XFEL Photo Injector Simulations

Preliminary trials to shorten an electron bunch and increase a beam current

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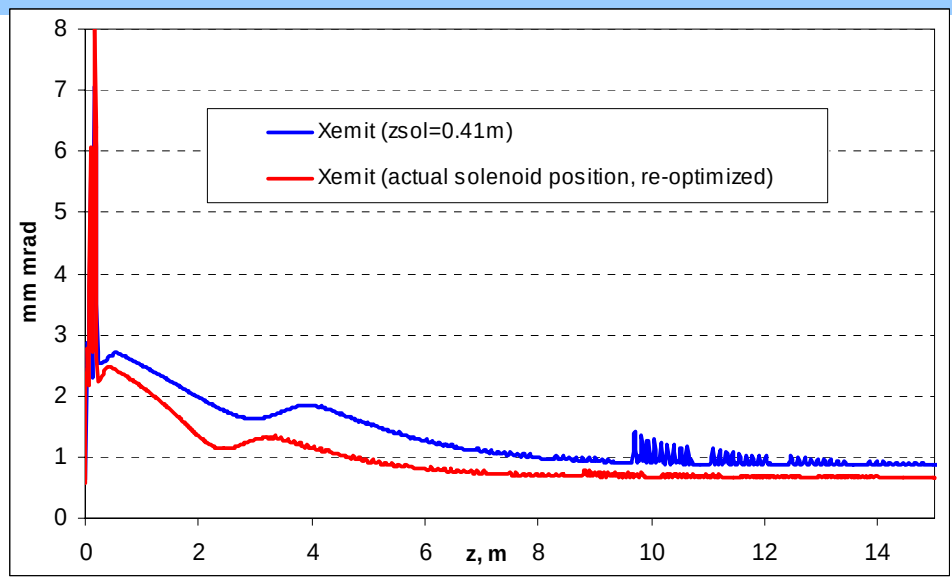
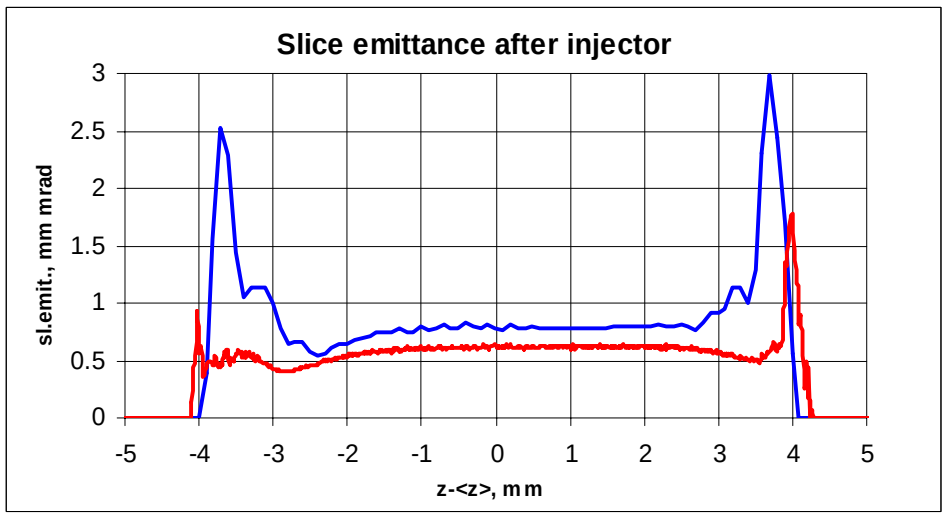
Outline

- Method 1: Cathode laser shorting – 10ps instead 20ps FWHM
- Method 2: Velocity bunching by the first TESLA cavity in ACC1

Optimization for nominal (20ps) cathode laser duration

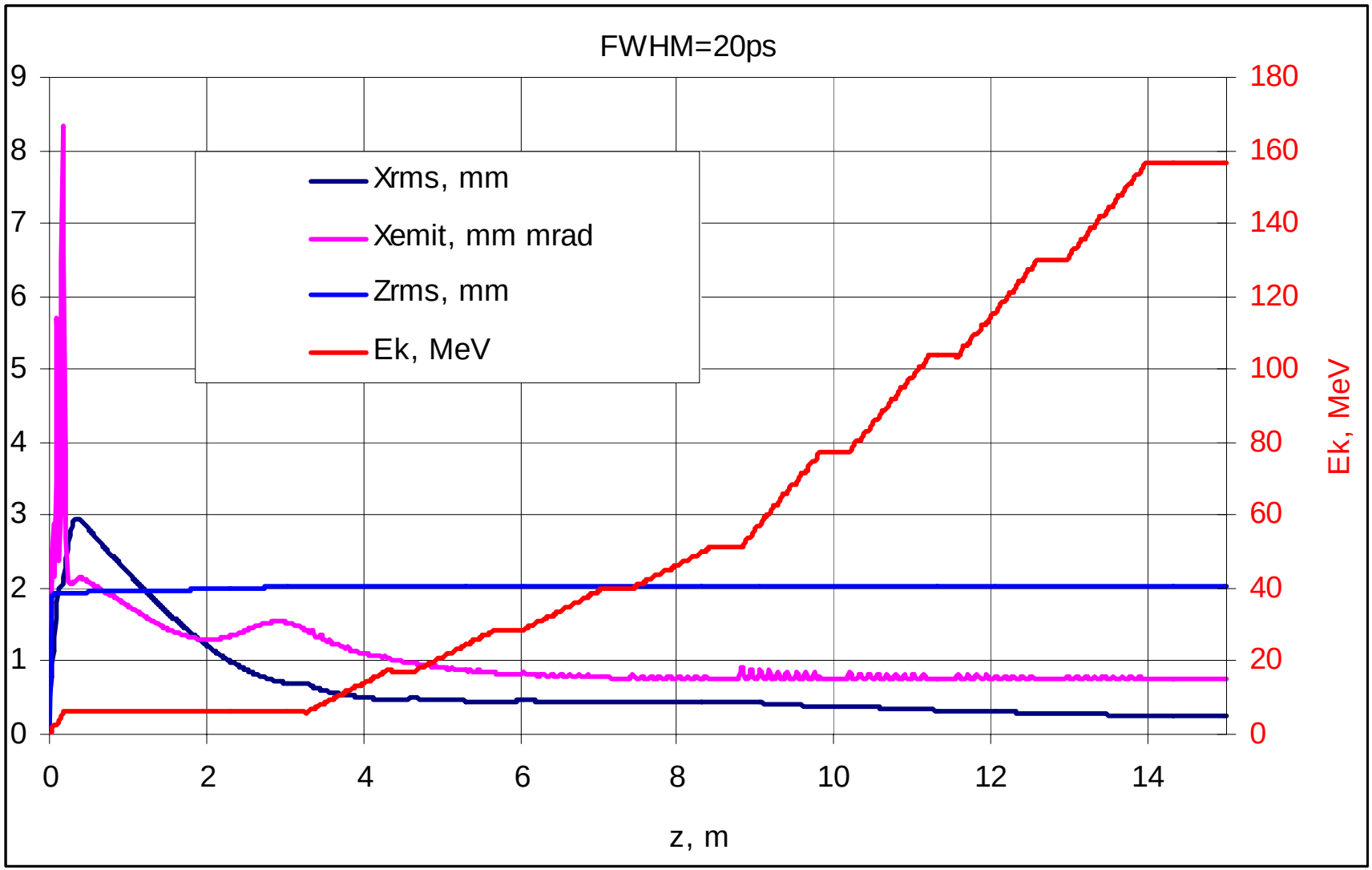
cathode laser	transverse	distribution		homogen.	homogen.
		XYrms	mm	0.55	0.438
	temporal	distribution		flat-top	flat-top
		Lt	ps	19.6	20
		rt	ps	2	2
		Trms	ps	5.69	5.8
	thermal	Ek	eV	0.55	0.55
		emittance	mm mrad	0.46	0.37
gun	RF	Ecath	MV/m	60	60
		launch phase	deg	-1.64	-0.55
	solenoid	z-position	m	**0.41**	**0.276**
		MaxB(1)	T	-0.1938	-0.22466
		MaxB(2)	T	0.000551	0.01113
booster	4xTESLA	z-position	m	4.66(+1.66)	3.77(+0.78)
		Emax	MV/m	15	21.5
		phase	deg	-16	-15.7
ACC1	4xTESLA	Emax	MV/m	50	50
		phase	deg	-16	-15.7
sim.	ASTRA	number of part.		200k	200k
e-beam	@z=15m	charge	nC	1	1
		energy	MeV	143	157
		trans.emittanc	mm mrad	**0.87**	**0.676**
		slice emit.(cen	mm mrad	0.83	0.639
		rms en. spread	MeV	1.8	2.1
		long.emittance	mm keV	346	460
		rms length	mm	1.9	2.0





