# Decoupling Cathode and Gun Emittance Improvements from a 100 pC, 100 MeV injector system

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## Introduction

We present simulation results that start to decouple the respective emittance contributions from gun or cathode upgrades from the final emittance out of a 100 MeV, 100 pC electron injector system. We aimed our simulations at the LCLS-II HE project and documented the expected emittance payoffs in pursuing SRF gun technology versus improving the beam profile off of the cathode. The LCLS-II HE project benefits from lower emittance injector systems as lower emittance at the undulator could significantly increase the deliverable photon range. The expected 95% RMS transverse emittance out of the current LCLS-II injector is 0.23 mm mrad The goal for the LCLS-II HE project is 0.1 mm mrad at the undulators, indicating that injector improvements are required to hit the goal.

## Methodology

We used ASTRA driven by the NSGA-II genetic algorithm to determine a solution set of the tradeoffs between the competing parameters, 95% RMS transverse emittance versus longitudinal RMS bunch length. We initially optimized various injector systems with a "perfect" cathode where we define perfection as a cathode that produces an electron beam with no longitudinal or transverse momentum spread. With the LCLS-II HE project in mind, we then reoptimized with FEL specific energy constraints. To do this, we further limit the allowed overall and higher order (HO) energy spreads at the end of the injector and pictorially show how the Pareto Front shifts.

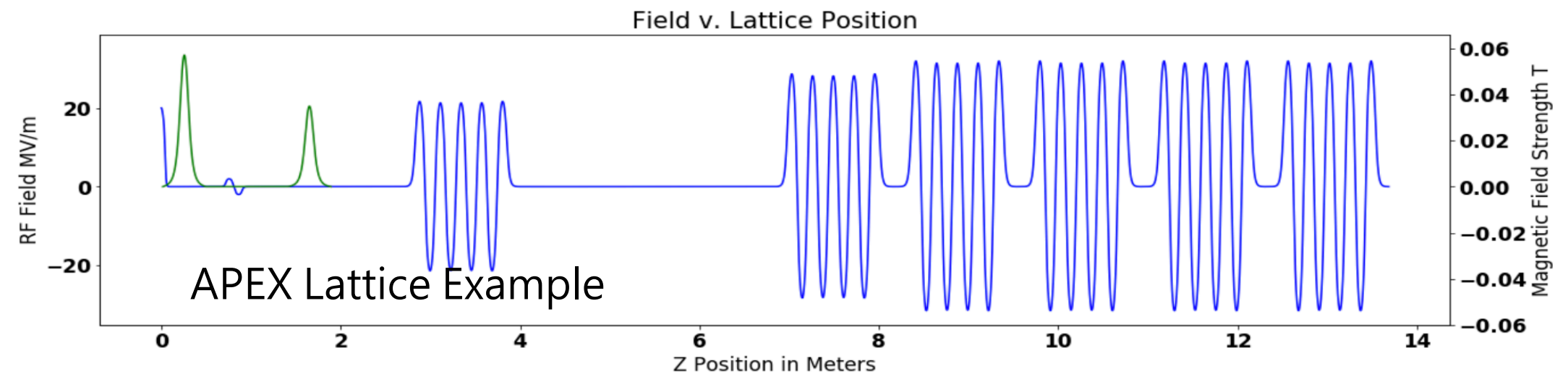
Lastly, we reoptimized at various cathode thermal emittances (Temit) to map out the dependence of cathode emittance versus final emittance out of various injector systems.

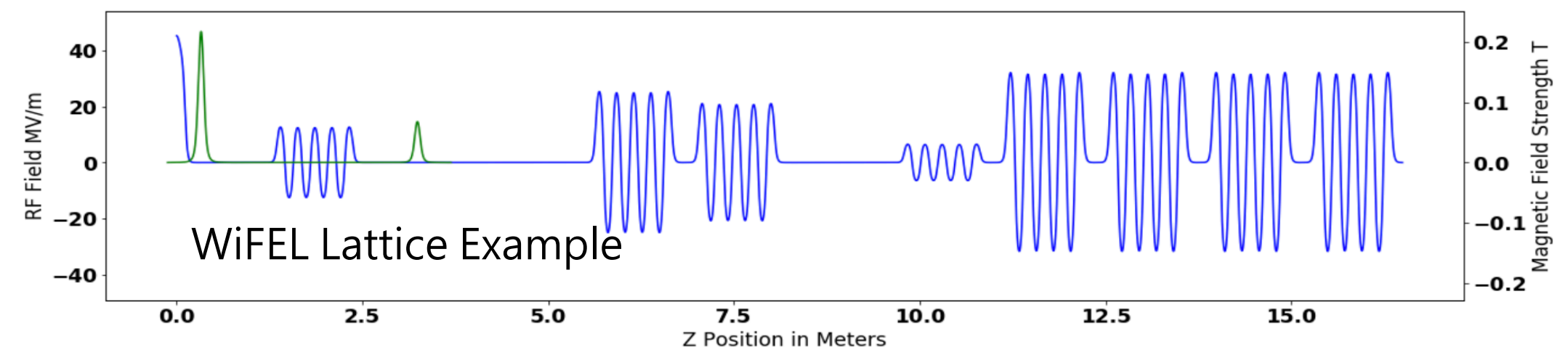
| Knob | Value Range |
|---|---|
| RMS sigma at cathode | 0.05-1 mm |
| Bunch length at cathode | 5-70 ps |
| Gun Gradient | 20-50 MV/m |
| Gun phase | -60-60 deg. |
| Sol. 1 field | 0-0.4 T |
| 9 cell field | 0-32 MV/m |
| 9 cell phase | -180-180 deg. |
| Capture Cavity Offset | 0-2 m |
| Sol. 2 field | 0-0.3 T |
| Sol. 2 Offset | 0-1.5 m |
| Cryomodule Offset | 0-3 m |
| Cavity 1 field | 0-32 MV/m |
| Cavity 2 field | 0-32 MV/m |
| Cavity 4 field | 0-32 MV/m |
| Cavity 1 phase | -90-90 deg. |
| Cavity 2 phase | -90-90 deg. |
| Cavity 4 phase | -90-90 deg. |

