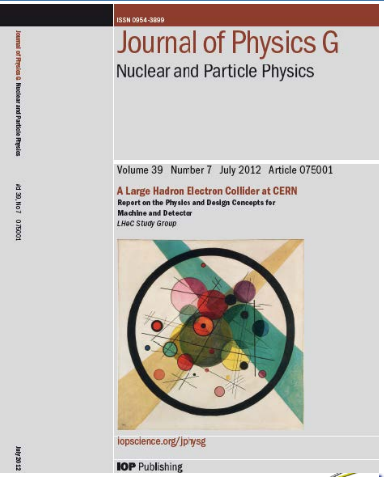
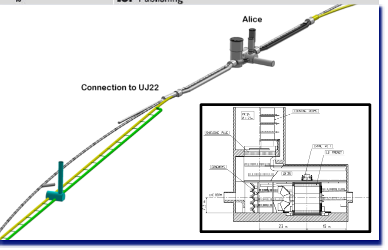
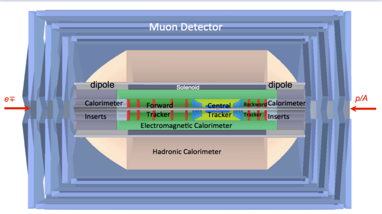
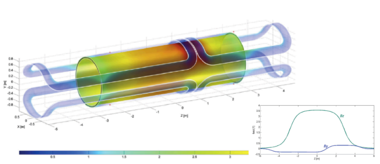
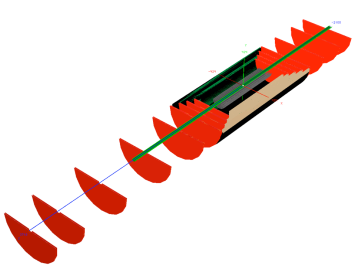
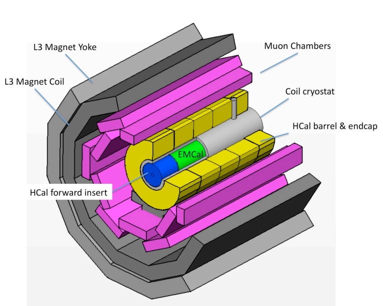

Journal of Physics G
Nuclear and Particle Physics
Volume 39 Number 7 July 2012 Article 075001
A Large Hadron Electron Collider at CERN
Report on the Physics and Design Concepts for Machine and Detector
LHeC Study Group
iopscience.org/jphysg
IOP Publishing








# The LHeC Detector

## P.Kostka
## on behalf of the LHeC Study Group

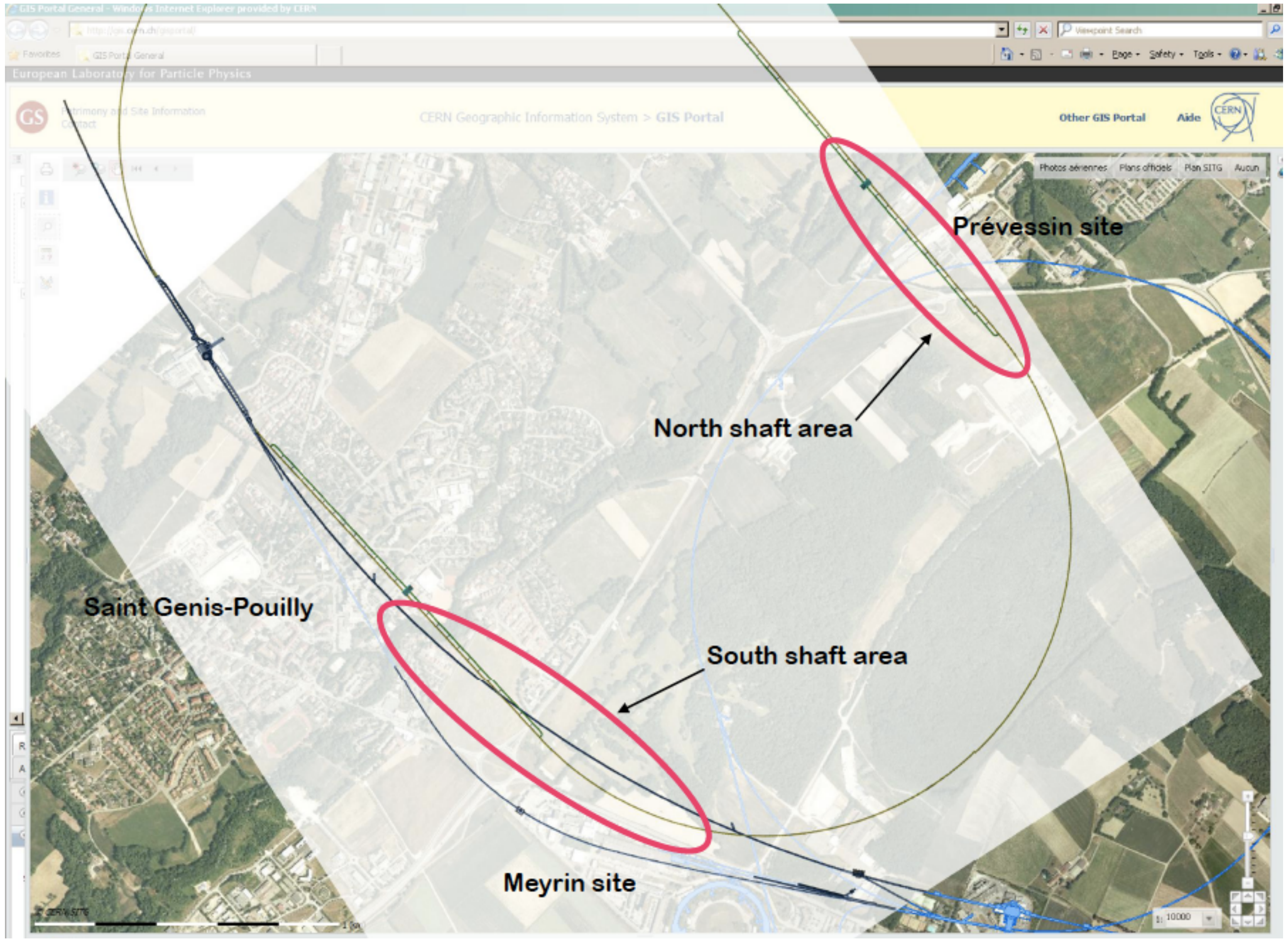
http://cern.ch/lhec

CDR: “A Large Hadron Electron Collider at CERN”
LHeC Study Group, arXiv:1206.2913
J. Phys. G: Nucl. Part. Phys. 39 (2012) 075001

*LHeC UK Discussion Meeting* *8 May 2013*

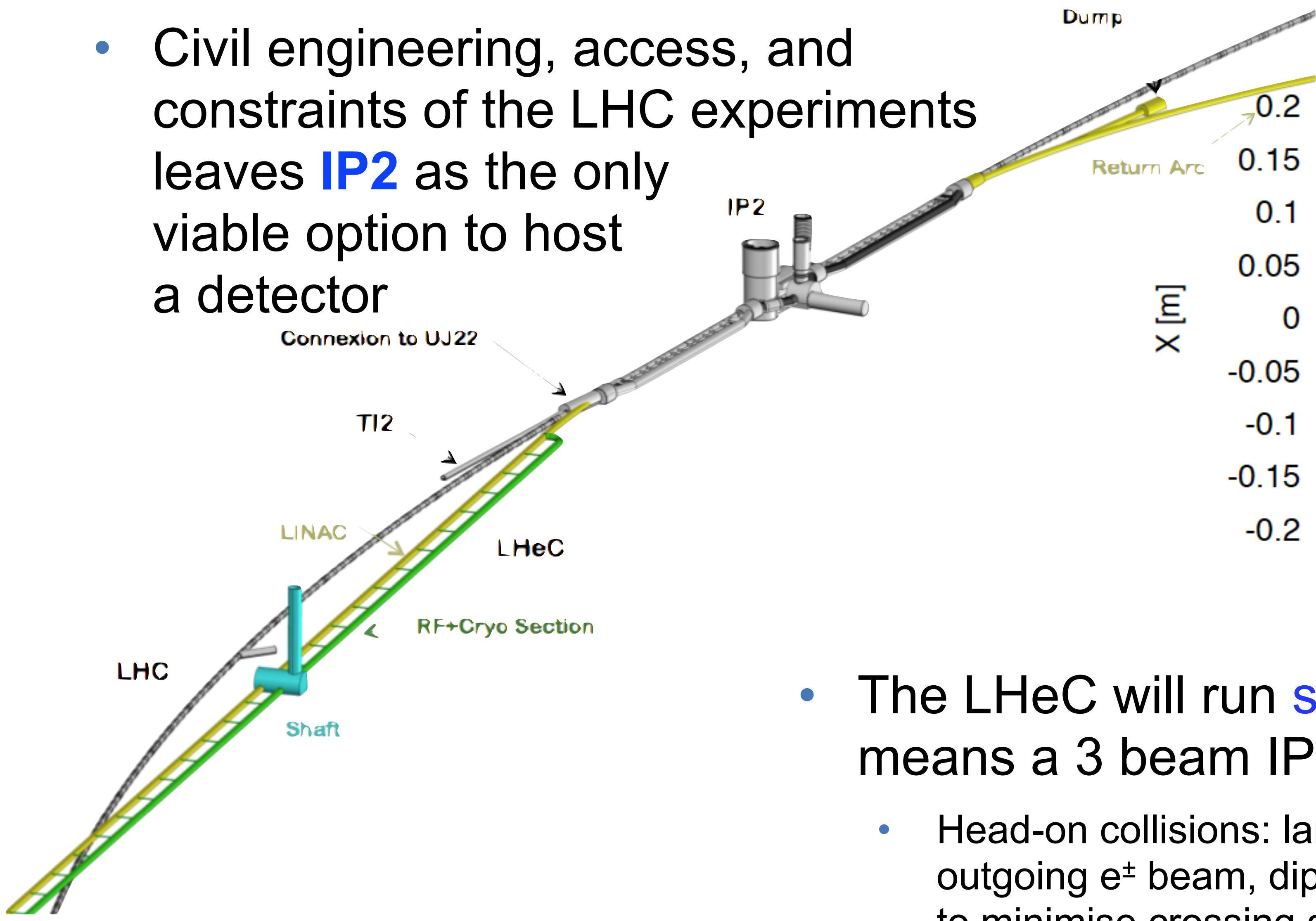
# The LHeC accelerator design

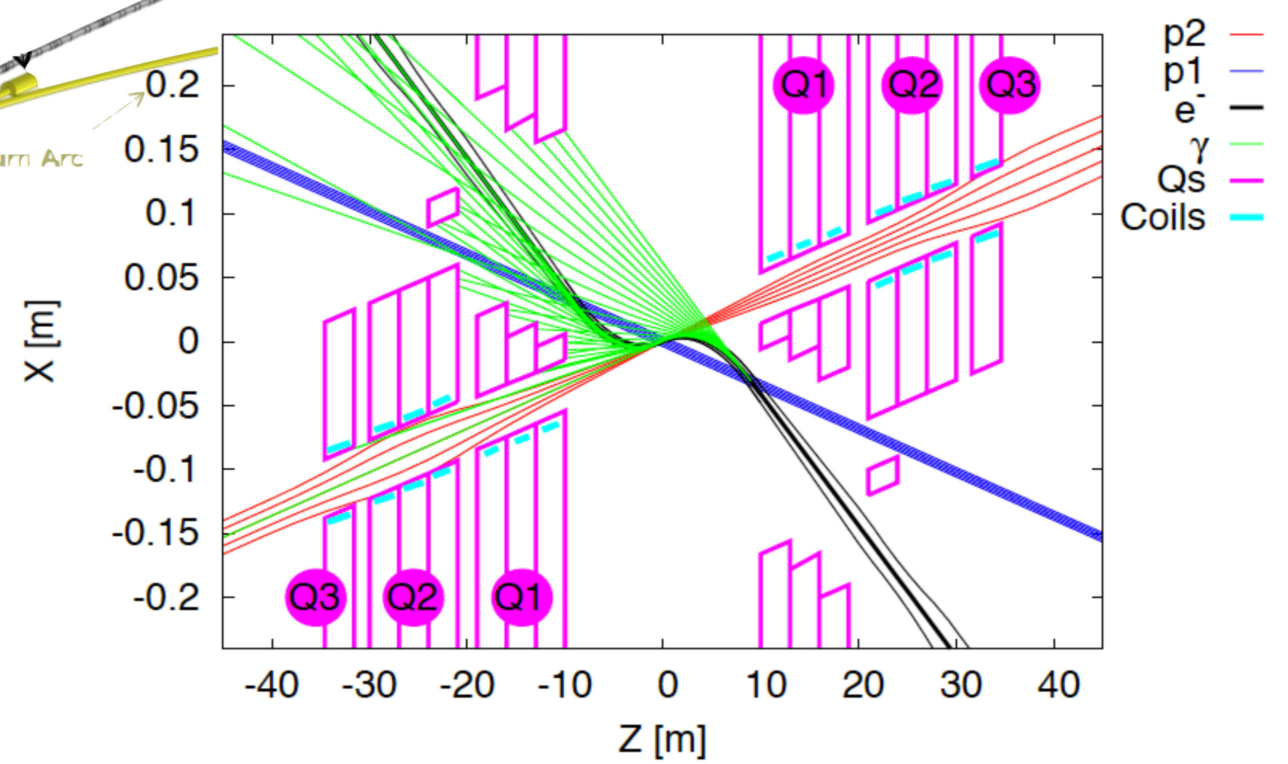
- Linac-Ring design employs two 1km long Linacs, with energy recovery
  - Novel new accelerator design
  - Default option due to reduced impact on the LHC schedule (compared to RR design)
  - Lower luminosity for positron running



# The LHeC detector location and interaction region

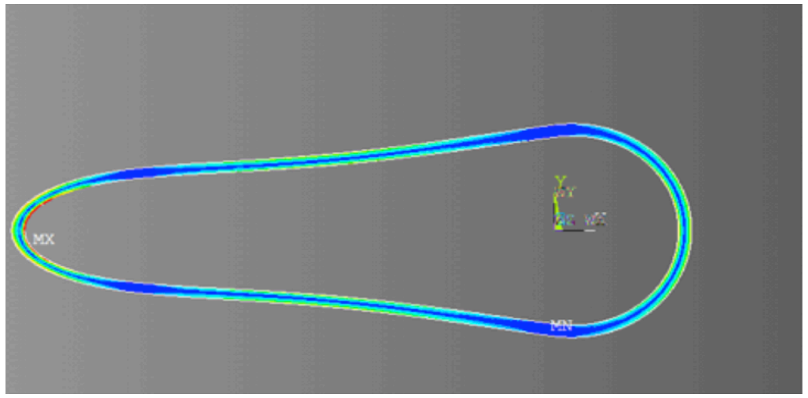
- Civil engineering, access, and constraints of the LHC experiments leaves **IP2** as the only viable option to host a detector




- The LHeC will run simultaneously with the LHC, means a 3 beam IP with compatible optics
  - Head-on collisions: large synchrotron radiation fan from outgoing $e^{\pm}$ beam, dipoles along the whole beam-pipe (±9m*) to minimise crossing angle and to get high luminosity (*ATS will change)

- Elliptical beam-pipe design necessary:
  - Inner dimensions employed: circular(x)=2.2cm, elliptical(-x)=10cm & (y)=2.2cm
  - CDR: 6m length, Beryllium 2.5-3mm thickness(!), composites also investigated



# Key elements to the detector design

- To provide a baseline detector design, which satisfies not only the **physics requirements** but fits the **machine and interaction region** constraints for running during phase 2 of the LHC

- The detector needs to be designed, constructed and **ready for use 12 years from now**, to be able to run concurrently with the other LHC pp and pA experiments, in order to record the respective ep and eA data

