HIGH LEVEL APPLICATIONS FOR ELI-NP

12 October 2017 - Accelerator Physics PhD

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PhD supervisor: Prof. Luigi Palumbo
PhD tutor: Dr. Susanna Guiducci

Outline

- ELI-NP project introduction
- High level applications
- Development framework: eleMML
- Trajectory correction studies
- Single accelerating section BBA
- Validation at FERMI
- Summary

ELI – Nuclear Physics

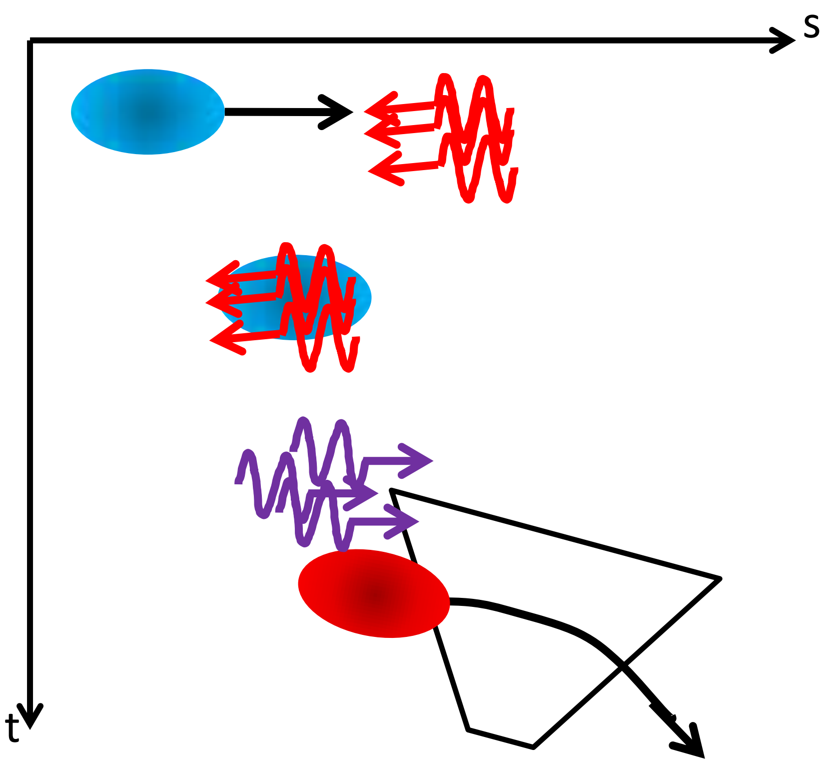
- User facility for Nuclear Physics experiments based on **Compton Back-Scattering (CBS)**
- The **Gamma Beam System (GBS)** is composed of a LINAC to accelerate 32 bunches of relativistic electrons and a complex optical recirculator for a high power laser

Table 2: Electron Beam Parameter List for the Different Working Points relative to the Gamma-Ray Source Energies.

γ-ray energy	**0.2**	**1.0**	**2.0**	**3.5**	**10.0**	**13.5**	**19.5**	***MeV***
e^- energy	75	165	234	312	530	605	740	*MeV*
e^- energy spread	1.14	0.86	0.82	0.80	0.45	0.43	0.48	‰
e^- rms bunch length	275	274	273	278	272	273	278	*μm*
e^- $\varepsilon_{n\,x,y}$	0.51	0.44	0.44	0.41	0.44	0.44	0.41	*mm mrad*
e^- $\beta_{x,y}$	0.16	0.43	0.43	0.55	0.71	0.71	0.95	*m*
e^- beam spot size at IP	23.5	20.0	19.6	19.4	17.3	17.3	16.2	*μm*

C. Vaccarezza *et al.*, "Optimization Studies for the Beam Dynamic in the RF Linac of the ELI-NP Gamma Beam System", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW041

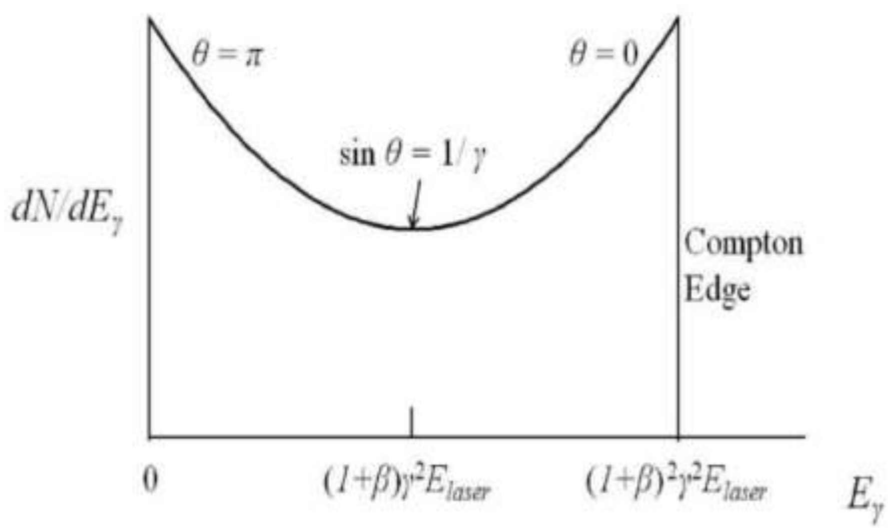
Compton Backscattering



If head-on collision, ultra-relativistic electrons, lower energy photons, then max energy is

$$\omega_2 \approx 4\gamma^2\omega_1$$

The spectral shape is given by
The differential cross section

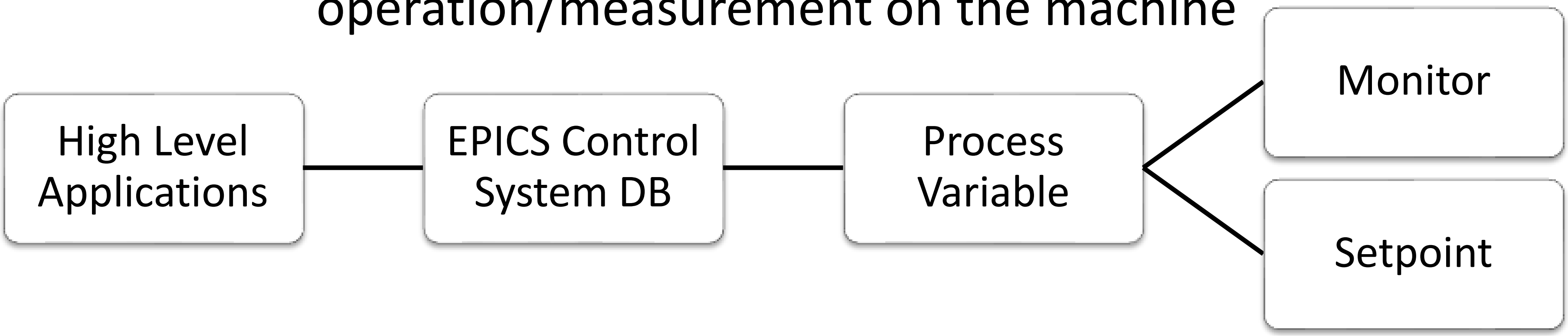


To optimize the spectral photon density:

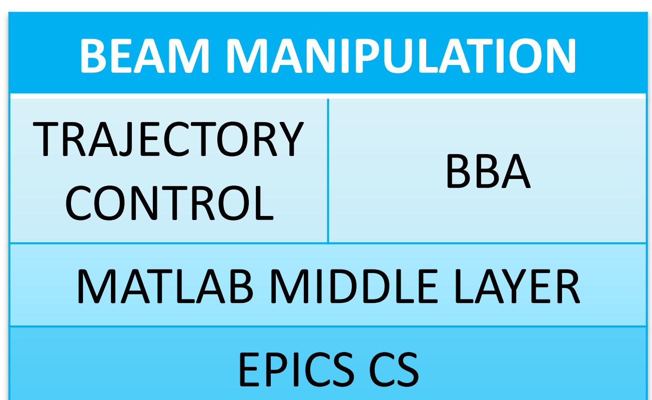
$$SPD \equiv N_\gamma^{bw} / \sqrt{2\pi} h\Delta\nu \propto \frac{Q}{\varepsilon_n^2}.$$

High Level Applications

An **High Level Application (HLA)** is a **set of automated commands and operation** to perform a specific operation/measurement on the machine

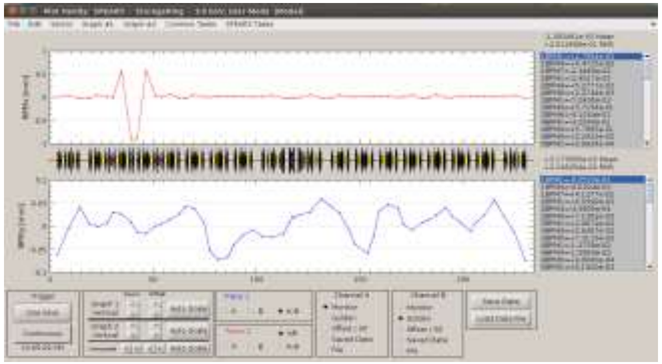


To maximize SPD it is important to avoid emittance growth due to errors and misalignments



MATLAB Middle Layer

- **Set of tools to model and control particle accelerators** Currently ALS, Spear, CLS …
- Accelerator Toolbox (AT) model **enables to test applications and simulate machine commissioning** on a model of the machine
- Currently only for RING physics → **need for a different accelerator physics engine for a LINAC**



WEBD2 Proceedings of IPAC2015, Richmond, VA, USA

SURVEY OF COMMISSIONING OF RECENT STORAGE RING LIGHT SOURCES*

M. Borland, ANL, Argonne, IL 60439, USA
Riccardo Bartolini, Ian Martin DLS, Oxfordshire, UK

Which factors advanced commissioning most rapidly? The most-cited factor was thorough subsystem commissioning (7), followed by control system ready and tested (5). Under the latter heading, MATLAB Middle Layer (MML, 3) and model-based tools (2) were emphasized. Other factors included first-turn BPMs (2), anticipating failures and problems (1), robust rf bellows

CONCLUSIONS

Our survey of recently-commissioned rings garnered de-

[…]

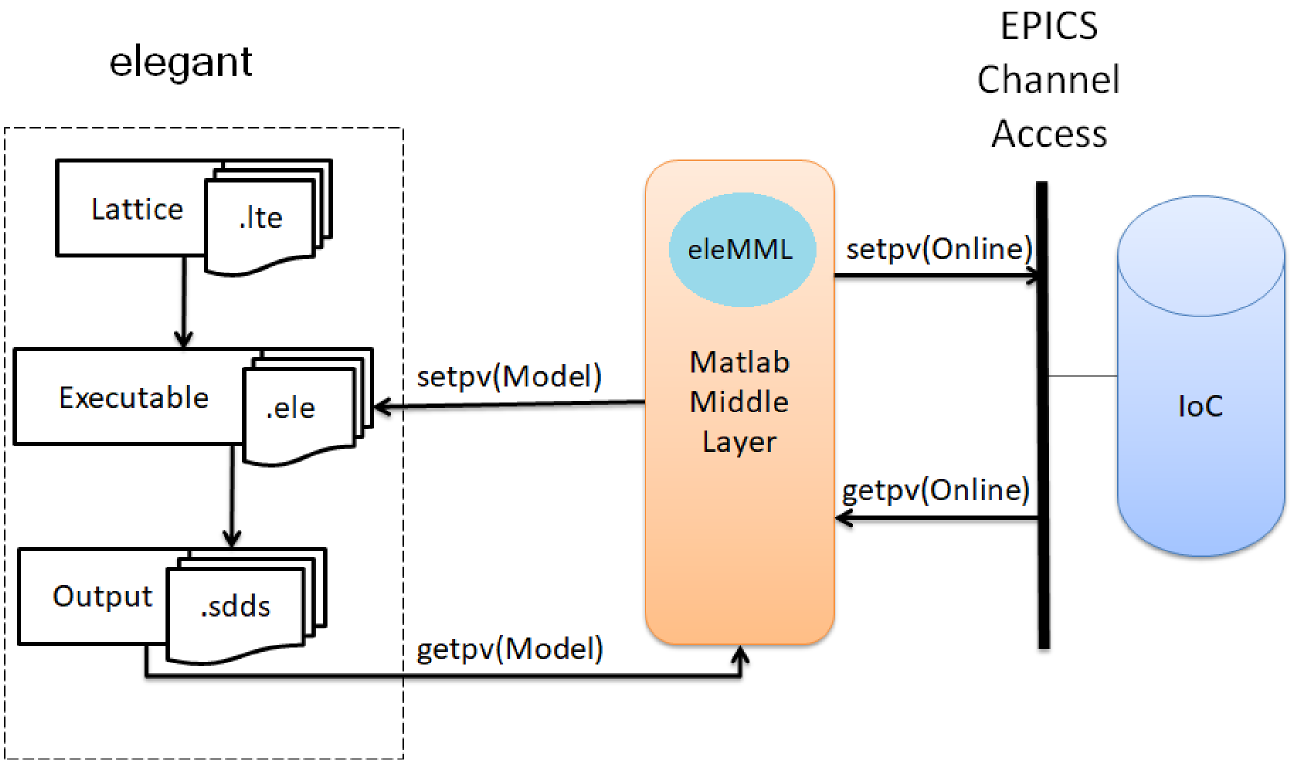
time if problems had been avoided.

Keys to success include thorough subsystem commissioning without beam and having controls software tested ahead of time. Delays in the commissioning of new rings are most likely to be caused by the difficulty of getting (sufficient) stored beam in new lattices, the lack of full subsystem commissioning, vacuum system issues (heating, obstructions), and delivery delays.

