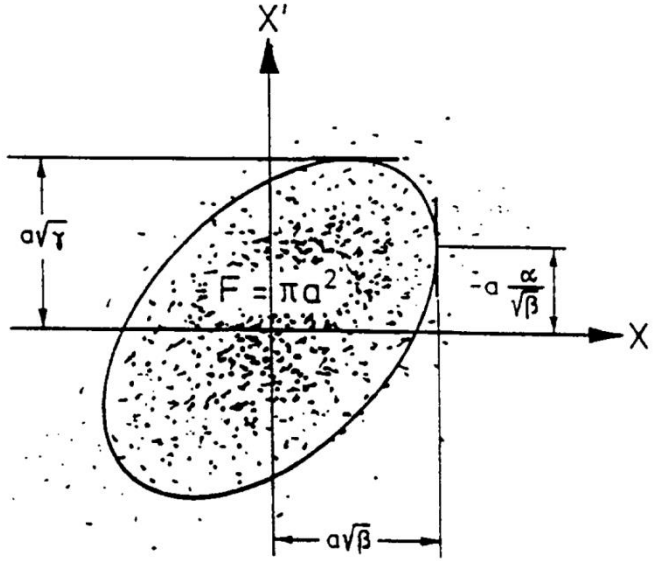
Teaching: Slice emittance measurements with SlitScanner.m

Raffael Niemczyk, Zeuthen, January 10th 2018

Emittance

A recap

- Every particle of beam has…
  - Long. Position and energy/momentum (z, p)
  - Transverse position and angle in both planes (x, x', y, y')
- In total: 6 dimensions per particle
- Area covered by particles in phase space is called **emittance**
- Emittance is conserved in linear optics (Liouville's theorem)
- Small emittance required for many applications, including lasing



