OPERATIONAL ASPECTS RELATED TO TRANSVERSE BEAM DYNAMICS AT FLASH

CANDLE – DESY – PSI
COLLABORATION WORKSHOP

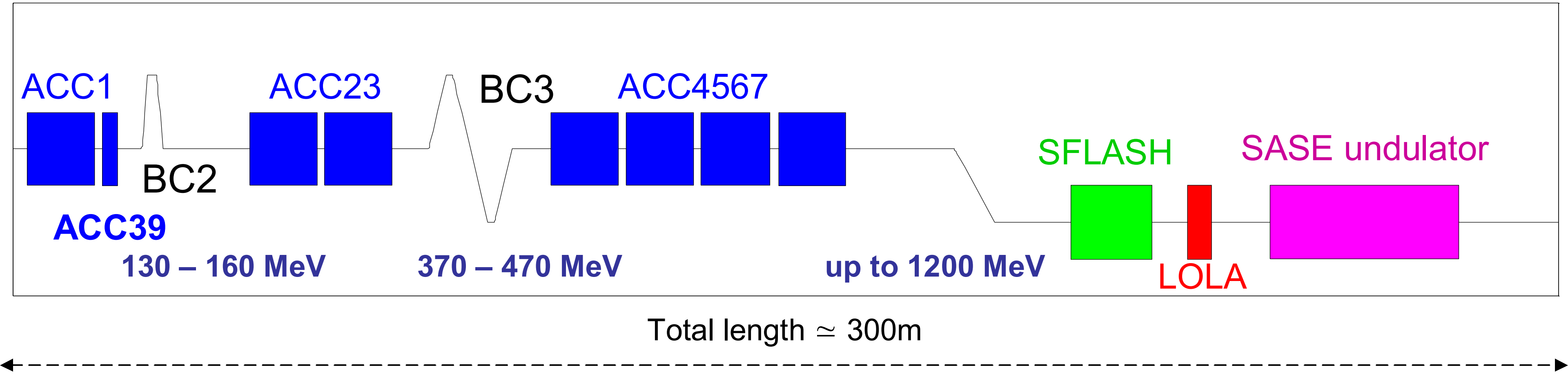
Eduard Prat, DESY
June 30th, 2010
CANDLE, Yerevan

eduard.prat@desy.de

Contents

- **Introduction**: **FLASH**
- **Optics**
  – Info: optic options, error sensitivities, tools …
  – Main issues: optics implementation, 2010 commissioning, difficulties, …
- **Orbit**
- **Dispersion**: effect to electron beam, to SASE performance, …
- **Summary & conclusion**

FLASH
Free-electron LASer in Hamburg



Upgrade 2009/2010: installation of ACC39, ACC7, SFLASH
Commissioning with beam started April 2010
First lasing at 4.4 nm at the beginning of June

Maximum beam energy	1200 MeV
Minimum radiation wavelength	4.4 nm
Nominal bunch charge	0.5 nC
Bunch peak current	1 – 2.5 kA
Normalized emittance	2 µrad
Repetition Rate	10 Hz
Intrabunch repetition rate	0.1 – 3 MHz
Maximum rf pulse (µs)	800 µs/ 2400 bunches

Optic options

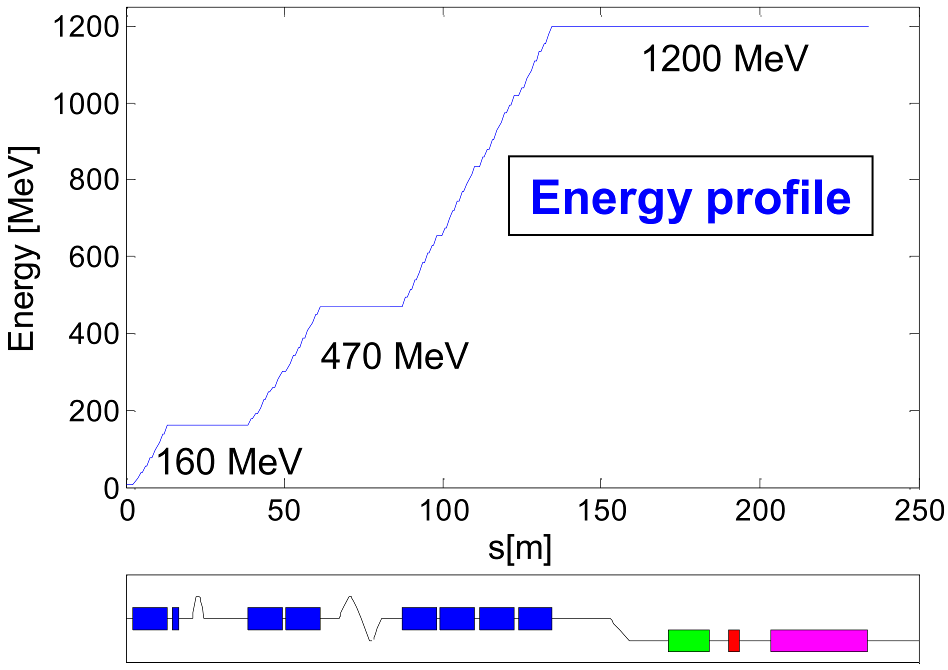
	Between BC2 and ACC7		Between ACC7 and SFLASH		
	$\Delta\mu_{OTRs}$ in emit meas. section	Optimized for CSR	Optimized for SFLASH	Optimized for IBFB	Optimized for LOLA
Lite	30 deg.	Yes	No	No	No
Med	45 deg.	More	Yes	No	Yes
Sharp	45 deg.	Even more	Yes	Yes	Yes

lite/med/sharp is a qualitative indicator for error sensitivities

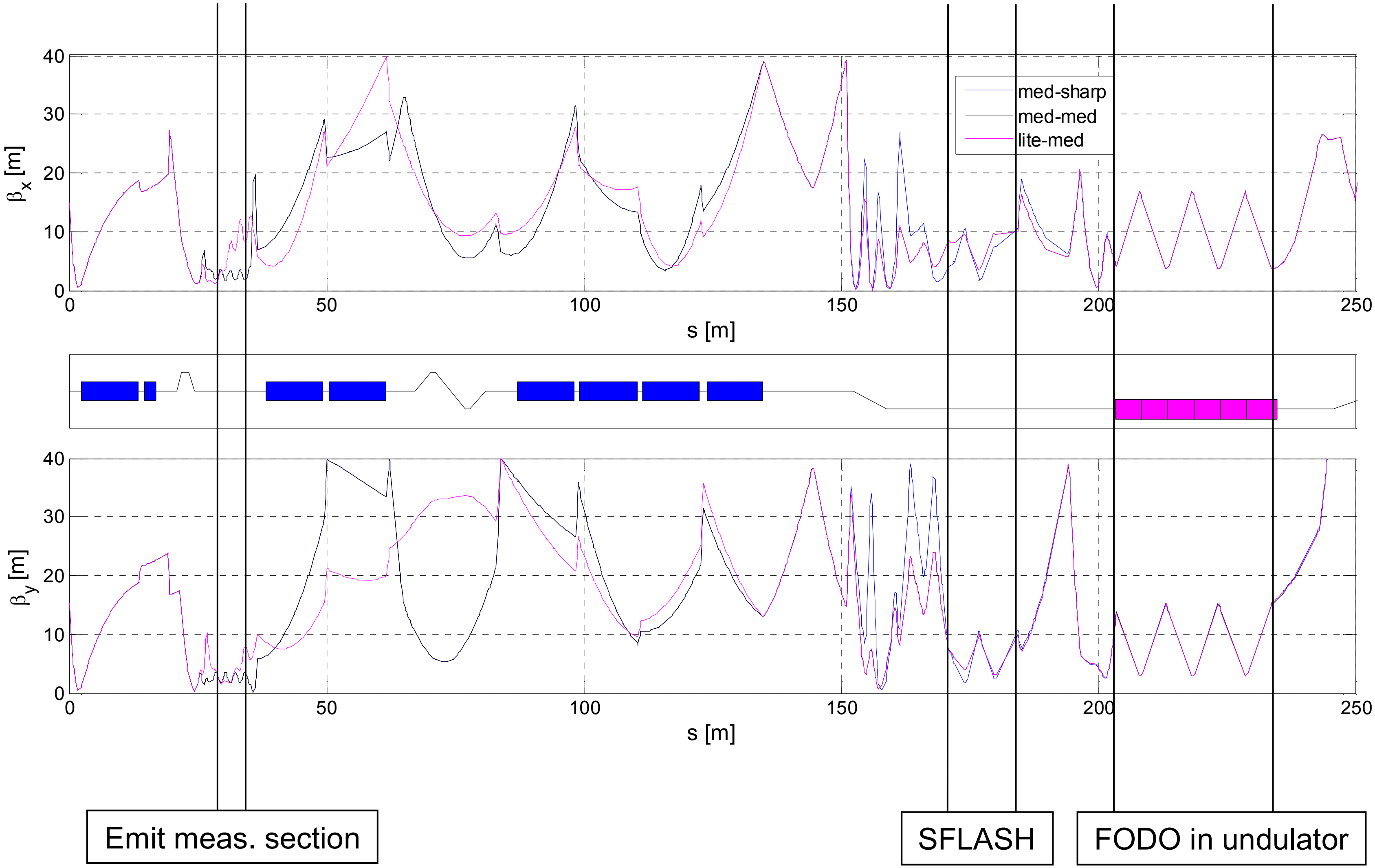
sharp in the first part and *lite* in the second are not developed yet (and will probably not be needed)

