High-energy & high-luminosity electron-proton collisions

the ep/eA@CERN Study for the LHeC and FCC-eh

updated website: https://indico.cern.ch/e/LHeCFCCeh

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Vrije Universiteit Brussel & Nikhef

fwo

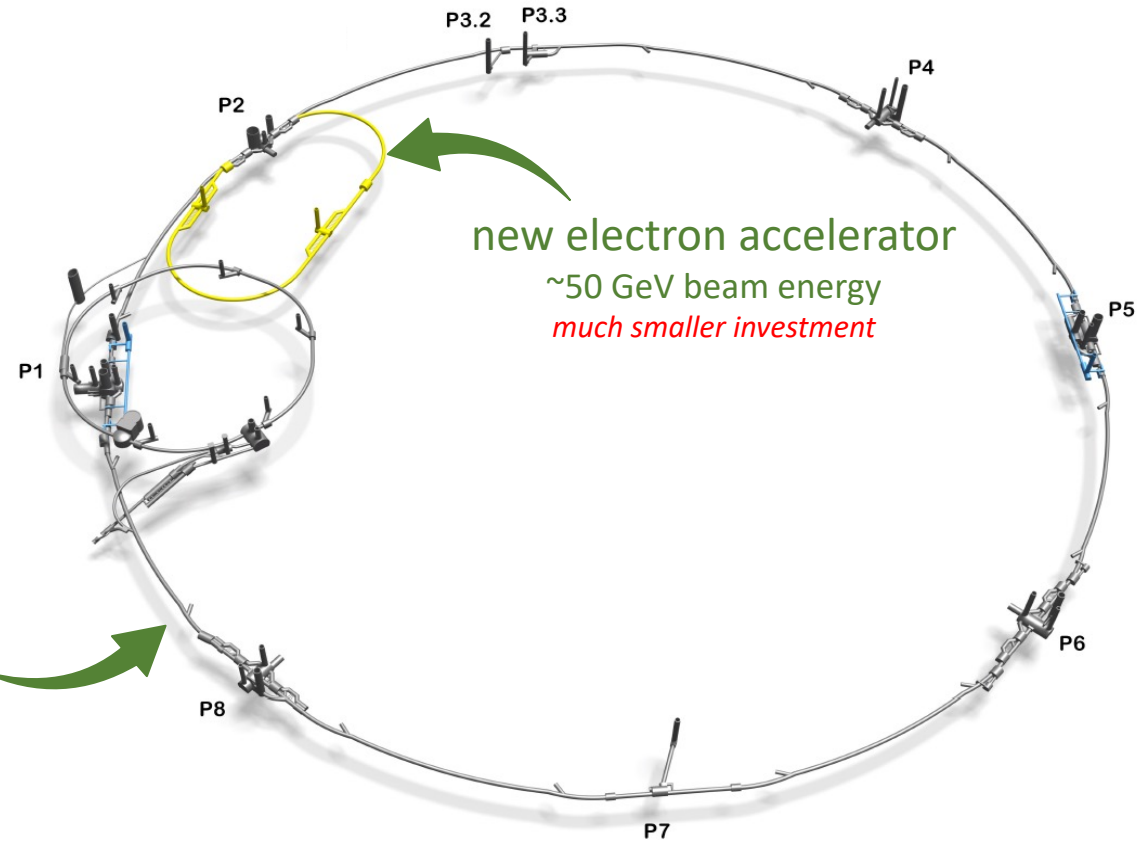
iihe BRUXELLES BRUSSEL

VUB HIGH-ENERGY PHYSICS RESEARCH CENTRE

Nikhef

Towards the LHeC White Paper, Nov 2024

high-energy & high-luminosity electron-proton collisions



new electron accelerator

~50 GeV beam energy

much smaller investment

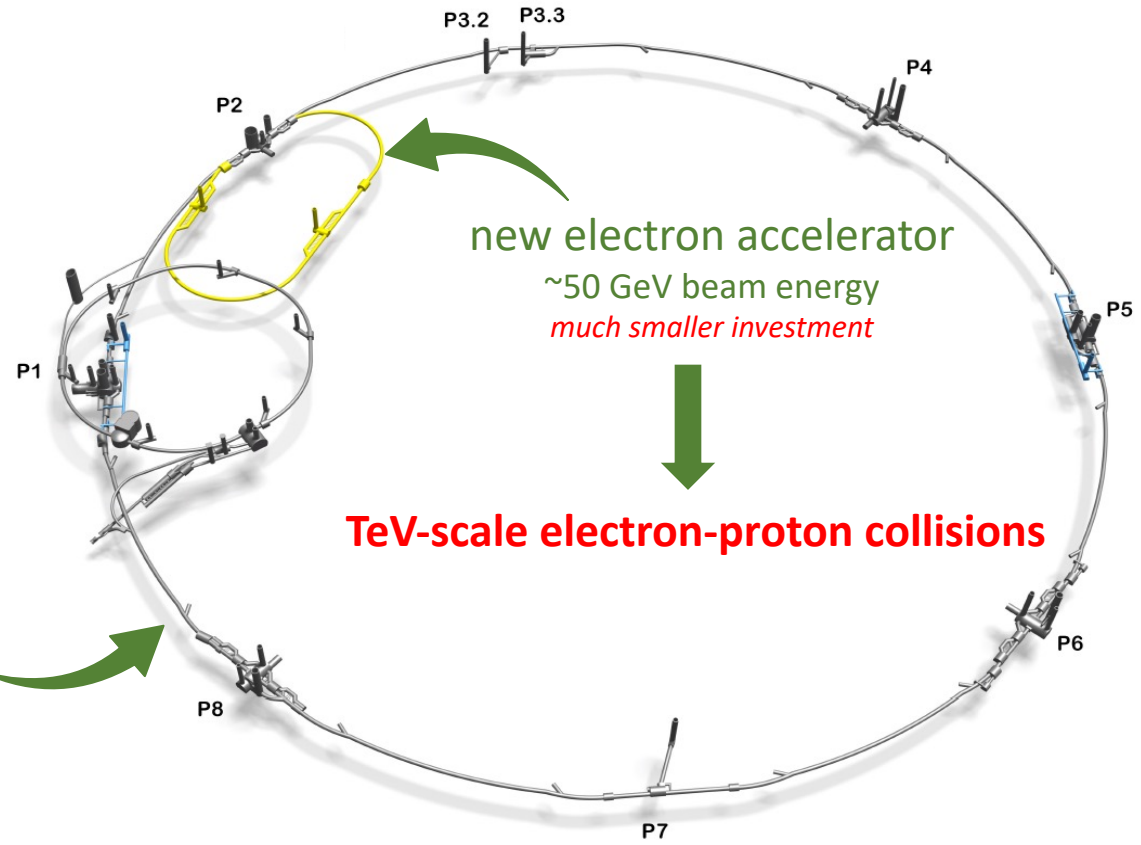
existing/future
proton & ion accelerator

