

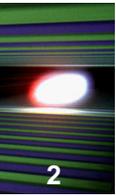
Beam Optics and Emittance

Bolko Beutner

21.01.2020

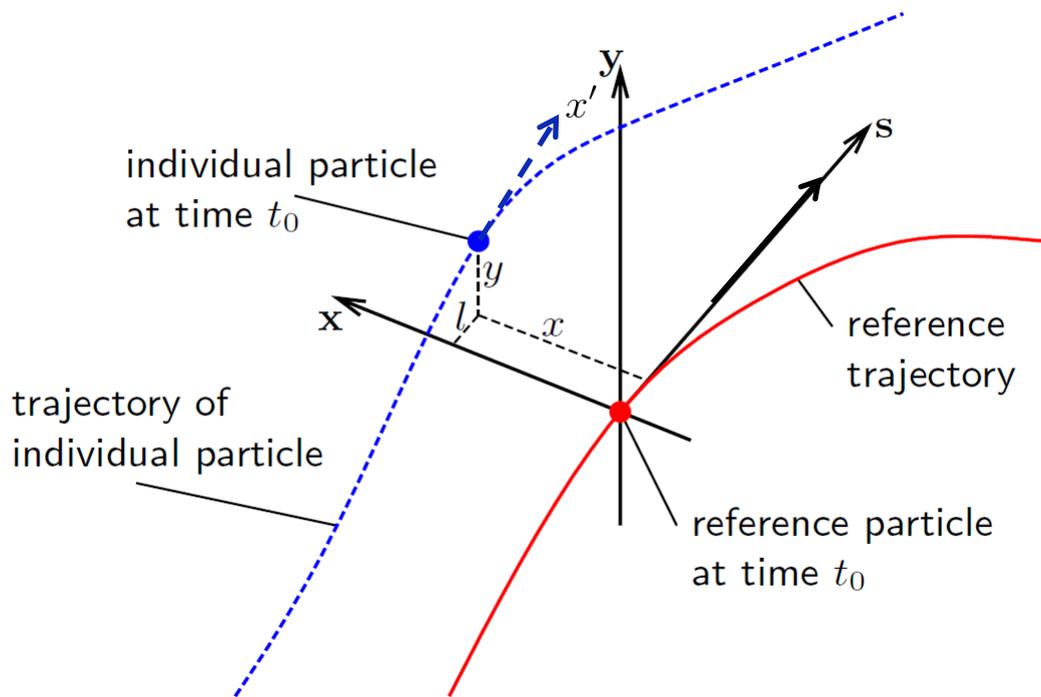
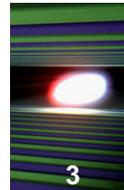


HELMHOLTZ
| ASSOCIATION

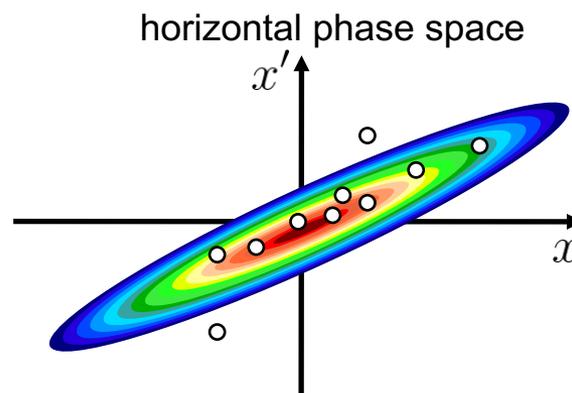


Introduction

Beam Dynamics Coordinates

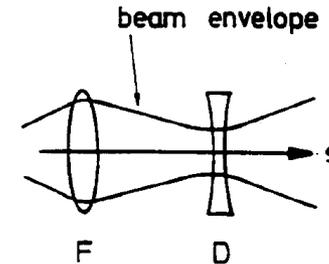
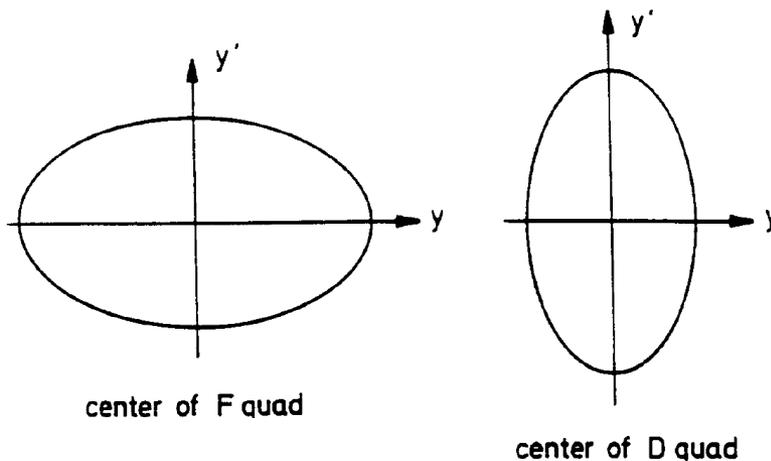


$$\mathbf{X}(s) = \begin{pmatrix} x \\ x' \\ y \\ y' \\ l \\ \delta \end{pmatrix}$$

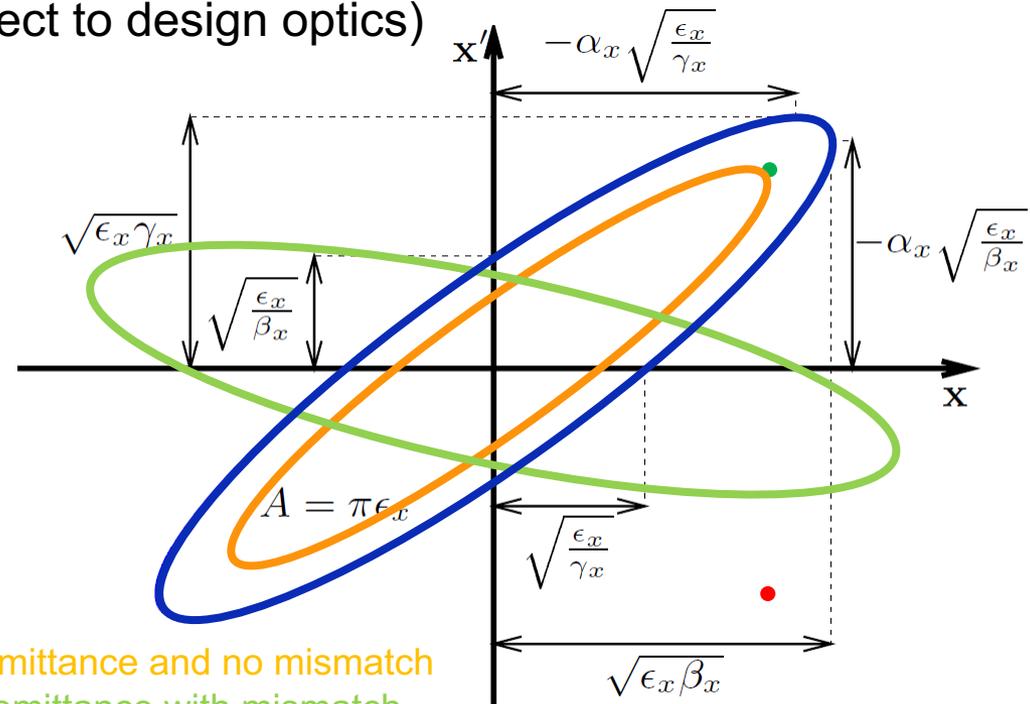
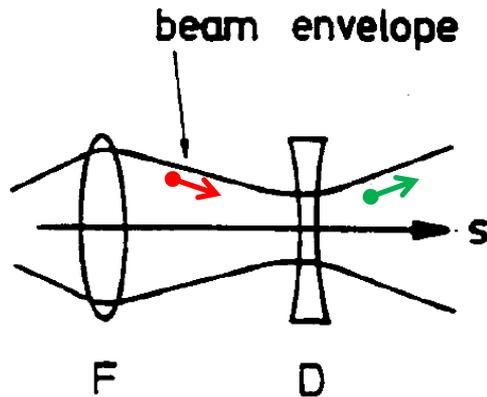


- Co-moving coordinate system with respect to design trajectory (right-handed-system at XFEL)
- Phase space is generated between distance and angle to the design orbit in each plane

- Area covered by particles in phase space is called emittance
- We can assume an elliptical distribution
- Emittance is conserved in linear optics (Liouville's theorem)
 - => beam behaves like an incompressible liquid
 - => focusing the beam will increase its divergence
- Small beams with little divergence as required for SASE lead to small emittance requirements

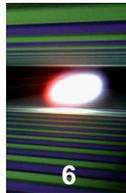


- While the area is conserved the orientation of the phase space ellipse is not
- Beam orientation is measured with the “twiss” parameters (α, β, γ)
- “slope” of such ellipses are a signature of convergent or divergent beams
- A beam which does not have the same orientations is called “mismatched” (with respect to design optics) even if the emittance is the same

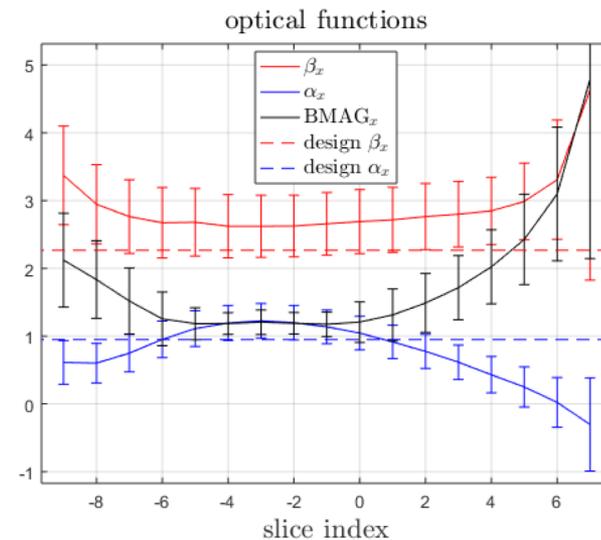
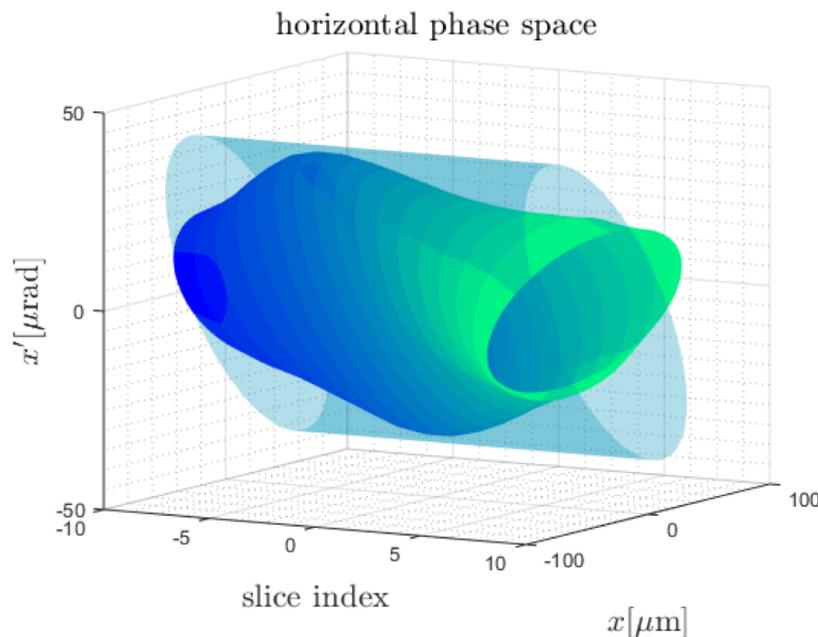
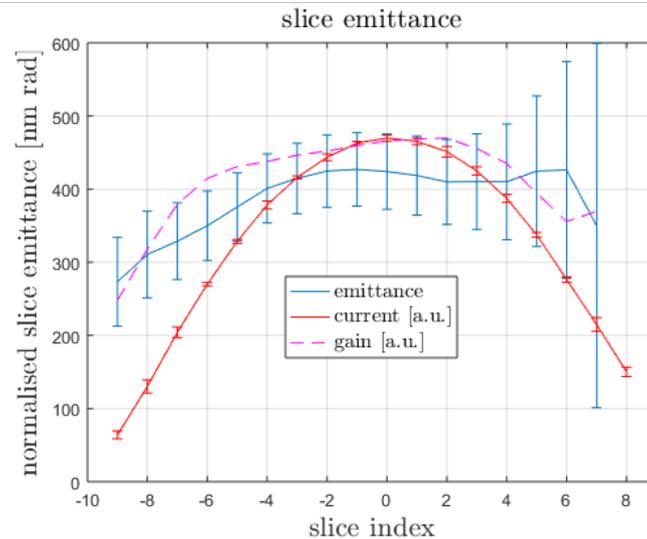


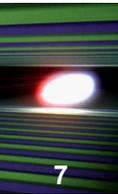
smaller emittance and no mismatch
same emittance with mismatch

Slice Emittance



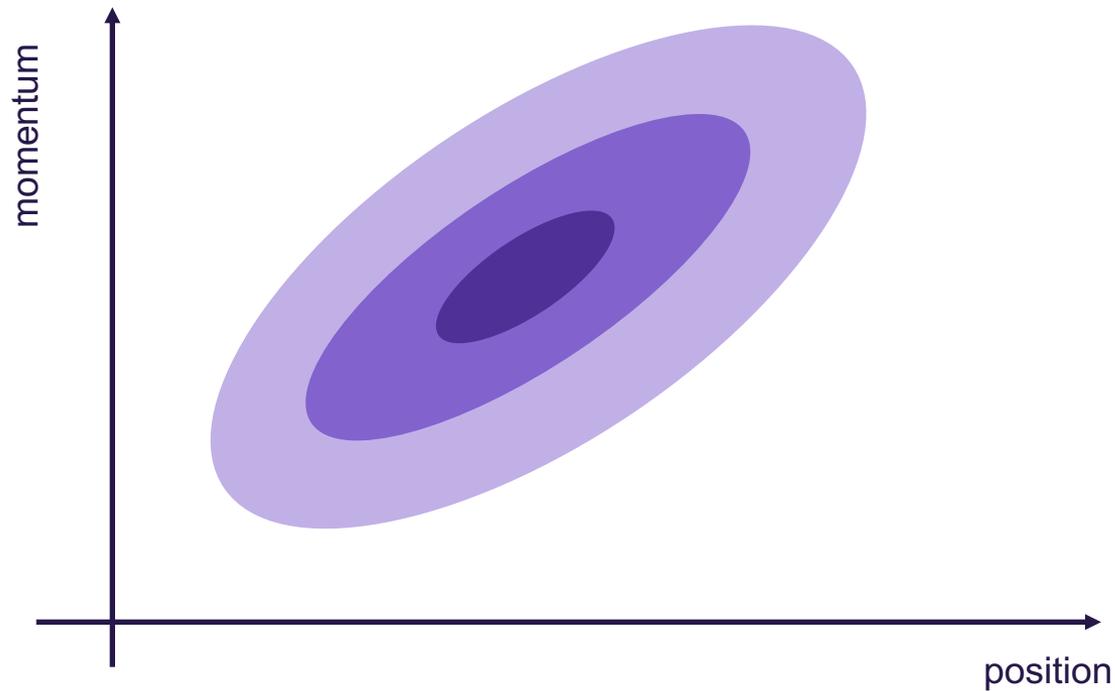
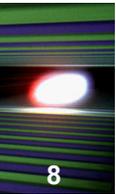
- FEL Process acts in a “slice” much shorter than the bunch length
- Projected emittance would underestimate the phase space density of each slice
- Longitudinal resolved measurements using a transverse deflecting structure (TDS)



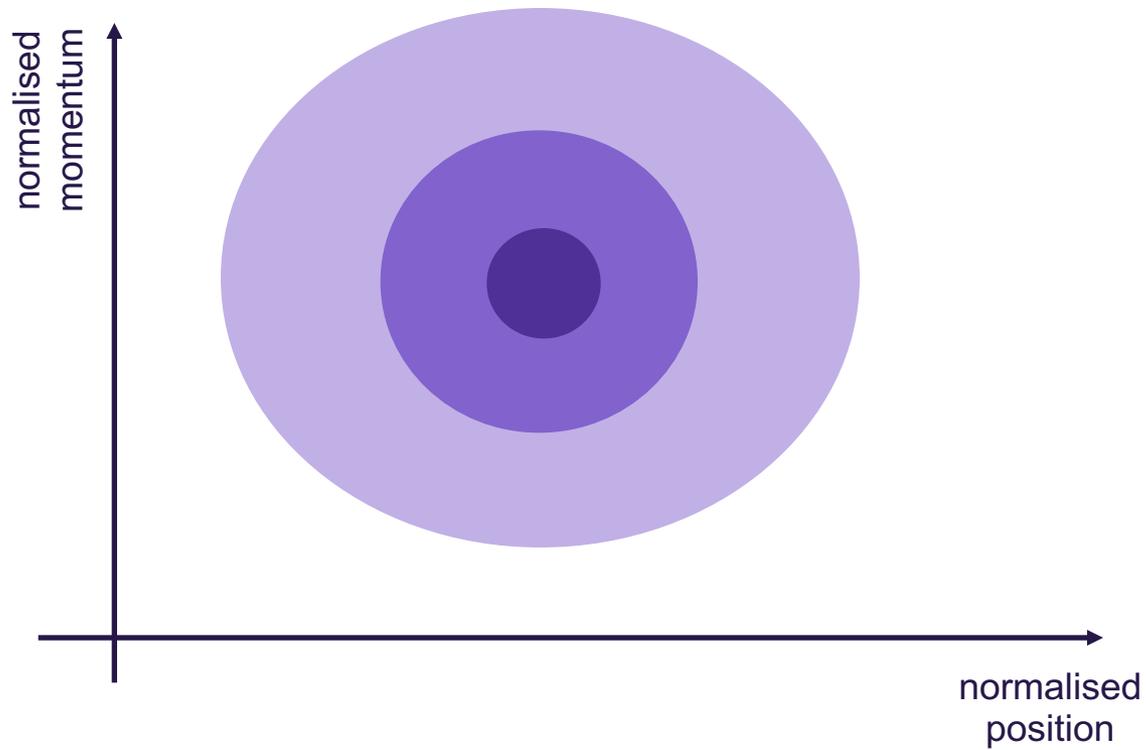
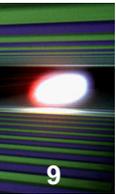


