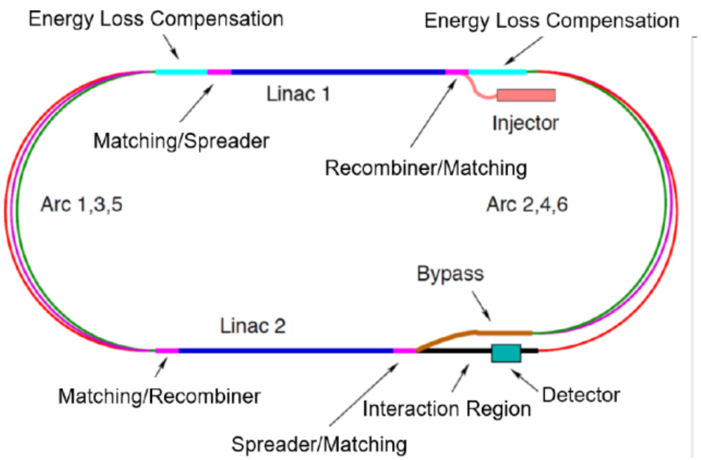
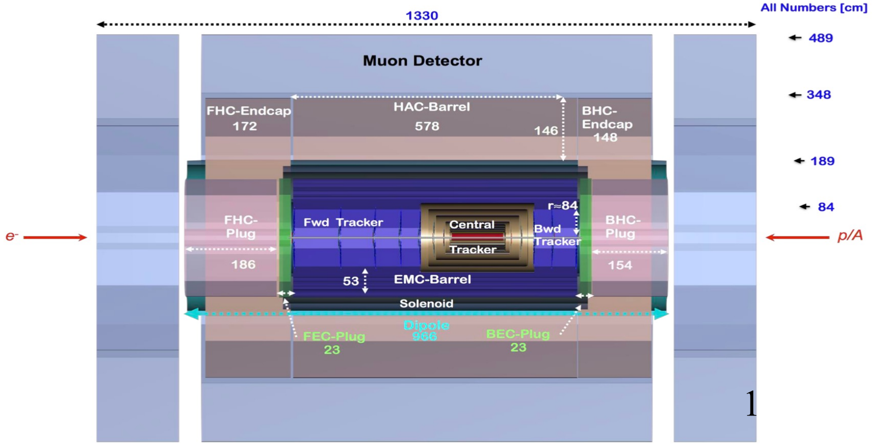
An Interaction Region and Detector for High Energy DIS at CERN

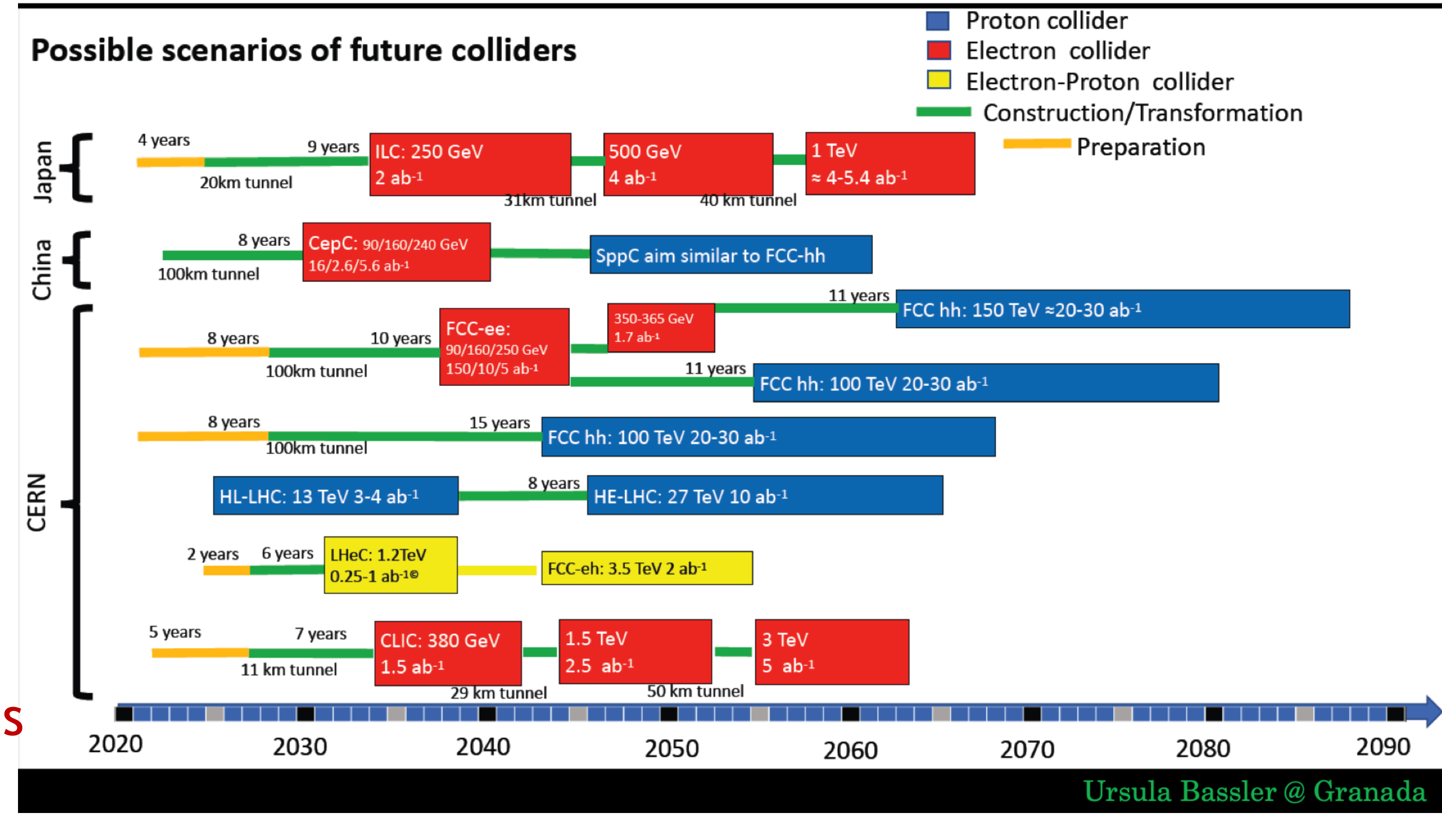
Paul Newman (Birmingham)
for the LHeC / FCC-eh study group

28 March 2023





Possible DIS Futures at CERN



- Energy frontier ep Physics (LHeC or FCC-eh) remains a possible future CERN direction

- Revised mandate:

Following the publication of the updated CDR, CERN continues to support studies for the LHeC and the FCC-eh as potential options for the future and to provide input to the next Update of the European Strategy for Particle Physics.

- Revised leadership: Jorgen d'Hondt takes over coordination following Max Klein's retirement.

Material

2008 2009 2010 2012 2014 2015 2017 2018 2019 2022

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

The Large Hadron-Electron Collider at the HL-LHC

LHeC and FCC-he Study Group

- 10 dedicated workshops over 15 years
- Original LHeC CDR (2012)
- Updated CDR (2020), motivated by:
  - → Physics landscape (eg Higgs discovery)
  - → Accelerator design optimization,
    - … Lumi: 10^{33} $cm^{-2}s^{-1}$ → 10^{34} $cm^{-2}s^{-1}$
    - … Lepton energy 60 → 50 GeV
  - → Technology advancement

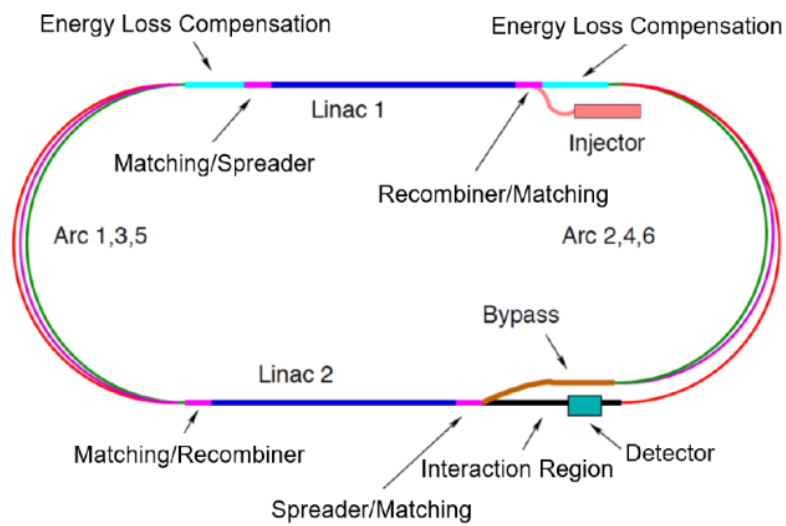
Material here is a mixture of the revised CDR and subsequent developments

