Detector(s) for Energy-Frontier eh Scattering

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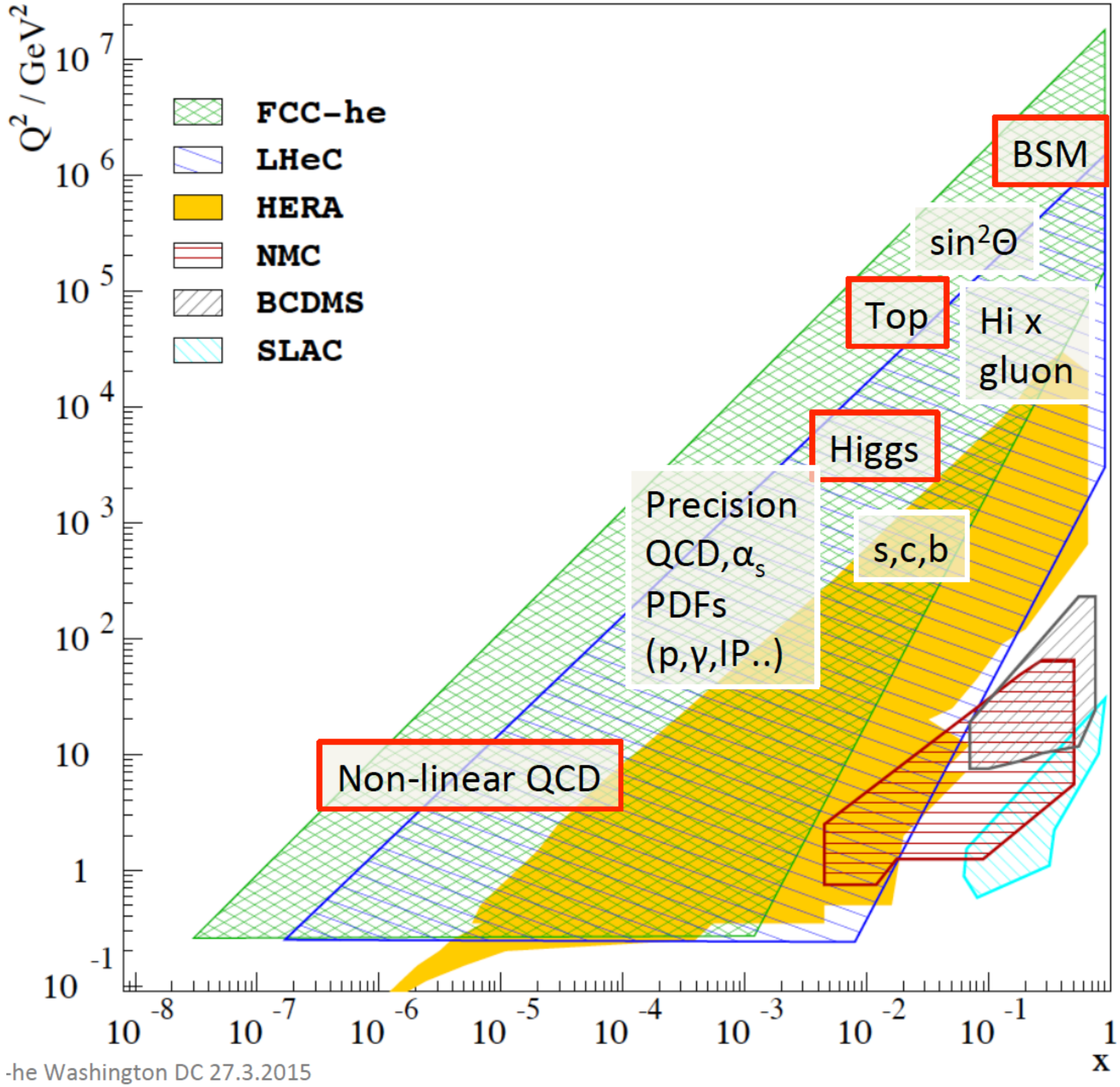
on behalf of the LHeC Study Group

presented by M.Klein

http://www.lhec.cern.ch [next workshop 24-26.6.2015]

CDR: "A Large Hadron Electron Collider at CERN"
LHeC Study Group, [arXiv:1206.2913]
J. Phys. G: Nucl. Part. Phys. 39 (2012) 075001
"On the Relation of the LHeC and the LHC" [arXiv:1211.5102]

Q^2-x Range and Physics



60 GeV ERL added to LHC 7 TeV at 10^{34}cm^{-2} s^{-1}

→ LHeC

60 GeV ERL added to FCC 50 TeV at 10^{34}cm^{-2} s^{-1}

→ FCC-he

Status in Brief

- **LHeC Detector has been designed for 1-179° coverage [CDR 2012]**
- **New:**

  - Higgs discovery: LHeC 10^{34} and max (fwd) rapidity crucial

  - FCC study: "joint" hh-he-ee software development

  - Conceptual design of FCC-eh detector

  - Upgrades of LHC detectors
- **Of special interest:**

  - new generation of Si trackers (all 4 LHC detectors)

  - very forward tracking and calorimetry
- **Differences of ep vs pp**

  - Radiation level down by few orders of magnitude

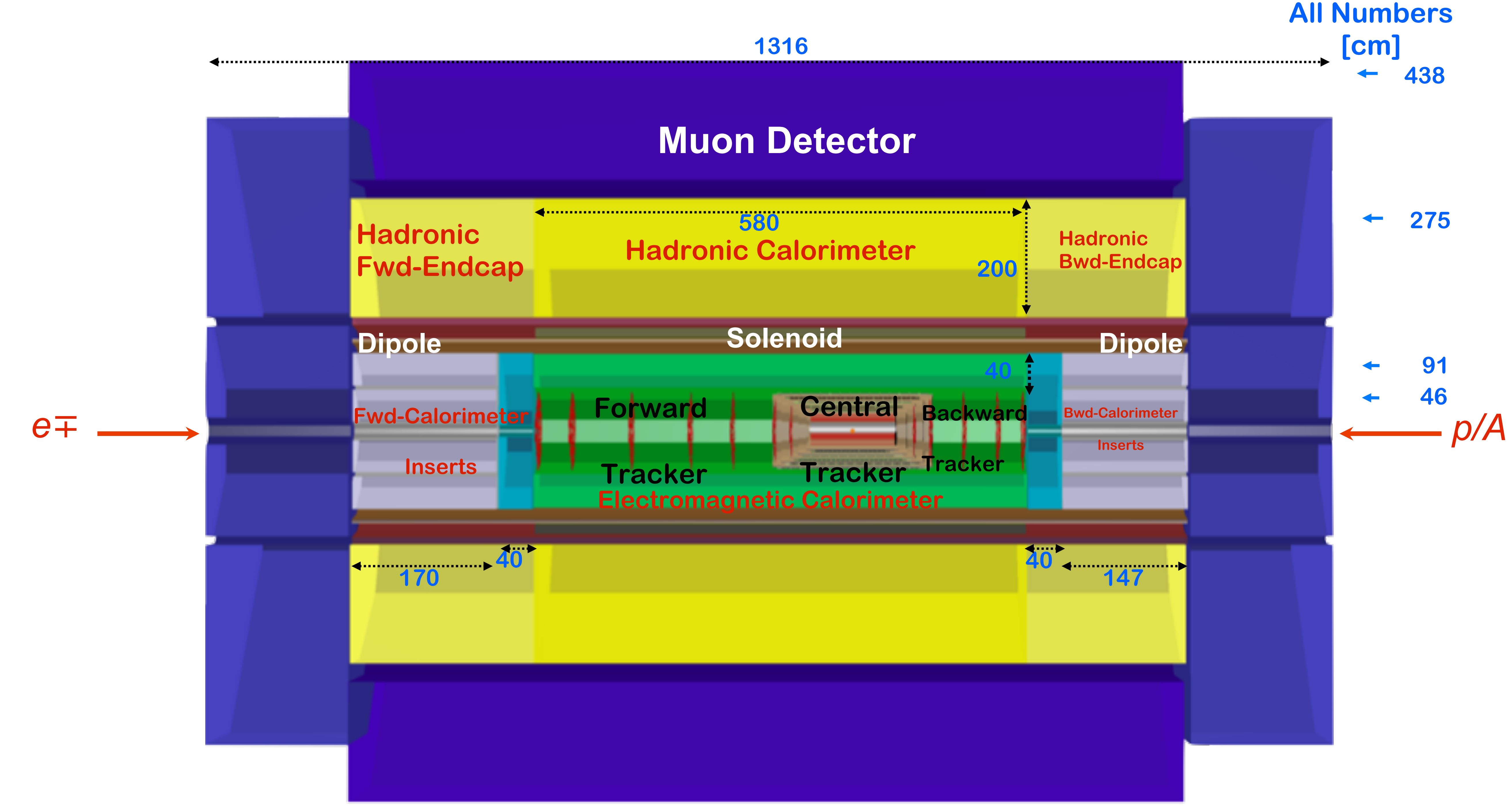
  - No pile-up in ep

  - Electron and hadron detection for very high precision

→ **This presentation:**

Brief progress report on the design of the LHeC detector and conceptual ideas on an FCC-he detector and IR

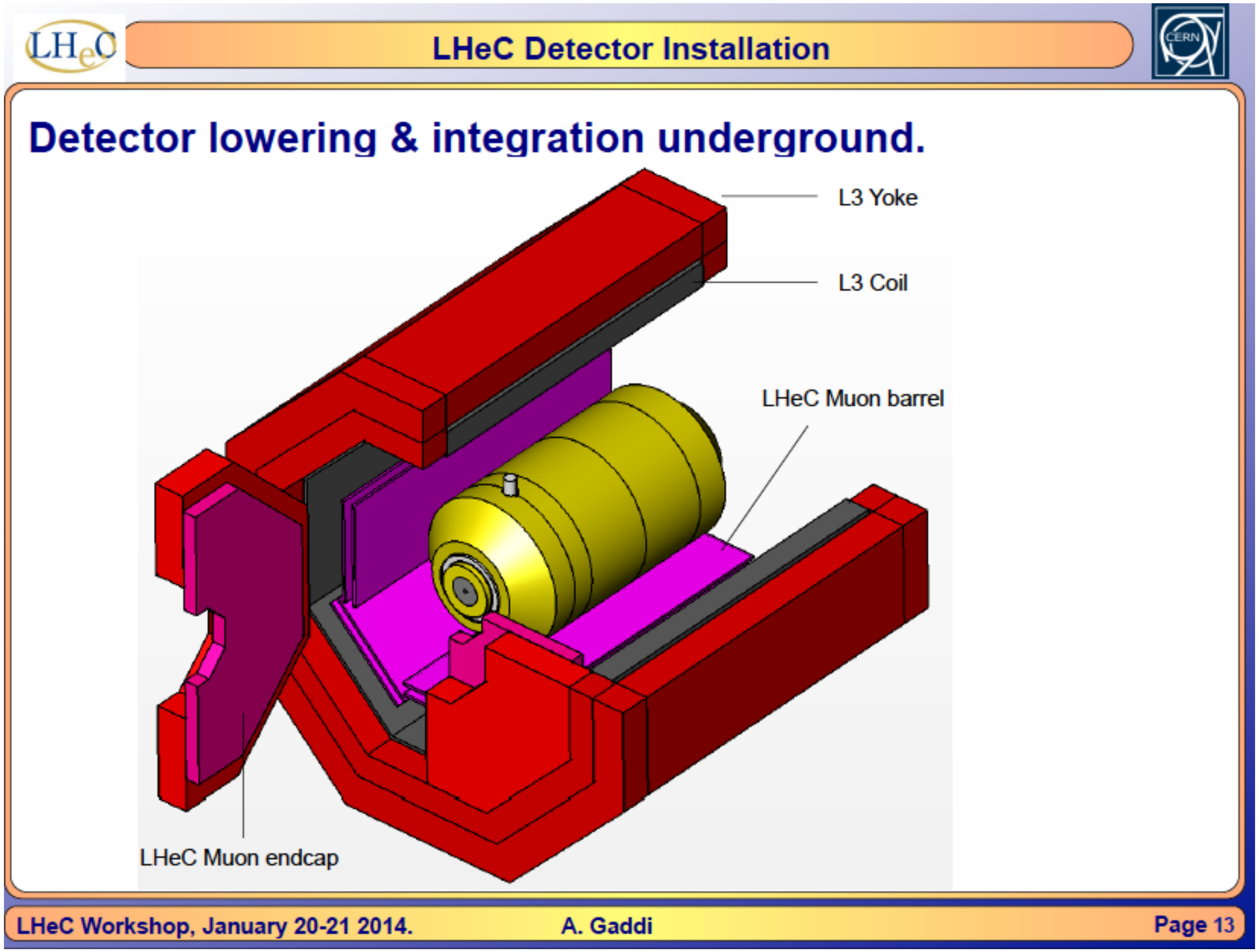
LHeC ep/A Detector



3 beams: e∓ + proton1 + proton2 (also heavy ions A) Detector has been costed as 106MSF (core)

Dipole magnets to guide the e-beam in and out, for making electrons to collide head-on with p-beam1;
0.3 T transverse field along 2 x 9 m (internal shown only)

