LINAC Longitudinal Simulation and Measurement of Output Energy

Milena Safaryan, Under Advisor Dr. Ralitsa Sharankova, Glendale Community College
CCI Summer Intern

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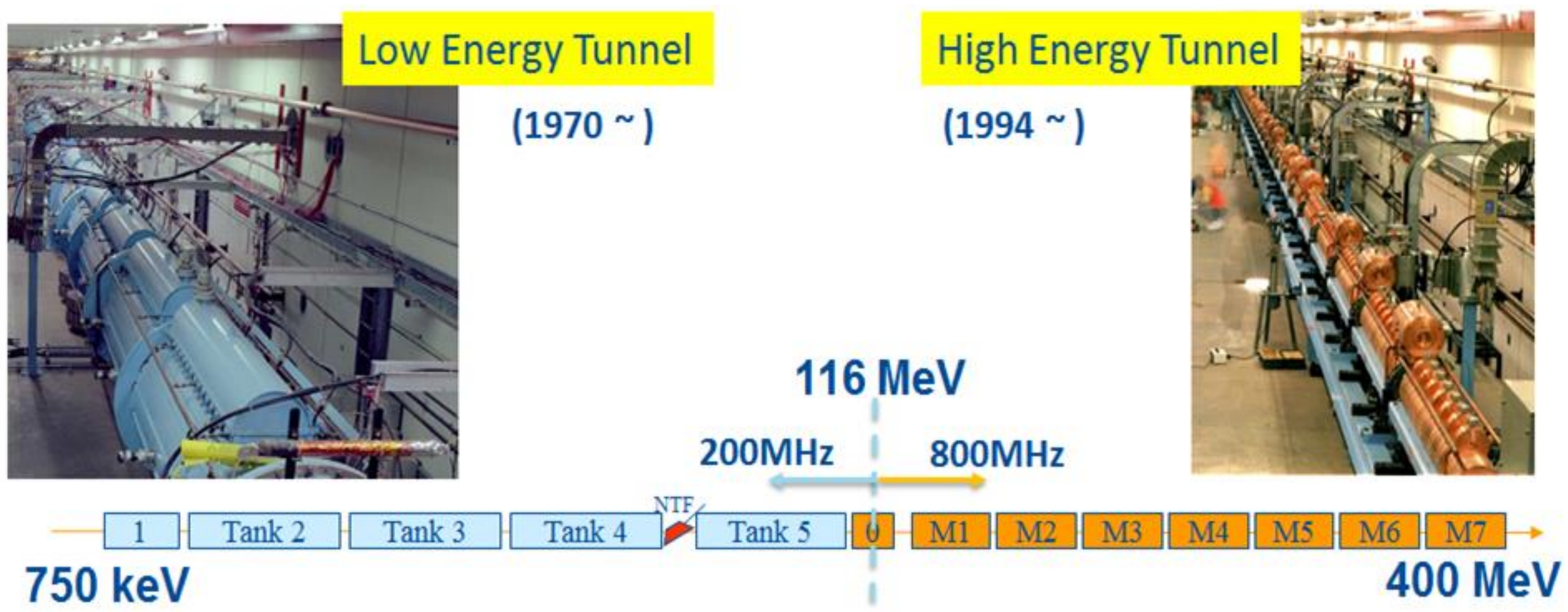
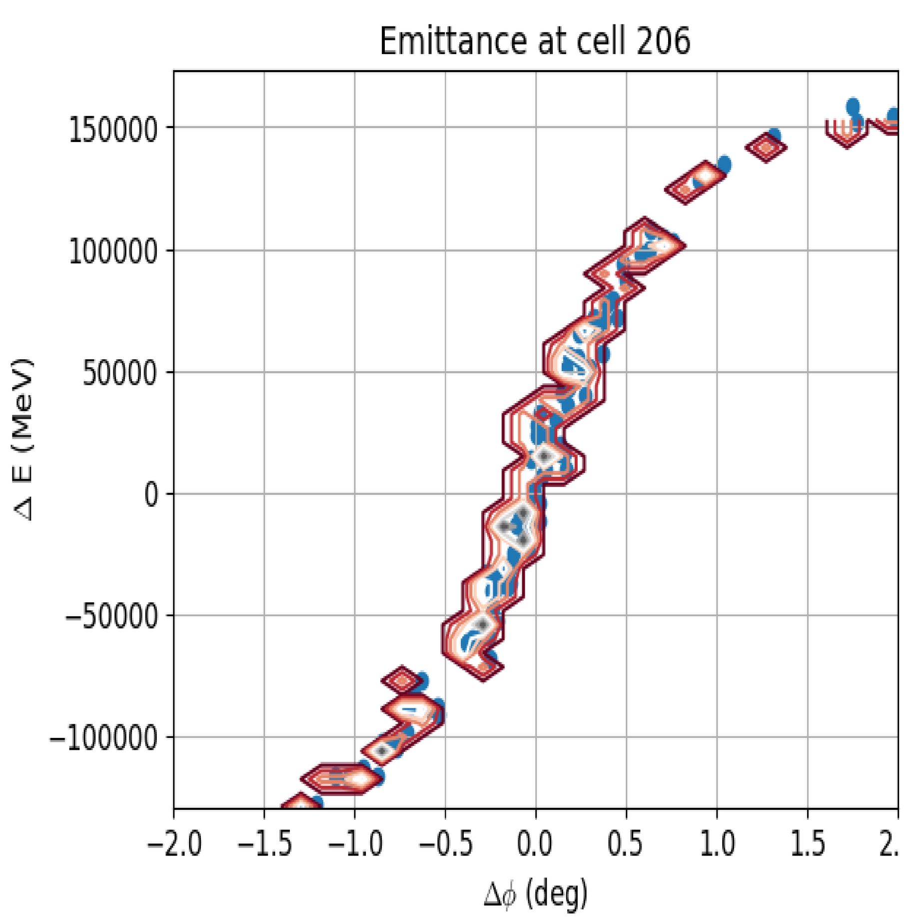
Background

