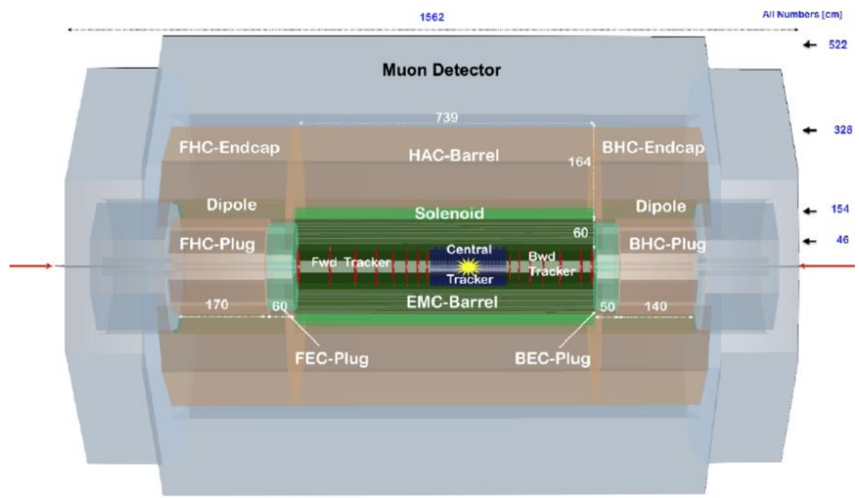
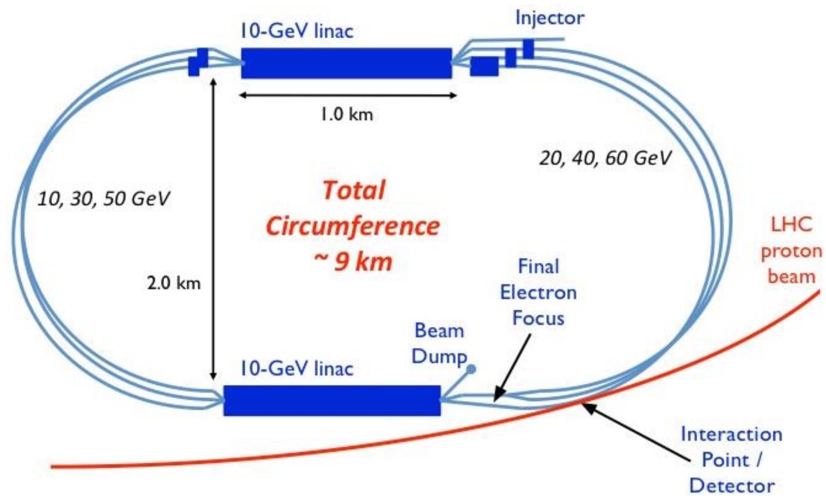
Detectors for the LHeC and FCC-eh



Paul Newman
(University of Birmingham)

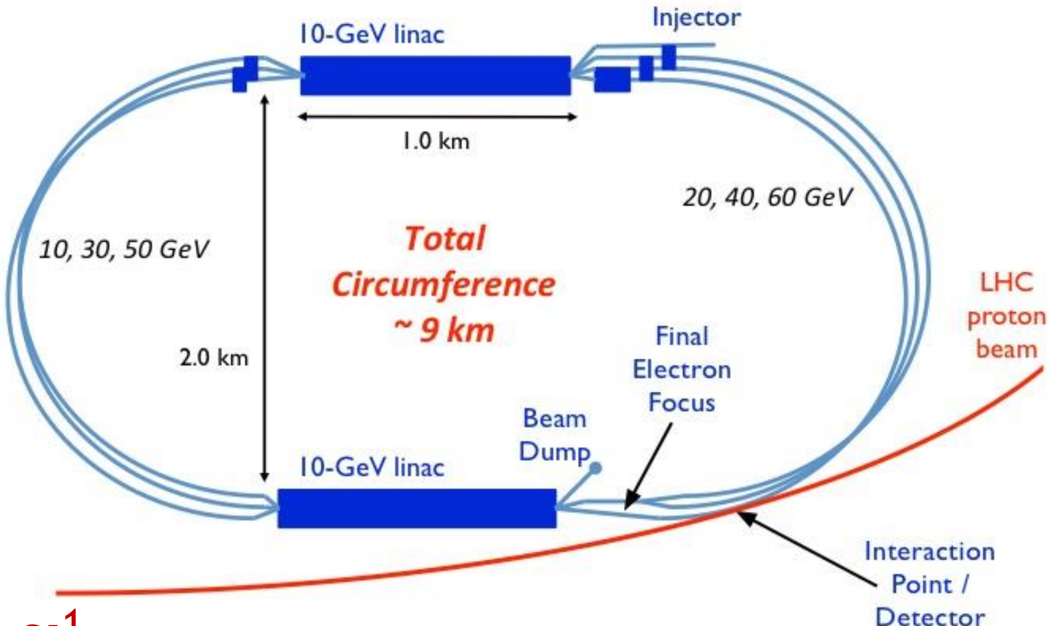


Baseline Design (Electron "Linac")

LHeC CDR, July 2012 [arXiv:1206.2913]

Design constraint: power consumption < 100 MW → E_e = 60 GeV

- Two 10 GeV linacs,
- 3 returns, 20 MV/m
- Energy recovery in same structures



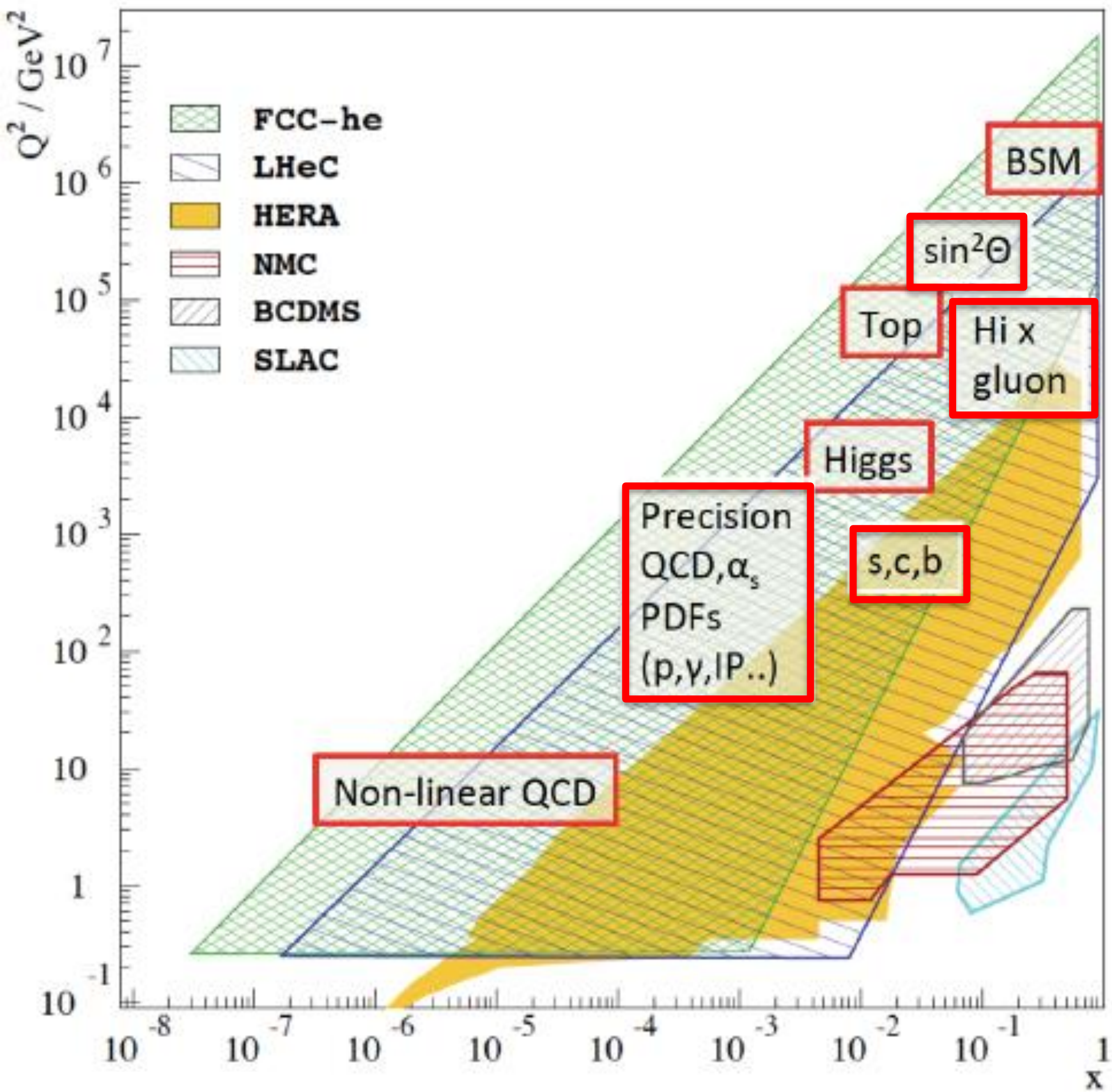
- LHeC ep lumi → 10^{34} cm^{-2} s^{-1}

→ ~100 fb^{-1} per year →~1 ab^{-1} total

- e-nucleon Lumi estimates ~ 10^{31} (3.10^{32}) cm^{-2} s^{-1} for eD (ePb)

- **Similar schemes in collision with protons of 7 TeV (LHeC), 13 TeV (HE-LHeC) and 50 TeV (FCC-eh)**

Physics Targets throughout Kinematic Plane



- Standalone Higgs programme

- Revolutionary proton PDF precision enhances LHC new physics sensitivity

- Elucidates low x dynamics in ep & eA

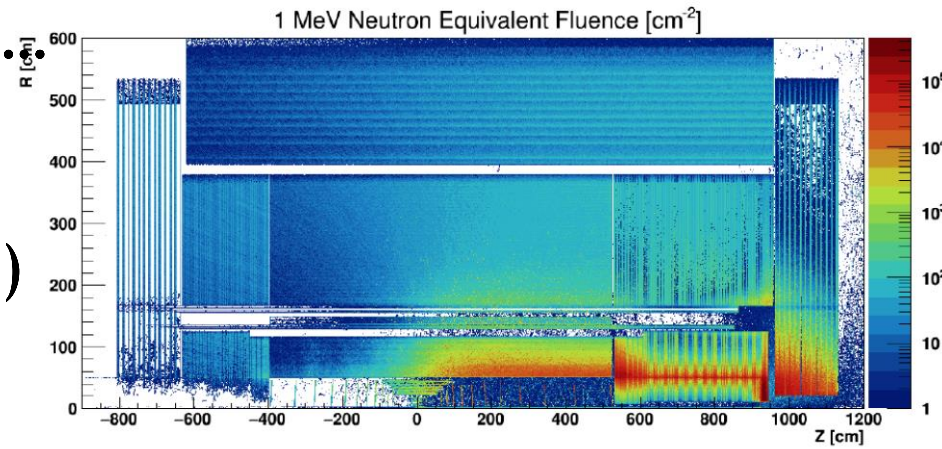
- 4 orders of mag. in kinematic range of nuclear structure

- No polarised targets

Detector Design: Philosophy

- Detector technologies evolve fast; current designs can only be indicative / based on current knowledge … will change

Fluences



- Conditions are relatively ‘easy’ …
… fluences <~ 10^5 1 MeV n cm^{-2} equiv (tiny fractions of HL-LHC)
… pile-up ~ 0.1 (cf 200 at HL-LHC)

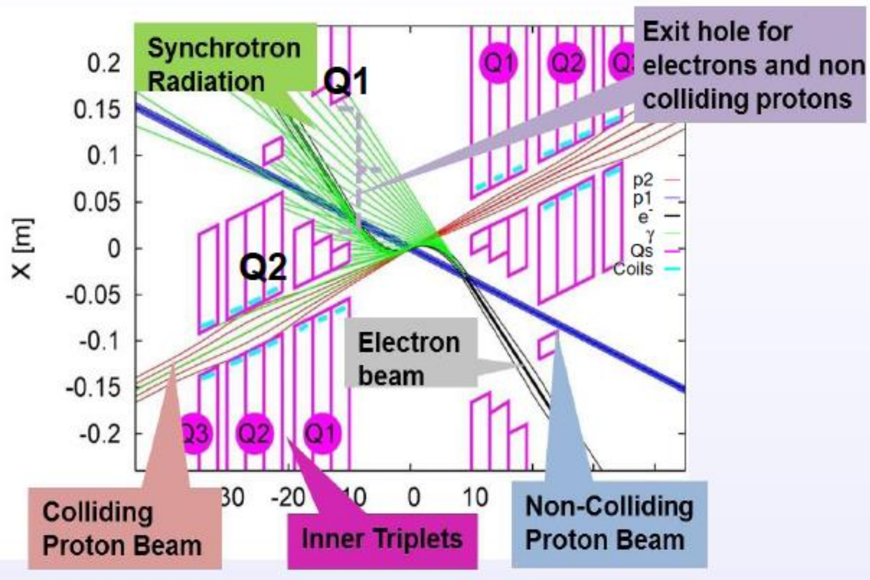
- Current `baseline’ remains 2012 CDR (with ongoing work in several areas)

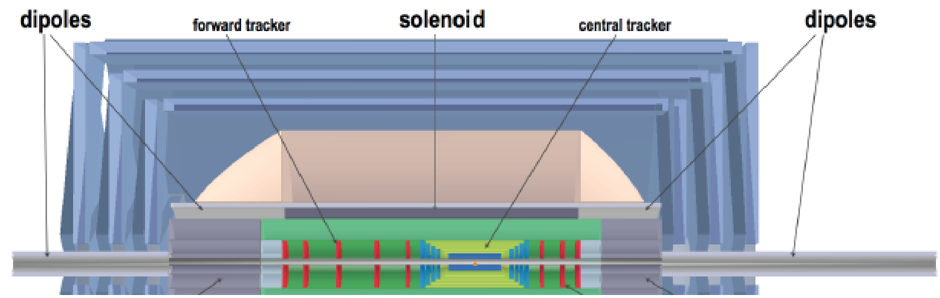
→ Leans heavily on LHC (esp. ATLAS) technologies (but they are over-spec’ed for radiation hardness)

