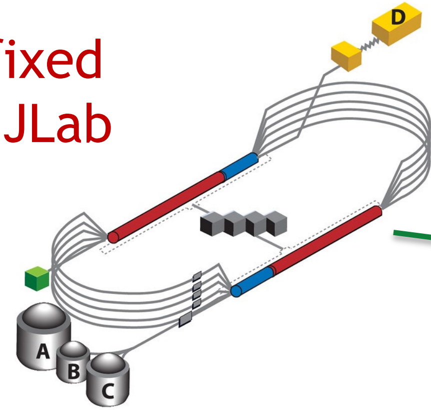
Energy-Frontier DIS at CERN: Programme Options & Detector Challenges

Paul Newman (Birmingham)

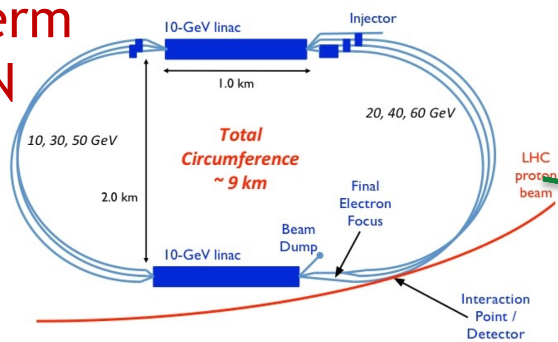
with Yuji Yamazaki (Kobe)
and the LHeC/FCC-eh working group

Current and Future ep Colliders

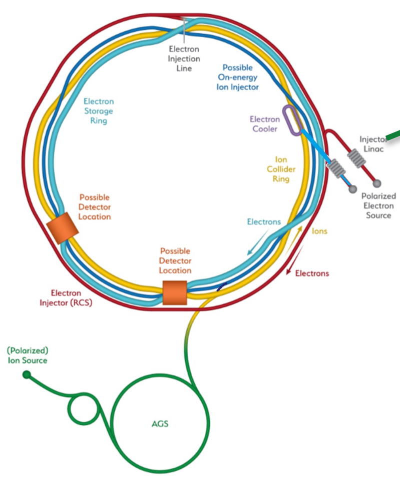
Ongoing fixed target @ JLab

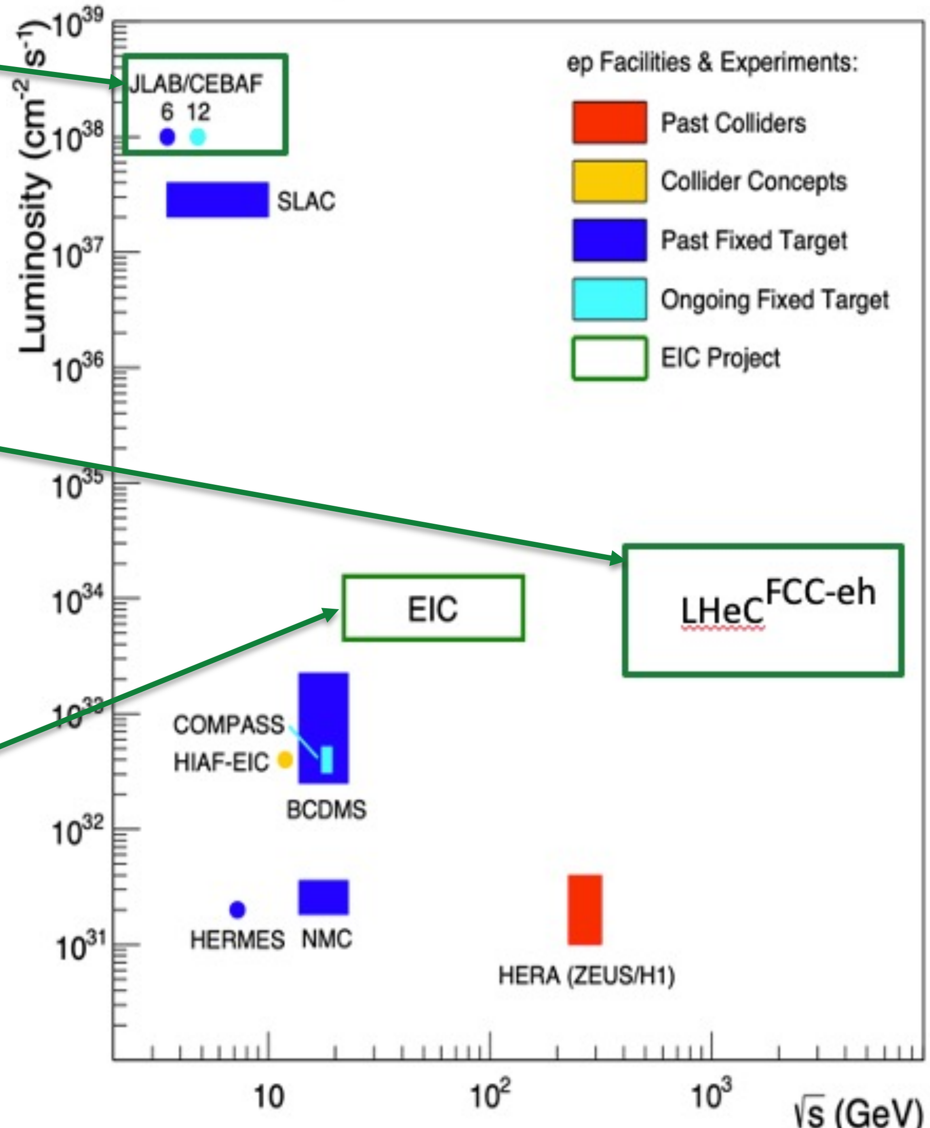


Longer-term @ CERN



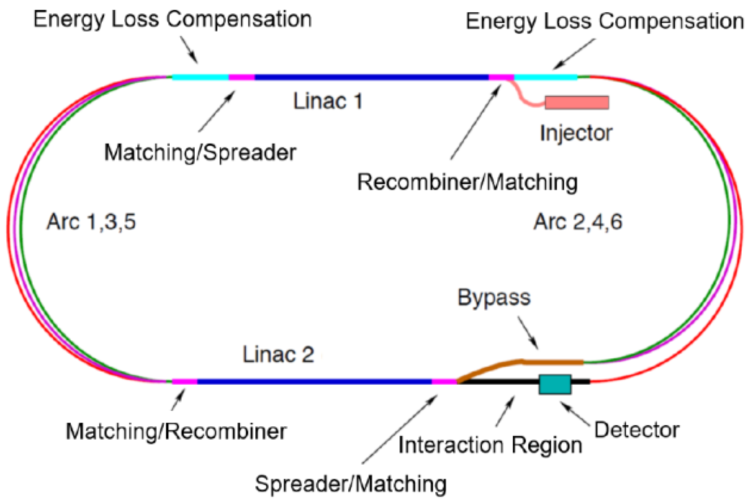
On-target for early 2030s @ BNL





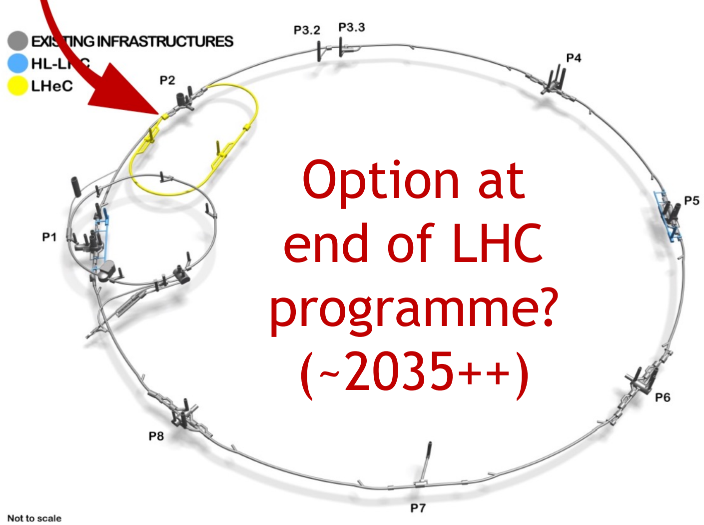
Machine Overview

- Power consumption constraint (< 150 MW) and need for high lumi imply **energy recovery** for electrons



