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

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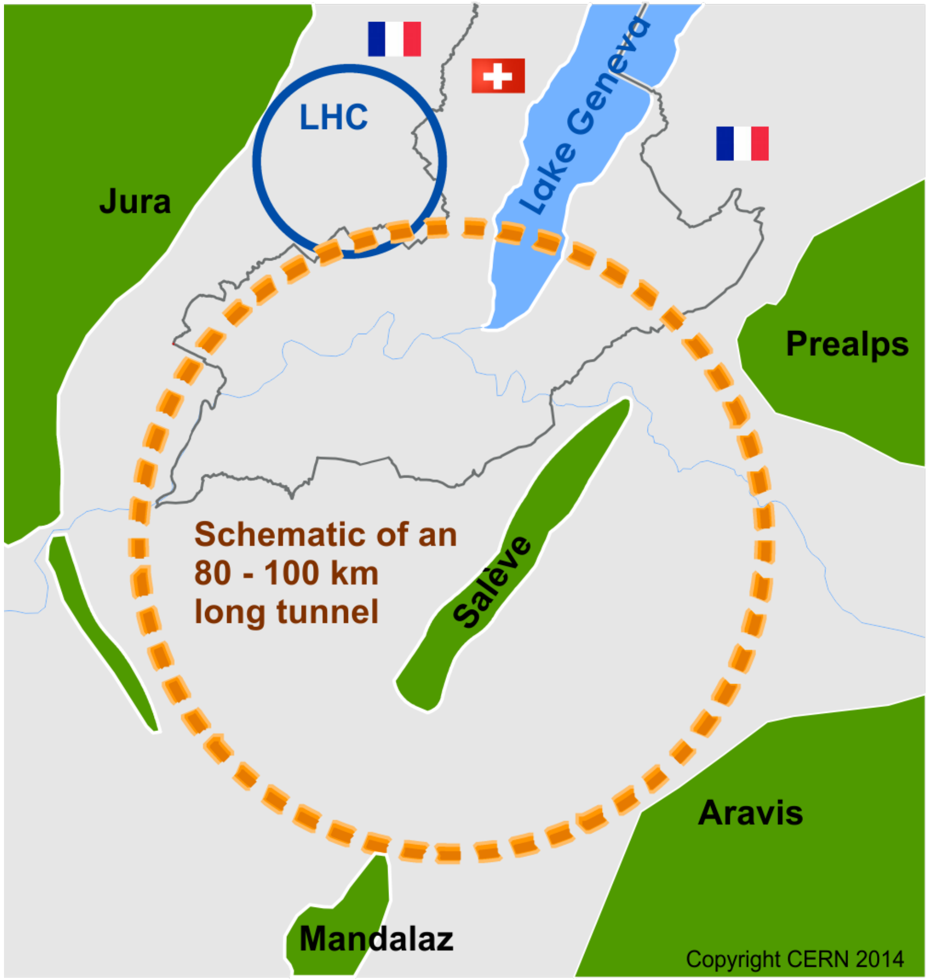
Future Circular Collider Study



Future Circular Collider Study

Consists of three sub-studies:

- FCC-hh: 100 TeV proton collider
- FCC-ee: 91-350 GeV lepton collider
- FCC-he: electron-proton option

Each 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 housing 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: $\rightarrow \rho = 8.5$ km

$B = 16$ T: $\rightarrow \rho = 10.7$ km

$B = 16$ T achievable with Nb_3Sn technology!

(FCC-ee: $B = 55$ mT)

2) Circumference

- Approx. 67% of circumference C are bends:

  $B = 20$ T, $\rho = 8.5$ km → $C = 80$ km

  $B = 16$ T, $\rho = 10.7$ 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

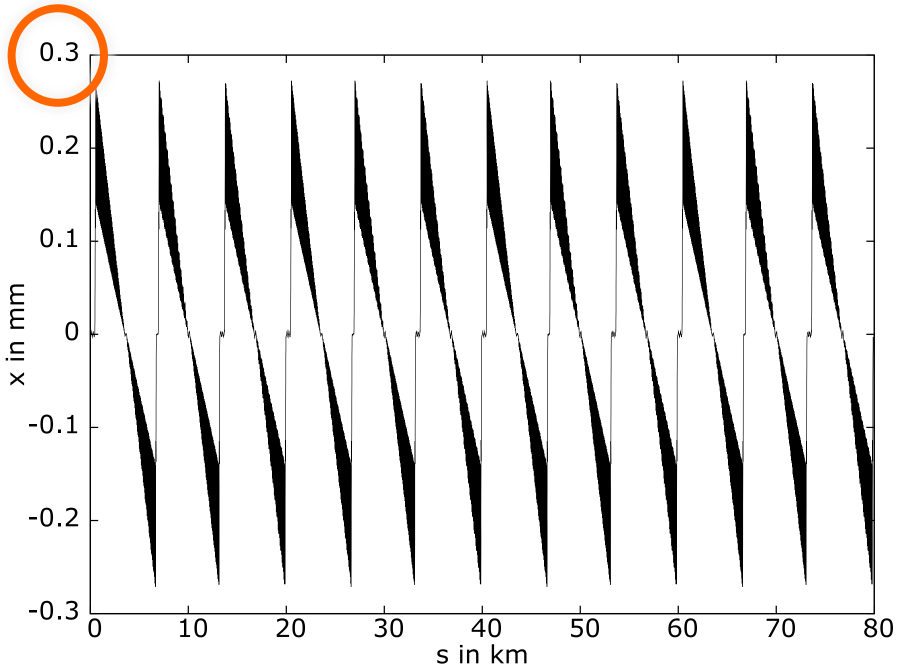
$$P_\gamma = \frac{2}{3}\alpha\hbar c^2 \frac{\gamma^4}{\rho^2}$$

