Transverse beam diagnostics at MAX IV

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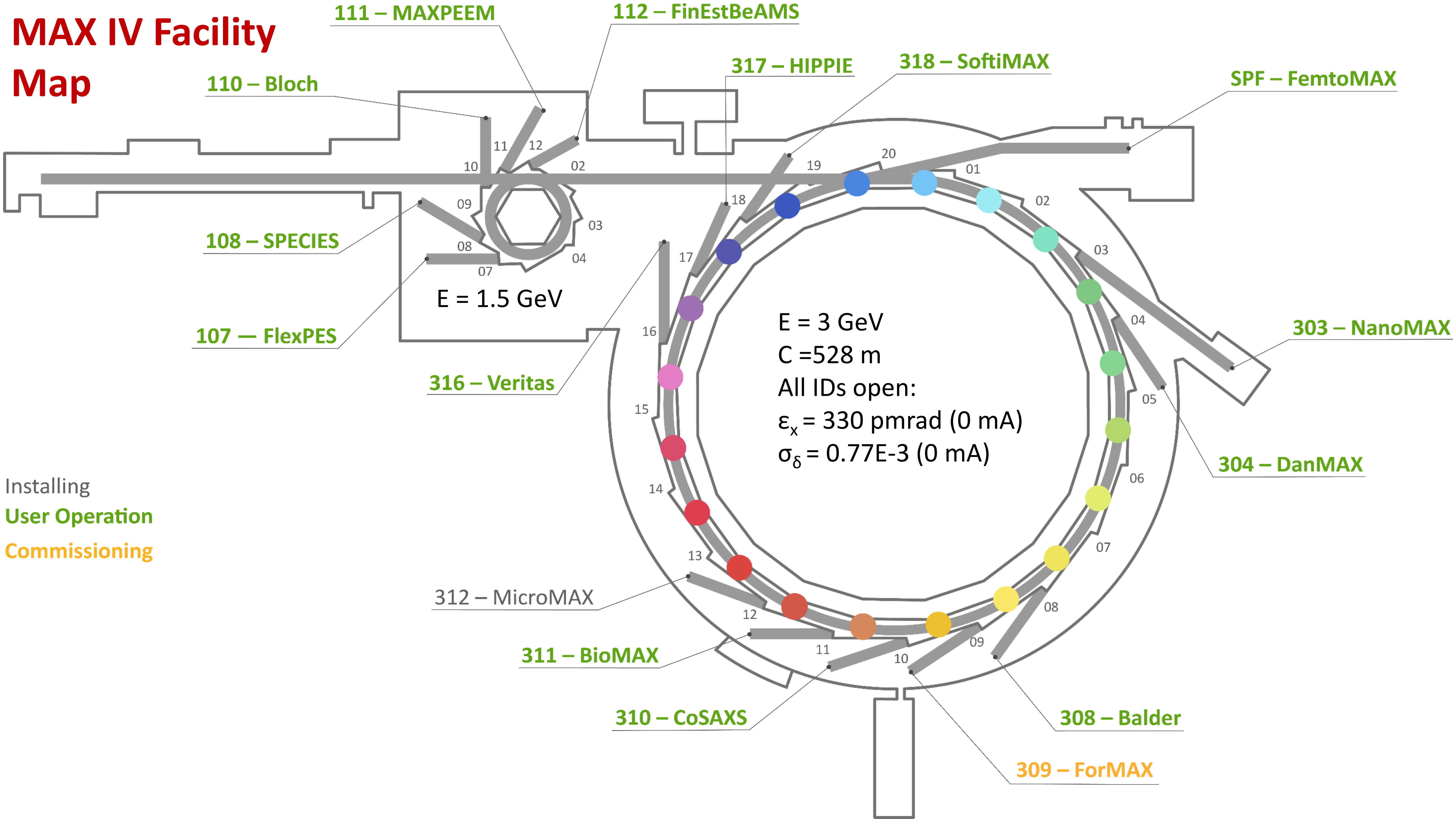
Outline

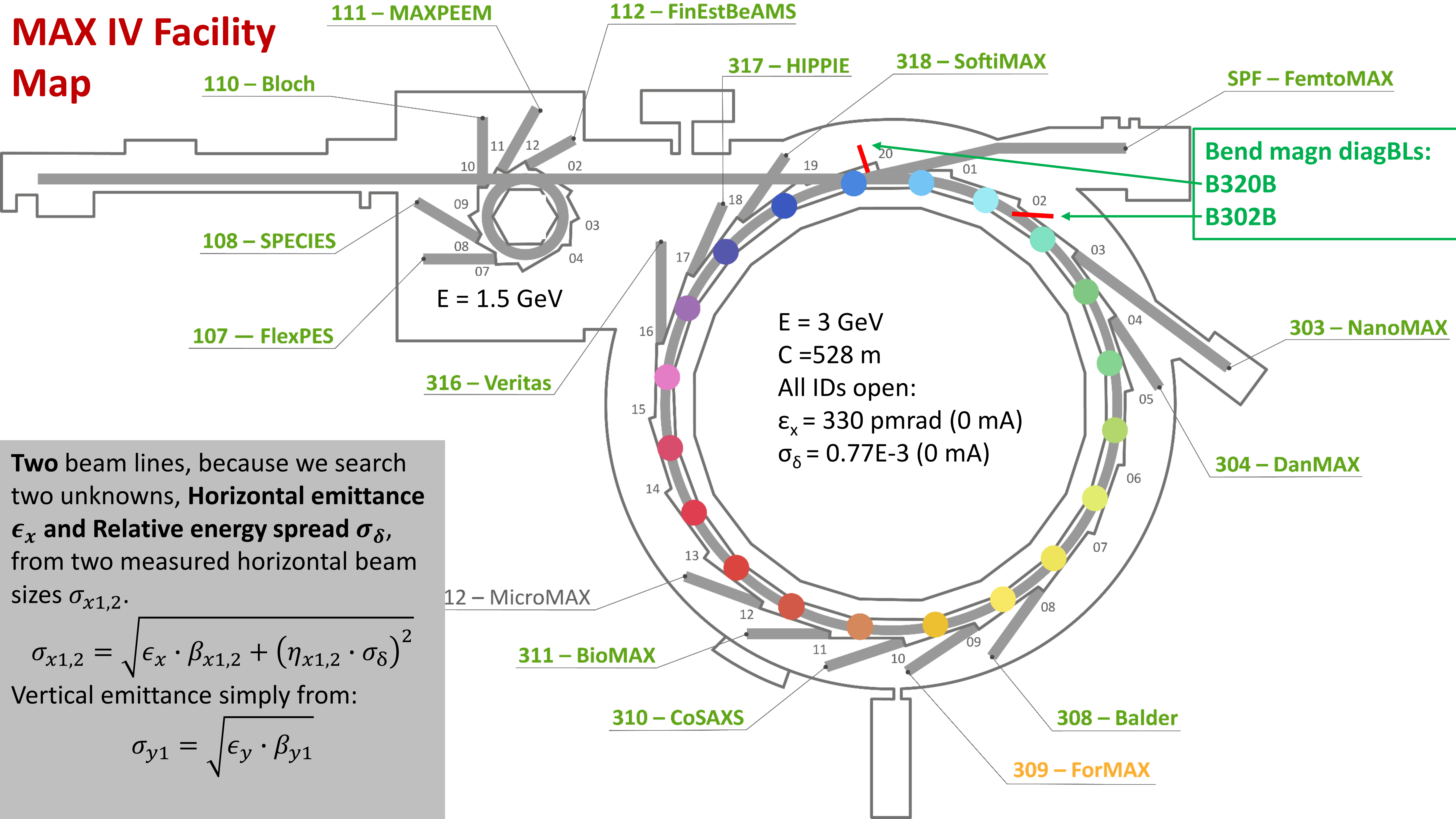
- Mission and basic concepts
- Diagnostic BLs description
- Results
- Limitations, Improvements
- Summary

Mission and basic concepts:

- **Continuously** extract and **monitor** three fundamental beam properties, **Vertical emittance, Horizontal emittance** and **Relative energy spread**, from two beam size measurements at different locations.
- Don’t use any straight sections, since they are too valuable! ==> **Bending magnet SR**
- Utilize the inherent properties of the synchrotron radiation (SR) emission and focussing. **Preserve the SR coherence properties** through the diagnostic beam lines. Evaluate the beam size through the incoherent contribution.
- Stay close to the **visible range SR**, since there exists off-the-shelf, high quality, optical components and detectors. Not too expensive!


MAX IV Facility Map
110 – Bloch
111 – MAXPEEM
112 – FinEstBeAMS
108 – SPECIES
107 — FlexPES
E = 1.5 GeV
316 – Veritas
317 – HIPPIE
318 – SoftiMAX
SPF – FemtoMAX
303 – NanoMAX
304 – DanMAX
E = 3 GeV
C =528 m
All IDs open:
εx = 330 pmrad (0 mA)
σδ = 0.77E-3 (0 mA)
312 – MicroMAX
311 – BioMAX
310 – CoSAXS
309 – ForMAX
308 – Balder
Installing
User Operation
Commissioning

MAX IV Facility Map



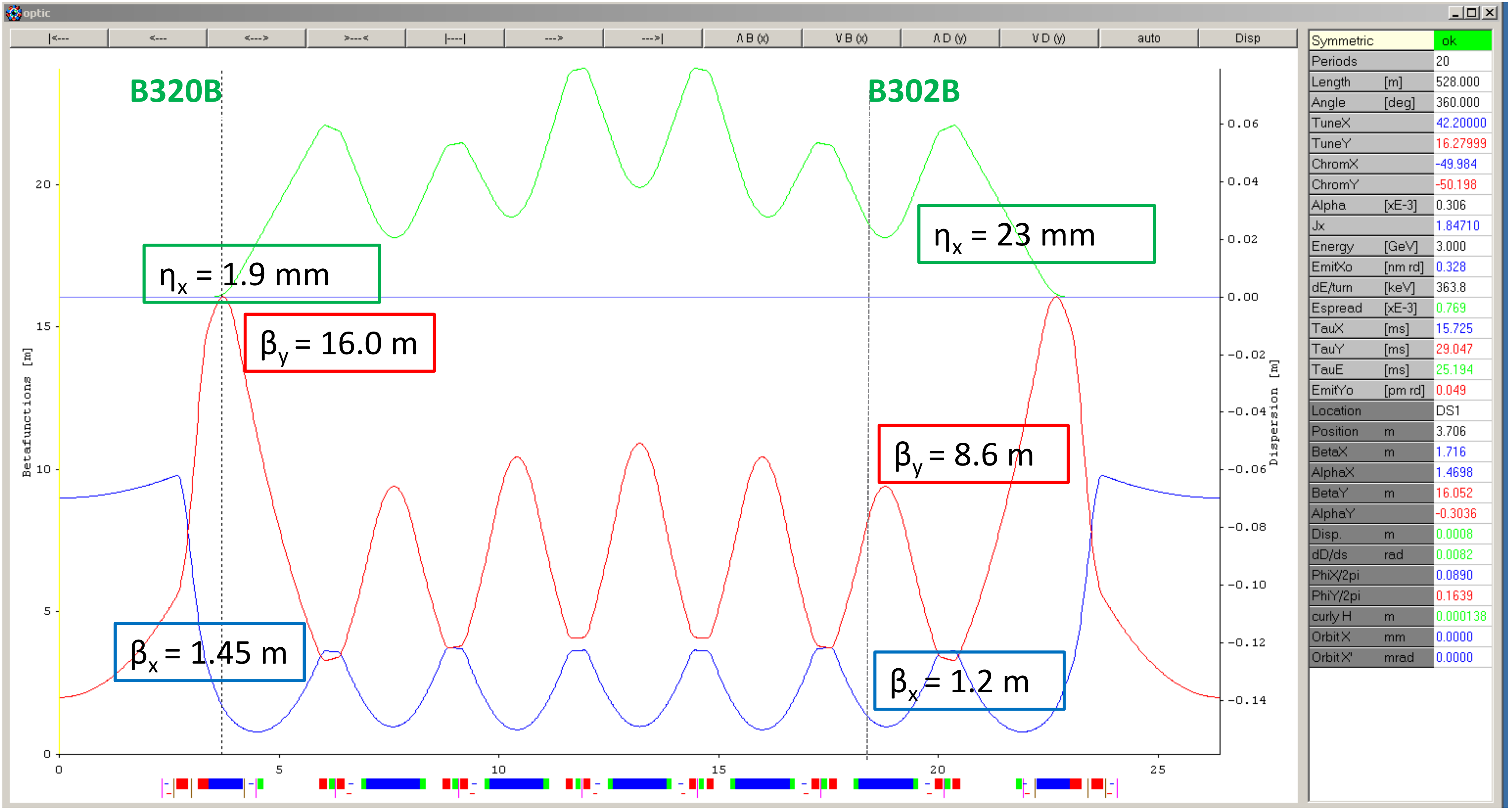
Two beam lines, because we search two unknowns, **Horizontal emittance ϵ_x and Relative energy spread σ_δ**, from two measured horizontal beam sizes $\sigma_{x1,2}$.