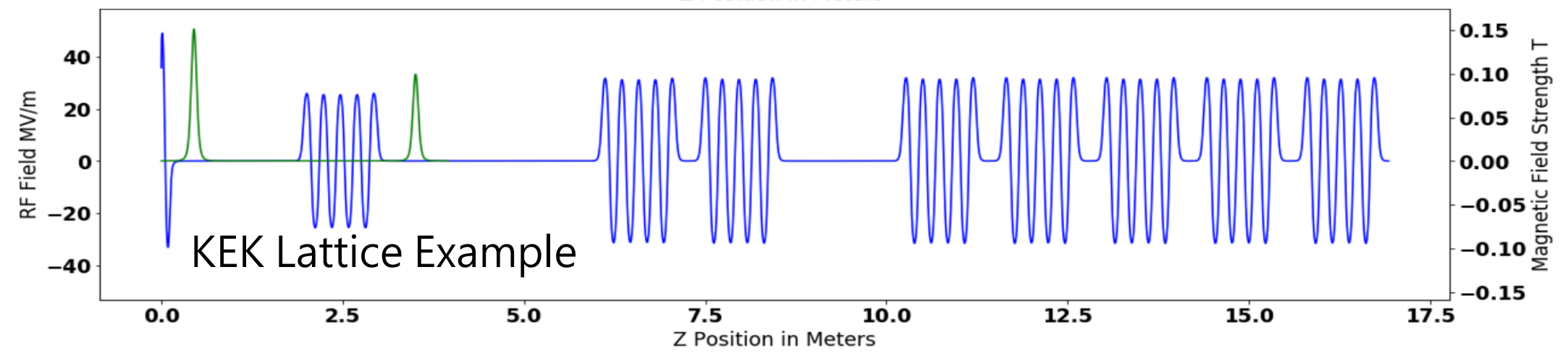
Table 1: Knobs varied in the NSGA-II algorithm for the KEK and WiFEL style guns.

| Knob | Value Range |
|---|---|
| RMS sigma at cathode | 0.05-2 mm |
| Bunch length at cathode | 5-50 ps |
| Gun phase | -45-10 deg. |
| Sol. 1 field | 0.01-0.2 T |
| 2 cell field | 0-2 MV/m |
| 2 cell phase | -120-0 deg. |
| Sol. 2 field | 0-0.2 T |
| Cavity 1 field | 0-32 MV/m |
| Cavity 4 field | 0-32 MV/m |
| Cavity 1 phase | -90-90 deg. |
| Cavity 4 phase | -90-90 deg. |

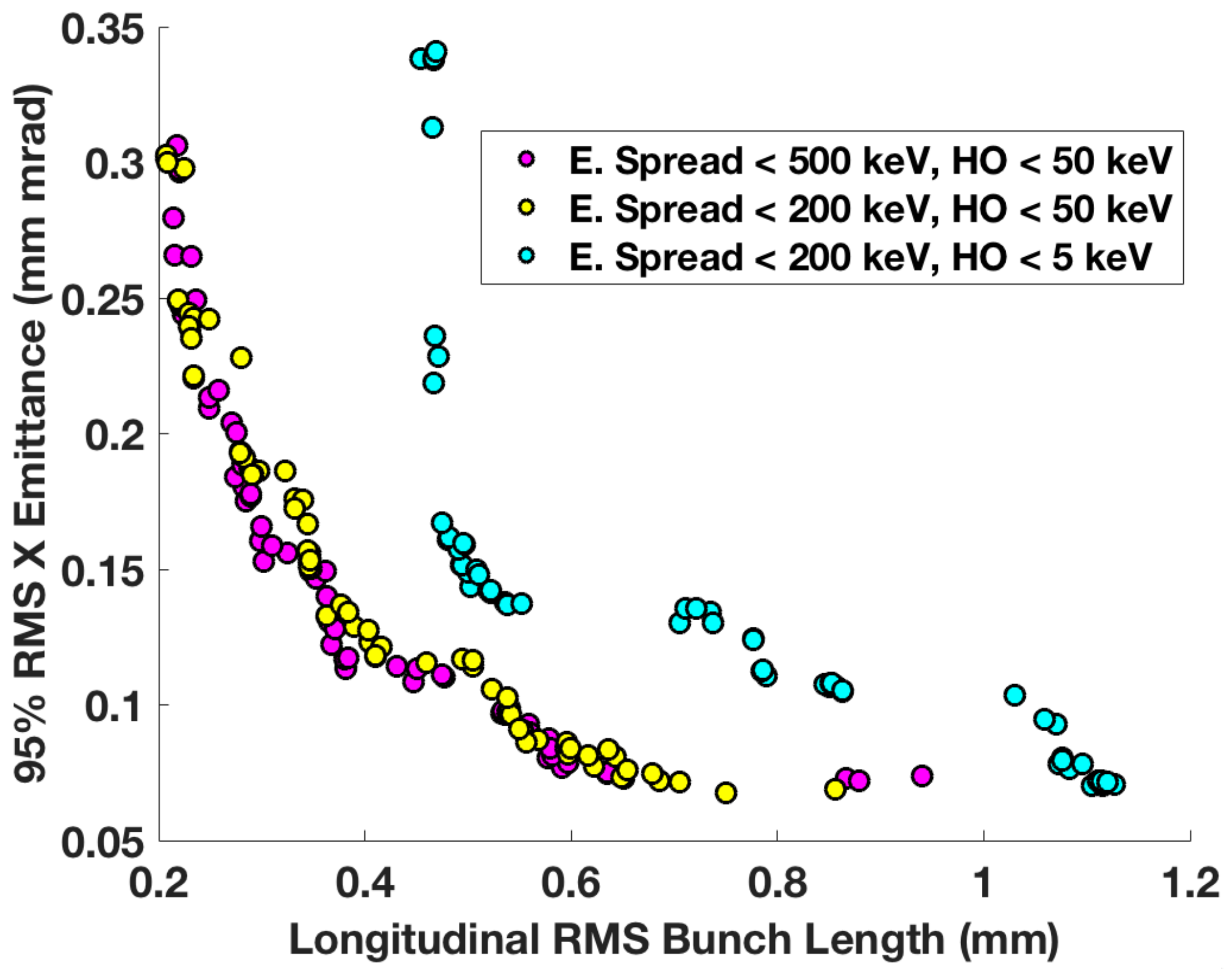
Table 2: Knobs varied in the NSGA-II algorithm for the APEX gun. Zero degrees is defined as on crest for max acceleration and the field gradients are the value of the maximum field in the field file