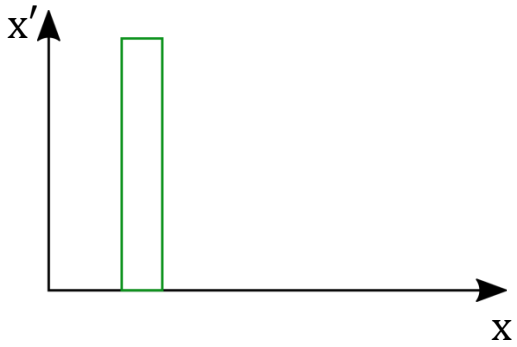
Horizontal phase space

Emittance measurement

Slit-based emittance measurement

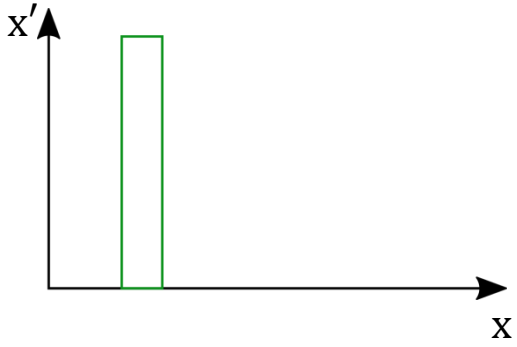
Emittance measurement

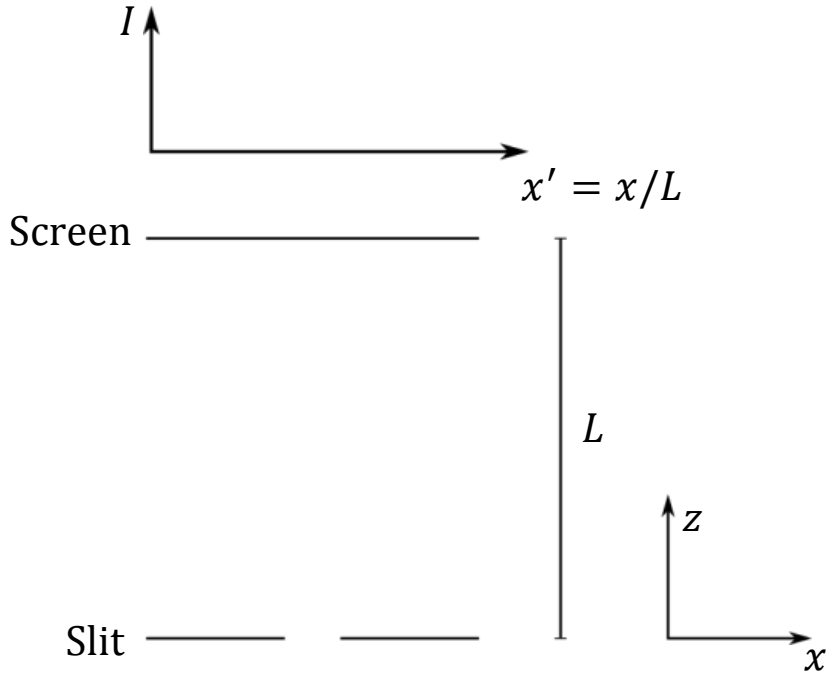
Slit-based emittance measurement



Emittance measurement

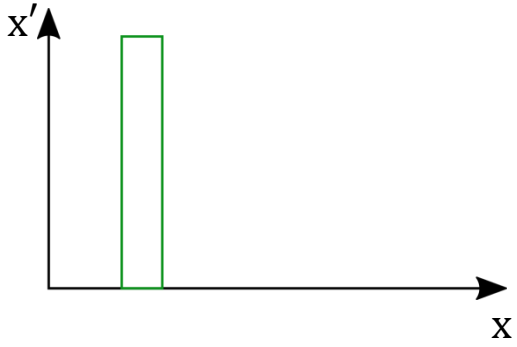
Slit-based emittance measurement

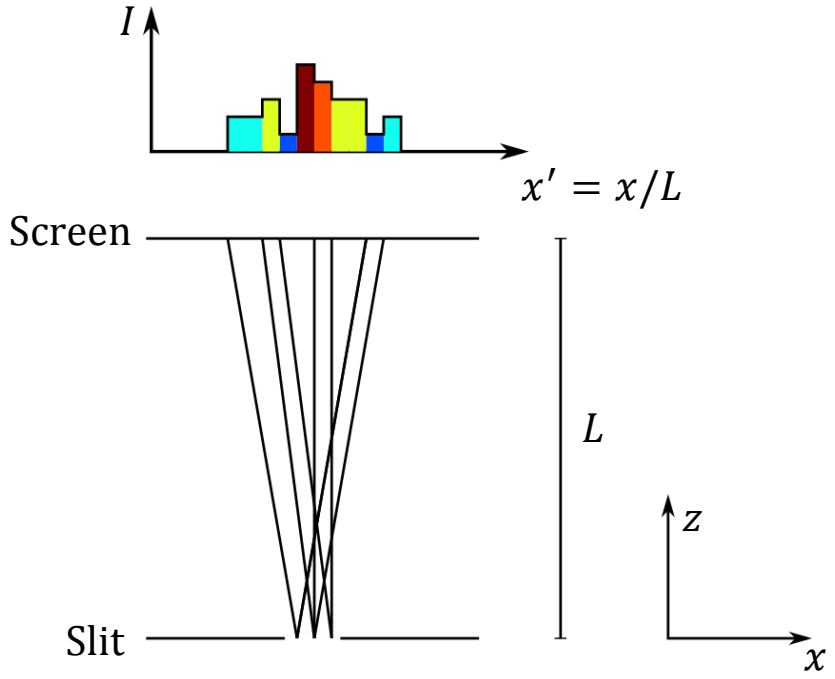




Emittance measurement

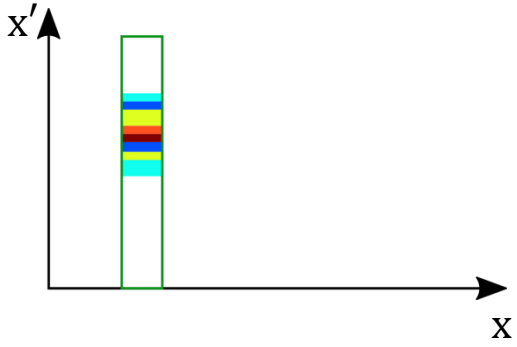
Slit-based emittance measurement

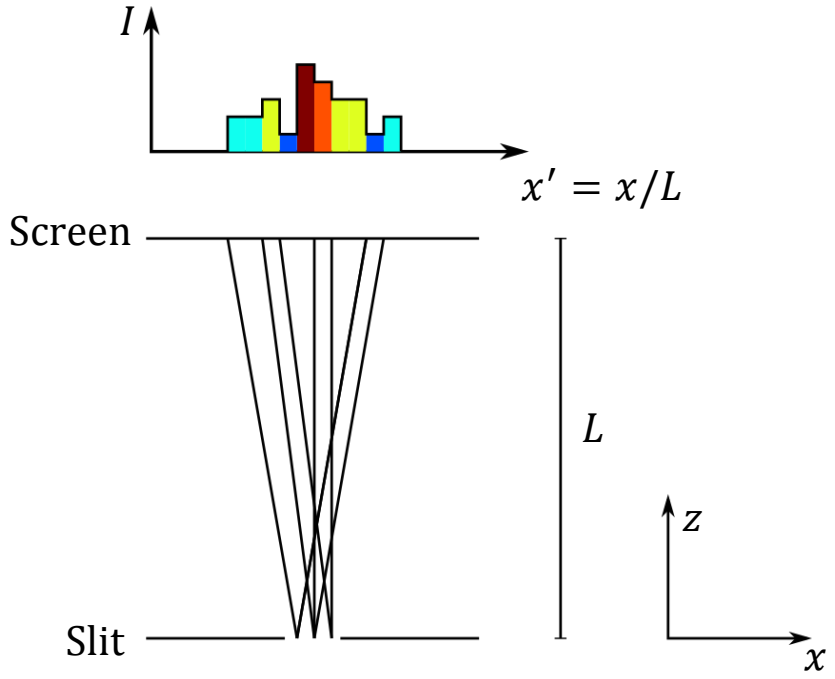




Emittance measurement

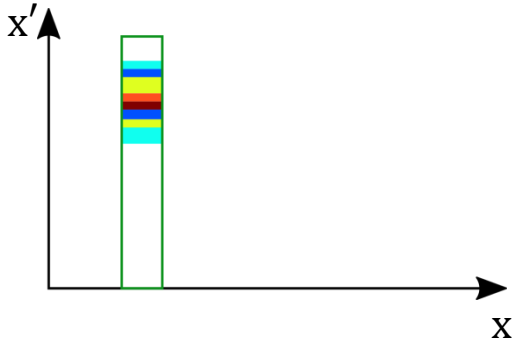
Slit-based emittance measurement

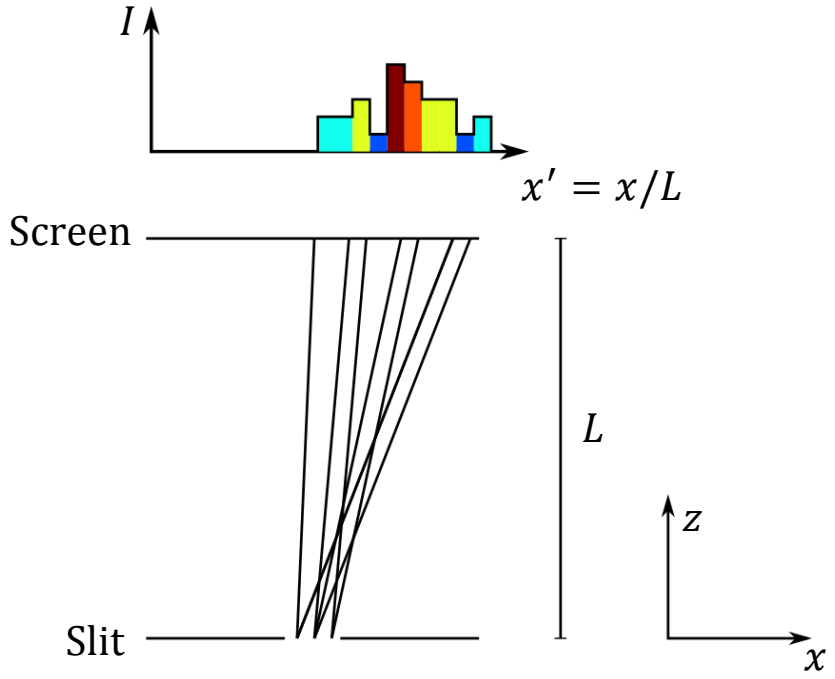




Emittance measurement

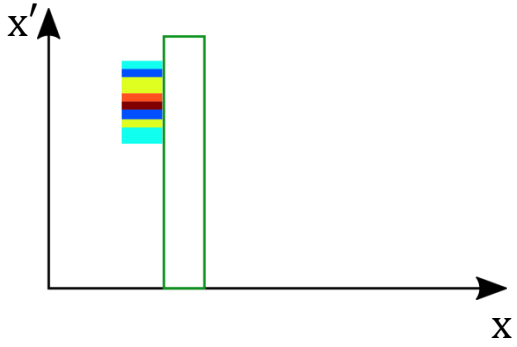
Slit-based emittance measurement

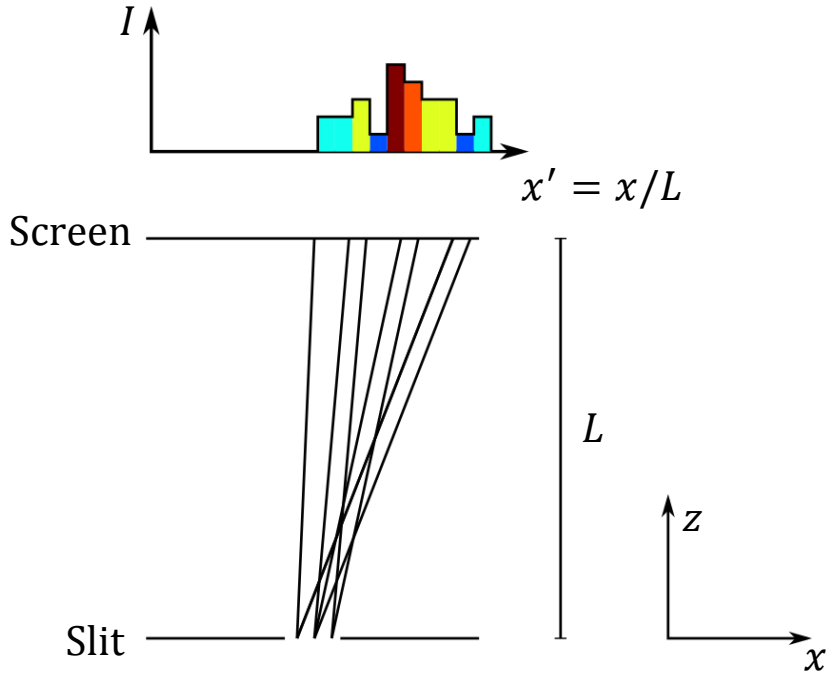




