Synchrotron radiation studies for the FCC-ee arc with FLUKA

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FCC-ee Week 2021 (30/06/2021)

Acknowledgments to J. Bauche, M. Benedikt, R. Garcia-Alia, G. Lerner, R. Kersevan & F. Valchкова Georgieva
Agenda

1. Simulation setup
2. Synchrotron radiation
3. Power and dose comparison
4. R2E levels
5. Conclusion
Simulation Setup

- **182.5GeV (ttbar)**: most challenging case for energy deposition studies
- Representative arc cell → periodic re-insertion of the particles
  - 140m
  - 5 dipoles, 5 quadrupoles, 4 sextupoles
- SR source: photons emitted in dipoles → indirect approach
  - Soon: e-, e+ in all magnets → direct approach
Magnets

**General:** 30cm beam separation

**Dipoles (MB):**
- Long: 24.64m ($l_{mag}$)
  (Simulations were performed before 24m long model was abandoned)
- Short: 21.44m ($l_{mag}$)
- 56.6mT at 182.5GeV

**Quadrupole (MQ):**
- 2.9m ($l_{mag}$)
- 3.2m ($l_{mech}$)
- Maximum gradient: 10.0T/m

**Vacuum chamber (VC):**
- Copper
- 2mm
- Winglets

**Sextupole (MS):**
- 1.4m ($l_{mag}$)
- No prototypes and technical drawings so far (ending of coils, ...)

Magnets designed from scratch in Fluka. Technical drawings received from J. Bauche
Model comparison: absorber vs continuous shielding

Absorbers (ABS):
- CuCrZr alloy
- Length: 30cm
- 5-6m distance
- Angled surfaces for even power distribution
- Water cooled
- 25 ABS in each beam (MBs, MQs)

(Design and initial placement by R. Kersevan)

Continuous shielding:
- Equivalent to LEP layout
- Continuous shielding around VC in MBs
  - Due to space restrictions from yoke and coils respectively, no shielding in MQs and MSs.
- Intermet180 (Tungsten alloy)
- Shielding thickness:
  - Top/bottom: 1cm
  - Sides: 1.3cm

30/06/2021
FCC Week 2021 - SR studies done with FLUKA
Synchrotron Radiation (SR)

- **Electromagnetic radiation** emitted tangentially with an angular spread by charged particles moving along a curved trajectory.
- The **lighter** the particle and the higher the **energy**, the stronger the effect: 
  \[ \Delta E \propto \frac{E^4}{m^4} \]
- **SR related numbers in FCC-ee** \((\rho = 10.76 \text{km})\):
  - Energy loss \((\Delta E)\): 9.2 GeV/turn
  - Critical energy \((E_C)\): 1.25 MeV
  - Power whole ring: 50 MW
  - Power 140m: 168 kW

* **Critical energy** \((E_C)\): half of energy is carried by particles below, the other half above.
Absorber working & reflection

Compton scattering: photon collides with electron and is scattered into a different direction, dominant in the MeV range

External beam: reflected particle → magnet yoke

Internal beam: reflected particle → tunnel
# Power distribution on the tunnel & magnets

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>ABS</th>
<th>Continuous</th>
<th>MB *</th>
<th>MQ</th>
<th>MS</th>
<th>ABS, Shield/VC</th>
<th>Tunnel</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoke</td>
<td>Iron</td>
<td>23.4kW</td>
<td>3.5kW</td>
<td>23.4kW</td>
<td>2.9kW</td>
<td>0.1kW</td>
<td>131kW</td>
<td>9.5kW</td>
<td>167kW</td>
</tr>
<tr>
<td>Coils</td>
<td>Copper</td>
<td>2.9kW</td>
<td>17.4kW</td>
<td>2.9kW</td>
<td>17.4kW</td>
<td>7.1kW</td>
<td>131kW</td>
<td>9.5kW</td>
<td>167kW</td>
</tr>
<tr>
<td>VCR/VCL</td>
<td>Copper</td>
<td>0.1kW</td>
<td>7.1kW</td>
<td>&lt;0.1%</td>
<td>1.7%</td>
<td>4.2%</td>
<td>1.7%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>ABS</td>
<td>CuCrZr</td>
<td>131kW</td>
<td>135kW</td>
<td>78%</td>
<td>10.4%</td>
<td>10.4%</td>
<td>78%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Shielding</td>
<td>INERM180</td>
<td>135kW</td>
<td>135kW</td>
<td>81%</td>
<td>81%</td>
<td>81%</td>
<td>81%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Component**

