A Detector(*) for the Large Hadron-electron Collider

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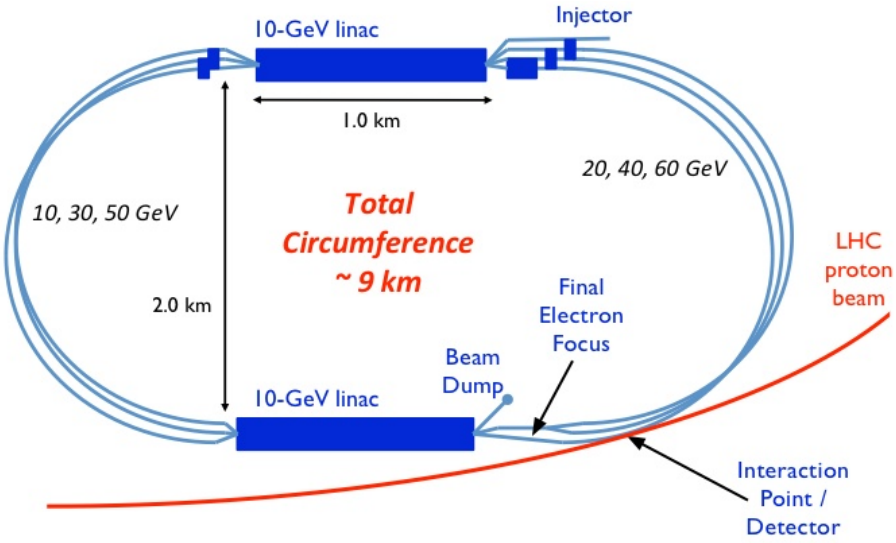
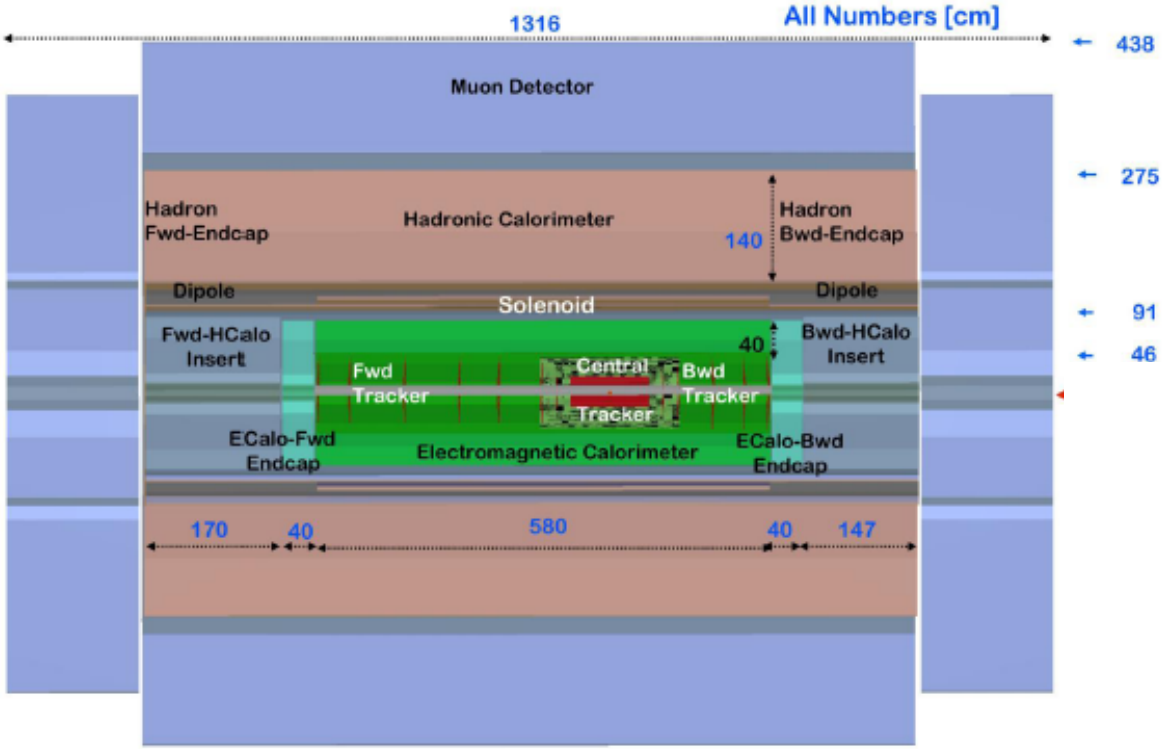
Birmingham University

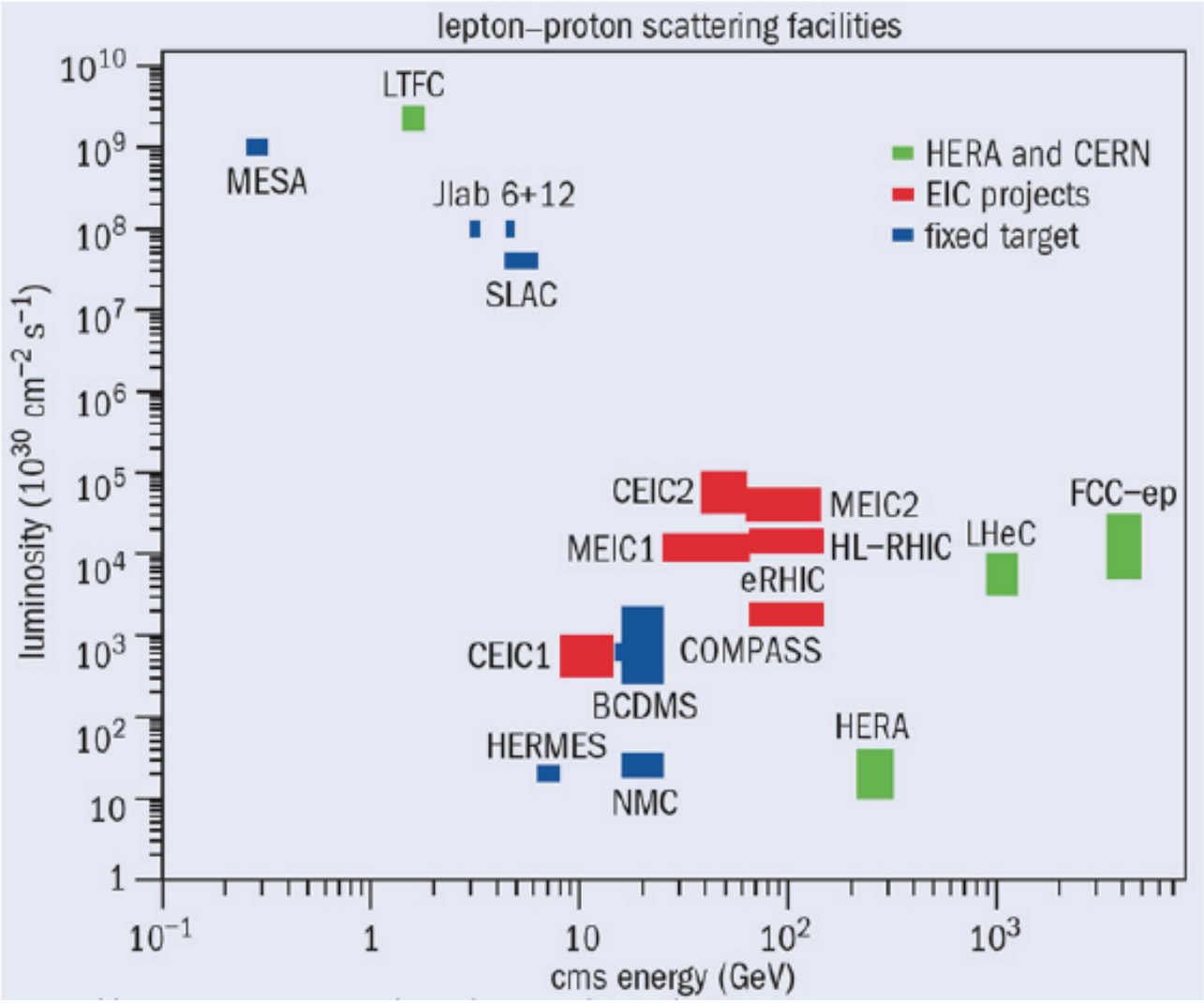




EPS 2015
Vienna
24 July 2015

(*) Current Baseline Linac-Ring Version

LHeC / FCC-he Context



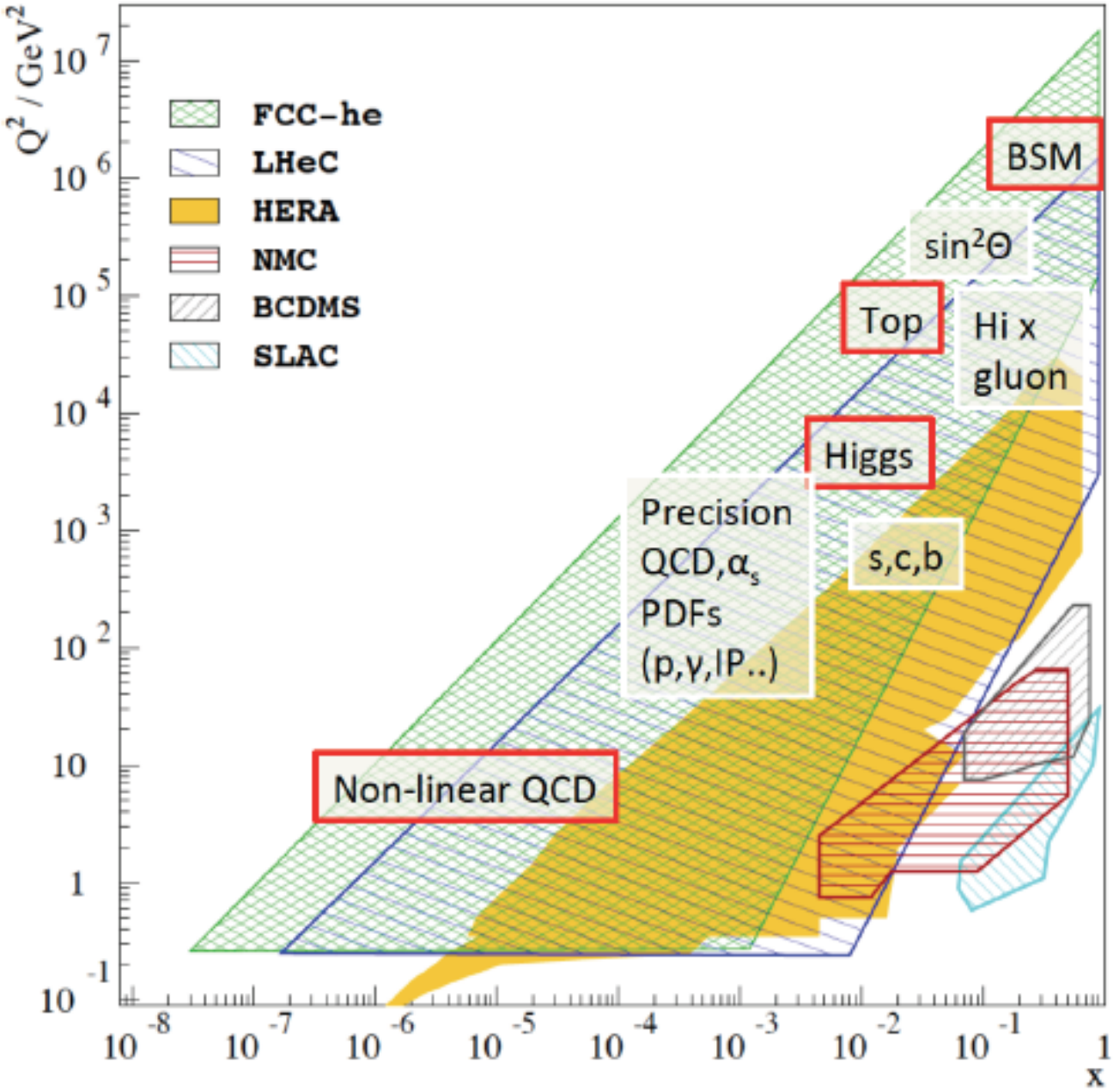
LHeC CDR, July 2012 [arXiv:1206.2913]

