BEAMSTRAHLUNG DUMP AND RADIATION LEVELS IN THE EXPERIMENT IRS

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Introduction

In the FCC-ee interaction regions different processes generate an intense photon flux collinear to each outgoing beam, i.e., two photon beams exiting the IP

- synchrotron photon production in the EM field of the counter-rotating beam (\textit{beamstrahlung}) – 369 kW for Z-pole operation
- synchrotron photon production in the fringe field of the solenoid and anti-solenoid – 77 kW for Z-pole operation
- other synchrotron radiation sources to be considered as well

→ two high-power beam dumps per IP needed to safely dispose of these photons

\[\text{this study presents some preliminary estimates with FLUKA for the design of the beam dump, taking into account only the beamstrahlung source @Z-pole, ttbar}\]
 Beamstrahlung radiation in the FCC-ee IRs

Beamstrahlung photon spectra for Z and ttbar operation, simulated with Guinea-Pig by A. Ciarma

<table>
<thead>
<tr>
<th></th>
<th>Z</th>
<th>ttbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy [GeV]</td>
<td>45</td>
<td>182.5</td>
</tr>
<tr>
<td># of bunches/beam</td>
<td>10000</td>
<td>36</td>
</tr>
<tr>
<td>bunch intensity [$10^{11}$]</td>
<td>2.43</td>
<td>2.64</td>
</tr>
<tr>
<td>beam current [mA]</td>
<td>1280</td>
<td>5</td>
</tr>
</tbody>
</table>

Challenging beam dump design

- Z-pole: 369 kW
- ttbar: 76 kW
High-power beam dumps

**Requirements**

- absorb the energy carried by the beam
  
  ↓

  **DUMP CORE**

  it must withstand high power densities

  → **graphite**: low density, high service temperature, easier design (common choice for dumps)

  → **liquid lead**: compactness, better heat dissipation, no concern for DPA, high boiling temperature, high Z and density

- limit radiation-induced effects and damage to other equipment

- limit induced radioactivity to protect personnel

- avoid induced background in the detector
  
  ↓

  **SURROUNDING SHIELDING**

  it must contain most of the electromagnetic and particle showers induced by the impacting beam
High-power beam dumps - example

**SPS beam dump**, designed for 300 kW deposition in the most demanding scenario

**Dump’s Components:**

- Multi-material external shielding:
  - Cast-iron → 520 tons
  - Concrete → 90 tons
  - Marble → 48 tons

- ~ mass 676 tons
- ~8.8 m
- ~3.6 m
- Total width ~4.8 m

- Cast iron first shielding → ~16 tons
- Dump core and vacuum chamber → ~2 tons
Beamstrahlung dumps

Dump placement:
- **external** to the beamline
- **500 m** downstream of the IP

- enough space for shielding between dump and booster, e⁻ and e⁺ rings, but 500 m long photon extraction line needed

Tunnel layout from F. Valchkova

Potentially challenging for transport and handling
FLUKA simulation model

- **Extraction line**
  - 500 m long
  - straight and directed as the outgoing beam (15 mrad)

- **Concrete tunnel surrounded by soil**

- **Two options for the dump core**
  - graphite (1.8 g/cm$^3$), cylindrical (3 m long, 35 cm radius)
  - liquid lead (10.678 g/cm$^3$), cylindrical (0.2 m long, 35 cm radius)

still no beamlines or other equipment included in the FLUKA geometry
Dump analysis
Distributions on the face of the dump @500m

Photon beam spot on the dump:
- horizontal shift due to non-zero angle of emission of beamstrahlung photons with respect to the outgoing electron beam axis

Energy impacting on the dump:
- further horizontal shift due to the correlation between the energy and the angle of emission of beamstrahlung photons
Power density in the graphite dump

**Horizontal plane:** average for y in [-1,1] cm around the impact centre
Distribution of max longitudinal power density

Graphite dump

- Power density: 136 W/cm³
- Z-pole: 97.6%
- ttbar: 99.0%

Fraction of power absorbed by the dump core:
- Z-pole: 97.6%
- ttbar: 99.0%

Liquid lead dump

- Power density: 1920 W/cm³
- Z-pole: 98.4%
- ttbar: 99.1%

Fraction of power absorbed by the dump core:
- Z-pole: 98.4%
- ttbar: 99.1%

- Compatibility of these peak powers with these materials to be studied in thermomechanical studies
Annual DPA graphite dump

