Beam transport of short pulses and new spectroscopic capabilities

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(with contributions from XRO, ME and FEL R&D)

European XFEL, Germany

Status and development of SCS Instrument,
Hamburg, 23.01.2025

SASE3: Soft X-ray beamline

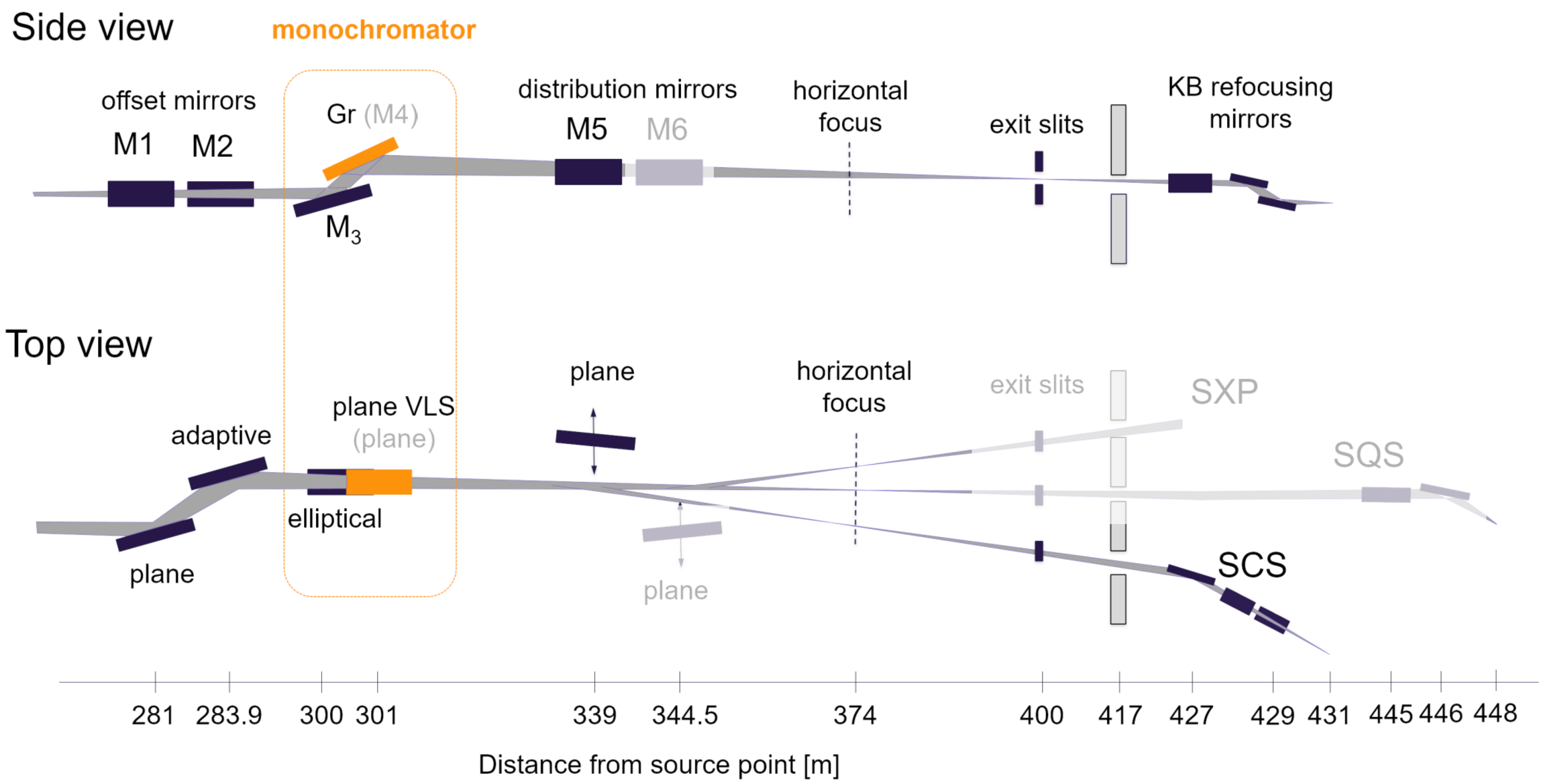
SASE3 beamline:

- Operational range: **250 eV – 3000 eV** (experiments performed in the range 380eV – 3000eV)
- Reflective optical elements, **grating** monochromator

SASE3 Monochromator:

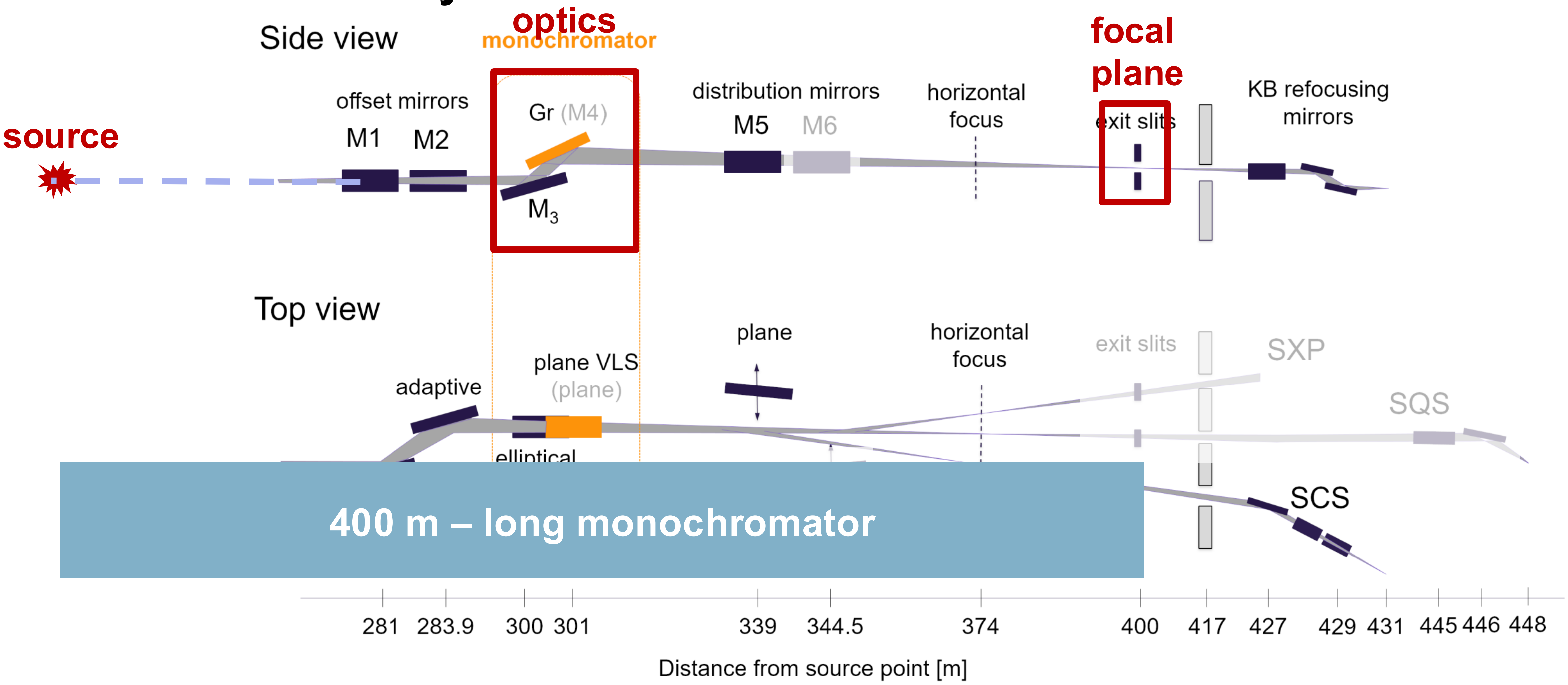
- To provide **further monochromatization** of the FEL beam
  (FEL bandwidth 0.2 – 1% in the soft X ray range)
- Goal **resolving power**: 5.000 & 20.000
- Beam transport **close to transform limit**

SASE3 beamline: layout, monochromatic operation



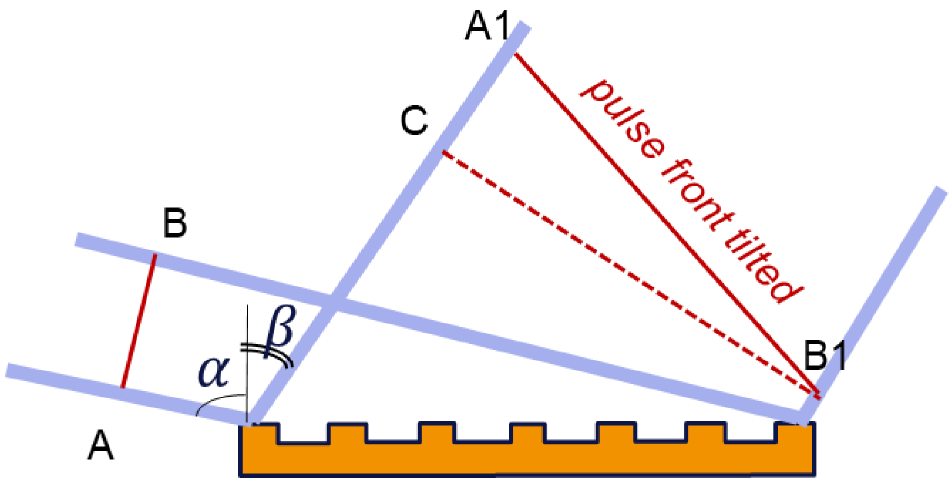
H. Sinn et al., *Technical design report: X-ray Optics and Beam Transport (2012); XFEL.EU TR-2012-006*

