http://cern.ch/lhec

The LHeC Detector
(introduction)

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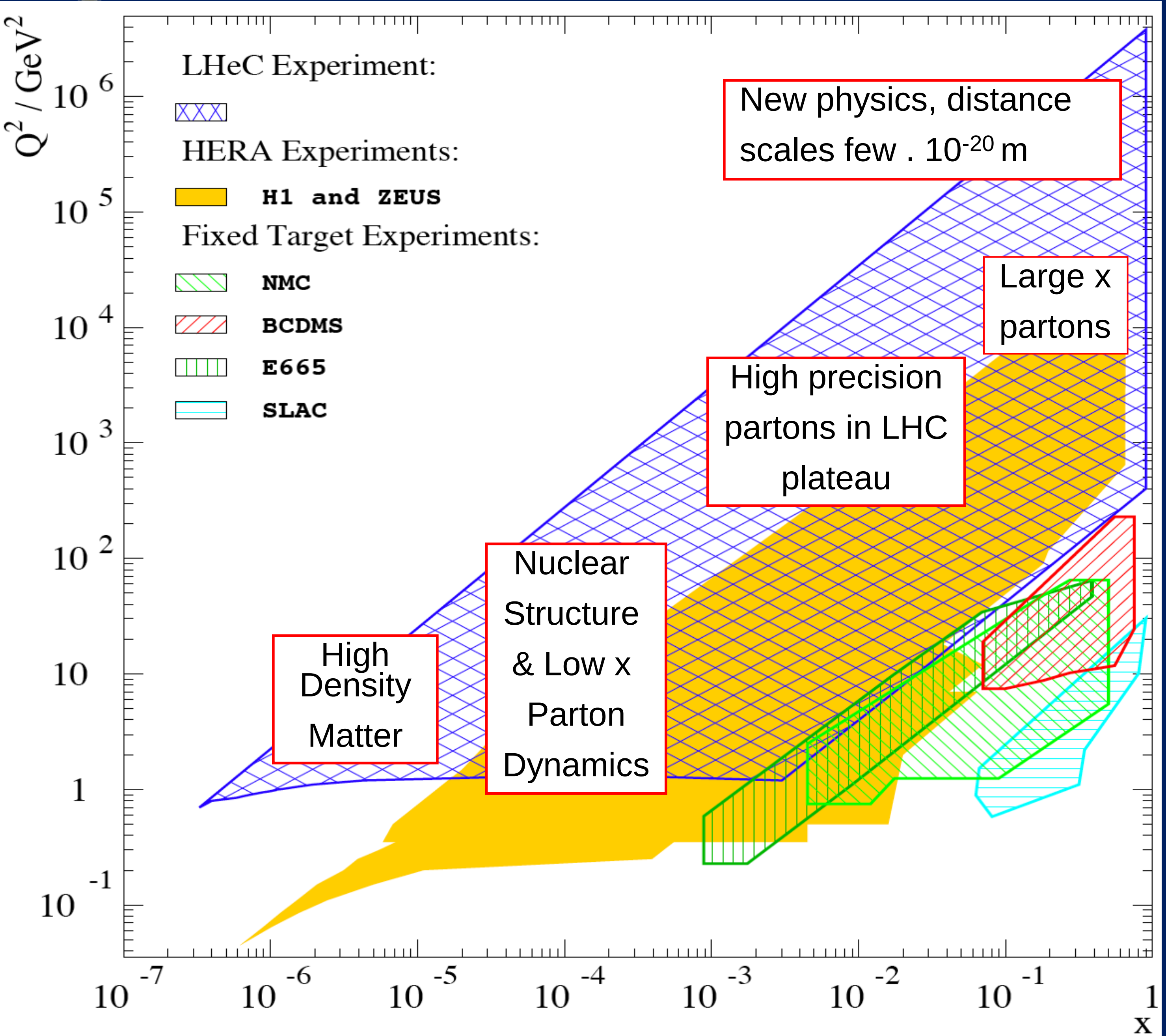
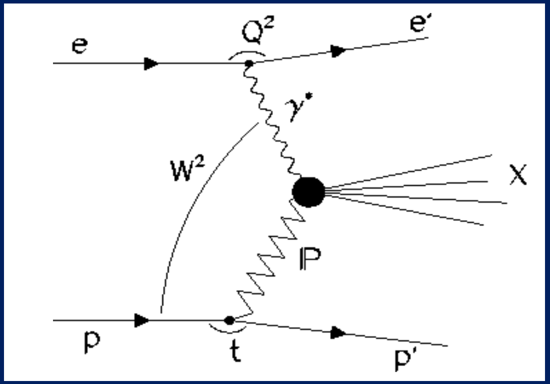
Outline:

- Experiment requirements and accelerator boundaries (Physics, Machine, Interaction Region and Detector)
- Present Detector Design
- Detector Session and Workshop Discussion
- Future and Outlook

Kinematics & Motivation (60 GeV x 7 TeV *ep*)



$\sqrt{s}$= 1.4 TeV



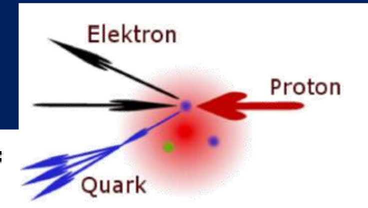
- High mass (M_{eq},Q^2) frontier

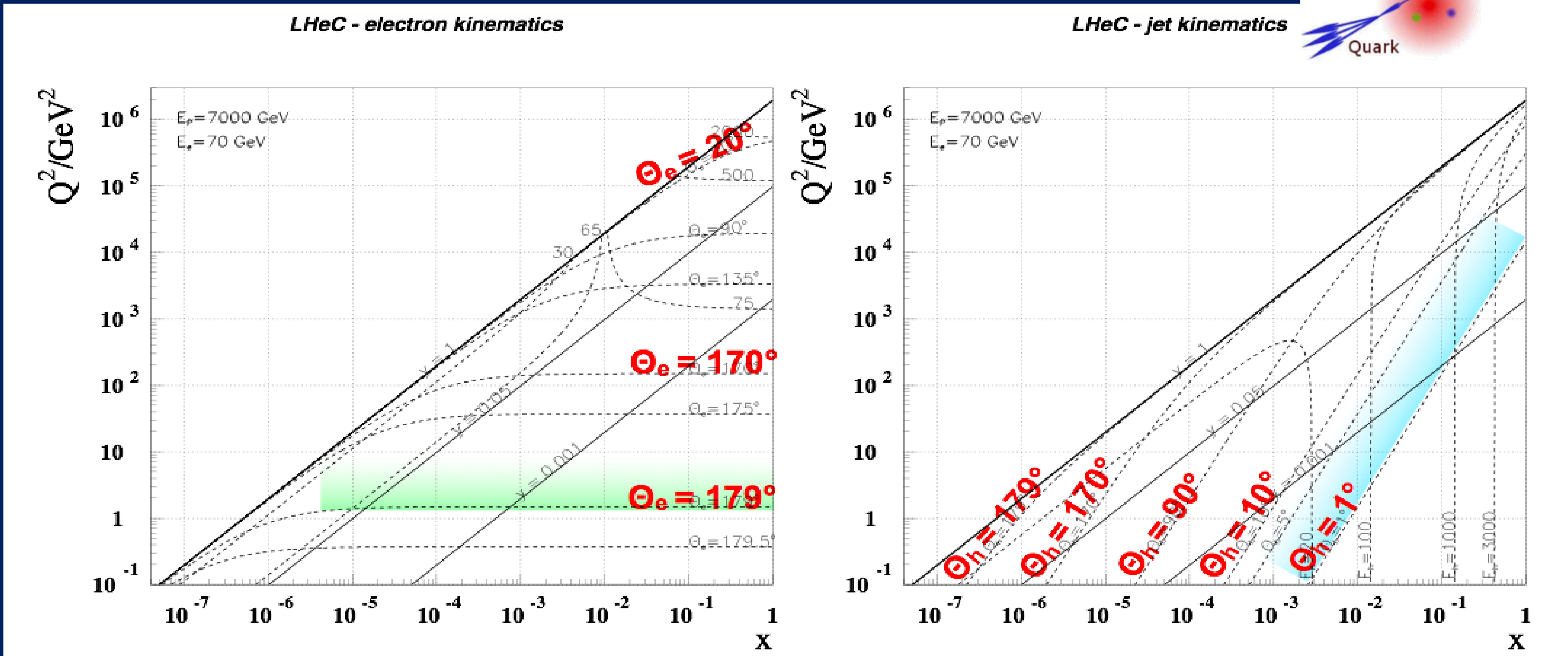
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs

- Low x frontier [x below 10^{-6} at Q^2 ~ 1 GeV^2]

→ novel QCD …

LHeC Kinematics





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

➔ Need forward calorimeter of few TeV energy range down to 10º and below. Mandatory for charged currents where the outgoing electron is missing. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%

- Scattered electron:

➔ Need very bwd angle acceptance for accessing the low Q^2 and high y region.

Design Approach

- Provide a baseline design which satisfies the Physics requirements along with the constraints from the machine and interaction region for running during the PHASE II of LHC

- Having to run along with the LHC, the detector needs to be designed and constructed in about 10 years from now to be able to run concurrently with the other LHC experiments designed for *pp* and *AA* studies in the *ep*/*eA* mode, respectively.

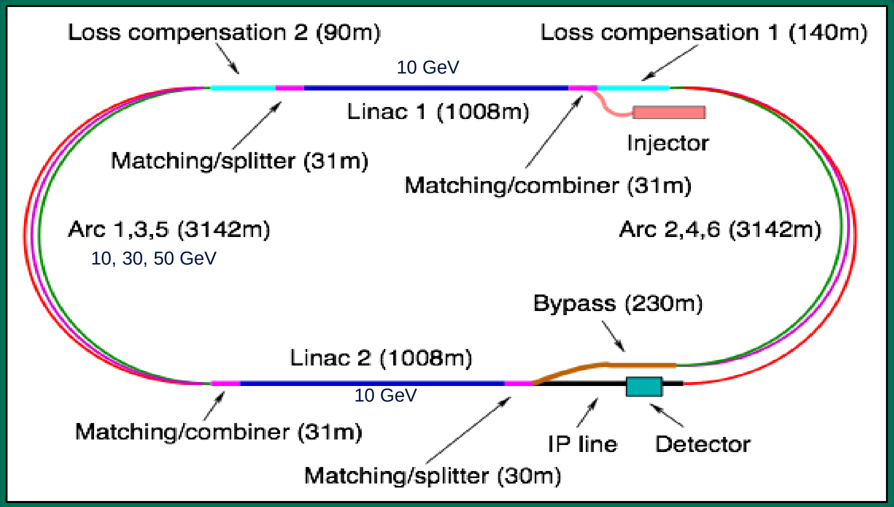
- While avoiding large R&D programs, the final LHeC detector can profit from the technologies used nowadays at the LHC and the related developments and upgrades

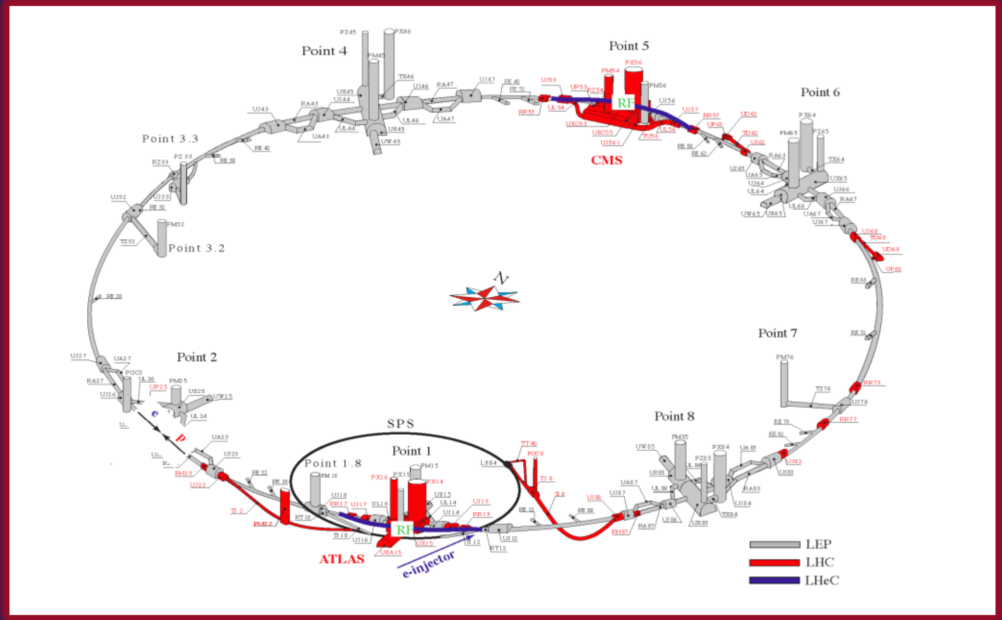
- Modular and flexible accommodating upgrade programs; Detector assembly above ground; Detector maintenance (shutdown)

- Affordable - comparatively reasonable cost.