Measurements

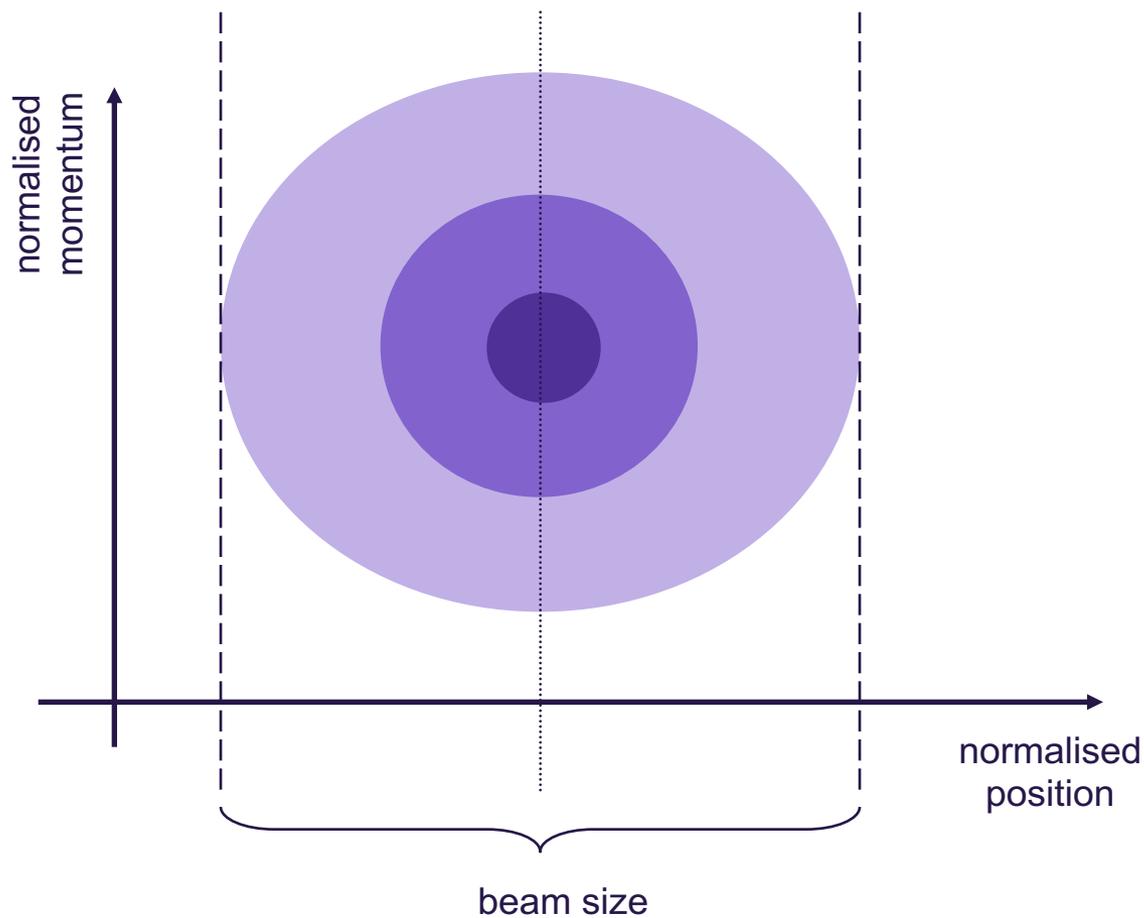
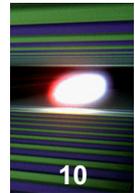
Principle of Optics Measurements



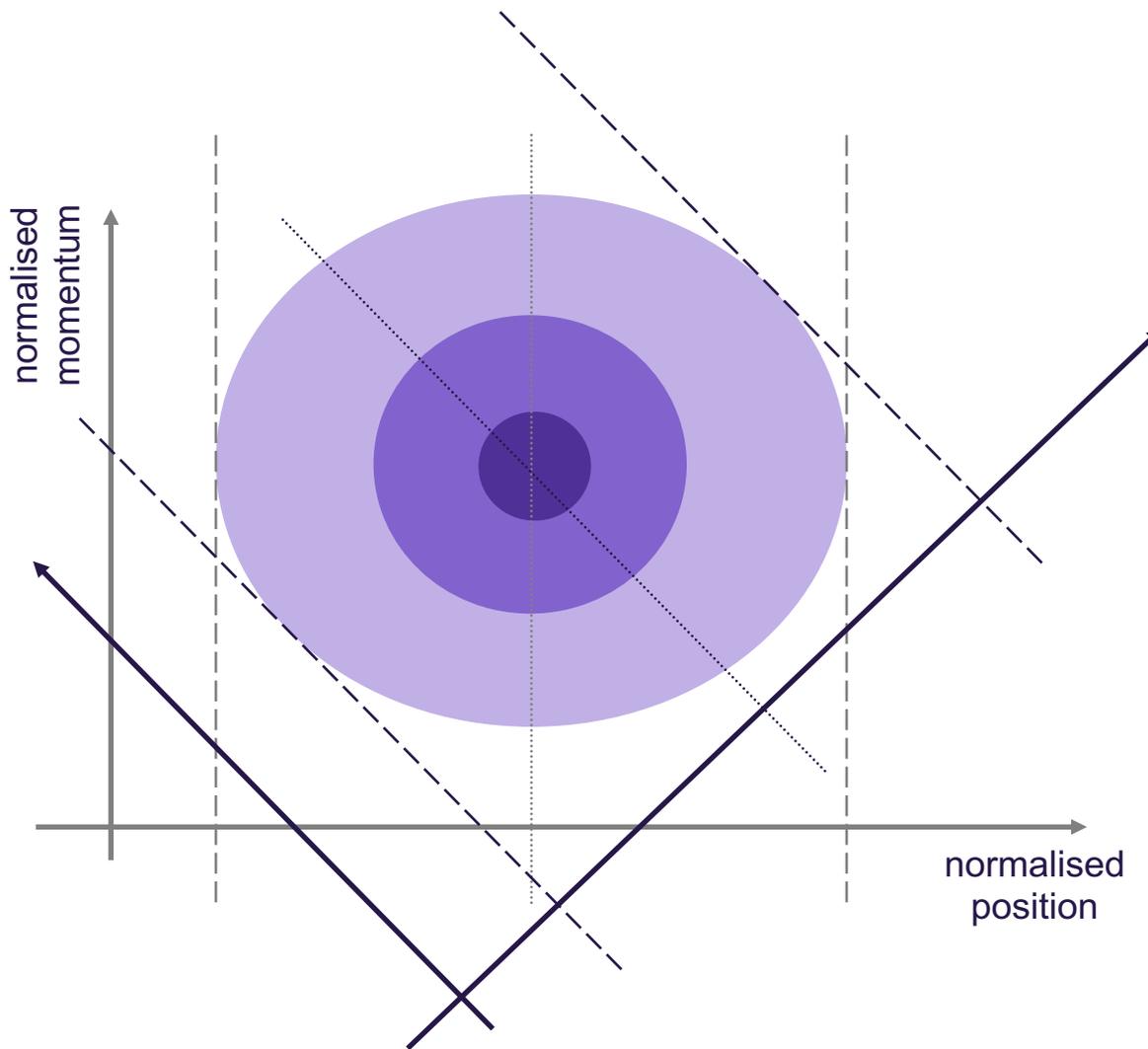
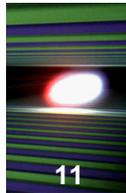
Principle of Optics Measurements



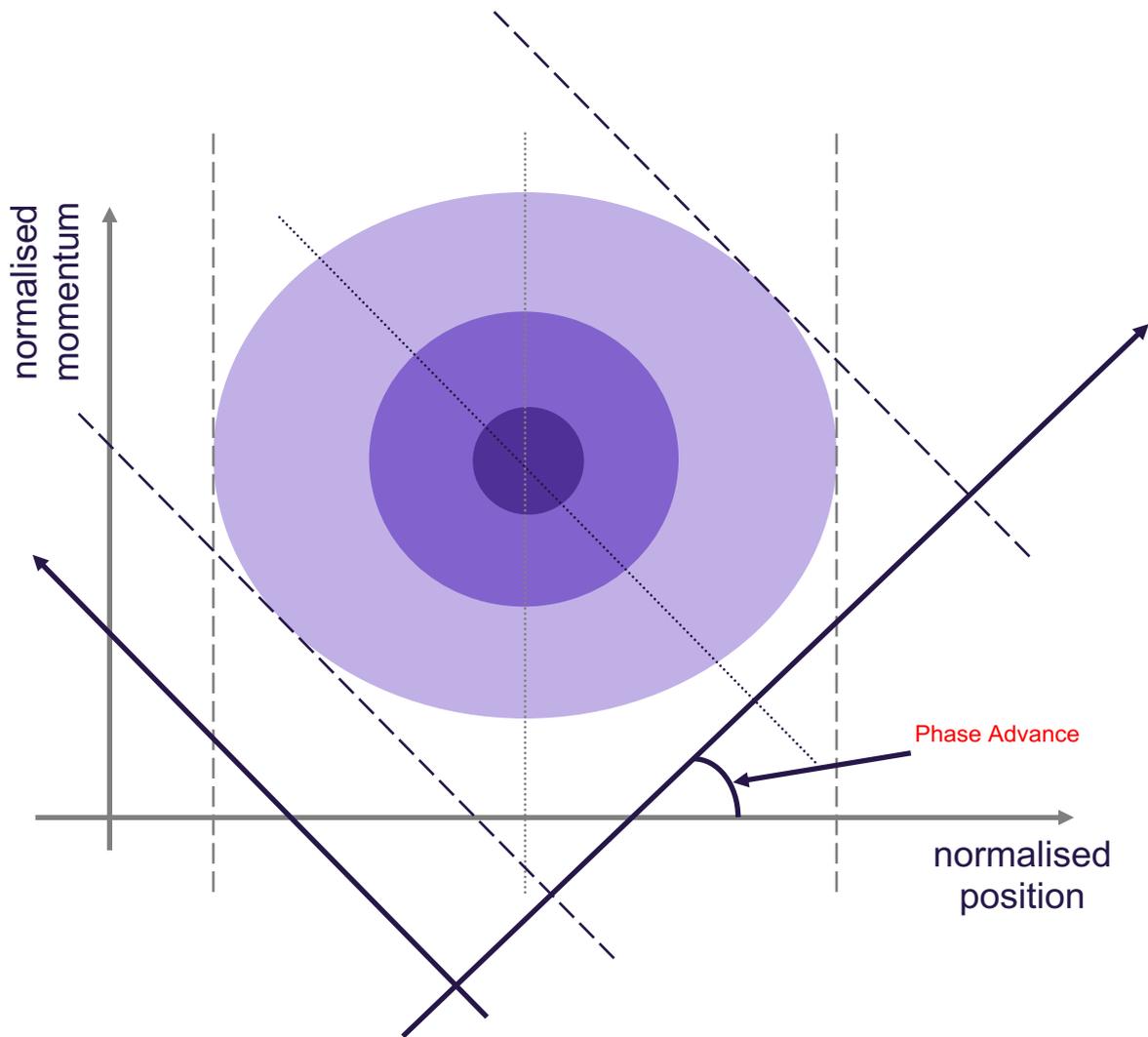
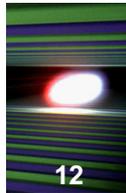
Principle of Optics Measurements



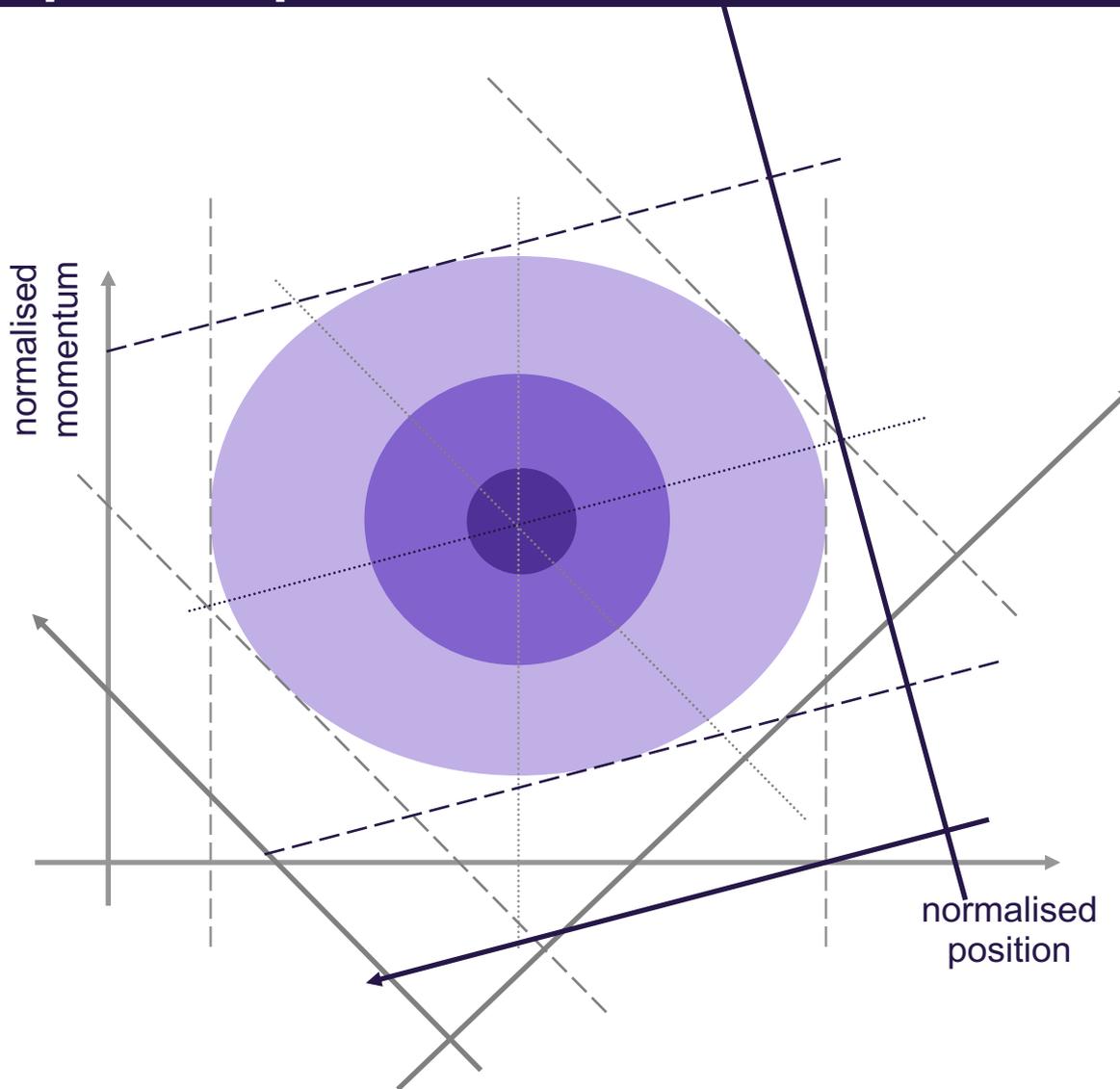
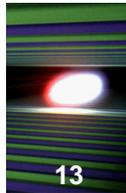
Principle of Optics Measurements



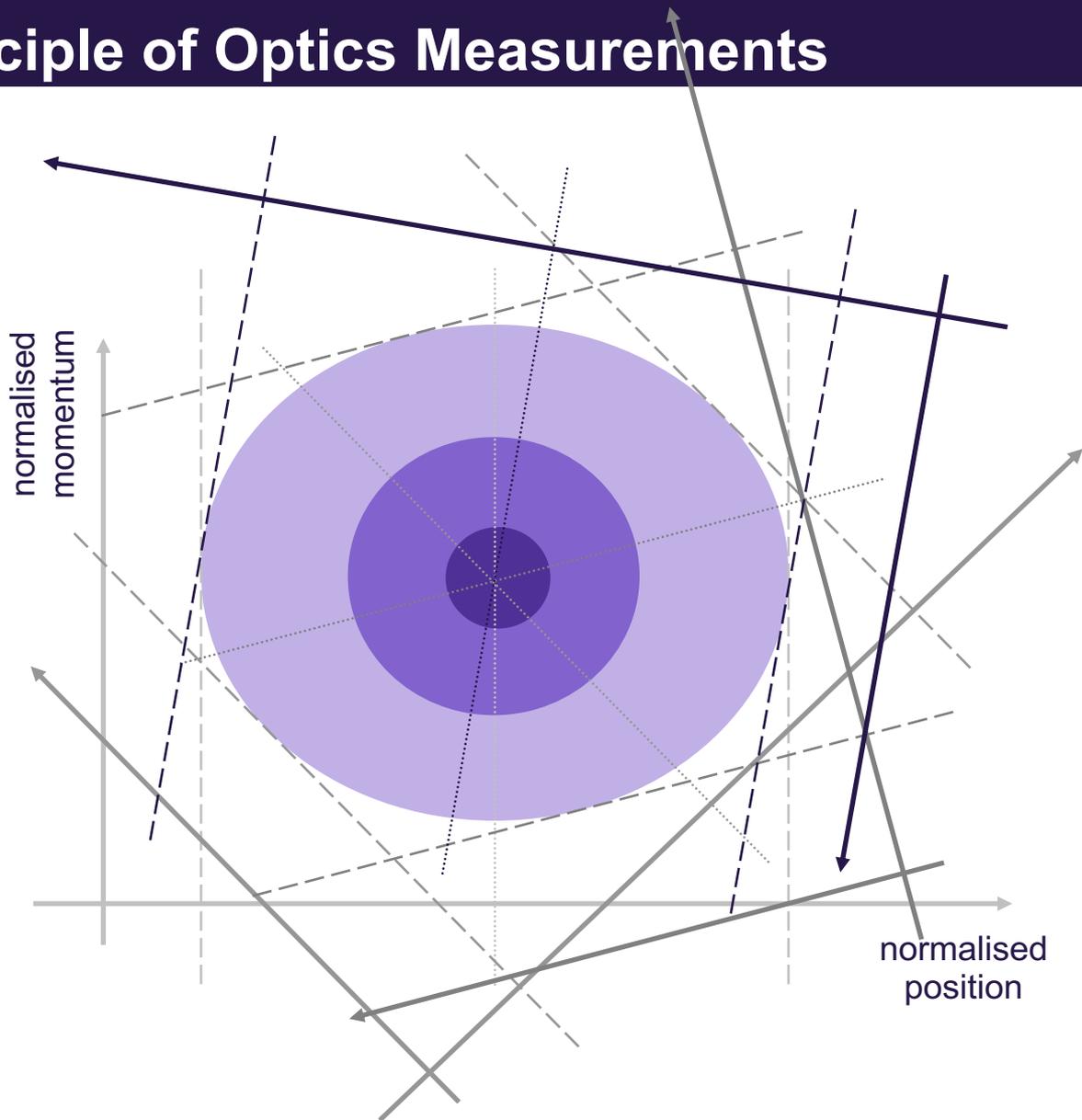
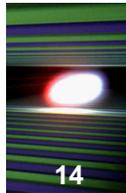
Principle of Optics Measurements



