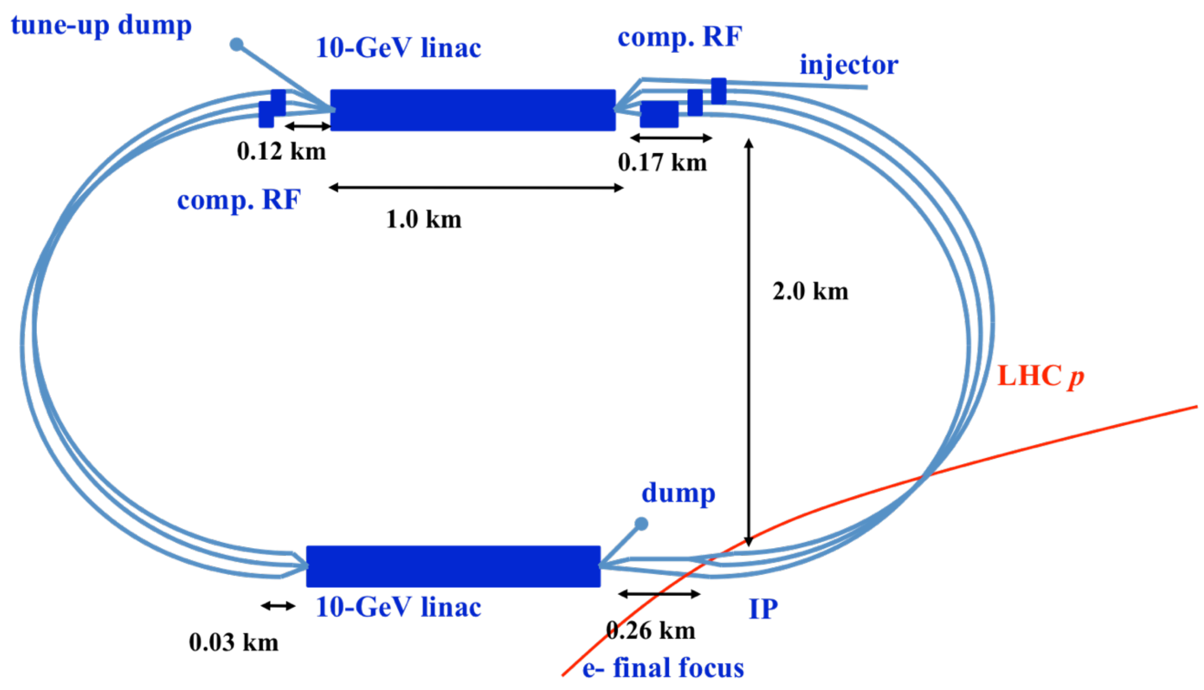
RING-RING DESIGN

Miriam Fitterer, CERN - KIT
for the LHeC study group

LHeC Design Options

LHeC Design Options

Linac-Ring



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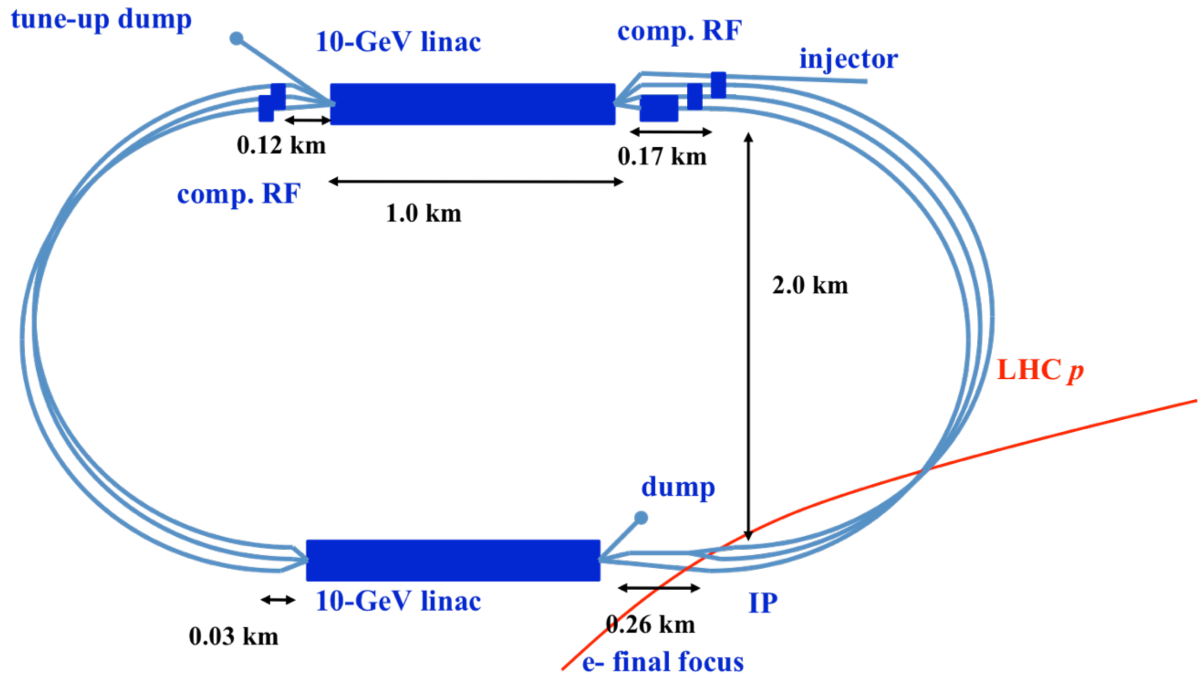
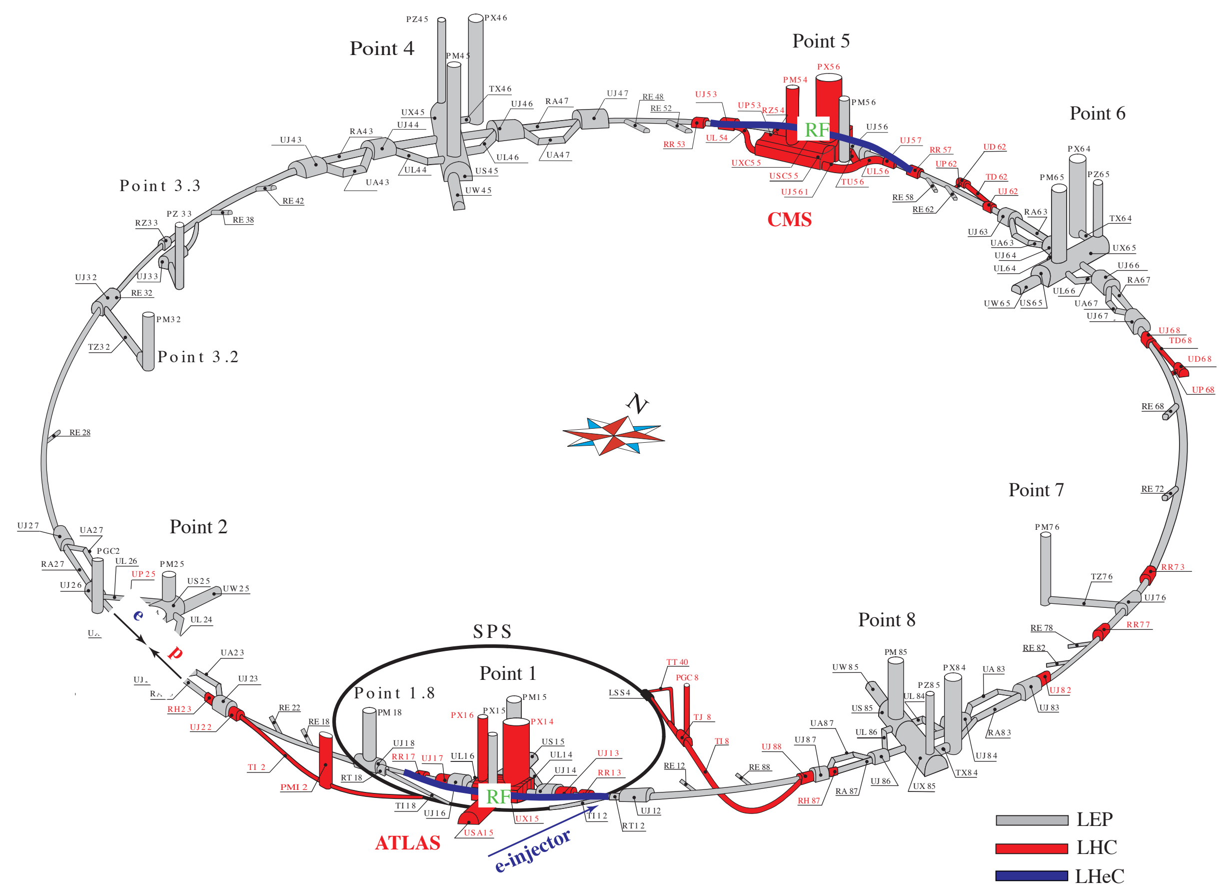


Ring-Ring



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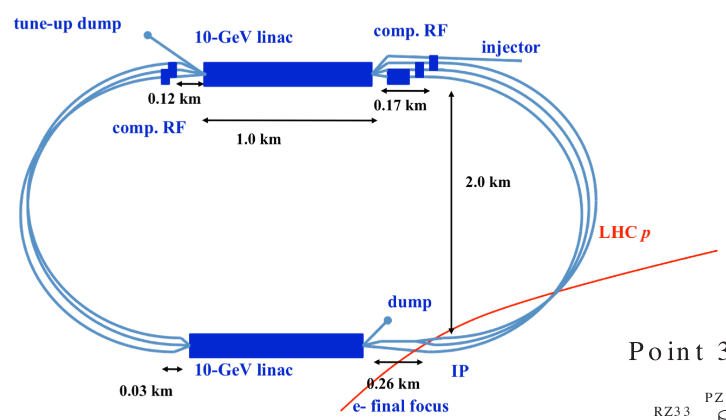

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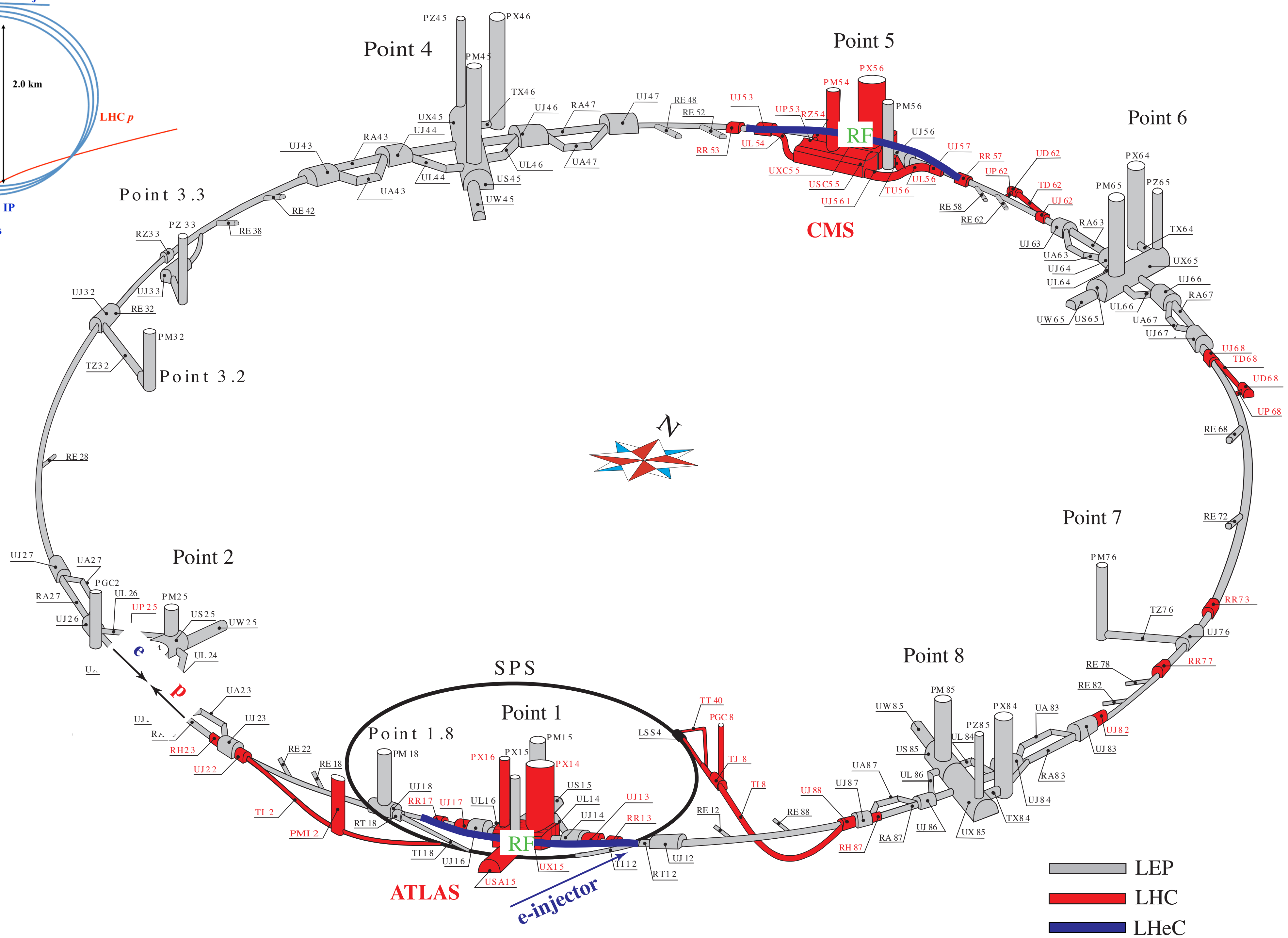