[*] M. Borland, et al. "Survey of Commissioning of Recent Storage Ring Light Sources", in Proc. 6th International Particle Accelerator Conference, Richmond, VA, USA, paper WEBD2, pp. 2482-2484, ISBN: 978-3-95450-168-7

eleMML Architecture overview

- **elegant** is a powerful tracking code for LINACs and rings, by M. Borland(ANL) and collabotators
- It uses **SDDS (Self Describing Data Sets)** flexible file output format



The data from the simulations can be accessed
in the same way as the data on the machine

eleMML basic functions

[AM, tout, DataTime, ErrorFlag] = getpv(..,..,..,'Mode','Model')

↓

array = sddsreadany(filename, col_par, col, pag)

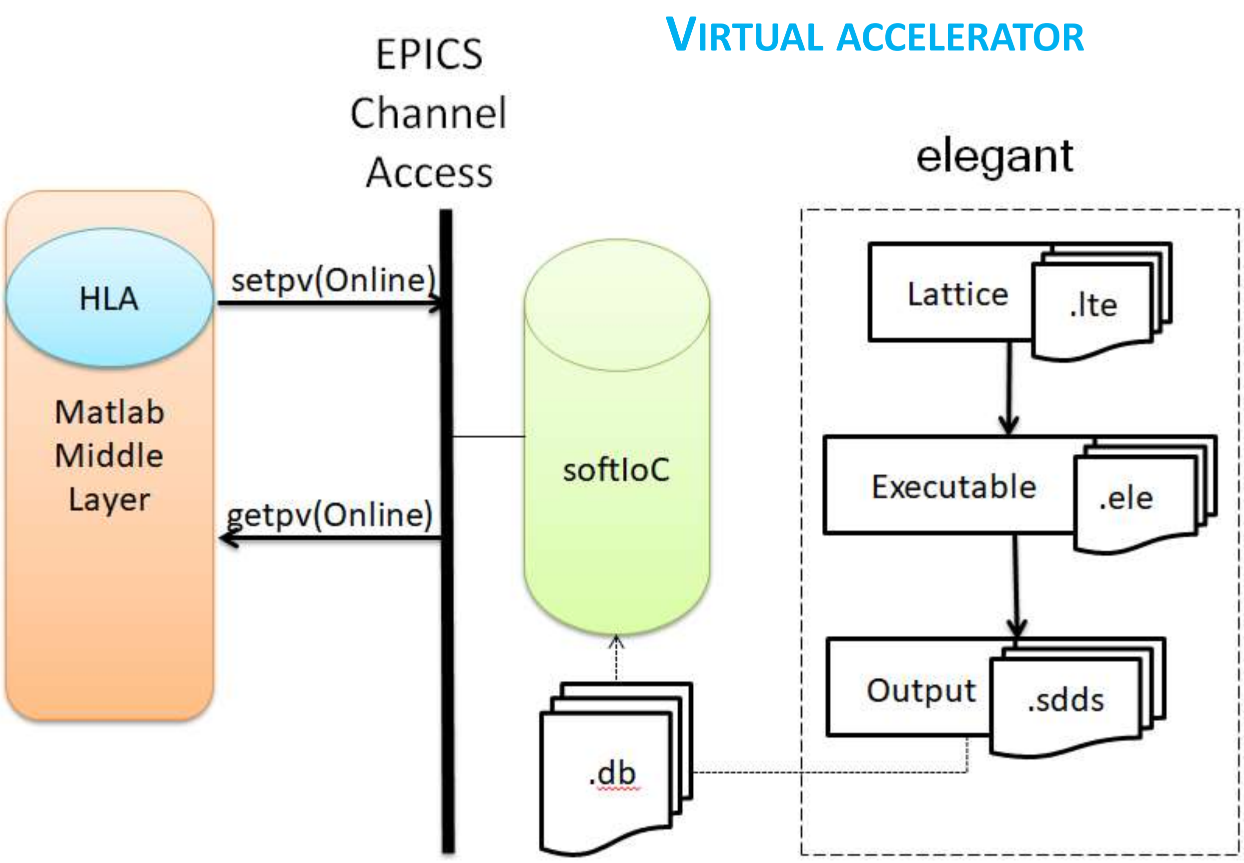
ErrorFlag = setpv(..,..,..,'Mode','Model')

↓

[Status, Result] = system(['elegant virtualacc.ele -macro=' ...
AO.(thisFam).FamilyName '=' ...
AO.(thisFam).SetPoint])

