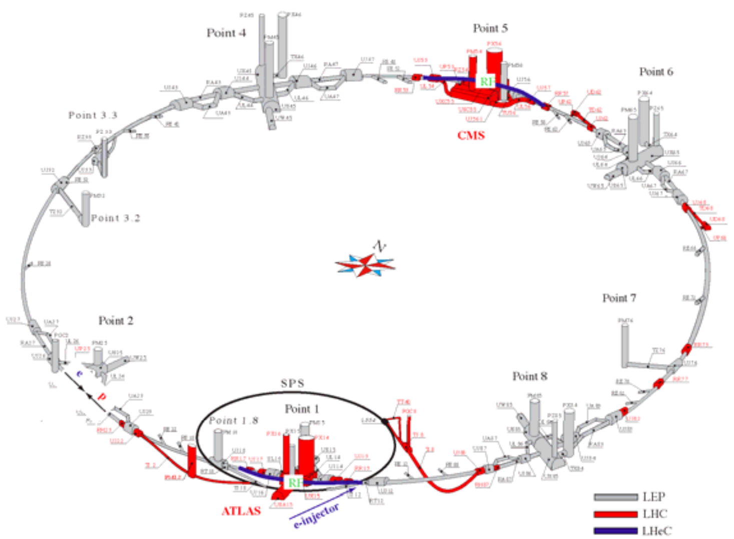
From LHeC to FCC-he Detector

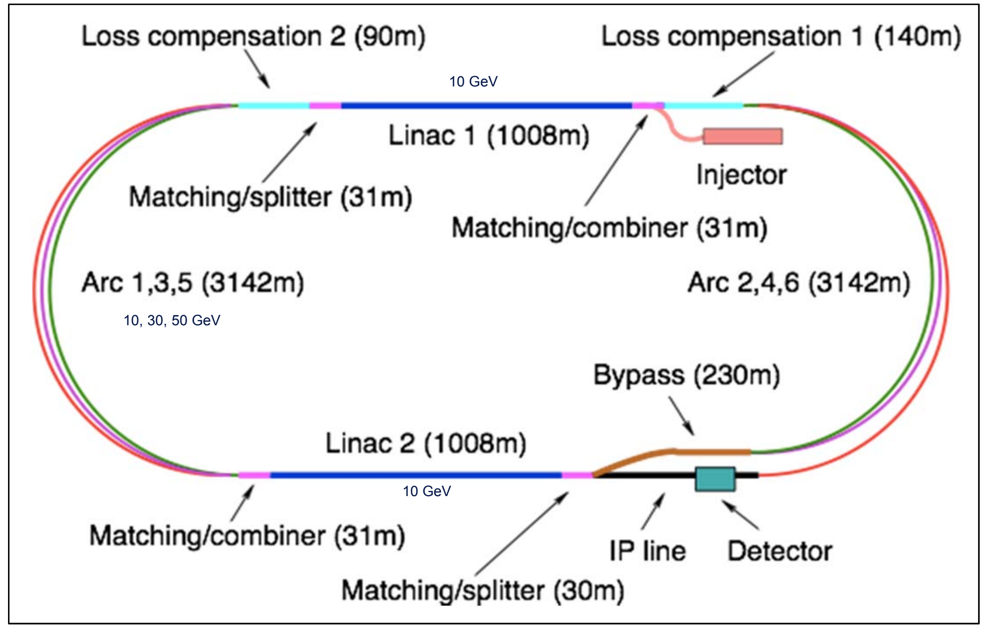
P.Kostka, A.Polini
on behalf of the LHeC Study Group

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]

$e^{\pm}$ Beam Options: RR and LR





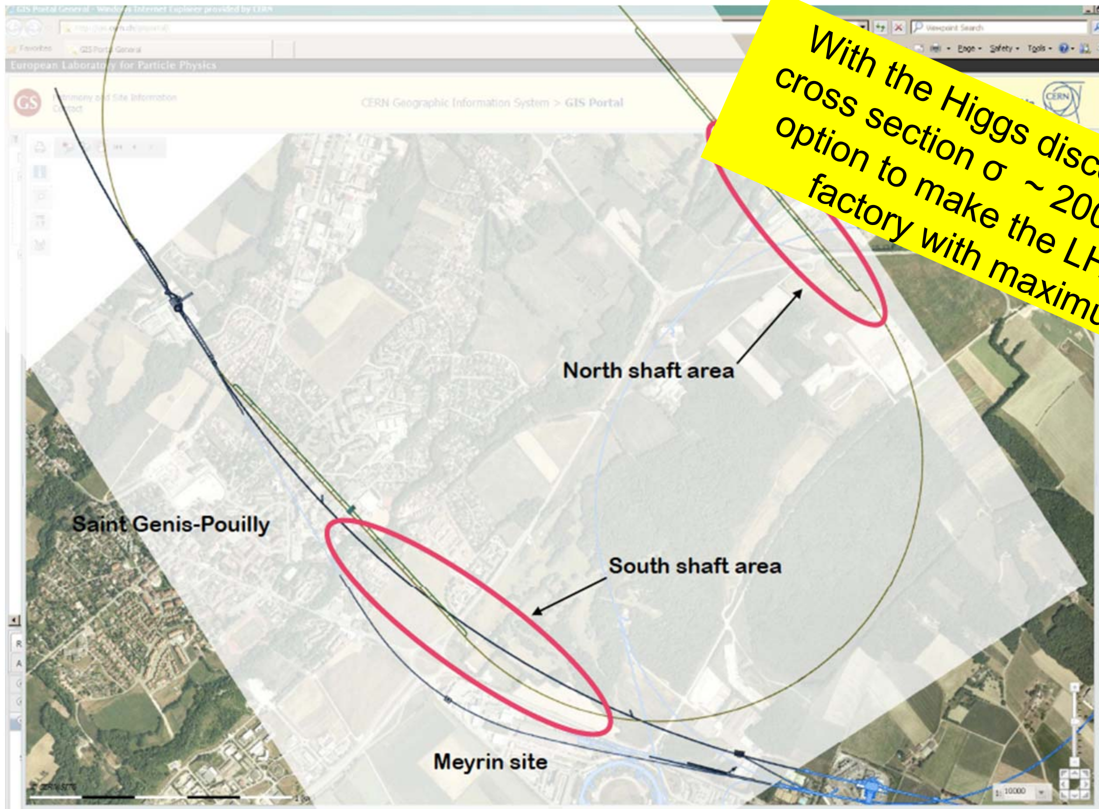
- **Ring-Ring**
  - $e^{\mp}p$ and $e^{\mp}A$ (A=Pb, Au, …) collisions
  - More "conventional" solution, like HERA, no difficulties of principle - at first sight - but constrained by existing LHC in tunnel
  - polarization 40% with realistic misalignment assumptions
- **Linac-Ring (default)**
  - $e^{\mp}p$ and $e^{\mp}A$ (A=Pb, Au, …) collisions, polarized e^- from source, somewhat less luminosity for e^+
  - New collider type of this scale, Energy Recovery Linac

Baseline: Energy Recovery Linac

- Linac-Ring design employs two 1km long Linac's, with energy recovery
  - Novel new accelerator design
  - Default option due to reduced impact on the LHC schedule (compared to RR design)
  - Lower luminosity for e^+ running (e$^-$ - a few x10^{34}cm^{-2}s^{-1} achievable)

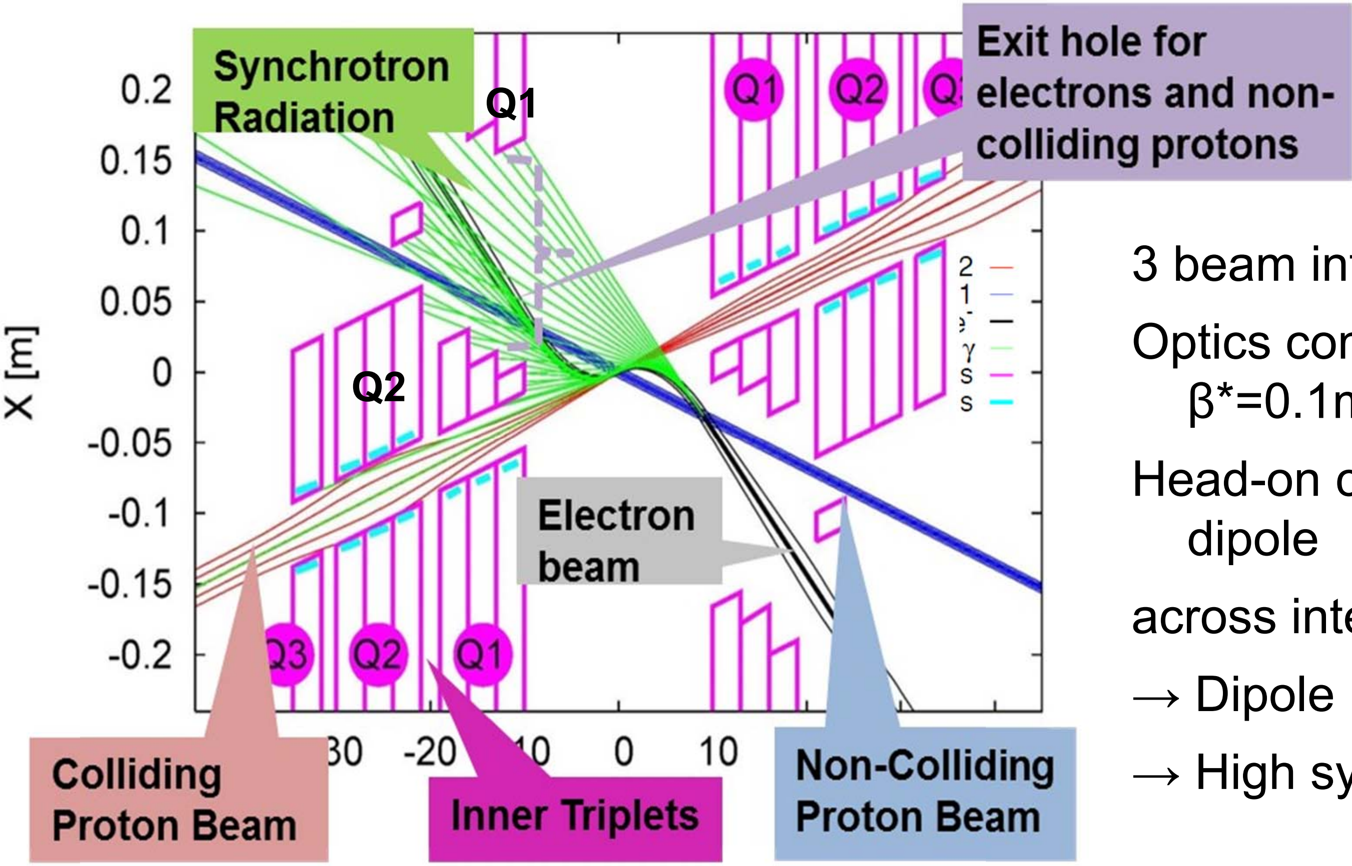
Luminosity [10^{33}cm^{-2}s^{-1}]	1-10**
Detector acceptance [deg]	1
Polarization [%]	90
IP beam sizes [μm]	7
Crossing angle [mrad]	0
e- L* [m]	30
Proton L* [m]	15
e- beta*$_{x,y}$ [m]	0.12
Proton beta*$_{x,y}$ [m]	0.1
Synchrotron power [kW]	22

** high luminosity achievable according to recent estimates



With the Higgs discovery and measured cross section σ ~ 200fb there is a striking option to make the LHeC a clean Higgs factory with maximum luminosity