Installation



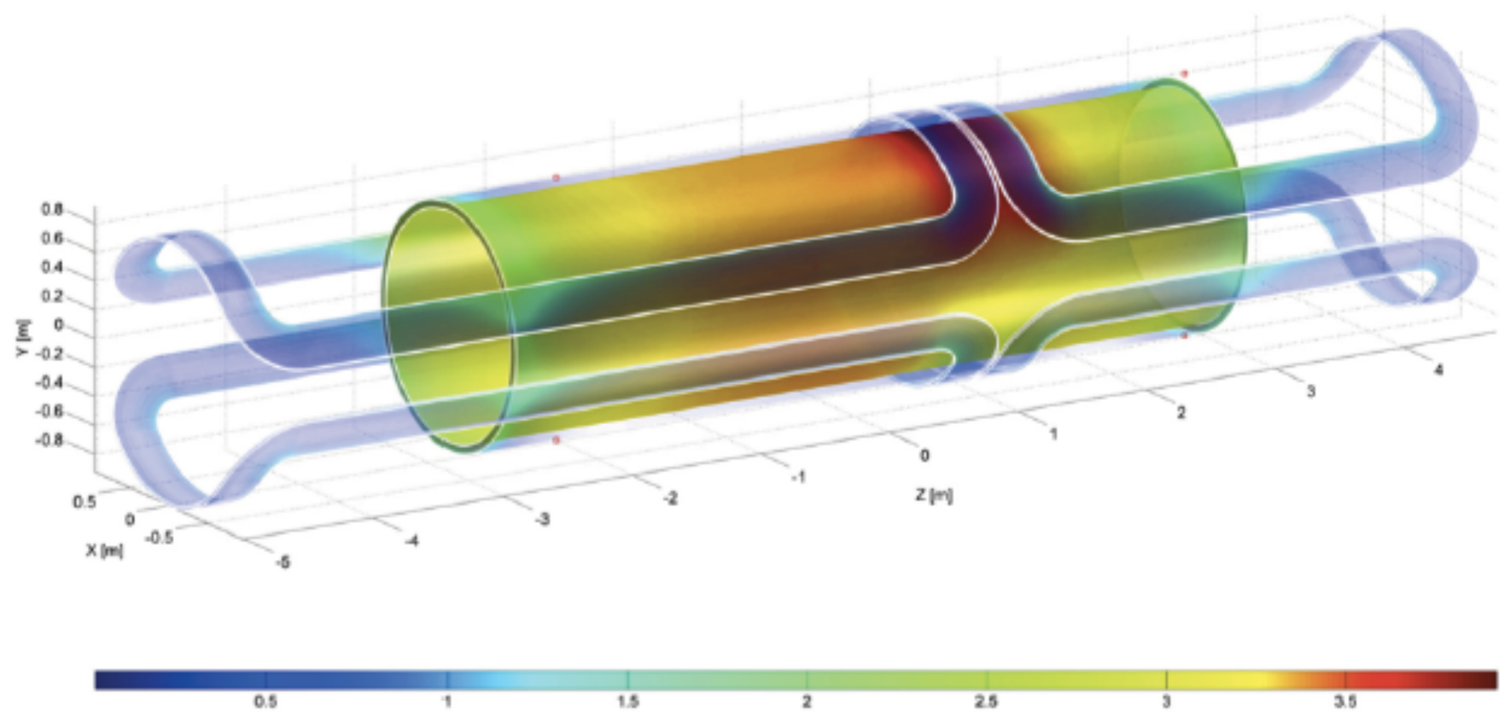
The schedule for detector installation & commissioning could finally meet the LS3 plans, or, under some provisions, even the shorter LS4, providing that most of the assembly is done on surface and Alice detector can be quickly (i.e. < 7 months) dismantled.

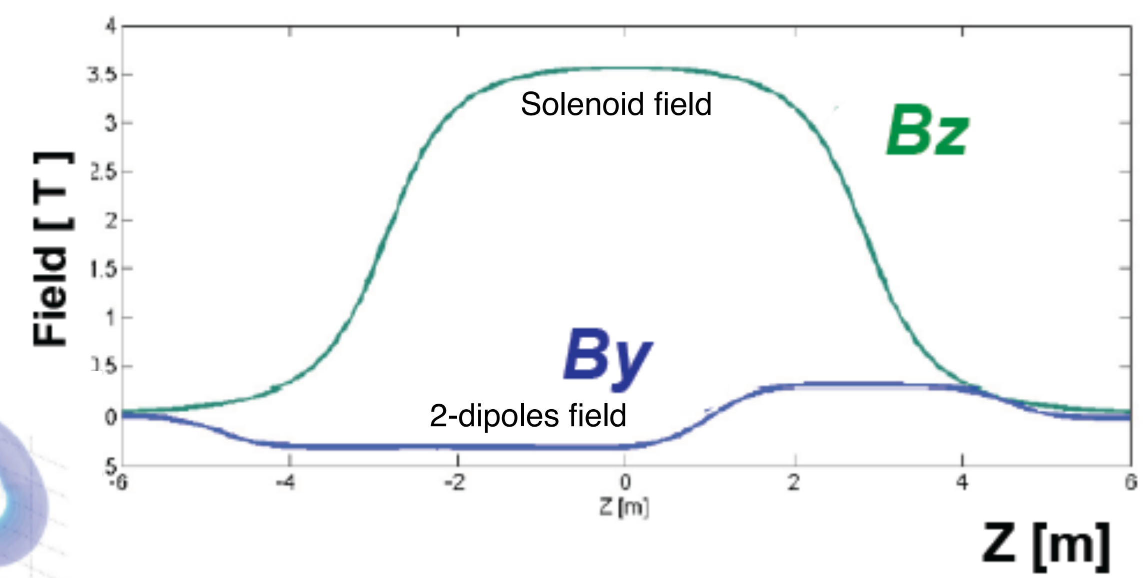
Detector Magnets: Solenoid and Dipoles

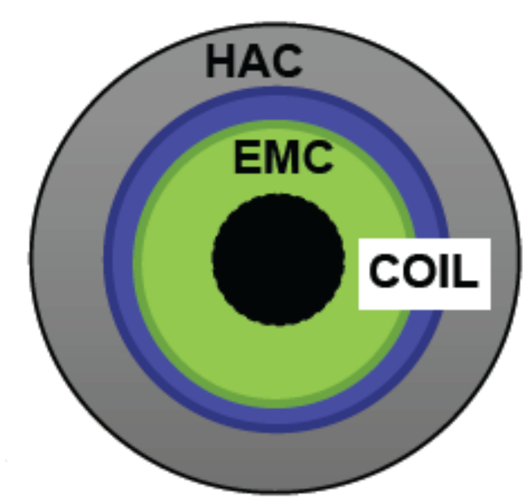
courtesy Herman ten Kate and Alexey Dudarev

- Baseline: Solenoid (3.5 T) + dual dipole 0.3 T (Linac-Ring Option)
  - Large coils (double solenoid): Containing full calorimeter, precise muon measurement, large return flux

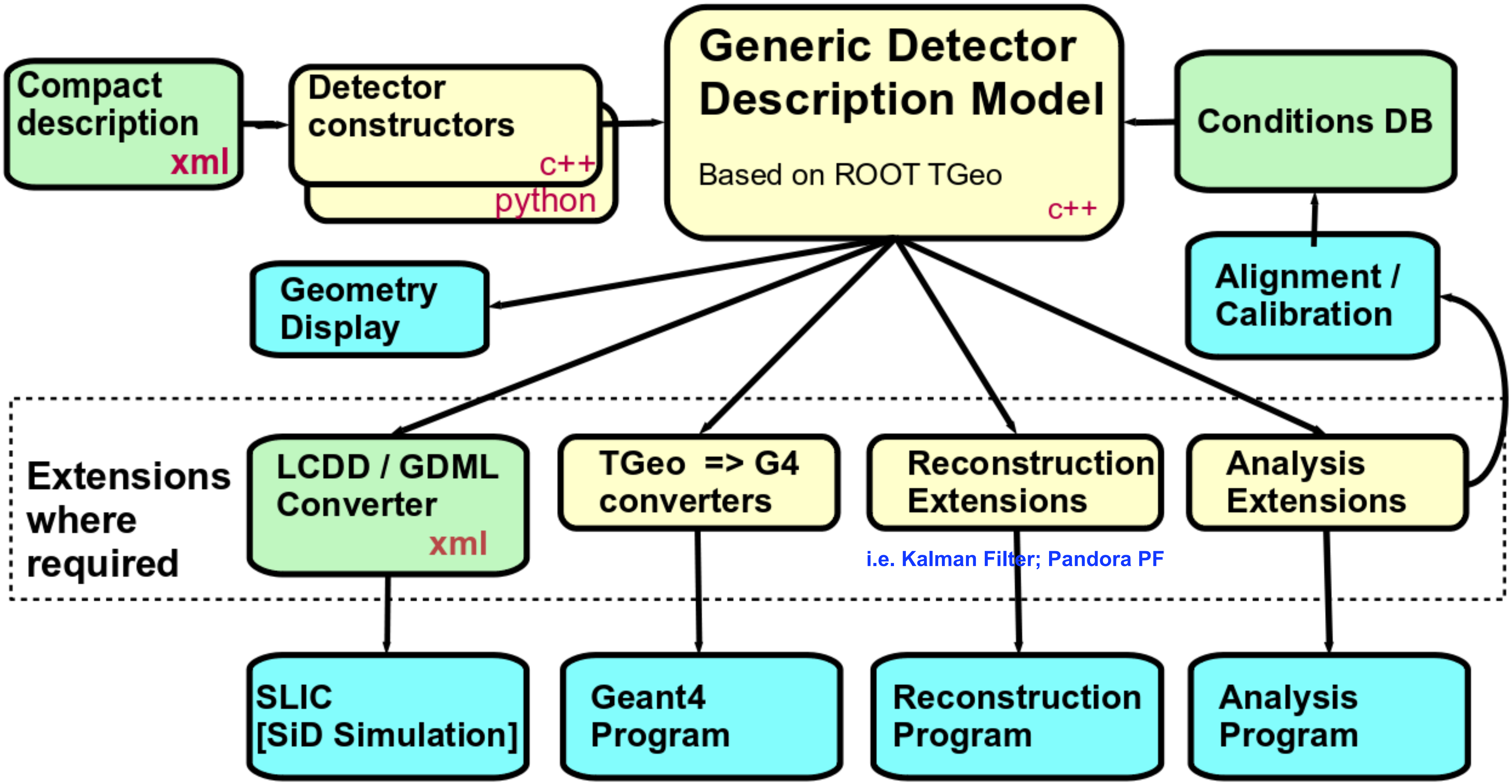
- Small coil: Cheaper, less iron for return flux, solenoid and dipoles conveniently within the same cold vacuum vessel, but no muon measurement





