Booster position optimization for flat-top and 3D ellipsoidal laser profiles

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with varied beam energy
- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
- Emittance optimization for 3D ellipsoid with fixed booster position of Z=2.9m
- Emittance optimization for flat-top profile with fixed booster position of Z=2.7m
- Summary

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PITZ Physics Seminar
14.11. 2013

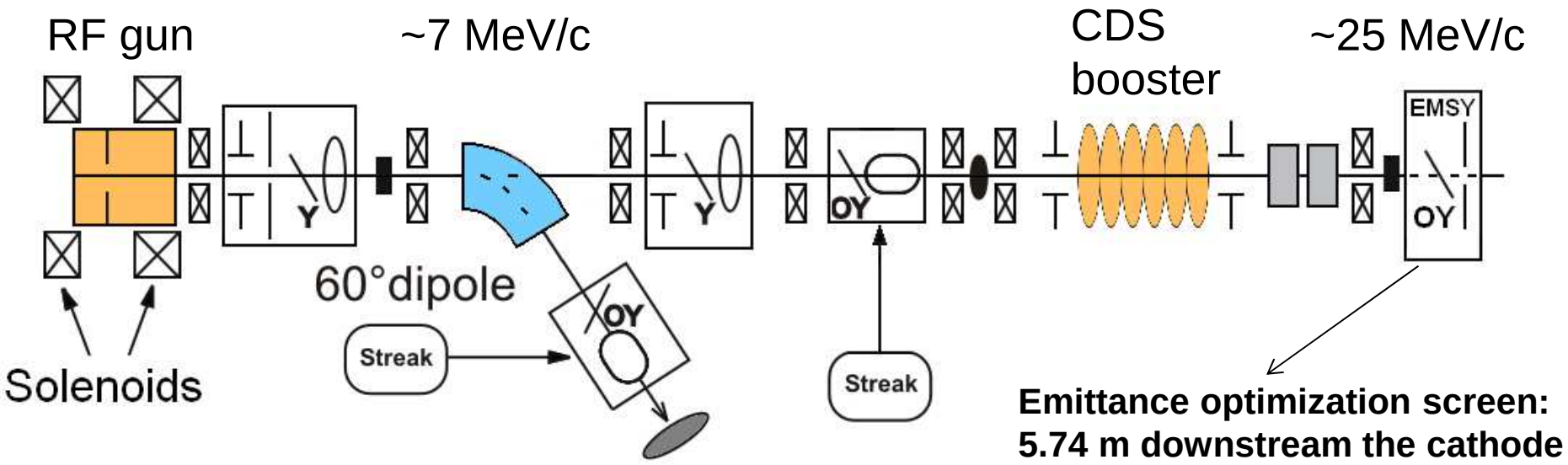
HELMHOLTZ ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

DESY

PITZ setup used in ASTRA simulations

Setup used in ASTRA simulations



Fixed parameters in ASTRA simulations

- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m (Pz~6.7 MeV/c beam momentum after the gun at max acceleration phase)
- 200 000 macroparticles
- Bunch charge: 1 nC
- Optimization of transverse emittance at EMSY1 (Z=5.74 m)

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
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- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
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Optimization of the booster position (fixed beam energy)

ASTRA simulation setup: fixed parameters

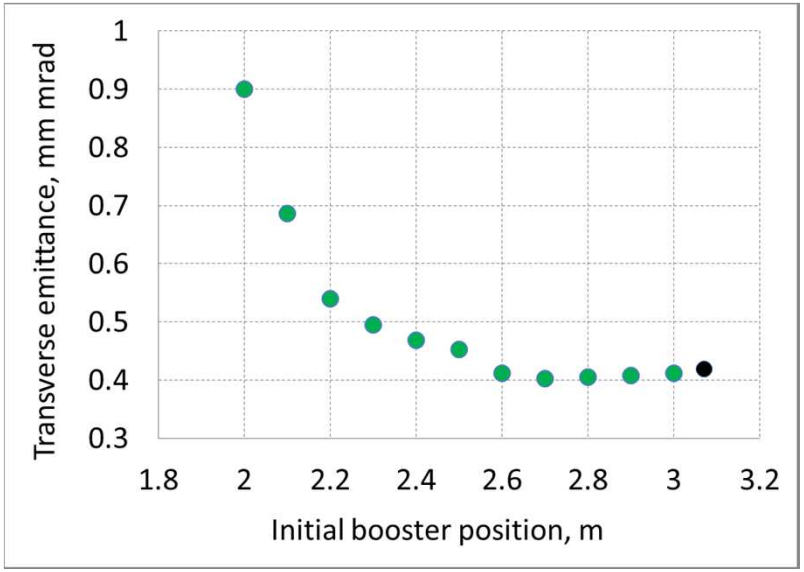
- **3D ellipsoidal** cathode laser pulse with 6.1 ps rms emission time (initial bunch length)
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- CDS booster gradient: 19.76 MV/m corresponding to Pz~24 MeV/c final beam momentum
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

ASTRA simulation setup: varied parameters

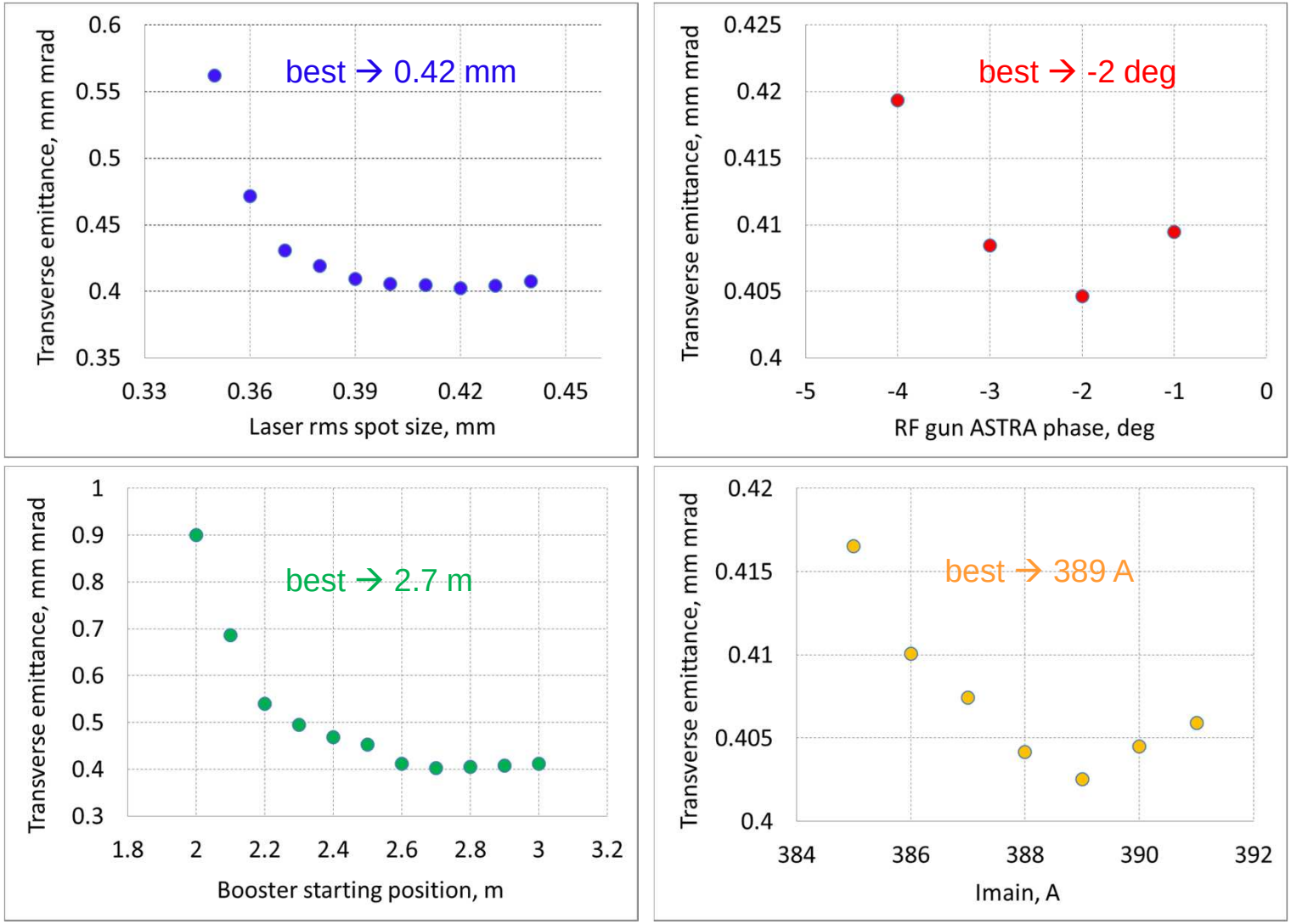
- Laser transverse rms spot size on the cathode → [0.35:0.01:0.44] mm
- Gun phase → [-4:1:-1] deg
- Initial Z position of CDS booster → [2:0.1:3] m
- Main solenoid current → [385:1:391] A

Z=2.7 m was found to be an optimum
(currently Z=3.07 m)

Best laser rms spot size → 0.42 mm
Best gun phase → phase of max acceleration
Best solenoid current → 389A



3D ellipsoid: fixed beam energy



Transverse emittance as a function of machine parameters after multi parameter scan.

Optimization of the booster position (fixed beam energy)

ASTRA simulation setup: fixed parameters

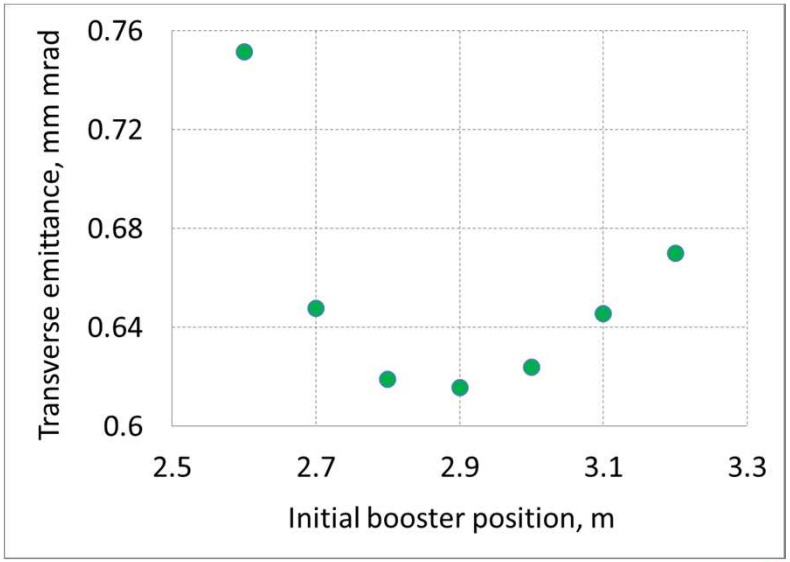
- Laser temporal profile: **flat-top** with 21.5ps FWHM length and 2ps rise and fall times
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- CDS booster gradient: 19.76 MV/m corresponding to Pz~24 MeV/c final beam momentum
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (z=5.74 m)

ASTRA simulation setup: varied parameters

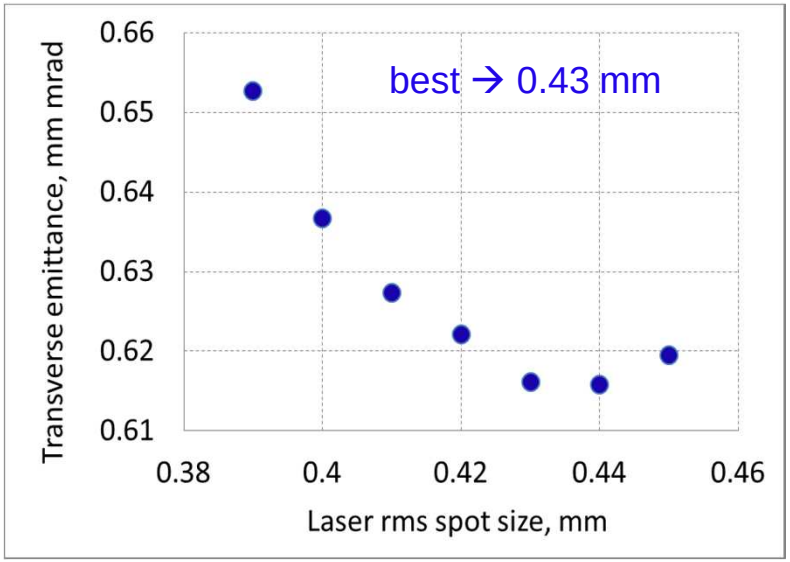
- Laser transverse rms spot size on the cathode → [0.39:0.01:0.45] mm
- Gun phase → [-3:1:1] deg
- Initial z position of CDS booster → [2.6:0.1:3.2] m
- Main solenoid current → [384:1:390] A