SASE3 beamline: layout



Base-line grating: line density

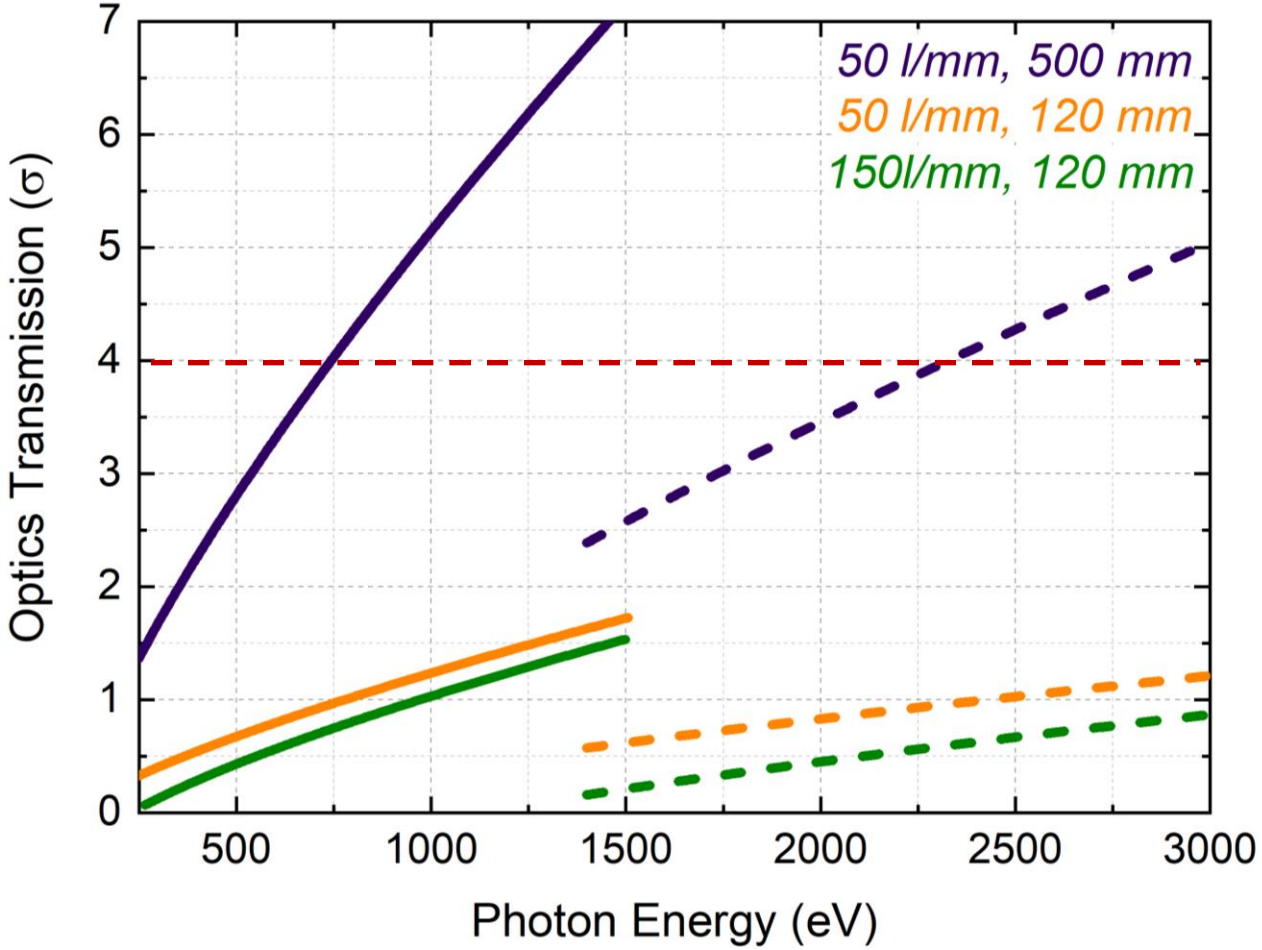
Grating	Low-resolution design grating
Optical surface size	500 mm x 25 mm
Slope error, RMS	< 50 nrad
Height error, PV	< 3 nm
Roughness, RMS	< 0.2 nm
Included angle	π - 18 mrad, π - 40 mrad
VLS law:	$n(w)=b0+b1*w+b2*w^2+..$
Central line density b0	**50 l/mm**
b1	$1.01*10^{-3}$ l/mm^2
b2	0 l/mm^3
Groove profile	Blazed, 0.1° blaze angle



Base-line grating

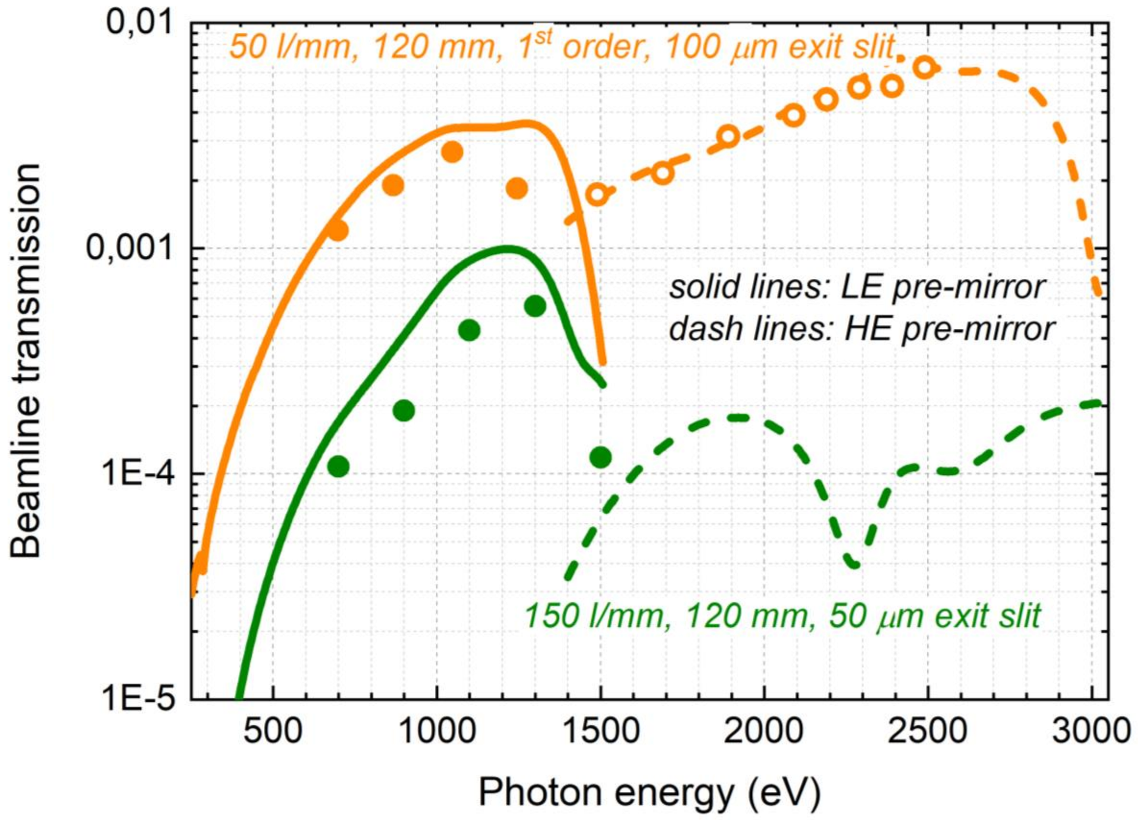
Grating	Low-resolution **design** grating	**Low-resolution** installed grating	**High-resolution** installed grating
Optical surface size	500 mm x 25 mm	**120 mm** x 17 mm	**120 mm** x 20 mm
Slope error, RMS	< 50 nrad	**200 nrad**	**130 nrad**
Height error, PV	< 3 nm	**6 nm**	**3.6 nm**
Roughness, RMS	< 0.2 nm	<0.2 nm	<0.6 nm
Included angle	π - 18 mrad, π - 40 mrad		
VLS law:	$n(w)=b0+b1*w+b2*w^2+..$		
Central line density b0	50 l/mm	50.05 l/mm	150 l/mm
b1	$1.01*10^{-3}$ l/mm^2	$1.0*10^{-3}$ l/mm^2	$3.029*10^{-3}$ l/mm^2
b2	0 l/mm^3	**$-1.2*10^{-6}$ l/mm^3**	**$-8.7*10^{-8}$ l/mm^3**
Groove profile	0.1° blaze angle	Laminar, 16 nm depth	Laminar, 16 nm depth