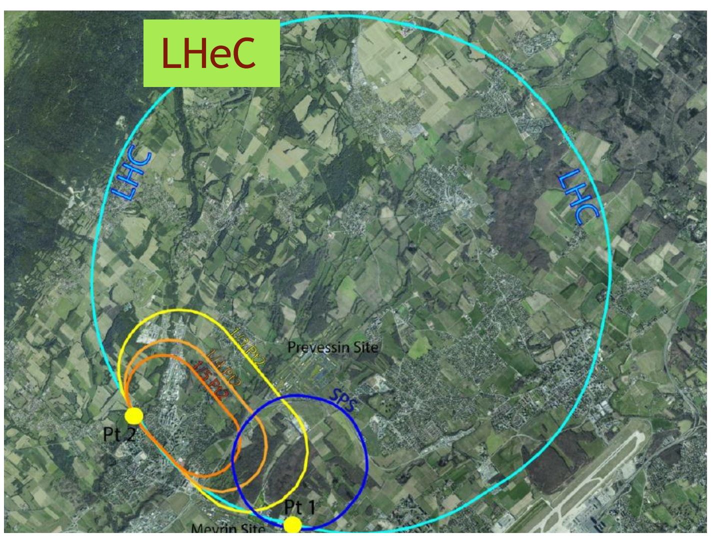
Baseline: Electron Energy Recovery Linac

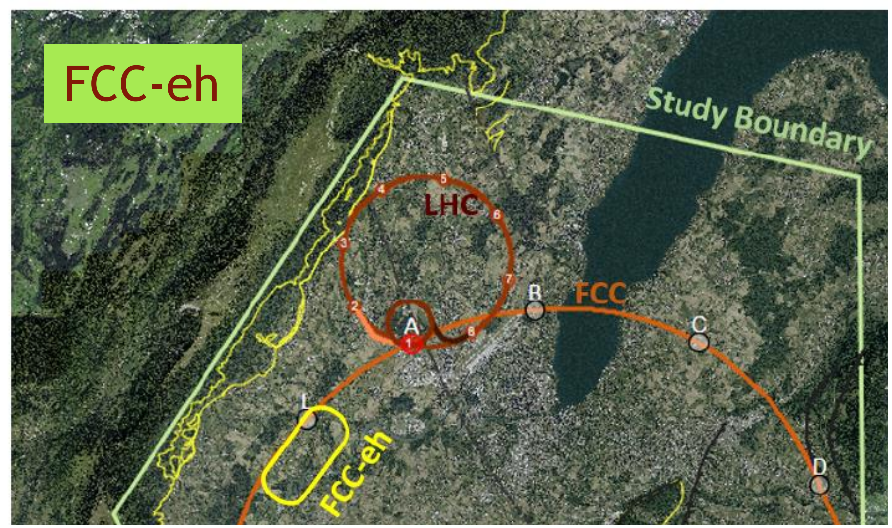
- Power consumption constraint (< 150 MW) and need for high luminosity imply energy recovery for electrons

- With 20 MV/m acceleration, 5.4km racetrack well matched 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)