→ High fill factor

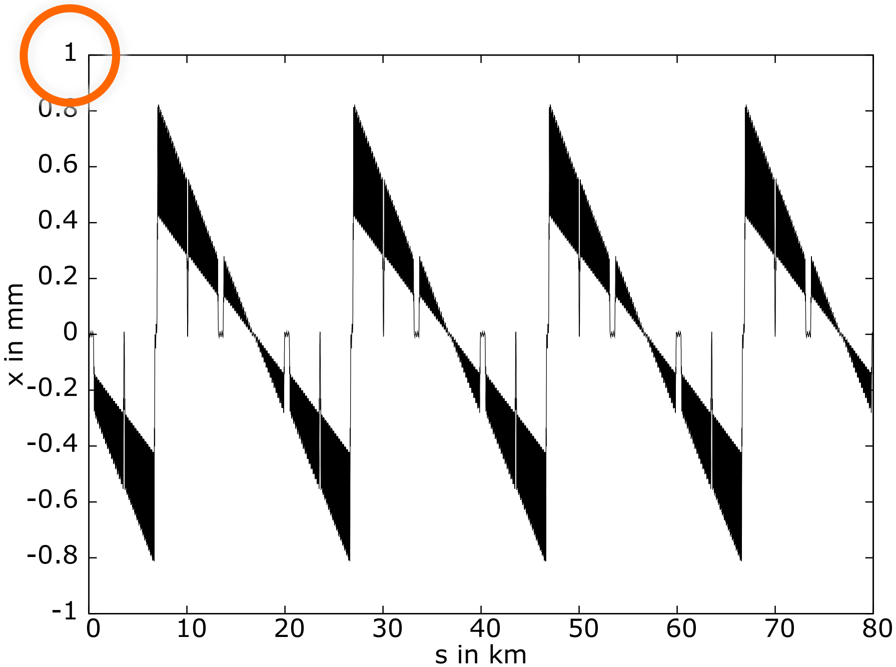
→ High bending radius

→ Many straight sections for RF to limit sawtooth effect

FCC-ee: Sawtooth effect



12 RF sections



4 RF sections

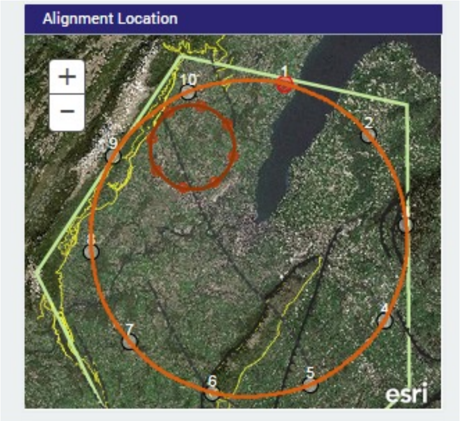
$$x(s) = x_\beta + D\frac{\delta p}{p}$$

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

4) Shape

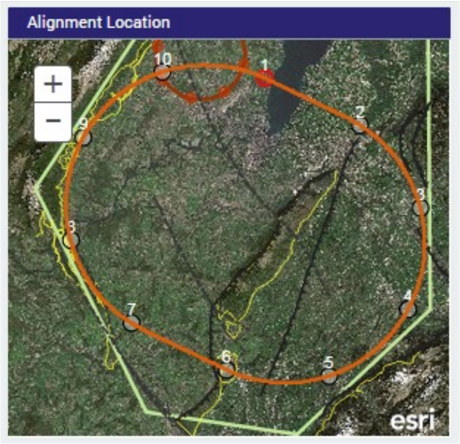
Circular shape (like LHC)

- Preferred for lepton collider



Racetrack (like SSC)

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

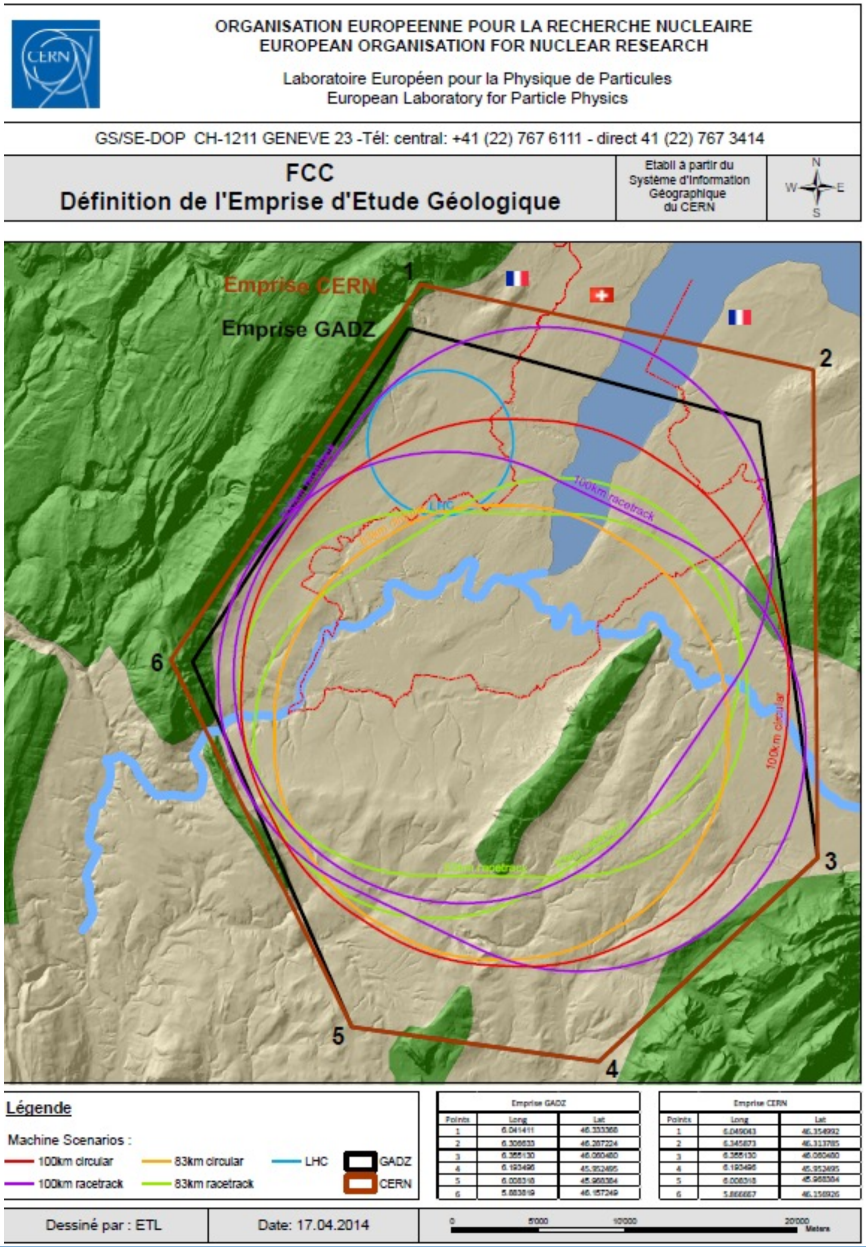


Courtesy: John Osborne et al.

5) Geology

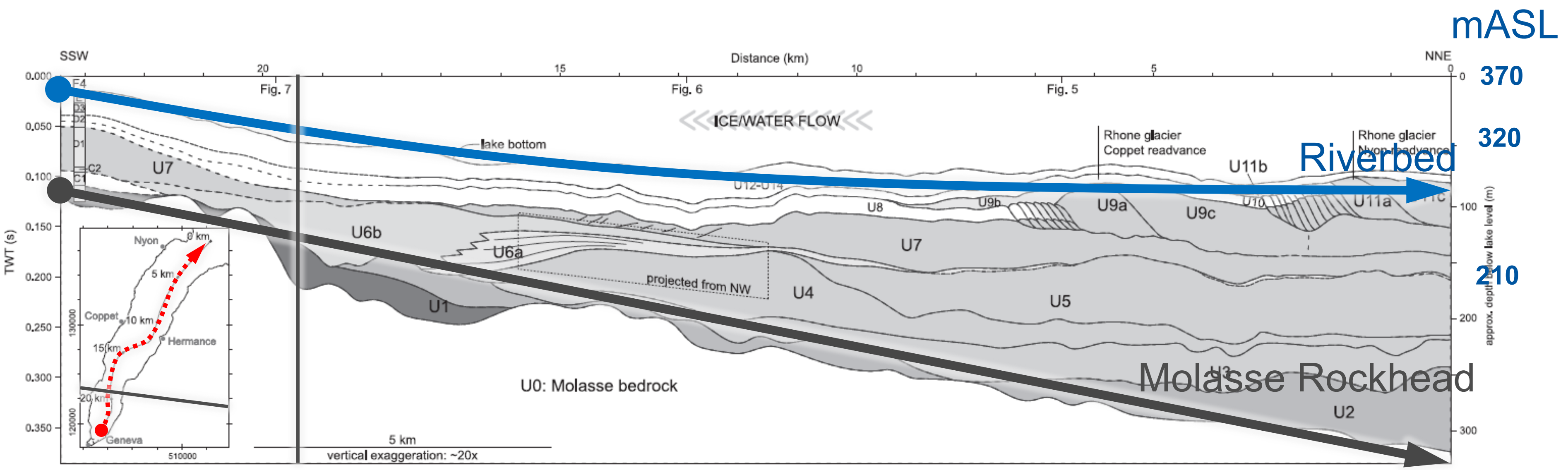
Boundary Limits:

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



Courtesy: John Osborne

Lake Geneva

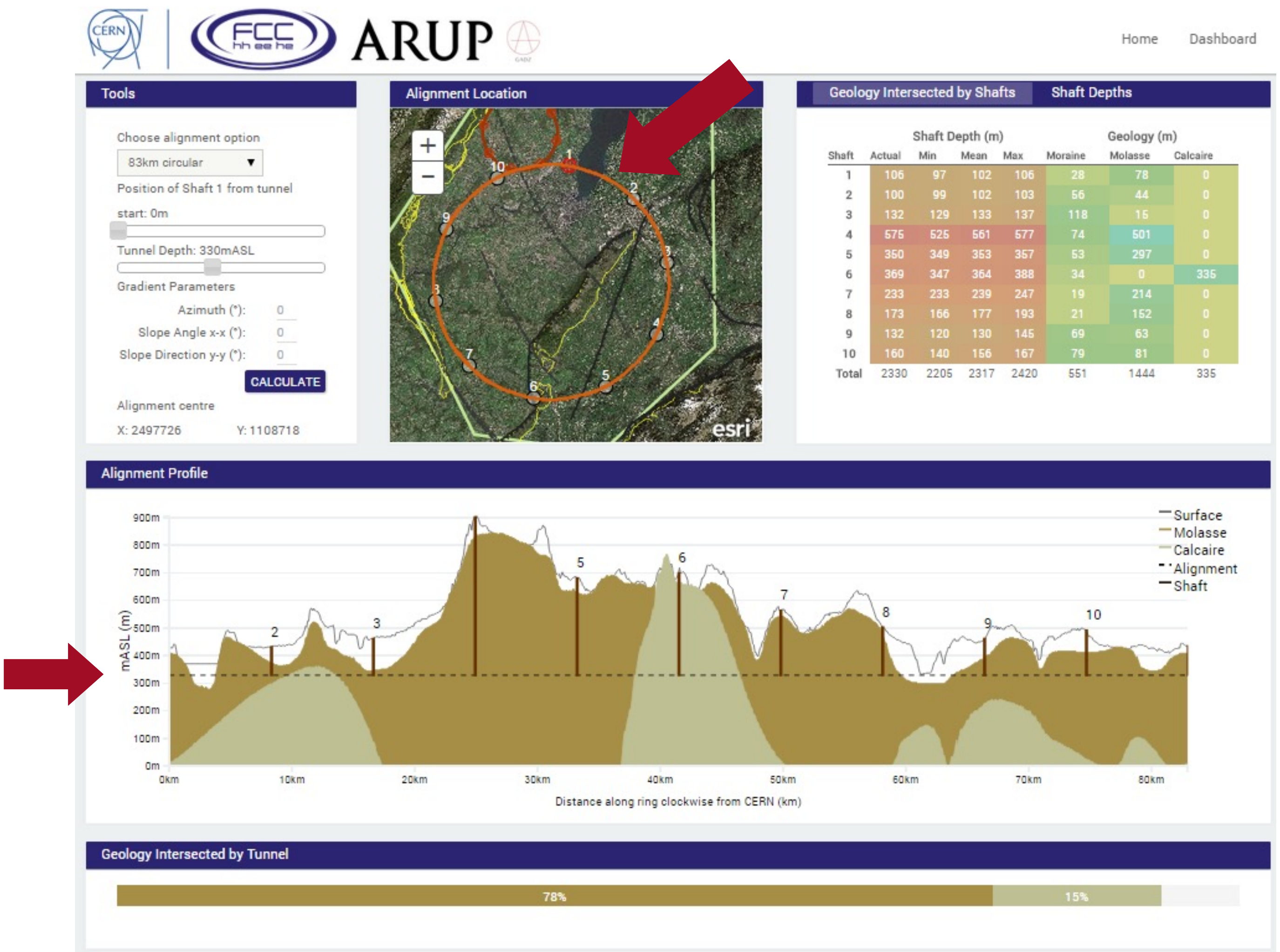


Courtesy:
John Osborne

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

→ The tunnel level must be deeper in the earth

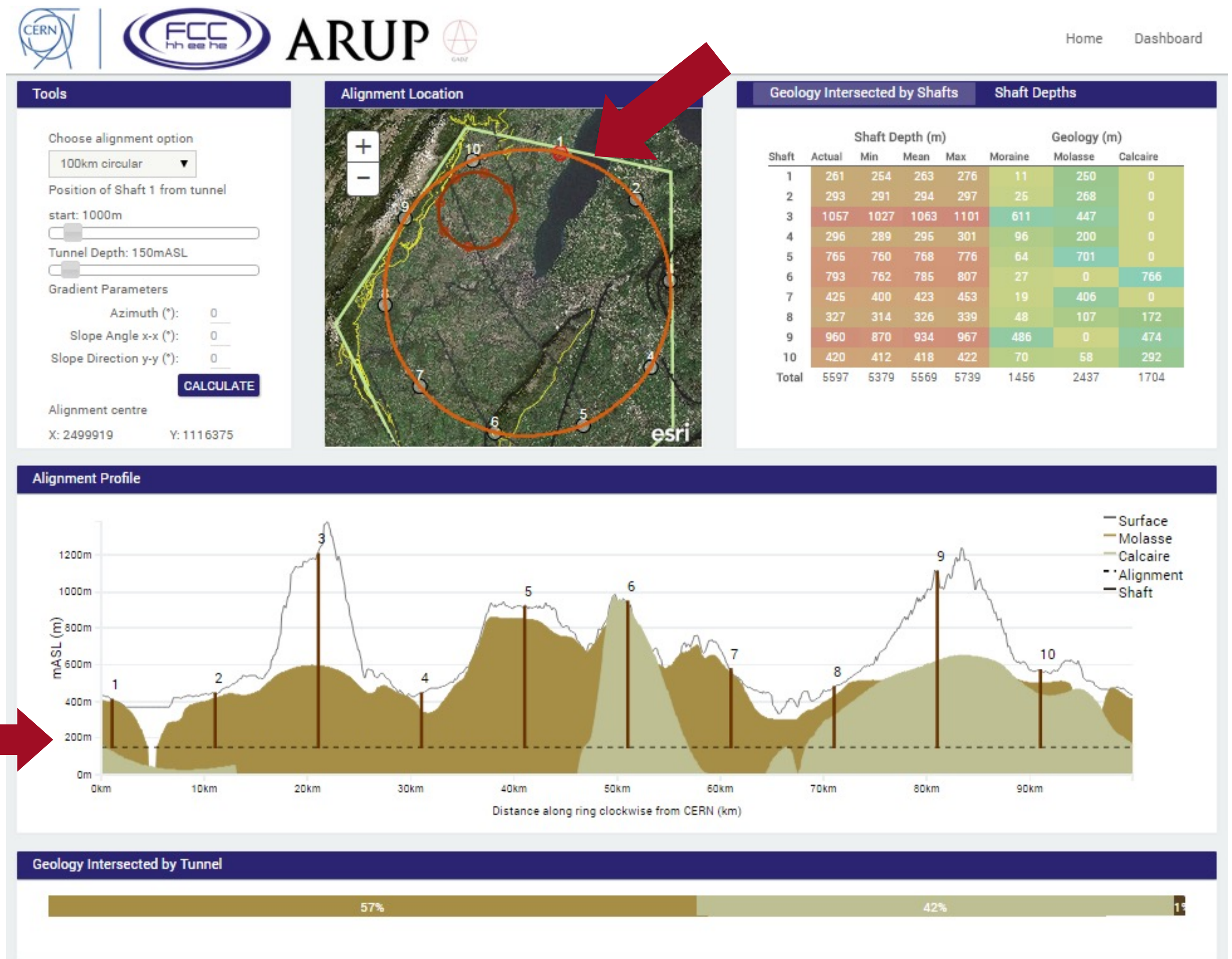
80 km circle



	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 Depth (m)				Geology (m)		
Shaft	Actual	Min	Mean	Max	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

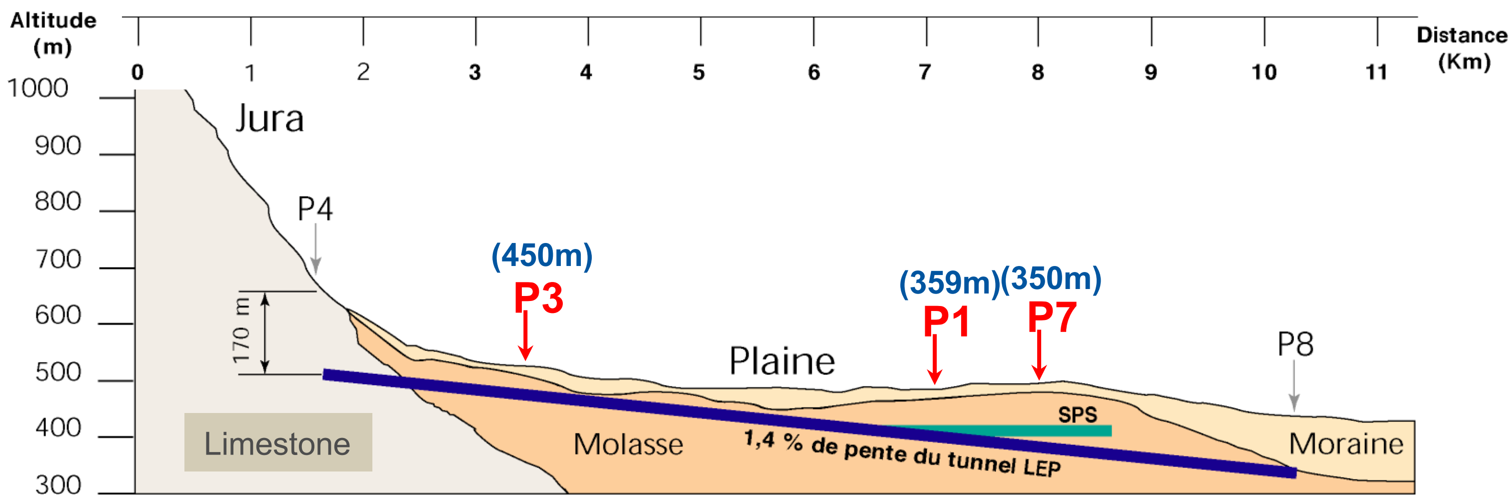
Courtesy: John Osborne, Yung Loo

Tilting the tunnel

- LEP/LHC: 1.42 %

  → Maximize tunnel extend in Molasse, minimize tunnel extend in Limestone and Moraines

  → Minimize the depth of the access shafts



Courtesy: John Osborne

100 km circle with tilt

Home Dashboard

Tools

