Emittance optimization for 3D ellipsoidal laser shape at 1nC

Emittance optimization at 1nC charge for different beam energies by varying the shape of the 3D ellipsoid

Beam properties for different border widths

Summary

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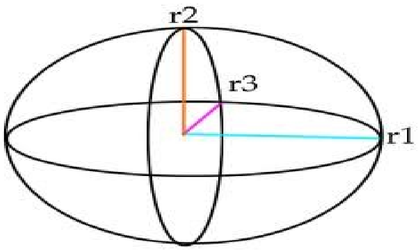
Reminder

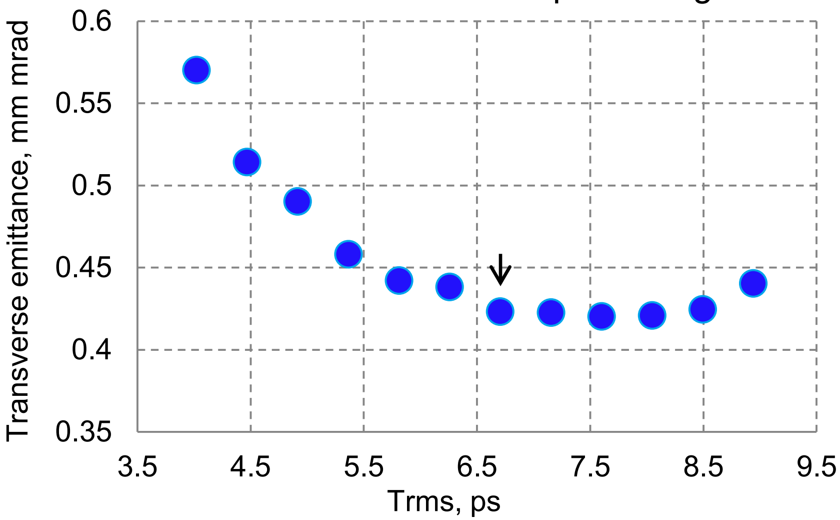
- Minimizing the space charge influence on beam emittance by shaping the photocathode laser to 3D ellipsoid
- Transverse emittance close to the cathode emittance
- Better longitudinal compression
- Reduced beam halo and less sensitivity to machine settings



$$r1 \rightarrow \ ,\ r2 \rightarrow \ ,\ r3 \rightarrow \ , \quad \frac{x^2}{L_x^2} + \frac{y^2}{L_y^2} + \frac{z^2}{L_z^2} \leq$$

$$T_{rms} = L_z / \sqrt{5}$$ → Rms emission time calculation

emittance VS rms “initial” pulse length



Optimization was done for the fixed final beam energy of 24 MeV/c !

Simulated emittance at 5.74m after cathode as a function of “initial” bunch length.

Emittance optimization: Description

Fixed parameters during emittance optimization

- Bunch charge (1nC),
- Electrons thermal kinetic energy at the cathode (0.55eV),
- Gun gradient (60.58MV/m), corresponding to Pz~6.7MeV/c after gun, at on-crest phase
- Gun and CDS booster phases were fixed to MMG phase
- Reference point was EMSY1 (5.74m downstream the cathode).

Variable parameters during optimization

- Dimensions of the 3D ellipsoid (Trms (r1), XYrms (r2,r3) → projection onto z axis):
- Trms → [5.3, 5.8, 6.3, 6.7, 7.1, 7.6, 8] ps, XYrms → [0.36, 0.37, 0.38, 0.39, 0.4, 0.41, 0.42, 0.43, 0.44, 0.45,0.46] mm
- Peak field of the main solenoid, Solenoid calibration: B(T)=B1*I(A)+B2, where B1=0.00058838, B2=0.000004084
- Peak field in the CDS booster (final beam energy) → [0,3,6,10:2:24] MV/m
- **Optimization with 500kp**