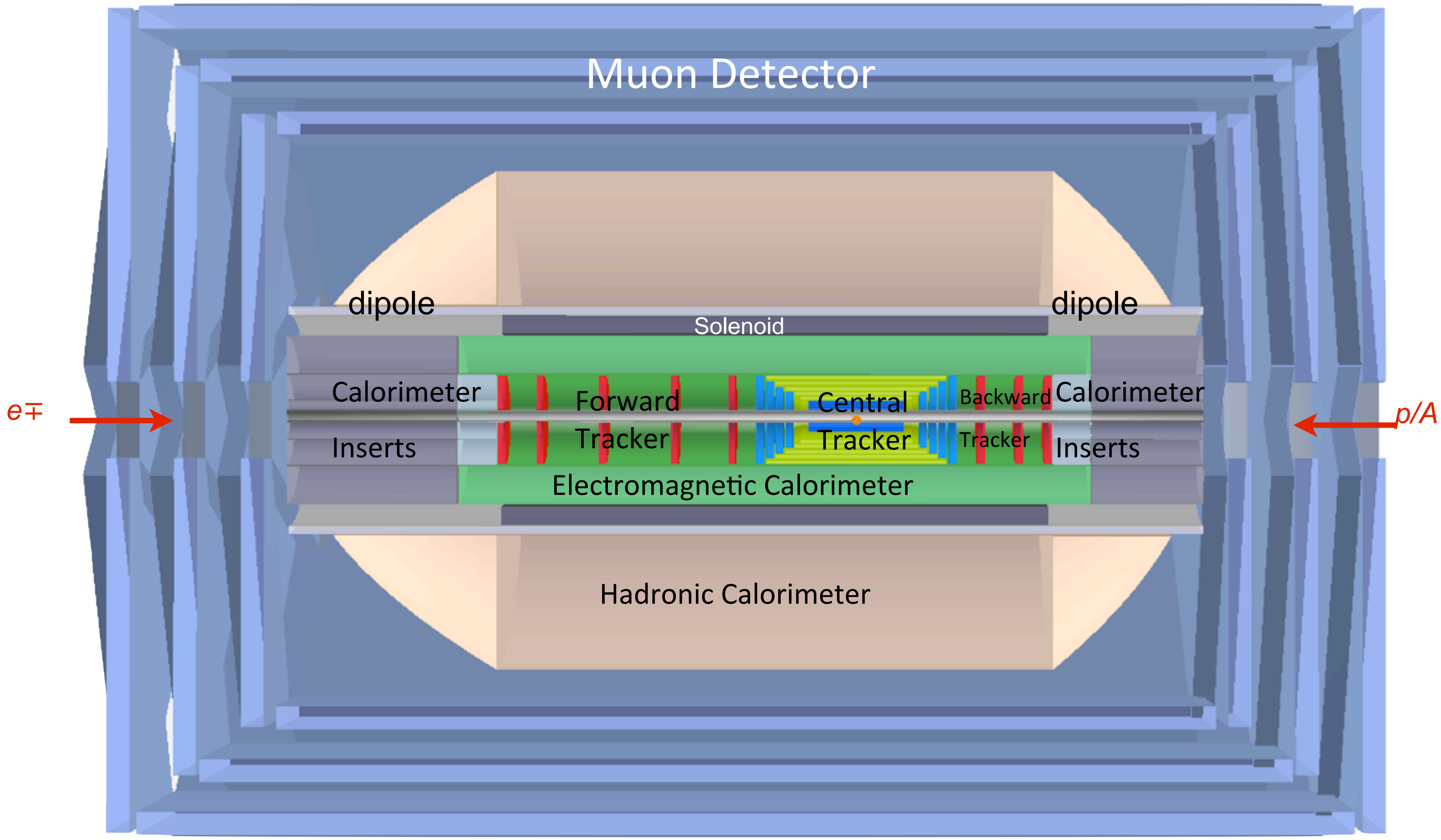
- Such a timescale **prohibits a dedicated, large scale R&D programme**, but the **LHeC detector can profit** from current and upgrade LHC technologies, as well as ILC development, and the HERA experience

- The LHeC detector therefore should be **modular and flexible in design**, with **assembly above ground**, be able to accommodate upgrade programmes and **be affordable**, with a comparatively reasonable cost

# Key detector requirements from the physics programme

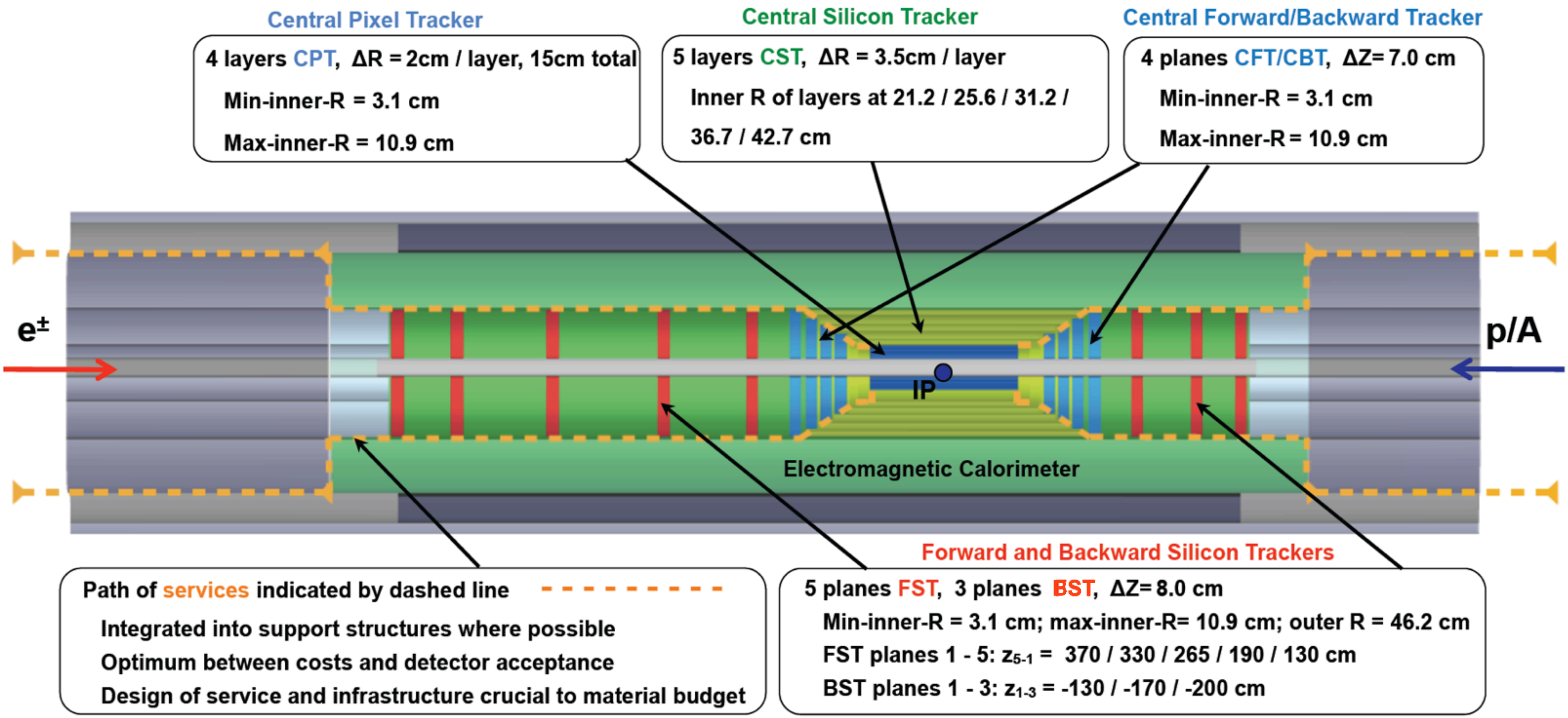
- A high resolution tracking system
  - **Excellent primary vertex resolution** and resolution of **secondary vertices** down to small angles in forward direction for high x heavy flavour physics and searches
  - **Precise $P_T$ measurement** and matching to calorimeter signals, calibrated and aligned to an accuracy of **1 mrad**
- Full coverage calorimetry
  - **Electron energy** measured to 10%/ √ E, calibrated using the kinematic peak and double angle method to the **per-mil level**
  - **Hadronic energy** measured to 40%/√ E, calibrated PT balance to an **accuracy of 1%**
  - Tagging of **backward scattered photons and electrons** for a precise measurement of luminosity and photoproduction physics
  - Tagging of **forward scattered protons, neutrons and deuterons** to fully investigate diffractive and deuteron physics
- A baseline muon system
  - For **tagging and combination with tracking**, no independent momentum measurement

# LHeC detector overview



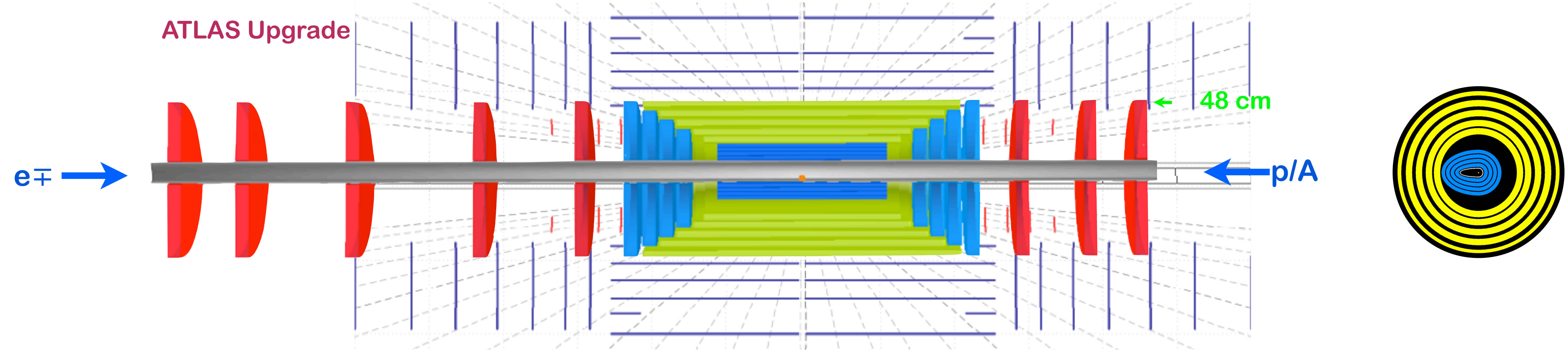

- Forward/backward asymmetry in energy deposited and thus in geometry and technology - 1
- Present dimensions: L x D = 14m x 9m (compared to CMS 21m x 15m , ATLAS 45m x 25 m)
- Not shown: Taggers at -62m (e), -100m (B-H photons), +100m (n) and +420m (p)

# High acceptance tracking design




- Very **compact** design, contained within the electromagnetic calorimeter
- More coverage in the proton direction: dense forward jet production (down to 1$^{o}$ in θ)
- Services and Infrastructure need **very careful design** being the main contributor to Material Budget

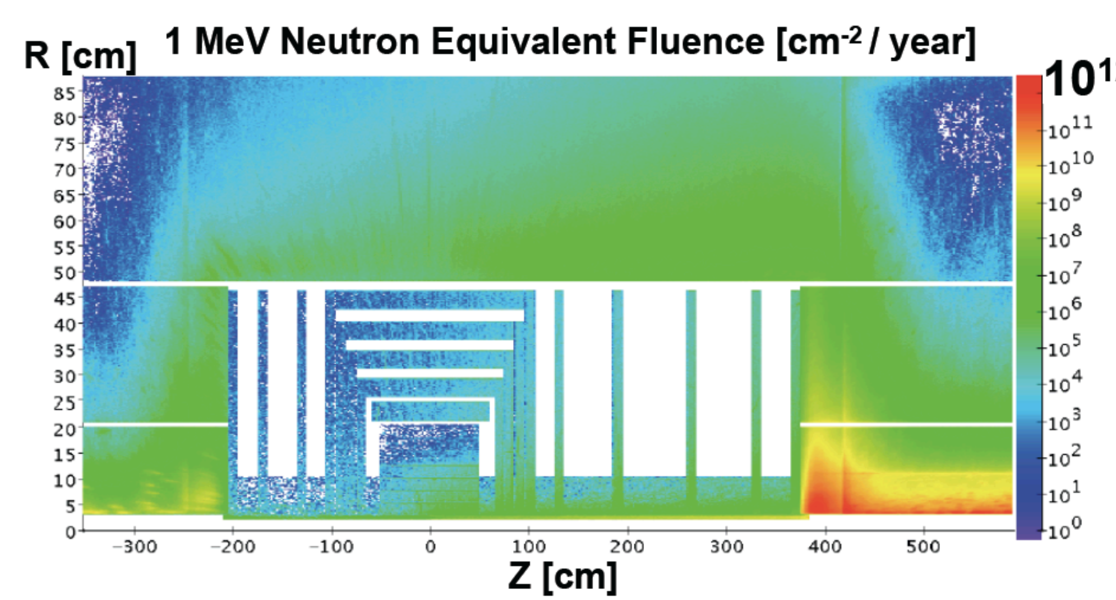
# Tracker technology




- All Silicon design, employing (e.g) Pixel and strip detectors, using available technologies from the LHC experiments
  - Advantages of Silicon: compact design, low budget material, radiation hard

- Radiation hardness in LHeC not as challenging as for the LHC

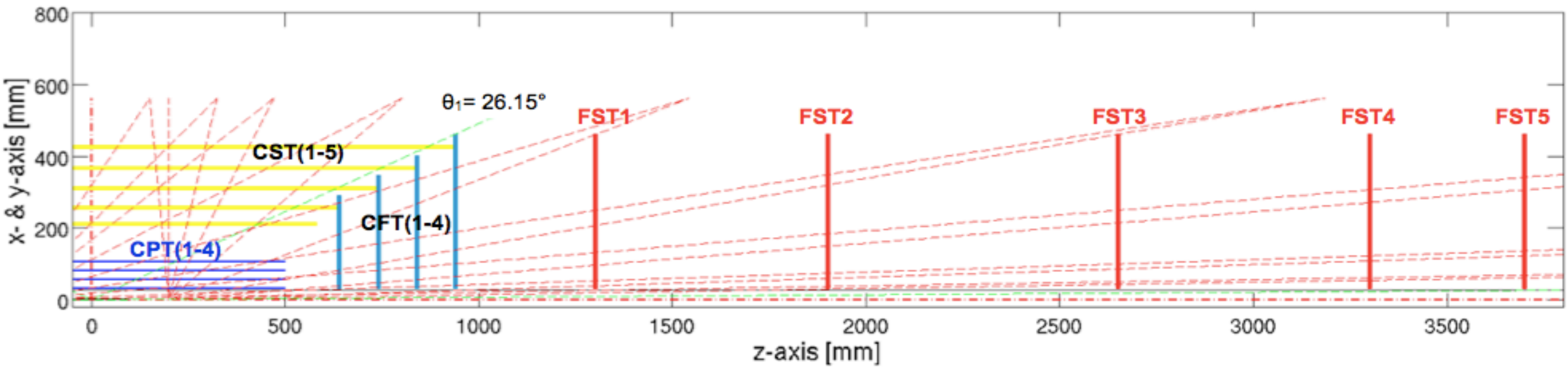
- Study of neutron fluences using GEANT4 and FLUKA show rates far lower than LHC (~ 5 x $10^{14}$) - ongoing

