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Constraints on the FCC-ee lattice from the compatibility with the FCC hadron collider

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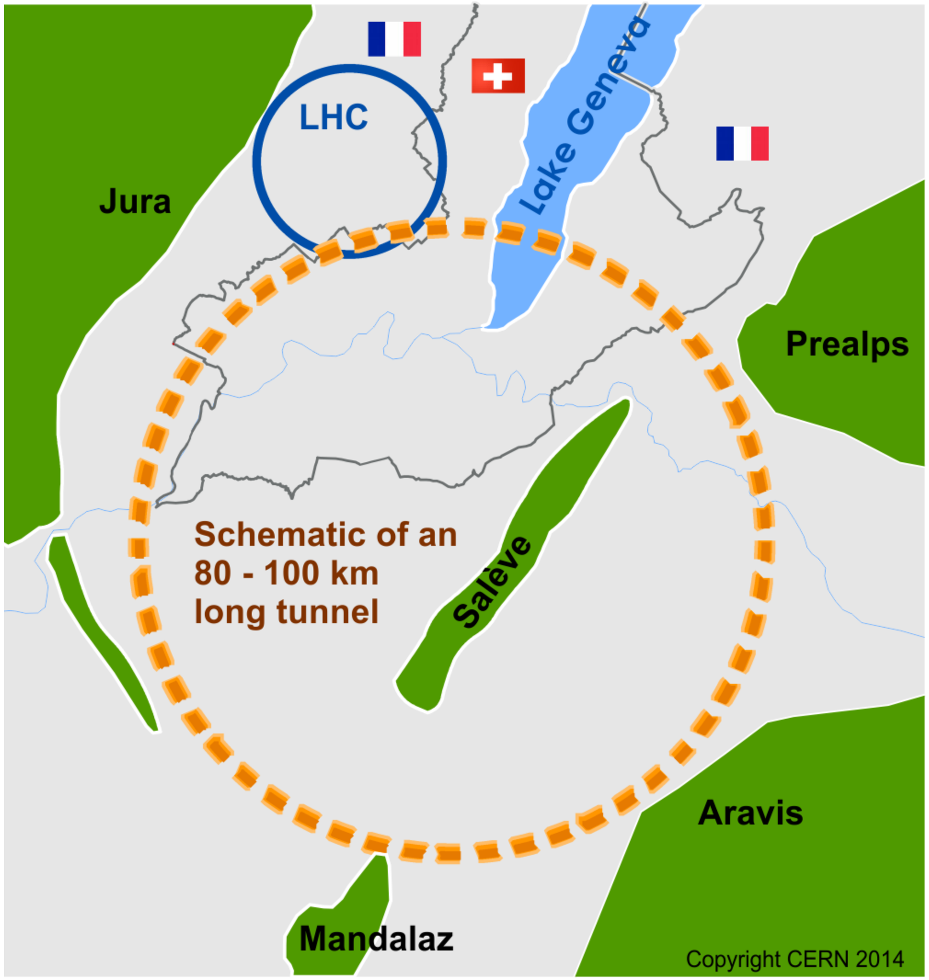
Future Circular Collider Study



Future Circular Collider Study

Consists of three sub-studies:

- FCC-hh: 100 TeV proton collider
- FCC-ee: 350 GeV lepton collider
- FCC-he: electron-proton option

Every study has its own requirements, but technology for FCC-hh is most challenging!

Constraints on FCC-hh

- Magnet technology (Nb_3Sn)
- Shape (racetrack vs. circle)
- Geology
- Overlap with LHC (if used as injector)
- Injection, beam dump, experiments

Not covered today:

- Constraints from hosting FCC-hh and FCC-ee in the tunnel at the same time
- Constraints from FCC-he

1) Bending radius

Proton beam energy: 50 TeV

Beam rigidity: $B\rho = p/e \approx 1.67 \times 10^5$ Tm

B = 20 T: → ρ = 8.5 km

B = 16 T: → ρ = 10.7 km

B = 16 T achievable with Nb_3Sn technology!

2) Circumference

- Approx. 67% of circumference C are bends:

  B = 20 T, ρ = 8.5 km → C = 80 km

  B = 16 T, ρ = 10.7 km → C = 100 km

- RF frequency should be a multiple of RF frequency of LHC (bunch to bucket transfer)

  → $C = 3 \times 26.7$ km = 80.1 km

  → $C = 4 \times 26.7$ km = 106.8 km

3) Layout objectives

Hadron machine

- Max. momentum limited by

$$\oint B(s)\,ds$$

→ High fill factor

→ As few straight sections as possible

Lepton machine

- Limited by synchrotron radiation power

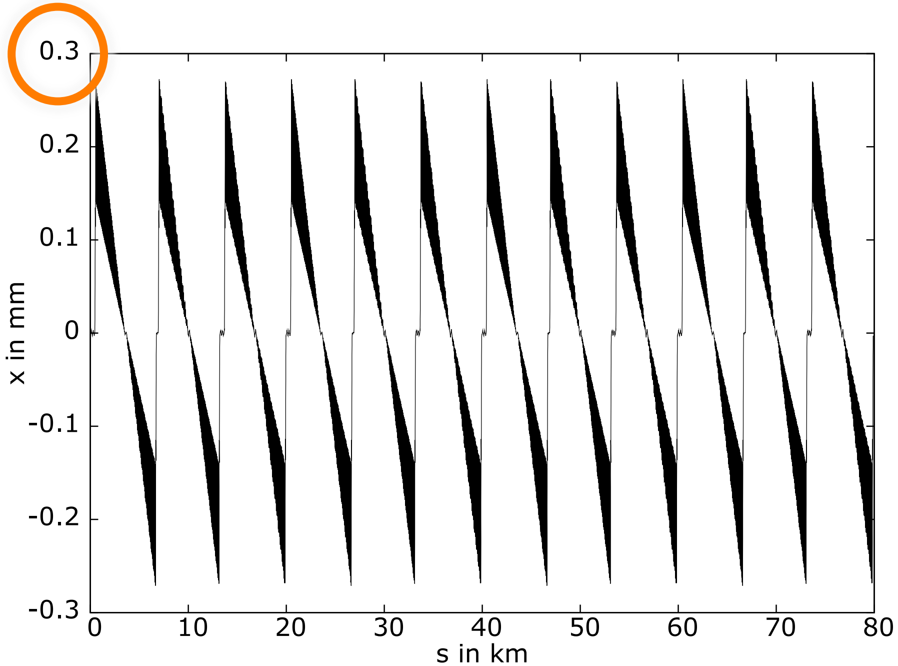
$$P_\gamma = \frac{2}{3}\alpha\hbar c^2 \frac{\gamma^4}{\rho^2}$$