Emittance measurement

Slit-based emittance measurement



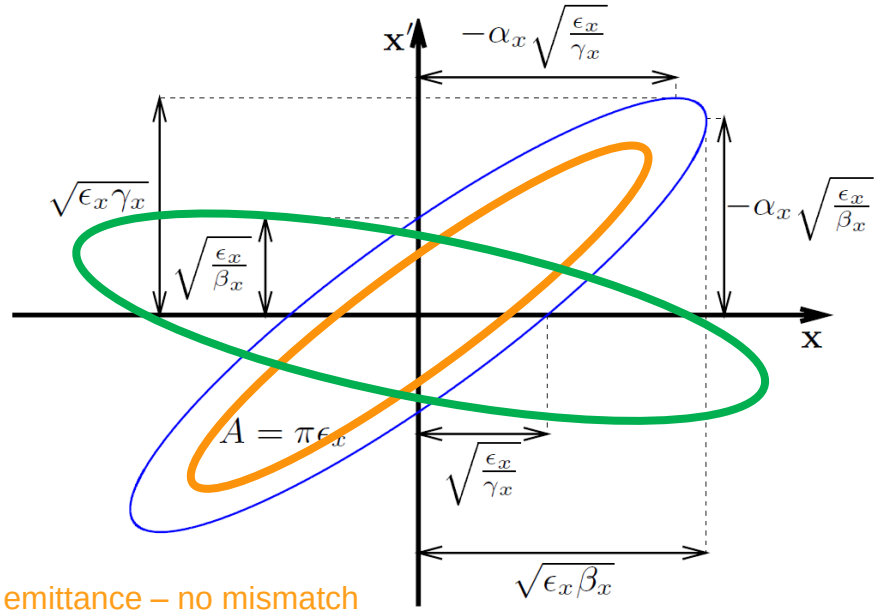


- Cut out emittance-dominated beamlets from space charge-dominated beam with a slit
  - Measure the **size**, **position** and **intensity** of each beamlet on screen
- **Reconstruct the phase space** at slit position
  - Emittance via $\epsilon = \beta\gamma \frac{\sigma_x}{\sqrt{<x^2>}} \sqrt{\langle {x_0}^2 \rangle \langle {x_0}'^2 \rangle - \langle x_0 x_0' \rangle^2}$

Beam optics

Phase space ellipse described via Twiss parameters

- Phase space area is conserved – Orientation is not
- Orientation and size of ellipse determined by Twiss parameters (α, β, γ)
- Beta function determines beam size
- Alpha function gives beam divergence
- Different ellipse orientation compared to design optics is referred to as **mismatch**



