FCC-hh Layout and Parameters

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EuroCirCol
A key to New Physics

Note: FCC-hh CDR

Will consist of two parts for the accelerator:

FCC-hh Design Overview
A concise description of the goals, main concepts, key issues and solutions
Should allow to understand the expected performance

FCC-hh Accelerator Design
Documents the studies performed
A resource to support the baseline concept
The basis for the next phase, highlights remaining R&D, alternatives, …

Tentative FCC-hh Design Overview

1) Design goals and basic choices

2) Parameter optimisation

3) Key design challenges and solutions

4) Optics design and beam dynamics

5) Machine performance and operation aspects

6) Enabling technologies

7) Site integration

8) Injectors

9) Additional options
- Ion operation
- lepton-hadron operation
- special purpose experiments

10) Detectors and experiments

11) Schedule and cost

12) Detailed Parameter Table

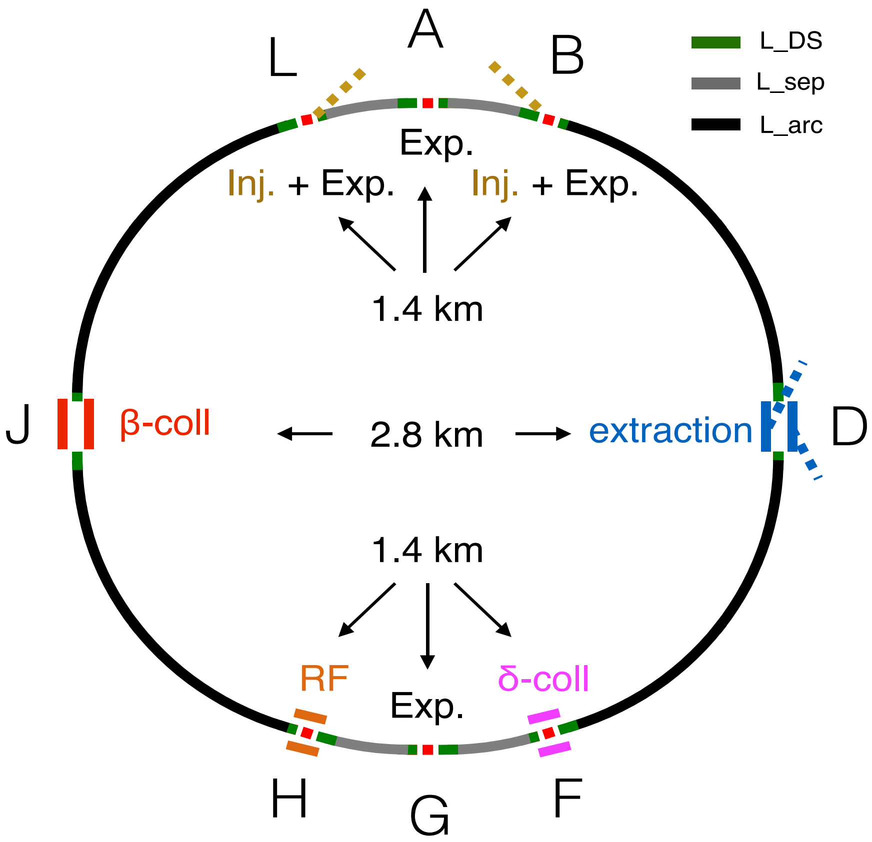
Tentative FCC-hh Accelerator Design

Descriptions of the collider areas	Experimental insertion region concept Collimation concept Injection and extraction concept RF insertion concept Arc concept
Performance evaluation	Integrated optics design Single beam current limitations Beam-beam effects Collimation system performance Operation cycle (incl. machine protection concept)
Options	Ion operation concept FCC-he concept
Technical components, e.g.	Magnets Beamscreen …

FCC-hh Layout

Layout has changed according to site requirements

- Two high-luminosity experiments (A and G)
- Two other experiments combined with injection (L and B)
- Two collimation insertions
  - Betatron cleaning (J)
  - Momentum cleaning (E)
- Extraction insertion (D)
- Clean insertion with RF (H)
- Circumference 97.75km
- Can be integrated into the area
- Can use LHC or SPS as injector



