

The Updated LHeC Detector

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40th International Conference on High Energy Physics

31 July 2020

Prague, Czech / Online

Scope of this talk

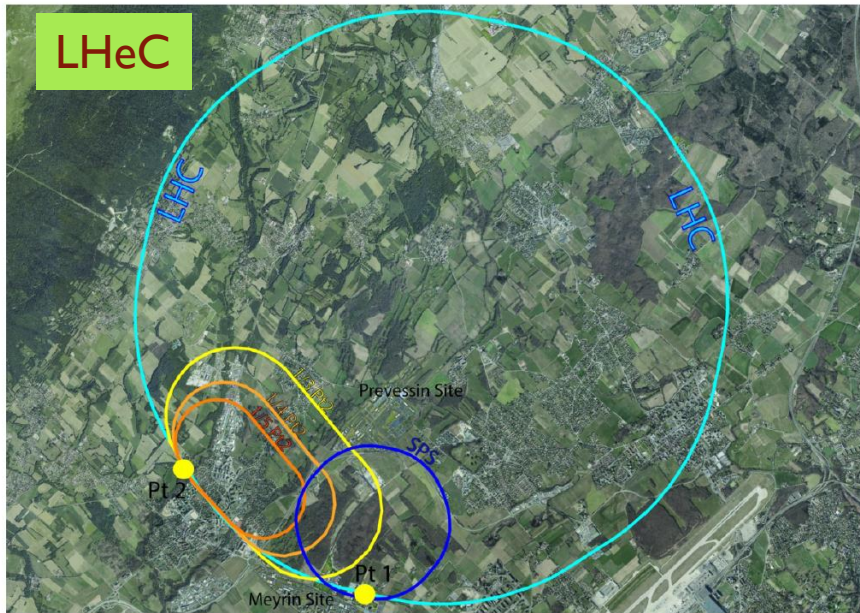
- Detector designs for future highest-energy ep/eA colliders
 - very detailed studies in LHeC CDR 2012
[LHeC Study Group, 2012 J. Phys. G: Nucl. Part. Phys. 39 075001](#)
 - for FCC-eh detector in FCC CDR vol. 3 [EPJ Special Topics 228, 755–1107\(2019\)](#)
- CDR update in 2020 (<https://arxiv.org/abs/2007.14491>) motivated by:
 - Accelerator design optimisation (ERL 60 → 50 GeV, higher lumi etc.)
 - Physics (e.g. Higgs)
 - Technology advancement + variation

Contents

- Introduction: detector for highest energy ep/eA collisions
- Detector update in CDR 2020
 - IP and detector magnets / Tracker / Calorimetry / Muon / Forward detectors
 - Extension to FCC-eh

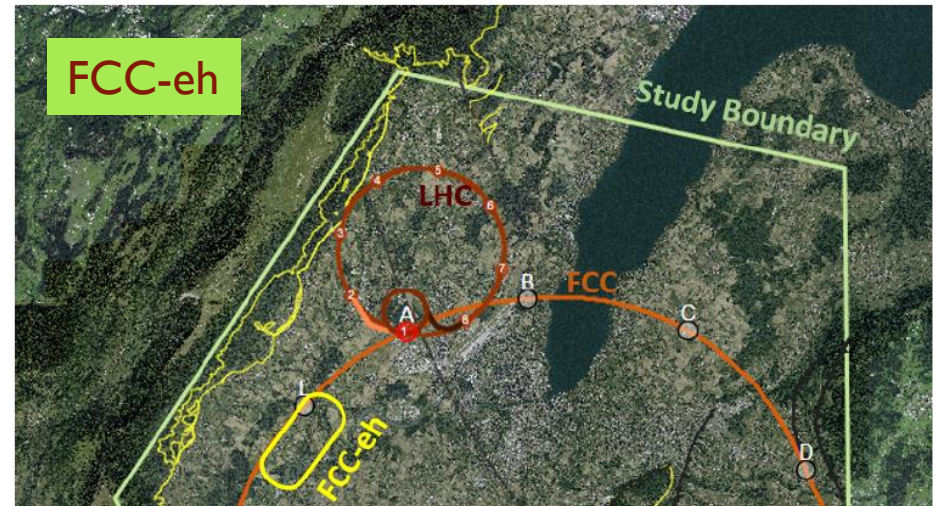
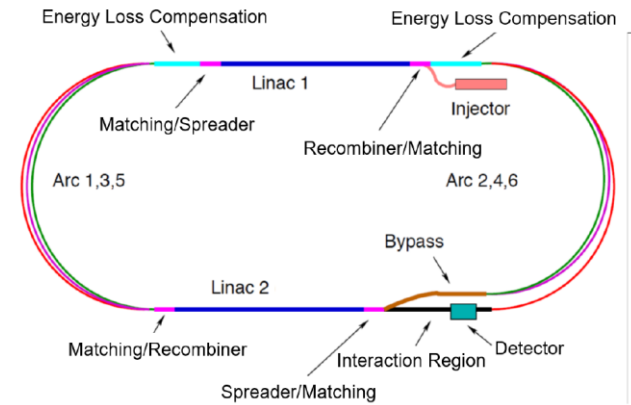
The LHeC and FCC-eh accelerators

- Electrons from dedicated Energy Recovery Linac
- Hadrons from LHC/FCC rings



50 GeV(e) × 7 TeV (p) 2.76 TeV/nucl. (A)

- $\sqrt{s} = 1.18$ (p) or = 0.74 (A) TeV
- $10^{33} - 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Electrons via 3-track ERL
~1/4 of LHC circumference

