Simulations for a passive Beam Dilution and Dump System for the FCC-ee

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122nd FCC-ee Optics Design Meeting

July 17th, 2020
• Short reminder of the FCC-ee dump system in the CDR
• Ideas from the last FCC Week (June 2019 Brussels)
• Design of a passive Beam Dilution System
• The Beam Dump
• Summary
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<th>Z</th>
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<td><strong>Beam Energy [GeV]</strong></td>
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<td>175</td>
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<td><strong>Bunches / beam</strong></td>
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<td><strong>Average bunch spacing [ns]</strong></td>
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2.8.2 Extraction and beam dump

The extraction system is designed to remove the electron and positron beams from the main ring and transport them to the external beam dump. The system of extraction kickers and a Lambertson septum deflects the beam downwards by 12 mrad. In order not to melt the dump absorber material, the beam is spread over the front surface of the dump in a spiral pattern by means of horizontal and vertical dilution kicker magnets. The energy density deposited in the graphite in the horizontal-longitudinal (x–z) plane is shown in Figure 2.42.

Beam dump block

Graphite has been chosen as the main material for the beam dump, because of its high melting temperature. A cylinder with 400 mm radius and a length of 5 m was chosen as shape of the absorber. With 57 turns of the spiral, which keeps the dilution sweep frequency below 200 kHz, the maximum energy deposition density in the graphite from the beam of electrons is found to be 130 J/cm³, equivalent to 76 J/g. The peak temperature rises in the graphite due to the impact of an electron beam is ~100°C (see Fig. 3.26 right).

Fig. 2.42. The energy deposition on the beam dump for FCC-ee.

**Fig. 3.26.** Waveform of horizontal dilution kicker and energy deposition at 100 cm depth in graphite dump block, for a 57 turn sweep. The sweep frequency increases from 152 to 193 kHz, while the amplitude decreases from 83 to 60 μrad. The vertical kicker waveform is virtually identical with a π/2 phase shift. The spacing between bunches and between turns is 0.89 mm.

CDR Extraction and Dump

- Similar to FCC-hh
- Heavy active dilution
- Extraction line of \(\sim 2.8 \text{ km}\)

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• Heavy active dilution
• Extraction line of $\sim 2.8$ km

$E_{\text{max}} = 130 \, \text{J/cm}^3$
$T_{\text{max}} = \sim 100 \, ^\circ\text{C}$

Fig. 3.26. Waveform of horizontal dilution kicker, with peak pulse position at 100 cm depth in graphite dump block, for a 57 turn sweep. The sweep frequency increases from 152 to 193 kHz, while the amplitude decreases from 83 to 60 $\mu$rad. The vertical kicker waveform is virtually identical with a $\pi/2$ phase shift. The spacing between bunches and between turns is 0.89 mm.

Talk by Armen Apyan:
"FCC-ee Beam Dump System Concept and Technological Challenges"

3 alternatives:
Talk by Armen Apyan:
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3 alternatives:
- internal dump with dilution
Internal beam dump (with dilution system)

- Absorber: Graphite, 1 g/cm$^3$
- Total length: ~6-7 m
- About 1500 deg C at return points
- Assumed dilution pattern:
  - Vertical speed $v = 350$ m/sec on dump surface $\rightarrow$ 1 mrad, 3 us rise time
  - Horizontal dilution = 8 kHz, amplitude = 5 cm, 0.5 mrad $\rightarrow$ reasonable kicker parameters

From 2019 FCC-Week talk of Armen Apyan
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- internal dump with dilution
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3 alternatives:

- internal dump with dilution
- external dump without dilution
- external dump with passive dilution
• Use a slab of graphite for dilution after the extraction kicker

Drawings from 2019 FCC-Week presentation of Armen Apyan
• Use a slab of graphite for dilution after the extraction kicker
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- In cooperation with ABT-BTP Group and Anton Lechner from the Fluka side.