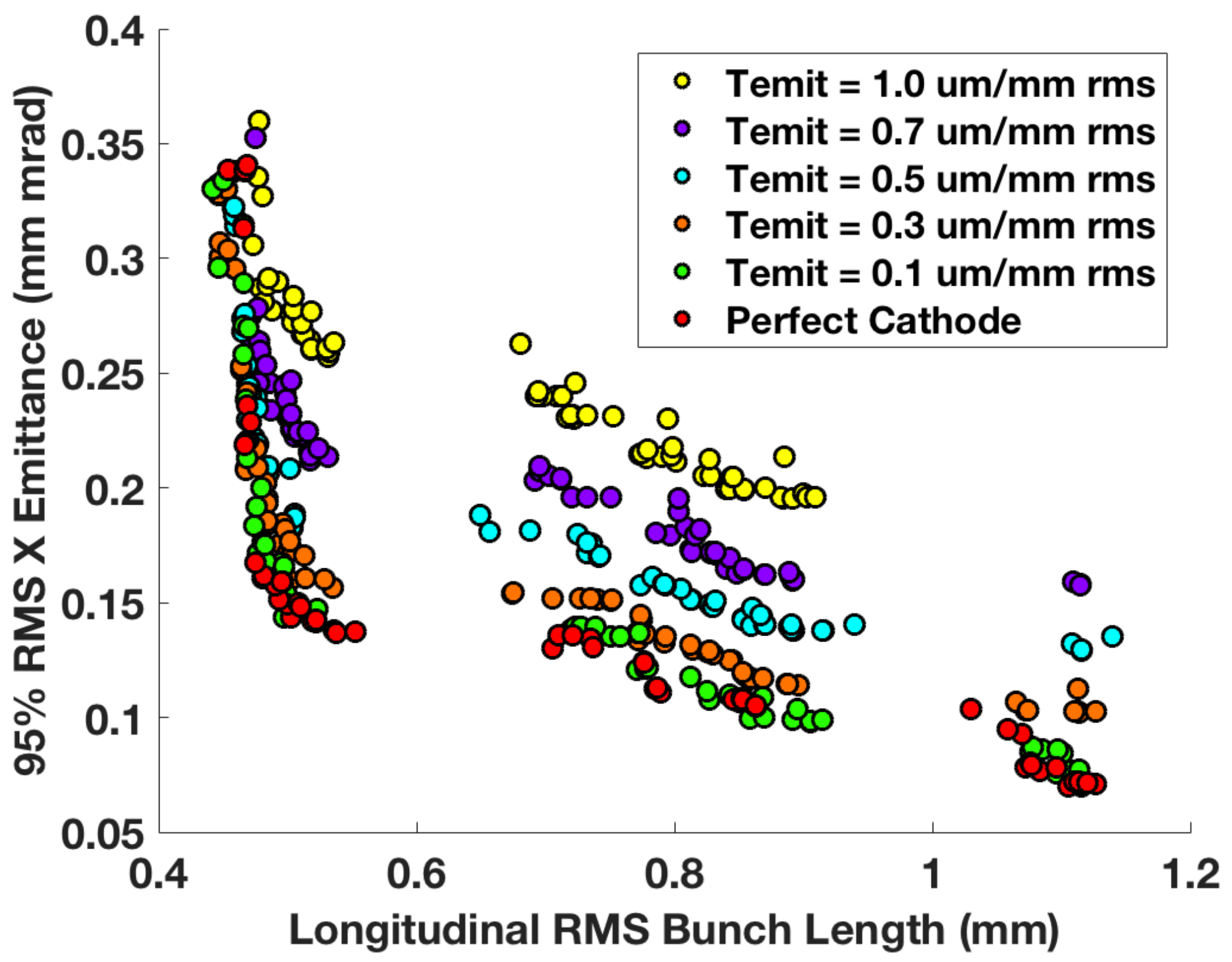




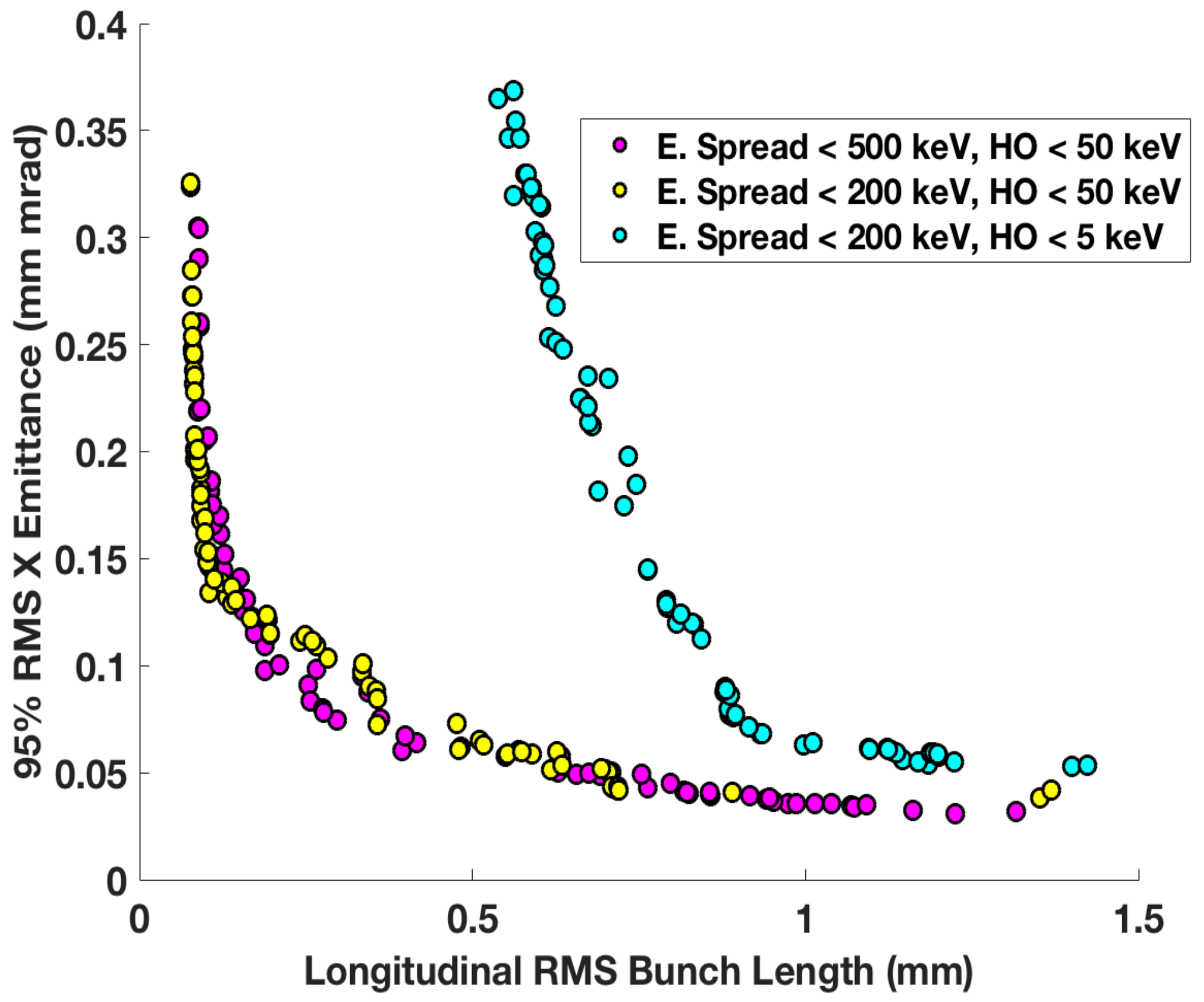


