XX International Workshop on Deep-Inelastic Scattering and Related Subjects

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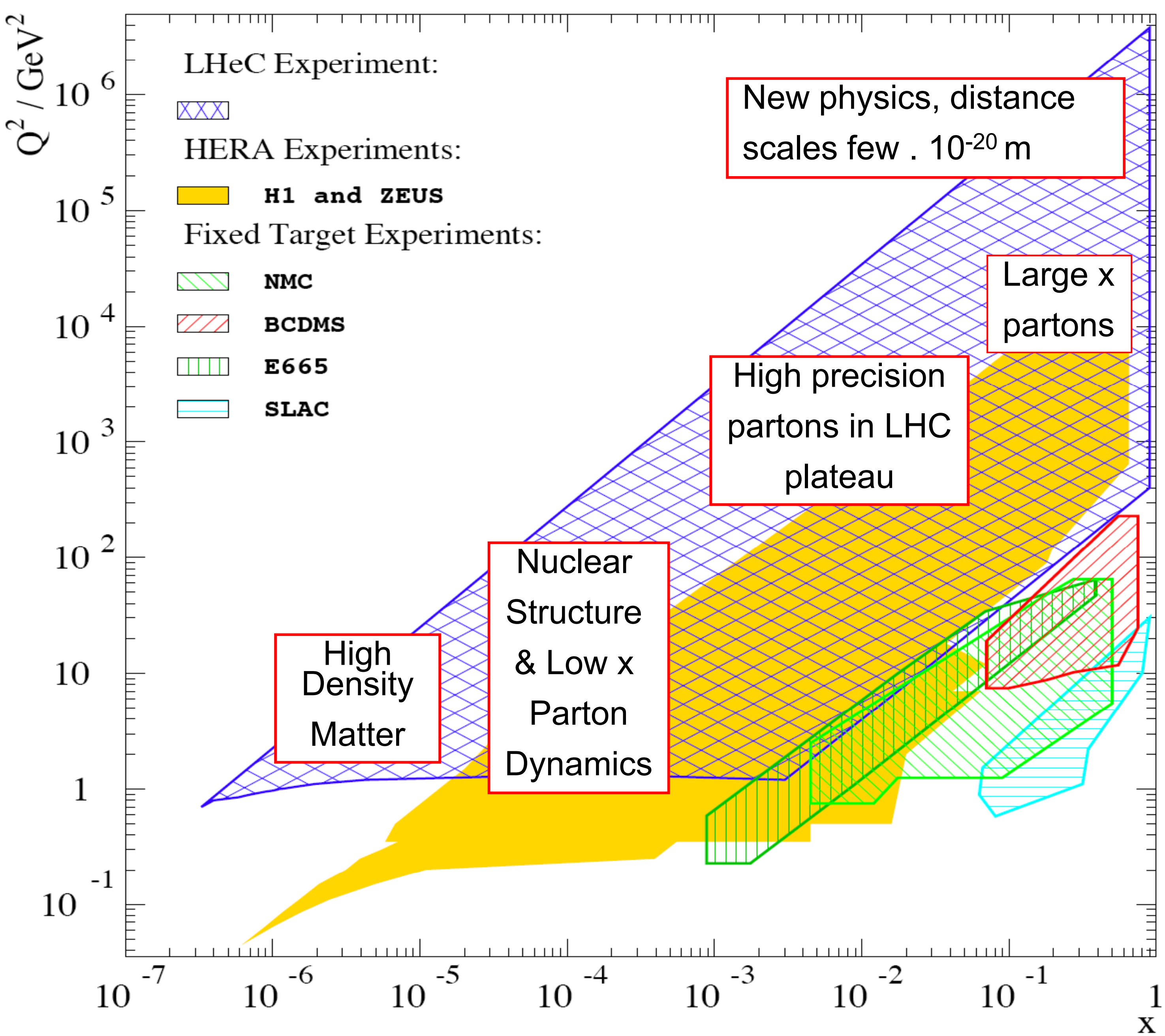
The LHeC Central Detector

P. Kostka, A. Polini, R. Wallny

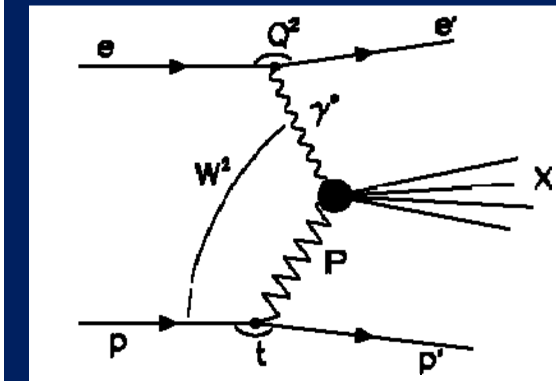
Outline:

- Experiment requirements and accelerator boundaries (Physics, Machine, Interaction Region and Detector)
- Present Detector Design
- Detector Components
- Architecture and Special Features
- Future and Outlook

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



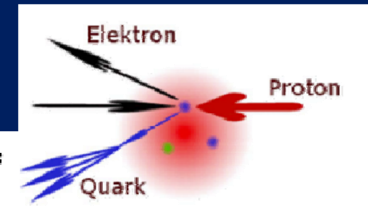
$\sqrt{s}$= 1.4 TeV

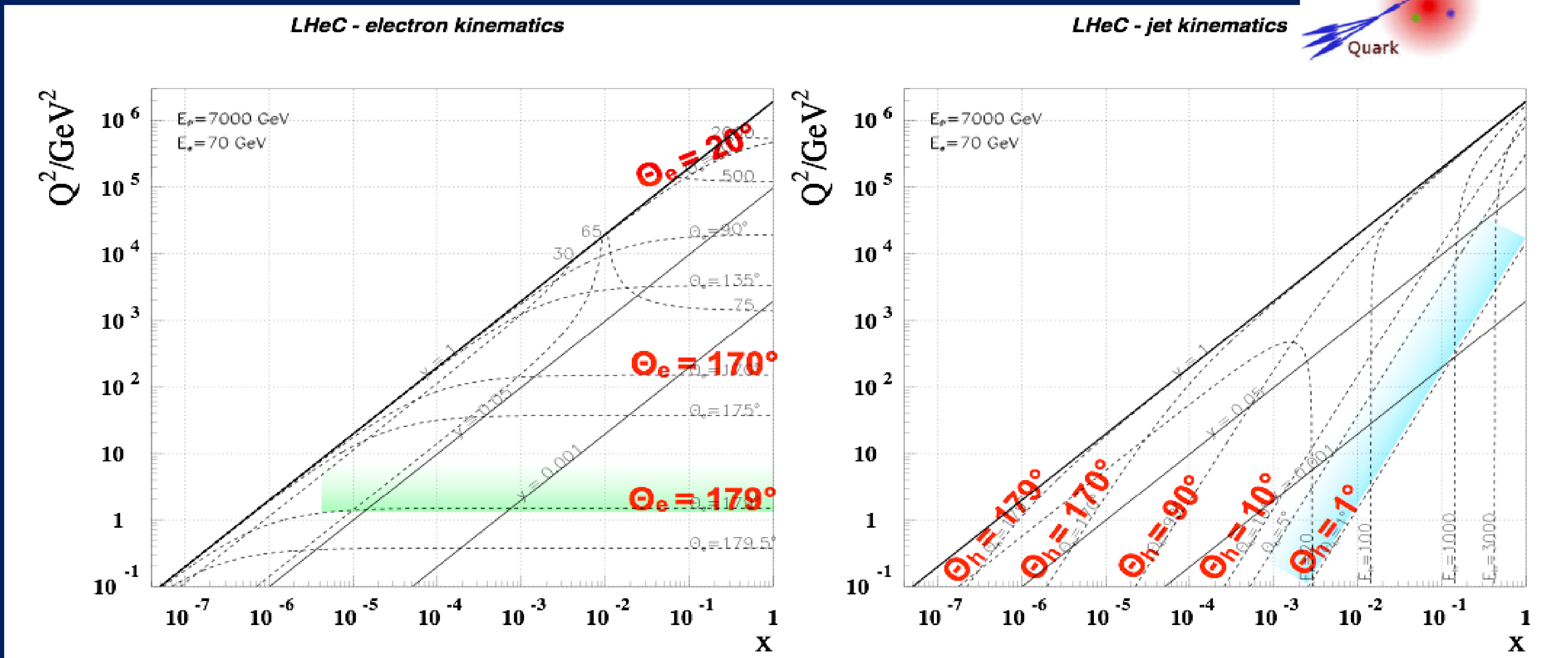


- High mass (M_{eq},Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier [x below 10^{-6} at Q^2 ~ 1 GeV^2]

→ 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 10° and below (blue). 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%

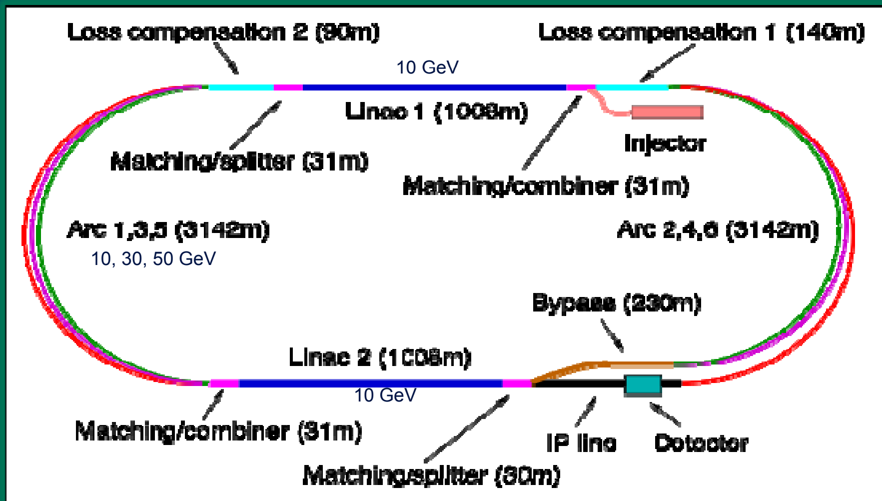
- **Scattered electron:**

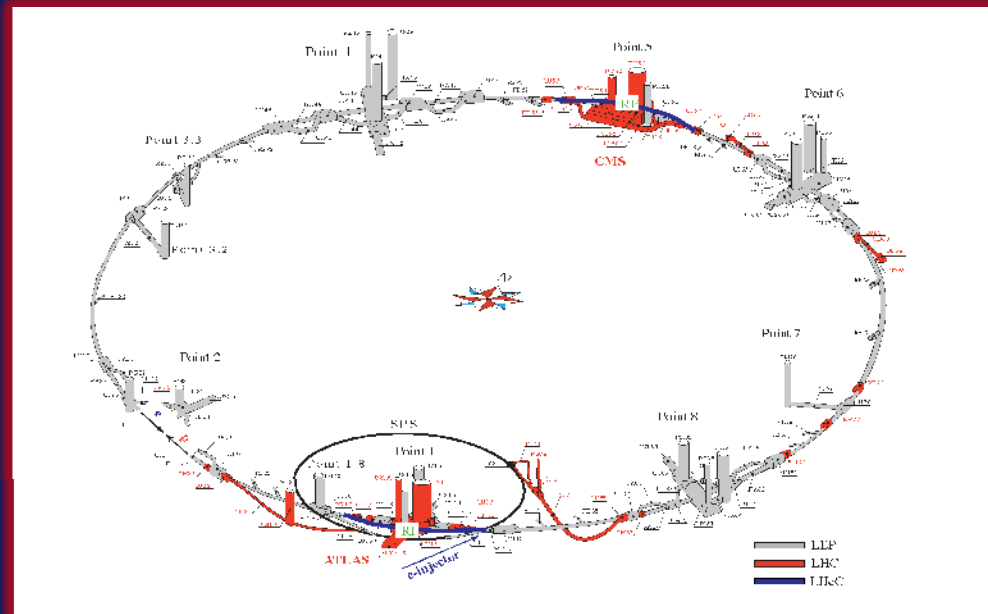
➔ Need very bwd angle acceptance for accessing the low Q^2 and high y region (green).

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.
- The final LHeC detector can profit from the technologies used nowadays at the LHC and the development and upgrade
- More refined studies will be required and will follow with the TDR and once a LHeC collaboration has been founded

Two Alternative Designs



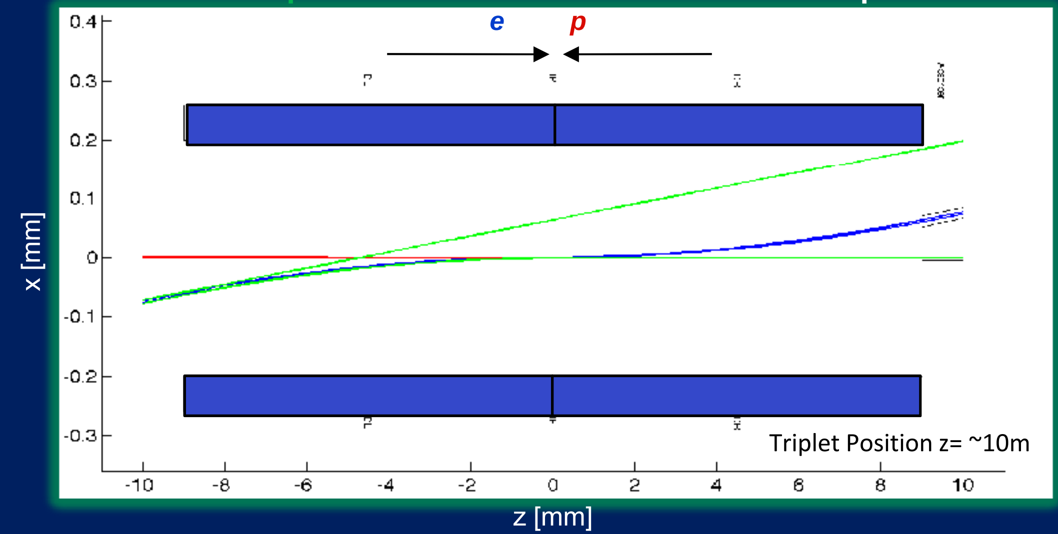


- Ring-Ring
  - e-p and e-A (A=Pb, Au, …) collisions
  - More “conventional” solution, like HERA, no difficulties of principle - at first sight - but constrained by existing LHC in tunnel
  - polarization 40% with realistic misalignment assumptions
- Linac-Ring
  - e-p and e-A (A=Pb, Au, …) collisions,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

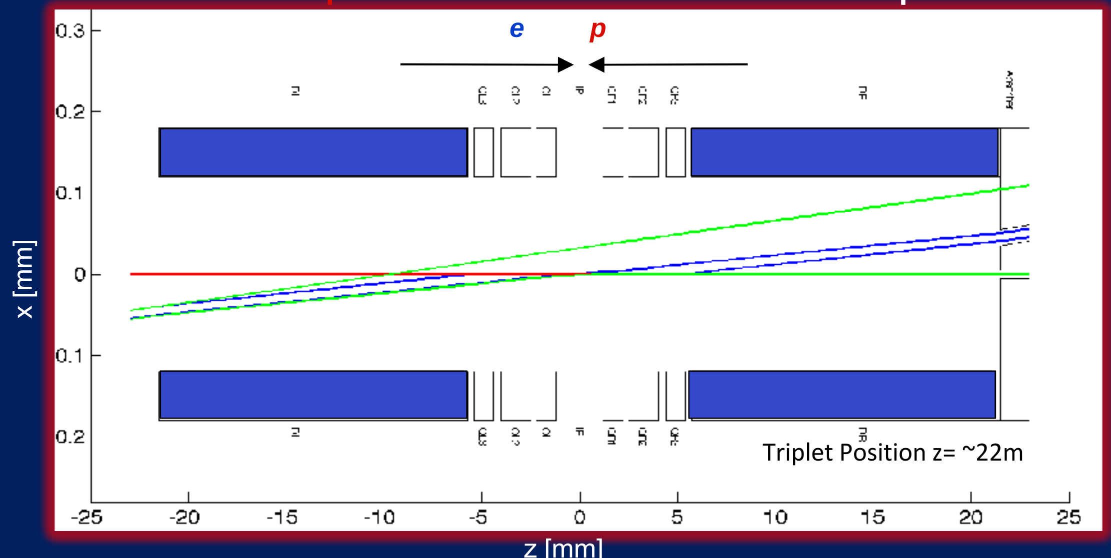
LR, RR option - Beam & SR

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 devoted to the interaction region design, which comprises beam bending (in/out), direct and secondary synchrotron radiation, vacuum and beam pipe demands.

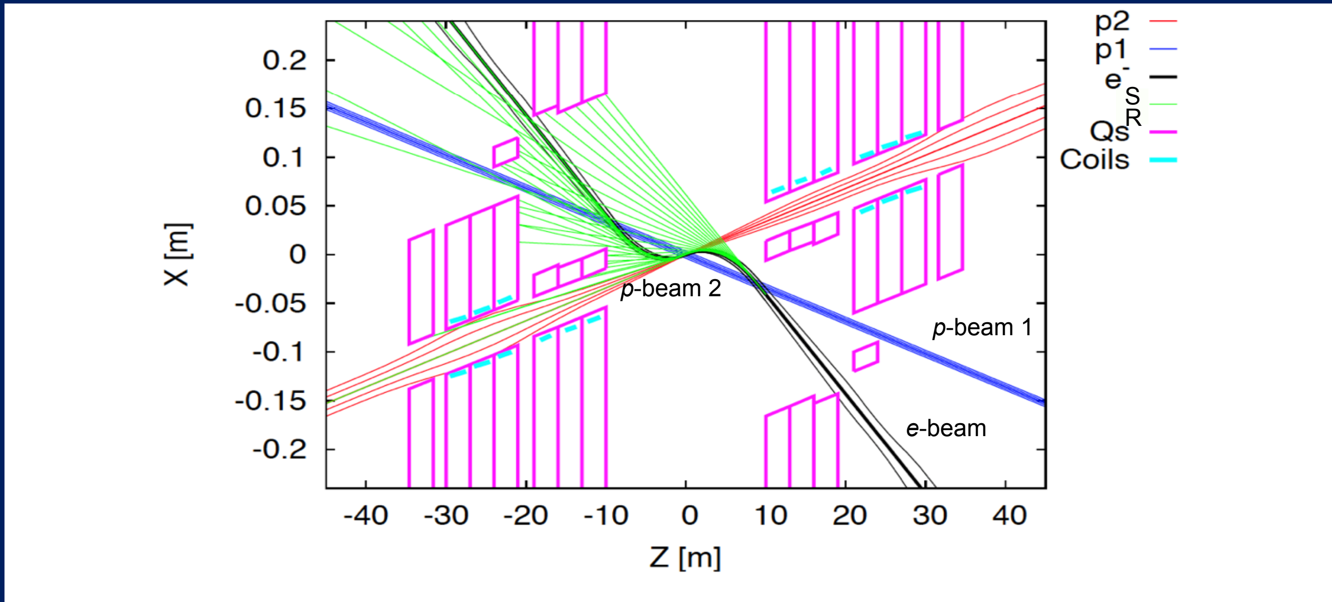
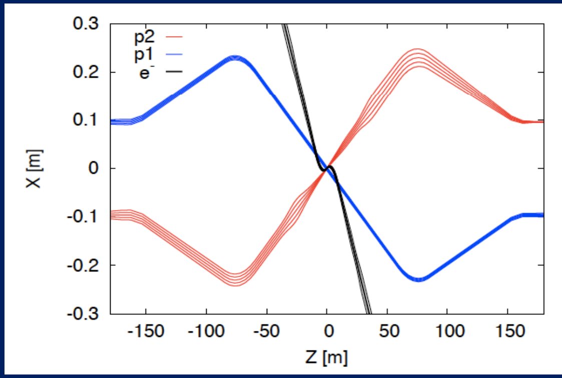
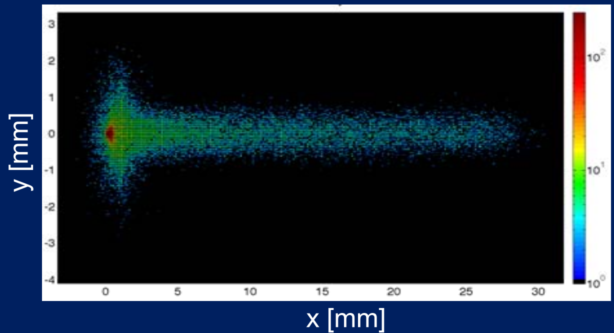


Figure 9.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam trajectories with 5σ and 10σ envelopes are shown.

