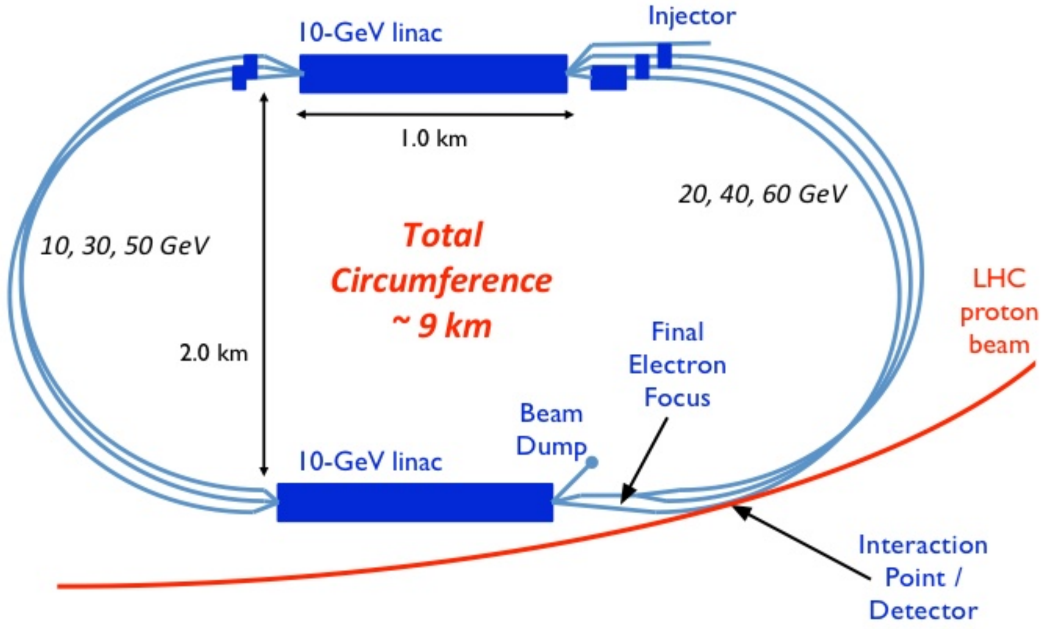
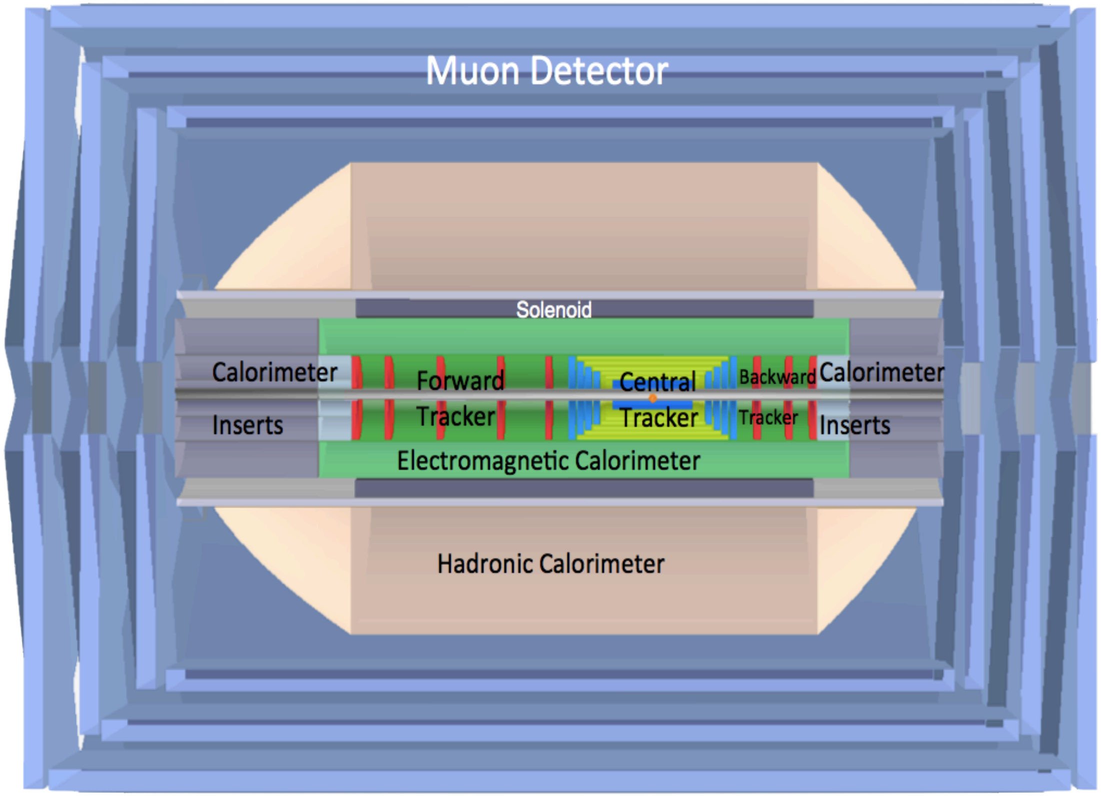
LHeC Overview & Detector

... lepton-hadron scattering at the TeV scale ...

Paul Newman
Birmingham University

DIS 2016
DESY Hamburg
12 April 2016





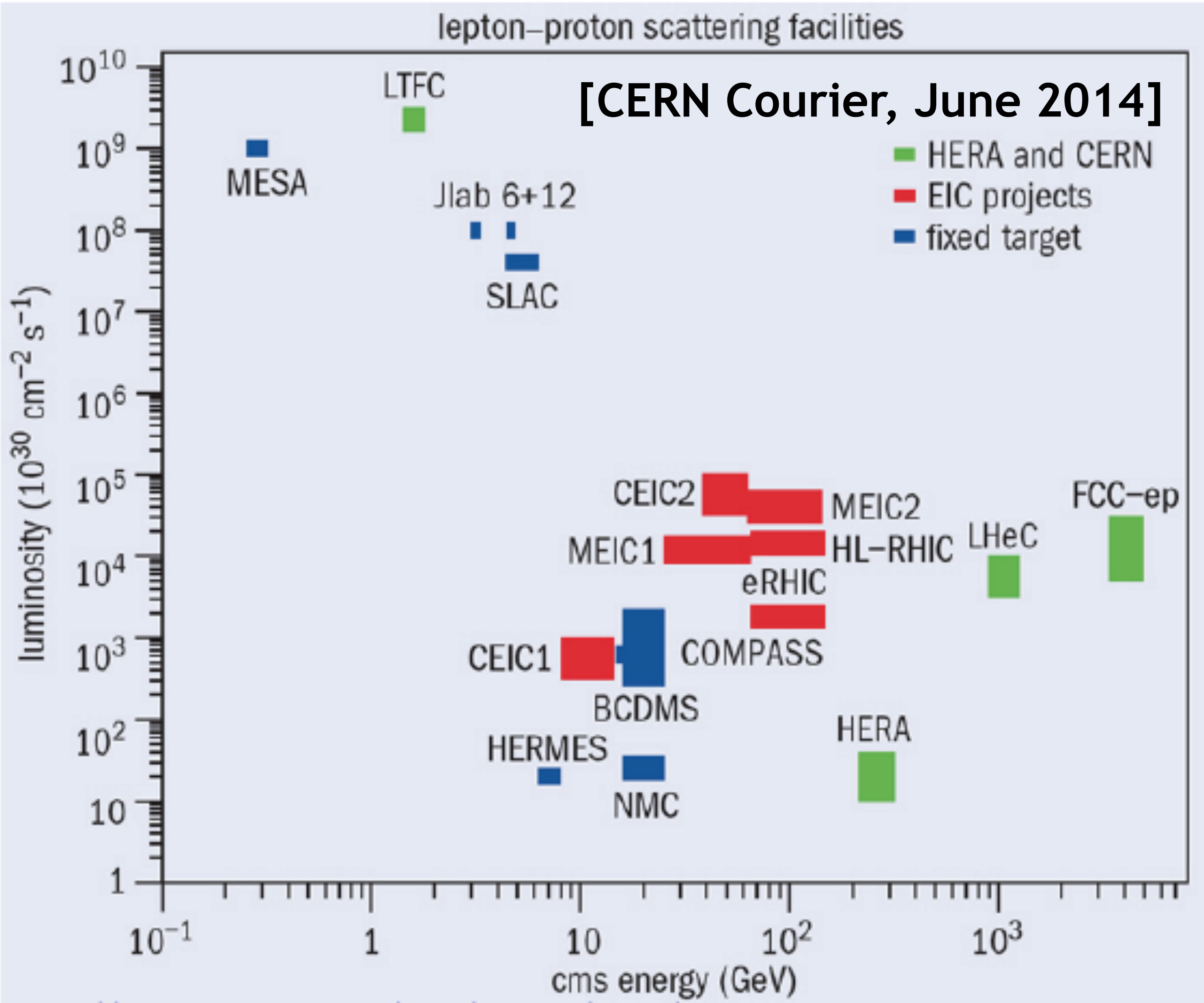
Other LHeC Talks at DIS'16 (all Tues 12/4)

Olaf Behnke:	Higgs and Top Physics at LHeC
Claire Gwenlan:	Low x Physics at LHeC
Mandy Cooper-Sarkar:	PDFs at LHeC
Ilkka Helennius:	eA Physics at LHeC

Other Useful Sources

- LHeC Chavannes Workshop (June 2015)
- LHeC web: http://lhec.web.cern.ch

LHeC Context



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-ep: 60 GeV electrons x 50 TeV protons from FCC (now @Roma)

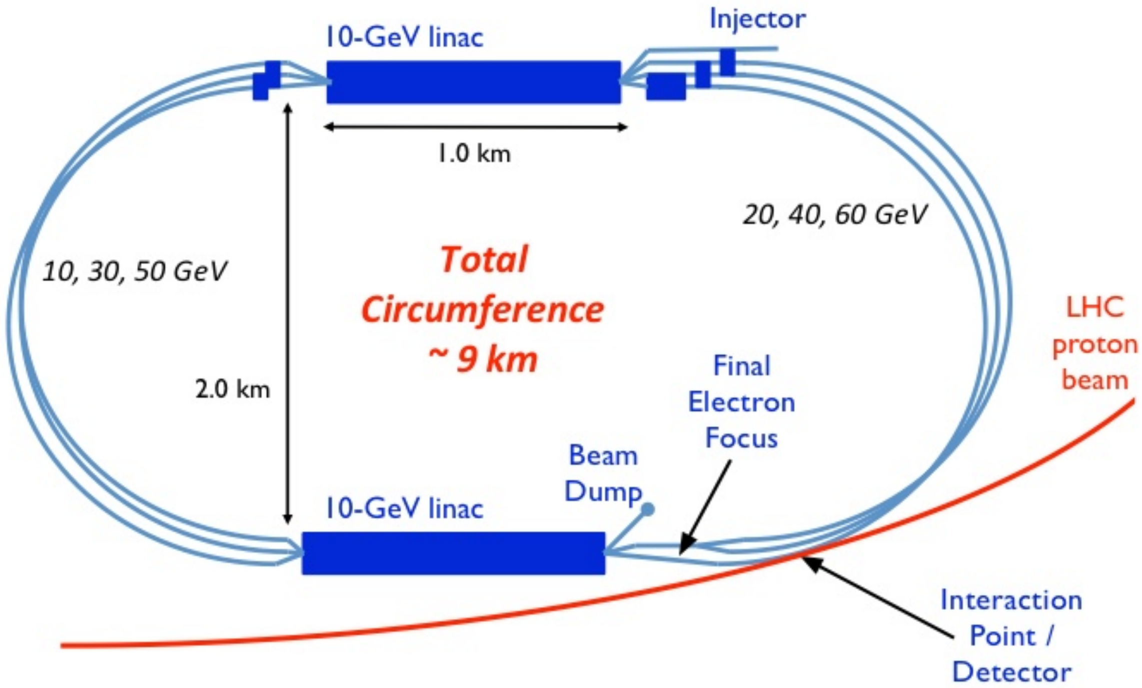
Natural next-step energy frontier ep / eA physics → TeV scale physics at 10^{34} cm^{-2}s^{-1}