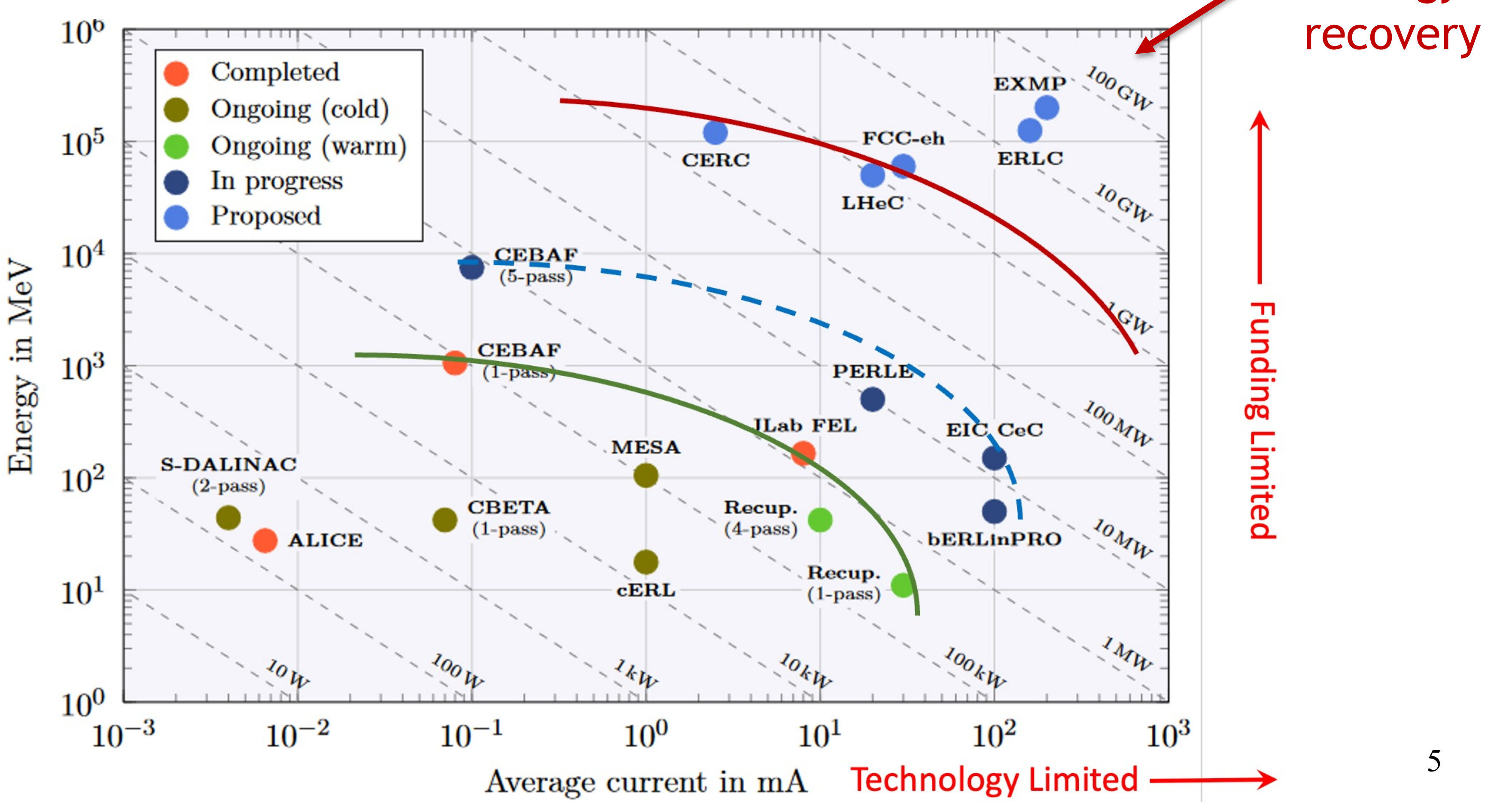




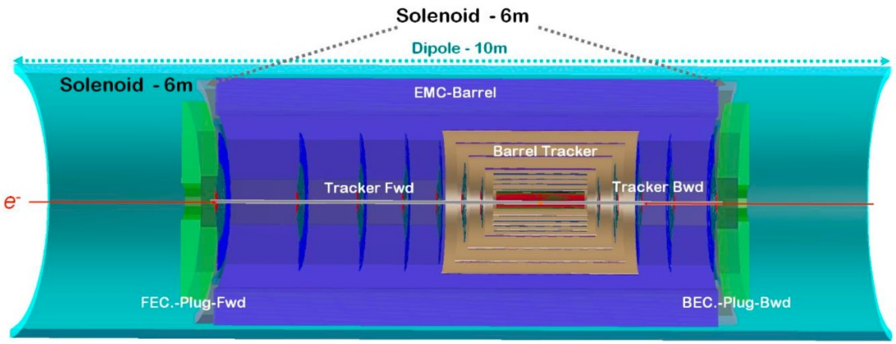


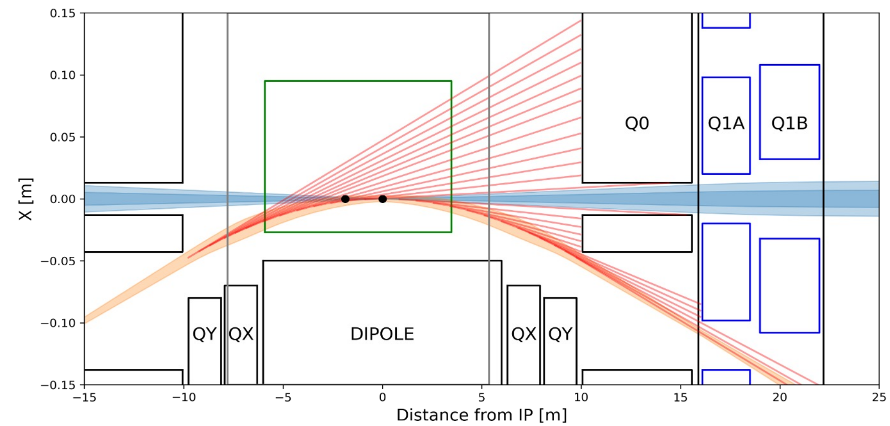
Developing Energy Recovery Linacs

PERLE prototype (Orsay) is critical path towards LHeC technical realisation

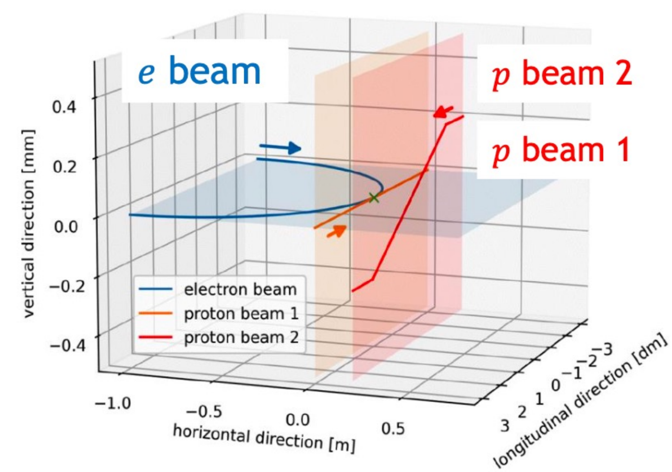


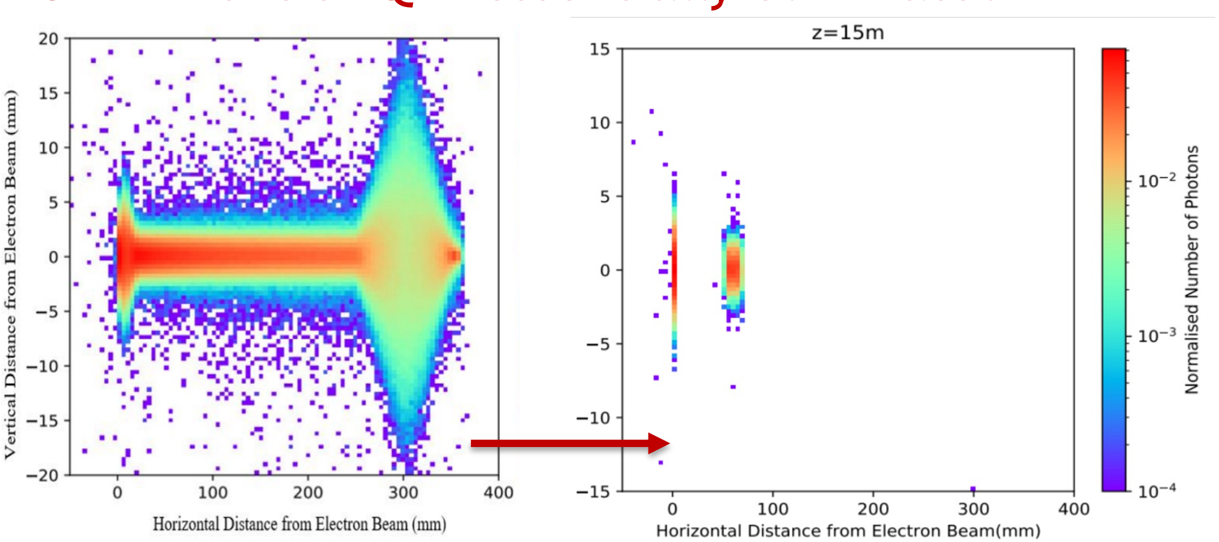
Interaction Region & Synchrotron Fan



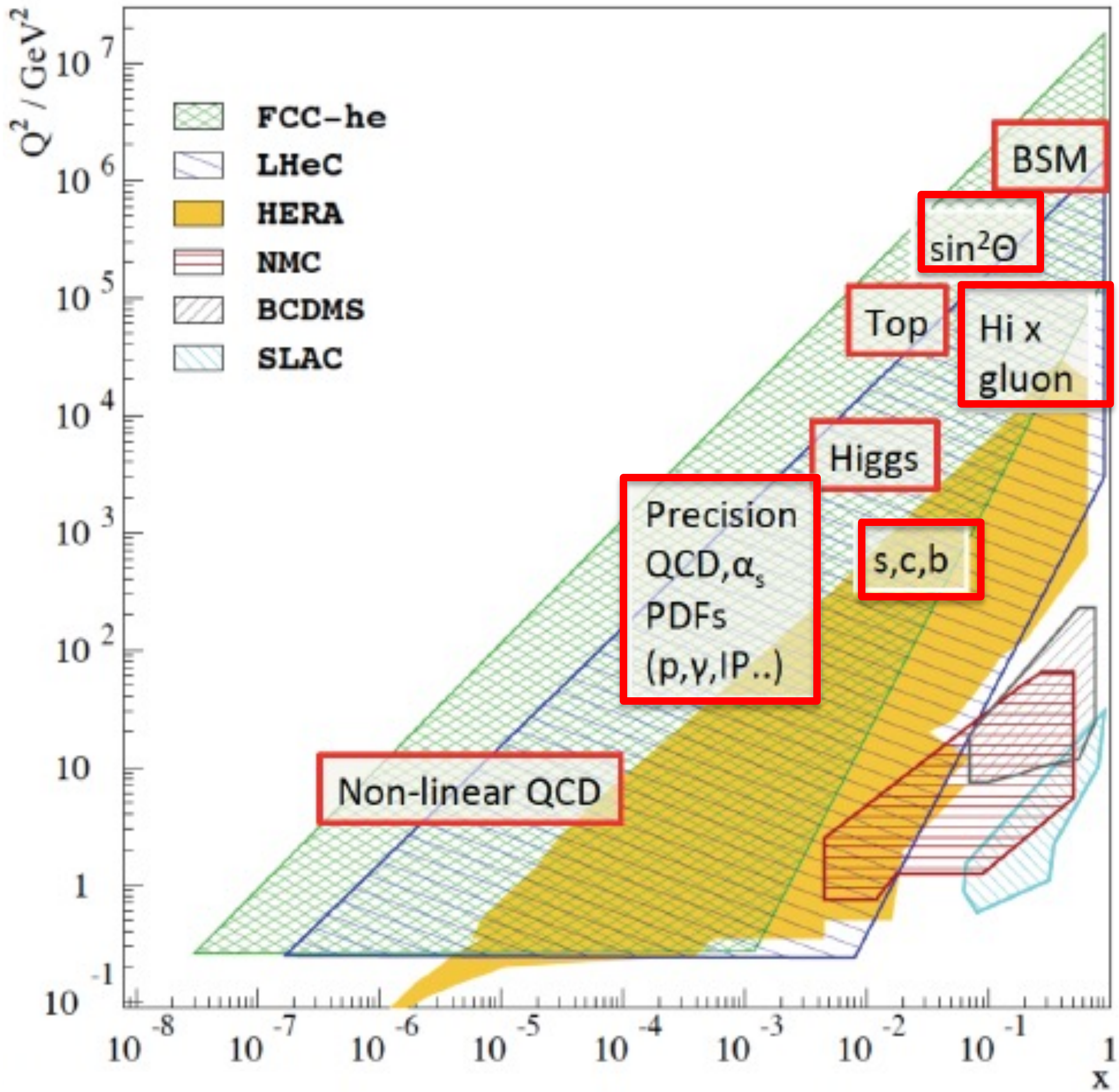


- Dipole magnets bend electrons to head-on collisions with p-beam-1
- p-beam-2 carried in a different plane
- Elliptical beampipe initially accommodates synchrotron radiation fan
- Synchrotron mitigated with 3 collimators and the Q0 normal conducting quadrupole.
- SR in front of Q1A essentially eliminated





