



# NLS Beamlines

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8 Sept 2009



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# ODR Beamlines

- FEL-1 (50 - 300 eV, fundamental only)
  - Direct beamline
  - Pulse length preserving (PLP) mono
  - High spectral resolving power (HSRP) mono
- FEL-2 (250 - 850 eV, 850 - 2000 eV)
  - Direct beamline
  - Multi-function grating mono (PLP & HSRP)
- FEL-3 (430 - 1000 eV, 2000 - 3000 eV, 3000 - 5000 eV)
  - Direct beamline
  - Multi-function grating mono (PLP & HSRP) <1000 eV
  - Crystal mono ~2000 to 5000 eV



# ODR Reasoning

To provide a suite of beamlines that covers a wide range of spectral ranges and photon conditioning options whilst minimizing the total number of beamlines

- Reduce cost
- Leave floor space for future developments

These are suggestions based on what is practical from a technological point of view

**A better match to science needs is required**

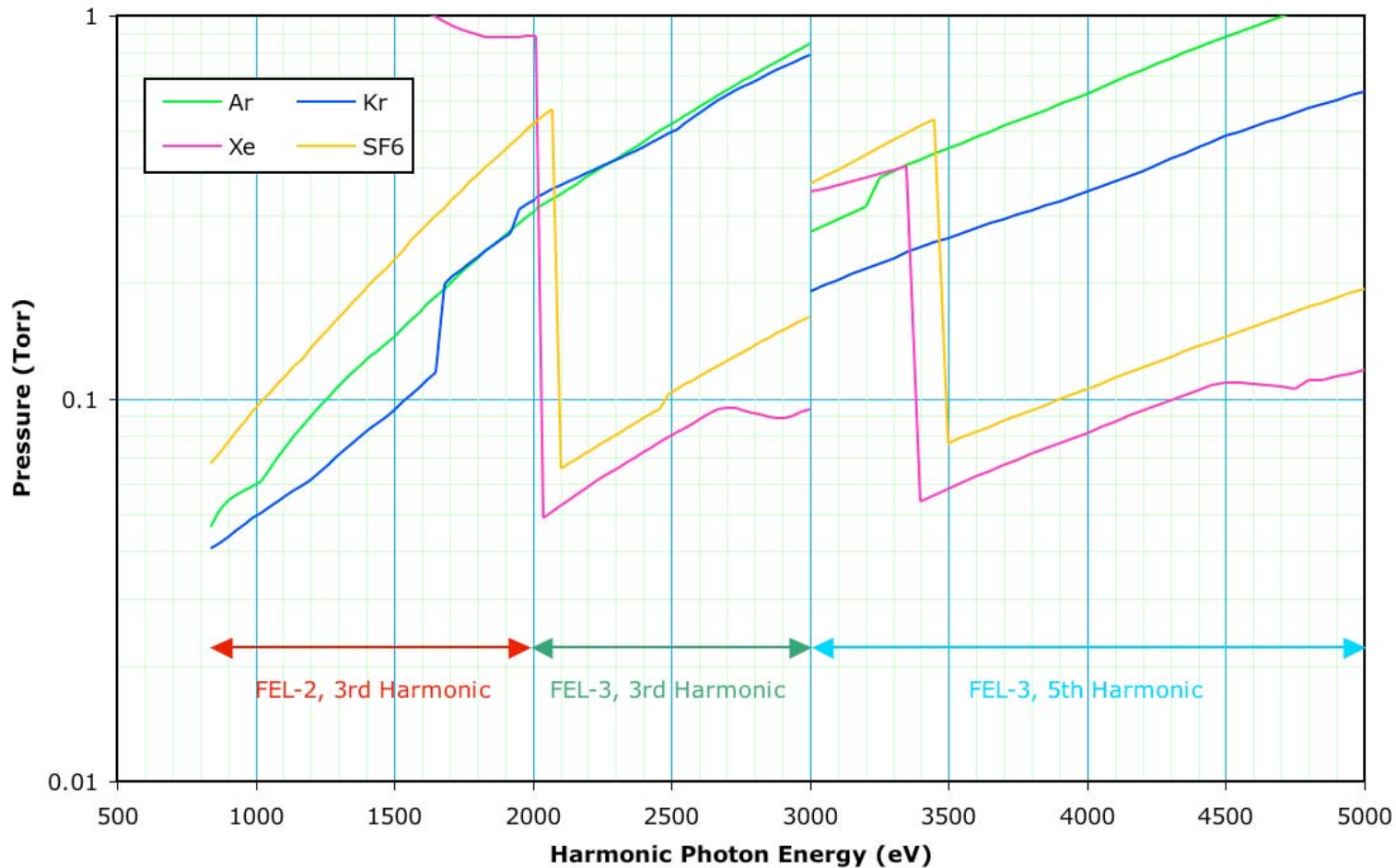
These slides should give you an idea as to what can be achieved. Your input is required to define the most important design goals



