BEAM-GAS BACKGROUND CHARACTERIZATION IN THE FCC-EE IR

F. Collamati, O. Blanco, M. Boscolo
H. Burkhardt, M. Lueckhof, R. Kersevan
Approach

- **MDISim** ([link](#)) is a set of C++/Root classes that allows to import beam pipe geometry, magnetic elements and beam characteristics in GEANT4 to perform a **full simulation**.

- It is being used to study **Synchrotron Radiation** backgrounds (see M. Lueckhof poster).

- However, having in **GEANT4** the beam pipe geometry and the beam characteristics (realistic emittance, energetic and angular spread..) opens the way to several **other possible applications**!
Beam gas studies

- Very rare process, due to very low density of Vacuum in the pipe

- However, within certain limits, can be “enlarged” by rising this density
(inelastic) Beam gas
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- A primary electron beam is generated ~900m from the IP (s coord.), and tracked for about 1km
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- Rising the Vacuum density of about 9 orders of magnitude (MC biasing), it is possible to start to see some Beam-Gas interactions:
  \[ P_{\text{real}} \sim 10^{-9} \text{ mbar} \rightarrow P_{\text{MC}} \sim 1 \text{ mbar}!!! \]
- \( \text{N}_2 \) was chosen as gas (worst case)
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  - \( P_{\text{real}} \sim 10^{-9} \text{ mbar} \rightarrow P_{\text{MC}} \sim 1 \text{ mbar}!!! \)
  - \( N_2 \) was chosen as gas (worst case)
- **Event recognition:**
  - Primary electron undergoes “\( eBrem \)” process with >1 MeV energy transfer
  - The primary electron is then lost in the pipe
Due to the highest current, the Z configuration is expected to have the highest rate of Beam Gas lost particles.

Plots will be shown for this case (but the study has been performed on all 4 running configurations).

<table>
<thead>
<tr>
<th>Beam current</th>
<th>190</th>
<th>147</th>
<th>29</th>
<th>6.4</th>
<th>5.4</th>
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<tbody>
<tr>
<td>Average bunch spacing</td>
<td>9.6</td>
<td>251</td>
<td>994</td>
<td>2783</td>
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<td>Bunch population</td>
<td>1.7</td>
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<td>1.8</td>
<td>2.2</td>
<td>2.3</td>
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<tr>
<td>Horizontal emittance $\varepsilon_x$</td>
<td>0.27</td>
<td>0.84</td>
<td>0.63</td>
<td>1.34</td>
<td>1.46</td>
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<tr>
<td>Vertical emittance $\varepsilon_y$</td>
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<td>1.7</td>
<td>1.3</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>14.8</td>
<td>7.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results normalisation
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• Imagine we simulate $N_{MC}$ primary electrons, and that we obtain that $N_{e\text{loss}}$ particles are lost in the considered range (-830m, 170m):
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  - $N_{MC}/N_{e\,\text{loss}}$ is thus the fraction of beam particles getting lost
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  - Remember that the MC simulation is using a Gas Pressure that is $10^9$ times higher than the “true” case
    (10^{-9} \text{ mbar}) → has to be taken into account!
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\[
N_{e^-\text{loss}}/\text{beam} = \frac{N_{e^-\text{loss}}}{N_{e^-\text{prim}}_{MC}} \times N_{e^-}/\text{bunch} \times N_{\text{bunch}}/\text{beam} : \frac{P_{MC}}{P_{\text{Real}}}
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$$N_{e_{loss}/beam} = \frac{N_{e_{loss MC}}}{N_{e_{prim MC}}} \times N_{e/bunch} \times N_{bunch/beam} \times \frac{P_{MC}}{P_{Real}}$$

“calibration factor” MC <-> Rate
Results normalisation

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$$\frac{N_{e^-}}{beam} = \frac{N_{e^-\text{loss,MC}}}{N_{e^-\text{prim,MC}}} \times \frac{N_{e^-}}{\text{bunch}} \times \frac{N_{\text{bunch}}}{\text{beam}} : \frac{P_{MC}}{P_{\text{Real}}}$$

$P_{MC}$ <-> Rate

```
\text{Rate}_{e^-\text{loss}/\text{beam}}[Hz] = \frac{N_{e^-\text{loss}/\text{beam}}}{\Delta T_{rev}[s]}
```

“calibration factor”

MC <-> Rate
Z position where the BG interaction that will lead to particle loss happened.
Remaining energy fraction of the primary electron that is lost after a BG interaction
Loss Map

Z position where a primary electron is lost after a BG interaction

Beam Origin
Loss Map

Since the y axis is “Rate per beam”, the integral of this histogram gives the total loss rate in the considered range:

Z position where a primary electron is lost after a BG interaction
Loss Map

Since the y axis is “Rate per beam”, the integral of this histogram gives the total loss rate in the considered range:

\[ R = 147 \, \text{MHz} \]

Z position where a primary electron is lost after a BG interaction.
Zoom around IP

**Loss Map**

- Z position where a primary electron is lost after a BG interaction.