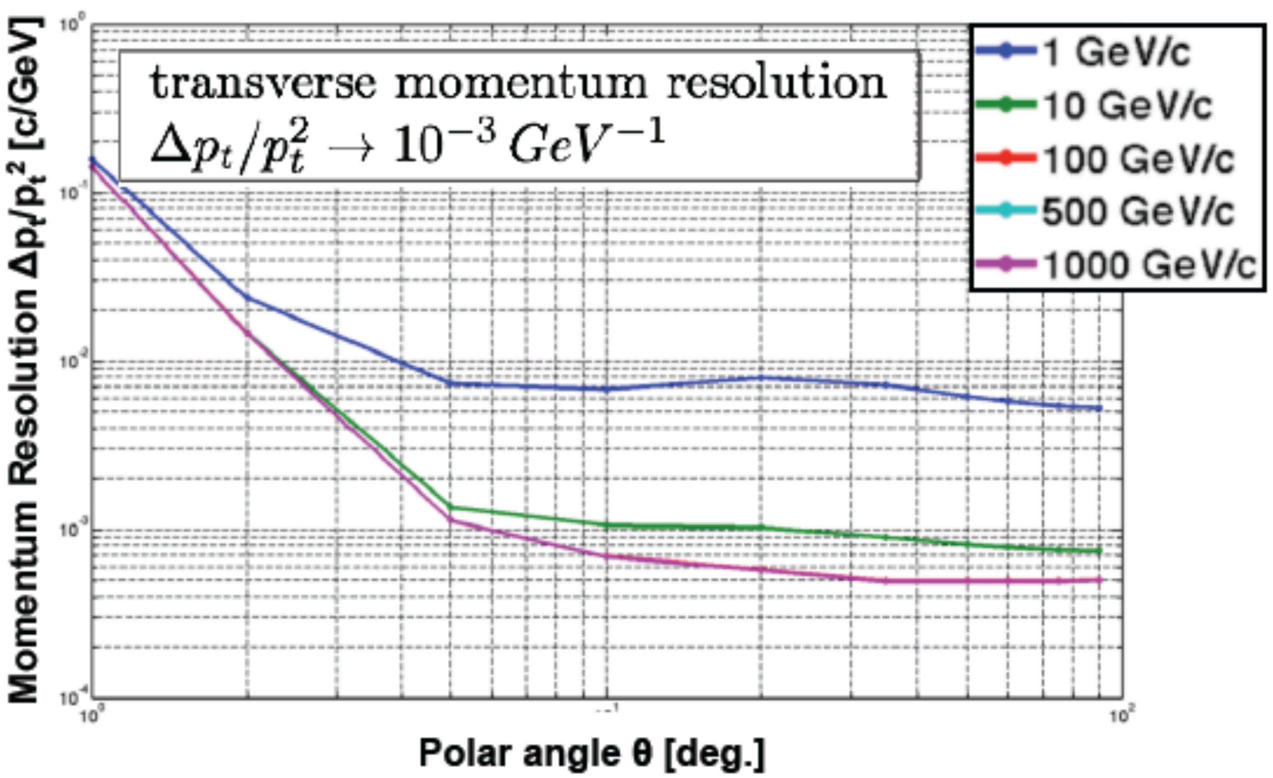


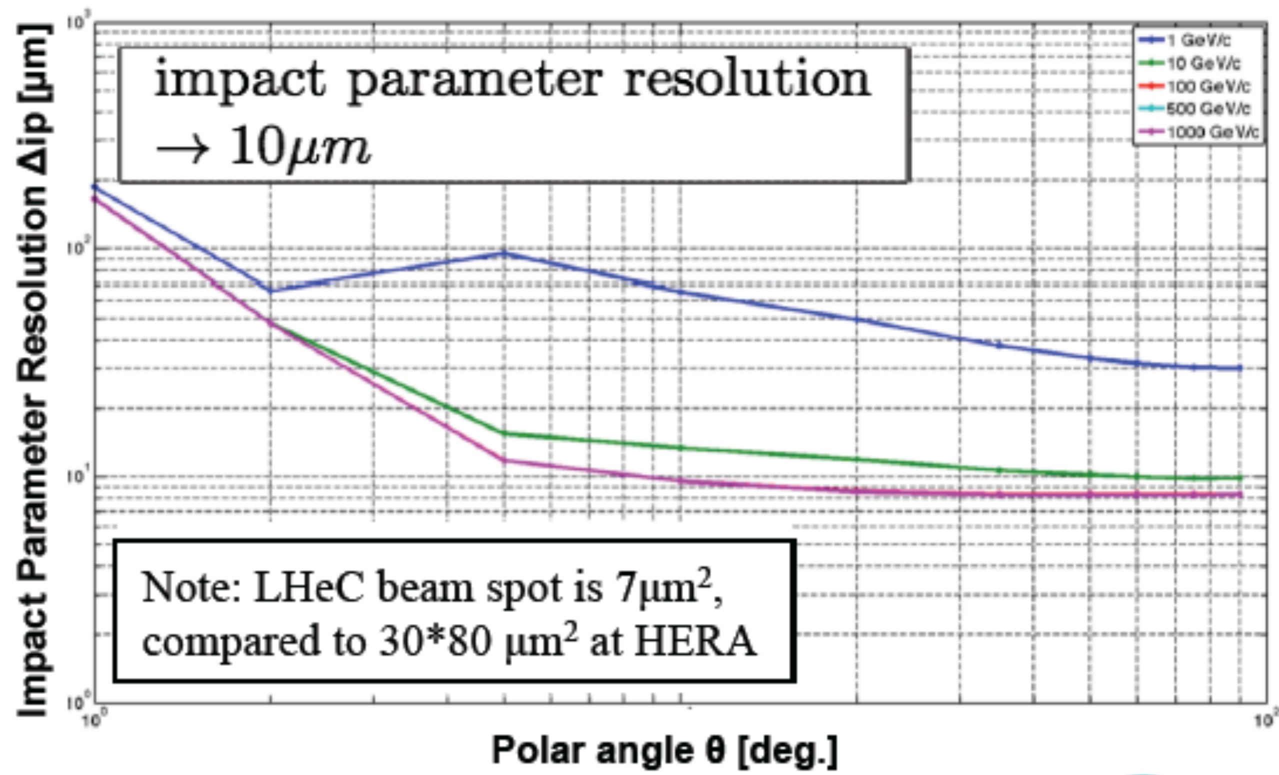
# Tracker simulation

LicToy http://wwwhephy.oeaw.ac.at/p3w/ilc/lictoy/UserGuide_20.pdf

- Studies of tracker design using LicToy2, shown here for the

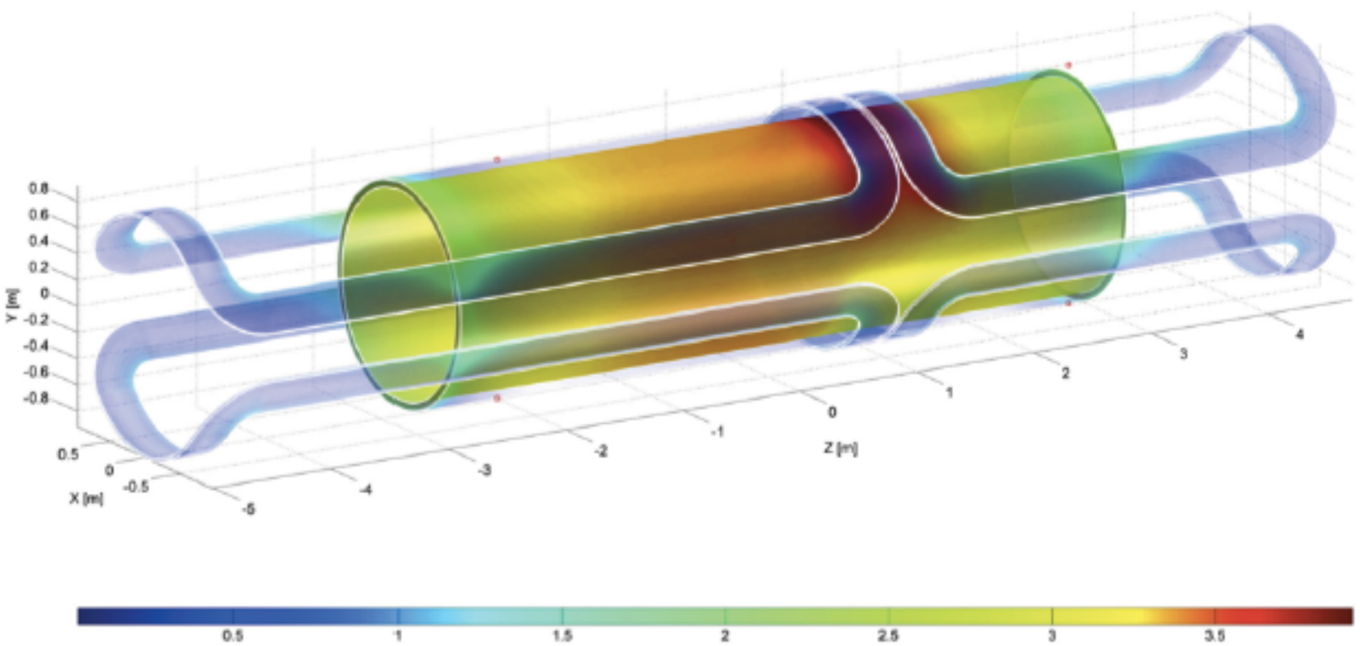


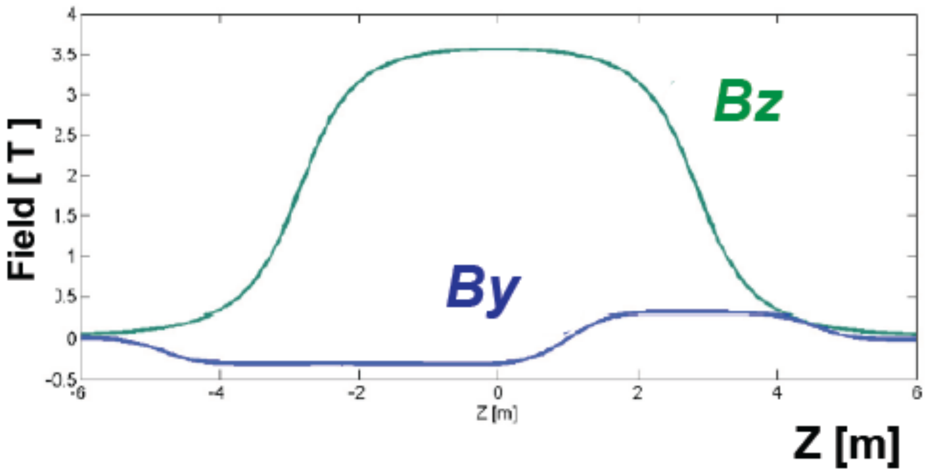



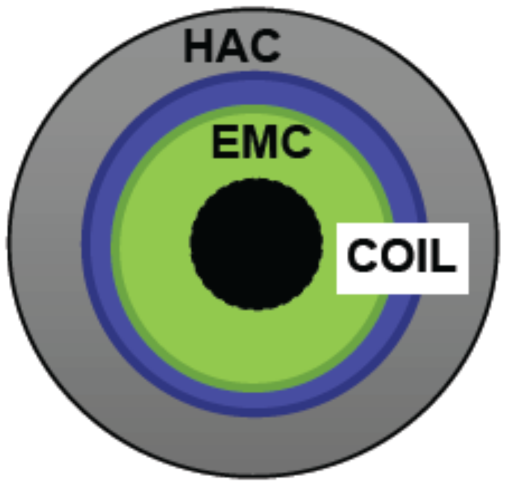
# Detector magnets: solenoid and dipoles

- Both large and small 3.5 T coil options considered, placing either the complete calorimeter or just the EMC part within the solenoid
  - Large coil: 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

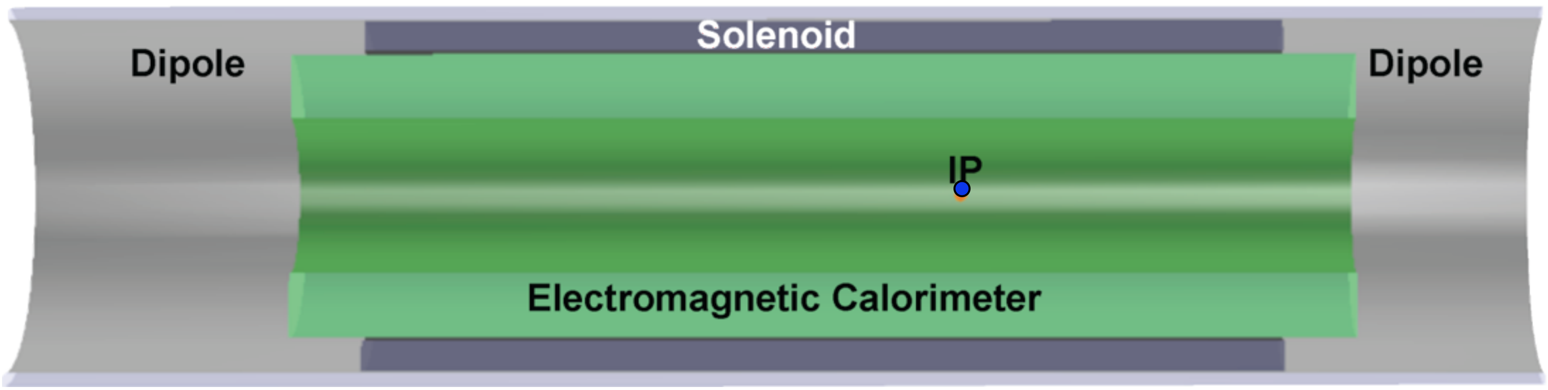


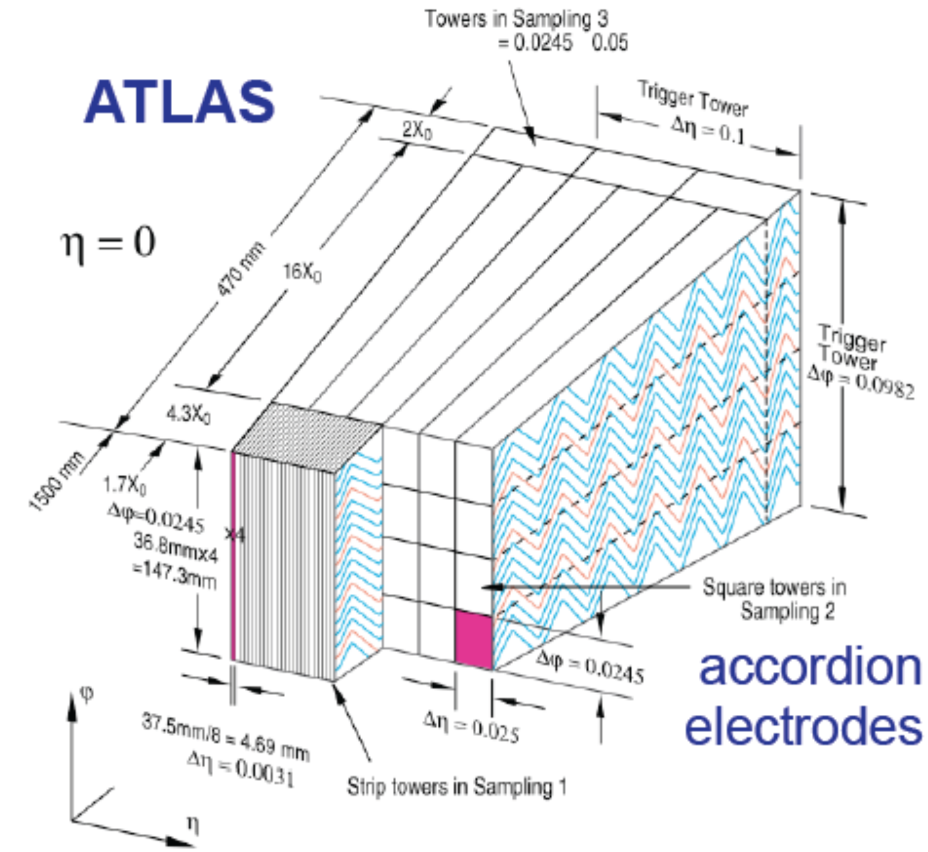



- Baseline design: small coil solenoid + dual dipole
  - Magnets embedded into the EMC LAr cryogenic system
  - Impact of having dead material between EMC and HAC under study

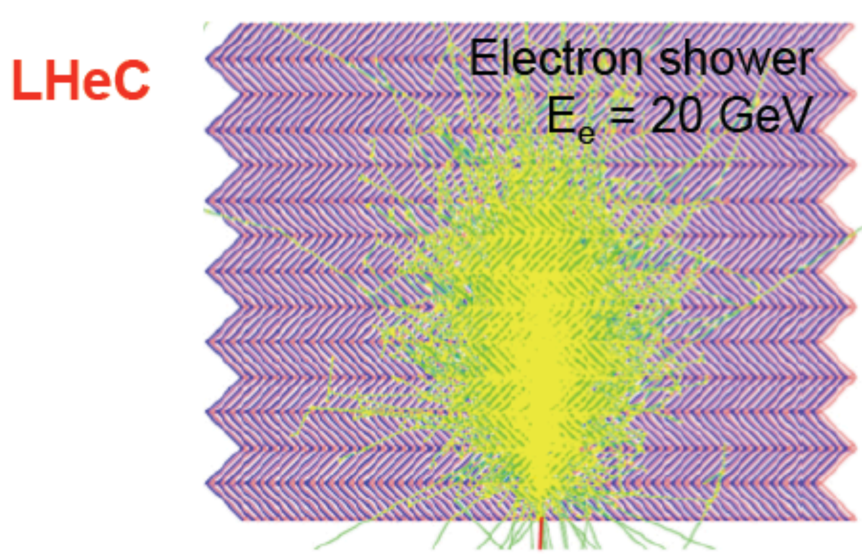


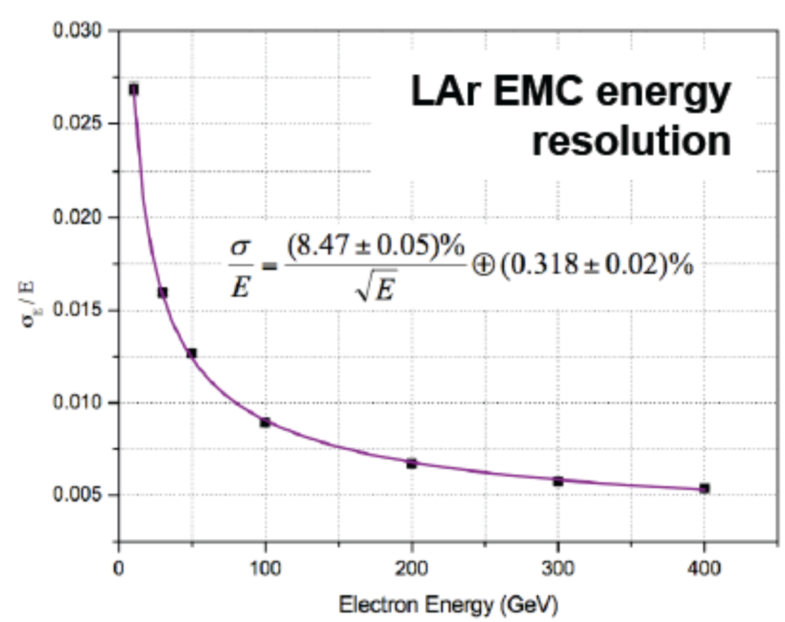
# Electromagnetic calorimeter




- Main EMC, in the barrel region: 2.8 < η < -2.3
  - Based on LAr/Pb design used in ATLAS, ~25-30 X0
  - Employs 3 different granularity sections longitudinally
  - Alternative design using Pb/Scintillator also investigated
- Simulation studies of simplified design with respect to ATLAS
- Warm (Pb/Sci) option also investigated; 30 $X_0$ ($X_0$(Pb)=0.56 cm; 20 layers)