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



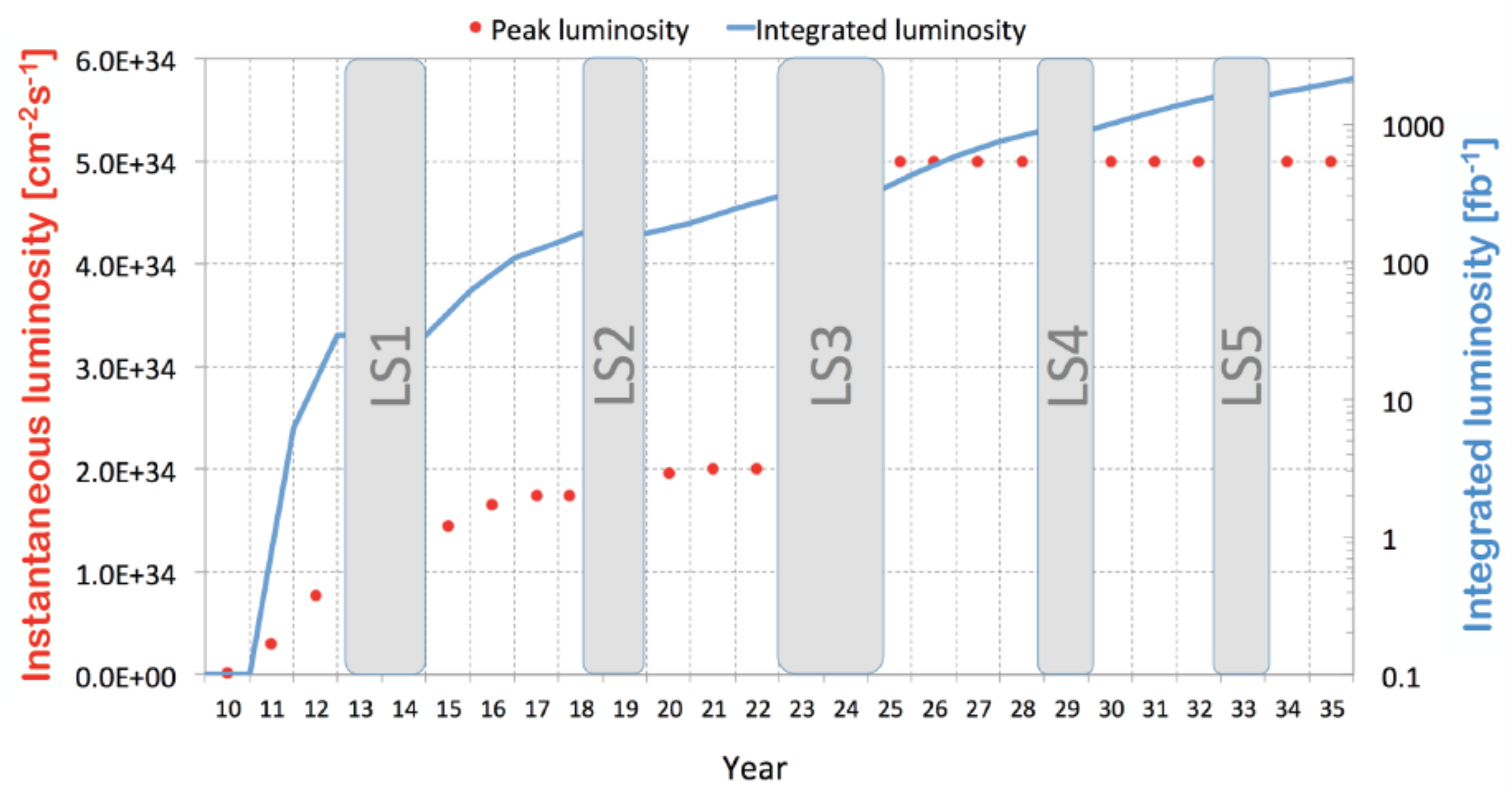
- ep lumi → 10^{34} cm^{-2} s^{-1}
→ ~100 fb^{-1} per year →~1 ab^{-1} total
- **eD and eA collisions have always been integral to programme**
- **e-nucleon Lumi estimates ~ 10^{31} (3.10^{32}) cm^{-2} s^{-1} for eD (ePb)**

Alternative designs based on electron ring and on higher energy, lower luminosity, linac also exist

Machine Parameters

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [$10^{33}cm^{-2}s^{-1}$]	16	16
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20
Beta Function $\beta^*_{x,y}$ [m]	0.05	0.10
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4
rms Beam divergence $\sigma'_{x,y}$ [μrad]	80	40
Beam Current [mA]	1112	25
Bunch Spacing [ns]	25	25
Bunch Population	$2.2*10^{11}$	$4*10^{9}$
Bunch charge [nC]	35	0.64

When?

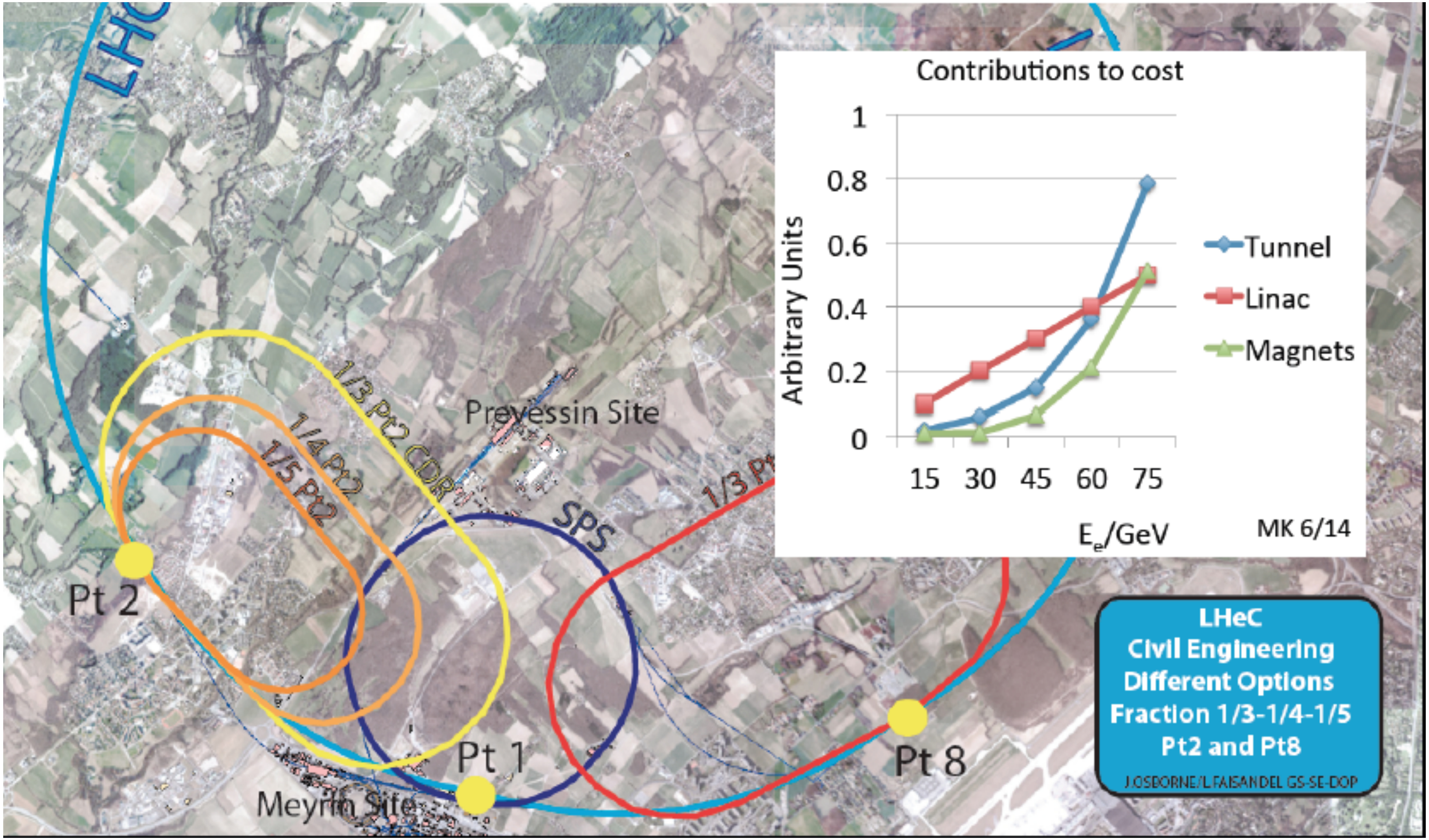


… Not defined … but note LHC schedule extends to ~2035, with further shutdowns beyond LS3 / HL-LHC upgrade

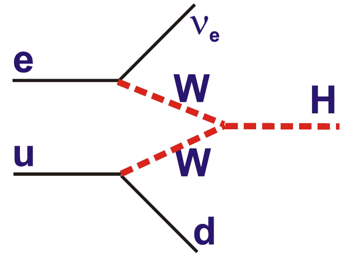
… Major part of LHeC physics programme (complementing and enhancing LHC) only makes sense if LHC & LHeC run in parallel

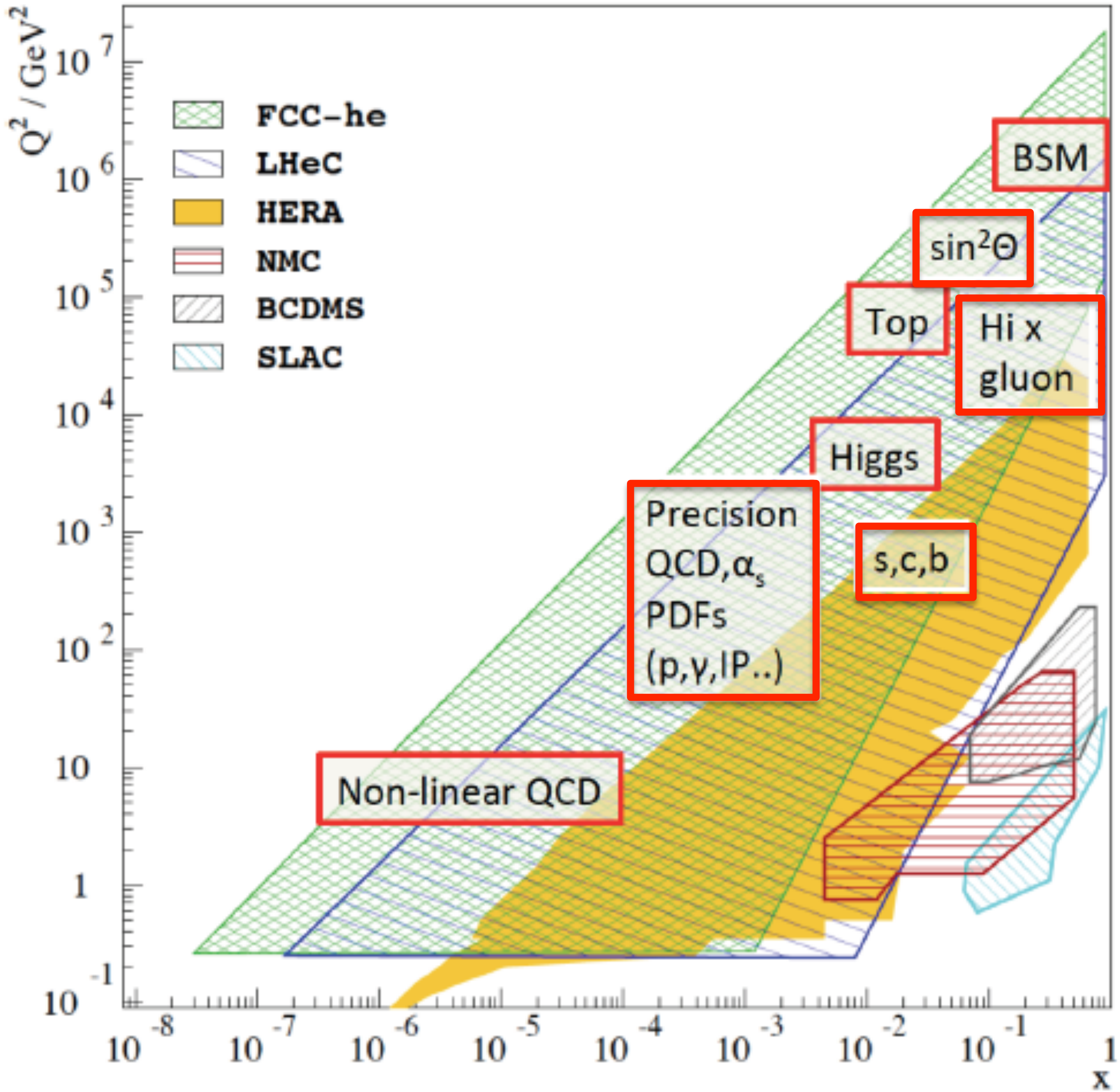
Where?