Drawings from 2019 FCC-Week presentation of Armen Apyan
Passive Beam Dilution

Spoiler, ~10 cm (Graphite, 1 g/cm³)

~70m

Spoiler → initial shower build-up and Coulomb scattering increases the angular spread of the energy carried by the beam

Dump (Graphite, 1 g/cm³)
Thickness is determined by shower build-up and by Coulomb-Scattering.
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For graphite: $\chi_0 = 42.7 \text{ g cm}^{-2}$
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For $1.0 \, \text{g cm}^{-3}$ graphite: length should be $\sim 10.7 \, \text{cm}$

For $1.8 \, \text{g cm}^{-3}$ graphite: length should be $\sim 5.9 \, \text{cm}$
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consider mechanical and thermal properties.
Choice of material

Dump: 6 m, 1.0 g cm$^{-3}$ graphite
Material: 1.8 g cm$^{-3}$ Graphite
Diameter: 10 cm
Length: 6 cm
Encased in Ti tube.
Design of the Spoiler

Maximum temperature in the dump

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Spoiler: 6 cm, 1.8 g cm$^{-3}$ graphite
First LS-Dyna and Ansys simulations showed extremely high surface stresses.
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To estimate material failure, the Christensen failure criterion was used.
(much better for brittle materials than for example van-mises.)

\[
\left( \frac{1}{T} - \frac{1}{C} \right) (\sigma_1 + \sigma_2 + \sigma_3) + \frac{1}{2TC} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right] \leq 1
\]

With a maximum compressive strength \( C = 120 \text{ MPa} \)
And a maximum tensile strength \( T = 40 \text{ MPa} \)

**Values \( > 1 \) show material failure**
Design of the Spoiler

beam direction
Together with Wolfgang Bartmann and Salim Ogur (TE-ABT-BTP) an optimisation of the beam spot size on the spoiler was carried out.
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Spoiler length reduced to 3 cm and multiple spoilers in succession
Revised Spoiler design

Material: 1.8 g cm$^{-3}$ Graphite
Diameter: 20 cm
Length: 3 cm
Encased in Ti tube (∼1 cm)
3 spoilers in succession
Energy Deposition in Dump with improved beam profile

- no spoiler
- 6 cm spoiler
- 3x3 cm spoiler

max. E-Dep. [J/cm³] vs. s [cm]
Revised Spoiler mechanical simulations
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beam direction
Revised Spoiler mechanical simulations

Time = 0.00016799
Contours of
min=-0.76818, at elem# 597582
max=0.300462, at elem# 6264
Revised Spoiler mechanical simulations

Time = 0.00016799
Contours of
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~300 µm
beam direction
Further optimisations are carried out. Shrink-fitting of the spoiler inside a titanium ring will further increase the strength.
- For now the Dump itself is still very similar to the CDR version.
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- ~6 m long graphite core
- Between $1.0 \, \text{g cm}^{-3}$ and $1.8 \, \text{g cm}^{-3}$ density
- A diameter between 30 cm and 60 cm
- Shielding depending on position and access requirements.
The Beam Dump

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- Further optimization of material, length, shielding, etc.
- Dump can be inside the straight section, no extra tunnel needed.
Long. E-Dep. in the Dump Shell (Steel)

max. E-Dep. [J/cm$^3$]

s [cm]

- core, $r = 30$ cm
- core, $r = 15$ cm
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  • (i.e. in the same plane as the ring, above or below)

• Determine access requirements and estimate shielding requirements.

• A HiRadMat test is planned for the spoiler and low density materials, hopefully in 2021.
Thank you
Irradiation Dump, old config

- 1 sec
- 1 h
- 8 h
- 1 d
- 7 d
- 1 m

max. Dose [mSv/h] vs. r [cm]
Irradiation Spoiler, old config

The graph shows the maximum dose [mSv/h] as a function of distance r [cm]. The data is presented for different time intervals: 1 sec, 1 h, 8 h, 1 d, 7 d, and 1 m. The dose decreases with increasing distance, with distinct curves for each time interval, indicating the decay of radiation over time.