LHeC Tracking

A forward look – LHCb

Themis Bowcock

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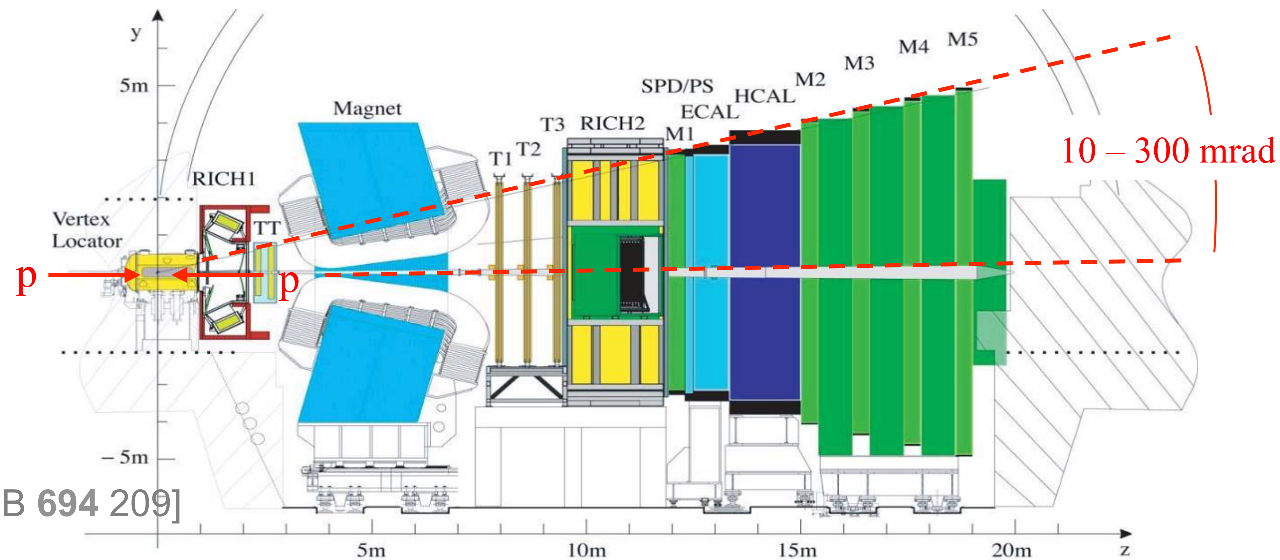
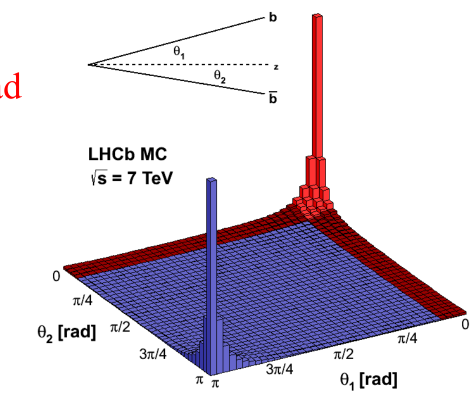
14/6/12

Forward spectrometer



PLB **694** 209]



[PYTHIA]

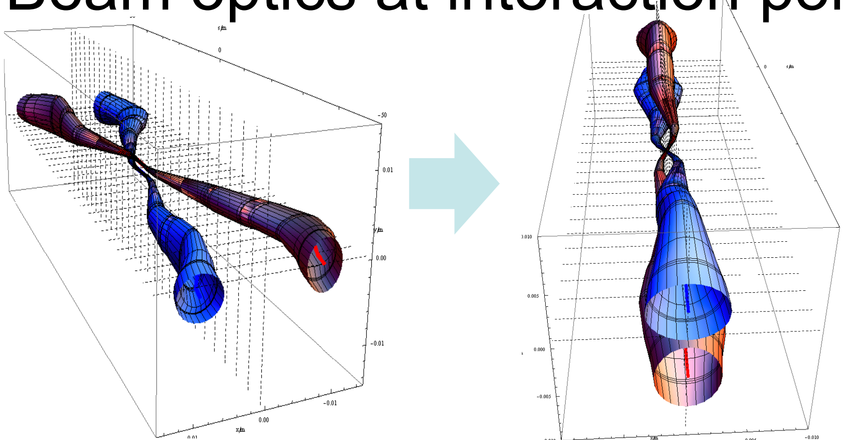
→ ~ 100,000 $b\bar{b}$ pairs produced/second ($10^4 \times$ B factories)
Charm production factor ~20 higher!

[CONF-2010-013]

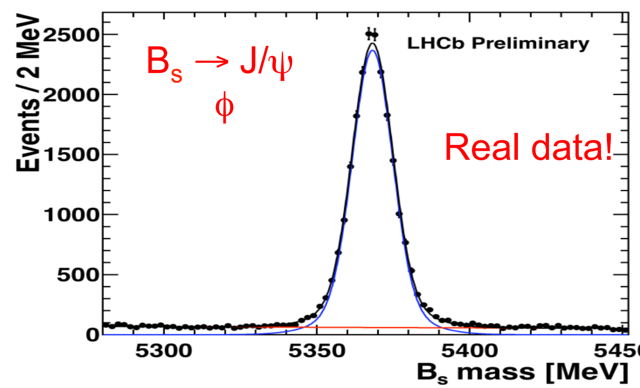
Tracking performance

- Dipole magnet, polarity regularly switched to cancel systematic effects
- *New this year:* beam optics changed to decouple crossing angles from LHC (V) and spectrometer magnet (H)

Beam optics at interaction point



$\Delta p/p = 0.4 - 0.6$ % (5–100 GeV/c)



[CONF-2012-002]

$\sigma(m_B) = 8$ MeV/c^2

~ 16 MeV/c^2 [CMS DPS-2010-040]

22 MeV/c^2

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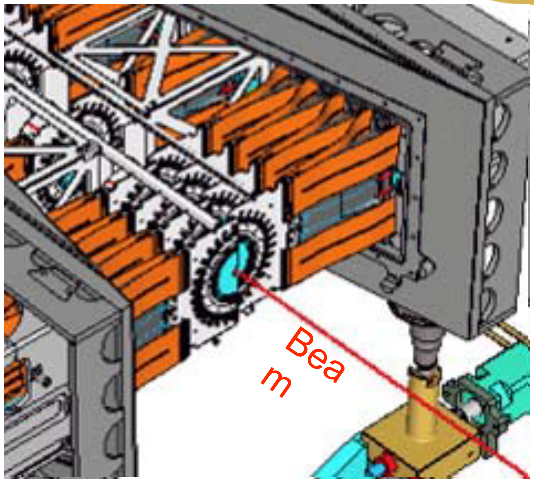
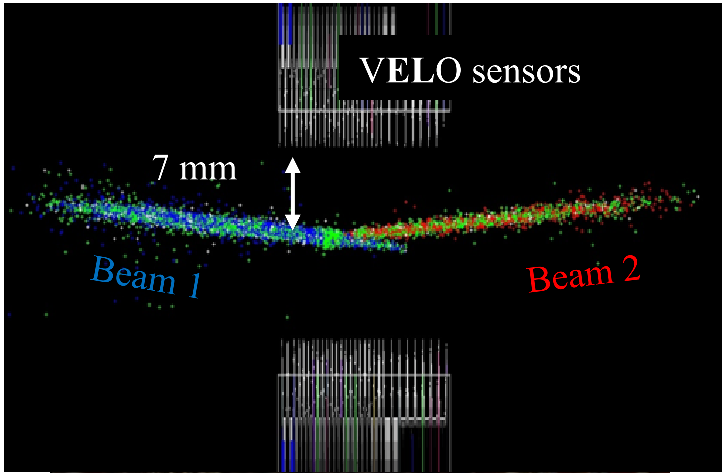
Vertex detection

VELO (Vertex Locator)
- 21 modules of r-ϕ silicon sensor disks
- Retracted for safety during beam injection