Physics Targets and their Detector Implications



Standalone Higgs, Top, EW, BSM programme

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

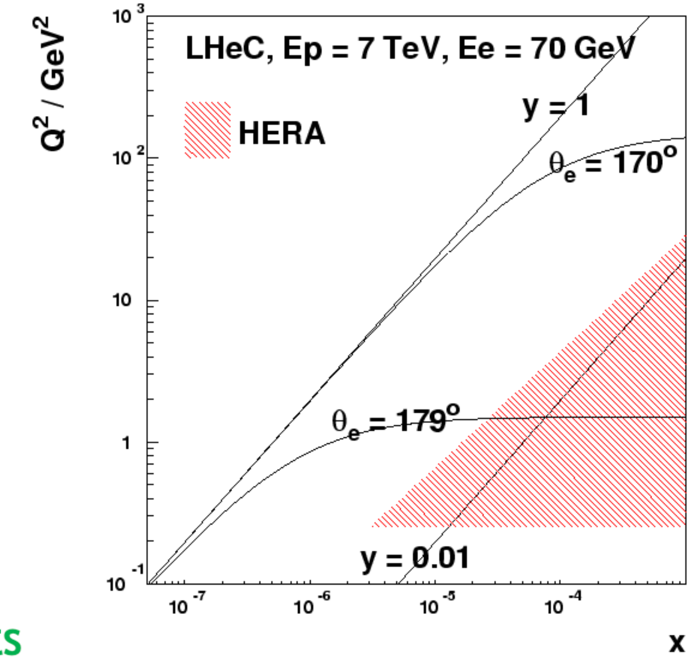
Precision proton PDFs, including very low x parton dynamics in ep,eA

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

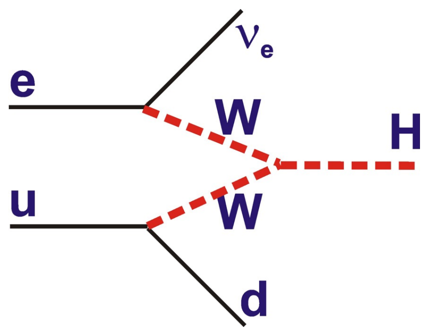
Complementarity with EIC in physics scope, timescale and technologies.

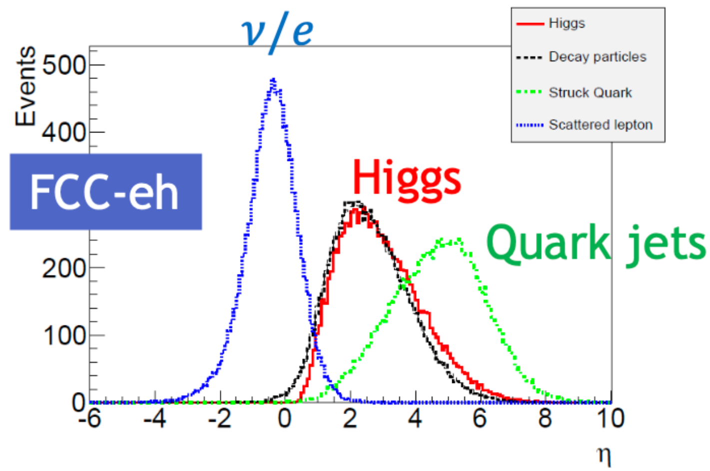
Example Acceptance Requirements

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

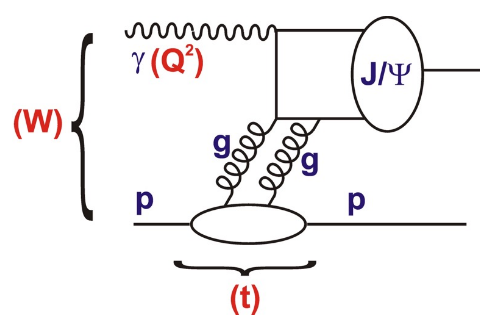


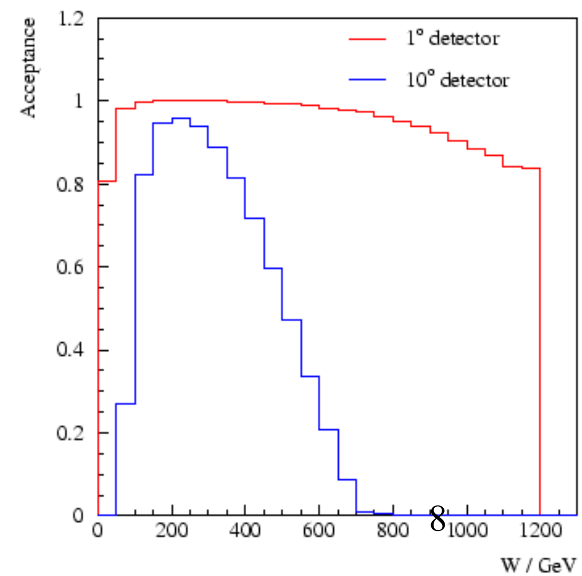
- Higgs production dominated by forward jet configurations





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





Detector Overview

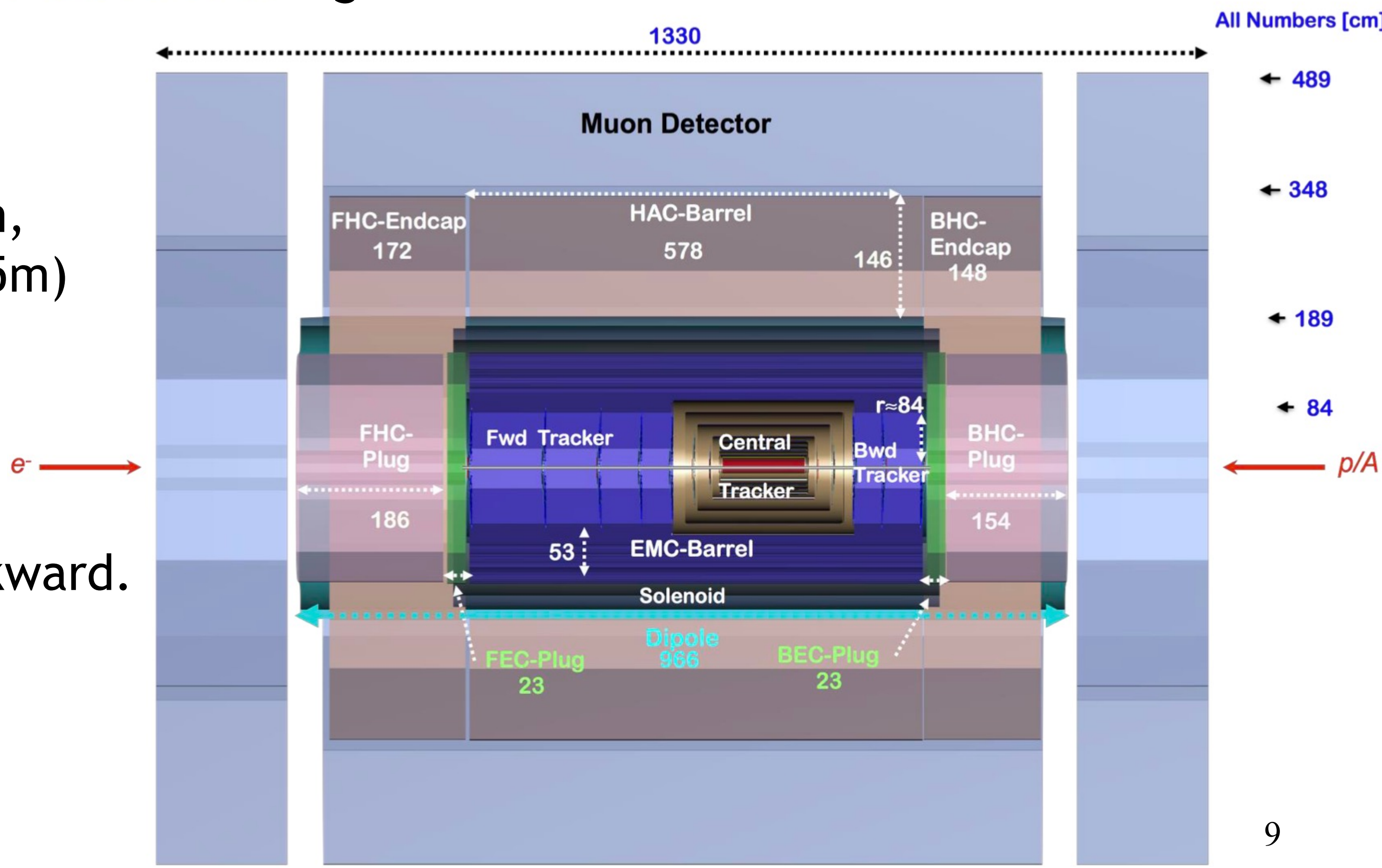
- Detector technologies are evolving fast → current designs can only be indicative, and borrow heavily on LHC upgrades (especially ATLAS)