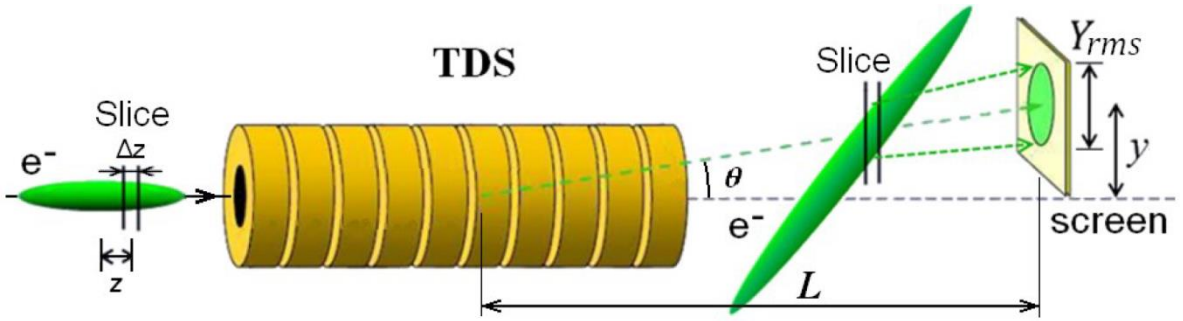
Smaller emittance – no mismatch
Same emittance – with mismatch

B. Beutner, Teaching on slice emittance measurements

Slice emittance

Emittance within a bunch (~ 1 ps resolution)

- FEL lasing happens in a short slice of the bunch. Hence the FEL lasing performance is described correctly by the slice emittance ✘
- I want to graduate ✓
- Projected emittance can overestimate slice emittance (when slices are mismatched to each other)
- Slit scan as ‘standard’ emittance measurement
- Transverse deflecting structure (TDS) enables time resolution



D. Malyutin, PhD thesis (2014)

- That’s the setup for slice emittance measurement!

Slice emittance measurement (SLEM)

How to prepare the beamline for slice emittance measurements

- Both EMSY stations have 10 µm slit (high res.) and 50 µm slit (high signal)
- Slit mask, TDS streak and long drift reduce the signal strength at observation screen…
- Two quads before EMSY1
- Four quads between EMSY1 and EMSY2
- Five quads between EMSY2 and PST.Scr1
- Problem: We want to scan I_{main}, which changes beam size and divergence behind booster

Slice emittance measurement

How to prepare the beamline for slice emittance measurements

- Hence the lattice has to be optimized for each SLEM
- Demands:
  - Intermediate hor. beam size x_{rms} at slit mask (too small = low res., too big = little charge in beamlets)
  - Vertical focus on observation screen (minimize y_{rms}) for good time resolution
  - Intermediate hor. beam size x_{rms} at observation screen (for a reasonable S2N ratio)
  - No quads between slit mask and observation screen set, as little steering as possible
- Two quads not enough to fulfill all demands -> EMSY2 has to be used

Slice emittance measurement

How to achieve a proper beam transport for SLEM?

- Degauss High1.Q7 to High1.Q10 and PST.QM's (quads between slit and PST.Scr1)
- Beam size x_{rms} at slit mask: Use Q1/Q2 to tweak the beam on the slit mask
- Beam size at observation screen: Use Q5/Q6 to shape the beam on observation screen

Slice emittance measurement

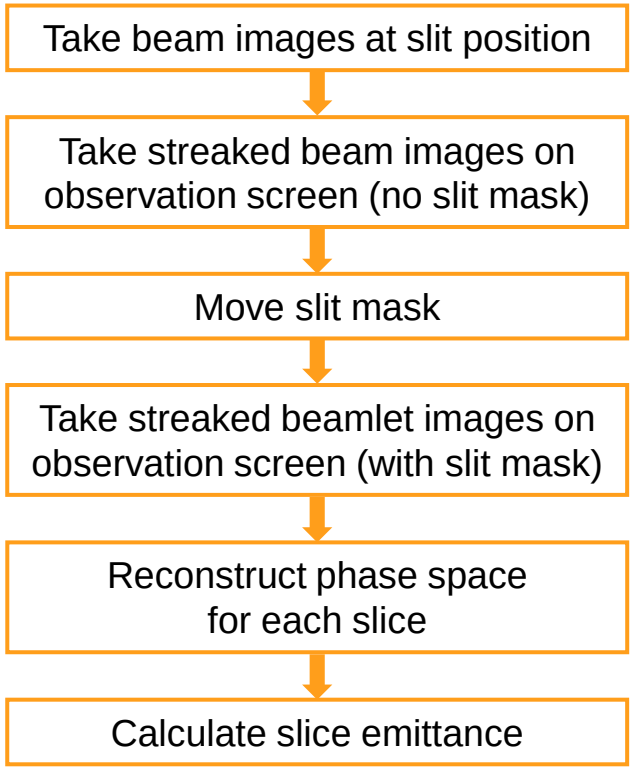
What else do we need?

1. Beam momentum is needed -> HEDA scan, ideally done first
2. Apply the optics (print the settings into logbook)
3. Bunch length measurement with TDS.m (determines zero-crossing phase, streak parameter and time resolution)
   - By default, use the LYSO screen (high sensitivity)
   - Use (2 x 2)-binning (less noise)
   - Use 10 µs exposure time for the camera
4. Set TDS zero-crossing phase
5. Slice emittance measurement via SlitScanner.m

SlitScanner.m

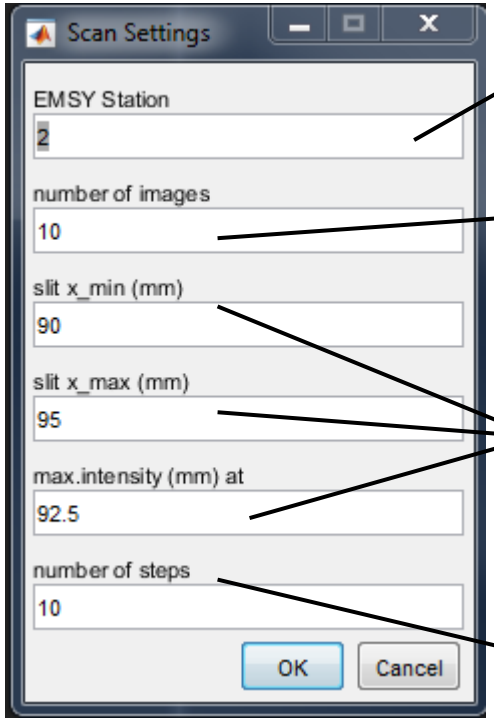
How to use it

- Automated slit scan for SLEM with analysis within runtime
- Found at '/doocs/measure/scripts/Actual_Scripts_SVN/MatlabScripts/SlitScanner/SlitScanner.m'
- …or in the PITZ GUI 'tools > open MATLAB 16b with Standard Measurement Scripts > SlitScanner.m'



