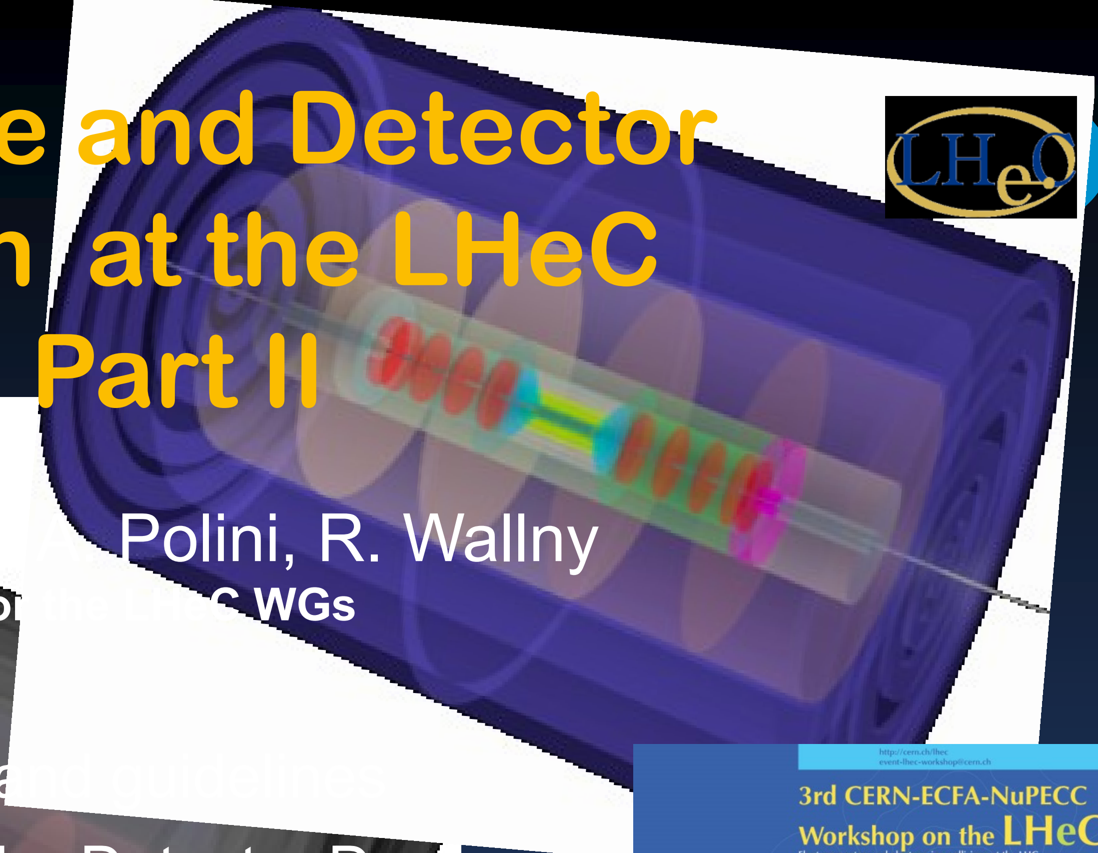
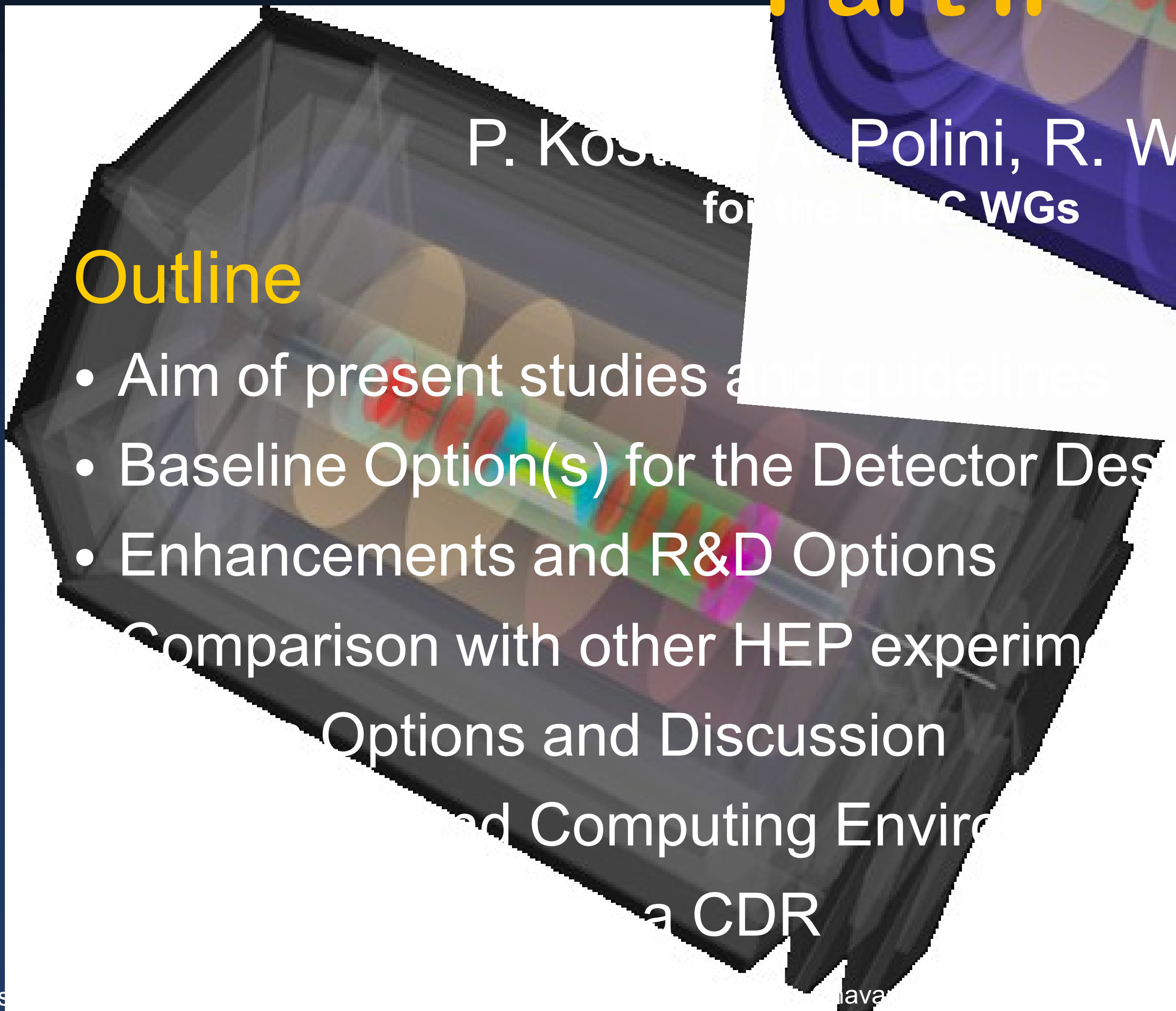
Machine and Detector Design at the LHeC Part II





