SQS X-Ray Beam Transport and Focusing Optics

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Scientific Instrument SQS
Instrument Scientist

SQS Early User Workshop
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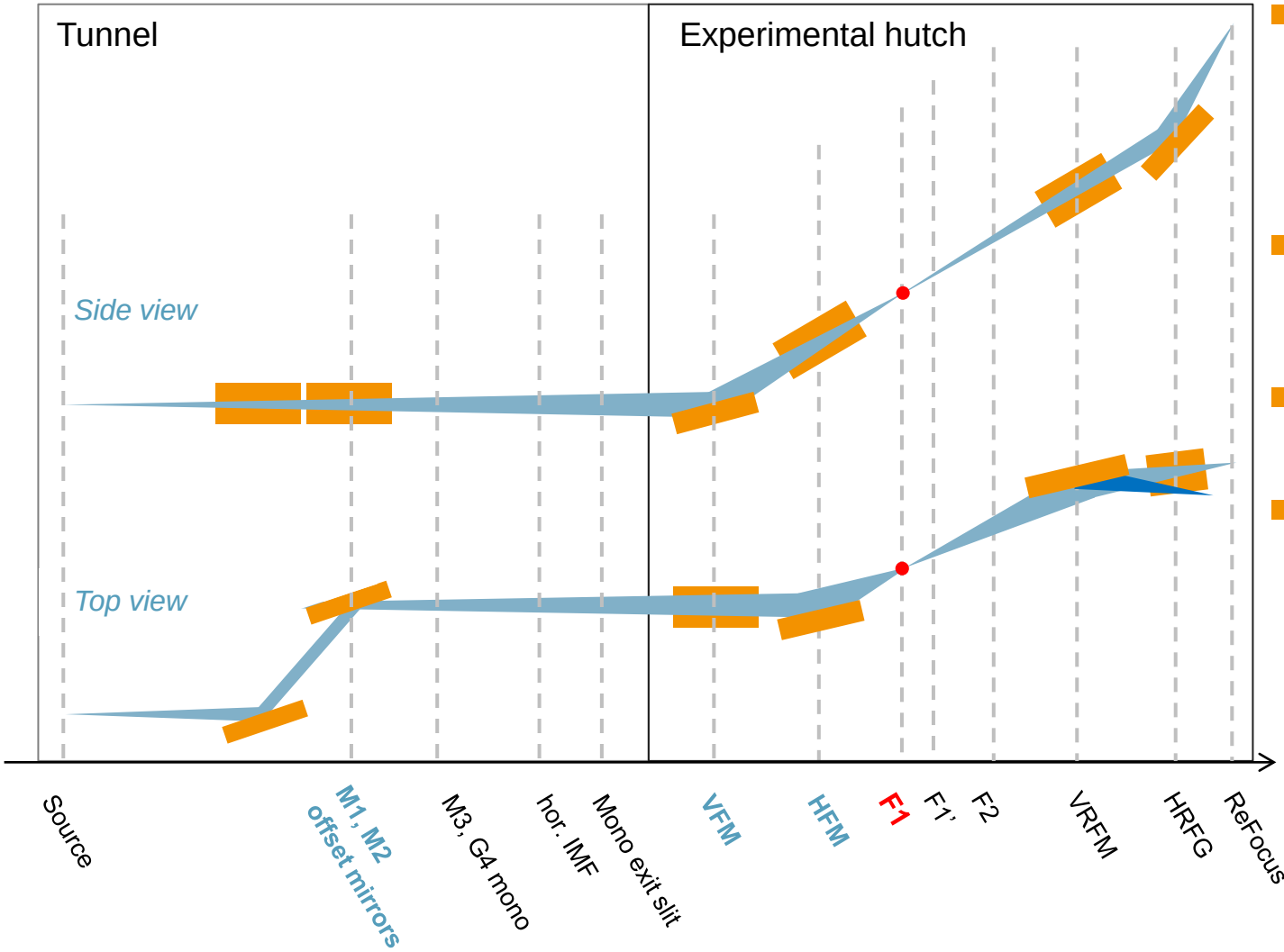
Outline

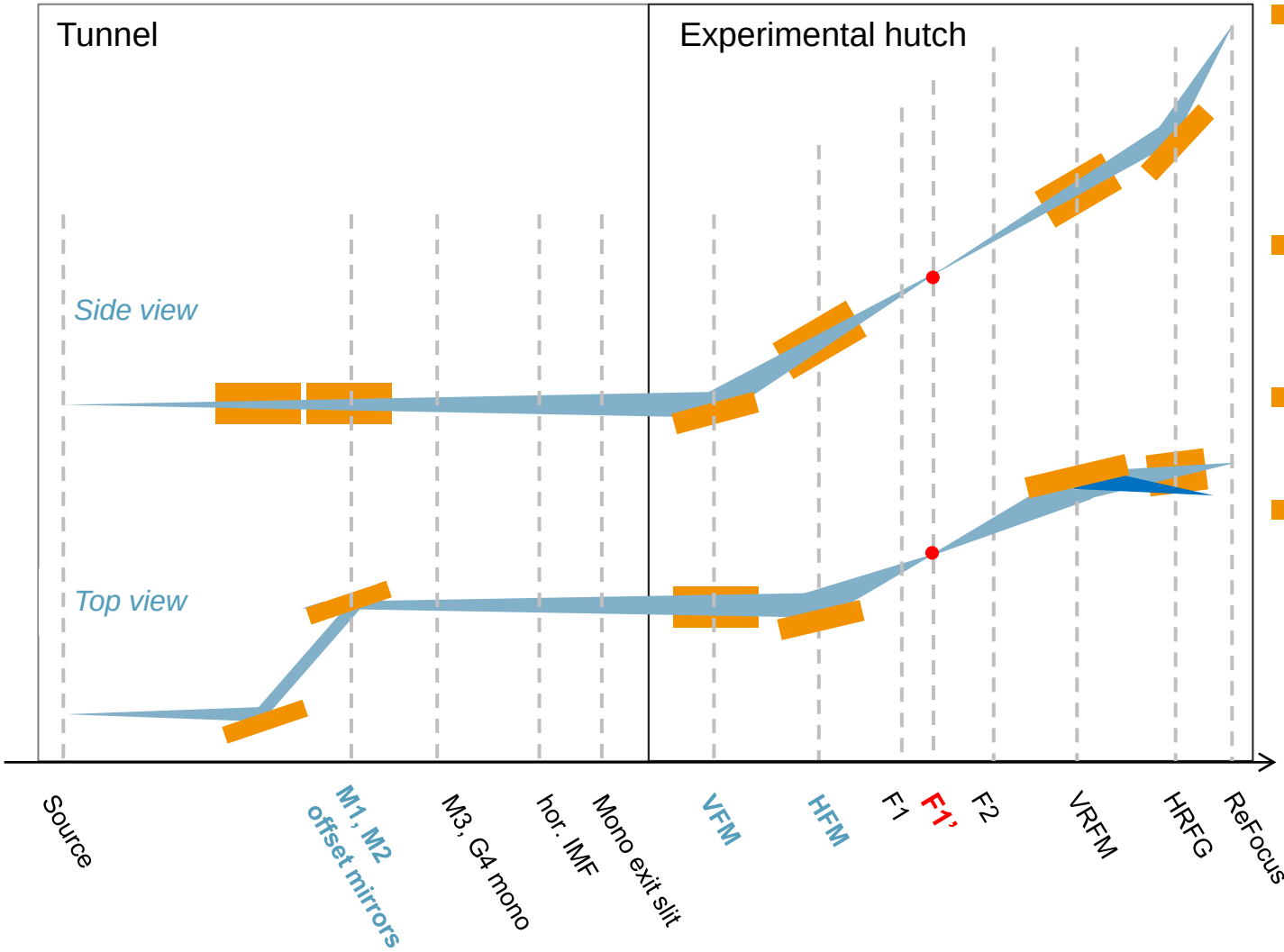
- SQS Beam Transport Layout
- Focusing System for “Day 1”
  - characteristics and status of the SQS Interim Focusing Mirrors System
  - Mirror and mirror system characterization
  - Expected focusing performances
- Focusing Metrology
  - Focusing characterization strategies
- Beam Transport for diagnostics purposes
  - Refocusing system: concept and expected performances
  - Status and timeline

Final beam transport layout: Direct Focusing of pink beam



- Beam is transported by a total of 4 optical elements
  - M1, M2 offset mirrors
  - VFM, HFM KB focusing mirrors
- Source distance is >400m → high demagnification factor
- HFM and VFM are polished for focusing in **F1**
- The beam is transported downstream and refocused for diagnostic purposes

Final beam transport layout: Direct Focusing of pink beam



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  - they are laterally shaped to focus in **F1'** with no residual error when bent

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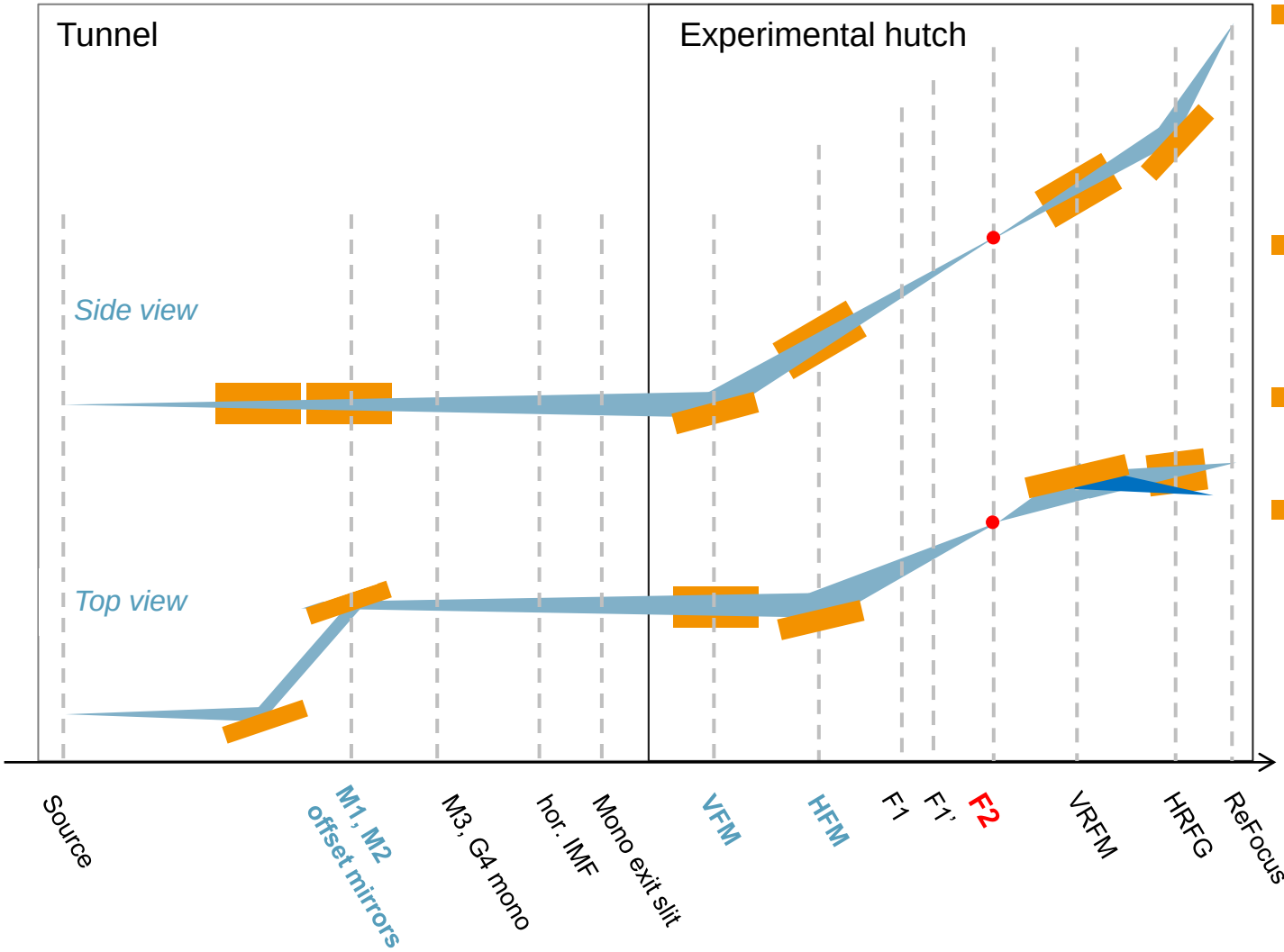

