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Ulrich Wagner :: Beamline Optics Group :: Paul Scherrer Institut

The Optics of the Athos Soft X-ray Beamlines at SwissFEL

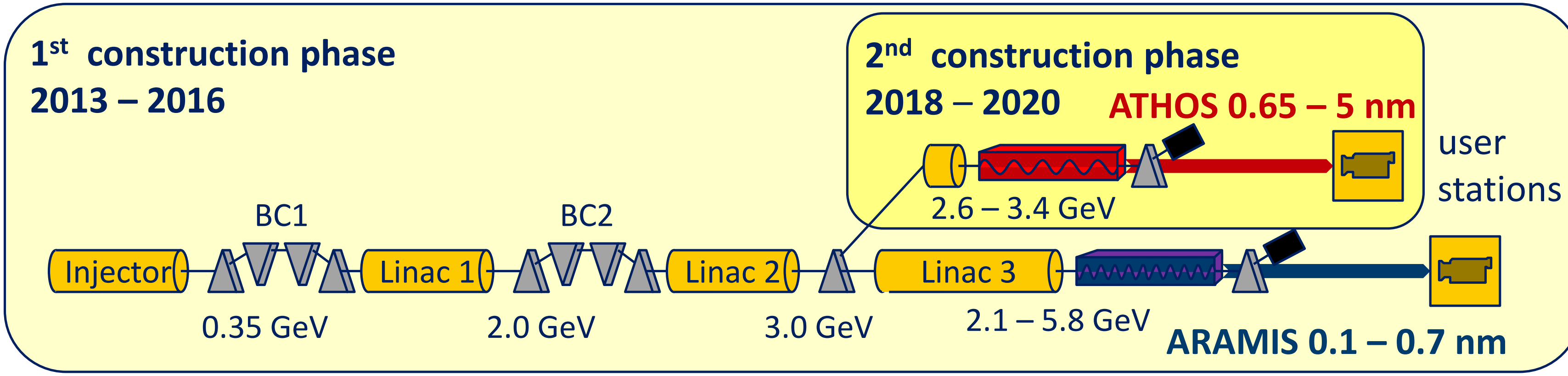
Photon Meadow 2023

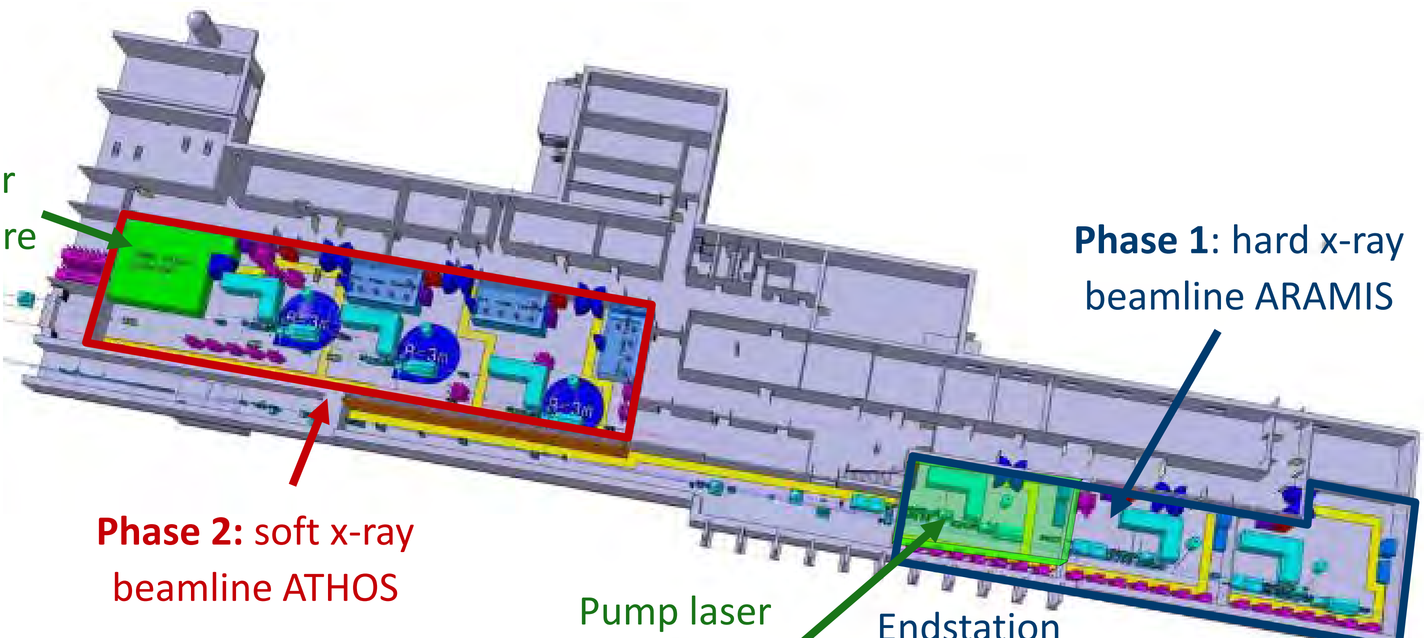
12.09.2023

PAUL SCHERRER INSTITUT PSI

SwissFEL

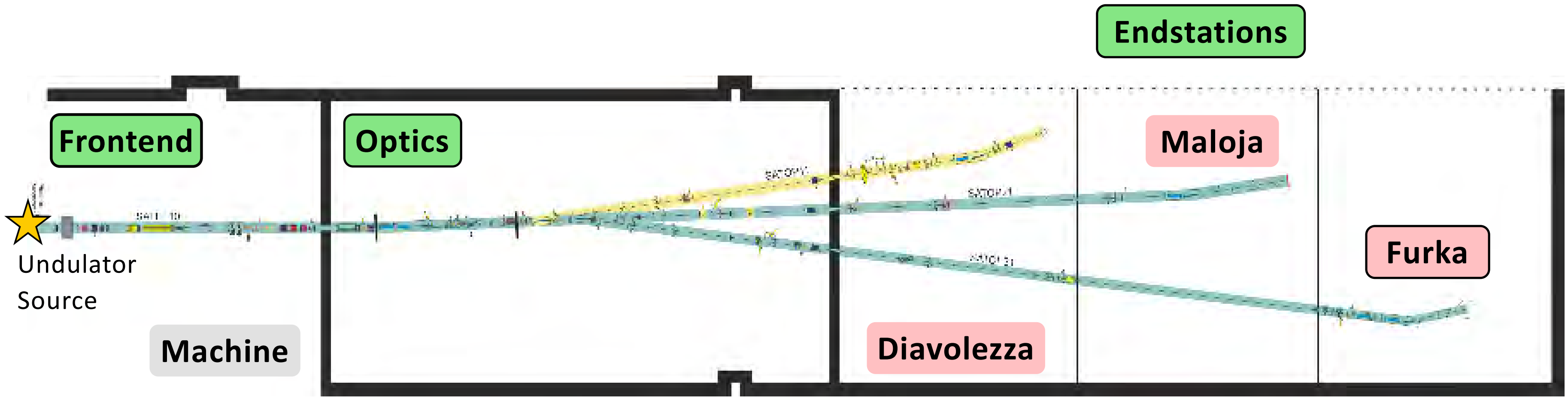
SwissFEL Aramis & Athos Branches



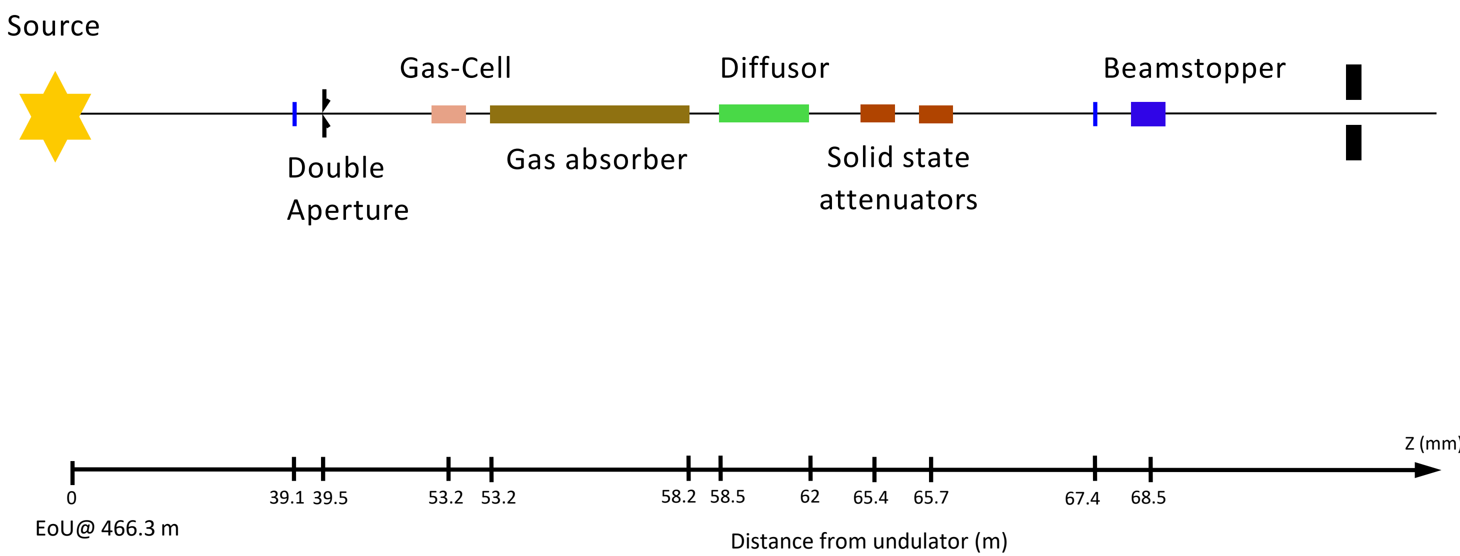


R. Abela, J. Synchrotron Rad. 26, 1073–1084 (2019)

The Athos Photonics Section of SwissFEL



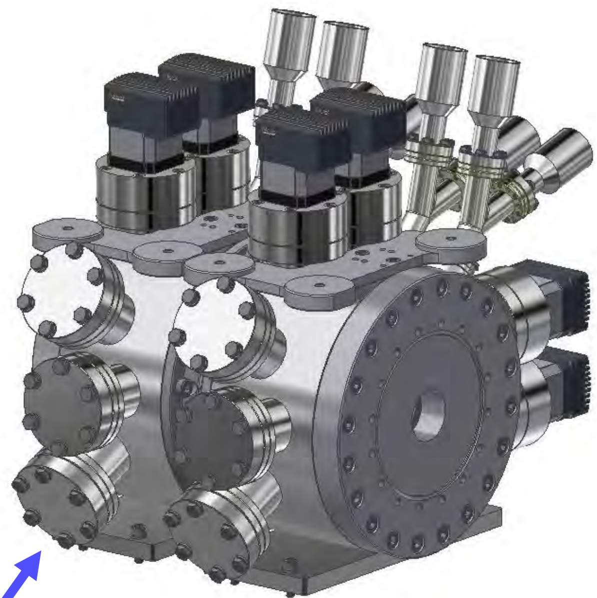
ATHOS Frontend



HL4.0, 12.4.2019

OAPU & OATT

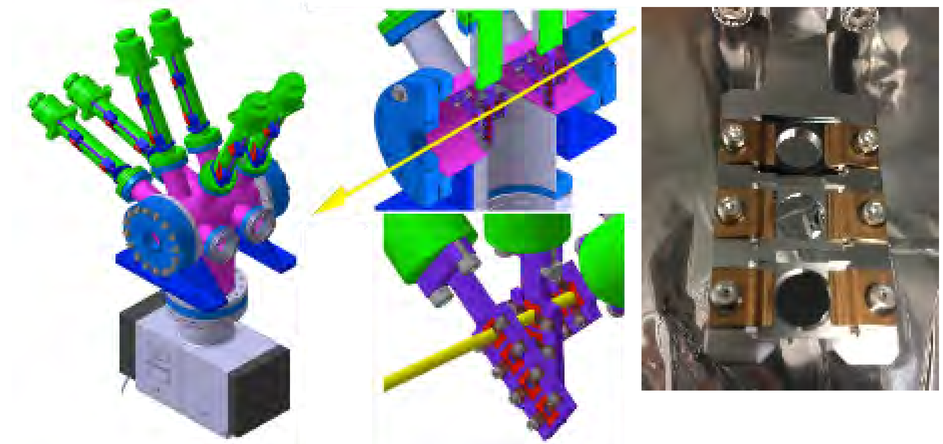
Double Aperture Unit



B$_4$C Blades

Tungsten Blades

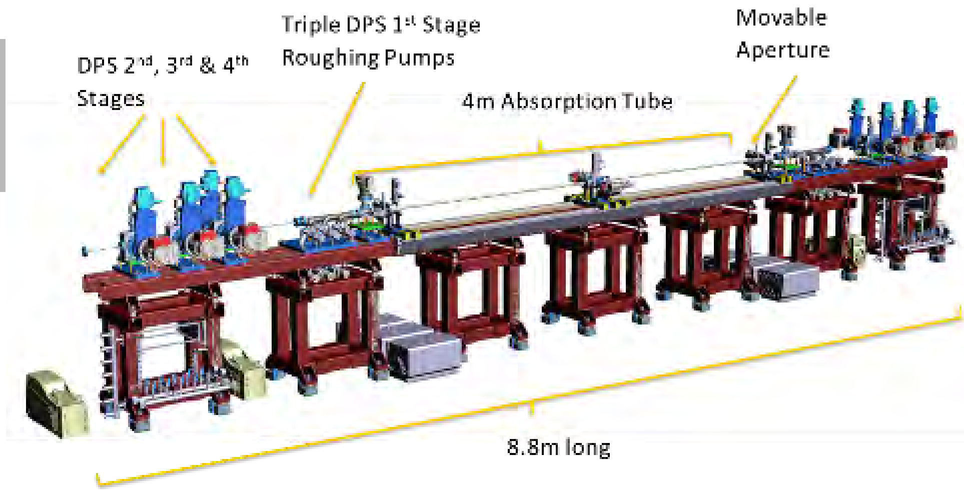
Solid State Attenuator

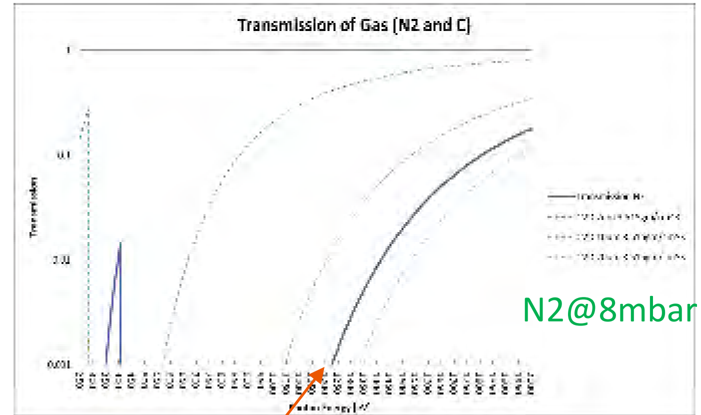


	Slot 1	Slot 2	Slot 3
Mover 1	Si 10 µm	CVD Diamond 20 µm	CVD Diamond 50 µm
Mover 2	Si 10 µm	Aluminum 0.8 µm	CVD Diamond 20 µm
Mover 3	Si 5 µm	Aluminum 0.8 µm	CVD Diamond 10 µm
Mover 4	Si 5 µm	Aluminum 0.4 µm	CVD Diamond 10 µm
Mover 5	Si 1 µm	Iron 0.2 µm	Aluminum 0.2 µm
Mover 6	empty	Aluminum 0.4 µm	empty

Selects the best matching set of foils for a given energy and transmission automatically.