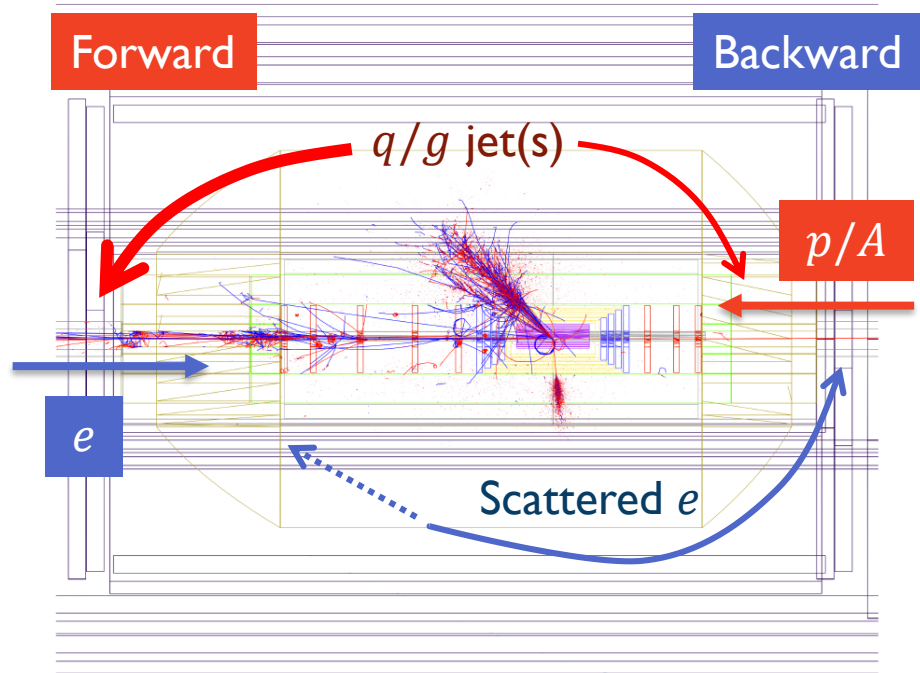


60 GeV(e) × 20 – 50 TeV (p)
7.9 – 19.7 TeV/nucl. (A)

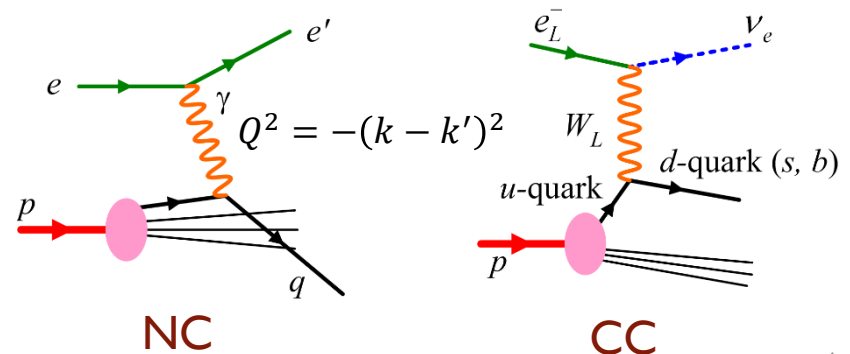
- $\sqrt{s} = 2.2 - 3.5$ (p) or 1.4 – 2.2 (A) TeV
- $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Processes & Challenges at LHeC/FCC-eh

- Neutral current (NC) $ep \rightarrow eX$
 - Scattered electron (e) towards small angle ($< 179^\circ$) to access low- Q^2 events
 - Hadron (X) forward-going jets from high- x events AND from QCD radiation
 - Flavour tagging for decomposing parton-density functions
 - Charged current (CC) $ep \rightarrow \nu X$
 - missing p_T : need hermetic detector* small beam holes ($< 1^\circ$) + good calorimeter energy resolution
- * also important for cross-calibration