Beam Parameters

Baseline: 1.25ab^{-1} per 5 year cycle

- considering shutdowns, stops, MDs, …

= 2fb^{-2} per day

Ultimate: 5ab^{-1} per 5 year cycle

= 8fb^{-2} per day

Total 17.5ab^{-1}

	FCC-hh Baseline	FCC-hh Ultimate
Luminosity L [$10^{34}cm^{-2}s^{-1}$]	5	20-30
Background events/bx	170 (34)	<1020 (204)
Bunch distance Δt [ns]	25 (5)	
Bunch charge N [10^{11}]	1 (0.2)	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2(0.44)	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8 (3)	3.5 (1.6)
RMS bunch length σ_z [cm]	8	
Crossing angle [σ□]	12	Crab. Cav.
Turn-around time [h]	5	4

Focus on ultimate parameters

Injection energy 3.3TeV

Luminosity Drivers

$$\mathcal{L} \propto \frac{N}{\epsilon}\frac{1}{\beta}N n_b f_r$$

Maximise the beam current

Risks:

- High stored energy and losses
- Impedance and electron cloud
- Aperture should be minimised for dipole cost
- High synchrotron radiation load due to high beam energy

Squeeze the beam as much as possible
Harder than in HL-LHC (scaling with energy)
More collision debris due to higher luminosity and energy

Limited by emittance growth and particle losses

Somewhat more difficult than HL-LHC due to longer L^*

For integrated luminosity:

- Fast turn-around critical for luminosity
- Minimise time for stops etc.
- High availability with more components than LHC
- Maximising current also maximises time between new fills

Power and Choice of Temperature

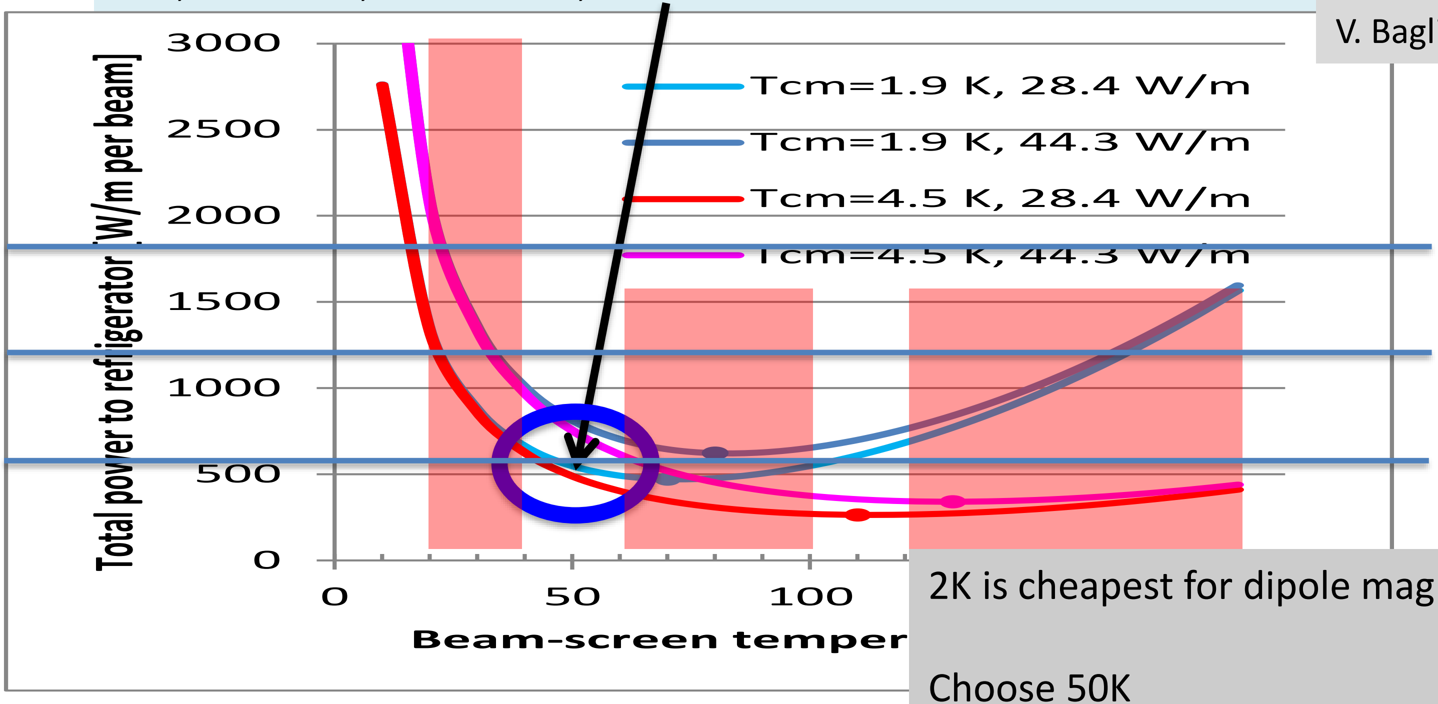
Can only use some temperatures in order to maintain good vacuum
<20, 40K-60K, 100K-120K, >190K

