HE-LHC Lattice Design and **Optics Integration**



JACQUELINE KEINTZEL TU VIENNA CERN, MEYRIN

> FCC Week 2019 27th June 2019 Brussels, Belgium



Acknowledgements to Michael Benedikt, Michael Hofer, Rogelio Tomás, Léon v. Riesen-Haupt, Thys Risselada, Demin Zhou, Frank Zimmermann





HE-LHC Requirements

- Same tunnel as the LHC
- Similar Design
 - Two counter rotating proton beams
 - Eight arcs
 - Eight IRs
- Small geometry offset to LEP
- Centre-of-mass energy: 27 TeV
- Beam Stay Clear > 10 σ







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→ Generate and test different arc cell and dispersion suppressor options

→ Tool: ALGEA (Automatic Lattice Generation Application)



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ALGEA

- Tool to generate fast and easy HE-LHC lattice options
 - Similar layout as LHC
 - Same circumference
 - Eight interaction regions
- Geometry optimisation
- Based on few input parameters generation of
 - Sequence
 - Powering
 - Aperture definition
 - Arcs, made of FODO cells
 - Different dispersion suppressor options
 - Beam 1 and beam 2

Two designs \rightarrow 18x90 and 23x90 (cell number x phase advance)



The Algea were the spirits of pain and suffering of both the mind and body.



Ref: https://www.greekmythology.com



Geometry Optimisation

• Strict geometry constraints due to existing tunnel \rightarrow small offset to LEP

• Change of cell length \rightarrow curvature of arcs





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Geometry Optimisation

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- Change of cell length \rightarrow curvature of arcs
- Change middle position of arc \rightarrow tilt of the arc
- Change position of the DS \rightarrow IR offset





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Arc FODO cells



	18x90	23x90
Phase Advance per Cell [°]	90	90
Cell Length [m]	137.19	106.9
Dipoles per Cell [-]	8	6
Filling Factor [%]	81	77
Quadrupole Length [m]	2.8	3.3
Quadrupole Gradient [T/m]	335	355
β_{min}/β_{max}	230/40	177/32
D _{min} /D _{max}	3.60/1.76	2.20/1.10

18 Cells Layout

23 Cells Layout

- Correction Sextupoles (MCS) attached to every Dipole (MB)
- Octupole (MCO) and Decapole Corrector (MCD) after every second MB
- Short straight section includes
 - Beam Position Monitor (BPM)
 - Trim Quadrupole (MQT)
 - Lattice Sextupole (MS)
 - Orbit Correctors (MCB)



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Dispersion Suppressor

- Identical DS scheme integrated in both options at every IR
- Features different dispersion suppression and matching techniques
 - Reduced number of dipoles
 - Individually powered quadrupoles (MQ8 MQ10)
 - Drift space between DS structure and first arc FODO cell
 - First arc FODO cell part of the DS
 - Individually powered trim quadrupoles (MQT11-MQT13)





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Dispersion Suppressor Collimators

- Tracking studies predict the need of additional collimators (TCLD)
- Installation in the dispersion suppressor next to IR1, IR3, IR5 and IR7
- Two TCLDs per dispersion suppressor
- Demanding appr. 3 m per TCLD of additional space
- Space gaining by moving MB11 MQ10 towards arc and MB8 MQ7 towards IR



Courtesy to Thys Risselada



Dispersion Suppressor Collimators

- Change length of the DS ightarrow no longer optimised
- Position of DS needs to be adjusted



total s-correction : 2 * disp * (cos(4*a.mb) - cos(2*a.mb)) / cos(2*a.mb)
radial shift : disp * cos(4*a.mb)*(tan(4*a.mb) - tan(2*a.mb))

Courtesy to Thys Risselada



Lattices without TCLDs

- Transverse peak-to-peak offset to LEP
 - LHC: 7 cm
 - HE-LHC 18x90: 8 cm
 - HE-LHC 23x90: 4 cm
- \rightarrow Geometries optimised
- \rightarrow HE-LHC can to fit in the tunnel