$$\sigma_{x1,2} = \sqrt{\epsilon_x \cdot \beta_{x1,2} + (\eta_{x1,2} \cdot \sigma_\delta)^2}$$

Vertical emittance simply from:

$$\sigma_{y1} = \sqrt{\epsilon_y \cdot \beta_{y1}}$$

Locations in the lattice



MAX IV

Derivation of the quantities:

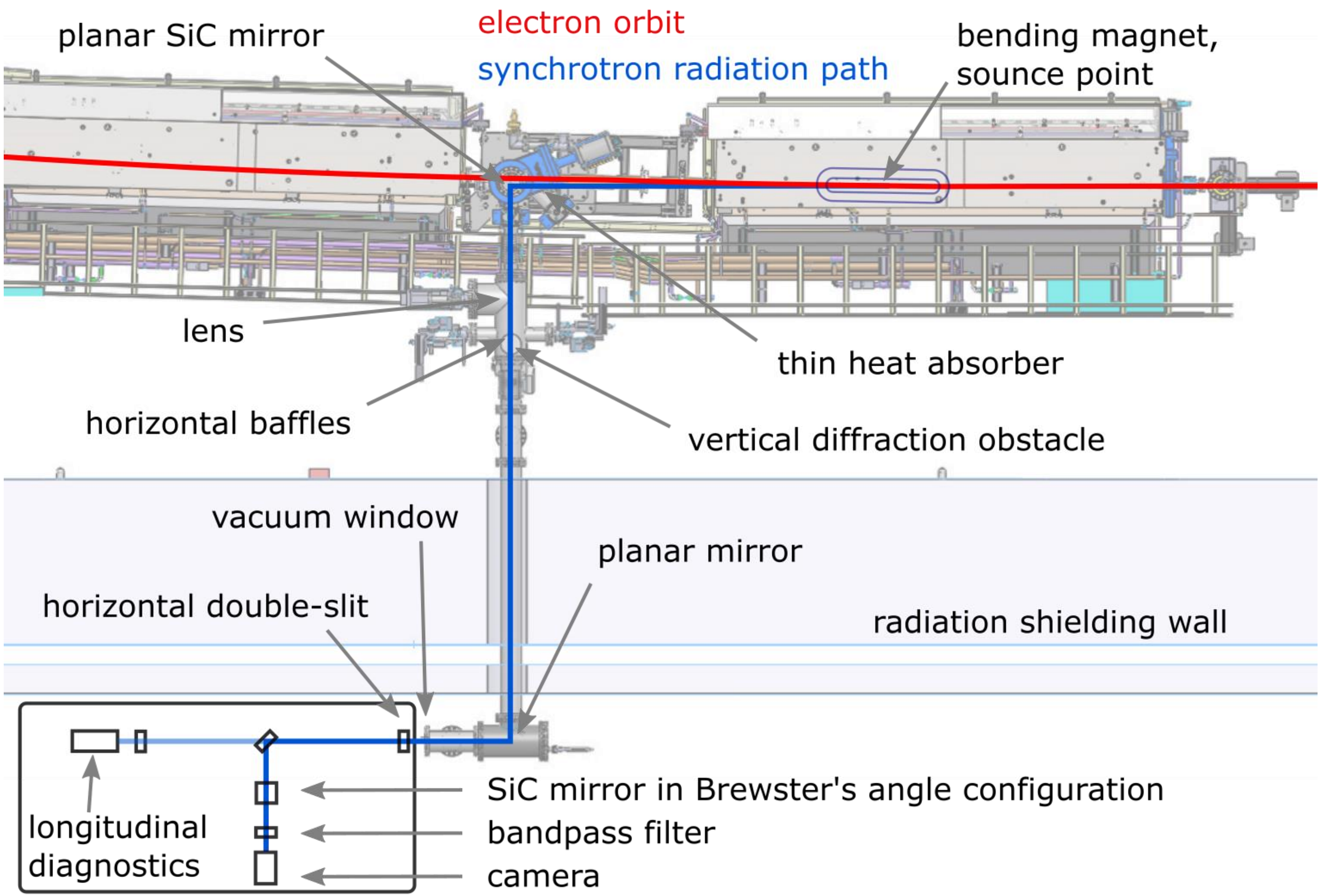
$$\varepsilon_x = \frac{\sigma^2_{x,2} - \left(\frac{\eta_{x,2}}{\eta_{x,1}}\right)^2 \sigma^2_{x,1}}{\beta_{x,2} - \left(\frac{\eta_{x,2}}{\eta_{x,1}}\right)^2 \beta_{x,1}}$$

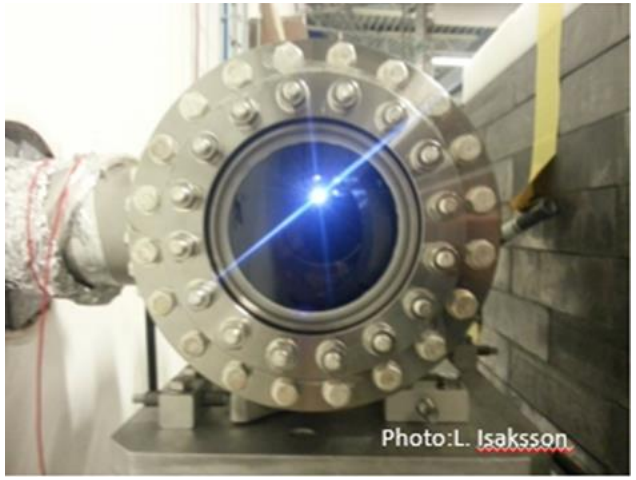
$$\sigma_\delta = \left[\frac{\sigma^2_{x,2} - \left(\frac{\beta_{x,2}}{\beta_{x,1}}\right)\sigma^2_{x,1}}{\eta^2_{x,2} - \left(\frac{\beta_{x,2}}{\beta_{x,1}}\right)\eta^2_{x,1}}\right]^{1/2}$$

In the limit $\eta_{x,1} \to 0$ $\quad \epsilon_x = \frac{\sigma^2_{x,1}}{\beta_{x,1}}$; $\quad \sigma_\delta = \sqrt{\frac{\sigma^2_{x,2}}{\eta^2_{x,2}} - \frac{\beta_{x,2}\epsilon_x}{\eta^2_{x,2}}}$

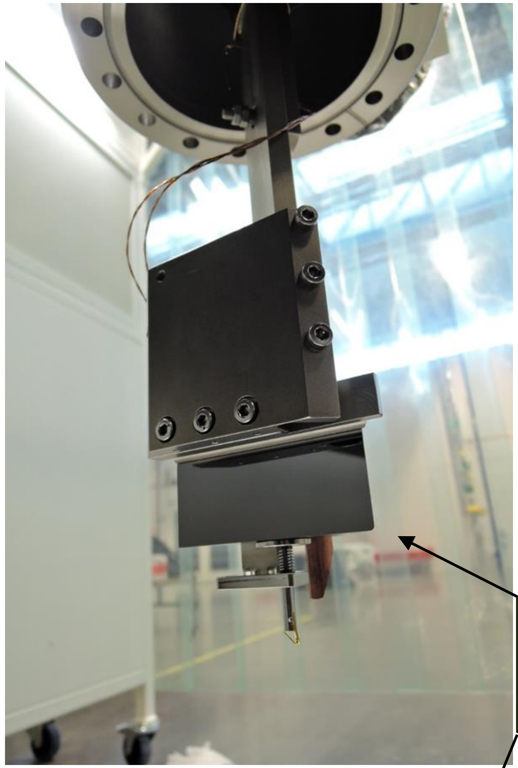
- However, we derive according to the exact formulae
- Also, we measure both dispersion and sigma, at each beam line
- Only the two beta-functions are provided by LOCO

Detailed top view of B320B

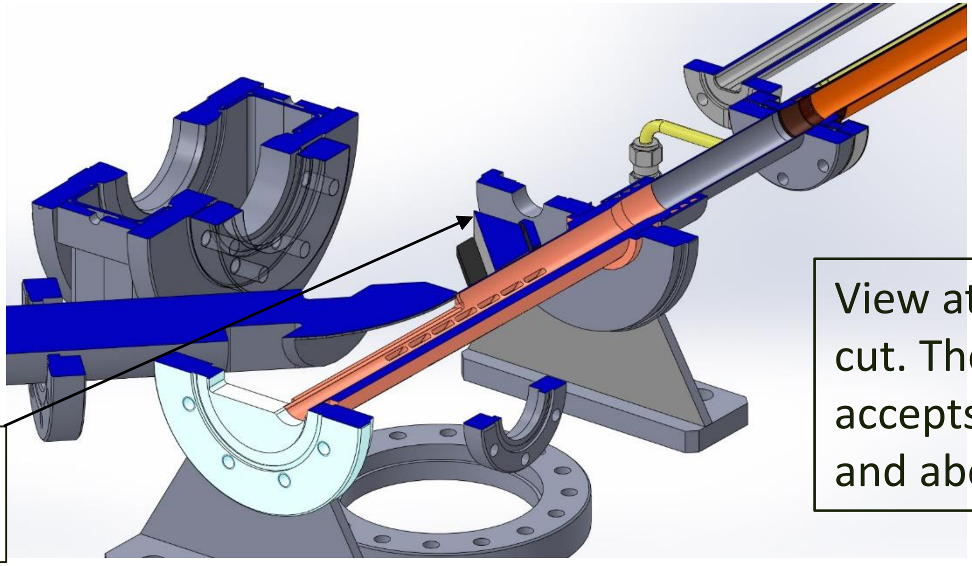




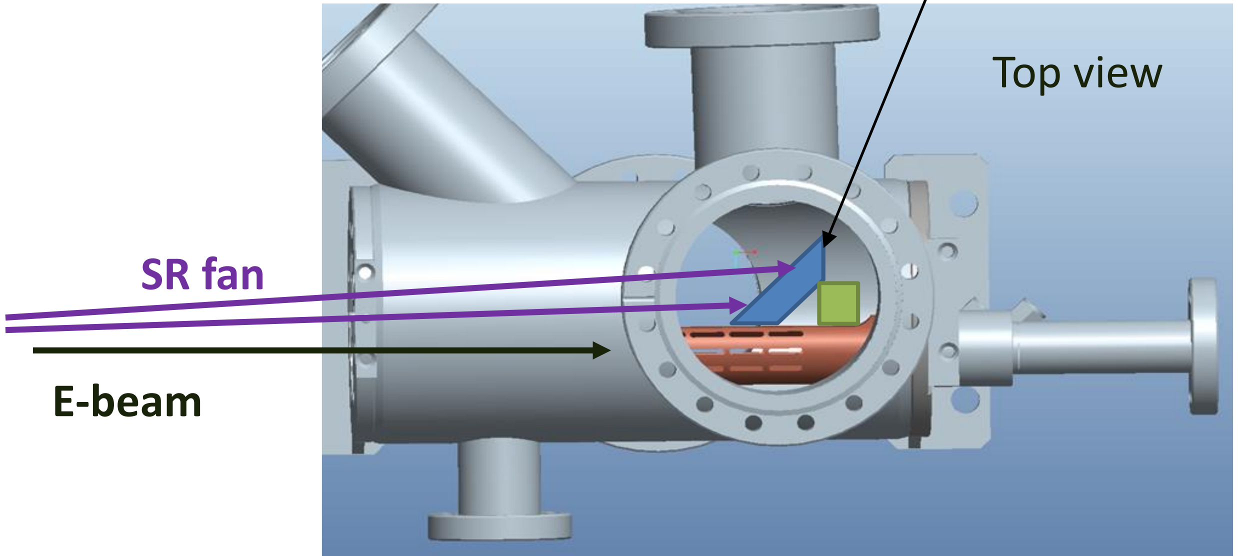
B320B ”Cold Finger” Absorber & Mirror

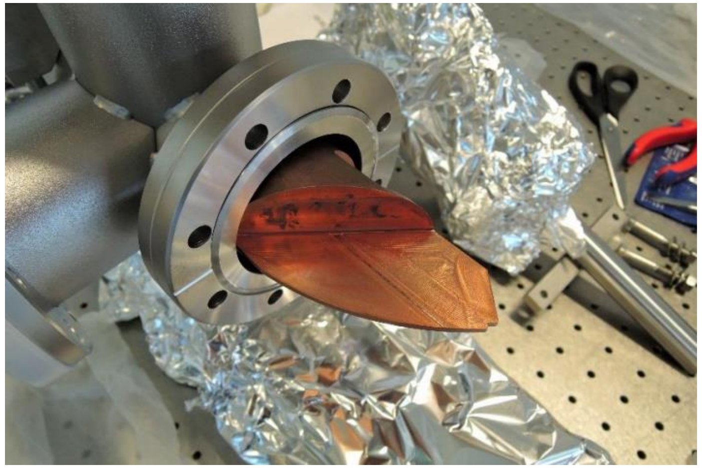


Planar SiC-Mirror



View at the mid plane cut. The mirror accepts SR both below and above.

