Development of Double Drift Harmonic Buncher Concepts

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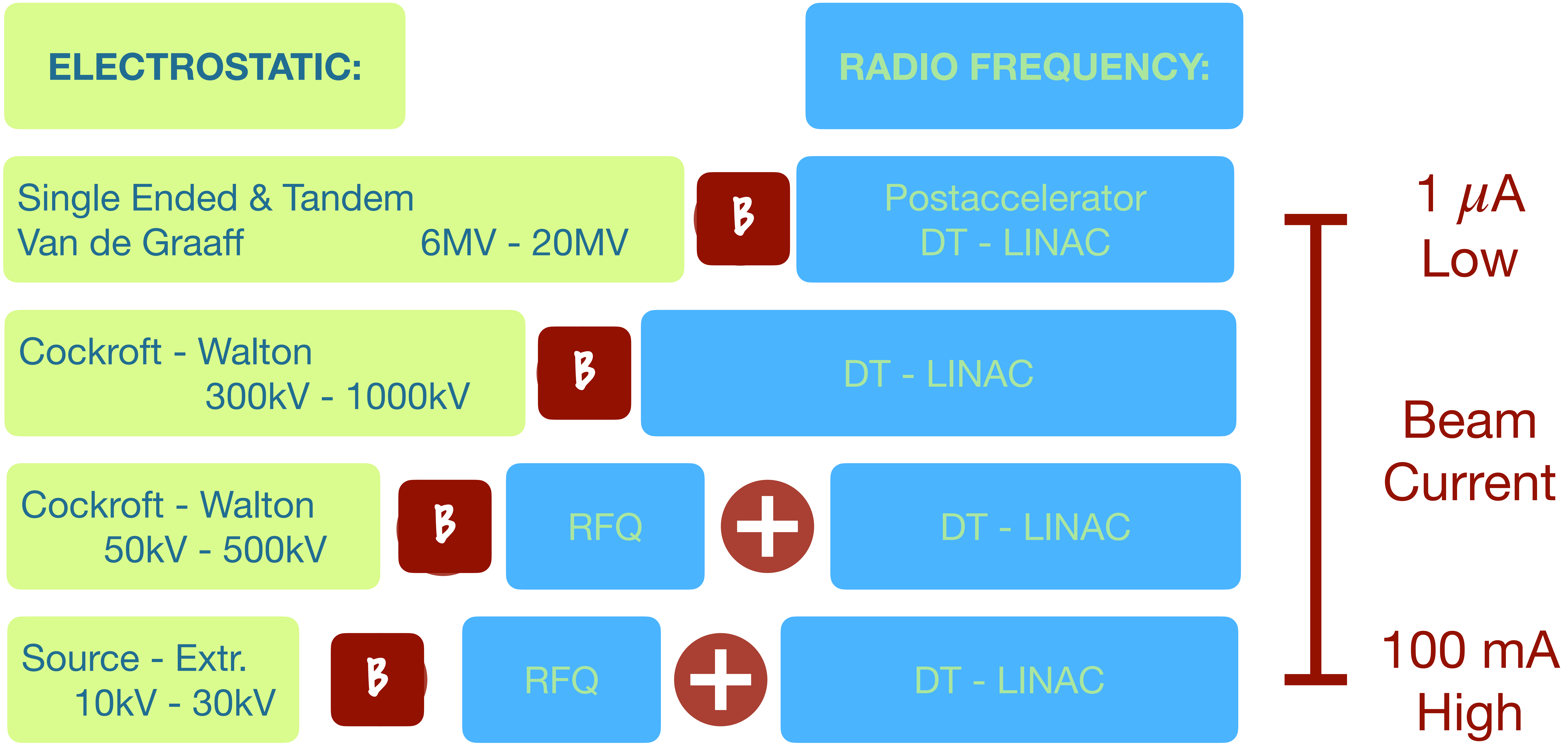
Content:

- Motivation
- Harmonic Bunch Formation & DDHB* Concept
- BCDC* - Multi-Particle Tracking Programm
- Applications

DDHB*: Double Drift Harmonic Buncher
BCDC*: Beam Creation of DC beam

Historical Evolution of Ion Linac Conceptual Design:



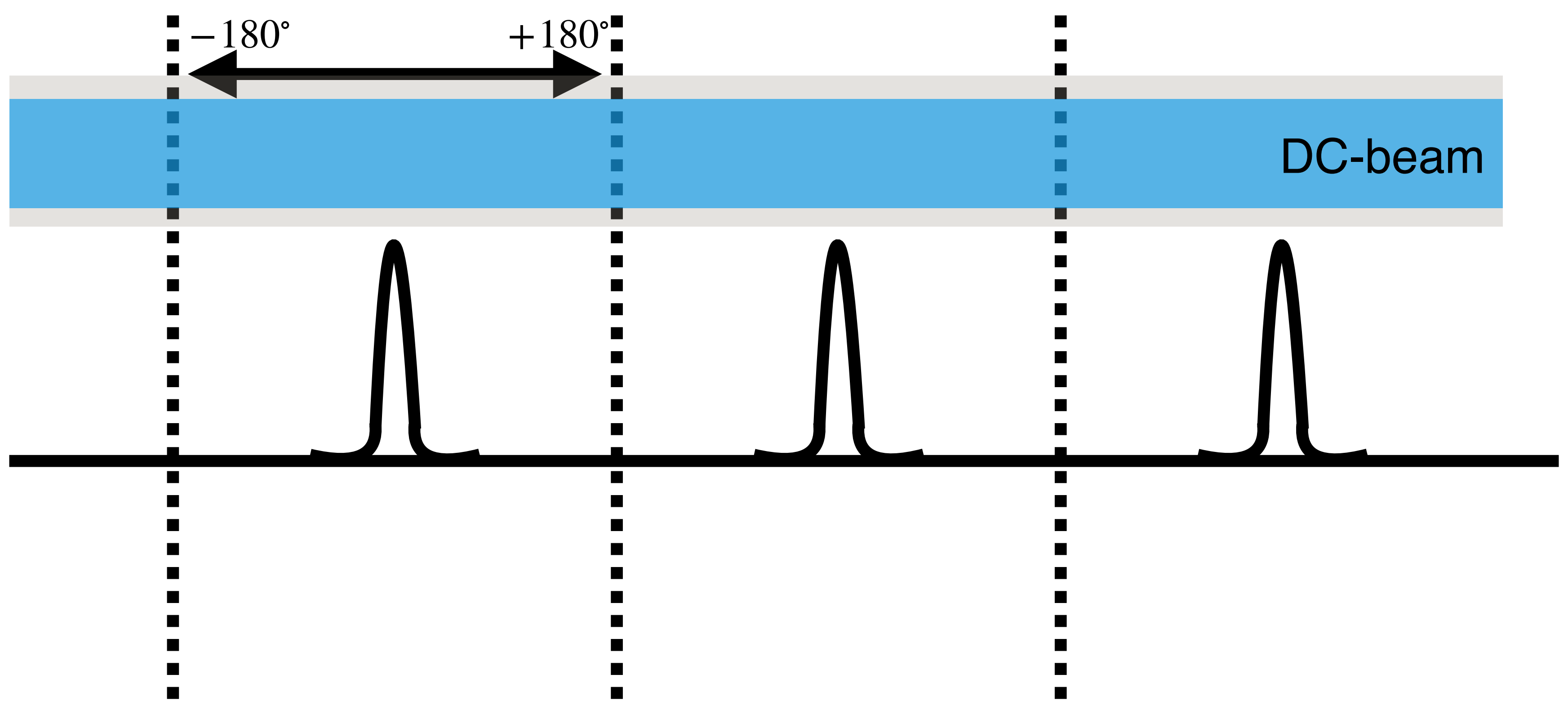
" Effiziente Hochfrequenz-Linearbeschleuniger für leichte und schwere Ionen" - U. Ratzinger, 1998

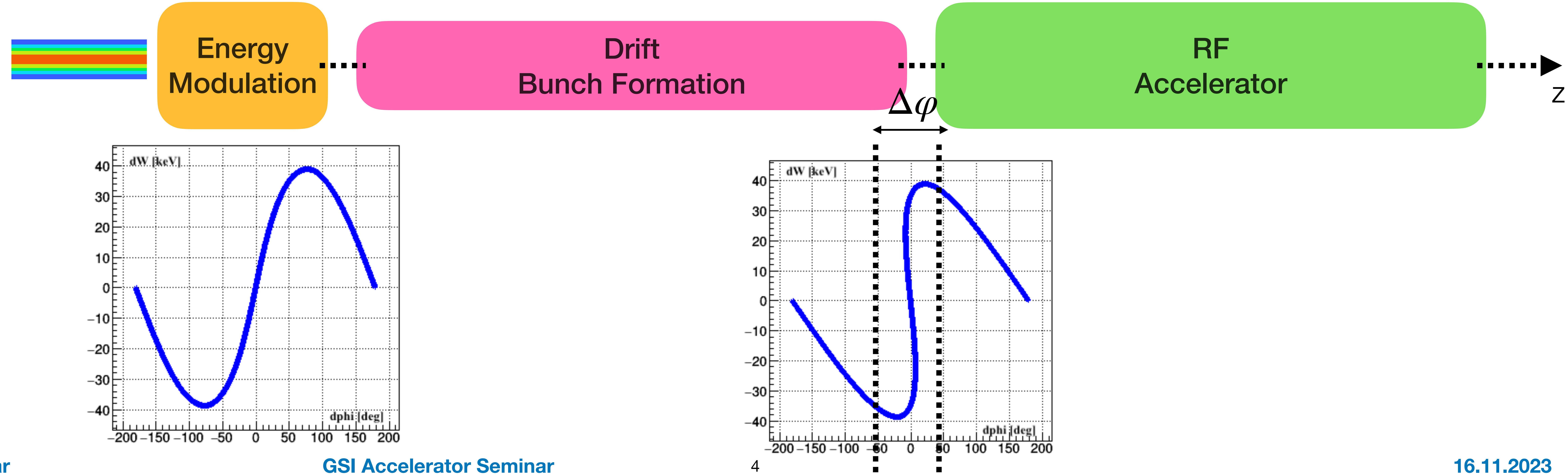
Motivation:

Check double harmonic bunching systematically and see under which conditions does it functional and effective.

- Make bunching within a shorter distance
- Get high particle acceptance
- Get bunching formation more controllable
- Have smaller longitudinal emittance at low current

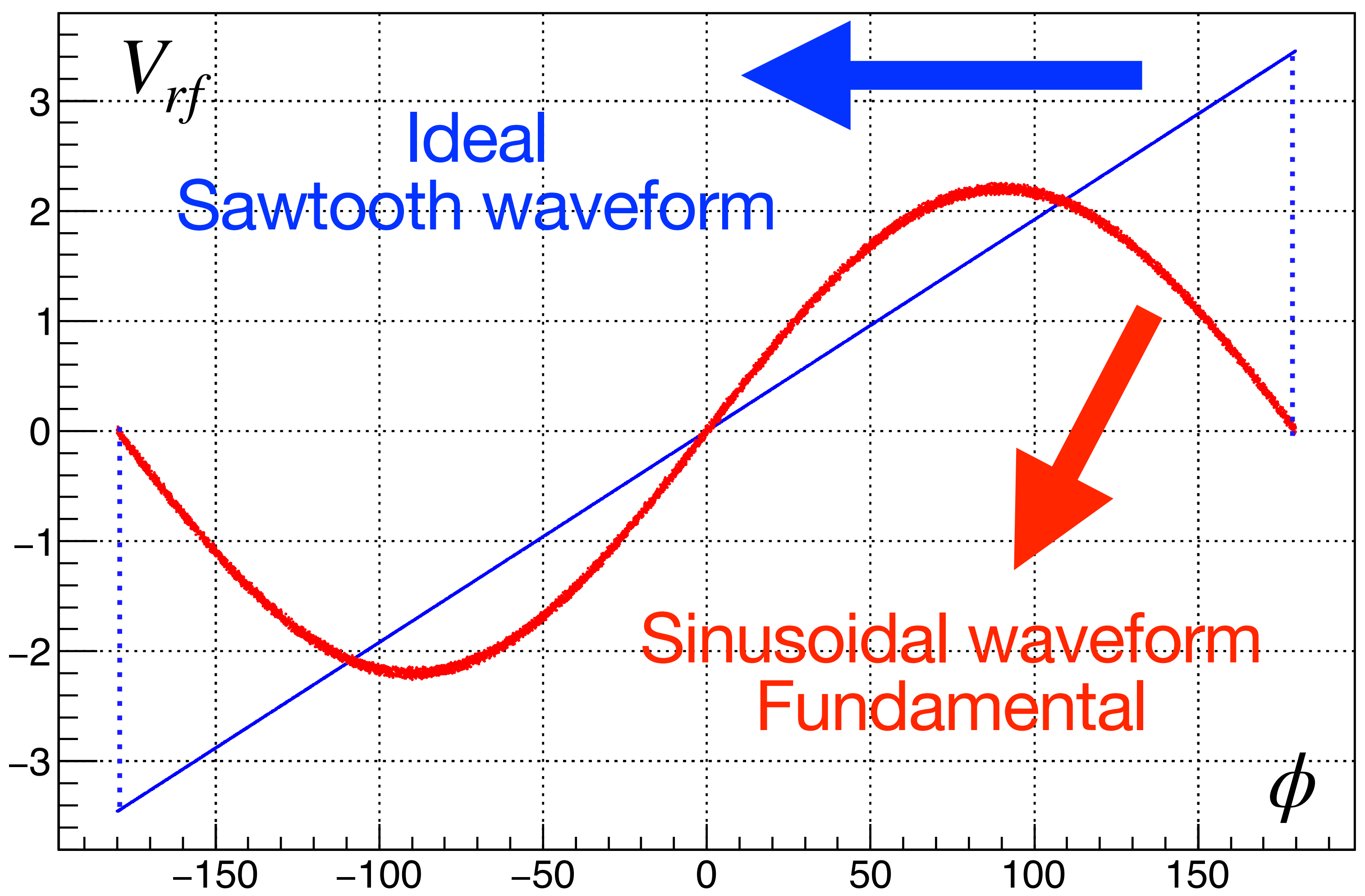
DC Beam:



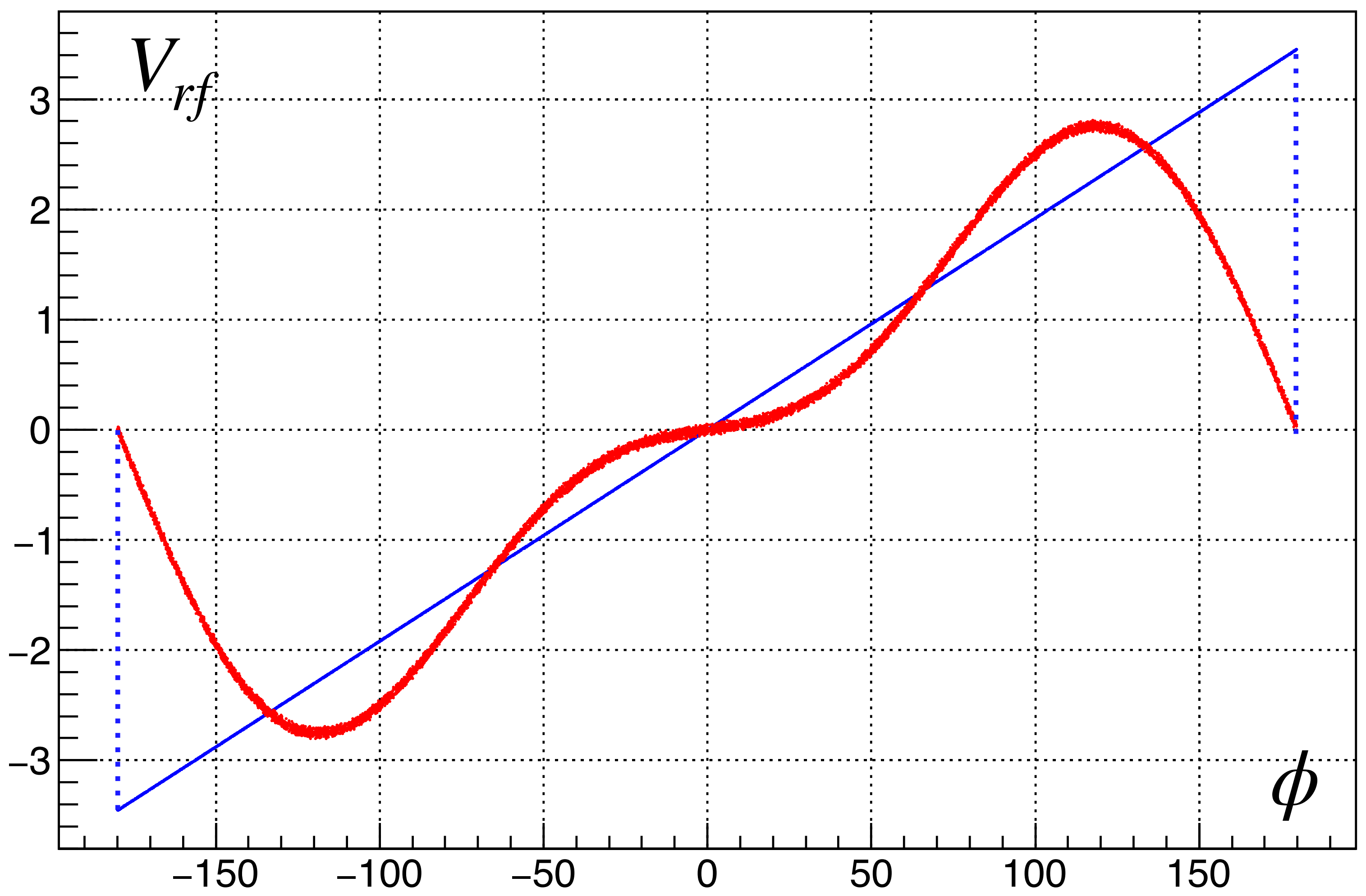


Multi-Harmonic Buncher System

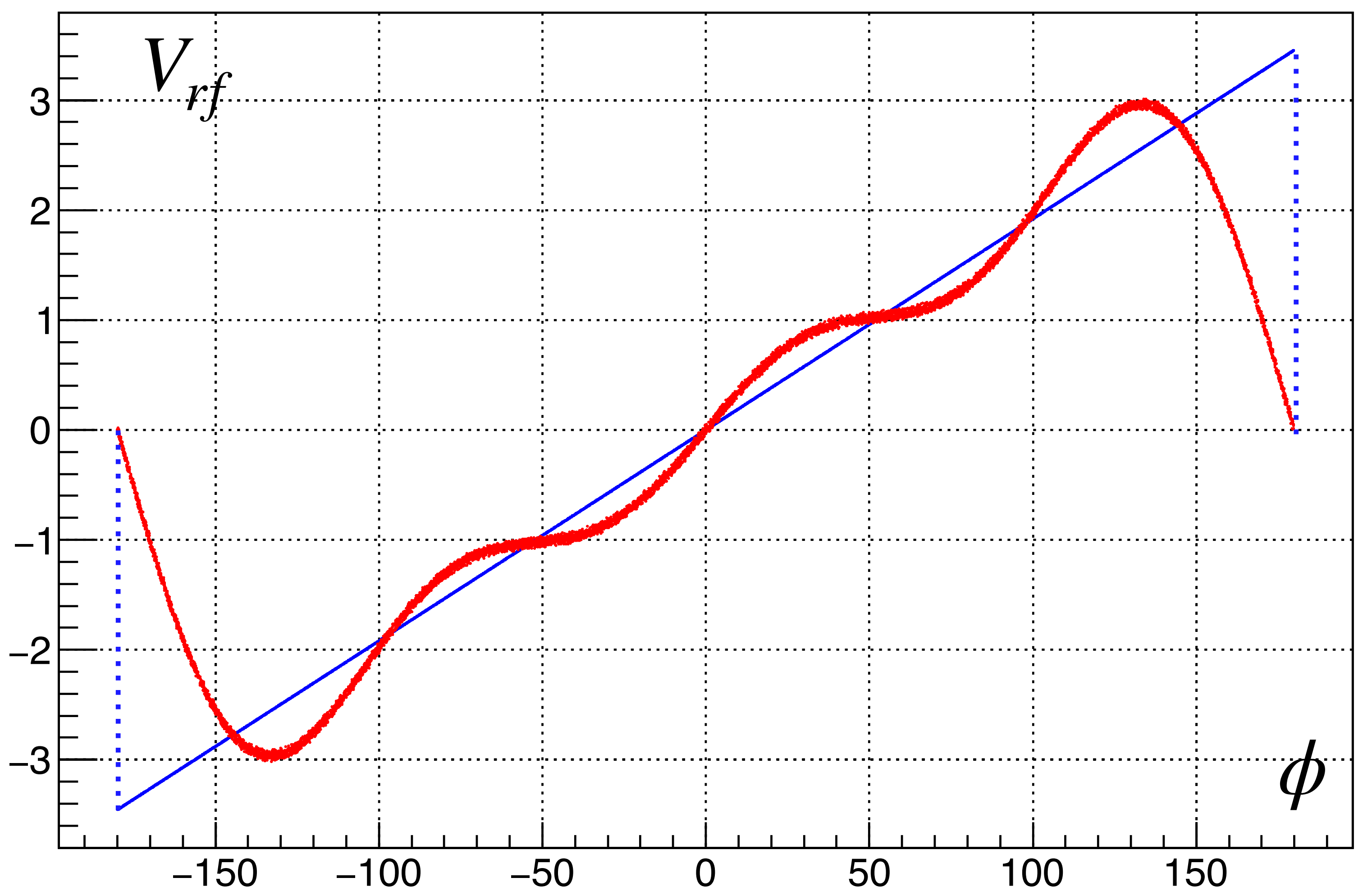
Harmonic Bunch Formation



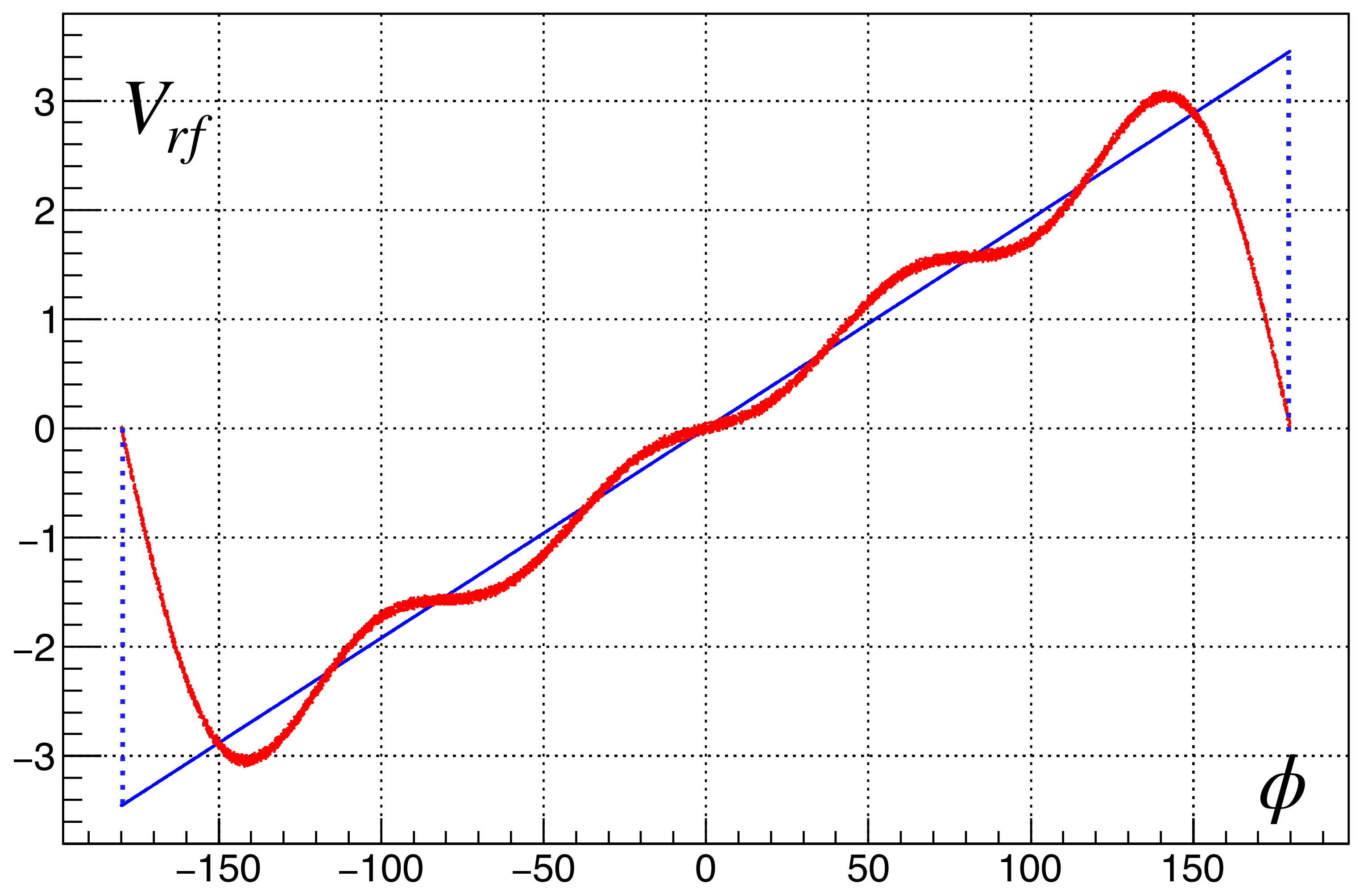
Fundamental (f)