→ High fill factor

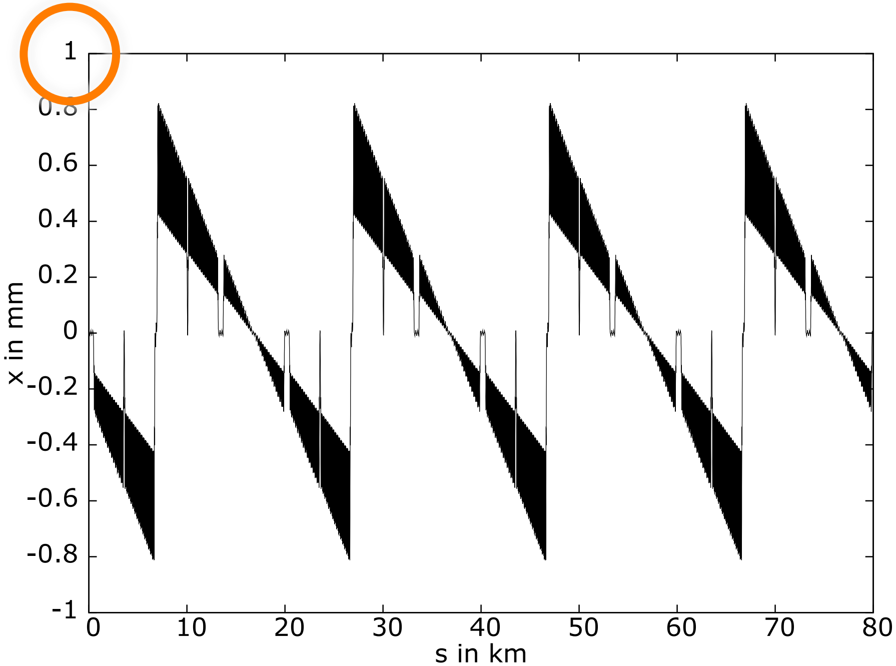
→ High bending radius

→ Many straight sections for RF to limit sawtooth effect

FCC-ee: Sawtooth effect



12 RF sections

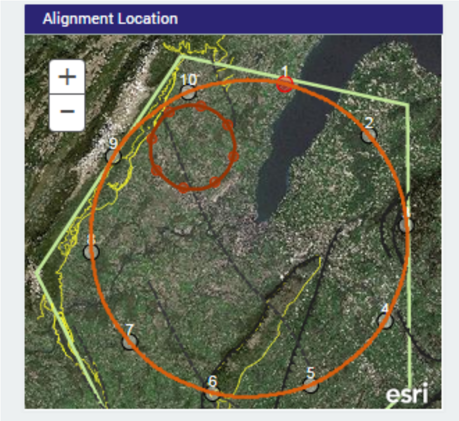


4 RF sections

$$x(s) = x_\beta + D\frac{\delta p}{p}$$

Energy loss per turn (175 GeV beam energy): **U_0 = 7.7 GeV (4.3 %)**

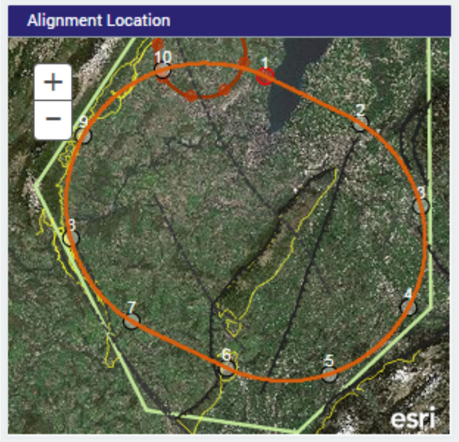
4) Shape



Circular shape (like LHC)

- Preferred for lepton collider
- Less resonances due to superperiodicity

Racetrack (like SSC)

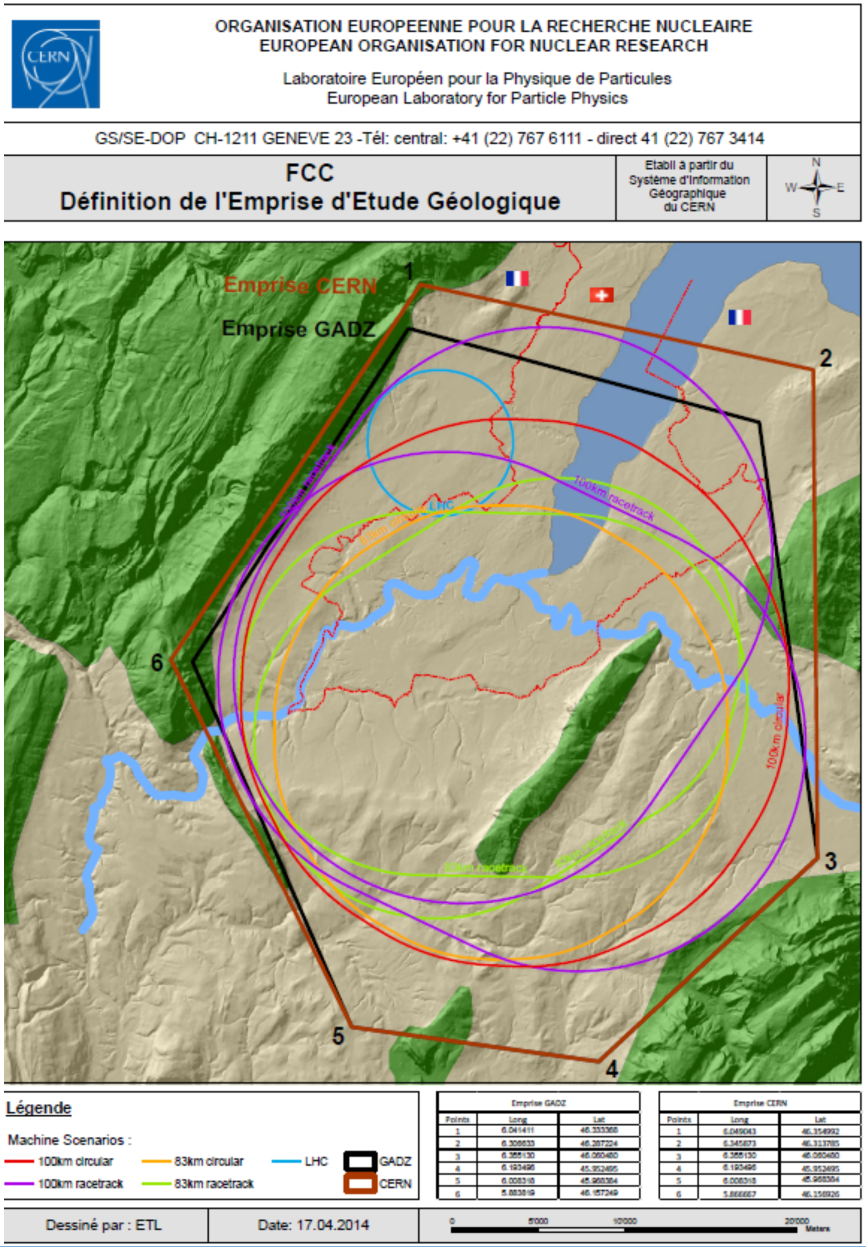


- Most of the infrastructure can be concentrated at two main sites
- Chromaticity correction easier

