FCC ring layout

J. Wenninger with input from J. Osborne (also slides), D. Schulte, M. Benedikt, P. Lebrun

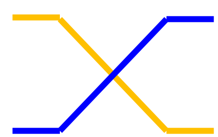
Ring layout and RF distribution

FCC-hh layout proposals

Matching FCC with the local geology

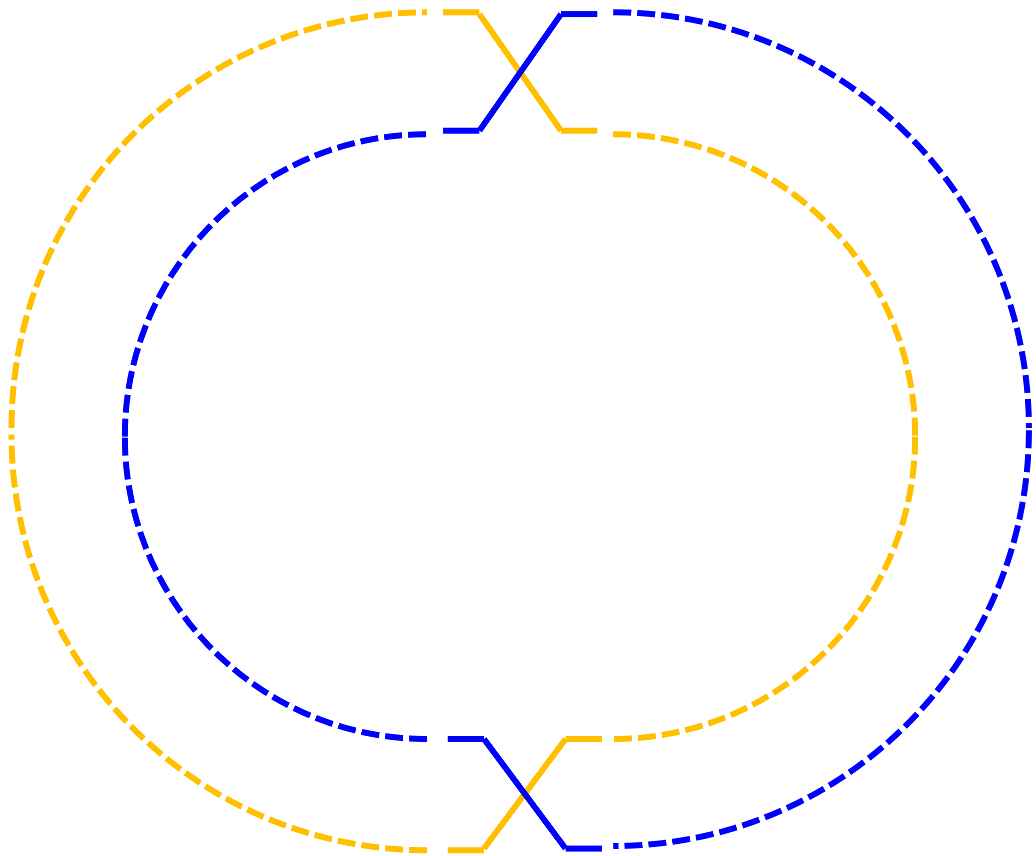
Crossing points & IRs

- We consider a machine with 2 rings. The 2 rings are side by side, i.e. no vertical stacking (dispersion → ε, polarization).
- Follow some *trivial* considerations on the geometry.
  - ✓ The path length of both beams must be identical (same energy & v/c). Consequently they must spend the same fraction of the circumference on inside and outside ring → symmetry constraint on crossing points.
  - ✓ At every crossing (with or without collisions) the beams exchange roles wrt inside and outside → to close the ring properly the total number of IPs and crossings must be an even number.
  - ✓ A priori I assume that we have only crossings at experiments – no extra ones (beam-beam, need for separation, extra bending → energy loss…).

2 N ×  with N integer

Simplest case with 2 crossing points / experiments and a circular ring.

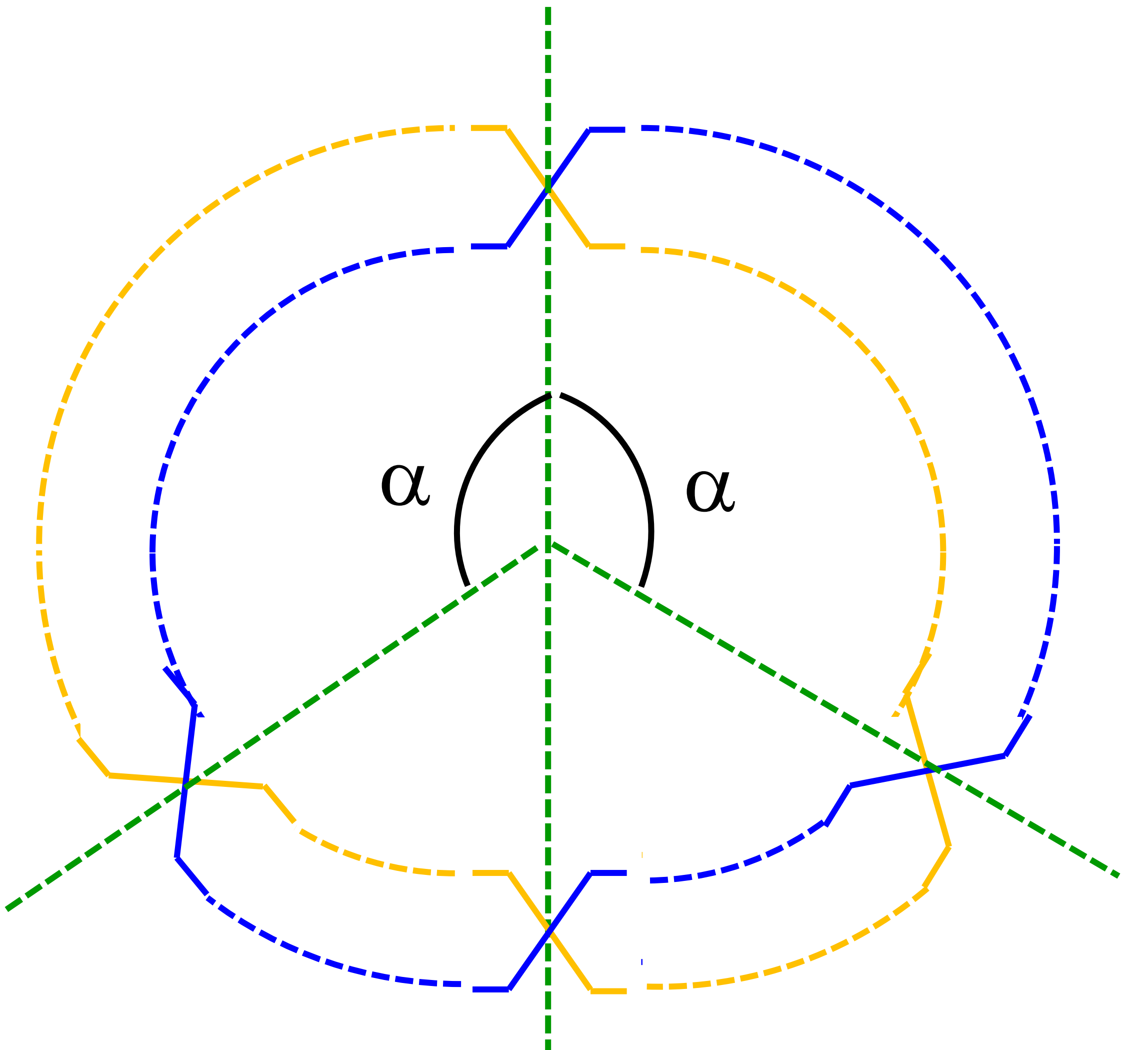
- They must be on opposite sides of the ring: path length is the same for both beams.



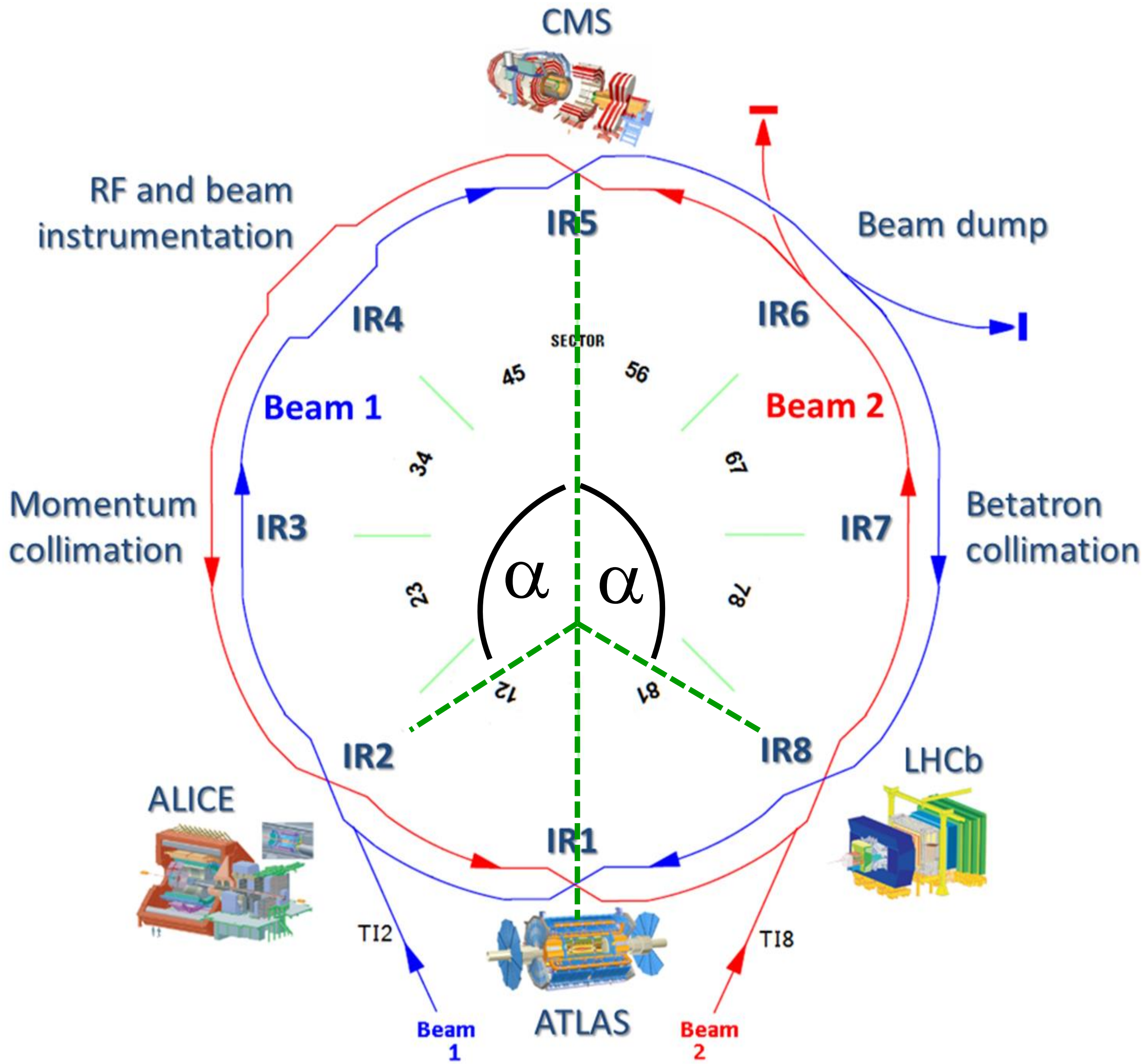
Symmetry and crossing

Additional crossing points / experiments and a circular ring.

