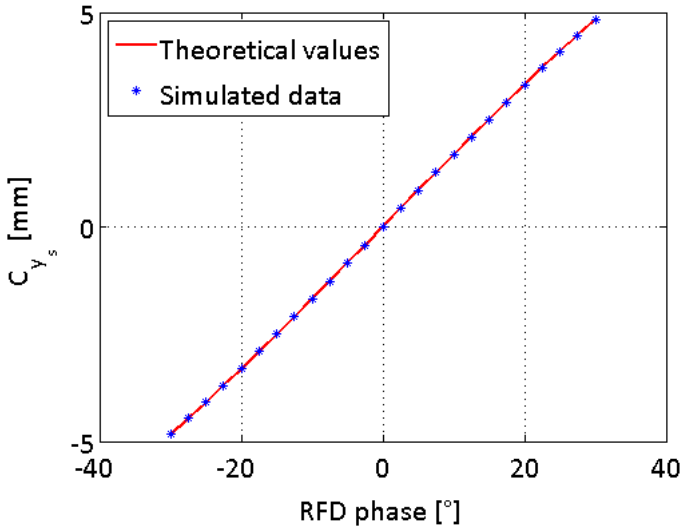

Figure 1: Vertical centroid at the screen "SCR_08_C" (watching point 3: w3) placed after the RF Deflector (RFD) "RFD0" versus RFD phase. Theoretical prediction in red line and simulated data in blue stars.

In the annexed folder "ELI-NP", there are the files "eli_lowen_24_11_2015_234MeV.ele" and "eli_lowen_24_11_2015_234MeV.lte". In Fig. 1, the plot of the **vertical centroid** at the screen "SCR_08_C" (watching point 3: w3) placed after the RF Deflector (RFD) "RFD0" versus RFD phase is depicted. The plot **shows a good match between theoretical and simulated data**. From theory, the vertical bunch centroid at a screen placed after a RFD is given by [1, 2]:

$$C_{y_s} = LC_{rfd}sin(\varphi), \tag{1}$$

where L is the distance between the RFD center and the screen, φ is the RFD phase (notice that the RFD phase in this notation φ is different from the RFD phase in ELEGANT notation $\Delta\phi$: $\varphi = \Delta\phi + \frac{\pi}{2}$), $C_{rfd} = \frac{qV_T}{pc}$, where q is the charge particle, V_t is the deflecting voltage amplitude, p is the particle momentum, and c is the light velocity.

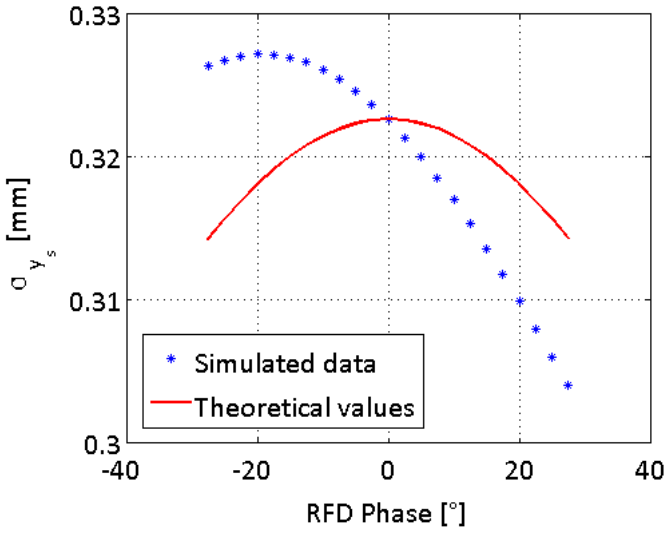

Figure 2: Vertical spot size at the screen "SCR_08_C" (watching point 3: w3) placed after the RF Deflector (RFD) "RFD0" versus RFD phase. Theoretical prediction in red line and simulated data in blue stars.

The **problem** is in Fig. 2. In Fig. 2, the plot of the **vertical spot size** at the screen "SCR_08_C" (watching point 3: w3) placed after the RF Deflector (RFD) "RFD0" versus RFD phase is depicted. The plot **doesn't show a good match between theoretical and simulated data**. From theory, the vertical spot size at a screen placed after a RFD is given by [1, 2, 3]:

$$\sigma_{y_s}^2 = \sigma_{y_s,off}^2 + K_{cal}^2 \sigma_{t_0}^2, \tag{2}$$

where $\sigma_{y_s,off}$ is the vertical spost size at screen with RFD off, σ_{t_0} is the bunch length, and K_{cal} is given by:

$$K_{cal} = 2\pi f_{RF} L C_{rfd} cos\left(\varphi\right), \tag{3}$$

where f_{RF} is the deflecting voltage frequency. From Fig. 3, we can notice that the spot size relative error between theoretical predictions and simulated data is under 4%.