General Layout

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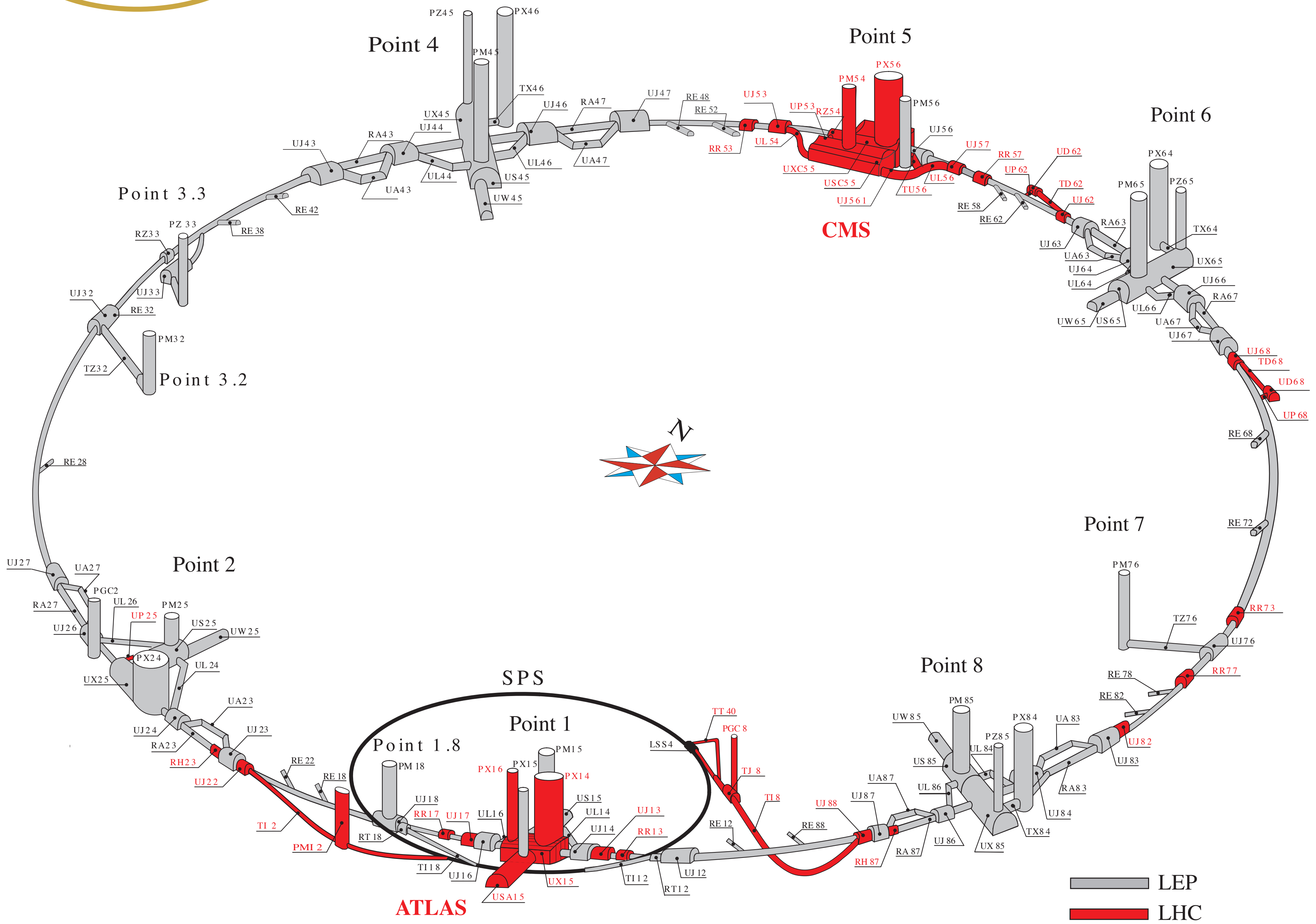

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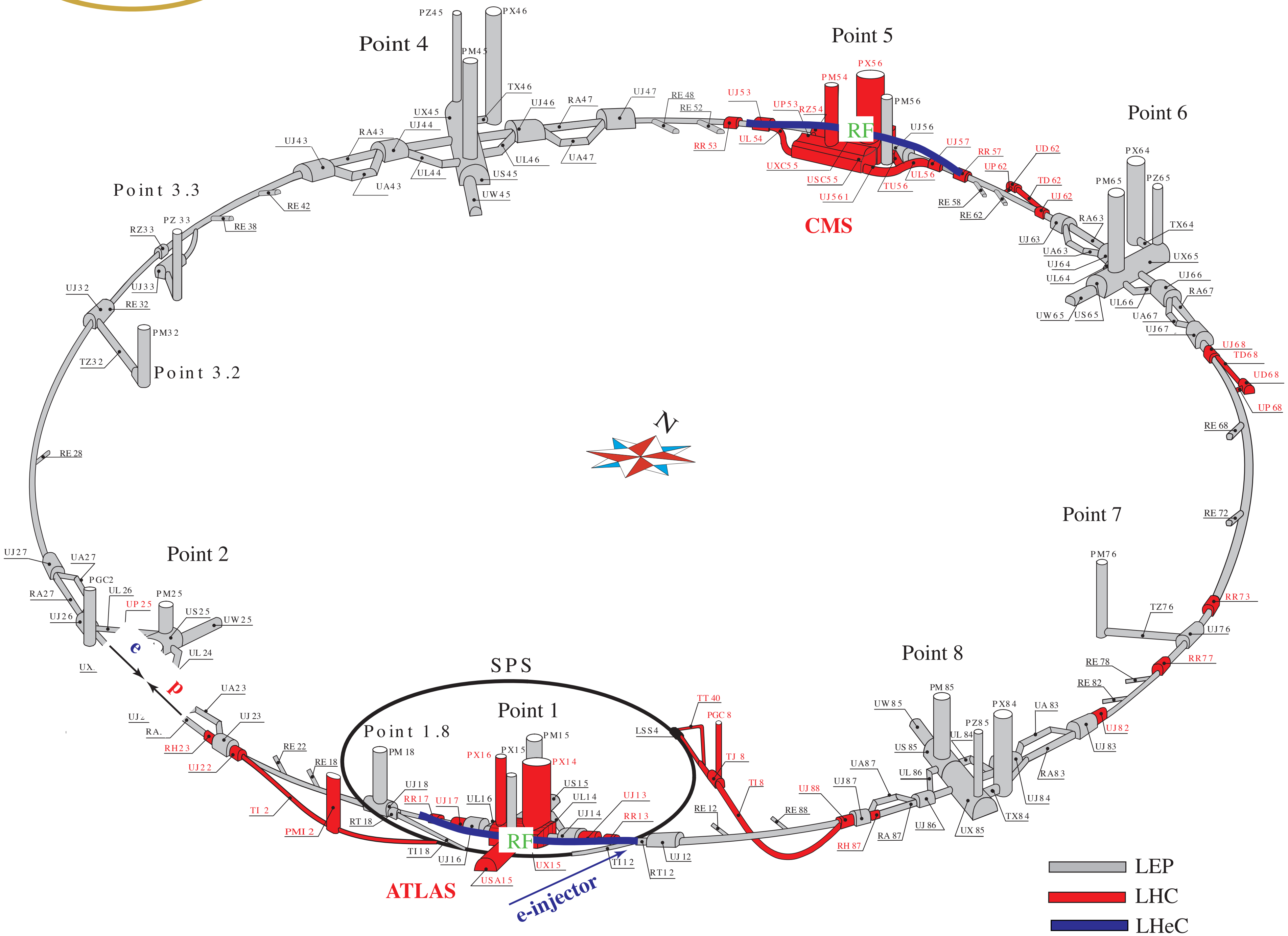
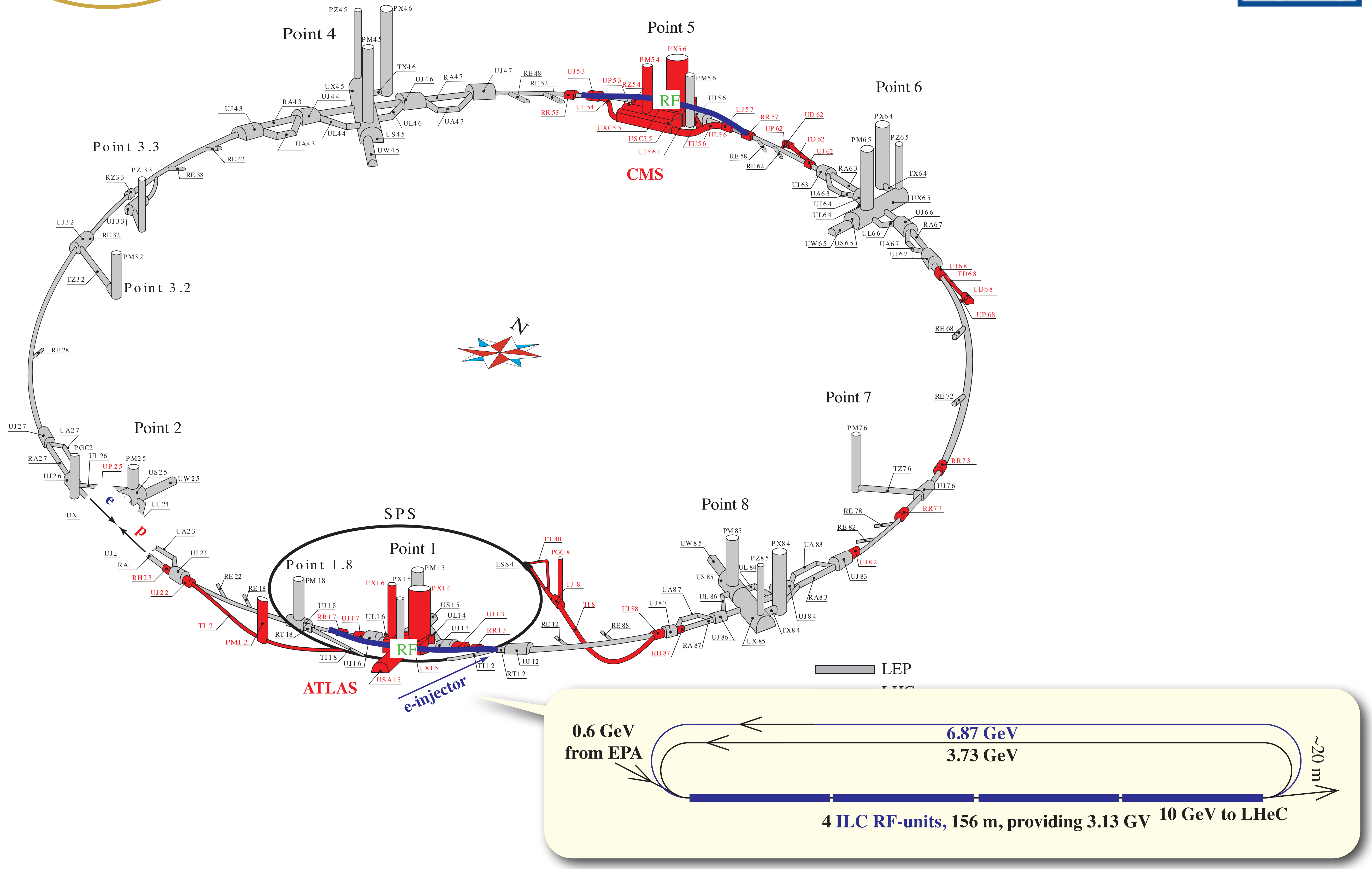


Miriam Fitterer - LHeC Ring-Ring Design

DIS 2011, Newport News 12.04.2011

General Layout



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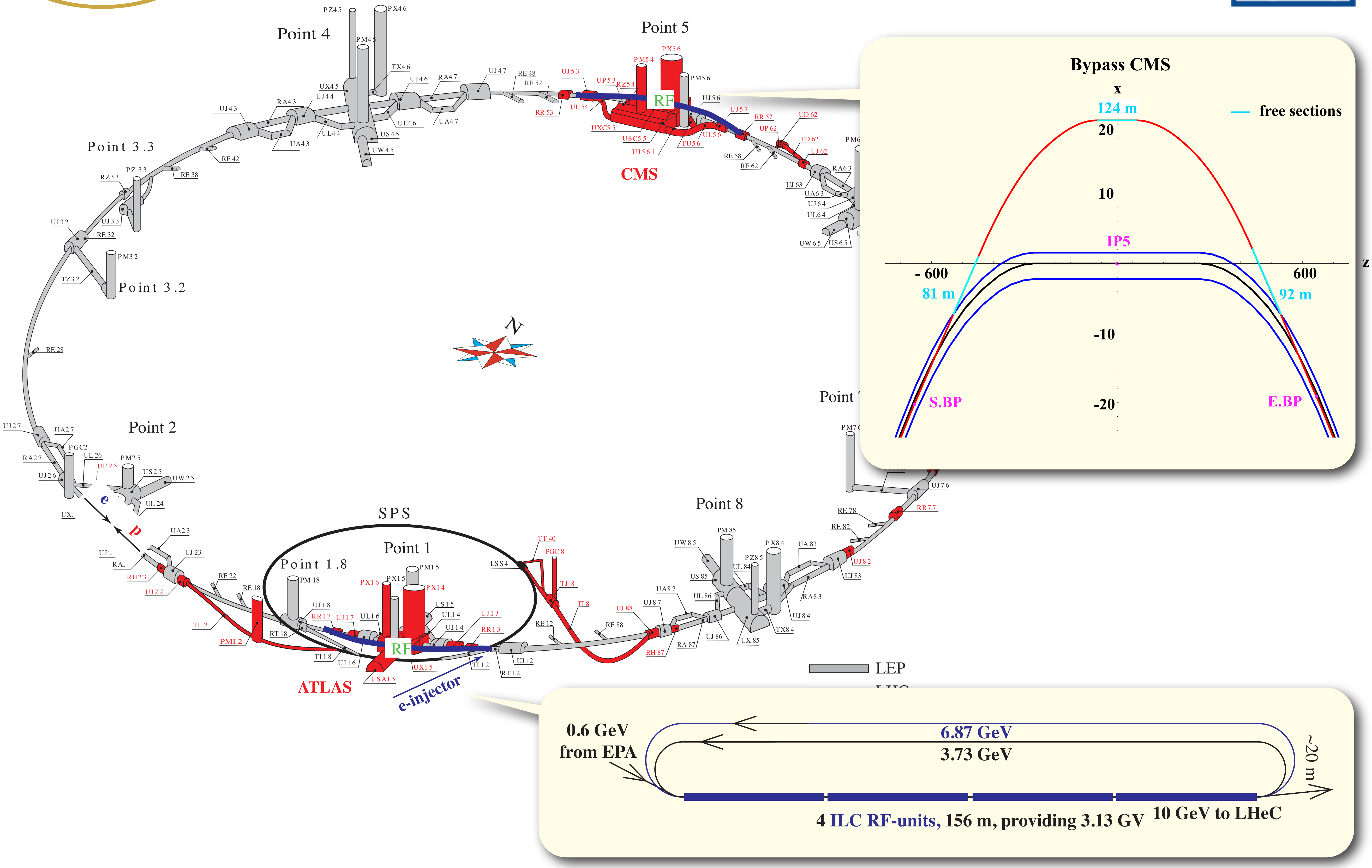