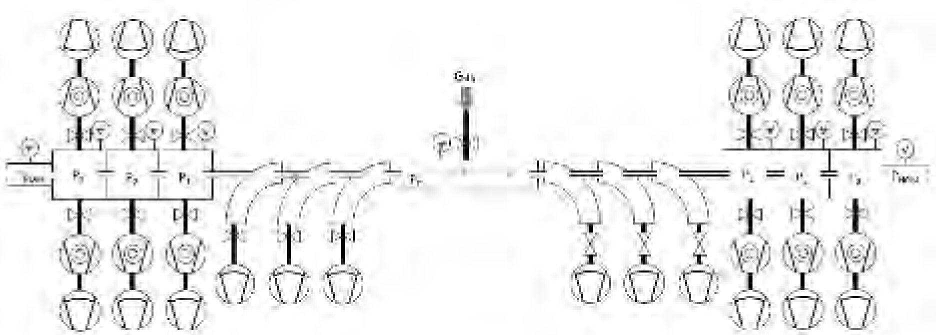
ATHOS Gas Attenuator

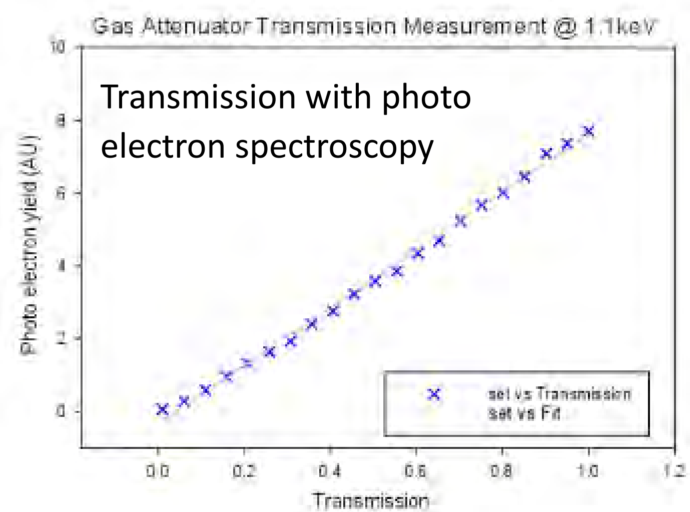




8mbar N_2 → absorption of 10^3 @ 1200eV

Commissioned for **nitrogen, argon and neon**



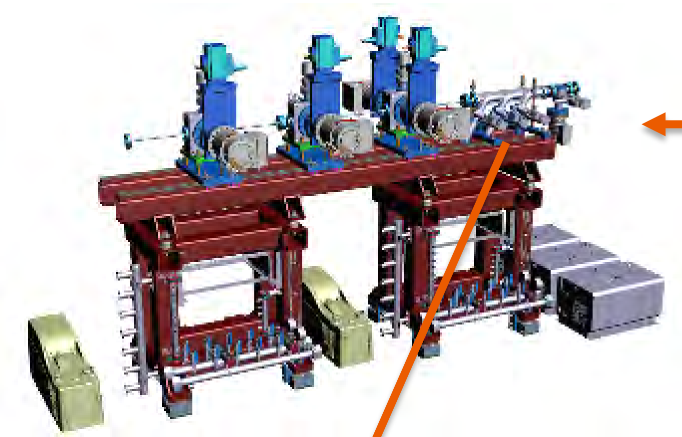


Pradervand, J. Synchrotron Rad. 30, 717-722 (2023)

Courtesy: C. Pradervand

Gas Attenuator: Adaptive Manufacturing for UHV

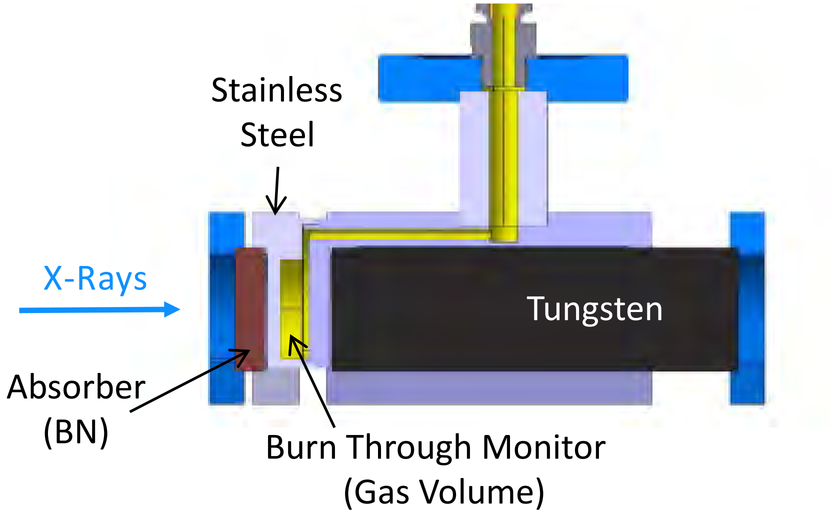
Differential Pumping Stages



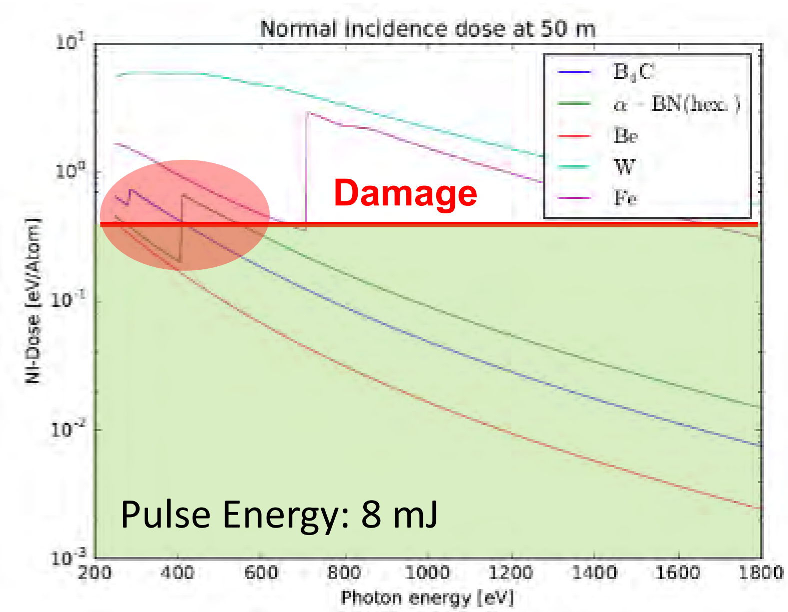
3D metal printed manifold

Courtesy: C. Pradervand

Frontend Photon Beam Absorber



Damage Threshold



Burn through rate

Pulse Rate 100 Hz

Pulse Energy 8 mJ

Dose to melt **150 kJ/mol**

Density 2.3 g/cm^3

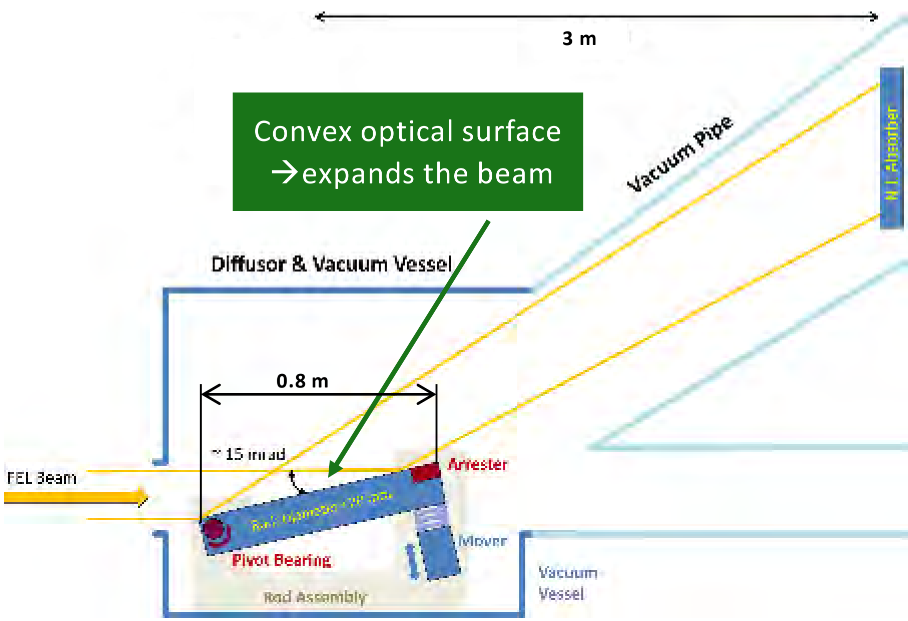
Beamsize 1 mm diameter

Burn through rate:

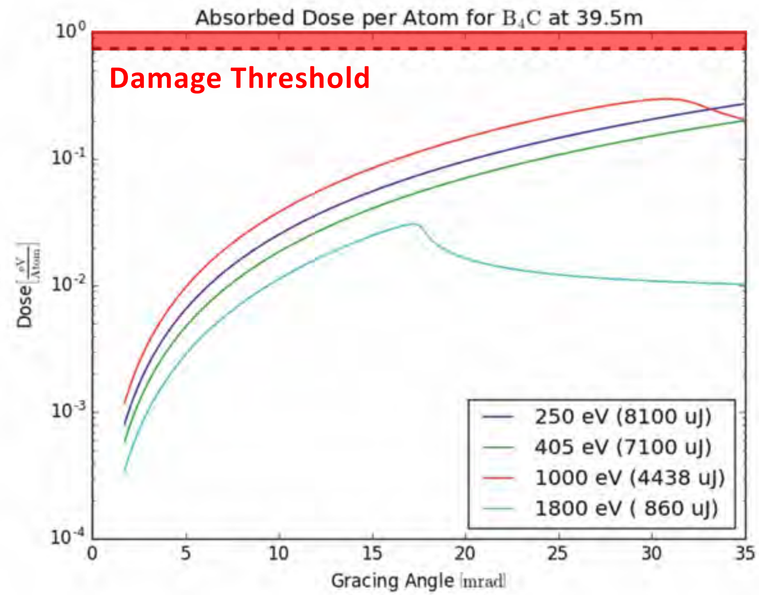
4 mm/min

The Photon Beam Diffusor

Operational Principle



Damage Threshold



Bending of the Diffusor Rod at JJ X-Ray

B_4C coated

U. Wagner, AIP Conf. Proc. **2054**, 030017 (2019)

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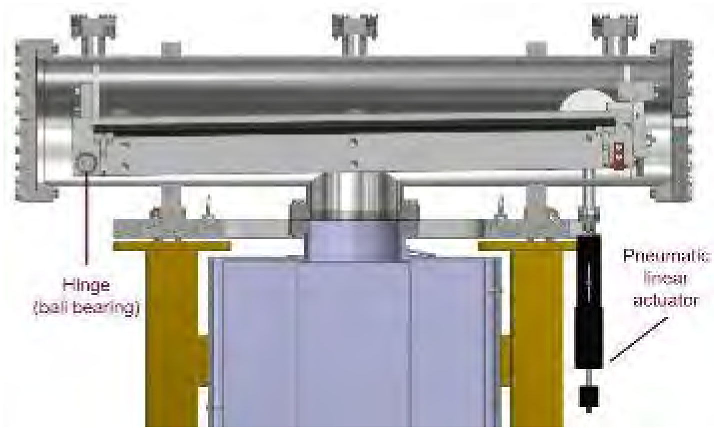
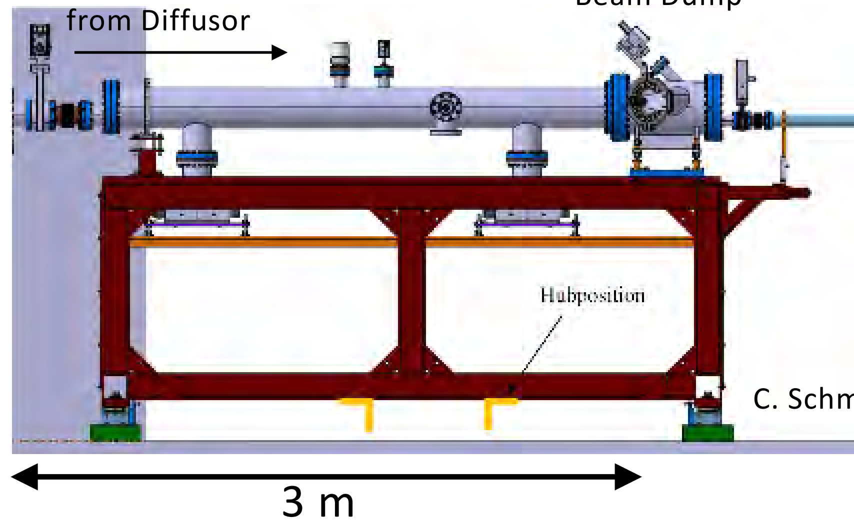
Diffusor (JJ X-Ray)

