Non-scaled, scaled, scaled-2, core, fractional-core, etc.

Emittance measurements at PITZ: used setup → close to CW SC gun: 40MV/m, 100pC

M. Krasilnikov, 06.06.2019

Why

Motivation

- Significant charge cut by slit-scan technique
- Smaller emittance → becomes sensible to emittance scaling procedure
- Core emittance – figure of merit for FEL
- Bring measured emittance closer to simulations?
- Next steps in emittance optimization procedure

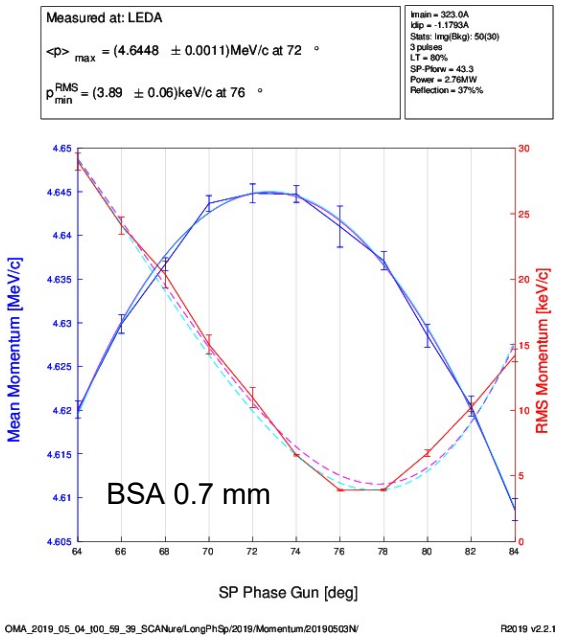
Experimental data used:
“PITZ experimental optimization for the aimed cathode gradient of a SC CW RF Gun“

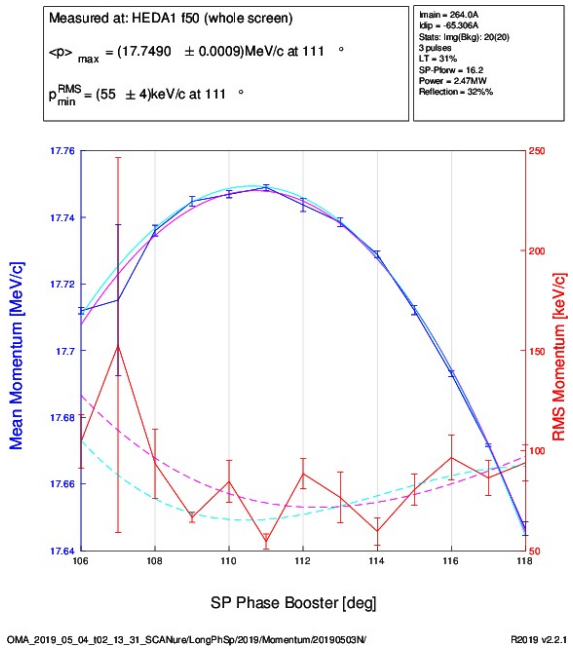
- Ecath=40MV/m, MMMG
- Booster: 3MW, MMMG
- Qbunch=100pC
- Temporal: Gaussian (~6ps FWHM) vs. flattopp (~18ps FWHM)
- Optimized: BSA, Imain, gun quads
- E-beam trajectory: might be not fully optimized

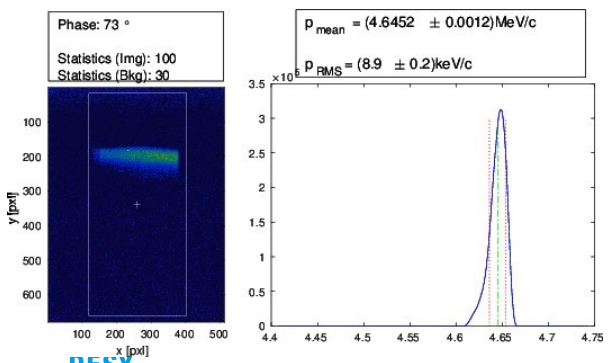
PITZ gun at CW SC gun gradient

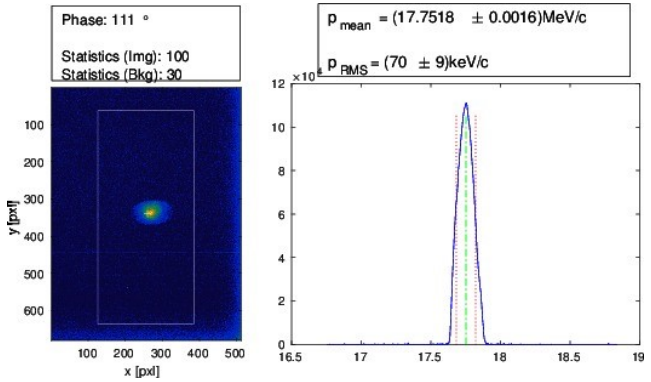
100 pC emittance, gun 4.6 MeV/c; final 17.8MeV/c

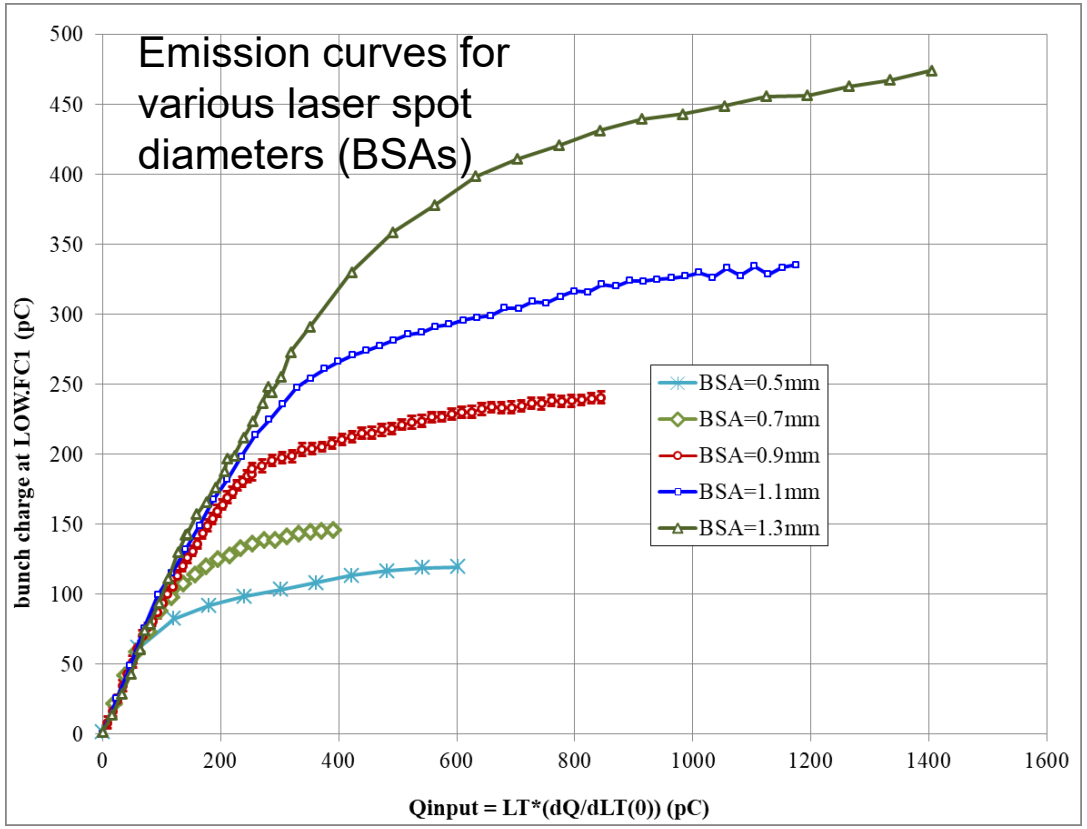
Photocathode laser: temporal Gaussian ~6.2ps FWHM



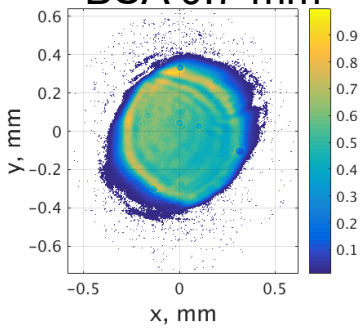


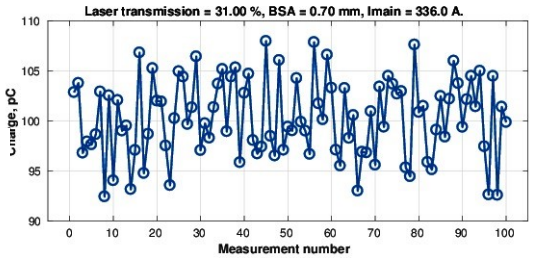


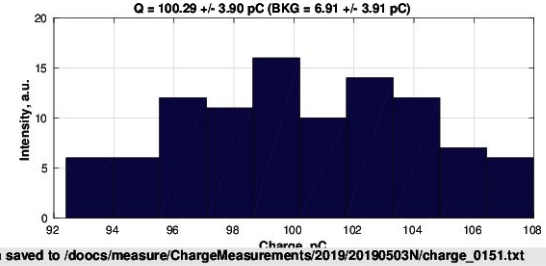




Laser
BSA 0.7 mm







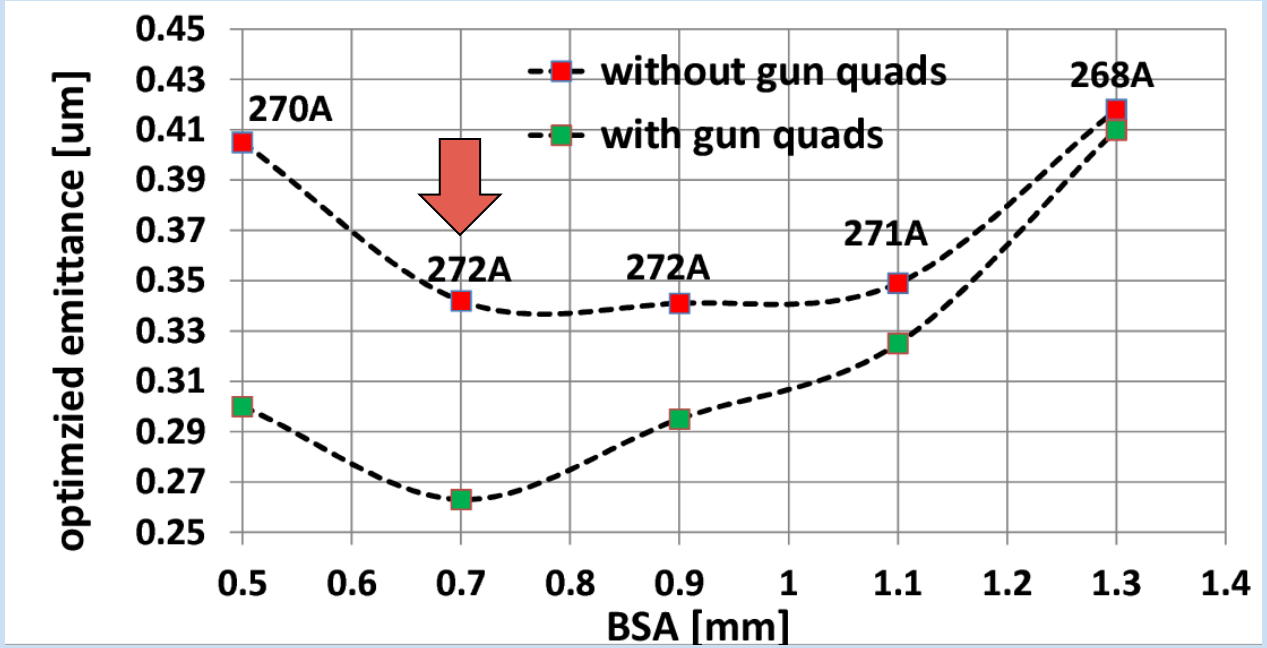
Data saved to /doocs/measure/ChargeMeasurements/2019/20190503N/charge_0151.txt
Charge measurement using Low.FC1; calibration corrected by 1/0.82; stat.:100/100

DESY.

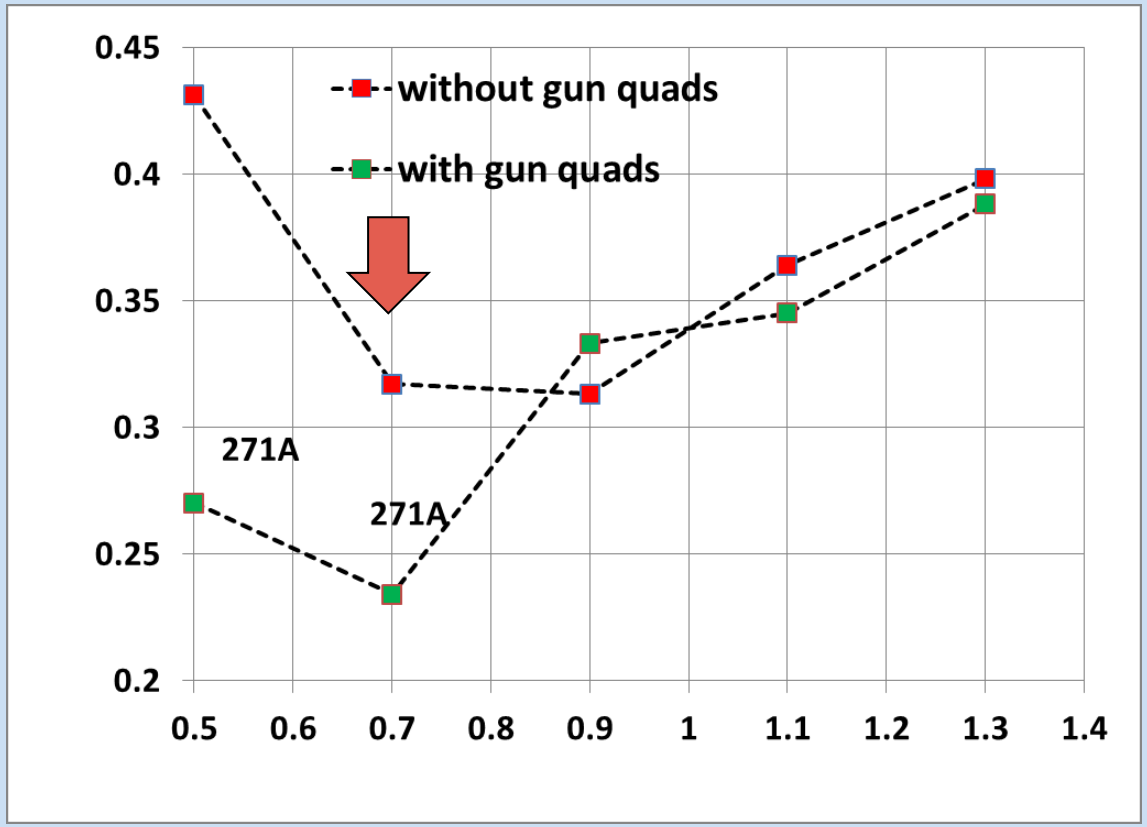
PITZ gun at CW SC gun gradient

Optimized 100 pC emittance min[ε_{xy}(Imain)](BSA)

