

# Simulation of errors in ThomX Linac

MB, Reunion dynamique faisceau ThomX, 25 Avril 2017

# MAC report: Linac beam dynamics

## 3.1. Comments

To meet the requirements of emittance for Compton and the energy spread for injection in the ring need increasing transverse dimensions of laser spot and decreasing the laser pulse duration. The simulations are well advanced and demonstrate that it is difficult to meet the TDR values.

The optimized solution to include one additional solenoid closer to the gun exit improves the required parameters. This gives emittance of 7mm.mrad at the exit of the transfer line. The requirement in the ring is for 5mm.mrad. This value is without considering any errors or tolerances. More realistic simulations with errors are required to understand the emittance budget. Are there mitigation strategies if the required emittance and energy spread are not achieved (operation of lower charges for example)?

Simulations are carried out using ASTRA and in-house developed code which includes space charge and coherent synchrotron radiation (CSR). CSR and space charge together increase the transverse emittance from 5.8 mm.mrad to 7 mm.mrad.

Magnesium cathode will be used to obtain 1nC charge, this has been tested on PHIL. It is anticipated that there will be a need to clean this cathode with the laser (once a week?)

# MAC report: Linac beam dynamics

## 3.2. Recommendations/questions

- If the measured multipole components in gun solenoids are known, these should be included in the simulation.
- The effect of errors in the photo injector, LINAC and transfer line should be studied to decide the best suited parameter regimes.
- What is the plan for measurement and monitoring of the photo injector laser pulse length duration and the transverse size? Is virtual cathode included in the laser transport?
- To use dipoles in ASTRA is quite tricky and these are not included in simulations. Does the in-house code include dipoles? How is the agreement between ASTRA and in-house code with space charge?
- A strategy of the alignment of the magnetic axis of solenoids with the center of the gun needs to be clearly defined. The PI laser position on the cathode as required in practice will complicate it further.
- Is the dark current from the gun expected to cause any problem?
- What is expected lifetime of magnesium cathode? Are there plans to install photocathode transfer system to increase availability? The cathode surface finish can significantly affect the emittance as well as dark current, has the decision been taken on how best this can be done?
- Gun and LINAC commissioning in advance may address some issues giving some time to optimize the placement of solenoids for emittance compensation and other issues related to laser shaping and cathode. At what stage third solenoid needs to be ordered?

# Simulation of errors in ELI-NP Linac

**“6D phase space electron beam analysis and machine sensitivity studies for ELI-NP GBS”**

A. Giribono, A. Bacci, C. Curatolo, I. Drebot, L. Palumbo, V. Petrillo, A.R. Rossi, L. Serafini, C. Vaccarezza, A. Vannozzi, A. Variola

<http://dx.doi.org/10.1016/j.nima.2016.02.042>

Nuclear Instruments and Methods in Physics Research  
Section A: Accelerators, Spectrometers, Detectors and  
Associated Equipment, Volume 829, 2016, 274–277

# Machine sensitivity studies

- Simulation of several errors which can deteriorate beam design parameters
- Study performed for a **250 pC charge, 280 MeV** beam with 30k macro-particles (*ThomX: 1 nC, 50 MeV*)
- Sensitivity to errors study needed to evaluate:
  - Emittance growth → spot size @IP
  - Energy spread growth
  - Large transverse trajectory errors
- Photo-injector simulated with **ASTRA** (with space charge), tolerances and specs for:
  - cathode laser system,
  - power supplies,
  - solenoids
- C-band Linac simulated with **Elegant** (with wakefields + longitudinal space charge + ISR & CSR in dipoles), tolerances and specs for:
  - magnets,
  - power supplies,
  - BPM resolution