The Interaction Region



3 beam interaction region

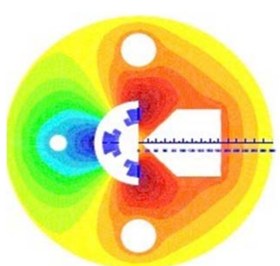
Optics compatible with LHC running and β*=0.1m

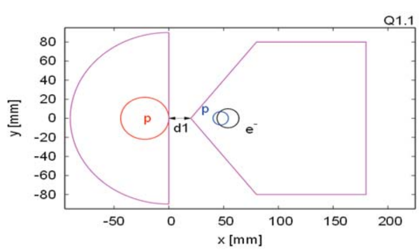
Head-on collisions achieved via long dipole

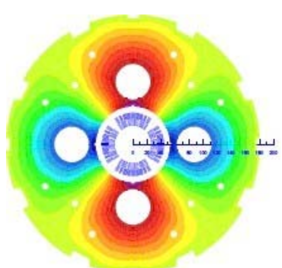
across interaction region

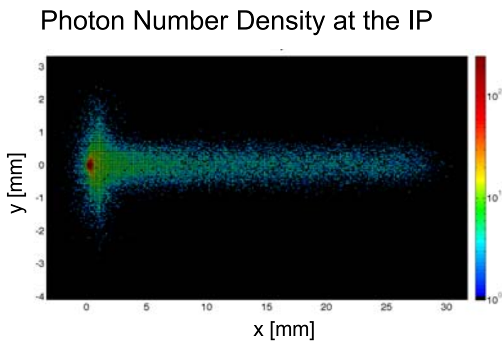
→ Dipole in main detector

→ High synchrotron radiation load

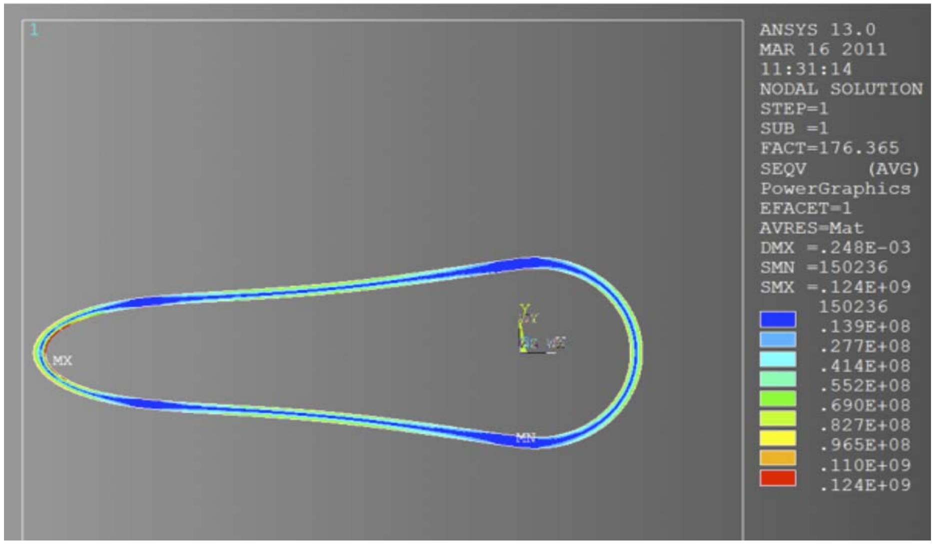


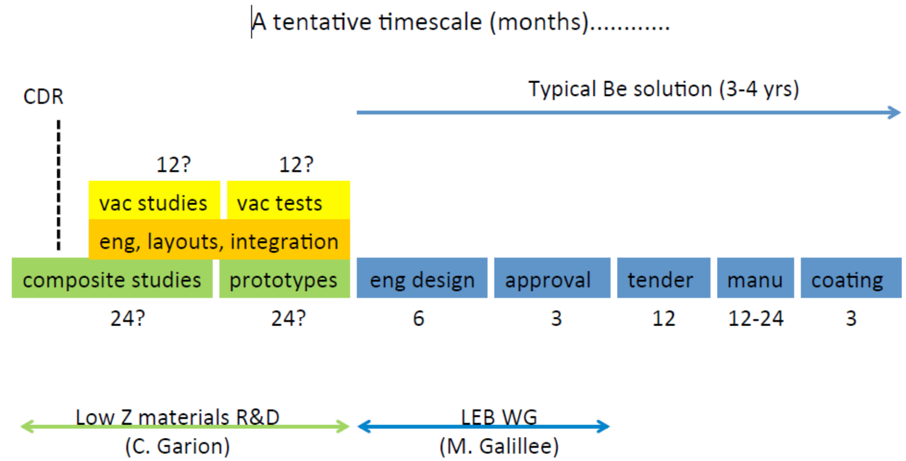






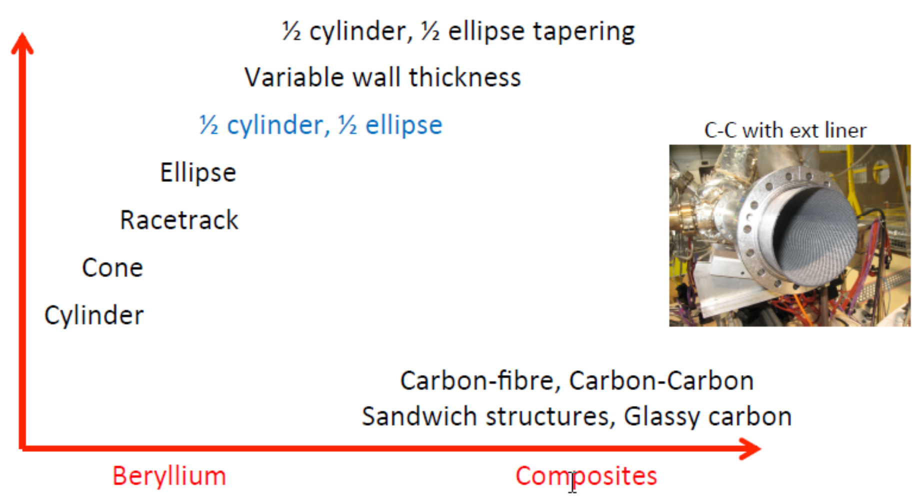
Beam Pipe Considerations



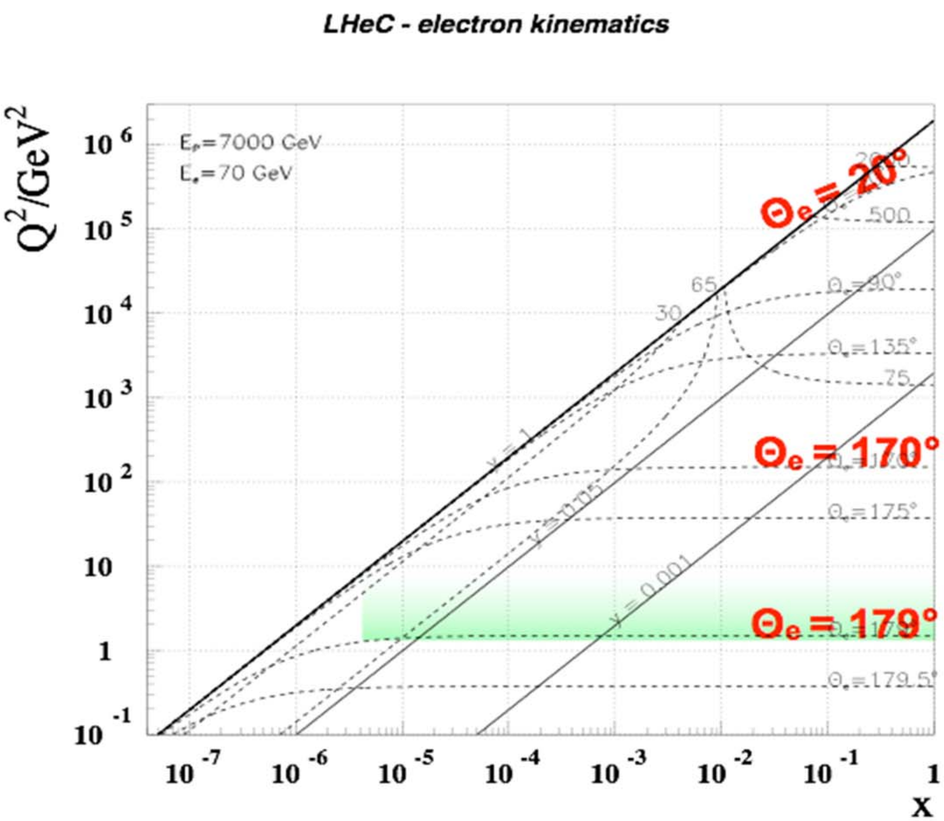


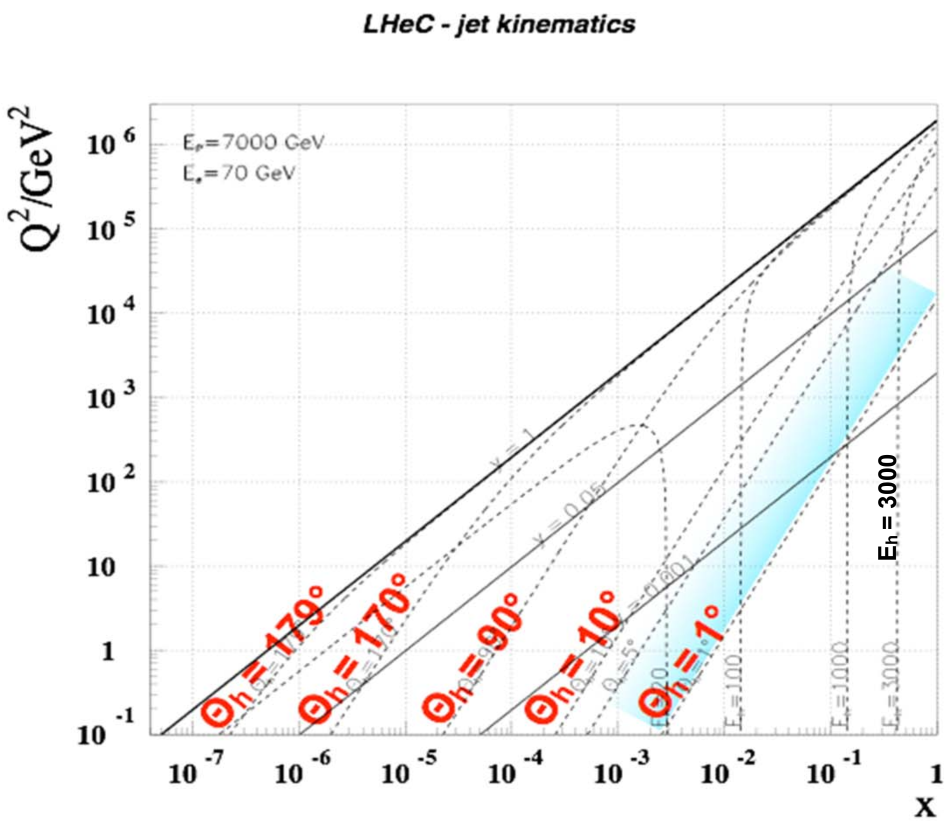
Additional manpower is necessary to advance on LHeC eng & vacuum physics issues