Gaussian photocathode laser pulse

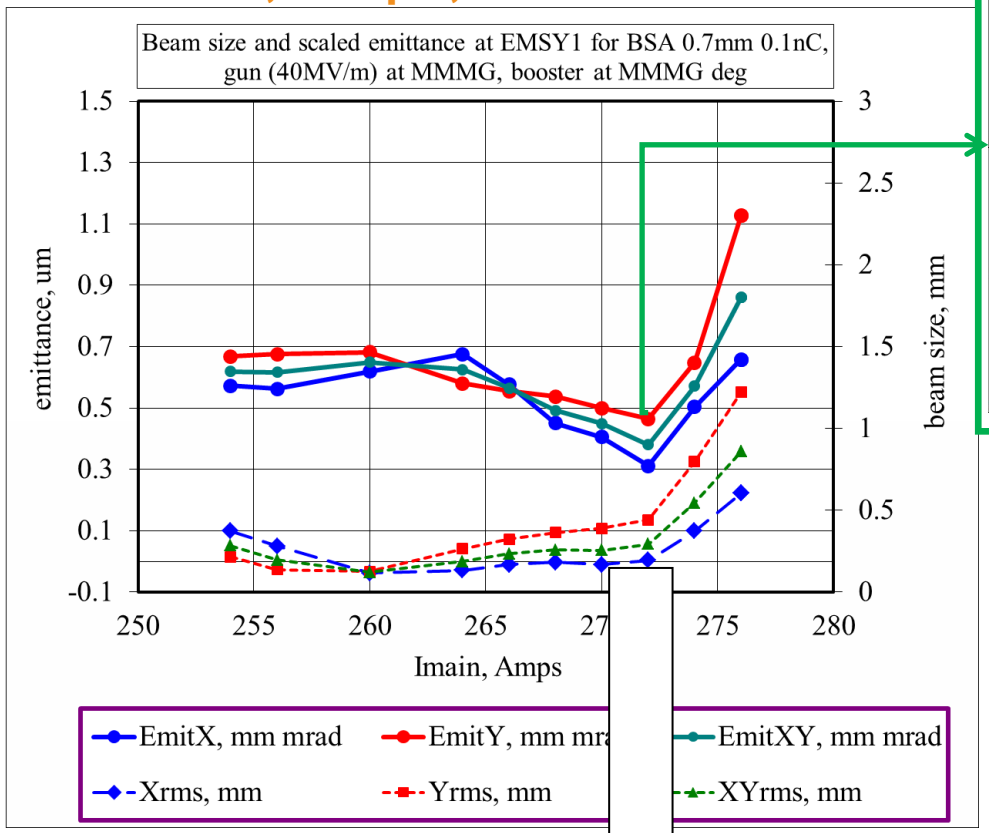


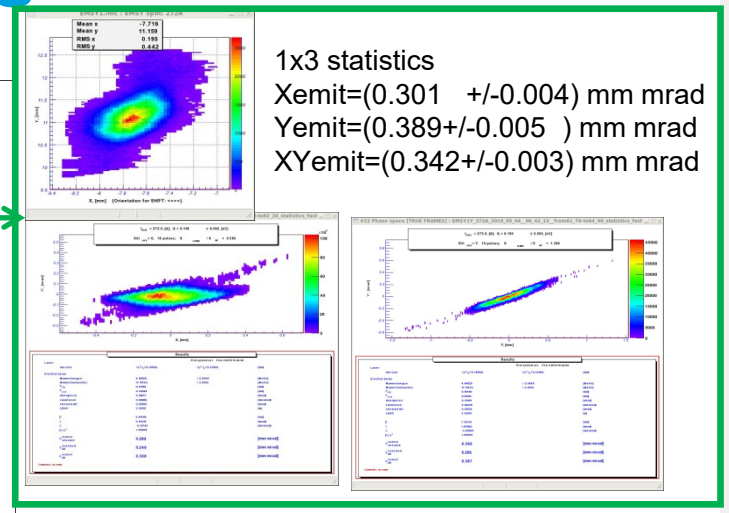
Flattop photocathode laser pulse



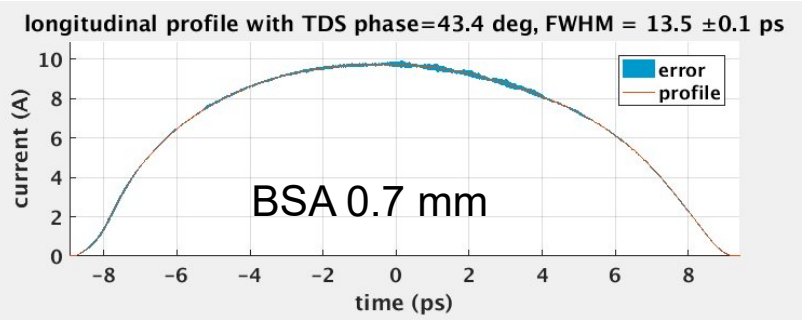
PITZ gun at CW SC gun gradient

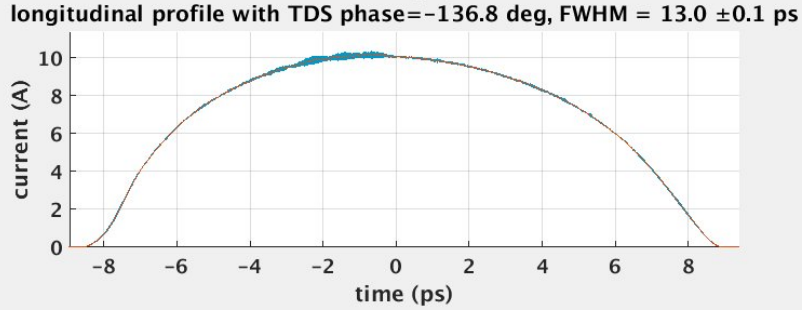
Gaussian, 100 pC, BSA=0.7mm

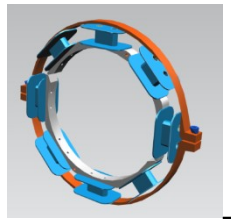


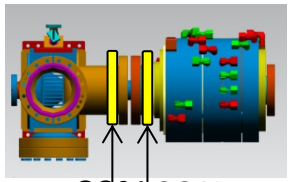


1x3 statistics
Xemit=(0.301 +/-0.004) mm mrad
Yemit=(0.389+/-0.005) mm mrad
XYemit=(0.342+/-0.003) mm mrad

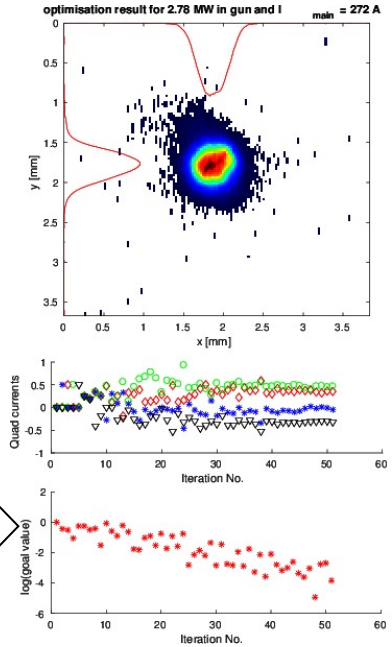


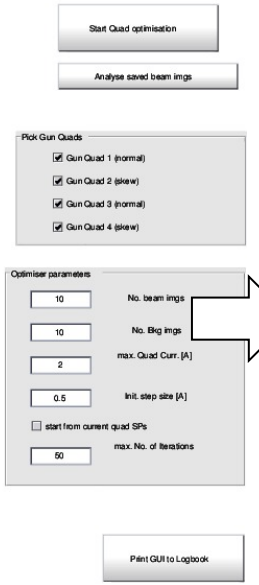


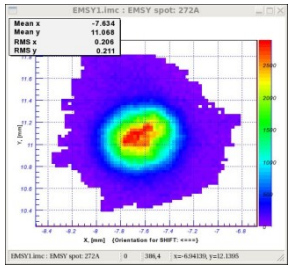




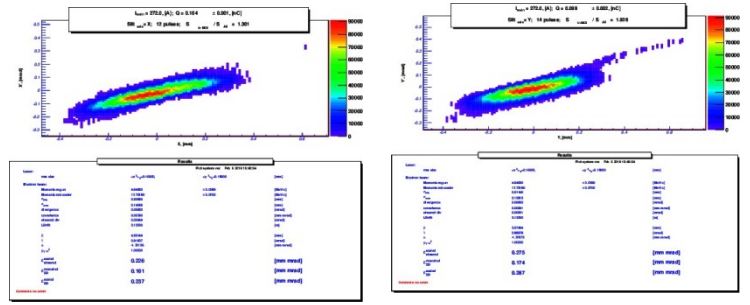
Optimizing gun quads







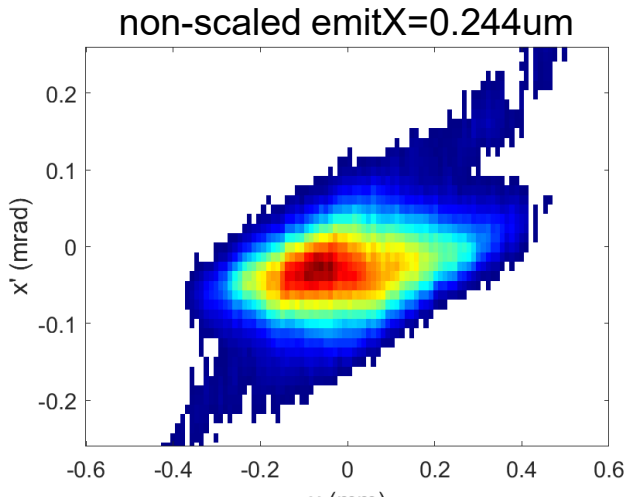
1x3 statistics
Xemit=(0.236+/-0.004) mm mrad
Yemit=(0.292+/-0.004) mm mrad
XYemit=(0.263+/-0.003) mm mrad

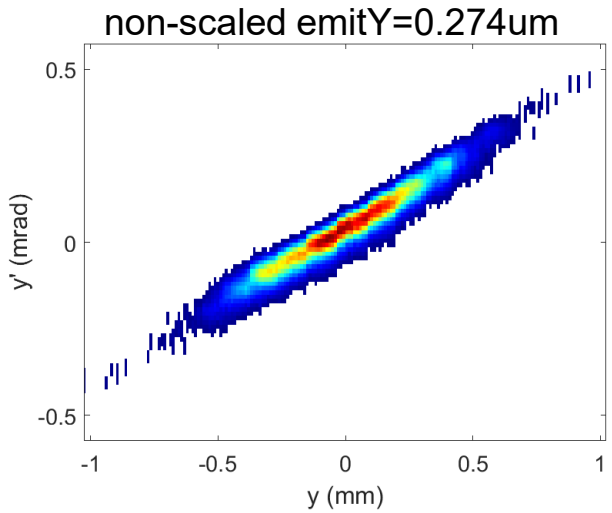


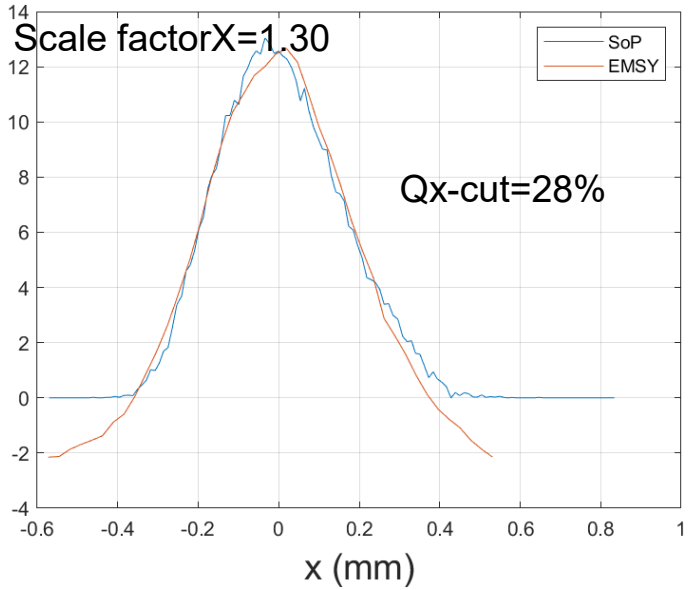
Charge cut analysis

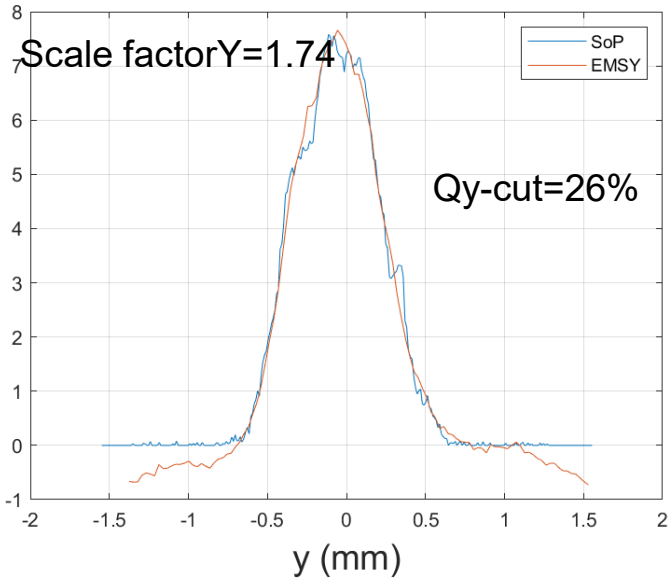
Gaussian, 100 pC, BSA=0.7mm; Imain=272A

Used matlab class:
emwiz_scan(fpath, xfname)
Implemented by G. Georgiev
emcalc3 filters applied