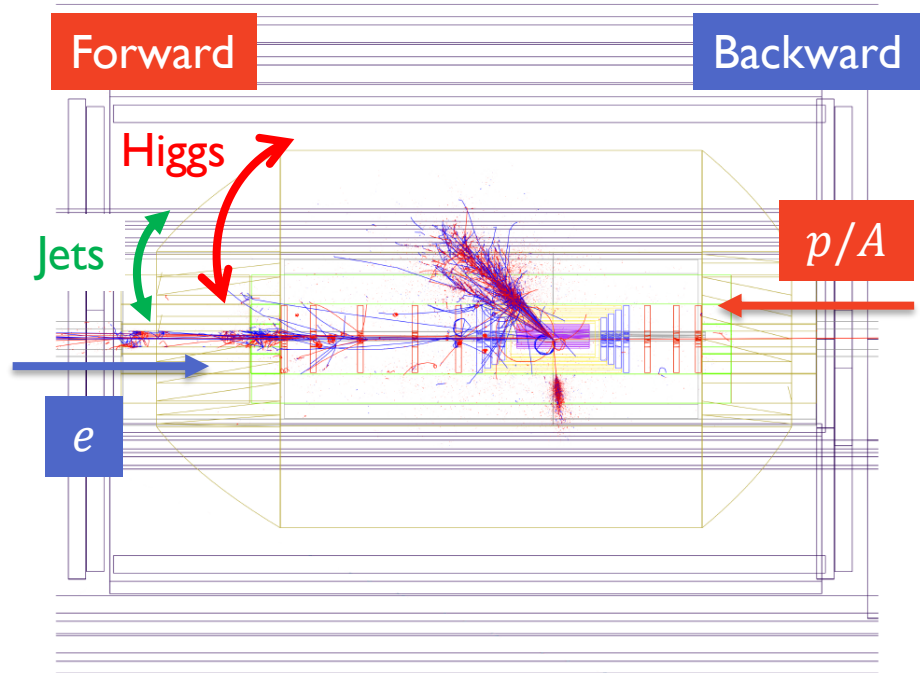


A NC (leptoquark) event



Processes & Challenges at LHeC/FCC-eh

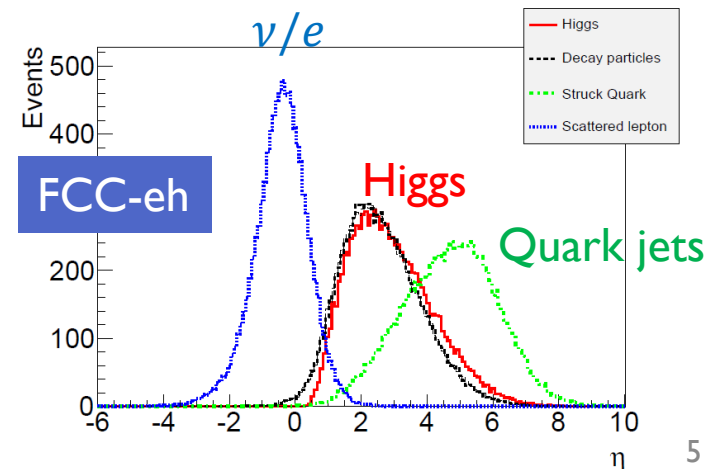
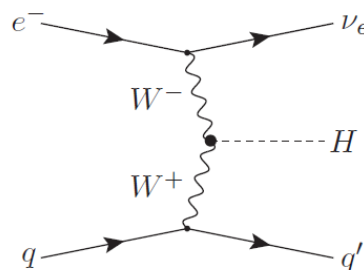
- Higgs couplings
 - Thru WW fusion in CC: forward “VBF jet”
 - Precise coupling to $b\bar{b}$, $c\bar{c}$, and $\tau\tau$:
 - Flavour tagging in forward direction
 - Jet resolution for mass reconstruction



- EW and top physics
- QCD studies (soft and hard)

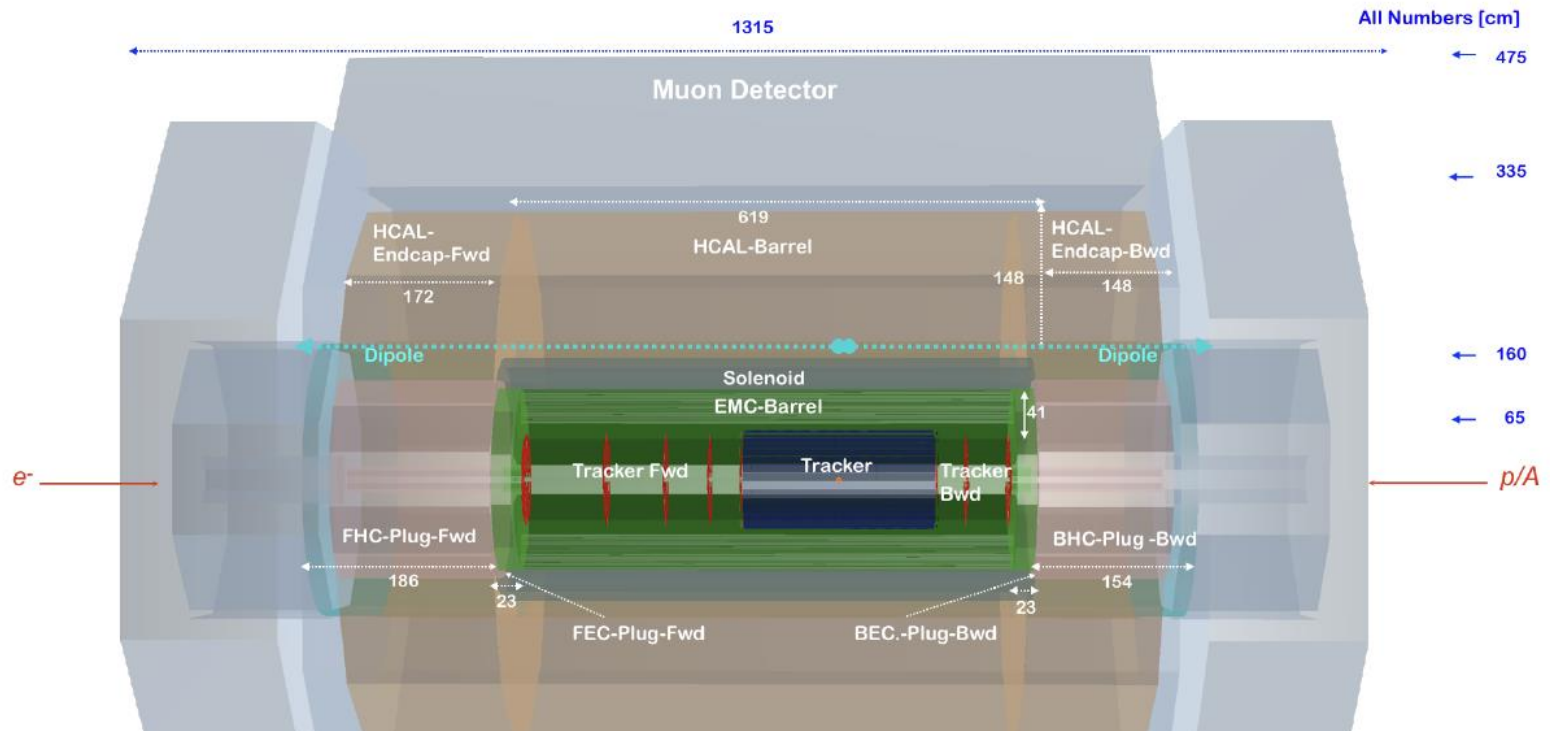
– Also photoproduction
 $\gamma p \rightarrow X$