→ Was costed at CHF106M core cost

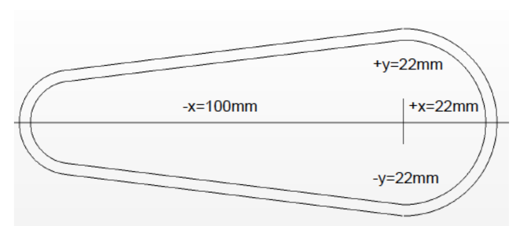
- Most challenging technology aspects are interaction region (synchrotron) and ER linac

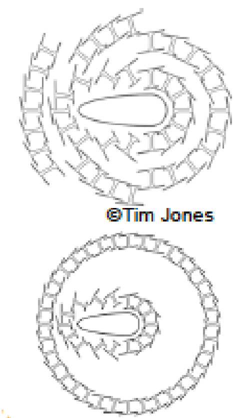
Interaction Region & Magnets





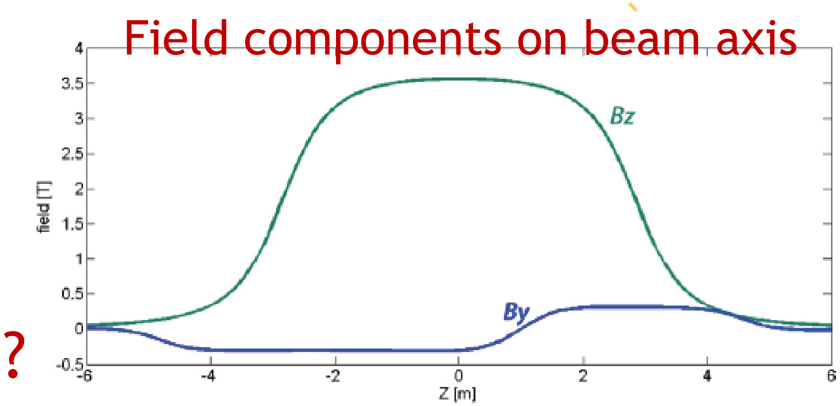
- Dual dipole magnets (0.15 – 0.3 T) throughout detector region (|z| < 14m) bend electrons into head-on collisions





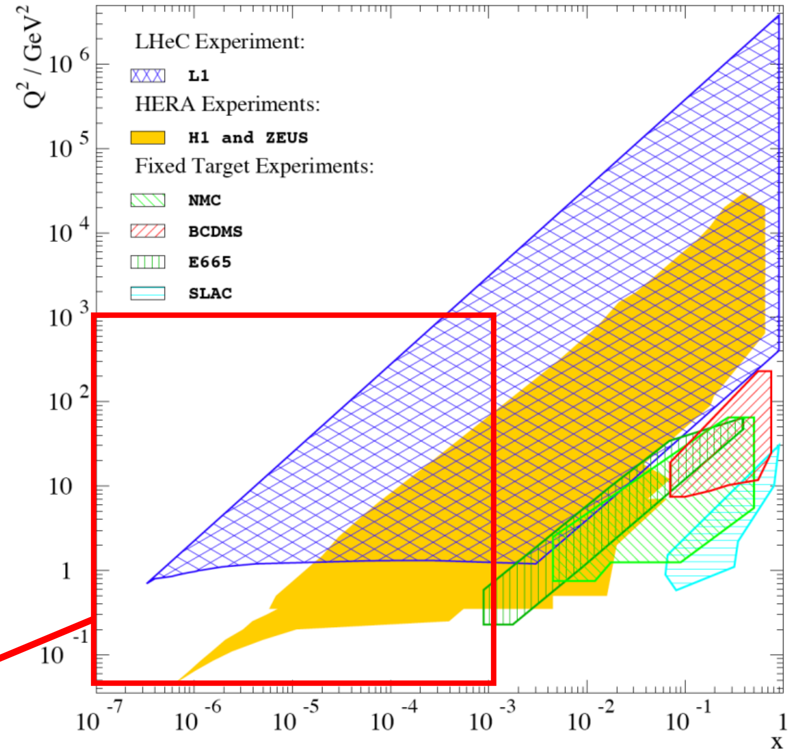
- Eliptical beampipe (6m x 3mm Be) accommodates synchrotron fan

- 3.5 T Superconducting NbTi/Cu solenoid in 4.6K liquid helium cryo.

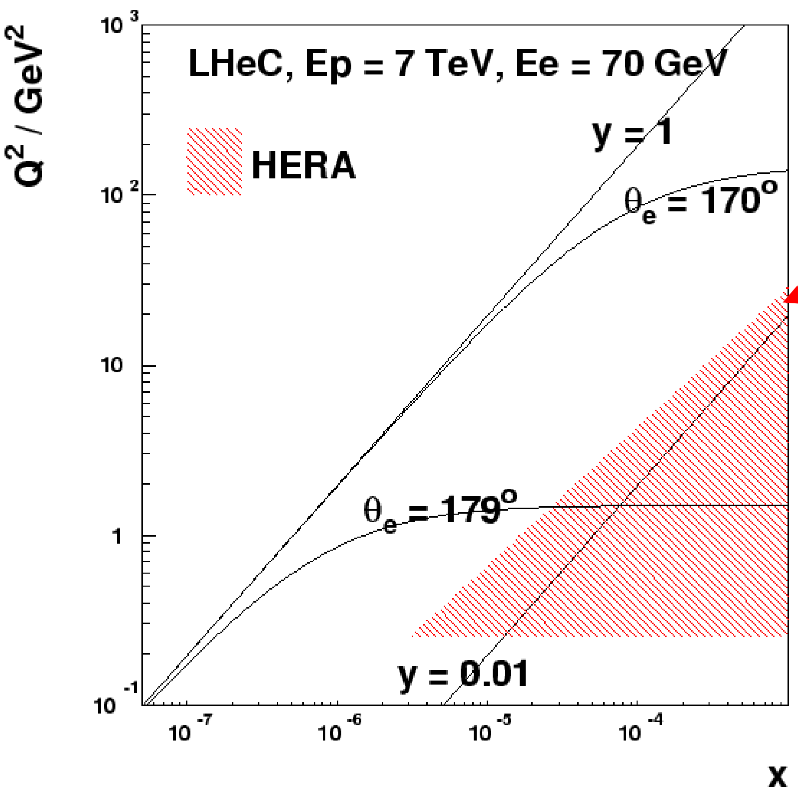


Re-evaluating → reduce synchrotron?

LHeC Detector Acceptance Requirements

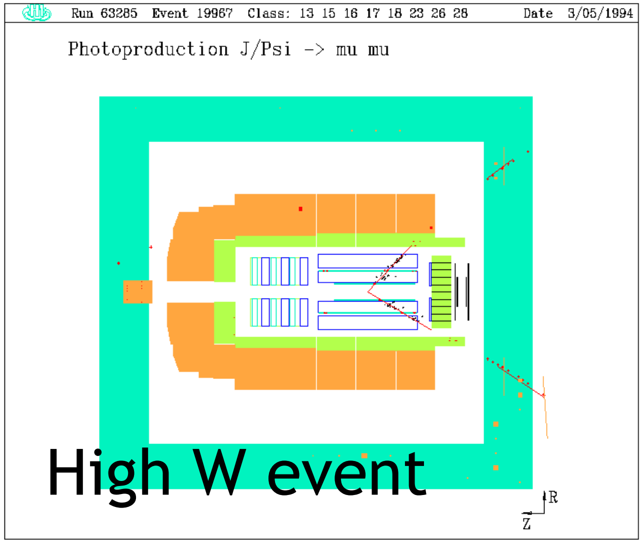


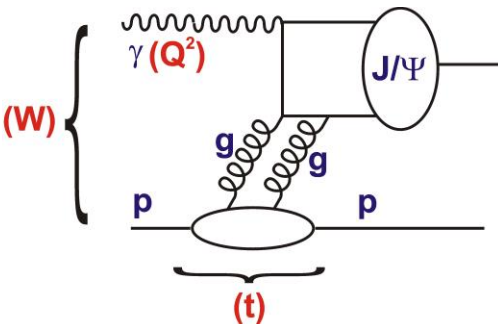
Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°



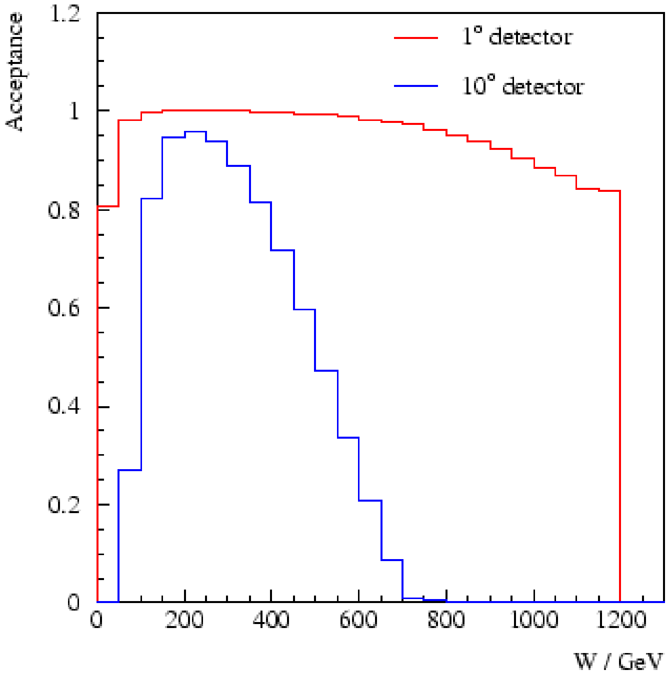
Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x (essential for good kinematic reconstruction)

