An ep/eA FCC-Detector Design

P.Kostka, P.Laycock, E.Pilicer, A.Polini
on behalf of the LHeC Study Group

http://cern.ch/lhec

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]

Prologue

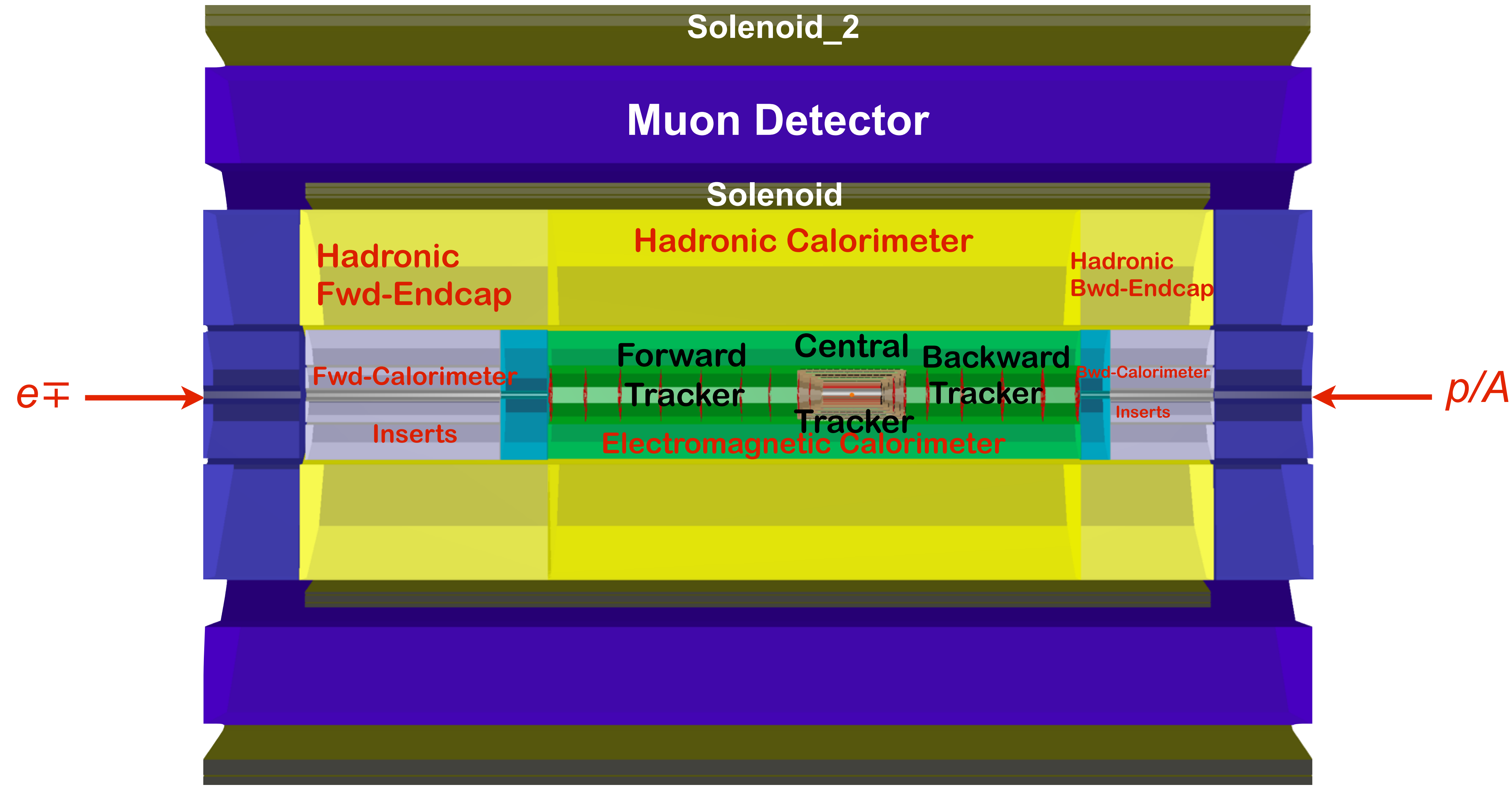
- Designing a new detector needs:
  - some experience - reuse those of others
  - physics questions / expectations to be answered / confirmed or ruled out
  - A detector model mimic/simulate the response on physics, on reconstruction schemes, on analysis chains
  - A toolbox covers
    - full detector description: geometry, materials, visualisation, readout, alignment, calibration, etc.
    - support of all phases of the experiment life cycle: detector concept development, detector optimization, construction, operation
    - single source of detector information for simulation, reconstruction, analysis

I'll illustrate the implementation, the 1^{st} order detector models for the LHeC / FCC

Outline

- Design of a new detector - Software framework DD4hep/DDG4
- Peculiarities of an ep detector
- Layout of FCC-he detector - 1^{st} version
- Machine-detector interface in simulation environment
- Event Display - e(60GeV/c) - p(7TeV/c) Higgs-> $b\bar{b}$
- DD4hep/DDG4 Development
- FCC Software Effort
- Extensions for ep/eA Detector Simulation
- Bright Prospectives
- Epilogue

FCC-he Detector Layout

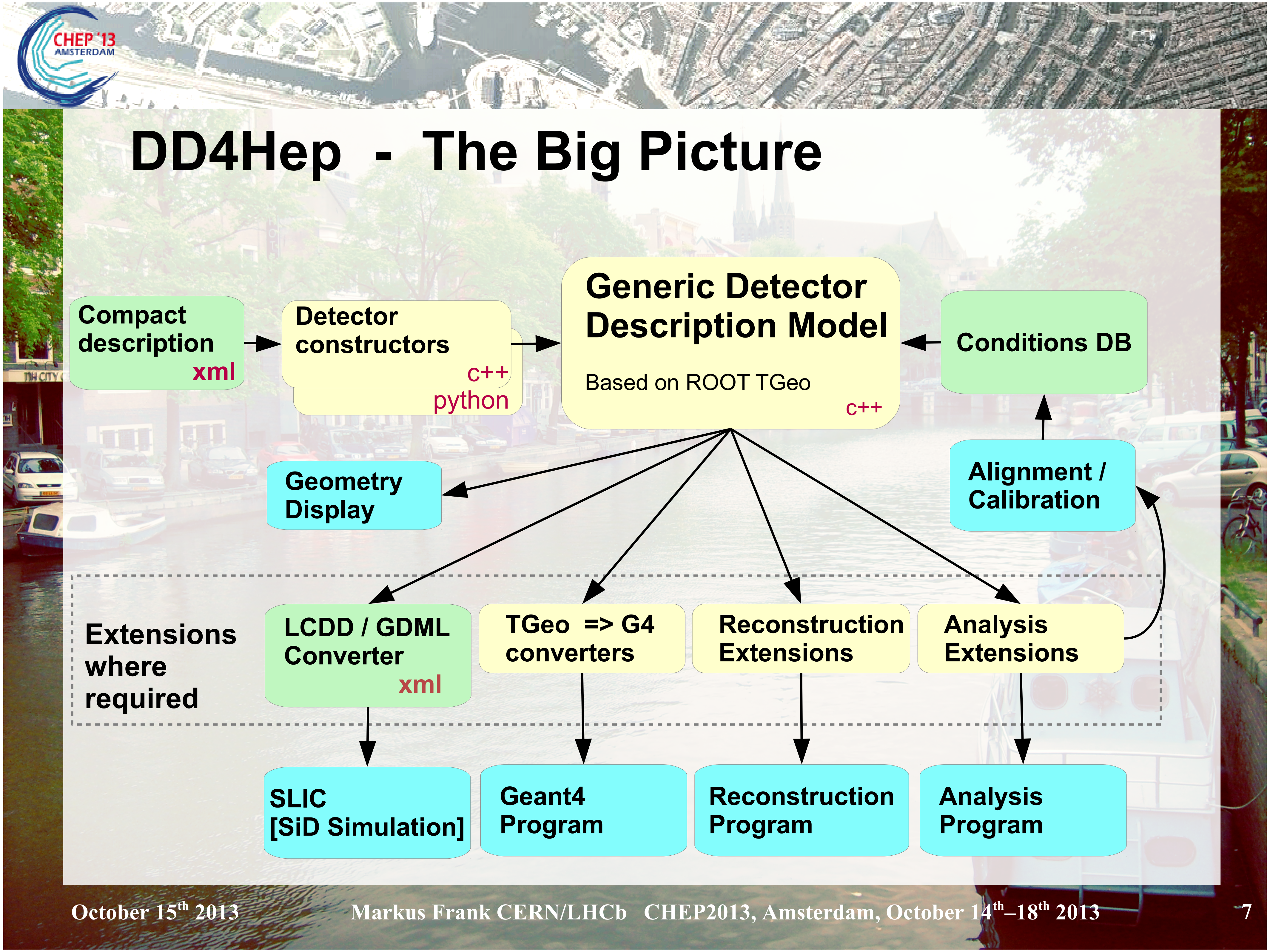


DD4Hep/DDG4 **Detector Design / Simulation / Reconstruction Environment**
linked to and working with ROOT-5.34.26 (ROOT-6 being implemented) and
GEANT4-10.01 (fast simulation coming)

Identical software for LHeC and FCC detector - DD4hep xml-description different only