# Using the Harmonics

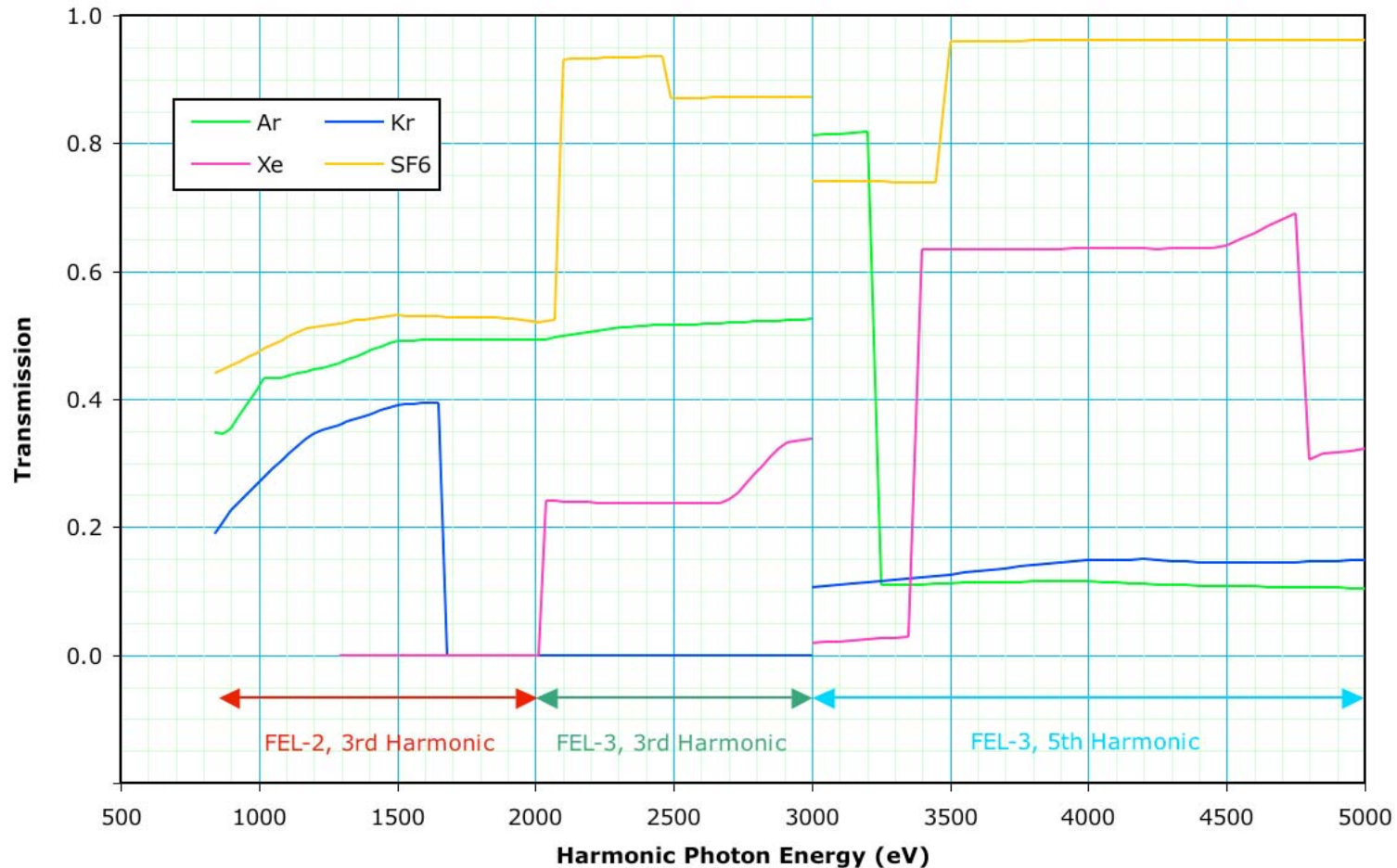
- To use the harmonics, it is **assumed** that it will be necessary to suppress the fundamental to a small fraction of the harmonic intensity (e.g. ~1% or below)
  - **IS THIS CORRECT??**
- Fundamental suppression to this level is not, I believe, practical with the gas attenuators - because the 3rd and 5th harmonics intensities are <1% and <0.02% of the fundamental intensity
- Therefore, a monochromator must be used if the fundamental is to be so strongly suppressed