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°)

RR Beam Optics and Detector Acceptance

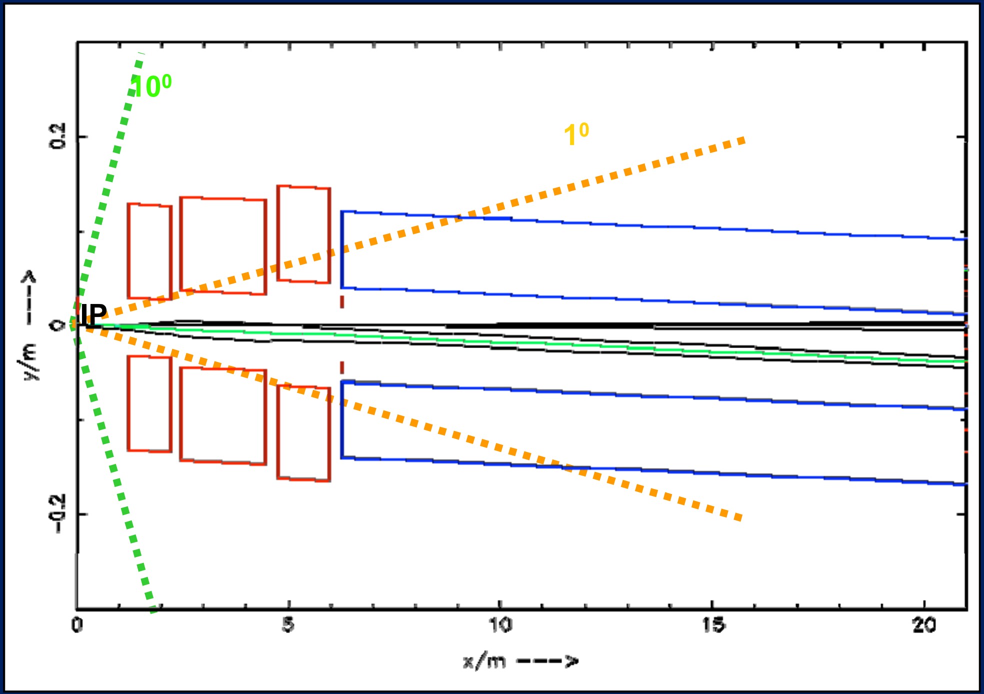
High Acceptance

– L ~ 7.3 x 10^{32} cm^{-2} s^{-1} (1° < θ < 179°)
first e beam magnet placed at z= ±6.2m

↕ Luminosity factor ~ 2 only

High Luminosity

– L ~ 1.3 x 10^{33} cm^{-2} s^{-1} (10° < θ < 170°)
Low β* magnets near the IP (HERA2)
(at z= ±1.2m)



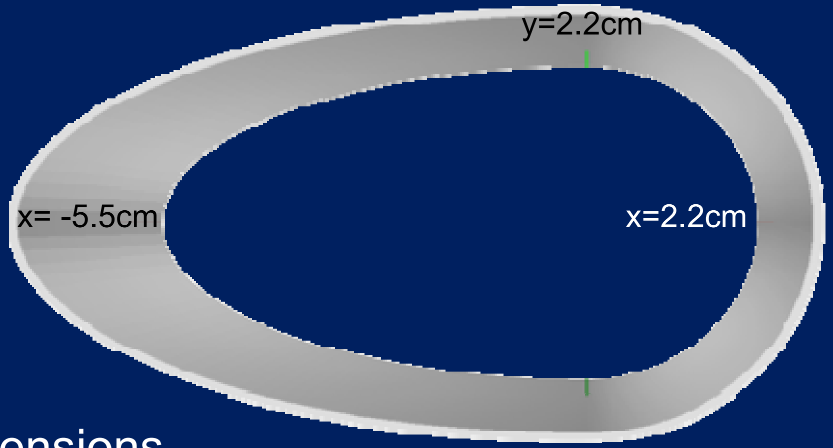
Consequences on detector design:

- RR Lower Lumi, Low Q^2 access → High Acceptance detector 1° - 179°
- RR Higher Lumi, High Q^2 access → High Luminosity detector 10° - 170°

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

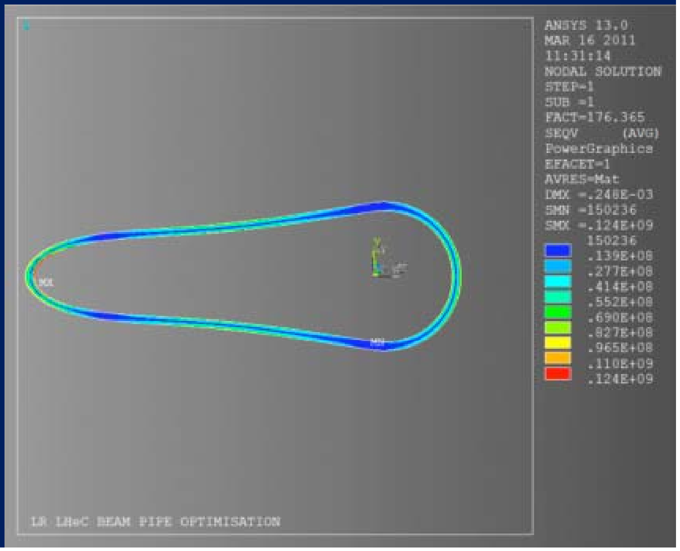
beam pipe dimensions reduced - using static / movable masks;



housing beam/SR envelopes
+ 1cm safety margin

Linac-Ring - Inner Dimensions

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



A. Polini

Machine Options - Impact

- Linac-Ring
  - 2 x 9m 0.3 T dipole over full detector length (and beyond)
  - Synchrotron fan
- Ring-Ring
  - High Luminosity requiring additional focusing quadrupoles near to the Interaction Point
    - Two configurations
    - Detector modular / removable forward / backward tracker & calorimeter end-caps
- Beam Optics / Synchrotron Radiation
  - beam pipe circular-elliptical - aperture φ-dependent
    → detector design - follow BP shape

The LHeC Detector Concept

- High Precision resolution, calibration, low noise at low y, tagging of **b**,**c**; based on the recent detector developments, using settled technology, avoiding R&D programs
- Modular and flexible accommodating the High Acceptance/High Luminosity physics programs (RR); Detector assembly above ground; Detector access (shutdown)
- Minimal radiation length tracker design: integrating services into support structure
- Small radius and thin beam pipe optimized in view of aperture (1-179^o acceptance covering low Q^2 , high x physics program), synchrotron radiation and background production.
- Affordable - comparatively reasonable cost.

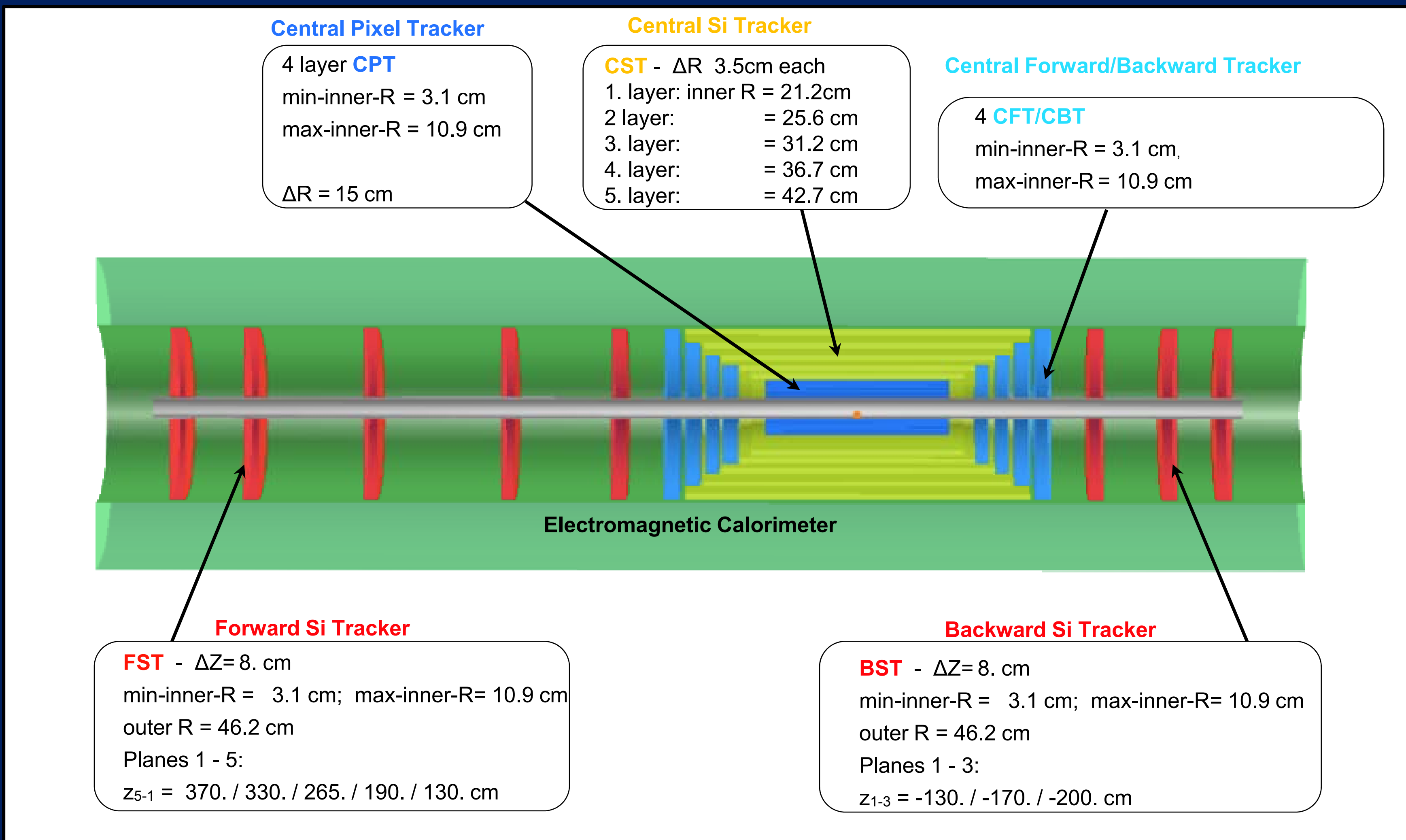
Requirements from Physics

- High resolution tracking system
  - excellent primary vertex resolution
  - resolution of secondary vertices down to small angles in forward direction for high x heavy flavour 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

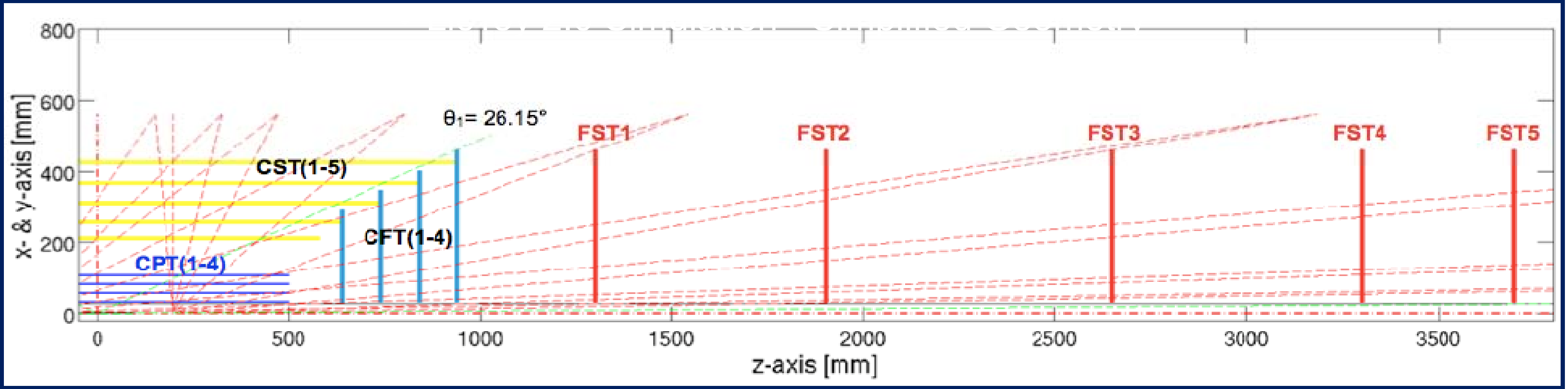
Tracking - High Acceptance

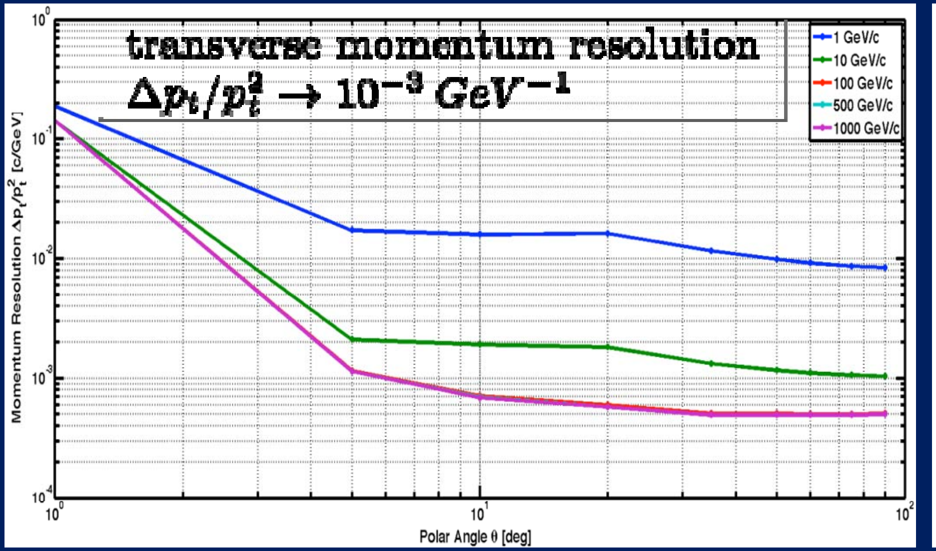
Dominant forward production of dense jets;
backward measurements relaxed



Tracker Simulation

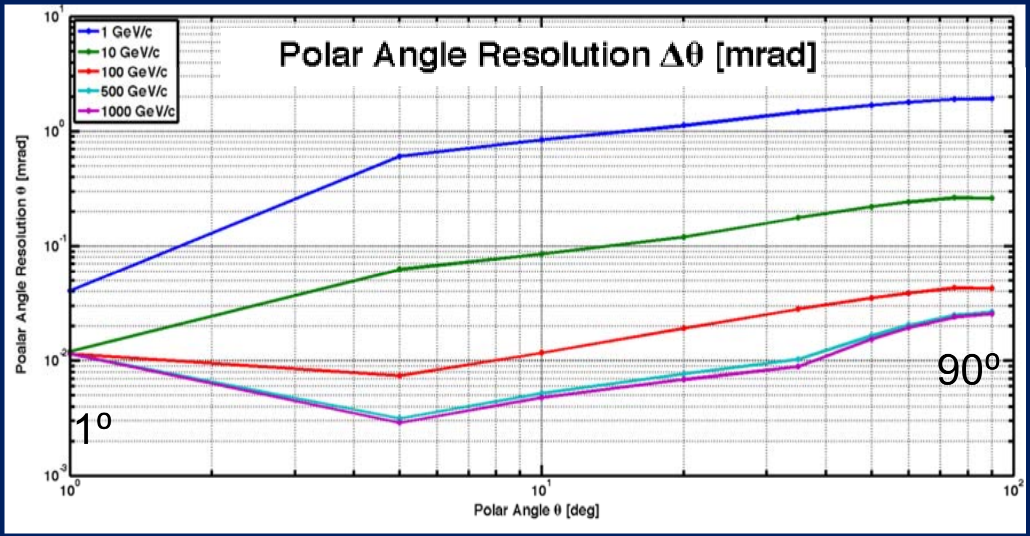
http://wwwhephy.oeaw.ac.at/p3w/ilc/lictoy/UserGuide_20.pdf