Default is 1/3 at Point 2 (currently ALICE) → 60 GeV electrons



Why?





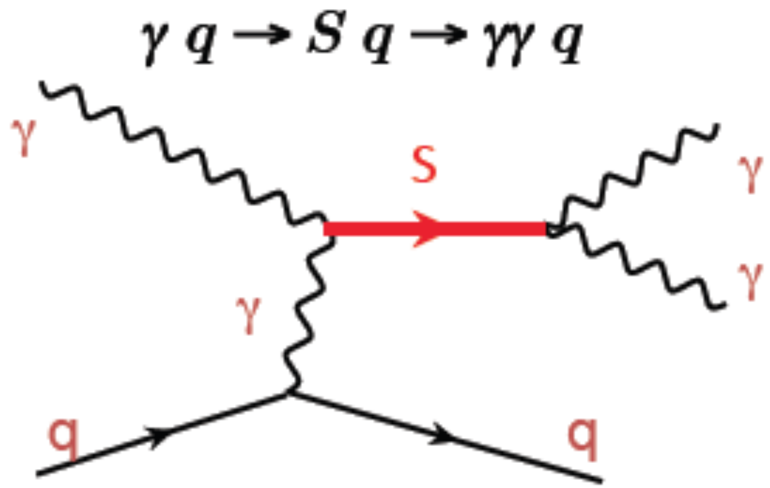
- Substantial Higgs programme

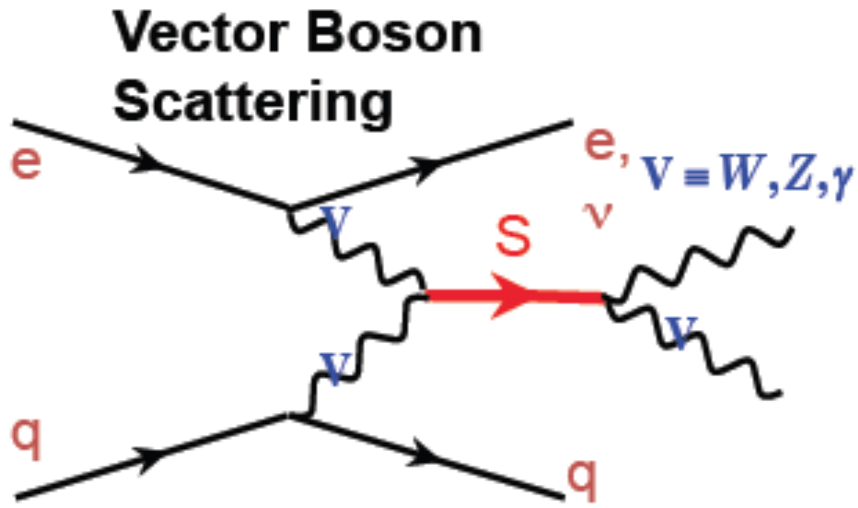
- Revolutionary p PDF (& α_s) precision improves LHC sensitivity to Higgs and new physics

- Elucidates low x dynamics in ep & eA

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

… and What If?...



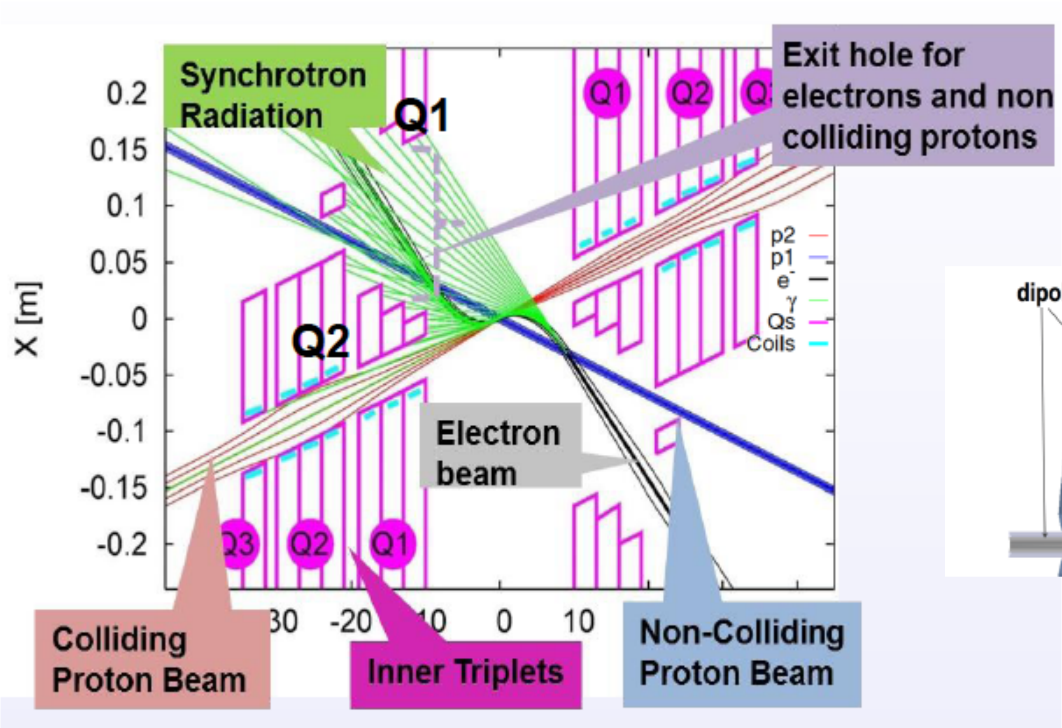


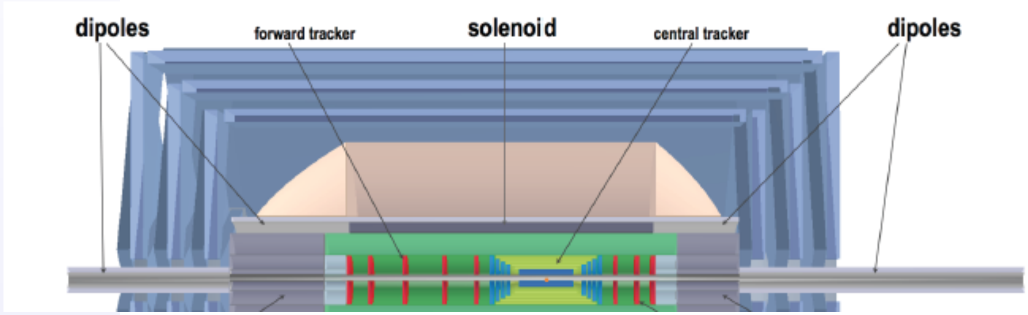
If a new scalar X(750) → γγ is confirmed at LHC, it is kinematically accessible at LHeC (with √s ~ 1.3 TeV)

- Background estimate in γp mode → ~ 0.01 fb

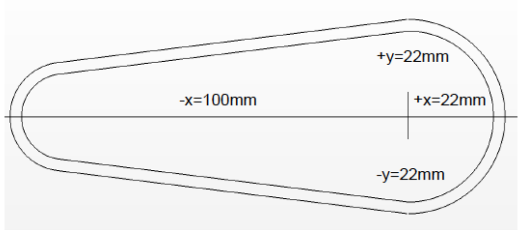
- VBF would be similar to Higgs analysis (Olaf's talk)
  … complementary to LHC; no possibility of production via gluon fusion in ep

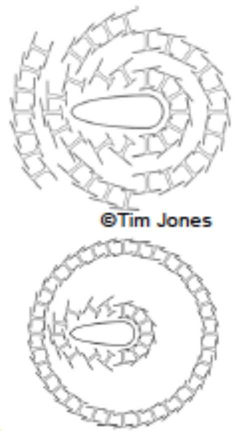
Interaction Region & Magnets





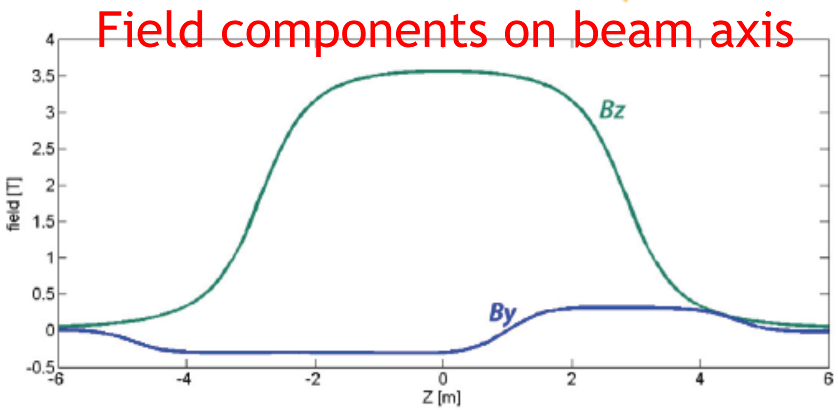
- Dual dipole magnets (0.15 – 0.3 T) throughout detector region (|z| < 14m) bend electrons into head-on collisions





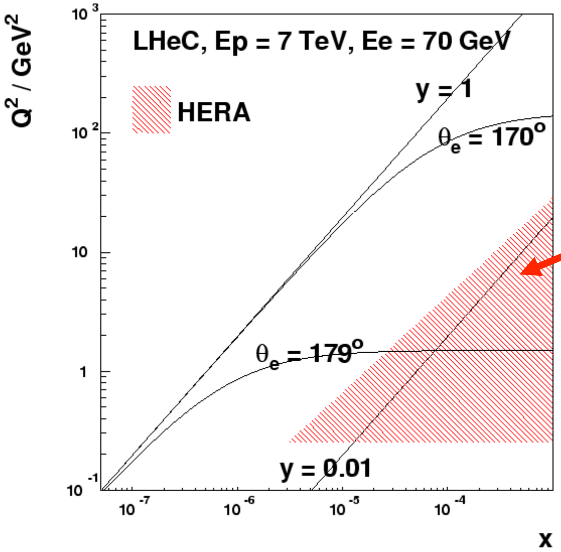
- Eliptical beampipe (6m x 3mm Be) accommodates synchrotron fan

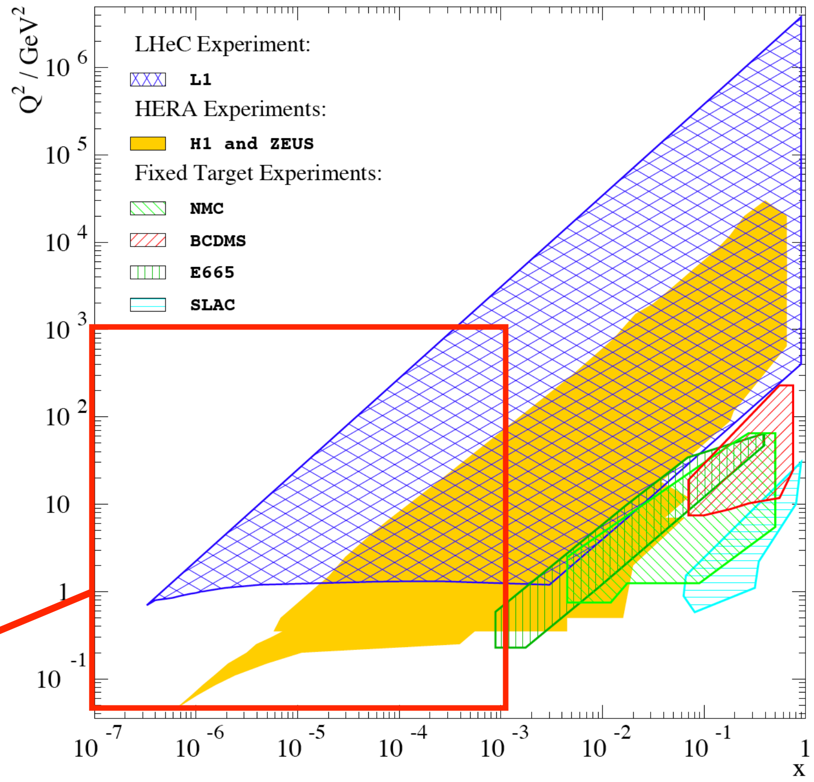
- 3.5 T Superconducting NbTi/Cu Solenoid in 4.6K liquid helium cryo.