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- HFM and VFM are bendable;
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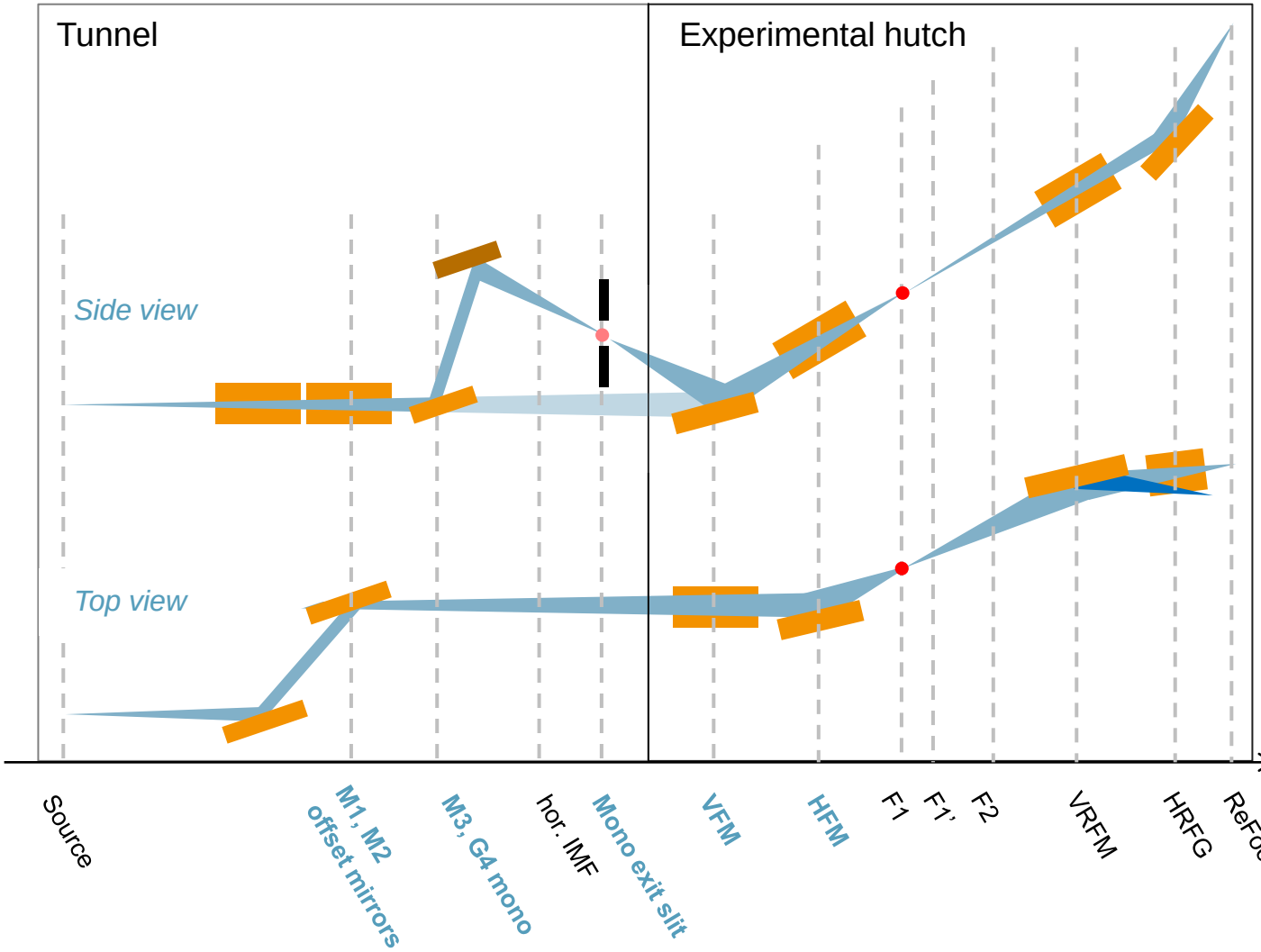
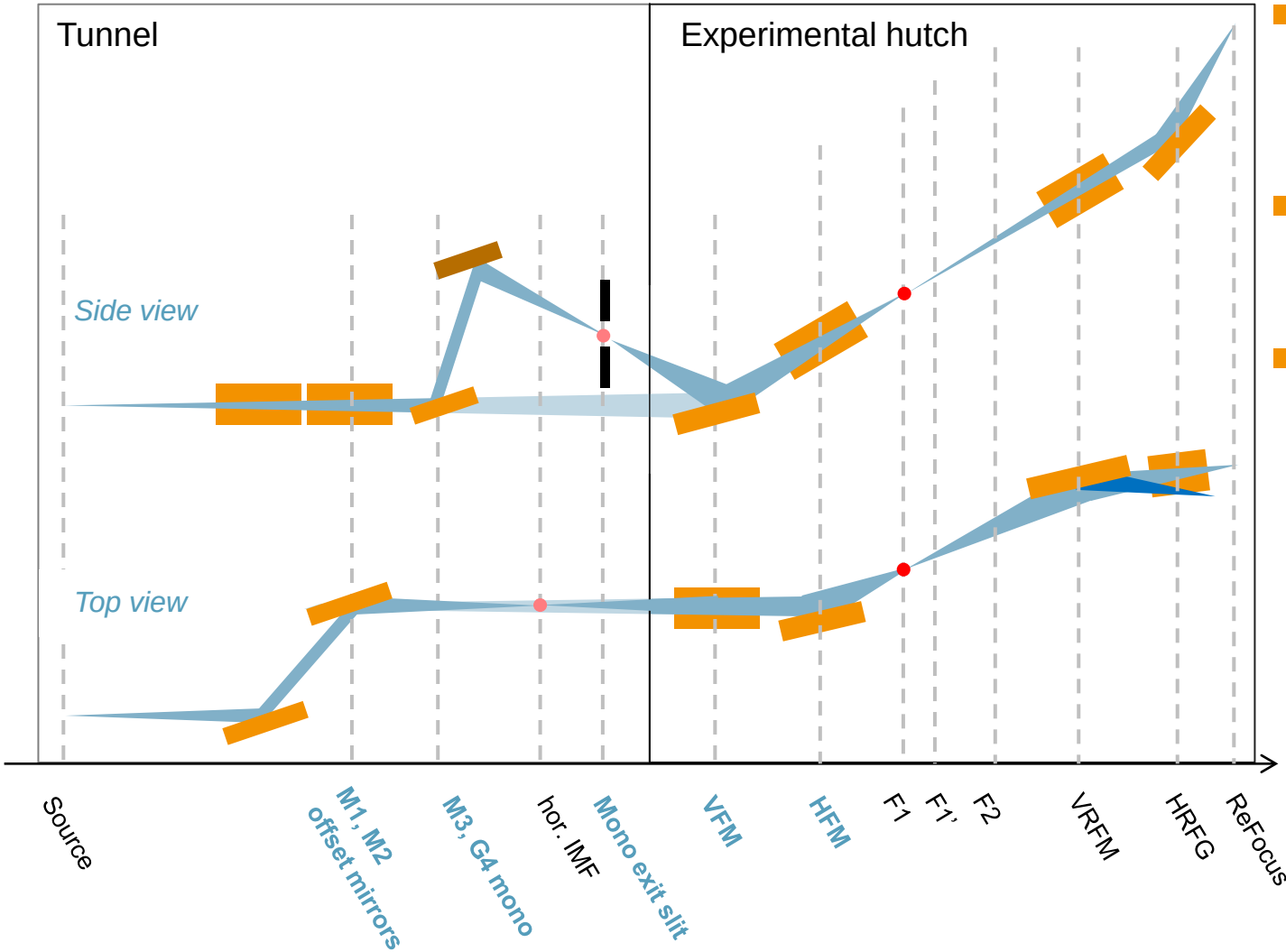
  - They can be bent to focus also in **F2**