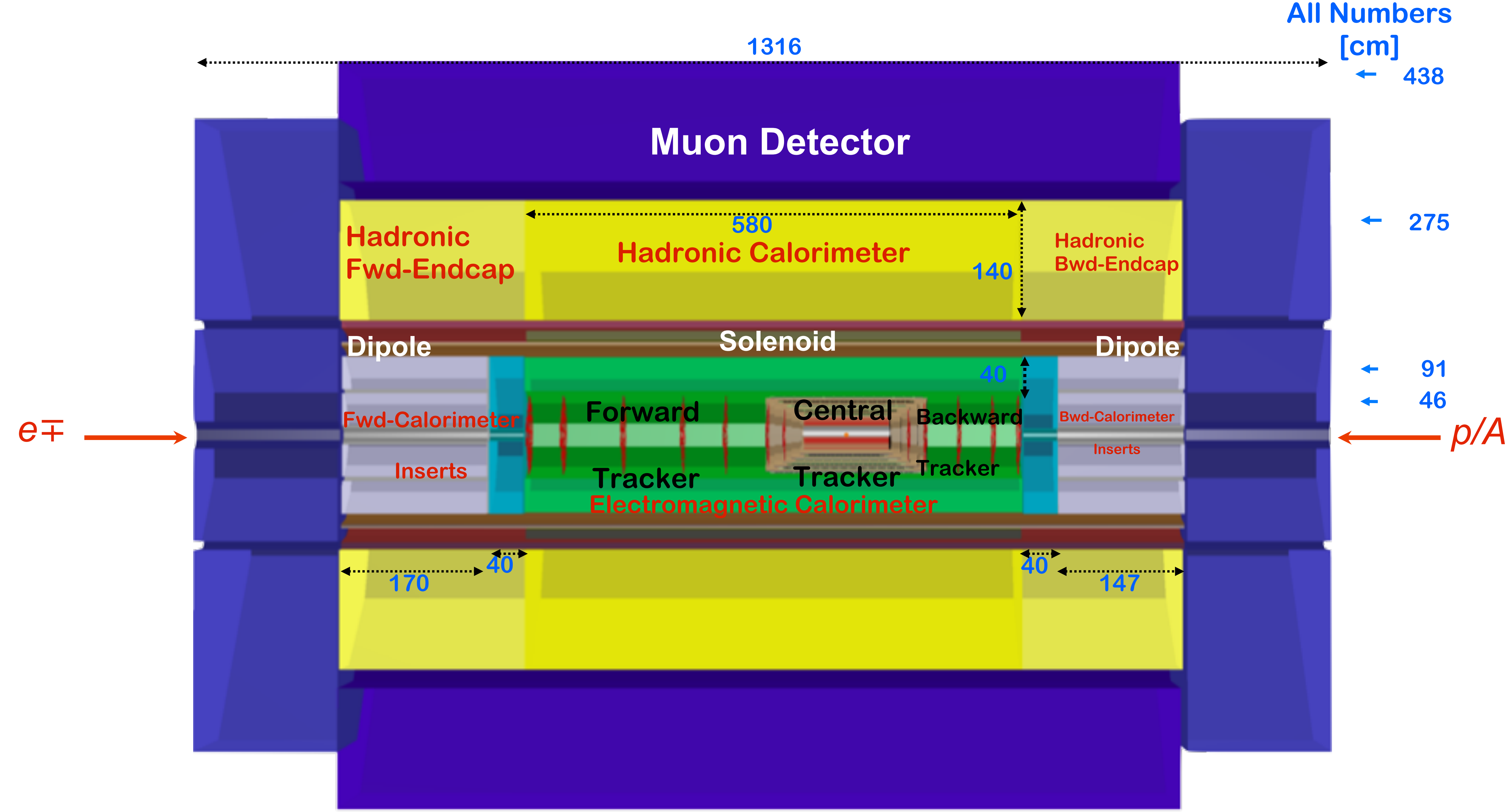


Detector Design/Sim/Rec - DD4Hep



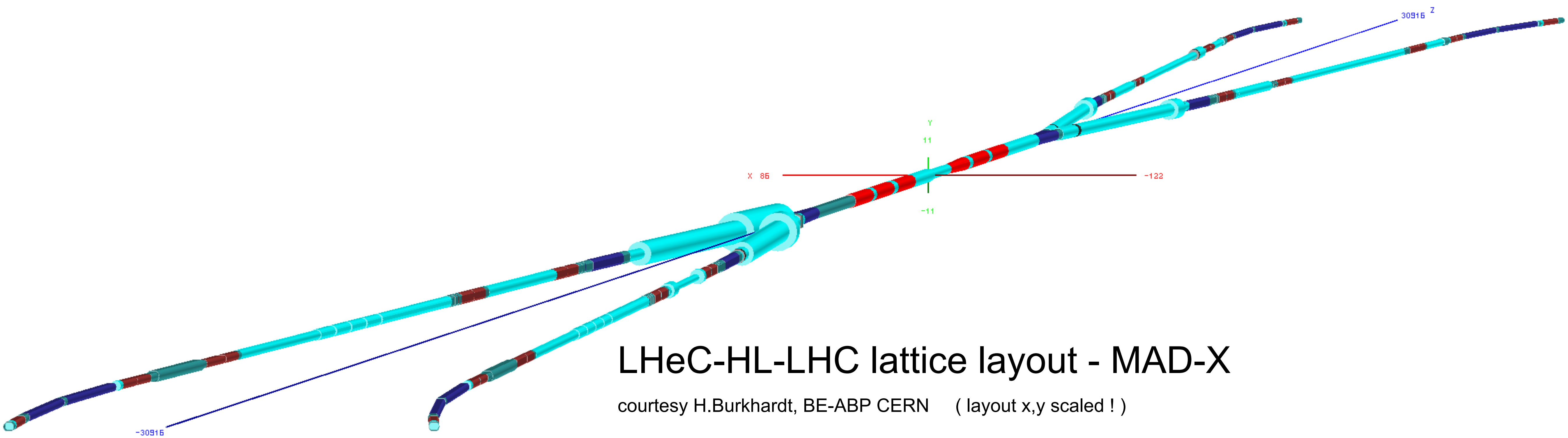
http://http://aidasoft.web.cern.ch/DD4hep software: svn co https://svnsrv.desy.de/public/aidasoft/DD4hep/trunk

LHeC Detector / DD4Hep Layout



DD4Hep/DDG4 Detector Design / Simulation / Reconstruction Environment
linked to and working with ROOT-5.34.26 (ROOT-6 being implemented) and
GEANT4-10.01 (fast simulation being worked on)
Identical software for LHeC and FCC detector - DD4hep xml-description different only

Interaction Region Design



LHeC-HL-LHC lattice layout - MAD-X

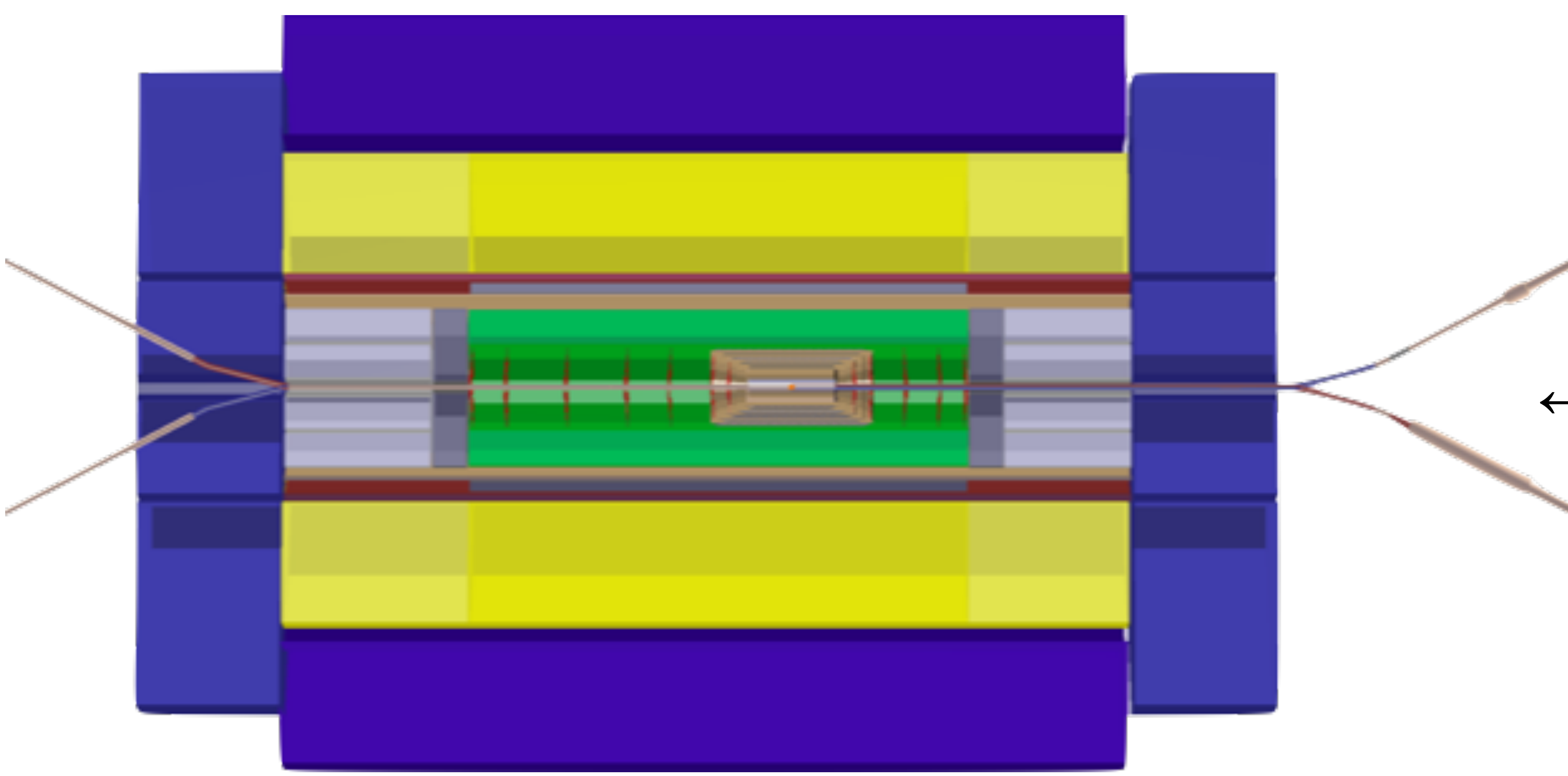
courtesy H.Burkhardt, BE-ABP CERN (layout x,y scaled !)

- **Incorporated the HL-LHC optics and geometry (cf also Emilia Cruz’s talk)**
- **Interface MAD-X-to-detector: design tools to develop (presently ‘by hand’)**
- **Placement of SR - masks / absorbers (in CDR a HERA like initial design)**
- **Combined machine and detector treatment to design the interaction region**

Interaction Region Design

- **Beam Pipe -**
  - **low X_0, λ_I material, stable, capable for very fwd/bwd tracks !**
  - **allowing low p_T particle measurement**

- **SR - masks / absorber placements - critical issue for ep-detector machine lattice combined with detector magnet setup (inner dipole & solenoid)**



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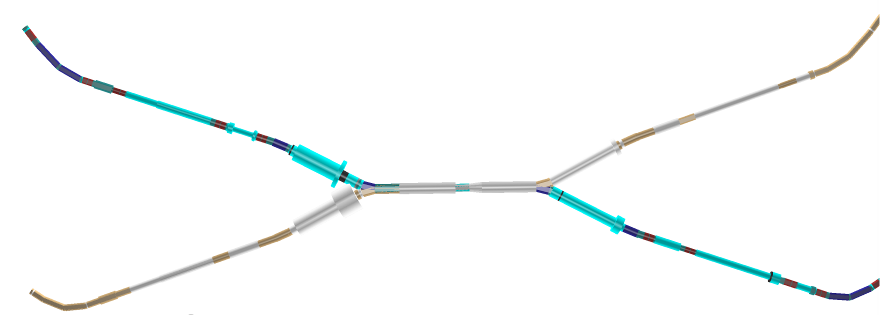
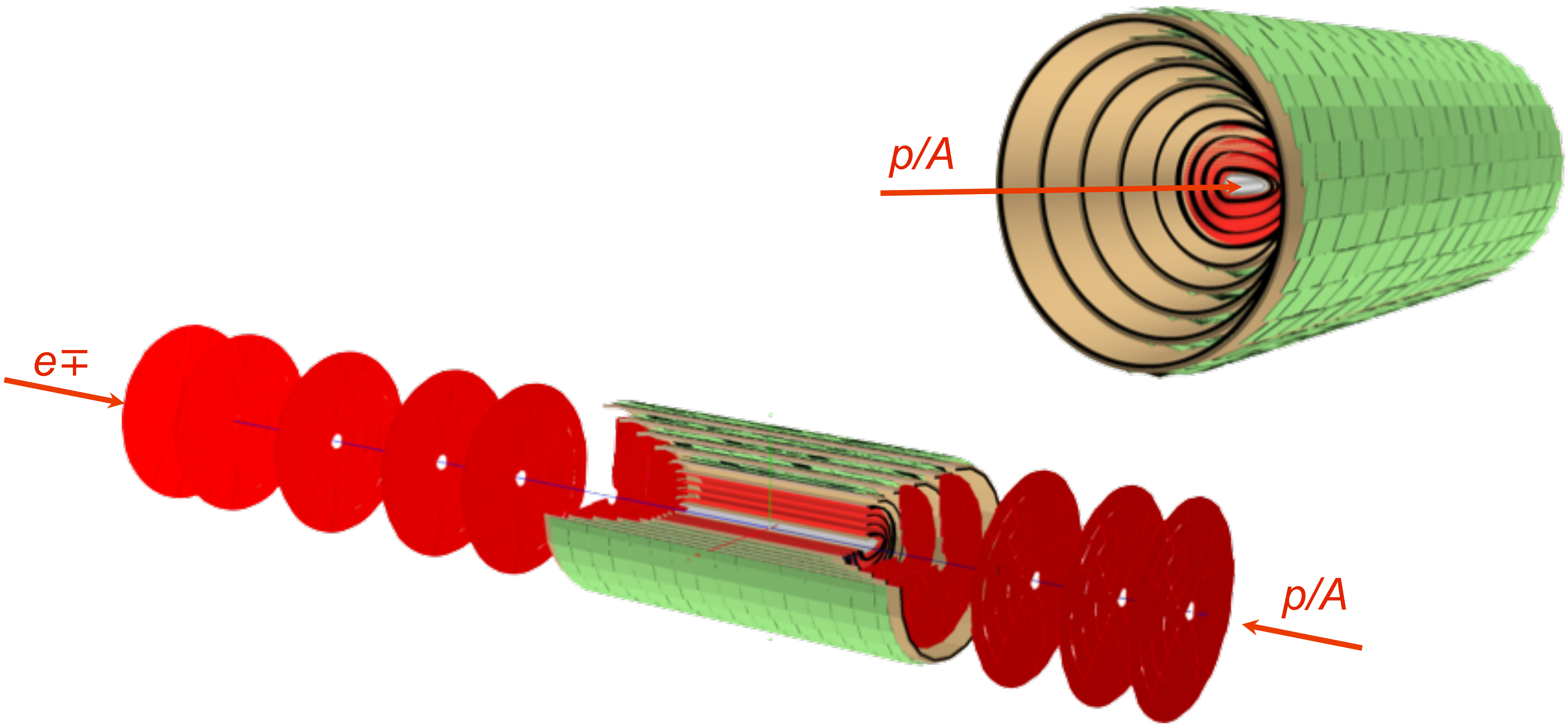


LHeC accelerator lattice

courtesy H.Burkhardt; (scaled !!)

