Longitudinal Phase Space Study on Injector Beam of High Repetition Rate X-ray FEL

Qiang Gu, Zheng Wang

For the SHINE injector team

Shanghai Advanced Research Institute

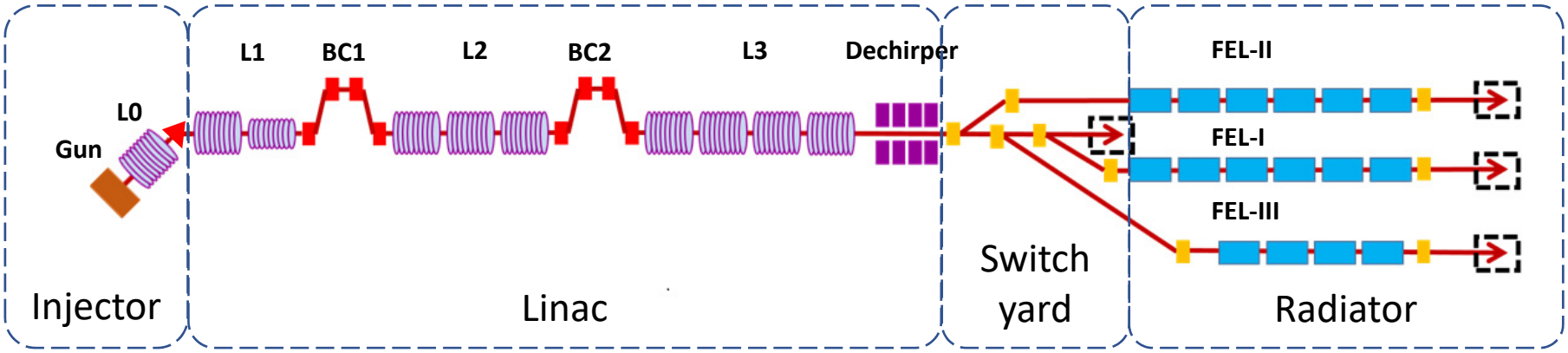
SHINE

Outline

- Motivation
- Longitudinal phase space manipulation in the injector
  - Methods
  - Results
- Summary

SHINE

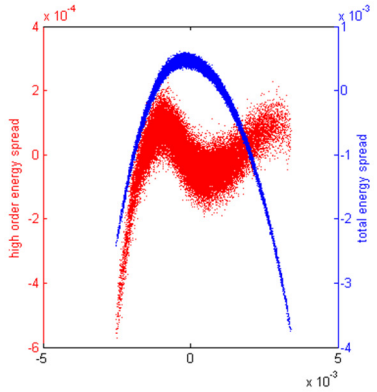
Beam parameters for the high repetition rate X-ray FEL

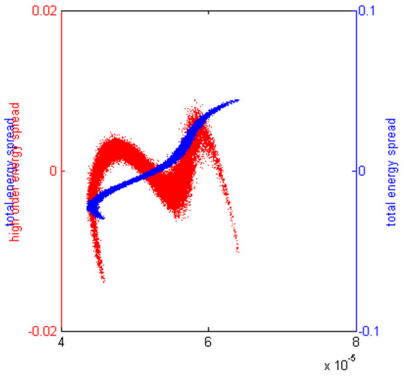


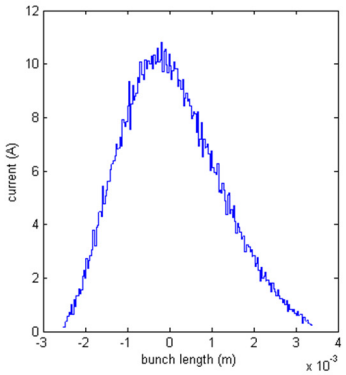
	Parameters	Value	Unit
Linac	Beam energy	8	GeV
	Bunch charge	100	pC
	Repetition rate	0.66	MHz
	Slice emittance, nor.	0.45	umrad
	Peak current	1.5	kA

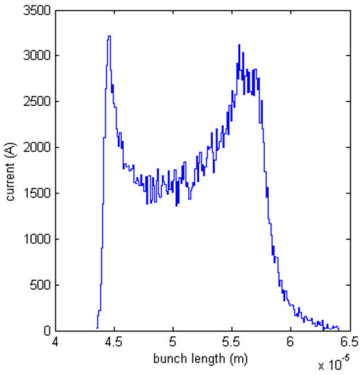
	Parameters	Design value	Unit
FEL-I	Photon energy	3.0-15.0	keV
	Photons per pulse, 10^{-3}BW	>10^{10}@12.4keV	
FEL-II	Photon energy	0.4-3.0	keV
	Photons per pulse, 10^{-3}BW	>10^{12}@1.24keV	
FEL-III	Photon energy	10.0-25.0	keV
	Photons per pulse, 10^{-3}BW	>10^{10}@15.0keV	