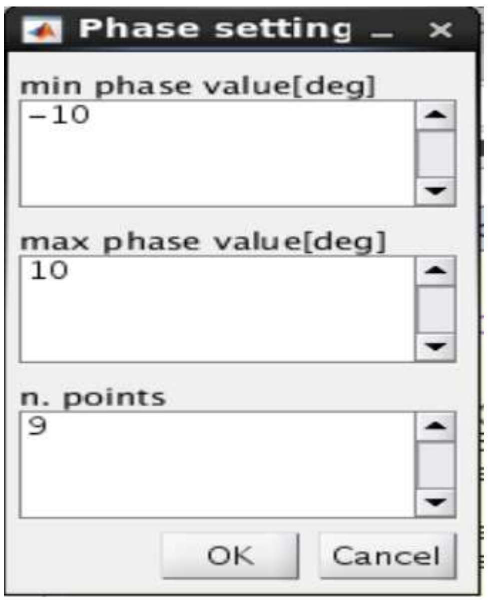
eleMML Model Server

The simulation output data can be pushed on one or more virtual devices

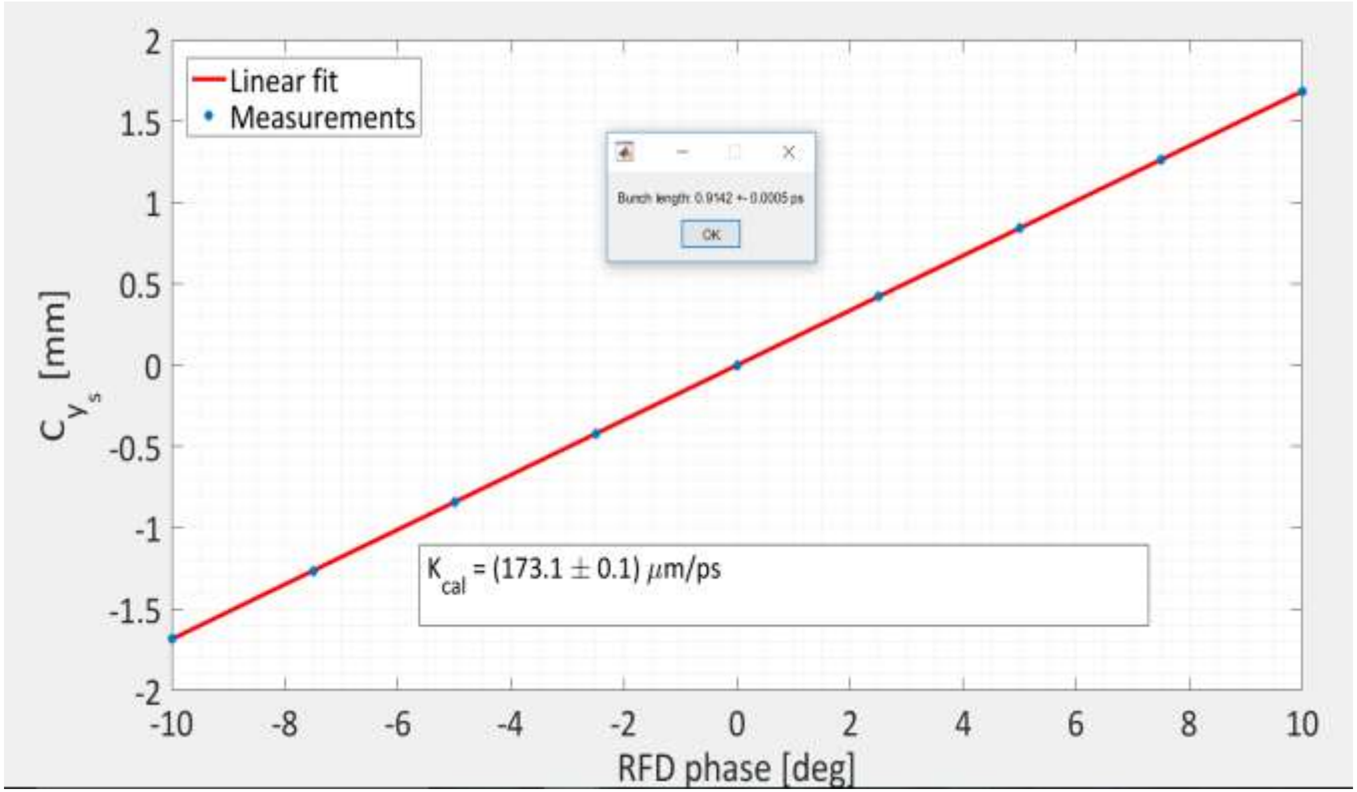


Bunch length measurement

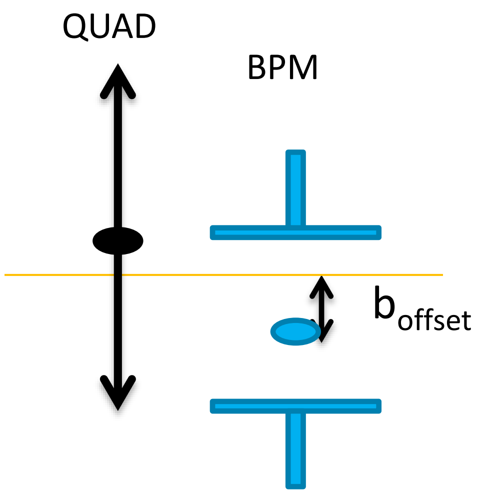
- The beam gets streaked by the transverse deflecting cavity (TDC) on a screen downstream
- The operator can select the range of TDC phase to vary and the number of points to acquire
- The calibration line and the resulting bunch length value are then shown on the screen



$$s_{t_0,m} = \frac{\sqrt{s^2_{y_s}(j) - s^2_{y_{s,off}}}}{\left|K_{cal}(j)\right|}.$$



Electron beam trajectory studies



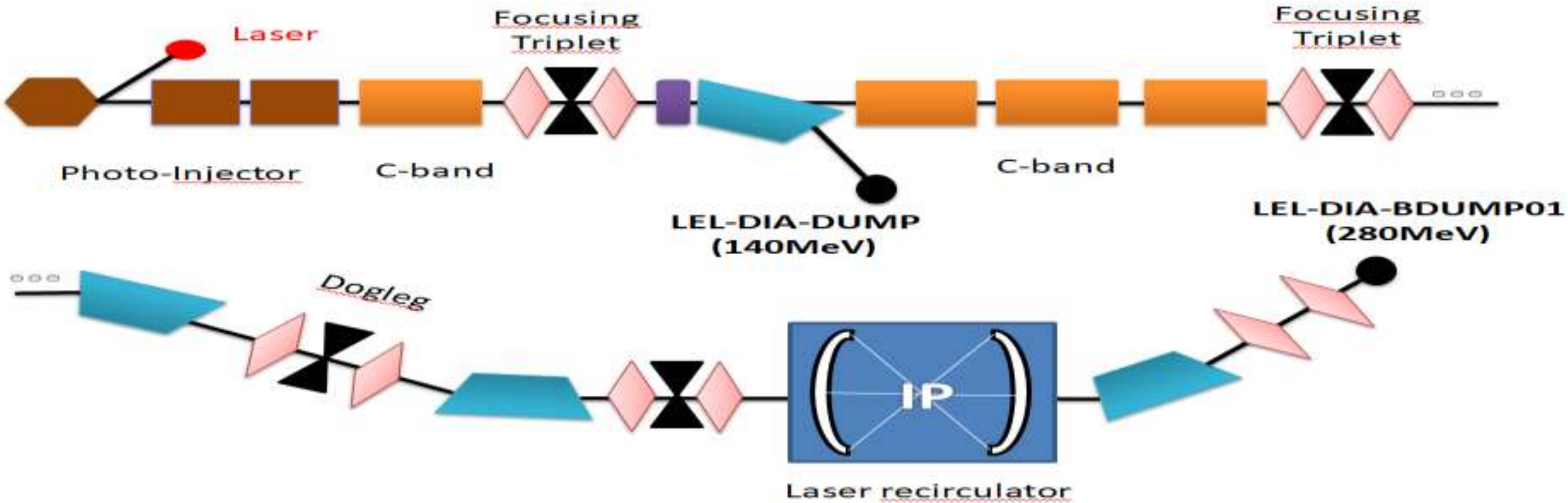
Method Name	Minimization problem to solve
One-to-one	$\theta_i \parallel y_{i+1}^{BPM} = 0 \, \forall i = 1, \dots, m$
Global or Fast Orbit Feedback (FOF)	$\mathbf{y} = \mathbf{R}\theta$
Dispersion Free Steering (DFS)	$\begin{pmatrix} \mathbf{y}(E_0) \\ \omega \cdot \Delta\mathbf{y} \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R}(E_0) \\ \omega \cdot \Delta\mathbf{R} \\ \beta \cdot \mathbf{I} \end{pmatrix} \theta$

$$\begin{aligned} \Delta y_i &= y_i(E_0) - y_i(E_0(1-\delta)) = \\ &= b_i(E_0) + b_{offset} - (b_i(E_0(1-\delta)) + b_{offset}) = \\ &= b_i(E_0) - b_i(E_0(1-\delta)) \end{aligned} \quad (1)$$