Tracker Design



Interaction region design - Impact of Synchrotron Radiation

Elliptical Beam Pipe and Vertex Pixel Detector placement around

1st version describes sensitive / passive elements
(sensors / support structure / I-O elements)
Many details to be solved

LHeC/FCC-he design differ in fwd/bwd wheels placement only (currently)

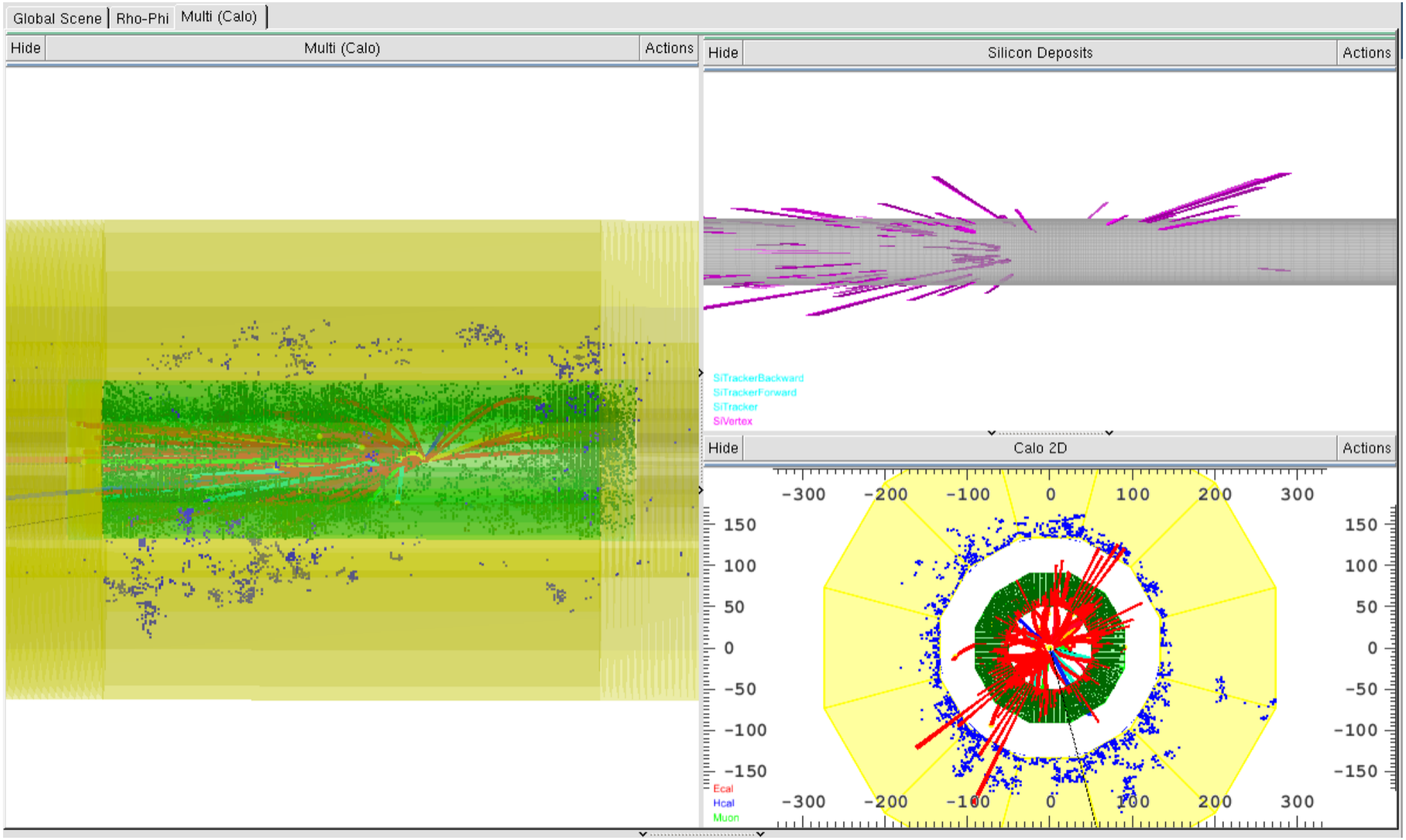
Also:
cf talk by Tim Jones at LHeC WS 2014

MUCH smaller than new ATLAS or CMS Trackers for HL LHC
No pileup, e-h asy..

Pythia-event → LHeC-Higgs-bƀ→ DDG4 →LHeC-DDEve

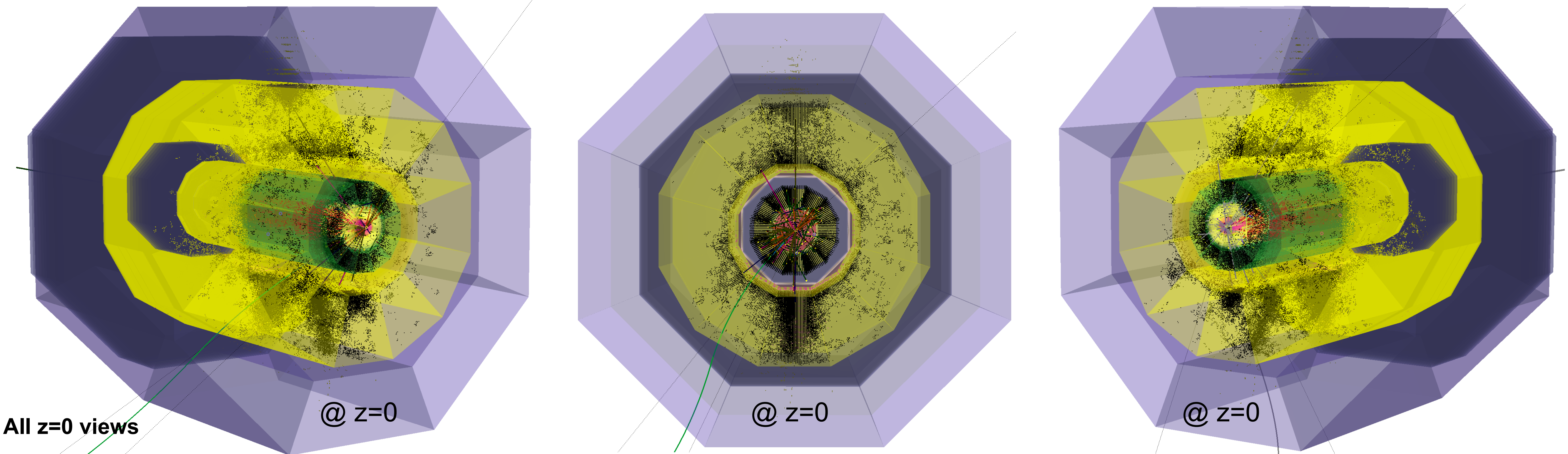
courtesy U.Klein

Event displays - now managed to illustrate hits, tracks, energy depositions

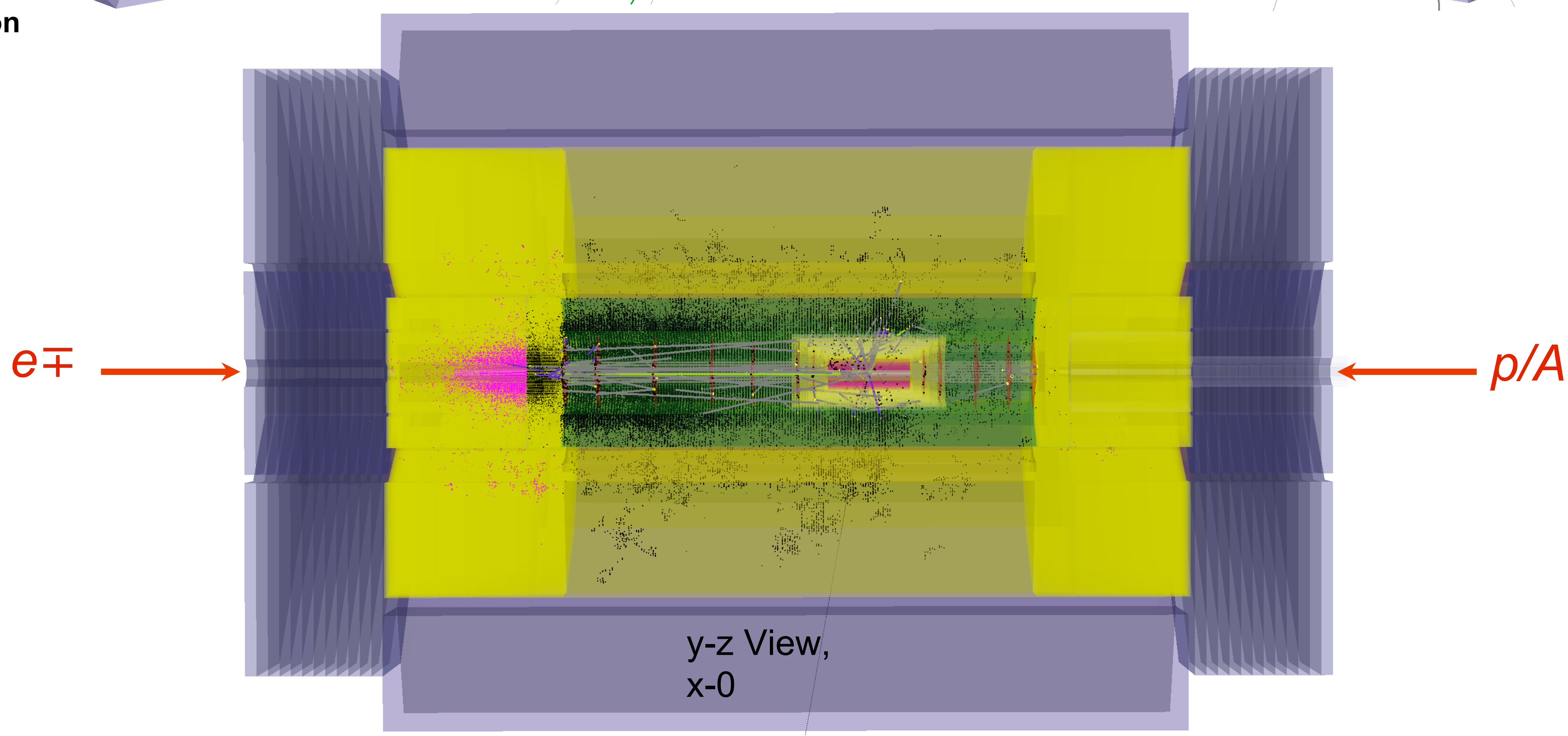


Pythia-event → LHeC-Higgs-b$\bar{b}$ → DDG4 → LHeC-DDEve

courtesy U.Klein



All z=0 views
into proton direction



DD4hep/DDG4 Development

DD4hep/DDG4 - driven by ILC/CLIC based developers - pre-release software

- **LCIO event data model (EDM)**
- **LCIO - connecting all modules in DD4hep/DDG4, being worked on to cope with future requirements**
- **Generator data import into the framework - root, stdhep- and hepmc2-file formats**

- **Python, C++ int./ext.**
  - **LHeC/FCC detector geometry (being optimised), material description, R/O description as needed, segmentations and surfaces - ingredients for reconstruction**
  - **DDEve - event display tool for quality judgment and control …**

Thanks to DD4hep developers for a very fruitful collaboration!

ep/eA Detector Simulation

Extensions needed – mainly various generators also for ep/A

- besides ROOT and GEANT4 - FLUKA to be incorporated

- Standard generators - e.g. PYTHIA8, HERWIG, SHERPA - currently do not describe ep and even less eA processes sufficiently

- FLUKA is handling nuclear evaporation/fragmentation
  - For eA we need a handle on radiative corrections, bigger than in ep see Néstor Armesto: eA at the LHeC: detector requirements and simulations: http://indico.cern.ch/getFile.py/access?contribId=8&sessionId=1&resId=0&materialId=slides&confId=281921
  - FLUKA - drawback: licensed software
  - dedicated manpower needed!

Guidelines

Use of software tools as available

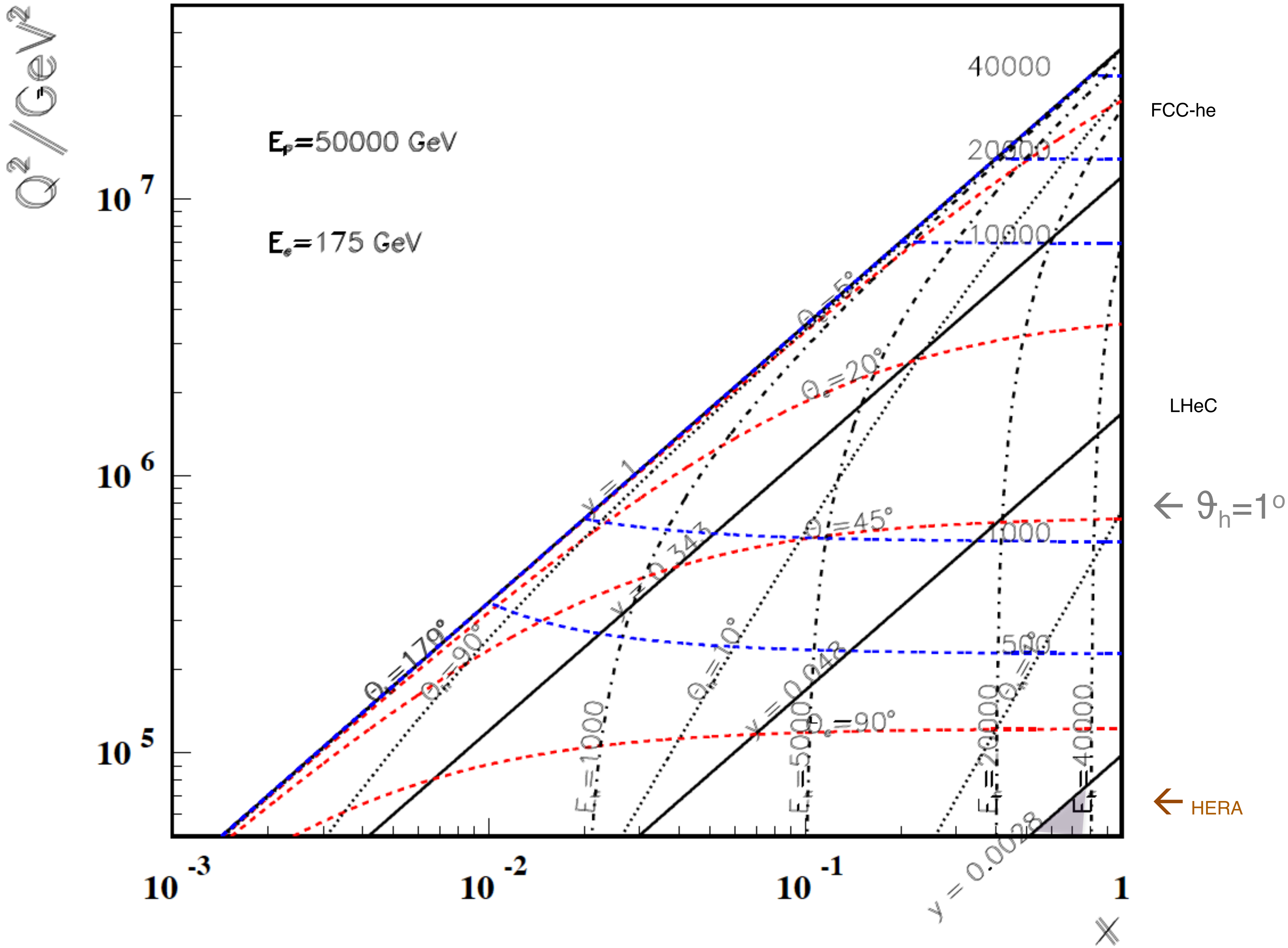
Follow the main developments &
build a detector model answering physics questions
(reuse of experience and implementations)