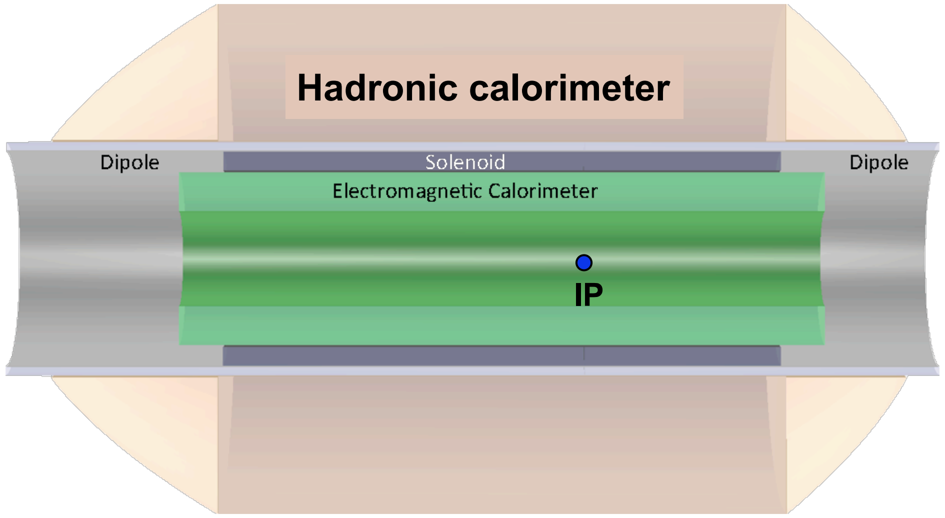

*Calorimeter resolution:*

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

*stochastic term, a*
*constant term, b*

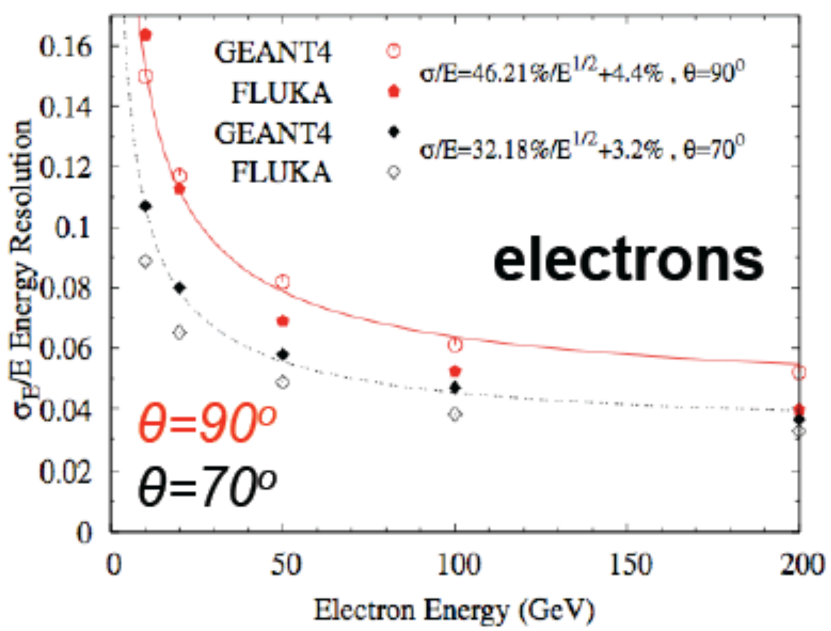
# Hadronic calorimeter

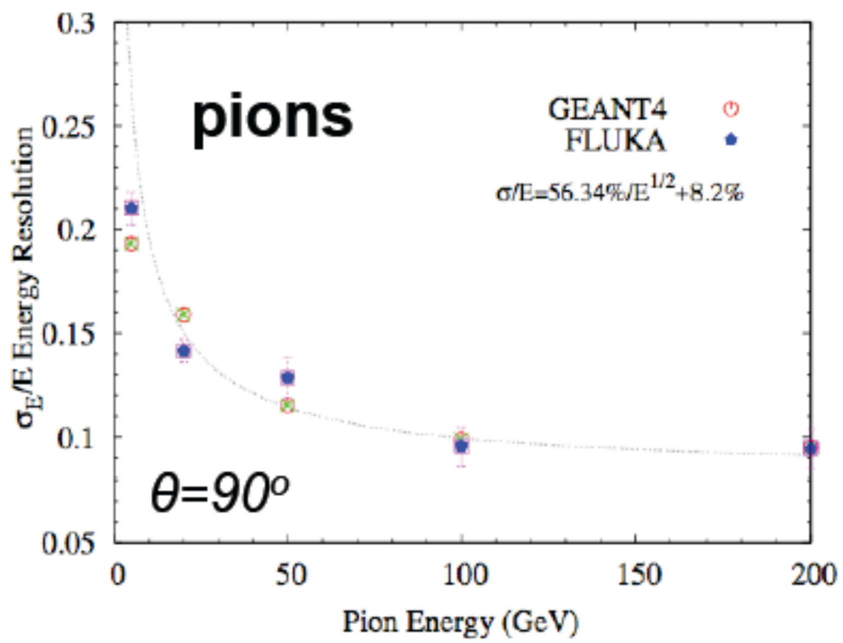
- Baseline design uses steel absorber and scintillator sampling plates
  - Similar to the TILE calorimeter in ATLAS
  - Steel structure provides support for inner detectors and return flux for the solenoid
  - Interaction lengths of ~ 7-9 $\lambda_I$

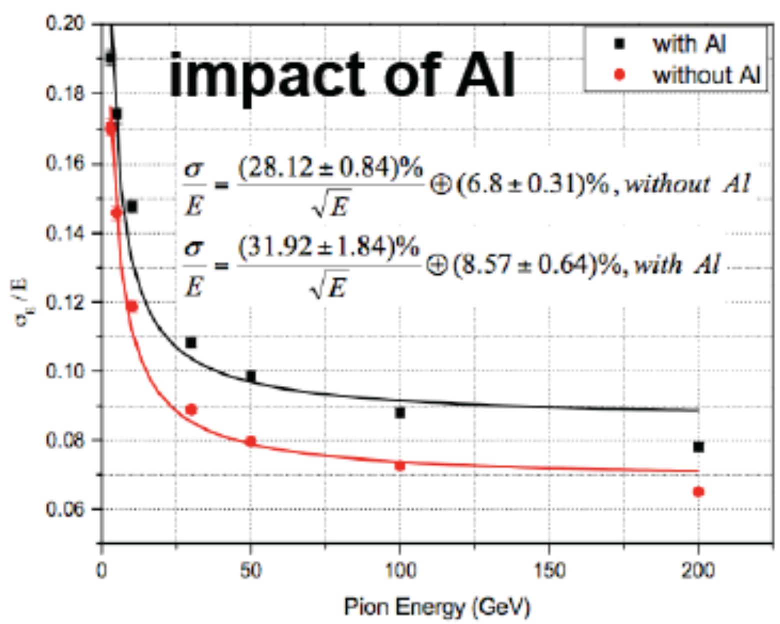



| Tile Rows | Height of Tiles in Radial Direction | Scintillator Thickness |
|---|---|---|
| 1-3 | 97 mm | 3 mm |
| 4-6 | 127 mm | 3 mm |
| 7-11 | 147 mm | 3 mm |

- Many simulation studies performed with GEANT4+FLUKA: details in CDR
  - Performance optimisation: containment, resolution, combined HAC & EMC (Pb/Sci)

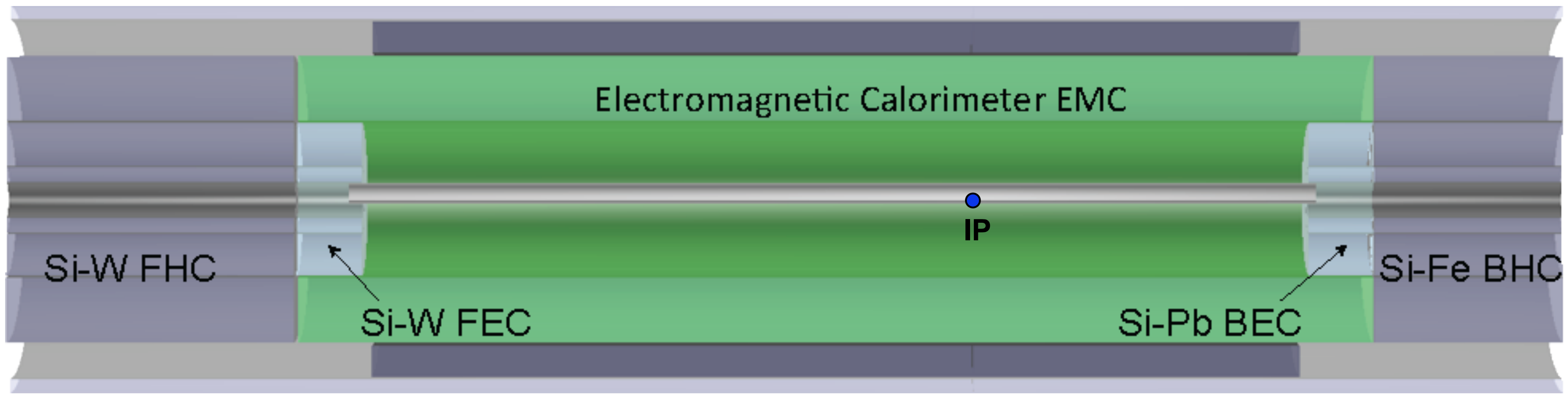


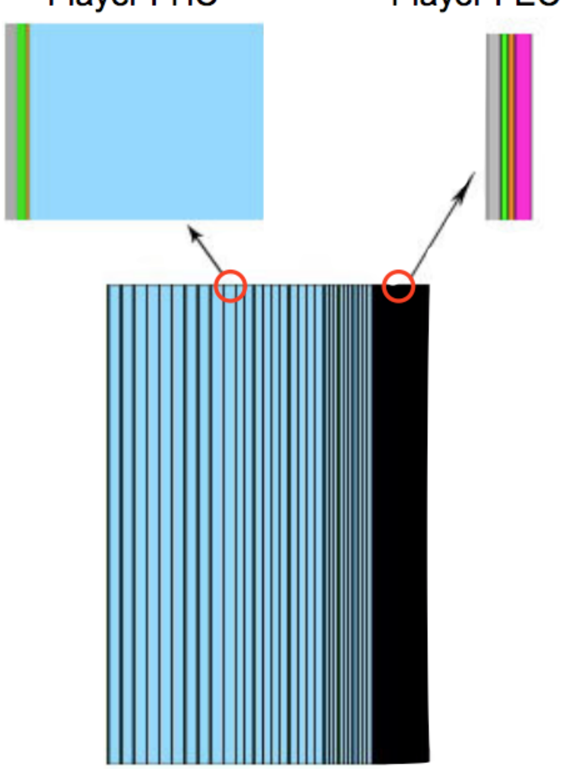
# Forward and backward calorimetry

FEC: ~30 $X_0$
FHC: ~ 8-10 $\lambda_I$




BEC: ~25 $X_0$
BHC: ~ 6-8 $\lambda_I$

- Both electromagnetic and hadronic inserts in forward, backward regions
  - FEC+FHC: High granularity radiation hard Si-W, high jet energy resolution
  - BEC+BHC: Needed for precise e-tagging, Si-Pb (BEC) and Si-Fe/Cu (BHC)



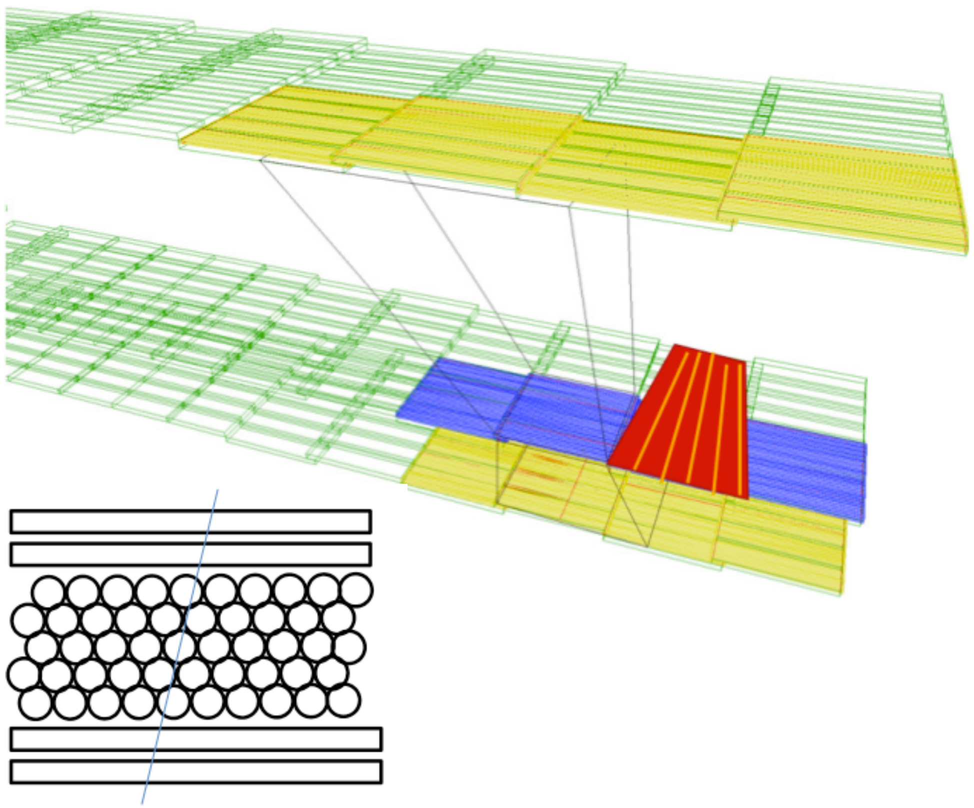

FHC & FEC composite Calorimeter

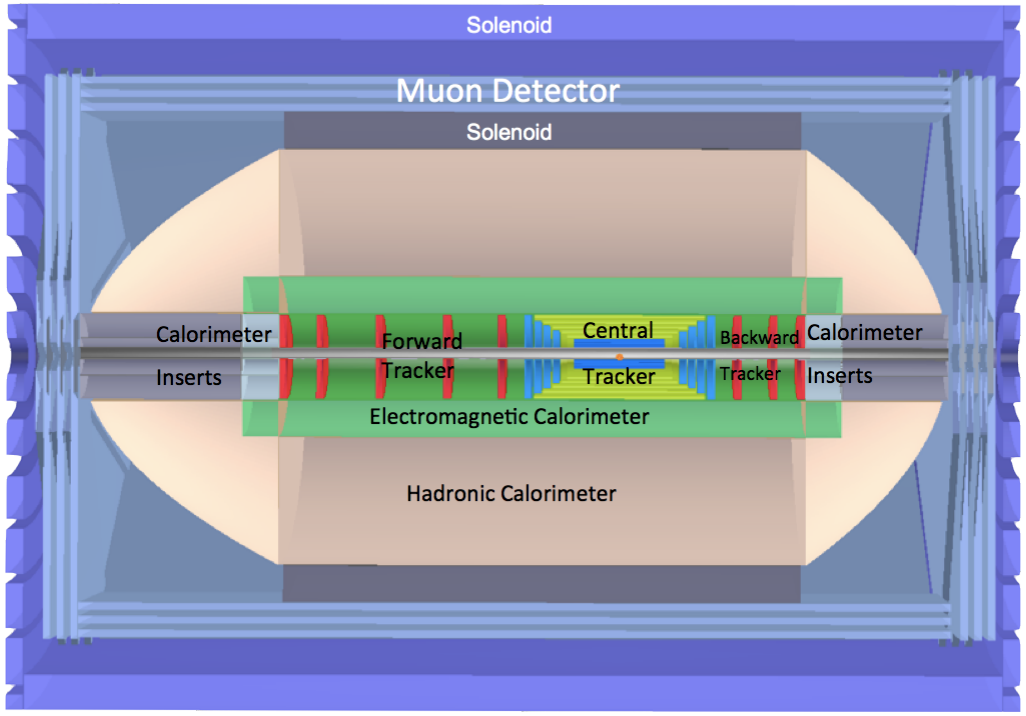
- GEANT4 simulation performed
  - Forward region: Containment and multi-track resolution
  - Backward region: e-tagging and energy measurement

| Calorimeter Module (Composition) | Parameterised 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 | |
| $\mathrm{FEC}_{(\mathbf{W-Si})}$ & $\mathrm{FHC}_{(\mathbf{W-Si})}$ | $\frac{\sigma_E}{E} = \frac{(45.4 \pm 1.7)\%}{\sqrt{E}} \oplus (4.8 \pm 0.086)\%$ |
| $\mathrm{FEC}_{(\mathbf{W-Si})}$ & $\mathrm{FHC}_{(\mathbf{Cu-Si})}$ | $\frac{\sigma_E}{E} = \frac{(46.0 \pm 1.7)\%}{\sqrt{E}} \oplus 6.1 \pm 0.073)\%$ |
| $\mathrm{BEC}_{(\mathbf{Pb-Si})}$ & $\mathrm{BHC}_{(\mathbf{Cu-Si})}$ | $\frac{\sigma_E}{E} = \frac{(21.6 \pm 1.9)\%}{\sqrt{E}} \oplus (9.7 \pm 0.4)\%$ |

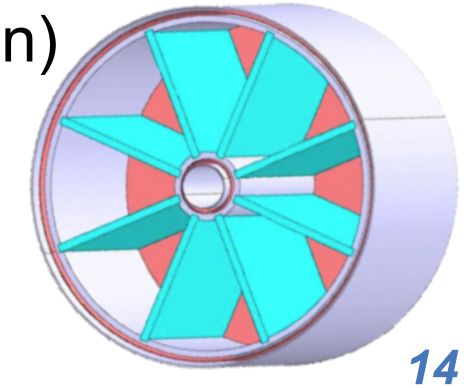
# Muon system

- Muon system with 2-3 super-layers, possible layout: each with double trigger layer and a layer for measurements
  - Baseline design: muon momentum from inner tracker, also in combination with signals from muon system, no independent measurement
  - Use technologies as at LHC (and elsewhere): Thin Gap Chambers, Resistive Plate Chambers, Drift tubes...