Emittance optimization for different beam energies

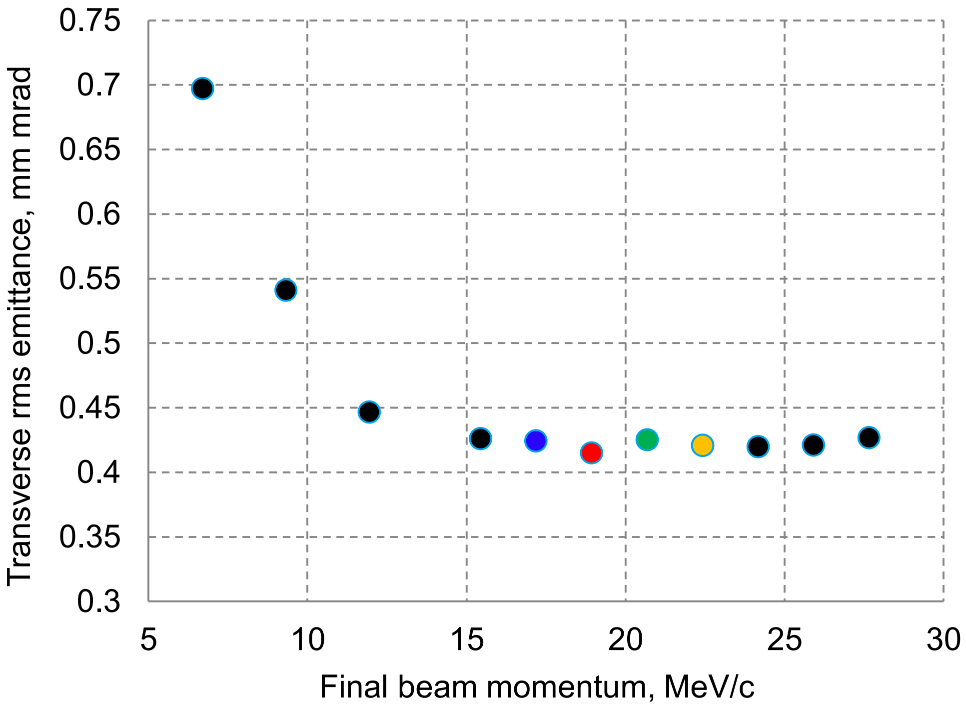
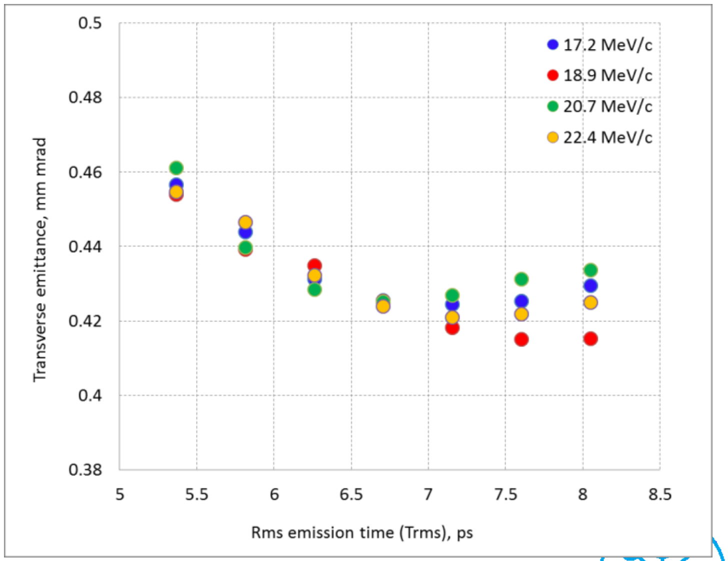


Fig.1. Optimized emittance as a function of the final beam momentum.

E_boo, MV/m	Pz final, MeV/c	Trms, ps	XY_rms, mm	Imain, A	Emittance, mm mrad
0	6.7	5.3665	0.43	386	0.697
3	9.32	8.0498	0.36	386	0.541
6	11.94	6.2609	0.42	390	0.447
10	15.44	6.2609	0.41	389	0.426
12	17.18	7.1554	0.38	389	0.425
14	18.93	7.6026	0.37	389	0.41
16	**20.68**	**6.7082**	**0.4**	**390**	**0.425**
18	22.42	7.1554	0.39	390	0.421
20	24.17	7.6026	0.38	390	0.42
22	25.91	8.0498	0.37	390	0.421
24	27.66	8.0498	0.36	390	0.427

Fig.2. An example of emittance vs. emission time.



Flat emittance behavior after beam momentum of 15 MeV/c !