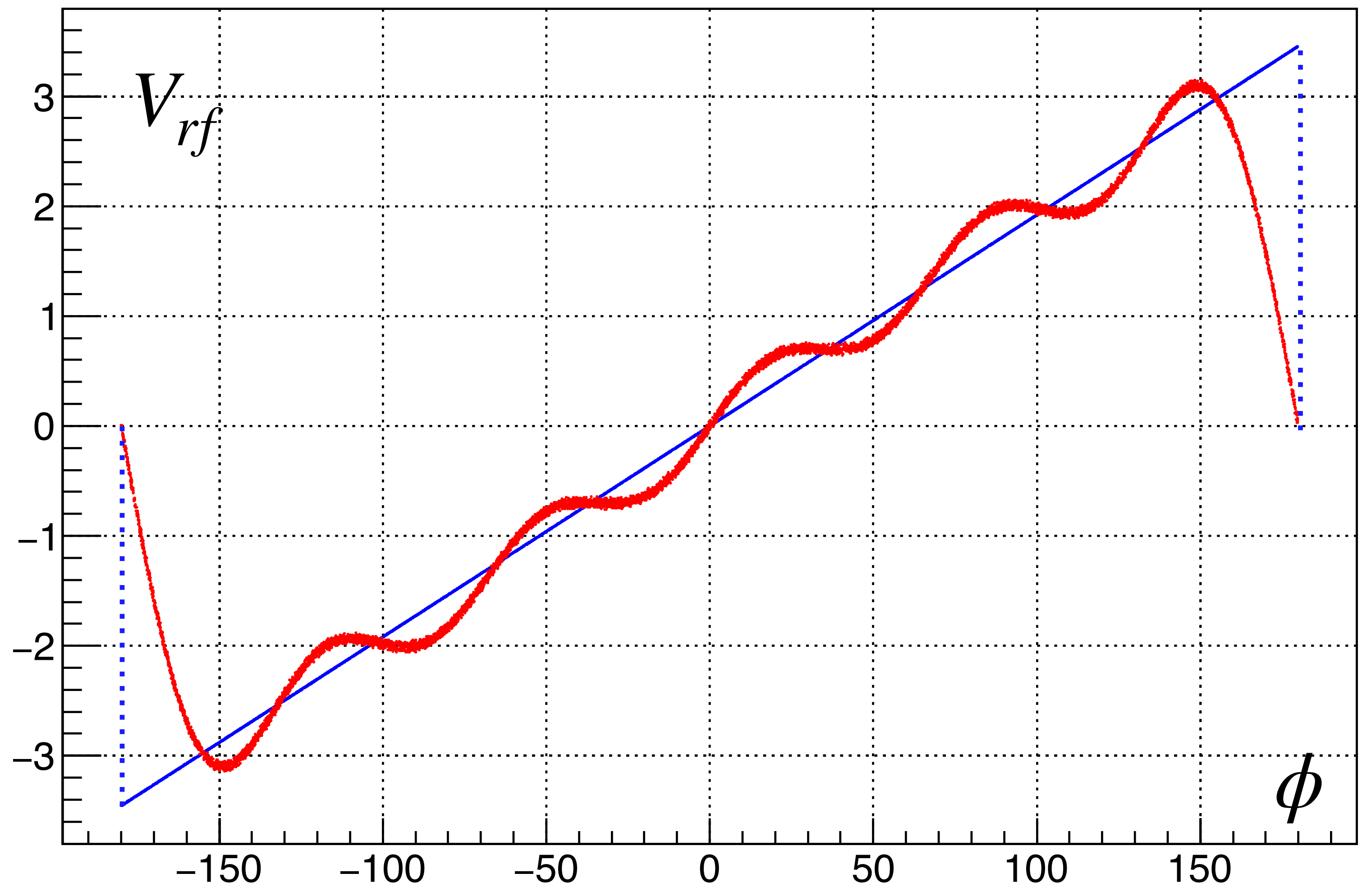
f + 2f



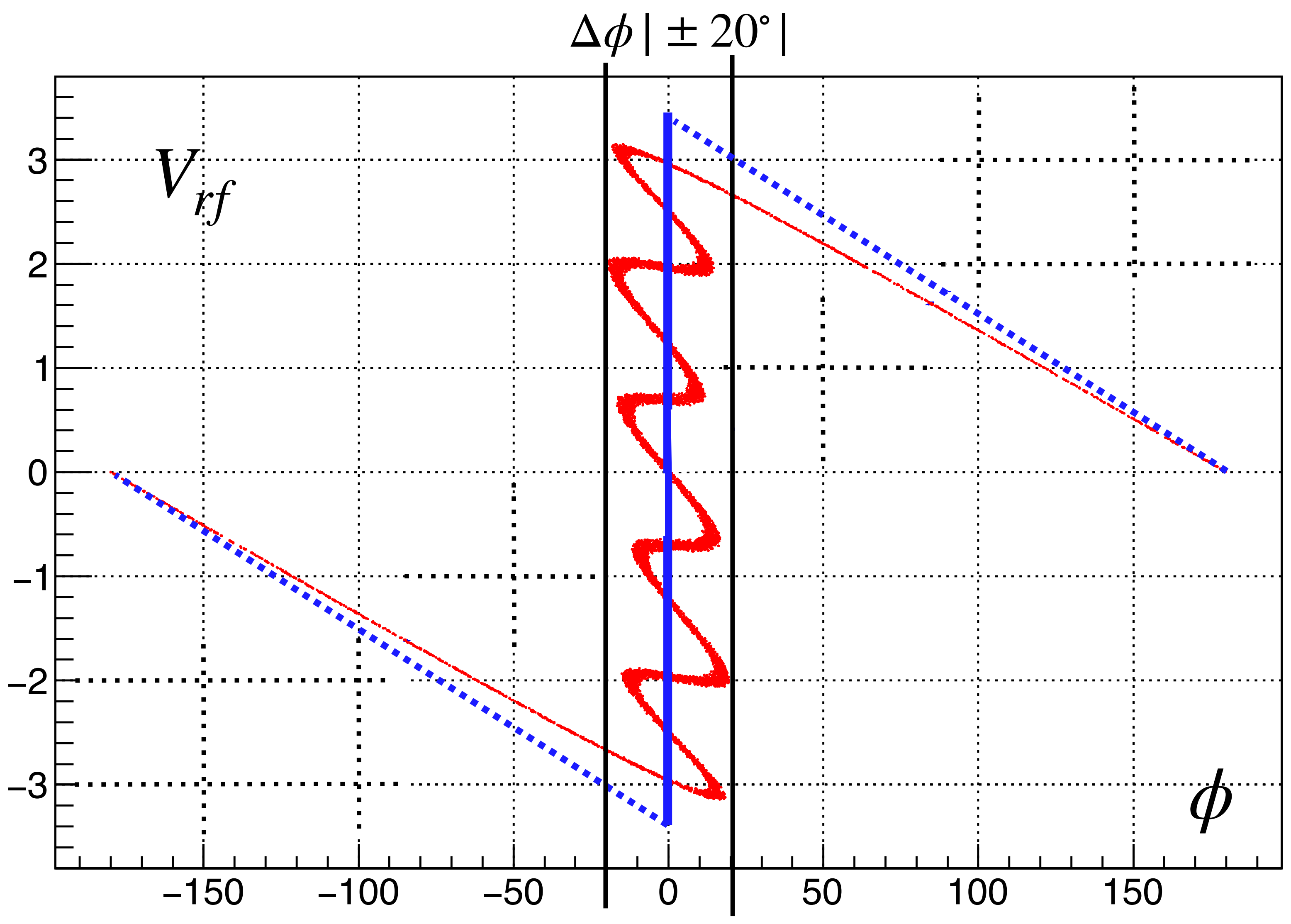
f + 2f + 3f



f + 2f + 3f + 4f

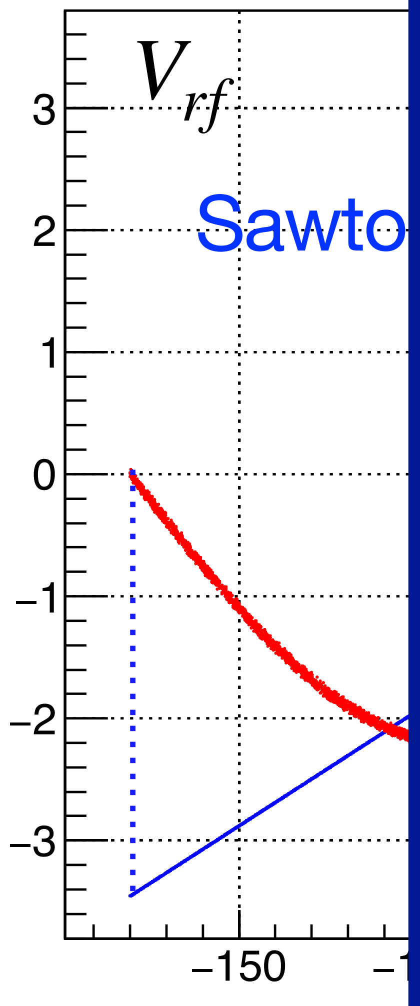


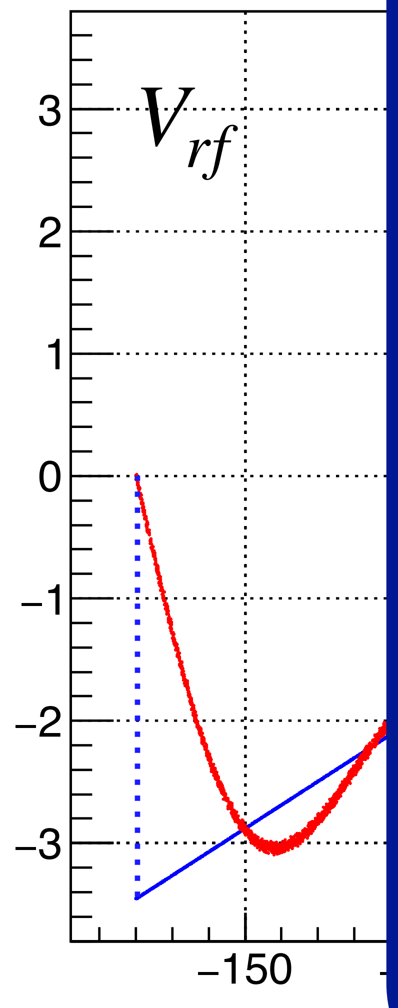
f + 2f + 3f + 4f + 5f

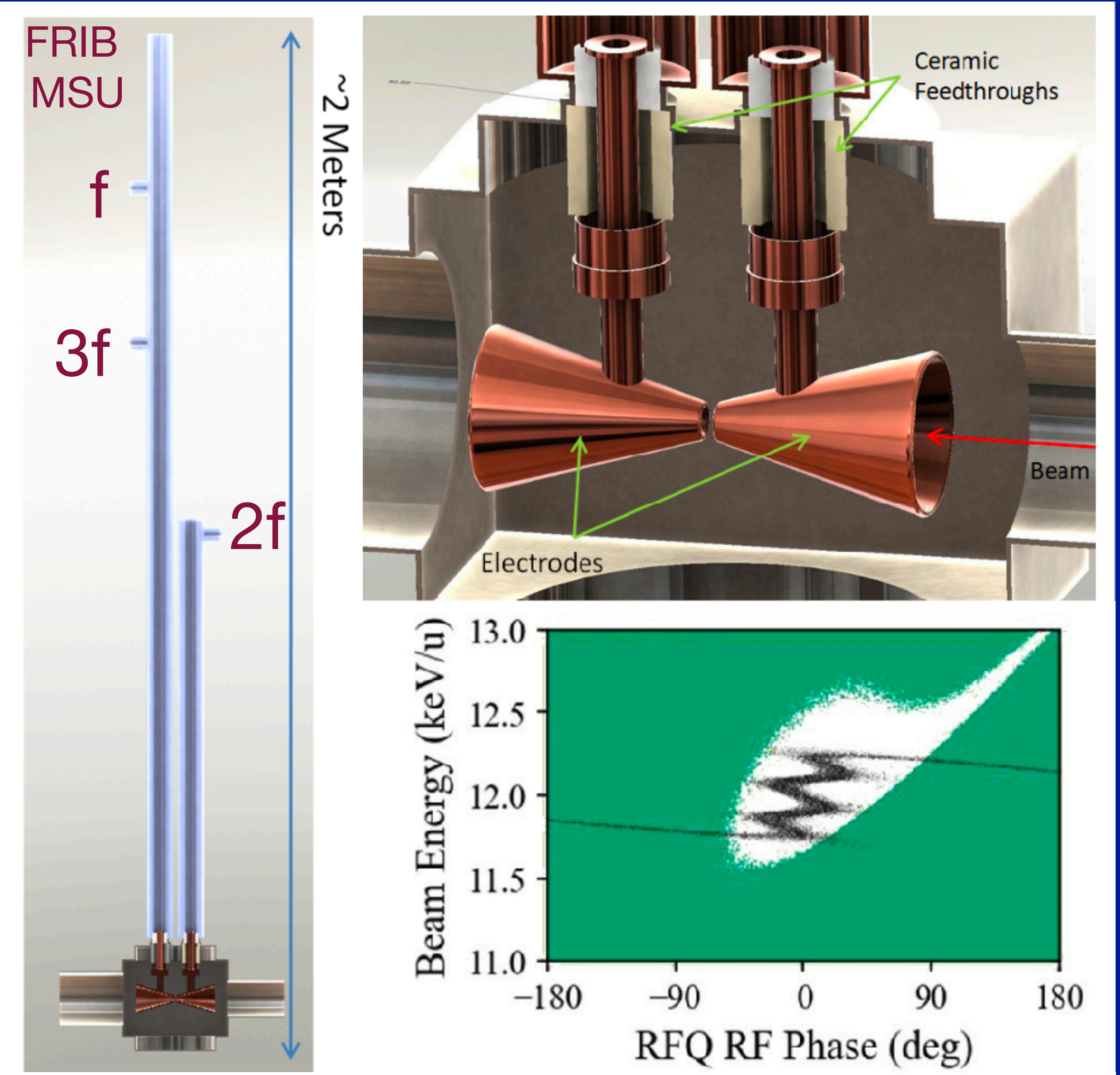


f + 2f + 3f + 4f + 5f + drift

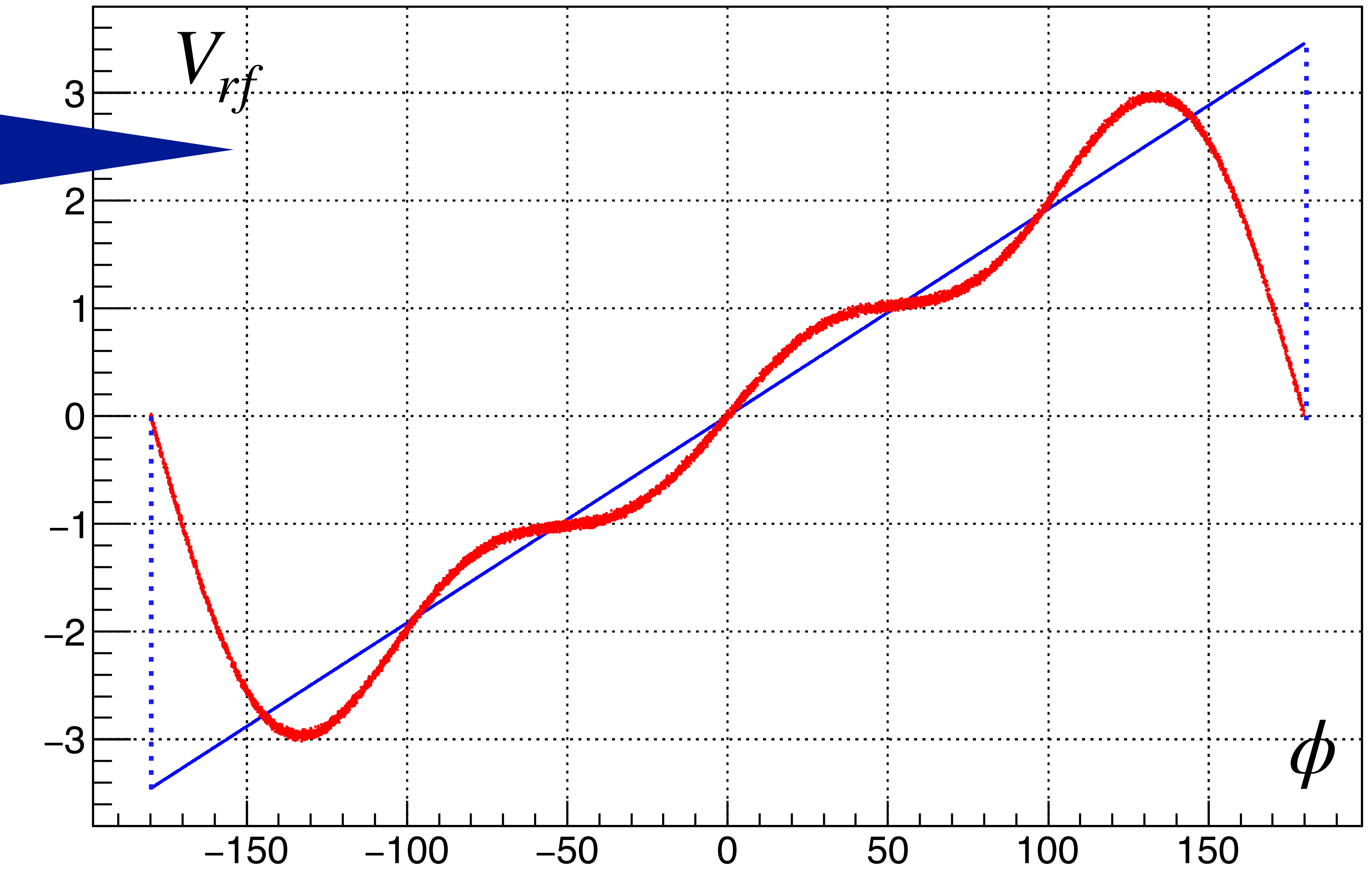
Har



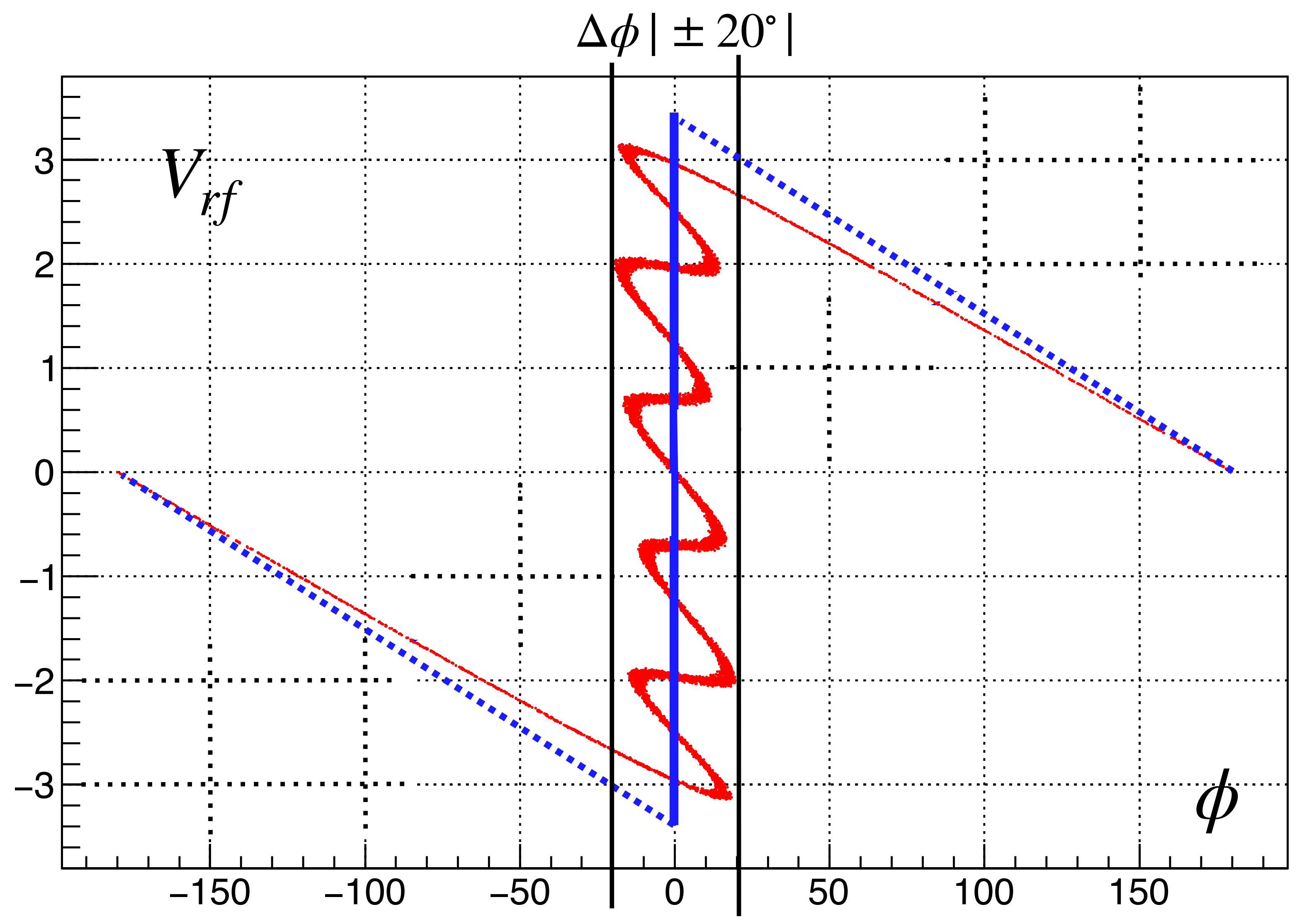




Pozdeyev, E, Brandon, J, Bultman, N, Rao, X, York, R, and Zhao, Q. Report on Design, Development, and Characterization of a Coaxial Resonator Based Single-gap Gridless Multiharmonic Buncher. United States: N. p., 2013. Web. doi:10.2172/1073065.