- More refined studies are required and will follow with the TDR and once a LHeC collaboration has been founded

Two Alternative Designs



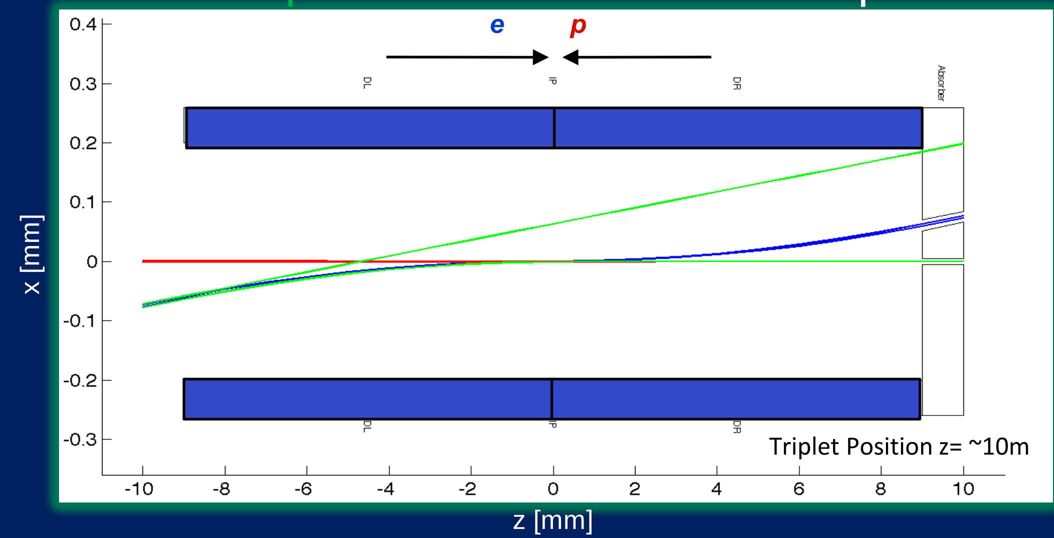


- Ring-Ring
  - e-p and e-A (A=Pb, Au, …) collisions
  - More “conventional” solution, like HERA, no difficulties of principle - at first sight - but constrained by existing LHC in tunnel
  - polarization 40% with realistic misalignment assumptions
- Linac-Ring
  - e-p and e-A (A=Pb, Au, …) collisions, polarized *e* from source, somewhat less Luminosity/Power
  - New collider type of this scale

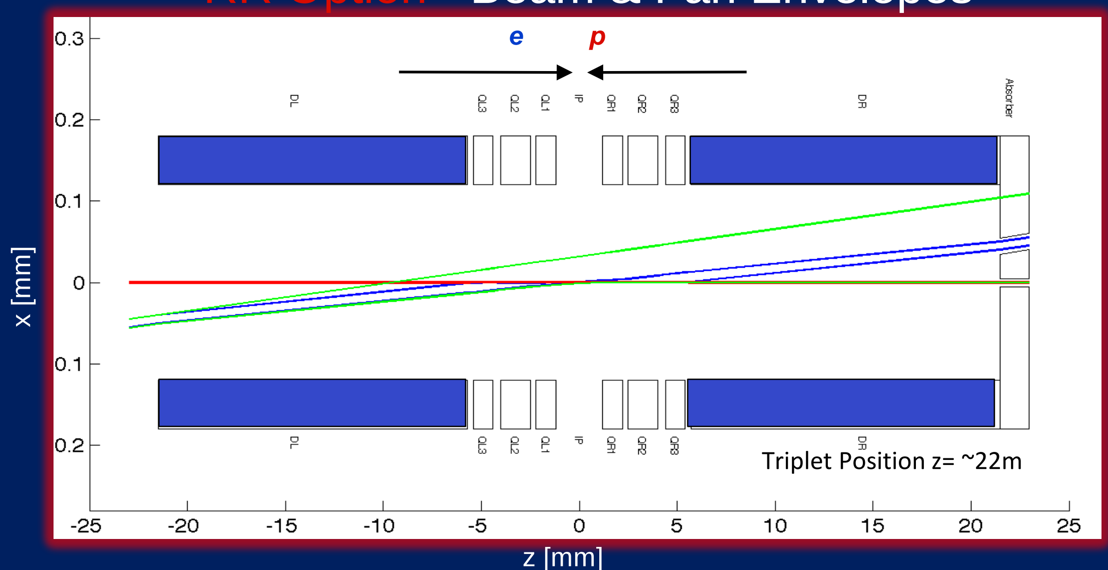
LR, RR option - Beam & SR

SR Fan growth with z

LR Option - Beam & Fan Envelopes



RR Option - Beam & Fan Envelopes



Legend : Dipole

SR Fan growth with z

(high luminosity case)

LR Interaction Region

- Special attention is required to the interaction region design, which comprises beam bending (in/out), direct and secondary synchrotron radiation, vacuum and beam pipe

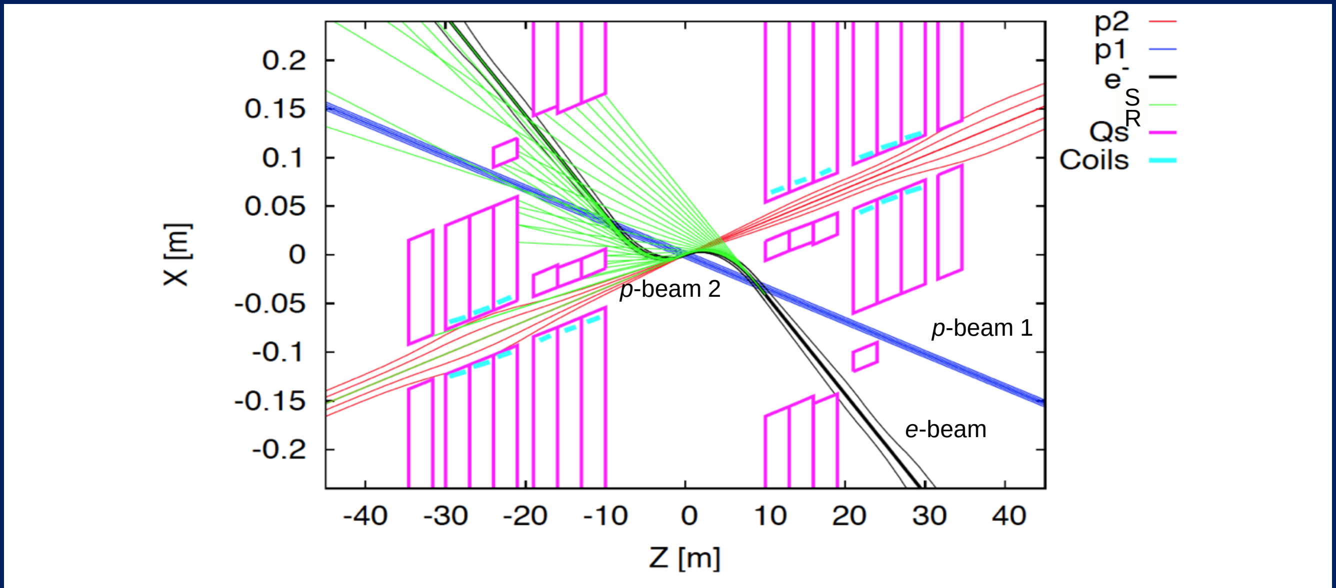
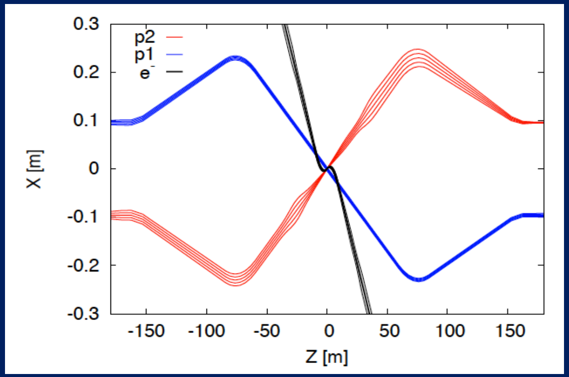
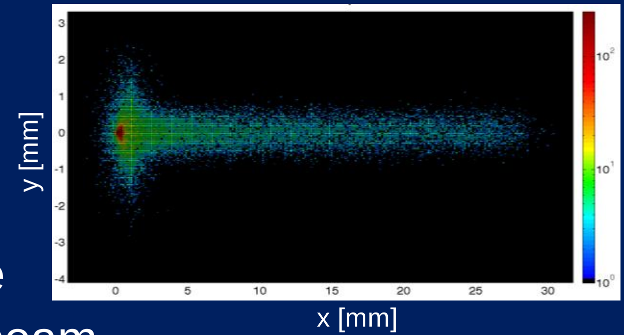


Figure 9.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam trajectories with 5σ and 10σ envelopes are shown.

3 beams, head-on collisions



Photon Number Density at the IP



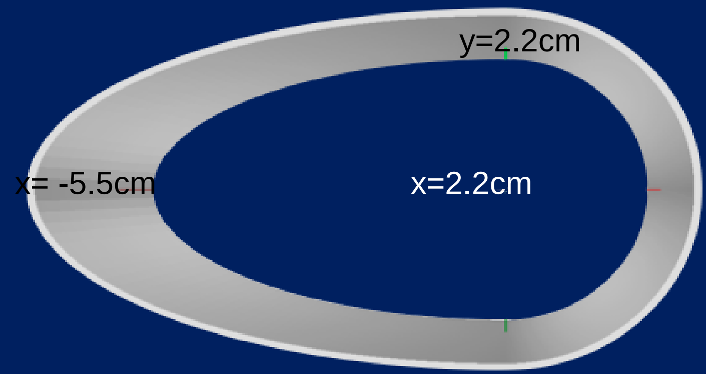
- Dipoles around the IP (2 x 9m, 0.3T) for making electrons collide head-on with *p-beam 2* & safely extract the disrupted electron beam.
- Simulation of Synchrotron Radiation (SR) load in the IR and design of absorbers / masks shielding SR from backscattering into the detector & from propagating with $e^{\pm}$ beam.
- Beam pipe design - space for SR fan - tracking/calorimetry close to the IP / beam line (goal: 1° - 179°)

Beam Pipe / Profile - SR Fan

Ring-Ring - Inner dimensions (masks at 6, 5, 4m - primary SR shield)

Circular(x)=2.2cm (LHC upgrade); Elliptical(-x)=-5.5, y=2.2cm

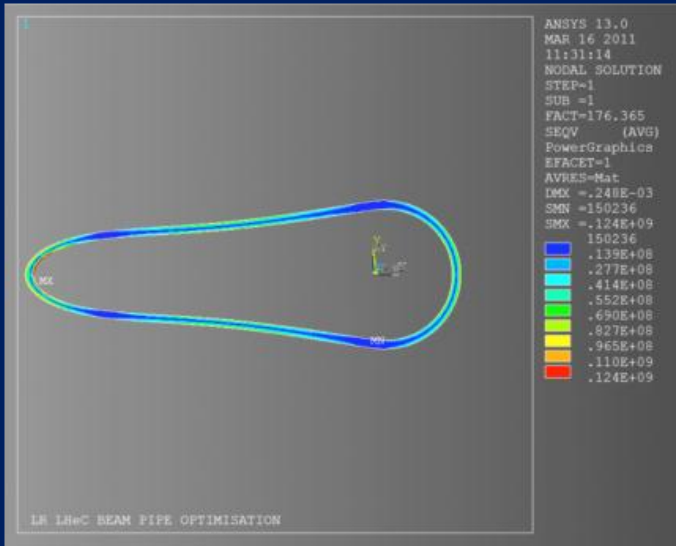
beam pipe dimensions reduced - using static / movable masks;



housing beam/SR envelopes
+ 1cm safety margin

Linac-Ring - Inner Dimensions

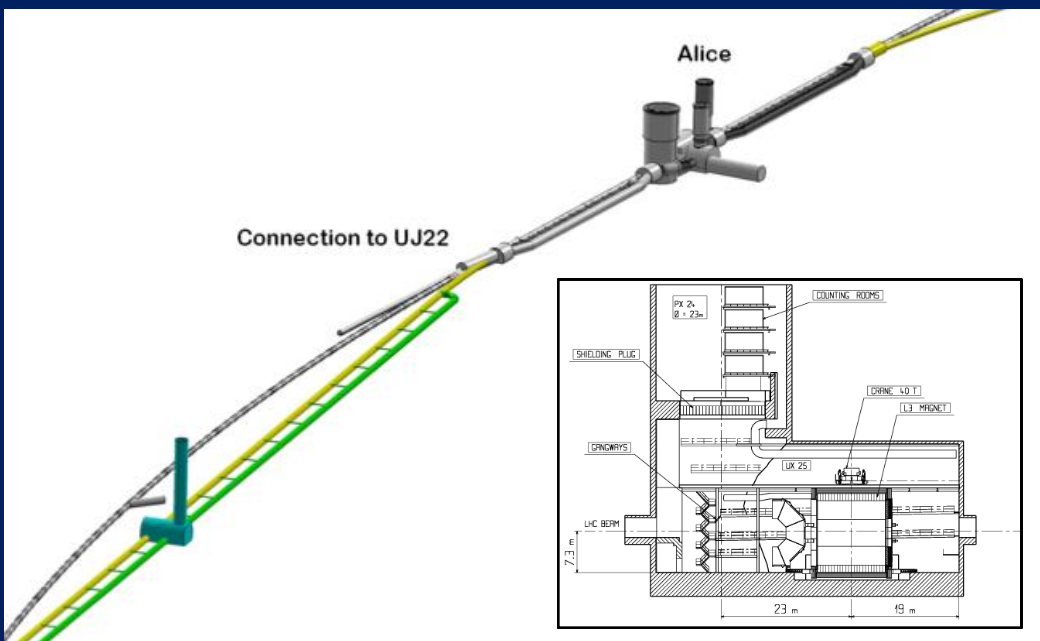
Circular(x)=2.2cm; Elliptical(-x)=-10., y=2.2cm