Beam tolerances for the best point (Trms=6.708 ps)

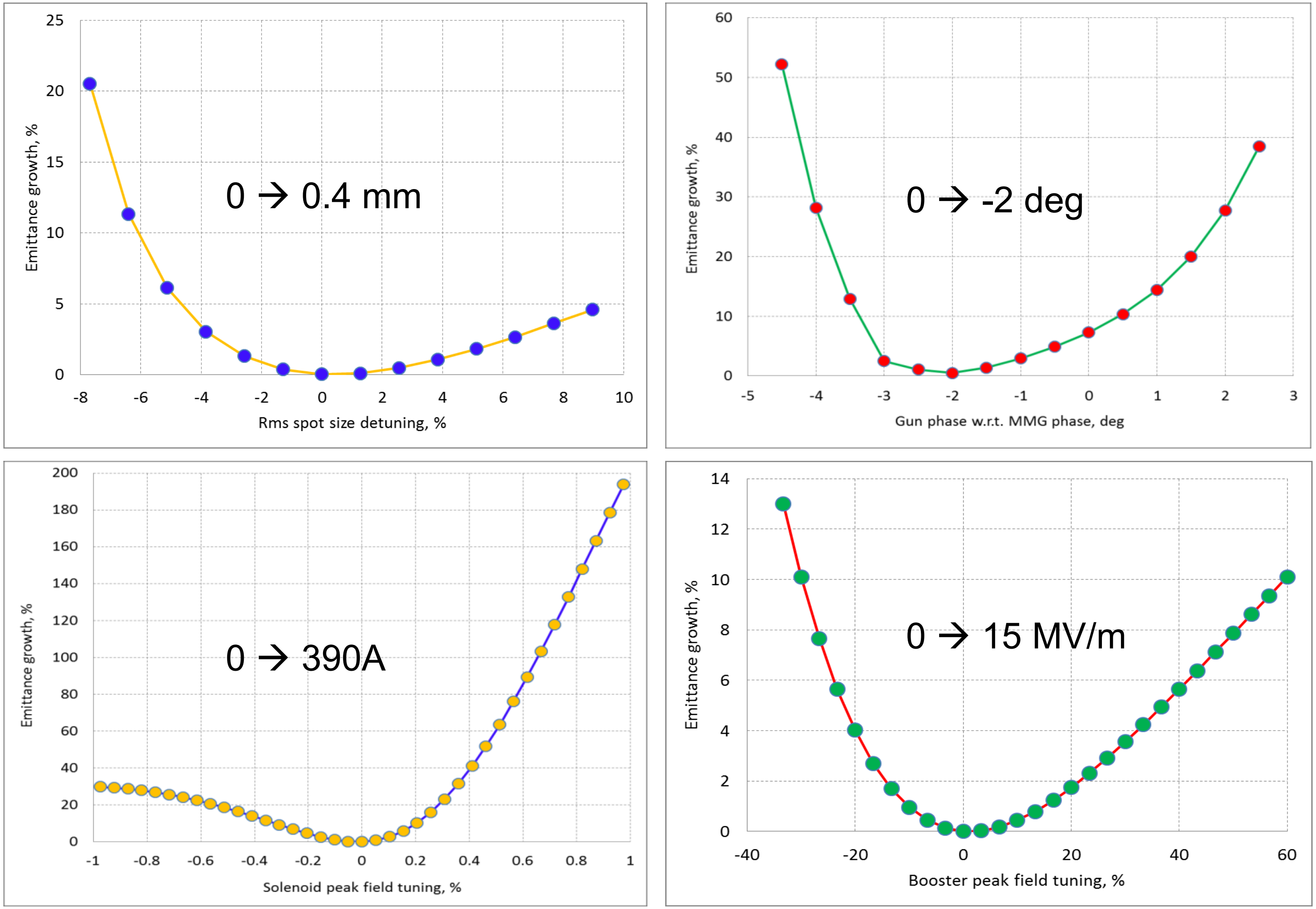


Fig.3. Tolerance studies for the optimized parameters yielding minimum transverse emittance.

Best option for min emittance at Trms=6.708 ps

	parameter	unit	value
cathode laser	Laser	profile	3D ellips
	Trms	ps	6.708
	XYrms	mm	0.4
	Ek	eV	0.55
	th. emit	mm mrad	0.339
RF gun	Ecath	MV/m	60.58
	phase	deg	-2.0
	maxBz	T	0.2295
CDS	maxE	MV/m	15
	phase	deg	0
beam @ EMSY1	charge	nC	1
	momentum	MeV/c	19.8
	proj. emit	mm mrad	0.4
	th./proj. em.	%	85
	Av. slice emit. 100 slices	mm mrad	0.345