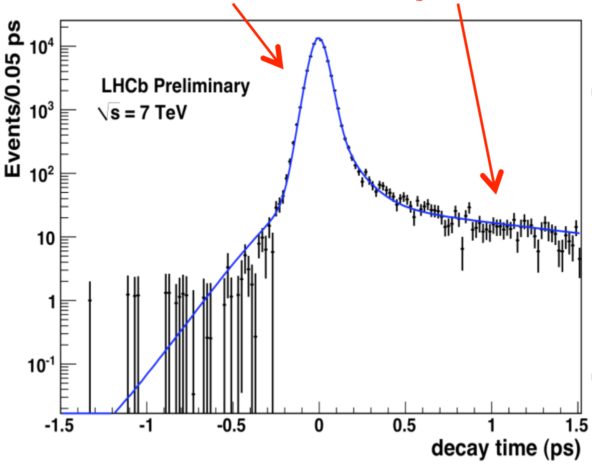
Reconstructed beam-gas vertices
- (used for luminosity measurement)

Impact parameter resolution ~ 20 μm
- Proper-time resolution: σ_t = 45 fs
- *cf* CDF: σ_t = 87 fs [PRL **97** 242003]





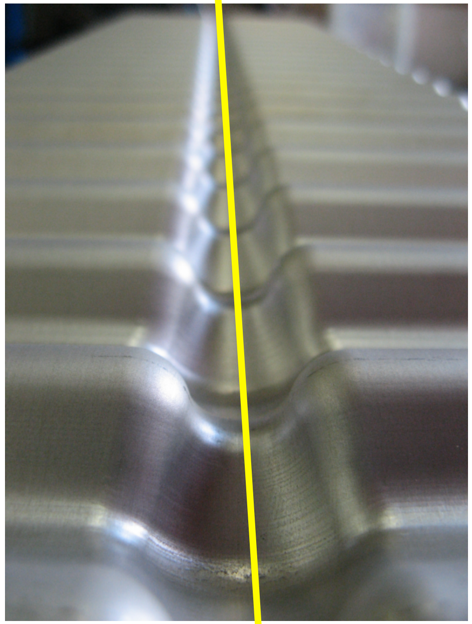
[PLB 693 69]



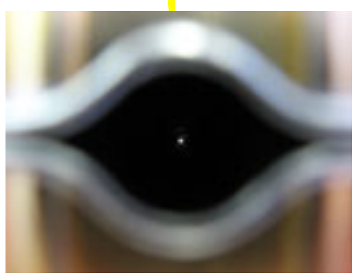
[CONF-2012-002]

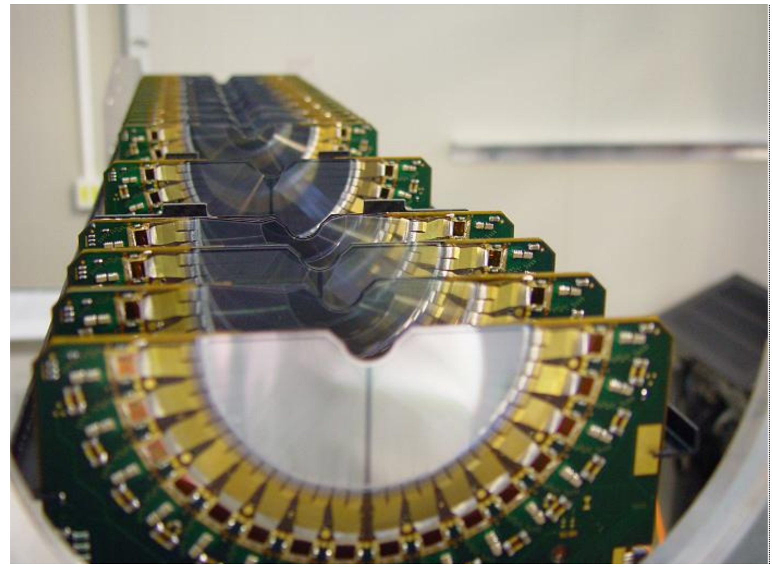
VELO: Complete half

O(300μm foil)

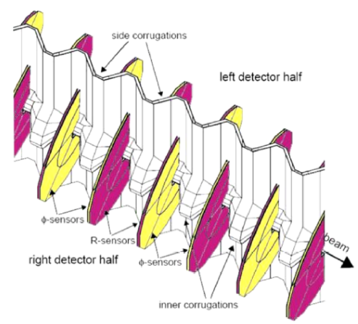


Using ripples same as cylinder





Resolution about 4microns at 6°

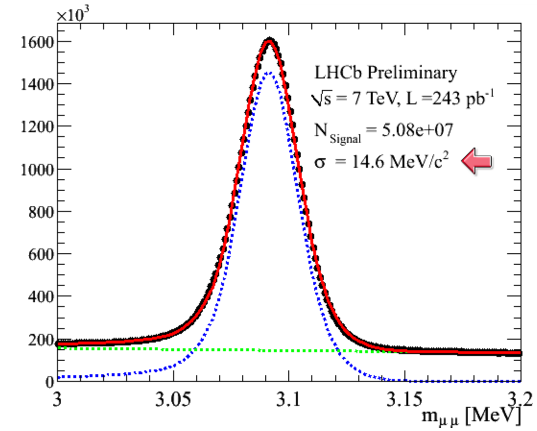


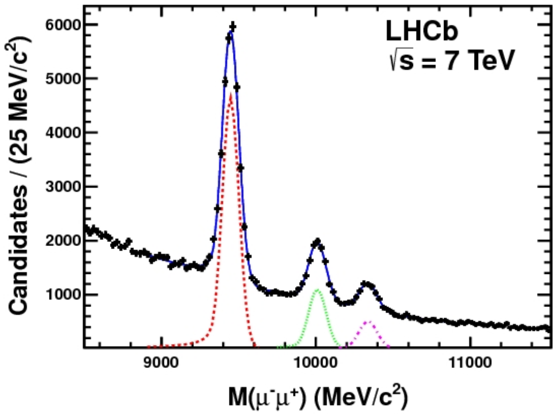
LHEC TRACKER

Requirements

Tracking requirements (from CDR)

- Accurate measurements in p_T and θ
- Secondary vertexing in maximum polar angle
- Resolution of complex, multiparticle, highly energetic states in the fwd direction
- Charge identification of scattered electron
- Measurement if vector mesons of μ pairs (J/ψ,ϒ)





Resolution (solenoid)

Resolution approx.

$$\frac{\delta p_T}{p_T^2} \sim \frac{\Delta}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