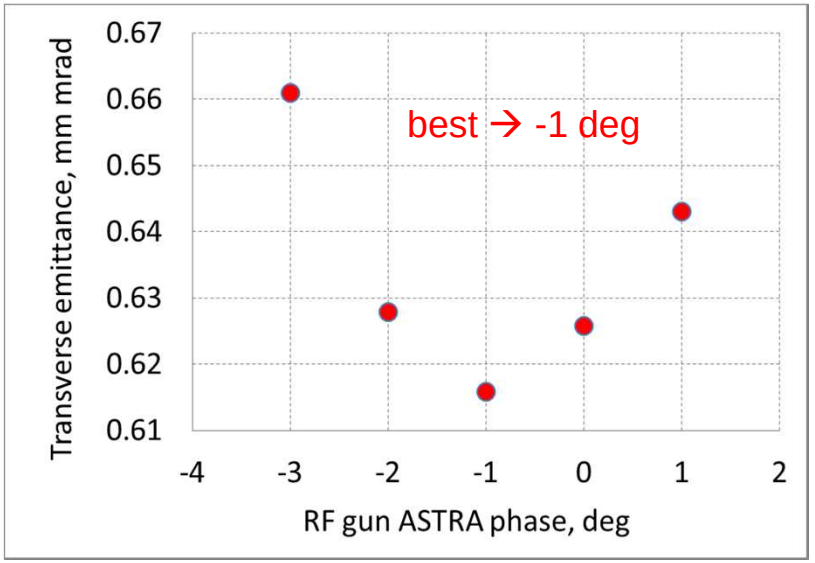
z=2.9 m was found to be an optimum
(currently z=3.07 m)

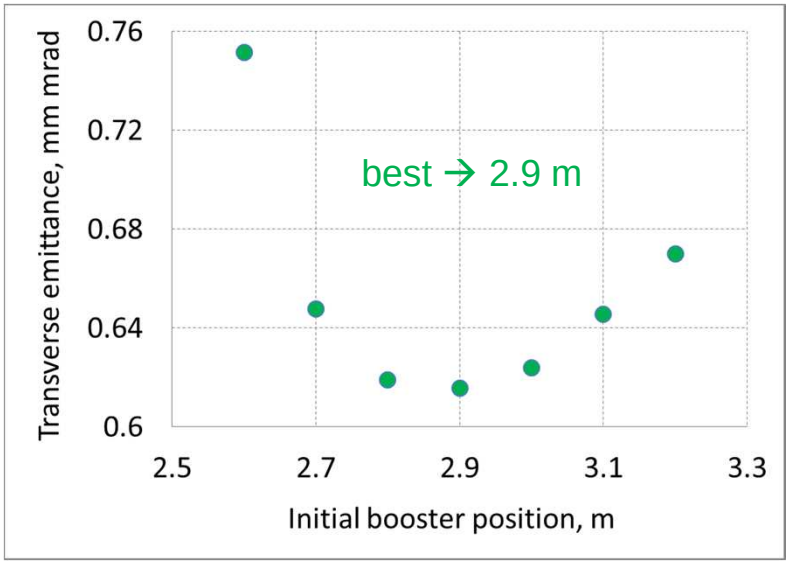
Best laser rms spot size → 0.435 mm
Best gun phase → phase of max acceleration
Best solenoid current → 387A

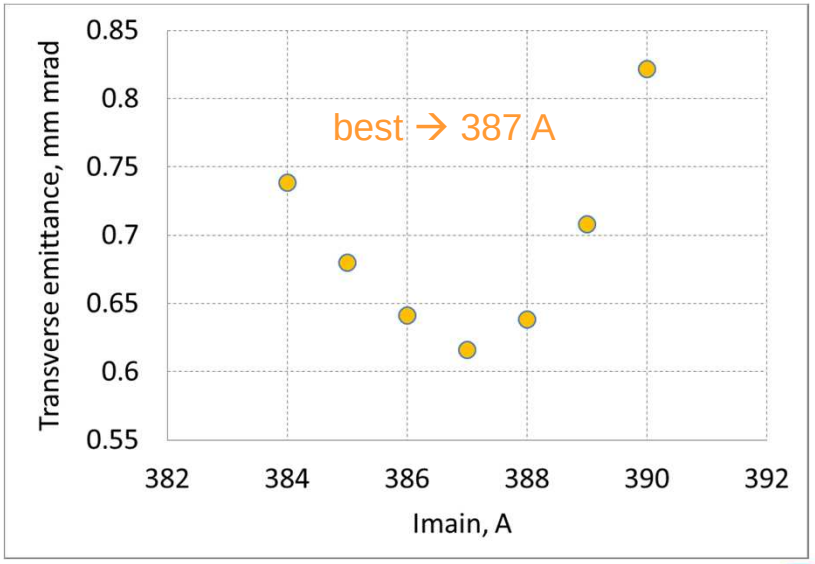


Optimization of the booster position (flat-top)





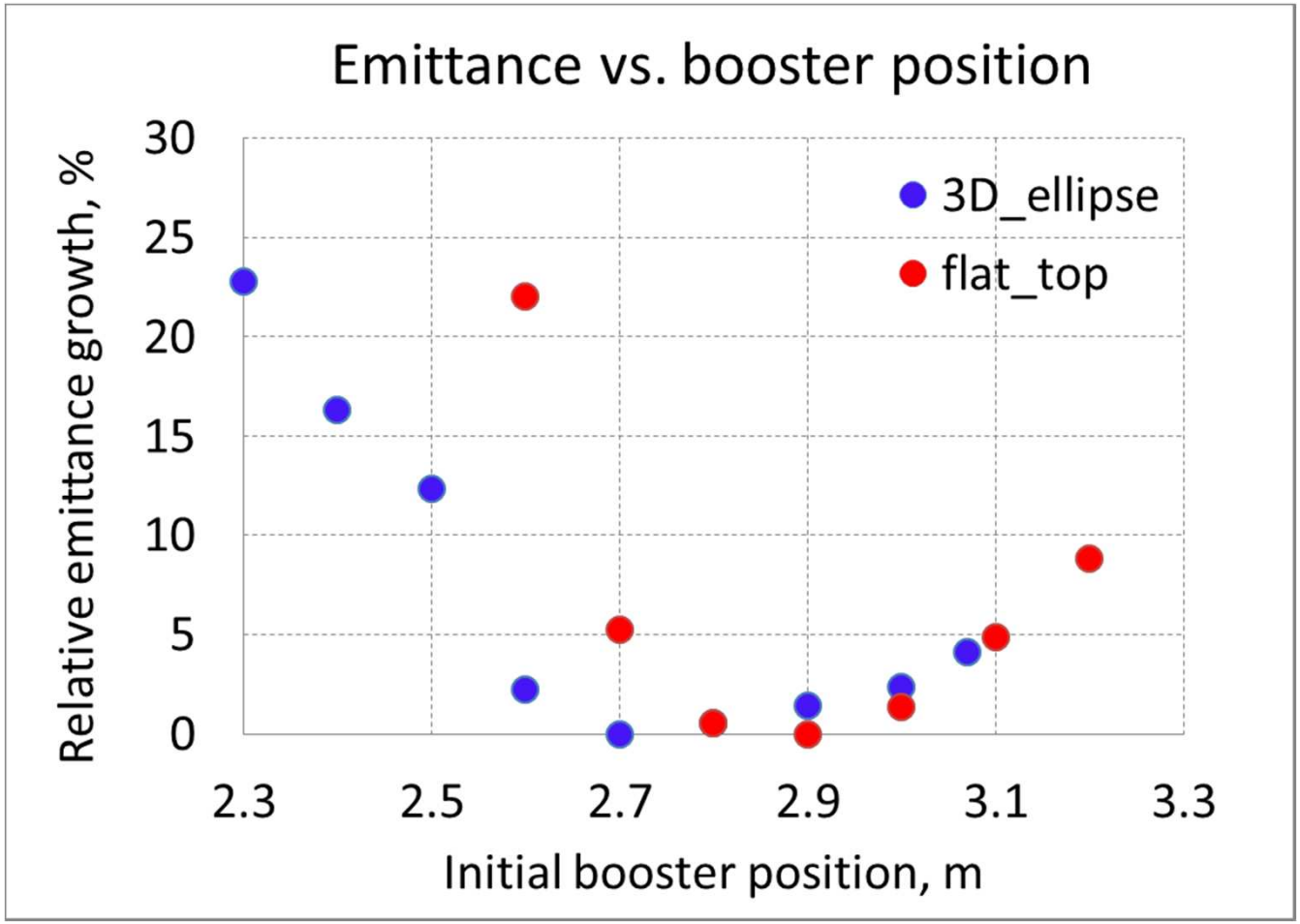




Transverse emittance as a function of machine parameters after multi parameter scan.

Emittance growth vs. booster position for two cases

Beam energy fixed !! (23.5 MeV)



Z=2.8 m can be a good compromise …

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with varied beam energy
- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
- Emittance optimization for 3D ellipsoid with fixed booster position of Z=2.9m
- Emittance optimization for flat-top profile with fixed booster position of Z=2.7m
- Summary

Optimization of the booster position (varying booster gradient)

ASTRA simulation setup: fixed parameters

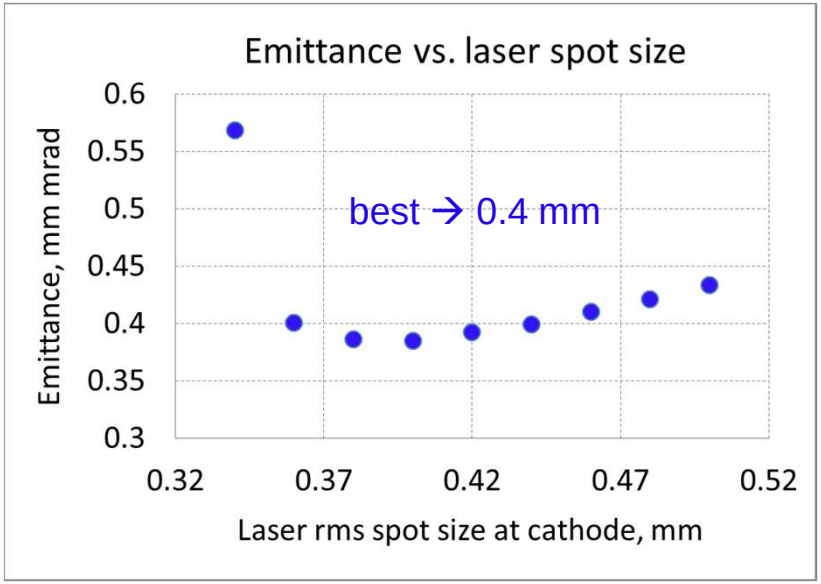
- **3D ellipsoidal** cathode laser pulse with 6.1 ps rms emission time (initial bunch length)
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- Gun ASTRA phase fixed to -2 deg !!
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

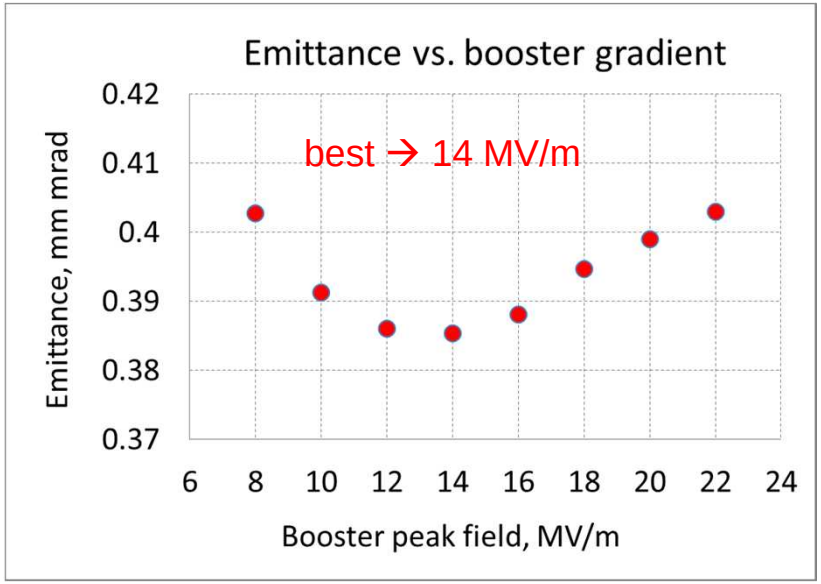
ASTRA simulation setup: varied parameters

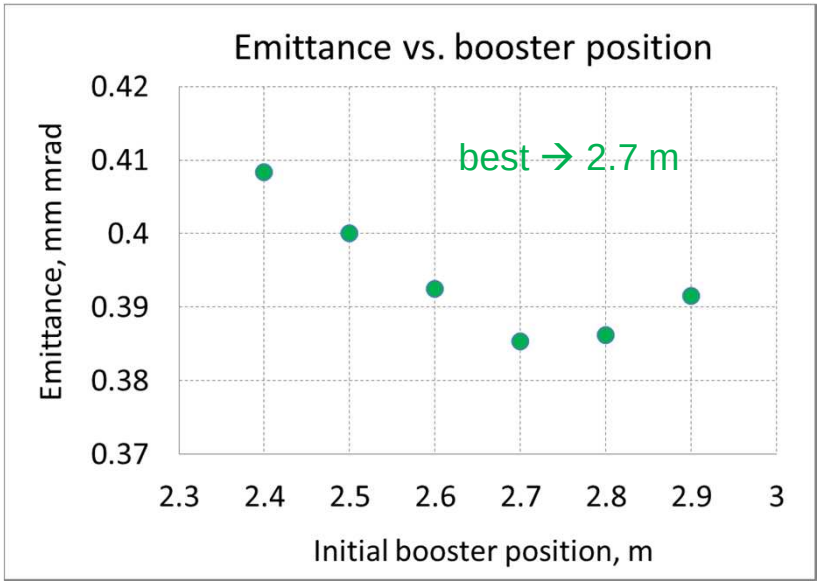
- Laser transverse rms spot size on the cathode → [0.34:0.02:0.5] mm
- Booster gradient → [8:2:22] MV/m
- Initial Z position of CDS booster → [2.4:0.1:2.9] m
- Main solenoid current → [380:2:394] A