Final beam transport layout: Focusing of monochromatic beam



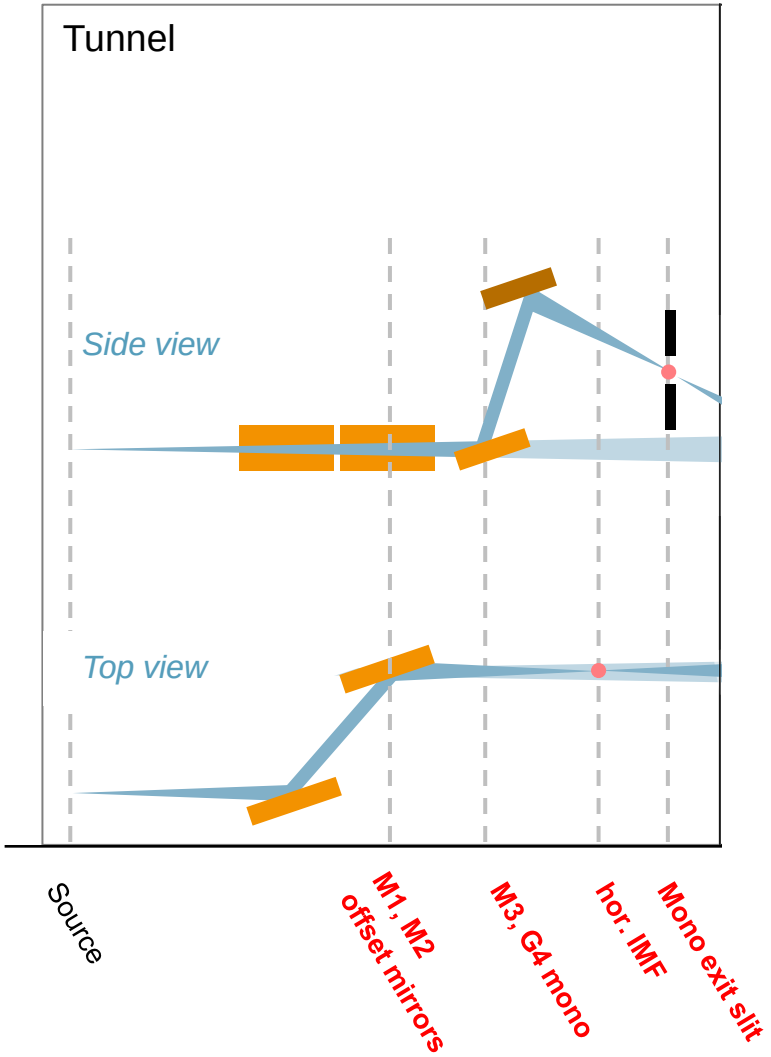
- Beam is vertically deflected by M3 on G4; dispersed beam is focused on the exit slit
- VFM KB bending is used to image in F1 / F1' / F2 the monochromatic source

Final beam transport layout: Horizontal intermediate focusing



- Beam is vertically deflected by M3 on G4; dispersed beam is focused on the exit slit
- VFM KB bending is used to image in F1 / F1' / F2 the monochromatic source
- Beam can be focused horizontally into an intermediate focus; HFM KB can be bent to image in F1 / F1' / F2 this virtual source (larger geometric transmission / spot size shaping)

Day 1 beam transport layout: Final KB system not available, interim KB pair adapted



- **Fixed radii substrates,** focusing the IMF in both H and V **in one single focal position;**
- The focal position **"Fi"** is placed 200 mm downstream F1
- **HFM and VFM positions are swapped** respect to the final configuration → Beam is off by ~25mm in both V and H directions at the interaction point
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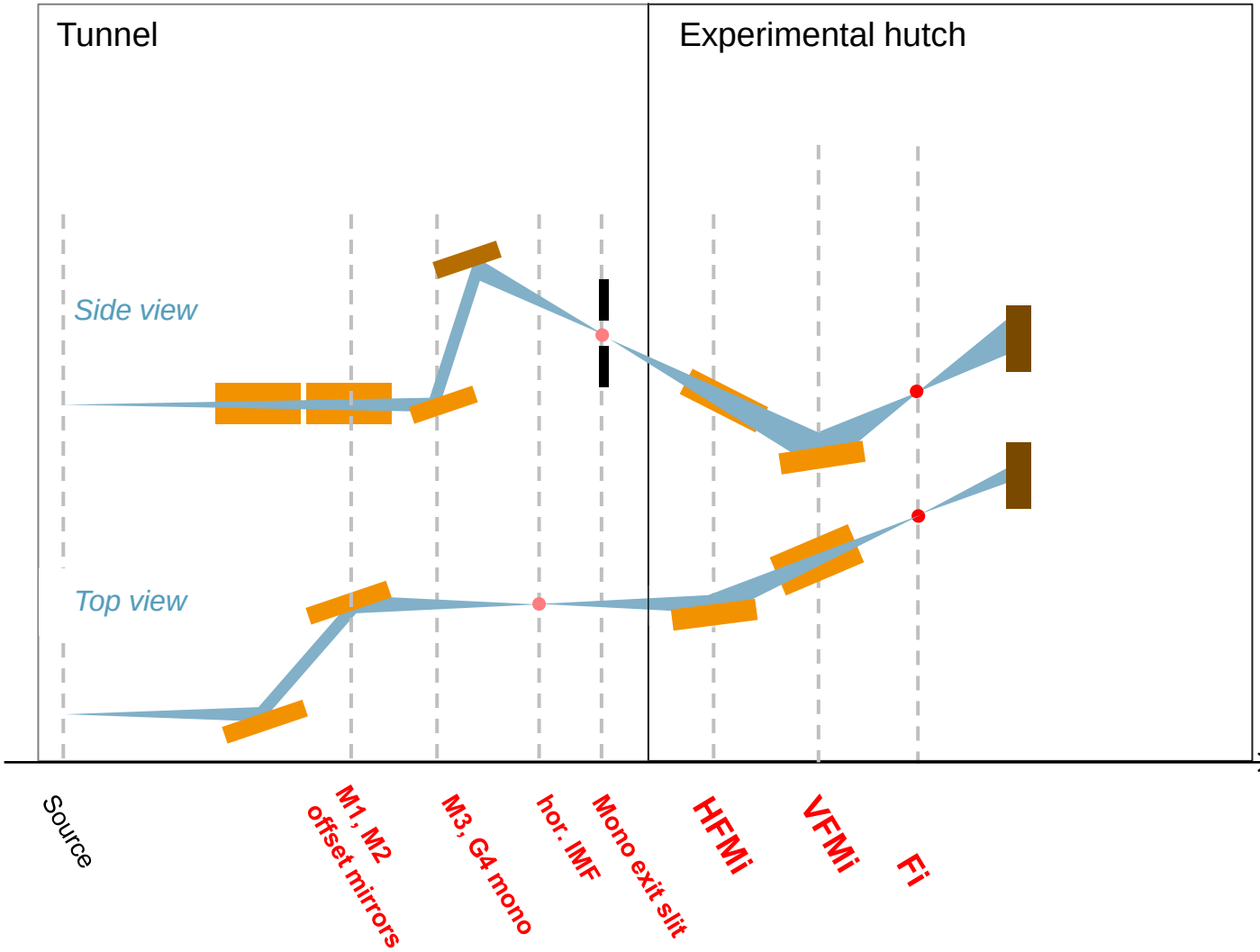

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- **No beam transport downstream the interaction region** (no downstream diagnostics)

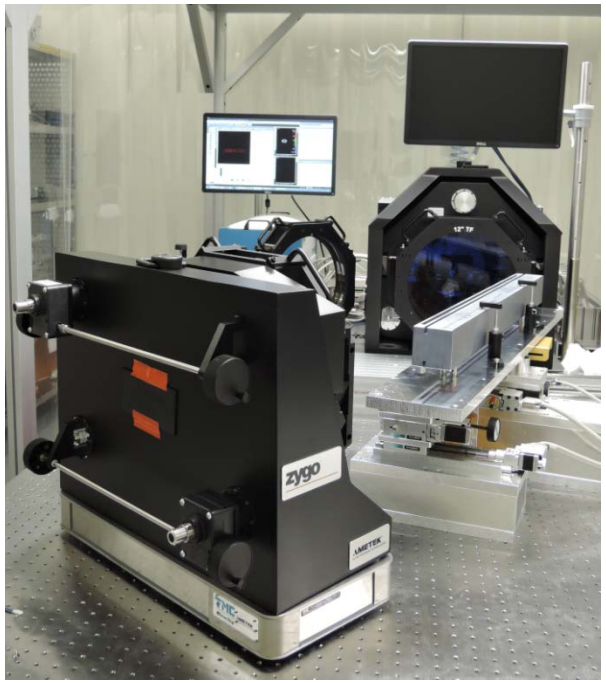
SQS Interim Focusing Mirrors System Facts

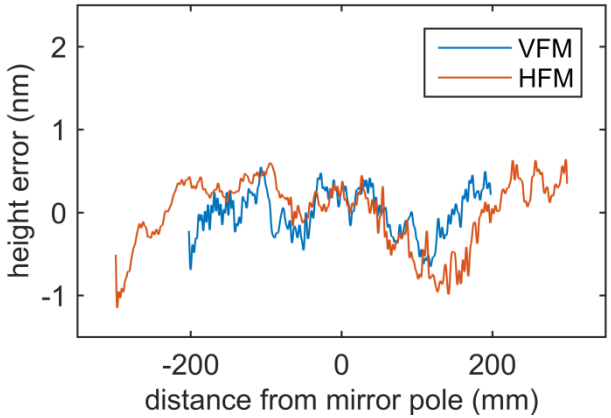
Specifications				
Manufacturer		JTEC Corp., Japan		
Focusing		EEM polished elliptical substrates, **height error 2nm PV**, fixed radii; *incidence angle detuned to adopt them to the SQS beam transport design*		
Physical dimensions (L x W x T) Clear aperture	H	800x70x70mm, **CA=600mm**		
	V	600x70x70mm, **CA=400mm**		
SASE 3 beam transport layout		Intermediate beamline focusing (both H and V)		
Spot size tuneability		Not available (chamber shifting along z possible)		
Parameters		**Source distance p [m]**	**Image distance q [m]**	**Incidence angle [mrad]**
Specified ellipse parameters	H	52.0	3.3	9
	V	28.0	2.0	9
Measured ellipse parameters	H	52.75	3.3	8.96
	V	27.97	2.0	8.95
Imaging parameters	H	71.0	3.3	9.14
	V	43.0	2.0	9.24
Schedule				
Status of mechs / vacuum		Ready for delivery, waiting for hutch readiness		
Status of substrates		Delivered, characterized in XFEL Metrology Lab, In the queue for being coated		
System Timeline		To be installed in Apr-May 2018		

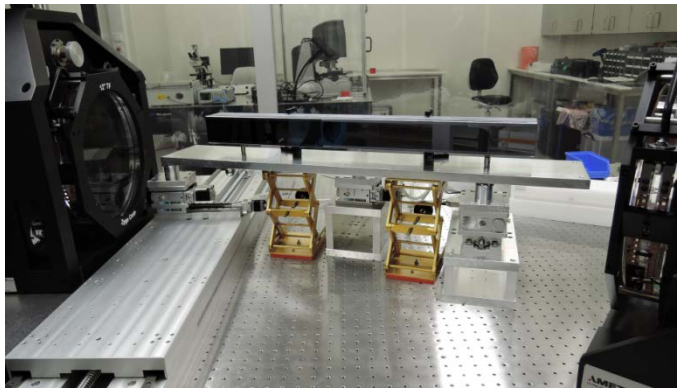
SQS Interim Focusing Mirrors Substrates Metrology

The EEM polished substrates were characterized in the XFEL Metrology lab by a large aperture Fizeau interferometer in “grazing incidence” setup (October 2017)

- Strong curvature → systematic errors in the measurements + limited CA characterized → obtained results are an upper limit to the accuracy of the surfaces;
- Obtained results confirm (to an upper limit) the metrology report by the vendor, that says **Residual height error < 2nm PV**.