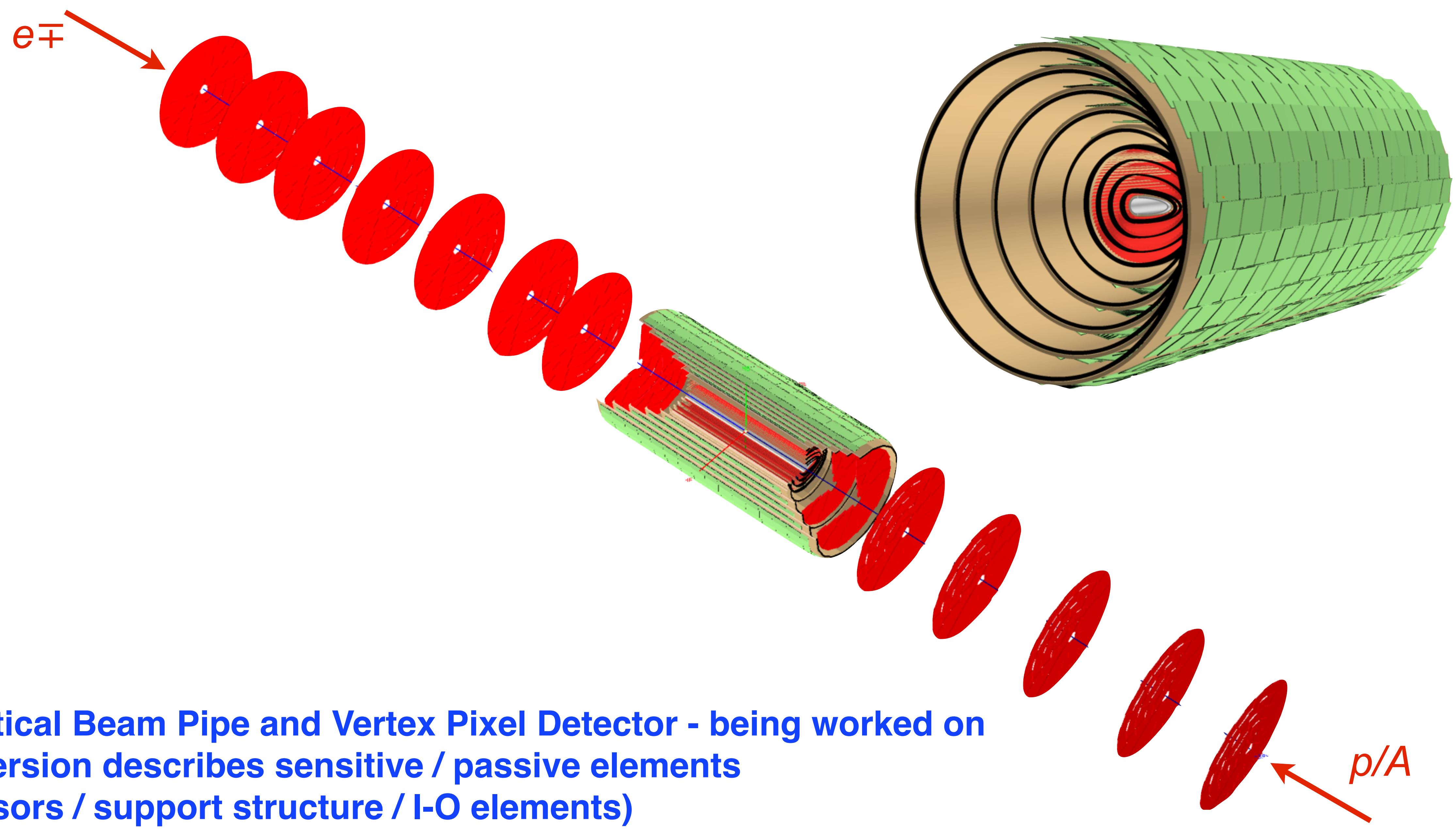
http://http://aidasoft.web.cern.ch/DD4hep svn co https://svnsrv.desy.de/public/aidasoft/DD4hep/trunk

Detector Design/Sim/Rec - DD4Hep



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

Tracker

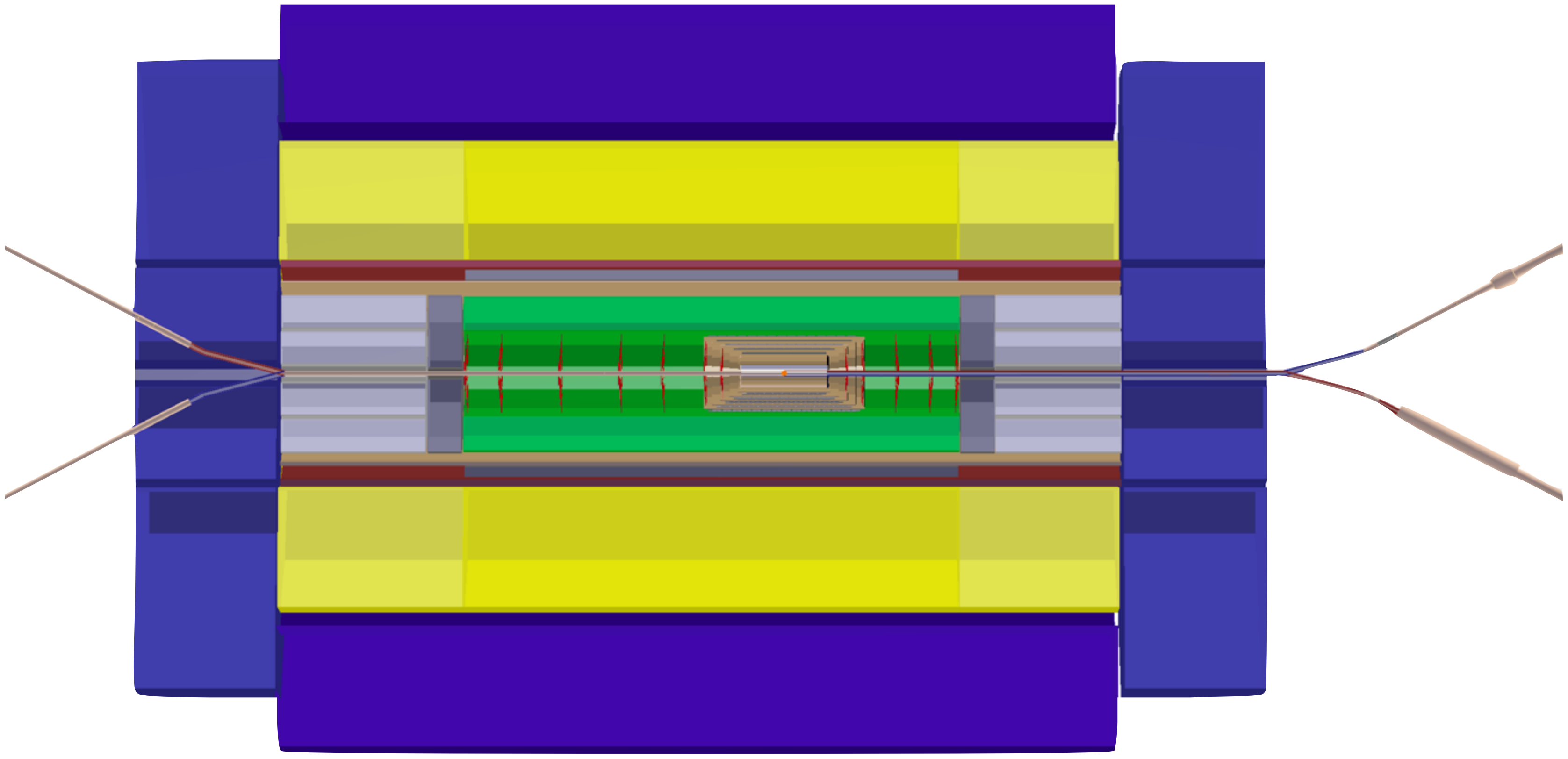


Elliptical Beam Pipe and Vertex Pixel Detector - being worked on
1st version describes sensitive / passive elements
(sensors / support structure / I-O elements)

Interaction region design - Impact of Synchrotron Radiation

Interaction Region Design

- **Beam Pipe** -
  - low X_0, λ_I material, stable, capable for 1^0 tracks !
  - allowing low p_T particle measurement
  - R&D needed (new ideas - most probably tracker included)
- SR - masks / absorber placements - critical issue for ep-detector
  machine optics combined with detector magnet setup (inner dipole & solenoid)



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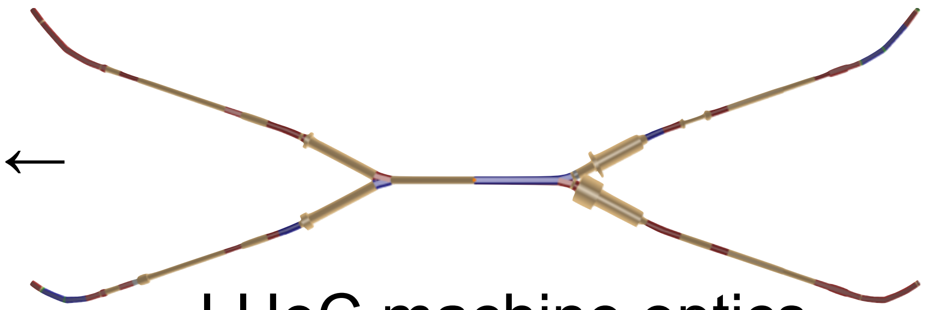
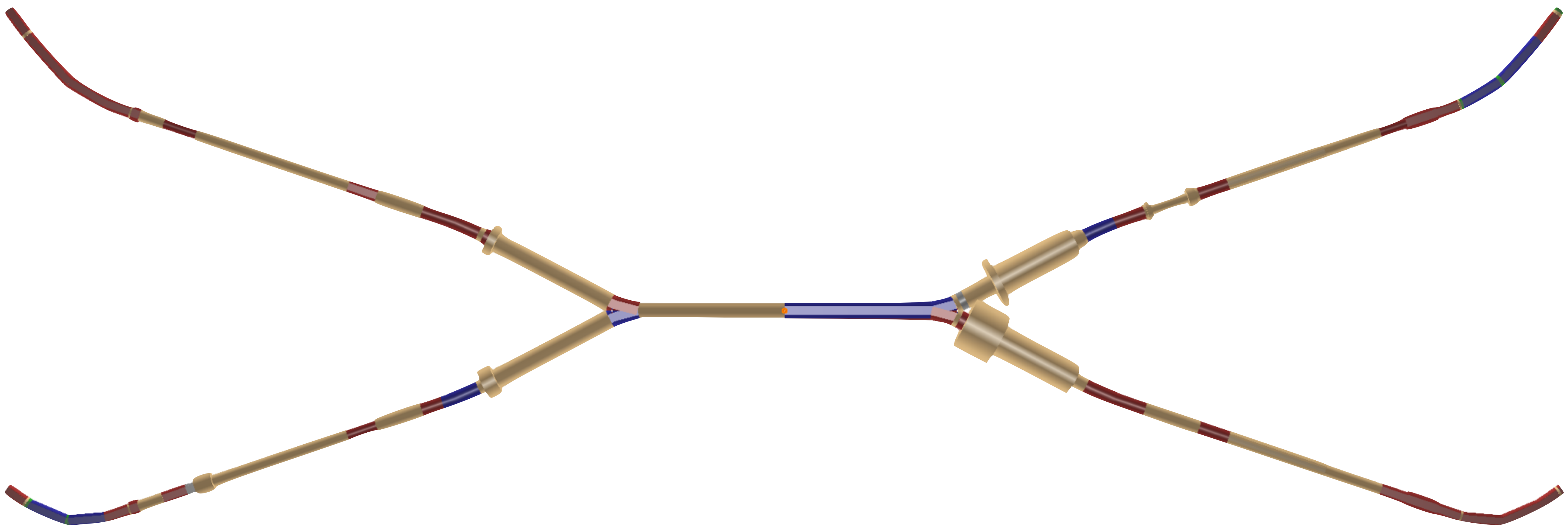