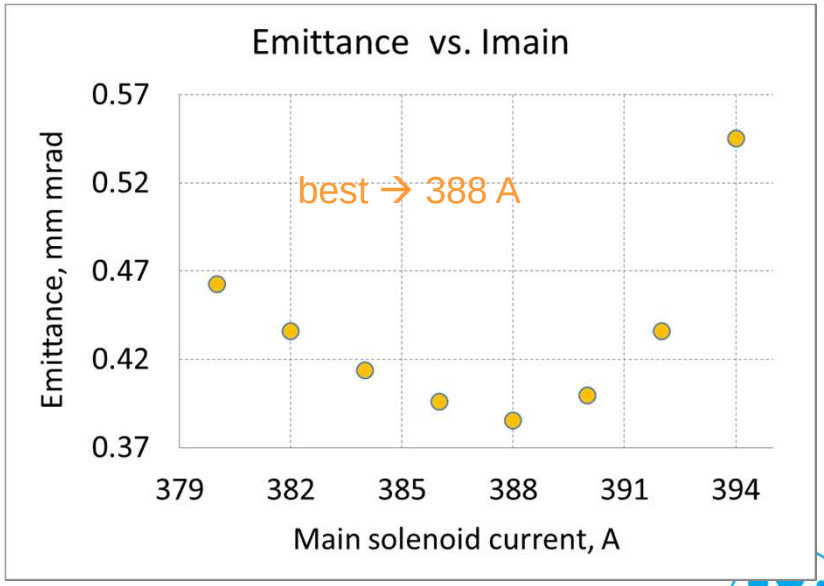
Best laser rms spot size → 0.4 mm
Best initial booster position → 2.7 m
Best booster gradient → 14 MV/m
Best solenoid current → 388A

3D ellipsoid: varied booster gradient









Optimization of the booster position (varying booster gradient)

ASTRA simulation setup: fixed parameters

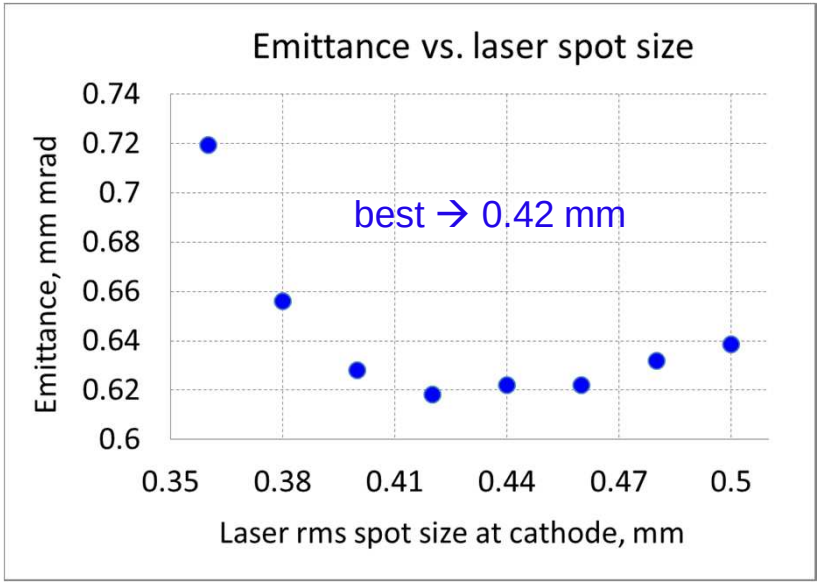
- **Flat-top** cathode laser pulse with 21.5ps FWHM length and 2ps rise and fall times (Trms=6.272 ps)
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- Gun ASTRA phase fixed to -1 deg !!
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

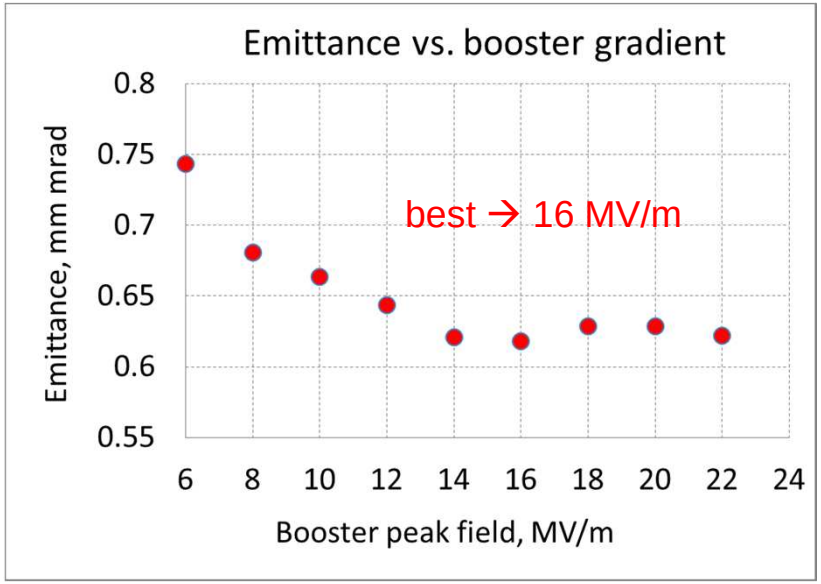
ASTRA simulation setup: varied parameters

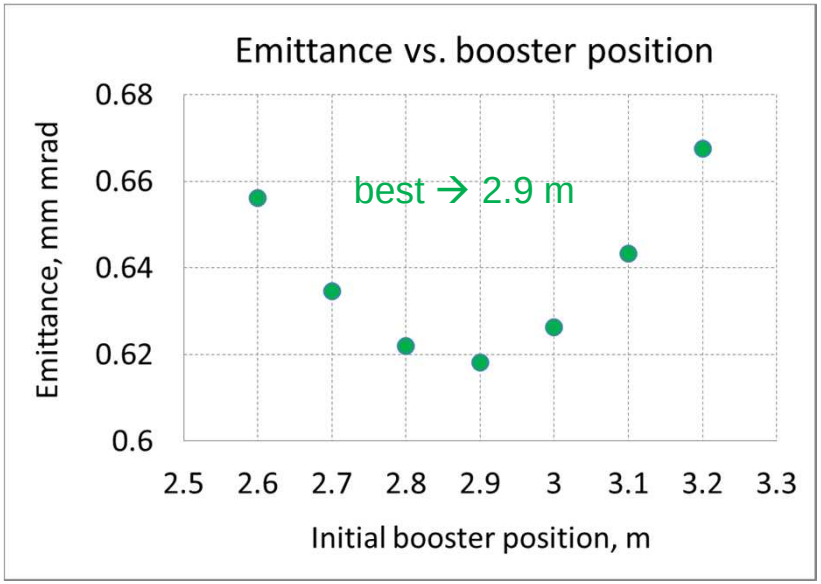
- Laser transverse rms spot size on the cathode → [0.36:0.02:0.5] mm
- Booster gradient → [0:2:22] MV/m
- Initial Z position of CDS booster → [2.6:0.1:3.2] m
- Main solenoid current → [380:2:390] A

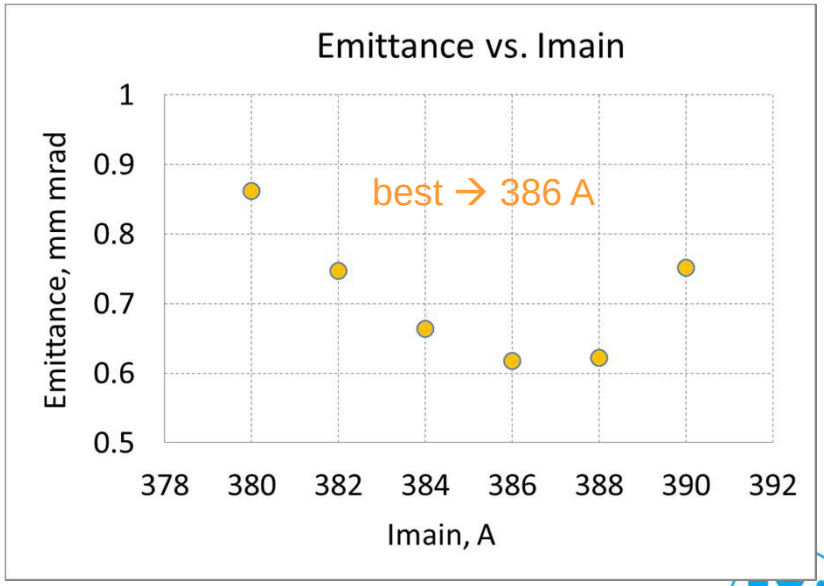
Best laser rms spot size → 0.42 mm
Best initial booster position → 2.9 m
Best booster gradient → 16 MV/m
Best solenoid current → 386A

Flat-top: varied booster gradient



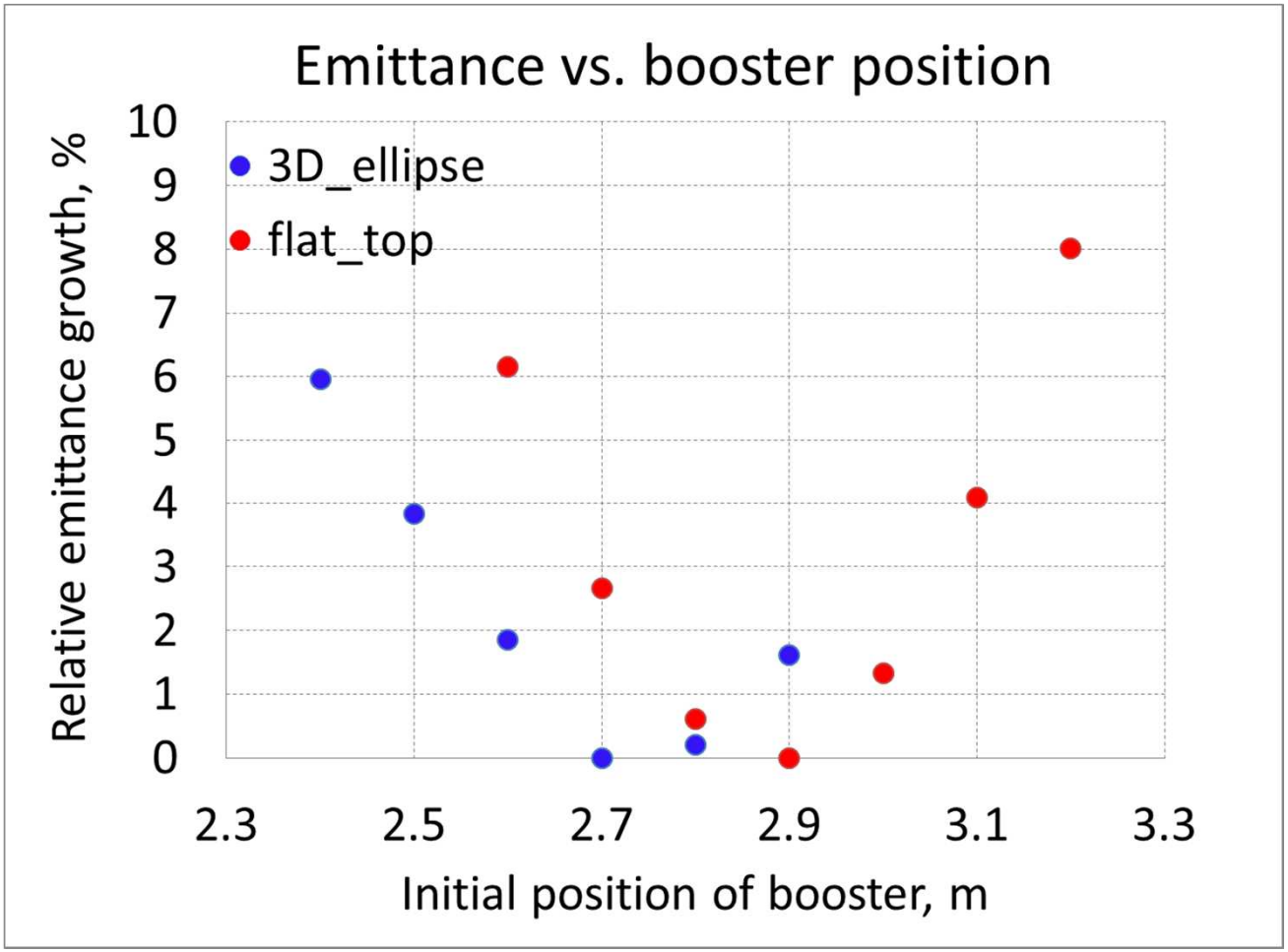






Emittance growth vs. booster position for two cases

‘Optimized’ by varying the beam energy !



