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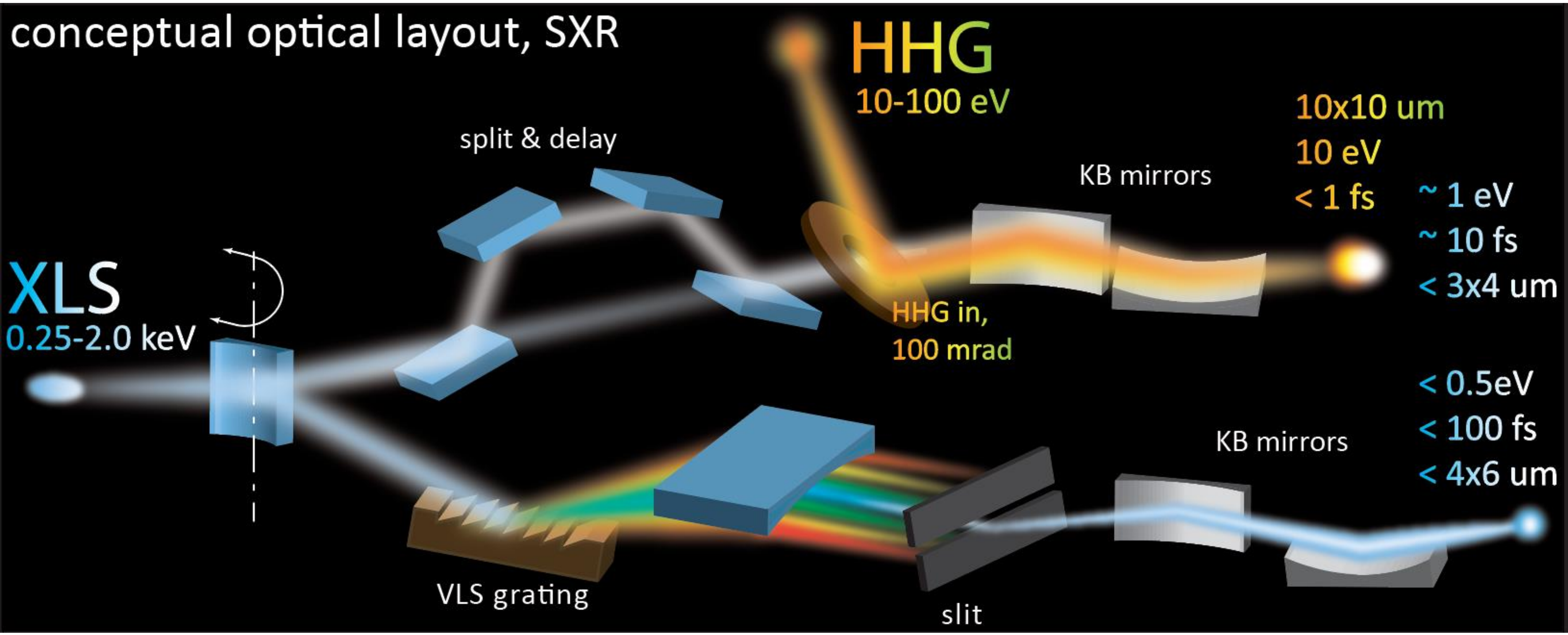
Photon beamline for CompactLight: v. 2.0

Vitaliy Goryashko, Peter Salen

CompactLight Meeting, November, 2020

Conceptual layout of beamline



Key parts of the beamline:

- Pink (microscopy) and monochromatic (spectroscopy) branches
- Focusing optics
- Monochromator (only for mono branch)
- Split & delay unit
- External lasers for pump-probe experiments

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Naming convention

$$B_{1,S,p}$$

Regime of operation:

- m – monochromatic
- p – pink

No. of FEL beamline:

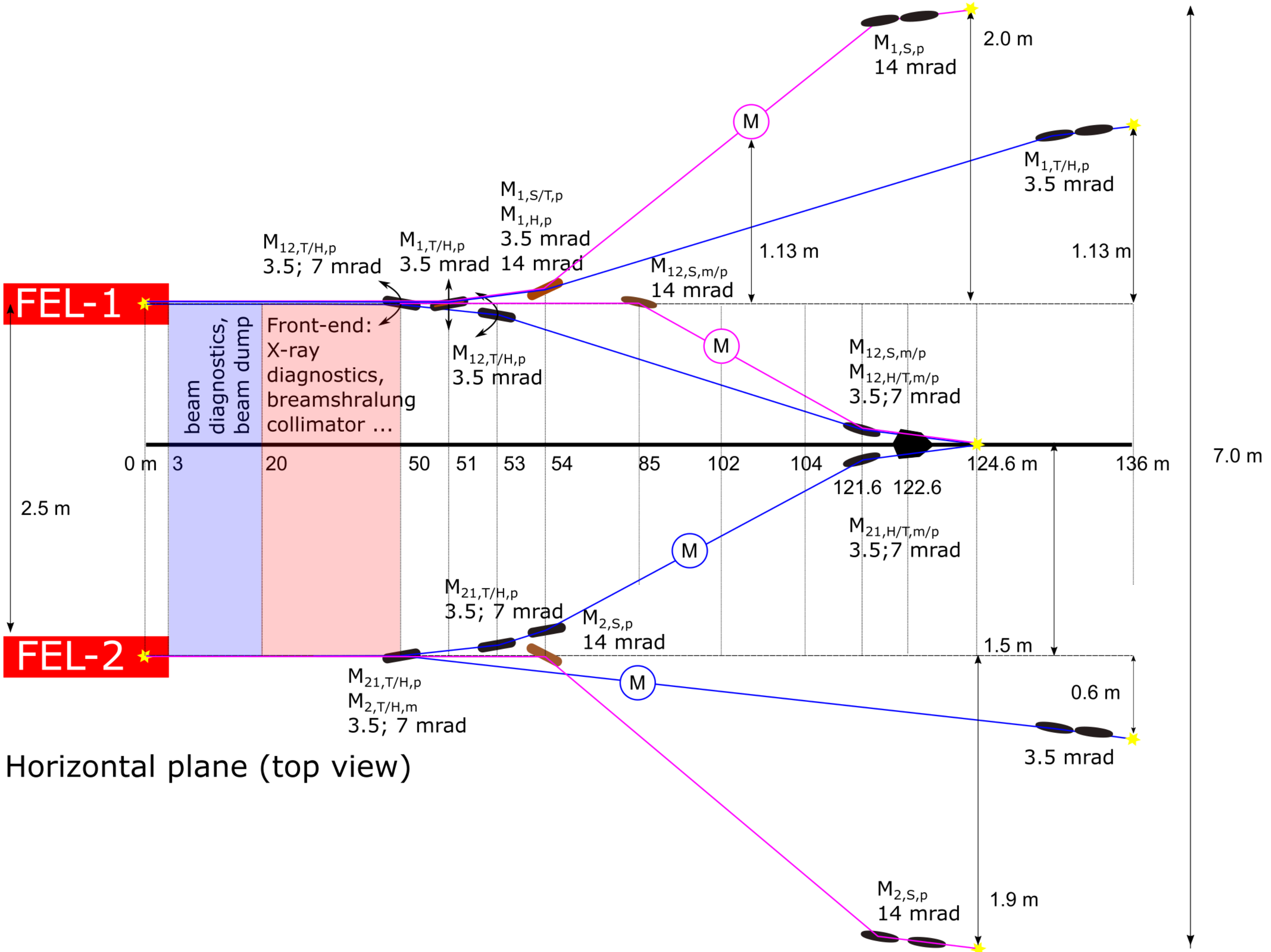
- 1 – for FEL 1
- 2 – for FEL 2
- 12 – for FEL 1 pump/FEL 2 probe
- 21 – for FEL 2 pump/FEL 1 probe

X-ray range:

- S – soft: 0.25 – 2 keV
- T – tender: 2 – 4 keV
- H – hard: 4 – 16 keV

- 24 possible name configurations
- Only half of names is used at the moment
- Beamlines with similar names share some optical components

2D beamline layout



Horizontal plane (top view)