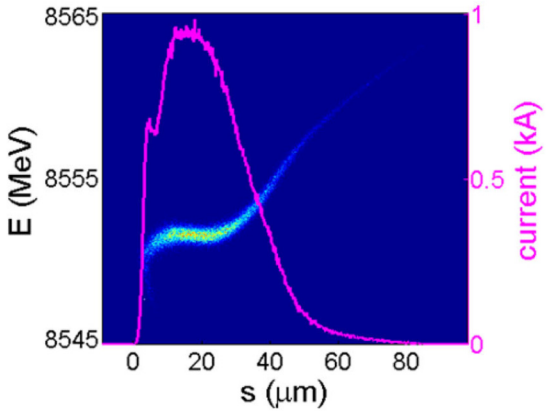
SHINE

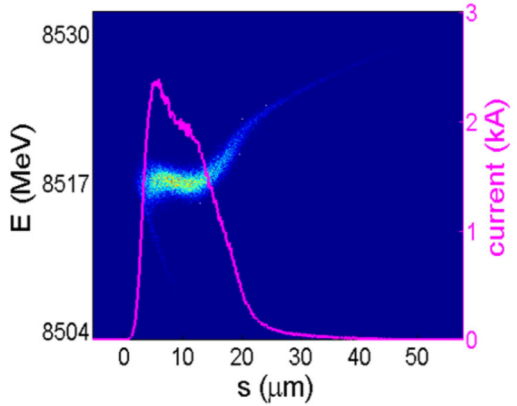






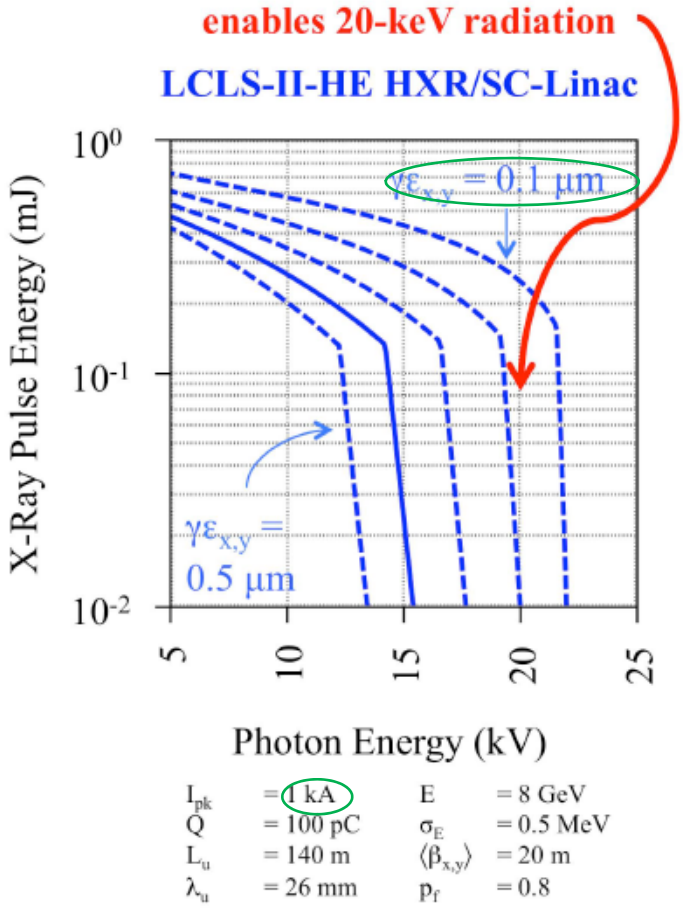


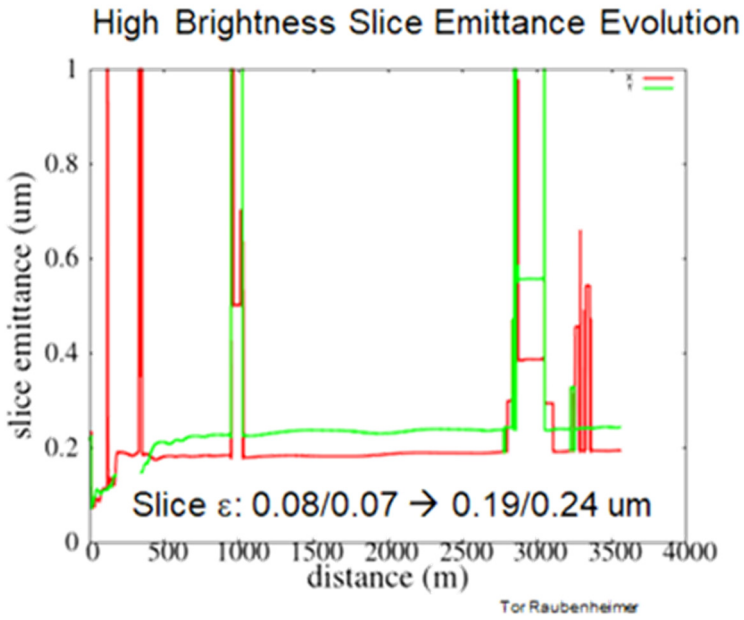




SHINE

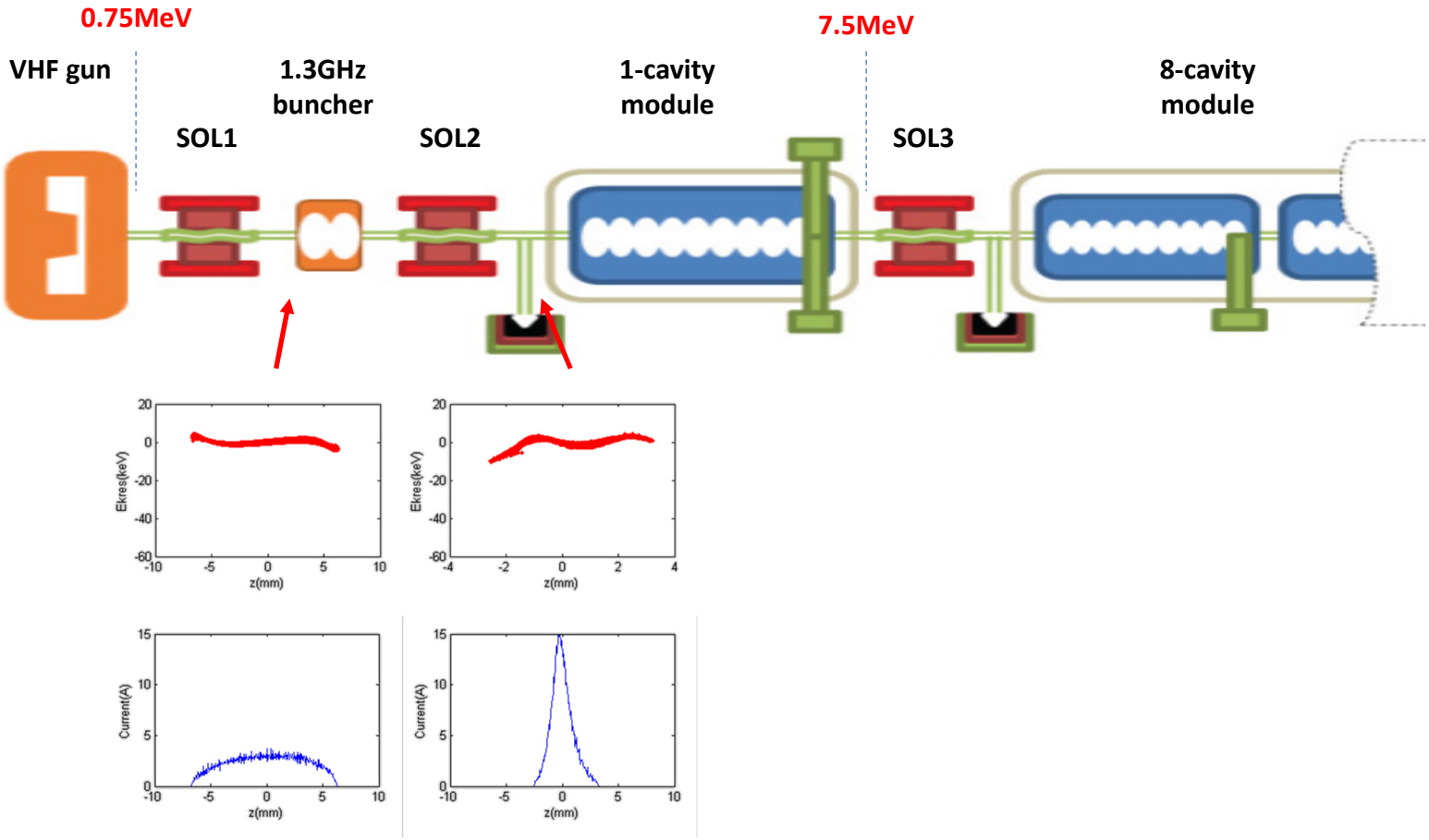
Zhen Wang, et al., NUCL SCI TECH (2018) 29:175





