

Longitudinal Design Considerations

6.2c: Xband – Kband Inrz - BC1 - Xband - BC2 - Xband

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CONTENT

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 - X-band structure
 - K-band structure
 - ϕ_s, R_{56} and compression ratio
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 - Following plans
- 
- Injector independent

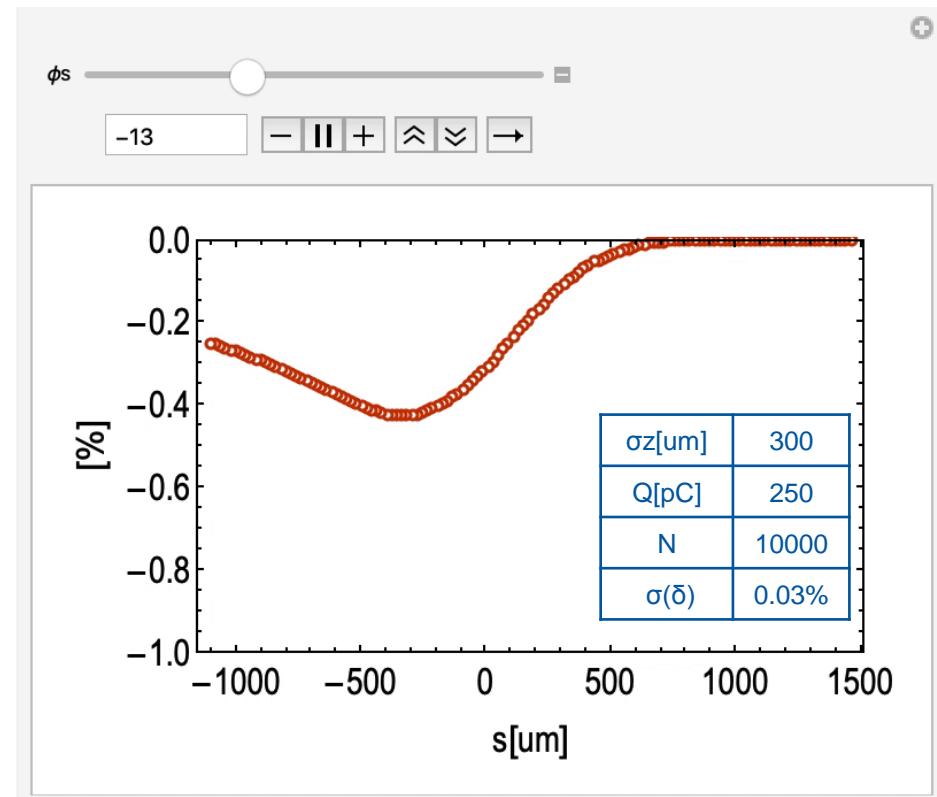
X-band structure and wake effects (ϕ_s dependence)

$$\frac{\Delta V_{\text{wake}}(s)}{V_{\text{acc}}(s)} = \frac{q * L_{\text{RF}}}{Ez * L_{\text{RF}} * \cos(\phi_s - ks)} \int_{-\infty}^s W_L(s - s') \lambda(s') ds'$$

independent of structure/linac length:
“longitudinal wake budget” once the RF design is chosen”

a [mm]	g[mm]	L[mm]	Ez[MV/m, max]
3.5	6.332	8.332	65

A. Gallo, P9, WP4_present_20_09_19.pdf



Even for 250 pC with $\sigma z = 100\mu\text{m}$,
the energy modulation due to present X-band is less than 1%.

Preliminary K-band structure*

		K-band structure gradient [MV/m] *				
		Structure Length [m]				
		0.14	0.3	0.5	0.8	1.1
Aperture [mm]	2	32.90	30.92	28.67	25.70	23.14
	3	15.33	14.97	14.54	13.92	13.33
	4	8.91	8.79	8.64	8.43	8.22
	5	5.77	5.71	5.65	5.56	5.46
	6	4.11	4.08	4.05	4.00	3.95

*scaled from 1MW results(old), courtesy by Graeme Burt (Cockcroft)

Cell parameters to use for evaluating wake effects

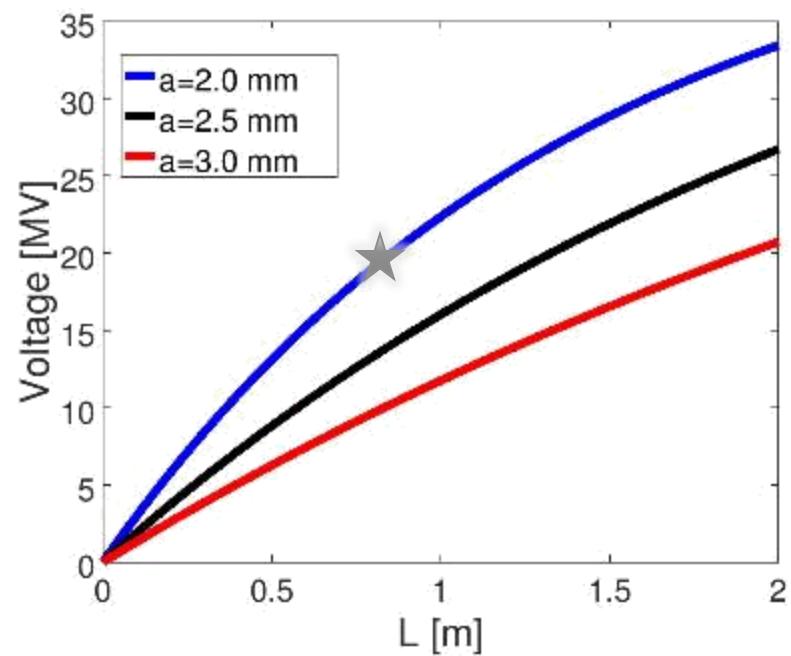
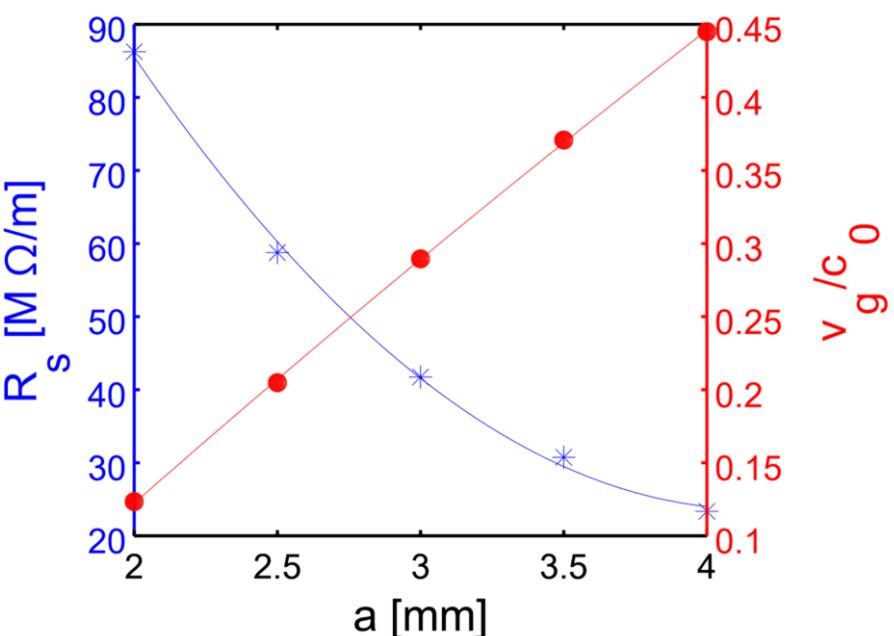
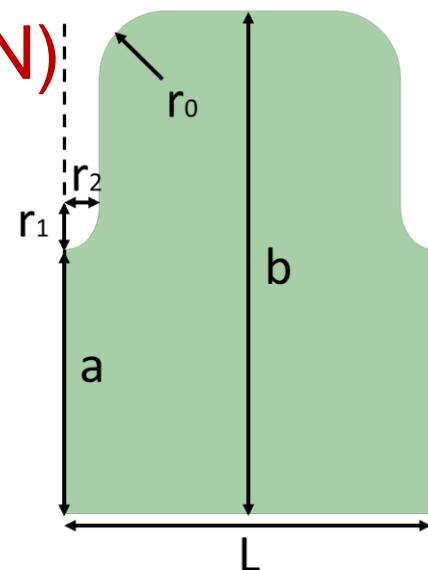
	P_in [MW]	a [mm]	g	L(120°)	Ez[MV/m, max]	
S1		8	2	2.178	2.778	30 → 25 (updated)
S2			3			15

*updated from Graeme Burt Team, Dec 3, 2018

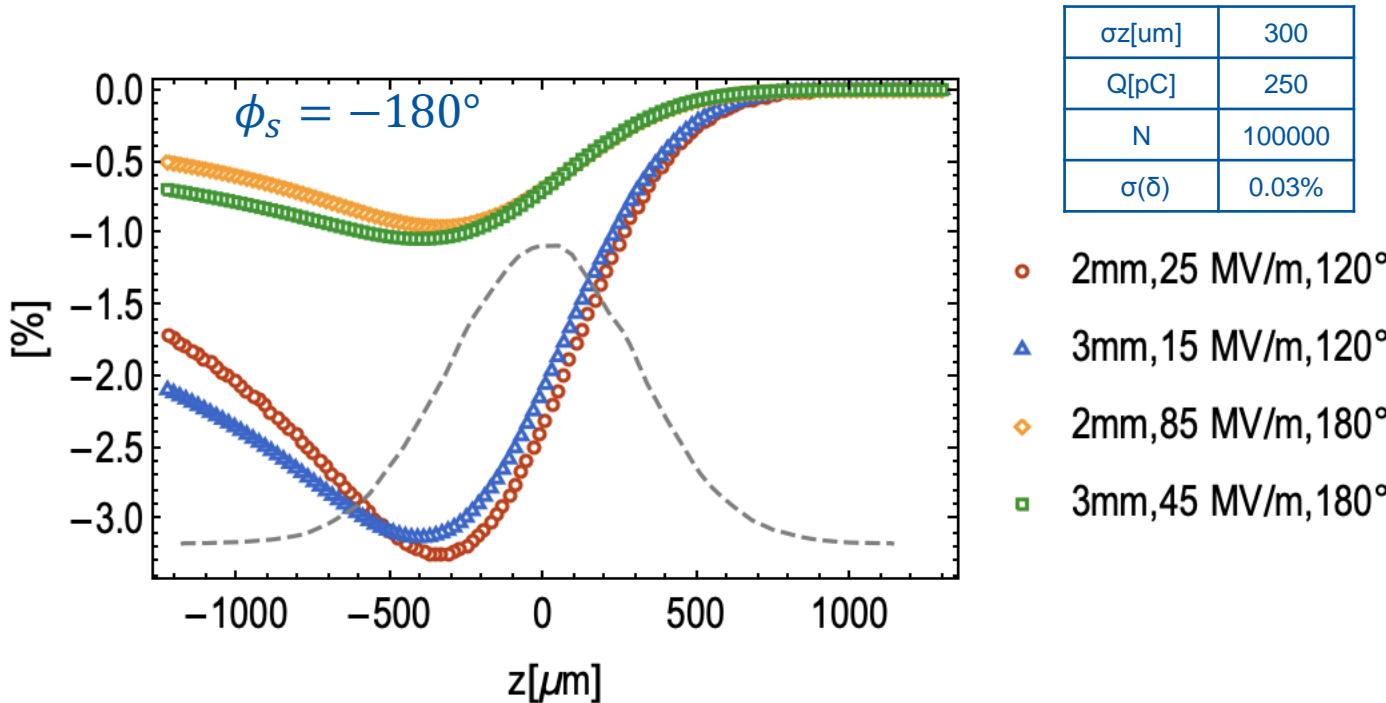


*K-band Structure Design (by X. Wu@CERN)

- Structure analytical optimization
 - Working at 36 GHz, $2\pi/3$ mode
 - Constant impedance structure
 - 22.4 MV at 8 MW input power for 1 meter Ka-band structure
 - Consistent with Lancaster's results



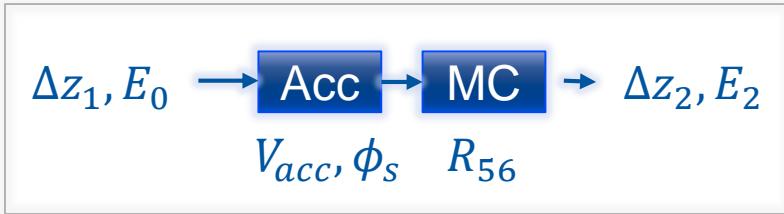
K-band longitudinal wake effects



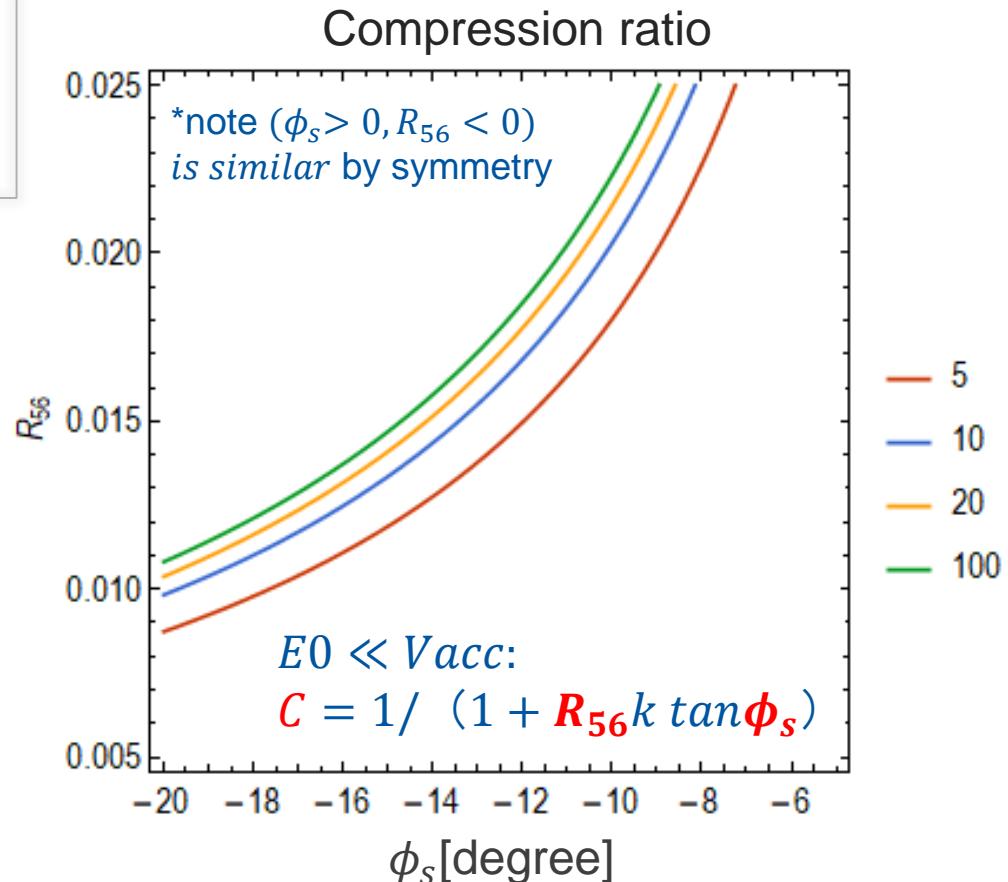
‘2mm-25MV/m’ and ‘3mm-15MV/m’ are similar for the longitudinal wake:
1~3% of energy modulation to the bunch core($\pm 1\sigma z$).