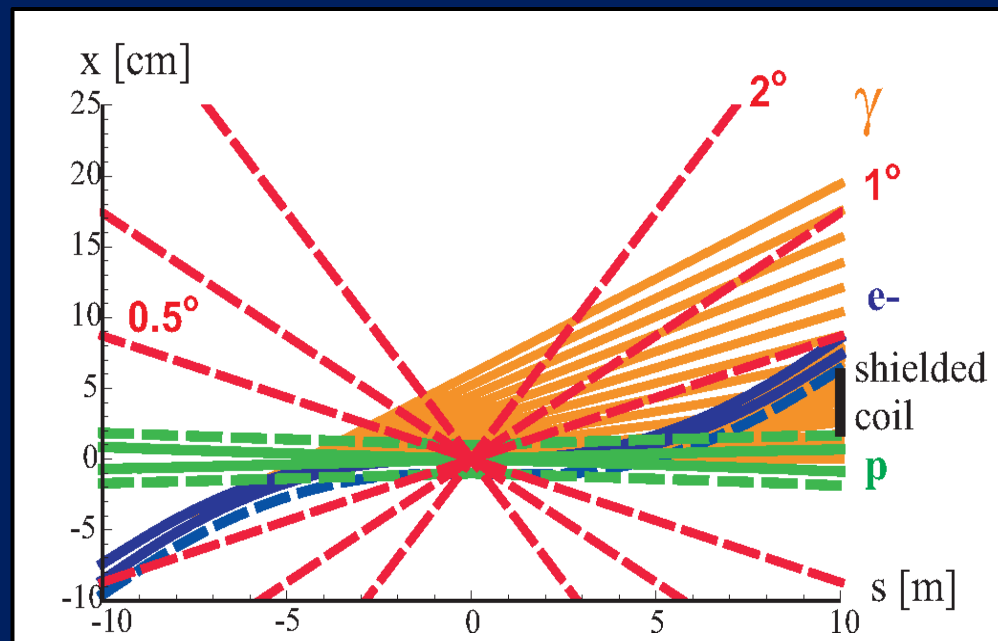


Linac Ring: Favored Option

Linac-Ring:

- Reduced impact on the LHC schedule
- New Accelerator Design (Energy Recovery Linac)
- Dipole Field along the whole interaction region
- LHC Interaction Point P2





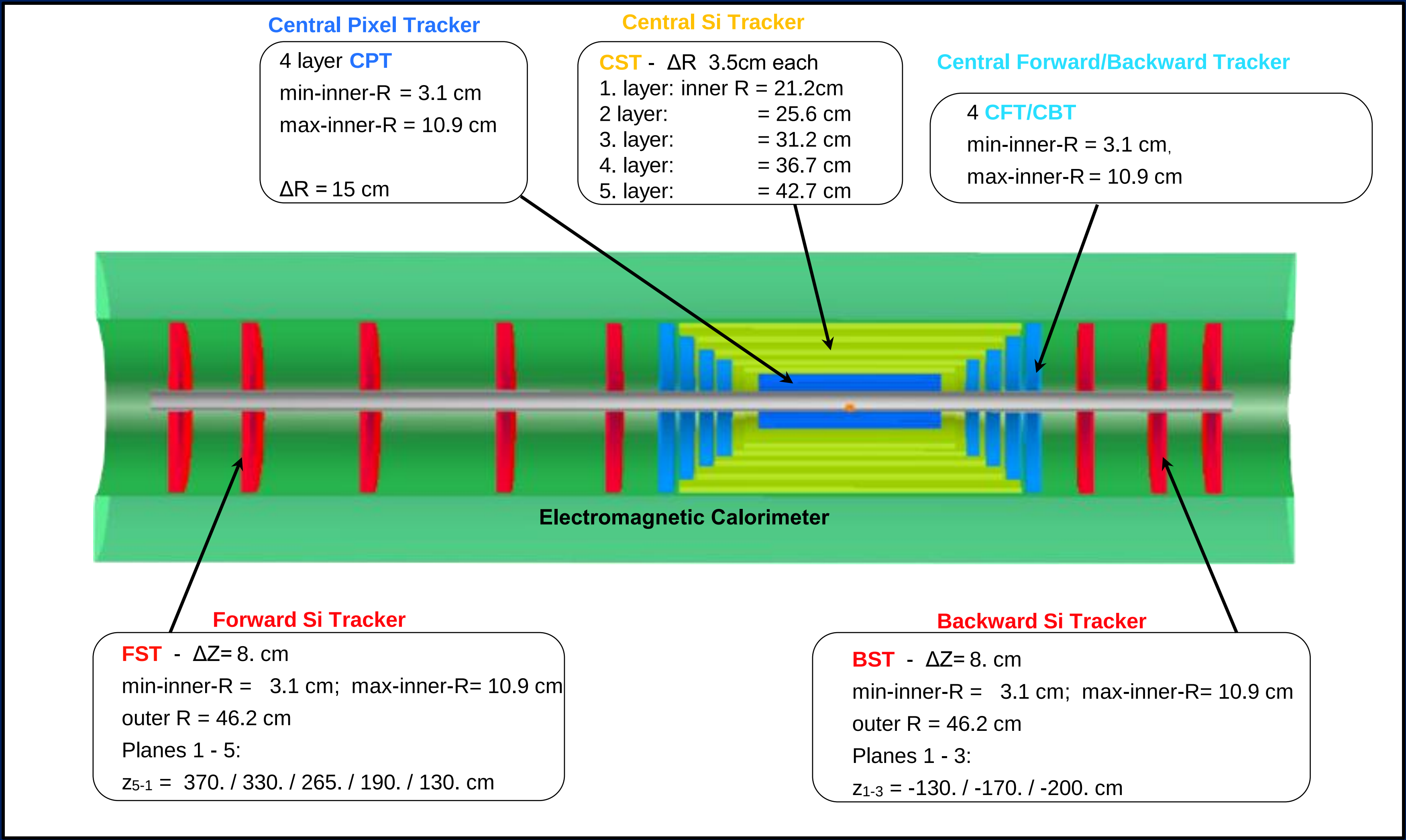
Requirements from Physics

- High resolution tracking system
  - excellent primary vertex resolution
  - resolution of secondary vertices down to small angles in forward direction for high x heavy flavor physics and searches
  - precise p_t measurement matching to calorimeter signals (high granularity), calibrated and aligned to 1 mrad accuracy
- The calorimeters
  - electron energy to about $10\%/\sqrt{E}$ calibrated using the kinematic peak and double angle method, to permille level

    Tagging of γ's and backward scattered electrons -
    precise measurement of luminosity and photo-production physics
  - hadronic part $30\%/\sqrt{E}$ calibrated with p_{t_e}/p_{t_h} to 1% accuracy
    - Tagging of forward scattered proton, neutron and deuteron - diffractive and deuteron physics
- Muon system, very forward detectors, luminosity measurements

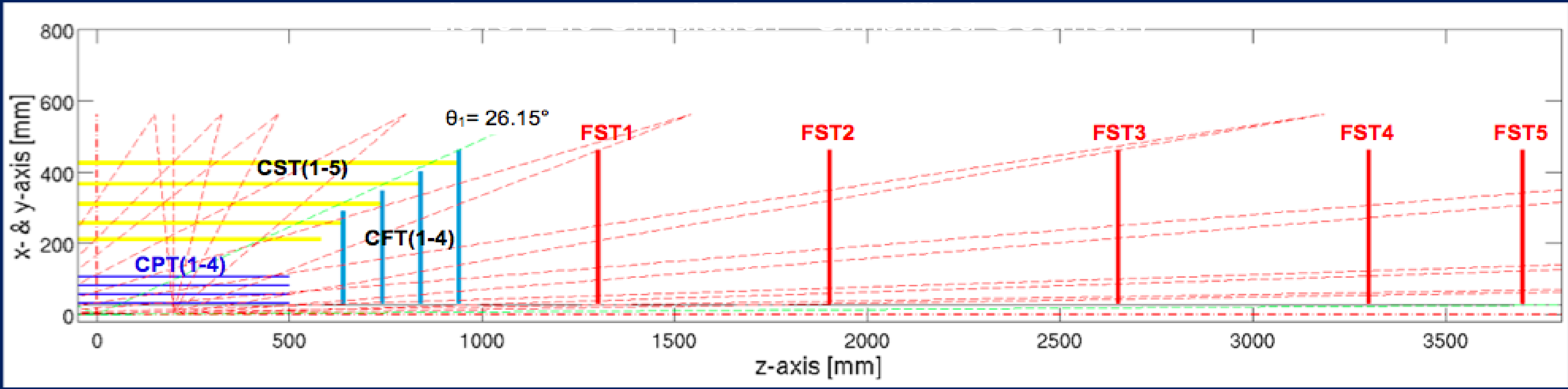
Tracking - High Acceptance

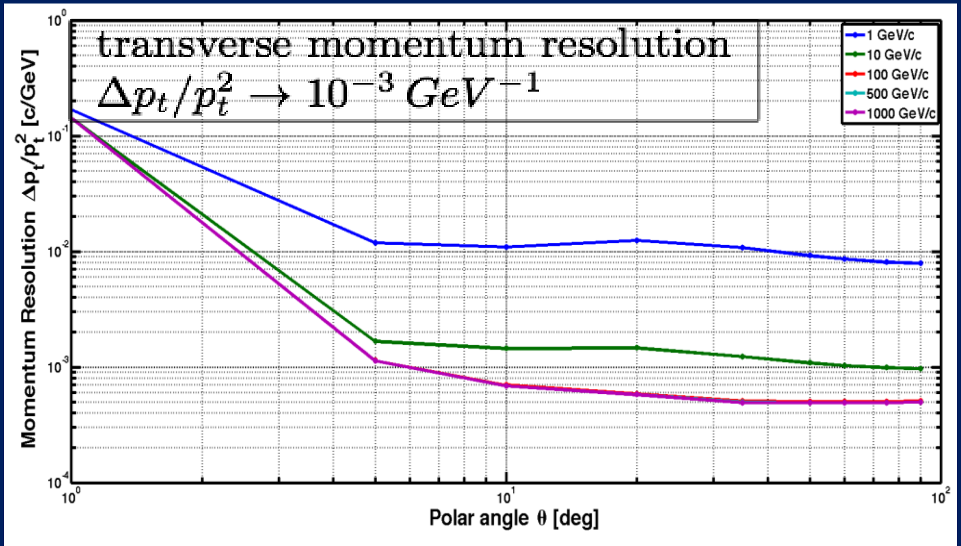
Dominant forward production of dense jets;
backward measurements relaxed