- 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



LHeC Kinematics





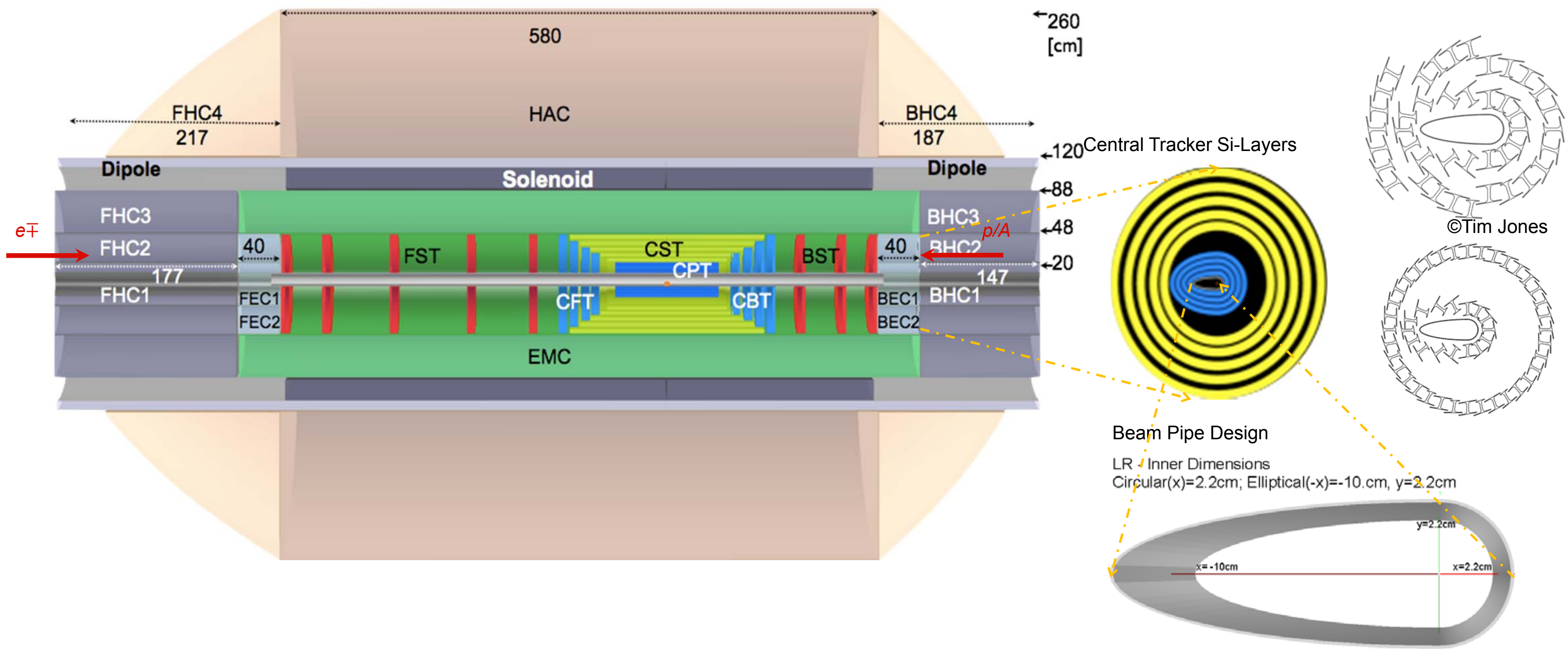
- High x and high Q^2: few TeV HFS scattered forward:
- → Need forward calorimeter of few TeV energy range down to 1^0
- Mandatory for charged currents where the outgoing electron is missing
- Scattered electron:
  → Need very bwd angle acceptance for accessing the low Q^2 and high y region

Detector 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 40%/$\sqrt{E}$ 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

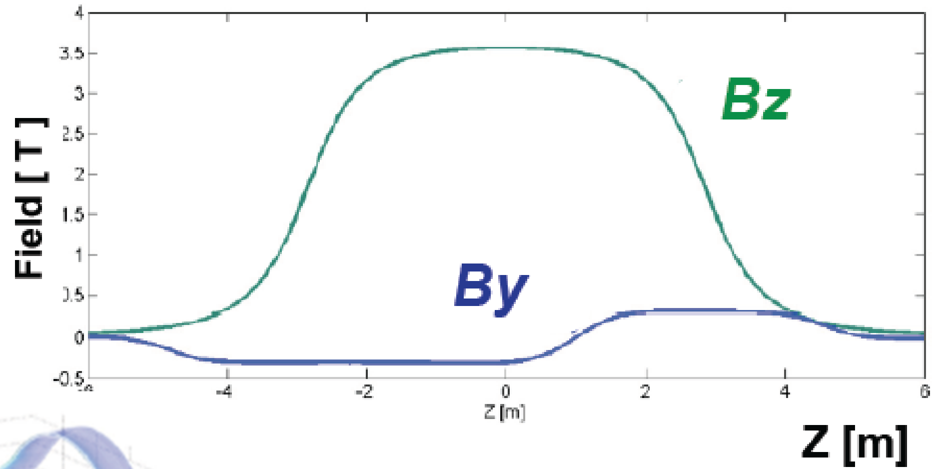
Baseline Detector

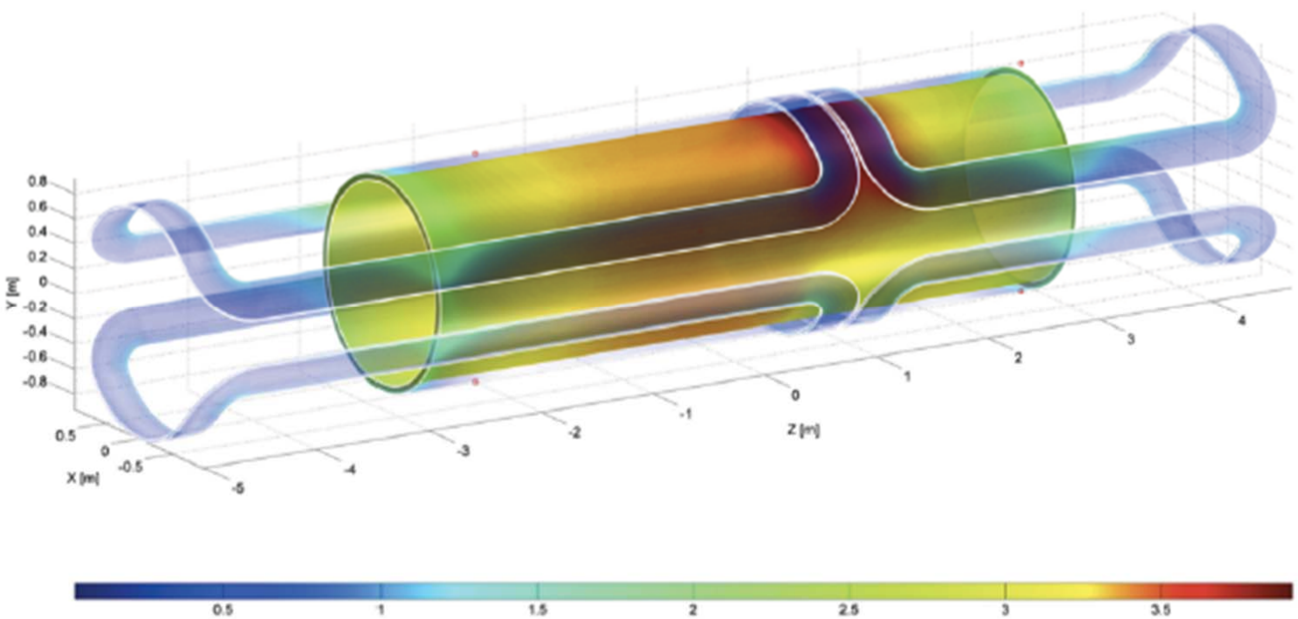


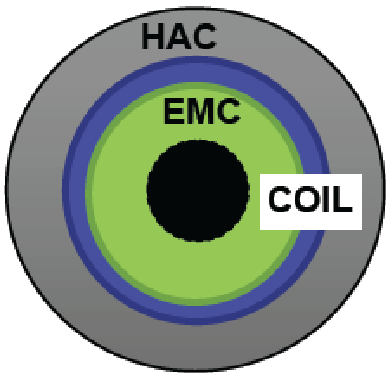
- High acceptance Silicon Tracking System ~1°
- Liquid Argon Electromagnetic Calorimeter (or Pb/Scintillator)
- Fe-Scintillator Hadronic Calorimeter (magnet return flux)
- Forward Backward Calorimeters: Si/W Si/Cu …

Detector Magnets: Solenoid and Dipoles

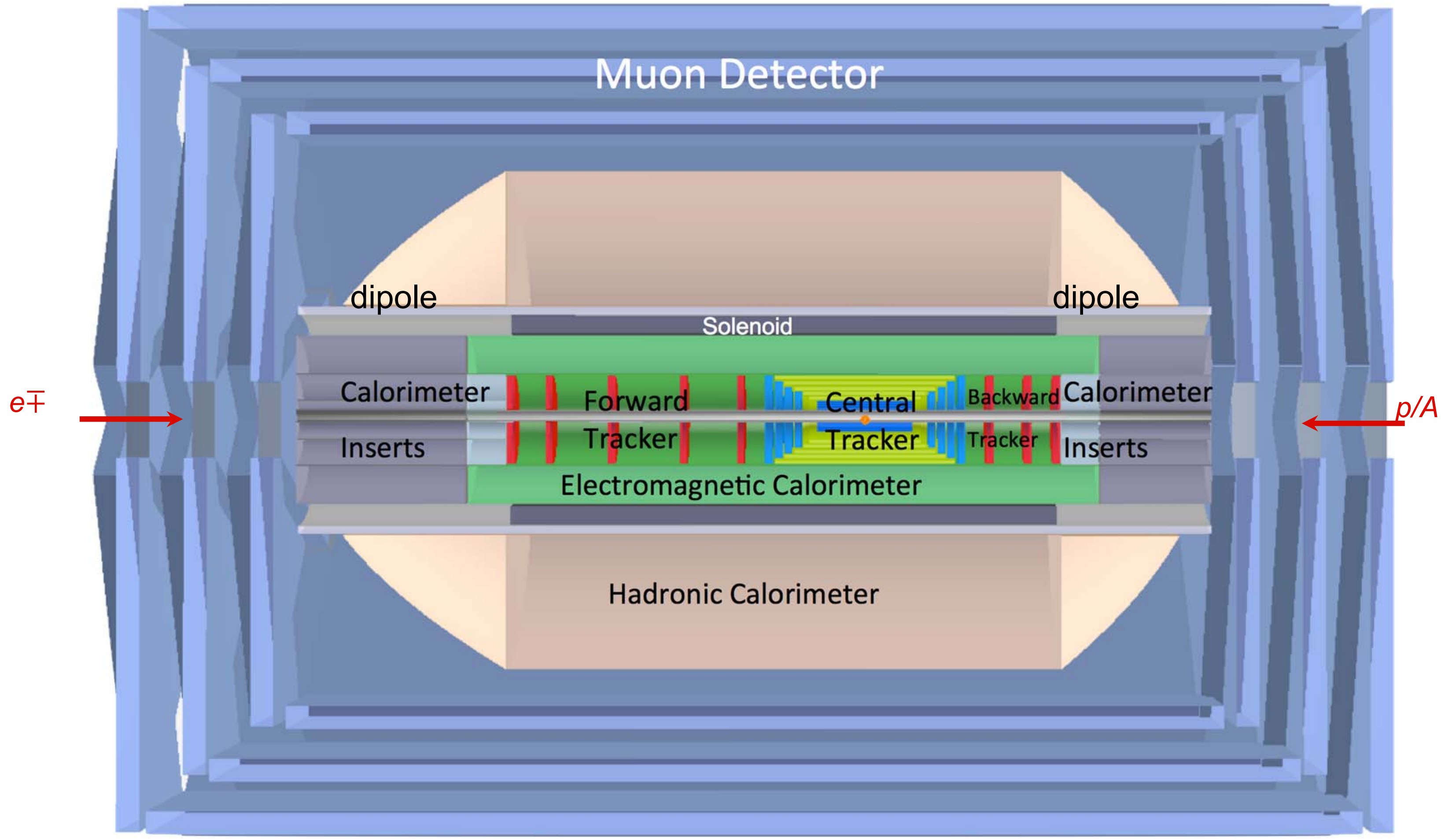
- Baseline: Solenoid (3.5 T) + dual dipole 0.3 T (Linac-Ring Option)
  Both magnets (may be) embedded into EMC LAr Cryogenic System
  - Large coils (double solenoid): Containing full calorimeter, precise muon measurement, large return flux
- Small coil: Cheaper, less iron for return flux, solenoid and dipoles conveniently within the same cold vacuum vessel, but no muon measurement