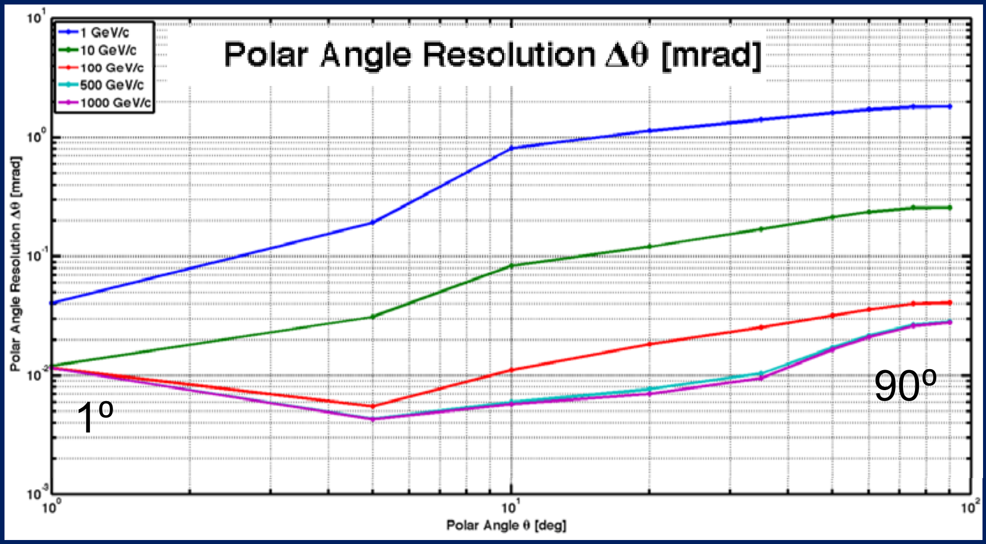


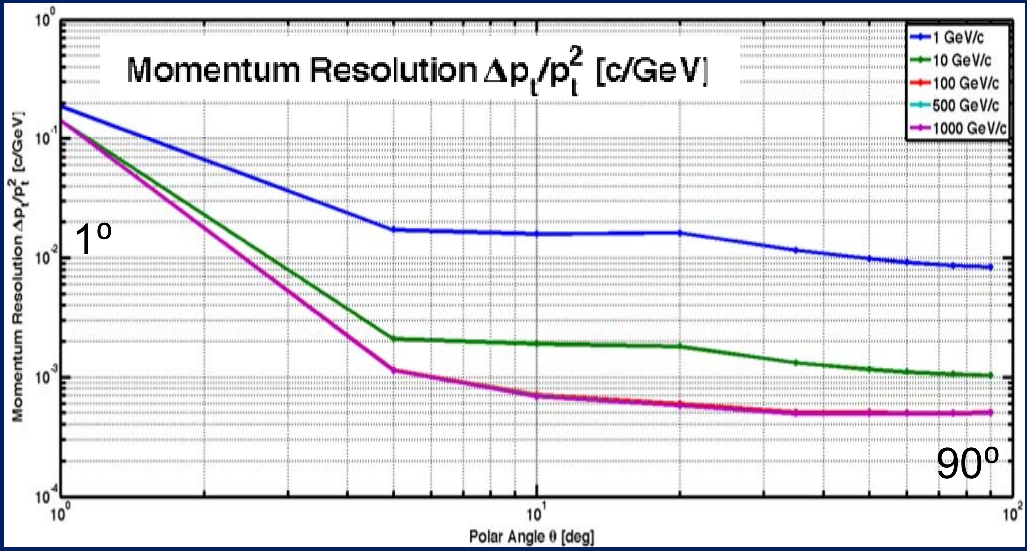


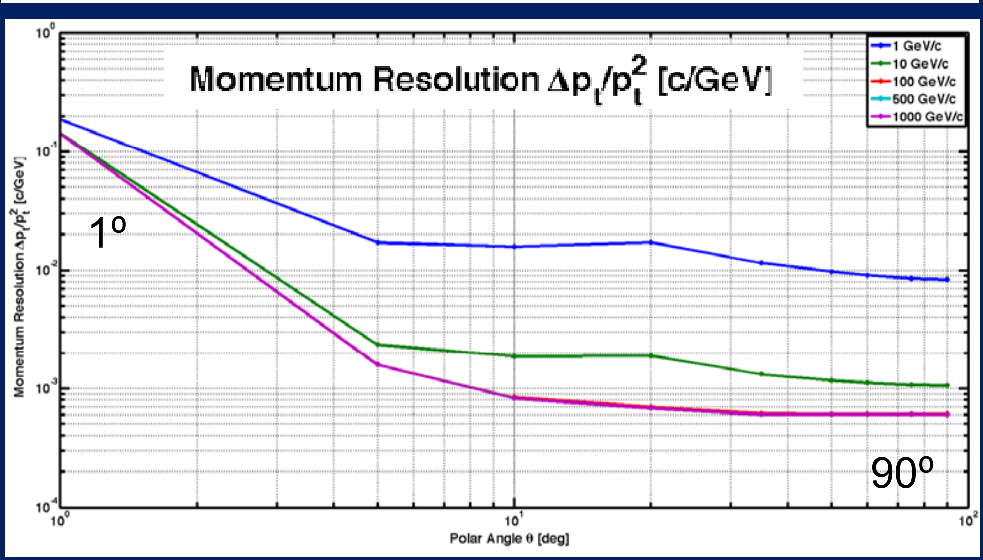
- Silicon: compact design, low budget material, radiation hard

Tracker Simulation (ii)



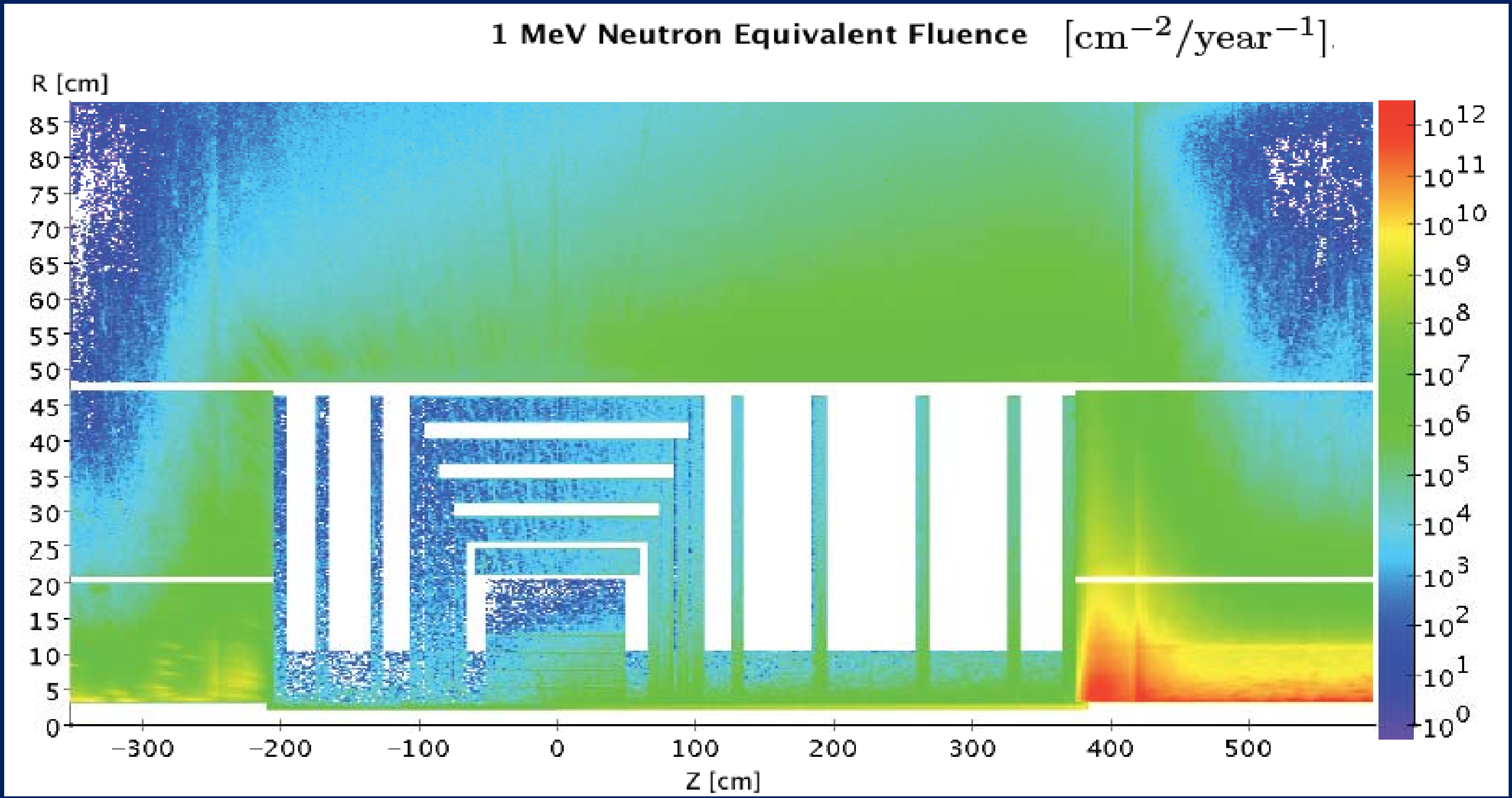






- Same plots (left) and (small) deterioration in case of innermost barrel layer failure (right)

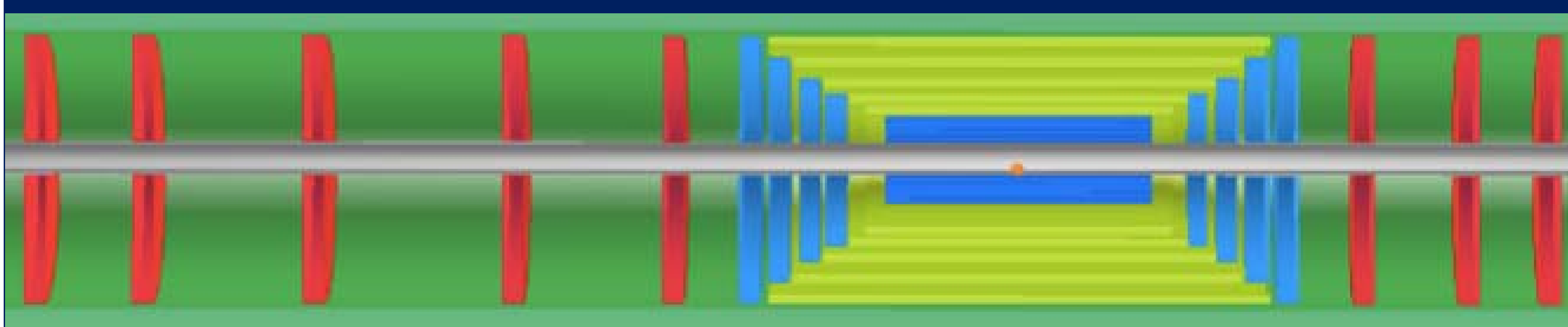
GEANT4 - Fluences

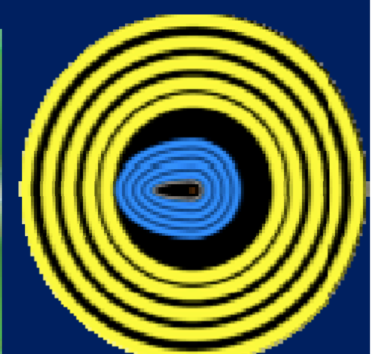


- Similar studies being done with FLUKA
- Most critical the forward region
- Rates far lower than LHC (LHC ~5 x 10^{14})

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

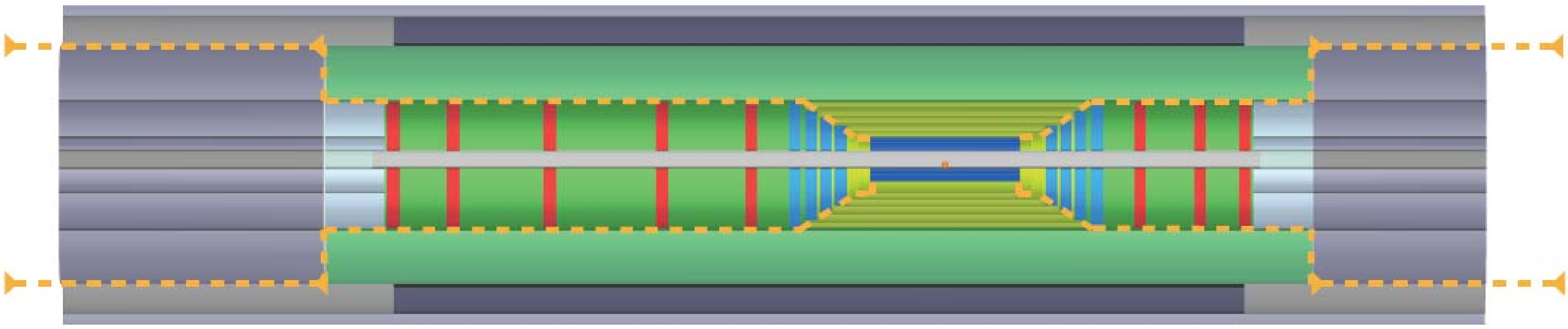
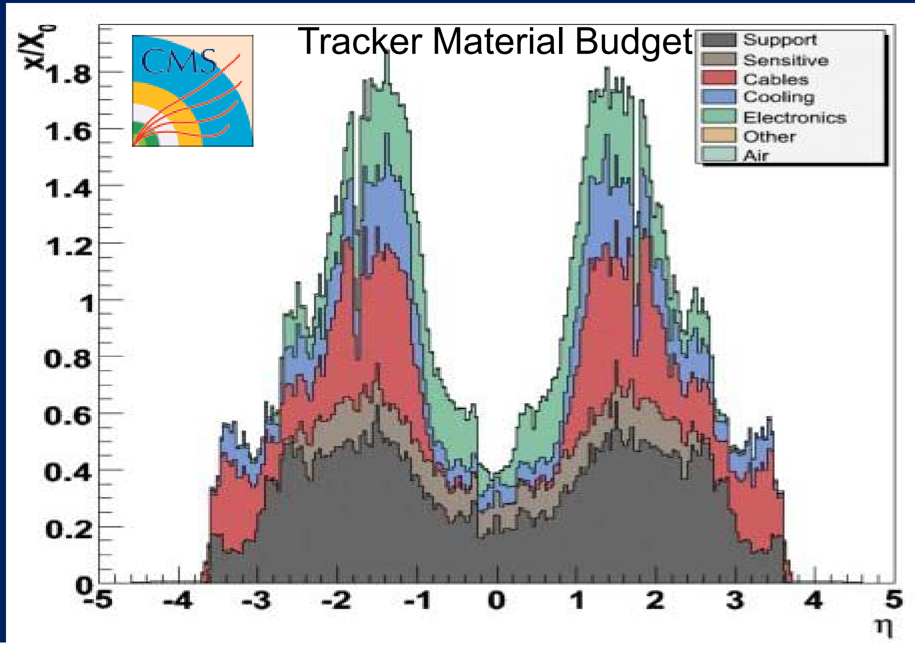
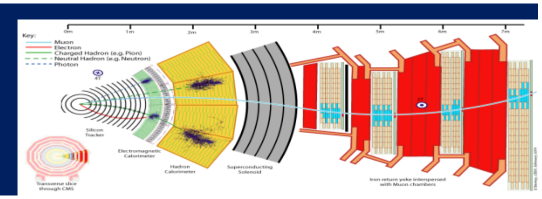


Figure 13.29: Path of services for all tracking detectors (shown in orange). The services are integrated into support structures whenever possible

- 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



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

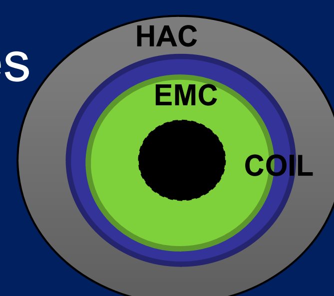
Large Coil

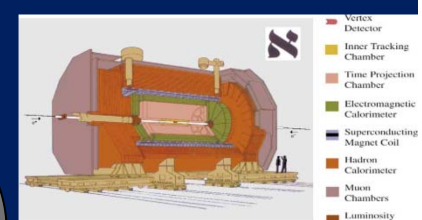
- Large Solenoid containing the Calorimeter
- 3.5 T Solenoid of similar to CMS/ILC
- Precise Muon measurement
- Large return flux either enclosed with Iron or

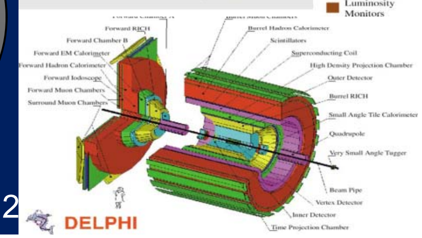
  Option of active B shielding with 2nd solenoid

Small Coil

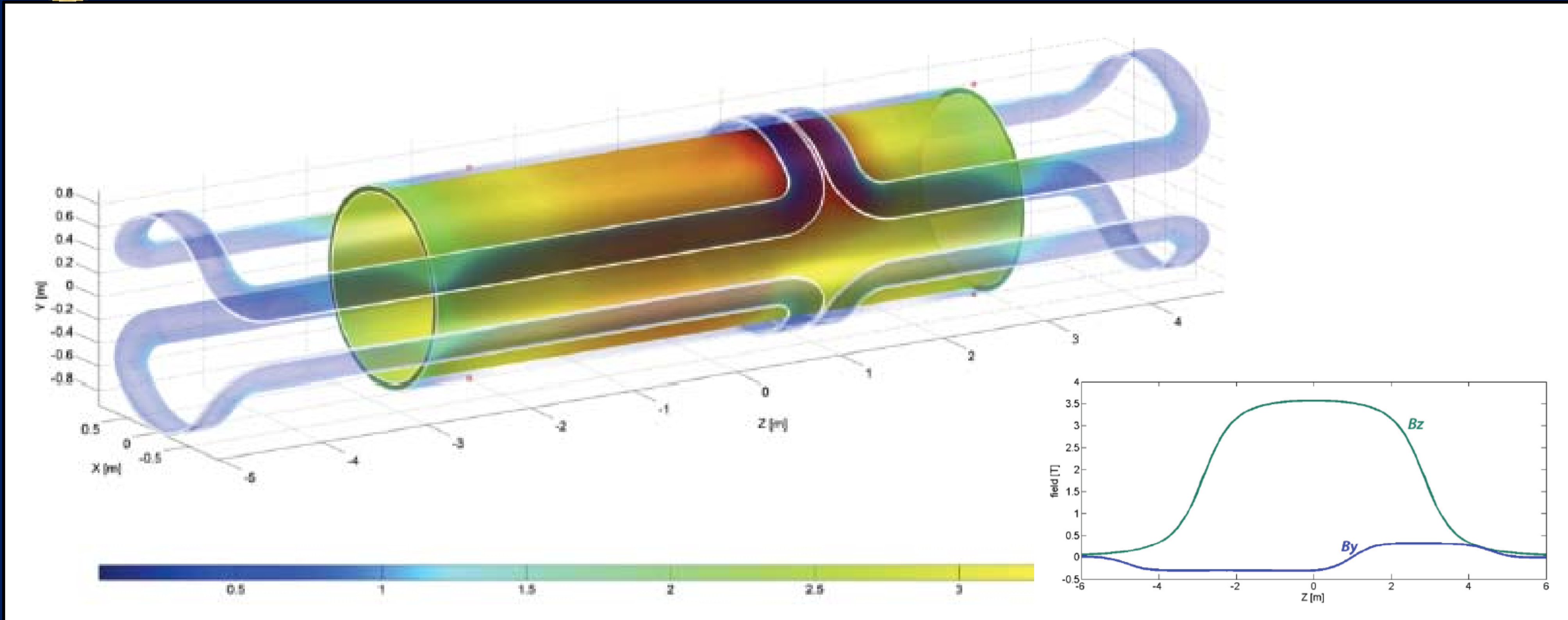
- Smaller Solenoid placed between EMC and HAC
- Cheaper option
- Convenient displacement of Solenoid and Dipoles in same cold vacuum vessel (Linac-Ring only)
- Smaller return flux (less iron required)
- Muon p, p_t measurement compromised







