Slice emittance

Comparison of slice and projected emittance of a temporal flattop profile beam

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Zeuthen, 01.10.2020

Beam operation in week 27/28

Run & shift summary

- Slightly misaligned High1.Scr4 & Scr5
- Current fluctuations from main solenoid power supply
- Laser instabilities, e.g. charge drifts:

* Charge drift from 240 pC to 311 pC from beginning to after emittance statistics, BSA1mm, almost 30% up

09.07.2020 02:50 pitzop	**charge drift from 240 pC to 311 pC**
see entry 00:11	

PHAROS

Tue Jun-30	Wed Jul-01	Thu Jul-02	Fri Jul-03	Sat Jul-04	Sun Jul-05	Mon Jul-06	Tue Jul-07	Wed Jul-08	Thu Jul-09
Emittance with flattop laser (6-9 ps) 0.25nC (BSA1mm) ~~0.5 nC (BSA1.3mm)~~ Proj emittance Setup 1D flattop shaping with overfilled BSA					THz nC beam studies ~~Parabolic shaping~~ Flattop laser emit @0.25 nC Slice emit				Slice emit Slice energy spread Energy
Koschitzki	Koschitzki	Koschitzki	Koschitzki	Gross	Gross	Gross	Gross	Gross	Koschitzki

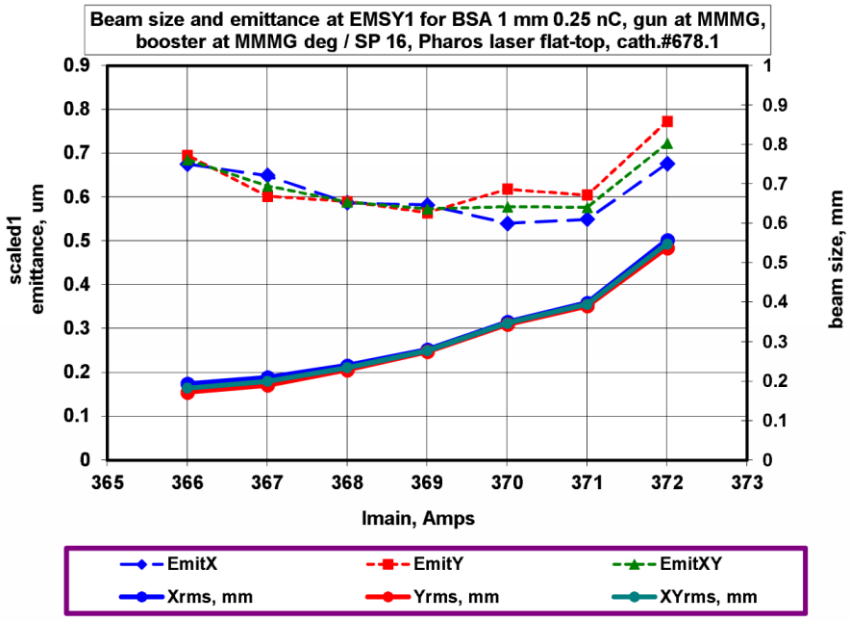
Time	Action/Status
00:27	Solenoid scan starts, H1.S5 YAG
01:14	Solenoid scan ends, 1x3 stat @369A
01:31	1x3 stat on YAG ends: ε = (0.56 ± 0.01 µm)
01:32	Start 1x3 statistics on H1.S5 LYSO
02:45	1x3 stat on LYSO ends: ε = (0.73 ± 0.01 µm)
02:50	Charge drift noticed, readjusting bunch charge
03:30	Start redoing solenoid scan on LYSO
04:22	Start preparing slice emittance measurements

Beam operation in week 27/28

Machine set up & projected emittance measurements

- Pharos laser, 9ps FWHM flattop profile
- BSA = 1mm, 250 pC
- p_{Gun} = 6.3 MeV/*c*, p_{Boo} = 19.44 MeV/*c*
- Solenoid scan, observed on High1.Scr5
  - **Emittance minimum** @ Imain = 369 Amps

