DE LA RECHERCHE À L'INDUSTRIE

Booster Design – Open points and where help is needed

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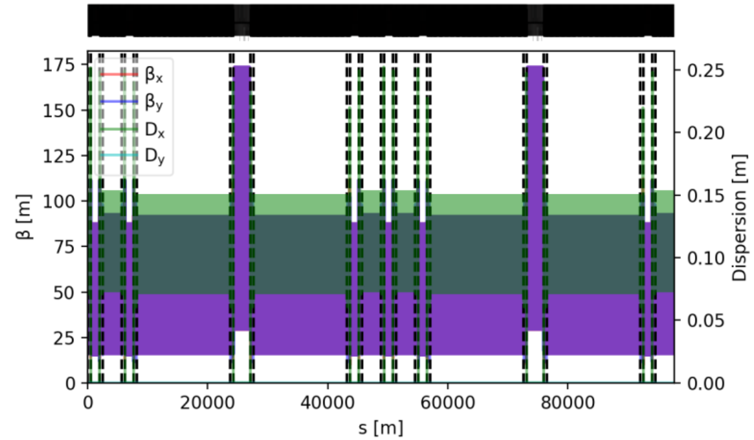
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

Status in a few words

Python scripts used to generate:

- Booster geometry
- Mad-X files

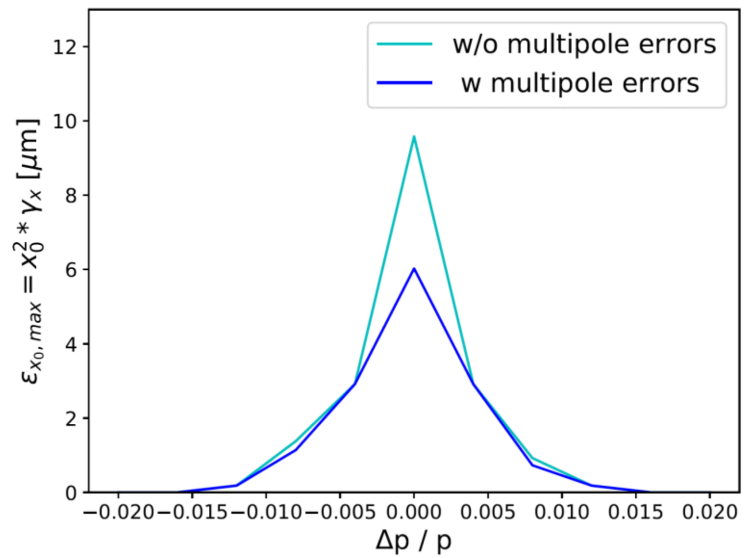
Existing optics for the 2 and 4 IPs geometry