LHeC machine optics

courtesy H.Burkhardt

Interaction Region Design

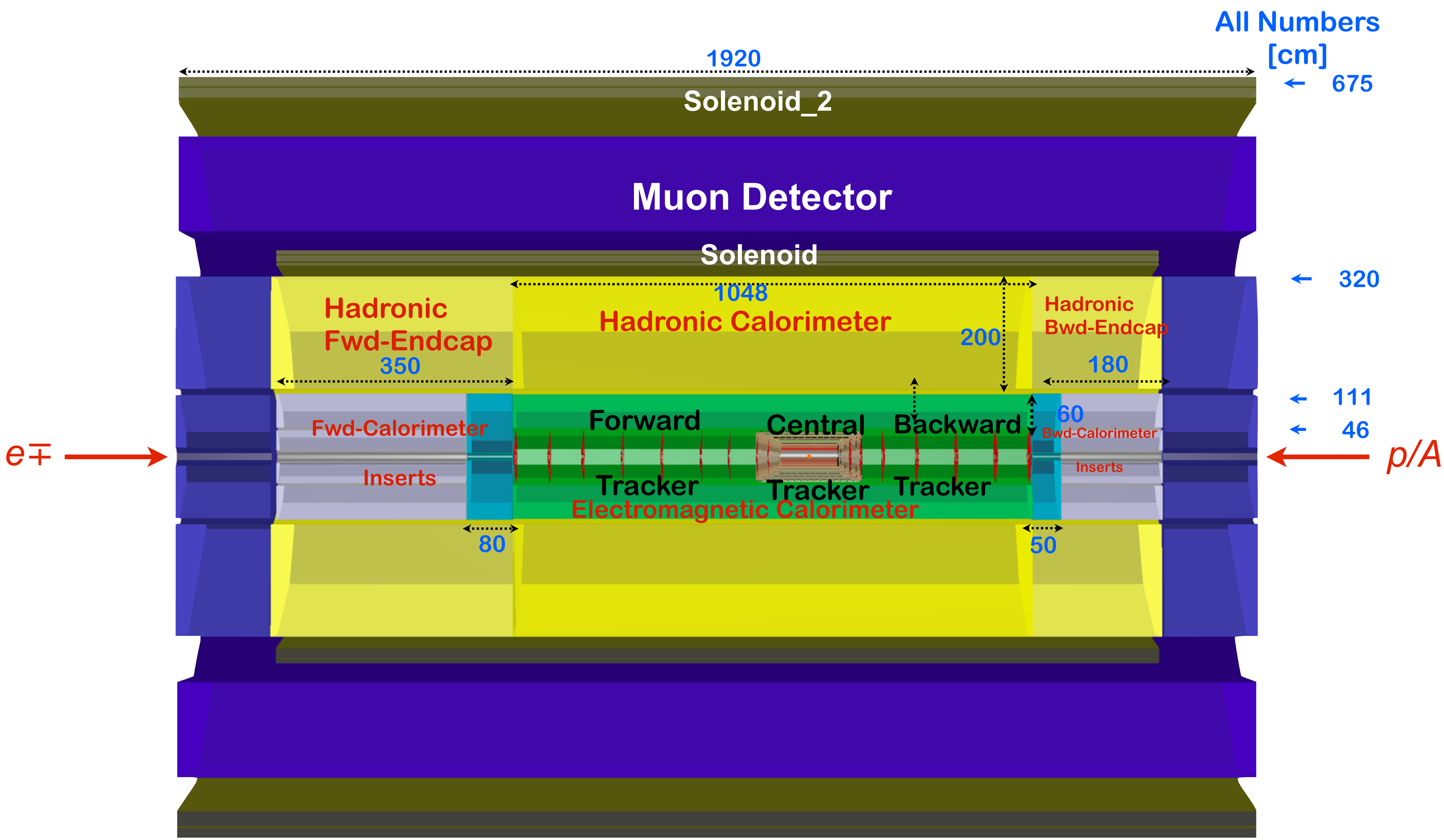


LHeC machine optics elements layout - MAD-X

courtesy H.Burkhardt, BE-ABP CERN

- **Interface MAD-X to detector design tools desired**
- **Placement of SR - masks / absorbers**
  combined machine and detector study defining the interaction region design

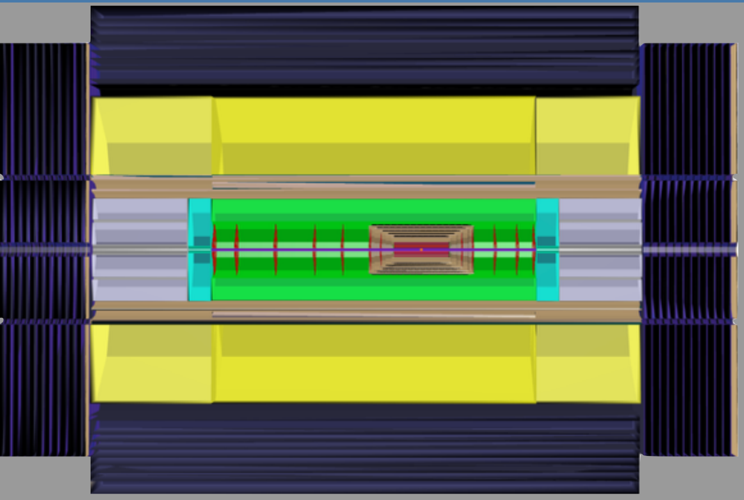
FCC-he Detector / YZ-View



Based on the LHeC design; figure shows the version using a double solenoid system; Solenoid_2 outside of Muon-Det.: independent momentum measurement - hadrons, min. interacting leptons. Single solenoid version not excluded.

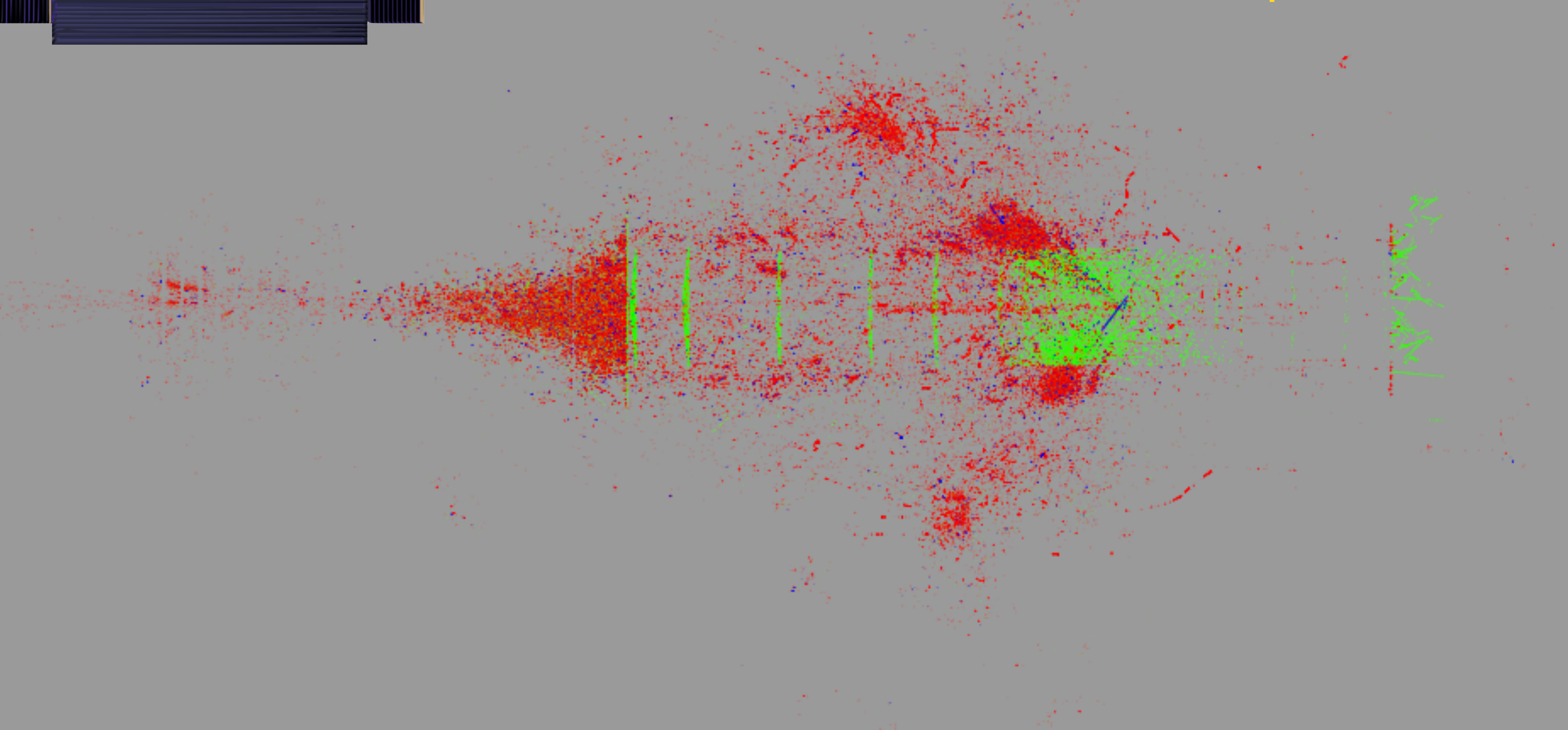
(Pythia-event → DD4hep) → GEANT4 Simulation