LHC and/or FCC

(LHeC and/or FCC-eh)

major investment

high-energy & high-luminosity electron-proton collisions



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TeV-scale electron-proton collisions

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The ep/eA programs: at current & future hadron colliders

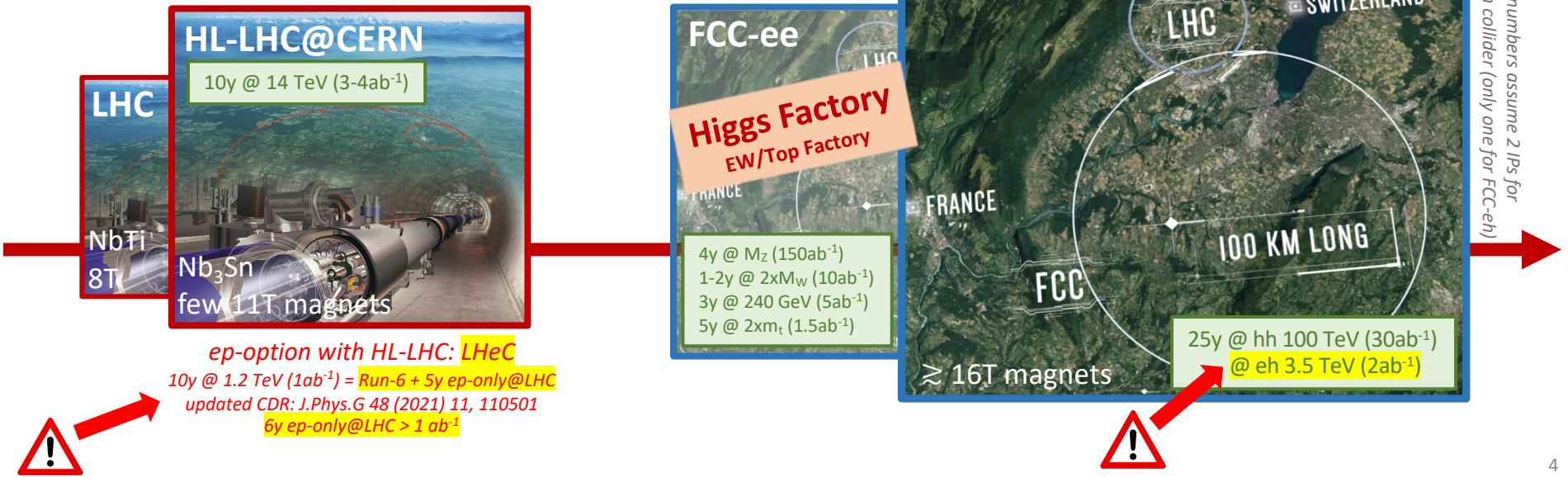
Current flagship (27km)

impressive programme up to ~2040

Future Circular Collider (FCC)

big sister future ambition (100km), beyond 2040

attractive combination of precision & energy frontier



ep-option with HL-LHC: LHeC

10y @ 1.2 TeV (1ab^{-1}) = Run-6 + 5y ep-only@LHC

updated CDR: J.Phys.G 48 (2021) 11, 110501

6y ep-only@LHC > 1 ab^{-1}

the synergistic physics impact of ep collisions

(briefly some highlights)

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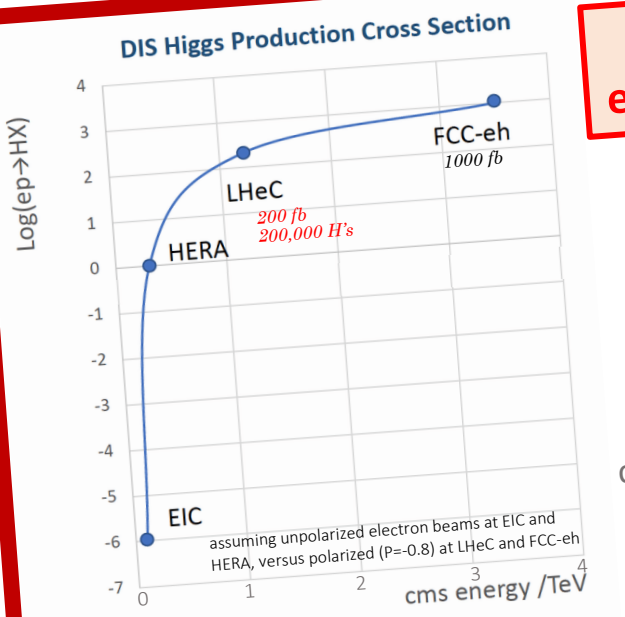
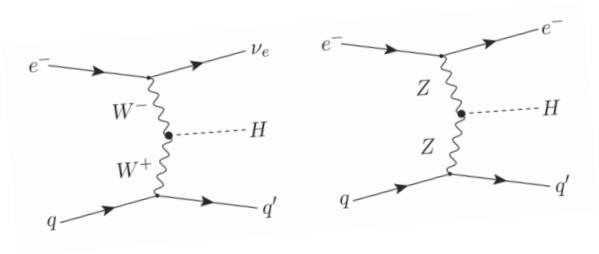