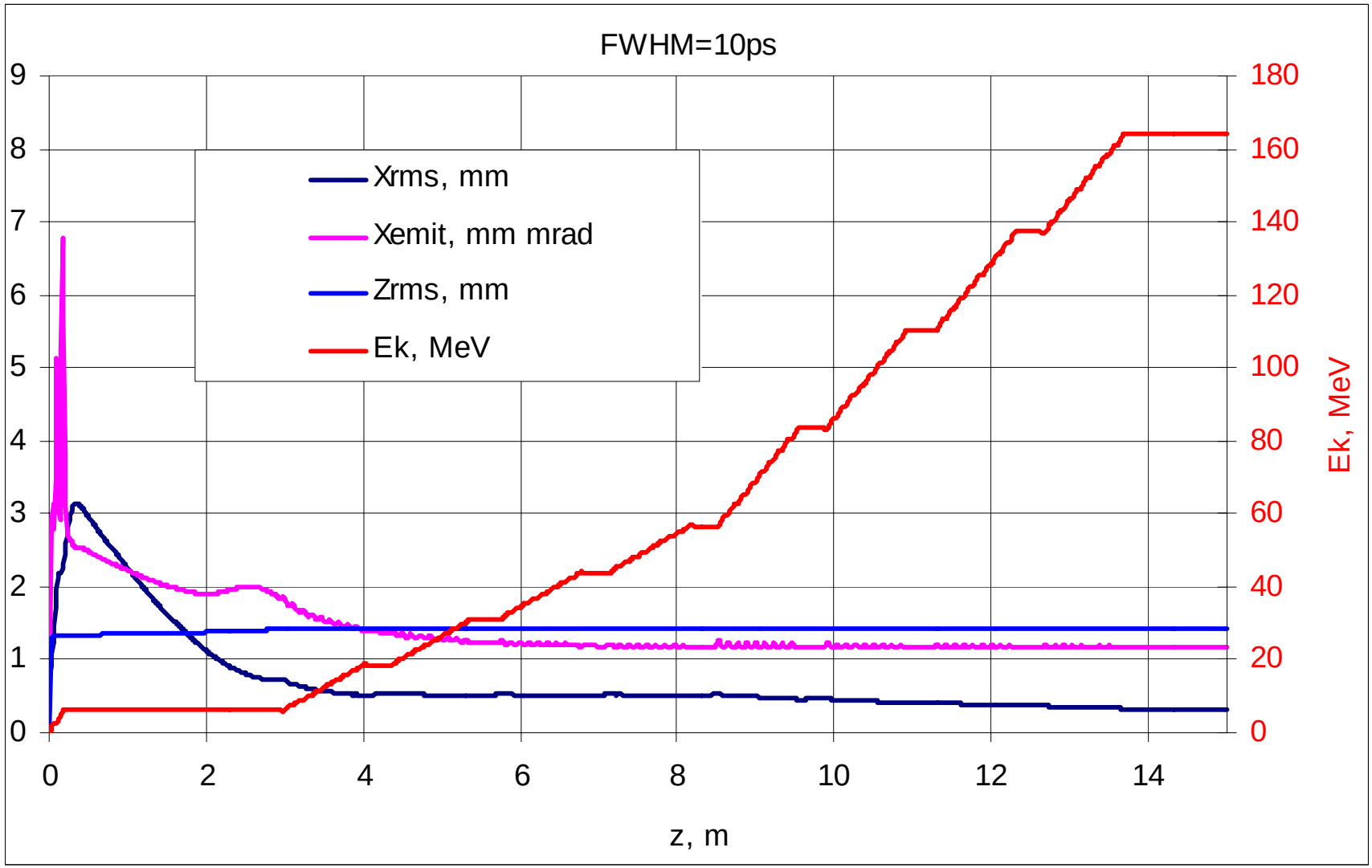
Method 1: Cathode laser shorting – 10ps instead 20ps FWHM

"Nominal" → Cathode laser FWHM=20ps



10 ps cathode laser FWHM, preliminary (10k ASTRA macroparticles) optimization

Cathode laser: FWHM=10ps, rise/fall time=2ps



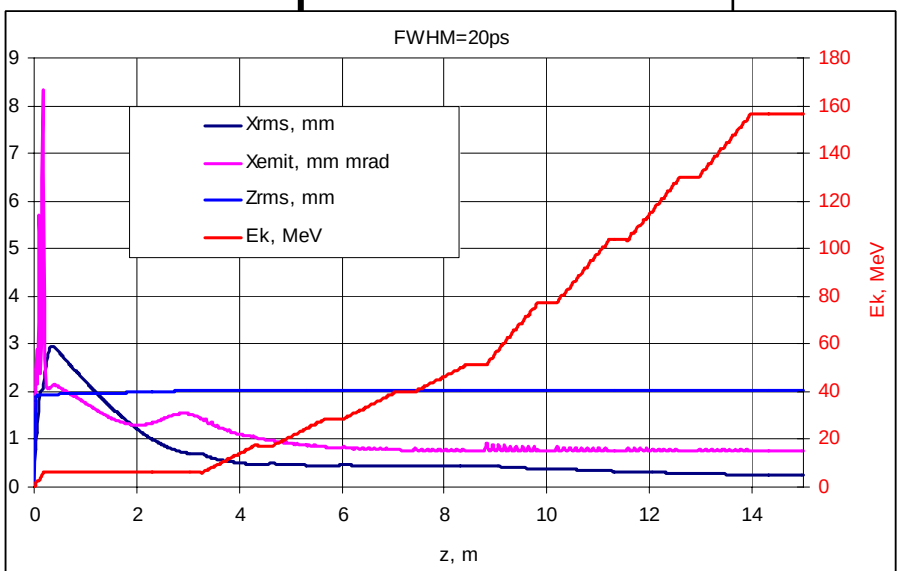
10 ps cathode laser FWHM, preliminary (10k ASTRA macroparticles) optimization