LHeC Detector Overview



- Forward / backward asymmetry reflecting beam kinematic / energy flow
- Present size: 14m x 9m (c.f. CMS 21m x 15m , ATLAS 45m x 25 m)
- e/γ taggers ZDC, proton spectrometer integral to design from outset system providing tagging, no independent momentum measurement

Forward Energy and Acceptance

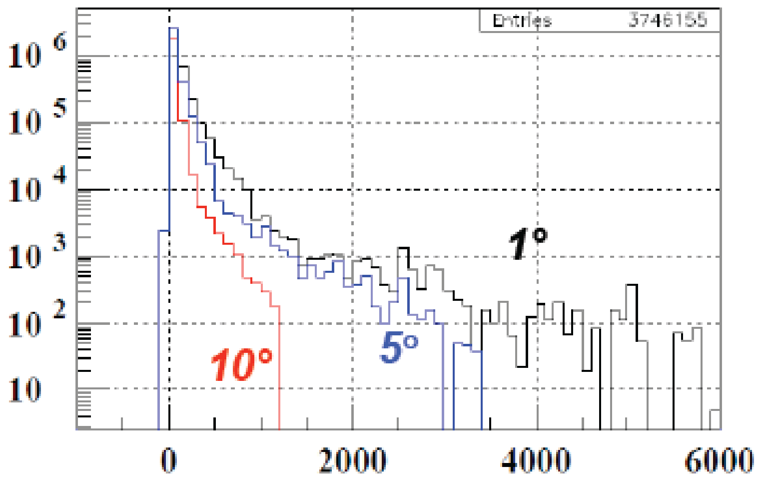
RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

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

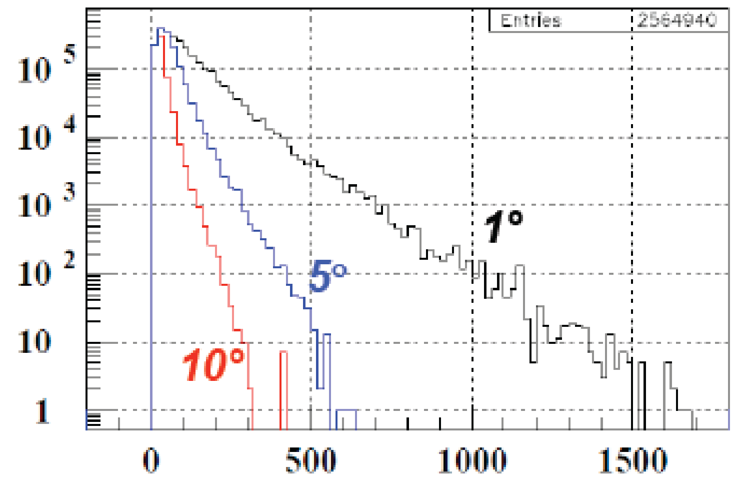
selection: q^2.gt.5

→ Highest acceptance desirable

RAD: 60 GeV electron x 7 TeV proton

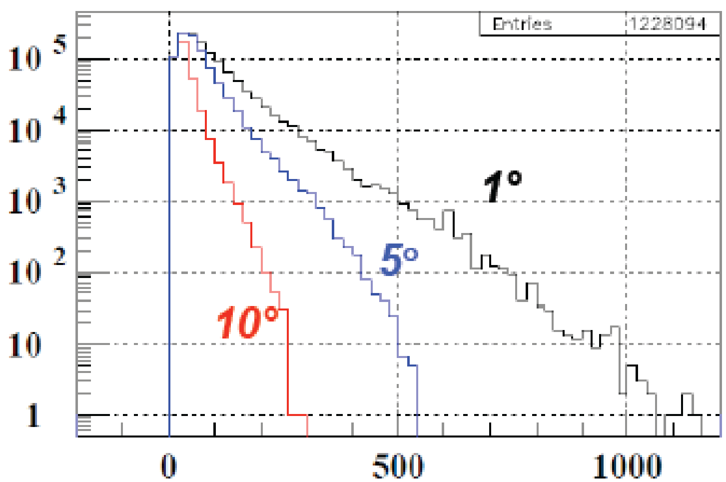


CHARM: 60 GeV electron x 7 TeV proton

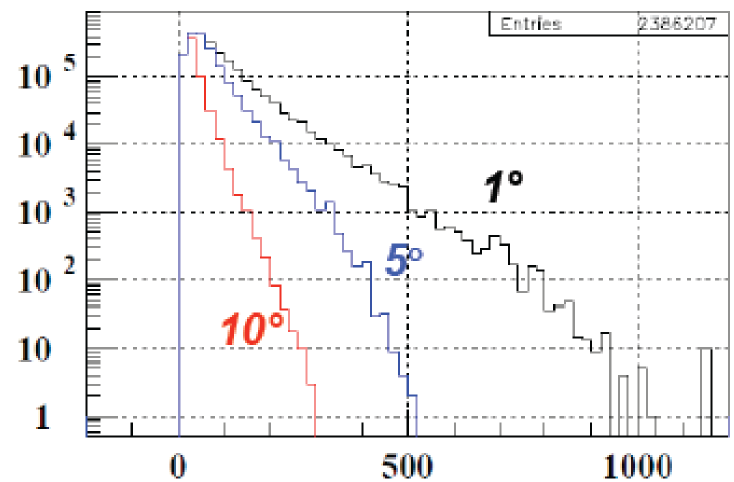


Jet Energy [GeV]

DIFF : 60 GeV electron x 7 TeV proton



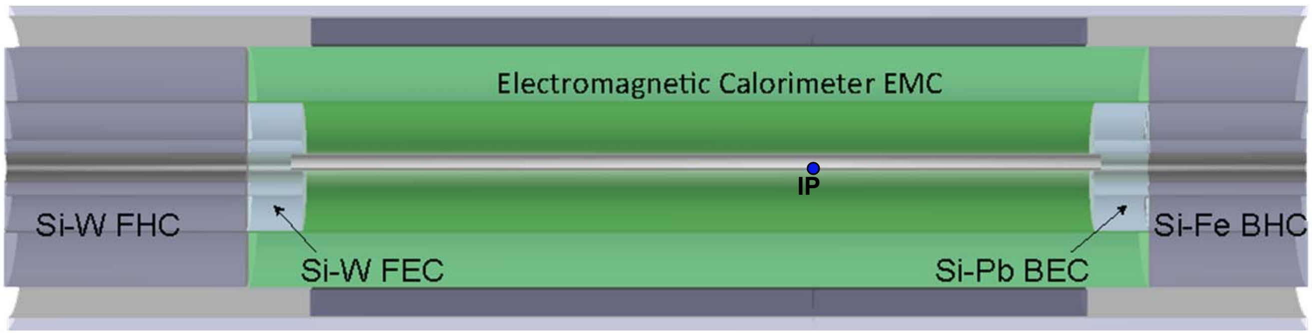
NRAD: 60 GeV electron x 7 TeV proton



Jet Energy [GeV]

Fwd/Bwd Calorimeters

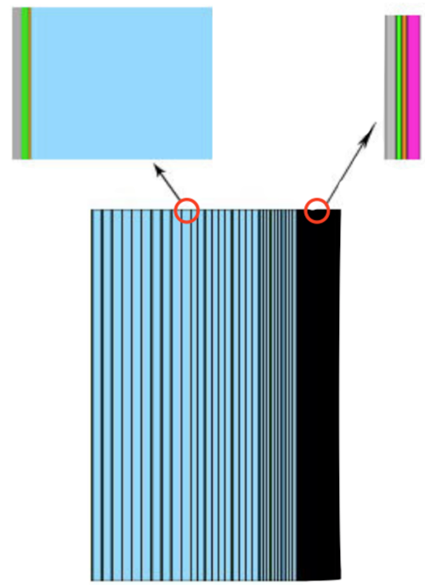
FEC: ~30 X_0
FHC: ~ 8-10 λ_I



BEC: ~25 X_0
BHC: ~ 6-8 λ_I

- Forward/Backward Calorimeters
- Forward FEC + FHC: tungsten high granularity; Si (rad-hard)
  high energy jet resolution
  FEC: ~30X0; 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)
  $e^{\mp}$ tagging/E measurement (backward)

Highest energies in forward region
Radiation hard
High Granularity
Linearity

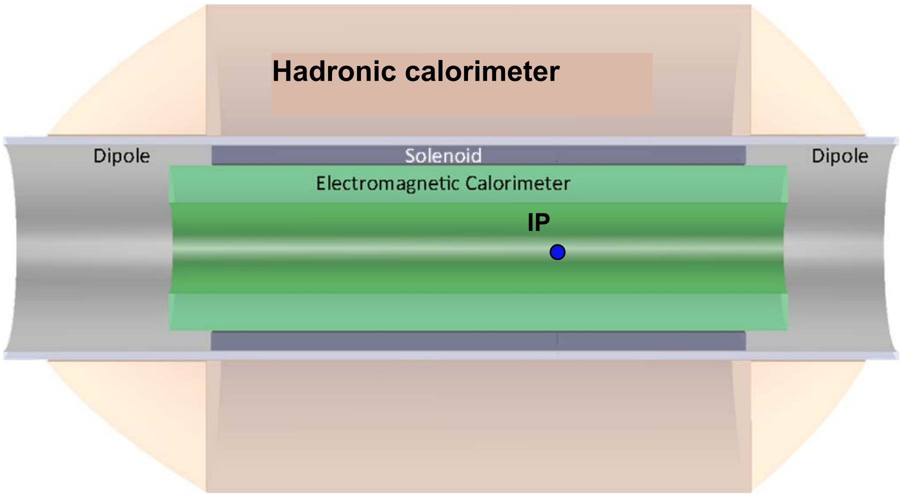


FHC & FEC composite Calorimeter

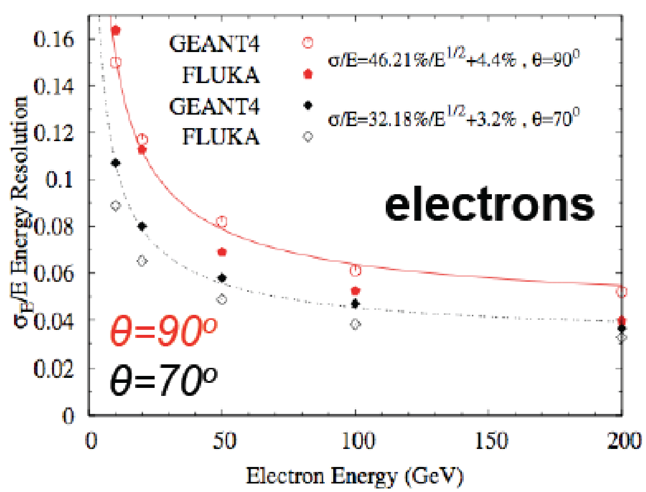
Hadronic Calorimeter

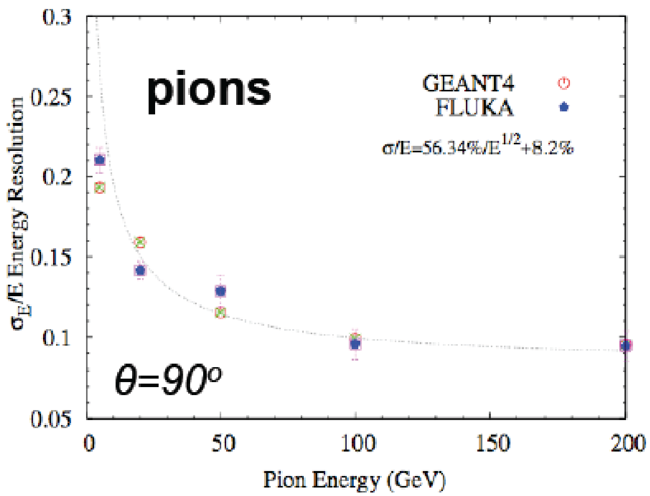
- Baseline design
  - HAC iron absorber (magnet return flux)
  - scintillating plates (similar to ATLAS TILE CAL)
  - Interaction lengths of ~ 7-9 λ_I