Z=2.8 m can be a good compromise …

Conclusion

- Optimum initial booster position for 3D ellipsoidal laser profile → Z=2.7m (consistent)
- Optimum initial booster position for flat-top laser profile → Z=2.9m (consistent)
- Bigger laser spot size at cathode for the case of optimum setups with fixed beam energy (Eb=19.76MV/m) and shifted booster position: flat-top and 3D ellipsoidal laser profiles
- Z=2.8m initial booster position is a good compromise

- Complete emittance optimization for flat-top profile by varying the booster gradient

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with varied beam energy
- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
- Emittance optimization for 3D ellipsoid with fixed booster position of Z=2.9m
- Emittance optimization for flat-top profile with fixed booster position of Z=2.7m
- Summary

Emittance optimization for the fixed Zboo and Eboo

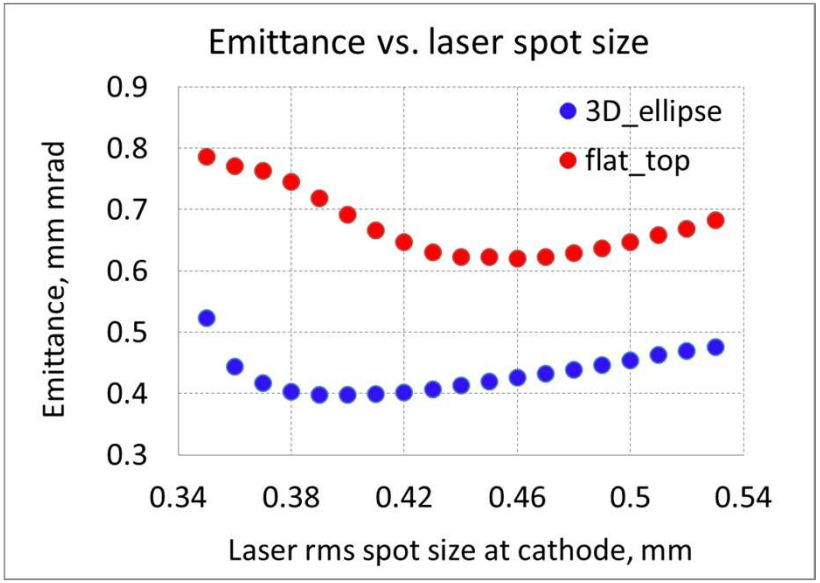
ASTRA simulation setup: fixed parameters

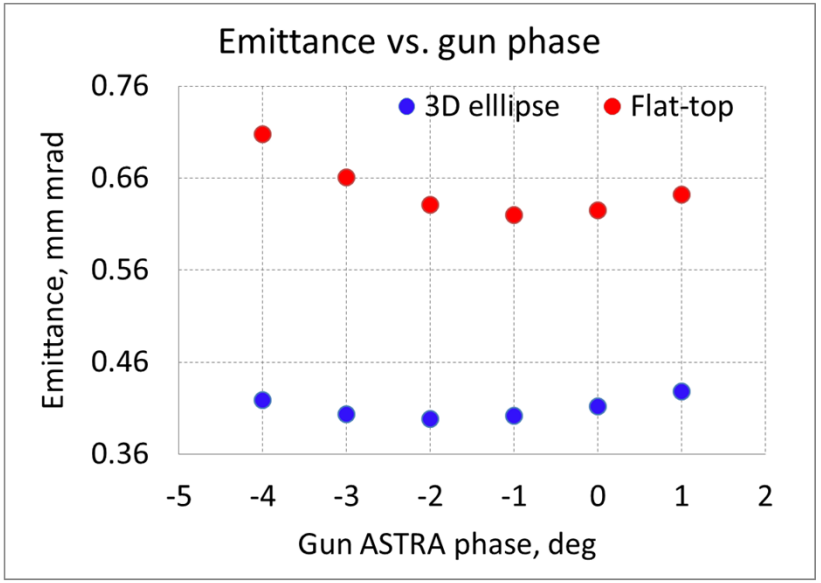
- **3D ellipsoidal** (Trms=6.1 ps) and **flat-top** (Trms=6.272 ps) cathode laser pulses
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- **Initial booster position fixed to 2.8m !!**
- **Booster gradient fixed to 20 MV/m !!** (24 MeV final momentum at on-crest phases)
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

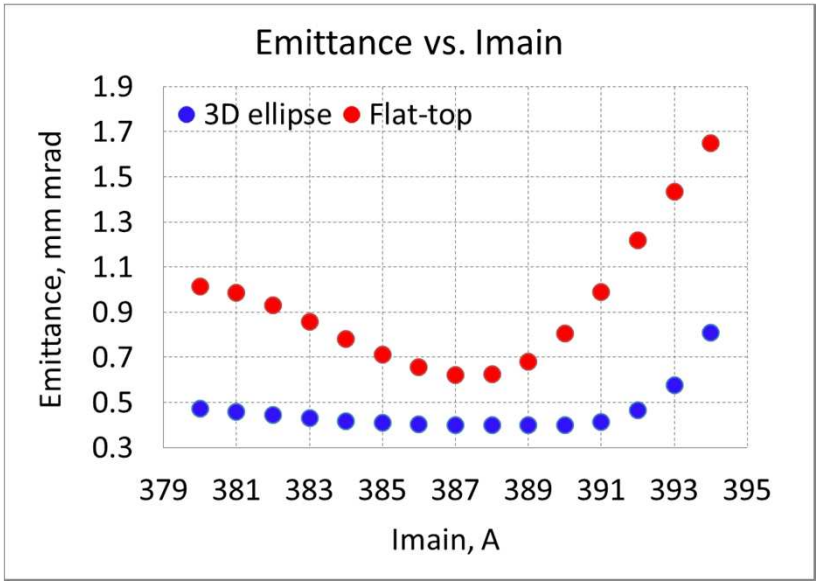
ASTRA simulation setup: varied parameters

- Laser transverse rms spot size on the cathode → [0.35:0.01:0.53] mm
- RF gun ASTRA phase → [-4:1:1] deg
- Main solenoid current → [380:1:394] A

Emittance optimization: two different laser profiles





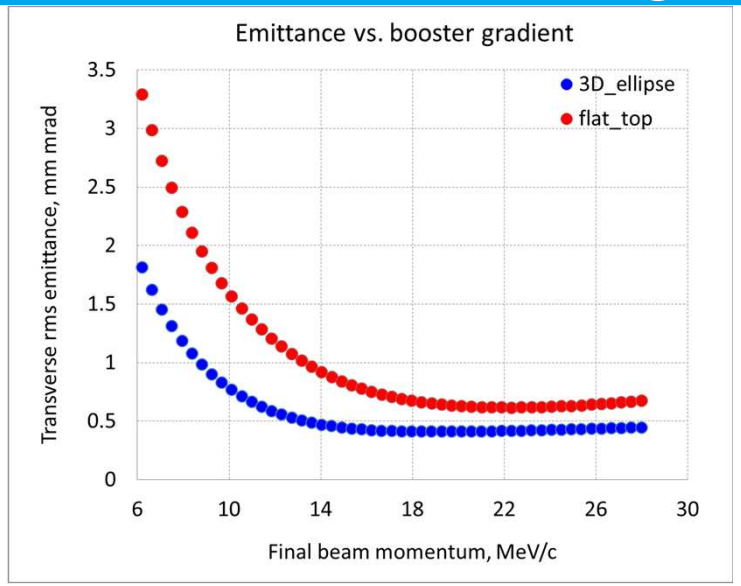


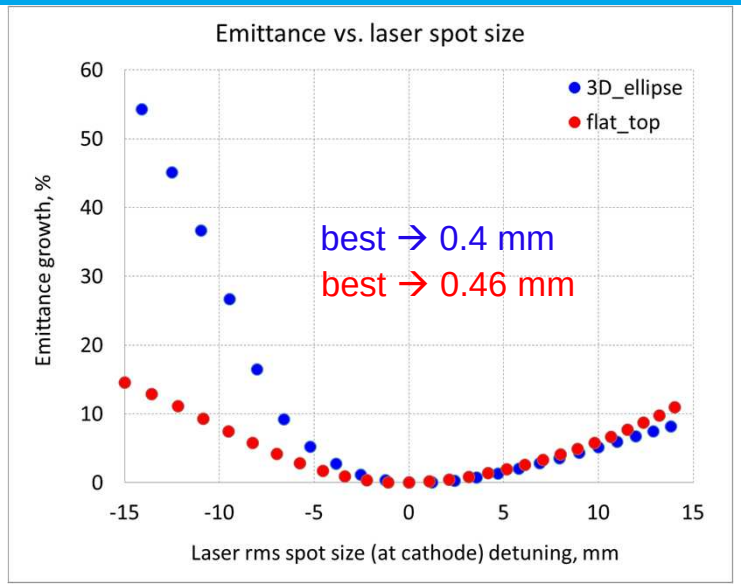
- Booster Z position 2.8m !!
- Booster gradient 20 MV/m !!

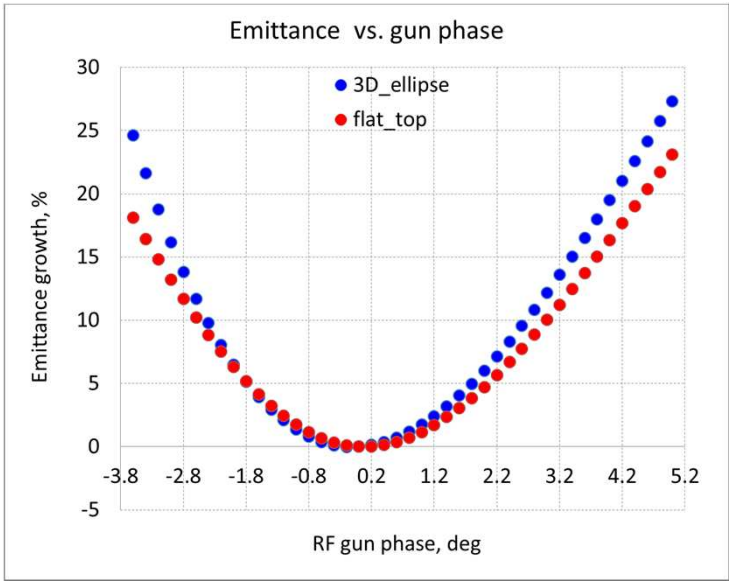
- Electron bunch rms length at EMSY1 7% smaller compared to 3D ellipsoidal case

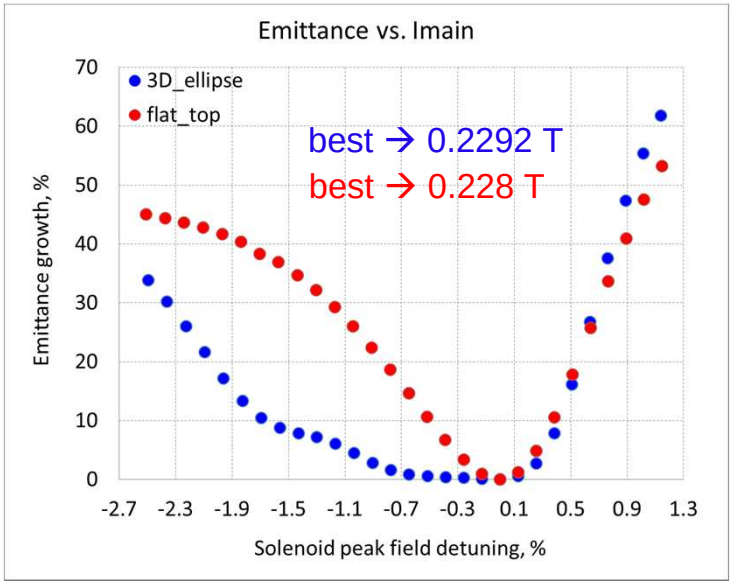
- 0.46 mm optimum laser spot size for flat-top case while 0.4 mm for the 3D ellipsoidal

Beam tolerances at Zboo=2.8m: flat-top +3D ellipsoid with same rms bunch length at EMSY1