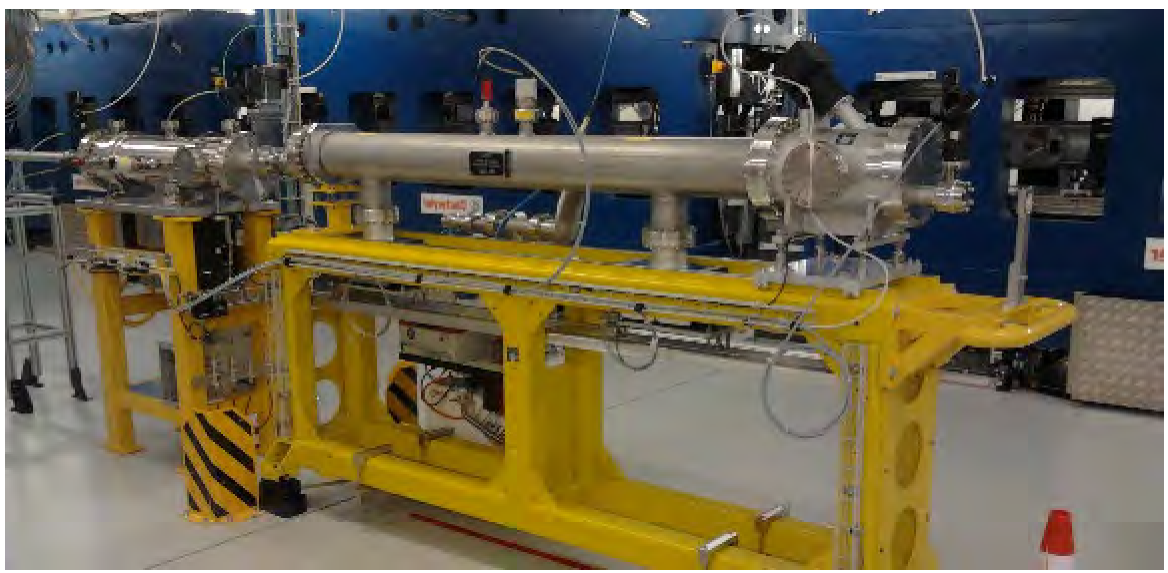
Diffusor



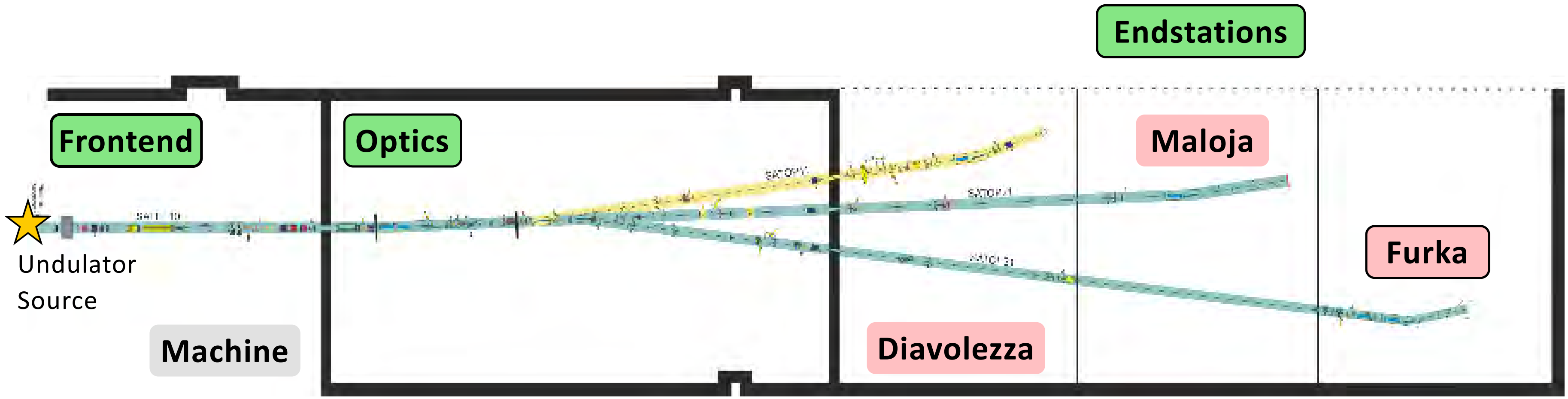
Absorber



C. Schmidt

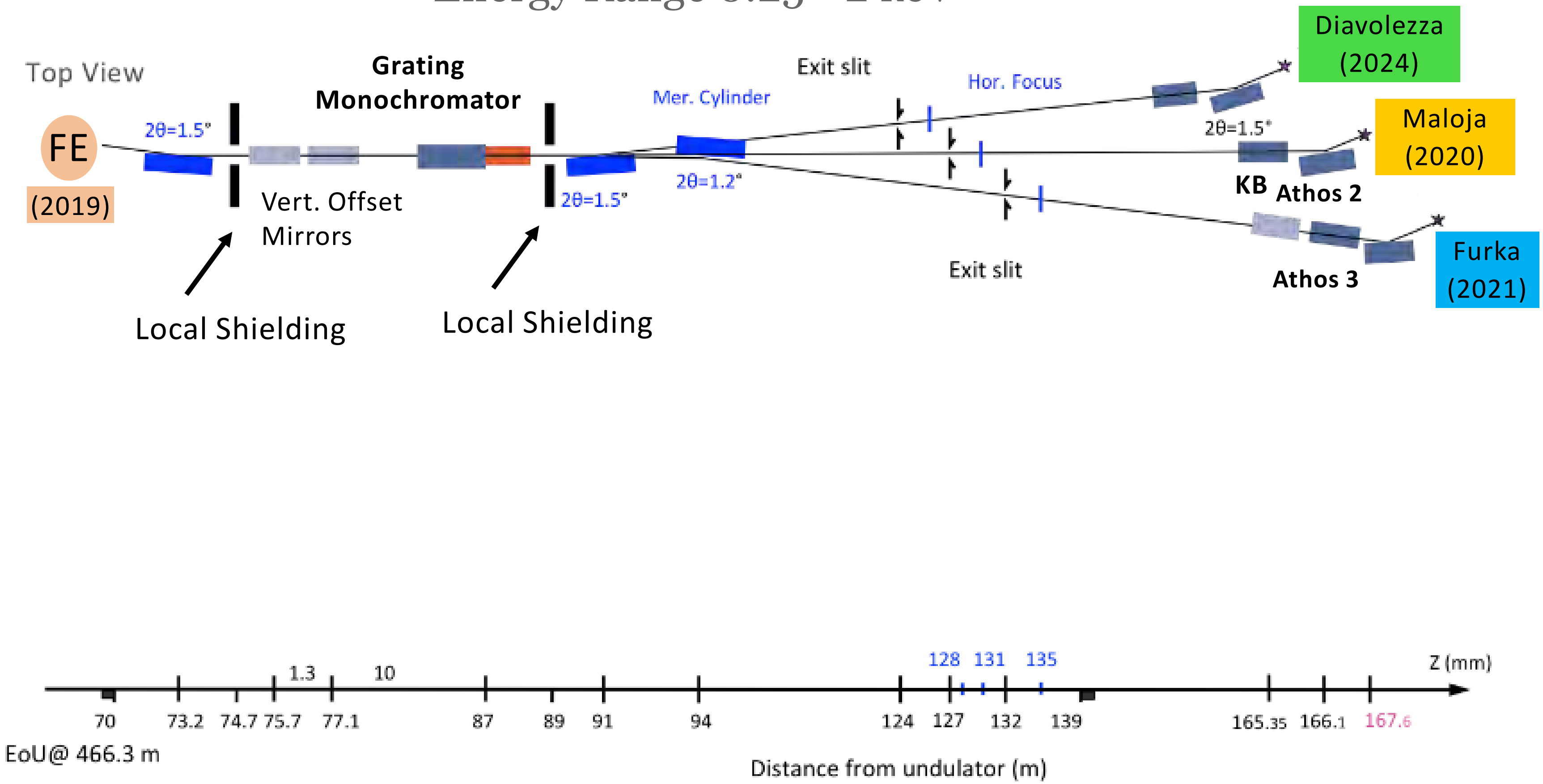


The Athos Photonics Section of SwissFEL

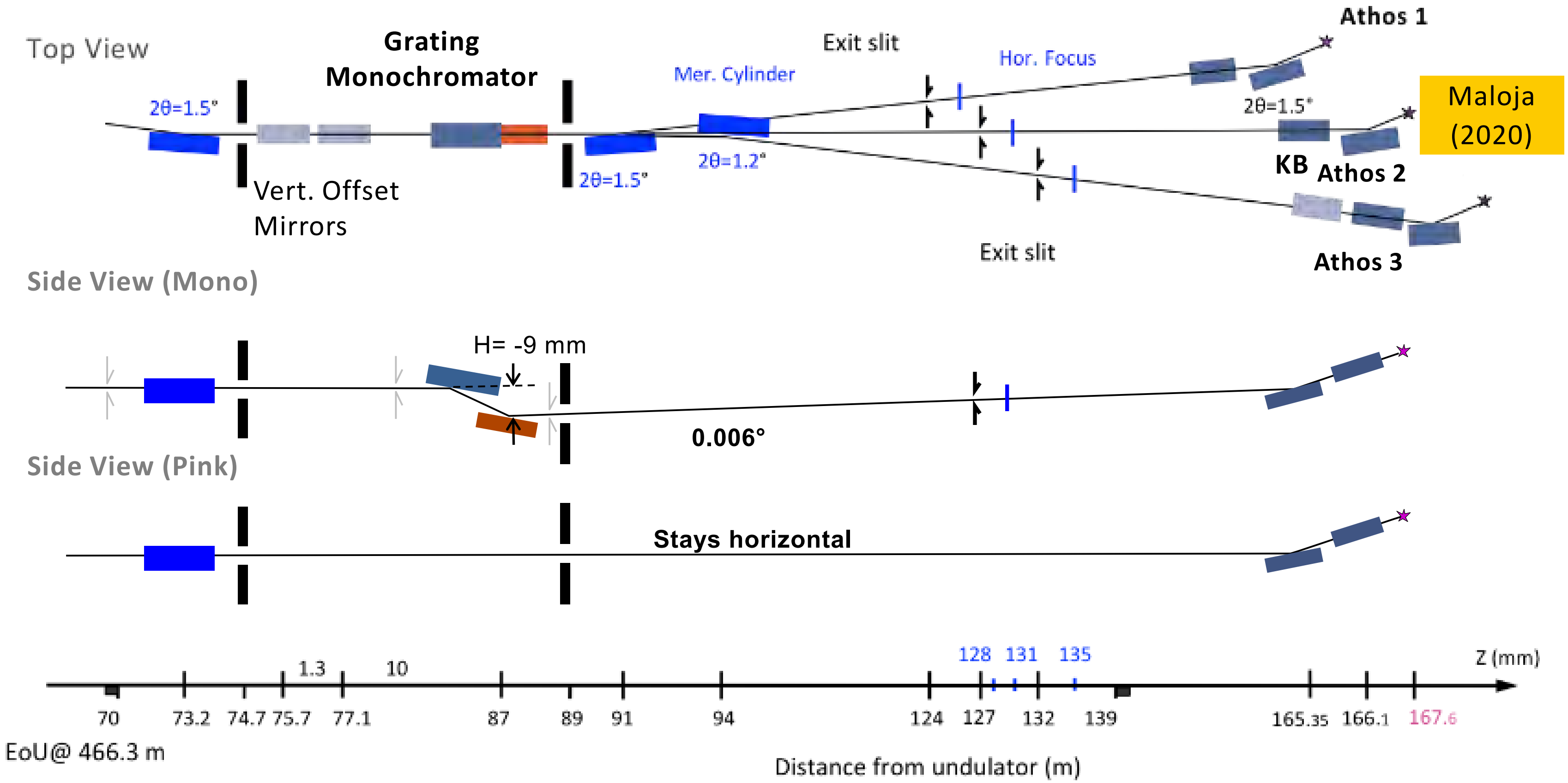


Directing the Beam to the Endstations

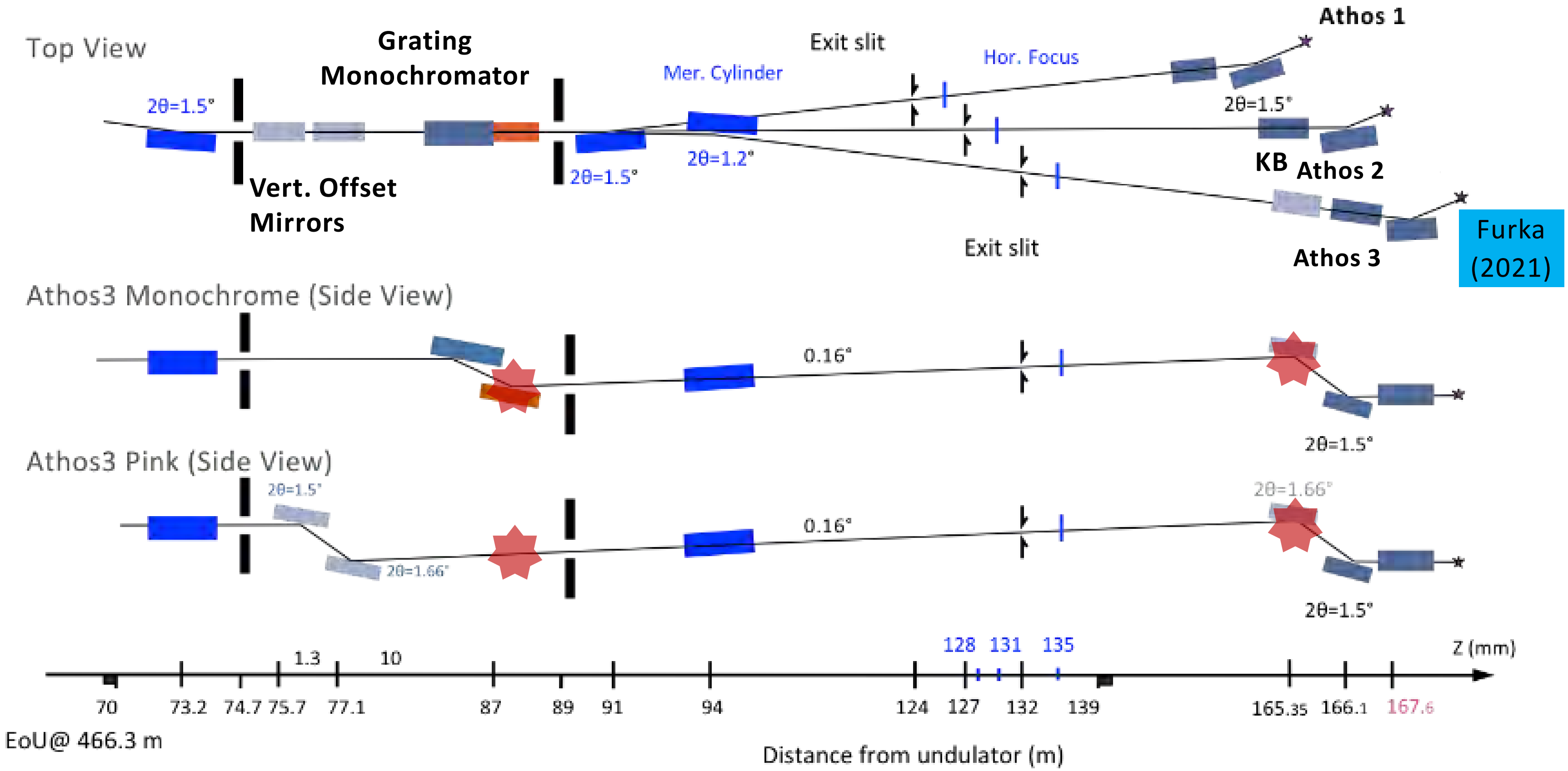
Energy Range 0.25– 2 keV



Directing the Beam to Maloja



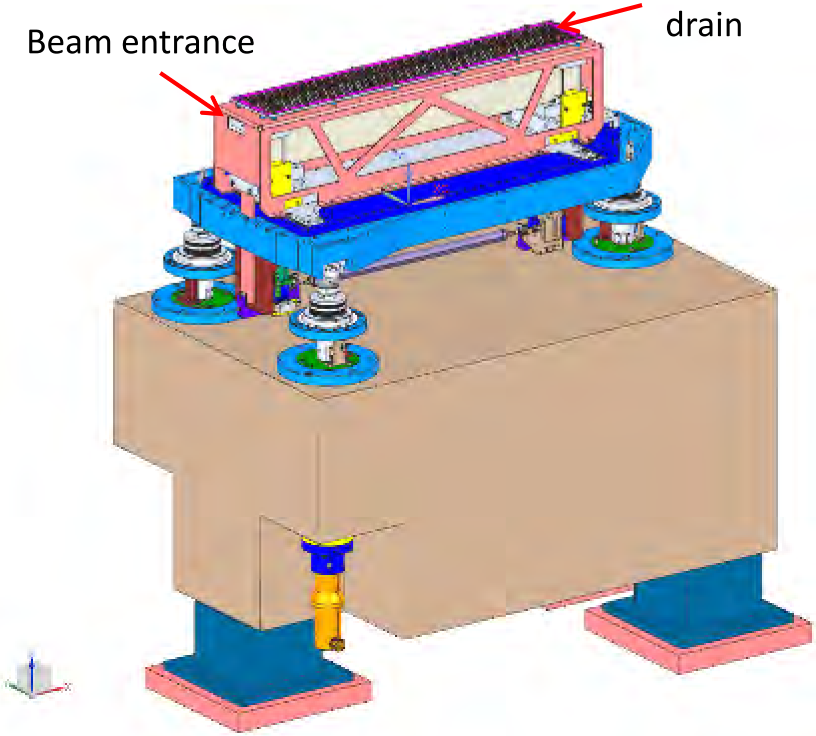
Directing the Beam to Furka



Identical beam-paths for monochromatic and pink beam operation

Offset Mirrors (KBs)

Upward deflecting



History

- Design originally by PSI
- Refined at DESY for P11
- Adapted to ARAMIS by PSI
- Bendable mirrors
  - Vert. offset mirror, t=80 mm: R > 10 km