Keep in mind that transverse wake is greatly affected by the aperture size

ϕ_s, R_{56} and compression ratio (C)



$$\begin{aligned}
 \frac{1}{C} &= \frac{\Delta z_2}{\Delta z_1} \\
 &= 1 + R_{56} \frac{\delta}{\Delta z_1} \\
 &= 1 + \frac{R_{56} k \tan \phi_s}{\frac{E_0}{V_{acc} \cos \phi_s} + 1} \\
 &= 1 + \frac{R_{56} k \sin \phi_s}{\frac{E_0}{V_{acc}} + \cos \phi_s}
 \end{aligned}$$



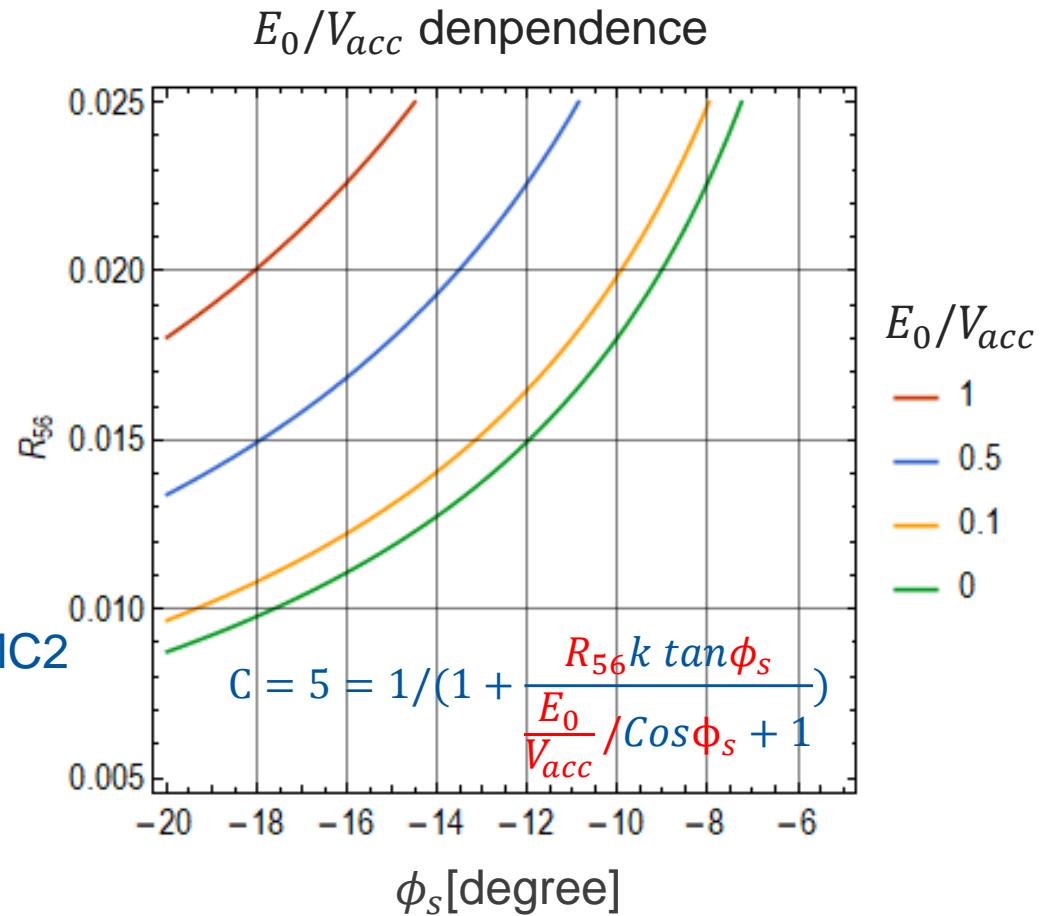
Concerning the parameter sensitivity:

- (1) (ϕ_s, R_{56}, C) is a set; (2) Smaller C; (3) proper range of ϕ_s

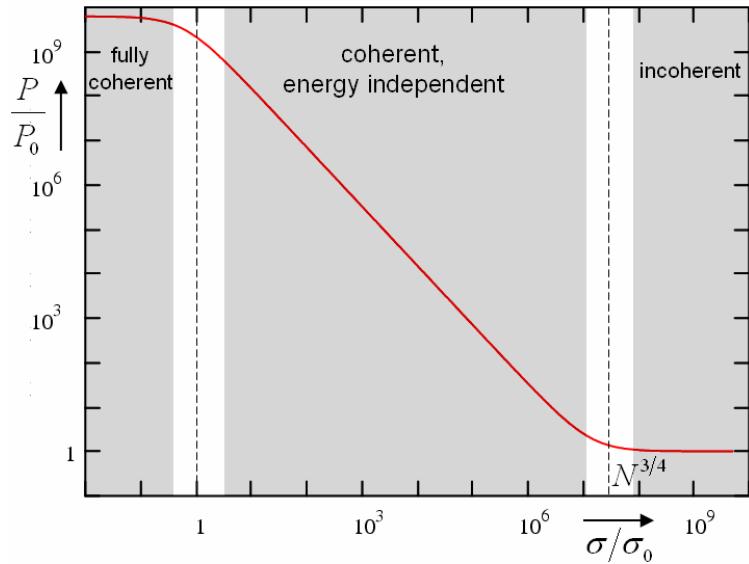
ϕ_s, R_{56} and C (continued)

Based on the design choice
of E_0/V_{acc} , the (ϕ_s, R_{56}, C)
set should be changed altogether

e.g. in two MCs setup, design of MC2



Coherent Synchrotron Radiation

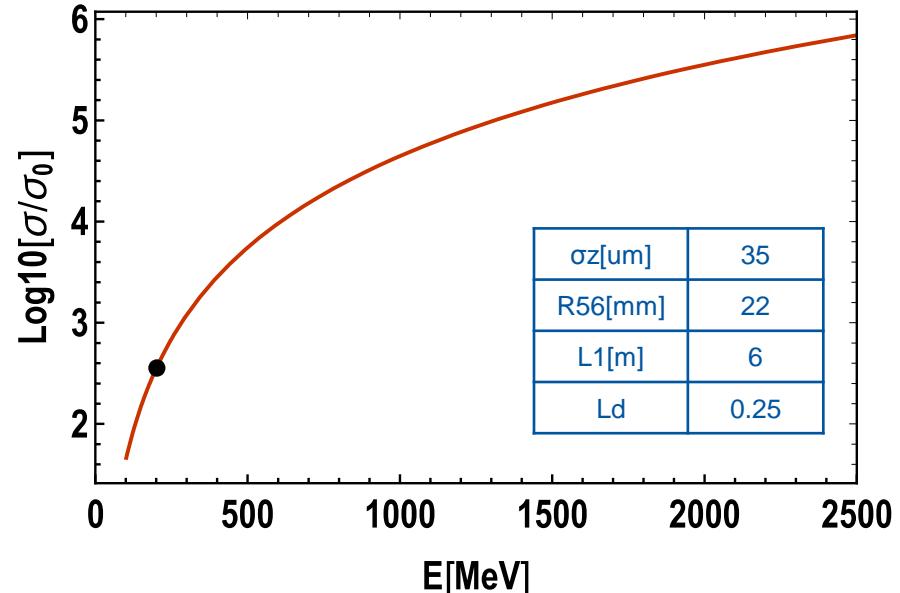


*B. Beutner. Phd Thesis, 2007, Hamburg

$$\sigma_0 \approx R/\gamma^3$$

$$\theta_0 = \frac{l_d}{R}$$

$$R_{56} \cong 2\theta_0^2(L_1 + \frac{2}{3}l_d)$$



Expect strong CSR effects in the bunch compressor(s)!

Injector Options

	BeamA	BeamB	BeamC
	Avni*-250pc	Mohsen*-100pc-2	Mohsen-50pc-1
Q[pC]	250	100	50
E_inj[MeV]	101	101.7	101.7
energy spread[%]	0.5	0.33	0.33
I_peak[A]	80	460	560
σ_t[fs]	974	73.5	33
σ_z[um]	292	22.05	9.9
$\sigma_{x,y}$[mm]	0.12	0.2	0.2
$\epsilon_{x,y}$[mm.mrad]	0.4	0.62	0.68

→ Full x-band with two BCs

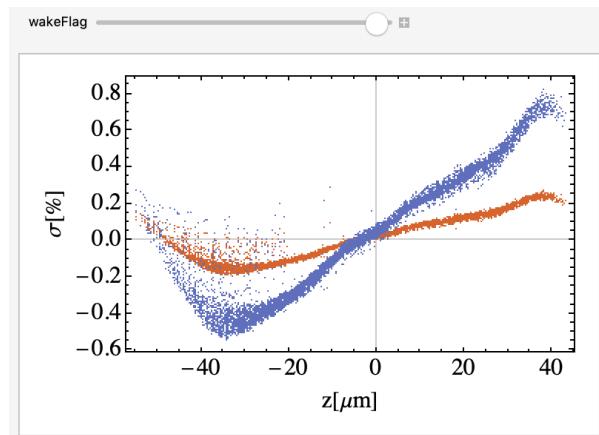
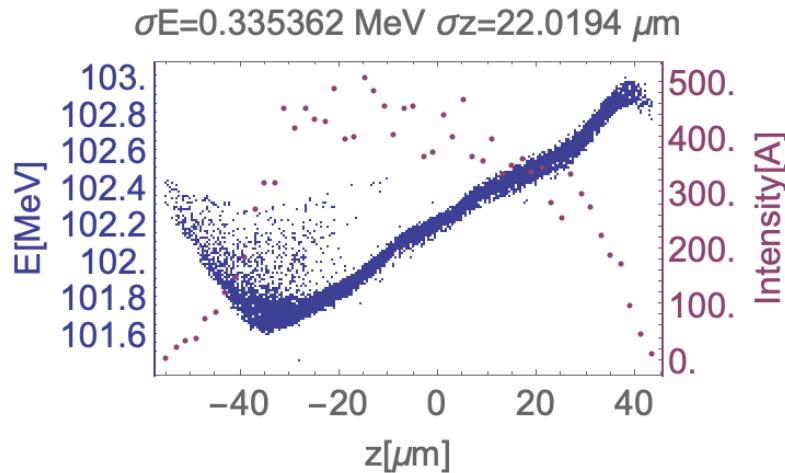
One BC?

No BC?

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* M. D. Kelisani@IRFS

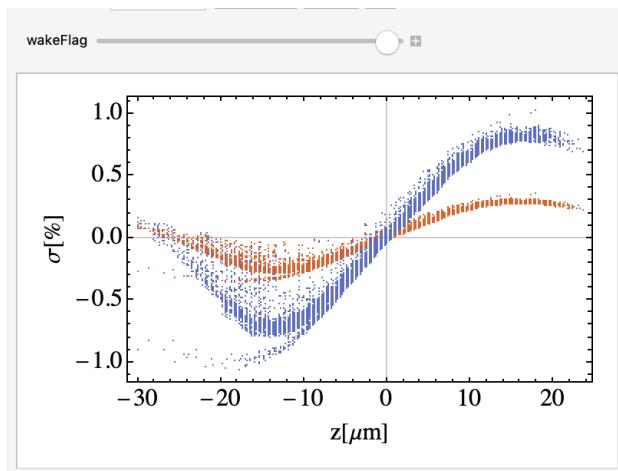
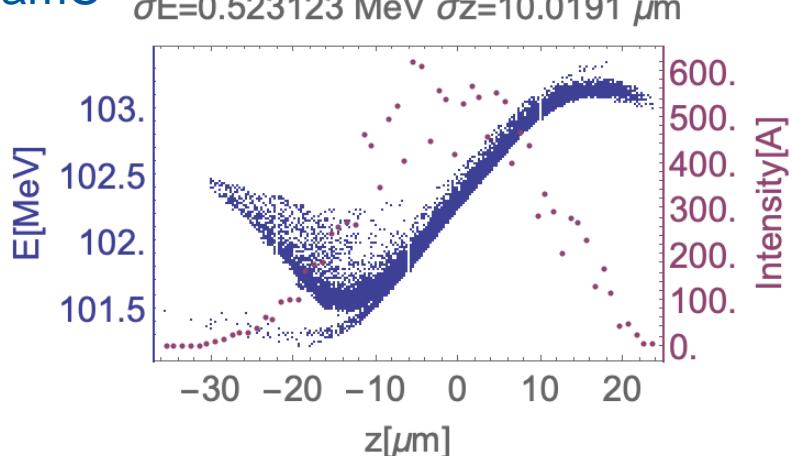


BeamB



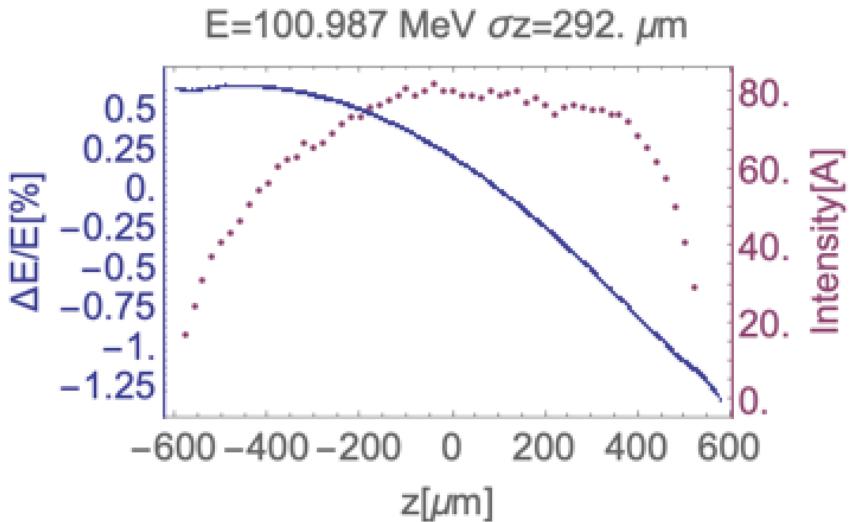
L1 [m]: 3.11172
Final:
E [MeV]: 299.604 $\sigma z [\mu\text{m}]$: 21.9464

BeamC



L1 [m]: 3.10938
Final:
E [MeV]: 299.774 $\sigma z [\mu\text{m}]$: 10.0554

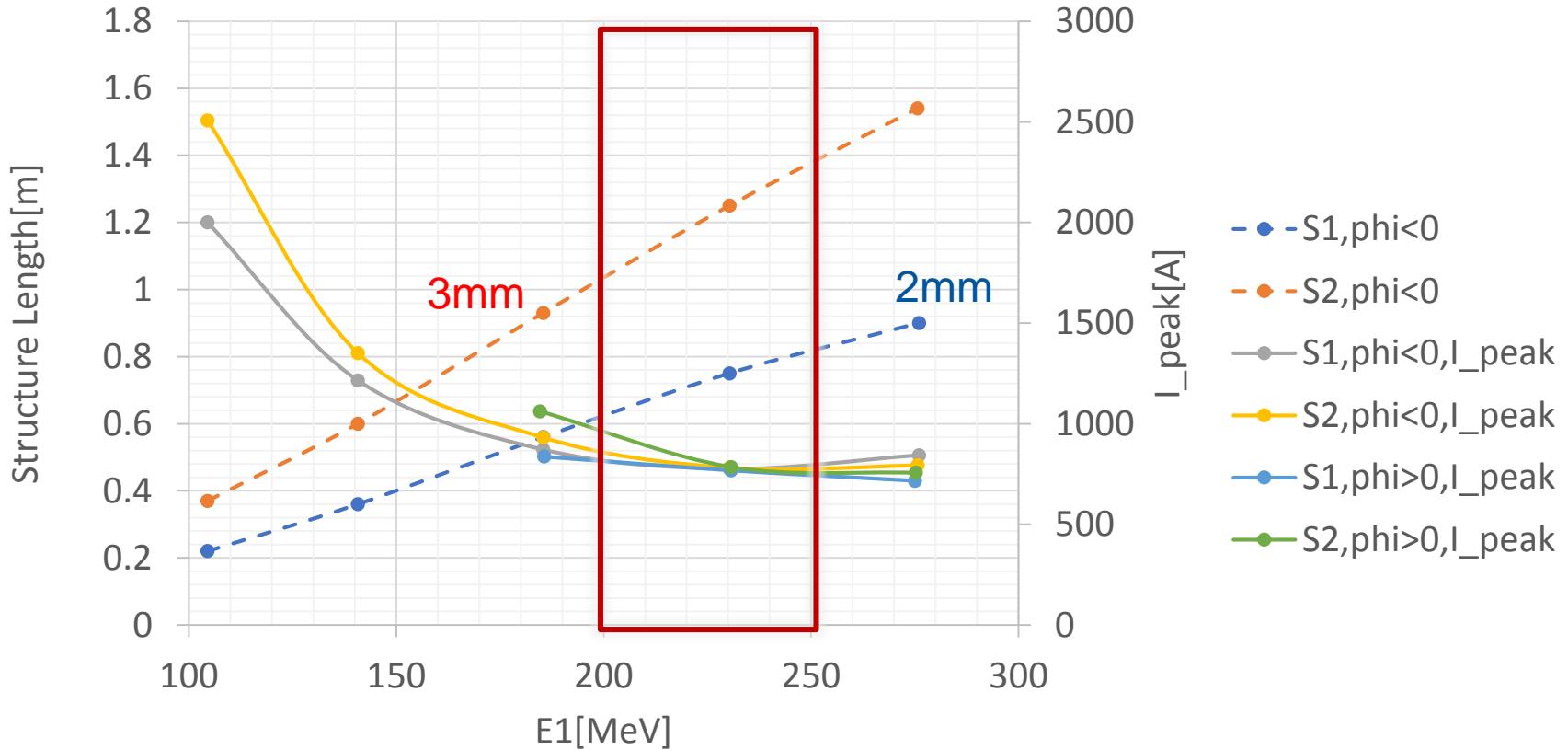
BeamA(x-band acc. & k-band)