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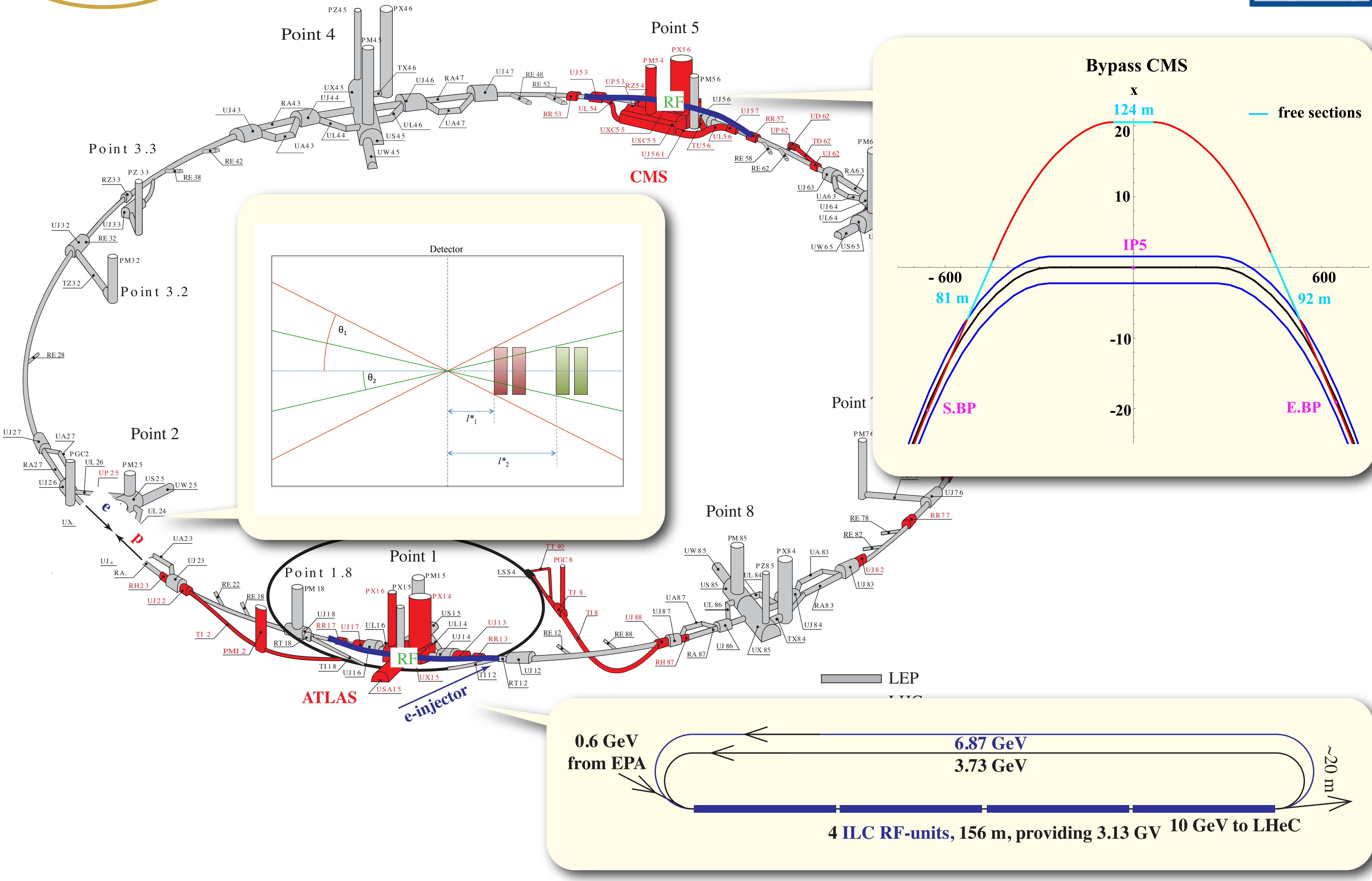
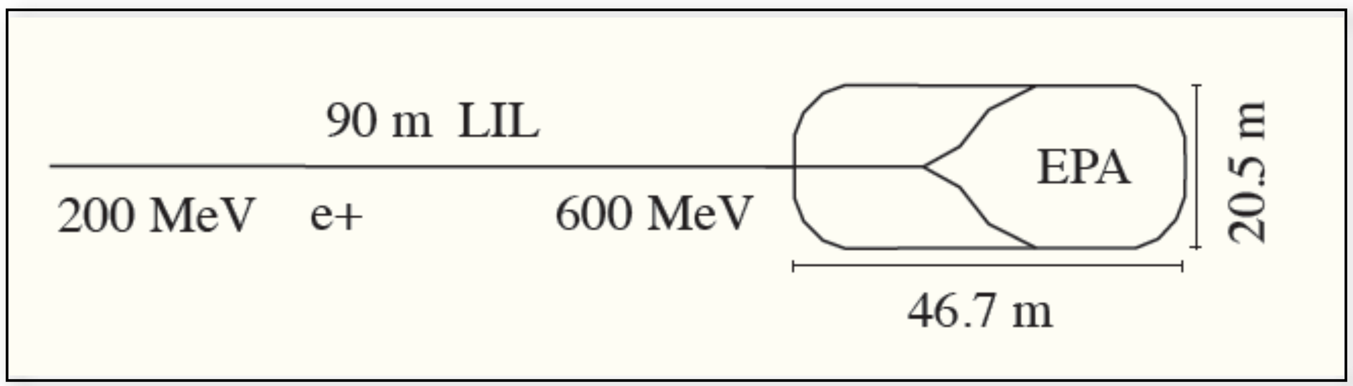


Injector

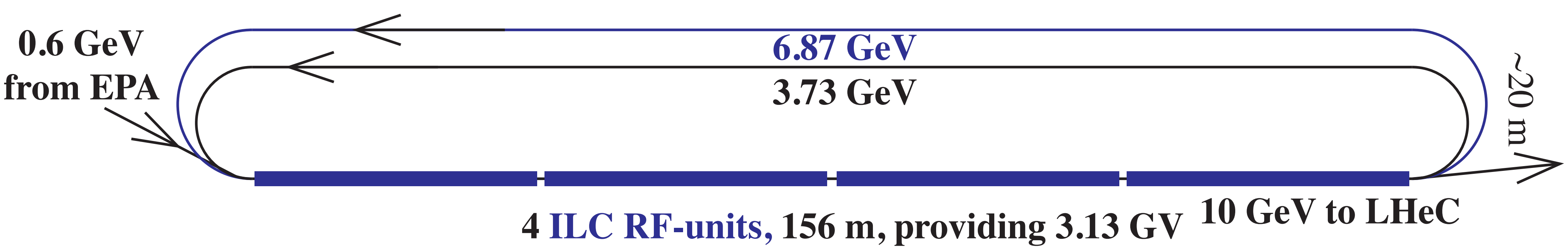
LHeC requires new 10 GeV e+/e- injector

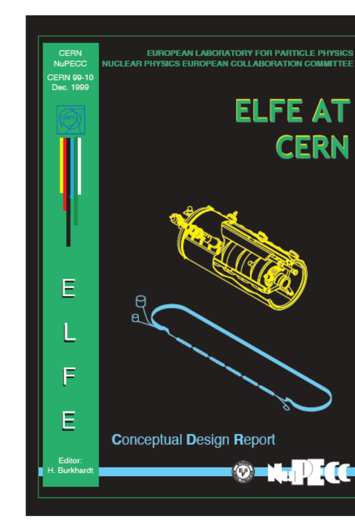
Pre-injector: e.g. **LIL+EPA** type e+/e- Injector (LEP) - 0.6 GeV at extraction



Total filling time less than 10 minutes

Injector: simplified and down scaled **ELFE** design:





Recirculating linac

Main Ring Design Parameters

	Electrons	**Protons**
Energy	60 GeV	7 TeV
Current	100 mA	860 mA
Part. per bunch	2×10^{10}	1.7×10^{11}
Numb. of bunches	2808	2808
$\varepsilon_x / \varepsilon_y$	5.0 / 2.5 nm	0.5 / 0.5 nm
P_γ	< 50 MW	

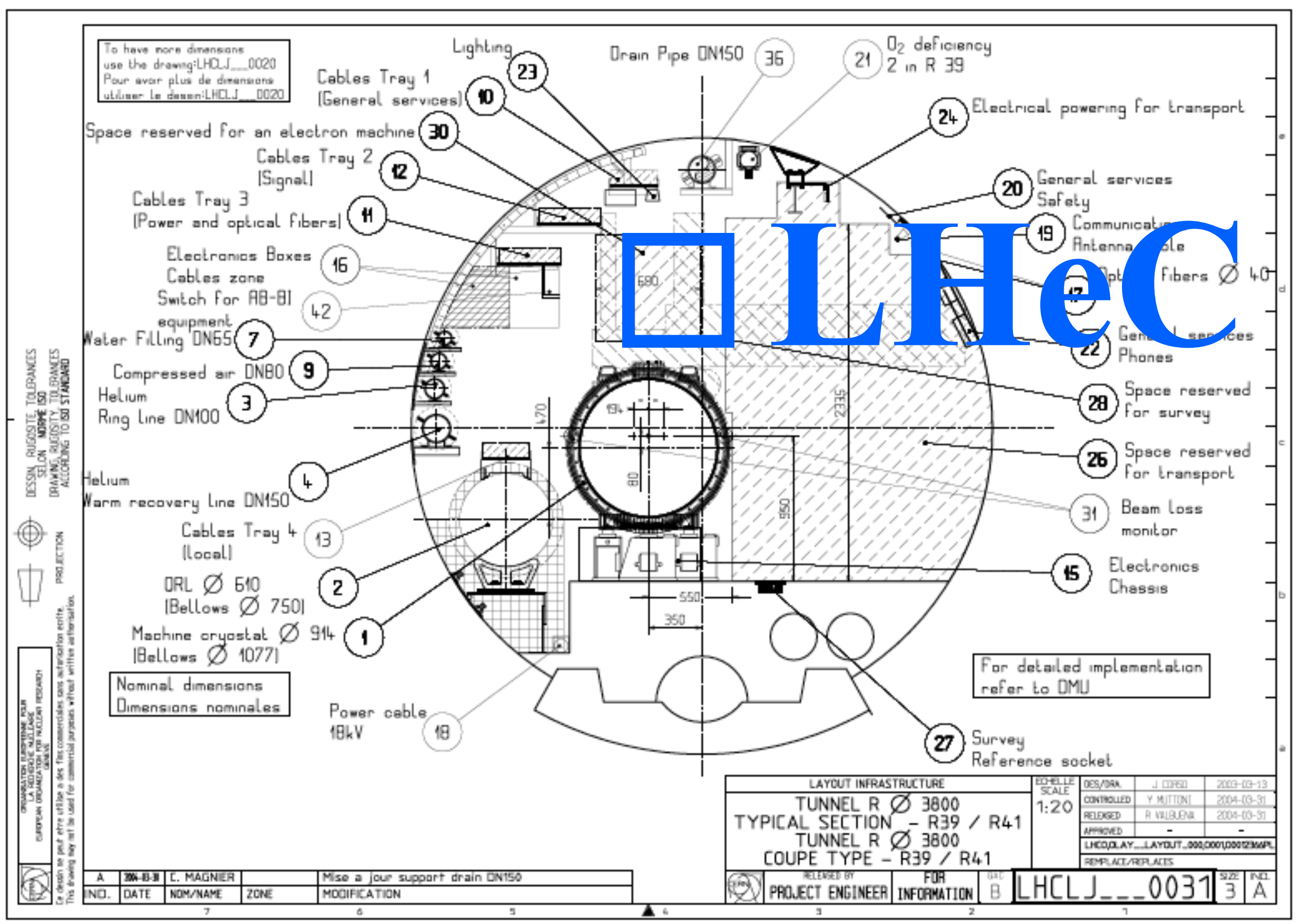
Main Ring - Integration I

p-ring and e-ring have to fit into the existing LHC tunnel

Match e-ring and p-ring circumference, because:

p-beam could be “heated” up by the e-beam in the case of asymmetric collision schemes [*]

[*] K. Hirata and E. Keil, “Barycenter motion of beams due to beam-beam interaction in asymmetric ring colliders,” Proc. EPAC 1990



Typical cross section of the LHC tunnel

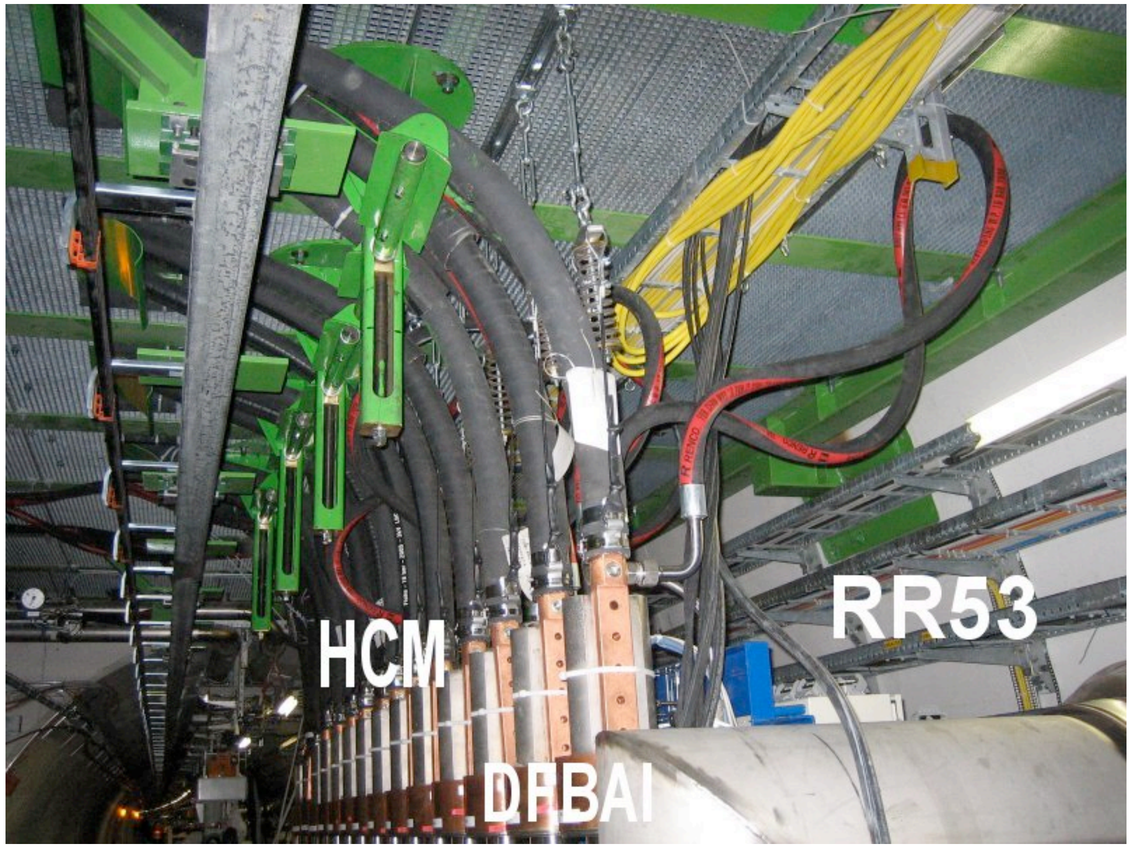
Bypasses increase the circumference

- compensation by placing the ring more on the inside in respect to the LHC

Main Ring - Integration II

Main Challenges:

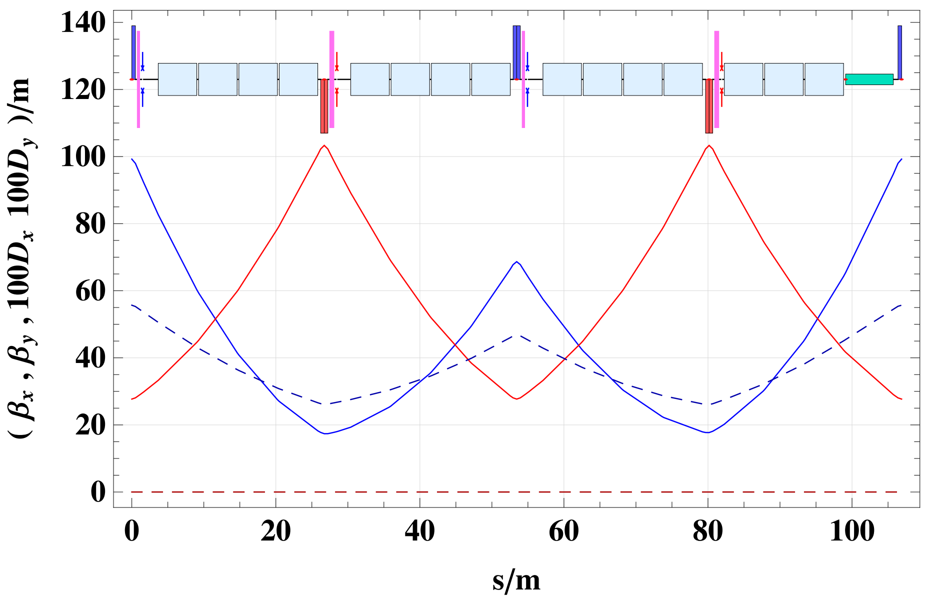
1. QRL jumper connection at every second proton quadrupole in the main arc and around 8 per straight section