P. Kos... A. Polini, R. Wallny

for the L...C WGs

Outline

- Aim of present studies and guidelines
- Baseline Option(s) for the Detector Design
- Enhancements and R&D Options
- Comparison with other HEP experim...s
- ... Options and Discussion
- ...d Computing Envir...
- ... a CDR

Aim of present studies

- Prove together with Physics & Machine WG the feasibility and the physics potential
- Establish the Machine and the Interaction Region constrains (beam-pipe, synchr. rad, magnets)
- Provide a detector baseline within reach of currently available and established technologies
- Verify that such solution already fulfills the physics requirements
- Foresee more advanced options means R&D available by the time of detector construction

Back to the Detector

- Tracking
  - High/low acceptance option (Ring Ring)
  - Bending Dipoles (Linac Ring)

- Solenoid
  - Size, Inside/outside CAL, Return Flux
  - ➔ Calorimeter options
  - Experience from HERA, new frontiers … TeV

➔ Full detector Layout
  - Comparison to present and future HEP Experiments
  - Discussion on technologies
- Foresee Heavy Ion running
- Detector construction within 10 years from now (?)

Tracking

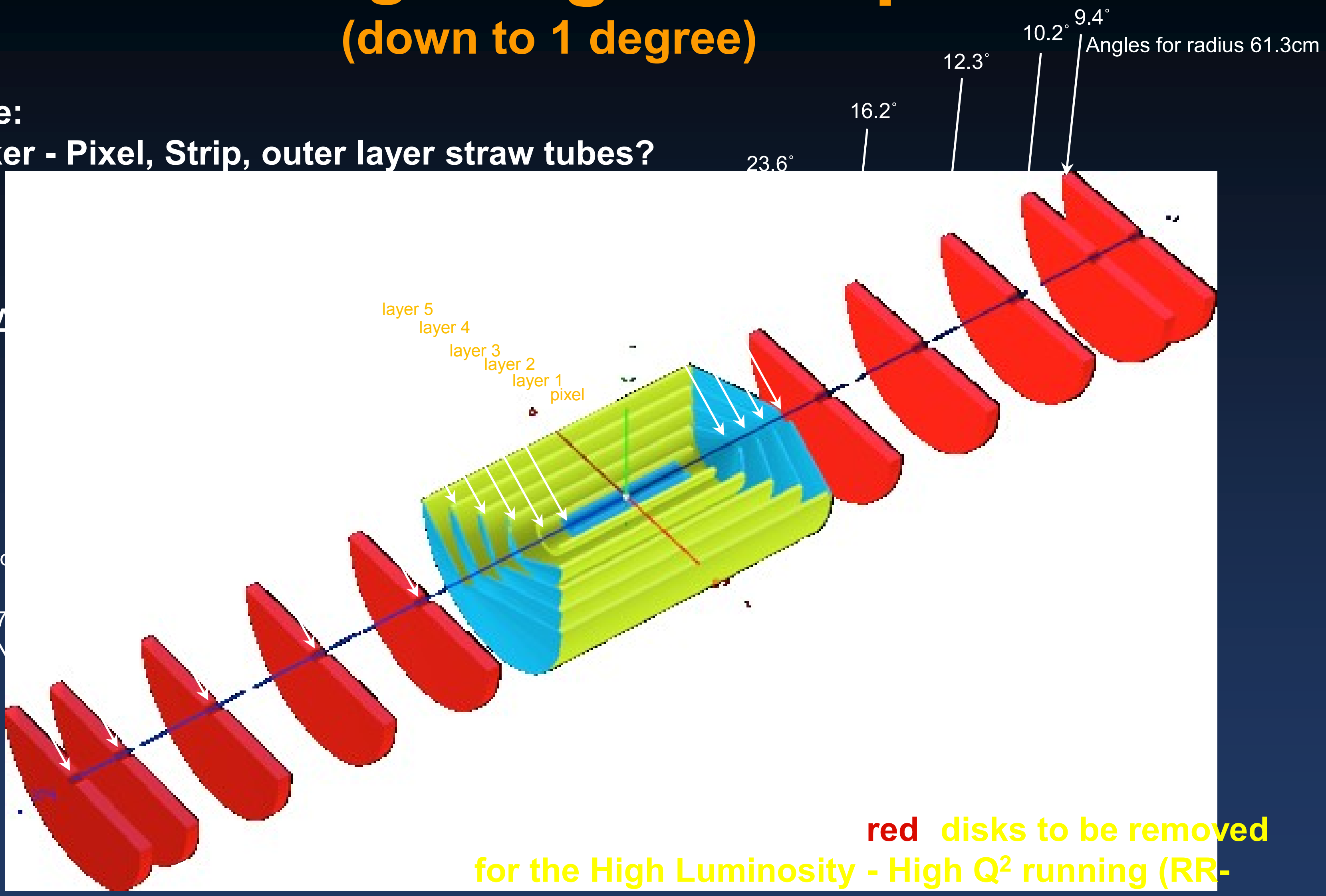
Full Tracking - High Acceptance
(down to 1 degree)

Baseline:
Si Tracker - Pixel, Strip, outer layer straw tubes?

Track A

Angles for rad

0.7



red disks to be removed for the High Luminosity - High Q^2 running (RR-option)

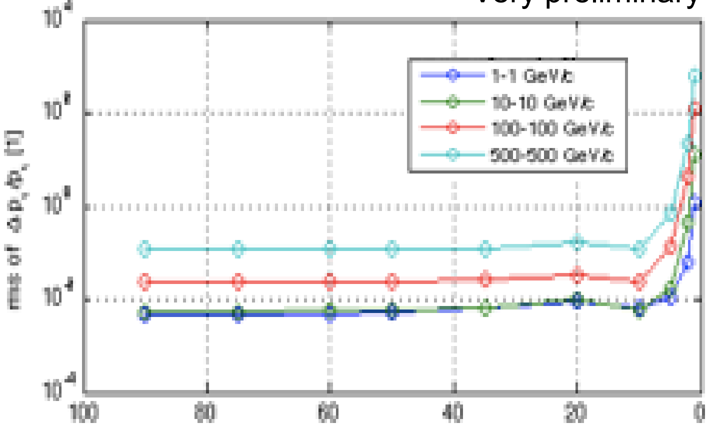
Alternative technologies: MAPS, DEPFET, GOSSIP* (talk of H.van de Graf)