- They must be placed symmetrically around the symmetry axis defined by first 2 experiments / crossings.



A famous example

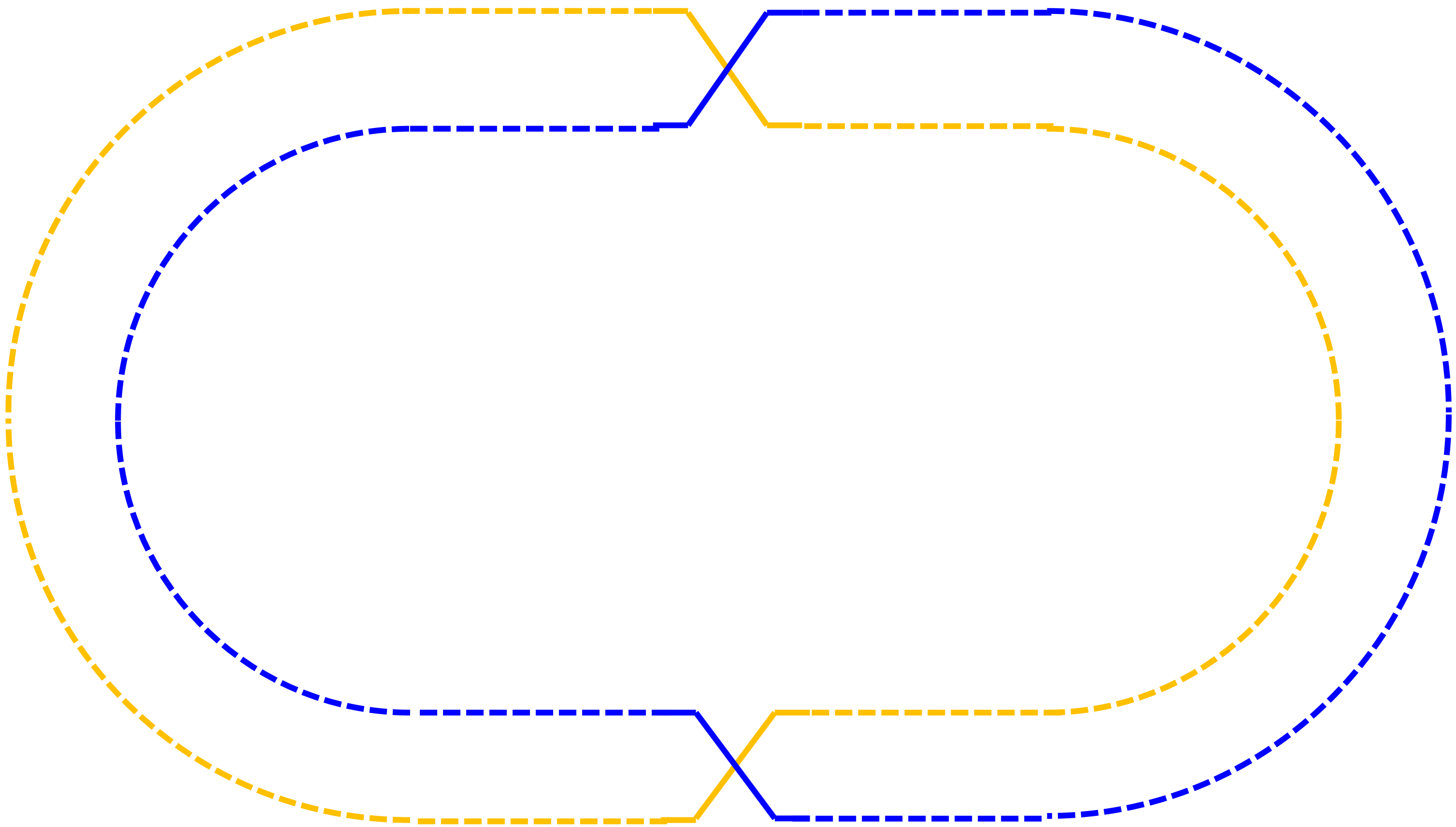


Racetrack

To minimize the number of crossings → no crossing in the ½ arcs →the two beams must exchange roles (in ⇔ out) in the long straights.

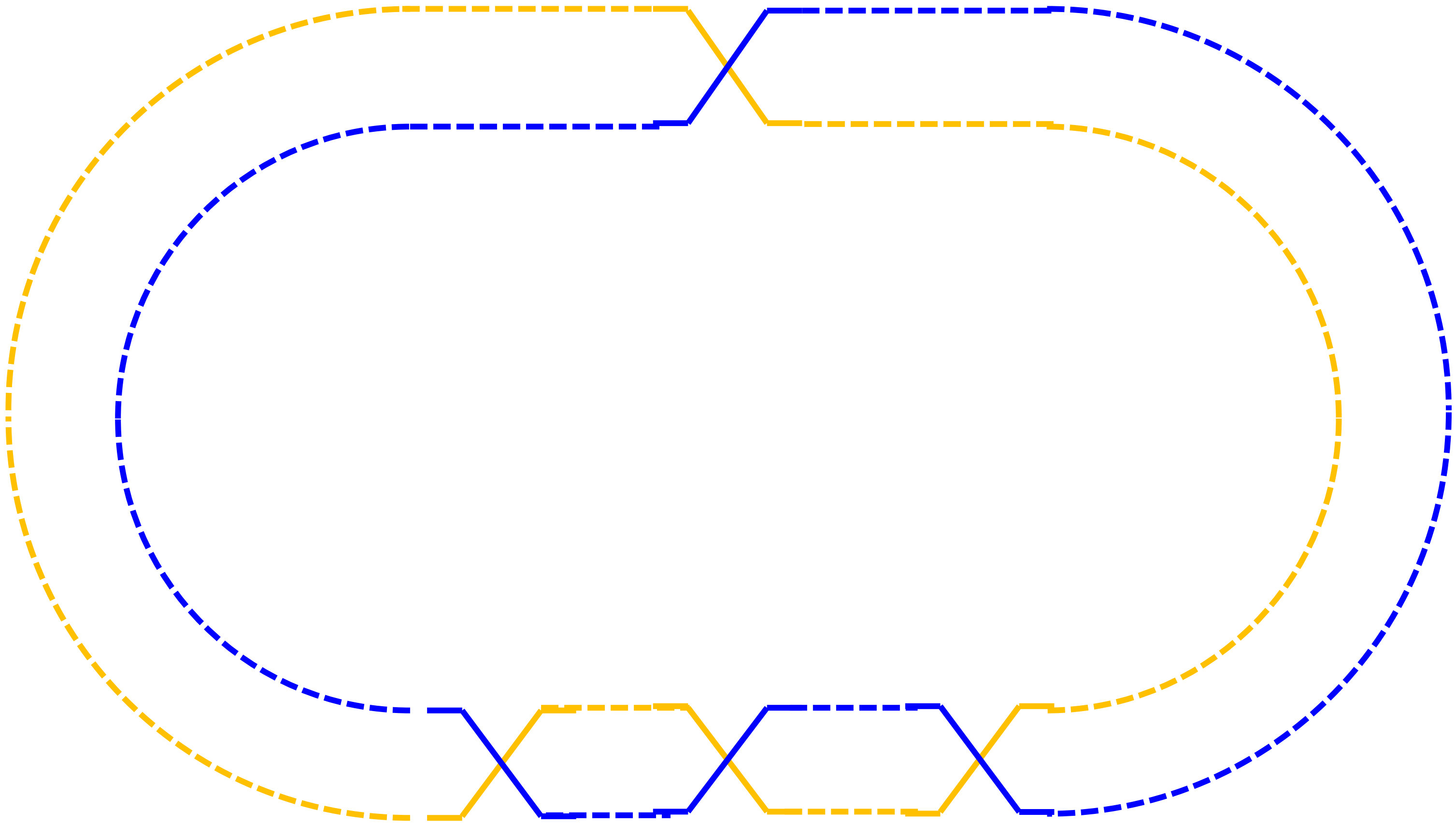
- There must be **AT LEAST ONE** crossing / experiment in each long straight !
- The number of crossings / experiments per long straight must be an **ODD number**!

  -- 2 experiments per long straight does not work (or one needs extra crossings !)



Racetrack with 4 experiments

A racetrack ring with 4 experiments and no extra crossing has one long straight with one experiment and the other with 3 experiments.