- With 20 MV/m acceleration, 5.4km racetrack matches to 50 GeV leptons (1/5 of LHC circumference).
- LHeC ep lumi → 10^{34} cm^{-2} s^{-1} (~100 fb^{-1} per year, ~1 ab^{-1} total)

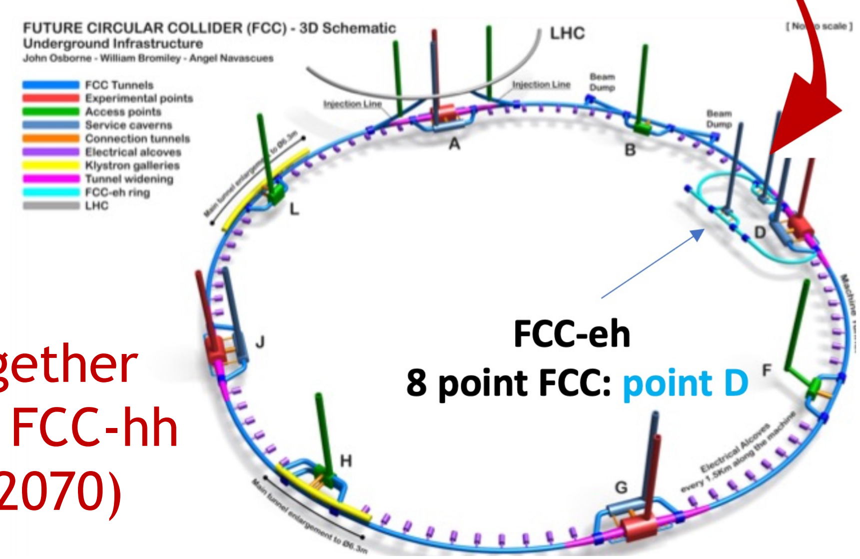
LHeC (>50 GeV electron beams)
E_{cms} = 0.2 – 1.3 TeV, (Q^2,x) range far beyond HERA
run ep/pp together with the HL-LHC (≳ Run5)



Option at end of LHC programme? (~2035++)

FCC-eh (60 GeV electron beams)
E_{cms} = 3.5 TeV, described in CDR of the FCC
run ep/pp together: FCC-hh + FCC-eh

Together with FCC-hh (~2070)

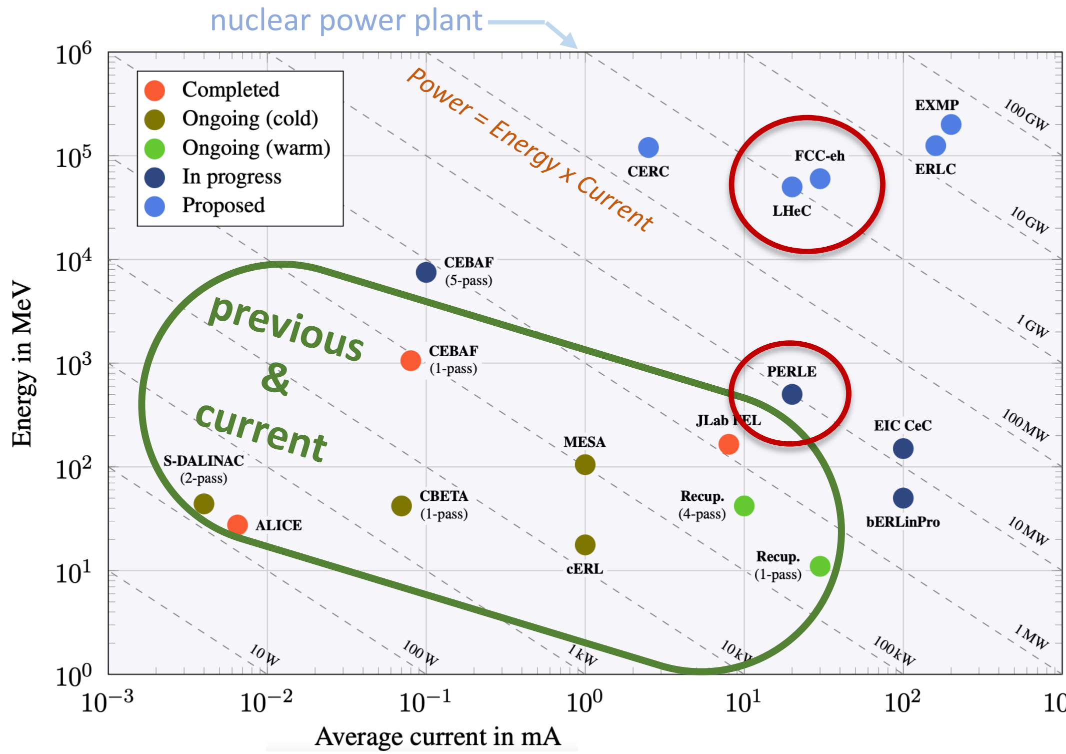


Energy Recovery Linacs

Sustainability will be a key consideration for any future accelerator:

→ Superconducting RF cryomodules

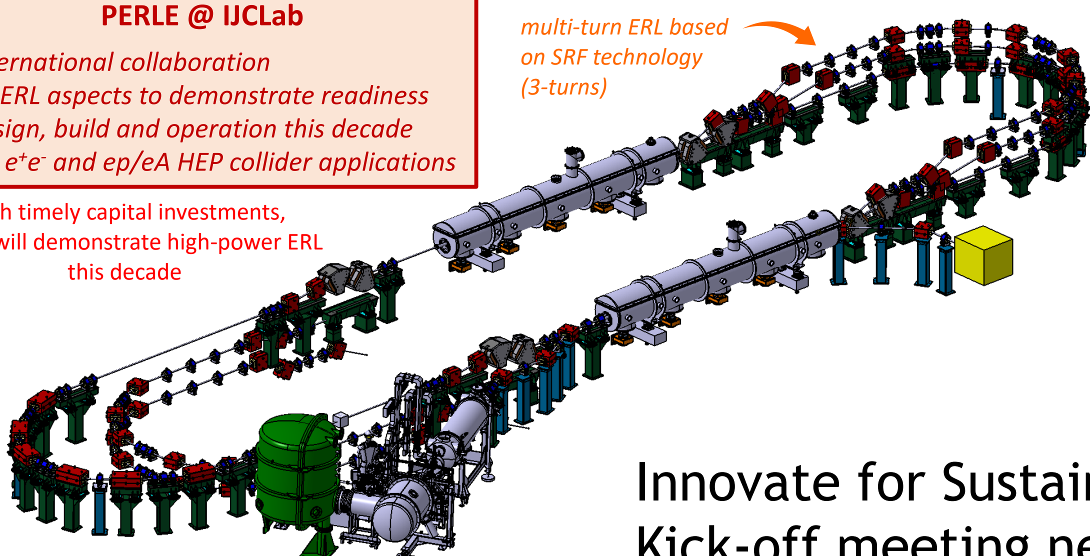
→ Energy Recovery linacs



PERLE @ IJCLab

- *international collaboration*
- *all ERL aspects to demonstrate readiness*
- *design, build and operation this decade*
- *for e⁺e⁻ and ep/eA HEP collider applications*

With timely capital investments, PERLE will demonstrate high-power ERL this decade



- PERLE is critical path towards LHeC technical realisation
- See also bERLinPRO

Innovate for Sustainable Accelerator Systems: Kick-off meeting next week: https://indico.ijclab.in2p3.fr/event/10302/

Structure of CERN-mandated study towards Next European Strategy (Material input: March 2025!)