10 times better than H1

Similar to ATLAS in central region

Magnetic Field

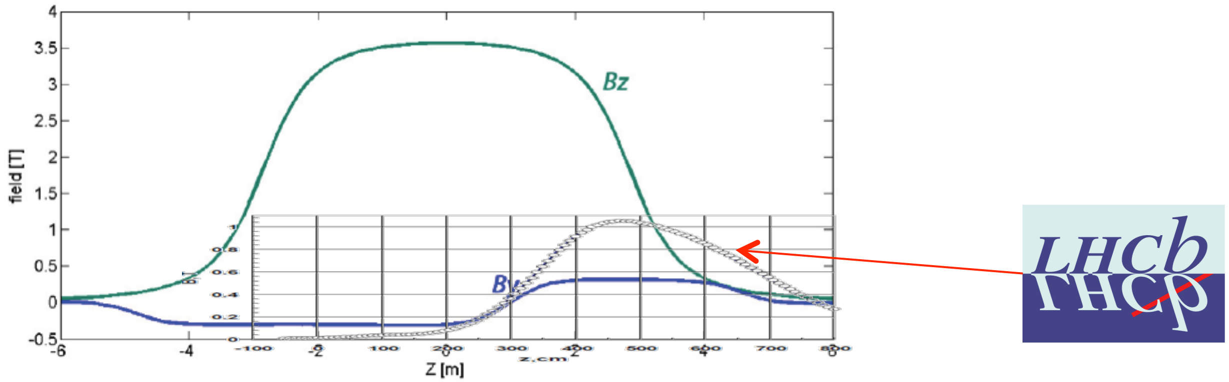
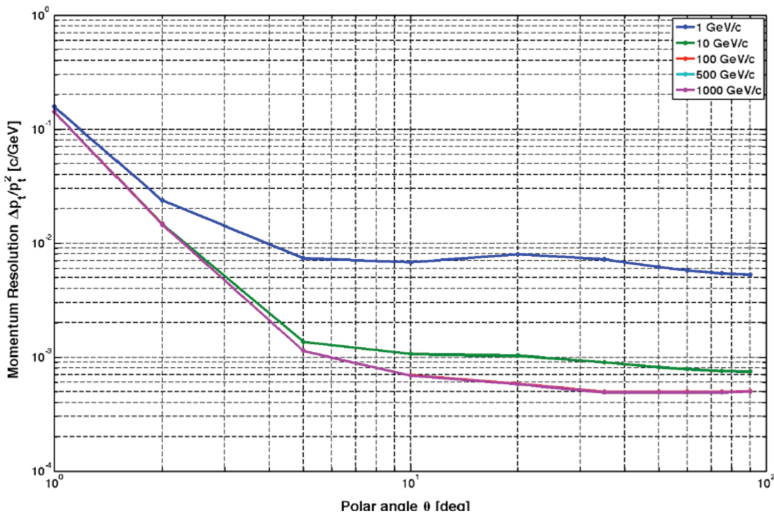
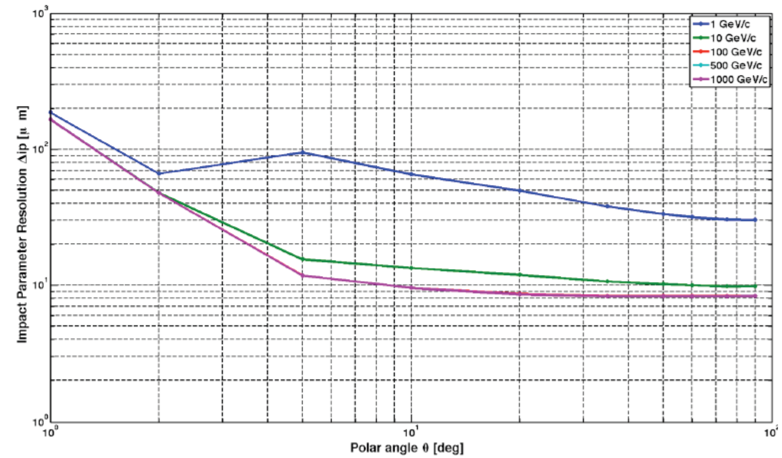
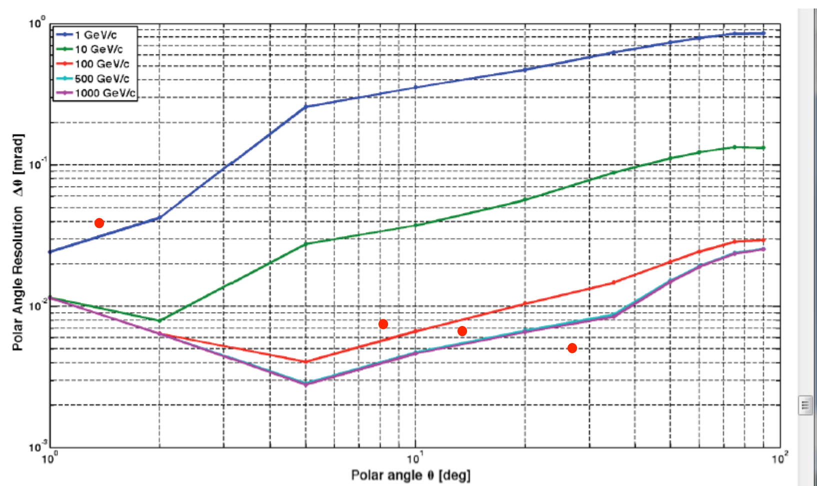


Figure 12.14: Magnetic field components B_z (solenoid) and B_y (set of internal dipoles) on the beam axis across 12 m in z. Note, the magnetic field of the external electromagnets are not included here.

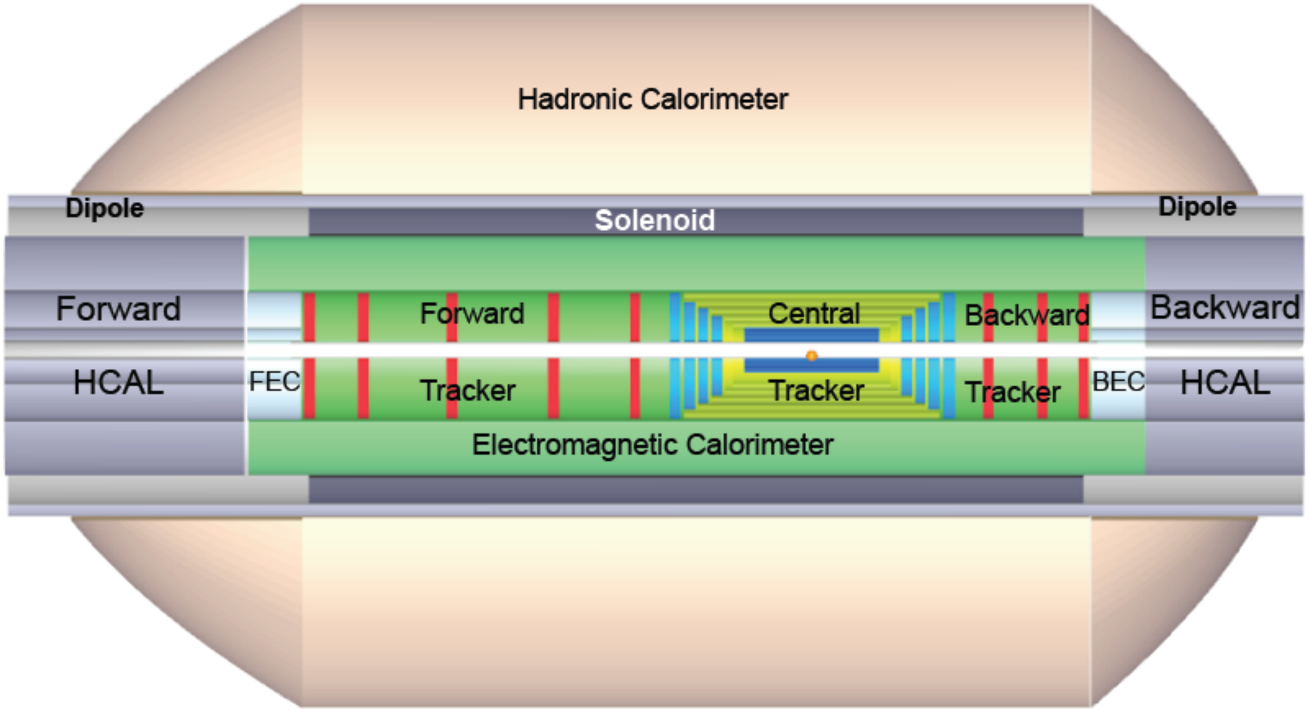
Baseline (A)


1 GeV/c
10 GeV/c
100 GeV/c
500 GeV/c
1000 GeV/c
Momentum Resolution Δp_t/p_t^2 [c/GeV]
Polar angle θ [deg]


1 GeV/c
10 GeV/c
100 GeV/c
500 GeV/c
1000 GeV/c
Impact Parameter Resolution Δip [μ m]
Polar angle θ [deg]


1 GeV/c
10 GeV/c
100 GeV/c
500 GeV/c
1000 GeV/c
Polar Angle Resolution Δθ [mrad]
Polar angle θ [deg]

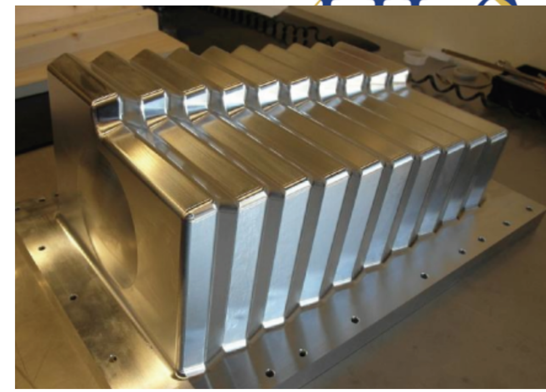
Baseline (A)



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

Beam Pipe

Power/cooling?