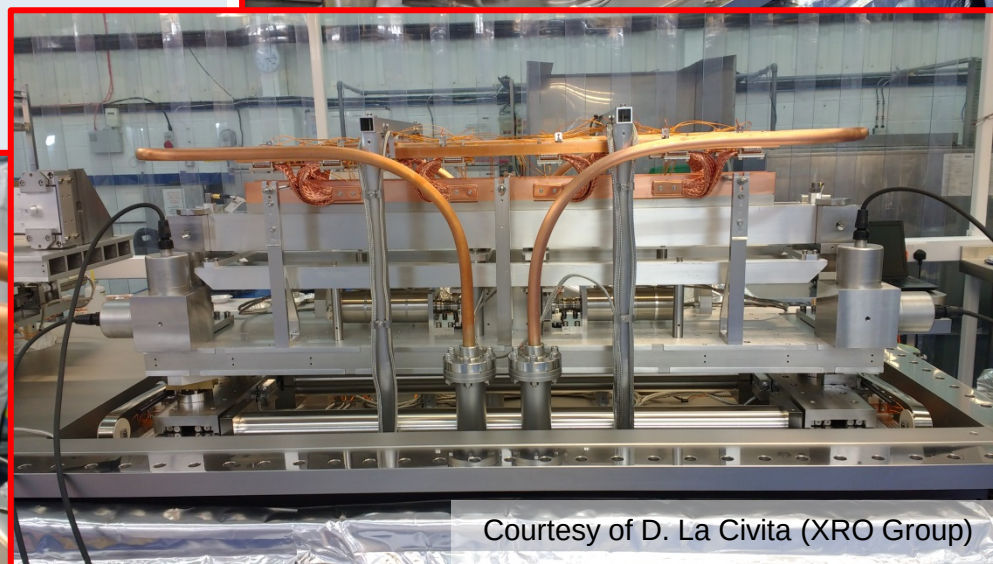


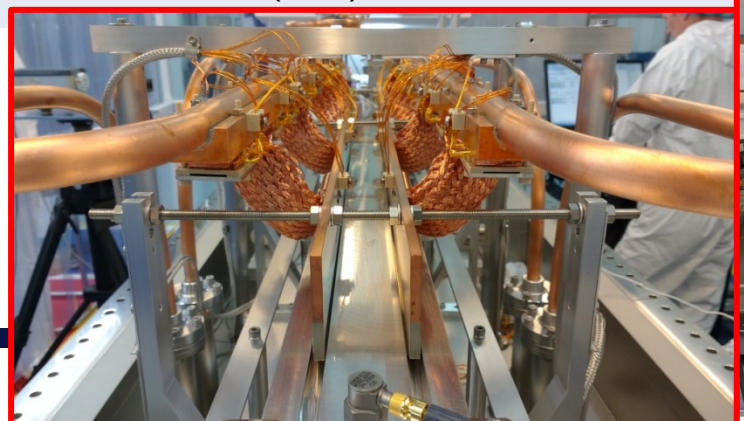
Courtesy of M. Vannoni (XRO Group)

SQS Interim Focusing Mirrors
Vacuum and Mechanics Stability

FAT of the Mirror System tank and mechanics at the FMB Oxford premises (July 2017)

- Vacuum < 1e-9 mbar after baking
- Mechanical stability checked by accelerometry:
  - low vertical transfer function for both HFM and VFM
  - Acceptable horizontal transfer function for both HFM and VFM
  - Angular pitch stability:
    - ► 65nrad RMS (VFM)
    - ► 54nrad RMS (HFM)





Courtesy of D. La Civita (XRO Group)

Expected performances: ray tracing simulations

Source size and divergence *(calculated by Yurkov et al.)*

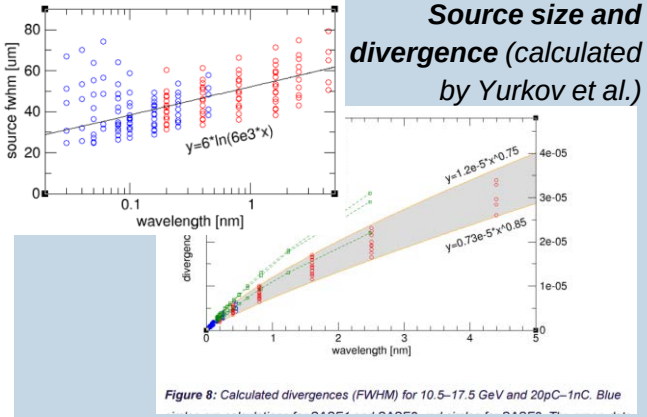


Figure 8: Calculated divergences (FWHM) for 10.5–17.5 GeV and 20pC–1nC. Blue

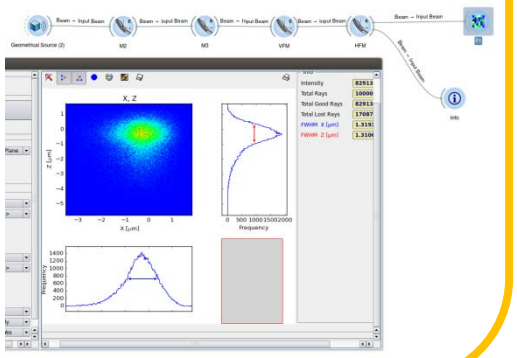
H. Sinn et al., CDR X-Ray Optics and Beam Transport April 2011

Beamline 3D geometry

https://www.elettra.trieste.it/oasys.html

Including ShadowOui, user interface for Shadow3 (new release of the widely used x-ray optics simulation package)

Credits:
M. Sanchez del Rio (ESRF)
L. Rebuffi (Elettra)

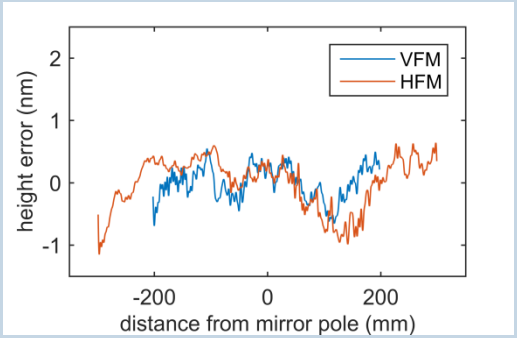


+

- ✓ Mirrors reflectivity from the CXRO database
- ✓ Diffraction simulated by a randsinc2 contribution

Mirrors reflecting surface profiles

- Polishing error from metrology



Output:

- ✓ *Focal spot profile*
- ✓ *Rayleigh length*
- ✓ *Transmission*

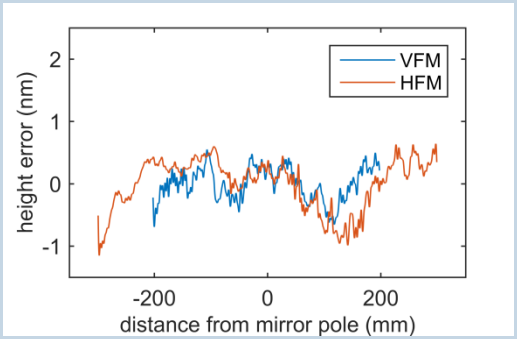
Expected performances: wavefront simulations

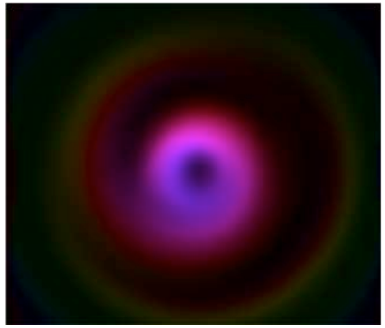
Gaussian beam

Beamline 3D geometry

Mirrors reflecting surface profiles

- Polishing error from metrology





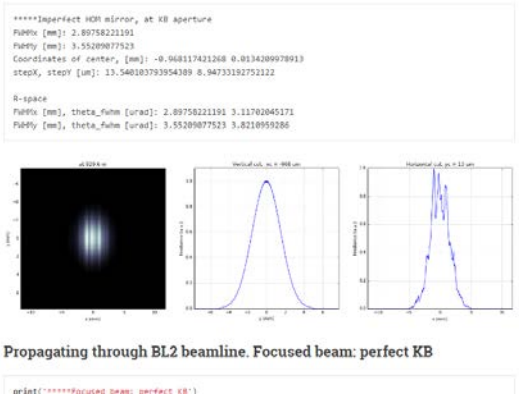
WPG

WaveProperGator

with SRW/C++ library

Credits:
Alexey Buzmakov (Russian Academy of Science),
Liubov Samoylova (XFEL.eu),
Oleg Chubar (BNL)

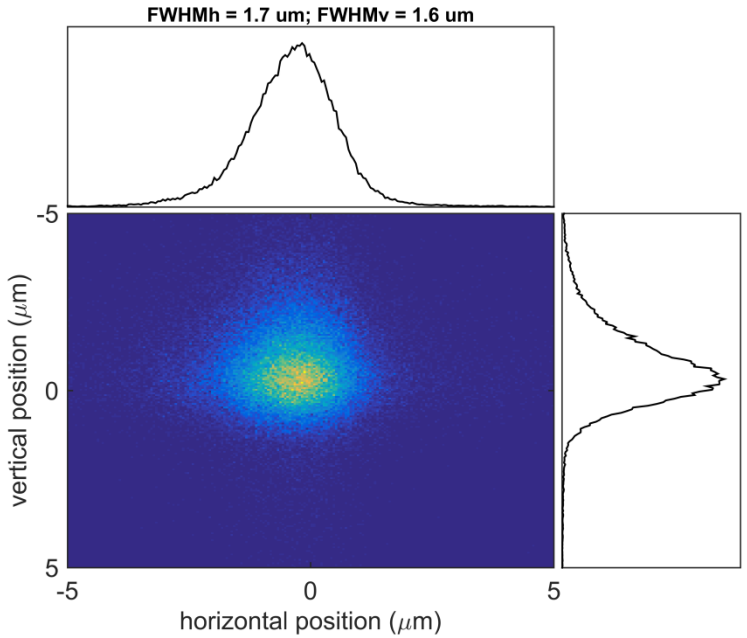
http://wpg.readthedocs.io/en/latest/index.html