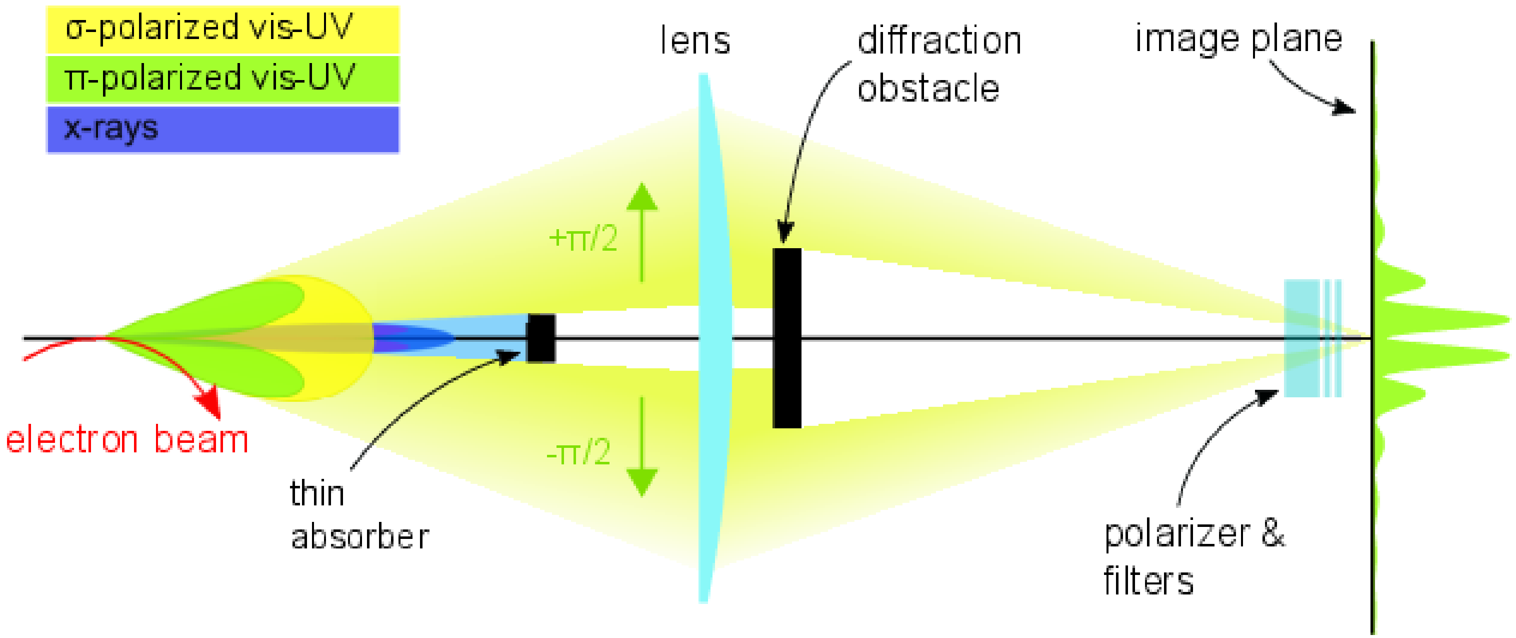




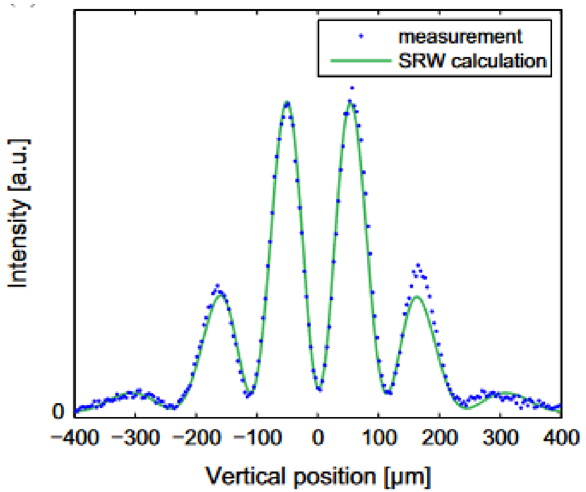
Cold Finger Absorber, ca 3mm thick.

MAX IV LABORATORY

Resolving a vertical beam size < 5 µm



Diffractometer Method:

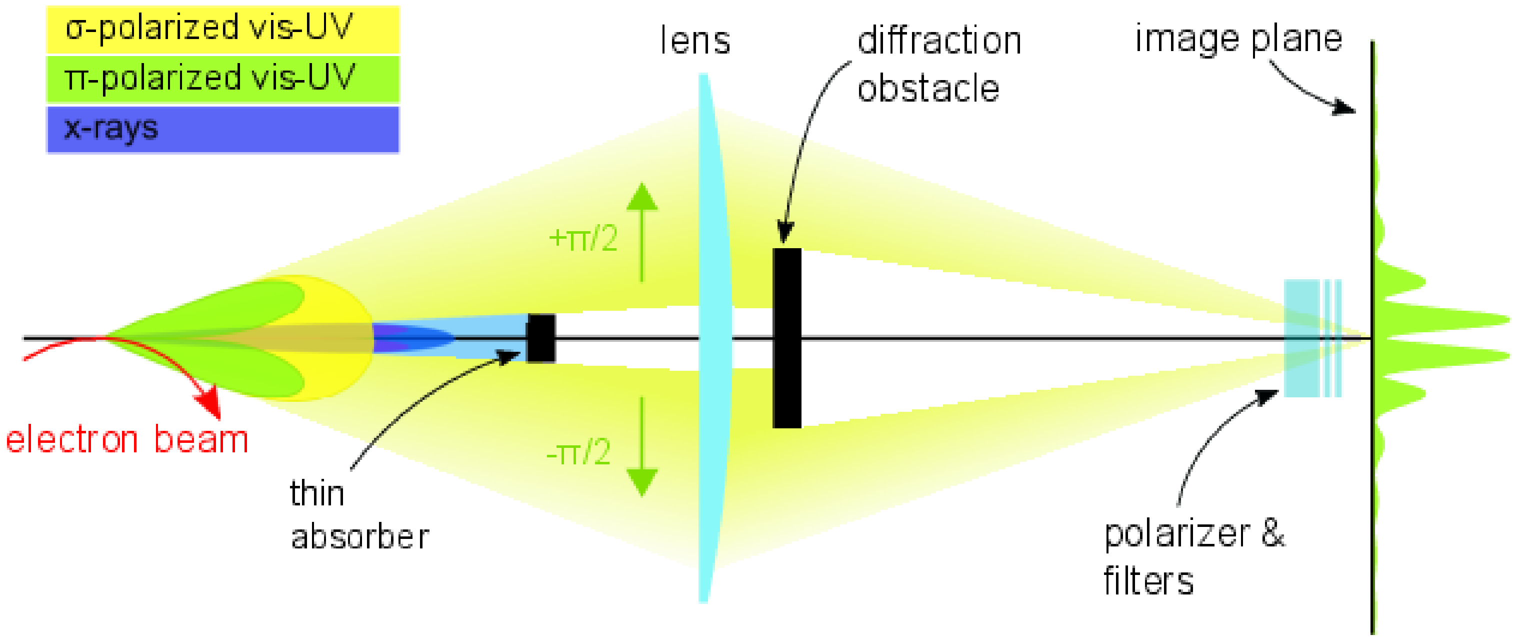


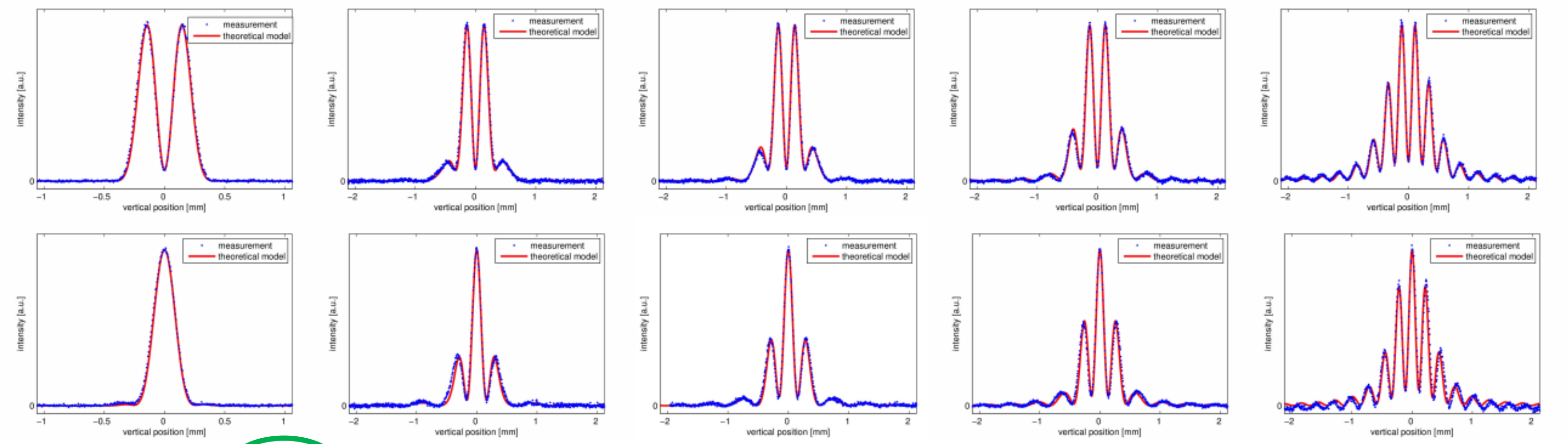
The **diffractometer** method was implemented at the SLS (TIARA collaboration): $\sigma_y = 4.7 \pm 0.1$ µm

J. Breunlin et al, "Methods for measuring sub-pm rad vertical emittance at the Swiss Light Source", Nucl. Instrum. Meth. A 803, 55-64 (2015).

MAX IV

The same method at MAX IV, during first commissioning year.





J. Breunlin et al, "Emittance diagnostics at the MAX IV 3 GeV storage ring", IPAC 2016.

Vertical profiles at 488 nm for pi- and sigma- polarized SR. Measurement and theoretical calculation.
Imaging (left) and with diffraction obstacles of increasing height (4 to 9mm, 1.6 to 3.7 mrad).

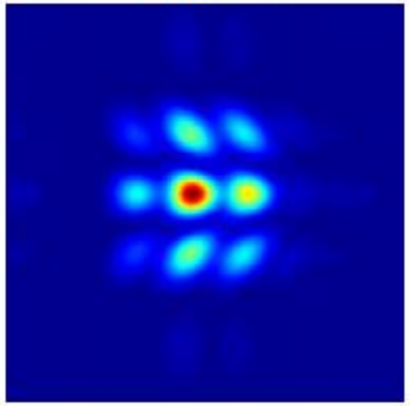
→The vertical beam size was measured 11±0.3 µm, corresponding to a vertical emittance of 6.4±0.9 pm rad.