- Conditions are relatively 'easy' → tiny fluences compared with HL-LHC and pile-up ~ 0.1 is 3 orders of magnitdude smaller

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

Hermetic
1° tracking acceptance forward & backward. Beamline well Instrumented

Modular



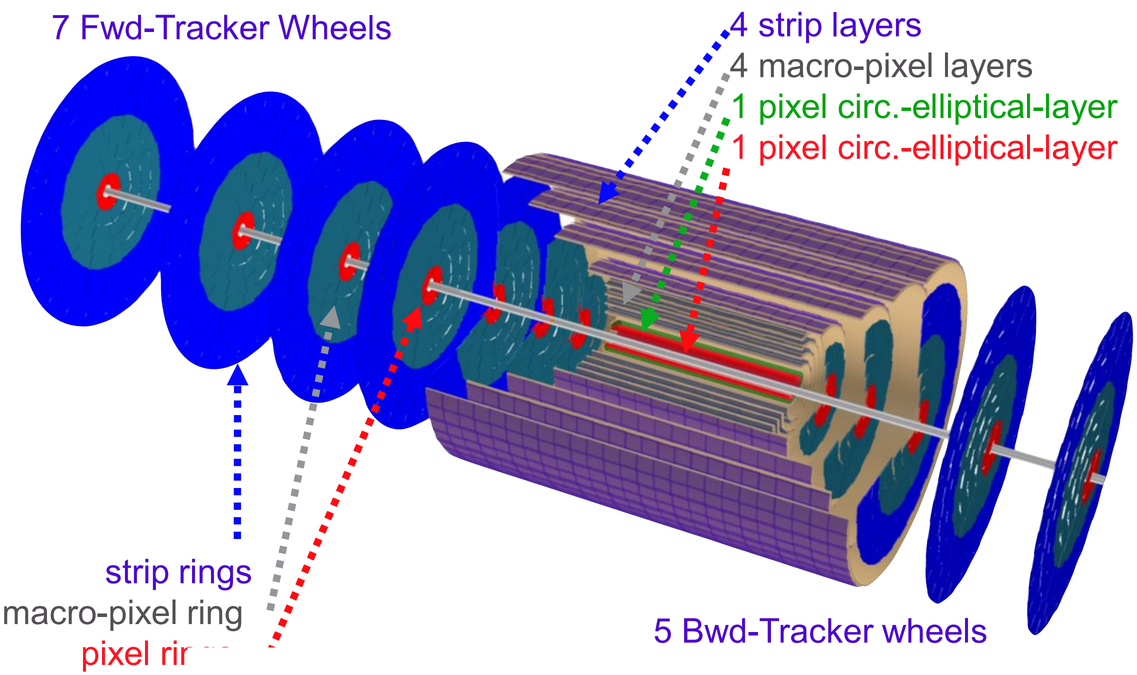
Central Tracker

- All silicon

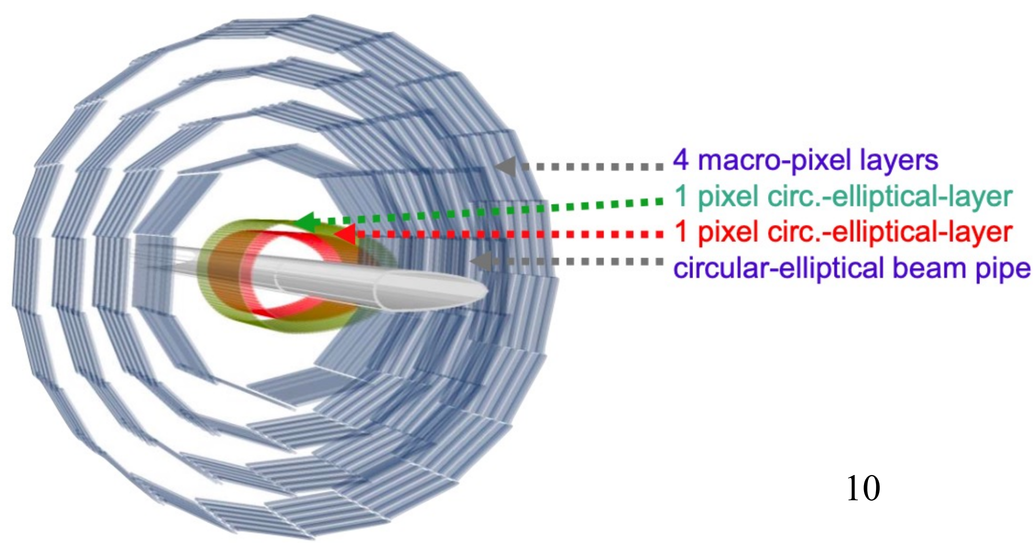
- HV-CMOS MAPS technology is low material (0.1mm) and cost-effective

- Bent / stitched wafers for inner layers (as ALICE and ePIC)

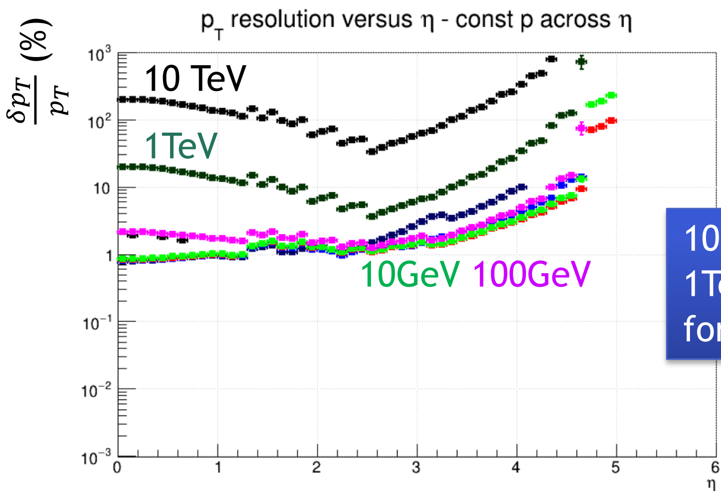
- Semi-elliptical inner layers



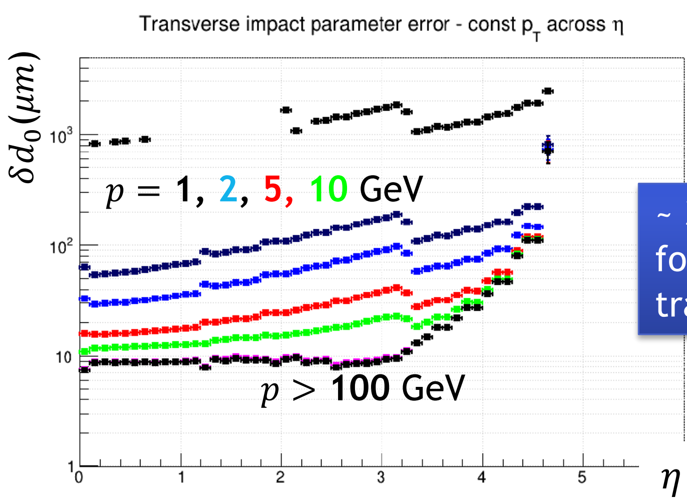
Pitch (μm)	$r\phi$	z
pixel	25	50
macro pixel	100	400
strip	100	10-50mm



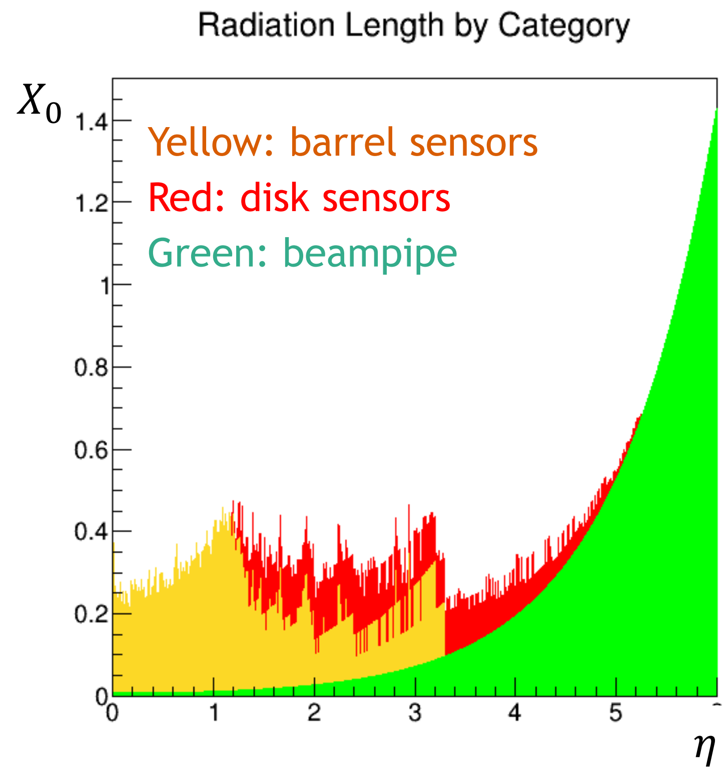
Tracking Performance



100MeV - 100 GeV: 1-3%
1TeV: 5-30%
for $\eta < 4$



~ 30 μm resolution
for high momentum
tracks at $\eta \sim 4$



- Material budget is ~20% of a radiation length up to η~4.5

- p_T and impact parameter resolutions (from tkLayout) show high performance over wide η range.