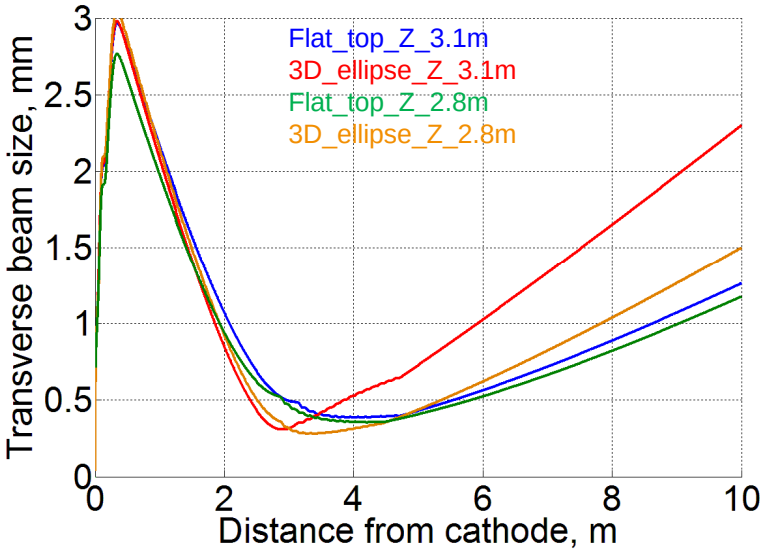


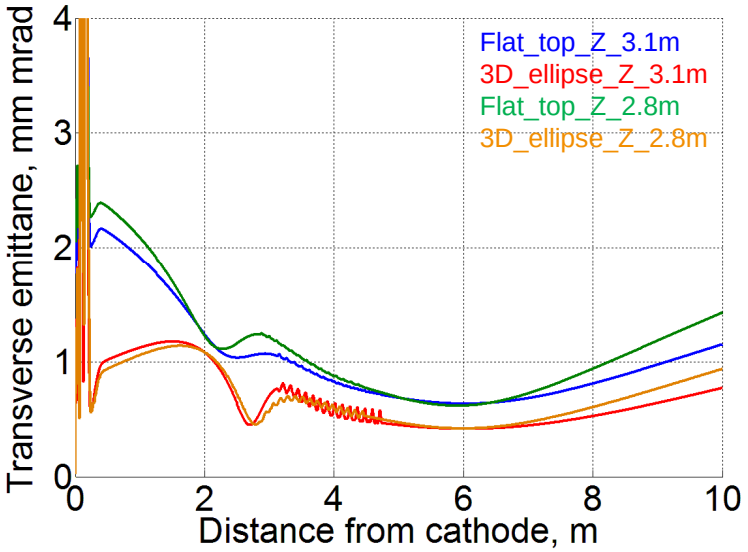


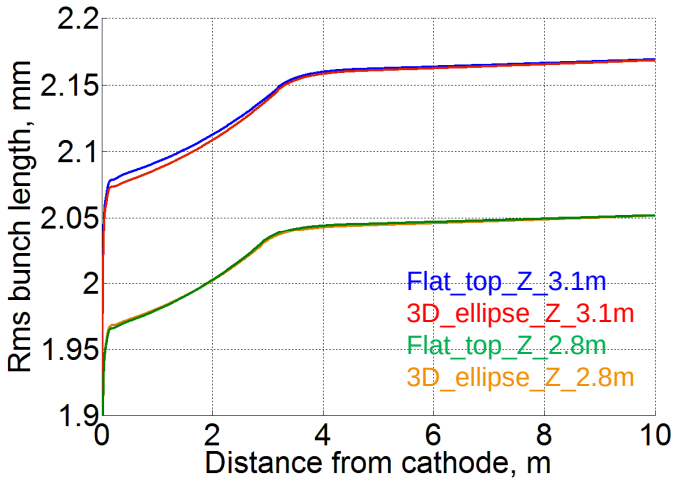
Same rms bunch length at EMSY1 !

Beam dynamics comparing 4 different cases

Transverse beam properties along beamline: 4 different cases

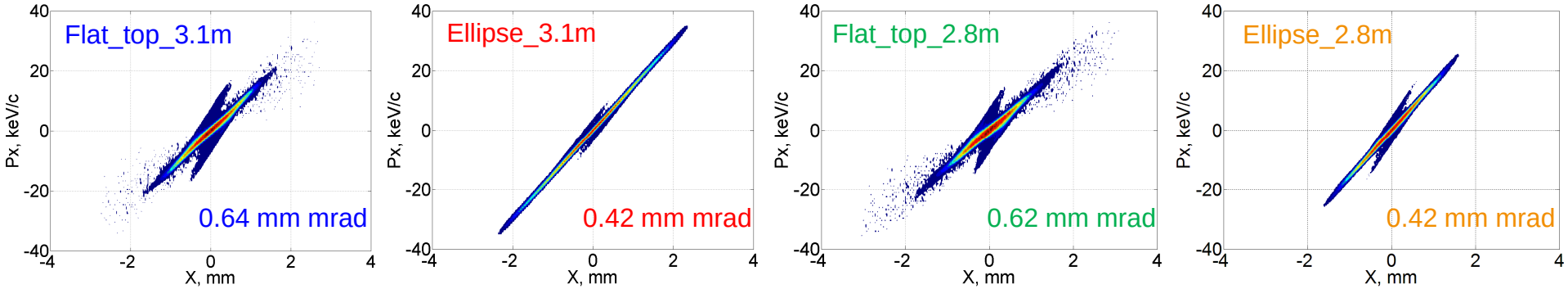




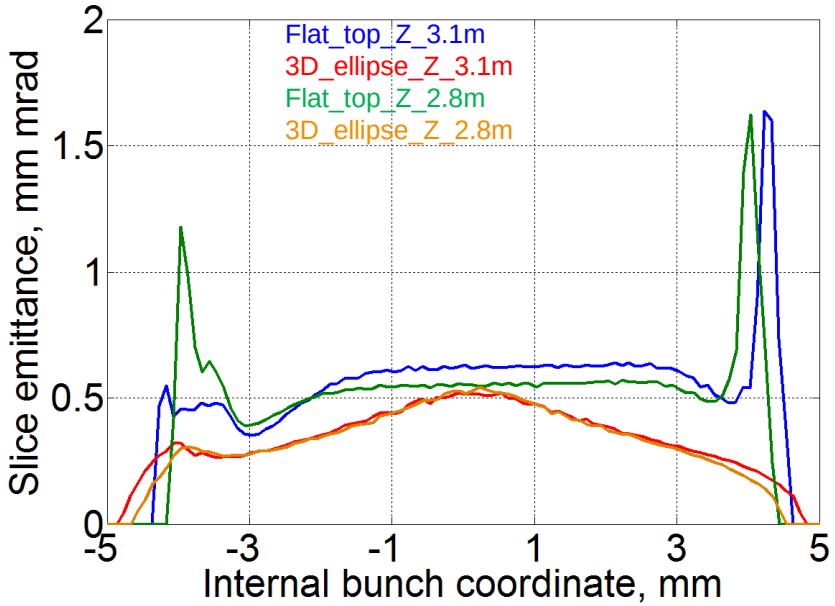


Beam dynamics comparing 4 different cases

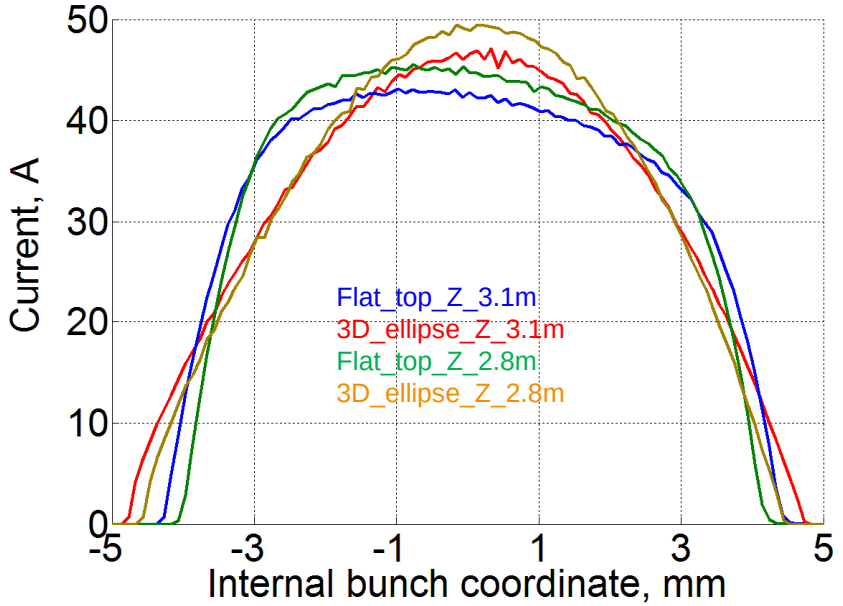
Transverse phase spaces at EMSY1: 4 different cases