Magnets

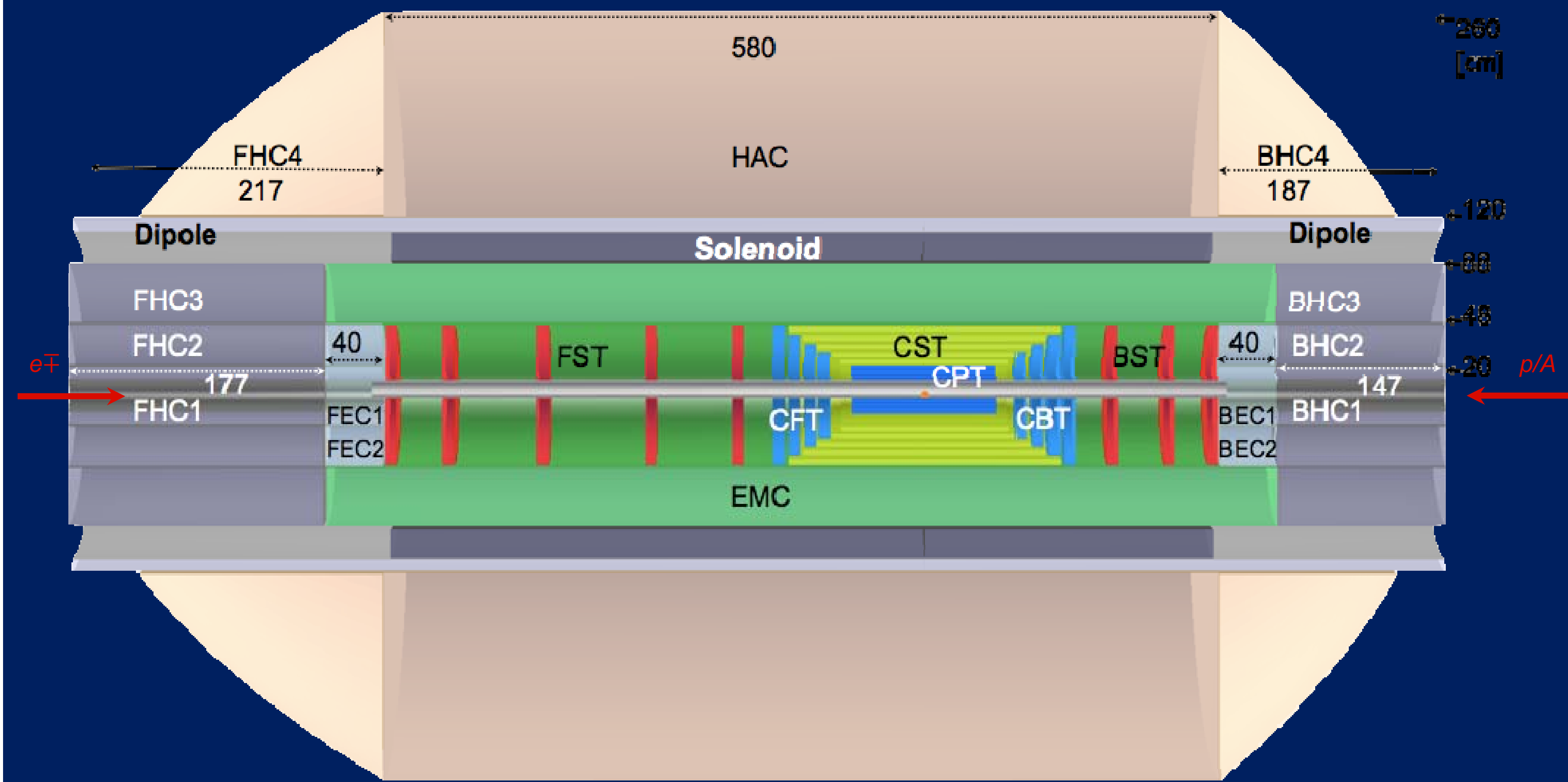


Baseline Solution:

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

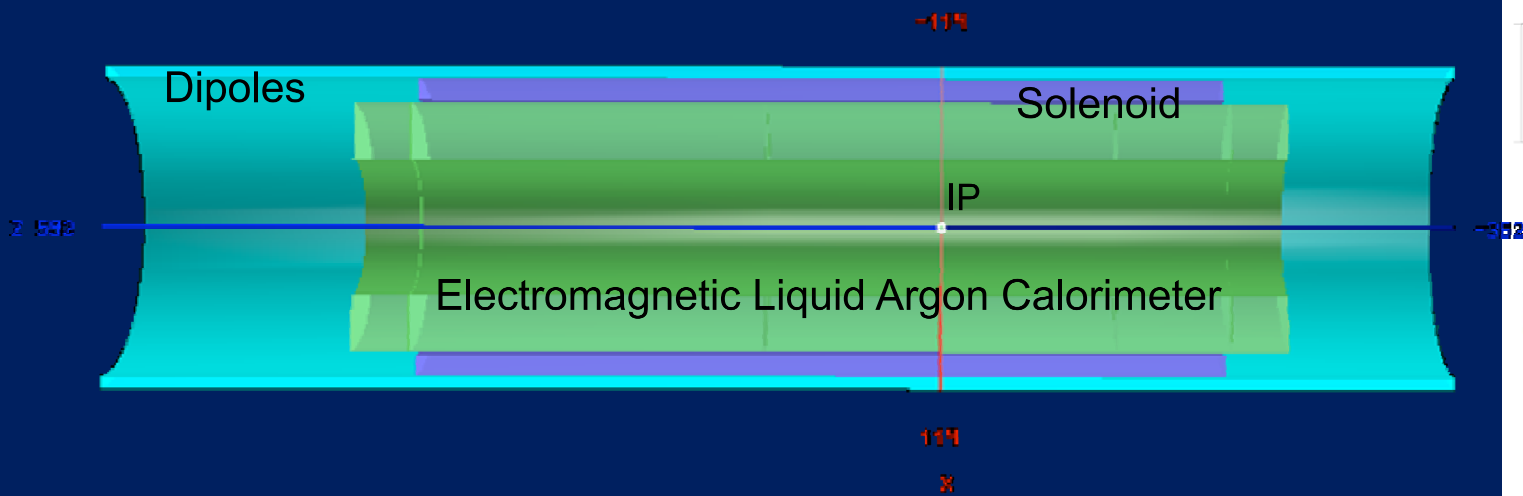
→ Need of study the Calorimeter Performance and impact of dead material between EMC and HAC sections; it might be possible placing the magnet system even in front of the EMC - at even lower radius at just outside of the tracking system

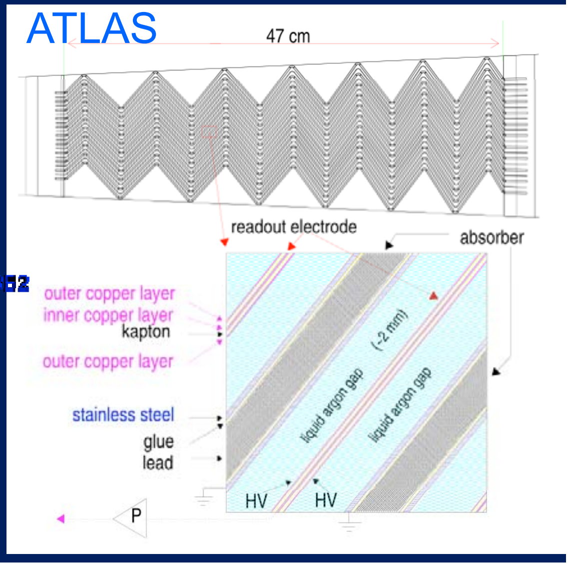
Baseline Detector



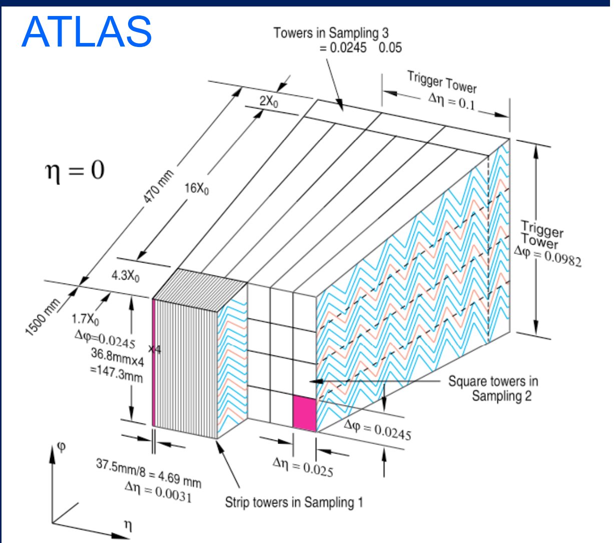
Electromagnetic Calorimeter (i)

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

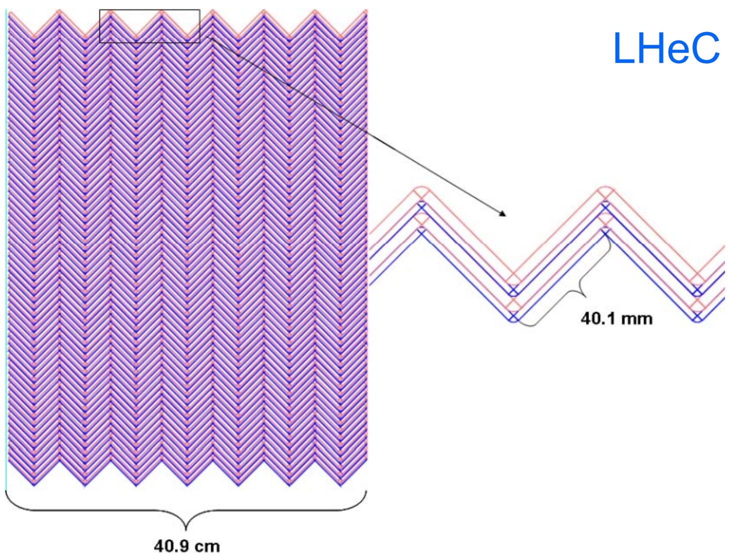


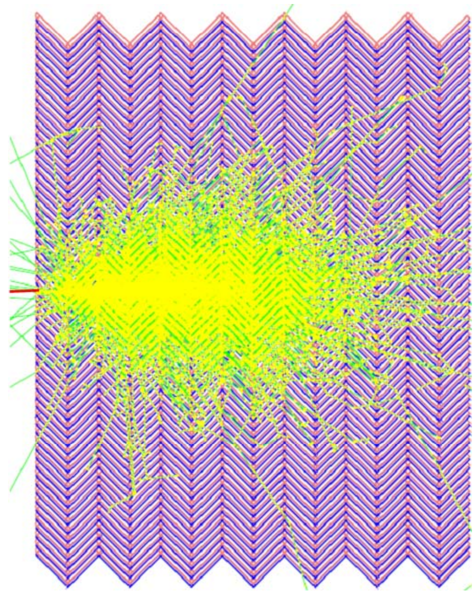


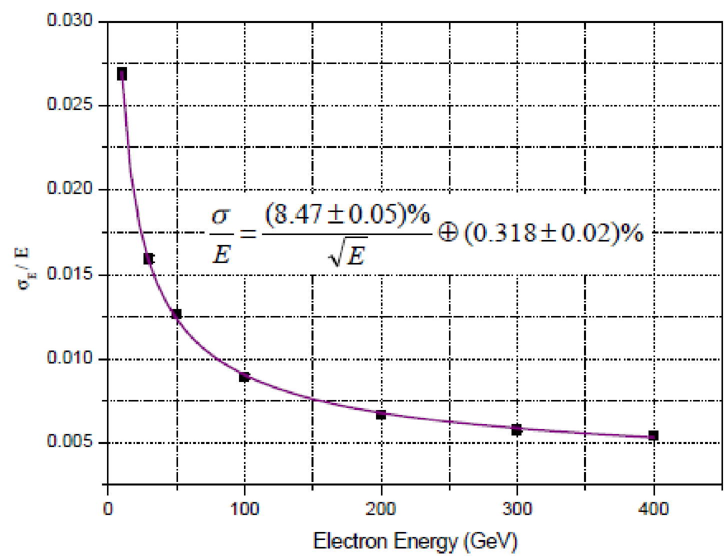
- Advantage: same cryostat used for solenoid and dipoles
- GEANT4 simulation (*)
- Simulation results compatible with ATLAS
- barrel cryostat being carefully optimized pre-sampler optimal
- 3 different granularity sections longitudinally



Electromagnetic Calorimeter (ii)







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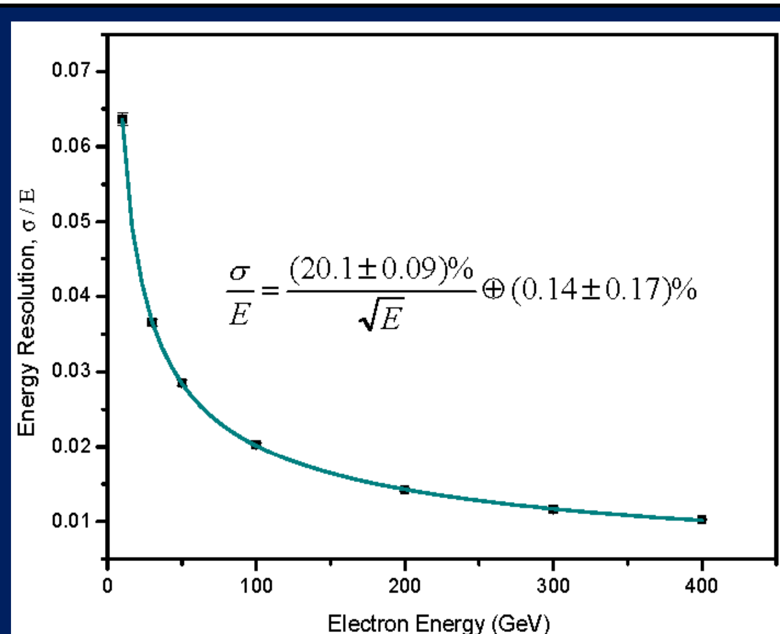
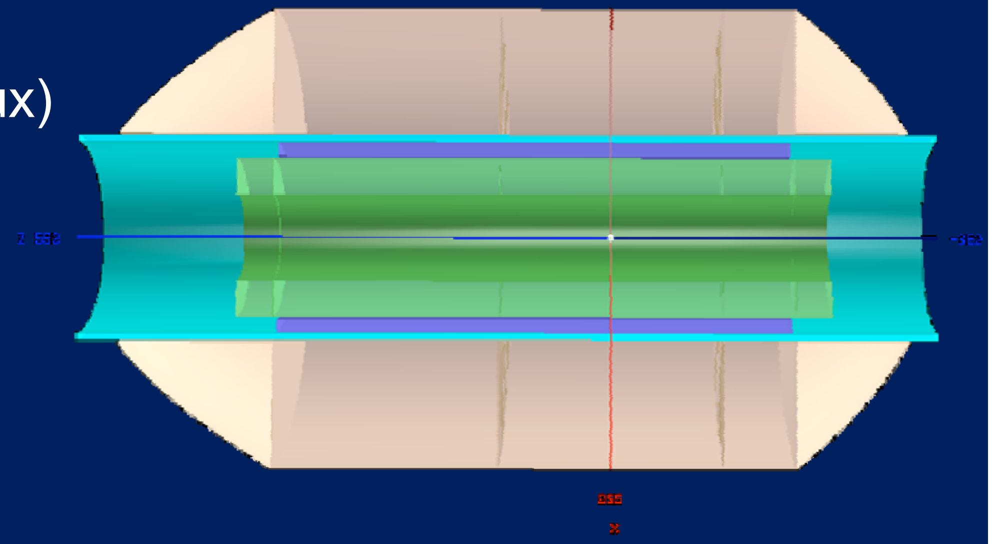
- Simulation with simplified design w.r.t.Atlas
- LAr Calorimeter : good energy resolution, stable performance
- Simulation results compatible with ATLAS
- Warm (Pb/Sci) option also investigated
- $30X_0$ (X_0(Pb)=0.56 cm; 20 layers) →

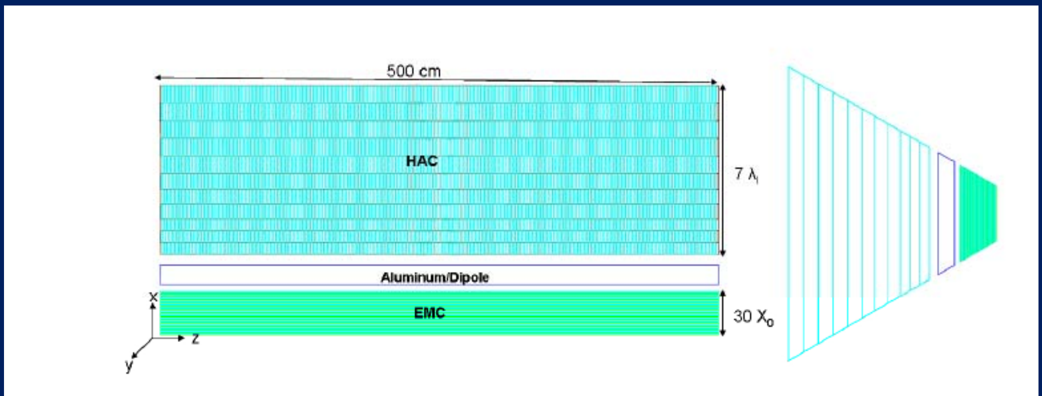


Hadronic Calorimeter (i)