  - Hor. offset mirror, t=50 mm: R > 2.5 km

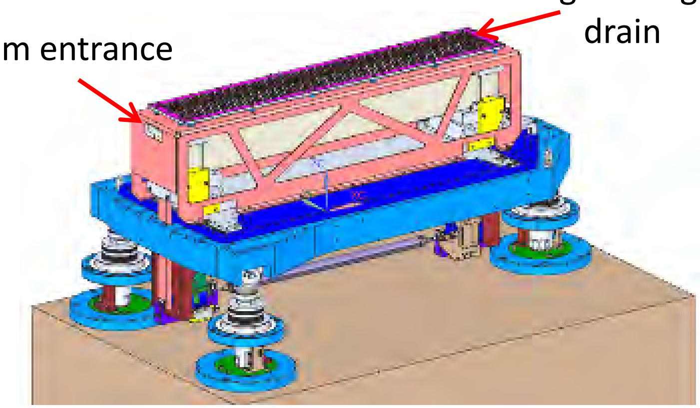
Motion Matrix

X		-0.9927759	0.9946473	0	1	0.0003716	0	M1
Y		-0.1826618	0.6781994	0.4997205	0	0	0	M2
Rx	=	0.7812420	0.7812420	-1.5624990	0	0	0	M3
Ry		0	0	0	0	2.7397280	0	M4
Rz		4.3477990	-4.3477990	0	0	0	0	M5

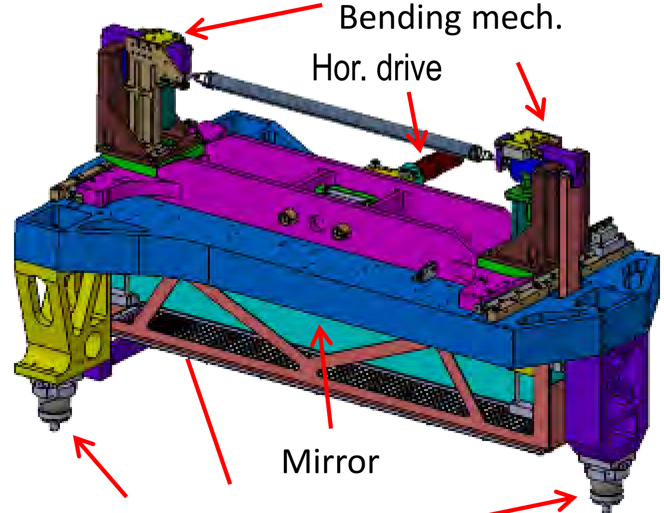
P. Heimgartner, M. Affolter, M. Locher

Design Variations

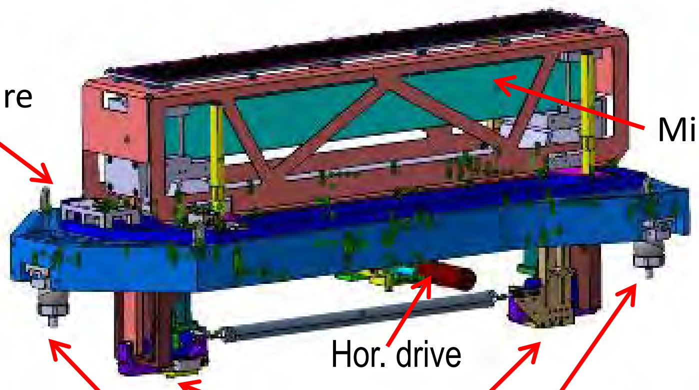
Upwards deflecting



Downwards deflecting



Sideways deflecting



For SLS II

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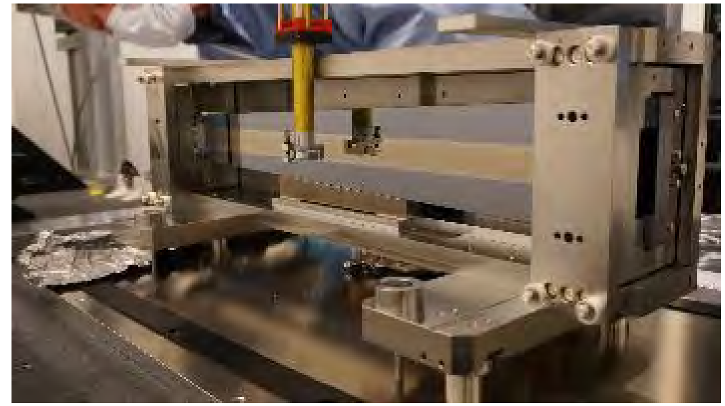
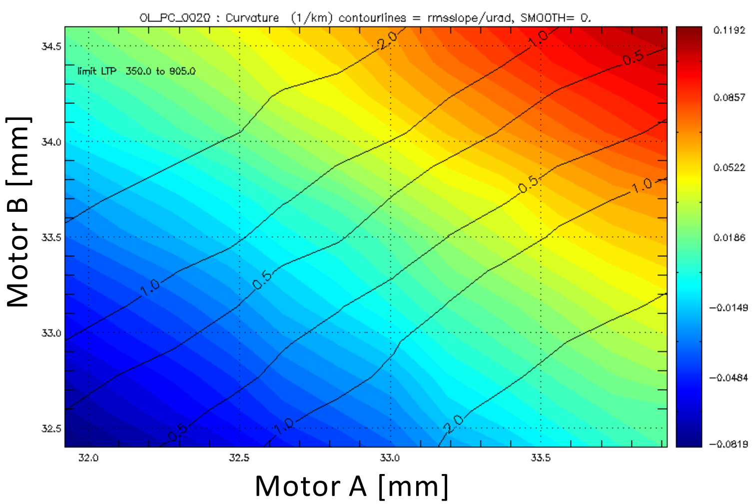
Bender Characterisation