Collaboration inside the FCC-Software effort at CERN

recent documents: http://indico.cern.ch/event/337673/session/5/contribution/22

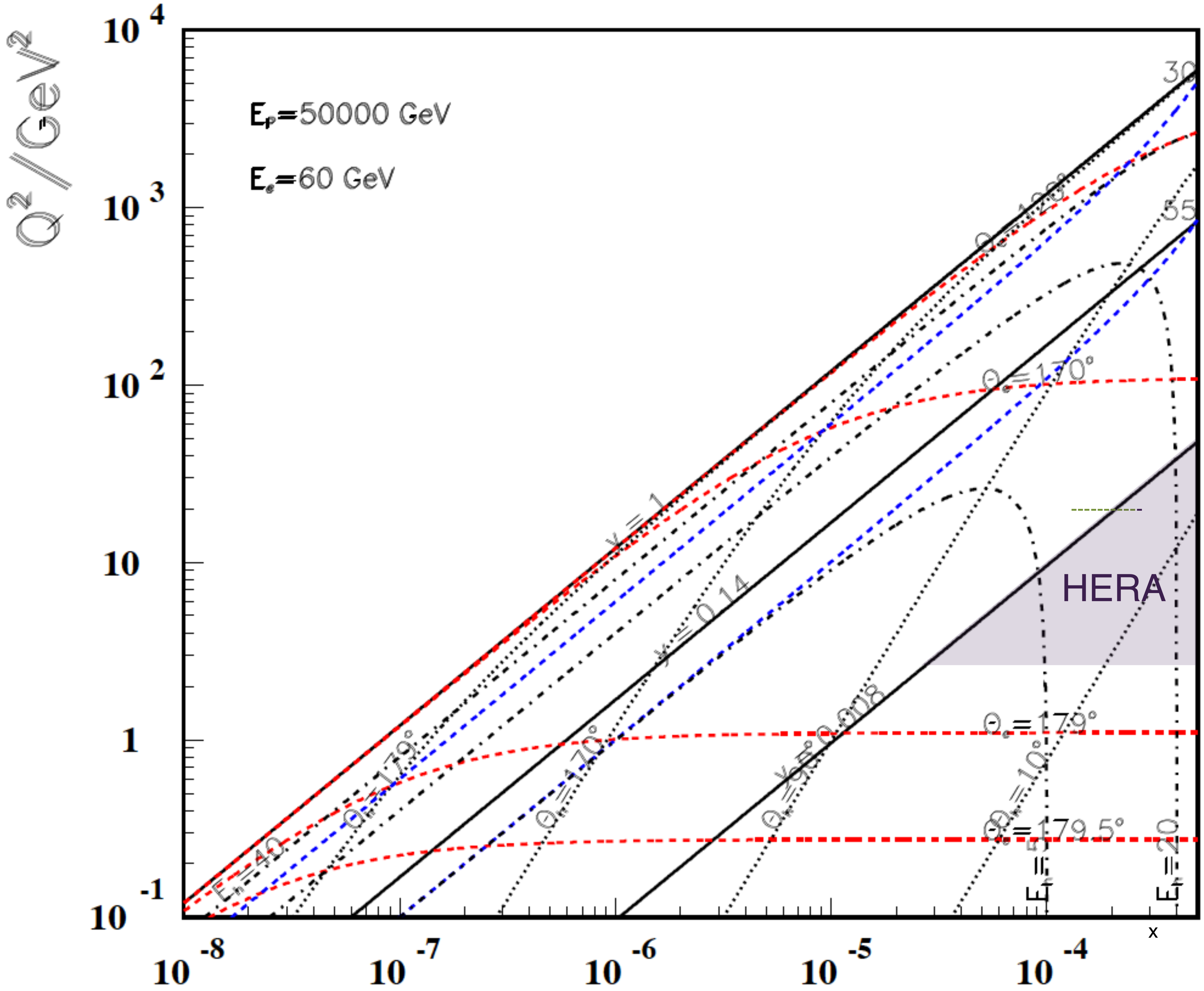
Hardware optimisation according to latest R&D (HL-LHC …)

High Q^2



Q²/GeV²
E_p=50000 GeV
E_e=175 GeV
40000
20000
10000
1000
500
θ_e=5°
θ_e=20°
θ_e=45°
θ_e=90°
θ_e=179°
θ_h=90°
θ_h=10°
y = 1
y = 0.343
y = 0.042
y = 0.0028
E_h=1000
E_h=5000
E_h=20000
E_h=40000
x
FCC-he
LHeC
← ϑ_h=1°
← HERA

Low x



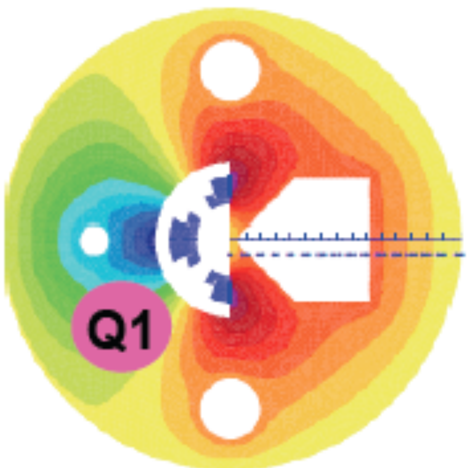
FHeC

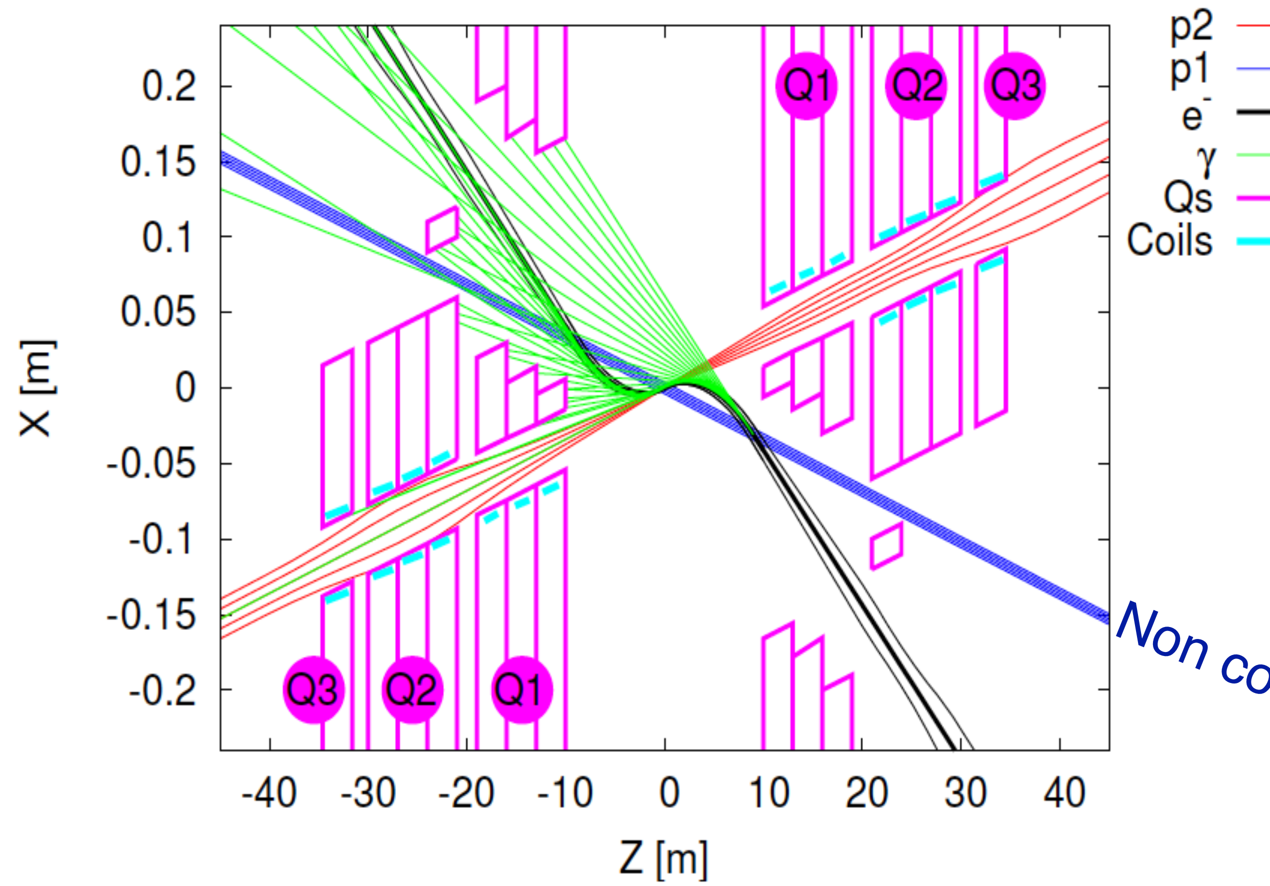
LHeC

← 179° @ 180 GeV .. very low x requires not the maximum of E_e

Very low x reaches direct range of UHE neutrino physics →

Interaction Regions for ep with Synchronous pp Operation

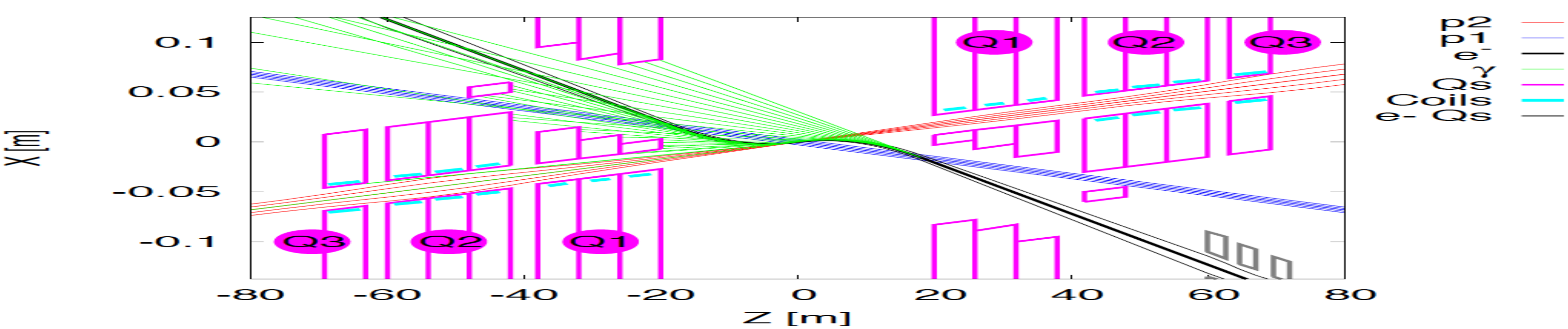




Non colliding p beam

LHeC (CDR)
60 GeV * 7 TeV

Likely one IR.
Matching e and p beams
Limit synchrotron radiation
Design of inner magnets
Beam-beam effects ….