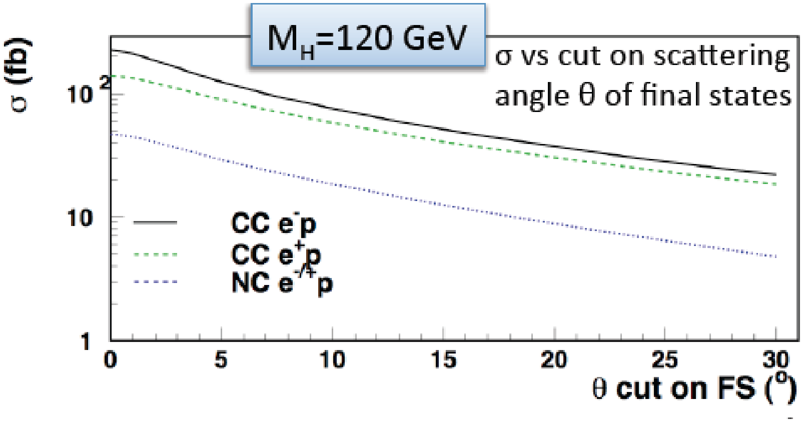
Acceptance Requirements, Final States



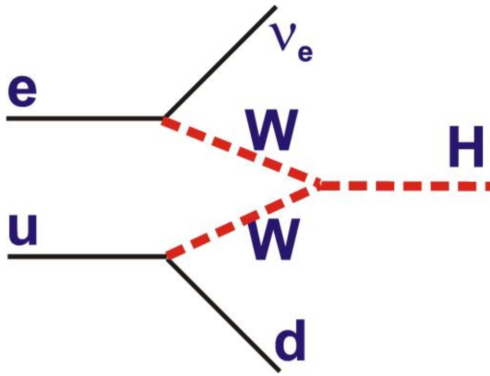


- Elastic J/Ψ Photoproduction

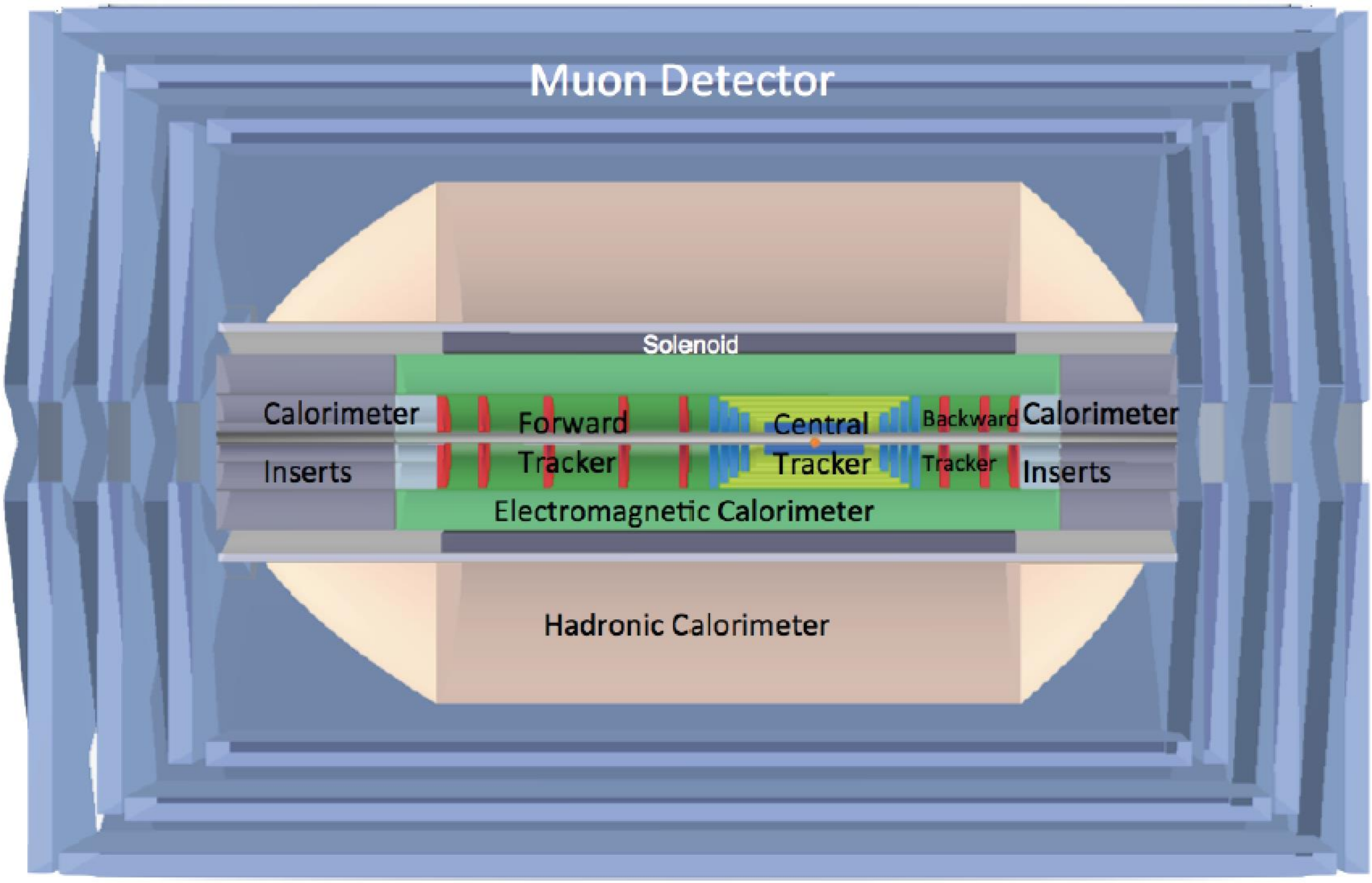




- Higgs Production



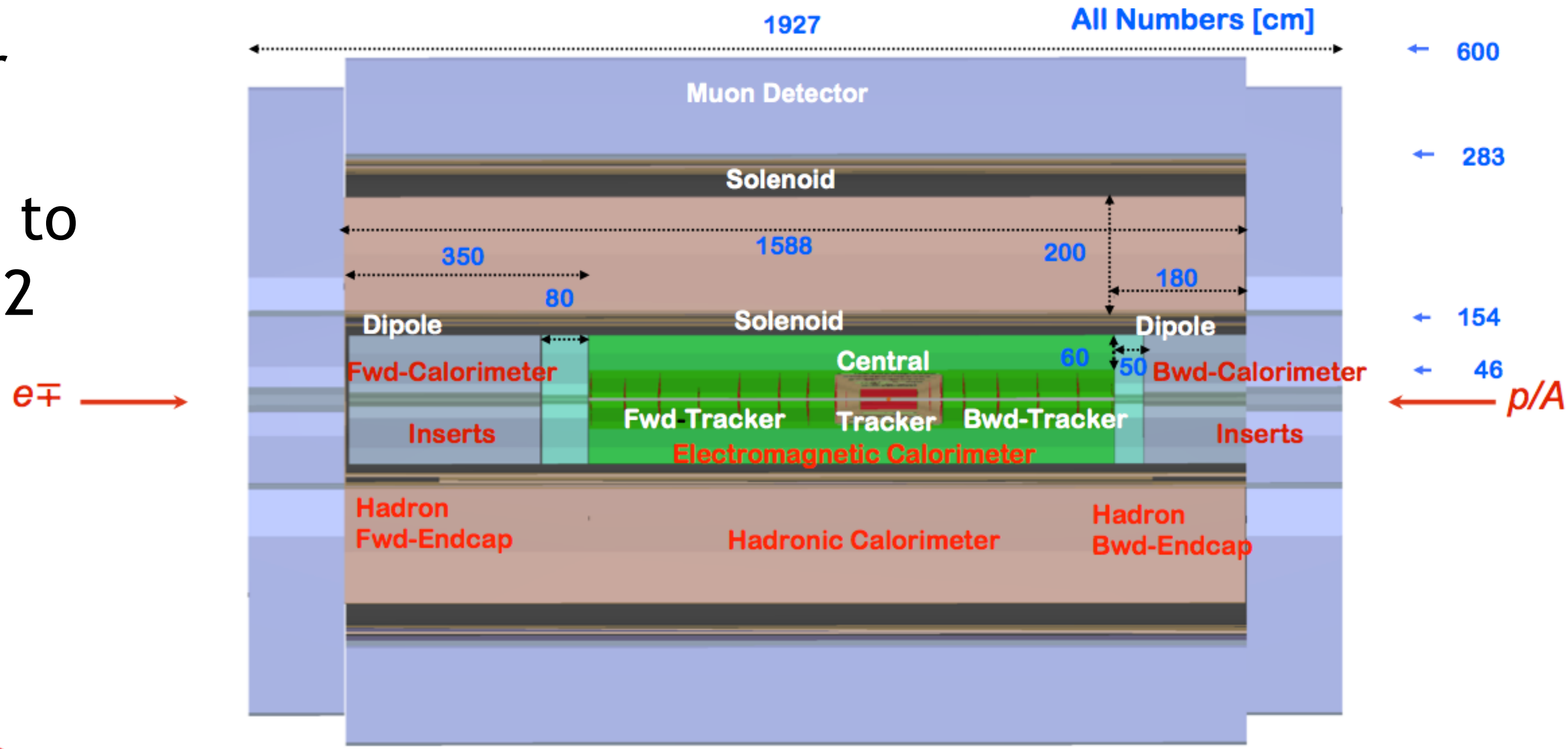
Detector Design from the CDR (2012)

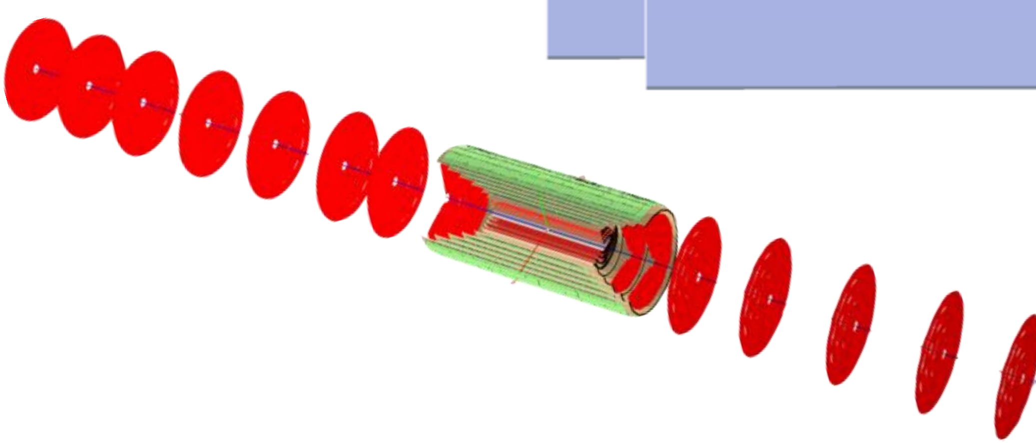


- Size 13m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- 1° tracking acceptance in both forward & backward directions
- Forward & backward beam-line instrumentation integrated

Detector for ep at a Future Circular Collider

- Detector scales in size by up to ln(50/7)~ 2





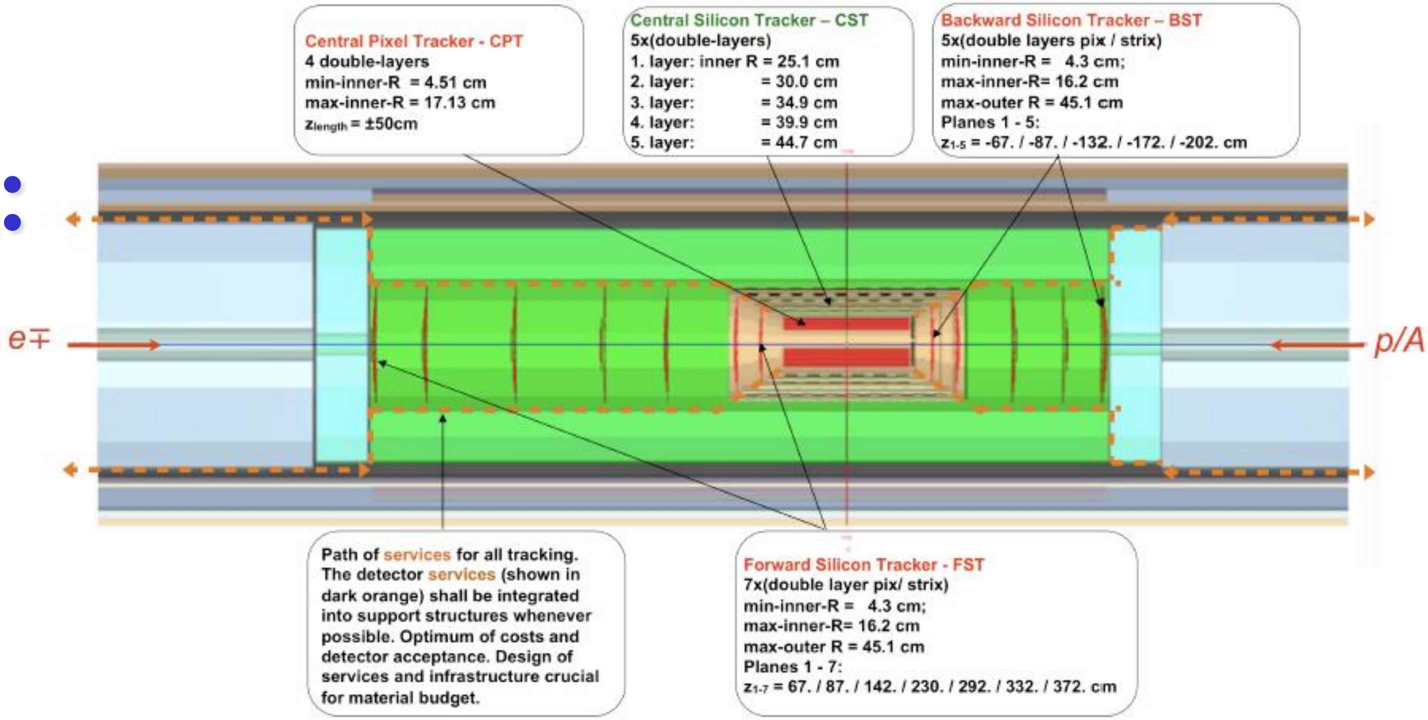
- Double solenoid + Dipole

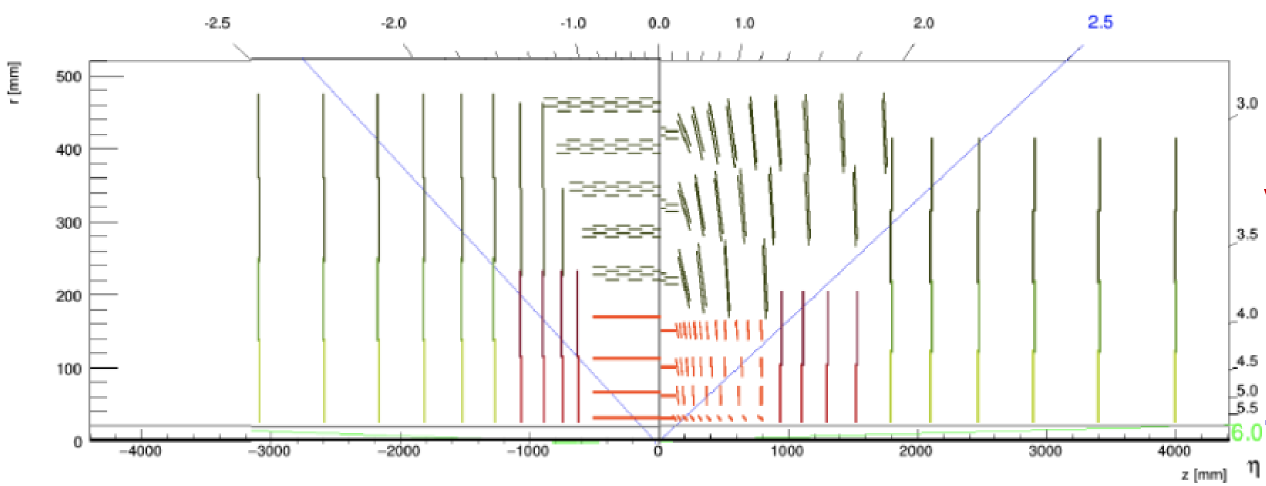
- Even longer track region to retain 1° performance

Inner Tracking:

an LHeC Design

… and an HE-LHC design

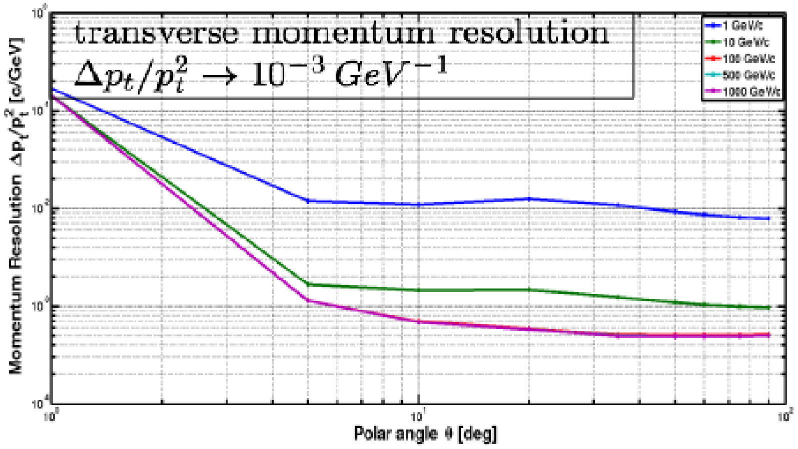


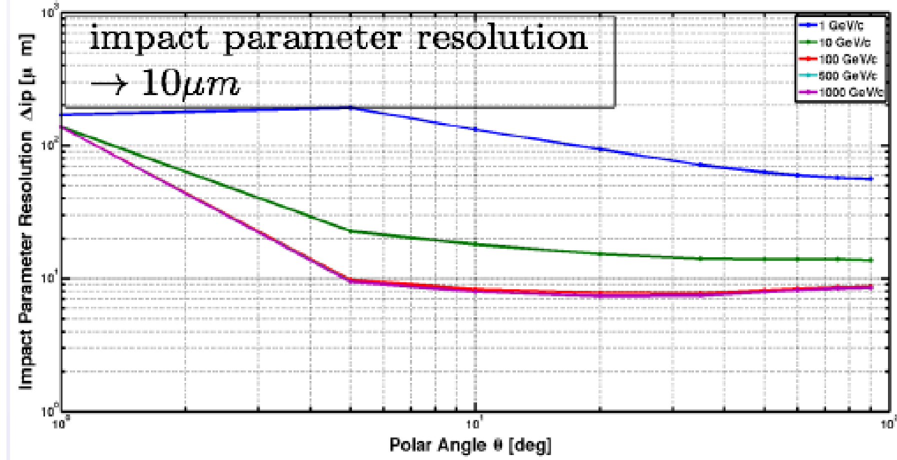


bwd - planar design **fwd - tilted design**

- 1° electron hits 2 tracker planes
- Forward direction allows particle flow with boosted jets
- **Pixels + strips;** Perfect application for HV-CMOS (cf EIC R&D programme)