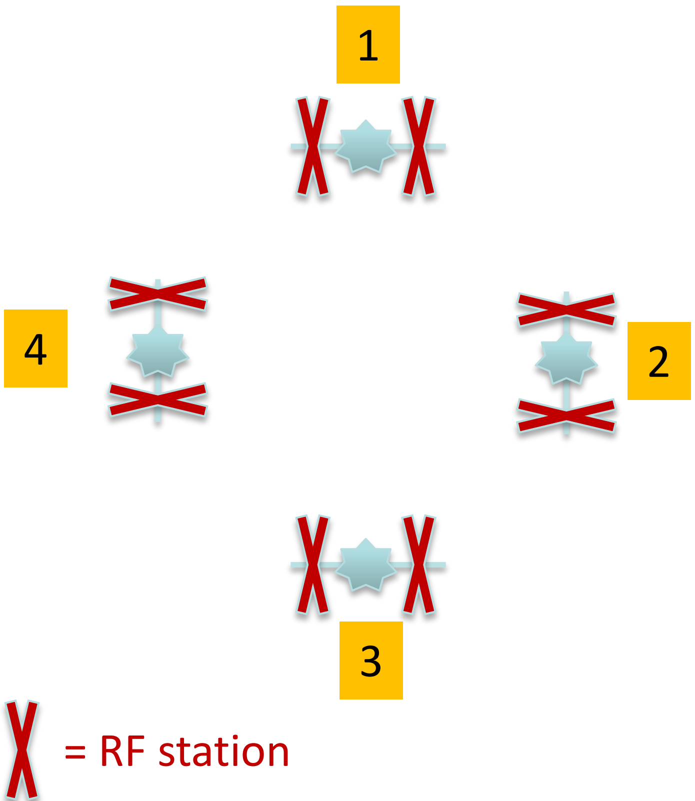


RF system consideration

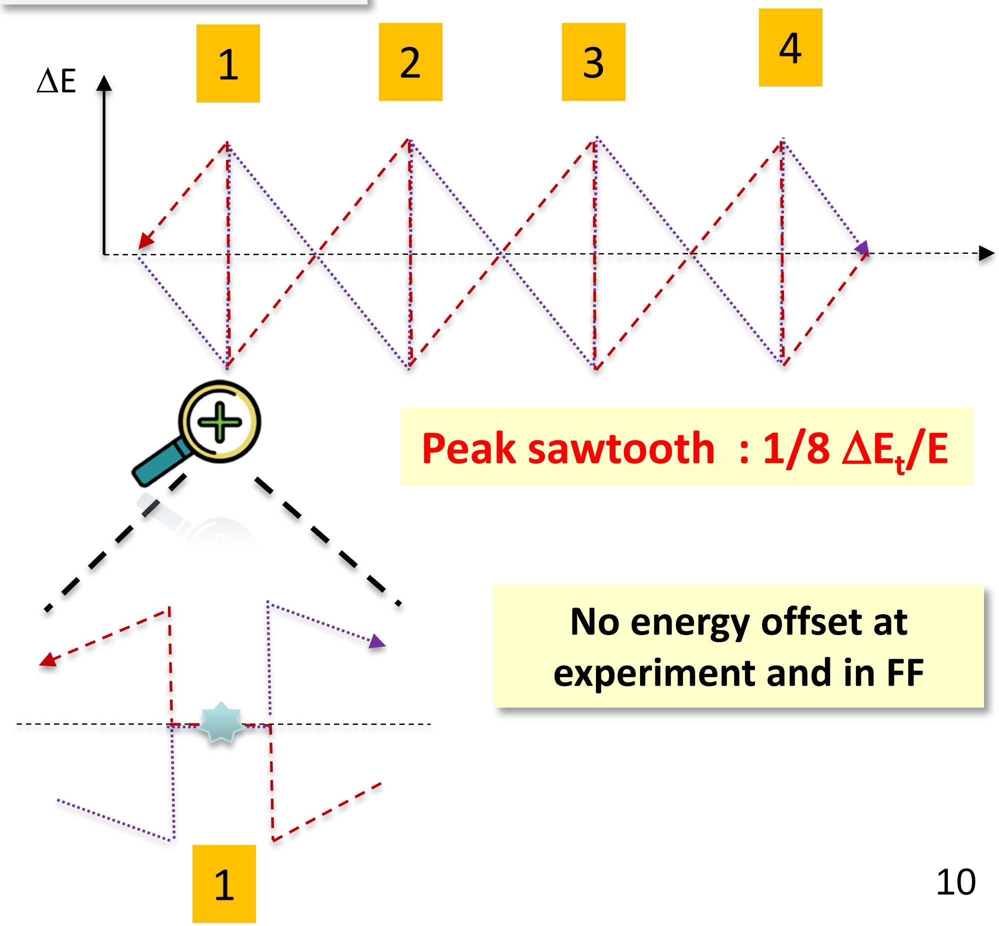
- The RF system should ideally be distributed over all LSS to minimize the energy sawtooth and the associated optics perturbations.
  - And the distribution should ideally be symmetric around the ring.
- Each experiment should be surrounded by RF sections to ensure that the energy offset can be minimized in the final focus region.
  - Additional RF stations may be required along the ring to control the energy excursions due to the energy sawtoothing – impact on optics.
- Energy loss per turn (100 km):
  - 120 GeV: $\Delta E_t = 1.67$ GeV → $\Delta E_t/E = 1.4\%$
  - 175 GeV: $\Delta E_t = 7.7$ GeV → $\Delta E_t/E = 4.3\%$
- If only 2 LSS are equipped with RF (opposite sides of ring):
  - 120 GeV: peak sawtooth = $\pm\frac{1}{4}\,\Delta E_t/E = \pm\,0.35\%$
  - 175 GeV: peak sawtooth = $\pm\frac{1}{4}\,\Delta E_t/E = \pm\,1.1\%$

RF & sawtooth : symmetric ring

- Ring with 4-fold symmetry – 8 RF stations surrounding the experiments. **Same RF voltage for each station**.



Energy sawtooth



Peak sawtooth : 1/8 $\Delta E_t/E$

No energy offset at experiment and in FF

Ring layout and RF distribution

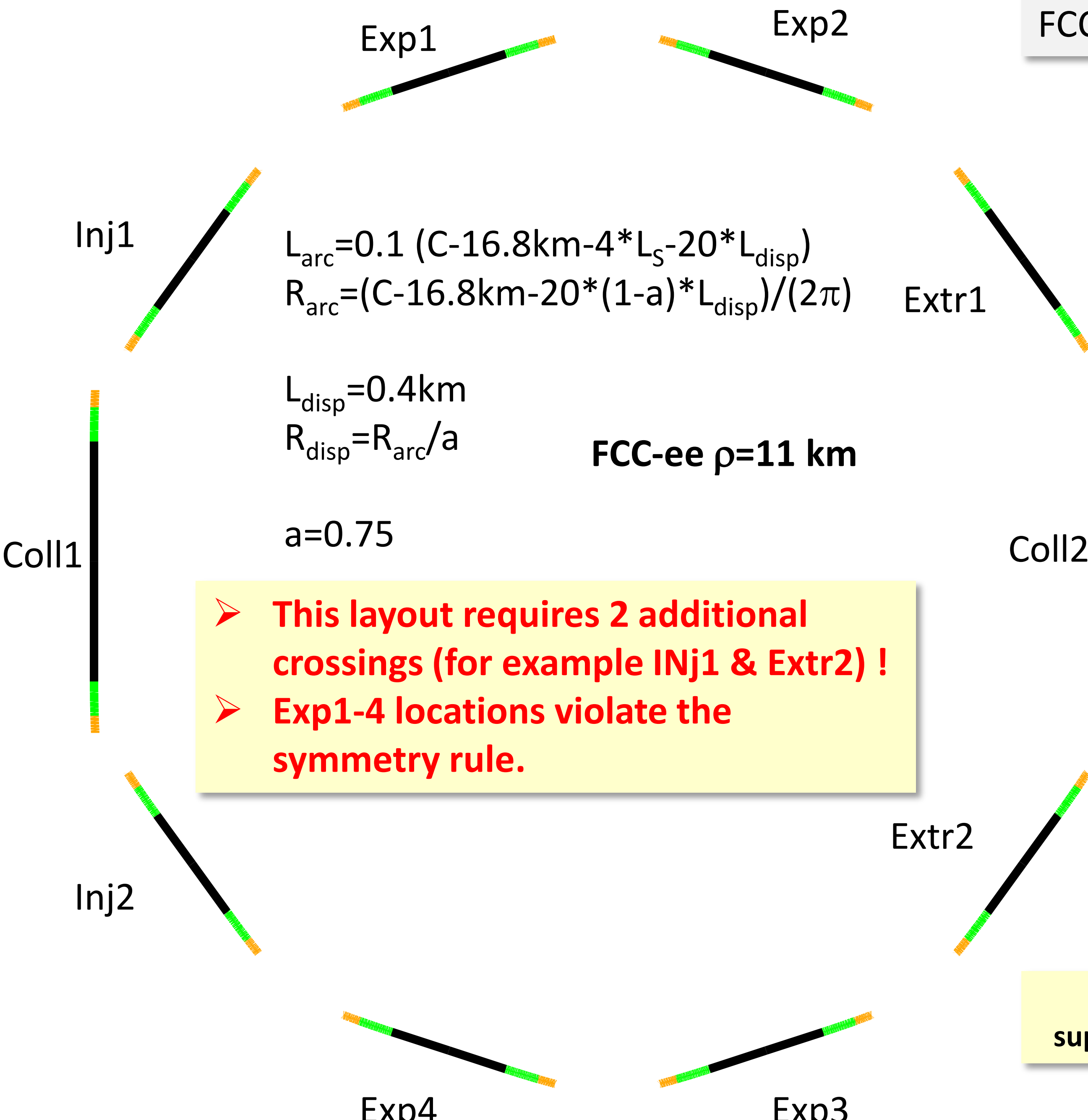
FCC-hh layout proposals

Matching FCC with the local geology

FCC-hh ring layout proposals

- Two (very preliminary) proposals for FCC-hh by D. Schulte.
- One proposal is a ring with (almost) 10-fold symmetry, one proposal is a racetrack.
  - *Bear in mind that the length of the sections for extraction (dump) and collimation are not well known, not the total number of straights..*
- The ring proposal actually violates the symmetry rule on the distribution of experiments that also applies to the hh machine.
- The racetrack has *pseudo* long straights:
  - *The long straight is split into 3 straight sections and small bending sections (> 100 mrad) to lower potential muon backgrounds.*

FCC-hh ring by D. Schulte



L_{arc}=0.1 (C-16.8km-4*L_S-20*L_{disp})
R_{arc}=(C-16.8km-20*(1-a)*L_{disp})/(2π)

L_{disp}=0.4km
R_{disp}=R_{arc}/a

a=0.75

FCC-ee ρ=11 km

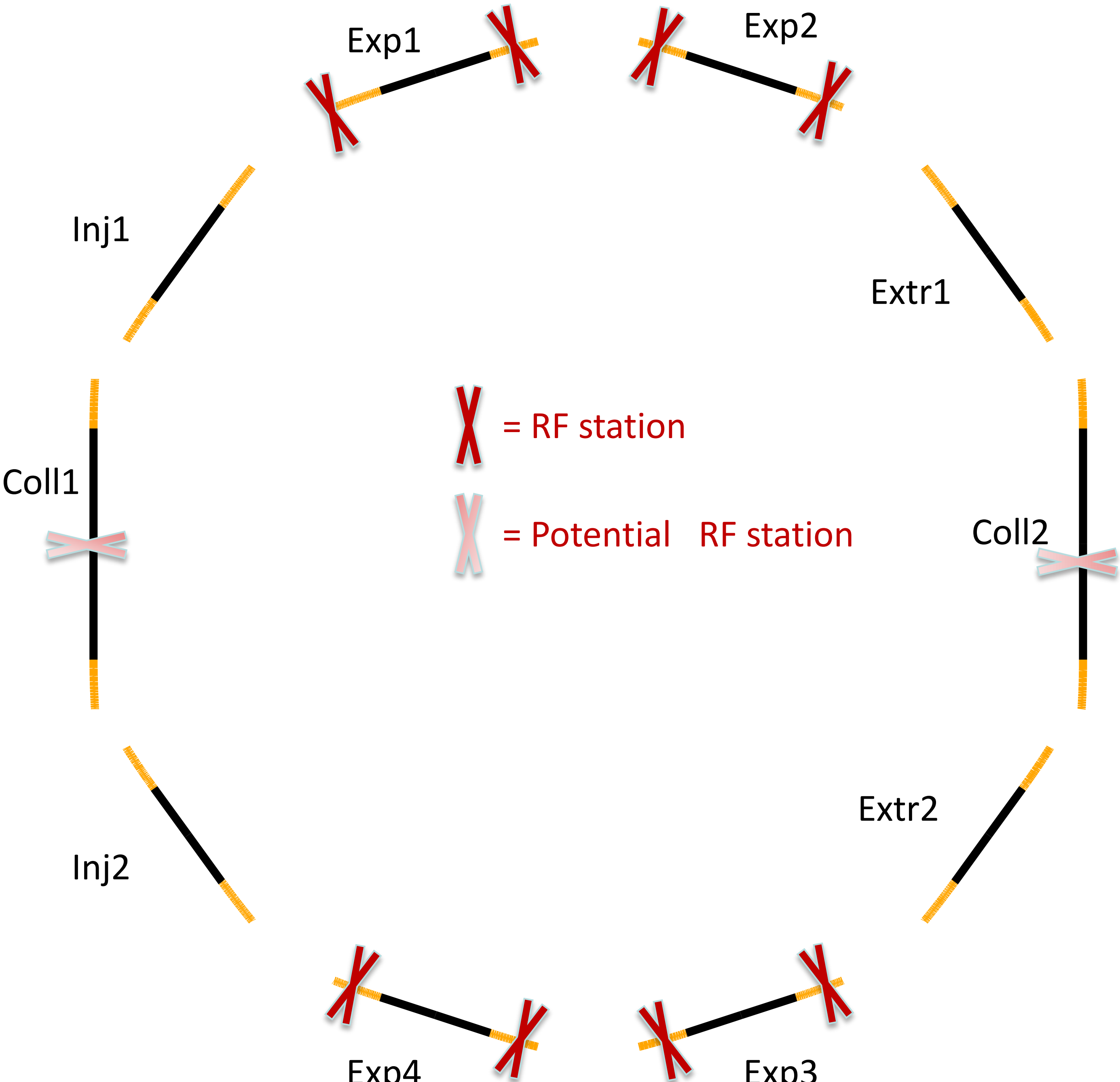
- **This layout requires 2 additional crossings (for example INj1 & Extr2) !**
- **Exp1-4 locations violate the symmetry rule.**

Insertion	Length
Exp1	1.4 km
Exp2	1.4 km
Exp3	1.4 km
Exp4	1.4 km
Coll1	2.8 km
Coll2	2.8 km
Inj1	1.4 km
Inj2	1.4 km
Extr1	1.4 km
Extr2	1.4 km

Dispersion suppressors in green

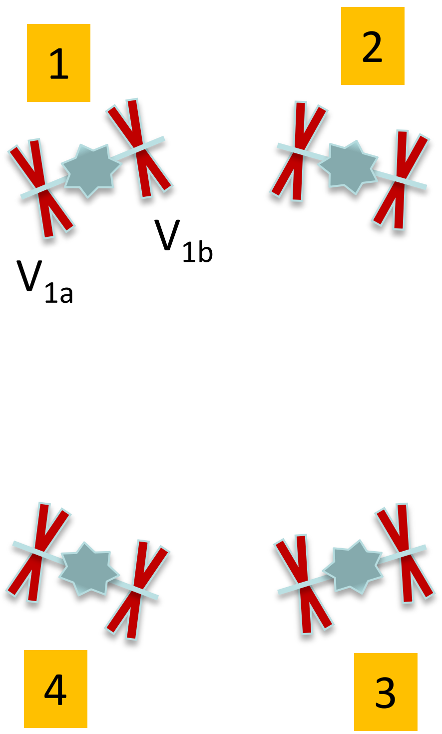
FCC-hh versus FCC-ee

- The proposed FCC-hh layout can easily be adapted for FCC-ee since the space requirements for injection, extraction and collimation are much reduced.
  - Can fit both injections in the same LSS, and the same remark is valid for collimation or extraction system.
  - RF installed wherever necessary to control the sawtooth.