# Gas cell pressure to attenuate fundamental to 1% of harmonic intensity



20 m gas cell

# Gas cell transmission after attenuating fundamental to 1% of harmonic intensity



20 m gas cell

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# Direct Beamlines

- Minimise the number of optics to give high highest possible transport efficiency
- No spectral filtering (other than mirror cut-off and harmonic suppression from the gas attenuator)
- Preserve pulse length and wavefront
- Flexible end-station optics, e.g.
  - High demagnification for non-linear studies
  - Beam splitter/combiner for x-ray pulse-probe
- Combine with THz
- Combine with conventional lasers

# Crystal monochromator

- Required when working in the harmonics to suppress the fundamental
- Likely Si(111) due to need for highly perfect crystals
  - Lowest energy limited to ~2000 eV
- Double crystal design for fixed output beam position
- Very high efficiency in linear polarisation for 20 fsec transform limited pulse
  - Pulse BW is narrower than rocking curve width
- But strong polarising effect near Brewster angle (~2300 - 3450 eV)
  - This is hard to avoid
  - Remember also that a high degree of CP is hard to generate in the harmonics in the first place
- Some pulse stretch is also unavoidable
  - ~1.5 fsec per crystal



# Grating monochromators

- Reasons for using a grating monochromator are:
  - Improving the spectral resolving power
  - Removing the fundamental when operating on the harmonics
  - Spectrally isolating the seeded part of the pulse from the SASE background
  - Define the wavelength that reaches the sample

**Which of these are required?**

- Spectral filtering comes at a cost
  - Reduced transport efficiency
  - Pulse stretch

# Gratings and short pulses

A diffraction grating works because it adds one wavelength of optical path difference (times the diffraction order) per illuminated groove.

A consequence of this is that the pulse after the grating is longitudinally tilted and so effectively stretched in time.

The time stretch is much worse at longer wavelengths (greater OPD per groove and, in general, greater illuminated footprint)



# Pulse Length Issues - 1

If the pulse needs to be spectrally filtered (to the transform limit) but the pulse length kept at 20 fs FWHM, then a monochromator using **two gratings** will be needed. This will be **inefficient** ( $< \sim 1\%$ ) and **inflexible**.

If some pulse stretch can be tolerated, then a single grating can be used and it should be possible to give the option for the same beamline to work in high spectral resolving power. This option will be more efficient ( $> \sim 10\%$ ) and more flexible.