- BSM physics



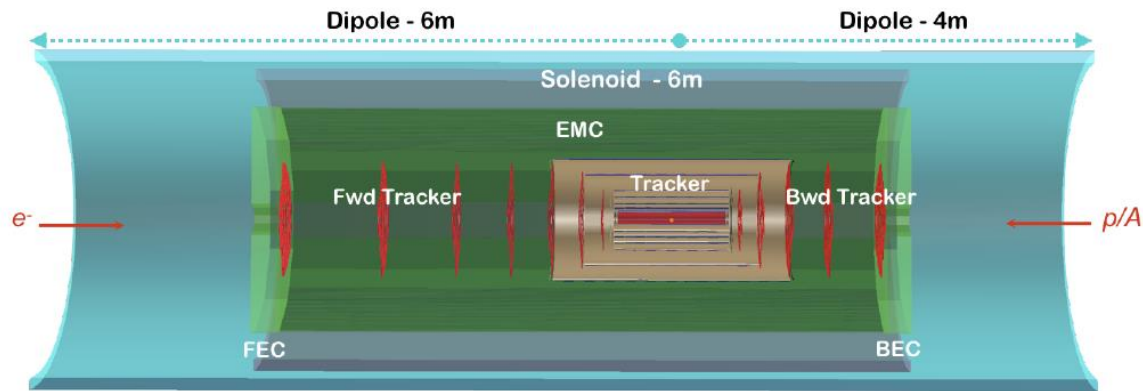
The LHeC detector

- Based on LHC experience and HL-LHC upgrade, BUT:
 - No pile-up (max 0.1) + **much less radiation ($O(1/1000)$)**
Technology developed for elsewhere (e.g. ILC) may also be applicable
- Aims for compact, modular but very hermetic detector
 - For installation in IP2 (currently for ALICE) during a 2-year shutdown
 - Coverage from 1 to 179 degrees

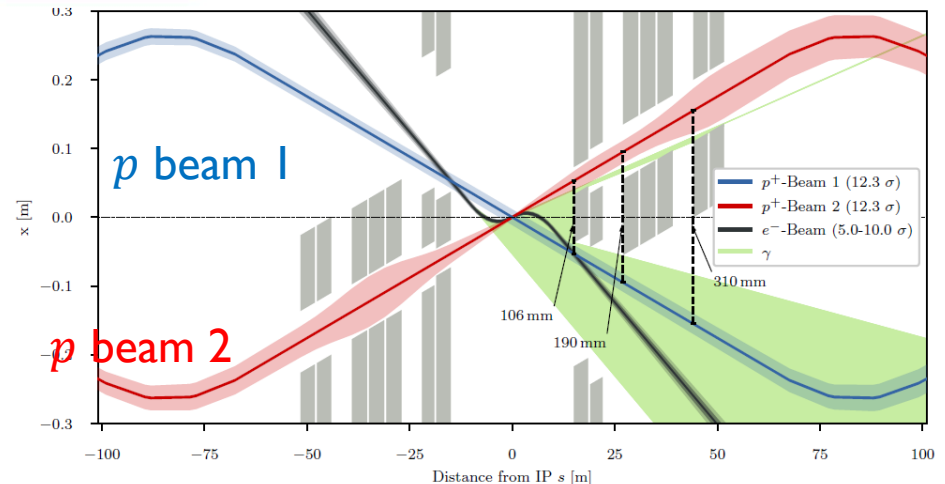
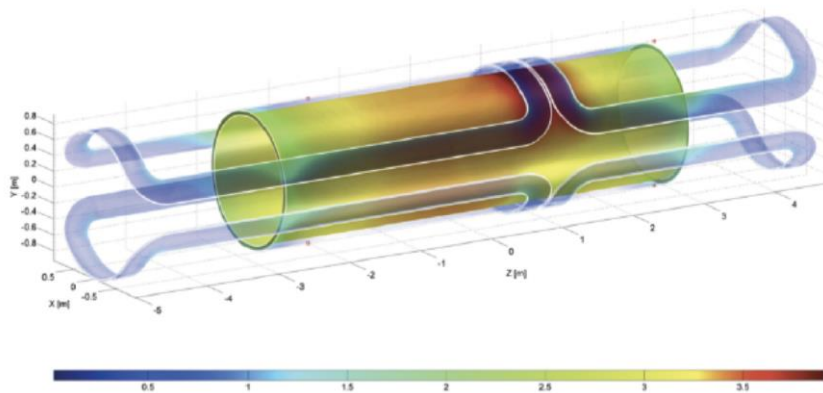


Interaction point and magnet

- Dipole magnet integrated in the detector to bend electron beam
 - Beam-2 p and e brought in head-on collisions
 - Beam-1 with finite angle, unaffected



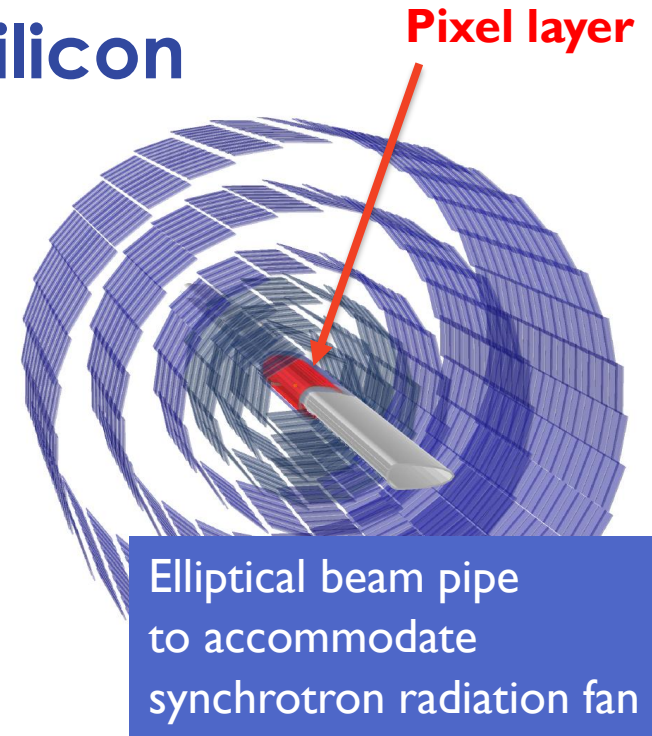
New re-designed, optimised IR in CDR 2020