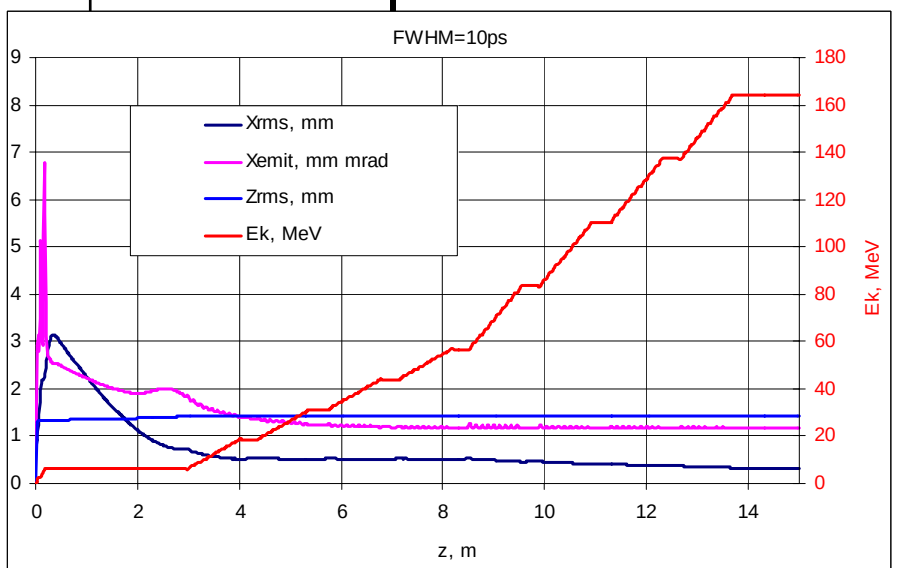
Optimized parameters

	20 ps	**10 ps**
Cath.laser XYrms, mm	0.438	0.559
Gun phase, deg	-0.56	-5.11
Solenoid peak field, T	-0.22466	-0.225203
Booster Emax, MV/m	21.5	23.5399
Booster phase, deg	-15.7	-9.796
Booster position, m	3.77(+0.78)	3.49(+0.5)
Bunch rms length, mm	**2.1**	**1.4**
Norm.tr.emittance, mm mrad	**0.68**	**1.17**