			- []
	18x90	23x90	
Momentum Compaction [10-4]	5.8	3.5	Small geometry offset to LEP
Working Point at Inj. [-]	50.28/49.31	61.28/58.31	Centre-of-mass energy: 27 Te
Working Point at Col. [-]	50.31/49.32	61.31/58.32	Beam Stay Clear > 10 σ
Required Field for 27 TeV c.o.m. [T]	15.89	16.73	beam beay clear + 10 0
c.o.m. Energy with 16 T Dipoles [TeV]	27.18	25.81	



TeV

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suppressor

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Lattices with TCLDs

- With TCLDs lattice is no longer fully optimised with respect to the tunnel
- Local increased geometry offset
- Additional offset of about
 3 cm in DS due to TCLDs



Small geometry offset to LEP 🗸

Centre-of-mass energy: 27 TeV ~ v

Beam Stay Clear > 10 σ

Courtesy to Thys Risselada



Aperture

- Minimum beam stay clear of 10 σ
- 450 GeV injection energy for LHC
- At 450 GeV in one arc FODO cell 18x90: 7.8 σ
 23x90: 8.9 σ
- Bottlenecks in dispersion suppressor due to higher optics functions
 - 18x90: 6.6 σ (L IR 4)
 - 23x90: 6.1 σ (L IR 8)
- How can the beam stay clear be improved?



Parameter	Value
Aperture Tolerances [mm]	1, 1, 1
Halo Parameters [σ]	6, 6, 6, 6
Beam Size Beating [-]	1.05
Frac. Par. Disp. [-]	0.14
Closed Orbit Uncertainty [m]	0.002
Rel. Momentum Offset Inj. [-]	3.1 x 10 ⁻⁴
Rel. Momentum Offset Col. [-]	1.1 x 10 ⁻⁴



Aperture – Enlargement

- Inject with higher energy
 - 18x90: 800 GeV
 - 23x90: 600 GeV



- Combined function dipoles
 - b_2 units of about 450 x 10⁻⁴
 - Alternating sign \rightarrow 2 MB designs



- Apply a scaling factor to the beam screen
 - 18x90: 22 %
 - 23x90: 10 %
- Can lead to a reduced field (less than 16 T dipoles)



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Beam 1 Injection and 'ALICE'



• IR design taken from LHC



Momentum Collimation



• IR design for HE-LHC by T. Risselada



Radio Frequency



IR design for HE-LHC by
 P. Mirave and L. v. Riesen-Haupt



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Beam Dump



W. Bartmann and B. Goddard



Betatron Collimation



• IR design for HE-LHC by T. Risselada



Beam 2 Injection and 'LHCb'





Main Experiments – Injection Optics





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Main Experiments – Collision Optics





Spurious Dispersion Correction

- Crossing beams lead to propagating spurious dispersion
- Corrected with orbit bumps near MQ12, MQ13 at begin and end of arc
- Maximal orbit offset
 - 18x90: 7 mm
 - 23x90: 5 mm
- 7 mm orbit offset
 → 9 σ minimum beam stay clear at 13.5 TeV beam energy





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Conclusion

- Two baseline designs
 - 18x90
 - 7 cm peak-to-peak offset
 - 27 TeV
 - 23x90
 - 5 cm peak-to-peak offset
 - 26 TeV

Small geometry offset to LEP \checkmark

Centre-of-mass energy: 27 TeV ~

Beam Stay Clear > 10 σ \checkmark

- 10 σ can be reached at injection for the 18x90/23x90
 - 800 GeV/600 GeV injection energy
 - Combined function dipoles with $b_2 = 450 \times 10^{-4}$
 - Applying a scaling factor to the beam screen by 22%/10%
- BSC challenges at collision energy due to orbit bumps \rightarrow nearly 10 σ
- Lattice options featuring DS collimators





Thank you jacqueline keintzel for your attention

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Beam Screen Dimensions

23x90: 10 % larger

18x90: 22 % larger



• Beam screen dimensions to reach 10 σ at 450 GeV injection energy

