Ring-Ring Lattice and Optics

LHeC Workshop, 12.11.2010, Chavannes-de-Bogis

Outline

- Overall Layout
- Idealized Lattice
- Bypass Design
- Complete Lattice without Interaction Region

Overall Layout

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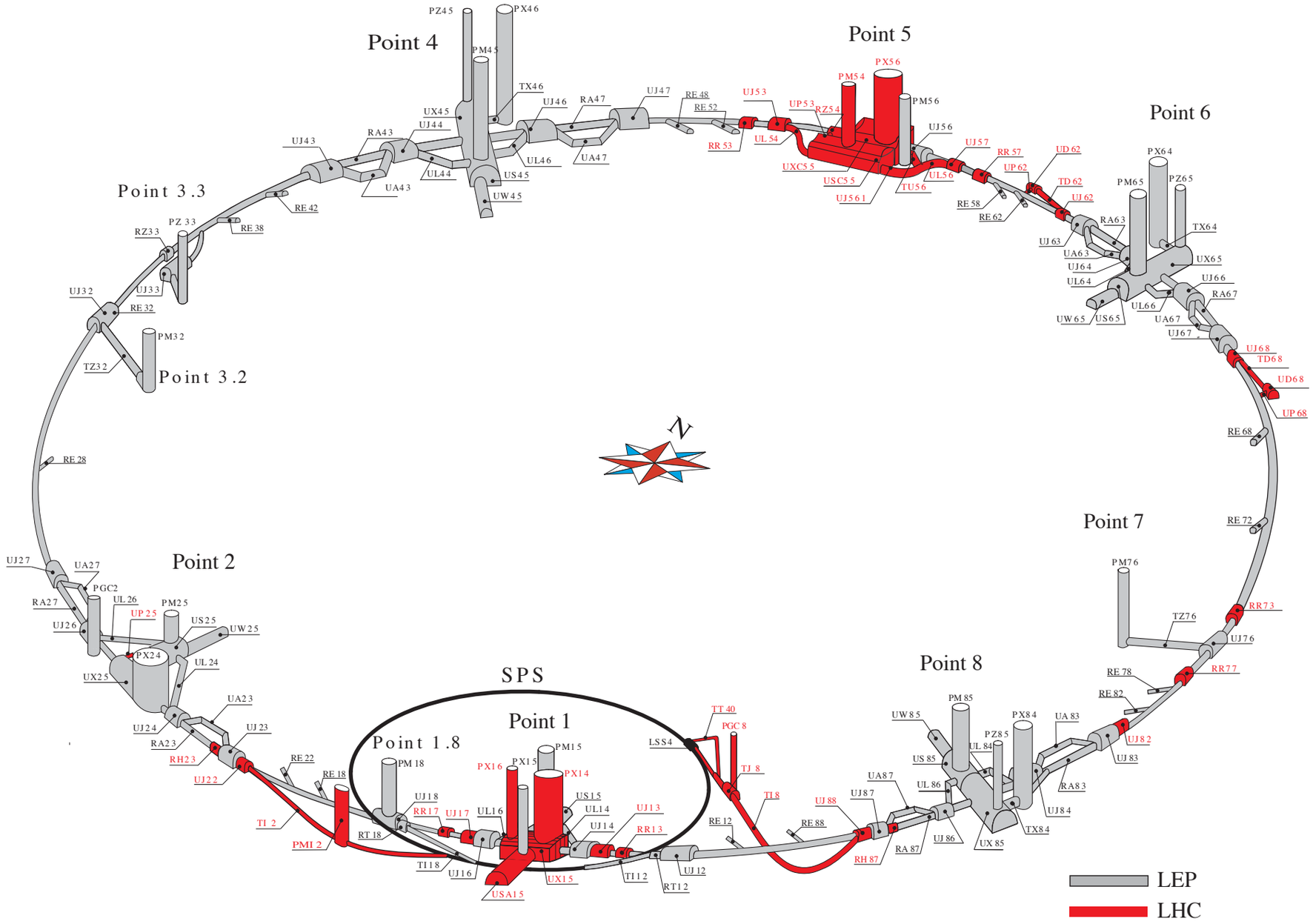

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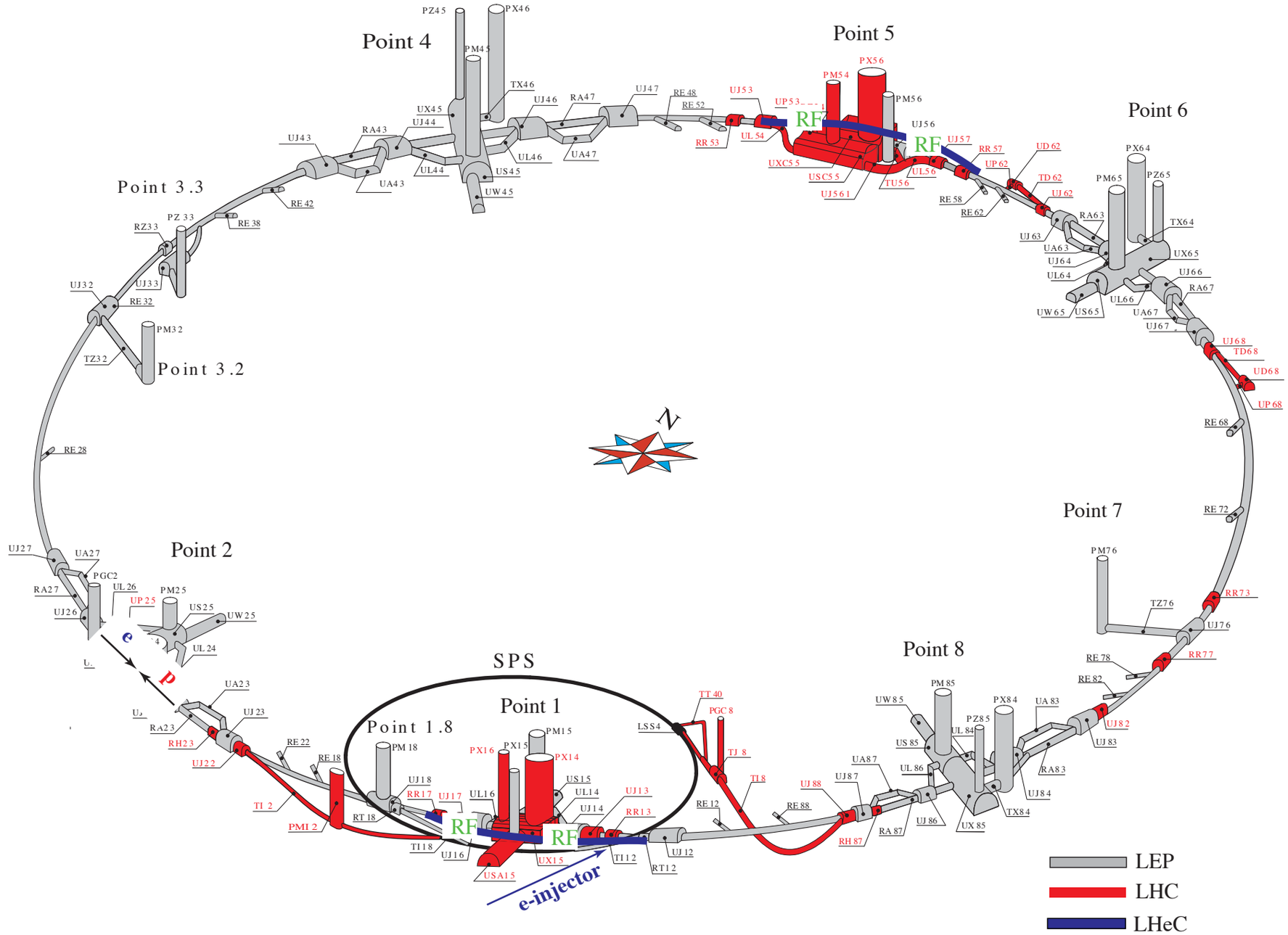

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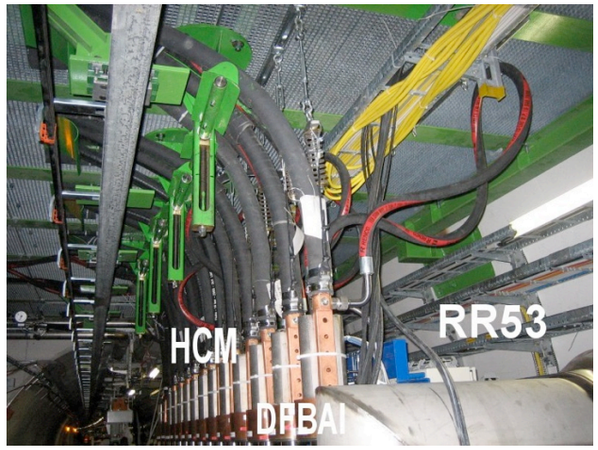

