Discussion on Emittance Evolution through FCC-e^+e^-

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SPS parameters with FCC pre-booster energies

The parameter table of SPS with FCC e^+e^- pre-booster energy scale;

SPS Parameters	
SPS Bending radius [m]	741.63
SPS injection energy [GeV]	6
SPS extraction energy [GeV]	20
Dipole length	6.26*4
Bending field @ injection [Gauss]	269.811
Bending field @ extraction [Gauss]	899.3703
Emittance @ injection	2.44×10^{-9}
Emittance @ extraction*	27.1×10^{-9}
Energy Loss / turn @ injection [MeV]	0.155
Energy Loss / turn @ extraction [MeV]	19.085
Transverse Damping time @ injection [s]	1.788
Longitudinal Damping time @ injection [s]	0.894

Should be 0.1 s or less*

*After discussion with Masamitsu

We scanned different wiggler magnet characteristics

Bw (T)	Lw (m)	Emittance (m.rad)	Energy loss Per turn (MeV)	Damping time (s)
1	111	0.16×10^{-9}	2.6	0.1
2	26	0.17×10^{-9}	2.5	0.1
3	12	0.16×10^{-9}	2.6	0.1
4	7	0.16×10^{-9}	2.7	0.1
5	4.5	0.16×10^{-9}	2.7	0.1
6	3	0.16×10^{-9}	2.6	0.1

Thus, we provided the parameters with wiggler magnets

Parameters	Values
Energy [GeV]	6 GeV
Circumference [m]	6911.5
Emittance [pm.rad]	0.432
Energy loss / turn [MeV]	2.55
Natural horizontal chromaticity	-72.54
Natural vertical chromaticity	-40.904
Dx max [m]	3.54
Betax max [m]	148.46
Betay max [m]	117.64
Horizontal Damping times [ms]	108
Vertical Damping times [ms]	108
Longitudinal Damping times [ms]	54
Energy spread	1.775×10^{-3}
Horizontal Tune	40.36
Vertical Tune	26.39
Wiggler magnetic field	3 T
Wiggler magnet length [m]	12

* This is the minimum emittance which provided after phase advance is scanned (phase advance~$3\pi/4$).

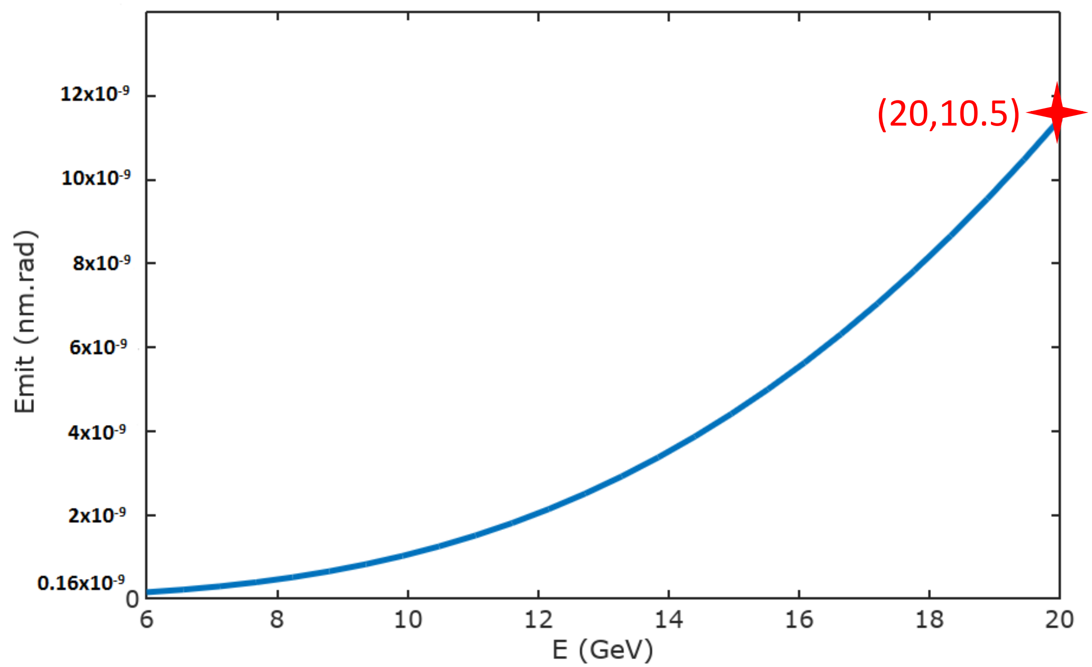
Equilibrium emittance of SPS

The wiggler magnet to reduce the damping time at injection will effect the emittance at the extraction.

