START TO END SIMULATIONS AND MACHINE SENSITIVITY STUDY FOR THE ELI-NP γ-SOURCE

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on behalf of the SPARC LAB and ELI-NP team

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Abstract

The ELI-NP Gamma Beam System is an advanced gamma ray source up to 20 MeV based on Compton back-scattering effect, presently under construction in Magurele-Bucharest (RO). Here the head-on collision is foreseen between an intense high power laser beam and a high brightness electron beam with a maximum kinetic energy of 740 MeV. Start to end simulations of the ELI-NP Gamma Source are here presented regarding the machine sensitivity to the possible jitters and misalignments. The effects on the beam quality are illustrated providing the basis for the alignment procedure and jitters tolerances.
The ELI-NP $\gamma$-source

Peculiarities of the $\gamma$-source are:

1. Energy tunability of the $\gamma$-source in the range $[0.2 - 20.0]$ MeV

2. Mono-chromaticity of the $\gamma$-source with a BW (rms) $\leq 0.5\%$

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1. Energy Tunability of Electron Beam
2. $0.04\% \leq$ Energy Spread of Electron Beam (%) $\leq 0.1\%$
The ELI-NP γ-source

81 MeV @Injector Exit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch charge</td>
<td>250 pC</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.161%</td>
</tr>
<tr>
<td>Bunch length</td>
<td>282 µm</td>
</tr>
<tr>
<td>$\varepsilon_{n_x,y}$</td>
<td>0.4 mm mrad</td>
</tr>
<tr>
<td>Spot Size</td>
<td>390 µm</td>
</tr>
</tbody>
</table>

Rms normalized transverse emittance, rms transverse envelope and rms bunch length at the injector exit

Courtesy of A. Bacci - INFN-MI
The ELI-NP γ-source

**LINAC**

**LINAC 1**
Low Energy Beamline

**INJECTOR**
The ELI-NP γ-source

LINAC

LINAC 2
High Energy Beamline

INJECTOR
The ELI-NP γ-source

LINAC

LINAC 1
Low Energy Beamline

LINAC 2
High Energy Beamline

INJECTOR

Beams Parameters @IP

**Electron Beam Q = 25 - 400 pC**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>80 - 740</td>
<td>MeV</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.04 - 0.1</td>
<td>%</td>
</tr>
<tr>
<td>Bunch length</td>
<td>100 - 400</td>
<td>µm</td>
</tr>
<tr>
<td>$\varepsilon_{n,x,y}$</td>
<td>0.2 – 0.6</td>
<td>mm mrad</td>
</tr>
<tr>
<td>Focal Spot Size</td>
<td>&gt; 15</td>
<td>µm</td>
</tr>
</tbody>
</table>

**Laser Beam $\lambda = 515$ nm**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>0.2 – 0.4</td>
<td>J</td>
</tr>
<tr>
<td>Focal Spot Size</td>
<td>&gt; 28</td>
<td>µm</td>
</tr>
</tbody>
</table>

**GBS - Beam Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>0.2 – 20.0</td>
<td>MeV</td>
</tr>
<tr>
<td>Flux within FWHM BW</td>
<td>$\leq 2.6 \times 10^5$</td>
<td>$N_{ph}$/pulse</td>
</tr>
<tr>
<td>Peak brilliance</td>
<td>$10^{20} - 10^{23}$</td>
<td>$N_{ph}/s\cdot mm^2\cdot mrad^2 \cdot 0.1%$</td>
</tr>
<tr>
<td>BW (rms)</td>
<td>$\leq 0.5$</td>
<td>%</td>
</tr>
<tr>
<td>Source Size</td>
<td>10 - 30</td>
<td>µm</td>
</tr>
</tbody>
</table>
Technical Design Report
E-Gammas proposal for the ELI-NP Gamma beam System
With 79 tables and 252 figures

Machine Error Sensitivity Studies

The Method:

- The beamline has been preliminary matched for the ideal electron beam.

- Misalignments and jitters have been introduced both in the injector and all along the linac with the aim to provide specifications for jitters and alignments of accelerating structures and magnets.

- Error matrices from injector and linac have been coupled one with each other randomly.

- Error value distributions are calculated according to the latin hypercube scheme (as reported in the TDR) by using a matrix of the latin hypercube randomly factorizes in the range [-100 : +100]% of error values.

- Data analysis has been done on 100 bunches, each composed of 30k macro particles.
Injector Error Sensitivity Studies

Specifications for cathode laser system, power supplies and solenoids

- Injector sensitivity analysis has been performed over a random sampling of 100 runs, by using the codes Giotto and Astra.