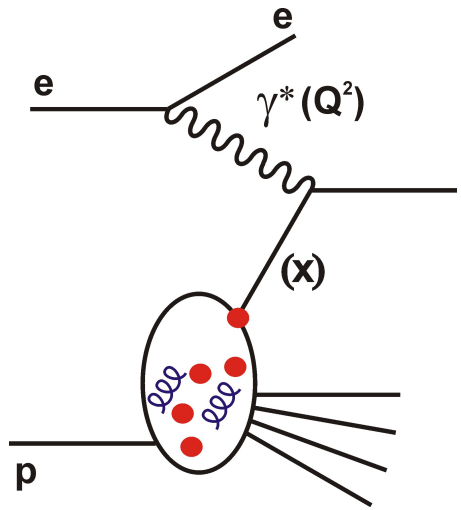
- Lepton-hadron scattering at the TeV scale …

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

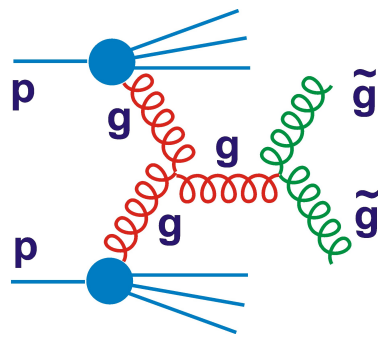
FCC-he: 60 GeV electrons x 50 TeV protons from FCC

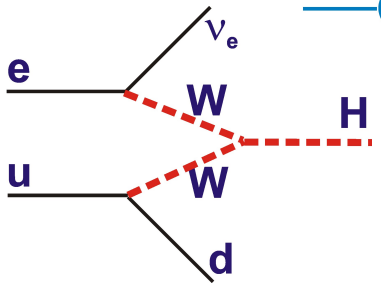
Physics Overview





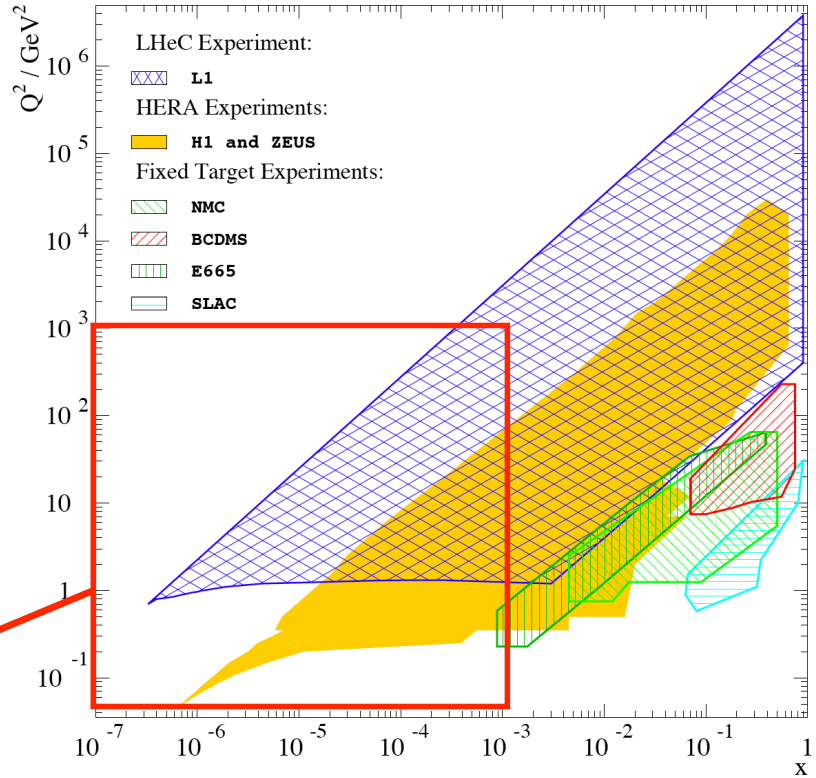
Diverse physics goals require precision throughout wide accessible kinematic region.

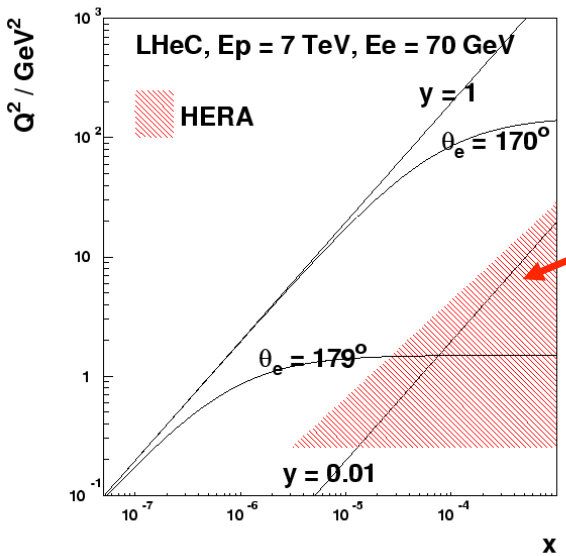


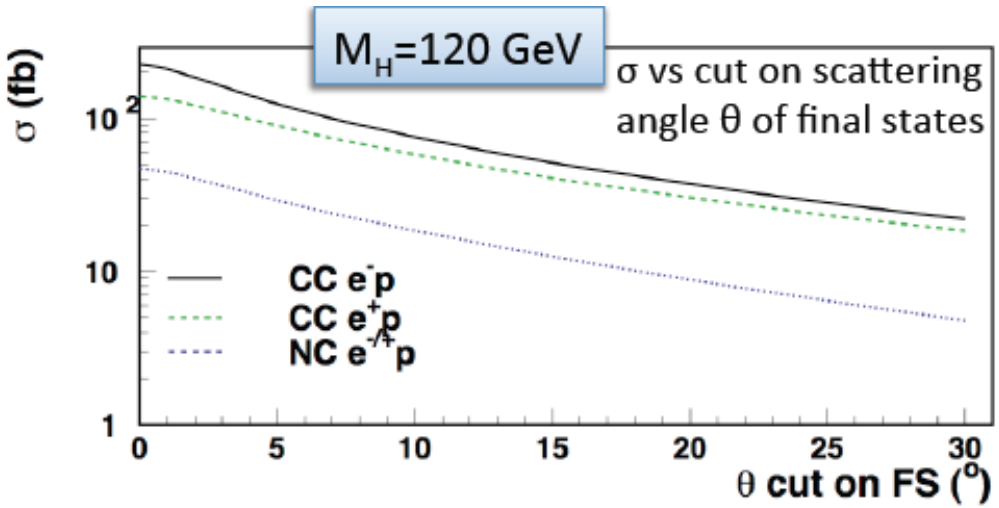


LHeC Kinematic Detector Requirements

Access to Q^2=1 GeV^2 for all x > 5.10^{-7} acceptance for electrons scattered through as little as 1°

