LHeC Detector(*) Design & Simulation

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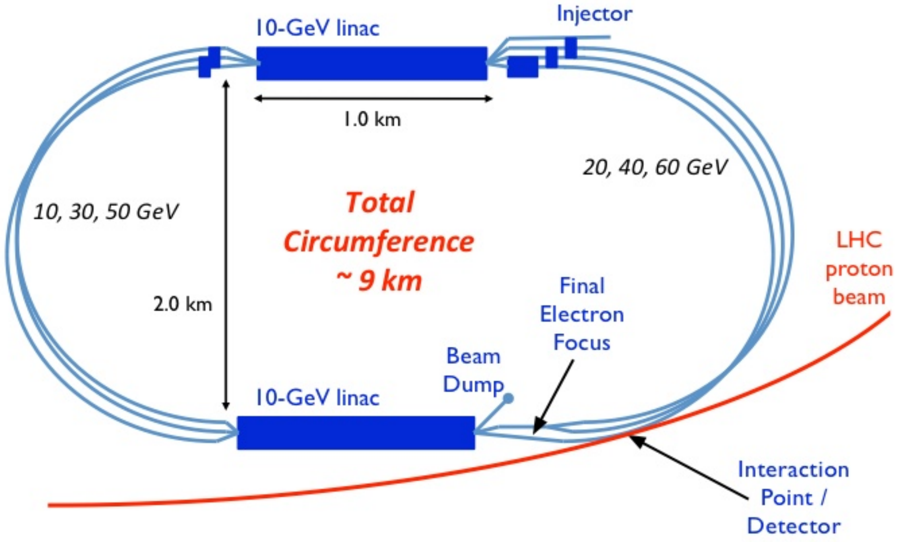
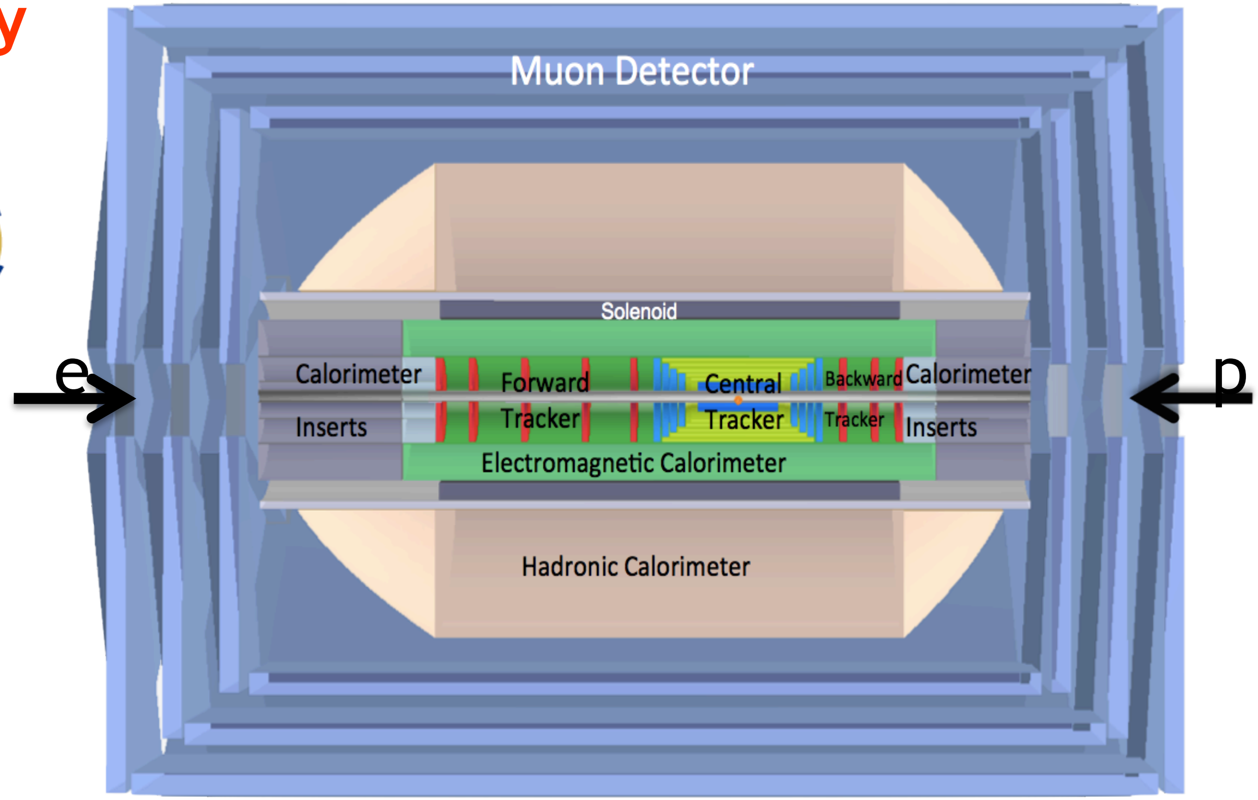
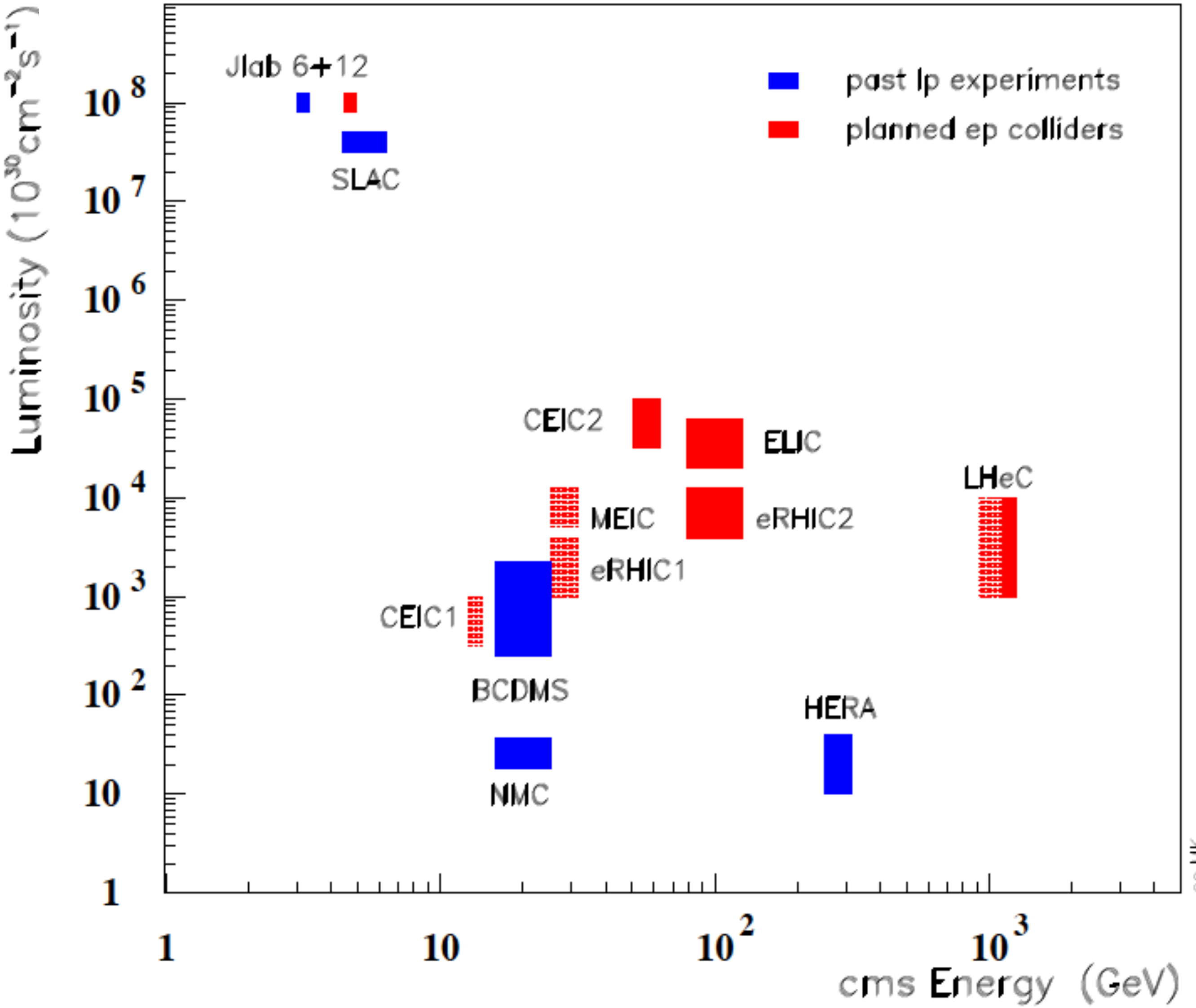




(*) Current Baseline Linac-Ring Version

LHeC Context

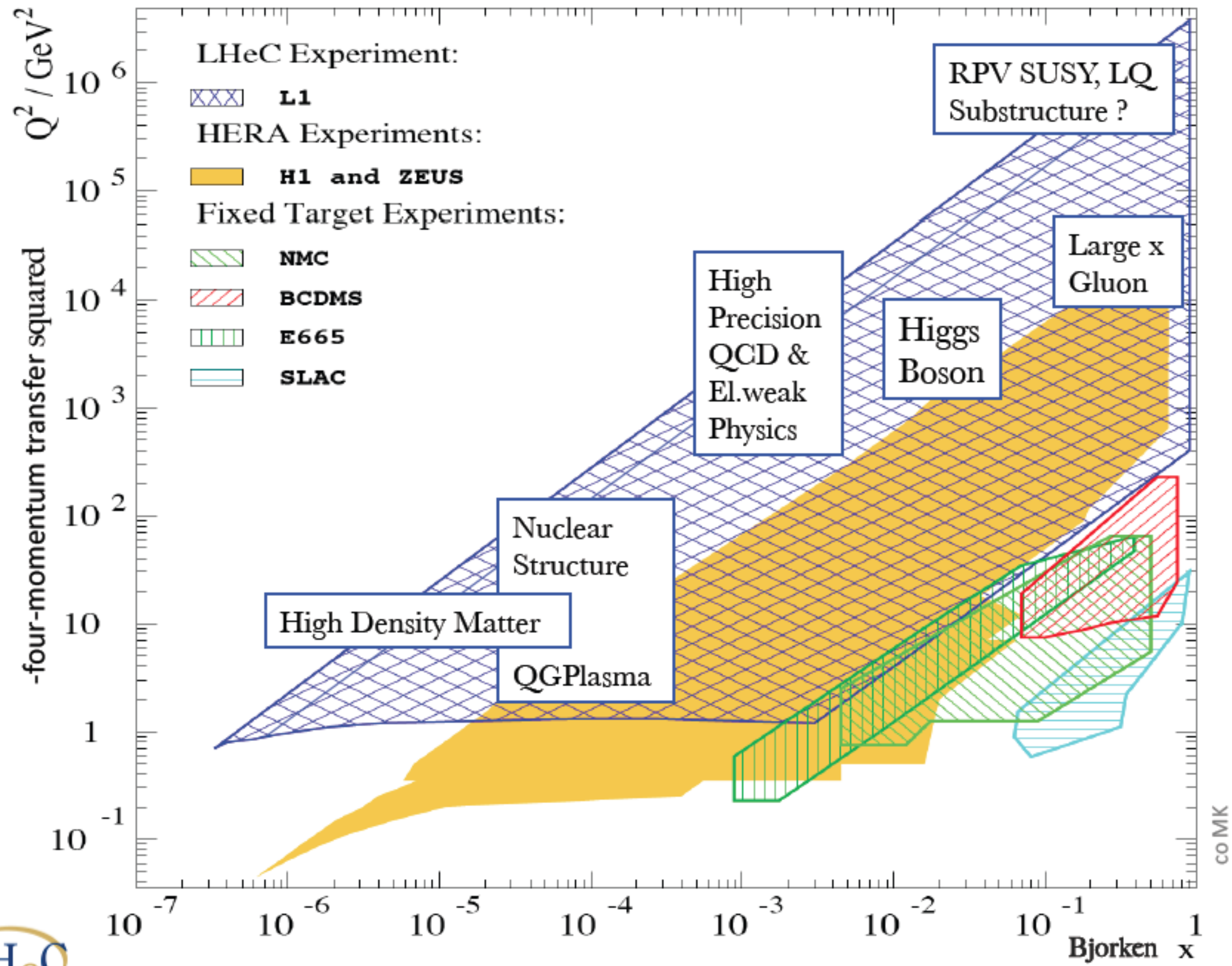


- Lepton-hadron scattering at the TeV centre of mass scale (60 GeV electrons x LHC protons & ions)