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

More information:
https://indico.cern.ch/event/1335332/

2023 | WS | 2024 | WS | 2025 | TWS | *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

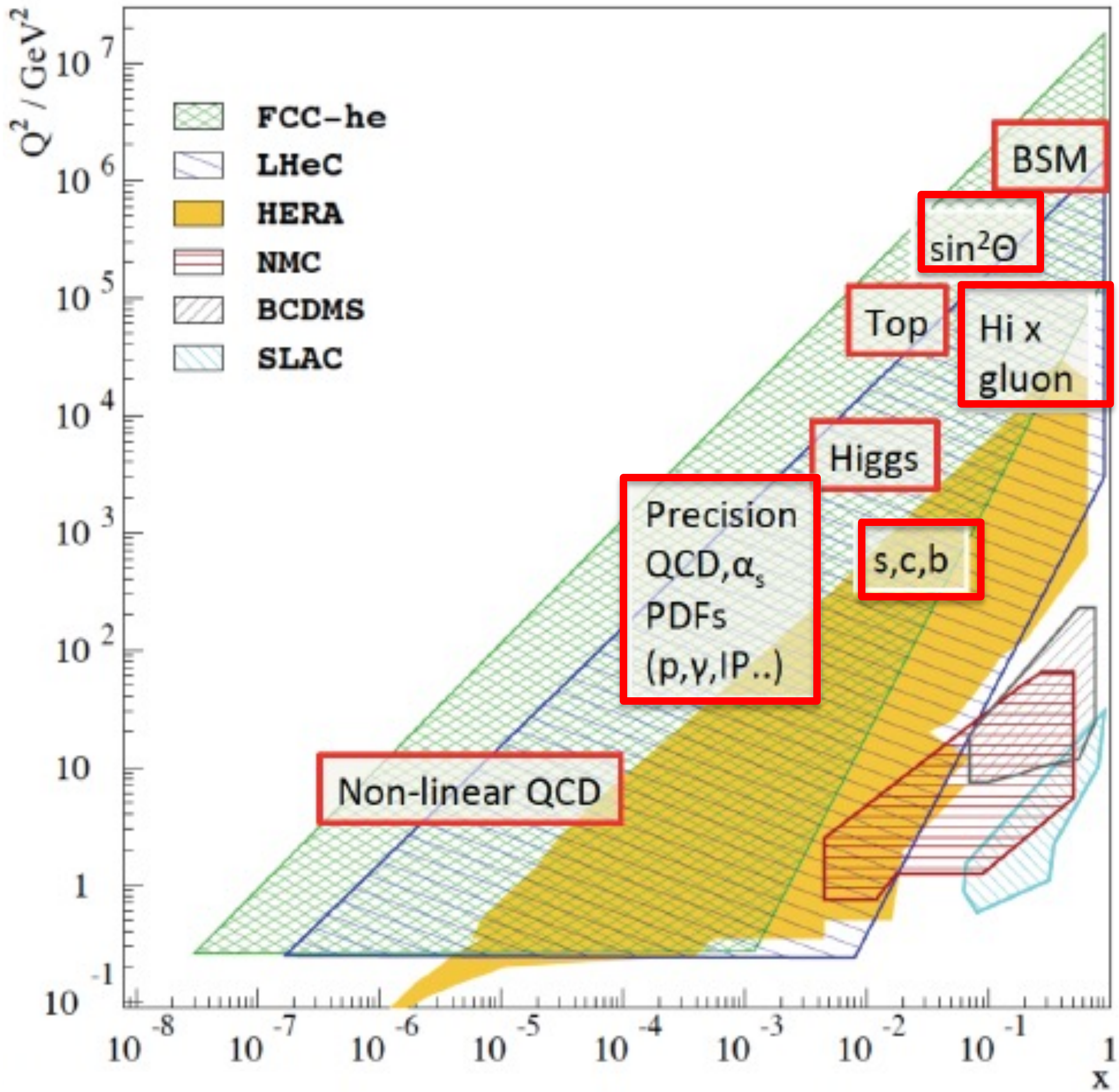
developing a general-purpose ep/eA detector for LHeC and FCC-eh
critical detector R&D (DRD collaborations), integrate in the FCC framework, one detector for joint ep/pp/eA/pA/AA physics
Paul Newman, Yuji Yamazaki

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**)
- final thematic workshop with closing reports to inform the upcoming Strategy process with impactful information (**TWS**)

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

LHeC Physics Targets and Detector Implications



See DIS'24 talks from Nestor Armesto, Mandy Cooper-Sarkar Bruce Mellado

Standalone Higgs, Top, EW, BSM programme

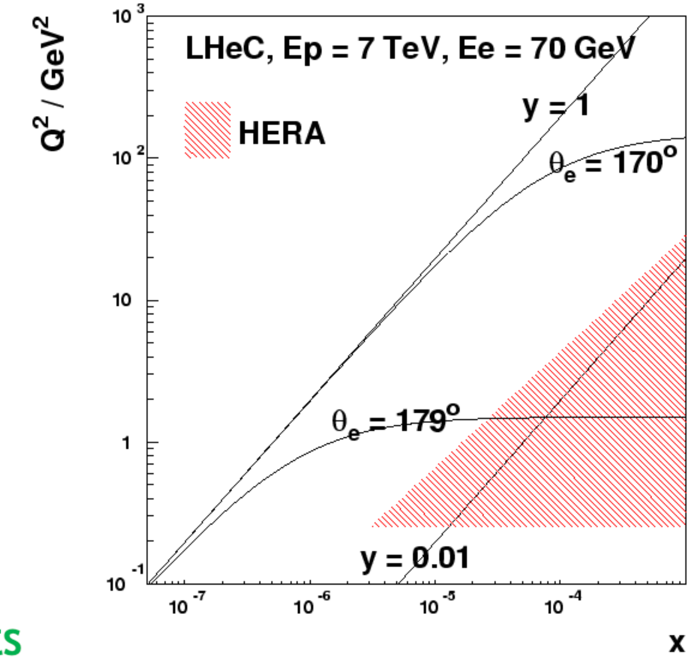
→ General purpose particle physics detector
→ Good performance for all high p_T particles
→ Heavy Flavour tagging

Precision proton PDFs, including very low x parton dynamics in ep,eA

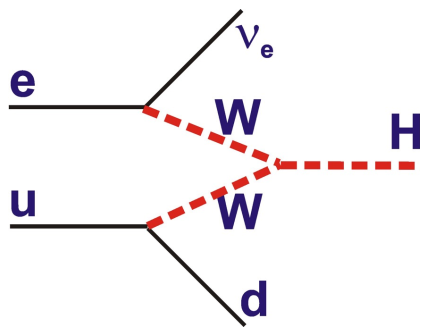
→ Dedicated DIS exp't
→ Hermeticity
→ Hadronic final state resolution for kinematics
→ Flavour tagging / PID
→ Beamline instruments

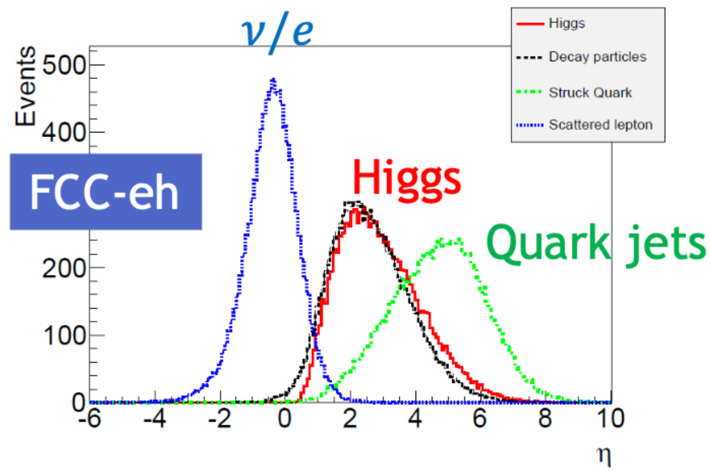
Detector Challenges: Hermiticity

- Access to Q^2=1 GeV^2 for all x requires scattered electrons to 179°

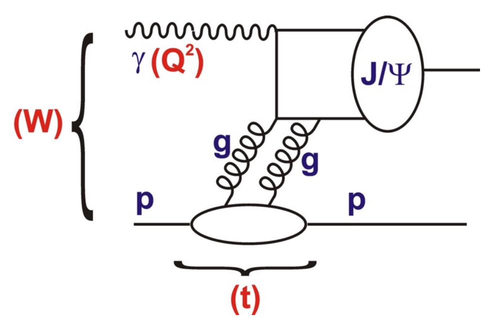


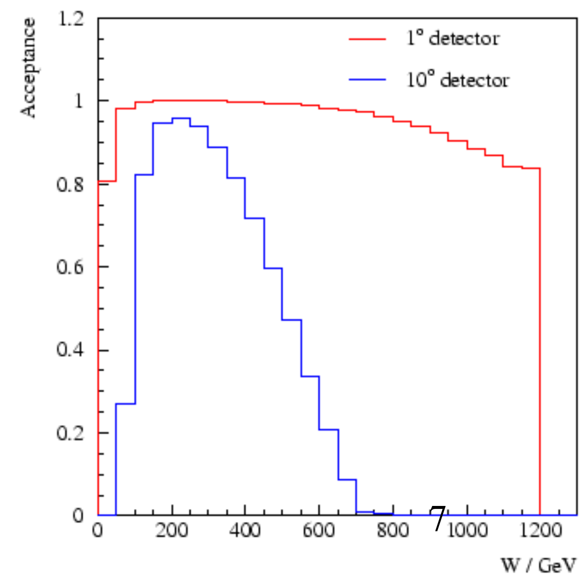
- Higgs production dominated by forward jet configurations