SlitScanner.m

How to use it



Chose EMSY station: ‘1’ or ‘2’. Use EMSY 2 as default

Number of images at each slit position, 10 is okay

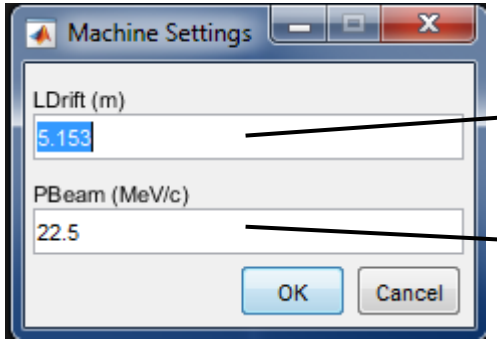
Range of the slit movement, with max. signal position (to set the gain later). You determine it by moving the slit by hand and observing the screen image. The range should be slightly larger chosen than the beamlet signal can be seen on the observation screen. **The slit range also determines the used slit width.** Use 10 µm slit, when the signal is strong enough

Total number of slit positions. For a quick measurement 20 – 30 are okay. If all possible beamlets should be taken, adjust the number of steps in a way that the spacing of the slit positions is equal to the slit width

SlitScanner.m

How to use it

Feeding more scan settings

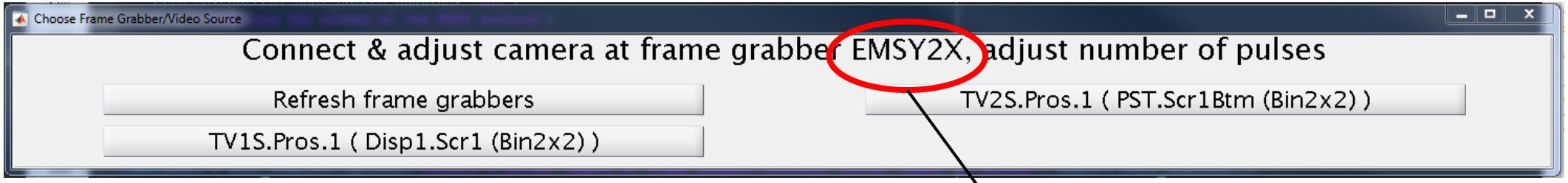


Drift length from slit station to observation screen

Beam momentum

Drift lengths:
EMSY1 -> PST.Scr1: 7.000 m
EMSY2 -> PST.Scr1: 5.153 m

Prepare taking of the image on the slit mask, set number of pulses (as many as accelerated, max ~ 200)



Taking the EMSY image

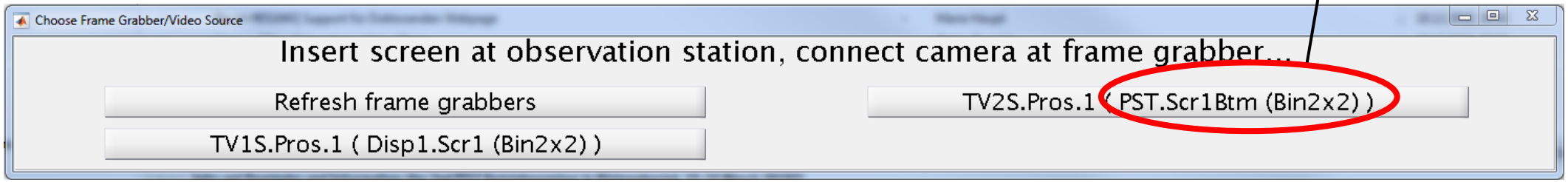
EMSY2 camera not connected in this example: OP has to do it!

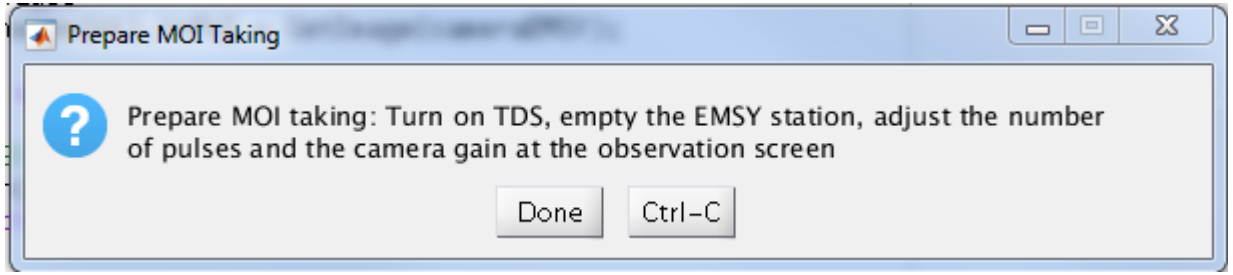
SlitScanner.m

How to use it

PST.Scr1Btm (LYSO) is standard option

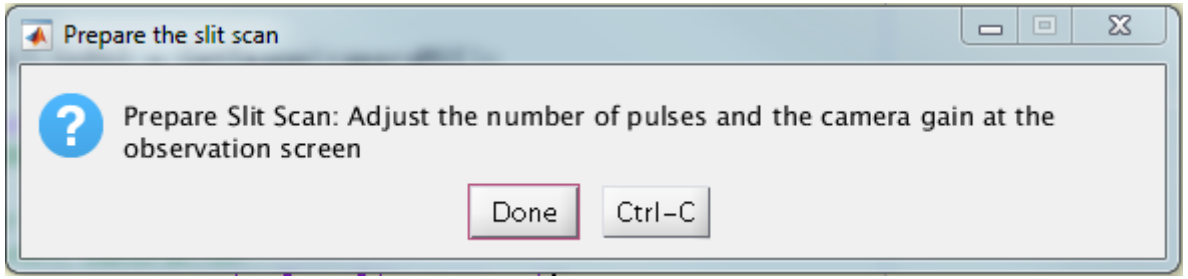
Prepare observation screen (insert screen and select frame grabber)