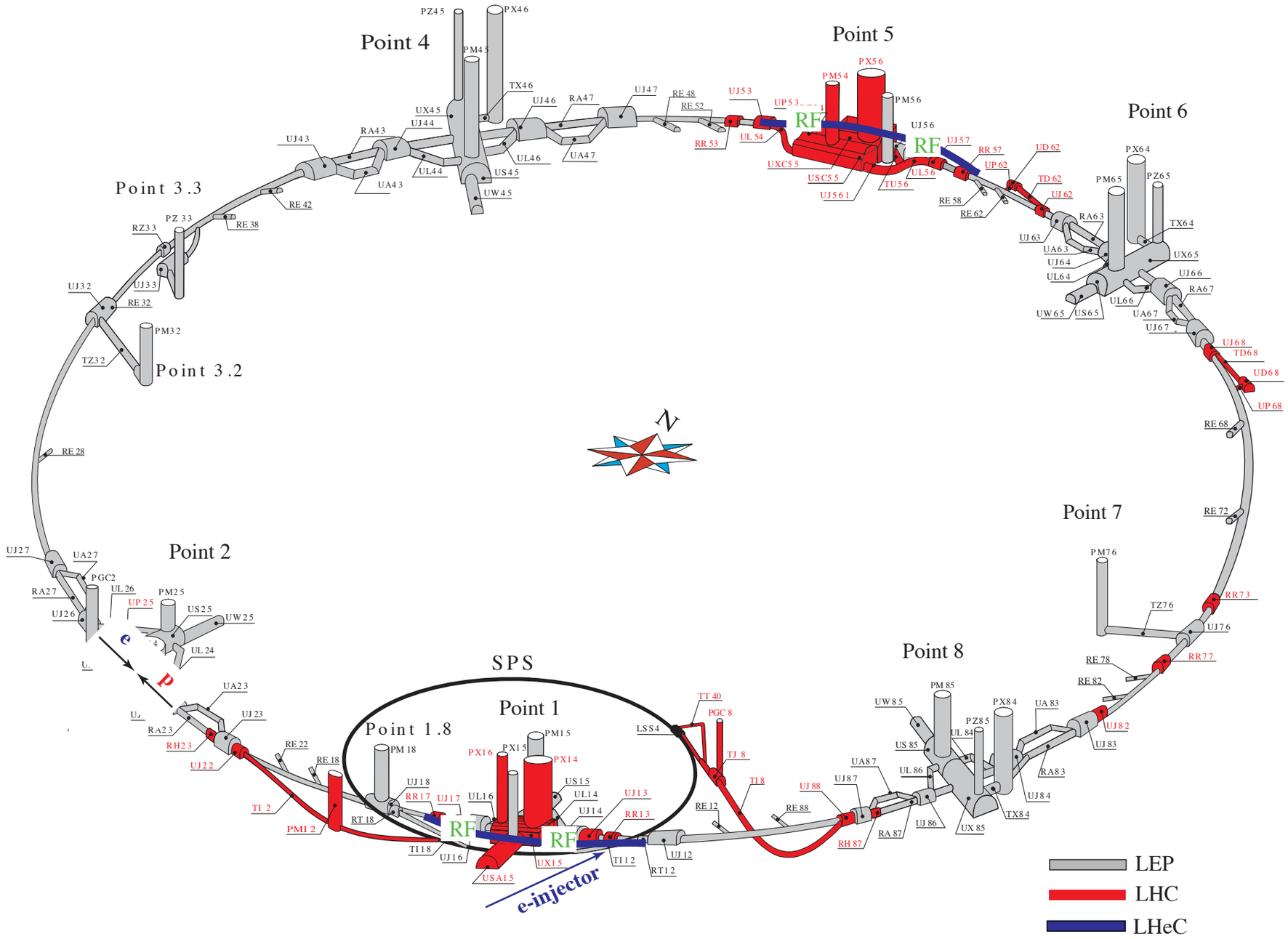

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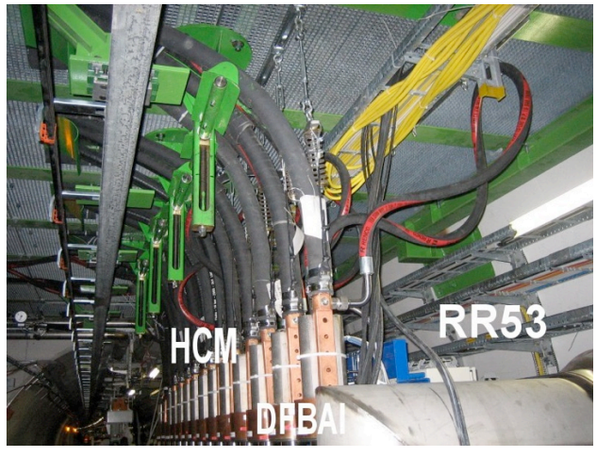
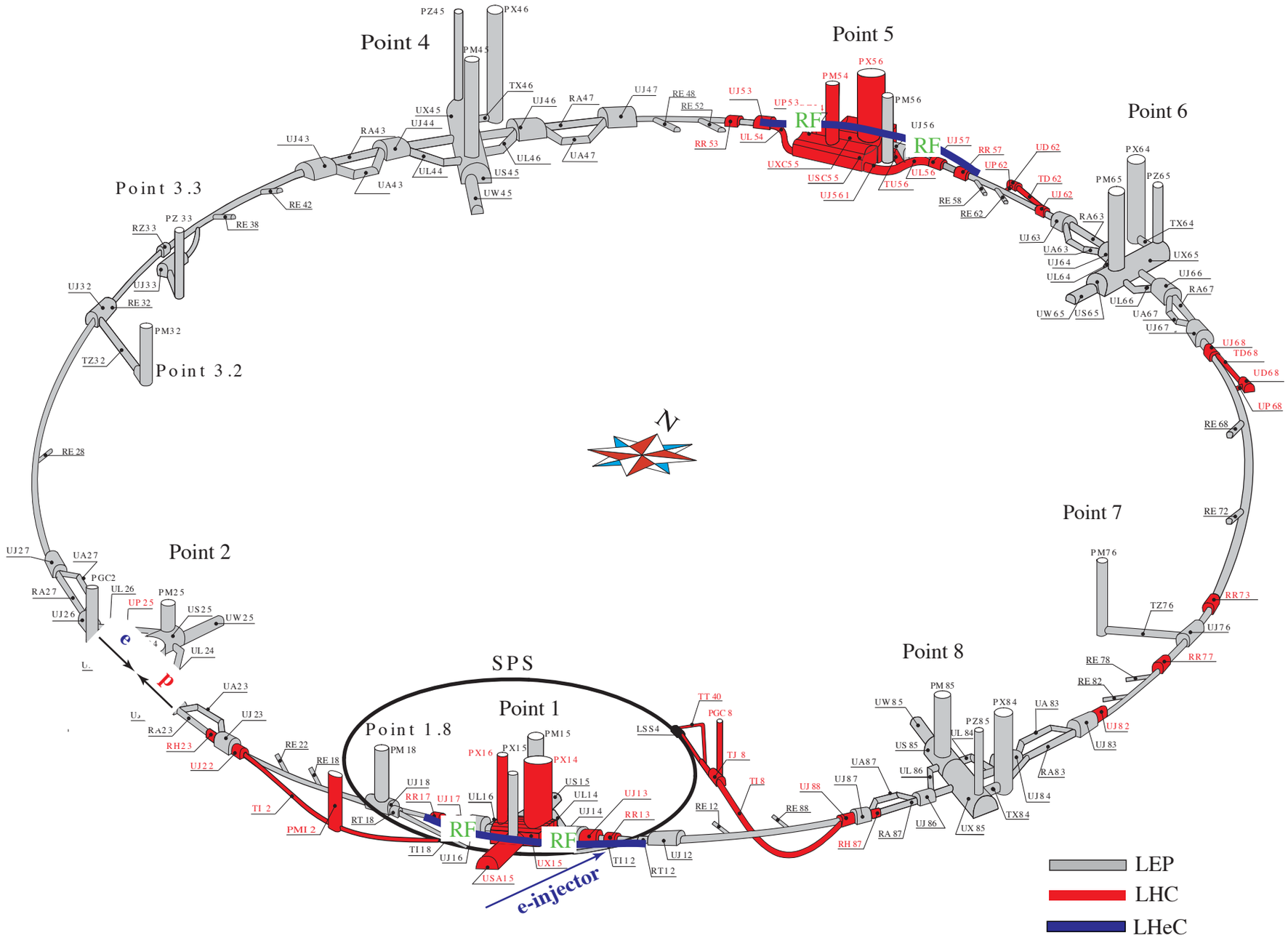


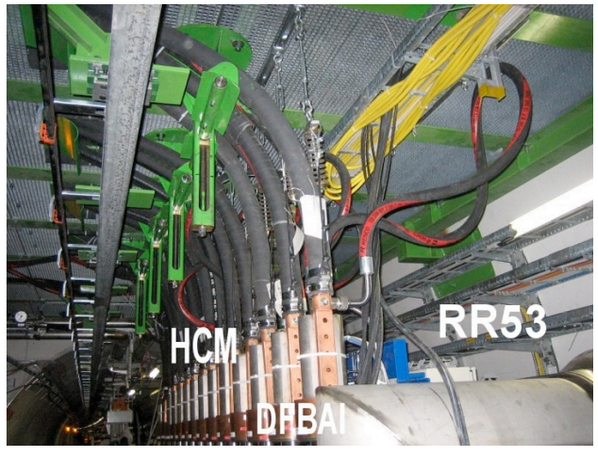
Lattice Design dominated by geometry:

- forbidden space (usually DFBMs) induces an asymmetric lattice
- asymmetric lattice needs to be matched to the symmetric LHC lattice

➡ most choices for the LHeC lattice structure are made due to integration



Overall Layout



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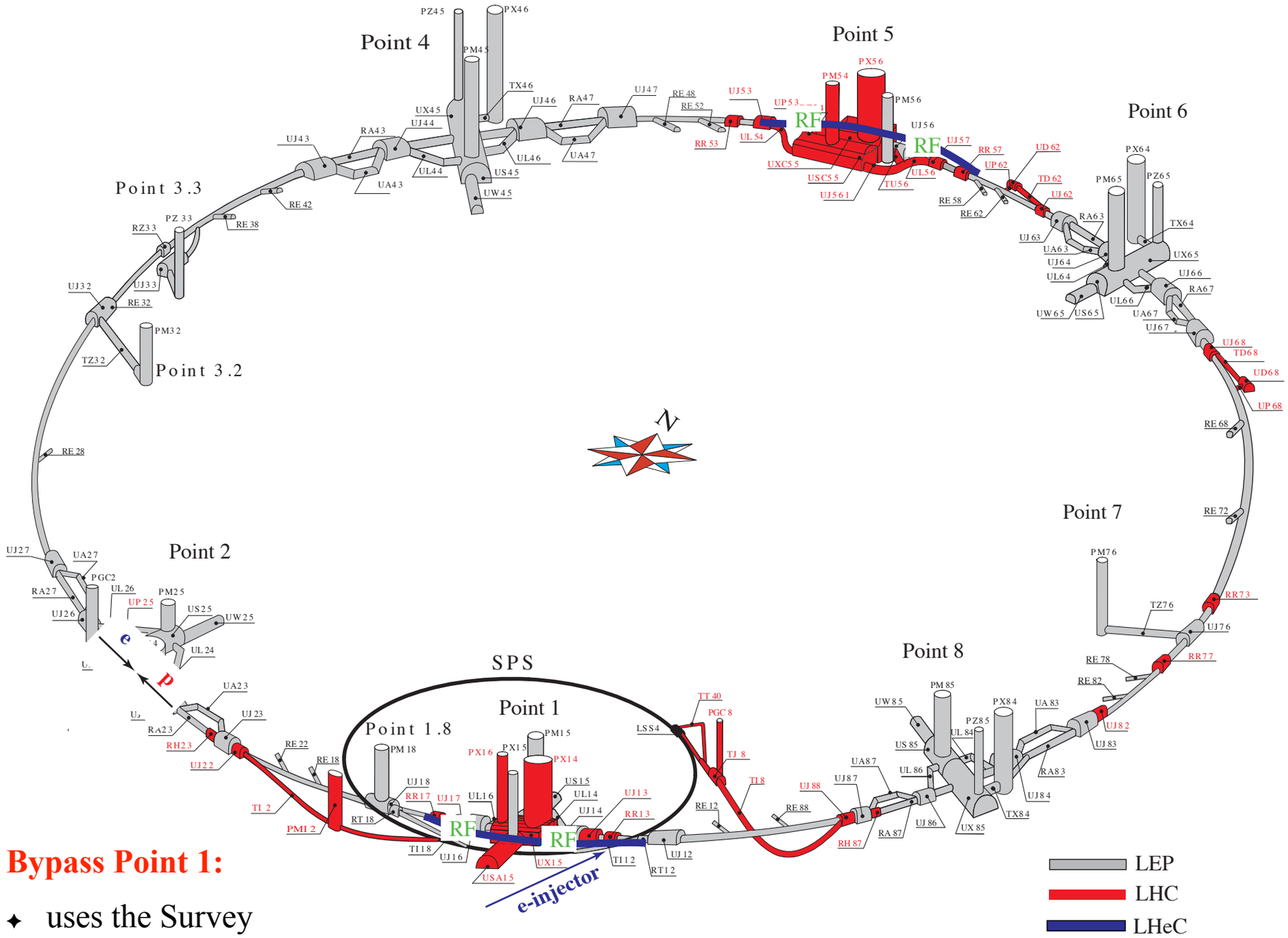
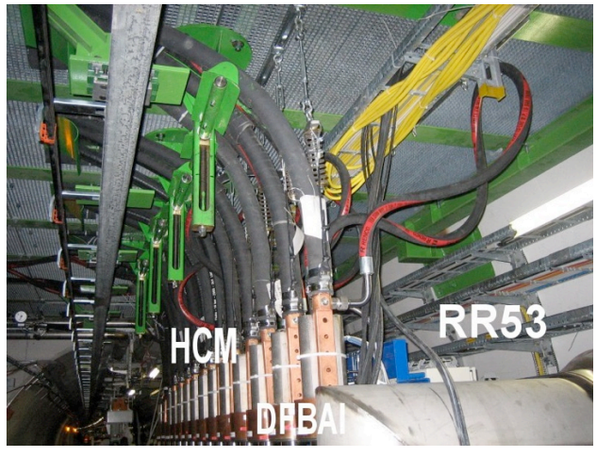


Bypass Point 1:

- uses the Survey Gallery
- Δ=16.25 Meter

Overall Layout



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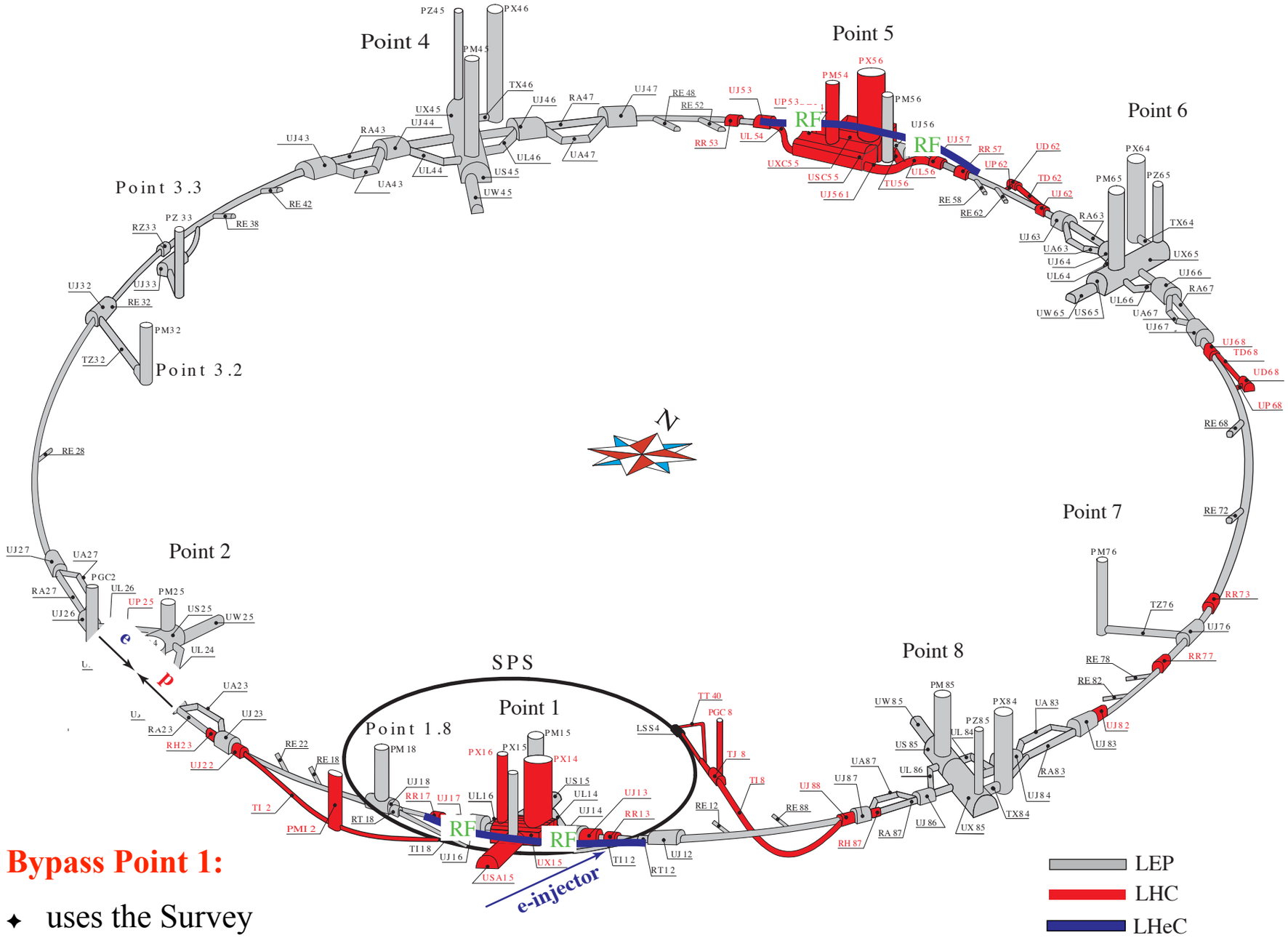
Bypass Point 5:

- adjustment of the circumference by varying the separation
- Δ=20.56 Meter



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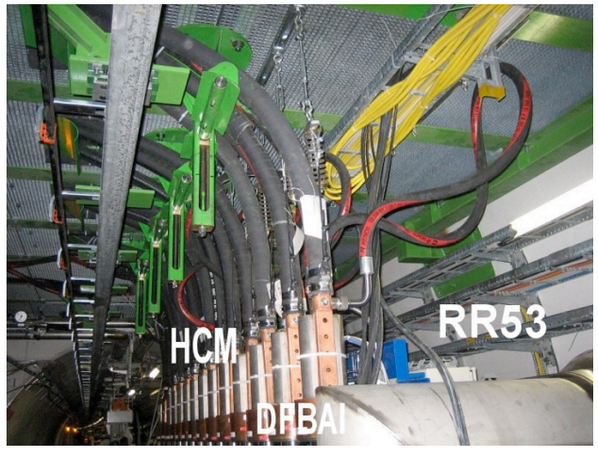
- uses the Survey Gallery
- Δ=16.25 Meter

Overall Layout



Lattice Design dominated by geometry:

- forbidden space (usually DFBMs) induces an asymmetric lattice
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➡ most choices for the LHeC lattice structure are made due to integration

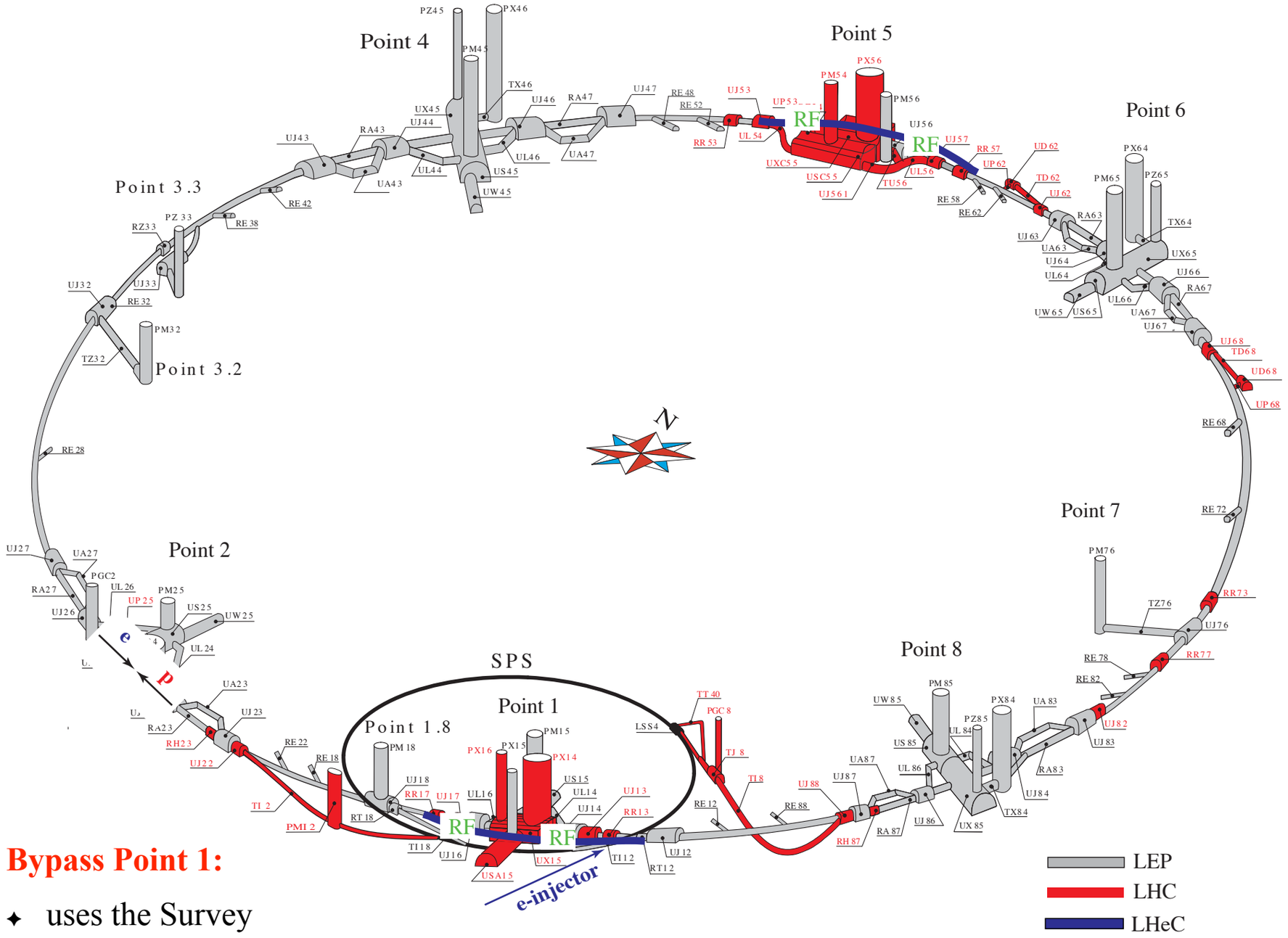
Bypass Design:

- Bypasses increase the circumference of the ring

➡ Compensation of the increase in circumference by placing the electron ring 0.61 cm to the inside of the LHC (Idealized Ring)

Bypass Point 5:

- adjustment of the circumference by varying the separation
- Δ=20.56 Meter



Bypass Point 1:

- uses the Survey Gallery
- Δ=16.25 Meter

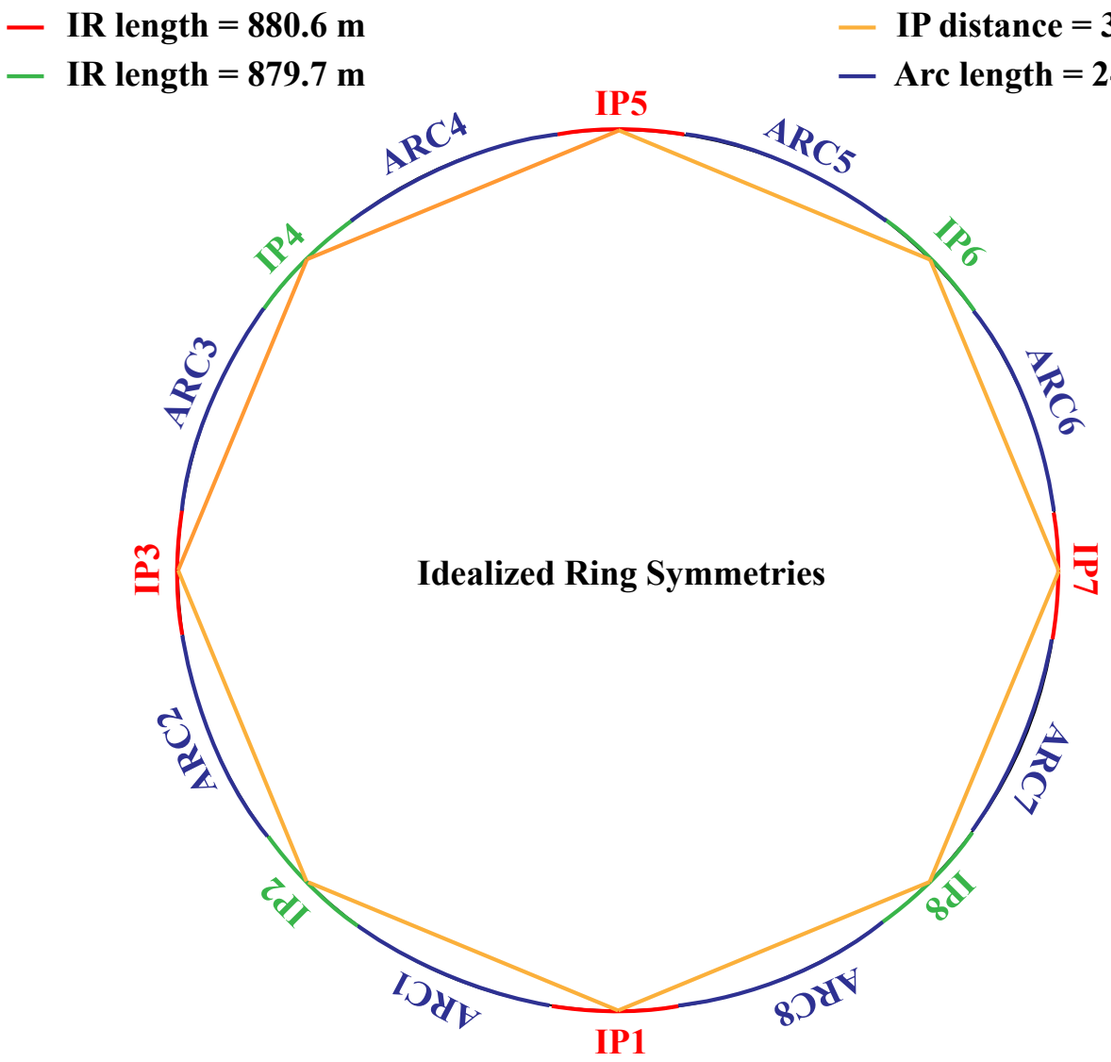
Idealized Ring

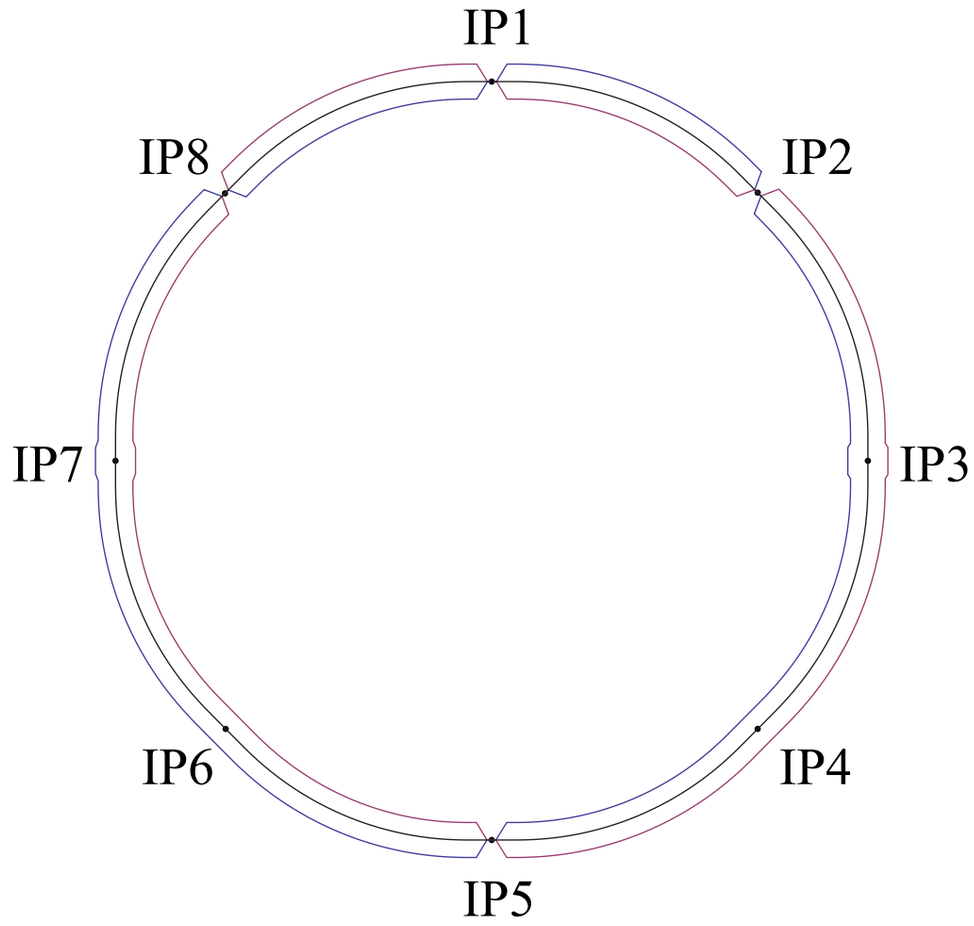
General Structure

- **Geometry:** electron ring is placed 61 cm to the inside of the LHC
- **Lattice:** Built out of different modules reflecting the LHC symmetries
  - Arc
  - Standard insertion for even points (DSL - straight section - DSR)
  - Standard insertion for odd points (DSL - straight section - DSR)

$L_{\text{Arc Cell}}$	106.881 m
$L_{\text{DSL, even}}$	172.78 m
$L_{\text{even straight section}}$	538.83 m
$L_{\text{DSR, even}}$	161.57 m
$L_{\text{DSL, odd}}$	173.72 m
$L_{\text{odd straight section}}$	537.81 m
$L_{\text{DSR, odd}}$	162.51 m

LHC Symmetry and Layout:



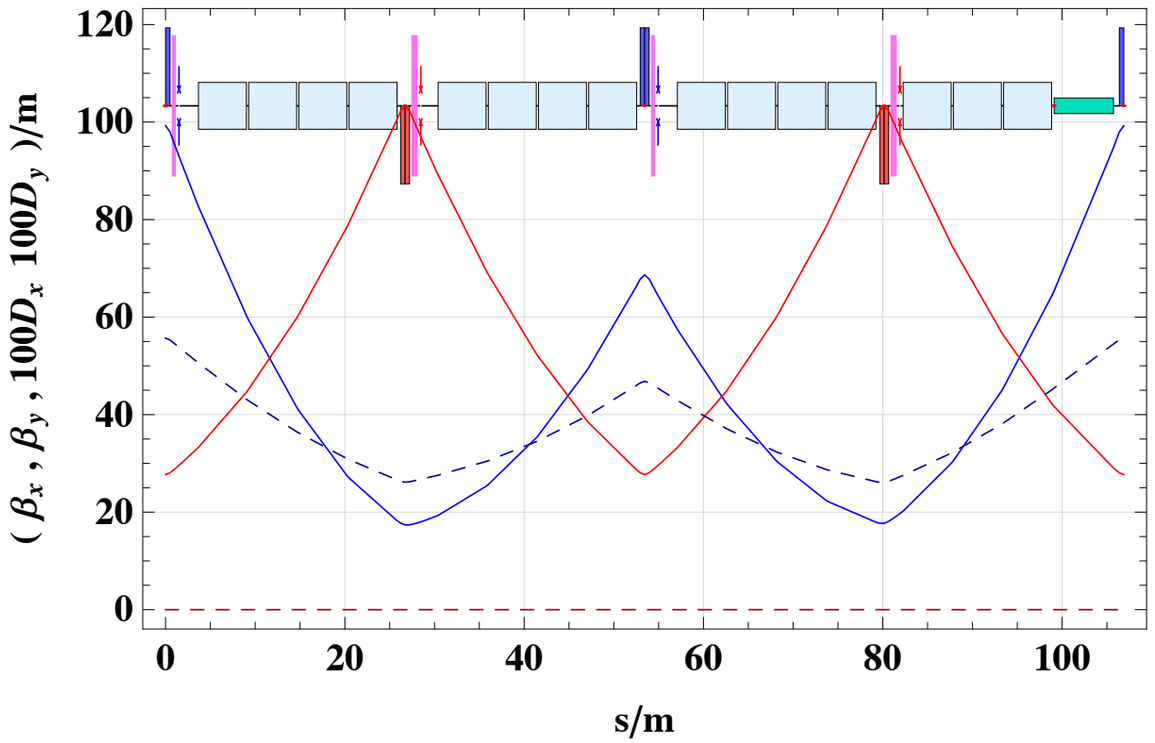


Arc Module

23 arc cells, L_{Cell}=106.881 m

Optics:

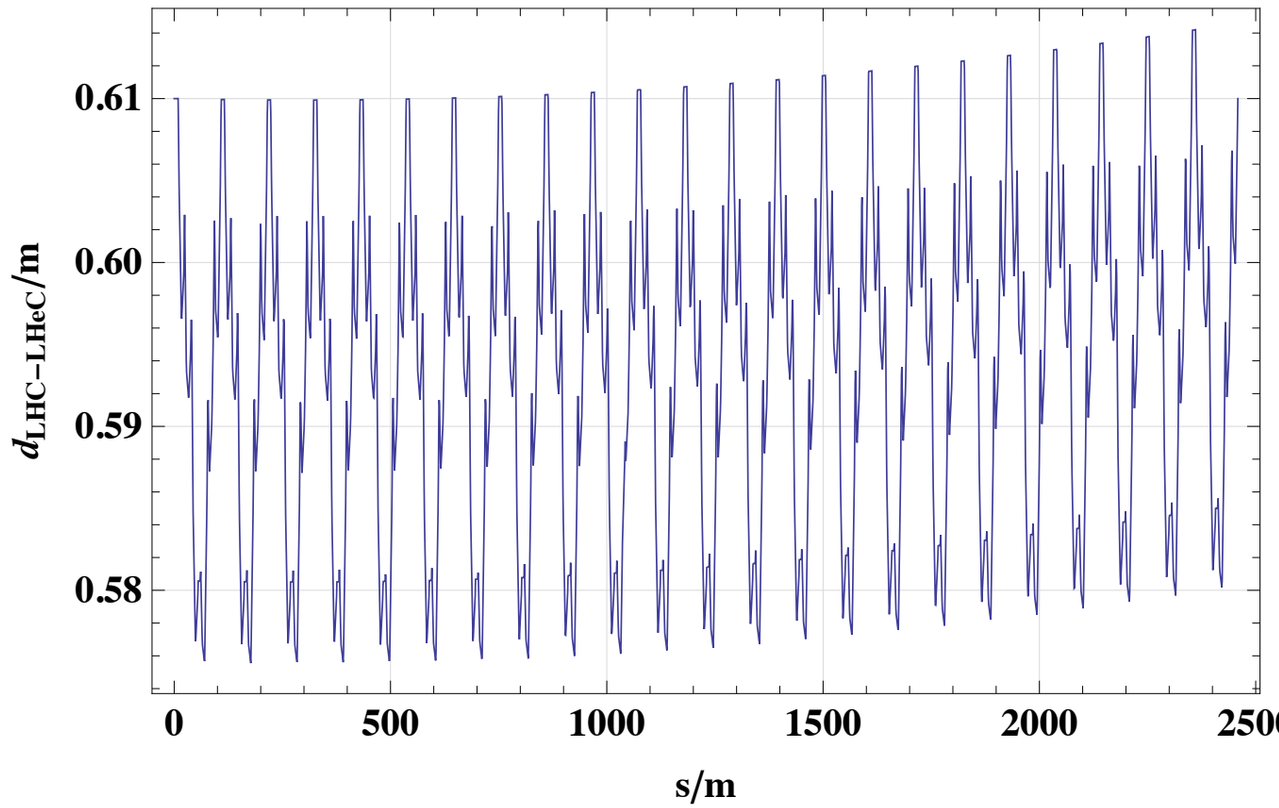
Beam Energy	60 GeV
Phase Advance per FODO Cell	$\approx 90°/60°$
Cell length	106.881 m
Dipole Fill factor	0.75
Damping Partition $J_x/J_y/J_e$	1.5/1/1.5
Coupling constant κ	0.5
Horizontal Emittance (no coupling)	4.70 nm
Horizontal Emittance ($\kappa = 0.5$)	3.52 nm
Vertical Emittance ($\kappa = 0.5$)	1.76 nm



Geometry:

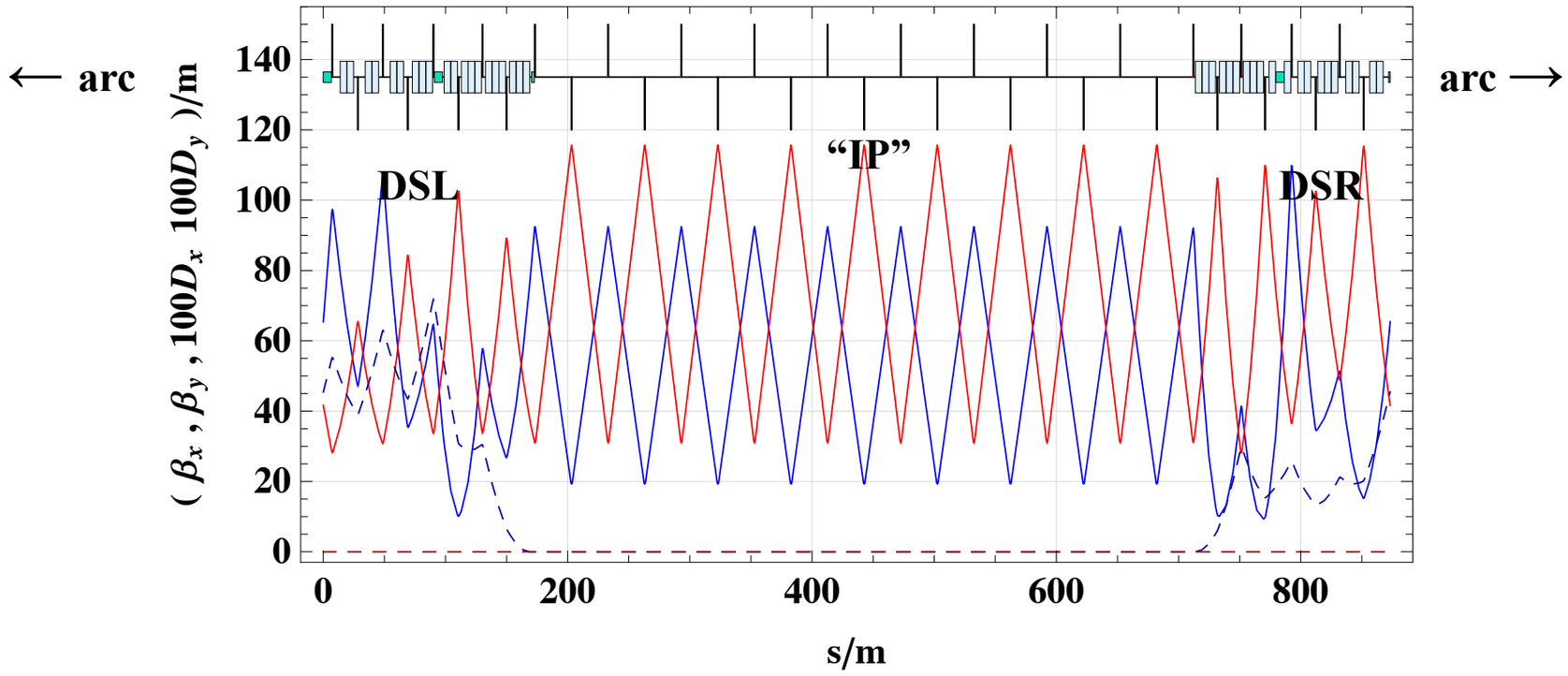
To meet the LHC geometry the dipoles must be shortened

➡ trade off between synchrotron radiation loss and geometry

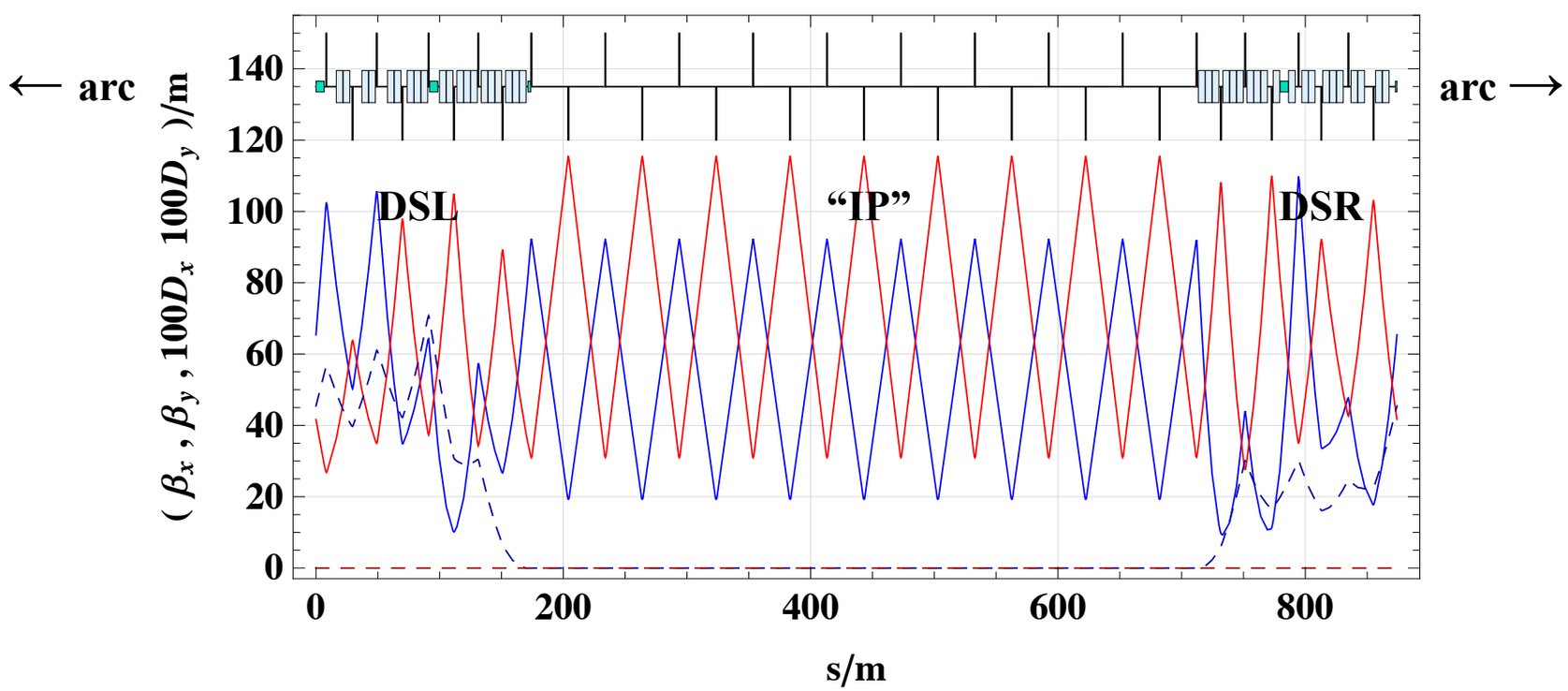


Insertion Module

Even Points



Odd Points



Geometry and Layout

Dispersion **S**uppressor **L**eft side and **R**ight side:

- Same layout for even and odd points, only different length
- Dipole configuration adapted to follow the LHC geometry

Straight Section:

- FODO cell (has to be adapted later to each insertion)

Optics

DSL

- Equal distance of quadrupoles between first and second DFBM and the second DFBM and the end of the DSL
- 8 matching quadrupoles

DSR

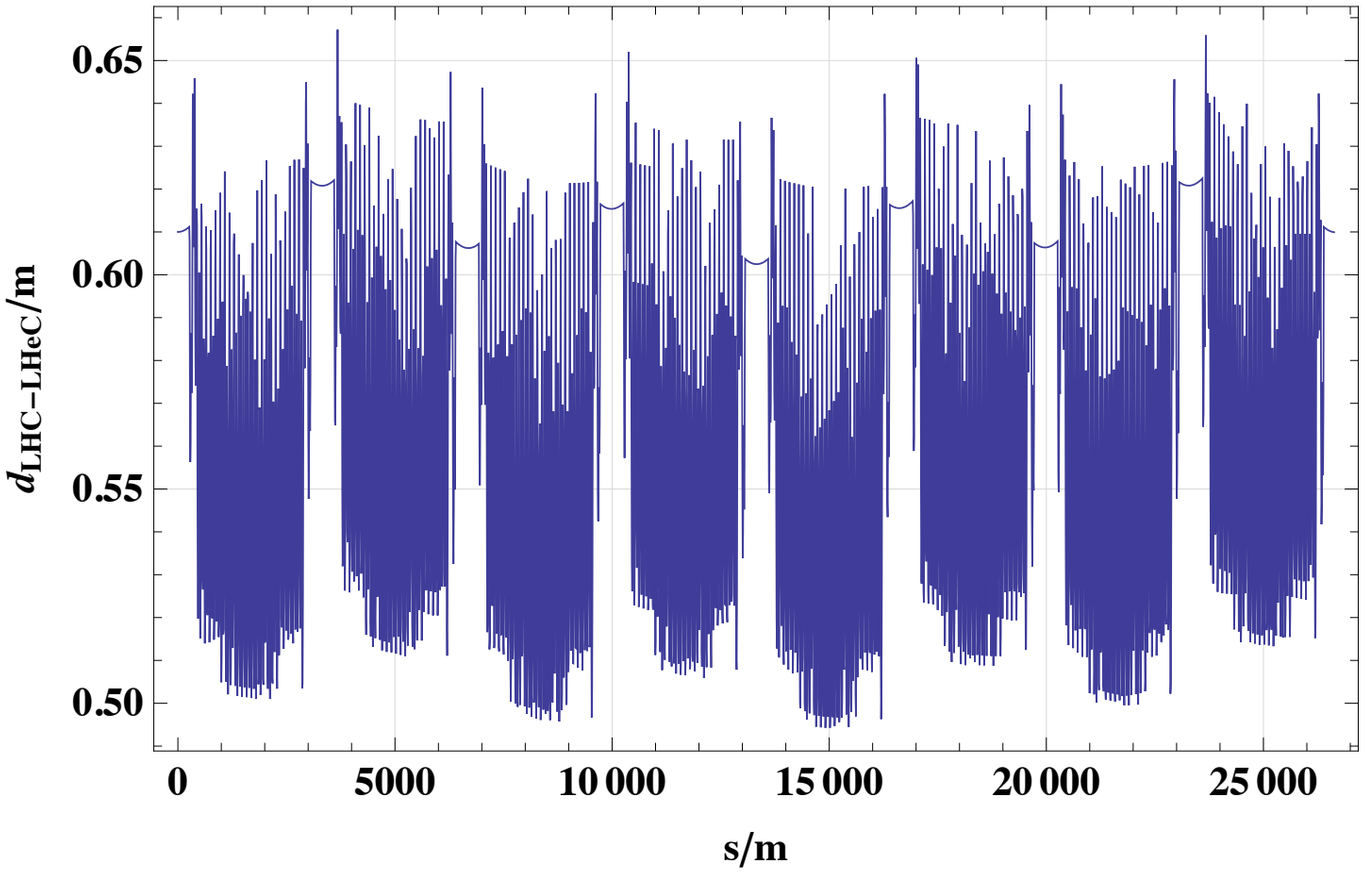
- Equal distance between all quadrupoles
- 8 matching quadrupoles