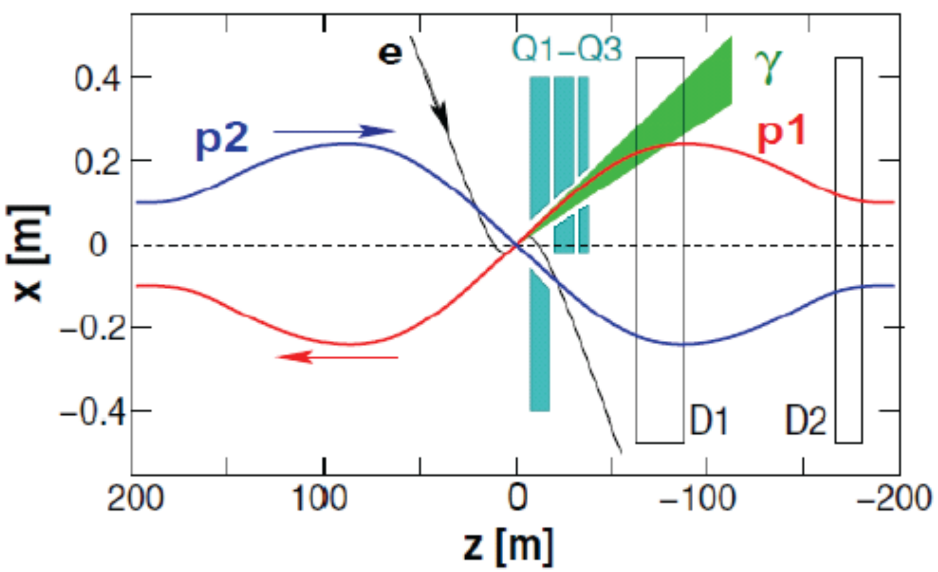


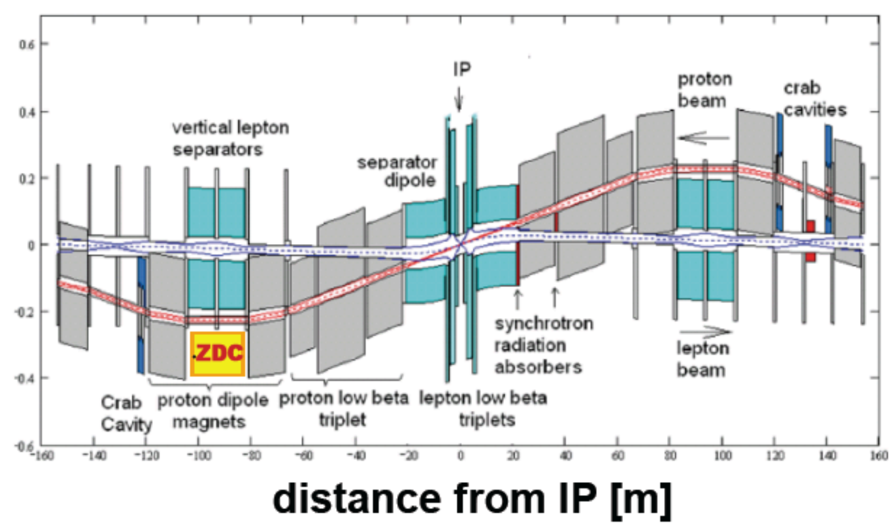

- Several muon system extensions possible, including:
  - Independent momentum measurement
  - Larger solenoid or dual coil system (with all of calorimeter within inner coil)
  - Forward toroid (air core design)

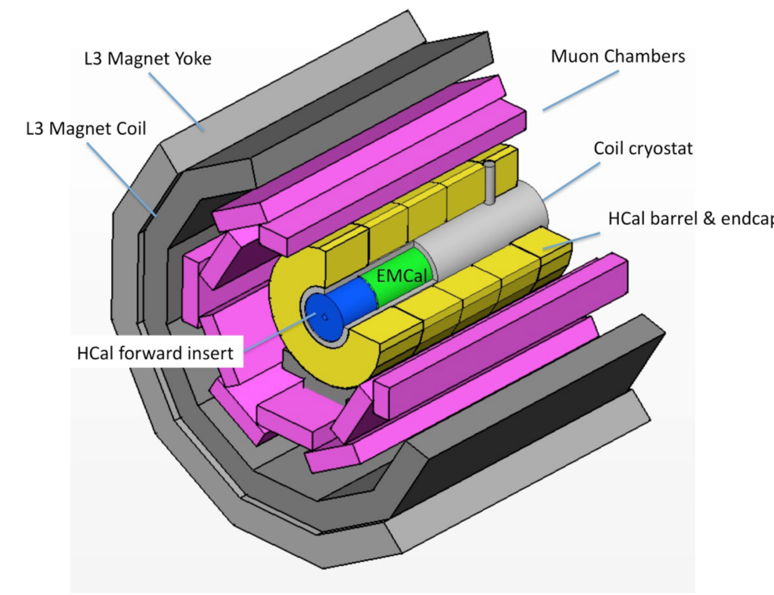


# Forward/Backward detectors // Main detector assembly

- Backward detectors: luminosity measurement and e-tagger
- Forward detectors: proton and neutron detection
- Main detector assembly and integration




- See :

*J. Phys. G39 (2012) 075001, arXiv:1206.2913*

*A.Polini, The Large Hadron electron Collider Detector Design Concept, POETIC 2013, Physics Opportunities at an ElecTron Ion Collider, March 2013, Valparaiso, Chile*

*D.South, The LHeC Detector - A detector design for the Large Hadron-electron Collider at CERN, DIS 2013, April, Marseille, France*

# Status and outlook

- Current Status
  - A LHeC baseline detector concept has been worked out, as described in the CDR *J. Phys. G39 (2012) 075001, arXiv:1206.2913*
  - The design depends heavily on the constraints from the machine and the interaction region and the LHC activities
  - A feasible and affordable concept, fulfilling the physics requirements has been presented
  - With respect to the baseline many improvements may become available; a more precise design will follow from more detailed simulations, engineering and knowledge of machine constraints


- Future Steps
  - Start a new phase in detector design
  - Complete software simulation environment now needed
  - Identify, address critical items, discuss timeline for realisation
  - Build a collaboration, move towards a Technical Design

*Many thanks to Alessandro Polini and David South from whom I reused many slides*

# Software framework

- Status:
  - Interaction region simulation → synchrotron radiation ← GEANT4, IRSYN(MadX)
  - Detector volumes, flux calculation: ROOT → GDML → GEANT4 (→ FLUKA)
  - For interaction region, (developing) beam optics, b-pipe constraints, synchrotron radiation, calorimetry description
  - General detector dedicated tools (LicToy, PGS).
  - Need complete detector simulation (simulation of real detector effects, busy events, pile-up (if any), and so on..)

- On-going:
  - Computer development & evaluate experiences of others
  - TGeo package interfacing GEANT3,4,(5) and FLUKA - backbone
  - Make use of achievements whenever possible
    - Optimise detector granularity, incorporate HL-LHC optics: interaction region design
    - DAQ/Trigger: physics, hardware / software driven decisions depend on the granularity needed,
    - pre-processing, trigger & bandwidth requirements
      - Benchmark channels dictate the required solutions
      - b tagging & maximal acceptance

# Critical items

- LHC HL-Optics has to be defined (ATS) (CERN BE-ABP, Cockcroft Institute)
  - Magnets design → option: longer dipoles (hope: **reduced Synchrotron Radiation** (**SR**)), lower field strength)
- **Beam Pipe design** - low $X_0$, $\lambda_I$ material, stable, capable for $1^0$ tracks, low $p_T$ particle measurement, LHC safety standard (CERN Technology Department ,Vacuum, Surfaces & Coatings Group)
- 3.5T solenoidal field sufficient?
- Simulation of SR and masks / absorber design - **interaction region simulation**
- Detector performance - general / for dedicated channels
  - tracker/trigger resolution ↔ secondary vertices, 3D resolution, background suppression; simulation of selected channel response
  - Matching of tracker and calorimeter resolution for **optimised Particle Flow Correction**
  - forward dense jet production/resolution ↔ detector granularity
  - physics analysis capabilities in detail

- Software framework for **Simulation** / **Reconstruction** / **Analysis**
- **Physics Generators $e^{\mp}p/e^{\mp}A$ sufficient/available?**
- **Dedicated $e^{\mp}A$ simulations!**

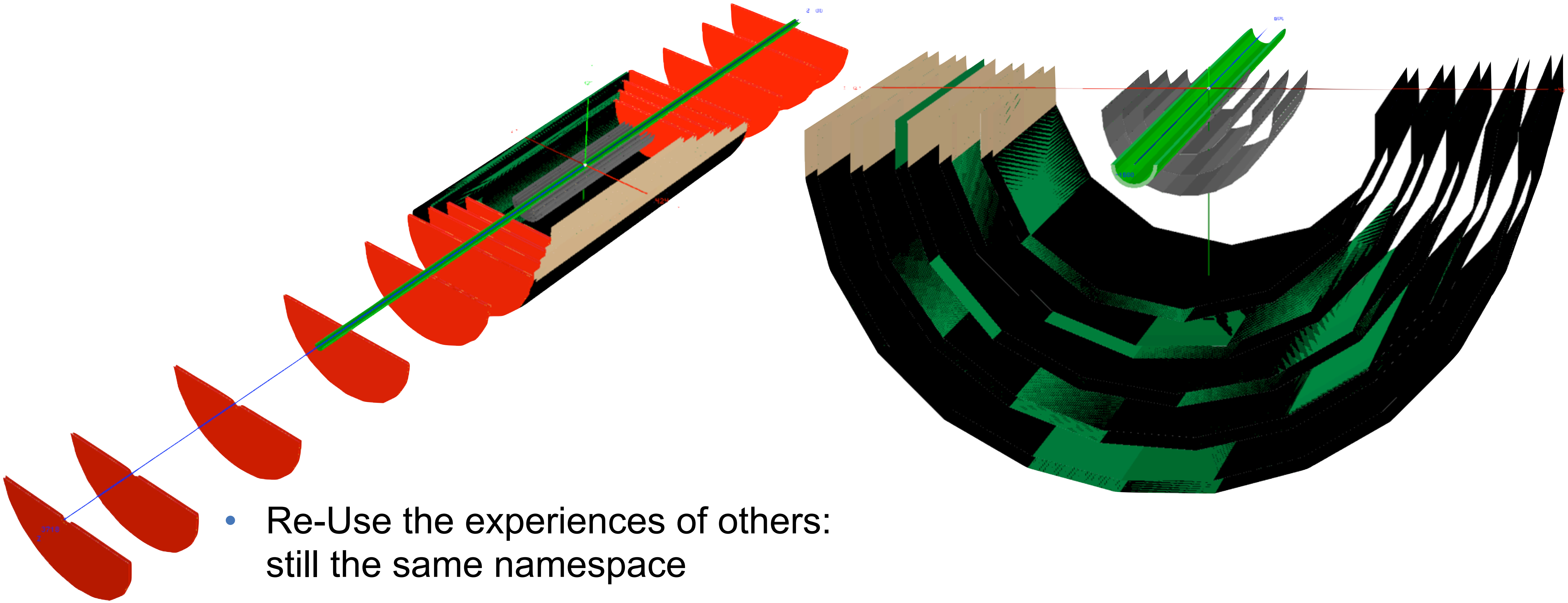
# Detector design/sim/rec - AIDA / DD4Hep

- **Re-Use the experiences/achievements of others**: e.g. →
  **AIDA**: **A**dvanced **I**nfrastructure for **D**etector development for future **A**ccelerators

- Linear Collider Software Meeting, Jan. 2013,
  *http://indico.cern.ch/conferenceDisplay.py?confId=228477*
- Markus Frank, DD4hepTutorial Session,
  *http://indico.cern.ch/getFile.py/access?contribId=0&sessionId=0&resId=0&materialId=slides&confId=228477*
- Markus Frank, DD4hep Simulation Isues,
  *http://indico.cern.ch/getFile.py/access?contribId=0&sessionId=0&resId=0&materialId=slides&confId=228477*
- LC-Software Meeting Closeout
  *http://indico.cern.ch/getFile.py/access?contribId=14&sessionId=2&resId=0&materialId=slides&confId=228477*

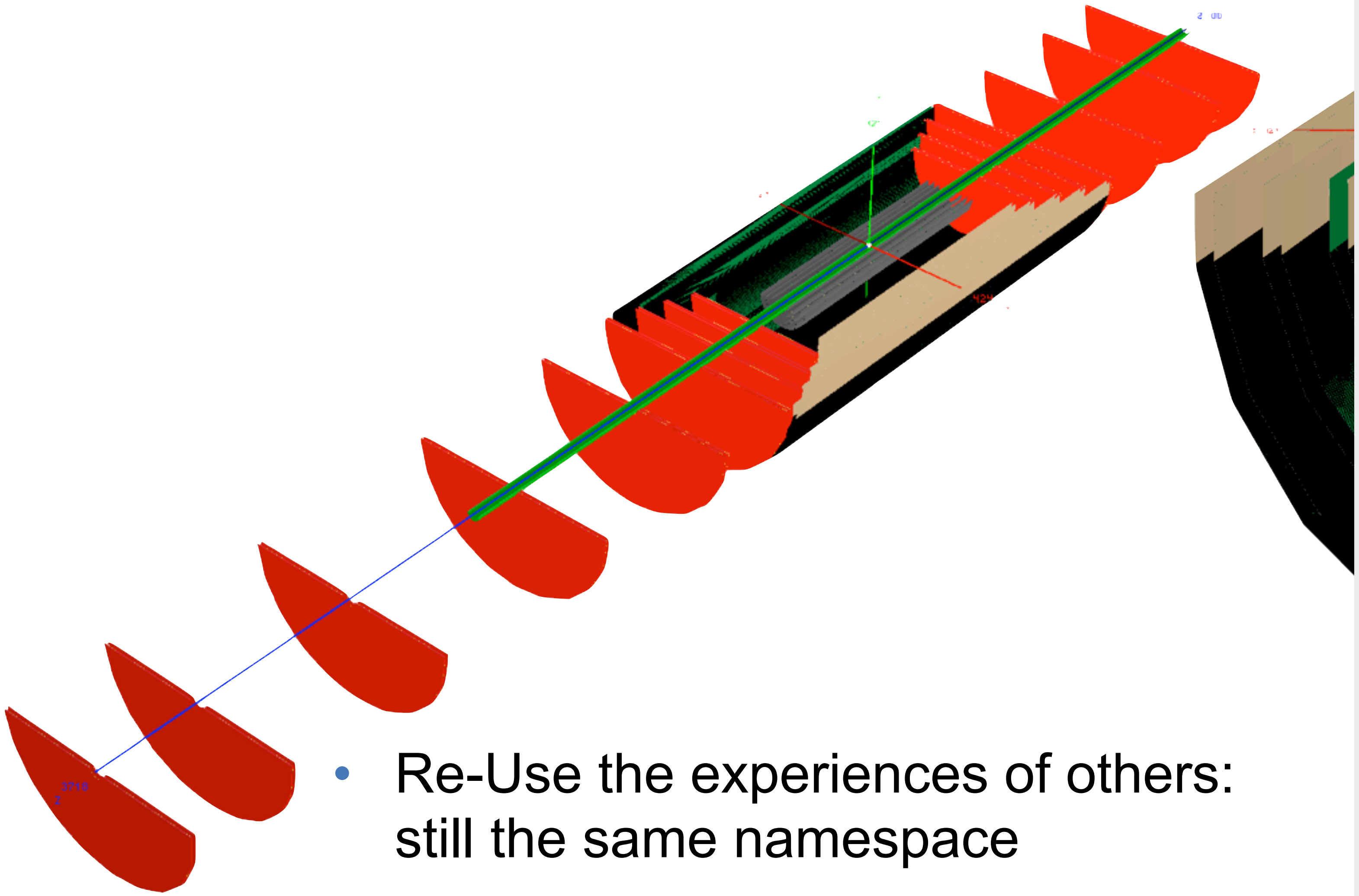
- Fast Detector Simulation in High Energy Physics
  *https://indico.desy.de/conferenceOtherViews.py?view=standard&confId=6681*
- Frank Gaede, ILC Geometry description,
  *https://indico.desy.de/getFile.py/access?contribId=16&sessionId=2&resId=0&materialId=slides&confId=6681*
- Look for further references therein
- **Is AIDA/DD4Hep an option for a LHeC software framework?**
  (No release version of AIDA/DD4Hep available; documentation pending, but code well readable)