5) Geology

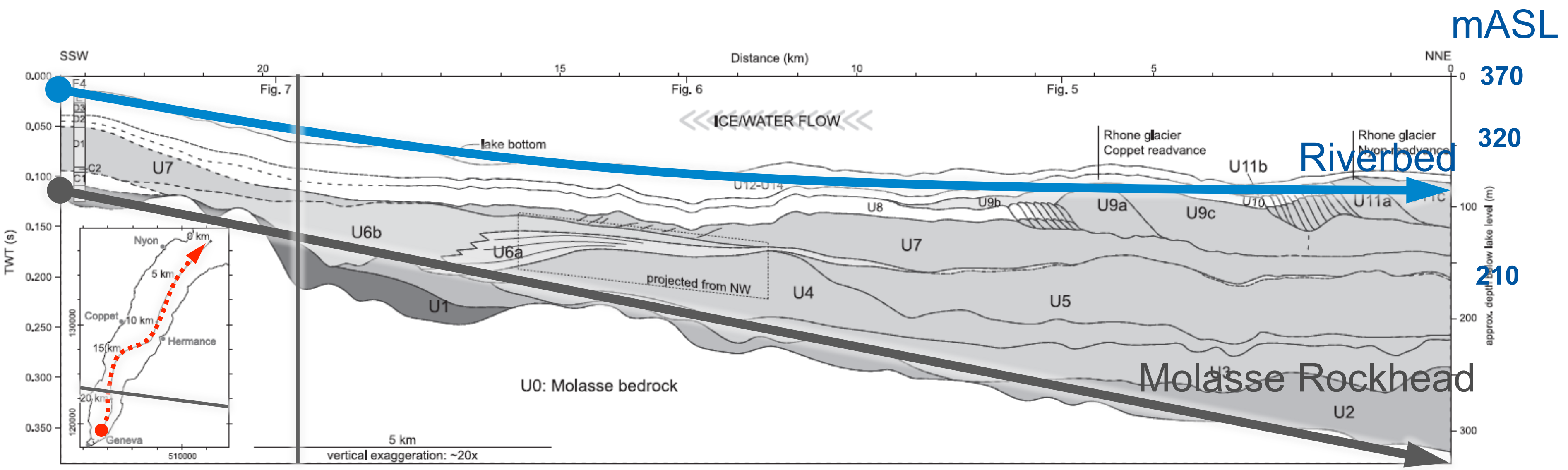
Boundary Limits:

- **East:** Pre-Alps
- **South:** Rhone, Vuache Mountain
- **West:** Jura
- **North:** Lake Geneva