Upwards deflecting mirror

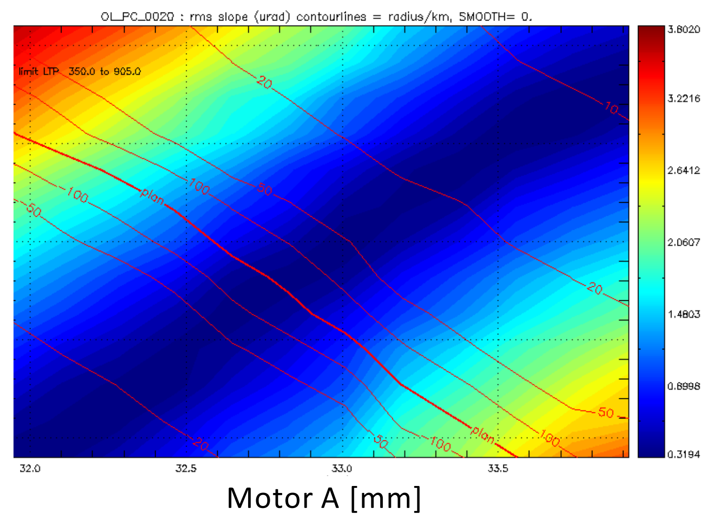
Sideways deflecting mirror on LTP



Radius of Curvature



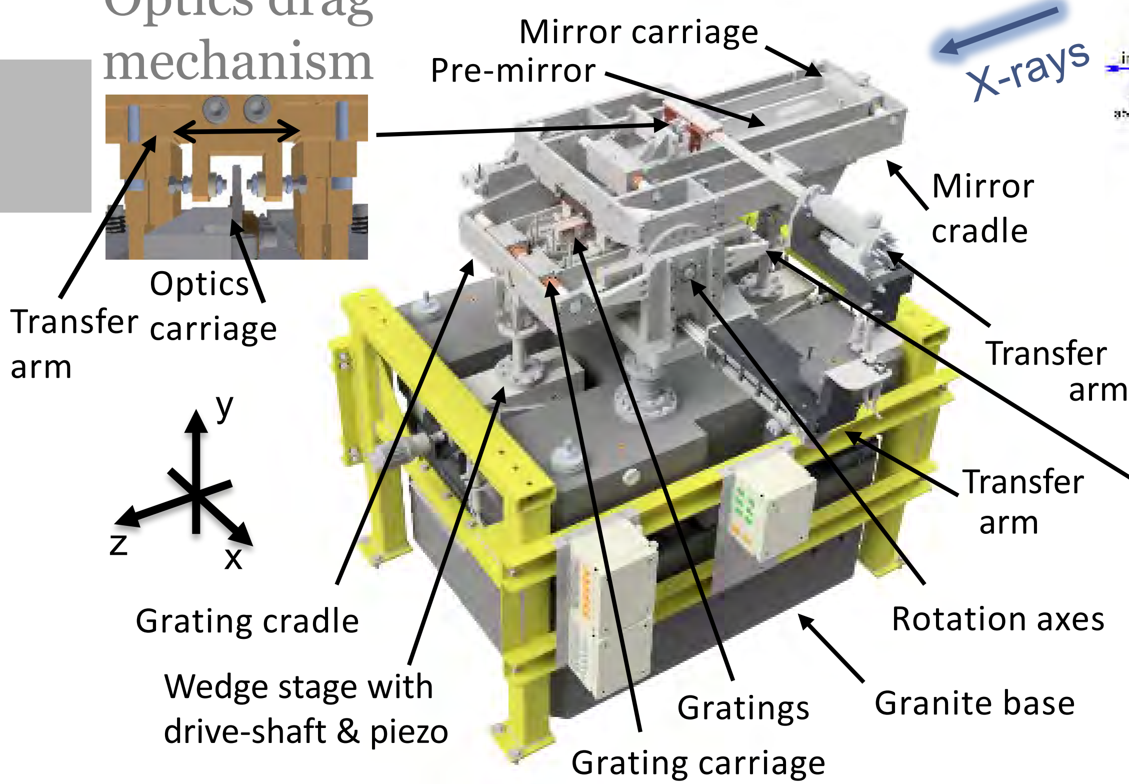
Slope Errors

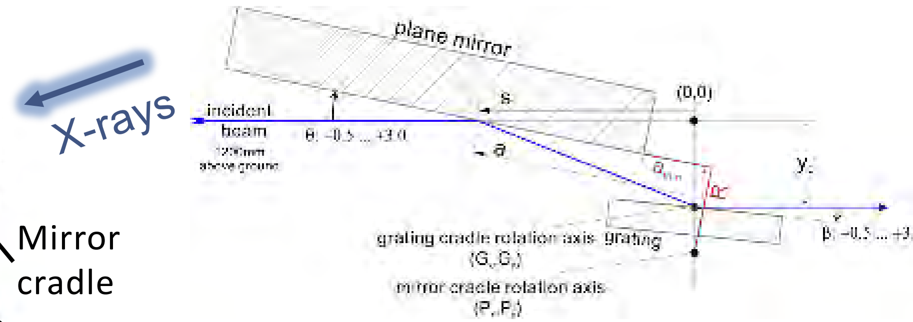


- Lookup table: Radius of curvature → Motor settings
- KB in analogy

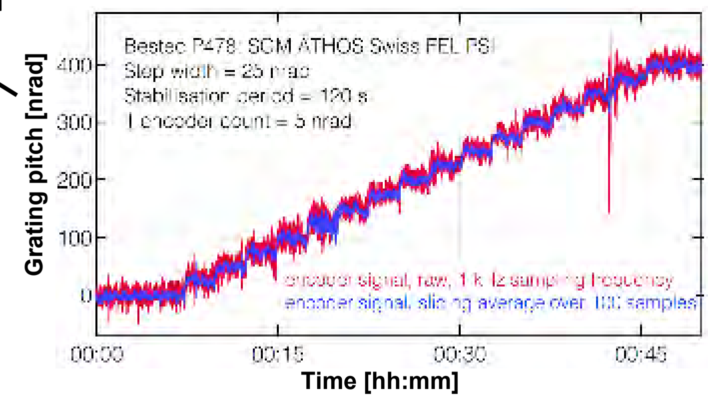
VLS Spherical Grating Monochromator

Optics drag mechanism





Single Step Resolution

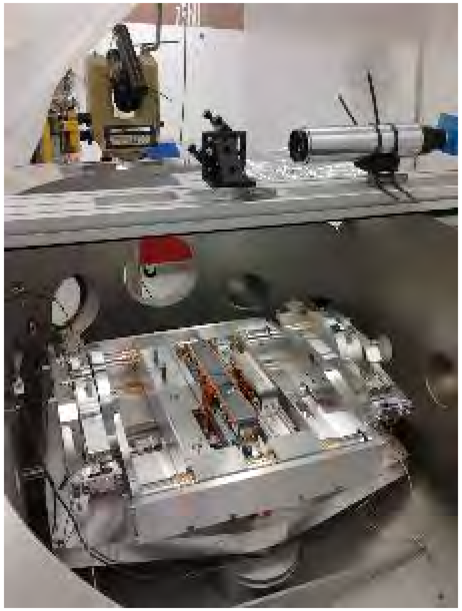


Geometry

Dimension	Value
Mirror rotation range	-0.5° … +3.0°
Grating rotation range	-0.5° … +3.0°
Vertical beam offset	9.00 mm
Grating cradle axis (y, z)	(-9.00 mm; 0.00 mm)
Mirror cradle axis (y, z)	(-13.52 mm; 0.00 mm)
Mirror rot. axis to mirror surface (Dy, Dz)	(9.02 mm; -80 mm)

VLS Spherical Grating Monochromator

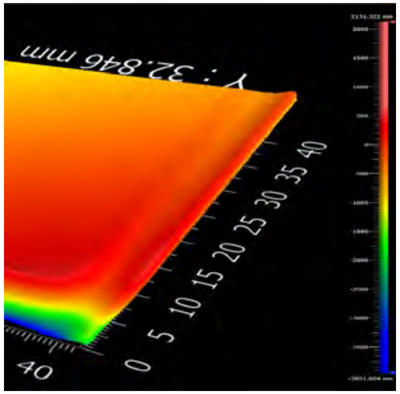
Grating Cradle



Mirror Cradle

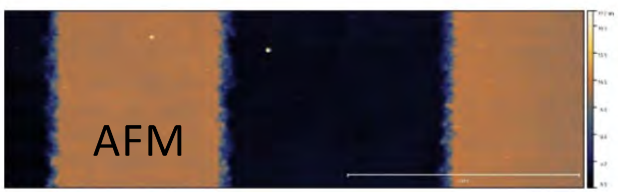
Assembled Mono

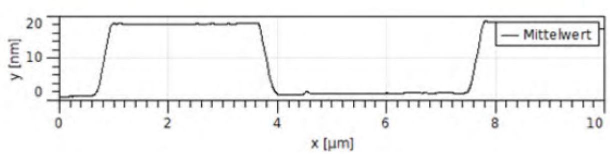
Interferogram of the Substrate (JTEC)

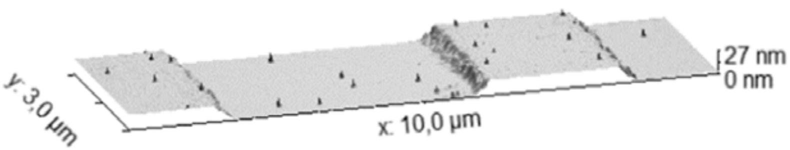


The spherical VLS-Gratings

Laminar Grating 150 l/mm







R_{curv} = 13 km

Courtesy: S. Lemke, HZB

Blazed Grating 50 l/mm (ruled)

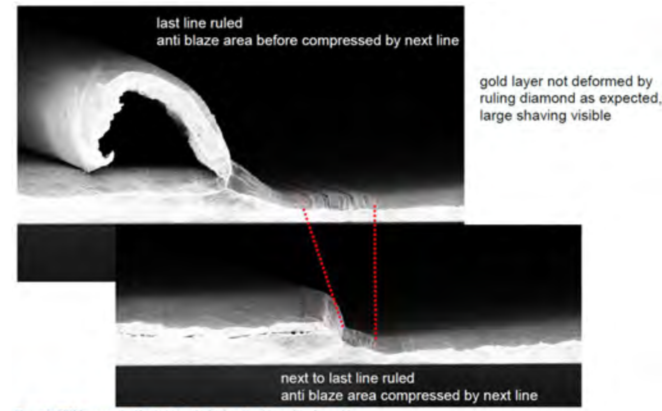
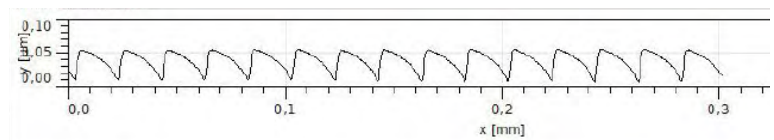
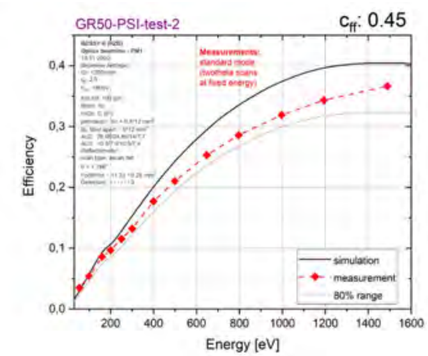


Figure 5: SEM images of a 3" ruled sample, broken for observation from side.



Reflectivity



R_{curv}: 8 km

Blaze angle: -0.15 deg

Grating Equation

Grating equation $m\, N_0 \lambda = \sin \bar{\alpha} + \sin \bar{\beta}$

Line Density $n(w) = \dfrac{dN}{dw} = N_0(1 + 2B_2 w + 3B_3 w^2 + \cdots)$

Focus condition

$$\Rightarrow F_{20} = \frac{\cos^2 \bar{\alpha}}{r} + \frac{\cos^2 \bar{\beta}}{r'} - \frac{2\cos^2 \bar{\alpha}}{R_m \cos\frac{\bar{\alpha}-\bar{\beta}}{2}} \frac{\cos \bar{\alpha} + \cos \bar{\beta}}{R_g} - 2mN_0\lambda B_2 = 0$$

Plane Grating | Curvature Pre-Mirror | Spherical Grating | VLS Grating

Parameters

Mirror & Grating (fixed) $R_m,\ R_g,\ B_2,\ N_0,\ m$

Beamline (mainly fixed) r, r', $\gamma > 0$: beam upwards

Variable (within limits) $\bar{\alpha}, \bar{\beta},\ \lambda$

Damage Threshold

$\bar{\alpha} > \bar{\Theta}_{Damage}$

$\bar{\alpha} - \bar{\beta} + \gamma > 2\bar{\Theta}_{Damage}$

Numerical Solutions only!

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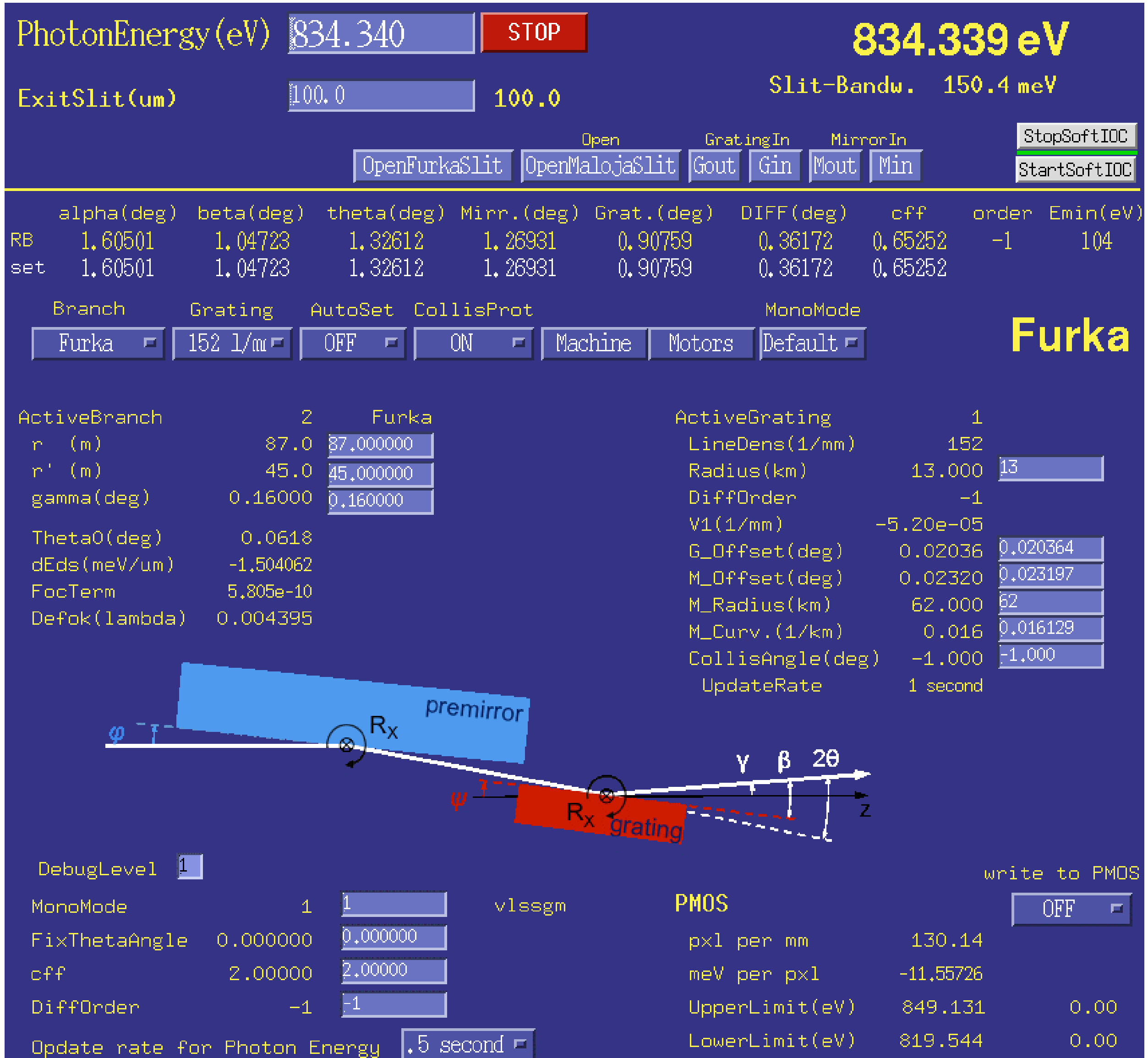
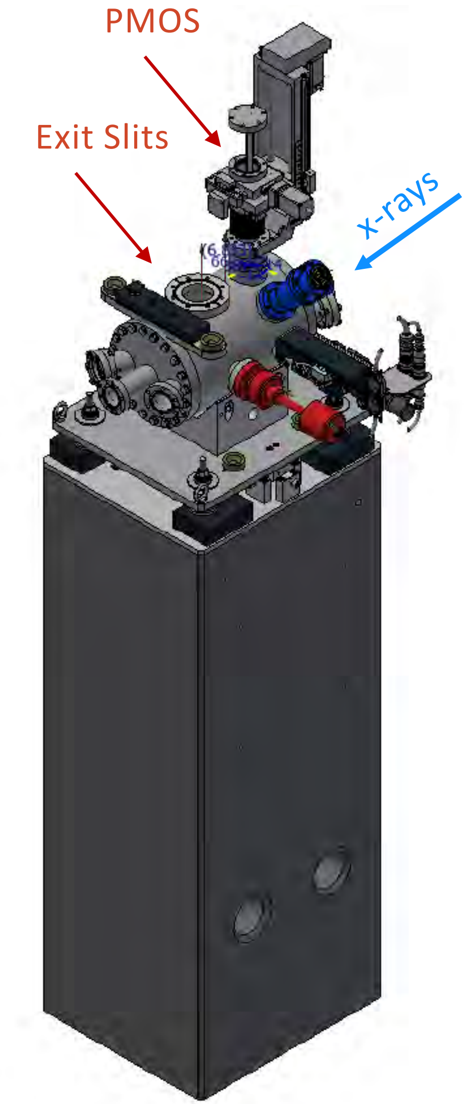
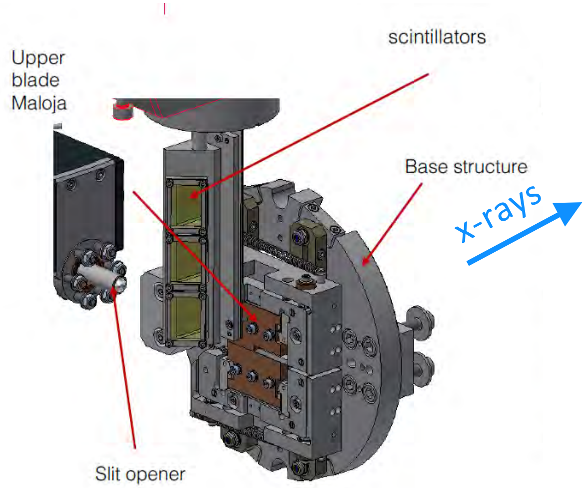
User Interface