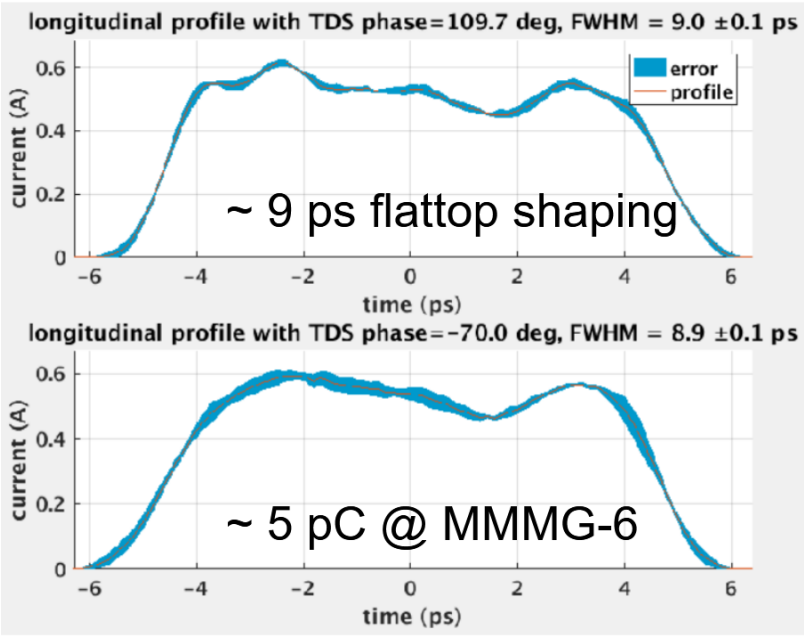
2020-07-09T0114



2020-07-09T0405 2020-07-09T0436

Twiss	FastScan	SlitScanner
Alpha	-1.13	-1.04 ± 0.01
Beta	4.34 m	(5.34 ± 0.05) m

2020-07-08T0403



Laser profile, measured with TDS, shown in RC

Projected emittance

(µm)	Xemit	Yemit	XYemit	SlitScanner
unscaled	0.56 ± 0.01	0.50 ± 0.02	0.53 ± 0.01	0.60 ± 0.01
Scaled1	0.59 ± 0.01	0.60 ± 0.03	0.60 ± 0.02	0.71 ± 0.01
Scaled2	0.63 ± 0.03	0.71 ± 0.05	0.70 ± 0.04	0.83 ± 0.03

Beam operation in week 27/28

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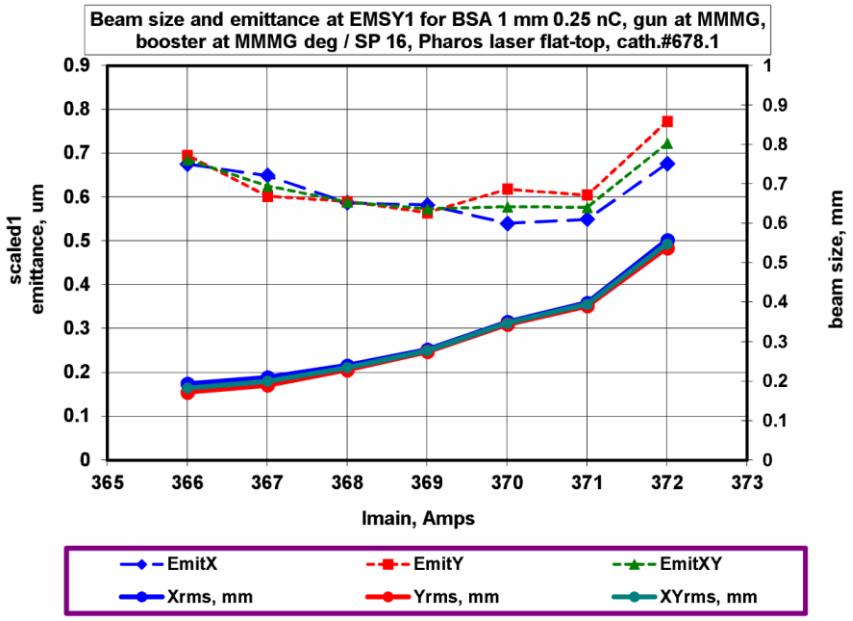