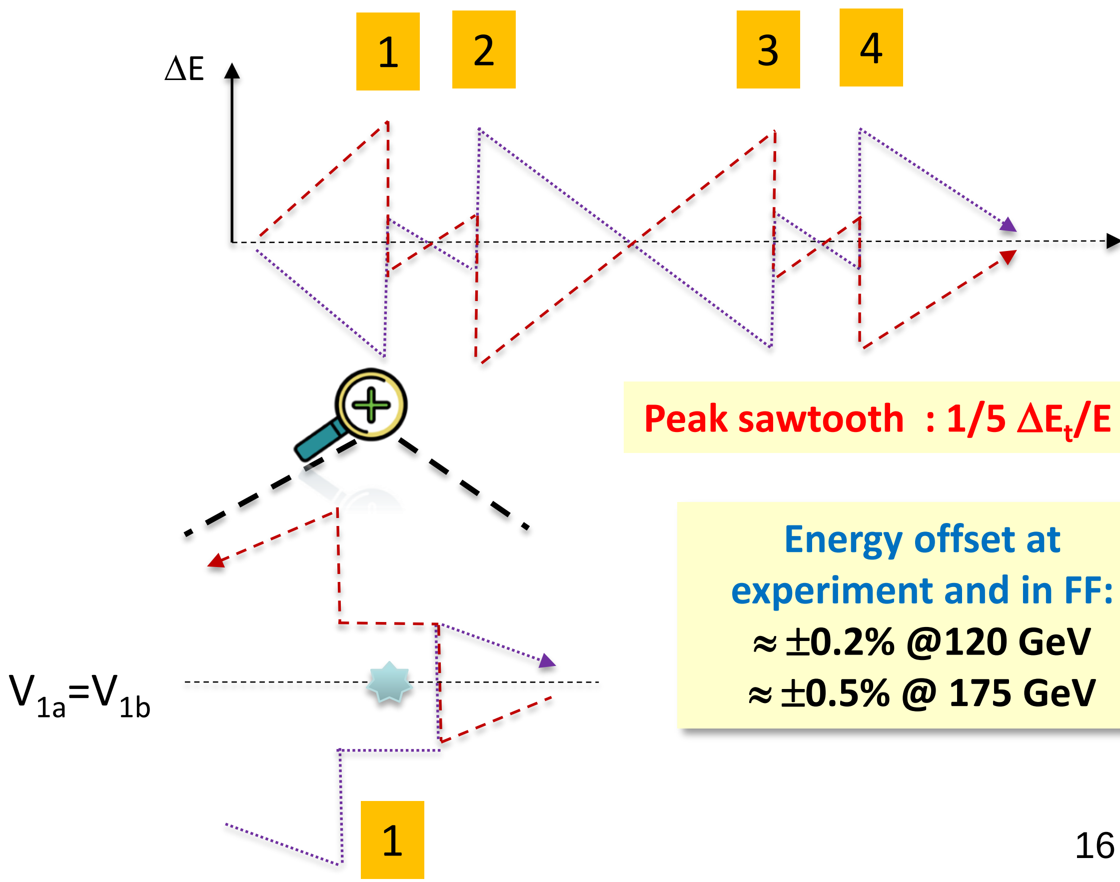


LSS	Length
Exp1	1.4 km
Exp2	1.4 km
Exp3	1.4 km
Exp4	1.4 km
Coll1	2.8 km
Coll2	2.8 km
Inj1	1.4 km
Inj2	1.4 km
Extr1	1.4 km
Extr2	1.4 km

- Consider the FCC-hh ring of the previous slide with 8 RF stations surrounding the 4 experiments - **same RF voltage for each station**.



Energy sawtooth



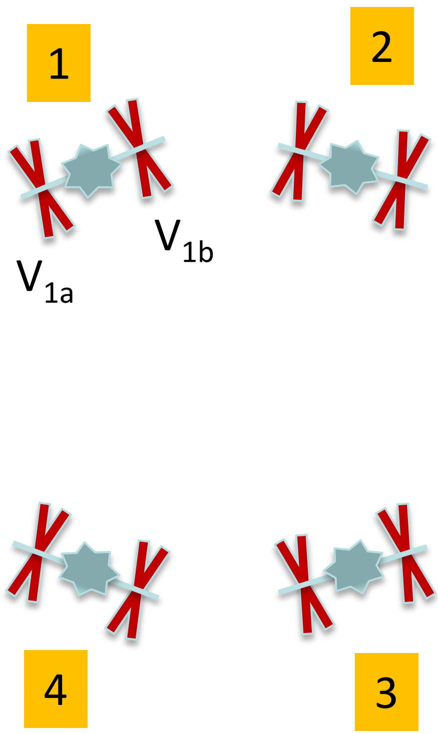
Peak sawtooth : 1/5 $\Delta E_t/E$

Energy offset at experiment and in FF:
≈ ±0.2% @120 GeV
≈ ±0.5% @ 175 GeV

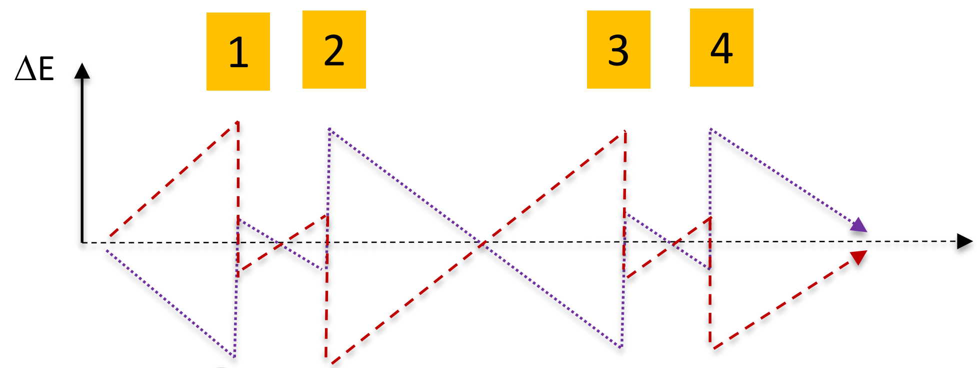
= RF station

RF & sawtooth - asymmetric ring

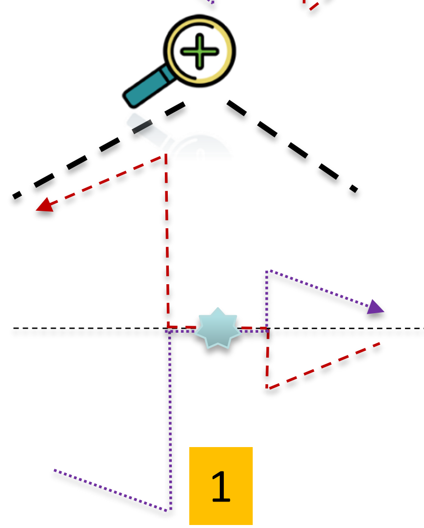
- Consider the same configuration as before, but this time with **asymmetric RF voltage/station**.



Energy sawtooth



Peak sawtooth : 1/5 ΔE/E



$V_{1a}>V_{1b}$

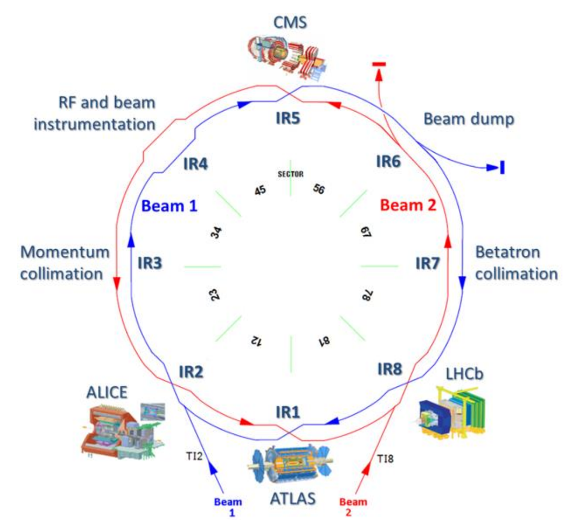
$V_{1a}=4V_{1b}$

No energy offset at experiment and in FF: ⇔ match RF voltage ratio to arc lengths (energy loss)