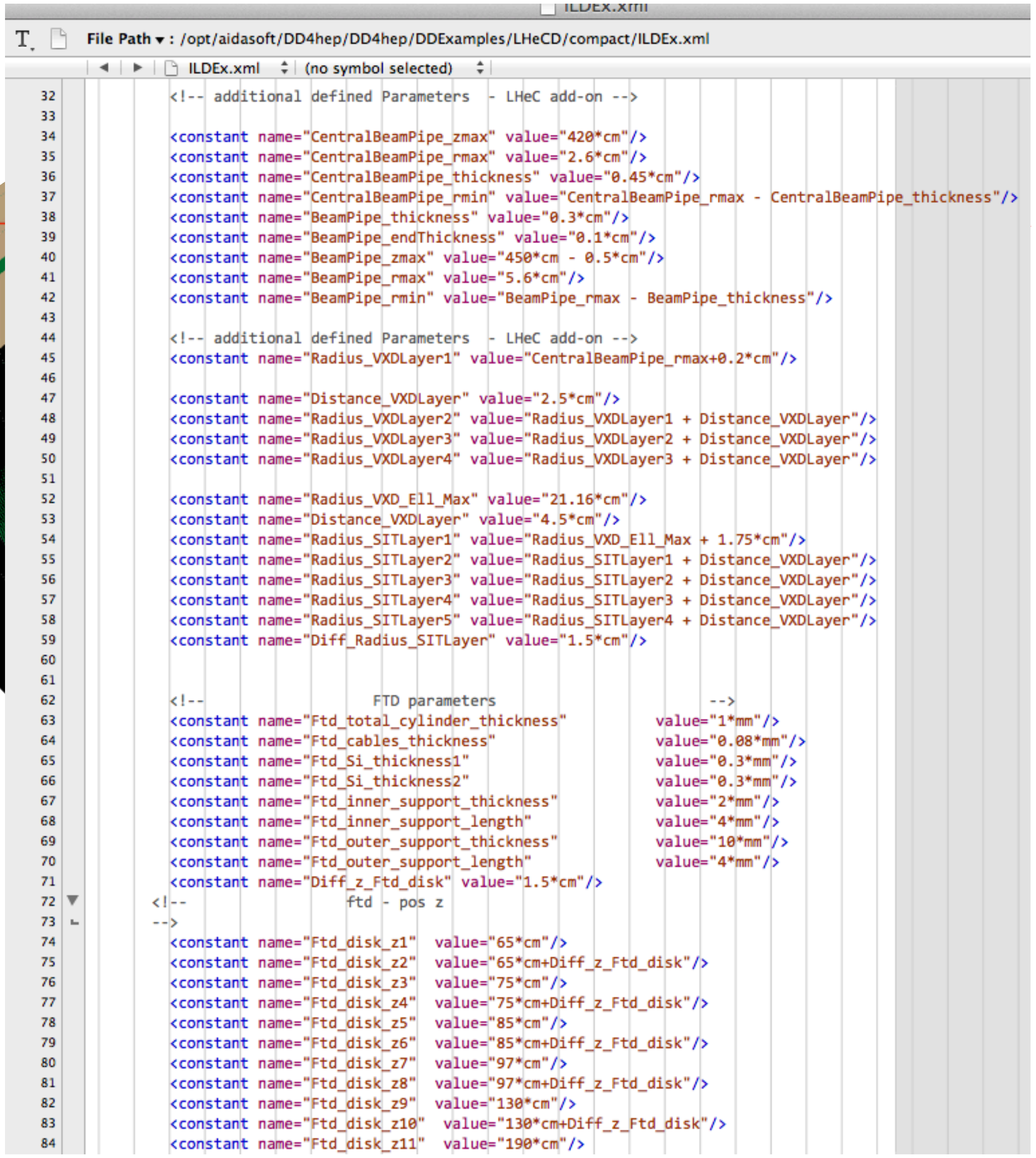
# Detector design/sim/rec - AIDA / DD4Hep



- Re-Use the experiences of others:
  still the same namespace
  - separate namespace (but carefull!)
  - cooperation with developers
- xml detector def. parsed into DD4hep-core; accessible from all modules extensions (sim, alignment, rec, analysis)
- based on TGeo (ROOT), GEANT4
- man power !

# Detector design/sim/rec - AIDA / DD4Hep





ILDEx.xml

File Path ▾ : /opt/aidasoft/DD4hep/DD4hep/DDExamples/LHeCD/compact/ILDEx.xml

ILDEx.xml (no symbol selected)

```xml
<!-- additional defined Parameters  - LHeC add-on -->

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<constant name="CentralBeamPipe_thickness" value="0.45*cm"/>
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<constant name="BeamPipe_zmax" value="450*cm - 0.5*cm"/>
<constant name="BeamPipe_rmax" value="5.6*cm"/>
<constant name="BeamPipe_rmin" value="BeamPipe_rmax - BeamPipe_thickness"/>

<!-- additional defined Parameters  - LHeC add-on -->
<constant name="Radius_VXDLayer1" value="CentralBeamPipe_rmax+0.2*cm"/>

<constant name="Distance_VXDLayer" value="2.5*cm"/>
<constant name="Radius_VXDLayer2" value="Radius_VXDLayer1 + Distance_VXDLayer"/>
<constant name="Radius_VXDLayer3" value="Radius_VXDLayer2 + Distance_VXDLayer"/>
<constant name="Radius_VXDLayer4" value="Radius_VXDLayer3 + Distance_VXDLayer"/>

<constant name="Radius_VXD_Ell_Max" value="21.16*cm"/>
<constant name="Distance_VXDLayer" value="4.5*cm"/>
<constant name="Radius_SITLayer1" value="Radius_VXD_Ell_Max + 1.75*cm"/>
<constant name="Radius_SITLayer2" value="Radius_SITLayer1 + Distance_VXDLayer"/>
<constant name="Radius_SITLayer3" value="Radius_SITLayer2 + Distance_VXDLayer"/>
<constant name="Radius_SITLayer4" value="Radius_SITLayer3 + Distance_VXDLayer"/>
<constant name="Radius_SITLayer5" value="Radius_SITLayer4 + Distance_VXDLayer"/>
<constant name="Diff_Radius_SITLayer" value="1.5*cm"/>


<!--                FTD parameters                  -->
<constant name="Ftd_total_cylinder_thickness"        value="1*mm"/>
<constant name="Ftd_cables_thickness"                value="0.08*mm"/>
<constant name="Ftd_Si_thickness1"                   value="0.3*mm"/>
<constant name="Ftd_Si_thickness2"                   value="0.3*mm"/>
<constant name="Ftd_inner_support_thickness"         value="2*mm"/>
<constant name="Ftd_inner_support_length"            value="4*mm"/>
<constant name="Ftd_outer_support_thickness"         value="10*mm"/>
<constant name="Ftd_outer_support_length"            value="4*mm"/>
<constant name="Diff_z_Ftd_disk" value="1.5*cm"/>
<!--            ftd - pos z
-->
<constant name="Ftd_disk_z1"  value="65*cm"/>
<constant name="Ftd_disk_z2"  value="65*cm+Diff_z_Ftd_disk"/>
<constant name="Ftd_disk_z3"  value="75*cm"/>
<constant name="Ftd_disk_z4"  value="75*cm+Diff_z_Ftd_disk"/>
<constant name="Ftd_disk_z5"  value="85*cm"/>
<constant name="Ftd_disk_z6"  value="85*cm+Diff_z_Ftd_disk"/>
<constant name="Ftd_disk_z7"  value="97*cm"/>
<constant name="Ftd_disk_z8"  value="97*cm+Diff_z_Ftd_disk"/>
<constant name="Ftd_disk_z9"  value="130*cm"/>
<constant name="Ftd_disk_z10"  value="130*cm+Diff_z_Ftd_disk"/>
<constant name="Ftd_disk_z11"  value="190*cm"/>
```
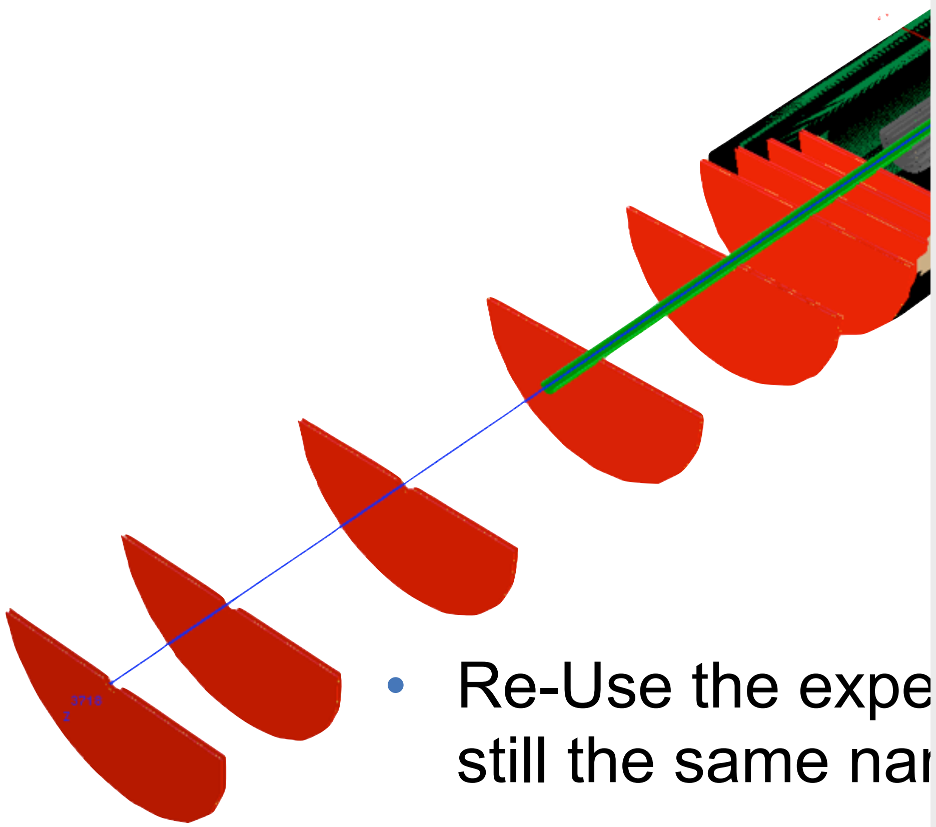

- Re-Use the experiences of others: still the same namespace
  – separate namespace (but carefull!)
  – cooperation with developers
- xml detector def. parsed into DD4hep-core; accessible from all modules extensions (sim, alignment, rec, analysis)
- based on TGeo (ROOT), GEANT4
- man power !

# Detector d

T File Path ▾ : /opt/aidasoft/DD4hep/DD4hep/DDExamples/LHeCD/compact/ILDEx.xml

ILDEx.xml (no symbol selected)

```xml
      <!-- additional defined Parameters  - LHeC add-on -->

      <constant name="CentralBeamPipe_zmax" value="420*cm"/>
      <constant name="CentralBeamPipe_rmax" value="2.6*cm"/>
      <constant name="CentralBeamPipe_thickness" value="0.45*cm"/>
      <constant name="CentralBeamPipe_rmin" value="CentralBeamPipe_rmax - CentralBeamPipe_thickness"/>
      <constant name="BeamPipe_thickness" value="0.3*cm"/>
      <constant name="BeamPipe_endThickness" value="0.1*cm"/>
      <constant name="BeamPipe_zmax" value="450*cm - 0.5*cm"/>
      <constant name="BeamPipe_rmax" value="5.6*cm"/>
      <constant name="BeamPipe_rmin" value="BeamPipe_rmax - BeamPipe_thickness"/>

      <!-- additional defined Parameters  - LHeC add-on -->
      <constant name="Radius_VXDLayer1" value="CentralBeamPipe_rmax+0.2*cm"/>

      <constant name="Distance_VXDLayer" value="2.5*cm"/>
      <constant name="Radius_VXDLayer2" value="Radius_VXDLayer1 + Distance_VXDLayer"/>
      <constant name="Radius_VXDLayer3" value="Radius_VXDLayer2 + Distance_VXDLayer"/>
      <constant name="Radius_VXDLayer4" value="Radius_VXDLayer3 + Distance_VXDLayer"/>

      <constant name="Radius_VXD_Ell_Max" value="21.16*cm"/>
      <constant name="Distance_VXDLayer" value="4.5*cm"/>
      <constant name="Radius_SITLayer1" value="Radius_VXD_Ell_Max + 1.75*cm"/>
      <constant name="Radius_SITLayer2" value="Radius_SITLayer1 + Distance_VXDLayer"/>
      <constant name="Radius_SITLayer3" value="Radius_SITLayer2 + Distance_VXDLayer"/>
      <constant name="Radius_SITLayer4" value="Radius_SITLayer3 + Distance_VXDLayer"/>
      <constant name="Radius_SITLayer5" value="Radius_SITLayer4 + Distance_VXDLayer"/>
      <constant name="Diff_Radius_SITLayer" value="1.5*cm"/>


      <!--                   FTD parameters                    -->
      <constant name="Ftd_total_cylinder_thickness"          value="1*mm"/>
      <constant name="Ftd_cables_thickness"                  value="0.08*mm"/>
      <constant name="Ftd_Si_thickness1"                     value="0.3*mm"/>
      <constant name="Ftd_Si_thickness2"                     value="0.3*mm"/>
      <constant name="Ftd_inner_support_thickness"           value="2*mm"/>
      <constant name="Ftd_inner_support_length"              value="4*mm"/>
      <constant name="Ftd_outer_support_thickness"           value="10*mm"/>
      <constant name="Ftd_outer_support_length"              value="4*mm"/>
      <constant name="Diff_z_Ftd_disk" value="1.5*cm"/>
    <!--                 ftd - pos z
    -->
      <constant name="Ftd_disk_z1"  value="65*cm"/>
      <constant name="Ftd_disk_z2"  value="65*cm+Diff_z_Ftd_disk"/>
      <constant name="Ftd_disk_z3"  value="75*cm"/>
      <constant name="Ftd_disk_z4"  value="75*cm+Diff_z_Ftd_disk"/>
      <constant name="Ftd_disk_z5"  value="85*cm"/>
      <constant name="Ftd_disk_z6"  value="85*cm+Diff_z_Ftd_disk"/>
      <constant name="Ftd_disk_z7"  value="97*cm"/>
      <constant name="Ftd_disk_z8"  value="97*cm+Diff_z_Ftd_disk"/>
      <constant name="Ftd_disk_z9"  value="130*cm"/>
      <constant name="Ftd_disk_z10"  value="130*cm+Diff_z_Ftd_disk"/>
      <constant name="Ftd_disk_z11"  value="190*cm"/>
```



- Re-Use the expe
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- xml detector def.
  modules extensi
- based on TGeo (
- man power !

# Dete

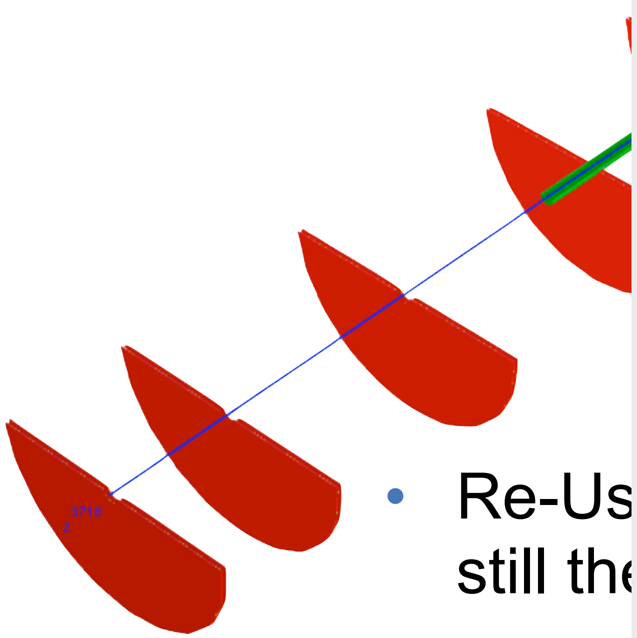
File Path ▾ : /opt/aidasoft/DD4hep/DD4hep/DDExamples/LHeCD/compact/ILDEx.xml

ILDEx.xml (no symbol selected)

```
    <!--          ftd01 parameters   -->
    <detector id="4"  name="FTD"  type="Tesla_ftd01"  readout="FTDHits">
      <cylinder thickness="Ftd_total_cylinder_thickness"
                material="Kapton"
                vis="FtdCylinderVis"/>

      <cables   thickness="Ftd_cables_thickness"
                material="Copper"
                vis="FtdCablesVis"/>
      <support material="Kapton"
               vis="FtdSupportVis">
        <inner thickness="Ftd_inner_support_thickness"  length="Ftd_inner_support_length"/>
        <outer thickness="Ftd_outer_support_thickness"  length="Ftd_outer_support_length"/>
      </support>
      <disks   si_thickness1="Ftd_Si_thickness1"
               si_thickness2="Ftd_Si_thickness2"
               material="silicon_2.33gccm">
   <!--              ftd - pos z
   -->
        <disk id="1" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer2+Diff_Radius_SITLayer" z="Ftd_disk_z1"
        vis="FtdDiskVis"/>
        <disk id="2" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer2+Diff_Radius_SITLayer" z="Ftd_disk_z2"
        vis="FtdDiskVis"/>
        <disk id="3" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer3+Diff_Radius_SITLayer" z="Ftd_disk_z3"
        vis="FtdDiskVis"/>
        <disk id="4" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer3+Diff_Radius_SITLayer" z="Ftd_disk_z4"
        vis="FtdDiskVis"/>
        <disk id="5" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer4+Diff_Radius_SITLayer" z="Ftd_disk_z5"
        vis="FtdDiskVis"/>
        <disk id="6" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer4+Diff_Radius_SITLayer" z="Ftd_disk_z6"
        vis="FtdDiskVis"/>
        <disk id="7" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z7"
        vis="FtdDiskVis"/>
        <disk id="8" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z8"
        vis="FtdDiskVis"/>
        <disk id="9" inner_r="Radius_VXDLayer1"   outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z9"
        vis="FtdDiskVis"/>
        <disk id="10" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z10"
        vis="FtdDiskVis"/>
        <disk id="11" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z11"
        vis="FtdDiskVis"/>
        <disk id="12" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z12"
        vis="FtdDiskVis"/>
        <disk id="13" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z13"
        vis="FtdDiskVis"/>
        <disk id="14" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z14"
        vis="FtdDiskVis"/>
        <disk id="15" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z15"
        vis="FtdDiskVis"/>
        <disk id="16" inner_r="Radius_VXDLayer1"  outer_r="Radius_SITLayer5+Diff_Radius_SITLayer" z="Ftd_disk_z16"
        vis="FtdDiskVis"/>
```