- High luminosity: 10^{33} - 10^{34} cm^{-2} s^{-1}

- Runs simultaneous with ATLAS / CMS in post-LS3 HL-LHC period

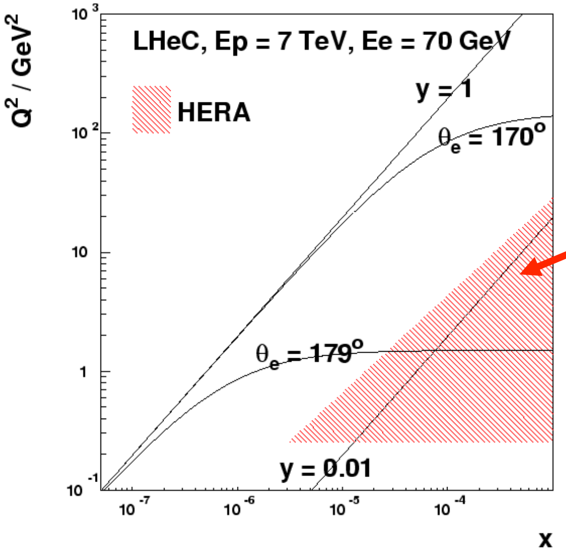
Physics Overview

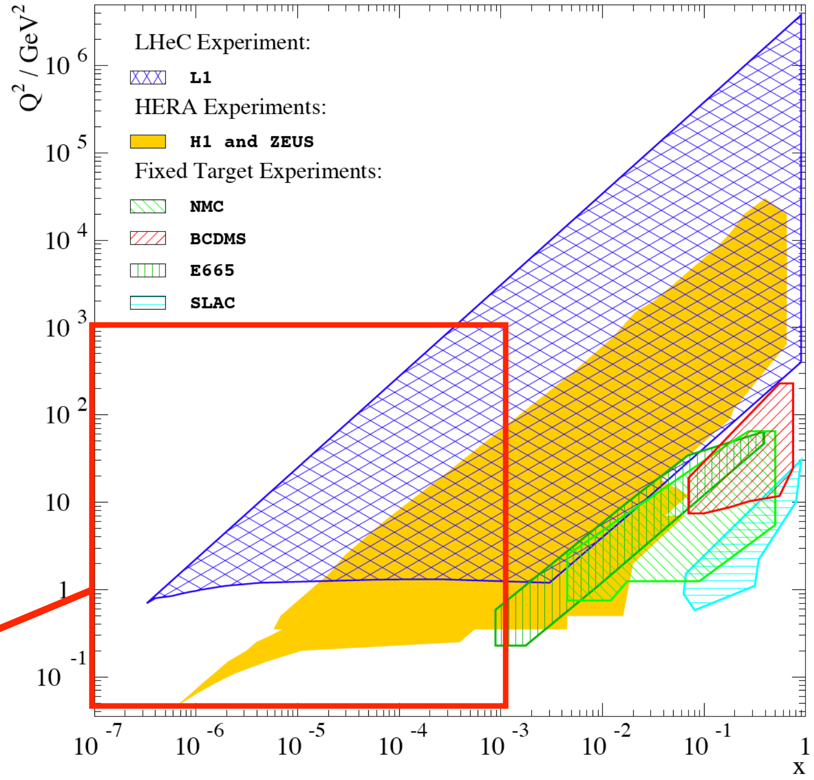


Varied physics goals require precise measurements throughout kinematically accessible region.

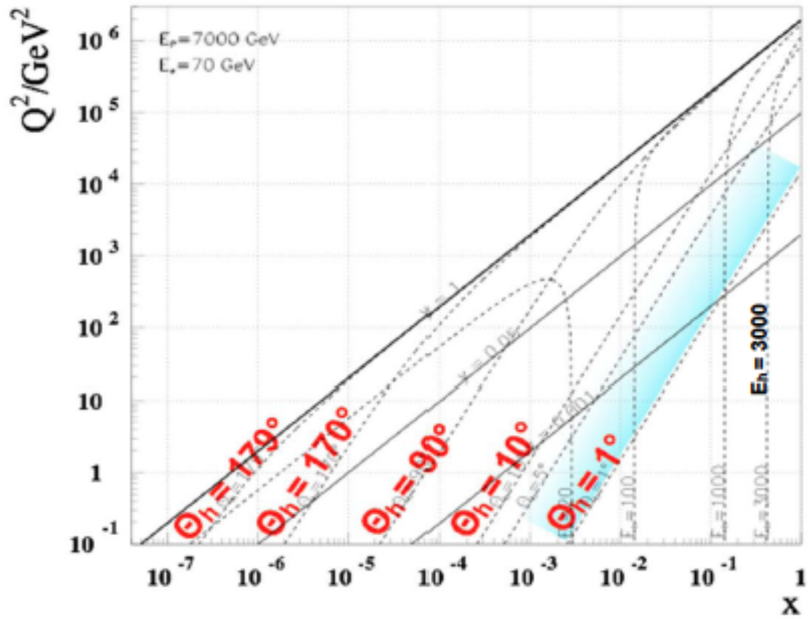
LHeC Kinematic Detector Requirements

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

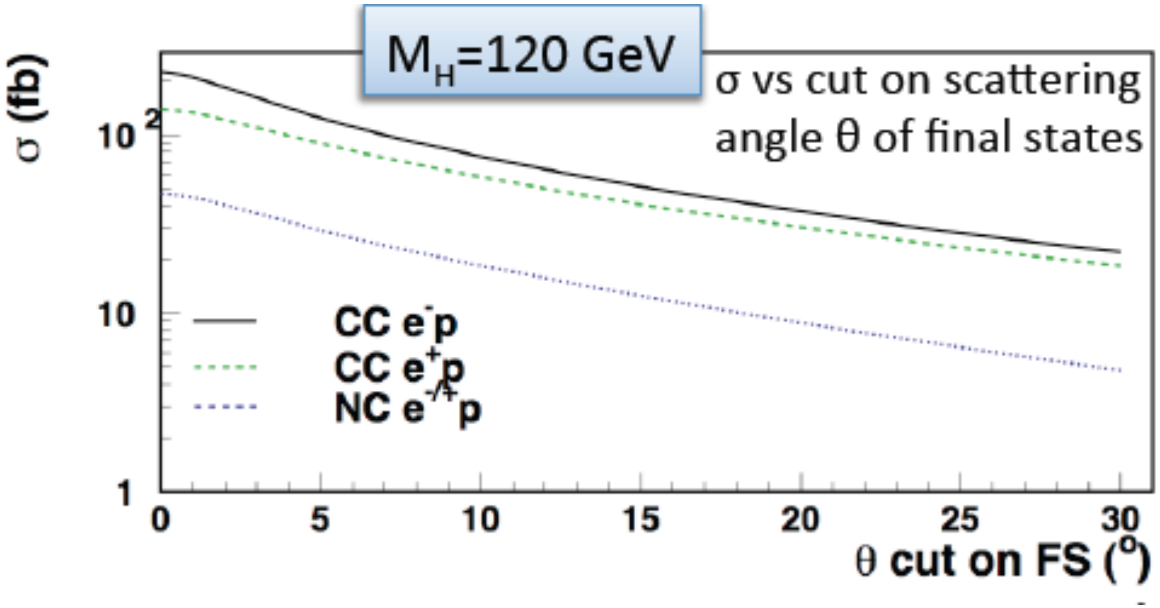




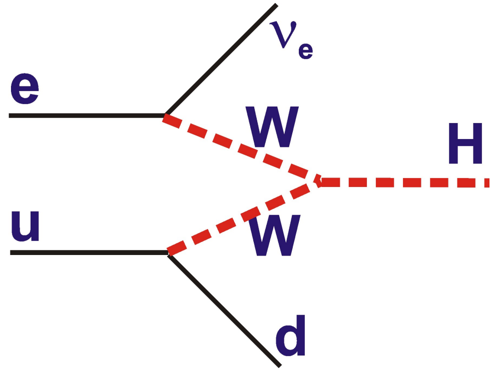
Also need 1° acceptance in outgoing proton direction to contain multi-TeV jets at high x (essential for kinematic reconstruction; electron-only method breaks down)

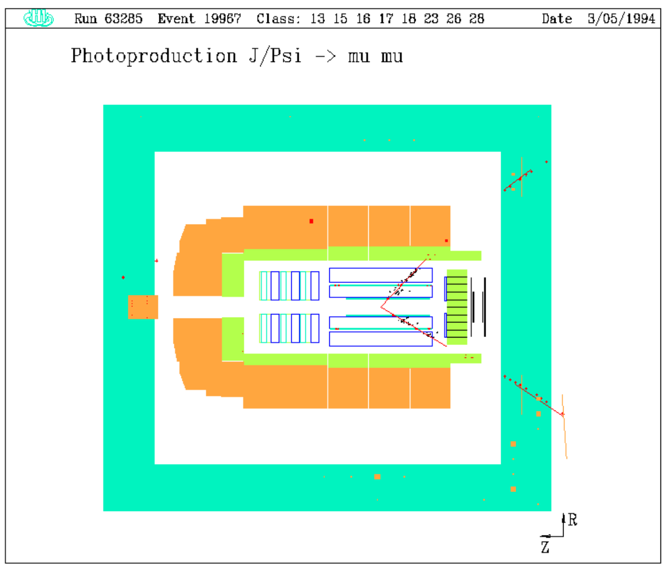


Kinematic Requirements in Specific Channels

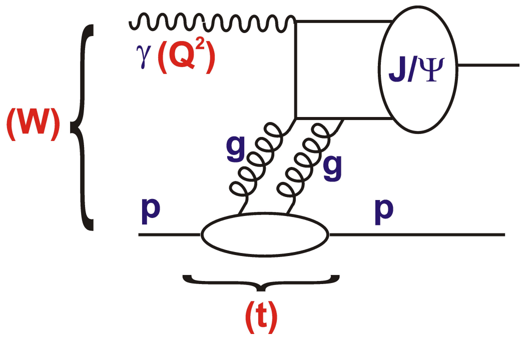


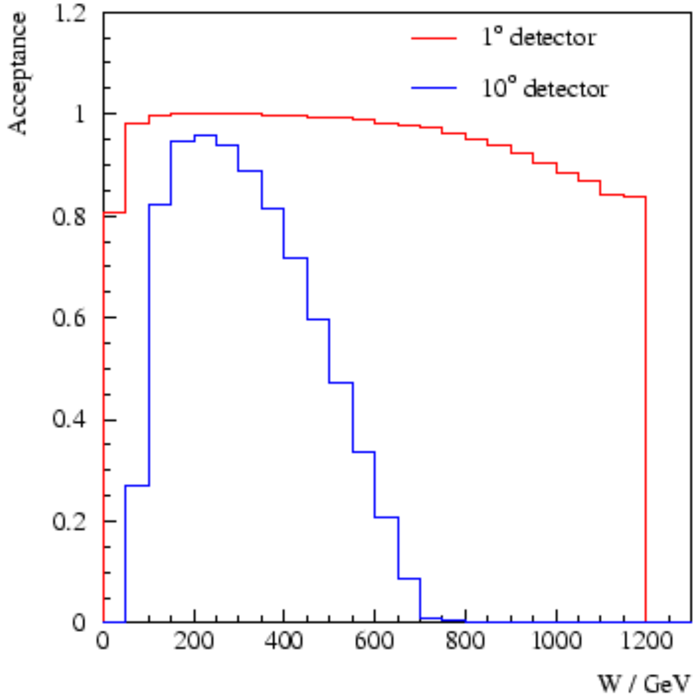
Higgs Production





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)