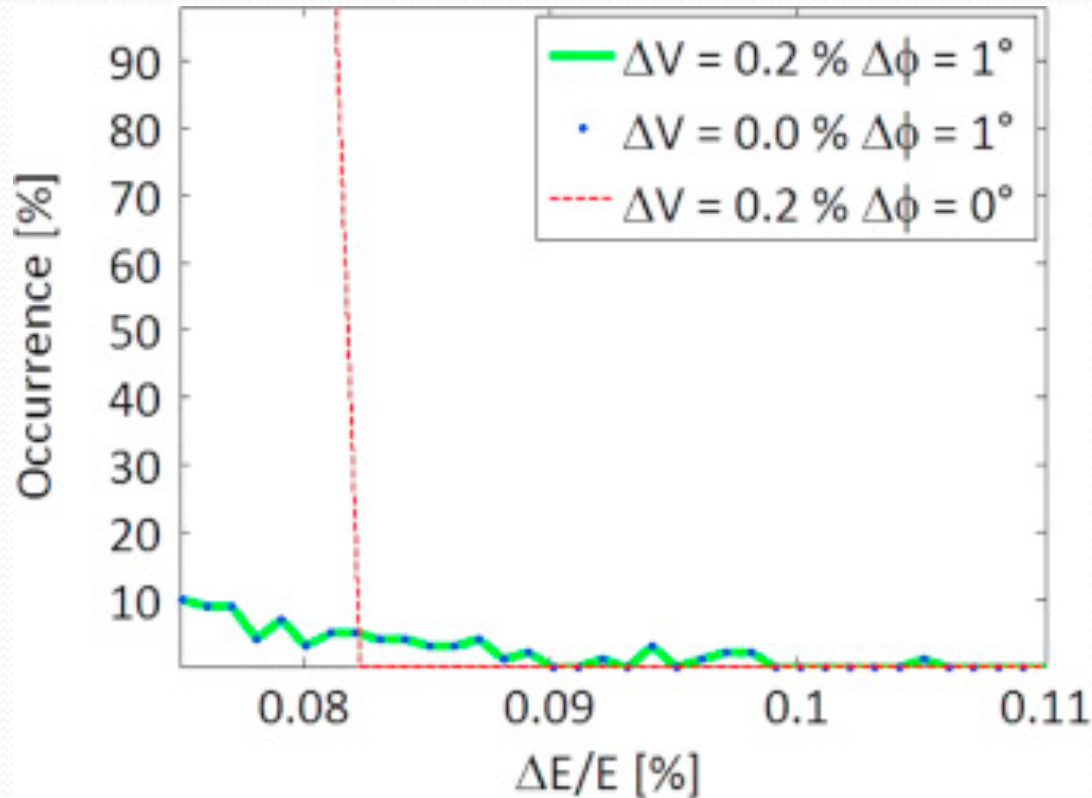
# Tolerances table on maximum errors

Injector	Error	Unit	C-band RF linac	Error	Unit
<b>GUN</b>			<b>C-band accelerating sections</b>		
RF voltage [ $\Delta V$ ]	$\pm 0.2$	%	RF voltage [ $\Delta V$ ]	$\pm 0.2$	%
RF phase [ $\Delta \Phi$ ]	$\pm 0.2$	deg	RF phase [ $\Delta \Phi$ ]	$\pm 1$	deg
<b>S-band accelerating sections</b>			Alignment on transverse plane [ $\Delta xy$ ]	$\pm 70, \pm 100$	$\mu\text{m}$
RF voltage [ $\Delta V$ ]	$\pm 0.2$	%	<b>Quadrupoles</b>		
RF phase [ $\Delta \Phi$ ]	$\pm 0.2$	deg	Geometric strength [ $\Delta k$ ]	$\pm 0.3$	%
Alignment on transverse plane [ $\Delta xy$ ]	$\pm 70$	$\mu\text{m}$	Alignment on transverse plane [ $\Delta xy$ ]	$\pm 70, \pm 100$	$\mu\text{m}$
<b>Solenoids on GUN &amp; TW cavities</b>			Tilt about incoming long. axis	$\pm 1$	mrad
Alignment on transverse plane [ $\Delta xy$ ]	$\pm 70$	$\mu\text{m}$	<b>Dipoles</b>		
<b>Cathode laser system</b>			Bend angle [ $\Delta B$ ]	$\pm 0.1$	%
Arrival time [ $\Delta t$ ]	$\pm 200$	fs	Tilt about incoming long. axis	$\pm 1$	mrad
Pointing instabilities [ $\Delta s$ ]	$\pm 20$	$\mu\text{m}$	<b>Steerers</b>		
Energy fluctuation	$\pm 5$	%	Strength [ $\Delta k_s \Delta k_s$ ]	$\pm 0.2$	$\mu\text{rad}$
			<b>Beam position monitors</b>		
			Resolution	$\pm 10$	$\mu\text{m}$