Optic restrictions:

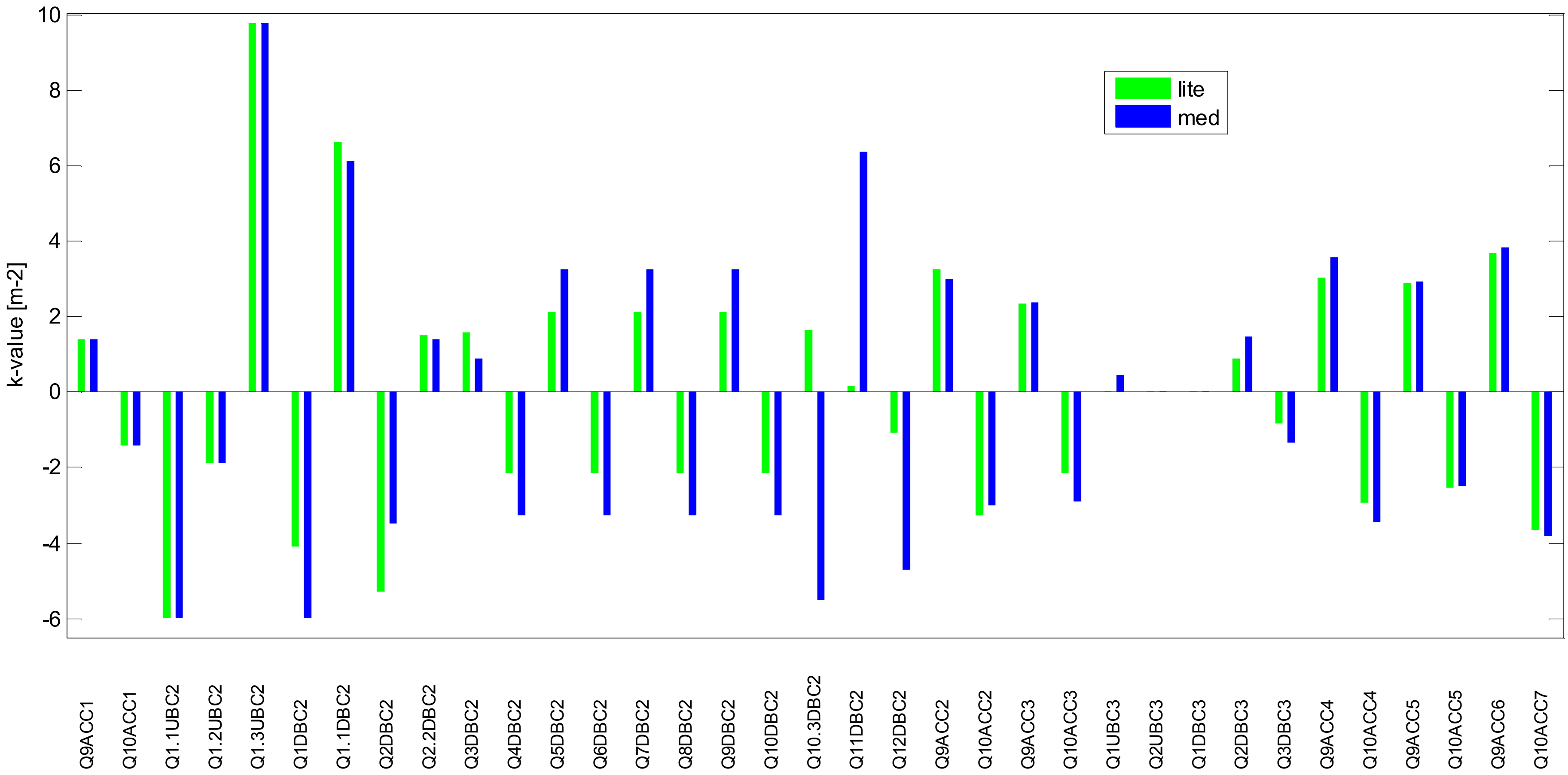
- CSR: minimize hor. beta function at BCs
- SFLASH: minimize beta → $\beta < 10.5$ m
- IBFB: maximize R12/R34 between kickers
  → R12 = 20.9 m, R34 = 16.2 m
- LOLA: minimize resolution $\alpha\ \beta(s_0)^{-1/2}\sin(\Delta\mu)^{-1}$
  → $\beta = 27.7$ m, $\Delta\mu = 89$ deg.