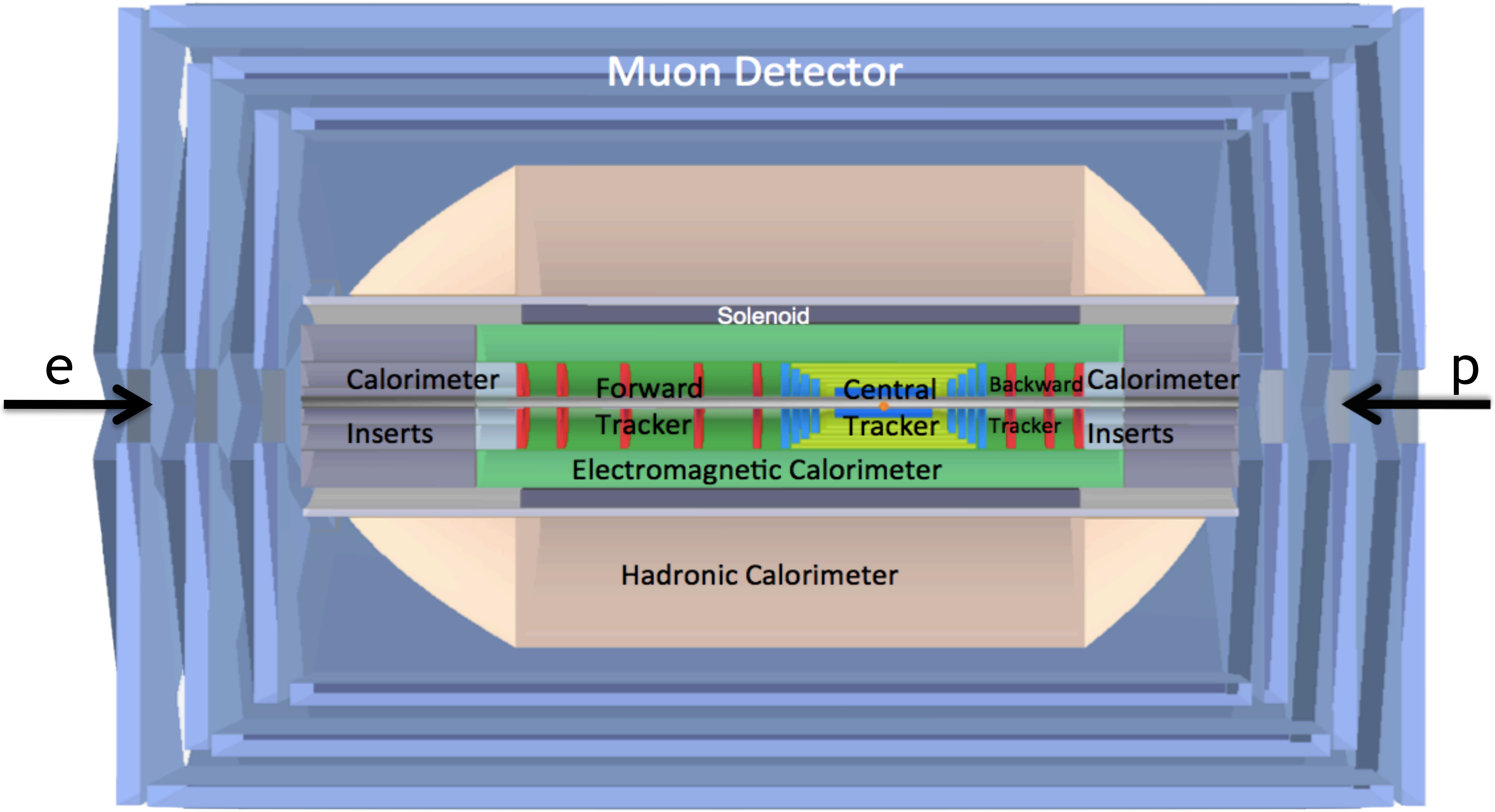
Hadrons

- 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)

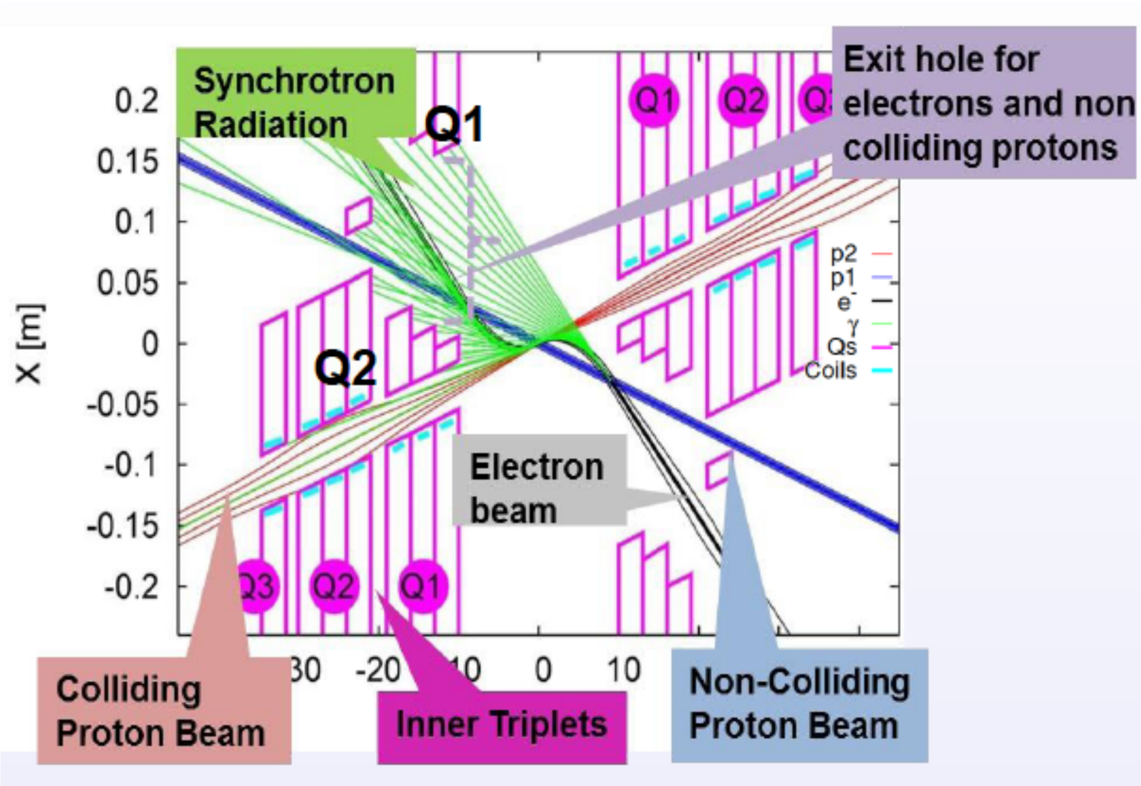
Beam-line

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

Detector Design Overview

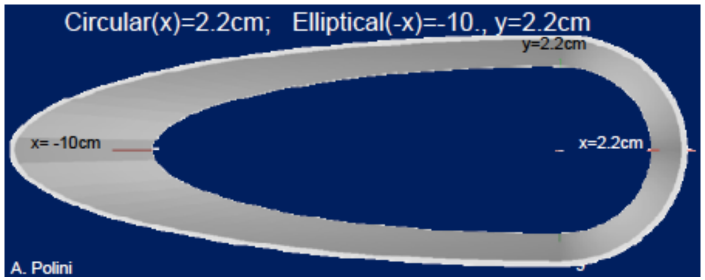


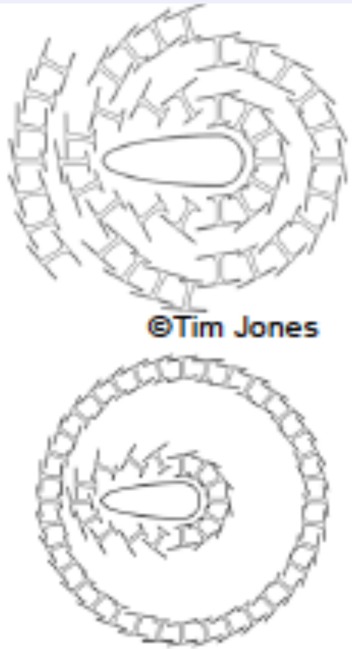
- Forward / backward asymmetry reflecting beam energies
- Present size 14m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- Beamline instrumentation (not shown) integral to design



Interaction Region & Beam-pipe

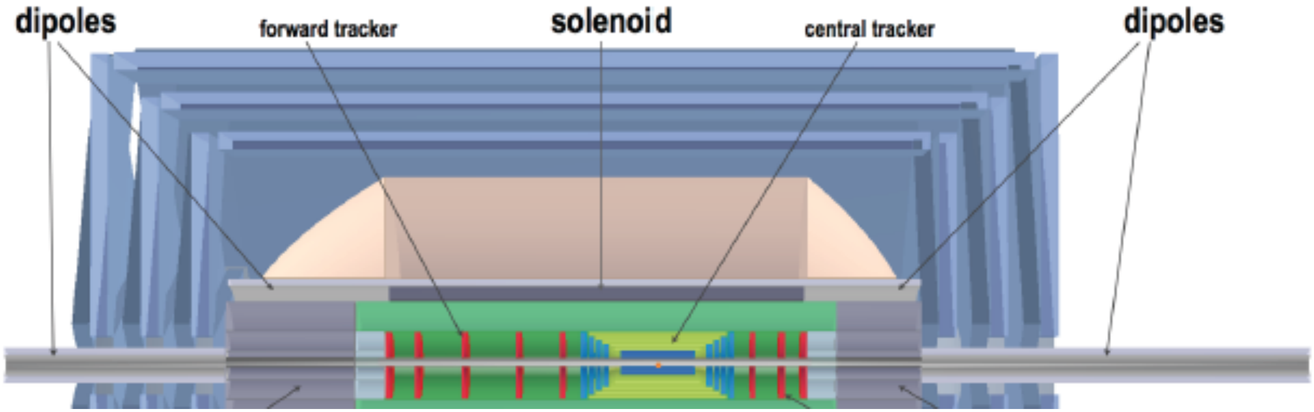
- Dipole magnets required throughout detector region to bend electrons into head-on collisions





- Resulting synchrotron fan has implications for
  - Beampipe (6m long, elliptical, 3mm Be wall)
  - Silicon detector layout

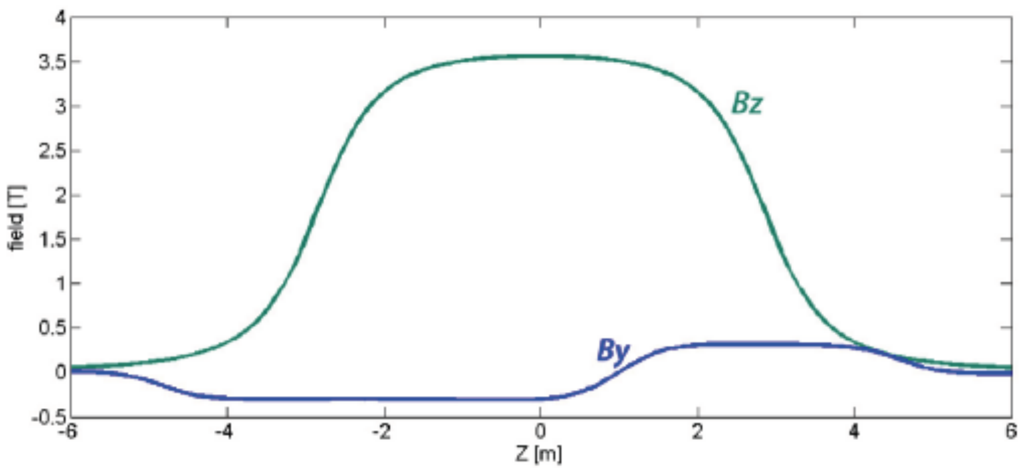
Magnets



- Superconducting 3.5T solenoid (NbTi / Cu in 4.6K Liquid Helium cryo)