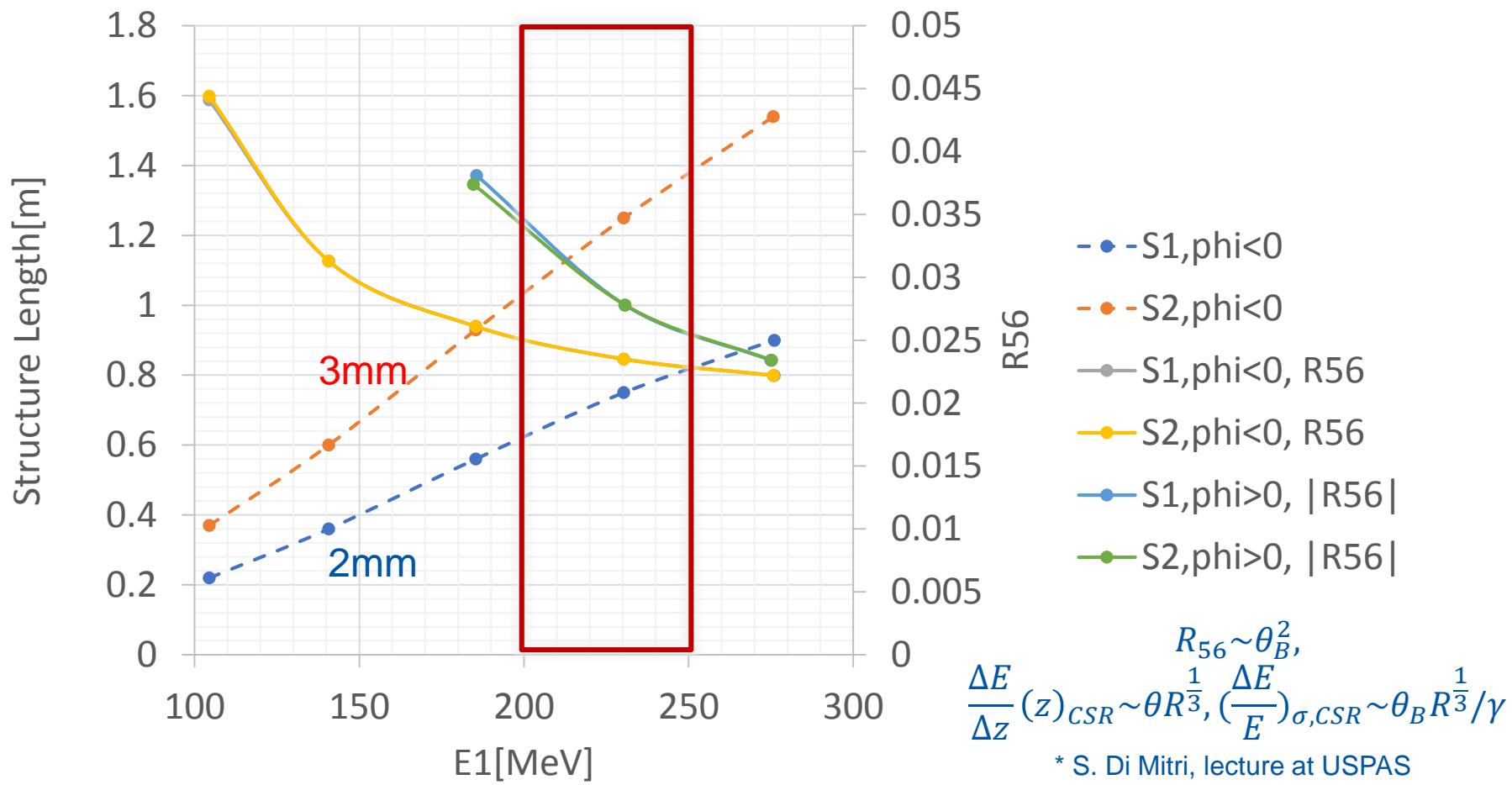


Total Charge[pC]	250	
E0[MeV]	100	
Z0[um]	292	
L1[m]	1.45	
phi_1[deg]	-12	12
Vk	?	
phi_k	-180	
E1[MeV]	105~275	185~275
C1(R56)	R56>0 (Chicane)	R56<0(Arc)
Z2[um]	~35	
L2[m]	-	
phi_2[deg]	-10	10
E2[MeV]	~300	

with K-band: S1(2mm) and S2(3mm)

S1: 2mm-25MV/m Vs. S2: 3mm-15MV/m





Where to put the k-band?

200~250 MeV

K-band structure length?

S1 (2mm- 25MV/m)

0.6~0.8m (15~20MV)

S1 (3mm- 15MV/m)

1~1.4m (15~20MV)

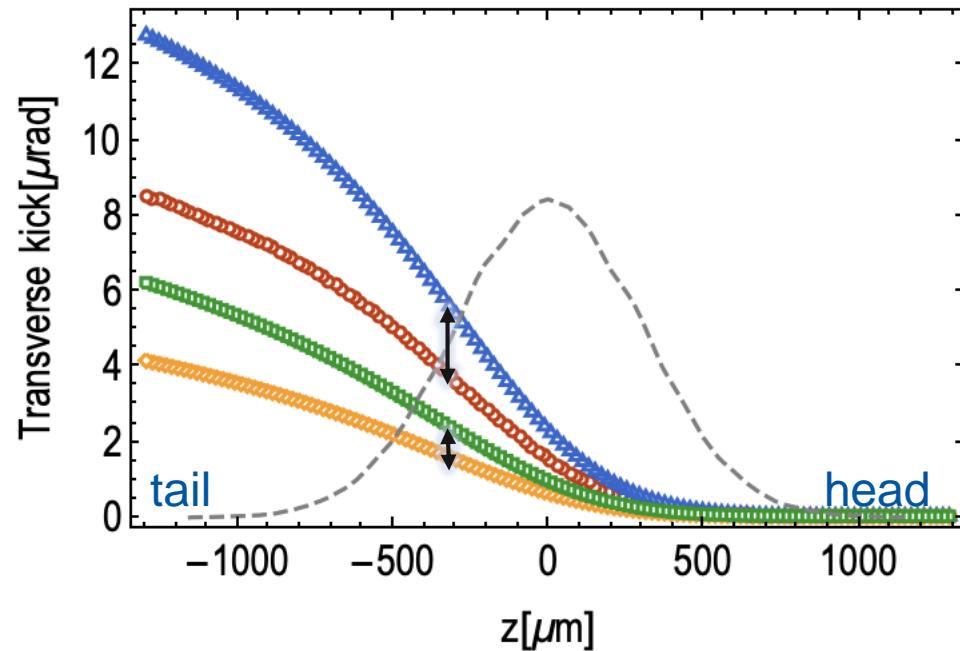
R56? Chicane or Arc?

0.022~0.025

Chicane

Transverse wake kick by K-band

Transverse jitter: $\Delta y = 10\sim15\% \sigma_y$



$\langle \beta_y \rangle$	6 m
$\epsilon_{n,y}$	0.4 μm
E	230 MeV
$\sigma_z[\mu\text{m}]$	300
Q[pC]	250
N	100000
$\sigma(\delta)$	0.03%

- 2mm, $0.1\sigma_y$, 0.75m, 19MV
- △ 2mm, $0.15\sigma_y$, 0.75m, 19MV
- ◇ 3mm, $0.1\sigma_y$, 1.25m, 19MV
- ◻ 3mm, $0.15\sigma_y$, 1.25m, 19MV

$$\sigma y' = \sqrt{\epsilon/\beta_y} = 12 \mu\text{rad}$$

The transverse kick due to short-range wake field kick seems acceptable in both cases given $10\sim15\% \sigma_y$ jitter in present rough estimation.

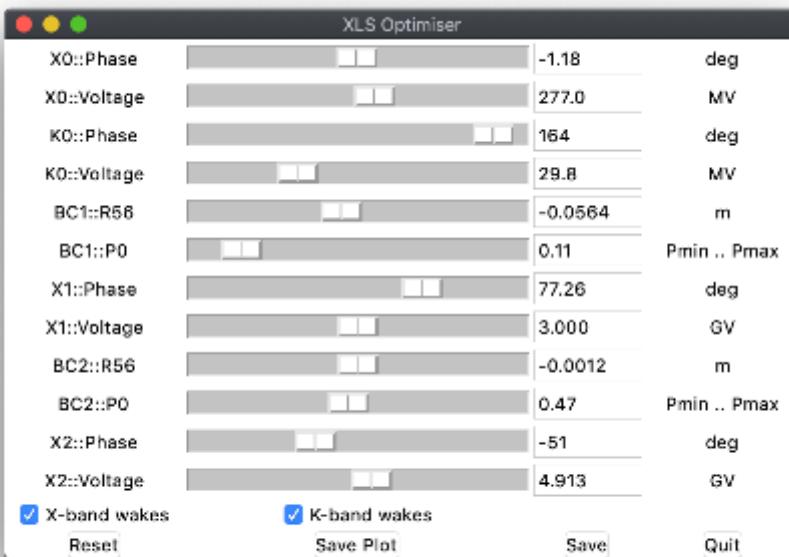


1D Longitudinal Optimization with Wake

By Andrea Latina (CERN)



XFEL-Code 1D (A. Latina)



bc1_sigmaZ = 34.807 um
bc1_meanE = 0.30007 GeV

bc2_sigmaZ = 8.7351 um
linac2_meanE = 3.9991 GeV

sigmaE = 0.0025413 GeV
sigmaE_E_percent = 0.063547

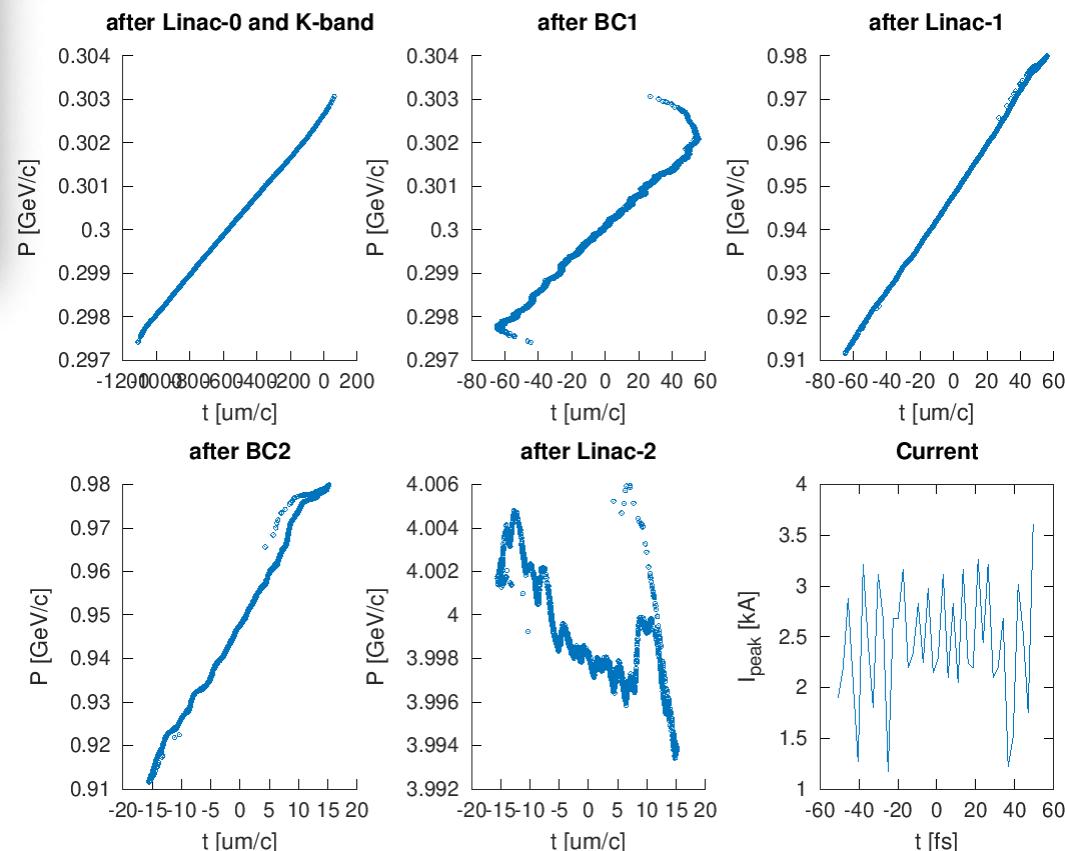
sigmaE_slice = 0.00032475 GeV
sigmaE_E_slice_percent = 0.0081228

4 GeV beam → uniform current

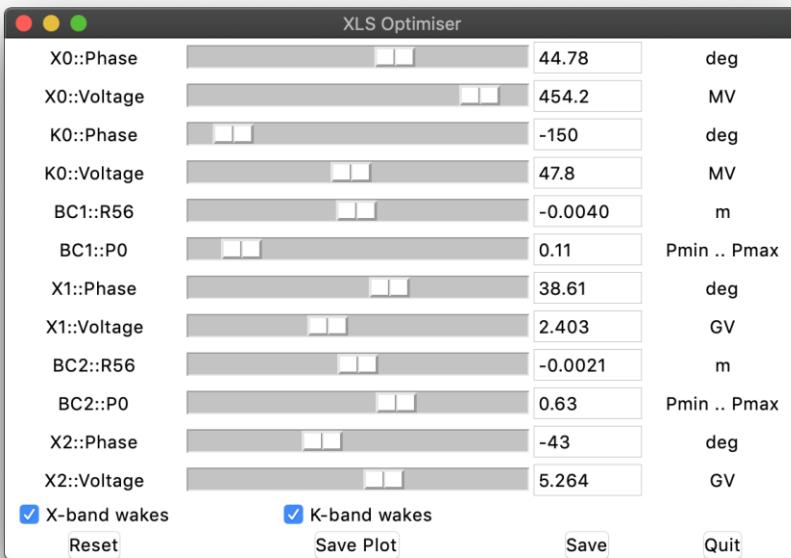
*X-band: Frascati's XLS structure

*K-band:

$$a = 2 \text{ mm}, L = 0.75 \text{ m}, G_{\max} = 25 \text{ MV/m}$$



XFEL-Code 1D (A. Latina)