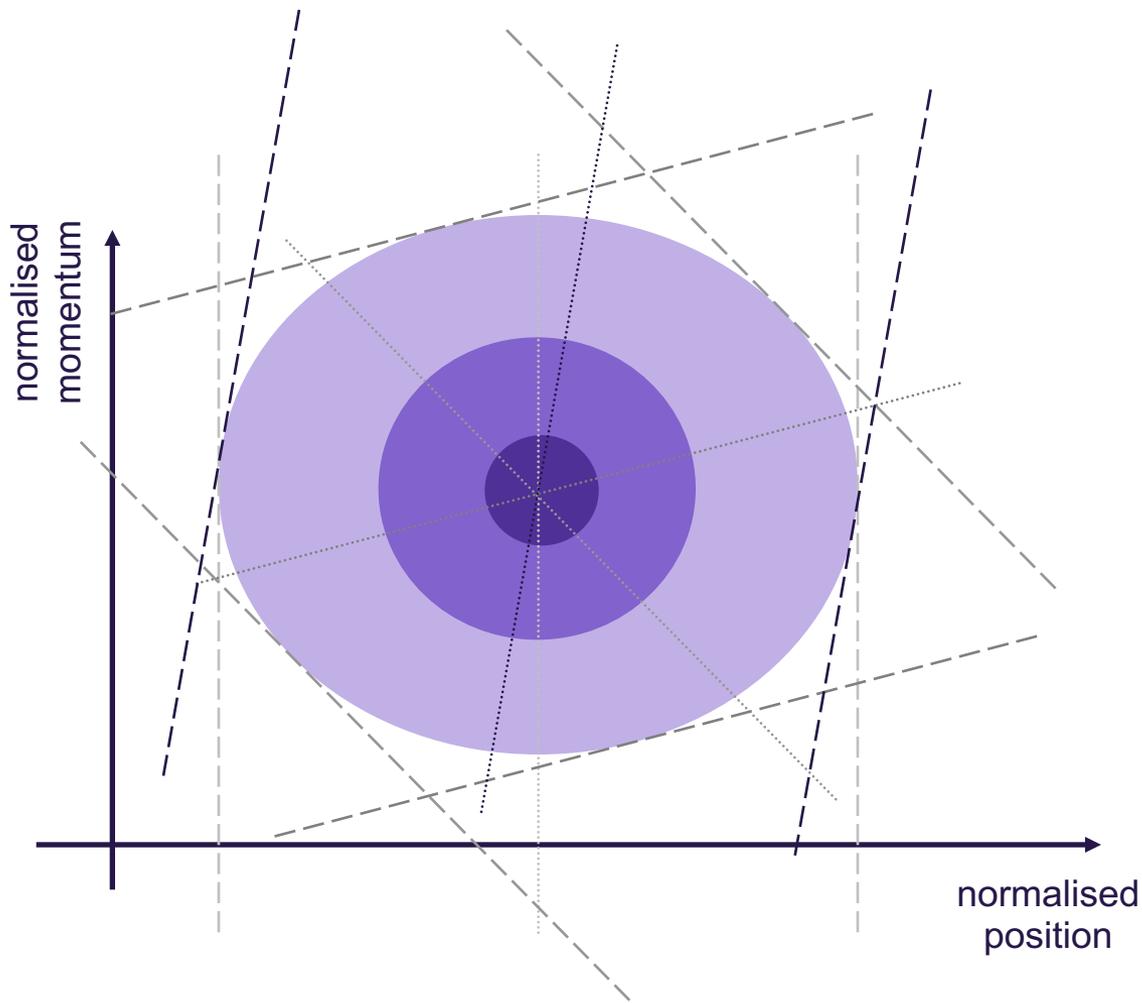
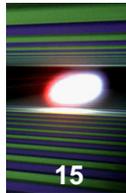
Principle of Optics Measurements



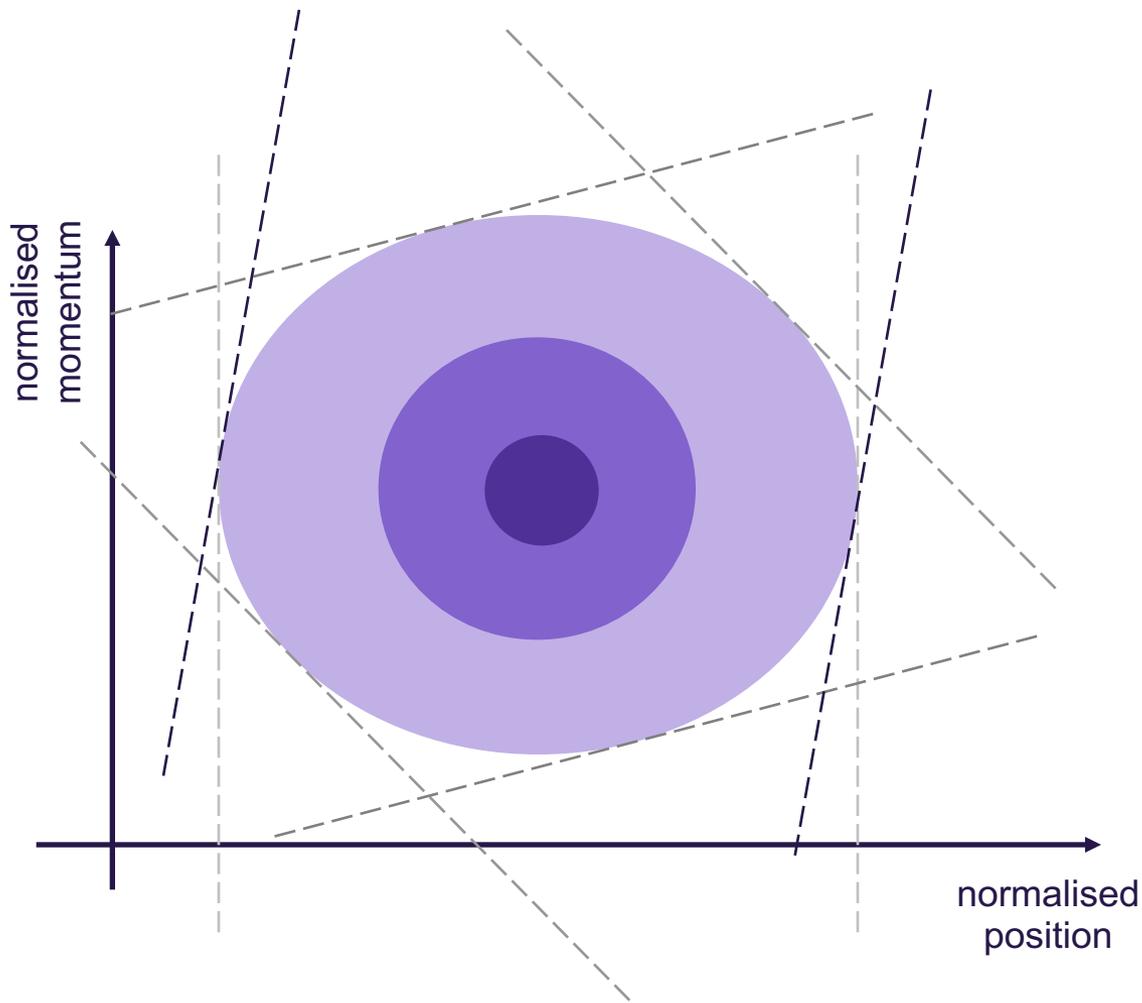
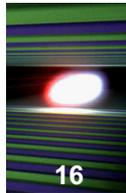
Principle of Optics Measurements



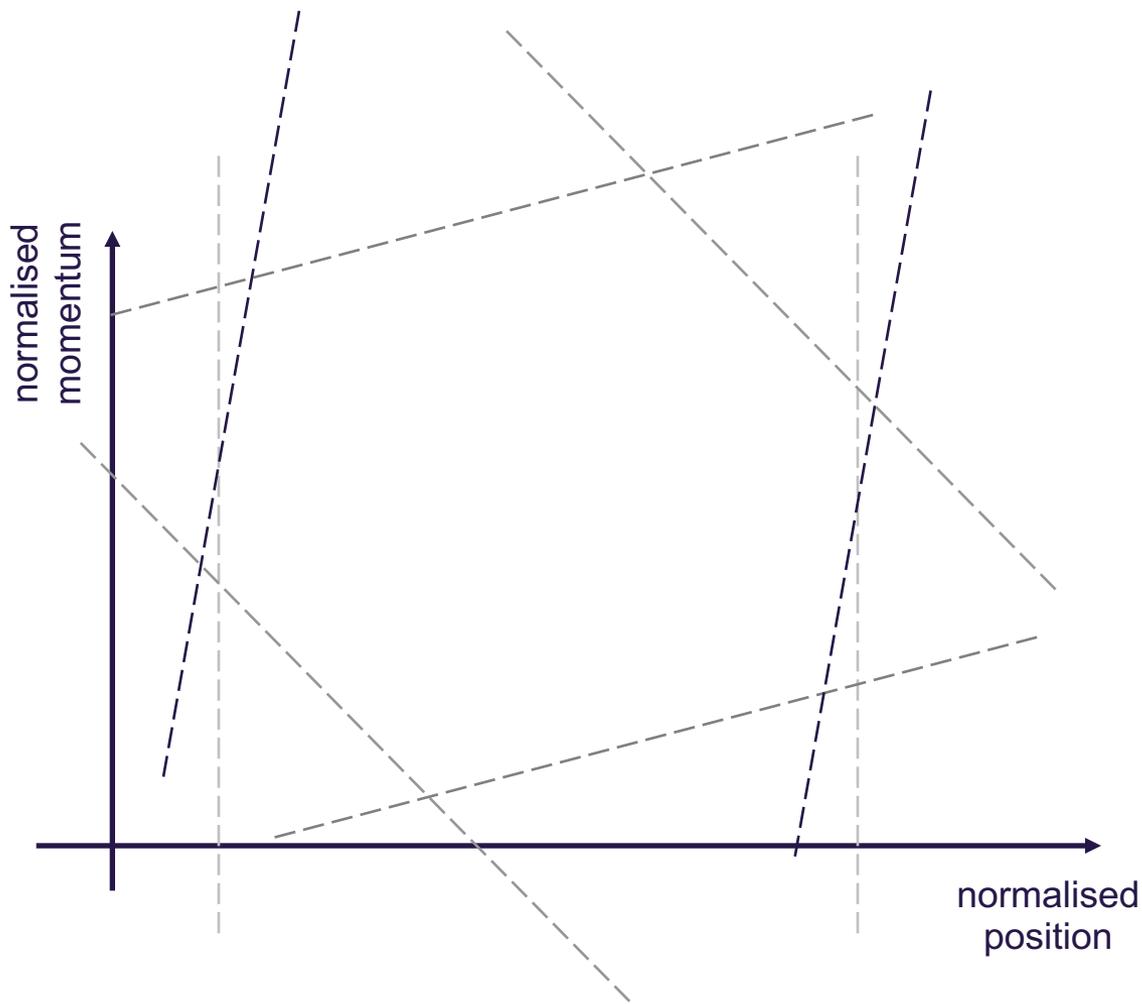
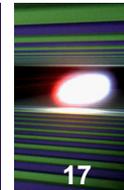
Principle of Optics Measurements



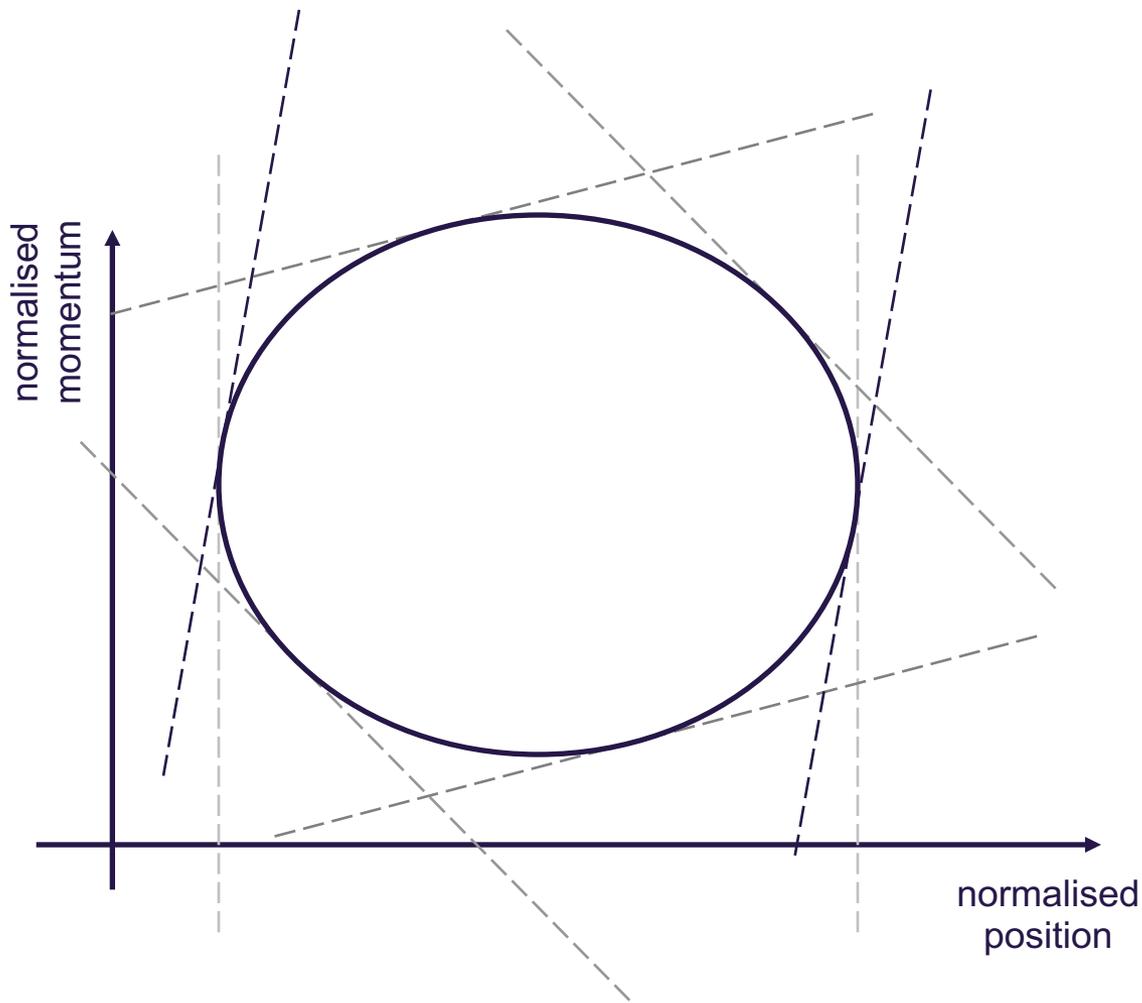
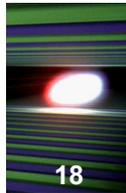
Principle of Optics Measurements



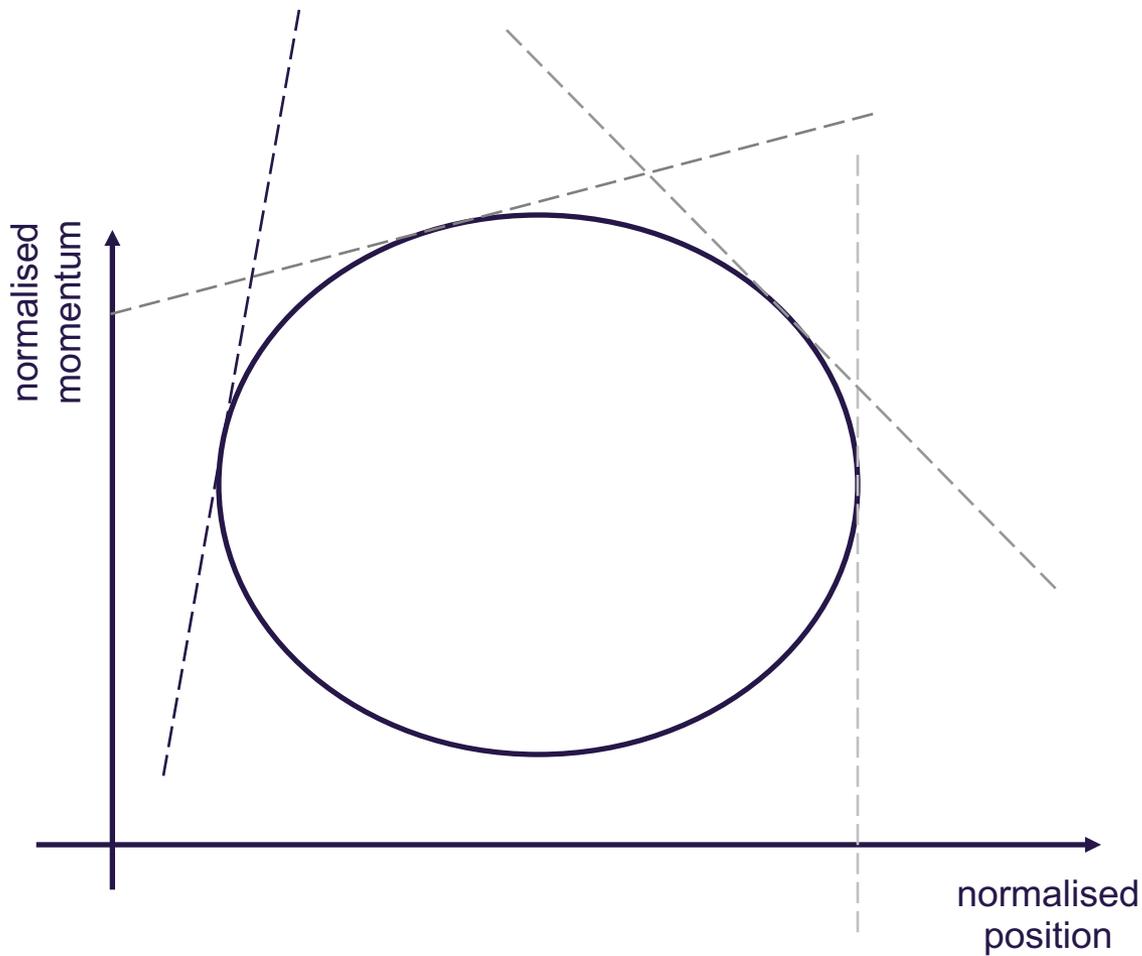
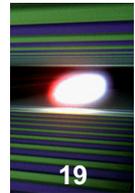
Principle of Optics Measurements