Found again CDR values: good agreement

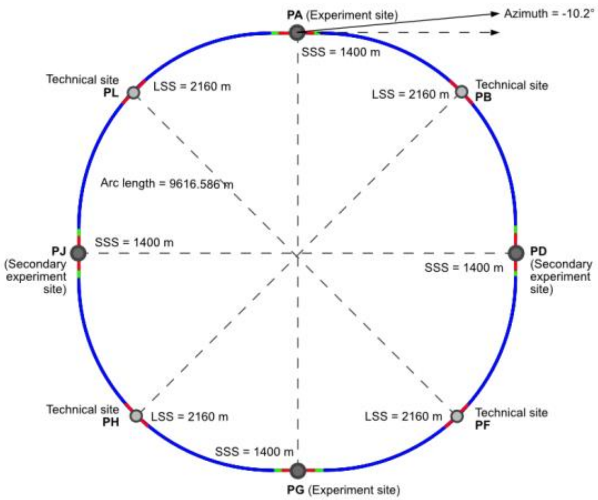
Preliminary dynamic aperture studies

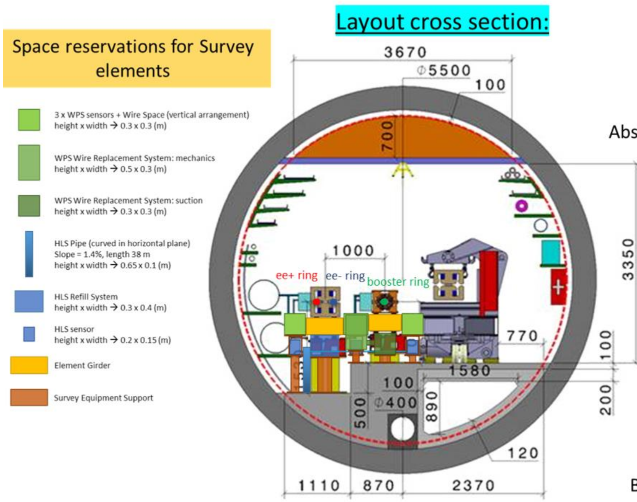
Beam energy [GeV]	Eq. emittance Optics 60°/60° [nm]		Eq. emittance Optics 90°/90° [nm]		Transverse damping time [s]	
	CDR	new	CDR	new	CDR	new
20	0.045	0.045	0.015	0.015	10.054	10.047
45.6	0.235	0.236	0.078	0.080	0.854	0.848
80.0	0.729	0.726	0.242	0.247	0.157	0.157
120.0	1.641	1.633	0.545	0.556	0.047	0.047
175.0	3.540	3.472	1.172	1.183	0.015	0.015

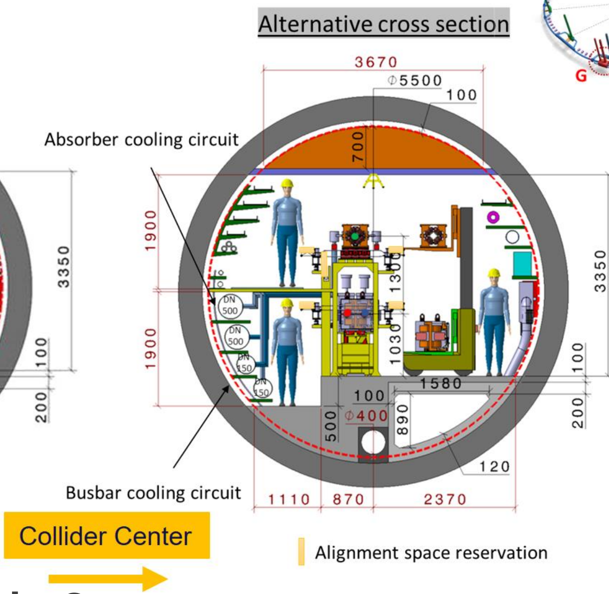


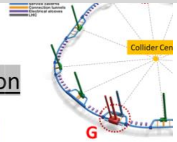
See « High energy booster » by Barbara Dalena on Tuesday 7 December

Collider geometry









- **Do we consider that the booster is on top of the collider?**
  - Several impacts: total arc length, curvature radius, radiation
- **In FCC-hh CDR, dispersion suppressors have some empty place to host collimators.**
  - What is the layout of FCC-hh with 4 Ips?
  - Change of the average curvature radius in the dispersion suppressors.
- **Bypass in the experimental regions to avoid any perturbation.**
  - Needs to have a sketch of the bypass.
  - Needs to modify the insertion (adds some dipoles).
  - May change the total path length.

Damping in the booste as in CDR

Courtesy: Bastian Haerer (KIT)

In CDR, the scenario is to damp before accelerating

Target damping time 0.1 s (to fulfill cycle time)

Wigglers reduce damping time and increase eq. emittance :

$$\tau_x \propto \frac{1}{E^3 I_2} \qquad \varepsilon_{eq} = \frac{C_q \gamma^2 I_5}{\left(I_2\left(1-\frac{I_4}{I_2}\right)\right)}$$

$$I_2 = \oint \frac{ds}{\rho^2} \qquad I_5 = \oint \frac{H_x}{|\rho^3|} ds$$

They **mitigate IBS** and **MI** too

A **normal conducting wigglers** foreseen

⇒ **Can be further optimized** for pole length and pole number

It **should be switched off** during acceleration

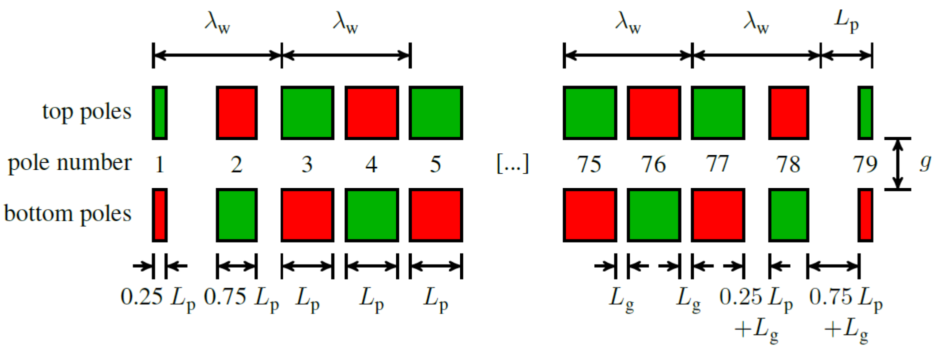
⇒ **Eddy current** effect to be investigated