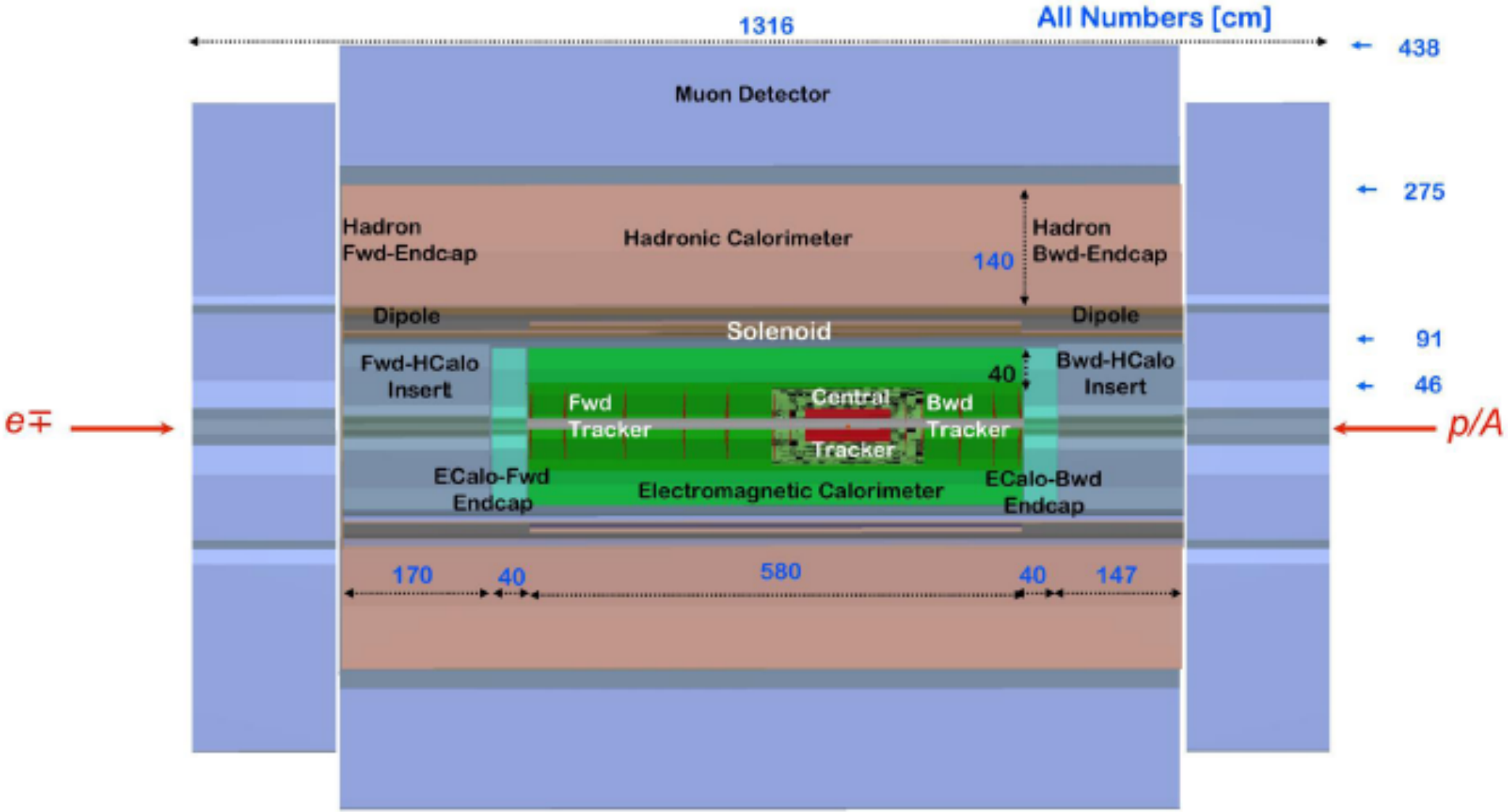






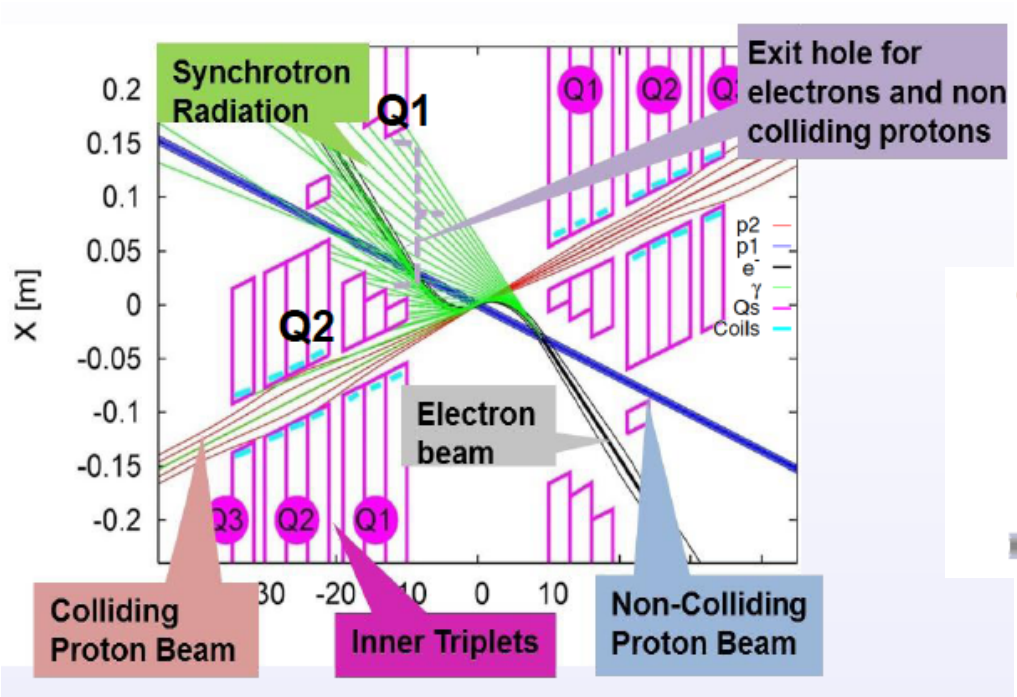
Also need 1° acceptance in outgoing proton direction to maximise acceptance for Higgs, sensitivity to high x signatures, and contain hadrons for kinematic reconstruction

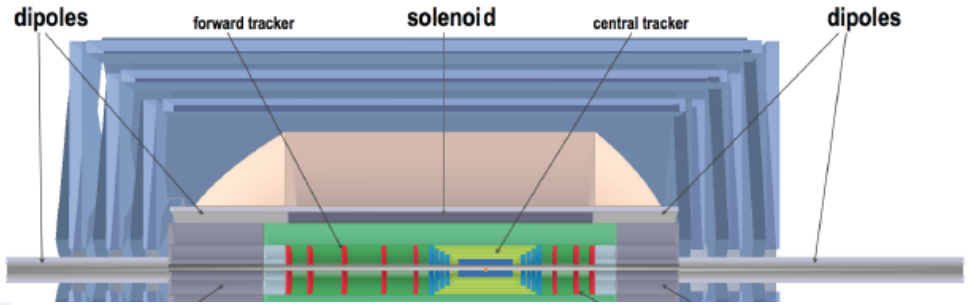
Detector Design Overview

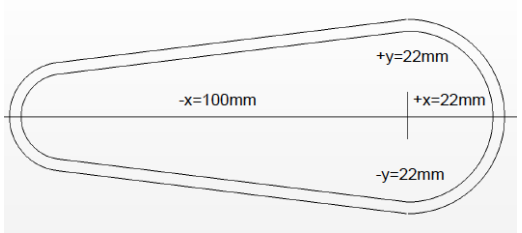


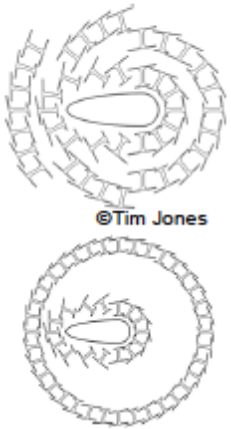
- Present size 13m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- Forward / backward asymmetry reflecting beam energies
- Demanding tracking → high fraction of pixels, wide acceptance

Interaction Region & Magnets





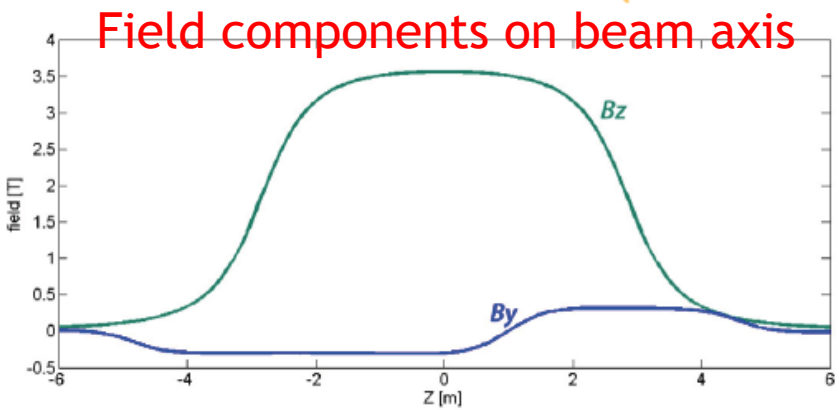




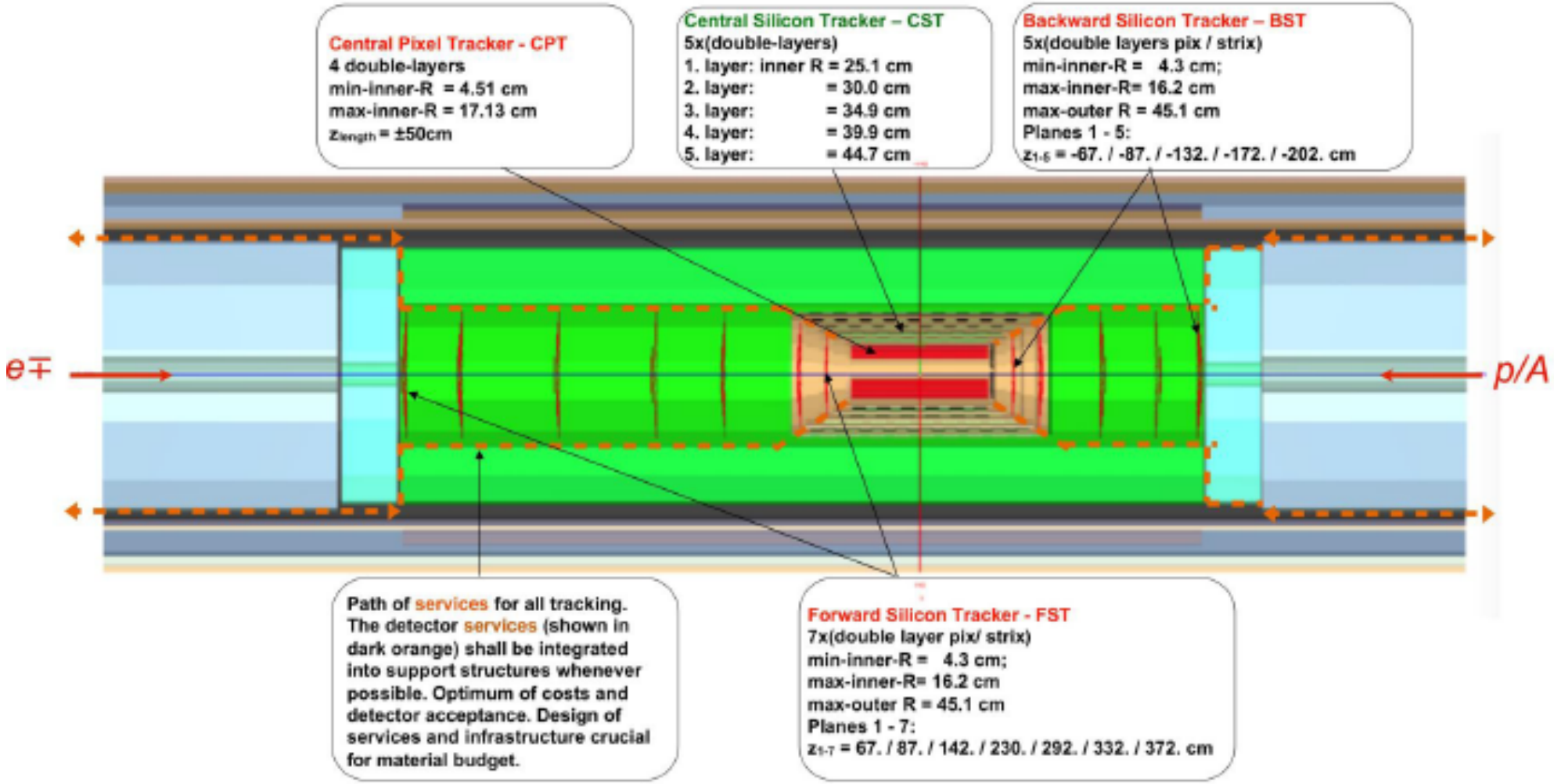
- Dual dipole magnets (0.15 – 0.3 T) throughout detector region (|z| < 14m) bend electrons into head-on collisions

