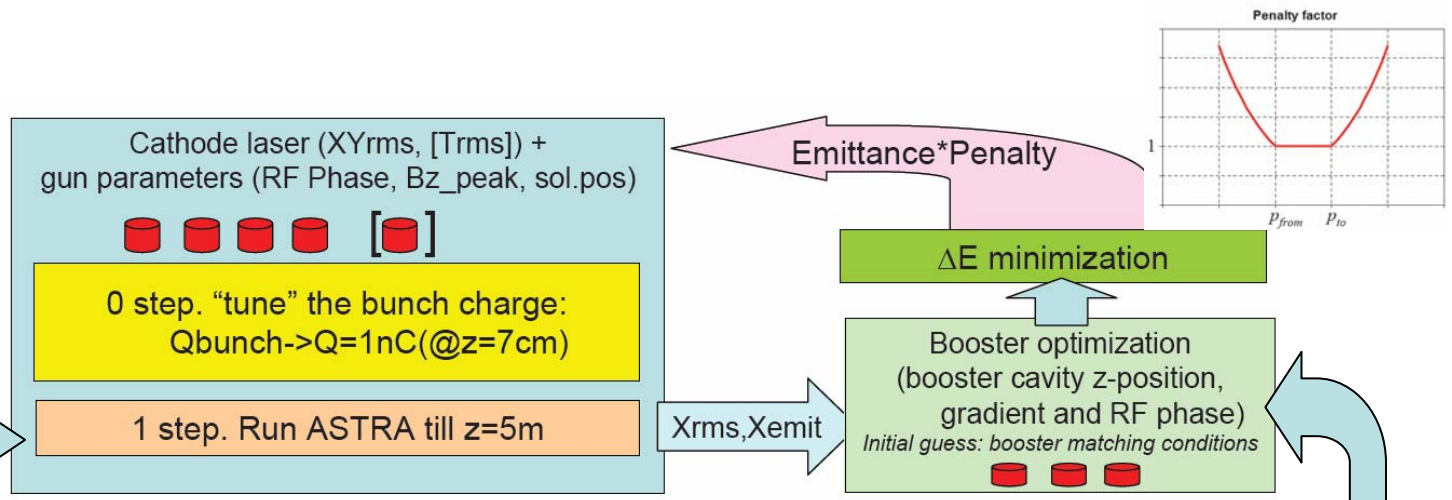
Status of the Simulations on Photo Injector Optimization for Low Charges

Yauhen Kot

BD Meeting, 01.02.2010

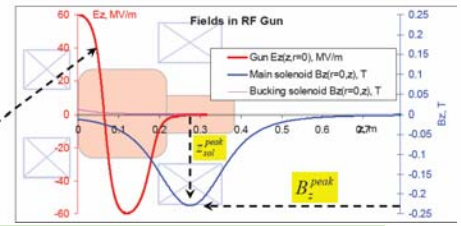
Preliminary results
work is not accomplished yet…

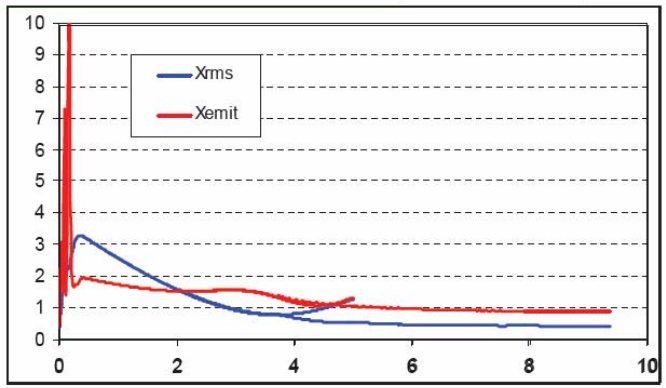
Optimization Code for the Photo Injector by M. Krasilnikov

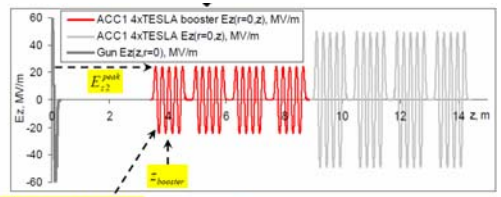


$E = E_{z1}(z) \cdot \sin(\omega t + \phi_1)$

$E_{z1}(z=0) = 60 MV/m$







$E = E_{z2}(z) \cdot \sin(\omega t + \phi_2)$

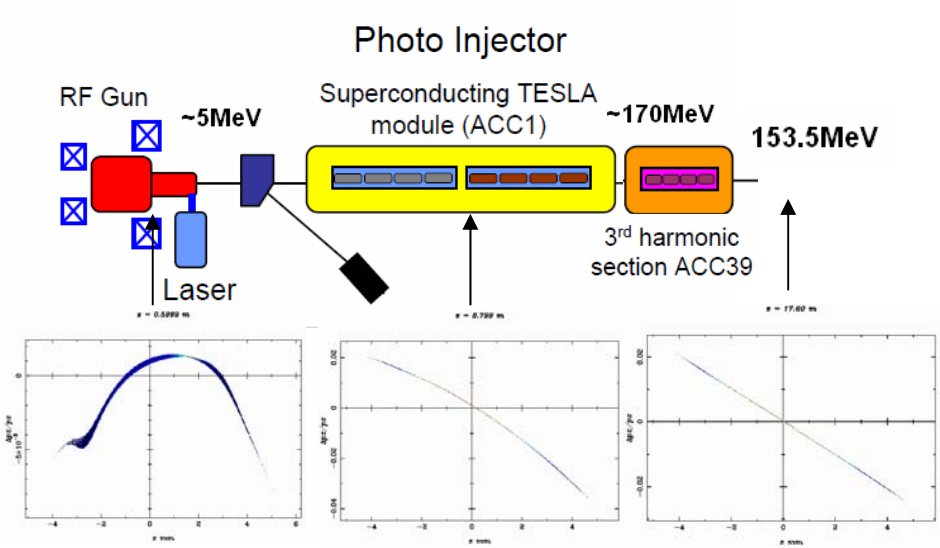
RF gun parameters to be optimized:

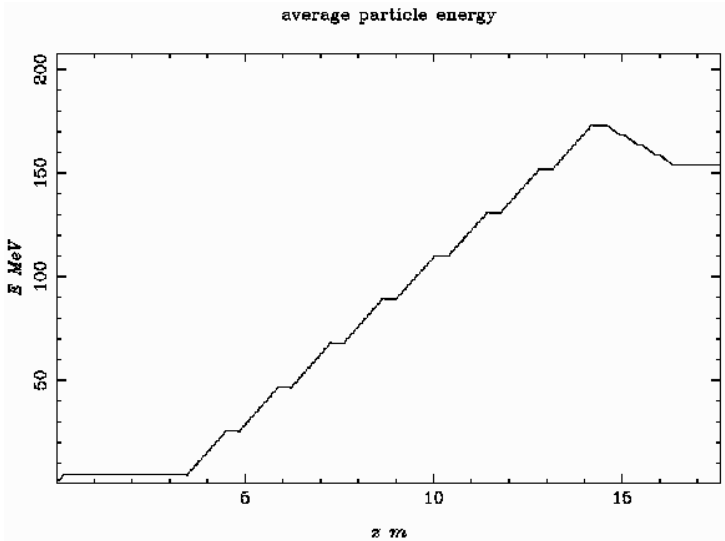
- Main solenoid peak field B_z^{peak}
- Main solenoid z-position z_{sol}^{peak}
- Cathode laser spot rms size $\sigma_{x,y}$
- RF gun launch phase ϕ_1

Booster parameters to be optimized :

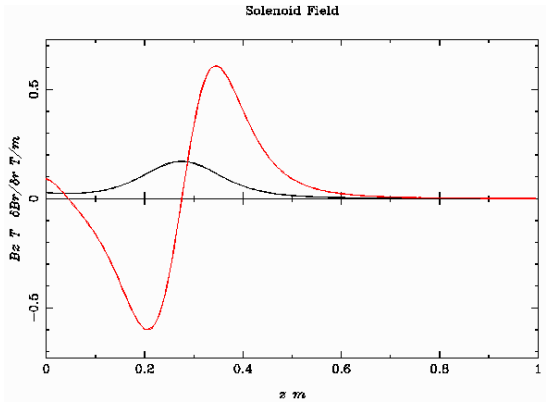
- Booster peak field E_{z2}^{peak}
- Booster z-position $z_{booster}$
- Booster rf phase ϕ_2

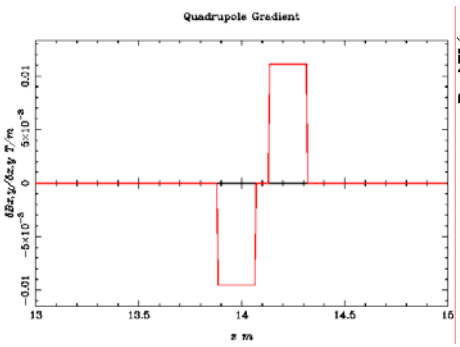
FLASH Photo Injector

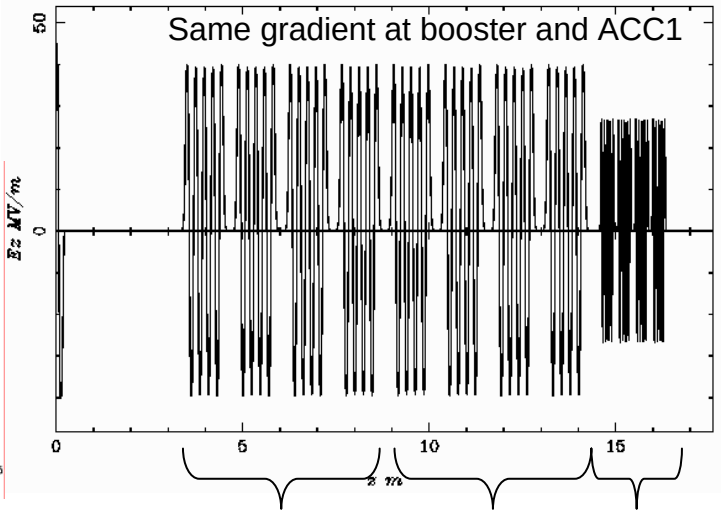




Booster phase is fixed







Gun Booster ACC1 3,9GHz

Optimization Code for FLASH Photo Injector

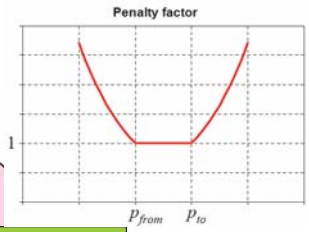
Cathode laser (XYrms, [Trms]) +
gun parameters (RF Phase, Bz_peak, sol.pos)

0 step. "tune" the bunch charge:
Qbunch->Q=1nC(@z=7cm)

1 step. Run ASTRA till z=5m

Xrms,Xemit

Emittance*Penalty

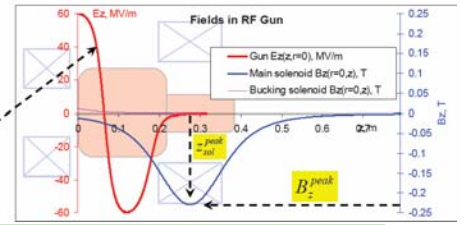


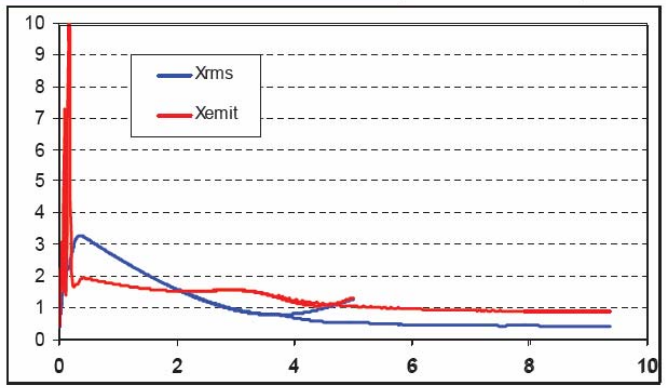
ΔE minimization

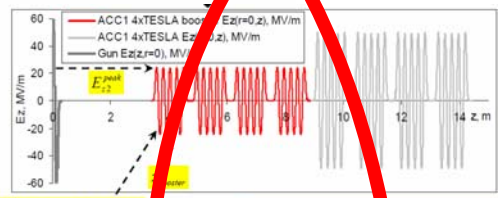
Booster optimization
(booster cavity z-position,
gradient and RF phase)
Initial guess: booster matching conditions