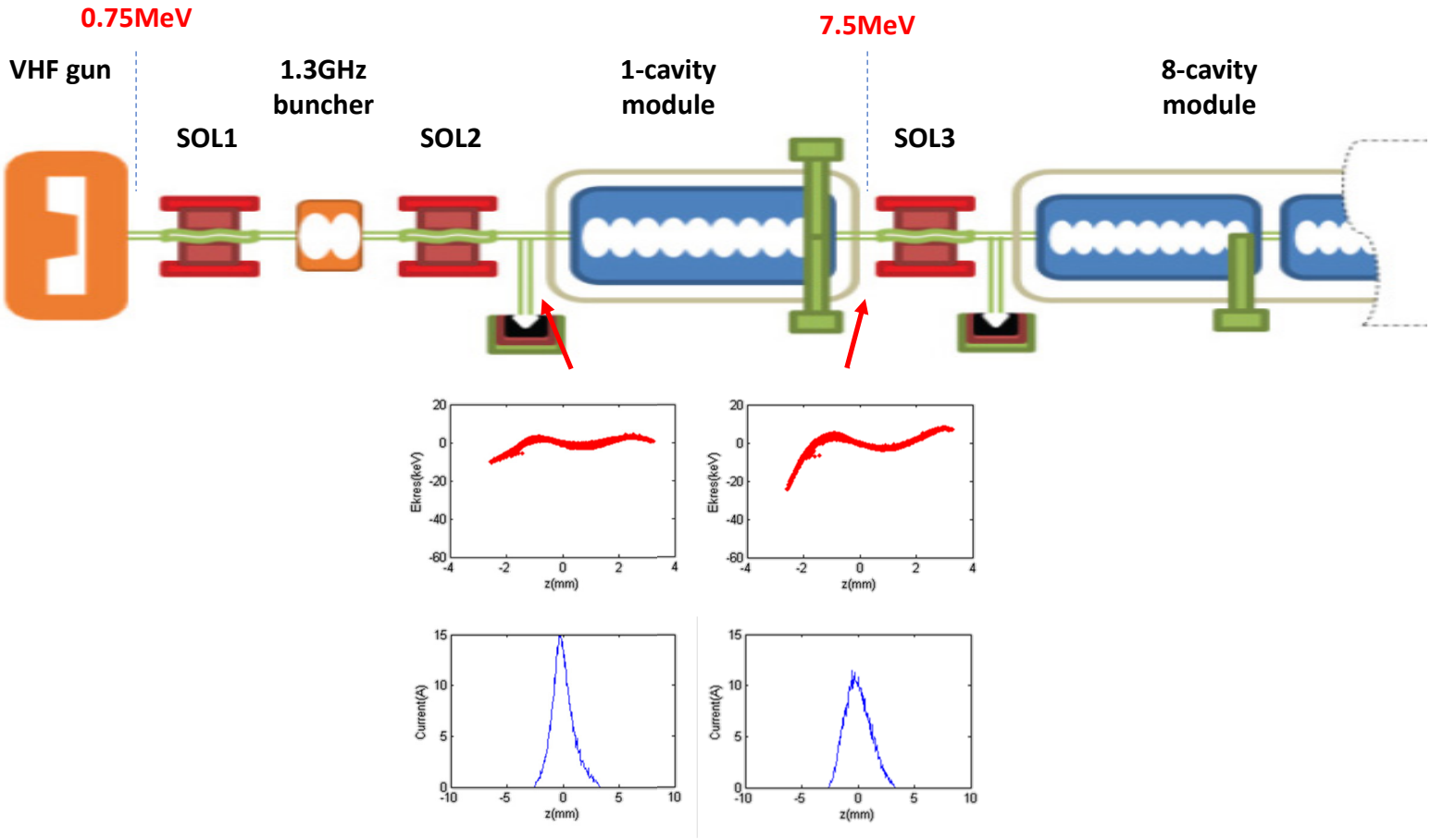
Bruce Dunham, Requirements and Challenges of Photocathodes for Free Electron Laser Applications, P3, 2018