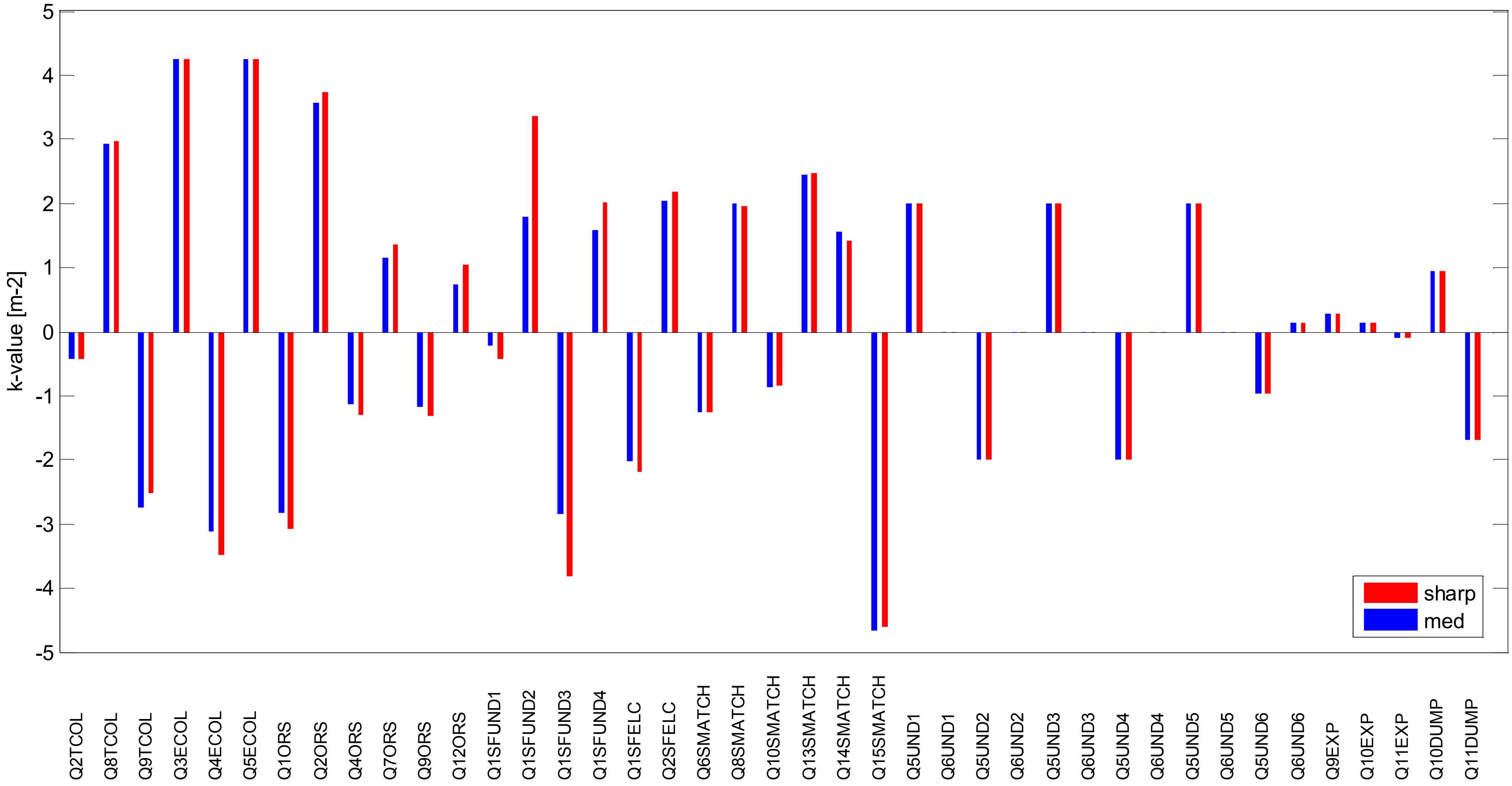
Optics – FEL mode



Quad values ACC1-ACC7



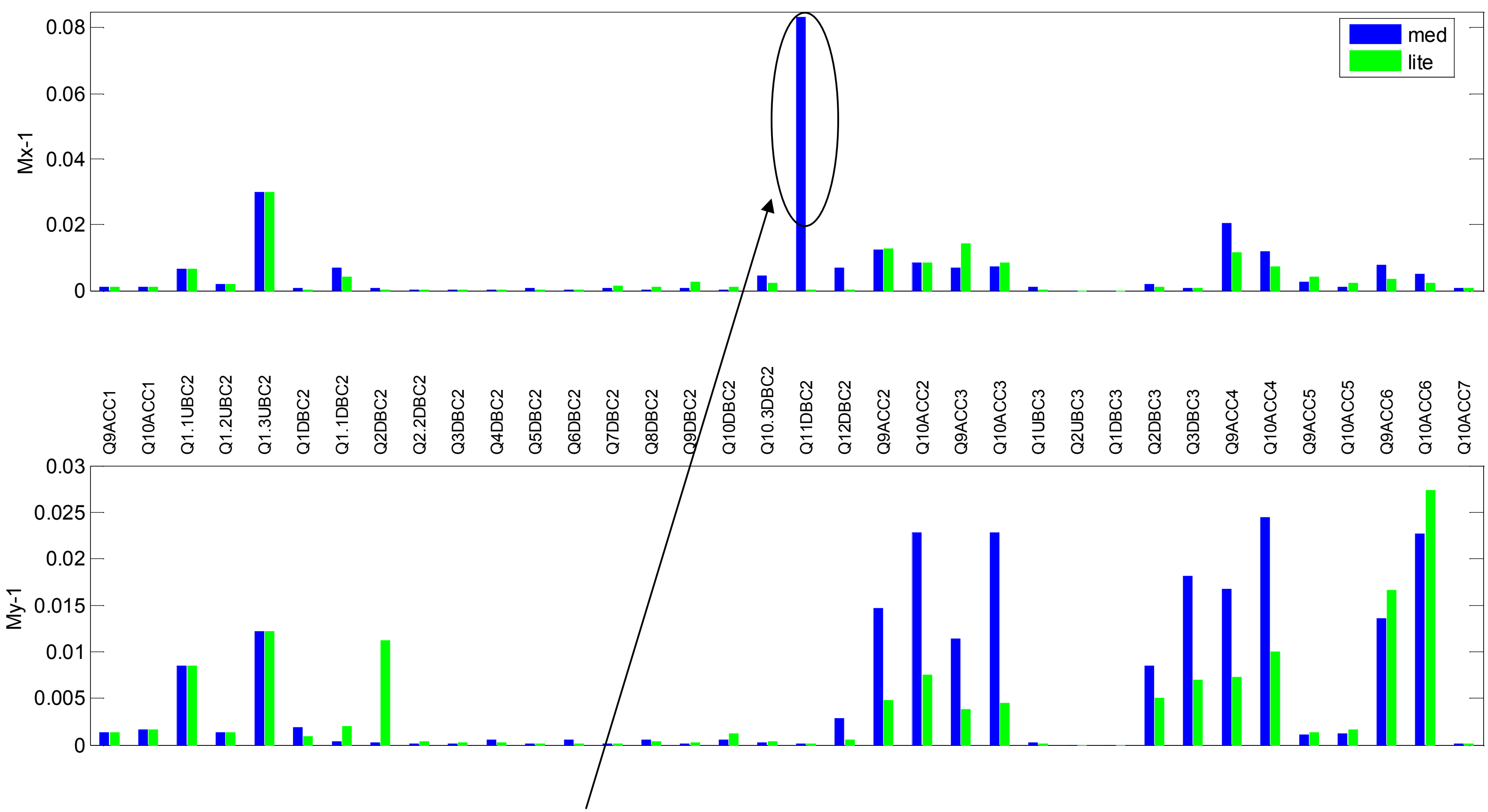
Quad values TCOL-DUMP



Error sensitivities ACC1-ACC7

Mismatch parameter:
$$M = 0.5 \cdot (\beta\gamma_d + \alpha\alpha_d + \gamma\beta_d)$$

Mismatch parameter error at the undulator entrance for 1% of quadrupole field error