Tracking Performance





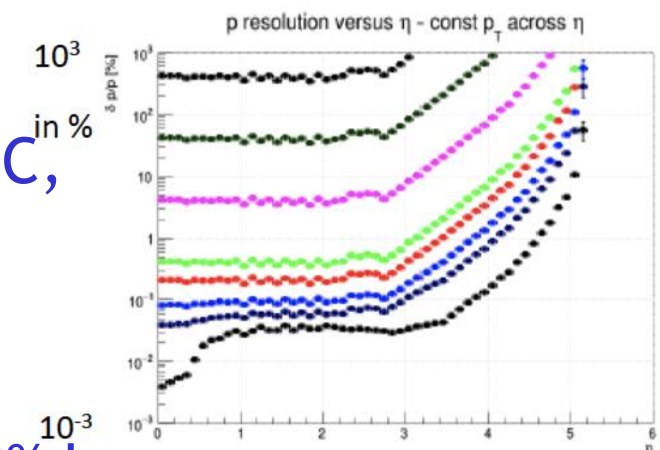
From CDR → Central track $\Delta p_t/p^2_t$ → 6 x 10^{-4} GeV^{-1}

Impact parameter resolution: → 10μm

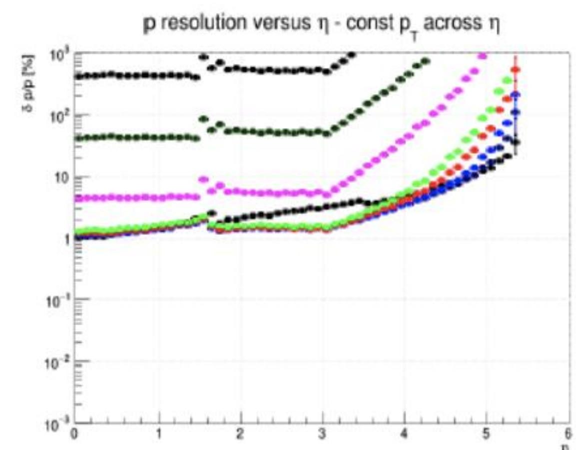
More recently →

- Studies of HE-LHeC, Including services

- Evaluation of HF tag performance (60% b, 30% c efficiency at 95% light quark rejection) → Extend from 40 → 60cm (H→bb, cc)?



No Material & No Services

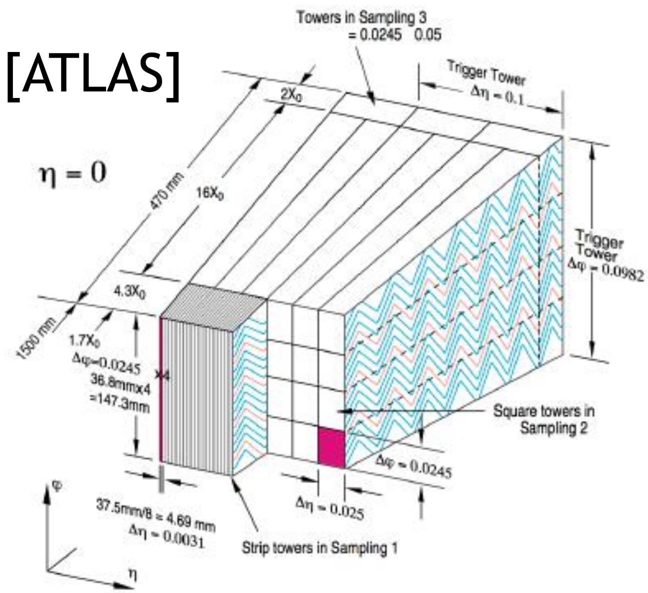


BeamPipe (3.5mm) & Active Materia

Barrel EM Calorimeter

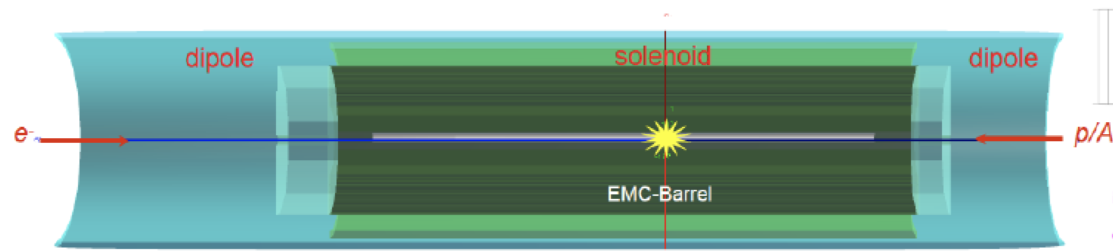
- $-2.3 < \eta < 2.8$
- CDR accordion geometry baseline design
- 2.2mm lead + 3.8mm LAr layers
- Total depth ~ 20 X_0

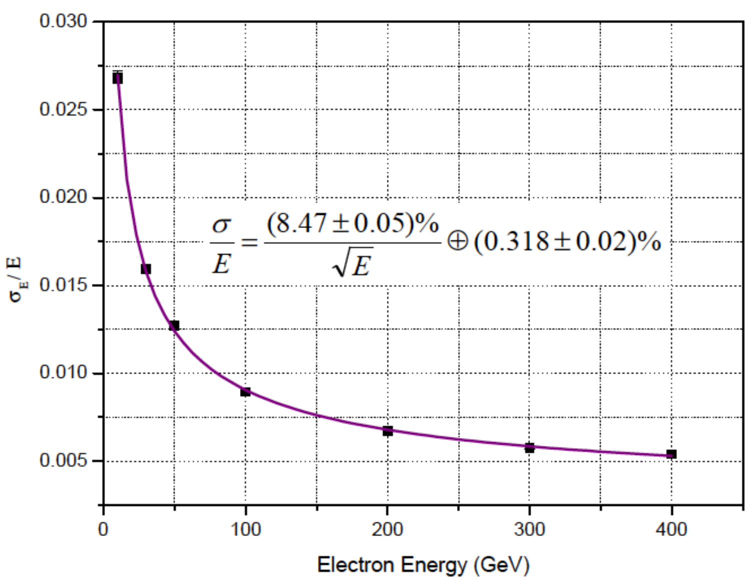
[ATLAS]



- GEANT4 simulation of response to electrons at normal incidence

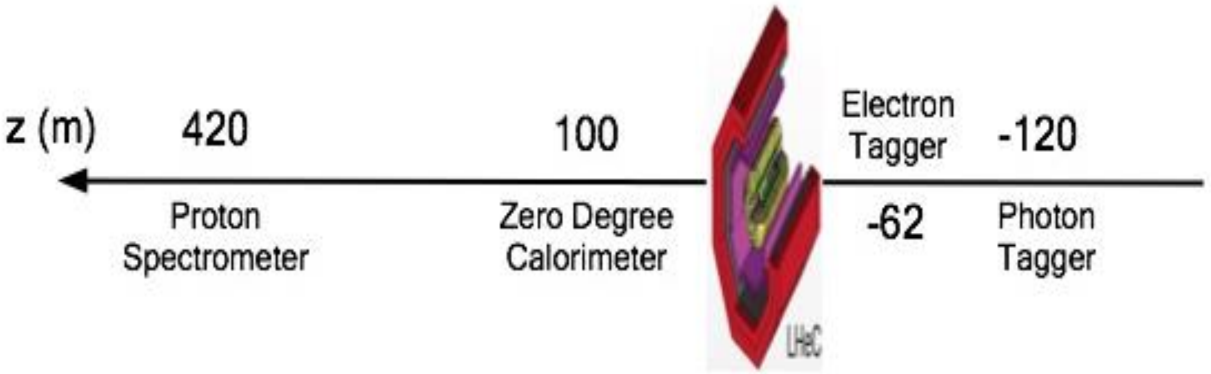
[cf ATLAS: 10%/√E + 0.35%]



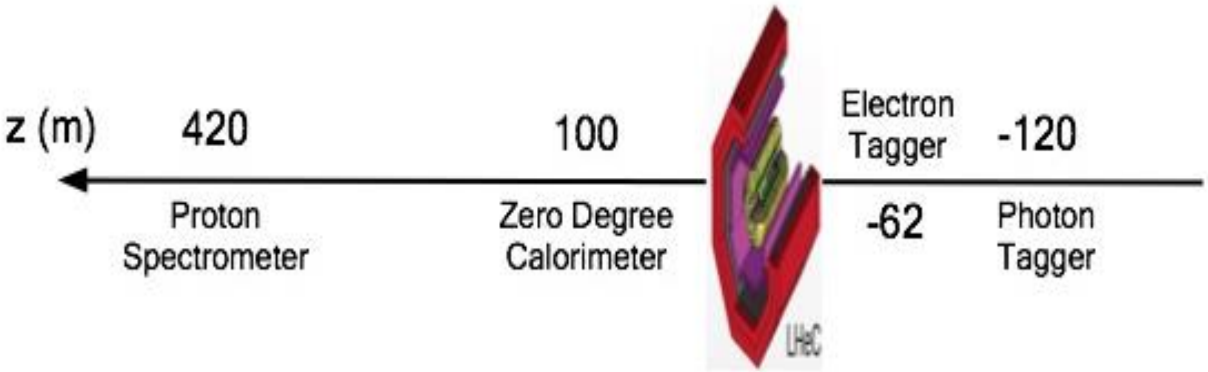


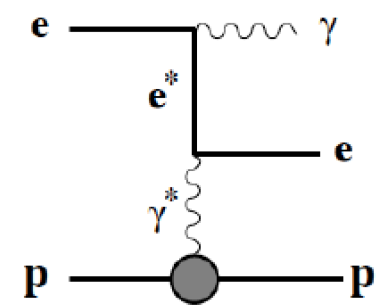
- Extended version (HE-LHeC) with 30 X_0 designed
- Current re-evaluation of entire calorimeter in light of resolutions required for H→WW, bb, Top etc …

Beamline Instrumentation



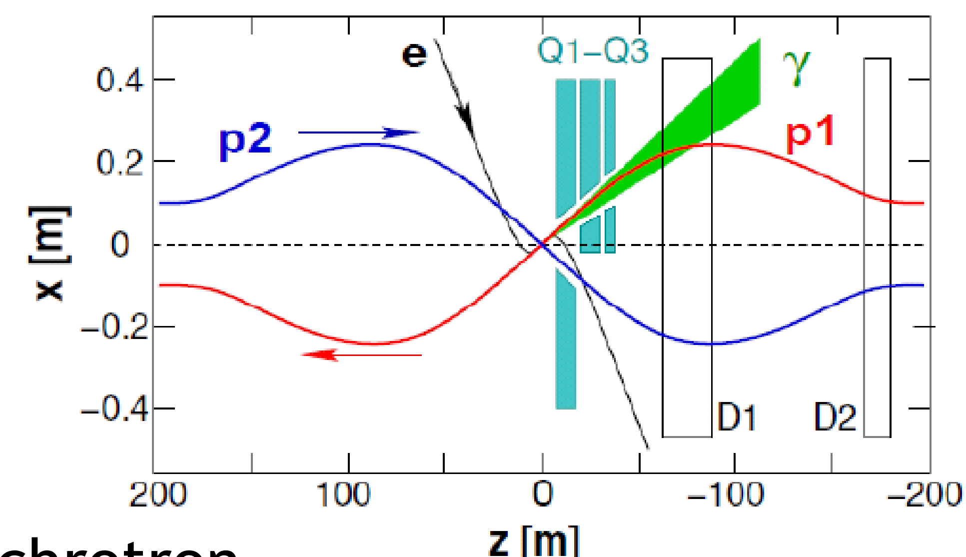
Beamline Instrumentation





Luminosity / Photon Tagging

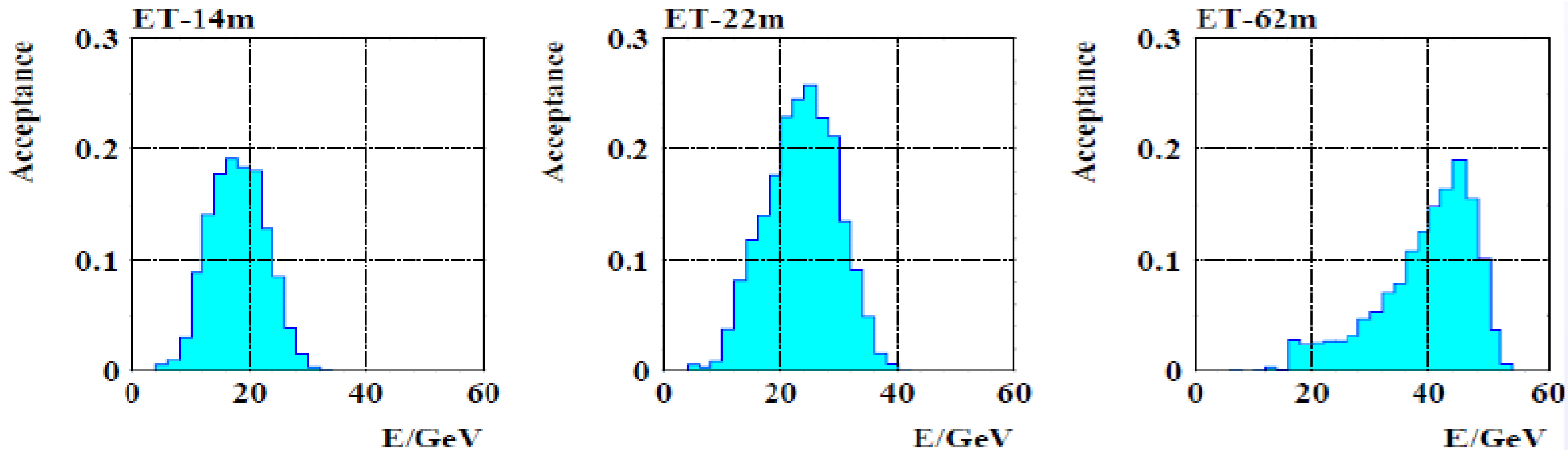
- Use Bethe-Heitler (as HERA), measurement based on photon



- Photons might be detected at z = -120 m after D1 proton bending dipole
- With sufficient apperture through Q1-Q3 magnets, 95% geometrical acceptance
- Signal via Cerenkov from synchrotron absorber coolant? → 1% lumi measurement? → Synchrorton OK?