Horizontal & vertical beam size

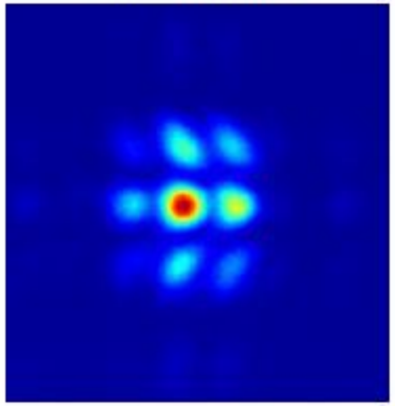
Everyday beam size monitoring scheme:

- Wavelength 488 nm, horizontal acceptance 5 mrad
- Diffraction from
  - Vertical obstacle, 2.1 mrad
  - Horizontal obstacle, 1.7 mrad

SRW calculation

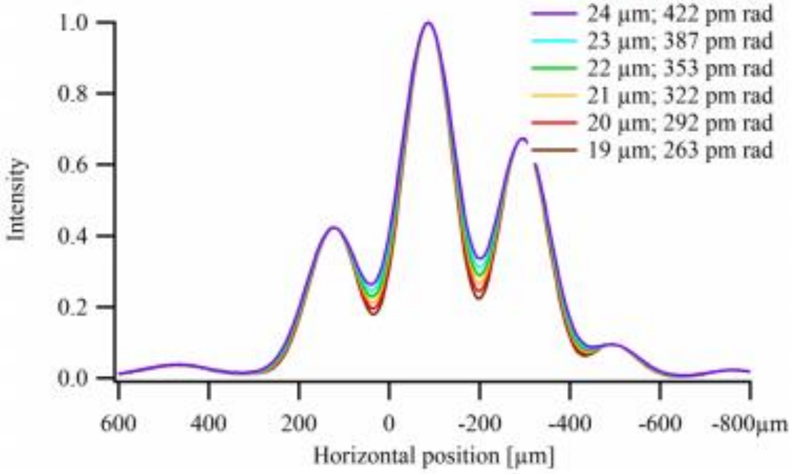


measurement

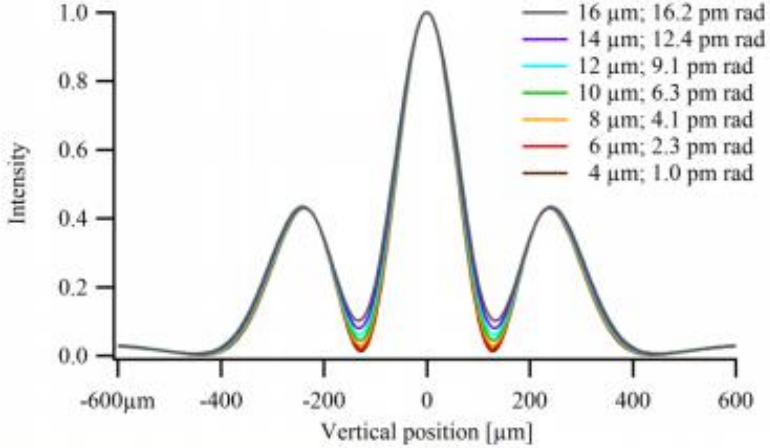


Horizontal diffraction obstacle and ‚footprint' of the SR

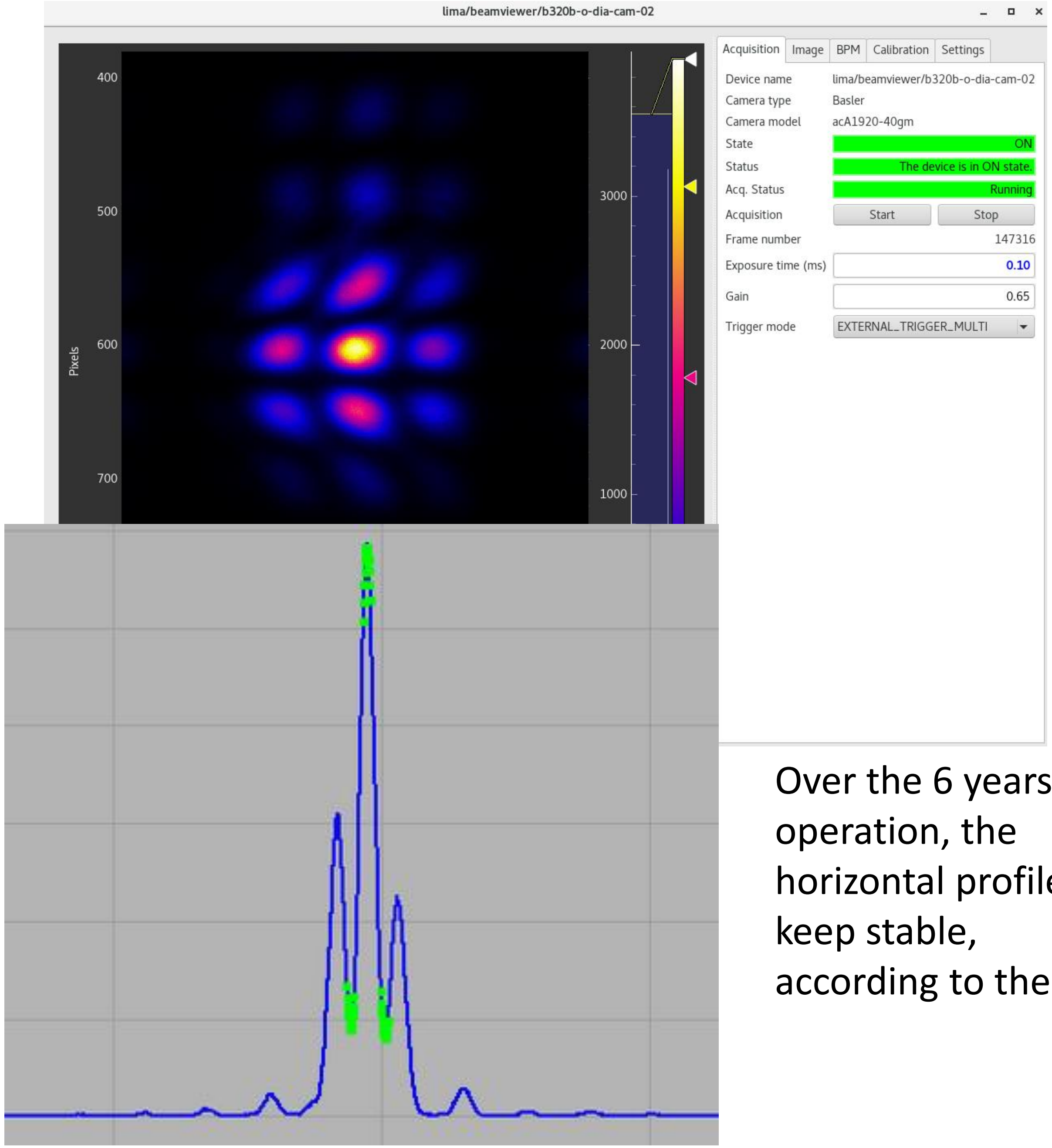
Horizontal intensity profile, sensitive to σ_x



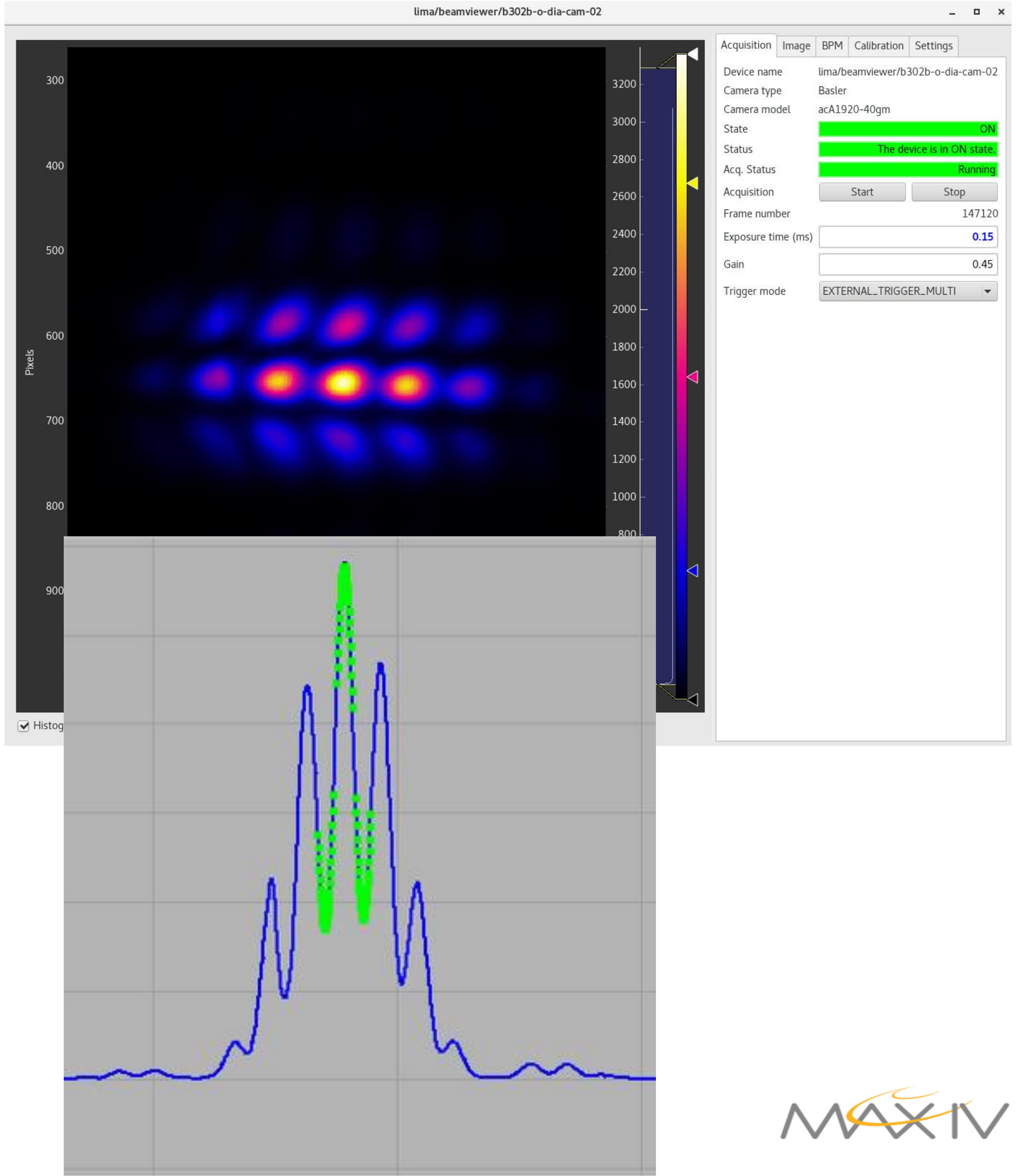
Vertical intensity profile, sensitive to σ_y