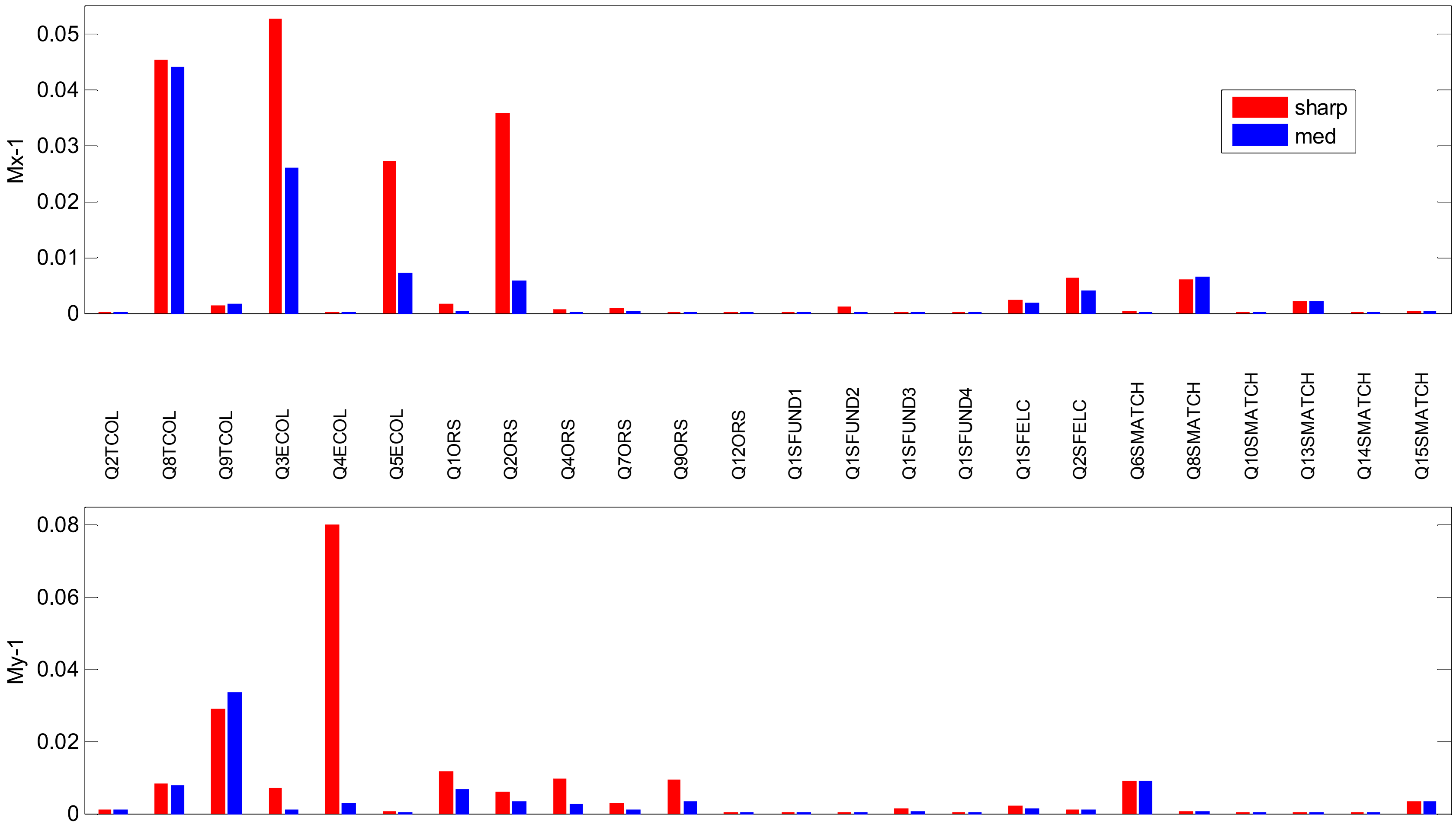


Q11DBC2 is very sensitive in med option (can be used as a tuning knob)

Error sensitivities TCOL-DUMP

Mismatch parameter:
$M = 0.5 \cdot (\beta\gamma_d + \alpha\alpha_d + \gamma\beta_d)$

Mismatch parameter error at the undulator entrance for 1% of quadrupole field error



Optics toolbox

It is a library of matlab functions which does:

- Transfer between physical and engineering units: k-value to current, kick to current, quad kick to quad mover displacement, etc.
- Calculate optics (also coupled): beta functions, transport matrices, etc.
- Calculate emittances and optics matching
- …

Model includes: all accelerator modules (ACC1-7, ACC39), SFLASH, SASE undulator

Created in 2006, updated and maintained up to 2009 by V. Balandin and N. Golubeva
Updated to 2010 by W. Decking and E. Prat (it includes ACC39, ACC7, SFLASH, etc.)

The following tools use the optics toolbox:

- Get “Save and Restore” files (get magnet currents file from the design optics for any wanted energy profile)
- Orbit correction and feedback
- Dispersion correction
- Orbit Response Measurement (ORM) & BPM calibration

Optic issues

OPTICS SET-UP

1) Determine energy profile along the accelerator

RF probes / dipole fields + beam position in dispersive sections (BC2, BC3, dog-leg)

2) Set dipole angles

BC2: 18 deg. / BC3: 3.8 deg. / DOG-LEG: 3.5 deg.

3) Measure emittance & optics and match at DBC2 → initial conditions

4) Check the optics at the rest of the lattice

- Measure and analyze R_{12}/R_{34}
- Measure beam sizes at OTRs & compare with model

COMMISSIONING 2010: implemented med-med option, SASE at 4.4nm with optics very close to design values

SPACE–CHARGE OPTICS → see talk by M. Dohlus

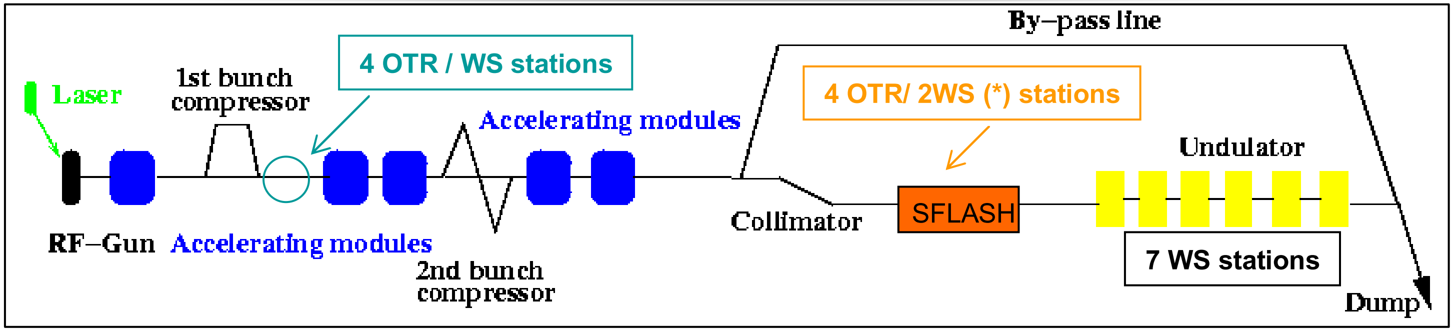
MAIN DIFFICULTIES

1) Problems to match in DBC2 using quads upstream BC2 (not possible in 2010)

Multiple possible reasons: coils, energy, BC2 model, quads, beta variation along the bunch …
Consequence: not possible to go from *med* to *lite* optics

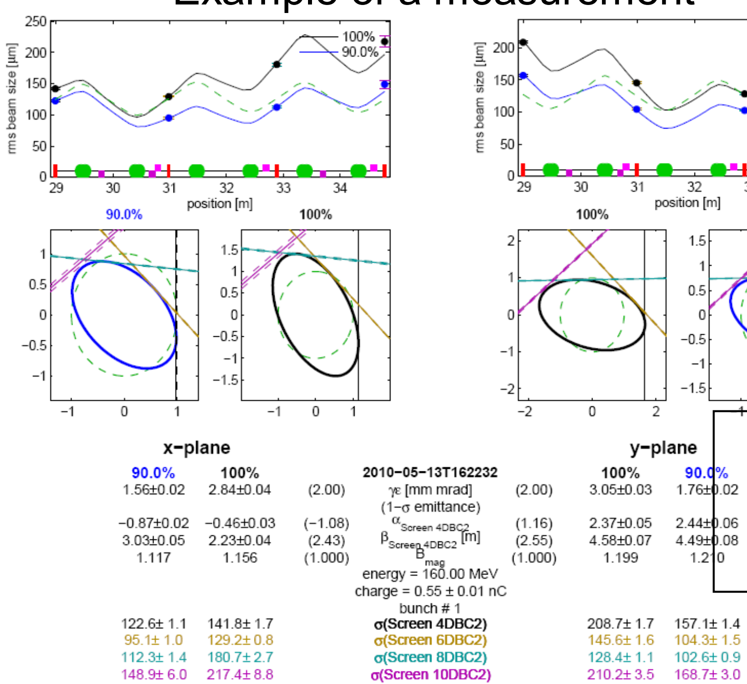
2) Problems to get precise energy profile: error in BC2/BC3 of 1-2%, discrepancies between rf probes and dipoles, …

Emittance measurements and optics matching



- Multi-monitor emittance measurements are possible at 3 different locations: Injector (DBC2), SFLASH, SASE undulator
- Several additional OTRs allow measurements along the linac (using quadrupole scan)
- Commissioning 2010: so far only measurements at DBC2 / only matching with quads in DBC2