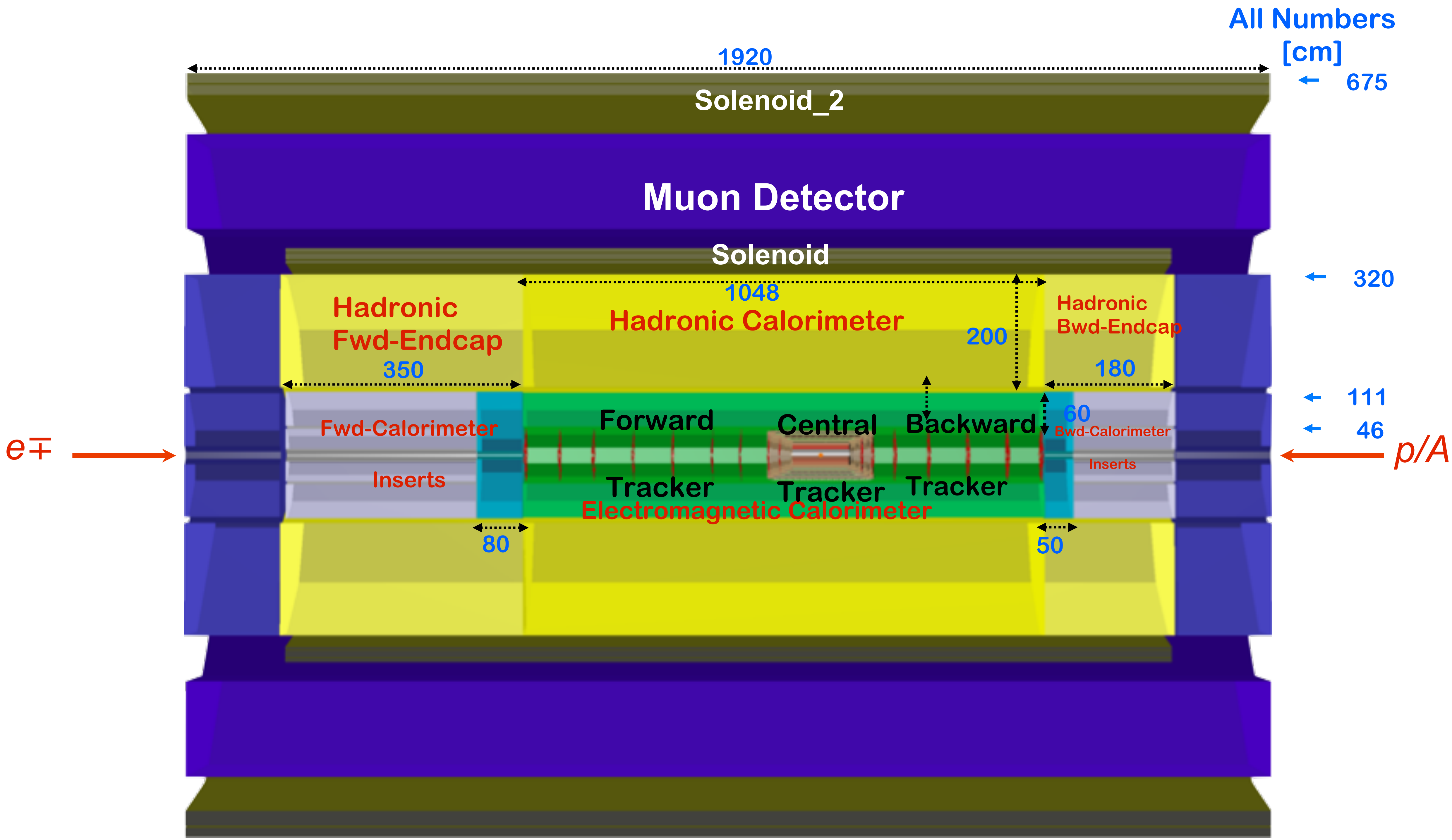


FCC-he (ERL)
60 GeV * 50 TeV

Tentative: ε_p=2µm, β*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

Rogelio Tomas, Max Klein, ICHEP14

FCC-he Detector / YZ-View



Based on the LHeC design; figure shows the version using a twin solenoid system; Solenoid_2 outside of Muon-Det.: independent momentum measurement - hadrons, min. interacting leptons. Single solenoid version also considered.

FCC-he Tracker / Calorimeter Summary

Tracker	FST	CFT	CPT	CST	CBT	BST
#Layers / Wheels	7	2	4	5	2	5
Min. Polar Angle $\theta[^0]$	0.4	2.2	3.2	32.5	2.2	179.5
Max. / Min. $\lvert\eta\rvert$	5.7	3.9	3.5	1. 0	-3.9	-5.2
Project Area $[m^2]$	11.0	0. 8	1.4	12.8	0.8	7.9

Calorimeter	FHC	FEC	EMC	HAC	BEC	BHC
Min. / Max. Polar $\theta[^0]$	0.4	0.4	6.8 / 171.1	15.1 / 160.7	179.4	179.5
Max. / Min. $\lvert\eta\rvert$	5.7	5.6	2.8 / -2.5	2.0 / -1.7	-5.3	-5.5
Volume $[m^3]$	18.9	1.5	41.7	443.4	-5.3	-5.5

Naturally that is work in progress (for a very long time..)

Summary

The LHeC detector has been conceptually designed. This design is being modified and updated for the Higgs measurements (fwd detection/c,b tags and high resolution hadronic calorimetry) and in view of the new technologies being applied at the LHC detector upgrades (low material, high resolution Silicon tracking and forward detection).

There is also on-going work on the IR design and the integration of the machine lattice (HI-LHC) into the detector concept. Both are crucial items for the ep/A collider.

Strong software efforts are on-going, jointly with hh and ee FCC detectors, and profiting from ILC/CLIC developments. DD4hep/DDG4 - main detector design toolset currently. Much of the LHeC (and FCC-he) detector has been programmed and events (hits, tracks, energies) can be displayed. The toolbox of the ep/A detector is growing and relies on the most up-to-date program versions such as G4.10-01 while ROOT6 is being implemented.

A common suitable Event Data Model for hh, he, ee communities is desirable. Detailed as well as fast simulations are at hand; an interface to Delphes being prepared.

Reconstruction - implementation of existing modules (Kalman, Pandora …) – and analysis software are to be developed.

For physics simulations it has been important to stress that many of the modern (pp) and old (ep) generators need to be adapted to the LHeC (and FCC-he) needs.

Based on the LHeC, first conceptual designs of an FCC-he detector and IR have been provided. The FCC has a strong H-HH potential and access to rarer H decay channels. This suggests to improve the muon momentum measurement, for example. The FCC-he forward region is extended by a factor of ln(50/7)=2 while the backward region is much determined by the electron beam energy and basically stays as is.

The goal of the LHeC detector design is to provide a realistic detector which may be built in 10 years.

The goal of the FCC-he detector design is to provide a design concept and integrated IR for ep hence.

BACKUP

Outline

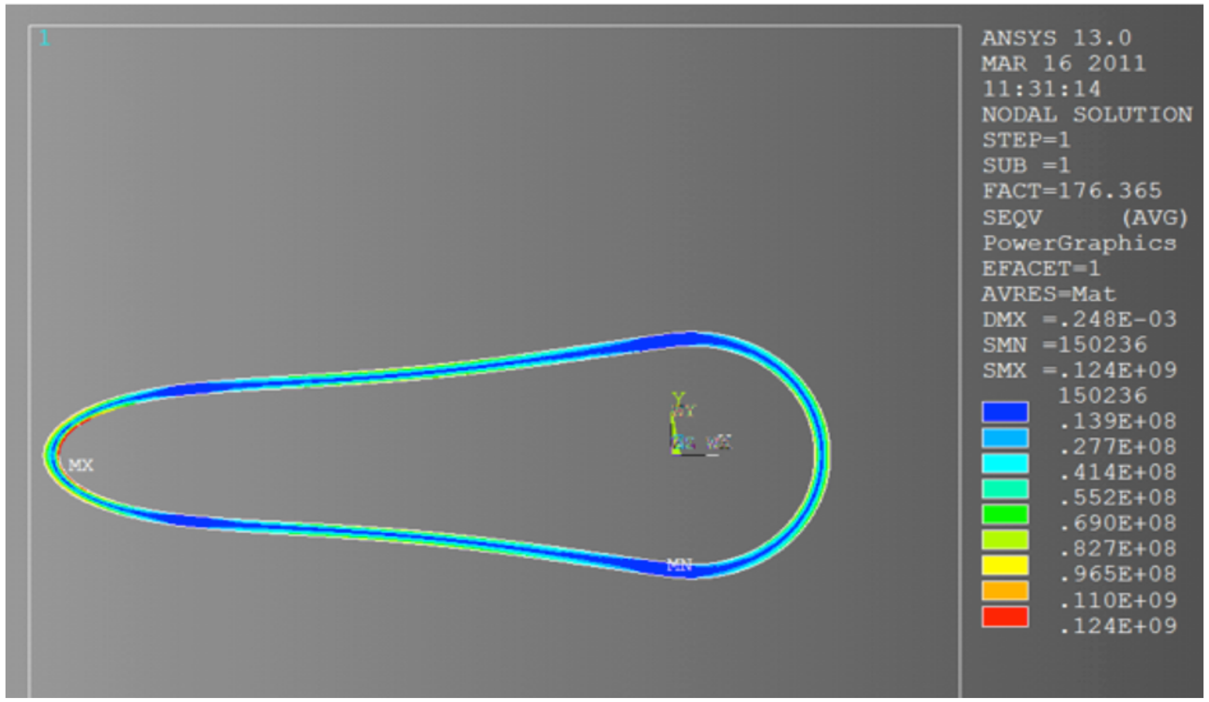
- Software framework DD4hep/DDG4 for design & evaluation
- Peculiarities of an LHeC ep/A detector
- Layout / LHeC → FCC-he
- Interaction Region - Machine-detector interface
- Consequences for tracking
- DDEve - Event Display - illustration of simulations
- DD4hep/DDG4 Development
- Extensions for ep/eA Detector Simulation
- Guidelines for further steps
- Bright Prospectives
- Summary

The Toolbox

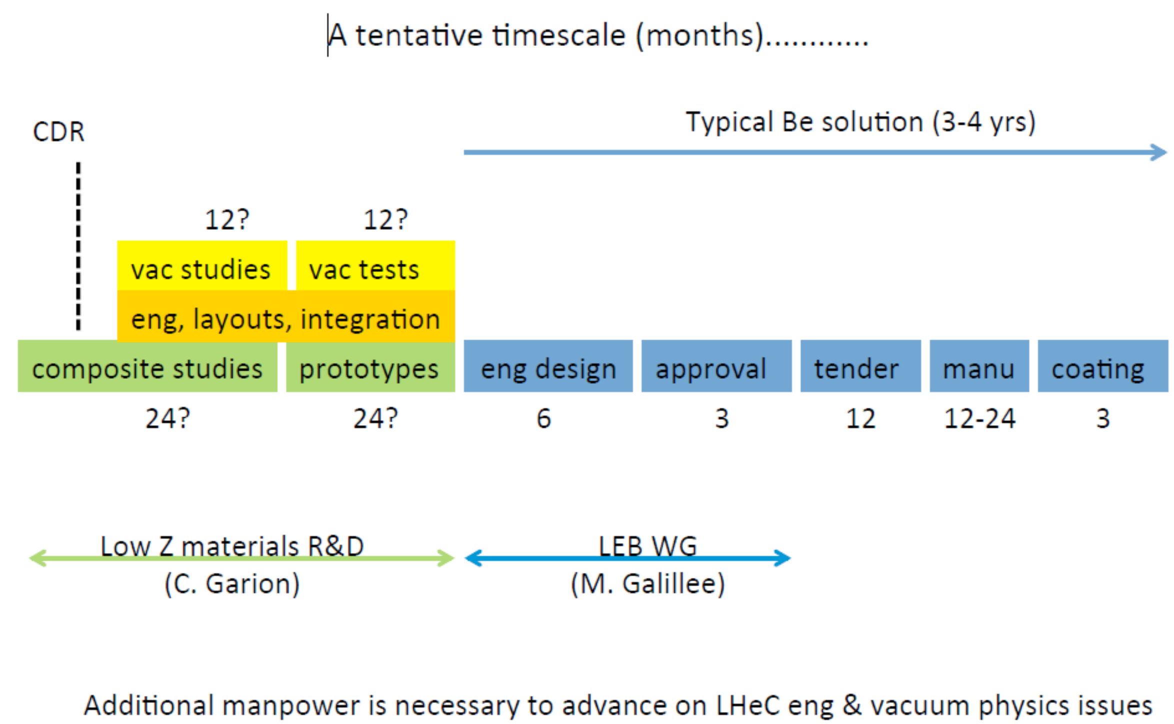
- A detector model mimic/simulate the response on physics, on reconstruction schemes, on analysis chains
- The toolbox covers
  - full detector description:
    geometry, materials, visualisation, readout, alignment, calibration…
  - single source of detector information for simulation, reconstruction, analysis
  - support of all phases of the experiment life cycle:
    detector concept development, detector optimization, construction, operation

Beam Pipe Considerations

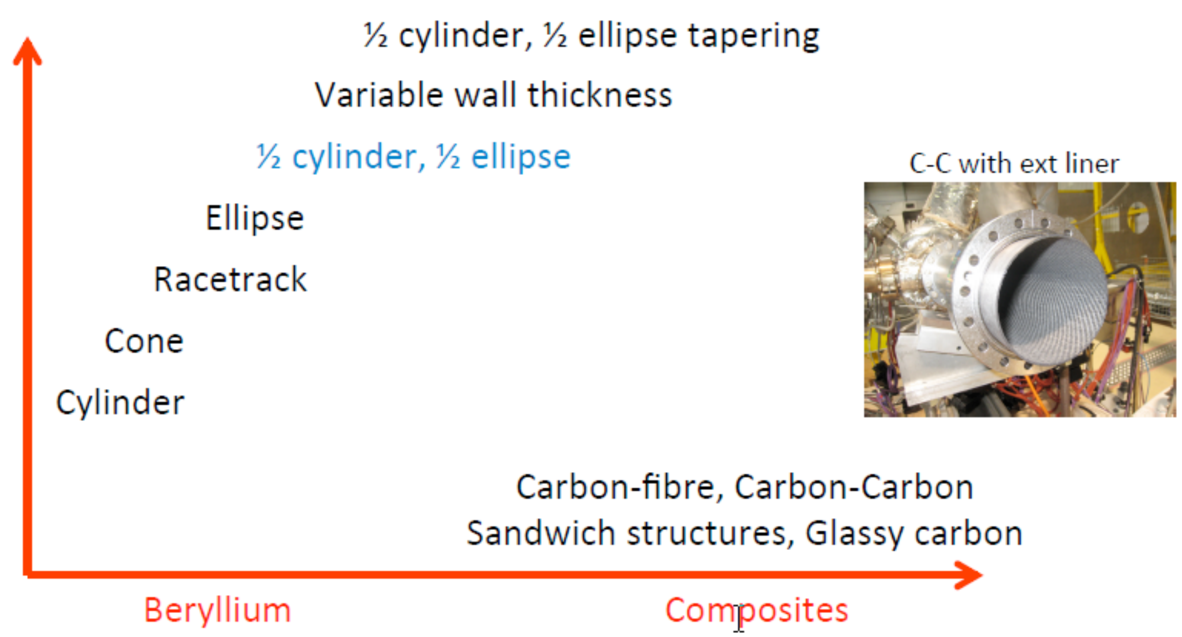
courtesy Paul Cruikshank, CERN



https://indico.cern.ch/event/183282/session/12/contribution/54/material/slides/1.pdf
https://indico.cern.ch/event/278903/session/13/contribution/56/material/slides/1.pdf