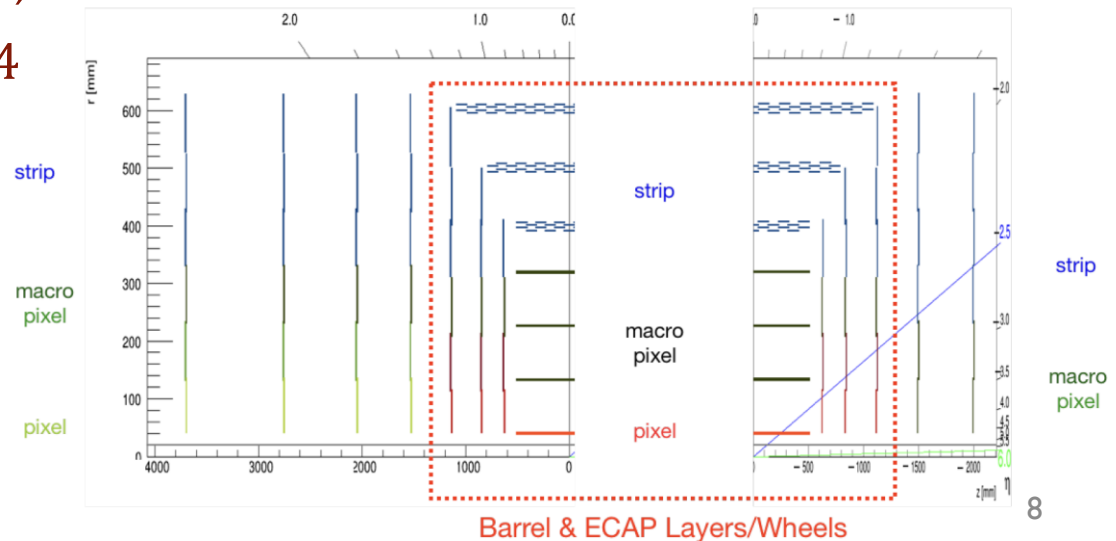
Synchrotron radiation fan (green)

Central tracker with modern silicon

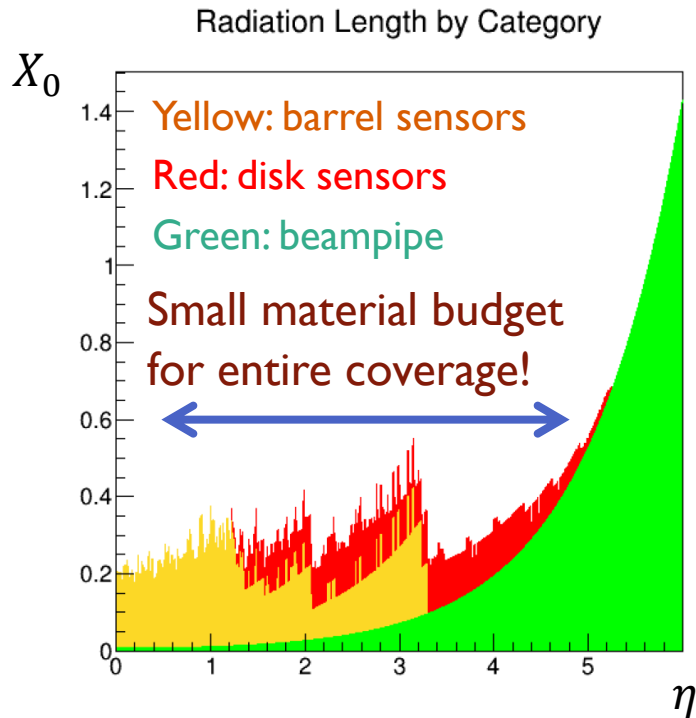
- Technology advanced from CDR period
- Low-material tracker by DMAPS
 - CMOS sensors (HV-CMOS for this update)
 - Readout electronics integrated
- Very thin: 0.1 mm for pixel, 0.2mm for strips
 - Small material budget for forward/backward
- Rad hard up to 2×10^{15} 1MeV n_{eq}/cm^2
(cf. HL-LHC fluence $\gtrsim 10^{16}$)
- 5-8 layers for $-3.5 < \eta < 4$
2 hits for $-4.2 < \eta < 5$