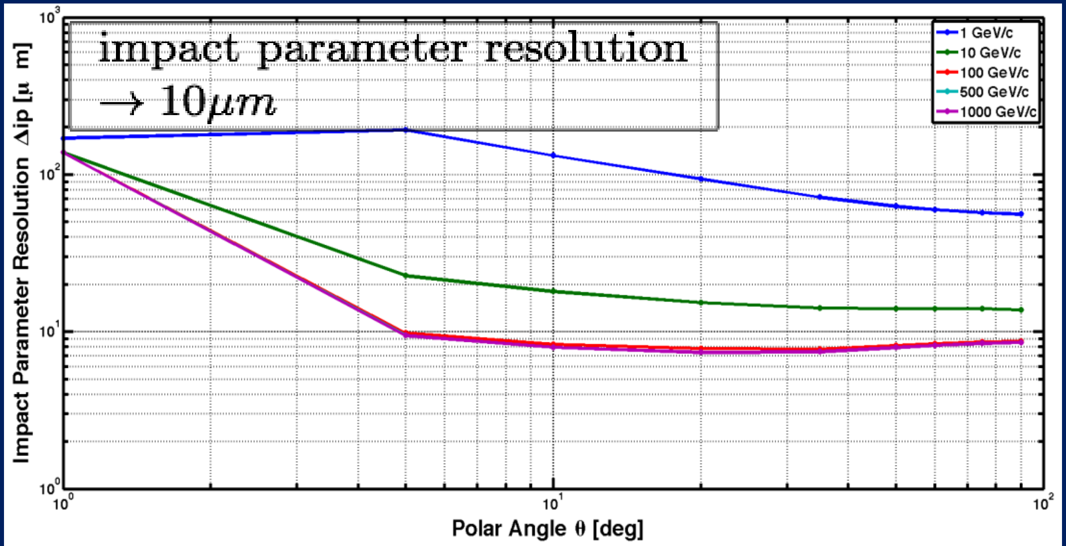


Tracker Simulation

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

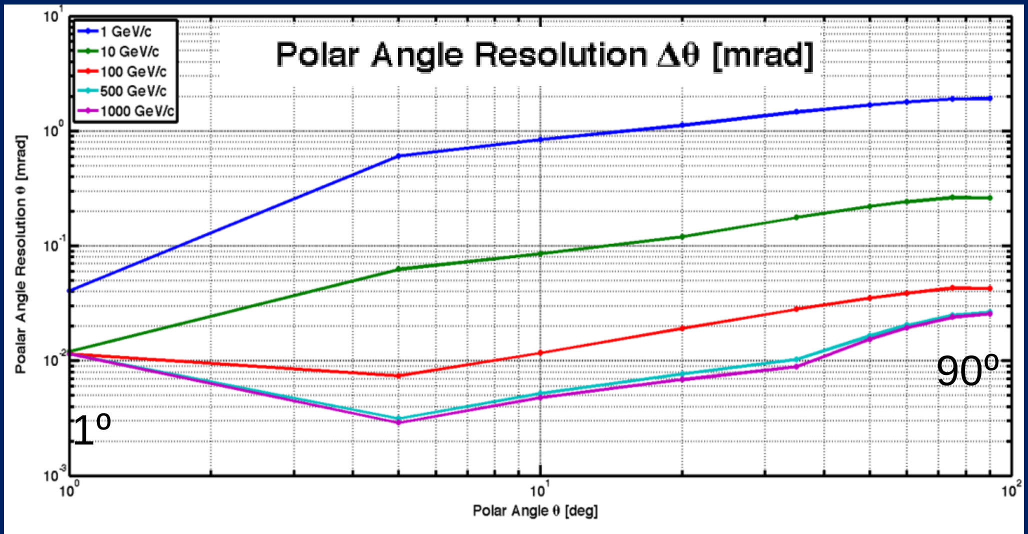


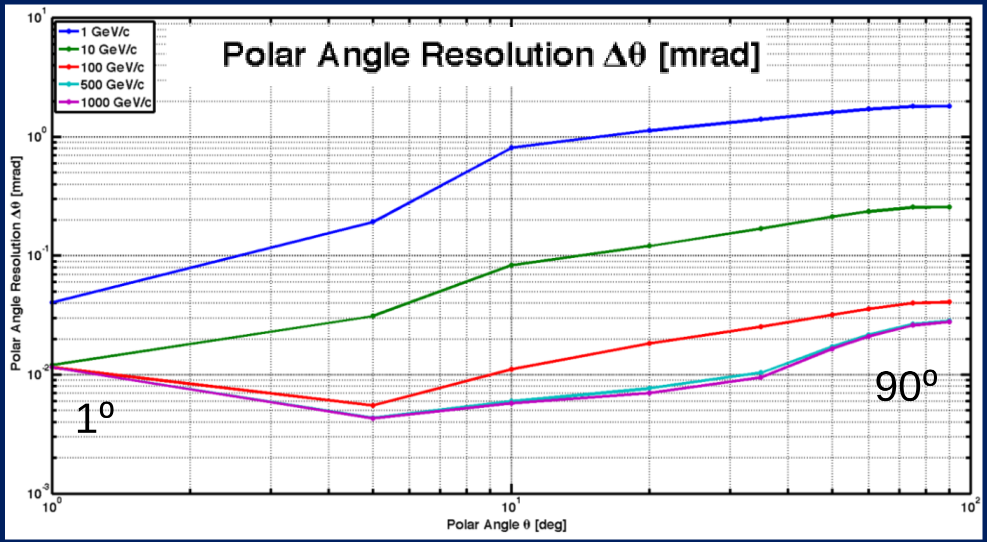


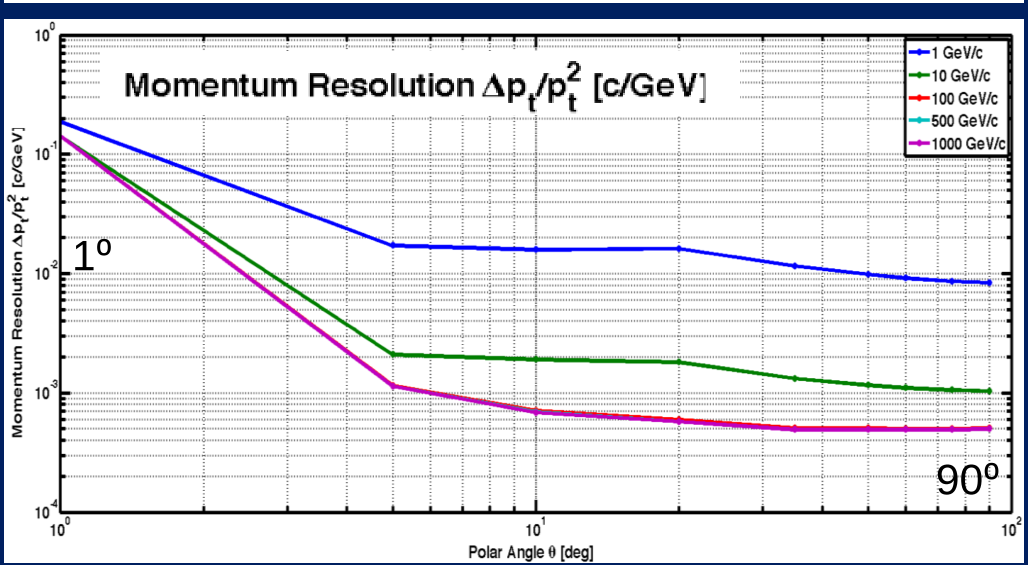


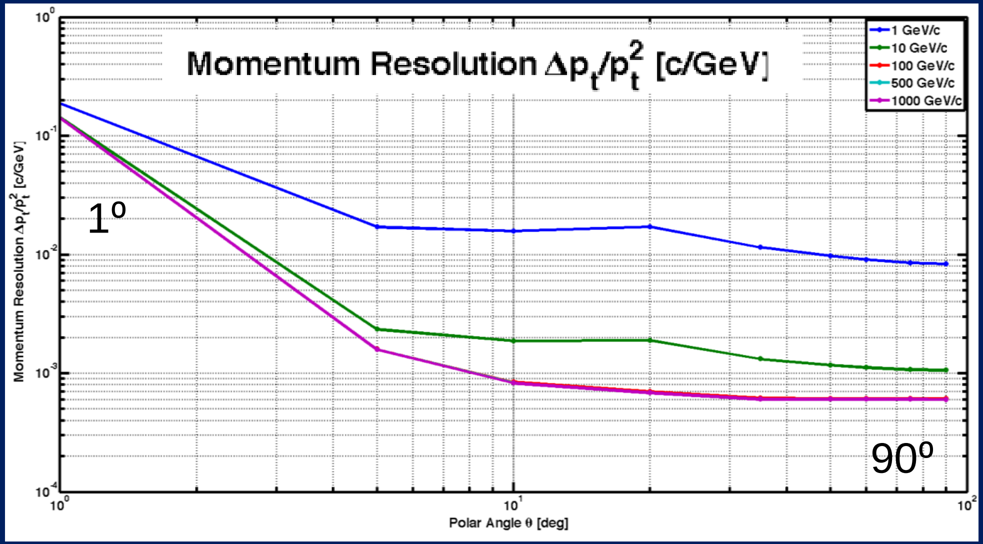
- Silicon: compact design, low budget material, radiation hard

Tracker Simulation (ii)



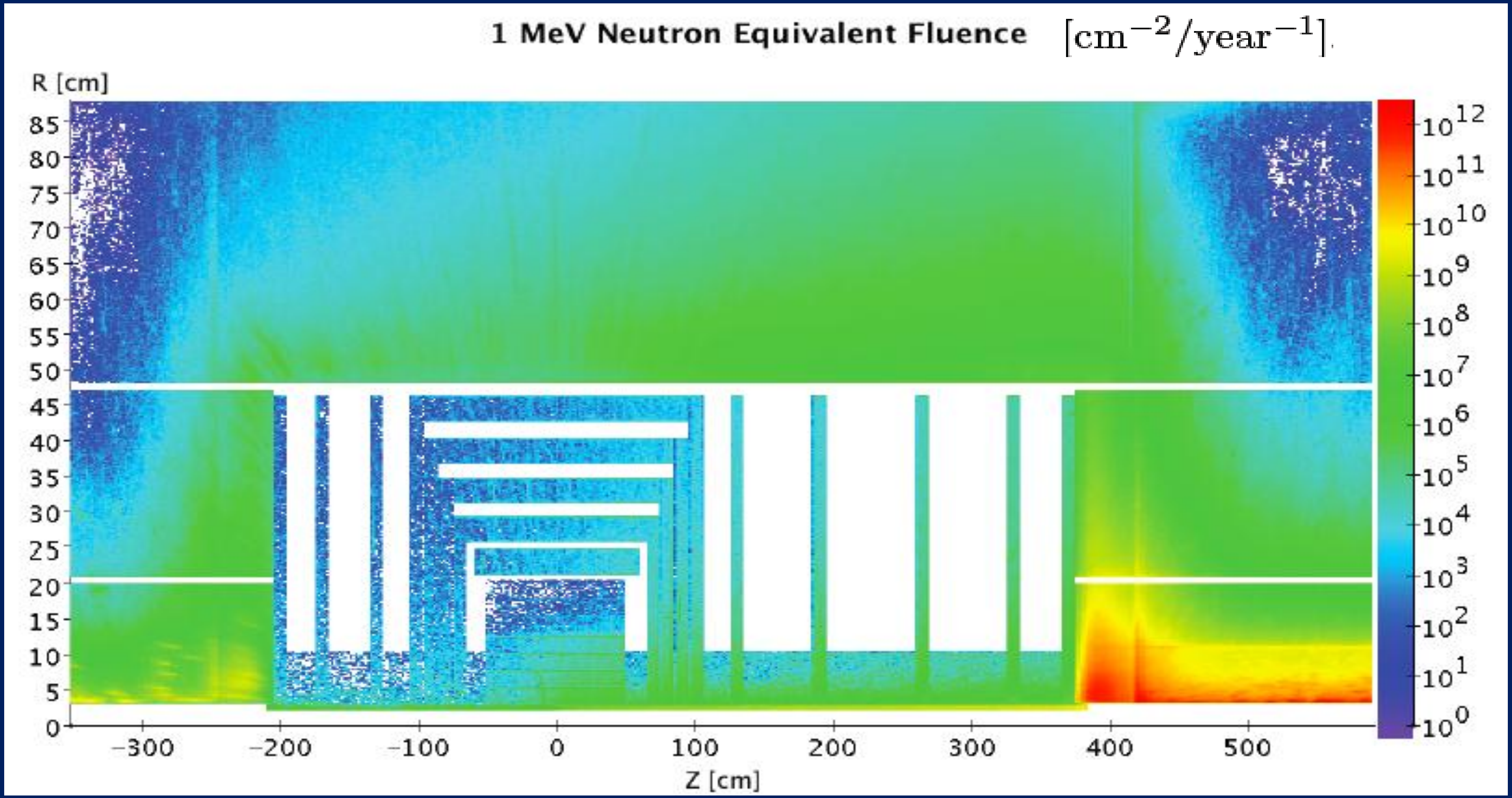






- Same plots (left) and (small) deterioration in case of innermost barrel layer failure (right)

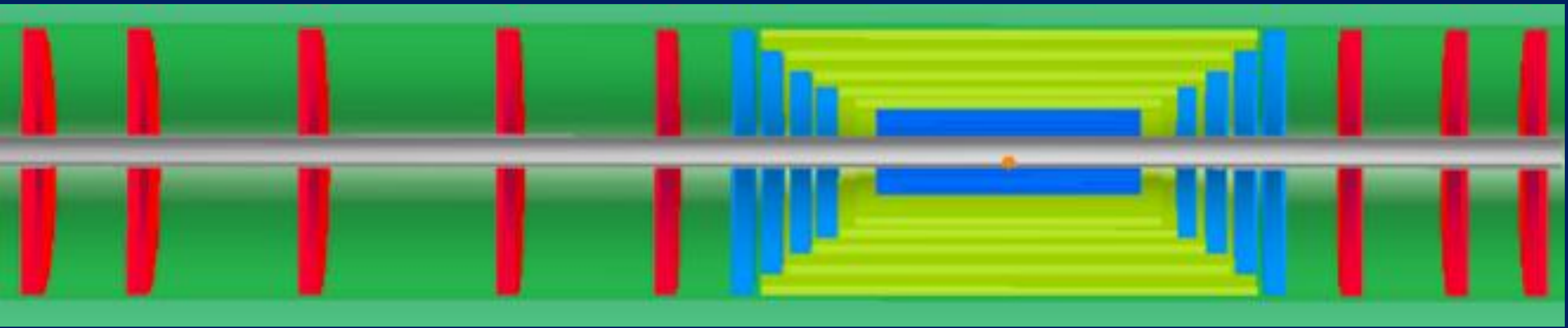
GEANT4 - Fluences

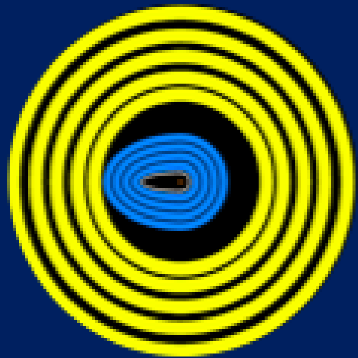


- Similar studies being done with FLUKA
- Most critical the forward region
- Rates far lower than LHC (LHC ~5 x 10^{14})

Tracker Detector Technology

- Choose among available technologies
  n-in-p (sLHC) or n^{+}-in-n (ATLAS/CMS/LHCb)
- Radiation hardness in LHeC not as challenging as in LHC
- Silicon Pixel, Strixel, Strips
- Detailed simulation to best understand the needs and implications
- Readout/Trigger, Services, # silicon layers
- Analog/Digital Readout
- Modular structure for best replacement / maintenance and detector adoption: RR high luminosity / high acceptance running
- Pixel Detector*) (barrel CPT 1-4 and inner forward/backward FST/BST)