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**Normalisation:**

- **Yoke**: Iron, Coils: Copper, VCR/VCL: Copper, ABS: CuCrZr, Shielding: INERM180

**Normalisation conditions:**

- **I=5.4mA**
- **E=182.5GeV**
- **Runtime: 10^7s**

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![Graphs showing power distribution](attachment:graphs.png)
Dose in the tunnel environment

<table>
<thead>
<tr>
<th>Location</th>
<th>Continuous</th>
<th>ABS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top, Center</td>
<td>120kGy</td>
<td>500kGy</td>
</tr>
<tr>
<td>Middle, ext.</td>
<td>200kGy/1.2MGy peak</td>
<td>600kGy</td>
</tr>
<tr>
<td>Middle, int.</td>
<td>200kGy</td>
<td>1.2MGy</td>
</tr>
</tbody>
</table>
Dose and energy density on the coils (MB)

Top-View MB:

- **ABS:**
  - Up to 500MGy at location of ABS;
  - Strongly localized around y=0
  - Other locations: <1MGy
- **CONT:** peak caused by missing lack of shielding in MQs
- Dose in coils of MQs negligible due to protection of yoke
Energy density on the BP

- Similar situation as for coils

ΔT:
- **ABS**: deal with strong peaks (up to 400W/cm³) at absorbers, otherwise low power
- **CONT**: constant power (up to 40W/cm³ peaks) on the vacuum chamber
  → Cooling feasible?

- **ABS**: deal with strong peaks (up to 400W/cm³) at absorbers, otherwise low power
- **CONT**: constant power (up to 40W/cm³ peaks) on the vacuum chamber over whole magnet, but lower power
R2E: Si-1MeV neutron equivalent fluence

- Low abundance of neutrons, since they are only produced by photons >~10MeV
- High abundance of electromagnetic particles leads to higher contribution
- CONT: em. contribution better shielded, no significant difference in the neutron contribution

Results normalized to $10^7$s (one year at the current design) and 5.4mA
R2E: high energy hadron equivalent fluence & thermal neutron equivalent fluence

Thermal neutron eq fluence:

- Neutrons create secondary neutrons and thermalize
- Thermal neutron equivalent looks identical for both cases

HEH-eq fluence:

- HEH-eq fluence is lower due to low energy of neutrons → low weight
- Similar results for both designs for HEH-eq fluence

Results normalized to $10^7$s (one year at the current design) and 5.4mA
Summary:

- Lower dose values in the tunnel for “continuous” scheme
  - Problem of space restrictions in MQs and MS
  - High peaks in places of MQs due to missing shielding
- Booster location on top: barely any fluctuations along z
- **Cont**: higher values for dose and peak power on coils and BP over the whole magnet → cooling?
- **ABS**: strong peaks for dose and peak power, but otherwise low values → dose levels feasible?
- No strong differences for R2E related values

Outlook:

- Superconducting MQs and MSs for improved power consumption
- Booster impact on the collider determined by its time at top energy
- Collimation system → beam-collimator interaction
- Other FCC-ee FLUKA related projects:
  - Dump system
  - Positron target
Any questions?
Fluence in the tunnel – ABS layout

**Neutron fluence:**
- Similar results for beam 1 and beam 2
- Magnets are “transparent” for neutrons
- Peak at 0.025eV from thermal neutrons

**Electromagnetic particles fluence:**
- Higher fluence obtained for B1 due to scoring at the outside of the tunnel
- Magnets stop particles from B2