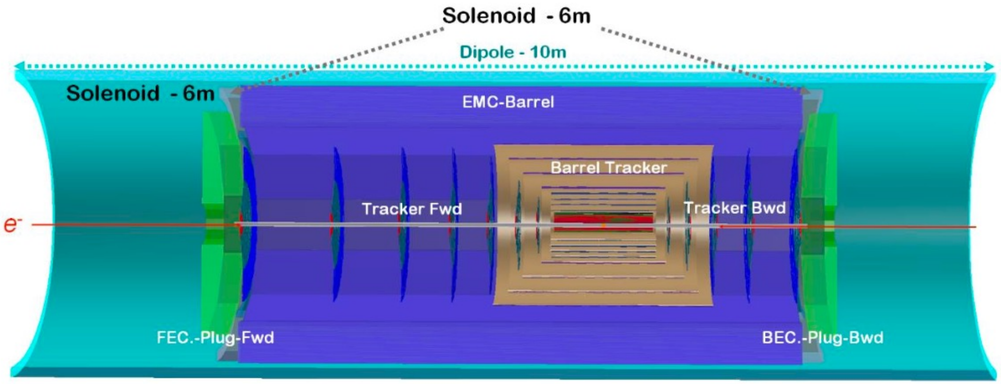


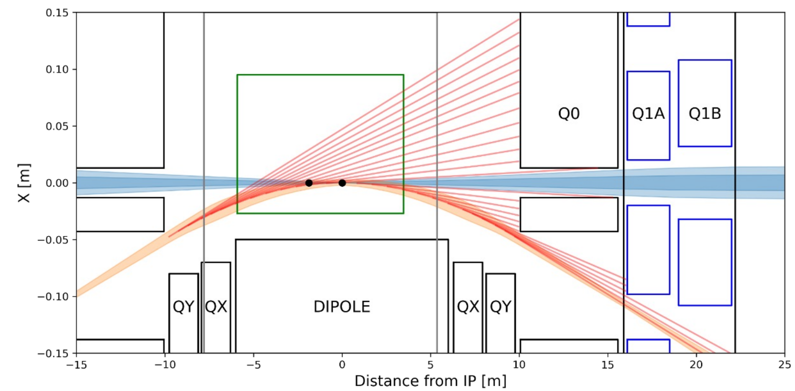
- High W exclusive J/Ψ requires lepton reconstruction up to 179°





Inner Detector Challenges: Synchrotron

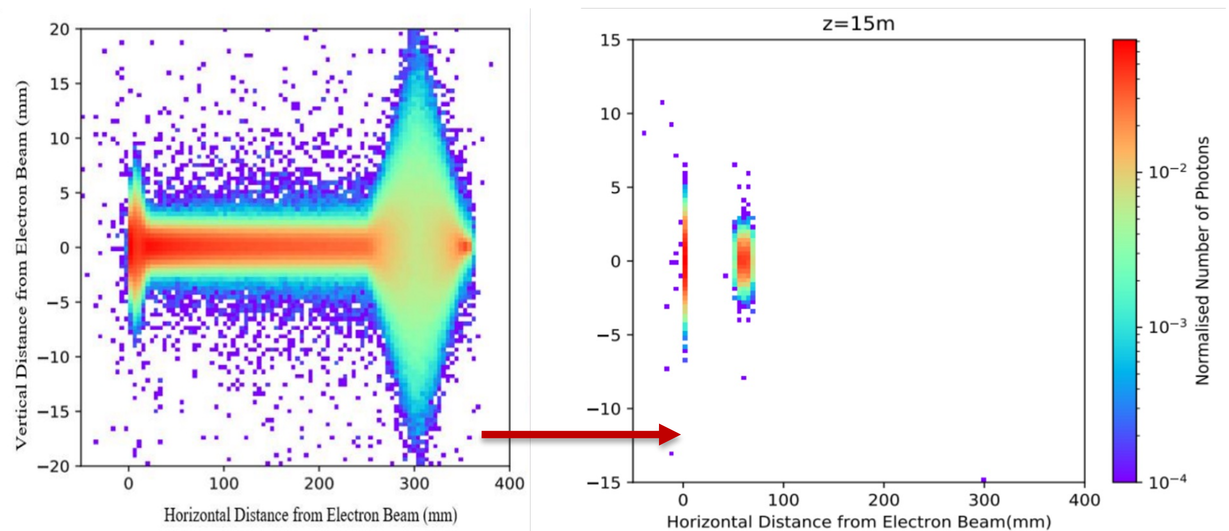




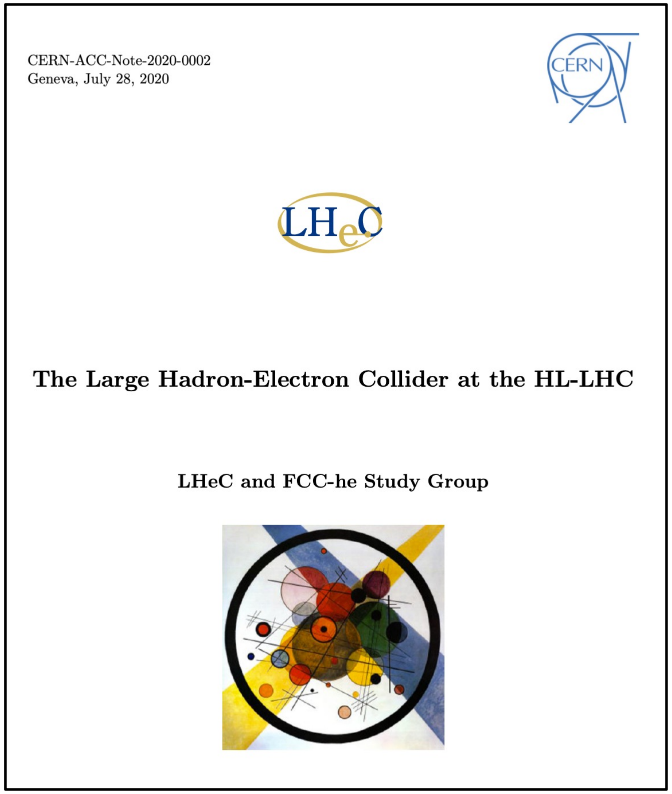
- Dipole magnets bend electrons to head-on collisions with protons

- Synchrotron mitigated with elliptical beampipe, collimators and absorption on the Q0 (normal conducting) quadrupole

- New initiative to extend studies of synchrotron load in interaction region (L. Forthomme) to the tracker / bemline detectors



Detetor Input Material and Connections


CERN-ACC-Note-2020-0002
Geneva, July 28, 2020

The Large Hadron-Electron Collider at the HL-LHC

LHeC and FCC-he Study Group

2008 2009 2010 2012 2014 2015 2017 2018 2019 2022

What we have already:

- 10 dedicated workshops over 15 years
- Original LHeC CDR (2012)
- Updated CDR (2020)
  → integrating (HL-)LHC ideas

Where we can learn / improve now:

- Connections to new / ongoing European DRD R&D collaborations
- Connections to more specific future colliders (FCC, ILC, CLIC…)
- Connections to Electron Ion Collider

Detector Overview (as in 2020 CDR Update)