 = RF station

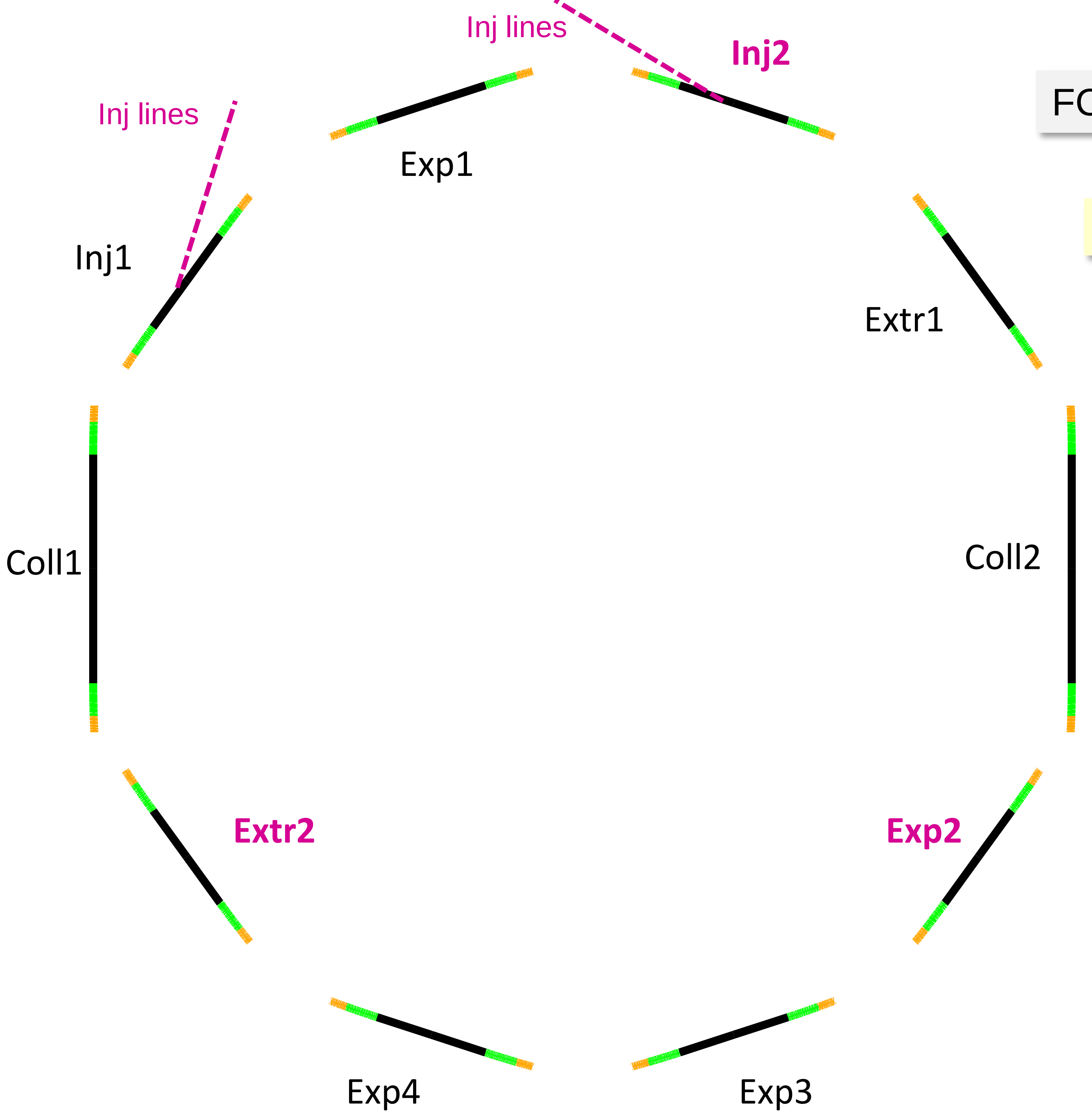
RF distribution

- For the previous case, additional RF stations in ‘Coll1’ and ‘Coll2’ (half-way) would lower the peak energy sawtooth to 1/10 $\Delta E_t/E$ → peak sawtooth of:
  - *<0.2% at 120 GeV – OK.*
  - *~0.4% at 175 GeV – OK?*
- In case of asymmetries, the RF voltage must potentially be different on the two sides of each experiments → on-momentum in FF.
- In case a 10-fold symmetric ring is chosen, it would be more appropriate to have a layout of experiments ‘a la LHC’:
  - 2 experiments opposite of each other, and 2 experiments on either side of one of the 2 experiments.
- For the hh option the 2 LSS around the isolated experiment could be used for injection, and located at the boundary of LHC → see later !

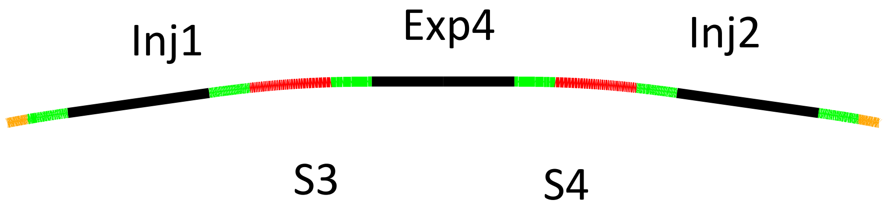


FCC-hh ring - adapted

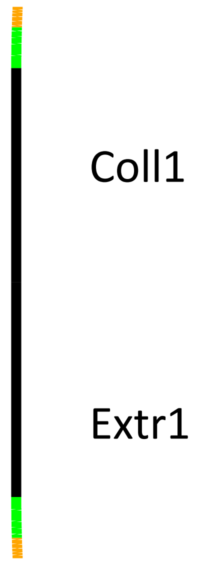
Changes in magenta



FCC-hh racetrack by D. Schulte



4 short arcs (100 mrad) to separate the experiments (Si) – in red

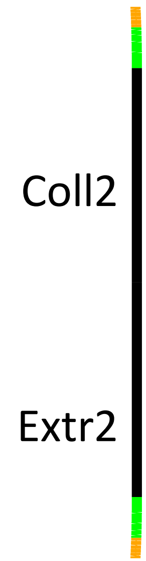


L_{arc}=0.25 (C-16.8km-4*L_S-16*L_{disp})
R_{arc}=(C-16.8km-16*(1-a)*L_{disp})/(2π)

L_S=0.8km
R_S=R_{arc}

L_{disp}=0.4km
R_{disp}=R_{arc}/a

a=0.75



Insertion	Length
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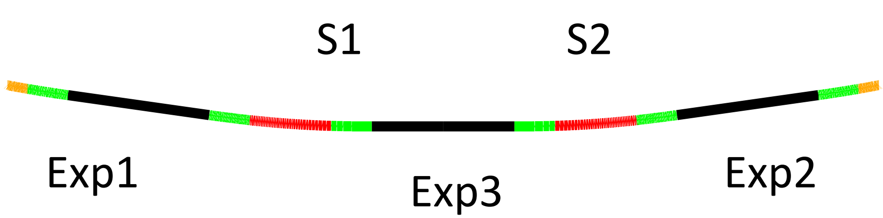
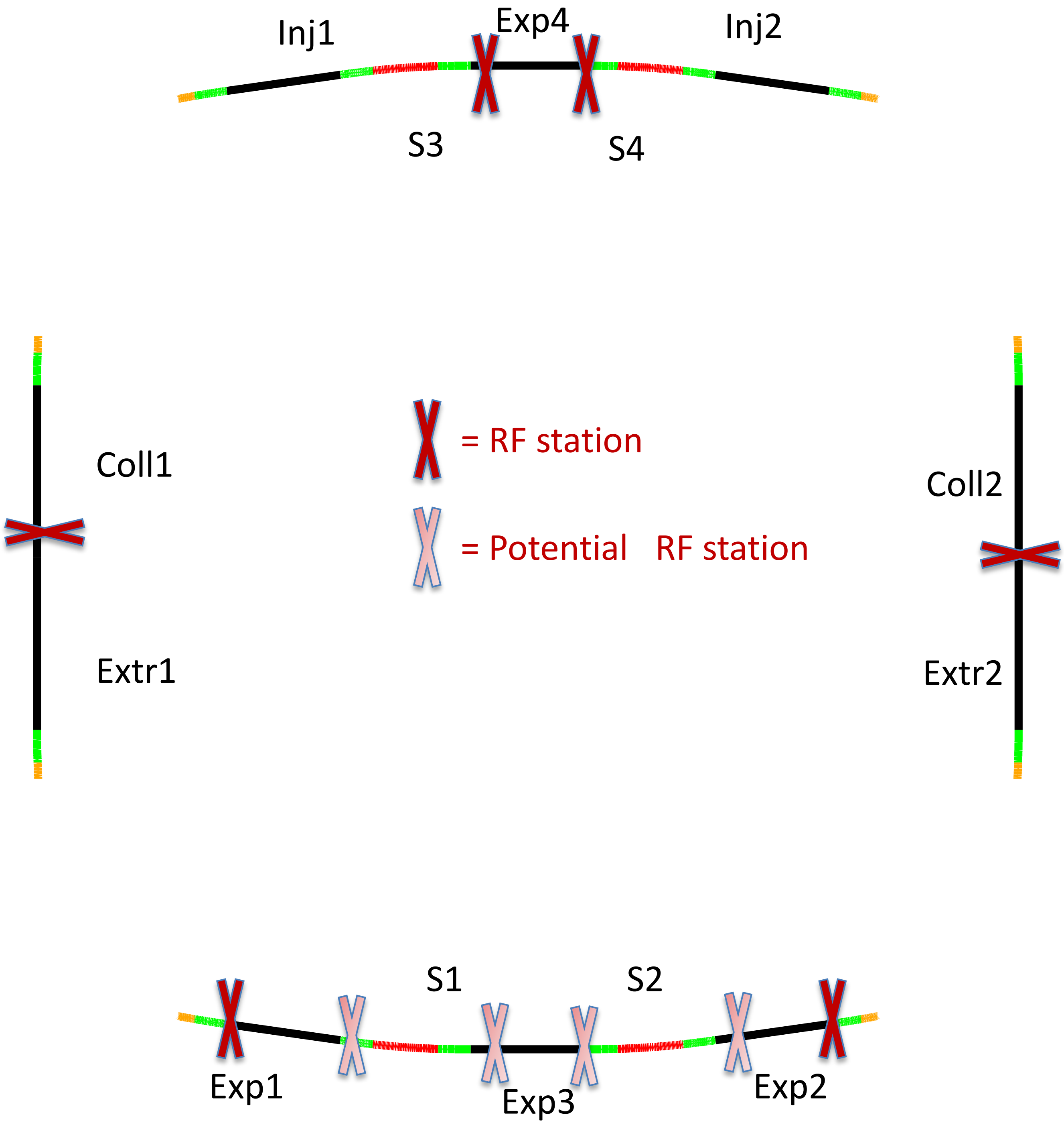
Exp2	1.4 km
Exp3	1.4 km
Exp4	1.4 km
Coll1	2.8 km
Coll2	2.8 km
Inj1	1.4 km
Inj2	1.4 km
Extr1	1.4 km
Extr2	1.4 km



Dispersion suppressors in green



Insertion	Length
Exp1	1.4 km
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Exp3	1.4 km
Exp4	1.4 km
Coll1	2.8 km
Coll2	2.8 km
Inj1	1.4 km
Inj2	1.4 km
Extr1	1.4 km
Extr2	1.4 km

Ring layout and RF distribution

FCC-hh layout proposals

Matching FCC with the local geology

Introduction

- Last Friday 26.09.2014 we had a joint meeting with FCC-hh, FCC-ee, infrastructure and a representative of the ARUP company to evaluate ring layout proposals.
  - Tunnel Optimisation Tool (TOT) provided by ARUP.
  - Local geology data from the Swiss geological company GADZ and from the French Geological Society (BRGM).

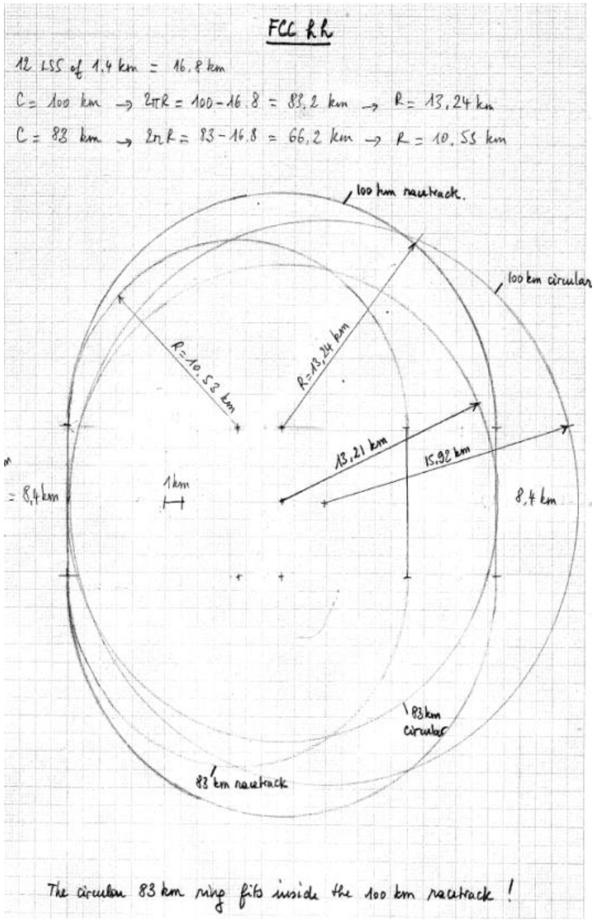
- Many of the following slides are borrowed from J. Osborne.