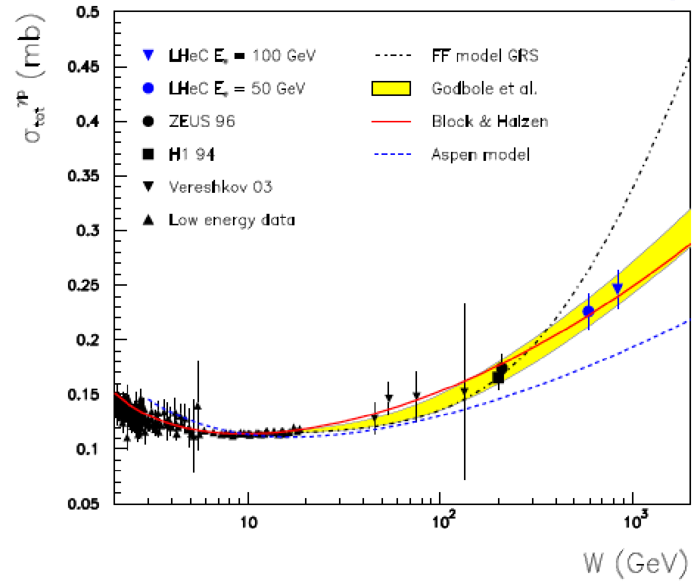
Low Angle Electron Tagging

- Reinforce luminosity measurement
- Tag γp for measurements and as background to DIS



- Acceptances ~ 20–25% at 3 different locations studied

- 62m is most promising due to available space and synchrotron radiation conditions

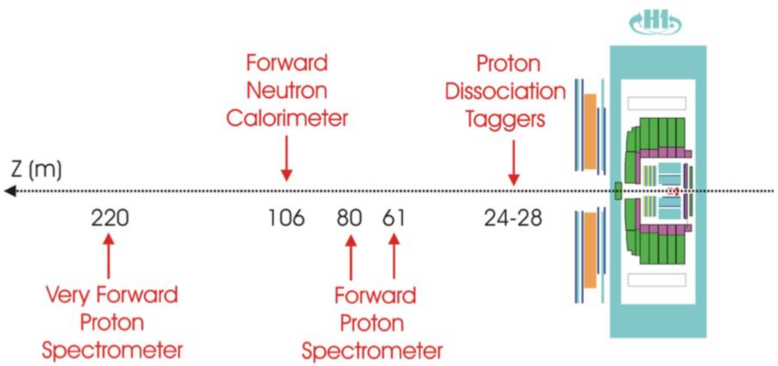


Methods for Diffraction

… old slide from diffraction at HERA

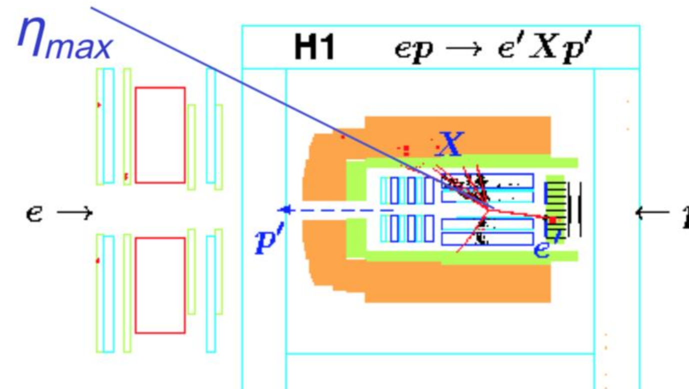
Signatures and Selection Methods

Scattered proton in Leading Proton Spectrometers **(LPS)**



Limited by statistics and p-tagging systematics

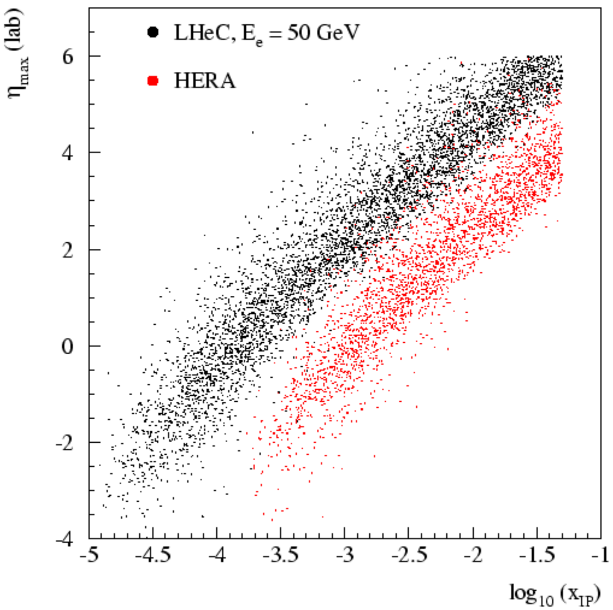
\`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton

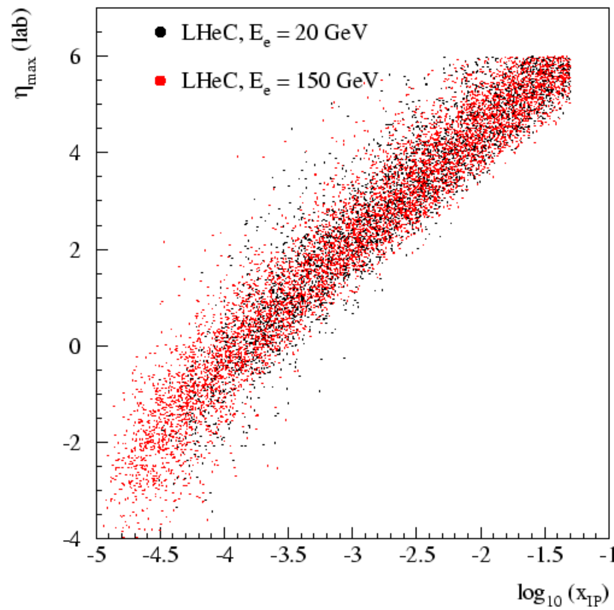


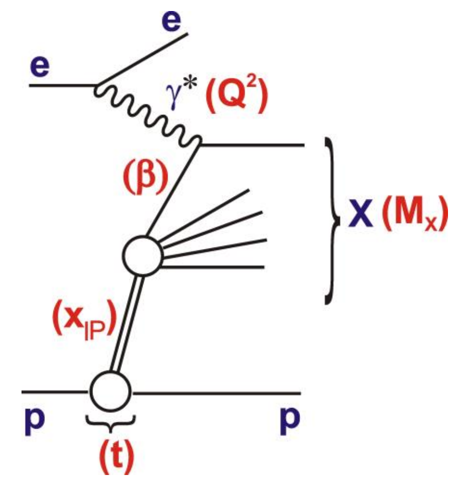
Limited by p-diss systematics

Partially still true for LHeC (but proton tagging technology got better and kinematics make rapidity gap methods harder)

Rapidity Gap Selection with LHeC Kinematics

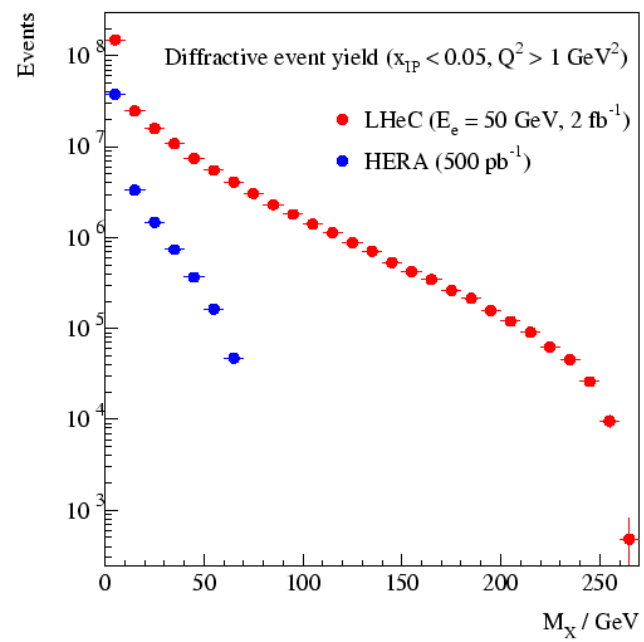




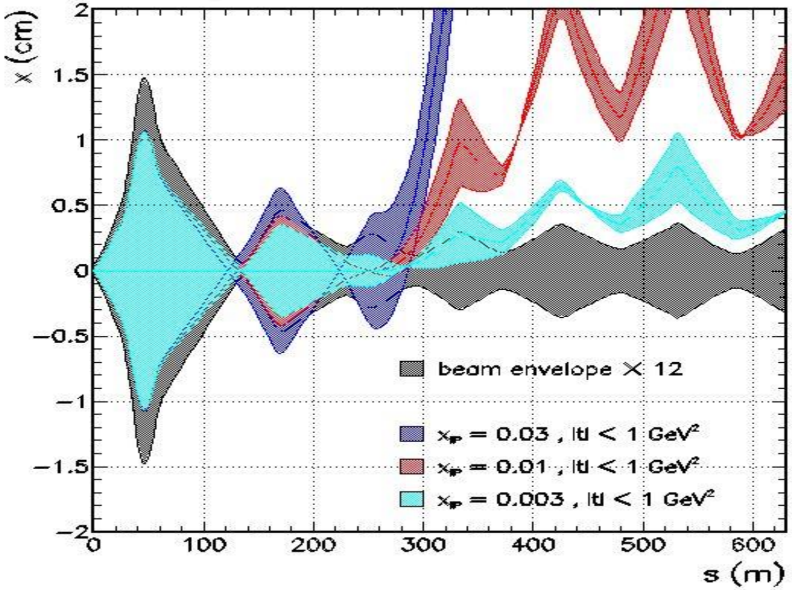


– η_{max} v ξ (= x_{IP}) correlation determined entirely by proton beam energy …
[LHeC proton kinematics same as LHC]

- LHeC cut around η_{max} ~ 3 selects events with x_{IP} <~ 10^{-3} (cf x_{IP} <~ 10^{-2} at HERA), but misses lots of diffractive physics at largest dissociation masses, M_X



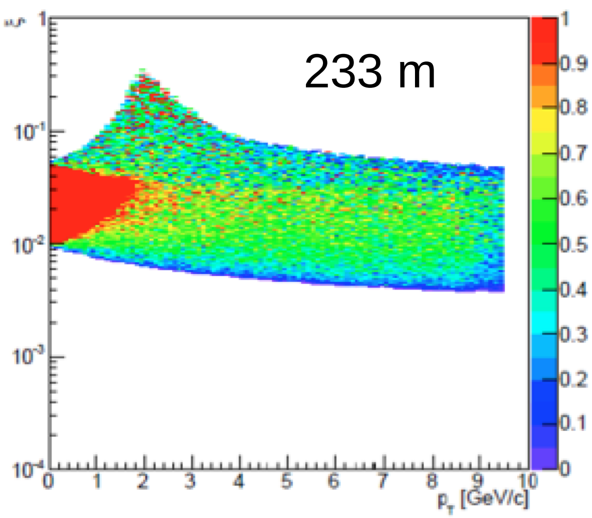
LHeC Forward Proton Spectrometer

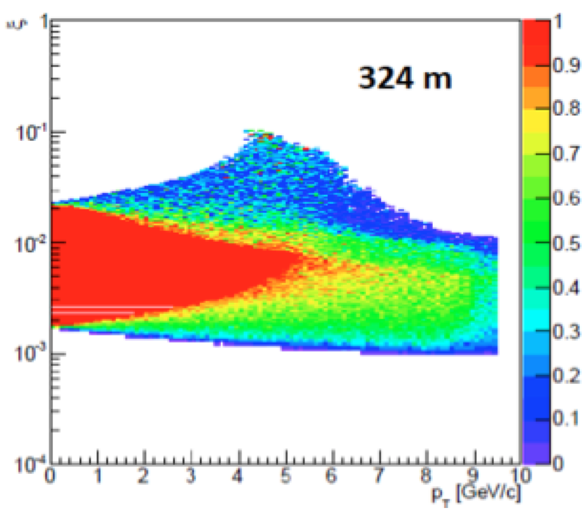


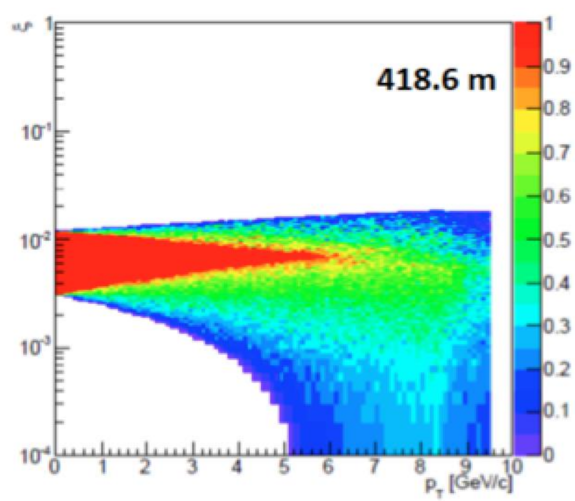
- Proton spectrometer is a copy of FP420 (proposal for low ξ Roman pots at ATLAS / CMS – currently being revisited)