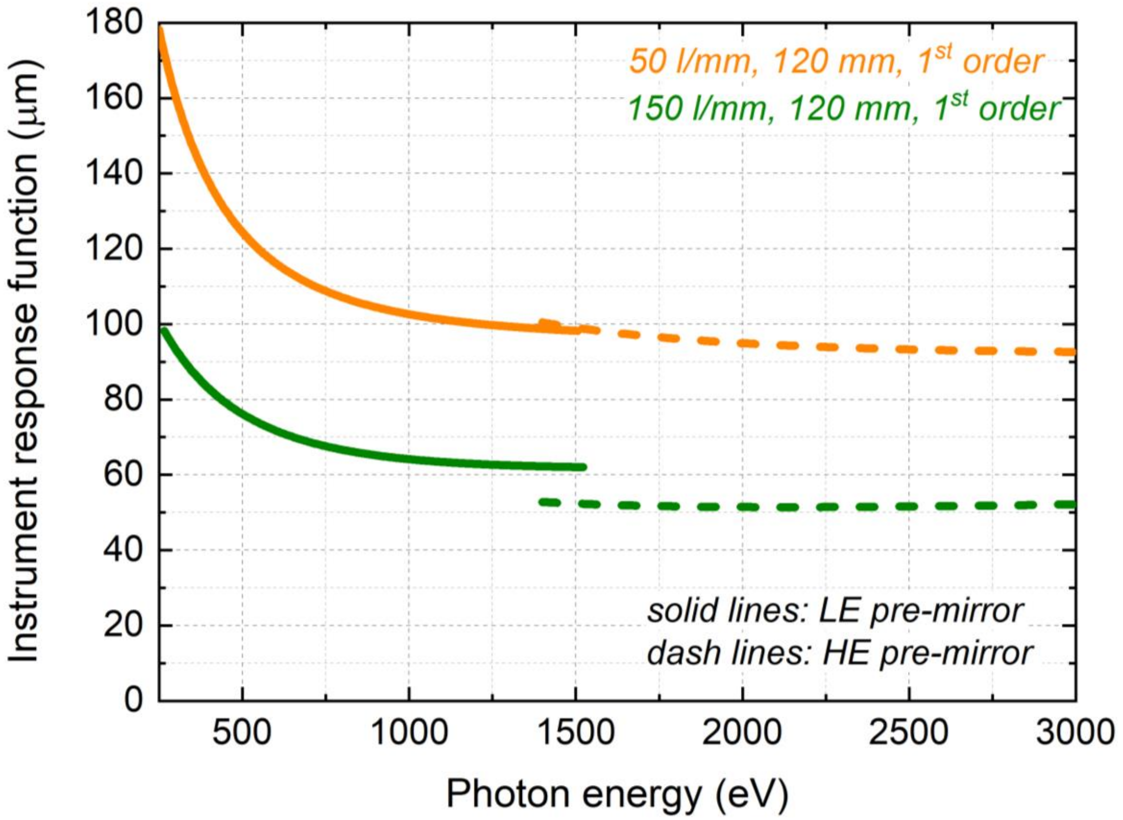
Geometrical transmission



N. Gerasimova et al., *J. Synchrotron Rad.* 29, 1299 (2022).

Transmission





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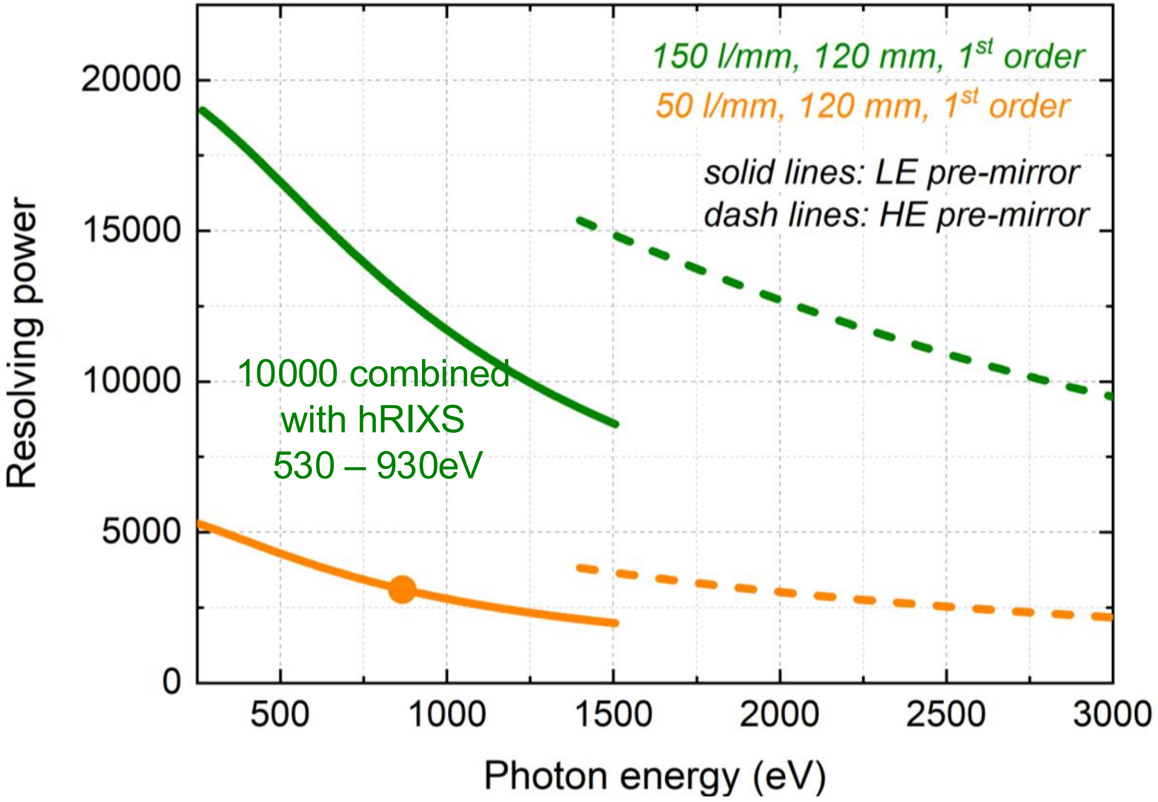
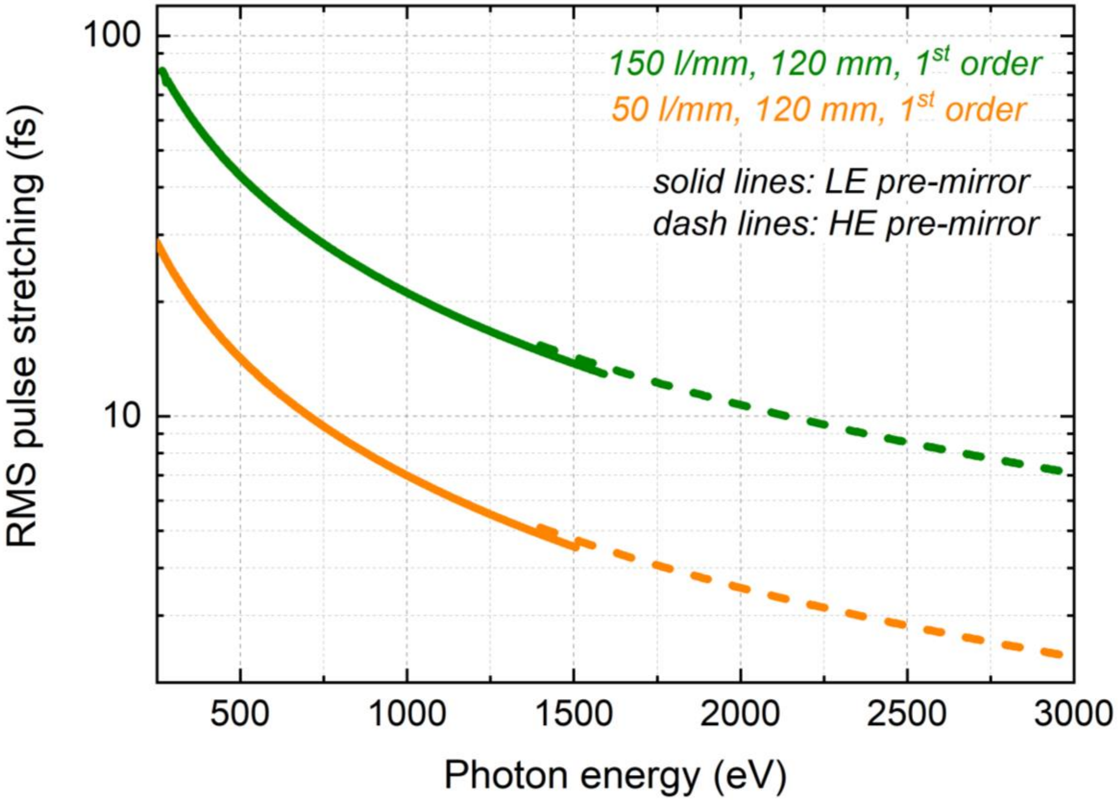
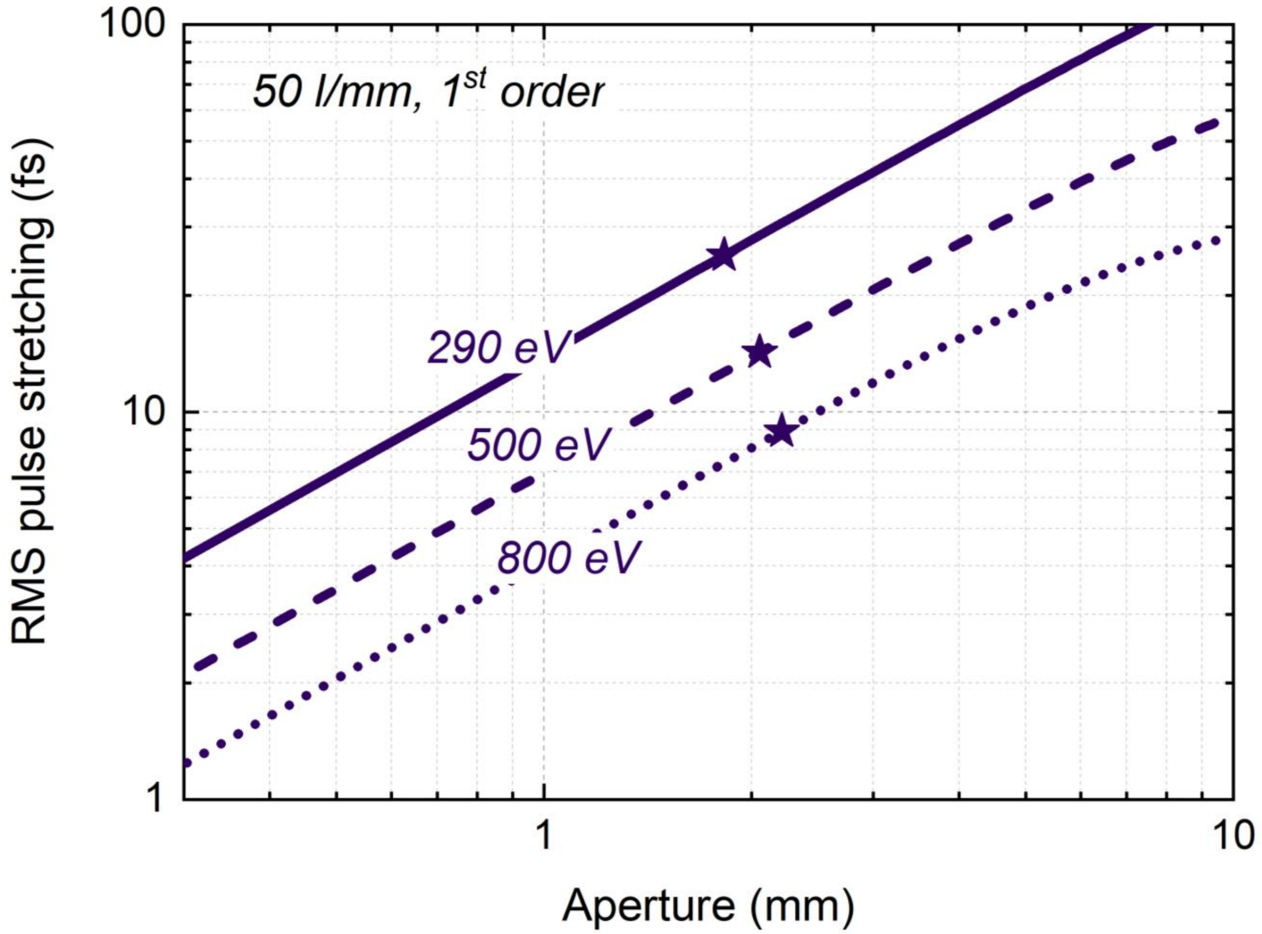
Resolving power *E/ΔE* and pulse stretching