Exit Slits & PMOS

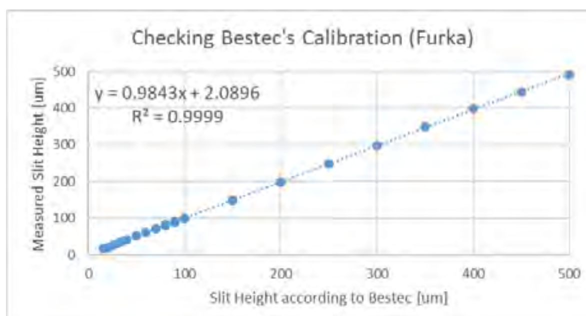


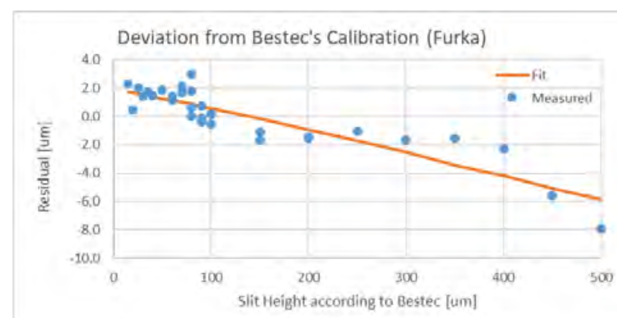
Internal Mechanics



Calibration

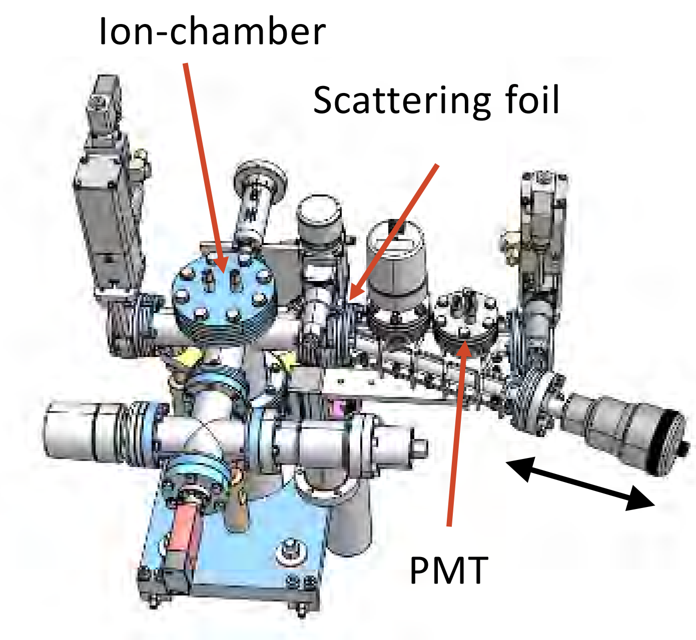
Results



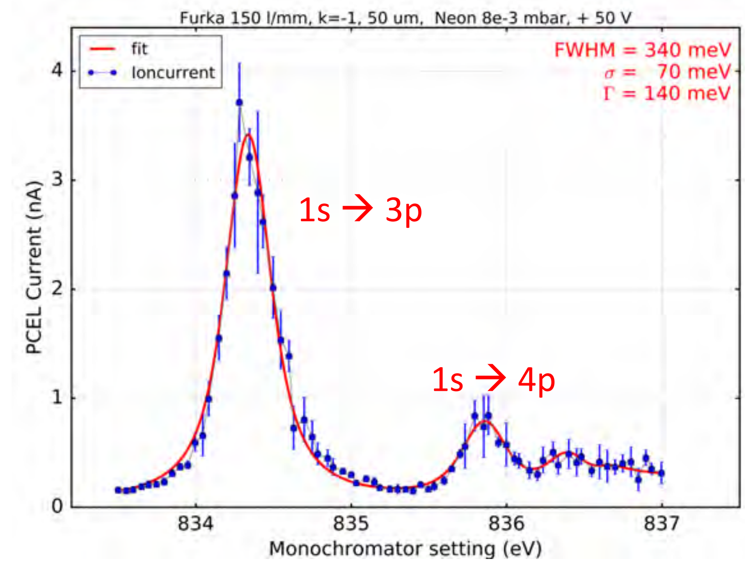


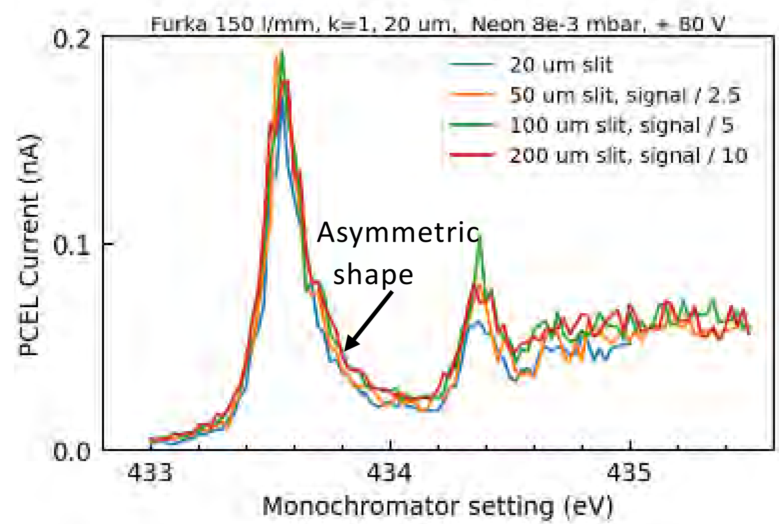
Calibrating the Mono

PCEL



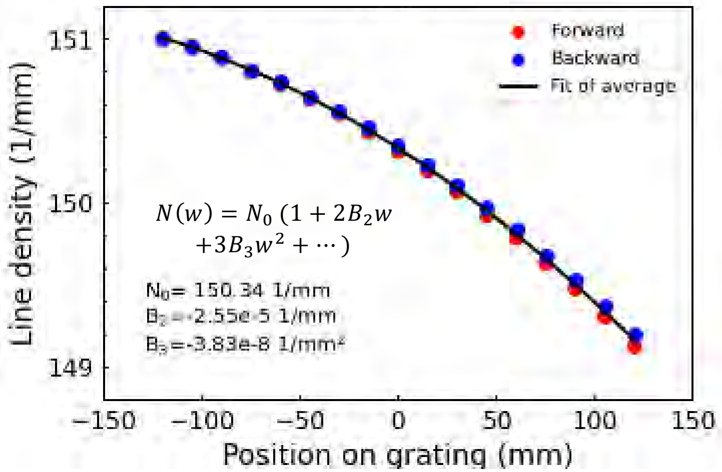
Grating orientation reversed



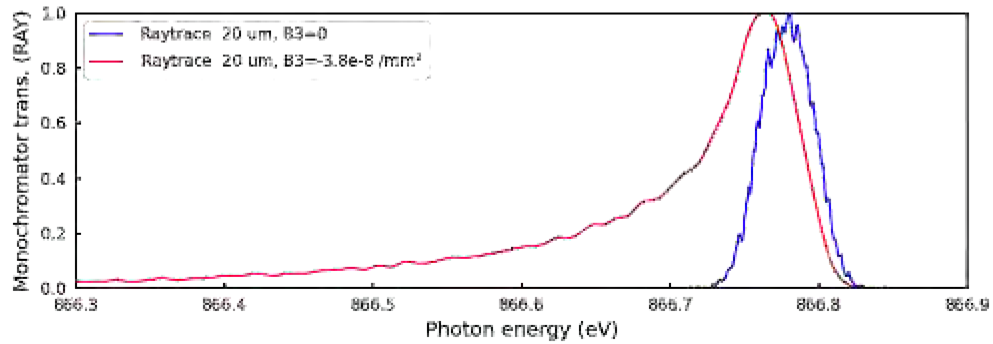


150 l/mm Grating & B3 VLS-parameter

Line density measured at HZB



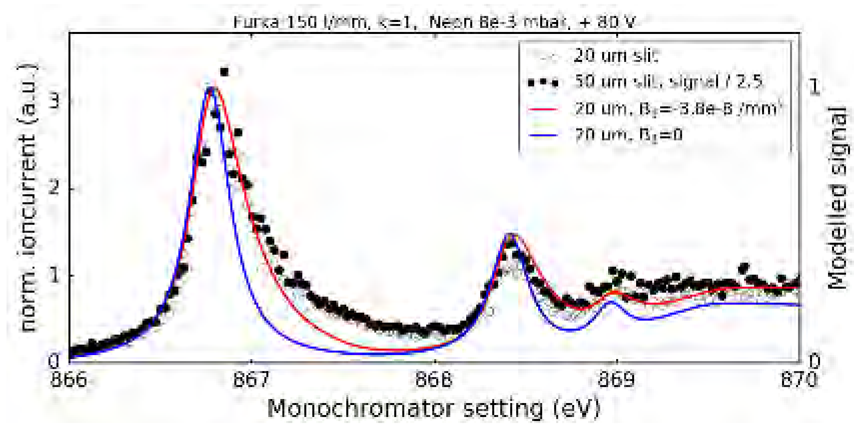
Monochromator transmission (RAY-trace)



Simulated Spectrum

- Monochromator transmission from RAY
- Neon spectrum with only 2 free parameter: Energy and Intensity of first peak

Rel. intensities, widths and positions are taken from UE49-PGM (BESSY) measurement in 2009



Courtesy: R. Follath

→ Energy resolution is limited by the B_3 line-density variation

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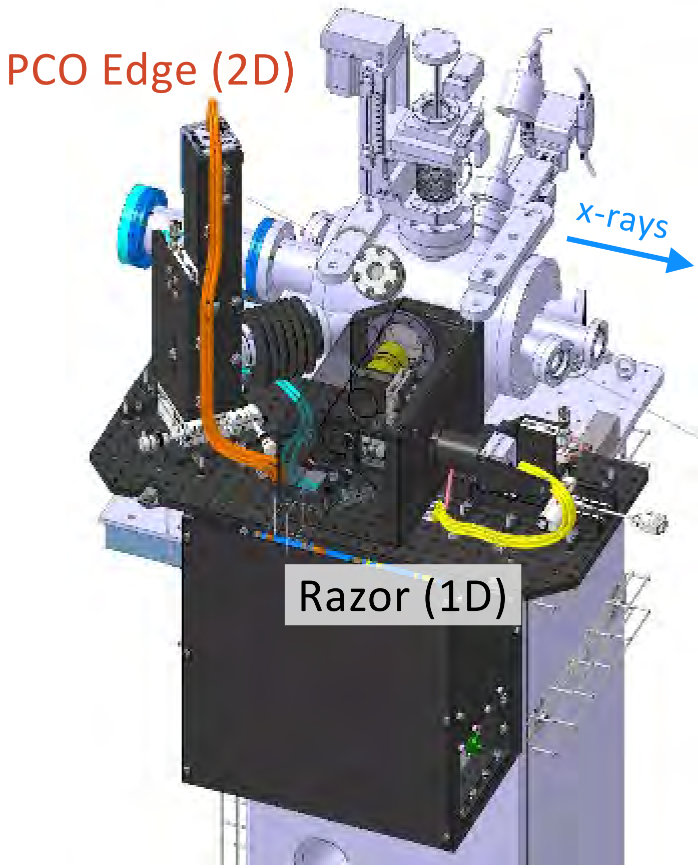
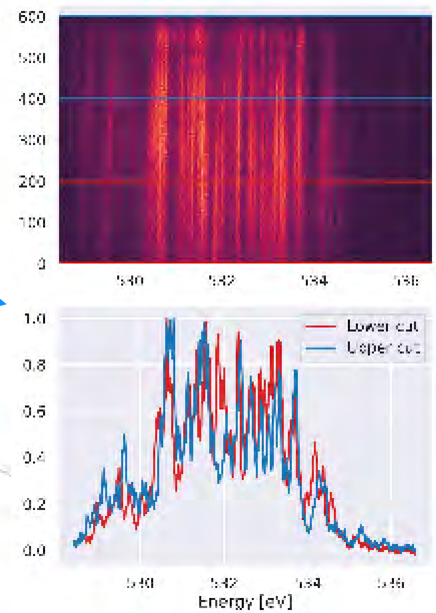
PMOS