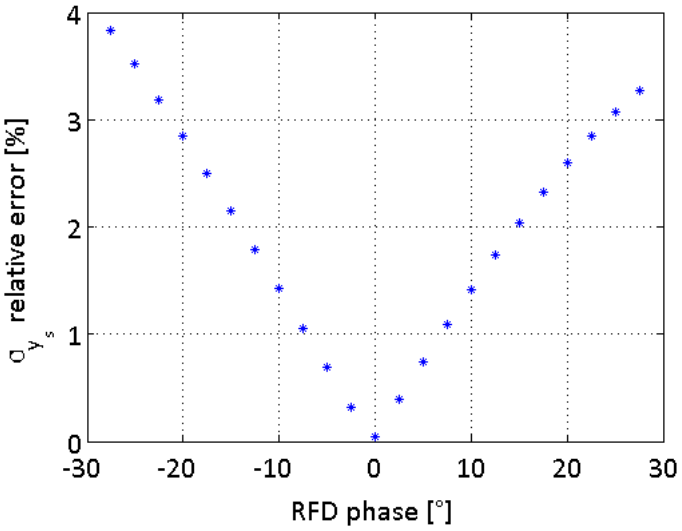

Figure 3: Spot size relative error between theoretical predictions and simulated data versus RFD phase.

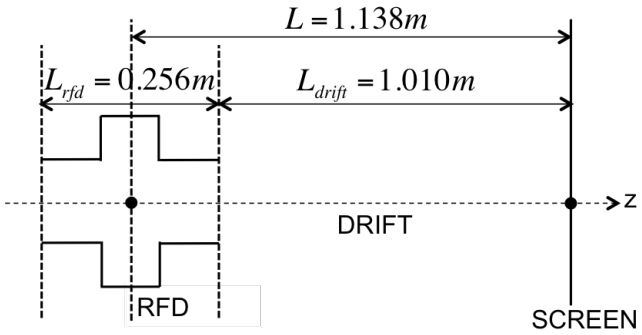

Figure 4: Lattice.

At the entrance of RF Deflector

	Name	Unit	Symbol Theoretical	Symbol ELEGANT	Value ELI-NP	Value Bunched beam	Absolute error	Relative error(%)
	Number of particle	dimensionless	N		50000	50000	0	0
Vertical	Twiss Parameter alpha	dimensionless	α_{y0}	alphay	11,22379	11,22379	0	0
	Twiss Parameter beta	m	β_{y0}	betay	69,24721	69,24721	0	0
	Emittance	m x rad	ε_{y0}	ey	1,807253E-09	1,807325E-09	7,2E-14	3,983947E-03
	Dispersion	m	η_{y0}	etay	-4,237071E-05	-4,237071E-05	0	0,000000E+00
	Dispersion function slope	dimensionless	η'_{y0}	etayp	8,027679E-07	8,027679E-07	0	0,000000E+00
	Centroid	m	C_{y0}	Cy	6,549168E-10	-1,459336E-21	6,54917E-10	1,000000E+02
	Spot Size	m	σ_{y0}	Sy	3,537615E-04	3,537686E-04	7,1E-09	2,007002E-03
	Divergence Average	dimensionless	$C_{y'0}$	Cyp	-3,360267E-09	-8,901300E-22	3,36027E-09	1,000000E+02
	Divergence Variance	dimensionless	$\sigma_{y'0}$	Syp	5,756582E-05	5,756699E-05	1,17E-09	2,032456E-03
Longitudinal	Bunch Length	m	σ_{t0}	St	9,117491E-13	9,117335E-13	1,56E-17	1,710997E-03
	Central Momentum	dimensionless	$\beta_{Lorentz,0}\gamma_{Lorentz,0}$	pCentral	2,300358E+02	2,300396E+02	0,0038	1,651917E-03
	Energy Spread	dimensionless		Δp/p0	6,053954E-03	6,052949E-03	1,005E-06	1,660072E-02
Horizontal	Twiss Parameter alpha	dimensionless	α_{x0}	alphax	1,169879E+01	1,169879E+01	0	0,000000E+00
	Twiss Parameter beta	m	β_{x0}	betax	7,190570E+01	7,190570E+01	0	0,000000E+00
	Emittance	m x rad	ε_{x0}	ex	1,845293E-09	1,845332E-09	3,9E-14	2,113486E-03
	Dispersion	m	η_{x0}	etax	4,079467E-06	4,079467E-06	0	0,000000E+00
	Dispersion function slope	dimensionless	η'_{x0}	etaxp	8,434335E-07	8,434335E-07	0	0,000000E+00
	Centroid	m	C_{x0}	Cx	5,092578E-08	-2,632443E-21	5,09258E-08	1,000000E+02
	Spot Size	m	σ_{x0}	Sx	3,642624E-04	3,642663E-04	3,9E-09	1,070657E-03
	Divergence Average	dimensionless	$C_{x'0}$	Cxp	-1,032269E-08	-1,393200E-22	1,03227E-08	1,000000E+02
	Divergence Variance	dimensionless	$\sigma_{x'0}$	Sxp	5,948028E-05	5,948089E-05	6,1E-10	1,025550E-03