Services and Infrastructure

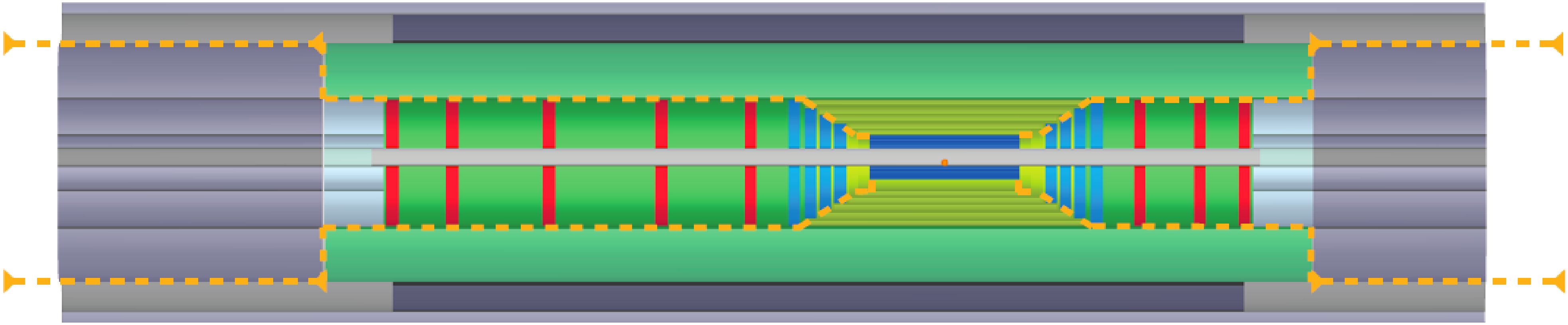
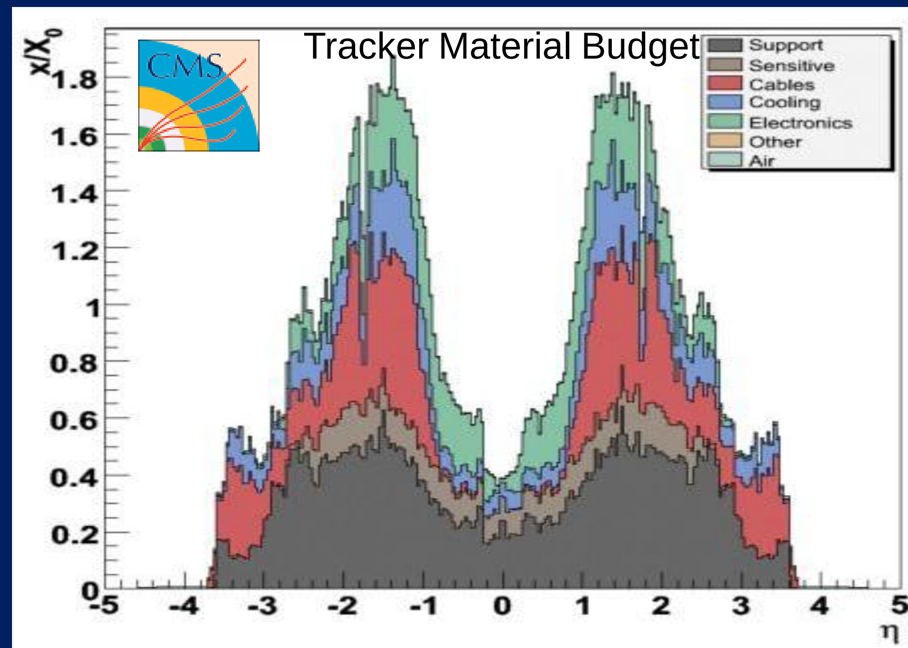
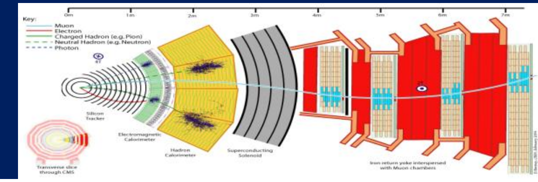


Figure 13.29: Path of services for all tracking detectors (shown in orange). The services are integrated into support structures whenever possible

- Detector of very compact design; It might be necessary to open places/grooves/tunnels for services affecting the aperture of the detector; Optimum between costs and detector acceptance needs to be found.
- Service and Infrastructure need very careful design being the main contributor to Material Budget ➔



Solenoid Options



Large Coil

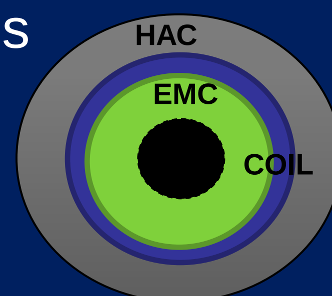
- Large Solenoid containing the Calorimeter
- 3.5 T Solenoid of similar to CMS/ILC
- Precise Muon measurement
- Large return flux either enclosed with Iron or

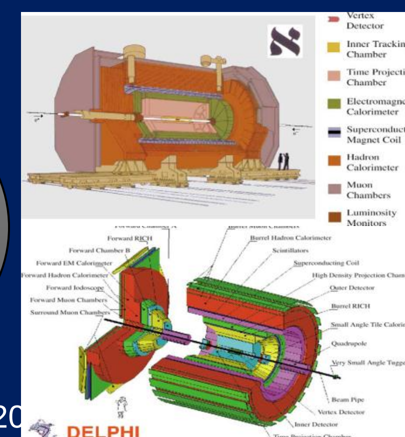
  Option of active B shielding with 2nd solenoid

General parameters	
Magnetic length	12.5 m
Free bore diameter	6.3 m
Central magnetic induction	4 T
Total Ampere-turns	41.7 MA-t
Nominal current	19.14 kA
Inductance	14.2 H
Stored energy	2.6 GJ
Cold mass	
Layout	Five modu coupled
Radial thickness of cold mass	312 mm
Radiation thickness of cold mass	3.9 X_0
Weight of cold mass	220 t
Maximum induction on conductor	4.6 T
Temperature margin wrt operating temperature	1.8 K
Stored energy/unit cold mass	11.6 kJ/kg
Iron yoke	
Outer diameter of the iron flats	14 m
Length of barrel	13 m
Thickness of the iron layers in barrel	300, 630 a
Mass of iron in barrel	6000 t
Thickness of iron disks in endcaps	250, 600 a
Mass of iron in each endcap	2000 t
Total mass of iron in return yoke	10 000 t

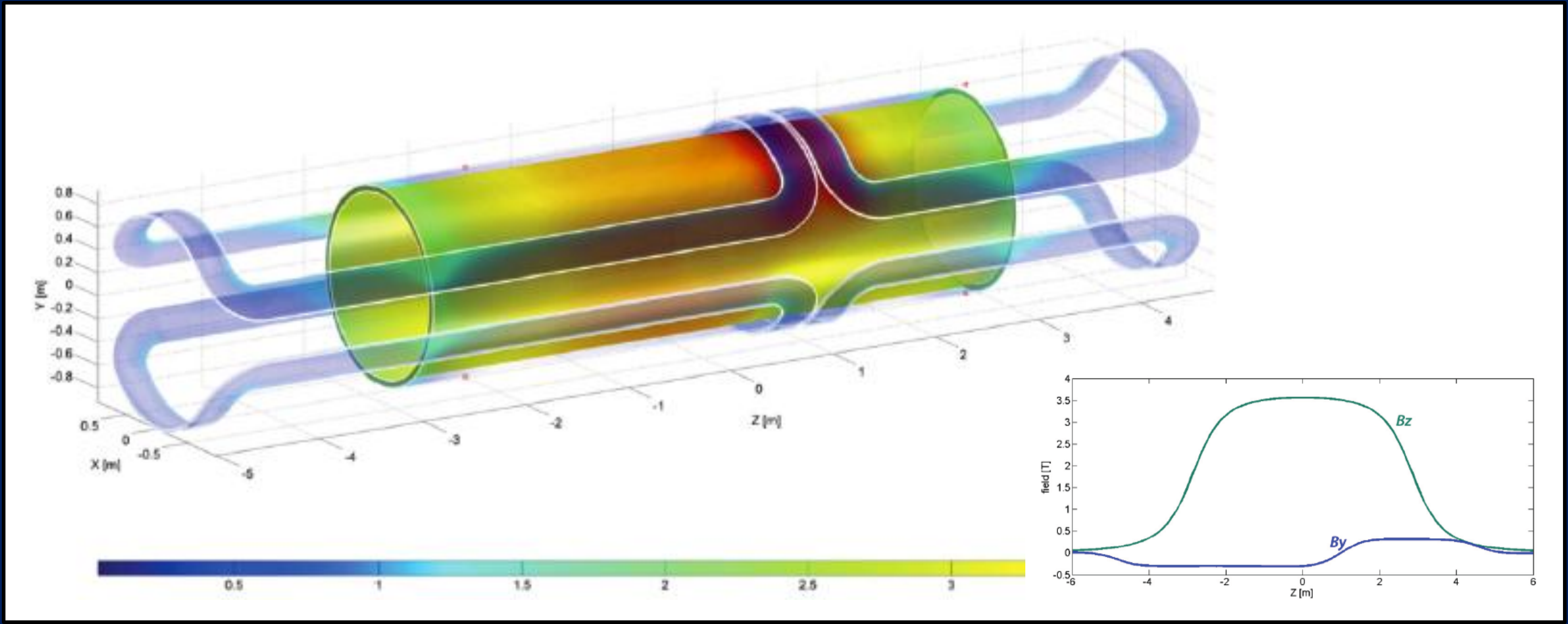
Small Coil

- Smaller Solenoid placed between EMC and HAC
- Cheaper option
- Convenient displacement of Solenoid and Dipoles in same cold vacuum vessel (Linac-Ring only)
- Smaller return flux (less iron required)
- Muon p, p_t measurement compromised





Magnets

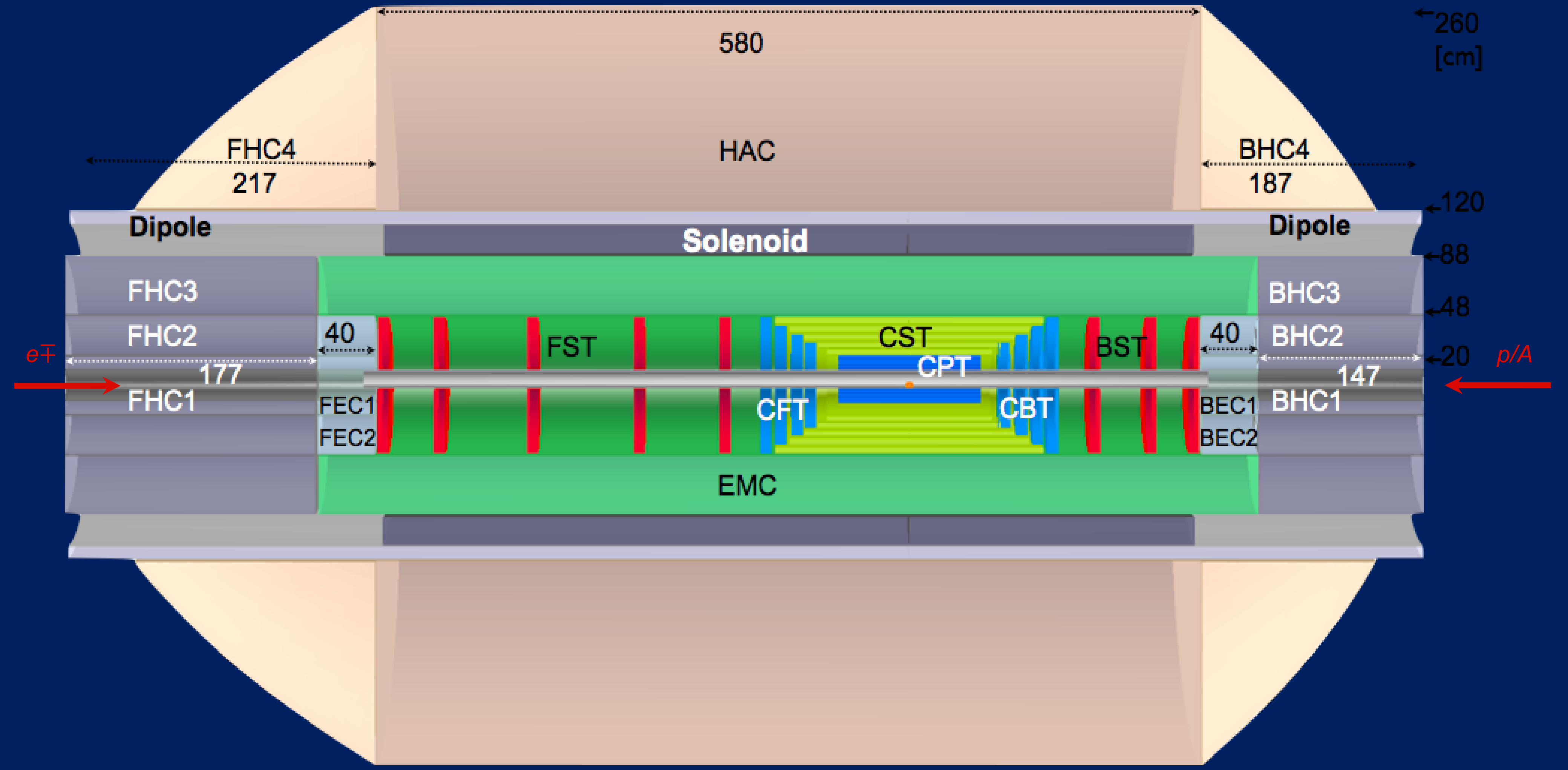


Baseline Solution:

- Solenoid (3.5 T) + dual dipole 0.3 T (Linac-Ring Option)
- Magnets (may be) embedded into EMC LAr Cryogenic System

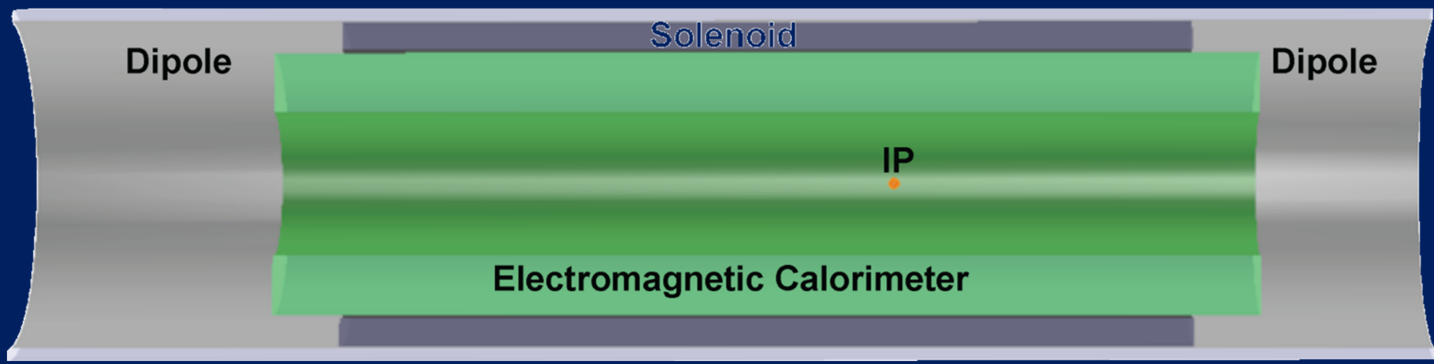
➔ Need of study the Calorimeter Performance and impact of dead material between EMC and HAC sections; it might be possible placing the magnet system even in front of the EMC - at even lower radius at just outside of the tracking system