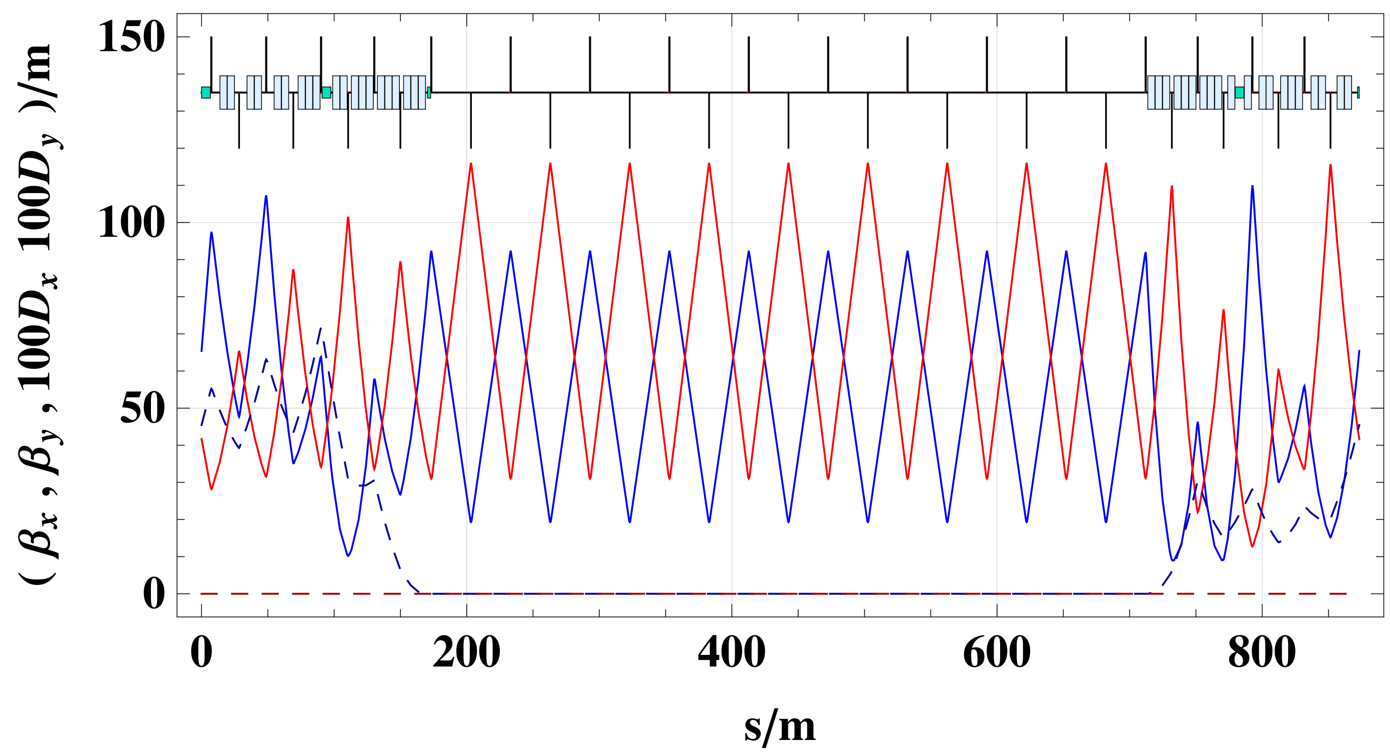


QRL jumper connection

2. Insertions, especially Dump Area, Collimation, RF, Cryogenics ...

Main Ring - Optics





Main Arc:

- $2\,L_{\text{FODO, LHeC}} \approx L_{\text{FODO, LHC}}$
- FODO lattice with no elements at positions of QRL jumper connection
  - → main integration interferences avoided

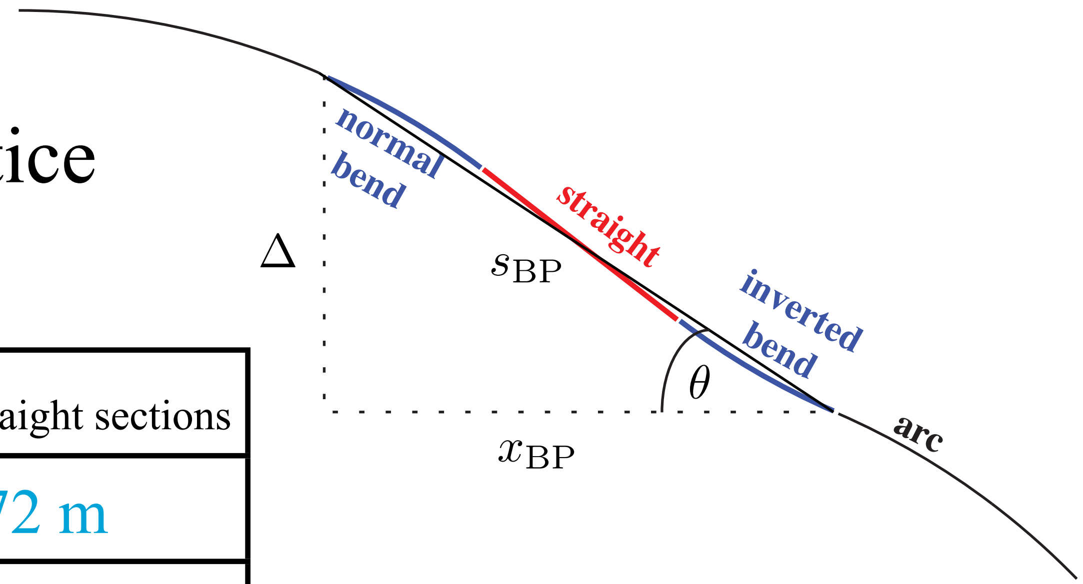
Insertions

- similar design for even and odd insertions
- exemplarily avoiding QRL jumper connections in insertions
  - → detailed design for each insertions at a later stage, but no real show stoppers

Bypass Layout

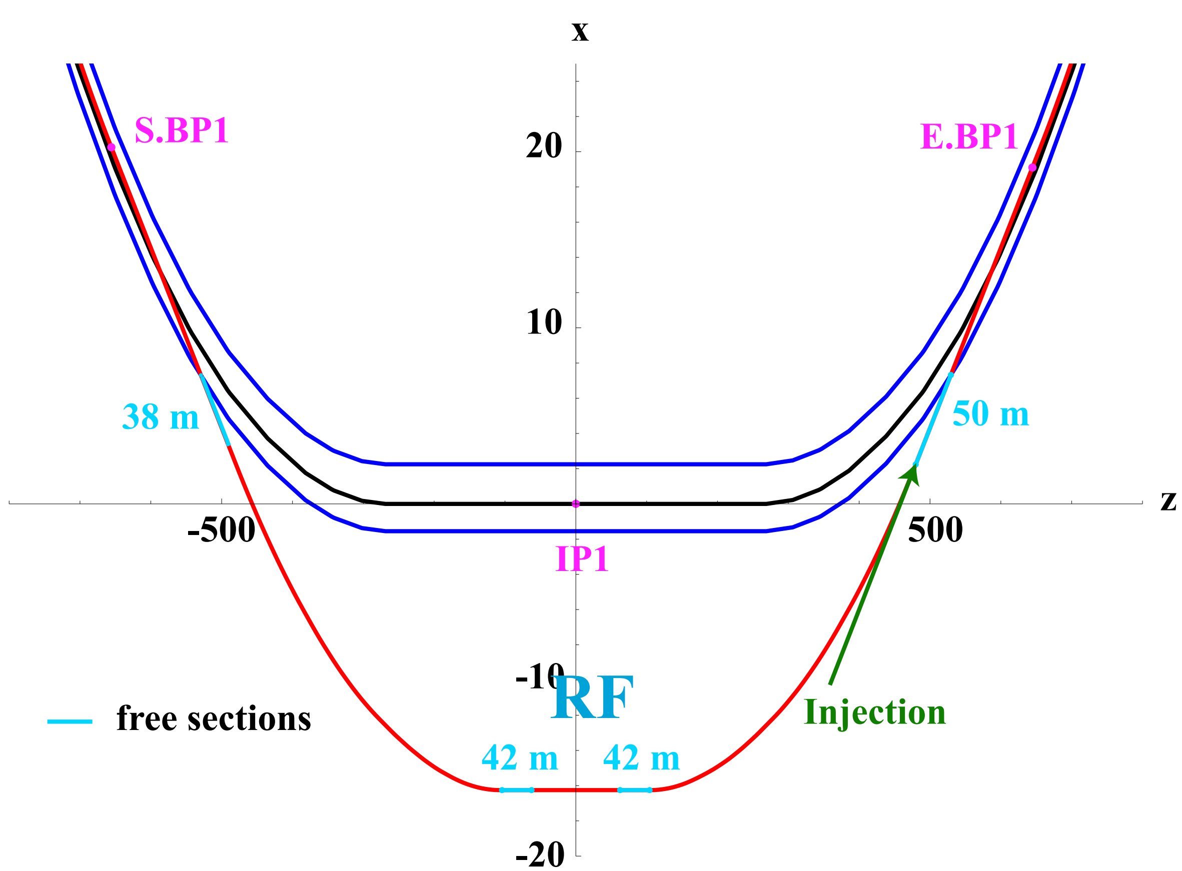
General Design:

Insertion of a straight section into the lattice leads to a separation Δ

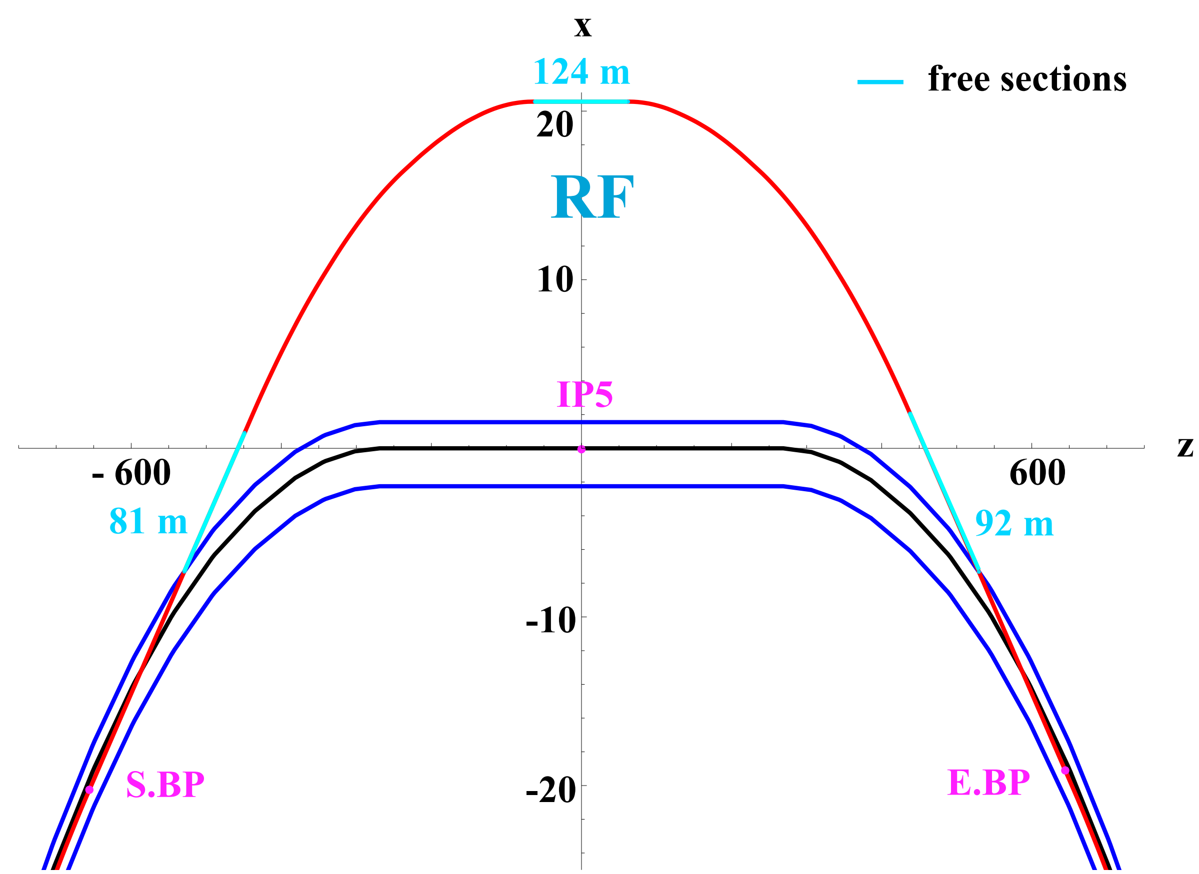


	Δ_{BP}	L_{BP}	$L_{\text{new tunnel}}$	$L_{\text{tot, straight sections}}$
ATLAS	16.25 m	1303.3 m	≈1061 m	172 m
CMS	20.56 m	1303.3 m	≈1061 m	297 m