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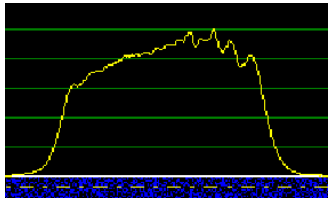

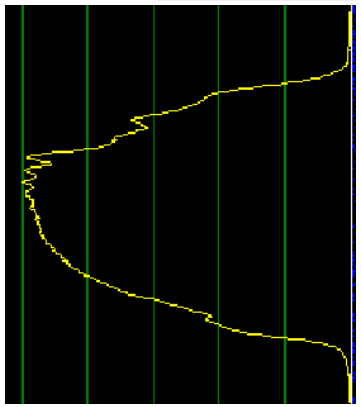

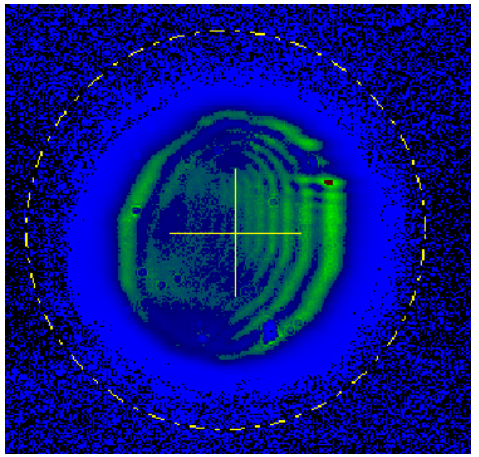

2020-07-09T0405 2020-07-09T0436

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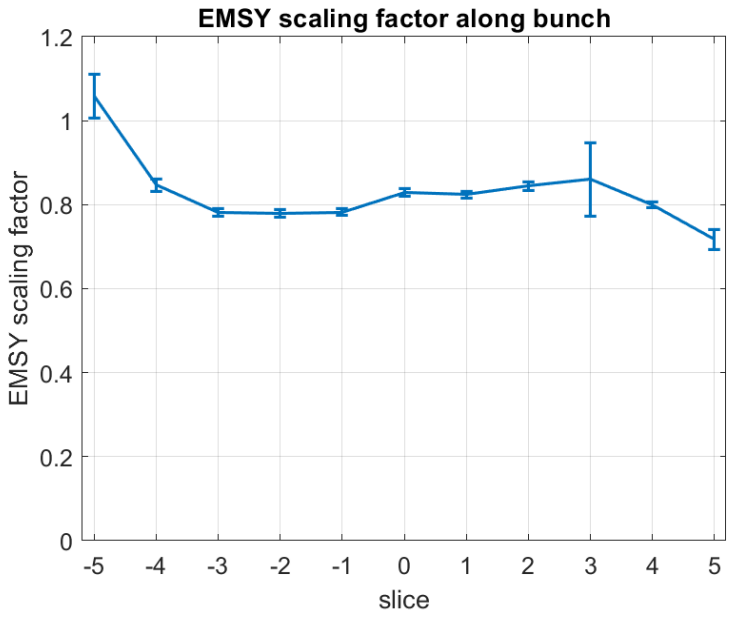
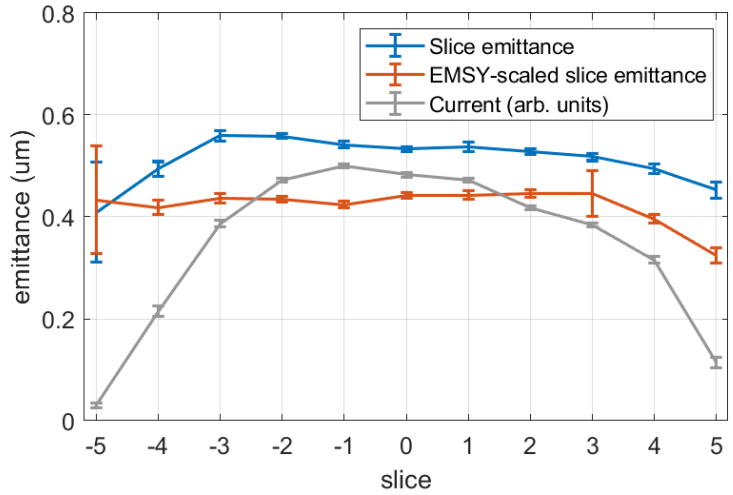
Slice emittance