courtesy U.Klein



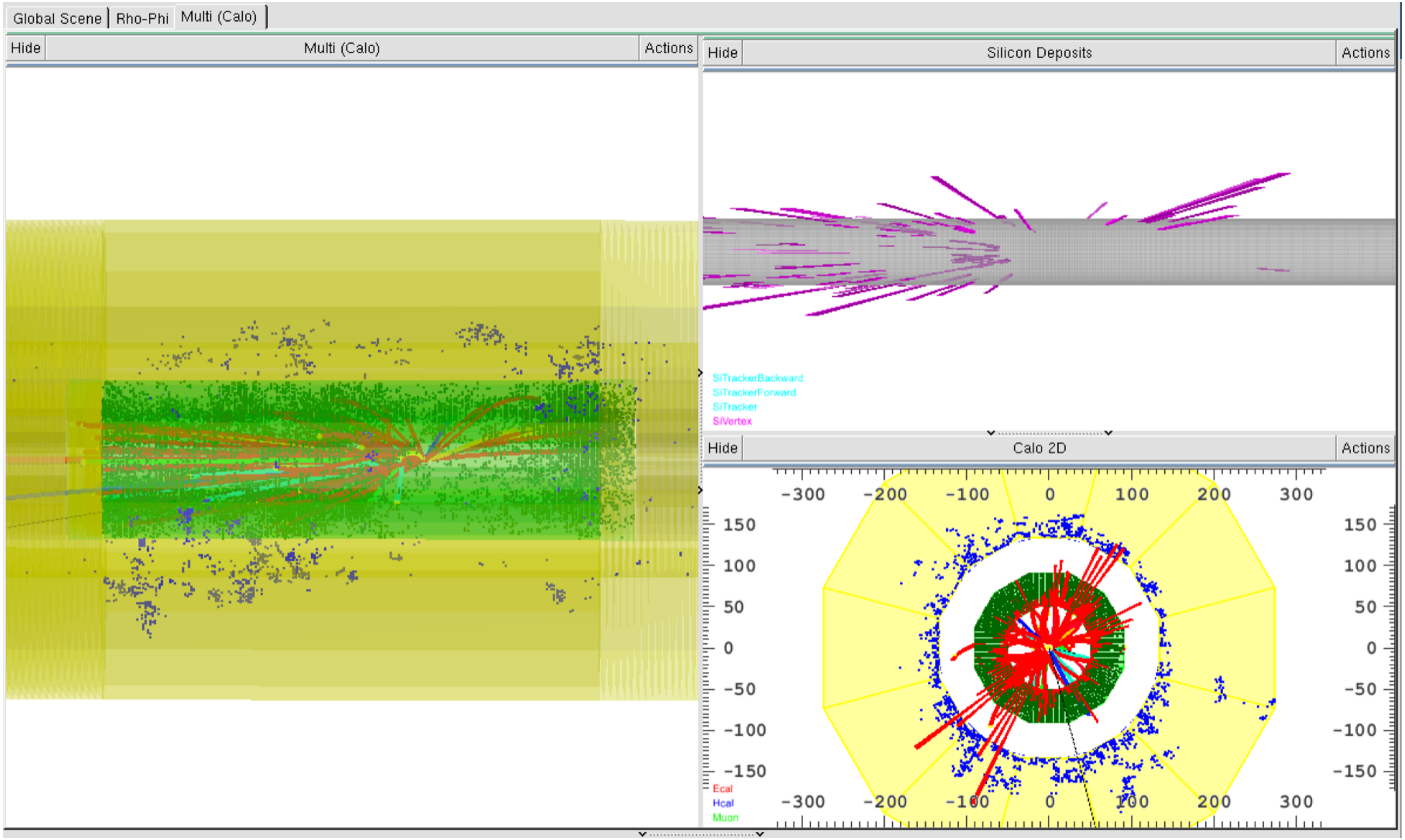
Higgs → b$\bar{b}$

LHeC-detector response



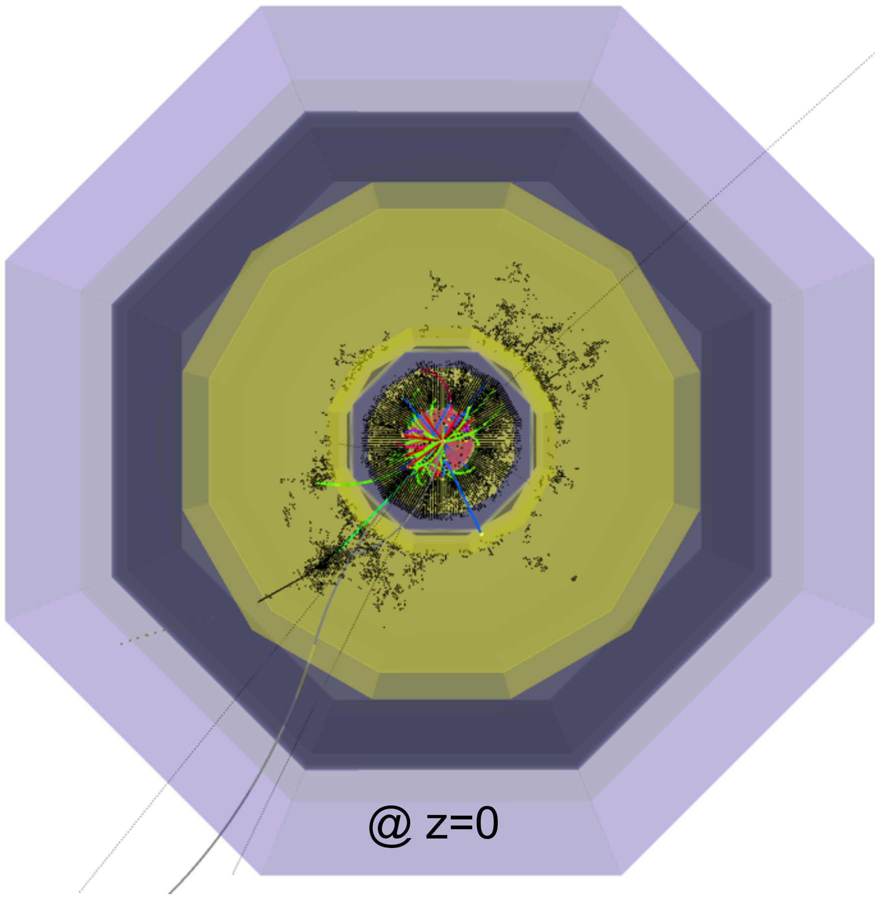
Pythia-event → LHeC-Higgs-bƀ→ DDG4 →LHeC-DDEve