Beam Line B320B

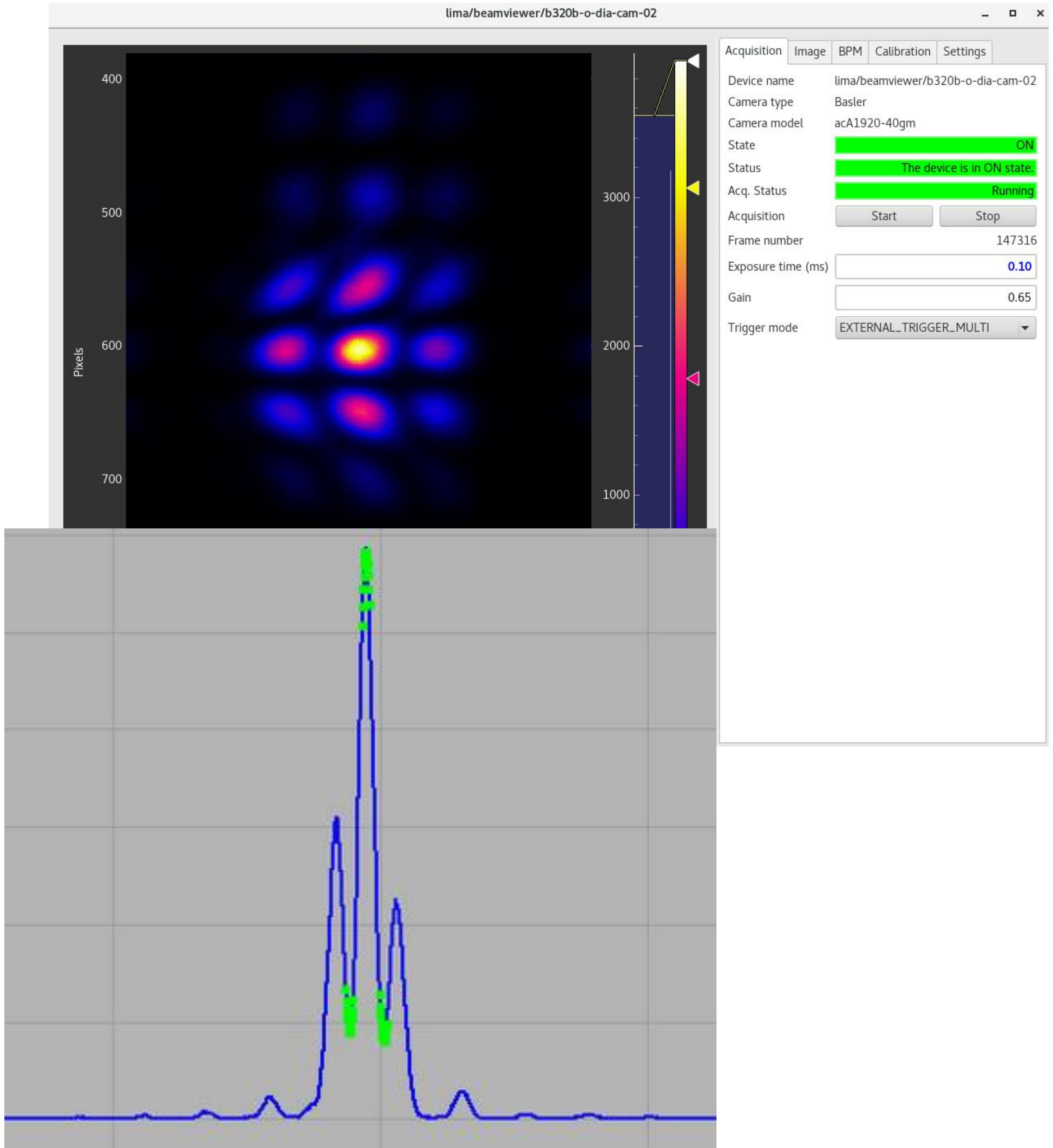


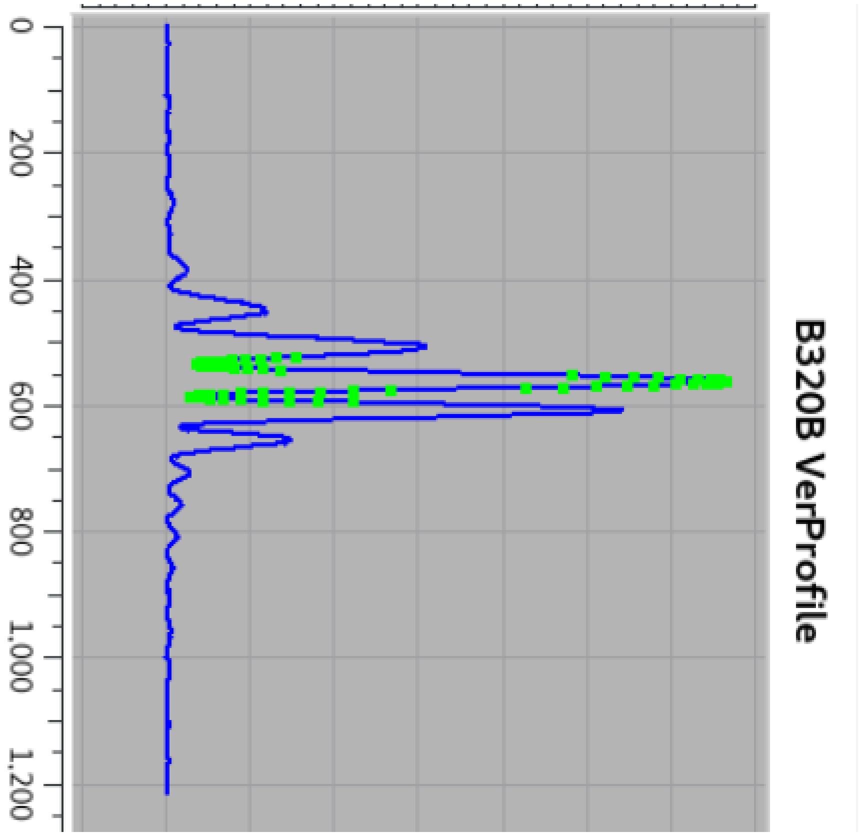
Beam Line B302B



Over the 6 years of operation, the horizontal profiles keep stable, according to theory.

Beam Line B320B





However, the vertical profile deteriorated over time. Modelling attempts tell that the resulting Valley/Peak ratio is still well describing the true vertical beam size. Culprit is carbon deposition on the lens.

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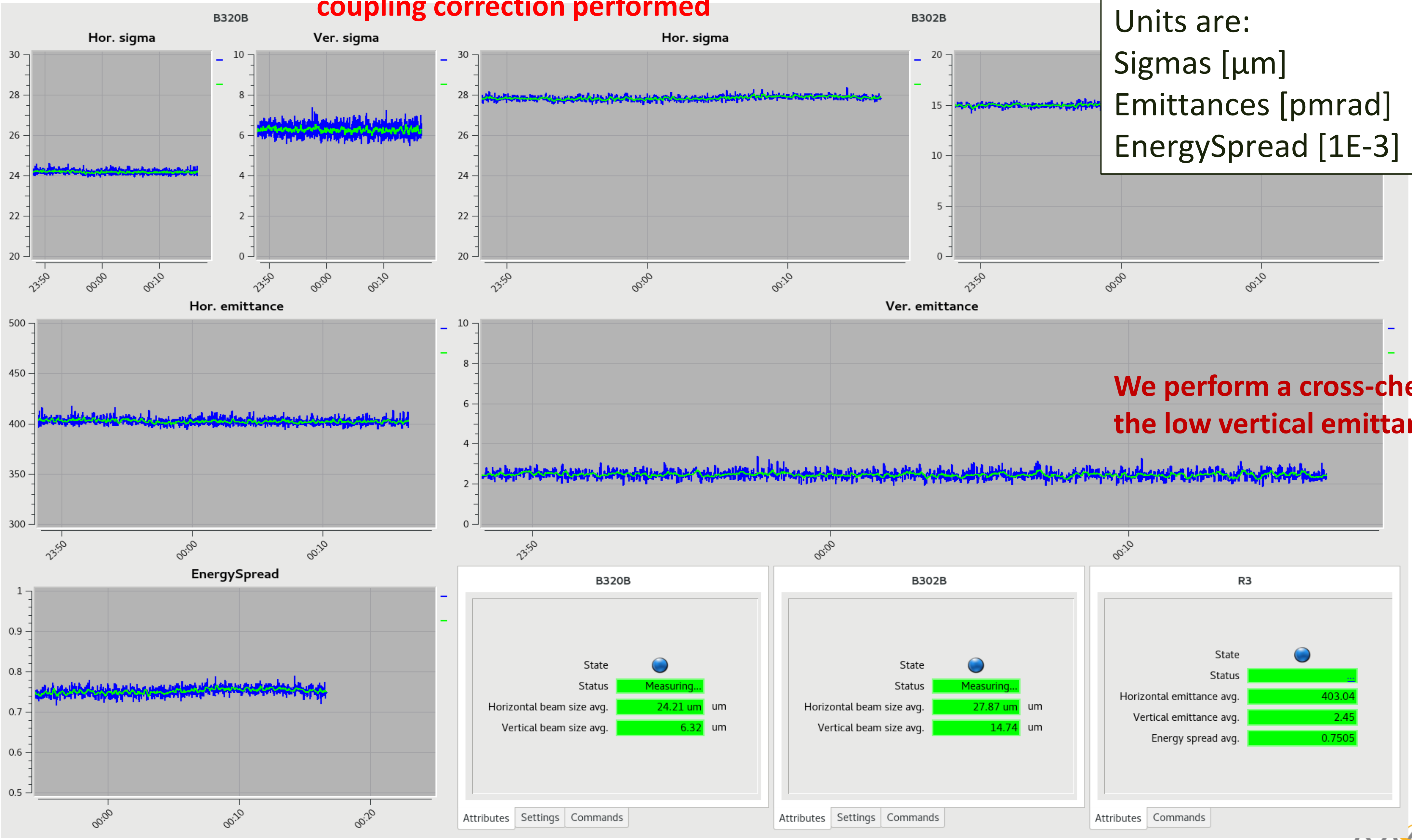
Control Room GUI: 300 mA, All ID gaps are closed, top-up every ten minutes

Units are:
Sigmas [μm]
Emittances [pmrad]
EnergySpread [1E-3]

Control Room GUI: 2 mA, All ID gaps are open and LOCO coupling correction performed



Units are:
Sigmas [µm]
Emittances [pmrad]
EnergySpread [1E-3]

We perform a cross-check of the low vertical emittance!