Comparison with measured projected emittance

- Slice emittances slightly below projected emittance
- Proj. emittance via SlitScanner.m = (0.60 ± 0.01) µm

- Time-resolved scaling factor: < 1
  - Due to charge fluctuations/power supply current fluctuations?





Projected emittance

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Slice emittance

Comparison with slice emittance of truncated Gaussian beam

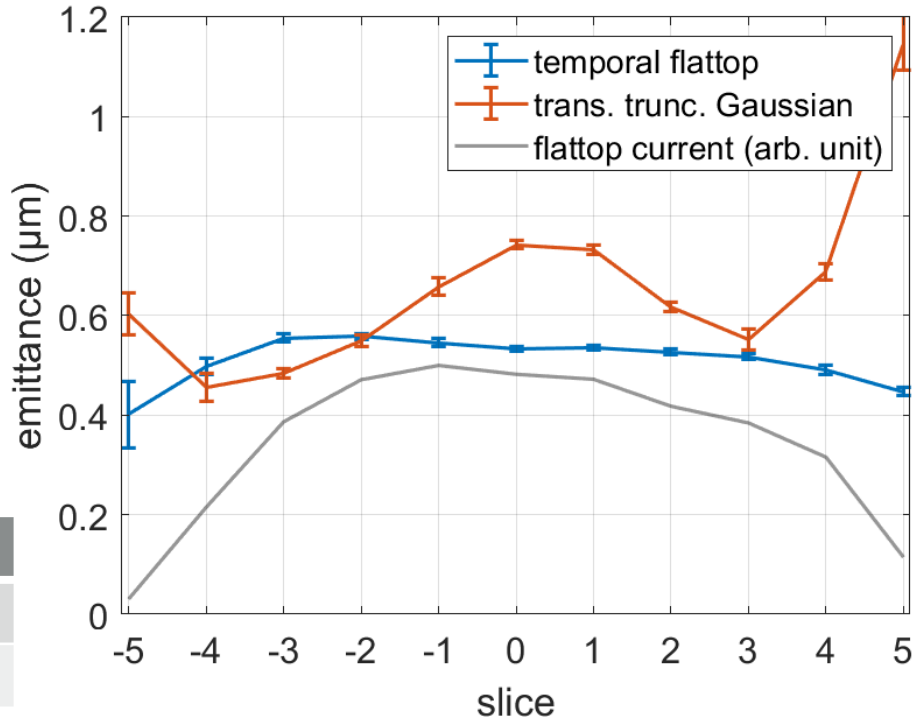
- Emittance lower than temporal Gaussian laser
  - Measured on 2019-12-20T0628
  - 6ps FWHM Gaussian laser pulse, BSA1.0mm
  - **90% transverse truncation**