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

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



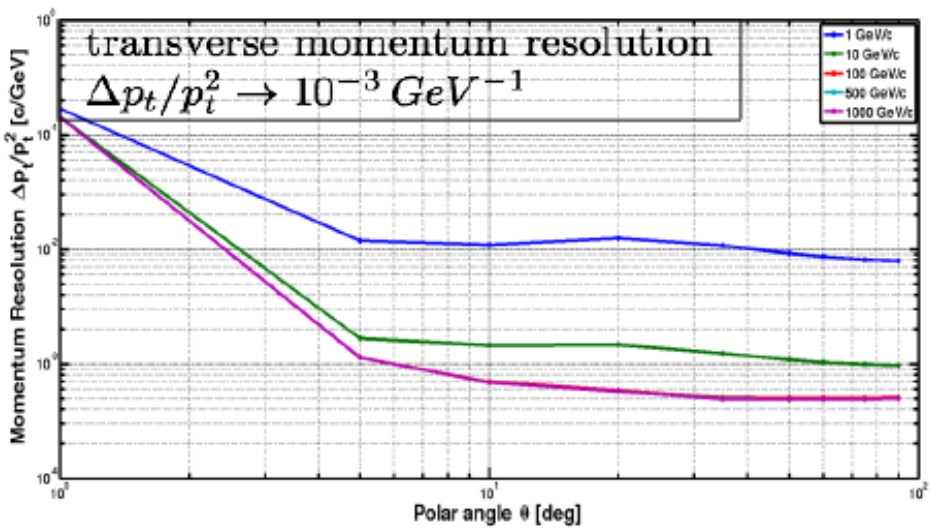
Tracking Region

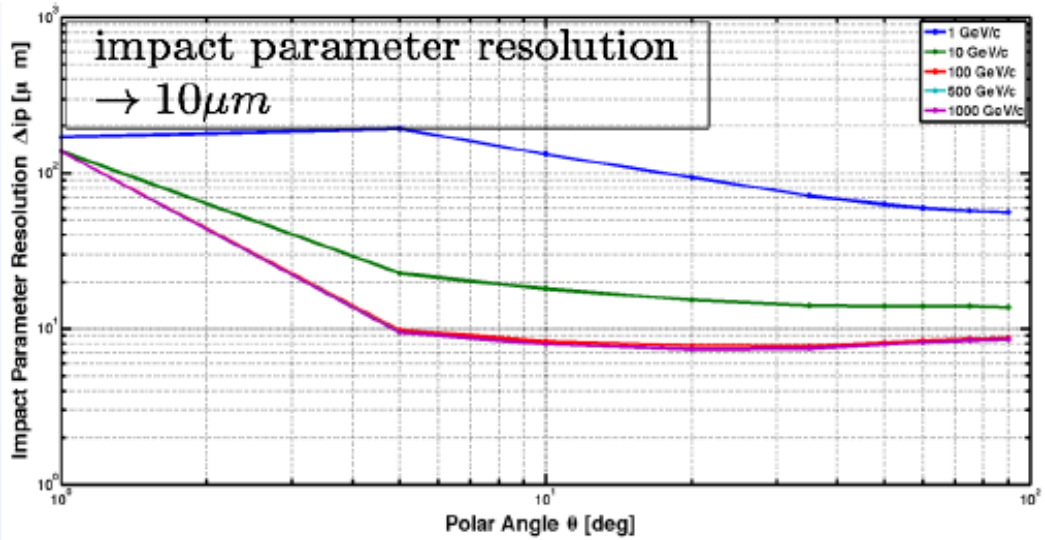


- Long tracking region → 1° electron hits 2 tracker planes
- Forward direction most demanding (dense, high energy jets)
- Pixels (CPT) + Strips; several technologies under discussion

Tracking Simulation

Performance evaluated from basic layout (LicToy 2.0 program)





- Central tracks:

  Excellent track resolution: $\Delta p_t/p^2_t \rightarrow 6.10^{-4}$ GeV^{-1}

  Excellent impact parameter resolution: → 10μm

- Forward / Backward tracks:

  Resolution degrades for θ <~ 5°

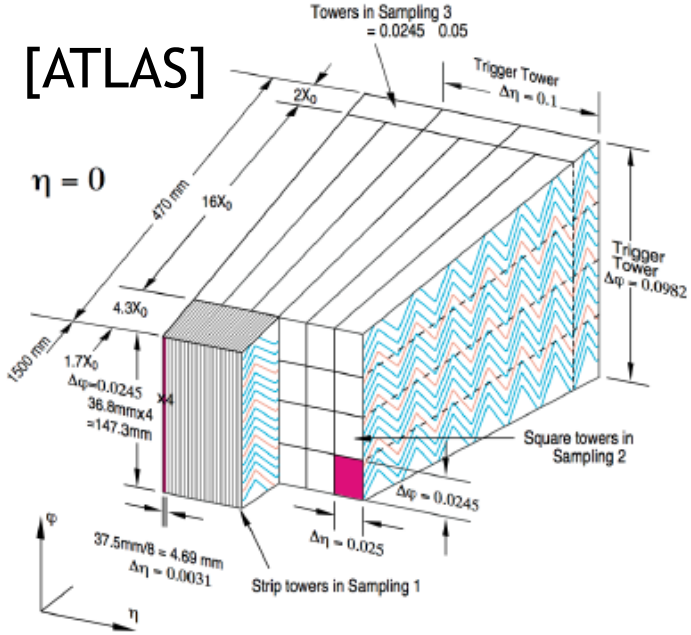
  At 1°, bending field component = 0.36 T (similar to dipole)

Barrel EM Calorimeter

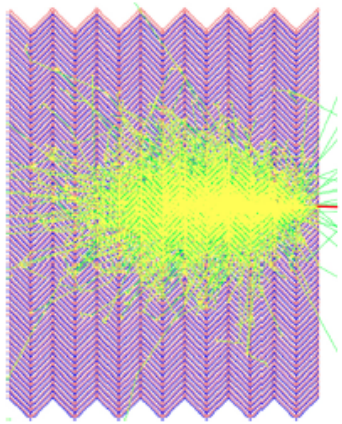
Liquid Argon Barrel EM Calorimeter inside coil

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

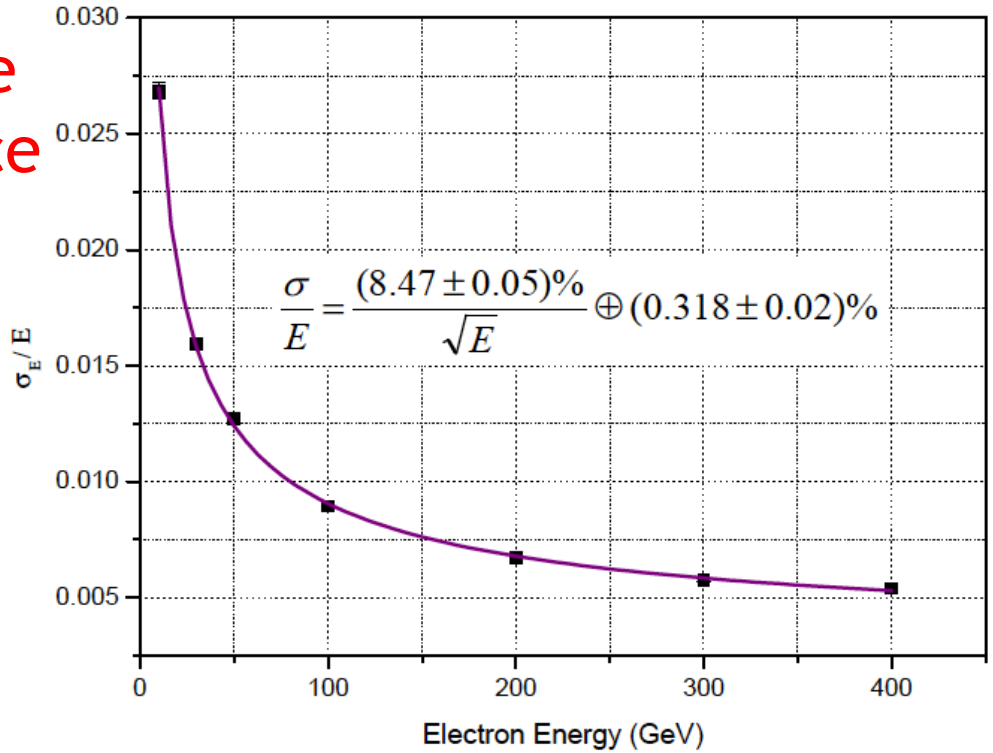
[ATLAS]



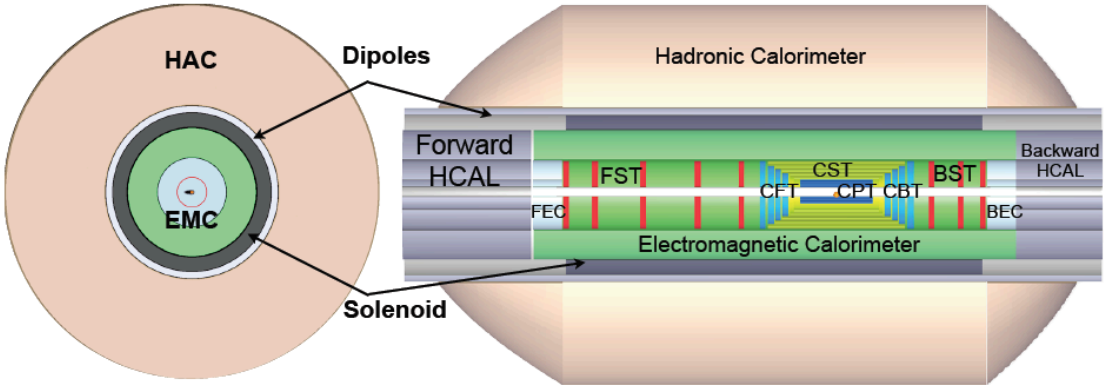
- Geant4 simulation of response to electrons at normal incidence [cf ATLAS: 10%/√E + 0.35%]



[20 GeV electron]



Calorimeters Overview

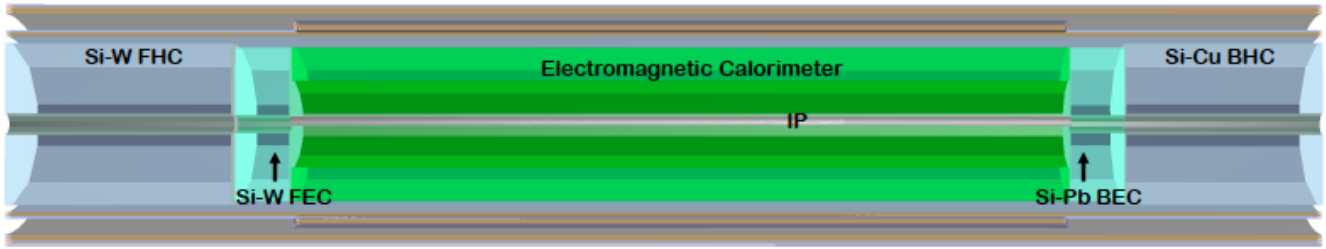


Current design based on (experience with) ATLAS (and H1), re-using existing technologies

- 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)