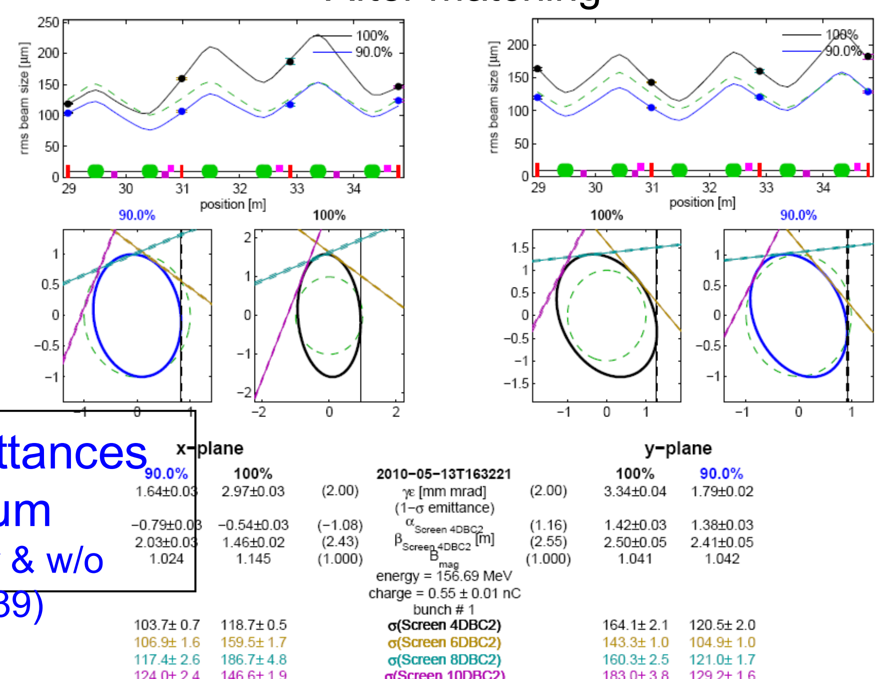
Example of a measurement



90% emittances < 2 µm

(0.5nC w & w/o ACC39)

After matching



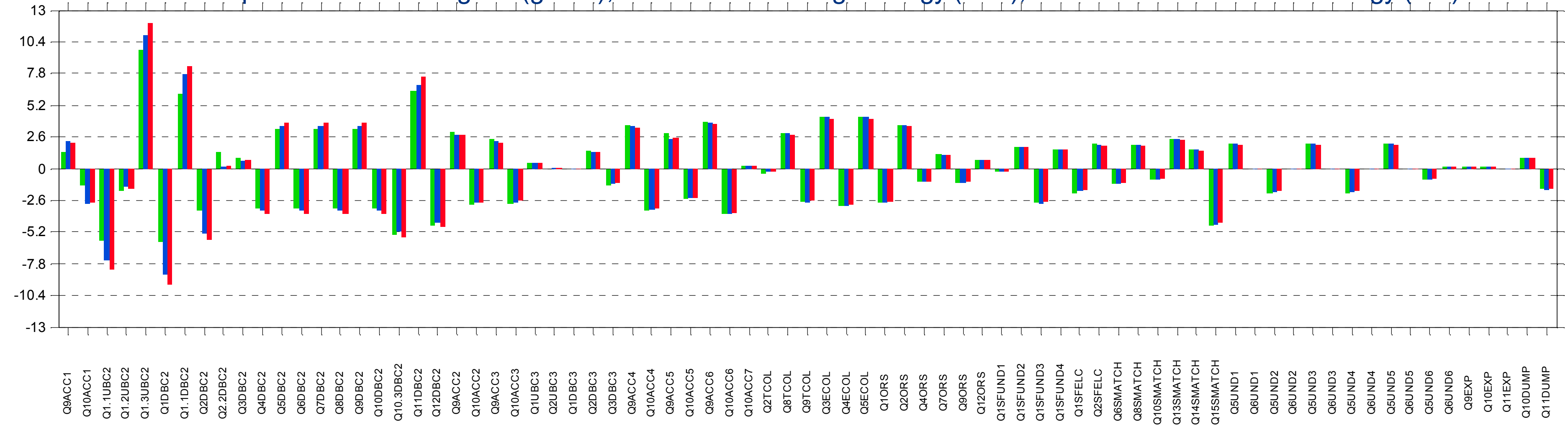
First SASE at 4.4 nm (06/06/10, 22.30h)
Optics very close to design (med-med)

HELMHOLTZ | GEMEINSCHAFT

DESY

FLASH

Quadrupole k-values: designed (green); calculated for design energy (blue); calculated for estimated energy (red)



Power supply currents: designed for design energy (green); designed for estimated energy (blue); actual (red)

	GUN	ACC1	ACC39	BC2	ACC2	ACC3	BC3	ACC4	ACC5	ACC6	ACC7	DOGLEG	D6DUMP
Designed	5.00	160.00	160.00	-18.00	300.70	469.97	-3.80	652.47	834.97	1017.48	1199.98	3.50	-19.00
Estimated	5.00	164.75	146.75	-18.83	303.44	495.57	-4.16	666.90	829.76	1030.13	1253.92	3.37	-18.41

Energy after accelerating modules (MeV) , and bunch compressors, collimator dogleg and dump dipole angles (degree)

ORM tool

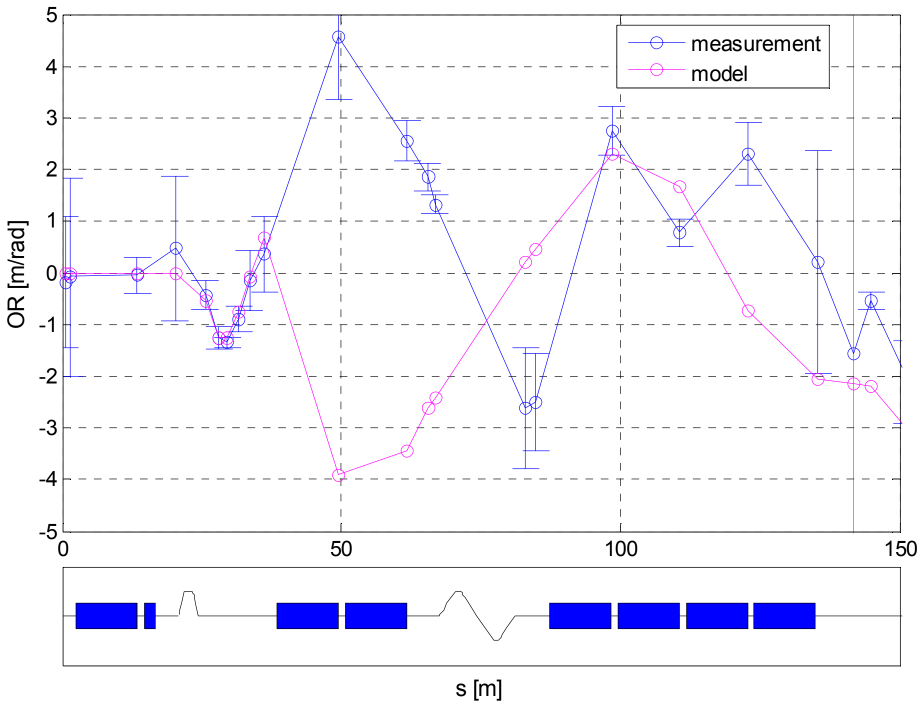
- Orbit response (OR): change of the orbit at BPM *i* relative to the change of the kick of the steerer *j*

$$OR_{i,j} = \frac{\Delta x_i}{\Delta \theta_j}$$

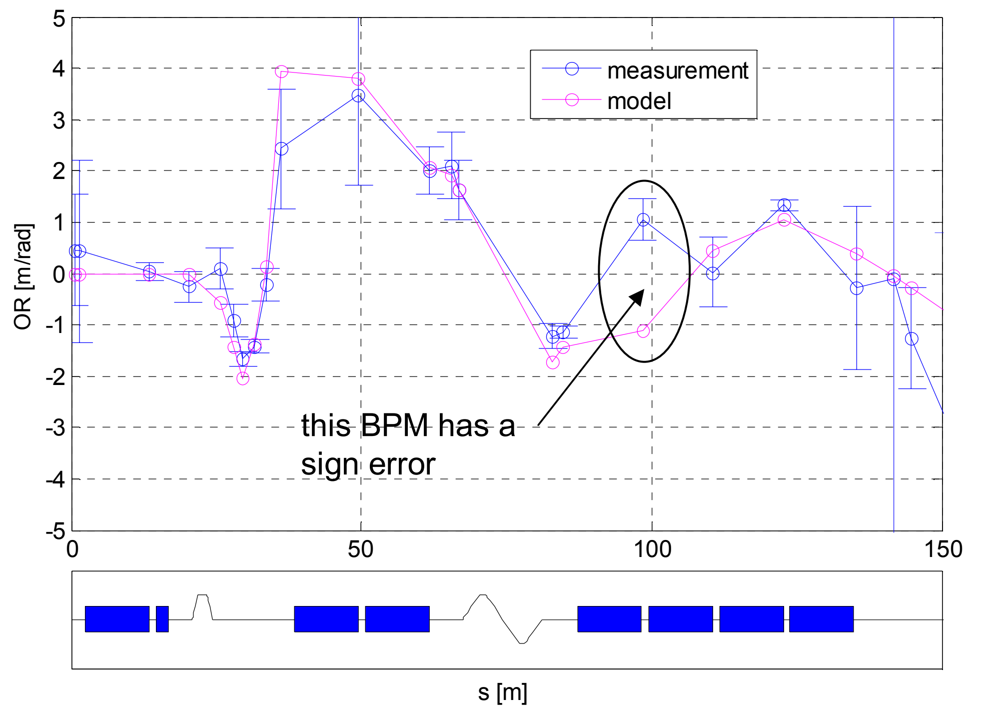
- Useful to detect model and machine imperfections: wrong energy, quad field errors, steerer field errors, BPM imperfections, etc.
- It can also be used to calibrate BPMs
- It needs to be improved (error analysis is missing)
- It has been very useful during 2010 commissioning

Orbit response measurement for H1DBC2

12/05/2010



13/05/2010 (after changing Q10.3DBC2 polarity)



Orbit control

Why the orbit has to be controlled?