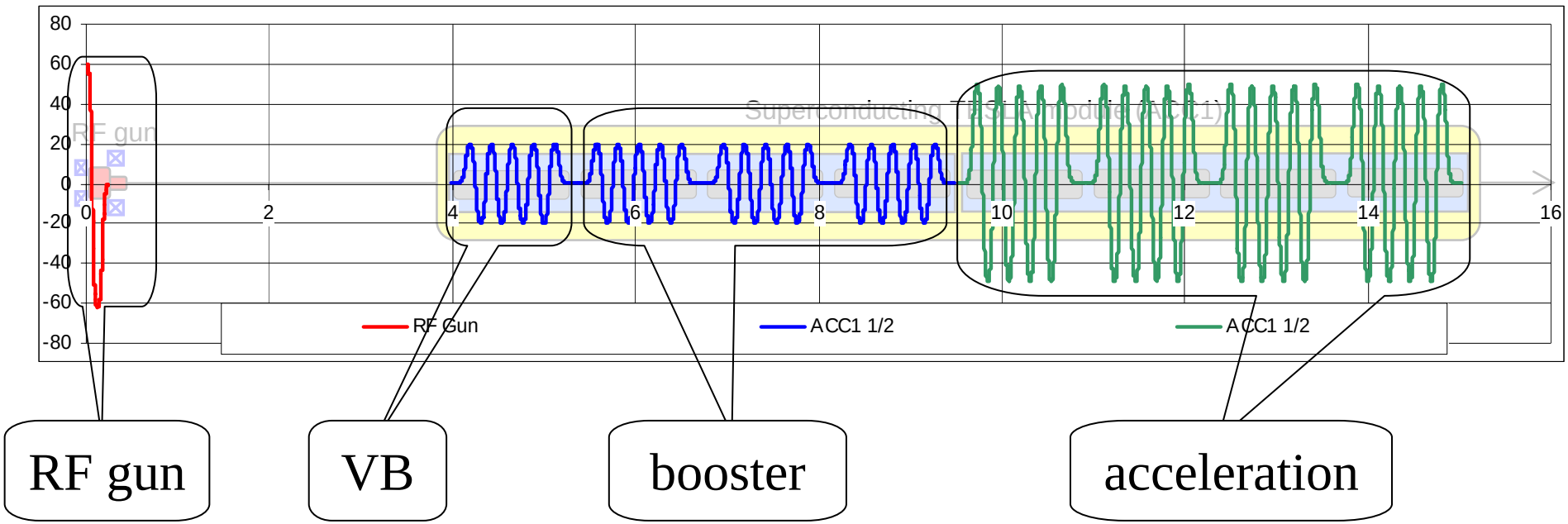
LSC

Cathode laser:
- FWHM=10ps
- rise/fall time=2ps
- Ek=0.55eV





Method 2: Velocity bunching



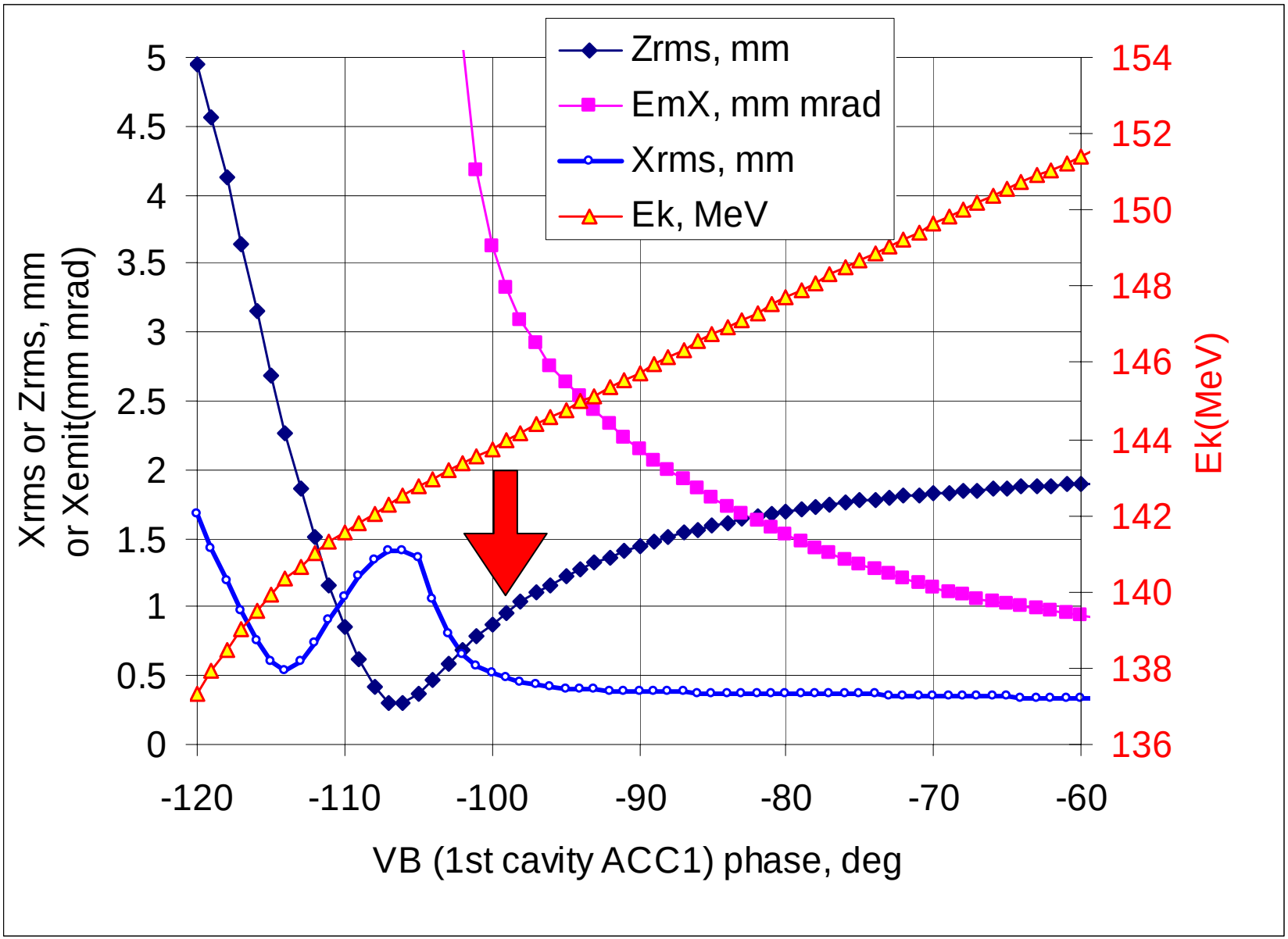
RF gun

VB

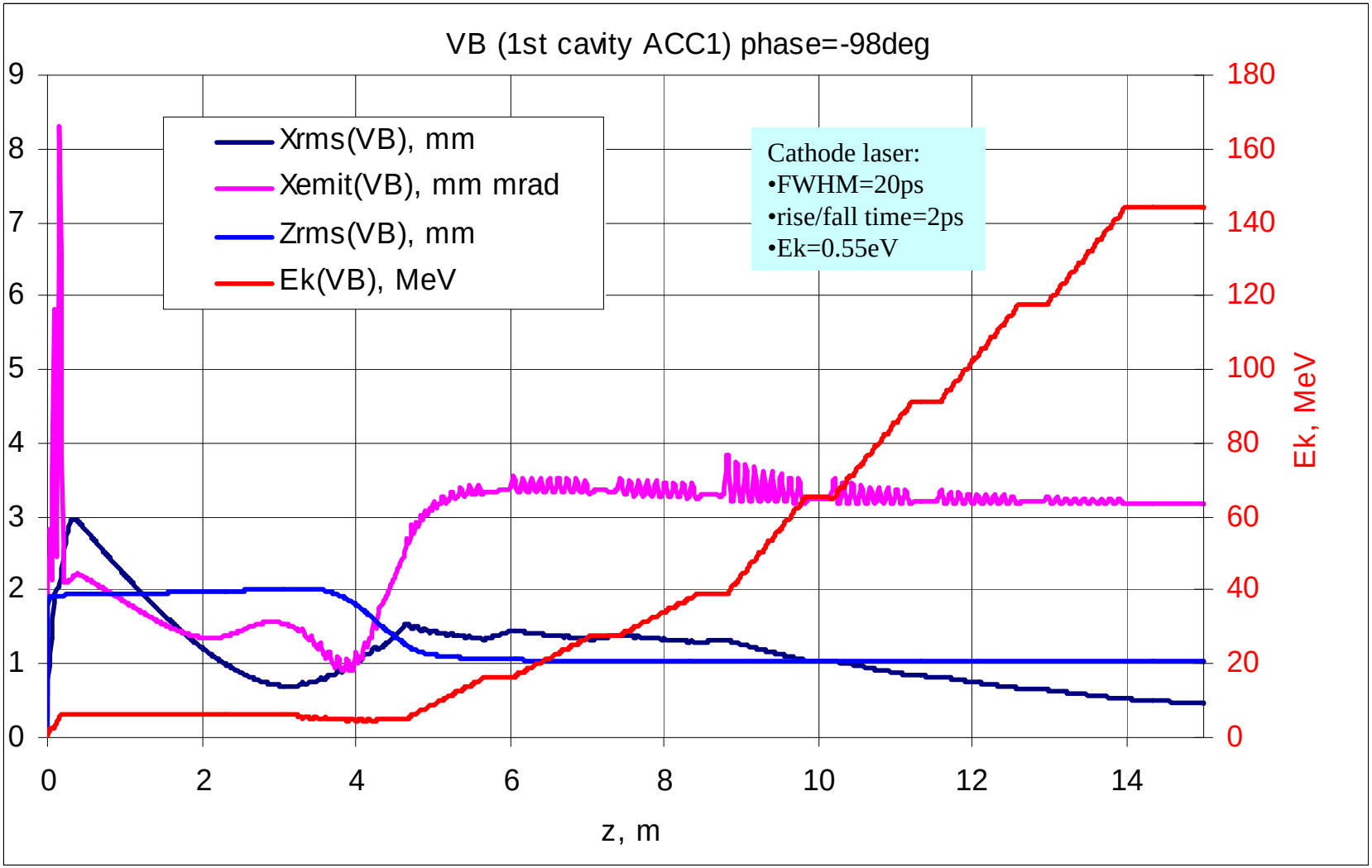
booster

acceleration

Velocity bunching. Beam parameters vs. first cavity phase

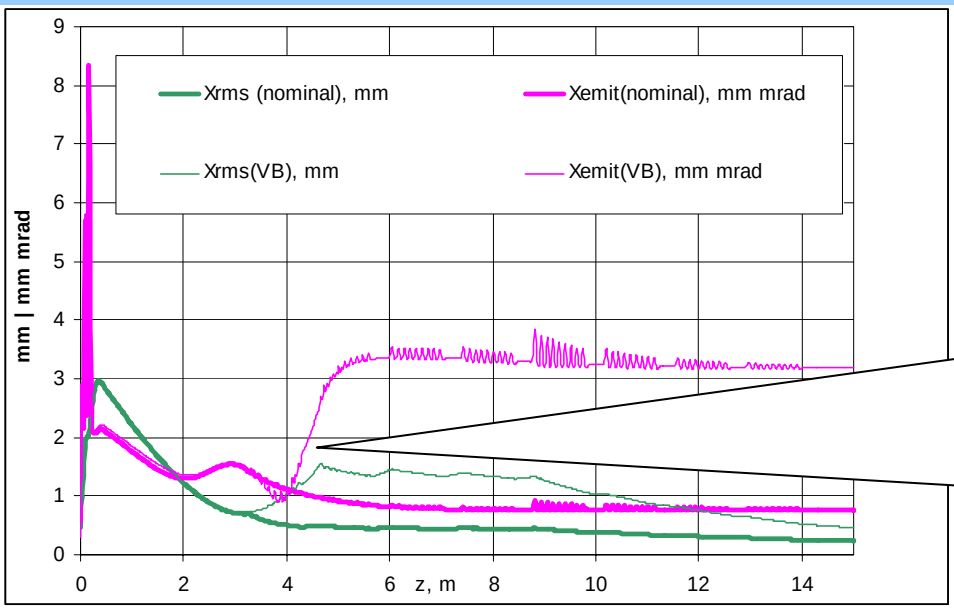


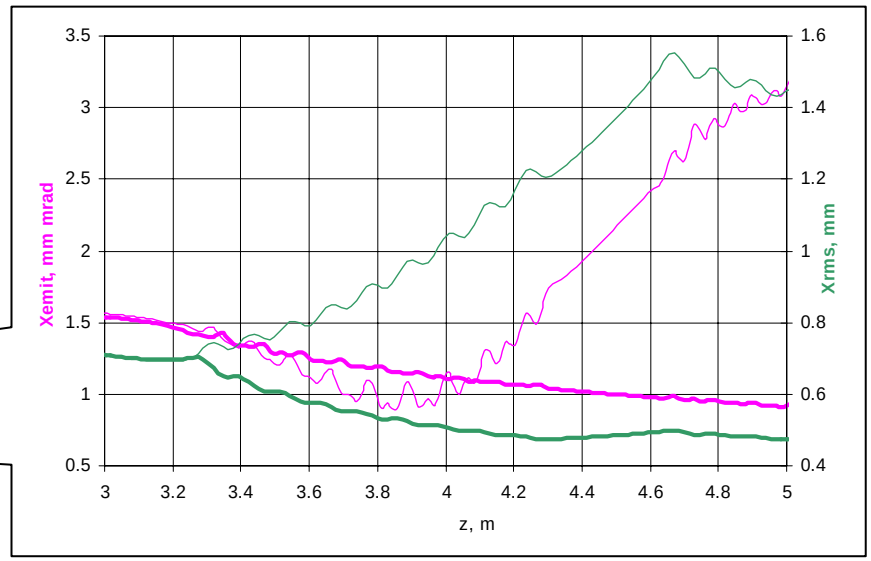
Velocity bunching. First cavity phase=-98deg