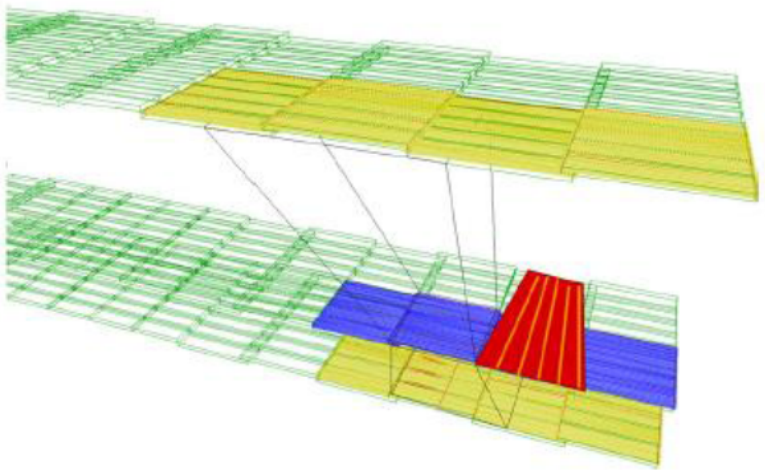


Muon System

Baseline: Provides tagging, but not momentum measurement
: Angular coverage → 1° vital eg for e.g. 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 + 2nd coord]

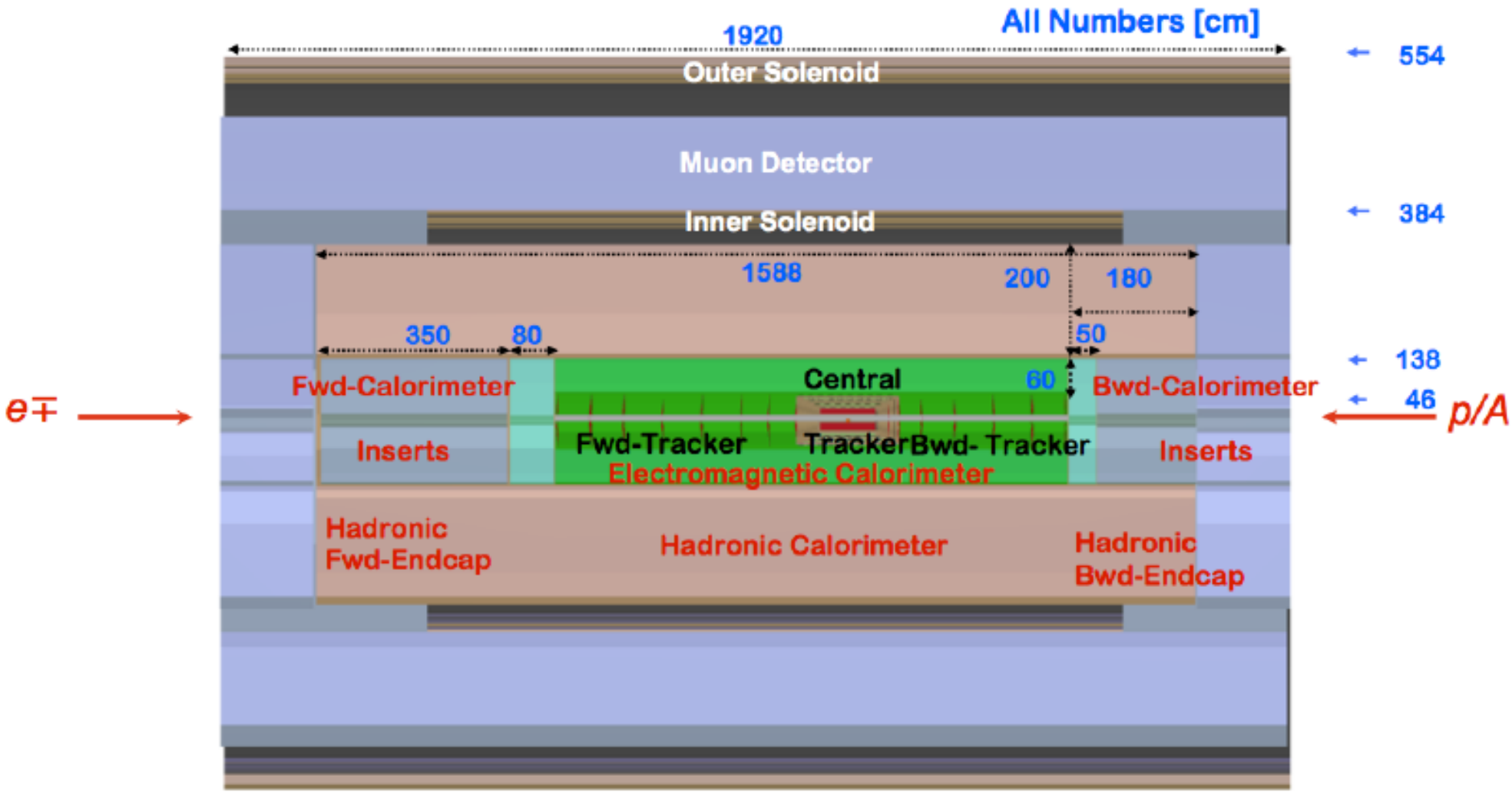


Beamline Instrumentation

- Forward proton & neutron tagging

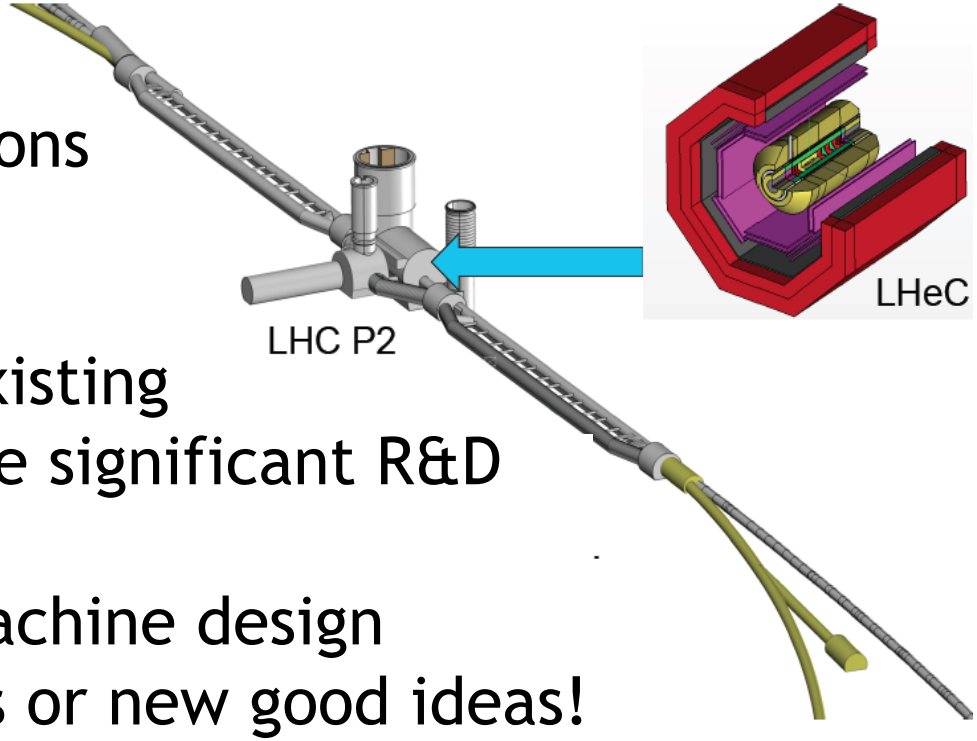
-Backward electron tagging & luminosity monitoring (ep→epγ)

First Thoughts on FCC-he Detector



- Shower depths: dimension x ln(50/7)~2 fwd, ~1.3 bwd, central
- How to ensure head-on-collisions? [p Crab cavities? Dipoles?]
- Higgs physics → improved muon detectors, b tagging …

Summary



- Possible LHeC detector solutions evaluated in some detail

- Ideas shown here based on existing technologies and do not require significant R&D

- May change in response to machine design development, physics demands or new good ideas!

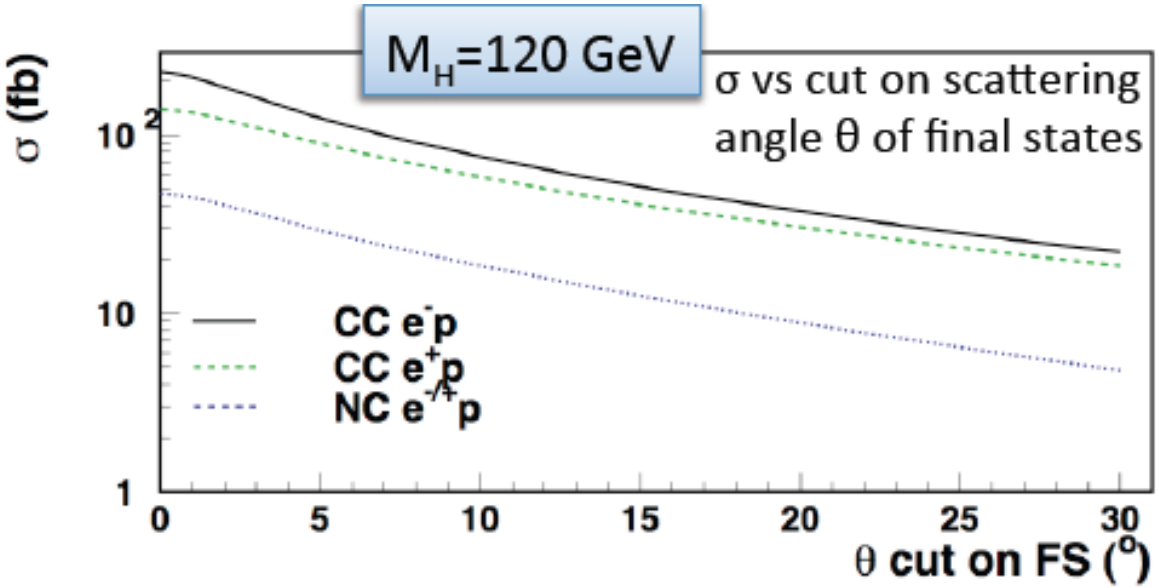
- Full detector simulation under development using DD4HEP tool-kit → towards a Technical Design Report

• More, at LHeC web …
lhec.web.cern.ch
and …

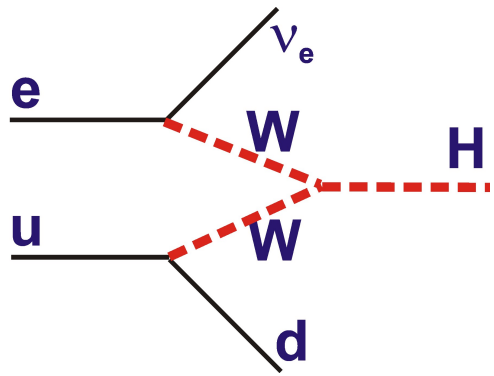
- LHeC Study Group (CDR), J Phys G39 (2012) 075001
- Klein & Schopper, CERN Courier, June 2014
- Newman & Stasto, Nature Phys 9 (2013) 448
- Bruening & Klein, Mod Phys Lett A28 (2013) 1130011