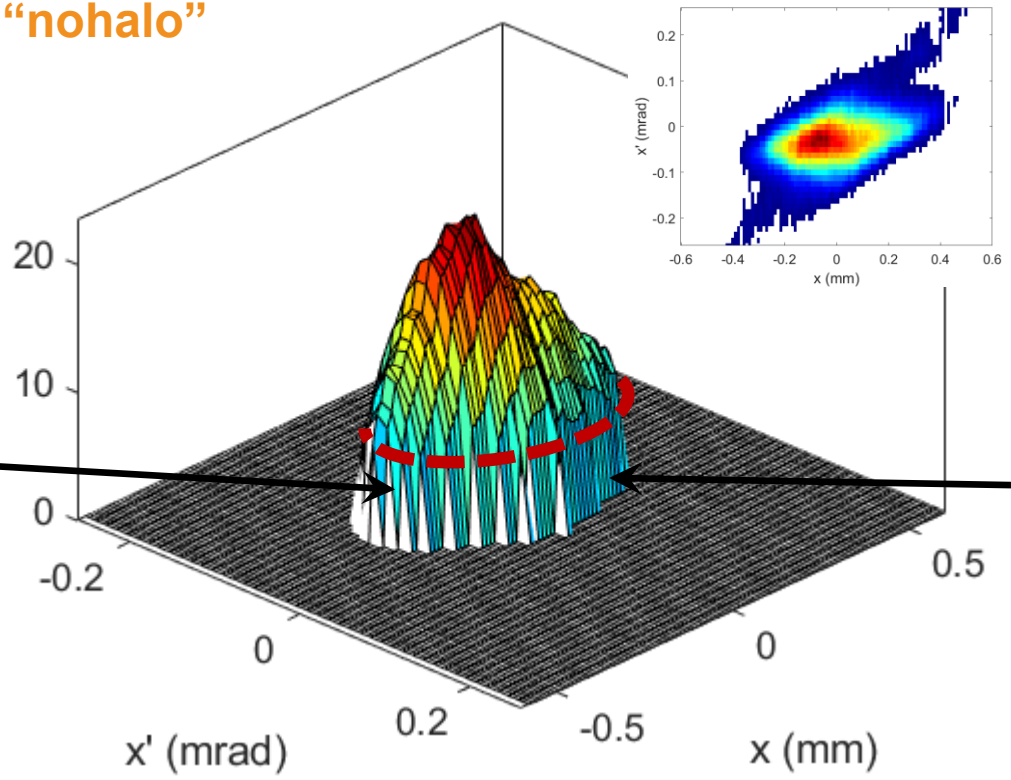






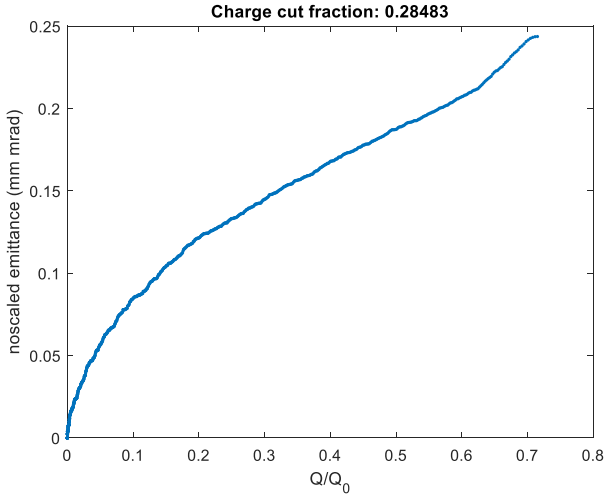
Further charge cut applied to the measured phase space

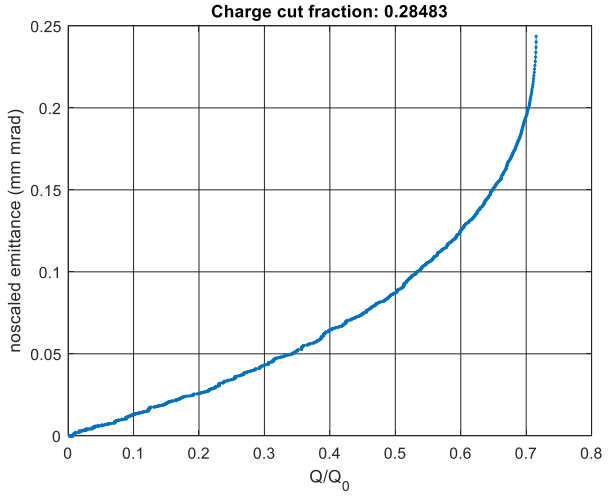
2 methods: “nobase” and “nohalo”



“nobase” X

+ “nohalo”



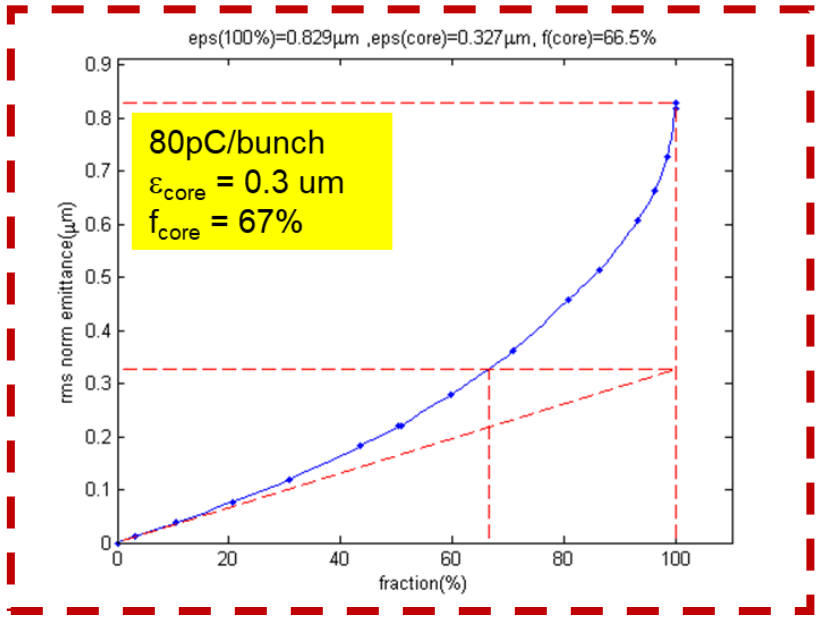


Other approaches to emittance calculation

Fractional core emittance

e.g. I.V. Bazarov, Overview of Photoinjectors for Future Light Sources, March 6, 2012

- Single RMS emittance definition is inadequate for linacs
  - Beams are not Gaussian
  - Various groups report 95% emittance or 90% emittance (or don't specify what exactly they report)
- The right approach
  - Measure the entire phase space, then obtain emittance of the beam vs. fraction (0 to 100%)



Single rms emittance is inadequate for comparisons

- **Better to quote 3 numbers**
  - **100% rms emittance (or 95% or 90%)**
  - **core emittance (essentially peak brightness)**
  - **core fraction**

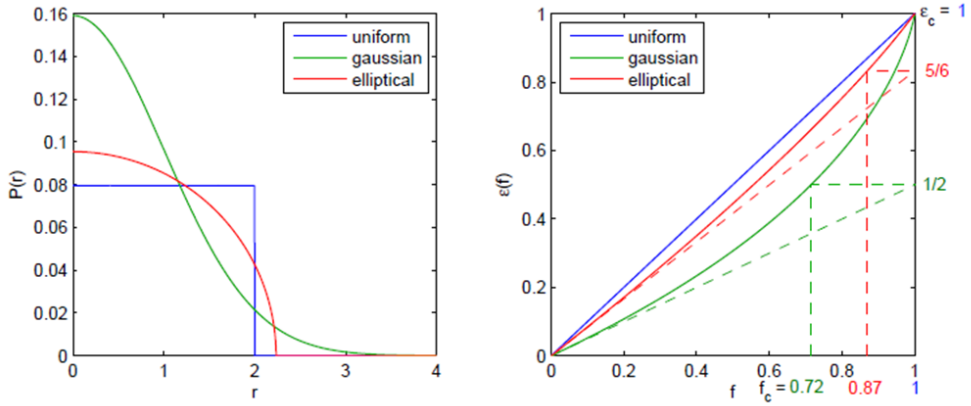
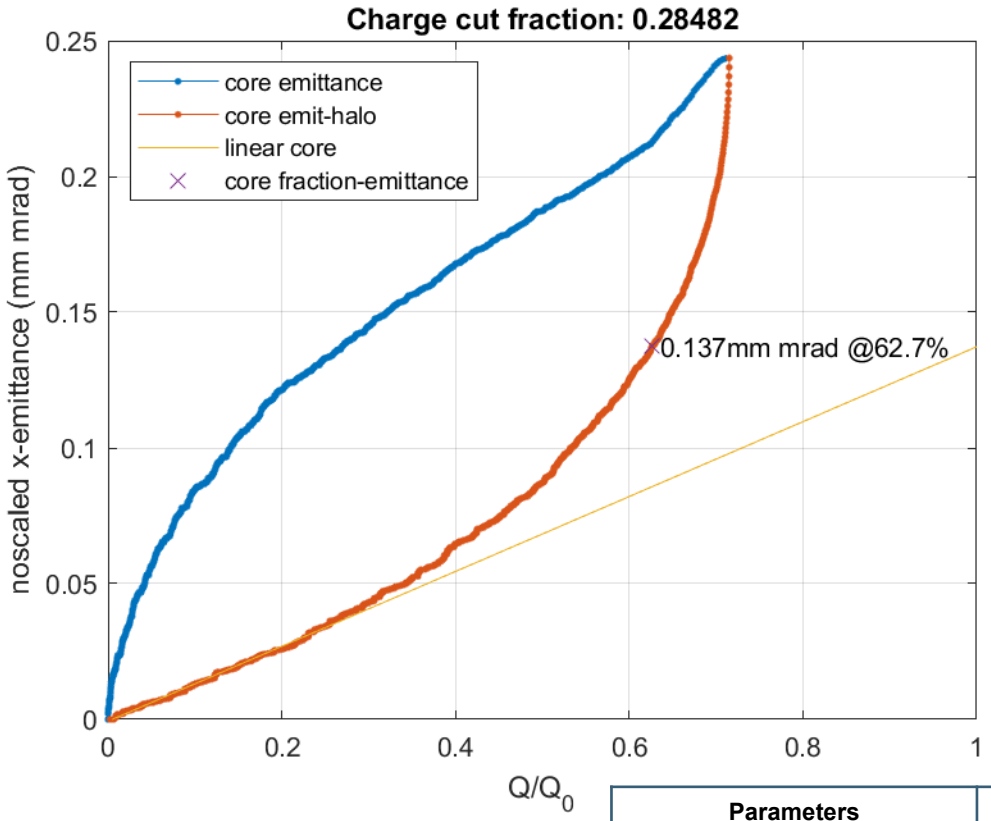


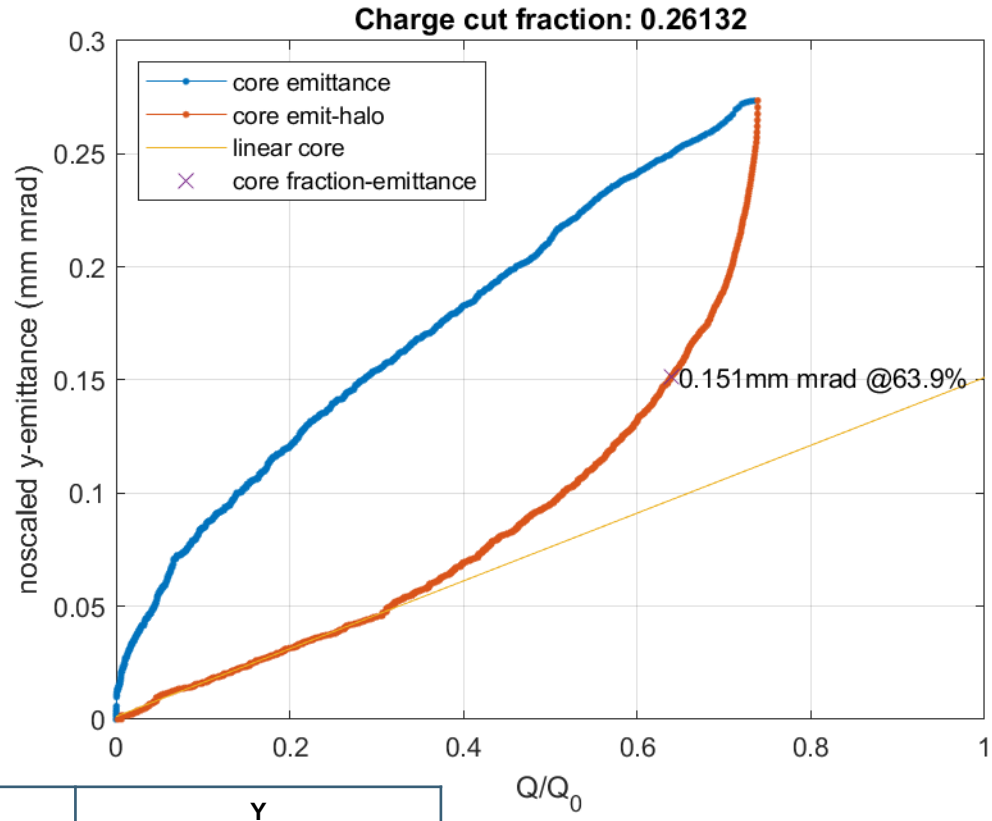
FIG. 8. Radial phase-space distributions (left) and corresponding emittance vs. fraction curves (right). All distributions are scaled to have $\epsilon = 1$. Core fraction and emittance for different distribution types are shown as well.

26

Charge cut and core emittance analysis

Gaussian, 100 pC, BSA=0.7mm; Imain=272A



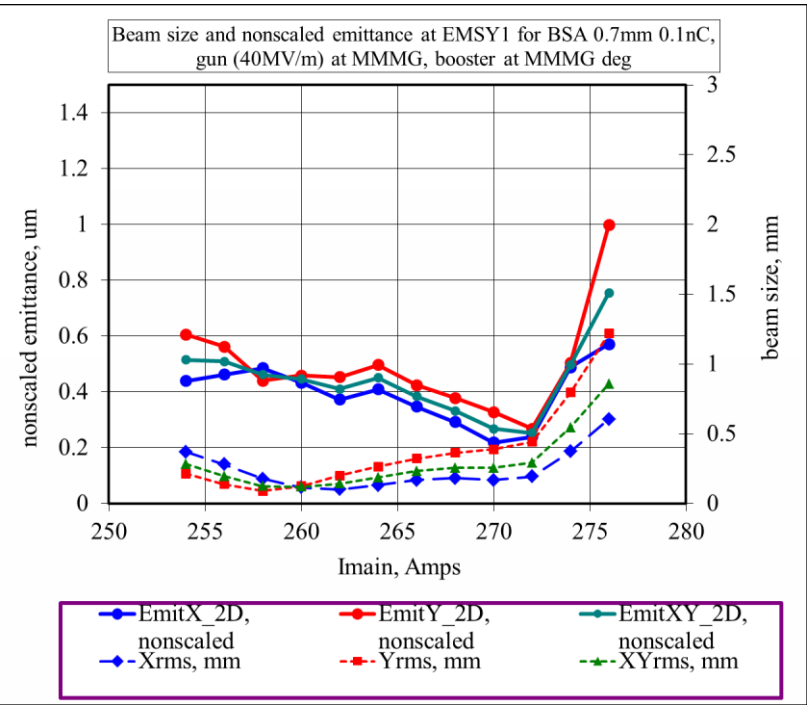


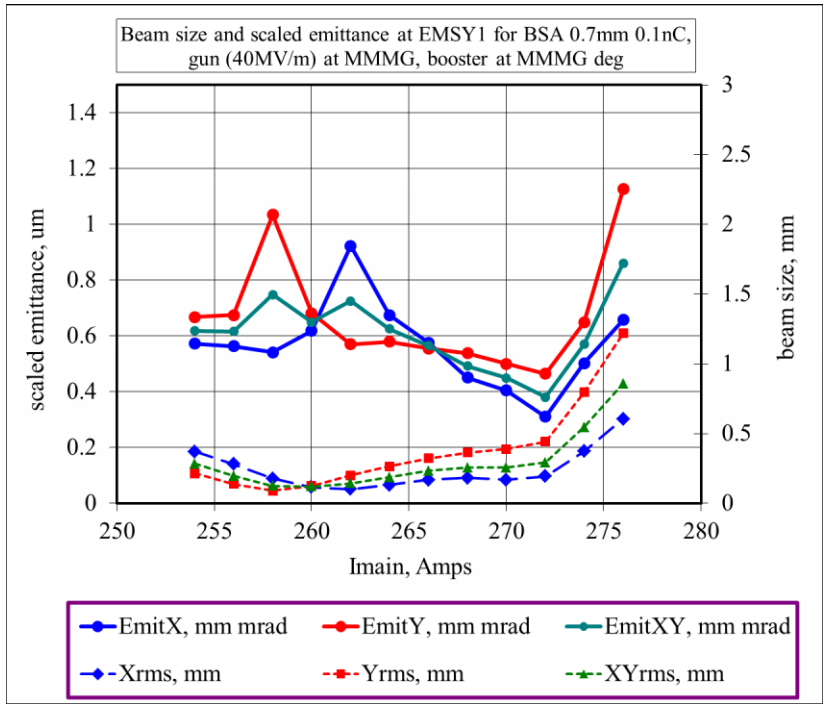
$$\varepsilon_{scaled} = \varepsilon_{non-scaled} \cdot SF$$
$$\varepsilon_{scaled-2} = \varepsilon_{non-scaled} \cdot SF^2$$