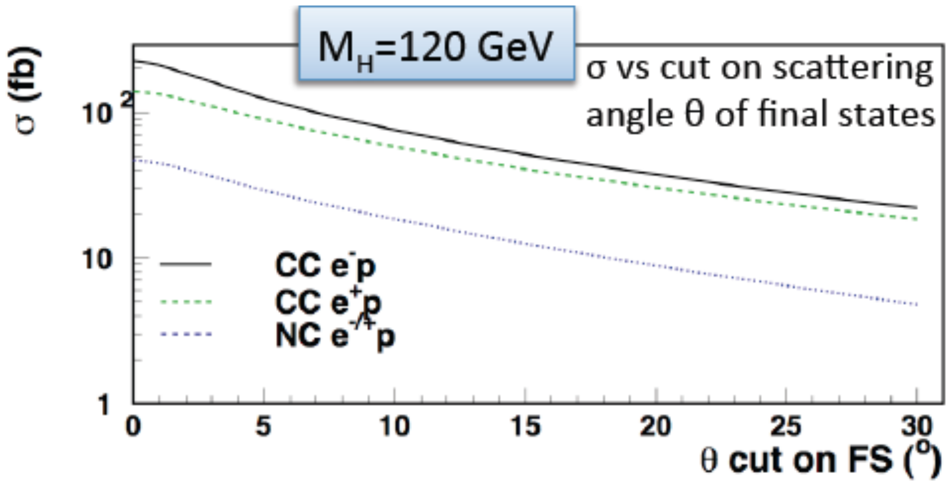
LHeC Kinematic Detector Requirements

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

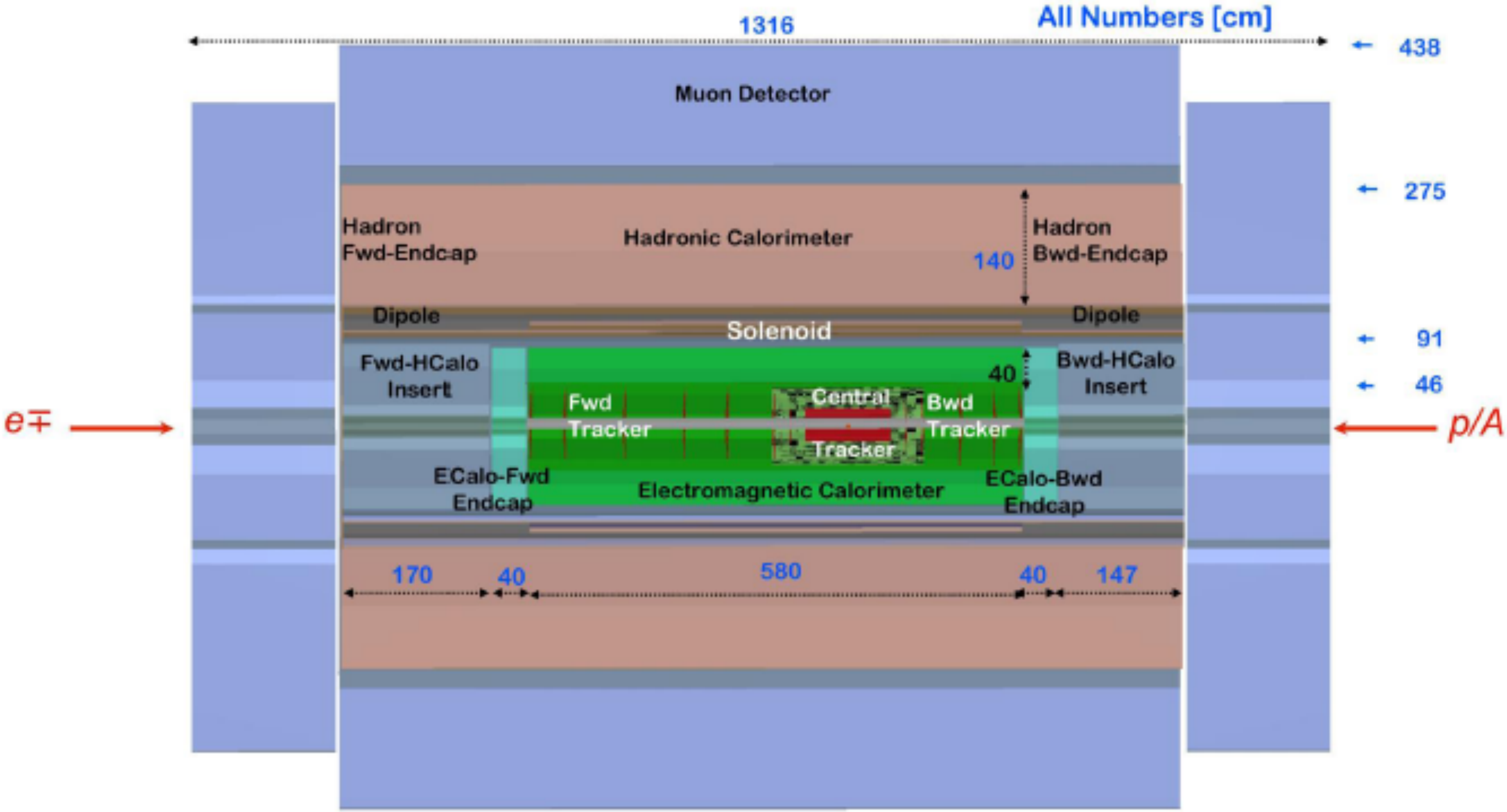




Also need 1° in outgoing proton direction to contain multi-TeV jets at high x (essential for kinematic reconstruction) and for Higgs / other acceptance