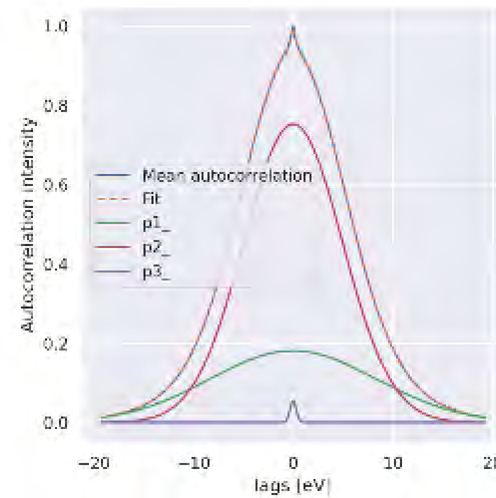
Elevation of PMOS



Focusing



C. Arrell

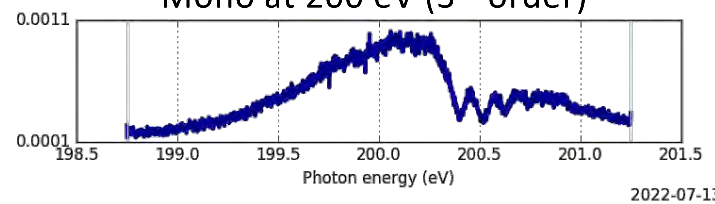


Scintillators

- Plane → diagnostic measurements
- Slotted → on-line analysis

Grating Mono Optimisation

Mono at 200 eV (3^{rd} order)



Gas attenuator: Nitrogen @ p=2.e-3 mbar

HERO Project: ESASE at 1 keV

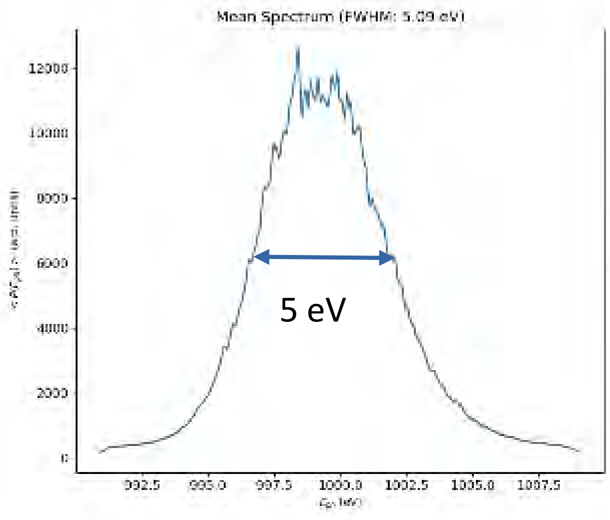
HERO: Hidden Entangled and Resonating Orders

Long-term Goal: Full control of amplitude and phase of the FEL-Pulses

The overall average width of the spectrum is determined by the spike length

(excluding impact of electron chirp)

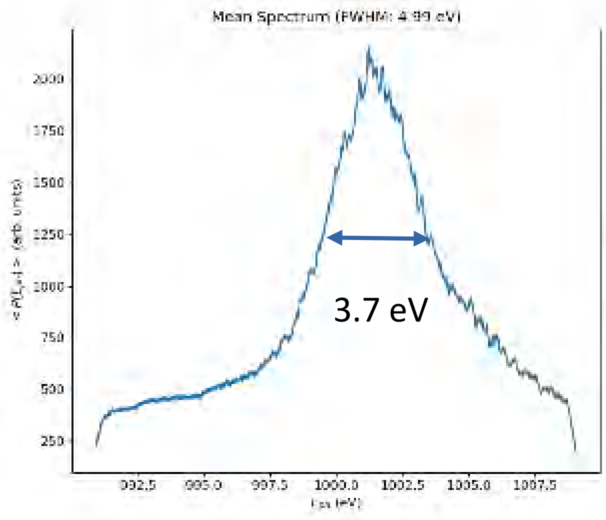
SASE (Chicane on, HERO Laser off)



220 as RMS duration (or longer)

(Anti-)ESASE

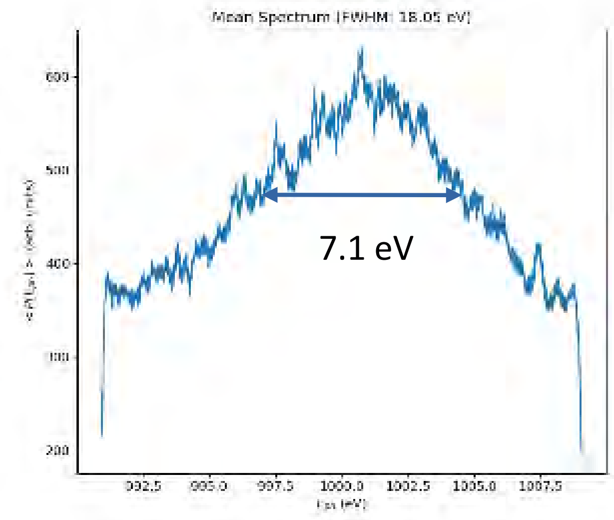
(HERO Laser on, no Taper)



290 as RMS duration (or longer)

ESASE

(HERO Laser on, positive Taper)

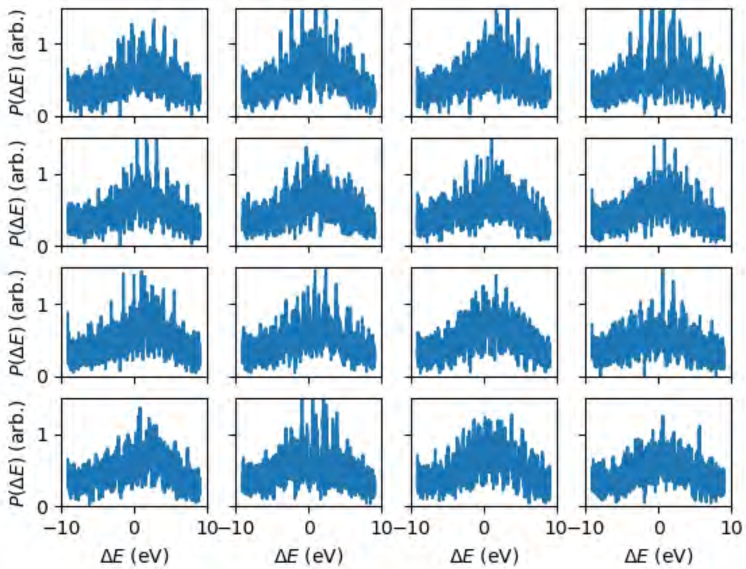


160 as RMS duration (or longer)

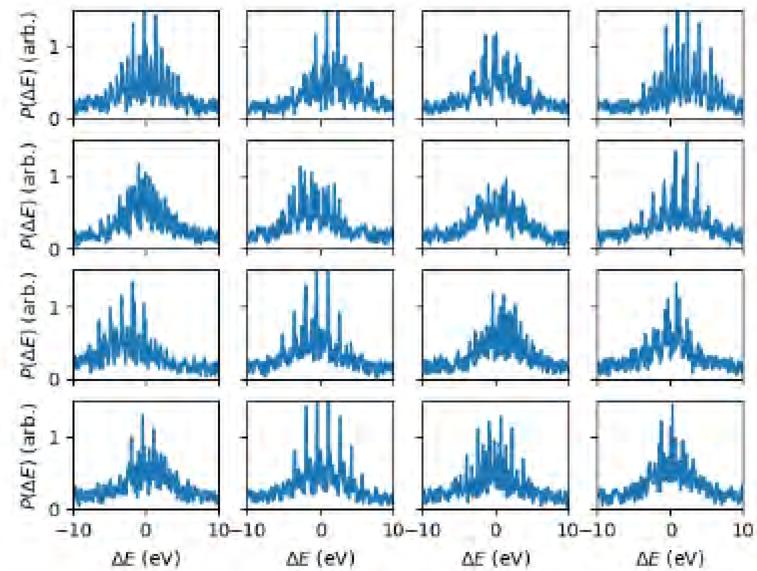
Courtesy: S. Reiche

Single Shot ESASE - Spectra

Sample Spectra: Single Shot Measurements



Sample Spectra: Simulation



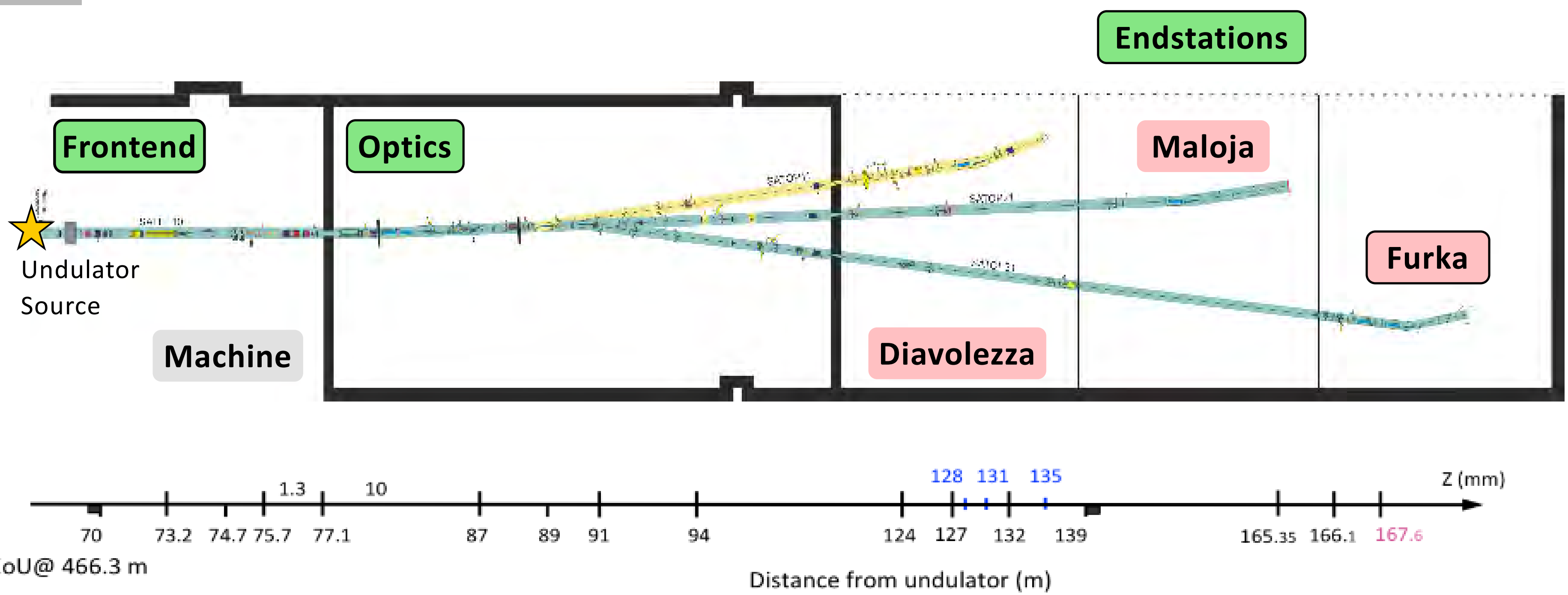
Courtesy: S. Reiche

Quality of PMOS signal excellent, also at lower photon energies (540 eV)

Spectra have typical signature of ESASE pulses. *(S. Reiche)*

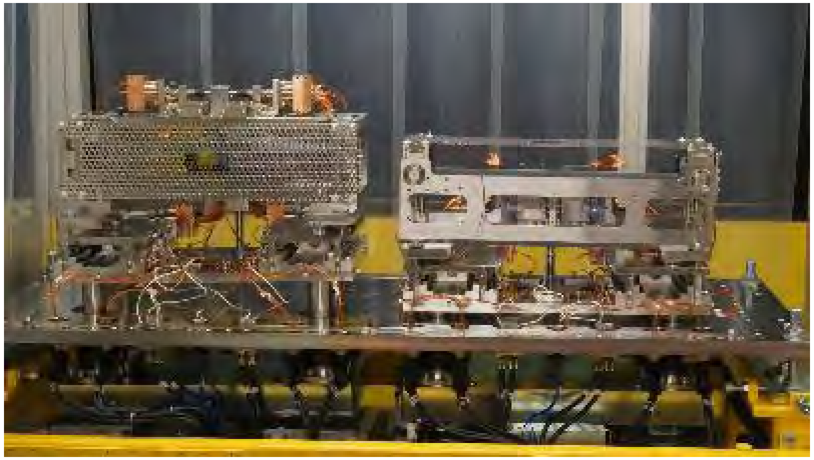
PMOS is a key diagnostic in characterizing the HERO pulses

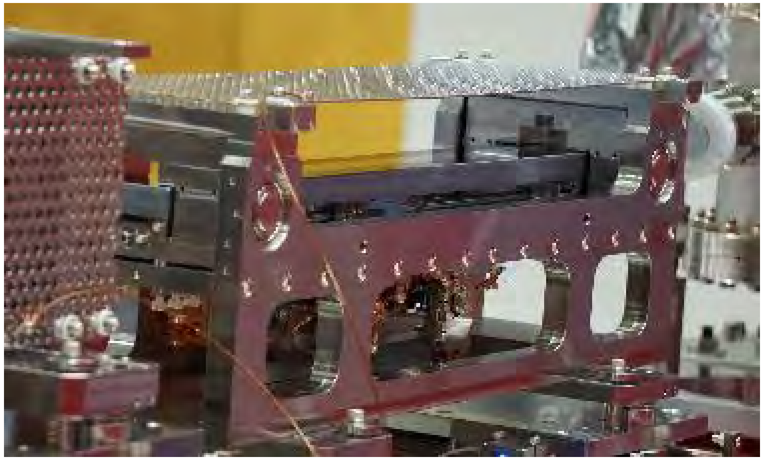
The Athos Photonics Section of SwissFEL



Refocusing

Similar KB-ystems to focus at all SwissFEL beamlines.