Figure 5: Comparison of the bunch parameters between the original bunch and the copied bunch by means of bunched beam at the entrance of RFD.

In the other annexed folder ”bunched beam”, there are the files ”elinp_screenRFD.ele” and ”lattice.lte”. In ”lattice.lte”, the equivalent line from RF Deflector (RFD) ”RFD0” to the screen ”SCR_08_C” has been created: a RFD and a drift (see Fig. 4). In ”elinp_screenRFD.ele”, a bunch has been created with the same characteristic at the entrance of ”RFD0” by means of the command bunched beam (see Fig. 5). From the Fig. 5, we can notice that the two bunches (the original bunch and the copied bunch by means of bunched beam) have similar characteristics.

At the screen with RF Dedlector off

	Name	Unit	Symbol		Value		Absolute error	Relative error(%)
			Theoretical	ELEGANT	ELI-NP	Bunched beam		
Vertical	Twiss Parameter alpha	dimensionless	α_{ys}	alphay	8,90251	8,902420E+00	9E-05	0,001010951
	Twiss Parameter beta	m	β_{ys}	betay	4,38E+01	4,376743E+01	0,00089	0,002033434
	Emittance	m x rad	ε_{ys}	ey	1,807253E-09	1,807284E-09	3,1E-14	0,00171531
	Dispersion	m	η_{ys}	etay	-3,220807E-05	-4,135441E-05	9,14634E-06	2,839767E+01
	Dispersion function slope	dimensionless	η'_{ys}	etayp	8,027679E-06	8,027679E-07	7,22491E-06	9,000000E+01
	Centroid	m	C_{ys}	Cy	-3,599013E-09	-4,861563E-21	3,59901E-09	1,000000E+02
	Spot Size	m	σ_{ys}	Sy	2,812480E-04	2,812475E-04	5E-10	1,777790E-04
	Divergence Average	dimensionless	$C_{y's}$	Cyp	-3,360267E-09	2,687737E-21	3,36027E-09	1,000000E+02
	Divergence Variance	dimensionless	$\sigma_{y's}$	Syp	5,756582E-05	5,756633E-05	5,1E-10	8,859424E-04
Longitudinal	Bunch Length	m	σ_{ts}	St	9,112779E-13	9,112715E-13	6,4E-18	7,023105E-04
	Central Momentum	dimensionless	$\beta_{Lorentz,s}\gamma_{Lorentz,s}$	pAverage	2,300358E+02	2,300396E+02	0,0038	1,651917E-03
	Energy Spread	dimensionless		Δp/p0	6,053954E-03	6,052949E-03	1,005E-06	1,660072E-02
Horizontal	Twiss Parameter alpha	dimensionless	α_{xs}	alphax	9,271642E+00	9,271540E+00	0,000102	1,100129E-03
	Twiss Parameter beta	m	β_{xs}	betax	4,535818E+01	4,535724E+01	0,00094	2,072394E-03
	Emittance	m x rad	ε_{xs}	ex	1,845293E-09	1,845224E-09	6,9E-14	3,739244E-03
	Dispersion	m	η_{xs}	etax	5,147212E-06	5,147254E-06	4,2E-11	8,159757E-04
	Dispersion function slope	dimensionless	η'_{xs}	etaxp	8,434335E-07	8,434335E-07	0	0,000000E+00
	Centroid	m	C_{xs}	Cx	3,785777E-08	1,528482E-11	3,78425E-08	9,995963E+01
	Spot Size	m	σ_{xs}	Sx	2,893080E-04	2,893048E-04	3,2E-09	1,106088E-03
	Divergence Average	dimensionless	$C_{x's}$	Cxp	-1,032269E-08	1,345072E-11	1,03361E-08	1,001303E+02
	Divergence Variance	dimensionless	$\sigma_{x's}$	Sxp	5,948028E-05	5,947434E-05	5,94E-09	9,986503E-03

Figure 6: Comparison of the bunch parameters between the original bunch and the copied bunch by means of bunched beam at the screen, placed after the RFD and a drift 1.1380 m long, when RFD is off.