These electron-proton collisions enable a general-purpose experiment

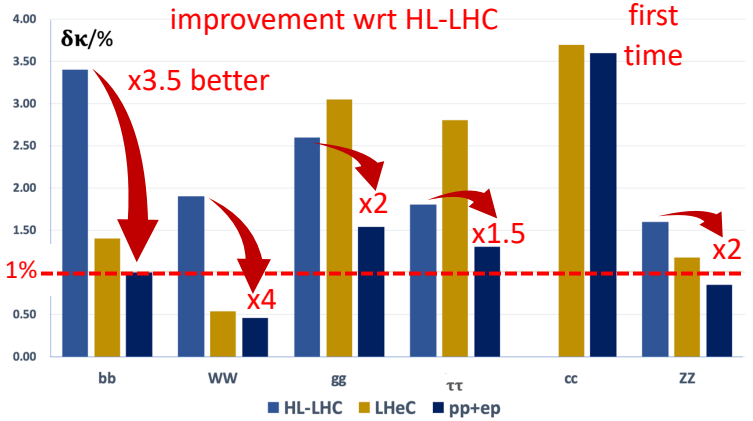


compared to proton collisions, these are reasonably clean Higgs events with much less backgrounds

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

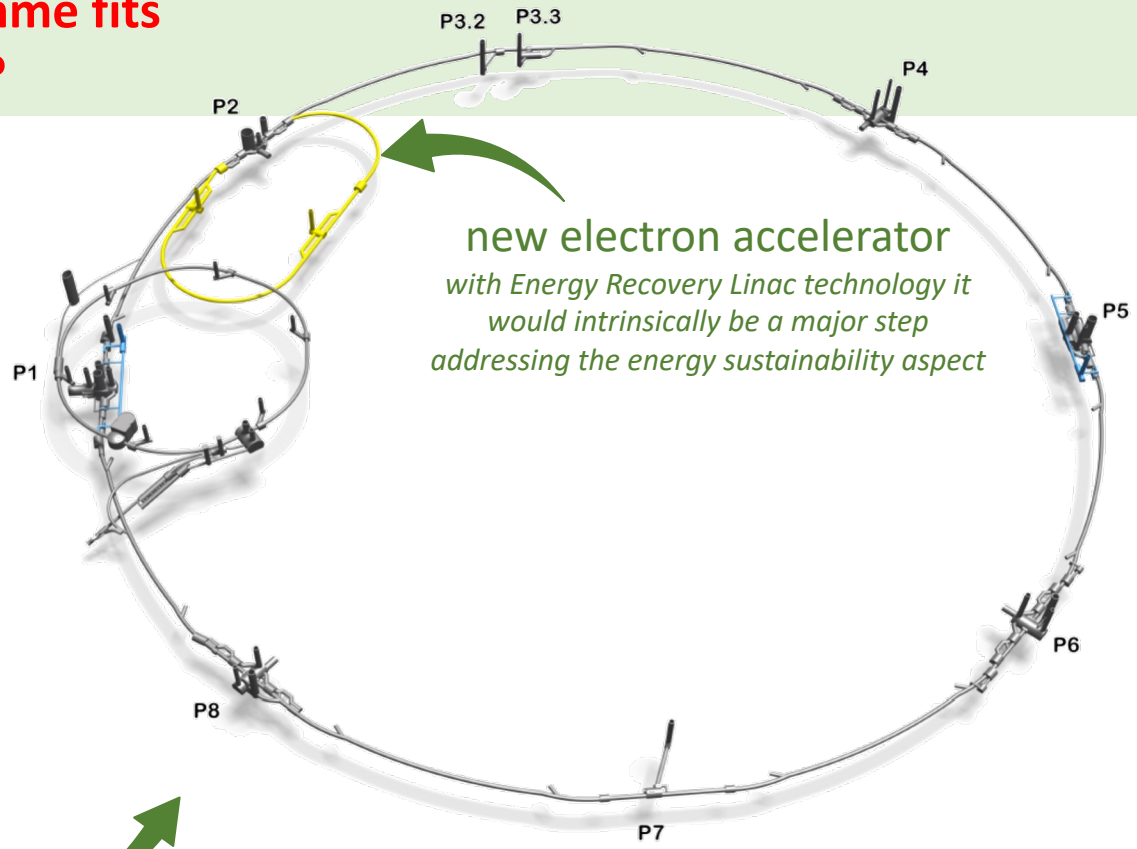
- complete unfolding of PDFs extended in (Q^2,x) by orders of magnitude

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)

How does the LHeC progamme fits into the collider landscape?