N. Gerasimova et al., *J. Synchrotron Rad.* 29, 1299 (2022).

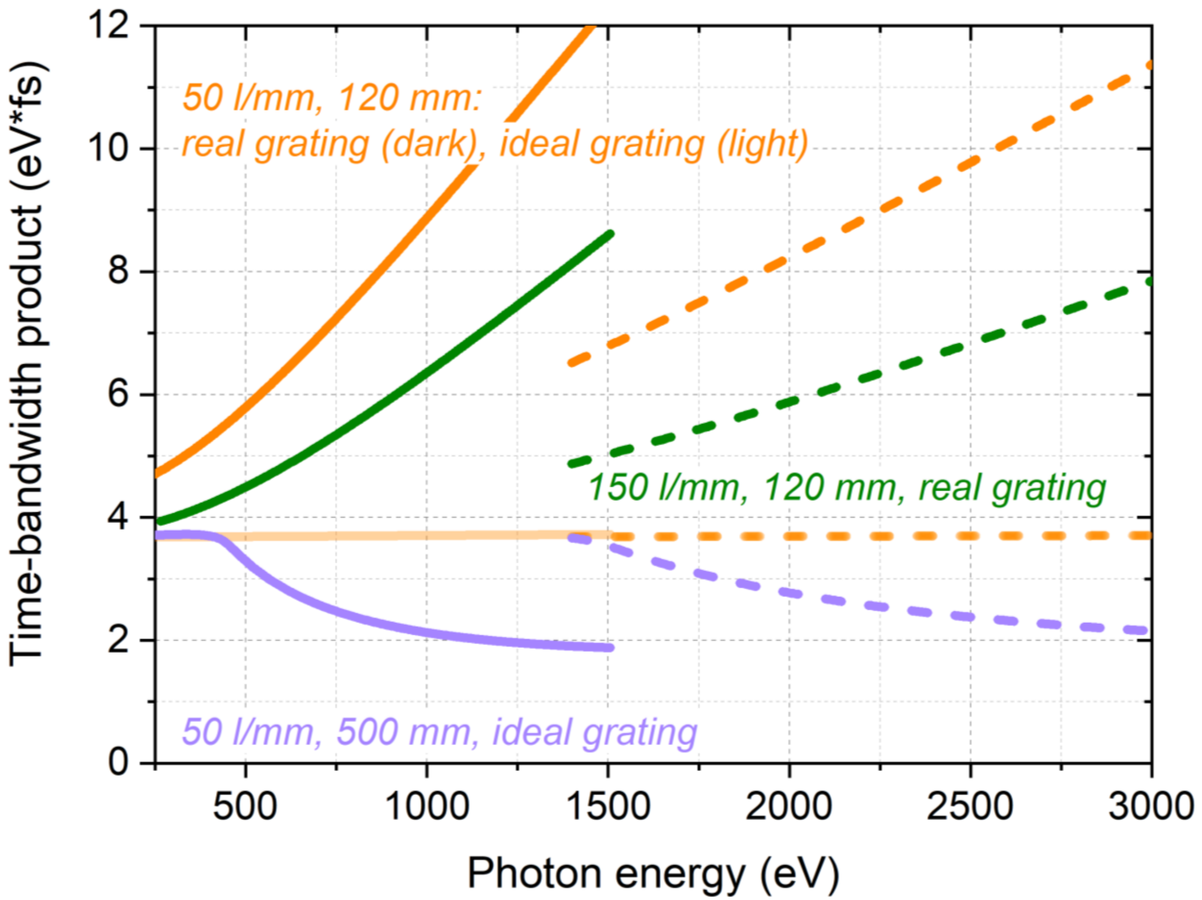
Pulse stretching by grating



Pulse stretching may be reduced by closing
an aperture before the grating
along with reduction of resolution

N. Gerasimova et al., *J. Synchrotron Rad.* 29, 1299 (2022).

Time-bandwidth product *ΔE*Δt*



N. Gerasimova et al., *J. Synchrotron Rad.* 29, 1299 (2022).

Towards design performance

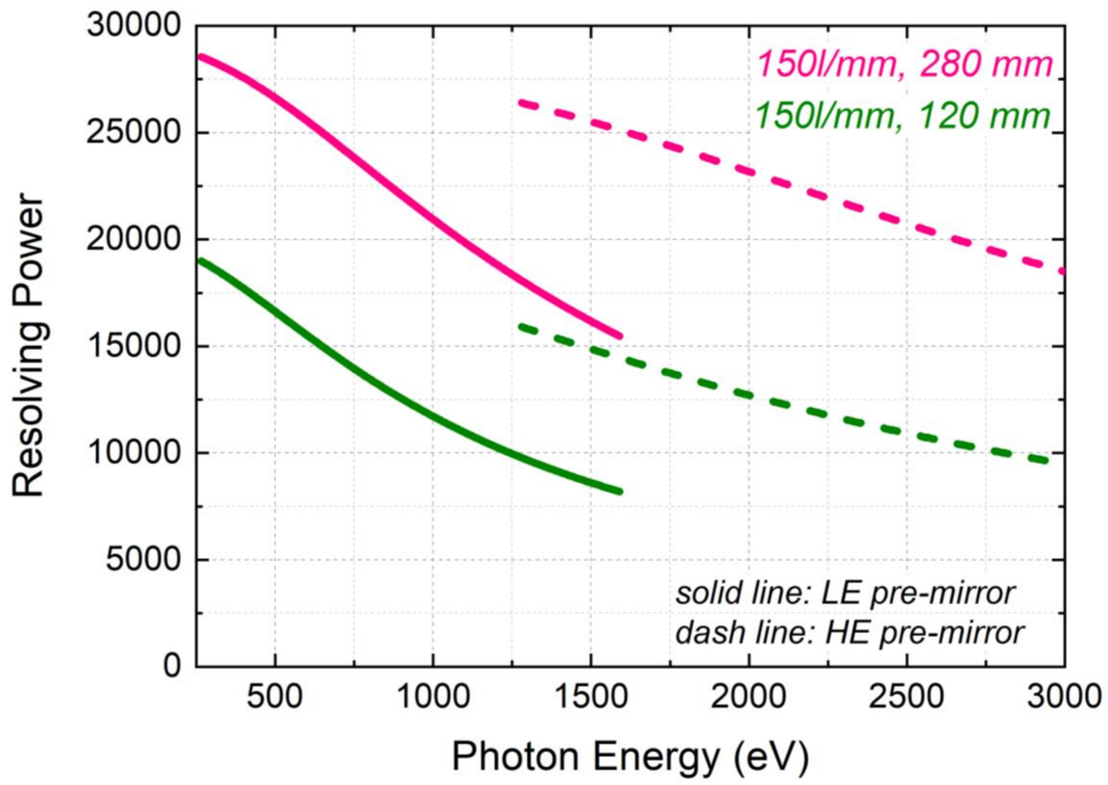
- Longer gratings *to increase* ***transmission*** *and* ***resolution***:

280 mm 150 l/mm grating is feasible

- production is straightforward
- hRIXS spectrometer: expected resolving power >20000

Aim to achieve >15000 combined resolving power for RIXS experiments

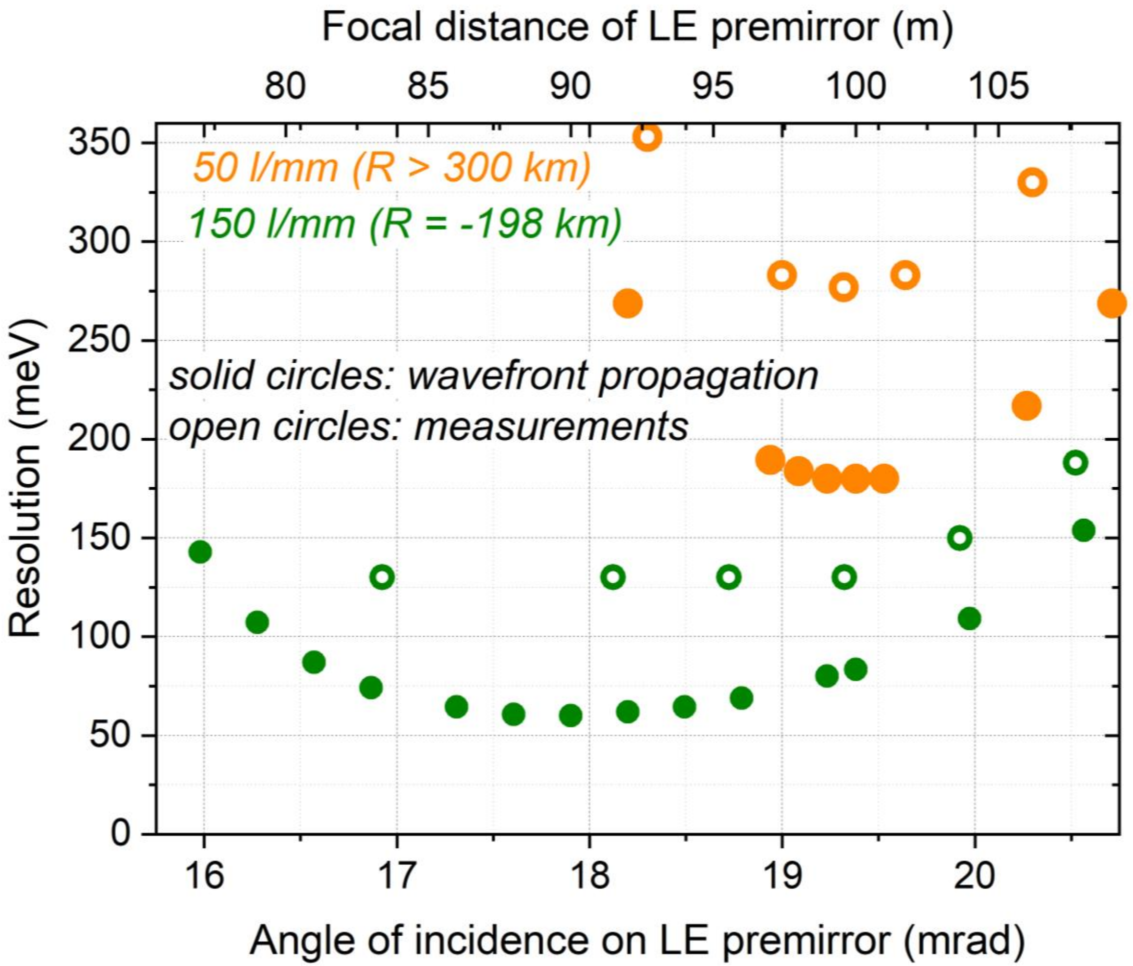
Expected in 2028



Towards design performance

- Longitudinal focusing:
  - *with longer grating effect of defocus increases*

Longitudinal focusing



Longitudinal focusing is strongly affected by:

- Residual grating radius
- Longitudinal source position (>120 m long undulators; operation with / without afterburner)

Bendable premirror option is in design

Expected in 2027-2028

Conclusions

Monochromatic operation:

- At present, two 120 mm gratings are installed:
  - low-resolution 50 l/mm grating allows for moderate resolving power of about 2000–5000 along with pulse stretching of a few to a few tens of femtoseconds RMS
  - high-resolution 150 l/mm grating reaches a resolving power of 10000 at the cost of larger pulse stretching

- Towards design performance:
  - 280 mm 150 l/mm grating is feasible
  - to control longitudinal focusing mechanical upgrade of pre-mirror to bendable option is in design phase

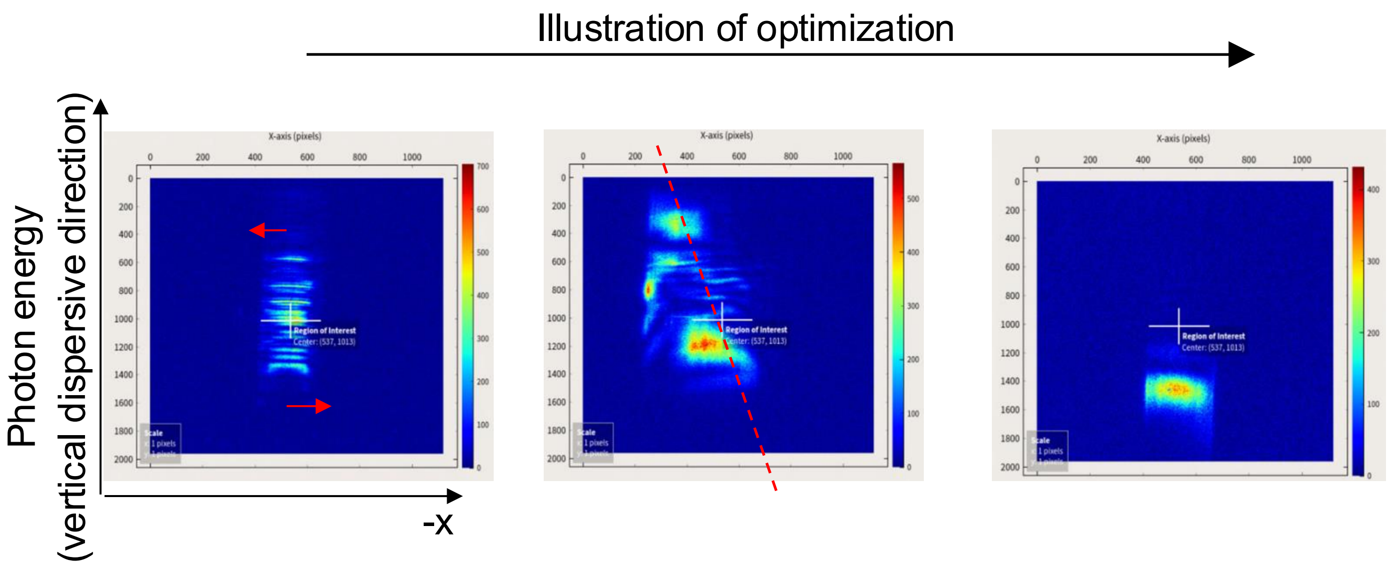
Special modes of operation

Applications – talk of L. Mercadier

- **Short pulses** (down to **attosecond** regime)
- **Two colors**

Special modes of operation

- **Short pulses** (down to **attosecond** regime):
  - Combination of nonlinear compression and dispersion leaking *(S.Serkez, G. Geloni, et al.)*
    - down to sub-femtosecond, up to hundreds μJ, provided for user operation few times