Ph. Lebrun, L. Tavian, V. Baglin et al.

300MW

200MW

100MW



2K is cheapest for dipole magnets

Choose 50K
Need 20x5MW=100MW for cooling

Proton beams emit about 5MW of synchrotron radiation

Beam Screen Concept

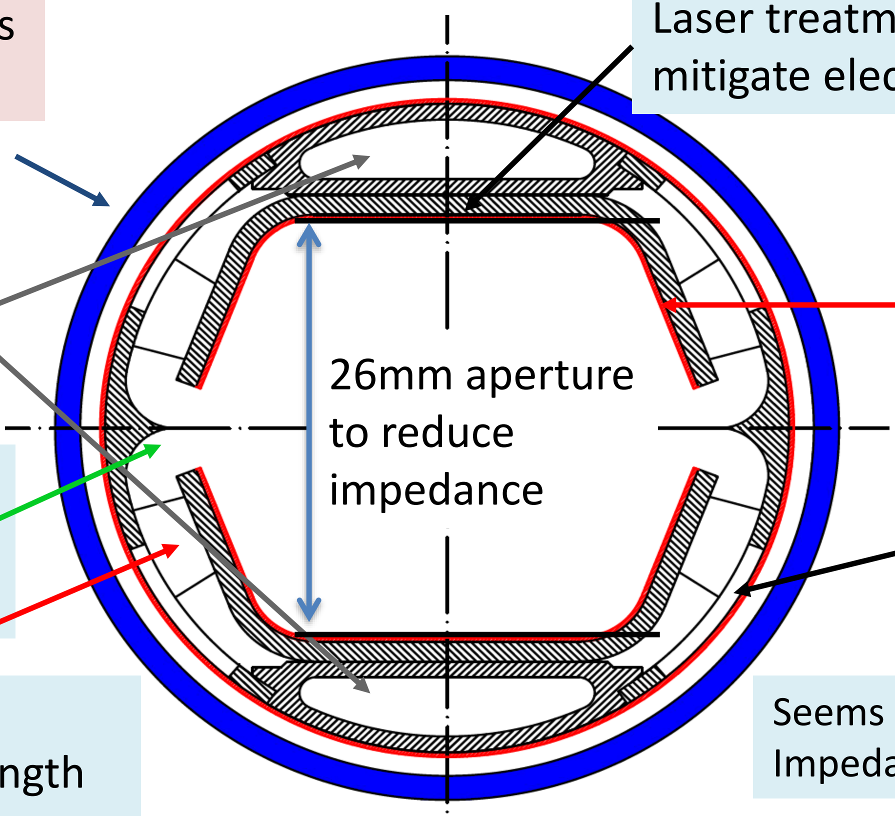
Magnet aperture is now 50mm

Magnet cold bore
T=2K

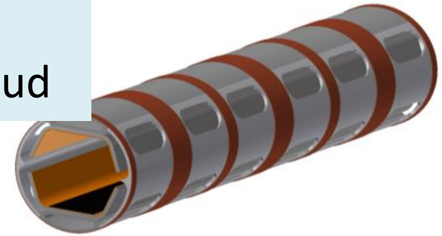
Cooling channels
T=50K for efficiency

Deflector minimises photons in main chamber

Ribs:
- Mechanical strength
- Photon stopper



Laser treatment to mitigate electron cloud



0.3mm copper layer to reduce impedance

Pumping holes
Hidden from beam
Prevents prohibitive impedance

Seems to be tight but OK
Impedance more important than in LHC

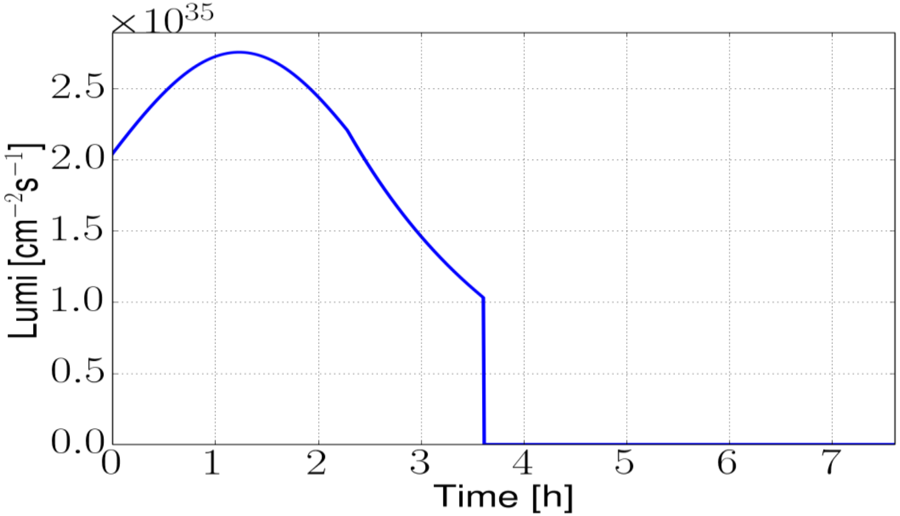
Parameter Optimisation

With our beam current can reach luminosity goal

$\Rightarrow$ Not much to be gained

- $\Rightarrow$ pushing beam-beam parameter increases risk and requires less noise
- $\Rightarrow$ reducing beta-function reduces triplet shielding or tightens collimation (impedance, higher risk)

$\Rightarrow$ Will reconsider for 5ns spacing



Important for integrated luminosity are

- Turn-around time
- Availability
- Operational schedule

Example options to be considered

- Electron lens
- Wires
- Pushing collision point beta-functions smaller during run

Parameter Optimisation

Physics looks for reduction of background

- Do not have a clear target, so will explore range of options
- Possibilities are a combination of
  - Longer bunches
  - Smaller bunch spacing and charge
  - Luminosity leveling

$$\mathcal{L} \propto \frac{N}{\epsilon}\frac{1}{\beta_y} N n_b f_r$$

- Will put emphasis on 5ns and 12.5ns bunch spacing parameters
  - Makes use of octupoles even harder, will have to use different scheme
  - Instrumentation already specified for 5ns spacing
  - Have to compensate or accept luminosity reduction
    - Main compensation is to use smaller beta-function
    - Still a relative loss remains
  - More sensitive to noise