Example of the performance of a pink branch

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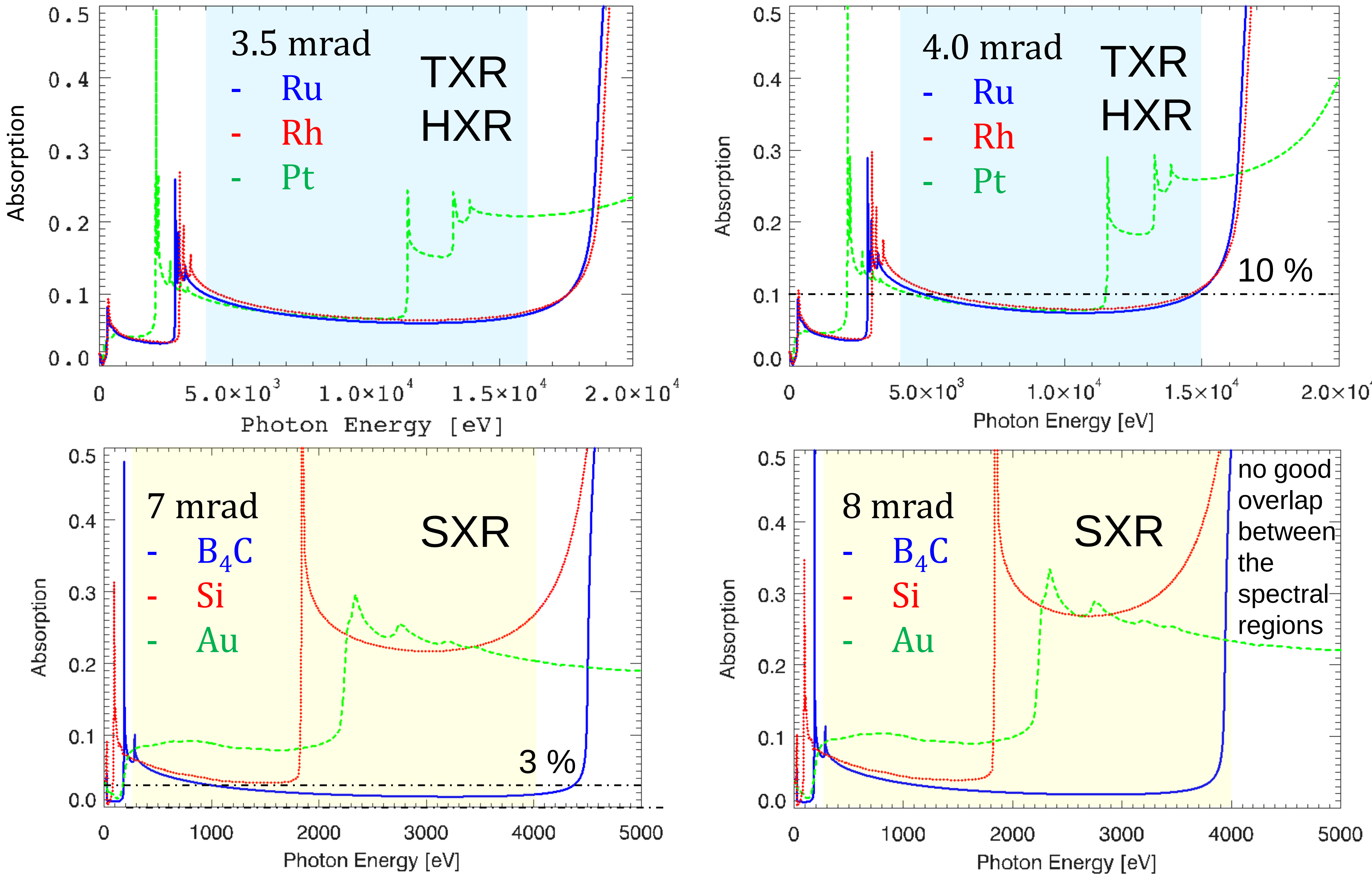
X-ray absorption of **pure** materials



Two types of coatings are needed: B_4C (0.25-4 keV) & Ru (4-16 keV).

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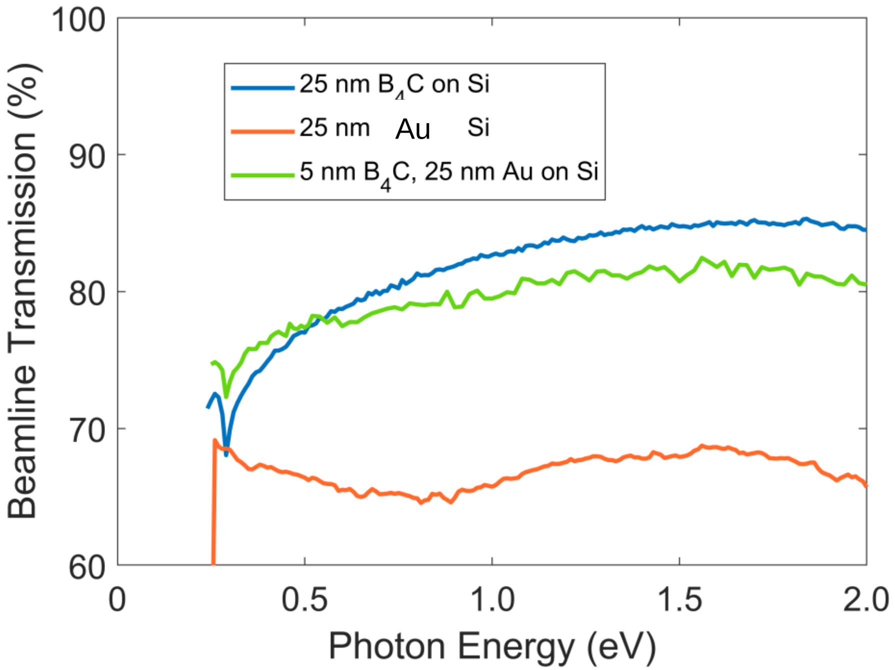
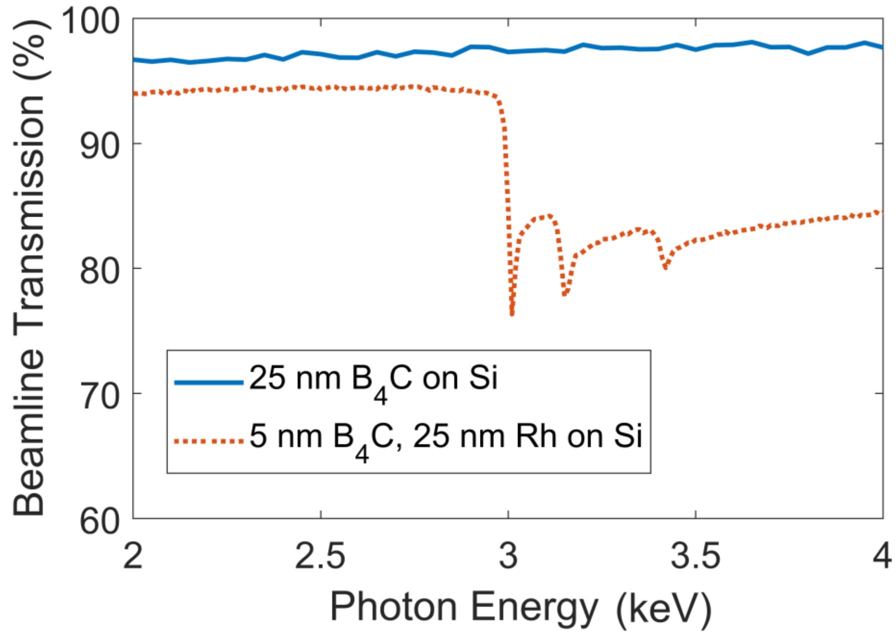
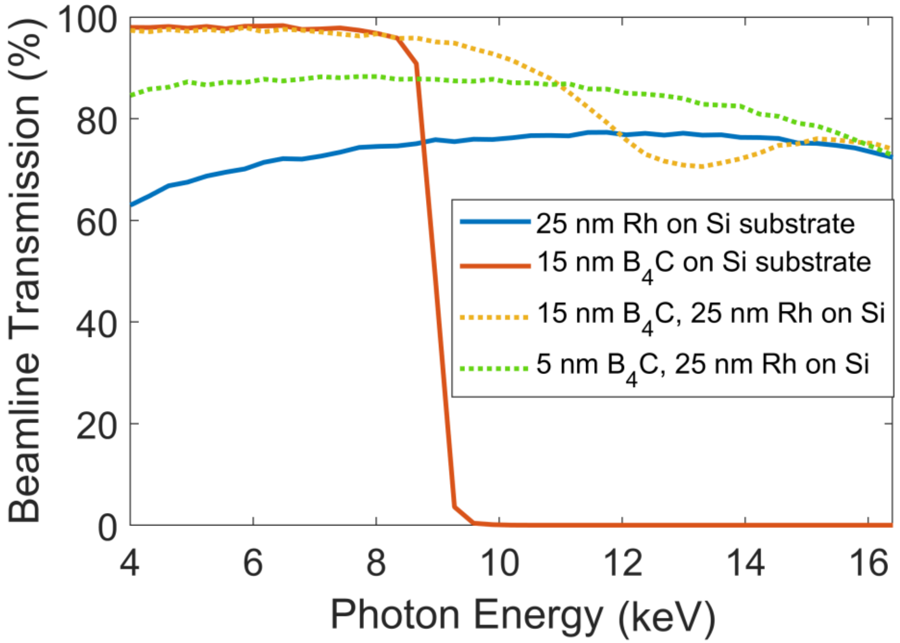
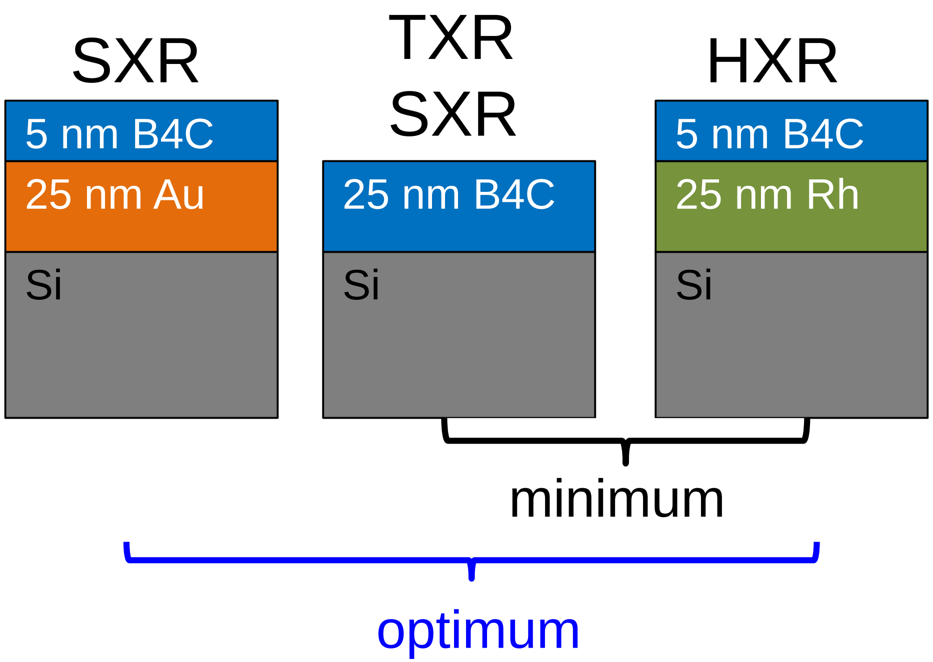
X-ray absorption of **coated** mirrors Compact