Be(not Al)
Very Non-Trivial
Very expensive

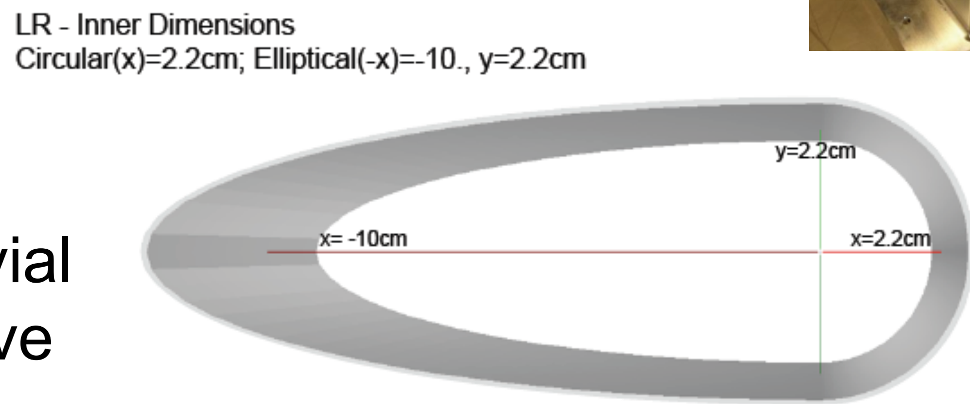
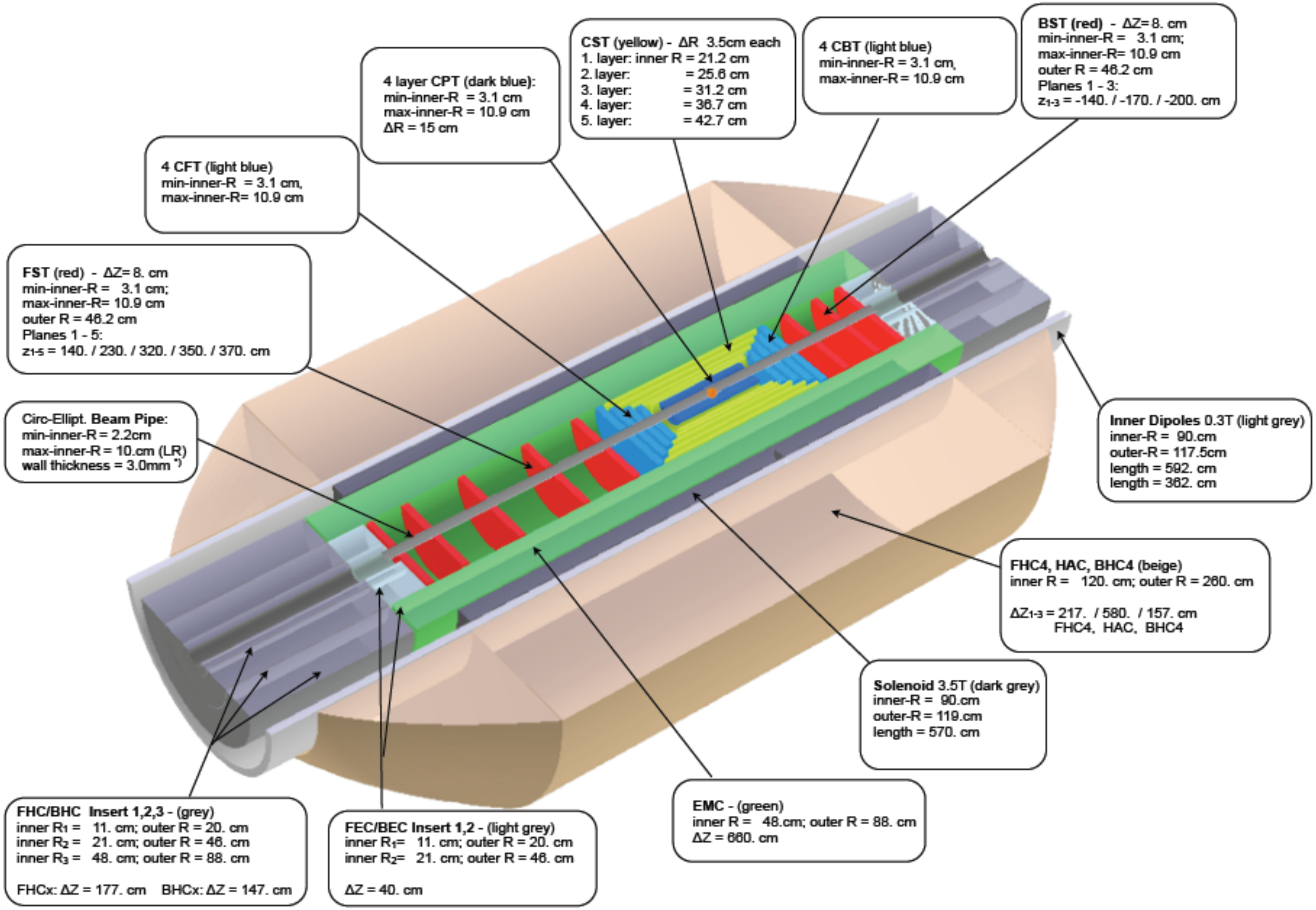
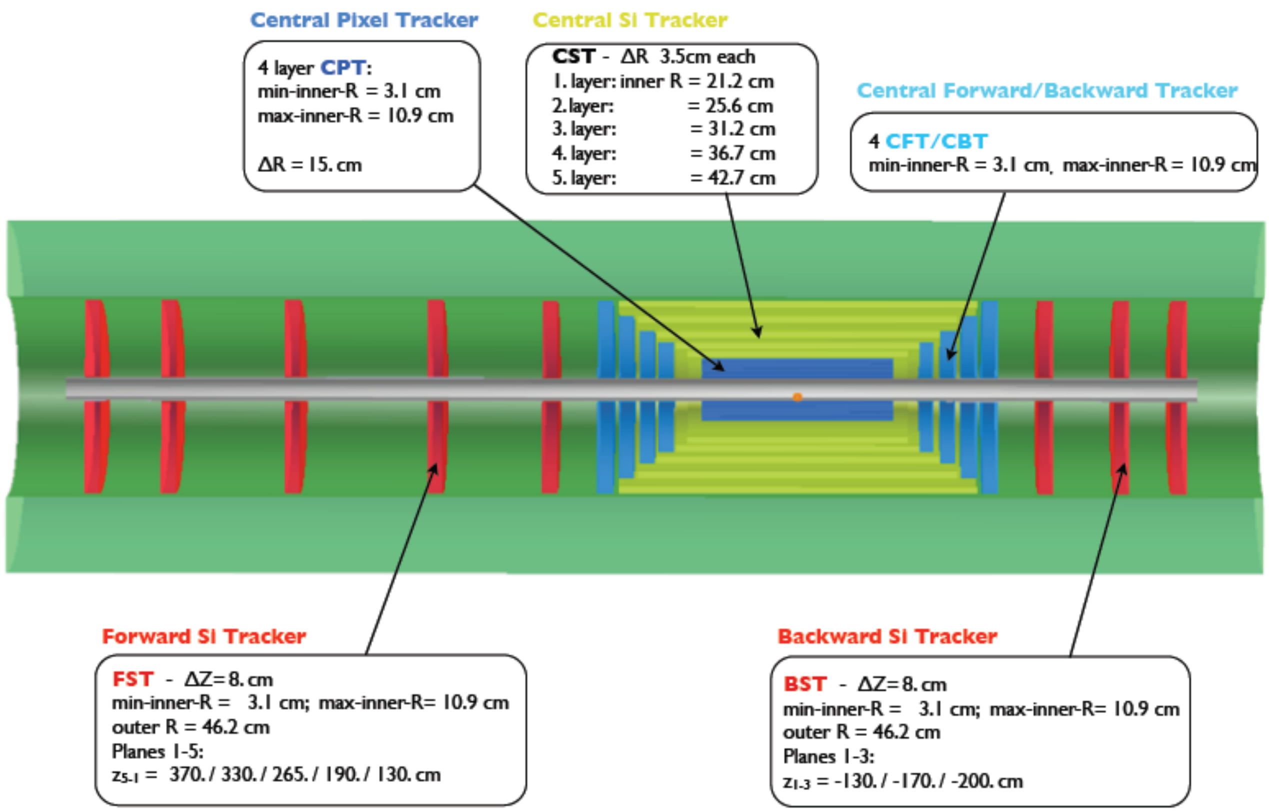


Figure 12.6: Perspective drawing of the beam pipe and its dimensions in the linac-ring configuration. The dimensions consider a 1 cm safety margin around the synchrotron radiation envelope.