$$\gamma\varepsilon_x = \frac{Cq\gamma^3}{12(1+F_w)J_x}\left(\frac{e_r\theta^3}{\sqrt{15}} + \frac{\beta_{xw}F_w {B_w}^3 {\lambda_w}^3}{16(B\rho)^3}\right)$$

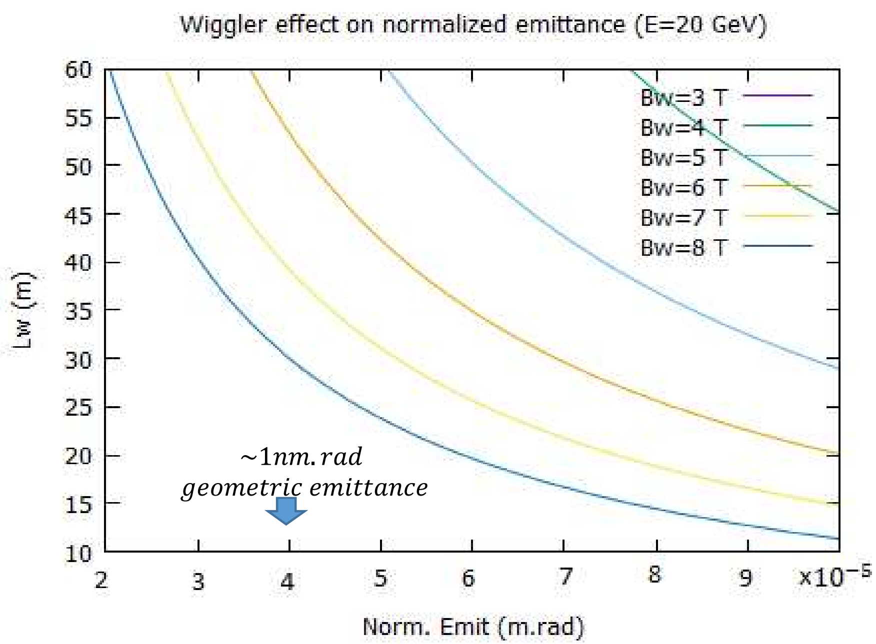
The equilibrium emittance of SPS including proposed wiggler magnet can be seen in the plot.

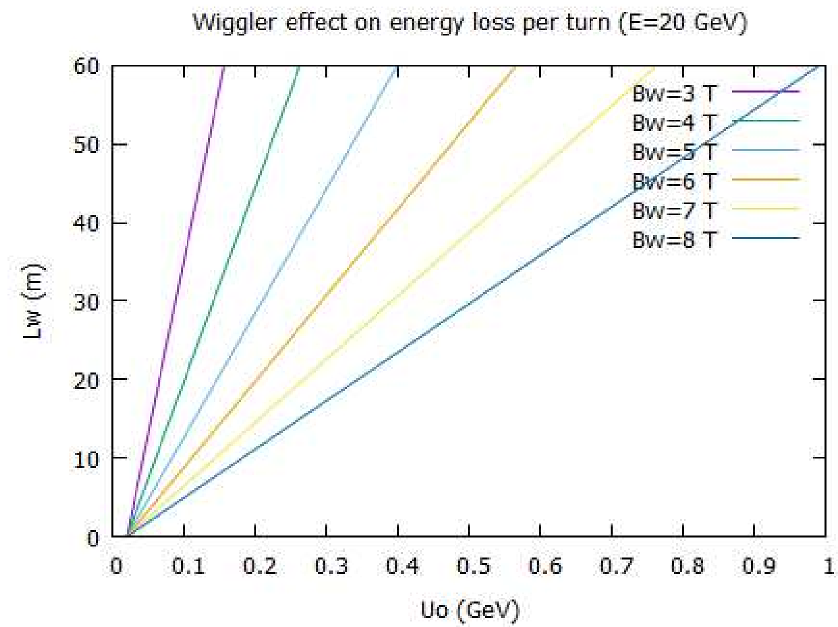
Eq. Emittance is around 10.5 nm.rad for 20 GeV energy including wiggler magnets: it was around 27 nm.rad without wiggler magnets.