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

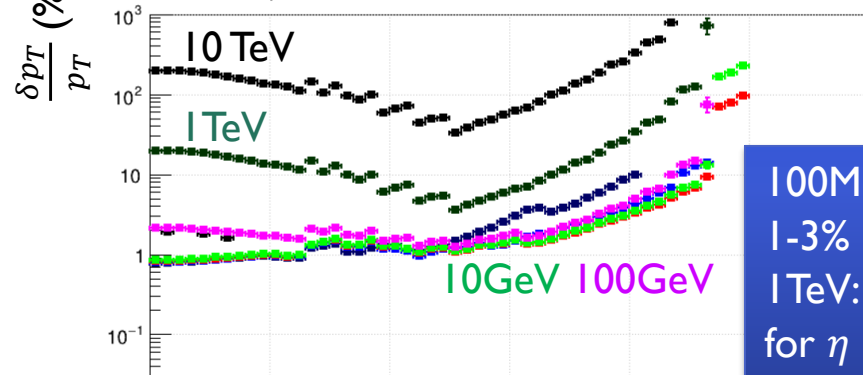


Central tracker: performance



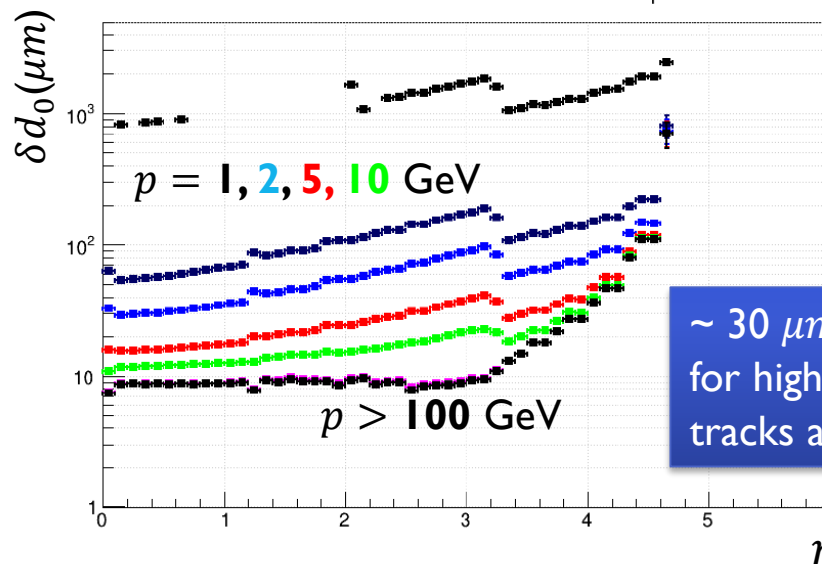
- Possible further improvements
 - 2nd pixel layer
 - Thinner backward beam pipe in diameter (SR fan thinner there)

p_T resolution versus η - const p across η



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

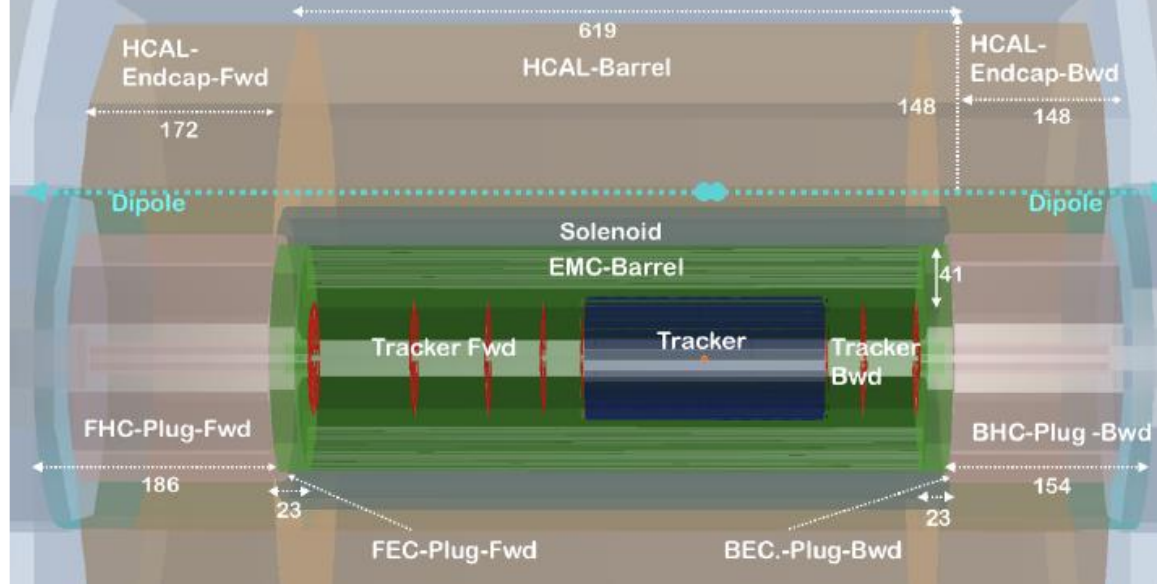
Transverse impact parameter error - const p_T across η



$\sim 30 \mu\text{m}$ resolution
for high momentum
tracks at $\eta \sim 4$

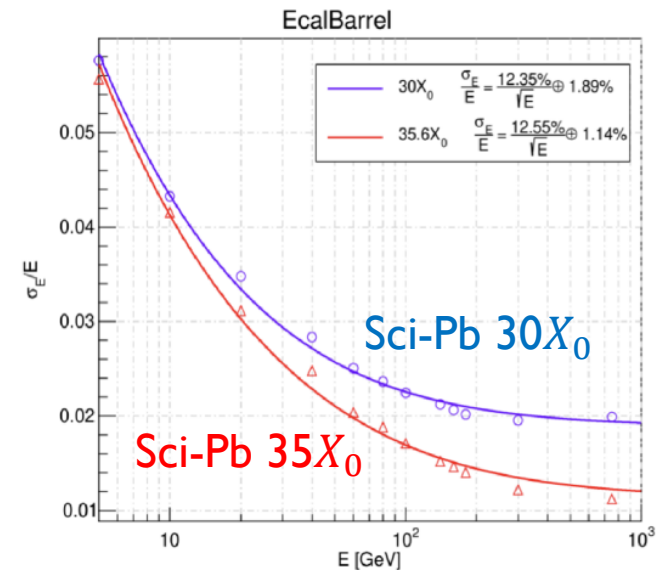
Calorimetry

- High-performance barrel
 - Baseline: LAr EM inside solenoid with shared cryostat
- Fine-segmented plugs with compact shower
 - technology developed for ILC
- "warm" option (new)
 - Sci-Pb: no need for cryostat → modular
 - Comparable performance: LAr still advantageous for resolution, segmentation, radiation stability