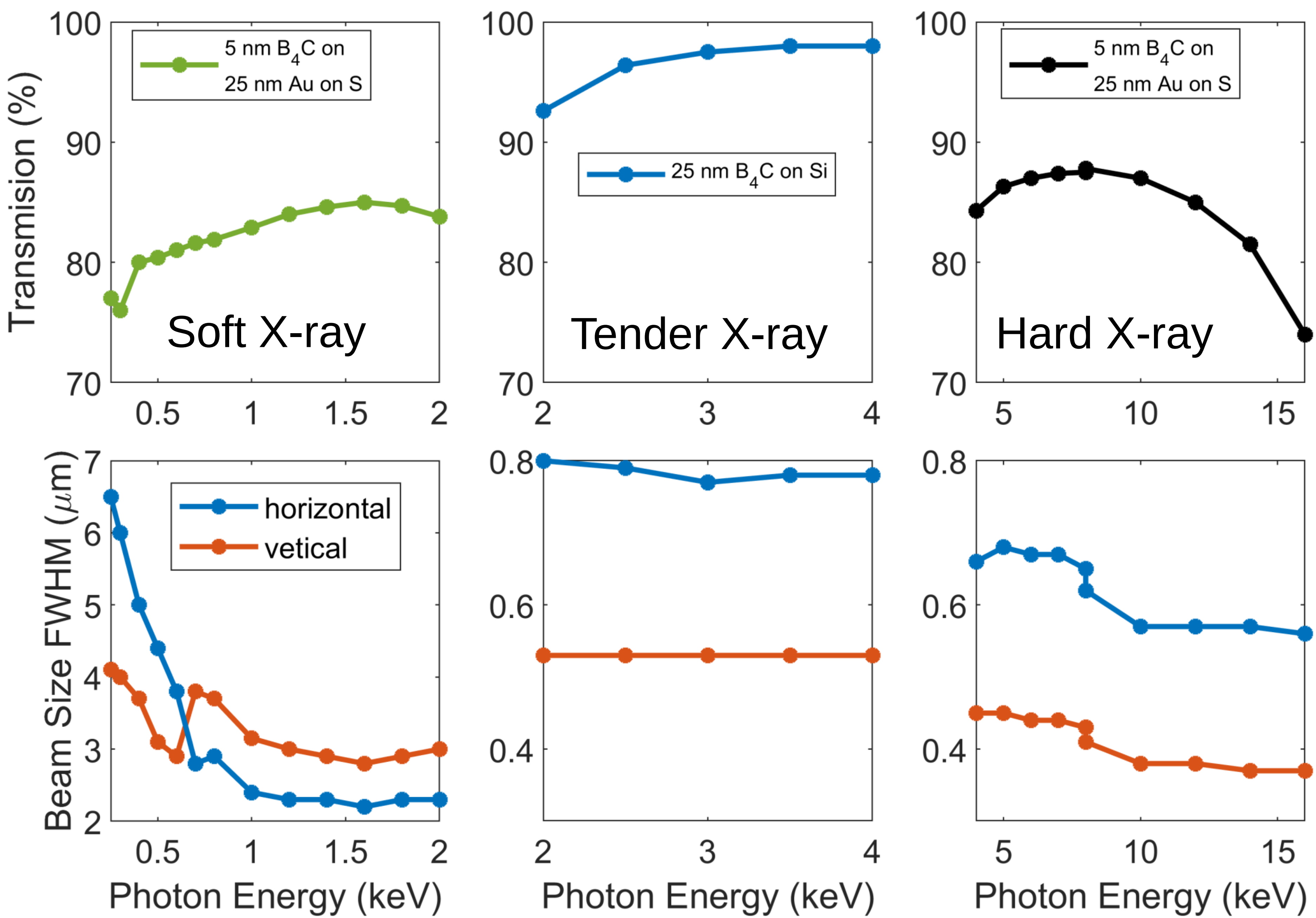








Pink beamline 1: summary



Example of the performance of a mono branch

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Grating type and mount

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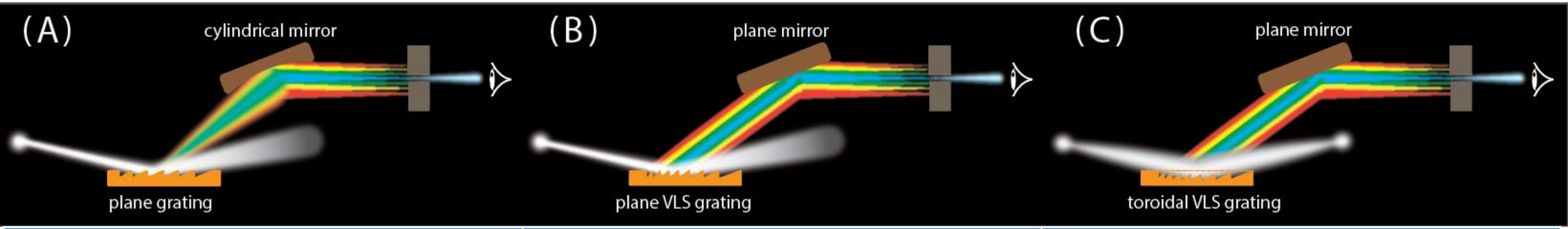
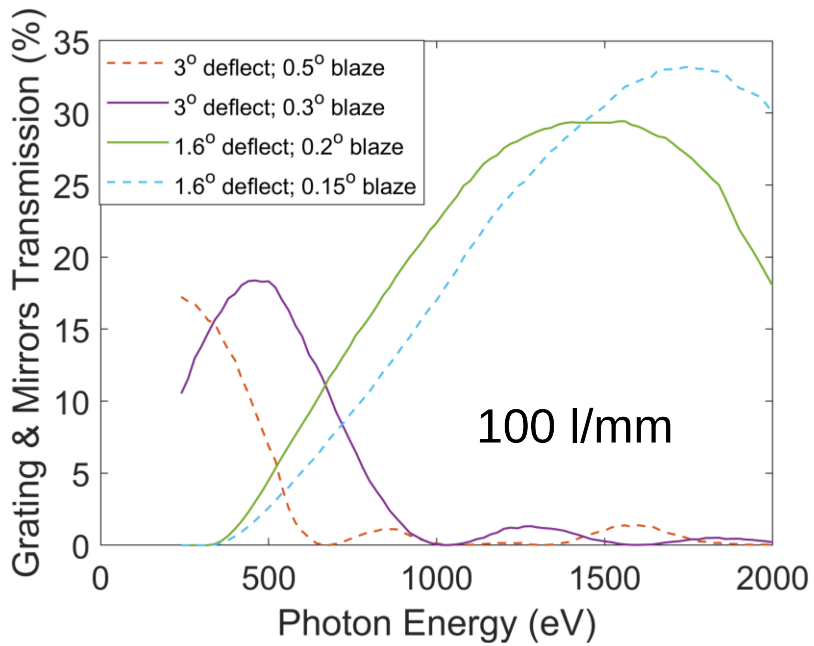
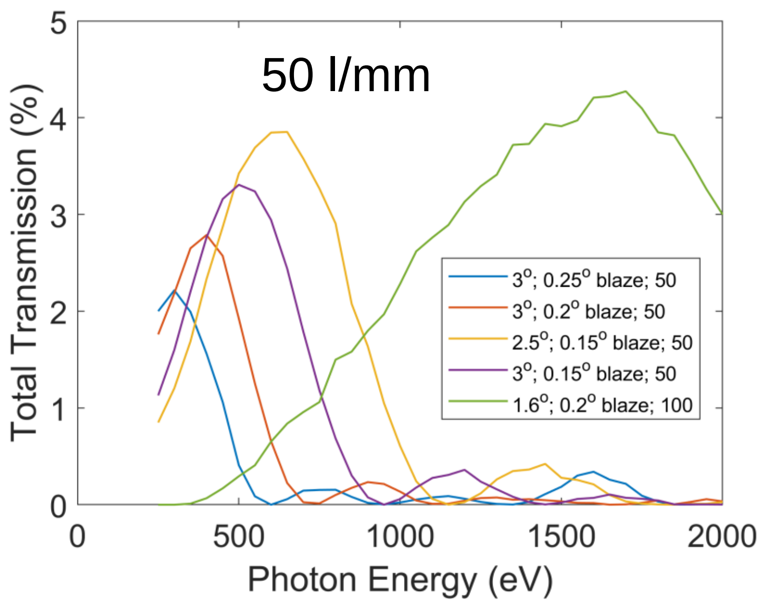
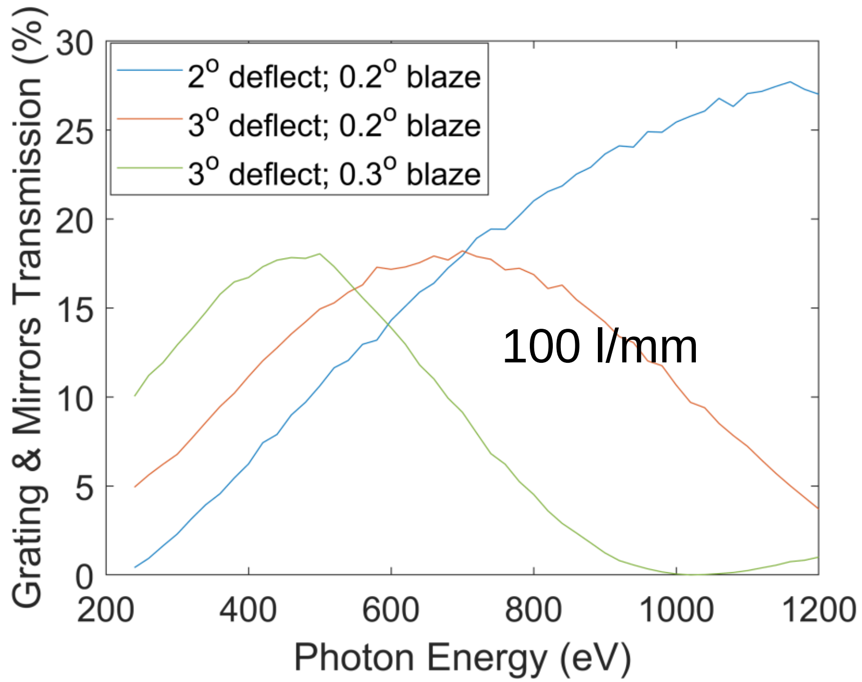