The approach in the ODR was the latter, except for FEL-1 where the multifunction mono is (probably) impossible



# Pulse Length Issues - 2

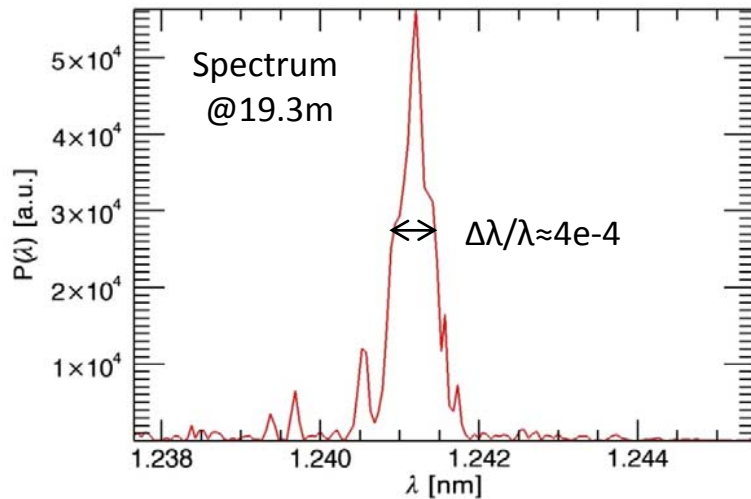
When working on the harmonics, the situation is easier. It is possible to give a small (<50%) pulse stretch whilst also allowing the same mono & beamline to work over the fundamental with high spectral resolving power.

But if the pulse length must be kept at 20 fs, then two gratings will still be needed. In the harmonic photon energy range, this will be **very** inefficient (<<1%).

Do we need to spectrally filter the FEL pulse to the transform limited bandwidth?



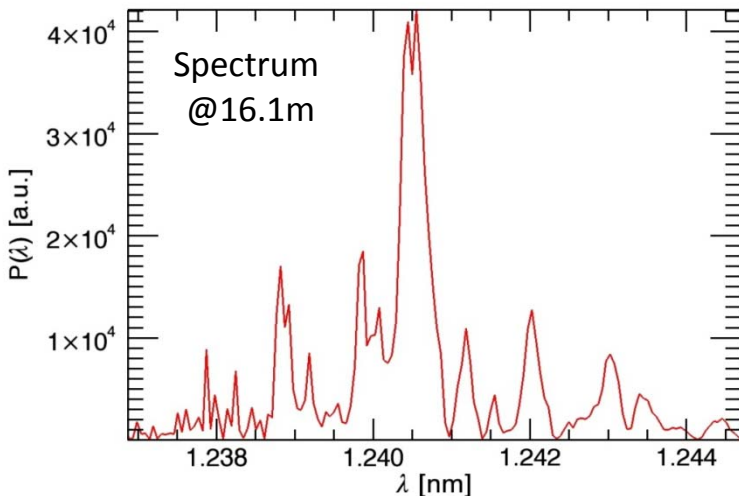
# Simulated FEL output



The upper graph shows the simulated output of FEL-3 at 1000 eV when the electron bunch is smoothed with a laser heater. Spectrally, the pulse is quite clean (though 0.4 eV FWHM), but there are some wavelength components outside the main peak.

**Do we need to remove these?**

The lower graph is the same electron bunch but without the smoothing. This is a much “richer” spectrum. NLS output should be more like the upper graph.



# Pulse Length Questions

1. If a mono has to be used whilst still giving short pulses, what is the maximum allowable pulse length?
2. Is it better to sacrifice efficiency to keep the pulses as short as possible (or vice versa)?
3. Is the ability to switch between pulse preserving and high spectral resolving power operation in the same beamline useful?

# Need for high spectral RP - 1

Is there a need for spectral resolving power higher than that given by the transform-limited bandwidth of  $\sim 0.1$  eV?