# Simulations results

- 100 different machines simulated with errors randomly extracted according to max errors in previous Table (special genetic procedure developed for errors generation)
- First step: to identify most dangerous errors contribution charge fluctuations due to laser energy jitter of  $\pm 5\%$  (237.5-262.5 pC) and errors inserted one-by-one were simulated
- Energy spread is mainly affected by **RF phase jitter**
- Transverse spot size is mainly affected by **transverse misalignment errors** in accelerating structures and quadrupoles

# Energy spread growth

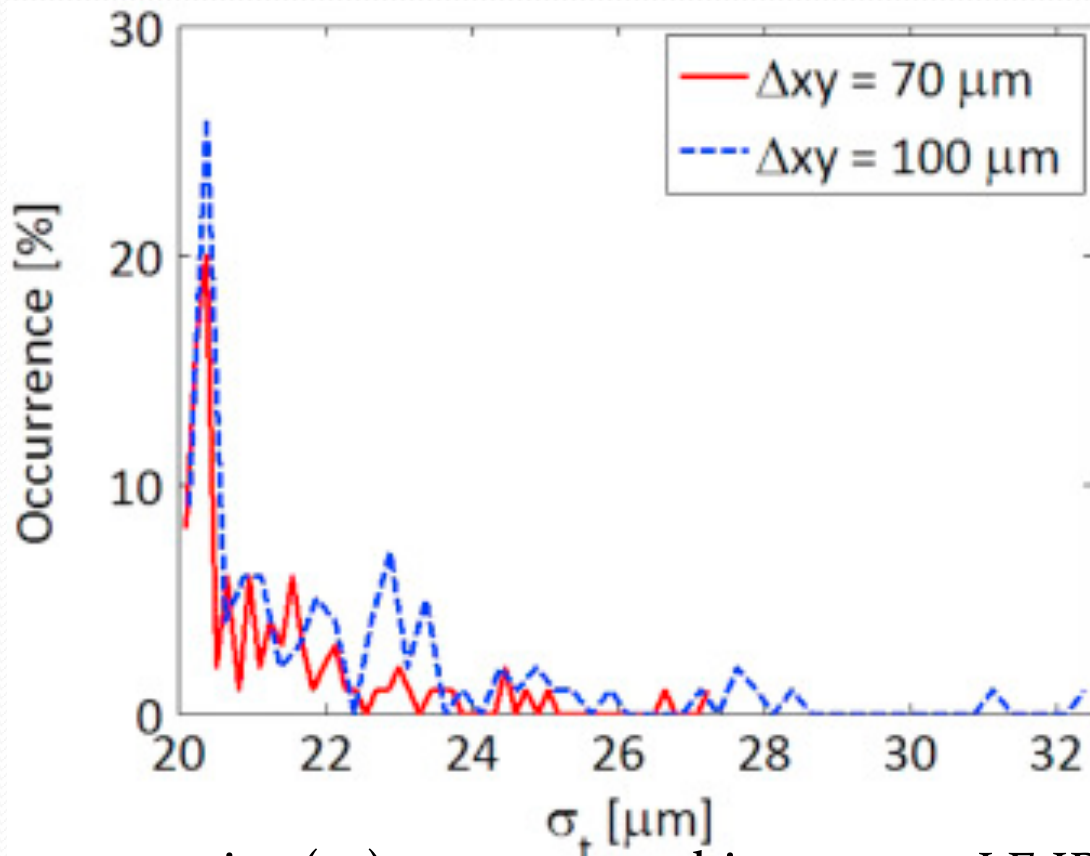


**Energy spread ( $\Delta E/E$ )** over 100 machine runs at LE IP in case of:

- RF voltage jitter (red dashed line),
- RF phase jitter (blue dots),
- RF phase and voltage jitter (green line)