## FST/BST Si-wheel properties -
## active & passive material
## geometry
## detector position



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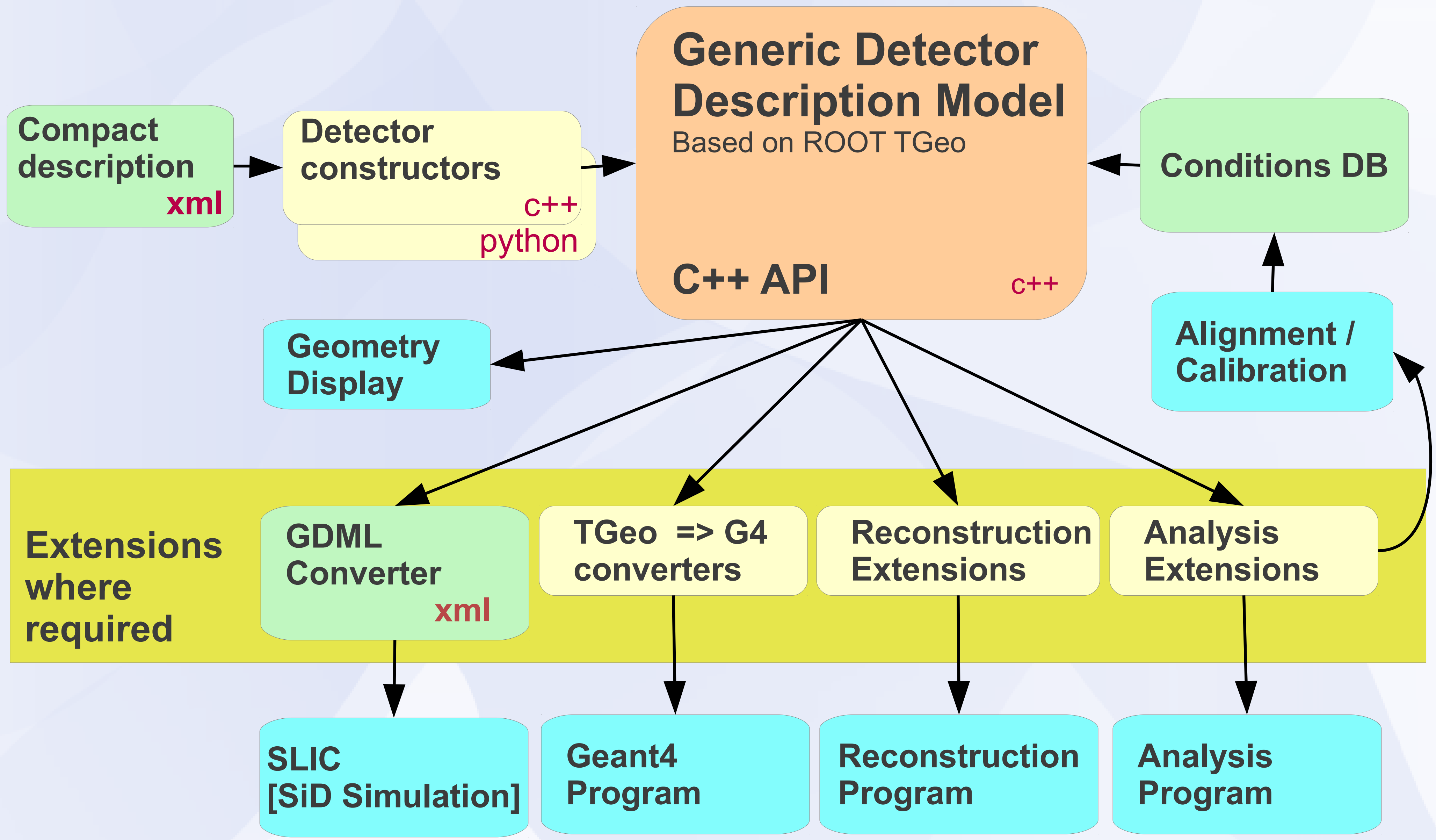
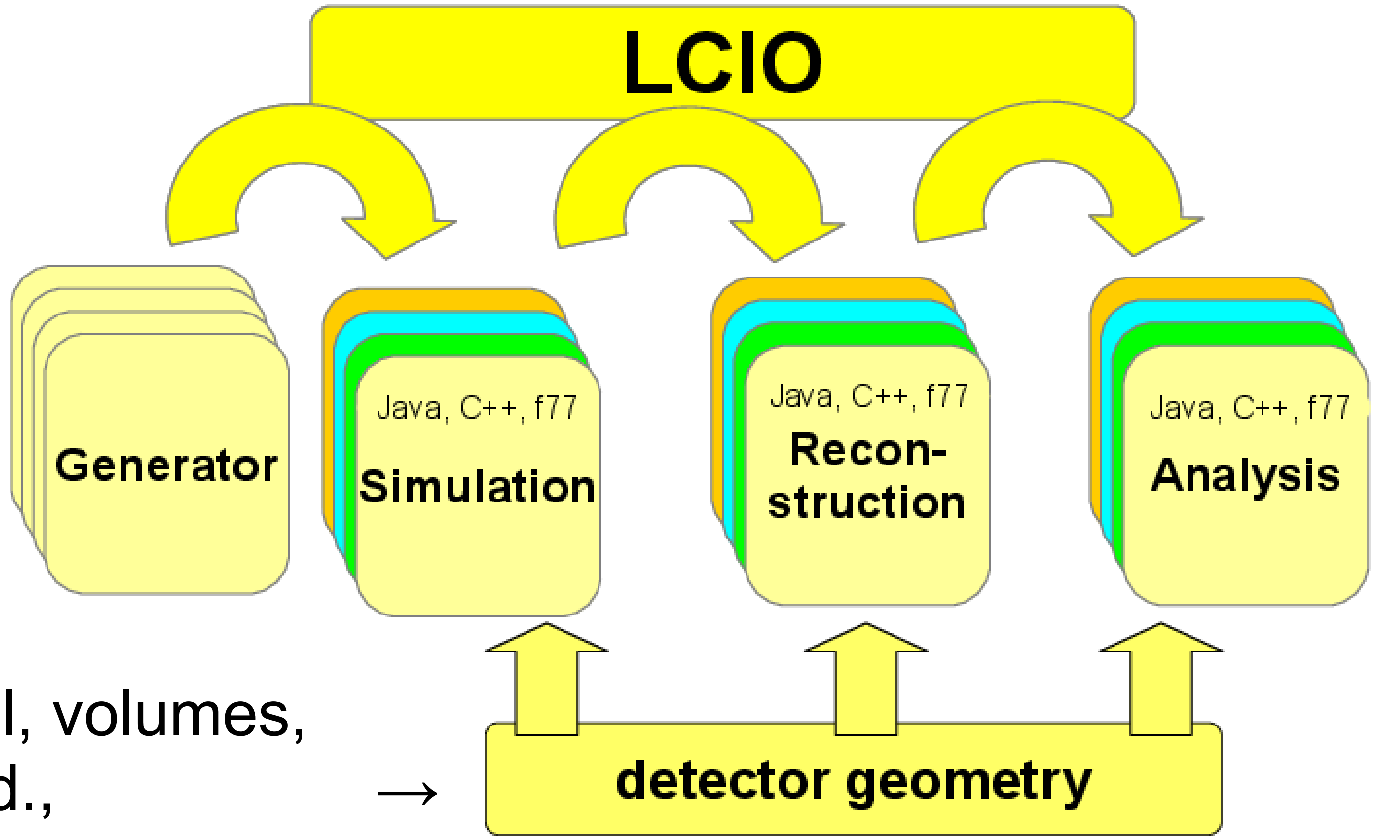
# DD4Hep - The Big Picture



## Common Software tools for Linear collider




**DD4Hep:** detector descr. - xml, volumes, alignment/calibration, DB cond., →

**AIDA: Advanced Infrastructure for Detector development for future Accelerators**

A common Event Data Model (LCIO) with persistency and a common detector geometry description are the requirements for the exchange and common development of software tools between detector concepts and working groups.
This can even work across languages (C++, Java, Fortran), provided EDM and Geometry provide interfaces for these languages.

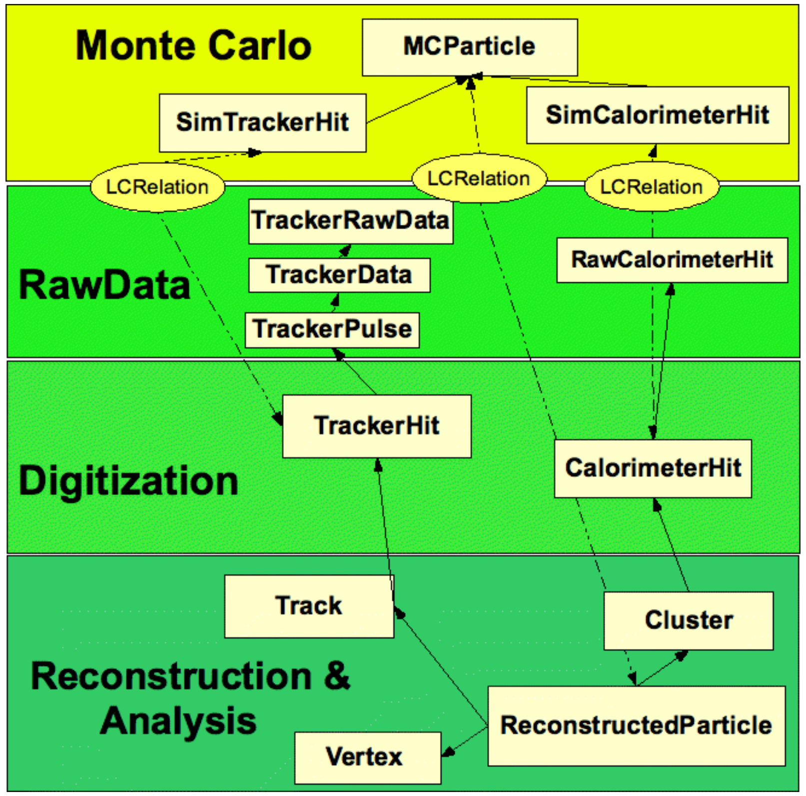
# XML Compact Description – Structure

- **lccdd** *Linear collider compact detector description*
  - **includes** *XML include files for material DB*
  - **info** *Info about the detector model, author etc.*
  - **define** *Constant definitions*
  - **materials** *Extensions to material DB*
  - **display** *Visualization settings*
  - **detectors** *Subdetector definitions*
  - **readouts** *Readout information for simulation*
  - **limits** *Limitsets for simulation*
  - **fields** *Electric/magnetic field definitions*

Also in DD C++ API

# LCIO

- hierarchical event data model
- implemented in C++ and Java
  - interfaces to C and Fortran
- common (non-ROOT) persistency
- optional ROOT dictionary
- see: http://lcio.desy.de
- SLAC and DESY project started in 2003 (!)




- LCIO used by all linear collider projects:
- ILC detector concepts, CLIC, test beam collaborations: Calice, LCTPC, EUPixelTelescope
- several hundred TByte of data and (mostly) Monte Carlo stored

# AIDA Project - WP2

- AIDA: Advanced Infrastructure for Detector development for future Accelerators
- Four year project of the Framework 7 Programme of the EU
- WP2: Common Software Tools:
  develop core software tools that are useful for the HEP community at large and in particular for the next big planned projects: sLHC and Linear Collider (ILC/CLIC)

Task 2.2: Geometry toolkit for HEP

- Allow the description of complex geometrical shapes, materials an sensitive detectors
- Provide interfaces to full simulation programs (Geant4), fast simulations, visualization tools and reconstruction algorithms
- Allow for the misalignment of detector components
- Provide an interface to calibration constants and conditions data

Task 2.3: Reconstruction toolkit for HEP

- Tracking toolkit based on best practice tracking and pattern recognition algorithms
- Provide alignment tools
- Allow for pile up of hadronic events
- Calorimeter reconstruction toolkit for highly granular calorimeters based on Particle Flow algorithms

# DD4Hep

- DD4Hep: Detector Description for High Energy Physics
- toolkit developed mainly CERN-SFT (P.Mato, M.Frank) in the context of AIDA WP2
- the goal is a replacement of existing geometry description in LC software while being applicable to generic HEP detector studies - incl. Fast Simulation
- DD4Hep is based on concepts from both LC frameworks and makes use of ROOT's TGeo classes for the description of the detailed placement of material volumes
- another project in WP2, USolids targets the unification of ROOT and geant4 geometry shapes
- see: http://aidasoft.web.cern.ch/DD4hep

# 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

# Detector design/sim/rec - AIDA / DD4Hep

- Is AIDA/DD4Hep an option for a LHeC software framework?
- My opinion: Yes, it is!
  first steps are promising - installed on lxplus (SL6) (in lhec afs project space) and on OSX (ML)

Backup

# Abbreviations

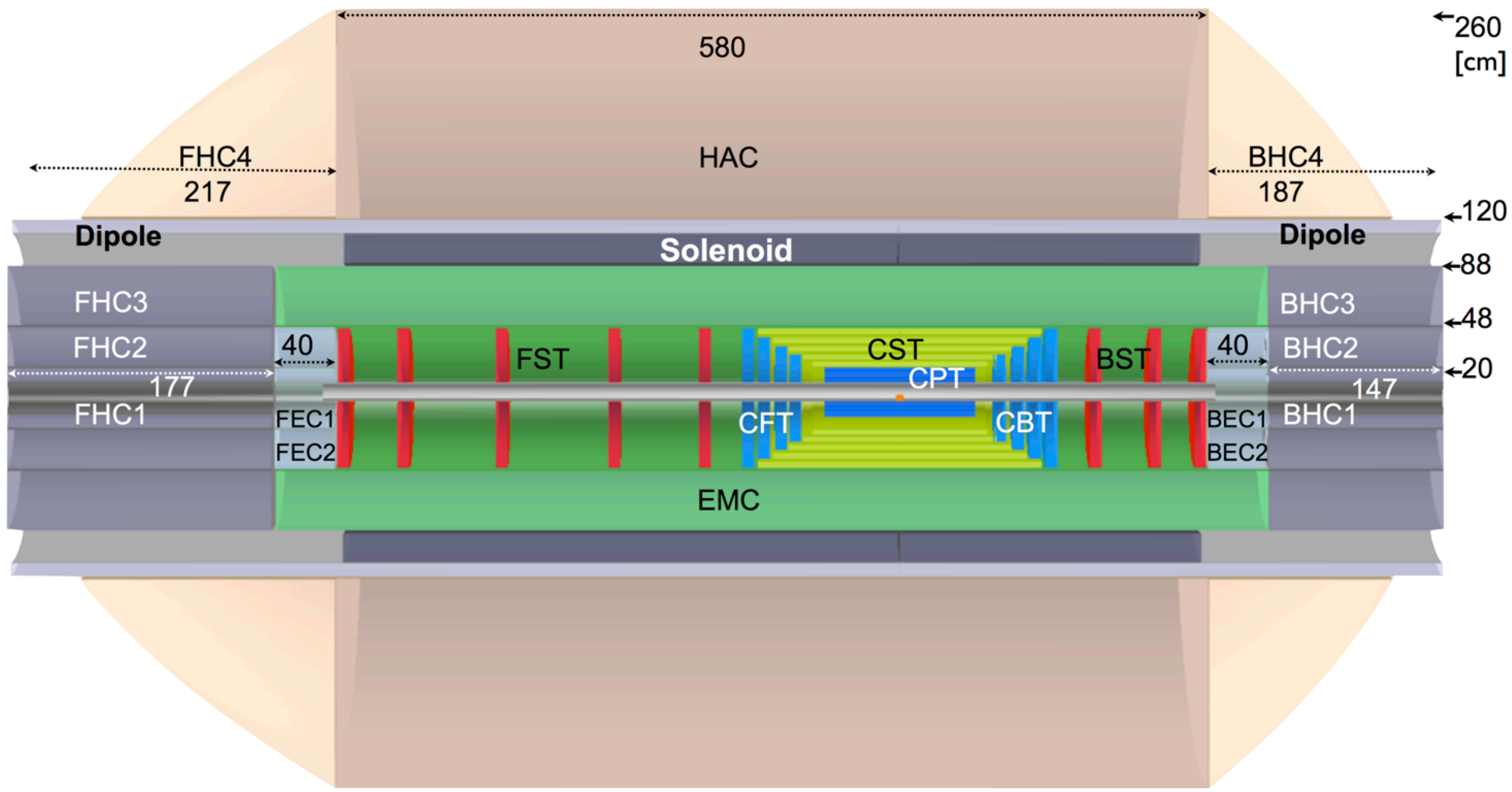
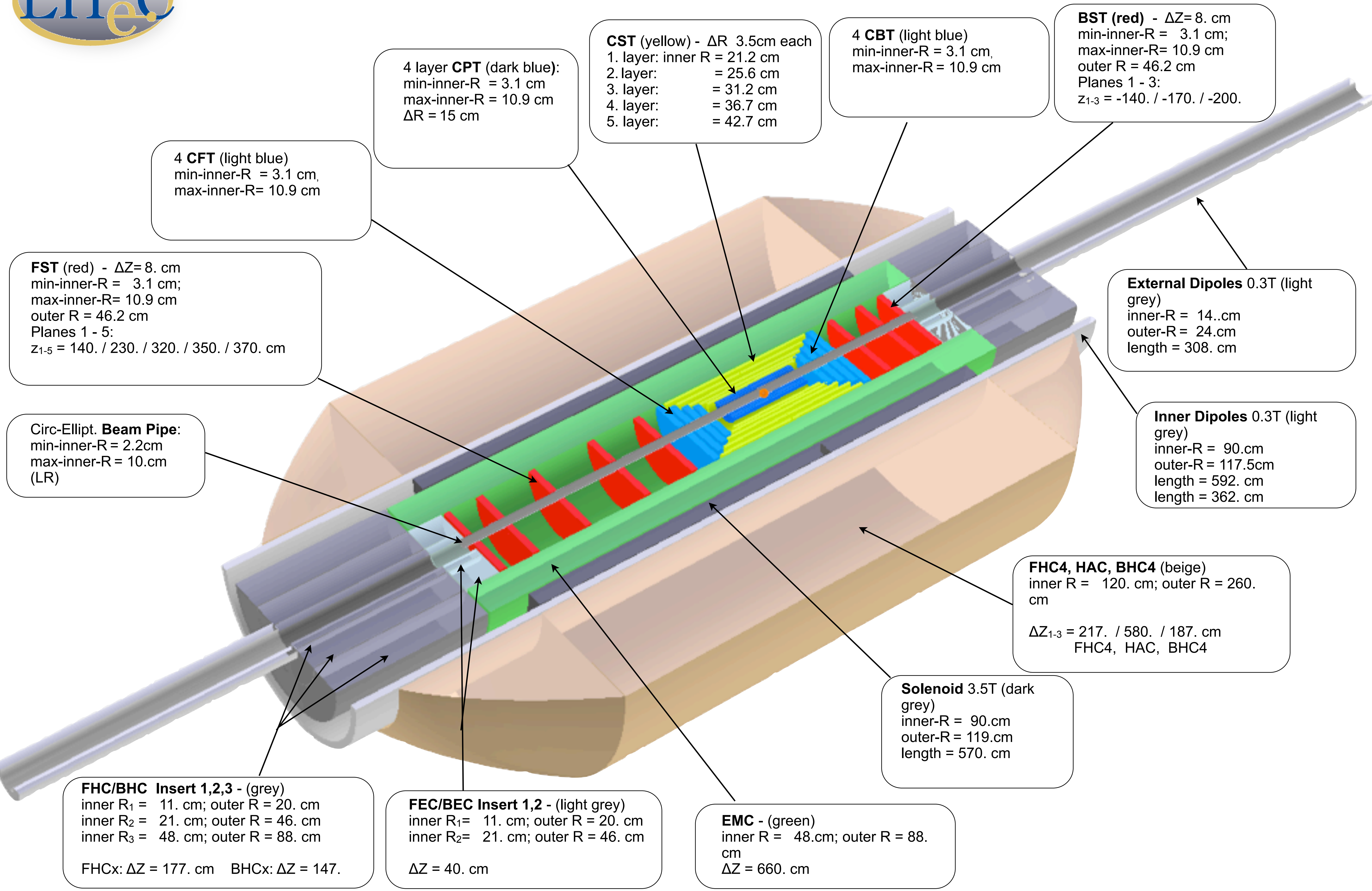