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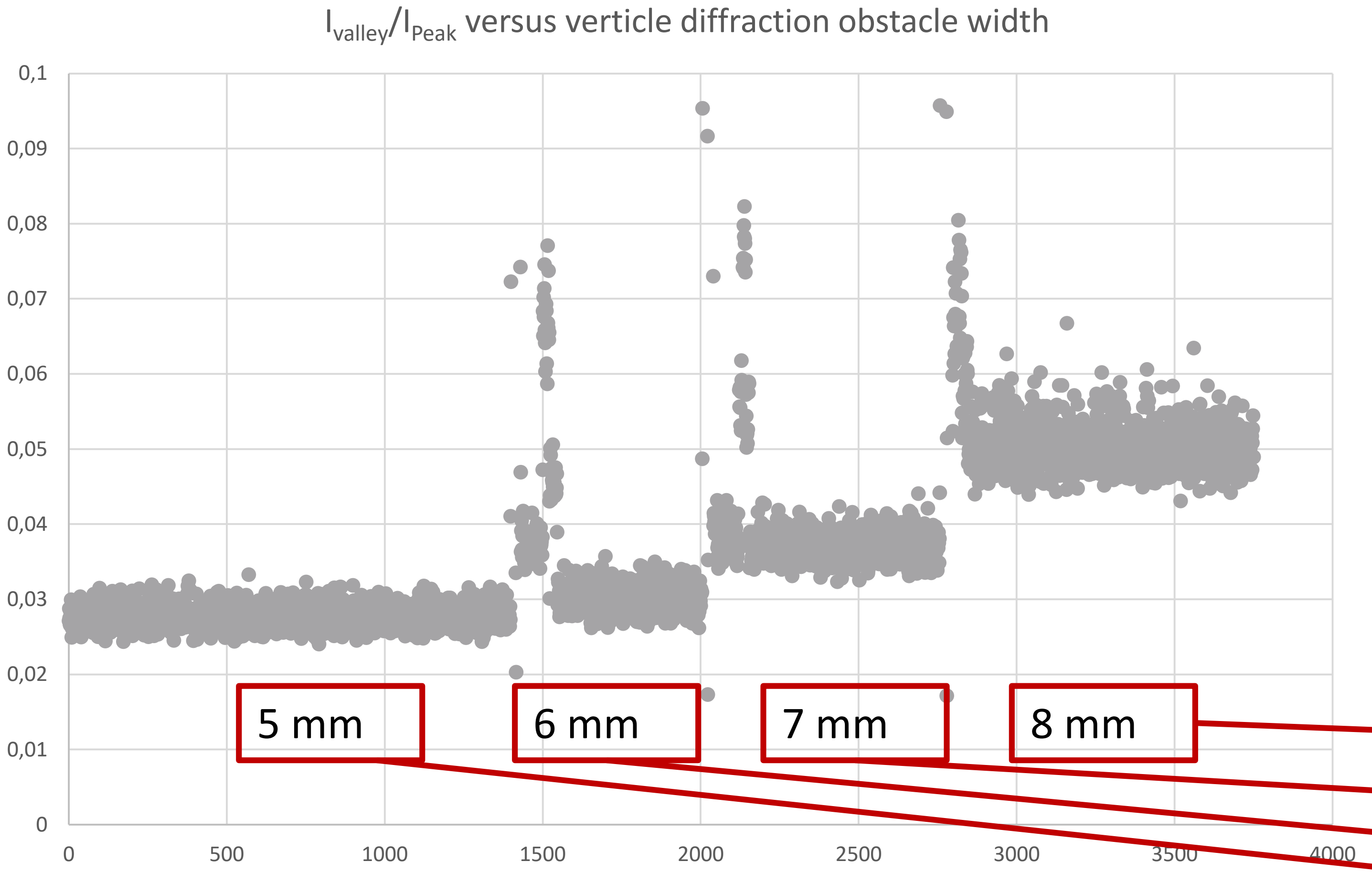
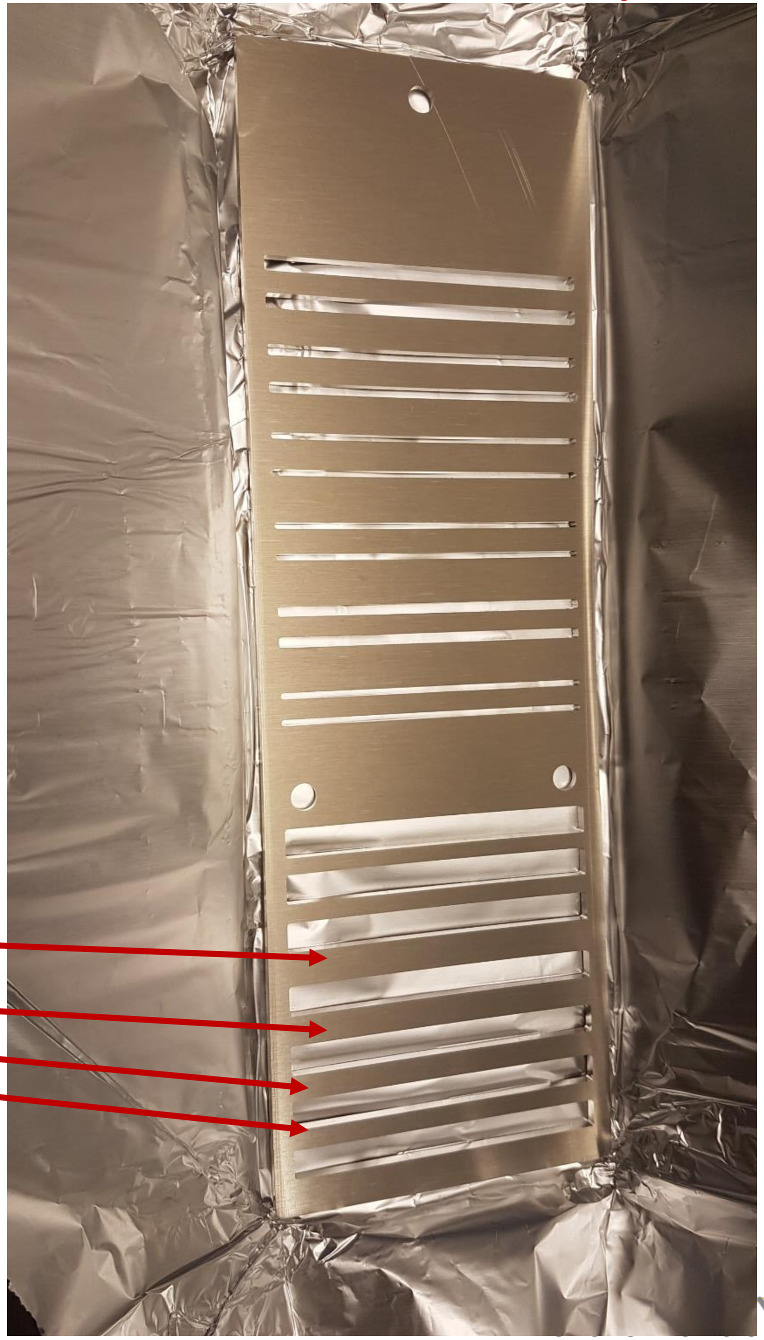
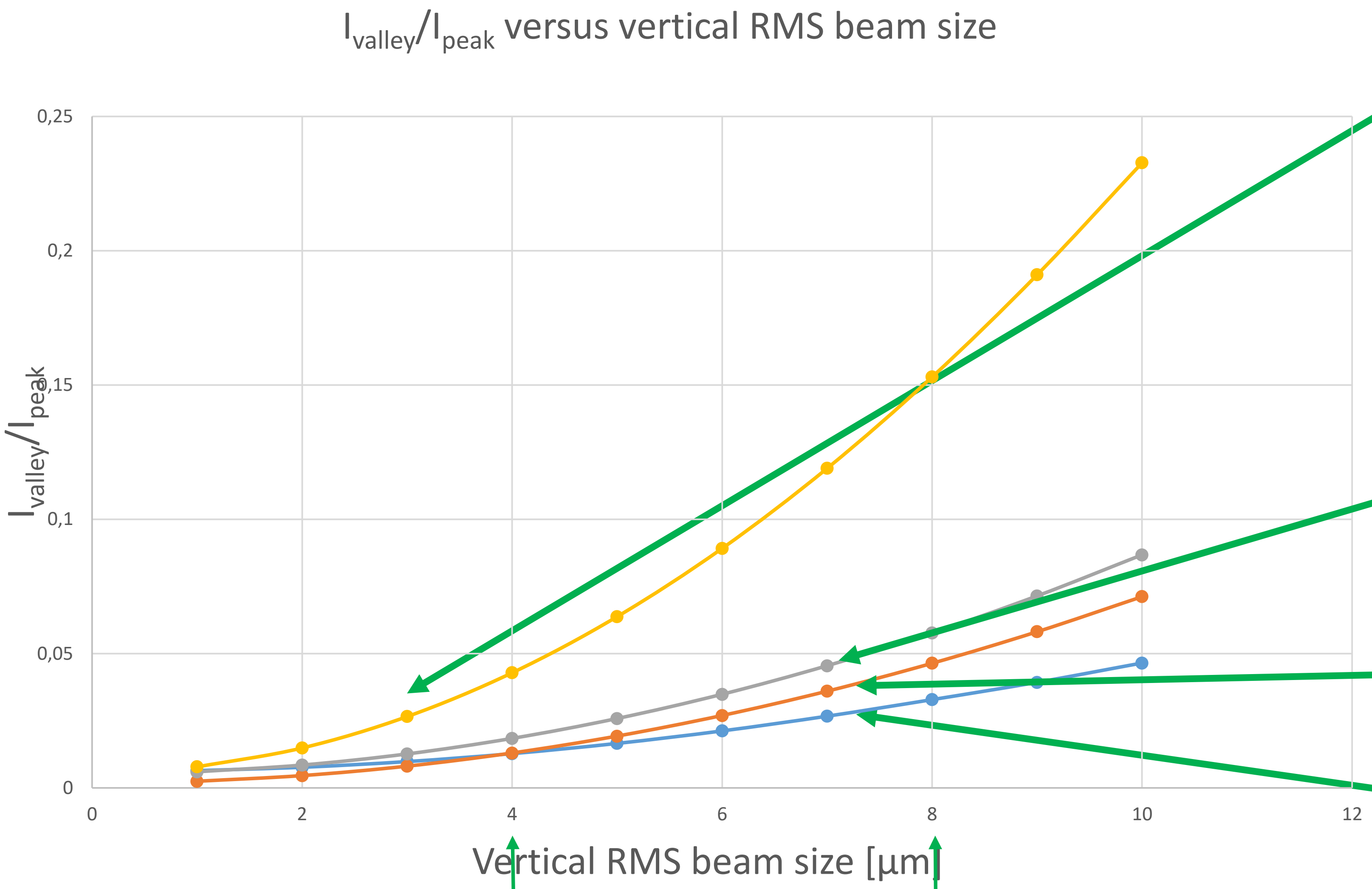


Vertical diffraction obstacle plate



Analysis: Vertical emittance = (3.7 +/- 0.5) pmrad
(Error is standard deviation)

Monitor response curve, vertical



Future:

Pi-polarized 264 nm
8mm obstacle:
~ 1.4 % per µm

Present:

Pi-polarized 488nm
8 mm obstacle:
~ 1.1 % per µm

Sigma polarized 488nm
8 mm obstacle:
~ 0.9 % per µm

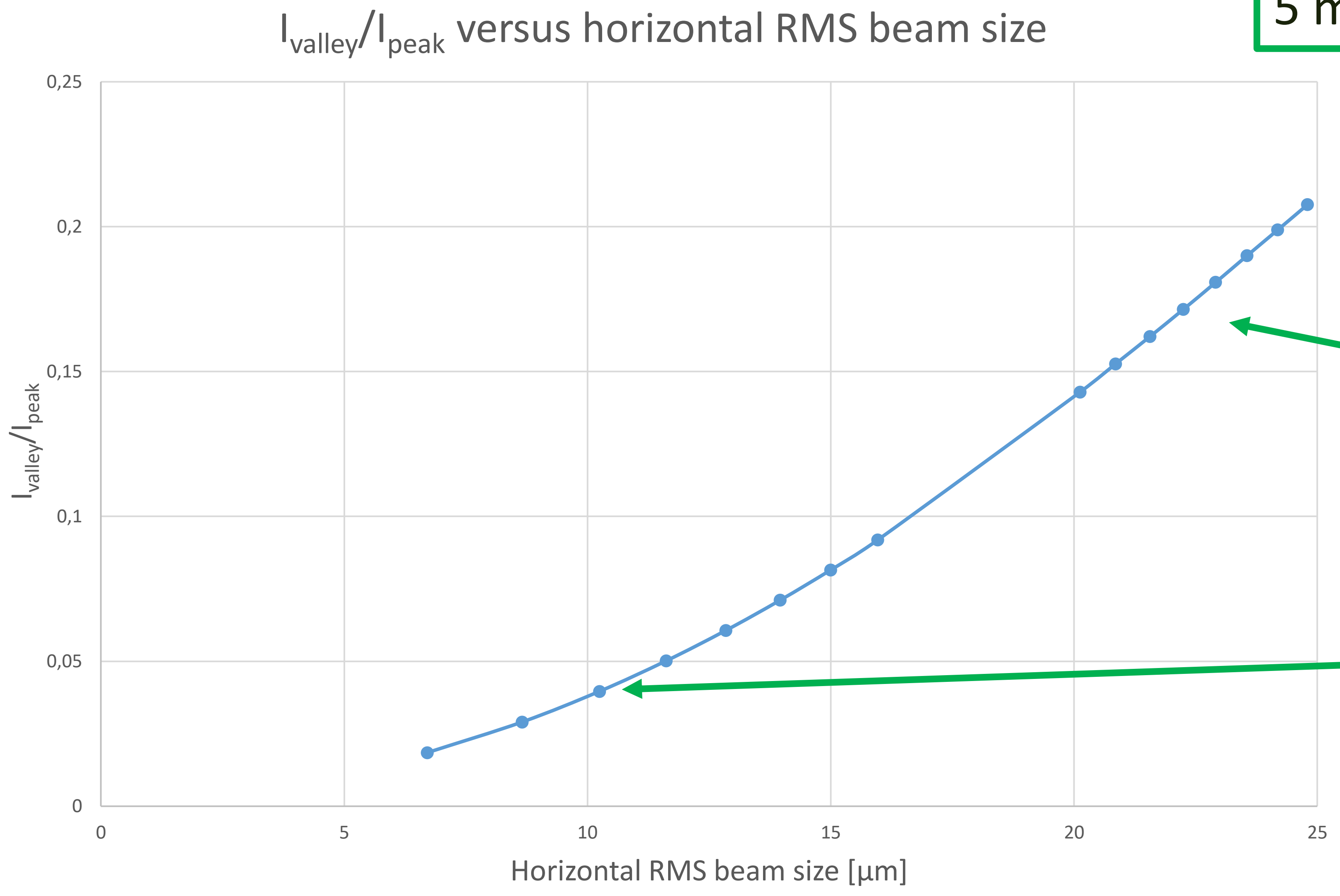
Sigma polarized 488nm
4 mm obstacle:
~ 0.6 % per µm

$\varepsilon_x = 1$ pmrad

$\varepsilon_x = 4$ pmrad

Monitor response curve, horizontal

Sigma polarized light
488 nm wave length
5 mrad hor acceptance



Where MAX IV is:
~ 1.5 % per µm

Future:

To measure sigx=10 µm:
~ 0.7 % per µm

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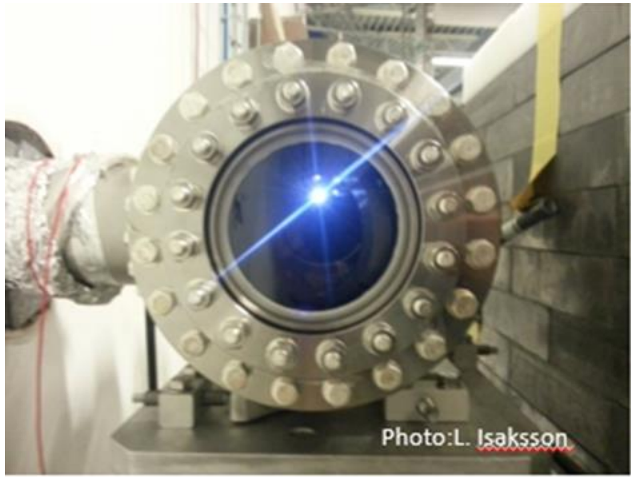
Limitations:

- Temperature changes in the BLs will alter the optical beam path slightly. Thus, the optical properties of different items must be uniform over a certain area.