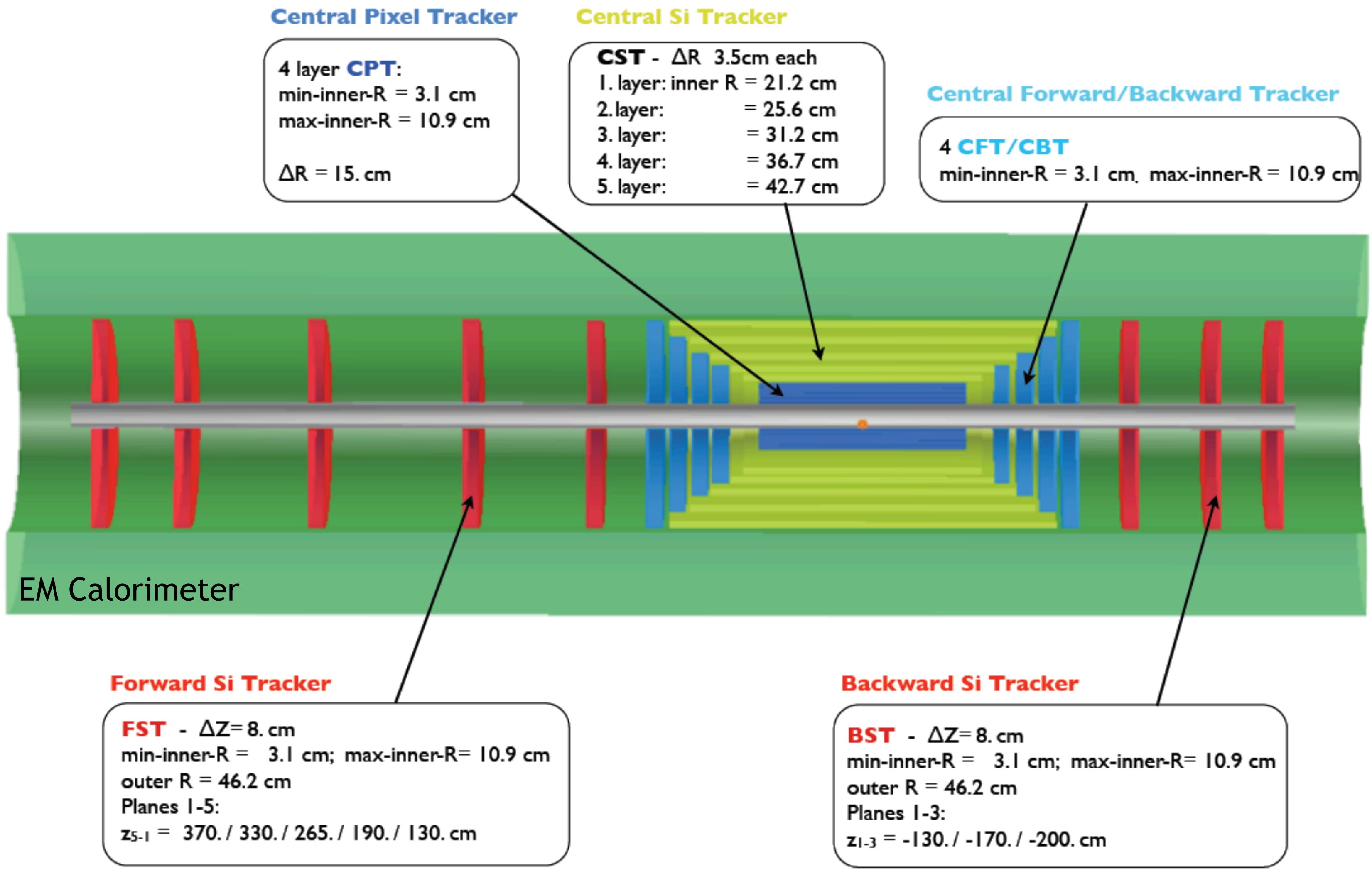
- Iron in HAC provides field return path

-Dual dipoles (0.15 – 0.3 T, covering |z| < 14m). Inner (cold) section integrated with solenoid, outer iron section warm.



Field components of solenoid (Bz) and dipoles (By) at beam axis in interaction region

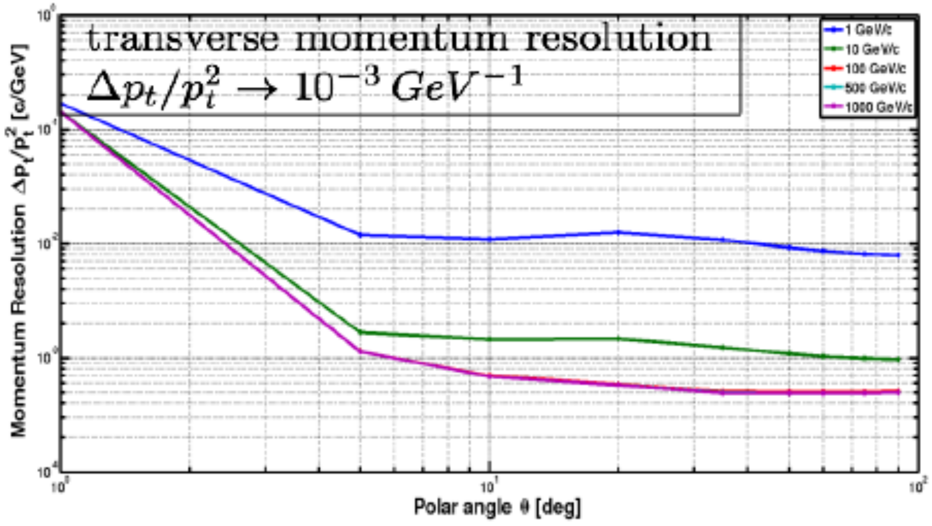
Tracking Region

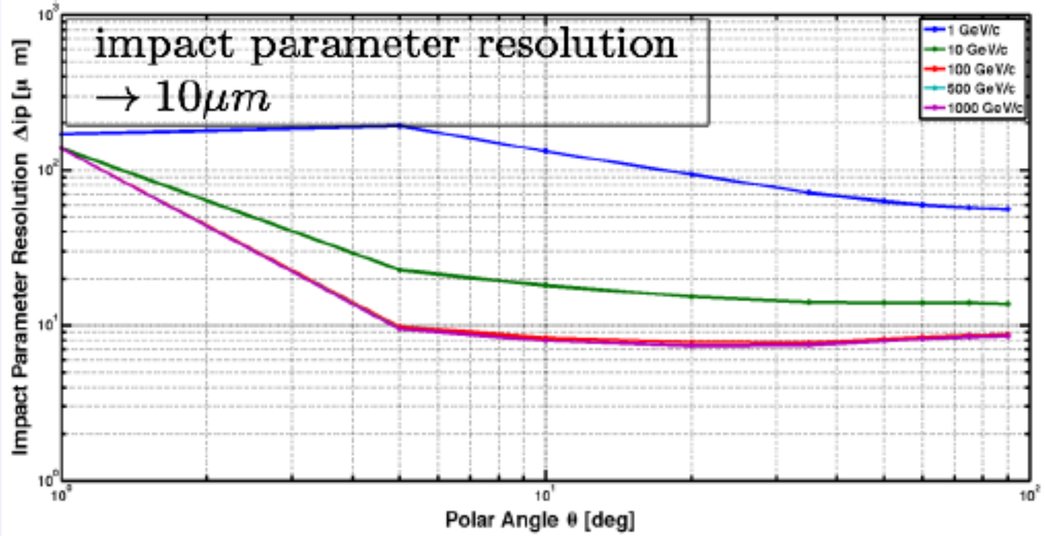


- Full angular coverage, long tracking region → 1° acceptance
- Forward direction most demanding (dense, high energy jets)
- Pixels (CPT) + Strips; several technologies under discussion

Tracking Simulation

Performance evaluated from basic layout (LicToy 2.0 program)

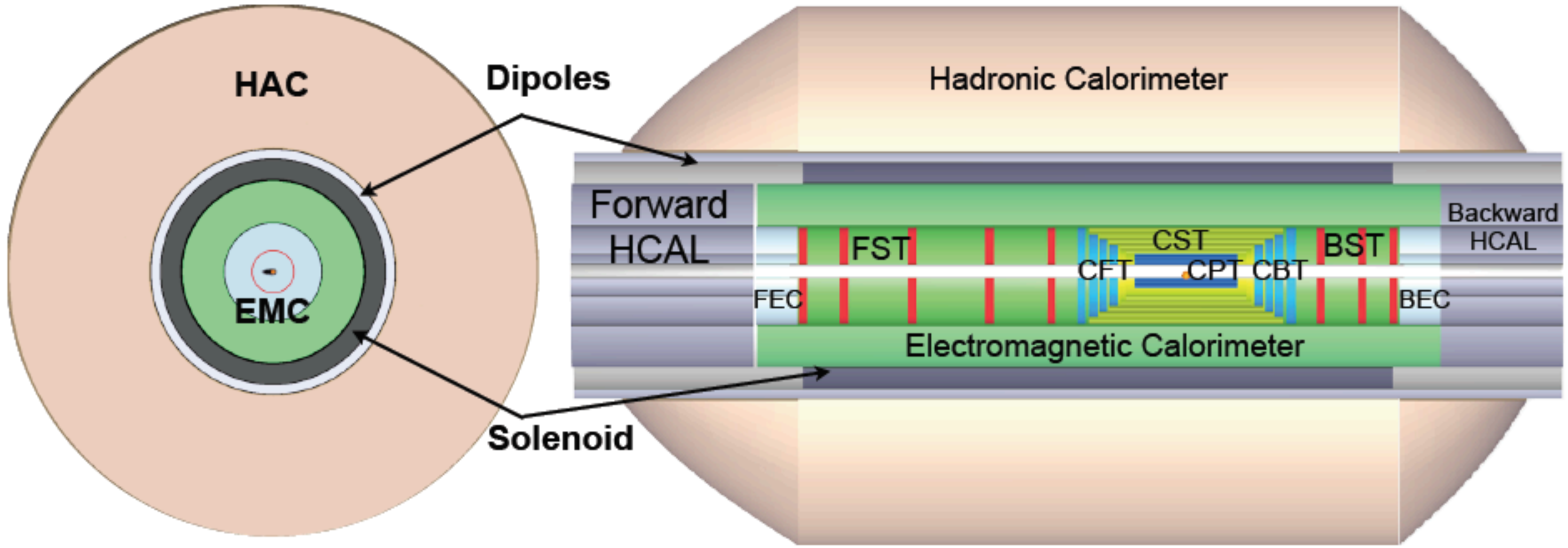




- Central tracks:
  - Excellent track resolution: $\Delta p_t/p^2_t \rightarrow 6\ 10^{-4}\ GeV^{-1}$
  - Excellent impact parameter resolution: → 10μm

- Forward / Backward tracks:
  - Degrades for θ <~ 5°, but still useful!
  - At 1°, bending field component = 0.36 T (similar to dipole)

Calorimeters Overview



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

- Liquid Argon EM calorimeter, possibly with accordion geometry (inside coil)

