

Photon Optics

Designing Beamlines for NLS

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The Sources

	Range (eV)	Bandwidth	Output	Polarisation
FEL-I	50 - 250	~0.09 eV (transform limit) for 20 fs pulse in seeded operation (below ~400 eV).	~1E12 to ~1E11 photons per pulse with a pulse length of ~20 fs FWHM	HLP, VLP, CP
	150 - 900			HLP, VLP
	250 - 1500			
FEL-II	250 - 850	>>0.1 eV for SASE operation		HLP, VLP, CP
	750 - 2550			HLP, VLP
	1250 - 4250			
FEL-III	430 - 1000			HLP, CP, VLP+
	1290 - 3000			HLP, +VLP
	2150 - 5000			above ~n*520 eV

+ Coherent THz and IR



The Challenges

- Preserving the source properties
 - Transverse coherence
 - Pulse length
 - Polarisation
- Modifying the source properties
 - Combining and Splitting beams
 - Spectral filtering
 - Strong focusing
 - Attenuation
- Understanding the source properties
 - Diagnostics
- Making the beamline work
 - Preventing ablation
 - Making the optics



Experimental requirements

The science case is being actively refined. However:

- Spectroscopic techniques are a common requirement
 - = Wavelength tunability / selectability
- Need for high fields / photon densities
 - = Strong focusing
- Combined beam experiments
 - » FEL + laser
 - » FEL + IR/THz
 - » FEL + FEL
 - > Only possible by splitting the FEL pulse



Spectral questions

- Is the source bandwidth sufficiently small?
- Do we need to remove the higher harmonics?
- Do we need to remove the fundamental?
- Do we need the fundamental and the harmonics in the same beamline?
- Do we need to remove the SASE output from the seeded FELs?
- Do we need to remove the spontaneous background?



Time Preserving Monochromator

- To spectrally clean-up the pulse without stretching it (e.g. remove spontaneous background, SASE output from around the seeded pulse)
- Single grating designs
 - Limit pulse stretch by illuminating only a few grooves
- Double grating designs
 - Correct the stretch of one grating by reversing it with a second.
- In either case classical or conical diffraction mounts can be used.
- For a single grating design with pulses of ~ 20 fs, conical mount is probably the only satisfactory route to give negligible pulse stretch (esp. < 500 eV). Classical mount is viable for ~ 50 fs pulse
- For a double grating design, either mount can be used, though conical can give higher efficiency.
- Overall transport efficiency is the major concern with double grating designs



Flexible Spectroscopy Beamline

Time resolved XAS

Working on FEL-II and FEL-III

Mode 1 - Transmit the fundamental with harmonic filtering only (preserve pulse length and polarisation, high efficiency)

Mode 2 - High spectral resolving power in fundamental (pulse length not important, preserve polarisation)

Mode 3 - High spectral resolving power in harmonics (above 2000 eV, pulse length sub-ps)



Flexible Spectroscopy Beamline

Beamline Concept

Hybrid Grating and Crystal monochromator

- Gratings below 2000 eV and crystal above 2000 eV

Grating mechanism based on SX700 monochromator (mirror & grating working together to give a variable included angle)

- Gratings for high spectral resolving power (will stretch pulse to ps level due to OPD)
- Low line density gratings for spectral clean-up and limited pulse stretch (~50 to 100 fs)
- One grating slot occupied by a mirror to give a variable-angle reflection harmonic filter (~1° to 10°) (Pt and Ni coatings)

Double crystal mechanism

- Si(111) crystal (80° Bragg angle to reach 2000 eV)
- Gas filter to remove fundamental (prevent damage to crystals)
- Resolution and pulse length determined by crystal bandwidth



Flexible Spectroscopy Beamline

Beamline Concept - The Issues

- Need to limit common mirrors to very grazing angles ($\sim 0.5^\circ$) to pass 5 keV so design is very constrained.
- Both grating and crystal monos give an OPD as the wavelength is changed (i.e. wavelength dependent pulse delay)
- Need many gratings to cover 250 to 2000 eV with different modes
- Reflection harmonic-filter needs at least two coatings
- Crystal monos are not usually UHV - risk of carbon contamination of gratings working over carbon edge
- Passing harmonics through mirror filter limited by minimum practical angle of $\sim 1^\circ$ (passes up to ~ 3 keV)
- Achieving flexibility means complicated design and compromises in performance - is this the best approach?



High Field Beamline

**Ultrafast Electron Dynamics and AMO Science
Working on FEL-I and FEL-II (seeded)**

Mode 1 - Highly demagnified beam to get the highest possible photon density at the sample (pulse length $< \sim 20$ fs, high degree of linear or circular polarisation, circular spot, attenuation from 1:1 to 1:1000)

Mode 2 - Focus spot of 10 to 20 μm to match with other colours for pump-probe (ditto)