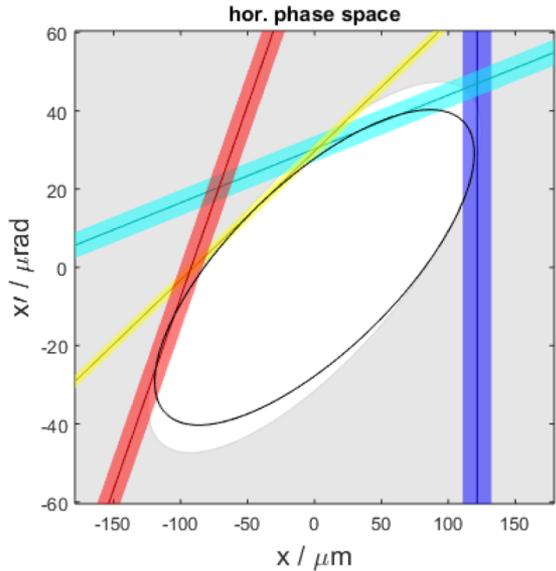
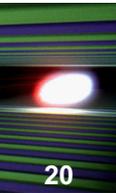
Principle of Optics Measurements



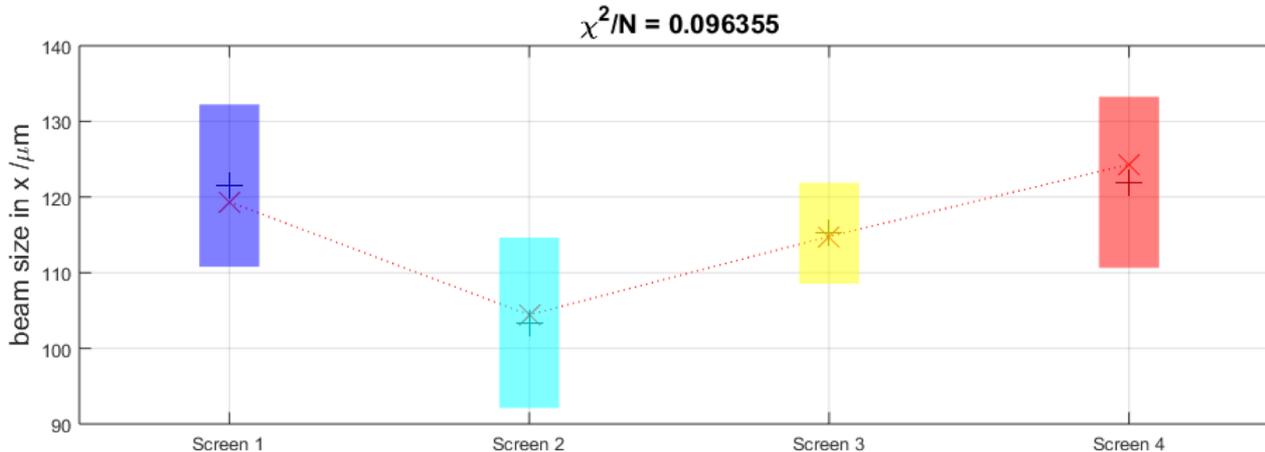
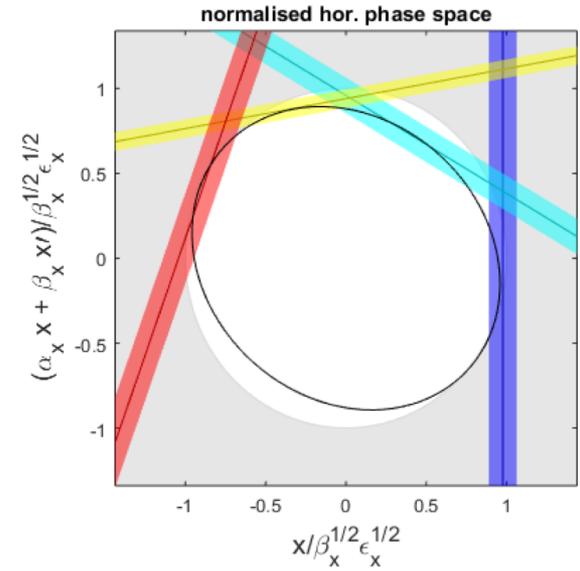
Principle of Optics Measurements



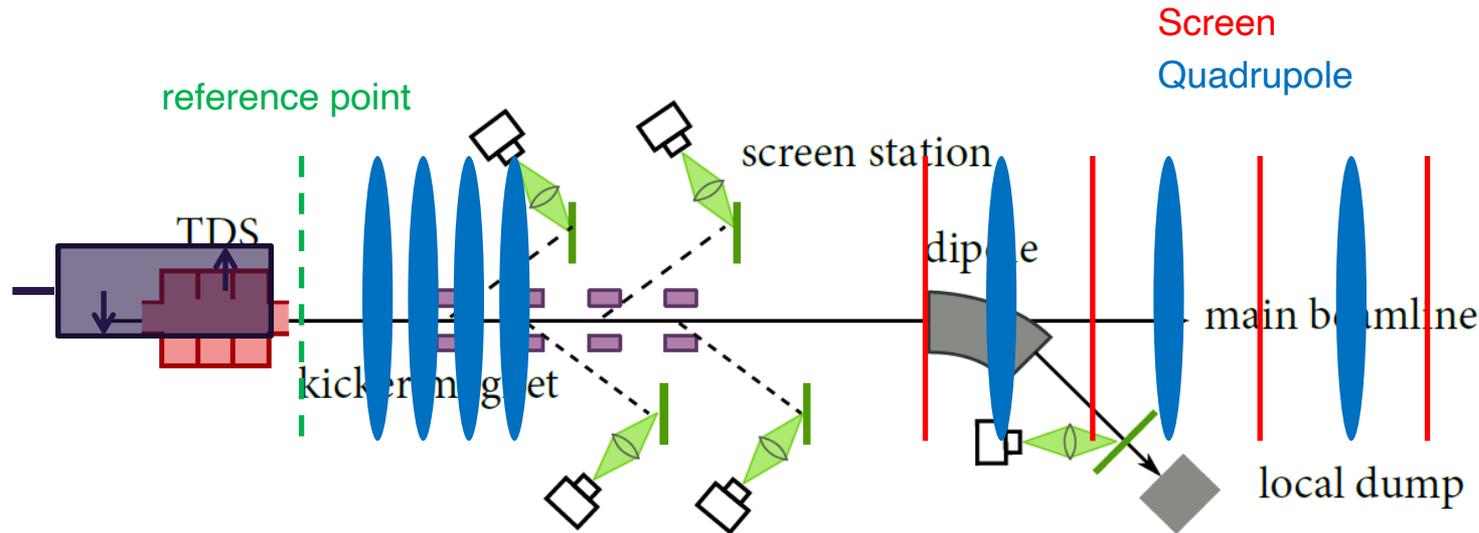
Measurement Fit Summary



- Different visualizations of the fit are displayed to judge measurement quality
- The design (white) and measured (black) ellipse should agree
- Measured ellipse (black) should touch all beam size measurement lines (colors)
- In normalised phase space the ellipse should be a circle



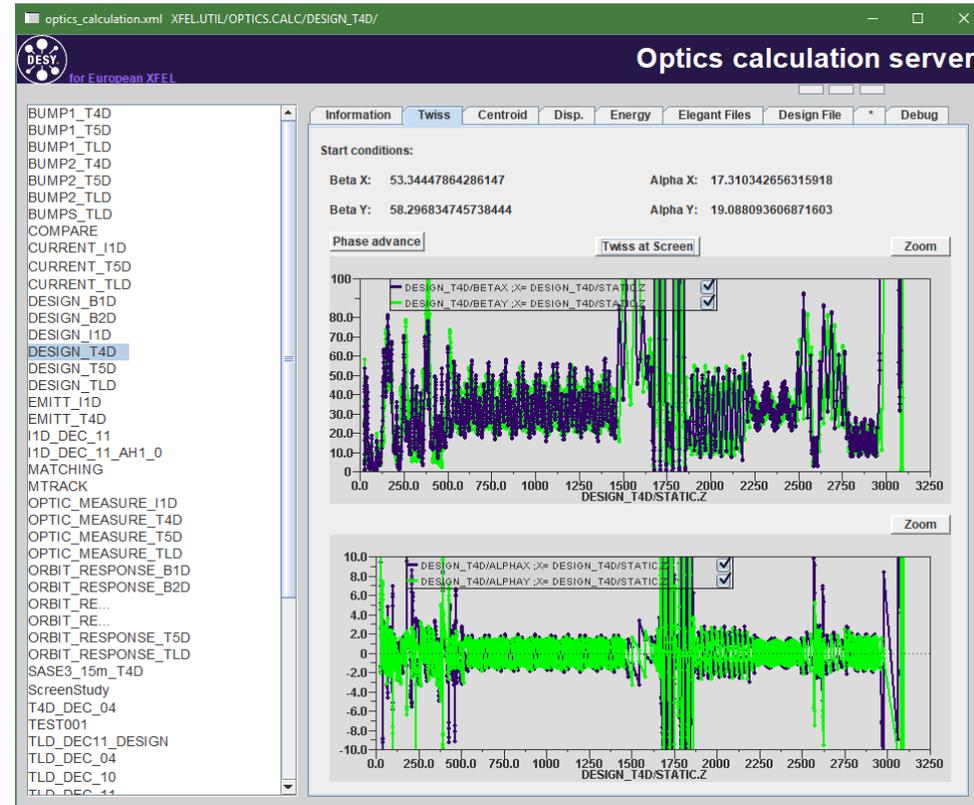
- Optics and Emittance is determined from beam size measurements:



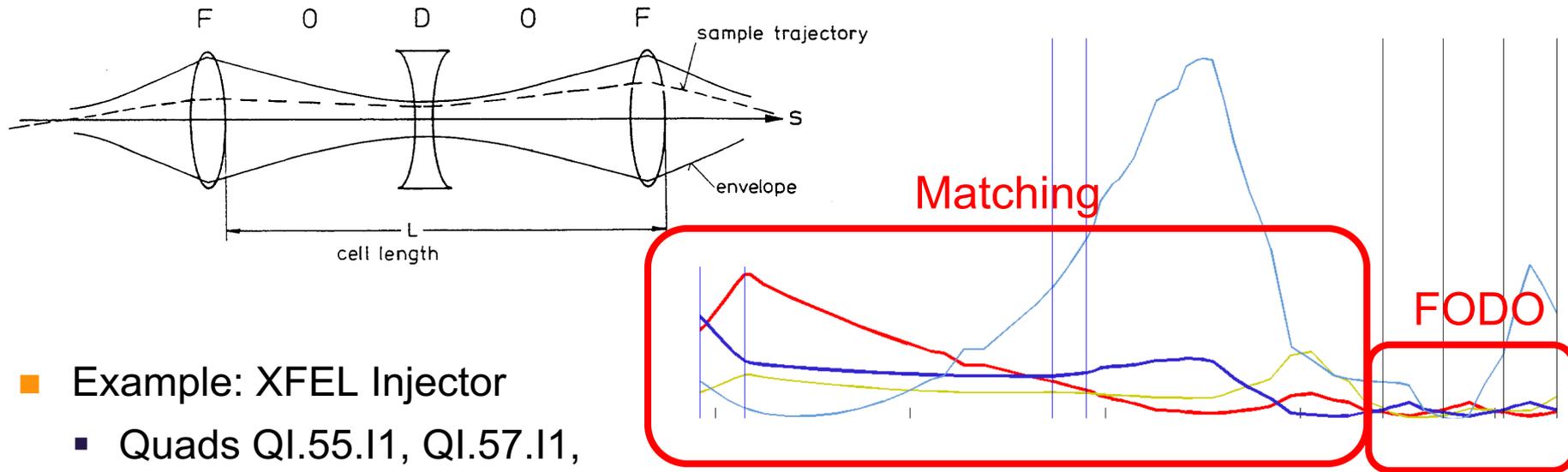
- Beam moments are determined at a reference point using either:
 - one screen while varying the quadrupole settings
 - at multiple positions along a constant lattice (FODO)
- Slice resolved measurements in combination with a transverse deflecting RF-structure (TDS)

Matching

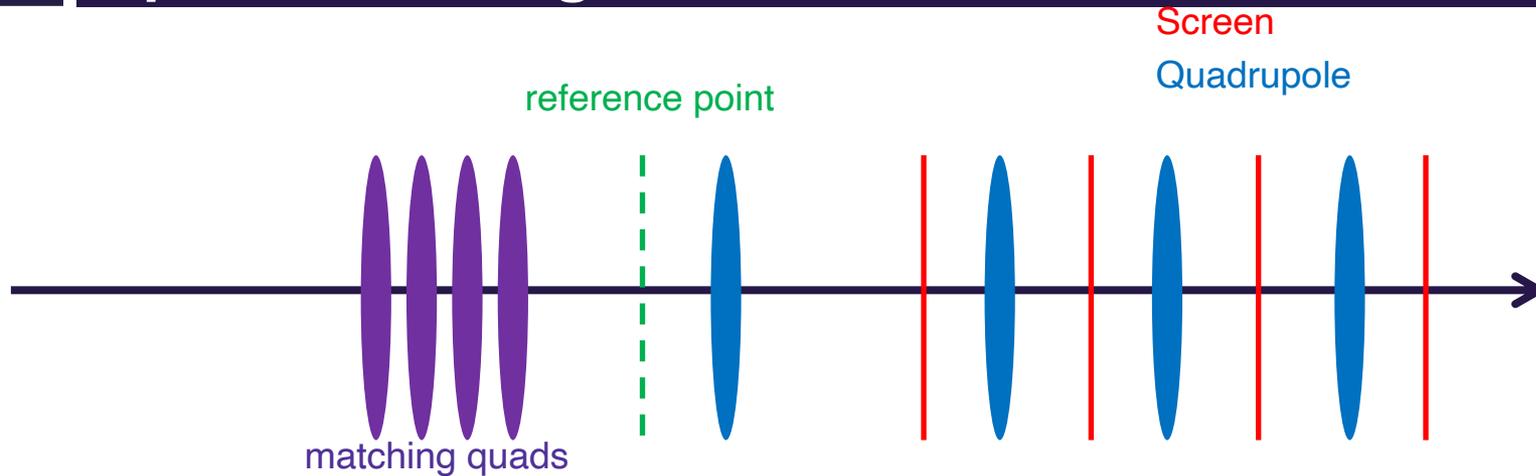
- Optics is designed for optimal beam transport, efficient collimation, FEL output power, ...
- Optics initial condition (after A1) determine the beam optics in the whole machine (different in storage rings)
- Deviations in the initial conditions or lattice inaccuracies have to be adjusted by matching quadrupoles



- Design optics in the Diagnostic Sections are defined by the periodic FODO lattice
 - Unique periodic solution

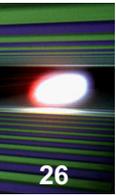


- Example: XFEL Injector
 - Quads QI.55.I1, QI.57.I1, and QI.59.I1 (same strength as QI.55.I1) define the periodic solution
 - Upstream quads match the beam from gun section to the periodic solution
 - Downstream quads are set assuming the periodic solution as a start e.g. transport to the I1D dump.



- A mismatched beam at a reference point can be “matched” by tuning upstream quads
- Results from a optics measurement are used from a matching tool to calculate a quad setup
- Another measurement is required to confirm improved BMAG
- Iterate until desired mismatch is reached (better than 1.1)

Matching or NOT Matching?

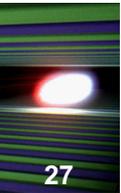


26

In standard operation we typically load a file from a previous SASE run. Therefore we can assume the configuration of the matching quads is correct if the gun is set correctly (otherwise SASE performance would be poor).