new electron accelerator

with Energy Recovery Linac technology it would intrinsically be a major step addressing the energy sustainability aspect

existing/future
proton & ion accelerator

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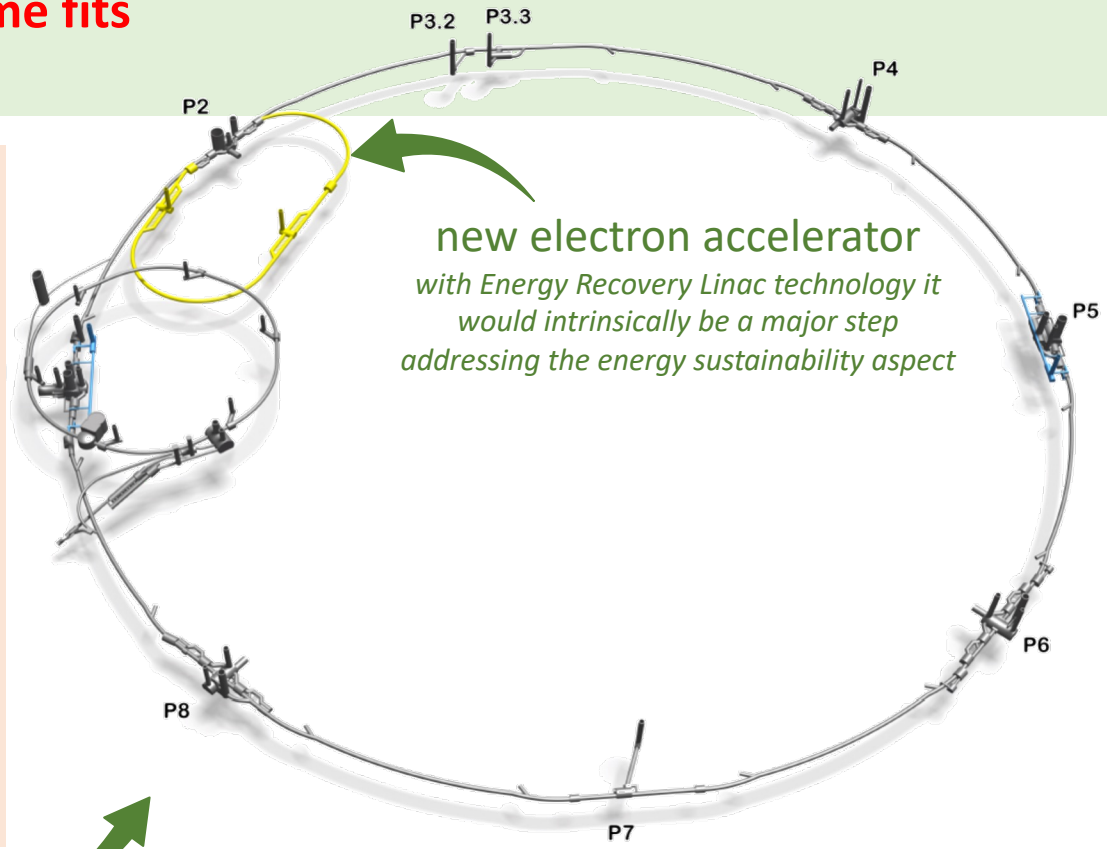
The LHeC (and/or FCC-eh) is not "*the*" major new collider for CERN, but enables an ultimate upgrade of the existing LHC (and/or future FCC) programme.



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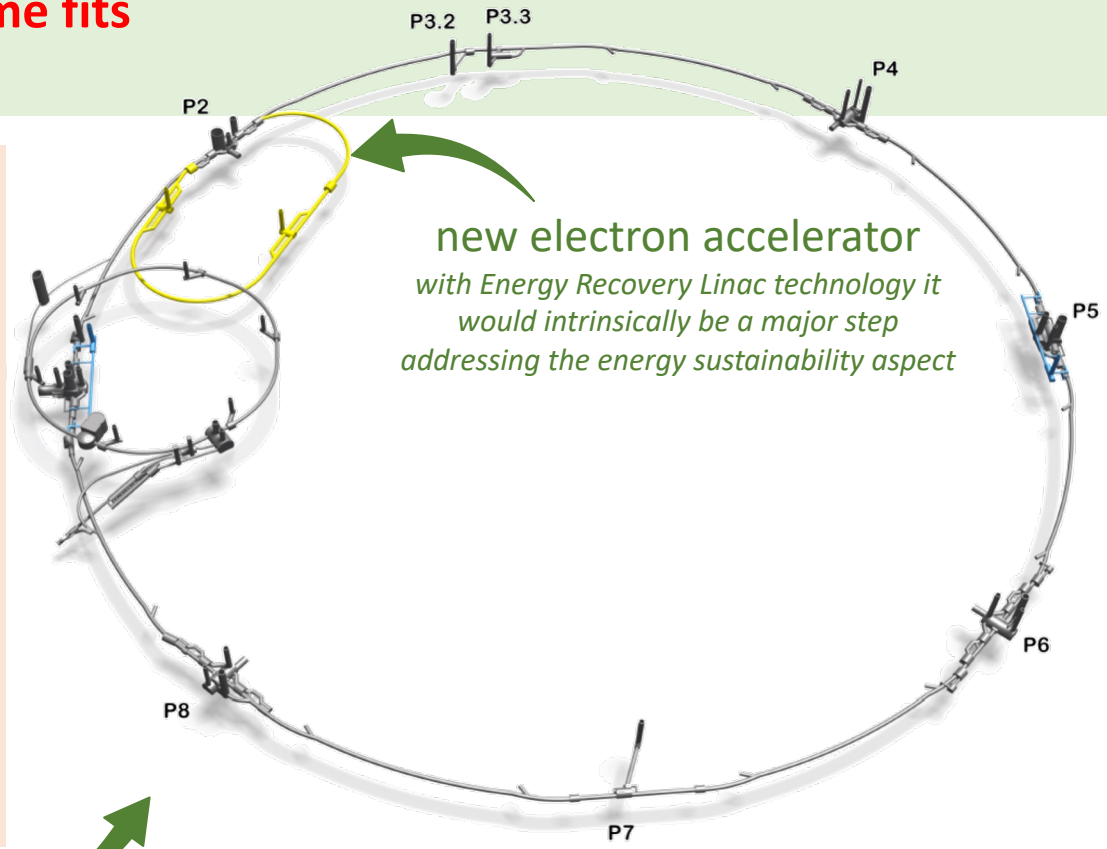