CST (yellow) - ΔR 3.5cm each
1. layer: inner R = 21.2 cm
2. layer: = 25.6 cm
3. layer: = 31.2 cm
4. layer: = 36.7 cm
5. layer: = 42.7 cm
4 CBT (light blue)
min-inner-R = 3.1 cm,
max-inner-R = 10.9 cm
BST (red) - ΔZ = 8. cm
min-inner-R = 3.1 cm;
max-inner-R = 10.9 cm
outer R = 46.2 cm
Planes 1 - 3:
z_{1-3} = -140. / -170. / -200. cm
4 layer CPT (dark blue):
min-inner-R = 3.1 cm
max-inner-R = 10.9 cm
ΔR = 15 cm
4 CFT (light blue)
min-inner-R = 3.1 cm,
max-inner-R = 10.9 cm
FST (red) - ΔZ = 8. cm
min-inner-R = 3.1 cm;
max-inner-R = 10.9 cm
outer R = 46.2 cm
Planes 1 - 5:
z_{1-5} = 140. / 230. / 320. / 350. / 370. cm
Circ-Ellipt. Beam Pipe:
min-inner-R = 2.2cm
max-inner-R = 10.cm (LR)
wall thickness = 3.0mm *)
Inner Dipoles 0.3T (light grey)
inner-R = 90.cm
outer-R = 117.5cm
length = 592. cm
length = 362. cm
FHC4, HAC, BHC4 (beige)
inner R = 120. cm; outer R = 260. cm
ΔZ_{1-3} = 217. / 580. / 157. cm
FHC4, HAC, BHC4
Solenoid 3.5T (dark grey)
inner-R = 90.cm
outer-R = 119.cm
length = 570. cm
FHC/BHC Insert 1,2,3 - (grey)
inner R_1 = 11. cm; outer R = 20. cm
inner R_2 = 21. cm; outer R = 46. cm
inner R_3 = 48. cm; outer R = 88. cm
FHCx: ΔZ = 177. cm BHCx: ΔZ = 147. cm
FEC/BEC Insert 1,2 - (light grey)
inner R_1 = 11. cm; outer R = 20. cm
inner R_2 = 21. cm; outer R = 46. cm
ΔZ = 40. cm
EMC - (green)
inner R = 48.cm; outer R = 88. cm
ΔZ = 660. cm

Layout

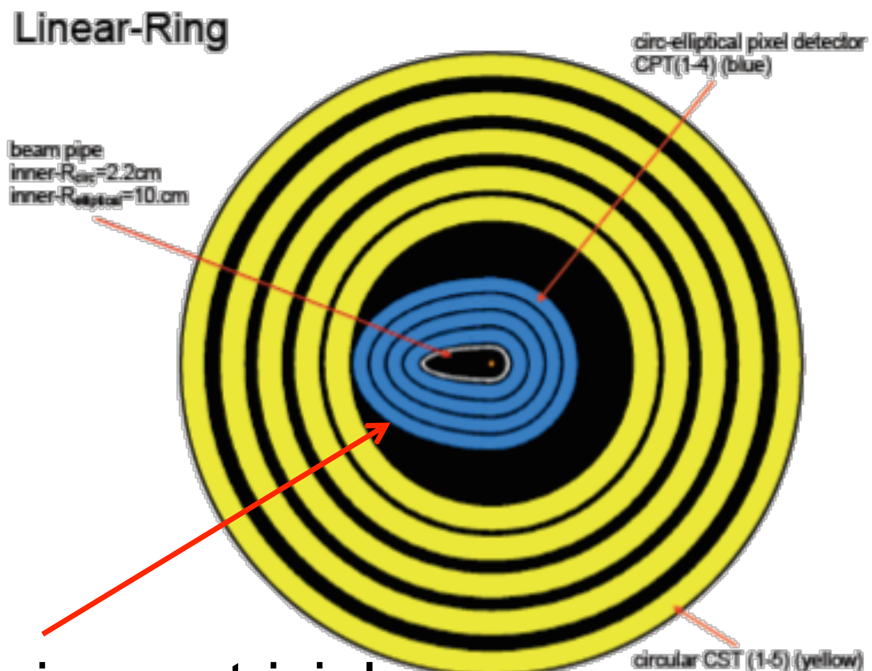


O(5M strips) + Pixels (~ 25kW)

Dimensions

Cen. Barrel	CPT1	CPT2	CPT3	CPT4	CST1	CST2	CST3	CST4	CST5
Min. R $[cm]$	3.1	5.6	8.1	10.6	21.2	25.6	31.2	36.7	42.7
Min. θ $[^\circ]$	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 $[m^2]$	1.4				8.1				
Cen. Endcaps	**CFT4**	**CFT3**	**CFT2**	**CFT1**		**CBT1**	**CBT2**	**CBT3**	**CBT4**
Min. R $[cm]$	3.1	3.1	3.1	3.1		3.1	3.1	3.1	3.1
Min. θ $[^\circ]$	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 $[m^2]$	1.8					1.8			
Fwd/Bwd	**FST5**	**FST4**	**FST3**	**FST2**	**FST1**		**BST1**	**BST2**	**BST3**
Min. R $[cm]$	3.1	3.1	3.1	3.1	3.1		3.1	3.1	3.1
Min. θ $[^\circ]$	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 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 $[m^2]$	3.3						2.0		