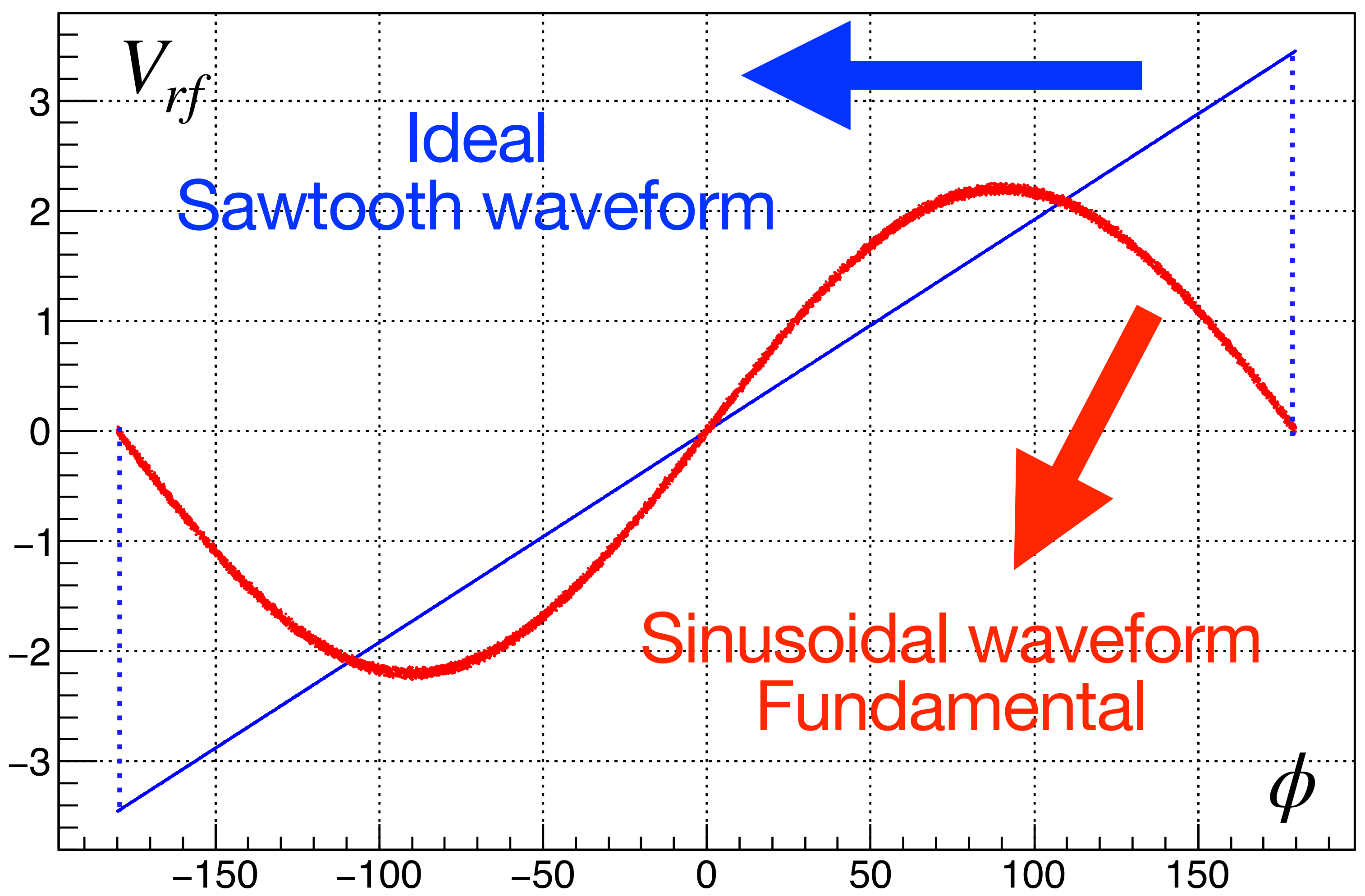


f + 2f + 3f

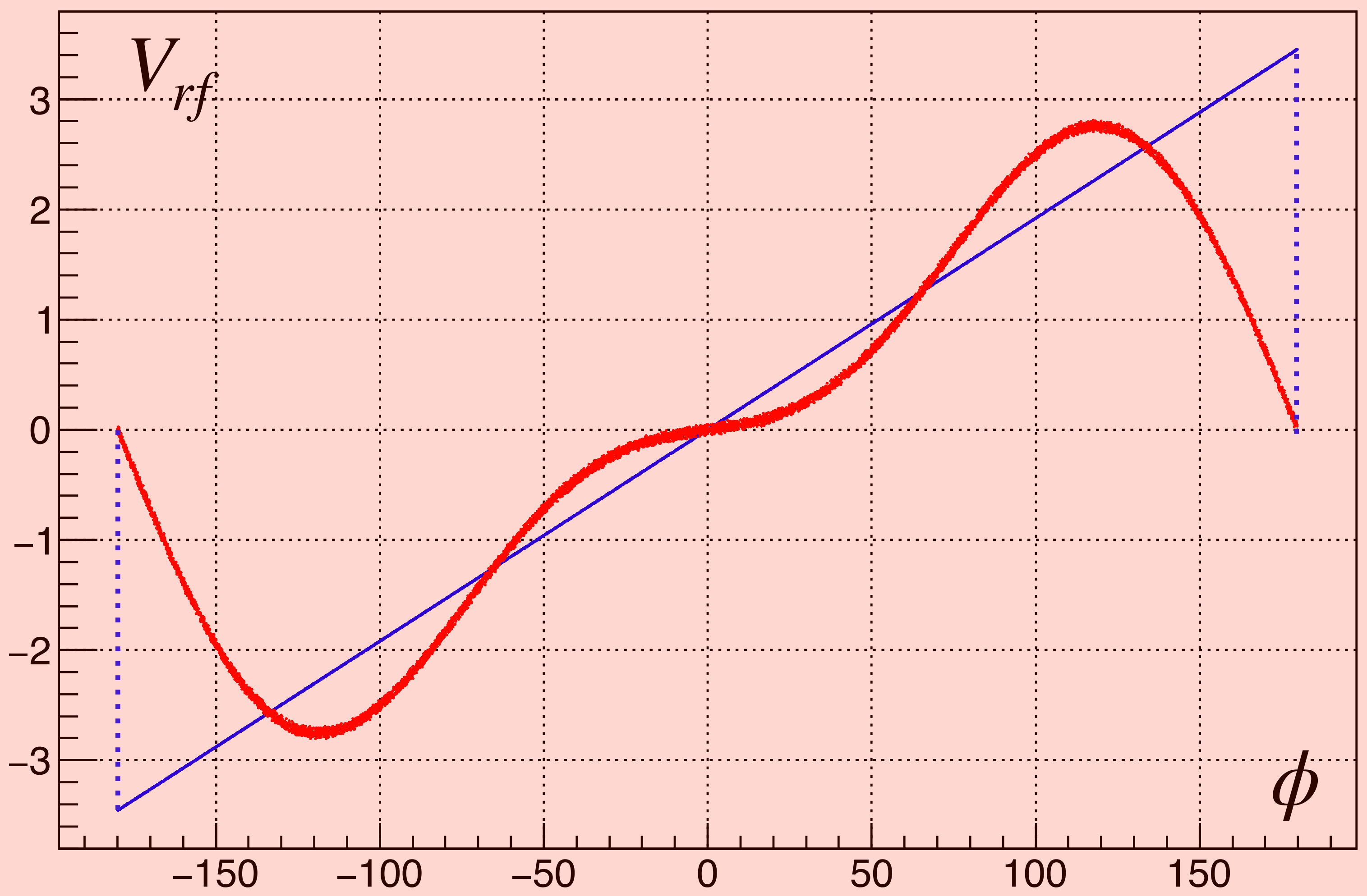


f + 2f + 3f + 4f + 5f + drift

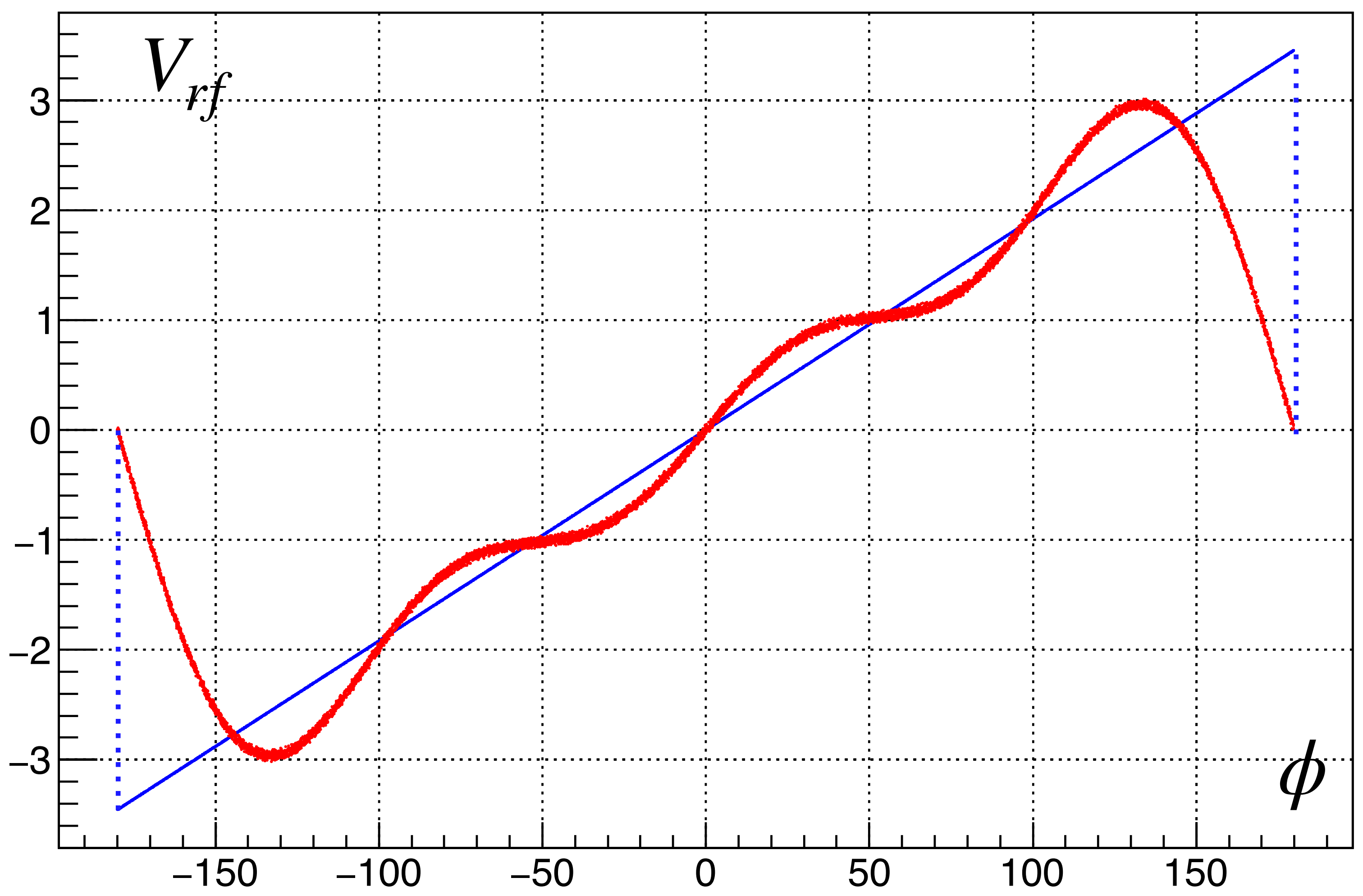
Harmonic Bunch Formation



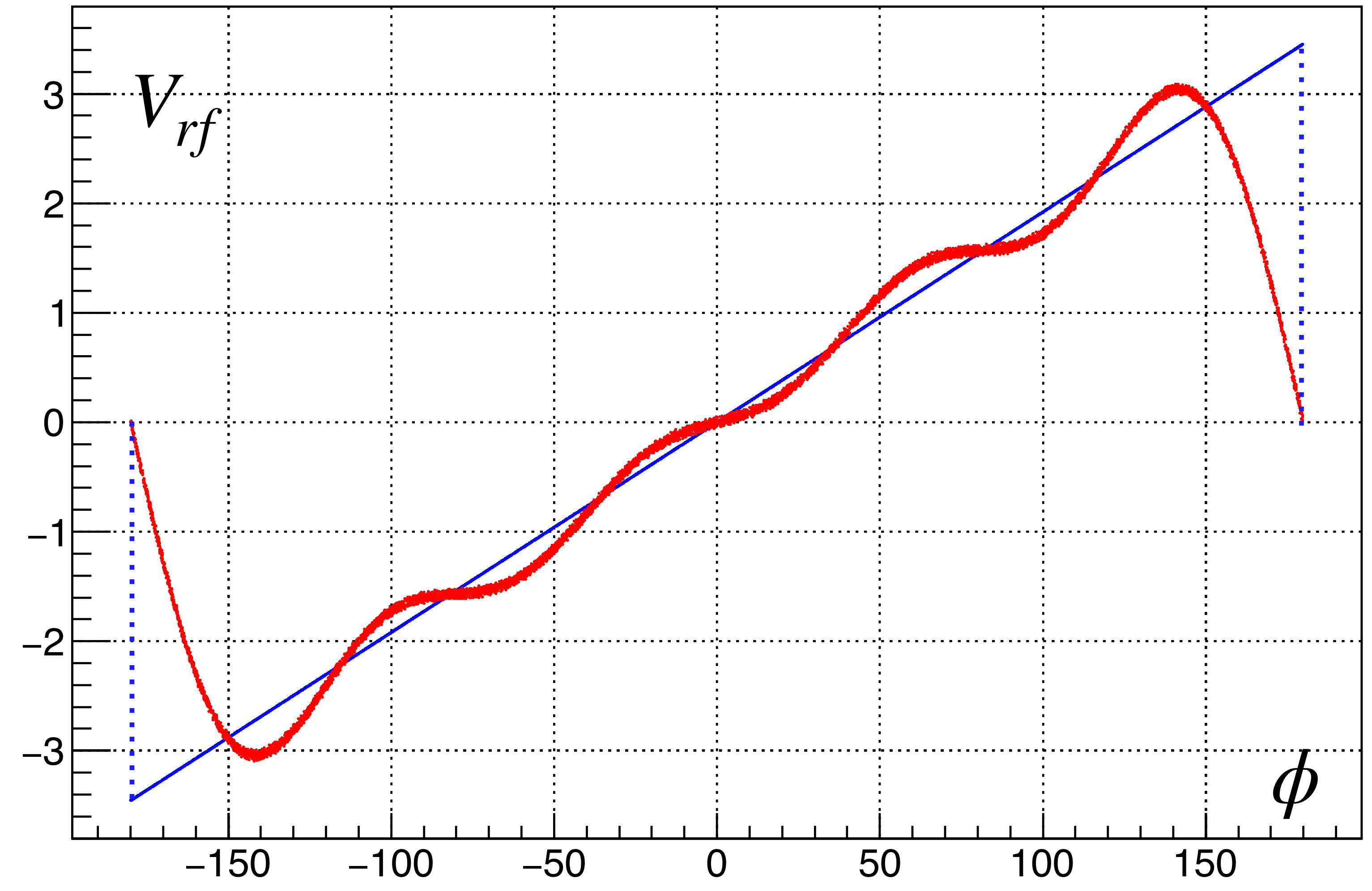
Fundamental (f)



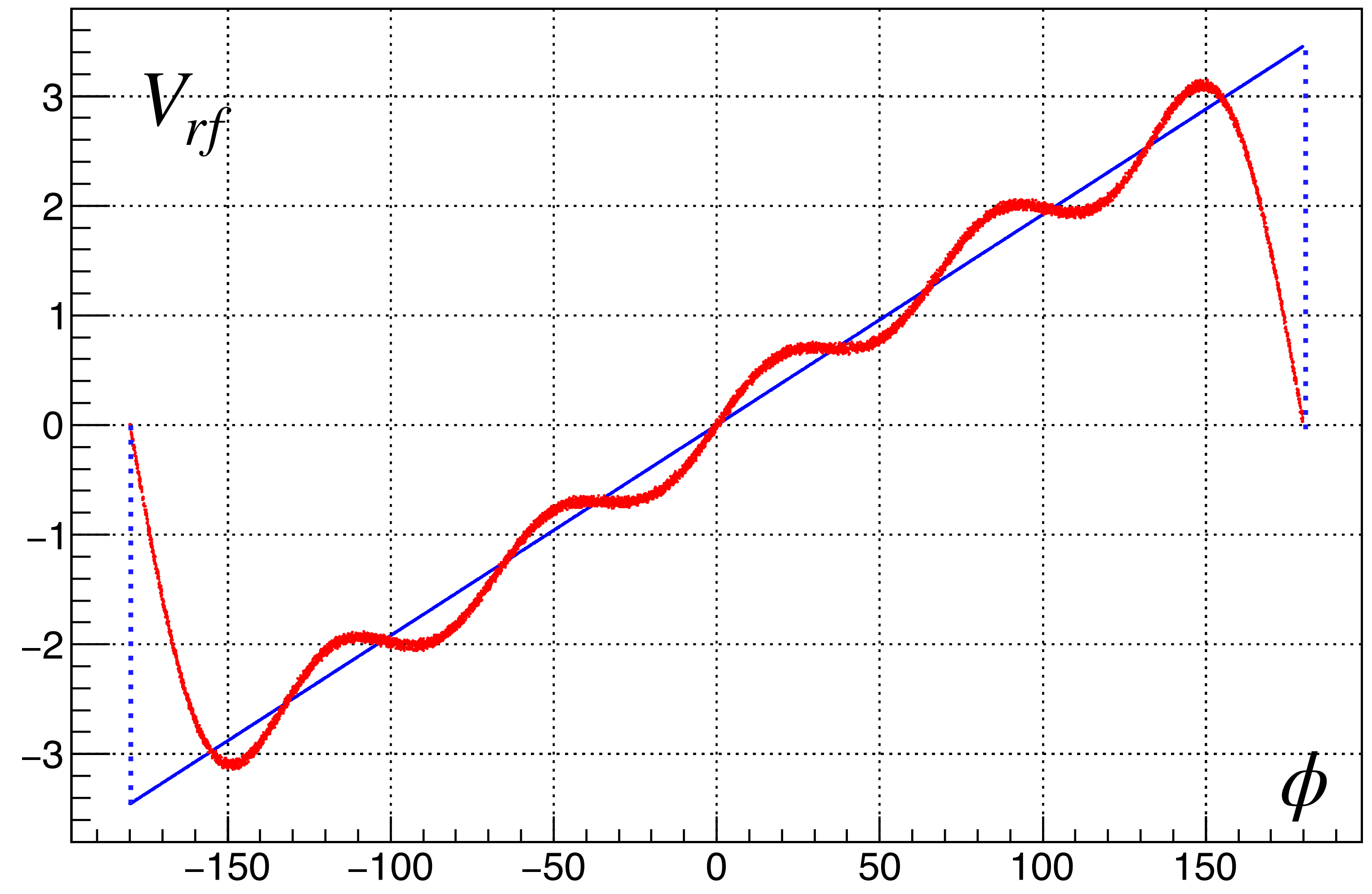
f + 2f



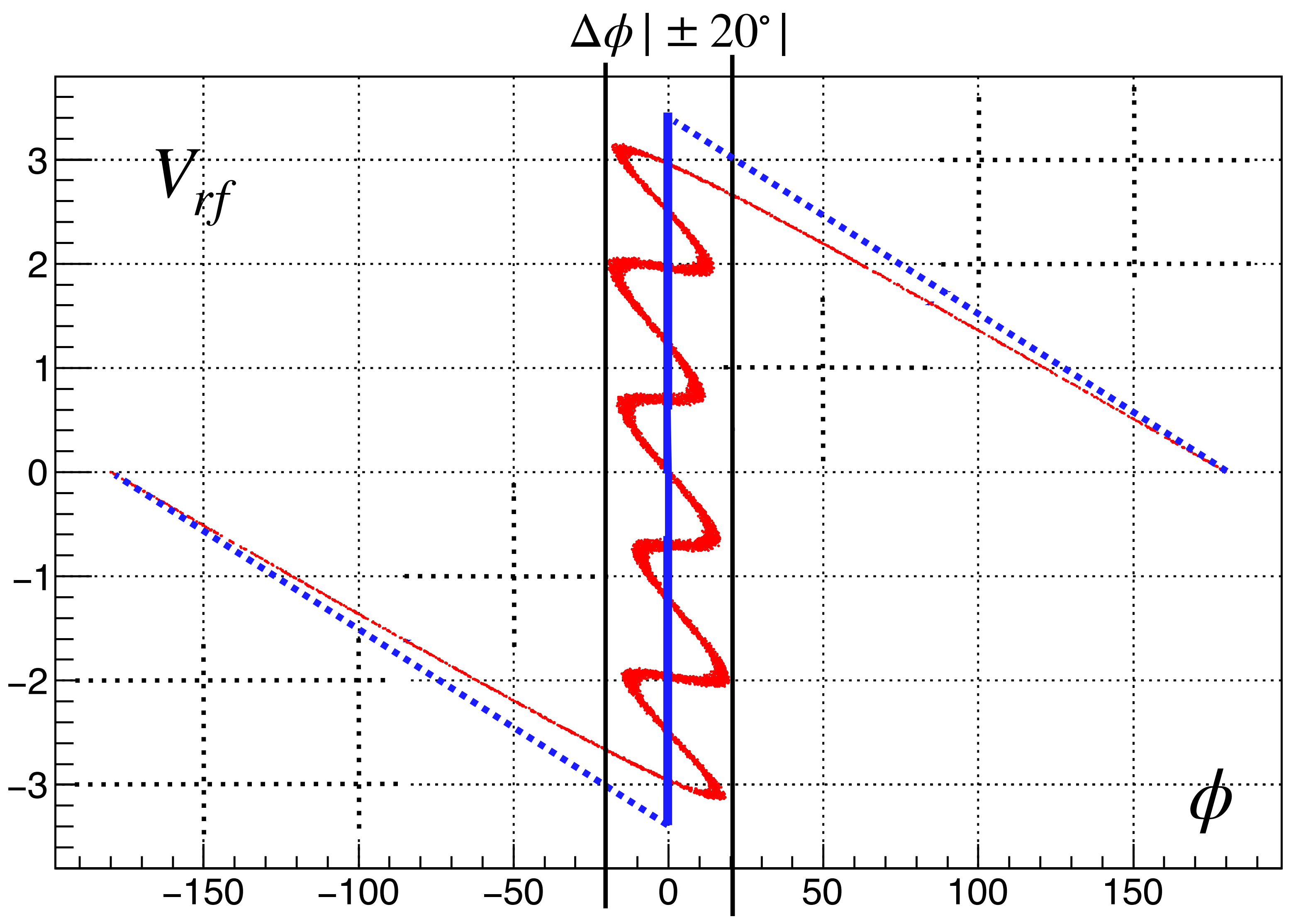
f + 2f + 3f



f + 2f + 3f + 4f



f + 2f + 3f + 4f + 5f



f + 2f + 3f + 4f + 5f + drift

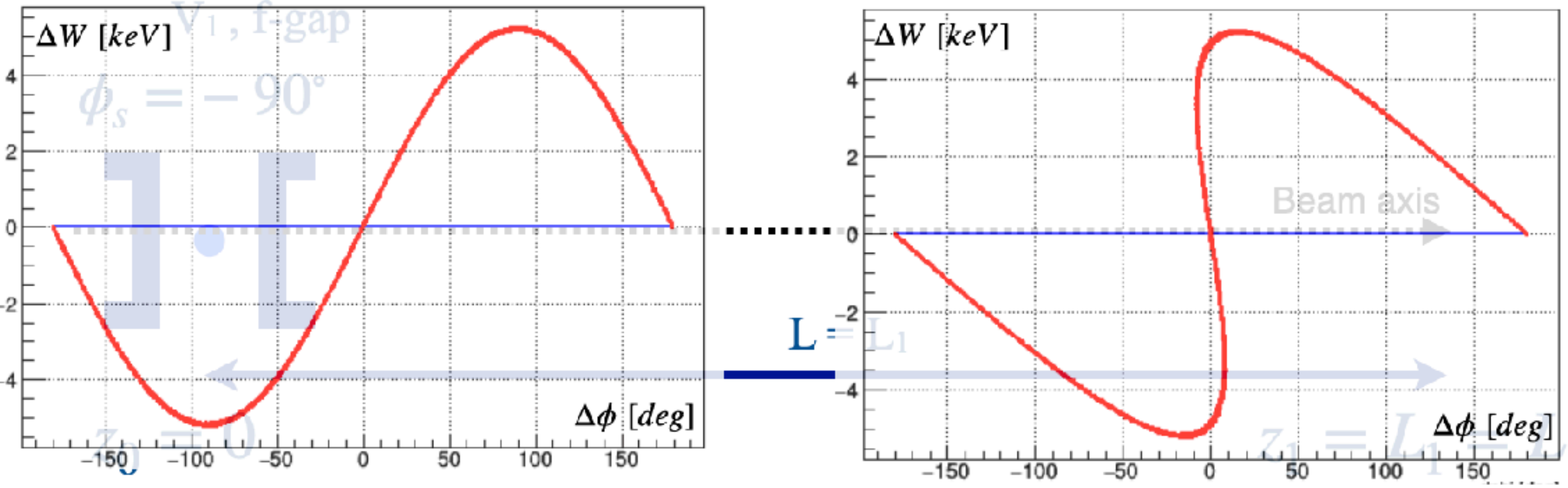
One-Harmonic Double Drift Buncher System