Total length of installed wigglers is > **100 m** in the **same straight line**

⇒ Possible stimulated **additional radiation** and **instability** to be studied

⇒ Fringe field in the wigglers to be considered

Beam energy (GeV)	Eq. emittance (nm rad) 60°/60° optics	Eq. emittance (nm rad) 90°/90° optics	Transv. damping time (s)
20.0	0.045	0.015	10.054
45.6	0.235	0.078	0.854
80.0	0.729	0.242	0.157
120.0	4.229	0.545	0.047
175.0	3.540	1.172	0.015



Pole length	0.095 m
Pole separation	0.020 m
Gap	0.050 m
Number of poles	79
Wiggler length	9.065 m
Magnetic field	1.45 T
Energy loss per turn	126 MeV
Hor. damping time	104 ms
Hor. emittance (60°optics)	300 pm rad

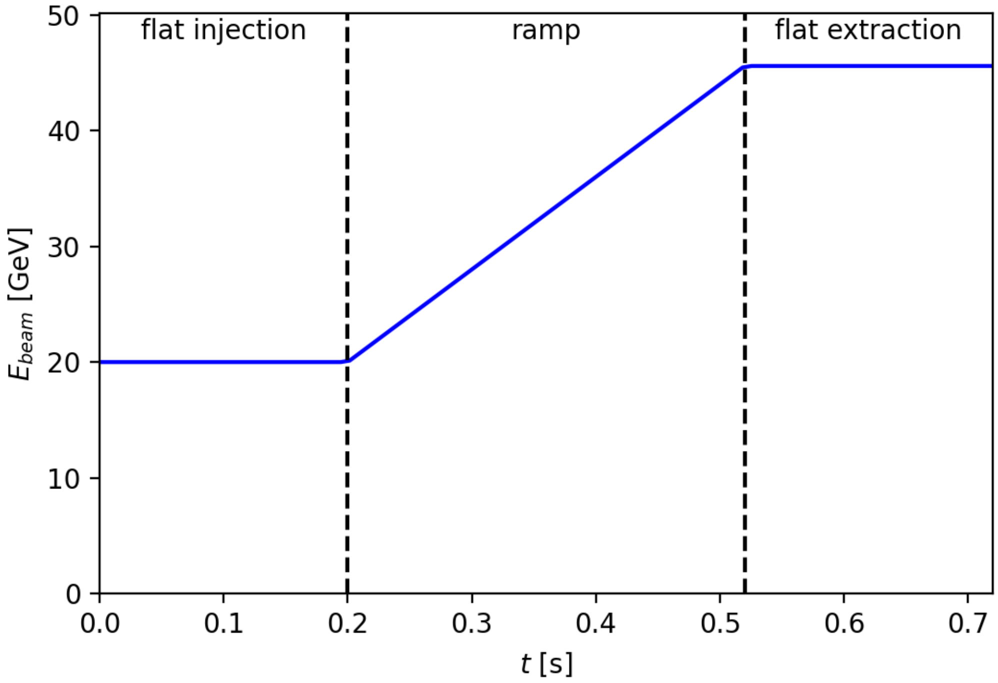
⇒ **Can we relax needs on I2 since damping time scales as $1/E^3$?**

Damping in the booster

- **We have several parameters for the booster operation optimization:**
  - Time before ramping
  - Acceleration time (here linear ramp but we can use other kind of ramp)
  - Time at maximum energy before injecting into the collider
- **Damping time scales as $1/I_2E^3$ but the radiated power scales as $I_2 E^4$.**
- **Tradeoff between accelerating damping and radiated power.**
- **1D Model of emittance and moment evolution (IBS will come later):**