Compact

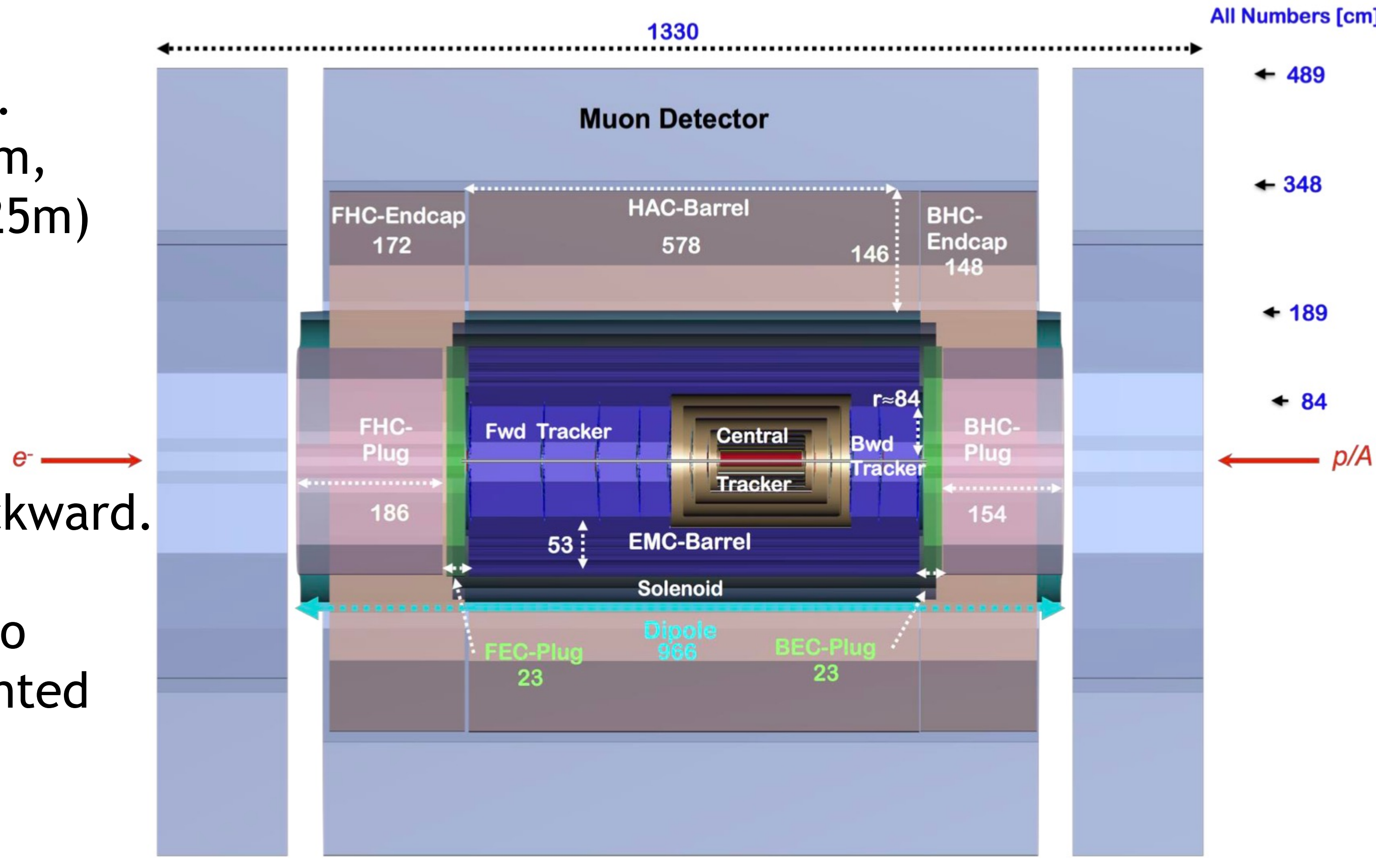
13m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)

Hermetic

- 1° tracking acceptance forward & backward.

- Beamline also well instrumented

Modular



‘Could be built now’, but many open questions:

- A snapshot in time, borrowing heavily from (HL)-LHC (particularly ATLAS)
- Possibly over-specified (eg for radiation hardness)?
- Possibly lacking important components for ep/eA (eg. Particle ID)
- Not particularly well integrated or optimised

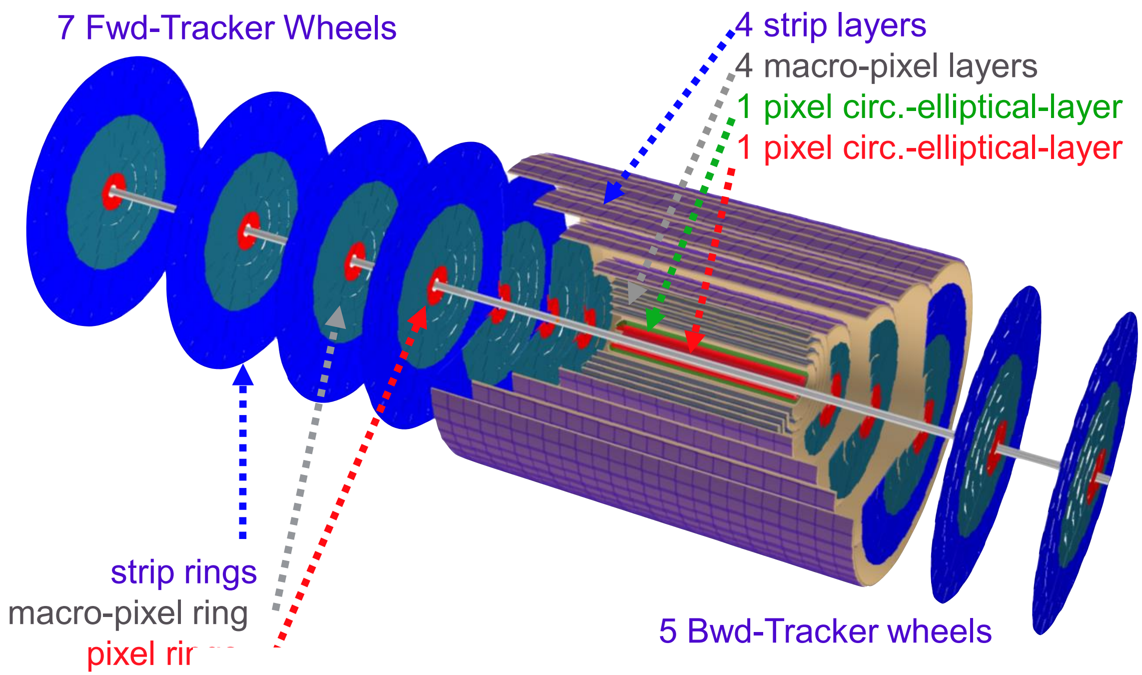
Central Tracker in CDR-Update

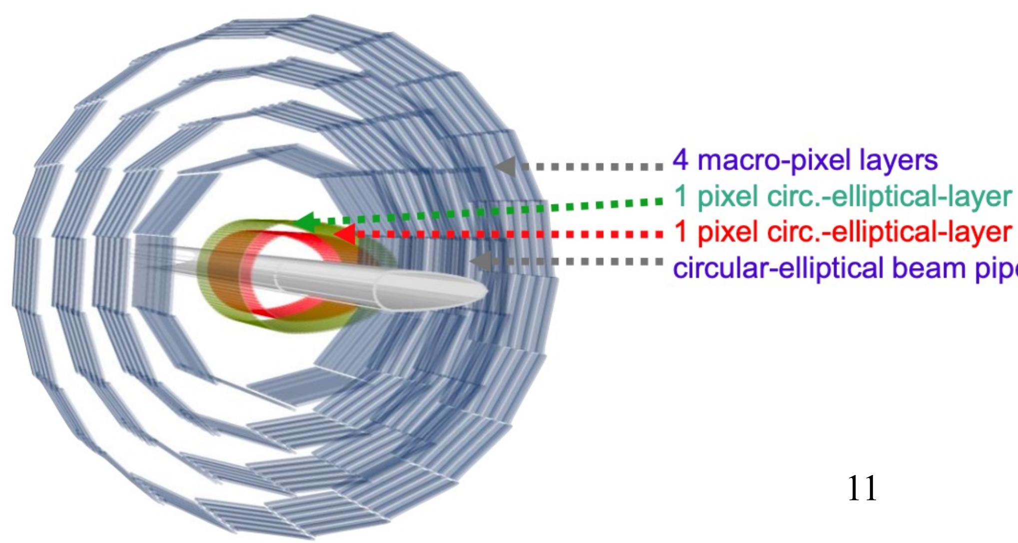
- HV-CMOS MAPS technology is low material and cost-effective
→ ~20% of a radiation length up to η~4.5