Taking of MOI (Observation screen while slit is out of beamline)
TDS has to be turned on (usually still on from TDS measurement)
Gain has to be set
Set number of electron bunches (max 3)

MOI is taken



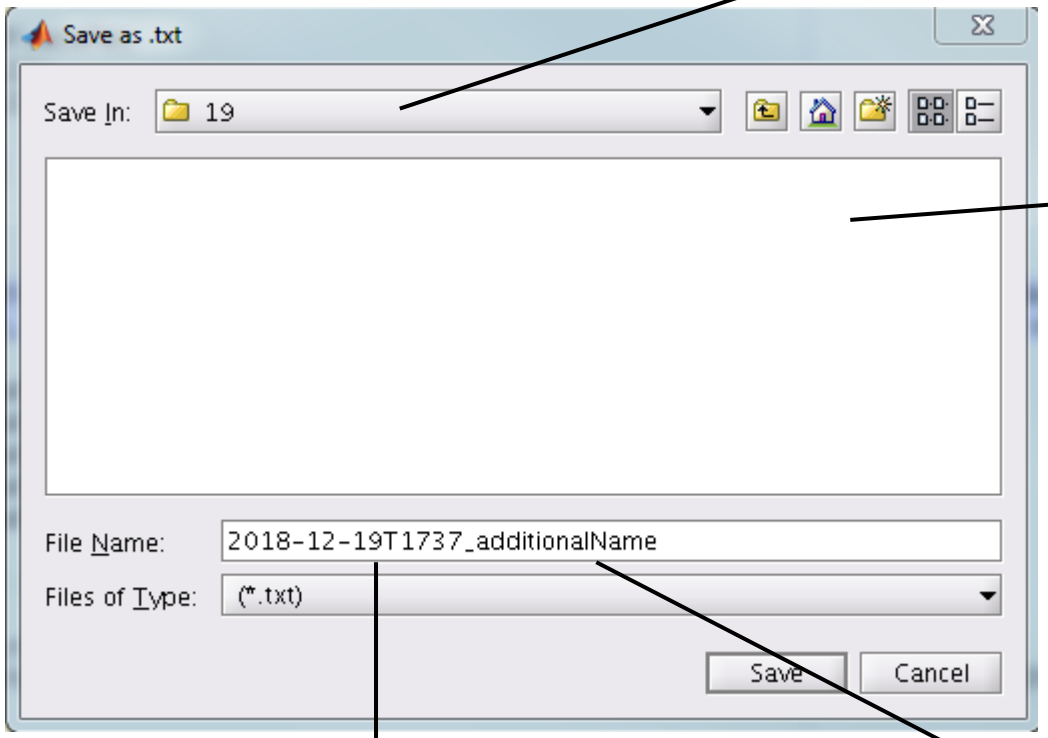
Adjust number of pulses (three max) and the camera gain
(slit automatically set to max. intensity position)

SlitScanner.m

How to use it

Select the name of the data

Folder is selected automatically, for the day of the start of the script



No measurement taken on that day so far…

Date & Time of start of script (keep this!)