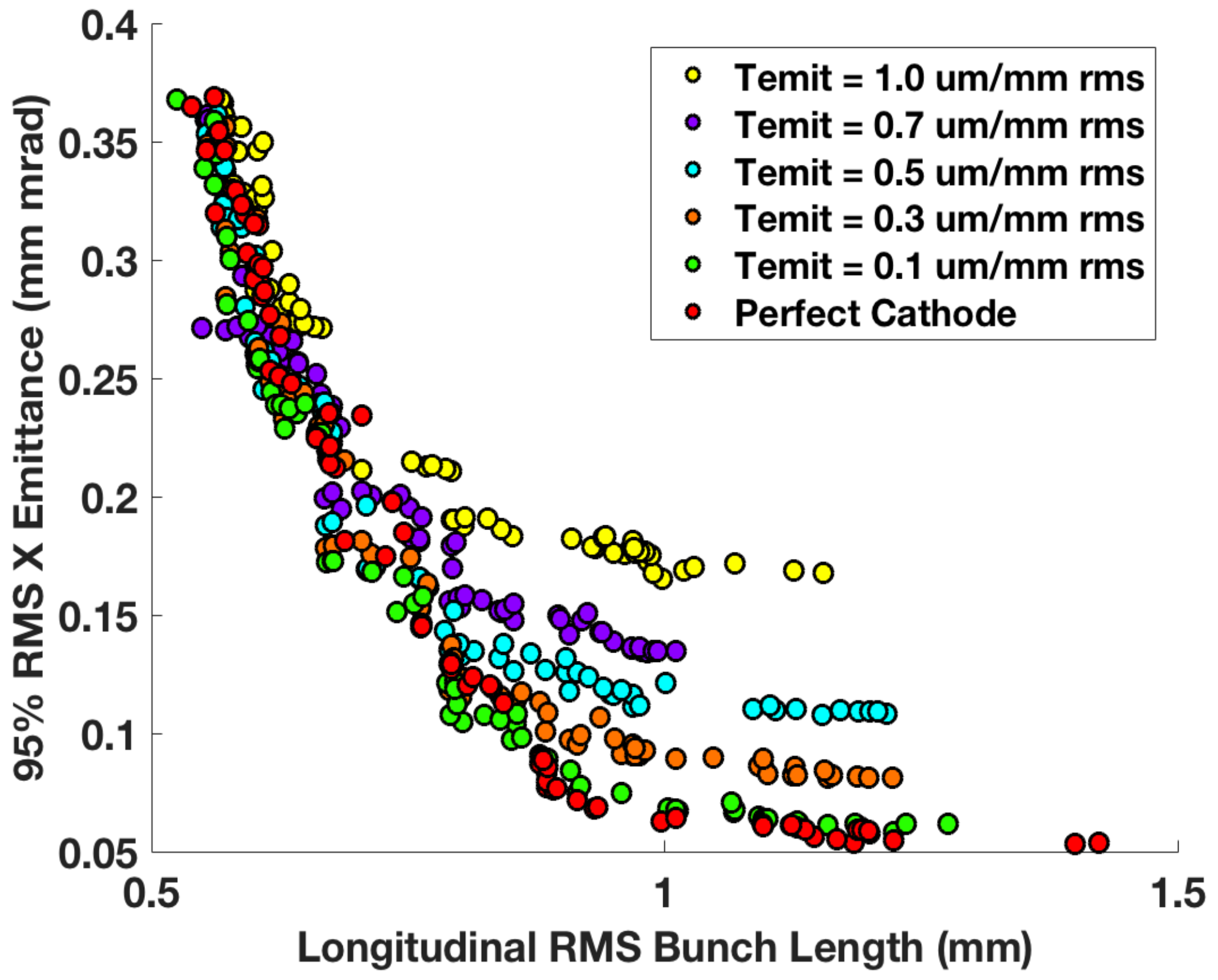
## NCRF Quarter Cell Gun (APEX style)