- Bent / stitched wafers for inner layers (as ALICE and ePIC)
→ High performance in p_T and vertex resolutions

- Semi-elliptical inner layers (synchrotron)

Pitch (μm)	$r\phi$	z
pixel	25	50
macro pixel	100	400
strip	100	10-50mm





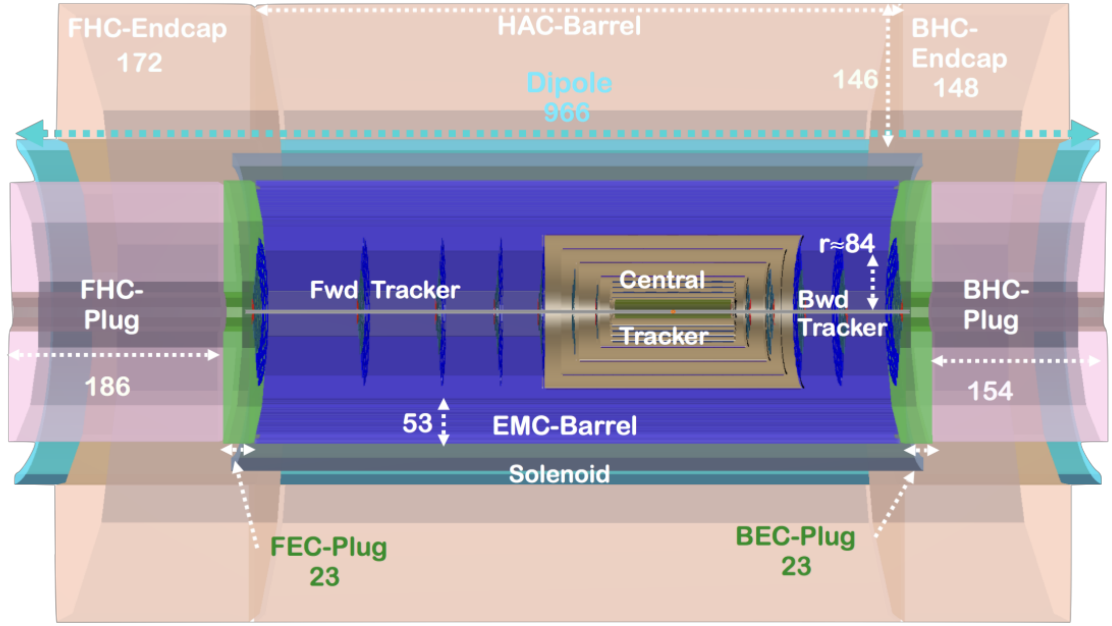
Calorimetry in CDR-Update

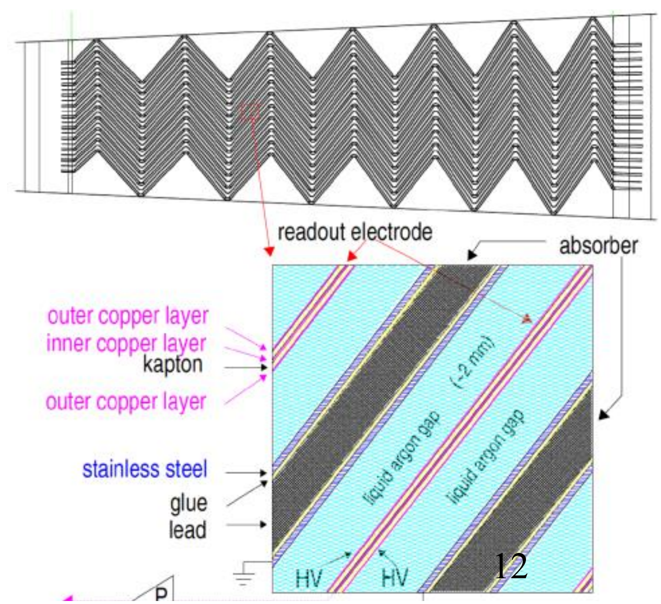
- ‘Accordion’ geometry Lar EM Barrel ($|\eta|<2.8$), inside solenoid / dipole

- Plastic-scintillator HCAL for e/h separation

- Finely segmented plugs (W, Pb, Cu) for compact showering, with Si sensors

- 25-50 X_0 and ~10λ throughout acceptance region



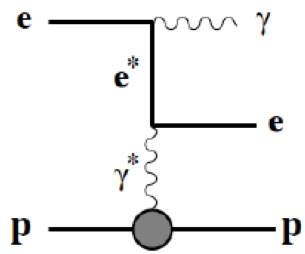


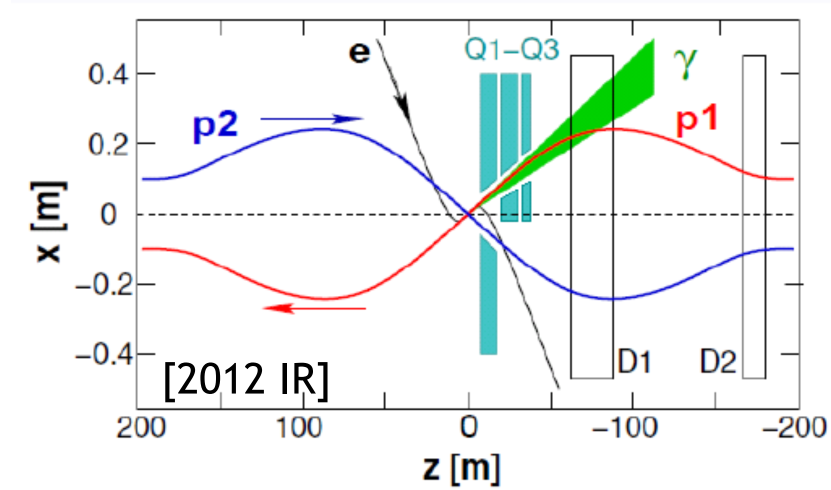
Baseline configuration		η coverage	angular coverage
EM barrel + small η endcap	LAr	$-2.3 < \eta < 2.8$	6.6° – 168.9°
Had barrel+Ecap	Sci-Fe	(~ behind EM barrel)	
EM+Had very forward	Si-W	$2.8 < \eta < 5.5$	0.48° –
EM+Had very backward	Si-Pb	$-2.3 < \eta < -4.8$	–179.1°

Beamline Instrumentation in CDR Update

<u>Outgoing electron direction:</u>

- Photoproduction e-taggers 14-62m and
- Photon detector at around 120m for lumi (Bethe-Heitler ep→epγ)