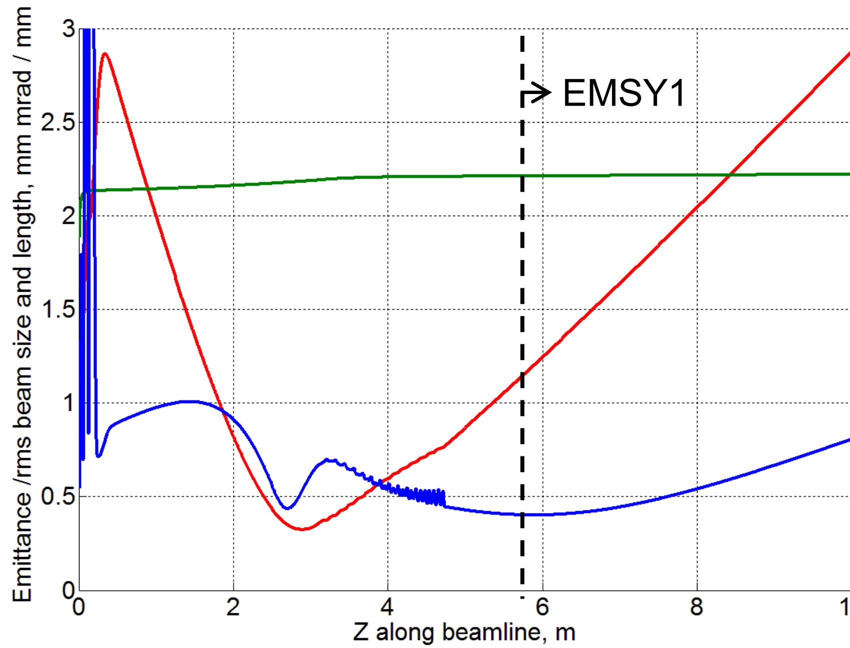


Fig.4. Beam emittance, transverse and longitudinal rms sizes along the beamline for the optimum point.

Booster phase was fixed to on-crest during the studies.

1. Sharpness of 3D ellipsoid edges

- border sharpness parameter

Modification of the initially homogeneous laser intensity distribution:

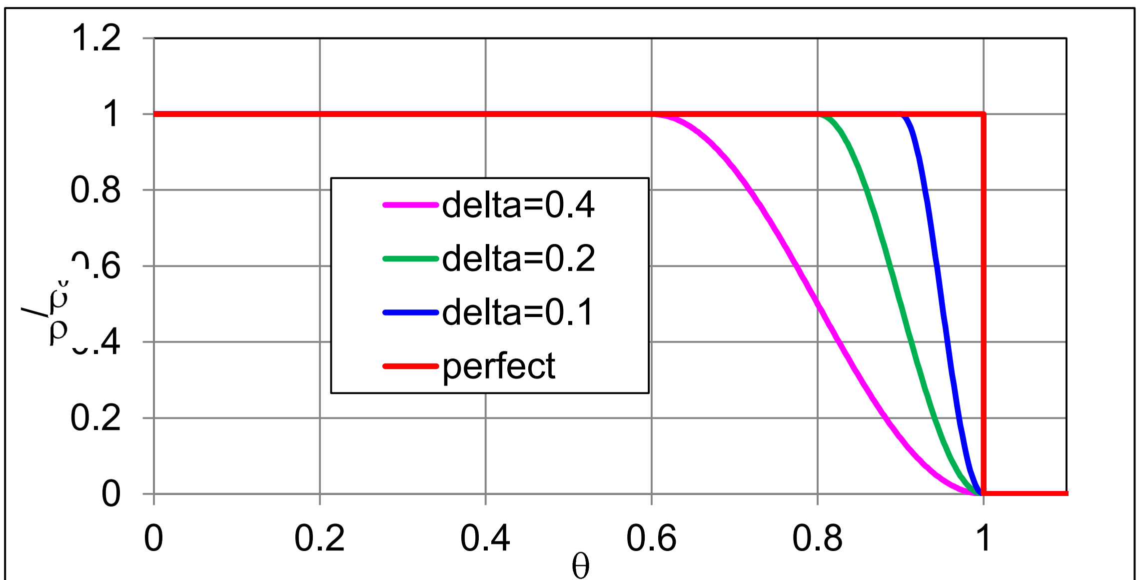
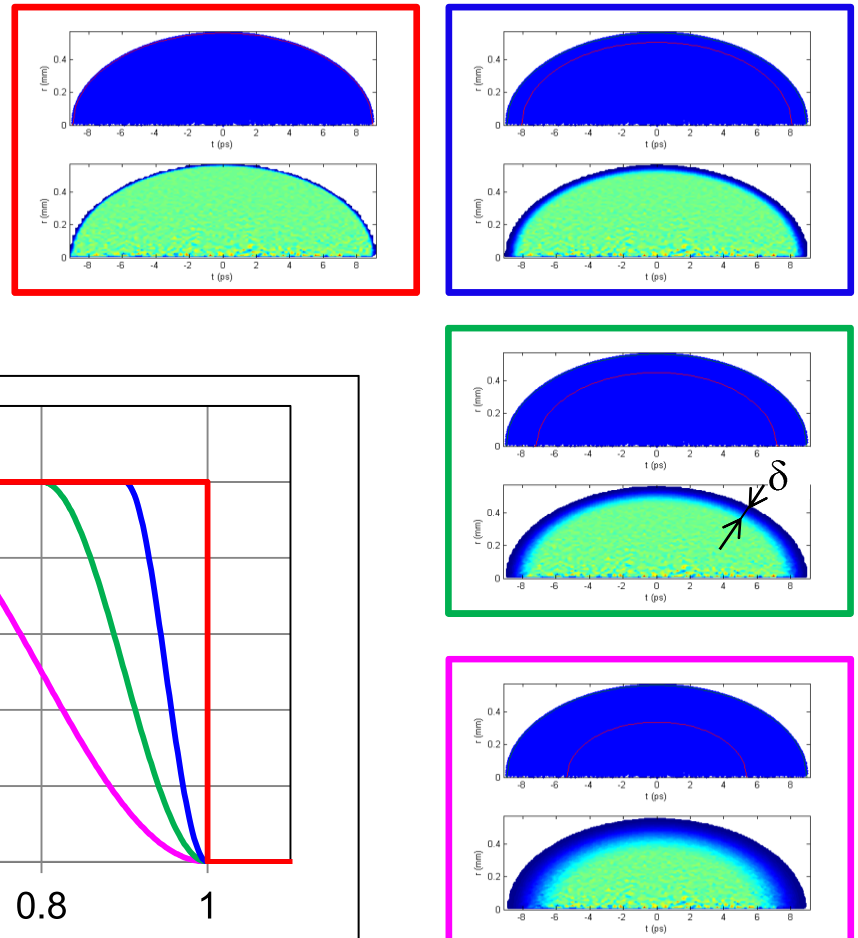