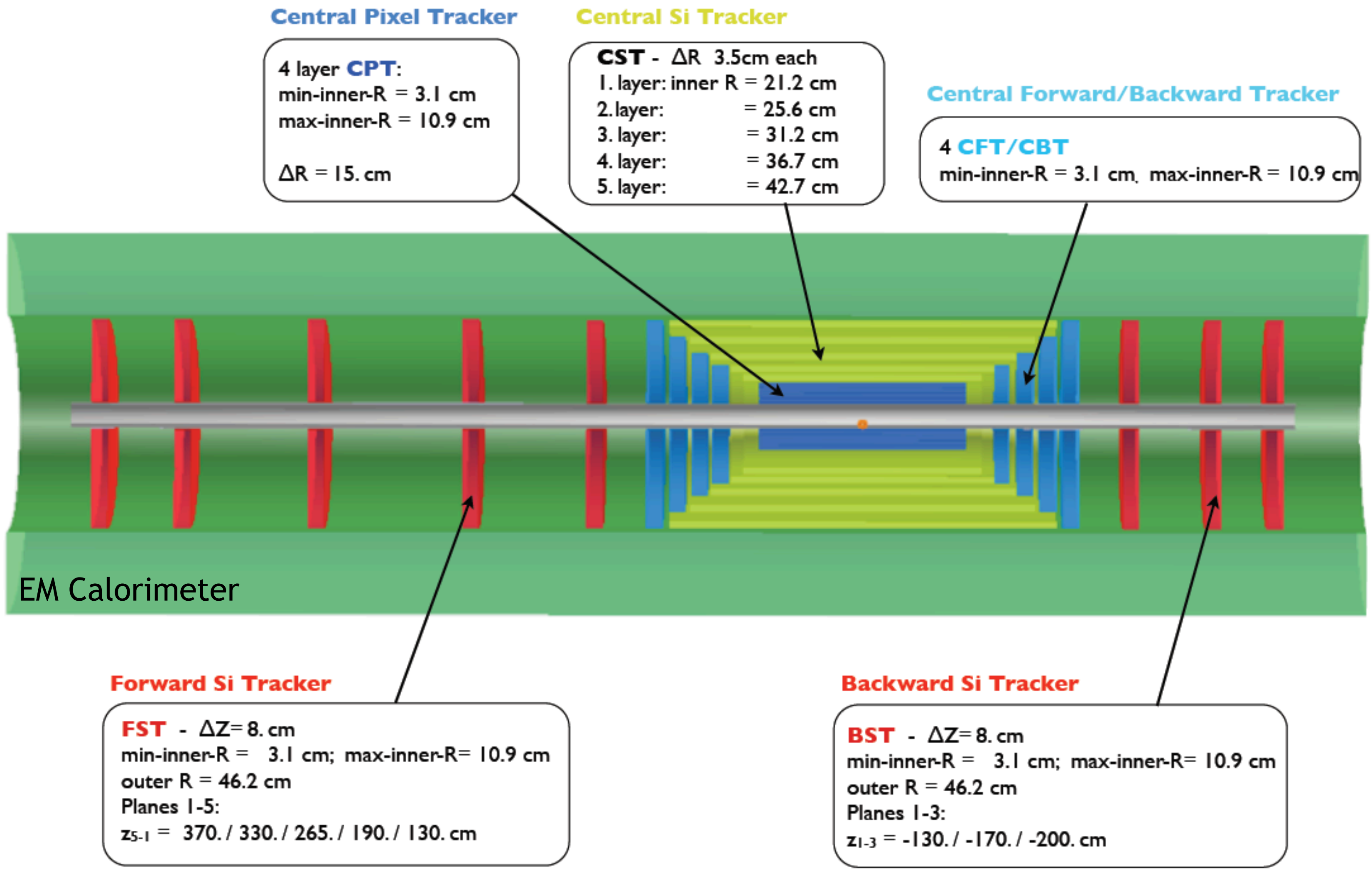


Detector Design Overview



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

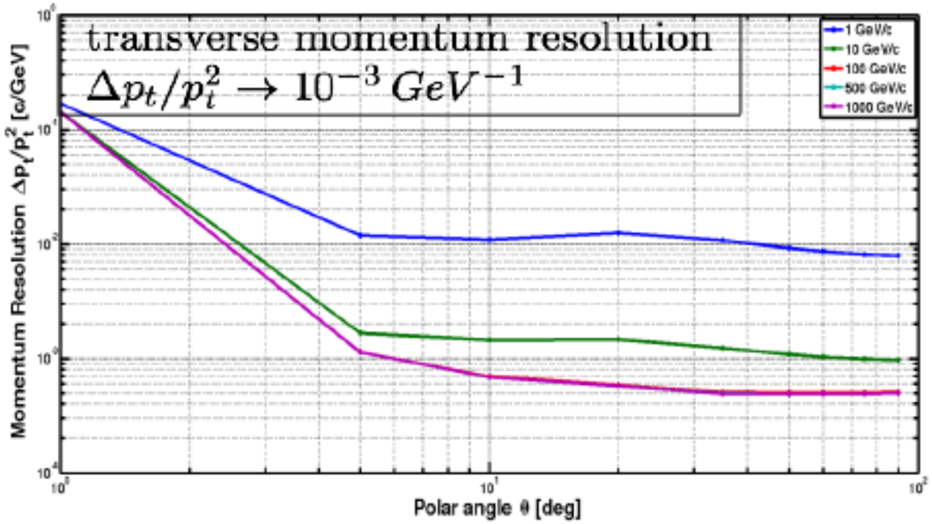
Tracking Region

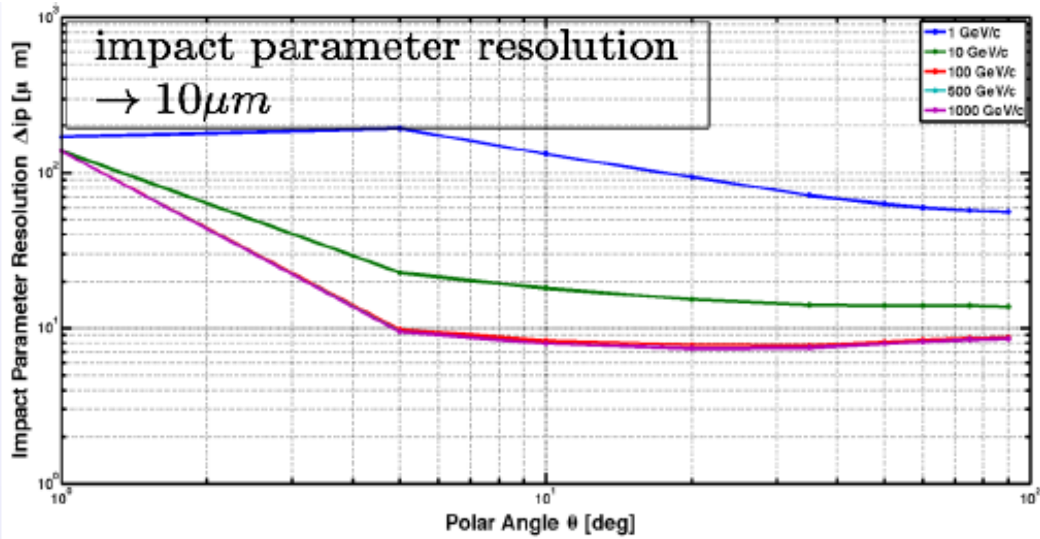


- Long tracking region → 1° electron hits 2 tracker planes
- Forward direction most demanding (dense, high energy jets)
- Pixels (CPT) + Strips; several technologies under discussion

Tracking Simulation

Performance evaluated from basic layout (LicToy 2.0 program)





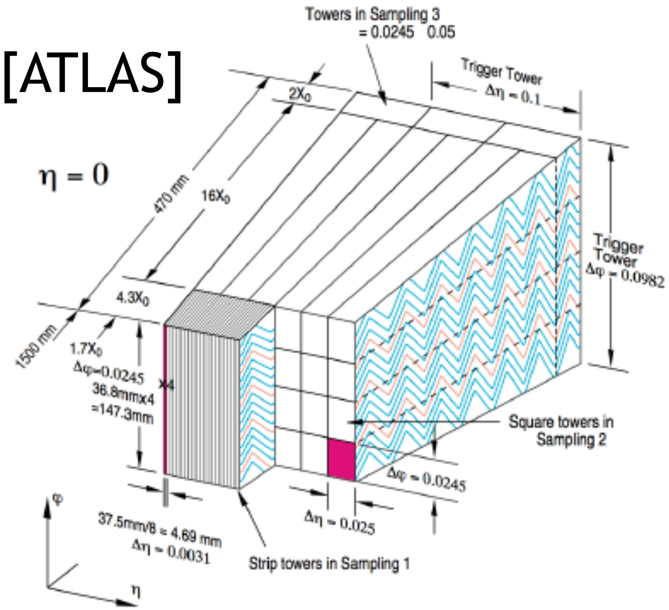
- Central tracks:
  - Excellent track resolution: $\Delta p_t/p^2_t \rightarrow 6\ 10^{-4}\ GeV^{-1}$
  - Excellent impact parameter resolution: → 10μm

- Forward / Backward tracks:
  - Degrades for $\theta <\sim 5^o$, but still useful!
  - At 1^o, bending field component = 0.36 T (similar to dipole)

Barrel EM Calorimeter

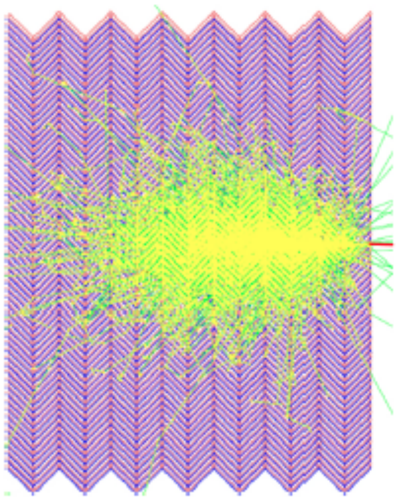
- $-2.3 < \eta < 2.8$
- Accordion geometry baseline design
- 2.2mm lead + 3.8mm LAr layers
- Total depth ~ 20 X_0

[ATLAS]

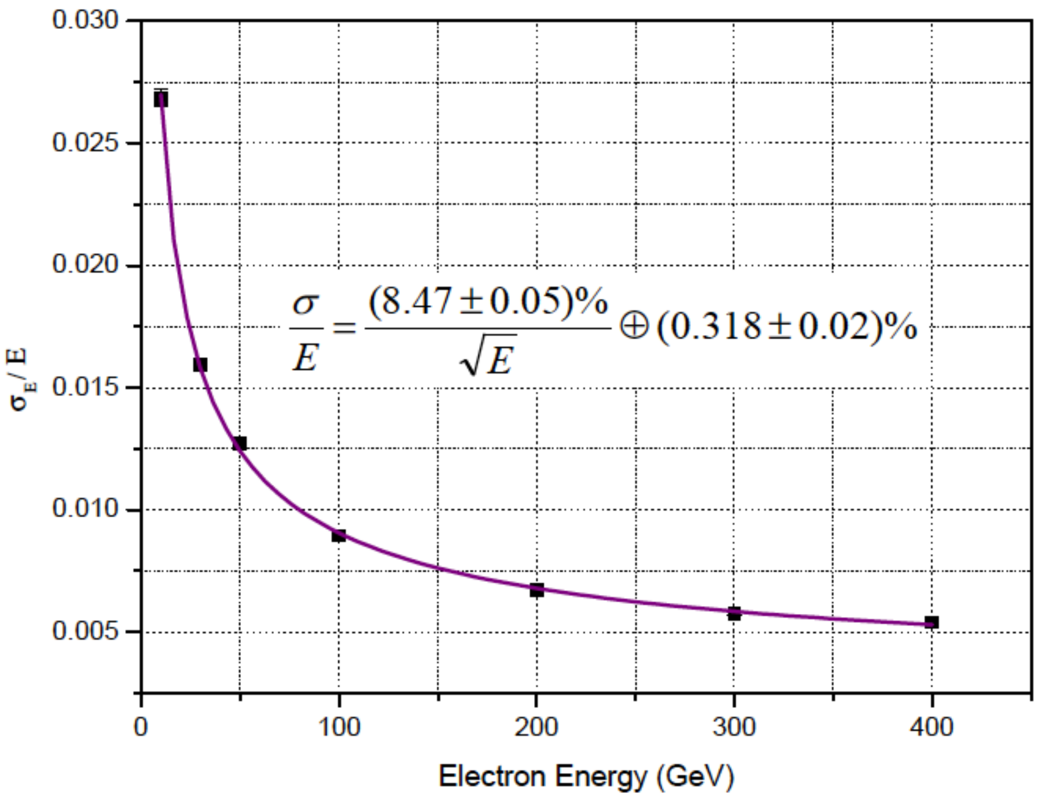


- Geant4 simulation of response to electrons at Normal Incidence

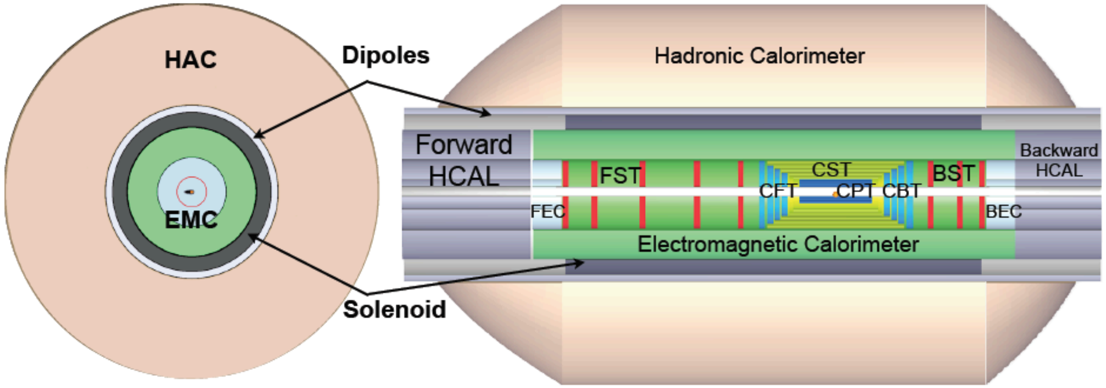
[cf ATLAS: 10%/√E + 0.35%]



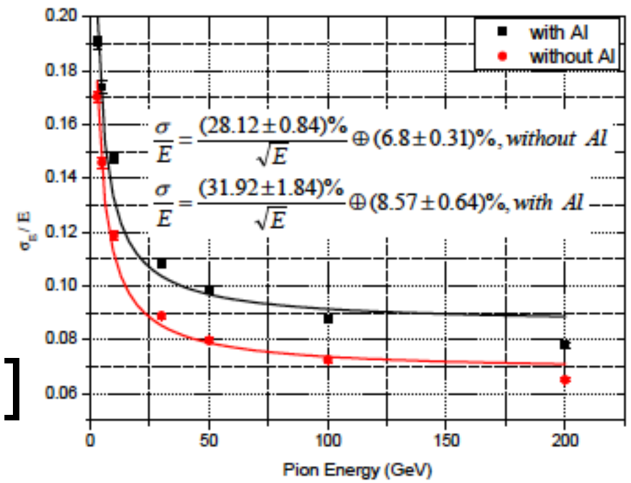
[20 GeV electron shower)]



Overview of Calorimeters



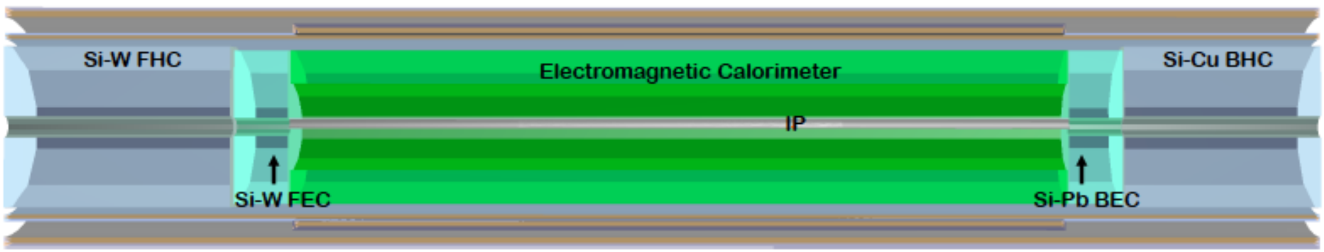
Current design based on (experience with) ATLAS (and H1), re-using existing technologies



- Barrel HAD calorimeter, outside coil
  → 4mm Steel + 3mm Scintilating Tile
  → 7-9 λ, σ_E/E ~ 30%/√E + 9% [~ ATLAS]

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

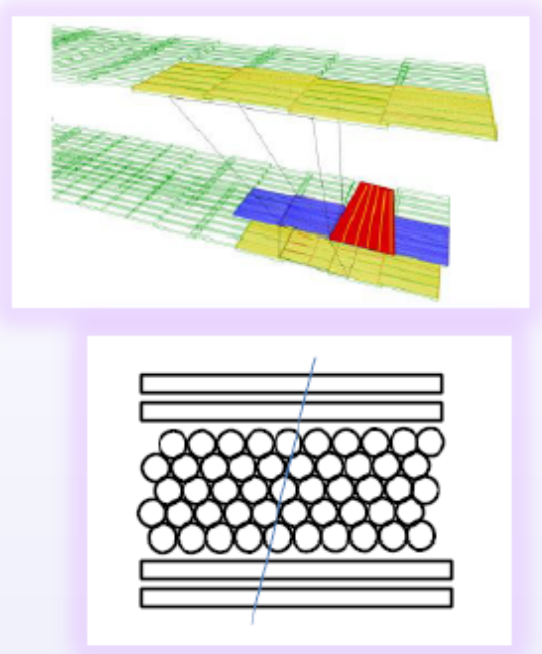
- Backward end-cap
Pb+Si for EM ($25X_0$)
Cu+Si for HAD (7λ)