Central Barrel

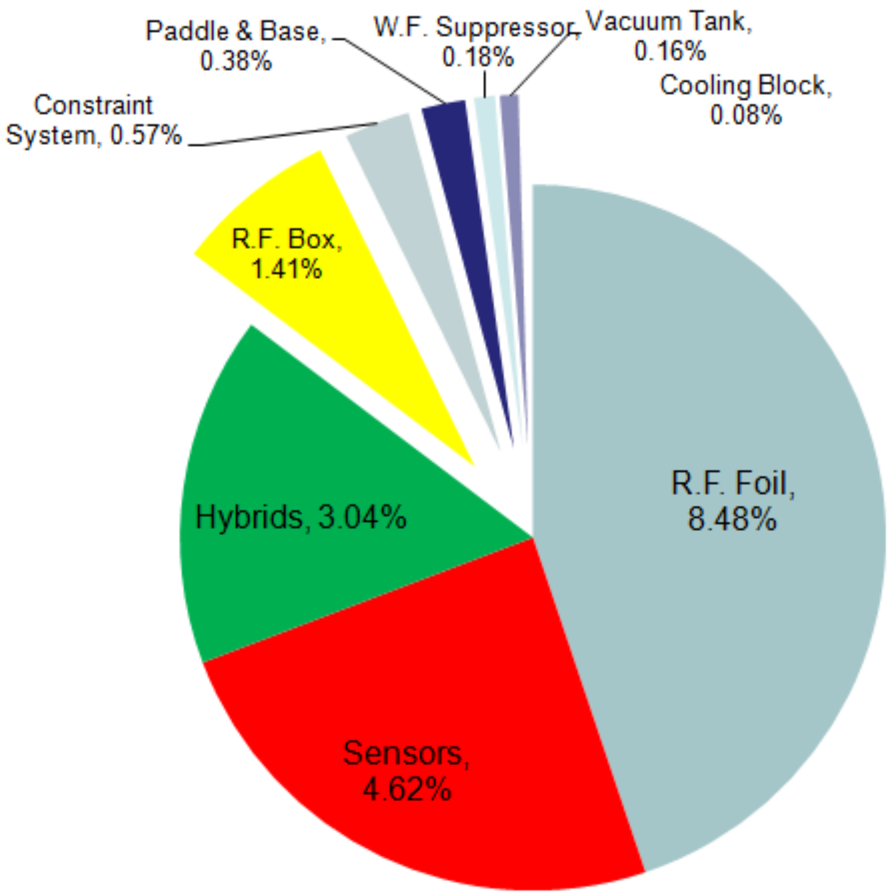


“sat on” shape is non-trivial

Estimated Performance

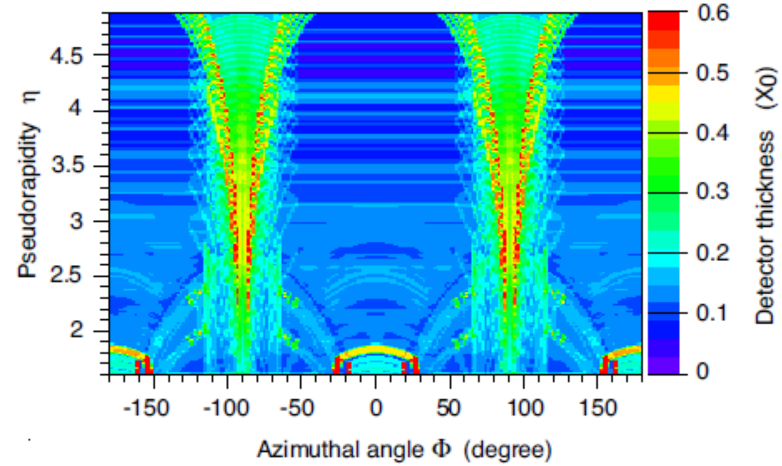
Parameters	
B	3.5T
X/X_0^{beampipe}	0.002
$X/X_{0\ per\ (double)\ layer}^{\text{CPT/CFT/CBT/FST/BST-det}}$	0.025
$X/X_{0\ per\ (double)\ layer}^{\text{CST-det}}$	0.02
efficiency	99%
Minimal inner radius	$3.15cm$
σ_{CPT}	$8\mu m$
$\sigma_{\text{CST,CFT,CBT}}$	$12\mu m$
$\sigma_{\text{FST,BST}}$	$15\mu m$

VELO: Material Budget



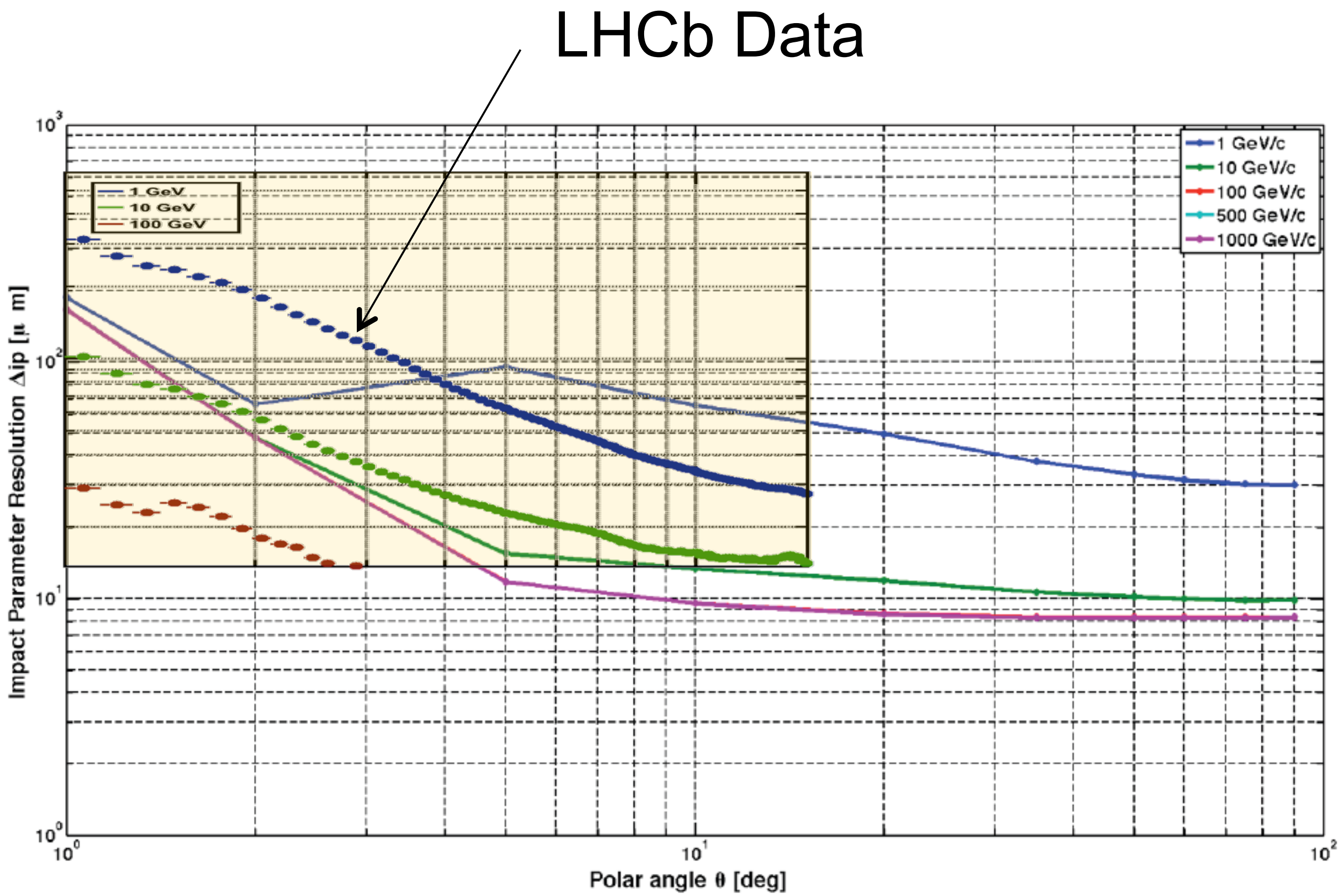
Material Budget (% X_o)

Average is 18.91% X_0
Particle exiting the



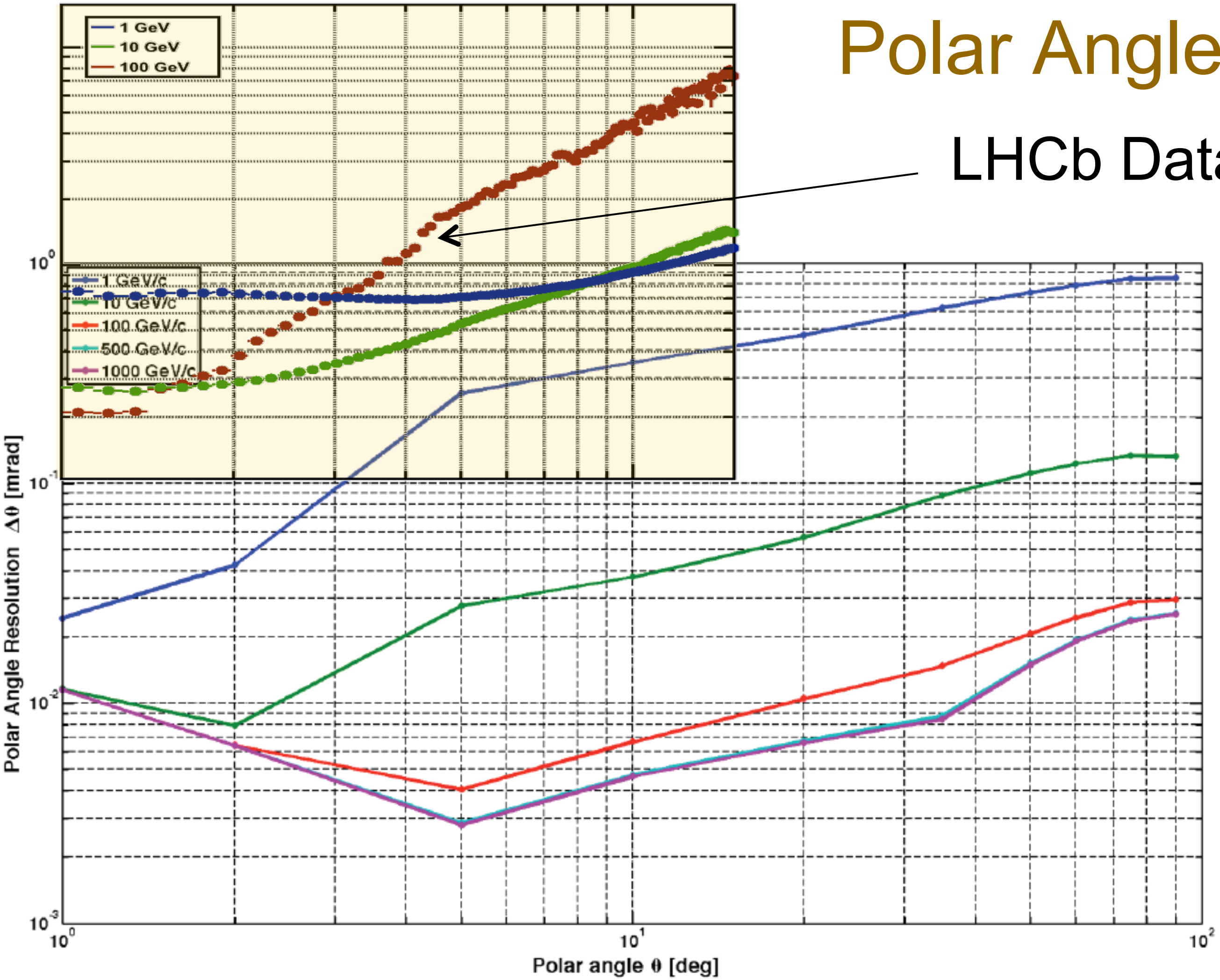
X_o)

