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Beam Abort System for FCC-ee

Armen Apyan, ANSL, Yerevan, Armenia
Brennan Goddard and Frank Zimmermann, CERN, Geneva, Switzerland
Katsunobu Oide, KEK, Tsukuba, Japan

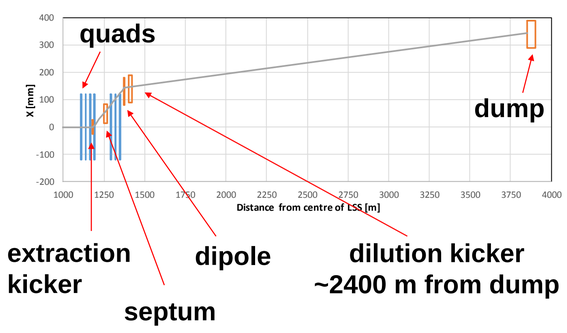
ABSTRACT The conceptual design of an abort system for the future electron positron circular collider is presented. A dedicated abort system has been studied based on MAD-X simulations. The proposed abort system consists of abort kickers, septum magnets and a dilution kicker system. The abort system must safely remove the beam from the accelerator ring and transport it to a dedicated beam dump. The dilution kickers must spread the beam evenly on the surface of the beam dump and on the vacuum chamber window, in order to prevent damages due to high energy electron and positron beams. Simulation studies are carried out in order to determine an operational configuration of the abort system and the required apertures of the abort beam lines.

INTRODUCTION

The extraction system is designed to remove the electron and positron beams from the main ring and transport them to the external beam dump. A set of kicker magnets is pulsed rapidly to kick the whole beam out of the machine in a single turn (333 μs). The kicker deflects the beam horizontally into a Lambertson septum, which provides a strong vertical deflection to clear the downstream lattice quadrupole. In order not to melt the dump block absorber material, the beam is spread over the front surface of the dump by means of horizontal and vertical dilution kicker magnets. The extracted beam is transported by 2.4 km long vacuum line to increase the beam size. It is deposited on absorber blocks specially designed to take the enormous instantaneous power (20 MJ in 333 μs is 60 GW). The extraction line geometry and dump block location are arranged so as to be compatible with the infrastructure of the FCC-hh dump.

Layout in FCC LSS

- A 99 m drift is needed after the kicker QD, containing the septum
- 3 'matching' quads are added each side of the extraction elements
- A steering dipole and dilution kickers placed at start of FCC arc
- Total length needed is 250-300 m, per beam (at ends of LSS)

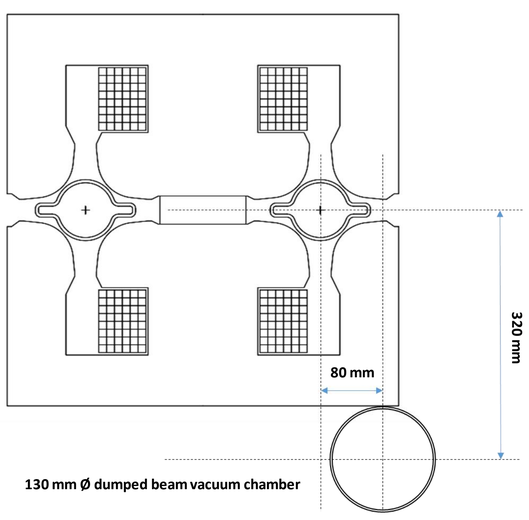


Beam energy (GeV]	45.6
Beam size σ_x [mm]	0.51
Beam size σ_y [μm]	32
Angular distr., $\sigma_{x'}$ [μrad]	0.51
Angular distr. $\sigma_{y'}$ [nrad]	32
# Particles per bunch [10^{11}]	0.4
# Bunches per beam	70760

FCC-ee beam parameters.