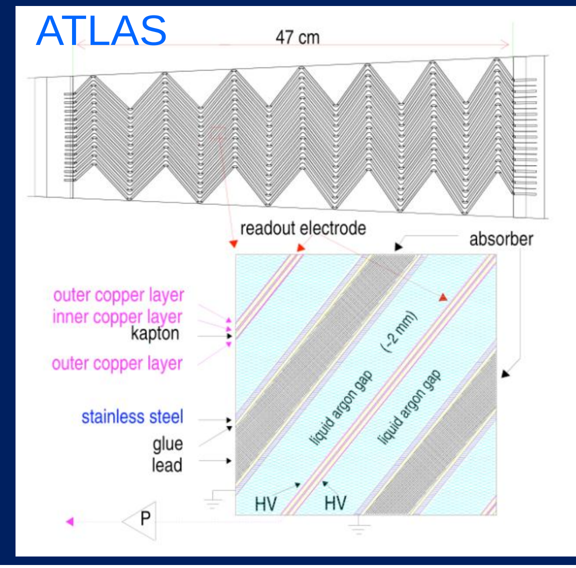
Baseline Detector



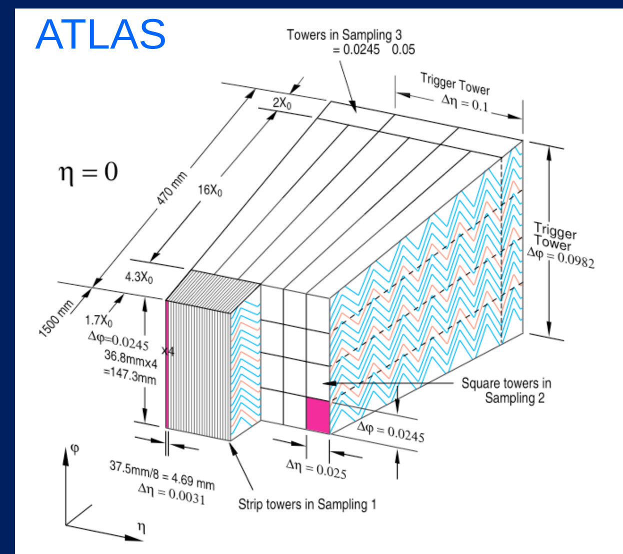
Electromagnetic Calorimeter (i)

- Baseline Electromagnetic Calorimeter
- LAr for barrel EMC calorimetry - ATLAS (~25-30 X_0)

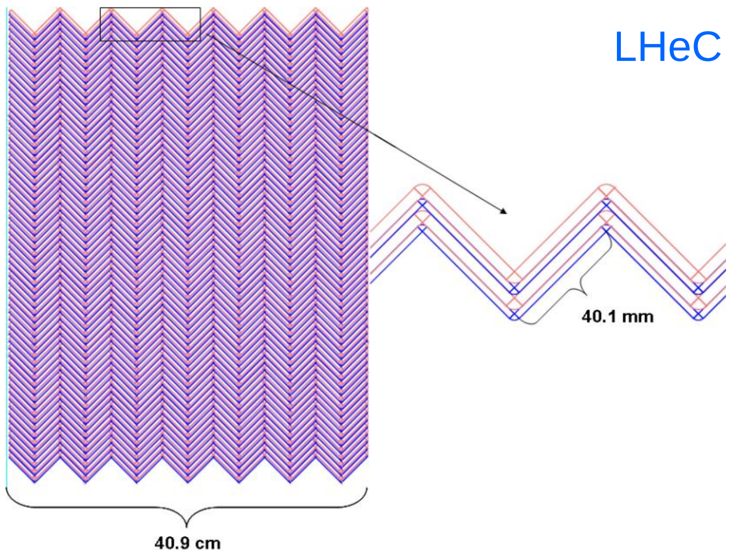




- – Advantage: same cryostat used for solenoid and dipoles
- – GEANT4 simulation (*)
- – Simulation results compatible with ATLAS
- – barrel cryostat being carefully optimized
  pre-sampler optimal
- – 3 different granularity sections longitudinally



Electromagnetic Calorimeter (ii)



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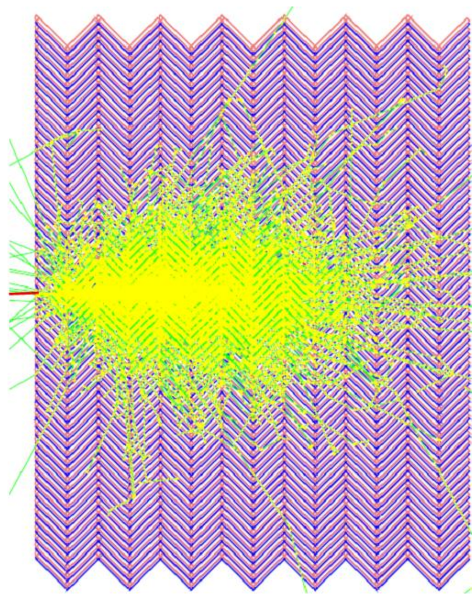
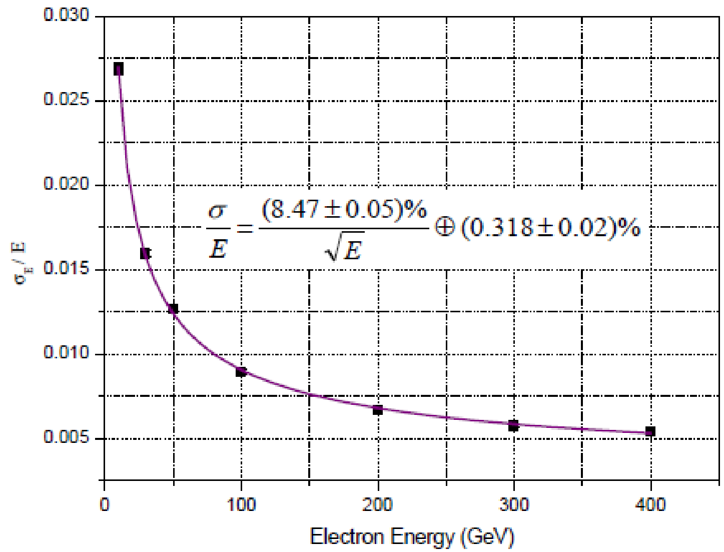
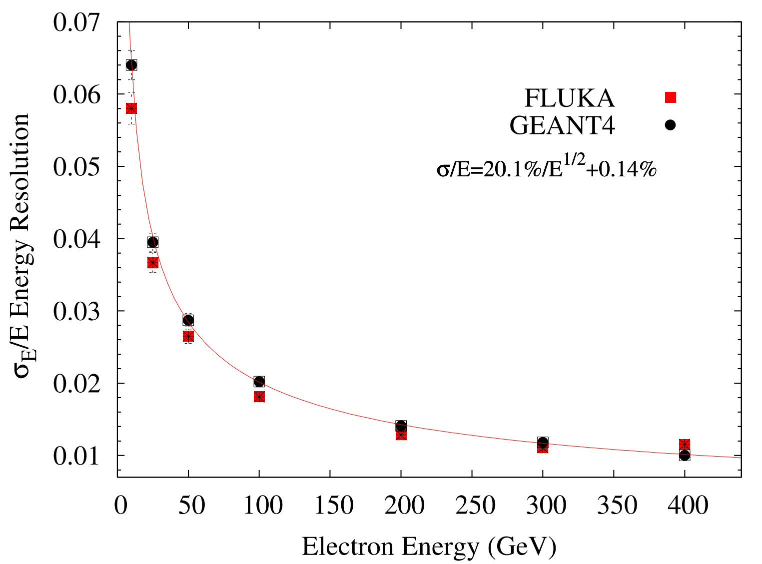


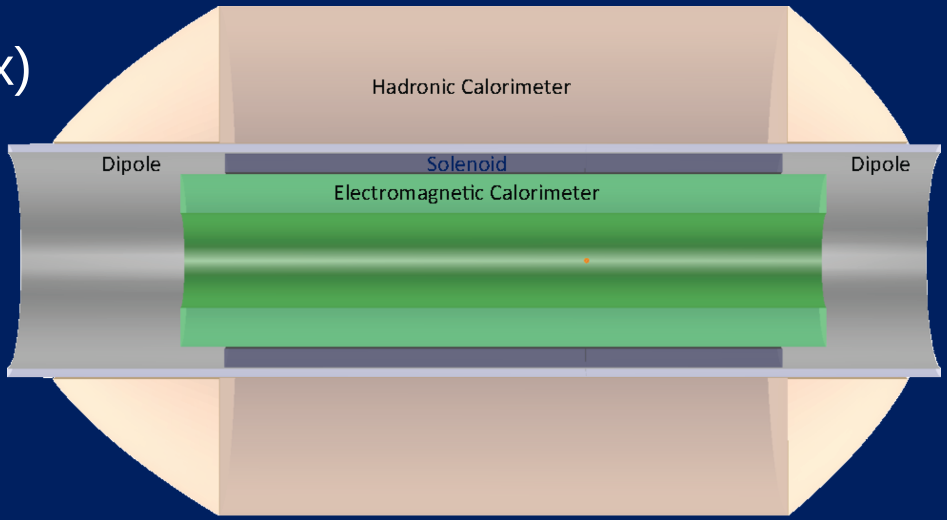


- Simulation with simplified design w.r.t.Atlas
- LAr Calorimeter : good energy resolution, stable performance
- Simulation results compatible with ATLAS
- Warm (Pb/Sci) option also investigated
- $30X_0$ (X_0(Pb)=0.56 cm; 20 layers) →



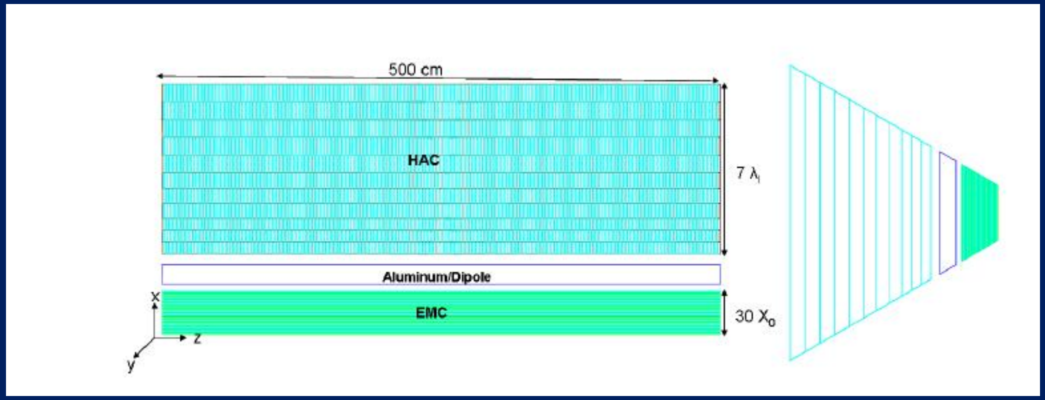
Hadronic Calorimeter (i)

- Baseline Design
  - HAC iron absorber (magnet return flux)
  - scintillating plates
    (similar to ATLAS TILE CAL)
  - Interaction Length: ~7-9 λ_I



- Setup:

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



- GEANT4 simulation (*)
- performance optimization:
  - containment, resolution, combined HAC & EMC response
  - solenoid/dipoles/cryostat in between

(*) F. Kocak, I. Tapan Uludag Univ.

Hadronic Calorimeter (ii)

- Preliminary studies on impact of the magnet system on calorimetric measurements (GEANT FLUKA)
- Energy resolutions
- Shower profiles

F.Kocak, I.Tapan, A.Kilic, E.Pilicer Uludag Univ.; E.Arikan, H.Aksakal Nigde Univ.