Analysis suggests that energy spread can grow up to **0.1%** if RF phase jitter in the range  $\pm 1^\circ$  arises (**design  $\Delta E/E$ : 0.081 %**)

# Transverse spot size @IP growth



Transverse spot size ( $\sigma_t$ ) over 100 machine runs at LE IP for:

- $\Delta xy = \pm 70 \mu\text{m}$  (red line)
- $\Delta xy = \pm 100 \mu\text{m}$  (blue dashed line)

Analysis suggests that spot size @IP can grow up to almost  $33 \mu\text{m}$  for  $\Delta xy = \pm 100 \mu\text{m}$  (design  $\sigma_t$ :  $20 \mu\text{m}$ )

# Genetic Algorithm (code GIOTTO)

- Developed to avoid lengthy procedure of changing input parameters by hand
- Whole parameters ensemble is a set of different quantities related by non trivial and non linear relationships → not easy to define an “optimized” configuration
- A genetic algorithm leads to fast and precise convergence on a good solution estimated by a “fitness function” defined as a pondered combination of physical quantities to be optimized

# GA

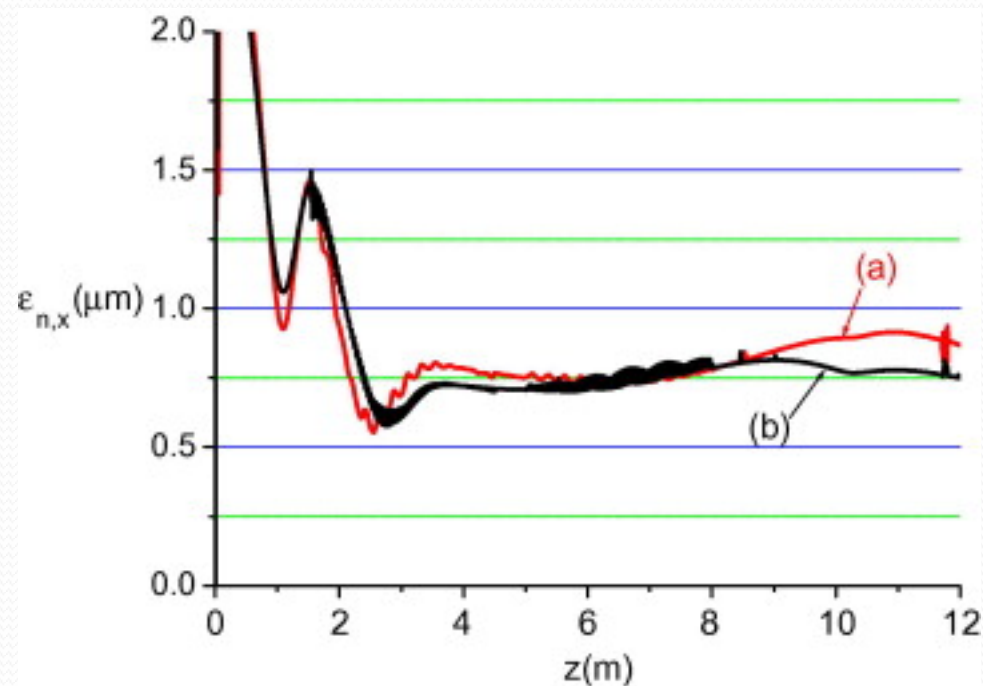
- Useful for optimization of a large number of input parameters
- Comparisons between “by hand” optimization and “genetic” one showed that the genetic code can work even without a known reference “working point”
- Parallelization helps since speed-up scales with population number
- This code could also be included in data acquisition system and optimize online performances
- A. Bacci, C. Maroli, V. Petrillo, A. Rossi, L. Serafini, **“Maximizing the brightness of an electron beam by means of a genetic algorithm”**, NIM B, <http://dx.doi.org/10.1016/j.nimb.2007.07.006>