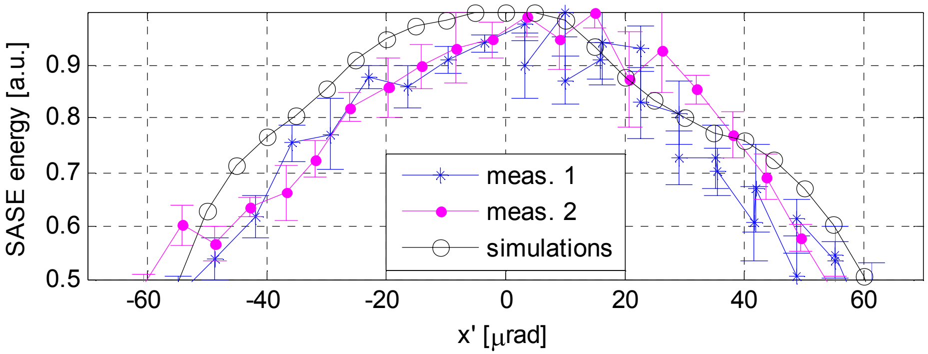
- To avoid loses
- To keep stable SASE (power and pointing)
- To be able to manipulate the beam keeping the orbit constant (e.g. changing compression)
- To get overlap between electron and laser beams (required by SFLASH)
- …

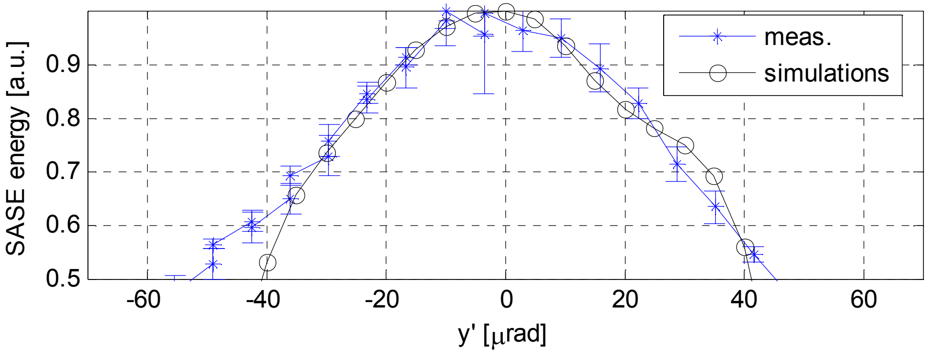
Orbit tools at FLASH:

- **Orbit correction tool** (at any wanted specific location).
- **Orbit feedback** (at any wanted location). First version tested during 2010 commissioning.
- **Intrabunch orbit feedback** (IBFB): 2 pairs of kickers + 2 pairs of BPMs (some tests during 2007/2008, to be commissioned at 2010)

SASE vs incoming trajectory kick

(single-spike mode)





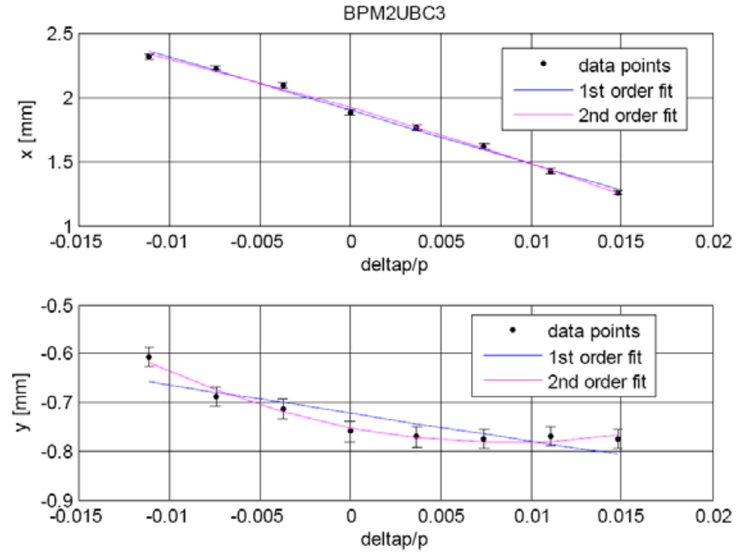
Power fluctuations < 10%

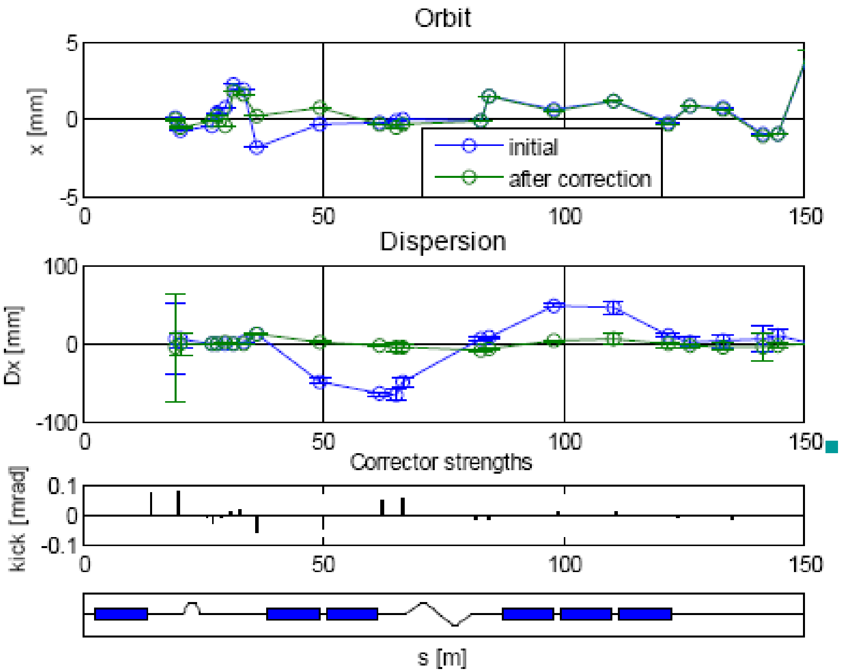
→ $\Delta x'/y' <$ **±15-20 μrad**

Dispersion

- Transverse dispersion is one of the major sources of emittance increase along the linac.
- Dispersion sources:dipole field errors, quad misalignments, quad field errors in dispersive sections, orbit errors, energy errors, etc.
- Dispersion **measurement** is done scanning the RF gradient of the modules and looking at the orbit changes downstream.

$$\epsilon_0^2 = \epsilon_\beta^2 + \epsilon_\beta \frac{\eta_0^2 + (\beta_0 \eta_0' + \alpha_0 \eta_0)^2}{\beta_0} < \delta^2 >$$