Impact Parameter

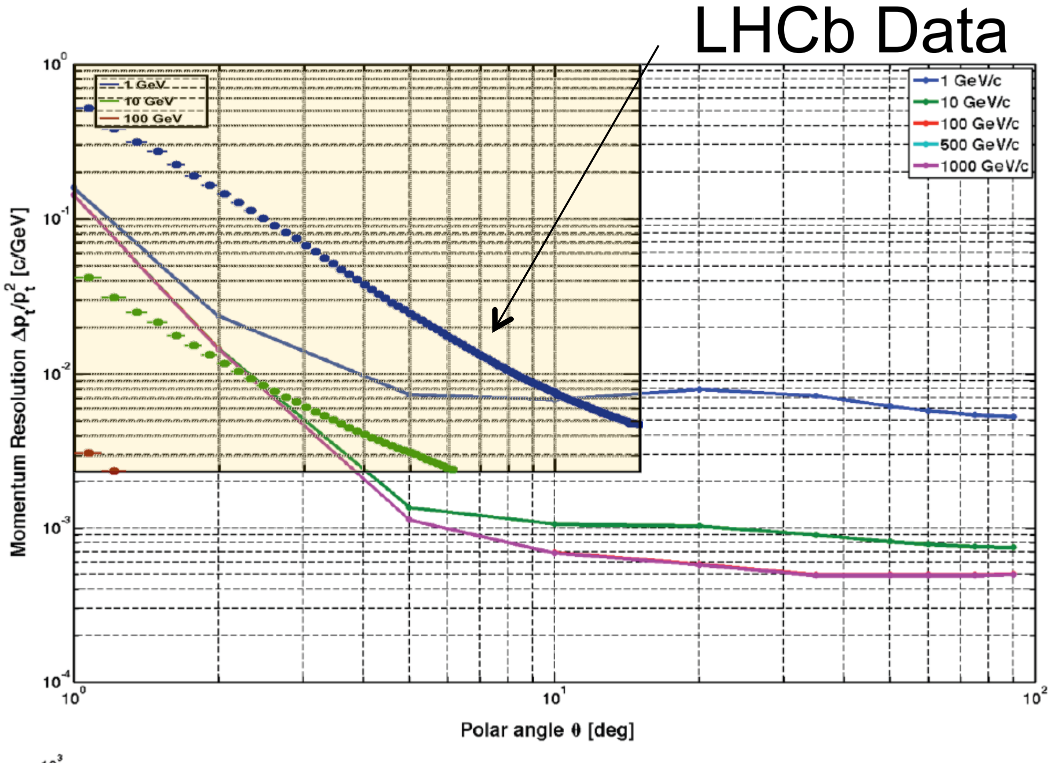


Polar Angle

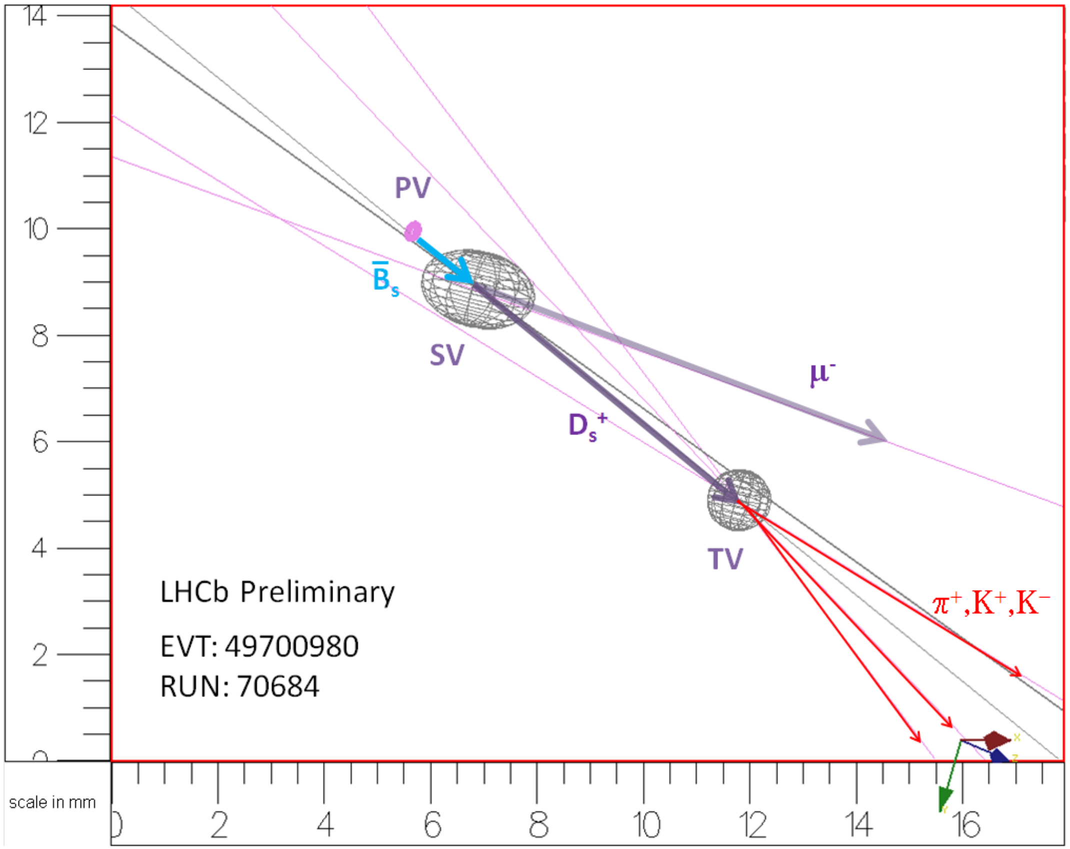
LHCb Data



Momentum Resolution



Heavy Flavour



Radiation

For the LHCb radiation is a key issue

- We chose n^+n technology
- Pioneered production of n^+p (cheaper and does not invert)

Have a spare VELO in case of disaster...