$$\Delta\mathbf{R} = \mathbf{R}(E_0) - \mathbf{R}(E_0(1-\delta))$$

$$R_{ij} = \frac{\partial y_i}{\partial \theta_j}$$

Beam dynamics simulations

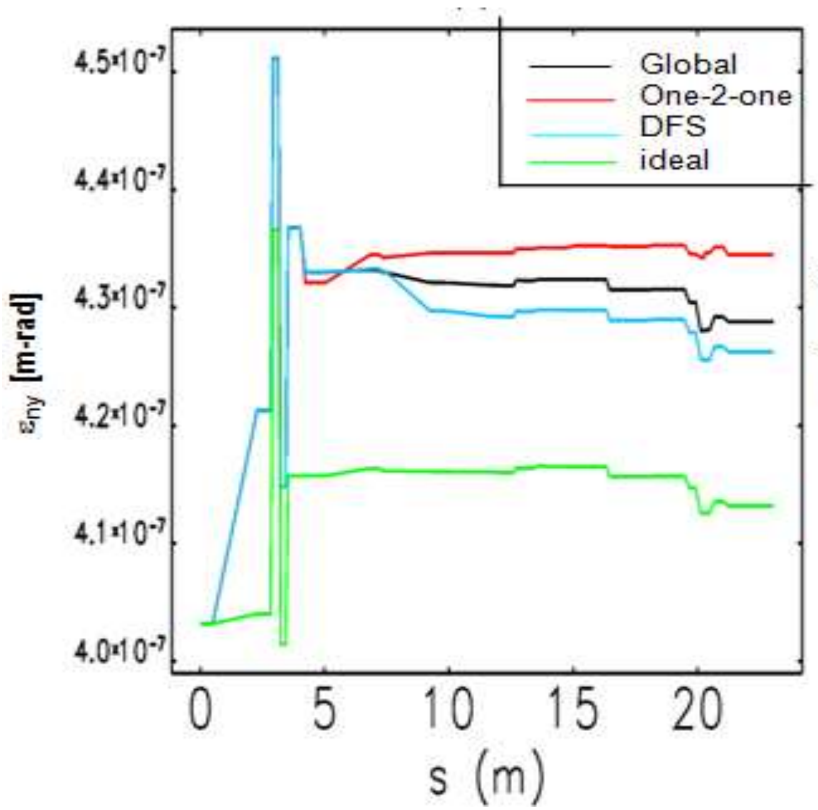


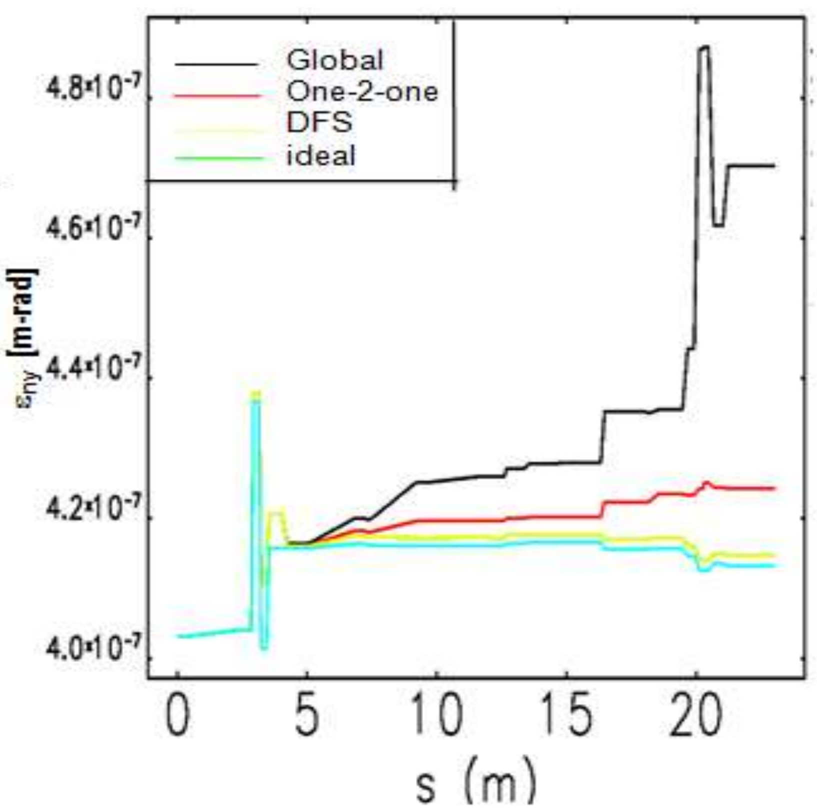
ELI-NP GBS Low Energy Line split layout (conceptual, not to scale)

Parameter	Value	Unit
γ source	2	MeV
E_e	234	MeV
$\Delta E/E$	<0.1	%
Q	250	pC
ϵ_n	0.44	$\mu m - rad$
σ_z	273	μm
$\sqrt{\sigma_x^2 + \sigma_y^2} = \sigma_t$	19.6	μm

Emittance comparison

With RF sections misalignments	Without RF misalignments

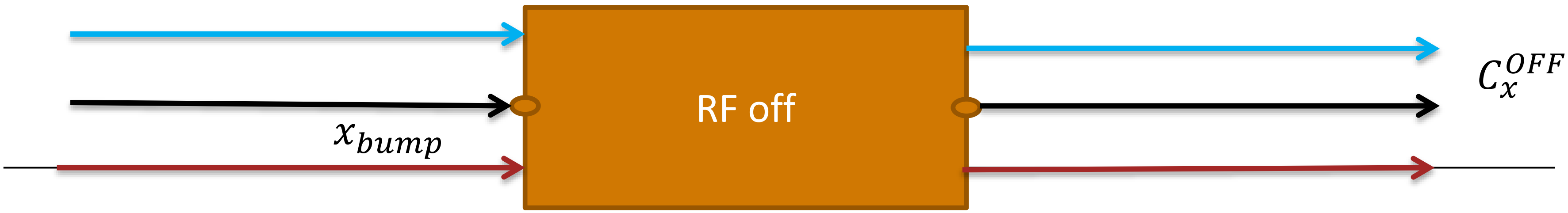




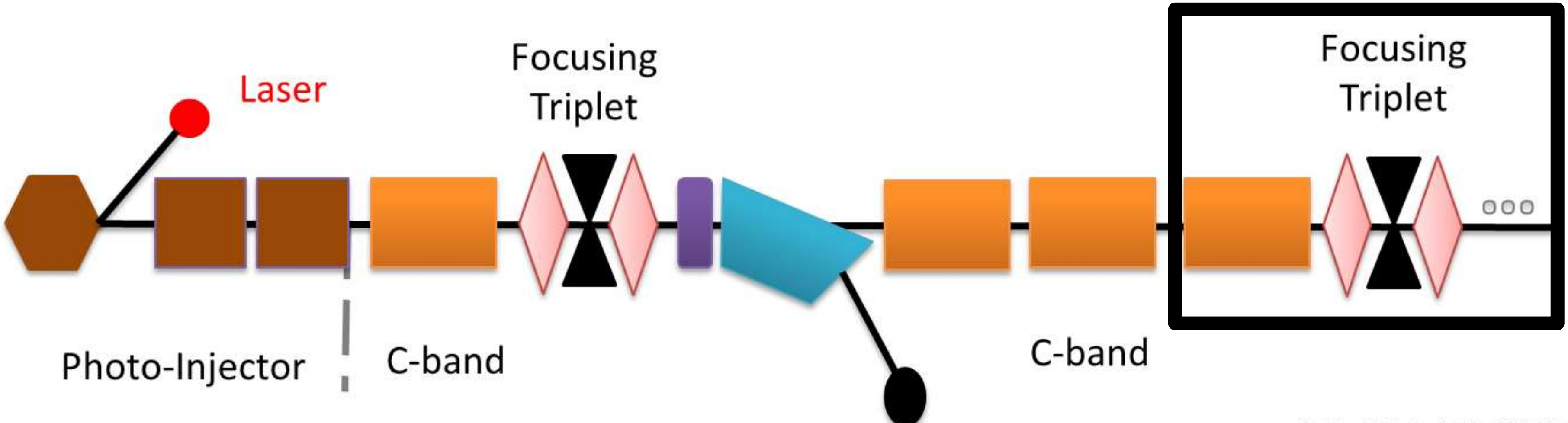
	symbol	μm
Quadrupole misalign.	σ_{quad}	70
RF sections misalign.	σ_{rfcav}	70
BPM misalign.	σ_{BPM}	70
BPM noise	σ_{noise}	5

- Errors distributed on a 2σ-truncated Gaussian
- Energy different between test beam an nominal beam $\Delta E/E = 8\%$