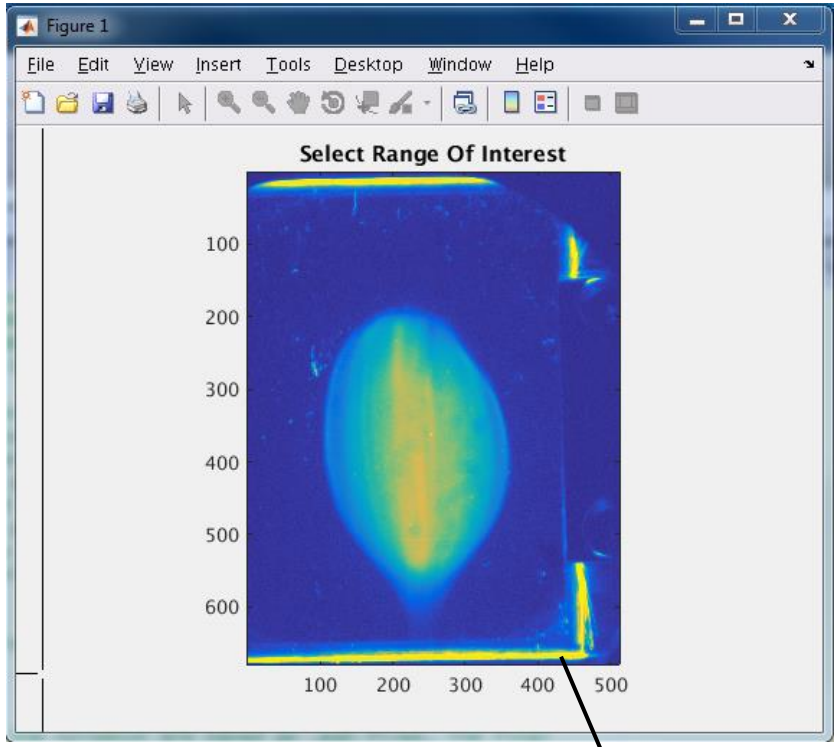
Additional information in file name

SlitScanner.m

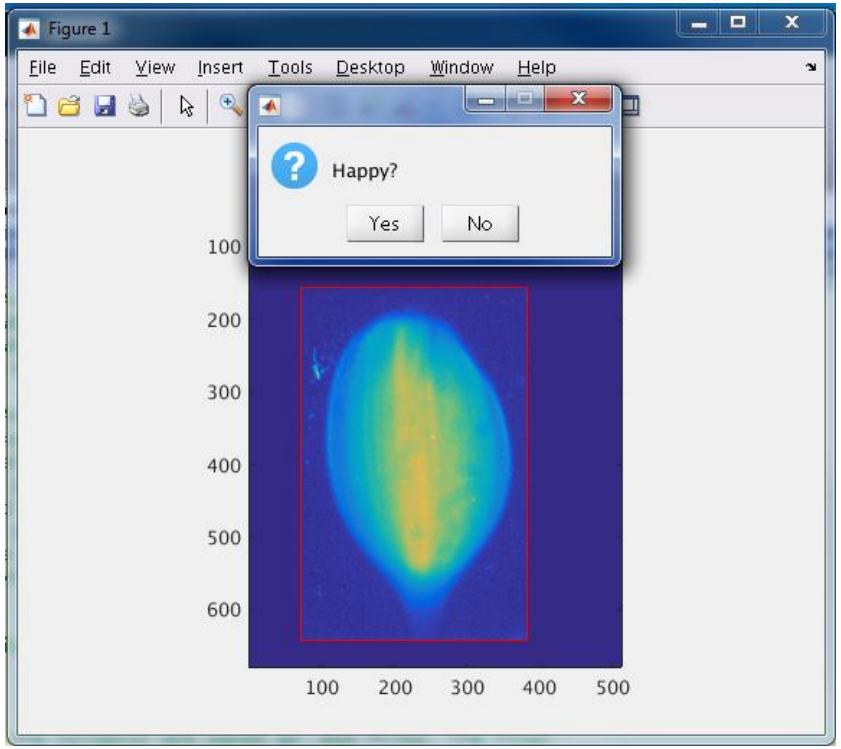
How to use it

Apply a manual MOI for the analysis of the data

Raw image



Example of a good cut



Use the manual MOI to crop the screen edges
(high intensity, but not a beam signal)

SlitScanner.m

Results printed into the logbook

18.12.2018 18:43 pitzop **from: zncups-pitz : SliceEmittanceMeasurement_txt**

```
Summary of slice emittance measurement


Measurement Setting:
Slit Station:           EMSY2
Slit movement range:    91.00 mm ... 92.30 mm
Max. beamlet int.:      91.80 mm
Num. of slit pos.:      27
Num. of slit images:    10
Slit spacing:           0.05 mm
Drift Length:           5.153 m
Beam momentum:          18.990 MeV/c

Machine Setting:
BSA:                    0.999 mm
LT  (EMSY):             18.00 %
NoP (EMSY):             2
LT  (MOI & beamlet):    18.00 %
NoP (MOI & beamlet):    2

Main solenoid current: 314.0 A
High1.Q1:               0.00 A
High1.Q2:               0.00 A
High1.Q3:               0.00 A
High1.Q4:               0.00 A
High1.Q5:               0.00 A
High1.Q6:               -1.00 A

Gun Power:              4.70 MW
Gun Phase:              5.0 deg
Booster Power:          2.36 MW
Booster Phase:          -5.0 deg
TDS Power:              0.50 MW
TDS Phase:              -154.0 deg
```

Scan settings

BSA, LT and camera setting

I_{main} & some quads

Cavities: Power and phase

Note: The measurement is only searchable, if the entry was opened and saved manually, even without changes. Ideally, put OP's name as author and give more meaningful title

SlitScanner.m

… and the table with the slice emittance values

ϵ : emittance

γ: Lorentz gamma

$\beta = v/c$

v: Particle speed, c = speed of light

$\langle {x_0}^2 \rangle$: Beam size of phase space

$\langle {x_0}'^2 \rangle$: Beam divergence pf phase space

$\langle x_0 {x_0}' \rangle$: Correlation term

Charge: Normalized, so that the max.-charged slice has 1.0

Alpha and beta function

Mismatch parameter: Mismatch between slice and projected phase space ellipse

By default: Slicing into 11 slices

Results:

slice #	current (a.u.)	beta (m)	alpha	mismatch	emittance (um)
projected	7.44	1.88	4.10	-	1.48
-5	0.05	0.52	0.68	2.31	0.36
-4	0.35	2.09	3.90	1.20	0.58
-3	0.69	3.73	6.66	1.80	0.74
-2	0.89	3.29	6.19	1.44	1.12
-1	1.00	2.68	5.44	1.12	1.47
0	1.00	2.03	4.38	1.00	1.72
1	1.00	2.20	5.14	1.06	1.41
2	0.95	2.04	5.14	1.22	1.25
3	0.81	1.93	5.28	1.54	0.95
4	0.55	1.59	4.75	1.97	0.60
5	0.17	0.89	2.93	2.35	0.33

Data was saved to '/afs/ifh.de/group/pitz/doocs/measure/TransvPhSp/2018/SliceEmittance/201812/18/2018-12-18T1832_EMSY2_PSTLYSO_GUNsp55_boosterSP17.txt'

Normalized, unscaled emittance of each slice and the projection

$$\epsilon = \beta\gamma\sqrt{\langle {x_0}^2 \rangle \langle {x_0}'^2 \rangle - \langle x_0 {x_0}' \rangle^2}$$

Path & file to which data has been saved

$$\text{mismatch parameter} = \frac{1}{2}(\beta_S\gamma_P - 2\alpha_S\alpha_P + \gamma_S\beta_P) \geq 1$$