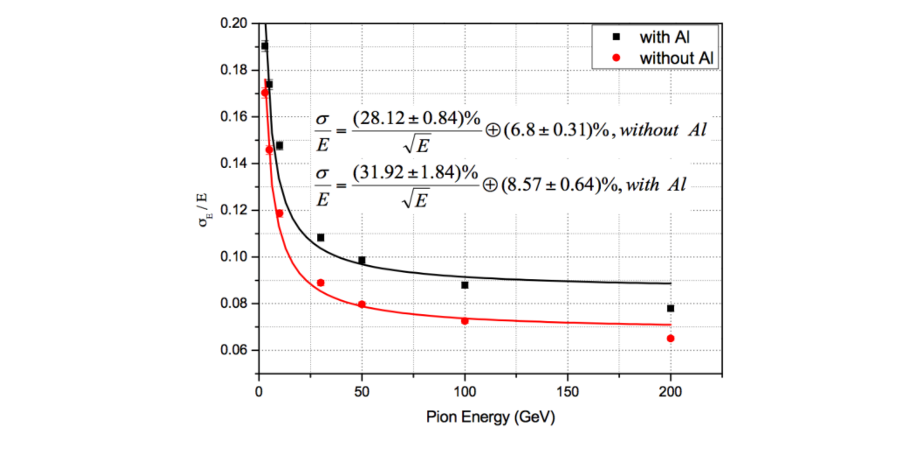


Figure 12.37: Combined LAr Accordion and Tile Calorimeter energy resolution for pions with and without 14 cm Al block (**GEANT4**)

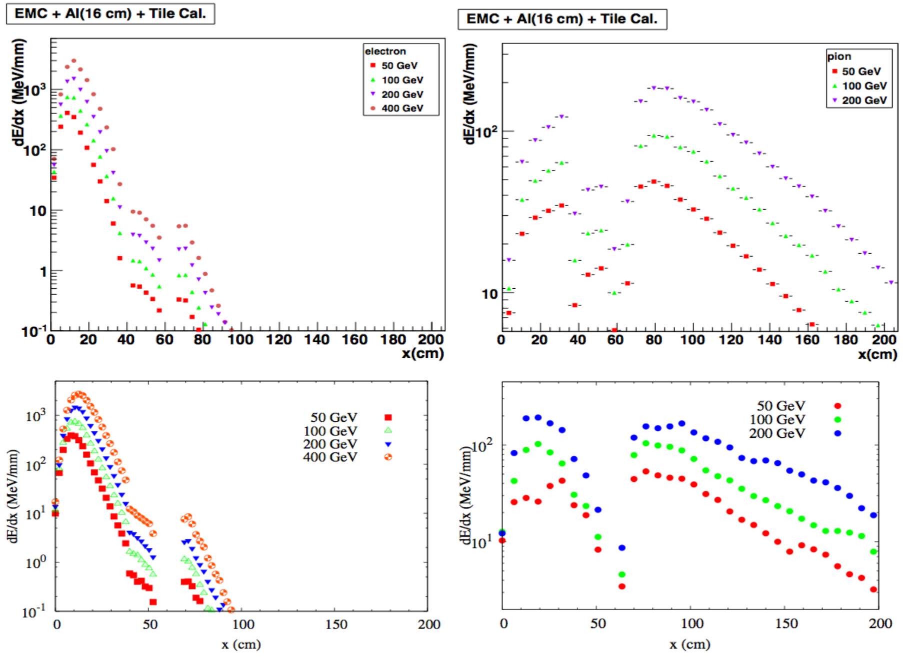


Figure 12.41: Electron (left) and Pion (right) longitudinal shower profile for the EMC_{Pb-Sc} / solenoid-dipole-system (Al-block) / HAC at various energies (**GEANT4** (top) and **FLUKA** (bottom)).

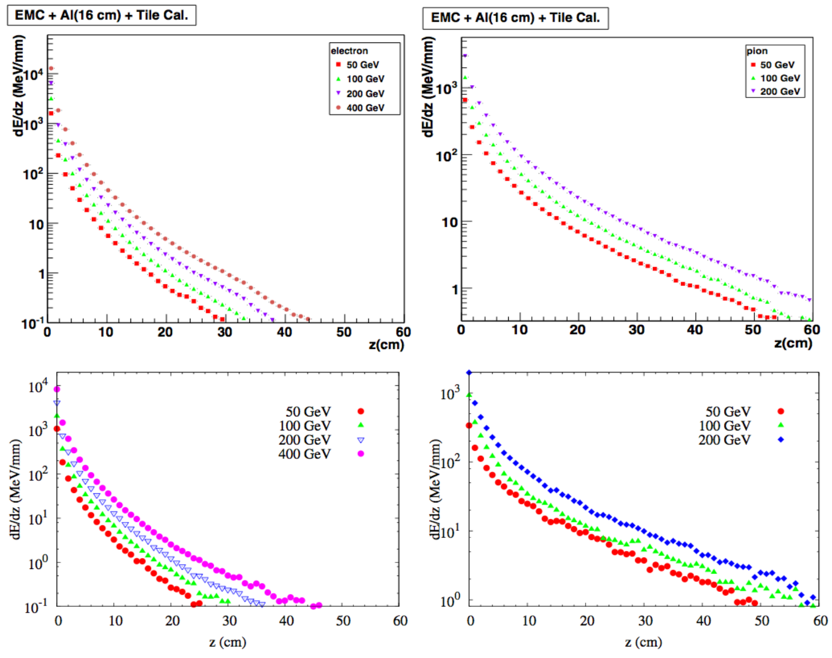


Figure 12.42: Energy deposit and transverse shower profiles for electron (left) and pion (right) - both for the EMC_{Pb-Sc} stack (**GEANT4** (top) and **FLUKA** (bottom)).

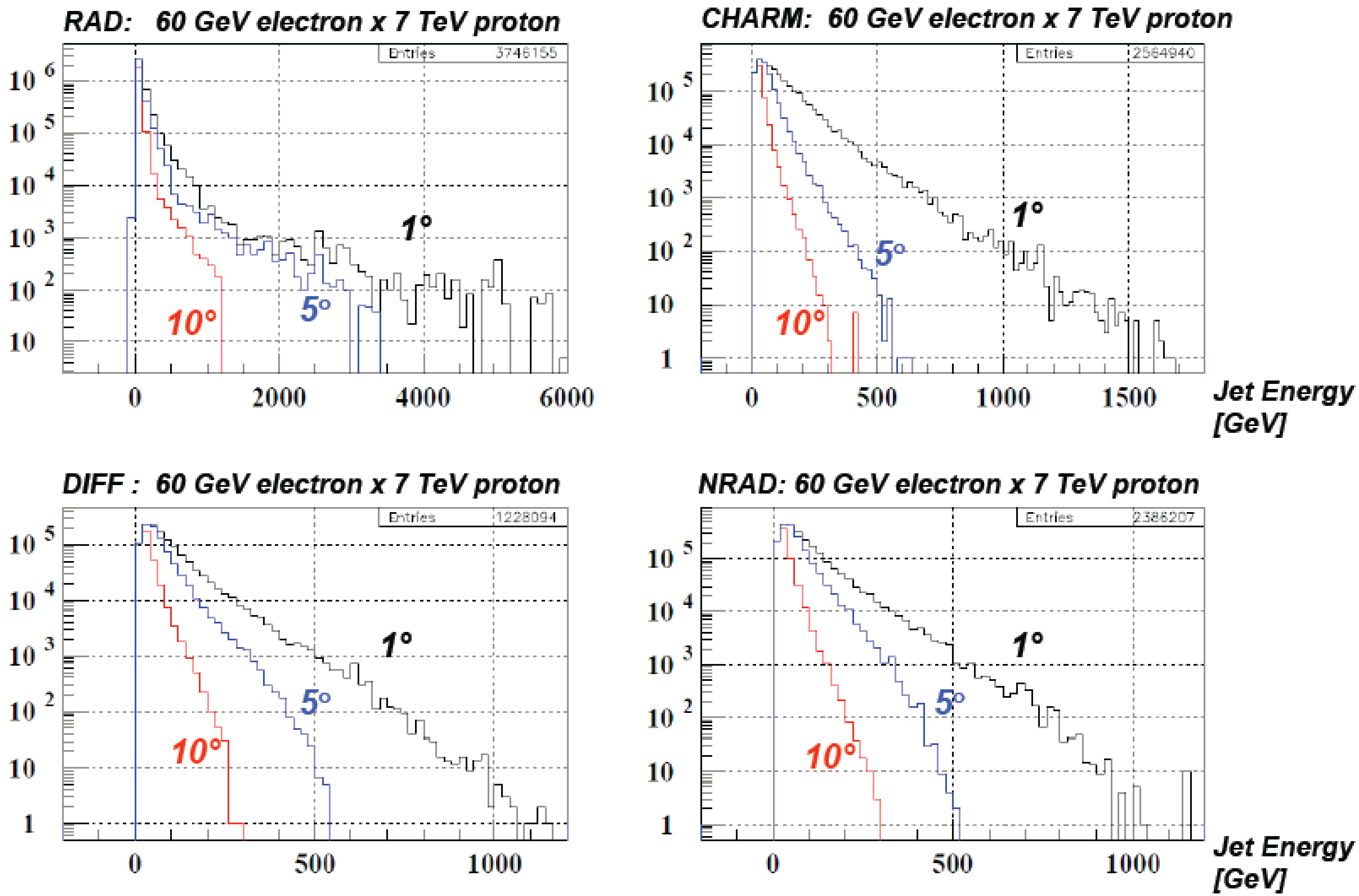
Forward Energy and Acceptance

RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

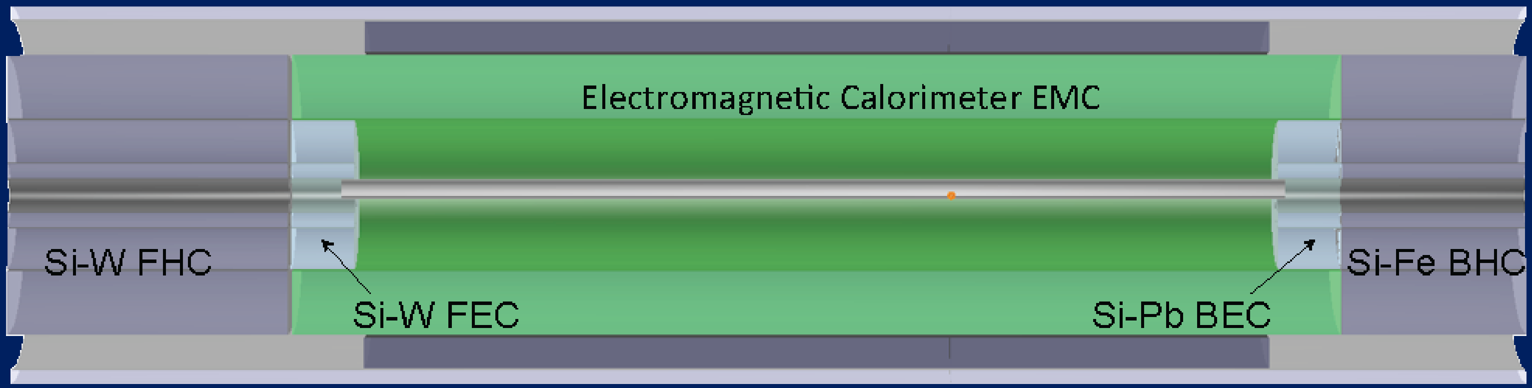
HzTooL-4.2 (H.Jung et.al. - http://projects.hepforge.org/hztool/)

selection: q^2.gt.5

→ Highest acceptance desirable

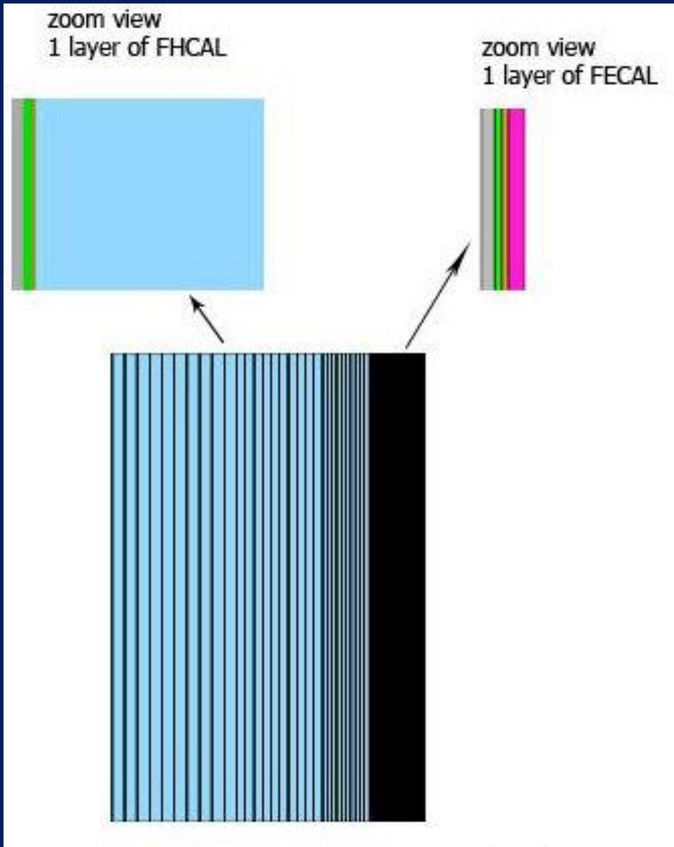


Endcap Calorimeters



Forward/Backward Calorimeters

- **Forward FEC + FHC:**
  - tungsten high granularity
  - Si (rad-hard)
  - high energy jet resolution
  - FEC: ~$30X_0$; FHC: ~8-10 λ_I
- **Backward BEC + BHC:**
  - need precise electron tagging
  - Si-Pb, Si-Fe/Cu (~$25X_0$, 6-8 λ_I)
- GEANT4 simulation *
  - containment, multi-track resolution (forward)
  - $e^{\pm}$ tagging/E measurement (backwards)