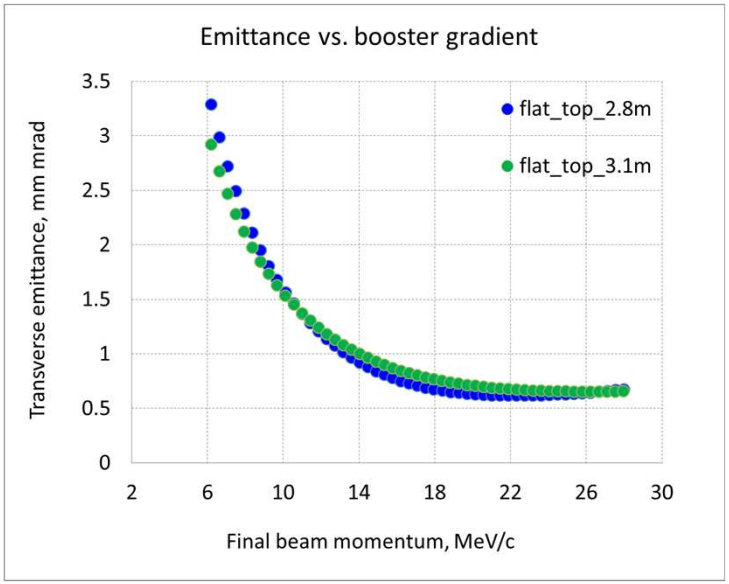
Slice emittances: EMSY1

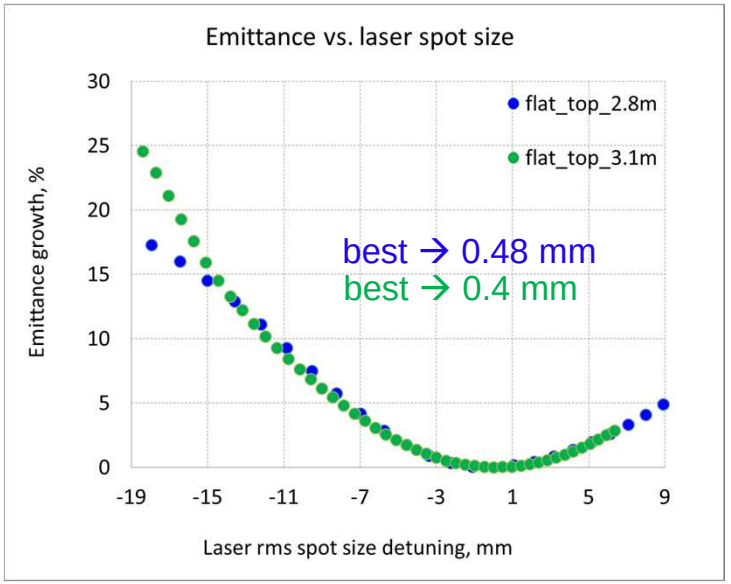


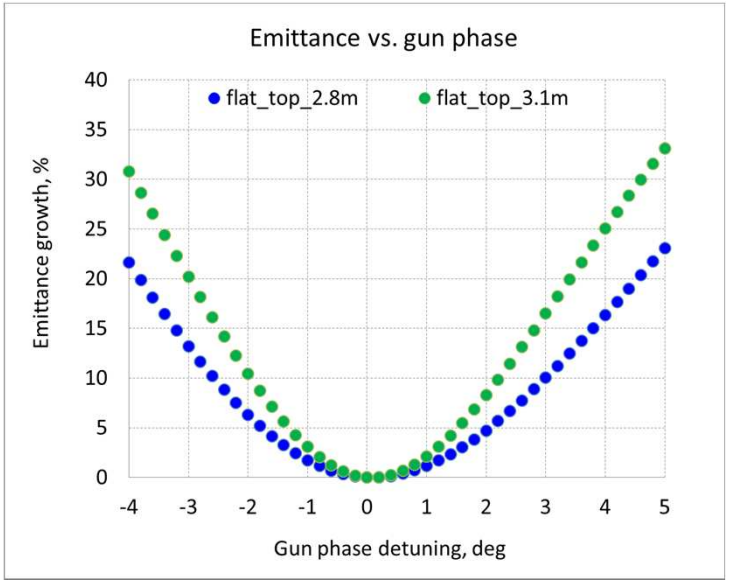
Slice currents: EMSY1

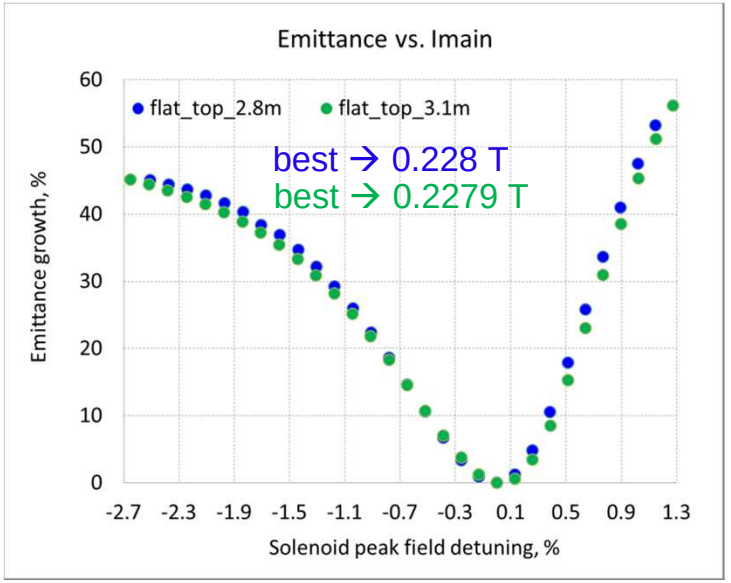


Beam tolerances comparing 2 booster positions for flat-top laser profile



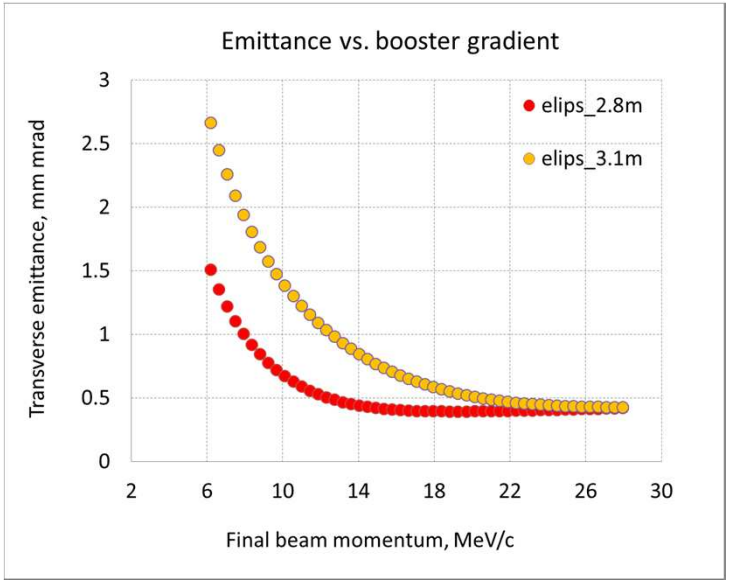


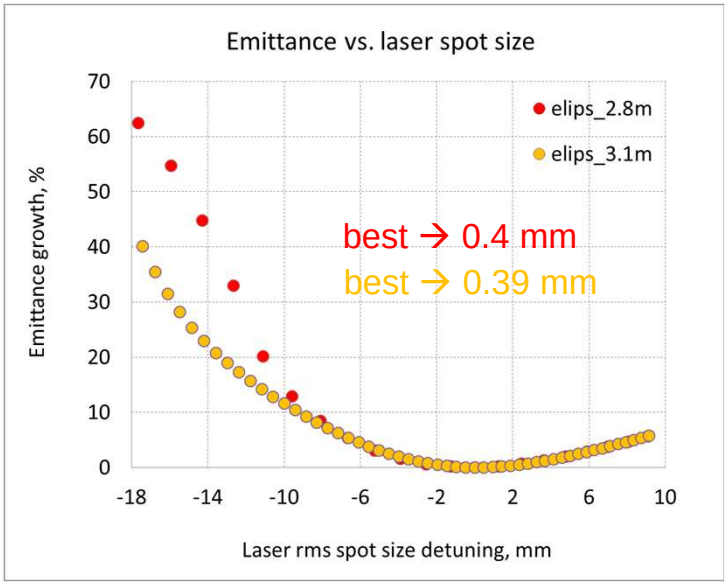


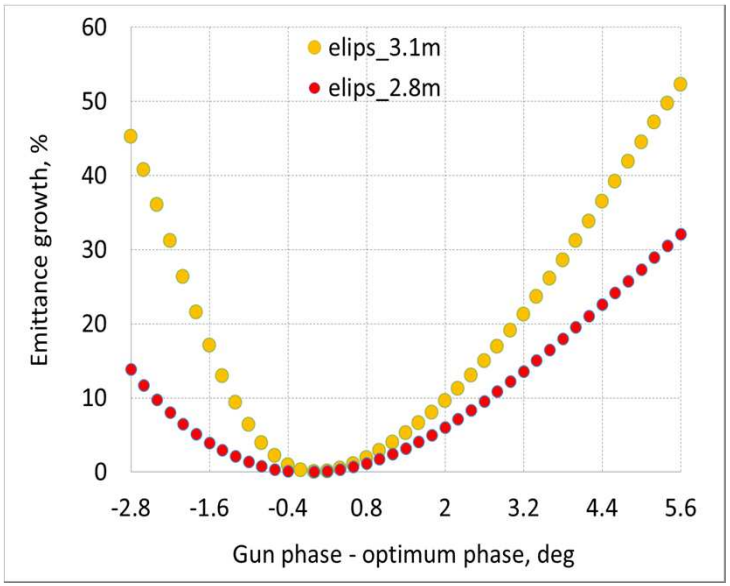


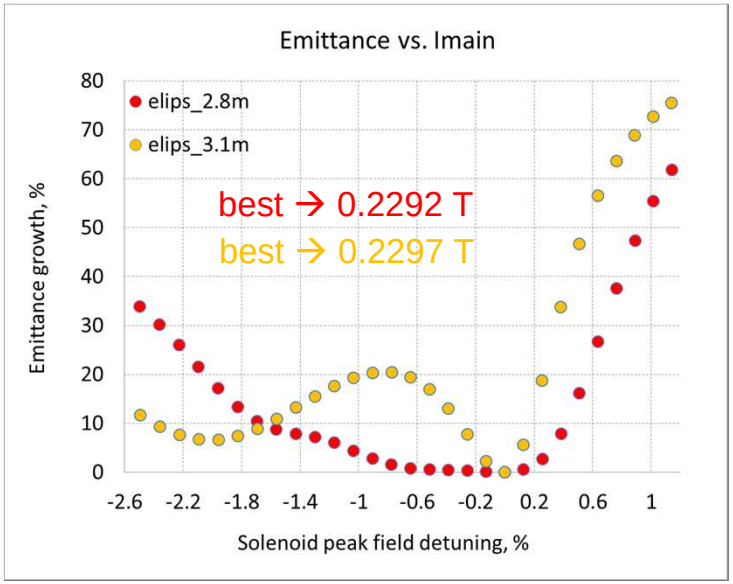
Different rms bunch lengths at EMSY1 !

Beam tolerances comparing 2 booster positions for 3D ellipsoidal laser profile









Different rms bunch lengths at EMSY1 !

Conclusion

Flat-top temporal laser profile:

- Bigger laser spot size required if booster is shifted towards the cathode
- Smaller transverse emittance (slice emittance) and higher peak current for Z=2.8m compared to the current case (current booster position)
- Better tolerances for Z=2.8m compared to the current case

3D ellipsoidal laser profile:

- ~50A peak current for the case of Z=2.8m !
- Transverse (slice) emittances comparable
- Beam tolerances better compared to the current case

- Emittance optimization for flat-top and 3D ellipsoidal laser profiles (Z=2.8m) by varying the booster gradient

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with varied beam energy
- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
- Emittance optimization for 3D ellipsoid with fixed booster position of Z=2.9m
- Emittance optimization for flat-top profile with fixed booster position of Z=2.7m
- Summary

Emittance optimization for 3D ellipsoid (Z=2.9m)

ASTRA simulation setup: fixed parameters

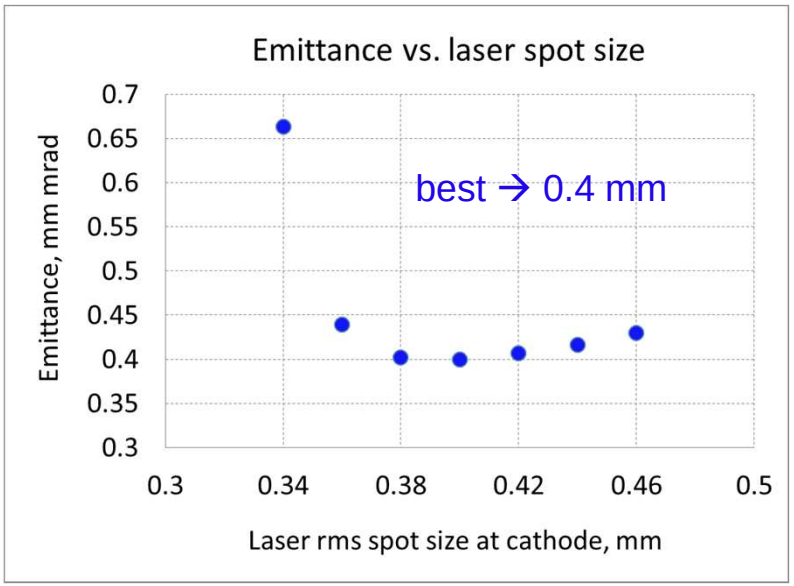
- **3D ellipsoidal** cathode laser pulse with 6.1 ps rms emission time (initial bunch length)
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- Booster starting position: 2.9m
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

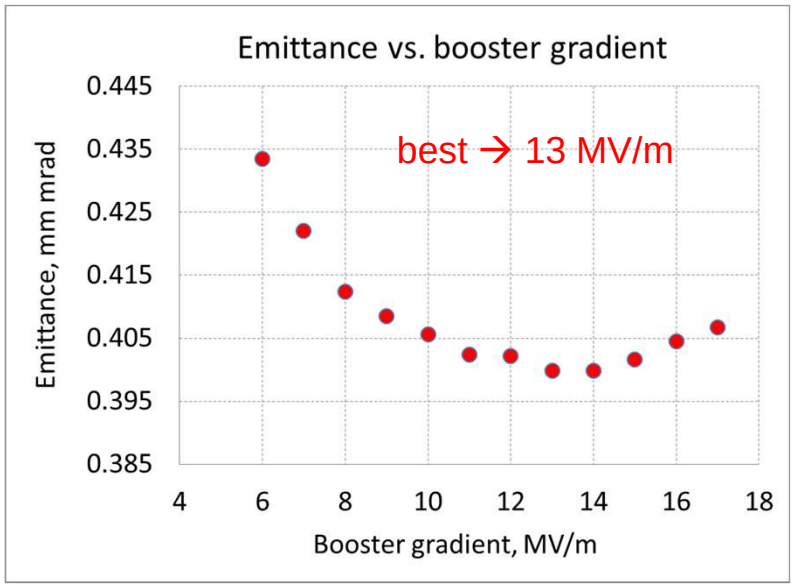
ASTRA simulation setup: varied parameters

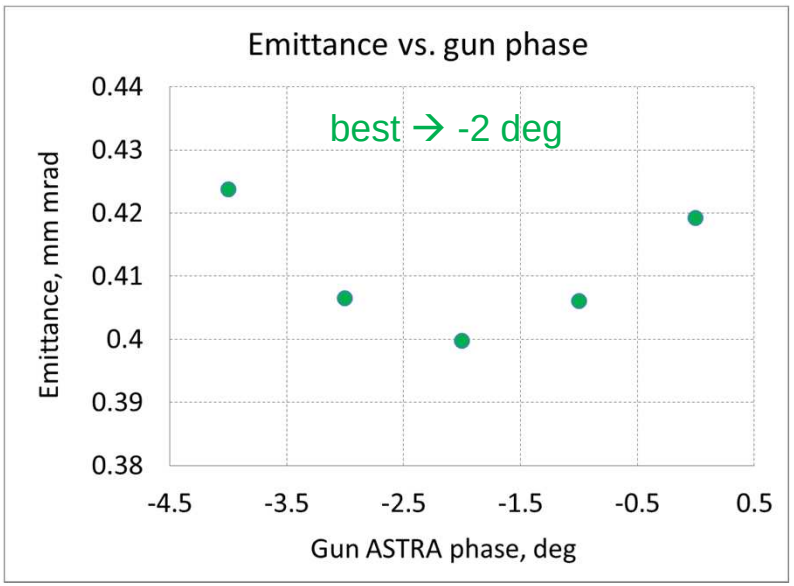
- Laser transverse rms spot size on the cathode → [0.34:0.02:0.46] mm
- Gun ASTRA phase → [-4:1:0] deg
- Booster gradient → [6:1:17] MV/m
- Main solenoid current → [384:1:392] A

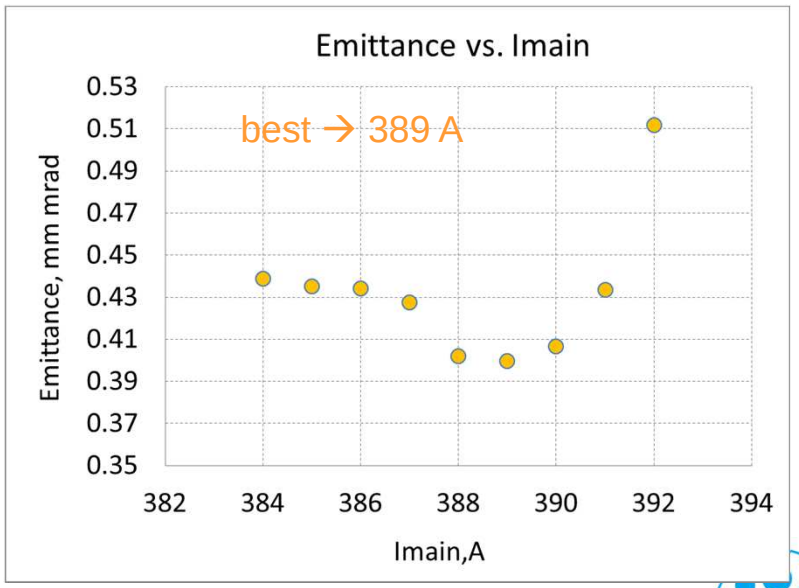
Best laser rms spot size → 0.4 mm
Best gun phase→ -2 deg
Best booster gradient → 13 MV/m
Best solenoid current → 389A

Emittance optimization with fixed booster position (Z=2.9m)