High order energy modulation evolution in the injector



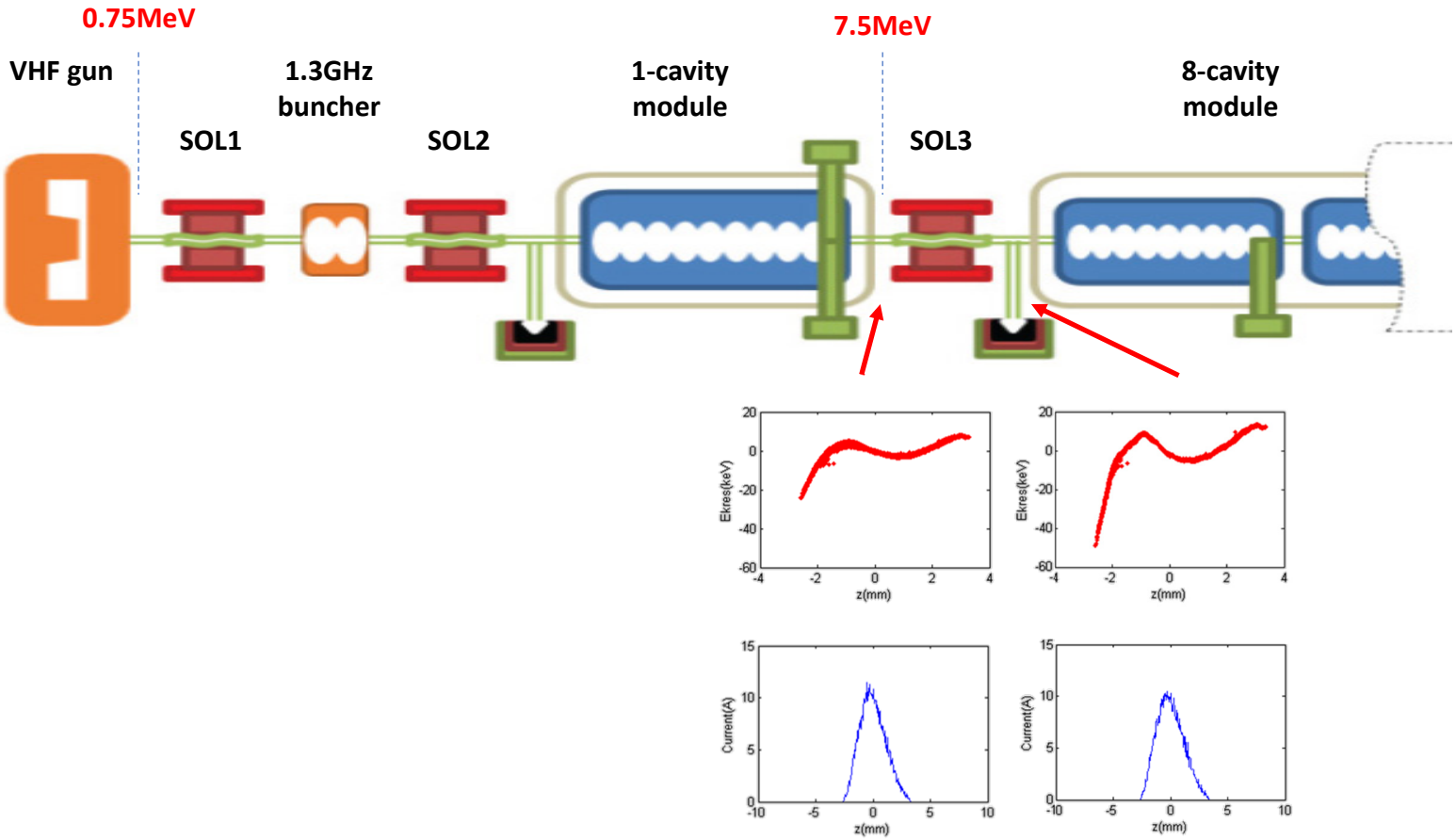
SHINE

High order energy modulation evolution in the injector

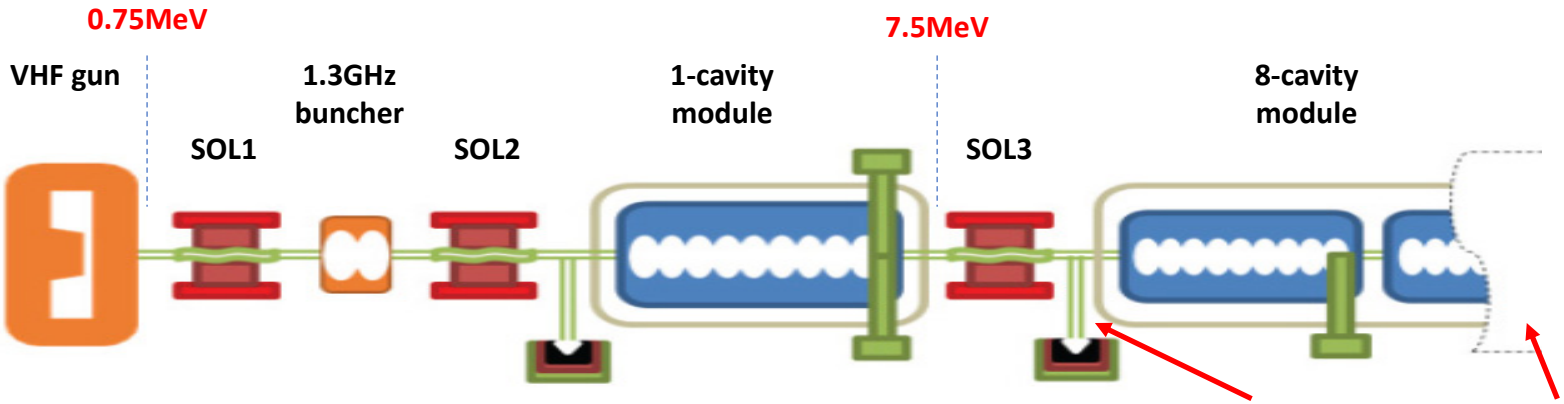


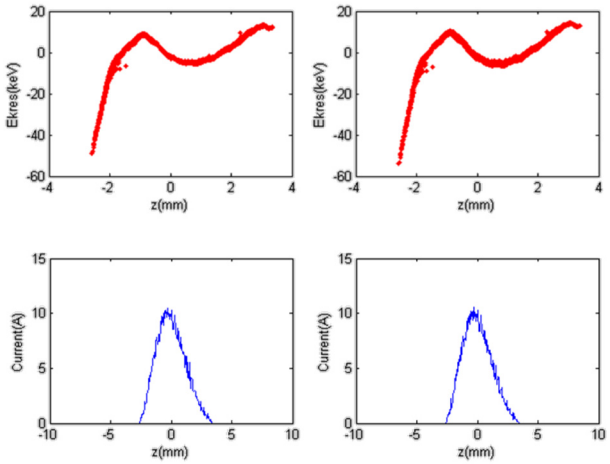
SHINE

High order energy modulation evolution in the injector



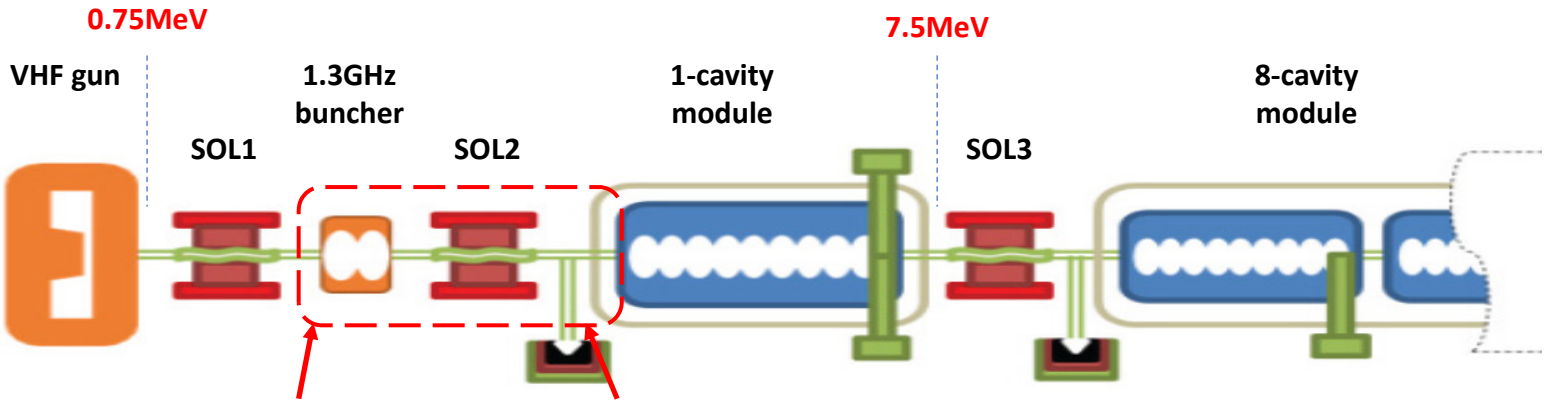