Fig.5. Intensity modification with the border sharpness.



Laser imperfection studies on beam emittance

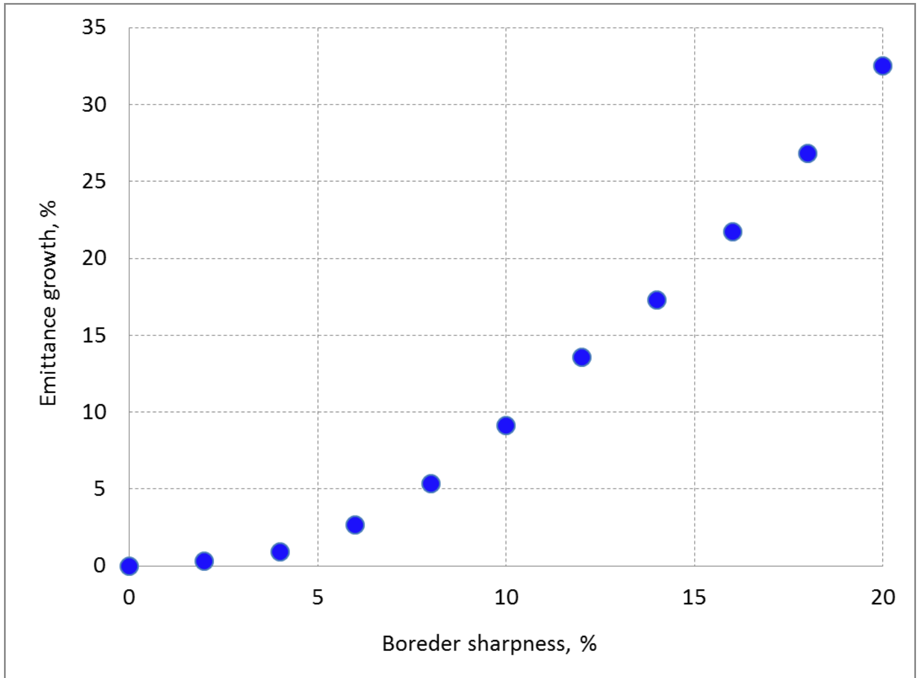


Fig.6. Emittance growth with border width.