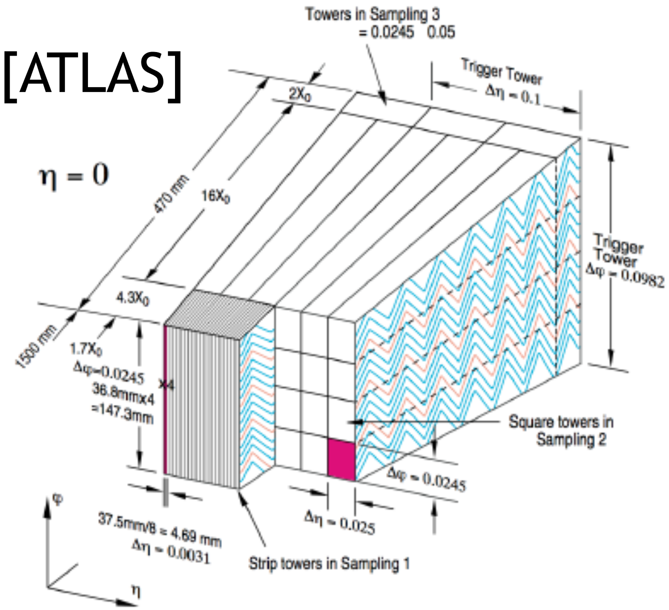
- Scintilating Tile HAD calorimeter (outside coil)

- Forward and Backward End-Cap Modules

Barrel EM Calorimeter

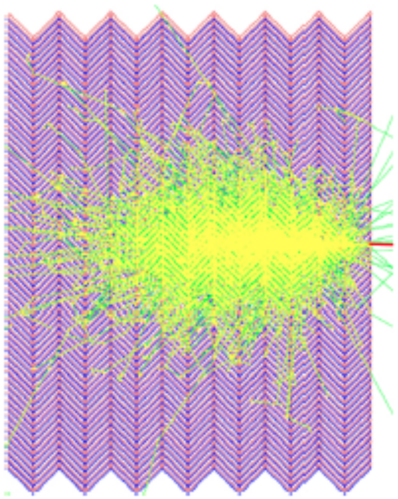
- -2.3 < η < 2.8
- Accordion geometry baseline design
- 2.2mm lead + 3.8mm LAr layers
- Total depth ~ 20 X_0

[ATLAS]

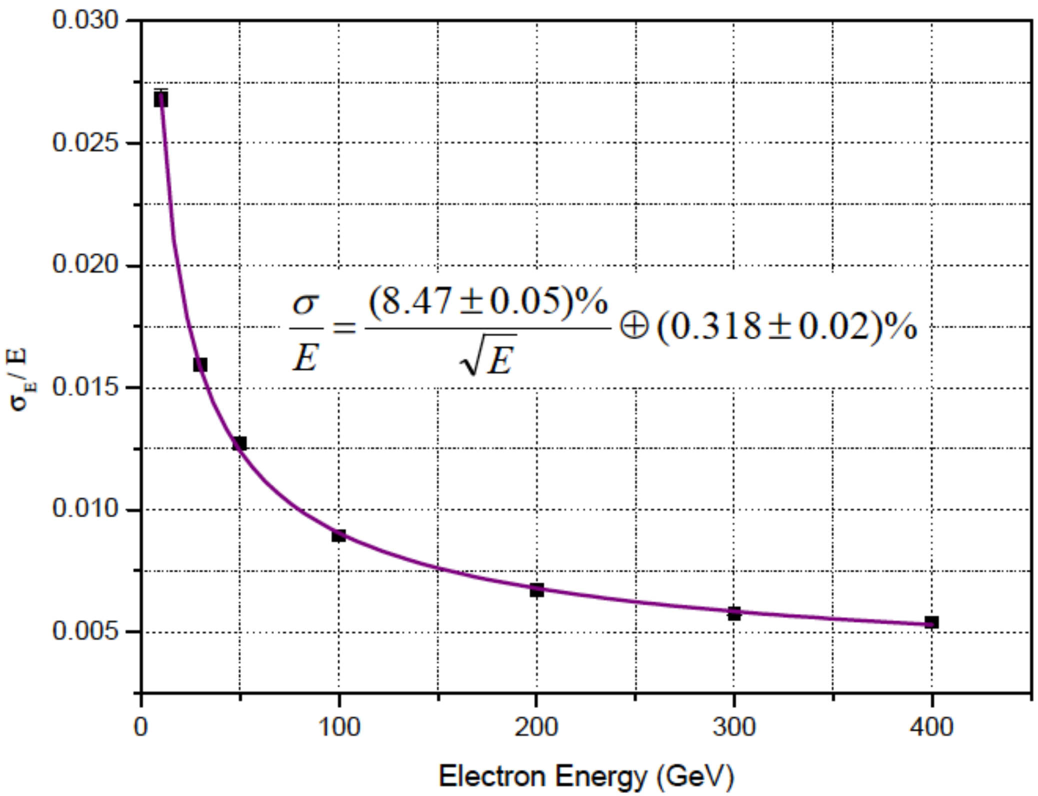


- Geant4 simulation of response to electrons at Normal Incidence

[cf ATLAS: 10%/√E + 0.35%]



[20 GeV electron shower)]



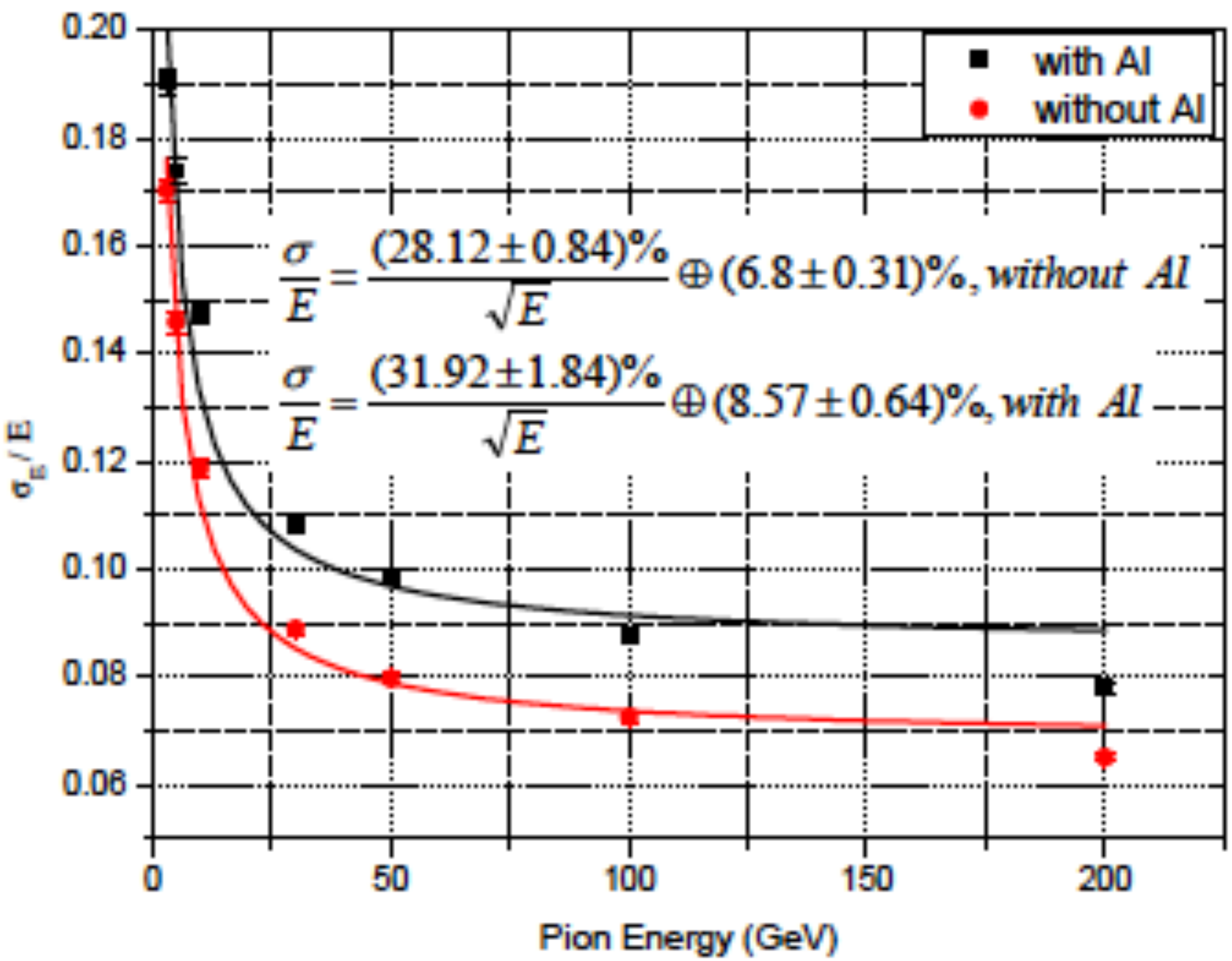
Barrel HAD Calorimeter

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

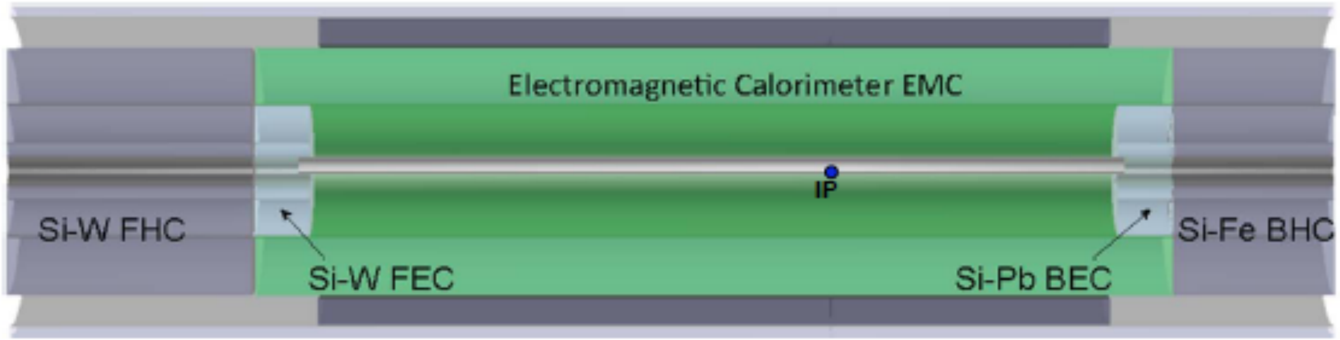
- Geant4 simulation of combined Lar + Tile response to charged pions at normal incidence

-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)

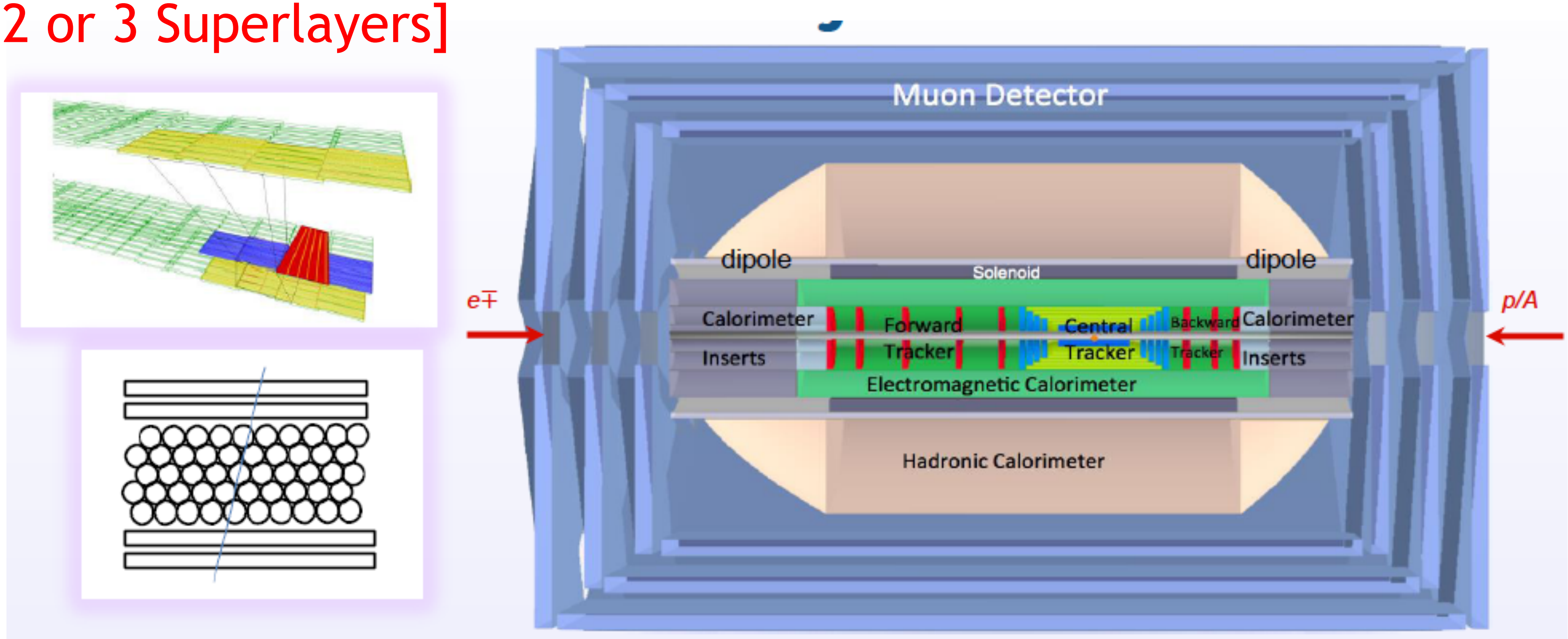
Copper + Si pads for HAD (~ 7 λ)