Equilibrium emittance of SPS

Calculations are made to see the wiggler requirement to decrease the emittance around 1 nm.rad:





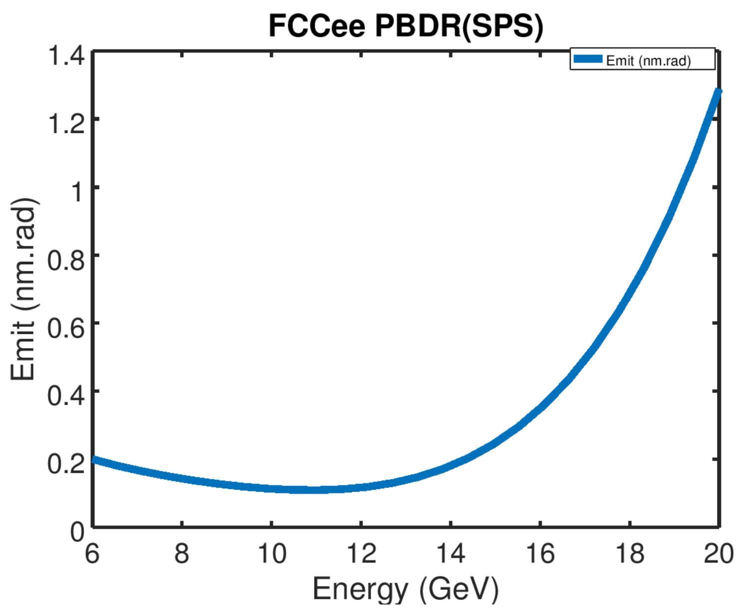
The wiggler length and magnetic field are needed to be very high as seen above, in the same time the energy loss per turn increases very much. Thus, decreasing the emittance to around 1 nm.rad in SPS cannot be an option with wiggler magnets

Equilibrium emittance of SPS

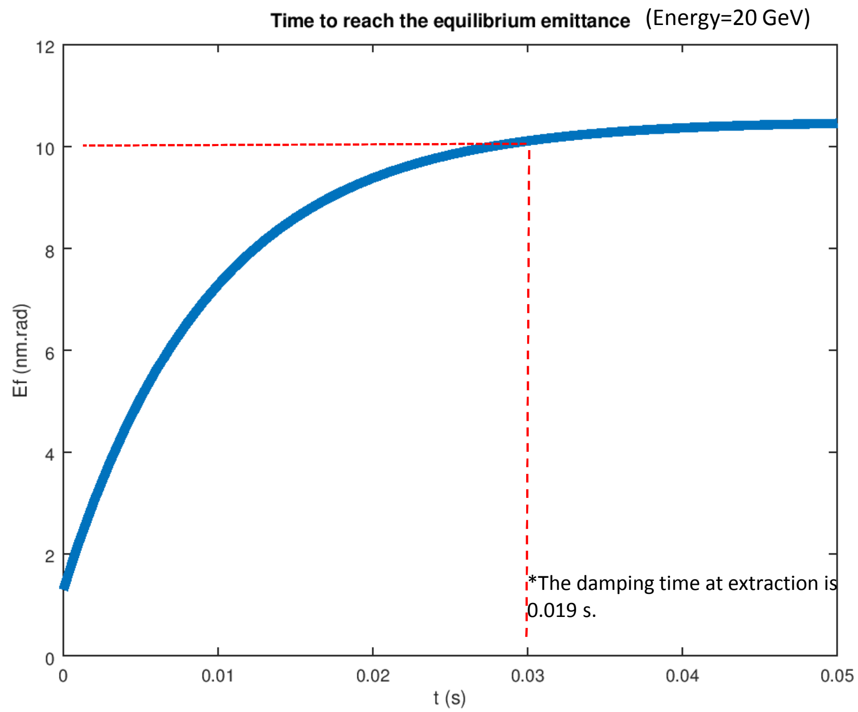
Another option could be extract the beam as soon as possible after energy ramping. The extraction plato of SPS as LEP injector was 30 ms*.

Thus, in 30 ms, SPS as pre-booster reaches already $\sim 10\ nm.rad$ as seen on the plot below.

*The performance of the SPS as LEP injector - Particle Accelerator Conference, 1989