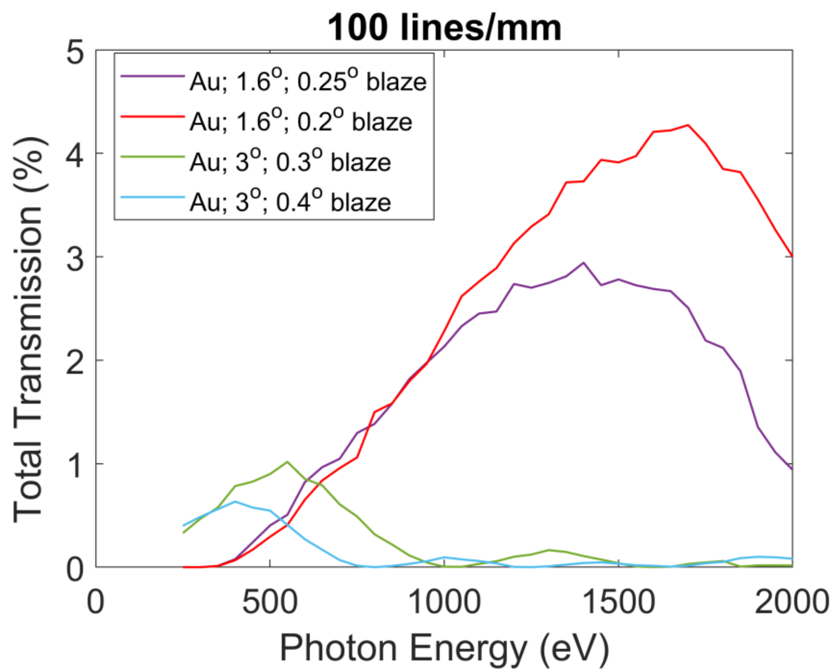
Regular plain grating + cylindrical mirror	VLS plain grating + plane mirror	VLS toroidal grating + plane mirror
Grating is used in the regime of a **constant-deviation mount**: $\theta_i + \theta_d = \text{const}$	Focusing is achieved via the **linear chirp** of the local grating period.	The focal length of the VLS toroidal grating can be made **wavelength independent**.
Energy scan is done by changing the yaw angle of the grating.	The focal length f of the VLS grating is **wavelength dependent**.	**Constant incidence angle** on the grating to keep f unchanged.
The **illuminated area** of the grating changes during an energy scan. **Varying energy resolution**.	The **incidence angle** on the grating must be **adjusted** for each wavelength to keep f unchanged.	**Constant illuminated area** of the grating, fixed geom. resolution. The **0^{th} order** is also **focused**.
Constant incidence angle on the focusing mirror.	**Varying incidence angle** on the focusing mirror.	**Varying incidence angle** on the focusing mirror.
The focal length of the system is **wavelength independent**.	**Operation** of the monochromator is **more difficult**: both of the angles (grating & mirror) must be tunes for each photon energy.	**Energy scan** is done by changing the yaw angle of the mirror.
Simplest operation		**Operation is more difficult** for a wide photon energy range