- Set machine (injector) on-crest (zero chirp and zero curvature) and energize the quads correctly
- If a file is loaded try to match without changing the quads – assuming the quads are set correctly before
 - vary gun phase
 - vary main solenoid
- Try matching with quads if gun phase and solenoid do not improve matching

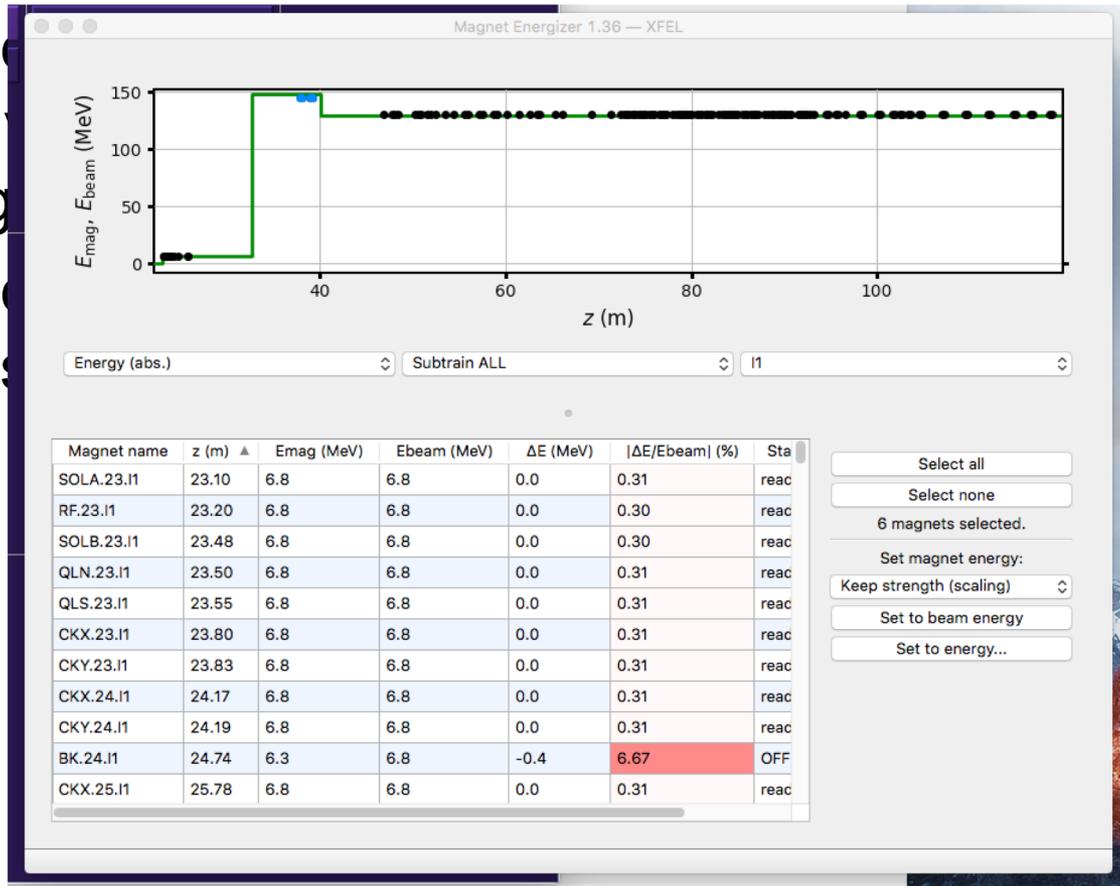
Energizing of injector cold quads



If matching with the quads is done on-crest the magnets between A1 and AH1 need to be:

- energized
- third derivative matching
- energized
- compressed

and
crest



RF sum I1

Sum Voltage ↑↓↑↓ . 0.00 H

Chirp ↑↑↓↓ . 0.00 H

Curvature ↑↓↑↓↑↓ . 0.00 H

Third Derivative ↑↓↑↓↑↓ . 0.00 H

ok ok

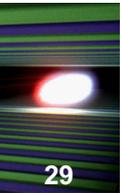
A1.I1 AH1.I1

↑↓↑↓ . 147.37 H ↑↓↑↓ . 21.05 H

↑↓↑↓↑↓ . 11.34 H ↑↓↑↓↑↓ . 169.26 H

I1

Tools at XFEL



The screenshot shows the XFEL Main Taskbar GUI with the following structure:

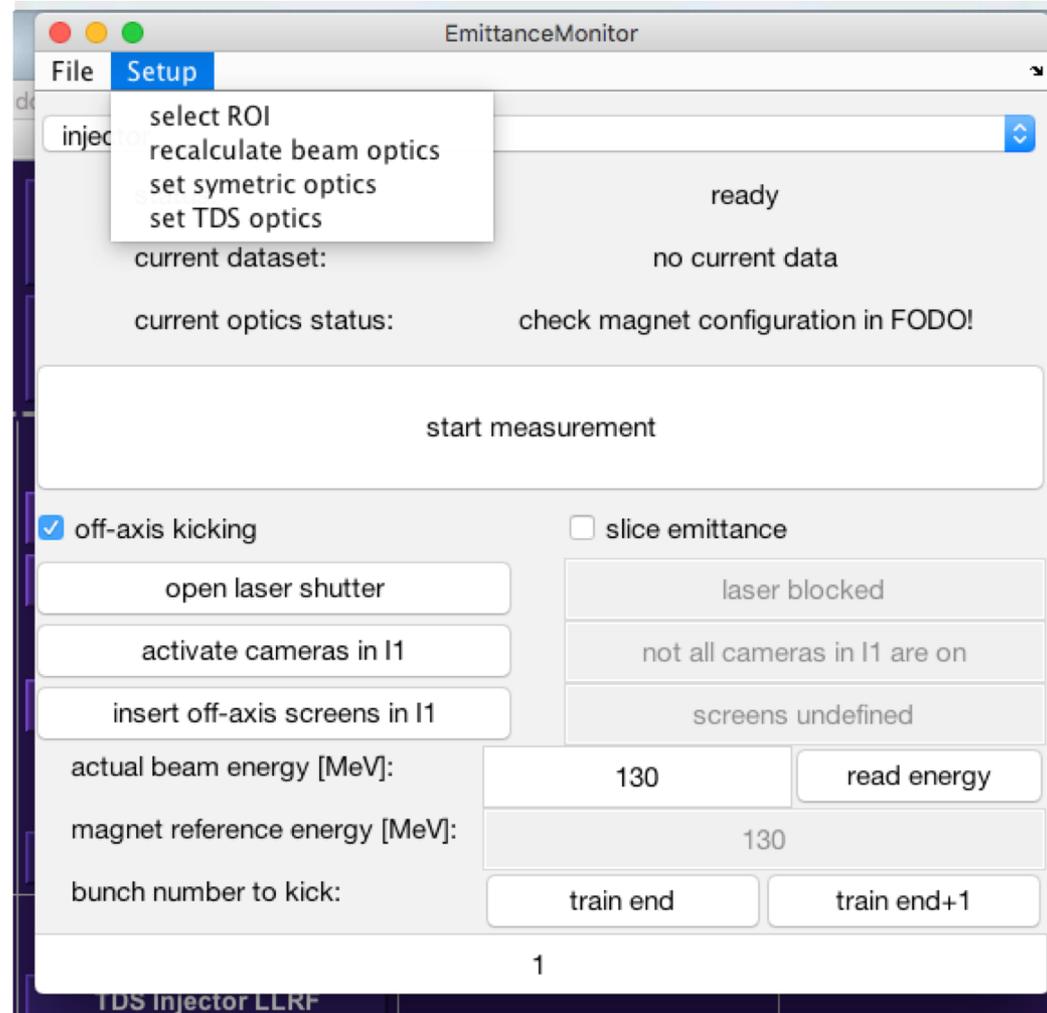
- Top Bar:** File View Help | 62Mb/8132Mb
- Navigation Bar:** Status, Operations Procedures, Feedbacks Automation, Diagnostics, Tools, Safety MPS, Injector RF, Orbit Photons, **Beam Dynamics** (highlighted), Magnets, Vacuum Cryo, Controls.
- Main Content Area:**
 - Beam Dynamics:** Emittance Monitor (highlighted), Multi Quad Scan GUI (highlighted), Slice Emittance (temp.), Multi Quad Scan GUI (old).
 - Longitudinal:** TDS Monitor, RF Tweak 5, TDS Tool (old), long. Parameter.
 - TDS:** TDS Injector LLRF, TDS BC2 LLRF, TDS Longitudinal Profile, TDS Bunch No., TDS BC2 Cond. Overview.
 - Trajectory:** Trajectory Response, Ocelot Orbit Correction, Trajectory Fit Server (exp.).
 - Optics:** Design Kick Server, Optics Calculation, Optics Measurement.
 - Miscellaneous:** Image Analysis Configurator, Diag Bunches Inj, Diag Bunches BC2.

- Unified Emittance and Optics Tool:
 - Projected Emittance
 - Slice Emittance (not in B1)
 - on-axis measurements
 - off-axis (presently only in I1)

- Optics Matching

- Can load old measurement data

- If kickers for off-axis screens are used a bunch number can be selected



- 2017
 - 52
 - 11
 - 13.03_M
 - 10
 - 09
 - 08
 - 07
 - 06
 - 05
 - 04
 - 03
 - 02
 - 01
- 2016
- 2015
- 2014
- 2013
- doc
- 2012

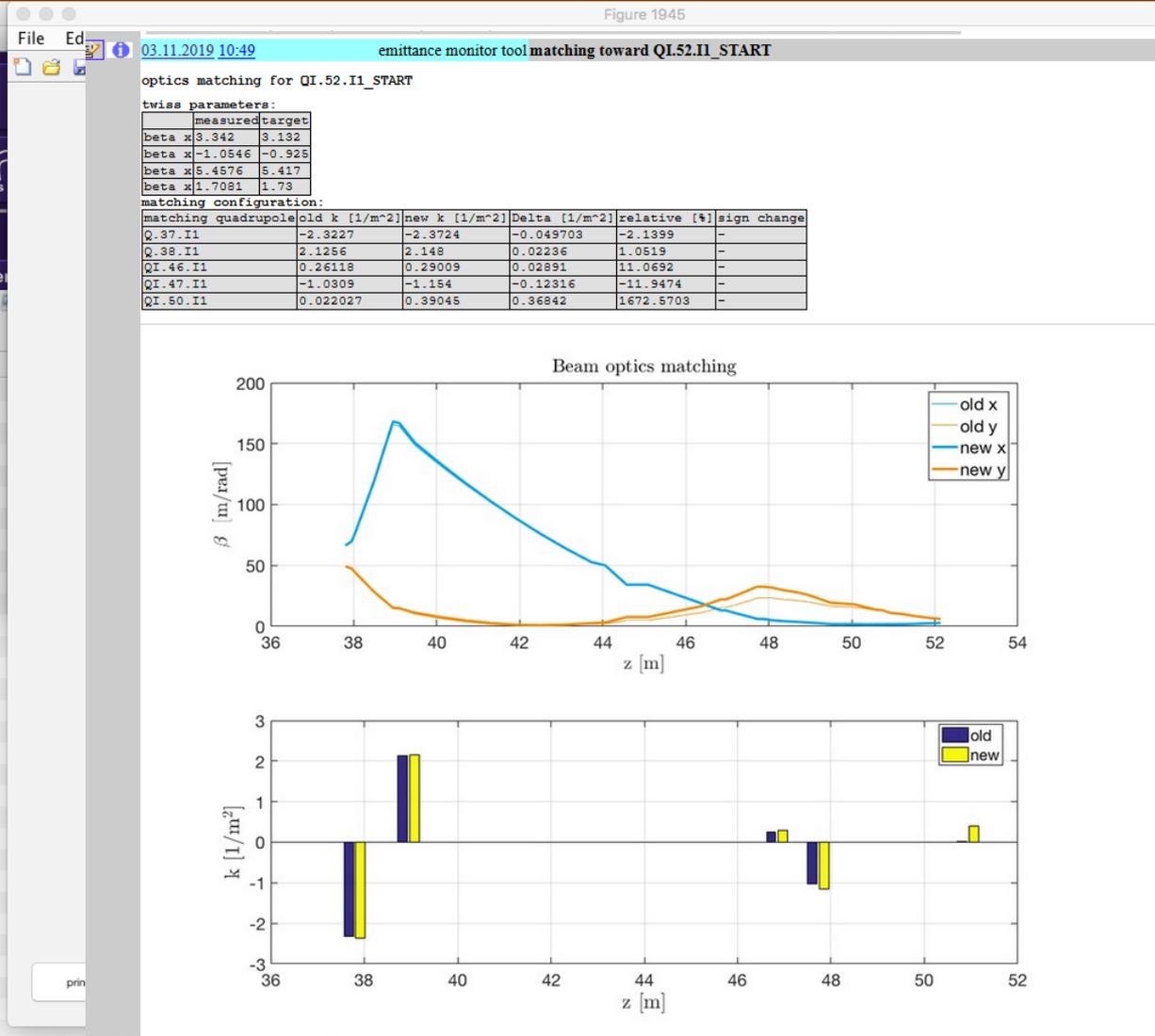
- View Current
- Hide Untagged
- All Errors
- All ToDo's
- Safety
- Schedule
- Access Requests
- Beam Time Request

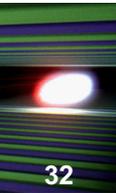
XFELBau Logbook

- Logbook Search
- Logbook Help

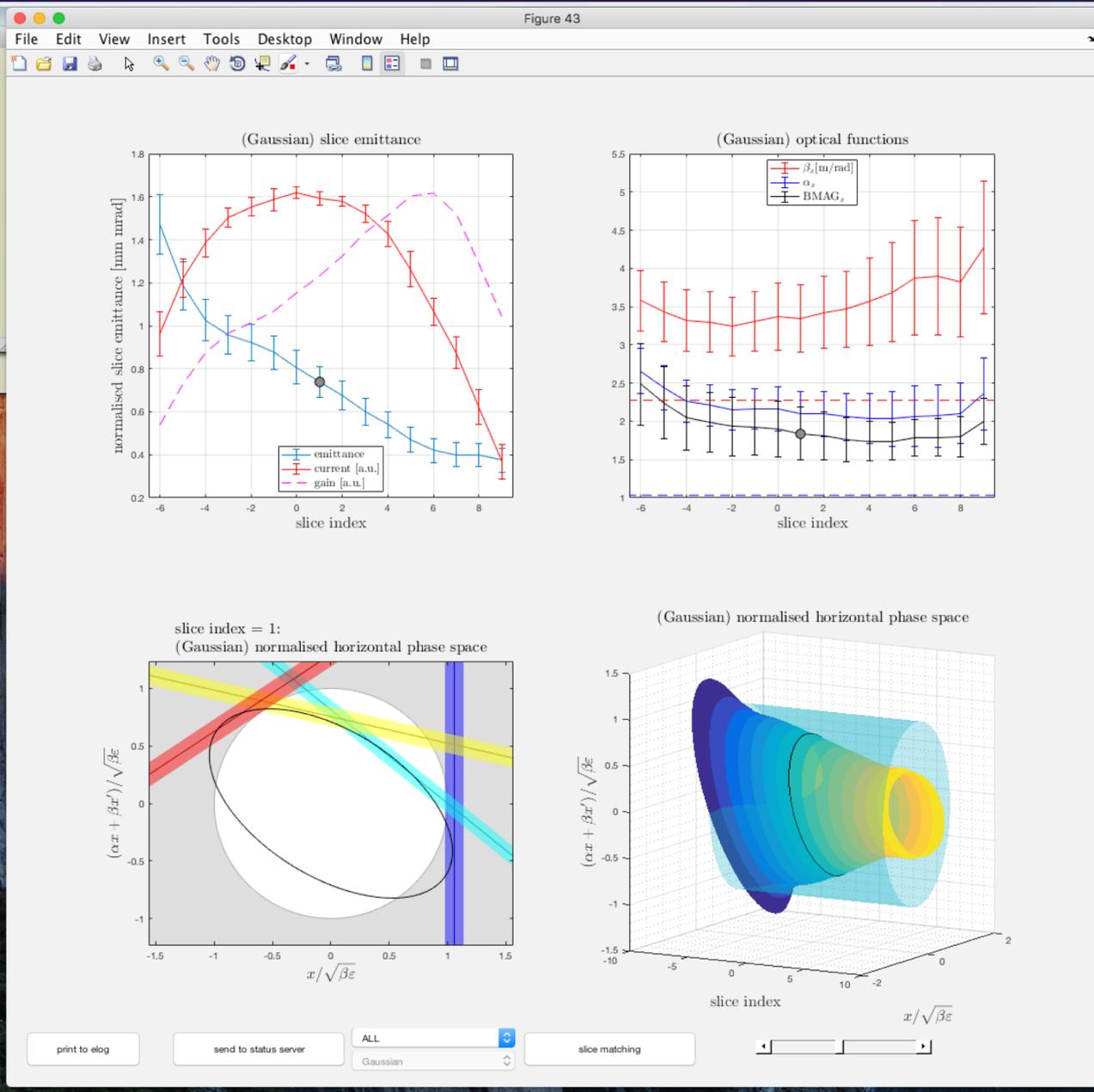
- XFEL.eu
- XFEL.desy
- XFEL Wiki

Printer: xfellog





- Using ... can be ...
- TDS n ...
- set ...
- TDS o ... set in ... (use d ...)



ready

current data

configuration in FODO!

distance

laser blocked

cameras in I1 are on

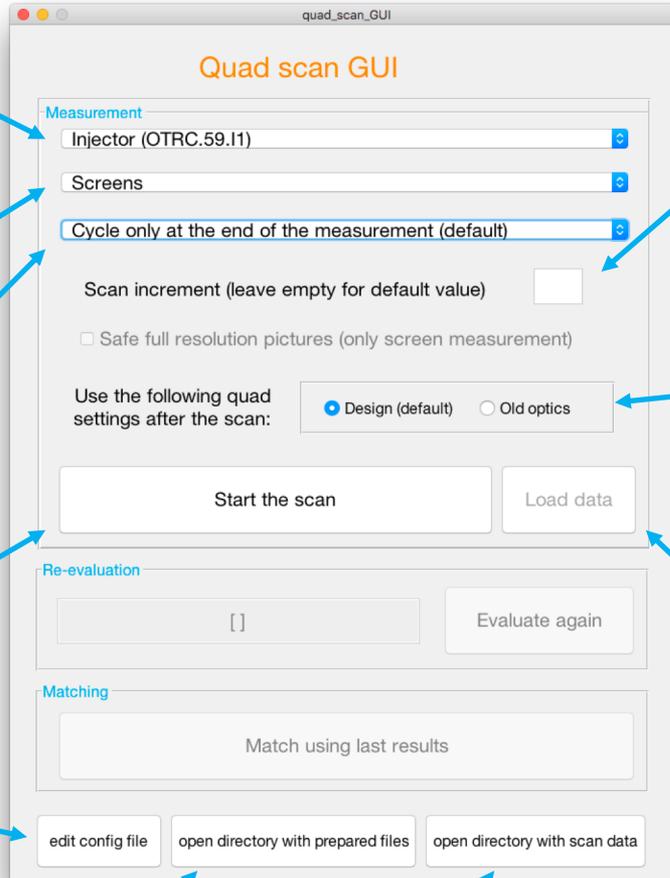
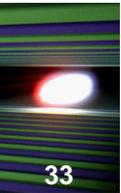
greens undefined

read energy

130

train end+1

Multi Quad Scan GUI



Select a beamline section

Select the measurement device: Screens or wires? The default device is automatically set for each beamline section.

Select the preferred cycling procedure.

Start the scan

It is necessary to change matching quads, wire scan detectors or something else? Press 'edit config file'.

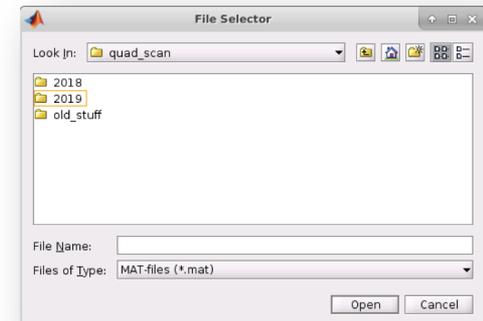
Access to the prepared quad scan files.