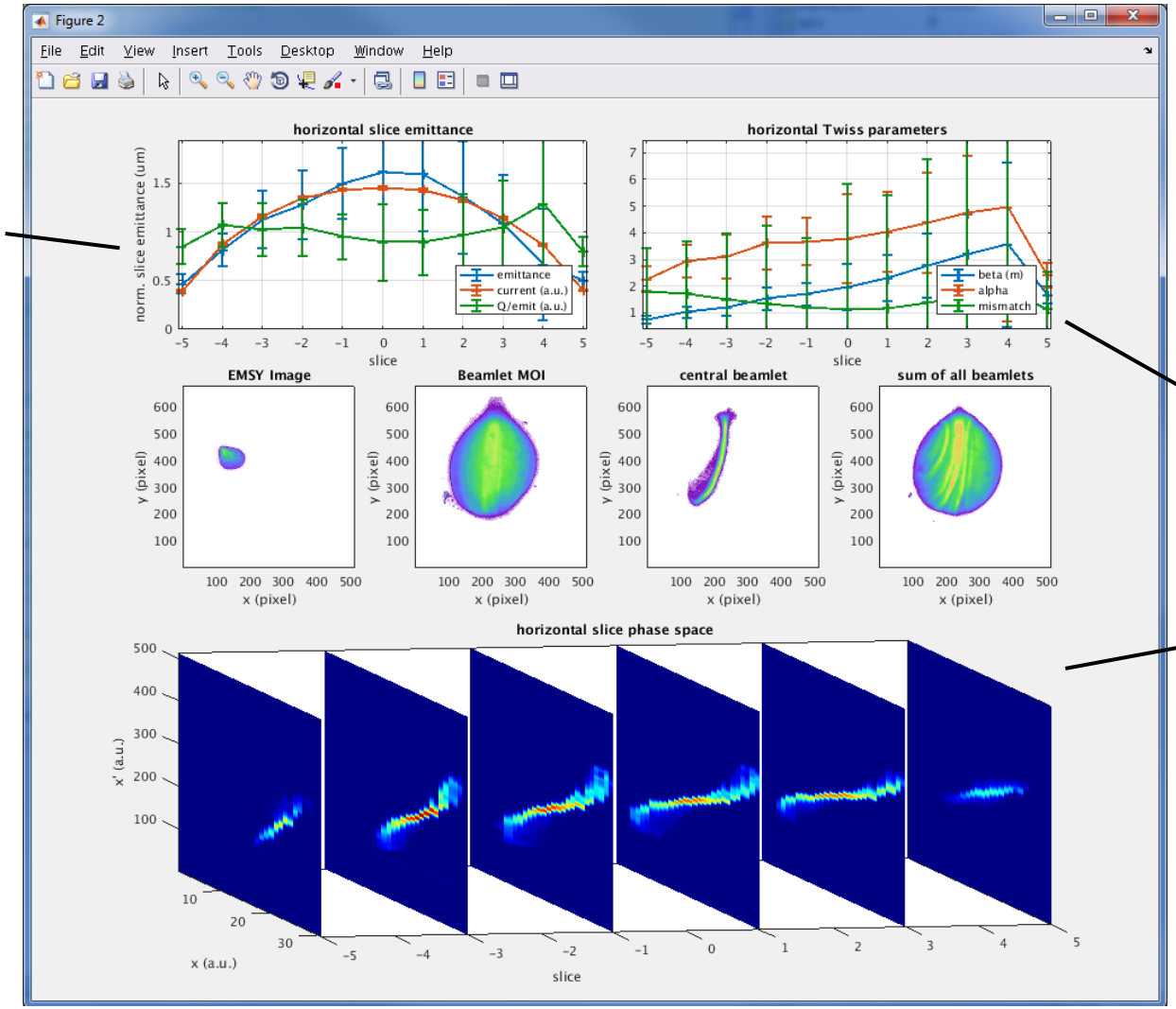
perfect match = 1

Twiss parameters for projection (P) and slices (S)

SlitScanner.m

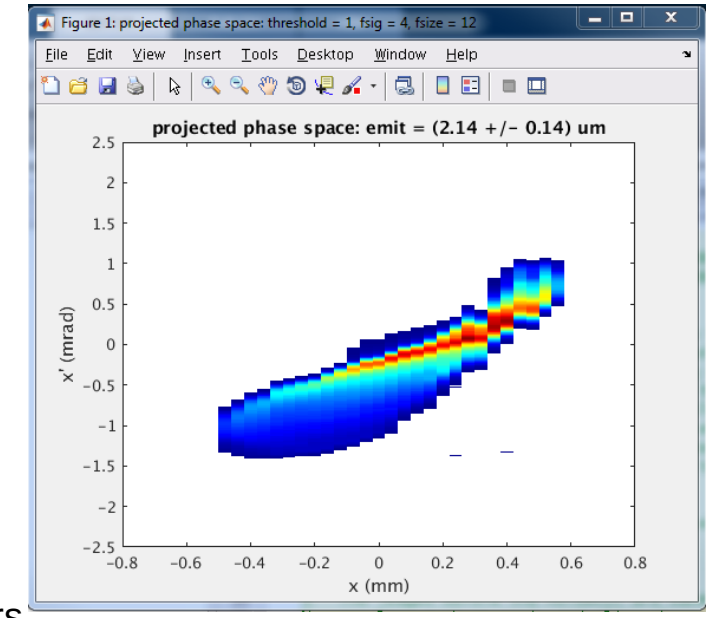
Generated plots with results

Emittance, charge and brilliance



Twiss parameters and mismatch

Slice phase space



Projected phase space and projected emittance

For now, SlitScanner.m does the analysis without calculation of the uncertainty (i.e. the errorbars will be missing)

Other remarks

- TDS stays untouched from SlitScanner.m, i.e. it has to be prepared beforehand
- You can’t see the beamlets on PST.Scr1?
  - Check quadrupoles currents, beam size on slit mask (too big?), scan range of the slit
- It’s still under development, the dialogues might change…
- Report errors in the program, unclear passages, etc…
- Program run takes several minutes, status of execution given in command line
- Bunch length measurements and optics preparation take most time at the moment

Further reading

If/when needed, or for the curious ones

- PITZ Wiki 'Measurements > Emittance > Slice Emittance using an rf deflector'
- R. Niemczyk et al, *Proof-of-Principle Tests for Slit-scan-based Slice Emittance Measurements at PITZ*, LINAC'18, Beijing, China (2018)
- H. Huck, *Report on Gun4.6 run at PITZ in 2016 – 2017,* internal report, 140ff, (2018)
- D. Malyutin, *Time resolved transverse and longitudinal phase space measurements at the high brightness photo injector PITZ*, PhD thesis, University Hamburg (2014)
- M. Hänel, *Experimental Investigations on the Influence of the Photocathode Laser Pulse Parameters on the Electron Bunch Quality in an RF – Photoelectron Source*, PhD thesis, University Hamburg (2010)
- L. Staykov, *Characterization of the transverse phase space at the photo-injector test facility in DESY, Zeuthen site*, PhD thesis, University Hamburg (2008)
- G. Vashchenko, *Transverse phase space studies with the new CDS booster cavity at PITZ*, PhD thesis, University Hamburg (2013)