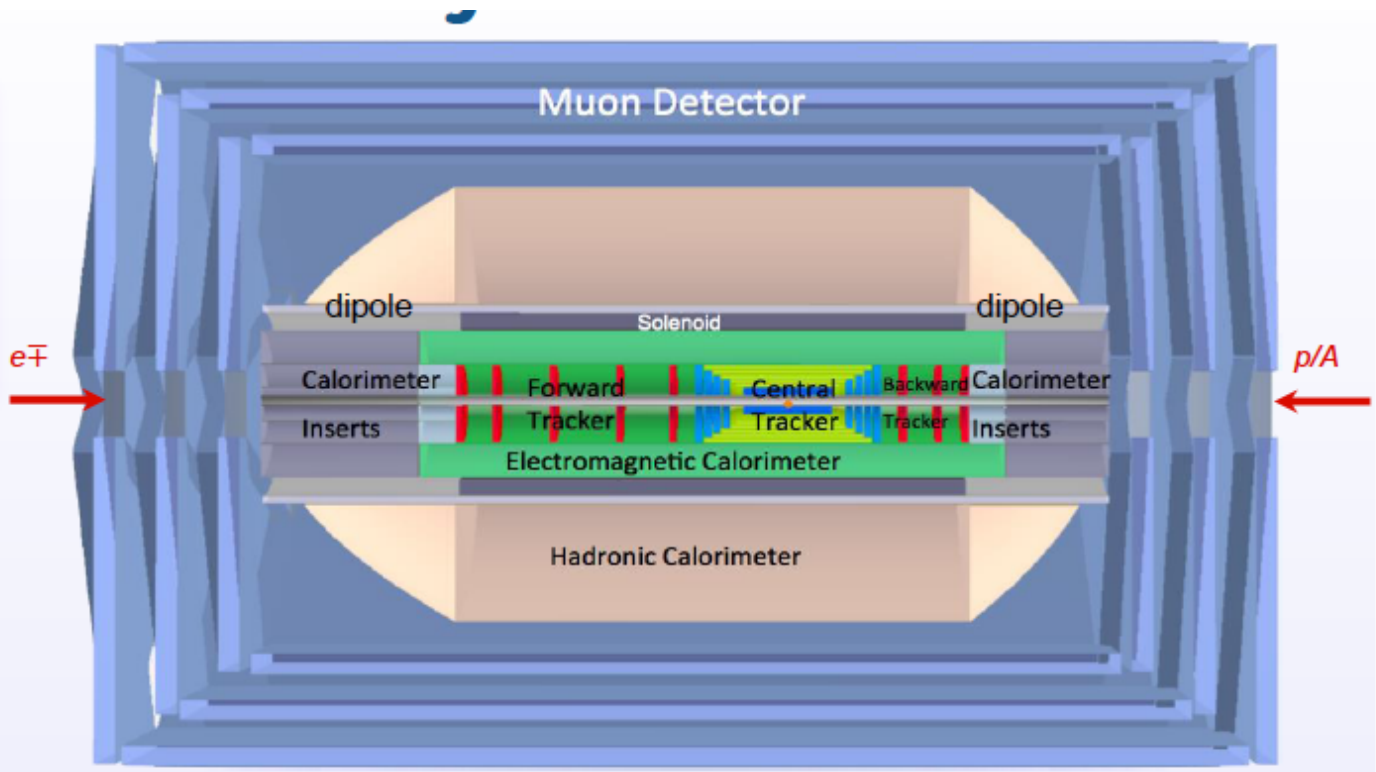


Muon System

Baseline: Provides tagging, but not momentum measurement
: Angular coverage → 1^o 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]

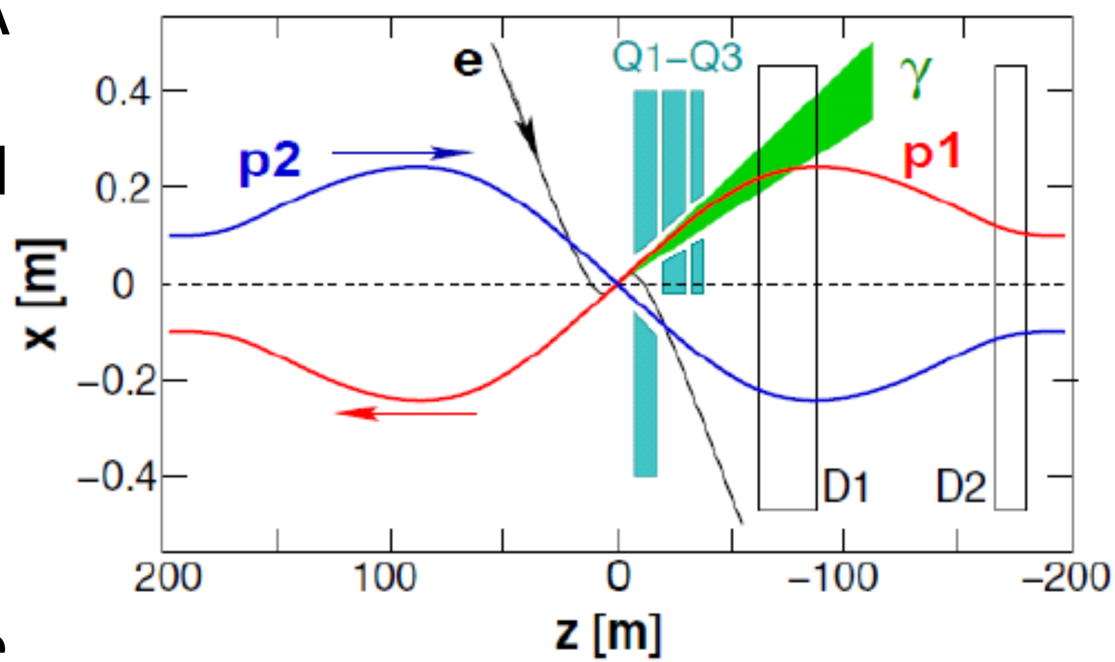
Beamline Instrumentation

Luminosity / Photon Tagging

- Use Bethe-Heitler, as HERA

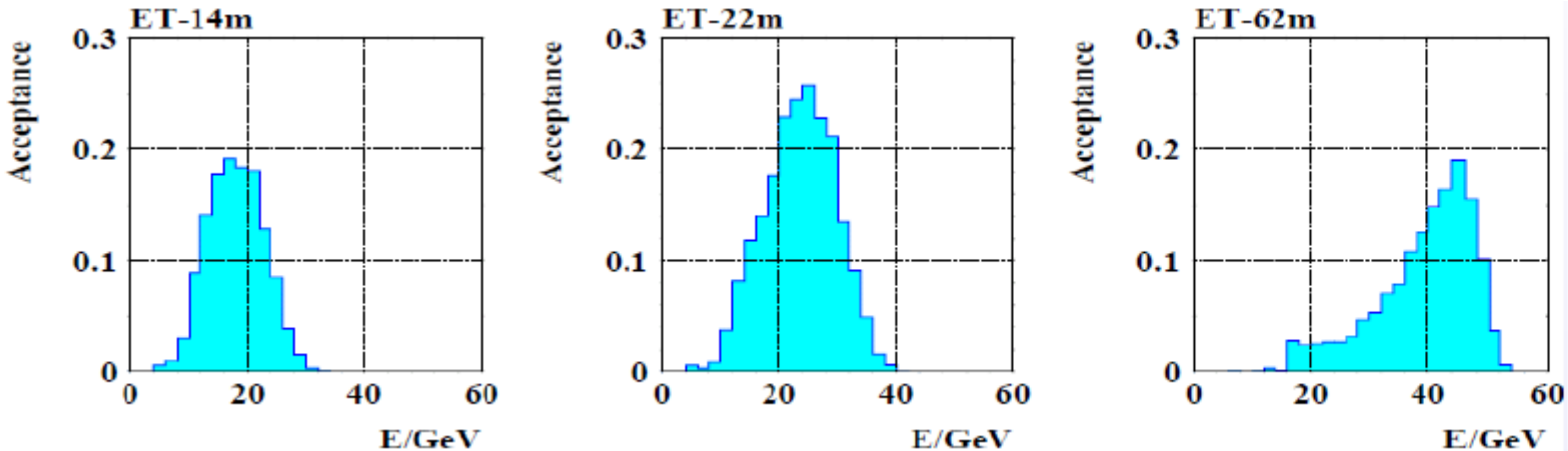
- Photons might be detected at z = -120 m after D1 proton bending dipole

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



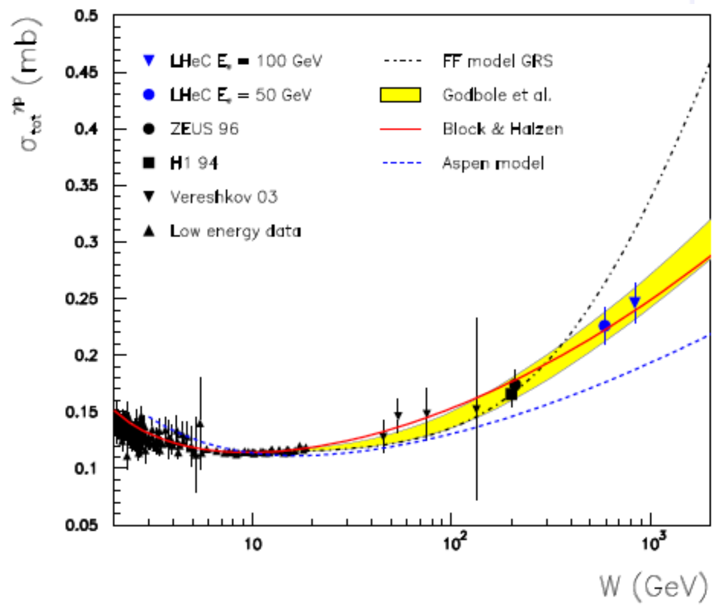
Low Angle Electron Tagging

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



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

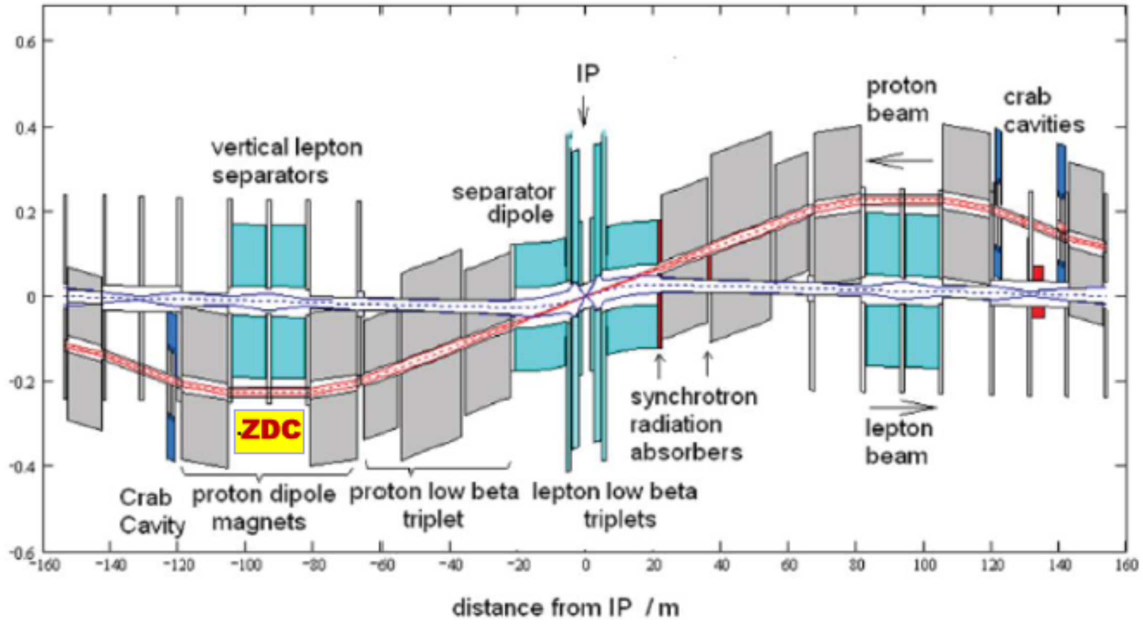
- 62m is most promising due to available space and synchrotron radiation conditions