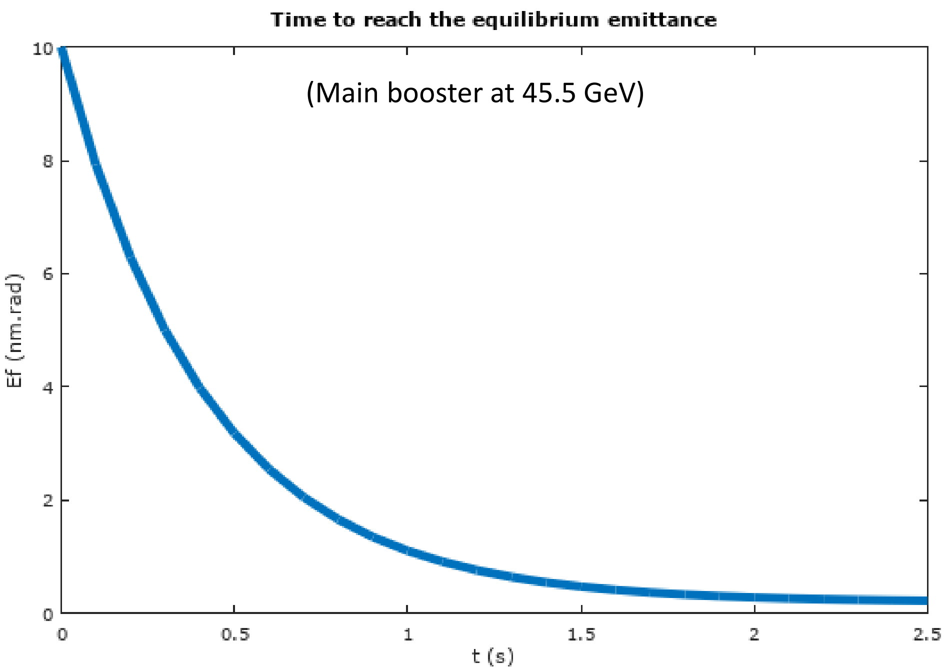
The plot above shows the emittance evaluation during ramping



Emittance at Main Booster

Thus, for the case of SPS as pre-booster, the extraction emittance will be around 10 nm.rad.

How the emittance can be reduced to 0.27 nm.rad (requested value for collider ring)in main booster?* *(*from D.Shatilov's presentation on 25th August in optic design meeting)*



At injection energy, the damping time is high but at extraction energy it is 0.84s for 45.5 GeV*.

As it can be seen on the left plot, it reaches to 0.27 nm.rad emittance in 2 s.

*For the calculation the table below is used from B. Haerer's previous presentation.

E(GeV)	ε_x (nm rad)*	τ (s)*
6.0	0.001	368
20.0	0.012	9.94
45.5	0.194	0.84
175.0	0.959	0.02

Mid-Summary

For SPS:

- It reaches the equilibrium emittance very fast because of the short damping time at injection and extraction,
- So, the emittance that it could extract from pre-booster is around 10.5 nm.rad,
- Main booster can reach the equilibrium state in a few second at extraction energy even if it has 10.5 nm.rad emittance,
- If a few seconds are acceptable in terms of cycle length, there is no issue for extracting around 10.5 nm.rad emittance from pre-booster to main booster, (extracting the beam faster than 30 ms should be also checked)
- If a few seconds are too long, wiggler magnet can be used in main-booster.

Further discussion on emittance

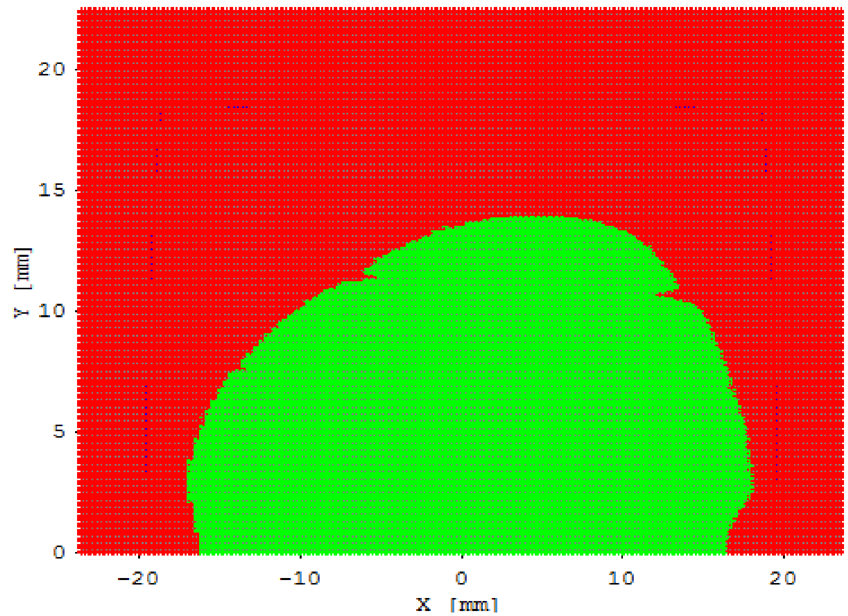
- There are two families sextupole magnets in SPS;
  - LSD: 0.42 m
  - LSF: 0.423 m

- There are 54 LSF and 54 LSD;
  - There are 6 ‘cell 1’ which includes LSF and LSD in one sextant,
  - There are 2 ‘cell 1’ which includes only LSD in one sextant,
  - There are 2 ‘cell 1’ which includes only LSF in one sextant,
  - There are 1 ‘cell 3’ which includes only LSD in one sextant,
  - There are 1 ‘cell 5’ which includes only LSF in one sextant,