Chirp + horizontal orbit dispersion = radiation angular dispersion

courtesy **S. Serkez, G. Geloni**

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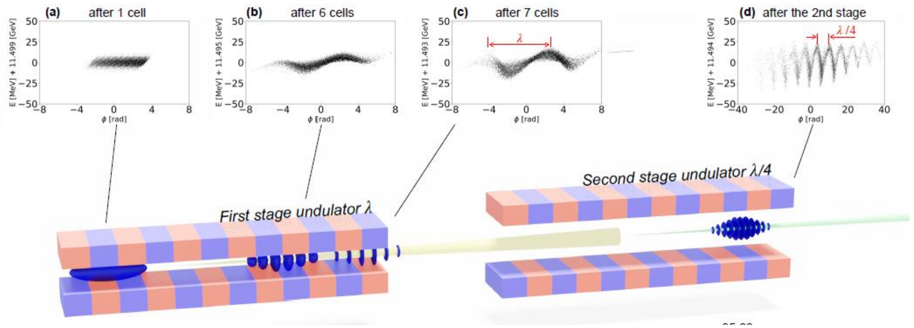
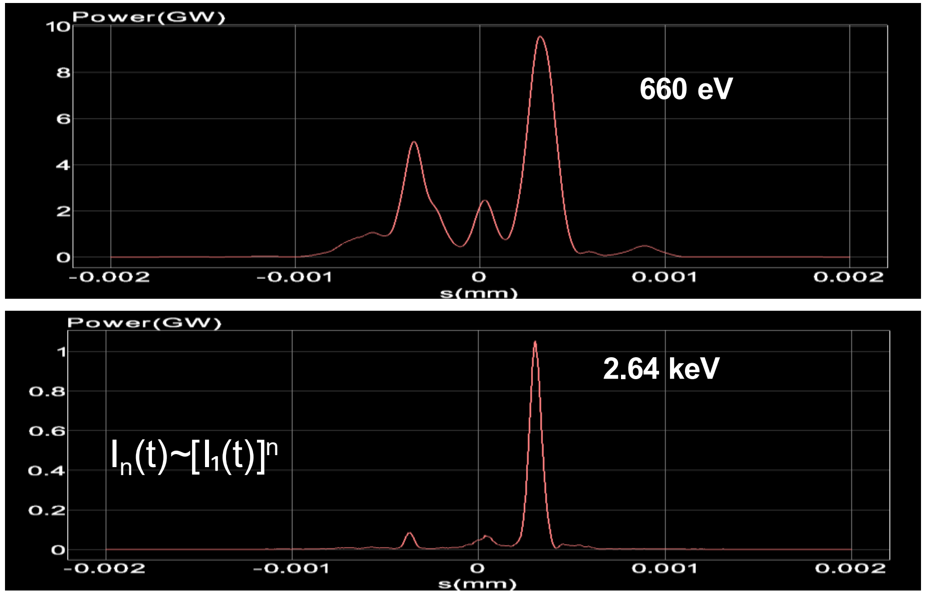
  - Harmonic conversion (*E. Schneidmiller, et al.)*
    - demonstrated, 10 µJ, high photon energies

E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov, *Opt. Comm. 212, 377 (2002).*



A. Trebushinin, et al., *Photonics 10, 131 (2023).*

Simulations



courtesy **E. Schneidmiller**

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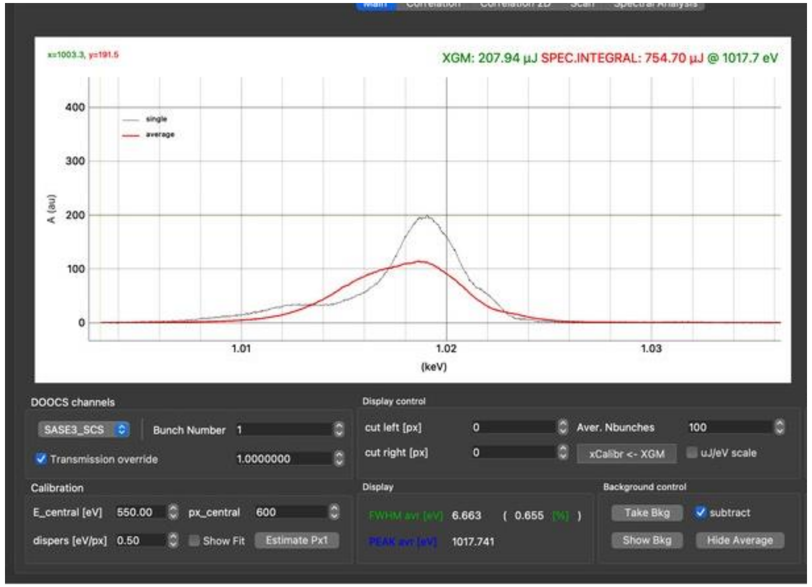

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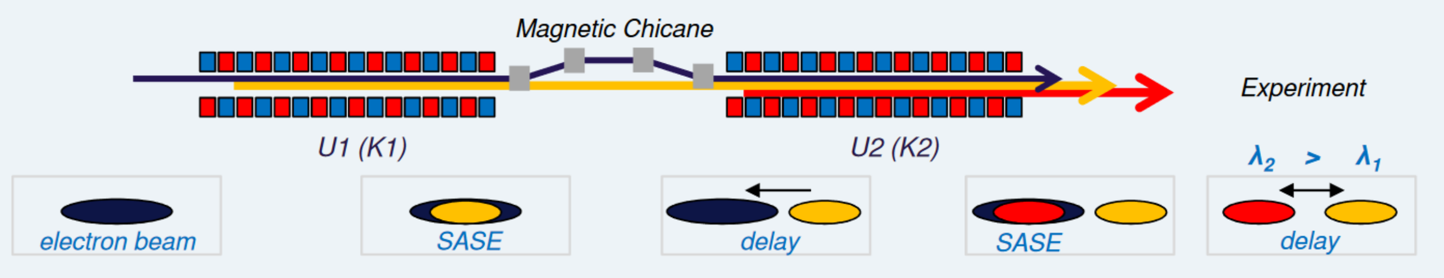
  - ASPECT
    - R&D
  - ….

Special modes of operation

S. Serkez et al., *Appl. Sci. 10, 2728 (2020).*



- **Two colors:**
  - split-undulator configuration

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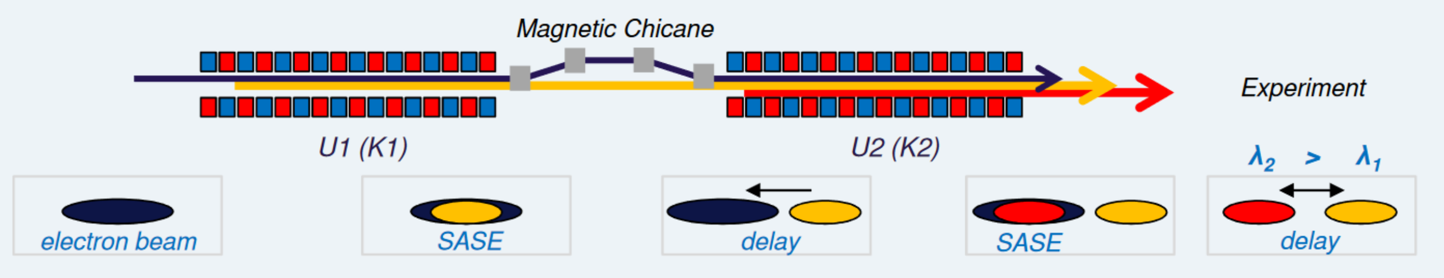

- **Two colors:**
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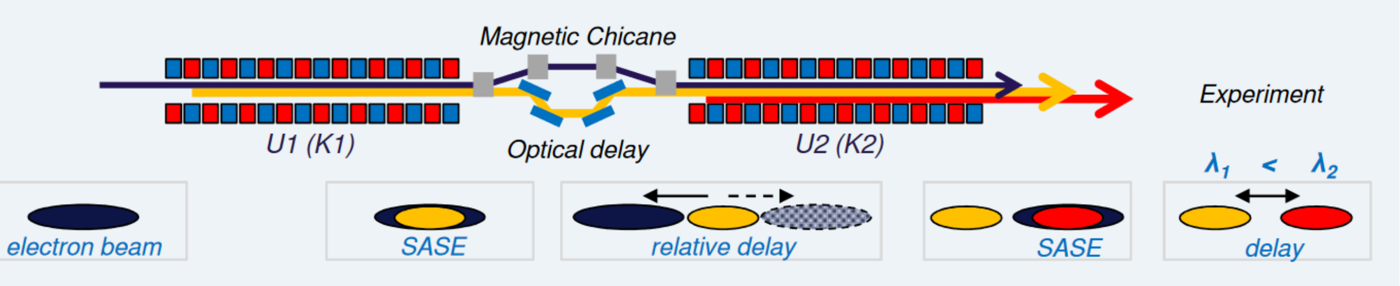
  - Installation of optical delay line during shutdown 2025

a)