Choose alignment option

100km circular

Position of Shaft 1 from tunnel

start: 1000m

Tunnel Depth: 273mASL

Gradient Parameters

Azimuth (°): 0

Slope Angle x-x (°): .5

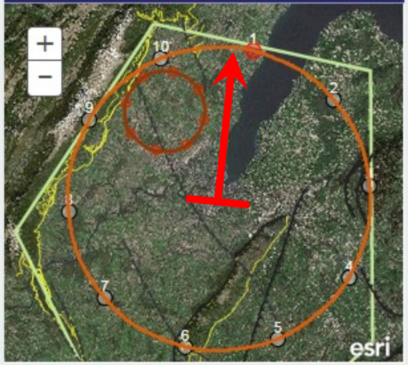
Slope Direction y-y (°): 0

CALCULATE

Alignment centre

X: 2499923 Y: 1116361

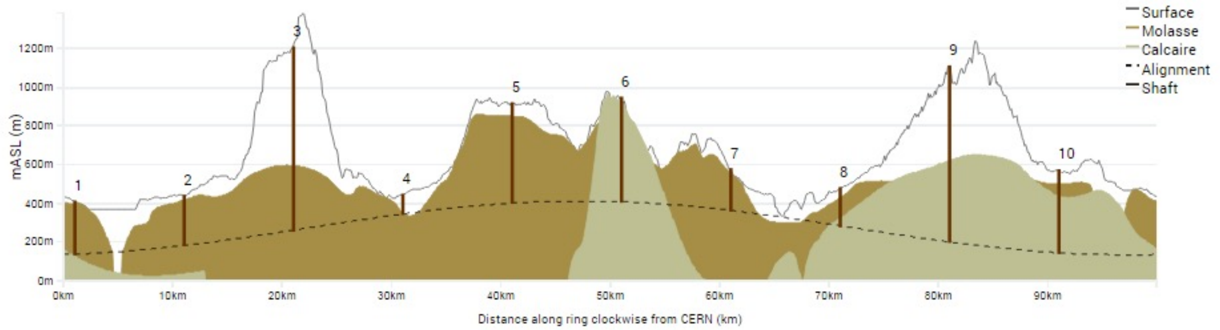
Alignment Location



Geology Intersected by Shafts | **Shaft Depths**

Shaft	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Moraine	Molasse	Calcaire
1	273	266	274	285	11	263	0
2	258	259	261	263	22	236	0
3	946	916	954	990	611	335	0
4	101	94	100	106	96	5	0
5	514	507	512	515	64	449	0
6	534	503	527	550	27	0	508
7	211	186	209	239	13	198	0
8	192	179	191	201	48	107	37
9	909	819	873	909	486	0	423
10	425	417	421	425	70	58	297
Total	4362	4146	4322	4483	1447	1651	1265