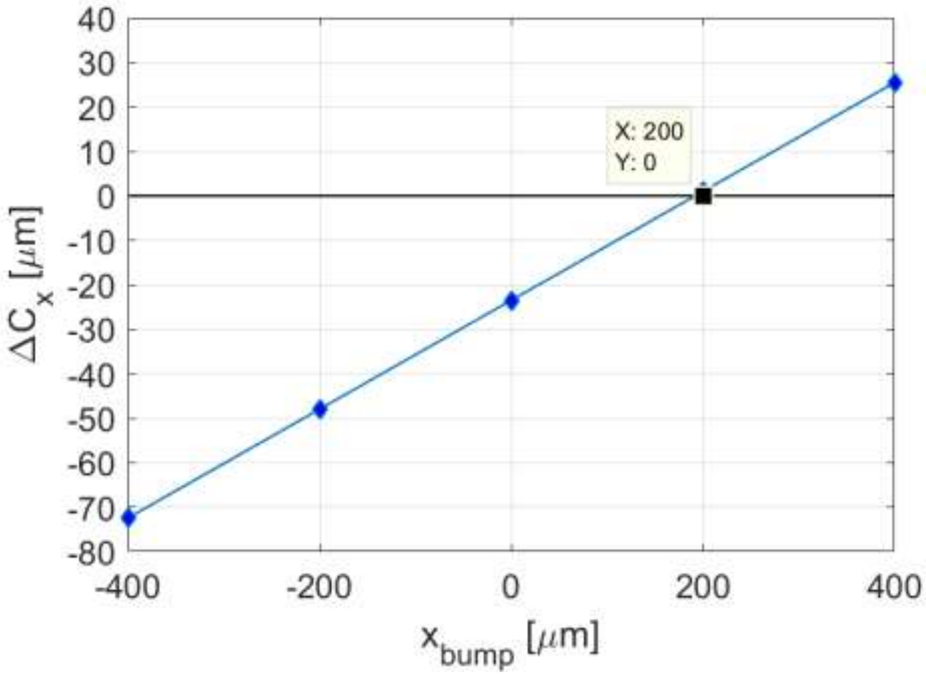
Accelerating section BBA



$$\Delta C_x = C_x^{ON} - C_x^{OFF}$$



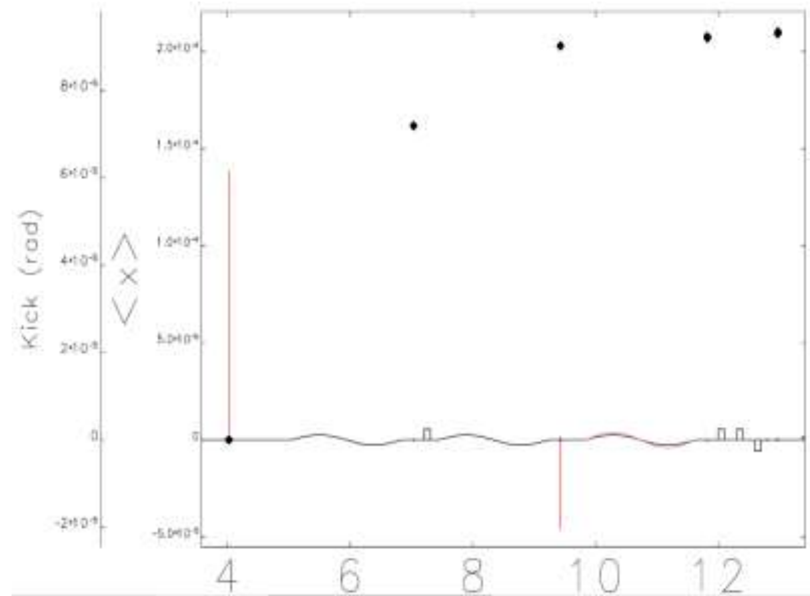
Simulation results



Above: Trajectory shift of the horizontal centroid induced at a downstream BPM as a function of the beam-position readback at the BPM nearest to the accelerating section being varied

Parameter	Symbol	Value	Unit
RF Misalignment	σ_x	200	μm
Initial e- energy	E_i	80	MeV
Final e- energy	E_f	243	MeV
Charge	Q	250	pC
Hor. Norm. Emit.	ϵ_{nx}	0.12	mm-mrad

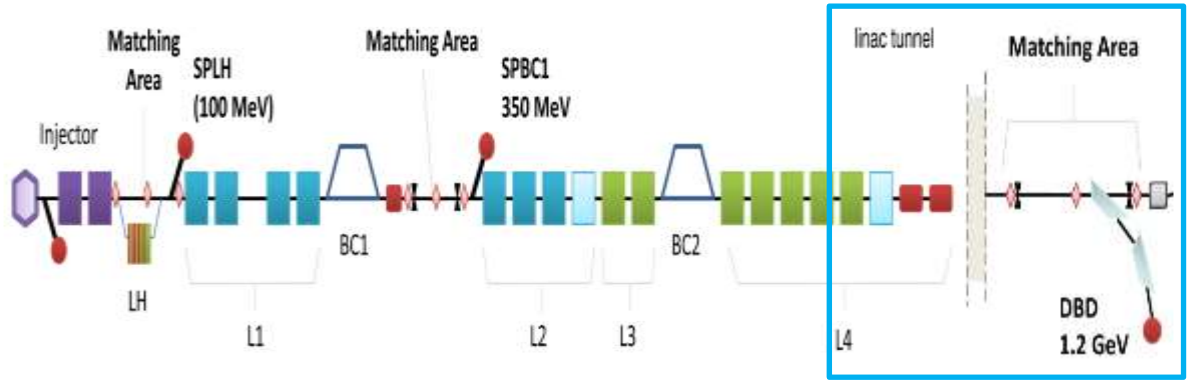
Below: position of the hor. beam centroid Cx at the BPMs across the accelerating section



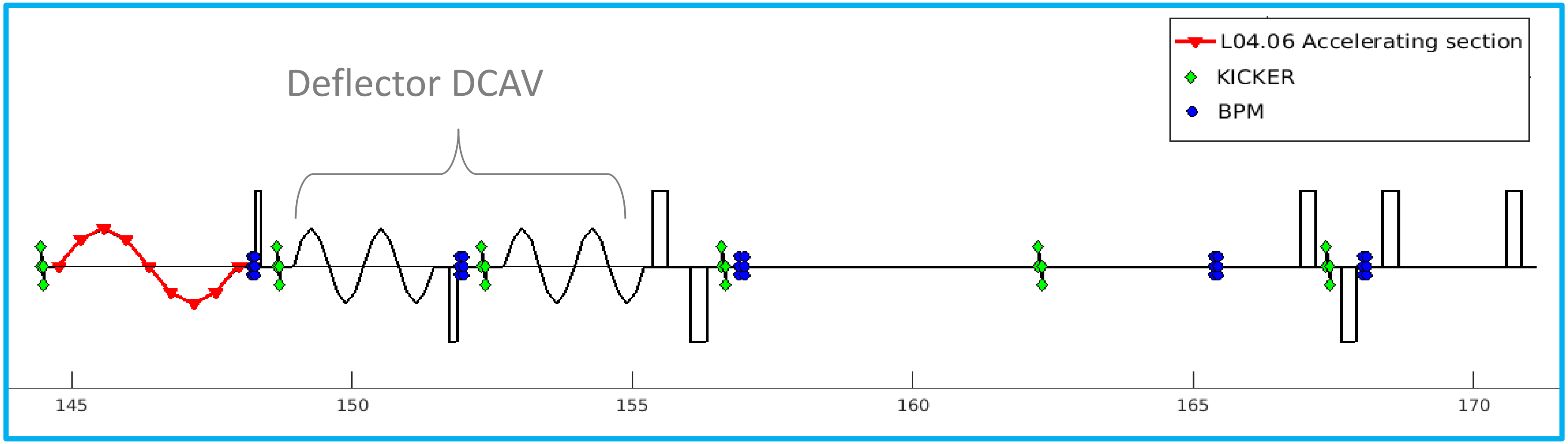
DFS Validation at FERMI LINAC

Conceptual layout of FERMI linac until the beginning of the transfer line to the undulator's hall, followed by a short summary of FERMI electron beam parameters

Image courtesy of S. Dimitri



	Value	Units
Energy	1.3	GeV
Slice energy spread	<0.2	MeV
Charge	700	pC
Norm. emittance	0.8-1	mm-mrad