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



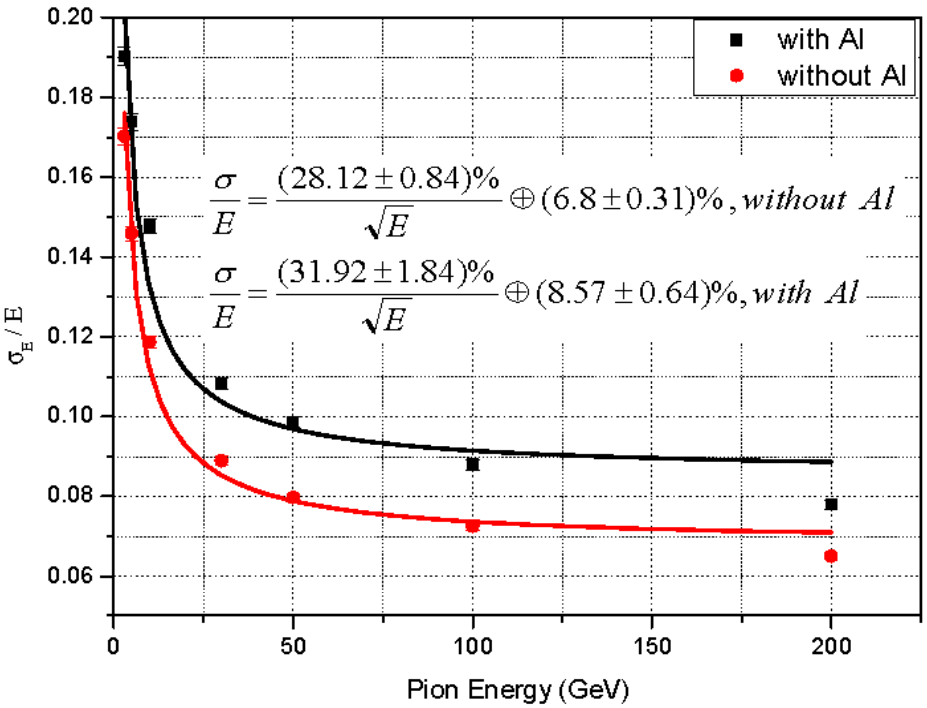
Tile Rows	Height of Tiles in Radial Direction	Scintillator Thickness
1-3	97mm	3mm
4-6	127mm	3mm
7-11	147mm	3mm

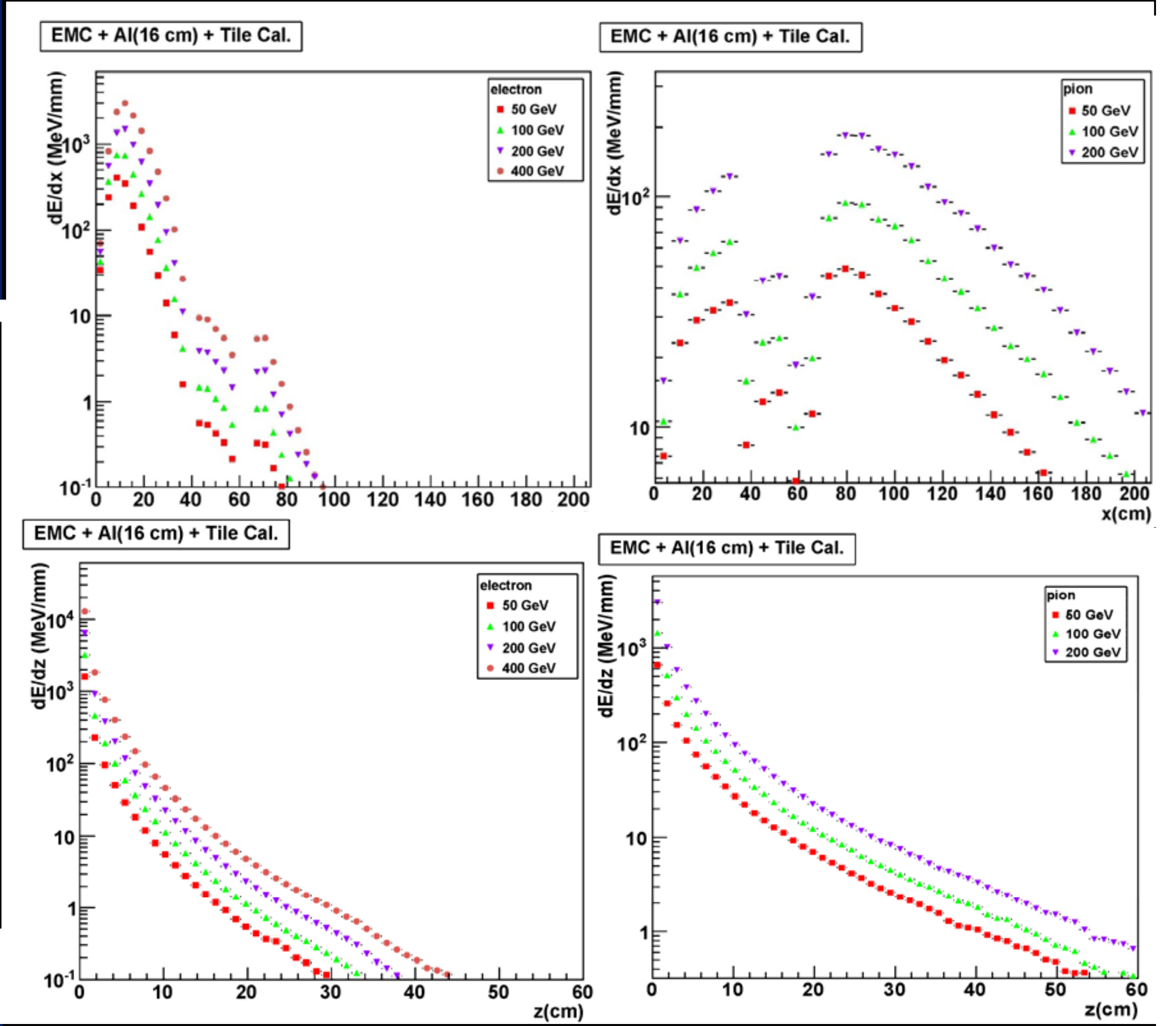


- GEANT4 simulation (*)
- performance optimization:
  - containment, resolution, combined HAC & EMC response
  - solenoid/dipoles/cryostat in between

Hadronic Calorimeter (ii)

- Preliminary studies on impact of the magnet system on calorimetric measurements
- Energy resolutions
- Shower profiles





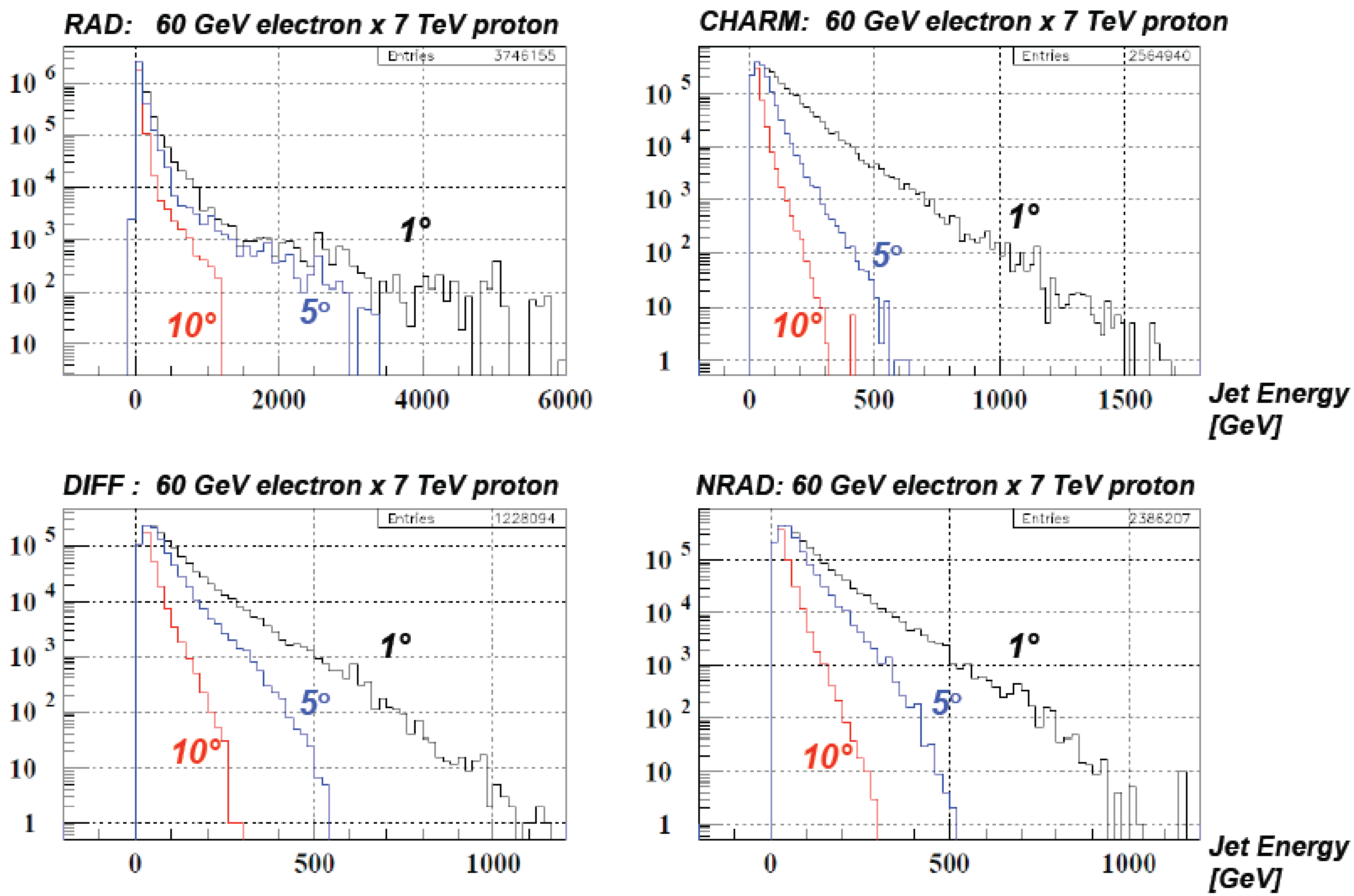
Forward Energy and Acceptance

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

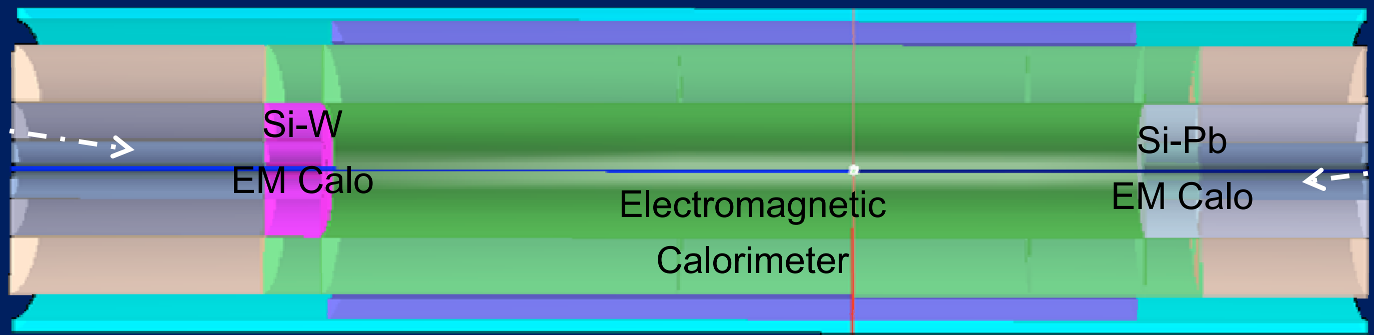
HzTooL-4.2 (H.Jung et.al. - http://projects.hepforge.org/hztool/)

selection: q^2.gt.5

→ Highest acceptance desirable

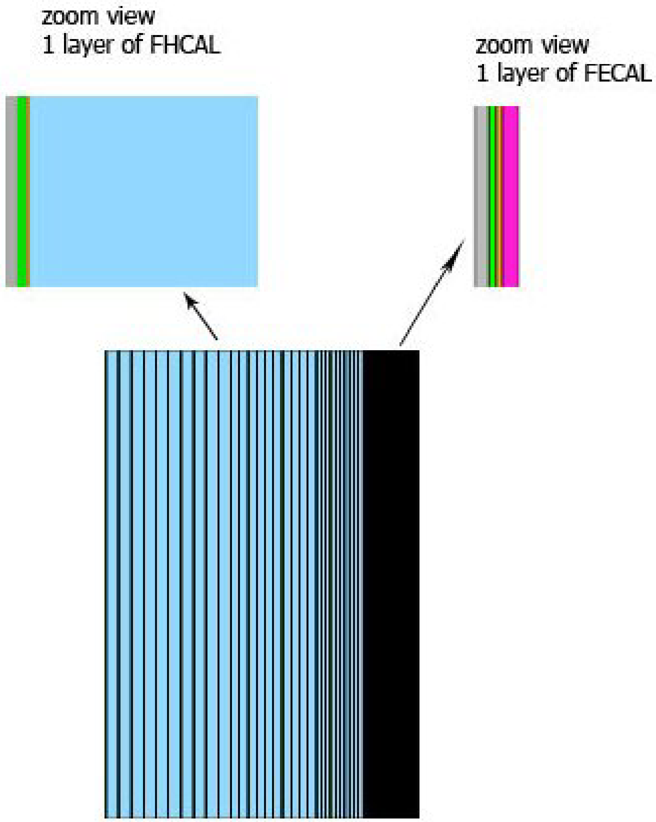


Endcap Calorimeters



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)



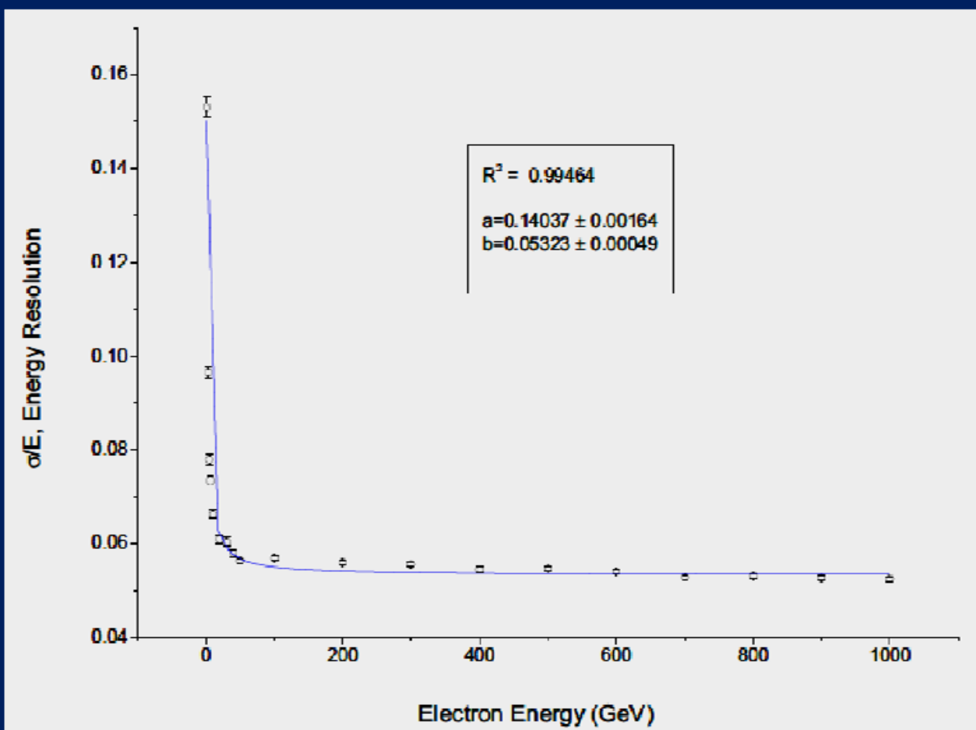
FECAL + FHCAL composite calorimeter

(*) A. Kilic, I. Tapan - Uludag University

Forward/Backward Calorimeters

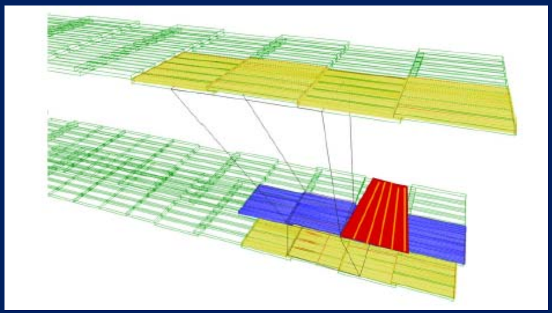
- Highest energies in forward region
- Radiation hard
- High Granularity
- Linearity

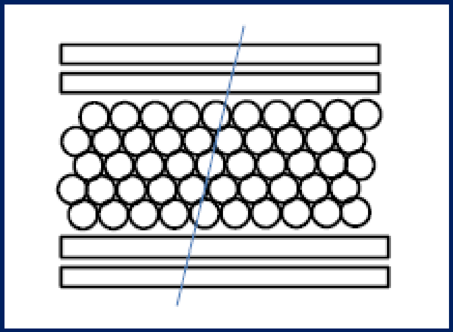
Calorimeter Module	Layer	Absorber	Thickness	Instrumented Gap	Total Depth
FEC(W-Si) 30x0	1-25 26-50	1.4 mm 2.8 mm	16 cm 19.5 cm	5 mm	35.5 cm
FHC (W-Si)	1-15 16-31 32-46	1.2 cm 1.6 cm 3.8 cm	39 cm 48 cm 78 cm	14 mm	165 cm
FHC (Cu-Si)	1-10 11-20 21-30	2.5 cm 5 cm 7.5 cm	30 cm 55 cm 80 cm	5 mm	165 cm
BEC (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

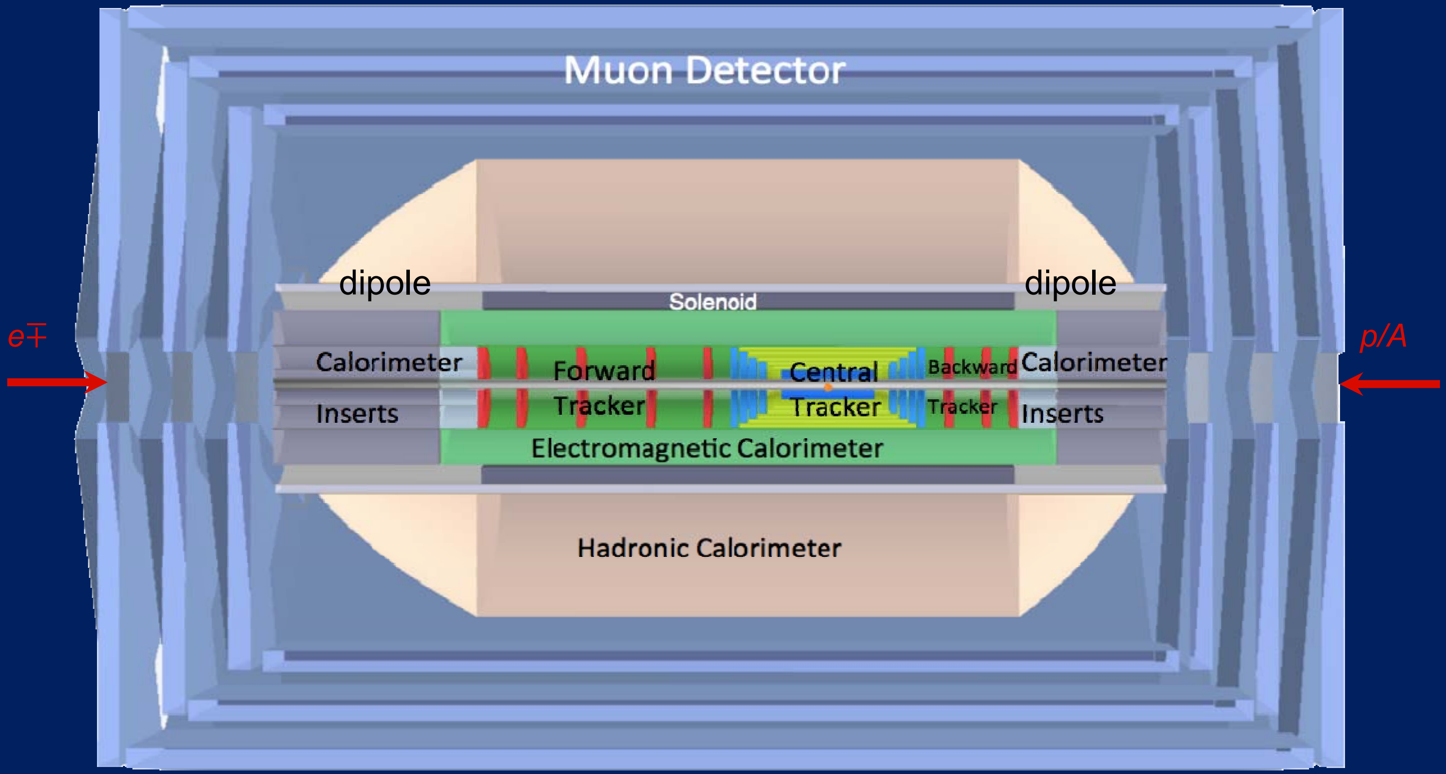


Calorimeter Module (Composition)	Parameterized Energy Resolution
Electromagnetic Response	
$\mathrm{FEC}_{(\mathbf{W-Si})}$	$\frac{\sigma_E}{E} = \frac{(14.0 \pm 0.16)\%}{\sqrt{E}} \oplus (5.3 \pm 0.049)\%$
$\mathrm{BEC}_{(\mathbf{Pb-Si})}$	$\frac{\sigma_E}{E} = \frac{(11.4 \pm 0.5)\%}{\sqrt{E}} \oplus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