- Luminosity leveling costs limited amount of integrated luminosity
  - E.g. limit to $10^{35}cm^{-2}s^{-1}$ leads to 30%-40% reduction

Conclusion

FCC-hh parameters have been derived systematically

The key design challenges have been identified

- Should be able to cope with them

There are interesting alternatives that will be considered to become baseline

- In case they are still too premature they will remain alternatives for now

Reserve

Parameter Optimisation

Choice of bunch spacing

- Put together a set of parameters for the 5ns (or 12.5ns) bunch spacing

Choice of working point

- Use LHC working point as starting point
- Would like to have a scan of the working point for impedance, dynamic aperture and beam-beam

Round vs. flat optics

- Need to see how far we progress with the flat optics
- Default will be round

Injection energy

- Waiting for the field errors at injection, so no calculation for dynamic aperture
- Collimation will be tight for lower injection energy, would require lower emittance

Parameter Optimisation

Operation of additional experiments under the different conditions

- Close interaction with the experiments is required

Operation with moving collimators

- Move collimators in as the beam burns off (constant impedance effect)
- Allows to reduce IP betafunction

Parameter Optimisation

Choice of collective effects stabilisation methods

- Main problem is transition into collision
- Switch off feedback before collision and only use octupoles?
  - Total octupoles need to be 20 times stronger than in HL-LHC for the same tuneshift
  - Tune shift is expected about up to 3 times higher
  - Further increase due to emittance damping (faster than burn-off)
  - Would need more than 60 times the LHC octupoles strength
  - Potentially further increase by factor 5 for 5ns spacing
- Can we use a feedback in spite of beta-beating?
  - Requires very low noise
  - E.g. proportional gain of 0.01 and resolution of 0.1µm (0.5% of beam size)