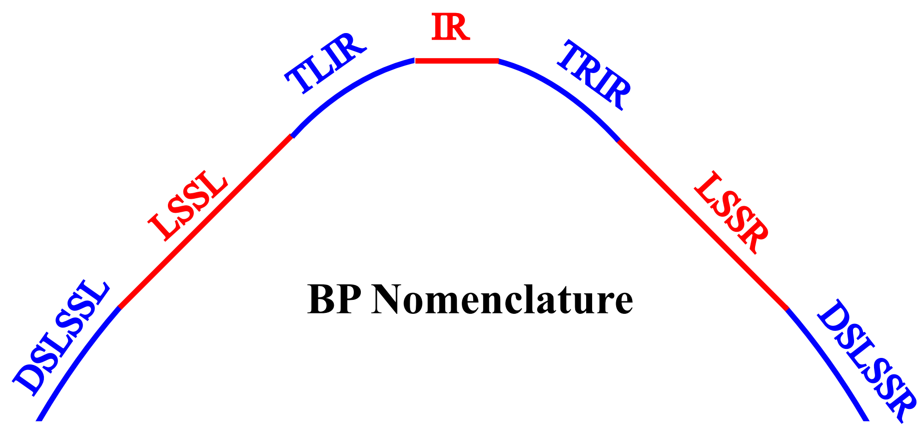
Bypass ATLAS



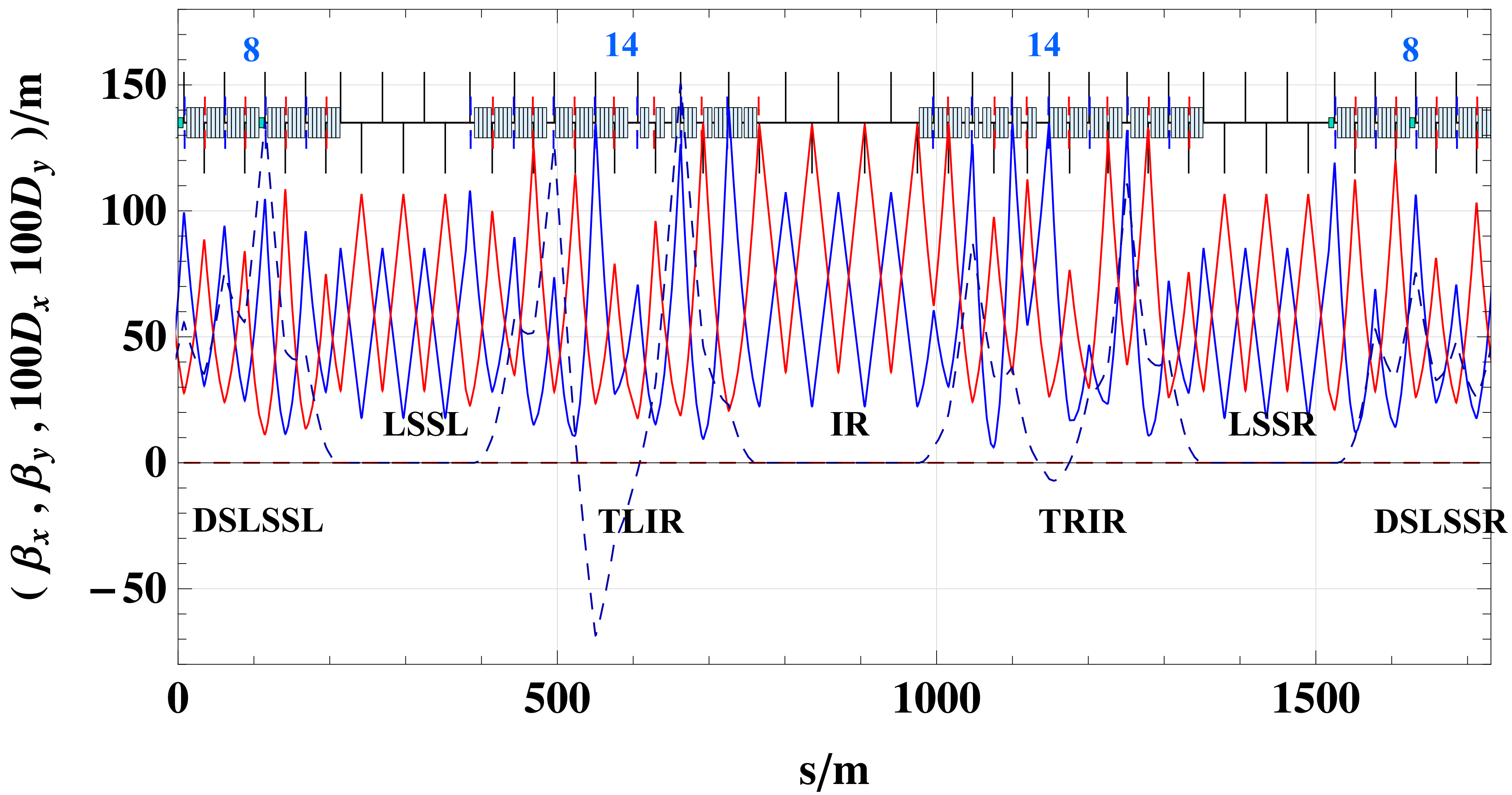
Bypass CMS



Bypass Optics

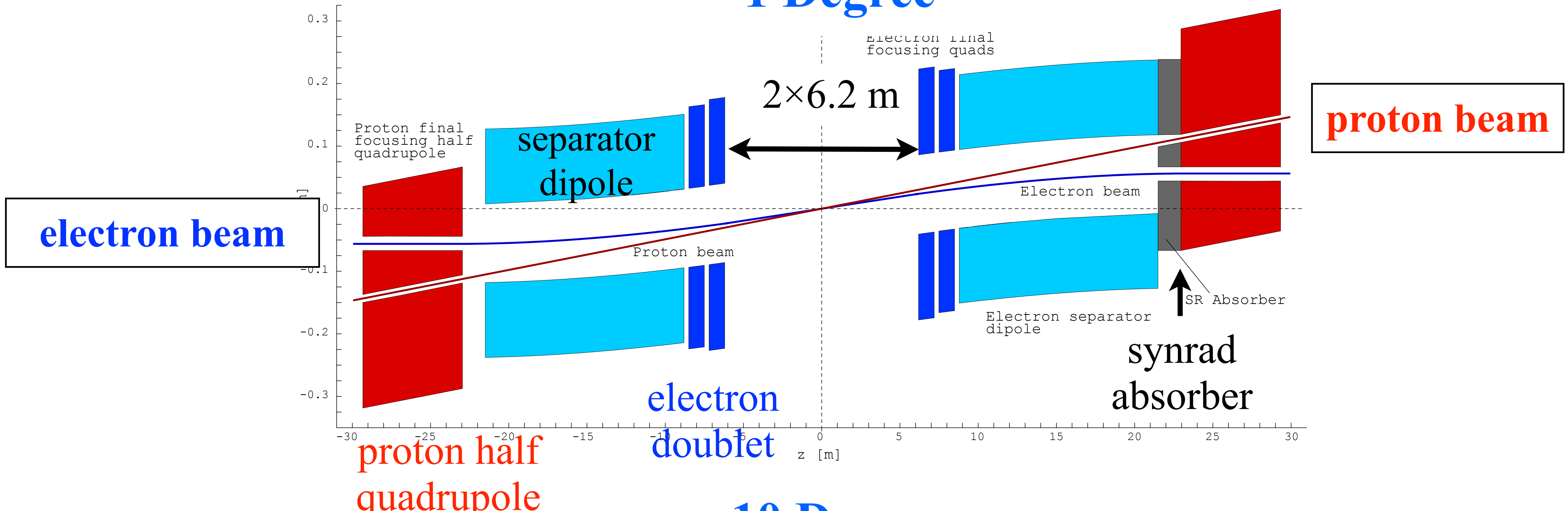


$\beta_{x,\,\mathrm{max}}$	142
$\beta_{y,\,\mathrm{max}}$	138

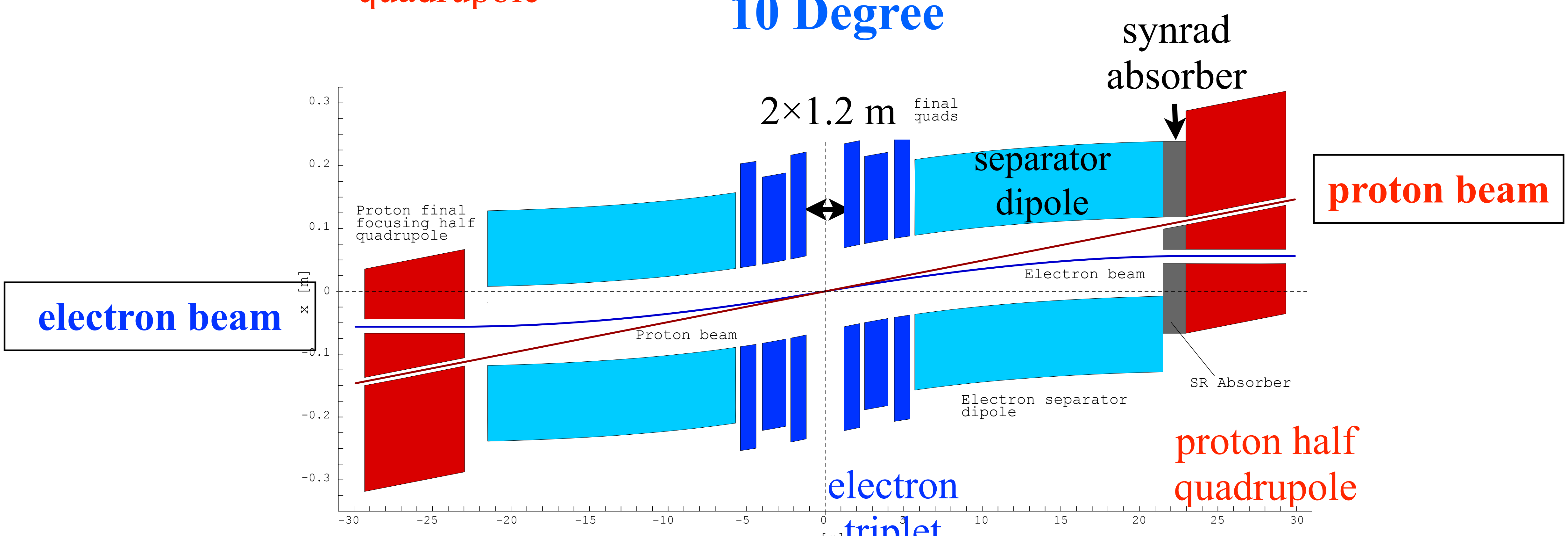


Interaction Region

1 Degree



10 Degree



Parameters

Reminder:

Beamsize: $\sigma = \sqrt{\beta\epsilon}$ **Beta-function (drift space)** $\beta(s) = \beta^* + \frac{{l^*}^2}{\beta^*}$

High Acceptance (1 Degree)

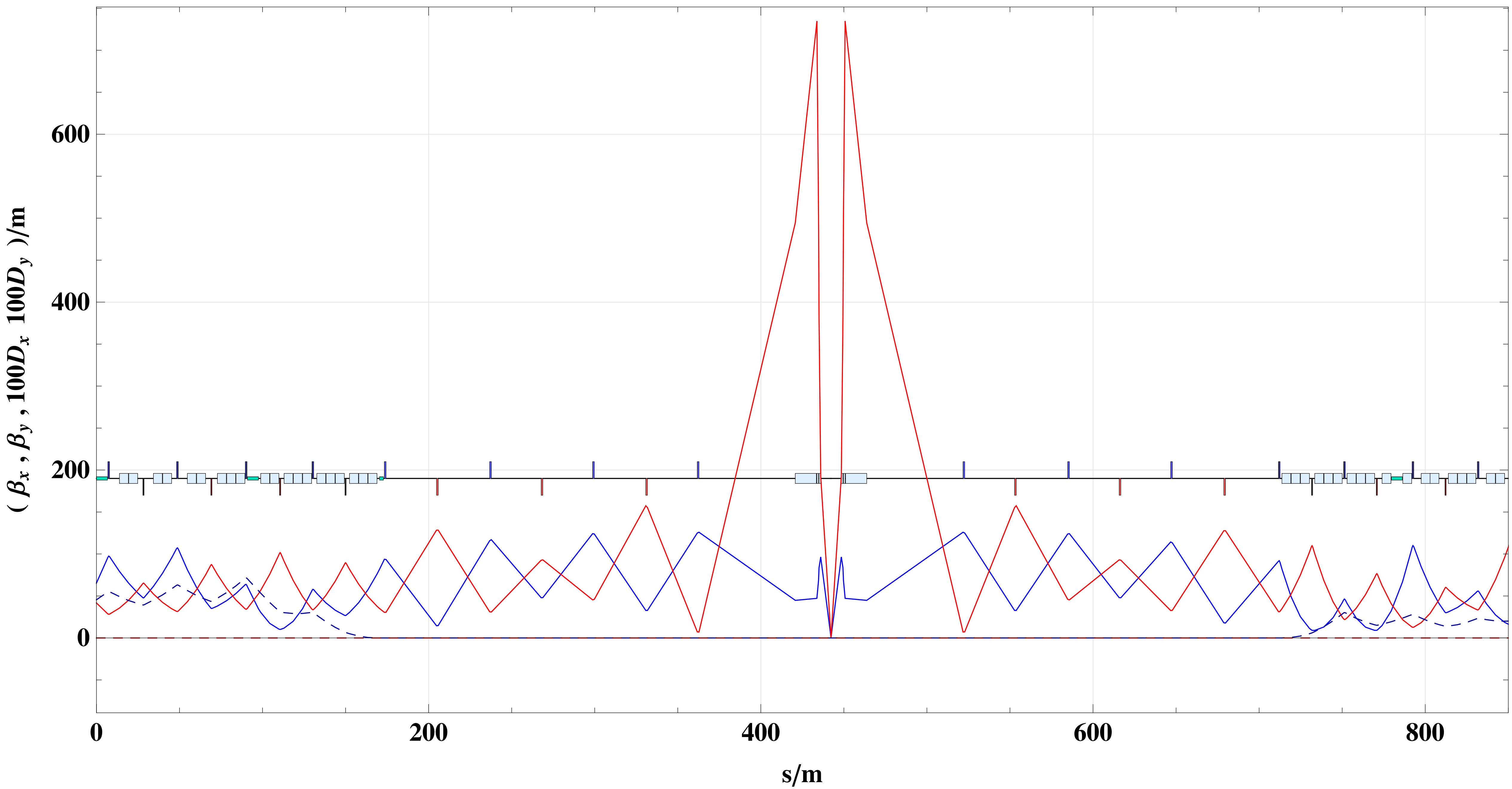
	Electrons	Protons
β_x	0.4 m	4.05 m
β_y	0.2 m	0.97 m
l*	6 m	22.96 m
σ_x	45 µm	
σ_y	22 µm	
Crossing angle	1 mrad	
Luminosity	$8.54\ 10^{32}$ cm^{-2} s^{-1}	
Luminosity loss factor	86%	
Luminosity	$7.33\ 10^{32}$ cm^{-2} s^{-1}	
P_γ	51 kW	
E_c	163 keV	

High Luminosity (10 Degree)

	Electrons	Protons
β_x	0.18 m	1.8 m
β_y	0.1 m	0.5 m
l*	1.2 m	22.96 m
σ_x	30 µm	
σ_y	15.8 µm	
Crossing angle	1 mrad	
Luminosity	$1.8\ 10^{33}$ cm^{-2} s^{-1}	
Luminosity loss factor	75%	
Luminosity	$1.34\ 10^{33}$ cm^{-2} s^{-1}	
P_γ	33 kW	
E_c	126 keV	

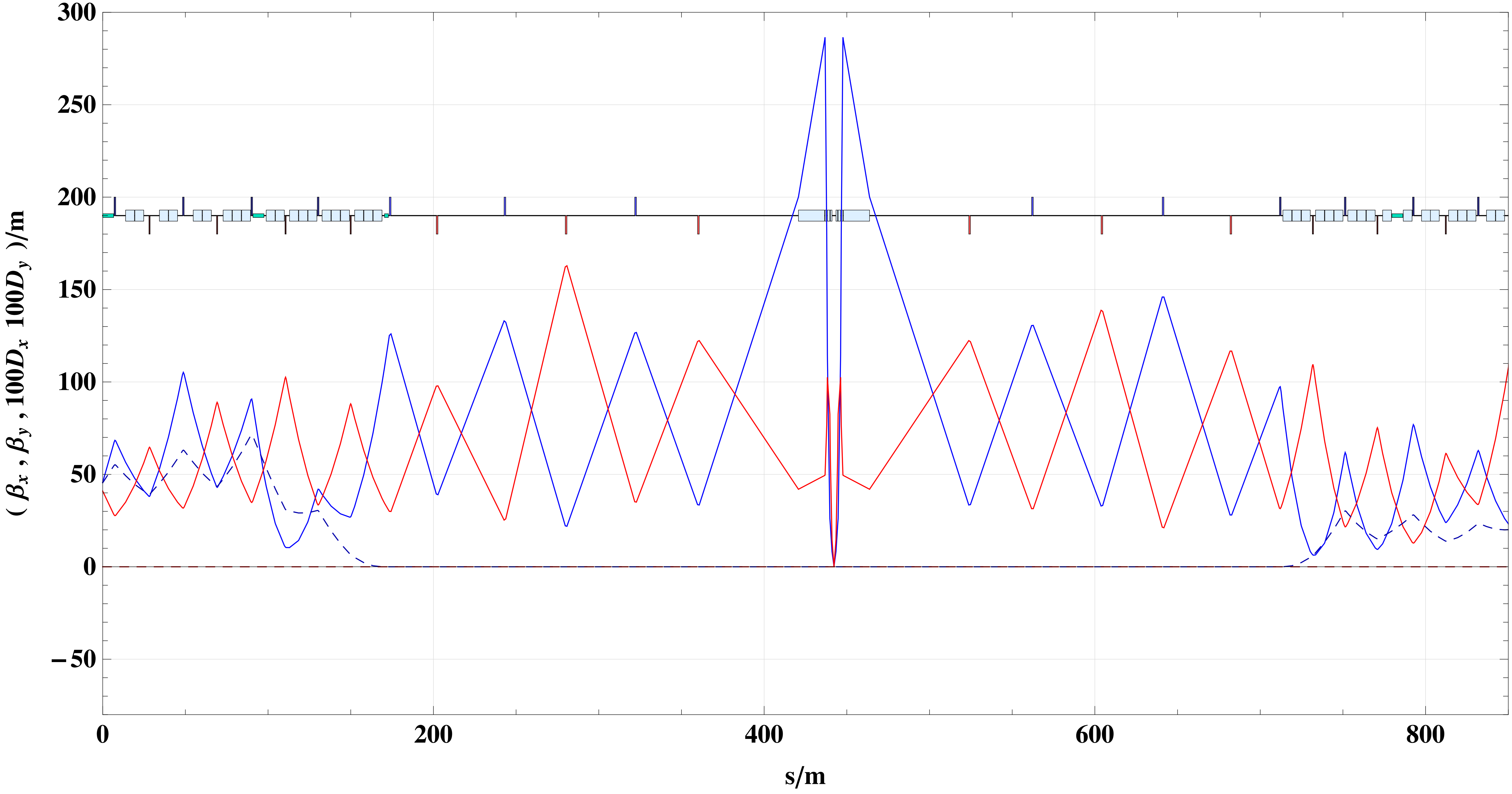
IR Optics - Electrons

1 Degree



IR Optics - Electrons

10 Degree



e-A Collisions

- Assume present **nominal Pb beam in LHC**:
  same beam size as protons, fewer bunches (592 bunches, $N_b=7\times10^7$ $^{208}Pb^{82+}$ nuclei)
- Assume e-injector chain can provide the desired bunch pattern (592 bunches of $N_b=6\times10^{10}$ e^-)

