Machine Detector Interface WG: Beam–Induced Background simulations

C. Curatolo* for RD_MUCOL

*INFN Milano, Italy
camilla.curatolo@mi.infn.it

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Machine Detector Interface WG of International Muon Collider Collaboration:

- INFN: BIB @ 1.5 TeV using MAP machine design and optics files OK
  BIB @ 3 TeV using MAP machine design and optics files to be optimized
  - BIB simulation tool setup: LineBuilder + FLUKA + Python script for analysis
  - Machine Detector Interface (MDI) layout description for 1.5 TeV CM energy
  - MARS15 vs FLUKA results @ 1.5 TeV CM energy
  - Preliminary FLUKA results @ 3 TeV CM energy

- CERN: original machine design @ 10 TeV and BIB studies
Simulation setup & MDI layout description for 1.5 TeV CM energy

Simulation tool: **LineBuilder + FLUKA**
Data analysis: **Python**

starting 200 m from IP

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam momentum</td>
<td>750 GeV/c</td>
</tr>
<tr>
<td>Beam momentum spread</td>
<td>0 GeV/c</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$2 \times 10^{12}$</td>
</tr>
<tr>
<td>$\epsilon_{x,y}$ normalised RMS emittance</td>
<td>$25 \times 10^{-6}$ m rad</td>
</tr>
<tr>
<td>$\epsilon_{x,y}$ geometric RMS emittance</td>
<td>$3.5 \times 10^{-9}$ m rad</td>
</tr>
<tr>
<td>$\beta_{x,y}$</td>
<td>1 cm</td>
</tr>
<tr>
<td>$\alpha_{x,y}$</td>
<td>0</td>
</tr>
<tr>
<td>$\sigma_{x,y}$ RMS beam size</td>
<td>5.96 µm</td>
</tr>
<tr>
<td>$\sigma_{x,y}$ RMS beam divergence</td>
<td>596 µrad</td>
</tr>
</tbody>
</table>

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IR Quadrupoles

Nozzle

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“Muon collider interaction region design” Y. I. Alexahin (2011)

“A study of muon collider background rejection criteria in silicon vertex and tracker detectors” V. Di Benedetto (2018)
• Realistic $\mu^-$ beam simulated 200 m from IP
• Lattice, optics and MARS15 simulated files provided by MAP
• MDI passive elements retrieved by MAP publications
• Energy threshold cuts: $\gamma$ & $e^+/e^-$ & charged hadron & $\mu^+/\mu^-$ 100 keV, neutron 1 meV
• Only muon decays within 25 m from IP considered for the comparison
• Secondary muons simulated via decays within 200 m from IP (backup slide)
• Implicit symmetry for counterpropagating $\mu^+$ beam
Very good agreement between MARS15 and FLUKA, reason for remaining discrepancies possible layout differences, missing infos about passive elements and absorbers

<table>
<thead>
<tr>
<th>Particle (E_{kin})</th>
<th>MARS15</th>
<th>FLUKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon (100 keV)</td>
<td>8.6 \times 10^7</td>
<td>5.1 \times 10^7</td>
</tr>
<tr>
<td>Neutron (1 meV)</td>
<td>7.6 \times 10^7</td>
<td>1.1 \times 10^8</td>
</tr>
<tr>
<td>Electron/pos (100 keV)</td>
<td>7.5 \times 10^5</td>
<td>8.5 \times 10^5</td>
</tr>
<tr>
<td>Ch. Hadron (100 keV)</td>
<td>3.1 \times 10^4</td>
<td>1.7 \times 10^4</td>
</tr>
<tr>
<td>Muon (100 keV)</td>
<td>1.5 \times 10^3</td>
<td>1 \times 10^3</td>
</tr>
</tbody>
</table>

“Detector Backgrounds at the Higgs Factory Muon Collider: MARS vs FLUKA” N. V. Mokhov (2018)
FLUKA simulations @ 3 TeV

- LineBuilder + FLUKA simulation setup ready for 3 TeV
- Lattice and optics provided by MAP not fully optimized
- Same IR used for 1.5 TeV: it has to be optimized
Many latest improvements to 1.5 TeV simulation still to be applied to 3 TeV: very preliminary results for 3 TeV
Work done

- New simulation setup LineBuilder + FLUKA:
  flexible tool to simulate BIB at any desired CM energy and optimize machine lattice and MDI
- Reproduction of MAP configuration at 1.5 TeV:
  high sensitivity of BIB at MDI design, nozzles filter higher energy $\gamma$ and $e^+/e^-$ (backup slide)
- FLUKA benchmarked against MARS15 results at 1.5 TeV:
  very good agreement, small discrepancies probably given by residual differences in MDI layout
- All results at 1.5 TeV and comparison with MARS15 submitted to JINST:
  “Advanced assessment of Beam Induced Background at a Muon Collider”
- computational needs @1.5 TeV:
  good statistics decays within 100 m run takes $\approx 500$ CPU hours and $\approx 2.5$ GB

Work in progress

- Study of FLUKA-based BIB in the detector
- Simulation of 3 TeV configuration based on MAP lattice: lattice, nozzle and IR optimization needed
- computational needs @3 TeV:
  low statistics $\approx 100$ configurations takes $\approx 100000$ CPU hours and $\approx 100$ GB
Backup slides
More on FLUKA results: nozzle YES or NO?

Camilla Curatolo INFN Milano, Italy

Beam–Induced Background Simulations
FLUKA @ 1.5 TeV: z primary muon decay, cumulative & secondary muons

Camilla Curatolo INFN Milano, Italy

Beam–Induced Background Simulations
Ex: 100 GeV electron exit at 3 m with 0.01 rad angle

reaches the inner layers of the tracking system
For bunch crossing, $2 \times 10^{12}$ muons/bunch, 200 days/year operation, 100 kHz bunch crossing rate