- Requires access to beam though cold part of LHC

- Acceptances under study with HL-LHC optics

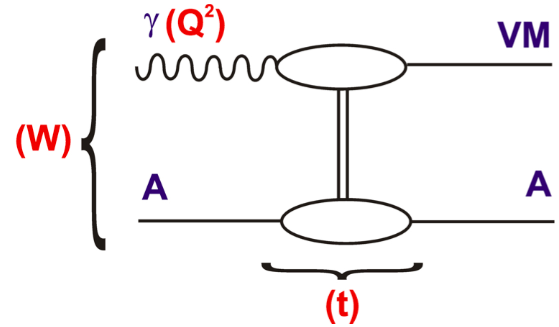




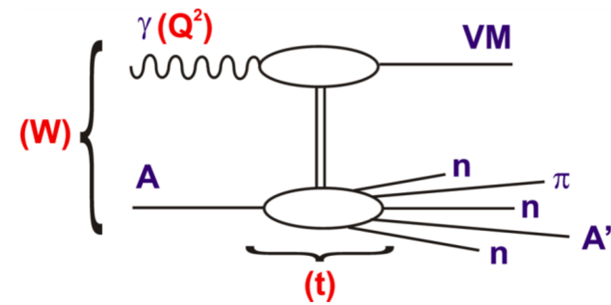


Leading Neutrons

- Crucial in eA, to determine whether nucleus remains intact e.g. to distinguish coherent from incoherent diffraction

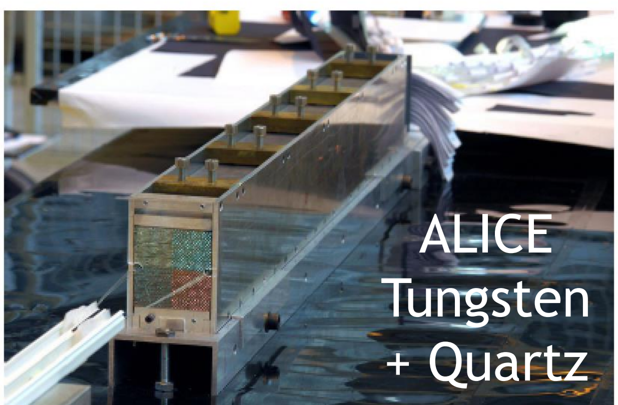


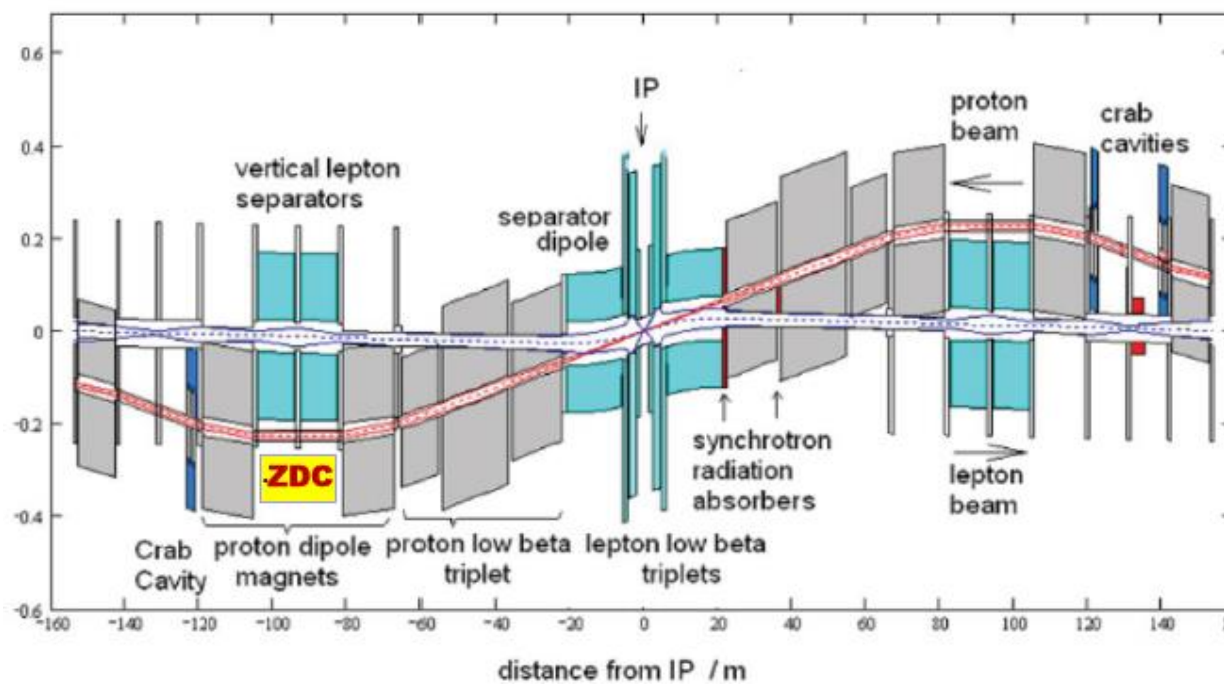
- Crucial in ed, to distinguish scattering from proton or neutron



- Possible “straight on” space at z ~ 100m

- For technology, learn from LHC





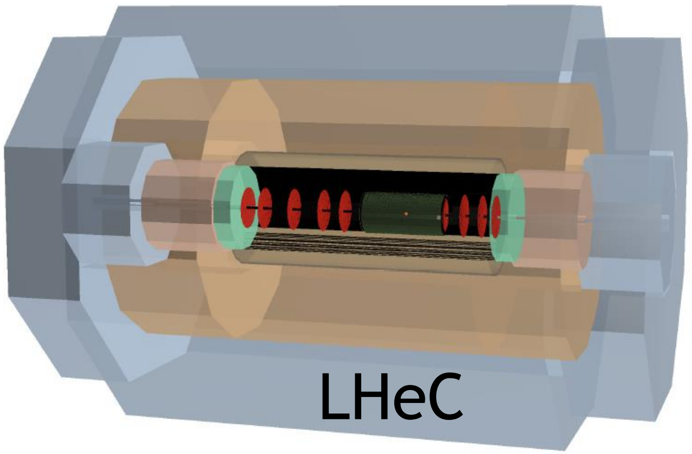
Summary

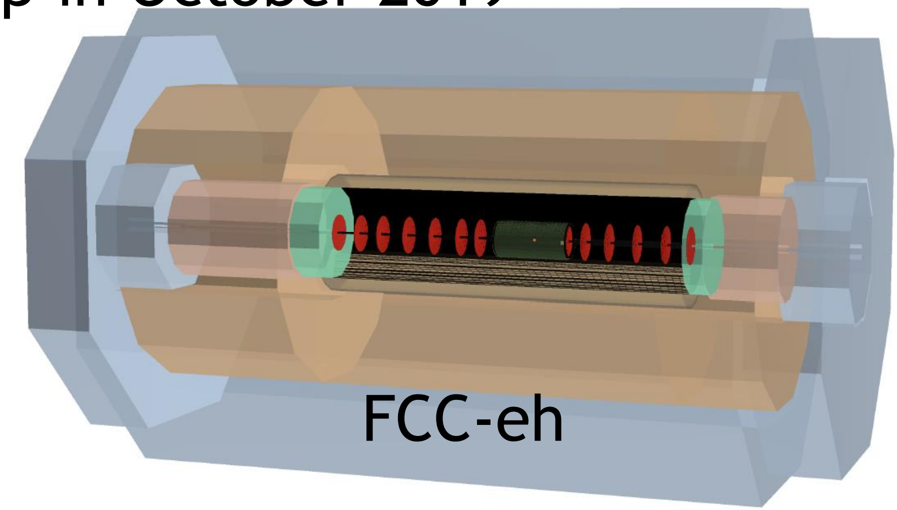
- CDR 2012

- Since then
  1) Possibility of 10^{34} cm^{-2} s^{-1} → new environment
  2) LHC Higgs discovery → new physics focus
  3) Longer term perspective of HE-LHeC / FCC-eh

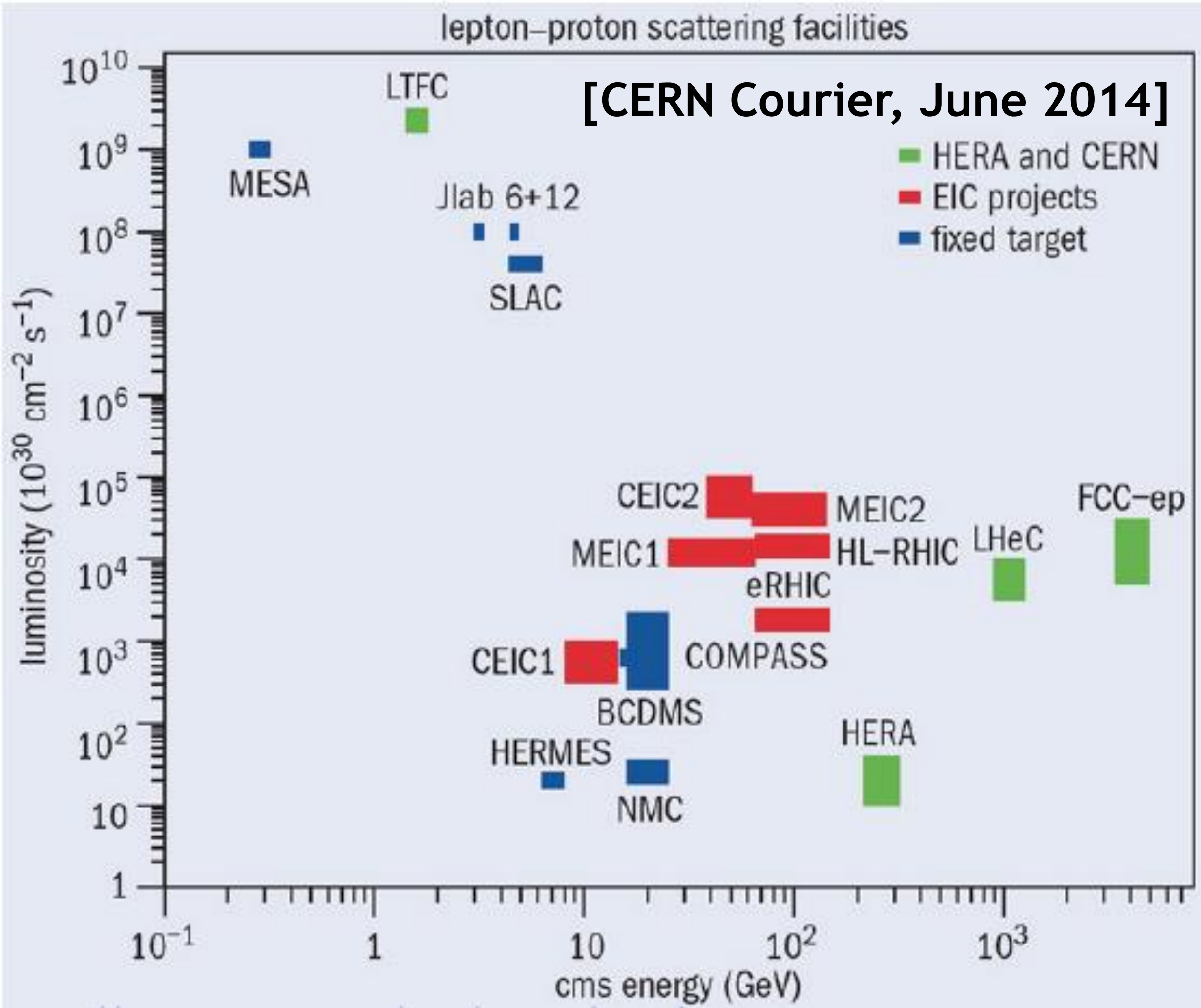
- Current ongoing work: optimize w.r.t. precision physics, H, t … re-evaluation of tracking & calorimetry, interaction region

- Next goal …
  1) Update CDR (physics, technical) → "The LHeC at High Luminosity" converging at workshop in October 2019





LHeC Context

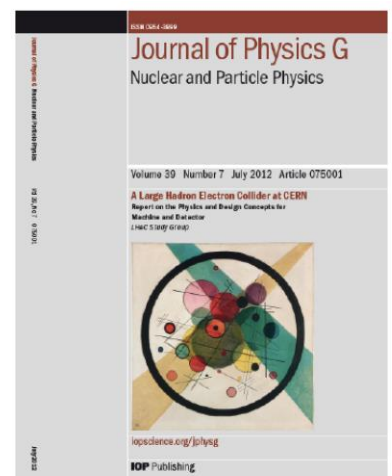


Proposed energy frontier high luminosity ep / eA facility → TeV scale physics at 10^{34} cm^{-2}s^{-1}

LHeC: 60 GeV electrons x LHC protons & ions
→ 10^{34} cm^{-2} s^{-1}
→ Simultaneous running with ATLAS / CMS in HL-LHC period