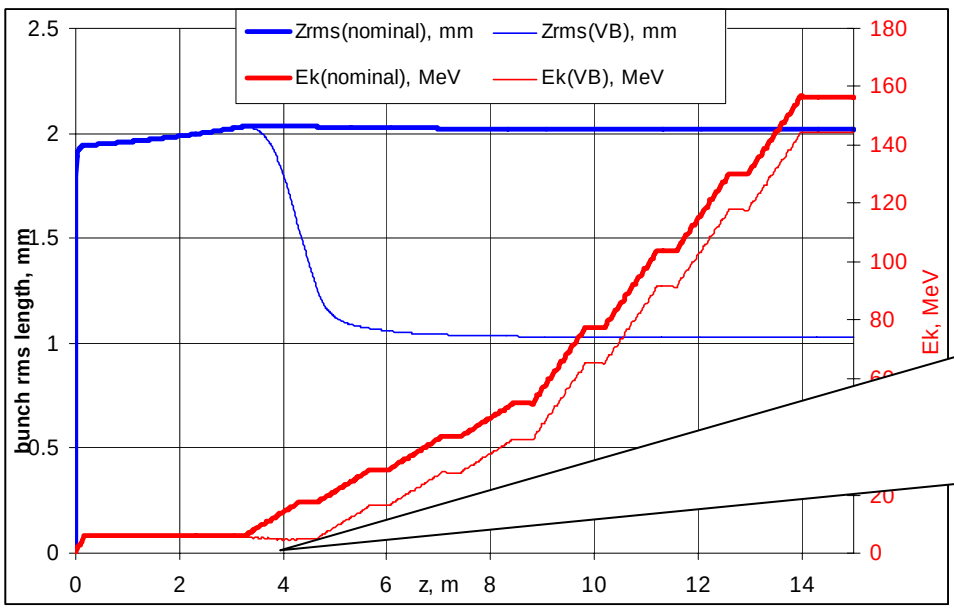


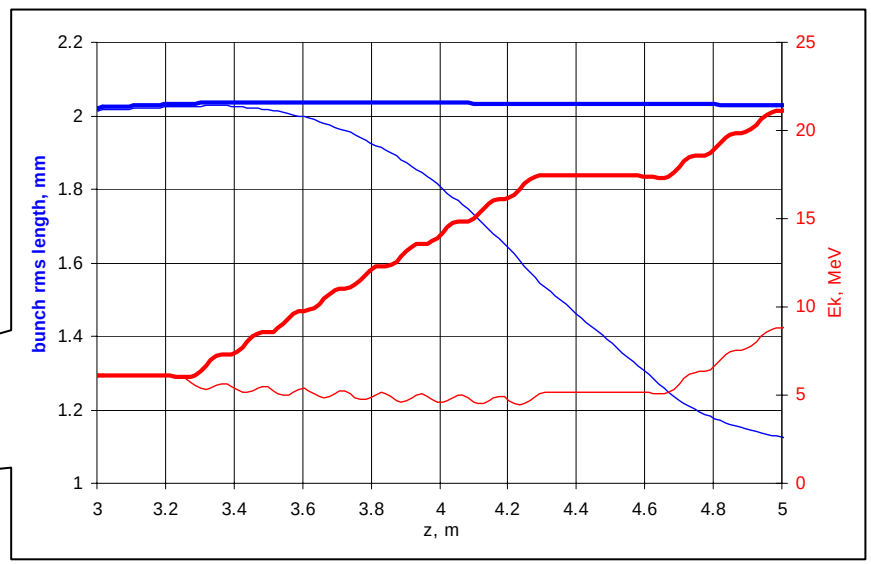
Not optimized:
- Main solenoid and cathode laser XYrms
- ACC1 position and booster gradient and phase

Velocity Bunching (VB) vs. **Nominal Case** (20ps)









10ps and Velocity Bunching (VB) vs. Nominal Case (20ps)

Based on **projected** parameters

	nominal	10ps	VB*
Zrms	2.1	1.4	1.03
Xemit	0.68	1.17	3.19
Q	1	1	1
~B	1.03	0.52	0.10