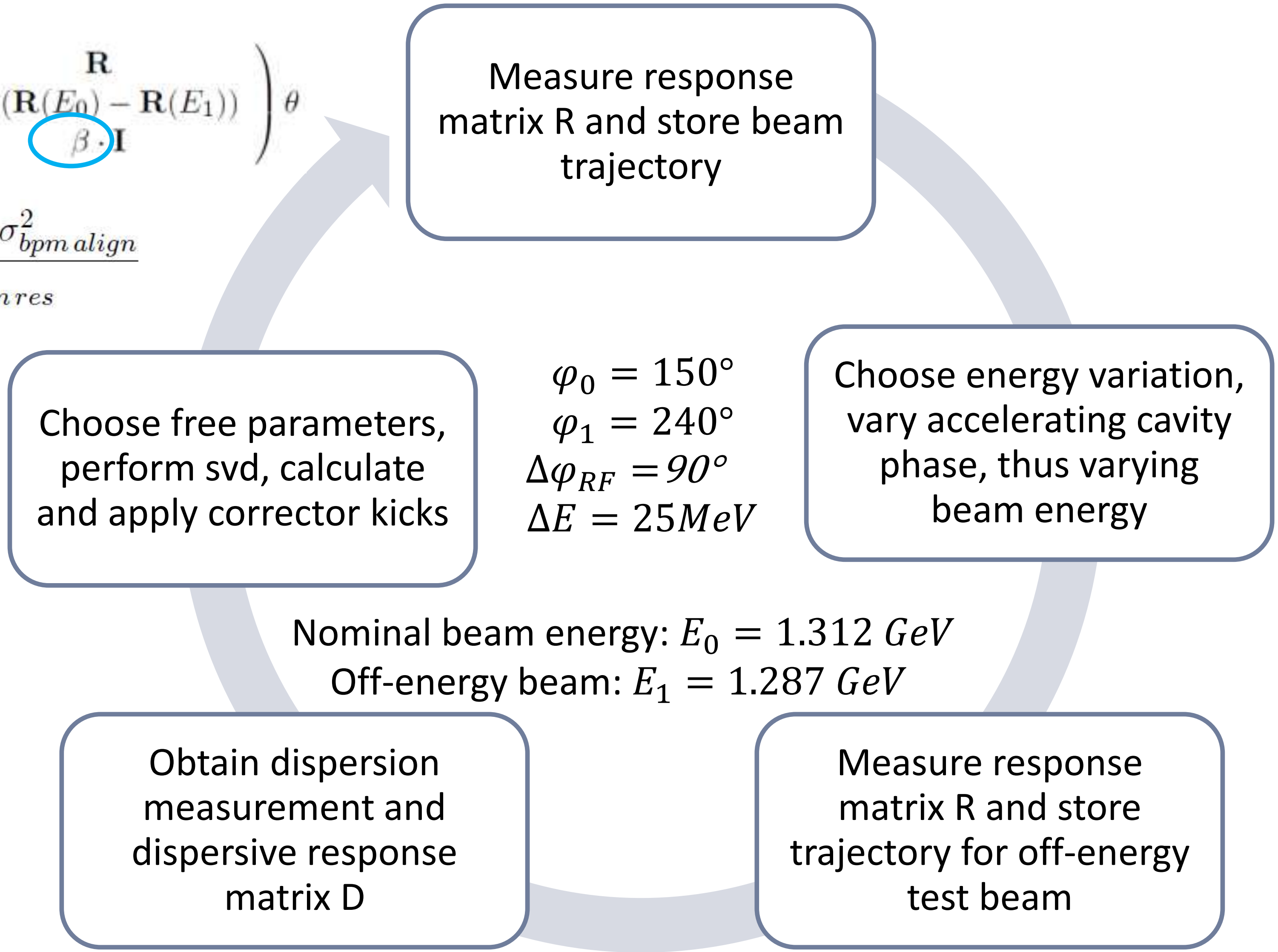


Zoom on the layout of the section of the FERMI LINAC used for testing the DFS method

Measurement procedure

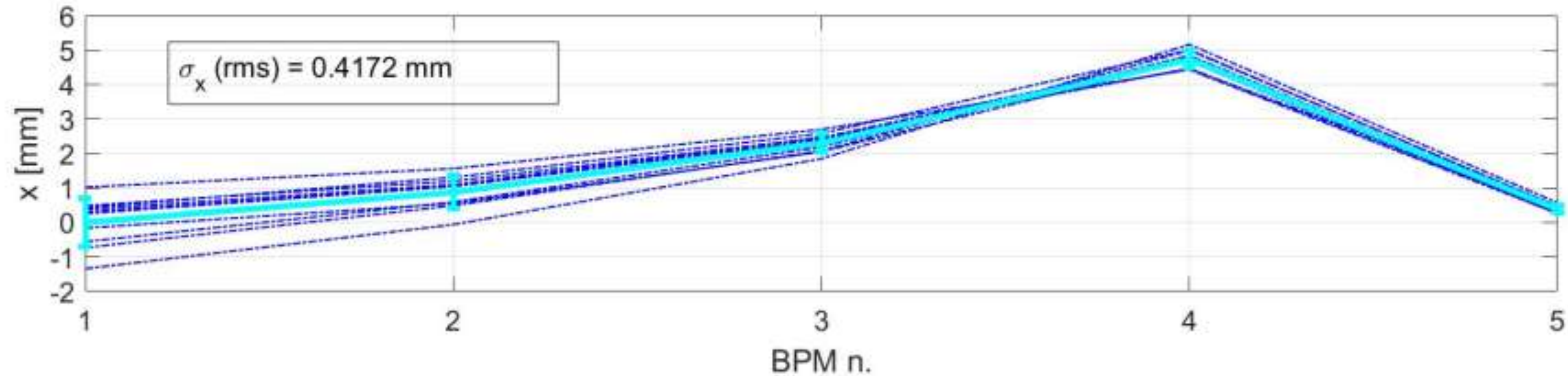
$$\begin{pmatrix} \mathbf{x}(E_0) \\ \omega \cdot \Delta \mathbf{x} \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega \cdot (\mathbf{R}(E_0) - \mathbf{R}(E_1)) \\ \beta \cdot \mathbf{I} \end{pmatrix} \theta$$

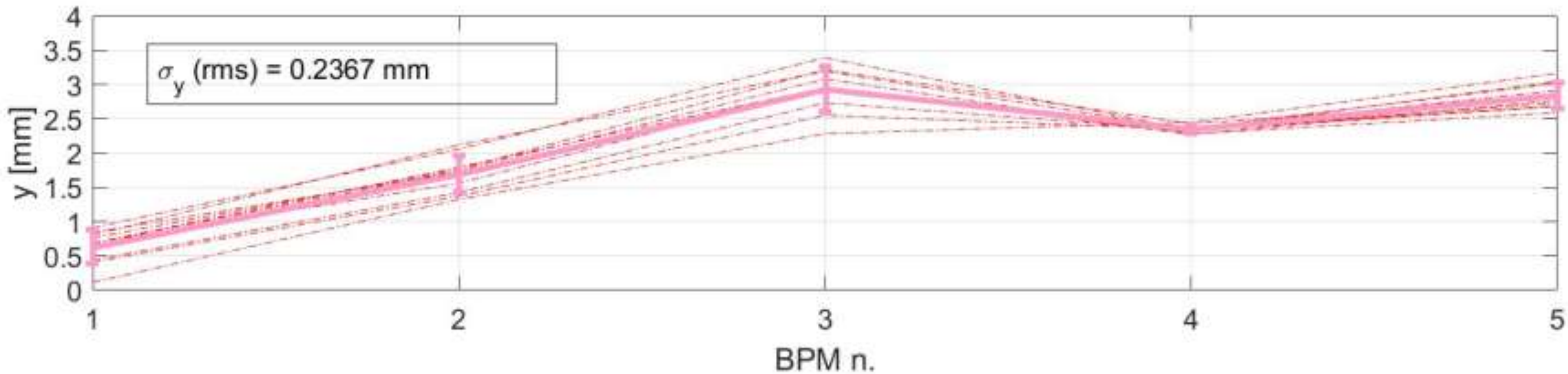
$$\omega = \frac{\sigma^2_{bpm\,res} + \sigma^2_{bpm\,align}}{2\sigma^2_{bpm\,res}}$$