$E = E_{z1}(z)\cdot\sin(\omega t+\phi_1)$

$E_{z1}(z=0)=45MV/m$







$E = E_{z2}(z)\cdot\sin(\omega t+\phi_2)$

RF gun parameters to be optimized:

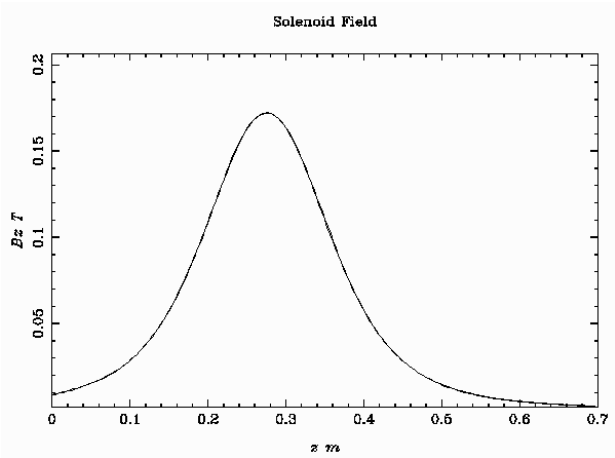
- Main solenoid peak field B_z^{peak}
- ~~Main solenoid z-position z_{sol}^{peak}~~
- Cathode laser spot rms size $\sigma_{x,y}$
- RF gun launch phase ϕ_1

Booster parameters to be optimized :

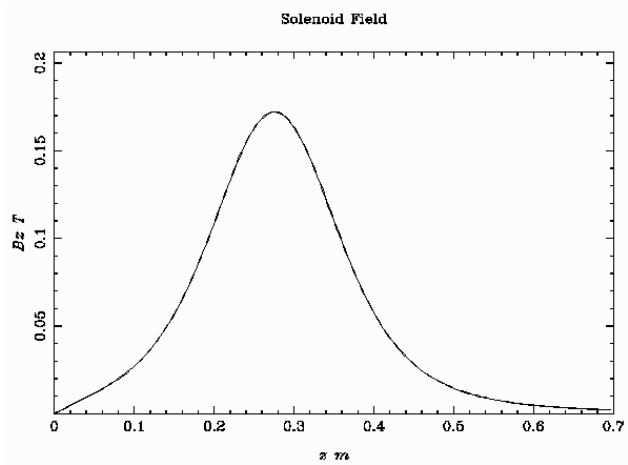
- Booster peak field E_{z2}^{peak}
- Booster z-position $z_{booster}$
- Booster rf phase ϕ_2

Setting the Field of the Bucking Coil

MaxB(1)=0.17211
MaxB(2)=0.00000



MaxB(1)=0.17211
MaxB(2)=-0.00858

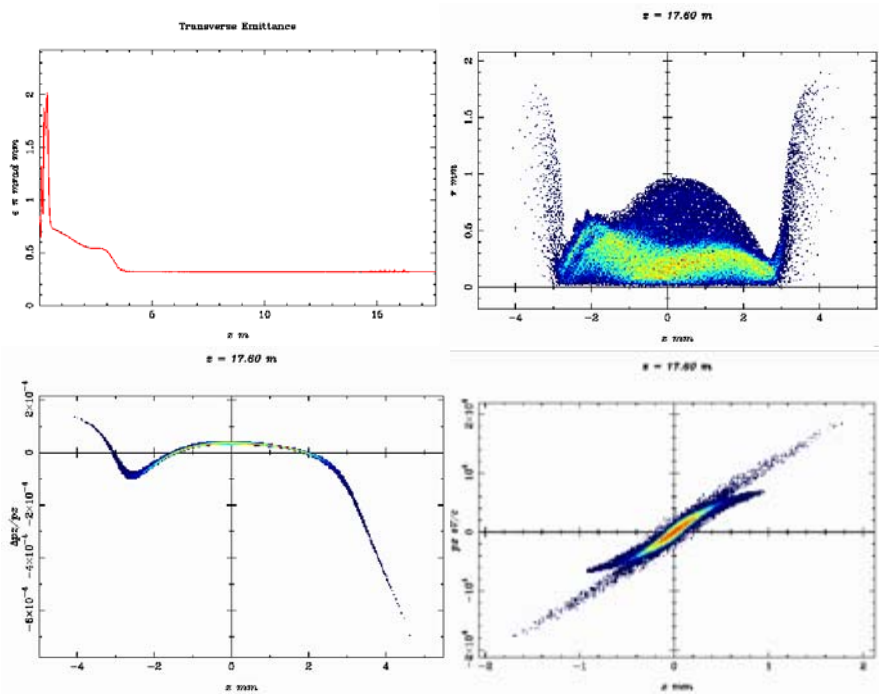


- Bucking Coil should compensate the solenoid field at s=0.00
- Bucking field is about 20 times weaker than the solenoid field and in the opposite direction

How important is this correction for the beam?

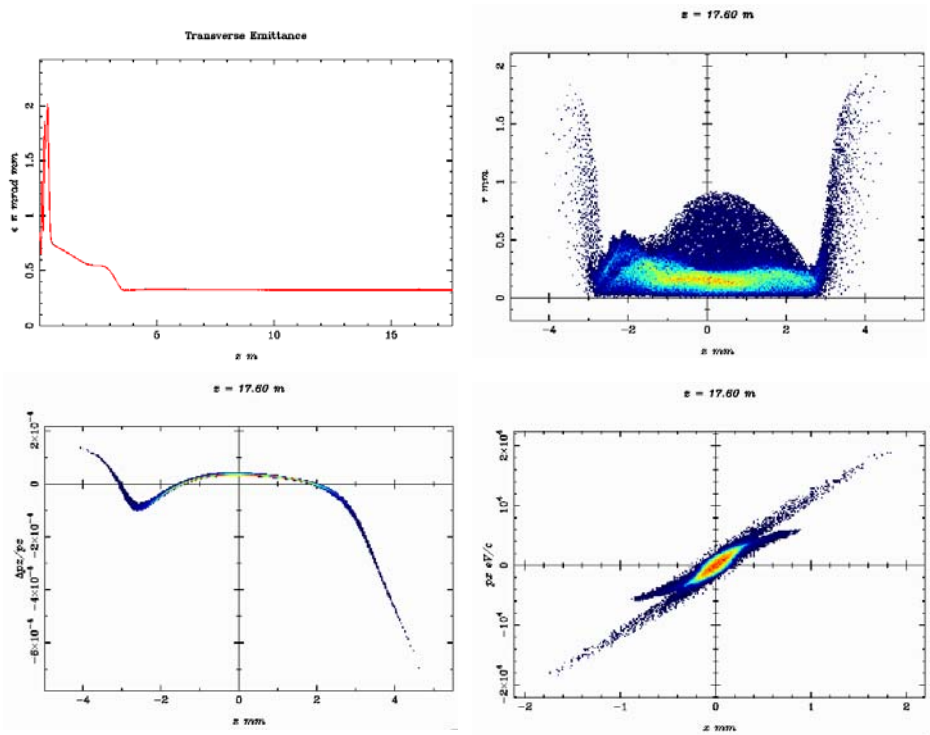
Compare with and without Bucking Coil
Test with 200000 particles

with bucking coil



→ Emittance at 17.60m = 0.322

without bucking coil



→ Emittance at 17.60m = 0.327

→ *Emittance growth 1.55% if the solenoid field not neutralized at the cathode*

Field Files for the Gun

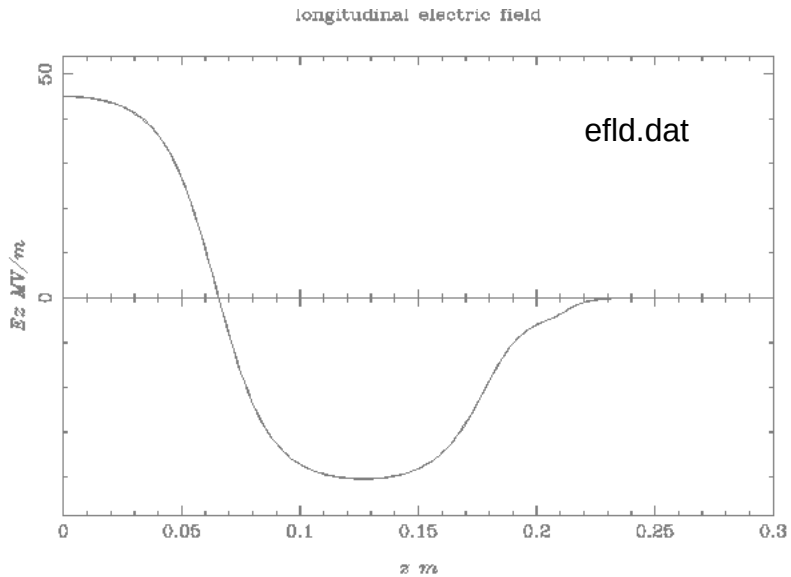
Slightly different files but big consequencies

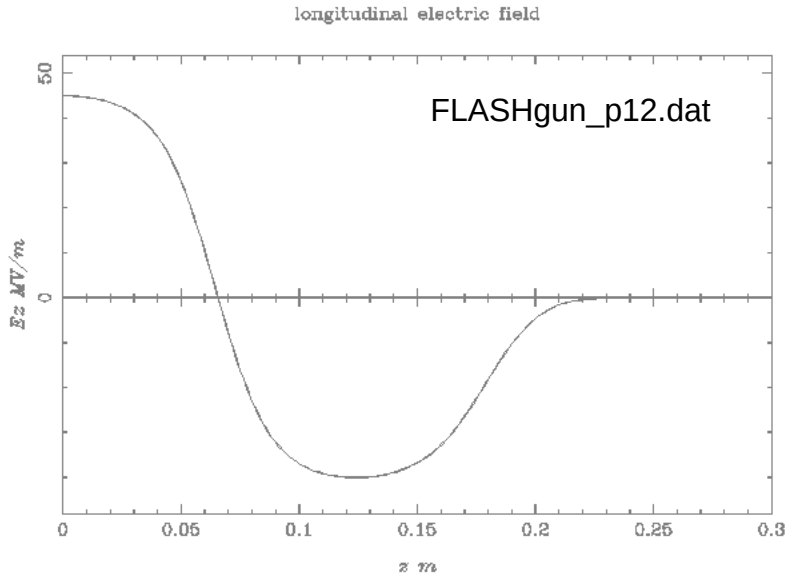
Tuning parameters for efld		
Beam size	**XYrms**	**0.170105**
Solenoid	**MaxB(1)**	**0.172724**
Bucking Coil	**MaxB(2)**	**0.019489**
Gun	MaxE(1)	45.00
	Phi(1)	**-1.34264**
Booster	MaxE(2)	40.12
	Phi(2)	-14.85

	hor	vert
ε	0.3278	0.3273
ε reduced	0.2988	0.2982
β	37.52	38.48
α	-2.204	-1.792

Tuning parameters for FLASHgun_p12		
Beam size	**XYrms**	**0.15929**
Solenoid	**MaxB(1)**	**0.171247**
Bucking Coil	**MaxB(2)**	**0.015844**
Gun	MaxE(1)	45.00
	Phi(1)	**-1.27222**
Booster	MaxE(2)	40.12
	Phi(2)	-14.85