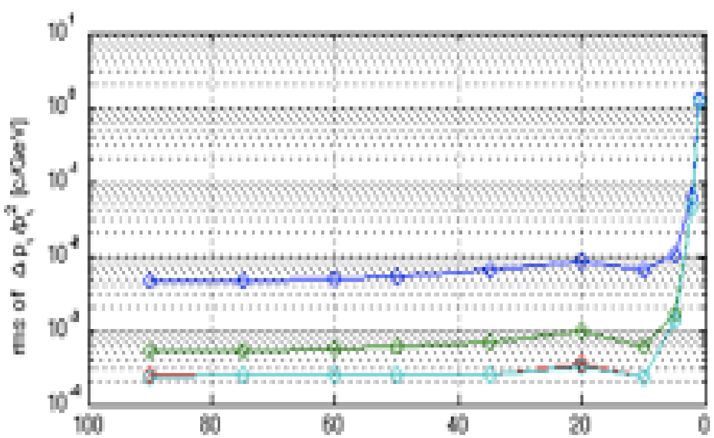
*Gas On Slimmed Silicon Pixels (or Strixels/Pads) - *NIKHEF*

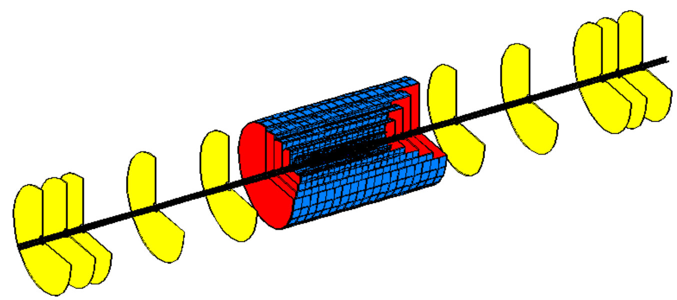
Tracking Simulation

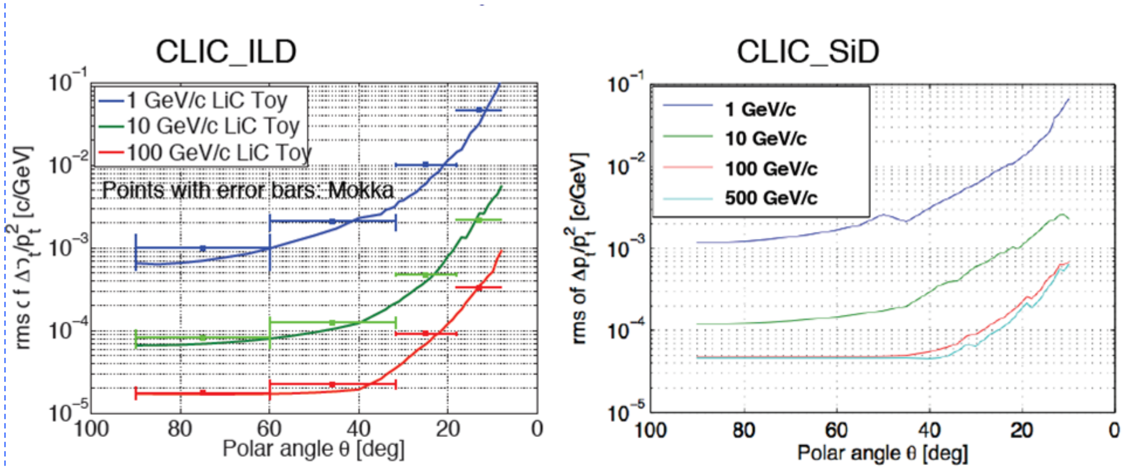
- LicToy 2.0 Simulation (http://wwwhephy.oeaw.ac.at/p3w/ilc/lictoy/UserGuide_20.pdf)
- Simplified Geometry (barrel cylinders, fwd/bwd disks, no fwd/bwd cones)
- with basic assumption (layer resolutions, X/X_0)