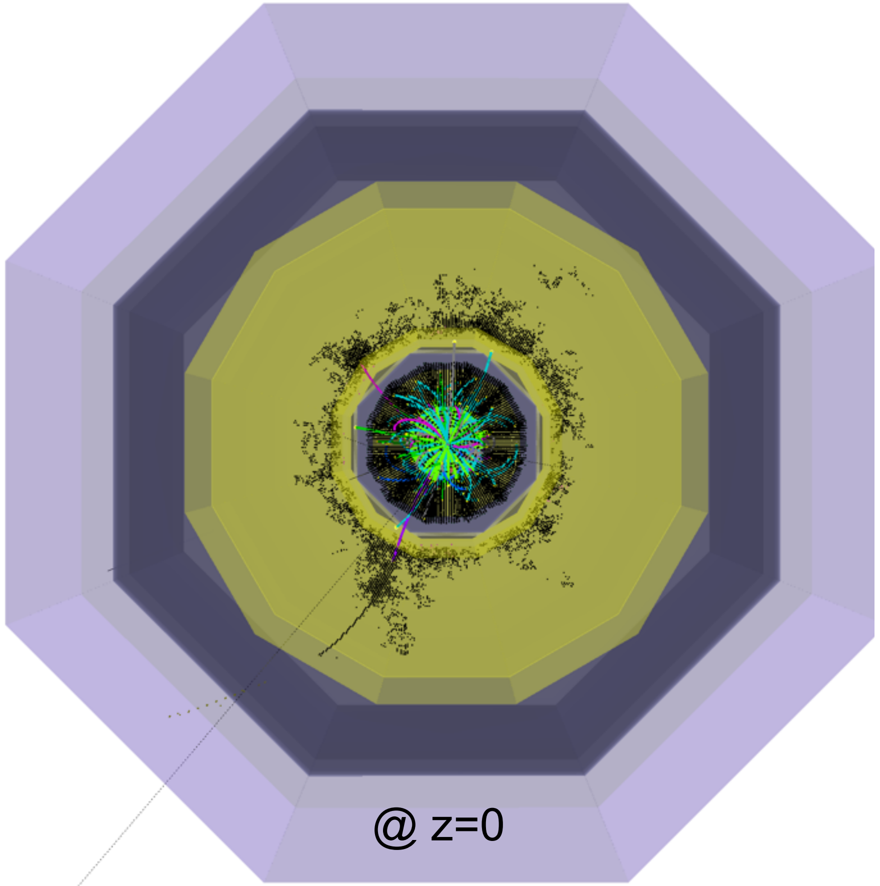
courtesy U.Klein

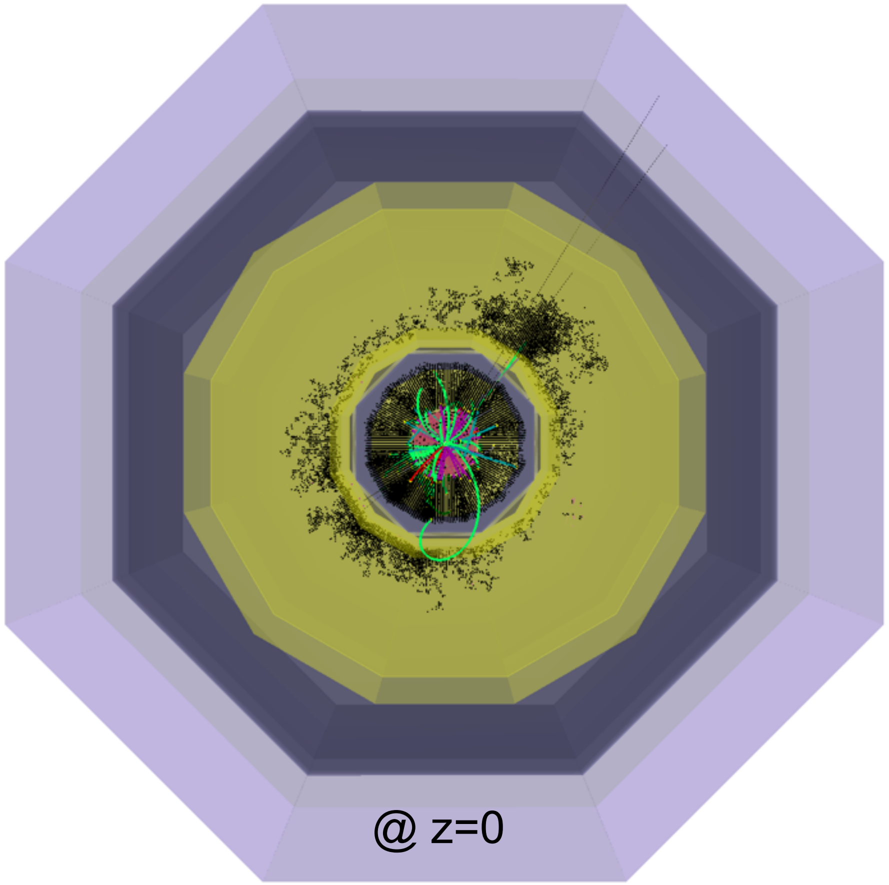


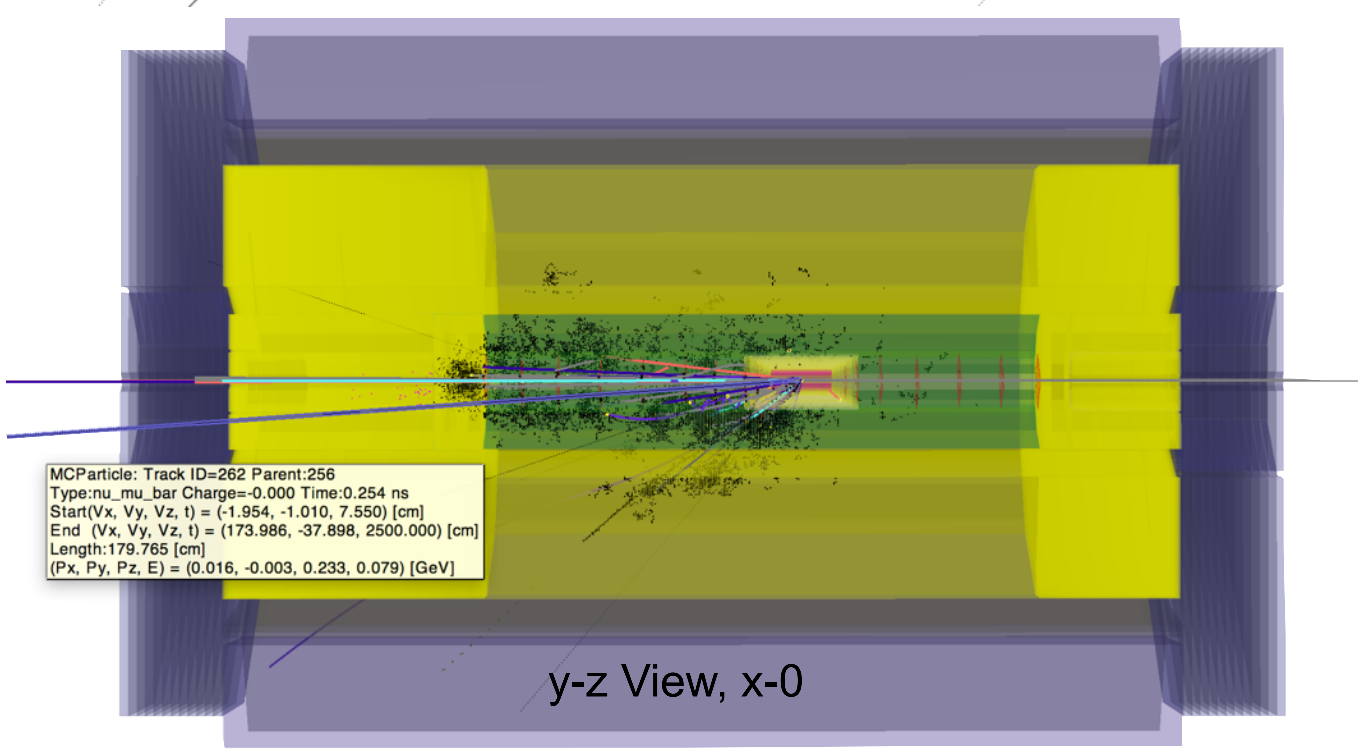
Pythia → LHeC-Higgs-bb̄ → DDG4 → FCC-DDEve

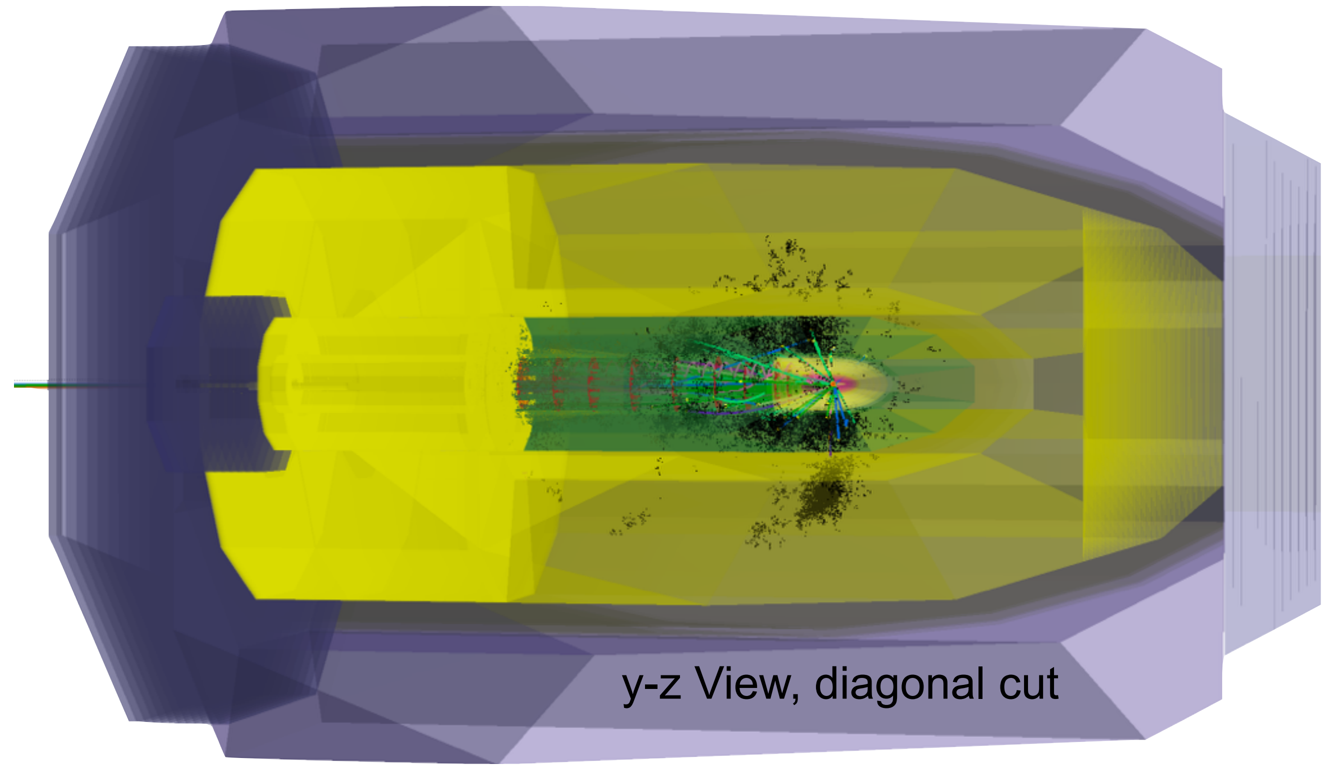
courtesy U.Klein e (60GeV/c) p (7 TeV/c) LHeC “scaled” detector











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 output import into the framework - stdhep- and hepmc-file formats**
- **Python, C++   int./ext.**
  - **LHeC/FCC detector geometry (being optimised), material (evolving), R/O description ongoing, segmentations and surfaces - ingredients for reconstruction (evolving)**
  - **DDEve - event display tool for quality judgment and control …**

Very fruitful collaboration with DD4hep developers!

Extensions needed?

- besides ROOT and GEANT4 - has **FLUKA** to be incorporated?
- Generators - PYTHIA8, HERWIG, SHERPA - do not consider standard ep and even less eA processes currently
- **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
  - drawback - licensed software
  - dedicated manpower needed!

FCC Software Effort

Based at CERN

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

Let me quote (Benedikt Hegner):

- **Adapt existing solutions from LHC: – Gaudi as underlying framework**
  - **ROOT for I/O**
  - **Geant4 for simulation**
  - **Python for user analysis/test**
- **Adapt software developments from ILC/CLIC**
  - **DD4hep for detector description**
- **Invest in better fast vs. full sim integration**
  - **Geant4 fastsim, Atlfast**
- **Invest in proper data model** ← common effort
  - **The LHC experiments' ones are over-engineered**
  - **The ILC/CLIC implementation isn't state of the art**

  Both are significantly under-performant on modern CPU's

eoq

ATLAS has spent LS1 simplifying it's EDM - a running experiment invested a lot of effort into it.

Simpler data structures will future-proof us for detector simulations and hardware developments.
ATLAS has addressed some performance issue by event-wise parallelism,
CMS do actually use multi-threading.

Status - see talk of Benedikt on Monday

Guidelines

Use of software tools as available

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

Hardware optimisation according to latest R&D (HL-LHC …),
new ideas if necessary

Bright Prospectives

- 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
    →   4 b-Jets to be identified and measured

  - **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 today, detector design will benefit from coming technology progress
  (sensors, magnets, low power consumption, cooling and mechanical systems …)

Epilogue

DD4hep/DDG4 - main detector design toolset currently

A common suitable EDM for hh, he, ee communities desirable

Detailed / fast simulations at hand

Reconstruction - Interfacing existing modules (adaption)

More detailed detector design - CAD interface ?!

Very forward region on test bench - extensions?