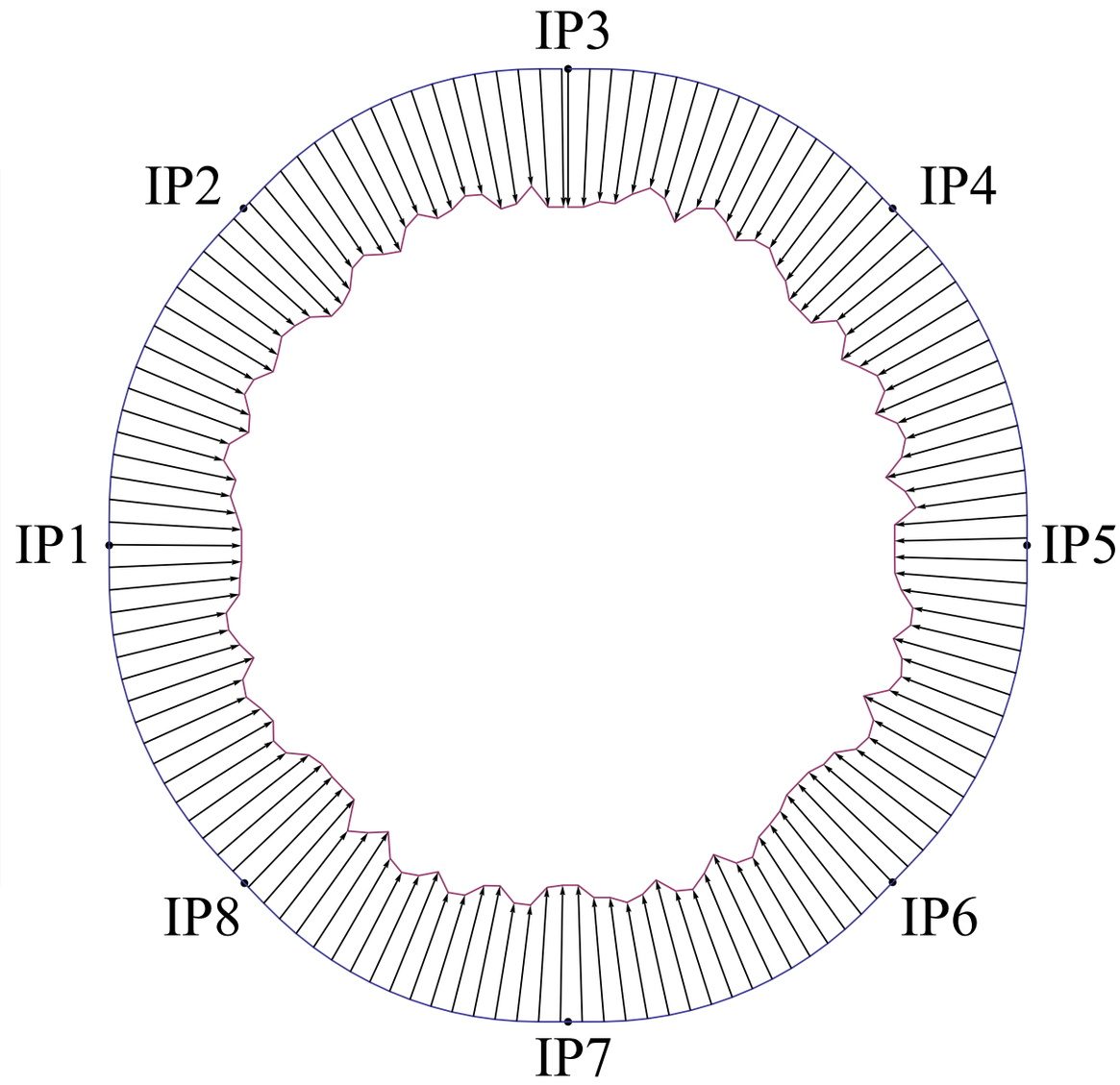
Straight Section

- FODO lattice with a phase advance of 90˚/60˚

Idealized Ring Geometry

Distance between the LHC and LHeC:





Maximum distance between LHC and LHeC: $d_{\mathrm{LHC-LHeC}} = 64.3\mathrm{cm}$

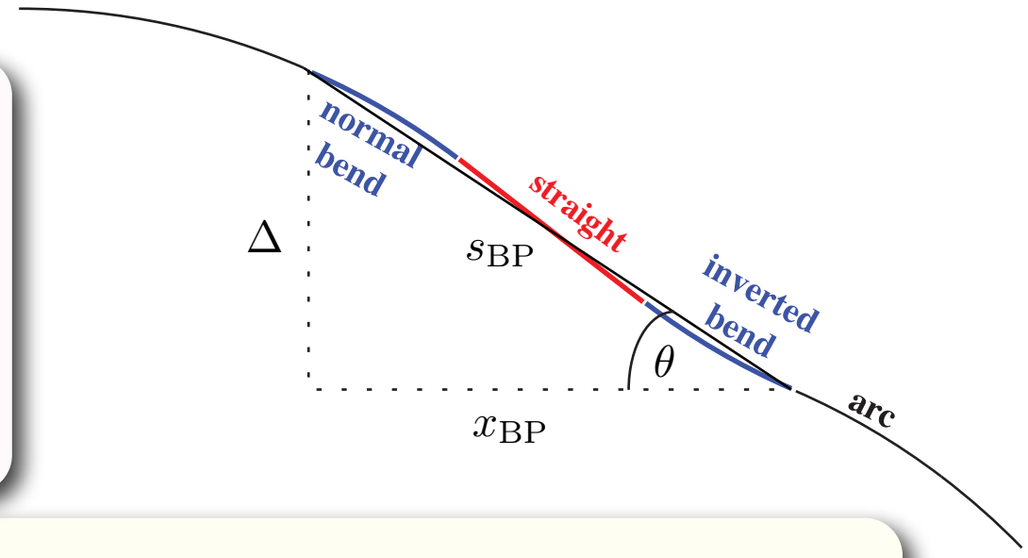
Maximum difference to the ideal value of 61 cm: $d_{\mathrm{LHC-LHeC}} - 61\mathrm{cm} = 11.6\mathrm{cm}$

Bypass Design

Bypass Design
Matching LHC and LHeC Circumference

General Design:

- Insertion of a straight section into the lattice leads to a separation Δ
- Both bypasses have the same lattice for the bend sections, but different length for the straight sections



Matching the circumference:

- Necessary change of radius to compensate the path length difference caused by the bypasses:

$$\Delta R = \frac{\Delta_{\mathrm{IP}}}{\pi \cot\left(\frac{\theta}{2}\right) - 2}\ , \quad \text{with } \Delta_{\mathrm{IP}} = \Delta_{\mathrm{IP1}} + \Delta_{\mathrm{IP5}}$$

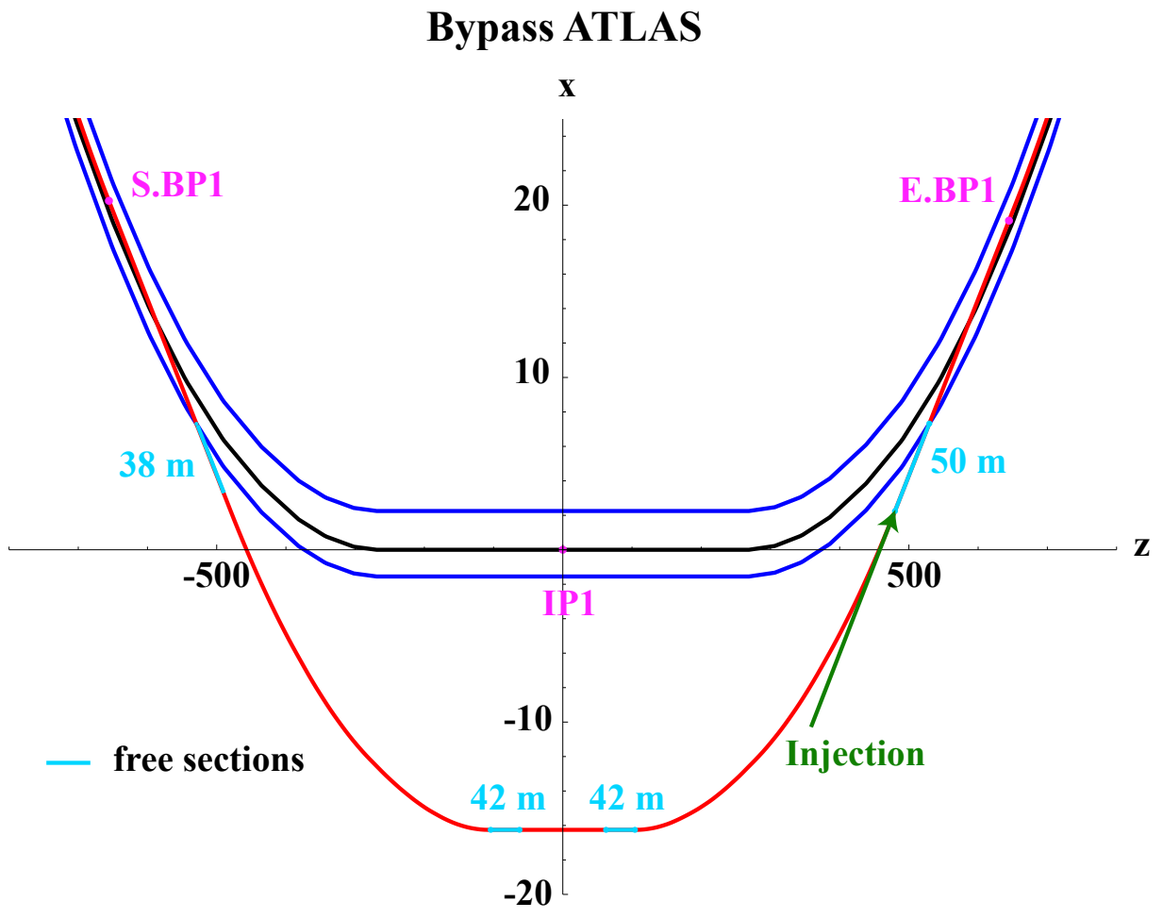
- Fine adjustment with the separation in Point 5 (the separation in Point 1 is fixed as the bypass has to pass through the survey gallery:

$$\Delta_{\mathrm{BP5}} = \frac{\Delta s_{\mathrm{BP5}}}{2(\frac{1}{\sin\theta} - \frac{1}{\tan\theta})}$$

- Final configuration:

$$\Delta R = 61 \text{ cm},\ \Delta_{\mathrm{BP5}} = 20.56 \text{ m},\ \Delta_{\mathrm{BP1}} = 16.25 \text{ m}$$

Bypass Layout



Bypass Point 1:

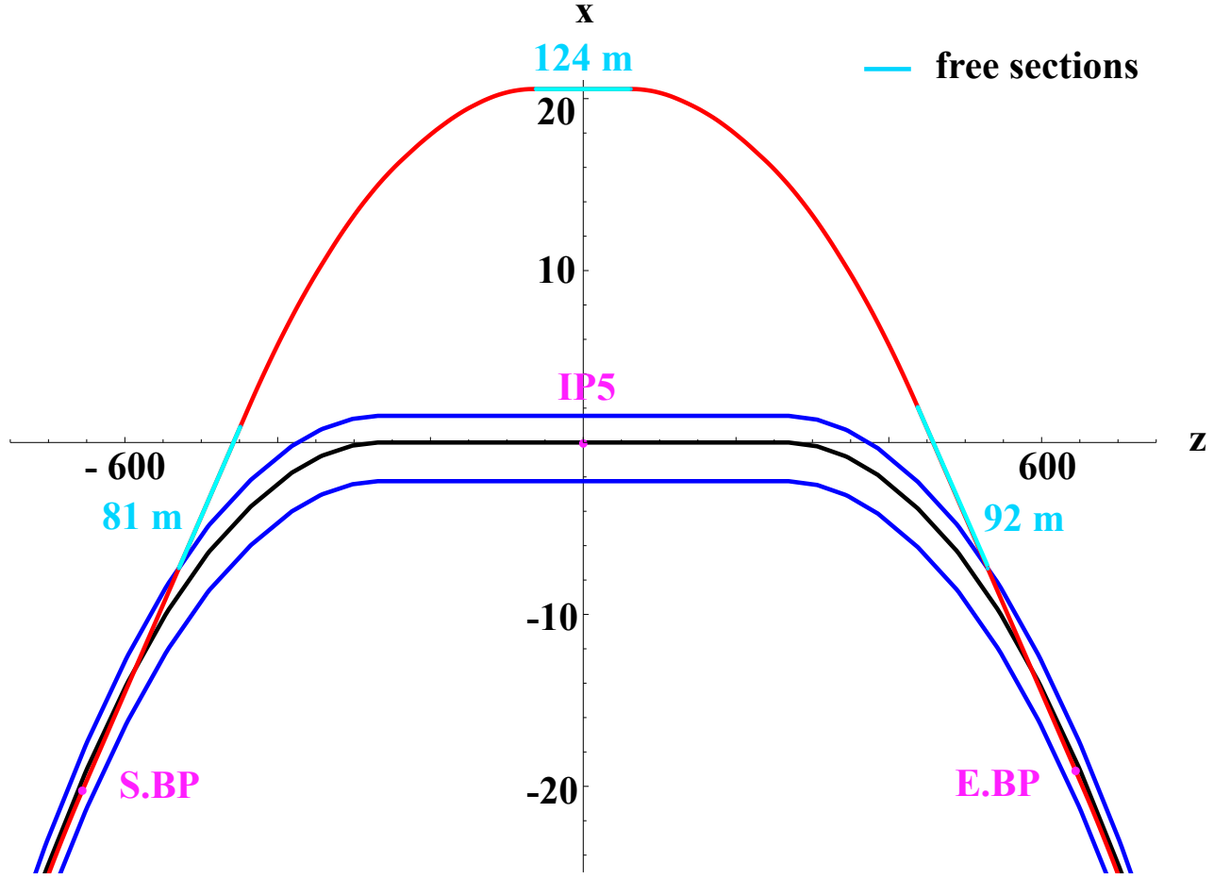
- **Injection** on the right side of the bypass
- long part of the straight section lies inside the tunnel
- straight sections used for Installation of the RF