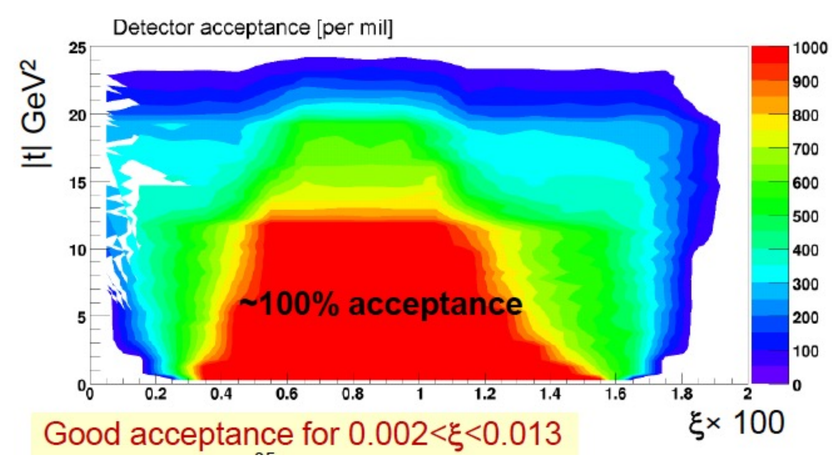


<u>Outgoing proton direction:</u>

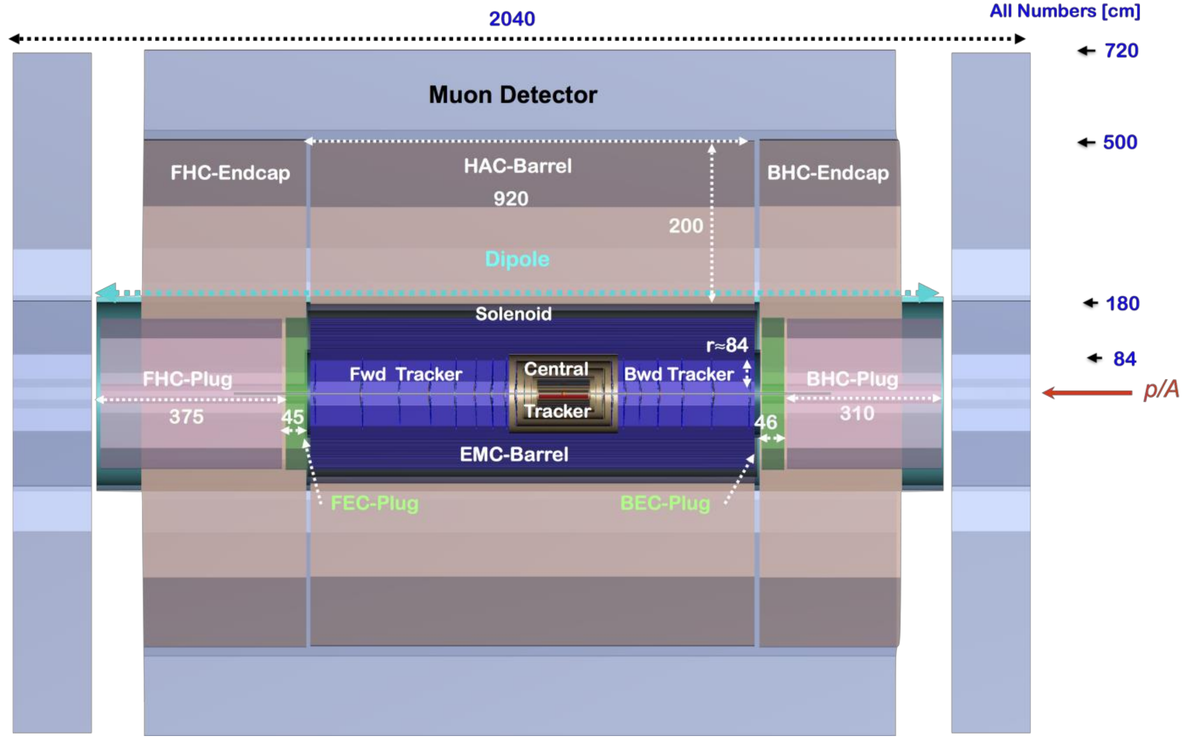
- Space for $\pm$30cm Si-W ZDC at 110m … could have highly segmented design similar to ALICE FoCAL

- Roman pot-based proton spectrometer at ~200m (as per ATLAS/CMS) → fractional proton energy-loss ξ~0.1
- Also at ~120m (new → ξ~0.2)
- Lowest x with 'FP420'-type insertion to cold region of beampipe at 420m?

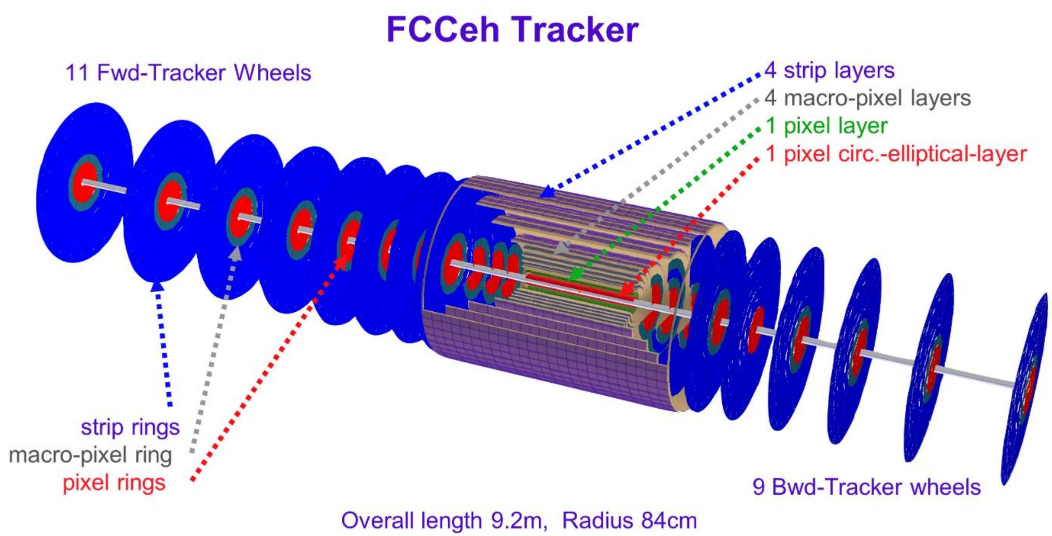
The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC



Modifications for 50TeV protons: FCC-eh



Current (limited!) design is scaled-up version of LHeC detector



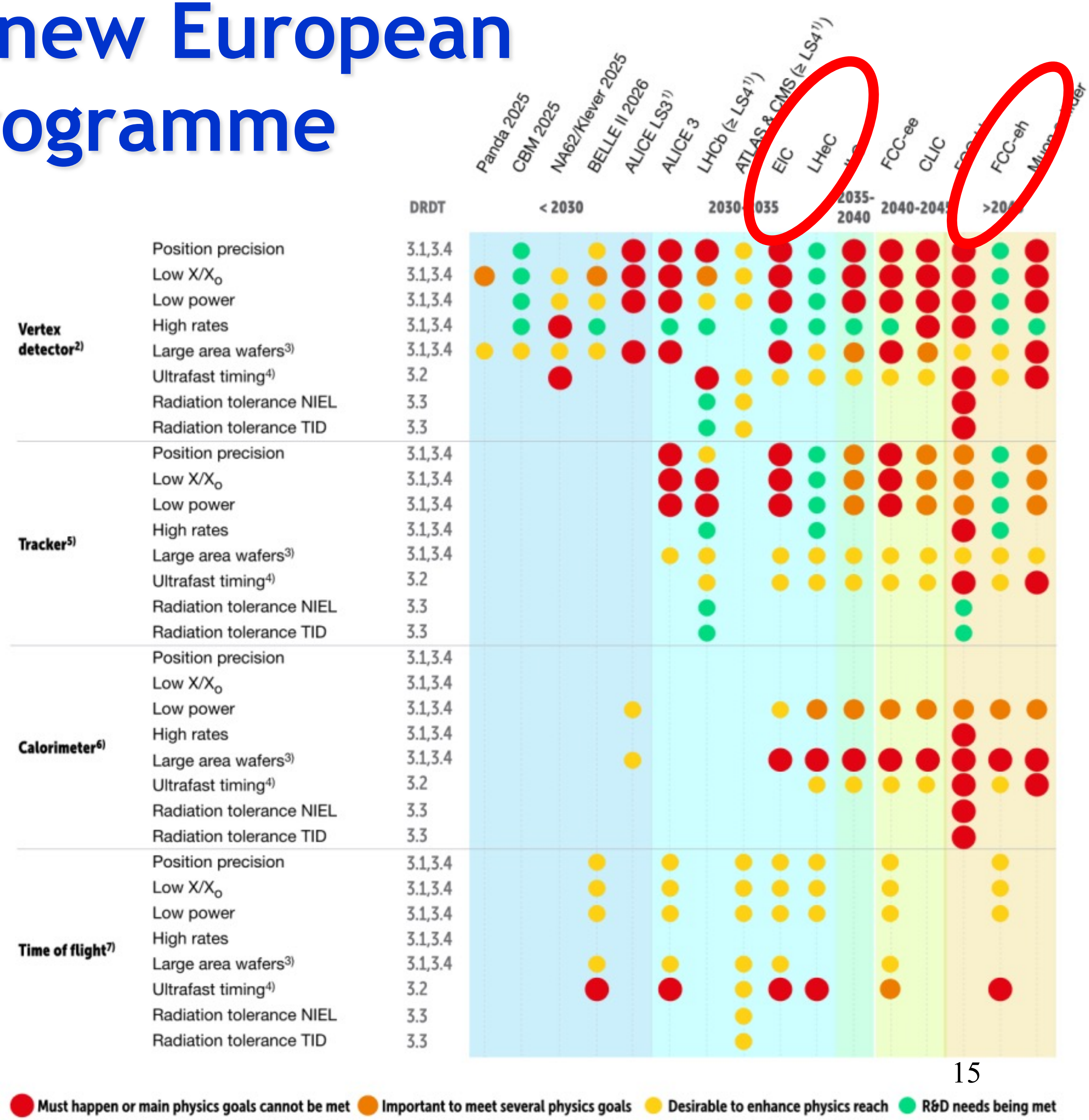
- Required calo depth scales logathmically … overall dimensions 20x7m retains 12-15 interaction lengths

- Longer tracker (~9m) to retain 1° acceptance … tilted wheels?