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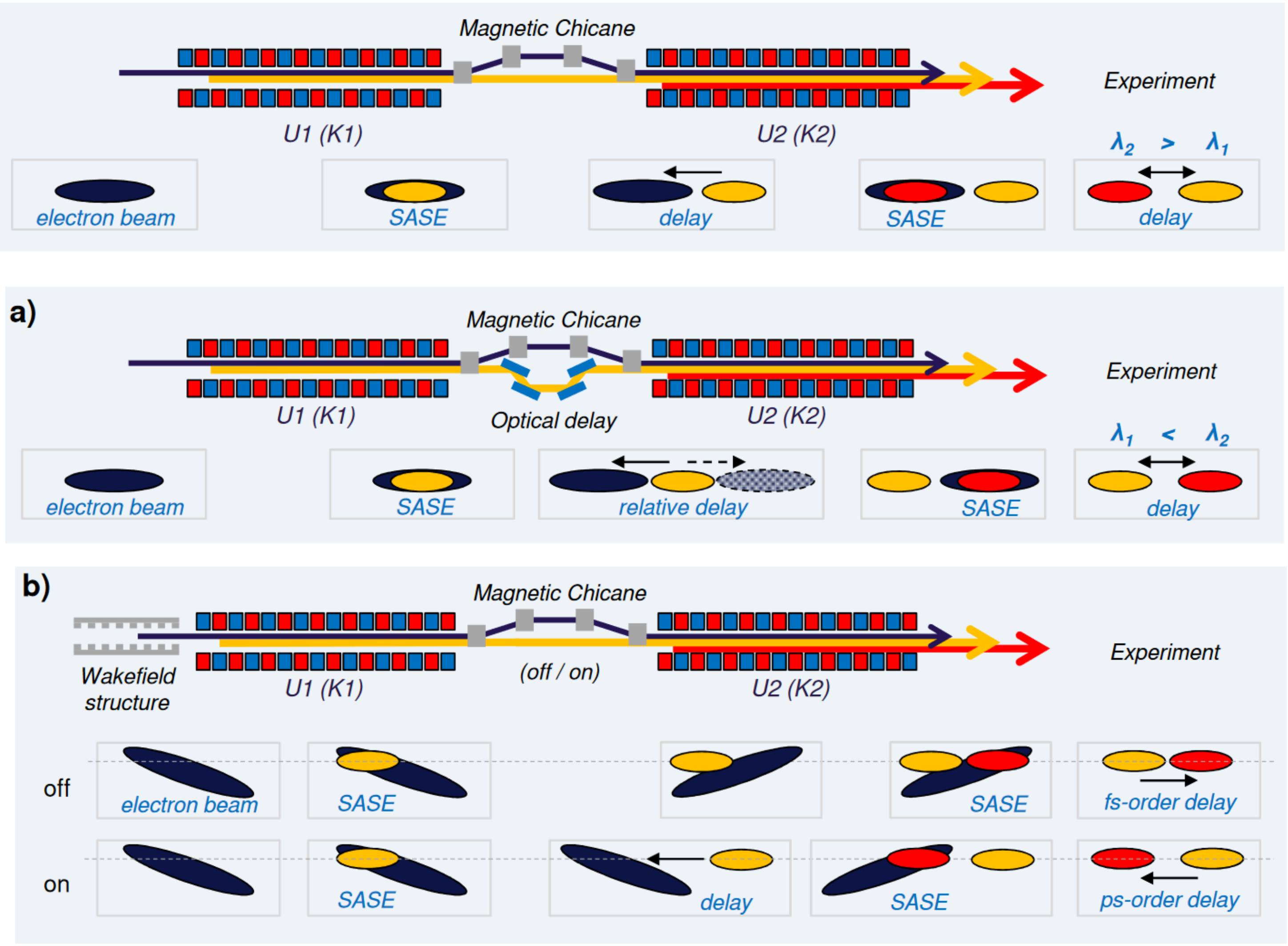
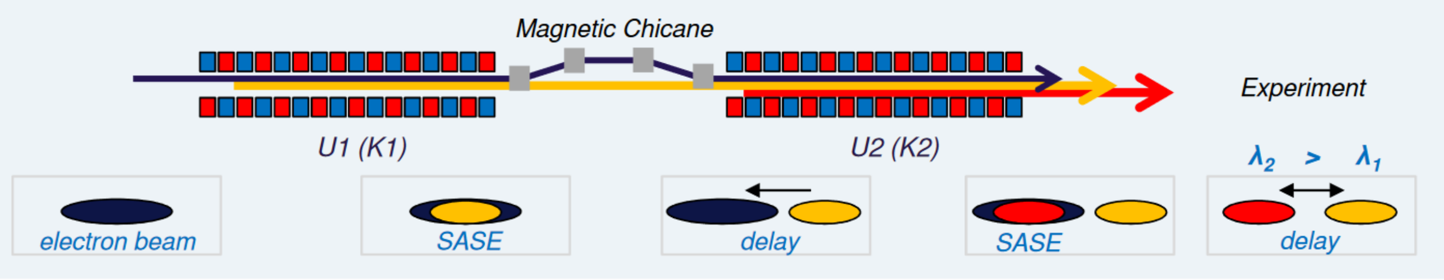


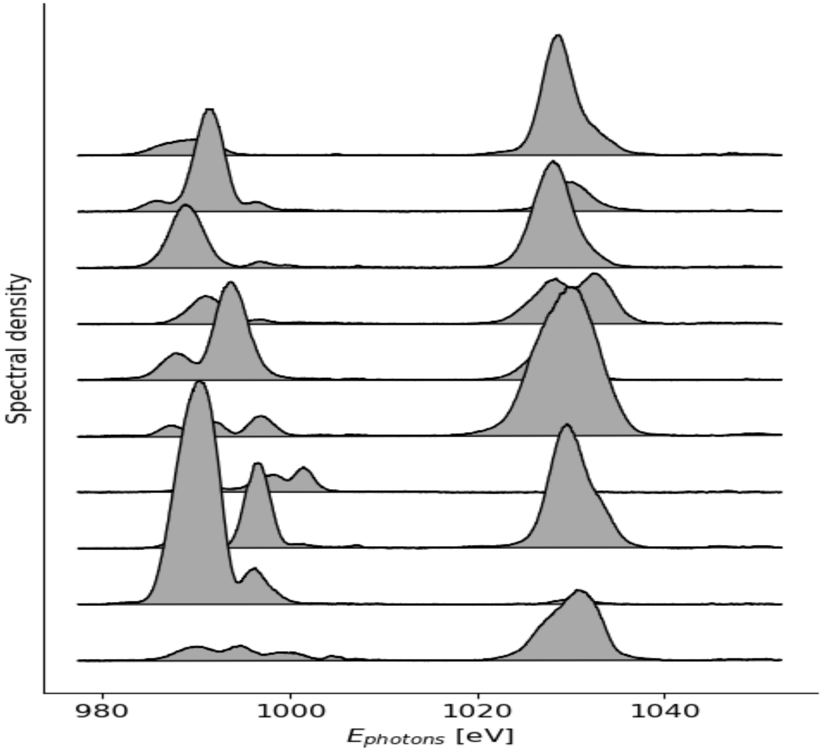
with fresh-slice technique

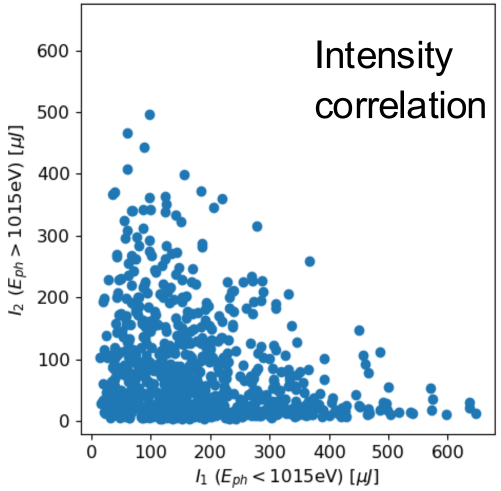
Special modes of operation

S. Serkez et al., *Appl. Sci. 10, 2728 (2020).*



- **Two colors:**
  - split-undulator configuration
  - Installation of optical delay during line shutdown 2025
- **Two colors & short**
- **Short & variable polarization**
- **…**





courtesy **S. Serkez, G. Geloni**

Special modes of operation

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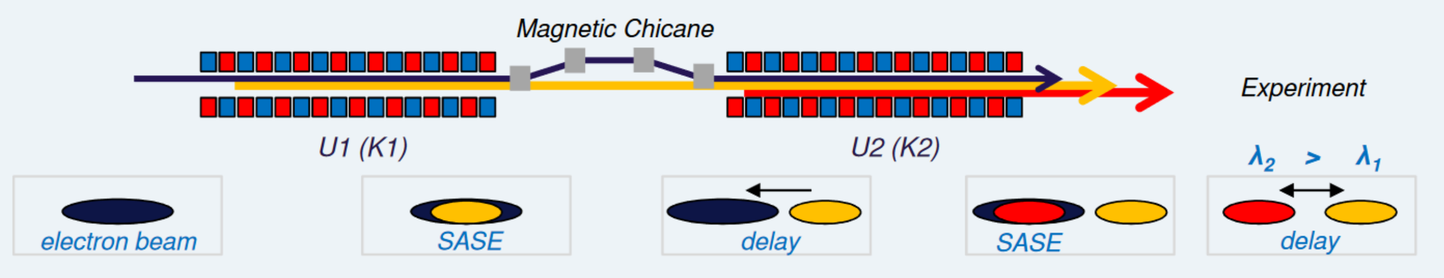