Interaction region design essential for ep detector - interface to machine optics tools desired

BACKUP

DD4Hep - Main Requirements

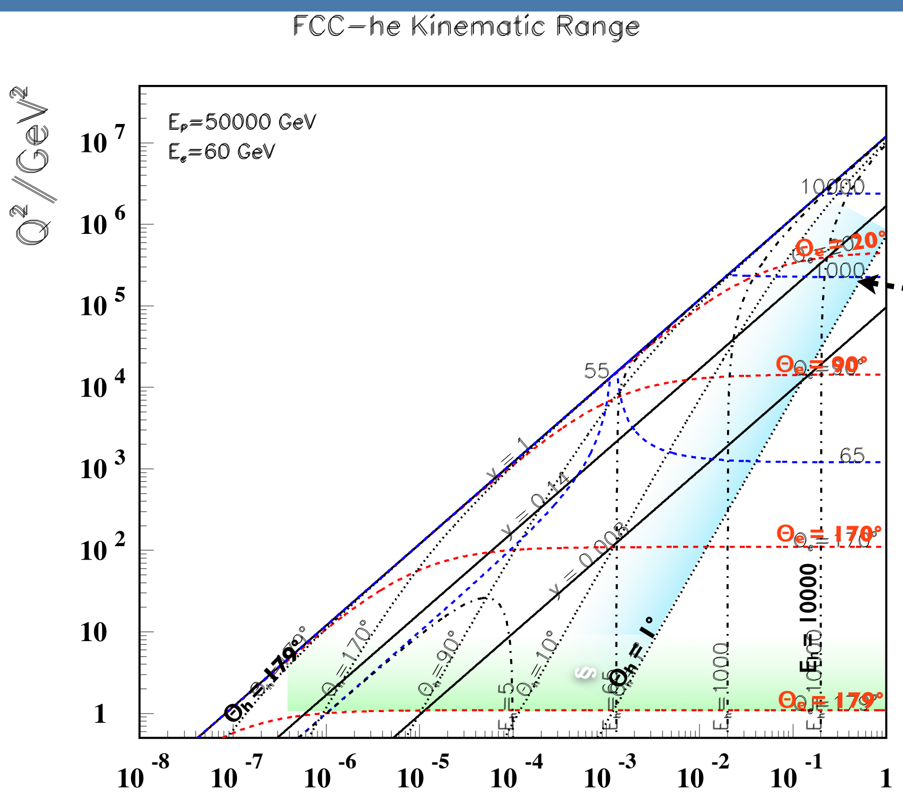
- full detector description
- includes geometry, materials, visualization, readout, alignment, calibration, etc.
- full experiment life cycle
- supporting all phases of the life cycle: detector concept development, detector optimization, construction, operation
- easy transition from one phase to the next
- consistent description
- single source of detector information for simulation, reconstruction, analysis
- ease of use
- only a few places to enter information - minimal dependencies

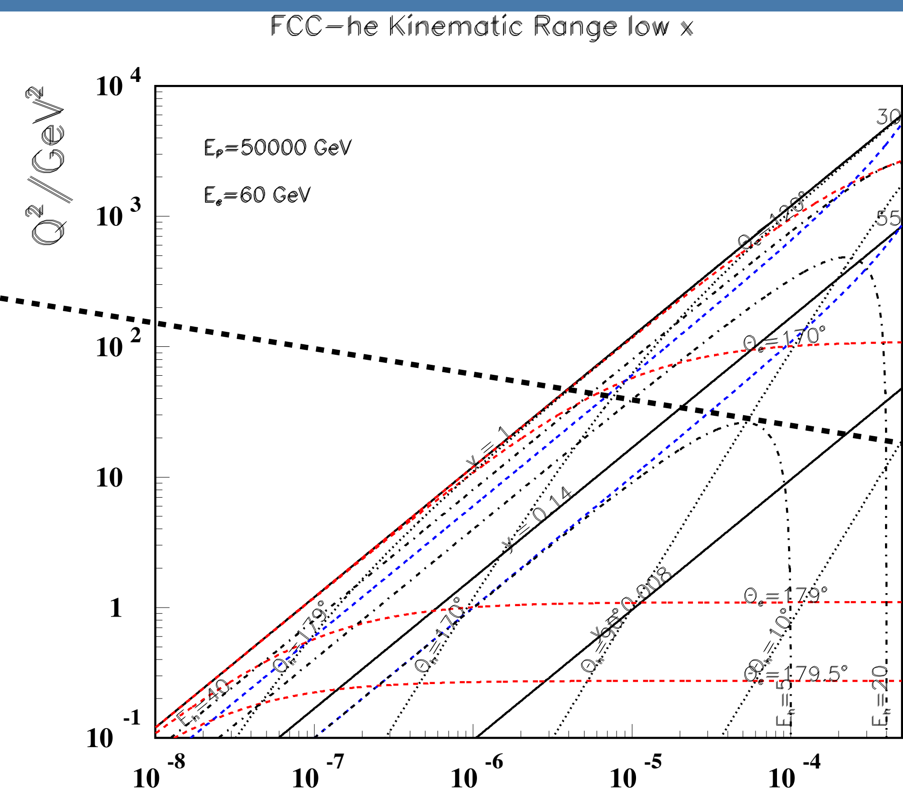
FCC-he Tracker / Calorimeter Summary

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

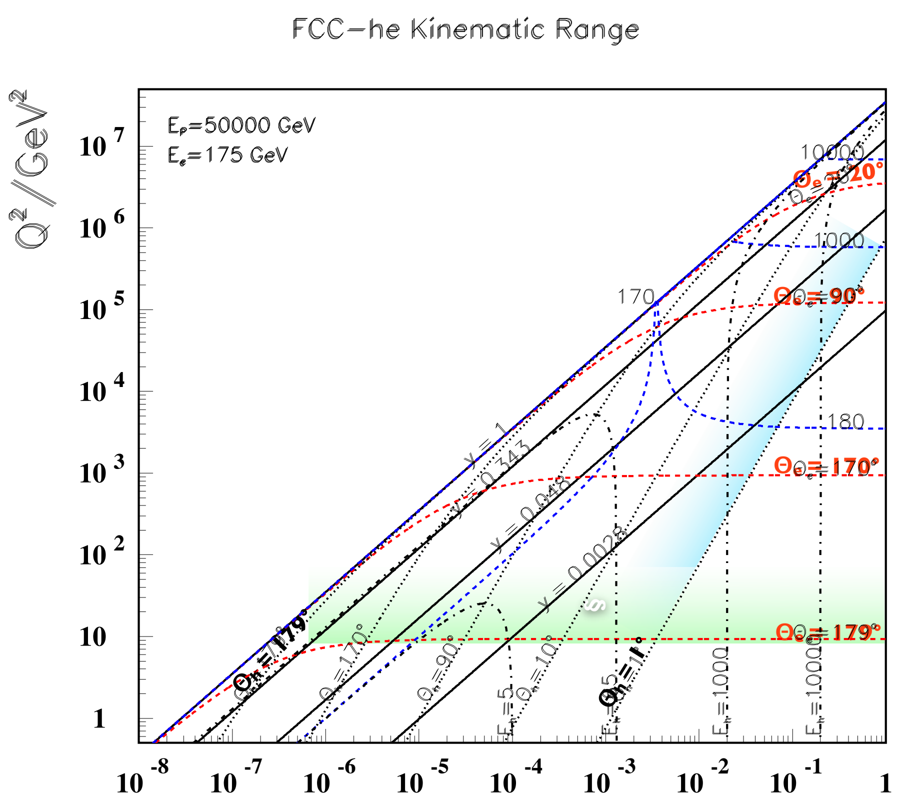
Calorimeter	FHC	FEC	EMC	HAC	BEC	BHC
Min. / Max. Polar $\theta[^0]$	0.4	0.4	6.8 / 171.1	15.1 / 160.7	179.4	179.5
Max. / Min. $\lvert\eta\rvert$	5.7	5.6	2.8 / -2.5	2.0 / -1.7	-5.3	-5.5
Volume $[m^3]$	18.9	1.5	41.7	443.4	-5.3	-5.5

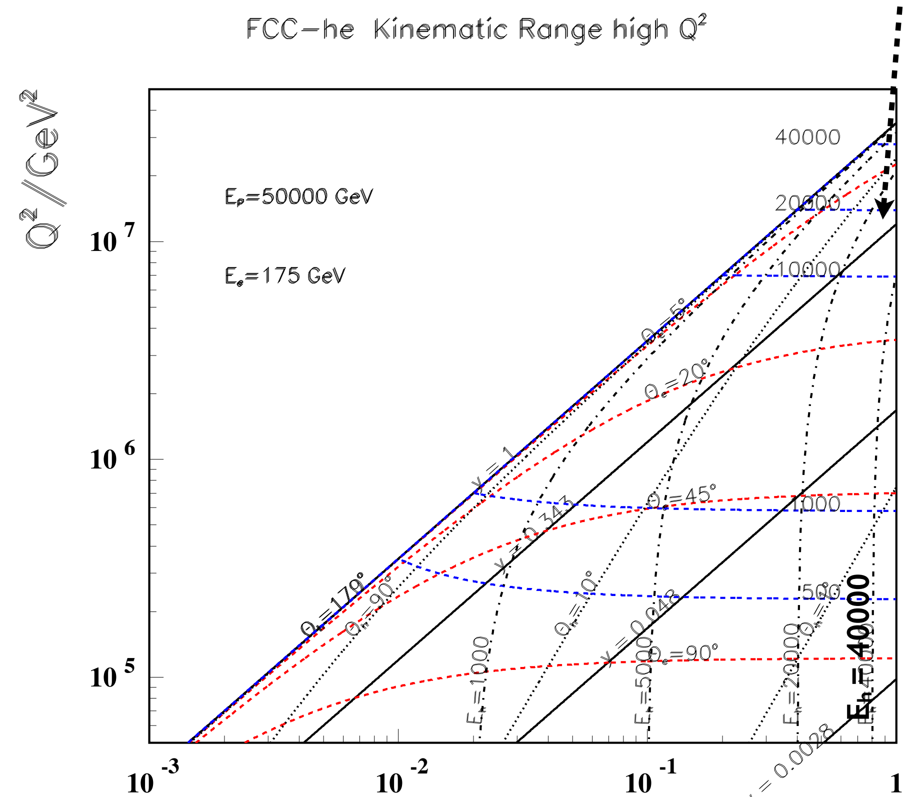
FCC-he - Machine Options





Linac-Ring: LHeC ERL e∓ at 60 GeV on p/A at 50 TeV (i.e. Pb at 20TeV (=50 x 82/207)