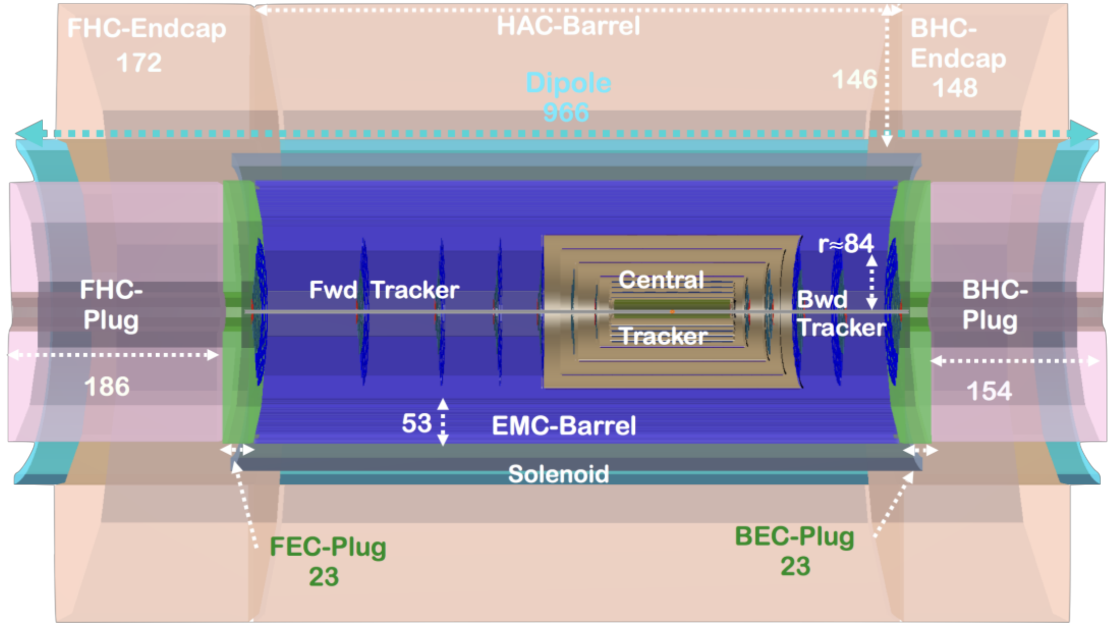
Calorimetry

- High performance ‘accordion’ geometry EM Barrel ($|\eta|<2.8$), inside solenoid / dipole

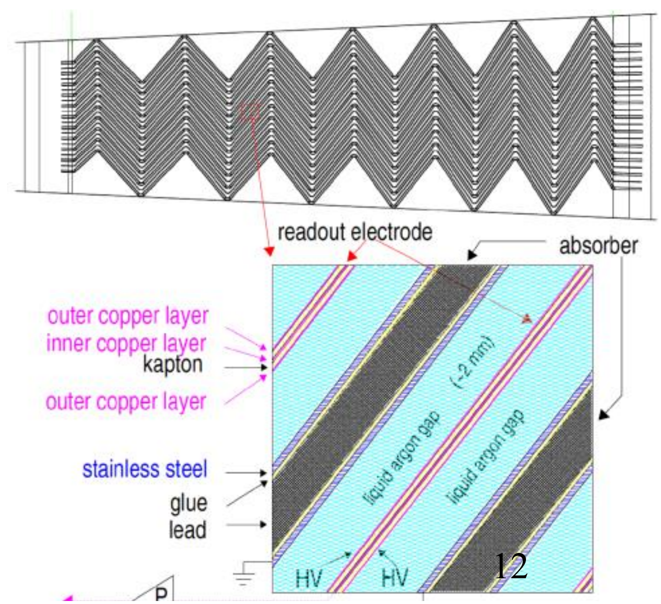
- Plastic-scintillator HCAL for e/h separation

- 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°



Barrel ECAL Performance

GEANT4 response to electrons at normal incidence

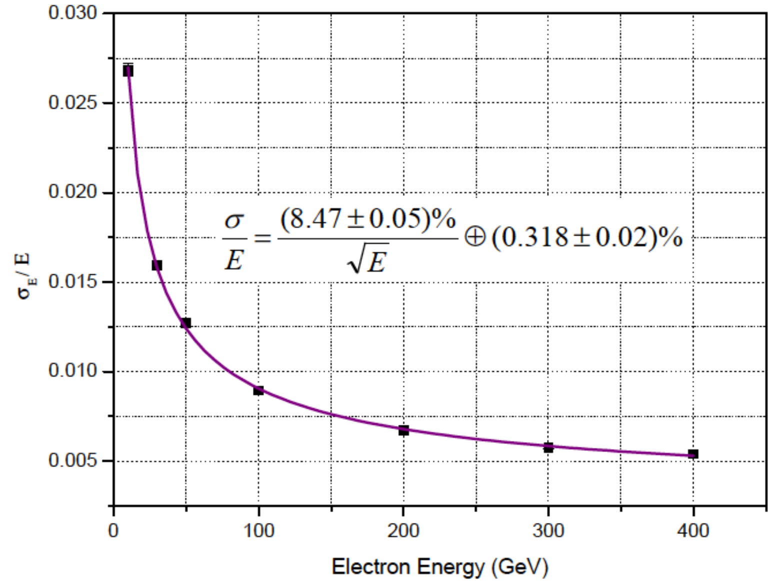
- Benchmarked against ‘warm’ alternative Sci-Pb design

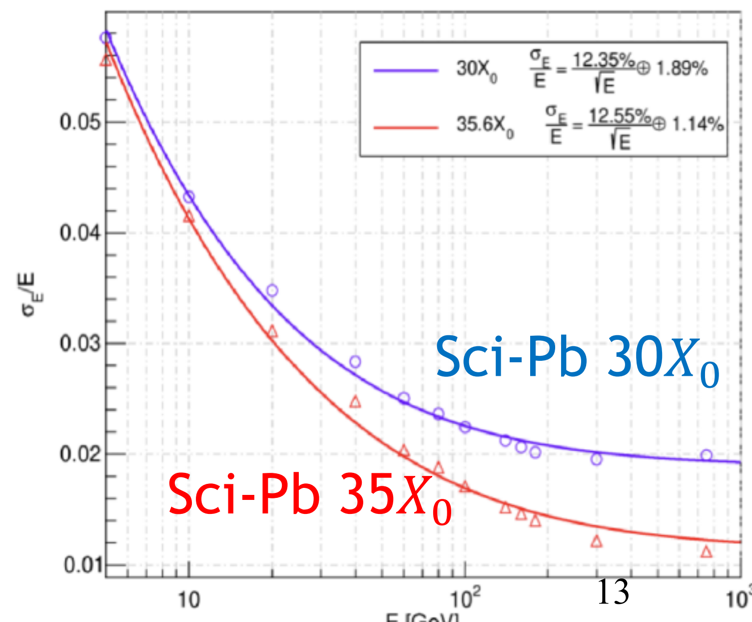
LAr ($\sim 25X_0$)	$8.47/\sqrt{E} \oplus 0.32\%$
Sci-Pb ($30X_0$)	$12.55/\sqrt{E} \oplus 1.89\%$

[cf ATLAS: 10%/√E + 0.35%]