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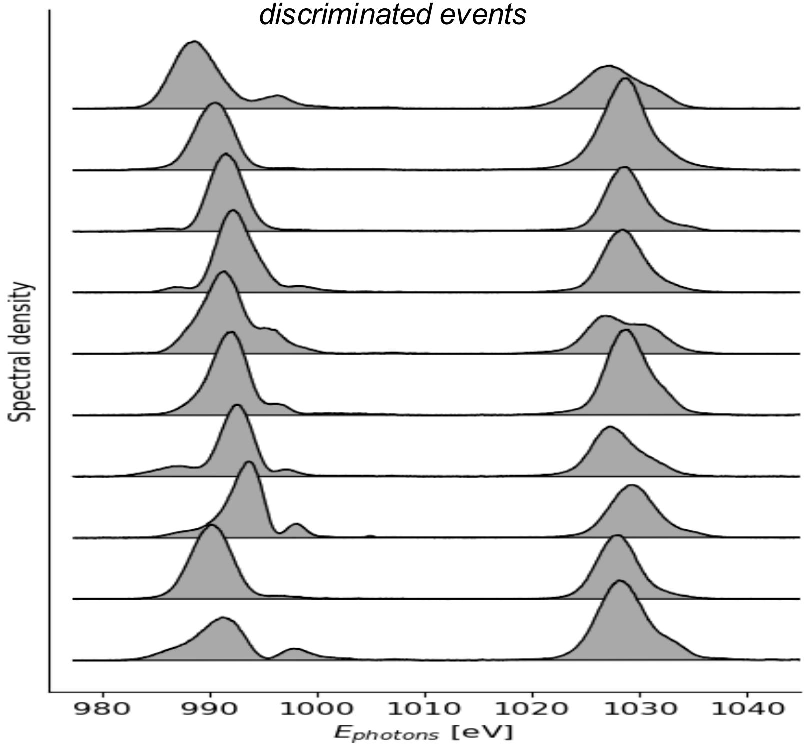

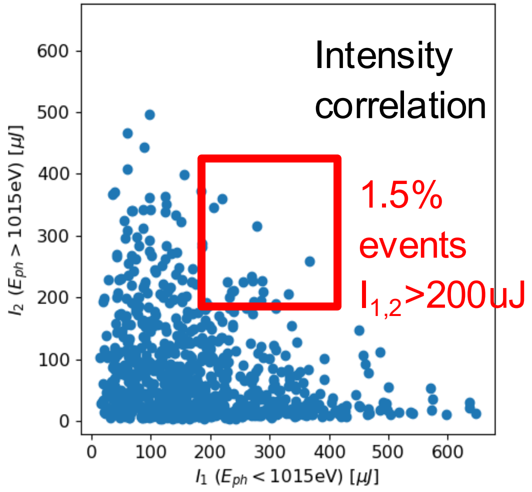

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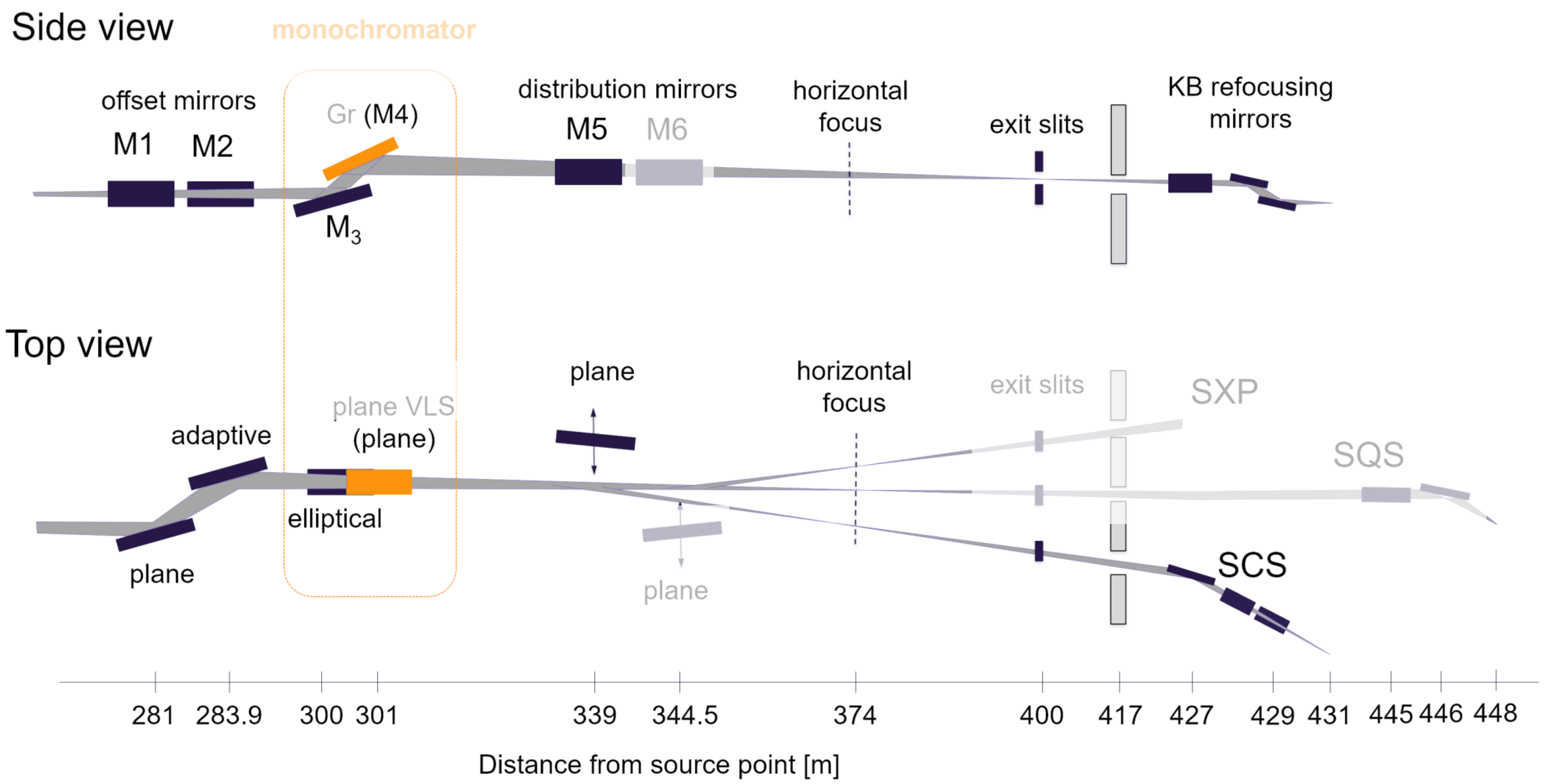
SASE3 beamline: layout, pink beam operation



H. Sinn et al., *Technical design report: X-ray Optics and Beam Transport (2012); XFEL.EU TR-2012-006*

High throughput spectrometer

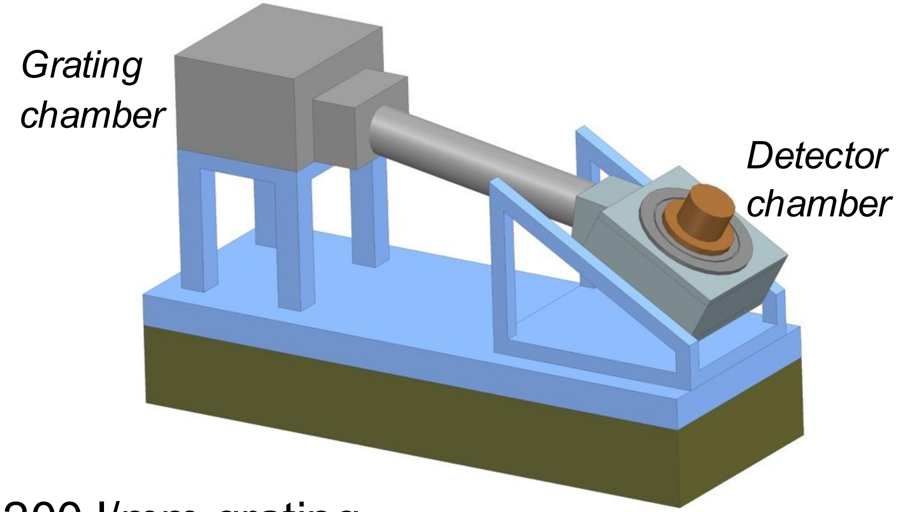
- **Spectrometer after the sample**:
  - Forward geometry possible
  - Throughput higher than hRIXS
  - Compactness
  - Resolving power 5000

High throughput spectrometer

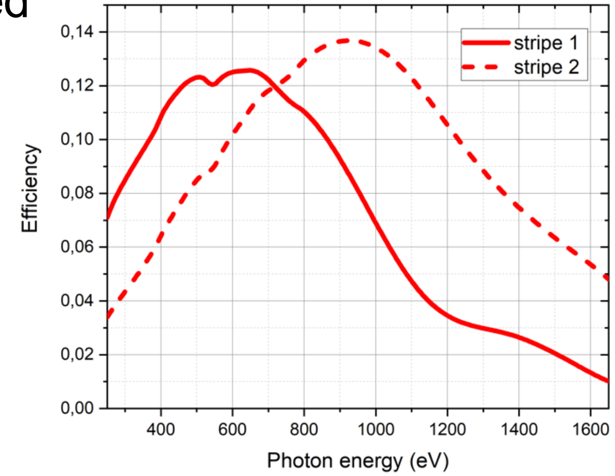
- **Spectrometer after the sample**:
  - Forward geometry possible
  - Throughput higher than hRIXS
  - Compactness
  - Resolving power 5000
- **Design**:
  - Slitless
  - ~2m long
  - Flat-field, based on VLS grating
  - Compatible with SCS detectors (Marana-X, Jungfrau)

*Technical commissioning expected in **fall 2026***

✓ Tender for the chamber in progress



✓ 1200 l/mm grating delivered



Thank you