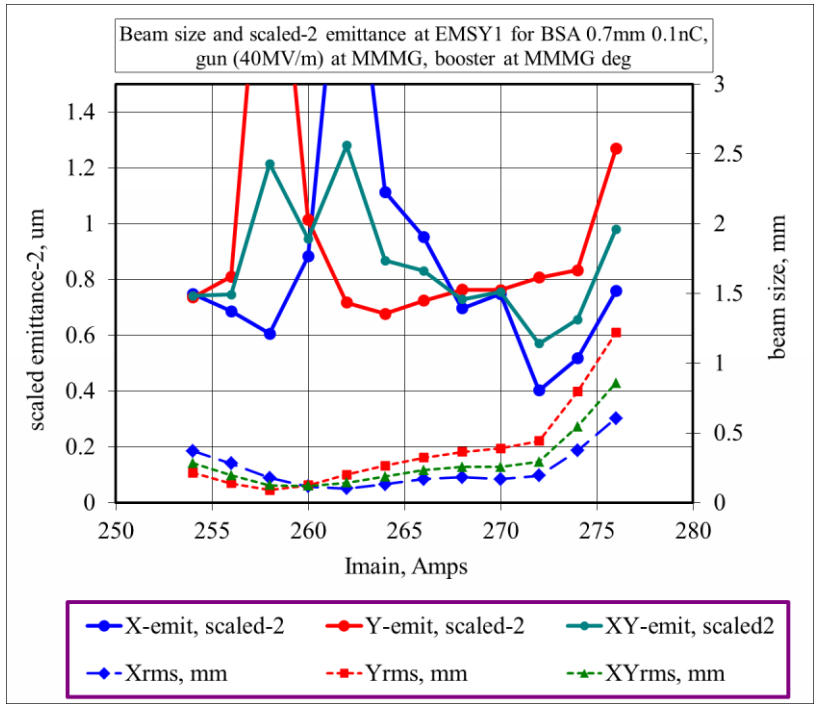
Parameters	X	Y
Non-scaled emittance	0.244 mm mrad	0.274 mm mrad
Charge cut	28%	26%
Scale factor (SF)	1.30	1.74
Scaled emittance	0.316 mm mrad	0.475 mm mrad
Scaled emittance-2	0.410 mm mard	0.825 mm mrad
Core fractional emittance	0.137 mm mrad	0.151 mm mrad
Core fractional charge	63%	64%

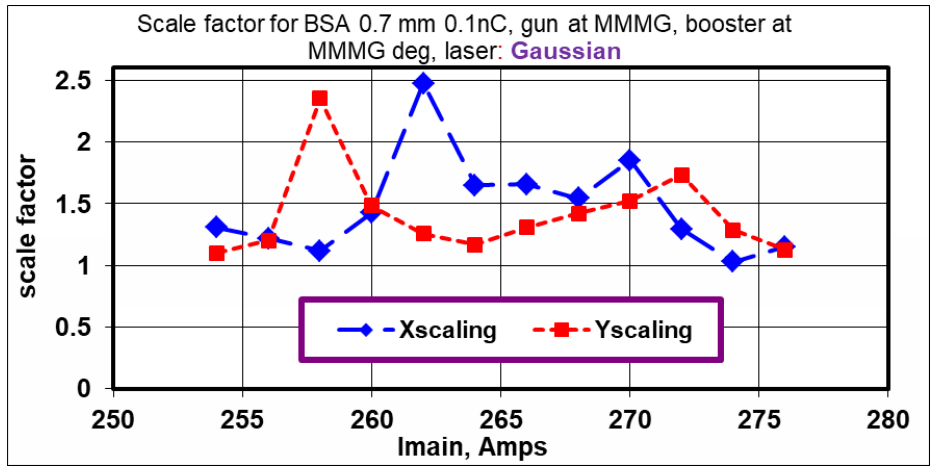
Core emittance analysis (Gaussian-40MV/m): Imain scan

Standard plots + scaled-2 emittance



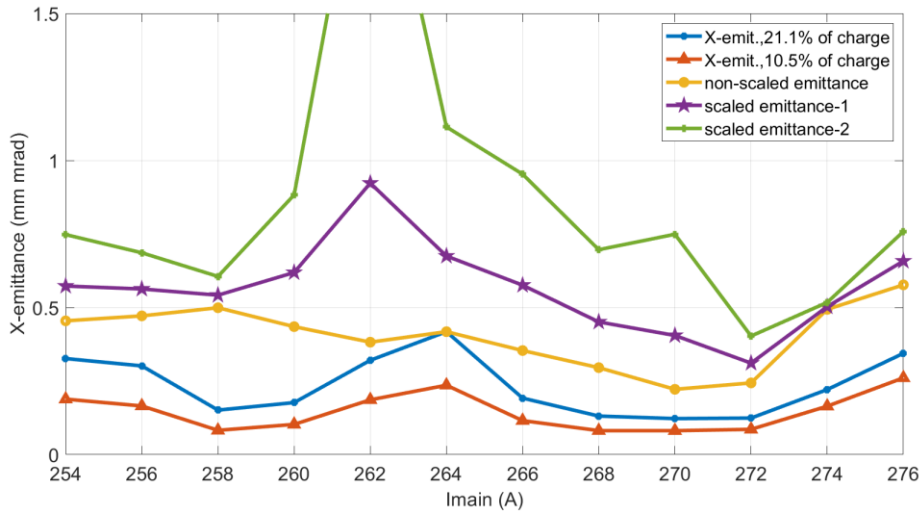


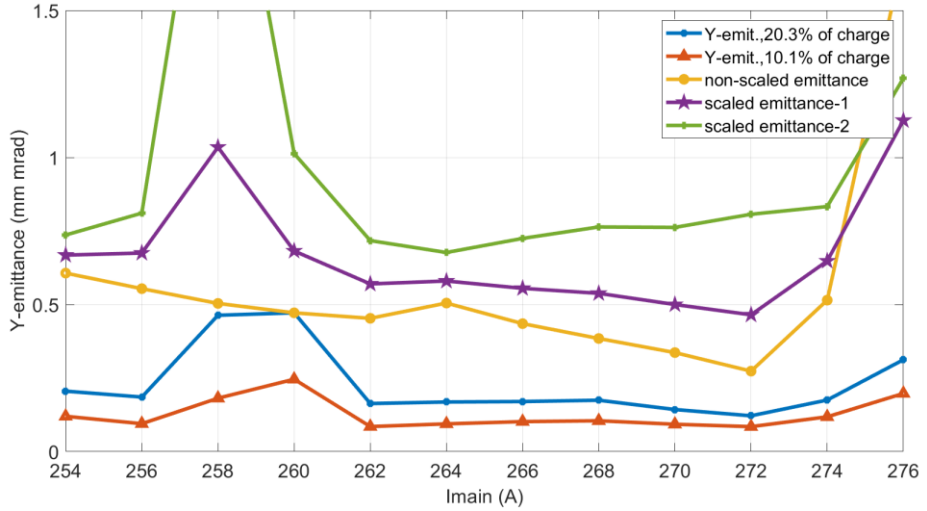


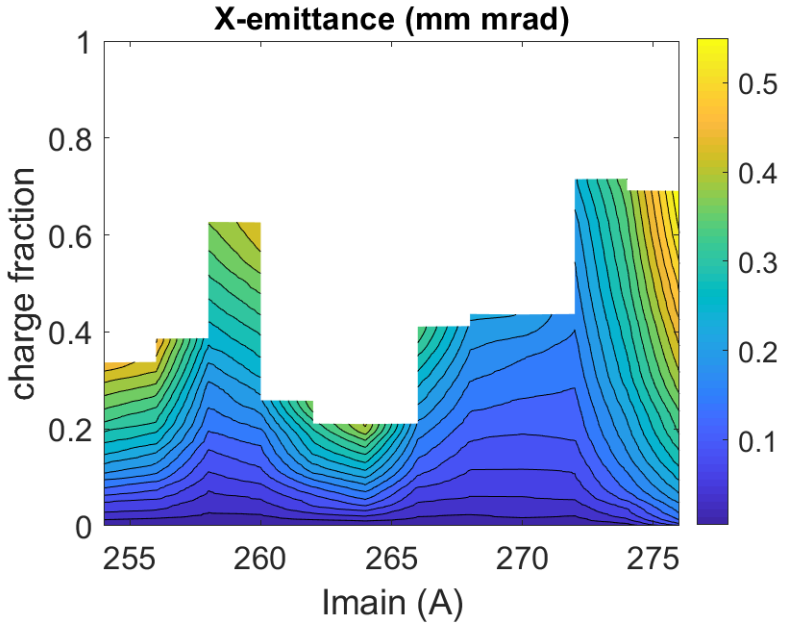


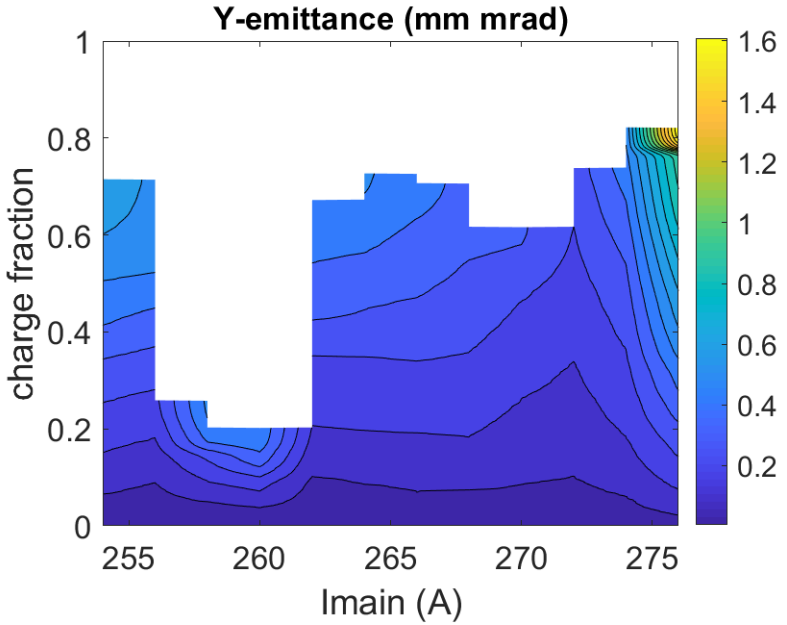
Core emittance analysis (Gaussian-40MV/m): Imain scan