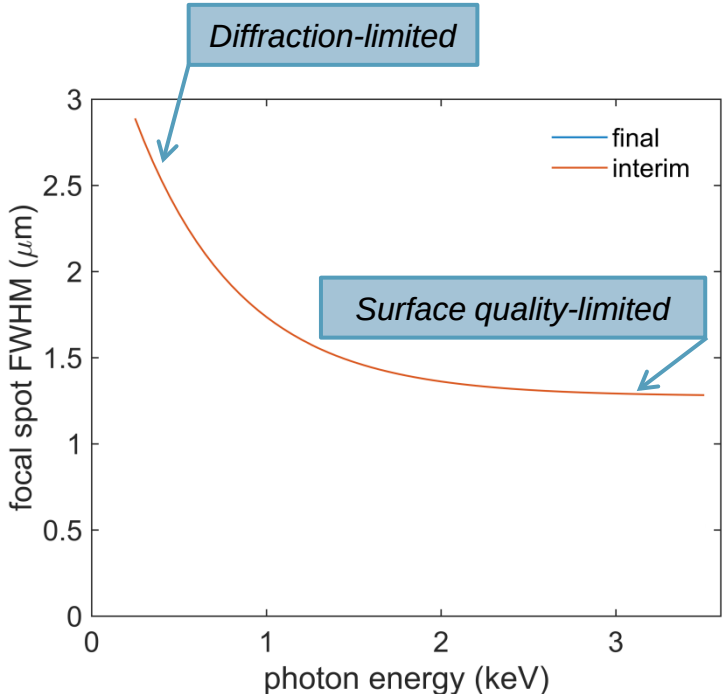
Output:

- ✓ *focal spot profile (relative estimate)*
- ✓ ***Wavefront***

SQS Interim Focusing Mirrors
Predicted Performances – spot size

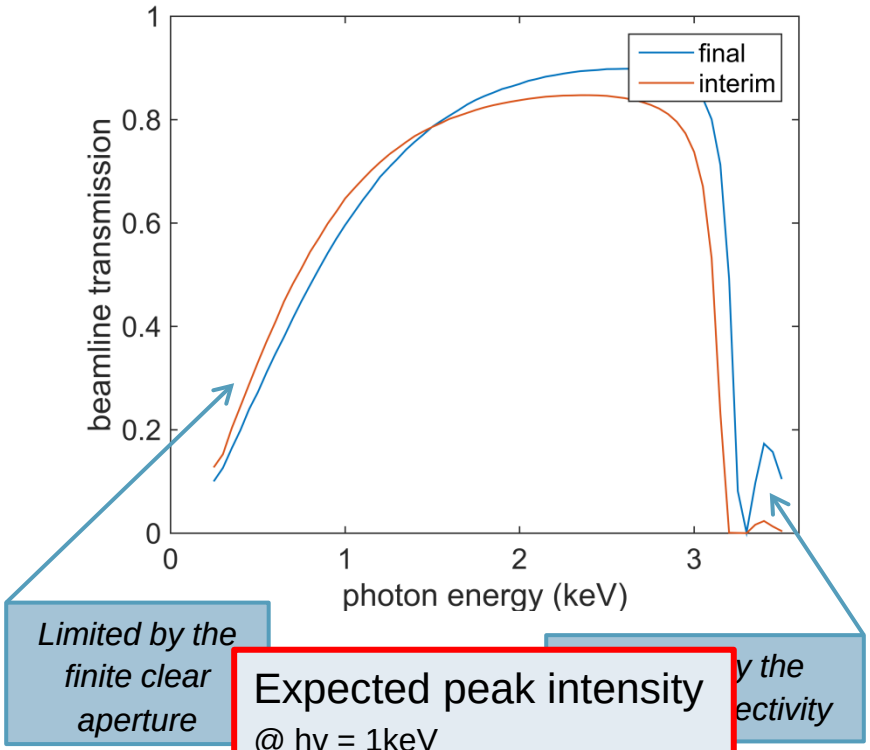


hv = 1keV



- Focal spot FWHM will be ~2-3 larger as compared to the final KB solution (hv-dependent)

SQS Interim Focusing Mirrors
Predicted Performances – spot size and transmission

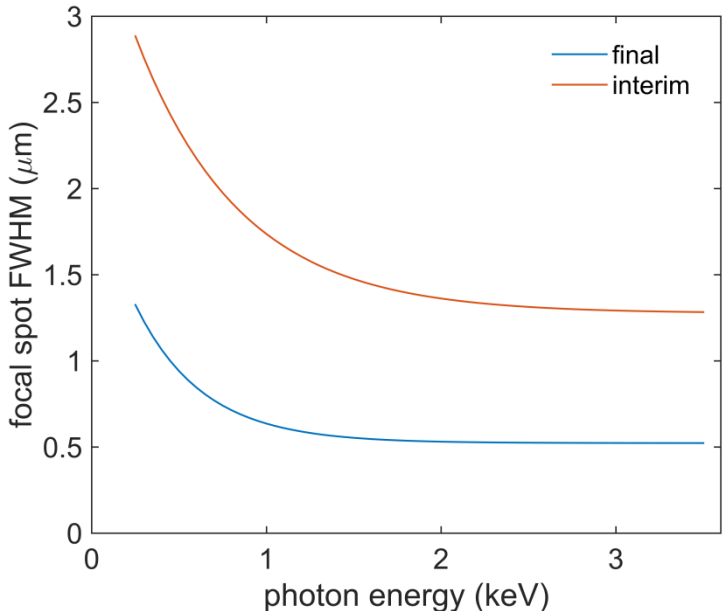


Limited by the finite clear aperture

...y the ...ectivity

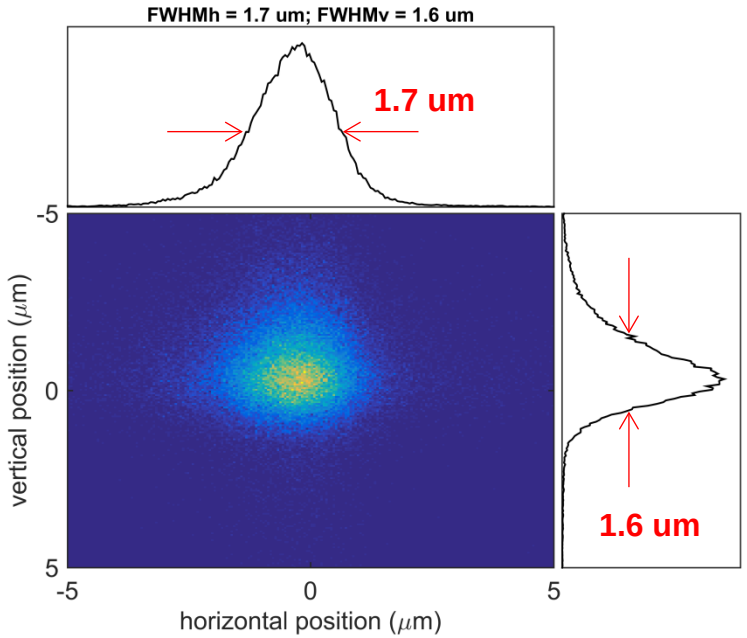
Expected peak intensity
@ hv = 1keV
@ pulse duration = 50fs
@ pulse energy = 1mJ

$I = 4\ 10^{17}\ W/cm^2$

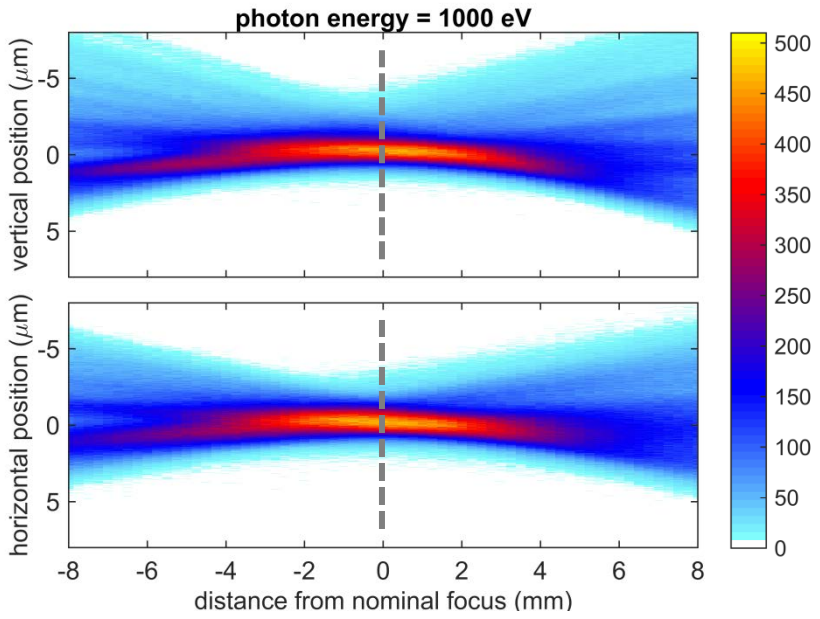


- Focal spot FWHM will be ~2-3 larger as compared to the final KB solution (hv-dependent)
- Overall beamline transmission will be comparable to what expected for the final KB solution

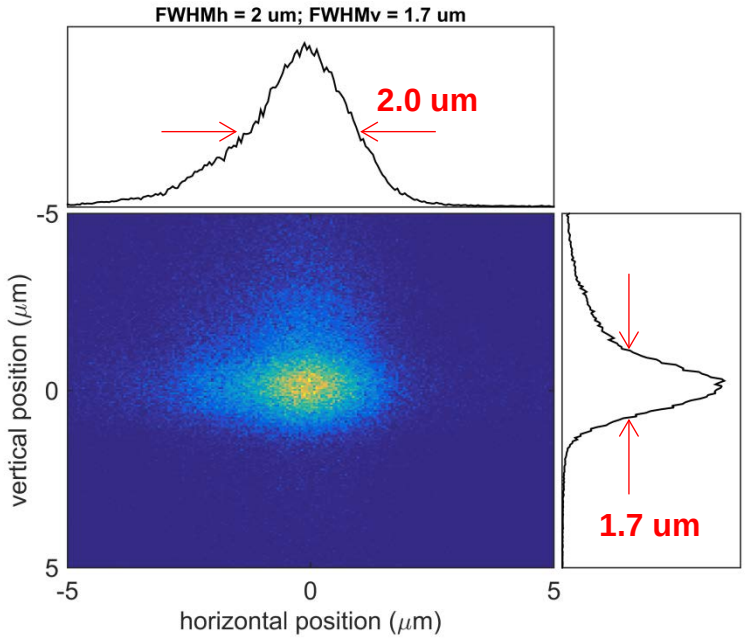
SQS Interim Focusing Mirrors
Predicted Performances – focal depth