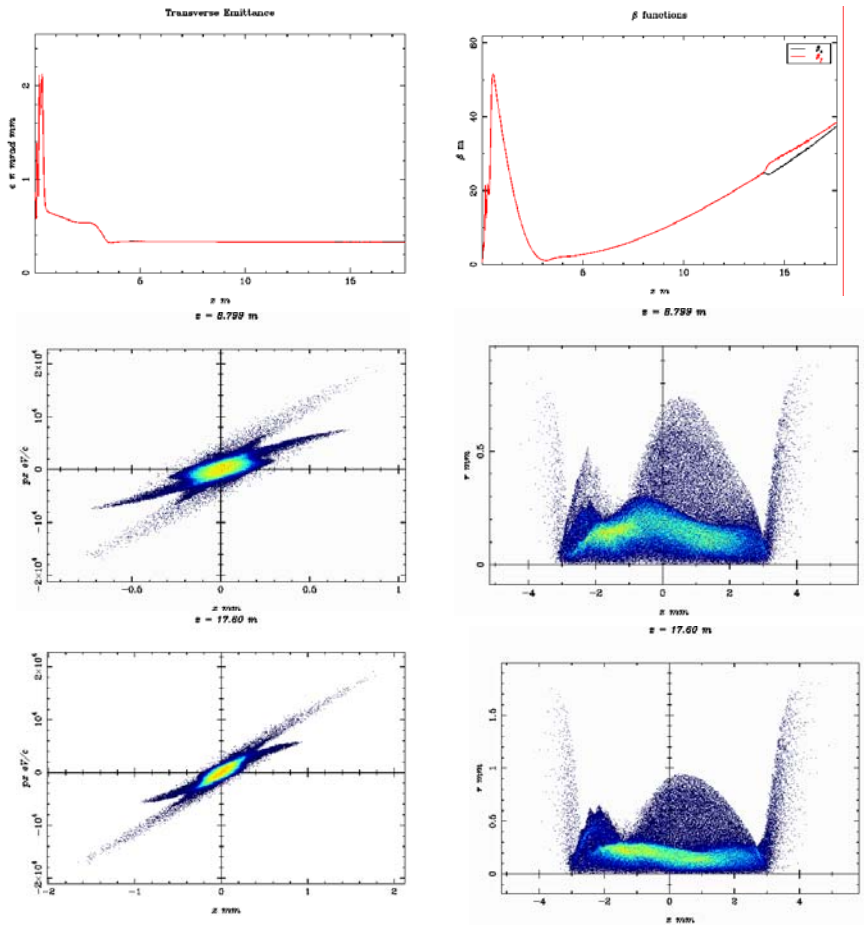
	hor	vert
ε	0.3131	0.3128
ε reduced	0.2949	0.2949
β	44.97	45.87
α	-2.873	-2.350





Calculated with best parameters for efld.dat. Comparison

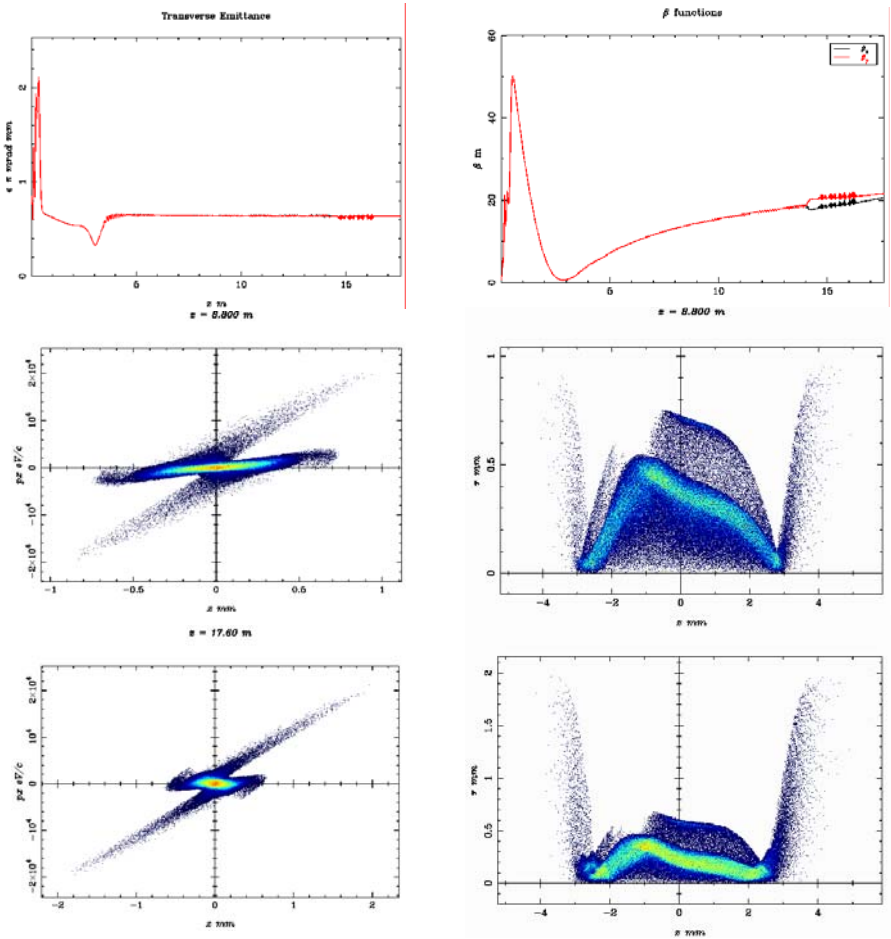
efld



β_x	37.52
β_y	38.48
α_x	-2.204
α_y	-1.792

ε	0.3266
ε w/o corr.	0.2988

FLASHgun_p12



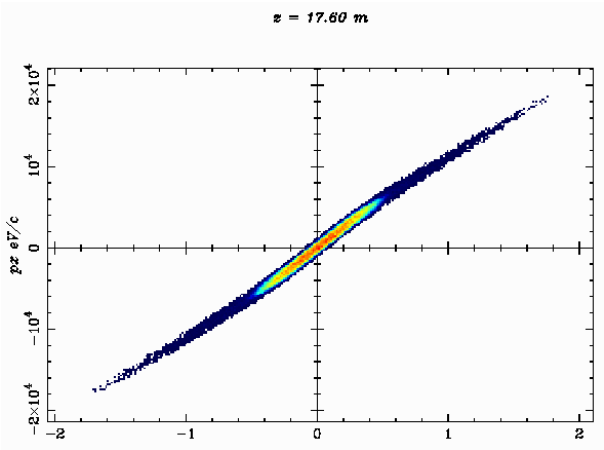
β_x	20.61
β_y	21.56
α_x	-0.509
α_y	-0.273

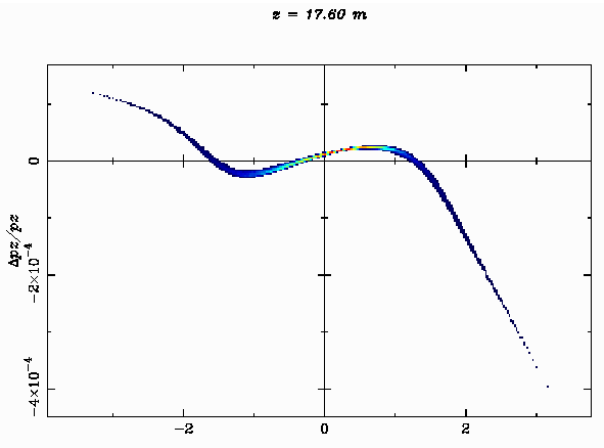
ε	0.6356
ε w/o corr.	0.4374

Bunch Shape or Emittance?

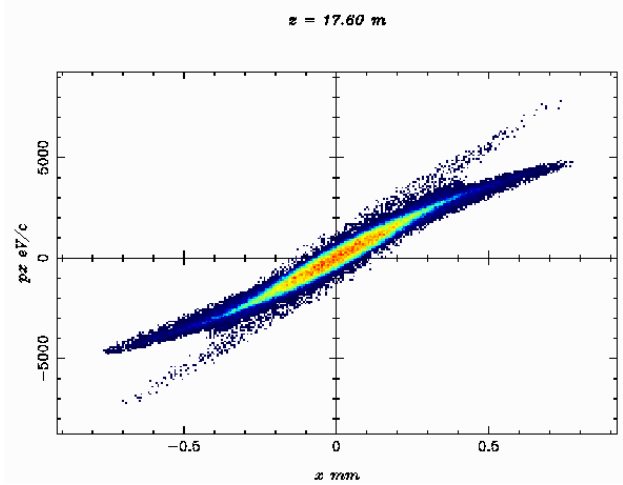
(Example with 20pC, 3.3ps)

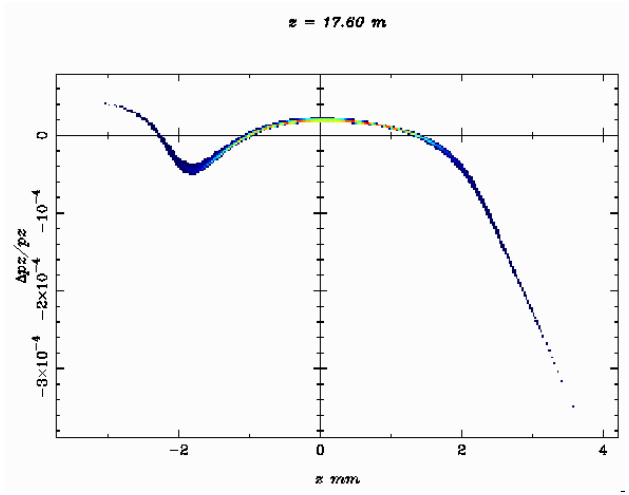
Bunch Shape Priority: XYrms=0.165



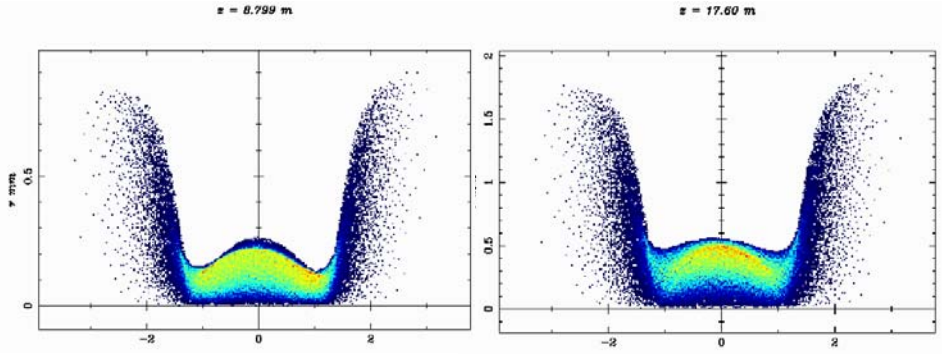


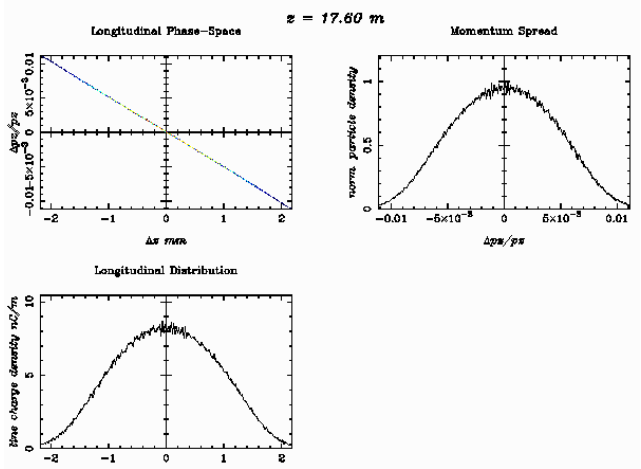
Emittance Priority: XYrms=0.072





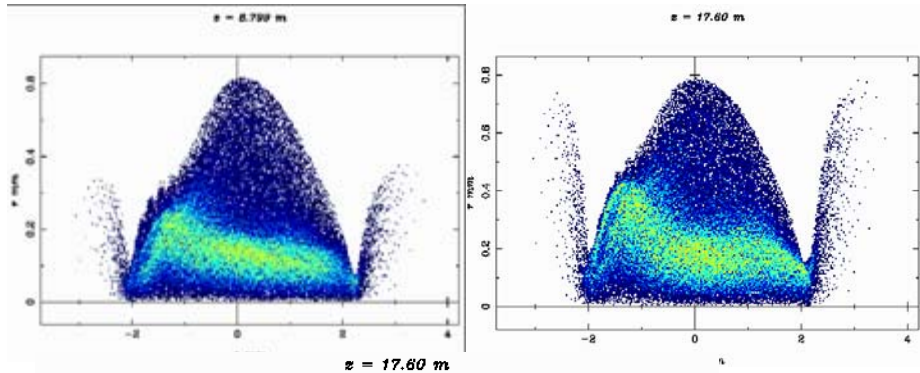
Bunch Shape Priority: XYrms=0.165

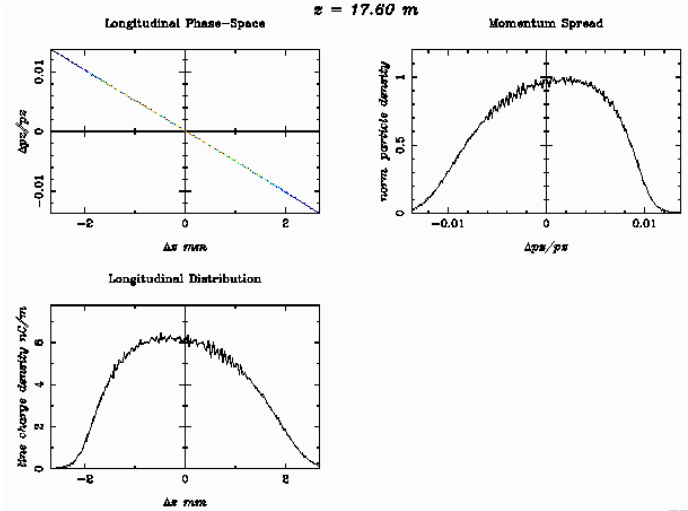




Emittance, mm mrad	0.1374
Emittance long. keV mm	3.940
Bunch length rms, mm	1.073
beta	92.96
alpha	-4.646