Alignment Profile

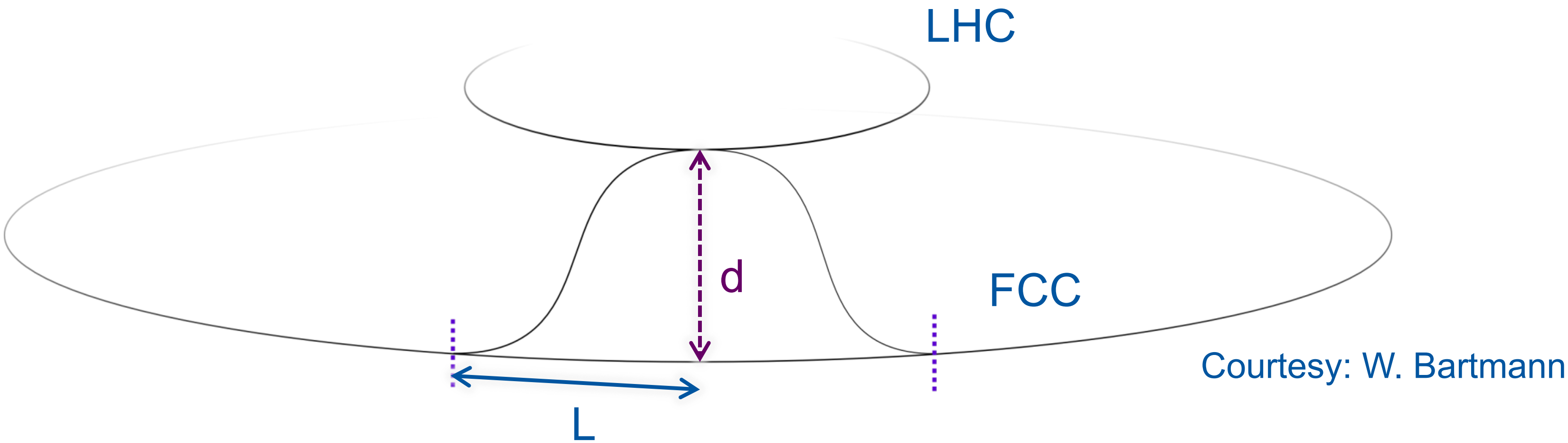


Geology Intersected by Tunnel

56% | 38% | 6%

Courtesy:
John Osborne,
Yung Loo

6) Location relative to LHC

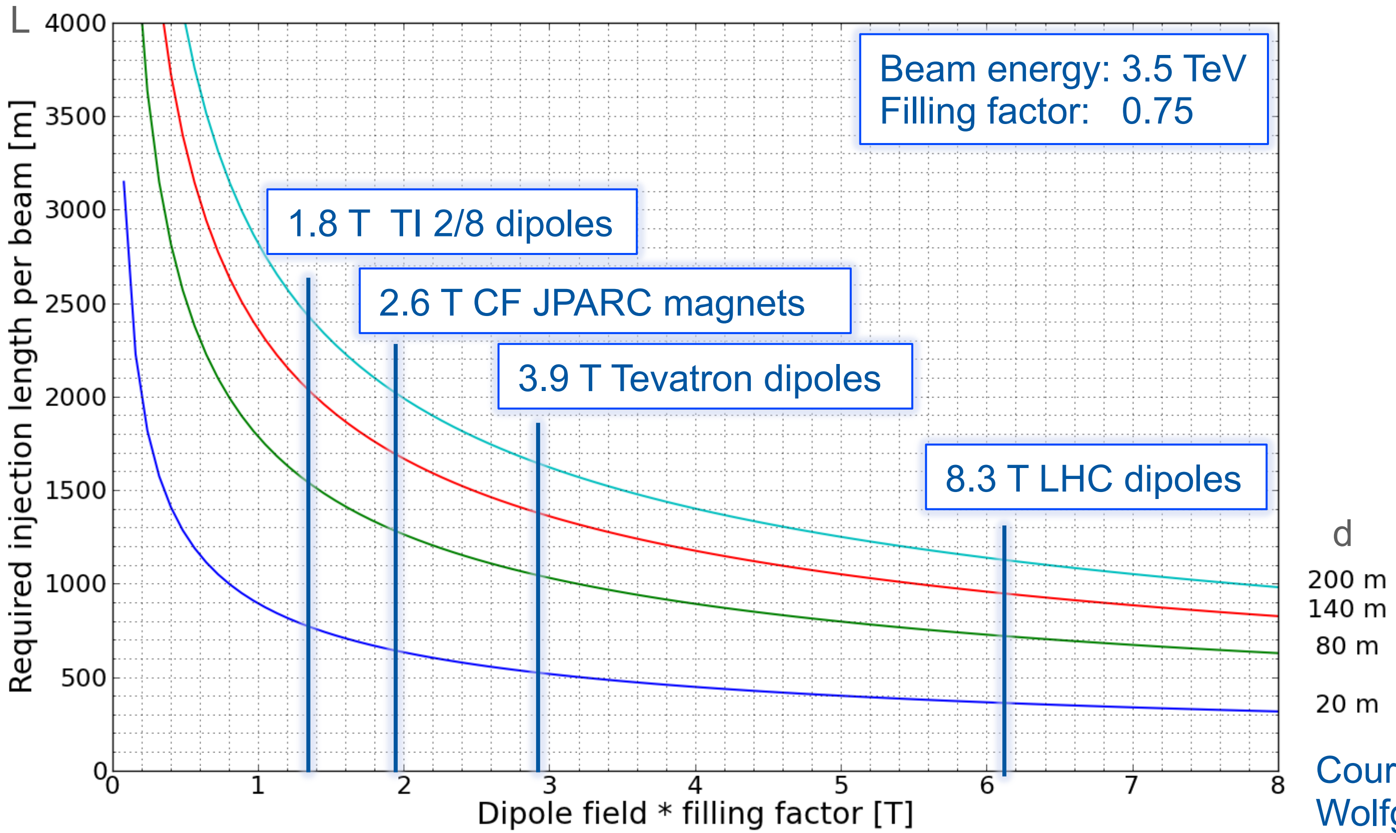


FCC and LHC should overlap, if LHC is used as injector

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: 3.5 TeV

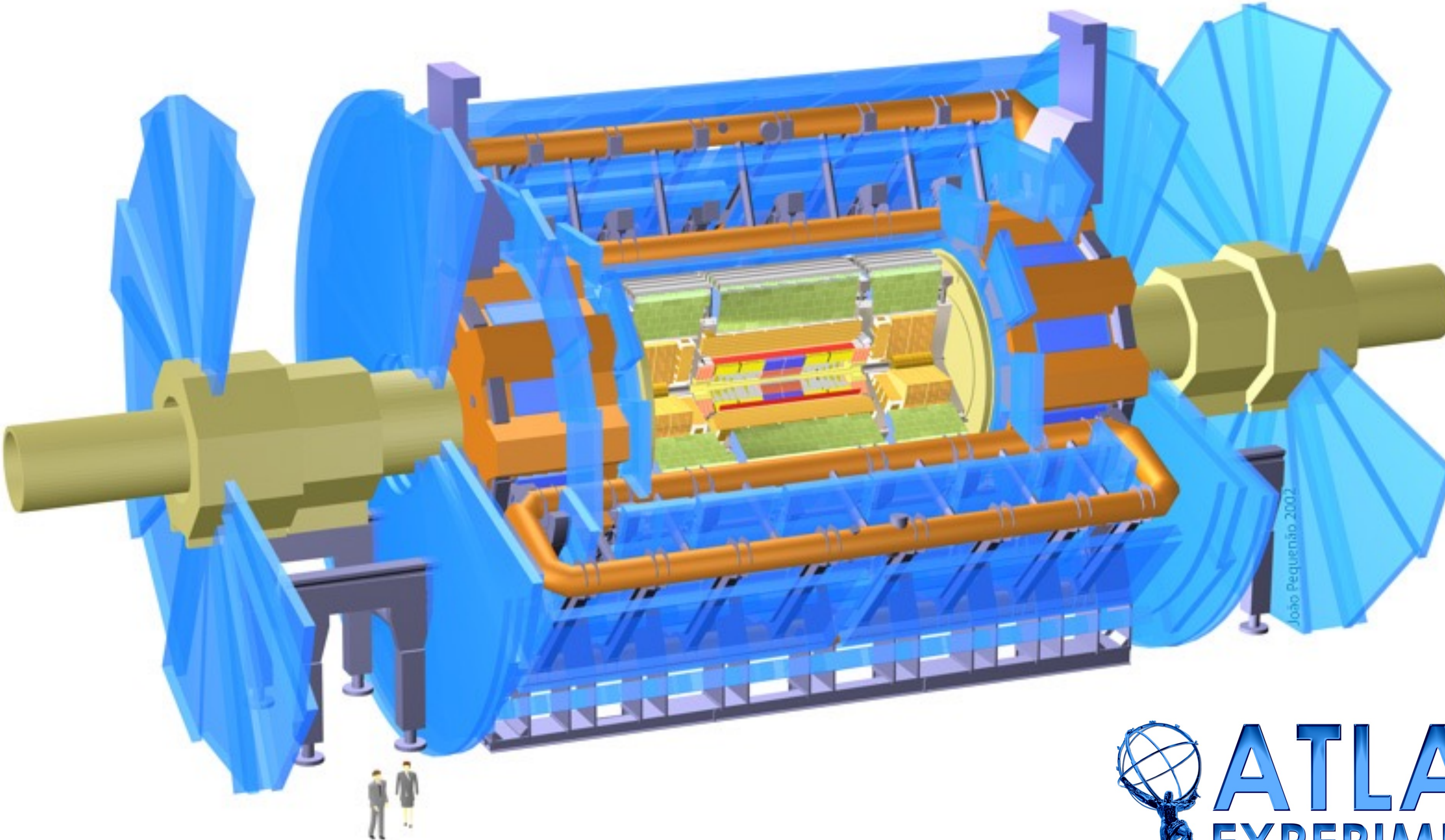
- 600 m

Beam dump: Energy: 50 TeV

- 800 m – 1000 m (?)

Collimation?