➡ **Lepton-nucleus and lepton-nucleon luminosity at 60 GeV and 45 MW synchrotron radiation losses**

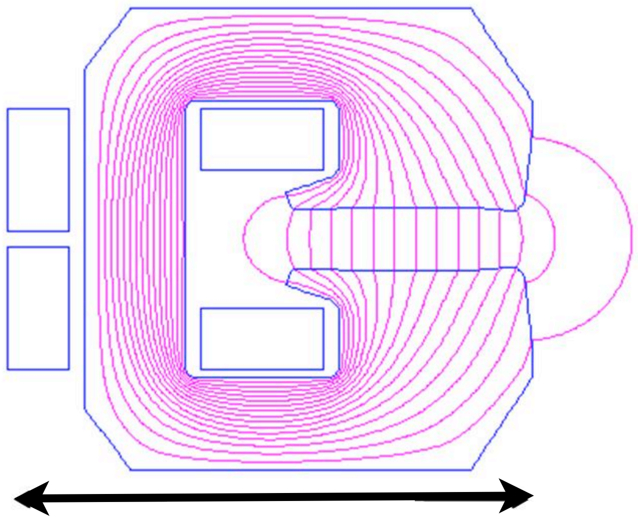
$$L=5\times10^{29}\ cm^{-2}s^{-1} \Leftrightarrow L_{en}=1\times10^{31}\ cm^{-2}s^{-1}$$

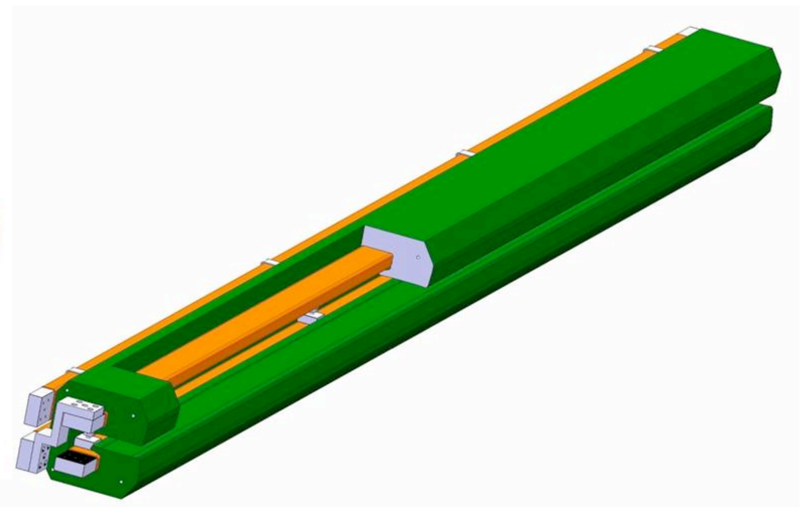
Main Ring NC Magnet Design

Dipole

Challenge:

- Field reproducibility at injection (10 GeV)
- Constant field quality during the ramp
- Compactness
- Compatibility with synchrotron radiation power





Beam Energy	10-60 GeV
Number of magnets	3080
Magnetic length	5.35 m
Magnetic field	127 -763 Gauss
Vertical aperture	40 mm
Pole width	150 mm
Conductor material	copper/aluminium
Total power consumption of all dipoles at 60 GeV	0.8 MW
Cooling	air or water (depending on tunnel ventilation)
Field reproducibility	<0.1 Gauss

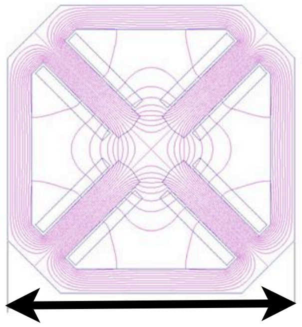
Models by BINP (silicon steel iron lamination) and CERN (interleaved iron plastic laminations plastic: iron=2:1) achieving required field reproducibility.

Main Ring NC Magnet Design

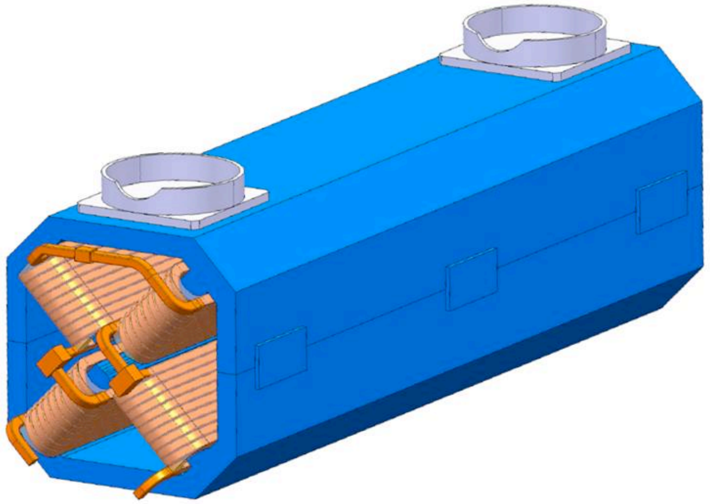
Quadrupole

Challenge: Compactness

Arc quadrupole:

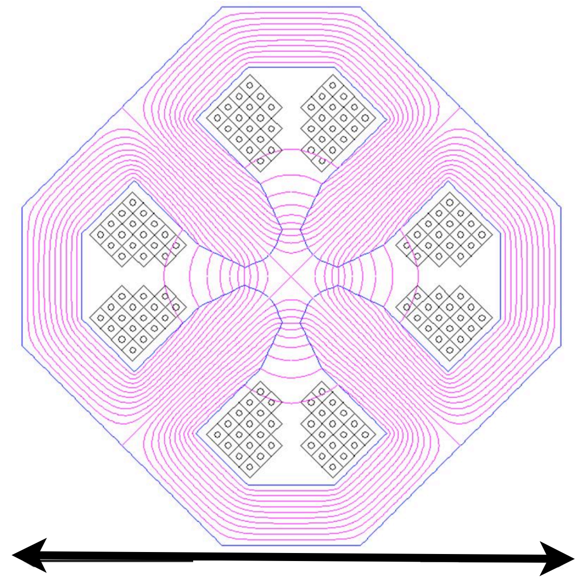


30 cm



Number of magnets	368 (QF) + 368 (QD)
Magnetic length	1.0 m
Magnetic field	8.4 (QD) 10.28 T/m (QF)
Radial aperture	30 mm
Weight	700 kg
Conductor material	copper
Total power (60 GeV)	2.5 kW
Cooling	water

Insertion/bypass quadrupoles:

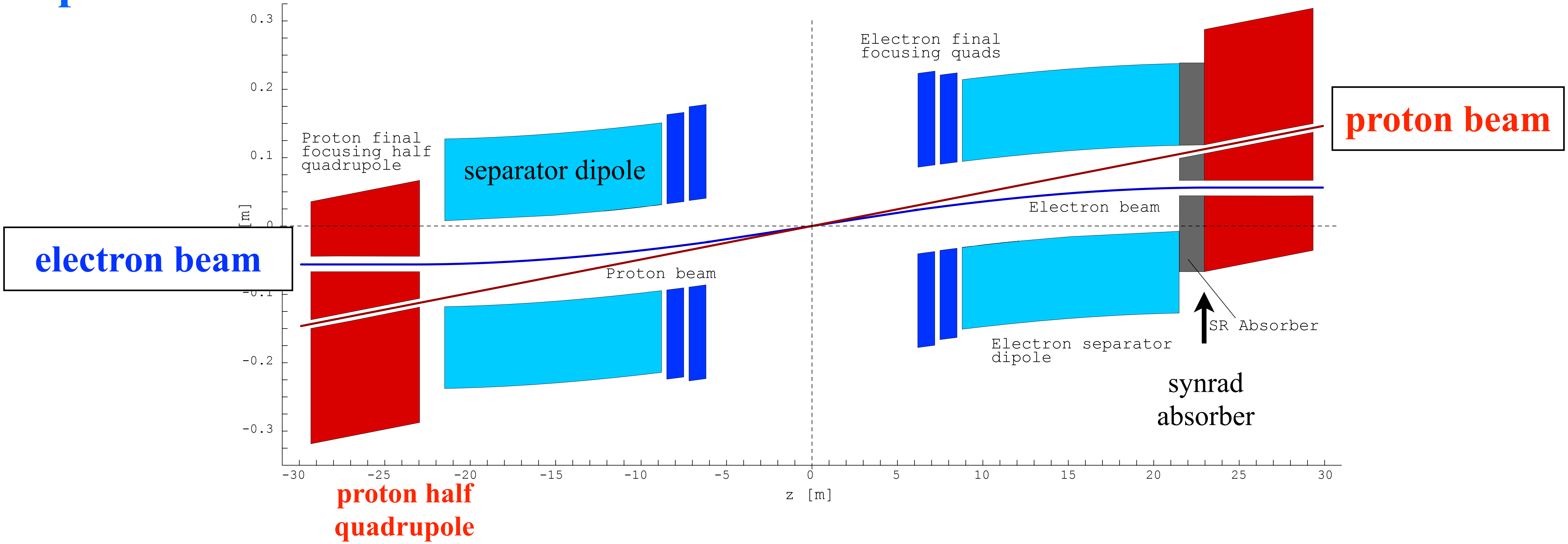


35 cm

Number of magnets	148 (QF) + 148 (QD)
Magnetic length	1.0 m (QF) / 0.7 m (QD)
Magnetic field	approx. 18 T/m
Radial aperture	30 mm
Weight	700 kg (QF) / 500 kg (QD)
Conductor material	copper
Total power (60 GeV)	6.0 kW (QF) / 4.5 kW (QD)
Cooling	water

Proton SC IR Magnets

Separation Scheme:



Magnet Design:

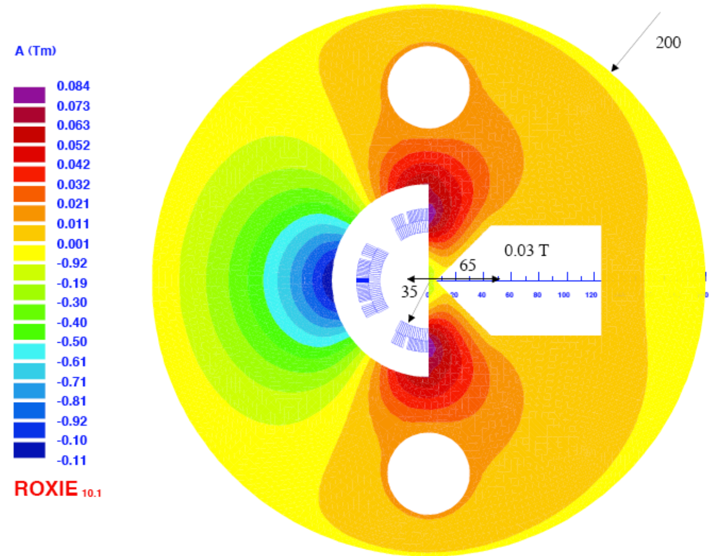
- similar to LHC MQXA magnets, no real challenges in respect of gradient
- **Challenge:**
  - field free region for electron
  - allow for a minimal distance between electron and proton beam