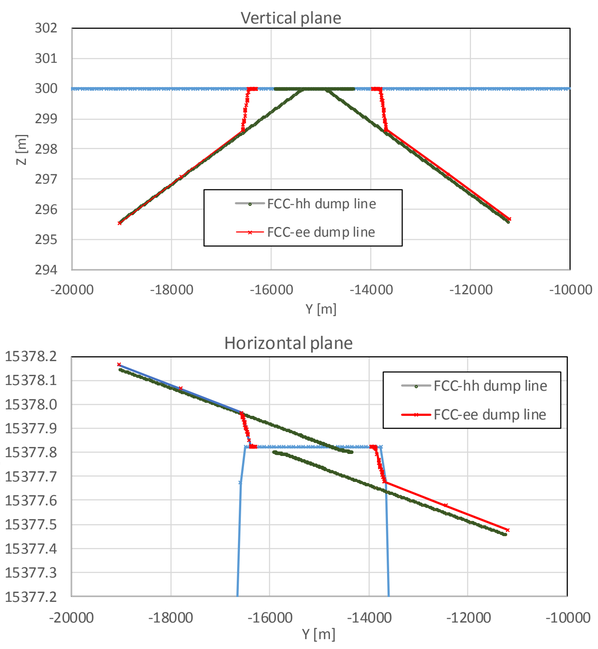
Extracted beam

- At QD, 7.3 mm off-axis gives additional 77% kick
- The beam clears the downstream lattice quadrupole vertically



Line geometry

- A bending of 10(1) mrad is needed in V(H) to match the trajectory to FCC-hh dumped beam t in both planes. This is easily incorporated



Extraction septum

- The Lamberston septum deflects the beam 12 mrad downwards. The half-aperture for the circulating and extracted beams is 20 mm, with 10 mm septum width. 1x 0.44 T magnet is needed at the Z-pole, 4x for tt.

Septum parameters		
Septum width	mm	10
Beam half-aperture	mm	20.5
K (V)	mrad	-12
Total L magnetic	m	16.0
Magnet length	m	4
Modules		4
B	T	0.44
Total length	m	19.0

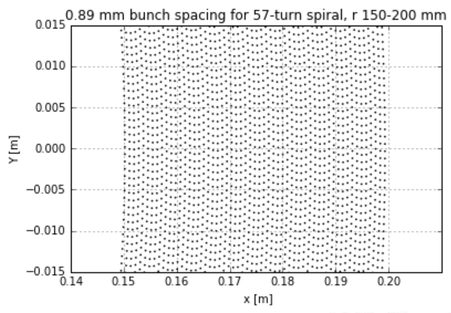
Extraction kicker

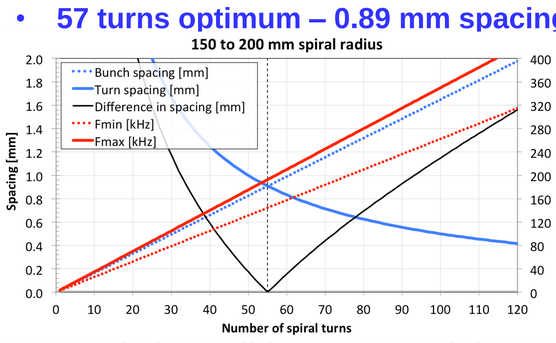
FCCee extraction kicker parameters			
pole		Z	tt
energy	GeV	45.5	175
Brho	Tm	151.7	583.3
K	mrad	0.5	0.5
L	m	1.5	6
# modules		1	4
B	T	0.0506	0.0486
V gap	**mm**	**50**	**50**
H gap	**mm**	**70**	**70**
magnet length	m	1.5	1.5
mu0		1.26E-06	1.26E-06
magnet inductance	uH	2.639	2.639
magnet filling time	ns	422.2	422.2
current	A	2011.5	1934.2
total rise time 2-98%	ns	1000	1000
switch rise time	ns	906.5	906.5
pulse length	us	333	333
flat-top ripple	+/- %	5	5
system impedance	Ohm	6.25	6.25
switch voltage	kV	25.1	24.2
inter-magnet gap	m	0.2	0.2

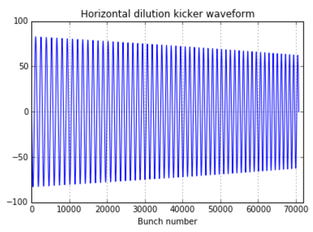
- Assume solid-state switches – 25 kV
- 0.5 mrad to make extraction compact
- 1 μs rise time (422 ns magnet filling time)
- 2 kA
- 6.25 Ohm impedance
- 50 mm V gap assumed
- 330 us flat-top - will be a challenge
- 4x 1.5 m magnets for tt operation (1 for Z)
- 7 m total system length