bc1_sigmaZ = 33.765 um
bc1_meanE = 0.30000 GeV

bc2_sigmaZ = 9.7789 um
linac2_meanE = 6.0000 GeV

sigmaE = 0.0032871 GeV
sigmaE_E_percent = 0.054785

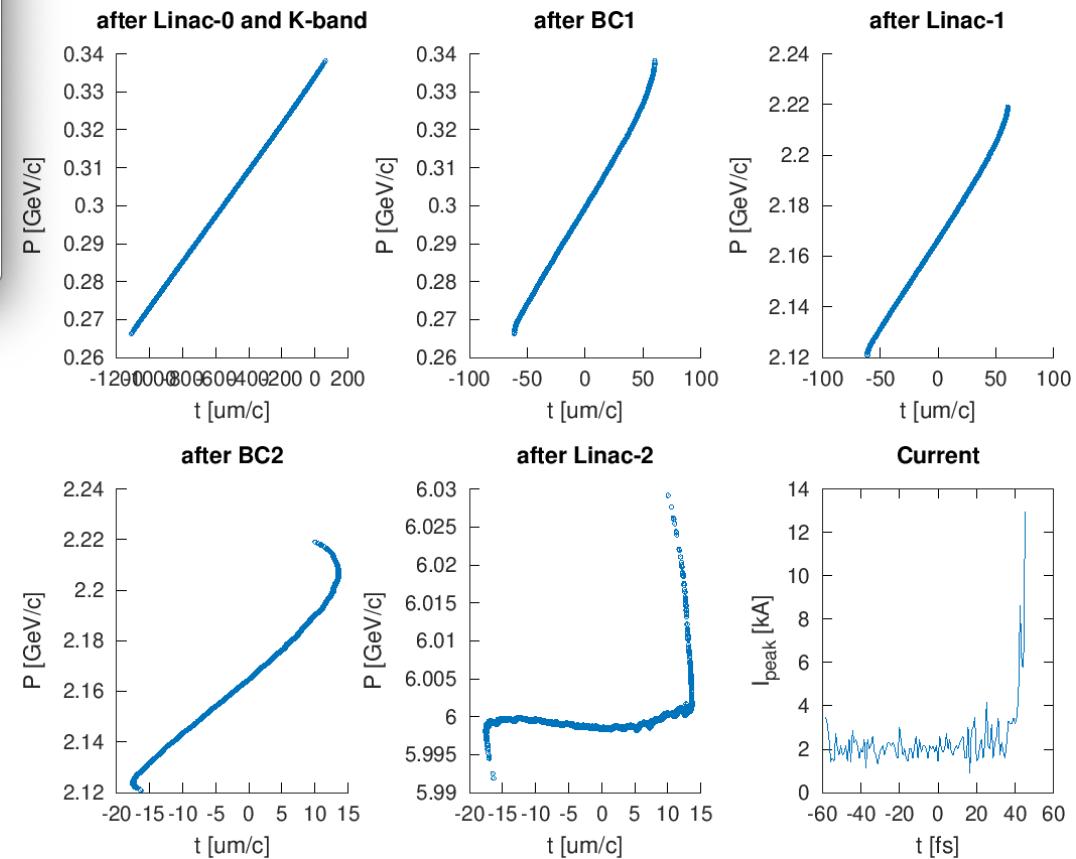
sigmaE_slice = 0.000090374 GeV
sigmaE_E_slice_percent = 0.0015066

6 GeV beam → uniform current

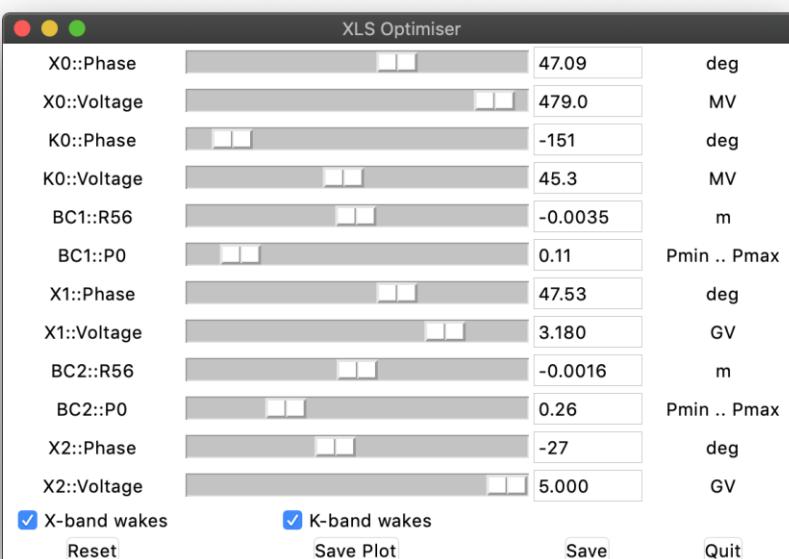
*X-band: Frascati's XLS structure

*K-band:

$$a = 2 \text{ mm}, L = 0.75 \text{ m}, G_{\max} = 25 \text{ MV/m}$$



XFEL-Code 1D (A. Latina)



bc1_sigmaZ = 33.765 um
bc1_meanE = 0.30000 GeV

bc2_sigmaZ = 9.9865 um
linac2_meanE = 9.0000 GeV

sigmaE = 0.0029932 GeV
sigmaE_E_percent = 0.033257

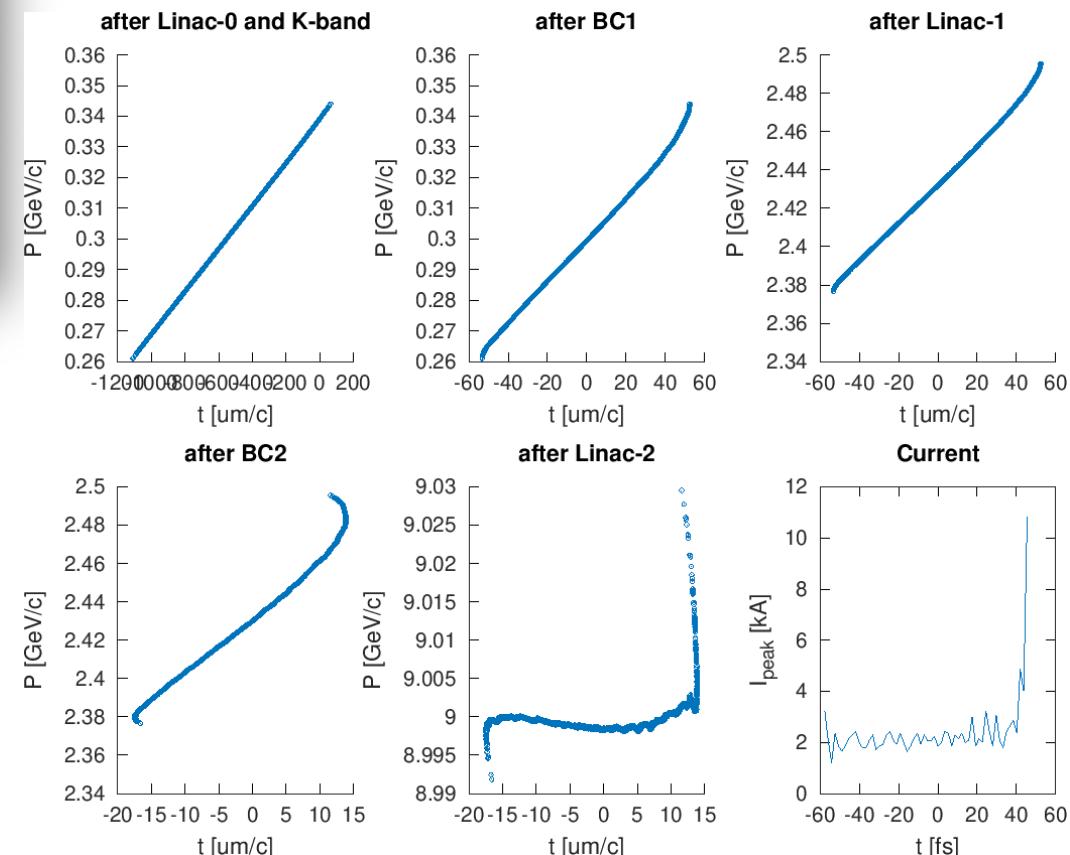
sigmaE_slice = 0.00011149 GeV
sigmaE_E_slice_percent = 0.0012390

9 GeV beam → uniform current

*X-band: Frascati's XLS structure

*K-band:

$$a = 2 \text{ mm}, L = 0.75 \text{ m}, G_{\max} = 25 \text{ MV/m}$$



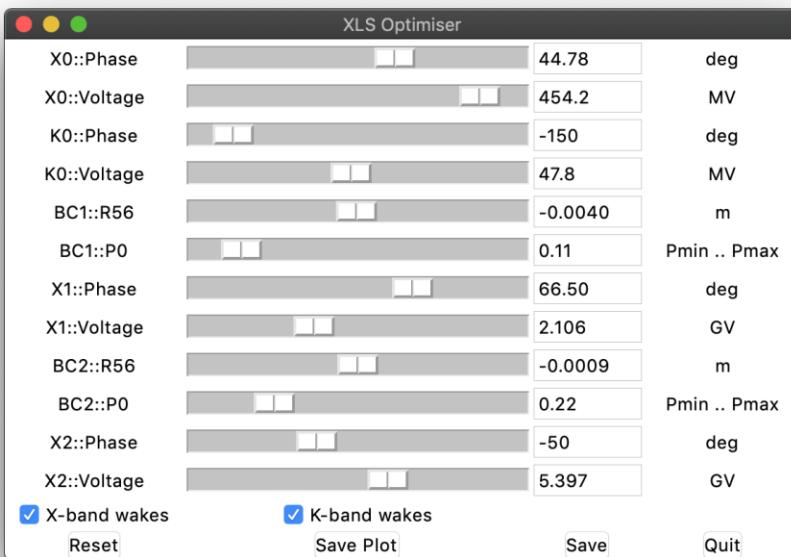
Summary and tasks to follow

- k-band structure (at this moment):
 - $a \rightarrow 2\sim 3 \text{ mm}$, $\text{length} \rightarrow \sim 1 \text{ m}$, $V \rightarrow \sim 20 \text{ MV}$
- Present results/conclusions are based on given injector options; more close collaborations with WP2/3/4 expected;
- Tasks to follow:
 - CSR effects (1D model)
 - Transverse motion design
 - Simulation tools adaption/development (6D tracking with SC, wake & CSR) S2E solution
 - Multi-parameters design optimization
 - Stability study/Error analysis

THANKS



XFEL-Code 1D (A. Latina)



bc1_sigmaZ = 33.765 um
bc1_meanE = 0.30000 GeV

bc2_sigmaZ = 10.412 um
linac2_meanE = 4.6003 GeV

sigmaE = 0.0043391 GeV
sigmaE_E_percent = 0.094324

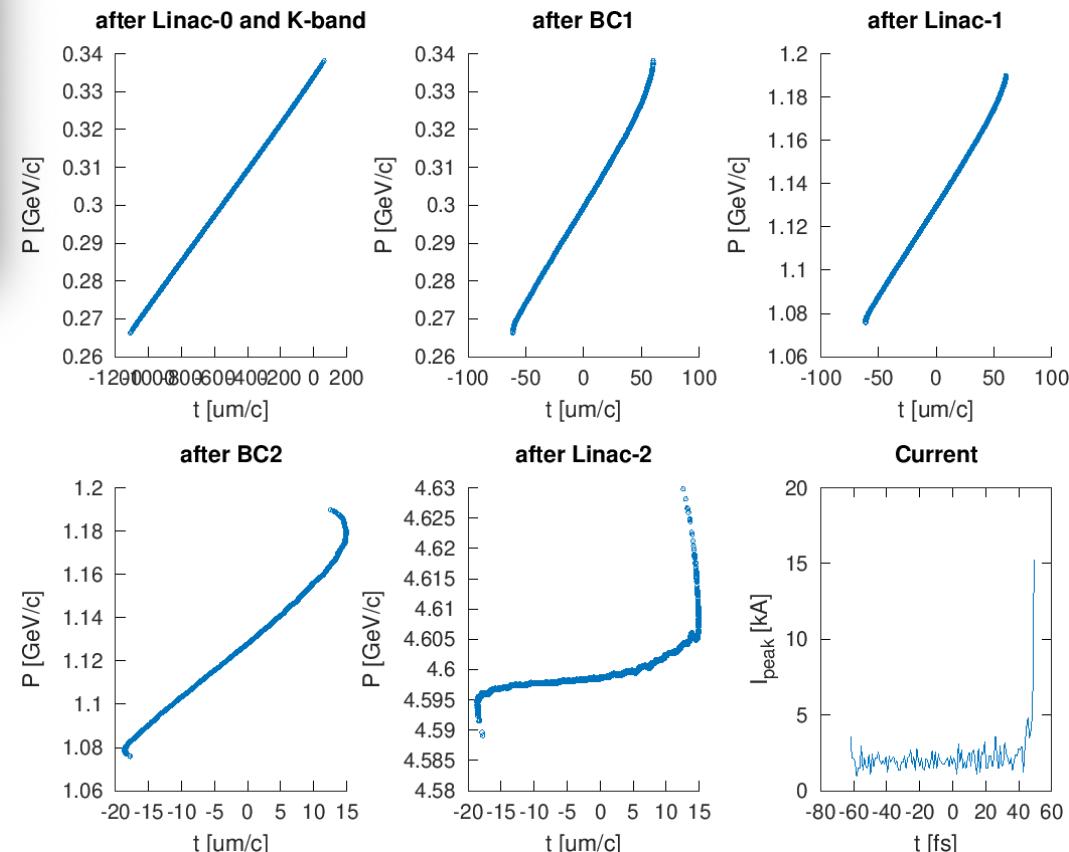
sigmaE_slice = 0.00013086 GeV
sigmaE_E_slice_percent = 0.0028455

4.6 GeV beam → uniform current

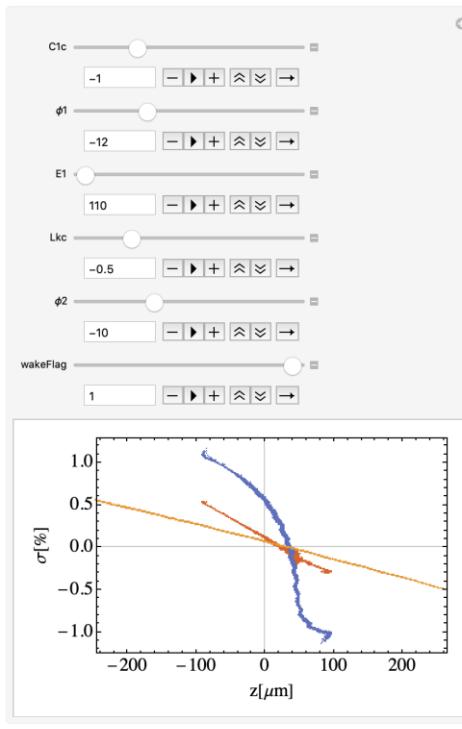
*X-band: Frascati's XLS structure

*K-band:

$$a = 2 \text{ mm}, L = 0.75 \text{ m}, G_{\max} = 25 \text{ MV/m}$$

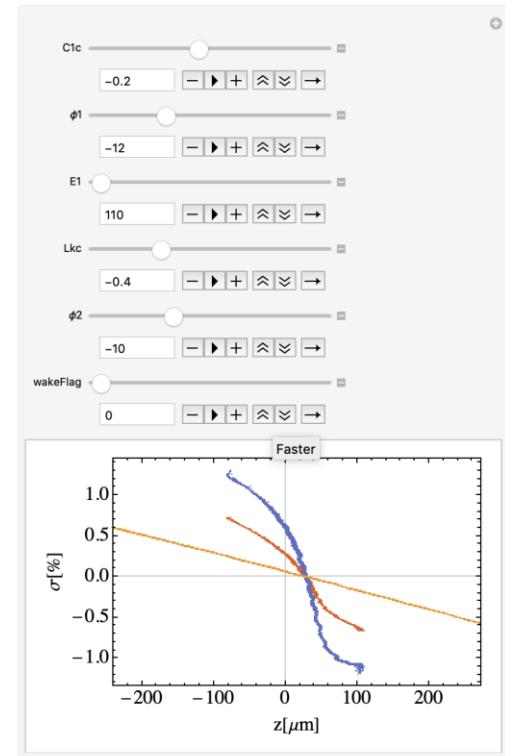
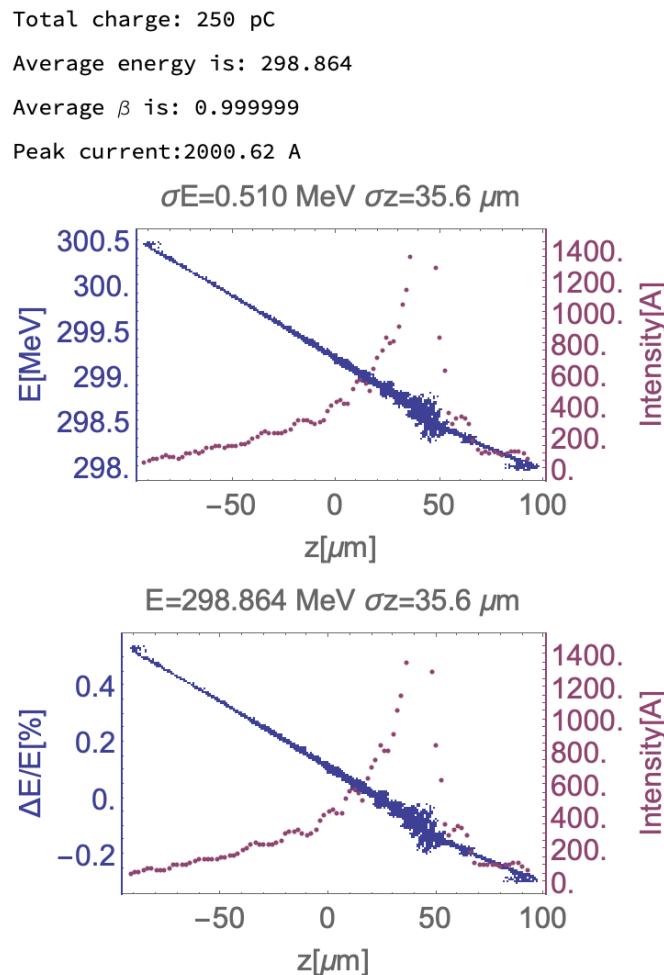