Charge cut using “nobase” method





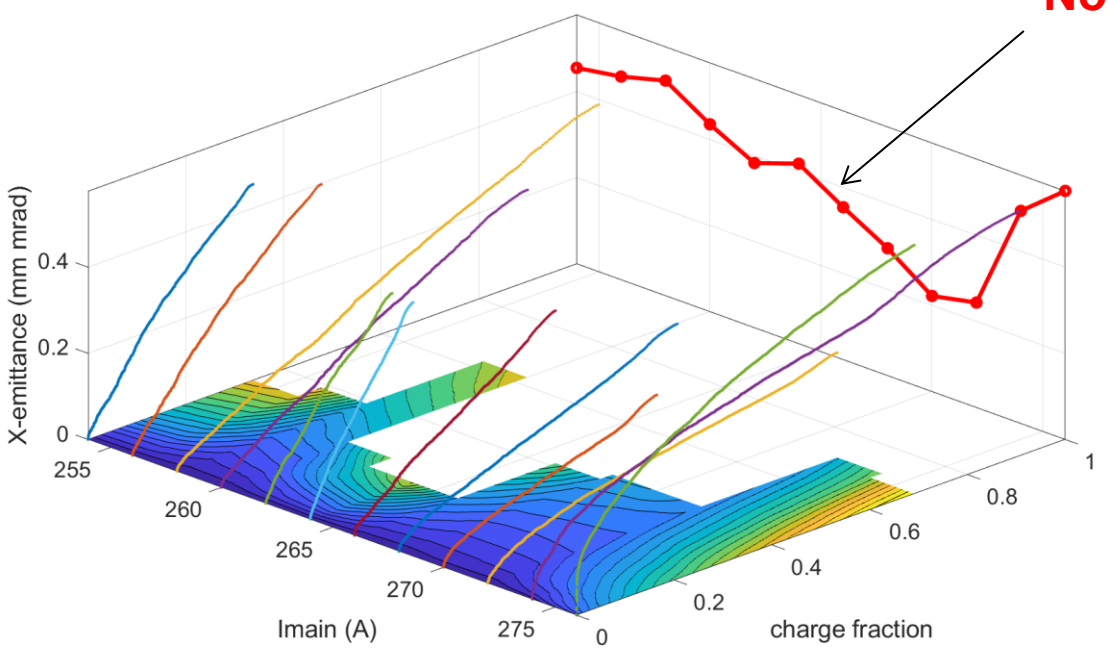


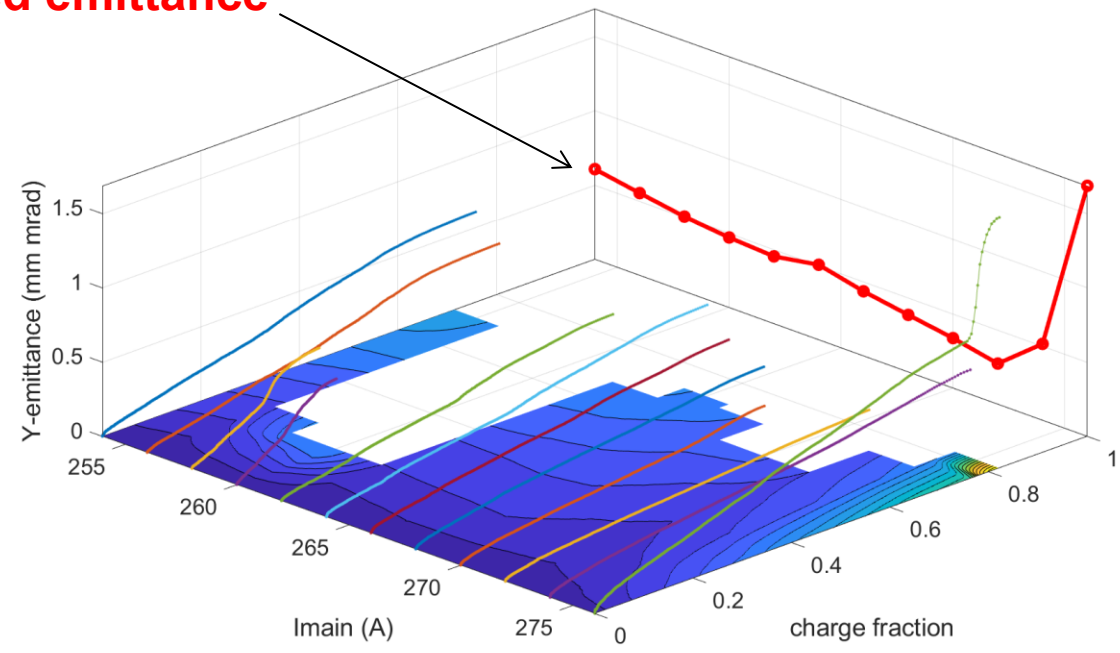


Core emittance analysis (Gaussian-40MV/m): Imain scan

Charge cut using “nobase” method

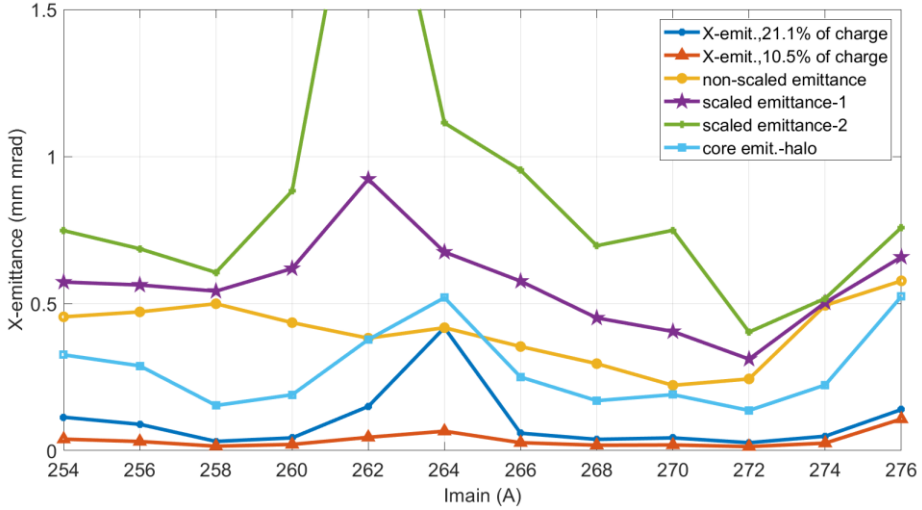
Non-scaled emittance

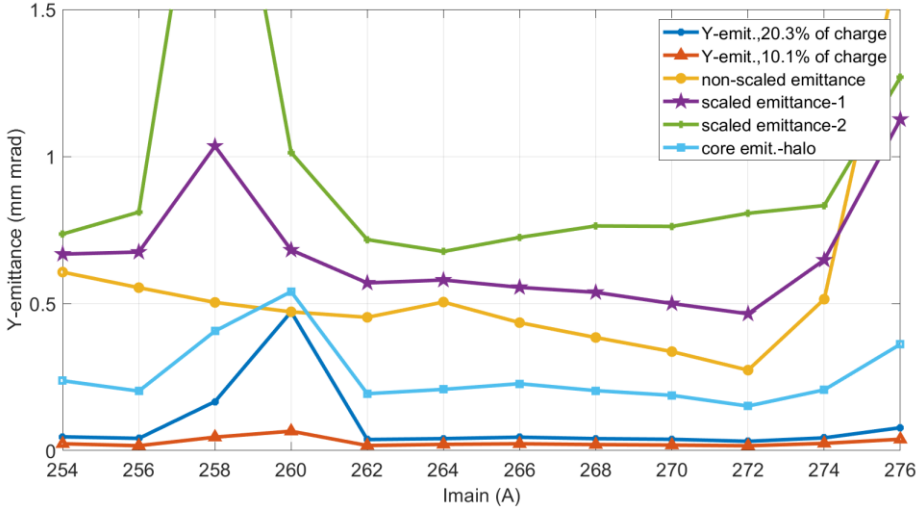


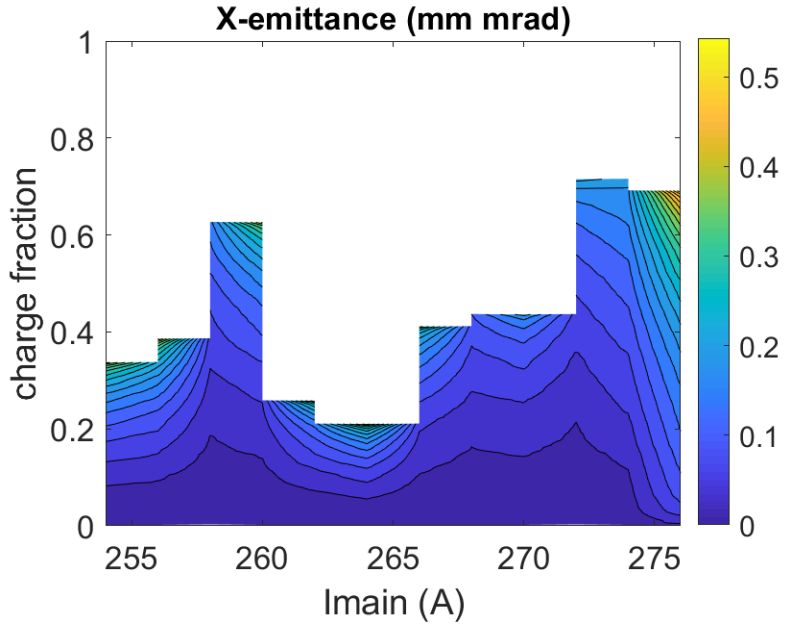


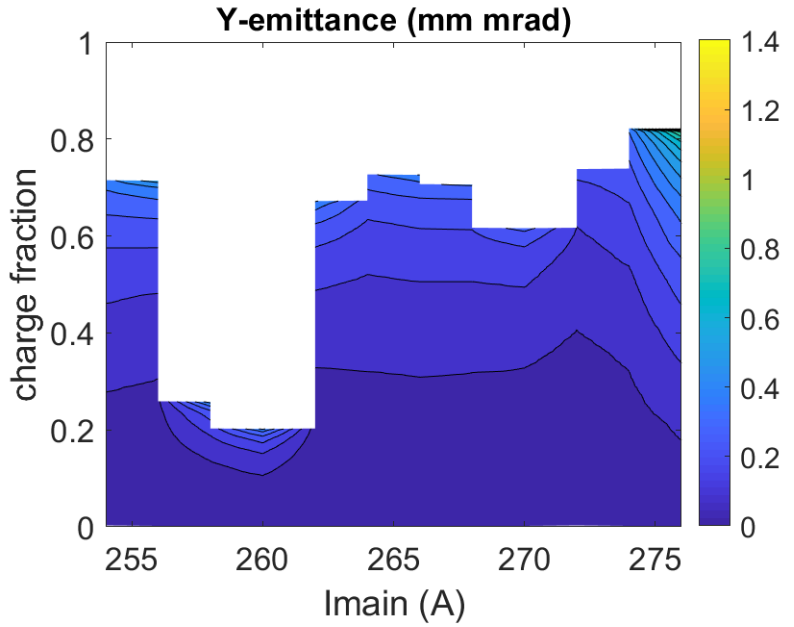
Core emittance analysis (Gaussian-40MV/m): Imain scan

Charge cut using "nohalo" method



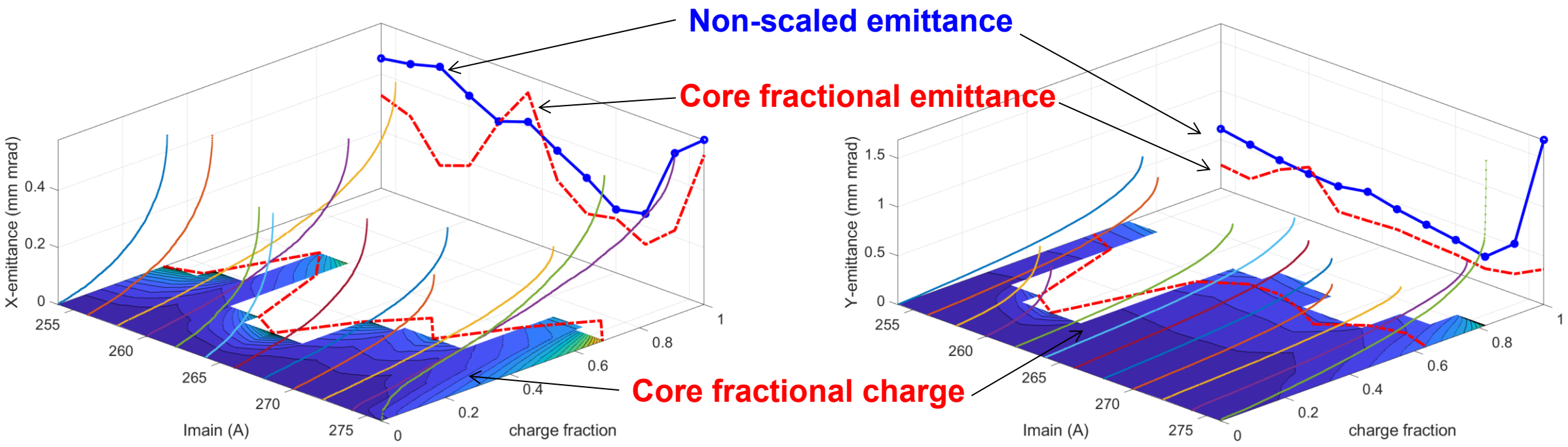






Core emittance analysis (Gaussian-40MV/m): Imain scan

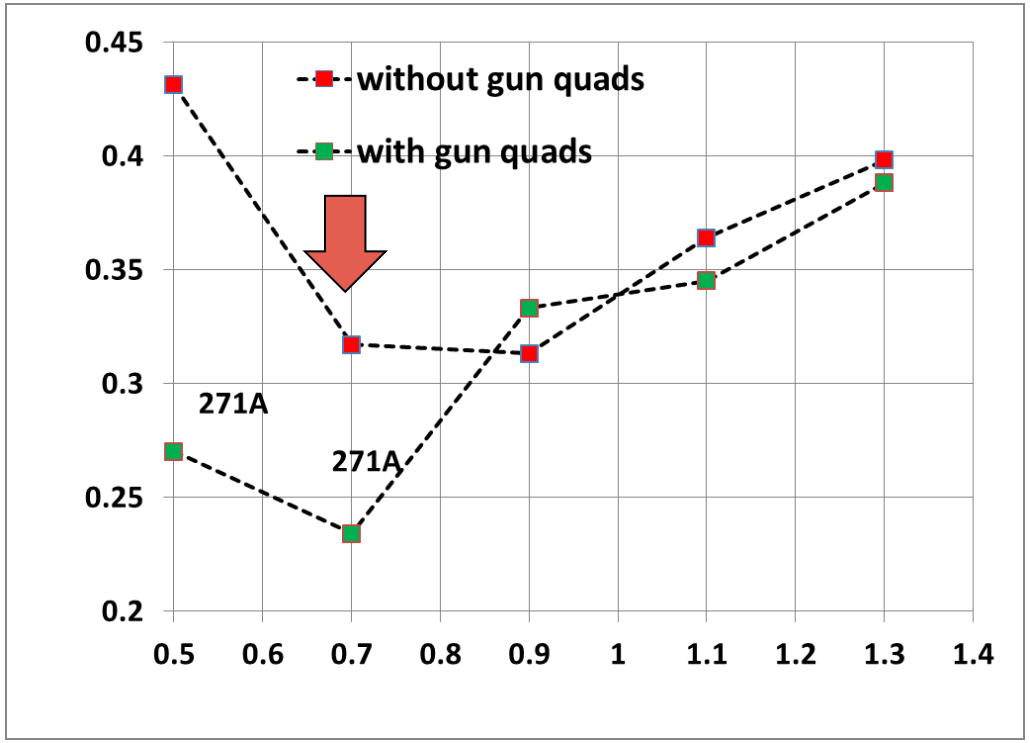
Charge cut using "nohalo" method



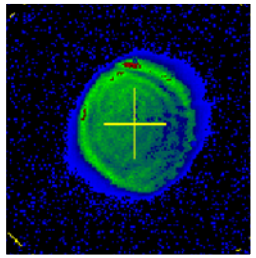
PITZ gun at CW SC gun gradient with Flattop laser pulses

FWHM=18.2 ps
rt=2.7 ps
σ_t=5.5 ps

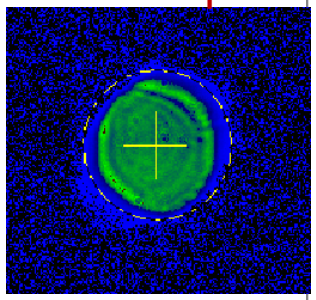
Optimized 100 pC emittance min[ε_{xy}(Imain)](BSA)