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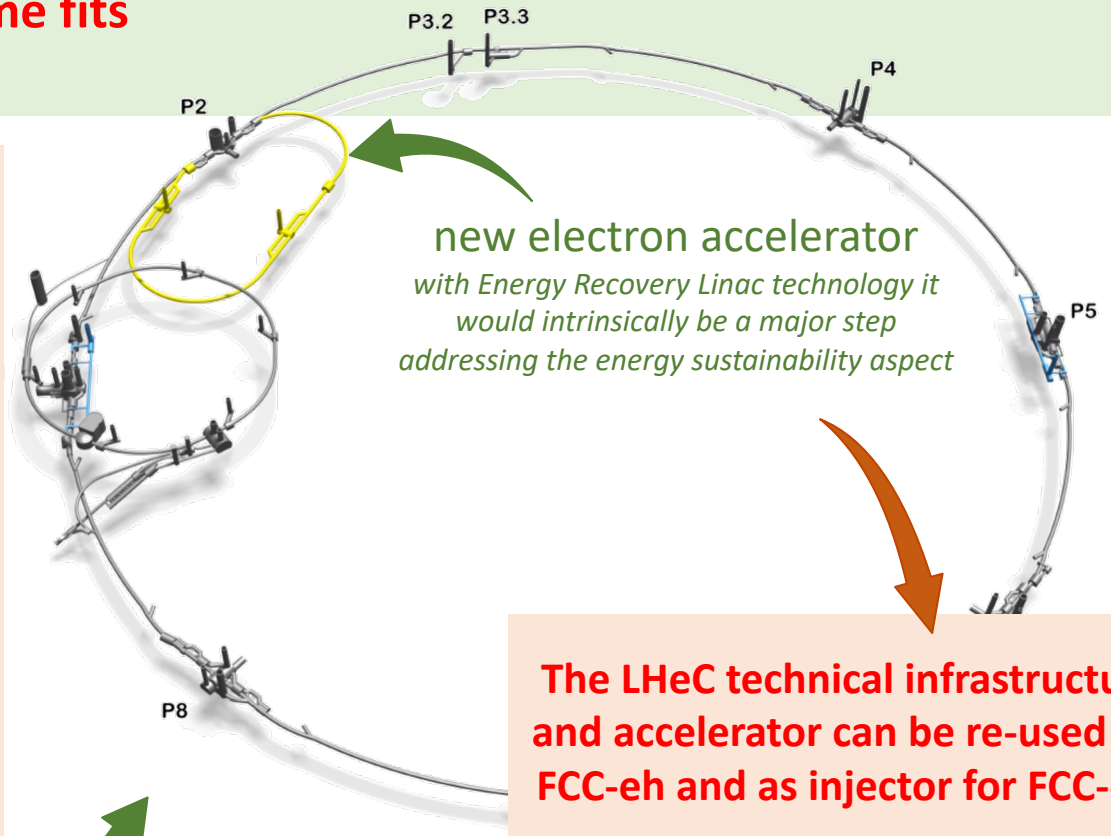

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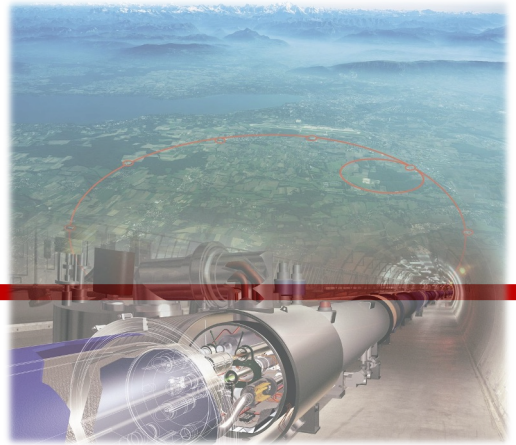
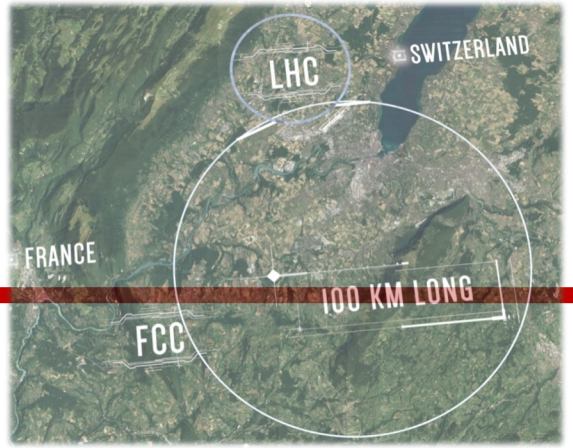
The LHeC technical infrastructure and accelerator can be re-used for FCC-eh and as injector for FCC-ee.

existing/future
proton & ion accelerator





LHC

FCC (ee or hh)