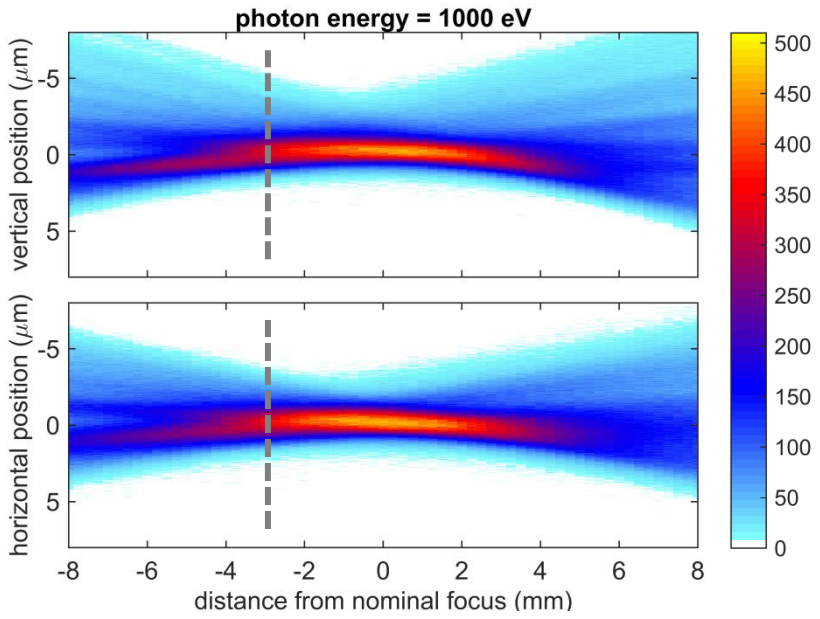
z = 0 mm



SQS Interim Focusing Mirrors
Predicted Performances – focal depth



z = -2.5 mm



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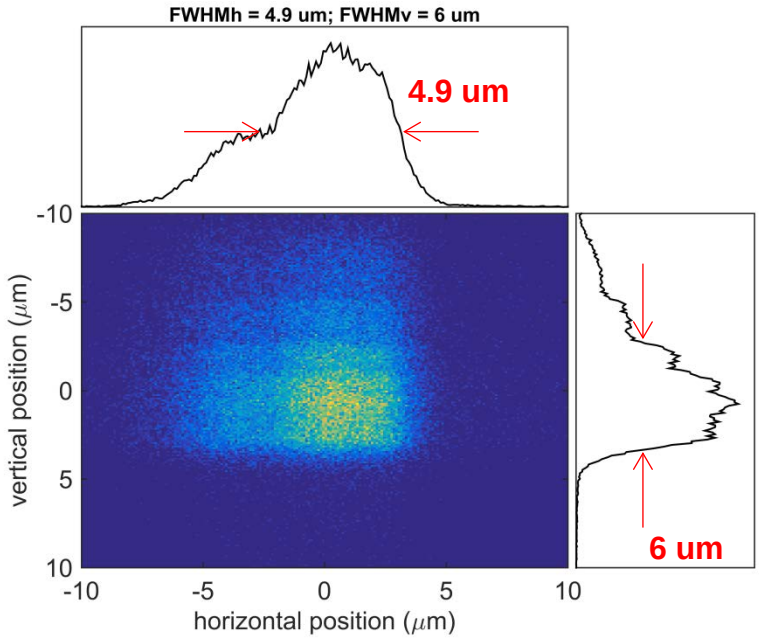
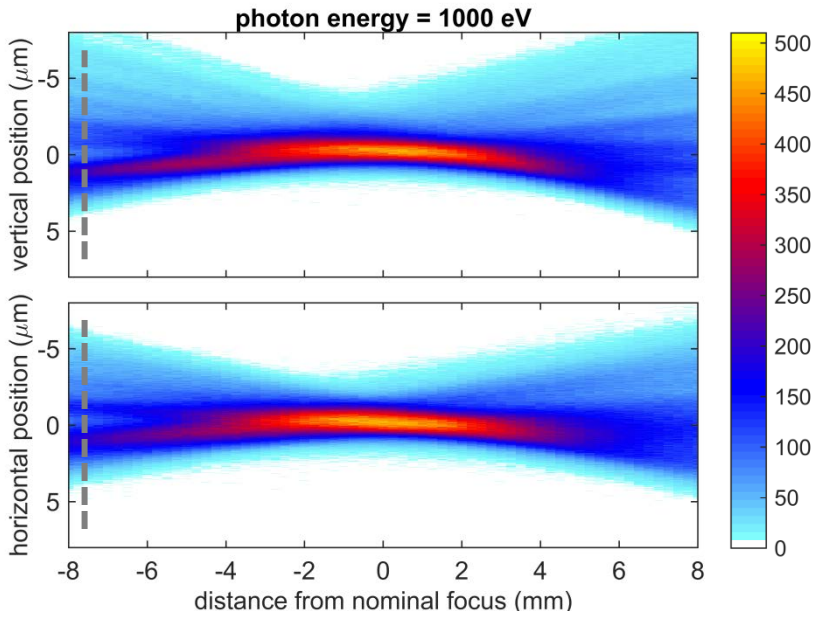
Predicted Performances – focal depth

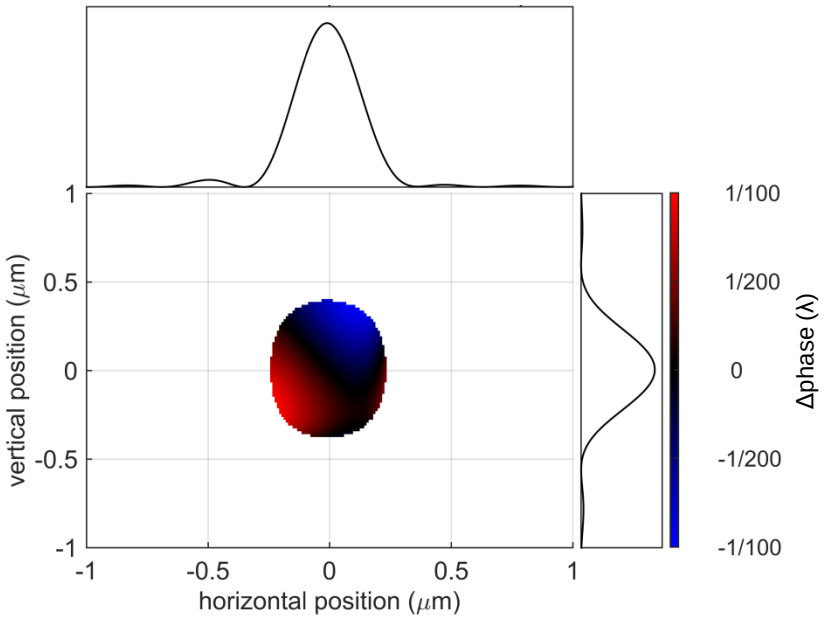


z = -7.5 mm



SQS Interim Focusing Mirrors
Predicted Performances – Wavefront

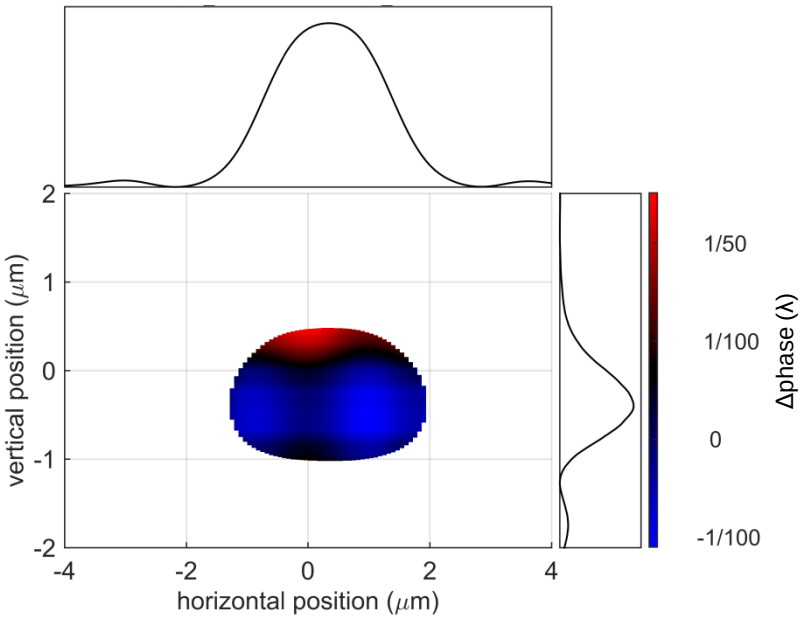
Final solution, F1, hv = 1keV



Wavefront error (rms)

$$w_e = 0.0052 \cdot \lambda \approx \frac{\lambda}{200}$$

Interim solution, hv = 1keV



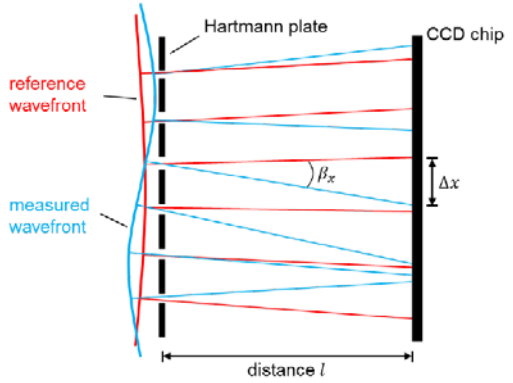
Wavefront error (rms)

$$w_e = 0.0078 \cdot \lambda \approx \frac{\lambda}{130}$$

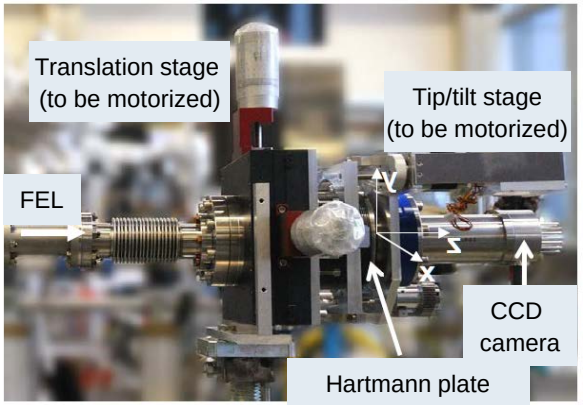
Focusing performances – metrology
Hartmann sensor

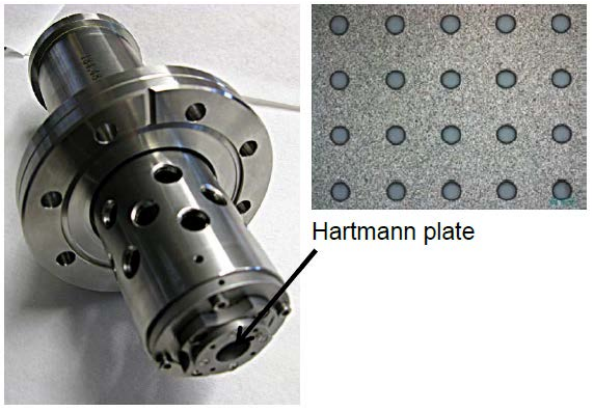
Components / features:

- X-ray sensitive camera
  - Softhard SHT MR285MC, 1392 x 1040 6.45 µm pixels
  - P43 coated chip
- Hartmann plate
  - 20um-tick Ni foil with electroformed holes (ø and pitch to be determined)
- Plate-to-CCD distance ~ 200mm
- Alignment:
  tip-tilt stage;
  x-y stage.