8) Experiments



ATLAS EXPERIMENT

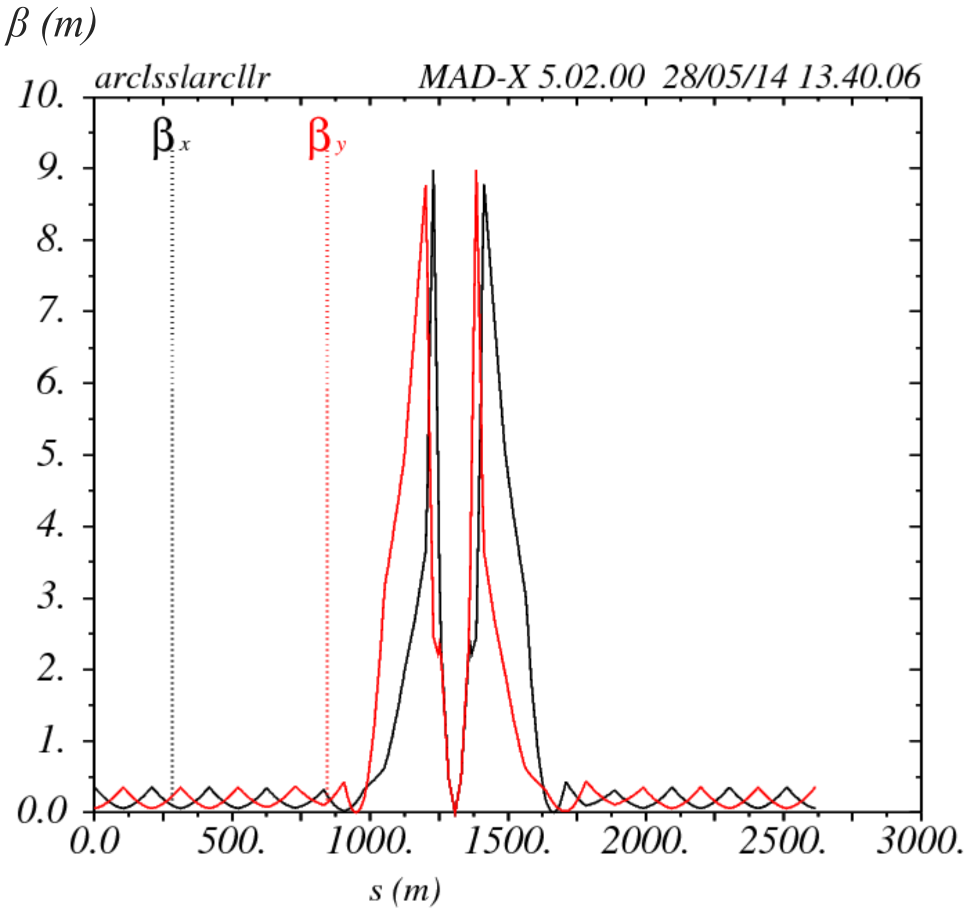
FCC-hh Interaction Region

Interaction region (IR) design for

- Huge Detectors

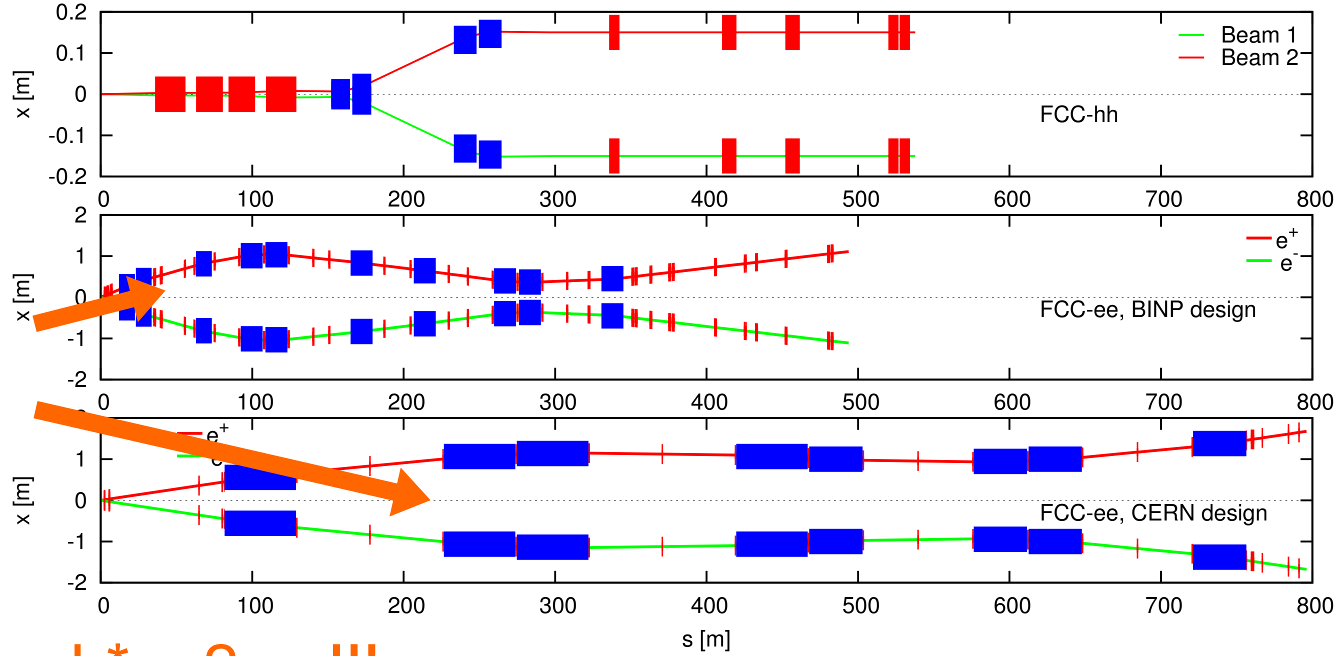
  → L* = 46 m !!!
- Length of single IR:

  → ≈ 1100 m
- Small crossing angle: → 11 µrad
- → β* = 1.1 m



Court. R. Alemany, B. Holzer

FCC-ee Interaction Region



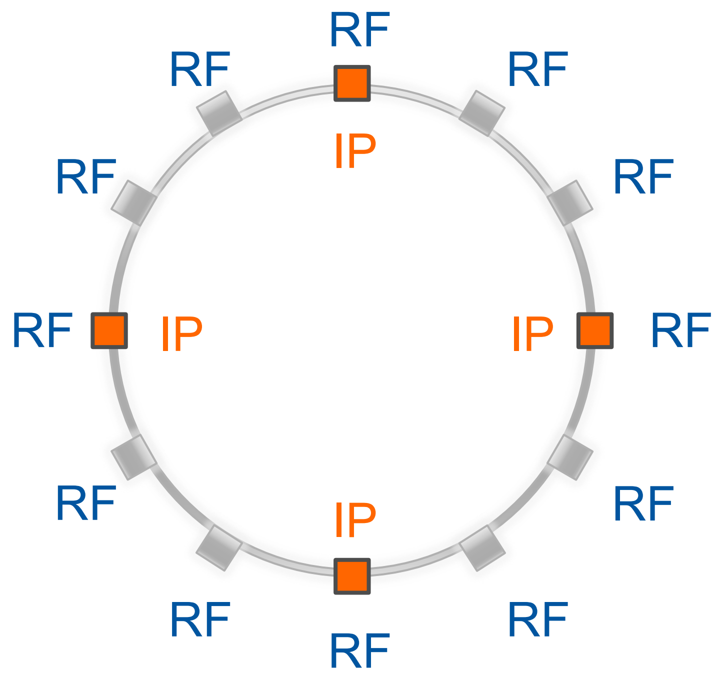
Local chromaticity correction scheme

- $\beta_y^* = 1$ mm, $L^* = 2$ m !!!
- Large crossing angle