- Circular-Elliptical beam-pipe design
  - Beryllium 2.5-3.0 mm wall thickness
  - Central beam pipe ~ 6 meters
  - TiZrV NEG coated
  - Wall protected from primary SR (upstream masks)
  - Minimised end flanges, minimised supports
  - optimisation needed - R&D



Bright Prospectives

- The ep configuration uniquely selects the WW-H and ZZ-H vertices for production
  - ep → νH(bb)X: O(1)% precision on H-bb couplings with matching theoretical uncertainty

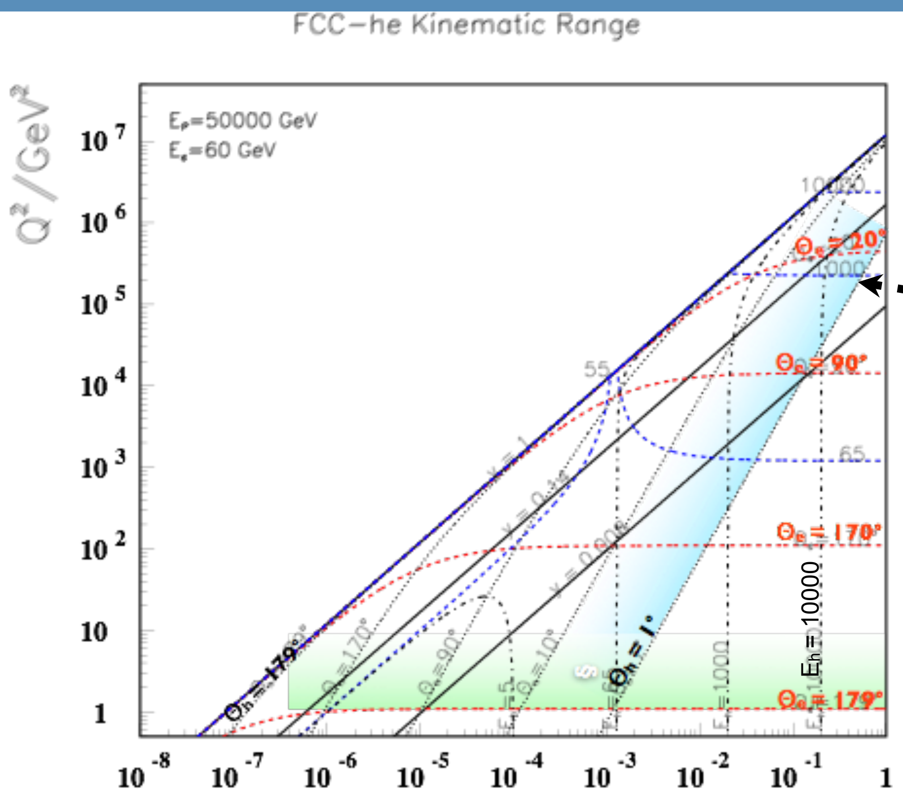
- FCC-he reaches the H→μμ decay, with O(1000) events
  - μ measurement essential - magnet placement

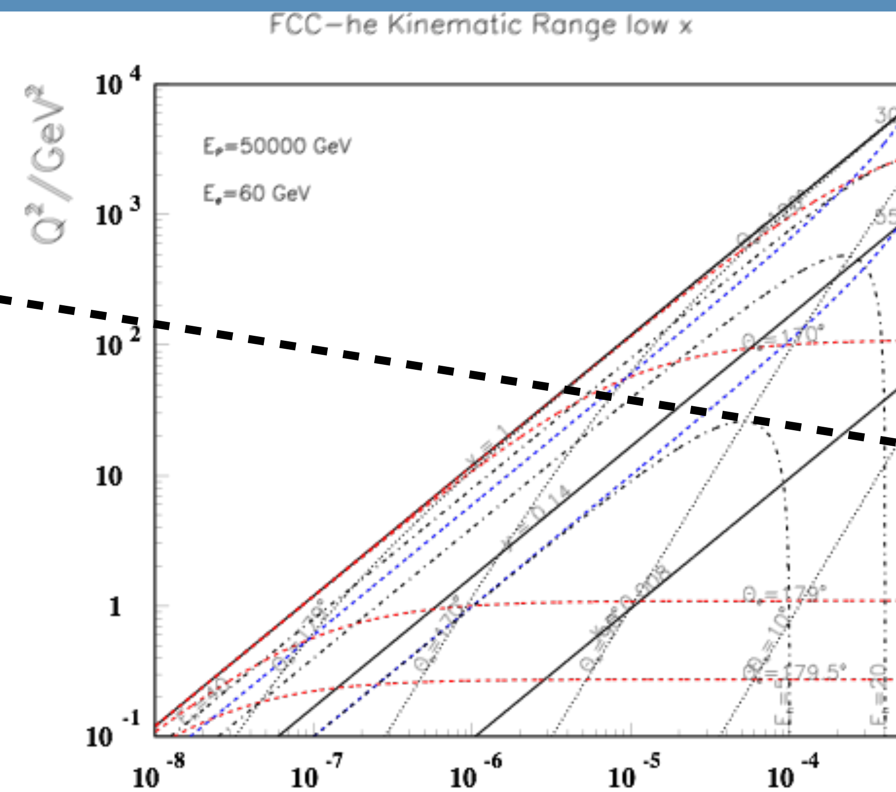
- Very demanding and to be studied in detail e.g.:
  - ep → νHHX   ep produces the Higgs from WW → double Higgs

- FCC-he will be a Higgs factory and the consequences are to be studied
  - desire to measure also rare decays,
  - maximum coverage for all kinds of decays → detector design

- Extrapolation from LHeC:
  the FCC-he detector is feasible using technologies available, detector design will benefit from coming technology progress
  (sensors, magnets, low power consumption, cooling, mechanical systems, electronics …)

FCC-he - Machine Options

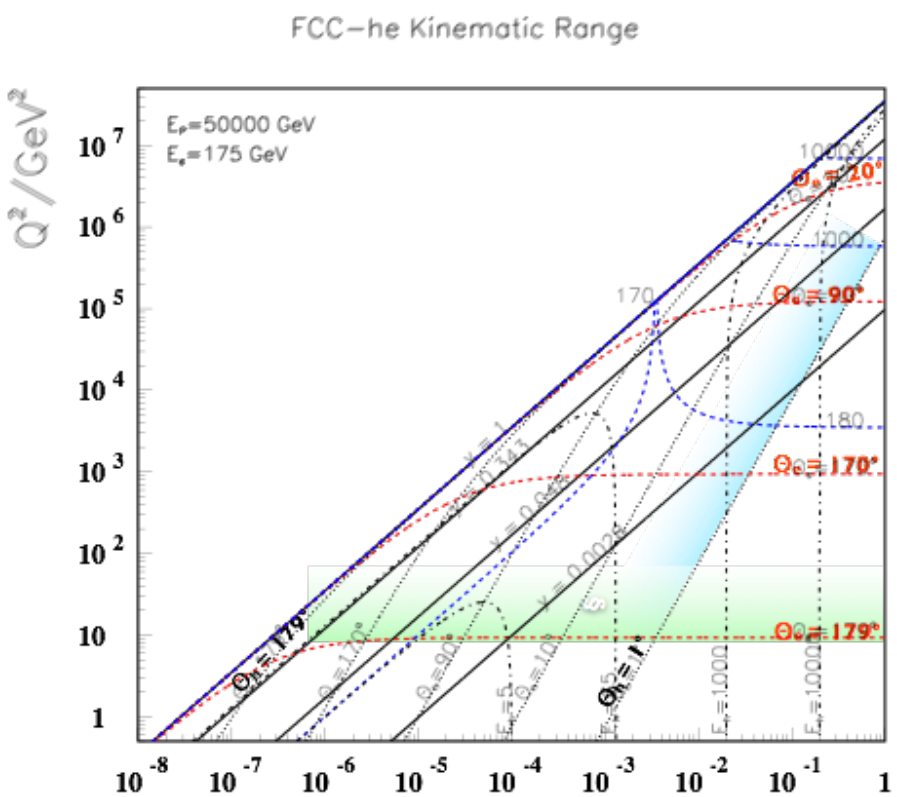


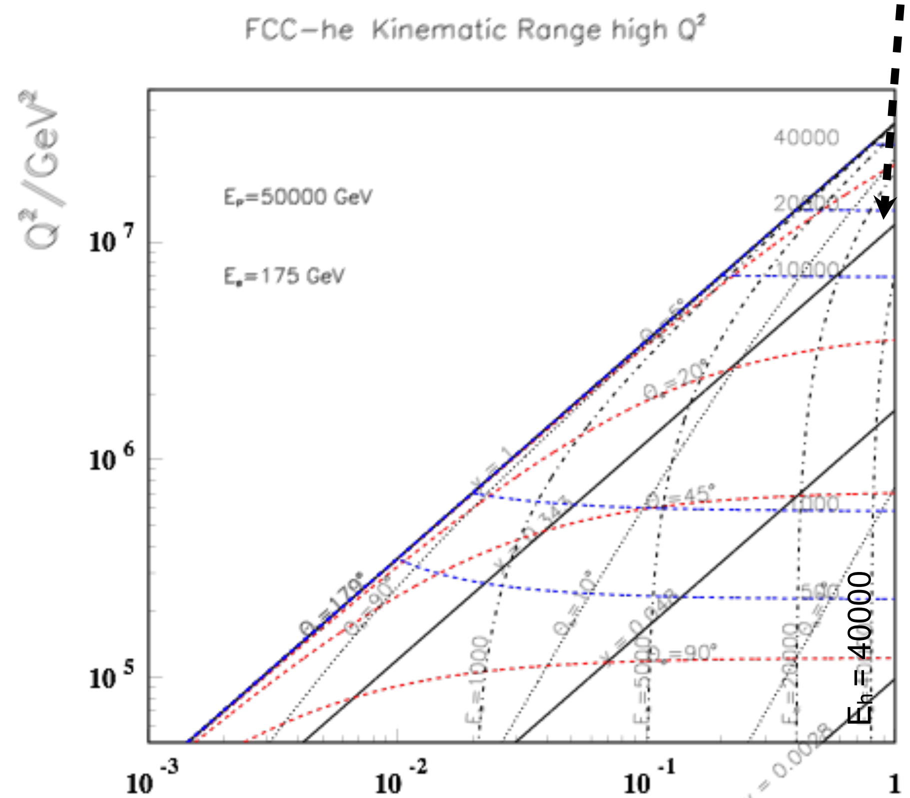


Forward calorimeter containment up to few 10thTeV down to 1^{0} →

~doubling the calorimeter depth compared to LHeC

Linac-Ring: LHeC ERL $e^{\mp}$ at 60 GeV on p/A at 50 TeV (i.e. Pb at 20TeV (=50 x 82/207)