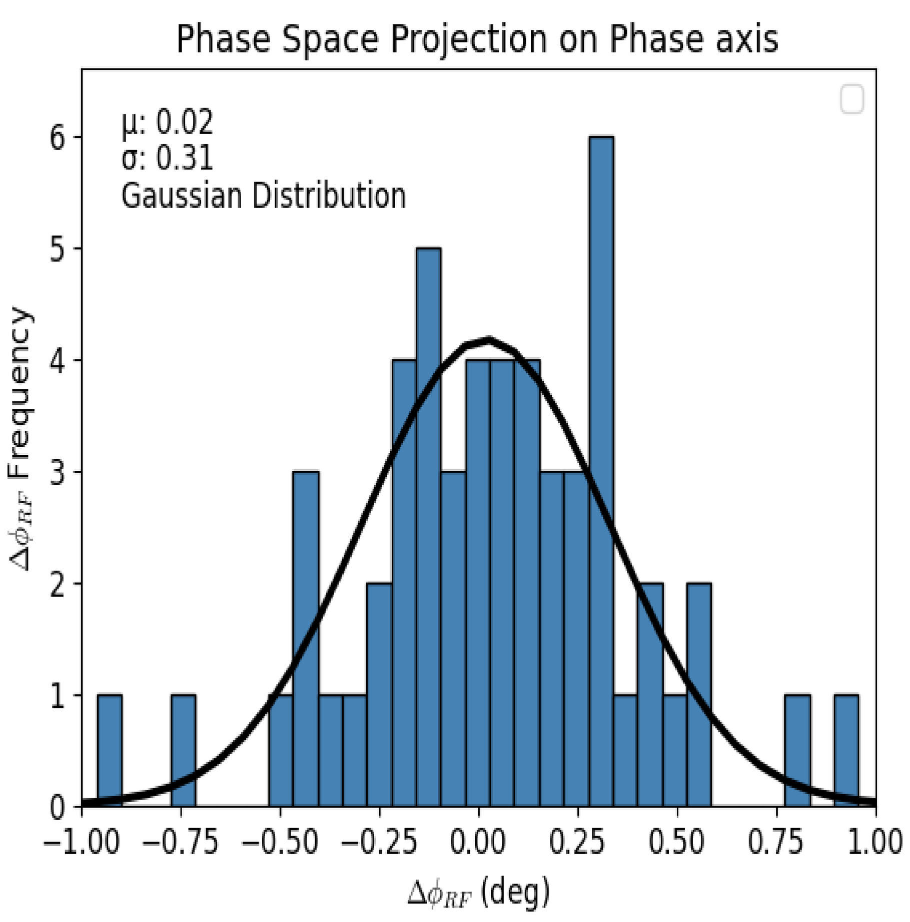
The Fermilab Linac (Linear Accelerator) is one of the oldest and most critical accelerators on the Fermilab site. It plays a vital role in the laboratory's overall operation by providing 400 MeV beam for other accelerating facilities. The Linac is divided into two main sections: the Low Energy Linac and the High Energy Linac. The output energy of Linac drifts daily requiring careful monitoring and machine tuning to ensure longitudinal matching to the Booster acceptance. To achieve this, we use Beam Position Monitors (BPMs) to examine and regulate the beam's energy. Additionally, we aim to regulate the longitudinal phase distribution to verify if it aligns with our predicted distribution from simulation. These examinations are critical for improving Linac longitudinal simulation as well as longitudinal tuning, to maintain the efficiency of the Linac.