Emittance Priority: XYrms=0.072





Emittance, mm mrad	0.2726
Emittance long. keV mm	3.495
Bunch length rms, mm	0.874
beta	98.00
alpha	-7.552

Tuning Parameters and Results. Overview

	Variable Tuning Parameters			
	20pC, 3.3ps	20pC, 4.4 ps	100pC, 3.3ps	100pC, 4.4ps
XYrms	0.0718	0.0679	0.1673	0.1637
Solenoid: MaxB(1)	0.171421	0.171417	0.171956	0.172187
Gun: Phi(1)	-0.7797	-0.6977	-1.6114	-1.5773

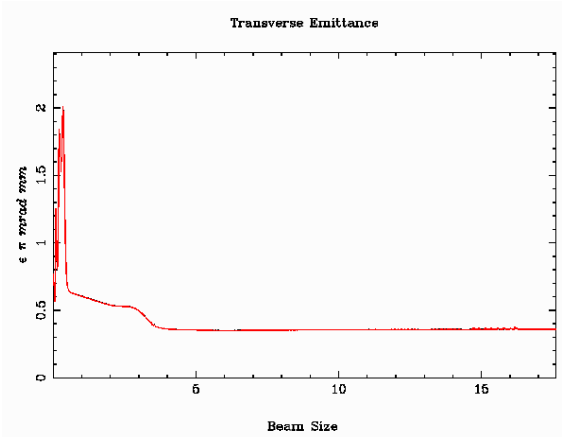
	Results at s=17.60m			
	20pC, 3.3ps	20pC, 4.4 ps	100pC, 3.3ps	100pC, 4.4ps
Emittance, mm mrad	0.137	0.135	0.360	0.322
Emittance w/o energy corr., mm mrad	0.120	0.113	0.342	0.308
Long. Emittance, keV mm	3.940	6.123	7.008	10.51
Energy rms, keV	846.6	996.4	1062	1174
Bunch length, mm	1.073	1.257	1.356	1.493
Beta, m	92.96	84.09	77.68	57.87
Alpha	-4.646	-4.159	-5.015	-3.865

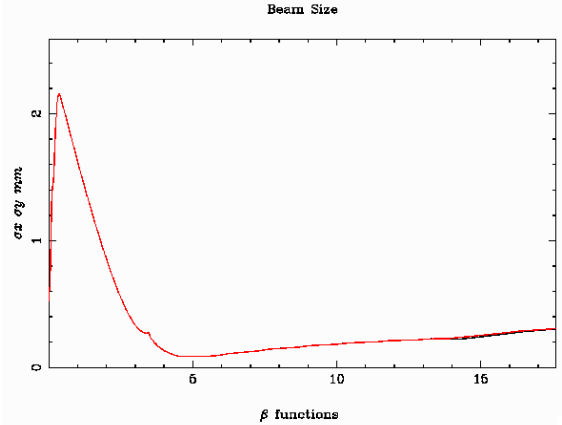
QBunch = 100pC, Laser Pulse: gaussian τ=3.3ps

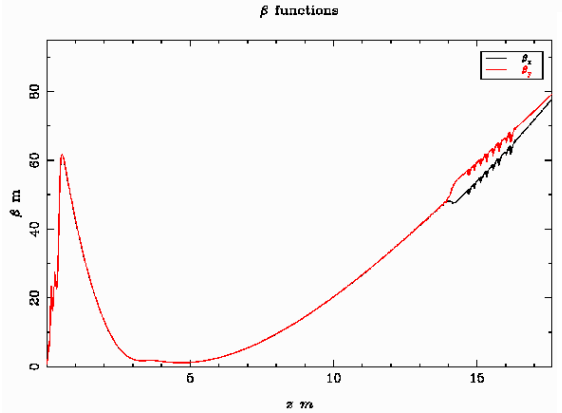
	Tuning Parameters found by optimization procedure with 2000 particles			
Beam	**XYrms=0.1673**	**Q=100pC**	**Laser: gauss, τ=3.3ps**	
Solenoid	**MaxB(1)=0.171956**		S_pos(1)=0.00	File=Main2003_3m
Bucking	**MaxB(2)=-0.008566**		S_pos(2)=0.00	File=Buck2003_0
Gun	MaxE(1)=45.0	**Phi(1)=-1.61138**	C_pos(1)=0.00	File=FLASHgun_p12
Booster	MaxE(2)=40.12	Phi(2)=-14.8525	C_pos(2)=3.970	File=TeSLA_4_9cells
ACC1	MaxE(3)=39.93	Phi(3)=-14.8517	C_pos(3)=9.512	File=tesla4cav13
3.9GHz	MaxE(4)=26.96	Phi(4)=-194.96	C_pos(4)=14.775	File=tesla4cav3

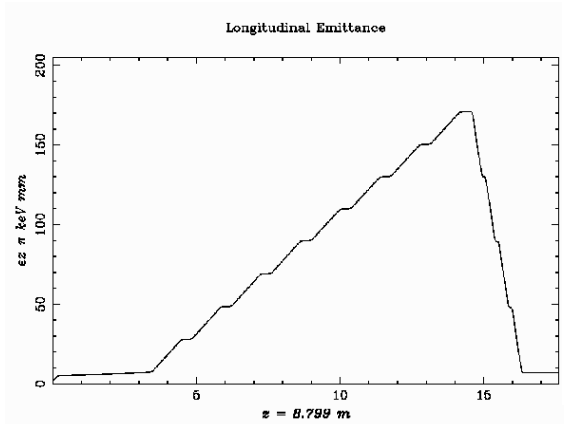
Results after Test with 200000 particles		
	8.80m (after booster)	**17.60m (after 3.9GHz)**
Emittance, mm mrad	**0.355**	**0.360**
Emittance w/o energy corr., mm mrad	**0.346**	**0.342**
Long. Emittance, keV mm	**89.87**	**7.008**
Energy rms, keV	**749.9**	**1062**
Bunch length, mm	**1.357**	**1.356**
Beta, m	**13.43**	**77.68**
Alpha	**-2.647**	**-5.015**

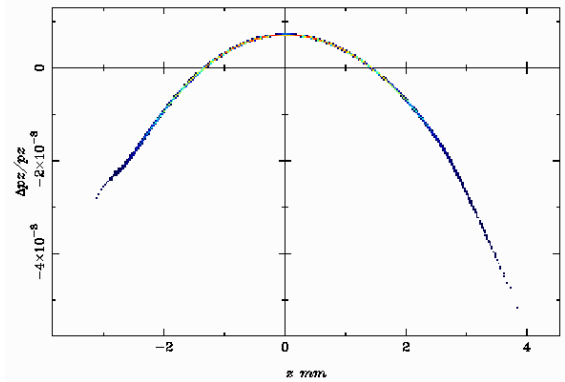
QBunch = 100pC, Laser Pulse: gaussian τ=3.3ps
Beam Development and Optics

