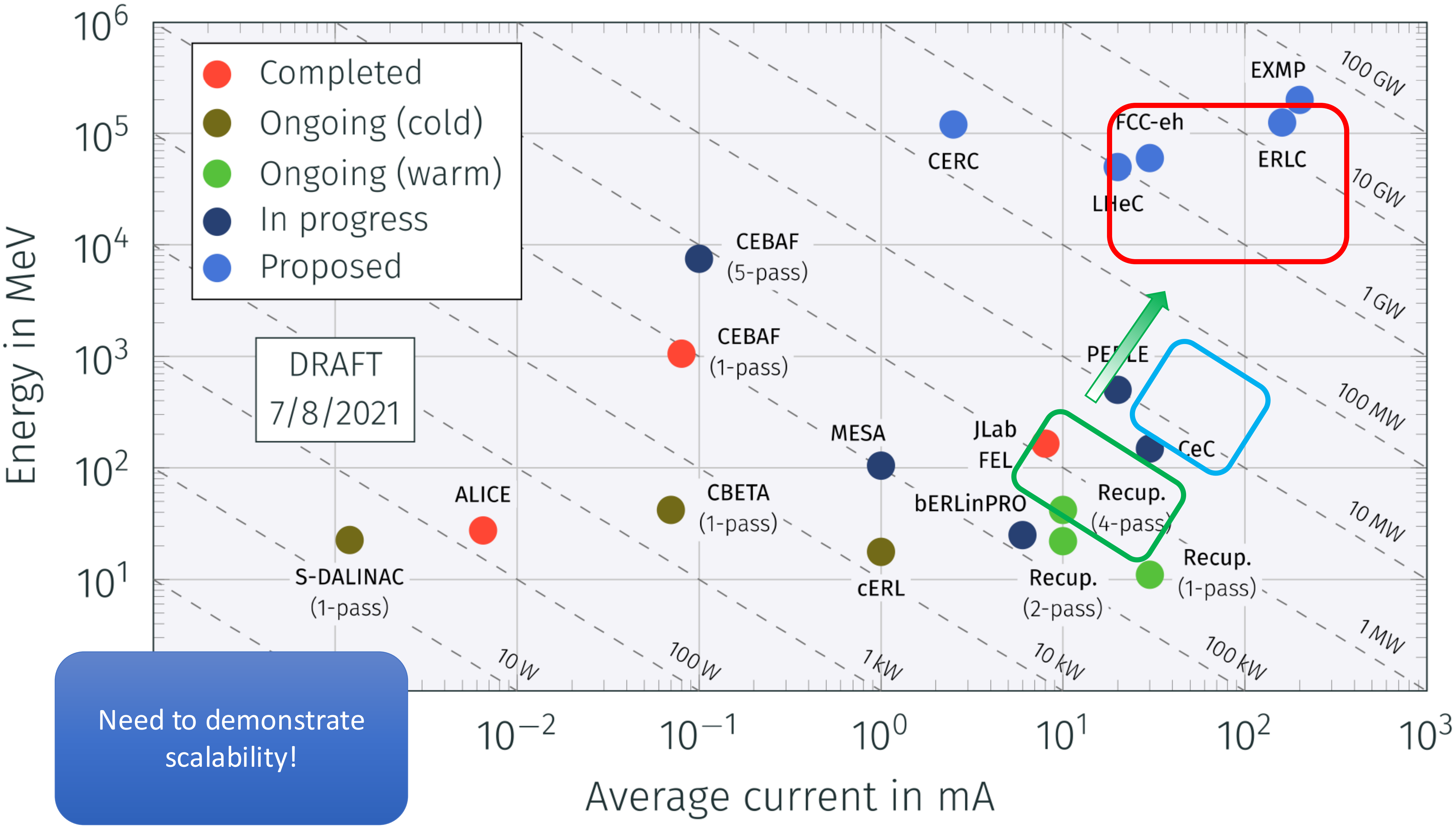
- Final focusing system is changed from NbTi to Nb3Sn
- D1 magnet superconducting
- crab cavities are inserted in IR 1 and IR 5
- Q4 is moved relative to the IP





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!