- In table the considered errors on all devices

<table>
<thead>
<tr>
<th>Errors on GUN</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Voltage [ΔV]</td>
<td>0.2</td>
<td>%</td>
</tr>
<tr>
<td>RF Phase [Δφ]</td>
<td>200</td>
<td>fs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on S-band Accelerating Sections</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Voltage [ΔV]</td>
<td>0.2</td>
<td>%</td>
</tr>
<tr>
<td>RF Phase [Δφ]</td>
<td>200</td>
<td>fs</td>
</tr>
<tr>
<td>Alignment on transverse plane [Δxy]</td>
<td>70</td>
<td>μm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on Solenoids (GUN &amp; TW cavities)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alignment on transverse plane [Δxy]</td>
<td>70</td>
<td>μm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on Cathode Laser System</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival time [Δt]</td>
<td>200</td>
<td>fs</td>
</tr>
<tr>
<td>Pointing Instabilities [Δs]</td>
<td>20</td>
<td>μm</td>
</tr>
<tr>
<td>Energy Fluctuation</td>
<td>5</td>
<td>%</td>
</tr>
</tbody>
</table>

Courtesy of A. Bacci - INFN-MI
Linac Error Sensitivity Studies

Specifications for power supplies and magnetic elements

- Linac sensitivity analysis has been performed over a recursive sampling of 100 runs, by using the Elegant code.
- In table the considered errors on all devices

<table>
<thead>
<tr>
<th>Errors on C-band Accelerating Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Voltage [ΔV]</td>
</tr>
<tr>
<td>RF Phase [Δφ]</td>
</tr>
<tr>
<td>Alignment on transverse plane [Δxy]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on Quadrupoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric strength [Δk]</td>
</tr>
<tr>
<td>Alignment on transverse plane [Δxy]</td>
</tr>
<tr>
<td>Rotation about incoming longitudinal axis [ΔΘ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on Dipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bend angle [ΔB]</td>
</tr>
<tr>
<td>Rotation about incoming longitudinal axis [ΔΘ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on Steerers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strenght Jitters [ΔB]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors on BPMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
</tr>
</tbody>
</table>
Linac Error Sensitivity Studies

Specifications for power supplies and magnetic elements

- Machine sensitivity analysis suggests that the most critical parameters are the RF phase jitter on accelerating structures and misalignments on magnetic elements.

Electron beam spot size at low energy IP in case of $\Delta xy=70-100\mu m$, jitters on RF system and on magnetic elements.
Linac Error Sensitivity Studies

Specifications for power supplies and magnetic elements

- Machine sensitivity analysis suggests that the most critical parameters are the RF phase jitter on accelerating structures and misalignments on magnetic elements.

Electron beam spot size at low energy IP in case of $\Delta xy = 70\text{–}100\mu m$, jitters on RF system and on magnetic elements.

**Misalignments have to be lower than 70µm**
Linac Error Sensitivity Studies

Specifications for power supplies and magnetic elements

- Machine sensitivity analysis suggests that the most critical parameters are the RF phase jitter on accelerating structures and misalignments on magnetic elements.

Electron beam spot size at low energy IP in case of $\Delta xy = 70$-$100\mu m$, jitters on RF system and on magnetic elements.

Energy spread [%] for the nominal 250pC electron beam in case of RF jitters.

Energy spread [%] for no misalignments.
Linac Error Sensitivity Studies

Specifications for power supplies and magnetic elements

- Machine sensitivity analysis suggests that the most critical parameters are the RF phase jitter on accelerating structures and misalignments on magnetic elements.

**Electron beam spot size at low energy IP in case of $\Delta xy=70-100\mu m$, jitters on RF system and on magnetic elements**

- **Misalignments have to be lower than 70\mu m**

- **RF phase jitters of accelerating structures have to be lower than 1°**
Machine sensitivity analysis suggests that the most critical parameters are the RF phase jitter on accelerating structures and misalignments on magnetic elements.
ELI-NP γ-Source

- γ-source sensitivity analysis has been performed in order to investigate degradation of the bandwidth and flux due to misalignments and jitters in the linac.

### 2.85 MeV @IP

<table>
<thead>
<tr>
<th></th>
<th>Without errors</th>
<th>With errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron bunch charge</td>
<td>250</td>
<td>250 ± 25</td>
</tr>
<tr>
<td>Collimation Angle [θ]</td>
<td>192.5</td>
<td>192.5</td>
</tr>
<tr>
<td>Total Flux</td>
<td>$8.7 \times 10^6$</td>
<td>$(8.0 \pm 1.7) \times 10^6$</td>
</tr>
<tr>
<td>Flux within FWHM BW</td>
<td>$1.4 \times 10^5$</td>
<td>$(1.3 \pm 0.2) \times 10^5$</td>
</tr>
<tr>
<td>BW</td>
<td>0.50</td>
<td>0.55 ± 0.02</td>
</tr>
</tbody>
</table>

Courtesy of I. Drebot - INFN-MI
Conclusions

- Start to end simulations has been presented for the ELI-NP Gamma Beam System
- Machine sensitivity analysis suggests that the machine is robust to errors in the specified range
- Tolerances regarding jitters and alignments of accelerating structures and magnets has been provided
Thank you!!!