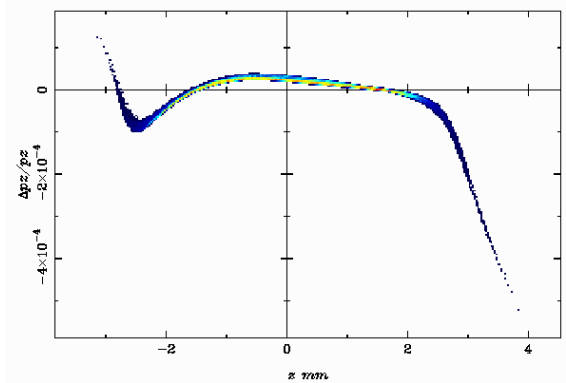






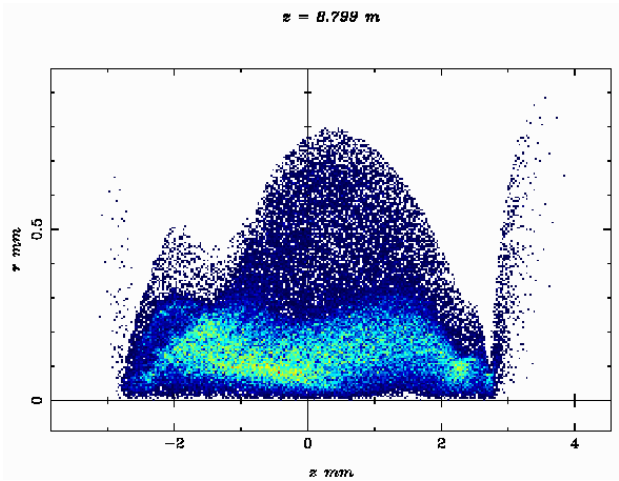


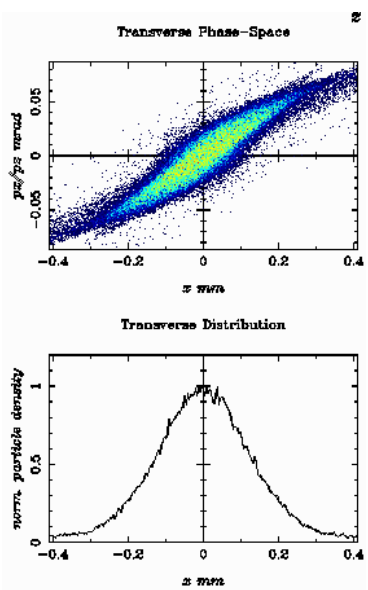


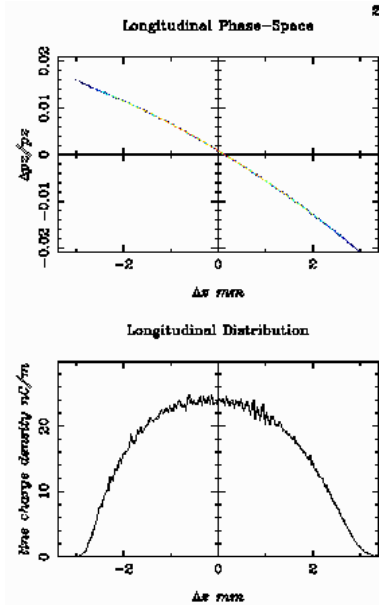


QBunch = 100pC, Laser Pulse: gaussian τ=3.3ps
Beam Shape

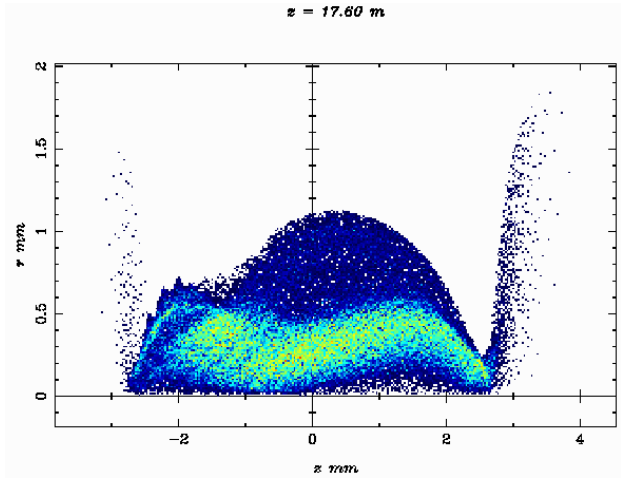
After Booster

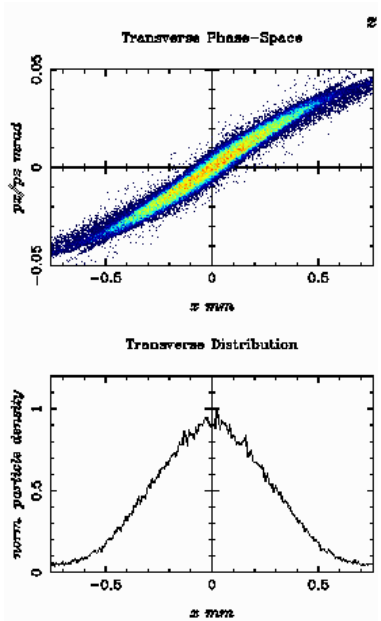


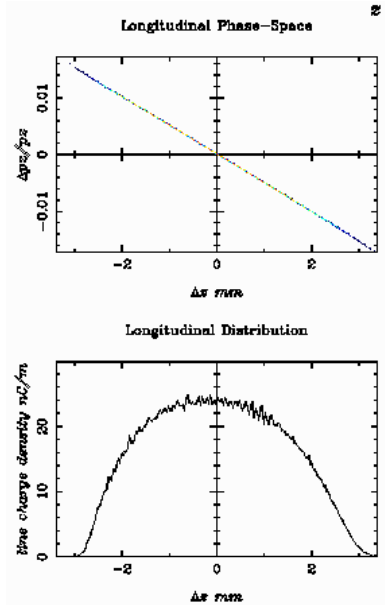




After 3.9GHz

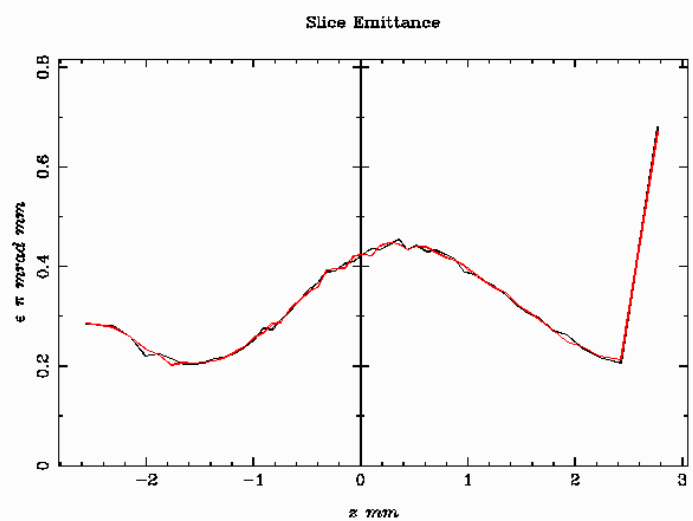


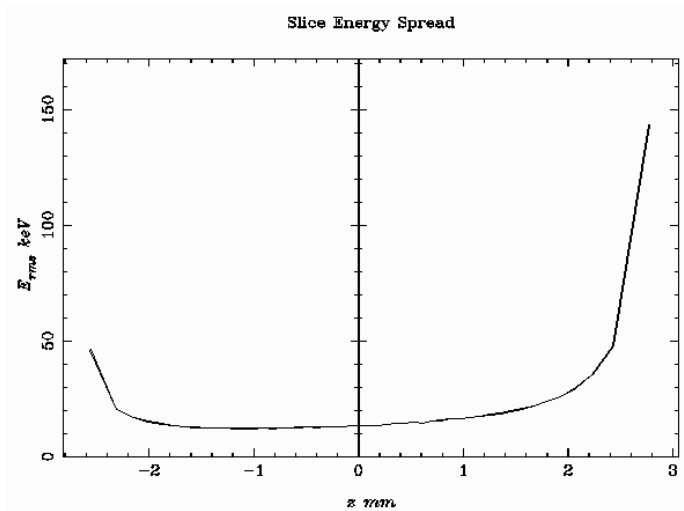




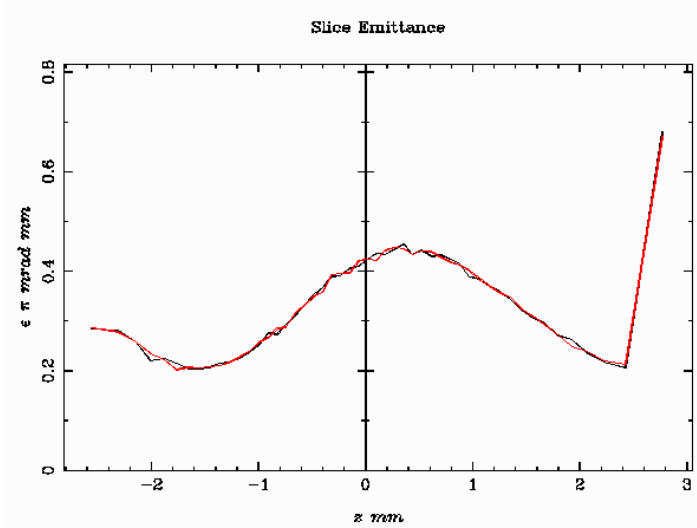
QBunch = 100pC, Laser Pulse: gaussian τ=3.3ps
Slices

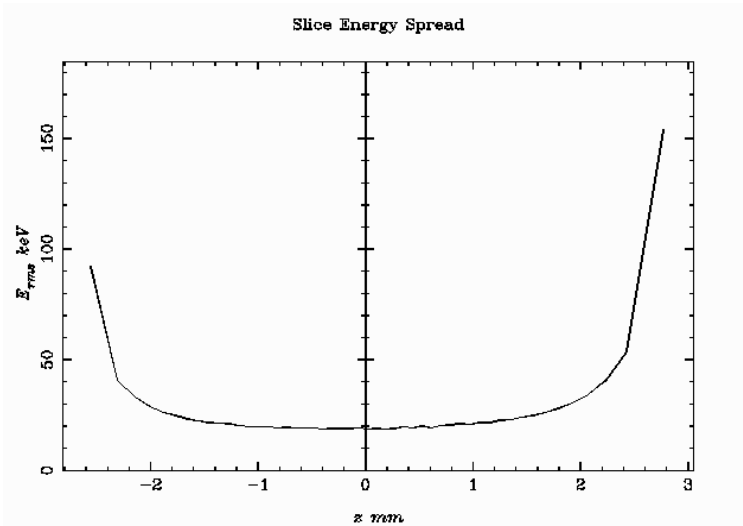
z=8.80m



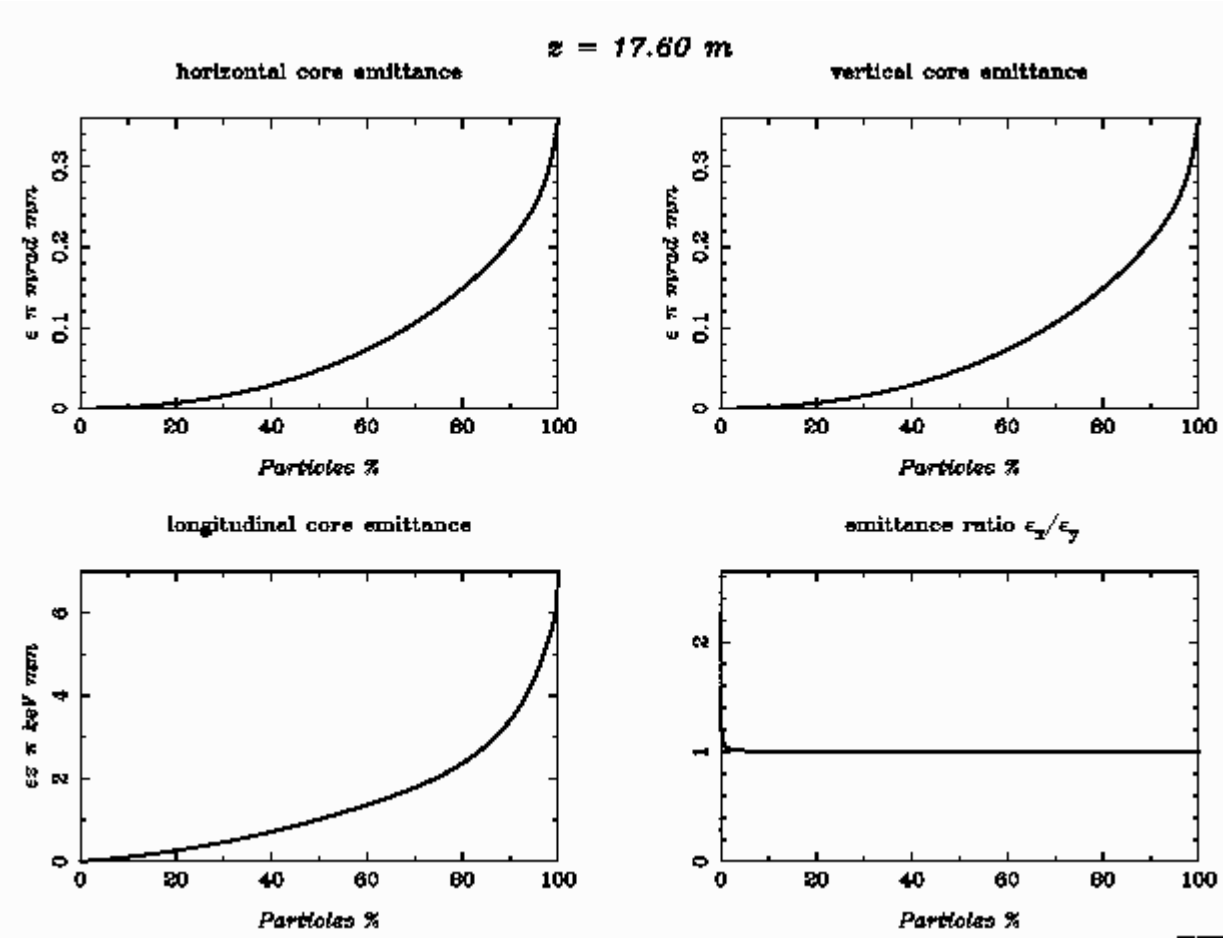


z=17.60m





QBunch = 100pC, Laser Pulse: gaussian τ=3.3ps
Core Emittance



core emittance

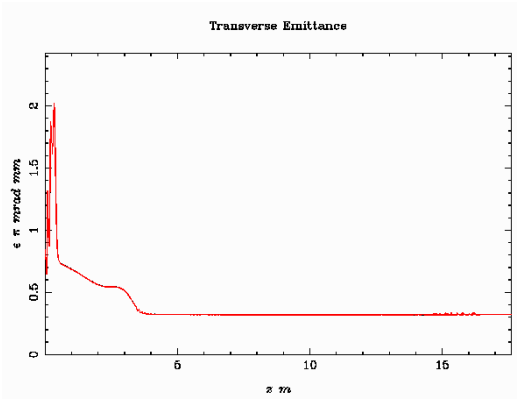
	100%	95%	90%	80%	
horizontal:	0.3594	0.2502	0.2074	0.1489	pi mrad mm
vertical:	0.3592	0.2502	0.2075	0.1491	pi mrad mm
long.:	7.007	4.406	3.411	2.373	pi keV mm

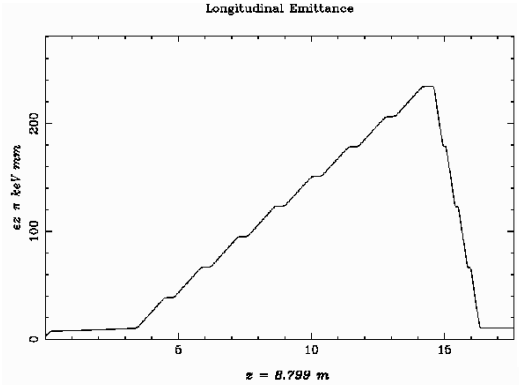
QBunch = 100pC, Laser Pulse: gaussian τ=4.4ps