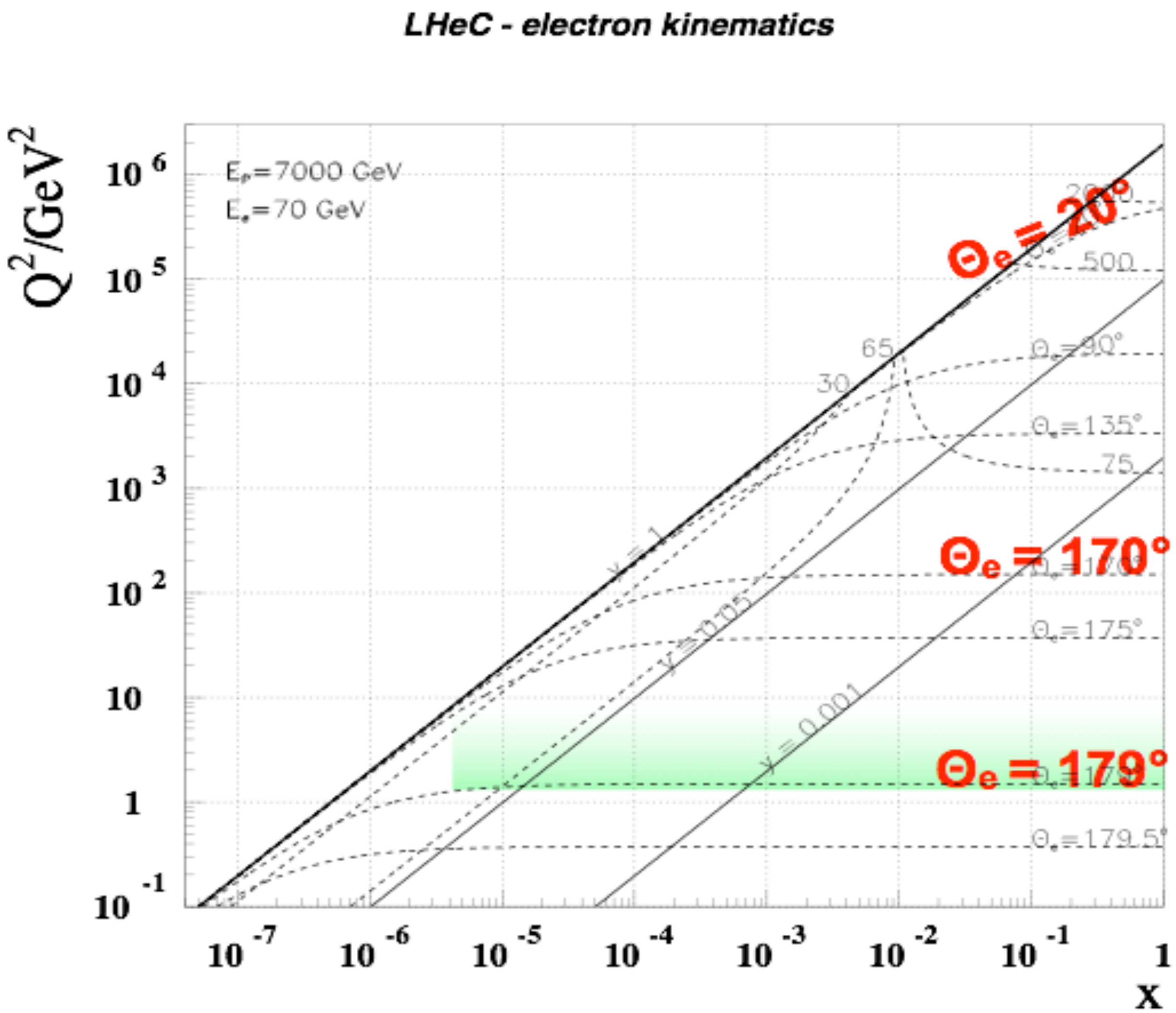


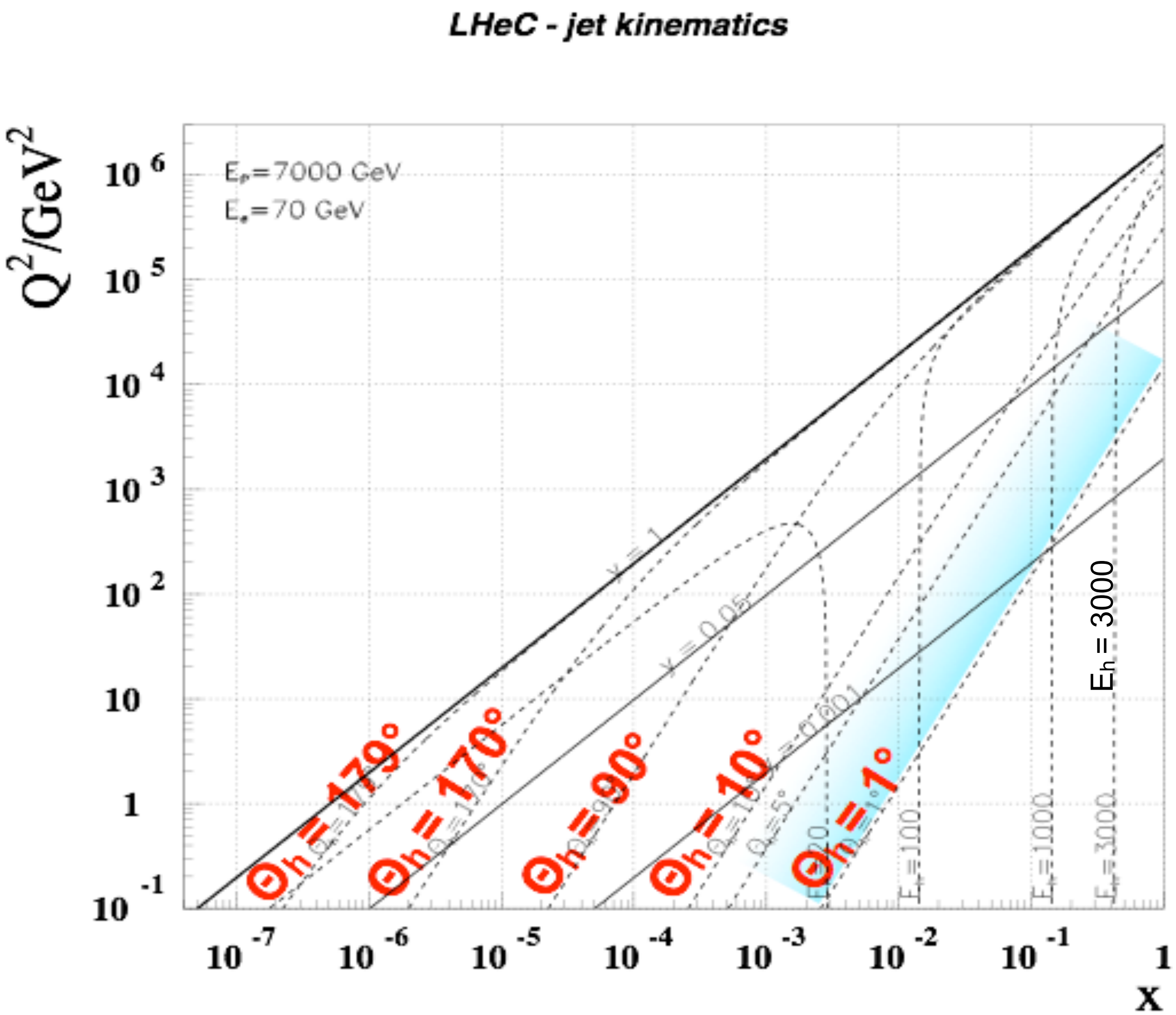
Kinematic coverage can also be achieved by lowering E_e (goes squared to lower Q^2) and lowering E_p (accesses larger x)

e/A interactions - splash of particles produced - to be measured

Ring-Ring: max $e^{\mp}$ at 175 GeV on p/A at 50 TeV

LHeC Kinematics





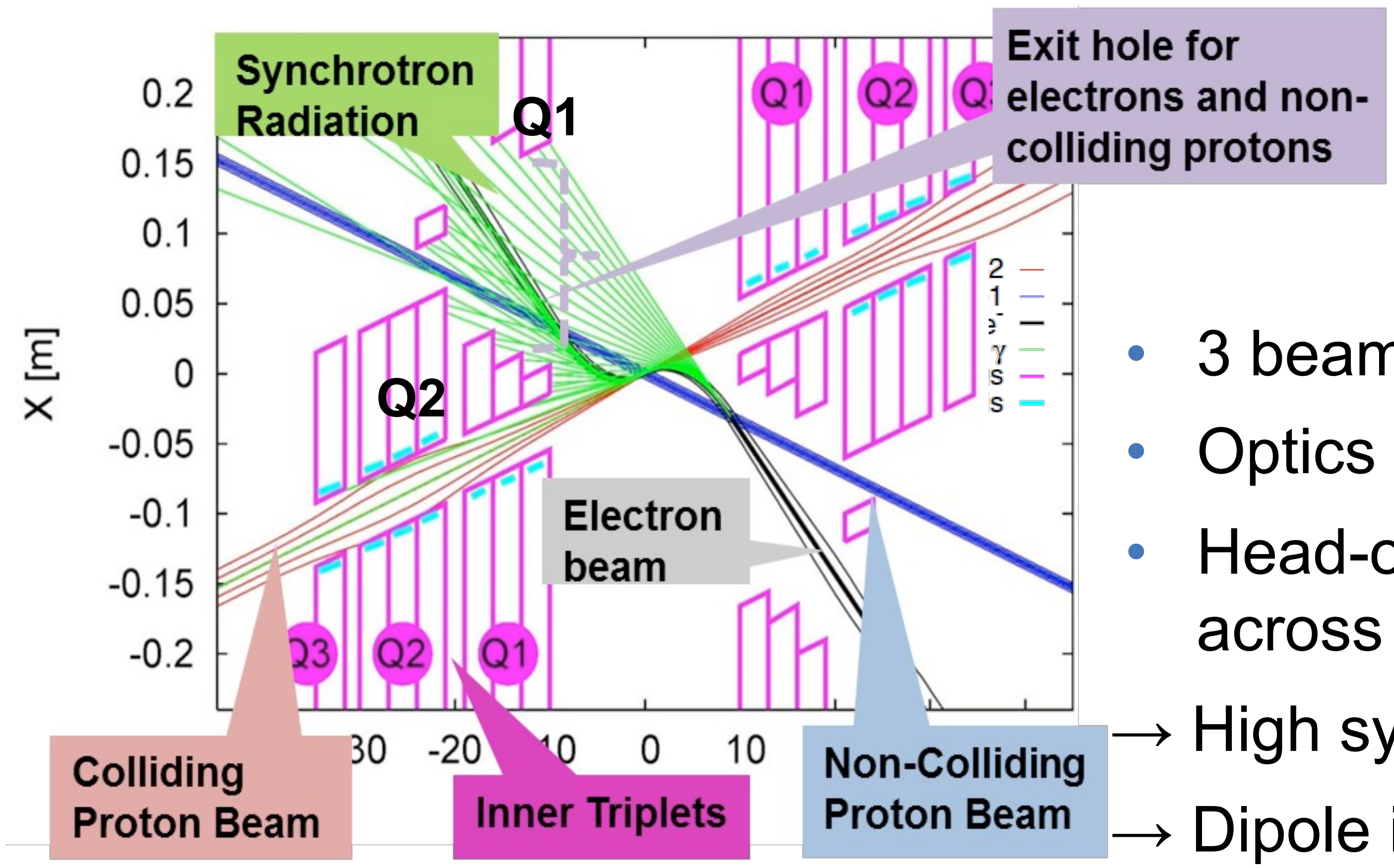
- High x and high Q^2: few TeV HFS scattered forward:

→ Need forward calorimeter of few TeV energy range down to 1^0

Mandatory for charged currents where the outgoing electron is missing

- Scattered electron:
  → Need very bwd angle acceptance for accessing the low Q^2 and high y region

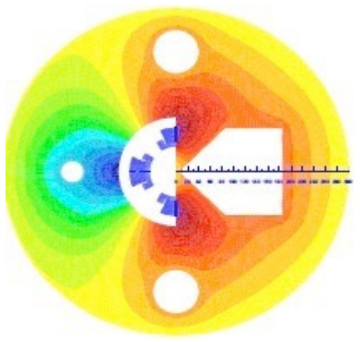
The Interaction Region



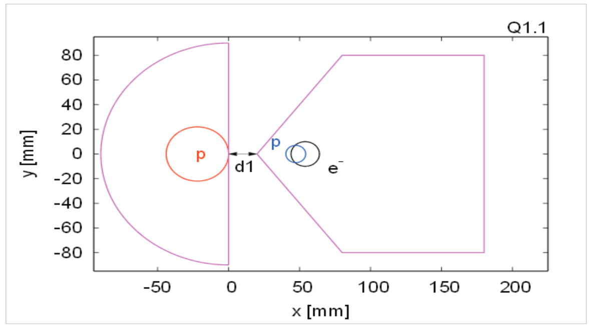
- 3 beam interaction region
- Optics compatible with LHC running and β*=0.1m
- Head-on collisions achieved via long dipole across interaction region

→ High synchrotron radiation load

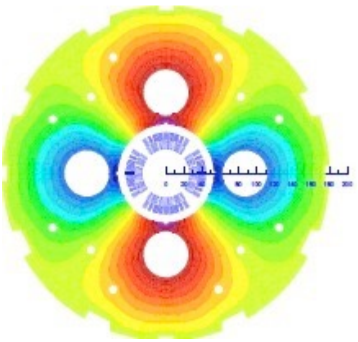
→ Dipole in main detector



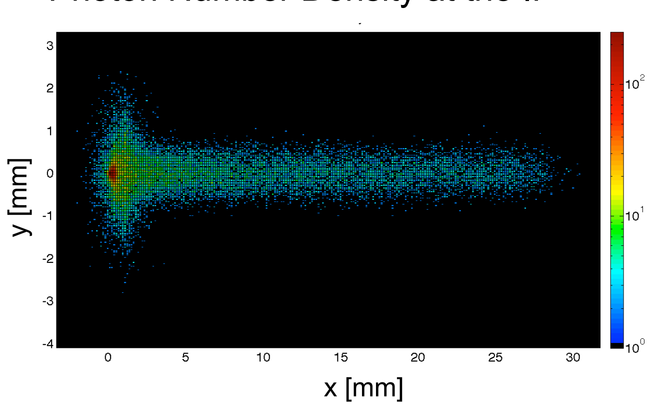
Q1



Q2



Photon Number Density at the IP



Summary

DD4hep/DDG4 - main detector design toolset currently

A common suitable Event Data Model for hh, he, ee communities desirable

Detailed / fast simulations at hand; an interface to Delphes being prepared

Reconstruction - implementation of existing modules (Kalman, Pandora …)

Forward / Backward regions being optimised

Machine-Detector unified design approach of importance for ep/A -
interface to machine lattice desired