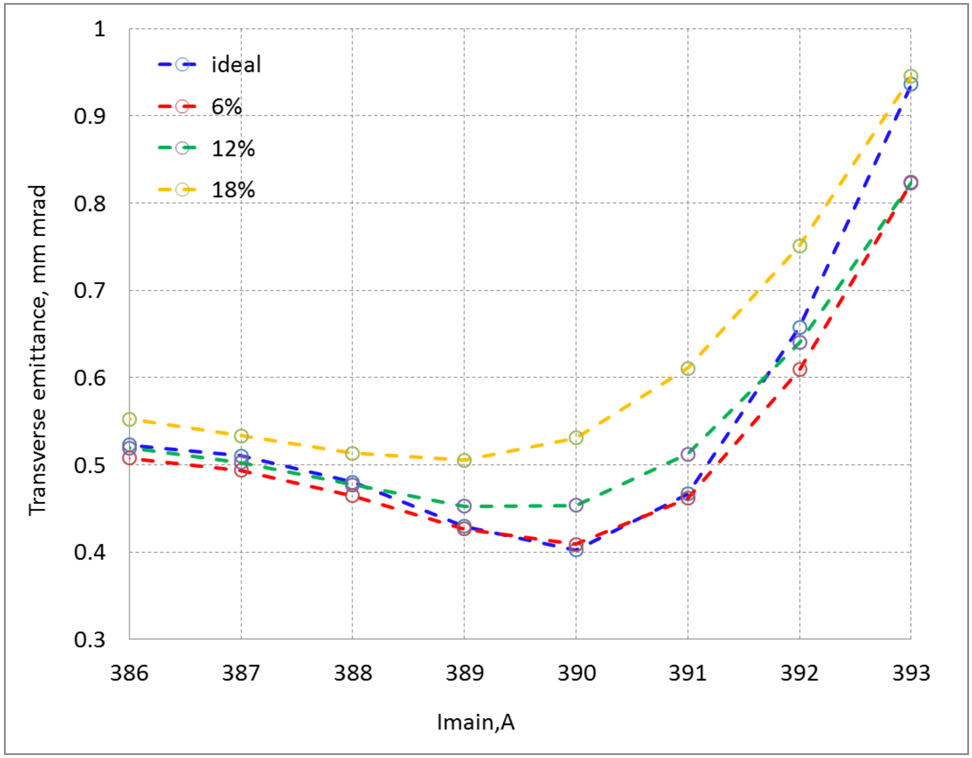


Fig.7. Emittance vs. Imain for different border widths.

Same solenoid current values (1A difference) for minimum emittance at different border widths.

Slice emittances for different border widths

Delta, %	Proj. emit., mm mrad	Av. slice emit., mm mrad	Max slice current, A
0	0.4	0.345	45.7
6	0.409	0.3505	42.8
12	0.453	0.382	39.8
18	0.506	0.43	37.1

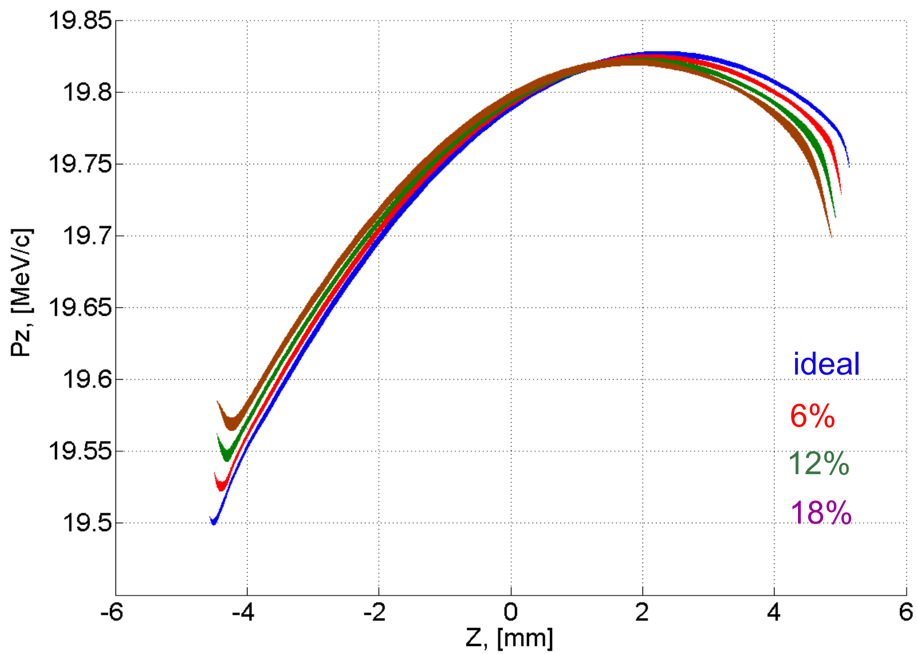


Fig.8. Longitudinal phase spaces for different deltas.