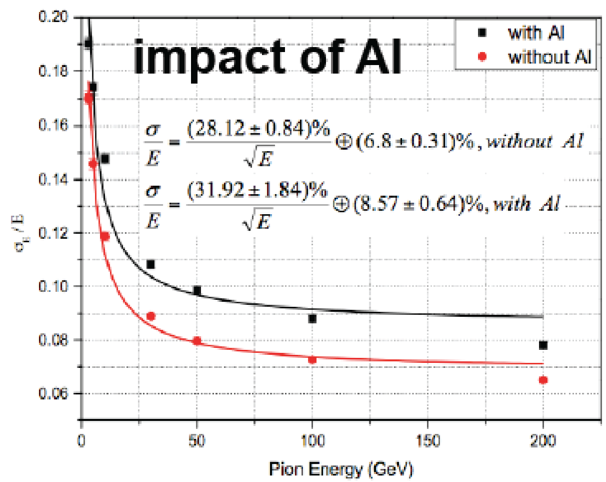
Tile Rows	Height of Tiles in Radial Direction	Scintillator Thickness
1-3	97 mm	3 mm
4-6	127 mm	3 mm
7-11	147 mm	3 mm



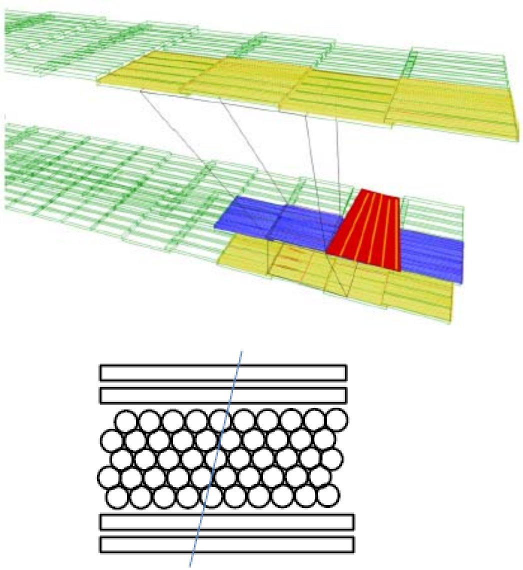
- GEANT4 + FLUKA simulations
  - containment, resolution, combined HAC & EMC response
  - solenoid/dipoles/cryostat in between

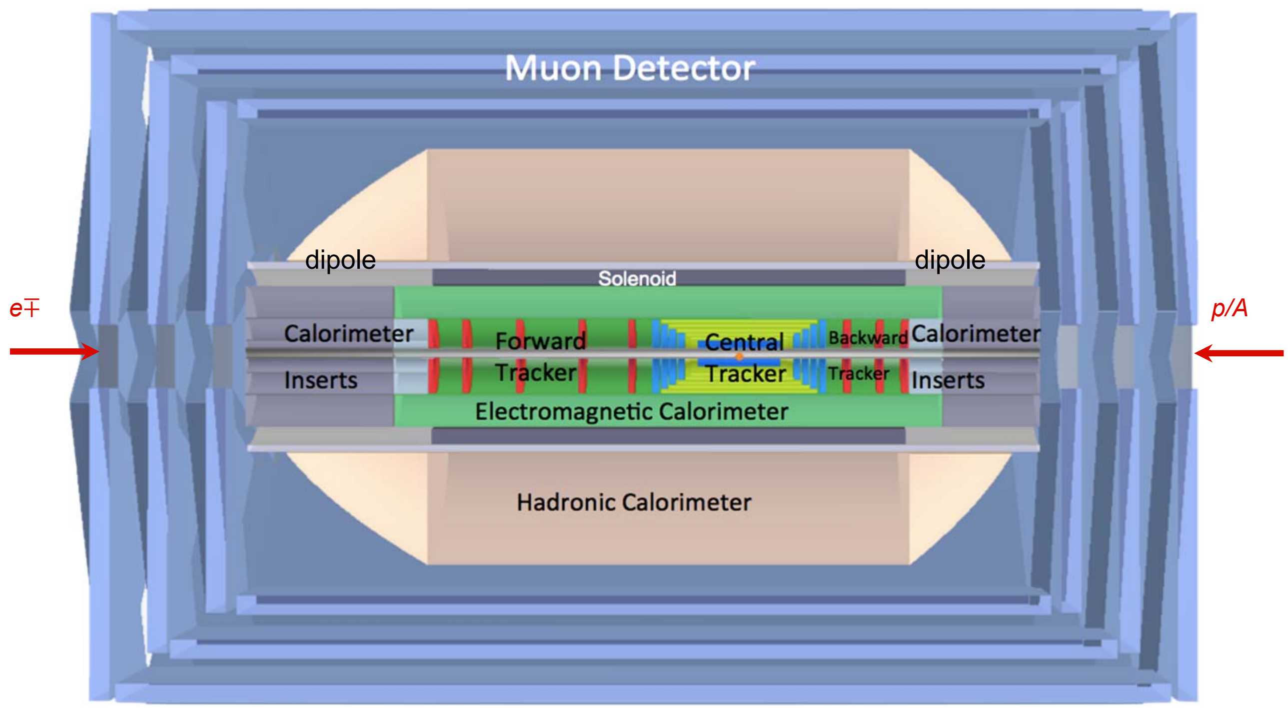






Muon System Baseline





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, TGC, MDT, mMegas etc.)

FCC hh ee he

Future Circular Collider Study
Michael Benedikt
FCC Kick-Off 2014

Design choice: beam parameters as available from *hh* and *ee*

- Max. $e^{\pm}$ beam current at each energy determined by 50 MW SR limit.
- **1 physics interaction point, optimization at each energy**

collider parameters	$e^{\pm}$ scenarios			protons
species	$e^{\pm}$ (polarized)	$e^{\pm}$	$e^{\pm}$	*p*
beam energy [GeV]	**80**	**120**	**175**	**50000**
luminosity [$10^{34}cm^{-2}s^{-1}$]	**2.3**	**1.2**	**0.15**	
bunch intensity [10^{11}]	0.7	0.46	1.4	1.0
#bunches per beam	4490	1360	98	10600
beam current [mA]	152	30	6.6	500
$\sigma_{x,y}$* [micron]	4.5, 2.3			

FCC-he design challenges

Integration aspects, machine detector interface

- Synchrotron radiation
- Large polar angle acceptance

IR optics & magnets with 3 beams

- Crossing scheme
- Detector integrated dipole, final SC quadrupoles, crab cavities,

Concurrent operation of $e^{\pm}h$ with *hh or/and* $e^{+}e^{-}$ operation?

Relevant expertise available worldwide and potential synergies:

⇔ **HERA, eRHIC, MEIC, HIAF-EIC,…**

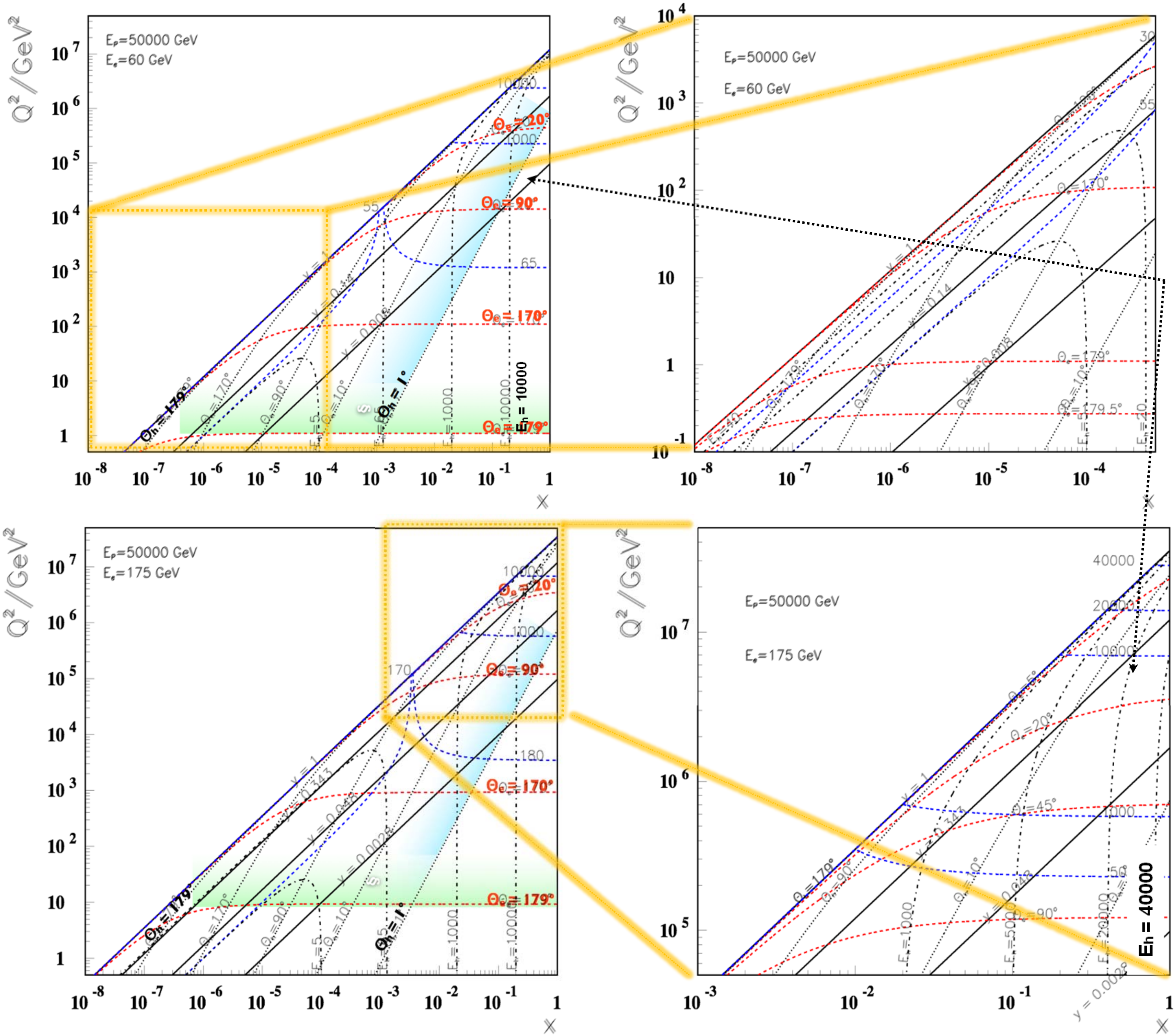
Alternative option for *eh* collisions in connection with *FCC-hh*:

- Potential reuse of an **energy recovery linac (ERL)** that is being **studied in the frame of the LHeC study.**

Ring-Ring: FCC-he
$e^{\mp}$ (max) 175 GeV + p/A 50 TeV

Linac-Ring:
LHeC ERL + FCC-hh
$e^{\mp}$ (60 GeV) p/A at 50 TeV

FCC-he Two Scenarios



Linac-Ring

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

increase the calorimeter depth compared to LHeC (especially in forward region)

Ring-Ring

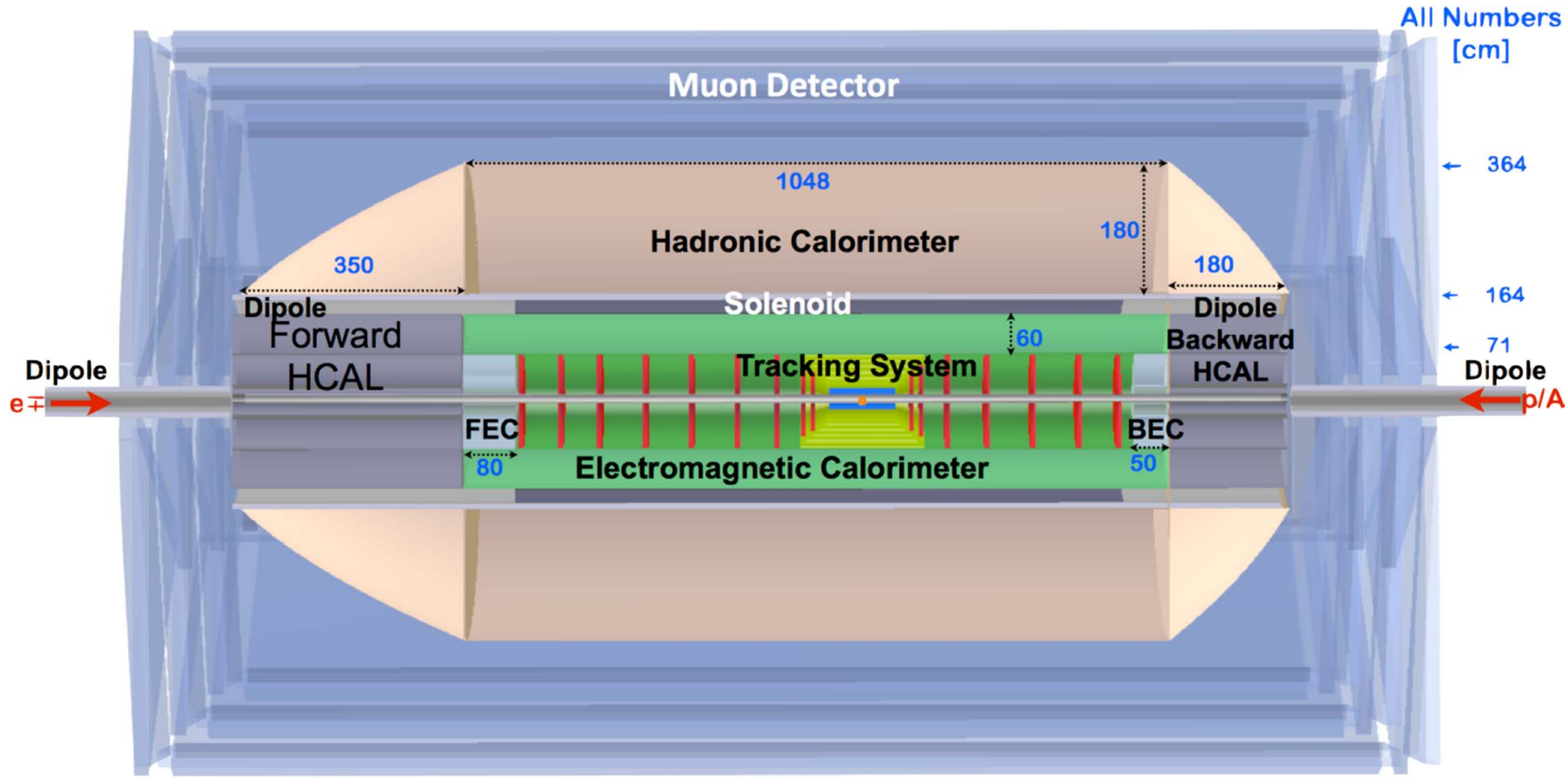
Kinematic coverage can also be achieved by lowering E_e (goes squared to lower Q^2)
and
lowering E_p (accesses larger x)

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

From the LHeC to the FCC

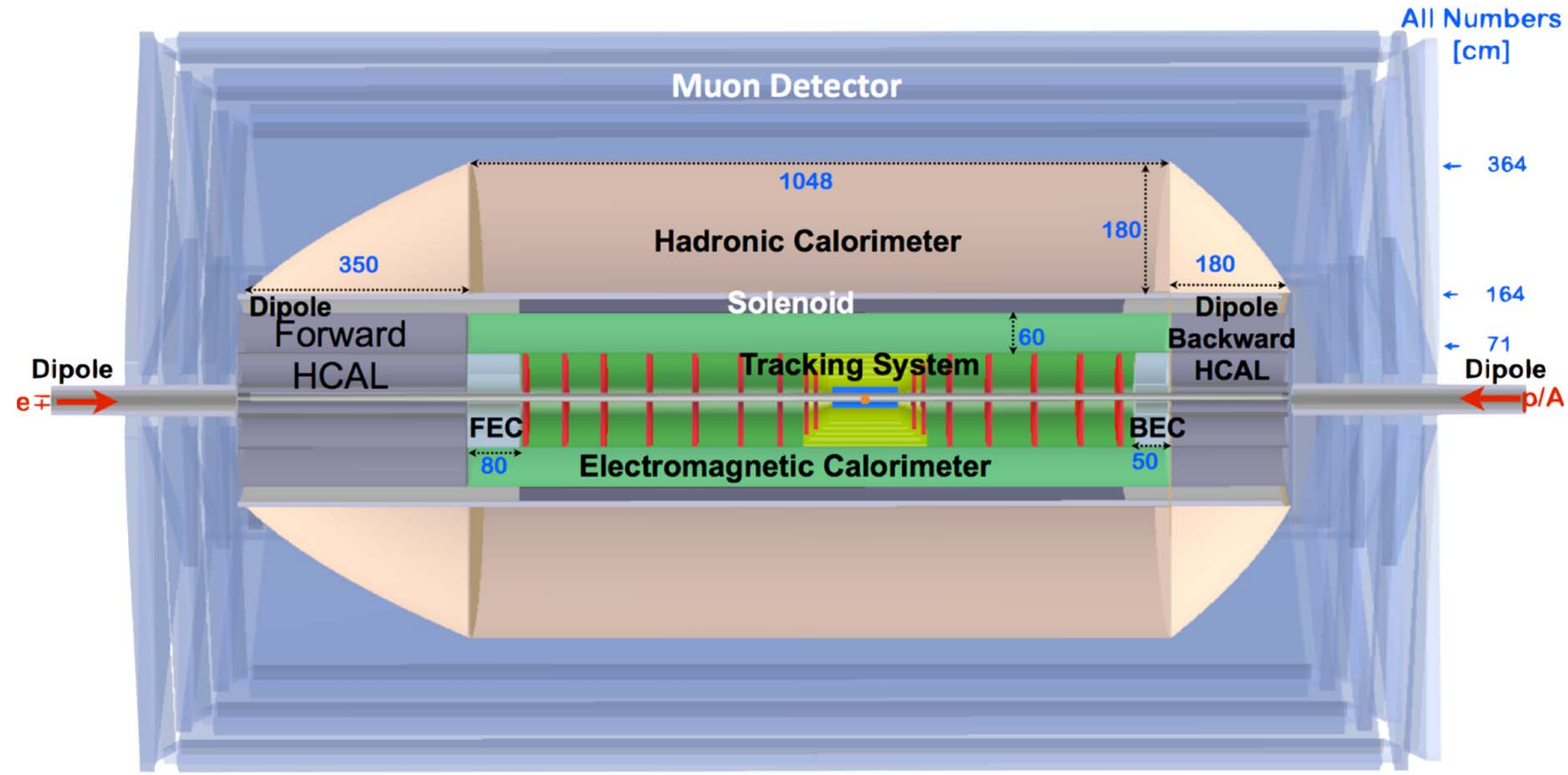
- Interaction region:
  - Assume similar interaction region as for LHeC
  - dipole field across the whole detector
  - $e^{\pm}$ syn radiation → elliptical beampipe
- Detector:
  - Higher momenta/energies → Larger BL^2 , Larger calorimetry
  - Large acceptance over η
  - Bunch spacing (25ns → 5ns), (pile up less of a problem in ep)
- Beam Pipe Design
  - low X_0, λ_I material, stable, capable for 1^0 tracks
  - allowing low p_T particle measurement
  - R&D needed (new ideas)

The FCC-he Detector Scheme - LR



- A very first arrangement based on the LHeC design using LR constraints (dipoles)
- Forward calorimeter containment up to few 10^{th} TeV down to 1°