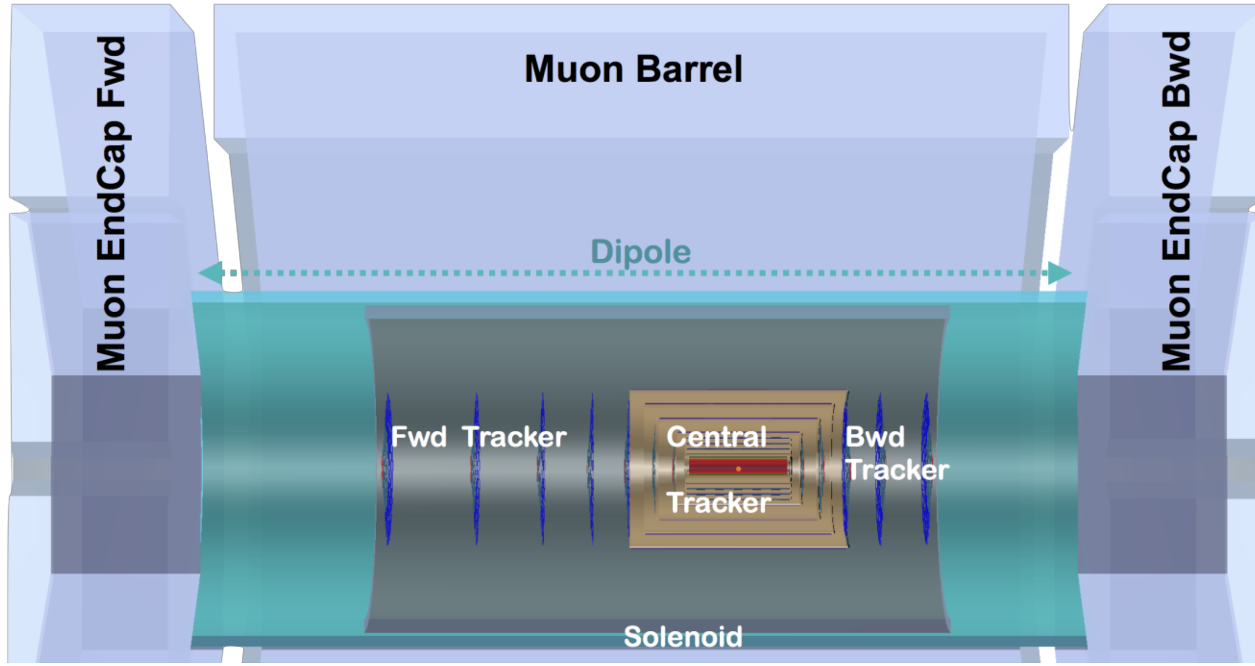
- Comparable resolution

- Cold Lar version currently preferred (segmentation, radiation stability …)





Muons



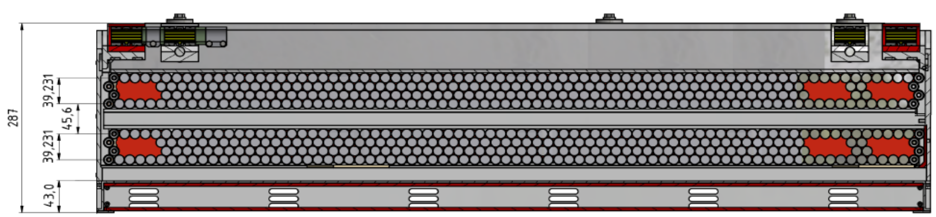
No dedicated outer magnetic field currently forseen

→ Momentum measurement in central tracker.

→ Outer muon detectors for tagging / triggering

HL-LHC technologies are more than adequate

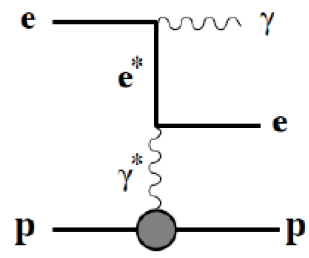
→ Multiple layers of thin RPCs (1mm gas gap) for fast response & small (1.5cm diameter) MDTs for spatial precision

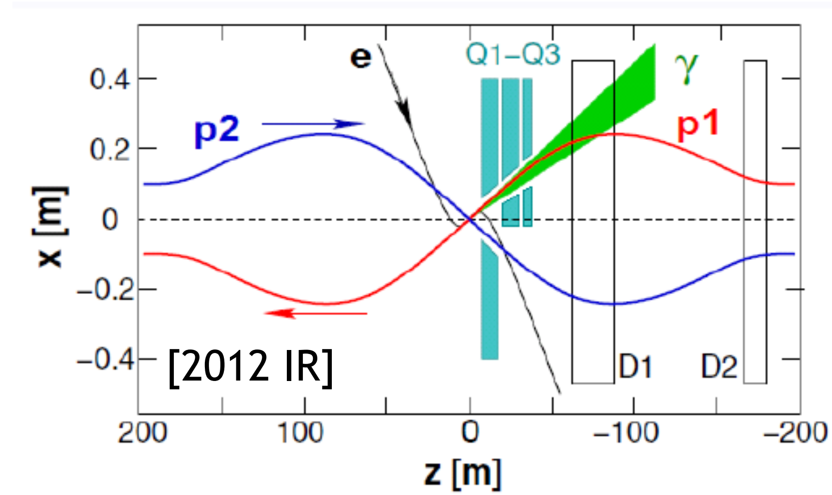


ATLAS Phase-I RPC-MDT assembly

Beamline Instrumentation

<u>Outgoing electron direction</u> contains photoproduction e-taggers 14-62m and photon detector at around 120m for lumi measurement via Bethe-Heitler

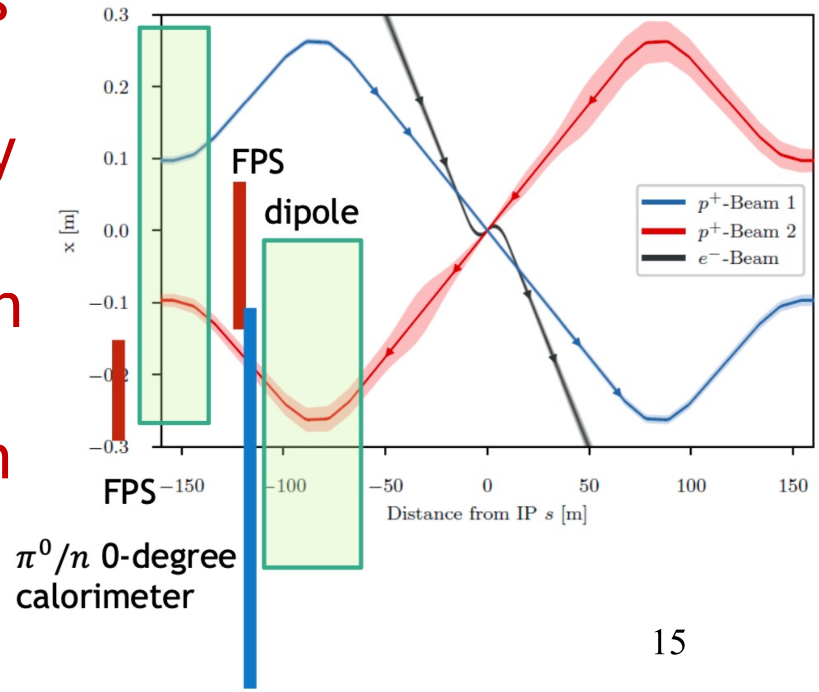




<u>Outgoing proton direction</u> includes Roman pot-based FPS around 200m (as per ATLAS/CMS) and additionally (for higher ξ) around 120m.