When the RFD is off, there is a simple drift between screen and RFD. In Fig. 6, the comparison of the bunch parameters between the original bunch and the copied bunch by means of bunched beam at the screen, placed after the RFD and a drift. The Fig. 6 shows a good match between the two bunches at screen.

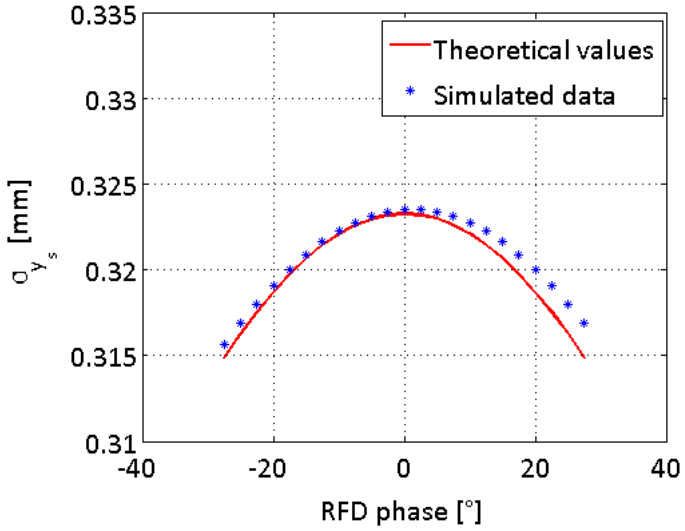

Figure 7: Vertical spot size at the screen (watching point 1: w1) placed after the RFD versus RFD phase. Theoretical prediction in red line and simulated data in blue stars.

With deflector on, the simulated data and the theoretical predictions of the vertical centroid at screen show a good match. In Fig. 7, the vertical spot size at screen of the copied bunch is shown. The theoretical predictions and the simulated data have a better agreement compared to the results of the original file. In Fig.8, the relative error between simulated data and theoretical prediction (is less than 0.7%) versus RFD phase is plotted.

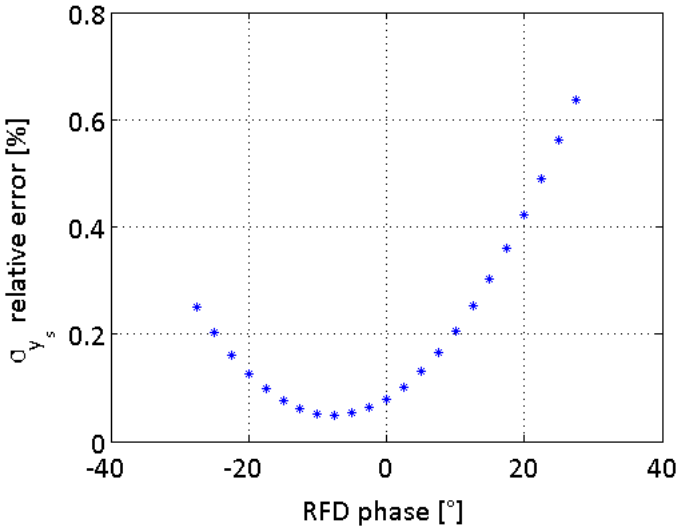

Figure 8: Spot size relative error between theoretical predictions and simulated data versus RFD phase.

The vertical spot sizes at screen, placed after the RF Deflector, in the two above mentioned cases are different. Only in the second case, a good match between theoretical predictions and simulated data of thevertical spot size at screen has been shown. Why?

References

[1] P. Emma, J. Frisch, and P. Krejcik, "A Transverse RF Deflecting Structure for Bunch Length and Phase Space Diagnostics", LCLS-TN-00-12, 2000.

[2] A. Cianchi, "Observations and Diagnostics in High Brightness Beams" proceedings CAS, "Intensity Limitations in Particle Beams", CERN, Geneva, Switzerland, 2 - 11 November, 2015, avaible on-line at http://cas.web.cern.ch/cas/Intensity-Limitations-2015/Lectures/Friday6/Cianchi.pdf

[3] D. Alesini et al., “Sliced beam parameter measurements”, in Proceedings of EPAC, 2009.