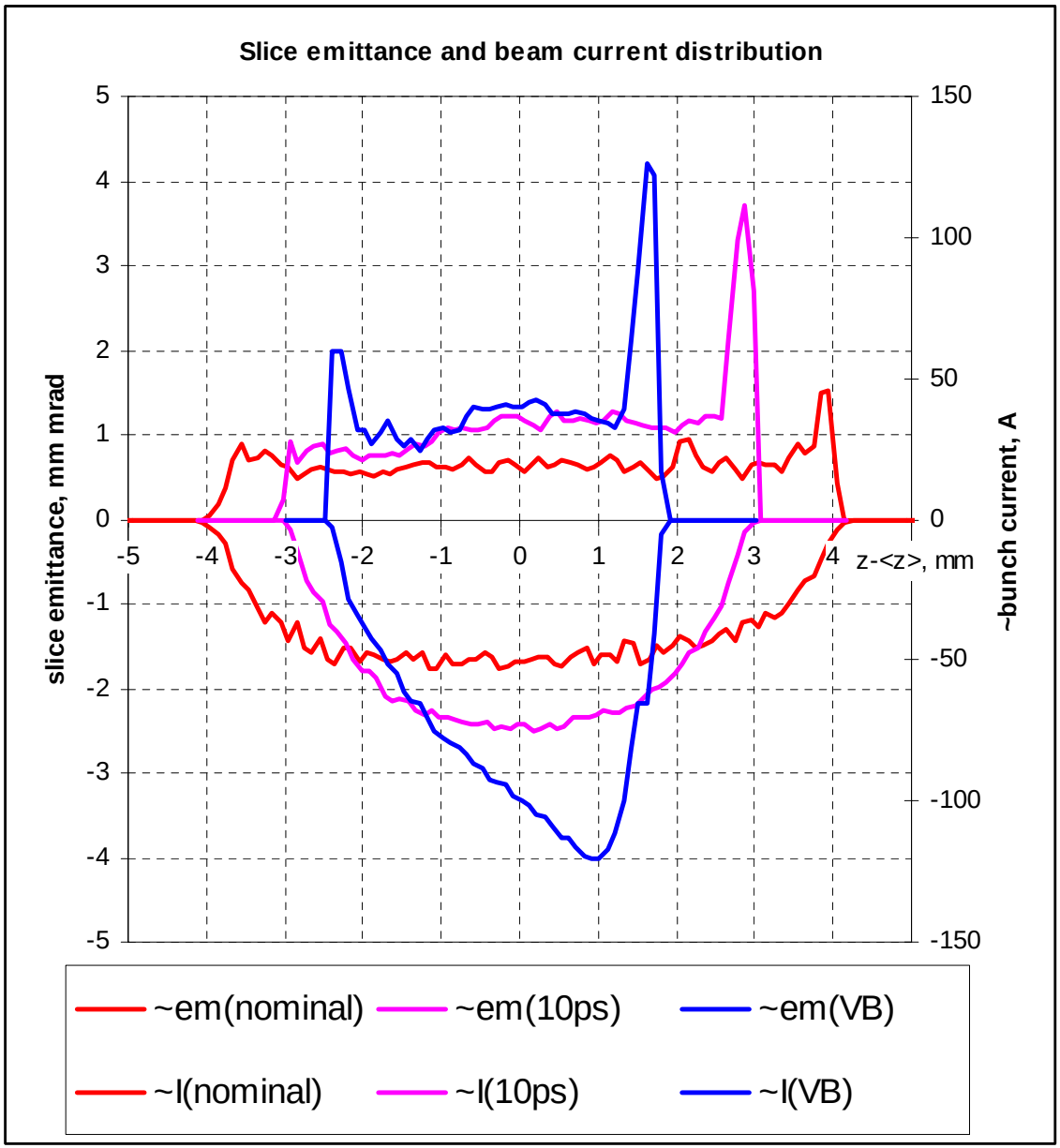
$$?B \sim \frac{Q}{Z_{rms}\varepsilon^2}?$$

XFEL photo injector options:

- Case 10 ps in a factor 2 worse
- VB* in a factor 10 worse

VB* = not optimized velocity bunching

Slice parameters at z=15m



- Nominal 20 ps
- 10 ps FWHM
- Velocity bunching (VB)

Based on **slice** parameters

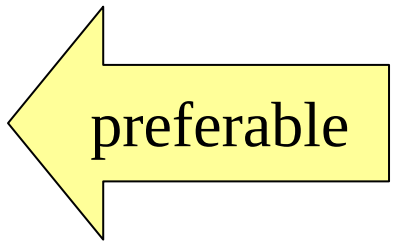
	nominal	10ps	VB	
Ipeak	50	75	100(center)	120(peak)
Xemit	0.6	1.2	1.3	1.2
~B	139	52	59	83

XFEL photo injector options:

- Case 10 ps in a factor ~2.7 worse
- VB in a factor ~1.7-2.3 worse

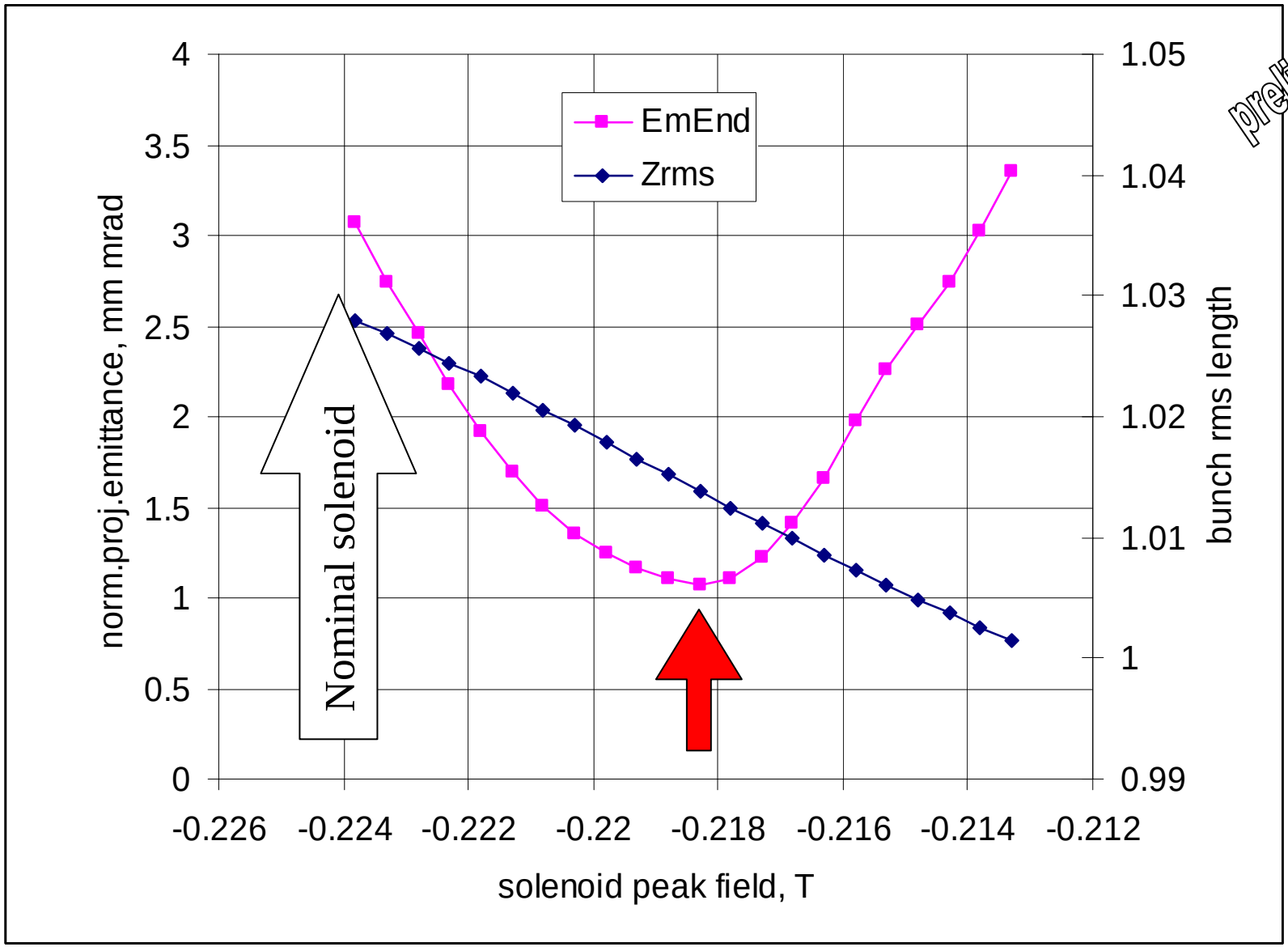
Velocity bunching optimization

- Fixed setup (ACC1 position):
  - Tune Imain and cathode laser XYrms
  - VBuncher gradient and phase
  - Booster gradient and phase*
  - ACC1(2nd half) gradient and phase**