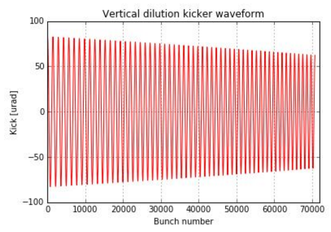
Dilution system and sweep on dump

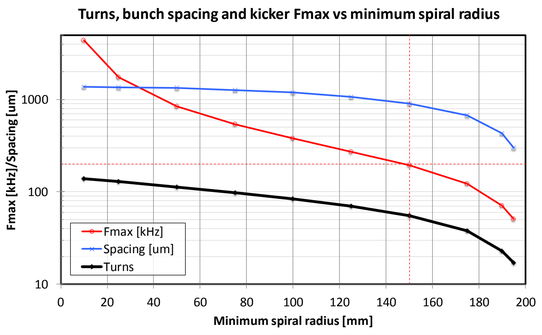
- Archimedean spiral with equal spacing between turns
- Fixed outer sweep radius as 200 mm
- Bunch spacing depends on inner radius
- Maximum kicker frequency 200 kHz (losses in tape-wound 50 μm steel)
- 57 turns optimum – 0.89 mm spacing





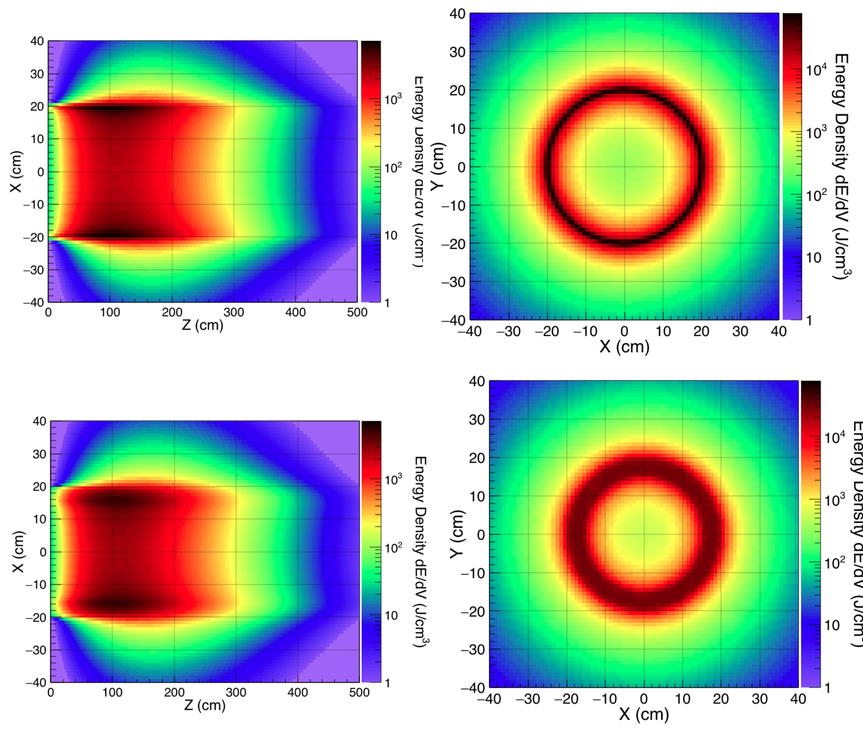






Dilution kicker parameters		
Number of turns		57
Sweep length	us	333.0
Frequency	kHz	193
K	mrad	0.083
B	T	0.0486
V gap	mm	70
H gap	mm	70
magnet length	m	1
mu0		1.26E-06
Inductance (incl. cables + stray)	uH	3.757
current	A	2707.8
switch voltage	kV	12.34

Deposited Energy Density in the Graphite



Upper plots: Number of turns in spiral is 1, distance between the center of bunches is 17.76 μm.

Bottom plots: Number of turns in spiral is 57, distance between the center of bunches is 890 μm.

The energy density deposited in the graphite beam dump in the vertical-longitudinal (x-z) plane.

The energy density deposited on the graphite beam dump in the transverse (x-y) plane.

Summary In case of one turn of the spiral, the maximum energy deposition density by the beam of electrons in the graphite is found to be 605 J/cm³, which is equivalent to 356 J/g. The associated peak temperature rise in the graphite due to the impact of a beam of electrons is 493 °C.

In case of 57 turns of the spiral, which keeps the dilution sweep frequency below 200 kHz, the maximum energy deposition density by the beam of electrons in the graphite is found to be 130 J/cm³, which is equivalent to 76 J/g. The associated peak temperature rise in the graphite due to the impact of a beam of electrons is 106 °C.

The next steps are to i) generate the full optics for the LSS, with the RF elements and beam envelopes, which may refine the kicker and septum openings and parameters, and ii) to study the feasibility of an extraction kicker rise time of ~100 ns, for RF beam-loading reasons.

REFERENCES

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