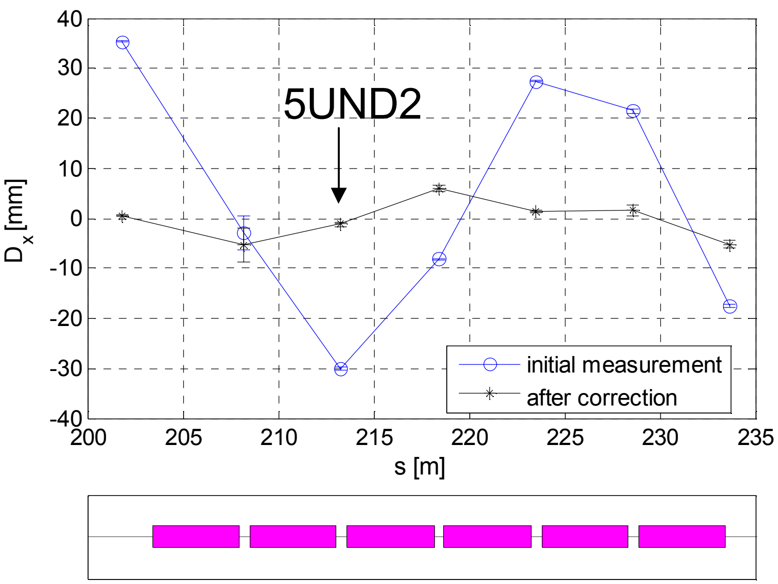
- Dispersion (and orbit) **correction** is performed using corrector coils and quadrupole movers along the linac

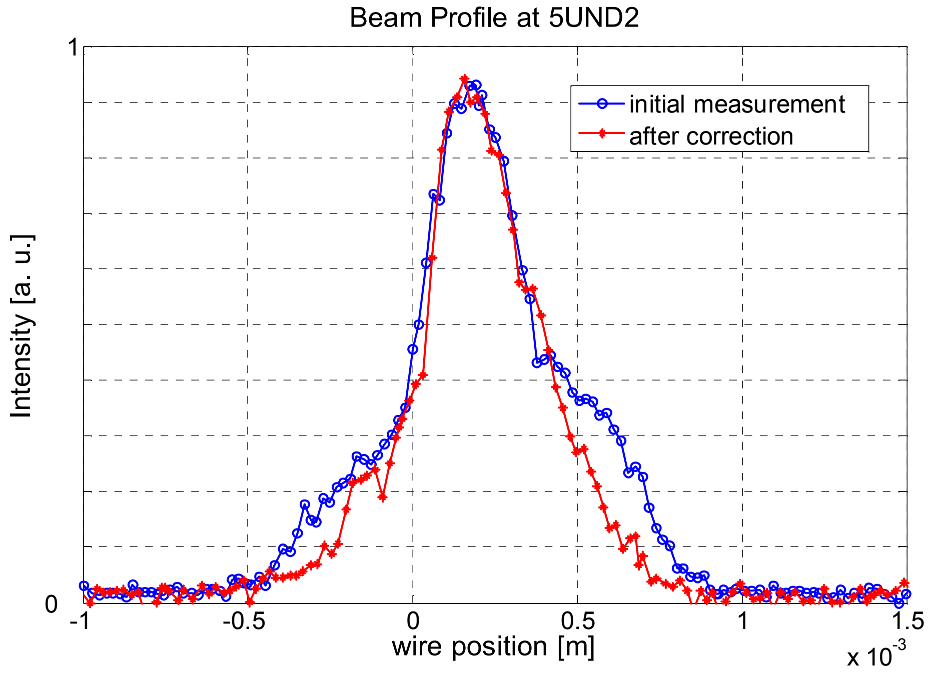
Dispersion can be corrected at FLASH down to 5 mm

Dispersion correction improves the transverse beam quality

Example

- Correction of D_x in the undulator from 22 to 4 mm (RMS)
- Beam shoulders vanished due to dispersion correction
- Beam emittance reduced by 20% (from 5.8 to 4.7 µm)

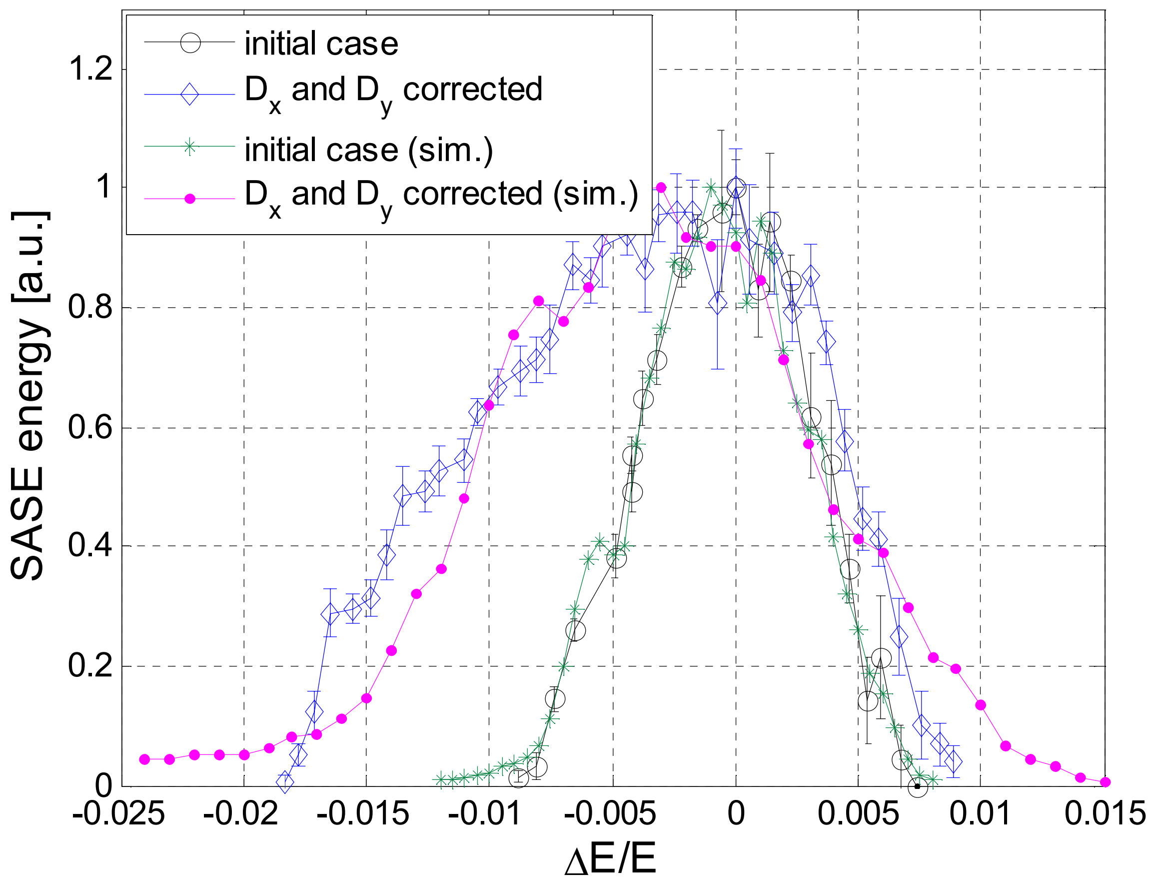




Dispersion correction (to less than 10 mm) is necessary for the conservation of the projected emittance

Dispersion correction reduces SASE power jitter due to electron energy fluctuations