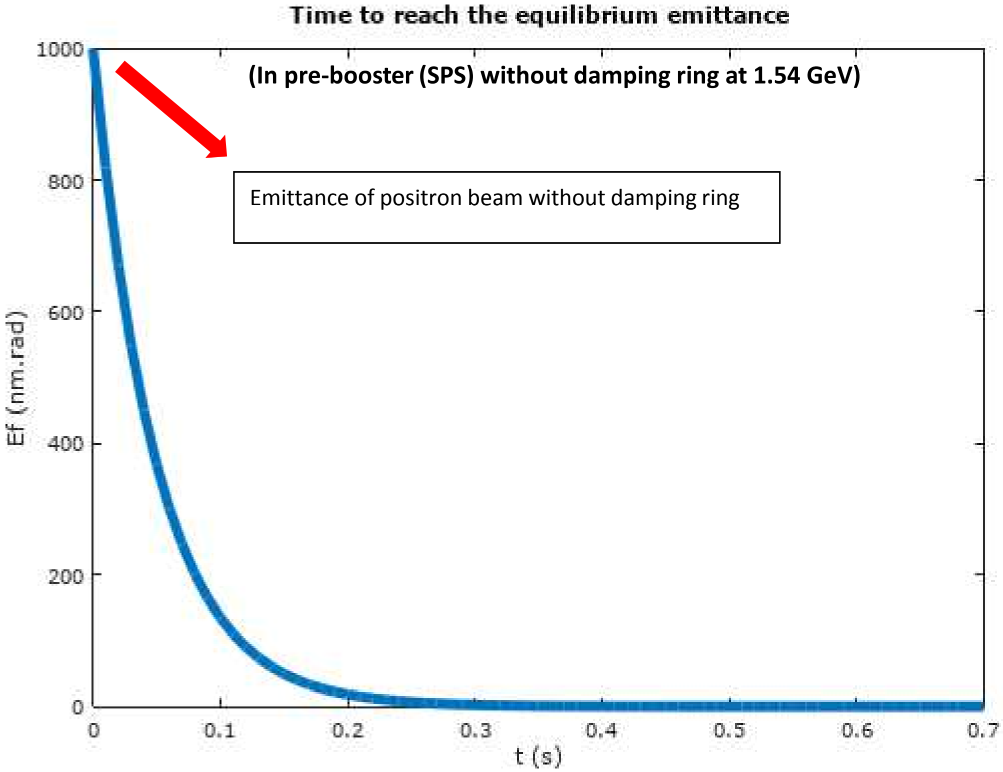
The strengths of sextupoles are calculated as below to correct the chromaticity;

Qx/Qy	LSF	LSD
-72/-40	-4.7×10^{-1}	2.4×10^{-1}

Preliminary results for DA in SPS as below;



Further discussion on emittance



The injection emittance is around $1\mu m$ **at injection energy of pre-booster** in the case **without using the damping ring**. Since we have very small damping time at injection in pre-booster, after around 0.7s, it reaches to the eq. emittance even if it is injected with an emittance of 1 µm. Thus, there is no problem about decreasing the emittance in short time in pre-booster.

First results of DA calculation for SPS, DA is around 15 mm.

In case the injection emittance is around $1\mu m$, the DA of SPS is around 5σ.

$$\sigma_{\varepsilon=1nm.rad} = \sqrt{1 * 10^{-9} * 10} \cong 0.1\ mm$$

$$\sigma_{\varepsilon=1\mu m.rad} = \sqrt{1 * 10^{-6} * 10} \cong 3.1\ mm$$

Considering we will work on the DA optimization to have better DA for SPS, we need to discuss to inject the e^+/e^- beams without using DR at 1.54 GeV.

Last comments also for alternative pre-booster ring

- It is also fast for alternative ring to reach equilibrium emittance,
- But, the DA is much smaller than SPS (optimization studies are still going on),
- But, the injection emittance can still be relaxed a bit;

For ε≅1 nm.rad, σ_size≅0.1 mm, DA ≅45σ
For ε≅5 nm.rad, σ_size≅0.2 mm, DA ≅23σ
For ε≅10 nm.rad, σ_size≅0.3 mm, DA ≅15 σ

- On the other hand, if the main booster is able to reduce the emittance to 0.27 nm.rad from 10 nm.rad (as discussed for SPS), we can also have bigger DA in pre-booster since it relax parameters for alternative ring. So, it may be also possible to eliminate the damping ring for both option.