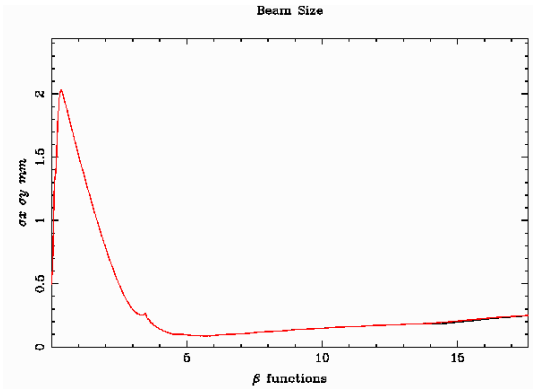
	Tuning Parameters found by optimization procedure with 2000 particles			
Beam	**XYrms=0.1637**		**Laser: gauss, τ=4.4ps**	
Solenoid	**MaxB(1)=0.172187**		S_pos(1)=0.00	File=Main2003_3m
Bucking	**MaxB(2)=-0.008575**		S_pos(2)=0.00	File=Buck2003_0
Gun	MaxE(1)=45.0	**Phi(1)=-1.57725**	C_pos(1)=0.00	File=FLASHgun_p12
Booster	MaxE(2)=40.12	Phi(2)=-14.8525	C_pos(2)=3.970	File=TeSLA_4_9cells
ACC1	MaxE(3)=39.93	Phi(3)=-14.8517	C_pos(3)=9.512	File=tesla4cav13
3.9GHz	MaxE(4)=26.96	Phi(4)=-194.96	C_pos(4)=14.775	File=tesla4cav3

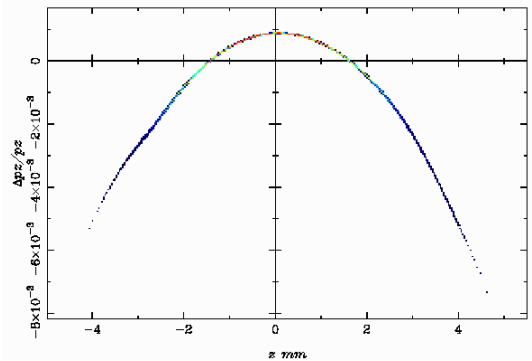
Results after Test with 200000 particles		
	8.80m (after booster)	**17.60m (after 3.9GHz)**
Emittance, mm mrad	**0.320**	**0.322**
Emittance w/o energy corr., mm mrad	**0.306**	**0.308**
Long. Emittance, keV mm	**123.4**	**10.51**
Energy rms, keV	**840.7**	**1174**
Bunch length, mm	**1.494**	**1.493**
Beta, m	**9.685**	**57.87**
Alpha	**-1.849**	**-3.865**

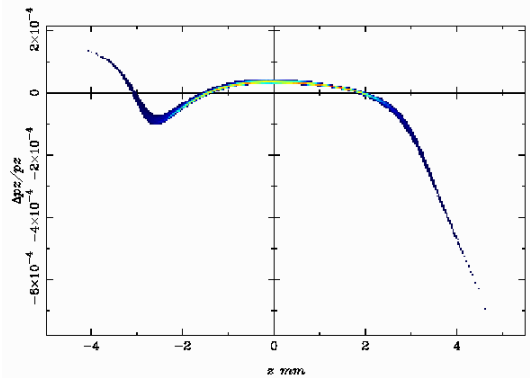
QBunch = 100pC, Laser Pulse: gaussian τ=4.4ps
Beam Development and Optics



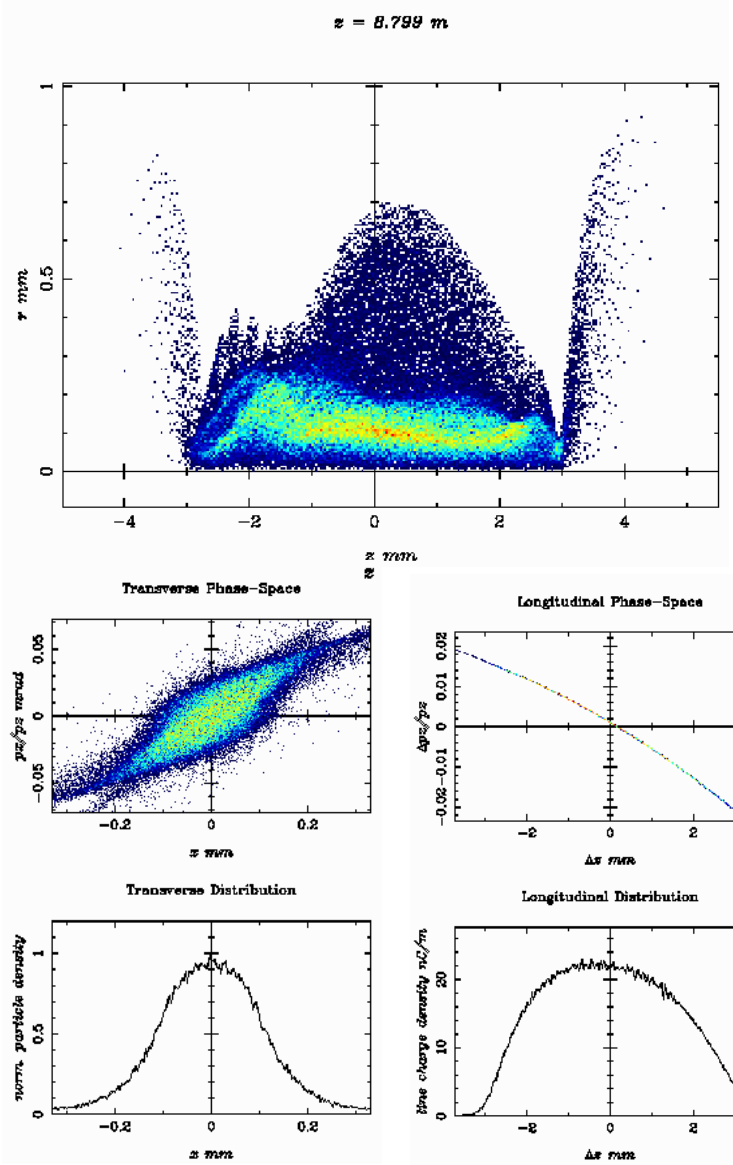


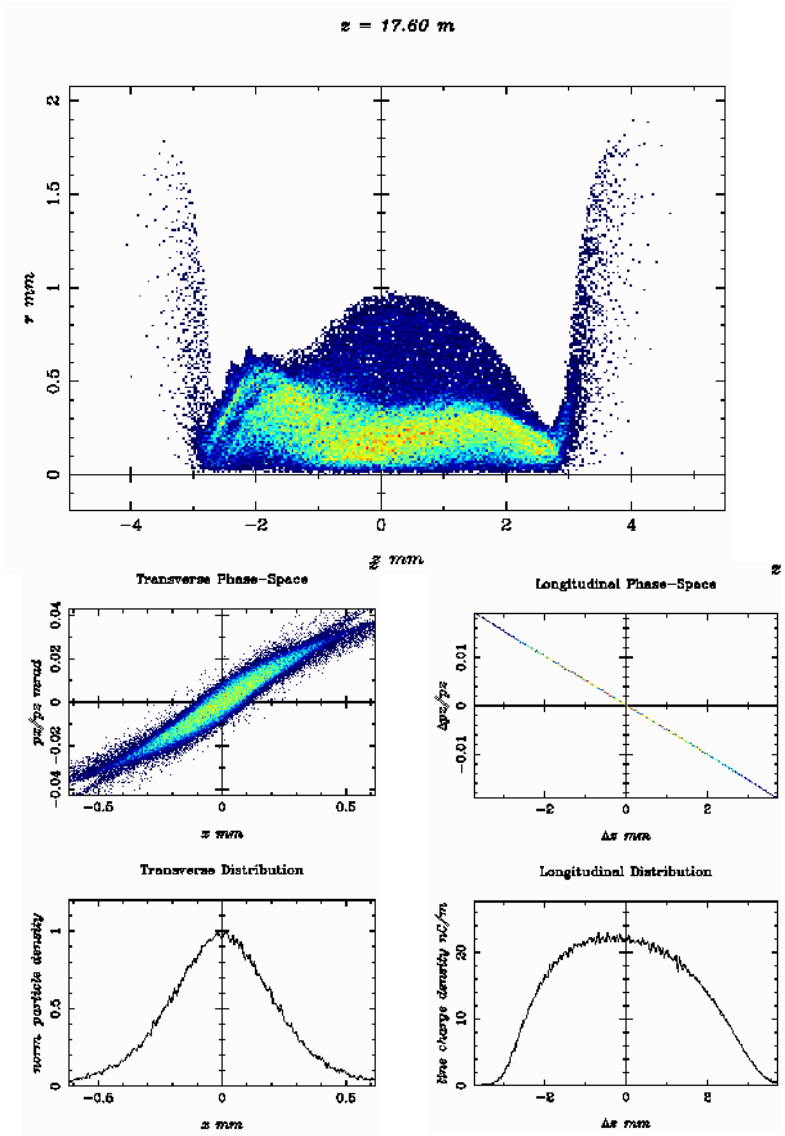






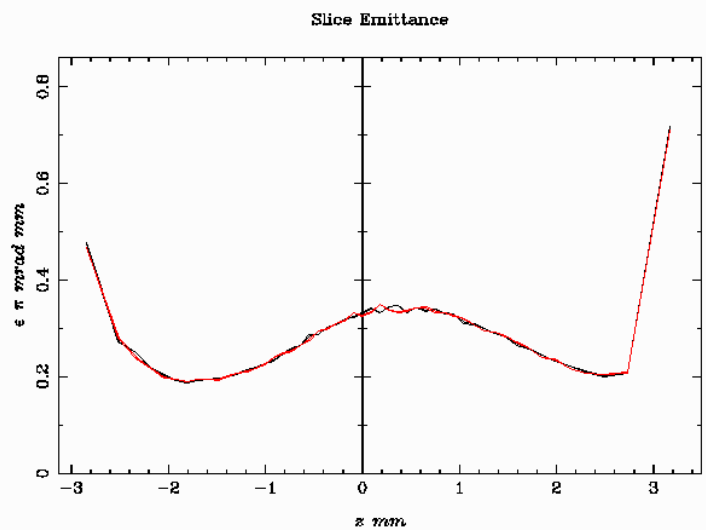
QBunch = 100pC, Laser Pulse: gaussian τ=4.4ps
Beam Shape

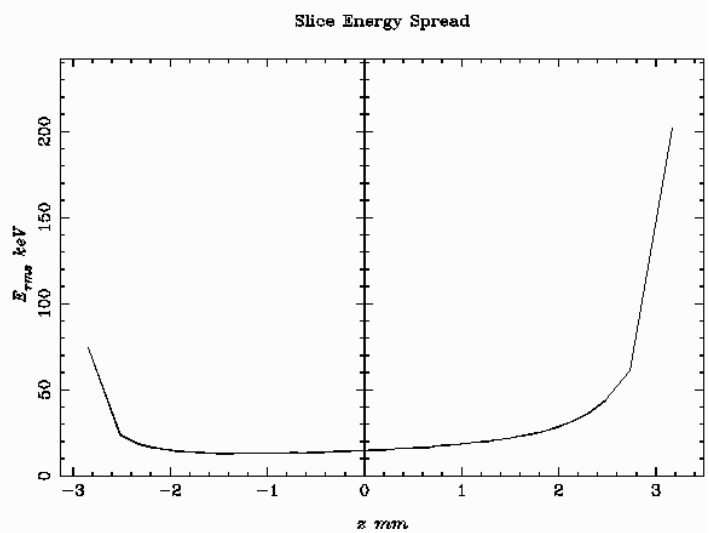




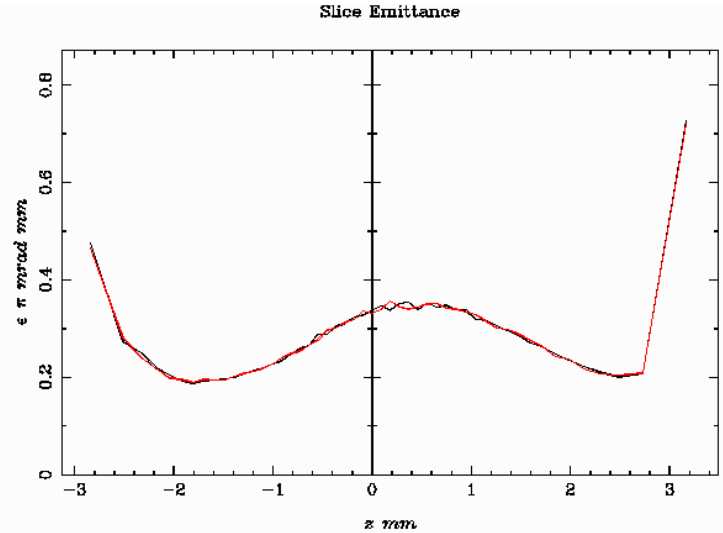
QBunch = 100pC, Laser Pulse: gaussian τ=4.4ps
Slices