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

Muon System

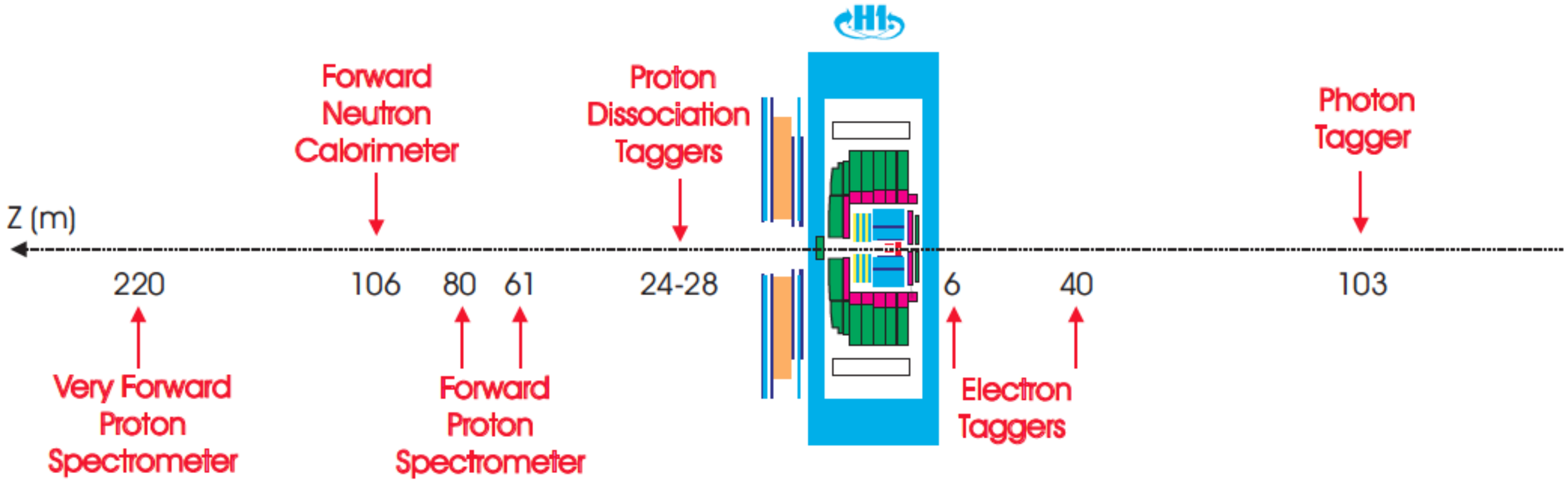
Baseline: Provides tagging, but not momentum measurement
: Angular coverage → 1° vital eg for elastic J/Ψ
: Technologies used in LHC GPDs and their upgrades
(more than) adequate

[2 or 3 Superlayers]



[Drift tubes / Cathode strip chambers → precision
Resistive plate / Thin Gap chambers → trigger + 2nd coord]

Beamline Instrumentation



- The beam-line at HERA hosted multiple detectors over a ~300m region

- LHeC beamline should be at least as heavily instrumented over an even wider region (-120m < z < 420m).

- The requirements of these detectors has to be bourne in mind from outset

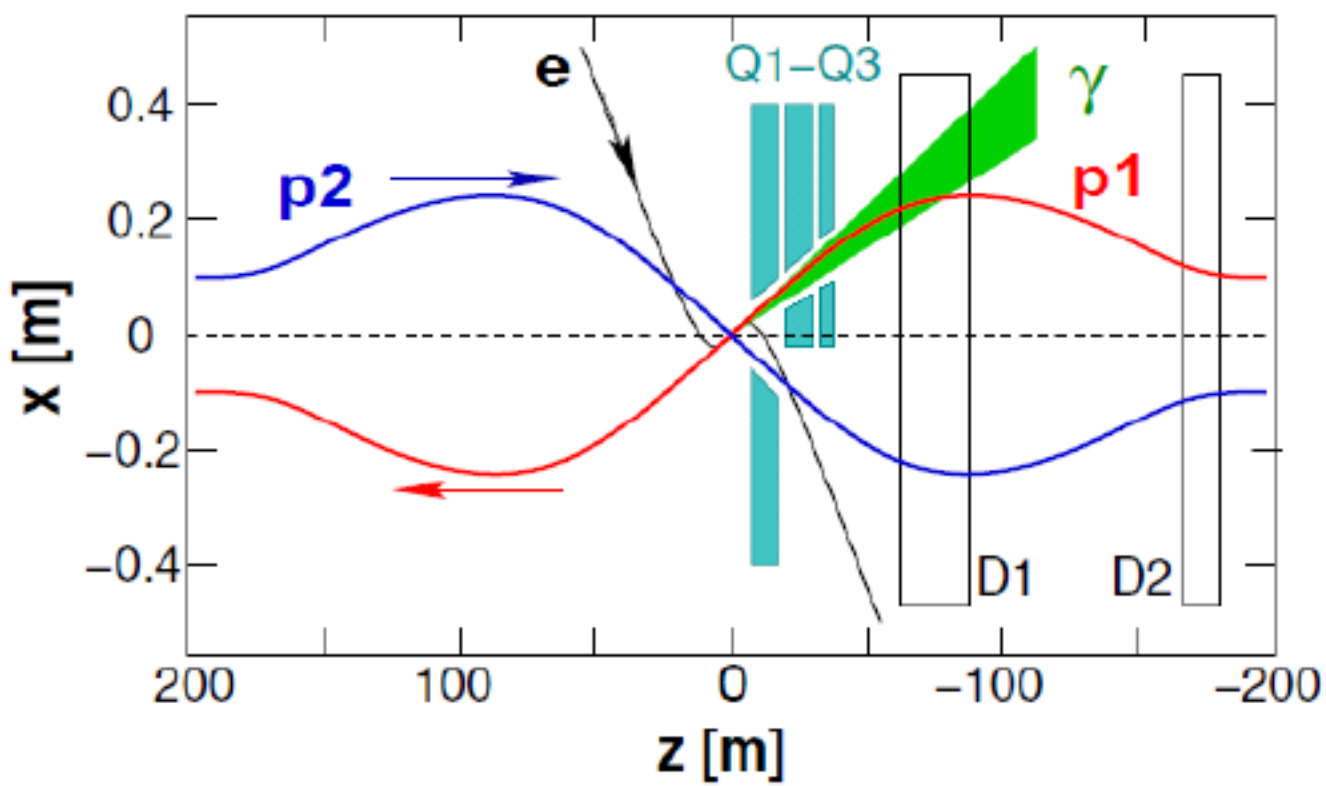
Luminosity / Photon Tagging

- 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.

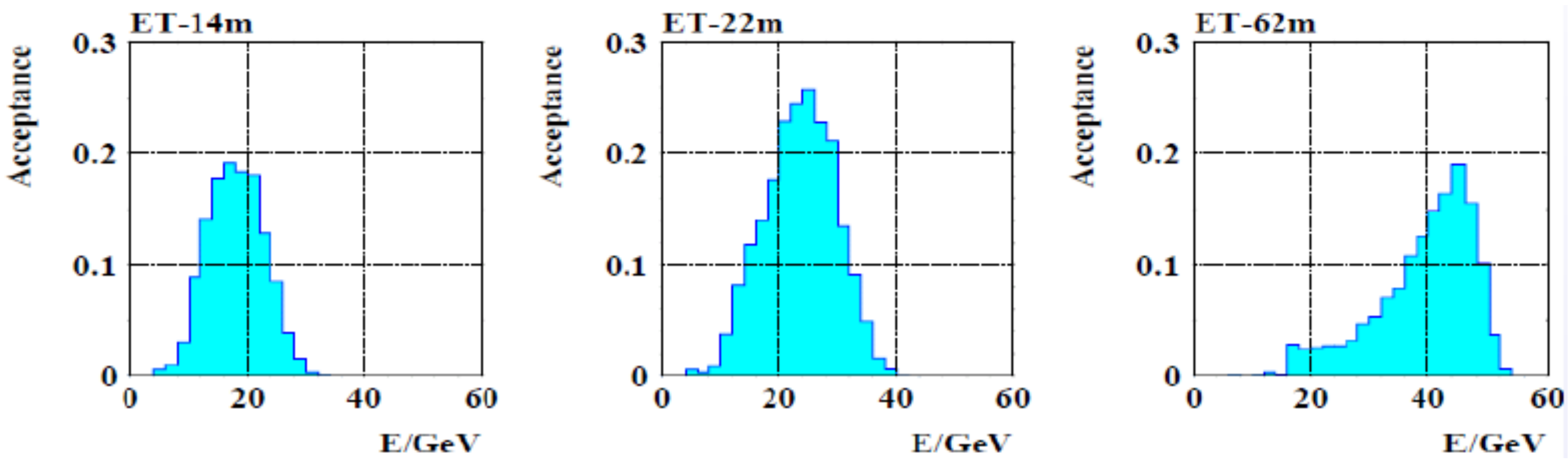
- With sufficient apperture through Q1-Q3 magnets, 95% geometrical acceptance possible