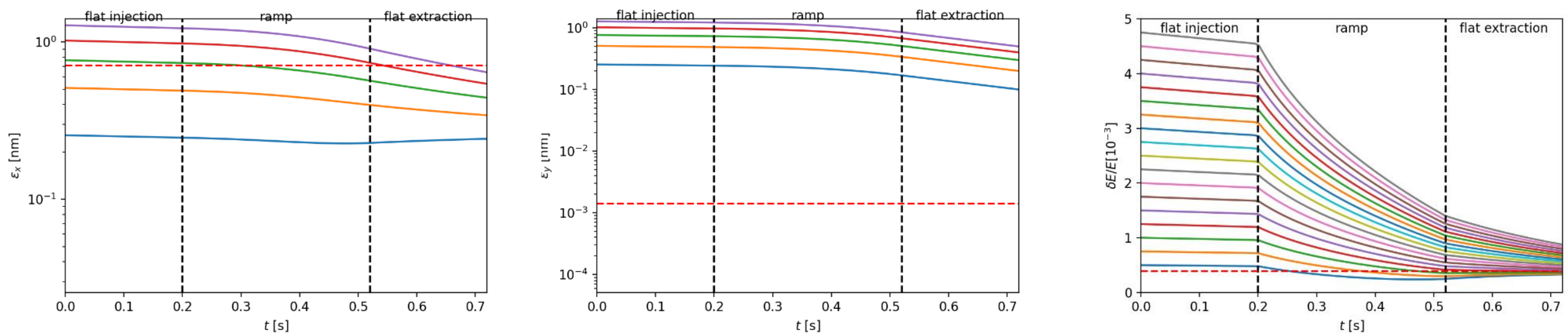
$$\frac{d\epsilon_x}{dt} = -2\frac{\epsilon_x - \epsilon_{\mathrm{eq}}(\gamma(t), I_2, I_5)}{\tau_x(\gamma(t), I_2)}$$

$$\frac{d\sigma_E^2}{dt} = -2\frac{\sigma_E^2 - \sigma_{E,\mathrm{eq}}^2(\gamma(t), I_2, I_3)}{\tau_\delta(\gamma(t), I_2)}$$



Injection parameters: 20 GeV, normalized emittance from 10 to 50 µm

- **Injection parameters:**
  - 20 GeV
  - Normalized emittance: 10 to 50 µm
  - Energy spread: 0.05% to 0.5%



With nominal parameters, the final vertical emittance is much above the target.

Needs to speedup the damping.

I2 and I5 are multiplied by 8.

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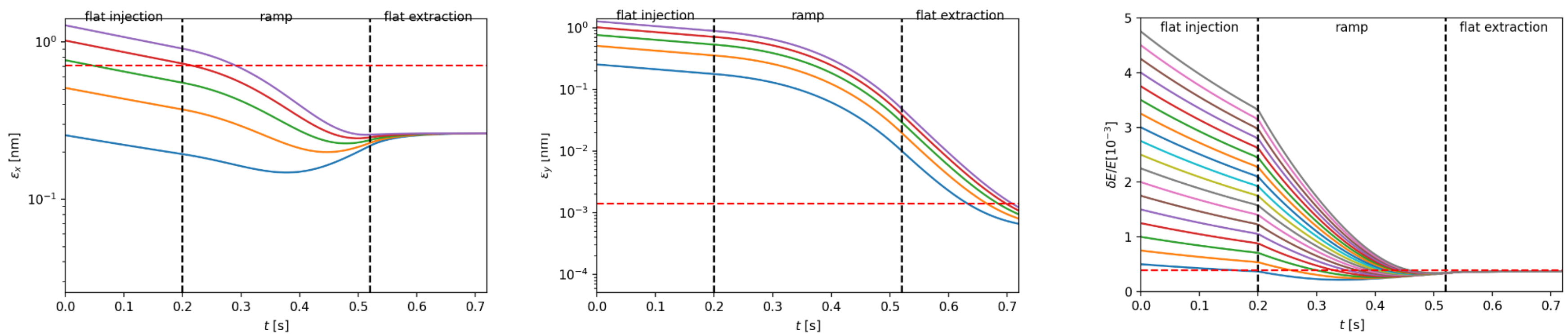

With I_2 and I_5 multiplied by 8, we get values below the target.

But we increase the radiated power: needs to find a good tradeoff and we have to optimize the cycling time for Z operation.