Courtesy: John Osborne

Lake Geneva

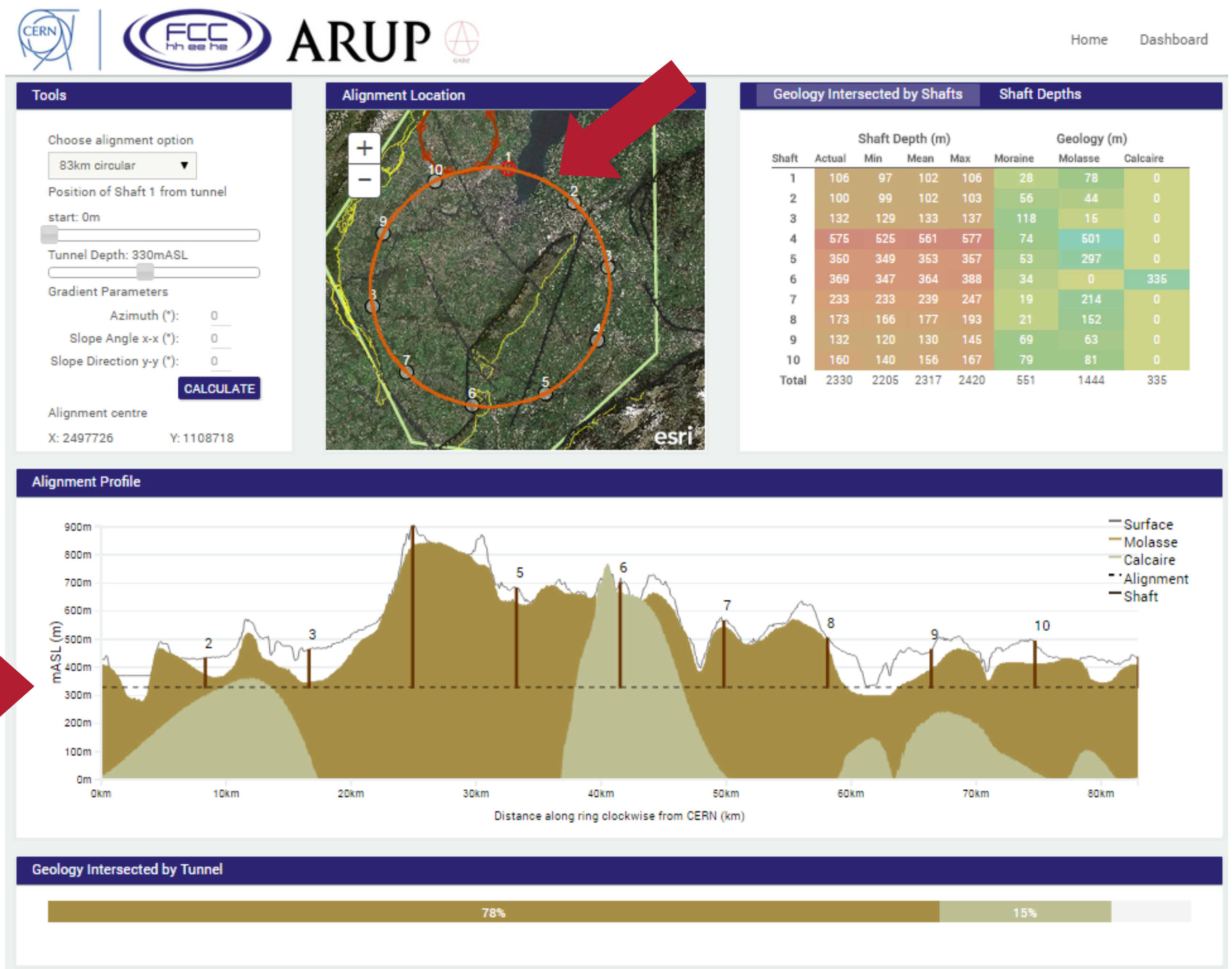


Courtesy:
John Osborne

- The lake gets deeper to the North
- The molasse rockhead as well

→ The tunnel level must be deeper in the earth

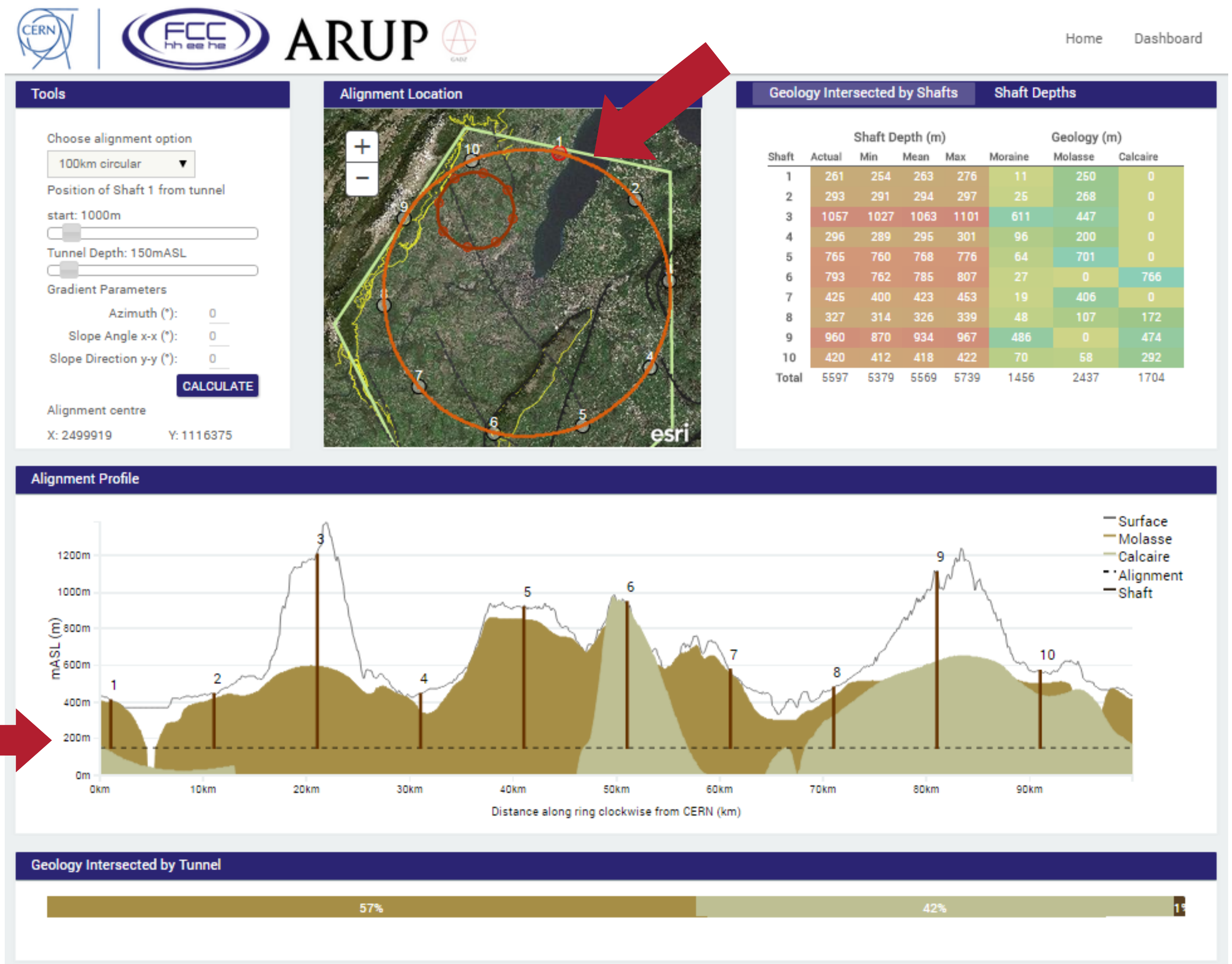
80 km circle



	Shaft Depth (m)				Geology (m)		
Shaft	Actual	Min	Mean	Max	Moraine	Molasse	Calcaire
1	106	97	102	106	28	78	0
2	100	99	102	103	56	44	0
3	132	129	133	137	118	15	0
4	575	525	561	577	74	501	0
5	350	349	353	357	53	297	0
6	369	347	364	388	34	0	335
7	233	233	239	247	19	214	0
8	173	166	177	193	21	152	0
9	132	120	130	145	69	63	0
10	160	140	156	167	79	81	0
Total	2330	2205	2317	2420	551	1444	335

Courtesy: John Osborne, Yung Loo

100 km circle



Shaft	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Moraine	Molasse	Calcaire
1	261	254	263	276	11	250	0
2	293	291	294	297	25	268	0
3	1057	1027	1063	1101	611	447	0
4	296	289	295	301	96	200	0
5	765	760	768	776	64	701	0
6	793	762	785	807	27	0	766
7	425	400	423	453	19	406	0
8	327	314	326	339	48	107	172
9	960	870	934	967	486	0	474
10	420	412	418	422	70	58	292
Total	5597	5379	5569	5739	1456	2437	1704

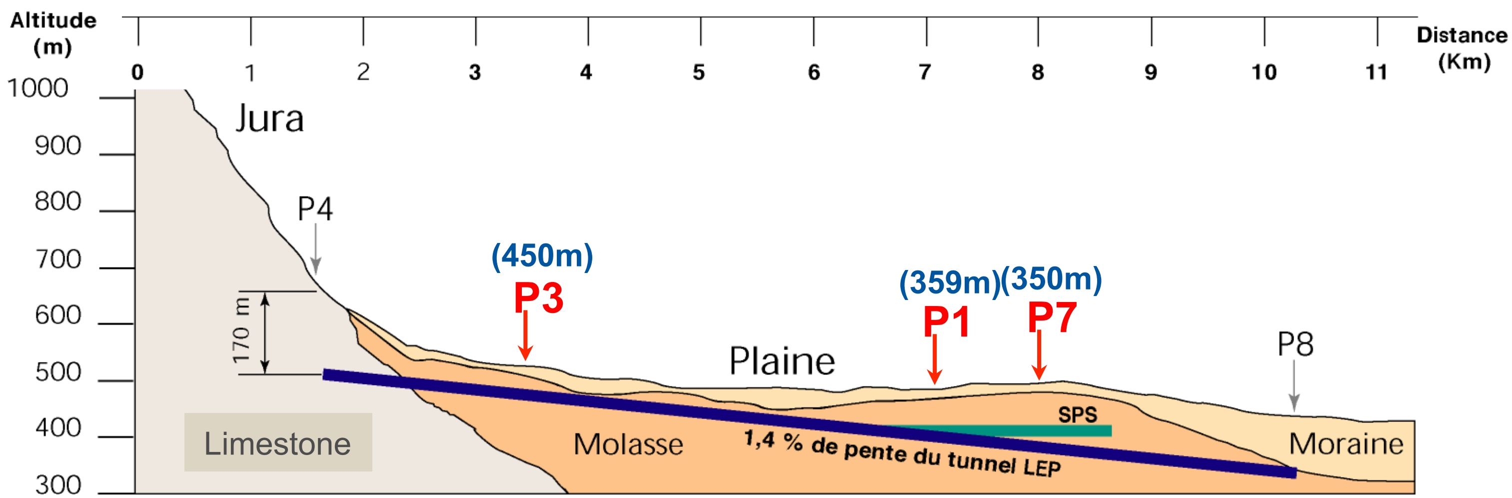
Courtesy:
John Osborne,
Yung Loo

Tilting the tunnel

- LEP/LHC: 1.42 %

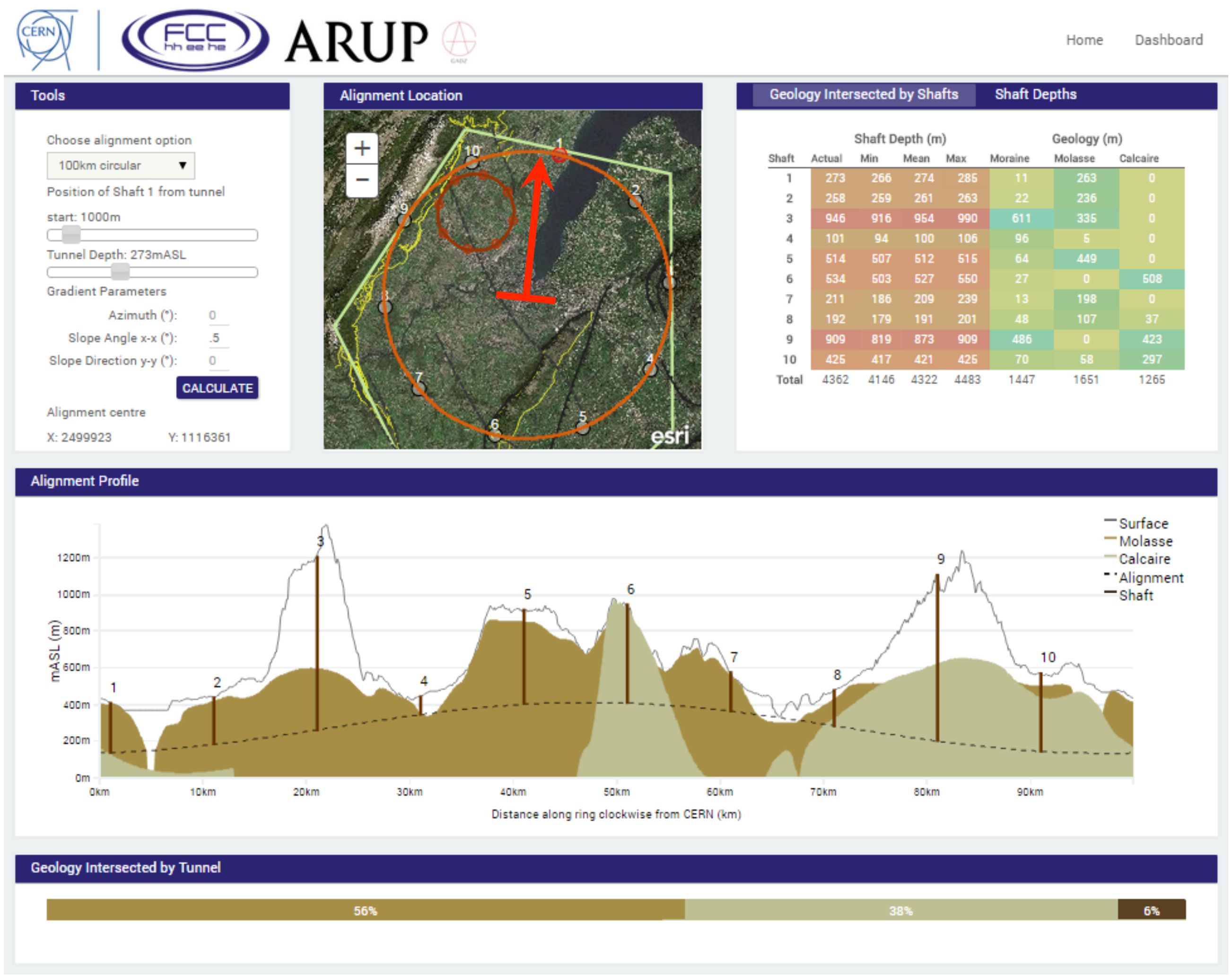
  → Maximize tunnel extend in molasse, minimize tunnel extend in limestone and moraines