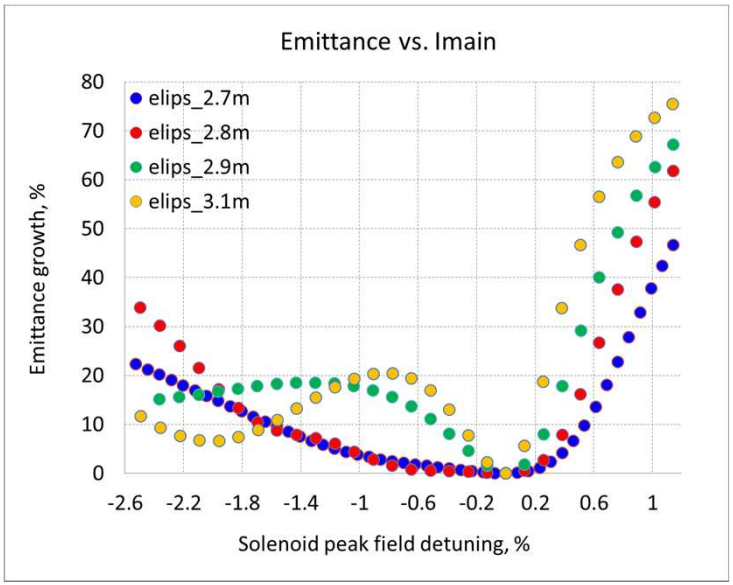


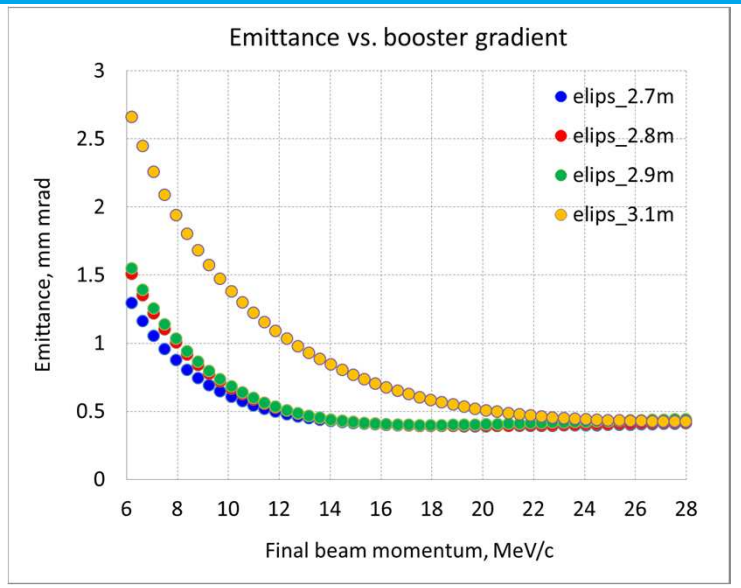


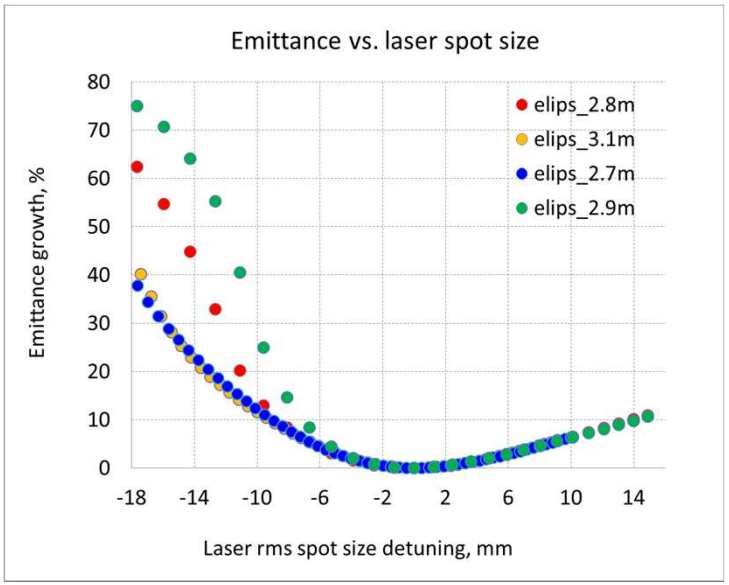


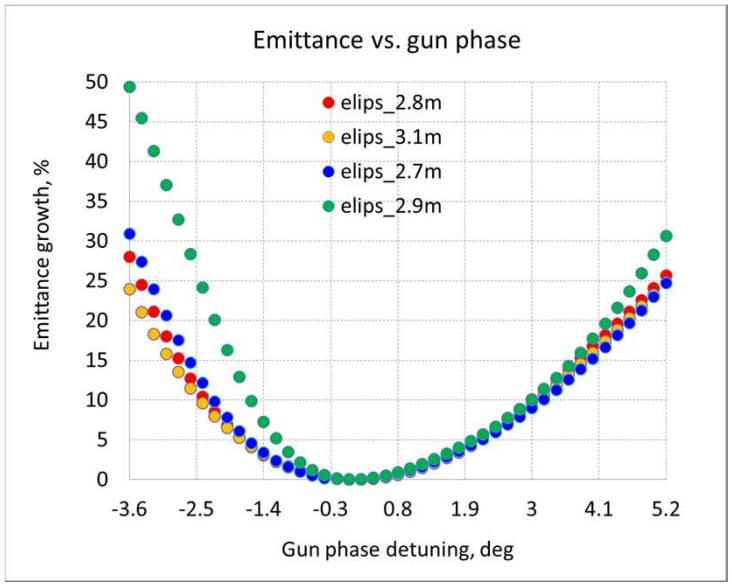


Beam tolerances: summary for 3D ellipsoid









Different rms bunch lengths at EMSY1 !

- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with fixed beam energy
- Booster position optimization for 3D ellipsoidal and flat-top laser shapes with varied beam energy
- Beam studies for flat-top and 3D ellipsoidal laser shapes with fixed booster position of Z=2.8m
- Emittance optimization for 3D ellipsoid with fixed booster position of Z=2.9m
- Emittance optimization for flat-top profile with fixed booster position of Z=2.7m
- Summary

Emittance optimization for flat-top (Z=2.7m)

ASTRA simulation setup: fixed parameters

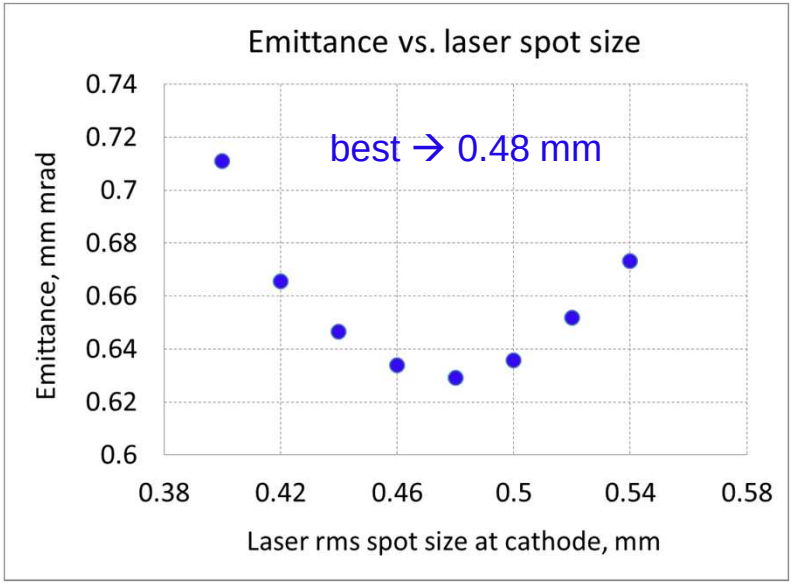
- **Flat-top** cathode laser pulse with 21.5ps FWHM length and 2ps rise and fall times
- 0.55 eV average kinetic energy of the photoelectrons
- Gun gradient: 60.58 MV/m corresponding to Pz~6.7 MeV/c beam momentum after the gun
- Initial booster position: 2.7m
- Bunch charge: 1 nC
- Searching for the best transverse emittance at **EMSY1** (Z=5.74 m)

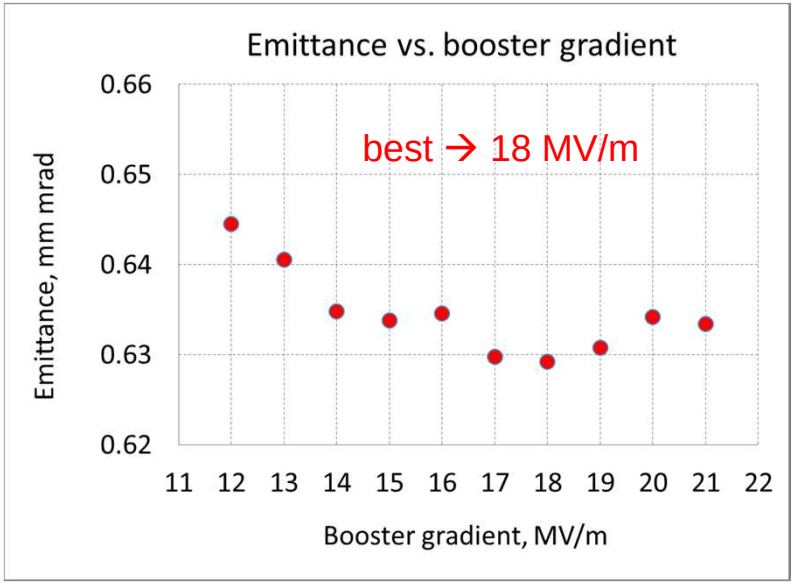
ASTRA simulation setup: varied parameters

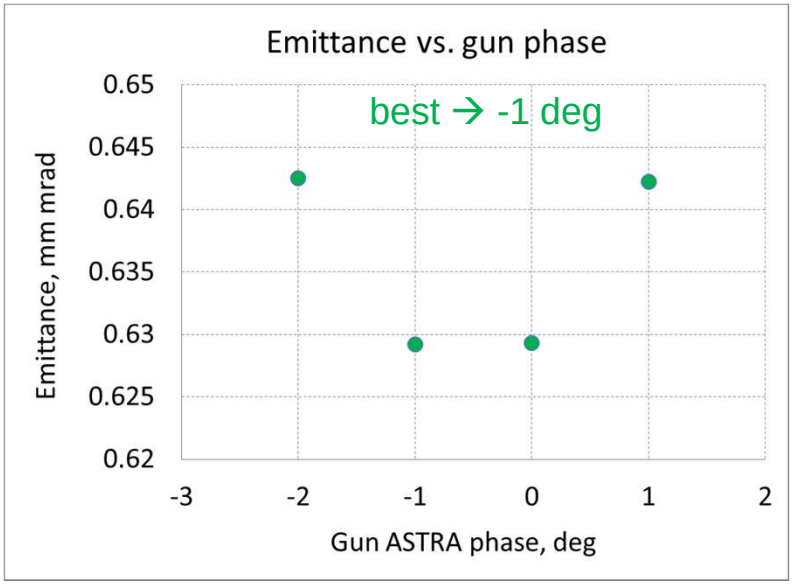
- Laser transverse rms spot size on the cathode → [0.4:0.02:0.54] mm
- Gun ASTRA phase → [-2:0.5:1] deg
- Booster gradient → [12:1:21] MV/m
- Main solenoid current → [384:1:389] A

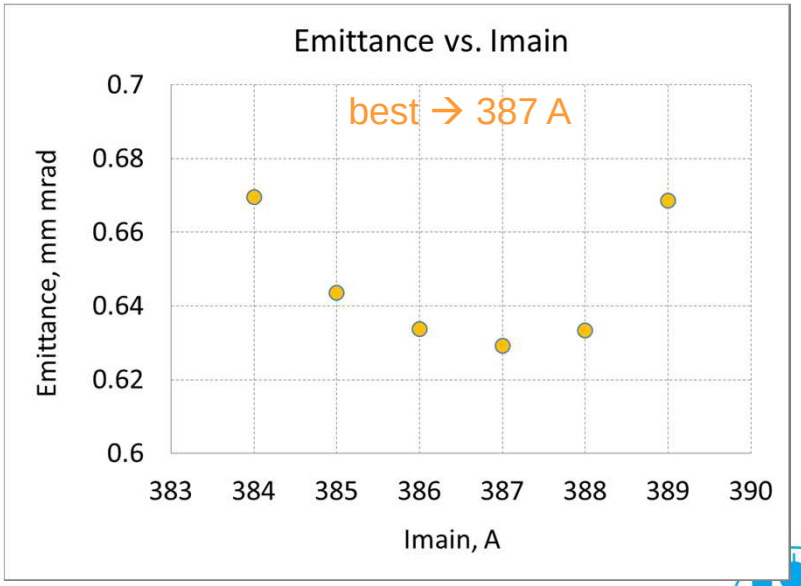
Best laser rms spot size → 0.48 mm
Best gun phase→ -1 deg
Best booster gradient → 18 MV/m
Best solenoid current → 387 A

Emittance optimization with fixed booster position (Z=2.7m)