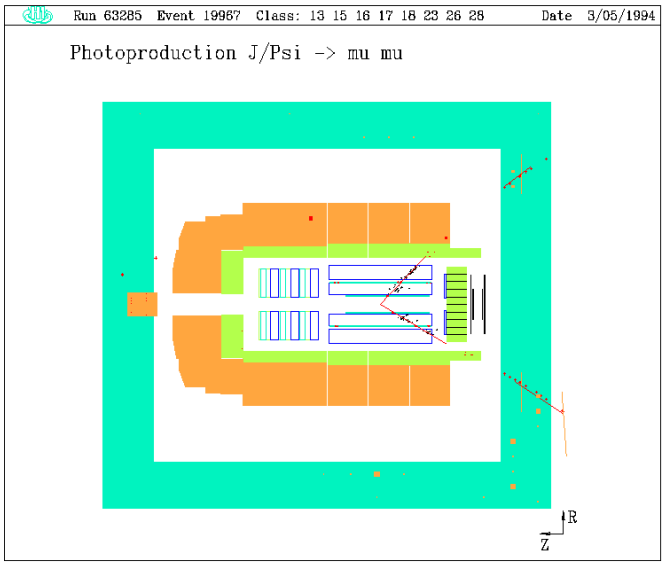
Back-ups Follow

Kinematic Requirements in Specific Channels

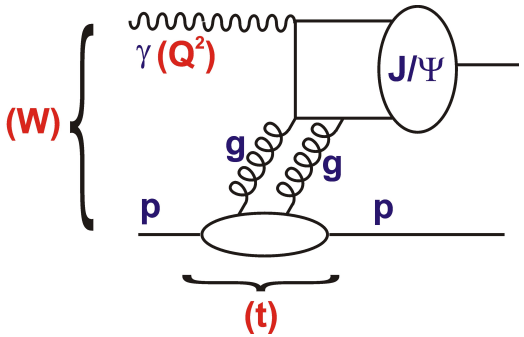


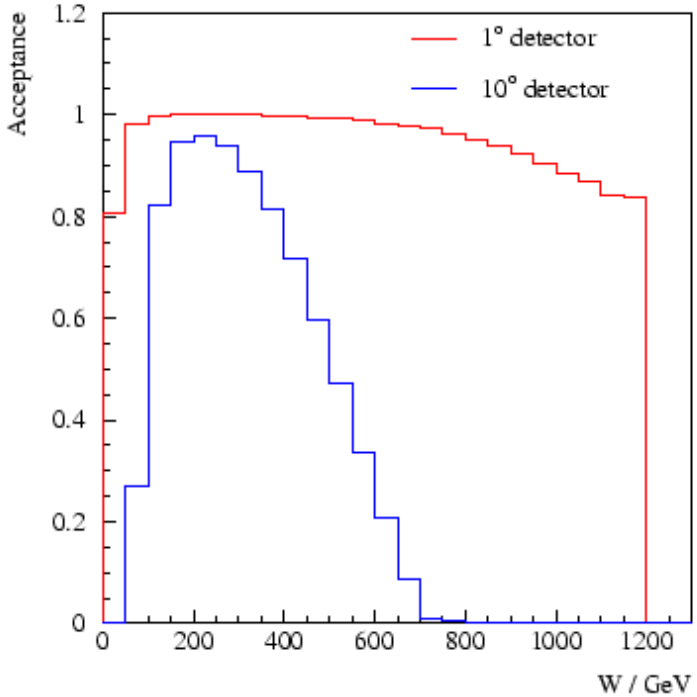
Higgs Production





Elastic J/Ψ Photoproduction





Requirements on Precision and Efficiency

Scattered Electron

- Good p_T and θ tracking resolution over maximum possible range (electron charge / angle)
- Minimal EM calorimeter scale uncertainty
- Excellent e/h separation at low energies
- Efficient tracking (e/γ separation)

Hadrons

- Primary vtx / p_T resolution (charged particles)
- Secondary vertex resolution (c, b quark ID)
- Excellent jet resolution & HAD calorimeter scale uncertainty (e.g. H→bbbar)
- Hermetic for missing E_T / CC identification
- Precise muons (searches, HF, vector mesons)

Beam-line

- Forward protons (diffraction / low x)
- Forward neutrons (heavy ions …)
- Backward photons (luminosity)
- Backward electrons (luminosity, photoproduction)

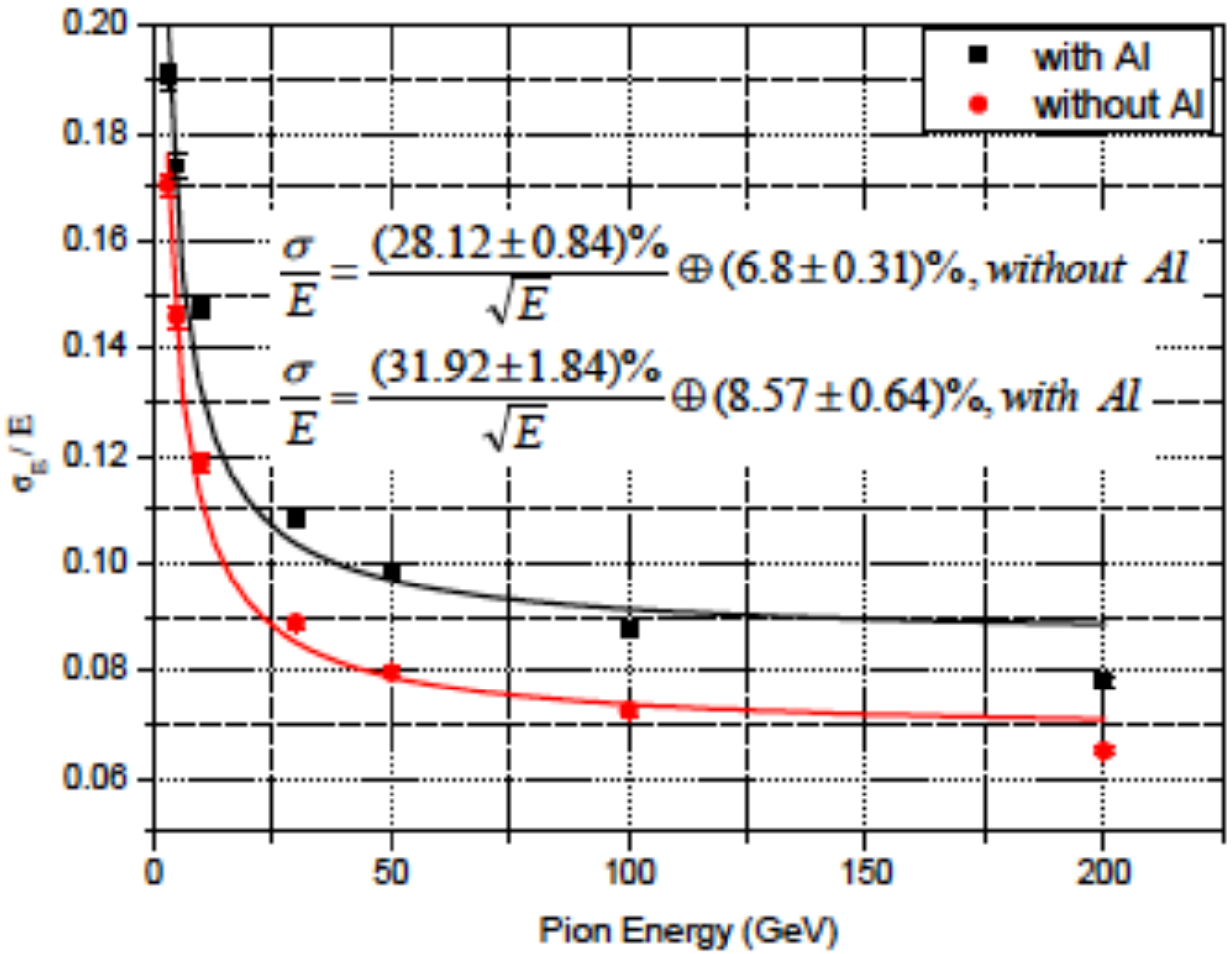
Barrel HAD Calorimeter

- Tile Sampling Calorimeter: 4mm steel, 3mm scintillator layers
- Total depth ~ 7-9 interaction lengths

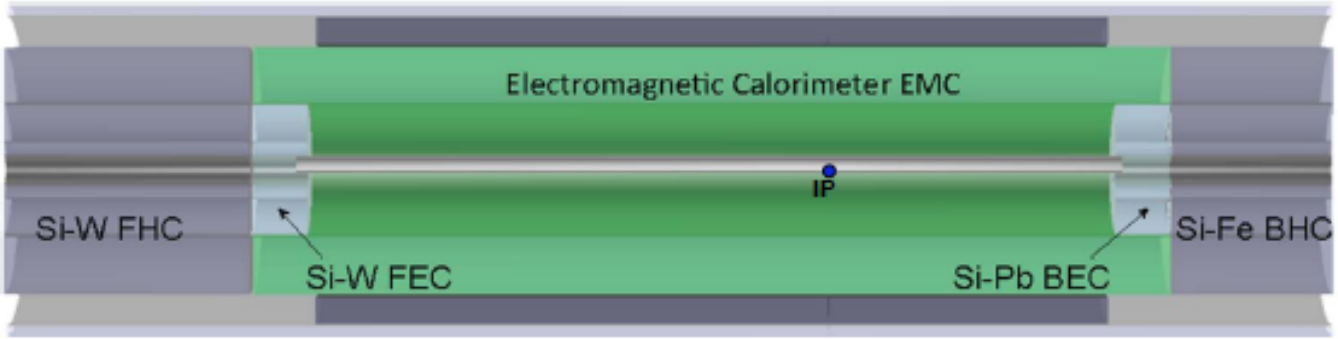
- Geant4 simulation of combined Lar + Tile response to charged pions at normal incidence

-14cm `Al' layer to simulate intermediate solenoid and cryo

[cf ATLAS:
30%/√E + 9%]



Forward & Backward Calorimeters



- Highest energies and multiplicities in forward direction.
  Radiation fluence also becomes an issue (but << LHC GPDs)
- Precision required in backward direction (scattered electron)

Fwd: Tungsten (short X_0) + silicon strips (EM) or pads (HAD)
EM ~ 30 X0, HAD ~ 9 λ

Bwd: Lead + Si strips
for EM (~ 25X0)

Copper + Si pads
for HAD (~ 7 λ)