  → 30 mrad, 11 mrad
- IR even longer

More about IR design:

Roman Martin's presentation

Current FCC-ee design



Circular shape,

100 km circumference

- 12 straight sections
  → Length: 1.5 km
- 4 experiments
- Length of arcs: 6.8 km
  → $\rho \approx 10.6$ km

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

Resume

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

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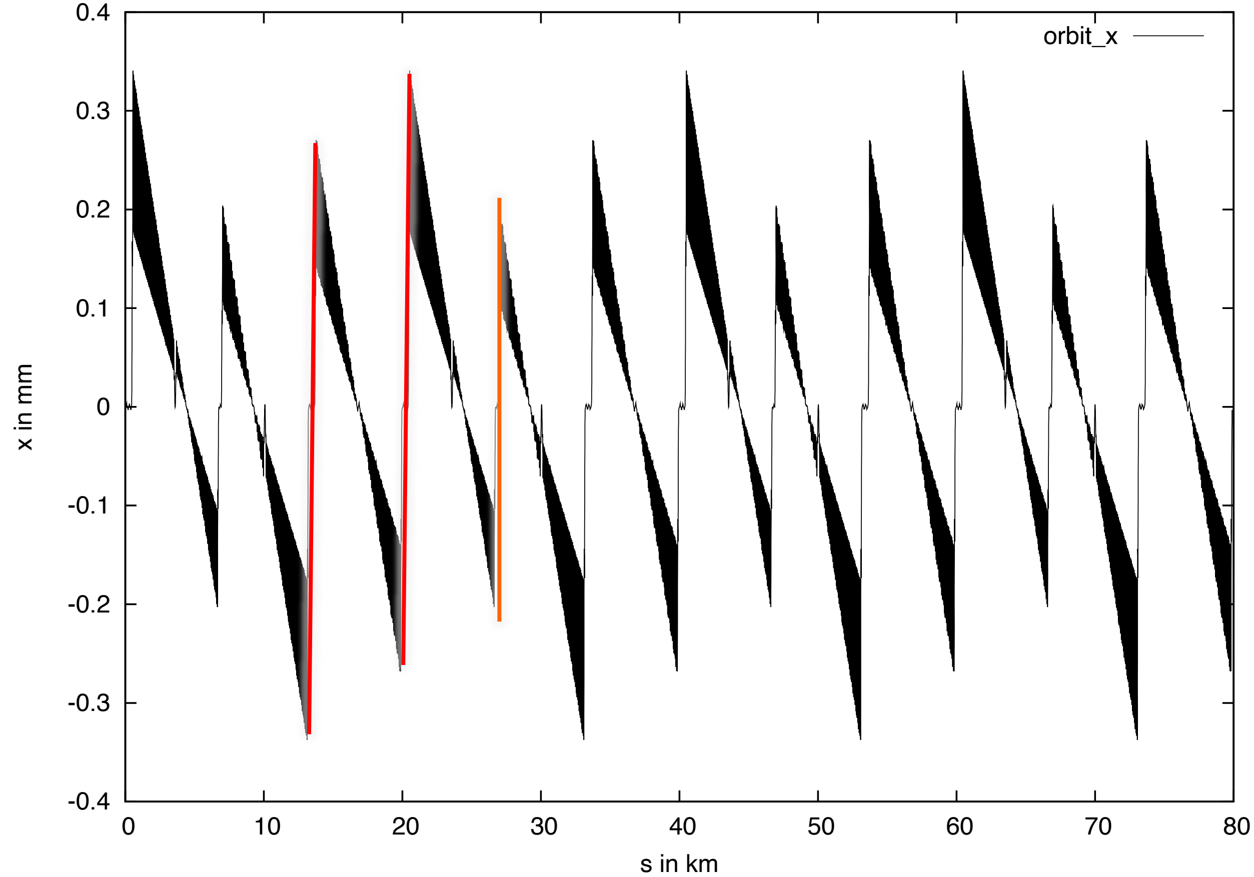
Thank you for your attention!