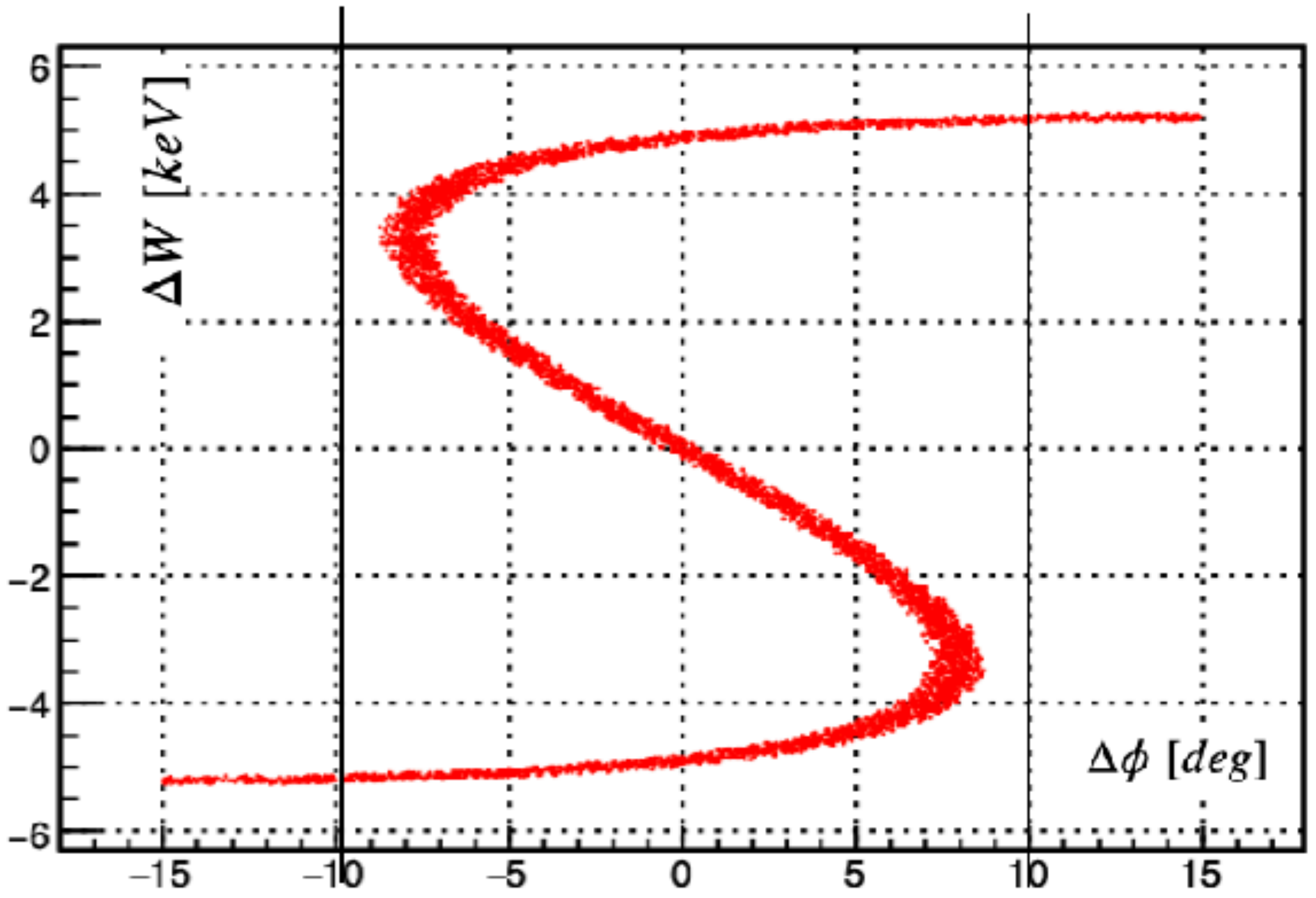
Vs

Double Drift Harmonic Buncher Concept (DDHB)

One Harmonic Double-Drift Buncher

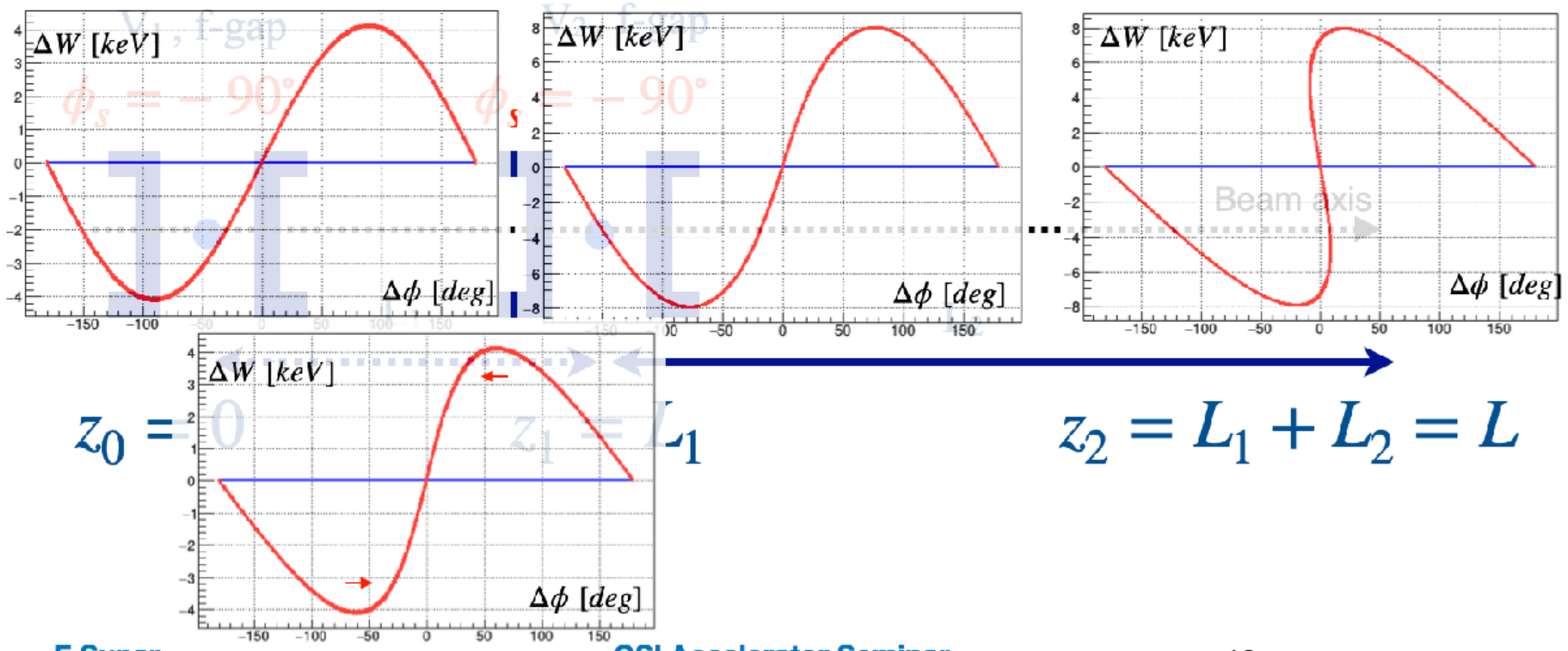
One single f-buncher



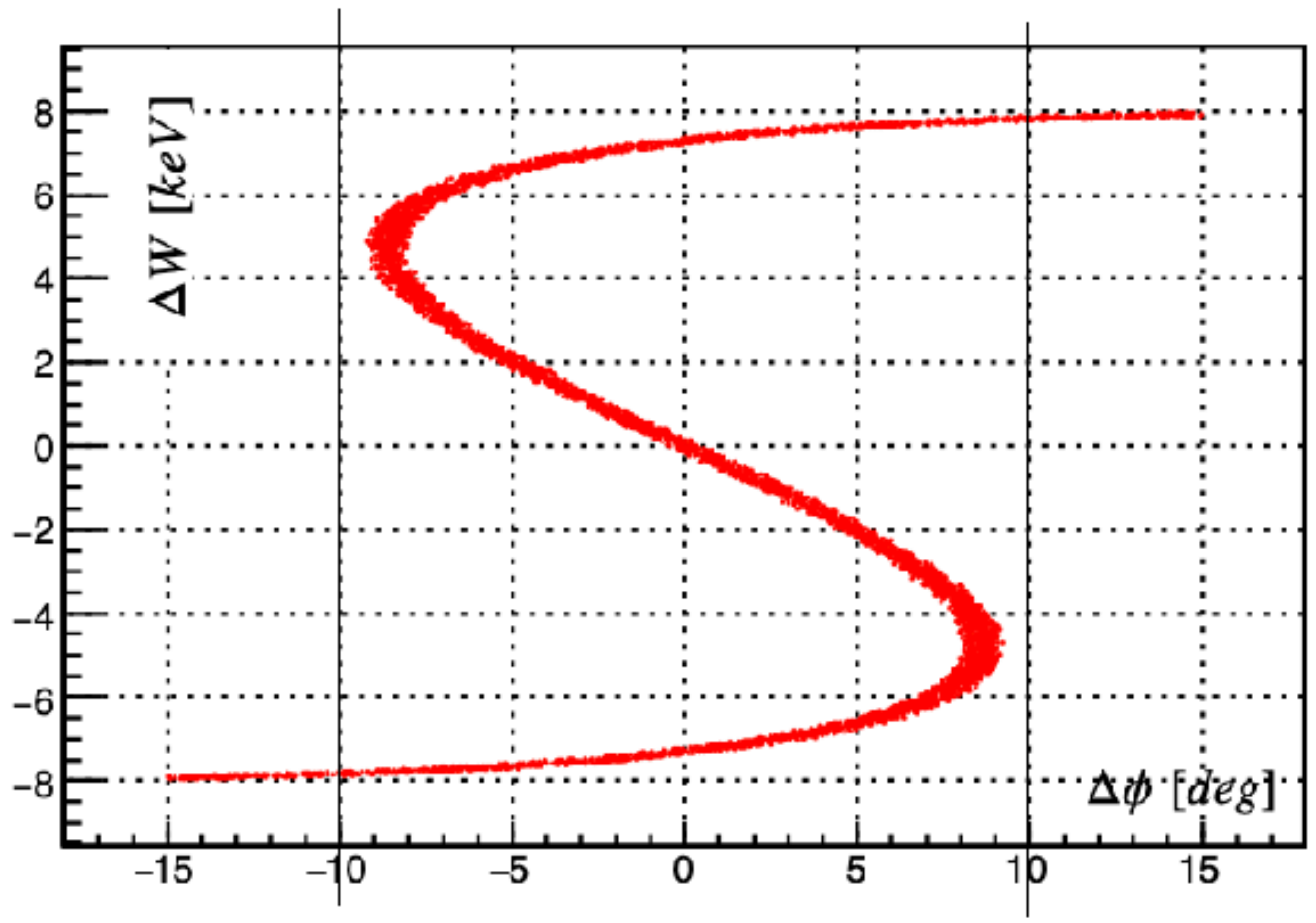


$|\Delta\phi| \leq 10^\circ \rightarrow 46.4\,\%$

Two single f-buncher

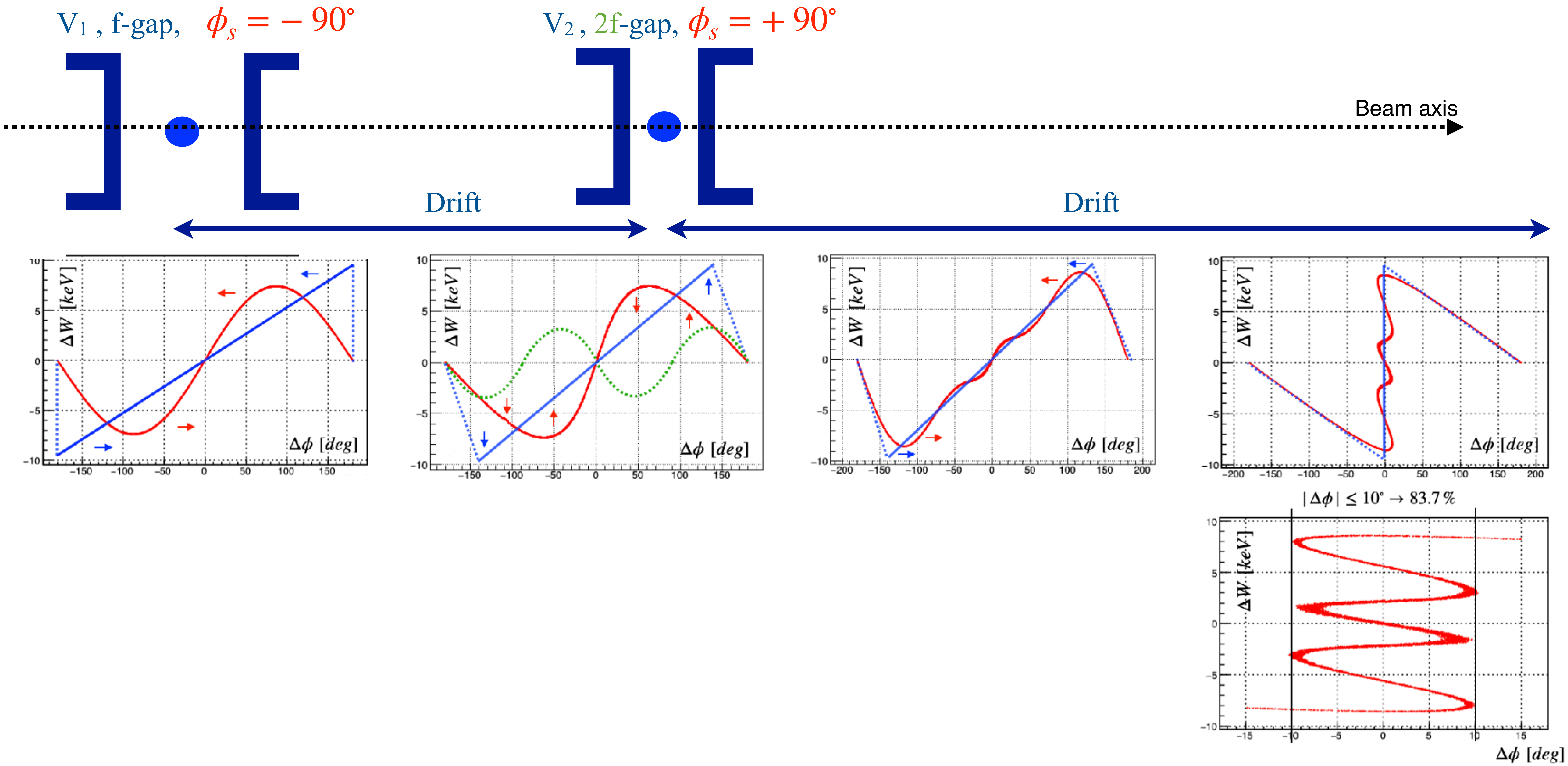


$z_2 = L_1 + L_2 = L$



$|\Delta\phi| \leq 10^\circ \rightarrow 52.7\,\%$

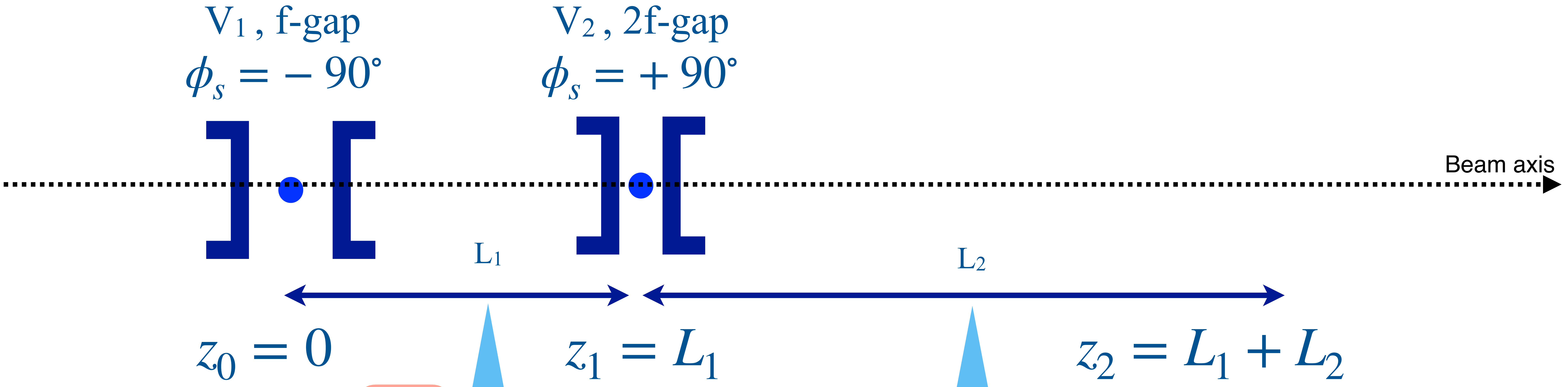
Double Drift Harmonic Buncher Concept



Double Drift Harmonic Buncher Concept

$$\Delta W_i\left(\Delta\phi_i(z_0)\right) = q\,.\,V_1\,.\,\sin\Delta\phi_i(z_0)$$

$$\Delta W_i\left(\Delta\phi_i(z_1)\right) = \Delta W_i\left(\Delta\phi_i(z_0)\right) - q\,.\,V_2\,.\,\sin\left(2\Delta\phi_i(z_1)\right)$$

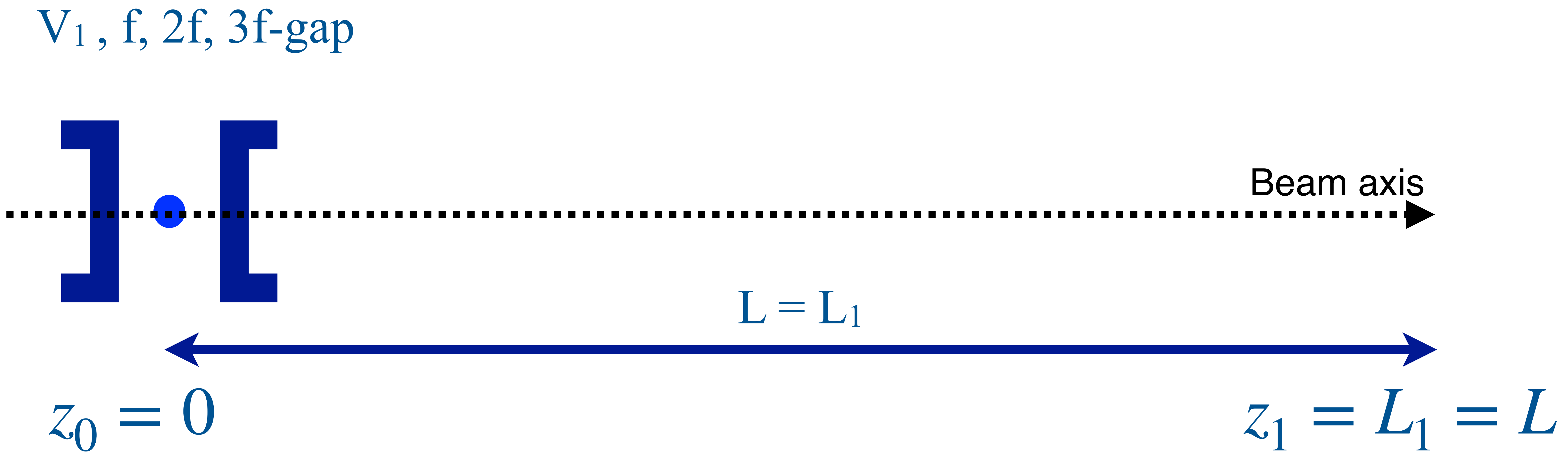


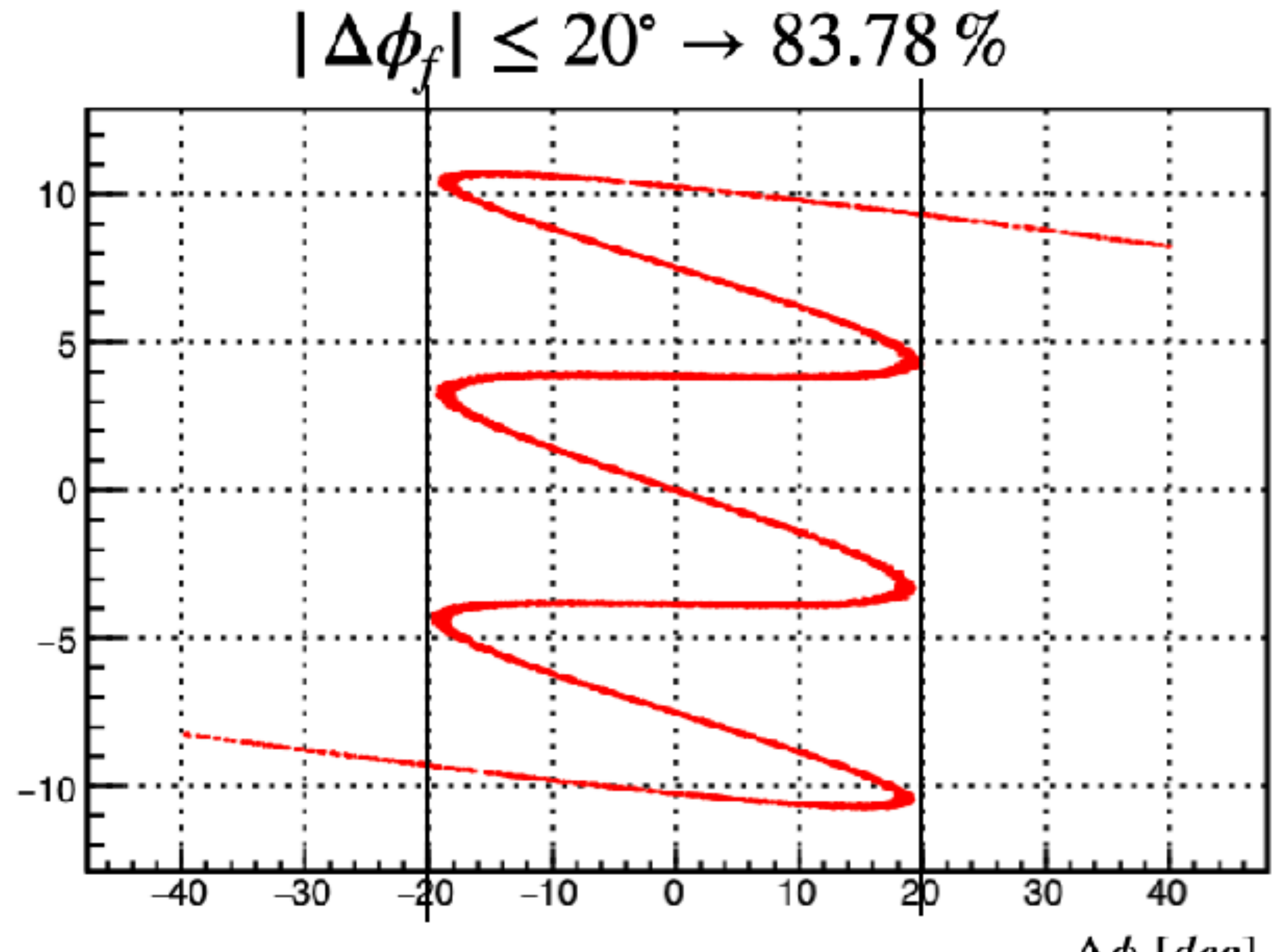
$$\Delta\phi_i(z_1) = \Delta\phi_i(z_0) - \frac{\omega\,.\,L_1}{\beta_s^3\gamma_s^2 c}\,.\,\frac{\Delta W_i\left(\Delta\phi_i(z_0)\right)}{W_s}$$

$$\Delta\phi_i(z_2) = \Delta\phi_i(z_1) - \frac{\omega\,.\,L_2}{\beta_s^3\gamma_s^2 c}\,.\,\frac{\Delta W_i\left(\Delta\phi_i(z_1)\right)}{W_s}$$

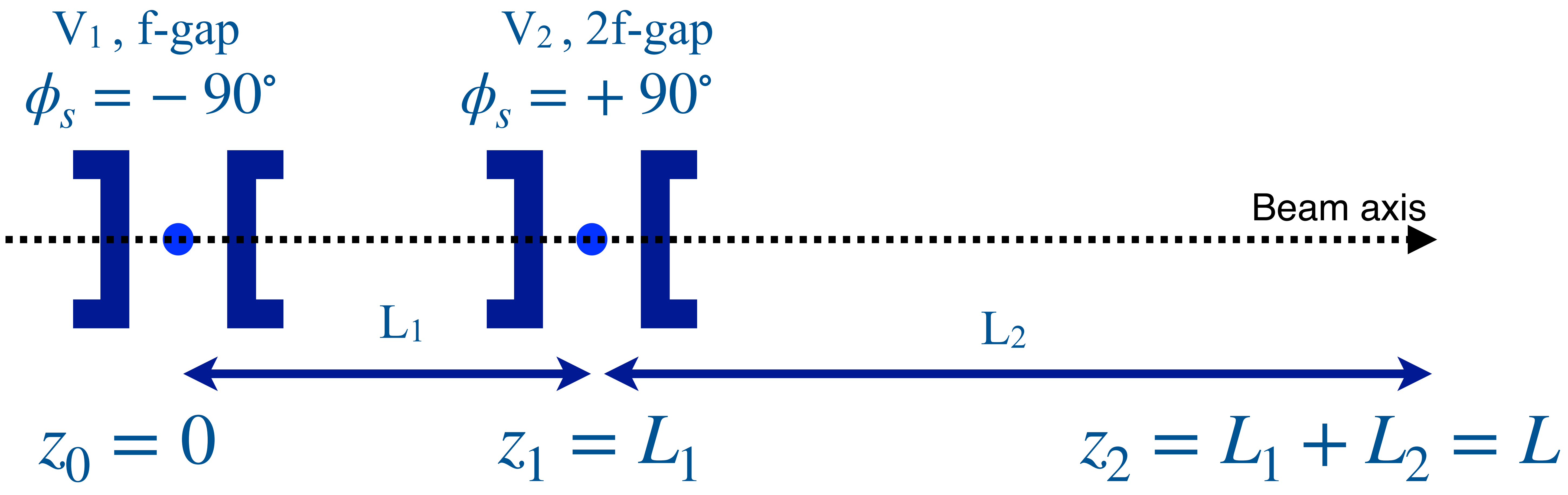
Comparison of Two Multi-Harmonic Systems