Mono SXR grating: 0.25-2 keV

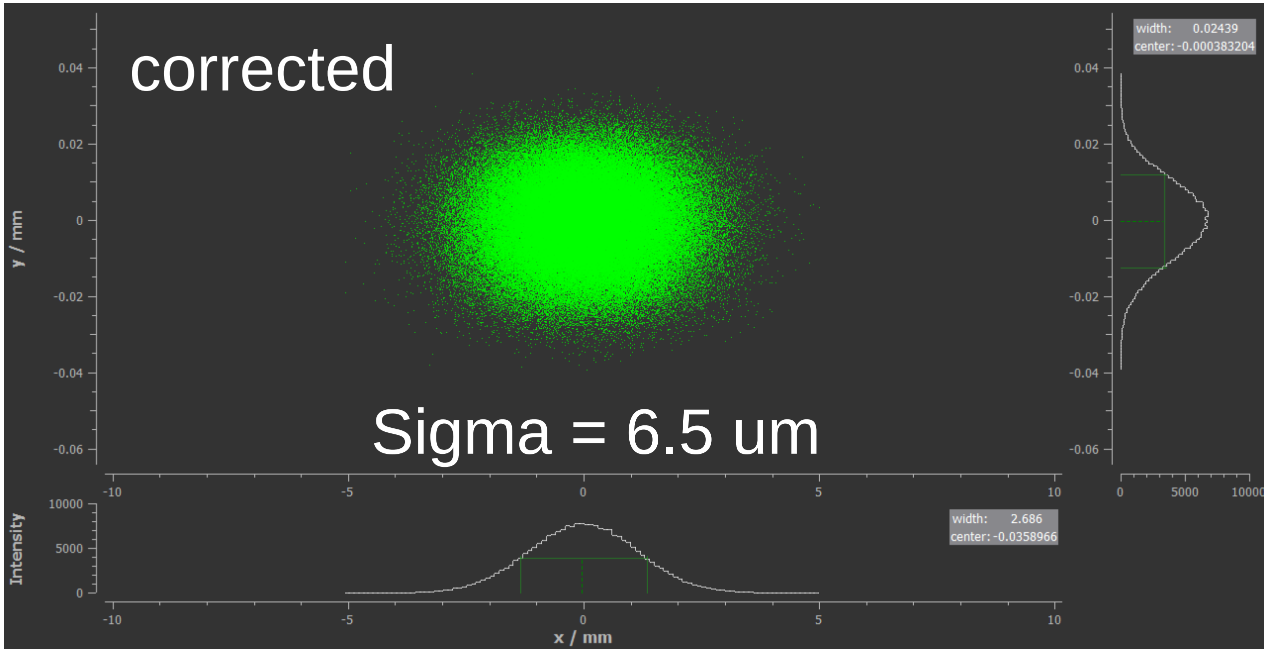


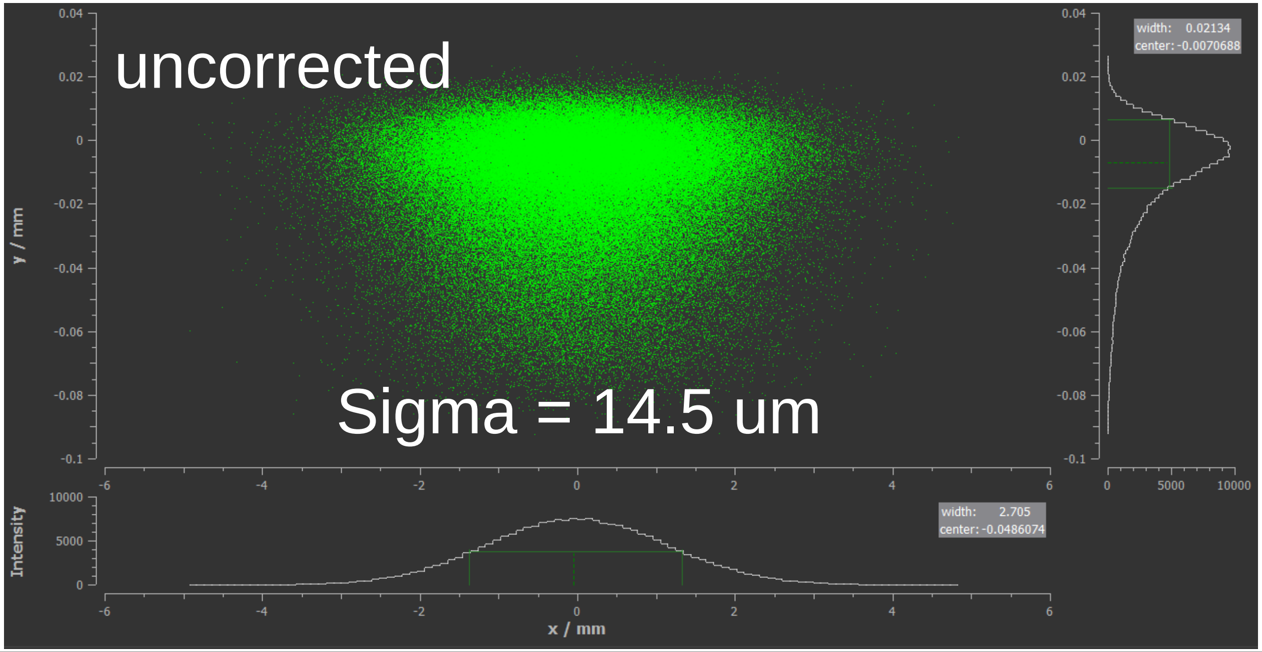




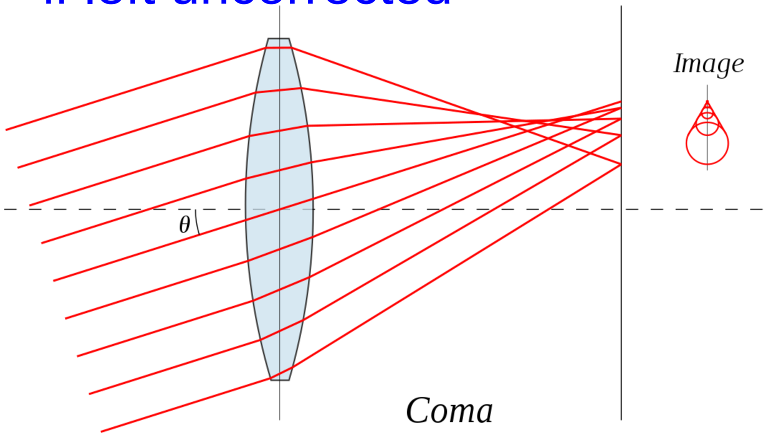


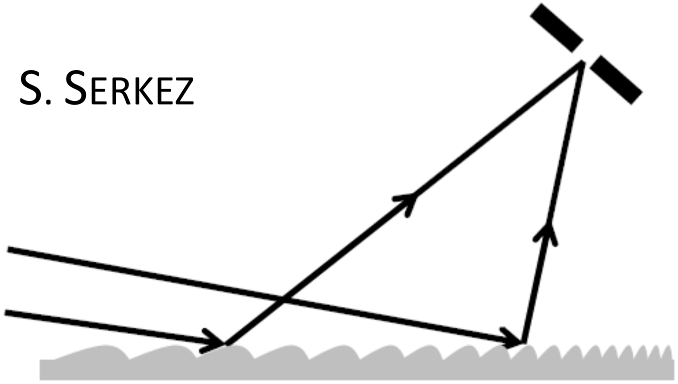
Coma aberration of the grating





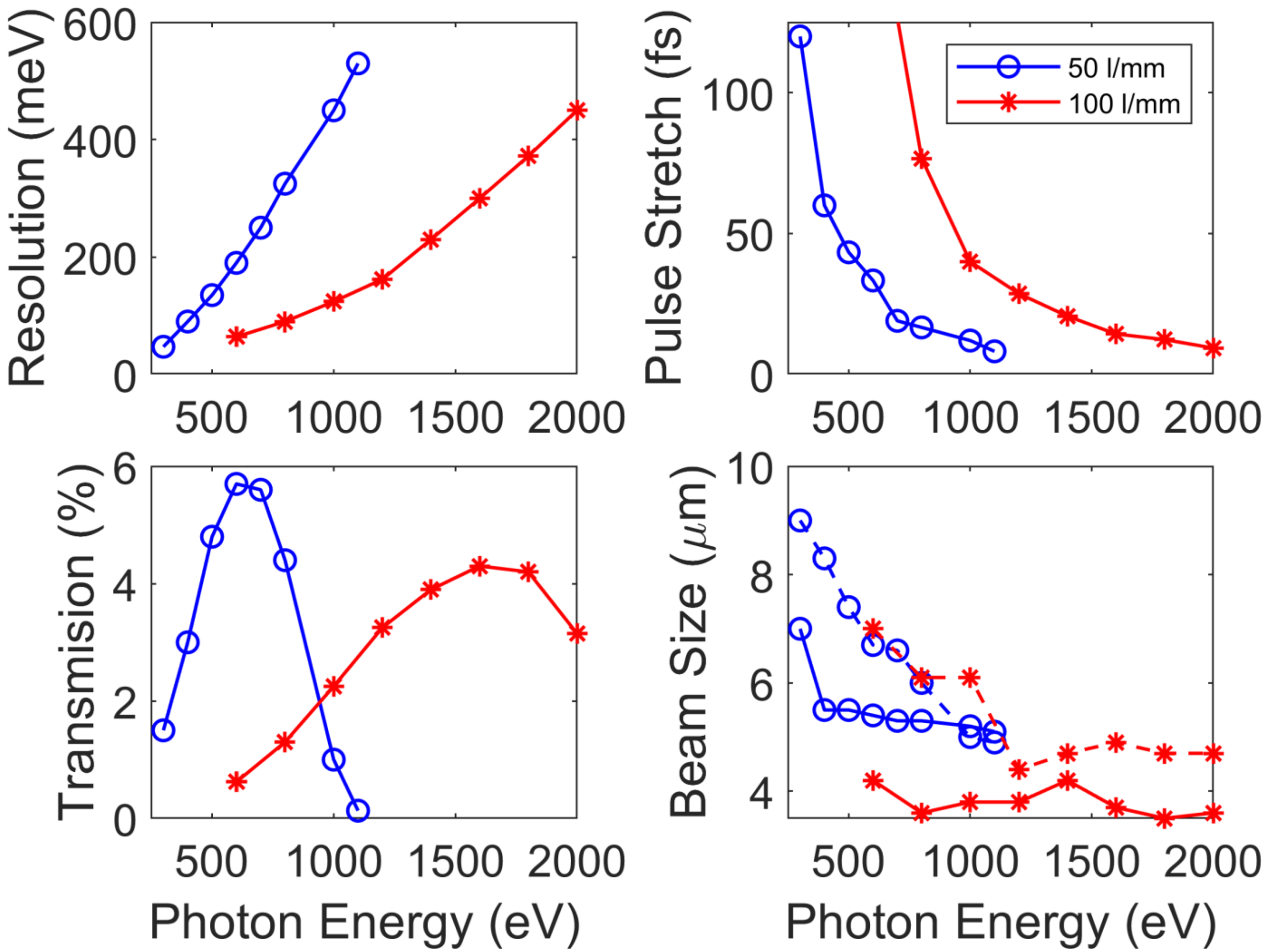
Results in coma aberration if left uncorrected





Coma aberration can be compensated for with a VLS grating

Mono SXR 1: summary



Grating 1:

- 50 l/mm
- Deflection 2.5°
- Blaze 0.15°

Grating 2:

- 100 l/mm
- Deflection 1.6°
- Blaze 0.2°

- Two gratings (50 and 100 l/mm) cover the whole SXR region with high transmission
- Balance btw the photon energy resolution and pulse stretching
- Sub 500-meV energy resolution and sub 100-fs temporal resolution
- Grating performance is aberration corrected for sub 5-um FWHM focusing

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Overview of beamline performance

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Summary of performance

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X-ray range	Mode of operation	Beamline	Type of coating	transmission* (%)	Photon energy resolution (meV)	Pulse stretch (fs)	Beam size (um)
Soft: 0.25-2 keV	Pink	B1,S,p	5 nm B4C, 25 nm Au on Si	75-85	-	-	6.5-2; 4-3
	Mono, grating	B1, S,m	5 nm B4C, 25 nm Au on Si + 25 nm Au** on Si	1-6	40-400	100-10	9-4.5; 7-4
Tender: 2-4 keV	Pink	B1,T,p	25 nm B4C on a Si substrate	90-98	-	-	0.8; 0.5
	Mono, DCM	B1,T,m					
Hard: 4-16 keV	Pink	B1,H,p	5 nm B4C on 25 nm Rh on a Si substrate	85-75%	-	-	0.7-0.6; 0.45-0.35
	Mono, DCM	B1,H,m					
…							

Time diagnostics

Target XLS parameters

XLS Deliverable D2.1

WP2: FEL Science Requirements and Facility Design

Prepared by: Alan Mak, Peter Salén, Vitaliy Goryashko and Jim Clarke

Prepared on: 20-12-2018

We need to measure fs pulse durations and fs two-pulse delays!