An impactful "*bridge*" between major colliders @ CERN

ep-option with HL-LHC: LHeC

updated CDR: J.Phys.G 48 (2021) 11, 110501

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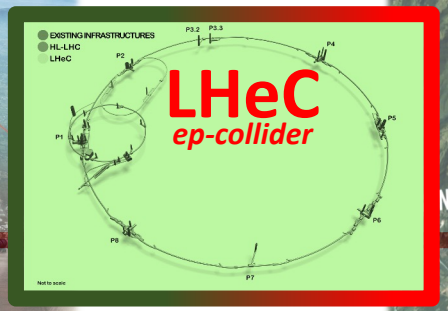
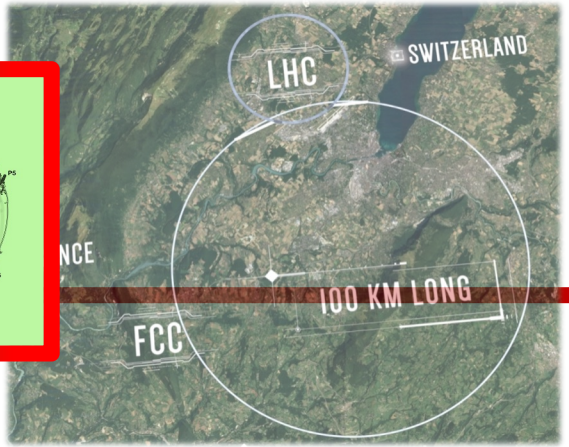
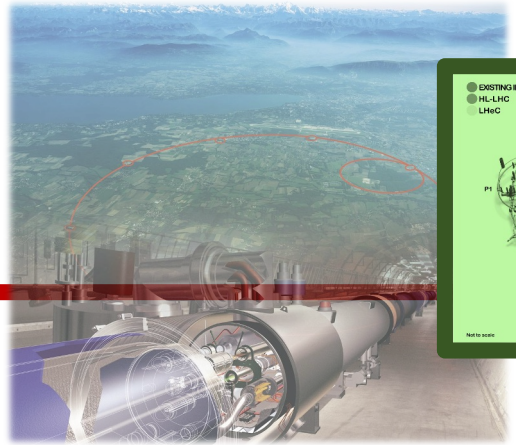
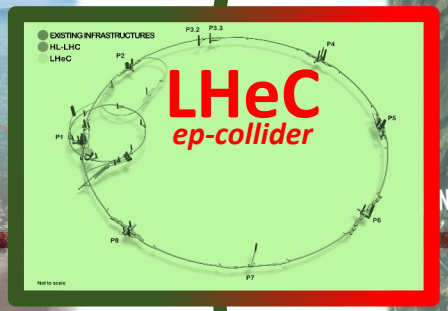


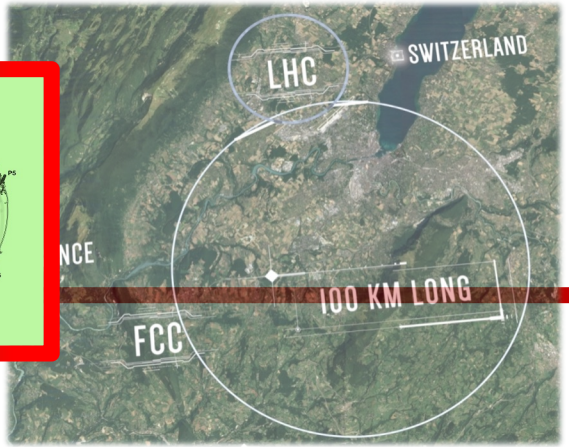


An impactful "*bridge*" between major colliders @ CERN

ultimate upgrade of the LHC physics reach







fast-track to new and impactful opportunities at colliders for attractive SM & BSM physics

An impactful "*bridge*" between major colliders @ CERN

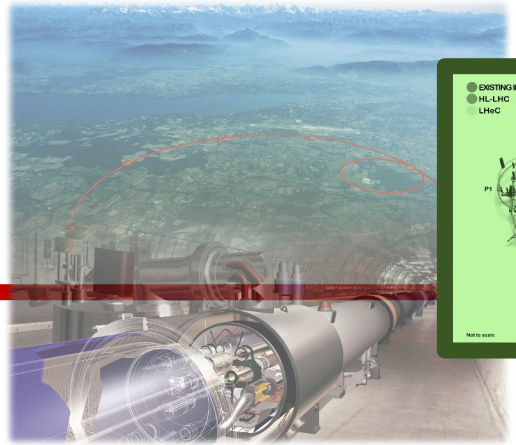
cost-effective investment

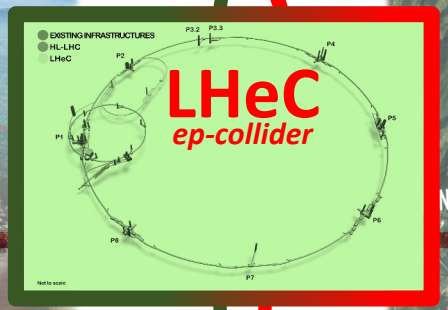
re-use

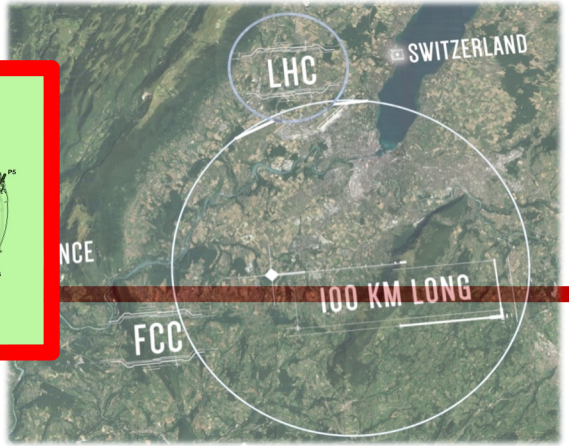
injector

ultimate upgrade of the LHC physics reach

essential enabler for the physics at any new high-energy hadron collider







i.e. SRF@LHeC as prototype series and training for SRF@FCC-ee

fast-track to new and impactful opportunities at colliders for attractive SM & BSM physics

fast-track to the optimal SRF performance of a H-factory & cost/risk reduction for SRF at FCC-ee