LHeC

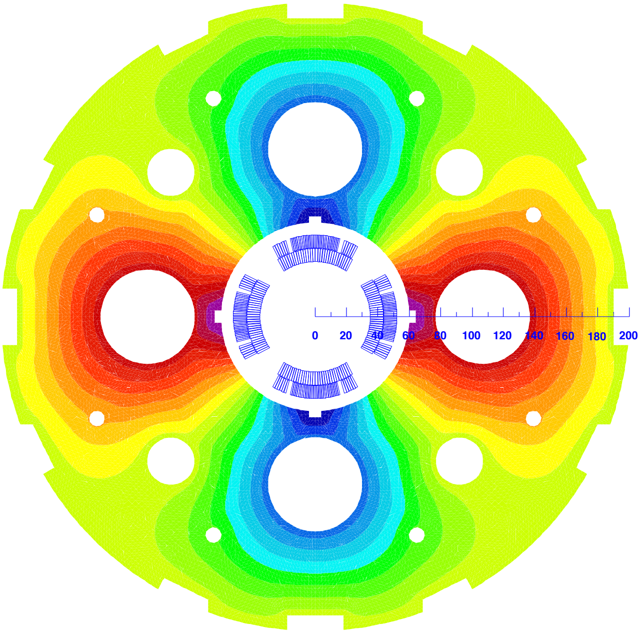
Proton SC IR Magnets

Proton SC magnet design

Q1: Half Quadrupole with field free regions for the e-beam



Q2: Single aperture



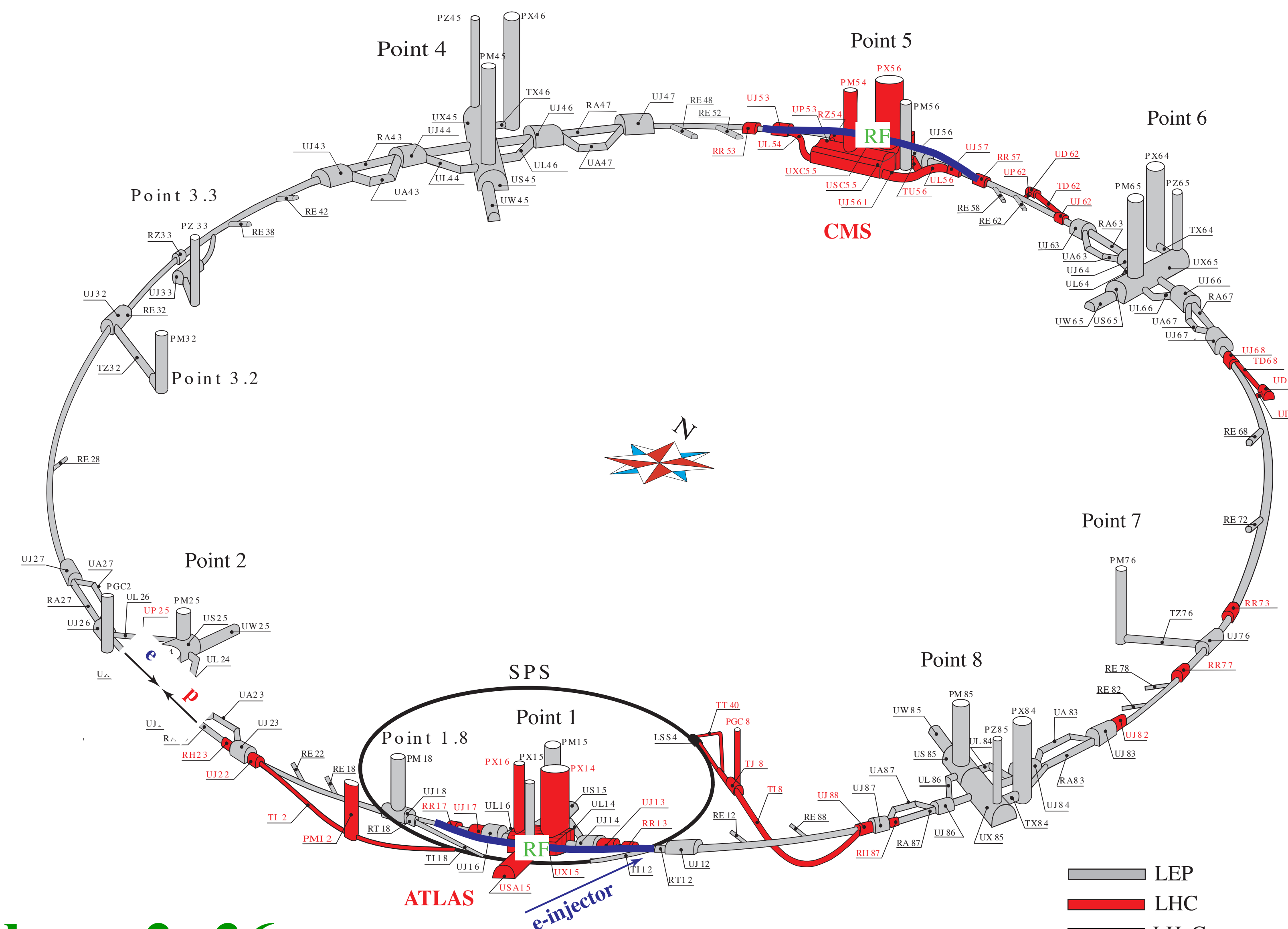
	Q1	Q2
Radial aperture	35 mm	36 mm
B_0	137 T/m	137 T/m
g_0	2.5 T	-
Beam separation	65 mm	107 mm
operation percentage on the load line of the sc	77%	73%
B_{fringe} e-aperture	0.03 T	0.016 T
g_{fringe} e-aperture	0.8 T/m	0.5 T/m

Main Ring RF

SPL type cavities:

- 120 cavities
- 721.4 MHz
- in total 500 MV
- 9.8 MV/m (conservative assumpt., SPL assumes 25 MV/m)
- 8 double cell cavities in 12 m cryomodules, 15 cryomodules total ->180 m + space for quads etc.
- feed two cavities with one 1 MW klystron

9 cryomodules = 108 m
36 klystrons



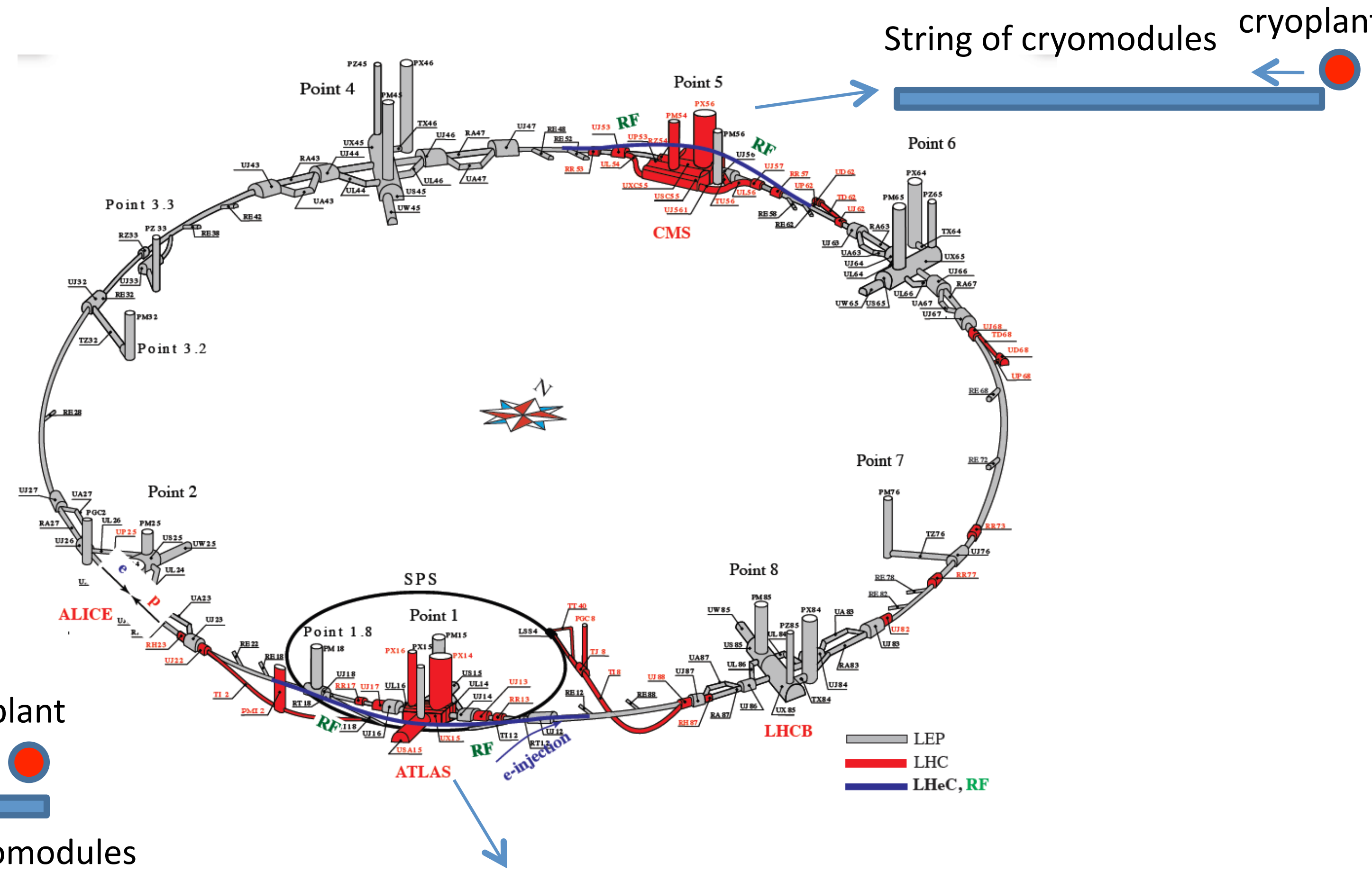
2×3 cryomodules = 2×36 m
2×12 klystrons

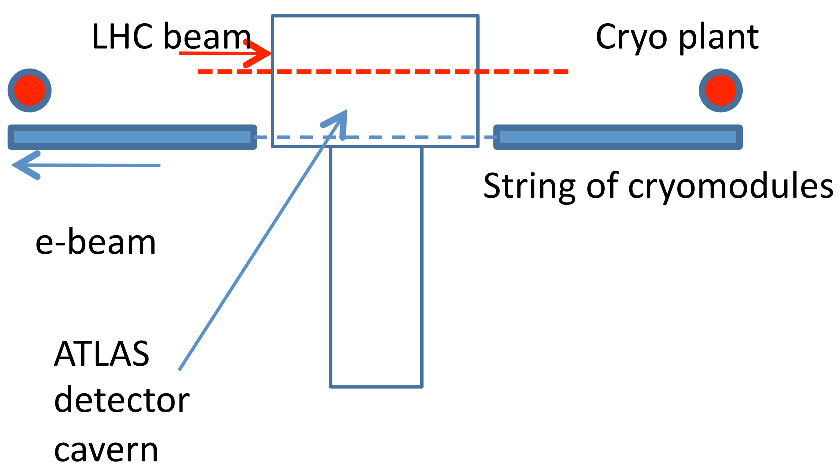
Cryogenics

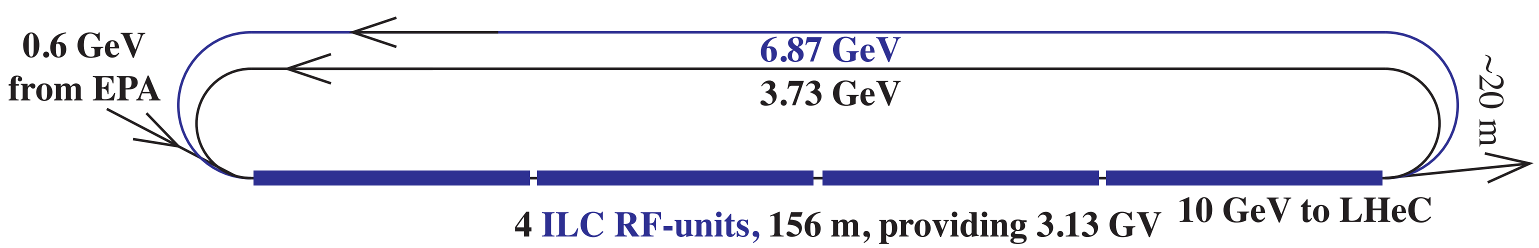
Bypasses:

Cryogenic requirements:
- SPL type cryomodules
- three cryoplants (like LHC/ LEP2)
- 2 K operation

Total electrical power:
- approx. 5 MW







Injector:

Cryogenic requirements:
- 12 ILC (XFEL) type cryomodules
- one cryoplant of modest size
- 2 K operation

Summary

Challenges:

- Integration (bypasses around the remaining p-experiments + e-ring integration into existing LHC tunnel)
- Main arc dipole magnet design (low field and high field quality dipole magnet)
- Interaction region (beam separation)
- Final focus proton magnets (quadrupoles with field free regions for the electron beam)

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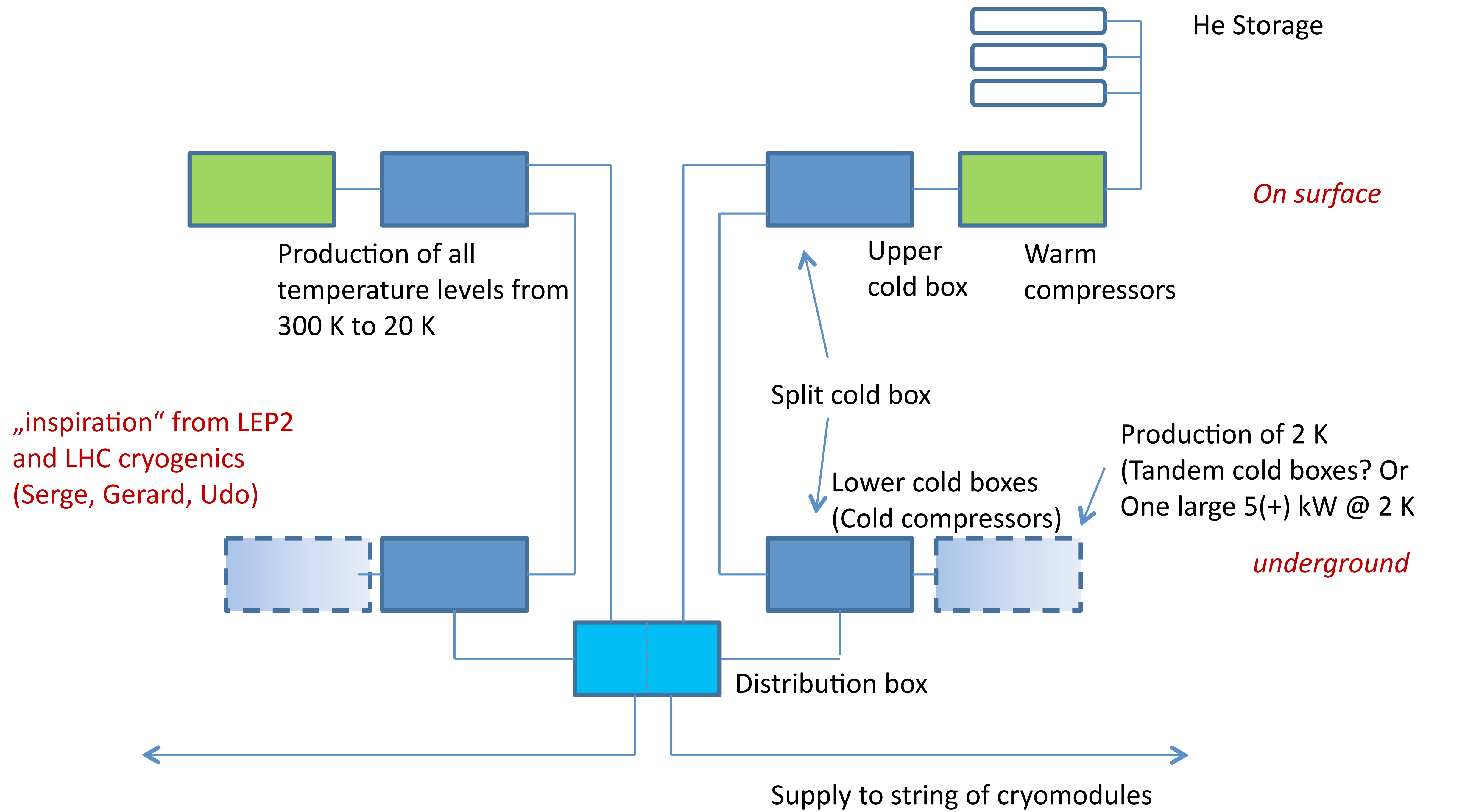
High luminosity ep/A-collisions reachable with proven technology