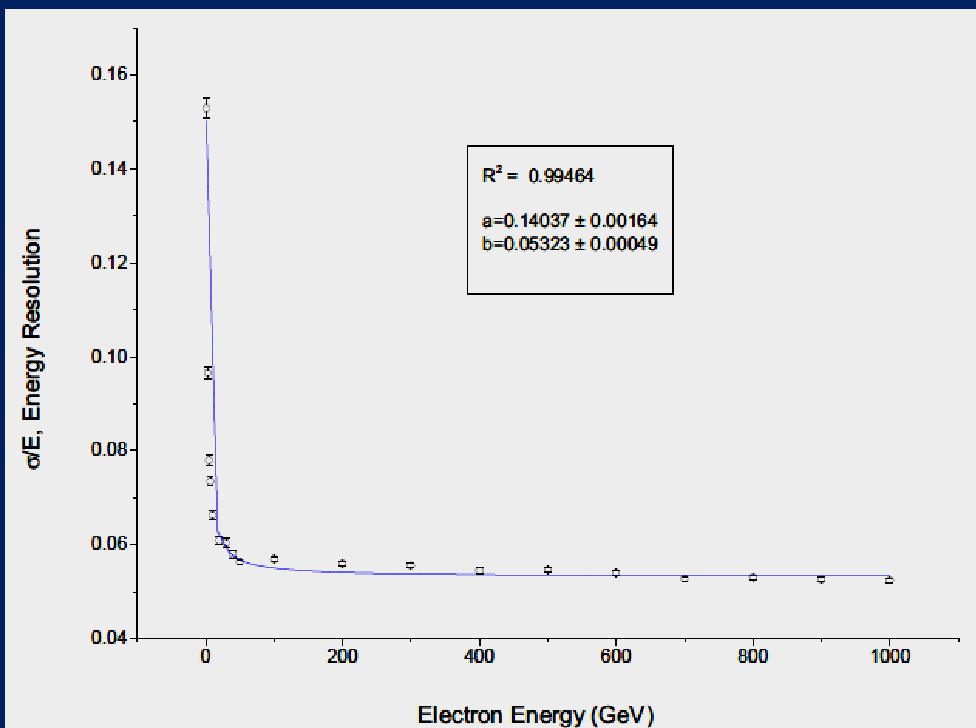
FECAL + FHCAL composite calorimeter

* A. Kilic, I. Tapan - Uludag University

Forward/Backward Calorimeters

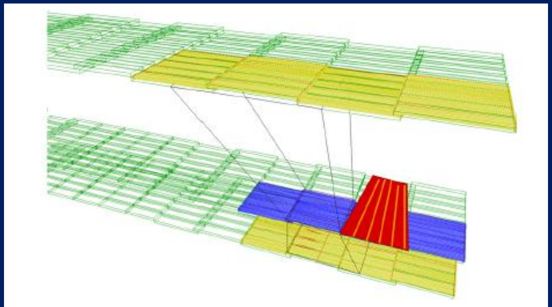
- Highest energies in forward region
- Radiation hard
- High Granularity
- Linearity

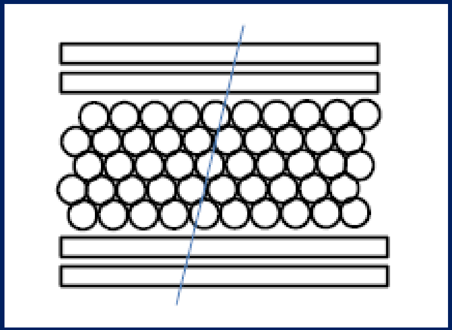
Calorimeter Module	Layer	Absorber	Thickness	Instrumented Gap	Total Depth
FEC(W-Si) 30x0	1-25 26-50	1.4 mm 2.8 mm	16 cm 19.5 cm	5 mm	35.5 cm
FHC (W-Si)	1-15 16-31 32-46	1.2 cm 1.6 cm 3.8 cm	39 cm 48 cm 78 cm	14 mm	165 cm
FHC (Cu-Si)	1-10 11-20 21-30	2.5 cm 5 cm 7.5 cm	30 cm 55 cm 80 cm	5 mm	165 cm
BEC (Pb-Si)	1-25 26-50	1.8 mm 3.8 mm	17 cm 22 cm	5 mm	39 cm
BHC(Cu-Si) 7.9	1-15 16-27 28-39	2.0 cm 3.5 cm 4.0 cm	39.75 cm 49.8 cm 55.8 cm	6.5 mm	145.35cm

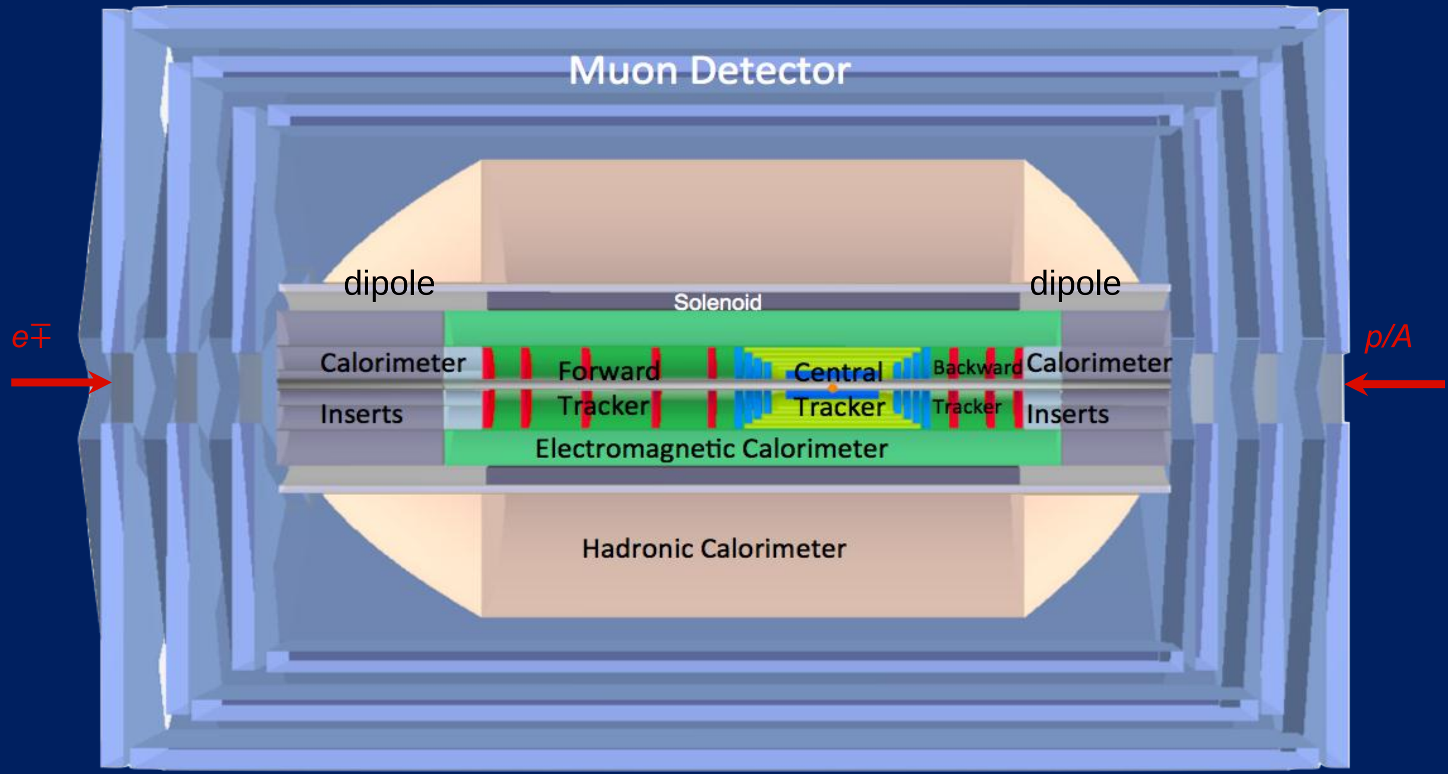


Calorimeter Module (Composition)	Parameterized Energy Resolution
Electromagnetic Response	
$\mathrm{FEC}_{(\mathbf{W-Si})}$	$\frac{\sigma_E}{E} = \frac{(14.0 \pm 0.16)\%}{\sqrt{E}} \oplus (5.3 \pm 0.049)\%$
$\mathrm{BEC}_{(\mathbf{Pb-Si})}$	$\frac{\sigma_E}{E} = \frac{(11.4 \pm 0.5)\%}{\sqrt{E}} \oplus (6.3 \pm 0.1)\%$
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 Baseline



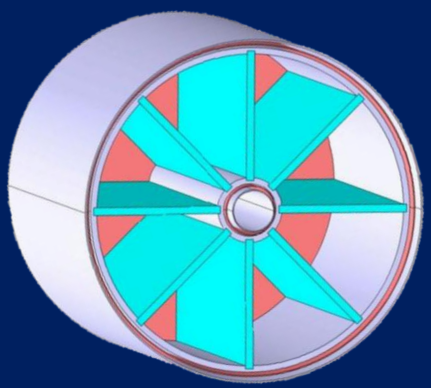


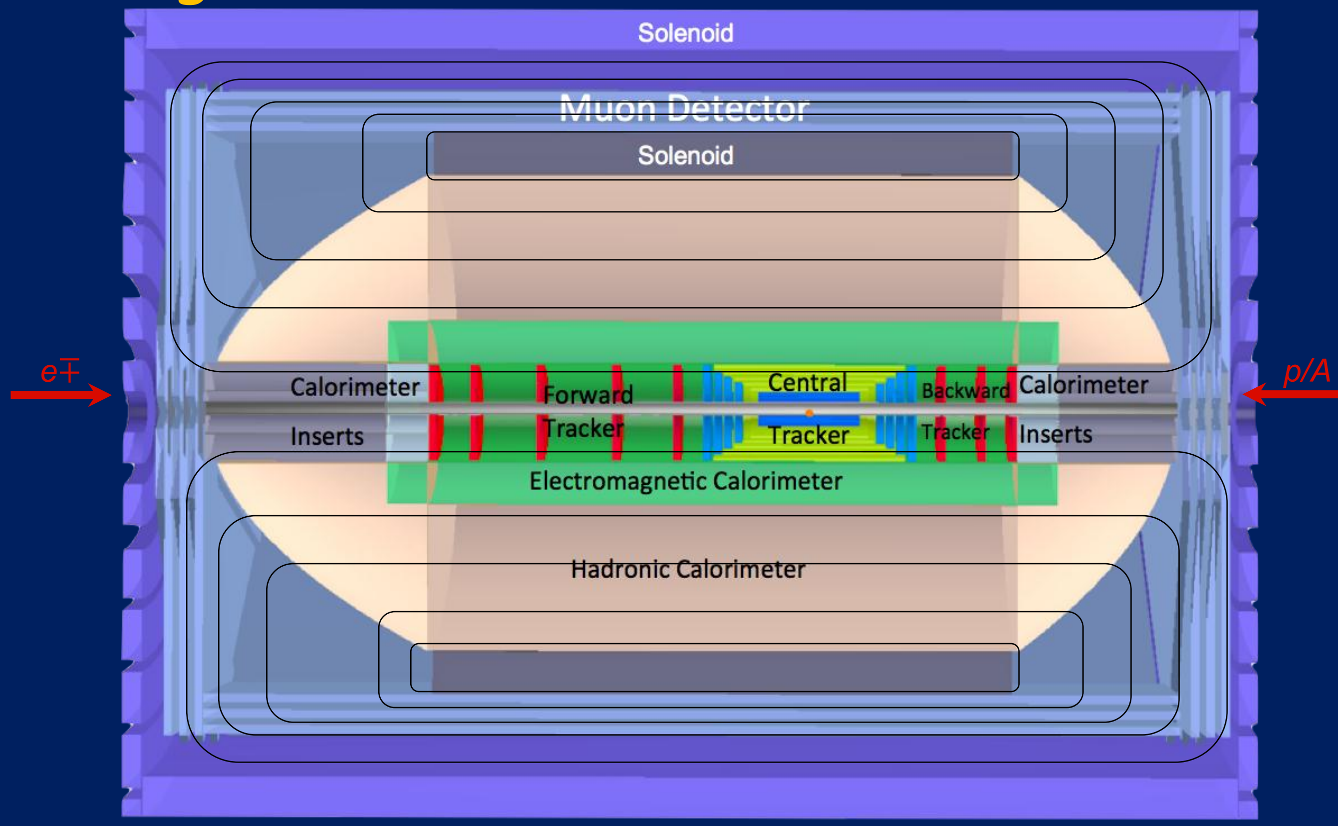


Baseline Solution:

- Muon system providing tagging, no independent momentum measurement
- Momentum measurement done in combination with inner tracking
- Present technologies in use in LHC exp. sufficient (RPC, MDT, TGC)

Muon System Extensions





Extensions:

- Independent momentum measurement
- Large solenoid (incompatible with LR dipoles)
- Dual Coil System (homogeneous return field)
- Forward Toroid System

Status and Outlook

- A LHeC baseline detector concept has been presented
- The design depends heavily on the constraints from the machine and interaction region
- For all cases a feasible and affordable concept which fulfills the physics requirements has been presented
- As a baseline many improvements available. A more precise design will follow from more detailed simulations, engineering and the knowledge of the machine constraints

This Workshop

- Start a new phase in detector design
- Collect people, experience, information
- Identify and address critical items, discuss the timeline for realization
- Build a collaboration and move next steps towards a Technical Design

Detector Session Agenda

Thursday:

Detector (14:00 ->18:00)		
14:00	Interaction Region (30')	Rogelio Tomas Garcia (CERN)
14:30	IR Beam Pipe and Vacuum (30')	Paul Cruikshank (CERN)
15:00	Muon Detection (30')	Ludovico Pontecorvo (Universita e INFN, Roma I (IT))
15:30	Detector Magnet Designs (30')	Herman Ten Kate (CERN)
16:00	Coffee (30')	
16:30	LHeC Tracker Design viewed from LHCb (30')	Themis Bowcock (CERN)
17:00	LHeC Tracker Design viewed from CMS (30')	Andrei Starodumov (Eidgenoessische Tech. Hochschule Zuerich (CH))
17:30	LHeC Tracker Design viewed from ATLAS (30')	Ilya Tsurin (University of Liverpool (GB))

Friday:

Detector (09:00 ->13:00)		
09:00	ECAL Design viewed from ATLAS and H1 (30')	Juraj Bracinik (University of Birmingham (GB))
09:30	Tile/hadronic Calorimeter Design viewed from ATLAS (30')	Claudio Santoni (Univ. Blaise Pascal Clermont-Fe. II (FR))
10:00	Developments in Hadron Calorimetry (30')	Jose Repond (Argonne National Laboratory)
10:30	Coffee (30')	
11:00	Forward and Backward Taggers (30')	Armen Bunyatian (DESY)
11:30	A Detector Installation Study (20')	Andrea Gaddi (CERN)
11:50	Resources Estimates (20')	Markus Nordberg (CERN)

Our Thanks to all who contributed, not only within the Detector Group, but also to the Physics, Interaction Region and Accelerator Groups

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