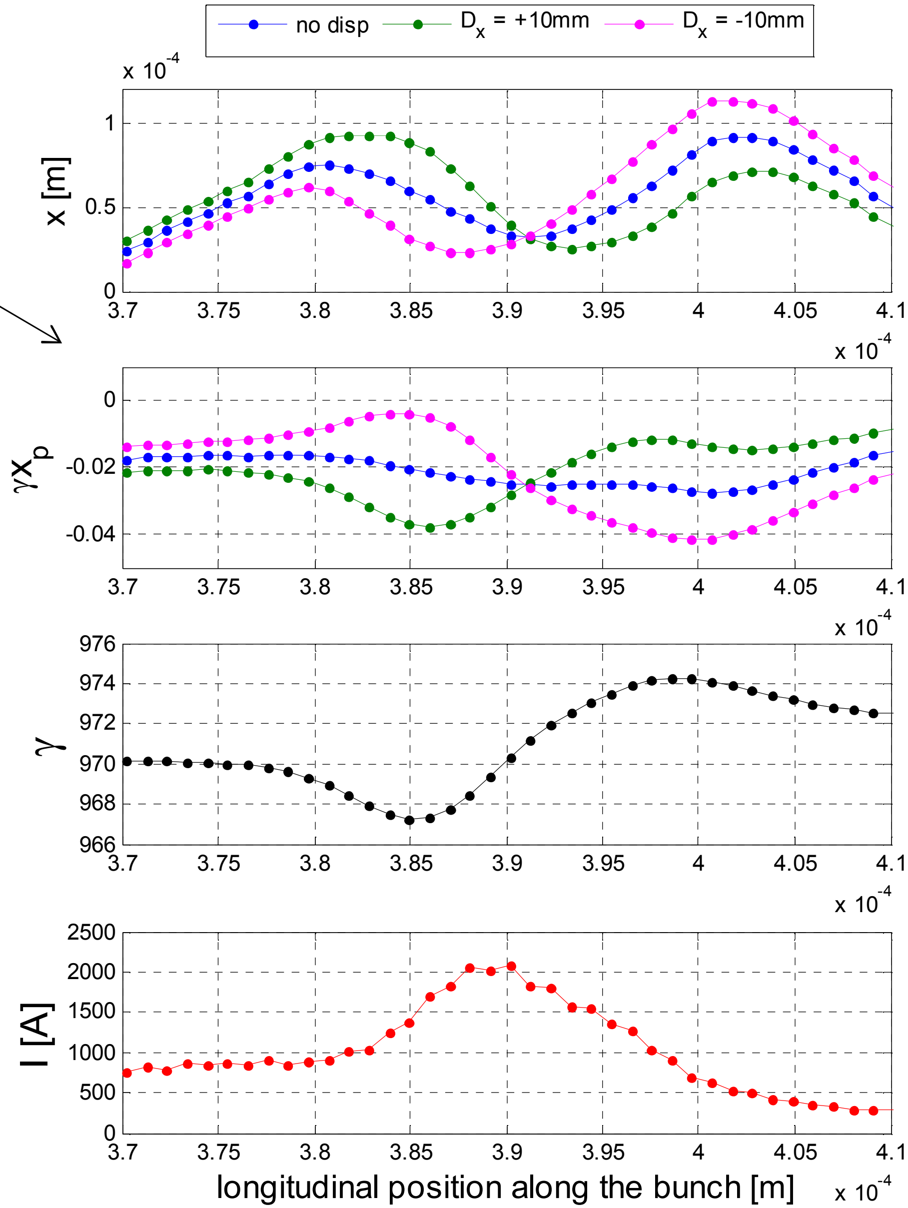
	D_x (RMS)	D_y (RMS)	FWHM in $\Delta E/E$
Initial measurement	22 mm	30 mm	0.82 %
After dispersion correction	11 mm	5 mm	1.72 %



Dispersion reduces the FEL power and affects the radiation spectrum (I)

Electron properties obtained from s2e simulations (M. Dohlus)

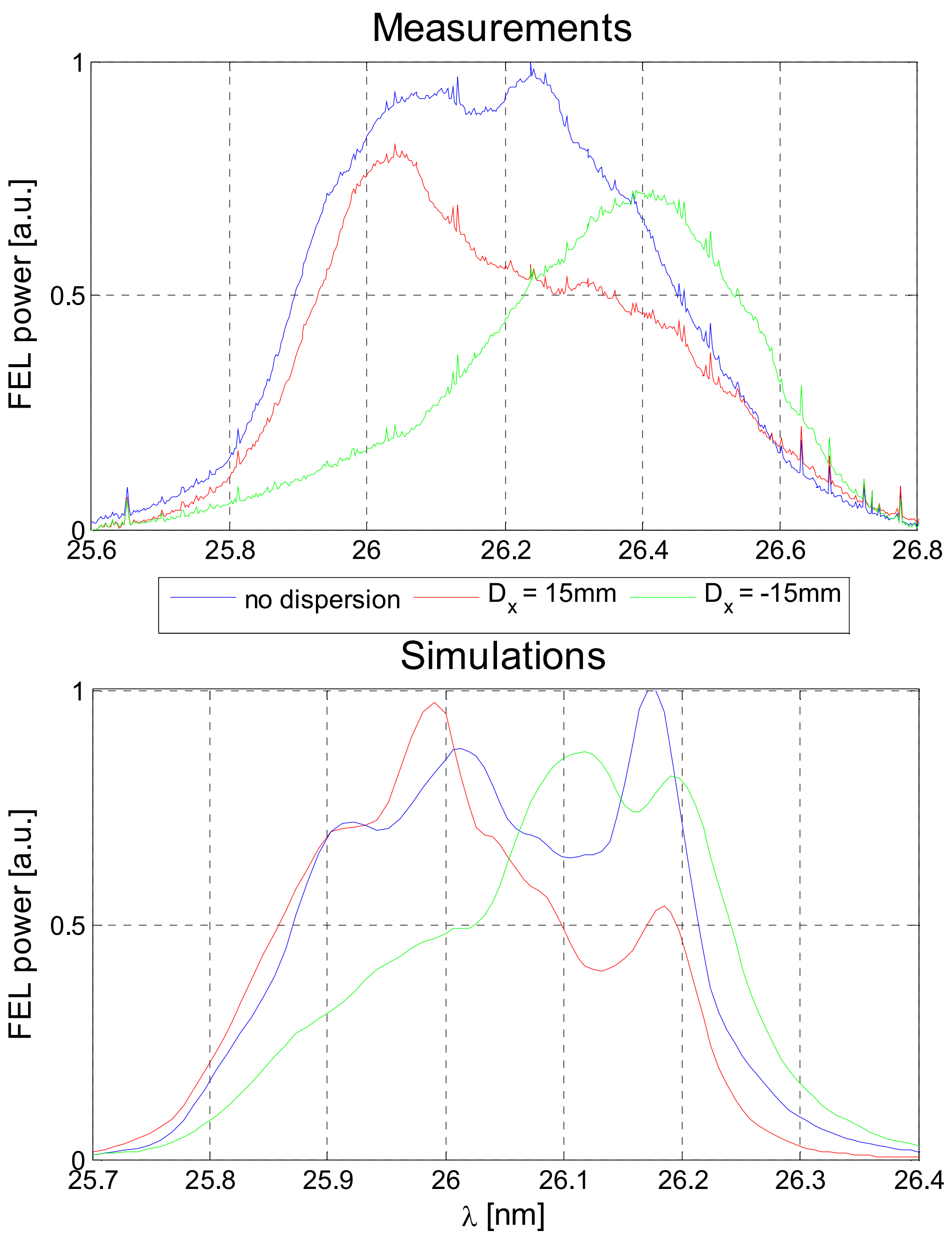
Considered cases:
- No dispersion
- Dx ±10mm



Trajectory changes:
$x(i) = x_0(i) + D_x \square \delta(i)$
$x'(i) = x'_0(i) + D'_x \square \delta(i)$

There is a 2nd order correlation between x and energy (e.g. due to CSR effects). In addition:
$x_0 = 50$ μm
$x'_0 = -20$ μrad

Dispersion reduces the FEL power and affects the radiation spectrum (II)



Qualitative agreement

$|D_x| > 0 \rightarrow$ FEL power $\downarrow$
QECOL $\uparrow \rightarrow \lambda_c \downarrow$
QECOL $\downarrow \rightarrow \lambda_c \uparrow$

Difference: wavelength range is bigger in the measurements (due to a bigger energy chirp)

Summary & conclusions

- Different optics have been developed at FLASH in order to have flexibility between error sensitivities & optic requirements.
- Successfully implemented med-med optics during commissioning 2010
- Main problems: match at DBC2 with quads in UBC2 & non-precise energy measurements.
- Orbit and dispersion must be controlled since they affect SASE performance
- Tools for optics control (emit measurement, optics matching, ORM) and orbit/dispersion correction are available at FLASH
- To do:
  - Improve some of the tools: orbit feedback, ORM (include error analysis)
  - Solve matching problem at DBC2
  - Continue commissioning: optimize emittance in the injector, implement other optic options, match at different places, commissioning IBFB, etc.