Very preliminary



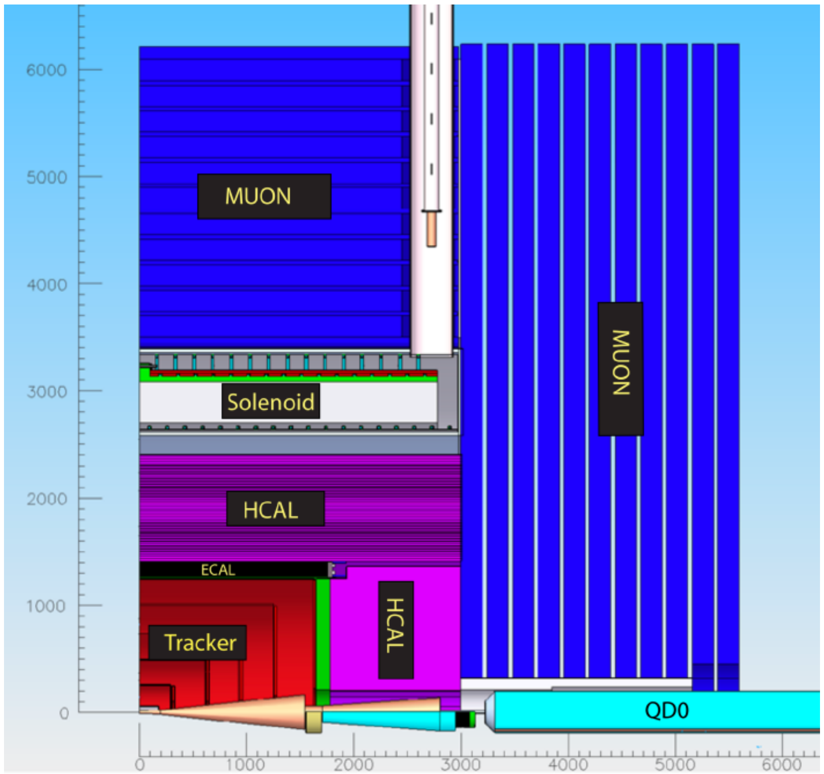






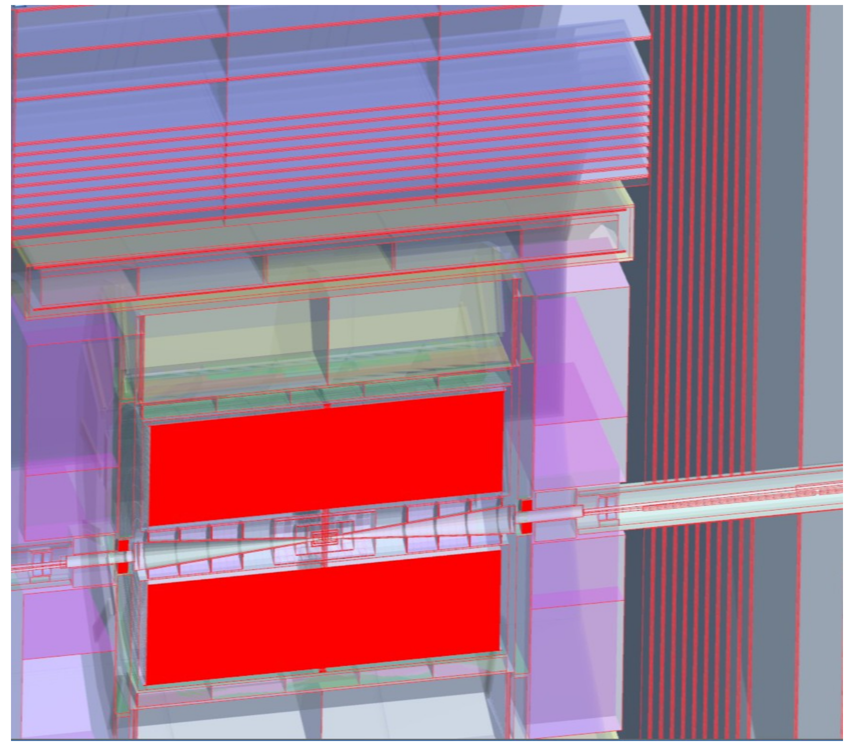
A look at … ILC/CLIC

SiD



- 5 T solenoid
- Full Silicon Tracker:
  5 cyl, 7+7 fwd pixel; 5 cyl + 4+4 fwd strip
- PFA Calorimetry
  (26 x_0 Si-W), (4.5 λ_i RPC/GEM-Iron)
- Iron Return + Muon

ILD

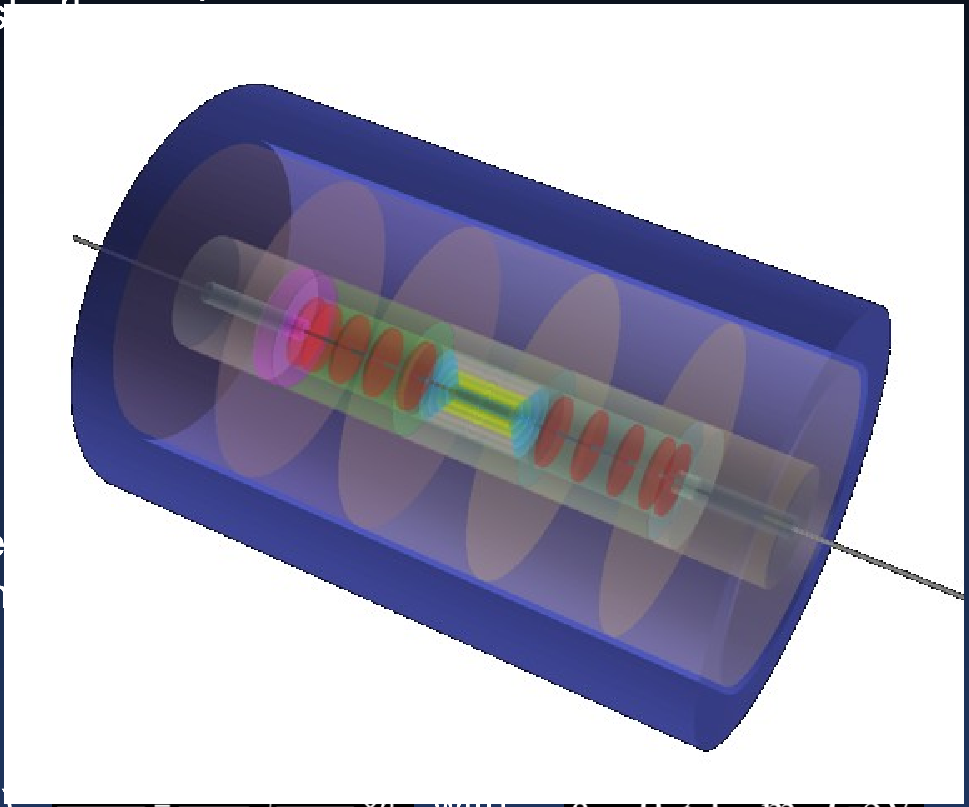


- 3.5 T solenoid
- Silicon Tracker
- Large TPC + Silicon Envelope
- PFA Calorimetry
  (25mm² for ecal, 1 to 9 cm² for the hcal)
- Iron Return + Muon

Solenoid

Modular structure:

- assembly CMS like on surface level or in the experimental area depending on time constraints and access s



Solenoid dimensions:

- 6m half length
- 300 cm inner radius
- B field = 3.5 T

Geometry constraints:

- Current beam pipe dimensions
- Requirement of 10° tracking cove
- Homogeneous B field in the trackin

Detector Track Resolution:

i.e. assuming / using (Glückstern relation): p_T = $aBL^2 \sqrt{N+4}$ $\times p_T$ with a = 0.3 T m GeV

N track points on L; length of track perpendicular to field B, accuracy σ(x)

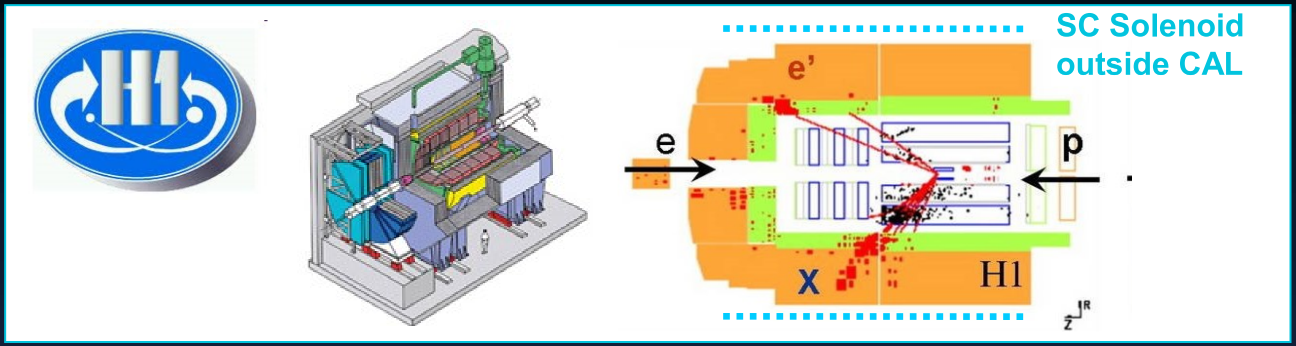
B = 3.5 T, N_{min}= 56 track points (2 x 5 (min. hits per layer) x 5 + 2 x 3 B-layer hits)