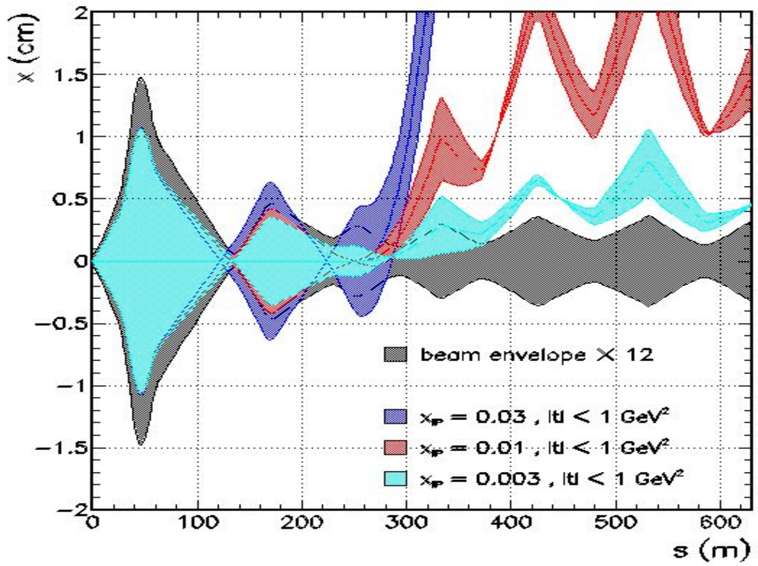


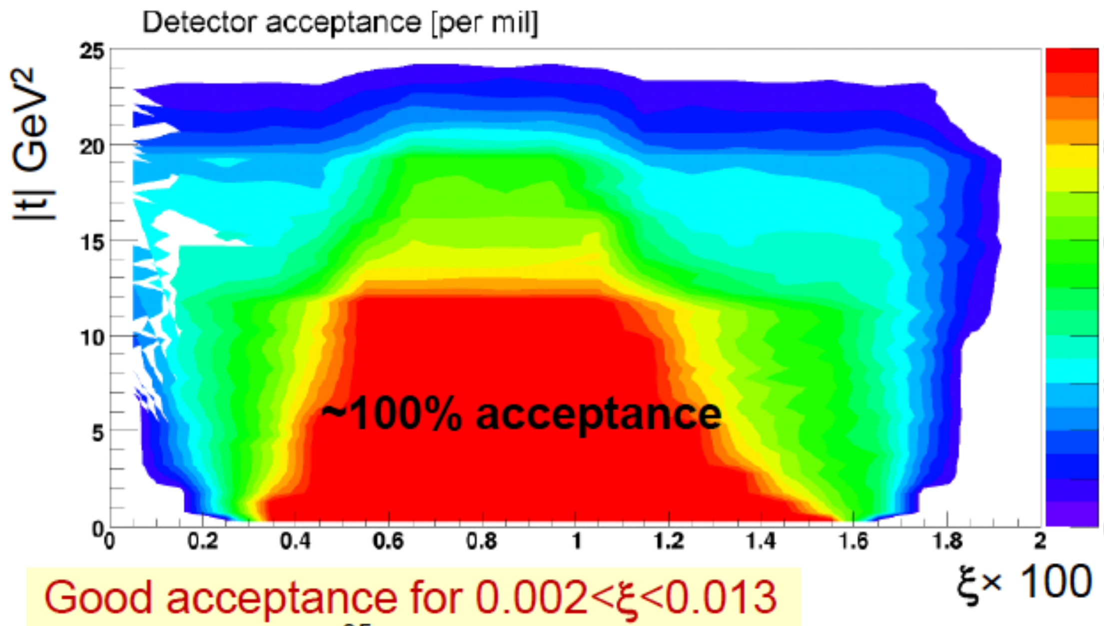
Leading Neutrons and Protons

- Possible space for neutron calorimeter at z ~ 100m

- "FP420 style" forward proton spectrometer gives very high acceptance [12σ (~250 μm) approach to beam assumed]



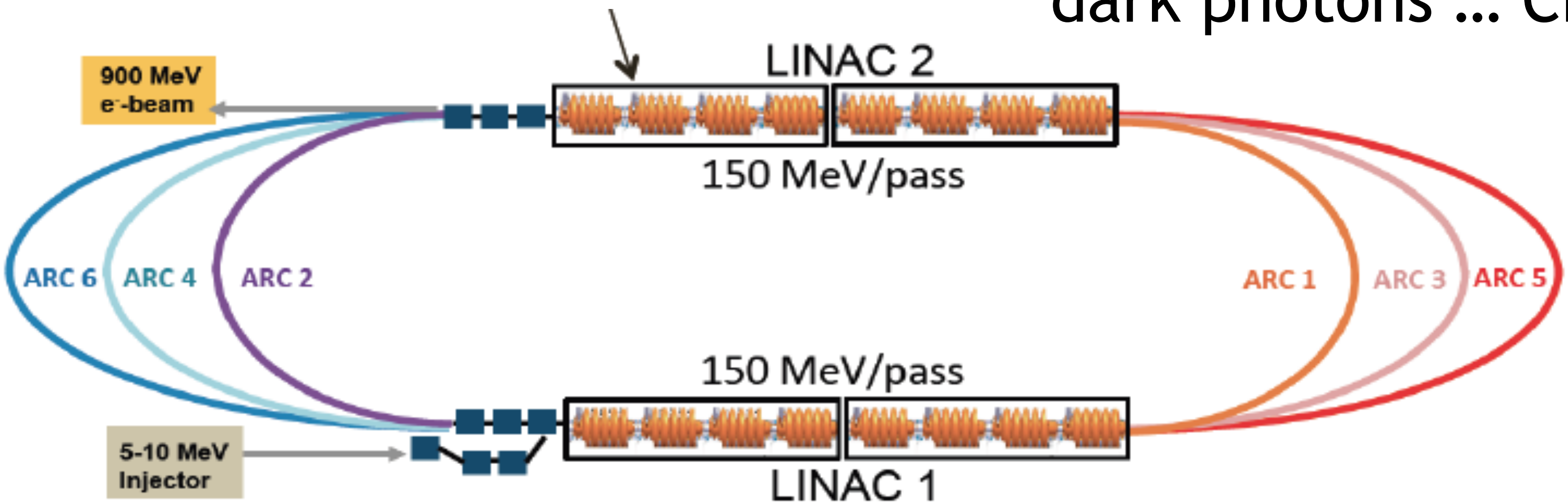




Good acceptance for $0.002<\xi<0.013$

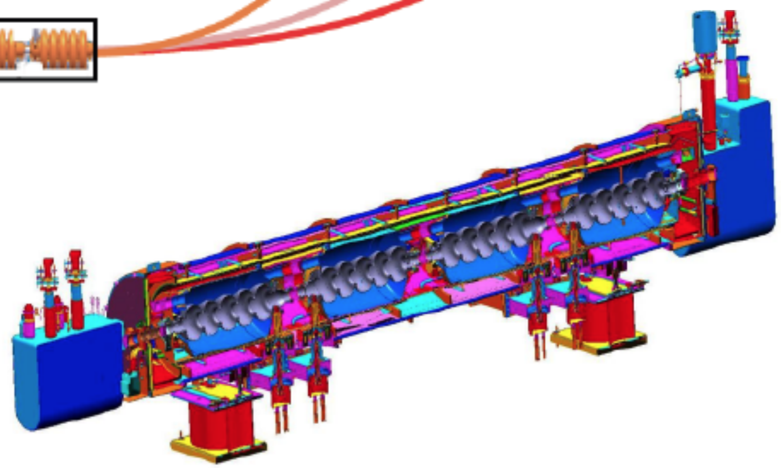
Proposed ERL Prototype (PERLE)

- Test centre for accelerator development, LHeC prototype
- 2 x 150 MeV linacs, 3 passes → 900 GeV at high current
- Significant standalone physics potential (10^{40} cm^{-2} s^{-1} fixed target) … EW parameters, proton radius, photonuclear physics, dark photons … CDR in litt



- 4 cryo modules, each housing 4 x 802 MHz 5-cell RF cavities giving ~20MV.

… under development (Jlab / CERN)



- Adaptation of JLab SNS high β cryo module

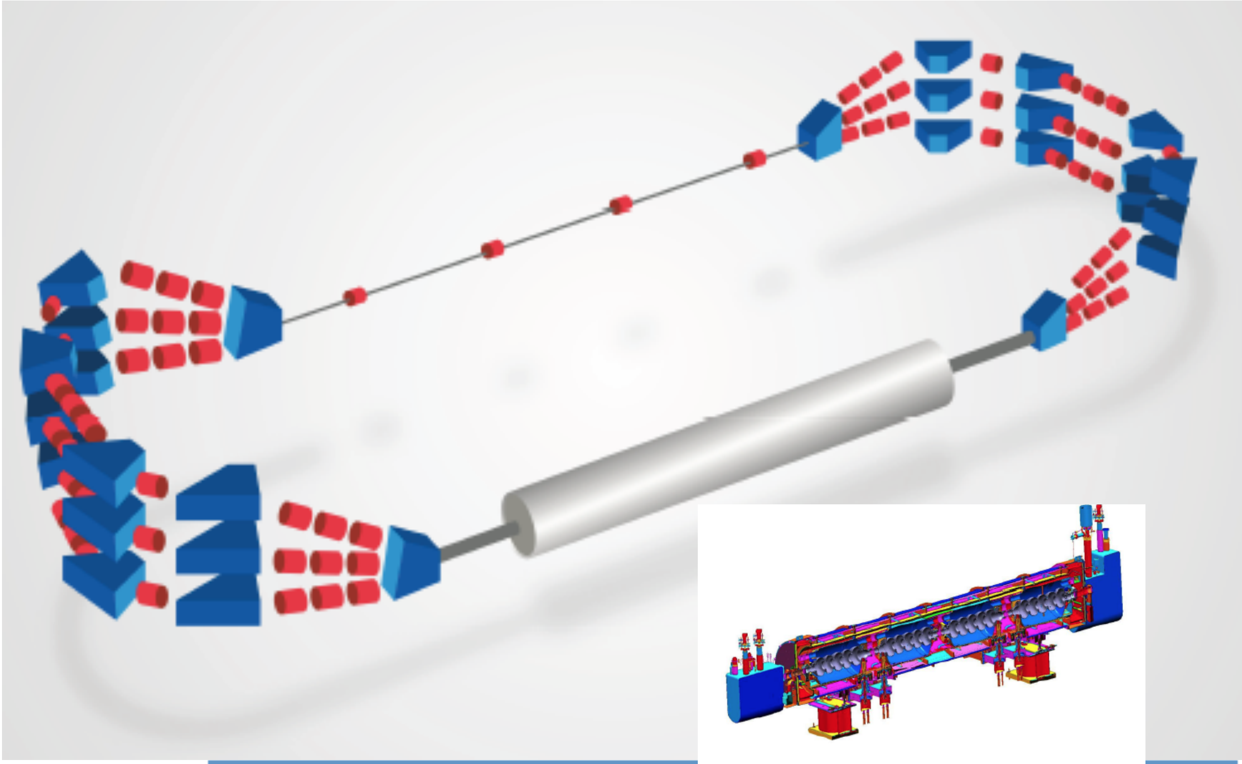
ERL Demonstrator

Reduced specification ERL prototype with two or even one cryo module, using the same 802MHz cavities

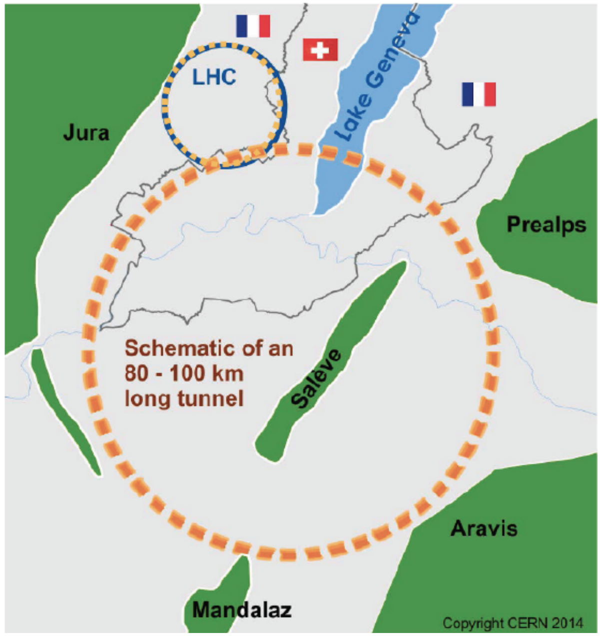
→ E_e = 400 (200) MeV

→ Lacks standalone physics programme

→ Sufficient for proof of principle of multi (3)-turn ERL with high (~10mA) current.