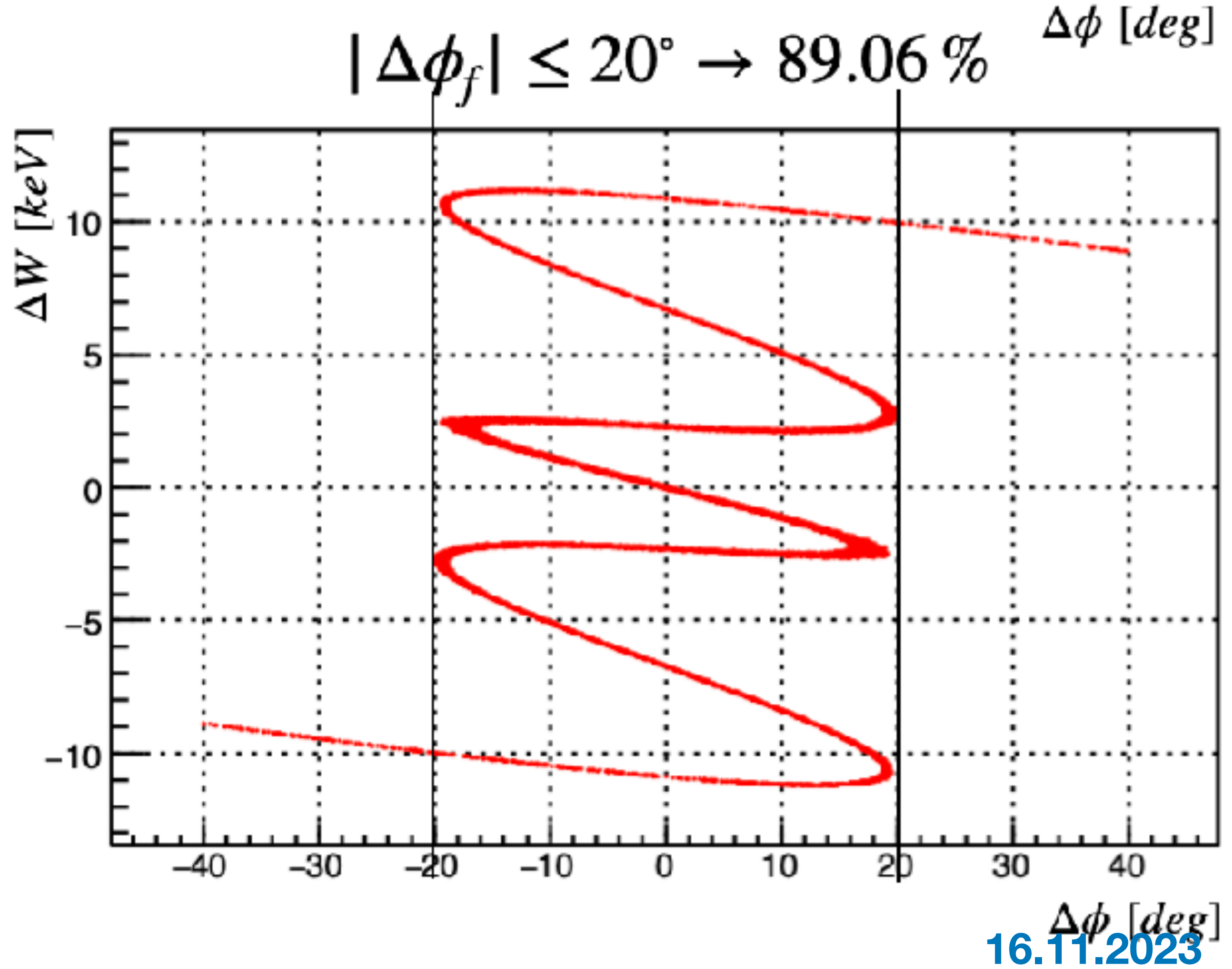
Triple Harmonics System: Overlapped Harmonics



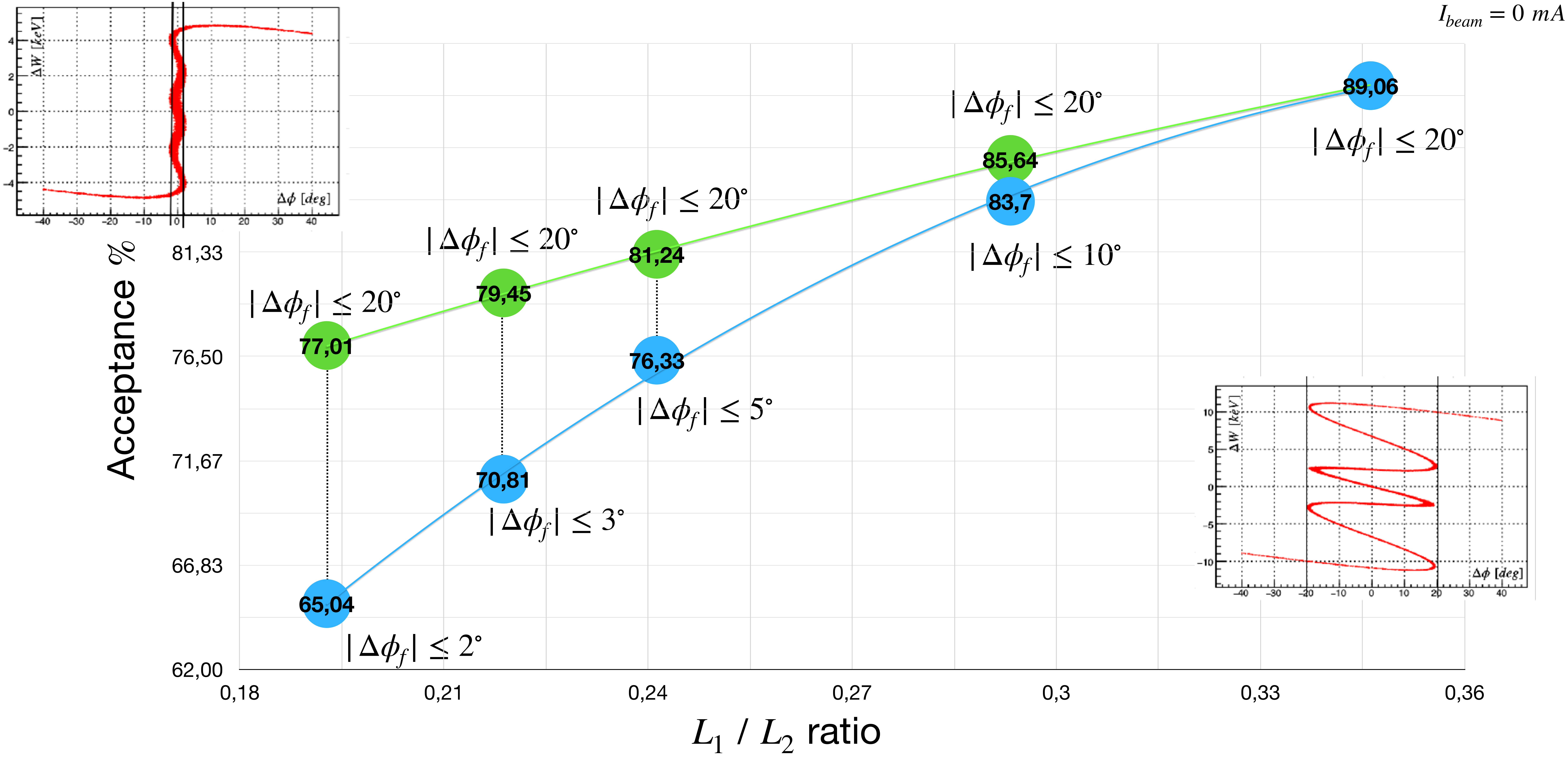


DDHB System





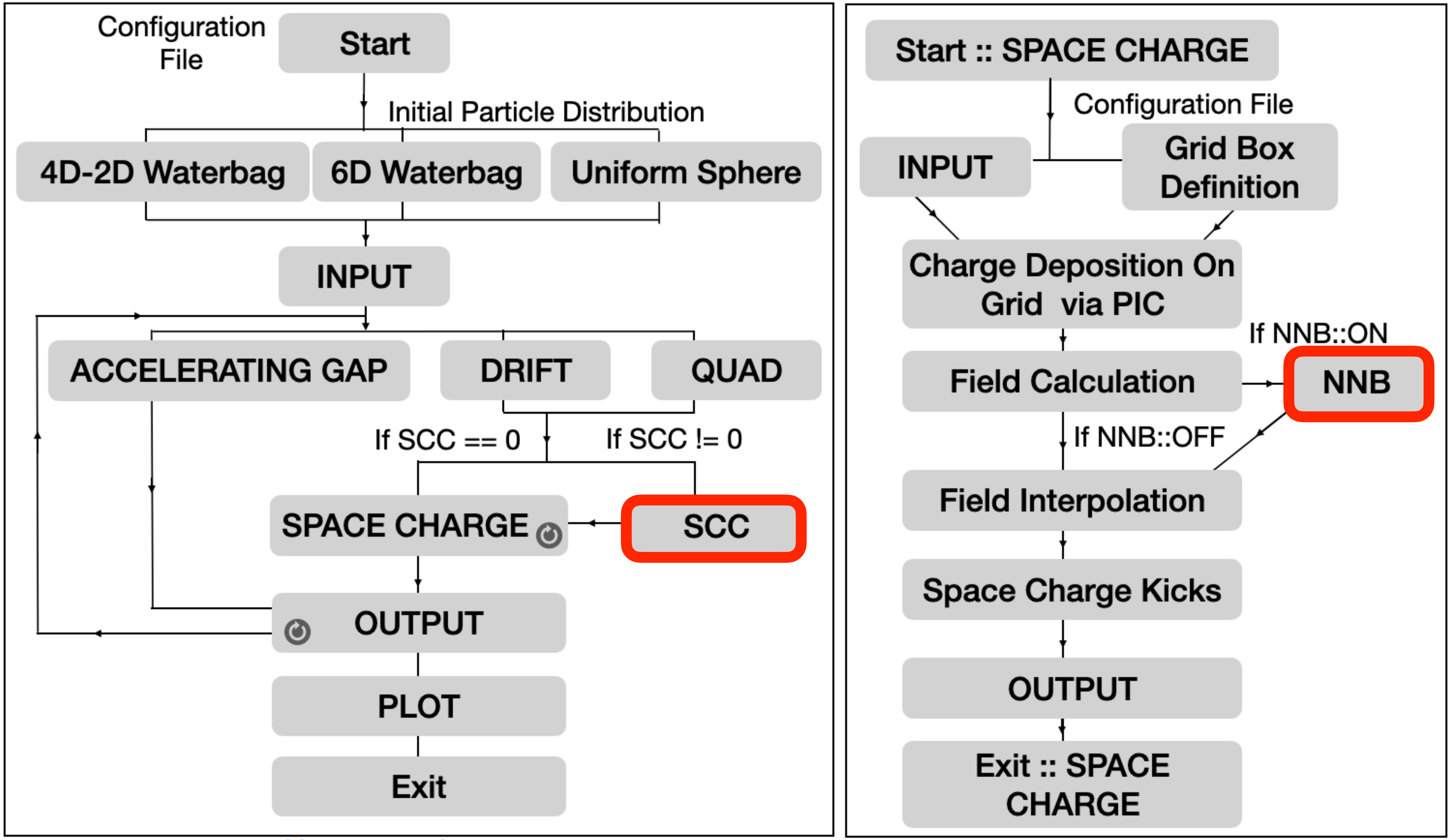
Dependence Of 4-Parameters In DDHB Concept