ARUP

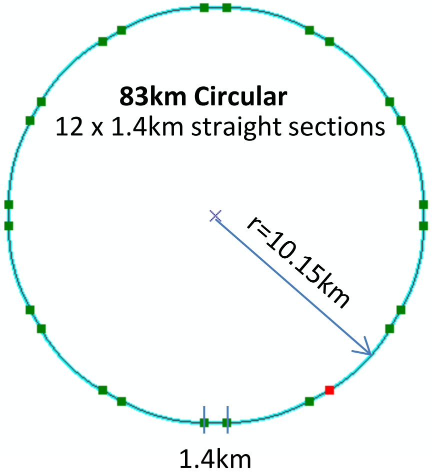
GADZ
GÉOTECHNIQUE APPLIQUÉE
DERIAZ S.A.

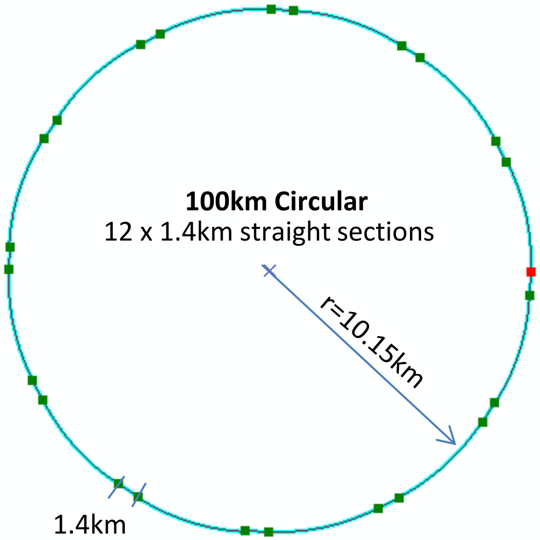
The 4 options

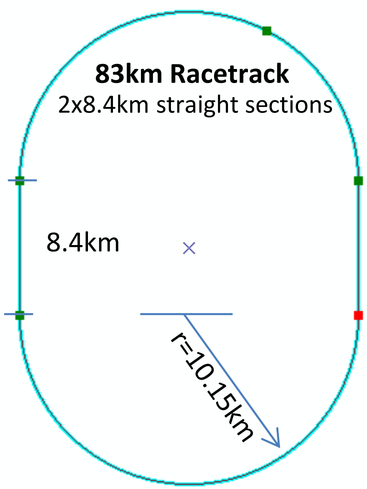
Original Sketch (Philippe Lebrun)

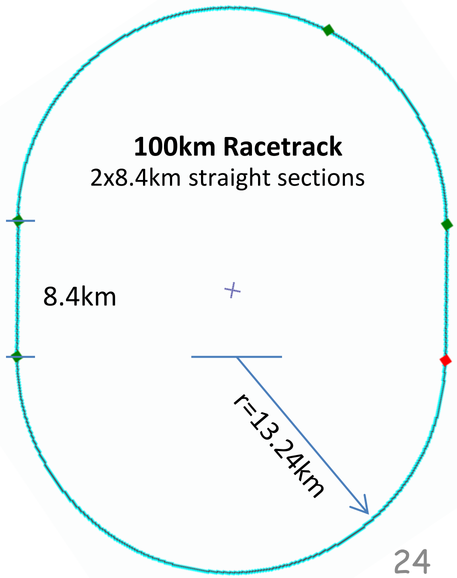


Machines in Tunnel Optimisation Tool (TOT)







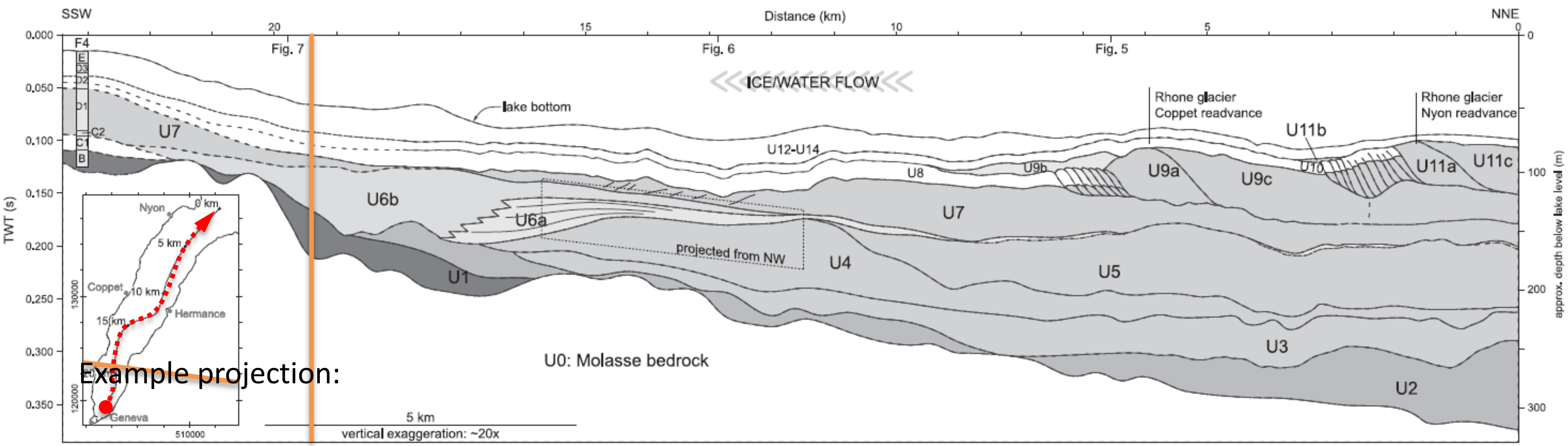


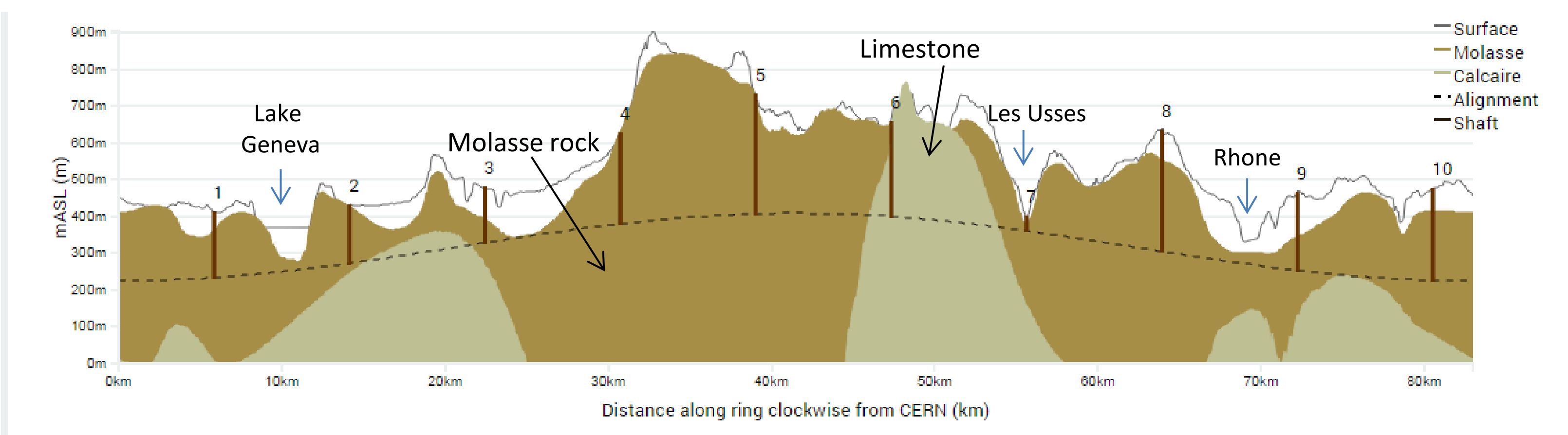
Derivation of parameters:
https://edms.cern.ch/document/1342402/1.0
N.B LHC injection was not decided in referenced document

Introduction to options

Some civil engineering constraints:

- Tunnel depth >20m into Molasse below Lake Geneva, The Rhone and Les Usses
- Limit of 15 bar (150m depth) in limestone for a closed tunnel boring machine





Options

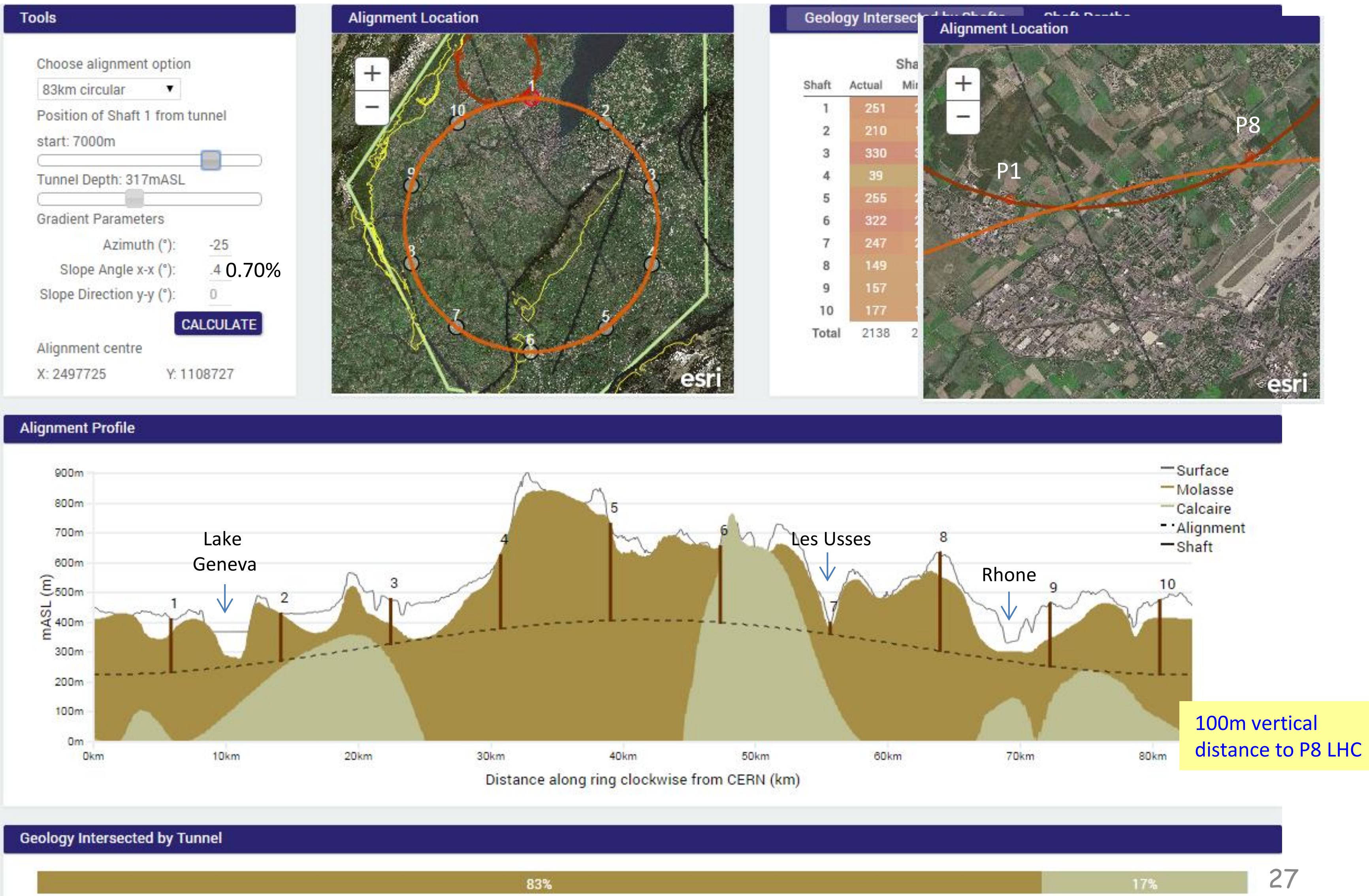
- Civil engineering preferences:
  - *Minimise tunnel extent in limestone and moraines,*
  - *Minimise tunnel shaft depths,*
  - *Minimise interaction with limestone.*

- Two interesting options (weighting the different factors) that also satisfy the overlap with the LHC ring are presented in the next slides.