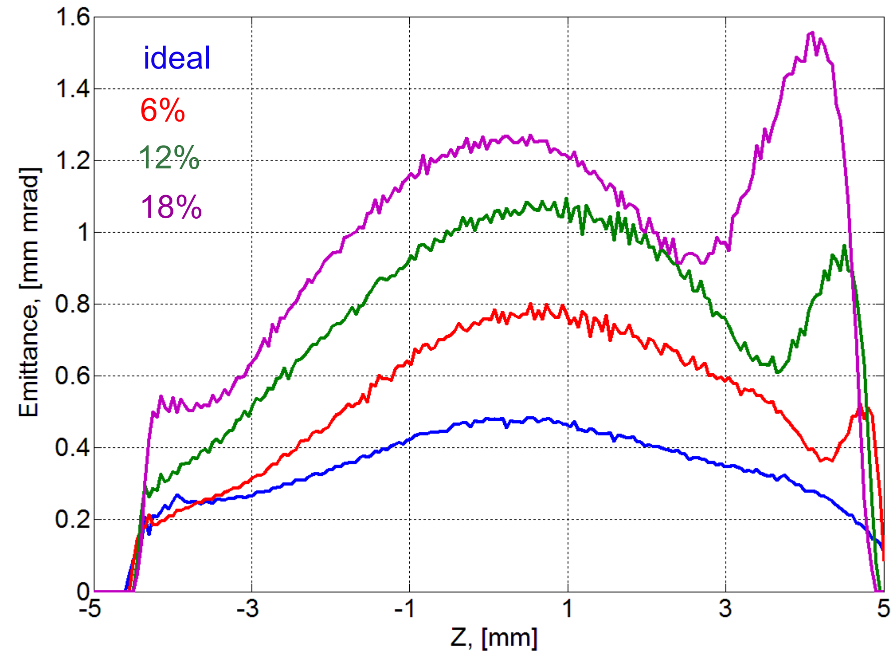
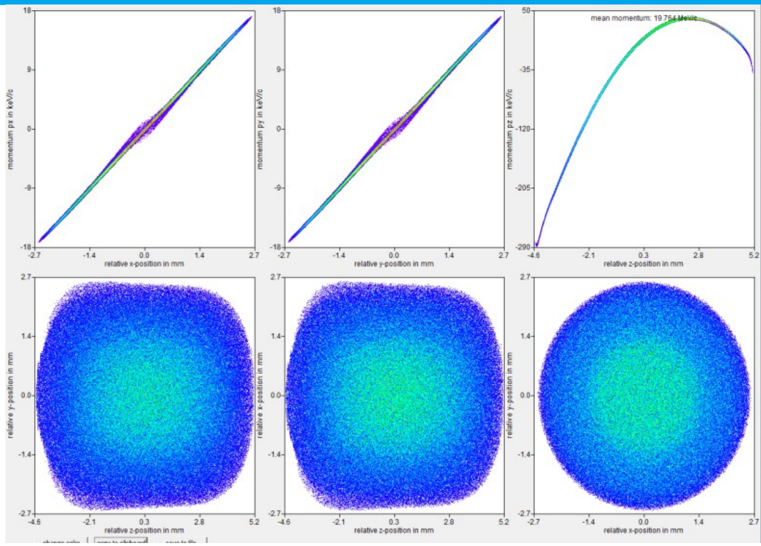


Fig.9. Slice emittances (for minimum projected emittances) at different border widths.

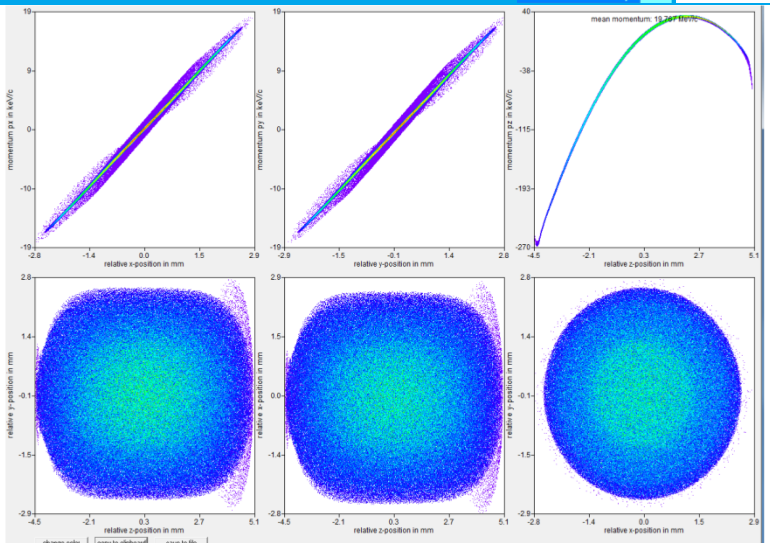
Smaller energy spread with bigger delta ?