Graph showing rate per beam [MHz] with a scale for Z [mm].
Loss Map

Z position where a primary electron is lost after a BG interaction

The two peaks seem to correspond to the two tapering!
- How many particles are lost in a certain $Z$ sub-interval? -
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This is the total number of particles lost from -850 to 250m:

~147 MHz
- How many particles are lost in a certain Z sub-interval? -

This is the total number of particles lost from -850 to 250m:
~147 MHz

This is the number of particles lost from -850 to 0m (IP):
~80 MHz

Cumulative Loss Map

Beam Origin
How many particles are lost in a certain $Z$ sub-interval?

This is the total number of particles lost from -850 to 250m:

$\sim 147 \text{ MHz}$

This is the number of particles lost from -850 to 0m (IP):

$\sim 80 \text{ MHz}$

The difference between these values gives the number of particles lost from 0 to 250m:

$147 \text{ MHz} - 80 \text{ MHz} = \sim 67 \text{ MHz}$
## GOING QUANTITATIVE

### Machine configuration

<table>
<thead>
<tr>
<th>Current</th>
<th>N_Bunch/beam</th>
<th>Rate ALL</th>
<th>R_ALL/Current</th>
<th>R_ALL/bunch</th>
<th>Rate Zoom</th>
<th>R.Zoom/Current</th>
<th>R.Zoom/bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>1390</td>
<td>147.00</td>
<td>1.1E-01</td>
<td>8.8E-03</td>
<td>29.20</td>
<td>2.1E-02</td>
<td>1.8E-03</td>
</tr>
<tr>
<td>W</td>
<td>147</td>
<td>15.80</td>
<td>1.1E-01</td>
<td>1.2E-02</td>
<td>3.43</td>
<td>2.3E-02</td>
<td>2.6E-03</td>
</tr>
<tr>
<td>H</td>
<td>29</td>
<td>2.96</td>
<td>1.0E-01</td>
<td>9.0E-03</td>
<td>0.54</td>
<td>1.8E-02</td>
<td>1.6E-03</td>
</tr>
<tr>
<td>t</td>
<td>5.4</td>
<td>0.53</td>
<td>9.7E-02</td>
<td>1.1E-02</td>
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<td>1.8E-02</td>
<td>2.0E-03</td>
</tr>
</tbody>
</table>

**optics: fcc_ee_208, P_{VAC}=10^{-9} mbar**

### Graphs

- **Rate Zoom/Current**
- **Rate All/Current**
- **Rate Zoom/All bunch**
- **Rate All/All bunch**

### Graph Details

- **Z, W, H, T**
- **Machine configuration**
- **Rate Zoom/Current [kHz]**
- **Rate All/Current [kHz]**
- **Rate Zoom/All bunch [kHz]**
- **Rate All/All bunch [kHz]**
Local pressure variations
Local pressure variations

• Up to now, in the study it was assumed that the pressure is constant all over the beam pipe

• However, this is not the case:
  • In fact, we expect to have a locally varying pressure profile due to gas desorption caused by:
    • Interaction of SR photons with the beam pipe
    • Pump effect gradient due to pipe conductance
  • It is possible to study this pressure profile using SynRad + MolFlow
  • This study was performed @t (182.5GeV) configuration (expected worst case)
Local pressure variations

Is it thus possible to use the pressure profile to “weight” the results of the BG studies?

The gas pressure (and hence the interaction probability) is not constant along the machine.
Local pressure variations

Rate per beam [kHz]

-800 -600 -400 -200 0 200 400

Z [m]

fcc_ee_208-T_182.5GeV

ZExit w/o P
ZExit w/ P
Local pressure variations

Zoom around IP

Rate per beam [kHz]

ZExit w/o P
ZExit w/ P

fcc_ee_208-T_182.5GeV
There is a \(~40\%\) increase in the total loss rate when considering local pressure profile.
Track display

Is it possible to track particles hitting the pipe into the detector to evaluate the impact (e.g. on luminometer)?