Motivation

The goal of this project is twofold: (1) to analyze the output energy of the beam exiting the Fermilab Linac, (2) to understand the longitudinal phase simulation, and enhance it by fitting it to experimental data. To accomplish this, I am using the Linac Python based simulation code, which models the beam's phase space after it passes through each cavity. This method allows us to understand the output energy based on the initial energy and phase differences relative to the synchronous particle. Simulation is compared to data collected with Beam Position Monitors (BPMs). BPMs provide average transverse(horizontal and vertical) beam position, as well as the longitudinal phase. These BPM data is used for calculation of the Linac energy change. For the longitudinal phase simulation, we examine the projection of phase space onto the phase axis and fit this with Gaussian to estimate bunch length. This can be directly compared to the beam longitudinal profile measured with the bunch length detector (BLD) installed just upstream of High Energy Linac.





Conclusion

The simulation of the Linac output energy allowed us to determine the optimal phasing correction for the final RF to achieve the desired energy. This simulation can be enhanced by integrating improved fitting algorithms for greater accuracy. Currently, the longitudinal phasing calculations are based on simulations due to the Linac shutdown, which prevented data collection. Further studies are necessary to confirm whether the predicted distribution is consistent with real-world conditions.

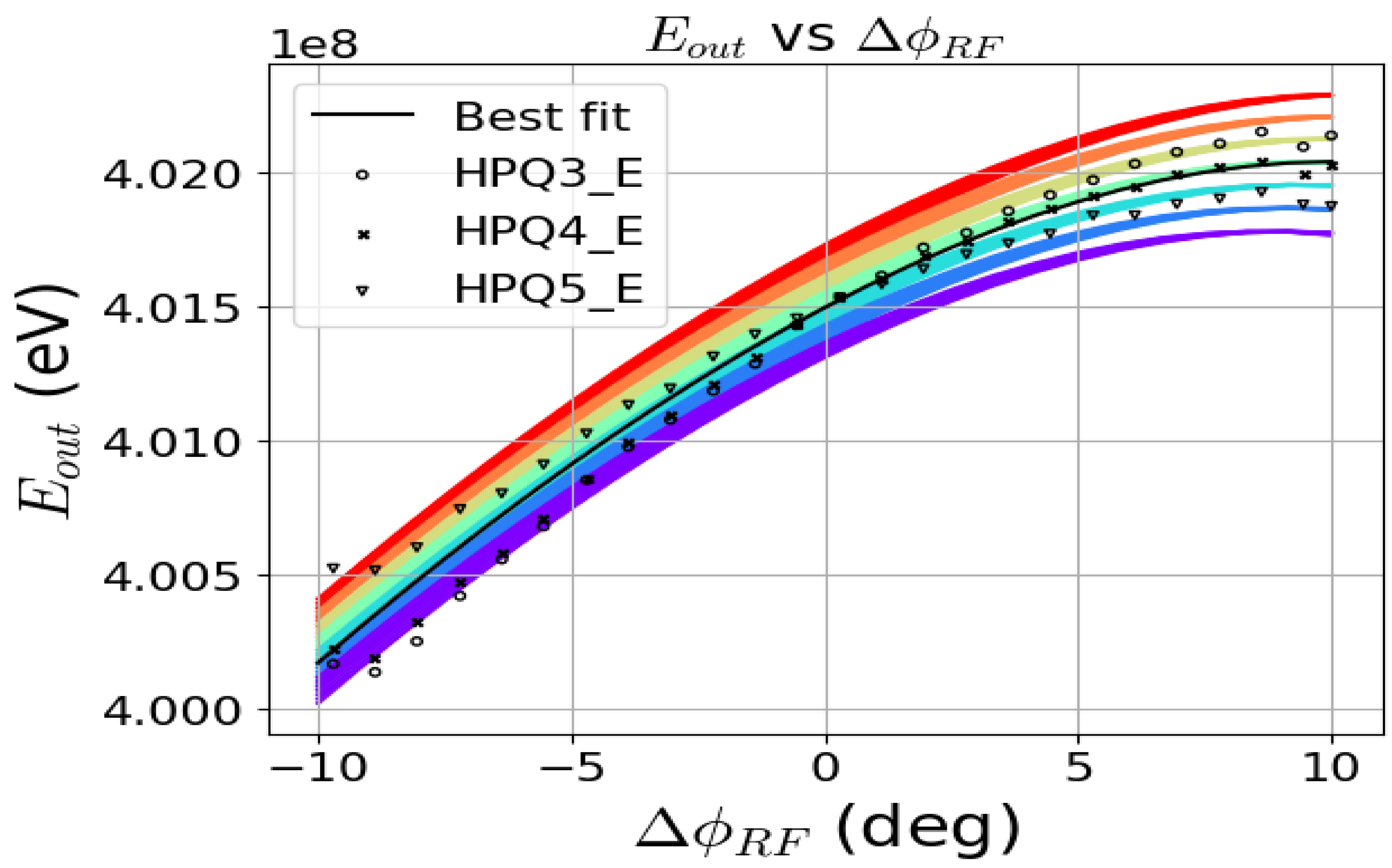
Linac Output Energy Measurement

Method 1

Beam leaving the Linac is injected into the Booster via 400 MeV line. Beam goes through dispersive regions (both horizontal and vertical). This approach uses dispersion coefficients to translate the observed BPM measurements into corresponding energy changes. We measure energy as a function of Module 7 RF phase. In the plot below, data from three BPMs is plotted against the simulated output energy for a range of input energy and phase values. This comparison allows us to validate our simulations against real-world measurements. Simulation is fitted to the data to extract input phase space parameters.