Beam Creation for DC beam

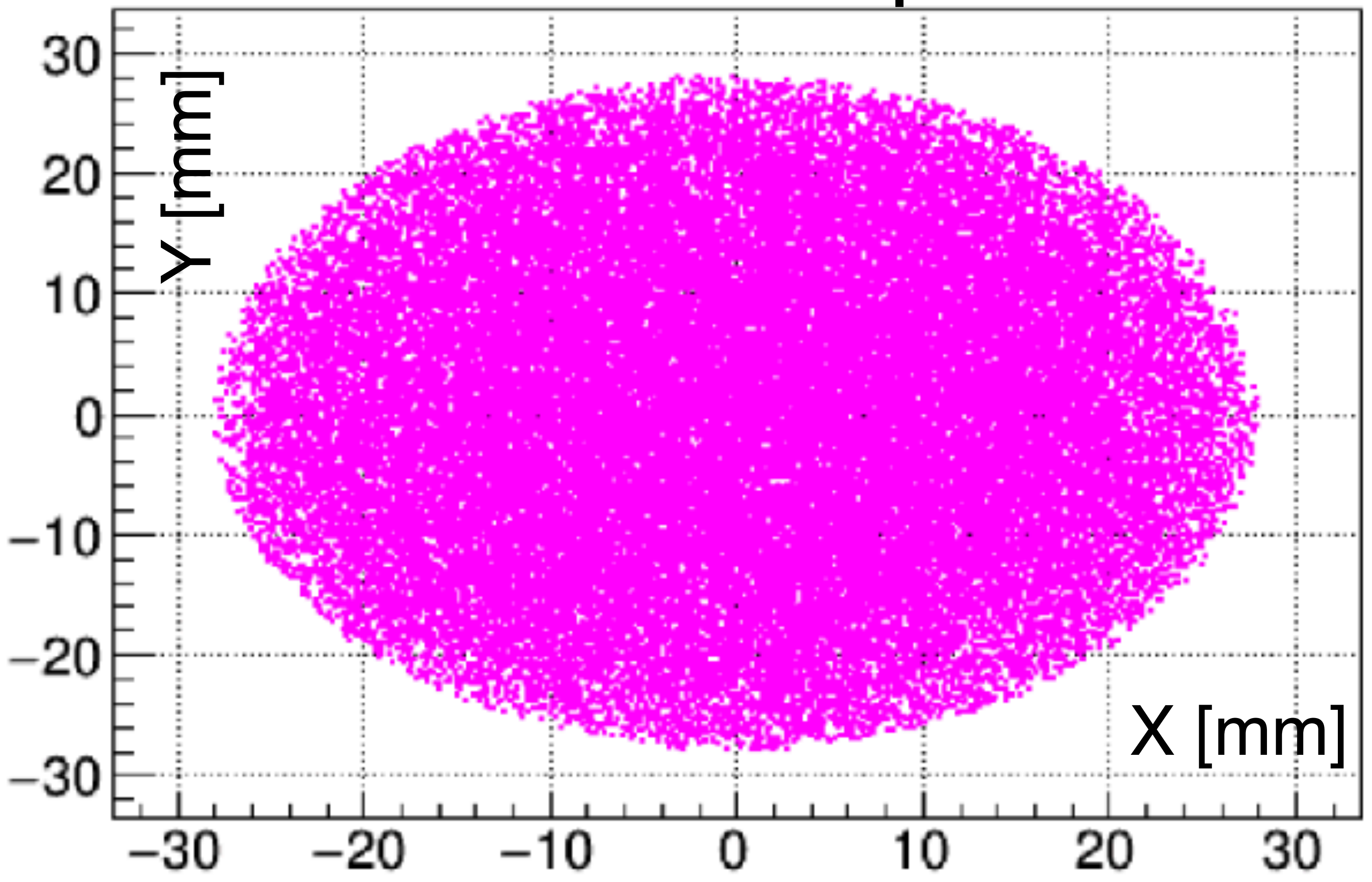
BCDC

Chart of BCDC

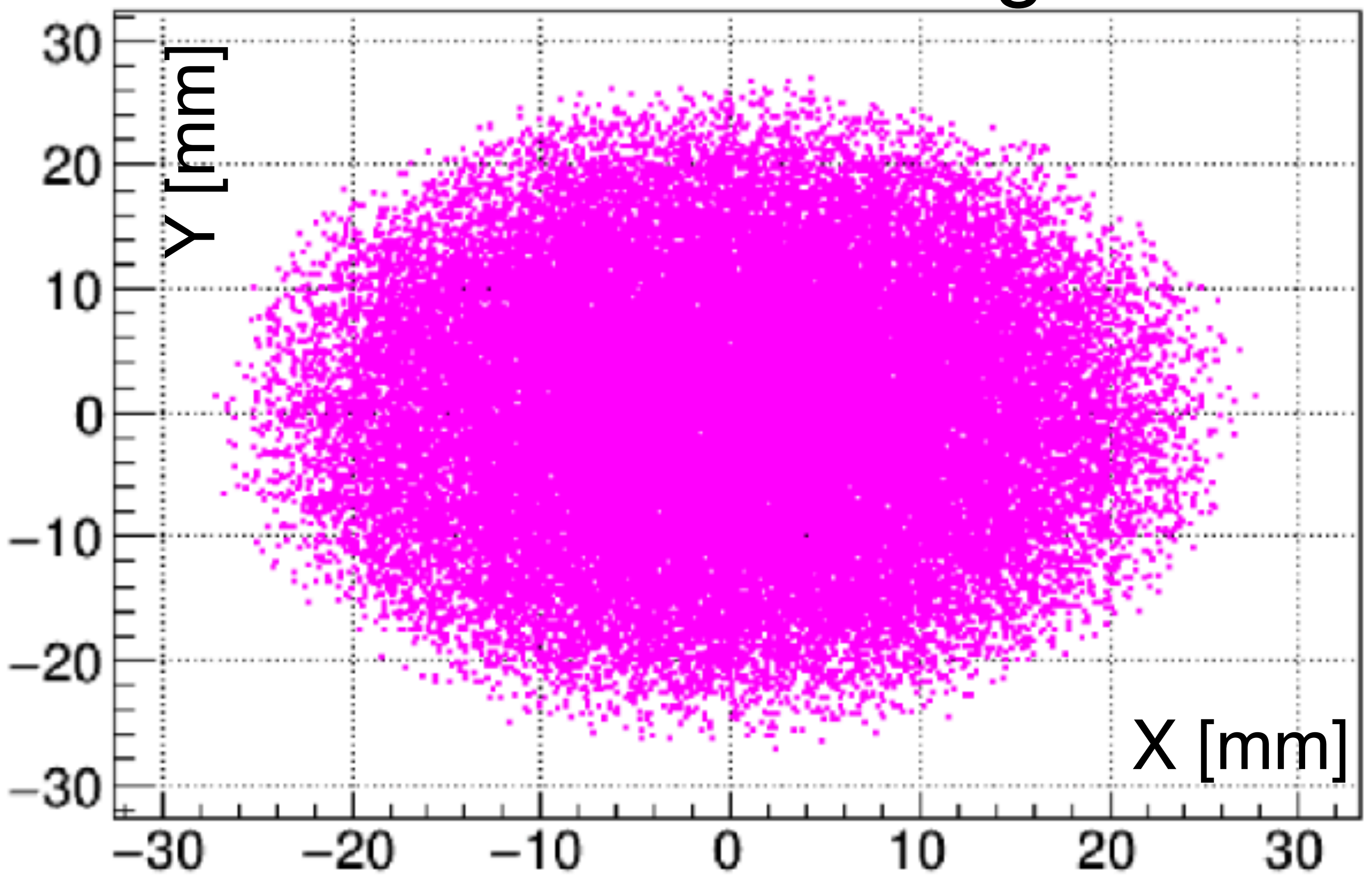


Space Charge Calculation: Particle Distributions

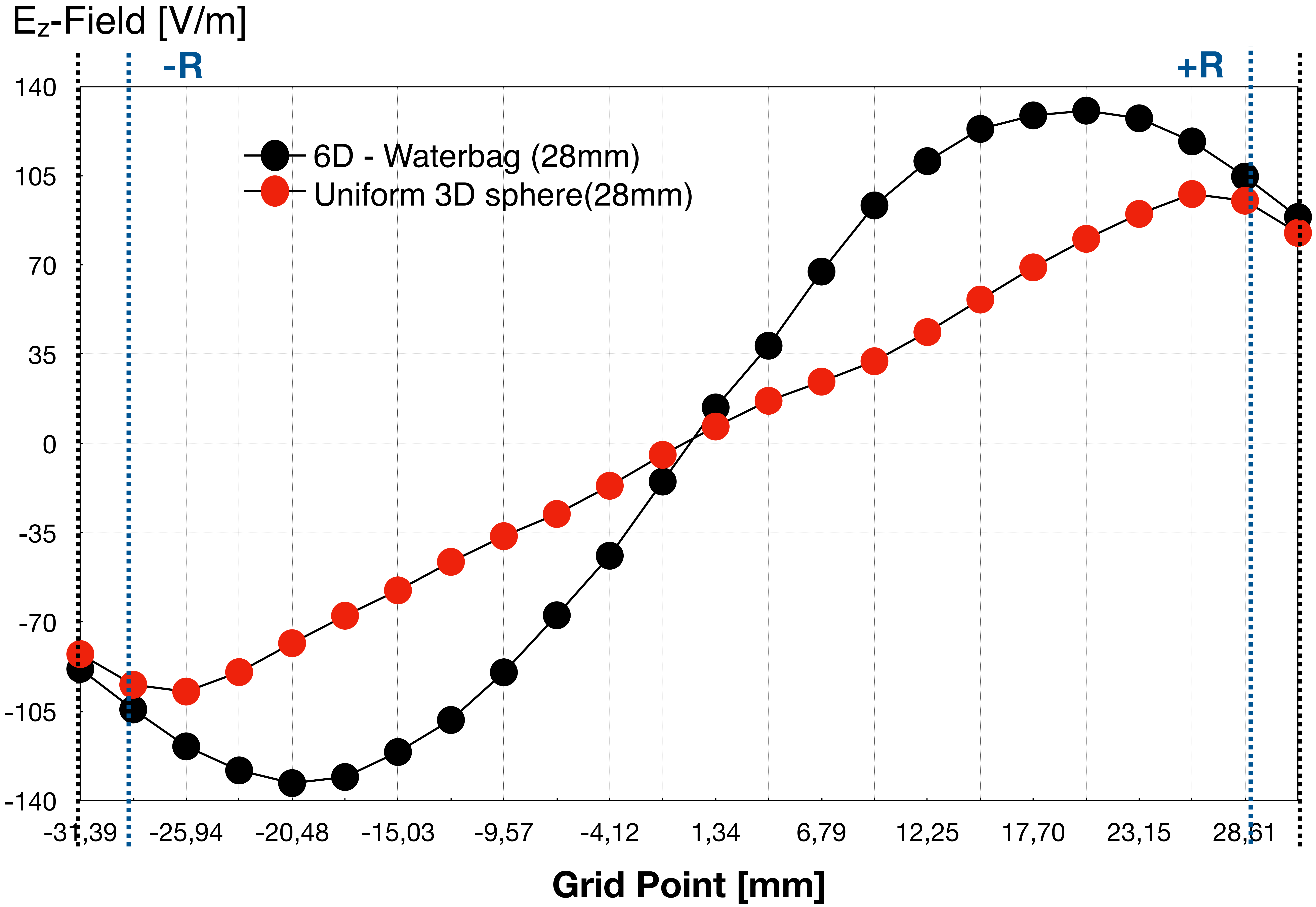
Uniform 3D sphere



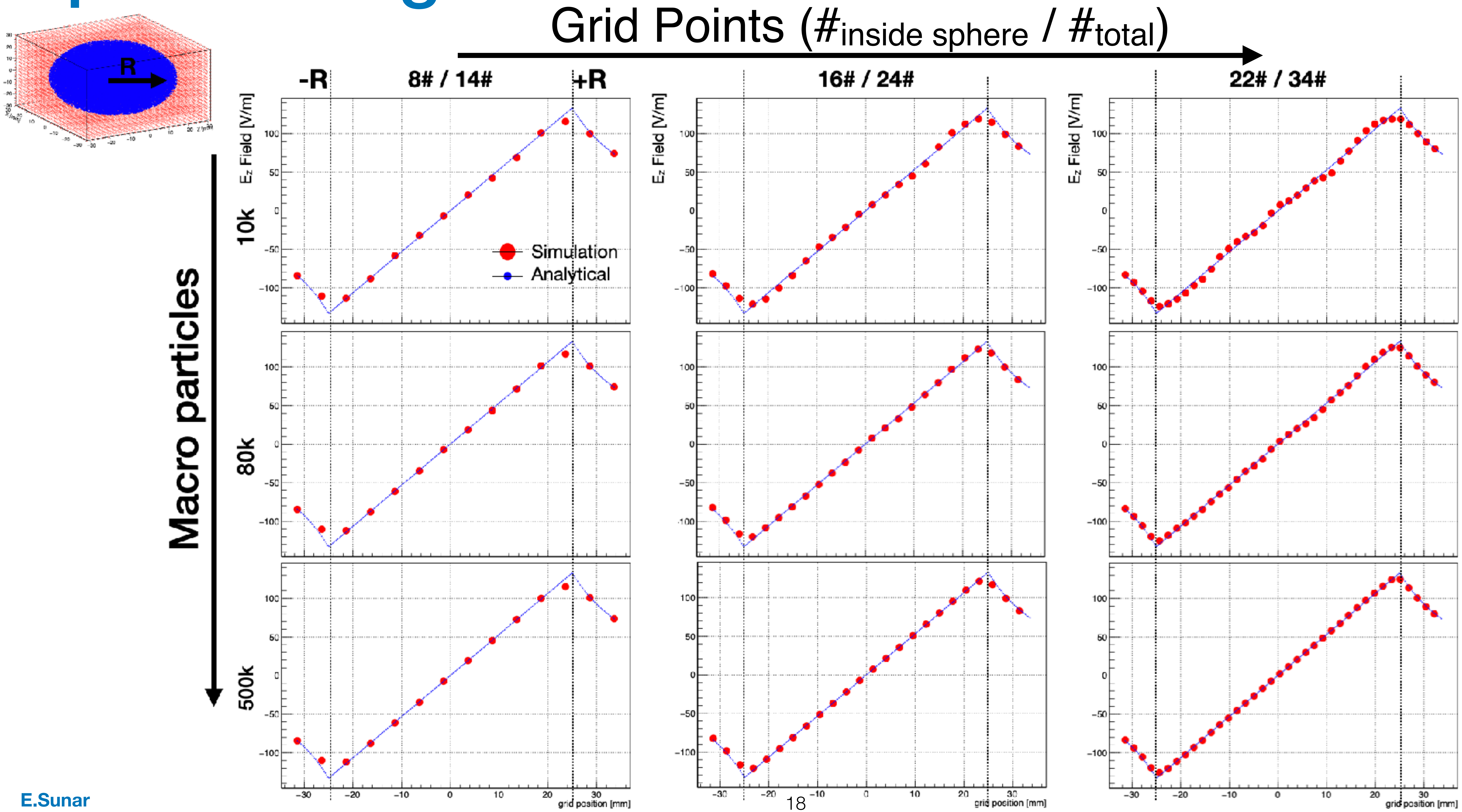
6D - Waterbag



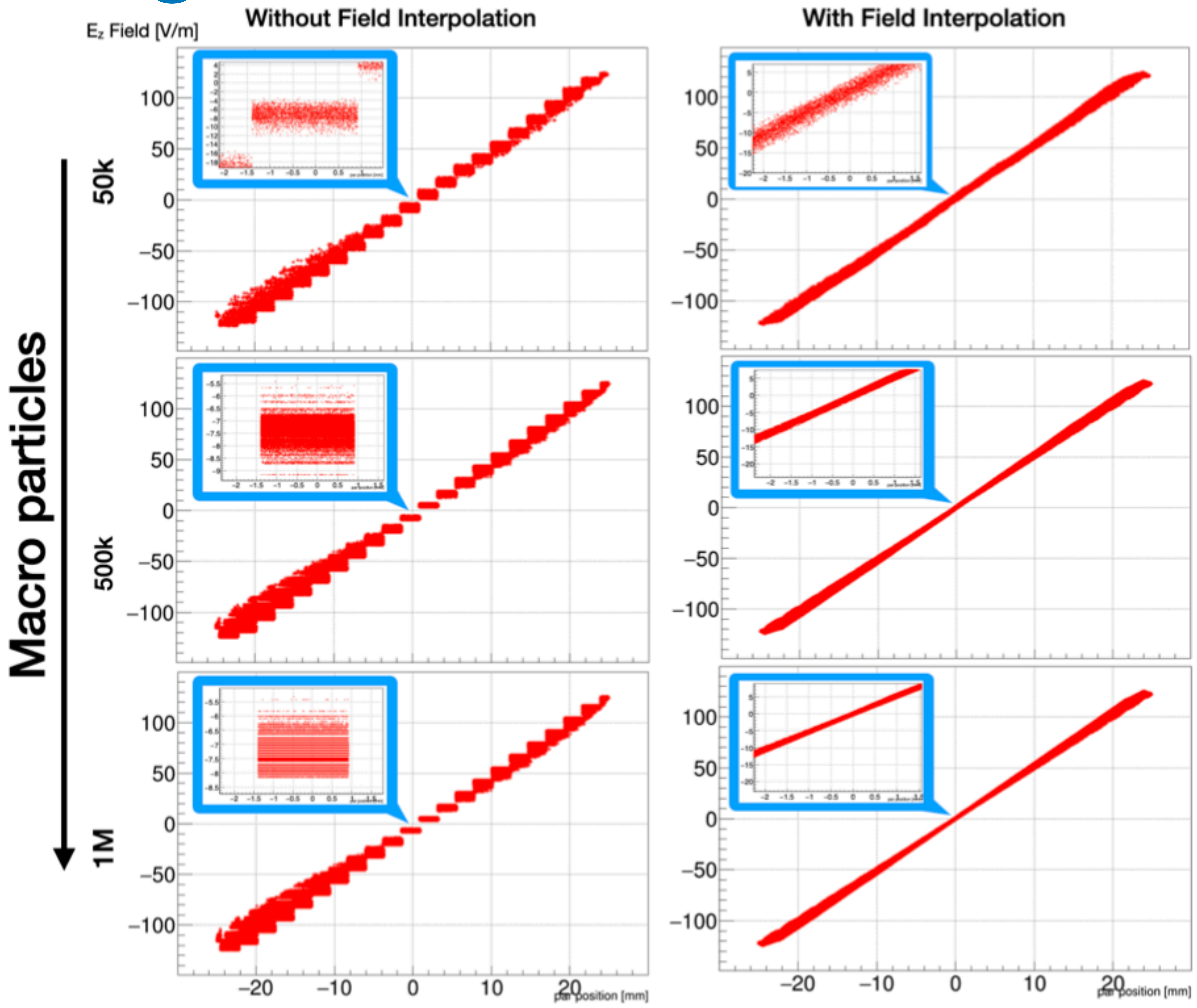
$I_{beam} = 0.5\ mA$



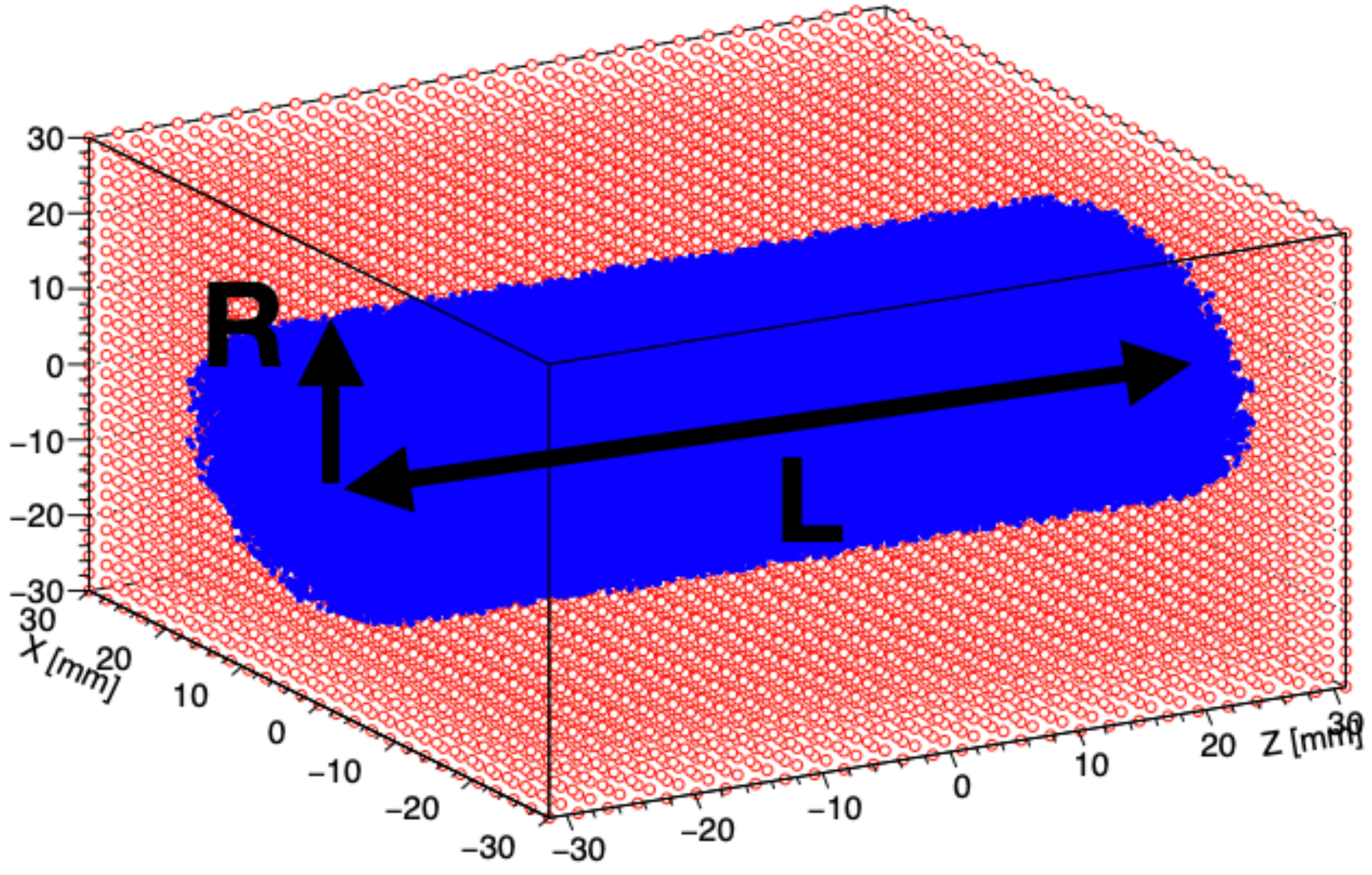
Space Charge Calculation: Dependent Parameters