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

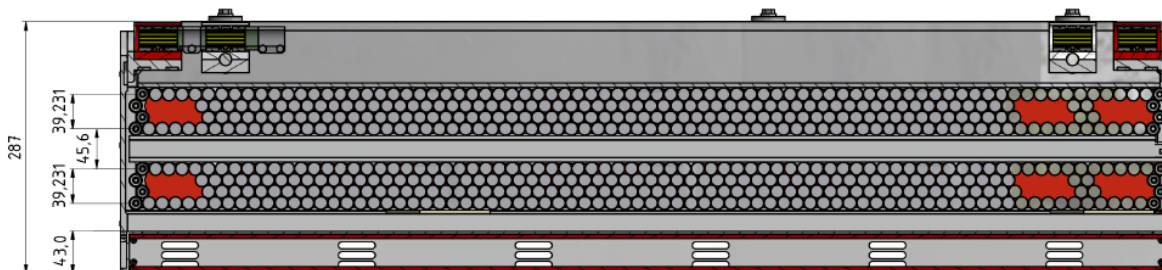
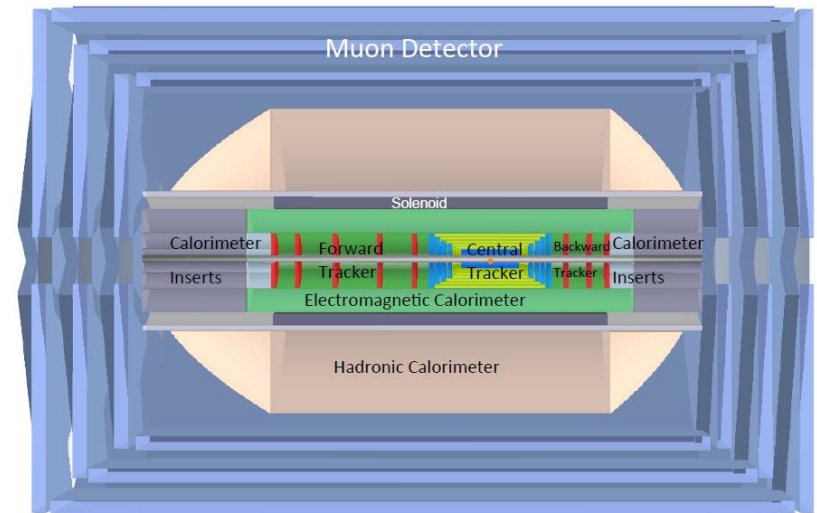
Baseline configuration		η coverage	angular coverage
EM barrel	LAr	$-2.3 < \eta < 2.8$	$6.6^\circ - 168.9^\circ$
Had barrel+Ecap	Sci-Fe	(~ behind EM barrel)	
EM+Had forward	Si-W	$2.8 < \eta < 5.5$	$0.48^\circ -$
EM+Had backward	Si-Pb	$-2.3 < \eta < -4.8$	-179.1°



Muon system

- Baseline: no dedicated magnetic field (solenoid return thru iron only)
 - Momentum by central tracker
 - Good tagging + fast trigger
 - 3-stations, each with \geq double layer
- HL-LHC technology serves for that
 - Very thin RPC (1mm gas gap) for higher rate capability and timing (< 1 ns)
 - sMDT: $\phi = 1.5$ cm drift tubes for precise position measurement
- Possible extensions
 - Dedicated forward toroid or outer solenoid