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

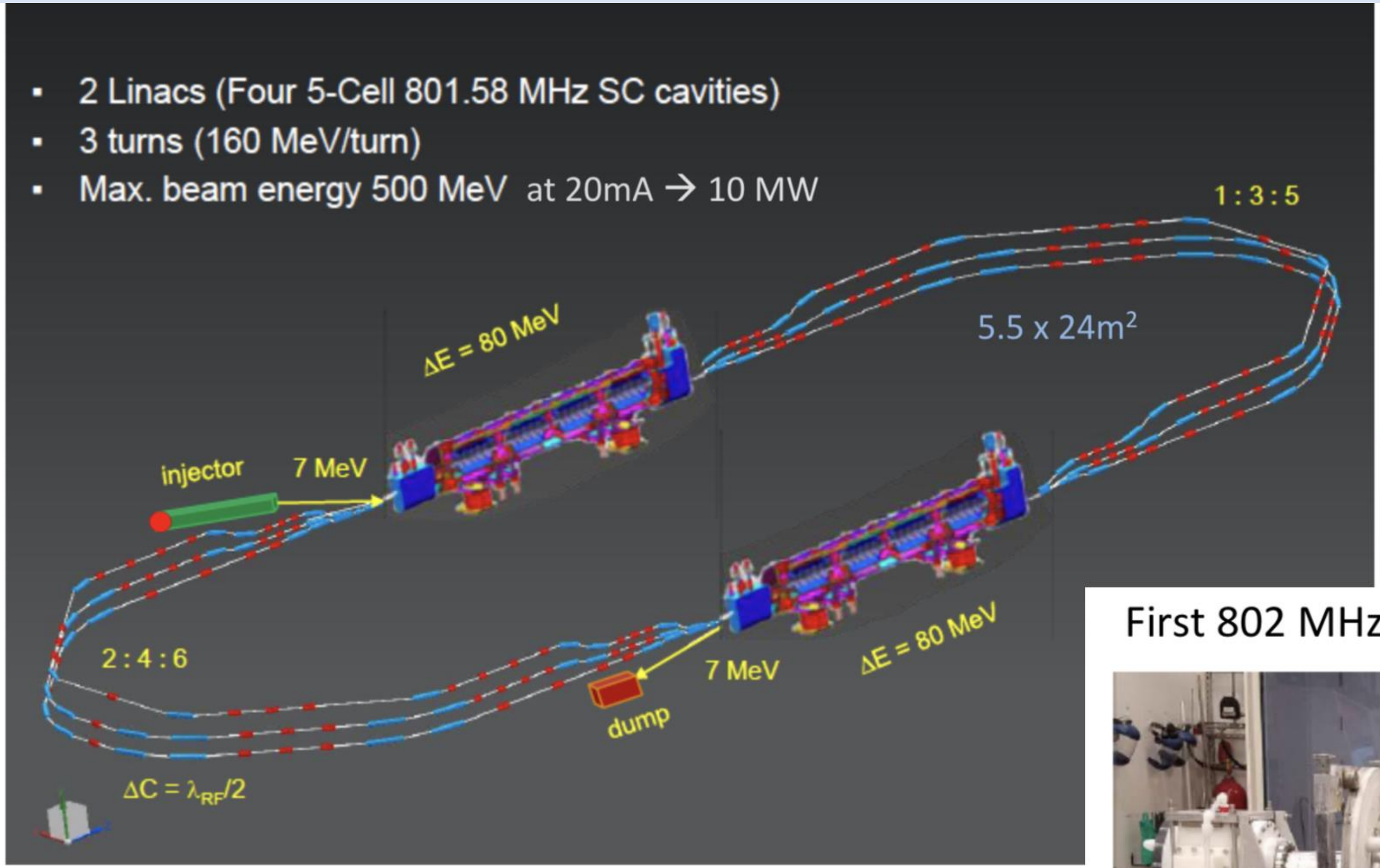
➔ Sustainable accelerator operation!

- 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

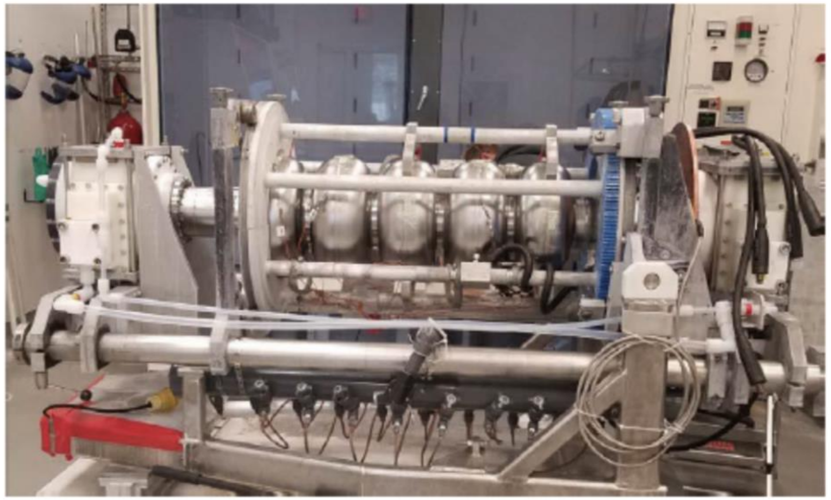
in Orsay

- 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