- We have identified need for the following items to be improved: **The Glan-Taylor Polarizer, The Bandpass Filter, The Lens (after several years of exposure to SR), The Vacuum Exit Window (after some year of SR exposure)**

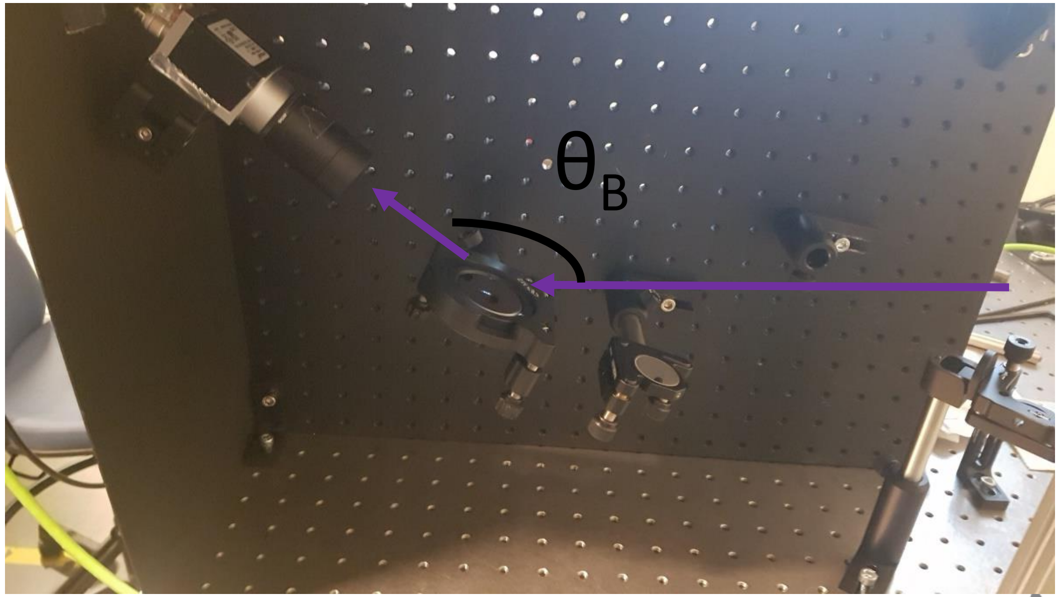
Limitations ➔ Improvements:

The Vacuum Exit Window:
We regularly change the relatively small light transit area, by moving the whole beam line end part.



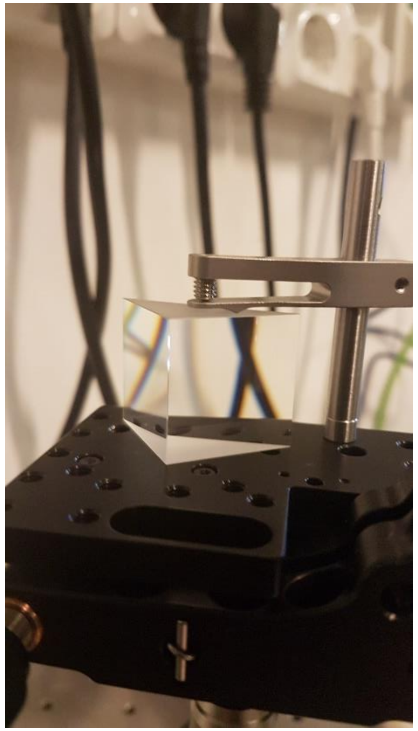
Diam= 90 mm

The Polarizer:
We introduced in one BL a **Brewster's angle polarisation with a flat SiC mirror**. Thus, only one polished surface instead of four in the G-T polarizer!

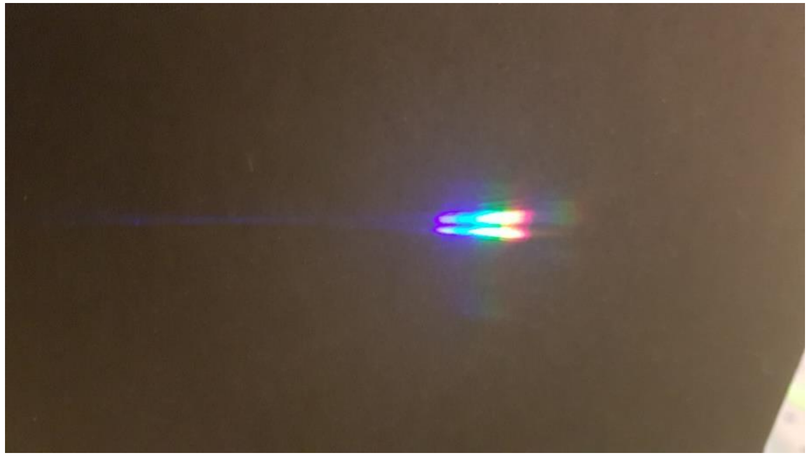


Limitations ➔ Improvements:

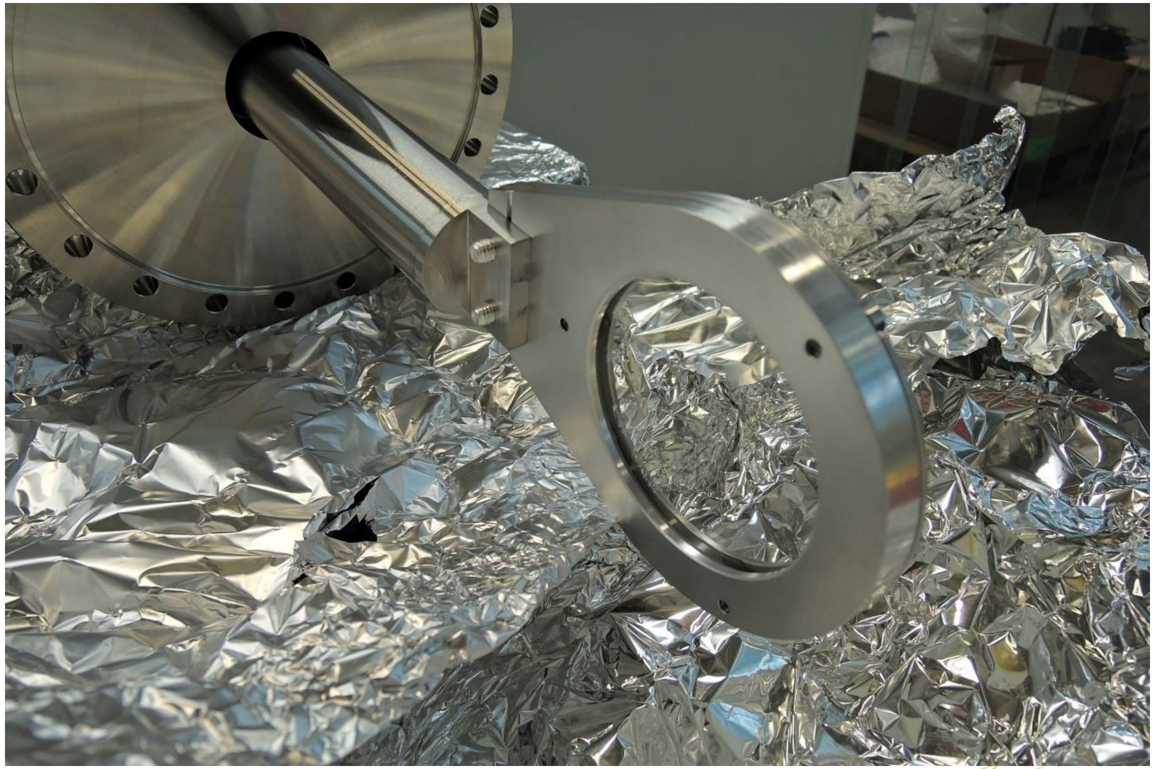
The Bandpass filter: "Back to basics": We are investigating a simple prism dispersion of the wavelengths; selection by slit:



Need then to sacrifice the simultaneous measurement of σ_x and σ_y .



The Lens:
We will change the lens this summer shutdown (after 6 years of operation)



Conclusions

- Uncertainties in results:

$\Delta\varepsilon_x$: +/-6% relative (max) error, @ around 300 pmrad to 400 pmrad (σ_x appr. 25 µm);

No major limitation for going down to σ_x appr. 10 µm

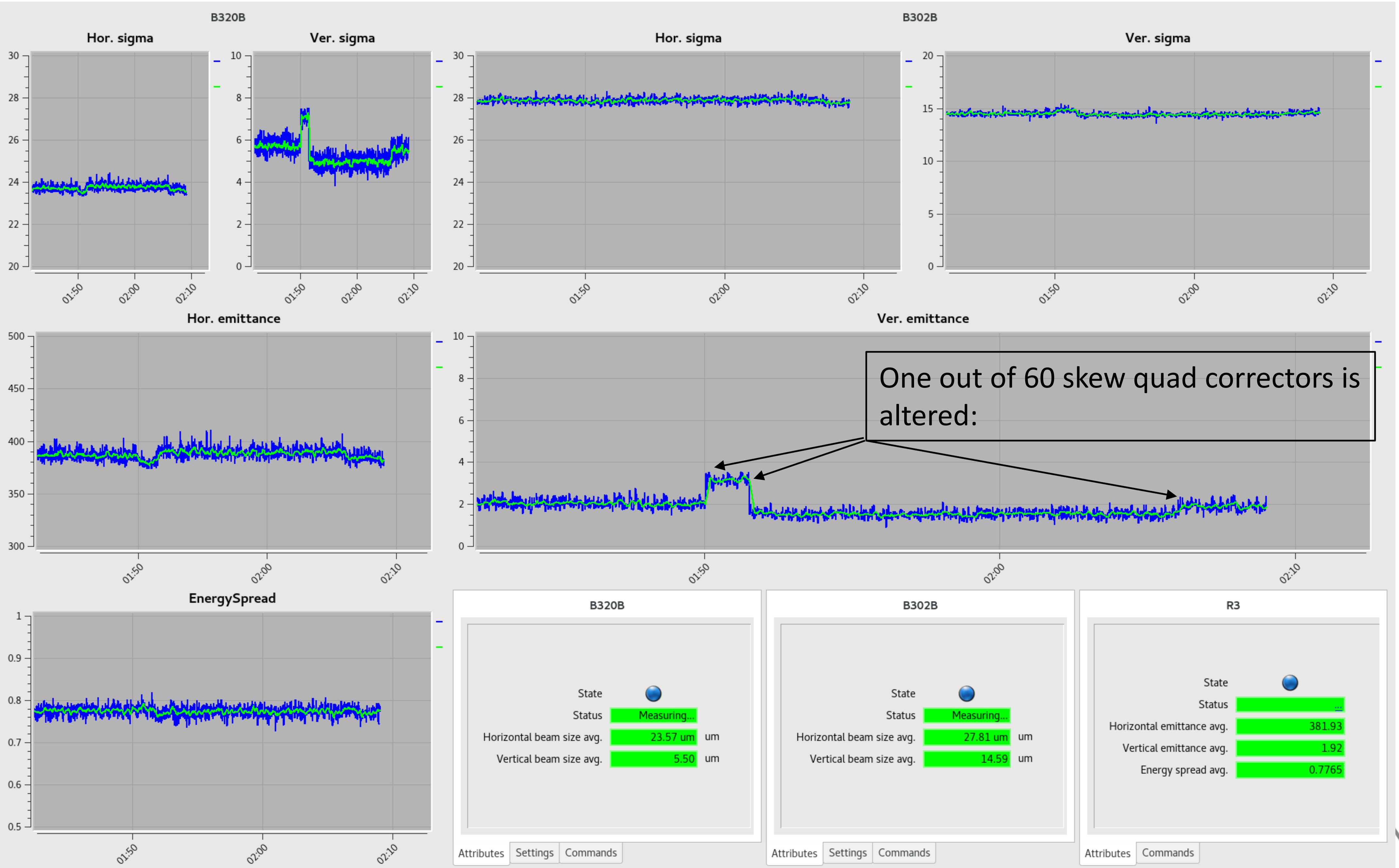
$\Delta\varepsilon_y$: +/-15% relative rms error, @3.7 pmrad (needs cross-checking methods)