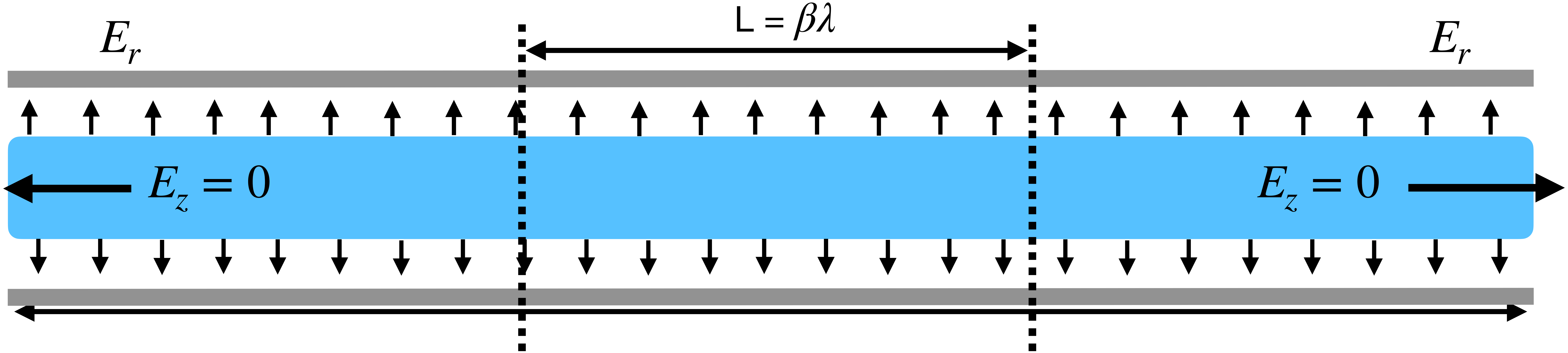


Space Charge Calculation: Field Interpolation

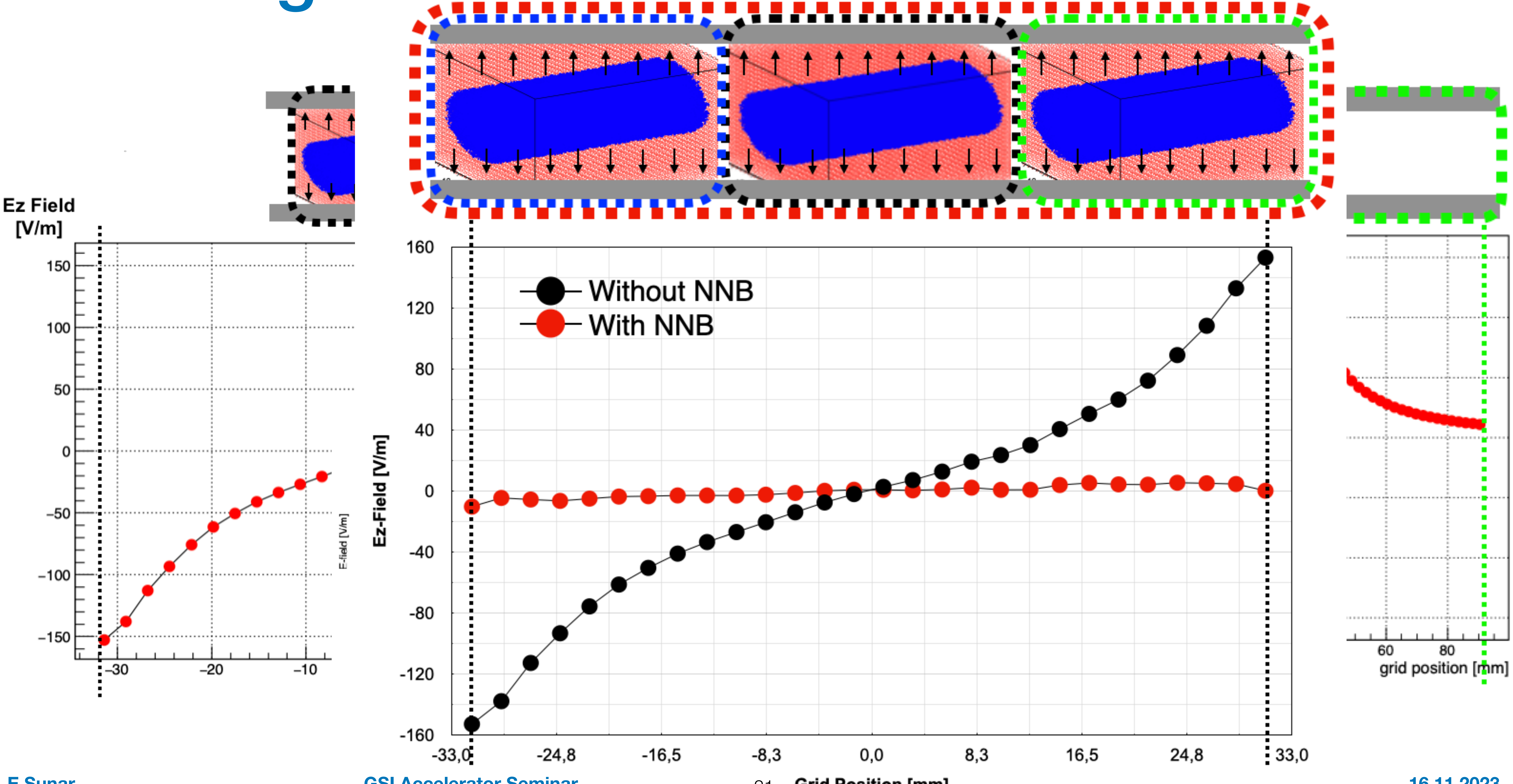


Motivation of NNB in BCDC

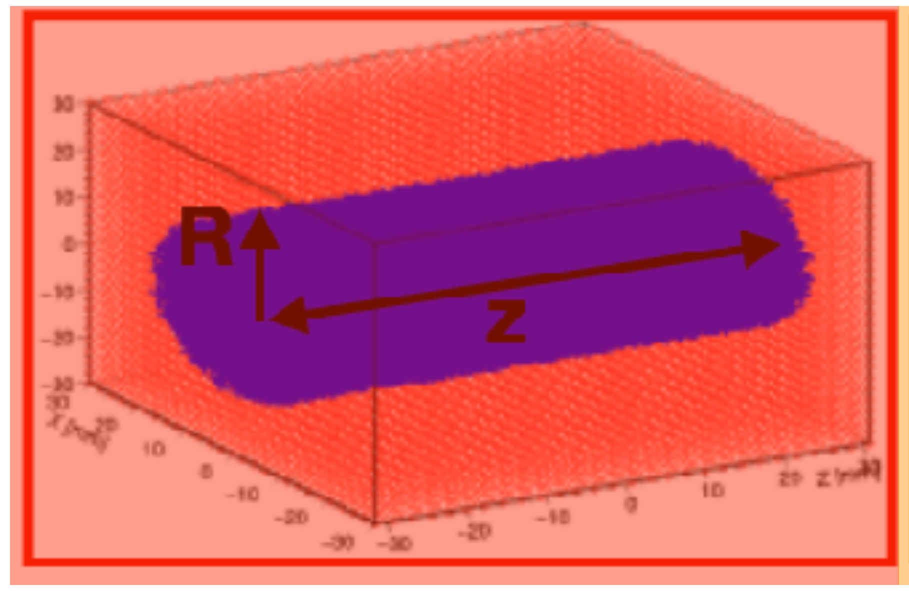




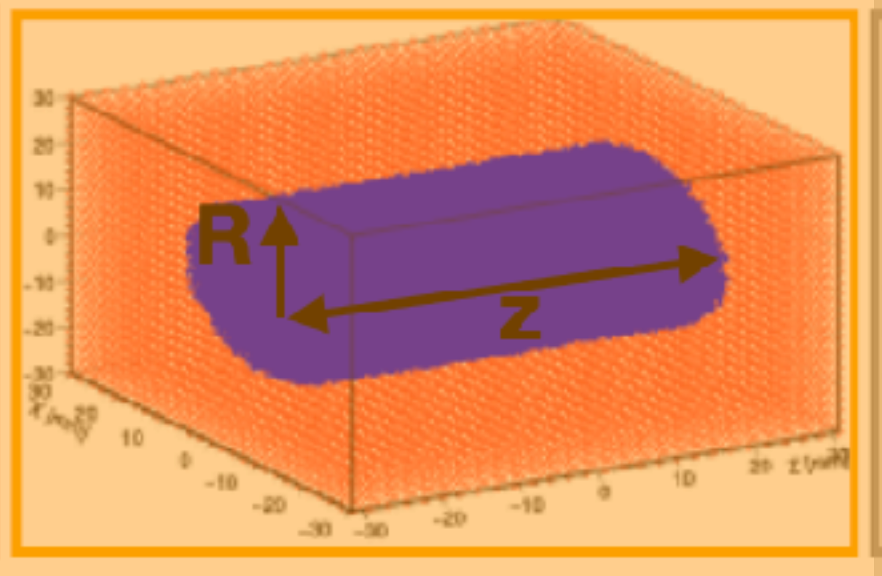
Next Neighbor Bunch - NNB



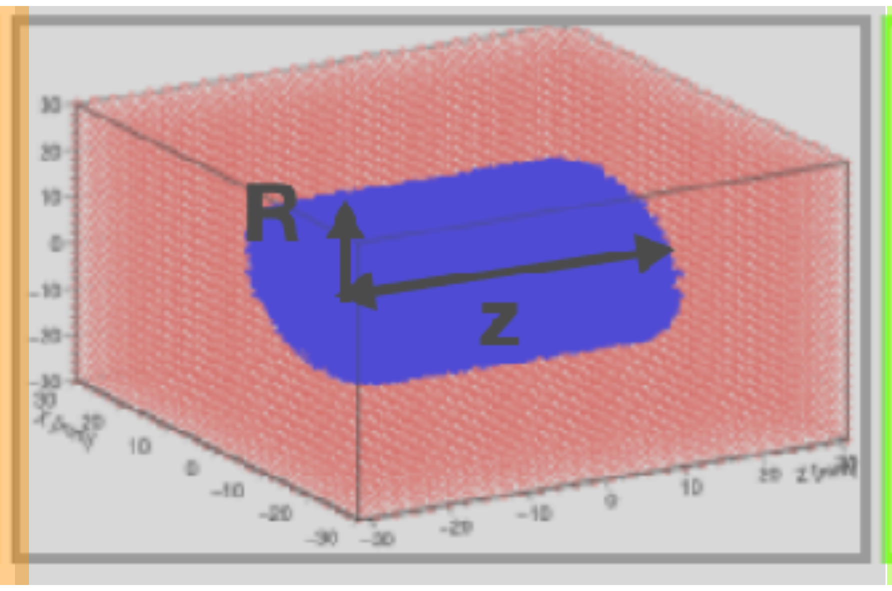
NNB: Results For Various Bunch Lengths



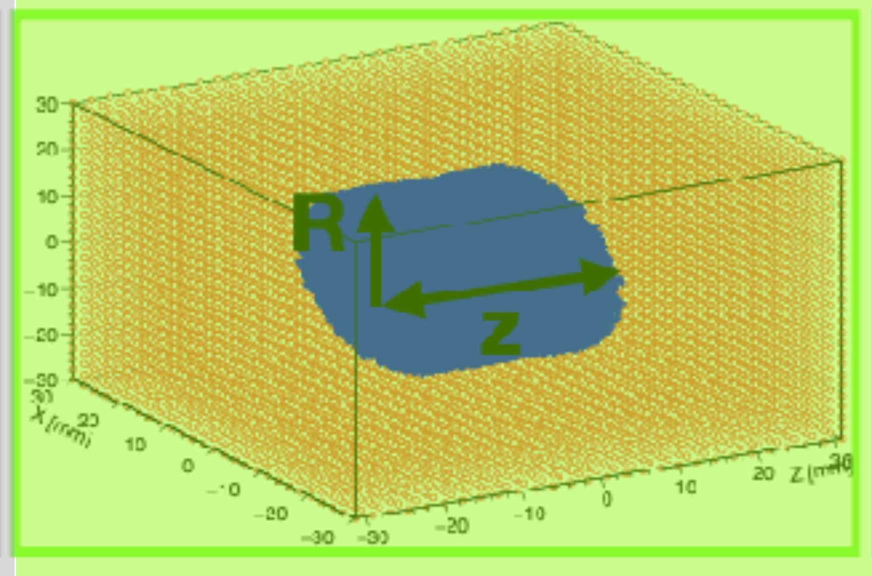
z = 62 mm



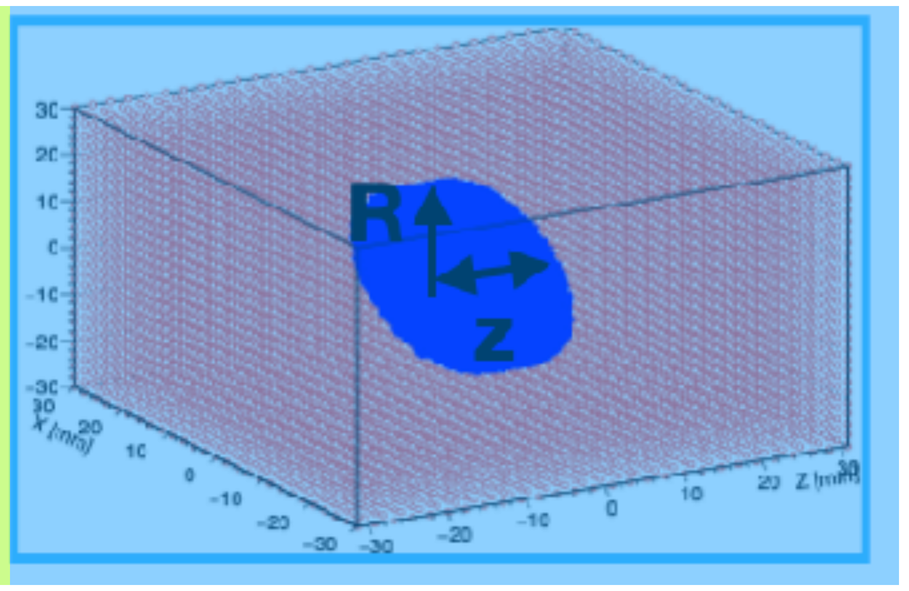
z = 48.2 mm



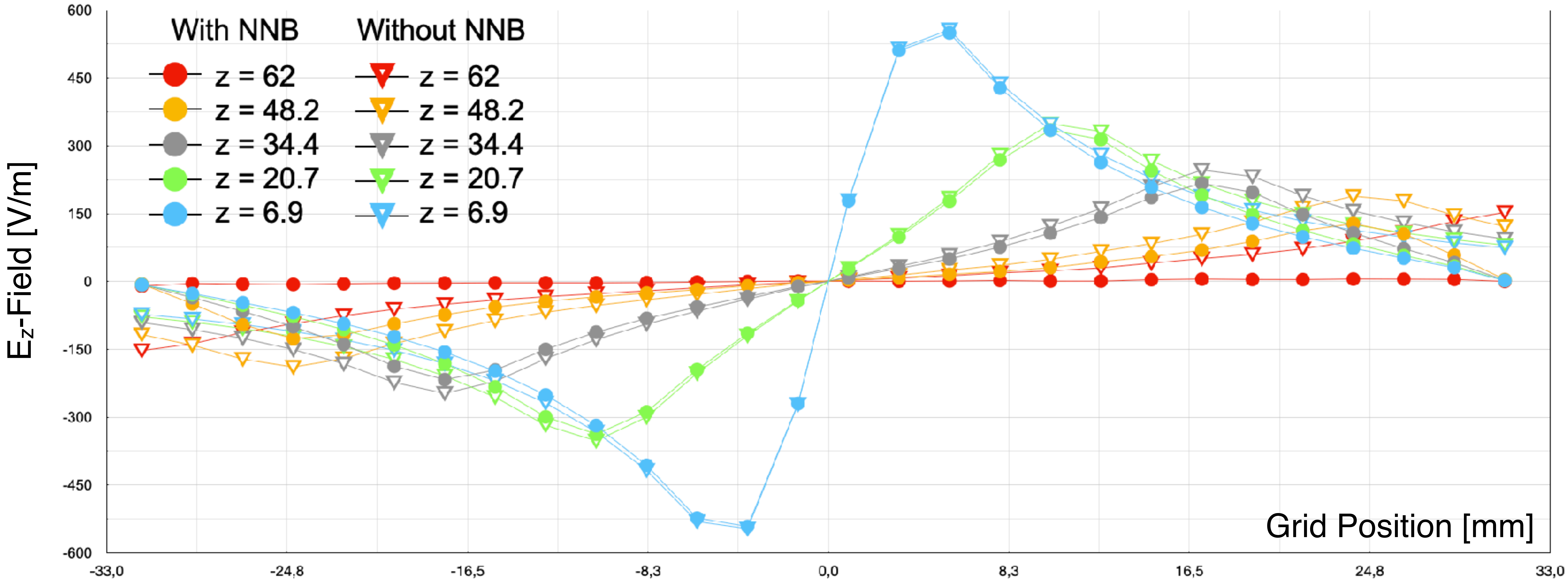
z = 34.4 mm



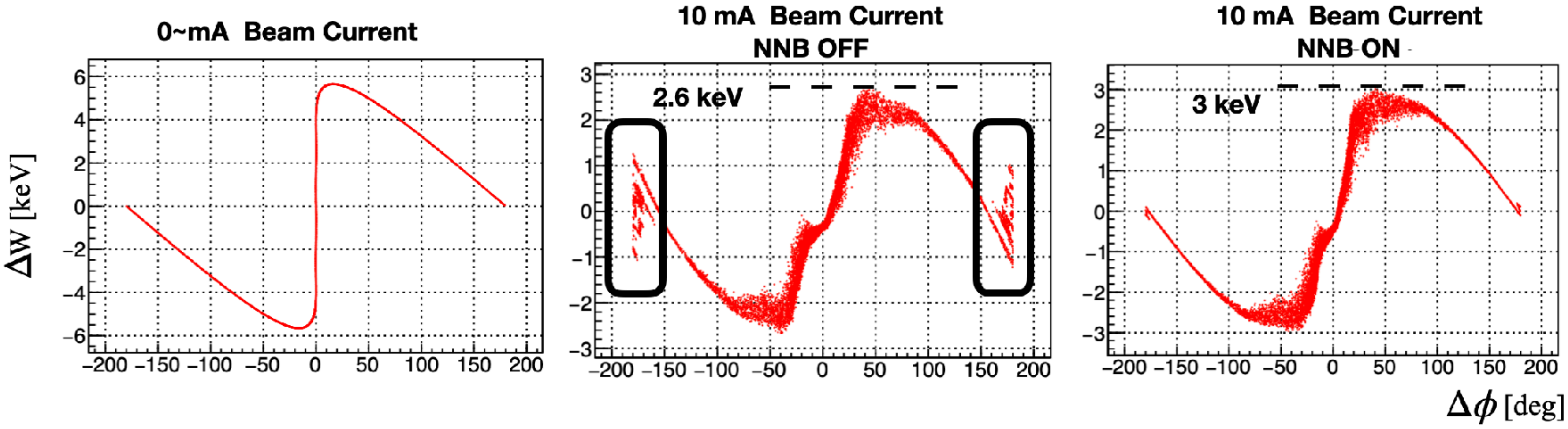
z = 20.7 mm



z = 6.9 mm

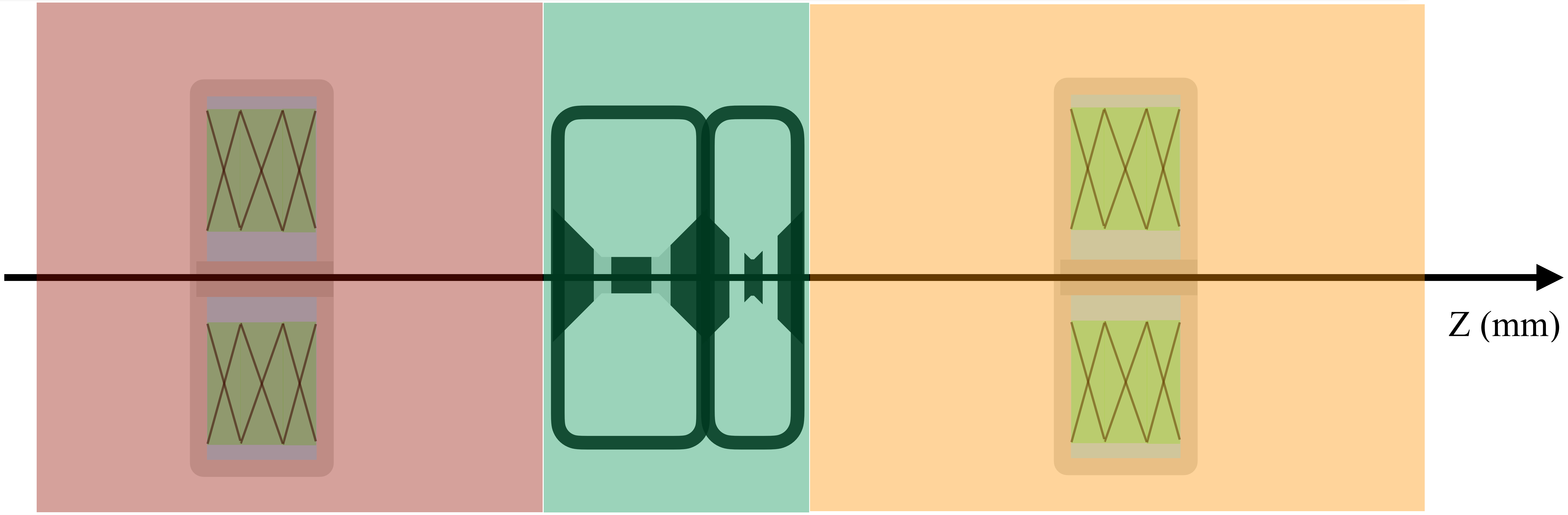


NNB: Output Distributions according to ON / OFF Status



Space Charge Compensation - SCC

	DC - Beam	E-field	Bunch formation
SCC :	**90%**	**0%**	**85%**

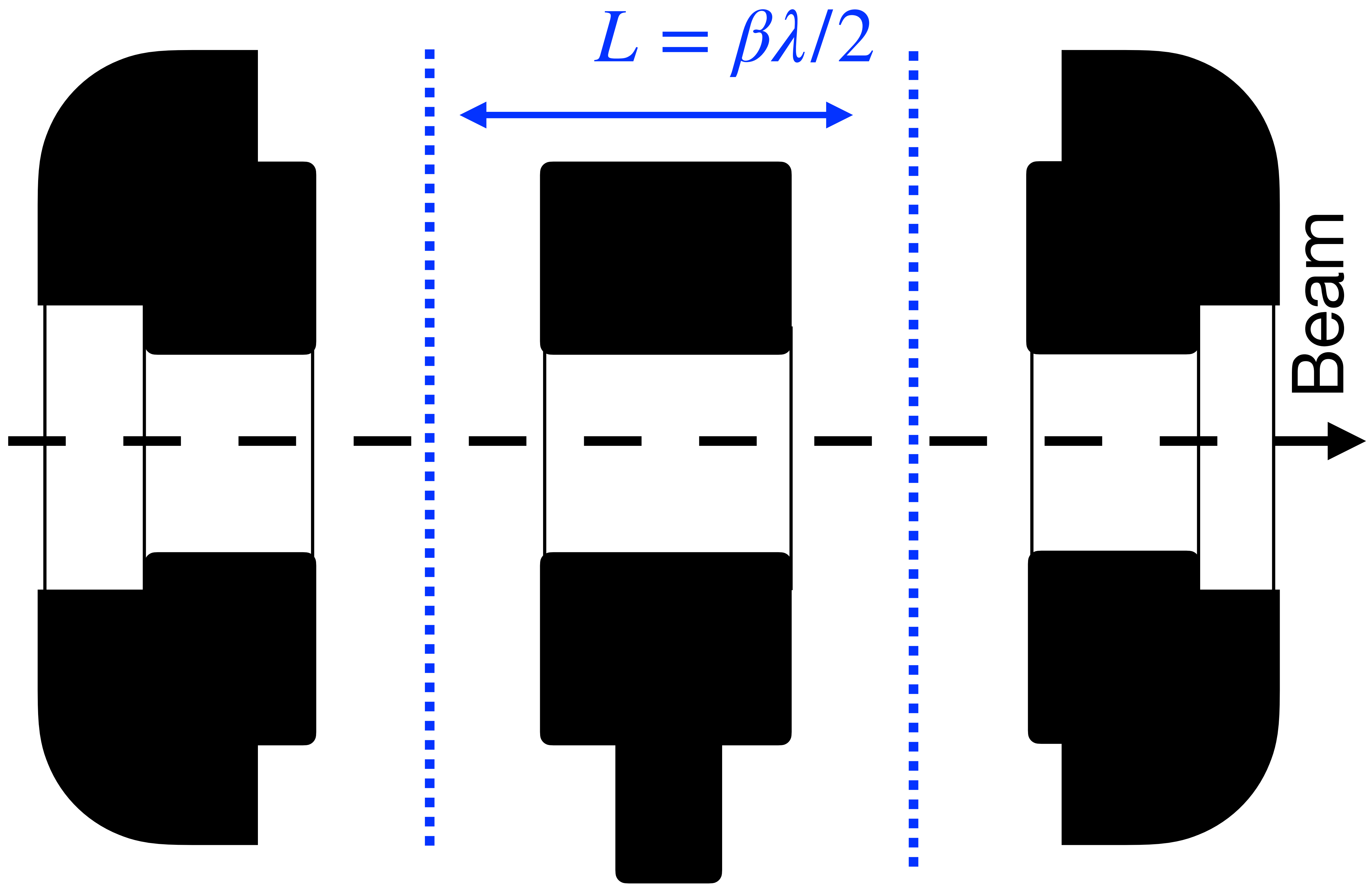


Vacuum Pressure : [mbar]	$\sim 10^{-6}$	$\sim 10^{-7}, 10^{-8}$

APPLICATIONS

Parameter Range for Applications :

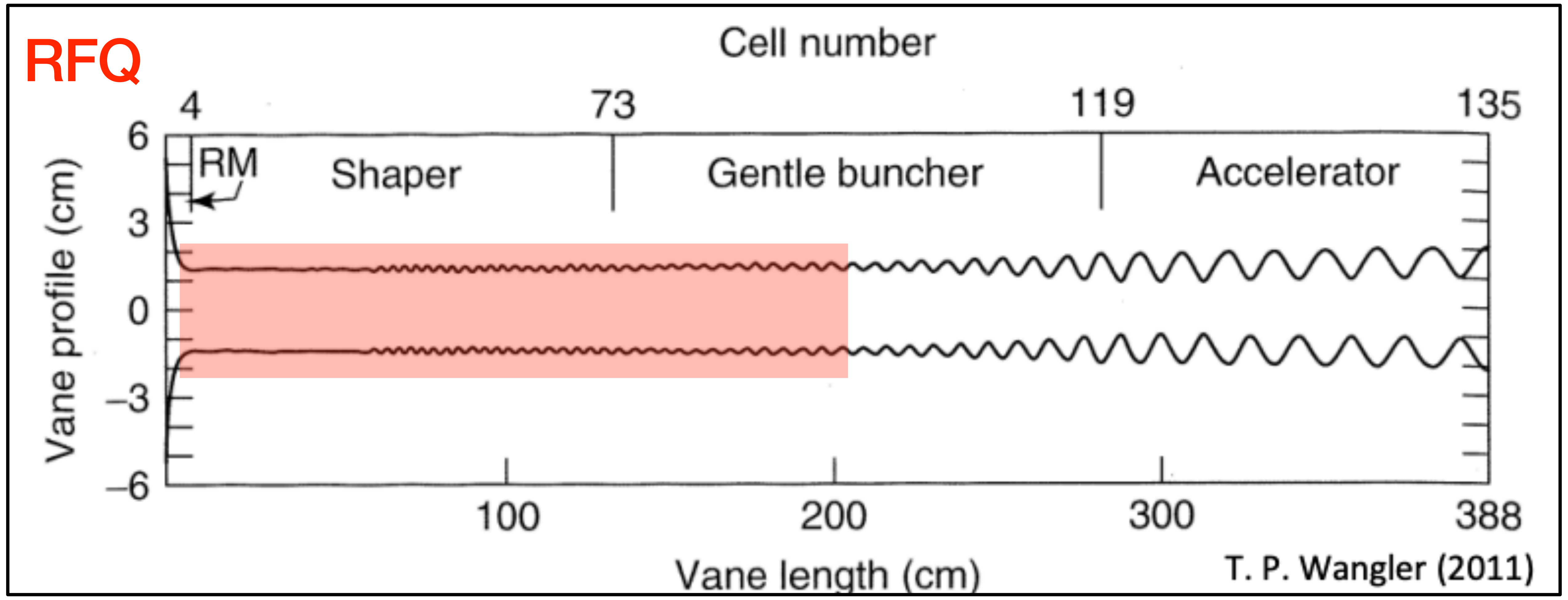
Input Energy [keV] \ Frequency [MHz]	$\beta\lambda/2$ [mm]		
	27	54	108
60	63	32	16
100	81	41	21

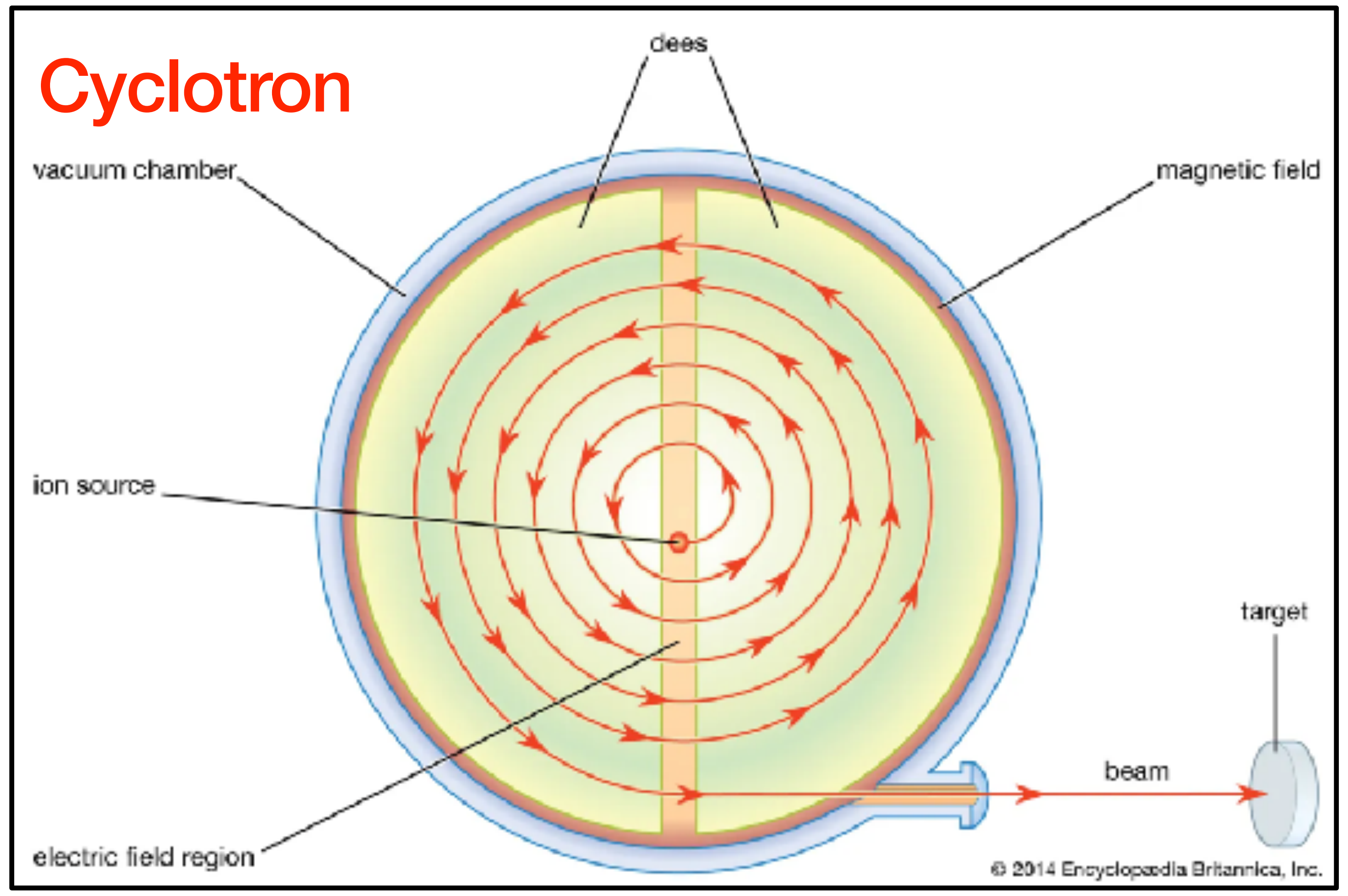


Cavity 1 : f-frequency

Summary of Applications

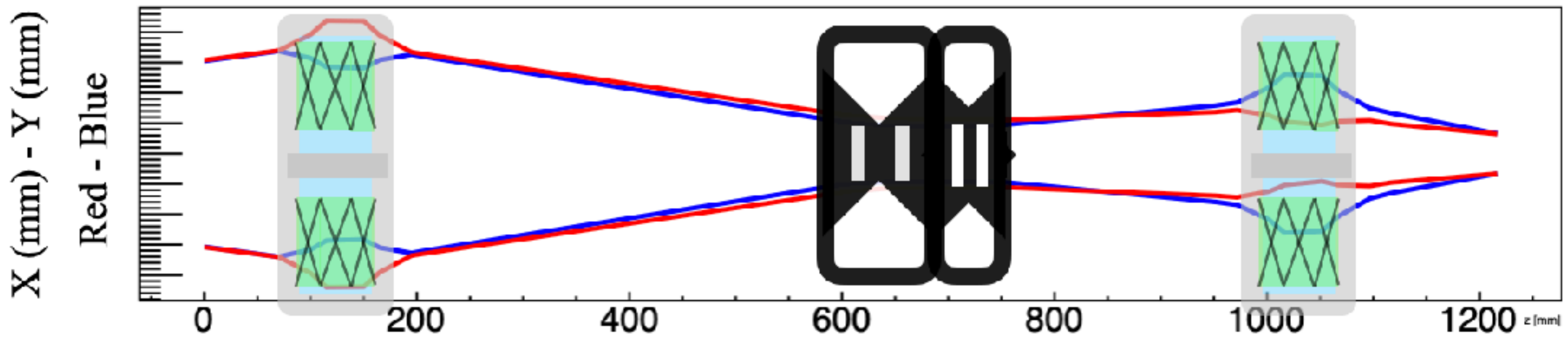
Parameter / Design	Input Energy	Beam Current	Capture Rate	Acceptance Phase [deg]
1	60 keV	0-10 mA	74-80%	$\lvert\Delta\phi\rvert \leq \pm 5^\circ$
2	60 keV	0-30 mA	85 %	$\lvert\Delta\phi\rvert \leq \pm 20^\circ$
3	100 keV	0-1 mA	70-77 %	$\lvert\Delta\phi\rvert \leq \pm 5^\circ$



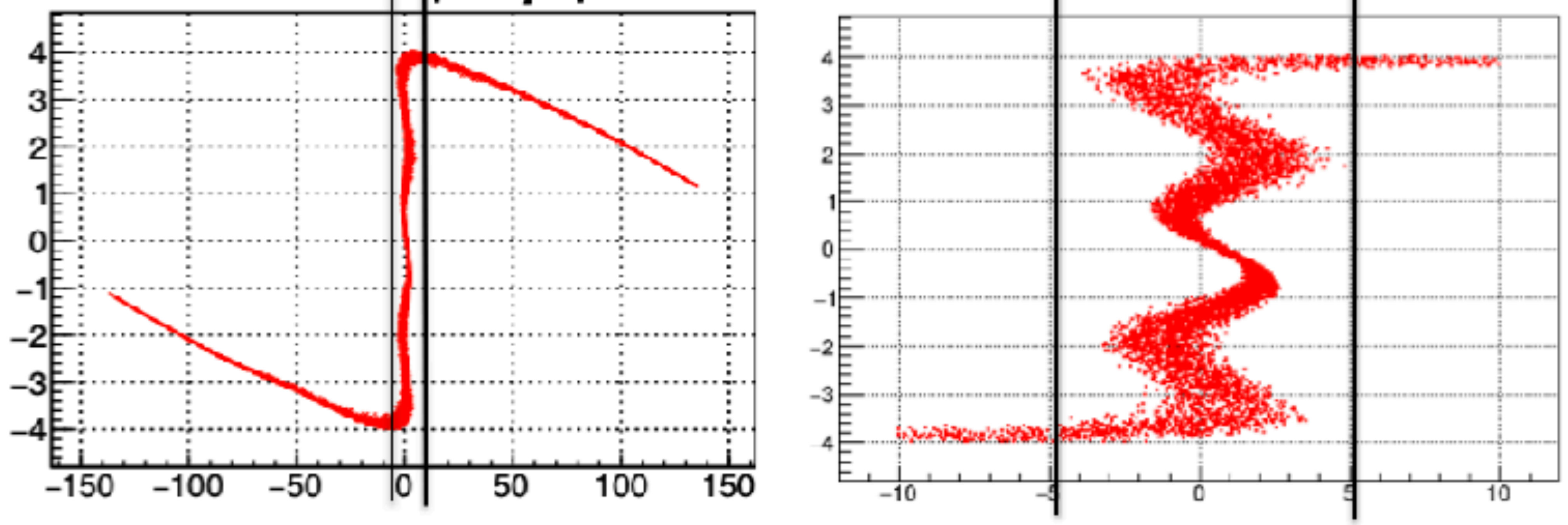


Three Designs For Possible Injection Applications

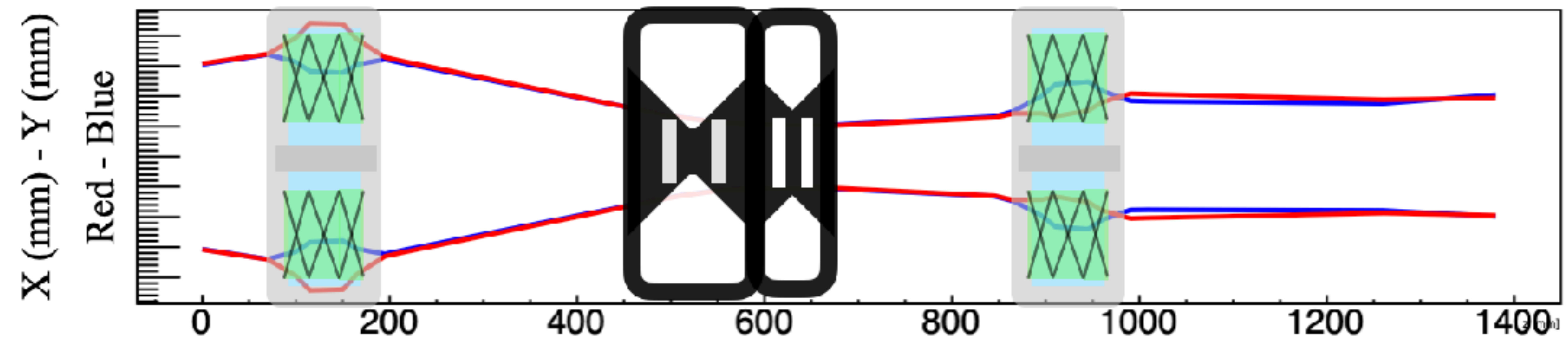
DTL Injection



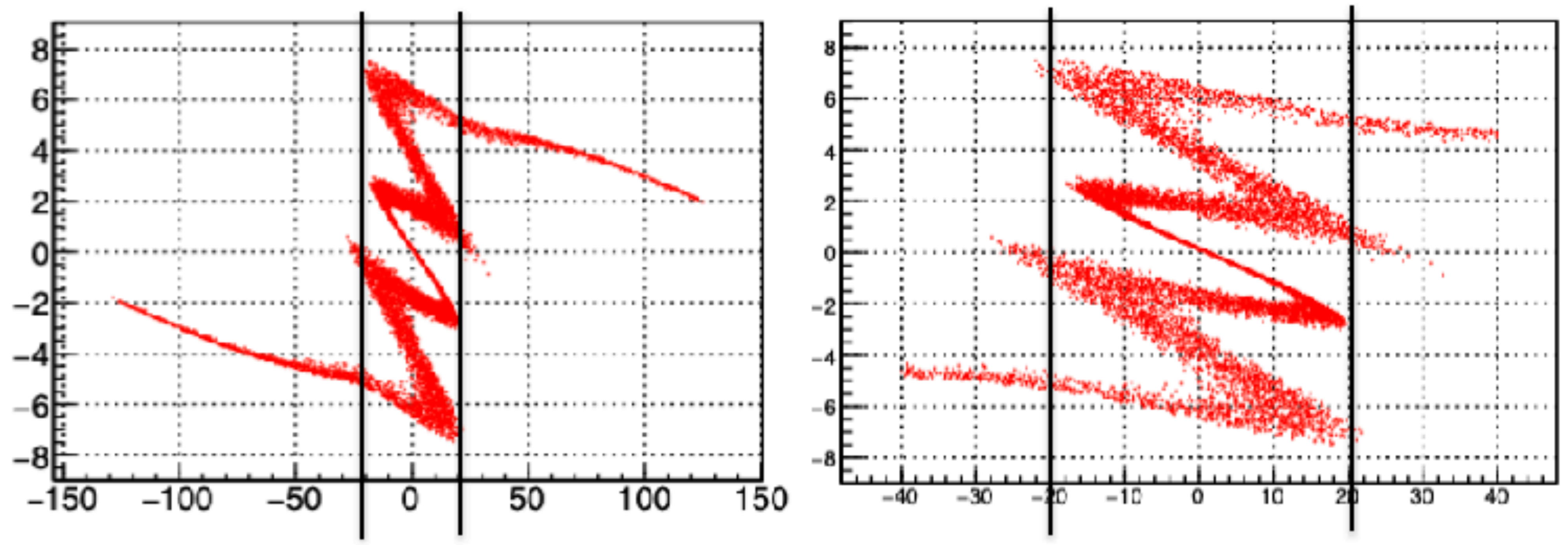
$|\Delta\phi| \leq 5^\circ \rightarrow 73.84\ \%$