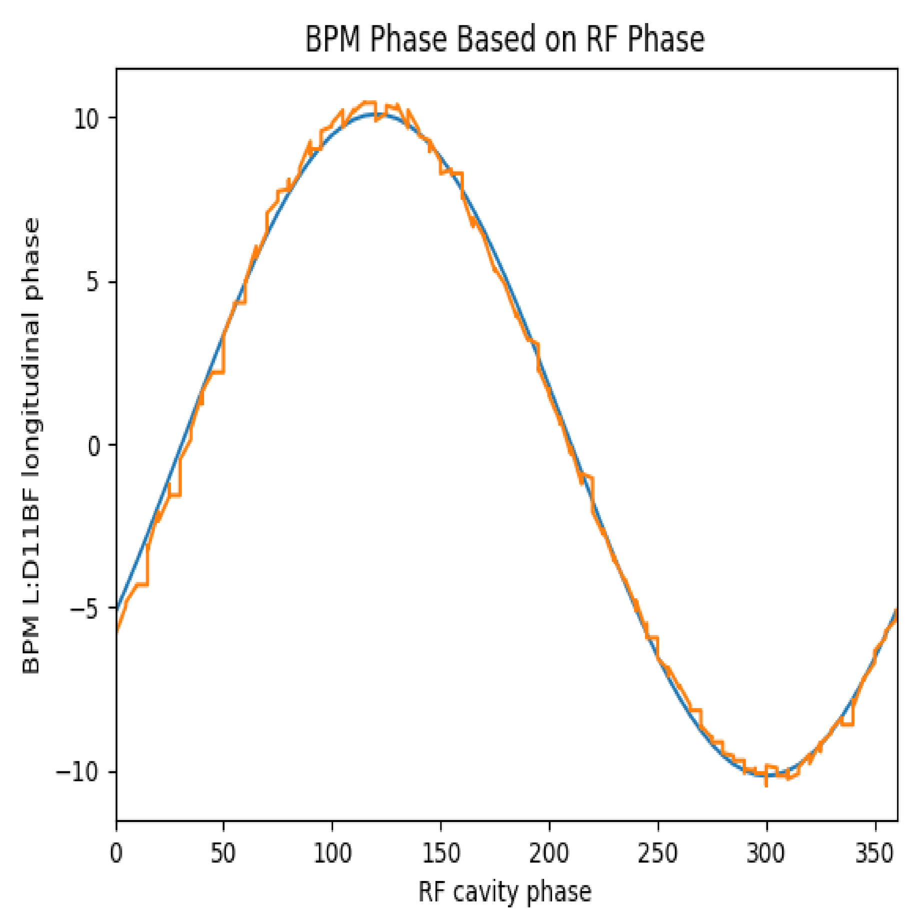
Method 2

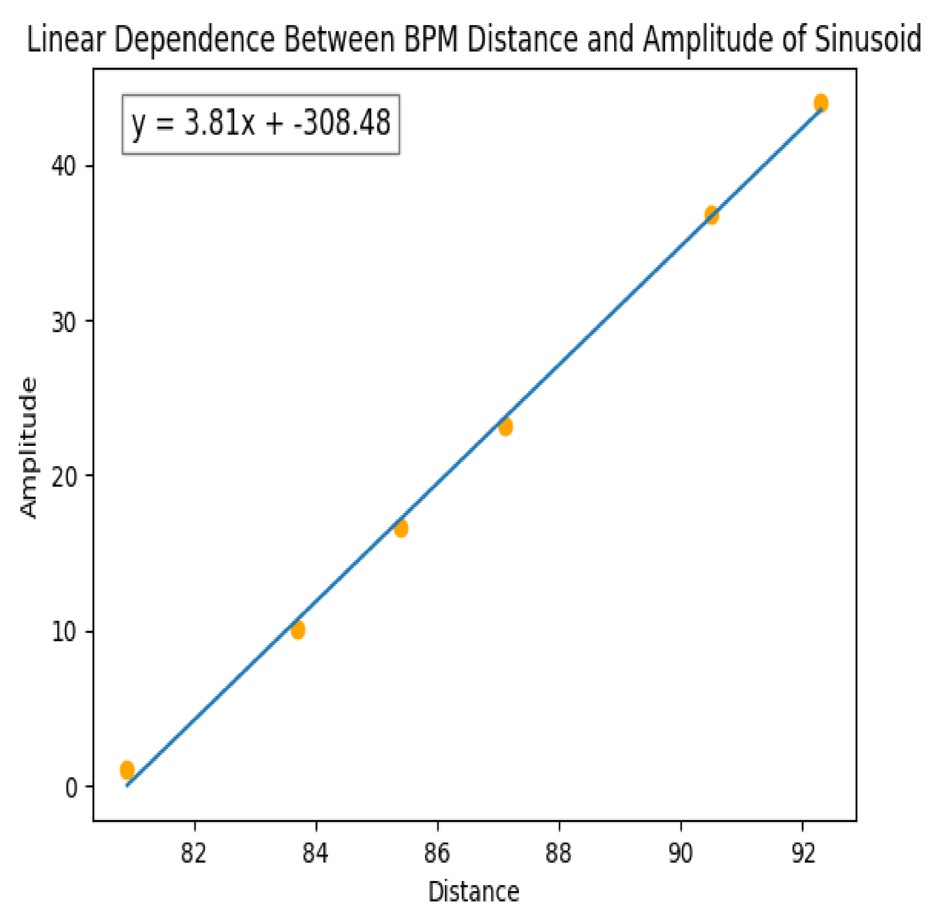
The second method utilizes beam phase from BPMs to calculate the output energy based on the beam time of flight. This method is complimentary to energy measurement with method 1. However, one limitation of this method is potential +/- 180 flips of measured phase at BPM board reboot.



Measurement of Cavity Phasing

For proper acceleration all cavities need to be operating at design resonance. However, environmental drifts can affect cavity resonance. Cavity phasing procedure (scanning RF phase 360 degrees) is done to ensure cavities are operating at design value. We measured cavity phasing for vernier cavity in Module 0 and confirmed that it operates as a thin lens. The left plot shows beam phase change from BPM as a function of RF phase setting with sin curve fitted to it and the plot on the right shows extracted sinusoid amplitude as a function of BPM longitudinal position.





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