To measure at or below 1 pmrad, need to use shorter w.length λ=264 nm

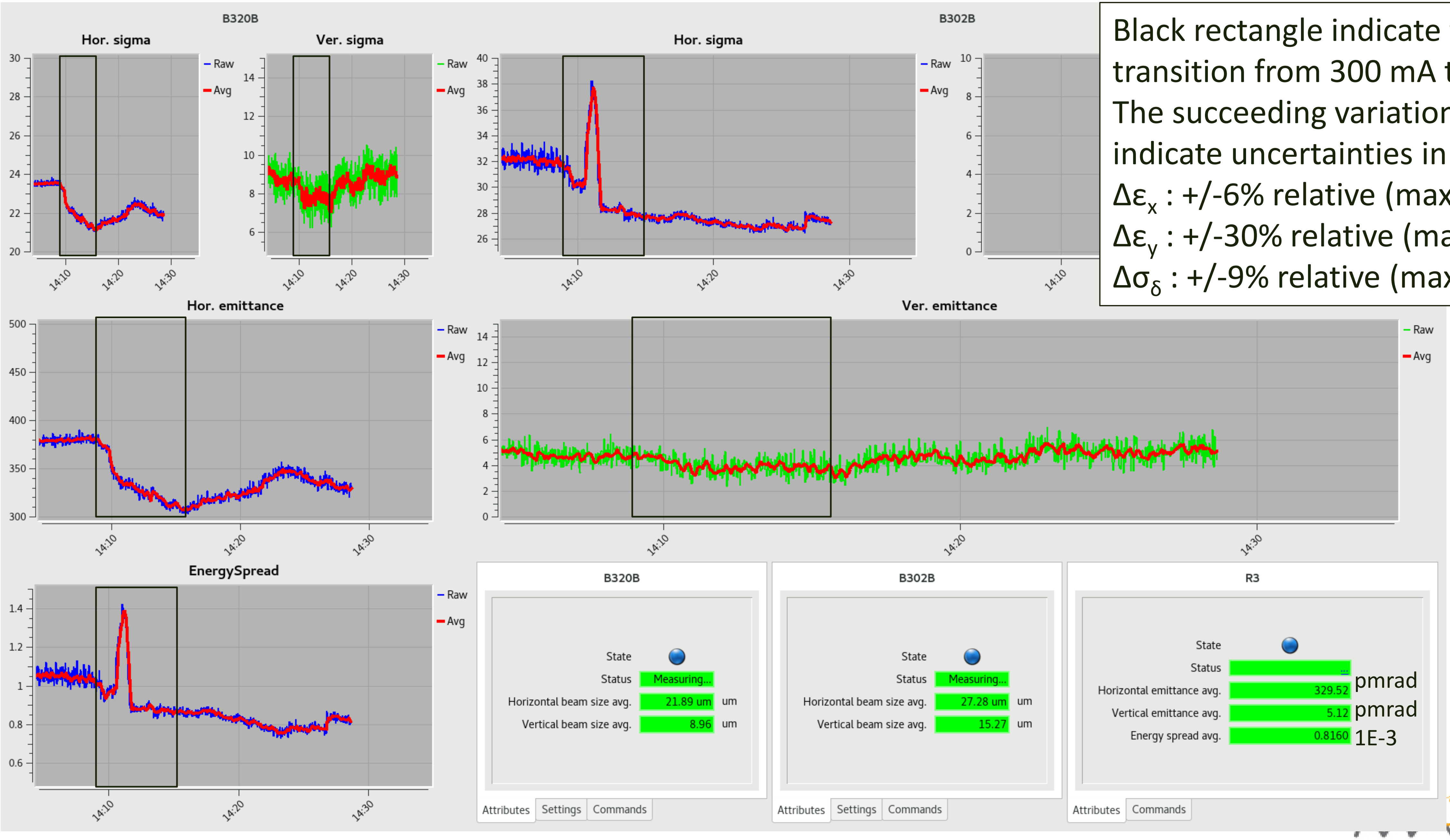
$\Delta\sigma_\delta$: +/-9% relative (max) error

- However, far more minute changes of the beam properties are detectable
- Work is in progress to lower all the errors (fewer and better optical surfaces), and to improve the vertical emittance measurement (using prism and/or shorter wavelengths).
- The monitor system was of specific importance at the **minimization of residual closed orbit disturbance from our Multipole Injection Kicker** , and for **minimization of energy spread while temperature tuning our six main cavities.**

Extra slides:


B320B
B302B
Hor. sigma
Ver. sigma
Hor. sigma
Ver. sigma
Hor. emittance
Ver. emittance
One out of 60 skew quad correctors is altered:
EnergySpread
01:50
02:00
02:10
B320B
State
Status
Measuring...
Horizontal beam size avg.
23.57 um
um
Vertical beam size avg.
5.50
um
Attributes
Settings
Commands
B302B
State
Status
Measuring...
Horizontal beam size avg.
27.81 um
um
Vertical beam size avg.
14.59
um
Attributes
Settings
Commands
R3
State
Status
Horizontal emittance avg.
381.93
Vertical emittance avg.
1.92
Energy spread avg.
0.7765
Attributes
Commands

Control Room GUI: “Stress test” 300 mA down to 3 mA; All ID gaps are closed



Black rectangle indicate the transition from 300 mA to 3 mA. The succeeding variations indicate uncertainties in results:

$\Delta\varepsilon_x$: +/-6% relative (max) error

$\Delta\varepsilon_y$: +/-30% relative (max) error

$\Delta\sigma_\delta$: +/-9% relative (max) error

Some improvements over the last years:

- New camera types; software developed by **Robin Svärd**
- Pre-programmed exposure times; **Jonas Breunlin**
- Precise measurement of the BL magnification, by exact movement of the lens (Å. Andersson)
- Feed-back beam steering by last in-vacuum mirror (J. Breunlin)
- Optical table re-arrangement; simultaneous longitudinal diagnostics (J. Breunlin)
- Optical filter improvements (J. Breunlin, Å. Andersson)
- Polarization improvement, using SiC mirror in Brewster angle (J. Breunlin, Å. Andersson)
- On-line emittance and energy spread calculation (R. Svärd)
- Remote control of last up-right obstacle at B320B (R.Svärd)
- Etc.
- One exchange of vacuum window at B320B (Esa Paju, Marek Grabski, Michael Gilch)

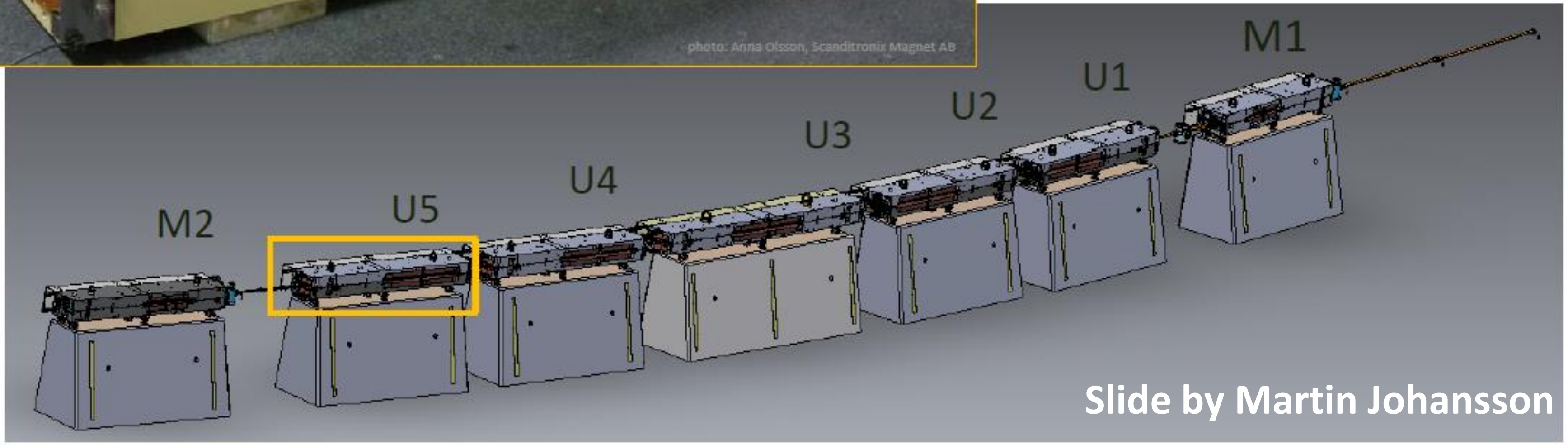
For reference:

	Beam size monitor 1	Beam size monitor 2
β_x [m] ; η_x [mm]	1.45 ; 1.9	1.19 ; 23.0
β_y [m] ; η_y [mm]	16.0 ; <0.2	8.63 ; <0.2
Dipole B-field [T]	0.53	0.53
Tot. Accept. Ang. (delivery settings) H ; V [mrad]	5 ; 7	4 ; 7
First (fixed) mirror ; Wave front Distorsion	SiC ; λ/20 (P/V)	SiC ; λ/20 (P/V)
Plano-Convex Lens ; Diam ; WfrontD	Fused Silica ; 75 mm ; λ/15 (P/V)	Fused Silica ; 100 mm ; λ/15 (P/V)
Dist. Source to Lens [m]	2.61	3.67
Magnification	-2.15	-2.91
# Additional Mirrors ; WfrontD	2 ; λ/20 (P/V)	4 ; λ/20 (P/V)
Vacuum window ; WfD	Fused Silica ; λ/10 (P/V)	?
Polarizer ; WfrontD	SiC in Brewster's angle ; λ/20 (P/V)	Calcite Glan-Taylor Prism ; λ/8 (P/V)
Polarization	horizontal	horizontal
Bandpass filter	488 nm ; 3 nm FWHM	488 nm ; 3 nm FWHM
Camera	Basler ; pix.size 5.86 µm	Basler ; pix.size 5.86 µm

MAX IV 3 GeV ring DC magnets

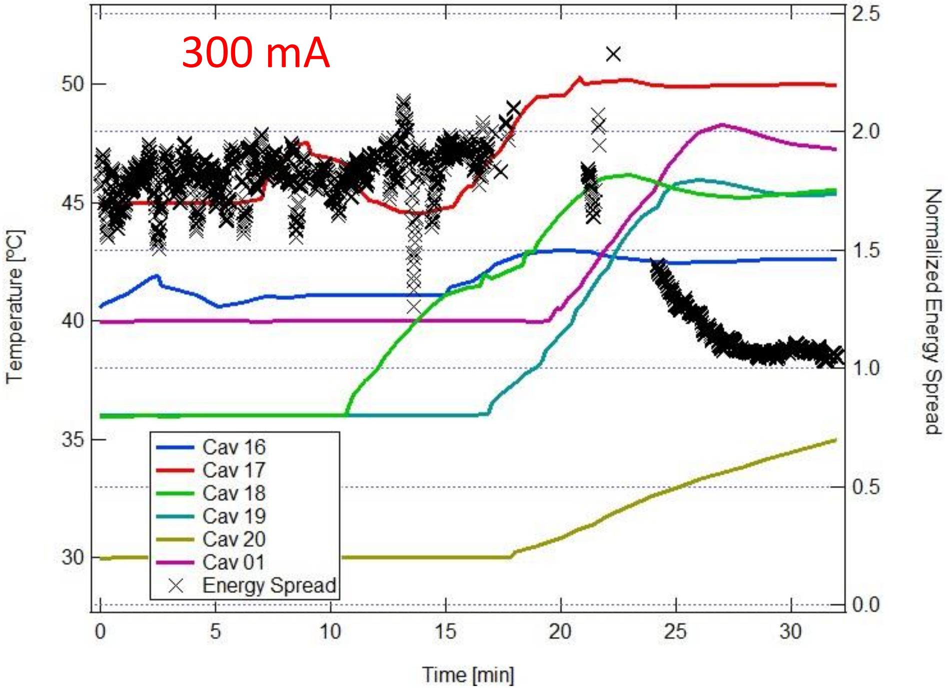
• Each cell is realized as one mechanical unit containing all magnet elements.
•Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.

- a U5 bottom half →
- ↓ an assembled U5

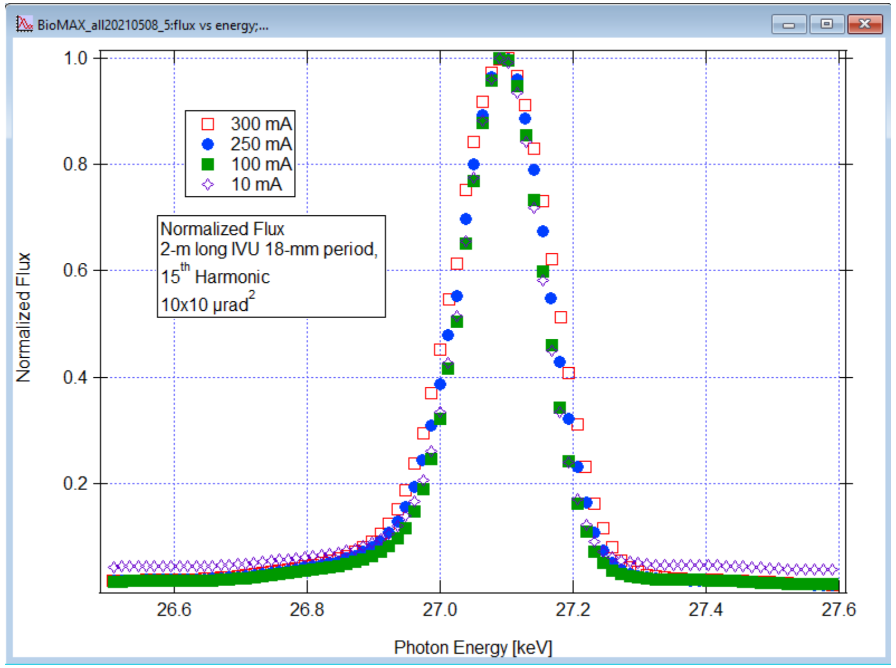


Collective Effects: Cavity Temperature/Voltage Optimization

- RCDS (Robust Conjugate Direction Search) for **optimum main and harmonic** cavity voltage amplitudes and temperatures in order to allow increasing the beam current **without increasing the total required RF power**.



Data by **Pedro F. Tavares**



Spectral Flux at **15th Harmonic** in pin-hole geometry at **BioMAX**

Data by **Ishkhan Gorgisyan**