  → Minimize shaft depths



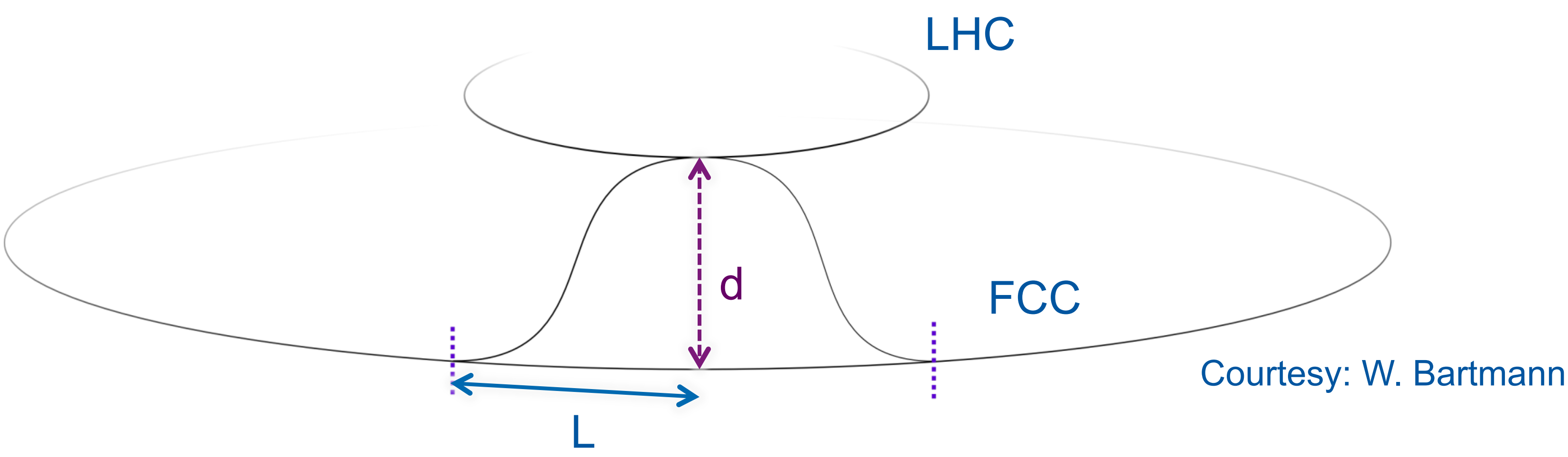
Courtesy: John Osborne

100 km circle with tilt



Courtesy:
John Osborne,
Yung Loo

6) Location relative to LHC

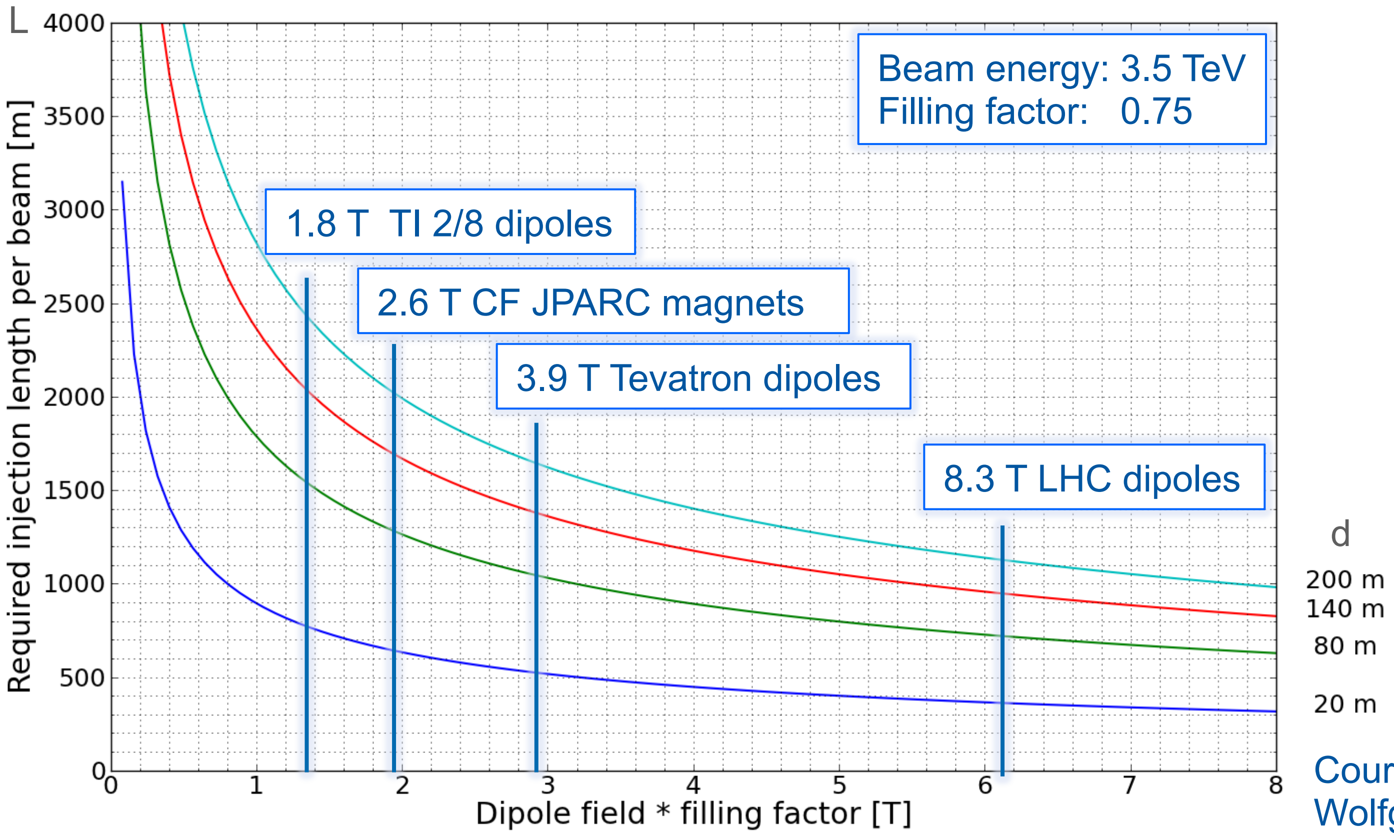


FCC and LHC should overlap, if LHC is used as injector

Required distance L for transfer lines depends on:

- Difference in depth d
- Magnet technology
- Beam energy
- Max. slope of tunnel 5%

Distance for transfer lines



Courtesy:
Wolfgang Bartmann

- Required length: L = 500 – 1500 m

7) Length of Long Straight Sections

Space for septum, kicker magnet and absorbers for machine protection

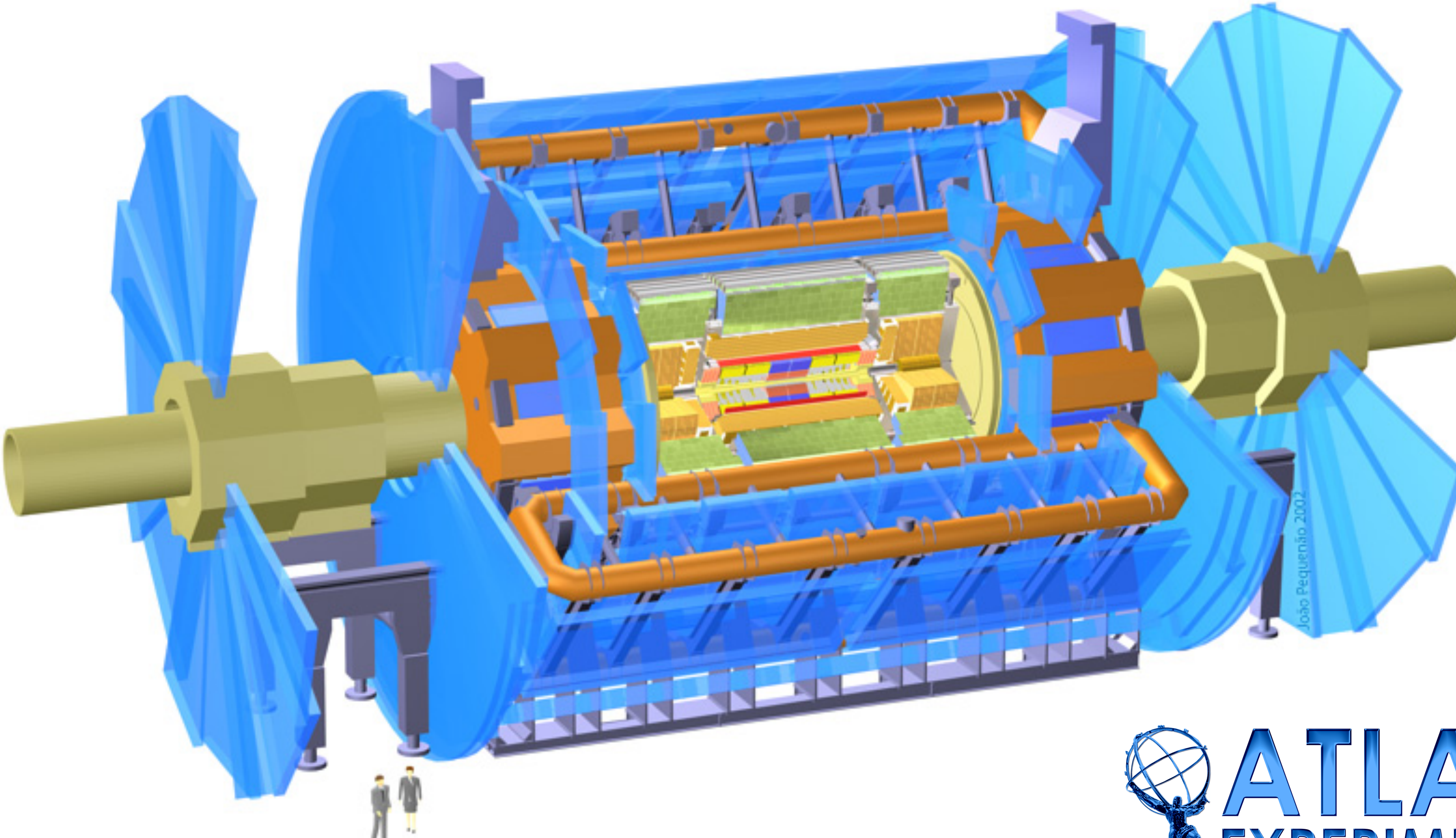
Injection: Energy: 3.3 TeV

- 600 m

Beam dump: Energy: 50 TeV

- 800 m – 1000 m (?)

8) Experiments

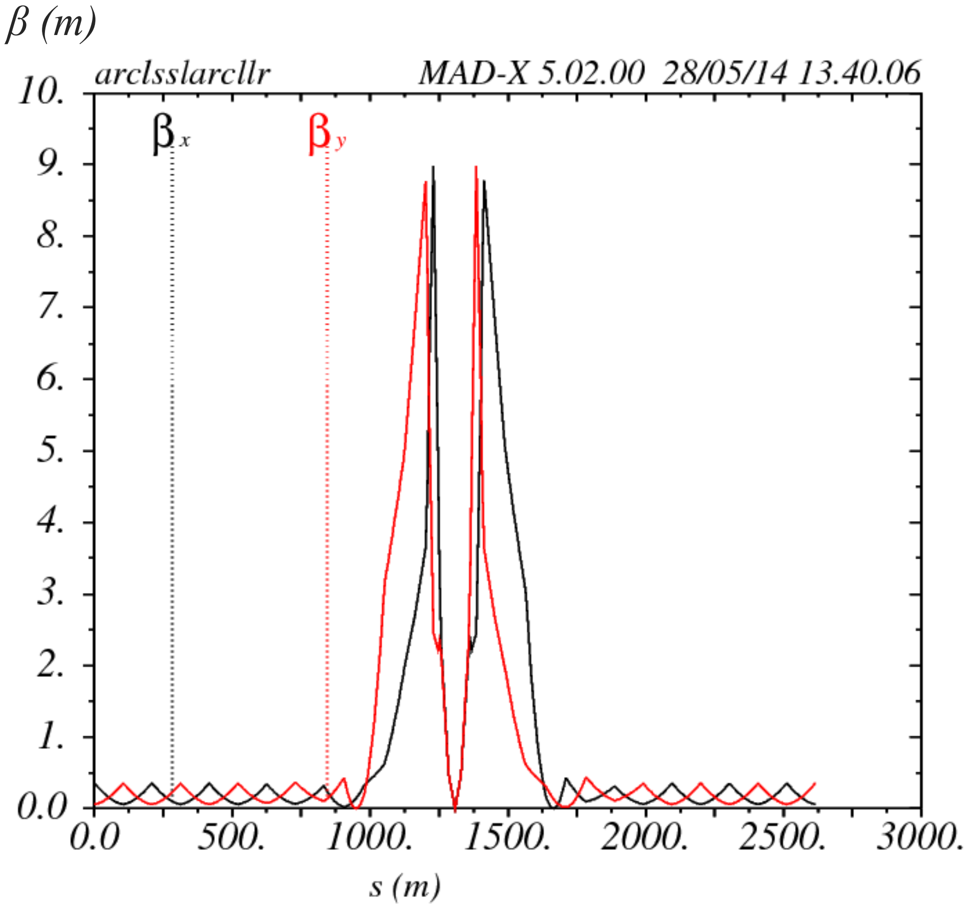


ATLAS EXPERIMENT

Experiments FCC-hh

Interaction region (IR) design for

- Huge Detectors
  → L* = 46 m !!!
- Length of single IR:
  → ≈ 1200 m
- Head-on collision scheme