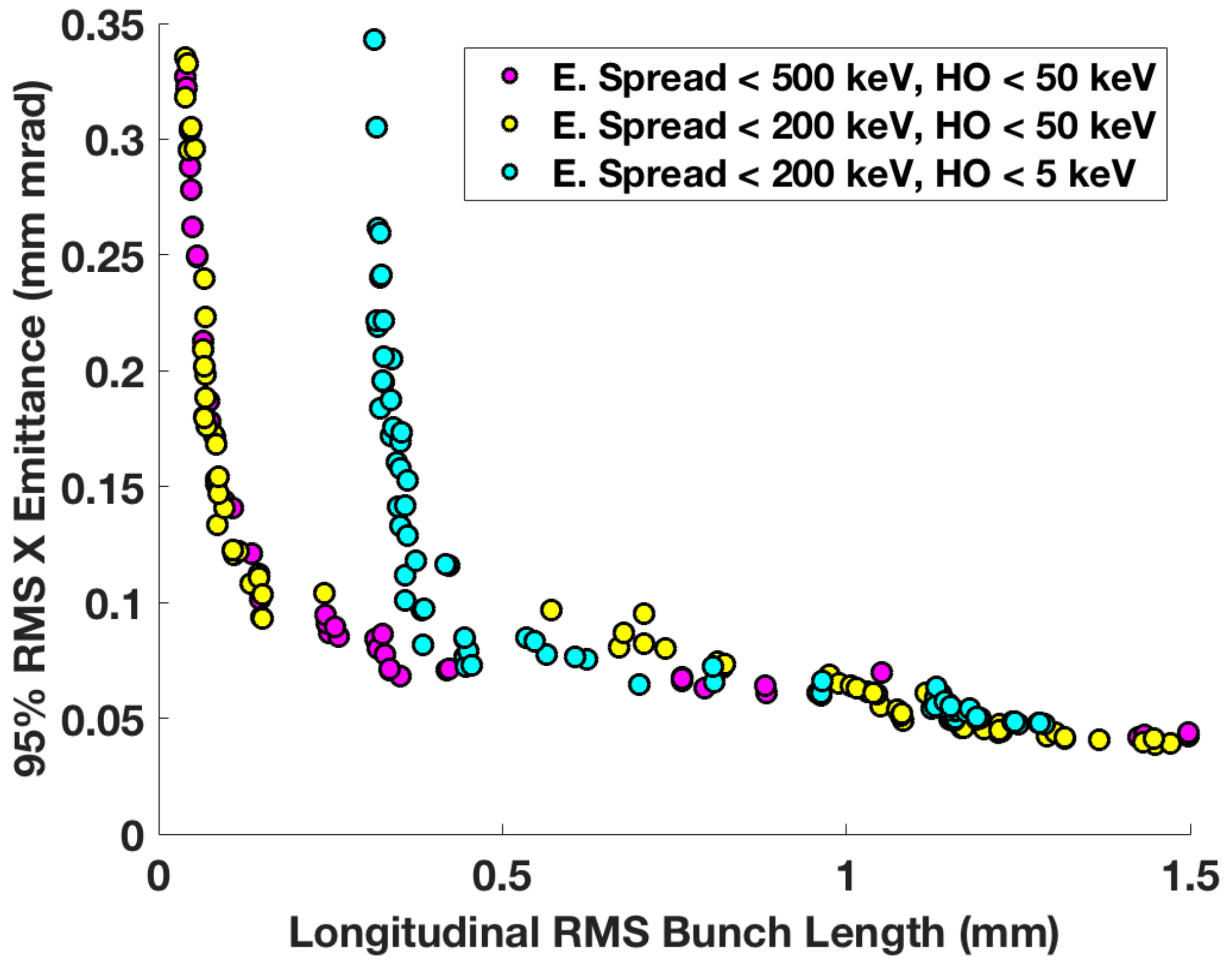


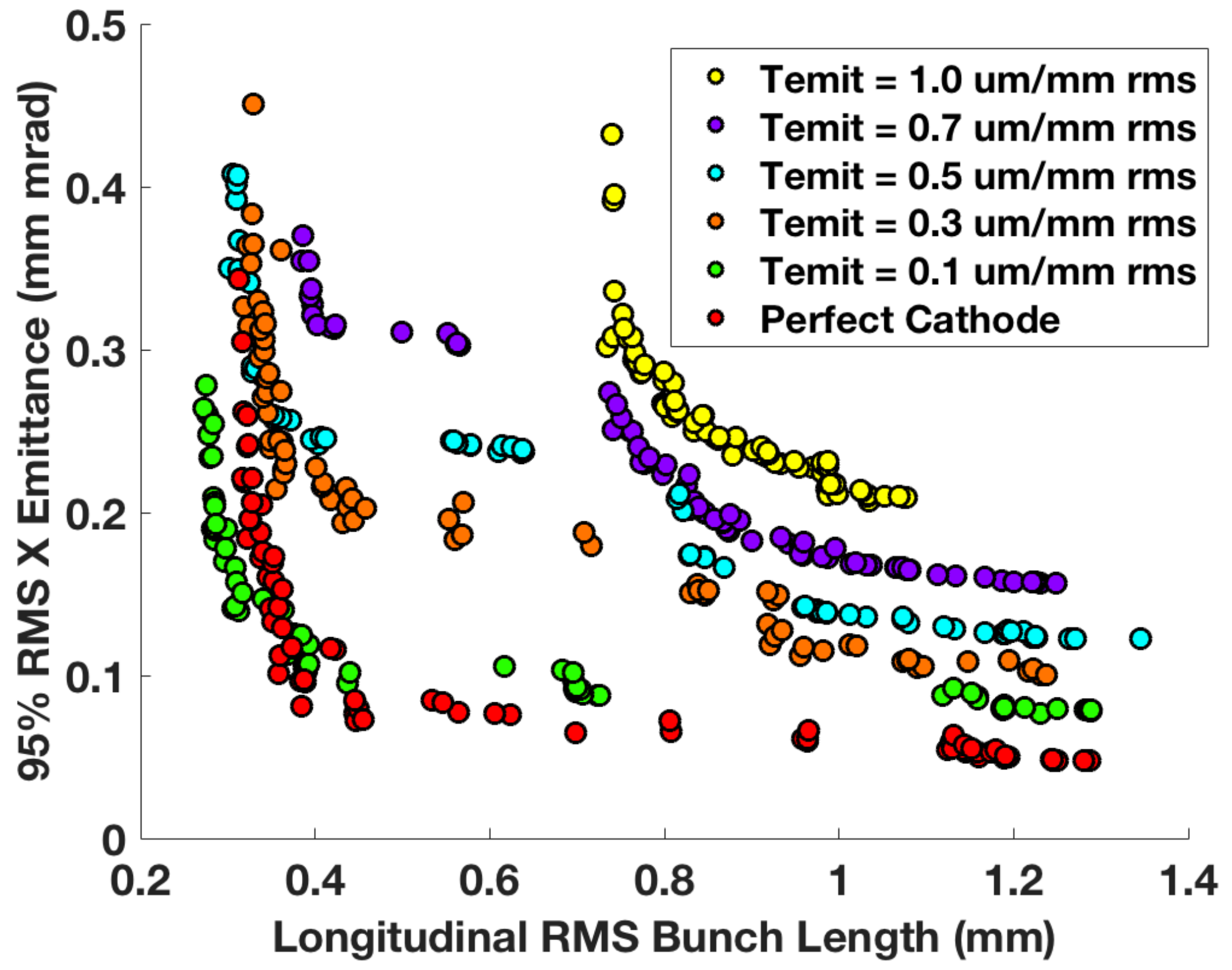
## SRF Quarter Cell Gun (WiFEL style)