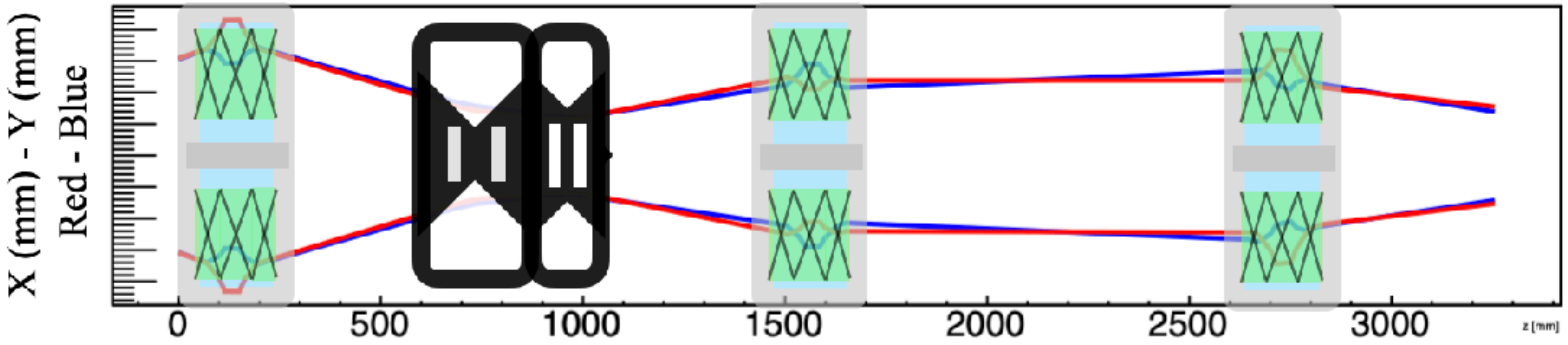
RFQ Injection



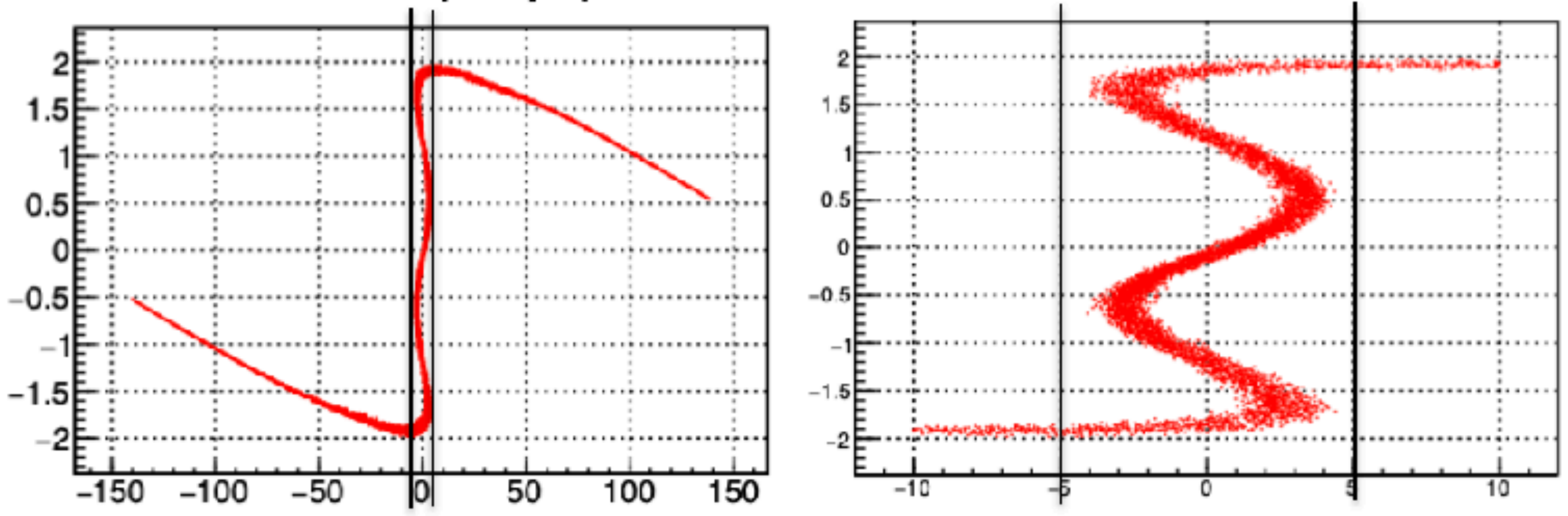
$|\Delta\phi| \leq 20^\circ \rightarrow 85.09\ \%$



Cyclotron Injection



$|\Delta\phi| \leq 5^\circ \rightarrow 69.24\ \%$

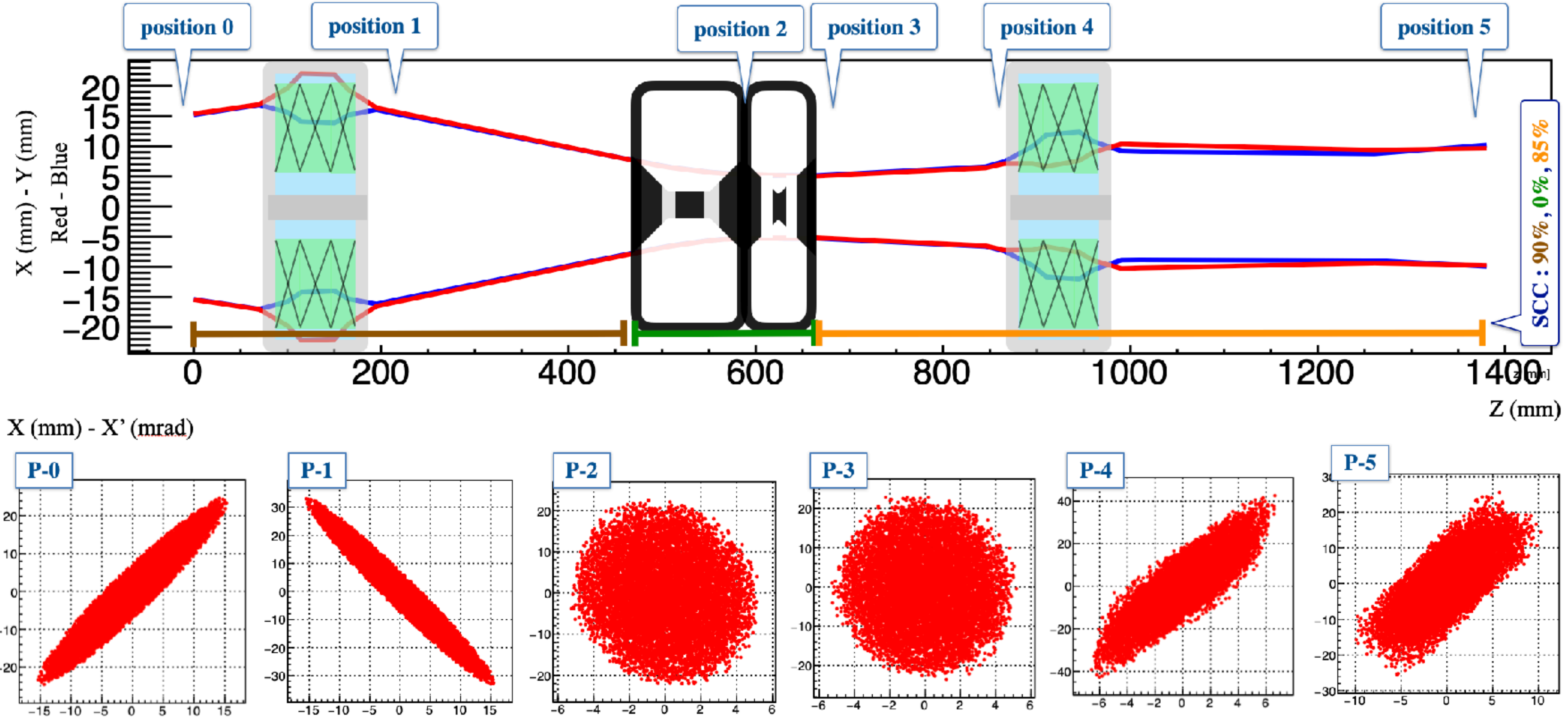


One Example for possible RFQ application:

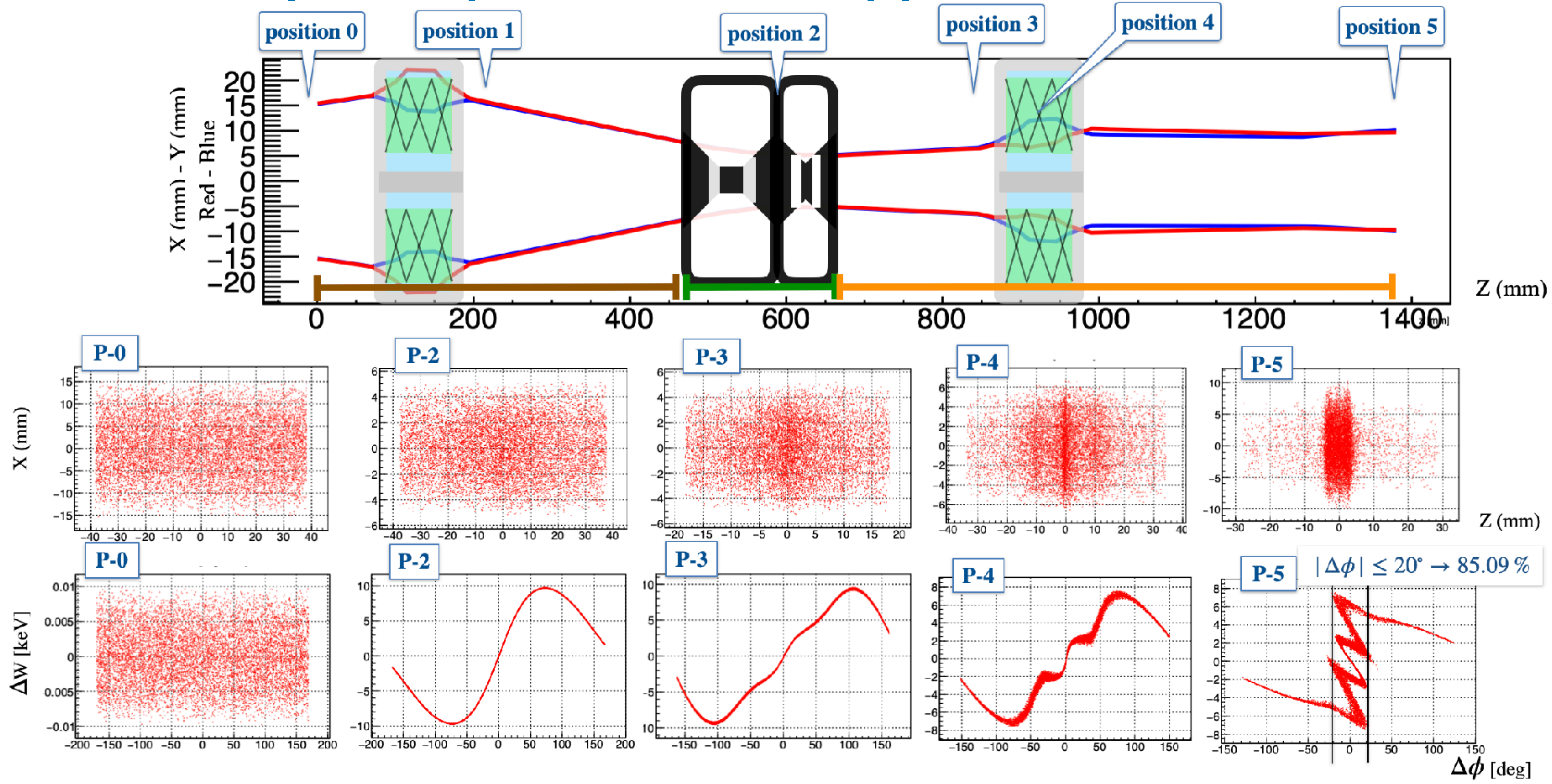
Design Parameter	30 mA
Input Energy [keV]	100
Frequency ($f-2f$) [MHz]	54, 108
Beam Current [mA]	30 mA
Synchronous Phase	$-90°$, $+90°$
SCC %	90, 0, 85
L_1,L_2 [mm]	110.2, 740.1
V_1,V_2 [kV]	5.0, 2.3

Capture % $\lvert\Delta\phi_f\rvert \leq 20°$	85.09
Capture % $\lvert\Delta\phi_f\rvert \leq 10°$	47.99
Capture % $\lvert\Delta\phi_f\rvert \leq 5°$	22.81
Capture % $\lvert\Delta\phi_f\rvert \leq 4°$	18.24
Capture % $\lvert\Delta\phi_f\rvert \leq 3°$	13.81
Capture % $\lvert\Delta\phi_f\rvert \leq 2°$	9.21

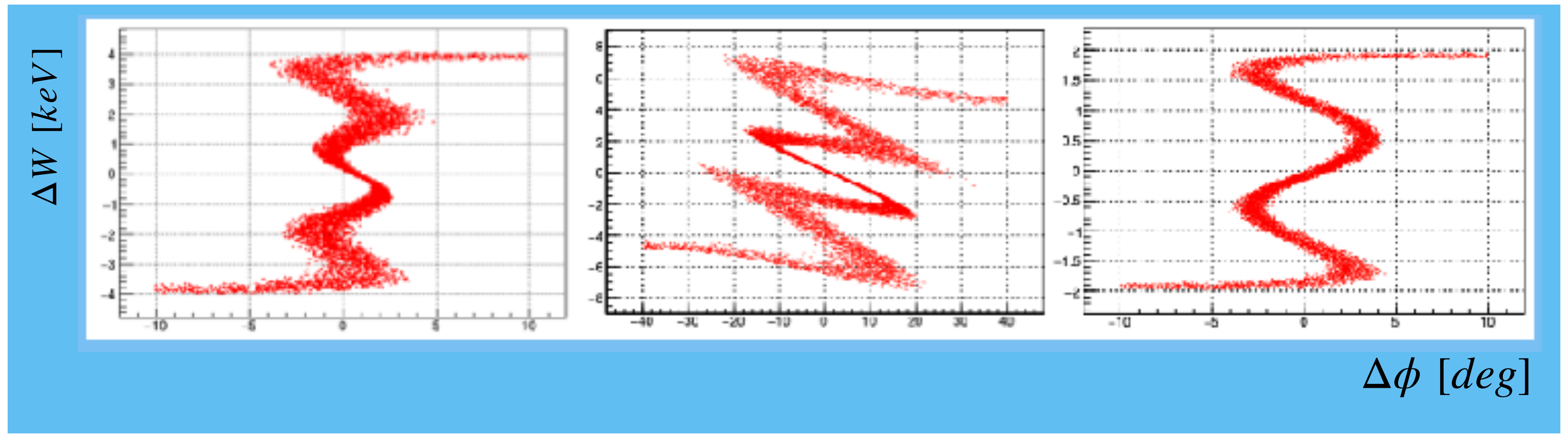
One Example for possible RFQ application:



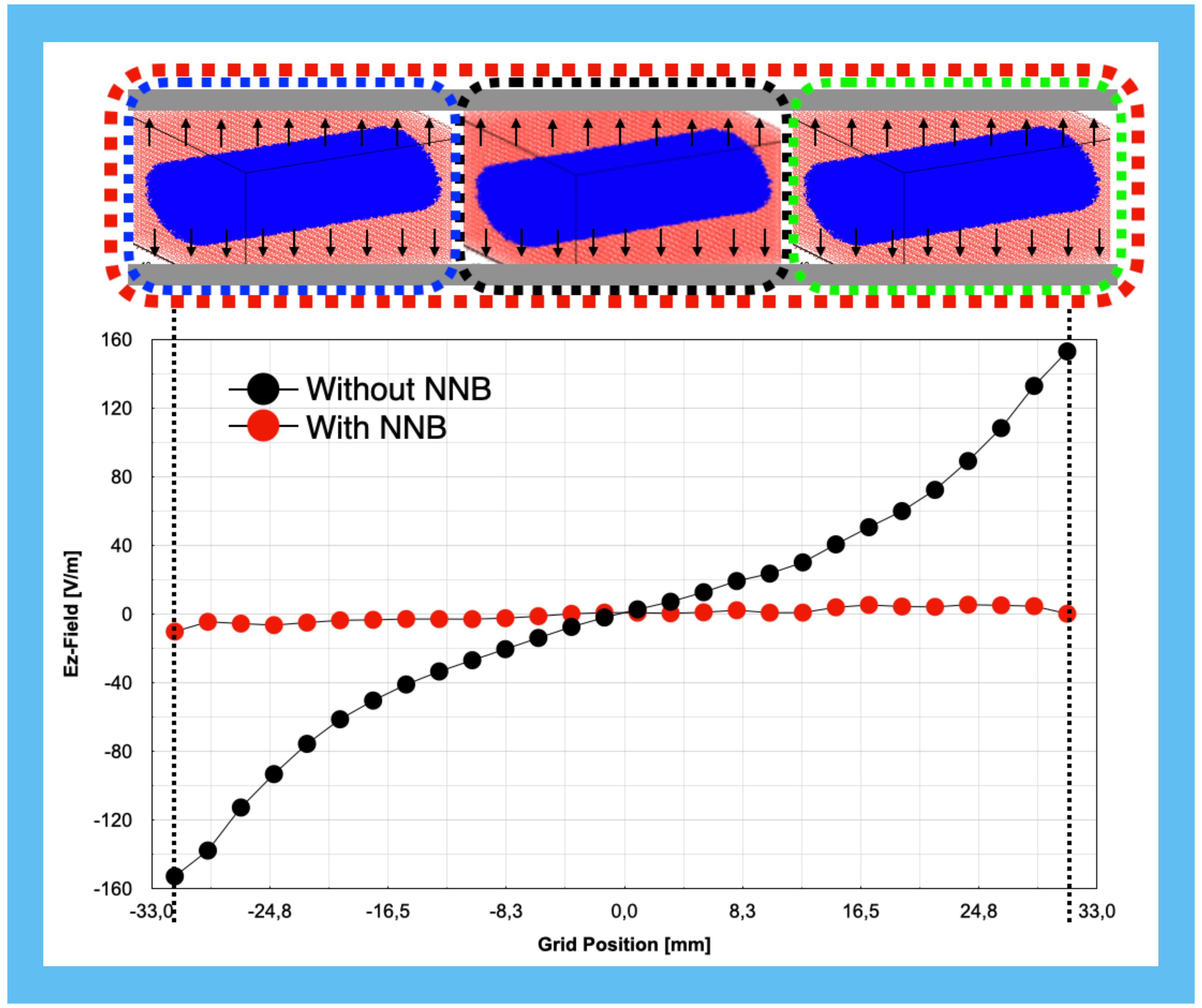
One Example for possible RFQ application: Longitudinal Beam Dynamics



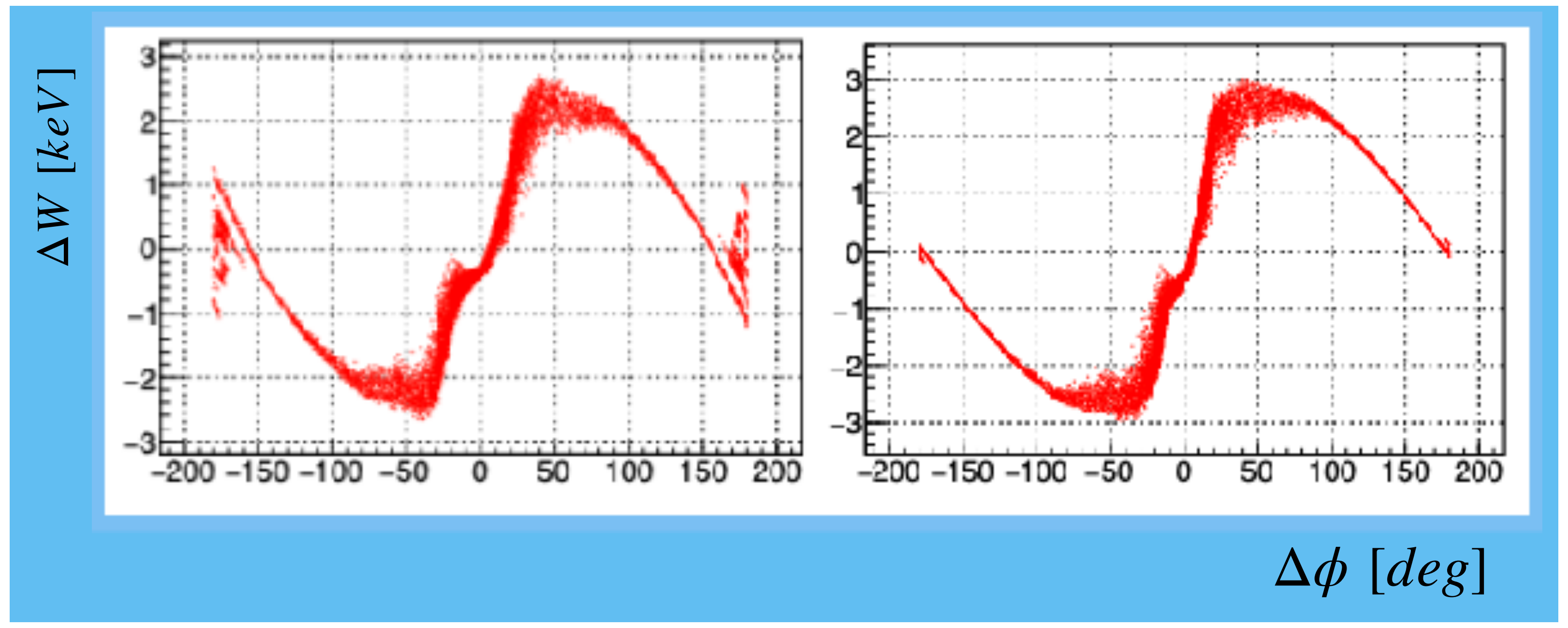
Conclusion:



- The investigation of the DDHB concept has been systematically checked and it shows the functionality as well as the efficiency w.r.t. :
  - Bunch formation in a shorter distance and more controllable
  - Sharp bunched beam depending on the next unit
  - High particle acceptance
  - Smaller longitudinal emittance at low current



- In addition to the concept, another task of this thesis was to develop a dedicated multi-particle tracking beam dynamics code - BCDC by computing the space charge effect during the bunch formation, starting from a DC beam.
  - NNB
  - SCC



Thank you for your attention!