Access to all quad scan measurement data.

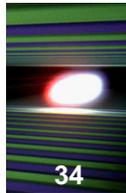
Increment: only every nth step of the measurement will be taken.

Chose beam optics after measurement: either design values or beam optics used before the measurement.

New button: load and plot old measurements. Opens a file selector GUI.



Measurement results for quad scans with screens



Well know measurement presentation after a quadrupole scan using screen as measurement devices.

quad_scan_GUI

Quad scan GUI

Measurement

Injector (OTRC.59.11)

Screens

Do not cycle at all

Scan increment (leave empty for default value)

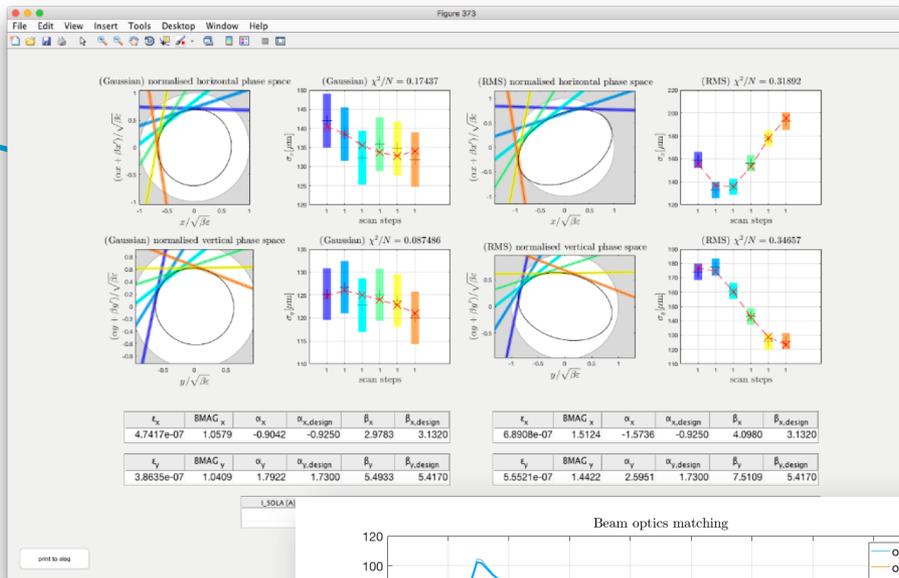
Safe full resolution pictures (only screen measurement)

Use the following quad settings after the scan: Design (default) Old optics

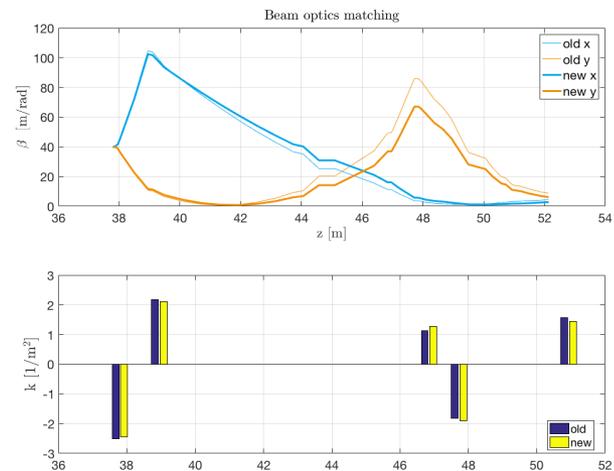
Re-evaluation

[3:14]

Matching

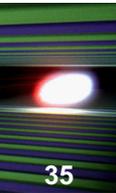


The matching routine uses either the last measurement or the last re-evaluation of the measurement data.

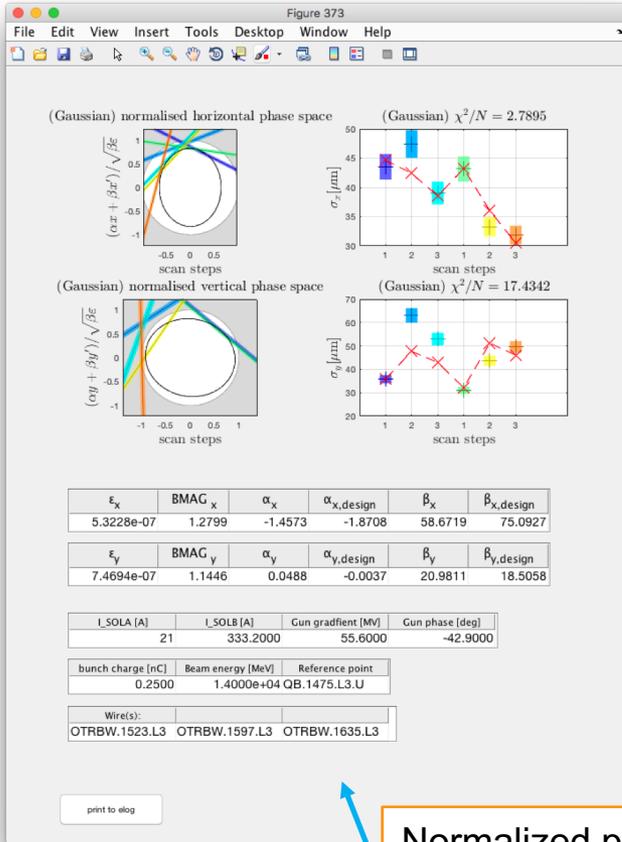


Typical result after matching calculation. This plot is only shown if the algorithm found a solution.

Measurement results for quad scans with wires



Signals from all wires and for all measurement steps

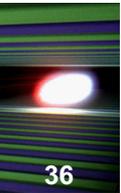


Normalized phase spaces and beam sizes as well crucial scan parameters from the measurement.



- Blue intensity traces indicate that the data from the respective detector is used for the evaluation.
- Thus, saturated signals should be presented in black, which means they are not considered in the evaluation.
- The upper plot is shown twice, one plot for each plane.

Deselecting single measurements



Use the following quad settings after the scan: Design (default) Old optics

Start the scan Load data

Re-evaluation

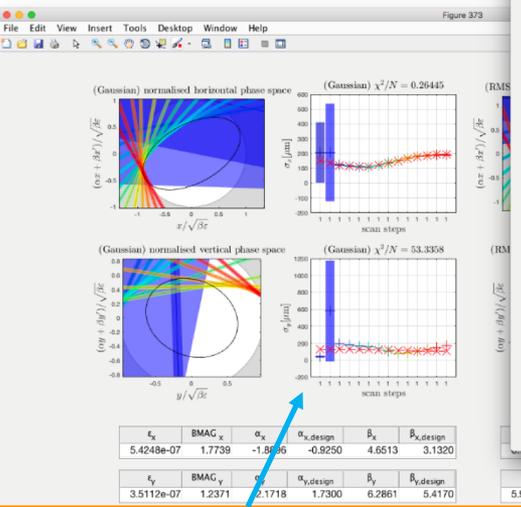
[3:14] Evaluate again

Matching

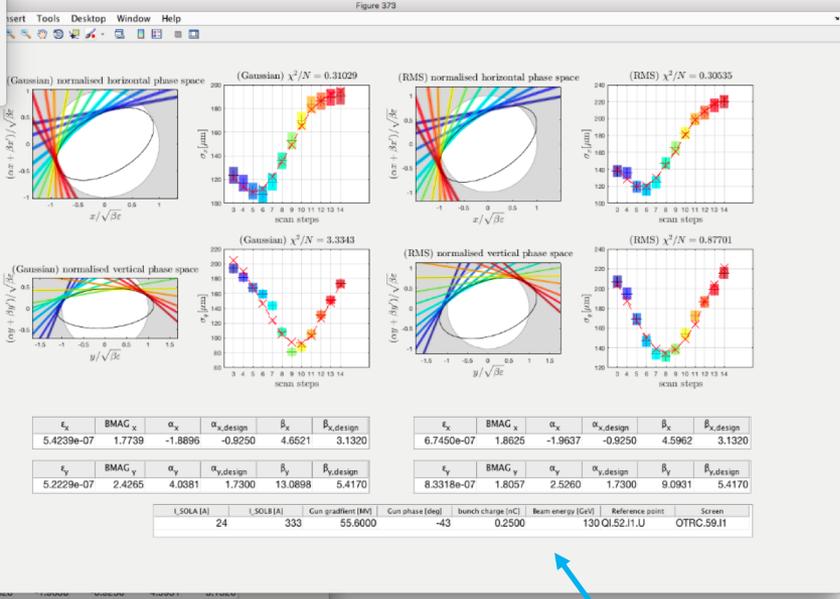
Match using last results

edit config file open directory with prepared files open directory with scan data

- It is possible to evaluate only a selection of the taken data steps.
- Write all step numbers that should into that field and press 'Evaluate again'.
- You can use MATLAB type vector definitions like [3:7] = [3 4 5 6 7].



The first two measurement steps were taken steps without beam.



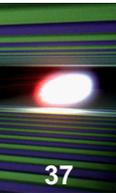
After deselecting the first two measurement steps

Be careful with the deselection of measurement steps and with the following evaluation of the data!

This functionality must only be used to deselect measurements steps that went clearly wrong (e.g. no beam).

It must not be used to deselect 'unwanted' measurement steps to improve e.g. emittance size or beam optics matching!

Camera Server Issues



37

XFEL CAMERA STATUS

Server

XFELCPUDI3011	XFELCPUDI5511	XFELCPUDI9411	XFELCPUDI204B1	XFELCPUDI240L2
0.60 %	1.50 %	0.50 %	87.78 %	0.60 %
XFELCPUDI416B2	XFELCPUDI463B2	XFELCPUDI1519L3	XFELCPUDI1601L3	XFELCPUDI1720CL
0.40 %	0.40 %	0.40 %	0.30 %	0.40 %
XFELCPUDI1828CL	XFELCPUDI1926TL	XFELCPUDI2017TL		
0.20 %	0.40 %	0.40 %		

Cameras on: **XFELCPUDI5511** Server Online All OFF

Name	Images	Light	Power	Server	Control
OTRL.50.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRC.64.I1D	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRC.59.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRC.58.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRC.56.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRC.55.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRL.48.I1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control
OTRD.64.I1D	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	On Off	Control

commonAll_In_One_Camera_Expert.xml XFELDIAG/CAMERA/OTRC.55.I1/

XFELDIAG CAMERA OTRC.55.I1

EXPERT Panel OTRC.55.I1

Camera ID: 22003129 **Offline**

Camera Connection: Server On, Power Off

Params: W: illegal prop., H: illegal prop., 16

Acquisition: Off, Frame: On, Activation: RisingEdge, Gain: Auto

Rate [Hz]: 0.0 (illegal property), Delay: illegal property

DAQ Mode: OFF

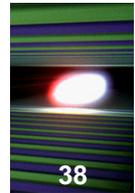
Camera SN: 22003129, Camera IP: illegal property, Interface IP: illegal property

Rate Control: On, Frame/s: illegal property, Bandwidth: illegal property

Image Format: In Mono8, Out Mono16, Truncate checked, Raw Size: illegal property

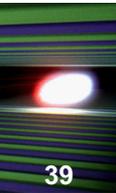
- Check CPU load
- Only the 4 cameras in the section should be powered
- Deactivate image acquisition

Camera (Server) Startup



The image displays three screenshots of the camera control software interface, arranged horizontally. Each screenshot shows a different camera configuration and its status.

- Left Screenshot:** Camera ID: 22003129. Status: Offline. Camera Connection: Server On, Power Off. Acquisition: Off. Rate [Hz]: 0.0. Delay: 0.000000. Fr Cnt: 0.000000. Camera SN: 22003129. Acq. Mode: SingleFrame. Exposure Mode: Auto. Black Level Selector: Value. Rate Control: On. Frame/s: 111111.1. Bandwidth (B/s): Max Act illegal property, MTU: 8228.
- Middle Screenshot:** Camera ID: 22003129. Status: Offline. Camera Connection: Server start up, Power On. Acquisition: Off. Rate [Hz]: 0.0. Delay: 0.000000. Fr Cnt: 0.000000. Camera SN: 22003129. Camera IP: illegal property. Acq. Mode: SingleFrame. Exposure Mode: Auto. Black Level Selector: Value. Rate Control: On. Frame/s: 111111.1. Bandwidth (B/s): Max Act illegal property, MTU: 8228.
- Right Screenshot:** Camera ID: 22Basler avA2300-25gmDSY#0030531E90... Status: Online. Camera Connection: Server On, Power On. Acquisition: Off. Rate [Hz]: 0.0 (max 27.3). Delay: 0.0. Fr Cnt: 0.0. Camera SN: 22003129. Camera IP: 169.254.70.10. Interface IP: 169.254.70.1. Acq. Mode: Continuous. Exposure Mode: Off. Black Level Selector: All. Binning: X bin 1, Y bin 1. Offset: 0, Width: 2330, Height: 1750. Gamma: 0.000. Raw Size (B): 4077500. Test Image: Off.

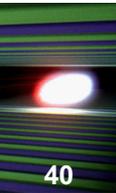


- Default Values of cameras are set if Emittance Monitor is used to activate them
- Proper settings:
 - IN: Mono12Packed
 - OUT: Mono16
 - Truncate: -1
 - Exposure: maximum 1000
 - Acquisition: off
 - Frame: on
 - “Tool Box” checkboxes: off

The screenshot displays the 'Expert Panel' for camera OTRC.55.11. The interface is divided into several sections:

- Camera Connection:** Server On, Power On (checked), Expert On.
- Params:** W: 2360, H: 1776, 16.
- Images:** Start / Stop (checkbox), Frame 0.
- Scale X/Y:** X Scale (checked), Y Scale (checked).
- image comp. jpeg:** off, rotation: 90, Flip: H (checked), V (checked).
- Tool Box:** BG. Subst., Histogram, X & Y Spectrum, ROI 1, ROI 2, Write Images, Write ROIs.
- Acquisition (def=off):** Off, Frame On, Activation RisingEdge, Gain Auto Off, Select All, Value 150.
- Trigger:** Src Line1, Delay 0.0, Fr Cnt.
- DAQ:** Mode, Sender: OFF.
- Configuration:** Cfg Restore (checked), Camera SN: 22003129, Camera IP: 169.254.70.10, Interface IP: 169.254.70.1.
- Acq. Mode:** Continuous.
- Exposure Mode:** Off, Value 8000.
- Black Level Selector:** All, Value 32.
- Binning:** X bin 1, Y bin 1, Width 2330, Height 1750.
- Configuration (Doocs):** User2, SAVE, Hold Off, LOAD, Auto Save (sec) 0.
- Rate Control:** On, Frame/s 64, Bandwidth (B/s) Max 139233292, Act 112497884, MTU 8228.
- Image Format:** In Mono8, Out Mono16, Truncate 0.00000000E+00, Gamma 0.000, Pixels 4077500, Raw Size (B) 4077500, Test Image Off.

Image Analysis Server Expert Tool



- Check if you can see images updating in "Continuous" mode
- In case of problems => restart image analysis server via the Doocs watchdog (call expert RC, BB, J. Wilgen, or any controls person with perm

The screenshot displays the 'WatchdogOverview.xml' interface for the XFEL system. The main window shows a list of services with their status and CPU usage. The 'SVR.IMAGEANALYSIS' service is highlighted with a red box. A secondary window titled 'commonFCT_CODE_117.xml' is open, showing configuration options for the 'SVR.IMAGEANALYSIS' service, with the 'Restart Server' button also highlighted in red.

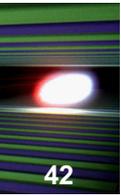
Service Name	Status	Online	Offline	CPU	State	Errors
SVR.BLMDMA	ok	Online	0	22.08%	sleeping	0
SVR.BLM	ok	Online	0	53.85%	sleeping	0
SVR.BHM	ok	Online	0	23.08%	sleeping	0
SVR.IMAGEANALYSIS	ok	Online	0	1.70%	sleeping	0
SVR.X2TIMER	ok	Online	0	1.10%	sleeping	0
SVR.DAMCBPM	ok	Online	0	10.39%	sleeping	0
SVR.SIS8300DMA	ok	Online	0	3.70%	sleeping	0
SVR.ADCSCOPE	ok	Online	0	-	-	-

Configuration window details for SVR.IMAGEANALYSIS:

- Program: UID: 406, GID: 406, PID: 2720, NICE: 0, PRI: 20, STATE: 2
- Operator: -1, 513
- Expert: 4945, 1433
- Customer: 0, 0
- SIZE: 2231912 kb, CPU-Util: 1.60%
- RSIZE: 77484 kb, time: 524598 msec
- START_SIZE: 2158180 kb
- Restarts (RPC): 7 Nr.
- SVR_Errors: 0
- RPC_LIBNO: 610489147, SVR LOC: XFELCPUDI5511_SVR
- Waittime for rpc_check after start: 120
- Min timedelay for restart: 150
- Kill after x rpc_check fails: 2
- x restarts: 2
- Last Start Times: 2019-11-28 11:26:02, 2019-11-28 06:29:36, 2019-11-27 10:30:58, 2019-11-25 10:32:36
- Buttons: Restart Server, Start and Online, Stop and Offline, Start, Stop, Kill Server

- Cameras die fast!
 - On average each camera was exchanged once during the injector run
 - Deactivate cameras every time you don't need them for a foreseeable time
 - Emittance Monitor Tools gives a list off all activated emittance cameras at shutdown and offers to close them
 - Do it.....

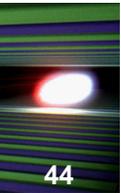




Thank You for Your Attention...