K-band($a=2$, $g=25\text{MV/m}$), $\phi_s < 0$



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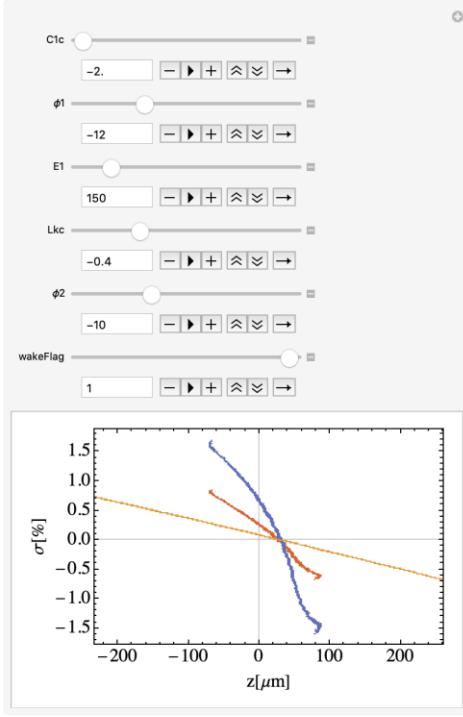
C1R56: 0.0440916
L1[m]: 0.141759 L2: 3.05409 Lk: 0.22
After first X-band acceleration:
E[MeV]: 104.457   oz[um] 292.434
After Compressor:
E[MeV]: 104.457   oz[um] 35.6424
Final:
E[MeV]: 298.864   oz[um] 35.6424
  
```



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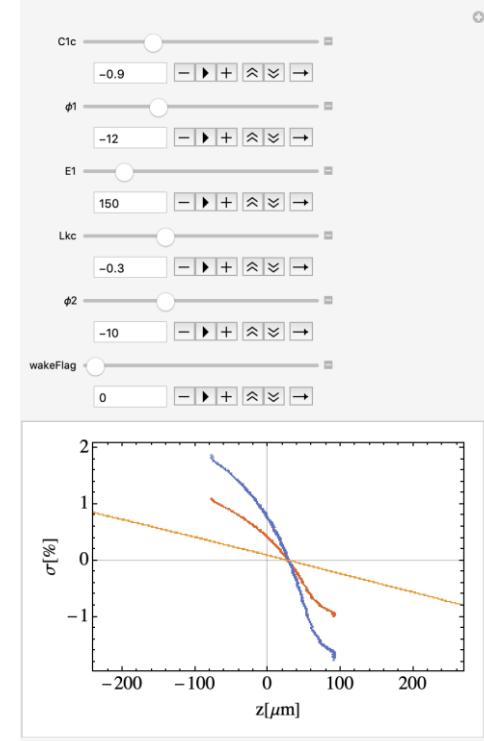
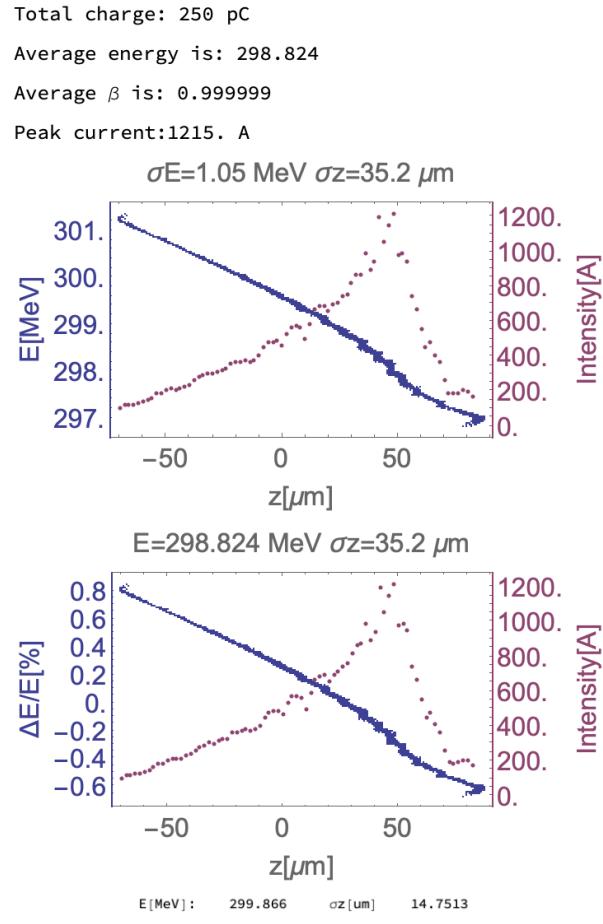
C1R56: 0.0398637
L1[m]: 0.141759 L2: 3.07127 Lk: 0.2641
After first X-band acceleration:
E[MeV]: 103.525   oz[um] 292.434
After Compressor:
E[MeV]: 103.525   oz[um] 34.7941
Final:
E[MeV]: 299.92    oz[um] 34.7941
  
```





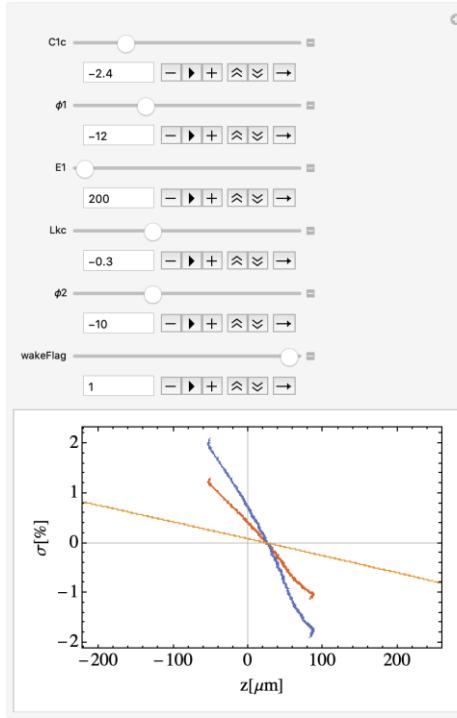
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C1R56: 0.031315
L1[m]: 0.770891 L2: 2.48389 Lk: 0.36
After first X-band acceleration:
E[MeV]: 140.701 oz[um] 292.434
After Compressor:
E[MeV]: 140.701 oz[um] 35.1699
Final:
E[MeV]: 298.824 oz[um] 35.1699
  
```



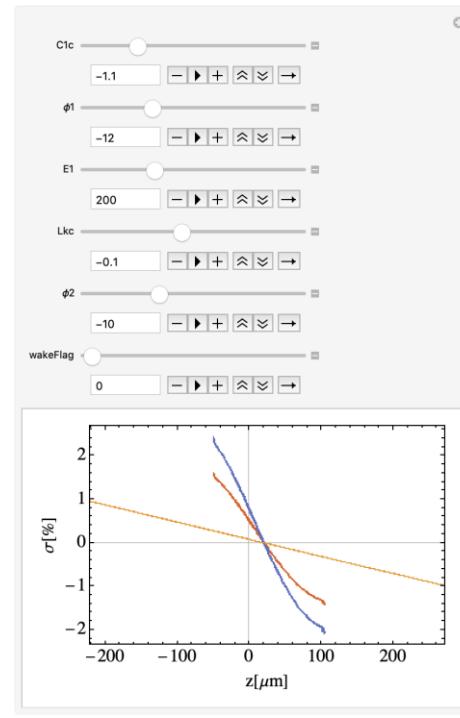
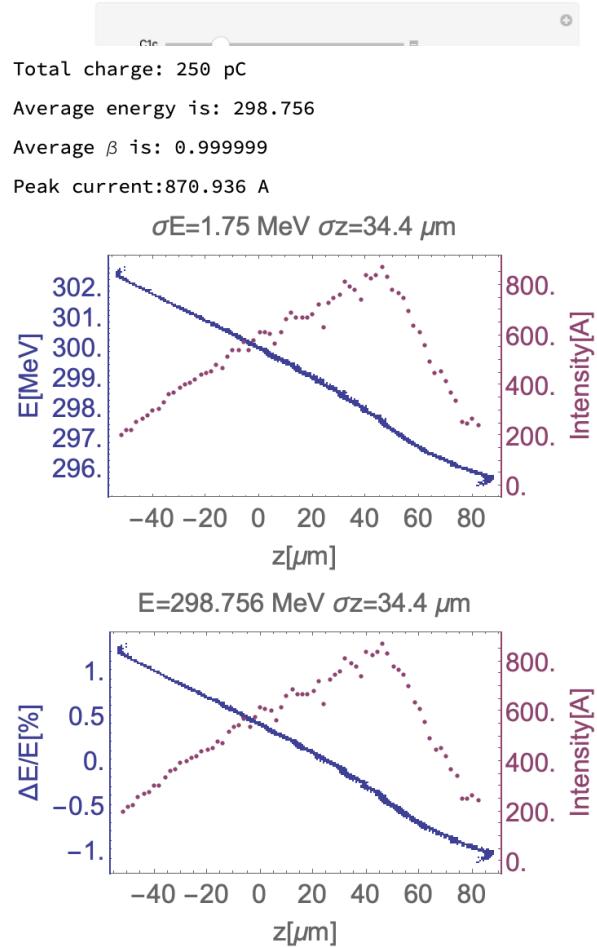
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C1R56: 0.0276281
L1[m]: 0.770891 L2: 2.50732 Lk: 0.42
After first X-band acceleration:
E[MeV]: 139.564 oz[um] 292.434
After Compressor:
E[MeV]: 139.564 oz[um] 36.2934
Final:
E[MeV]: 299.896 oz[um] 36.2934
  