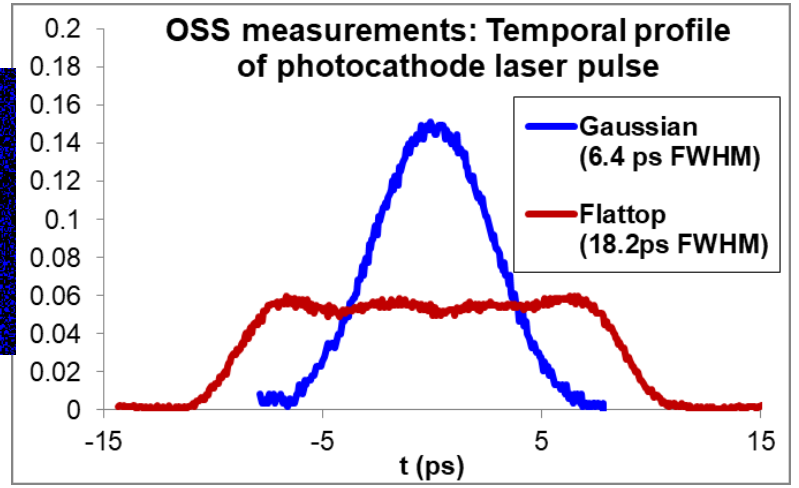


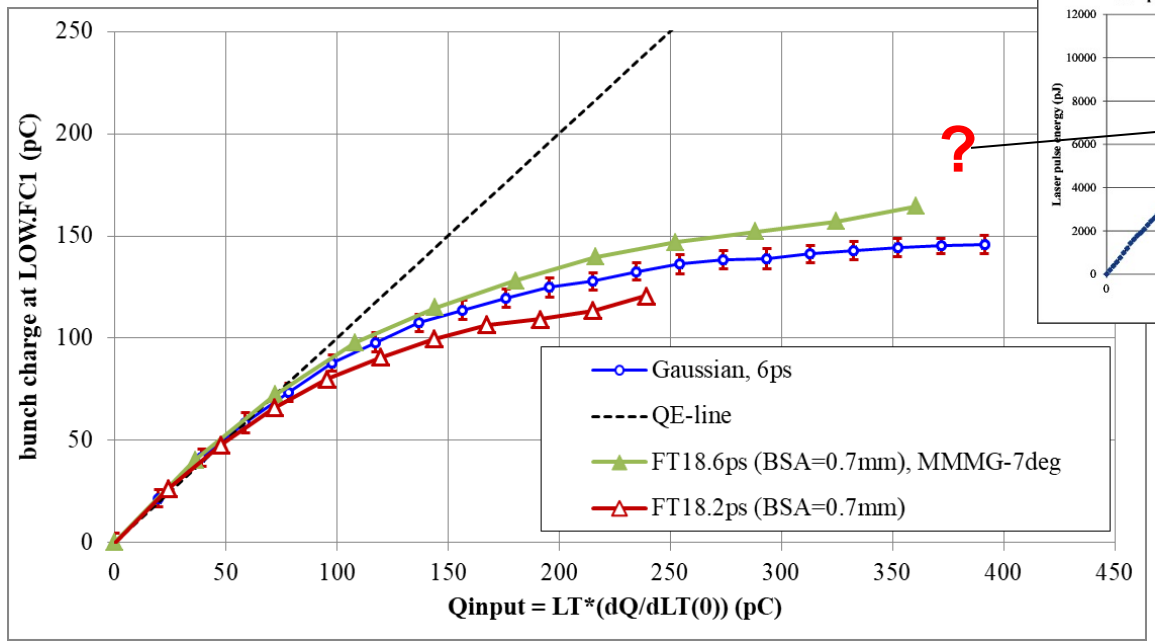
Gaussian

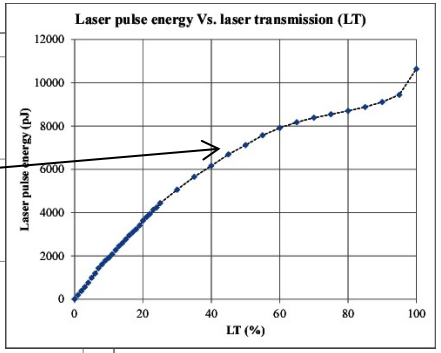


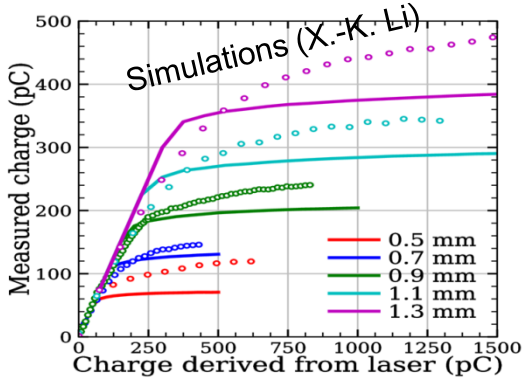
Flattop





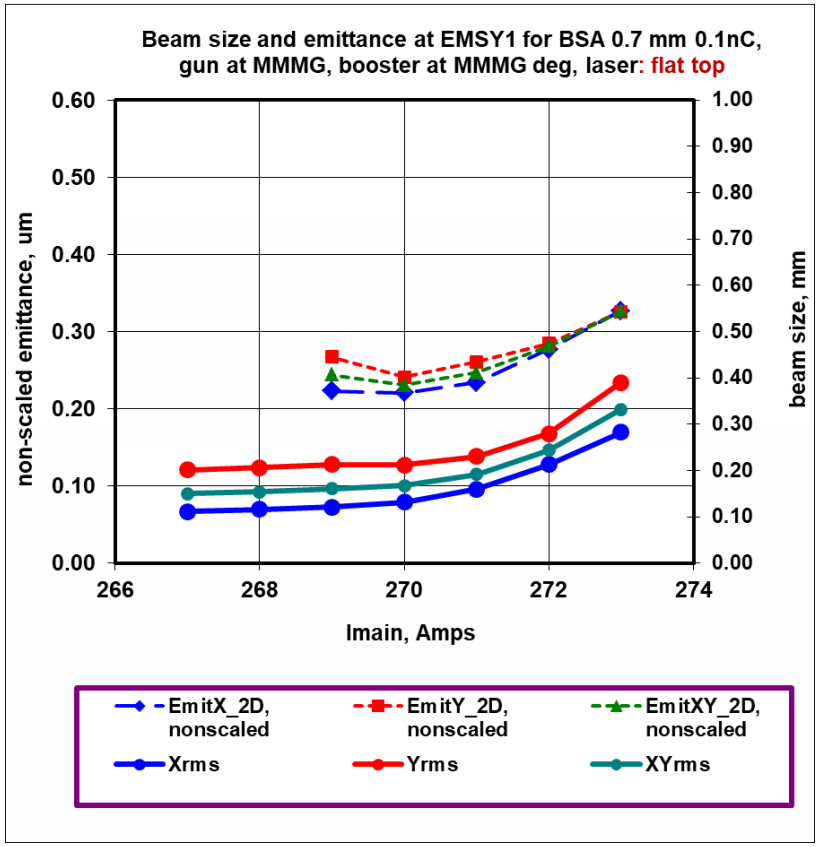


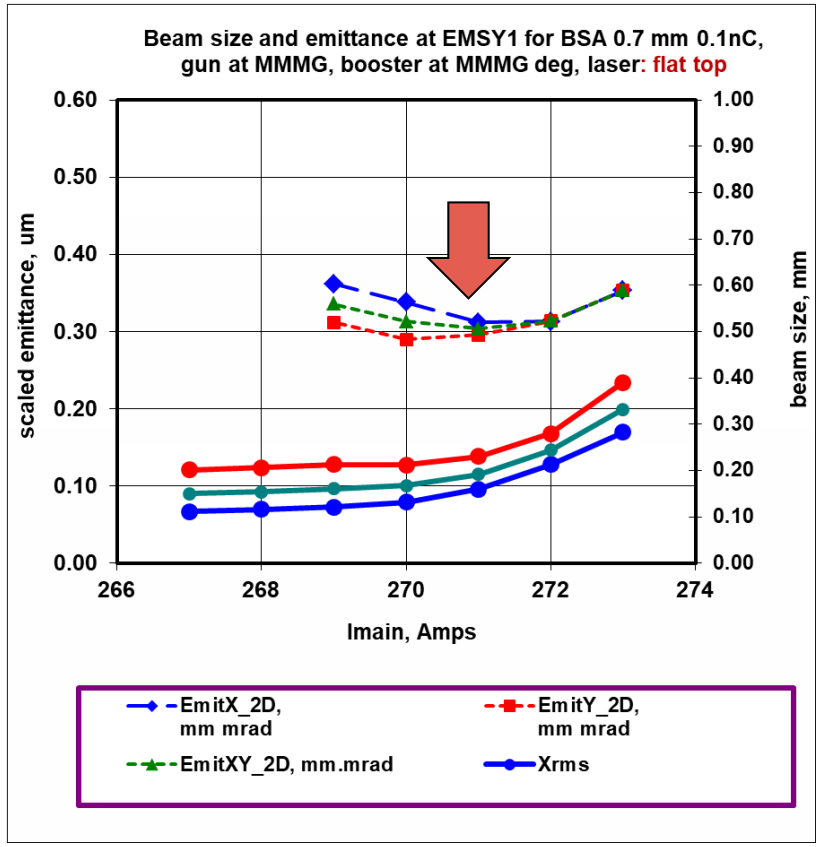


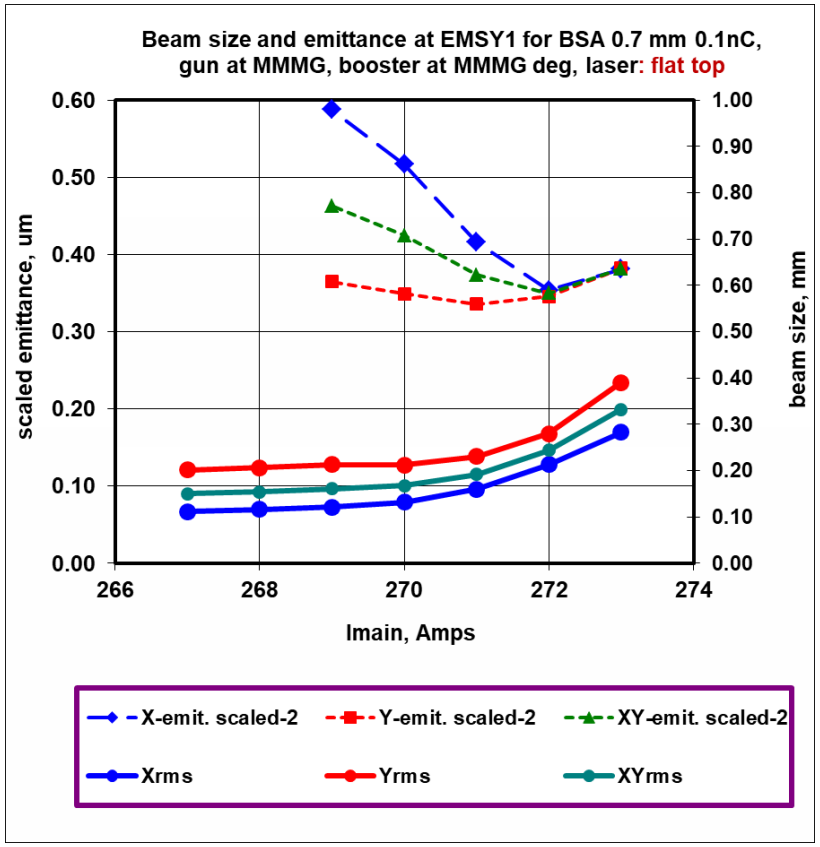


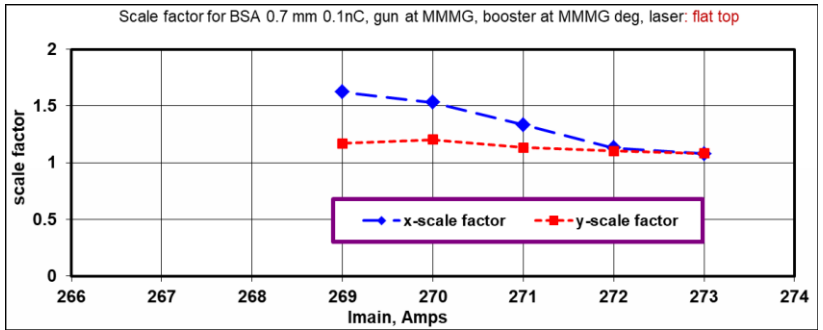
Core emittance analysis (Flattop-40MV/m): Imain scan