Literature:

- M. Minty and F. Zimmermann, “Measurements and control of charged particle beams”, Springer, Berlin, Heidelberg, New York, 2003.
- F. Loehl, “Measurements of the Transverse Emittance at the VUV-FEL”, DESY-THESIS 2005-014, TESLA-FEL 2005-03
- J. Rossbach and P. Schmueser, “Basic Course on Accelerator Optics”



Beam size at *point i* as a function of initial beam moments:

$$\sigma_{x,i}^2 = \langle x_i^2 \rangle = R_{11}^i \langle x_0^2 \rangle + R_{12}^i \langle x_0'^2 \rangle + 2R_{11}^i R_{12}^i \langle x_0 x_0' \rangle$$

From the beam moments emittance (and twiss parameters) are determined:

$$\varepsilon_x = \sqrt{\langle x_0^2 \rangle \langle x_0'^2 \rangle - \langle x_0 x_0' \rangle^2} \quad \begin{pmatrix} \beta_{x_0} \\ \alpha_{x_0} \\ \gamma_{x_0} \end{pmatrix} = \begin{pmatrix} \langle x_0^2 \rangle / \varepsilon_x \\ -\langle x_0 x_0' \rangle / \varepsilon_x \\ \langle x_0'^2 \rangle / \varepsilon_x \end{pmatrix}$$

In an ideal measurement three data points are sufficient:

$$\begin{aligned} \sigma_{x,1}^2 &= \langle x_1^2 \rangle = R_{11}^1 \langle x_0^2 \rangle + R_{12}^1 \langle x_0'^2 \rangle + 2R_{11}^1 R_{12}^1 \langle x_0 x_0' \rangle \\ \sigma_{x,2}^2 &= \langle x_2^2 \rangle = R_{11}^2 \langle x_0^2 \rangle + R_{12}^2 \langle x_0'^2 \rangle + 2R_{11}^2 R_{12}^2 \langle x_0 x_0' \rangle \\ \sigma_{x,3}^2 &= \langle x_3^2 \rangle = R_{11}^3 \langle x_0^2 \rangle + R_{12}^3 \langle x_0'^2 \rangle + 2R_{11}^3 R_{12}^3 \langle x_0 x_0' \rangle \end{aligned}$$

In a real measurement more than three data points are taken and the beam moments are determined by a least square fit:

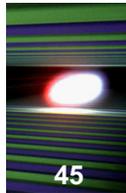
$$\chi^2 = \sum_i \left[\langle x_i^2 \rangle - \left(R_{11}^i \langle x_0^2 \rangle + R_{12}^i \langle x_0'^2 \rangle + 2R_{11}^i R_{12}^i \langle x_0 x_0' \rangle \right) \right]^2$$

unknowns to be determined by the measurement

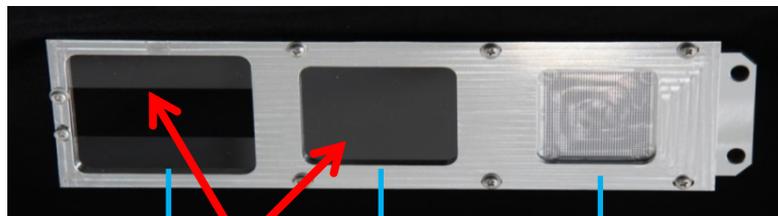
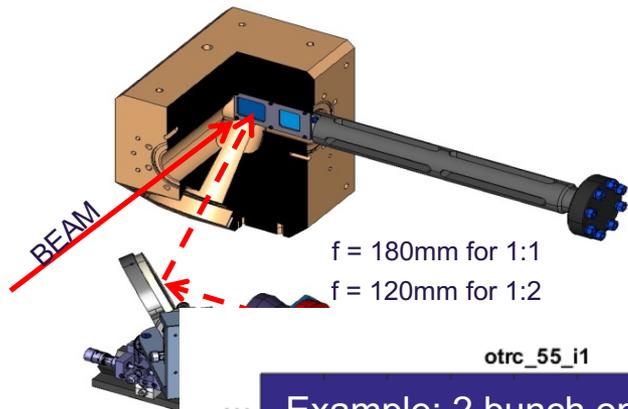
determined by diagnostics (screens / Image Analysis Server/ wire-scanner)

provided by beam dynamics (Optics Server)

Screen Station for European XFEL

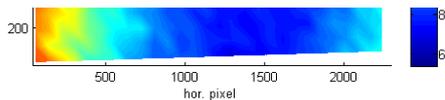
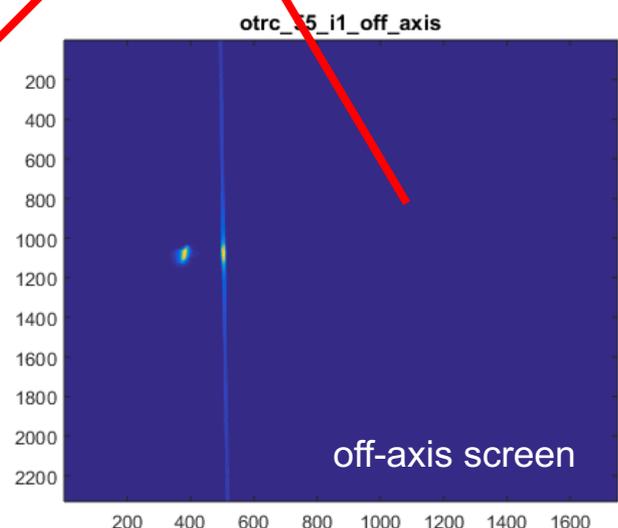
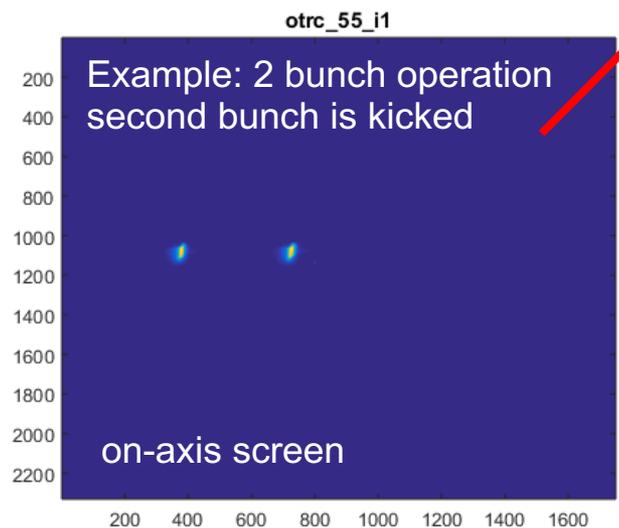
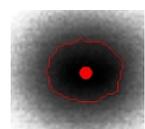


monitor setup

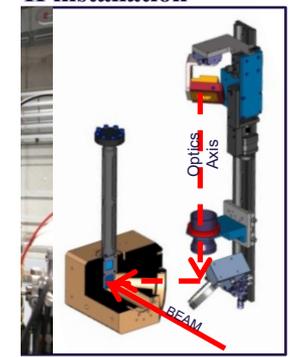


dot grid target (spot \varnothing .50mm)
 200 μ m thick LYSO screen (on-axis)
 2 half 200 μ m thick LYSO screens (off-axis)

optical



II installation

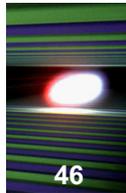


on geometry

lution
(unction)

Slide thanks to G. Kube

Ch. Wiebers et al. Proceedings of IBIC2013, Oxford, UK



```

"EmittanceMonitor"
R2013b (8,2,0.701) 64-bit (maci64)
August 13, 2013

To get started, type one of these: helpwin, helpdesk, or demo.
For product information, visit www.mathworks.com.

set section...
load ROI configuration
calculate transfer matrices in I1
Elapsed time is 0,612424 seconds.
phase advance in x/y : 76,28 deg / 74,69 deg
periodic solution in FODO at OTRC.55,I1 :
beta x/y = (2,3509,2,9357)
alpha x/y = (1,2222,-1,4439)
set section...
load ROI configuration
calculate transfer matrices in I1
Elapsed time is 0,319308 seconds.
phase advance in x/y : 76,28 deg / 74,69 deg
periodic solution in FODO at OTRC.55,I1 :
beta x/y = (2,3509,2,9357)
alpha x/y = (1,2222,-1,4439)
    
```

EmittanceMonitor

File Setup

injector

status: ready

current dataset: no current data

current optics status: Phase Advance: 76.28 deg / 74.69 deg

start measurement

close laser shutter

deactivate cameras in I1

remove screens in I1

laser shutter open

cameras in I1 on

off-axis screens in I1 inserted

off-axis kicking

take new background

fully remove screens

slice emittance

use "Optics Server"(TM)

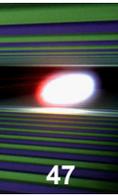
automatic gain control

match beam

actual beam energy [MeV]: 0 read energy

magnet reference energy [MeV]: 130

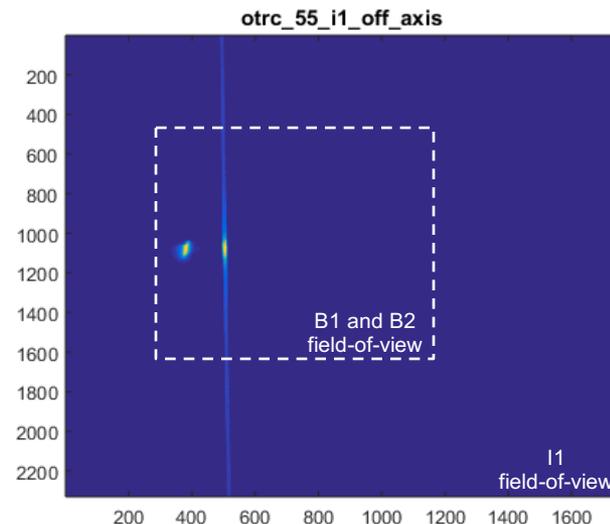
bunch number to kick: 1 train end train end+5

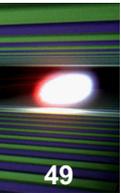


- Screens Inserted correctly / Cameras activated / ...
 - Use buttons on the tool
- Is the Orbit good?
 - Check if beam is on screen?
 - In case of off-axis measurement try on-axis
 - or start kickers manually
- Are the magnets properly set?
 - Strength and magnet energy
 - => check phase advance
 - » projected emittance: (76/76) deg
 - » slice emittance: (76/45) deg
- Are the cameras working properly?
- Is the Image Analysis Server in operation?
 - ROI configuration?

- Area of off-axis screens is smaller
 - Make sure the kicked beam hits them

- Screens in B1 and B2 are of the same size but the imaging on the chip is 1:1 (factor 2 in each plane compared to I1)
 - Field-of-view is 2.54 cm in diagonal
 - If beam is not visible insert screen in question and move beam with orbit correctors





EmittanceMonitor

File Setup

injector

status: ready

current dataset: no current data

current optics status: Phase Advance: 76.28 deg / 74.69 deg

start measurement

close laser shutter laser shutter open

deactivate cameras in I1 cameras in I1 on

remove screens in I1 off-axis screens in I1 inserted

off-axis kicking slice emittance

take new background use "Optics Server"(TM)

fully remove screens automatic gain control

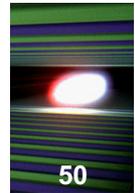
match beam

actual beam energy [MeV]: **0** read energy

magnet reference energy [MeV]: 130

bunch number to kick: 1 train end train end+5

Manual Setting of energy



EmittanceMonitor

File Setup

injector

status: ready

current dataset: no current data

current optics status: Phase Advance: 76.28 deg / 74.69 deg

start measurement

close laser shutter laser shutter open

deactivate cameras in I1 cameras in I1 on

remove screens in I1 off-axis screens in I1 inserted

off-axis kicking slice emittance

take new background use "Optics Server"(TM)

fully remove screens automatic gain control

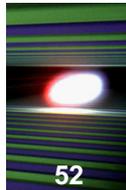
match beam

actual beam energy [MeV]: 130 read energy

magnet reference energy [MeV]: 130

bunch number to kick: 1 train end train end+5

Optics Options



EmittanceMonitor

File Setup

injection select ROI

recalculate beam optics

set symmetric optics

set TDS optics

ready

no current data

current optics status: Phase Advance: 75.96 deg / 75.96 deg

start measurement

close laser shutter

laser shutter open

deactivate cameras in I1

cameras in I1 on

remove screens in I1

off-axis screens in I1 inserted

off-axis kicking

slice emittance

take new background

use "Optics Server"(TM)

fully remove screens

automatic gain control

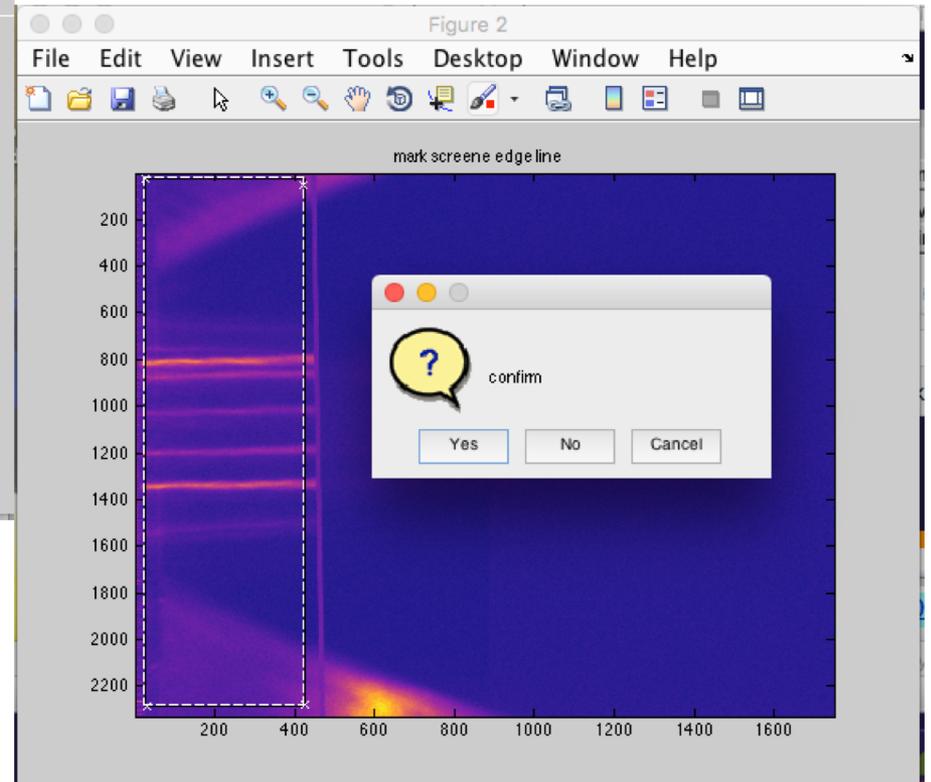
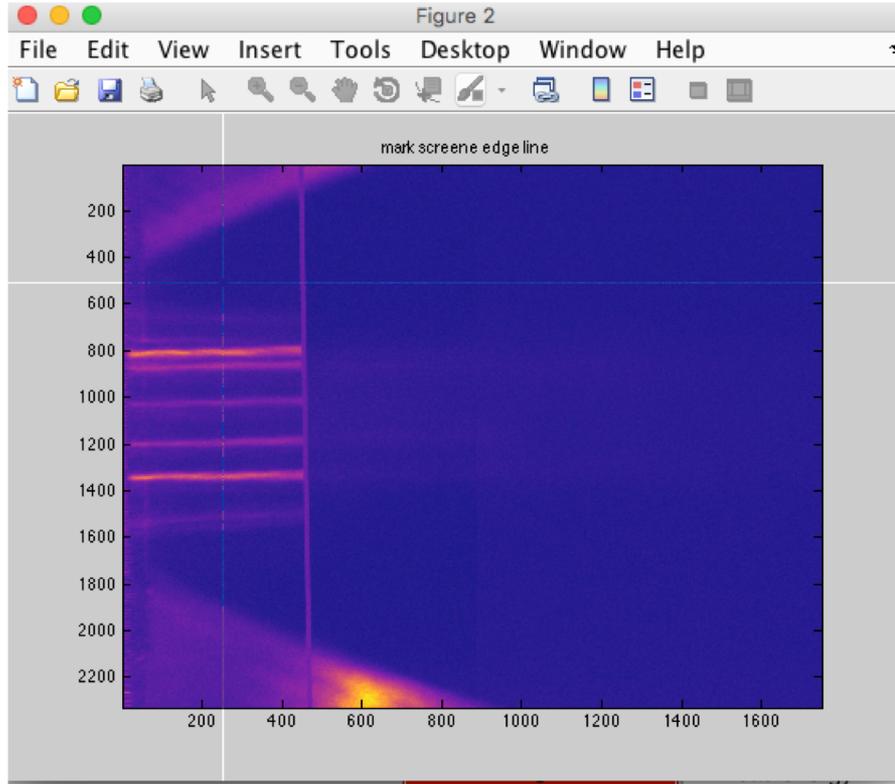
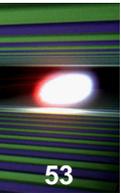
match beam

actual beam energy [MeV]: 130 read energy

magnet reference energy [MeV]: 130

bunch number to kick: 1 train end train end+5

ROI Configuration Tool

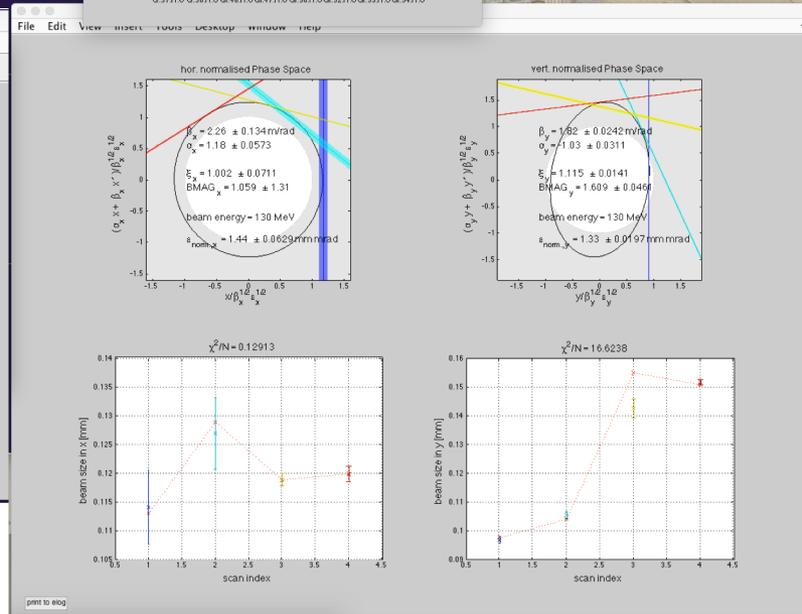
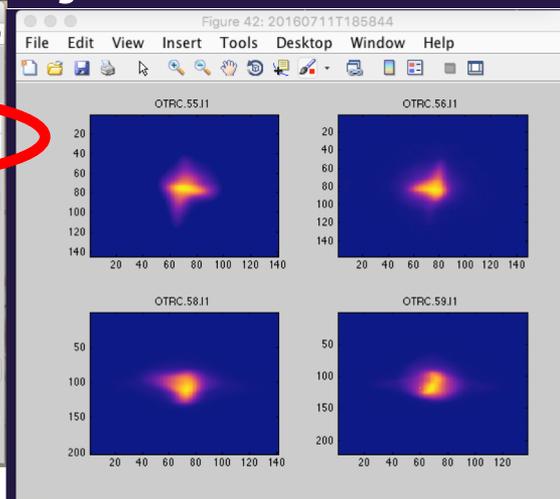
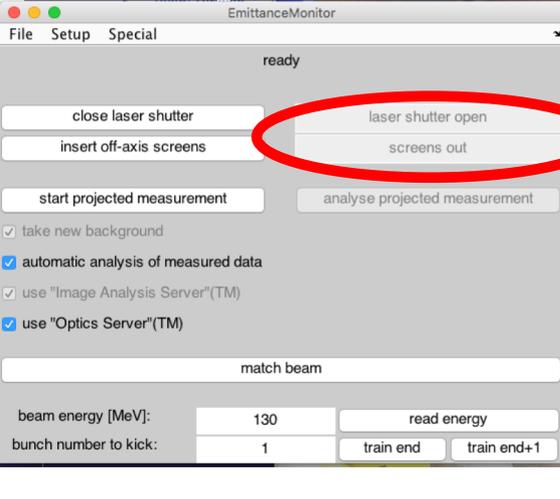
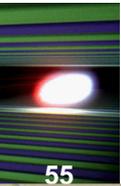