The actual beam is compared to a reference wave (spherical wave).





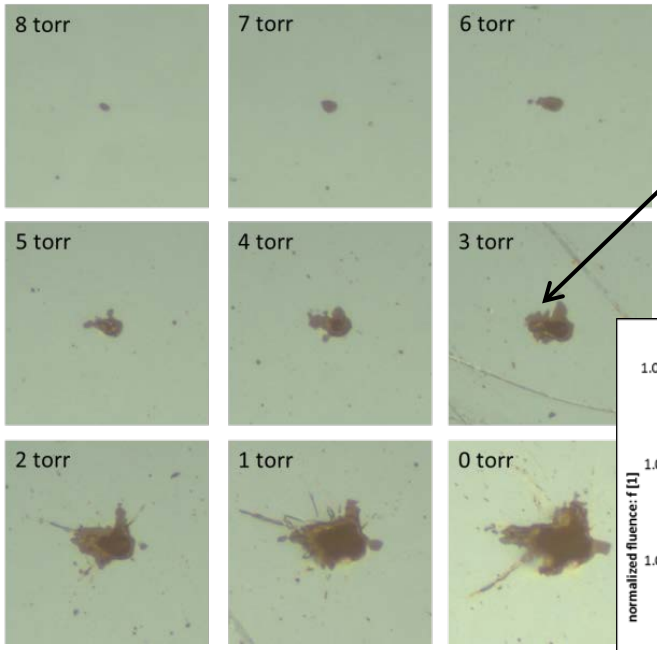
Collaboration with DESY and Laser-Laboratorium Göttingen e.V. (LLG)

Slide Courtesy of B. Keitel, E. Plönjes-Palm (DESY)

Focusing performances – metrology
Ablation / desorption imprinting

- Intensity profile recovered directly from the shape of ablated or desorbed imprints
- Material of choice (hv-dependent): $PbWO_4$, BiI_3, PbI_2 (ablation); PMMA (desorption)
- Retrieval methods:
  - f-scan
  - Z-scan
  - Phase-recovery scan
- Advantages:
  - direct "in focus" detector
  - very wide dynamic and spectral range
  - high spatial resolution
- Drawbacks:
  - ex situ

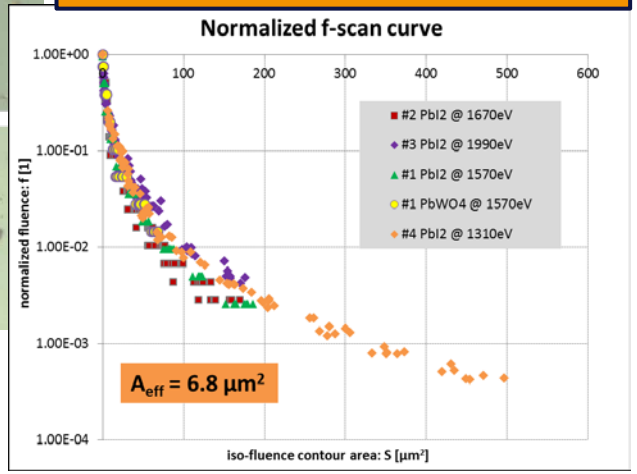
1570-eV LCLS beam recorded in thin PbI_2 layer



Ablative f-scan

damage pattern contour = "iso-fluence curve" for ablation threshold

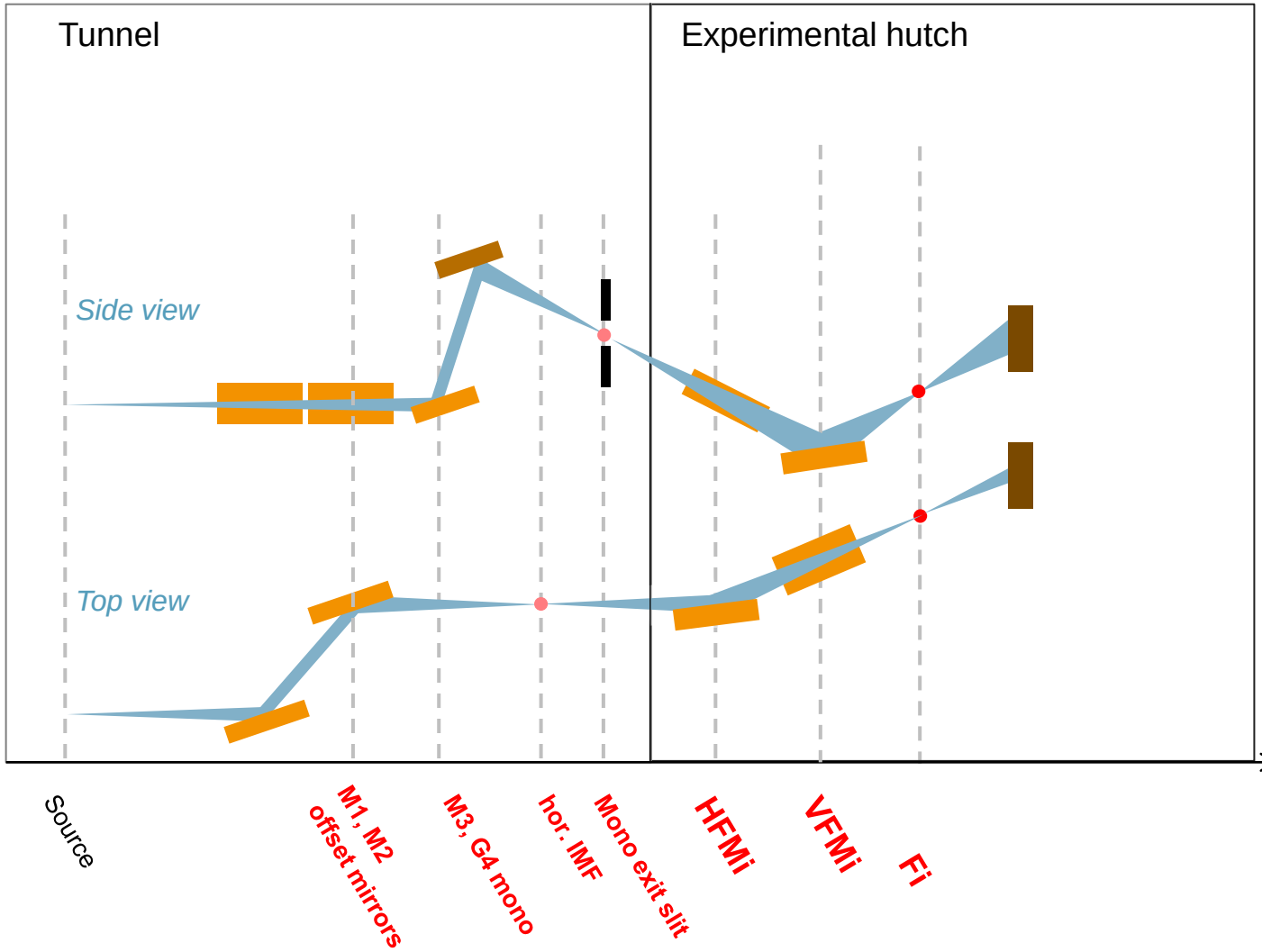
Iso-fluence – peak intensity relationship → effective beam area



Collaboration with L. Juha, J. Chalupsky et al. (Institute of Physics of the CAS, Prague)

Slide Courtesy of L. Juha and J. Chalupsky

Day 1 beam transport layout



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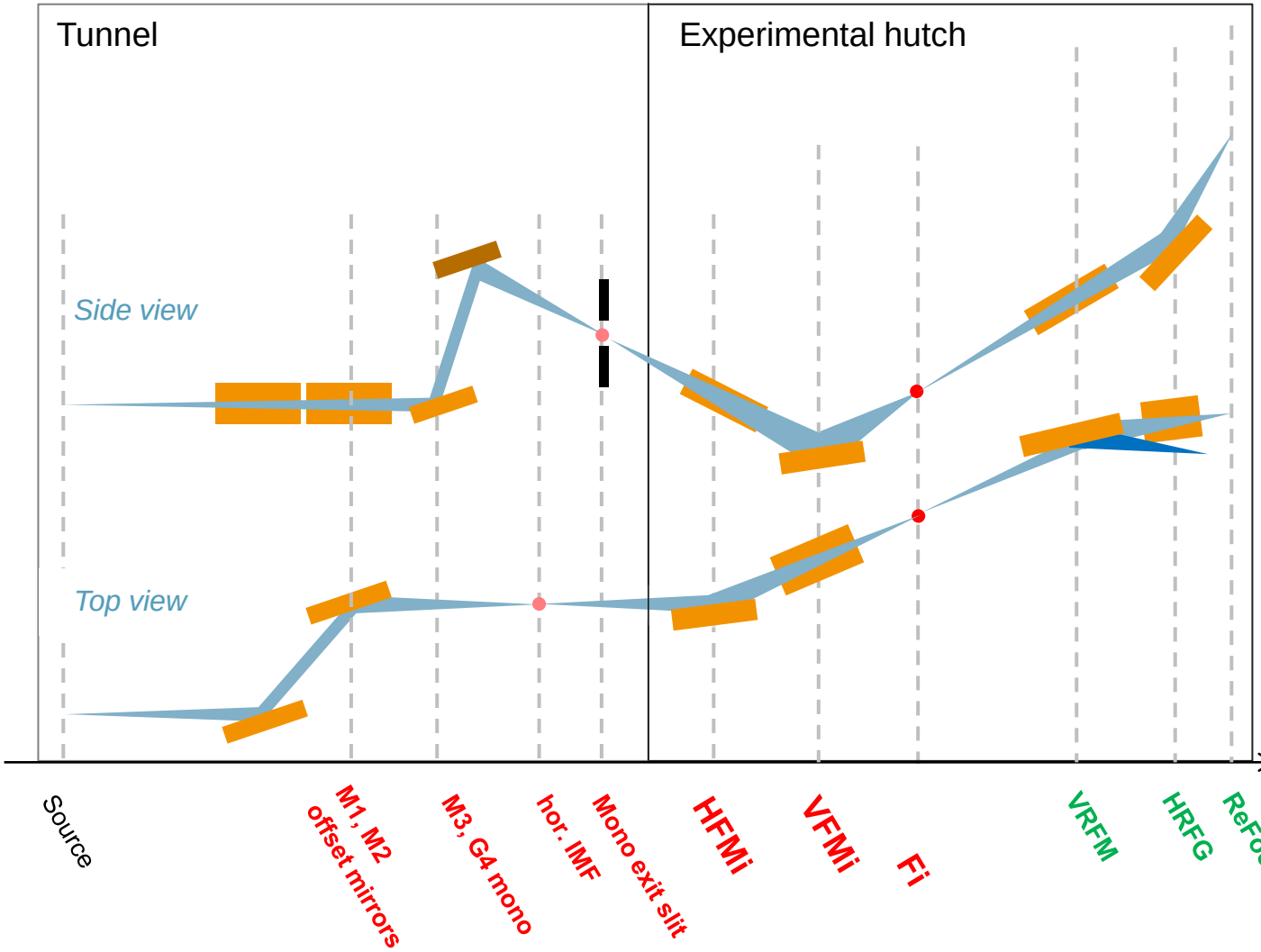
- **No beam transport downstream the interaction region** (no downstream diagnostics)