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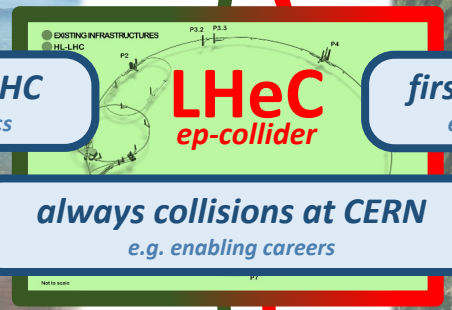
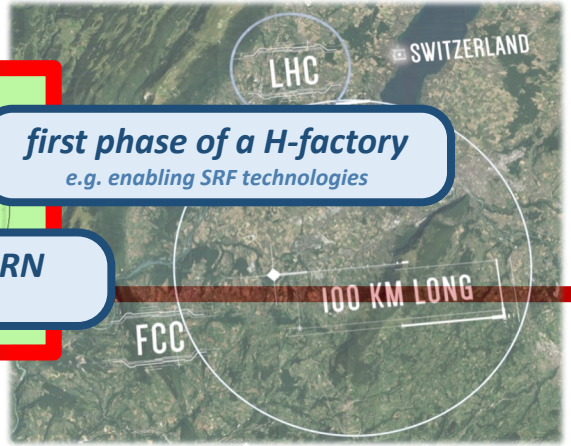


LHeC
ep-collider

last phase of the LHC
e.g. enabling more physics

first phase of a H-factory
e.g. enabling SRF technologies

always collisions at CERN
e.g. enabling careers



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White Paper (initial thoughts) – *input to the ESPP*

1. **The LHeC "bridge" project** (1p)
   - *scope, timing, bridging impact for LHC and FCC, connection with previous ESPP*
   - *career developments with a joint HL-LHC and LHeC involvement at CERN, from EIC to LHeC*
2. **The LHeC at the frontline of particle and nuclear physics** (4p)
   - *unique SM and BSM measurements and searches (examples with high impact)*
   - *the LHeC physics in the landscape & future combinations with future colliders in the 2040'ies (e.g. H & QCD)*
3. **LHeC physics enabling HL-LHC & high-energy proton collider physics** (4p)
   - *LHeC PDFs enhance the physics reach at the HL-LHC and future hadron colliders*
   - *synergies between LHeC and HL-LHC results to reach beyond current knowledge*
4. **LHeC technology enabling a Higgs factory** (4p)
   - *LHeC investments improve the FCC-ee program (cost, schedule, risk, training)*
   - *stepping stone for detector R&D towards Higgs factories*
5. **Technical feasibility of the LHeC** (4p)
   - *readiness of detector and accelerator technology to move forward with implementation*
   - *progress with ERL feasibility for high-power beams & sustainability aspects*
6. **The LHeC implementation plan** (4p)
   - *timeline and resources for installation and operation, including run & financing scenario*
   - *(optional) joint detector and program for ep/eA/pp/pA/AA physics*

The ep/eA study at the LHC and FCC

- The ESPP emphasizes the importance of studying the Higgs boson sector with improved precision and diversifying our search for new physics phenomena.
- Guided by these strategic objectives, we study how high-energy, high-luminosity ep/eA physics can empower pp/pA/AA physics at the LHC and FCC.
- There is important synergistic impact on topics such as proton structure, EW/H/top physics, Hidden Sector searches and Detector R&D.

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The LHeC project emerges as an impactful bridge between present and future major colliders at CERN