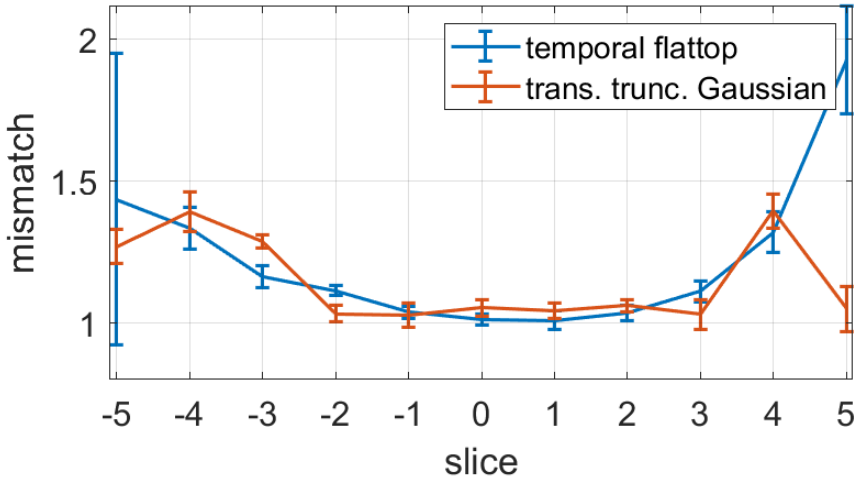
- Twiss parameters

Proj.	Flattop	Temp. Gaussian
α	-1.04 ± 0.01	-0.72 ± 0.01
β	5.34m ± 0.05m	1.27m ± 0.02m

- Mismatch parameter

$$M = \frac{1}{2}\left(\beta_{\mathrm{Slice}}\gamma_{\mathrm{Proj}} - 2\alpha_{\mathrm{Slice}}\alpha_{\mathrm{Proj}} + \gamma_{\mathrm{Slice}}\beta_{\mathrm{Proj}}\right)$$

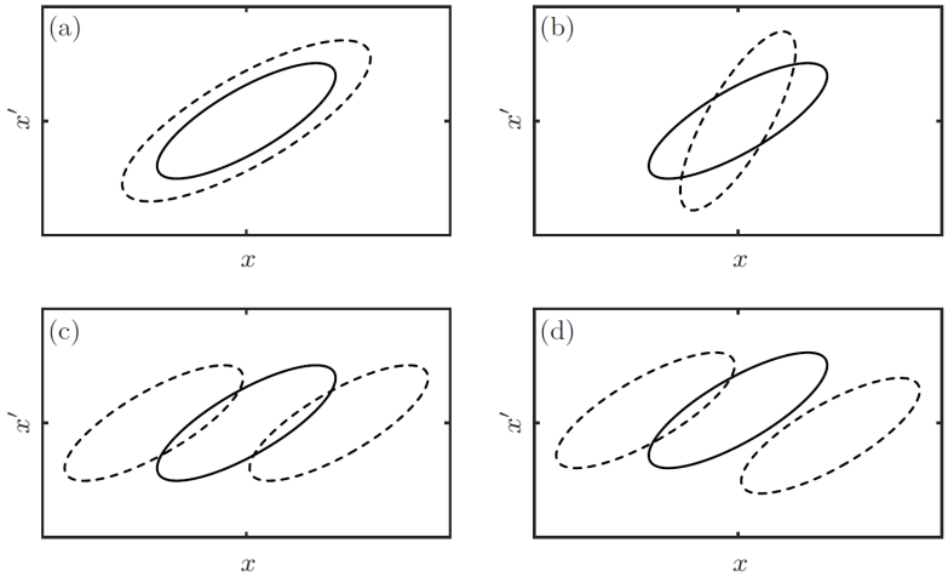




Emittance decomposition

Slice phase space contributions to projected emittance

- Projected emittance equals squared sum of different slice contributions [1]



Linear misalignment emittance

Mismatch emittance

$$\varepsilon_x{}^2 = \varepsilon_\perp{}^2 + \varepsilon_\mathrm{R}{}^2 + \varepsilon_\mathrm{int}{}^2 + \varepsilon_\parallel{}^2$$