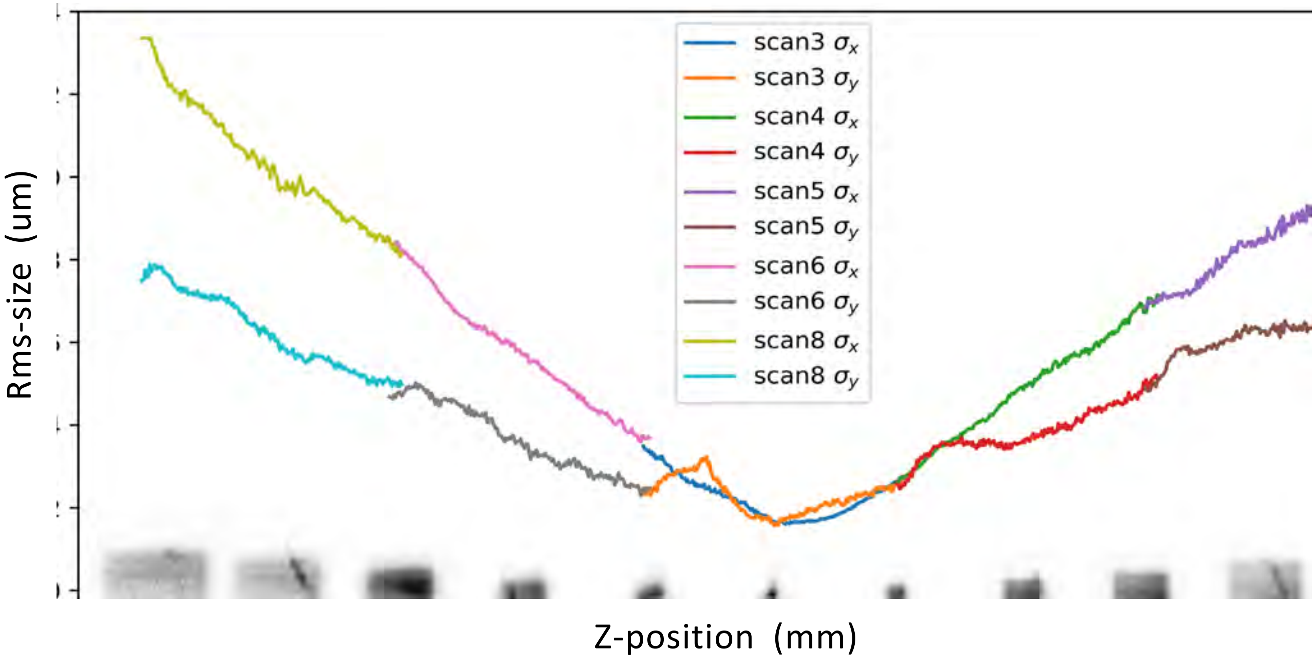


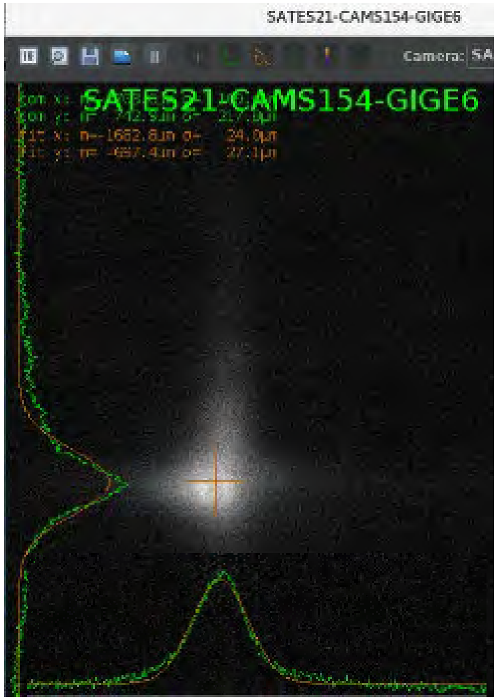


- Achromatic
- Flat mirrors bendable down to R=200 m
- Optical surface 550 x 30 mm^2
- Incident angle 2 – 15 mrad
- Mirrors by Zeiss and Jtec
- Gravity compensation via mirror shape
- Coatings by M. Störmer

Focus at Maloja

540 eV, 400 µJ, 5 Hz
Aperture 5x5 mm
Parasitic operation of ATHOS





Larger than expected 0.5 x 0.75 µm² (FWHM source limited)

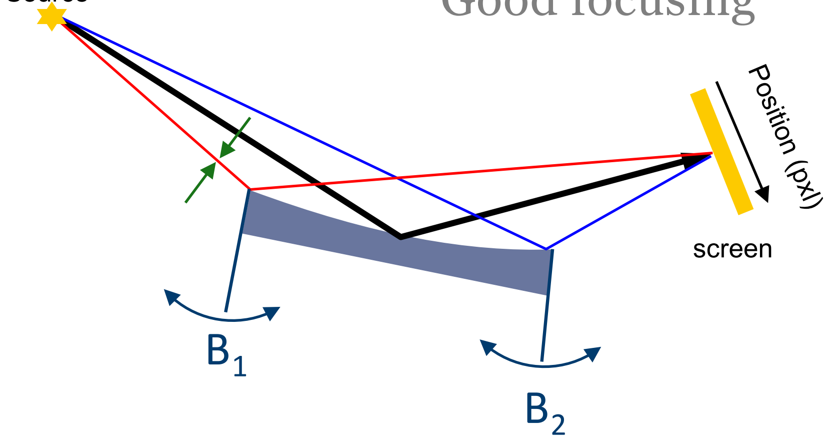
Gaussian fit:
3.8 x 4.2 µm² (FWHM)

23.10.2020: R. Follath, K. Schnorr, S. Augustin, G. Knopp, A. al Haddad : https://elog-gfa.psi.ch/SF-Photonics/800

Bender with 2 motors

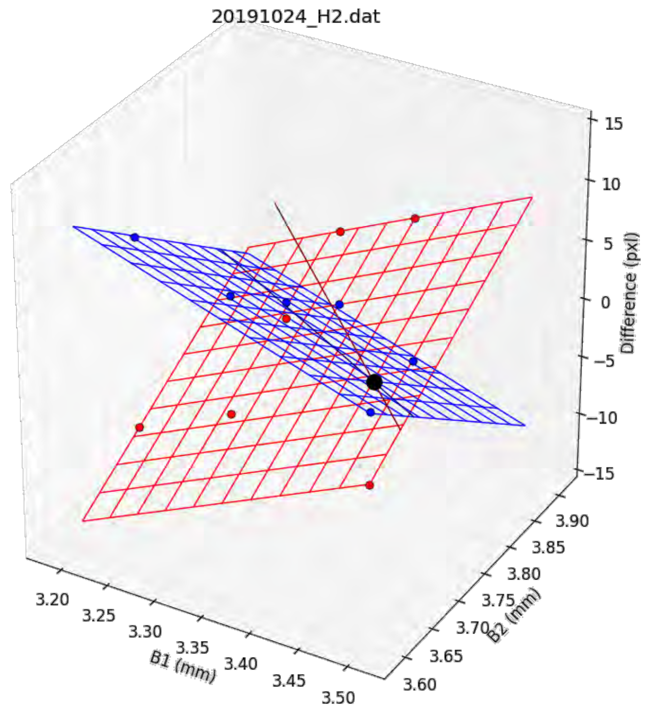
Problem: Spot on the screen is blurred and real spot size cannot be determined directly
But center can be fitted precisely

Good focusing



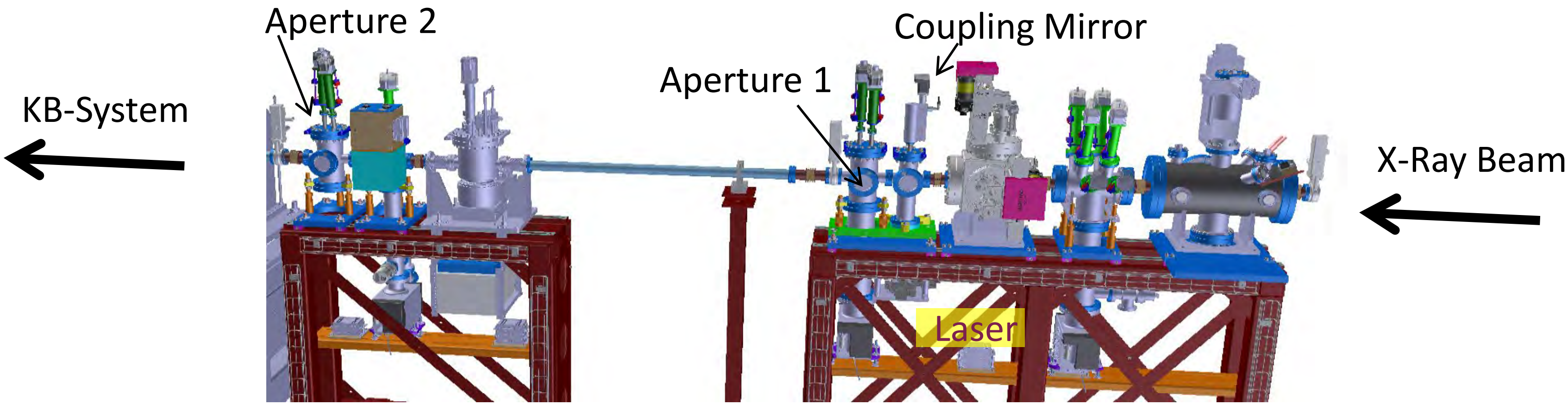
1. Use aperture to define beamlets
2. Use bender B_1, B_2 (unidirectional motion) into bring all beamlets to the same position on the screen

3d Plot

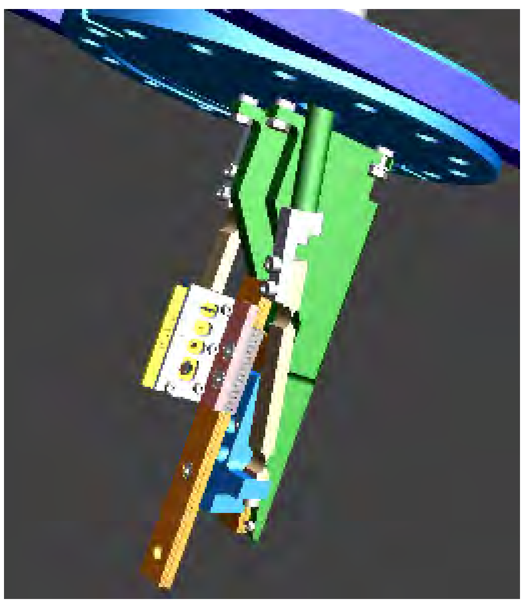


Considers the backlash of the system

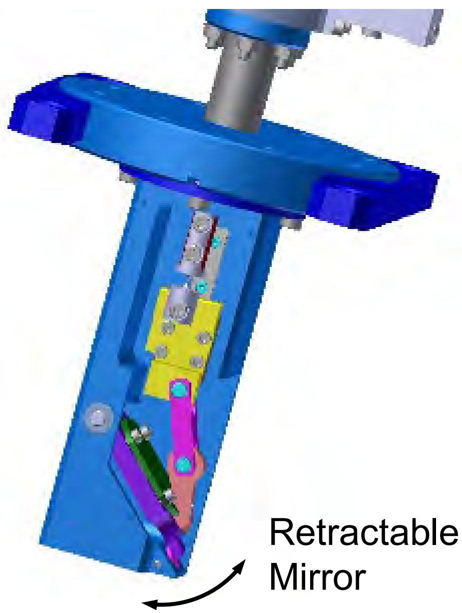
Optical Alignment System (OLIR)



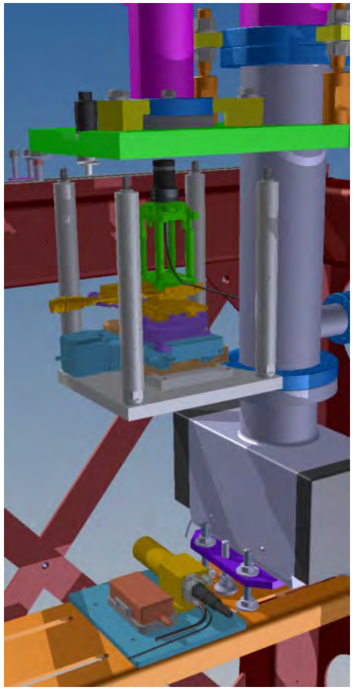
Apertures



Retractable Mirror



Laser

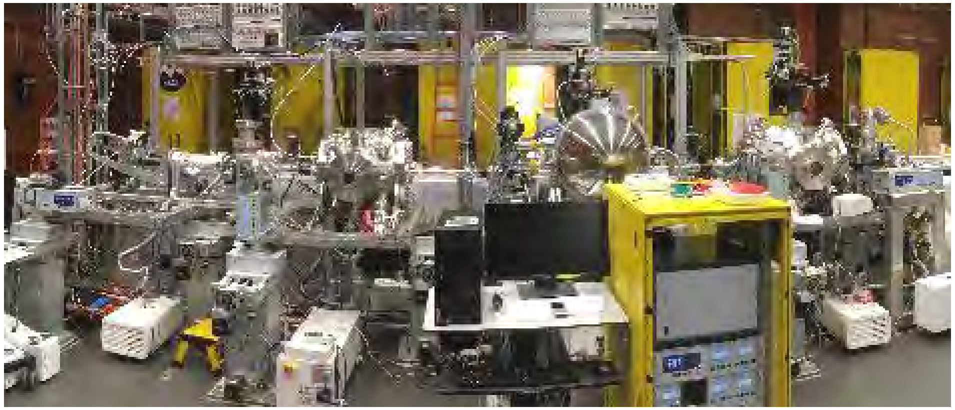


The Science

Furka

- Solid State Physics
- Resonant inelastic x-ray scattering

Maloja



- Atomic & molecular Physics
- Nonlinear x-ray physics & chemical dynamics
- Spectroscopy and single shot imaging

Diavolezza

under construction

- Seeded coherent x-rays
- Attosecond pulses & experiments
- ‘Bring-your own endstation’ experiments

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Thank you very much for your attention

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Wir schaffen Wissen – heute für morgen