The FCC-he Detector Scheme - LR

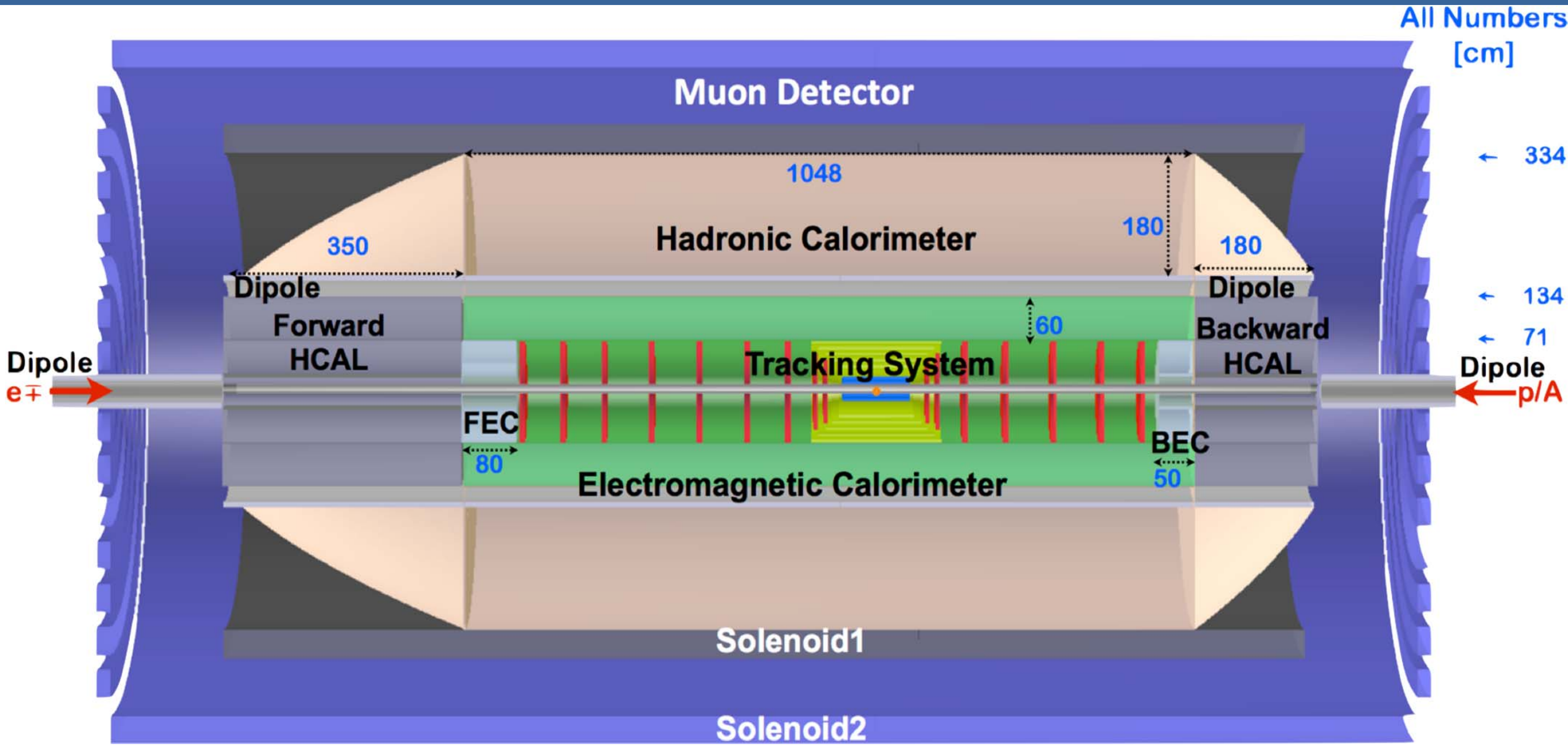


- Forward/backward taggers not shown but also present (FPS, ZDC, e γ taggers, e polarimeter)

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. $\|\eta\|$	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. $\|\eta\|$	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

The FCC-he Large (double) Solenoid



An arrangement based on the LHeC design with a large solenoid

- **Less material in front of HAC calorimetry**

Double solenoid system (second solenoid not to scale):

- **ample return field region for independent (muon) momentum measurement**
- **Lightweight structure**

Conclusions and Outlook

The FCC-he enlarges further the LHeC physics program

- DIS *ep* and *eA* in the widest x-Q^2 range
- Very precise Higgs physics (Can also explore H → HH)
- …

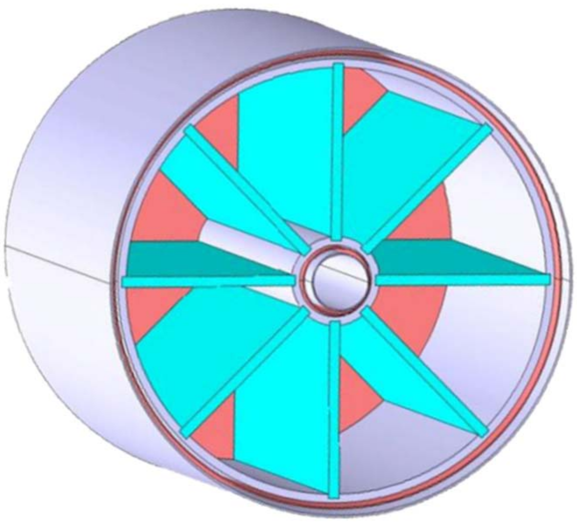
Higgs in e^-p		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N_{CC}^H	N_{NC}^H	N_{CC}^H
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	270 000
$H \to \mu\mu$	0.00022	50	5	1 000
$H \to 4l$	0.00013	30	3	550
$H \to 2l2\nu$	0.0106	2 080	250	45 000
$H \to gg$	0.086	16 850	2 050	365 000
$H \to WW$	0.215	42 100	5 150	915 000
$H \to ZZ$	0.0264	5 200	600	110 000
$H \to \gamma\gamma$	0.00228	450	60	10 000
$H \to Z\gamma$	0.00154	300	40	6 500

The detector:

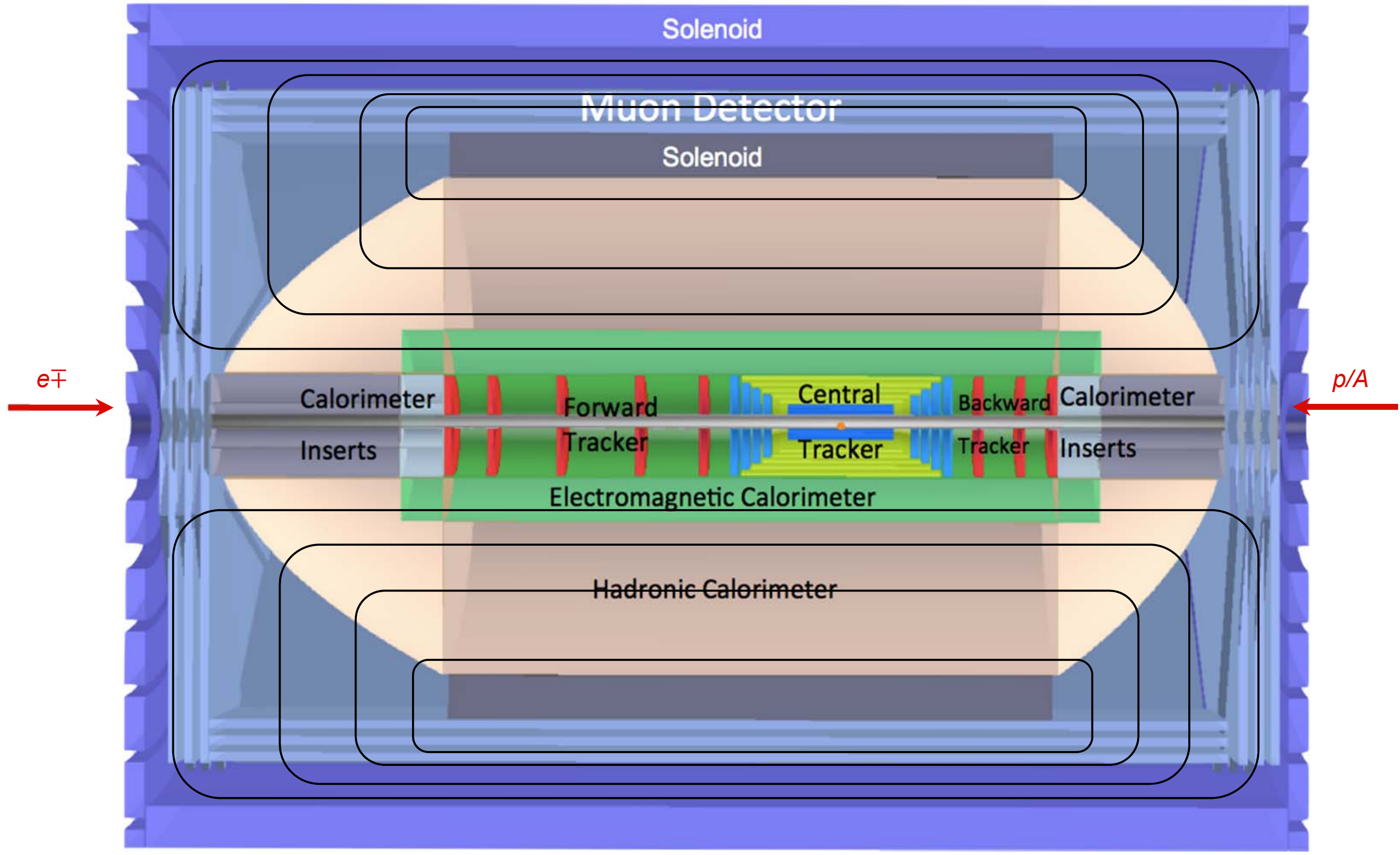
- A very preliminary draft has been presented
- An FCC-he detector appears feasible using todays technologies
- The detector design will benefit from coming technology progress
- Full simulation being setup based on DD4hep/DDG4 toolset
- The FCC-he detector provides a high level of synergy withing HEP and the FCC in some of the challenges

Backup

System Extensions LHeC



Forward Air Core Toroid



Extensions LHeC detector:

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

First feasibility studies

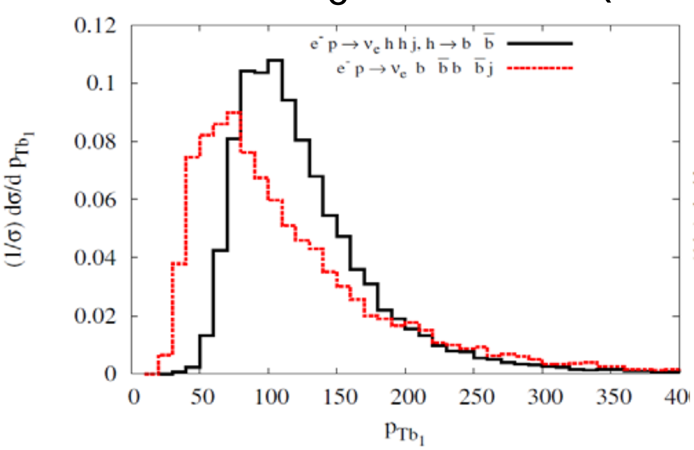
→ See Plenary talk by M. D.Onofrio

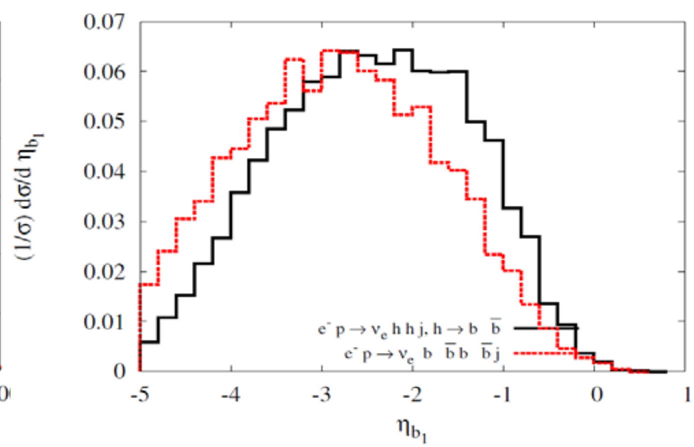
- Cross-sections for CC backgrounds in fb for E_e=60, 120,150 GeV