Projected emittance

Slice emittance

Nonlinear misalignment emittance

$$\varepsilon_\perp{}^2 = \mathrm{E}[\varepsilon_x(z)]^2$$

$$\varepsilon_\mathrm{R}{}^2 = \mathrm{Var}[\varepsilon_x(z)] - \mathrm{Cov}\left[\sigma_x{}^2(z), \sigma_{x'}{}^2(z)\right] + \mathrm{Var}[\langle \Delta x \Delta x' \rangle_z]$$

$$\varepsilon_\mathrm{int}{}^2 = \mathrm{E}\left[\sigma_x{}^2(z)\right]\mathrm{Var}\left[\mu_{x'}(z)\right] + \mathrm{E}\left[\sigma_{x'}{}^2(z)\right]\mathrm{Var}[\mu_x(z)] - 2\mathrm{E}[\langle \Delta x \Delta x' \rangle_z]\mathrm{Cov}\left[\mu_x(z), \mu_{x'}(z)\right]$$

$$\varepsilon_\parallel{}^2 = \mathrm{Var}[\mu_x(z)]\mathrm{Var}\left[\mu_{x'}(z)\right] - \mathrm{Cov}\left[\mu_x(z), \mu_{x'}(z)\right]^2$$

$$\mathrm{Var}[\Phi] = \mathrm{Cov}[\Phi, \Phi]$$

$$\mathrm{Cov}[\Phi_a, \Phi_b] = \mathrm{E}[(\Phi_a - \mathrm{E}[\Phi_a])(\Phi_b - \mathrm{E}[\Phi_b])]$$

$$\mathrm{E}[\Phi] = \int \Phi(z)\lambda(z)\mathrm{d}z$$

$\lambda(z) =$ longitudinal charge density

- Allows to
  - Identify significant emittance contributions
  - better compare with simulations

[1] C. Mitchell, *A General Slice Moment Decomposition of RMS Beam Emittance*, (2015).