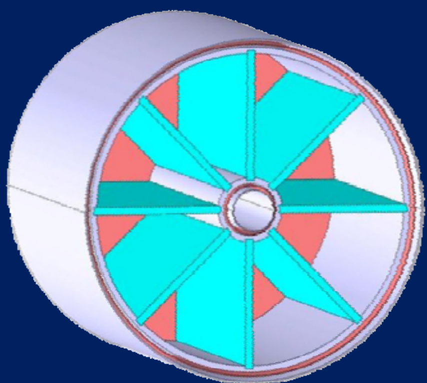


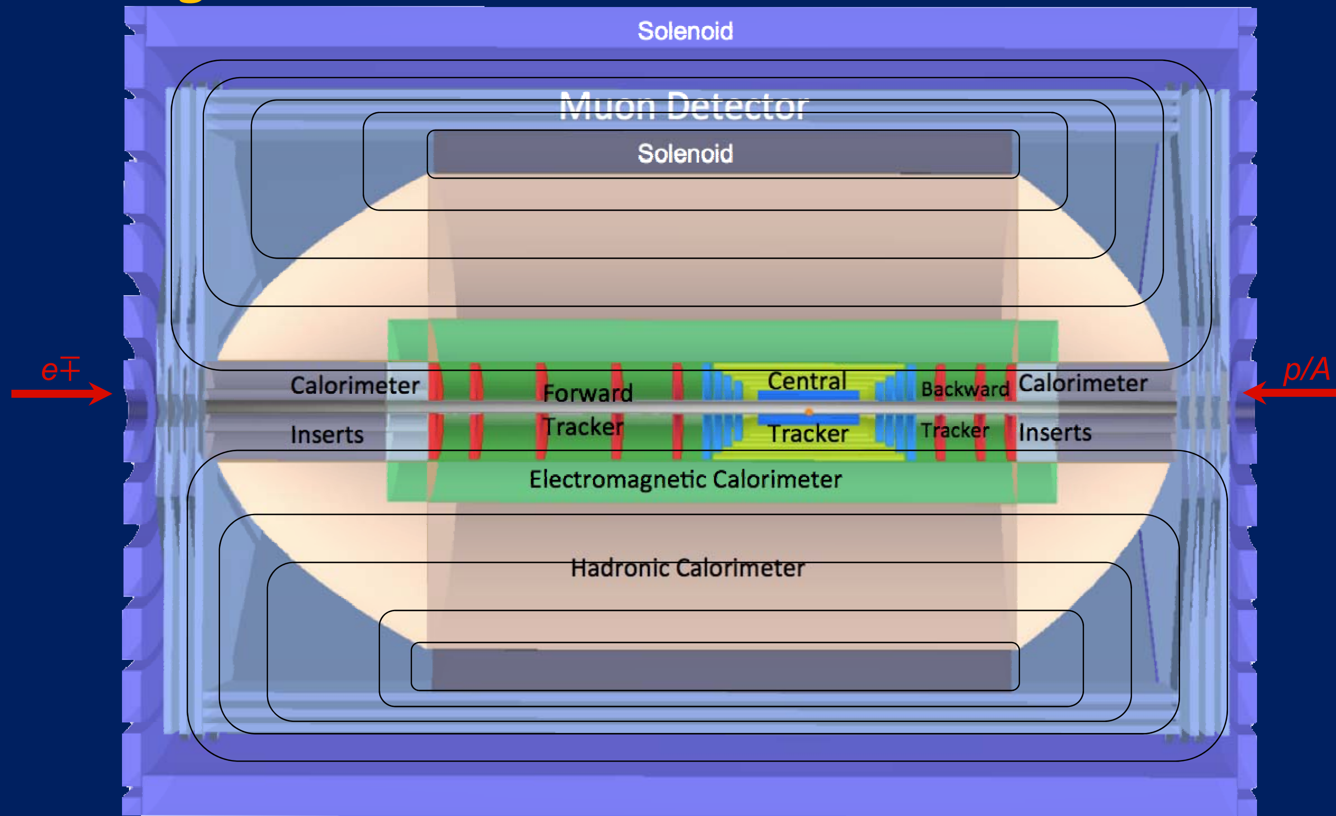


Baseline Solution:

- 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

Conclusions

- A LHeC baseline detector 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
- The experiment solenoid & dipoles are placed between EMC and HAC

- Tracker: central pixel, central strip, forward/backward disks.
- Calorimeter: barrel LAr+Tile (ATLAS), forward/backward end-caps
- Muon: tagging and combined momentum measurement
- Large solenoid option: best calorimeter resolution, full and independent muon momentum measurement possible

- As a baseline many improvements available. A more precise design will follow from more detailed simulations and the knowledge of the adopted machine option

Outlook

- *3 LHeC annual workshops*
- *CDR passed the Referee Report*
- *Final Checks*

➔*CDR by end of*
Spring 2012

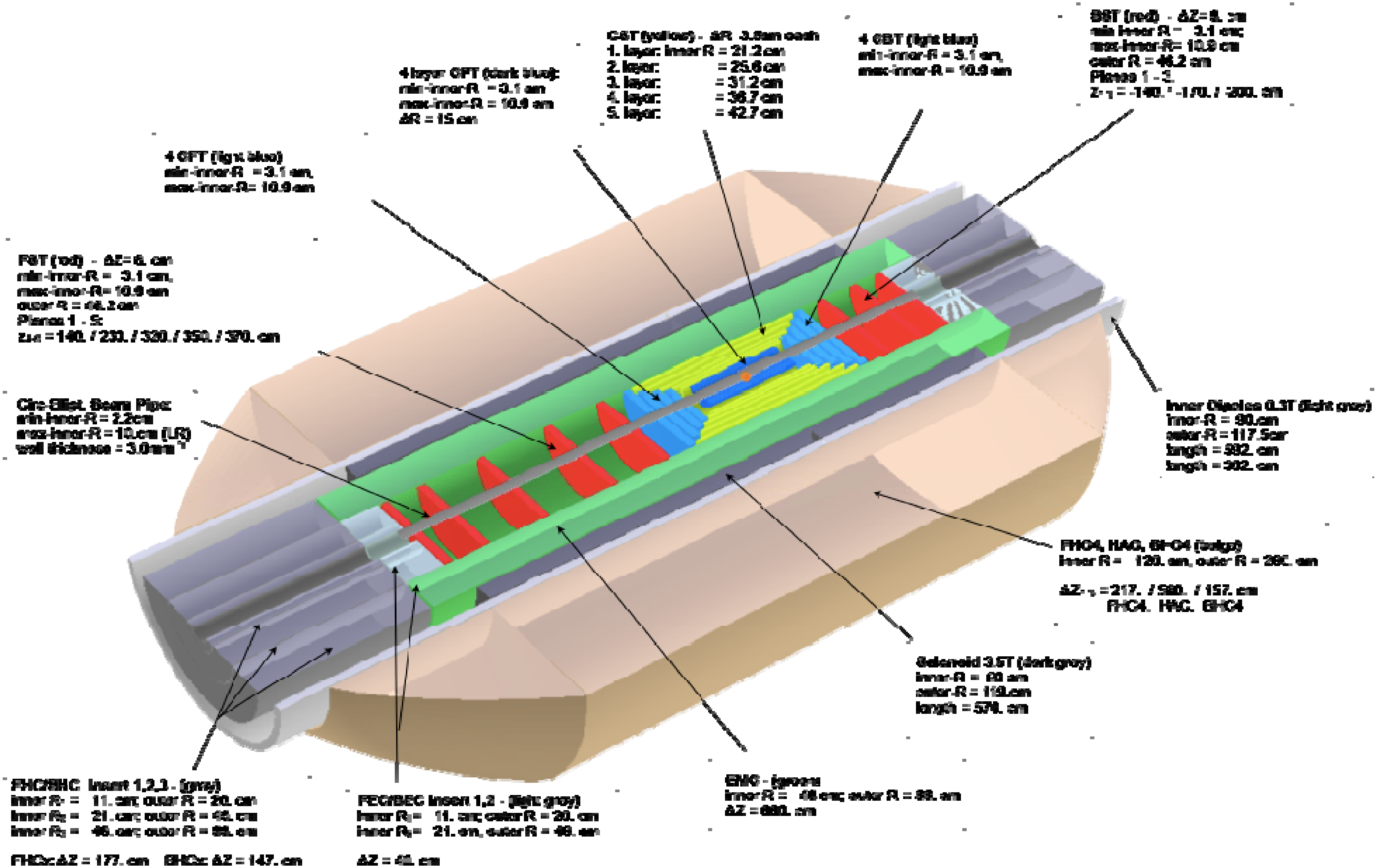
Next:

- *Setup a larger collaboration*

➔*Technical Design Report*

http://cern.ch/lhec

Backup Material


4 layer CFT (dark blue):
min-inner-R = 3.1 cm
max-inner-R = 10.9 cm
ΔR = 15 cm
CST (yellow) - ΔR 3.8cm 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= 6. cm
min inner R = 3.1 cm;
max-inner-R= 10.9 cm
outer R = 46.2 cm
Planes 1 - 3:
4 CFT (light blue)
min-inner-R = 3.1 cm,
max-inner-R= 10.9 cm
FST (red) - ΔZ= 6. cm
min-inner-R = 3.1 cm,
max-inner-R= 10.9 cm
Planes 1 - 5:
= 140. / 230. / 320. / 350. / 370. cm
Circ-Ellipt. Beam Pipe:
min-inner-R = 2.2cm
max-inner-R = 10.cm (LR)
wall thickness = 3.0mm
Inner Dipoles 0.3T (light grey)
inner-R = 90.cm
outer-R = 117.5cm
FHC4, HAC, BHC4 (beige)
ΔZ = 217. / 580. / 157. cm
FHC4. HAC. BHC4
Solenoid 3.5T (dark grey)
outer-R = 119.cm
FHC/BHC Insert 1,2,3 - (grey)
FHCs: ΔZ = 177. cm BHCs: ΔZ = 147. cm
FEC/BEC Insert 1,2 - (light grey)
EMC - (green)
ΔZ = 680. cm

Summary of Machine Parameters

Parameters of the RR and RL configurations.

		Ring	Linac
electron beam			
beam energy E_e	[GeV]	60	
e^- (e^+) per bunch	$N_e \cdot [10^9]$	20 (20)	1 (0.1)
e^- (e^+) polarisation	[%]	40 (40)	90 (0)
bunch length	[mm]	10	0.6
tr. emittance at IP $\gamma\epsilon^e_{x,y}$	[mm]	0.58, 0.29	0.05
IP β function $\beta^*_{x,y}$	[m]	0.4, 0.2	0.12
beam current	[mA]	131	6.6
energy recovery intensity gain		–	17
total wall plug power	[MW]	100	
syn rad power	[kW]	51	49
critical energy	[keV]	163	718
proton beam			
beam energy E_p	[GeV]	7000	
protons per bunch	$N_p \cdot [10^{11}]$	1.7	
transverse emittance $\gamma\epsilon^p_{x,y}$	[μm]	3.75	
collider			
Lum e^-p (e^+p)	$[10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	9 (9)	10 (1)
bunch spacing	[ns]	25	
rms beam spot size $\sigma_{x,y}$	[μm]	30, 16	7
crossing angle θ	[mrad]	1	0
$L_{eN} = A\, L_{eA}$	$[10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	0.3	1

The LHeC may be realised either as a ring-ring (RR) or as a linac-ring (LR) collider.

Components of the electron accelerators.

		Ring	Linac
magnets			
beam energy	[GeV]	60	
number of dipoles		3080	3600
dipole field	[T]	0.013 - 0.076	0.046 - 0.264
total nr. of quads		866	1588
RF and cryogenics			
number of cavities		112	944
gradient	[MV/m]	11.9	20
RF power	[MW]	49	39
cavity voltage	[MV]	5	21.4
cavity R/Q	[Ω]	114	285
cavity Q_0		-	$2.5 \cdot 10^{10}$
cooling power	[kW]	5.4@4.2 K	30@2 K

Kinematics at HE-LHeC

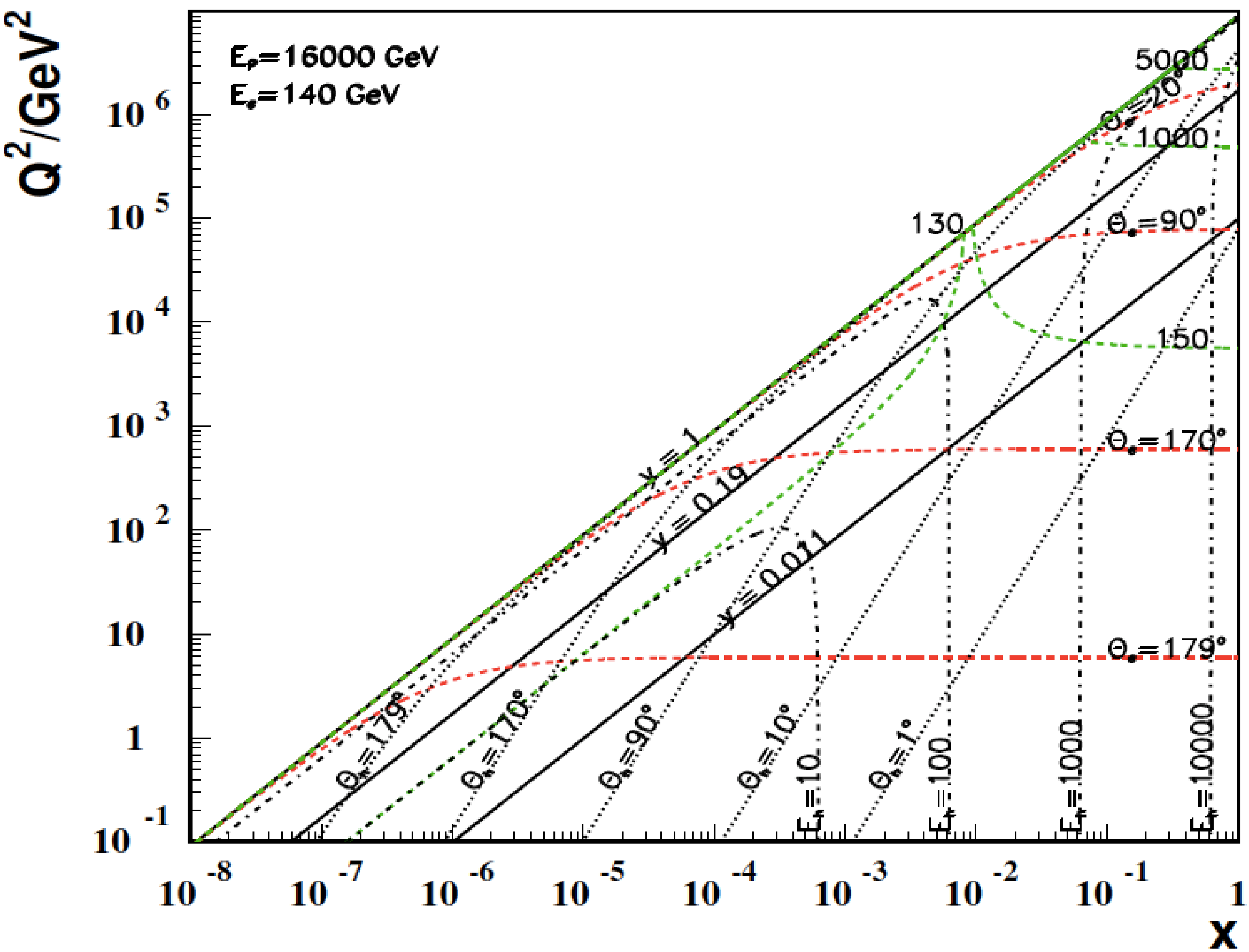


Figure 12.7: Scattered electron and hadronic final state kinematics for the HE-LHC at $E_p = 16\,\text{TeV}$ coupled with a 140 GeV electron beam. Lines of constant scattering angles and energies are plotted. The line $y = 0.011$ defines the edge of the HERA kinematics and $y = 0.19$ defines the edge of the default machine considered in this report ($E_e = 60\,\text{GeV}$ and $E_p = 7\,\text{TeV}$).