→ $\delta L \sim 1\%$

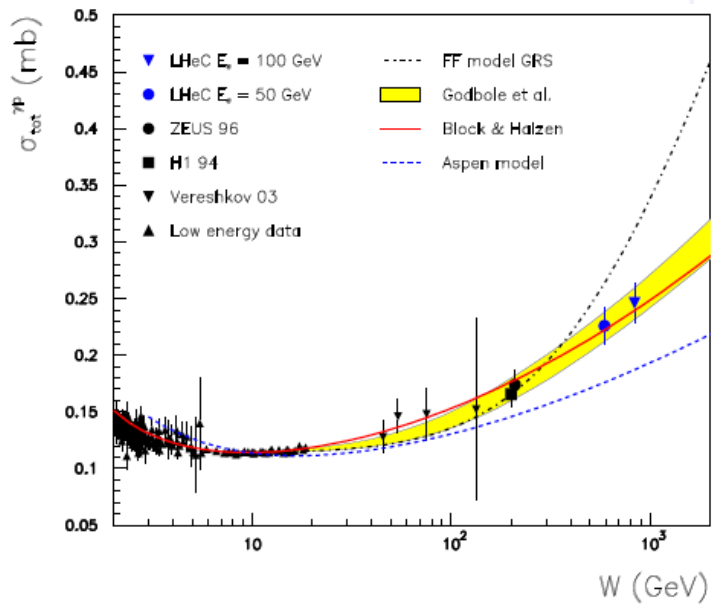


Low Angle Electron Tagging

- 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

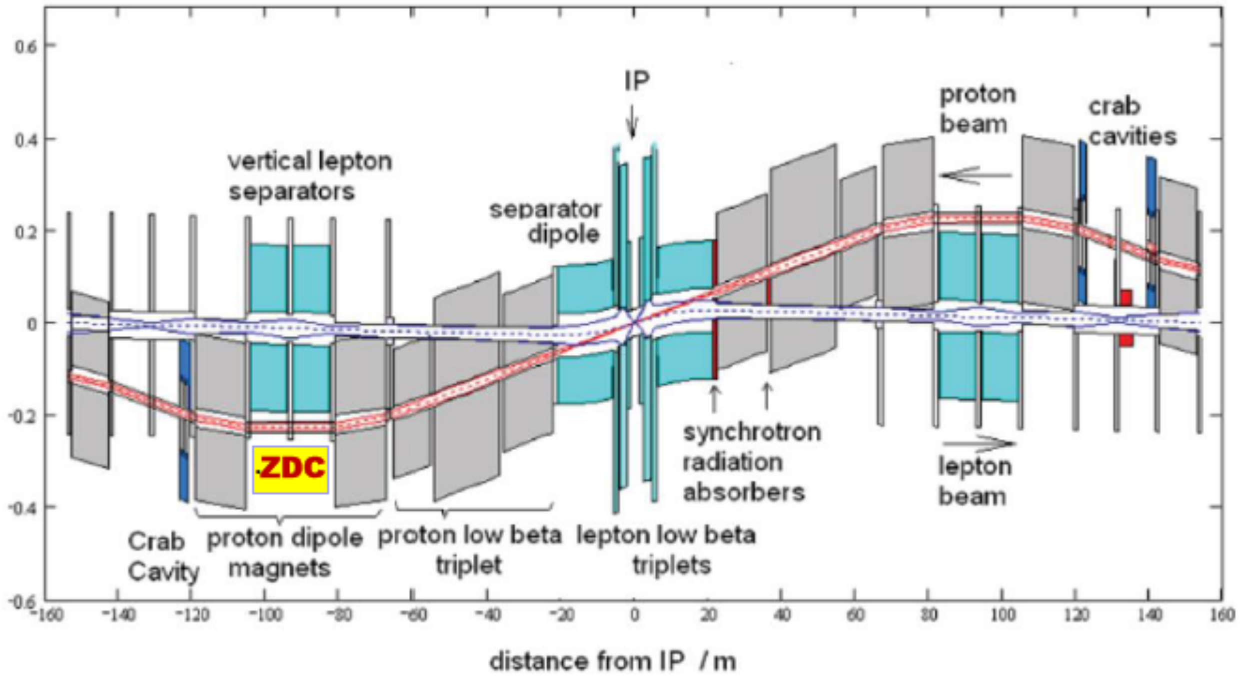
- Crucial in eA, to determine whether nucleus remains intact e.g. to distinguish coherent from incoherent diffraction

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

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

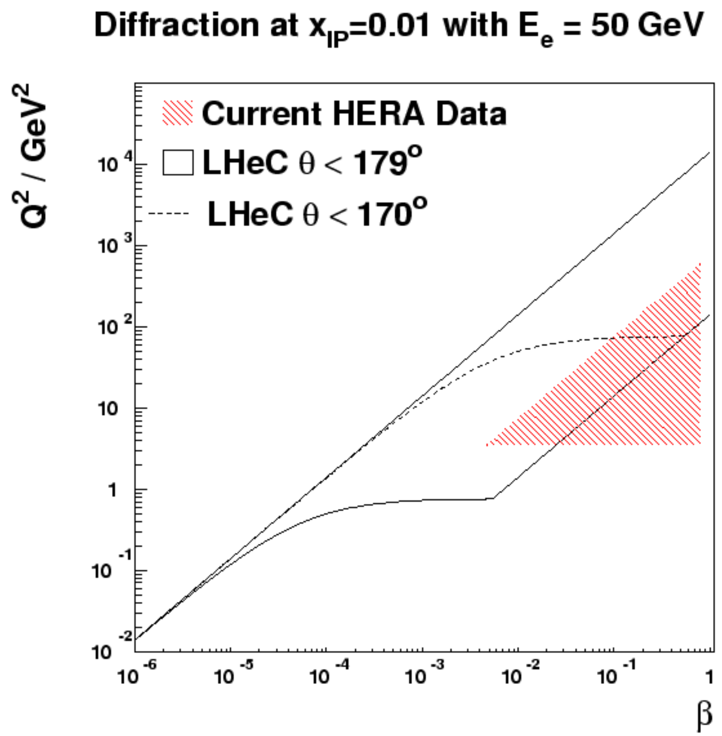
- Has previously been used in ep to study π structure function

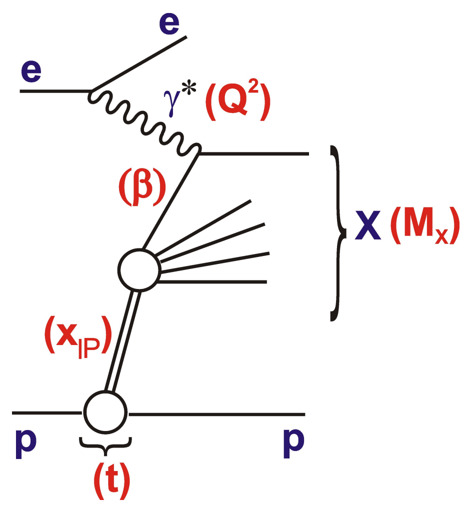
Possible space at z ~ 100m (also possibly for proton calorimeter)



... to be further investigated

Leading Protons / Diffraction

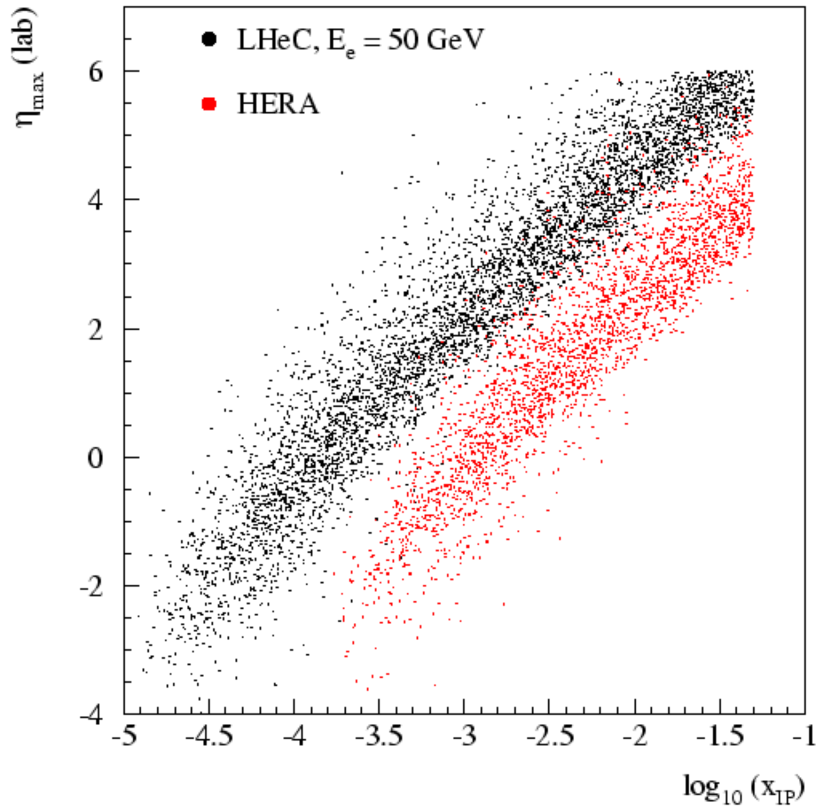




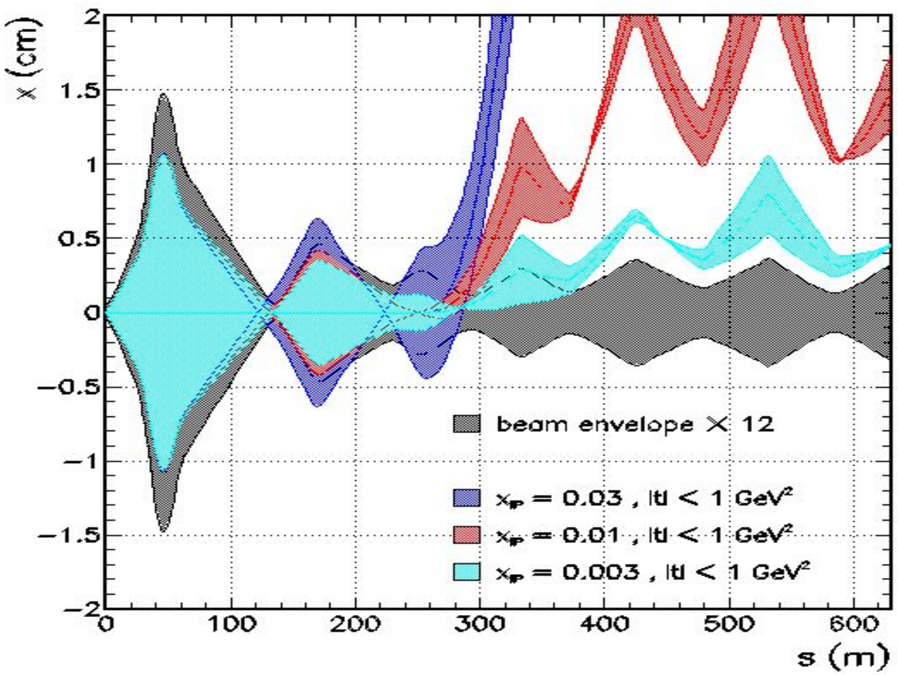
Exciting extensions to HERA diffractive kinematic range if events can be selected.

- 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.