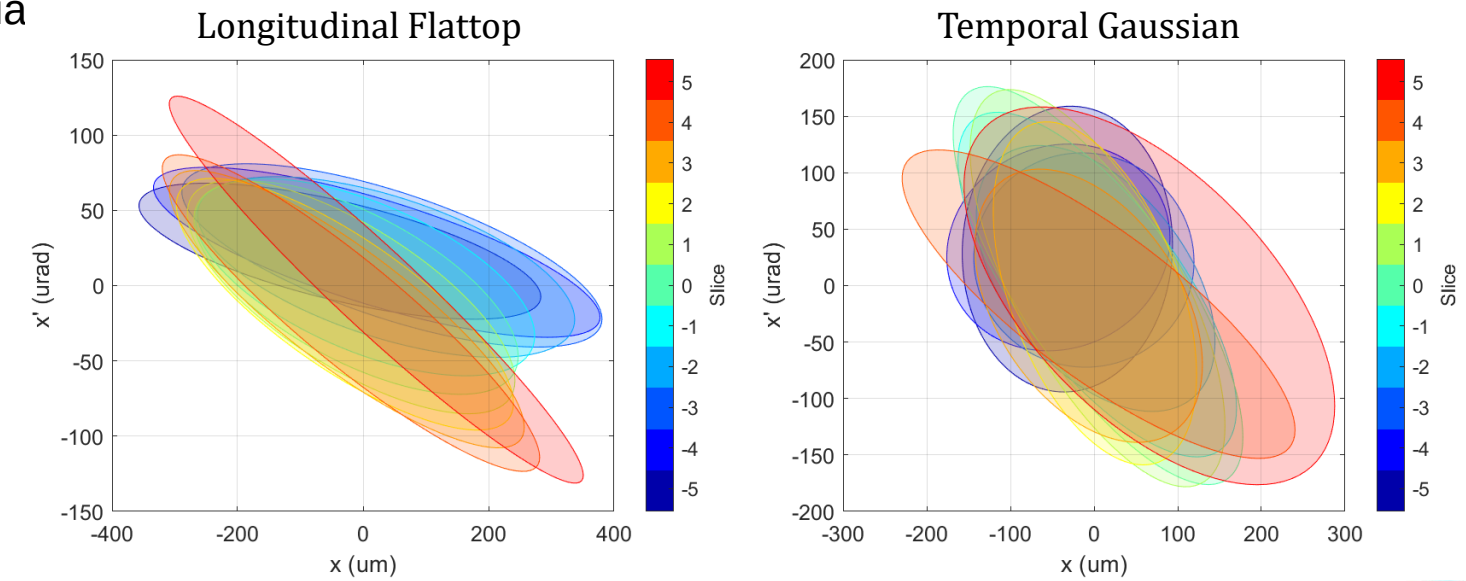
Emittance decomposition

Calculating emittance contributions from measurement data

- Single slice contributions calculated (table)
  - Main contribution: Slice emittance
  - Mismatch emittance makes up ~25% of projected emittance
    - Simulation: Cannot be improved via solenoid current
  - Misalignment emittances are negligible
  - Beam trajectory close to optimum
  - Reduction of projected emittance achievable via slice emittance reduction

$$\varepsilon_x{}^2 = \varepsilon_\perp{}^2 + \varepsilon_\mathrm{R}{}^2 + \varepsilon_\mathrm{int}{}^2 + \varepsilon_\parallel{}^2$$

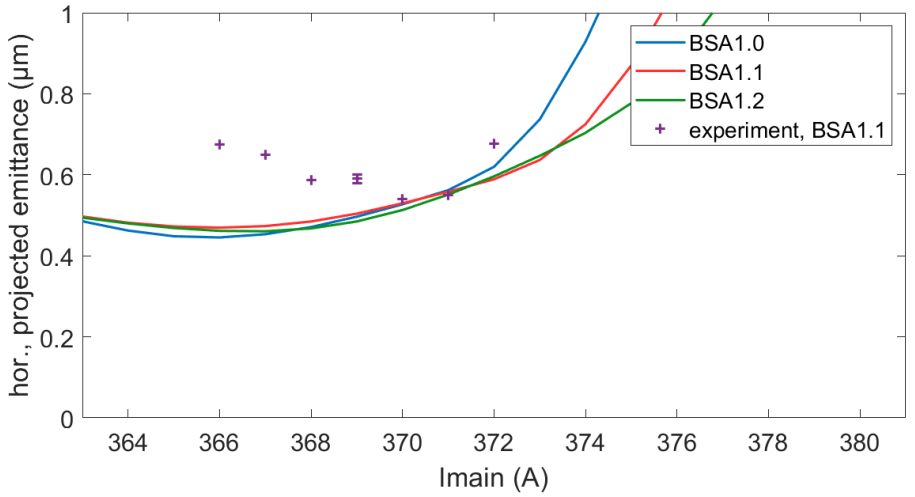
	Temp. Flattop	Temp. Gaussian
Projected emittance	0.61 µm	0.69 µm
Slice emittance	0.53 µm	0.63 µm
Mismatch emittance	0.27 µm	0.25 µm
Linear misalignment emittance	0.11 µm	0.09 µm
Nonlinear misalignment emittance	0.01 µm	<0.01 µm