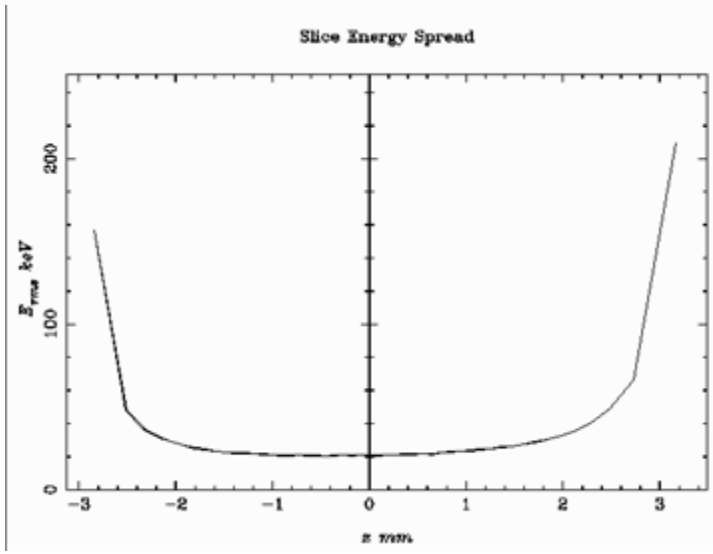
z=8.80m



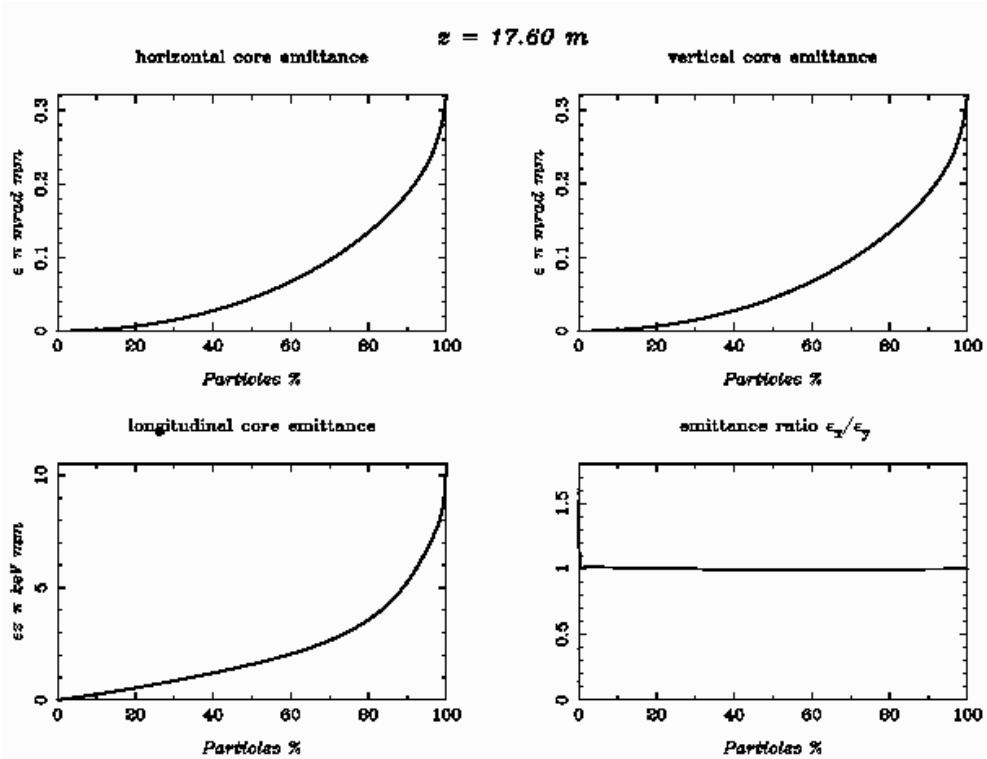


z=17.60m





QBunch = 100pC, Laser Pulse: gaussian τ=4.4ps
Core Emittance



core emittance

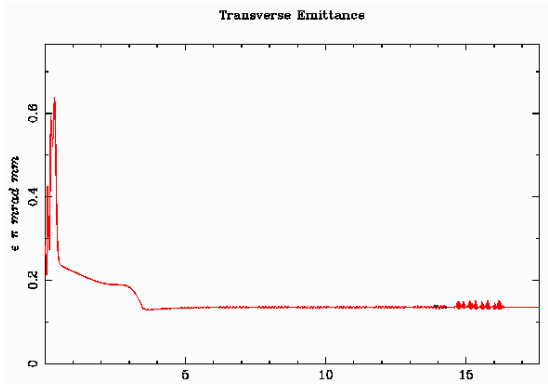
	100%	95%	90%	80%	
horizontal:	0.3208	0.2259	0.1871	0.1345	pi mrad mm
vertical:	0.3205	0.2258	0.1873	0.1346	pi mrad mm
long.:	10.51	6.693	5.252	3.569	pi keV mm

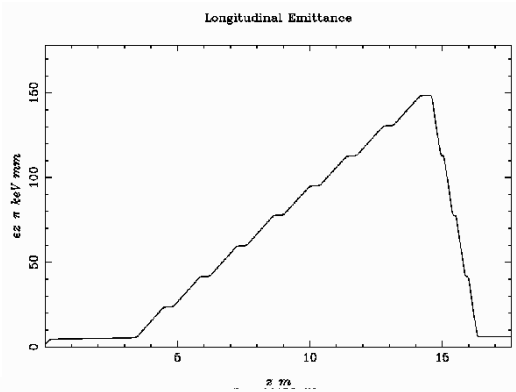
QBunch = 20pC, Laser Pulse: gaussian τ=4.4ps

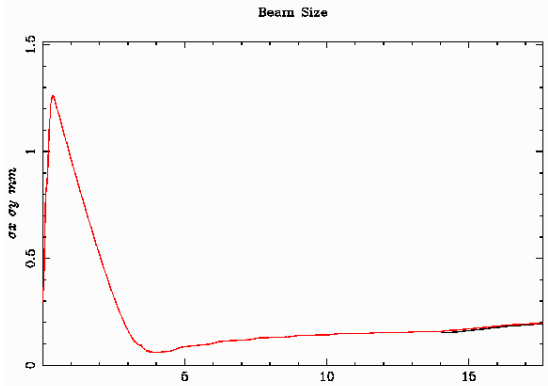
	Tuning Parameters found by optimization procedure with 2000 particles			
Beam	**XYrms=0.0679**	**Q=20pC**	**Laser: gauss, τ=4.4ps**	
Solenoid	**MaxB(1)=0.171417**		S_pos(1)=0.00	File=Main2003_3m
Bucking	**MaxB(2)=-0.008542**		S_pos(2)=0.00	File=Buck2003_0
Gun	MaxE(1)=45.0	**Phi(1)=-0.6977**	C_pos(1)=0.00	File=FLASHgun_p12
Booster	MaxE(2)=40.12	Phi(2)=-14.8525	C_pos(2)=3.970	File=TeSLA_4_9cells
ACC1	MaxE(3)=39.93	Phi(3)=-14.8517	C_pos(3)=9.512	File=tesla4cav13
3.9GHz	MaxE(4)=26.96	Phi(4)=-194.96	C_pos(4)=14.775	File=tesla4cav3

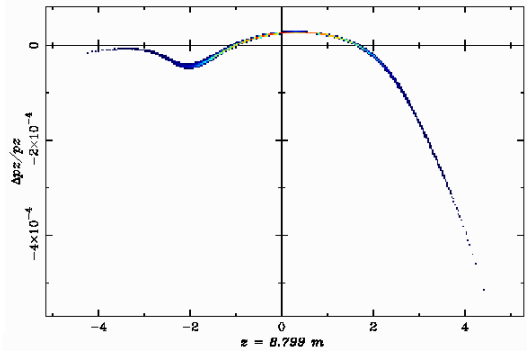
Results after Test with 200000 particles		
	8.80m (after booster)	**17.60m (after 3.9GHz)**
Emittance, mm mrad	**0.135**	**0.135**
Emittance w/o energy corr., mm mrad	**0.119**	**0.113**
Long. Emittance, keV mm	**77.72**	**6.123**
Energy rms, keV	**737.8**	**996.4**
Bunch length, mm	**1.257**	**1.257**
Beta, m	**23.70**	**84.09**
Alpha	**-3.297**	**-4.159**

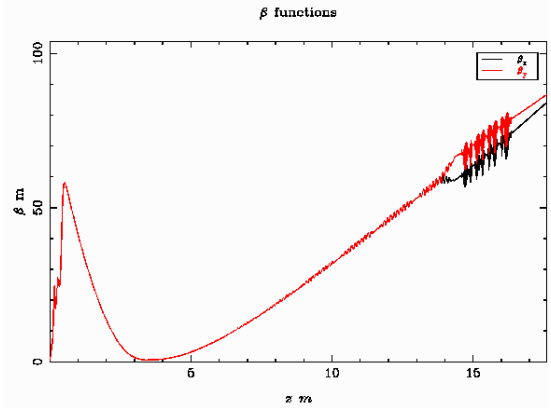
QBunch = 20pC, Laser Pulse: gaussian τ=4.4ps
Beam Development and Optics