Mapping to new European DRD programme

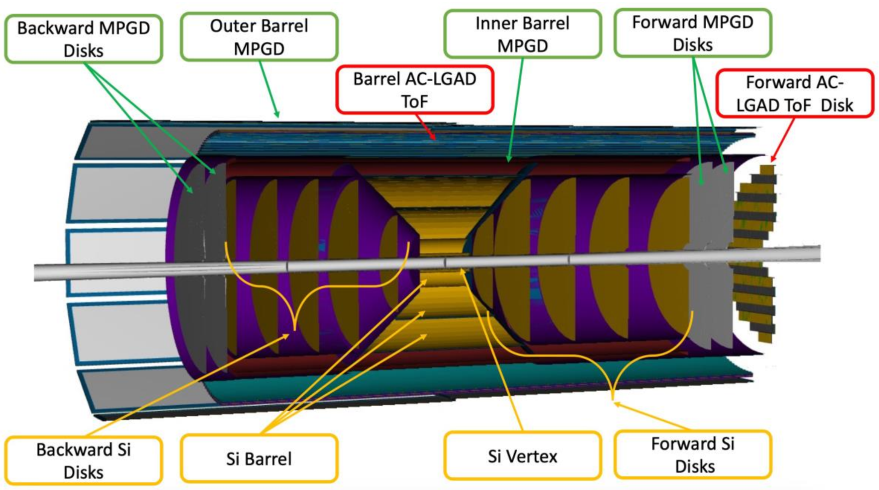
(From ECFA European R&D roadmap)

e.g. Solid State Devices

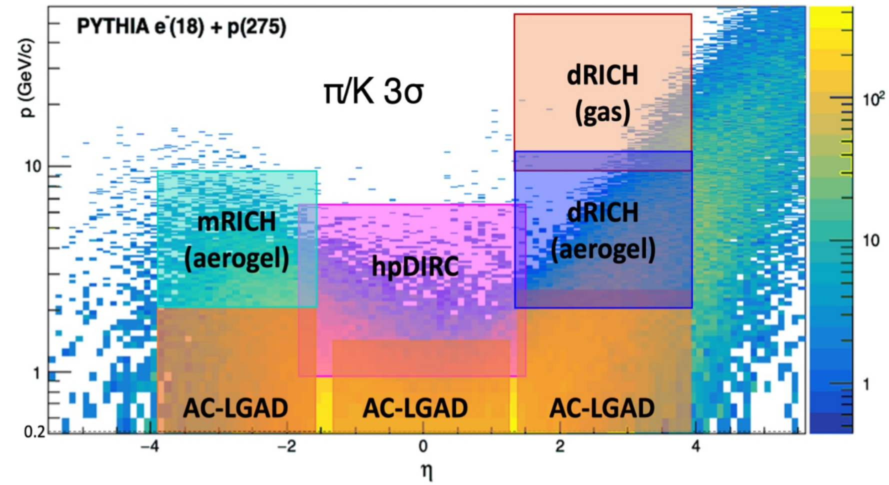


EIC Developments to Consider

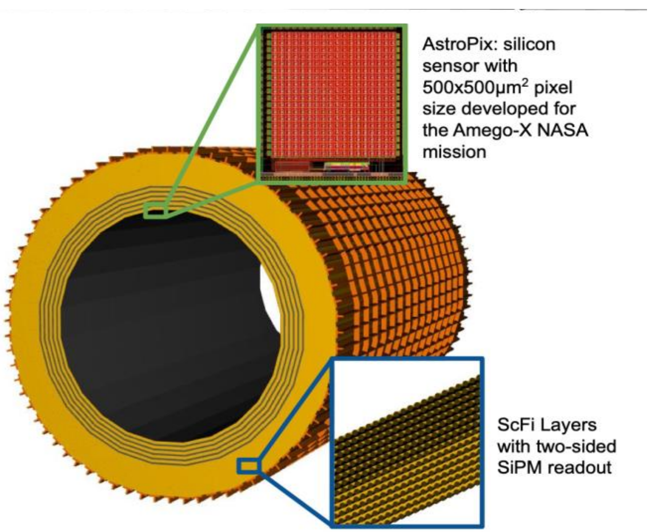
New Tracking Technologies: eg MPGDs?



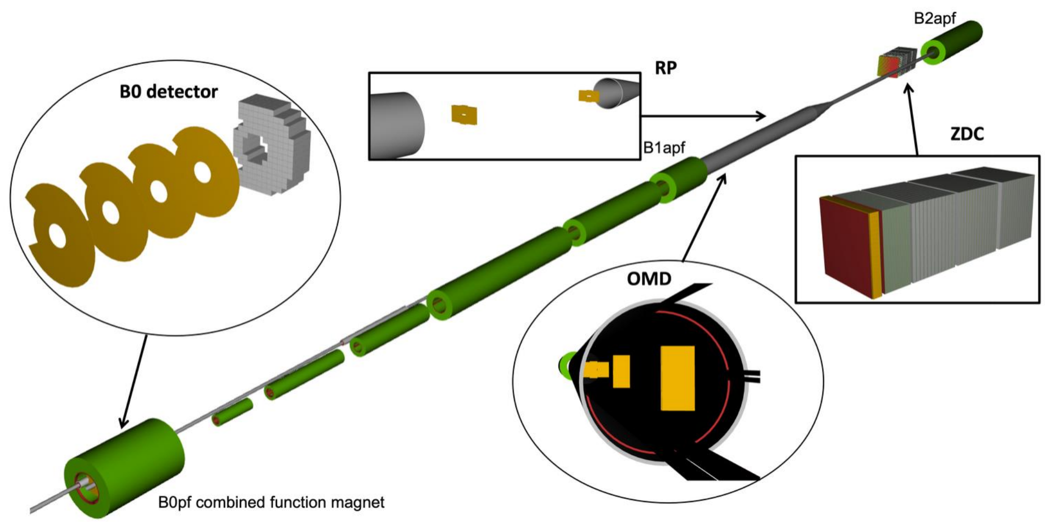
Include Particle ID?



Imaging eCAL?



Fully instrumented forward beamline



Some Open Topics

… including both consolidation and 'from scratch' addition of new capabilities

Design / simulation code base development

- Common framework to investigate (integrated) detector response

Detailed synchrotron radiation simulations

- Explore impact on inner regions more thoroughly

Optimising technology and layout of detectors near beamline

- Inner tracker technology / layout (Fluences? Sensor placement close to the beam)
- Forward / Backward instrumentation fully integrated with the IR design

Adding Particle ID capabilities (Cerenkov, TOF)

- (p_T / η) ranges / technologies to connect with EIC SIDIS and physics in AA
- Compromises with respect to other detector components?

Developing a Trigger / DAQ scheme

- Understanding the physics and background rates
- Obtaining a (triggered or streaming) concept for data acquisition

Reviewing aspects of the detector 'inherited' from ATLAS?

- Are calorimeter and muon designs really ideal for use in ep / eA?

LHeC versus FCC-eh

- Implications of higher energies … 'same again only bigger', or smarter?

A joint detector eh and hh detector?

- Technical challenges in simultaneously serving e-h and h-h studies
- Opportuities for cross-calibration and systematics reduction

“Circles in a circle”
Wassily Kandinsky (1923)
Philadelphia Museum of Art

SUMMARY

- LHeC / FCC-eh presents fresh instrumentation challenges

- ‘Technically possible’ LHeC design exists from CDR-update

- Extension to FCC-eh yet to be studied in detail

- Many opportunities for new innovation and connections …
    - Synergies with EIC detectors that approach reality
    - New technologies in European DRD programme & developments towards future energy frontier colliders

- Timescales for realisation may be long …
  … but the next European Strategy starts NOW

Self-subscribe to the WG mailing list: ep-eA-WG4-structure@cern.ch