High order energy modulation evolution in the injector

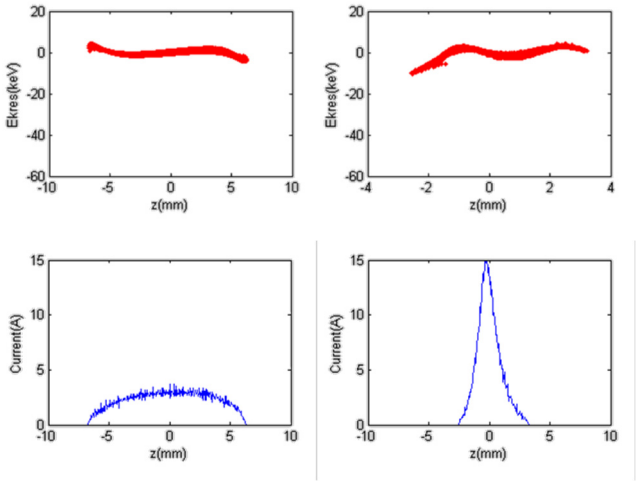




SHINE

High order energy modulation evolution in the injector





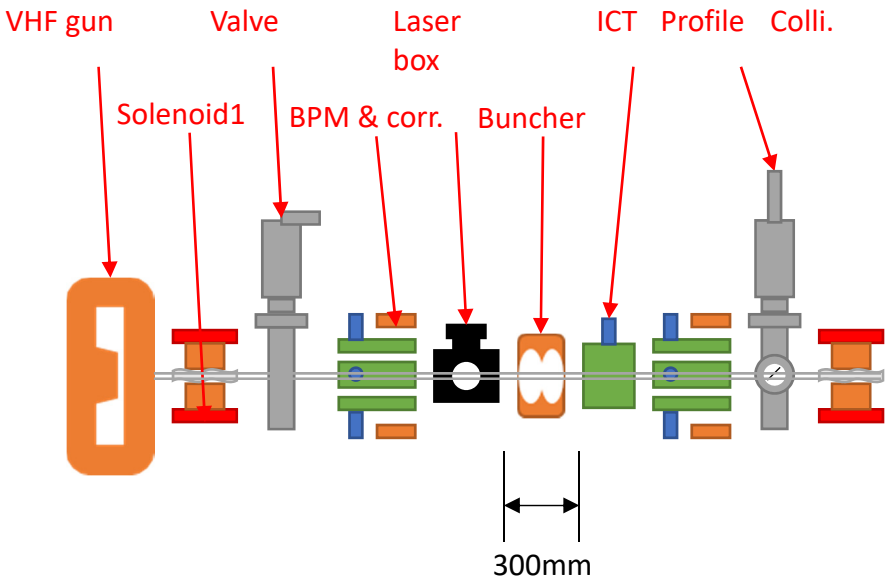
It is the most important area to control the high order energy modulation, as well as density distribution