Radiation Tolerance

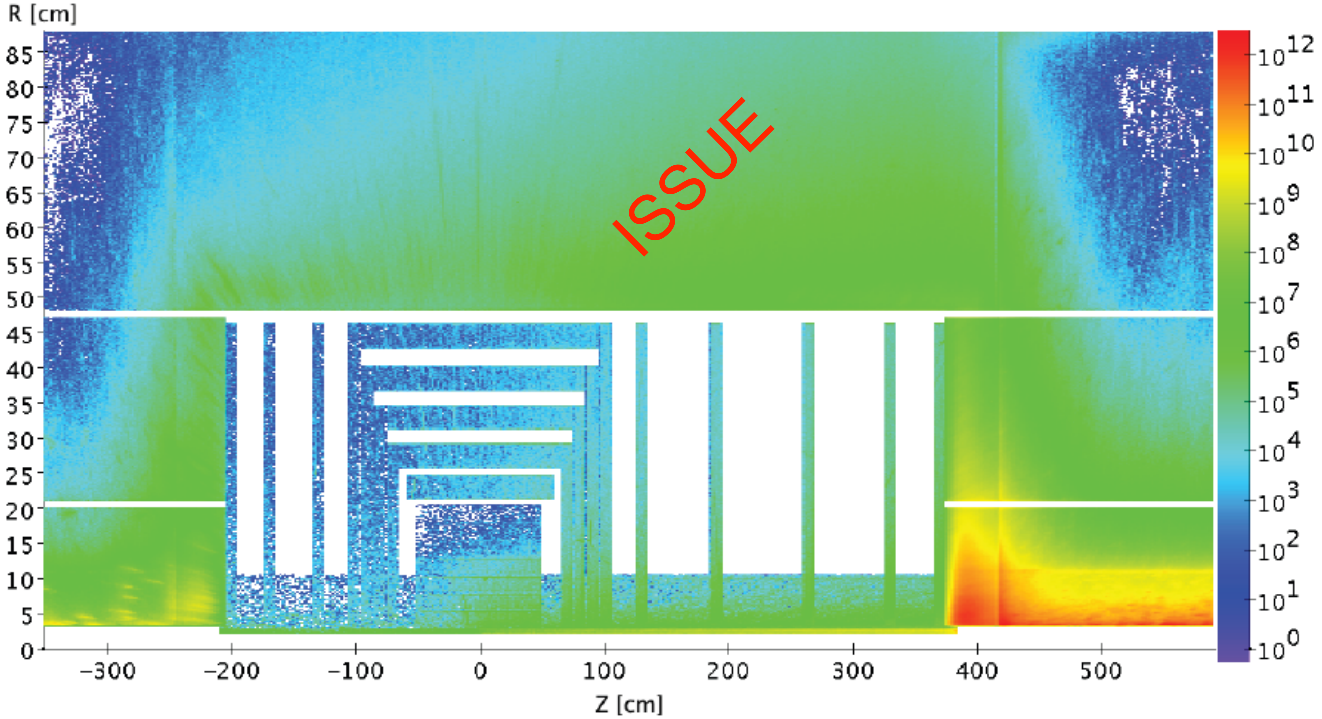


Figure 12.60: 1 MeV Neutron Equivalent Fluence [cm^{-2}/year].

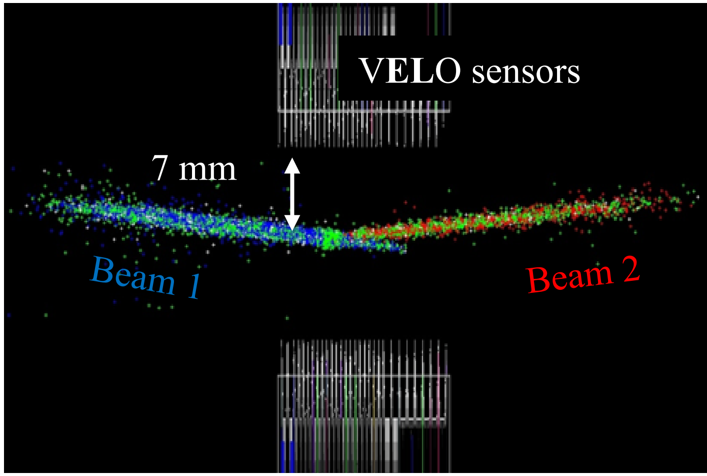
Radiation

LHCb pp

- At LHCb first hit ~ 10cm from IP on average although we go down to 0.8mm from beam
- LHCb designed for ~ 5×10^{14}p/cm^2
- Upgrade 5×10^{15}p/cm^2

Numbers indicate O(10^9 p/cm^2/yr) LHeC @ 5cm

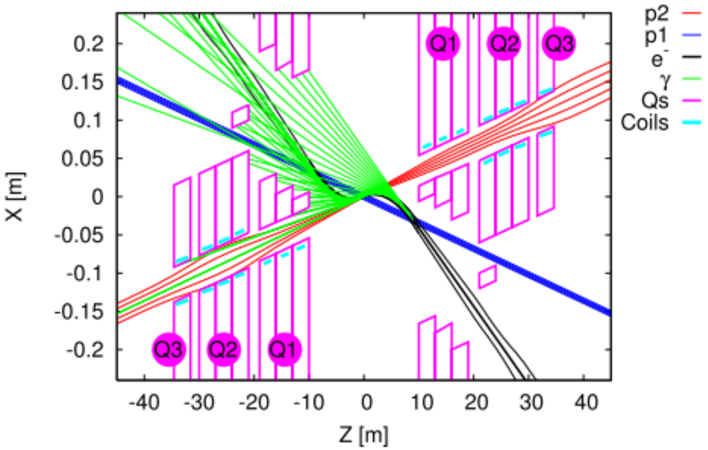
- 5cm sphere -> 300cm^2 -> 10^{13} p/cm^2/yr into acceptance
- Assuming 10^7s/yr at 40MHz
- Every 25ns < 0.01 particles (Cosmic rate!!)
  - Beam gas etc accounted for?
  - Ever take pp collisions?



Synchrotron Radiation

Important difference with LHCb

- Potentially severe problem
- Remember Belle destroyed in a few weeks
- Also heat into beam pipe ....



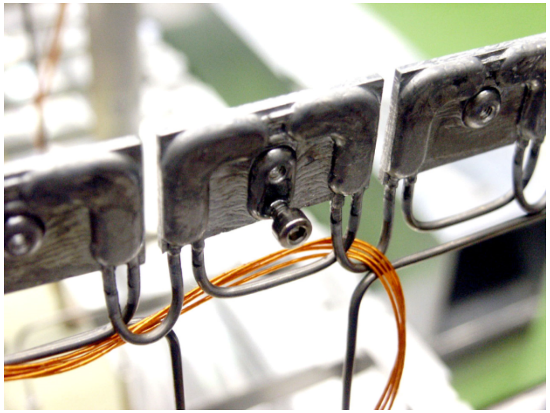
7.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam
ories with 5σ and 10σ envelopes are shown. The parameters of the Q1 and Q2
ıpole segments correspond to the Nb_3Sn half-aperture and single-aperture (with holes)
ıpole of Fig. 8.5

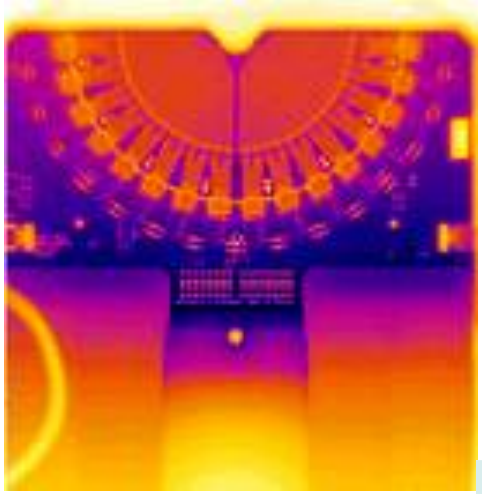
Cooling

For LHCb we used (first time) bi-phase CO_2 now adopted by ATLAS/CMS

LHCb in vacuum (makes problem worse)

- Each module around 25W
- Need to maintain about -7C for sensors
- Main power from electronics
- Little heat load from foil





LHeC Cooling

Proposed using same CO_2 system

- Note though
  - Small pipes difficult
  - LHCb cooling has needed “unblocking” twice (Filters)
- It is low mass
- Complicated (and non-trivial) thermal interface
- Lots of ATLAS R&D now

As with GPDs routing cooling & power is a major problem

- Geometry not the same so routing is not!

Requirements

Modular Design

Detector Technologies re-used rather than innovated

- HERA, LHC & Upgrades and ILC

From CDR: Practical Issues

Cost

This IS a big expensive detector

Huge undertaking (At least 4 separate systems) each one of which is complex.

Sensor Type

CDR Suggested p+n technology

MAPS/Planar Si

Radiation Tolerance

MIP and Synchrotron. A CRITICAL ISSUE

FLUKA, BG, (pp?)

Trigger & R/O Electronics

Not addressed here. Re-use CMS/ATLAS?

VELO used full Analog R/O 10bit ADCs

Power and Cooling

A serious undertaking (compact space with 20kW+ just from electronics)

Mechanical Support & Beampipe

Complex

Summary

Beautiful (aka challenging) detector to build(!)

High level of performance specified

- e, jets
- Also with serious flavour tagging capability

Very tight schedule for completion even re-using GPD technology

- Will be large undertaking by the community

Do not underestimate the mechanical/electrical engineering required

- Small changes are never such