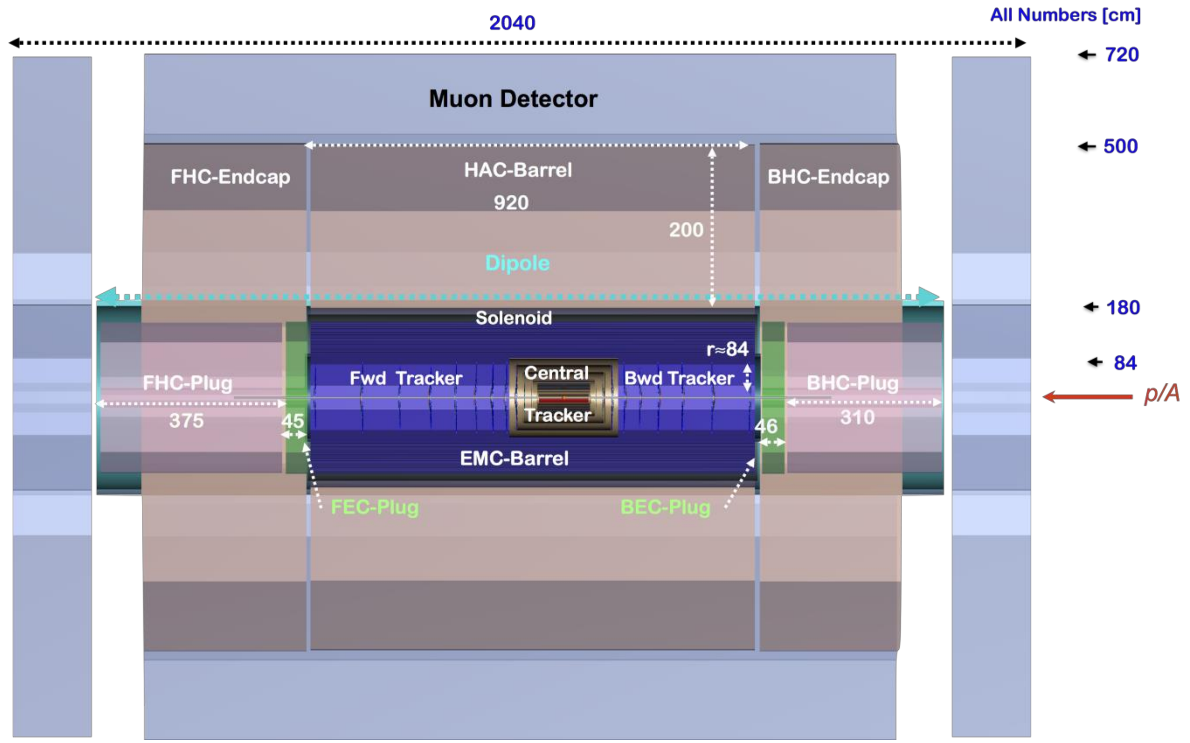
- Possibly lower ξ from FP420 design

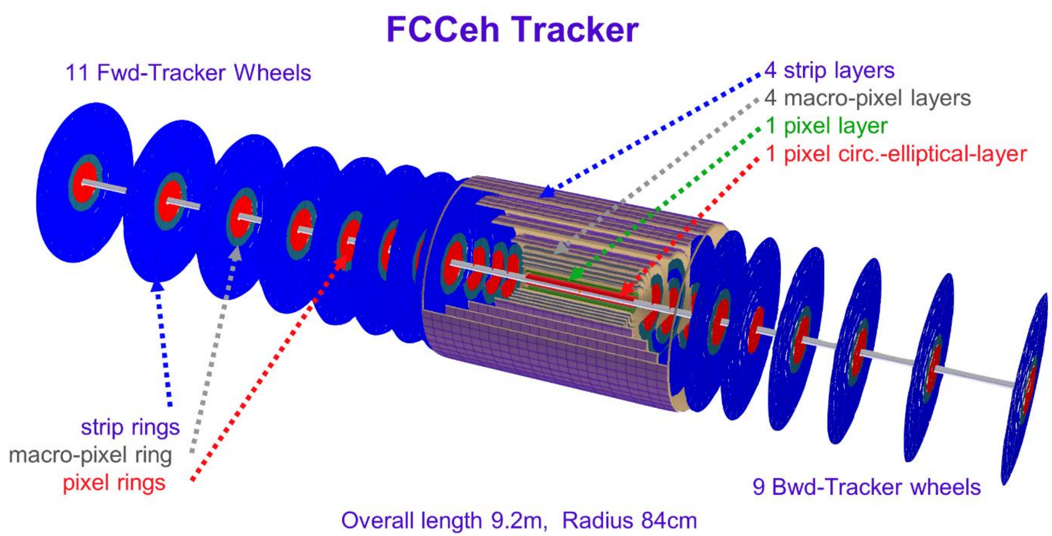
Si-W Zero Degree Calo around 110m could have highly segmented design similar to ALICE FoCAL



Modifications for 50TeV protons: FCC-eh

No big changes in technology choices are necessary





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

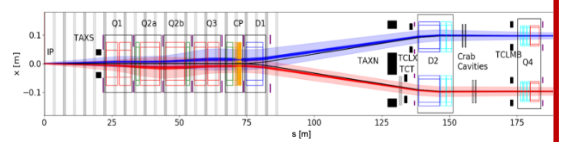
- Longer tracker (~9m) to retain 1^{o} acceptance … tilted wheels?

A Combined ep, eA, pp, pA, AA Interaction Point?

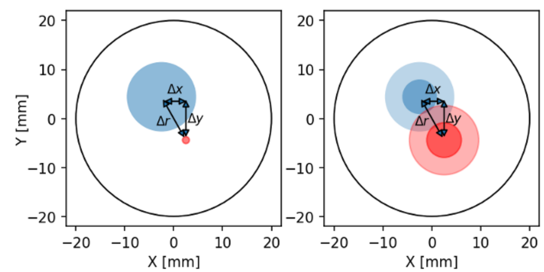
- Combine eh & hh functions at IP2 in latter stages of HL-LHC, or at FCC?
- Feasibility study of proton beam optics and machine-detector interface.

Combined hh|eh interaction region

- Based on HL-LHC optics and lattice design, the **two proton beams must be housed in the same quadrupole aperture** unlike the past LHeC proton interaction design.
- Horizontal separation at the IP and vertical crossing angle to avoid parasitic interactions.
- The second proton beam should have a **flexible optics design**:
  - a **relaxed optics design, during eh operation**, as it acts as a spectator beam with an “injection like optics”,
  - a **collision optics design, during hh operation**, to realise the HL-LHC luminosity
- Tradeoff between quadrupole aperture and achievable beam size at the IP for both eh and hh configurations.



LHC proton beam trajectories from the IP to the matching quadrupole Q4



Relaxed (left) and collision optics (right) in a quadrupole aperture

Slide from K. Andre’ (CERN)

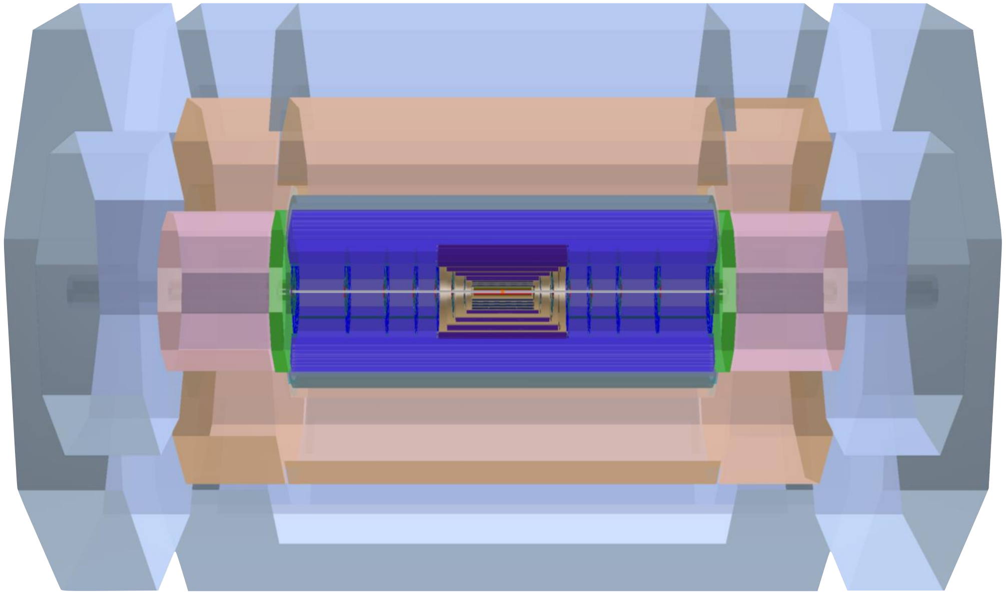
https://indico.ijclab.in2p3.fr/event/8623/

Technically promising. Requires symmetrised detector

Adapting LHeC / FCC-eh detector for hh

- Symmetrise detector by mirroring forward half … retains eh performance and would already be suitable for many hh tasks

- Tracker radiation hardness would need to be reassessed



- Some CALO re-optimization required at boundaries

- Dedicated particle ID detectors (ToF / Cerenkov) may be needed for ALICE-like programme

- Rethink would be needed for beamline detectors

- Enhanced ep calibration opportunies (hadrons v electron) would benefit hh programme!

Summary

- LHeC / FCC-eh presents different challenges from other LHC detectors (low fluence, low pile-up …)

- Updated CDR & subsequent work refined LHeC detector design
  → Low material MAPS-based silicon tracker
  → Hermetic and granular calorimetry
  → Muon system and beamline instrumentation

- Modified versions meet the needs of FCC-eh and possibly hh

Related Talks at DIS'23

- Status of PERLE (Robert Rimmer, Tues 16.50)
- Overview and BSM physics (Nestor Armesto, Wed 11.50)
- Proton structure / precision QCD (Francesco Giuli, Thurs 17.10)
- Diffraction / forward physics (Anna Stasto, Thurs 17.30)
- High energy QCD and eA (Claire Gwenlan, Thurs 17.50)