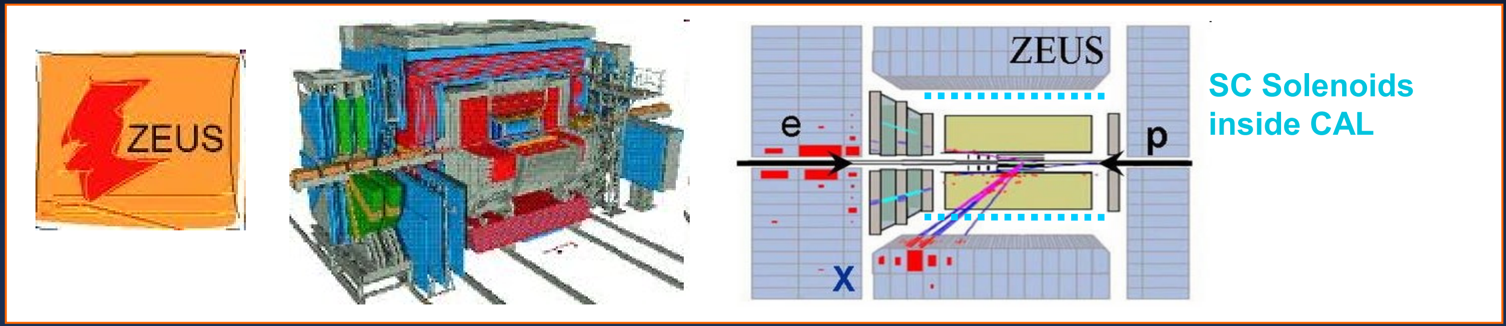
s-gas module ~10° inclined more track points for inclined tracks - extended track segments

➔ $\Delta p_T/p_T$ = 0.03% p_T

Calorimeter

HERA Calorimeters





- H1
  - Liquid Argon (cf. ATLAS)
  - High granularity, compensation achieved via software
  - Solenoid outside of the LAr CAL
- ZEUS
  - Compensating Calorimeter (Uranium Scintillator)
  - EMC 15%/$\sqrt{E}$; HAC 35%/$\sqrt{E}$, up to 7 λ_I
  - Lower granularity
  - Solenoid between central tracking and main CAL

HERA
- 920 GeV p
  27 GeV $e^{\pm}$
- c.m.s. energy
  $\sqrt{s}$ ~ 300 GeV

ATLAS and CMS

	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5\text{x}10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\text{x}10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 7$ % at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV only combining with tracker

Detector Acceptance

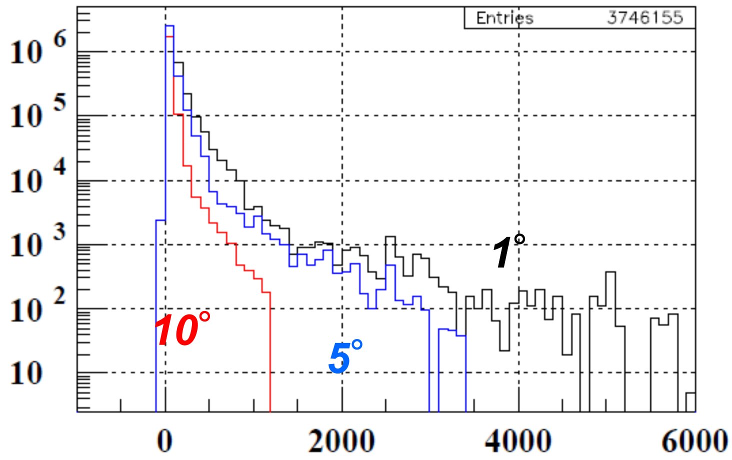
RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

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

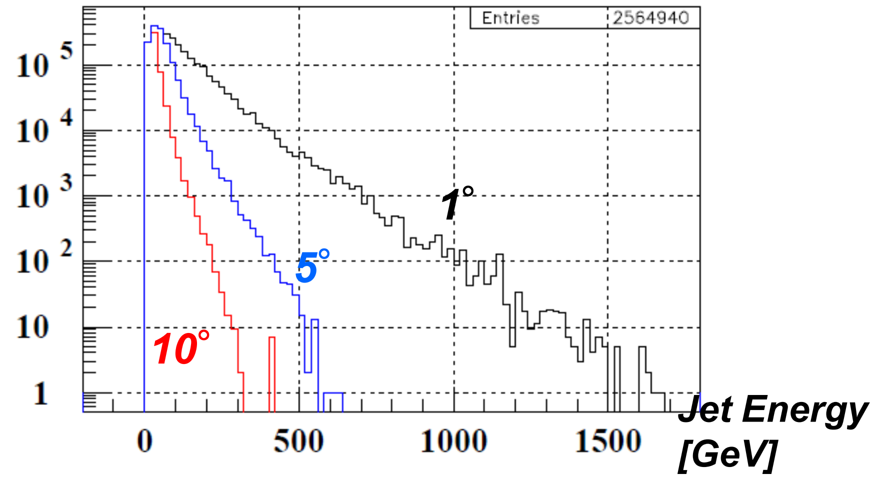
selection: q^2.gt.5.