Bypass Point 5:

- more space for Installation of RF or other special elements

Bypass Design Parameters:

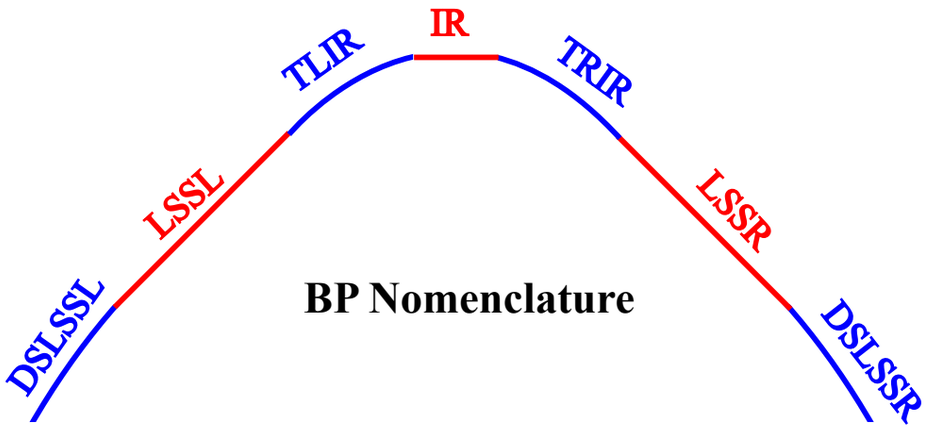
	ATLAS	CMS
L_{BP}	1303.3 m	1303.7 m
Δ_{BP}	16.25 m	20.56 m
$L_{tot,\ straight\ sections}$	172 m	297 m



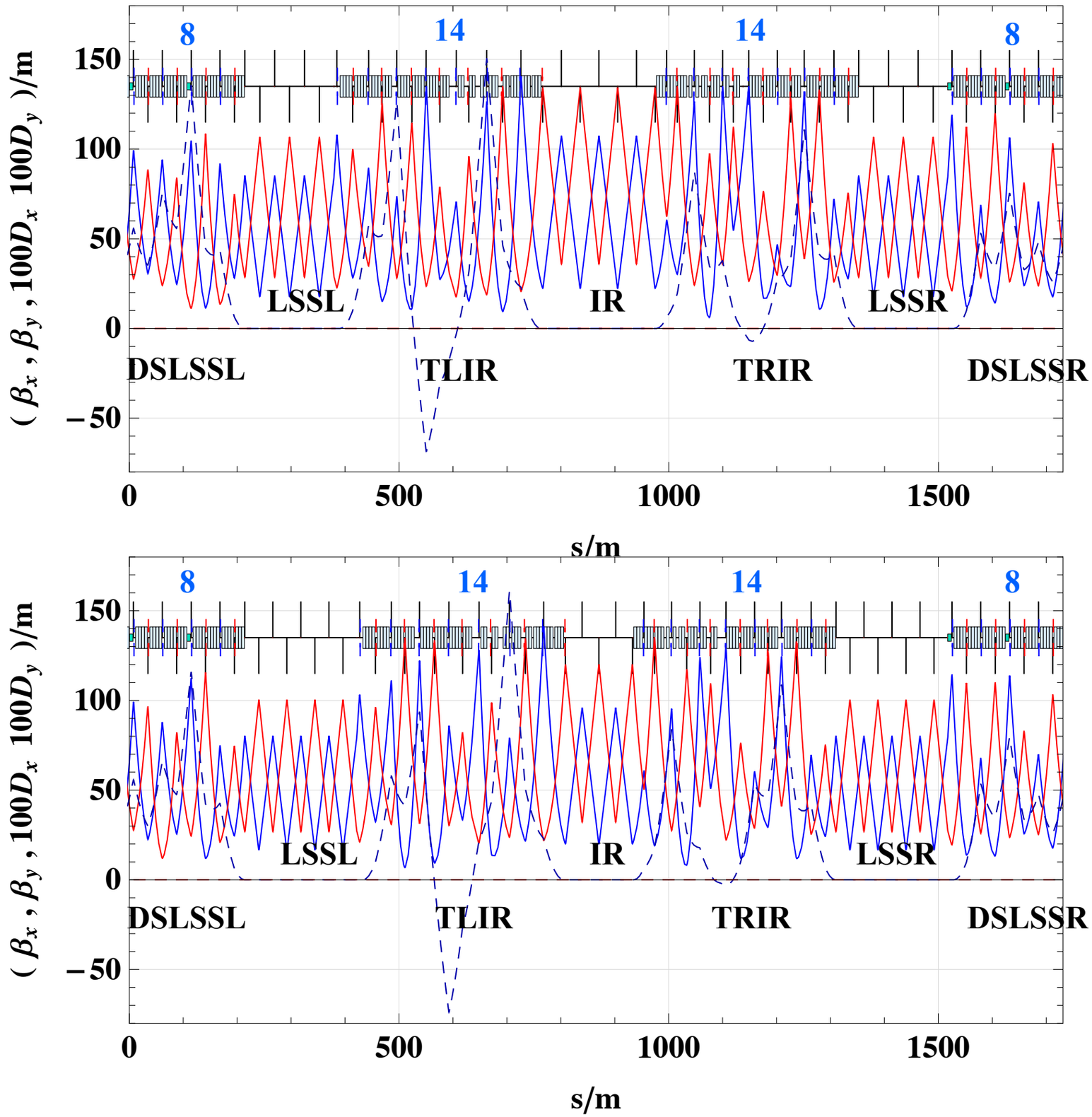
Bypass Optics

Bypass Point 1

- Total number of individually powered *matching quadrupoles:* 40
- Phase advance of 90°/60° in the FODO cell sections



BP Nomenclature



Bypass Point 5

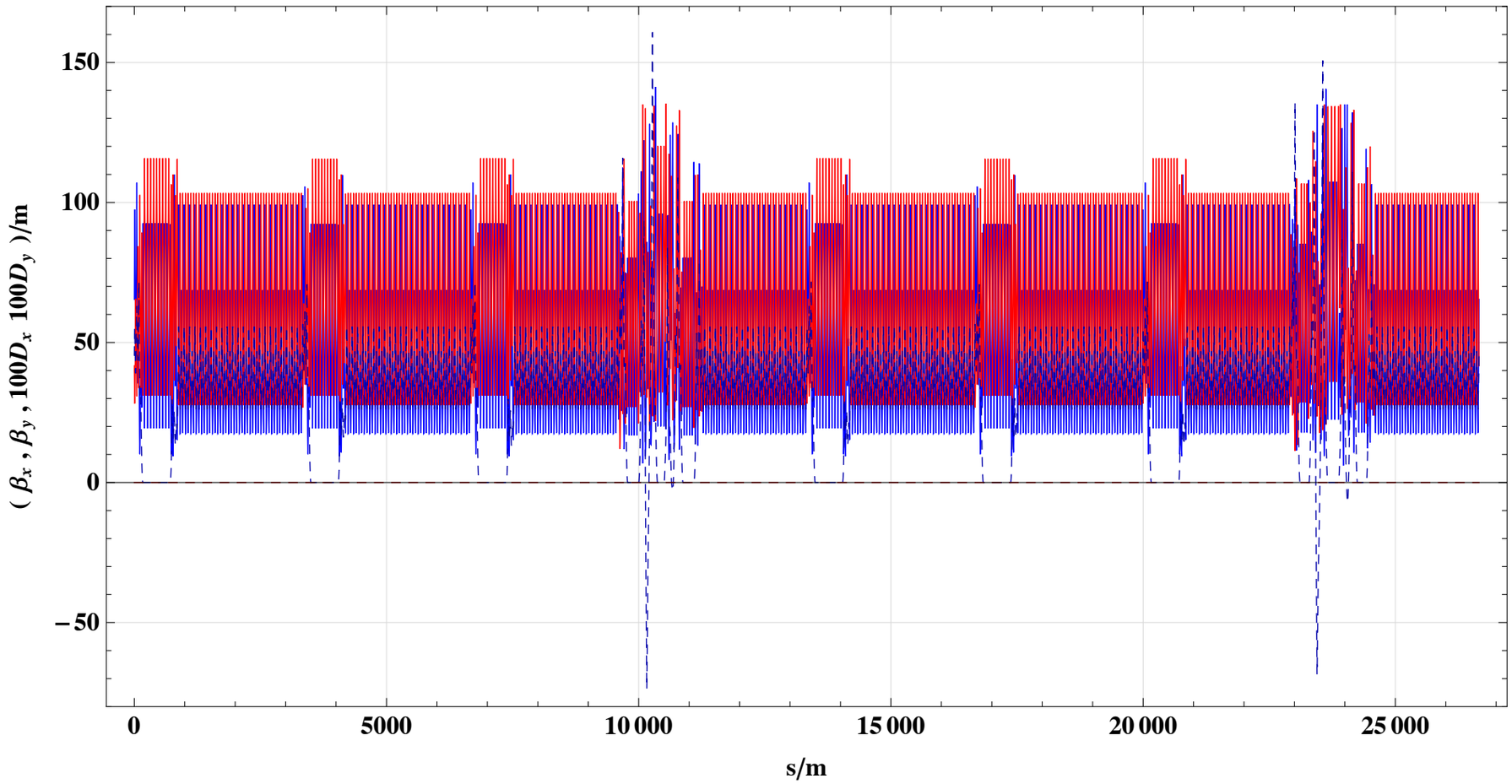
- Total number of individually powered *matching quadrupoles:* 40
- Phase advance of 90°/60° in the FODO cell sections

Ring Lattice and Optics

Optics without Interaction Region

Beam Energy	60 GeV
Numb. of Part. per Bunch	2.0×10^{10}
Numb. of Bunches	2808
Circumference	26658.8832 m
Syn. Rad. Loss per Turn	437.2 MeV
Power	43.72 MW
Damping Partition $J_x/J_y/J_e$	1.5/1/1.5
Damping Time τ_x	0.016 s
Damping Time τ_y	0.025 s
Damping Time τ_e	0.016 s

Polarization Time	61.7 min
Coupling Constant κ	0.5
Horizontal Emittance (no coupling)	5.49 nm
Horizontal Emittance ($\kappa = 0.5$)	4.11 nm
Vertical Emittance ($\kappa = 0.5$)	2.06 nm
RF Voltage V_{RF}	720 MV
RF frequency f_{RF}	359.856 MHz
Bunch Length	6.05 mm
Max. Hor. Beta	141.26 m
Max. Ver. Beta	135.25 m



Summary

- Optics look rather regular
- Largest peaks in dispersion and beta function in the bypasses

Not Yet Considered

- RF (Energy Sawtooth)
- Tune, Phase advance of Insertions
- Chromaticity correction and Resonances
- Adjustment of the damping partition number

Summary and Outlook

- Detailed lattice exists:
  - fits the LHC integration constraints
  - meets design parameters
- Next steps :
  - integrate RF
  - injection
  - further optimizations:

    Tune, Phase advance of insertions, chromaticity correction, (dynamic) aperture, adjustment of damping partition number ...