Baseline design



ATLAS Phase-I
RPC-MDT assembly

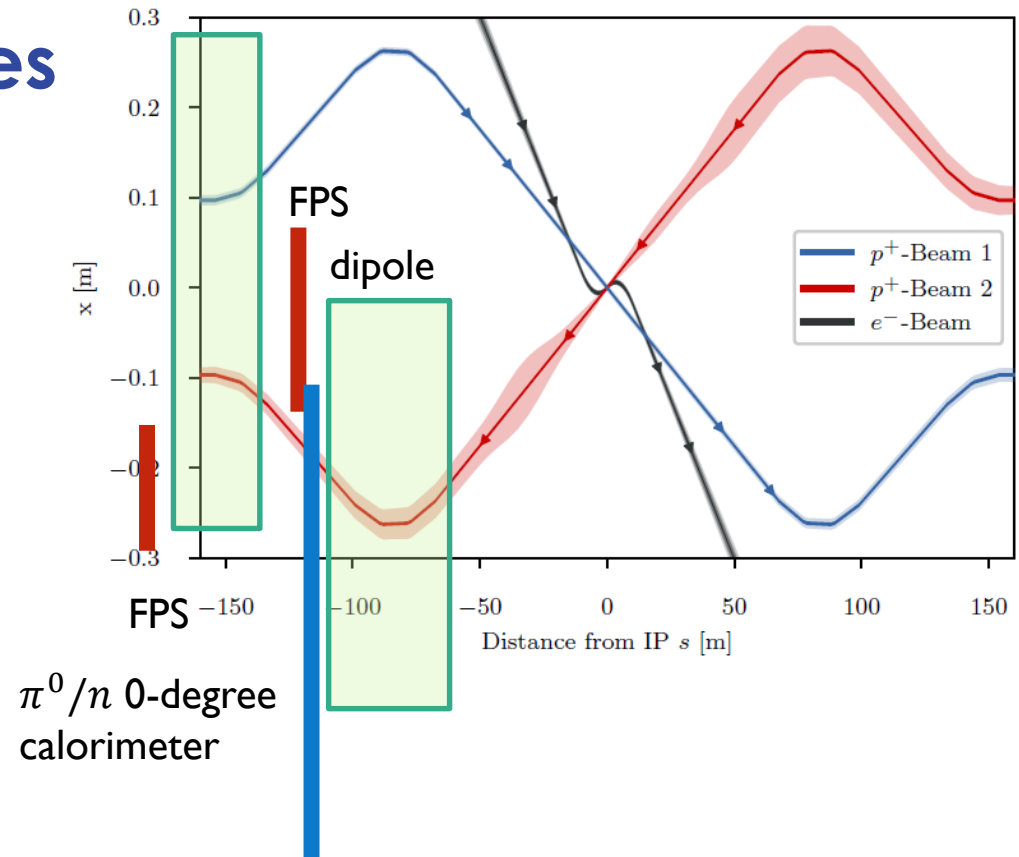
SMDT Multilayer 2

SMDT Multilayer 1

thin-RPC Triplet

Around zero-degrees

- Forward Proton spectrometer ~ following the LHC design apart from stations close to IP
- New IP design allows to place a ZDC
 - Transvers size ± 30 cm shower leak moderate
 - Aperture ~ 0.35 mrad or 2.4 GeV in p_T
- Technology candidate: Si-W
 - Need < 1 mm resolution for p_T resolution $\ll 100$ MeV for 7 TeV neutron i.e. very fine segmentation (e.g. ALICE FoCal)
 - Radiation dose: $O(10\text{MGy})$ or more
 - Much less than LHC, possibility to use silicon sensors



Detector design for FCC-eh

- Proton 20 and 50 TeV, electron 60 GeV
- Design for LHeC with extended volume / layers will serve also for FCC-eh
 - Forward/Central: scales in $\sim \log E_{had}$
 - Backward 50 or 60 GeV: similar to LHeC

Total length 13.1 \rightarrow 19.5m

Radius 4.8 \rightarrow 6.4m

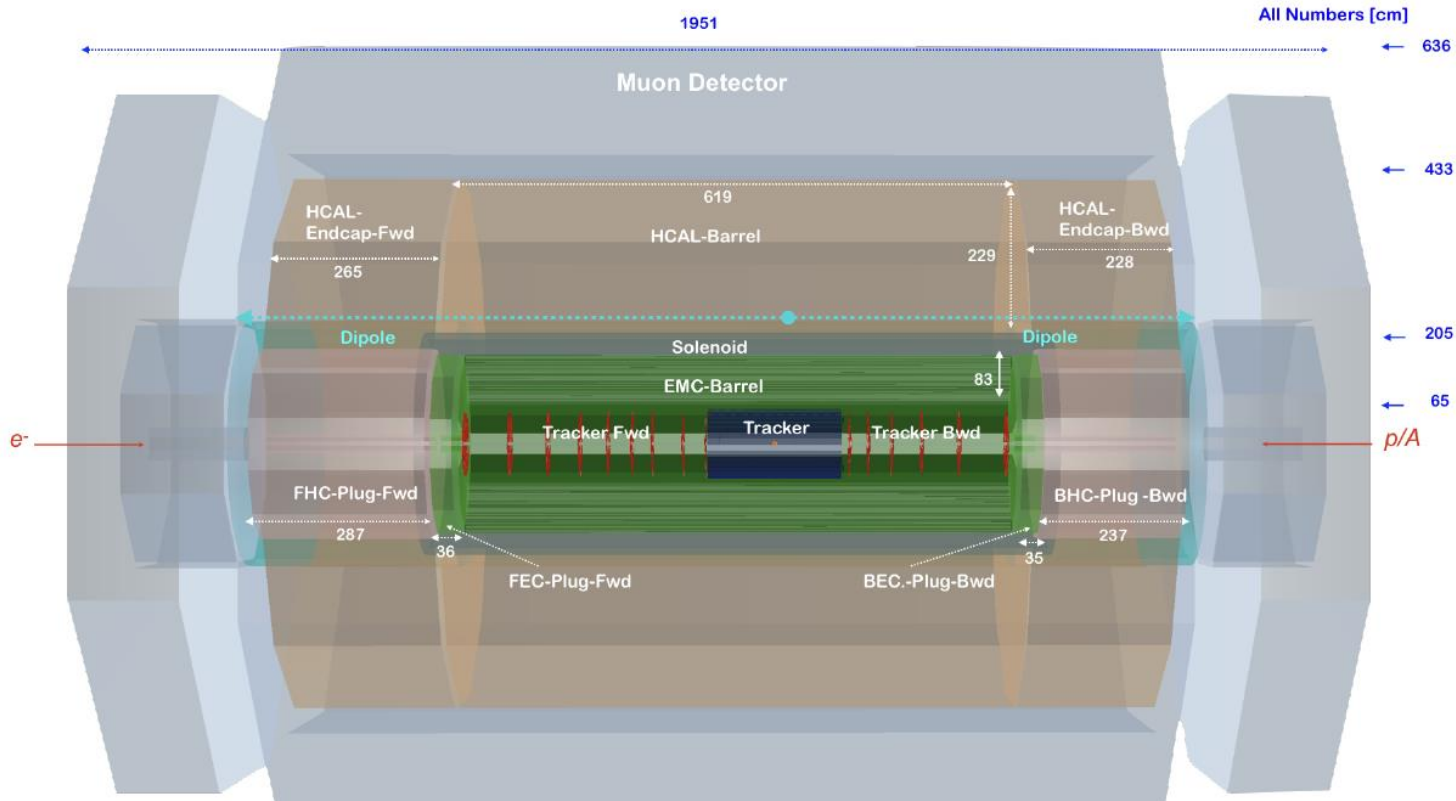
Central tracker
also with (tilted) wheels

Fwd tracker 4 \rightarrow 8 disks

Bwd 2 \rightarrow 6 disks

HadCal:

12-15 interaction lengths



Summary

- Having succeeded in designing a new generation ep/eA detector
 - For high-precision QCD+EW, Higgs, top and BSM physics
- With kinematic ranges and **acceptance** extended much beyond HERA
 - (even more) hermetic detector with good calorimetry
 - Forward / backward tracking for momentum + flavour tagging with cutting-edge technologies e.g. modern Si sensors
- Current design achieves these performance goals also for FCC-eh
 - Further optimisation ongoing