Table 1: Main parameters of the CompactLight FEL.

Parameter	Unit	Soft-x-ray FEL	Hard-x-ray FEL
Photon energy	keV	0.25 – 2.0	2.0 – 16.0
Wavelength	nm	5.0 – 0.6	0.6 – 0.08
Repetition rate	Hz	1000	100
Pulse duration	fs	0.1 – 50	1 – 50
Polarization		Variable, selectable	Variable, selectable
Two-pulse delay	fs	±100	±100
Two-colour separation	%	20	10
Synchronization	fs	<10	<10

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X-ray pulse characterization

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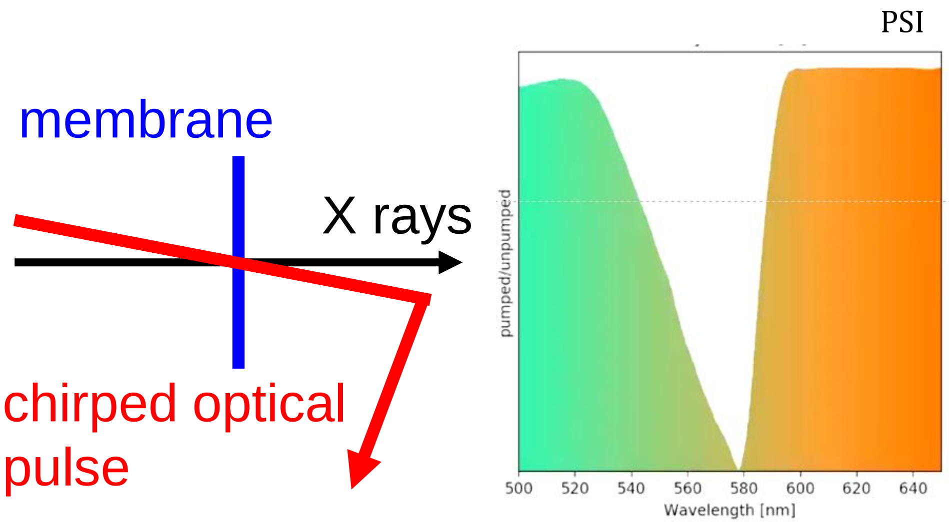
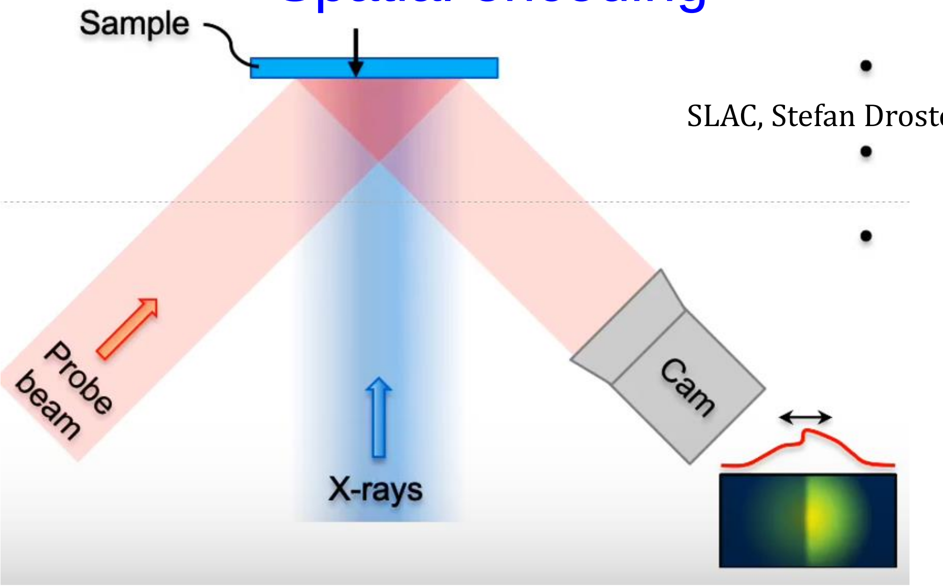
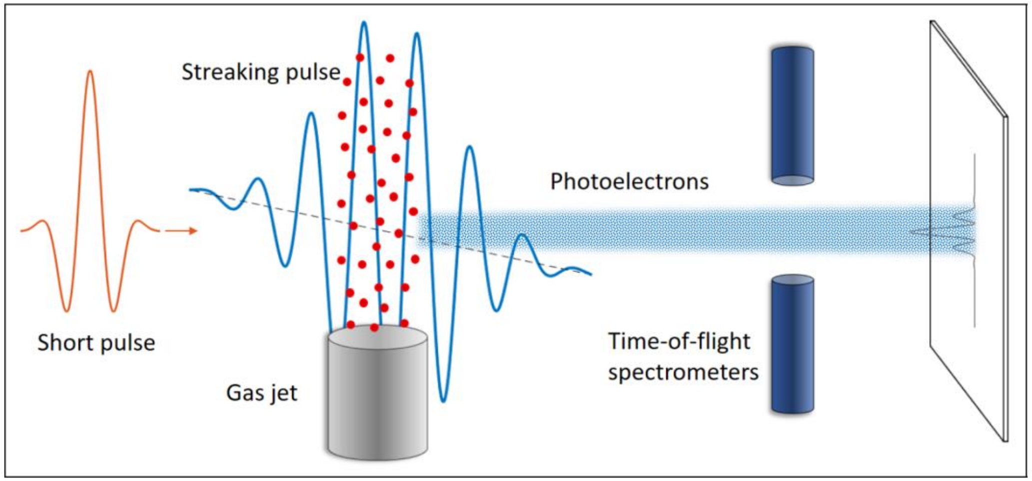
Spectral encoding



Spatial encoding

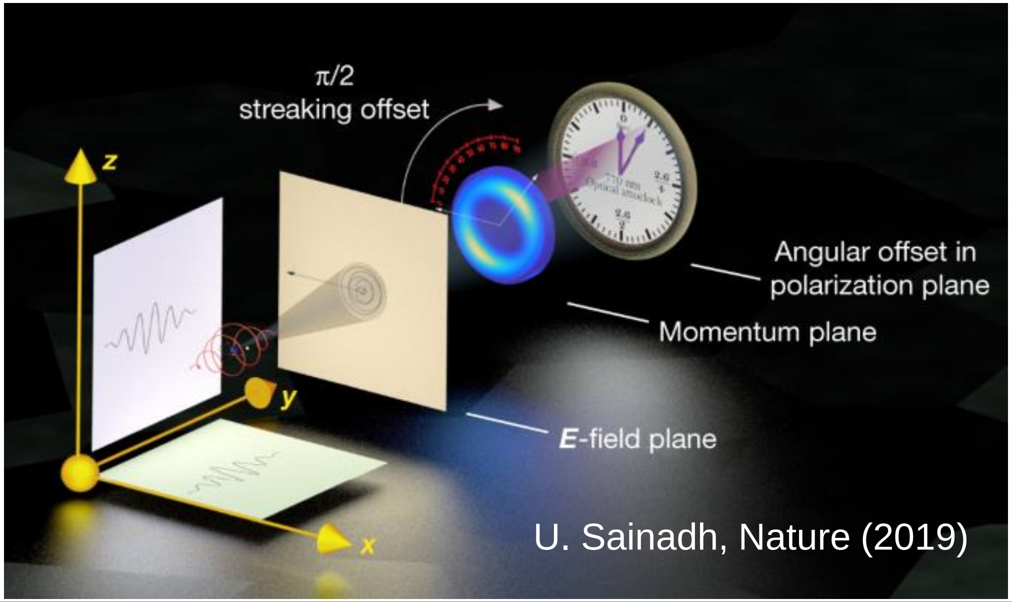


Linear THz streaking



UU, G. Shamuilov

Angular IR streaking



Comparison of methods

Method	Arrival time, accuracy (fs)	Pulse duration, resolution (fs)	Measurement interval (ps)	Double FEL pulses, accuracy (fs)
Spatial encoding	1.5	no	2	no
Spectral encoding	4.5	no	3	no
Spectrogram	< 1	no	~4	no
THz streaking	~10	~10 fs	0.5	25
mid-IR streaking	~1	0.25 (0.1 for double pulses)	0.34	1
VMI streaking*	N/A	~ 0.1	?	?

- Mid-IR angular streaking is a very complicated technique
- But only mid-IR angular streaking measurement capabilities comply with all the XLS science requirements
- In the baseline design, we could start with THz streaking that is simpler.