Court. R. Alemany, B. Holzer

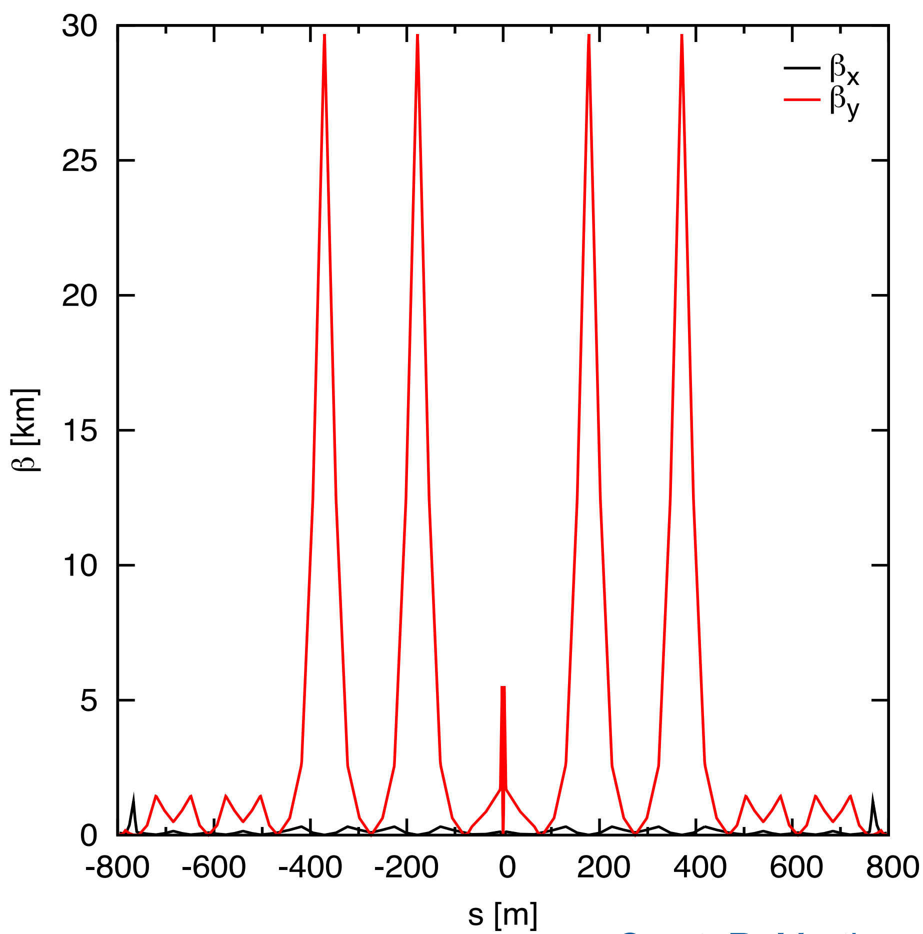
Experiments FCC-ee

Completely different IR design:

- Crossing angle
- β_y = 1 mm, L* = 2 m !!!
- Local chromaticity correction scheme
- IR length: ≈ 1600 m

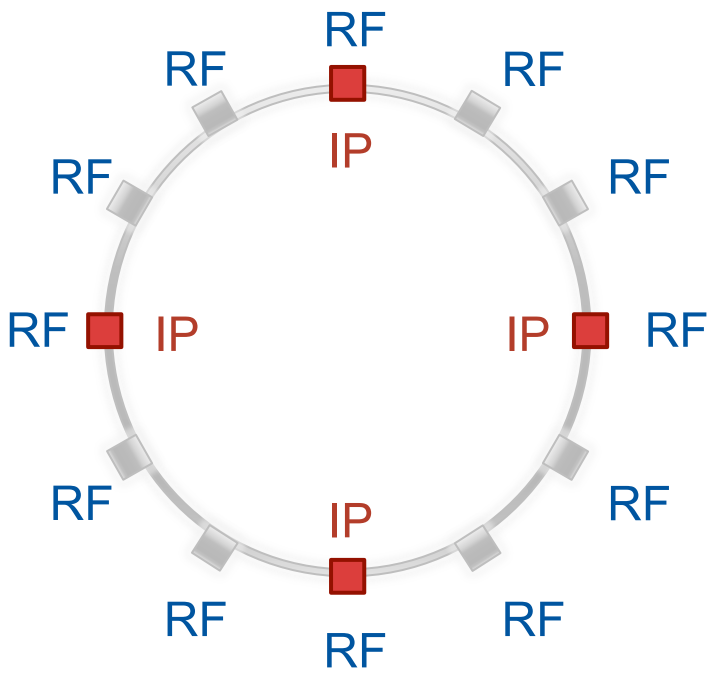
More about IR design:

Roman Martin's presentation



Court. R. Martin

Current FCC-ee design



Circular shape,

100 km circumference

- 12 straight sections
  → Length: 1.5 km
- 4 experiments
- Length of arcs: 6.8 km
  → ρ ≈ 10.6 km

Details of the FCC-ee lattice were presented in my other talk

Resume

- Magnet technology sets constraints on bending radius and circumference
- Compromise for the layout must be found
- Injection, beam dump and experiments define length of the straight sections
- Geology and transfer lines define location of FCC

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Thank you for your attention!

Court. J. Wenninger

4.2.2 Clustered Interaction Regions

An example of clustered IRs is shown in Fig. 3.3-2. The two IRs in the West cluster, adjacent to the two utility sections, are the high luminosity IRs with low β^*. The two IRs opposite the two utility sections are regarded in this example to be future IRs, undeveloped at the startup of the SSC, and optically identical to the two utility sections. The remaining pair of IRs are similar in structure to the low-β^* ones, but they have intermediate luminosity with a modest value of β^* and extended free space about the interaction points.