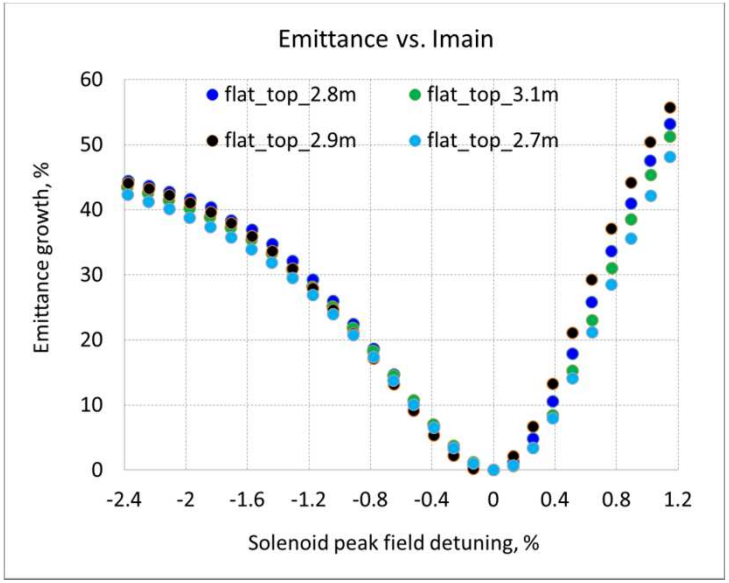


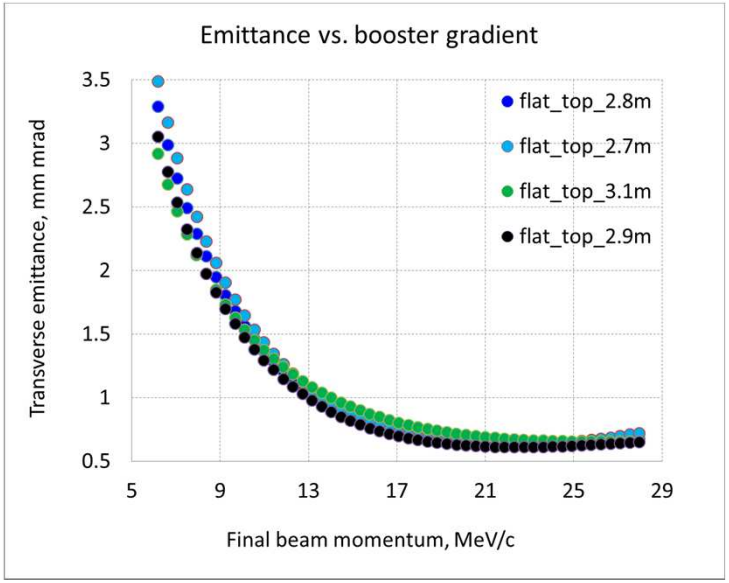


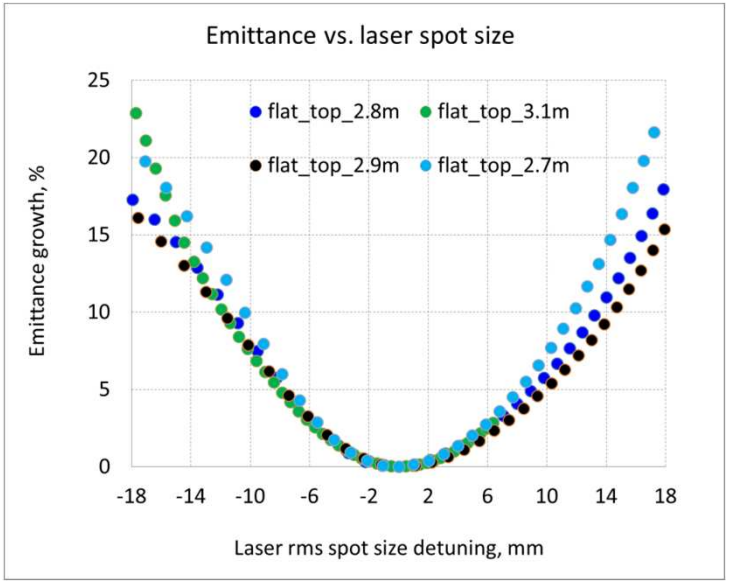


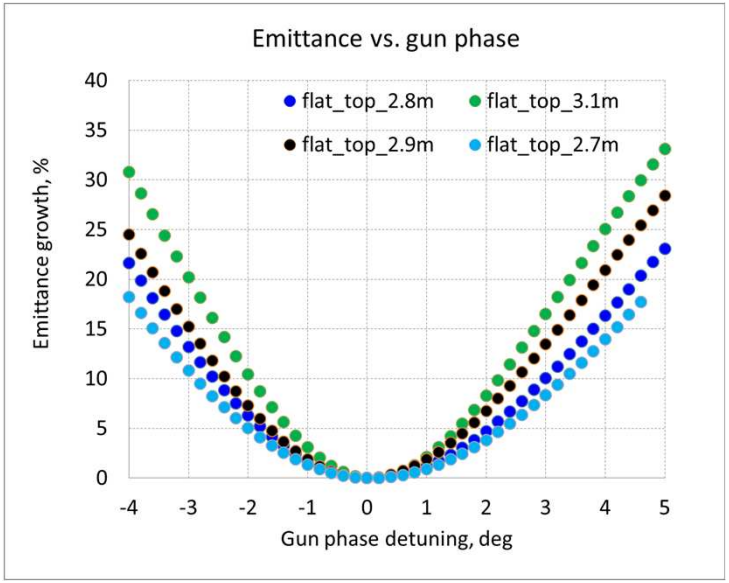


Beam tolerances: summary for flat-top





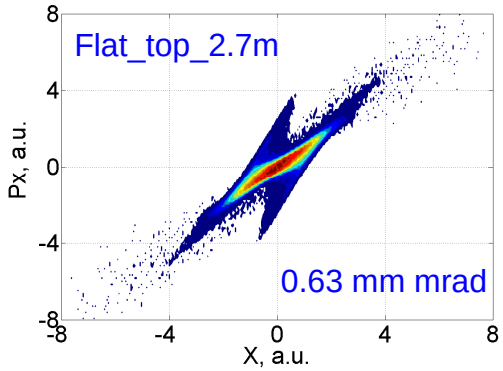


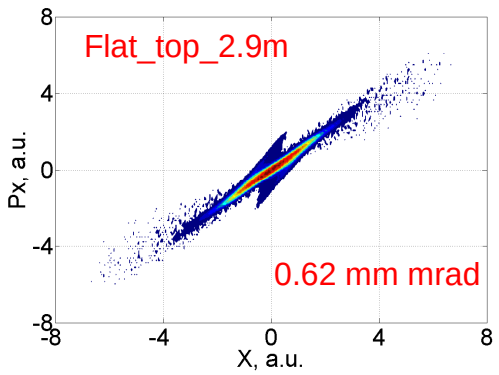


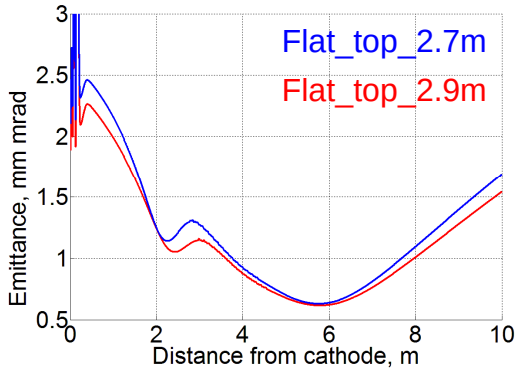
Different rms bunch lengths at EMSY1 !

Beam dynamics comparing 2 booster positions (flat-top)

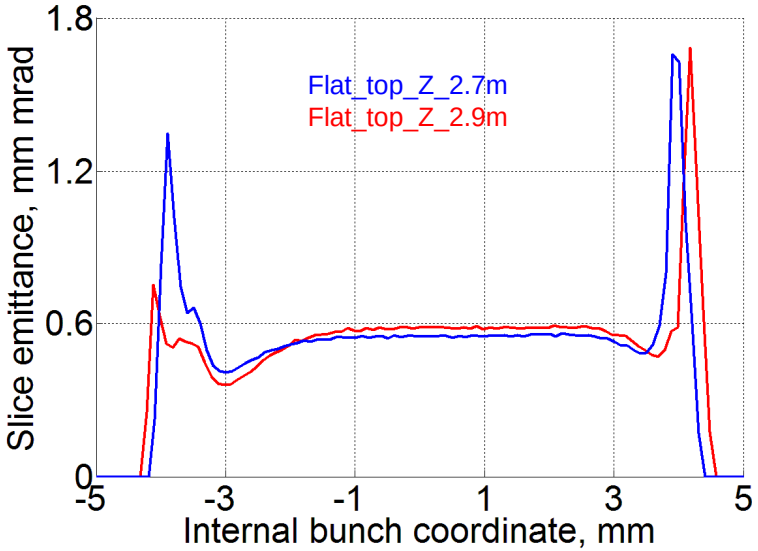
Transverse emittance: 2 different cases



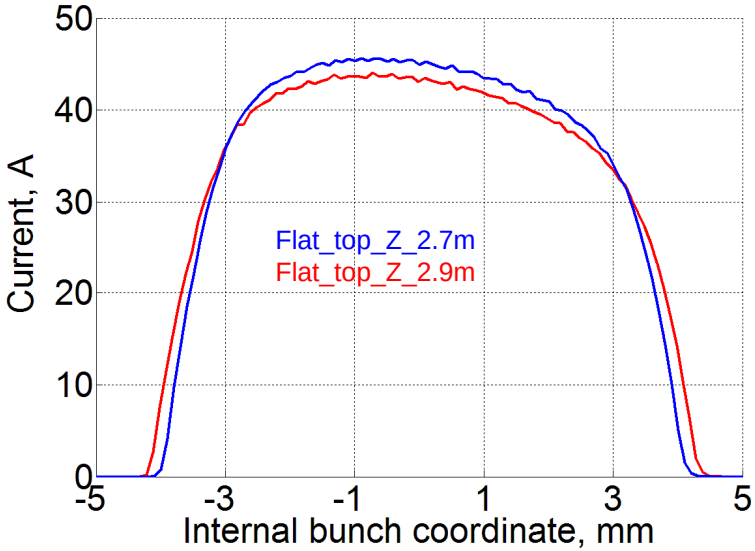




Slice emittances: EMSY1



Slice currents: EMSY1



Conclusion

Flat-top temporal laser profile:

- Z=2.7m yields to shorter bunch (higher peak current) compared to Z=2.9m case
- Tolerances comparable for Z=2.7m and Z=2.9m
- Z=2.8m acceptable

3D ellipsoidal laser profile:

- Best beam tolerances at Z=2.7m
- Worst beam tolerances at Z=2.9m (compared to all cases)
- Z=2.8m acceptable

Summary of beam studies for flat-top and 3D ellipsoidal laser profiles

Temporal	profile	Flat-top	3D homogeneous	Flat-top	3D homogeneous	Flat-top	3D homogeneous	Flat-top	3D homogeneous
Transverse	distribution	radial homogeneous	3D homogeneous	radial homogeneous	3D homogeneous	radial homogeneous	3D homogeneous	radial homogeneous	3D homogeneous
Trms	ps	6.272	6.1	6.272	6.75	6.272	5.5	6.272	6.1
XYrms	mm	0.401	0.39	0.42	0.42	0.46	0.4	0.48	0.4
Th. emit.	mm mrad	0.339	0.33	0.356	0.356	0.39	0.339	0.407	0.339
Ecath.	MV/m	60.58							
RF gun phase	deg	-1.5	-1.5	-1	-2	-1	-2	-0.5	-2
MaxBz	T	0.2279	0.2297	0.2277	0.2289	0.228	0.2292	0.2279	0.2284
CDS starting position	**m**	**3.07**	**3.07**	**2.9**	**2.7**	**2.8**	**2.8**	**2.7**	**2.9**
MaxE	MV/m	19.76	19.76	16	19.76	20	20	18	13
Charge	nC	1							
Momentum	MeV/c	23.96	23.96	20.68	23.96	24.2	24.2	22.4	18
Projected emittance	**mm mrad**	**0.639**	**0.419**	**0.62**	**0.4**	**0.62**	**0.423**	**0.63**	0.408
Th. / proj.	%	53	79	58	89	63	80	65	83
<Sl. emit.>	mm mrad	0.572	0.392	0.558	0.383	0.54	0.395	0.543	0.389
Rms bunch length	mm	2.163	2.162	2.12	2.163	2.05	2.05	2.02	2.13
Peak current	**A**	**43.2**	**46.8**	**43.9**	**46.8**	**45.4**	**49.8**	**45.7**	**47.3**
Longitudinal emittance	pi keV mm	98.2	88	84	91.7	86.7	72.3	79.9	61.9

Summary

Zboo=3.1m (current booster position)

- Flat-top → much better beam tolerances compared to 3D ellipsoid

Zboo=2.9m (optimum position for flat-top)

- Flat-top → higher peak current (Z=3.1m), smaller (slice) emittance, better tolerances (3.1m)
- 3D ellipsoid → comparable (slice) emittance (better tolerances (Z=3.1m), worse compared to other two

Zboo=2.8m

- Flat-top → higher peak current (Z=3.1m), smaller (slice) emittance, better tolerances (3.1m)
- 3D ellipsoid → 50A peak current, comparable (slice) emittance (Z=3.1m), better tolerances w.r.t. Z=3.1m but worse compared to Z=2.7m

Zboo=2.7m (optimum position for 3D ellipsoid)

- Flat-top → highest peak current, comparable (slice) emittance, better tolerances (Z=3.1m)
- 3D ellipsoid → best machine performance, best tolerances (Z=3.1m)

To be done

- Complete emittance optimization for flat-top by varying the booster gradient (Z=2.9m)
- Emittance optimization for flat-top and 3D ellipsoid by varying the booster gradient (Z=2.8m)
- Tolerance studies comparing different cases with the same rms beam length at EMSY1

Thank you for your attention !