* works well only for pulse energies > 100 uJ in SXR. Not tested for HXR

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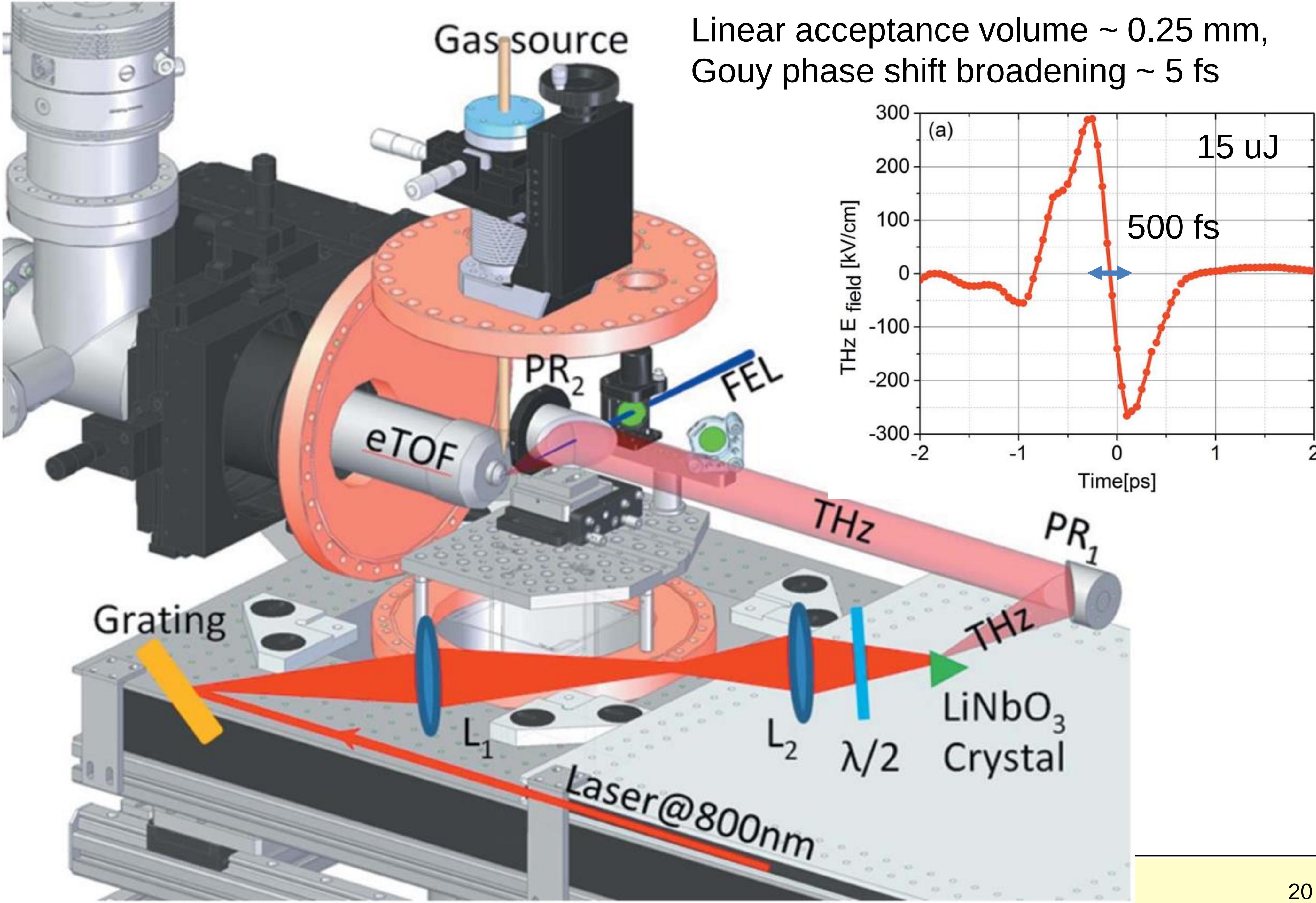
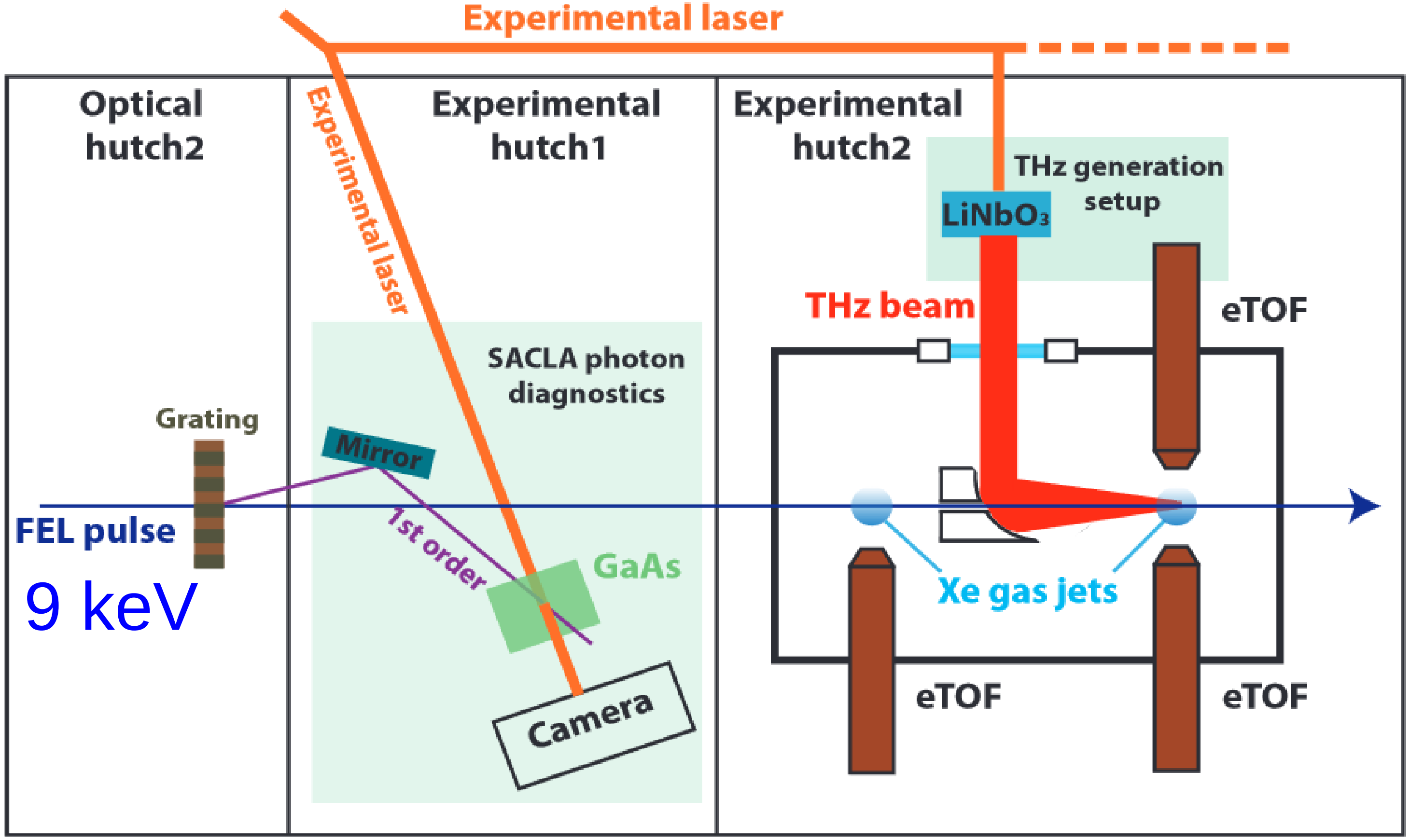
THz streaking at FLASH (2018)

Linear acceptance volume ~ 0.25 mm,
Gouy phase shift broadening ~ 5 fs



THz streaking at SACLA (2017) Compact



Optics Express 3 (2017)
http://dx.doi.org/10.1364/OE.25.002080

- pumping laser pulse energy ~ 10 mJ
- single-cycle THz pulse ~ 1.7 ps (frequency of 0.6 THz)
- THz field amplitude 8 MV/m, linear part of THz pulse ~500 fs
- accuracy of the THz streaking arrival monitor is 15 fs (limited by THz strength)
- delay between FEL pulses with an accuracy of 25 fs