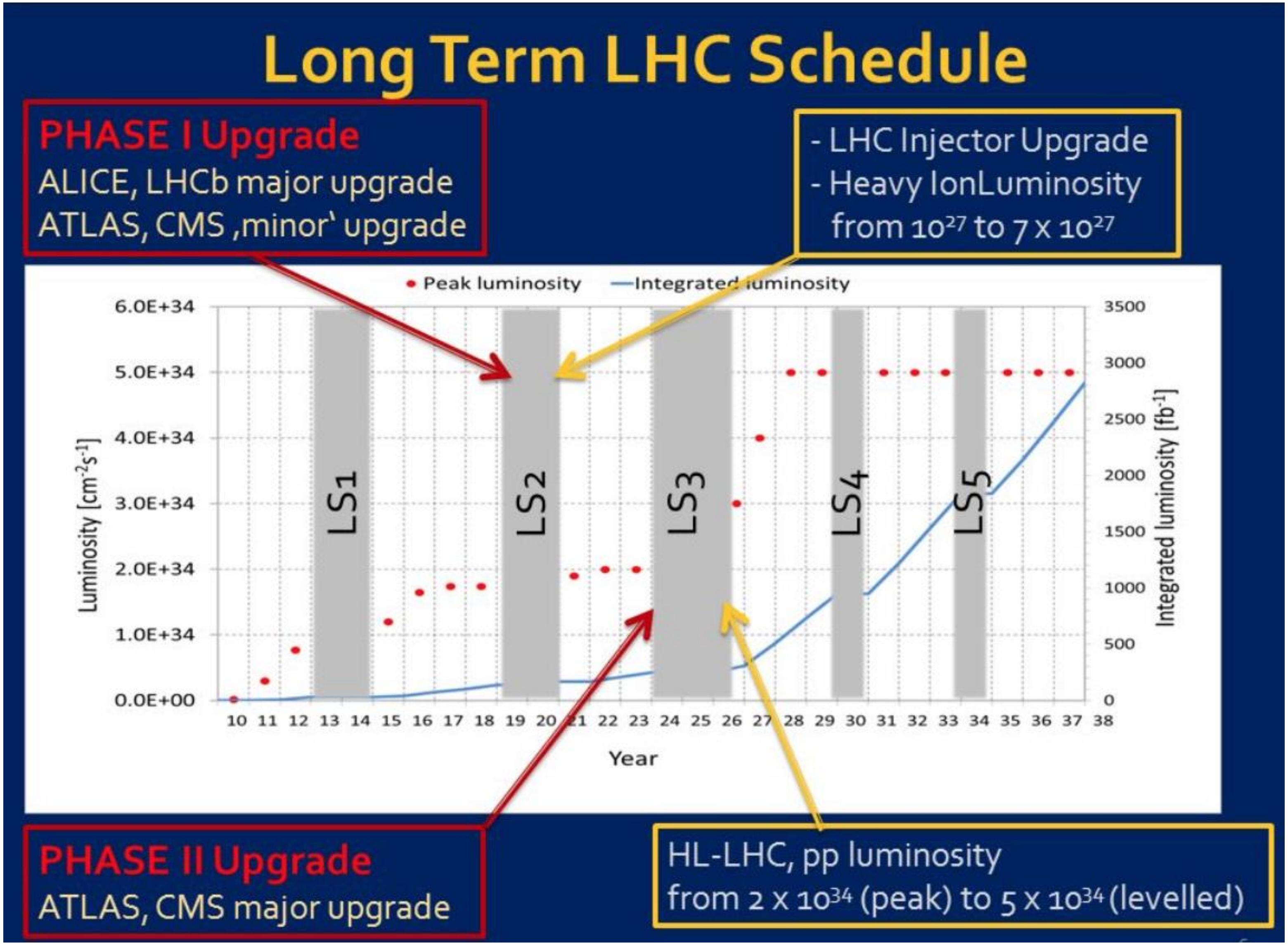
FCC-ep: 60 GeV electrons x 50 TeV protons from FCC

CDR 2012: "Fake news?" … lots changed



arXiv:1206.2913

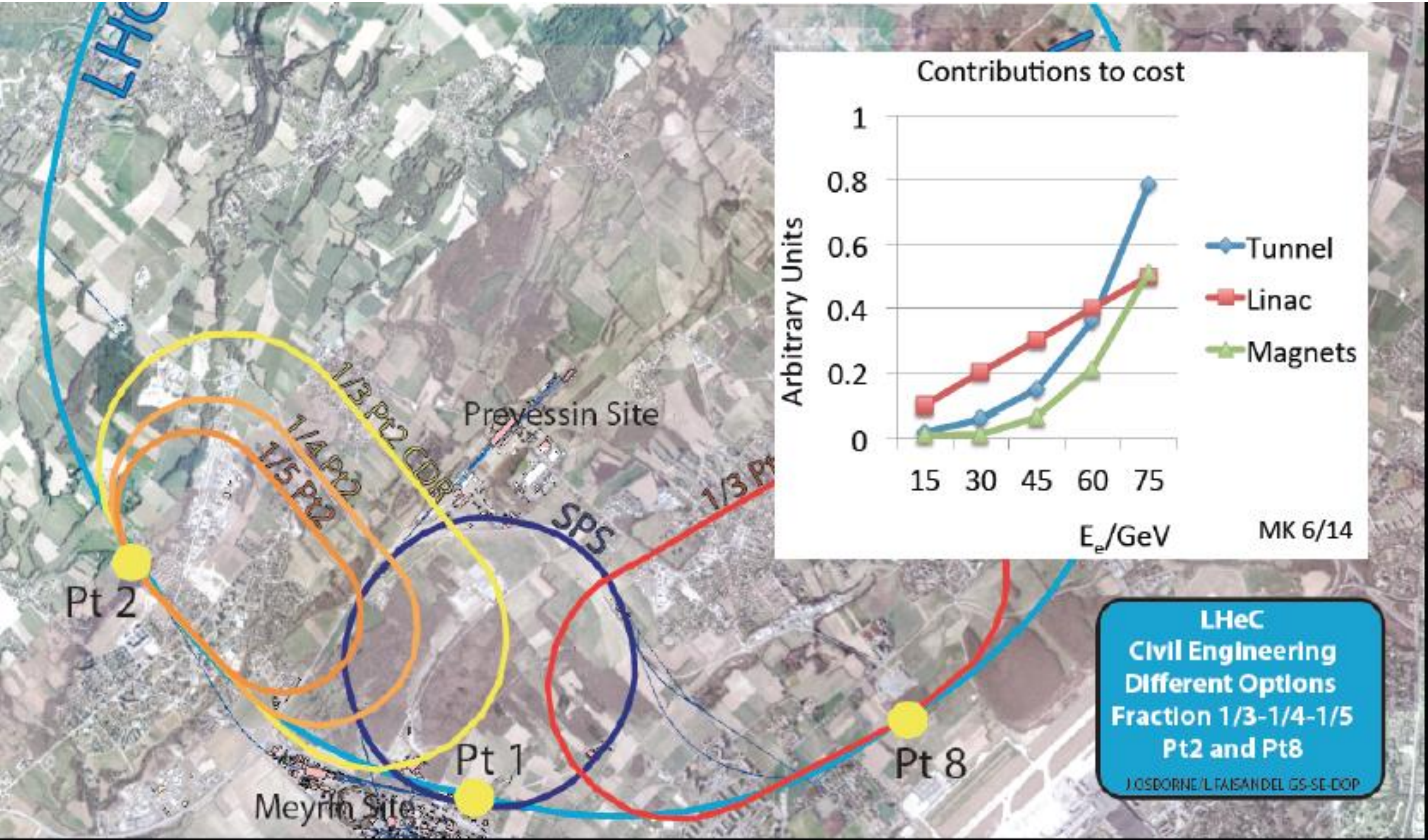
LHeC Timeline



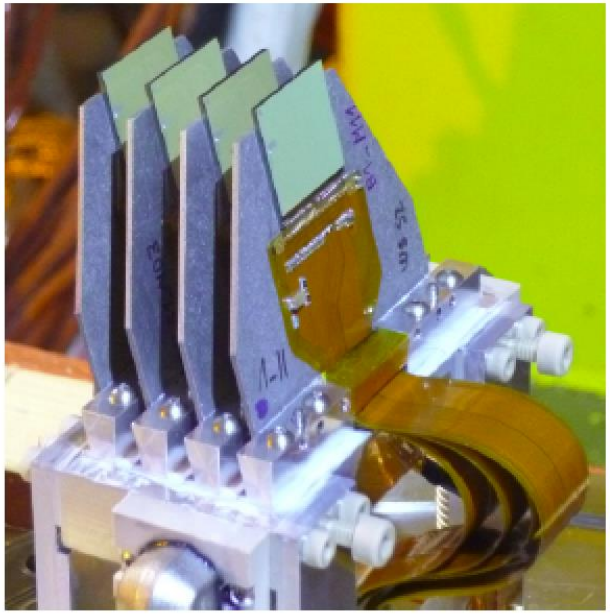
Not defined … but makes best sense in parallel with HL-LHC … schedule extends to 2040; LS4, LS5 are possibilities

Where could the LHeC be built?

- Default design is 1/3 at Point 2 (currently ALICE)
- Point 8 (currently LHCb) has also been considered

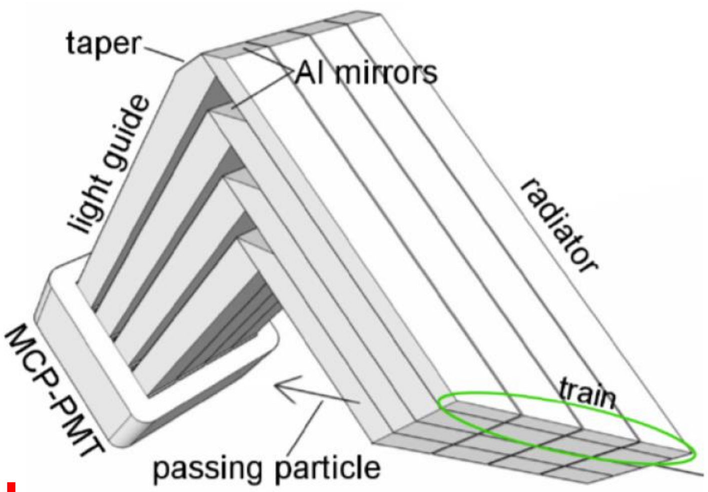


AFP Detectors inside Pots



Tracking: four slim-edge 3D pixel sensor planes per station (ATLAS IBL)
- Pixel sizes 50x250 μm
- 14^{o} tilt improves x resolution (hence ξ)
  → $\delta x = 6\ \mu m$, $\delta y = 30\ \mu m$
- Trigger capability

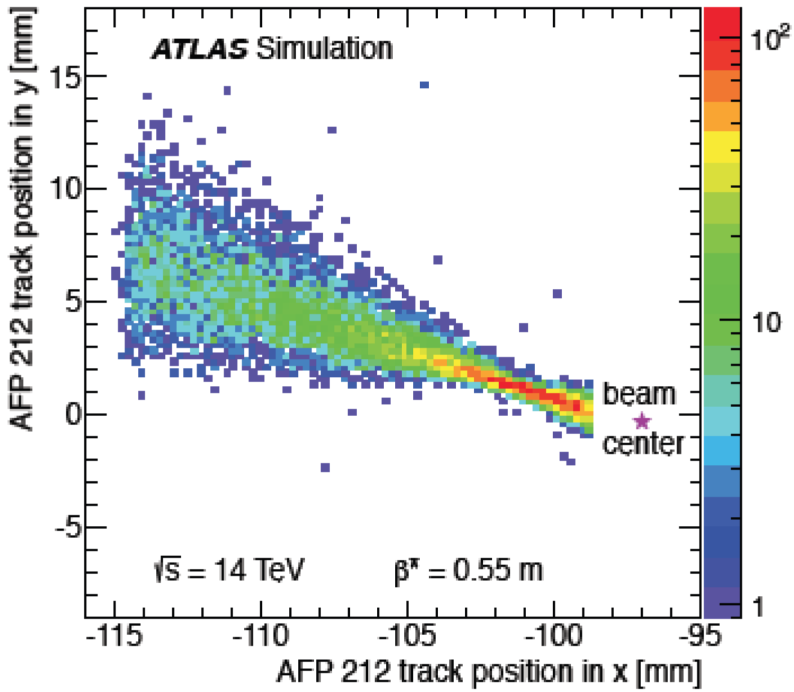
Timing: 4x4 quartz bars at Cerenkov angle to beam. Light detected in PMTs
→ expected resolution 25ps

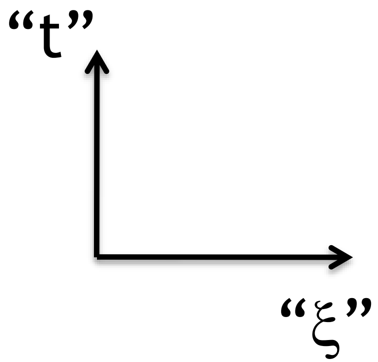


But we can't just put them everywhere!
- Locations of pots restricted by beam elements
- Scattered proton trajectories blocked by collimators etc
- Sensitive detectors can't approach arbitrarily close to beam

Acceptance Depends on Location and Orientation of Pot and on beam optics

AFP



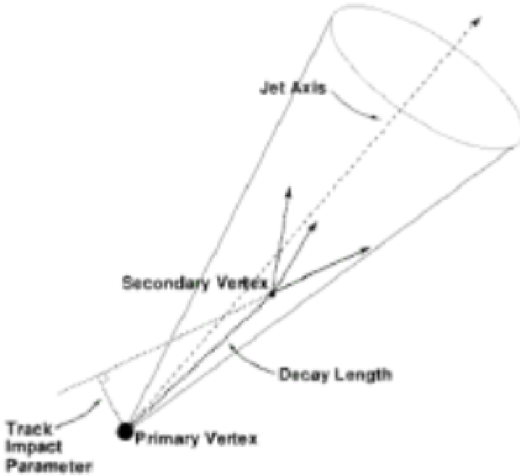


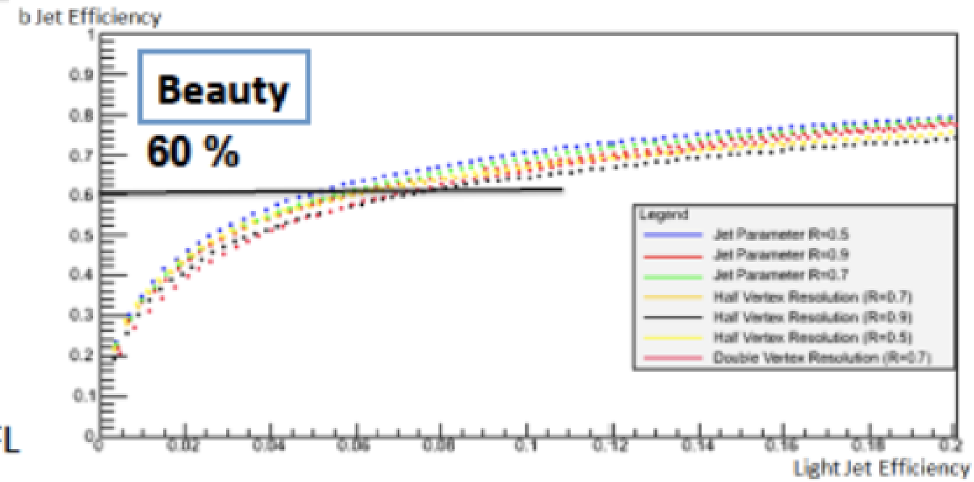
- In ATLAS case, complementarity between ATLAS ALFA (vertical approach) and AFP (horizontal approach)
- AFP acceptance for inelastic diffraction with ξ >~ 0.02
- Current situation is result of prolonged study, also with machine group, and optimisation / compromise on beam optics.