Abbreviations

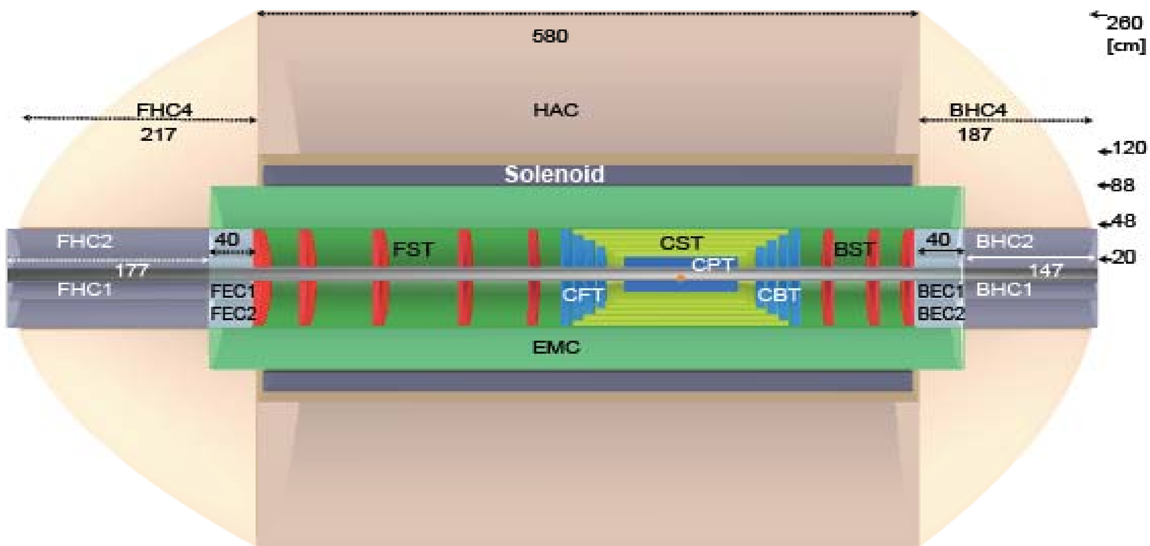
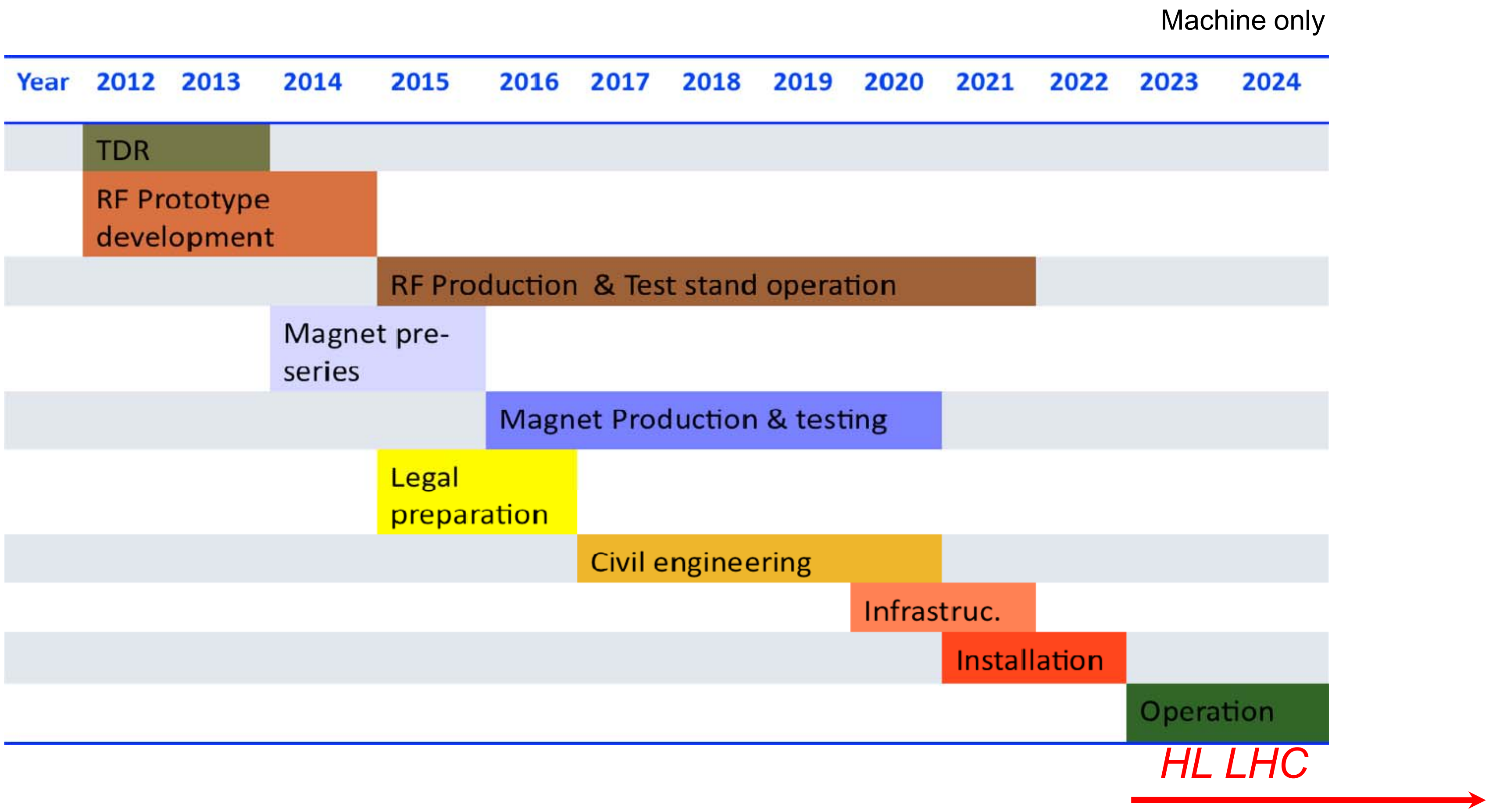


Figure 13.3: An rz cross section and dimensions of the main detector (muon detector not shown) for the Ring-Ring detector version (no dipoles) extending the polar angle acceptance to about 1° in forward and 179° in backward direction.

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

LHeC Tentative Time Schedule



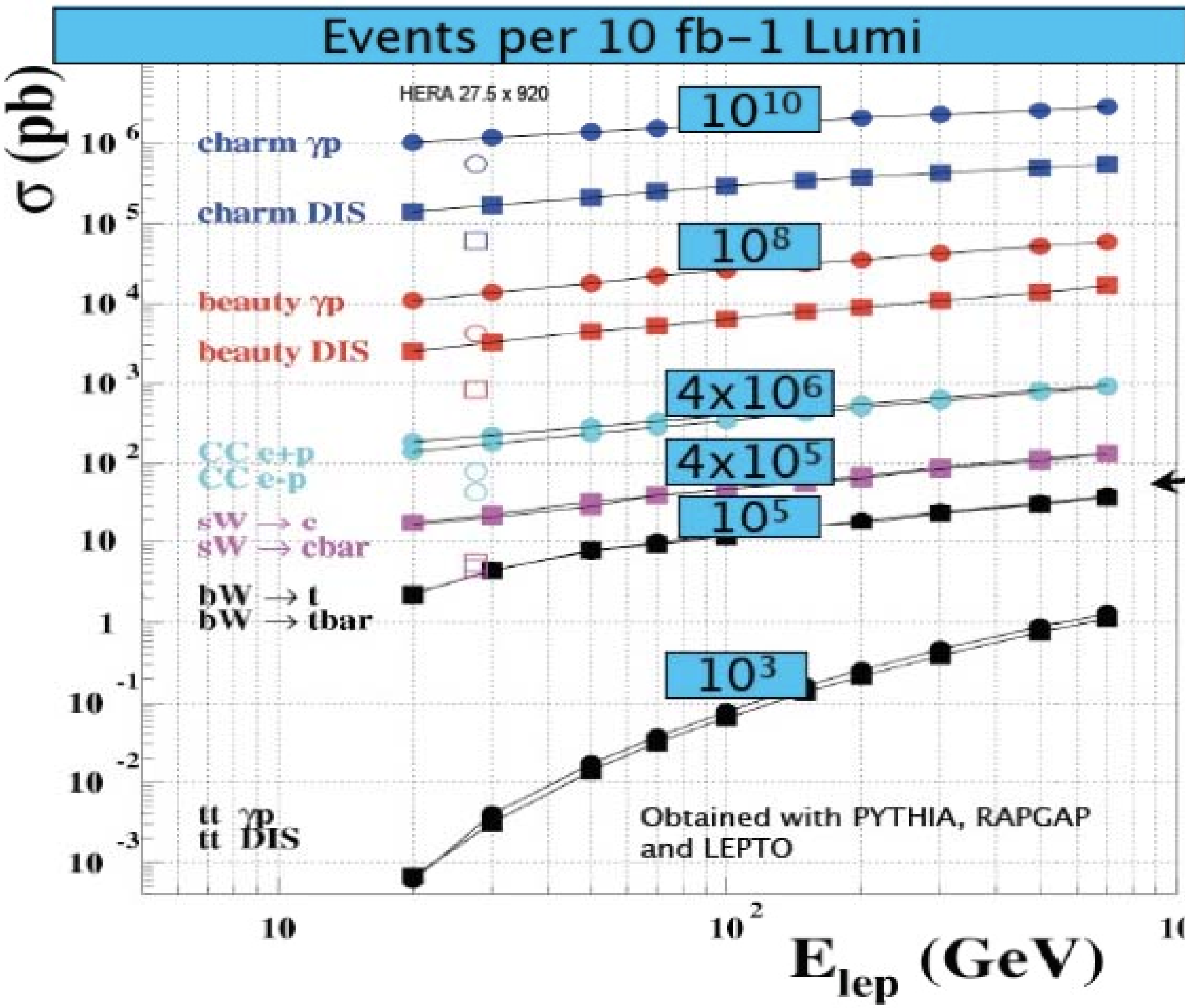
We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL). In

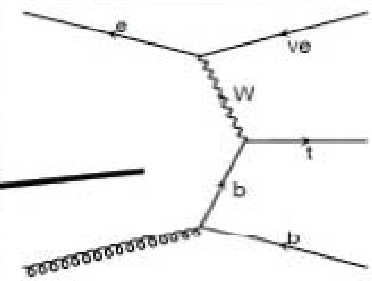
Tracker Dimensions

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
ΔR $[cm]$	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. η	4.2	4.0	3.9	3.8		-3.8	-3.9	-4.0	-4.2
Δz $[cm]$	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. η	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
Δz $[cm]$	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).

Heavy Flavour @ LHeC

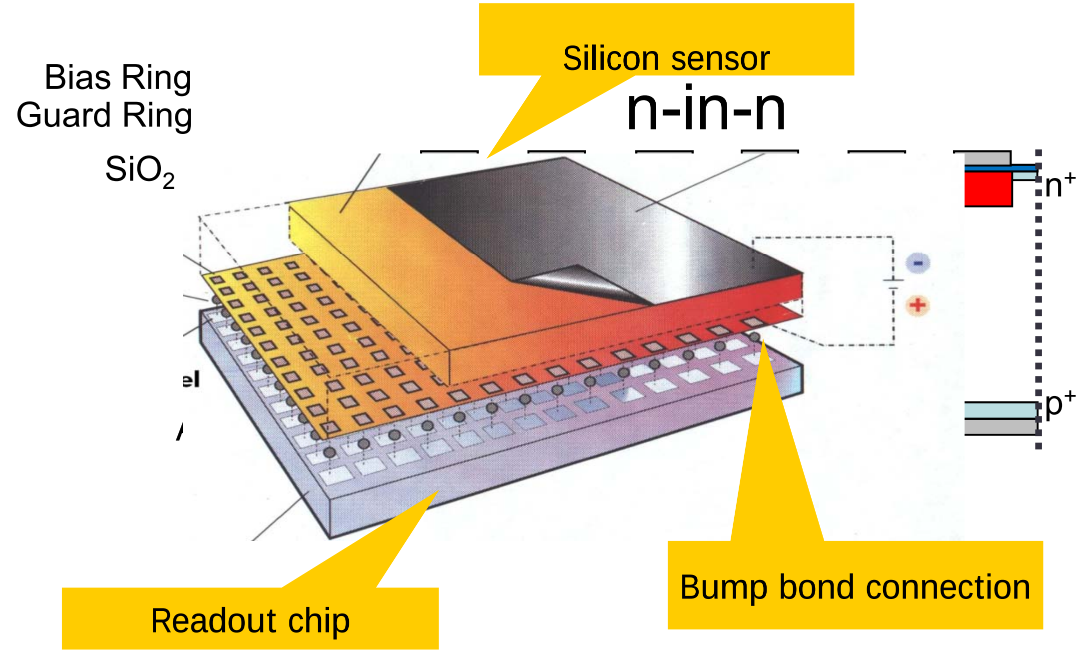




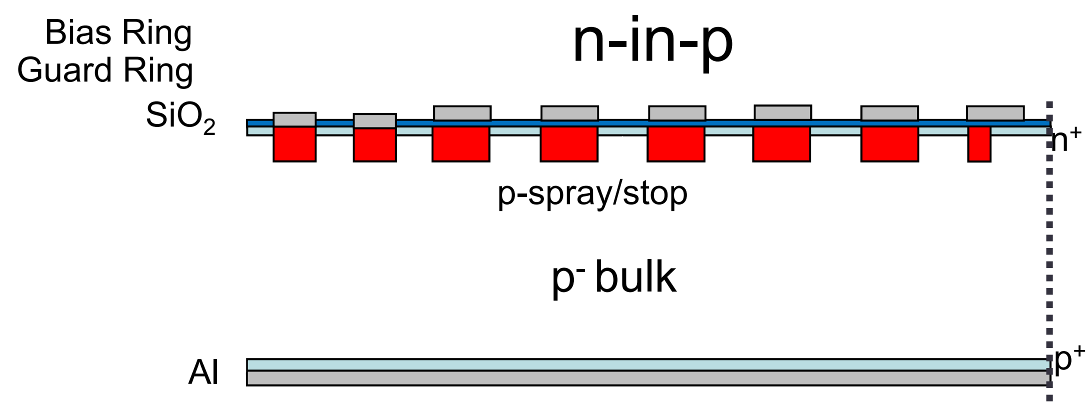
LHeC is a flavour factory

ATLAS Pixel Module Upgrade

- Hybrid pixel detector:
- The sensor and the readout electronic are realized in different semiconductor substrates
- Size of the electronic readout pixels is equal to the size of the sensor pixels
- The connection between the electronic and the sensor is done via bump bond connections



- n-in-p
- ~50% less expensive than n-in-n
- Single-sided processing
- More suppliers (including Hamamatsu)
- Limited production experience
  - 1 VELO module installed, spare system under construction
- As radiation hard as n-in-n
- n^+ R/O kept

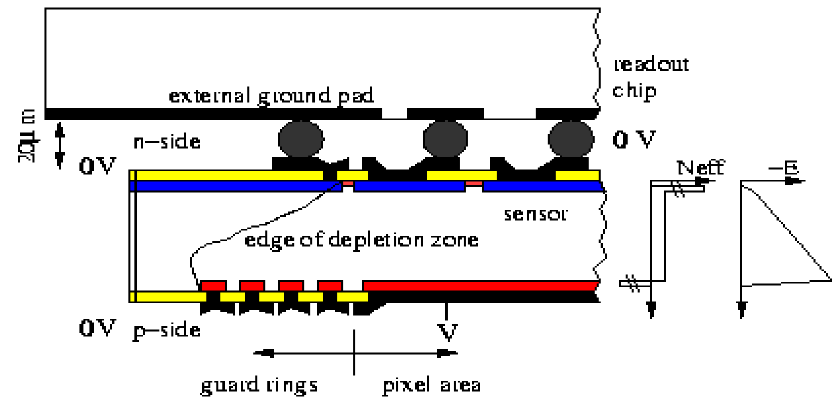


CMS Single-Sided (n-in-p) Sensors

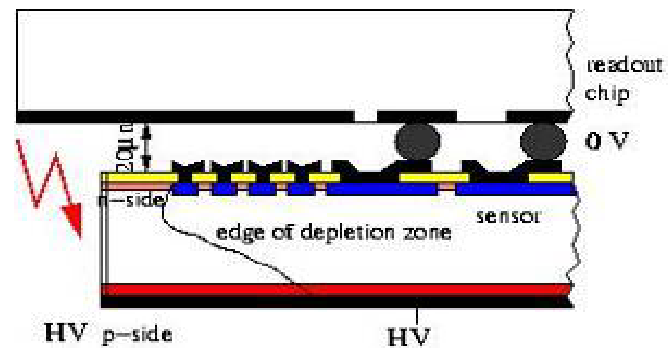
- **Present CMS pixel detector uses n-in-n-sensors**
  - double sided processing (back side is structured)
  - all sensor edges at ground
  - most expensive part of the module (only bump-bonding is more expensive)
- **Exploring n-in-p sensors as alternative**
  - recent studies show radiation hardness
  - single sided process promise price benefit of factor 2-3