# GIOTTO & ASTRA

- First developed for an incoherent Thomson scattering line at SPARC-LAB (30 MeV): gun+2 TW structures+solenoid+4<sup>th</sup> harmonics structure
- GIOTTO launches ASTRA for integration of equations for each error configuration
- Optimization of:
  - E field gradient
  - Injection phase
  - Max B field
  - Solenoids position
- Example of fitness function:

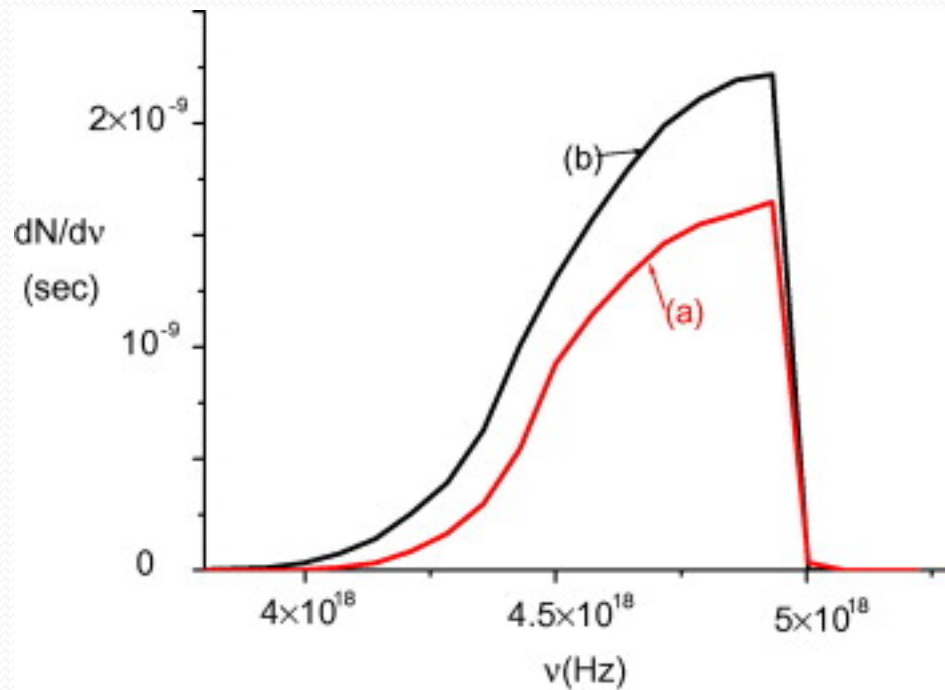
$$F = I^{3.5} / (\epsilon_{n-x,y} \times \sigma_{x,y} \times \sqrt{\Delta\gamma/\gamma})$$

# Normalized emittance



Transverse normalized emittance (in mm mrad) versus  $z$  (in meter) for: (a) reference case optimized by hand and (b) GIOTTO

# X-rays spectrum



Spectrum of X rays radiated for the reference case (a) and GIOTTO (b).

# PSPA studies

- With PSPA it is at present possible to run both ASTRA for the photo-injector and Elegant for the Linac
- A first study of errors has to be performed in order to find the most harmful ones
- ASTRA input files from Christelle & Luca
- After a first look, we can start the statistics study with GIOTTO (kindly provided by A. Bacci from Milan)
- A table of maximum error tolerances can finally be produced to allow for the ThomX design parameters to be achieved



Work just started....