On-Axis Projected Measurements

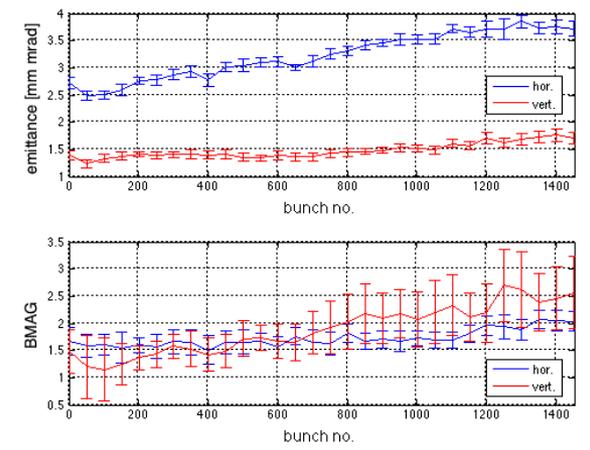
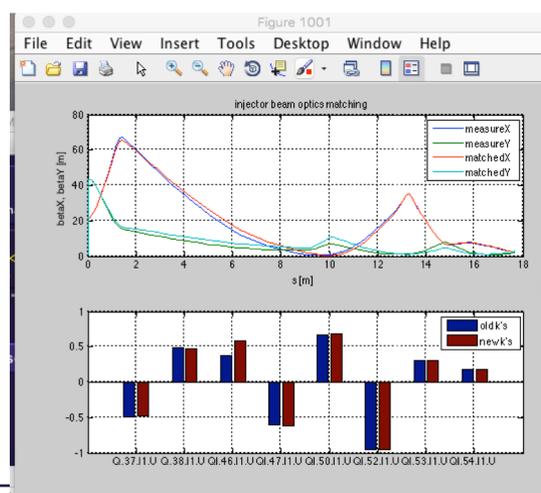
- Most reliable
- Takes more time than other methods (~ 5 minutes)
- Does not require kickers or TDS systems operational
- Only first bunch
- Should be the first choice for startup after shutdown etc.

	alpha meas.	alpha design	beta meas.	beta design	BMAG	alpha match	beta match	BMAG new
horizontal	1.0714	1.2902	2.7999	2.4228	1.5118	1.2896	2.4232	1.0008
vertical	-0.4316	-1.0193	2.5373	2.7787	1.6890	-1.0189	2.7787	1.0004

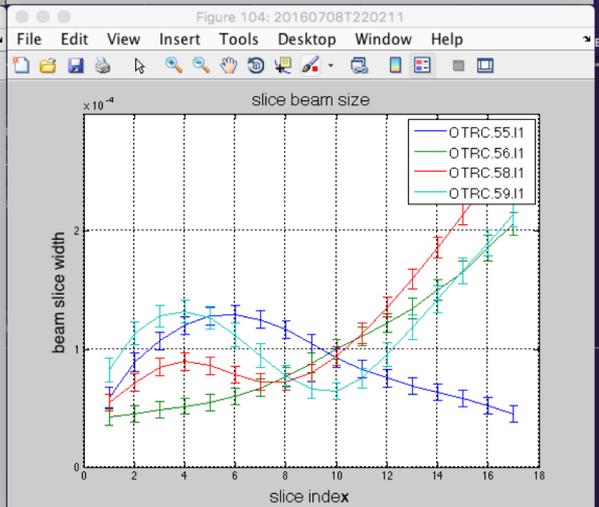
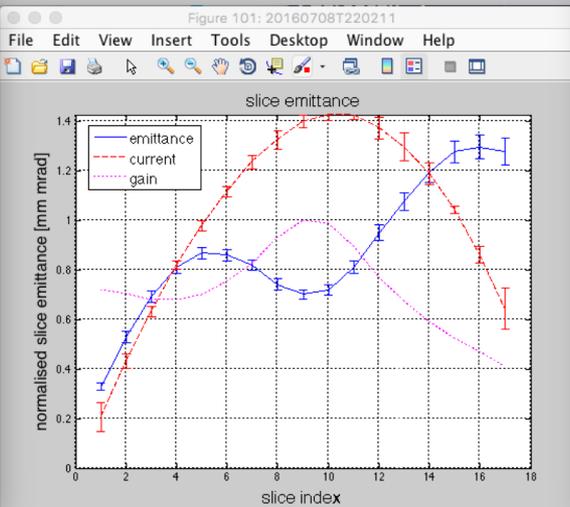
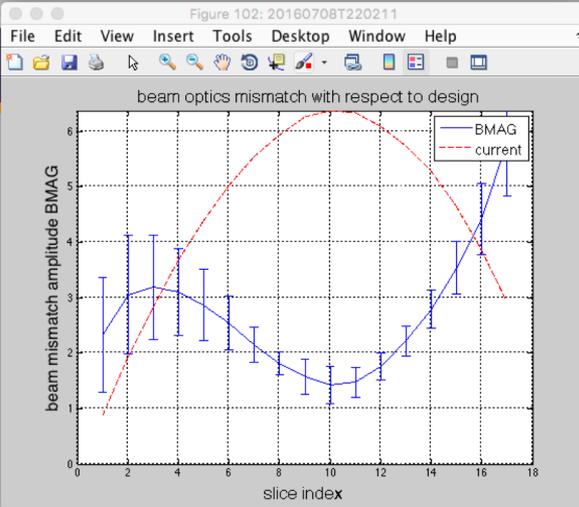
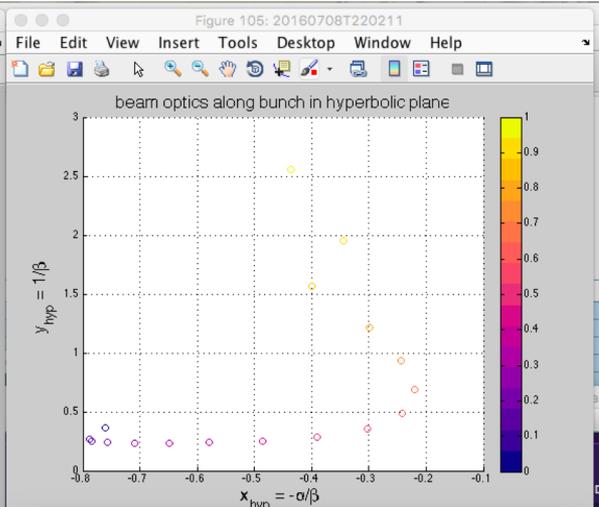
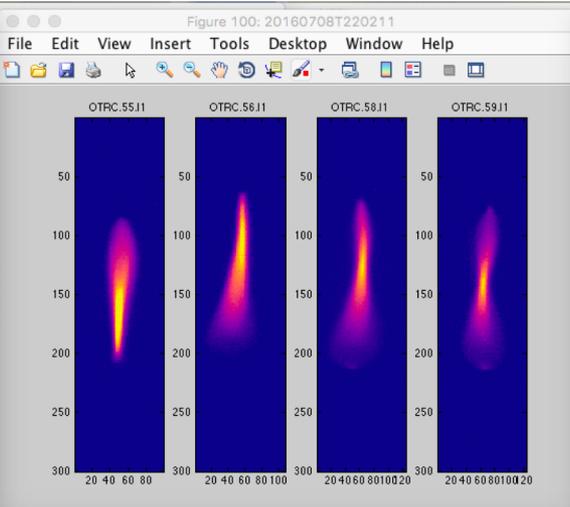
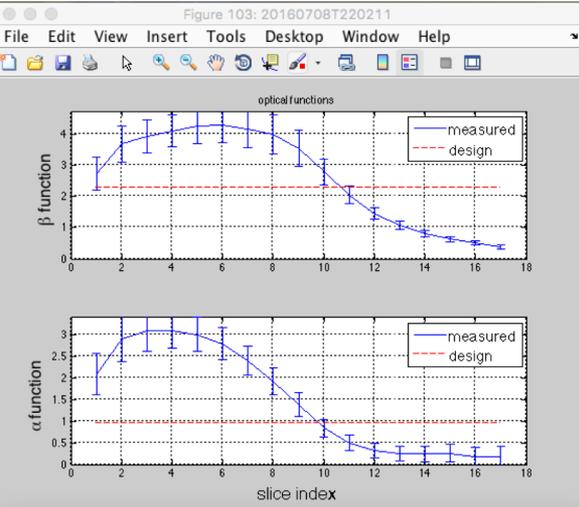
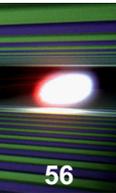
Off-Axis Projected Measurements



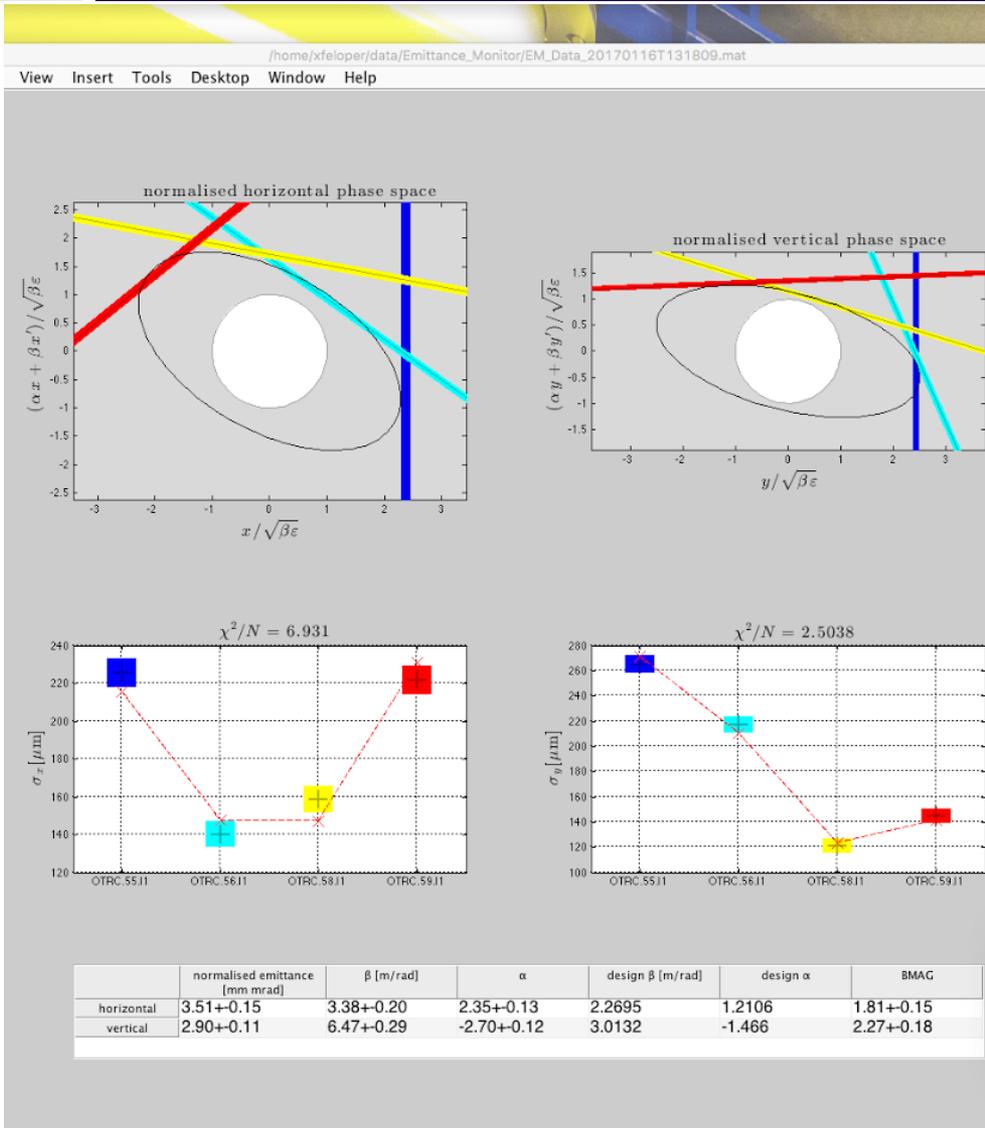
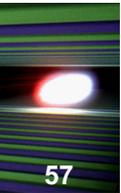
- Use of kickers allows for much faster measurements (about 20s)
- Orbit and optics mismatch needs to be good
- Allows for measurements of other than the first bunch
- Make sure that the energy chirp is removed
- Main tool for tuning of projected emittance



Slice Emittance Measurements



Combined Tool Results



EmittanceMonitor

File Setup Special

injector

status: geht gleich los

current dataset: EM_Data_20170116T131809.mat

start projected measurement analyse projected measurement

block laser mal sehen

activate cameras mal sehen

insert screens in I1 mal sehen

automatic analysis of measured data

take new background

Figure 1001

File Edit View Insert Tools Desktop Window Help

injector beam optics matching

measureX
measureY
matchedX
matchedY

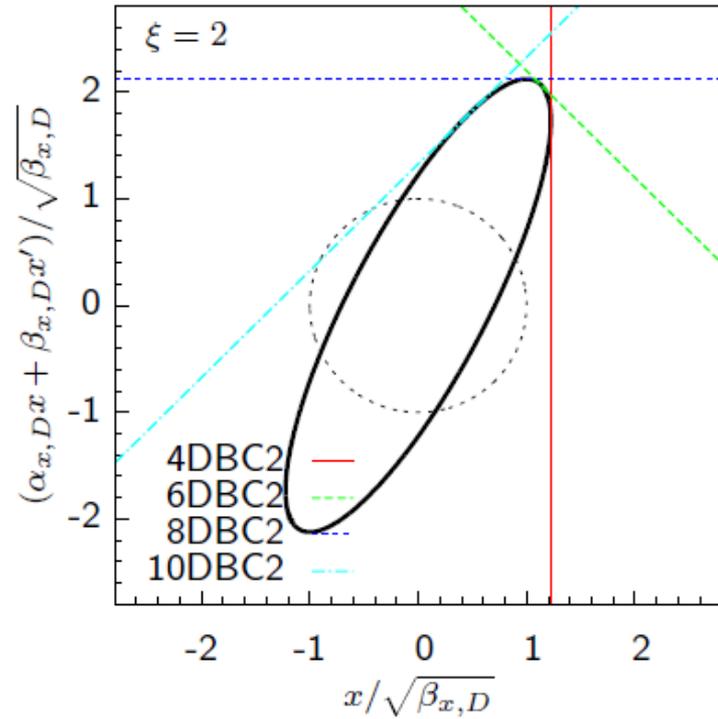
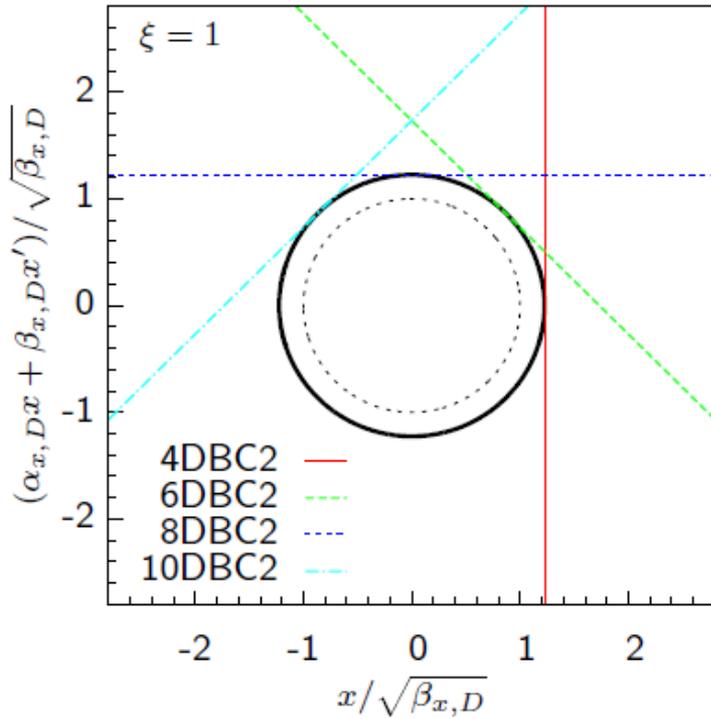
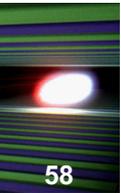
select one...

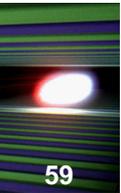
Do you want to apply the new quad settings?

YES and cycle YES, dont cycle NO

0 -1.465032e+00 3.013726e+00

0.0000





- A mismatched beam (with respect to design optics) is not only bad because of the resulting unknown beam transport – a mismatched beam makes the measurement itself unreliable
- If the beam is well matched in a periodic measurement lattice statistic beam size errors contribute with equal weights and partially compensate each other
- Do not trust measurements with mismatch higher than $\text{BMAG} = 2$
- Beam should be matched to $\text{BMAG} < 1.1$

$$\xi = \frac{1}{2} (\gamma\beta_0 - 2\alpha\alpha_0 + \beta\gamma_0)$$

$$\text{BMAG} = \xi + \sqrt{\xi^2 - 1}$$

$$\frac{\beta_0}{\text{BMAG}} < \beta < \text{BMAG} \cdot \beta_0$$