- All options consider a **FLAT** ring. No kinks are considered / necessary for the moment.
  - *Machine plane: typical slopes of 0.5-1%.*

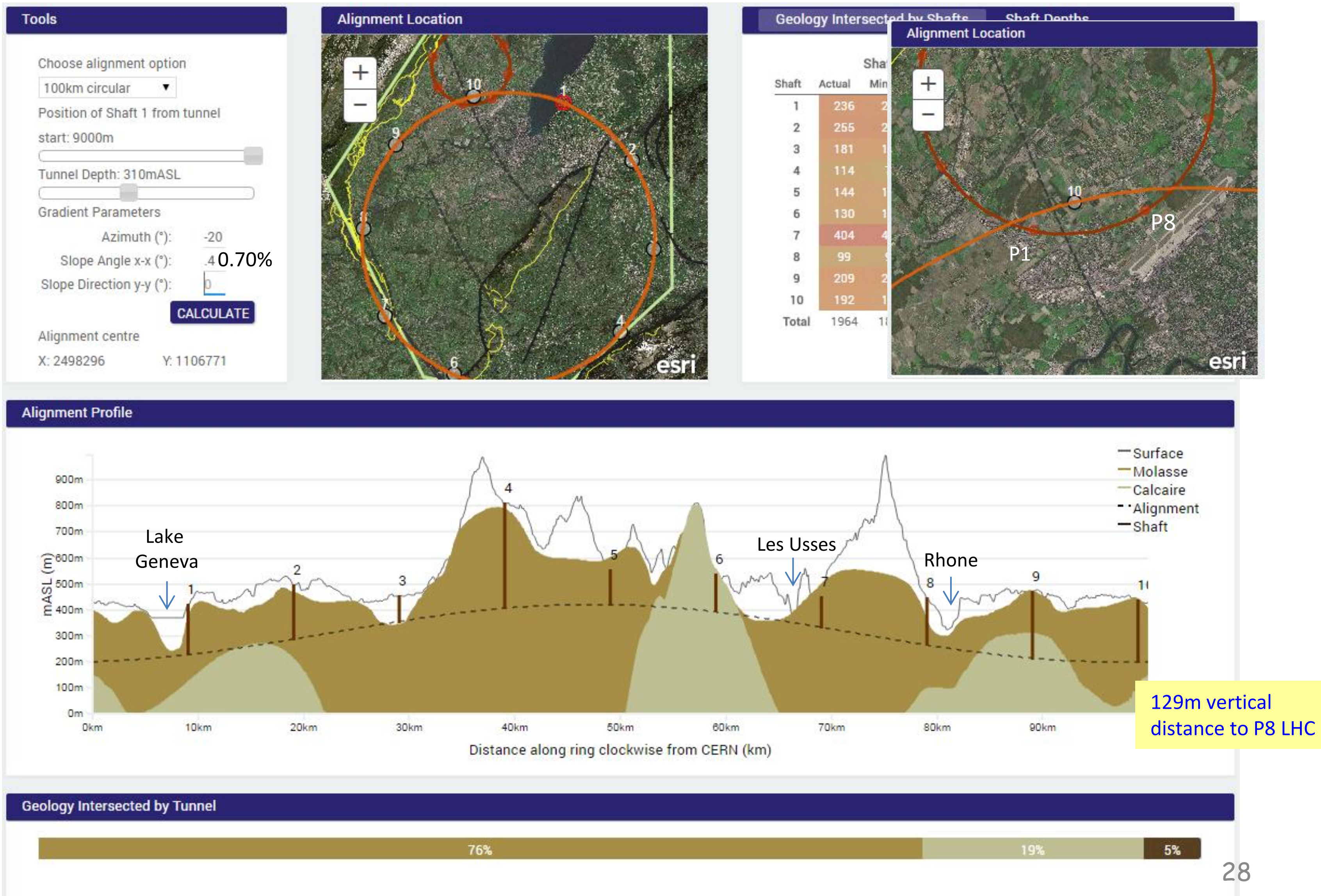
Options 5 – 8; CE & LHC Connection Considered

5 - 83km Circular - Considering CE & LHC Connection



Options 5 – 8; CE & LHC Connection Considered

7 – 100km Circular – Considering CE & LHC Connection



Modified racetrack

In the discussions we agreed on the following next iteration.

- We consider a modified racetrack with somewhat longer 'short arcs' up to ~4 km length.
- One experiment should be located close to the CERN sites of Meyrin and/or Prevessin.
- The injection lines of FCC-hh and their junction with LHC (difference in depth, total horizontal bending) present important constraints:
  - *Injection into FCC-hh in the two straights around the 'CERN-site experiment'.*