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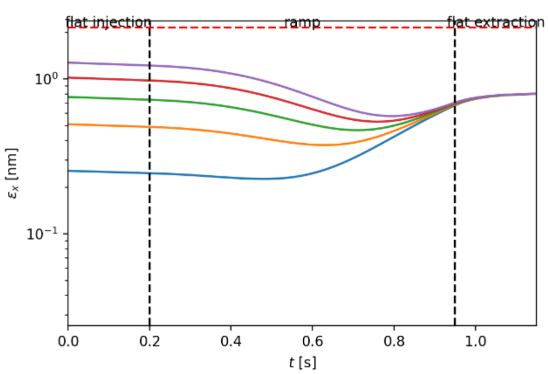

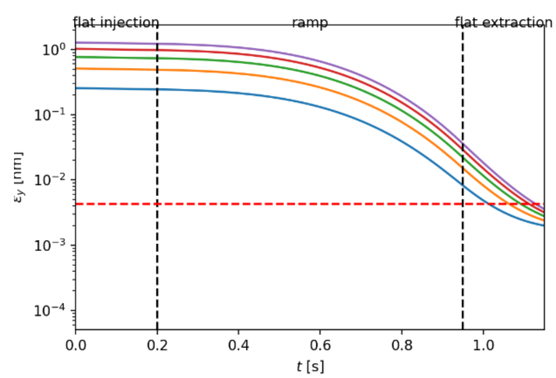

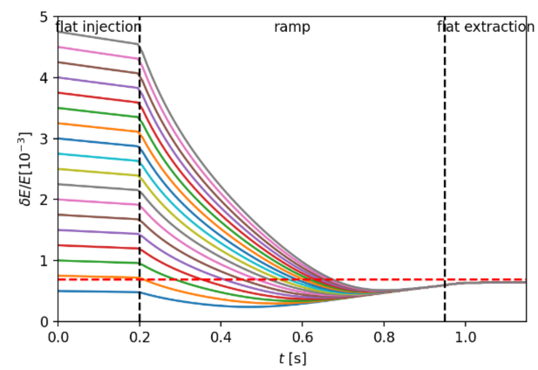

At W operation, we can get the target parameters: the issue takes place for Z operation.

Booster operation: open questions

- **To optimize the booster cycing and to relax some constraints, some input parameters are from high interest to optimize arc cells:**
- **Cycling time:**
  - What is the maximum allowed time?
  - Especially if we use the option with injection from a linac.
- **Radiated power:**
  - What is the maximum allowed radiated power during cycling?
  - Impact: maximum value on I_2 as a function of energy.
- **Magnet:**
  - Maximum derivative of the field.
- **Collective effects (IBS, TMCI,…)**
  - Impact for final emittance and energy spread.
  - Limitations on σ_z
- **RF frequency**
  - Do we have to consider also a frequency of 600 MHz?

- **Choice of the injection energy**
  - Experience from CEPC dipole prototypes shows some discrepancy between simulations and protypes for the field quality and field reproducibility.
  - What is the minimum dipole field to get field reproducibility?
  - Impact: dynamic aperture, optics correction.

- **In the case of injection from linac:**
  - The injection scheme is to be reviewed: what is the optimum bunch spacing and timing to inject into the booster for collective effects?

- **Transfer lines:**
  - Injection scheme into the booster not yet designed.

Code

- **We see a lot of synergy with code developments for the collider**
  - Synchrotron radiation
  - Correction schemes
  - Tracking studies
  - **Use of Xsuite and Xsequence**
- **We are very open to collaborate to apply the FCC-ee software framework to the booster.**
- **Open questions:**
  - We have already some first impressive results with the framework.
  - Is it already mature to begin producing booster optics using the lattice generator?
  - For instance, immediate applications for the booster:
    - using Xsequence to generate the booster lattice instead of our own homemade booster generator.
    - Using Xsuite for tracking studies
    - Using error generator as soon as it is available

Collaboration needs

We have numerous needs but collaboration has already begun

- **Magnets**
  - Jeremie Bauche and his team
- **IBS**
  - Michail Zampetakis, Fanouria Antoniou; Ozgur Etisken
- **RF integration**
  - Fani Kuncheva Valchkova
- **Injection/extraction**
  - Michael Hofer, Rebecca Louise Ramjiawan, Yann Dutheil
- **Code**
  - Tessa Charles, Leon Van Riesen-Haupt, Riccardo De Maria, Felix Carlier
  - MadX team and EPFL team for Xsequence and simulation ramework
- **Collective effects**
  - Ali Rajabi, Rainer Wanzenberg, Mauro Migliorati
- **And the FCC-ee team**
- **Sorry if I have missed anybody**
- **Thank you for the very helpful feedback!**

Thank you for your attention !