```



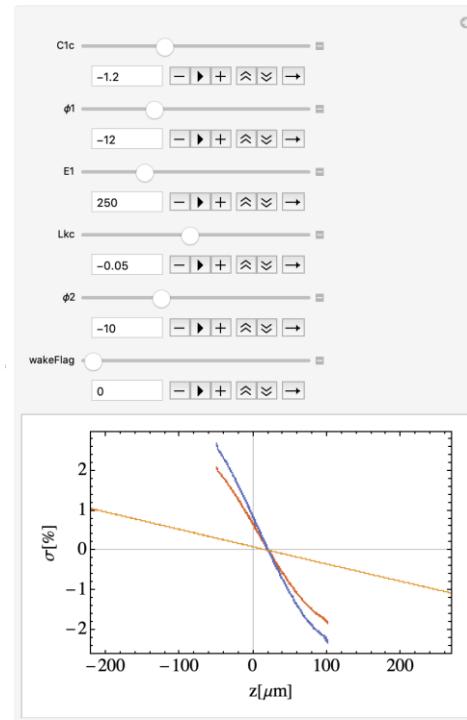
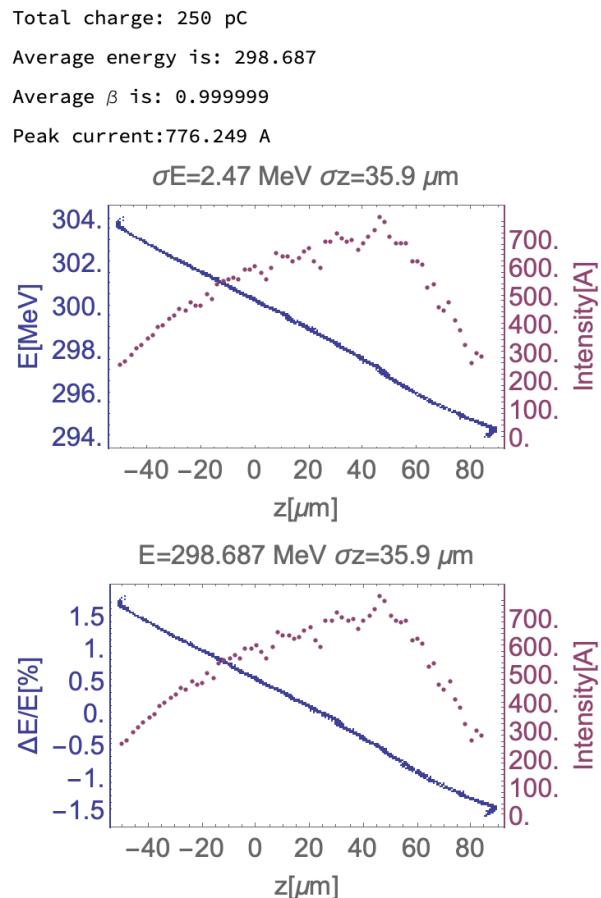
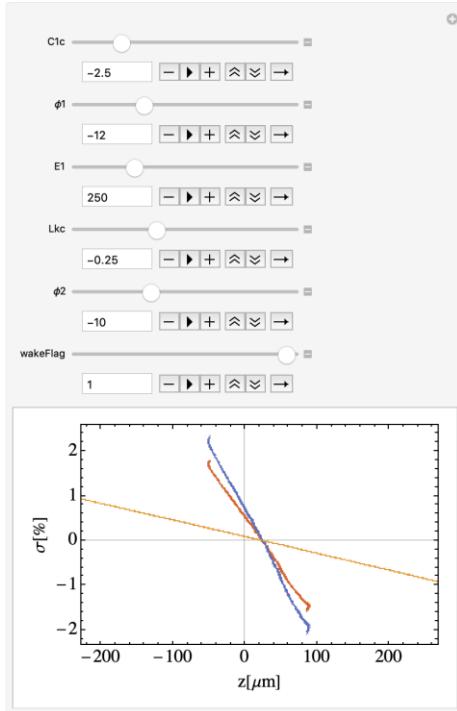
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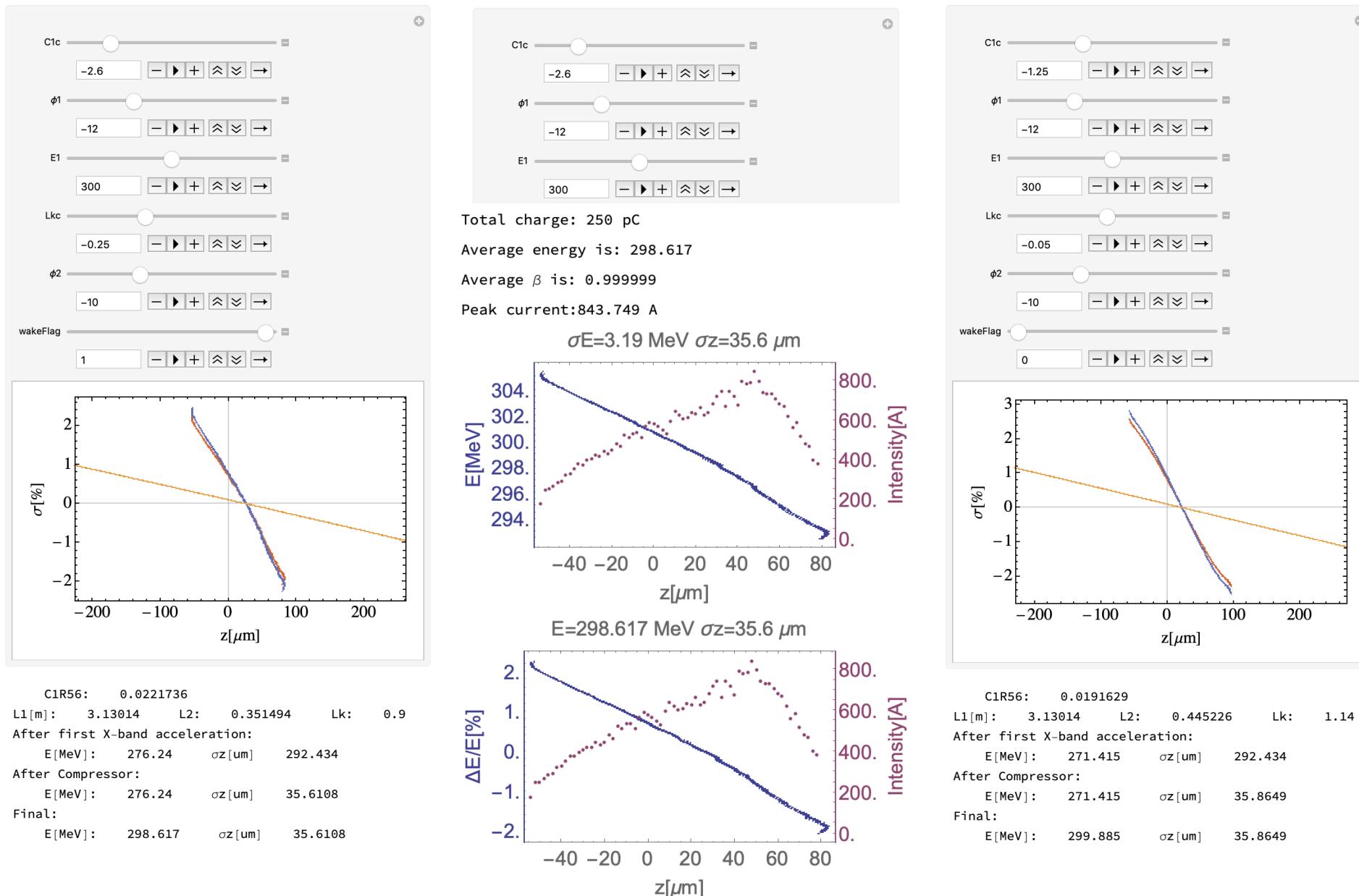
C1R56: 0.0260936
L1[m]: 1.55731 L2: 1.7809 Lk: 0.56
After first X-band acceleration:
E[MeV]: 185.382  $\sigma_z [\mu\text{m}]$  292.434
After Compressor:
E[MeV]: 185.382  $\sigma_z [\mu\text{m}]$  34.3894
Final:
E[MeV]: 298.756  $\sigma_z [\mu\text{m}]$  34.3894
  
```



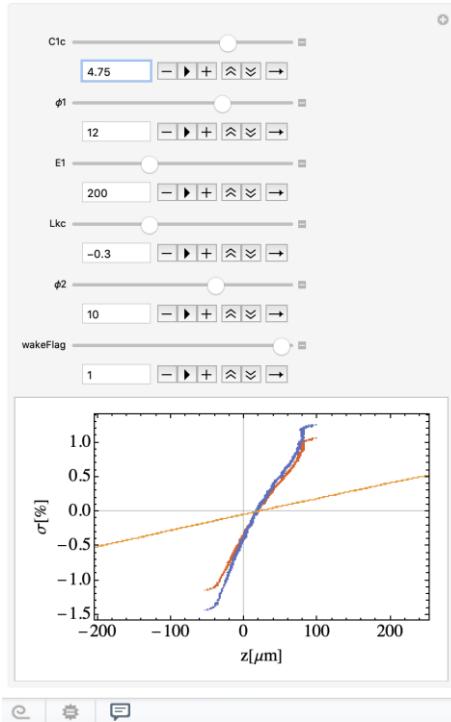
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C1R56: 0.0226119
L1[m]: 1.55731 L2: 1.84339 Lk: 0.72
After first X-band acceleration:
E[MeV]: 182.05  $\sigma_z [\mu\text{m}]$  292.434
After Compressor:
E[MeV]: 182.05  $\sigma_z [\mu\text{m}]$  35.0649
Final:
E[MeV]: 299.927  $\sigma_z [\mu\text{m}]$  35.0649
  
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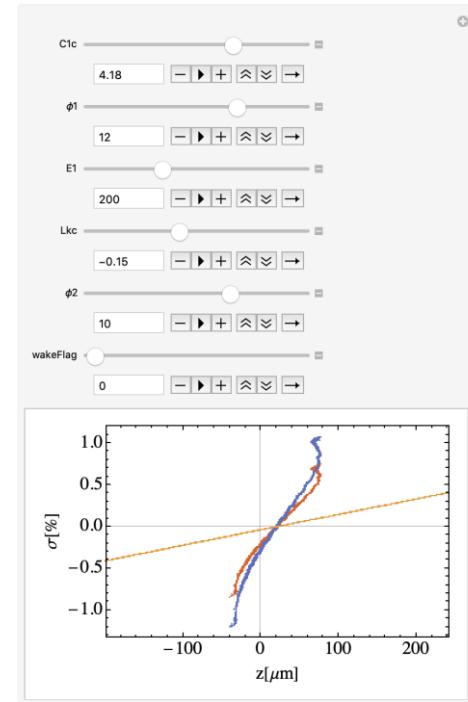
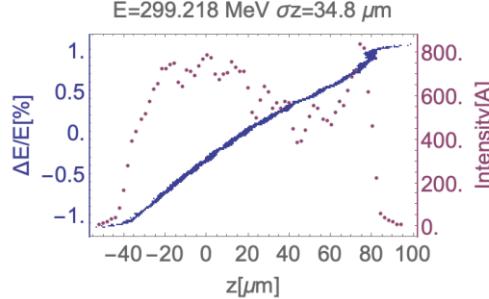
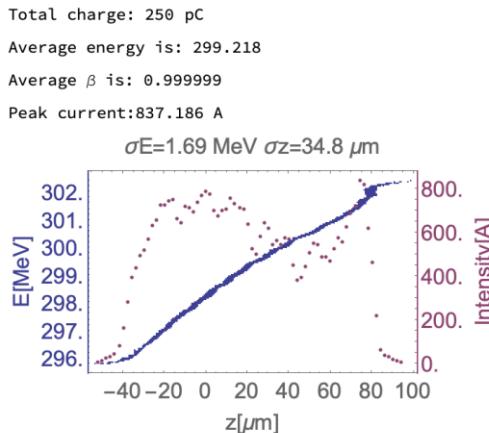
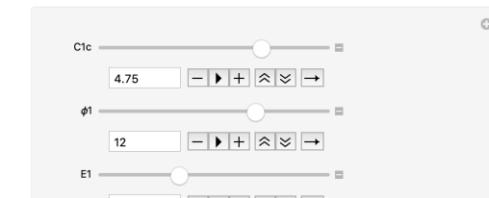


K-band($a=2$, $g=25\text{MV/m}$), $\phi_s > 0$



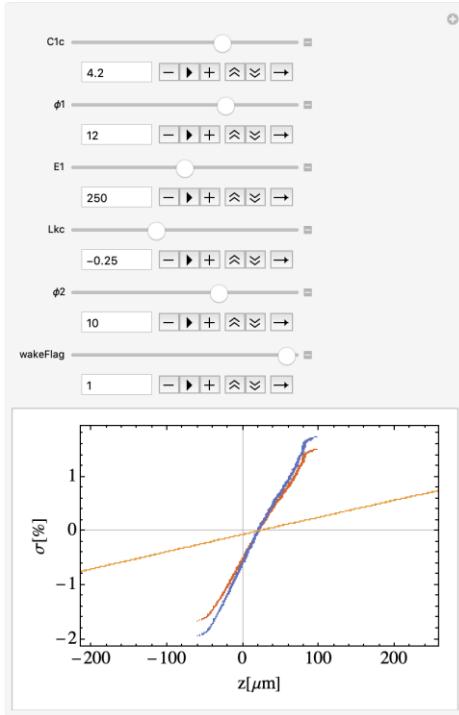
```

C1R56: -0.038131
L1[m]: 1.55731 L2: 1.7809 Lk: 0.56
After first X-band acceleration:
E[MeV]: 185.618 oz[um] 292.434
After Compressor:
E[MeV]: 185.618 oz[um] 34.8393
Final:
E[MeV]: 299.218 oz[um] 34.8393
  
```



```

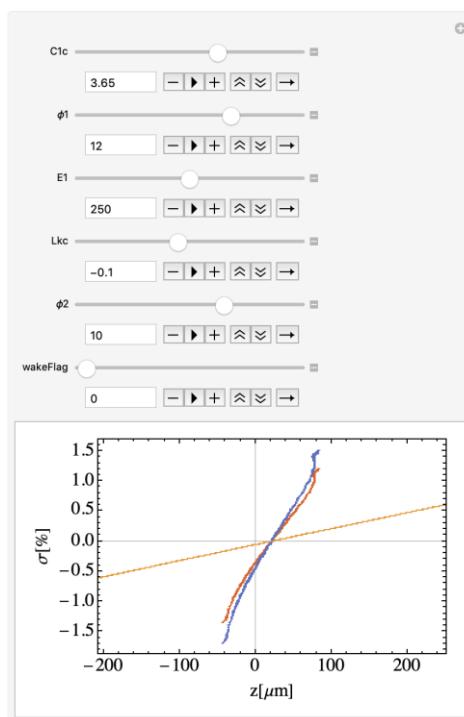
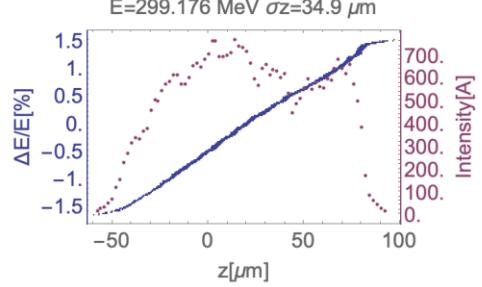
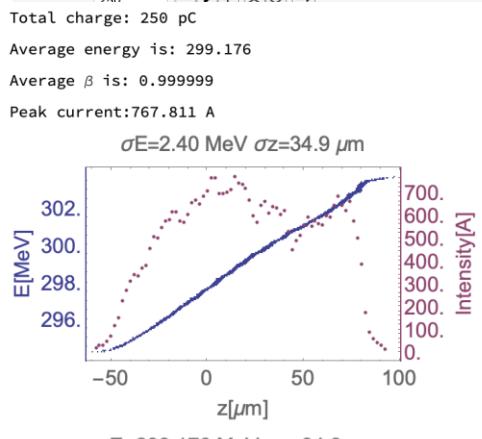
C1R56: -0.0465136
L1[m]: 1.55731 L2: 1.82777 Lk: 0.68
After first X-band acceleration:
E[MeV]: 183.262 oz[um] 292.434
After Compressor:
E[MeV]: 183.262 oz[um] 35.4541
Final:
E[MeV]: 300.371 oz[um] 35.4541
  
```



```

C1R56: -0.0278088
L1[m]: 2.34372 L2: 1.07401 Lk: 0.75
After first X-band acceleration:
E[MeV]: 230.667 oz[um] 292.434
After Compressor:
E[MeV]: 230.667 oz[um] 34.8835
Final:
E[MeV]: 299.176 oz[um] 34.8835

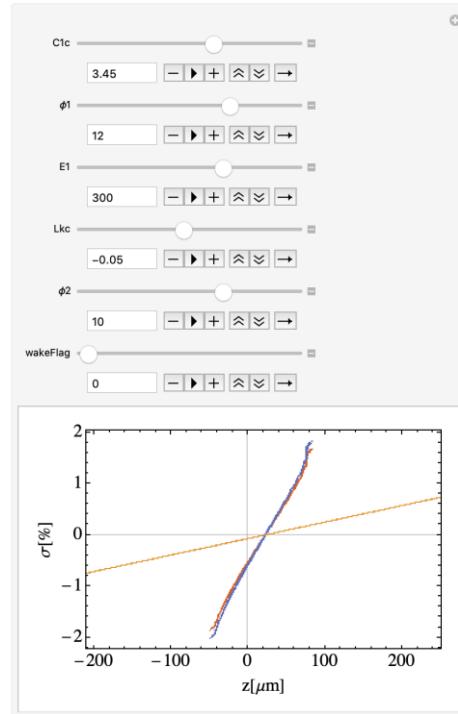
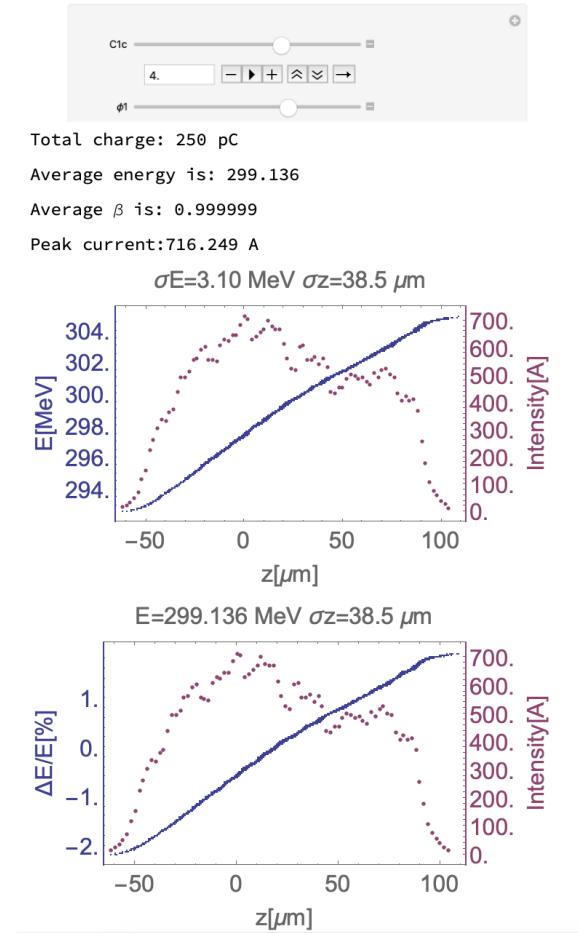
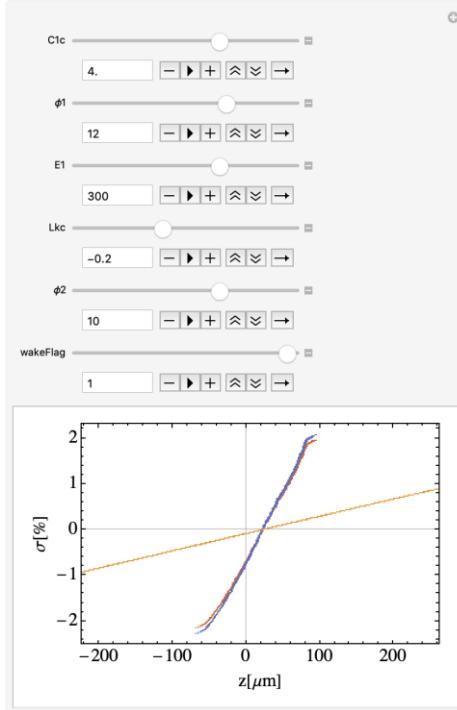
```



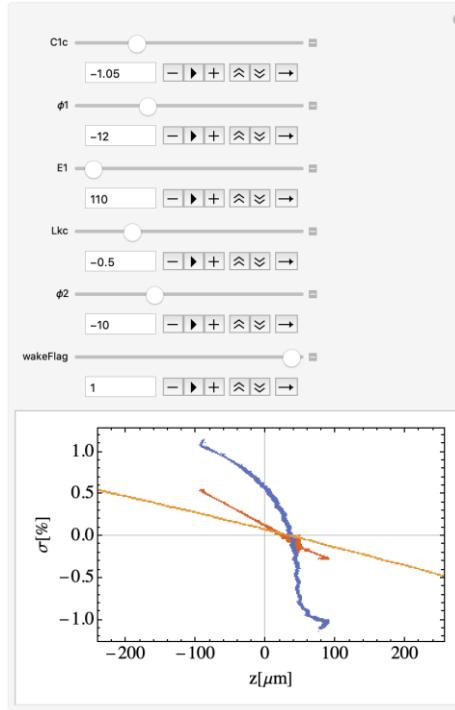
```