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

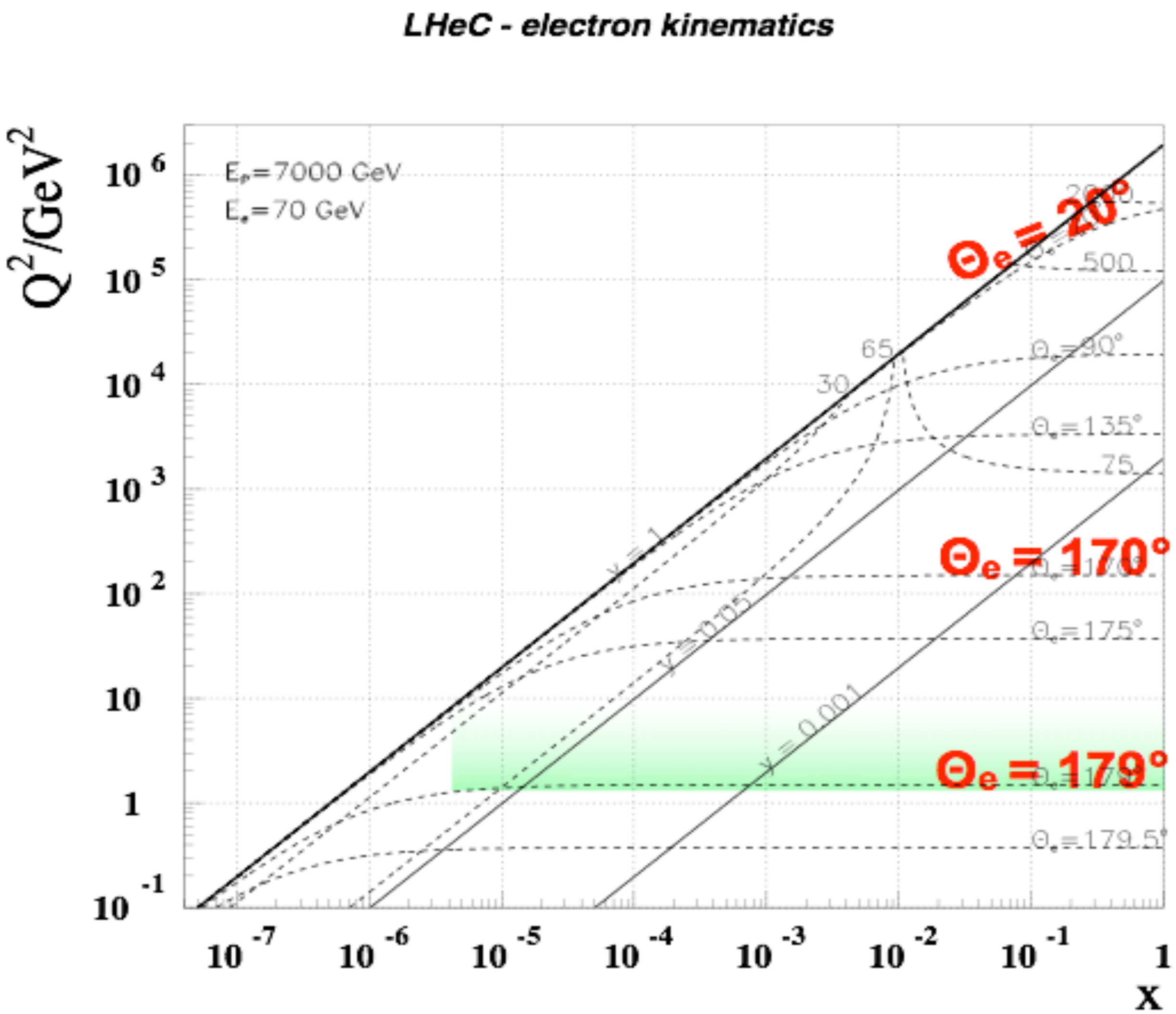
~doubling the calorimeter depth compared to LHeC

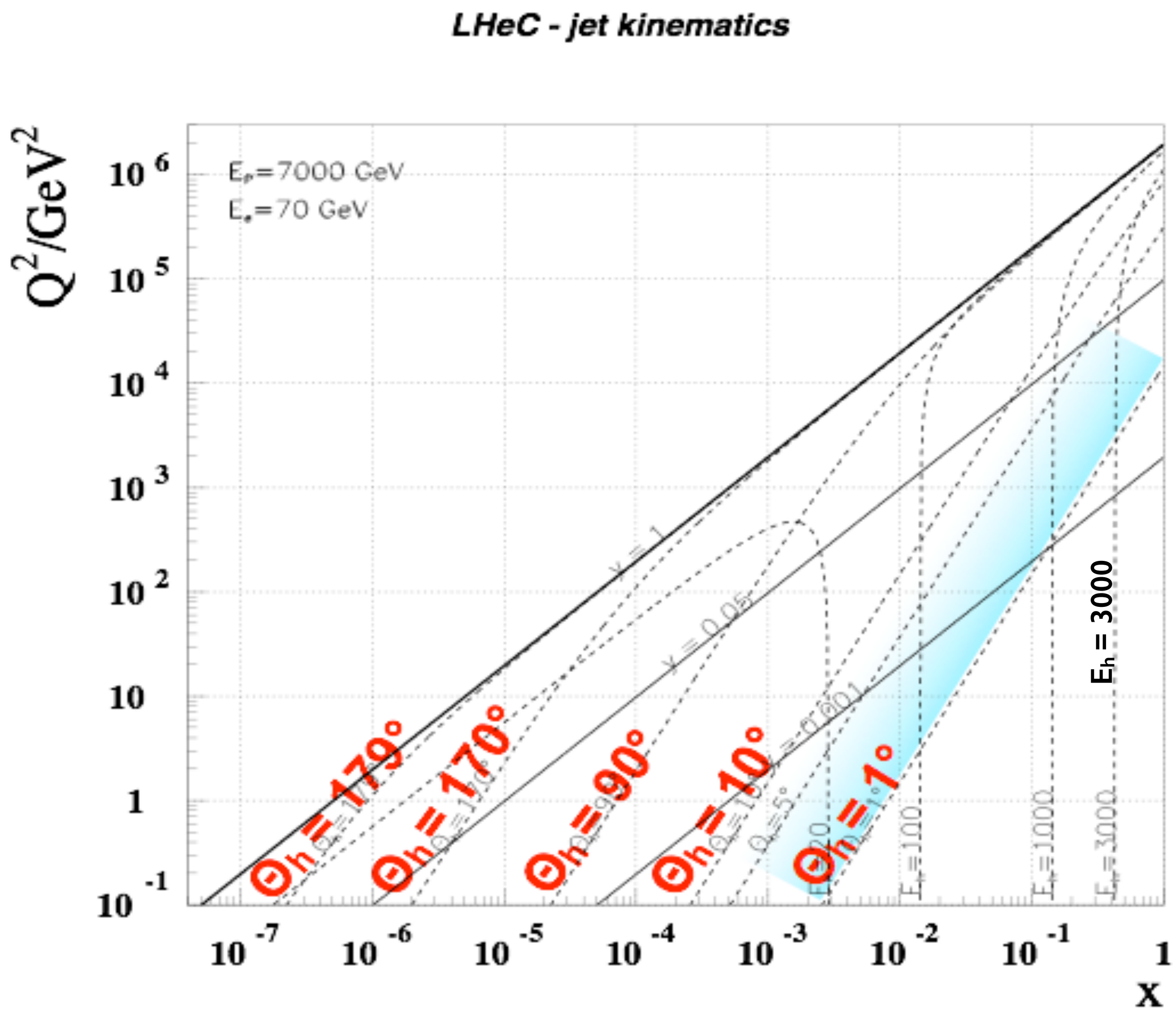
Kinematic coverage can also be achieved by lowering E_e (goes squared to lower Q^2) and lowering E_p (accesses larger x)

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

Ring-Ring: max e∓ at 175 GeV on p/A at 50 TeV

LHeC Kinematics



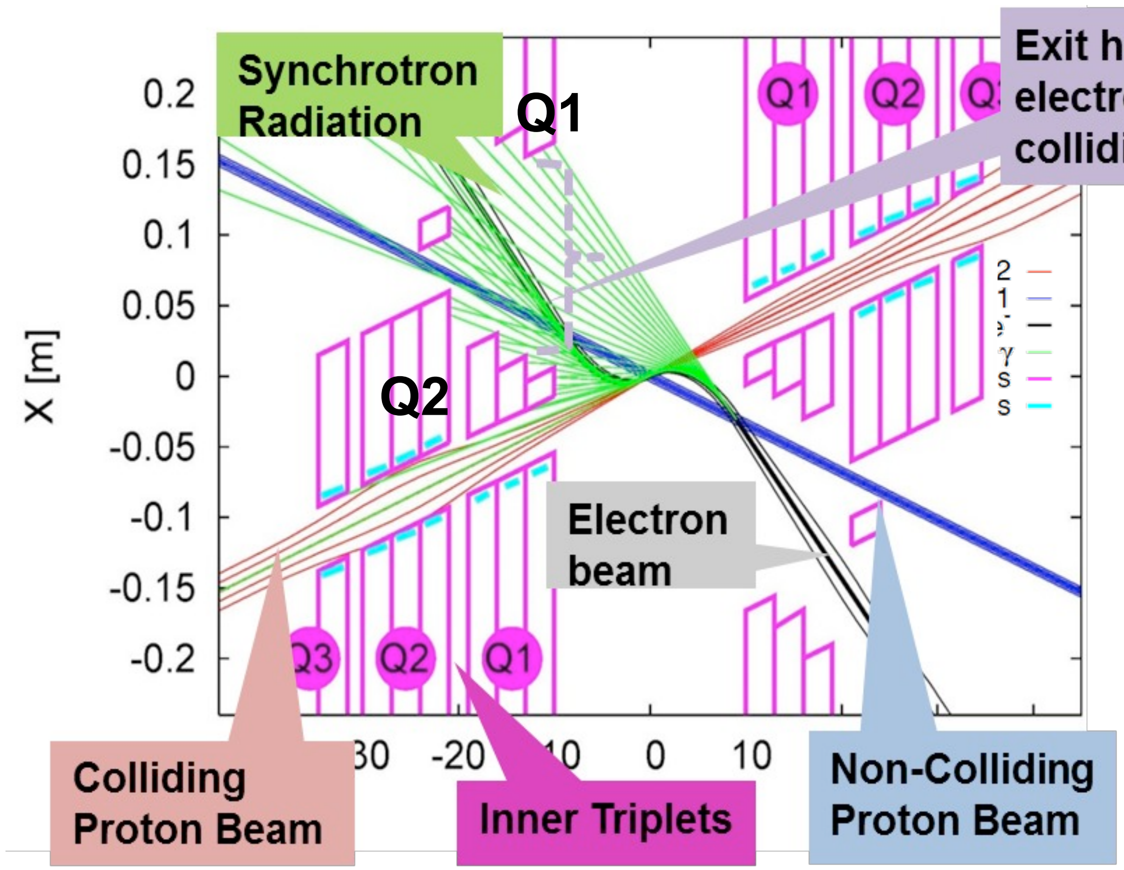


- High x and high Q^2: few TeV HFS scattered forward:

  → 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

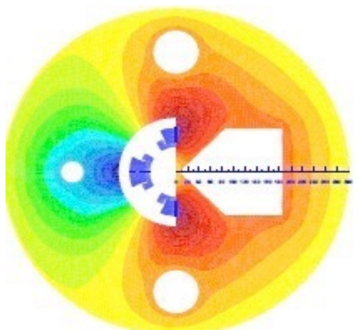


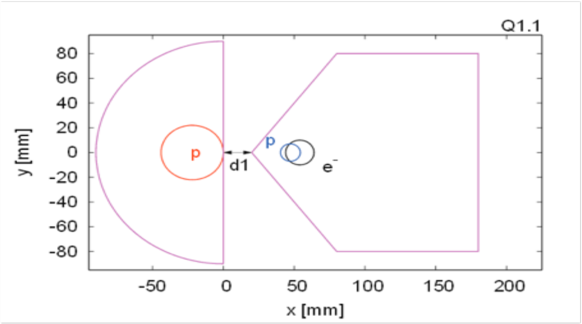
- 3 beam interaction region
- Optics compatible with LHC running and β*=0.1m
- Head-on collisions achieved via long dipole across interaction region

→ High synchrotron radiation load

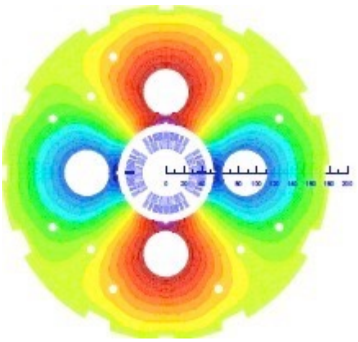
→ Dipole in main detector

Q1

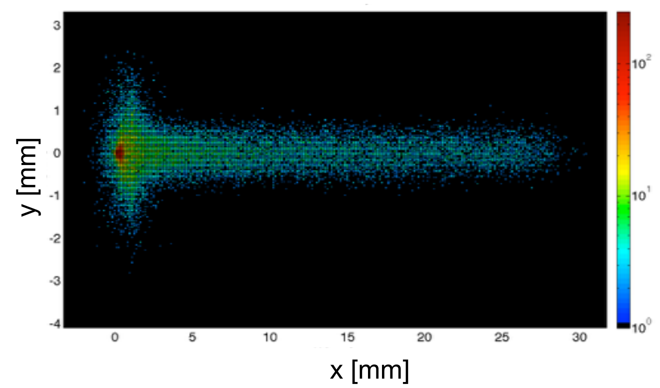




Q2

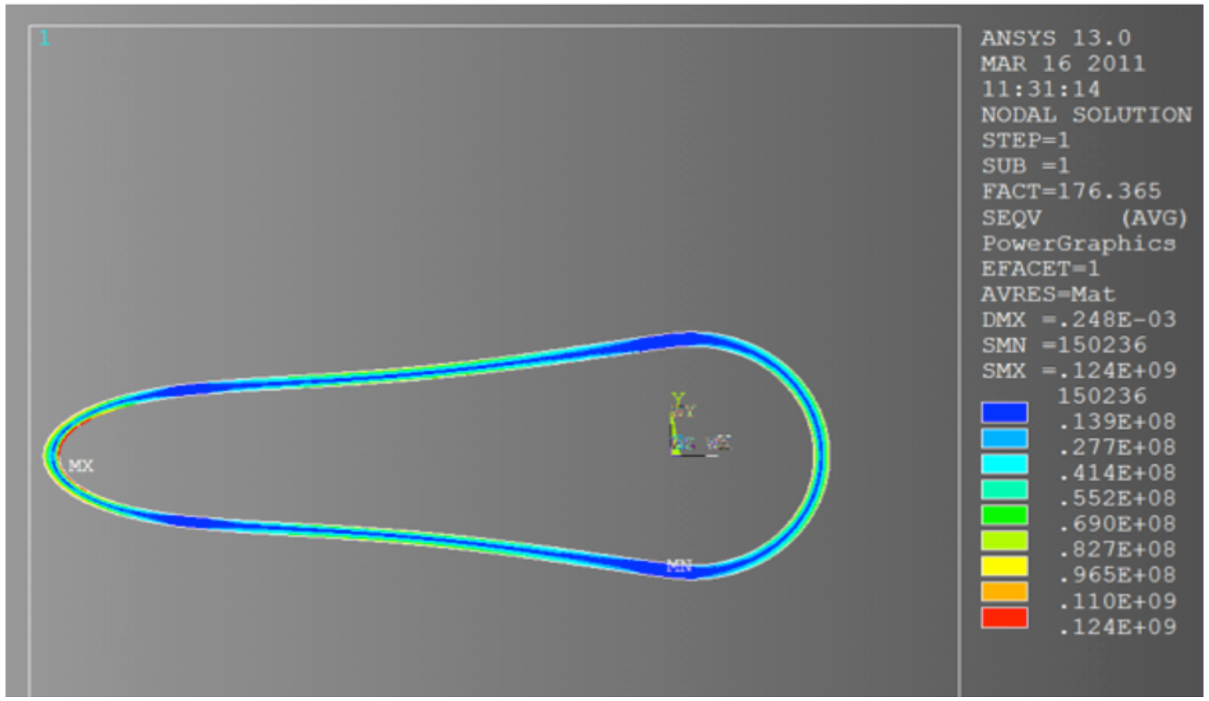


Photon Number Density at the IP



Beam Pipe Considerations

courtesy Paul Cruikshank, CERN



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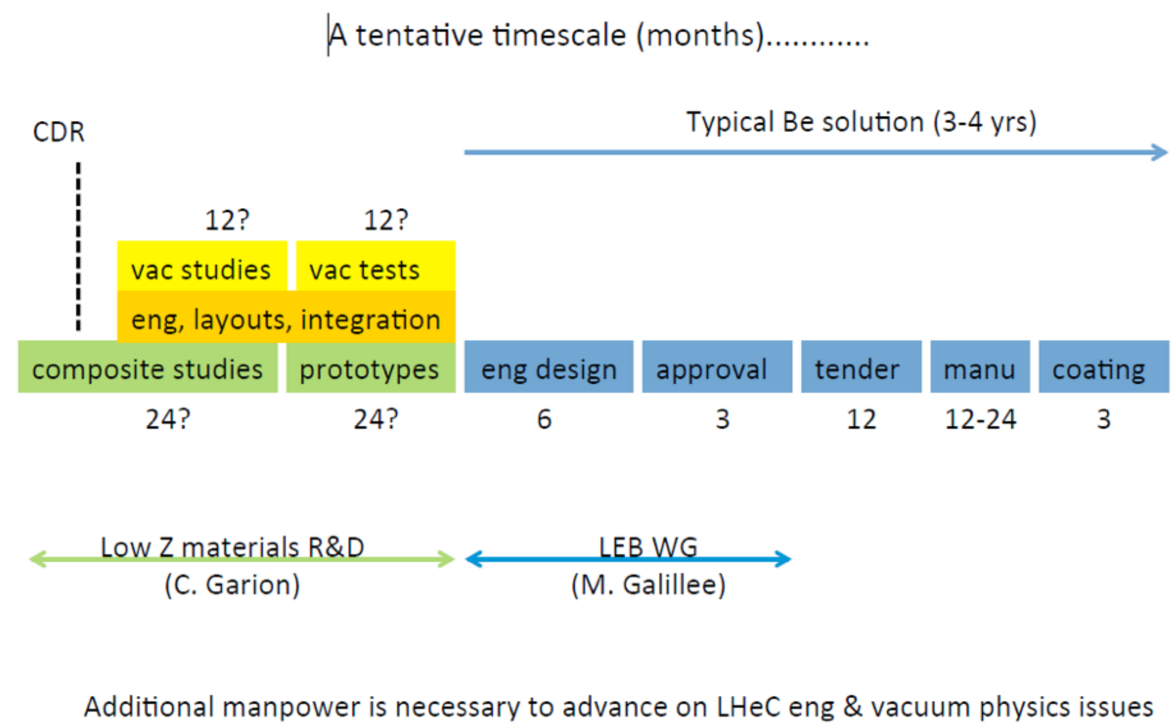
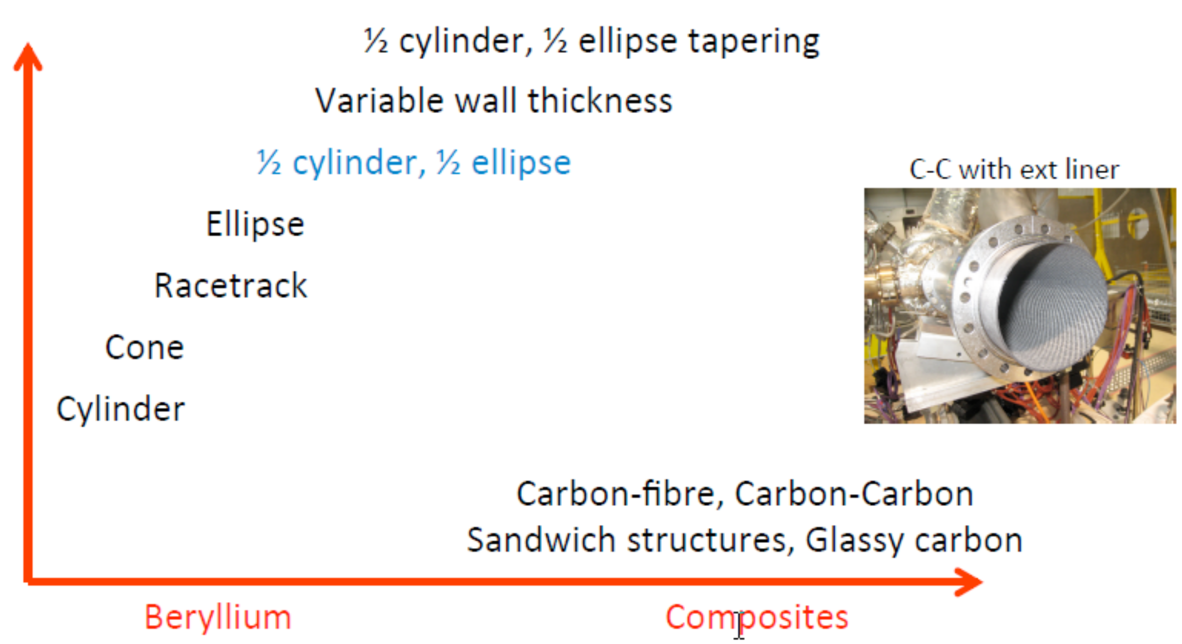


- Circular-Elliptical beam-pipe design
  - Beryllium 2.5-3.0 mm wall thickness
  - Central beam pipe ~ 6 meters
  - TiZrV NEG coated
  - Wall protected from primary SR (upstream masks)
  - Minimised end flanges, minimised supports
  - optimisation needed - R&D



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