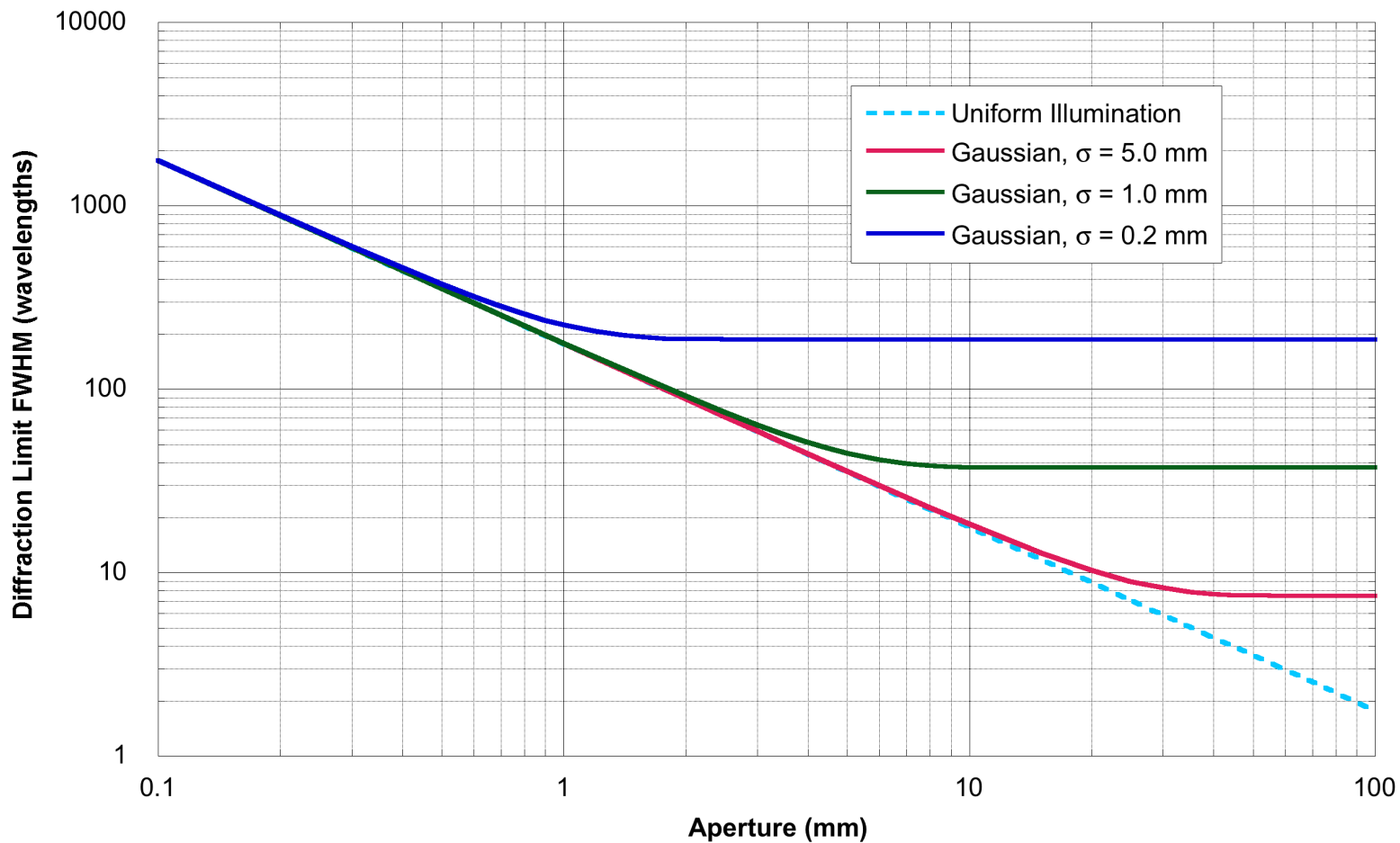
High Field Beamline

Strong focusing Issues

- Two basic focusing schemes in this spectral range *viz* a single asphere or a compound Kirkpatrick-Baez system
- Need a high numerical aperture to get the focus spot size as near to the wavelength as possible
 - Easier with a single asphere than a K-B type system
- Need highly perfect optics to limit slope error blurring of spot
 - Easier with a K-B system than with an asphere
- Circular spot
 - Not possible with K-B unless the source is not circular
- Need to model with wavefront propagation to ensure the coherent nature of the source is correctly modeled (use Daresbury FOCUS code, which includes slope error effects)



Diffraction Limit for Gaussian Beams



High Field Beamline

Beamline Concept

- No monochromator
- Minimise the number of optical components for optimum efficiency
- Wavelength scanning by tuning the FEL
- An interchangeable system of a single ellipsoidal mirror and a K-B pair of bendable elliptical mirrors OR two ellipsoidal mirrors with different demagnifications
- A gas attenuator to reduce the intensity as required



High Field Beamline

Beamline Concept - The Issues

- A single ellipsoid of sufficient quality will be rather small, will need to work at a large grazing angle and so will only work at relatively long wavelengths due to reflectivity (e.g. at 15° limit is ~ 100 eV)
- Cannot vary the demagnification with the ellipsoid (increasing spot size by moving off-focus usually gives poor results)
- Varying demagnification is possible with a bendable K-B pair but will require a moving experiment.
- The K-B system will not give as high overall demagnification as one direction must always be less than the orthogonal direction
- Switching between systems will give a mismatch in beam deflections



Summary

- The nature of the source will place great demands on the beamline design to realise its full potential
- The beamline design will depend very strongly on the nature of the source (e.g. seeded or SASE output)
- Each experiment will place its own unique demands on the beamline specification
- The beamlines need to be designed in close consultation with the experimenters to ensure that beamline suite matches their requirements as closely as possible
- We are only at the beginning of this process