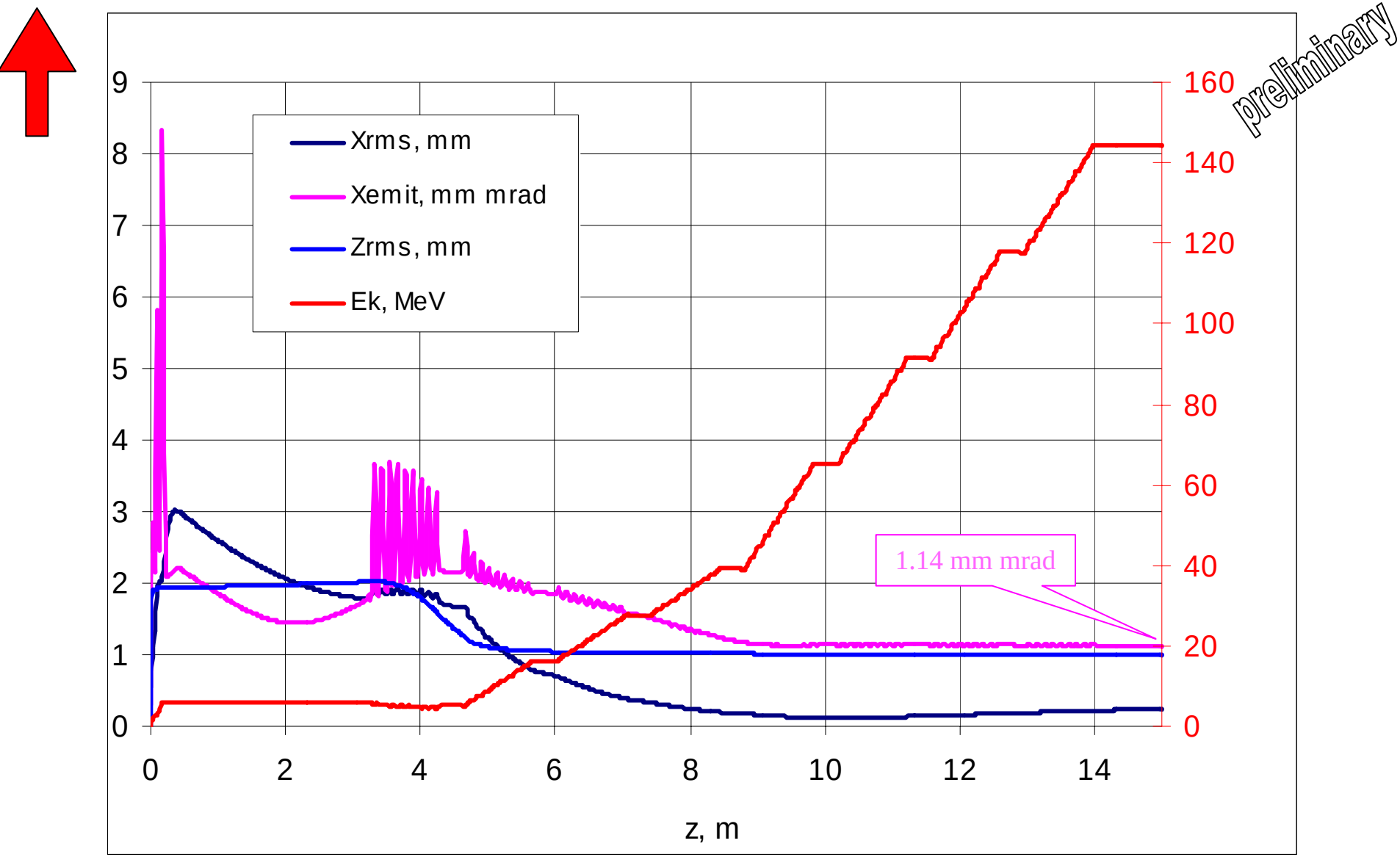


- CDS buncher+solenoid around + ACC1:
  - Plenty optimization work

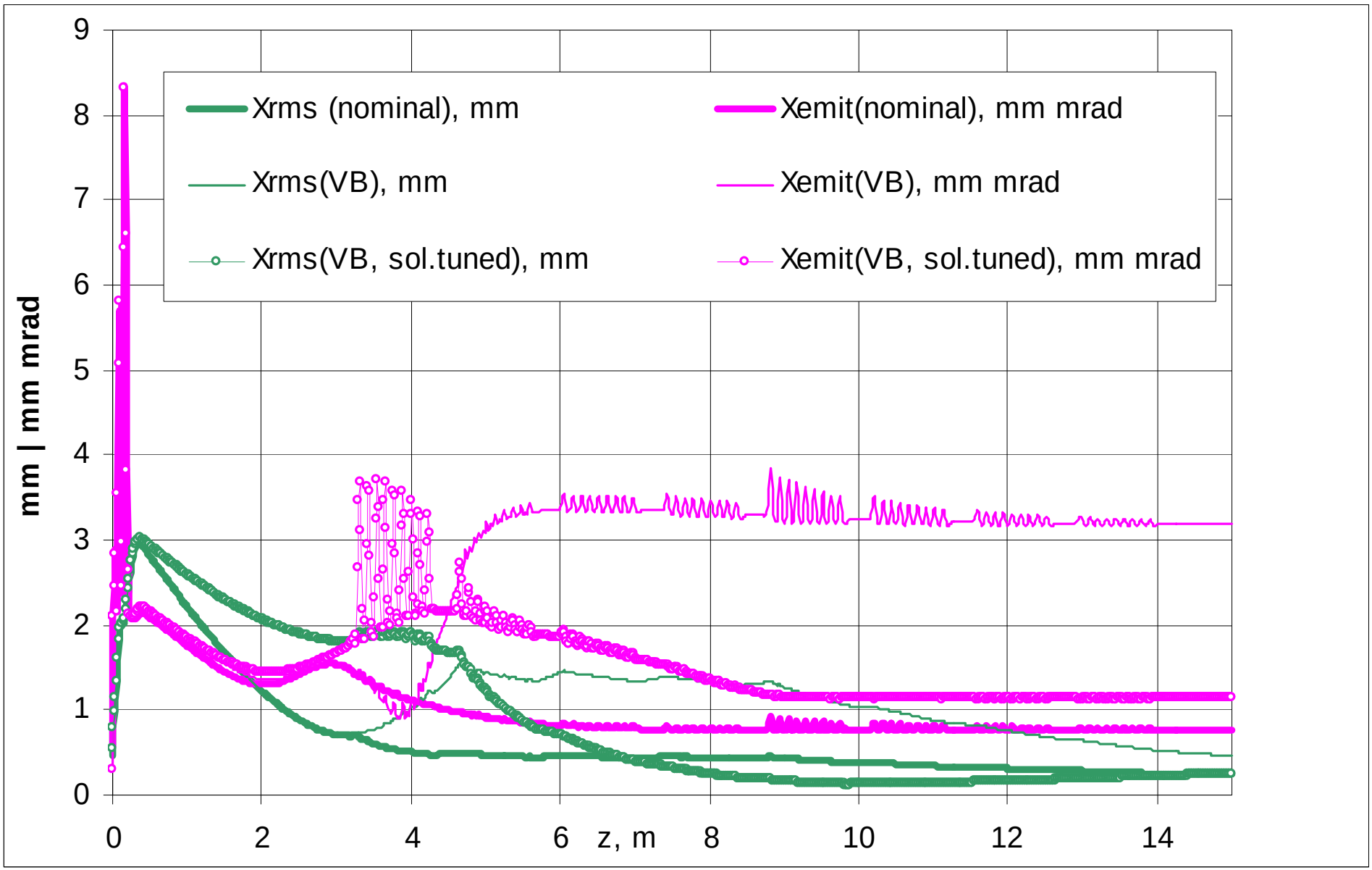
Appendix. Velocity bunching, solenoid scan



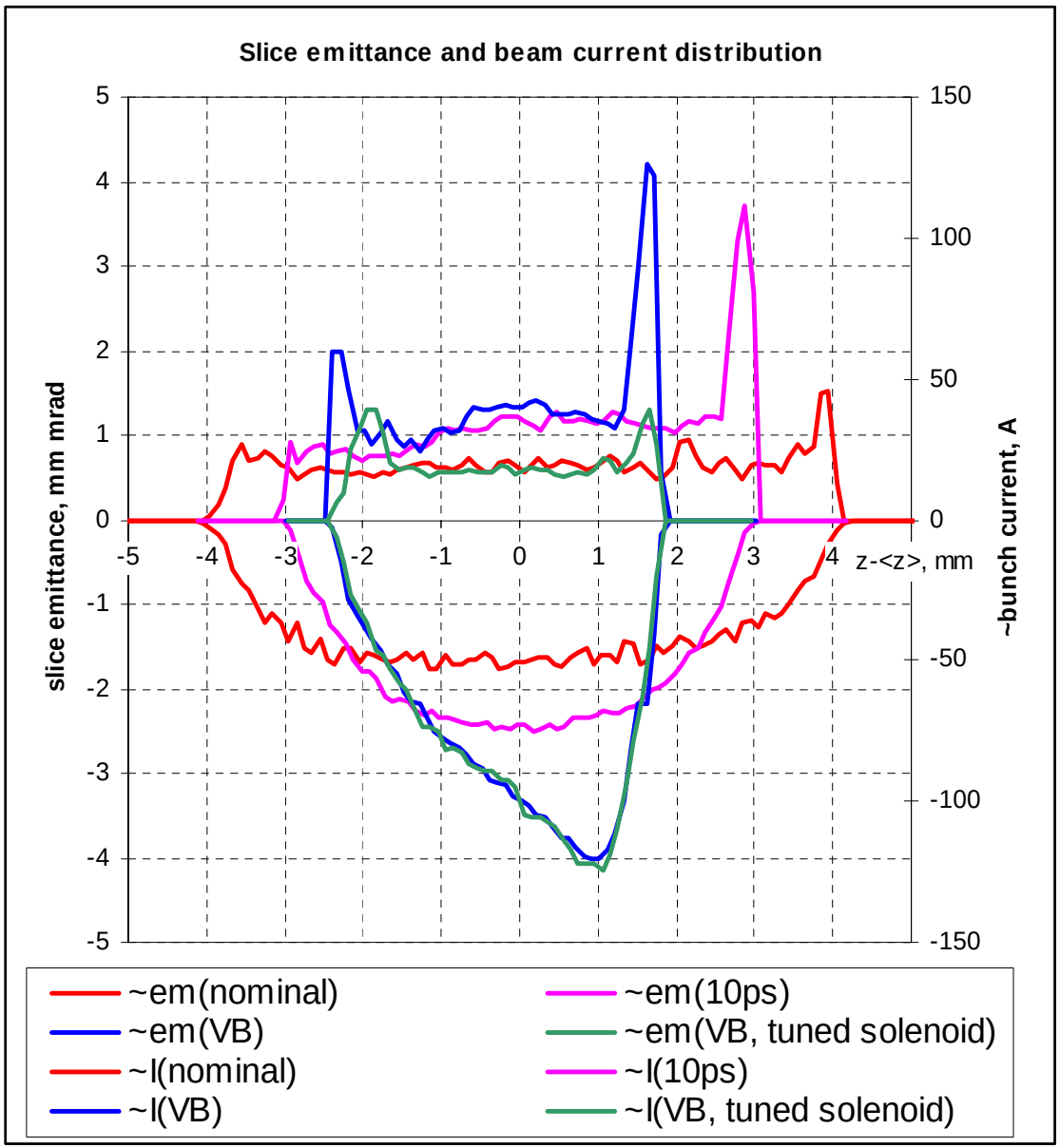
Appendix. Velocity bunching, “tuned” solenoid



Appendix. Velocity bunching, “tuned” solenoid



Slice parameters [2(10)k particles]



preliminary

Based on **projected** parameters

	nominal	10ps	VB	VB (sol.tuned)
Zrms	2.1	1.4	1.03	1.01
Xemit	0.68	1.17	3.19	1.14
Q	1	1	1	1
~B	1.03	0.52	0.10	0.76

Based on **slice** parameters

nominal	10ps	VB		VB (sol.tuned)	
50	75	100	120	100	120
0.6	1.2	1.3	1.2	0.6	0.6
139	52	59	83	278	333

?additionally: optimize the current ramping?

Conclusions (preliminary)

- Shorting the cathode laser (10ps instead 20ps) results only in ~25% shorter electron bunch but emittance growth in a factor of 2
- Fixed XFEL photo injector setup is more preferable for the option with velocity bunching using 1st cavity of ACC1
- More optimization studies are necessary
- More detailed specifications on electron beam properties after the photo injector (emittance, bunch length, current profile, energy spread, long.emittance etc) would simplify and accelerate these studies.