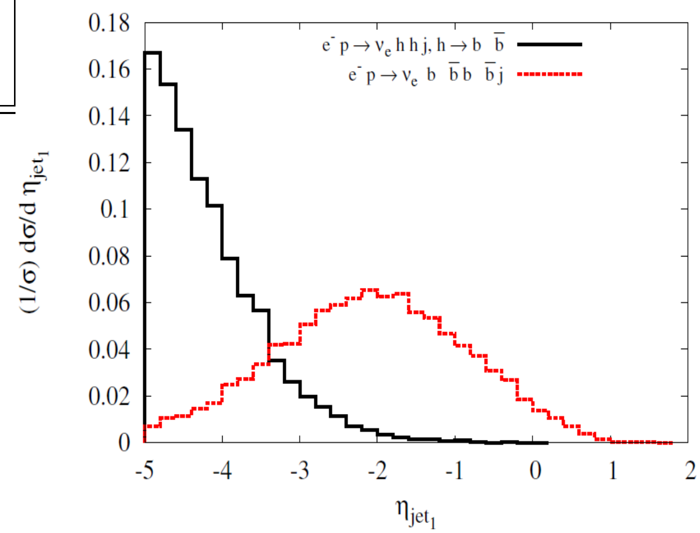
Processes	$E_e = 60$ GeV		$E_e = 120$ GeV		$E_e = 150$ GeV	
	σ(fb)	σ_{eff}(fb)	σ(fb)	σ_{eff}(fb)	σ(fb)	σ_{eff}(fb)
$e^-p \to \nu_e b\bar{b}b\bar{b}j$	0.086	0.022	0.14	0.036	0.15	0.038
$e^-p \to \nu_e b\bar{b}c\bar{c}j$	0.12	1.7×10^{-5}	0.36	1.8×10^{-3}	0.44	2.2×10^{-3}
$e^-p \to \nu_e c\bar{c}c\bar{c}j$	0.20	1.0×10^{-6}	0.24	3.4×10^{-5}	0.31	4.3×10^{-5}
$e^-p \to \nu_e b\bar{b}jjj$	26.1	3.9×10^{-3}	54.2	0.008	67.5	0.01
$e^-p \to \nu_e c\bar{c}jjj$	29.6	9.5×10^{-5}	66.9	2.0×10^{-4}	85.4	2.7×10^{-4}
$e^-p \to \nu_e jjjjj$	823.6	4.1×10^{-5}	1986	9.9×10^{-5}	2586	1.3×10^{-4}

Results assume 70% b-tagging efficiency, 0.1 (0.01) fake rates for c (light) jets

Plots for E_e=60 GeV (very similar for 120,150 GeV)





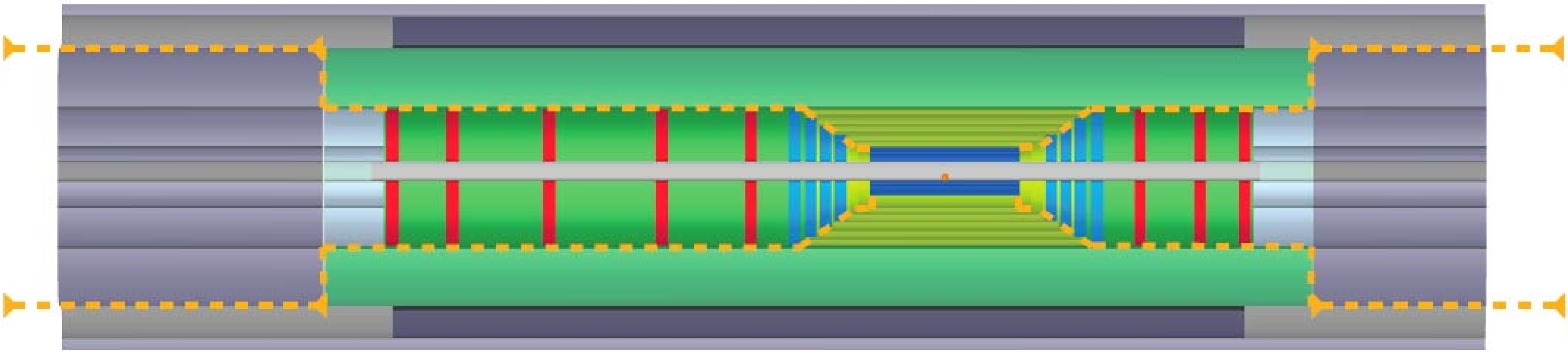


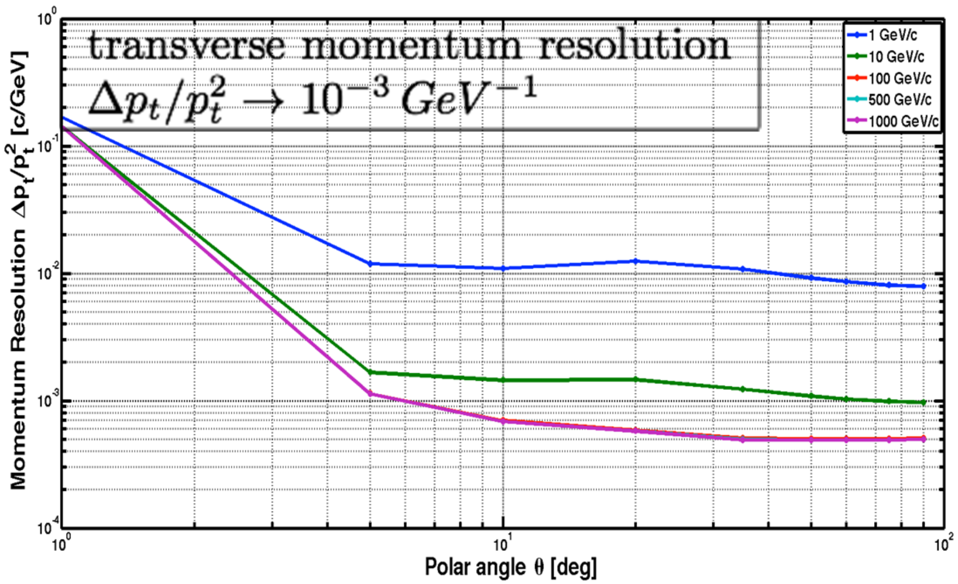
Despite large beam energy imbalance, b-jets are relatively central

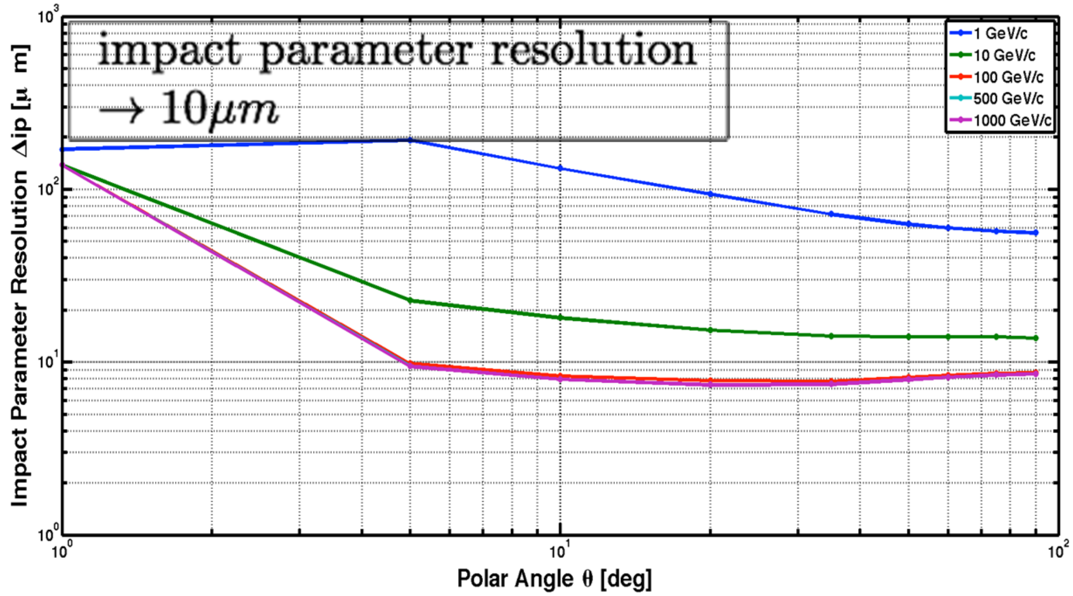
Scattered quark is more forward in signal → good discriminant!

Tracker Simulation

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

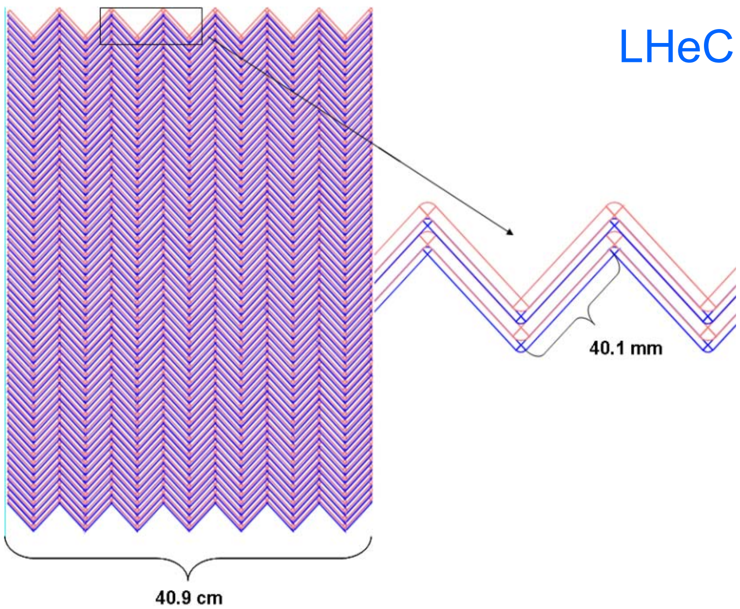




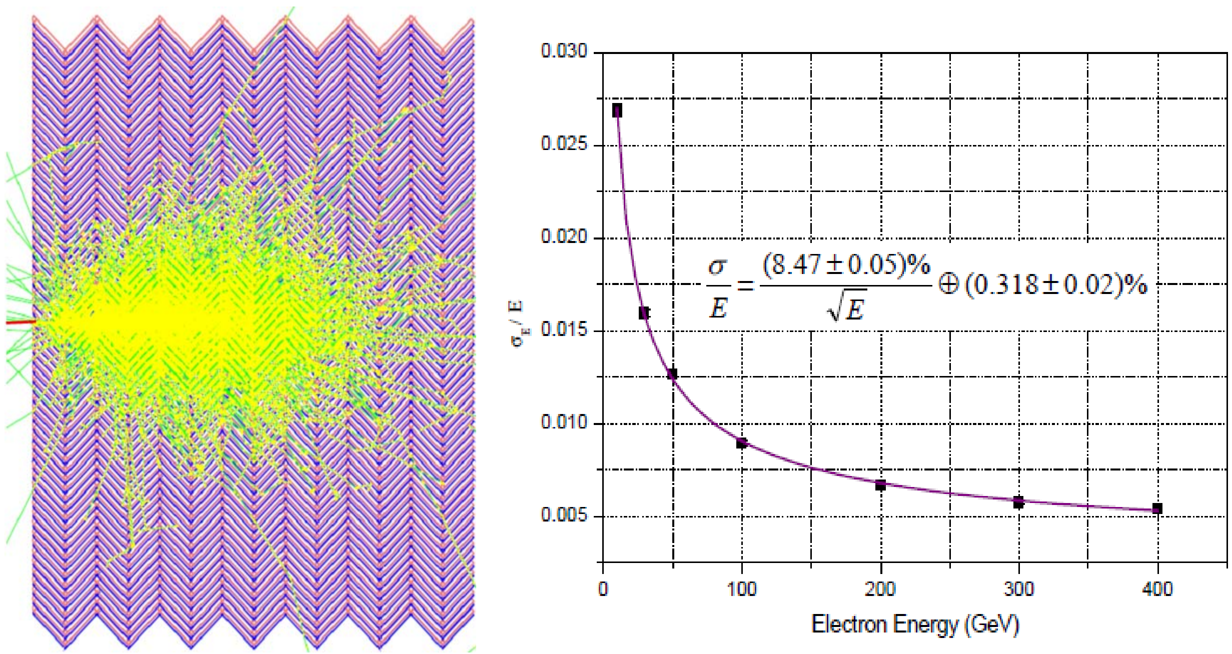


- Silicon: compact design, low budget material, radiation hard

Electromagnetic Calorimeter



F. Kocak, I. Tapan Uludag Univ.



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