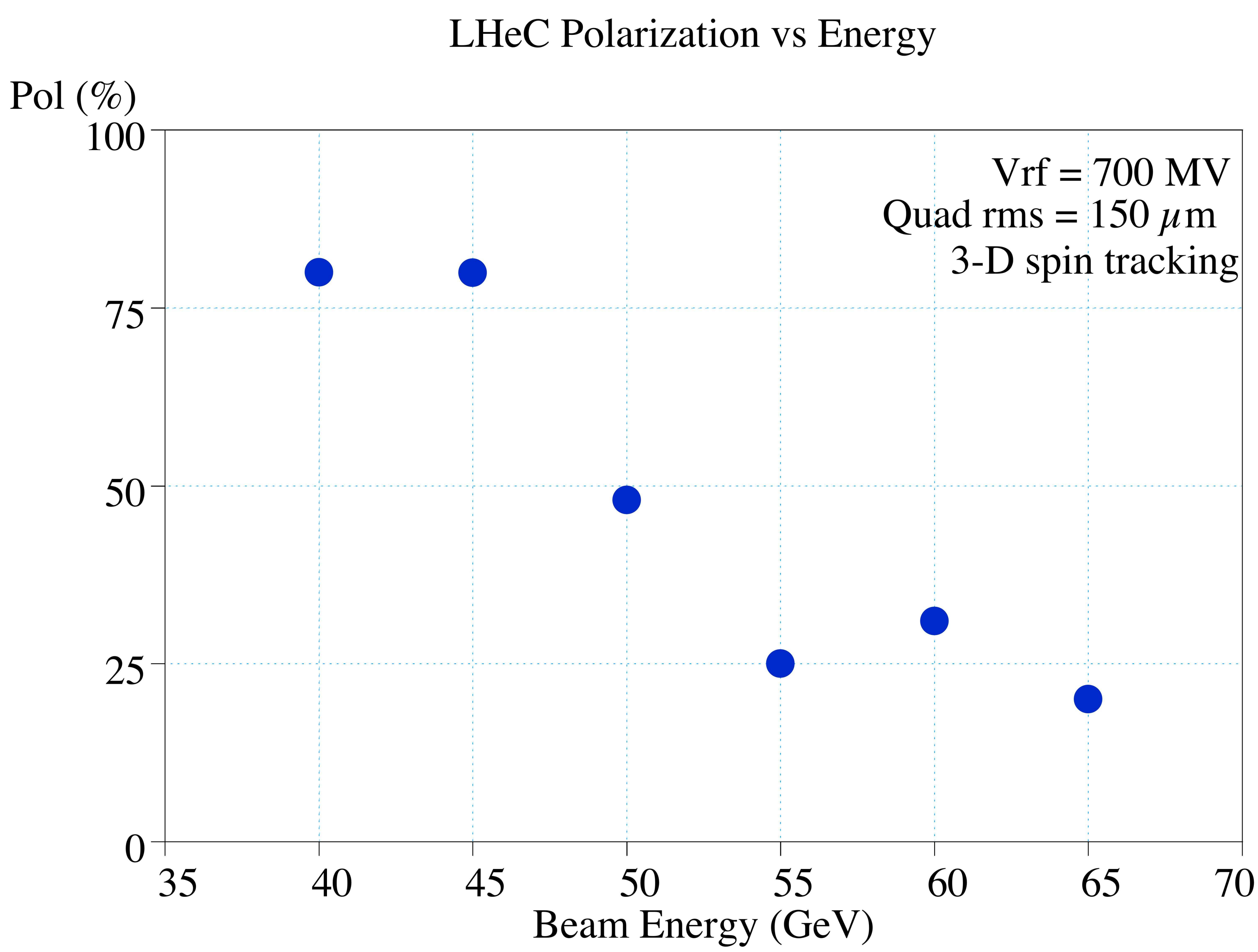
LHeC

THANK YOU FOR YOUR ATTENTION

Basic Refrigerator Layout



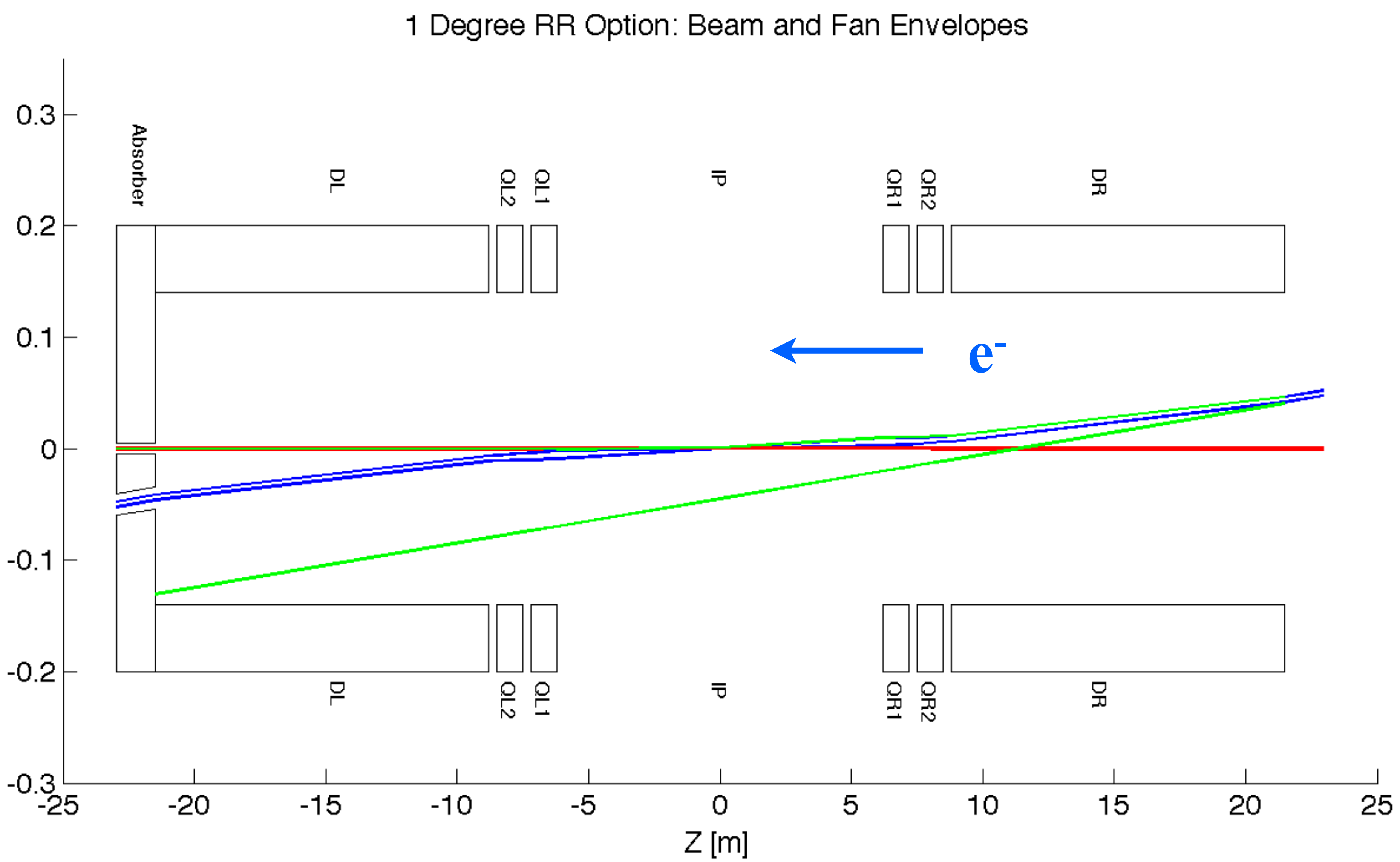
Polarization



- **Polarization of 25% to 40% at 60 GeV can be reasonably aimed for with harmonic closed orbit spin matching**
- **precision alignment of the magnets to better of 150 µm rms needed to achieve a high polarization level**
- **option of having siberian snakes**

Synchrotron Radiation IR

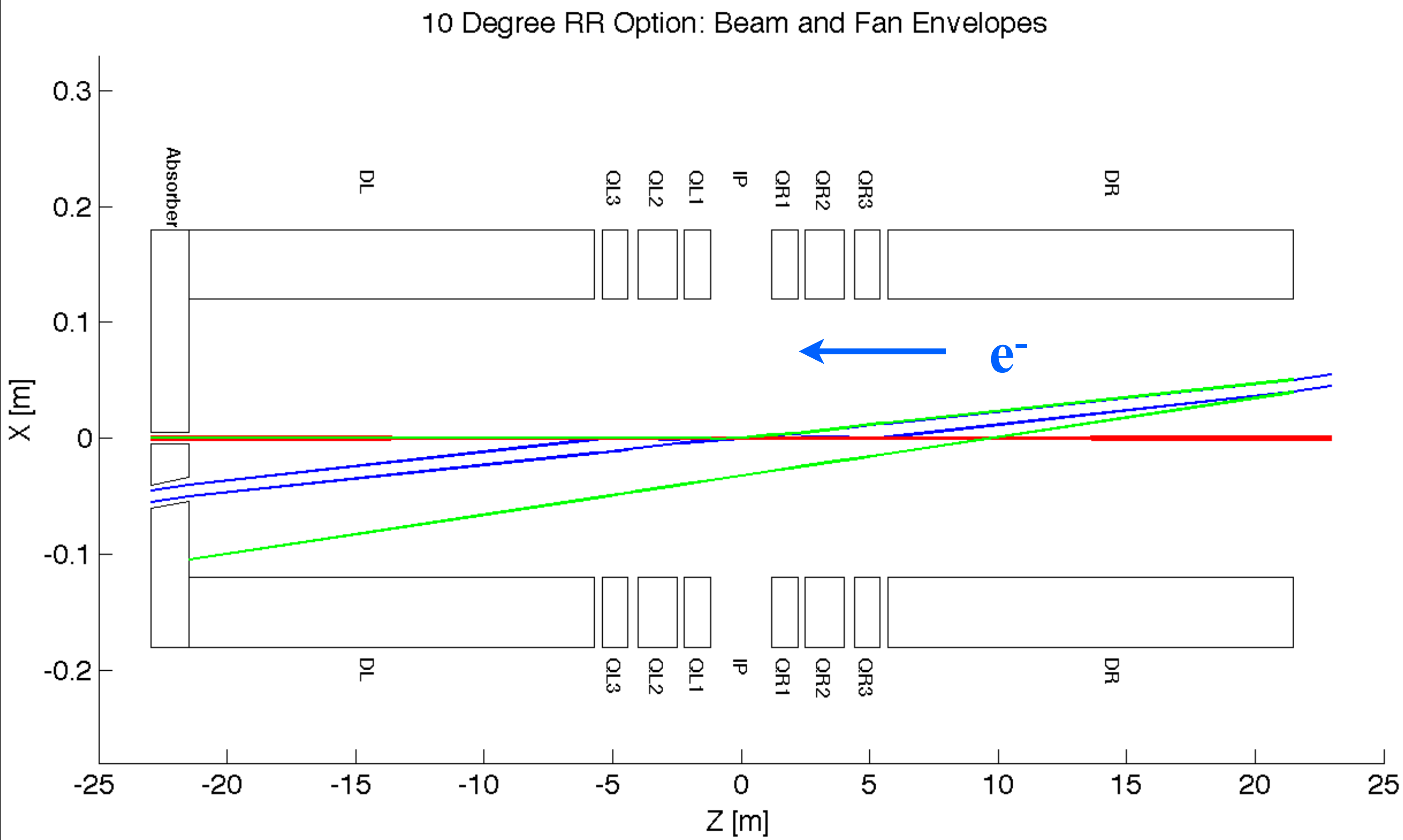
1 Degree



	Power [kW]	critical energy [keV]
DL	13.9	118
QL2	6.2	318
QL1	5.4	294
QR1	5.4	293
QR2	6.3	318
DR	13.9	118
Total/ Avg	51.1	163

Synchrotron Radiation IR

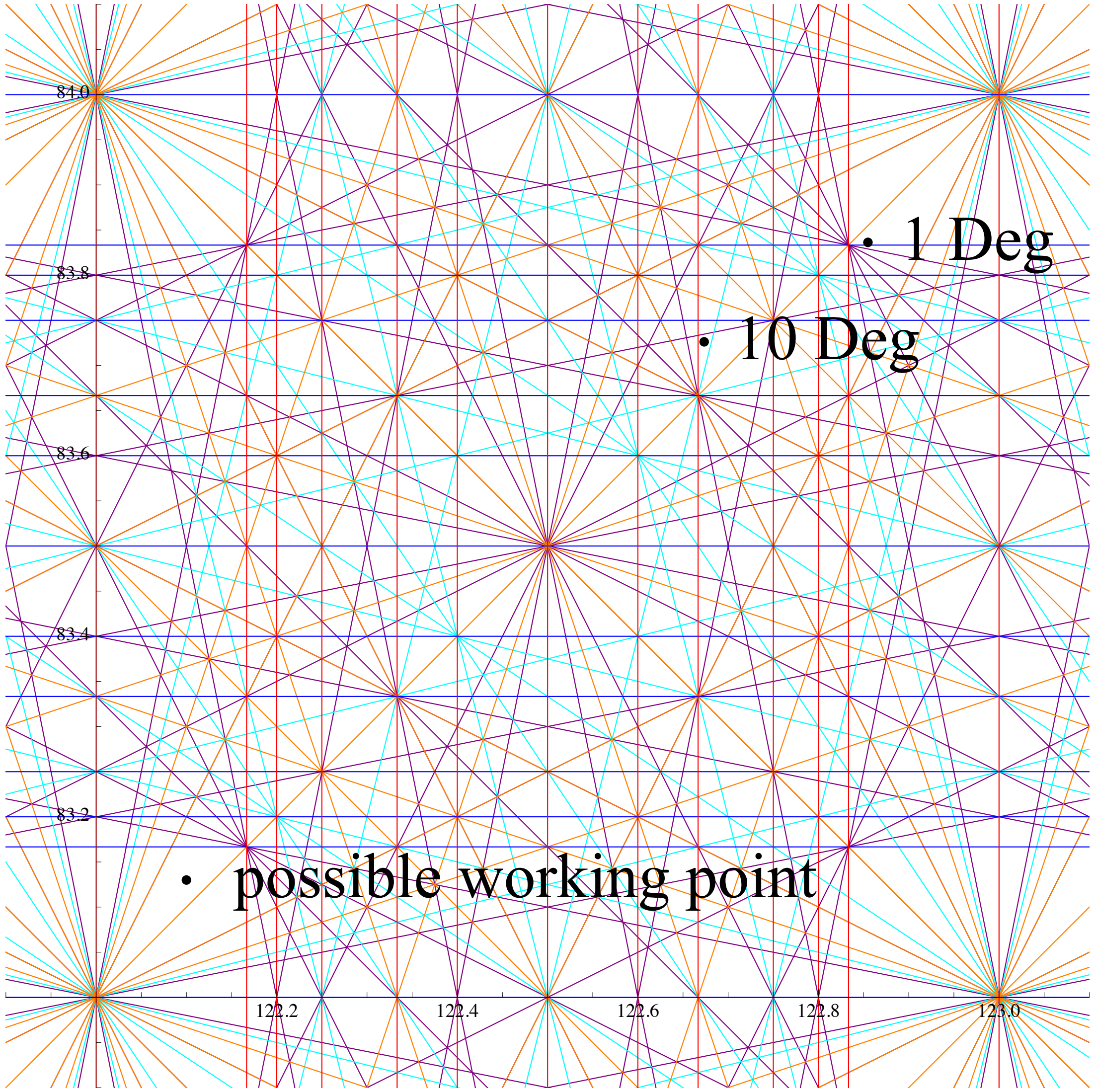
10 Degree



	Power [kW]	critical energy [keV]
DL	6.4	71
QL3	5.3	308
QL2	4.3	218
QL1	0.6	95
QR1	0.6	95
QR2	4.4	220
QR3	5.2	310
DR	6.4	71
Total/ Avg	33.2	126

Main Ring Lattice Parameters

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	61.71 min
Coupling Constant κ	0.5
Horizontal Emittance (no coupling)	5.53 nm
Horizontal Emittance ($\kappa = 0.5$)	4.15 nm
Vertical Emittance ($\kappa = 0.5$)	2.07 nm
RF Voltage V_{RF}	500 MV
RF frequency f_{RF}	721 MHz
Bunch Length	6.88 mm
Max. Hor. Beta	141.94 m
Max. Ver. Beta	138.43 m



123<Qx<24

83<Qy<84