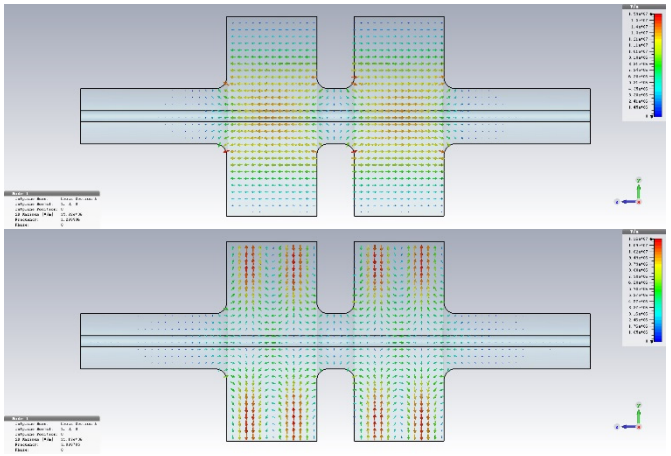
SHINE

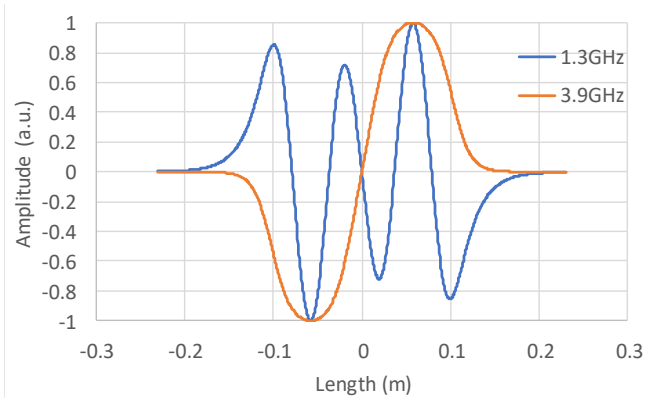
Possible methods to reduced the high order energy modulation

- Increase the bunch length to reduce the space charge force
- Using 3D ellipsoid distribution to linearize the energy modulation by space charge
- Using harmonic cavity to compensate the velocity modulation during bunching
- Using harmonic cavity to linearize the energy modulation by space charge