Horizontal plane: average for $y$ in $[-1,1]$ cm around the impact centre

1 year of operation
$1\times10^7$ s $\approx 116$ d
Radiation levels in the tunnel
Radiation effects to electronics and materials

Electronic components and systems exposed to a mixed radiation field experience **two main types of radiation effects:**

- **cumulative damage** – deterministic
  → evaluated through **total ionizing dose (TID)** [Gy]
  - 1 Gy = 1 J/kg of ionizing energy deposition

- **single event effects (SEEs)** for active electronics – stochastic
  → probability of occurrence as a function of
    **high-energy hadron equivalent** (HEH-eq) fluence [cm\(^{-2}\)]
    - **Gy scale**: ok for commercial-based electronics (with qualifications if dose > 1 Gy)
    - >10 kGy: only rad-hard electronics
    - **MGy scale**: material damage

- **earth surface radiation**: HEH ~10\(^5\) cm\(^{-2}\)/year
- **LHC tunnel electronics (DS)**: HEH up to >10\(^10\) cm\(^{-2}\)/year
Shielding the dumps

The dumps must be shielded to decrease the radiation levels in the tunnel to values safe for the machine equipment and the personnel

**Simple shielding model to evaluate the associated efficiency:**
- two-layer cylindrical shield implemented in the simulations of graphite dump

First investigation of shielding effectiveness: TID and HEH-eq fluence in the tunnel near the dump with and without the above shielding
Annual TID in the tunnel near graphite dump

- **highest dose @Z-pole without shielding**: up to few MGy around the dump, around 1 MGy at booster and $e^-$ ring ($x\approx0$)
- proposed shielding reduces the TID by a factor >>10
- significant **backscattering** for Z-pole, higher TID beyond the dump for ttbar

both fixable by further optimizing the shielding, in terms of thickness and length upstream/downstream the dump
**Annual HEH-eq fluence**

- Neutron spectra next to the dump around $x=0$

![Graph showing annual differential fluence vs. energy (MeV)]

- **Z no shielding**
- **Z shielding**
- **ttbar no shielding**
- **ttbar shielding**

- Annual differential fluence [cm$^{-2}$]
  - $1 \times 10^{17}$
  - $1 \times 10^{16}$
  - $1 \times 10^{15}$
  - $1 \times 10^{14}$
  - $1 \times 10^{13}$
  - $1 \times 10^{12}$
  - $1 \times 10^{11}$
  - $1 \times 10^{10}$
  - $1 \times 10^{9}$
  - $1 \times 10^{8}$

- **Energy [MeV]**
  - $0.0001$
  - $0.01$
  - $1$
  - $100$

- Spectrum

- **Summary:**
  - Mainly $17$ MeV scale neutrons from photonuclear reactions in the dump.
  - Peak HEH-eq fluence $10^{13}$ per year: extremely high for COTS electronics.
  - Shielding less effective on neutrons than on TID, especially at high energies.
  - Unlike the TID, higher HEH-eq fluence for ttbar due to higher-energy neutrons in the spectrum.
Conclusion

- we presented the challenges and main features of beamstrahlung dumps in terms of power deposition and DPA in the dump core, as well as radiation levels in the tunnel
- implications for the dump core design to be further studied and elaborated in collaboration with the CERN SY-STI-TCD team
  - choice of material still under discussion
- in the vicinity of the dump, high TID and HEH potentially leading to damage to equipment and electronics
  - further optimization for the shield needed
- to be further considered: implications of material activation in the vicinity of the dump for radiation protection (dose to personnel)
THANK YOU FOR YOUR ATTENTION!
Annual TID near graphite dump

- Z-pole, not shielded
- Z-pole, shielded
- ttbar, not shielded
- ttbar, shielded
Annual HEH-eq fluence near graphite dump

Z-pole, not shielded

ttbar, not shielded

Z-pole, shielded

ttbar, shielded

Annual HEHAD-EQ [cm$^2$]

$1 \times 10^{16}$

$1 \times 10^{15}$

$1 \times 10^{14}$

$1 \times 10^{13}$

$1 \times 10^{12}$

$1 \times 10^{11}$

$1 \times 10^{10}$

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