Calorimeter Module (Composition)	Parameterized Energy Resolution
Electromagnetic Response	
$\mathrm{FEC}_{(\mathbf{W-Si})}$	$\frac{\sigma_E}{E} = \frac{(14.0 \pm 0.16)\%}{\sqrt{E}} \oplus (5.3 \pm 0.049)\%$
$\mathrm{BEC}_{(\mathbf{Pb-Si})}$	$\frac{\sigma_E}{E} = \frac{(11.4 \pm 0.5)\%}{\sqrt{E}} \oplus (6.3 \pm 0.1)\%$
Hadronic Response	
$\mathrm{FEC}_{(\mathbf{W-Si})}$ & $\mathrm{FHC}_{(\mathbf{W-Si})}$	$\frac{\sigma_E}{E} = \frac{(45.4 \pm 1.7)\%}{\sqrt{E}} \oplus (4.8 \pm 0.086)\%$
$\mathrm{FEC}_{(\mathbf{W-Si})}$ & $\mathrm{FHC}_{(\mathbf{Cu-Si})}$	$\frac{\sigma_E}{E} = \frac{(46.0 \pm 1.7)\%}{\sqrt{E}} \oplus 6.1 \pm 0.073)\%$
$\mathrm{BEC}_{(\mathbf{Pb-Si})}$ & $\mathrm{BHC}_{(\mathbf{Cu-Si})}$	$\frac{\sigma_E}{E} = \frac{(21.6 \pm 1.9)\%}{\sqrt{E}} \oplus (9.7 \pm 0.4)\%$

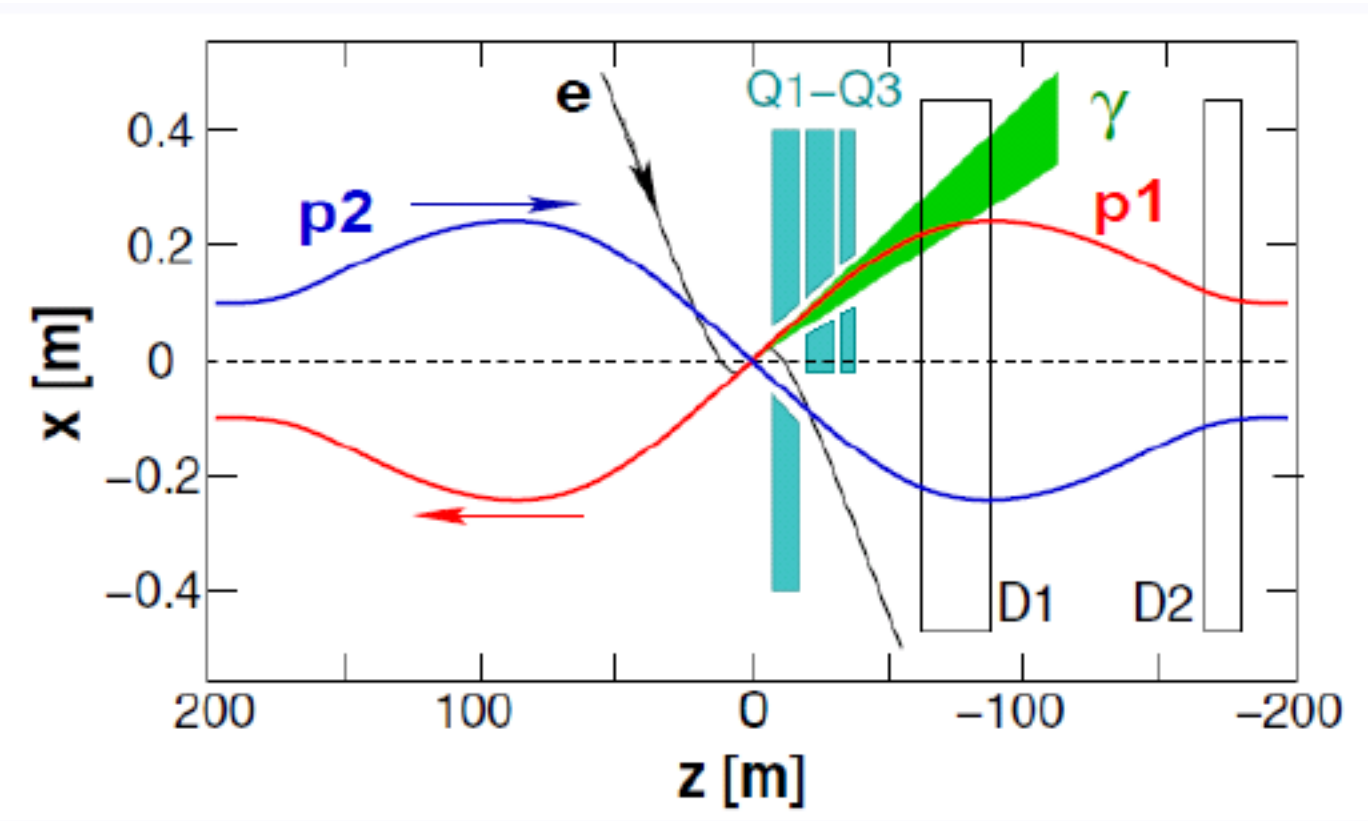
Luminosity / Photon Tagging

- Can measure luminosity (as at HERA) by tagging outgoing photons in Bethe-Heitler ep → epγ events

- With zero crossing angle, photons travel along beamline and might be detected at z = -120 m after D1 proton bending dipole.

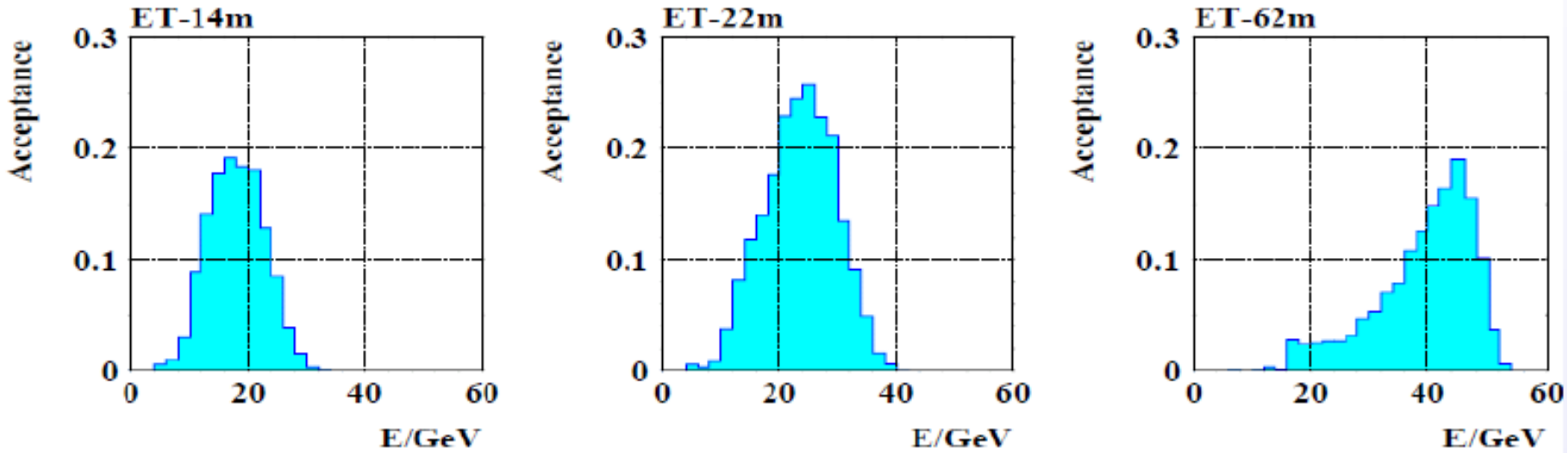
- With sufficient apperture through Q1-Q3 magnets, 95% geometrical acceptance possible

  → δL ~ 1%



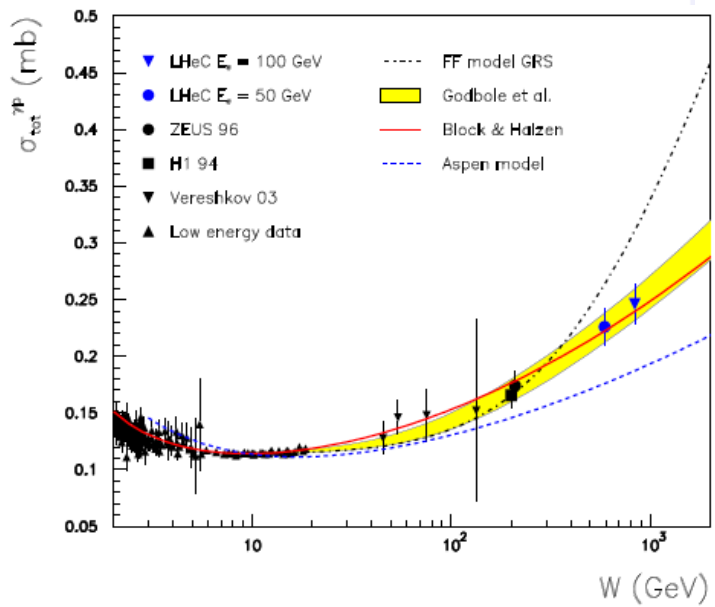
Low Angle Electron Tagging

- 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 → to be studied in more detail …



Leading Neutrons

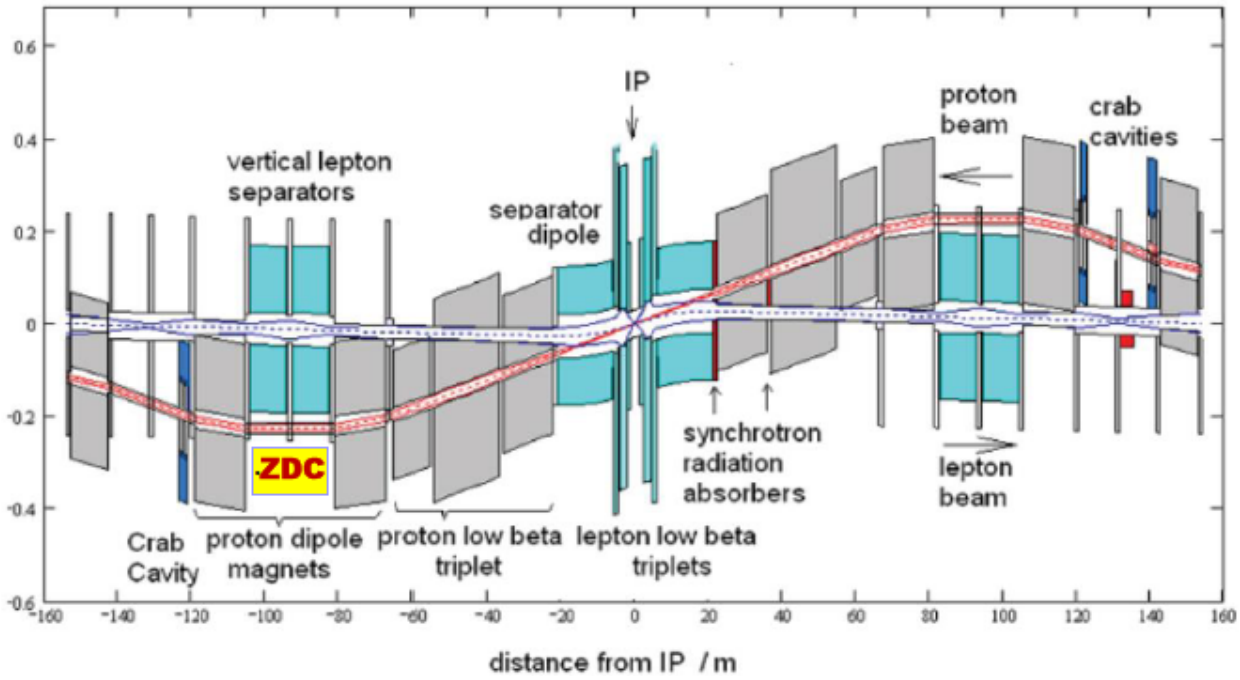
- Crucial in eA, to determine whether nucleus remains intact e.g. to distinguish coherent from incoherent diffraction