Figure 13.3: An $rz$ cross section and dimensions of the main detector (muon detector not shown) for the Ring-Ring detector version (no dipoles) extending the polar angle acceptance to about 1° in forward and 179° in backward direction.

| Detector Module | Abbreviation |
|---|---|
| Central Silicon Tracker | CST |
| Central Pixel Tracker | CPT |
| Central Forward Tracker | CFT |
| Central Backward Tracker | CBT |
| Forward Silicon Tracker | FST |
| Backward Silicon Tracker | BST |
| Electromagnetic Barrel Calorimeter | EMC |
| Hadronic Barrel Calorimeter | HAC |
| Hadronic Barrel Calorimeter Forward | FHC4 |
| Hadronic Barrel Calorimeter Backward | BHC4 |
| Forward Electromagnetic Calorimeter Insert 1/2 | FEC1/FEC2 |
| Backward Electromagnetic Calorimeter Insert 1/2 | BEC1/BEC2 |
| Forward Hadronic Calorimeter Insert 1/2 | FHC1/FHC2 |
| Backward Hadronic Calorimeter Insert 1/2 | BHC1/BHC2 |



4 layer **CPT** (dark blue):
min-inner-R = 3.1 cm
max-inner-R = 10.9 cm
ΔR = 15 cm
**CST** (yellow) - ΔR 3.5cm each
1. layer: inner R = 21.2 cm
2. layer: = 25.6 cm
3. layer: = 31.2 cm
4. layer: = 36.7 cm
5. layer: = 42.7 cm
4 **CBT** (light blue)
min-inner-R = 3.1 cm,
max-inner-R = 10.9 cm
**BST (red)** - ΔZ= 8. cm
min-inner-R = 3.1 cm;
max-inner-R= 10.9 cm
outer R = 46.2 cm
Planes 1 - 3:
$z_{1-3}$ = -140. / -170. / -200.
4 **CFT** (light blue)
min-inner-R = 3.1 cm,
max-inner-R= 10.9 cm
**FST** (red) - ΔZ= 8. cm
min-inner-R = 3.1 cm;
max-inner-R= 10.9 cm
outer R = 46.2 cm
Planes 1 - 5:
$z_{1-5}$ = 140. / 230. / 320. / 350. / 370. cm
Circ-Ellipt. **Beam Pipe**:
min-inner-R = 2.2cm
max-inner-R = 10.cm
(LR)
**External Dipoles** 0.3T (light grey)
inner-R = 14..cm
outer-R = 24.cm
length = 308. cm
**Inner Dipoles** 0.3T (light grey)
inner-R = 90.cm
outer-R = 117.5cm
length = 592. cm
length = 362. cm
**FHC4, HAC, BHC4** (beige)
inner R = 120. cm; outer R = 260. cm
$\Delta Z_{1-3}$ = 217. / 580. / 187. cm
FHC4, HAC, BHC4
**Solenoid** 3.5T (dark grey)
inner-R = 90.cm
outer-R = 119.cm
length = 570. cm
**FHC/BHC Insert 1,2,3** - (grey)
inner $R_1$ = 11. cm; outer R = 20. cm
inner $R_2$ = 21. cm; outer R = 46. cm
inner $R_3$ = 48. cm; outer R = 88. cm
FHCx: ΔZ = 177. cm BHCx: ΔZ = 147.
**FEC/BEC Insert 1,2** - (light grey)
inner $R_1$= 11. cm; outer R = 20. cm
inner $R_2$= 21. cm; outer R = 46. cm
ΔZ = 40. cm
**EMC** - (green)
inner R = 48.cm; outer R = 88. cm
ΔZ = 660. cm

# Tracker Dimensions

| Central Barrel | CPT1 | CPT2 | CPT3 | CPT4 | CST1 | CST2 | CST3 | CST4 | CST5 |
|---|---|---|---|---|---|---|---|---|---|
| Min. Radius $R$ $[cm]$ | 3.1 | 5.6 | 8.1 | 10.6 | 21.2 | 25.6 | 31.2 | 36.7 | 42.7 |
| Min. Polar Angle $\theta[^0]$ | 3.6 | 6.4 | 9.2 | 12.0 | 20.0 | 21.8 | 22.8 | 22.4 | 24.4 |
| Max. $\|\eta\|$ | 3.5 | 2.9 | 2.5 | 2.2 | 1.6 | 1.4 | 1.2 | 1.0 | 0.8 |
| $\Delta R$ $[cm]$ | 2 | 2 | 2 | 2 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| $\pm z$-length $[cm]$ | 50 | 50 | 50 | 50 | 58 | 64 | 74 | 84 | 94 |
| Project Area $[m^2]$ | 1.4 | | | | 8.1 | | | | |
| **Central Endcaps** | **CFT4** | **CFT3** | **CFT2** | **CFT1** | | **CBT1** | **CBT2** | **CBT3** | **CBT4** |
| Min. Radius $R$ $[cm]$ | 3.1 | 3.1 | 3.1 | 3.1 | | 3.1 | 3.1 | 3.1 | 3.1 |
| Min. Polar Angle $\theta[^0]$ | 1.8 | 2.0 | 2.2 | 2.6 | | 177.4 | 177.7 | 178 | 178.2 |
| at $z$ [cm] | 101 | 90 | 80 | 70 | | -70 | -80 | -90 | -101 |
| Max./Min. $\eta$ | 4.2 | 4.0 | 3.9 | 3.8 | | -3.8 | -3.9 | -4.0 | -4.2 |
| $\Delta z$ $[cm]$ | 7 | 7 | 7 | 7 | | 7 | 7 | 7 | 7 |
| Project Area $[m^2]$ | 1.8 | | | | | 1.8 | | | |
| **Fwd/Bwd Planes** | **FST5** | **FST4** | **FST3** | **FST2** | **FST1** | | **BST1** | **BST2** | **BST3** |
| Min. Radius $R$ $[cm]$ | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | | 3.1 | 3.1 | 3.1 |
| Min. Polar Angle $\theta[^0]$ | 0.48 | 0.54 | 0.68 | 0.95 | 1.4 | | 178.6 | 178.9 | 179.1 |
| at $z$ [cm] | 370 | 330 | 265 | 190 | 130 | | -130 | -170 | -200 |
| Max./Min. $\eta$ | 5.5 | 5.4 | 5.2 | 4.8 | 4.5 | | -4.5 | -4.7 | -4.8 |
| Outer Radius $R$ $[cm]$ | 46.2 | 46.2 | 46.2 | 46.2 | 46.2 | | 46.2 | 46.2 | 46.2 |
| $\Delta z$ $[cm]$ | 8 | 8 | 8 | 8 | 8 | | 8 | 8 | 8 |
| Project Area $[m^2]$ | 3.3 | | | | | | 2.0 | | |

Table 13.4: Summary of tracker dimensions. The 4 Si-Pixel-Layers CPT1-CPT4 (resolution of $\sigma_{\text{pix}} \approx 8\mu m$) are positioned as close to the beam pipe as possible. Si-strixel (CST1-CST5) (resolution of $\sigma_{\text{strixel}} \approx 12\mu m$) form the central barrel layers. An alternative is the 2_in_1 single sided Si-strip solution for these barrel cylinders ($\sigma_{\text{strip}} \approx 15\mu m$) [752]. The endcap Si-strip detectors CFT/CBT(1-4) complete the central tracker. The tracker inserts, 5 wheels of Si-Strip detectors in forward direction (FST) and 3 wheels in backward direction (BST), are based on single sided Si-strip detectors of 2_in_1-design ($\sigma_{\text{strip}} \approx 15\mu m$). They have to be removed in case of high luminosity running for the Ring-Ring option of the accelerator configuration (see Fig. 13.4).

# Calorimeter Dimensions

| E-Calo Parts | FEC1 | FEC2 | | EMC | | BEC2 | BEC1 |
|---|---|---|---|---|---|---|---|
| Min. Inner radius $R$ [cm] | 3.1 | 21 | | 48 | | 21 | 3.1 |
| Min. polar angle $\theta$ [°] | 0.48 | 3.2 | | 6.6/168.9 | | 174.2 | 179.1 |
| Max. pseudorapidity $\eta$ | 5.5 | 3.6 | | 2.8/-2.3 | | -3. | -4.8 |
| Outer radius [cm] | 20 | 46 | | 88 | | 46 | 20 |
| $z$-length [cm] | 40 | 40 | | 660 | | 40 | 40 |
| Volume [$m^3$] | 0.3 | | | 11.3 | | 0.3 | |
| **H-Calo Parts barrel** | | | **FHC4** | **HAC** | **BHC4** | | |
| Inner radius [cm] | | | 120 | 120 | 120 | | |
| Outer radius [cm] | | | 260 | 260 | 260 | | |
| $z$-length [cm] | | | 217 | 580 | 157 | | |
| Volume [$m^3$] | | | | 121.2 | | | |
| **H-Calo Parts Inserts** | **FHC1** | **FHC2** | **FHC3** | | **BHC3** | **BHC2** | **BHC1** |
| Min. inner radius $R$ [cm] | 11 | 21 | 48 | | 48 | 21 | 11 |
| Min. polar angle $\theta$ [°] | 0.43 | 2.9 | 6.6 | | 169. | 175.2 | 179.3 |
| Max/min pseudorapidity $\eta$ | 5.6 | 3.7 | 2.9 | | -2.4 | -3.2 | -5. |
| Outer radius [cm] | 20 | 46 | 88 | | 88 | 46 | 20 |
| $z$-length [cm] | 177 | 177 | 177 | | 117 | 117 | 117 |
| Volume [$m^3$] | | 4.2 | | | | 2.8 | |

Table 12.6: Summary of calorimeter dimensions.
The electromagnetic barrel calorimeter is currently represented by the barrel part EMC (LAr-Pb module, $X_0 \approx 25$ radiation length), with forward FEC1, FEC2 (Si-W modules ($X_0 \approx 30$) and backward module inserts BEC1, BEC2 (Si-Pb modules; $X_0 \approx 25$).
The hadronic barrel parts are represented by FHC4, HAC, BHC4 ( forward, central and backward - Scintillator-Fe Tile modules; $\lambda_I \approx 8$ interaction length) and the movable inserts FHC1, FHC2, FHC3 (Si-W modules; $\lambda_I \approx 10$), BHC1, BHC2, BHC3 (Si-Cu modules, $\lambda_I \approx 8$) see Fig. 12.9.

# Track Sagitta

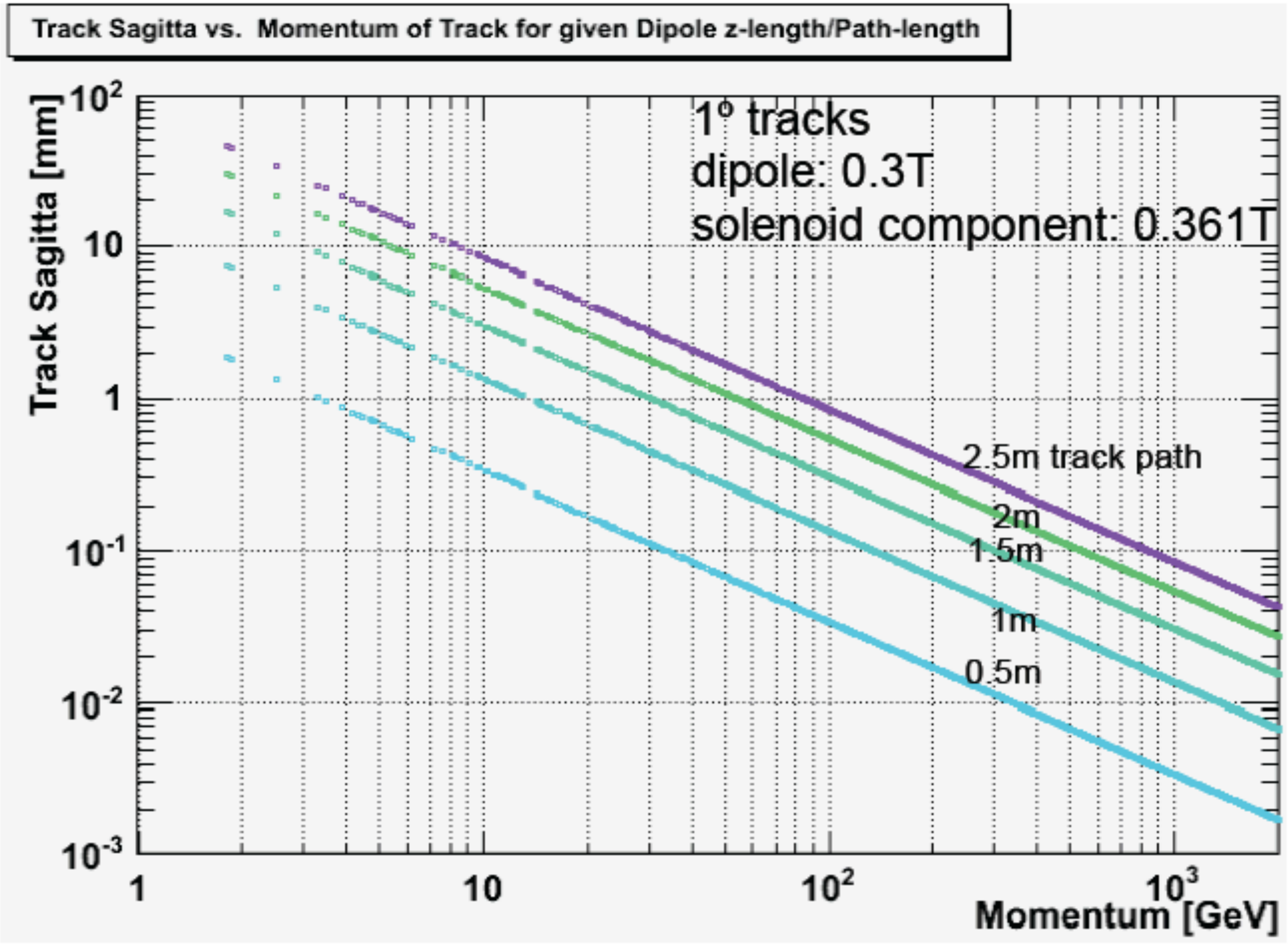



Figure 13.22: Track Sagitta vs. Momentum of 1°tracks in a superposed dipole/solenoidal field.