## SRF 1.5 Cell Gun (KEK style)

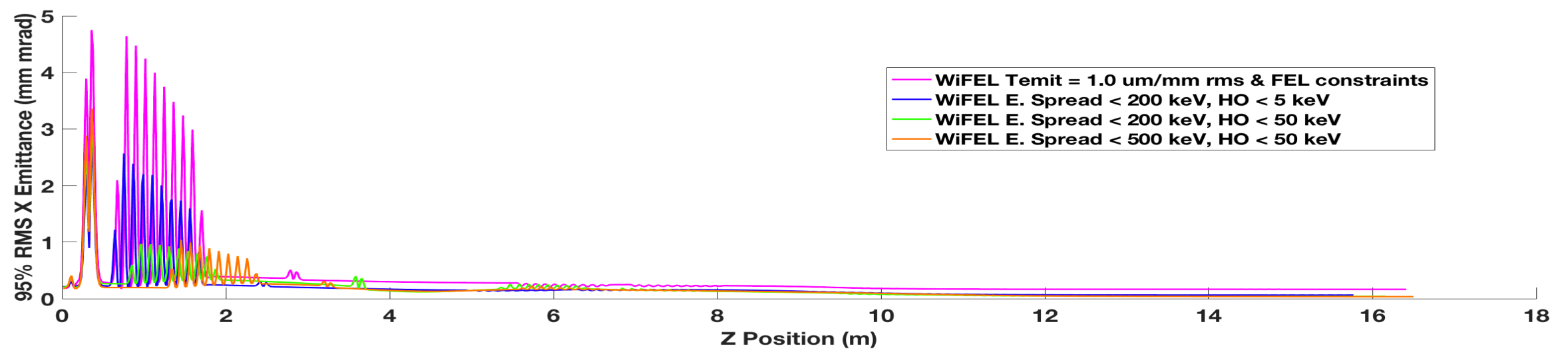


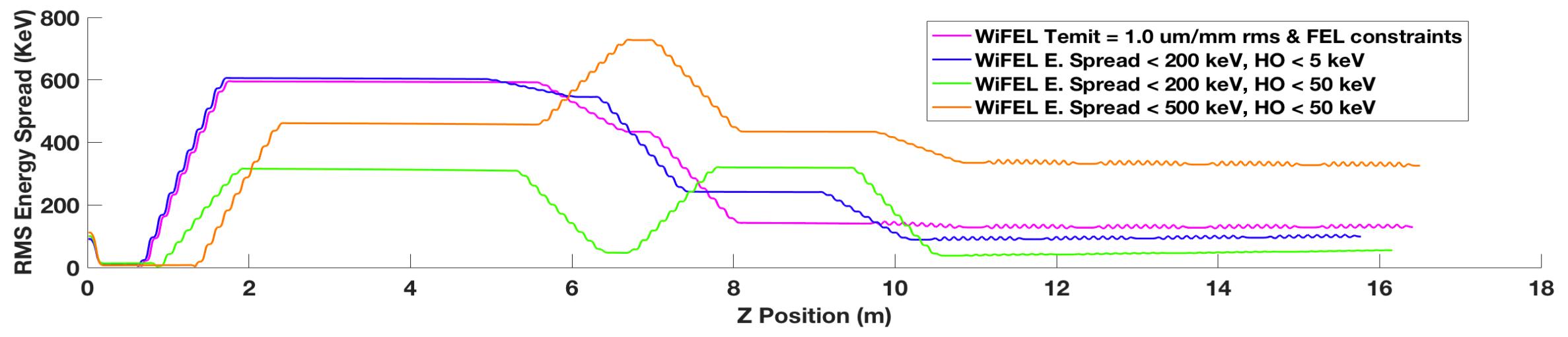


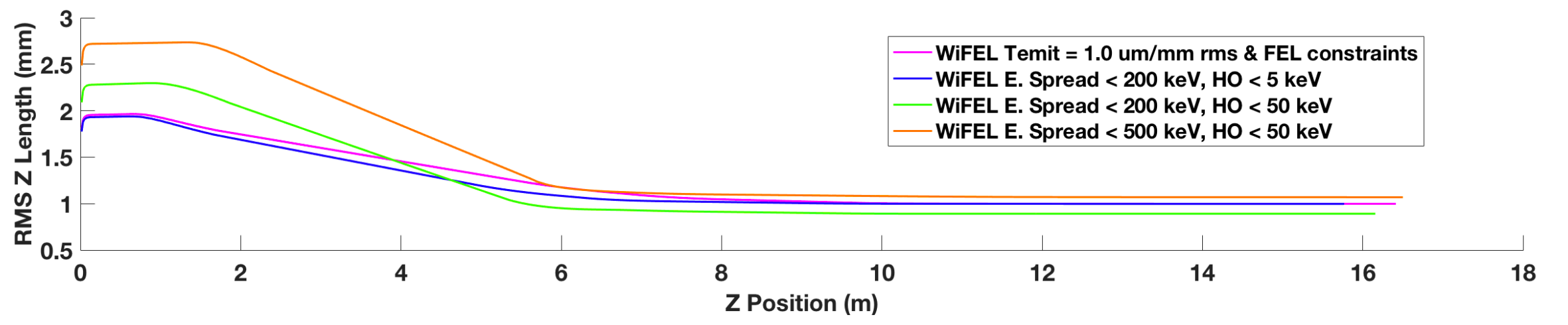
## Analysis

For LCLS-II, we are interested in a configuration that produces a beam close to 1 mm. Therefore, for the analysis plots, we manually selected configurations close to 1 mm to display. All displayed results are with 10,000 ASTRA particles with 100 pC.

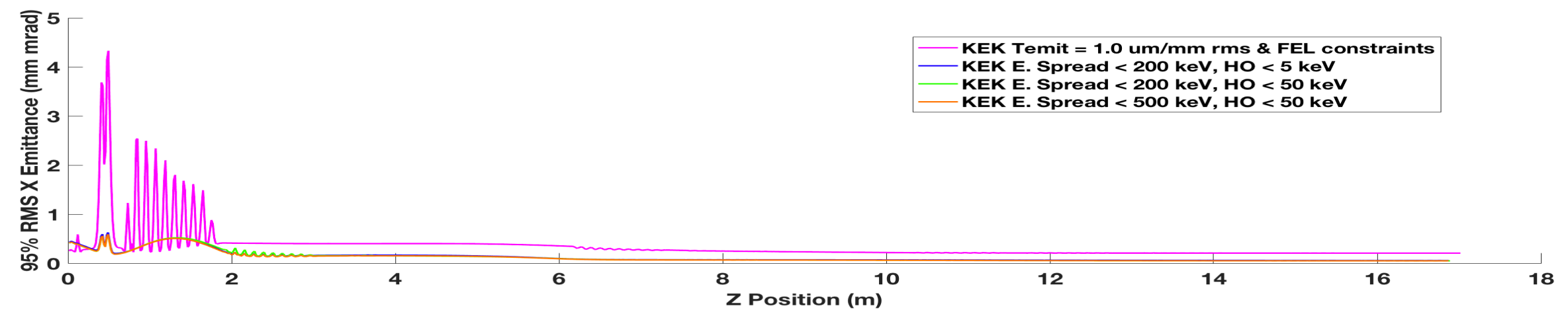
We plot the energy spread, 95% RMS transverse emittance and the bunch length as a function of the injector position, Z, to try and pictorially show which variables had to change to accommodate either a harder constraint value, or more spot size dependent emittance off of the cathode.