Modified racetrack

12 access points

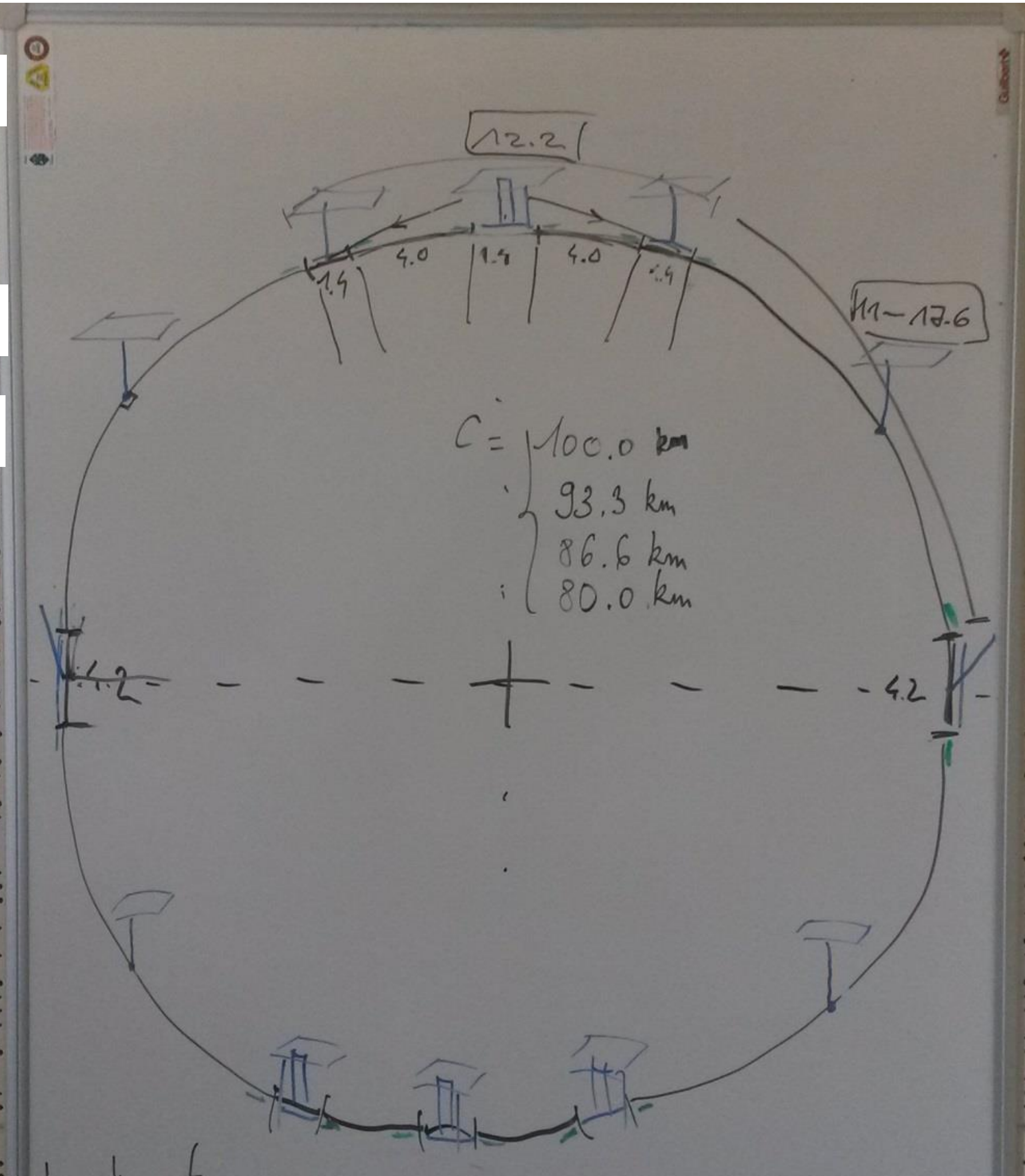
4 experiments

6 straights 1.4km

2 straights 4.2km

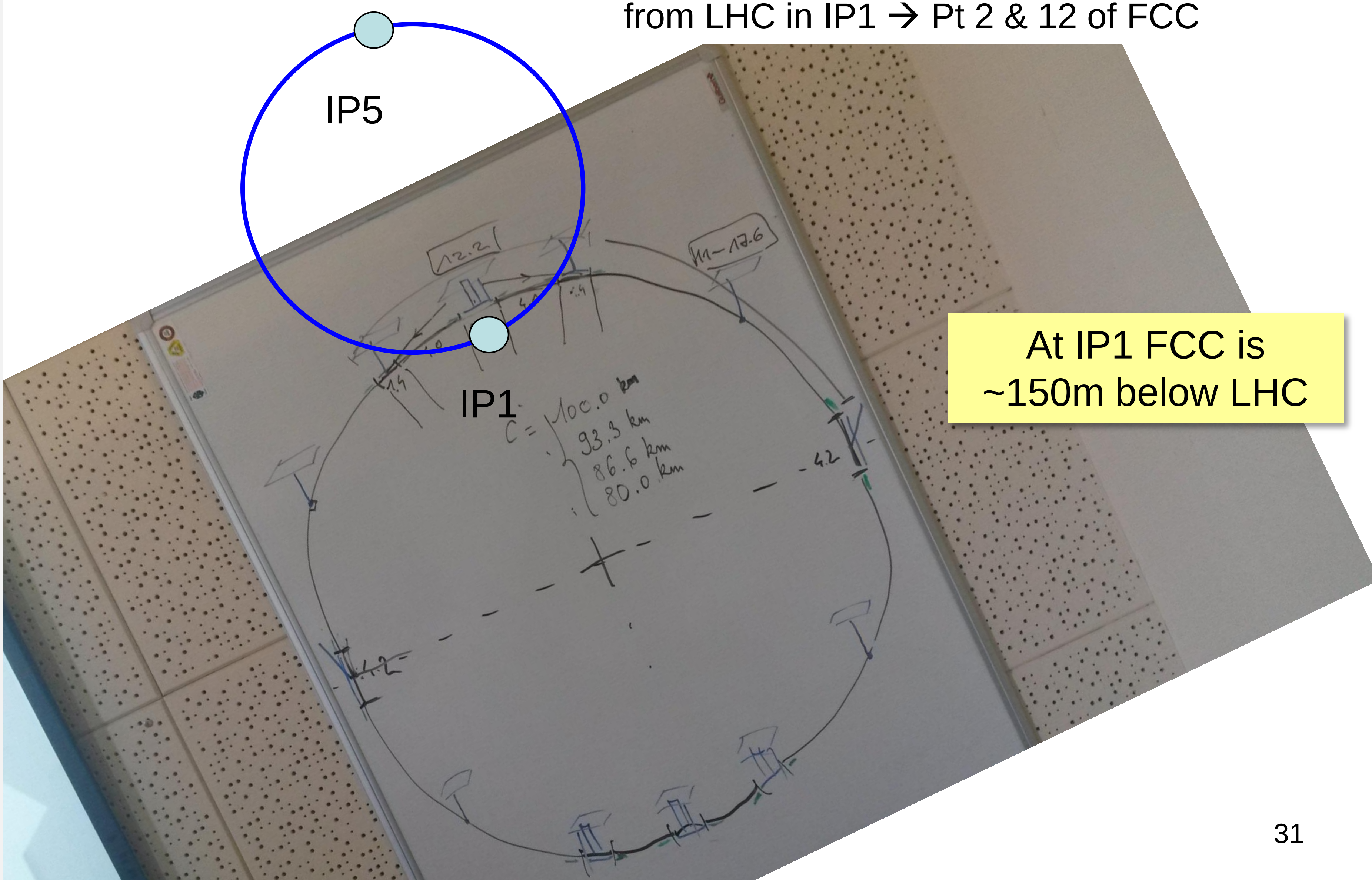
4 long arcs

4 short arcs 4km



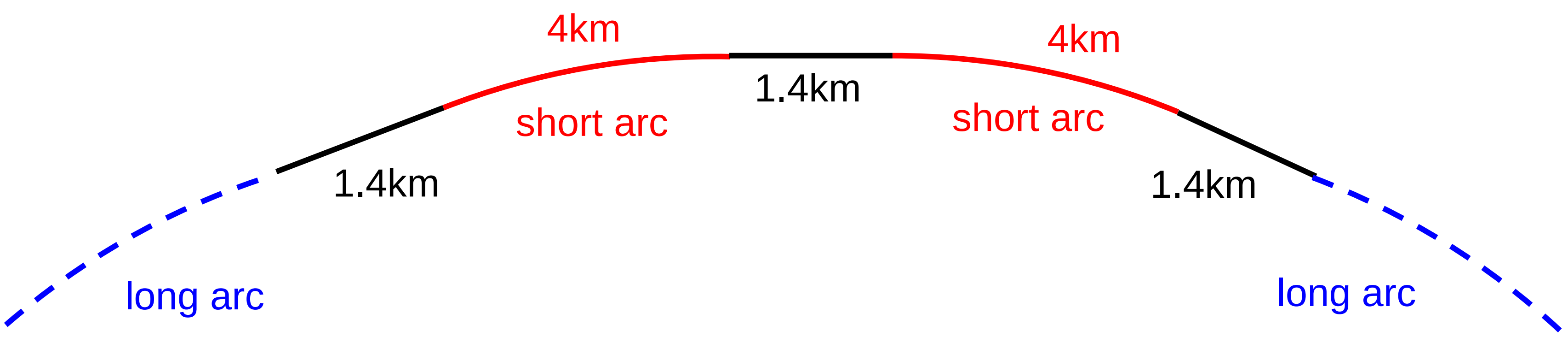
Orientation

Approximate orientation wrt LHC: extraction from LHC in IP1 → Pt 2 & 12 of FCC



At IP1 FCC is ~150m below LHC

Pseudo racetrack



- The 4km short arcs have the SAME bending radius than the long arcs.
- The same structure repeats on the opposite side of the pseudo-racetrack.

Almost circular racetrack

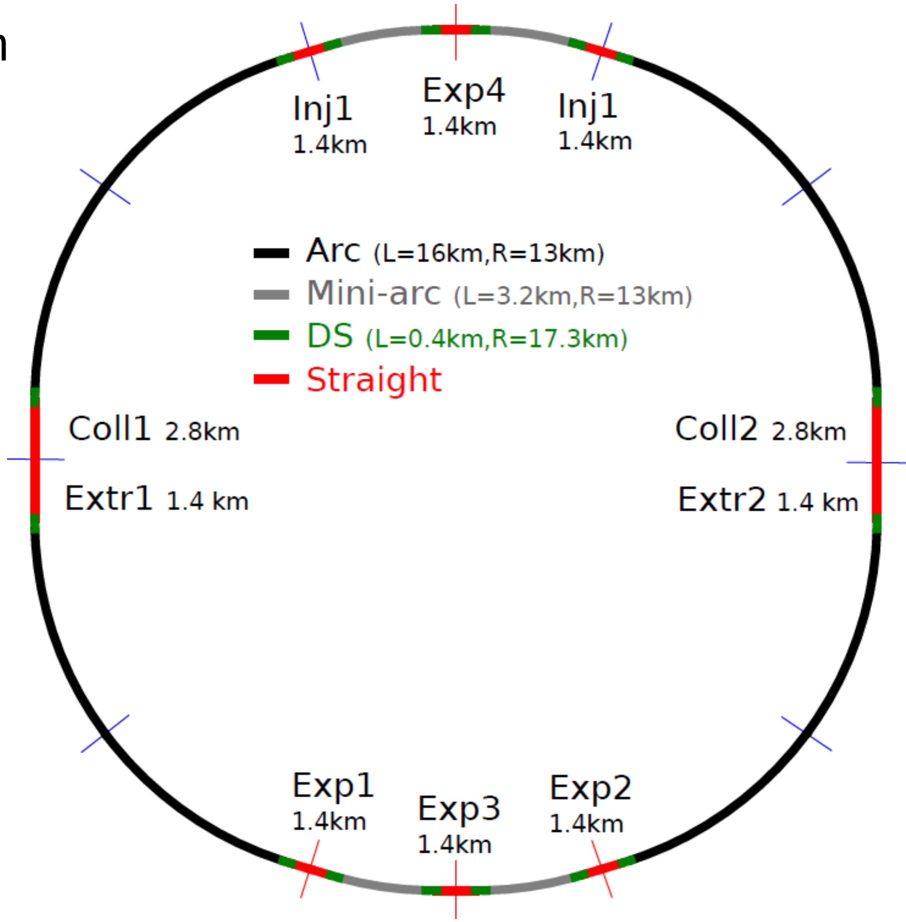
Long arc length = ¼(C – 6×1.4km – 2×4.2km – 4×4km)

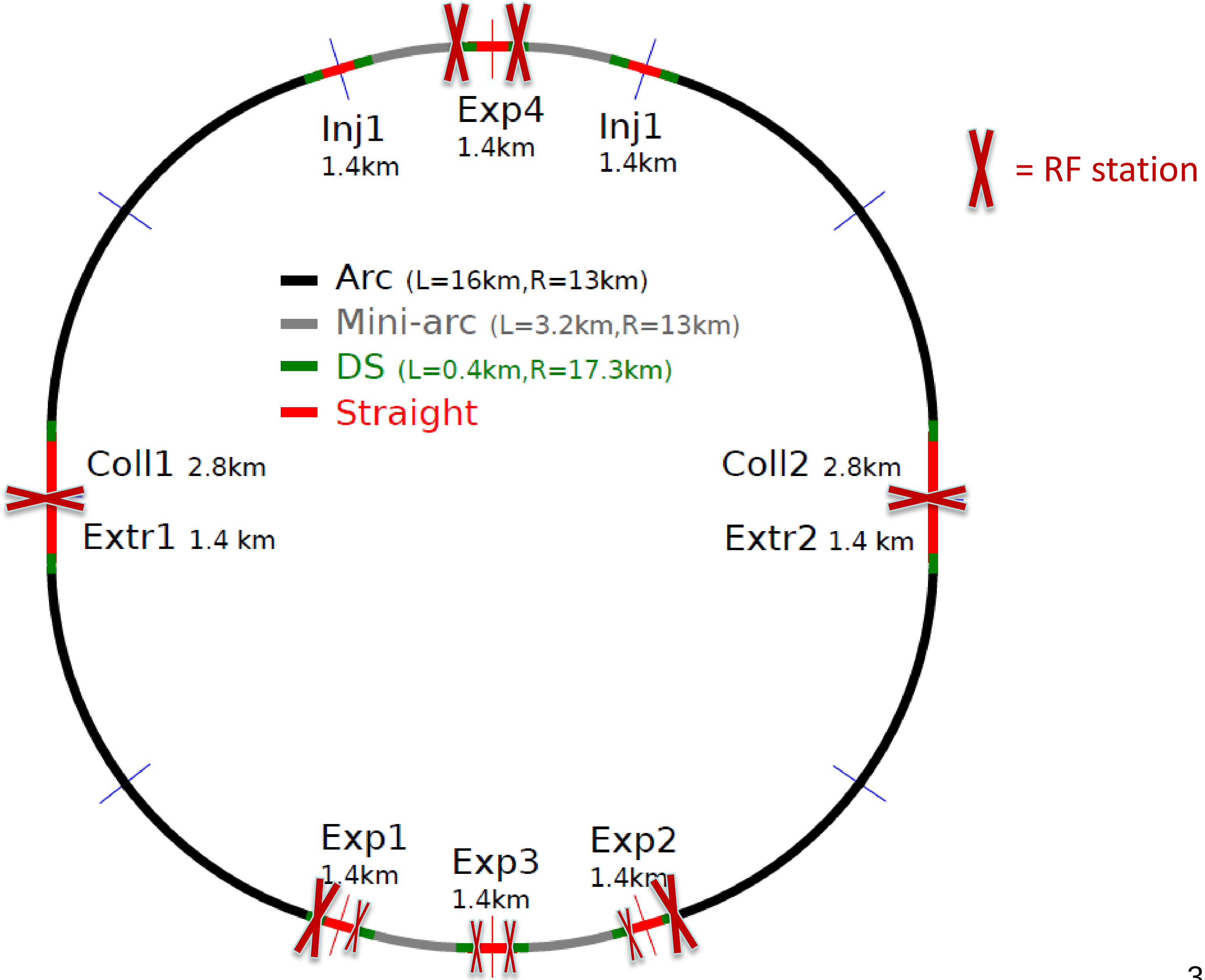
= 16.8km for C = 100km

= 11.8km for C = 80km

For FCC-ee:

- *RF stations in straights between short and long arcs.*
  - And other both sides of the experiments.
- *RF stations in the 4.2 km long straights.*
- *Could use long arcs for emittance matching (see B. Harer) while keeping optics fixed in short arcs.*
- *Etc…*




Exp4
1.4km
Inj1
1.4km
Inj1
1.4km
= RF station
Arc (L=16km,R=13km)
Mini-arc (L=3.2km,R=13km)
DS (L=0.4km,R=17.3km)
Straight
Coll1 2.8km
Extr1 1.4 km
Coll2 2.8km
Extr2 1.4 km
Exp1
1.4km
Exp3
1.4km
Exp2
1.4km

Next iteration

- The geometry of this oval racetrack will be modeled such that it can be entered into the geology tool.
- J. Osborne & will try to match this shape with the local geology for 4 circumference values:

  -- C= 80, 86.6, 93.3 and 100 km (3×LHC, 3.25×LHC, 3.5×LHC, 3.75×LHC)

  -- The length of the straight sections remains constant → adapt the arcs.

- The four options will be evaluated again from the geological point of view. The location of the access shafts will be analyzed.

  -- Next iteration in a few weeks.

- From the point of view of FCC-ee I suggest that we continue with the ring layout for the moment → get a closed ring with 12 (or 10 LSS).

  -- Wait until the dust settles.