- Crucial in ed, to distinguish scattering from p or n

- Forward γ and n cross sections relevant to cosmic ray physics

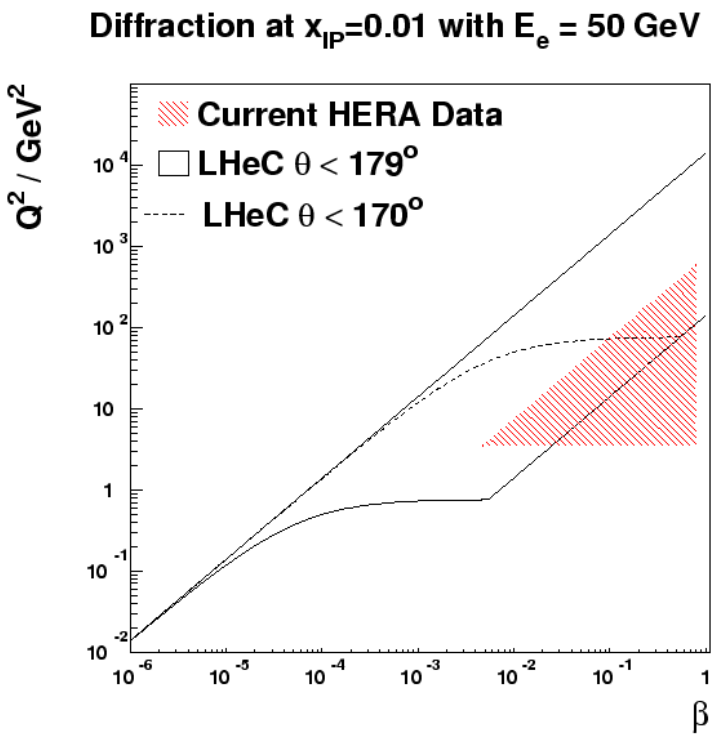
- Has previously been used in ep to study π structure function

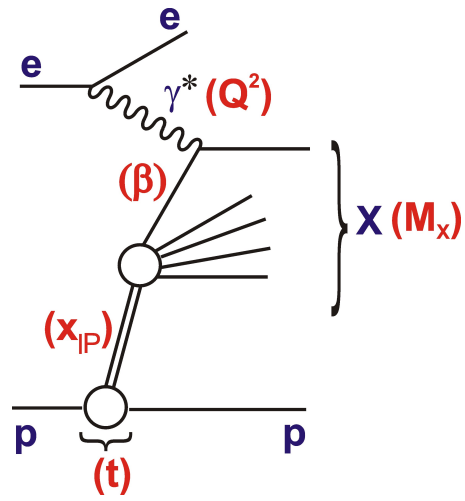
Possible space at z ~ 100m (also possibly for proton calorimeter)



… to be further investigated

Leading Protons / Diffraction

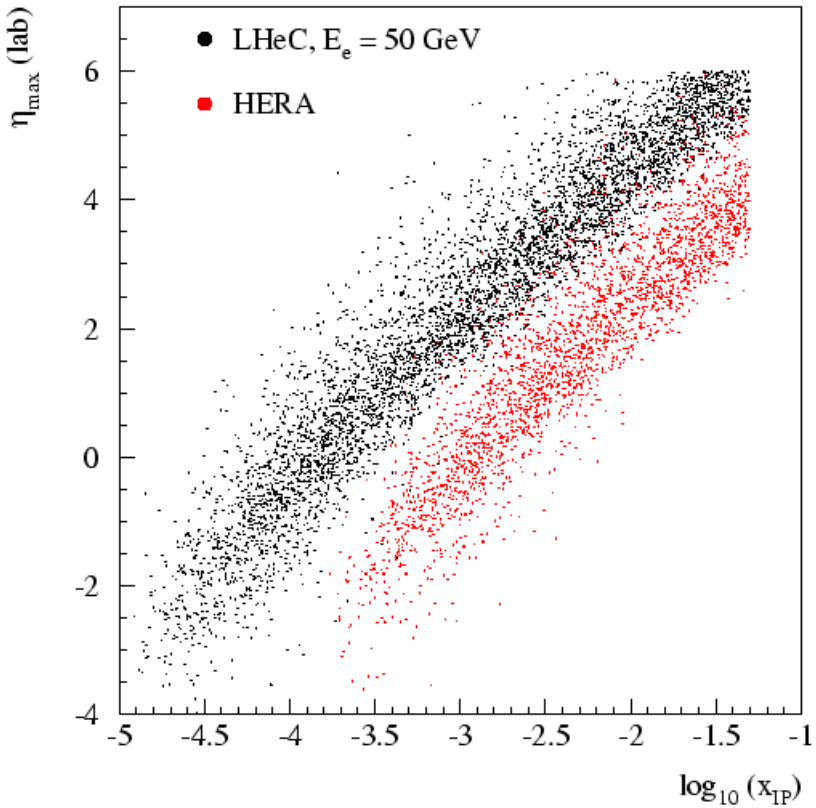




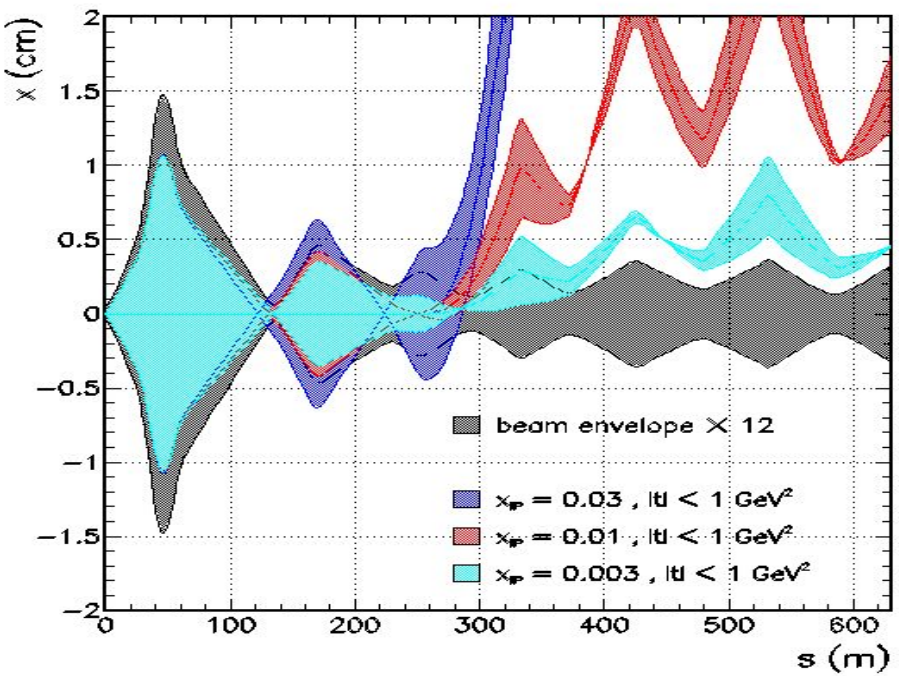
Exciting extensions to HERA diffractive kinematic range if events can be selected.

- η_{max} cut around 3 (as at HERA) selects events with x_{IP} <~ 10^{-3}

- To see higher x_{IP} (including compelling programme at high Mx), need to tag and measure protons in dedicated beamline spectrometers.



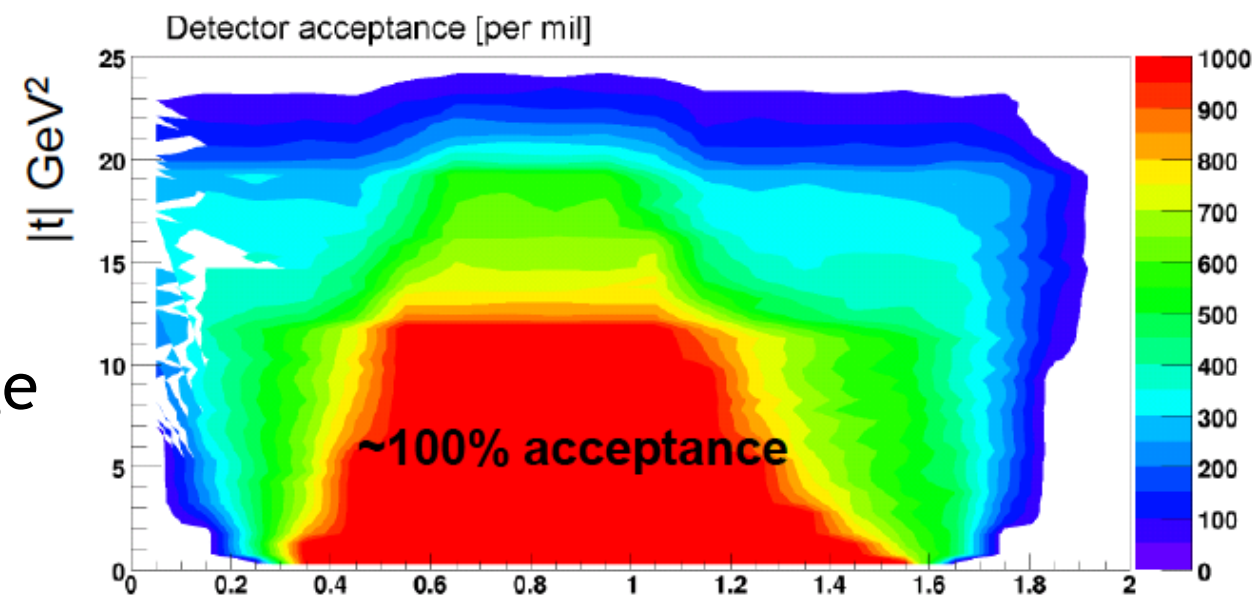
Forward Proton Spectrometer



With `FP420'-style proton spectrometer approaching beam to 12σ (~250 μm), can tag and measure elastically scattered protons with high acceptance over a wide x_{IP}, t range

Complementary acceptance to Large Rapidity Gap method

Together cover full range of interest with some redundancy



Good acceptance for 0.002<ξ<0.013