→ Highest acceptance desirable

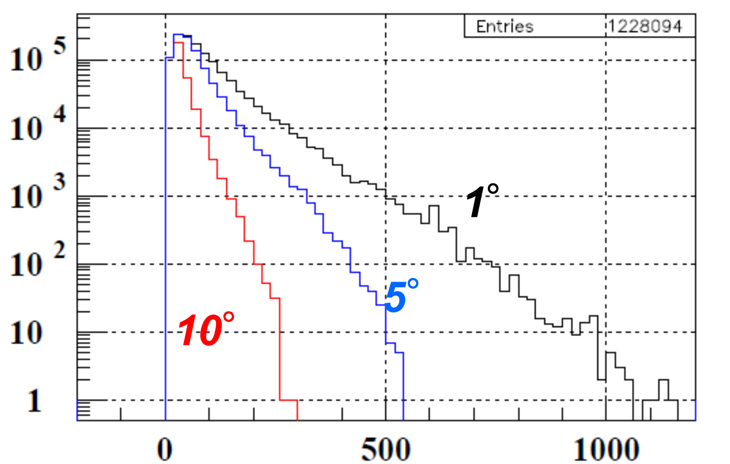
RAD: 60 GeV electron x 7 TeV proton



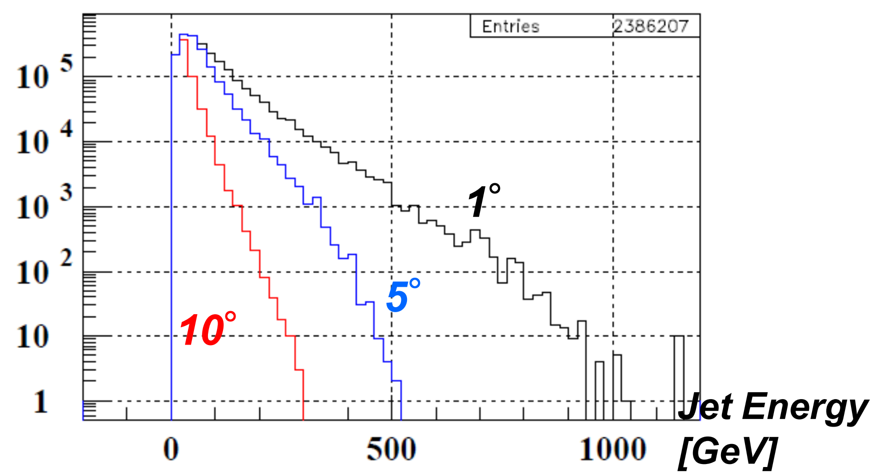
CHARM: 60 GeV electron x 7 TeV proton



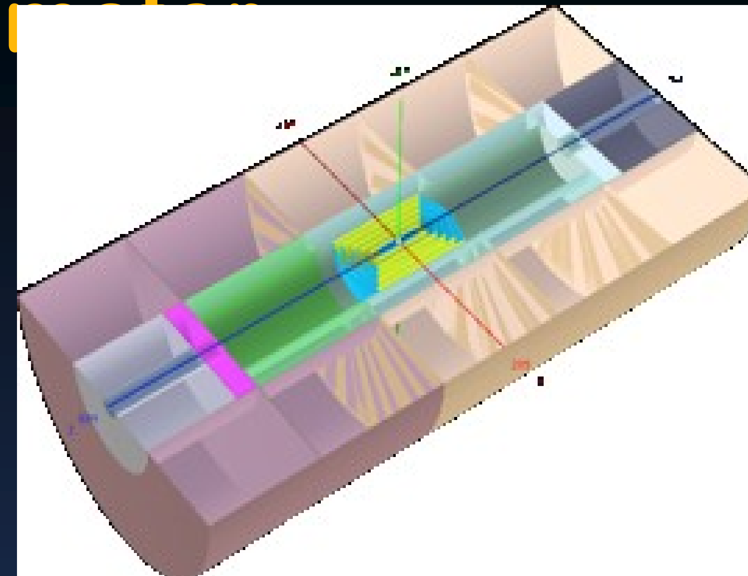
DIFF : 60 GeV electron x 7 TeV proton



NRAD: 60 GeV electron x 7 TeV proton



LHeC Calorimeter



For the geometry given:

- **Electromagnetic Calorimeter:**
  ~30 x X_0 Pb/W & different det./R/O
- **Hadronic Calorimeter:**
  6 ~10+ x λ_I Fe/Cu & different det./R/O

- **Presently the fwd/bwd calorimeter asymmetry more in functionality/detector response rather then in geometry**

- **A dense EmCAL with high granularity (small transverse size cells), high segmentation (many thin absorber layers), and with ratio λ_I/X_0 large, is optimal for E-Flow measurement → 3-D shower reconstruction**
- **Example Fe, W**

Material	Nuclear interaction length λ [cm]	Density [g/cm^3]	Moliere radius [cm]	Radiation length X_0 [cm]	λ/X_0
Fe	16.98	7.87	1.66	1.77	9.59
W	10.31	19.3	0.92	0.35	29.46

- **brass (Cu) an option also (CMS), λ_I =15.1cm - denser than Fe (adding λ_I)**
- **Liquid Argon Calorimeter (H1/ATLAS) being also considered as Baseline (B|R CAL)**

Calorimeter Discussion

Requirements:

- Precision physics
- Similar energies and resolution required for ILC
- Jet Energies ~ O(1 TeV) especially in the p forward region
- High energy resolution, higher granularity
- Possibly compact design (detector size)

Technologies:

- Liquid Argon (H1/ATLAS) concept applicable as baseline solution
- PFA (particle Flow Algorithm) → see F. Simon

  CALICE High granularity calorimeters. Software compensation & PID combining with information coming from the tracking system
- New Concepts

  New Materials, Silicon, RPC, etc.

  Full Active/Dual Readout Calorimeters: → see C. Gatto

  Combine energy and Cherenkov measurements

Overall Design Choices

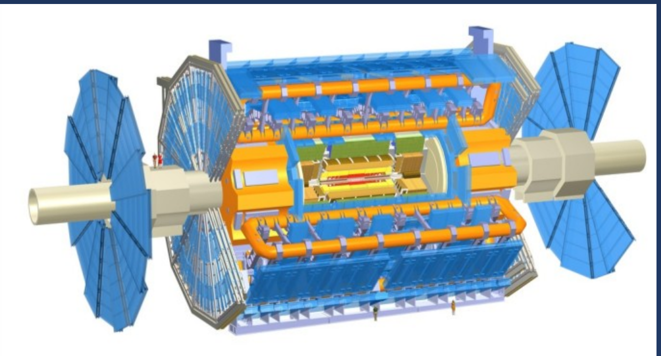
Overall Design

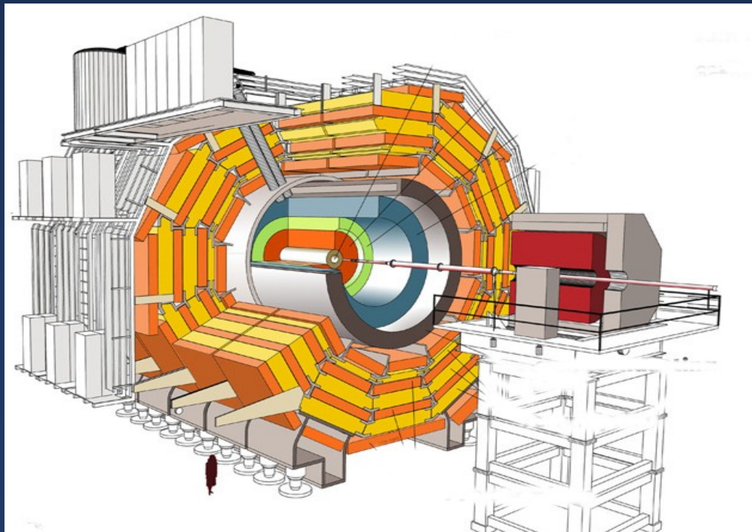
ILC /CLIC Calorimeters:

- No material between tracking and calorimeters
- Synergy with tracking, Particle Flow Algorithms
- High granularity, non compensating CAL
- CAL inside strong solenoidal field

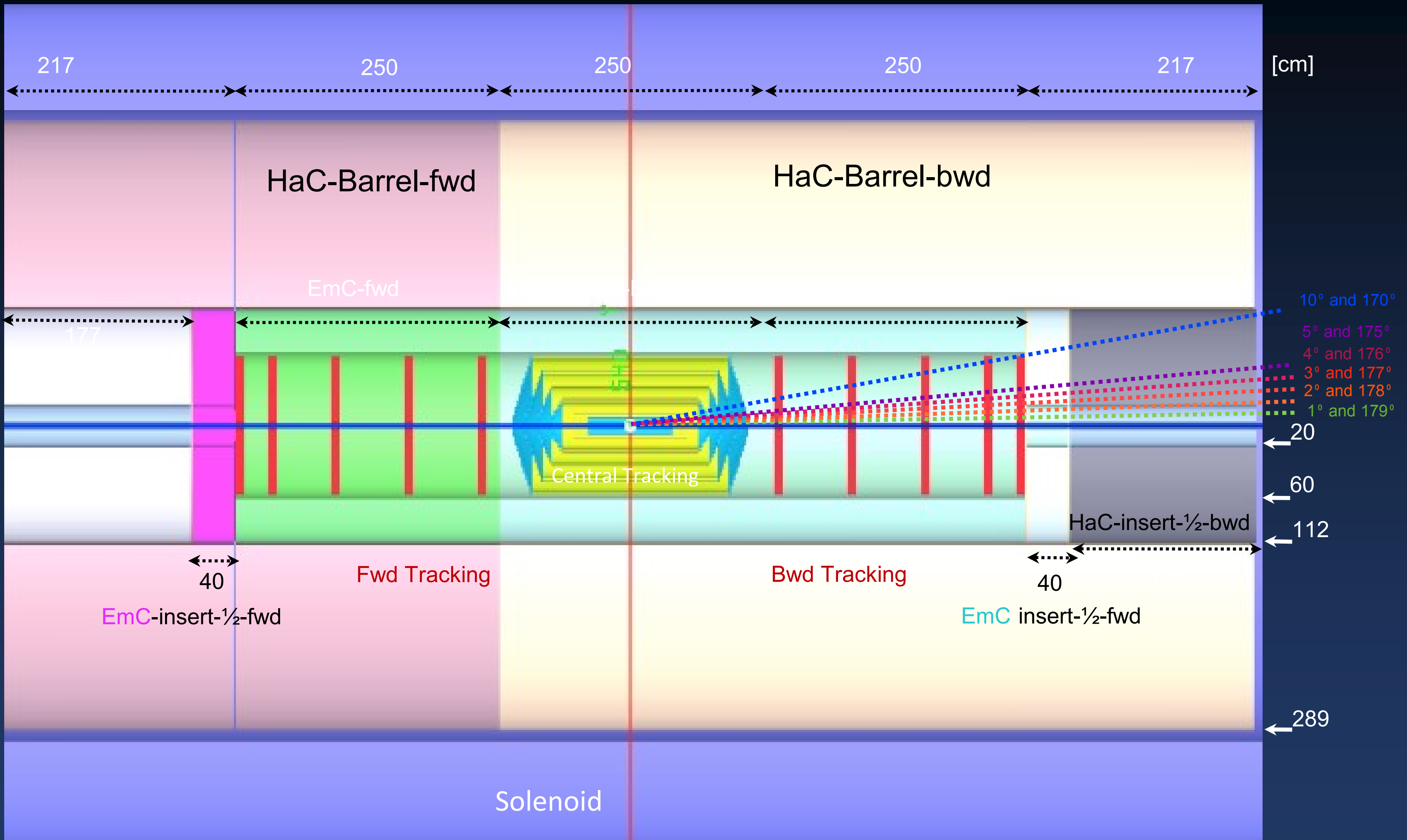
LHC:

- H1/CMS Cal inside
- ZEUS/ATLAS Cal outside



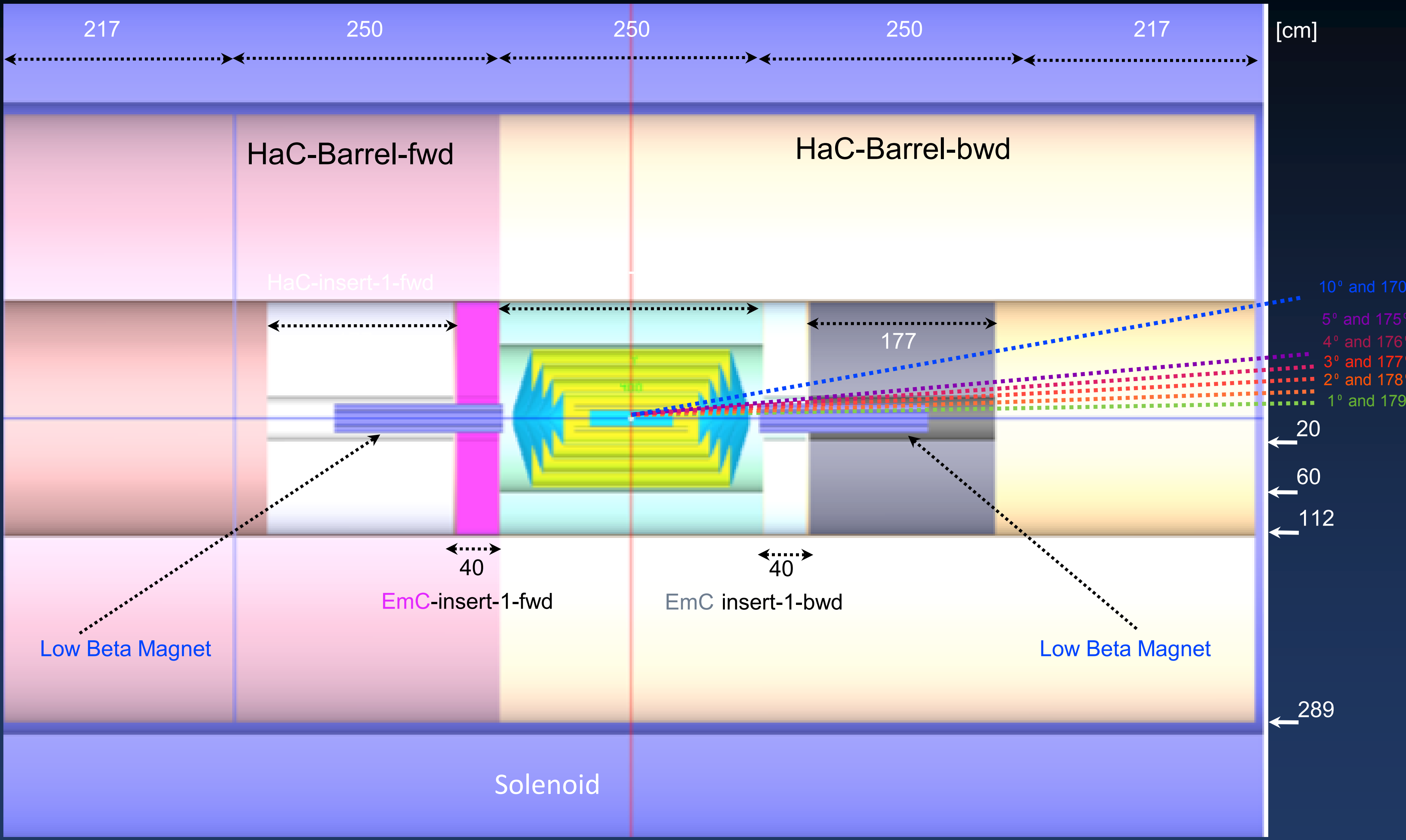


The Detector - High Acceptance



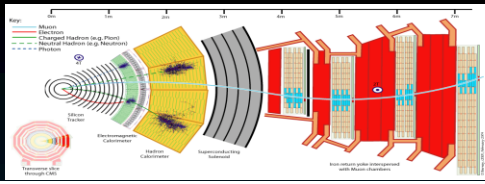
Fwd/Bwd asymmetry in energy deposited and thus in technology [W/Si vs Pb/Sc..]
Present dimensions: LxD =17x10m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]

The Detector - High Luminosity



➔Aim of current evaluations: avoid detector split in two phases: time and effort

Solenoid Options



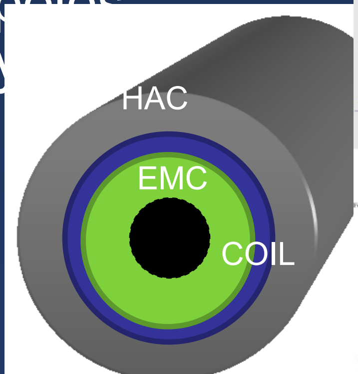
General parameters	
Magnetic length	12.5 m
Free bore diameter	6.3 m
Central magnetic induction	4 T
Total Ampere-turns	41.7 MA-t
Nominal current	19.14 kA
Inductance	14.2 H
Stored energy	2.6 GJ
Cold mass	
Layout	Five modu coupled
Radial thickness of cold mass	312 mm
Radiation thickness of cold mass	3.9 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

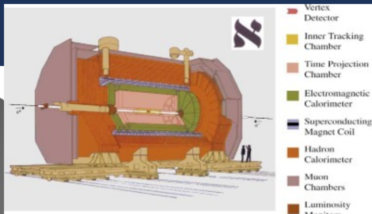
Option One

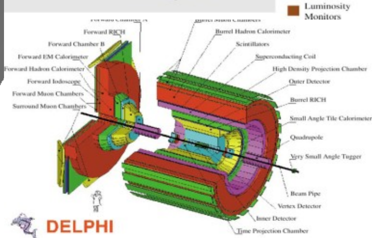
- Large Solenoid containing the Calorimeter
- 3.5 T Solenoid of similar to CMS/ILC
- Precise Muon measurement
- Large return flux either enclosed with Iron or Option of active B shielding with 2nd solenoid

Small Coil

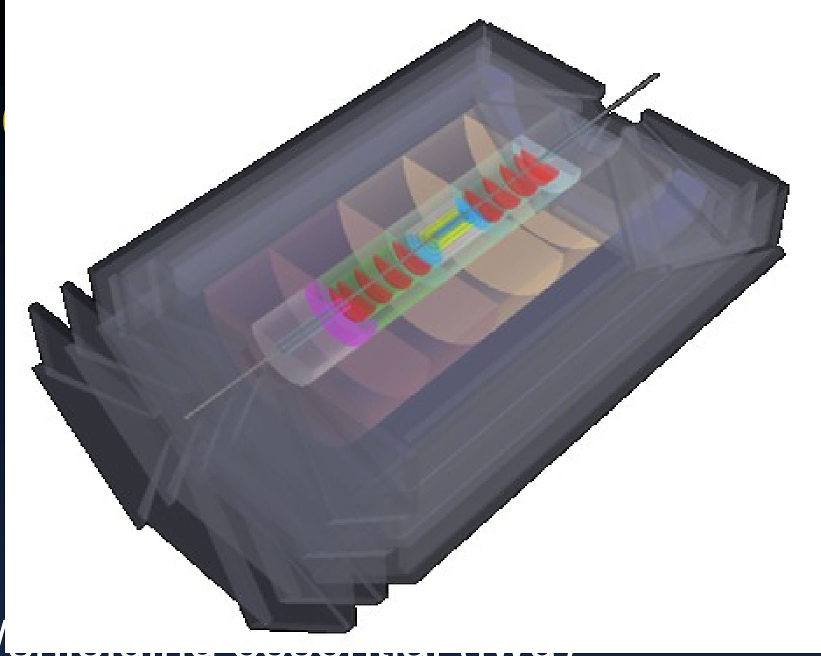
- Smaller Solenoid placed between EMC and HAC
- Cheaper option
- Convenient displacement of Solenoid and Dipoles in same cold vacuum vessel (Linac-Ring Only)
- Smaller return flux (less iron required)
- Muon p, p_t measurement compromised







Muon Dete



- Physics:
  - Heavy flavour
  - Vector Mesons
  - Diffraction etc.
- HERA Experience:
  - Beam background understanding/
  - Running in conjuction with tracking (forward) and CAL has shown to be very important both for trigger and RO
- LHeC Different Energy Range. Large acceptance could extend the LHeC physics potential
- Detector technologies
  - Detector technologies available (LHC) and very active R&D developments ongoing (sLHC)
- Magnet design essential for an independent momentum measurements

Summary - Outlook

- The beam p and the interaction region design pla defining the etector and currently in focus
- Big progres in defining and studying the detector constraints (Machine options and Interaction Region), the detector design heavily depends on.
- A baseline d tector concepts following the Physics requirements is being def together with attractive R & D options
- Detector-wi ne" with a large solenoid (CMS/ILC) is preferred. R R High Lumi Focussing Magnet or L-R bending rds different solution
- The CDR is
- The LHeC c sizabl an LHC det a fantastic challenge to it build.