Standard plots + scaled-2 emittance



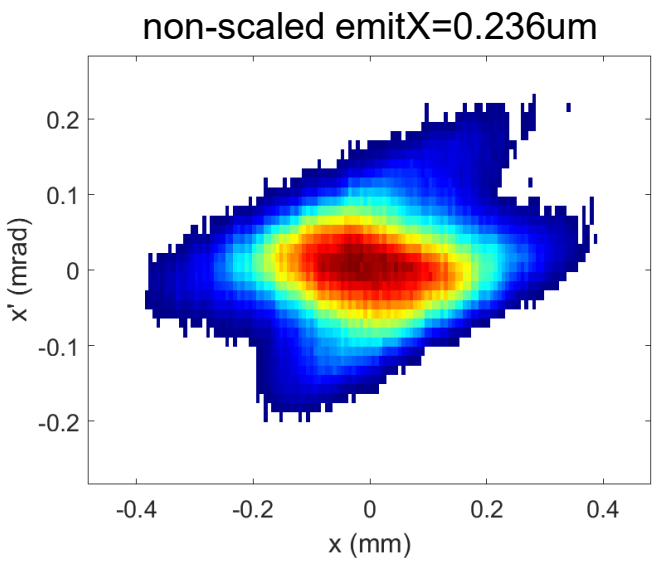


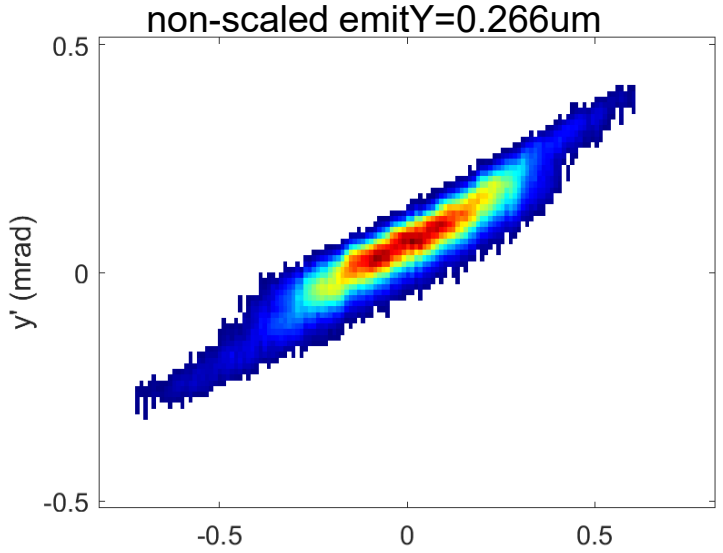


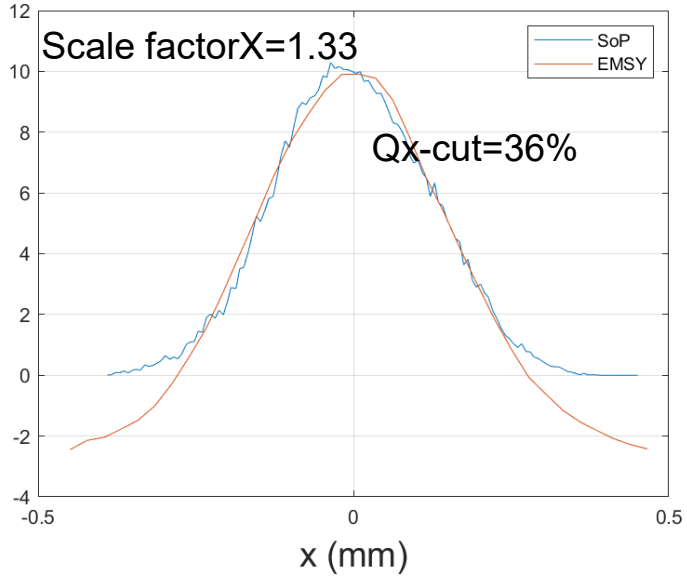


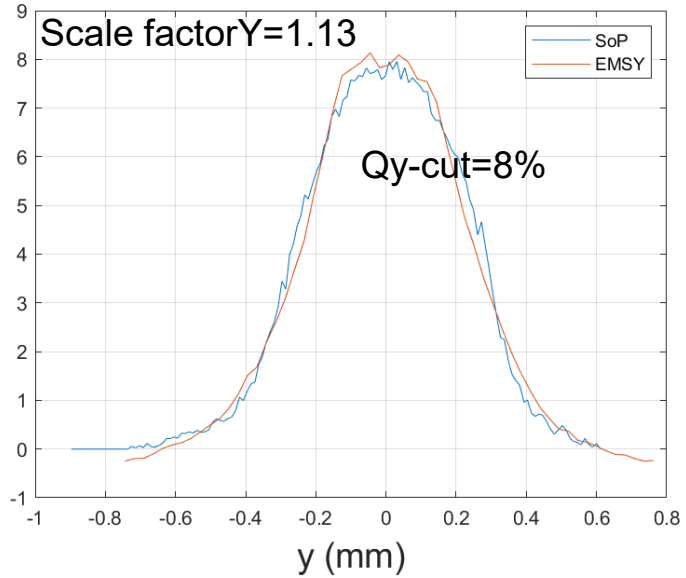
Charge cut analysis

Gaussian, 100 pC, BSA=0.7mm; Imain=271A



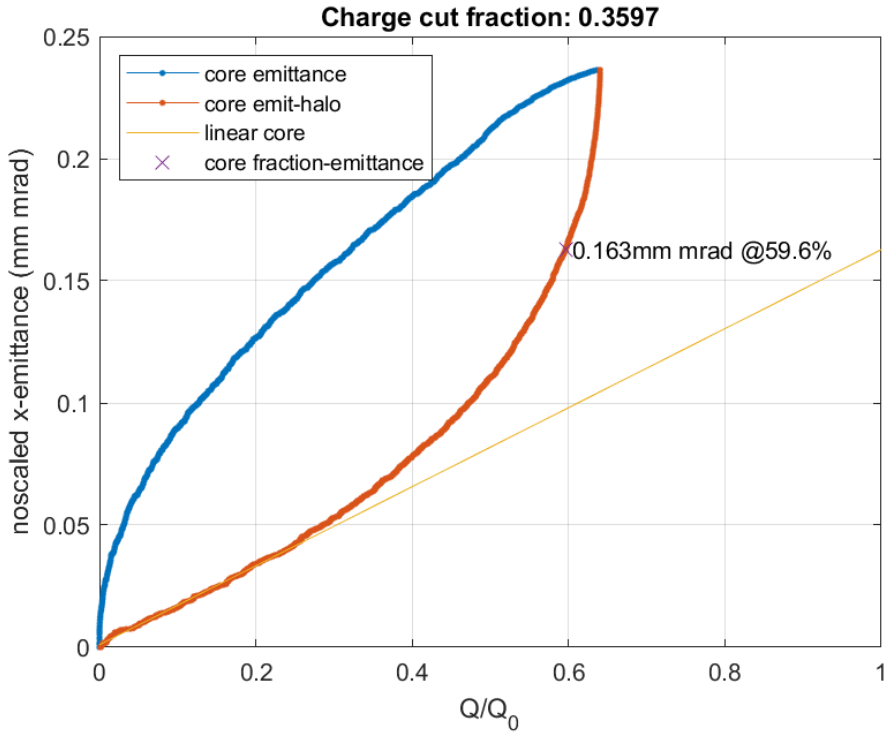


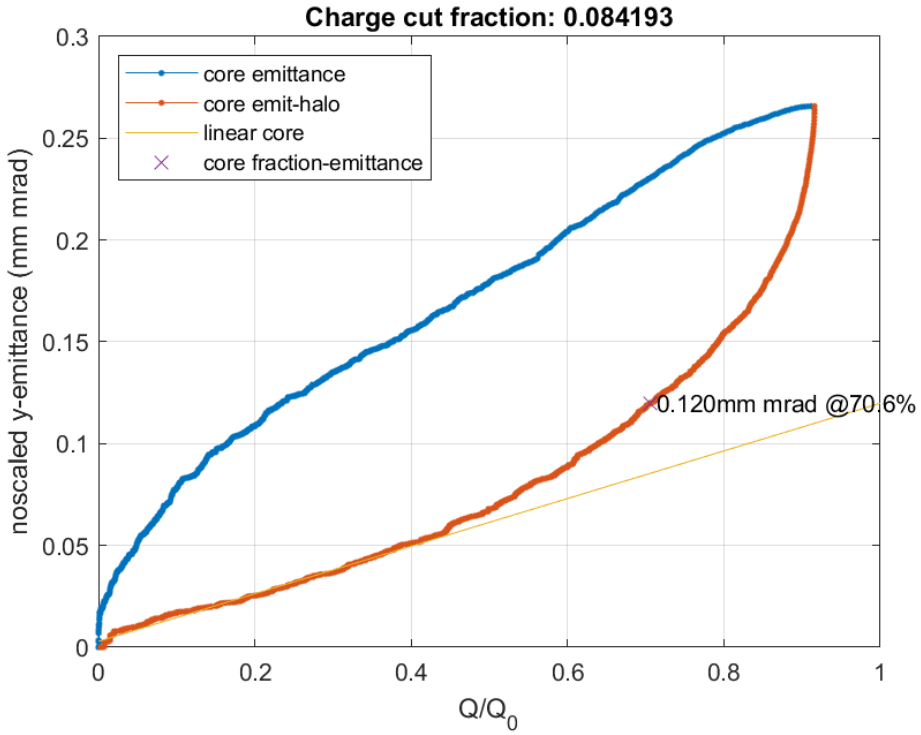




Charge cut and core emittance analysis

Flattop, 100 pC, BSA=0.7mm; Imain=271A



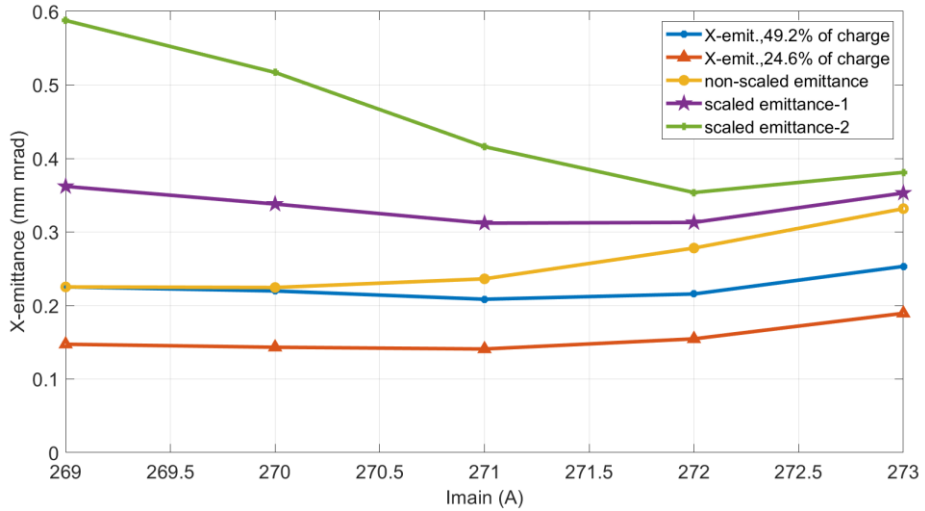


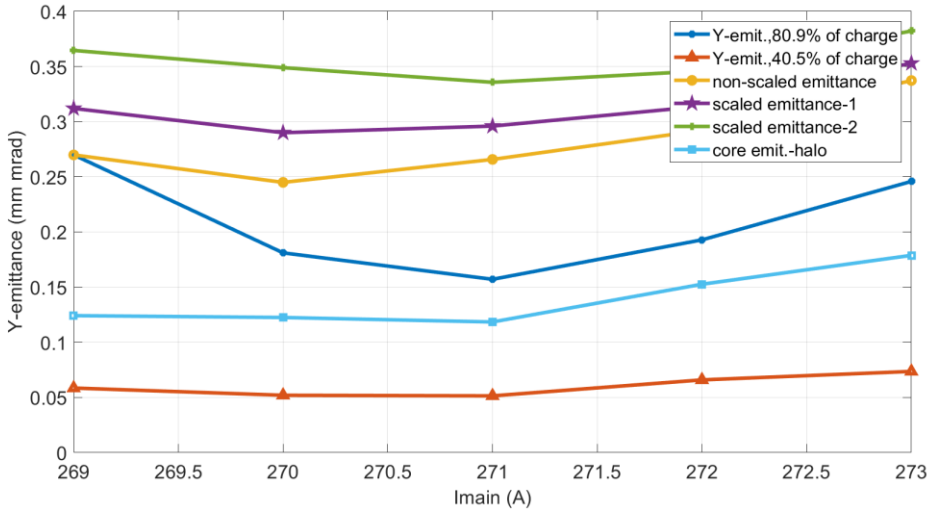
$$\varepsilon_{scaled} = \varepsilon_{non-scaled} \cdot SF$$
$$\varepsilon_{scaled-2} = \varepsilon_{non-scaled} \cdot SF^2$$

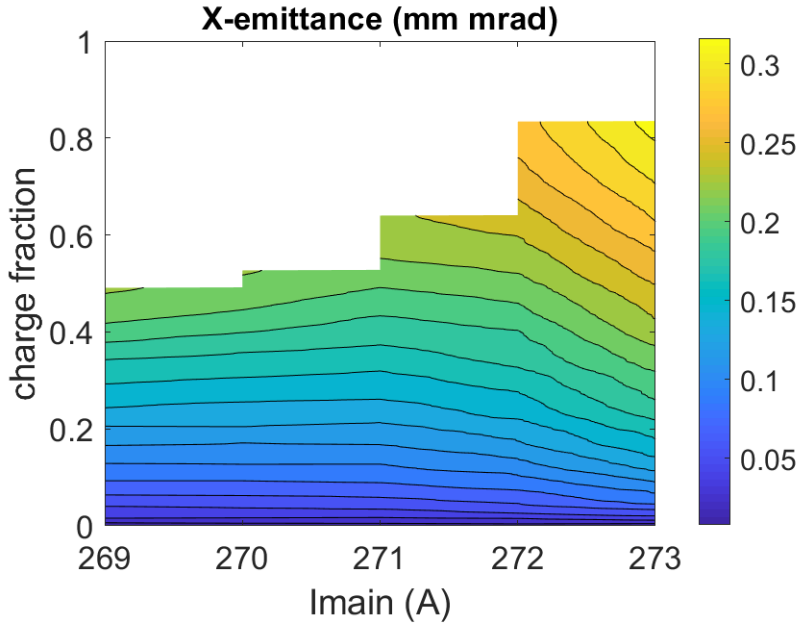
Parameters	X	Y
Non-scaled emittance	0.236 mm mrad	0.266 mm mrad
Charge cut	36%	8%
Scale factor (SF)	1.33	1.13
Scaled emittance	0.315 mm mrad	0.302 mm mrad
Scaled emittance-2	0.420 mm mard	0.342 mm mrad
Core fractional emittance	0.163 mm mrad	0.120 mm mrad
Core fractional charge	60%	71%

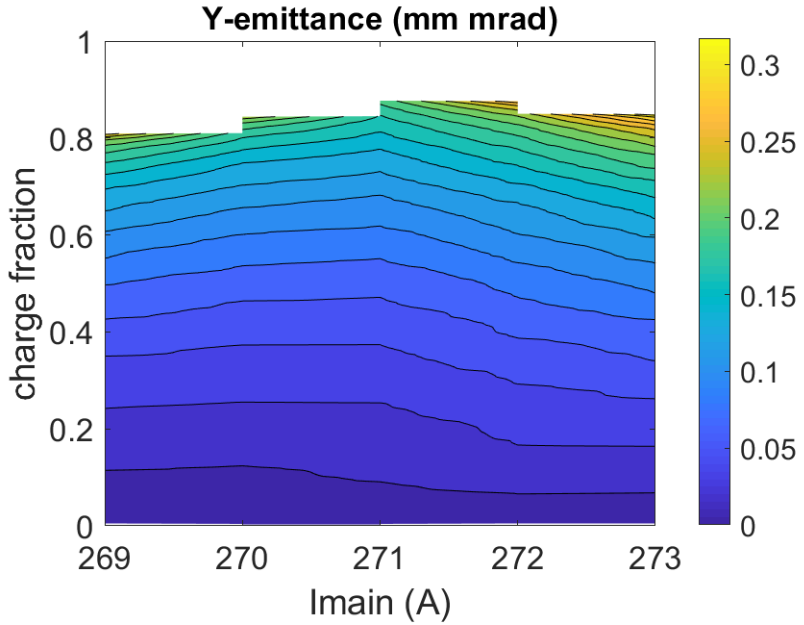
Core emittance analysis (Flattop -40MV/m): Imain scan