a White Paper will be developed for the ESPP input, with a workshop today

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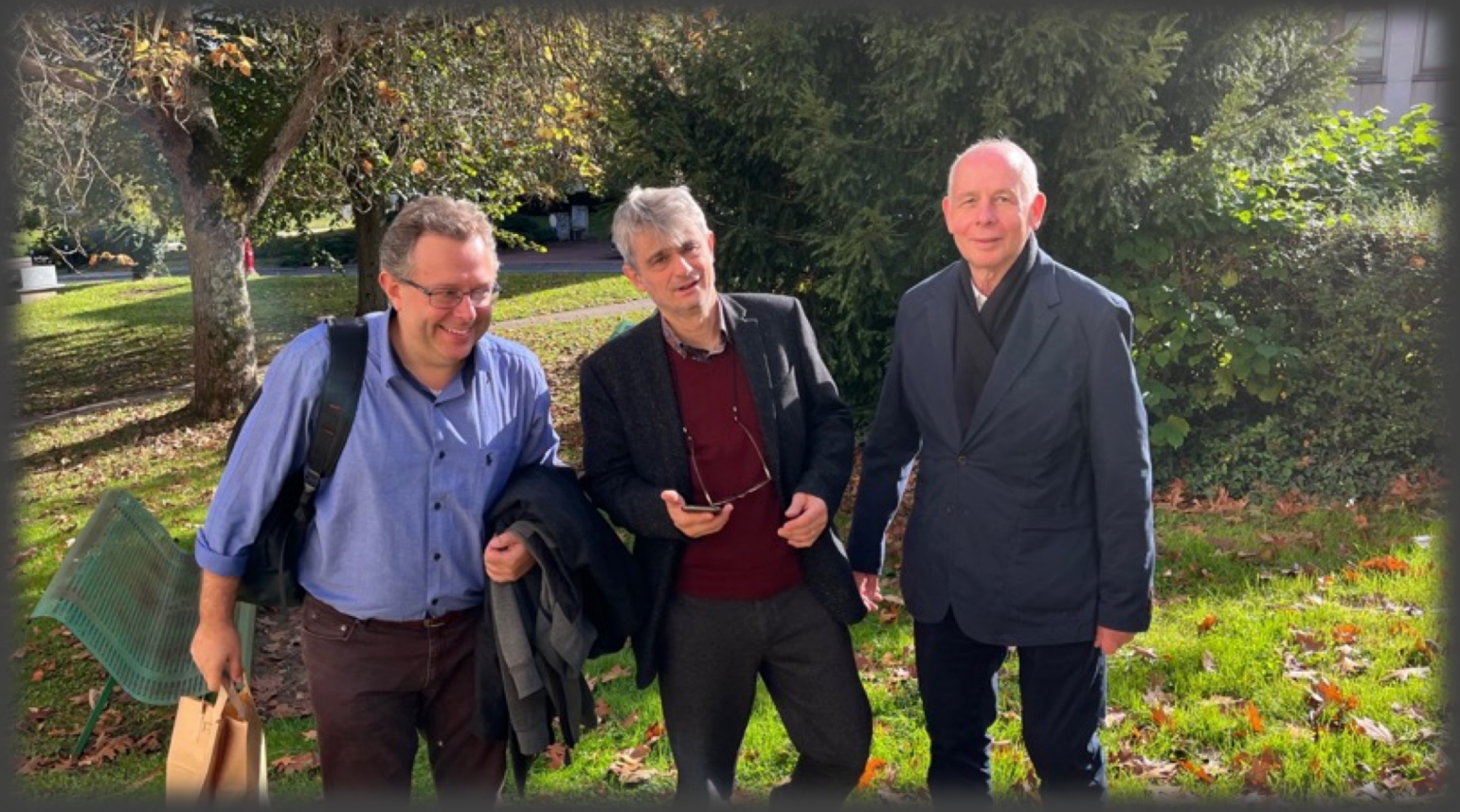
Thank you for your attention!
Jorgen.DHondt@nikhef.nl



Max Klein (1951–2024)

The challenge – high-power electron beam

From HERA to LHeC/FCC-eh

3 orders in magnitude in luminosity
1 order in magnitude in energy

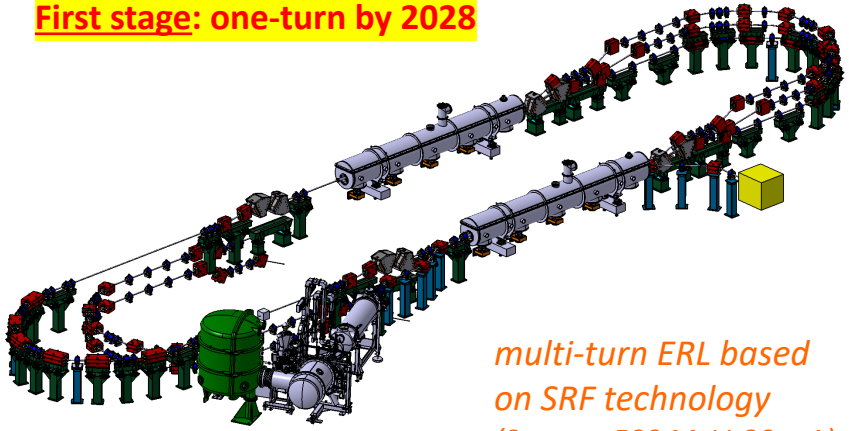
beam current × beam energy
= beam power

LHeC/FCC-eh ~ 1 GW beam power
equivalent to the power delivered by a nuclear power plant

PERLE @ IJCLab (Orsay)

being constructed to demonstrate all ERL aspects for LHeC/FCC-eh

First stage: one-turn by 2028



multi-turn ERL based on SRF technology (3-turns, 500 MeV, 20 mA)

CDR: *J.Phys.G* 45 (2018) 6, 065003

The planned R&D on Energy Recovery Linacs will enable to provide a 1 GW electron beam with only 100 MW power

The ep/eA study at the LHC and FCC – new impactful goals for the community

More information:
https://indico.cern.ch/e/LHeCFCCeh

2023 | WS | 2024 | WS | 2025 *input to ESPP*

proton and nuclear structure from EIC and HERA to LHeC and FCC-eh
novel QCD with high-energy DIS physics: what do we discover when breaking protons and nuclear matter in smaller pieces
Nestor Armesto, Claire Gwenlan, Paul Newman

general-purpose high-energy physics program: precision physics and searches
enabling direct discoveries and measurements in EW, Higgs and top physics with high-energy DIS collisions
Monica D'Onofrio, Uta Klein, Christian Schwanenberger

ep/eA-physics empowering pp/pA/AA-physics (LHC and FCC)
improving the ATLAS, CMS, LHCb and ALICE discovery potential with results from a high-energy DIS physics program
Maarten Boonekamp, Daniel Britzger, Christian Schwanenberger

developing a general-purpose ep/eA detector for LHeC and FCC-eh
critical detector R&D (DRD collaborations), integrate in the FCC framework, one detector for joint ep/pp/eA/pA/AA physics
Paul Newman, Yuji Yamazaki

developing a sustainable LHeC and FCC-eh collider program
design the interaction region, power and cost, coherent collider parameters & run plan, beam optimization, …
Oliver Bruning, Yannis Papaphilippou

- five thematic physics and technology working groups
- annual ep/eA workshops (**WS**)

Subscribe to mailing lists via https://e-groups.cern.ch/ : use the search option, and search for "lhec-fcceh-all" or "ep-eA-WG" in all e-groups