C1R56: -0.0326754
L1[m]: 2.34372 L2: 1.13259 Lk: 0.9
After first X-band acceleration:
E[MeV]: 227.819 oz[um] 292.434
After Compressor:
E[MeV]: 227.819 oz[um] 35.3115
Final:
E[MeV]: 300.387 oz[um] 35.3115

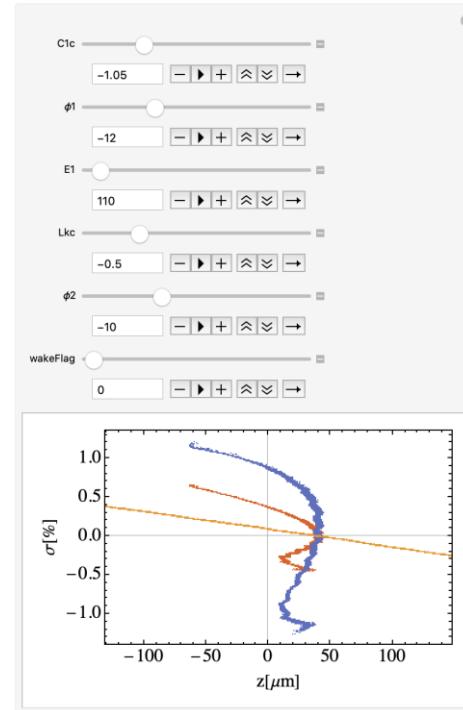
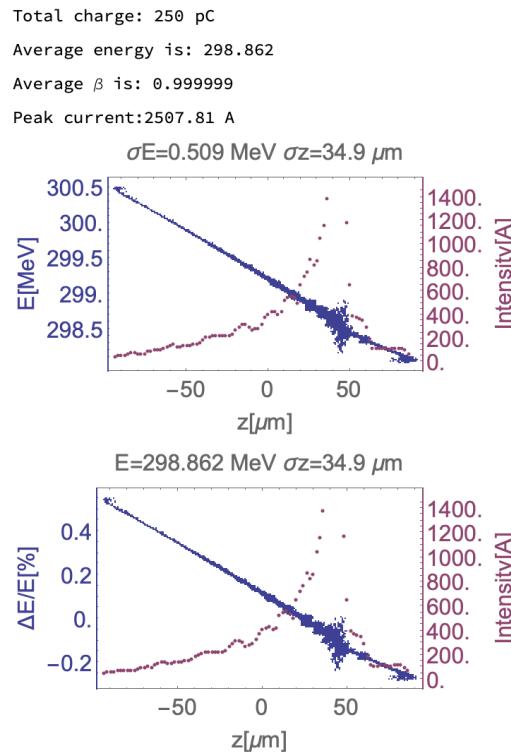
```



K-band($a=3$, $g=15\text{MV/m}$), $\phi_s < 0$

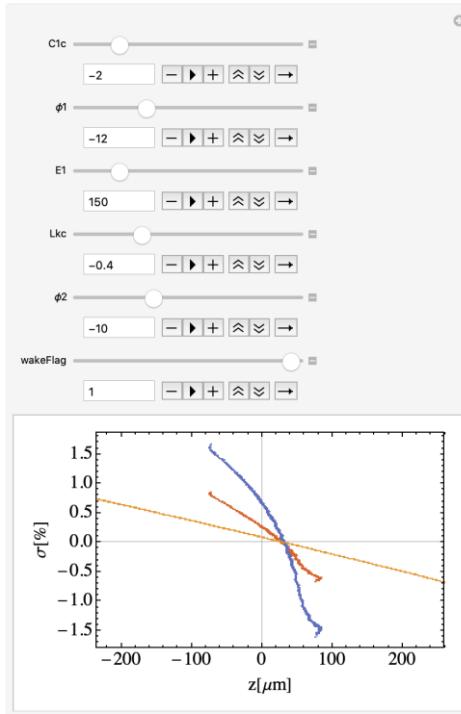


```
C1R56: 0.0443559
L1[m]: 0.141759   L2: 3.05409   Lk: 0.3666667
After first X-band acceleration:
E[MeV]: 104.466   oz[um] 292.434
After Compressor:
E[MeV]: 104.466   oz[um] 34.94
Final:
E[MeV]: 298.862   oz[um] 34.94
```



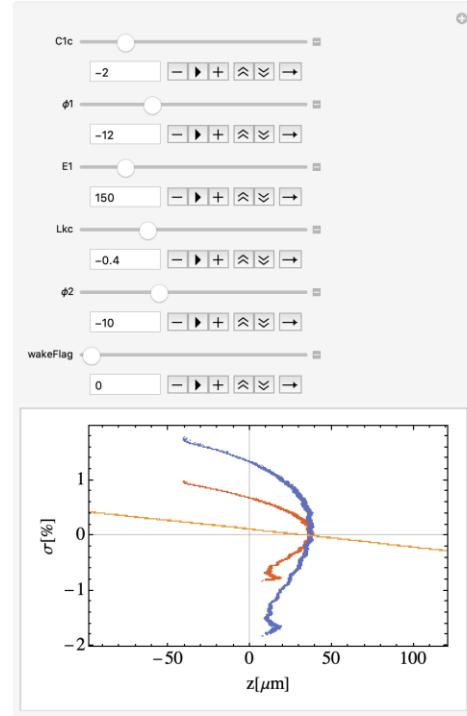
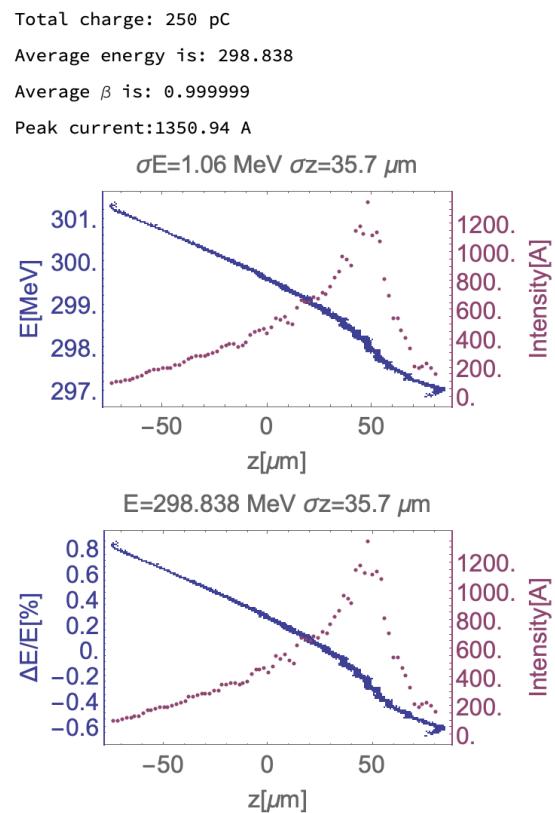
```
C1R56: 0.0443559
L1[m]: 0.141759   L2: 3.05409   Lk: 0.3666667
After first X-band acceleration:
E[MeV]: 104.598   oz[um] 292.434
After Compressor:
E[MeV]: 104.598   oz[um] 19.1061
Final:
E[MeV]: 299.9     oz[um] 19.1061
```





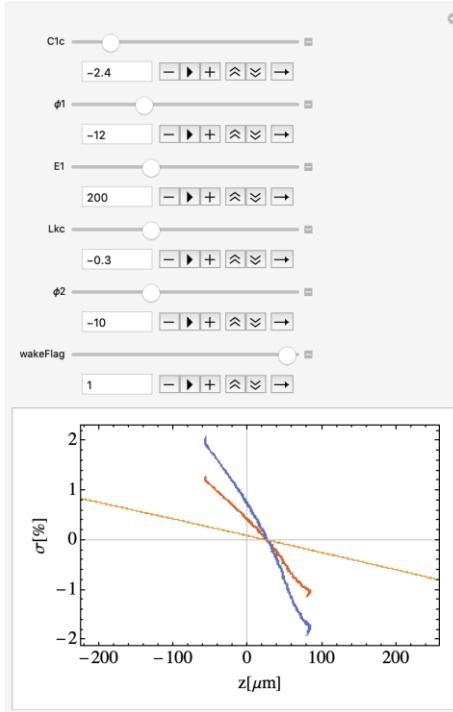
```

C1R56: 0.031315
L1[m]: 0.770891 L2: 2.48389 Lk: 0.6
After first X-band acceleration:
E[MeV]: 140.715 oz[um] 292.434
After Compressor:
E[MeV]: 140.715 oz[um] 35.6836
Final:
E[MeV]: 298.838 oz[um] 35.6836
  
```

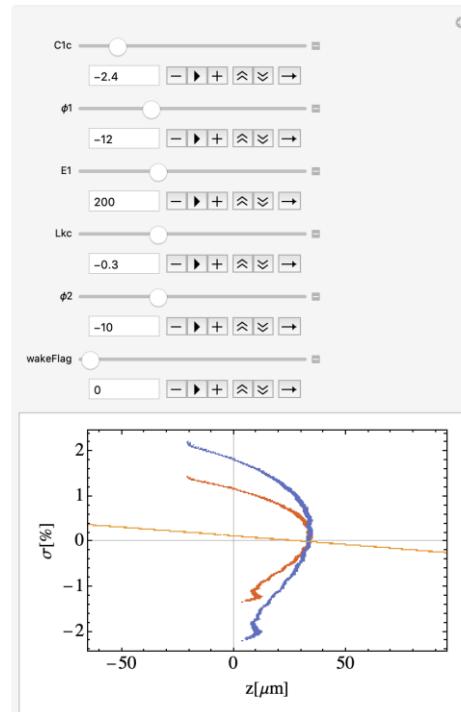
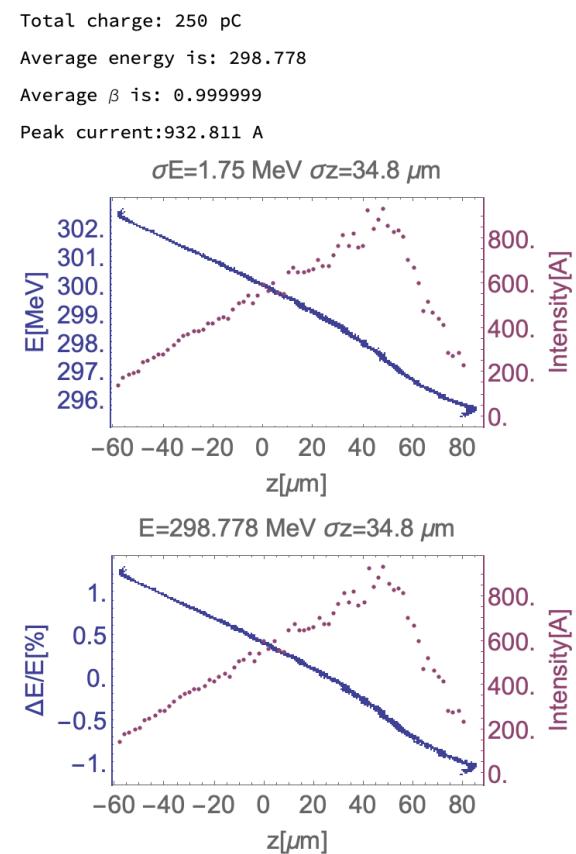


```

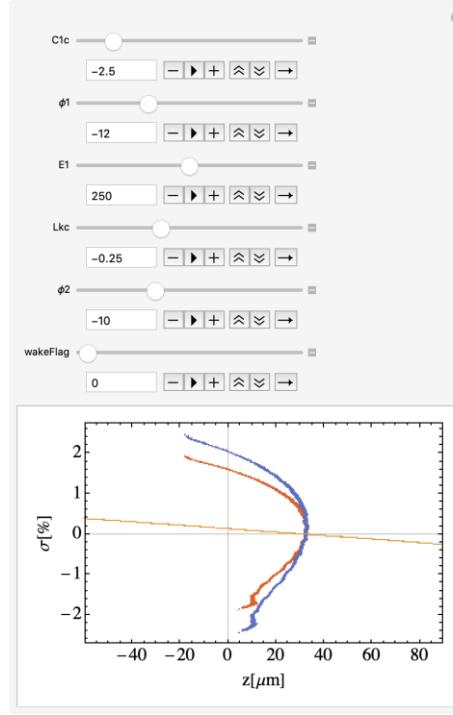
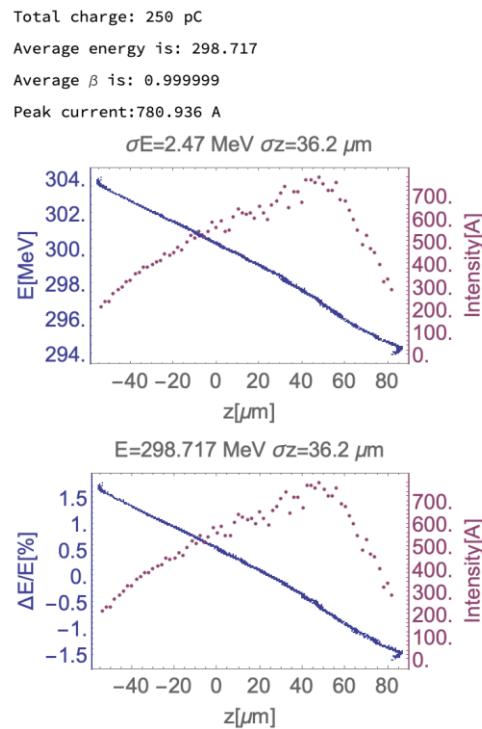
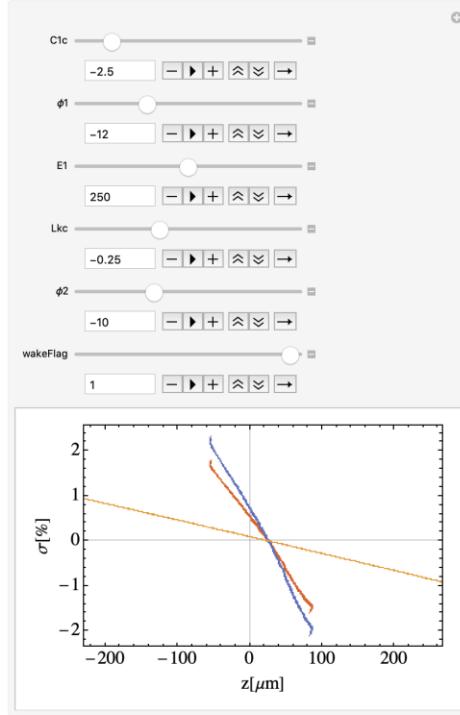
C1R56: 0.031315
L1[m]: 0.770891 L2: 2.48389 Lk: 0.6
After first X-band acceleration:
E[MeV]: 141.027 oz[um] 292.434
After Compressor:
E[MeV]: 141.027 oz[um] 14.7513
Final:
E[MeV]: 299.866 oz[um] 14.7513
  
```

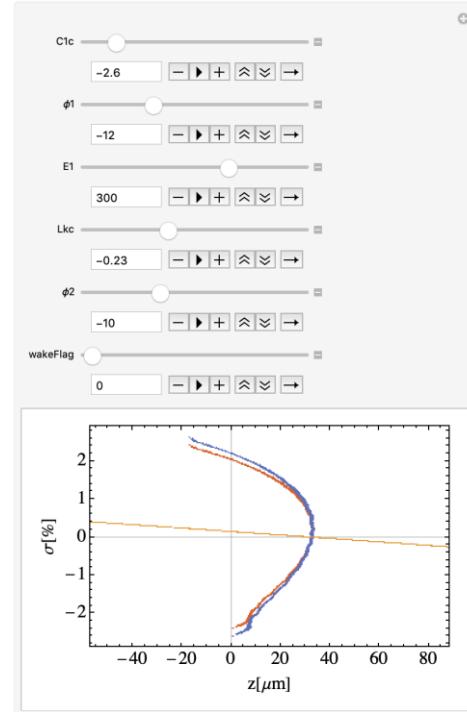
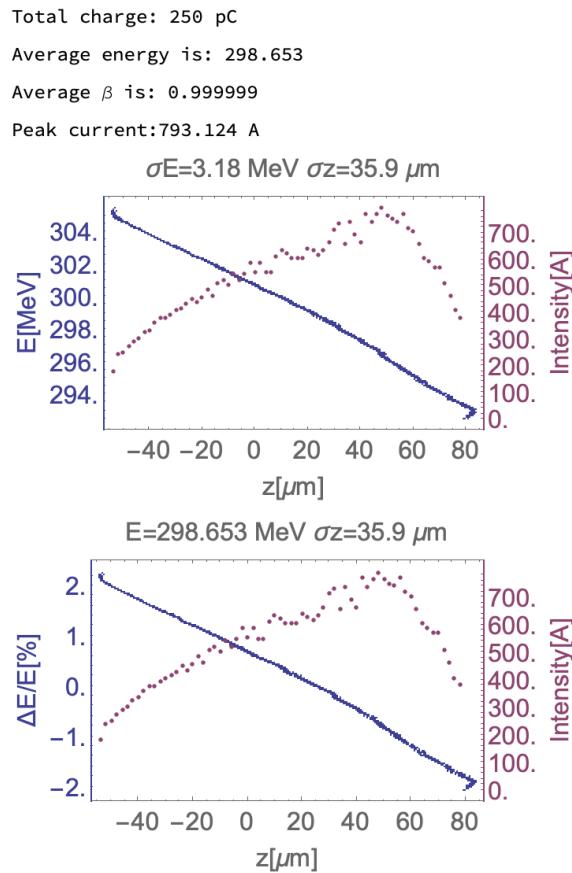
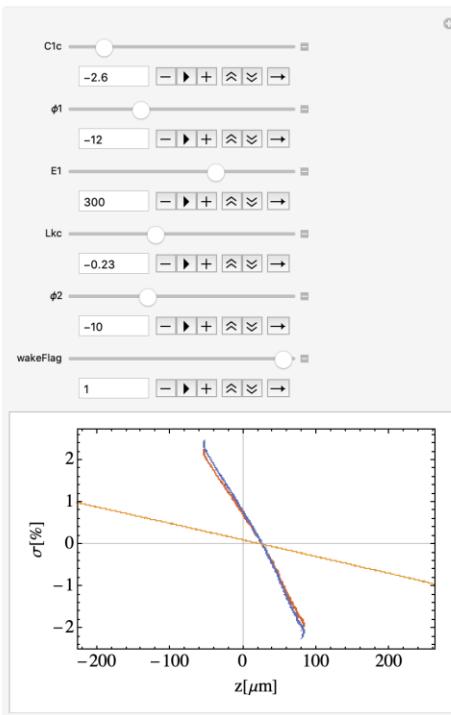