Parameter	Value
Dipoles per arc Dipole length Max B Field	3/4 50 cm 1.1 T
Quadrupoles per arc Quadrupoles in straight lines	5 4
Dipoles in Spreader/Combiner Quads in Spreader/Combiner	1-3 3
Dipoles for Injection-Extraction	6



More Distant Future: FCC-he

Ongoing work based on similar electron ERL to LHeC, with 50 TeV protons

A Baseline for the FCC-he

Oliver Brüning[1] Max Klein[1,2], Daniel Schulte[1], Frank Zimmermann[1]
[1] CERN, [2] University of Liverpool
March 3rd, 2016

Table 1: Baseline parameters of future electron-proton collider configurations based on the ERL electron linac.

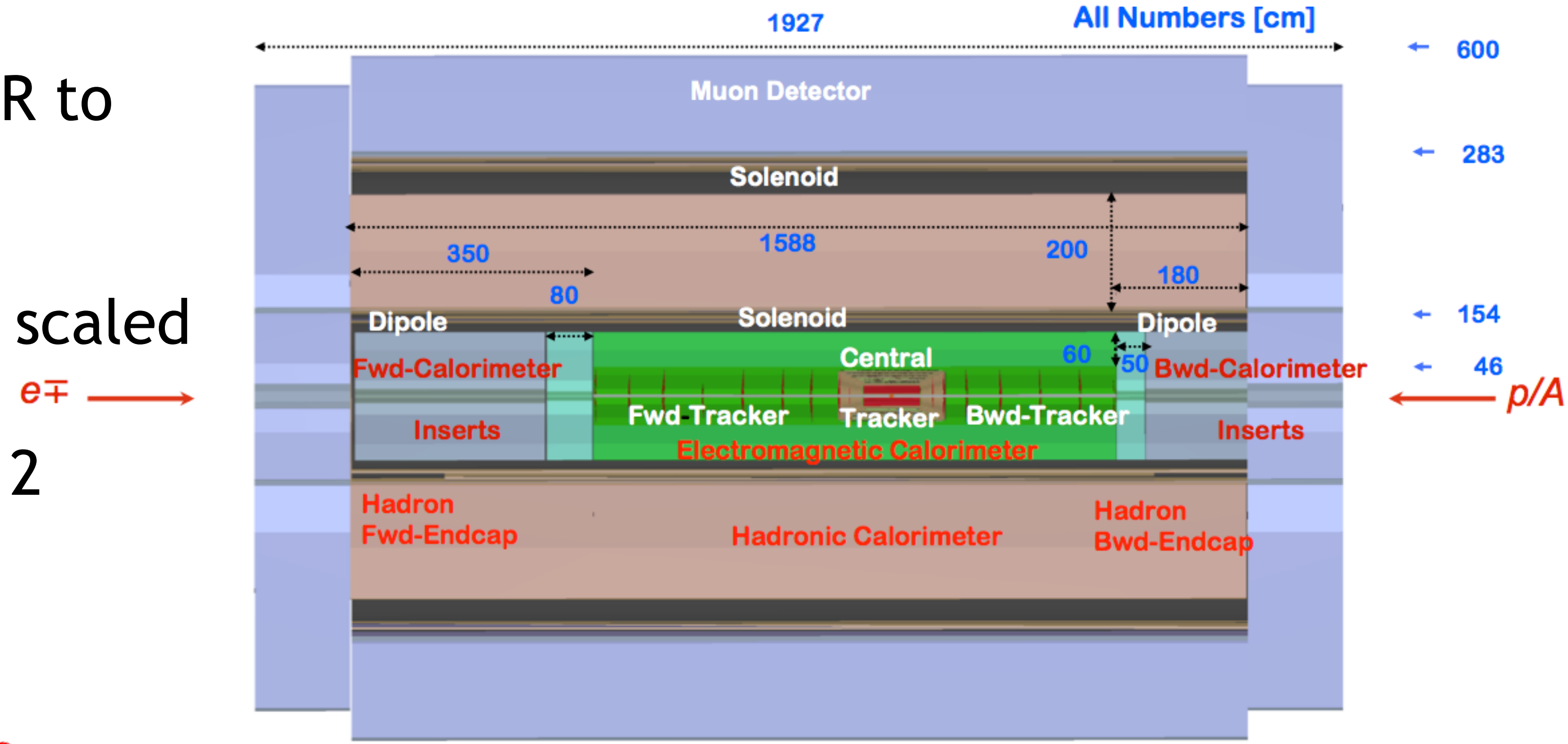
parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	15	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.9	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.2	1
ϵ_p [μm]	3.7	2	2	2.2
electrons per bunch [10^9]	1	2.3	2.3	2.3
electron current [mA]	6.4	15	15	15
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor	0.9	0.9	0.9	0.9
pinch factor	1.3	1.3	1.3	1.3
luminosity [10^{33}cm^{-2}s^{-1}]	1.3	10.1	15.1	9.2

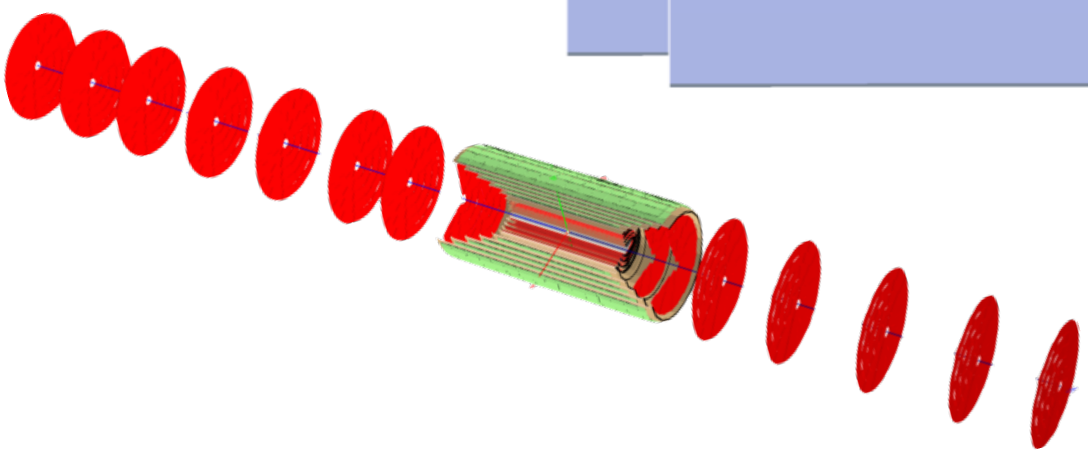
[Work in progress → 10^{35} cm^{-2} s^{-1} ep at $\sqrt{s}$ = 3.5 TeV, also eA]

Detector for ep at a Future Circular Collider

- Similar IR to LHeC

-Detector scaled by up to ln(50/7)~ 2





- Double solenoid + Dipole

- Even longer tracking Region than LHeC

Organisational Structure

International Advisory Committee

Guido Altarelli (Rome)+
Sergio Bertolucci (CERN)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – **Chair**
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (STFC)

Mandate to the International Advisory Committee

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.

Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

Chair: Herwig Schopper

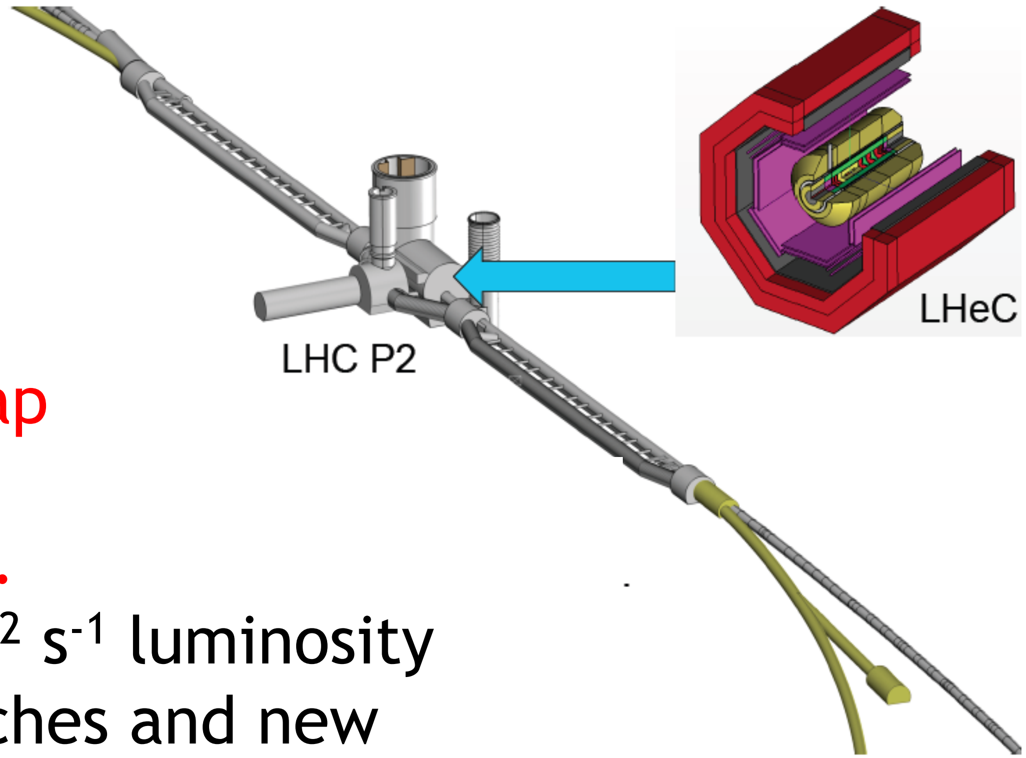
Coordination Group

Gianluigi Arduini
Nestor Armesto
Oliver Brüning
Stefano Forte
Andrea Gaddi
Erk Jensen
Max Klein
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

Physics Working Groups / Convenors

PDFs, QCD	Fred Olness, Voica Radescu
Higgs	Uta Klein, Masahiro Khuze
BSM	Georges Azuelos, Monica D'Onofrio
Top	Olaf Behnke, Christian Schwanenberger
Nuclei	Nestor Armesto
Small x	Paul Newman, Anna Stasto

LHeC Summary



- CDR 2012

- Recently presented to ECFA, on NuPECC (long-term) roadmap

- Renewed interest following …
    1) Possibility of 10^{34} cm^{-2} s^{-1} luminosity
    2) Higgs discovery, searches and new measurements at LHC→ PDFs & QCD limit HL-LHC.
    3) Technical interest (high gradient cavities, ER linacs)
    4) Longer term perspective of FCC

- Next goals …
    1) Development of 802 MHz SC RF → ERL prototype design
    2) Update CDR (physics, technical) for 2018 Euro Strategy
    3) Further development of FCC concept and physics