Backup Slides

Arc Cell Parameters

Arc Cell (60 GeV) :

Lcell → 106.881 Meter
phicell → 0.0305999
mux → 180.01
muy → 120
muxend → 180.01
muyend → 120.
muxmid → 90.5747
muymid → 60.
Ncell → 184
KSF → 0.303251
KSD → -0.279831
KQF → 0.0513678
KQD → -0.0419683
Lbend1 → 21.4 Meter
Lbend2 → 16.05 Meter
Lquad → 1.
Lsextf → 0.35
Lsextd → 0.6
Brho → 200.139 Meter Tesla
ΘBend1 → 0.00815998
ΘBend2 → 0.00611999
ρBend → 2622.56 Meter
Bbend → 0.0763143 Tesla
dBdxQF → $\frac{10.2807\ \text{Tesla}}{\text{Meter}}$
dBdxQD → $-\frac{8.39947\ \text{Tesla}}{\text{Meter}}$
betxQF1 → 99.2431 Meter
DxQF1 → 0.556893 Meter
DyQF1 → 0.1 Meter
betyQF1 → 27.7025 Meter
betxQF2 → 68.6604 Meter
DxQF2 → 0.468323 Meter
DyQF2 → 0.1 Meter
betyQF2 → 27.7025 Meter
betxQD1 → 17.3793 Meter
DxQD1 → 0.261443 Meter
DyQD1 → 0.1 Meter
betyQD1 → 103.326 Meter
betxQD2 → 17.7225 Meter
DxQD2 → 0.260766 Meter
DyQD2 → 0.1 Meter
betyQD2 → 103.326 Meter
I1 → 0.0108096 Meter
I2 → $\frac{0.000011668}{\text{Meter}}$
I3 → $\frac{4.44909\times10^{-9}}{\text{Meter}^3}$
I4 → 0
I5 → $\frac{1.5569\times10^{-11}}{\text{Meter}}$
I8 → $\frac{0.00163208}{\text{Meter}}$

alphac → 0.0000746189
DQ1 → 0.00537426
DQ2 → 0.00543496
Q1 → 0.500028
Q2 → 0.333333
EGeV → 60.
kappa → 0.5
Je → 1.5
Jx → 1.5
Jy → 1.
Jep → 279.754
U0 → 391.742 ElectronVolt Mega
Power → 39.1799 Mega Watt
taux → 0.0181572 Second
tauy → 0.0272358 Second
taue → 0.0181572 Second
Ex0 → 7.04931 Meter Nano
Ex → 4.69954 Meter Nano
Exc → 3.52466 Meter Nano
Eyc → 1.76233 Meter Nano
Polarizationtime → 68.8528 Minute
omegas → $\frac{1344.48}{\text{Second}}$
Qs → 0.11954
sigE → 0.00115886
sigL → 3.06879 Meter Milli
sigxQF1 → 0.875381 Meter Milli
sigxQD1 → 0.391218 Meter Milli
sigyQF1 → 0.249501 Meter Milli
sigyQD1 → 0.442181 Meter Milli
sigxQF2 → 0.732497 Meter Milli
sigxQD2 → 0.392156 Meter Milli
sigyQF2 → 0.249501 Meter Milli
sigyQD2 → 0.442181 Meter Milli
sigxmax → 0.875381 Meter Milli
sigymax → 0.442181 Meter Milli
dxmax → 0.556893 Meter
dymax → 0.1 Meter
15 sigxmax → 13.1307 Meter Milli
15 sigymax → 6.63272 Meter Milli
Dipole length → 5.35 Meter
Dipole Fillfactor → 0.750835

Complete Ring 6060

Ring with BP (60 GeV) :

Numb. of Part. per bunch → 1.97658×10^{10}
Numb. of Bunches → 2808
Rev. Frequ. → $\frac{11245.5}{\text{Second}}$
Circ → 26 658.9 Meter
I1 → 2.15833 Meter
I2 → $\frac{0.00239583}{\text{Meter}}$
I3 → $\frac{9.13546\times10^{-7}}{\text{Meter}^2}$
I4 → 0
I5 → $\frac{3.73513\times10^{-9}}{\text{Meter}}$
I8 → $\frac{0.372733}{\text{Meter}}$
d2Bydx2MSF1 → $\frac{95.0008\ \text{Tesla}}{\text{Meter}^2}$
d2Bydx2MSF2 → $\frac{93.843\ \text{Tesla}}{\text{Meter}^2}$
d2Bydx2MSF3 → $\frac{96.1749\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSD1 → $-\frac{86.7914\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSD2 → $-\frac{88.4025\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSF1 → $-\frac{88.4213\ \text{Tesla}}{\text{Meter}^2}$
ksf1 → $\frac{0.474675}{\text{Meter}^3}$
ksf2 → $\frac{0.46889}{\text{Meter}^3}$
ksf3 → $\frac{0.480542}{\text{Meter}^3}$
ksd1 → $-\frac{0.433656}{\text{Meter}^3}$
ksd2 → $-\frac{0.441706}{\text{Meter}^3}$
ksd3 → $-\frac{0.4418}{\text{Meter}^3}$

alphac → 0.0000807468
Q1 → 123.09
Q2 → 82.2287
Qs → 0.122529
DQ1 → 3.00012
DQ2 → 2.99993
EGeV → 60.
kappa → 0.5
Je → 1.5
Jx → 1.5
Jy → 1.
Jep → 311.152
U0 → 437.161 ElectronVolt Mega
Power → 43.7161 Mega Watt
taux → 0.0162731 Second
tauy → 0.0244096 Second
taue → 0.0162731 Second
tauxrev → 182.999
tauyrev → 274.498
tauerev → 183.026
Ex0 → 8.23629 Meter Nano
Ex → 5.49086 Meter Nano
Exc → 4.11814 Meter Nano
Eyc → 2.05907 Meter Nano
sigE → 0.00115886
sigL → 3.24027 Meter Milli
Polarizationtime → 61.7082 Minute

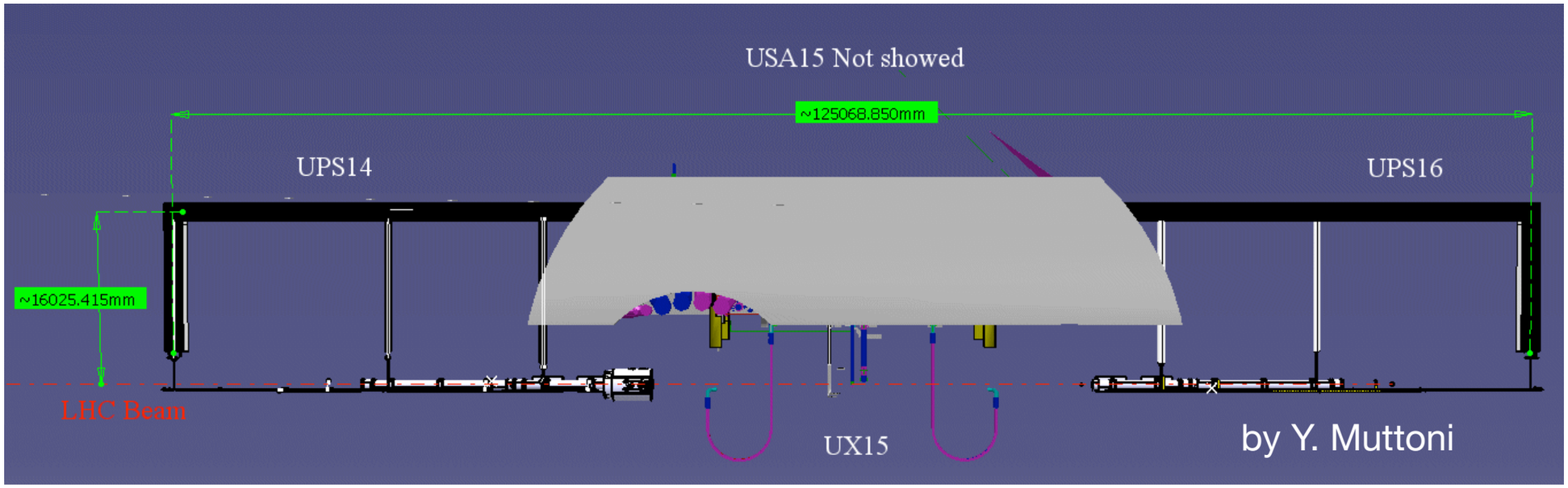
Ring with BP (10 GeV) :

Numb. of Part. per bunch → 1.97658×10^{10}
Numb. of Bunches → 2808
Rev. Frequ. → $\frac{11245.5}{\text{Second}}$
Circ → 26 658.9 Meter
I1 → 2.15833 Meter
I2 → $\frac{0.00239583}{\text{Meter}}$
I3 → $\frac{9.13546\times10^{-7}}{\text{Meter}^2}$
I4 → 0
I5 → $\frac{3.73513\times10^{-9}}{\text{Meter}}$
I8 → $\frac{0.372733}{\text{Meter}}$
d2Bydx2MSF1 → $\frac{15.8335\ \text{Tesla}}{\text{Meter}^2}$
d2Bydx2MSF2 → $\frac{15.6405\ \text{Tesla}}{\text{Meter}^2}$
d2Bydx2MSF3 → $\frac{16.0292\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSD1 → $-\frac{14.4652\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSD2 → $-\frac{14.7337\ \text{Tesla}}{\text{Meter}^2}$
d2Bydy2MSF1 → $-\frac{14.7369\ \text{Tesla}}{\text{Meter}^2}$
ksf1 → $\frac{0.474675}{\text{Meter}^3}$
ksf2 → $\frac{0.46889}{\text{Meter}^3}$
ksf3 → $\frac{0.480542}{\text{Meter}^3}$
ksd1 → $-\frac{0.433656}{\text{Meter}^3}$
ksd2 → $-\frac{0.441706}{\text{Meter}^3}$
ksd3 → $-\frac{0.4418}{\text{Meter}^3}$

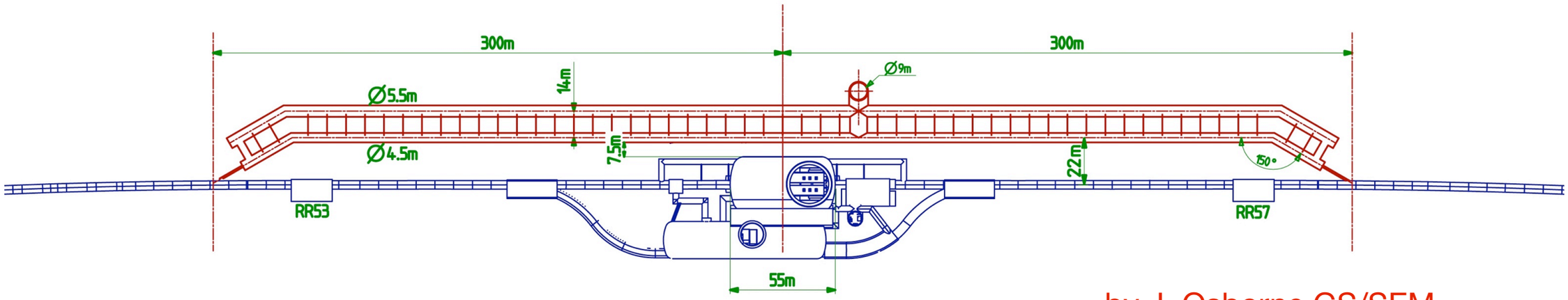
alphac → 0.0000807468
Q1 → 123.09
Q2 → 82.2287
Qs → 0.32102
DQ1 → 3.00012
DQ2 → 2.99993
EGeV → 10.
kappa → 0.5
Je → 1.5
Jx → 1.5
Jy → 1.
Jep → 311.152
U0 → 0.337316 ElectronVolt Mega
Power → 0.0337316 Mega Watt
taux → 3.51498 Second
tauy → 5.27248 Second
taue → 3.51498 Second
tauxrev → 39 527.8
tauyrev → 59 291.6
tauerev → 39 533.5
Ex0 → 0.228786 Meter Nano
Ex → 0.152524 Meter Nano
Exc → 0.114393 Meter Nano
Eyc → 0.0571965 Meter Nano
sigE → 0.000193144
sigL → 0.206128 Meter Milli
Polarizationtime → 479 843. Minute

Bypasses Point 1 and Point 5

ATLAS: **Bypass using the Survey Gallery** **Δ =16.25 Meter**



CMS: **Experimental hall is fully bypassed** **Δ =20.56 Meter**



by J. Osborne GS/SEM