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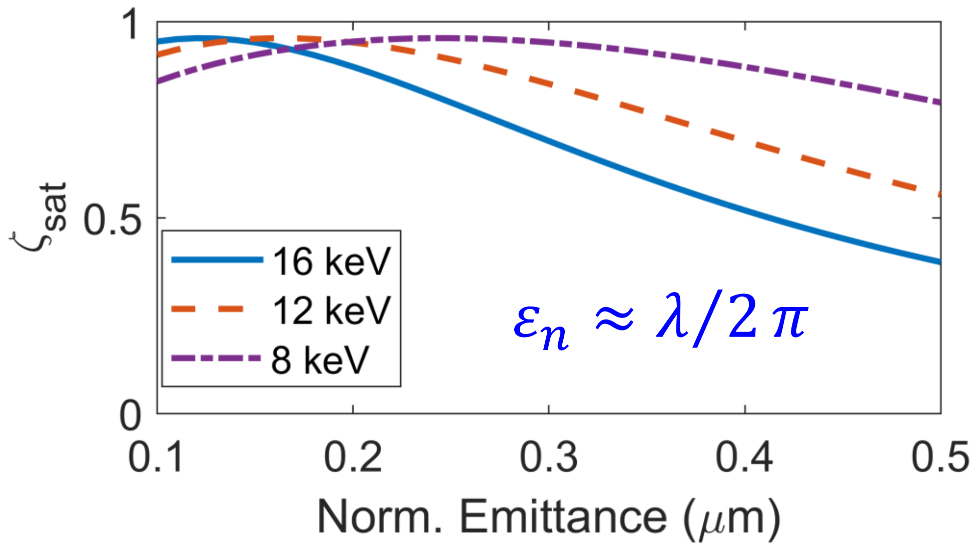
Operation at higher bunch charges

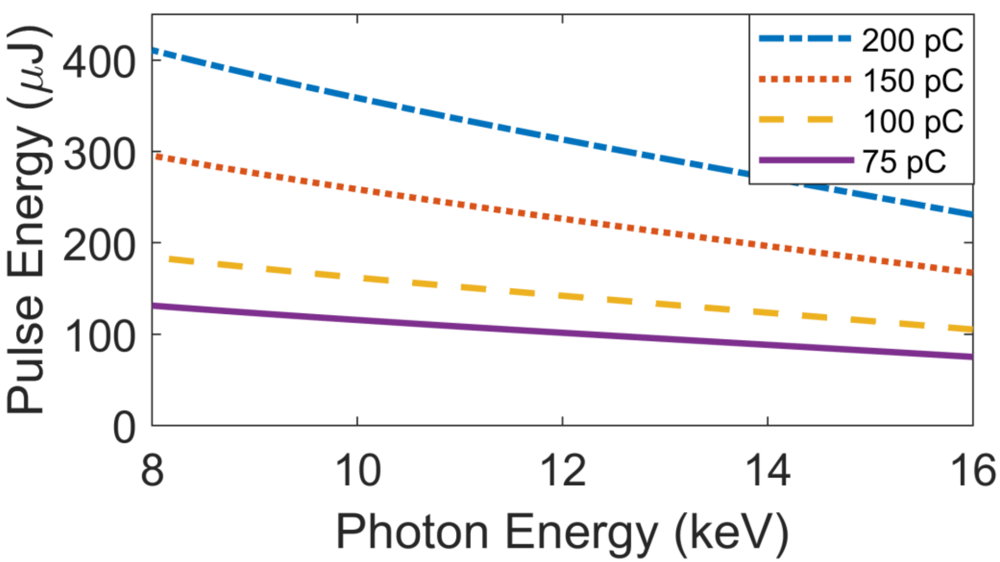
Operation at higher bunch charges

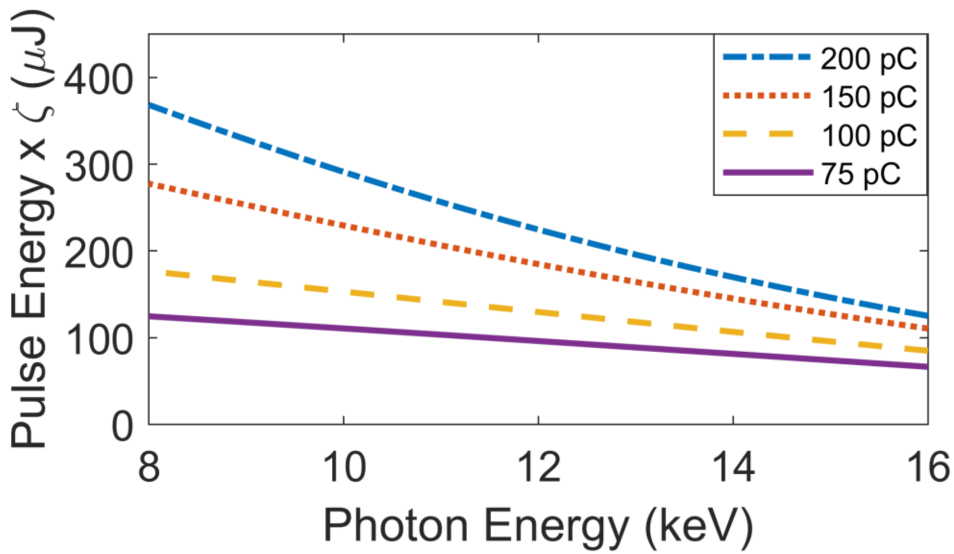


E.L. Saldin et al. "*Statistical and coherence properties of radiation from x-ray free-electron lasers*." **New Journal of Physics** 12 (2010): 035010.

$$\mathcal{E}_{\mathrm{FEL}}^{\mathrm{coherent}} \propto Q_b^{4/3}\zeta_{\mathrm{sat}}$$

$$\zeta_{\mathrm{sat}} \approx 1 - 0.2\,(\epsilon - 1)^2, \epsilon = \frac{2\pi\varepsilon_n}{\lambda}$$





The **emitted coherent pulse energy doubles for 150 pC bunches** despite emittance degradation and some decline in the degree of transverse coherence.

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Further work

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- Optimize the performance of tender/hard mono beamlines
- Photon diagnostics
- More detailed technical layout

Thank you!

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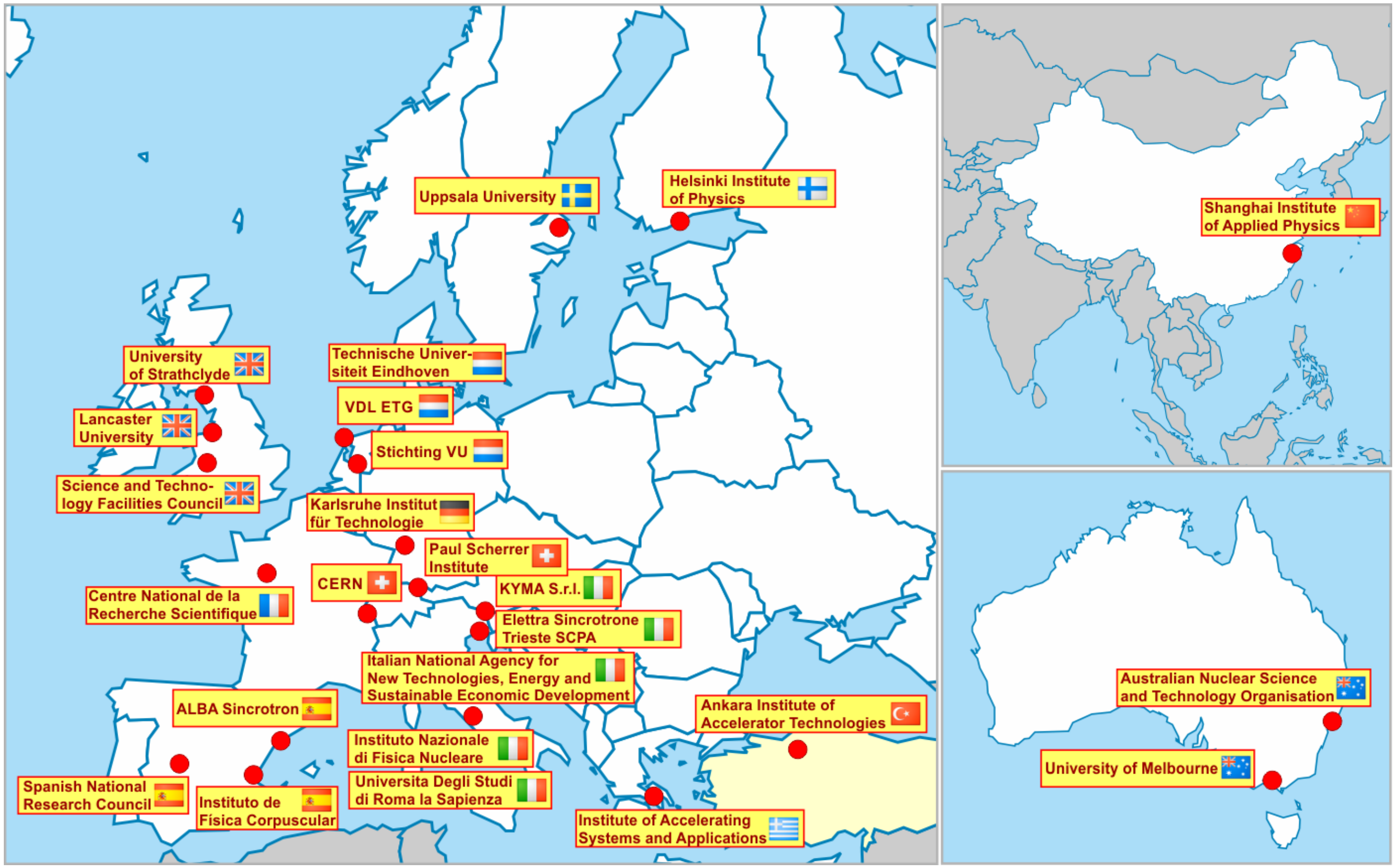

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