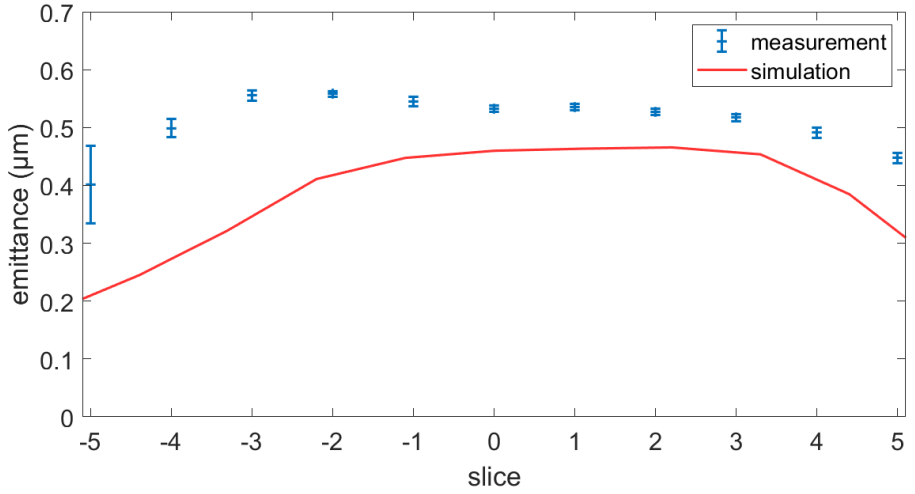


Slice and projected emittance

Comparison with simulations

- Projected emittance
  - Simulation minimum (BSA1.1): 0.47µm @ 366A
  - Hor. exp. minimum: 0.54µm @ 370A (fastScan)
  - Hor. emittance at minimum: ε_{xy} = (0.59 ± 0.01)µm (fastScan)
- Centre slice emittance
  - Simulation: 0.46 µm
  - Experiment: 0.53 µm
- Projected & slice emittance differ similarly in experiment & sim



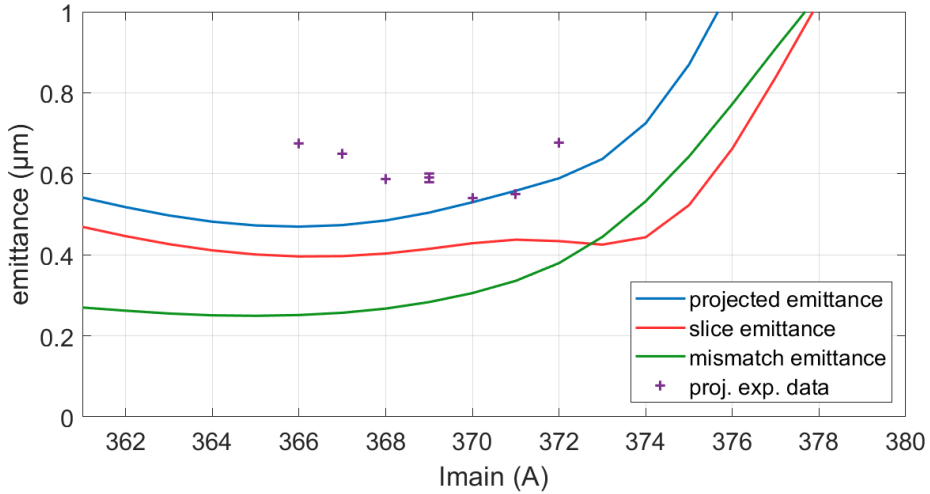


Slice emittance

Emittance decomposition in simulation and experiment

- Emittance contributions for BSA1.1 calculated
  - At minimum slice emittance dominates proj. emittance
  - For higher Imain mismatch emittance equally big

- At exp. projected emittance minimum (Imain = 369 A)
  - Mismatch emittance same: Simulation seems to fit to experimental result
  - Charge-weighted slice emittance: Simulation much smaller than experiment
    - Poor modelling of emission process reason?
  - Misalignment emittance
    - Vanishes in simulations → Due to missing steering, perfect symmetry
    - Insignificant in experiment → Good beam trajectory



Imain = 369 A	Experiment	Simulation
Projected emittance	0.61 µm	0.50 µm
Slice emittance	0.53 µm	0.41 µm
Mismatch emittance	0.27 µm	0.28 µm
Linear misalignment emittance	0.11 µm	<0.01 µm
Nonlinear misalignment emittance	0.01 µm	<0.01 µm

Summary & Outlook

Comparison of slice and projected emittance of a temporal flattop profile beam

- Slice emittance for temporal flattop measured
  - SlitScanner: Projected emittance matches fastscan scaled1
  - Beta functions different: Unstable laser/Imain power supply?
  - **Temporal flattop slice emittance lower** than temporal Gaussian laser

- Astra simulations
  - Simulated slice emittance **lower than experiment**
  - Same for projected emittance → **Emission model** in Astra likely at fault

- Emittance contributions calculated
  - **Mismatch emittance same** in experiment & simulation
    - To be further investigated by analysing mismatch emittance change with Imain
  - Slice emittance main reason for different projected emittance