Harmonic cavity





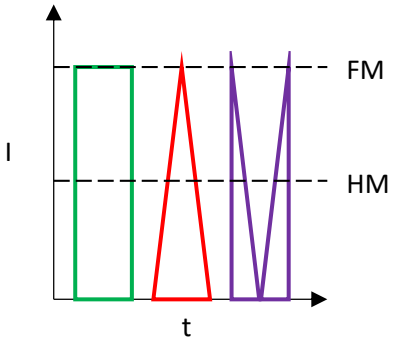


SHINE

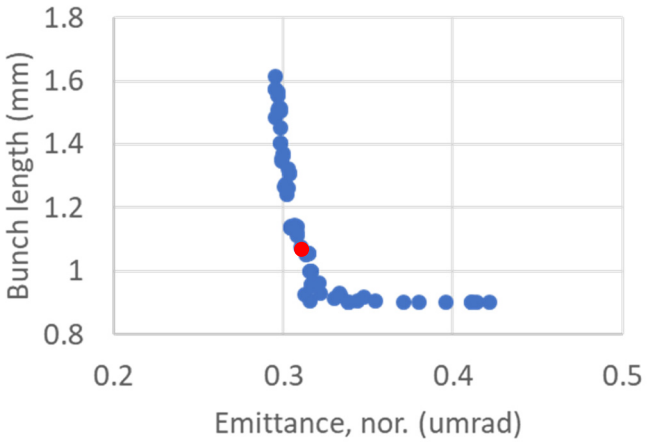
Beam dynamics study setup

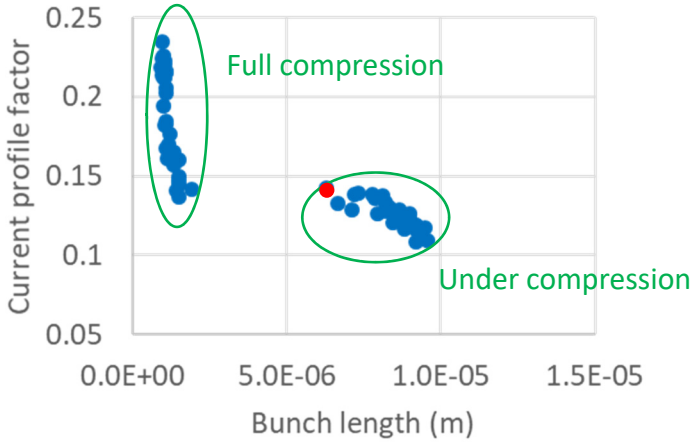
Astra with genetic algorithm

LiTrack with genetic algorithm



Current profile factor
= lower_frac-up_frac

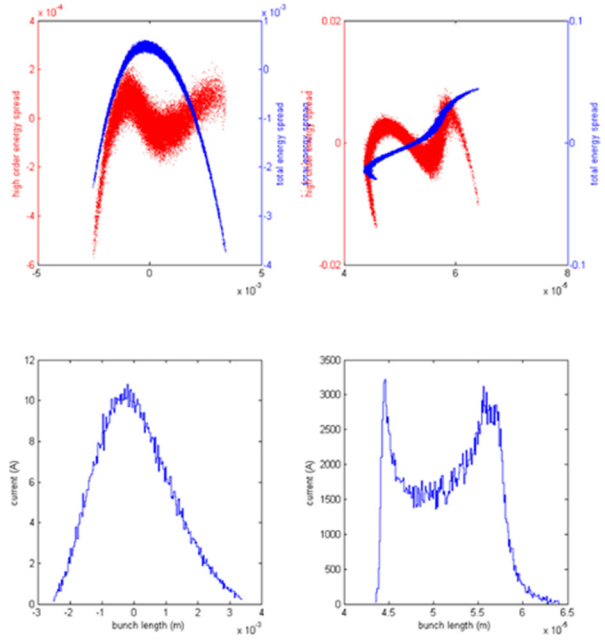




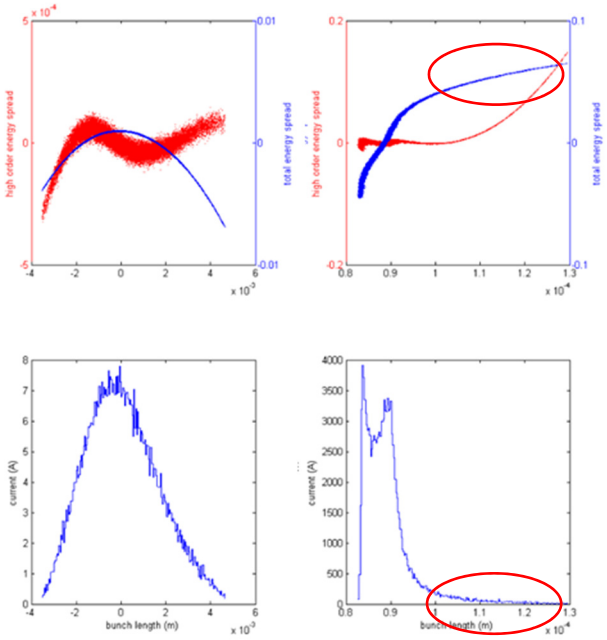
SHINE

Increase the injector beam bunch length

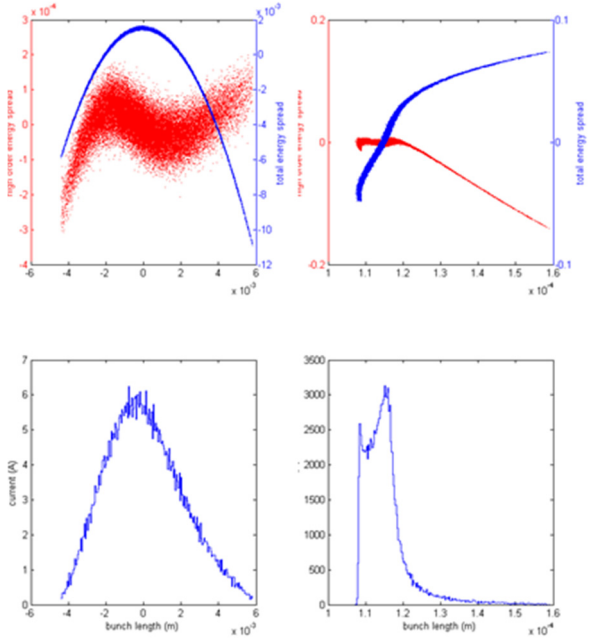
Bunch length
= 1.1mm



Bunch length
= 1.6mm

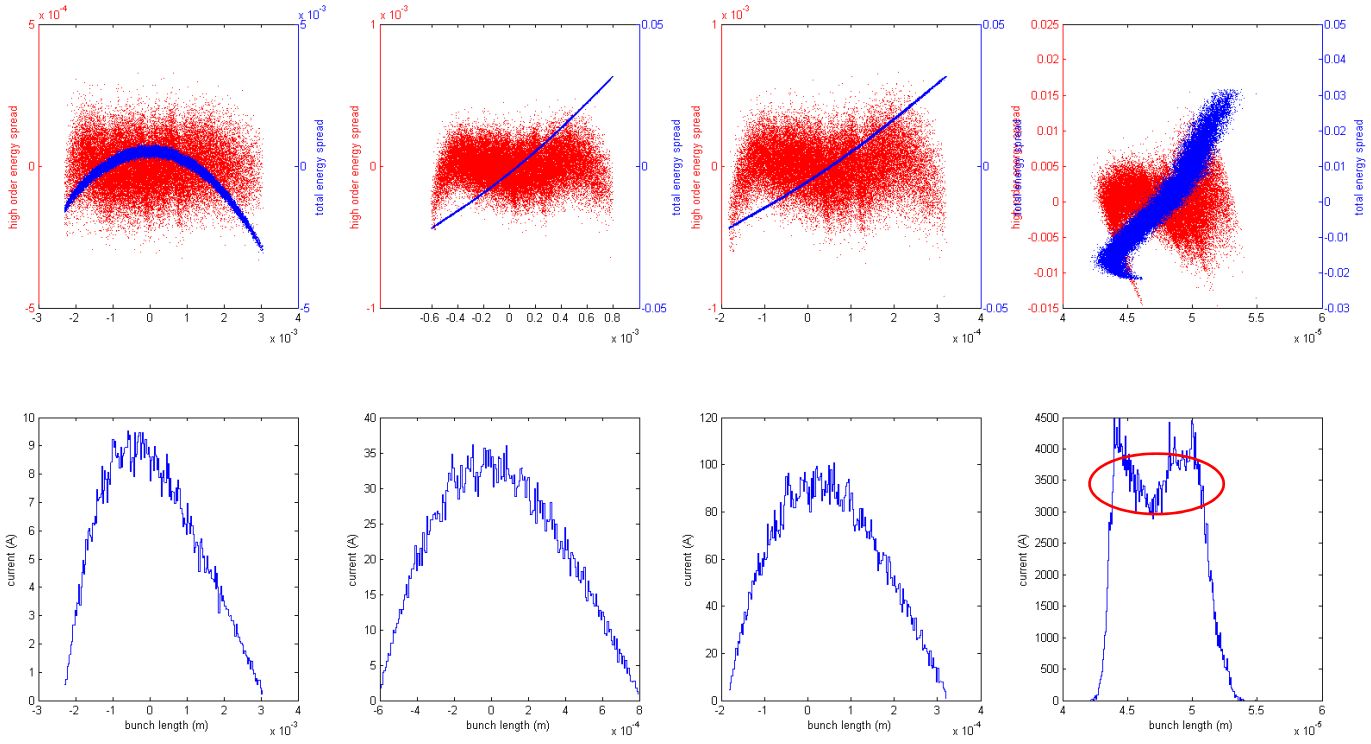


Bunch length
= 2mm



SHINE

3D ellipsoid distribution drive laser at cathode

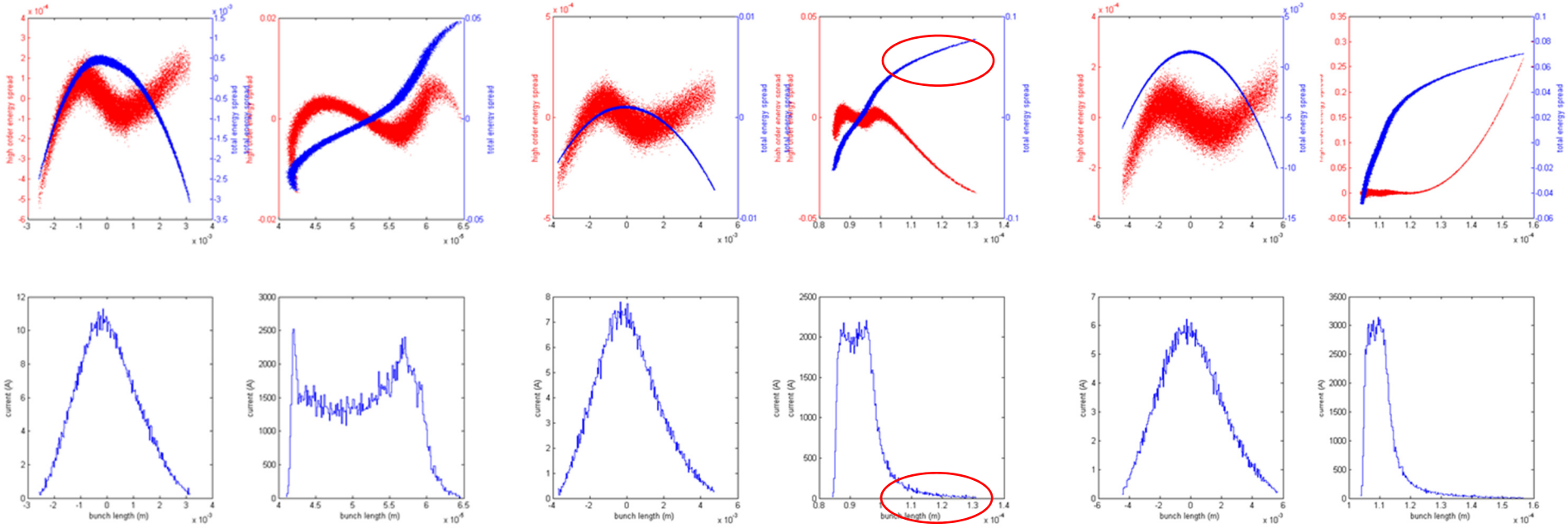


Nonlinear velocity modulation compensating

Bunch length
= 1.1mm

Bunch length
= 1.6mm

Bunch length
= 2mm



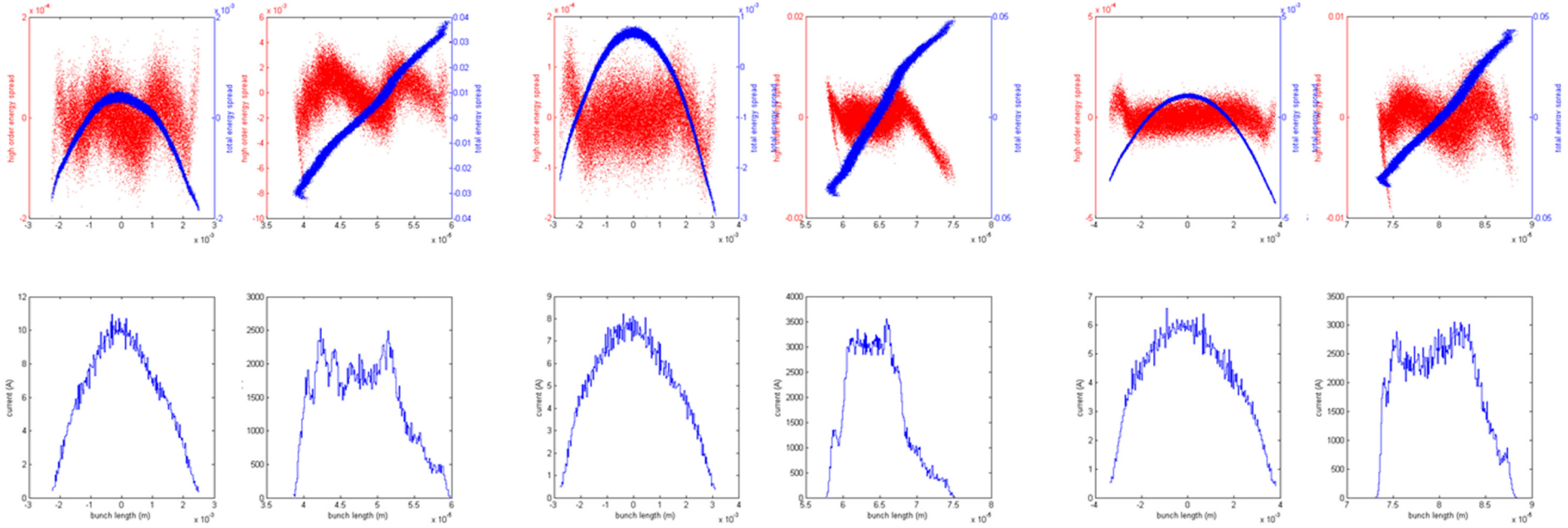
SHINE

Linearizing the energy modulation by harmonic cavity

Bunch length
= 1.1mm

Bunch length
= 1.6mm

Bunch length
= 2mm



SHINE

Summary

- Several methods has been studied to manipulate the longitudinal phase space in the injector and improve the current profile at the linac exit.
- A 3D ellipsoid distribution drive laser on cathode is a straight forward method. There are several approach to get the 3D ellipsoid distribution by pulse stacking, spectrum modulation, nonlinear optics, but there still some limitations to be adopted in the high repetition rate machine. Anyhow it is still considered as an upgrade path in the future.
- With longer injector beam, harmonic cavity could improve the core current profile of linac beam, but the beam tails is lengthened as well.
- The high order energy spread could be compensated by the harmonic cavity, but the cavity voltage is about 1MV for fundamental field and 0.4MV for the harmonic field which could not be supported by the normal conducting structure. With the higher energy gun, optimized injector optics, and SRF technology, this method could be realizable and flexible.

Thank you for your attention
Questions and comments please

SHINE