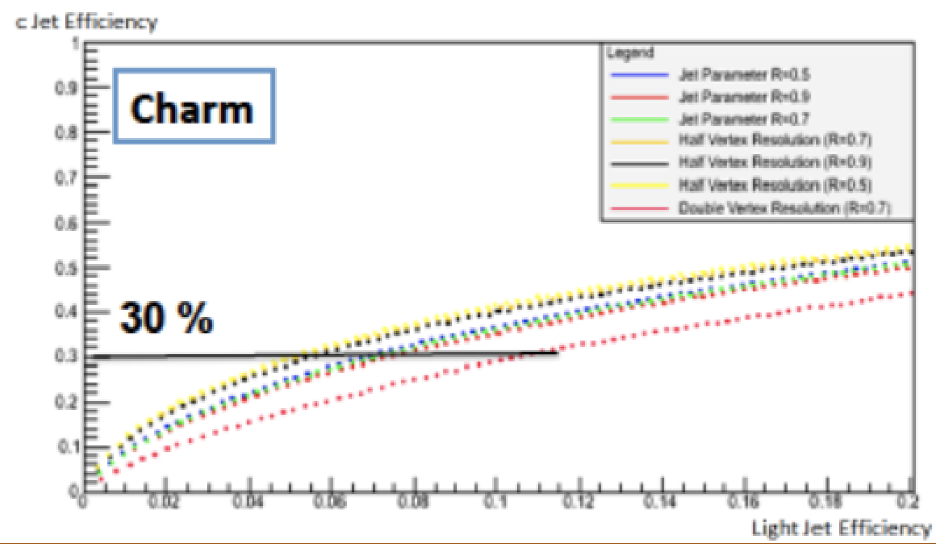
Secondary Vertex Tagging

HFL Tagging

Uta Klein &
Daniel Hampson







- → Realistic and conservative HFL tagging within Delphes realised, and dependence on vertex resolution (nominal 10 μm) and anti-kt jet radius studied
- → Light jet rejection very conservative, i.e. factor 10 worse than ATLAS
- → **used in full LHeC analysis and for FCC-eh extrapolations**

CDR Muon System

Baseline: Provides tagging, but not momentum measurement

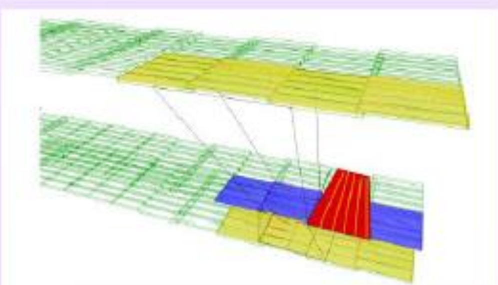
(under review in view of Higgs physics programme)

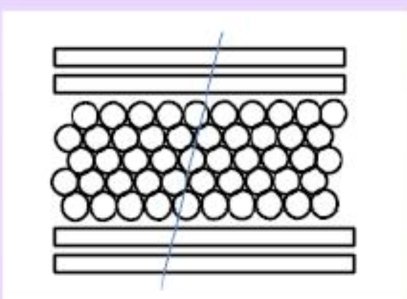
: Angular coverage → 1º vital eg for elastic J/Ψ

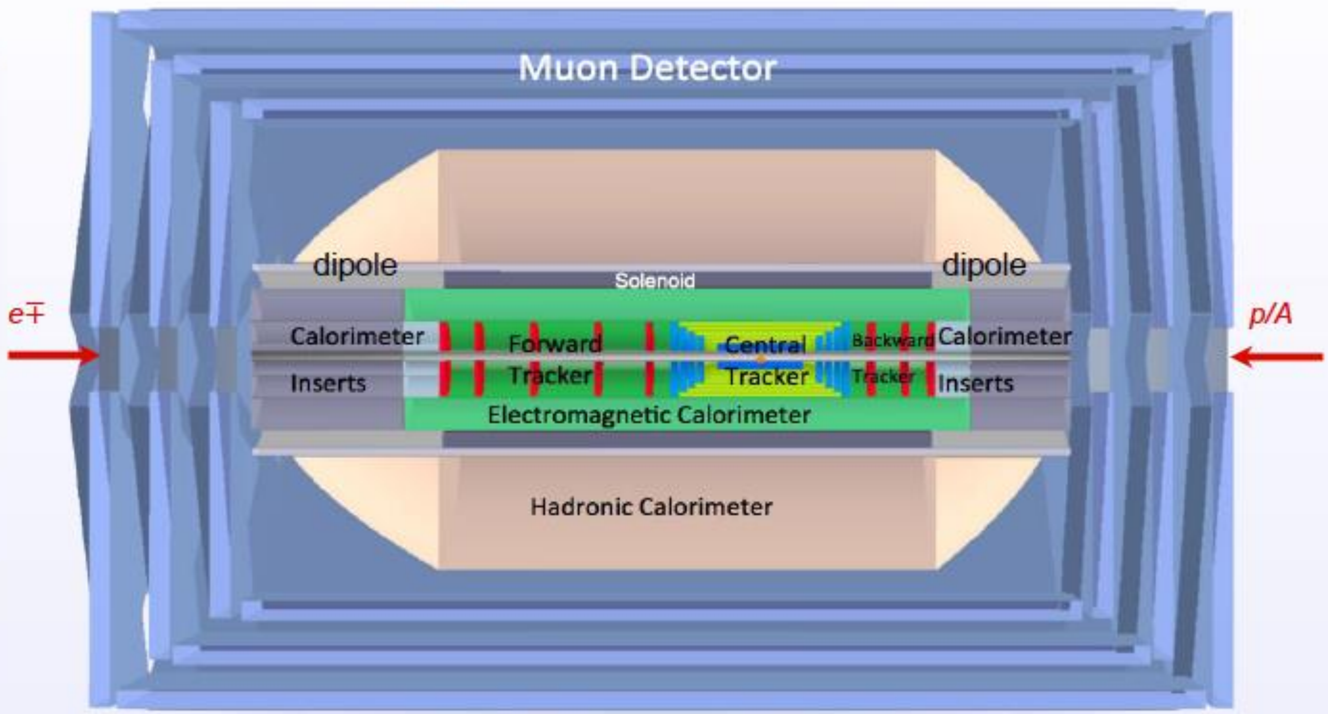
: Technologies used in LHC GPDs and their upgrades

(more than) adequate

[2 or 3 Superlayers]



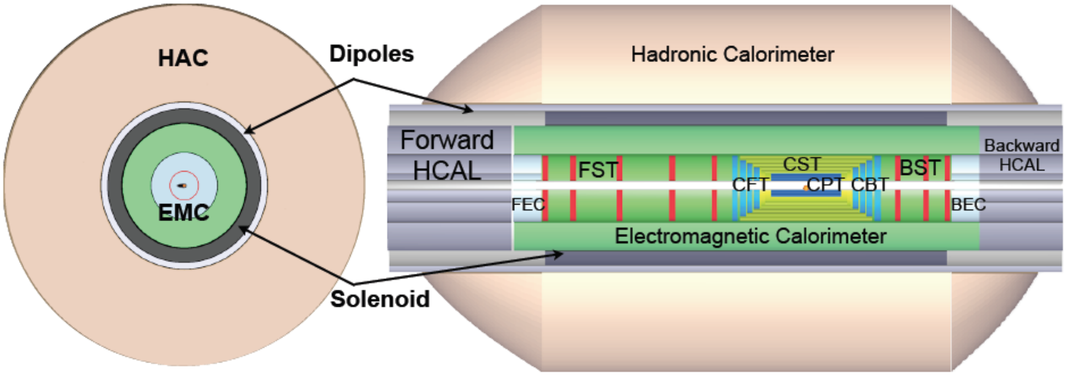




[Drift tubes / Cathode strip chambers → precision

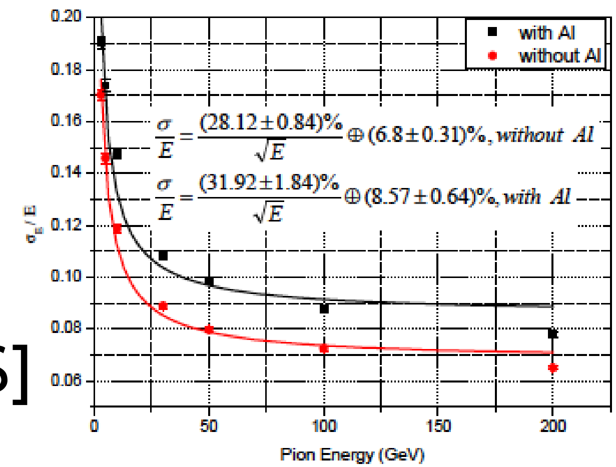
Resistive plate / Thin Gap chambers → trigger + 2^{nd} coord]

Other Calorimeters in the CDR



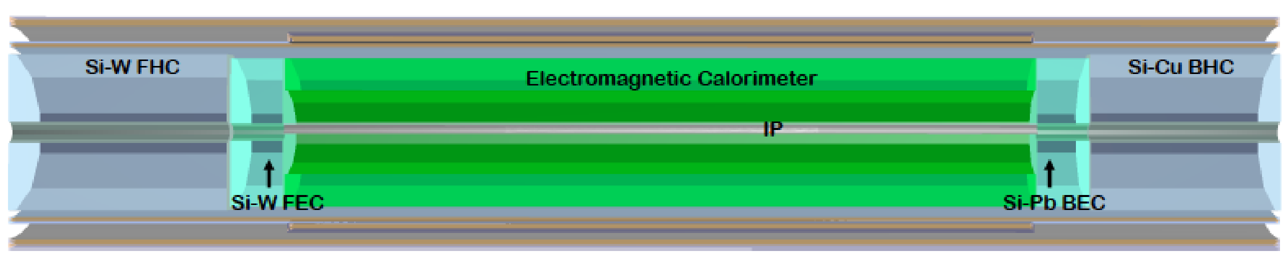
Current design based on (experience with) ATLAS (and H1), re-using existing technologies

- Barrel HAD calorimeter, outside coil
  → 4mm Steel + 3mm Scintilating Tile
  → 7-9 λ, $\sigma_E/E \sim 30\%/\sqrt{E} + 9\%$ [~ ATLAS]

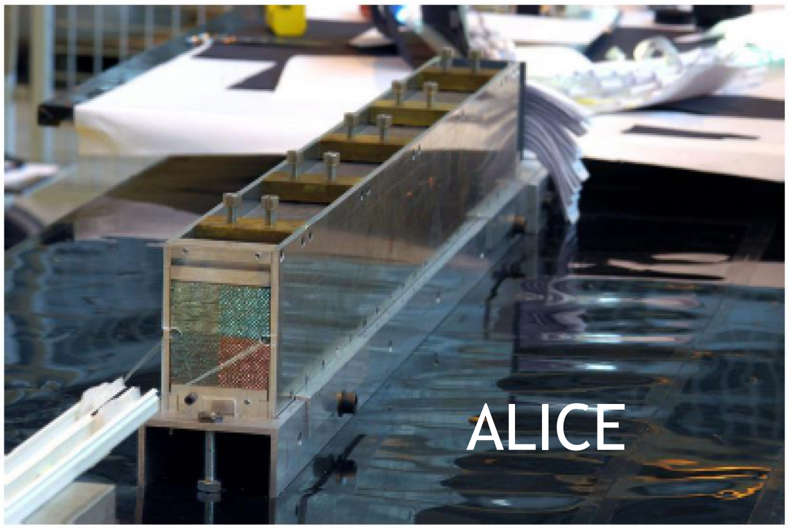


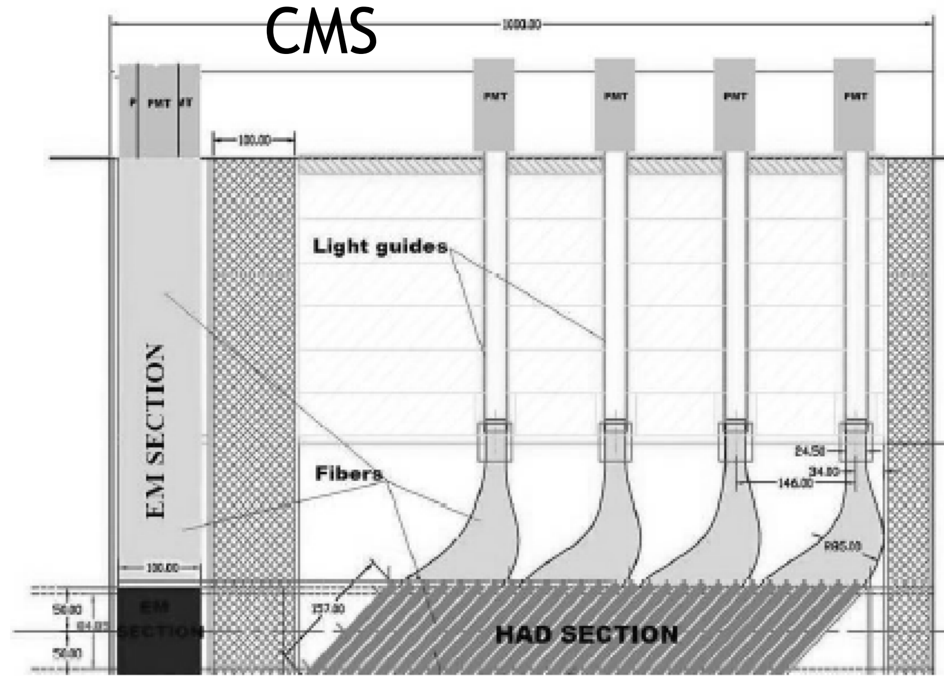
- Forward end-cap silicon + tungsten, to cope with highest energies & multiplicities, radiation tolerant EM → $30X_0$, Had→9λ

- Backward end-cap
Pb+Si for EM ($25X_0$)
Cu+Si for HAD (7λ)



Leading Neutrons: Solutions from LHC
… needs to be compact and radiation-hard





- ALICE, ATLAS, CMS all use tungsten absorber + quartz fibres (Cerenkov).
- LHCf uses tungsten + plastic scintillator in special runs
- Improve hadronic response with dual quartz / scintillator?
- Longitudinal segmentation essential to distinguish neutrons from photons.