Trajectory before correction

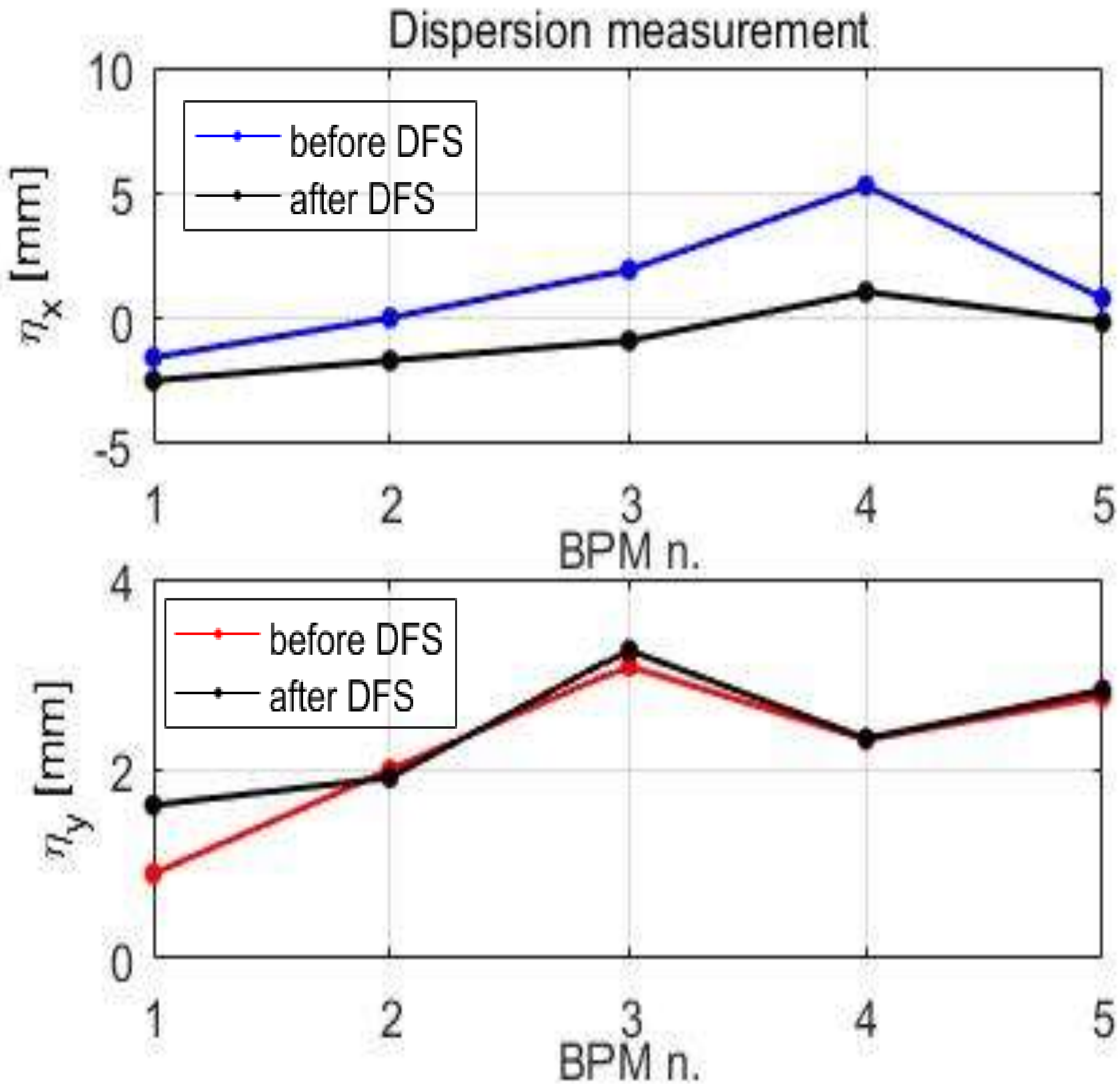
Ten trajectory samples have been acquired and the plot shows the fluctuation due to launching conditions of the beam at the entrance of the LINAC.





Residual dispersion correction

	Value	Unit
E_0	1.312	GeV
E_1	1.287	GeV
$\Delta E/E$	~2	%
ω	10	
β	1	
σ_x $BPMs$	0.42	mm
σ_y $BPMS$	0.23	mm



DFS accuracy depends on the energy difference and free parameters choice

Summary

- **eleMML** is a novel framework to develop and test high level applications on a virtual machine
- **Beam dynamics simulations** indicate that applying **DFS** for trajectory correction can improve beam quality in the GBS low energy line
- **Testing at FERMI** has shown that residual dispersion can be corrected with DFS, careful choice of the parameters is needed to correct both planes
- Beam dynamics simulations have shown that DFS is less efficient with accelerating section misalignments, thus **studies to perform BBA** have been performed

Publications

JOURNAL ARTICLES

- G. CAMPOGIANI, S. Guiducci, A. Giribono, C. Vaccarezza, A. Variola, “Electron beam trajectory and optics control in the ELI-NP Gamma Beam System”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* http://dx.doi.org/10.1016/j.nima.2016.08.055.

CONFERENCE PROCEEDINGS

- A. Giribono *et al.*, “ELI-NP GBS Status”, in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, paper MOPVA016, pp. 880-883, ISBN: 978-3-95450-182-3, https://doi.org/10.18429/JACoW-IPAC2017-MOPVA016, http://jacow.org/ipac2017/papers/mopva016.pdf, 2017.
- C. Vaccarezza *et al.*, “Optimization Studies for the Beam Dynamic in the RF Linac of the ELI-NP Gamma Beam System”, in *Proc. 7th International Particle Accelerator Conference (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW041, pp. 1850-1853, ISBN: 978-3-95450-147-2, doi:10.18429/JACoW-IPAC2016-TUPOW041
- A. Giribono *et al.*, “Electron Beam Dynamics Studies for ELI-NP GBS Linac”, in *Proc. 7th International Particle Accelerator Conference (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW043, pp. 1857-1860, ISBN: 978-3-95450-147-2, doi:10.18429/JACoW-IPAC2016-TUPOW043

POSTER

- G. Campogiani *et al.*, “Progress of the development of the ELI-NP GBS High Level Applications”, EAAC’17, Elba Island, Italy, September 2017
- G.Campogiani *et al.*, “Electron beam trajectory and optics control in the ELI-NP Gamma Beam System”, HBBPA’17, La Havana, Cuba, March 2016

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THANK YOU FOR THE ATTENTION

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