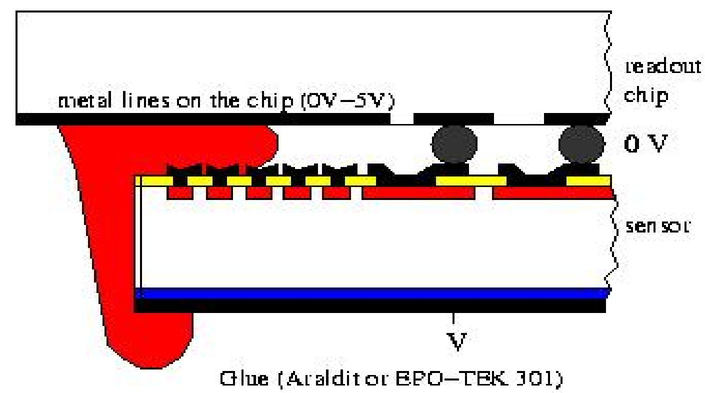
    – important as the pixel area will be doubled
  - Absence of guard rings on back side lead to fear of (destructive) sparking to the ROC

n-in-n



n-in-p

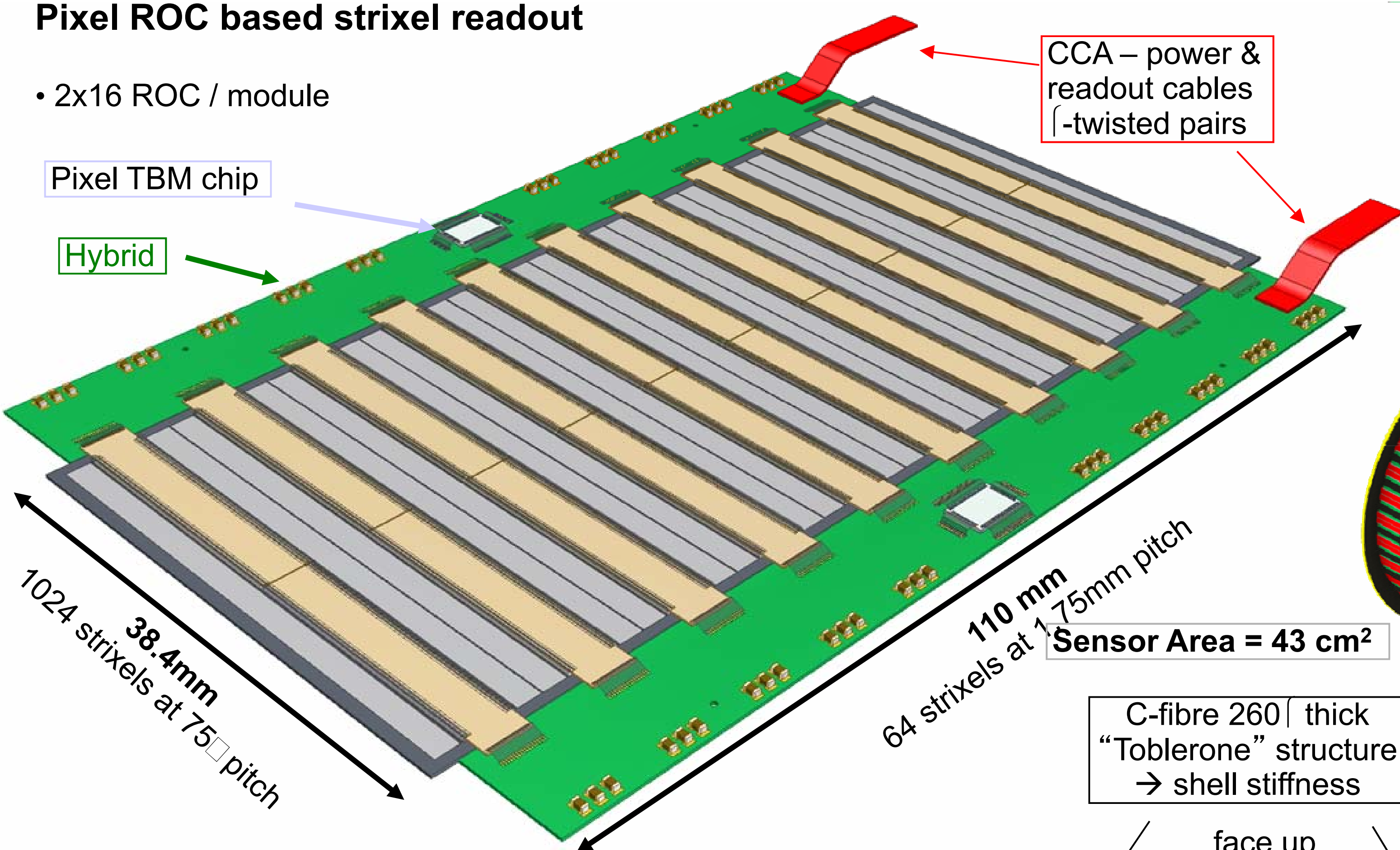


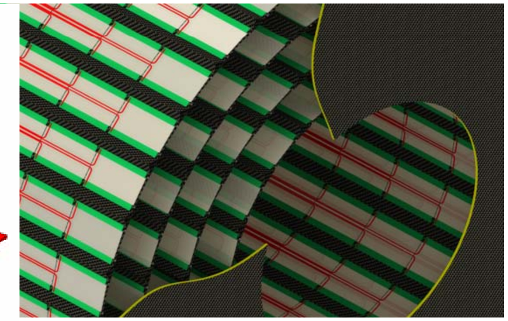


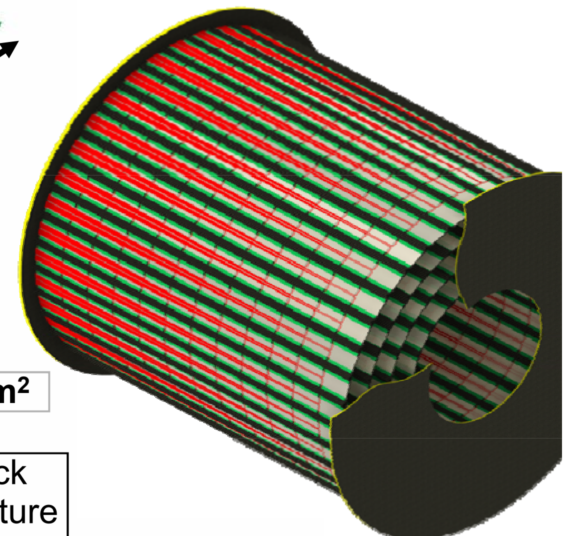
Strixel TIB Layers

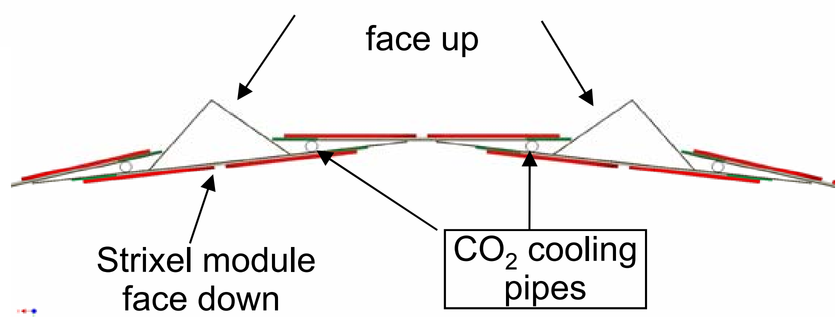
Pixel ROC based strixel readout

• 2x16 ROC / module



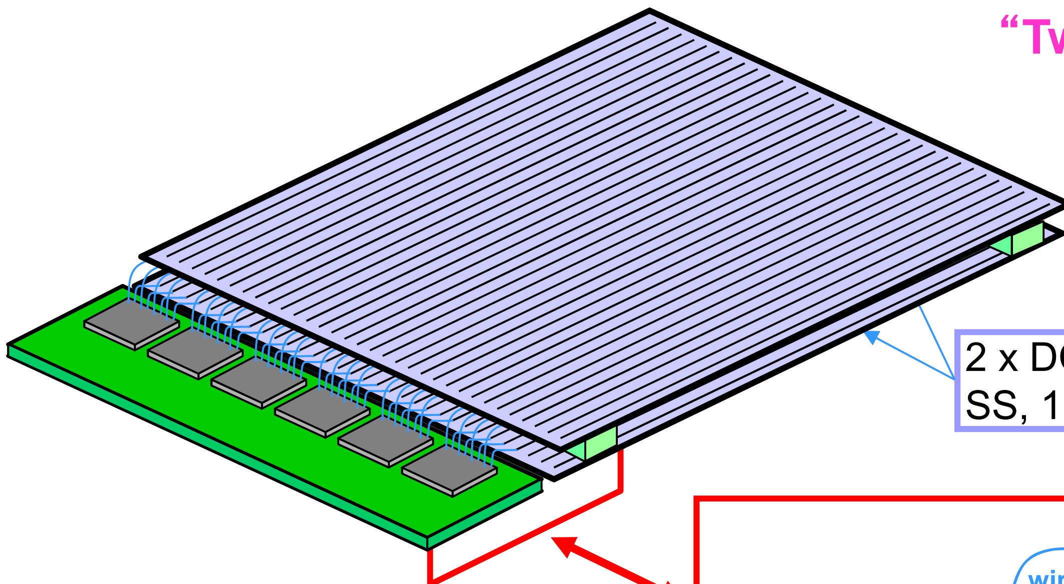




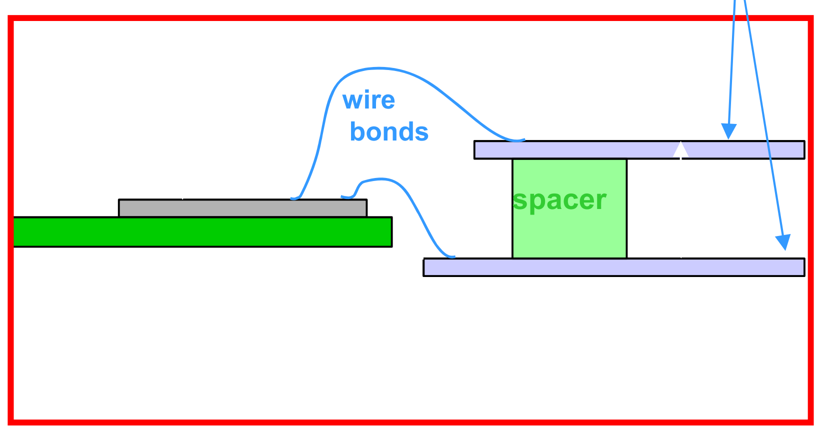


Pt - Trigger for TOB layers

"Two-In-One" Design



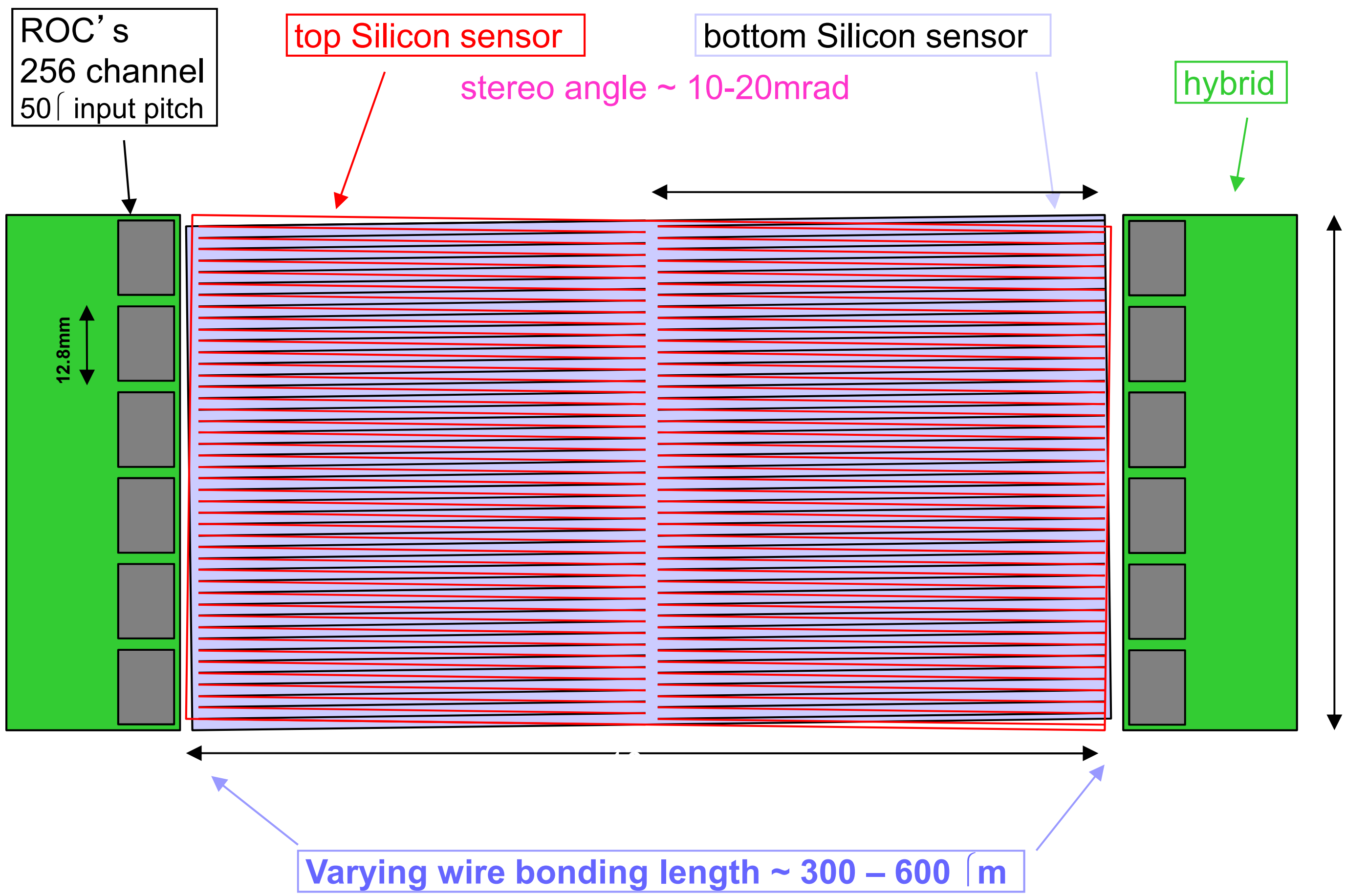
2 x DC coupled strip detectors
SS, 100µ pitch < 8CHF/cm^2



Strip Read Out Chip
2 x 100µ pitch with
on-chip p_t-correlator

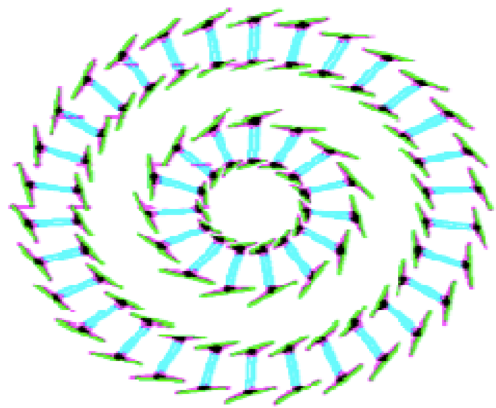
track angular resolution ~20mrad → good P_t resolution

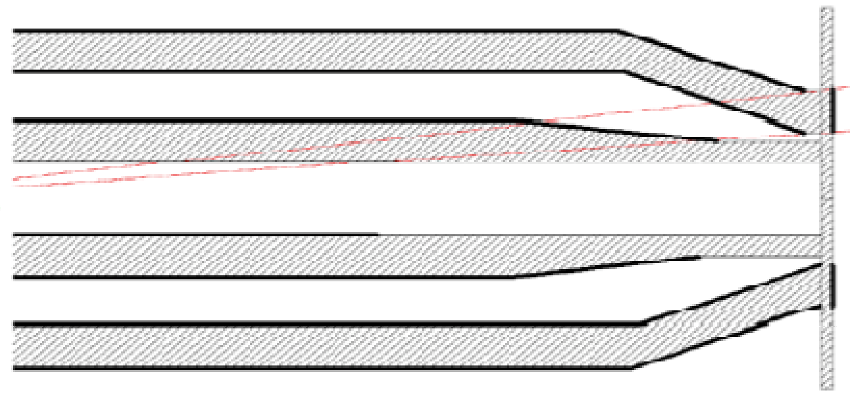
"Two-In-One"
Design as Stereo modules

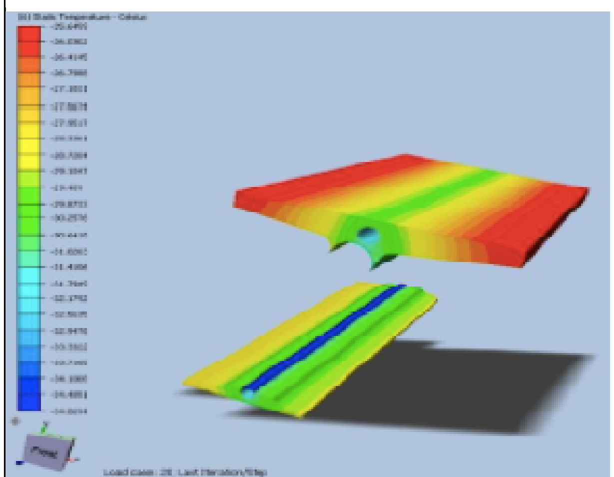


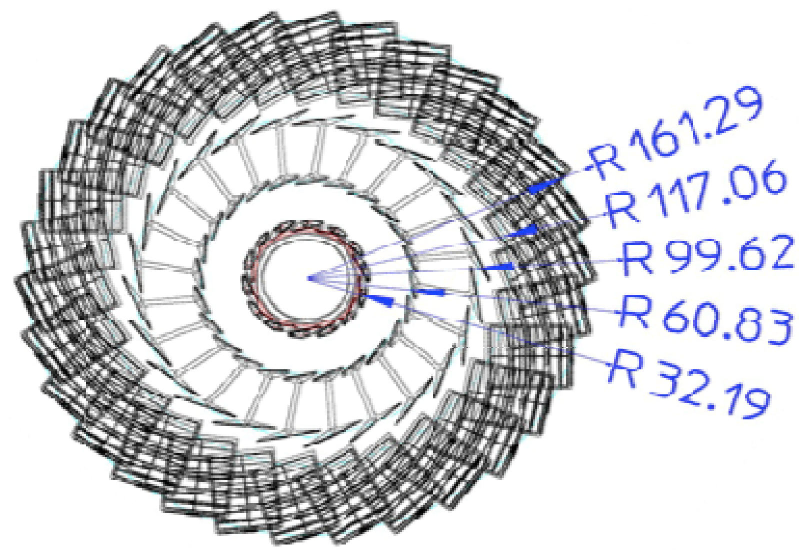
Material Reduction (ATLAS Upgrade)

I-beam prototype, LBNL 2010









Mechanics of Disks

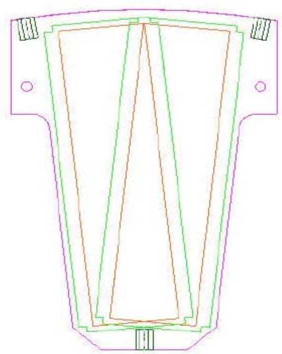
Inner & outer ring of blades

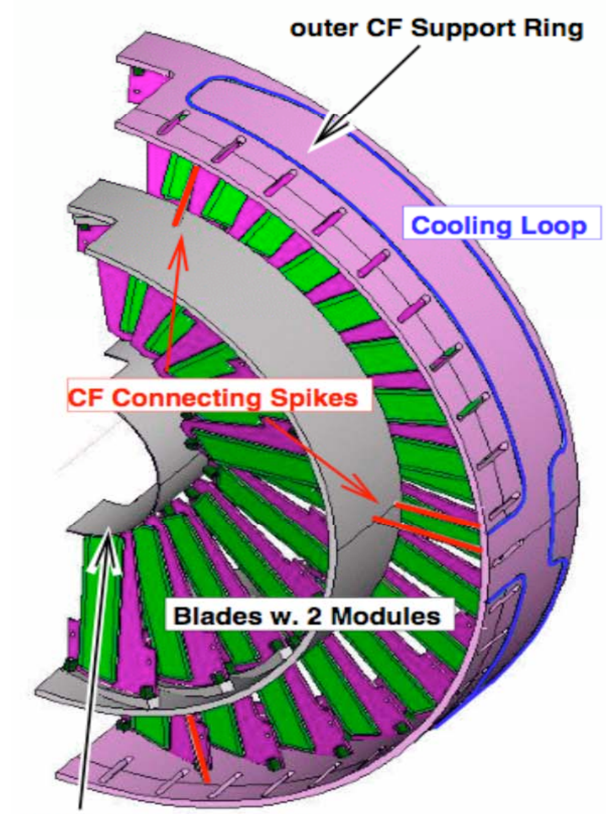
CO_2 tubes embedded in half disk support:

- support cylinder:
  - Carbon carbon
  - Grooves for cooling tube
  - Stainless steel tube:
  - 1.8mm OD, 100μm wall

Blades:

- all identical
- Rotated by 20° radial
- Tilted by 12° (inner ring)
- 2 modules per blade (ϕ overlap)
- individually replaceable





Shapes towards BP: half circular / half elliptical