```
C1R56: 0.0260936
L1[m]: 1.55731 L2: 1.7809 Lk: 0.933333
After first X-band acceleration:
E[MeV]: 185.404 oz[um] 292.434
After Compressor:
E[MeV]: 185.404 oz[um] 34.7763
Final:
E[MeV]: 298.778 oz[um] 34.7763
```

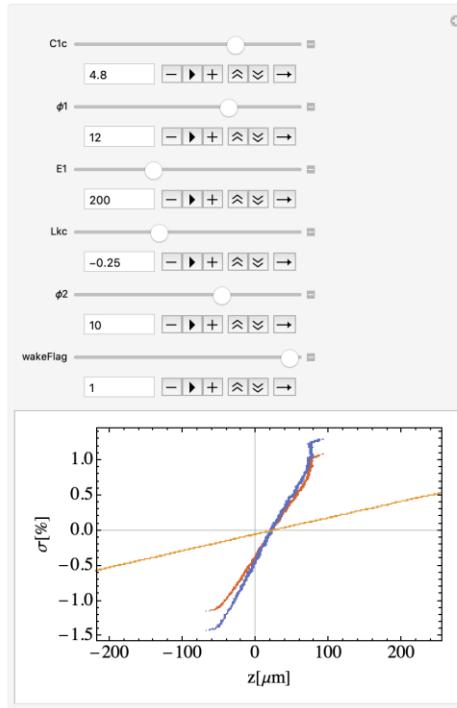


```
C1R56: 0.0260936
L1[m]: 1.55731 L2: 1.7809 Lk: 0.933333
After first X-band acceleration:
E[MeV]: 185.953 oz[um] 292.434
After Compressor:
E[MeV]: 185.953 oz[um] 10.9586
Final:
E[MeV]: 299.838 oz[um] 10.9586
```

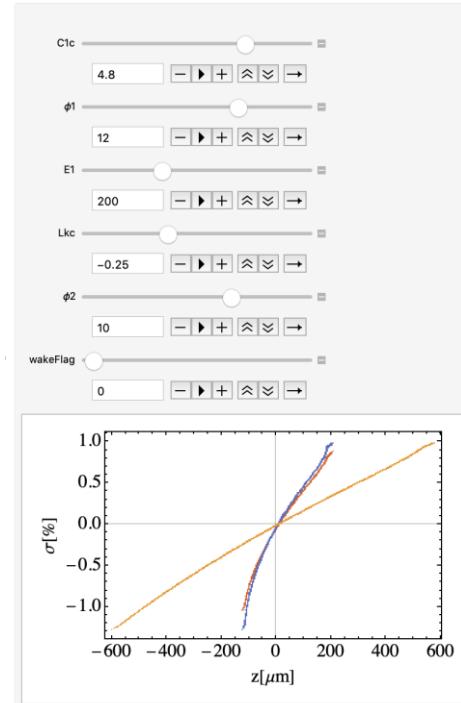
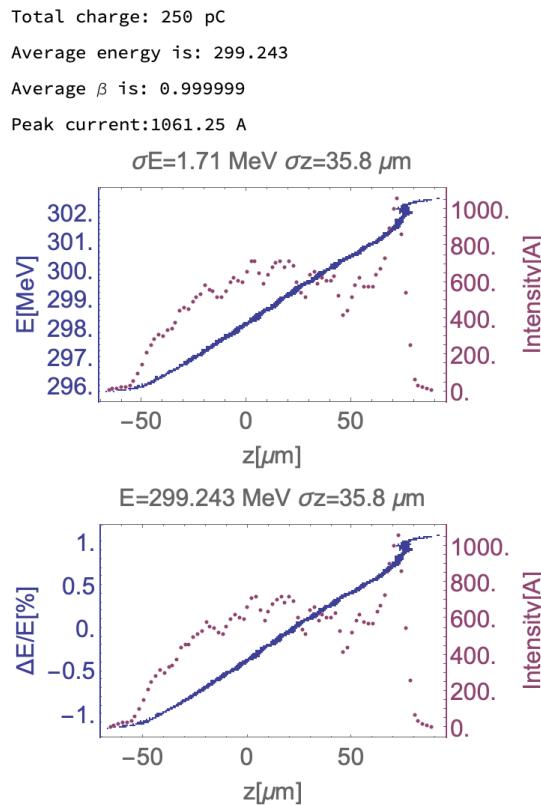




K-band($a=3$, $g=15\text{MV/m}$), $\phi_s > 0$

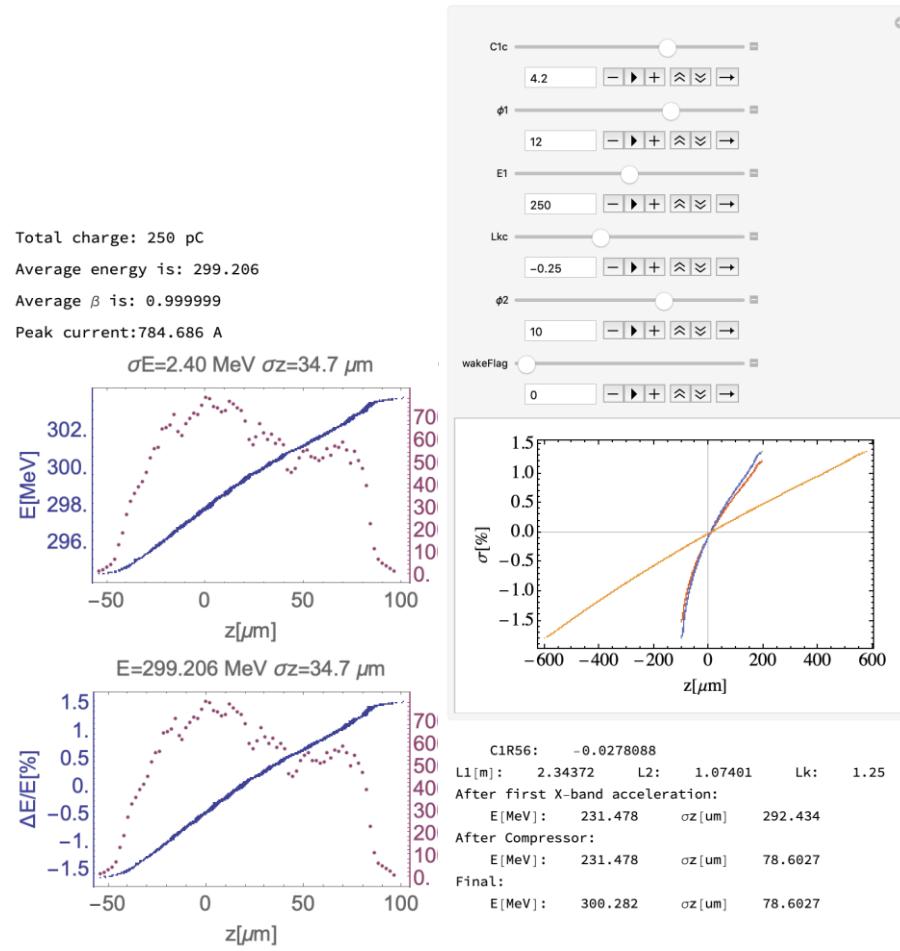
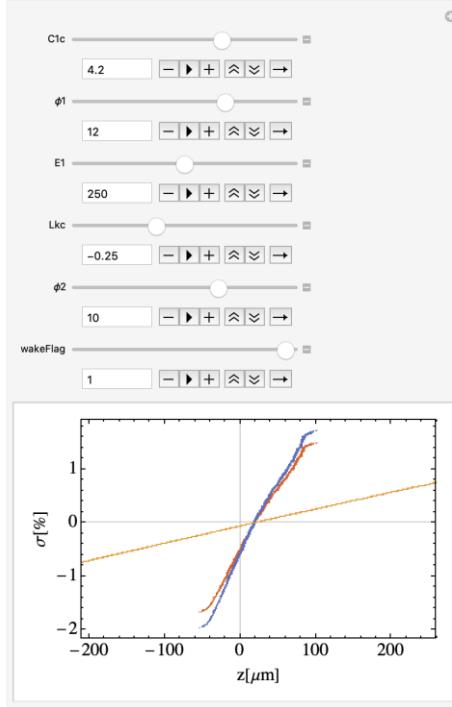


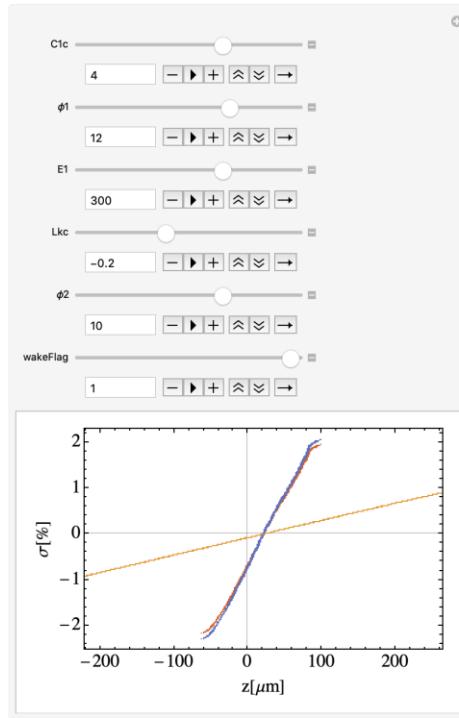
```
C1R56: -0.0373957
L1[m]: 1.55731   L2: 1.79652   Lk: 1.
After first X-band acceleration:
E[MeV]: 184.645   oz[um] 292.434
After Compressor:
E[MeV]: 184.645   oz[um] 35.7777
Final:
E[MeV]: 299.243   oz[um] 35.7777
```



```
C1R56: -0.0373957
L1[m]: 1.55731   L2: 1.79652   Lk: 1.
After first X-band acceleration:
E[MeV]: 185.213   oz[um] 292.434
After Compressor:
E[MeV]: 185.213   oz[um] 89.1248
Final:
E[MeV]: 300.296   oz[um] 89.1248
```



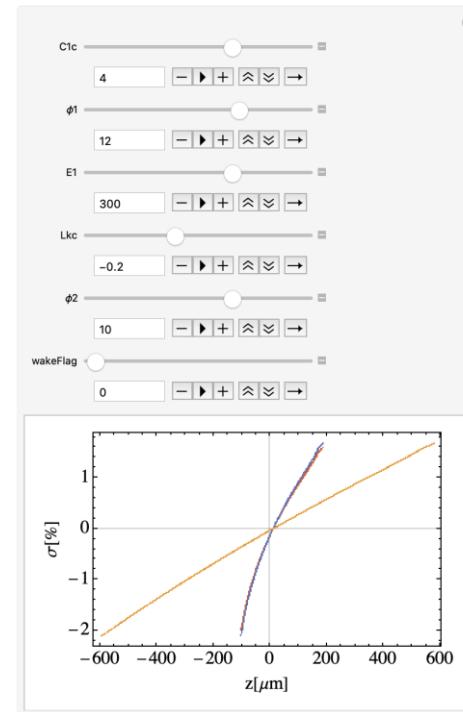
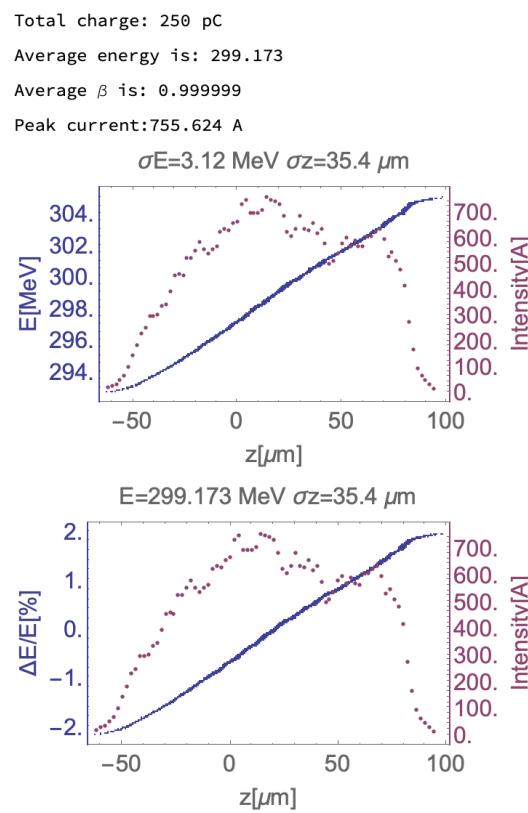




```

C1R56: -0.023372
L1[m]: 3.13014 L2: 0.374927 Lk: 1.6
After first X-band acceleration:
E[MeV]: 275.257 oz[um] 292.434
After Compressor:
E[MeV]: 275.257 oz[um] 35.4268
Final:
E[MeV]: 299.173 oz[um] 35.4268

```



```

C1R56: -0.023372
L1[m]: 3.13014 L2: 0.374927 Lk: 1.6
After first X-band acceleration:
E[MeV]: 276.279 oz[um] 292.434
After Compressor:
E[MeV]: 276.279 oz[um] 75.8476
Final:
E[MeV]: 300.298 oz[um] 75.8476

```