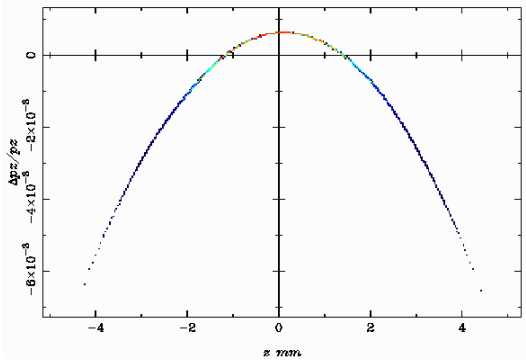




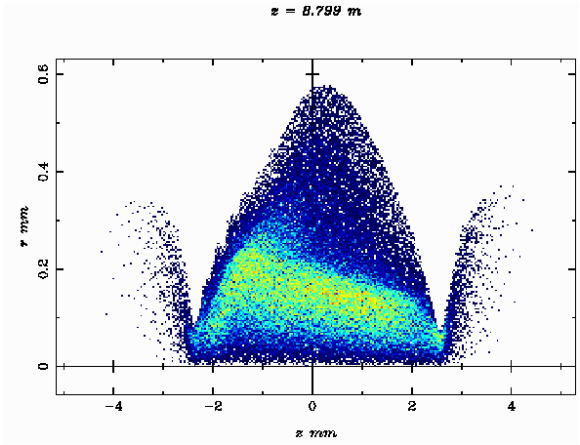


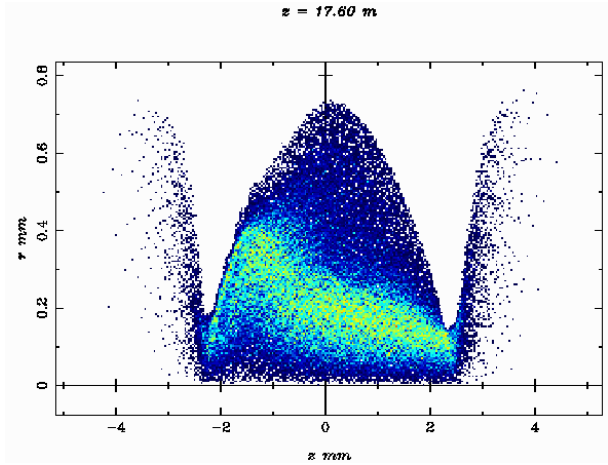


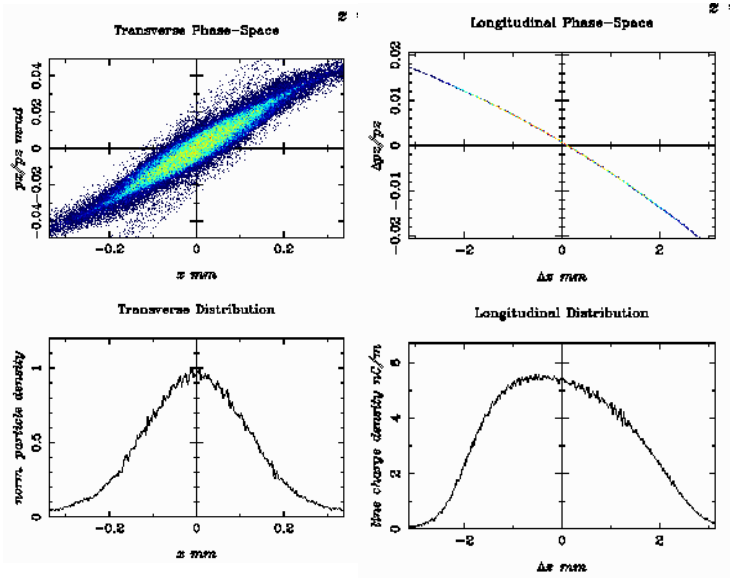


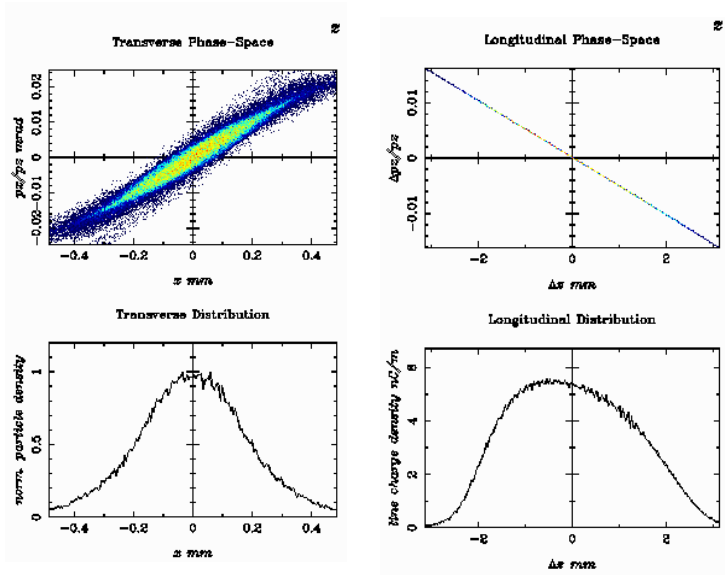


QBunch = 20pC, Laser Pulse: gaussian τ=4.4ps
Beam Shape



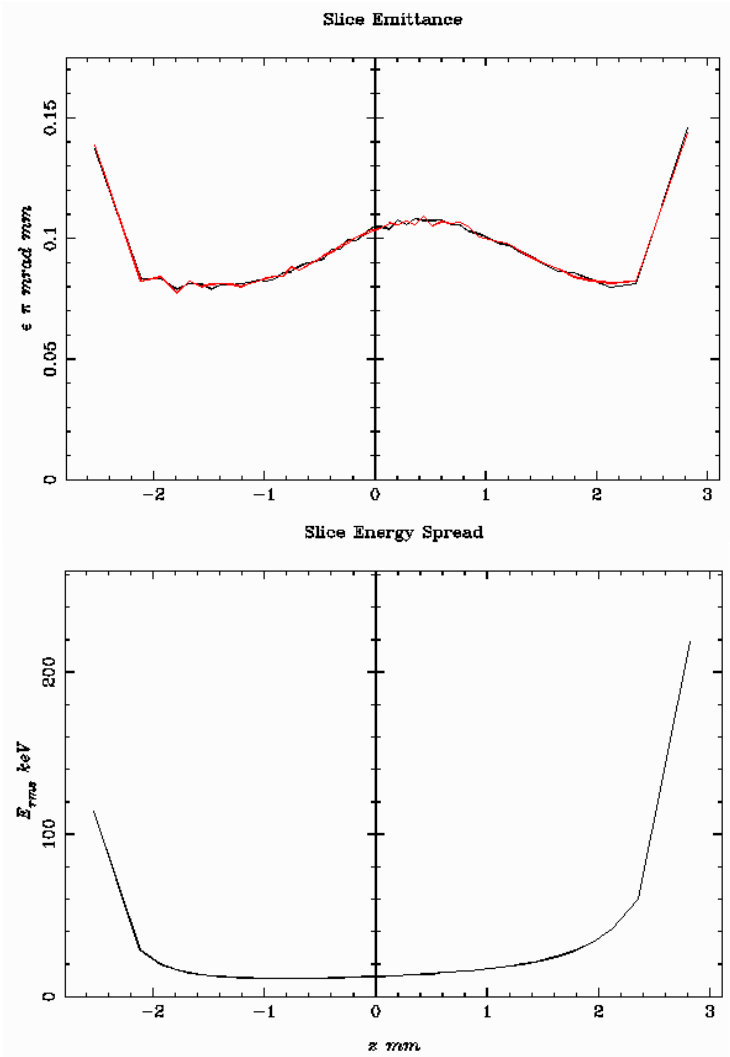




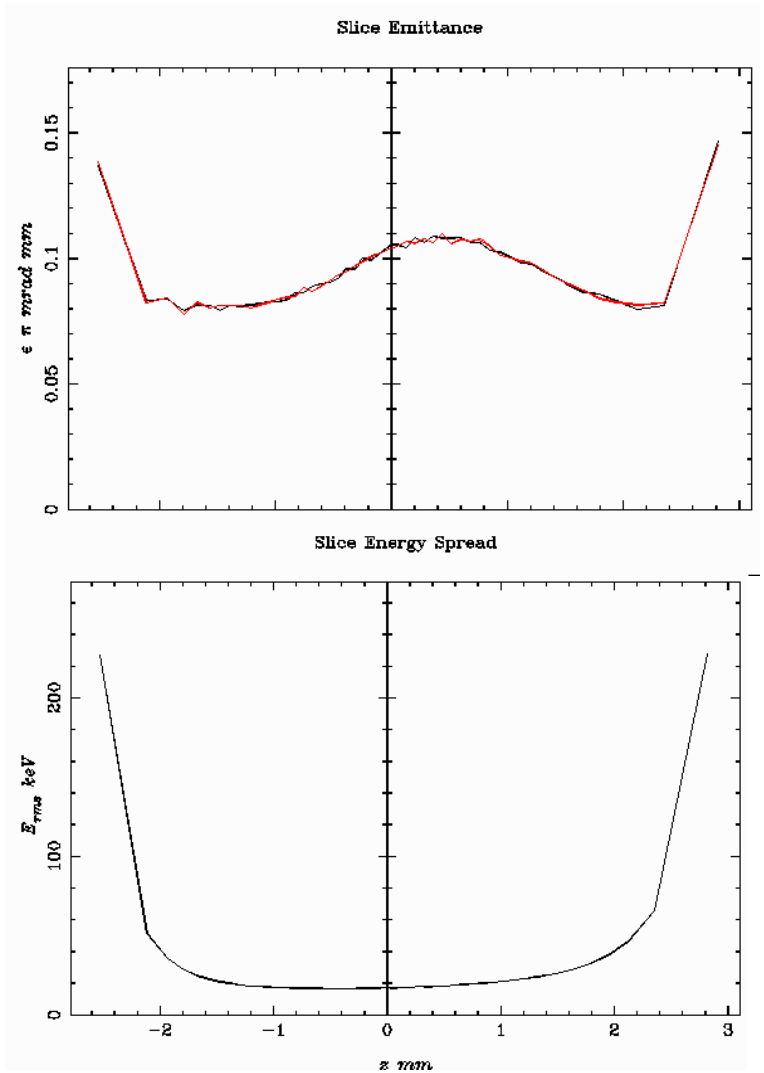


QBunch = 20pC, Laser Pulse: gaussian τ=4.4ps
Slices

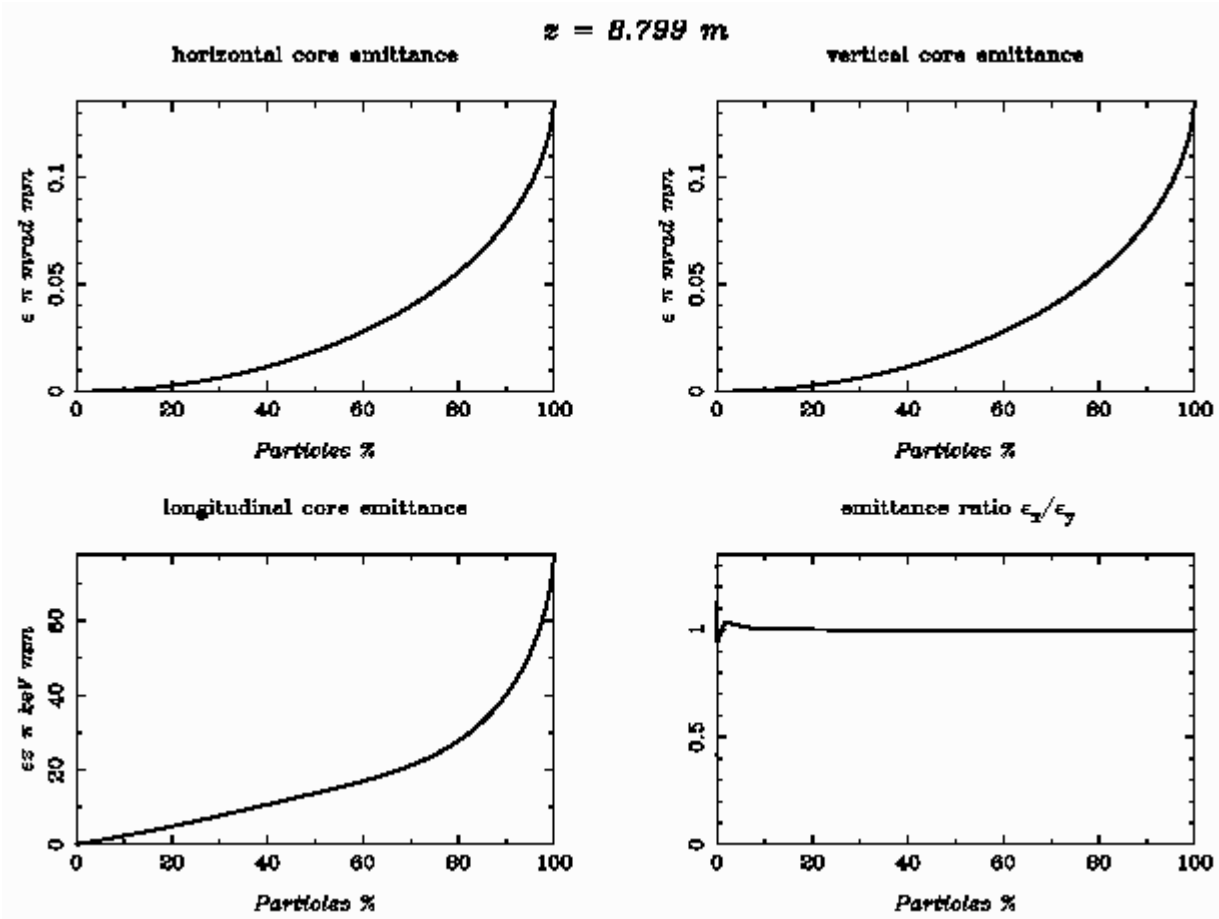
z=8.80m



z=17.60m



QBunch = 20pC, Laser Pulse: gaussian τ=4.4ps
Core Emittance



core emittance

	100%	95%	90%	80%	
horizontal:	0.1354	9.6515E-02	7.8960E-02	5.5796E-02	pi mrad mm
vertical:	0.1355	9.6568E-02	7.9031E-02	5.5840E-02	pi mrad mm
long.:	77.72	51.26	40.13	27.79	pi keV mm

Convergency: Slice Energy Spread and Slice Emittance

Test with more particles but the same amount of cell's

Q=100pC
Pulse Shape: Gaussian τ=4.4ps

Main parameters after booster at s=9.00m

N, x10^3	Mesh	ε, μm	σ, mm	τ_{rms},mm	E_{rms}, keV	β, m	α
200	15x25	0.341	0.132	1.478	58.43	9.13	-1.63
392	21x35	0.326	0.129	1.482	59.12	9.05	-1.66
800	30x50	0.324	0.129	1.482	59.36	9.11	-1.66
1500	41x68	0.323	0.129	1.481	59.28	9.20	-1.71