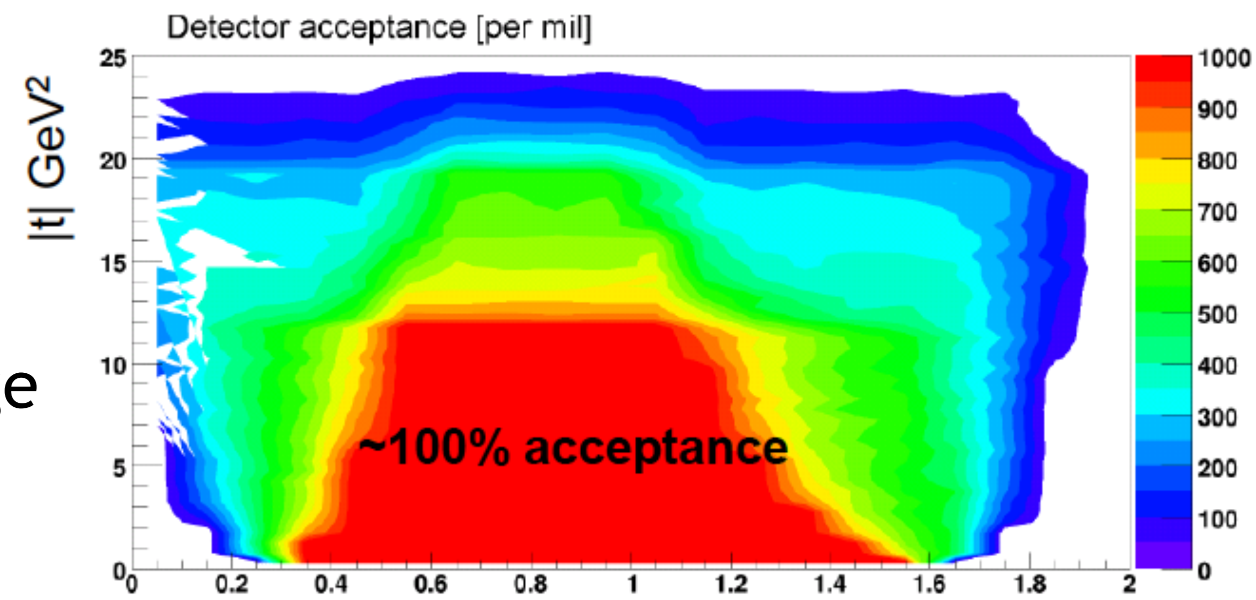
Forward Proton Spectrometer



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

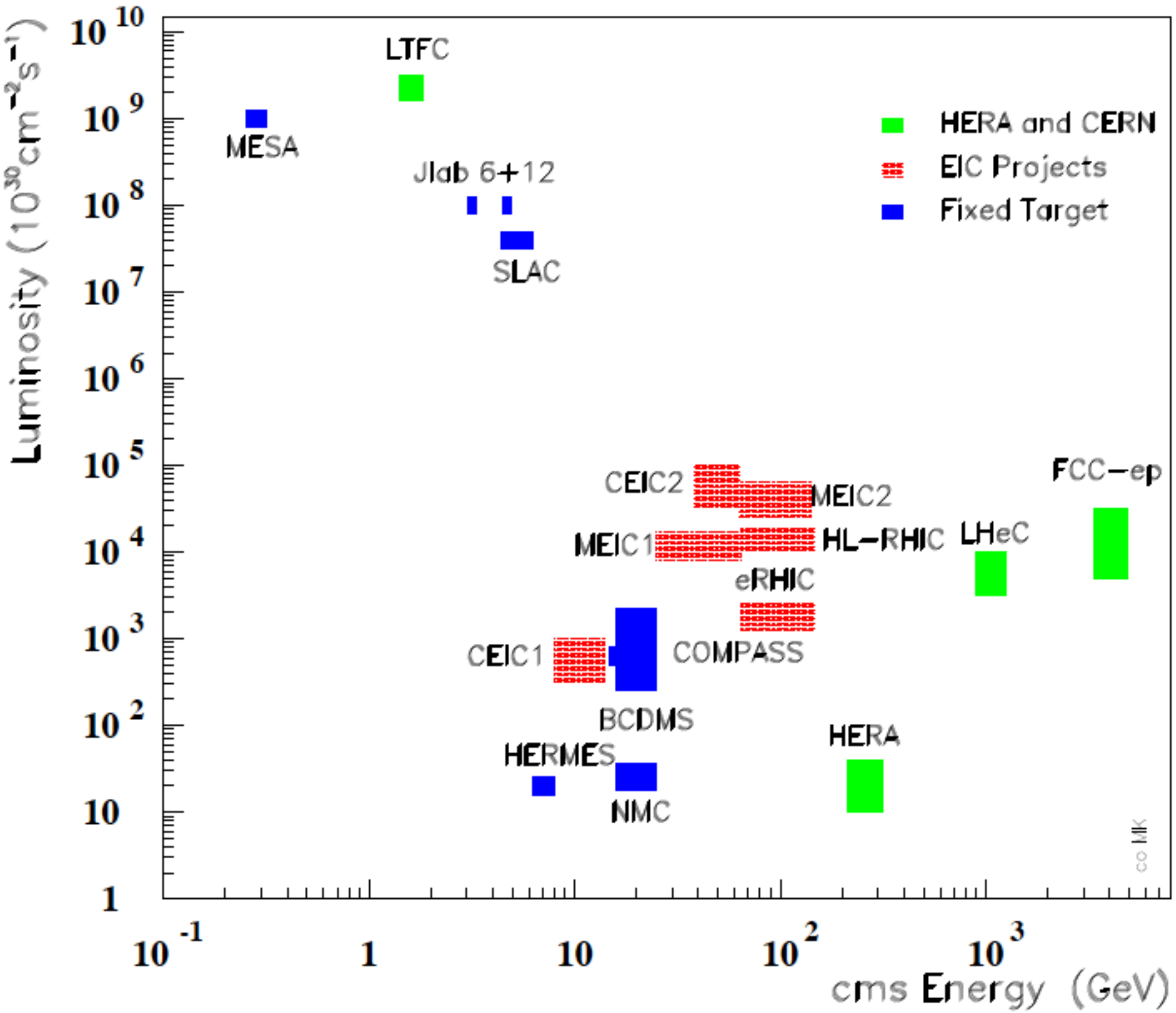
Together cover full range of interest with some redundancy



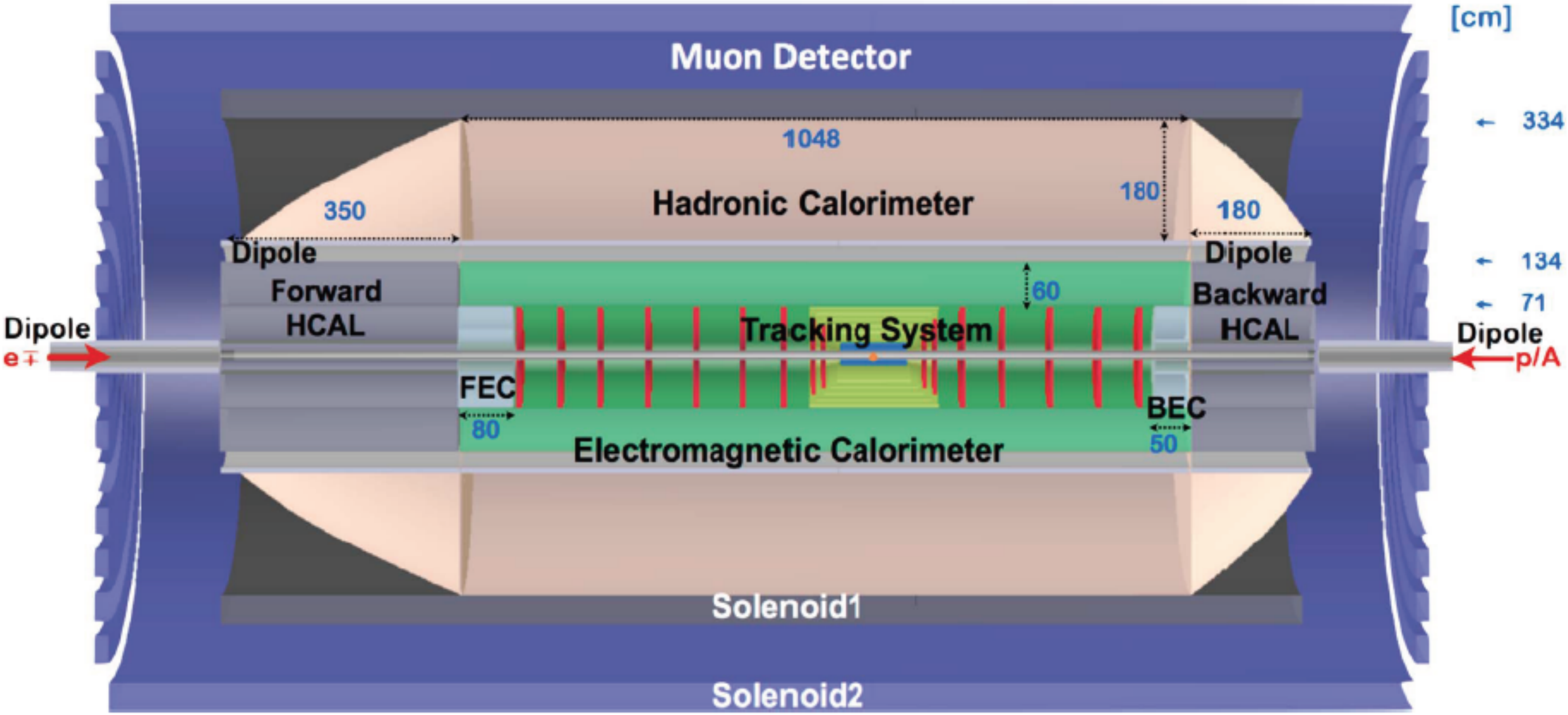
Good acceptance for 0.002<ξ<0.013

Future Circular Collider ep Detector: first ideas for 50 TeV p x 100 TeV e

(to be further developed by our children)



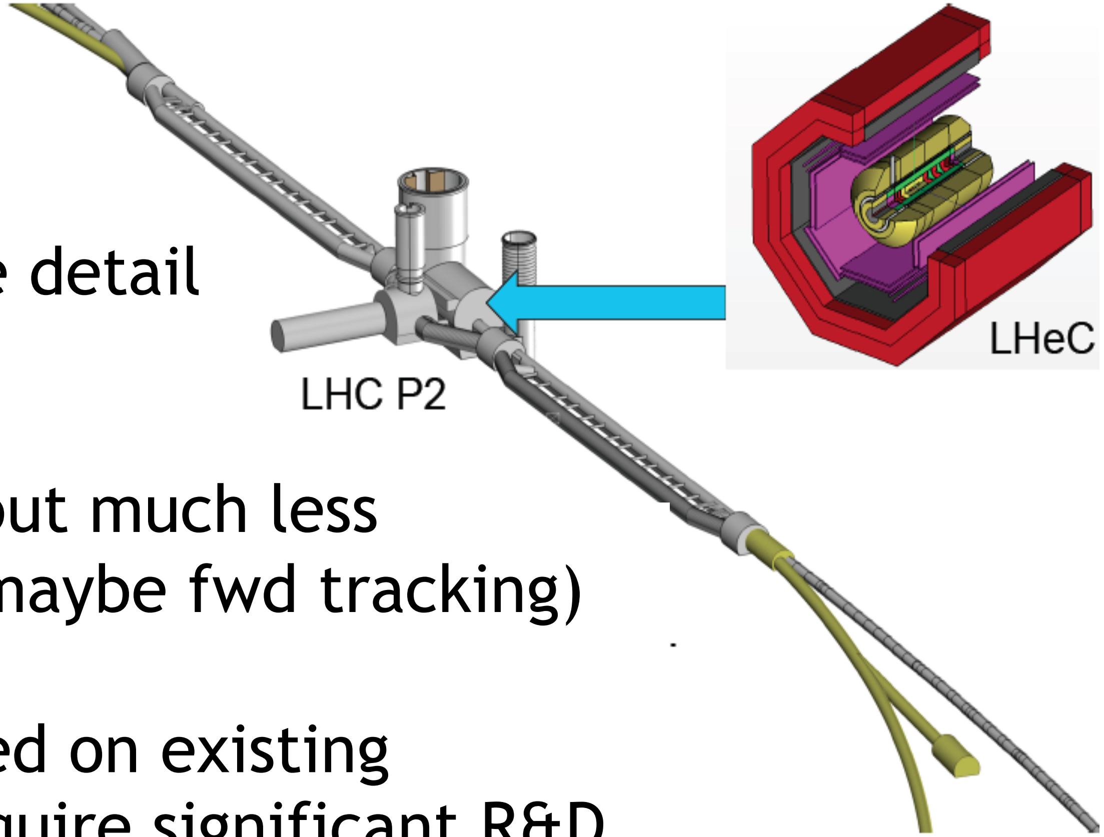
FCC-he Detector (B) – 0.1



Crab cavities for p instead of dipole magnet for e bend to ensure head on collisions
1000 H → μμ may call for better muon momentum measurement
H→ HH → 4b (and large/low x) call for large acceptance and optimum hadr. E resolution
Detector for FCC scales by about ln(50/7) ~2 in fwd, and ~1.3 in bwd direction
Full simulation of LHeC and FCC-he detectors vital for H and H-HH analysis

P.Kostka et al.

Summary



- Possible LHeC detector solutions evaluated in some detail

- Physics & environment requirements demanding, but much less so than LHC GPDs (except maybe fwd tracking)

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

- Any / all of this can change in response to machine design development, physics demands or new good ideas!

- Next step: full detector simulation under development using DD4HEP tool-kit → reassess physics performance and feed back to detector design → towards a Technical Design Report