Beam overviews for different border widths

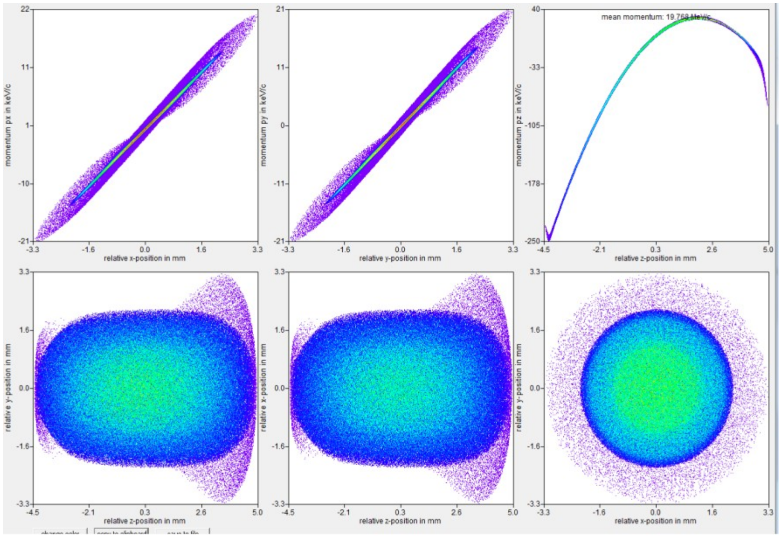
→ ideal



→ 6%



→ 12%



→ 18%

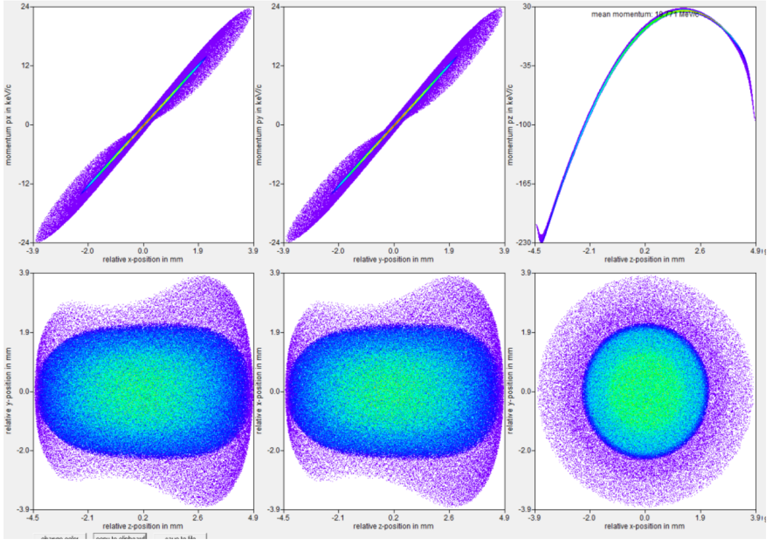


Fig.10. Beam overviews for different border thicknesses of laser shape.

Summary

- Minimum emittance value for 1 nC bunch charge with 3D ellipsoidal shape, at fixed gun gradient of 60.58 MV/m (6.7 MeV/c after gun) was found for:
  - rms laser spot size on the cathode (projection onto z axis): 0.4mm
  - Booster accelerating gradient: 15MV/m (19.8 MeV/c after booster)
  - Main solenoid current: 390 A
  - Gun launching phase w.r.t. MMMG phase: -2 deg
- $\varepsilon^{projected}{}_{xy}$ = 0.4 mm mrad
- $\langle \varepsilon^{slice}{}_{xy} \rangle$ = 0.345 mm mrad
- $\varepsilon^{thermal}{}_{xy}$ = 0.34 mm mrad
- $\varepsilon^{thermal}{}_{xy} / \varepsilon^{projected}{}_{xy}$ = 0.85

- Implement a new formula with separation of bunch in time and space into ASTRA (M. Krasilnikov)
- Repeat the studies

Thank you for attention !!