Charge cut using “nobase” method



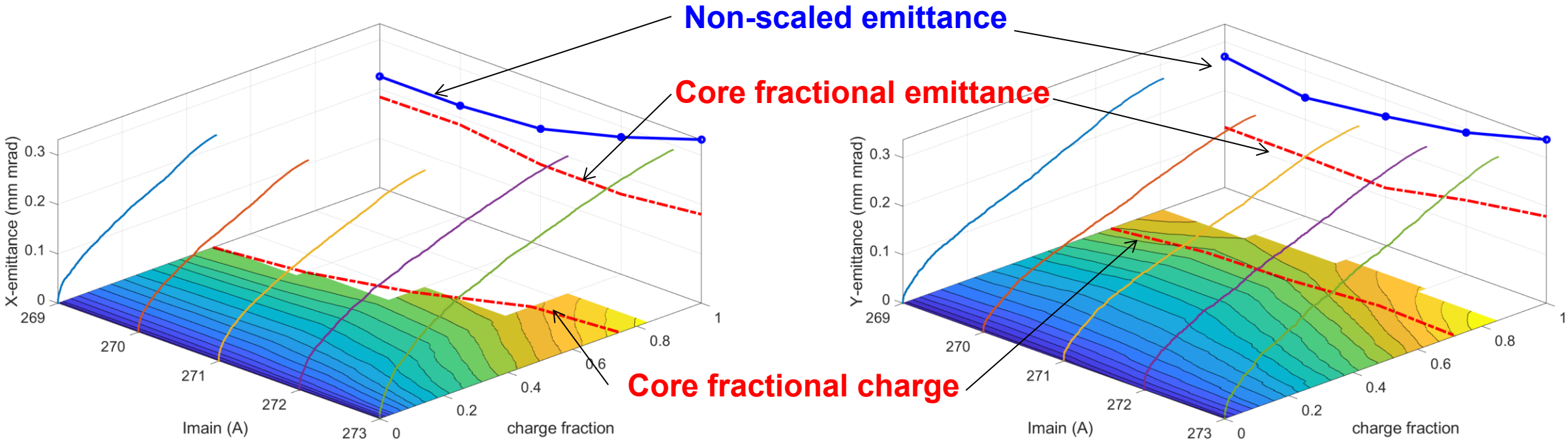






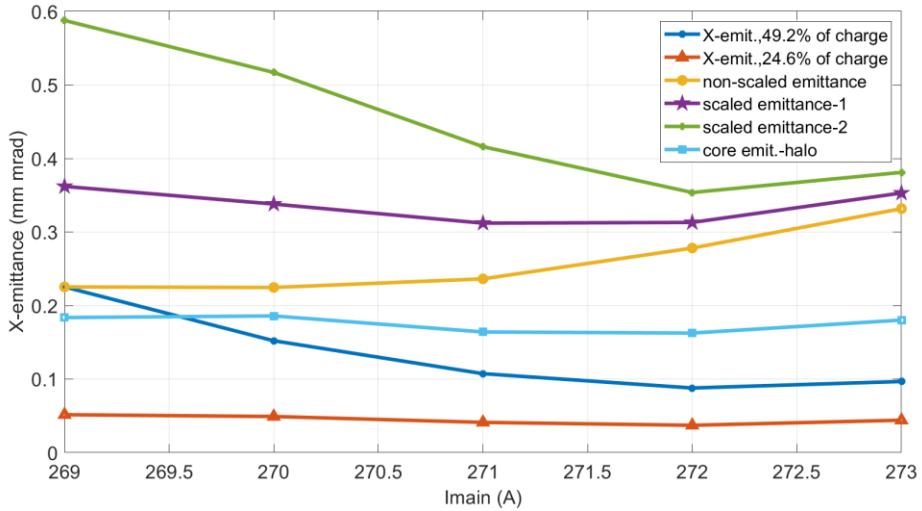
Core emittance analysis (Flattop-40MV/m): Imain scan

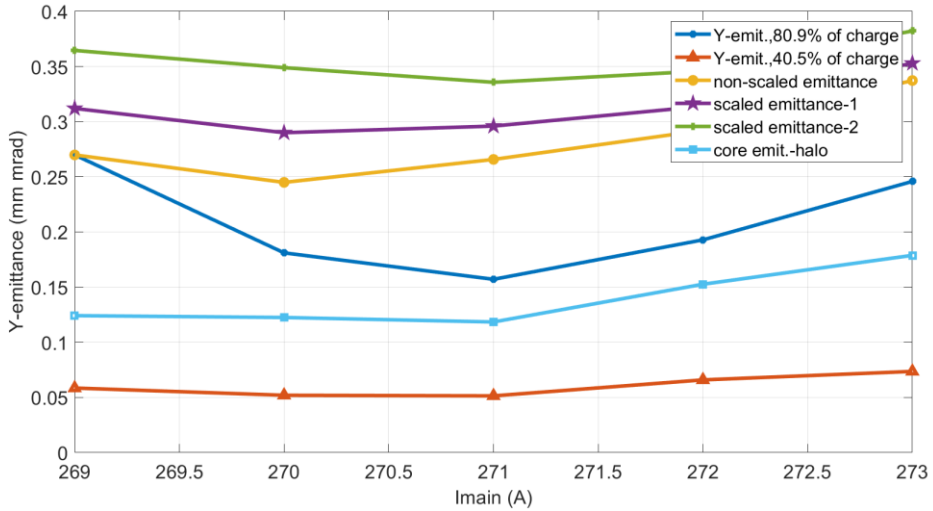
Charge cut using “nobase” method

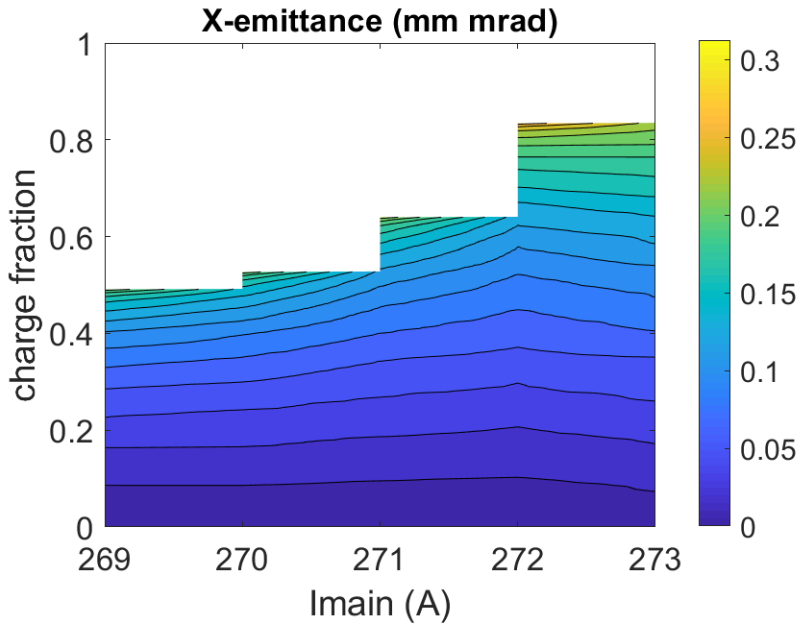


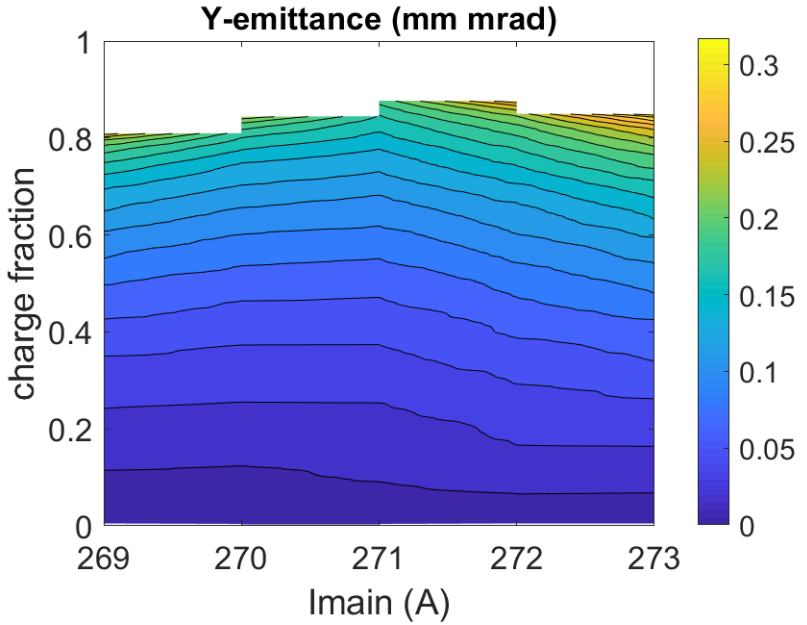
Core emittance analysis (Flattop-40MV/m): Imain scan

Charge cut using "nohalo" method



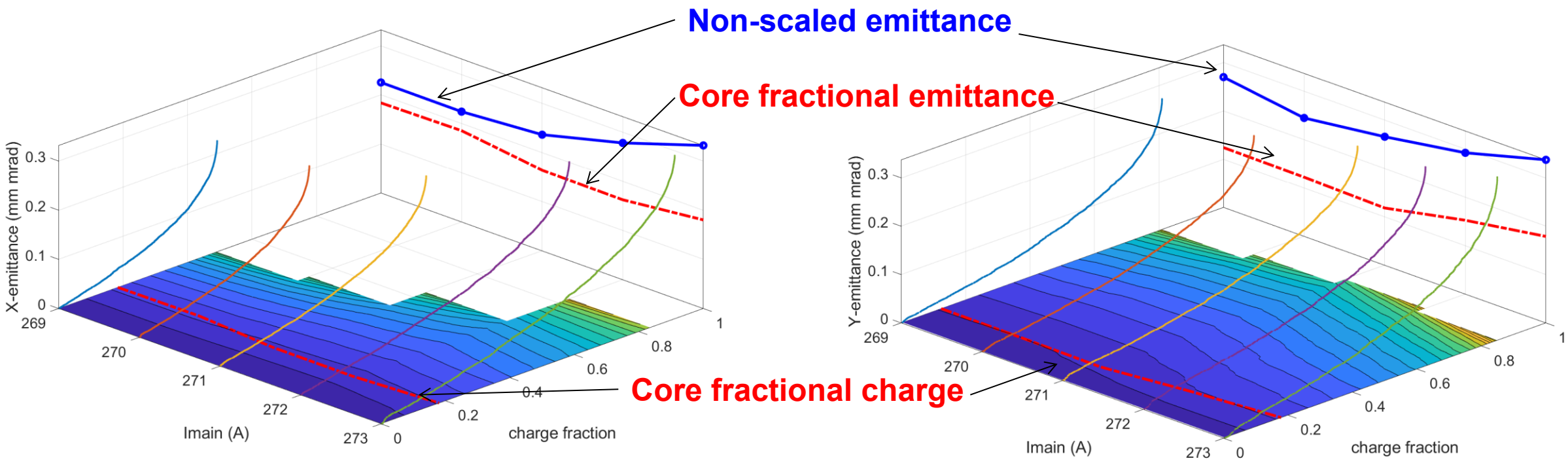






Core emittance analysis (Flattop-40MV/m): Imain scan

Charge cut using "nohalo" method



Conclusions and Outlook

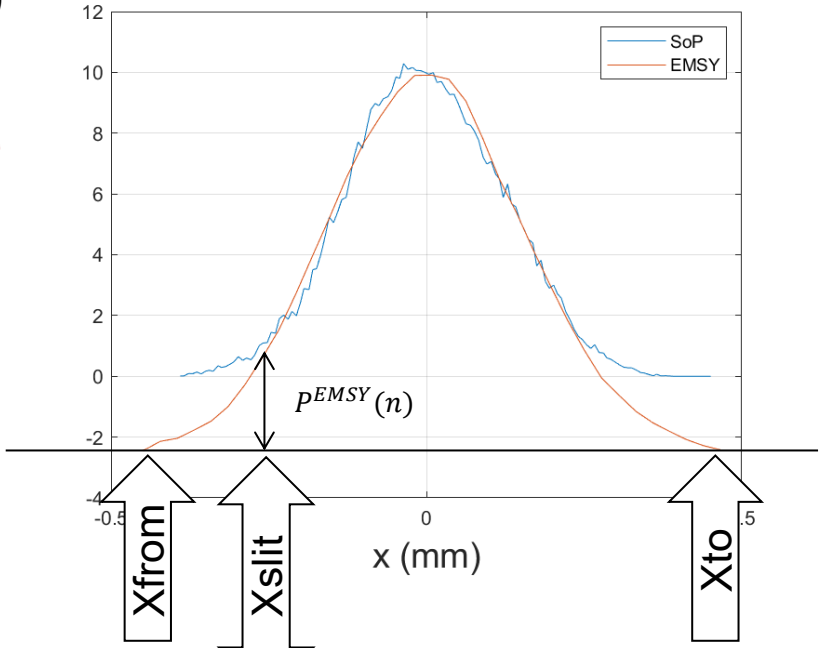
Phase space and emittance from slit scan

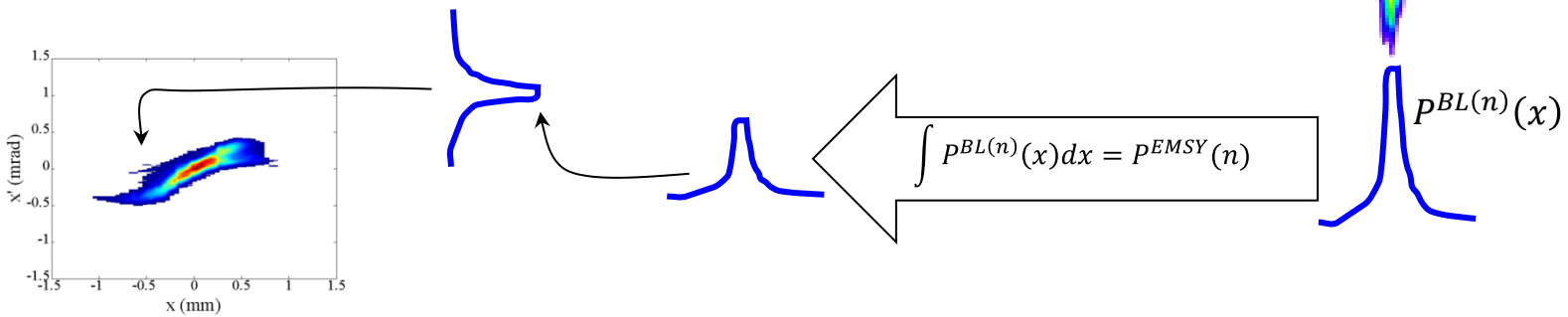
- Single slit scan technique at PITZ yields significant charge cut (w.r.t. EMSY beam image projection)
- Precise determination of the 100% RMS emittance is significantly complicated (non-Gaussian beams, noise, camera sensitivity, etc.)
- Core emittance should be taken into considerations
- Values currently available from slit-scan at PITZ:
  - Beam RMS size at EMSY
  - Non-scaled emittance
- Values and dependencies which could be derived from the slit scan data:
  - Scale factor, scaled emittance and scaled-2 emittance
  - Charge cut SoP←>EMSY-projection →Qcut
  - Core non-scaled emittance (Q=0..Qcut): two methods (“nobase” and “nohalo”)
  - Fraction emittance (linear trend at Q~0 from “nohalo” core emittance) and fraction charge → need more interpretation?
- Final decision to be taken after better agreement with simulations will be achieved…
- Outlook:
  - Repeat scans with increased NoP → then superpose phase spaces eliminating saturated cores?
  - Proposals for a modified slit-scan procedure → next slide

Outlook: Proposals for a modified slit-scan procedure

Detailed “stop-and-go” procedure?

1. Take EMSY and MOI beam images, treat EMSY image (filtering, BKG--)
2. Make “standard” scan: fixed (CamGain, NoP)
3. EMSY->SoP fit → find scan range (Xfrom:Xto) **based on EMSY profile**
4. Scan procedure (slit pos=Xfrom:Step~10-100um:Xto), for each position:
   a) Tune (CamGain, NoP) for the 3000 criterion for the raw beamlet image (autogain function!)
   b) Record beamlen image with statistics (10+10frames?)
5. Phase space reconstruction:
   a) For each beamlet treated image (filtering, BKG--) obtain its projection
   b) Normalize beamlet projection profile to corresponding value in the **EMSY profile**
   c) Put all normalized profiles into the phase space → calculate 100%(?) rms emittance





Back up

Emission curves for various laser spot diameters (BSAs)

100 pC emittance, gun 4.6 MeV/c; final 17.8MeV/c

Photocathode laser: temporal Gaussian ~6.2ps FWHM and Flattop 18-19ps FWHM