Court. J. Wenninger

Unequally distributed RF



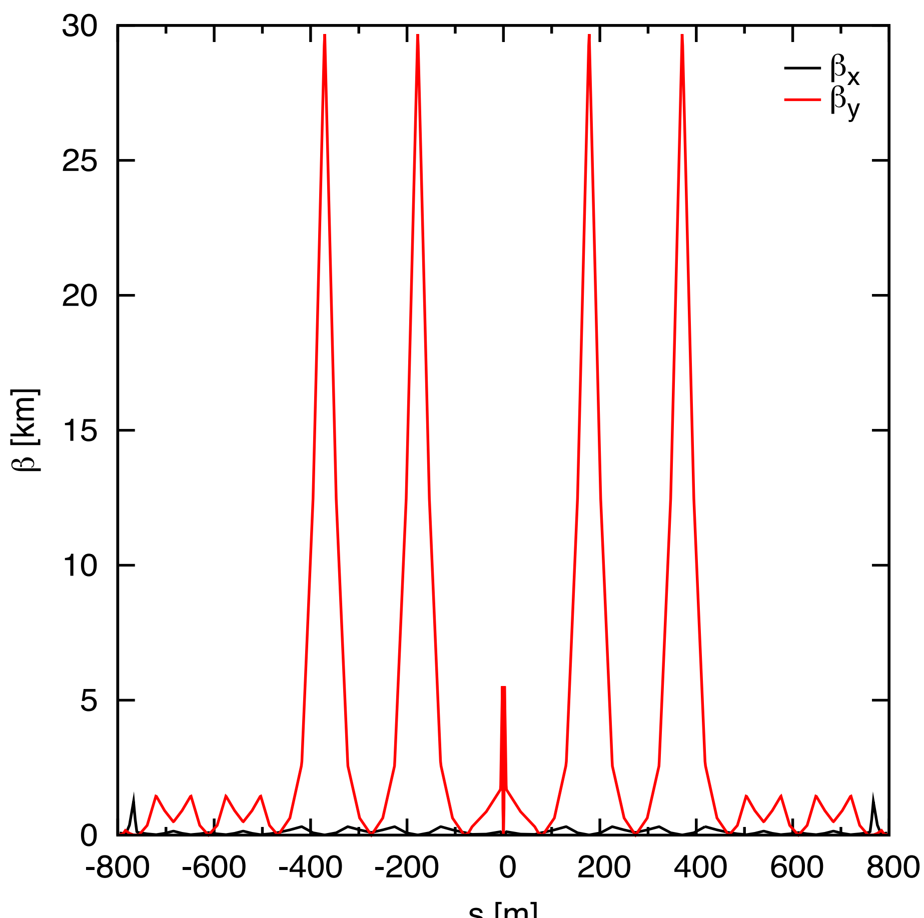
Experiments FCC-ee

Completely different IR design:

- Large crossing angle
- β_y = 1 mm, L* = 2 m !!!
- Local chromaticity correction scheme
- IR length: even larger

More about IR design:

Roman Martin's presentation



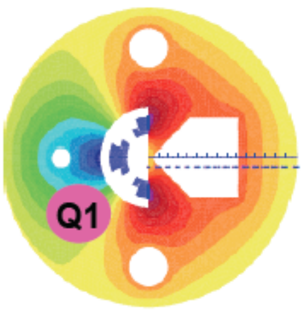
Court. R. Martin

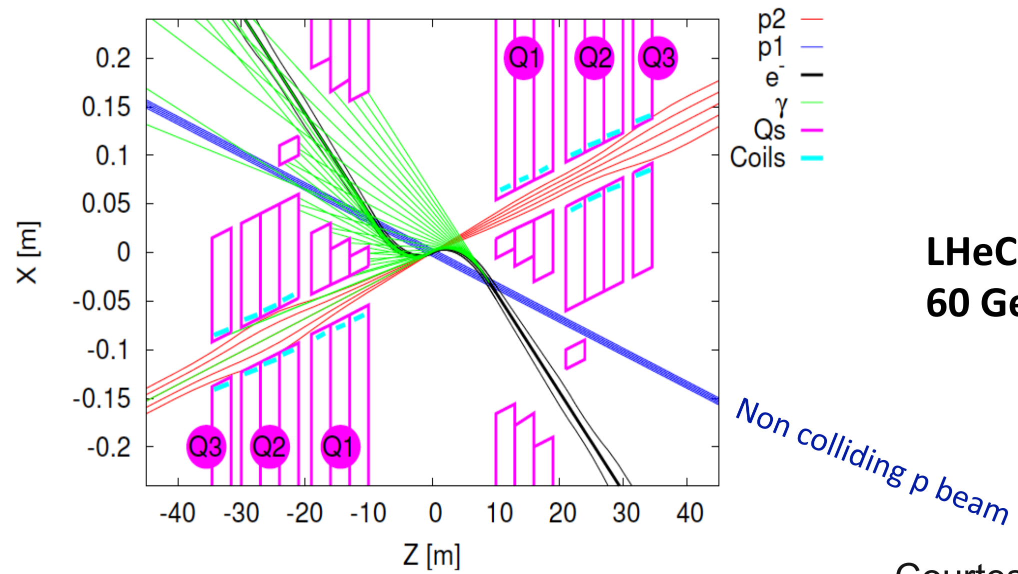
FCC-he design parameters

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	F.Zimmermann ICHEP14, June PRELIMINARY
CM energy [TeV]	3.5	3.5	4.9	
luminosity[10^{34}cm^{-2}s^{-1}]	**1.0**	**6.2**	**0.7**	

LHeC: IR layout

Interaction Regions for ep with Synchronous pp Operation





LHeC (CDR)
60 GeV * 7 TeV

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

Courtesy Max Klein

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