Day 1 beam transport layout
→ Beam transport layout by May/June 2019



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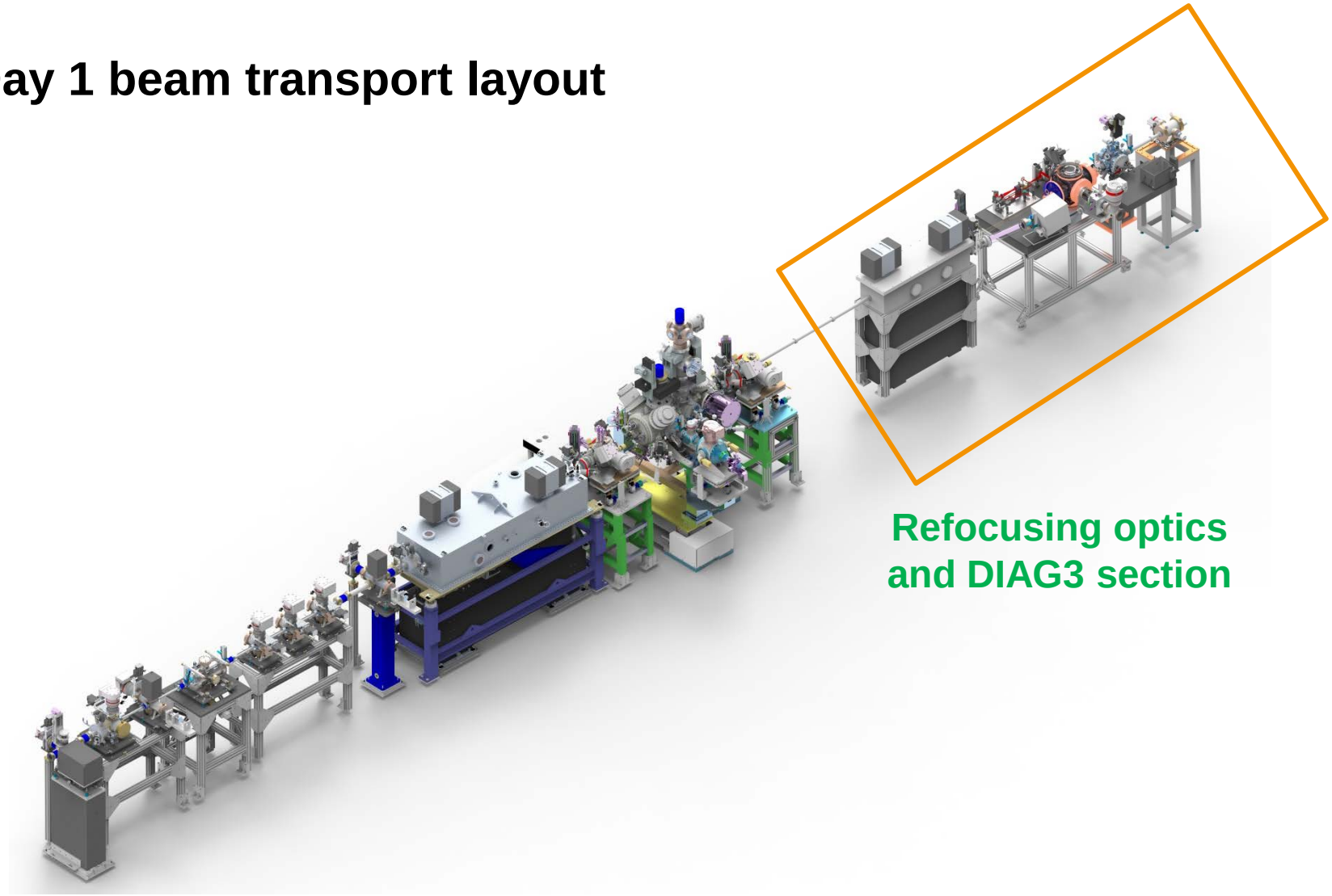
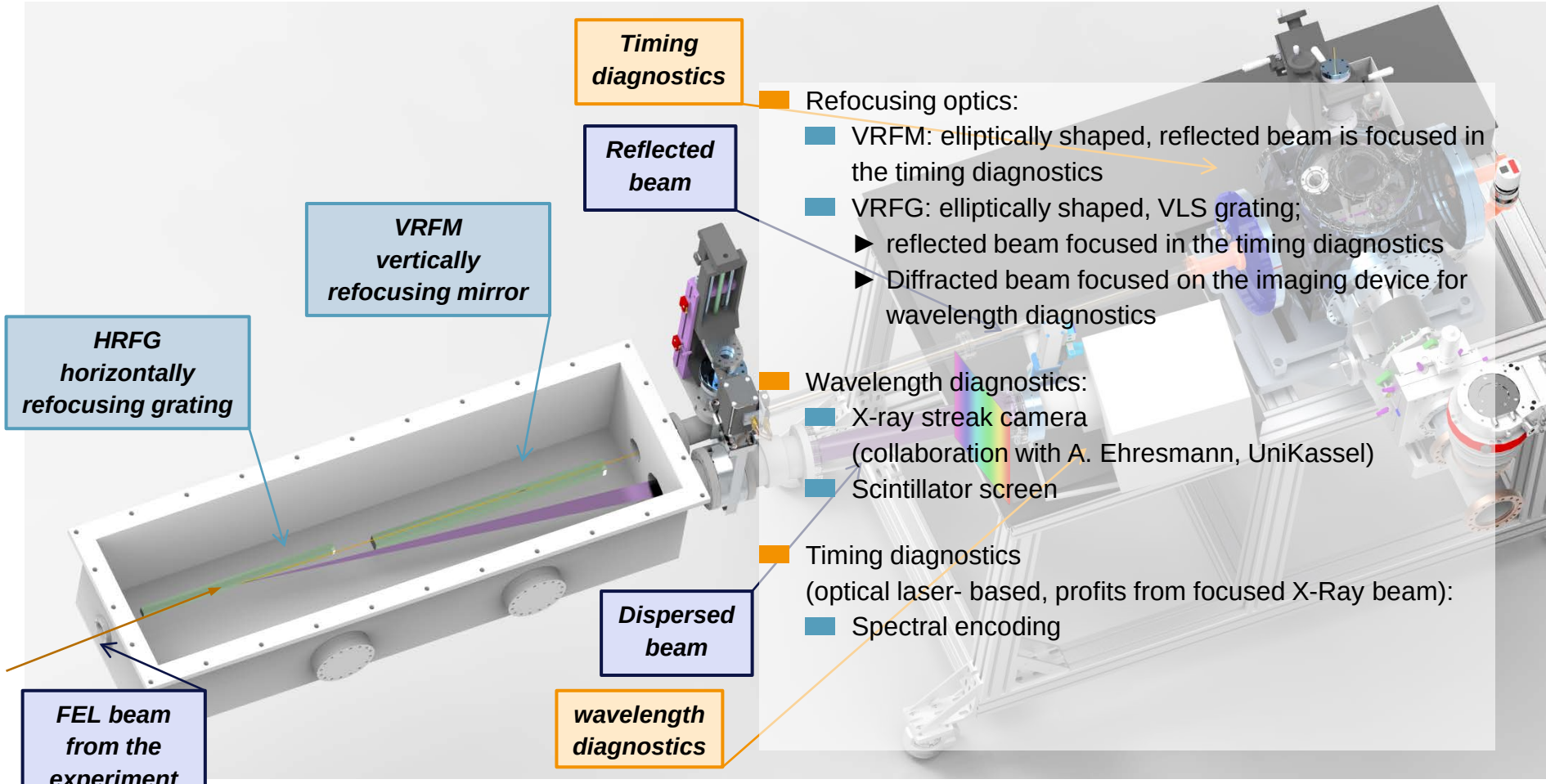
- KBs are adapted to the SQS beam transport by **detuning the incidence angle**
- **Refocusing optics and DIAG3 section**
  - Timing diagnostics
  - Wavelength diagn.

Day 1 beam transport layout



Refocusing optics and DIAG3 section

Refocusing Optics Conceptual Design



- Refocusing optics:
  - VRFM: elliptically shaped, reflected beam is focused in the timing diagnostics
  - VRFG: elliptically shaped, VLS grating;
    - ► reflected beam focused in the timing diagnostics
    - ► Diffracted beam focused on the imaging device for wavelength diagnostics
- Wavelength diagnostics:
  - X-ray streak camera (collaboration with A. Ehresmann, UniKassel)
  - Scintillator screen
- Timing diagnostics (optical laser- based, profits from focused X-Ray beam):
  - Spectral encoding

Summary

- Focusing optics for SQS: Day one solution
  - Very good (albeit not outstanding) focusing performances
  - Transmission comparable with final solution
  - Limited focal size tuneability, no flexibility in focal position
- Metrology strategies for the focus characterization
  - Hartmann sensor for the wavefront characterization
  - Ablation / desorption imprinting
- Refocusing optics system (under development)
  - Based on VLS grating
  - Dedicated to wavelength and timing diagnostics

Thank you for your attention

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