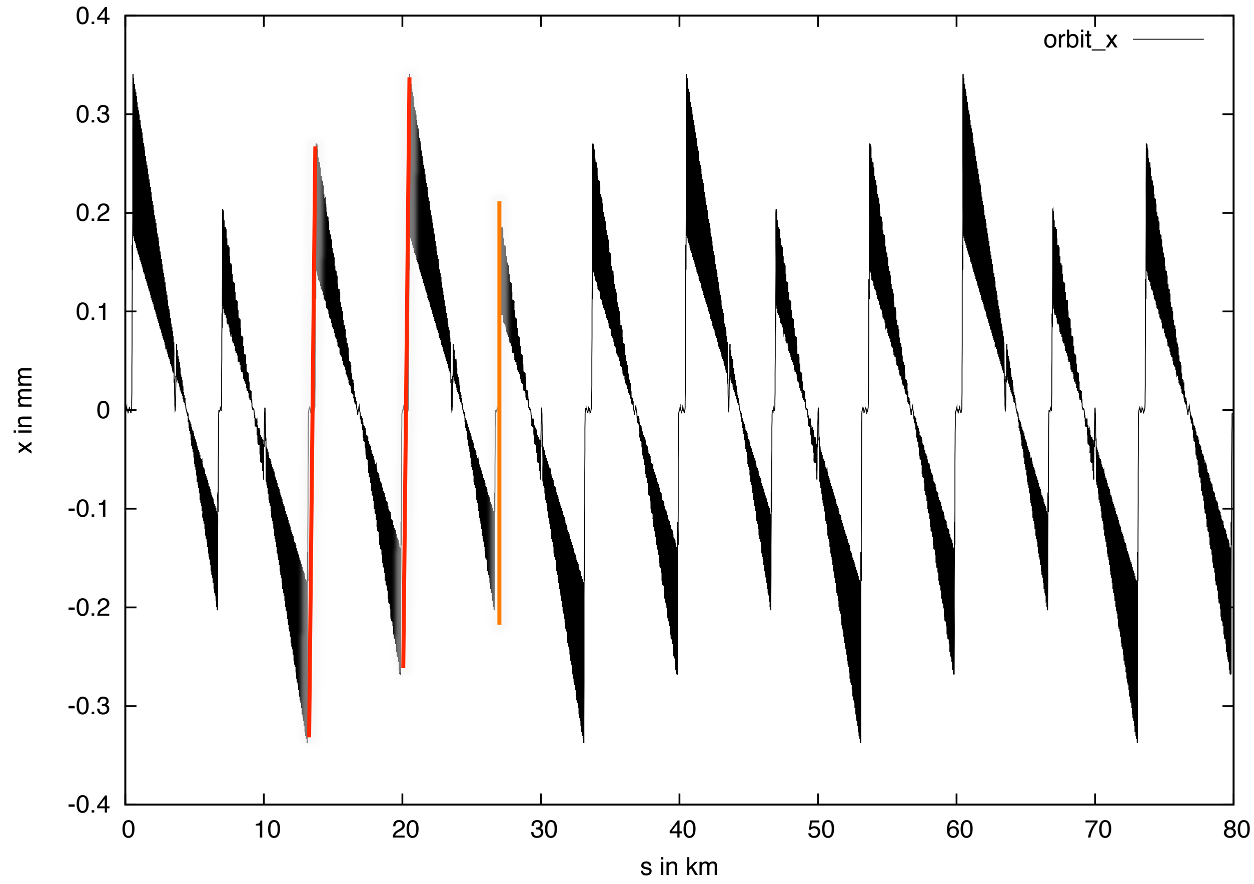
In this section, we discuss the various issues associated with clustering the IRs. Figure 3.3-2 is just one of several possible clustering configurations. Other configurations are sketched in Fig. 4.2-1. The layout of Fig. 3.3-2, the one selected for the conceptual design, is designated by $(2,4)_b$.

The beam optics, beam-beam effects, and background radiation are some of the accelerator physics issues to be considered when discussing clustered interaction regions. The results of a study of these questions [4.2-7] are summarized in the present section. More information on the beam-beam effect can be found in Section 4.5 and more on the backgrounds in Section 4.8. The main conclusion of the study is that both distributed and clustered IRs are acceptable for the SSC design from the accelerator physics point of view. However, the clustered scheme is more cost effective because of considerations concerning the conventional facilities and so was recommended for the SSC conceptual design.

Generally speaking, evenly distributed IRs permit a higher superperiodicity and thus fewer resonances in the tune space. For the case of SSC, this means a superperiodicity of 6, if the utility sections and crossings are ignored. Realization of the consequences of high superperiodicity requires correlation of particle motion in magnets that are separated by 1/6 of the ring circumference, i.e., about 14 km. Because of various magnet field and alignment errors, correlation over this long distance is not likely to be maintained. The superperiodicity is thus broken in reality and all low-order resonances, systematic and accidental, need to be avoided.

The fact that a high superperiodicity is not very important for the SSC is demonstrated by particle tracking using the programs PATRICIA [4.2-8] and RACETRACK [4.2-9] on various lattices [4.2-10]. The maximum amplitude of stable motion (referred to as the dynamic aperture in Sections 3.2 and 4.3) is plotted in Fig. 4.2-2 as a function of momentum deviation $\delta = \Delta E/E$. Random magnet multipole errors (Table 4.3-1) are included in these simulations. For each case, the same tunes are used, away from systematic resonances. The dependence of dynamic aperture on the IR layout, and thus the superperiodicity, is not significant.

Unequally distributed RF



FCC-he design parameters

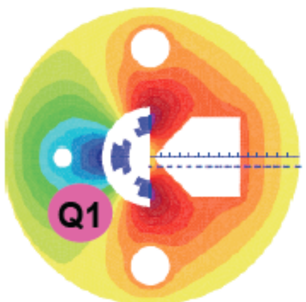
collider parameters	FCC ERL	FCC-ee ring		protons
species	e^- (e^+?)	$e^\pm$	$e^\pm$	*p*
beam energy [GeV]	60	60	120	50000
bunches / beam	-	10600	1360	10600
bunch intensity [10^{11}]	0.05	0.94	0.46	1.0
beam current [mA]	25.6	480	30	500
rms bunch length [cm]	0.02	0.15	0.12	8
rms emittance [nm]	0.17	1.9 (*x*)	0.94 (*x*)	0.04 [0.02 *y*]
$\beta_{x,y}$*[mm]	94	8, 4	17, 8.5	400 [200 *y*]
$\sigma_{x,y}$* [μm]	4.0	4.0, 2.0		equal
beam-b. parameter ξ	(D=2)	**0.13**	**0.13**	0.022 (0.0002)
hourglass reduction	0.92 (H_D=1.35)	**~0.21**	~0.39	
CM energy [TeV]	3.5	3.5	4.9	
luminosity[10^{34}cm^{-2}s^{-1}]	**1.0**	**6.2**	**0.7**	

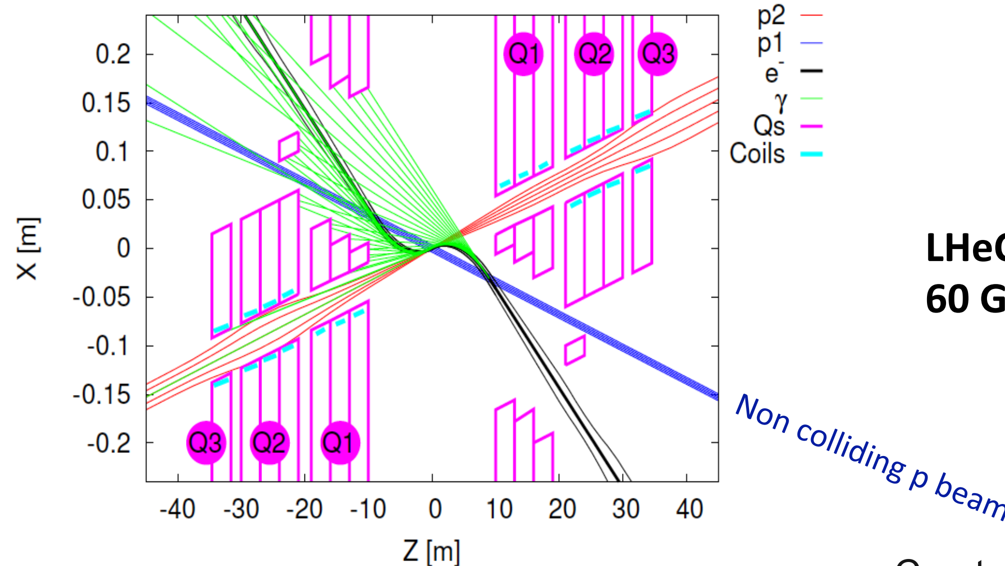
F.Zimmermann
ICHEP14, June

PRELIMINARY

LHeC: IR layout

Interaction Regions for ep with Synchronous pp Operation





Still work in progress: may not need half quad if L*(e) < L*(p)

LHeC (CDR)
60 GeV * 7 TeV

Courtesy Max Klein

- A similar interaction scheme needs to be designed for FCC-he

Experiments

ATLAS EXPERIMENT