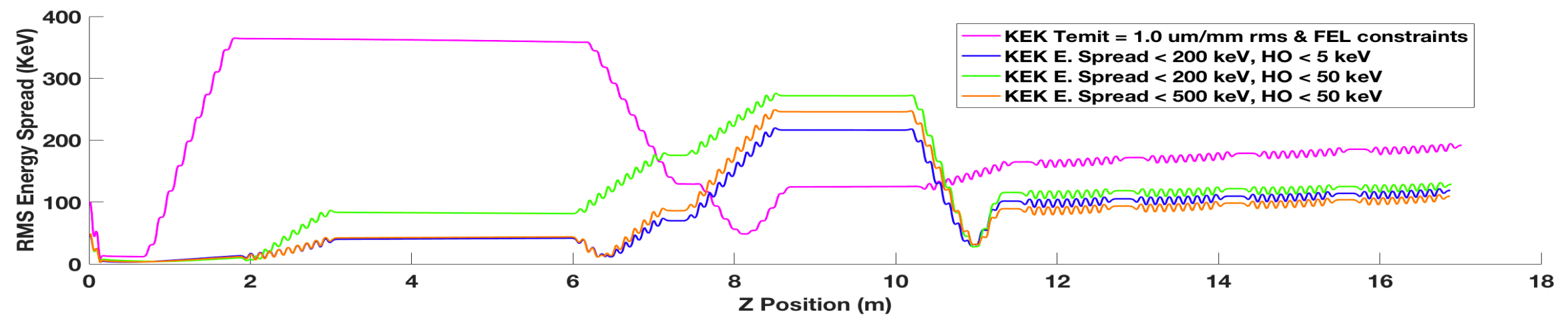


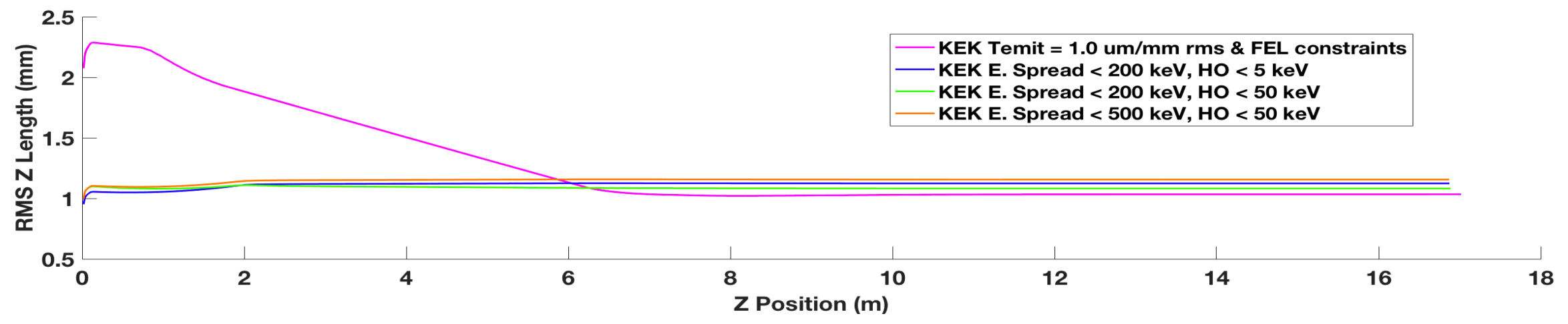




| WiFEL Configuration | Emit. at Cathode mm mrad | 100% X Emit. mm mrad | 95% X Emit. mm mrad | Long. Size mm | E. Spread keV |
|---|---|---|---|---|---|
| E. Spread $<$ 500 keV, HO $<$ 50keV | 0 | 0.071 | 0.035 | 1.07 | 325.5 |
| E. Spread $<$ 200 keV, HO $<$ 50 keV | 0 | 0.072 | 0.041 | 0.89 | 54.8 |
| E. Spread $<$ 200 keV, HO $<$ 5 keV | 0 | 0.091 | 0.063 | 1.0 | 98.7 |
| Thermal Emit $= 0.1\ \frac{\text{mm mrad}}{\text{mm rms}}$ | 0.022 | 0.096 | 0.068 | 1.01 | 81.9 |
| Thermal Emit. = 0.3 | 0.065 | 0.122 | 0.089 | 1.01 | 82.0 |
| Thermal Emit. = 0.5 | 0.088 | 0.140 | 0.110 | 1.11 | 71.7 |
| Thermal Emit. = 0.7 | 0.108 | 0.169 | 0.134 | 0.98 | 116.5 |
| Thermal Emit. = 1.0 | 0.127 | 0.211 | 0.165 | 1.0 | 129.1 |







| KEK Configuration | Emit. at Cathode mm mrad | 100% X Emit. mm mrad | 95% X Emit. mm mrad | Long. Size mm | E. Spread keV |
|---|---|---|---|---|---|
| E. Spread $<$ 500 keV, HO $<$ 50keV | 0 | 0.098 | 0.049 | 1.16 | 109.6 |
| E. Spread $<$ 200 keV, HO $<$ 50 keV | 0 | 0.098 | 0.049 | 1.16 | 109.6 |
| E. Spread $<$ 200 keV, HO $<$ 5 keV | 0 | 0.107 | 0.054 | 1.12 | 119.1 |
| Thermal Emit $= 0.1\ \frac{\text{mm mrad}}{\text{mm rms}}$ | 0.050 | 0.145 | 0.088 | 1.12 | 140.1 |
| Thermal Emit. = 0.3 | 0.060 | 0.140 | 0.105 | 1.09 | 152.0 |
| Thermal Emit. = 0.5 | 0.101 | 0.181 | 0.136 | 1.03 | 194.2 |
| Thermal Emit. = 0.7 | 0.146 | 0.207 | 0.161 | 1.13 | 87.9 |
| Thermal Emit. = 1.0 | 0.185 | 0.269 | 0.207 | 1.03 | 192.0 |

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