See Mogens Dam talk on Tuesday
Sum-up and perspectives
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- **MDISim** enables to **import** the whole **machine** configuration (beam + geometry) in **GEANT4** starting from MAD-X file
  - Initially thought for Synchrotron Radiation studies
  - Once in GEANT4, an accurate study of the **inelastic beam-gas** background induced in the IR can be done
    * (loss maps, scattering points, total loss rate, particle tracks)
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  - If **local pressure variations** due to gas desorption are taken into account, the total loss rate is increased of about **40%**
- Tracks of particles exiting the pipe can be fed into **detector simulations** to evaluate their impact
Backup
GOING QUANTITATIVE

<table>
<thead>
<tr>
<th>Current</th>
<th>N_{Bunch}/beam</th>
<th>Rate ALL</th>
<th>R_{ALL}/Current</th>
<th>R_{ALL}/bunch</th>
<th>Rate Zoom</th>
<th>R_{Zoom}/Current</th>
<th>R_{Zoom}/bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mA]</td>
<td>#</td>
<td>[MHz]</td>
<td>[MHz/mA]</td>
<td>[MHz]</td>
<td>[MHz]</td>
<td>[MHz/mA]</td>
<td>[MHz]</td>
</tr>
<tr>
<td>Z</td>
<td>1390</td>
<td>16640</td>
<td>147,00</td>
<td>8,8E-03</td>
<td>29,20</td>
<td>2,1E-02</td>
<td>1,8E-03</td>
</tr>
<tr>
<td>W</td>
<td>147</td>
<td>1300</td>
<td>15,80</td>
<td>1,2E-02</td>
<td>3,43</td>
<td>2,3E-02</td>
<td>2,6E-03</td>
</tr>
<tr>
<td>H</td>
<td>29</td>
<td>328</td>
<td>2,96</td>
<td>9,0E-03</td>
<td>0,54</td>
<td>1,8E-02</td>
<td>1,6E-03</td>
</tr>
<tr>
<td>t</td>
<td>5,4</td>
<td>48</td>
<td>0,53</td>
<td>9,7E-02</td>
<td>0,10</td>
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<td>2,0E-03</td>
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</tbody>
</table>

Machine configuration

![Graph showing machine configuration with Z, W, H, and T labels on the x-axis and Rate/Current and RateZoom/bunch on the y-axis.]
## GOING QUANTITATIVE

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate ALL</th>
<th>Rate ALL/Current</th>
<th>Rate ALL/bunch</th>
<th>Rate ALL/Current</th>
<th>Rate ALL/bunch</th>
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<tr>
<td>Z</td>
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<td>0,53</td>
<td>9,7E-02</td>
<td>1,1E-02</td>
<td>0,10</td>
</tr>
</tbody>
</table>

**Machine configuration**

- Z: 1390 16640
- W: 147 1300
- H: 29 328
- t: 5,4 48

**Optics**: fcc_ee_208, \(P_{VAC}=10^{-9}\) mbar
### GOING QUANTITATIVE

<table>
<thead>
<tr>
<th>Current</th>
<th>N_{Bunch/bunch}</th>
<th>Rate ALL</th>
<th>R_ALL/Current</th>
<th>R_ALL/bunch</th>
<th>Rate Zoom</th>
<th>R_Zoom/Current</th>
<th>R_Zoom/bunch</th>
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</thead>
<tbody>
<tr>
<td>Z</td>
<td>1390</td>
<td>16640</td>
<td>147,00</td>
<td>1,1E-01</td>
<td>8,8E-03</td>
<td>29,20</td>
<td>2,1E-02</td>
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<tr>
<td>W</td>
<td>147</td>
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<td>15,80</td>
<td>1,1E-01</td>
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<td>2,3E-02</td>
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</table>

**Machine configuration**

<table>
<thead>
<tr>
<th>Rate_All/Current</th>
<th>Rate_Zoom/Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>W</td>
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fcc_ee_208
### GOING QUANTITATIVE

<table>
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<th>Current</th>
<th>N_{Bunch/beam}</th>
<th>Rate ALL</th>
<th>R_{ALL}/Current</th>
<th>R_{ALL}/bunch</th>
<th>Rate Zoom</th>
<th>R_{Zoom}/Current</th>
<th>R_{Zoom}/bunch</th>
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<tbody>
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<td>H</td>
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<td>1.1E+04</td>
<td>9.6E+04</td>
<td>1.8E+04</td>
</tr>
</tbody>
</table>

Machine configuration:

- **Z**: 1.5E+08 Hz, 1.1E+05 Hz/mA, 2.9E+07 Hz, 2.1E+04 Hz/mA
- **W**: 1.6E+07 Hz, 1.1E+05 Hz/mA, 3.4E+06 Hz, 2.3E+04 Hz/mA
- **H**: 3.0E+06 Hz, 1.0E+05 Hz/mA, 5.4E+05 Hz, 1.8E+04 Hz/mA
- **t**: 5.3E+05 Hz, 9.7E+04 Hz/mA, 9.6E+04 Hz, 1.8E+04 Hz/mA