- Above 1000 eV, this gives a RP of 10,000, which will be hard to *significantly* better with a grating mono.
- At 2000 eV, a RP of  $>20,000$  is (probably) not attainable with a grating since the performance is strongly limited by slope errors on the optics

**For the harmonics, the main function of the grating is to remove the fundamental whilst preserving the pulse length**

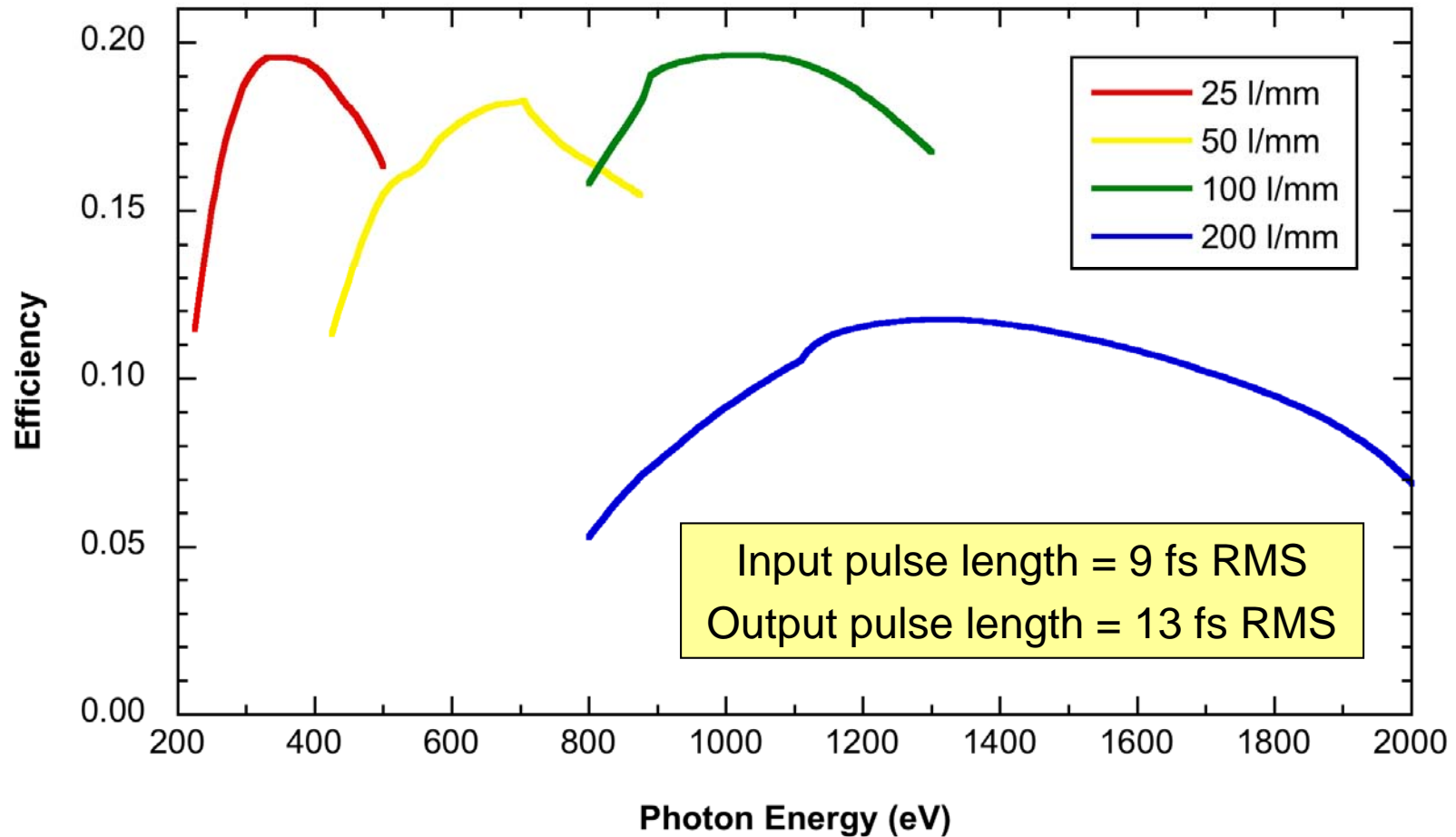


# Need for high spectral RP - 2

At low photon energies, the transform limited BW of 0.1 eV can be much improved with a grating mono

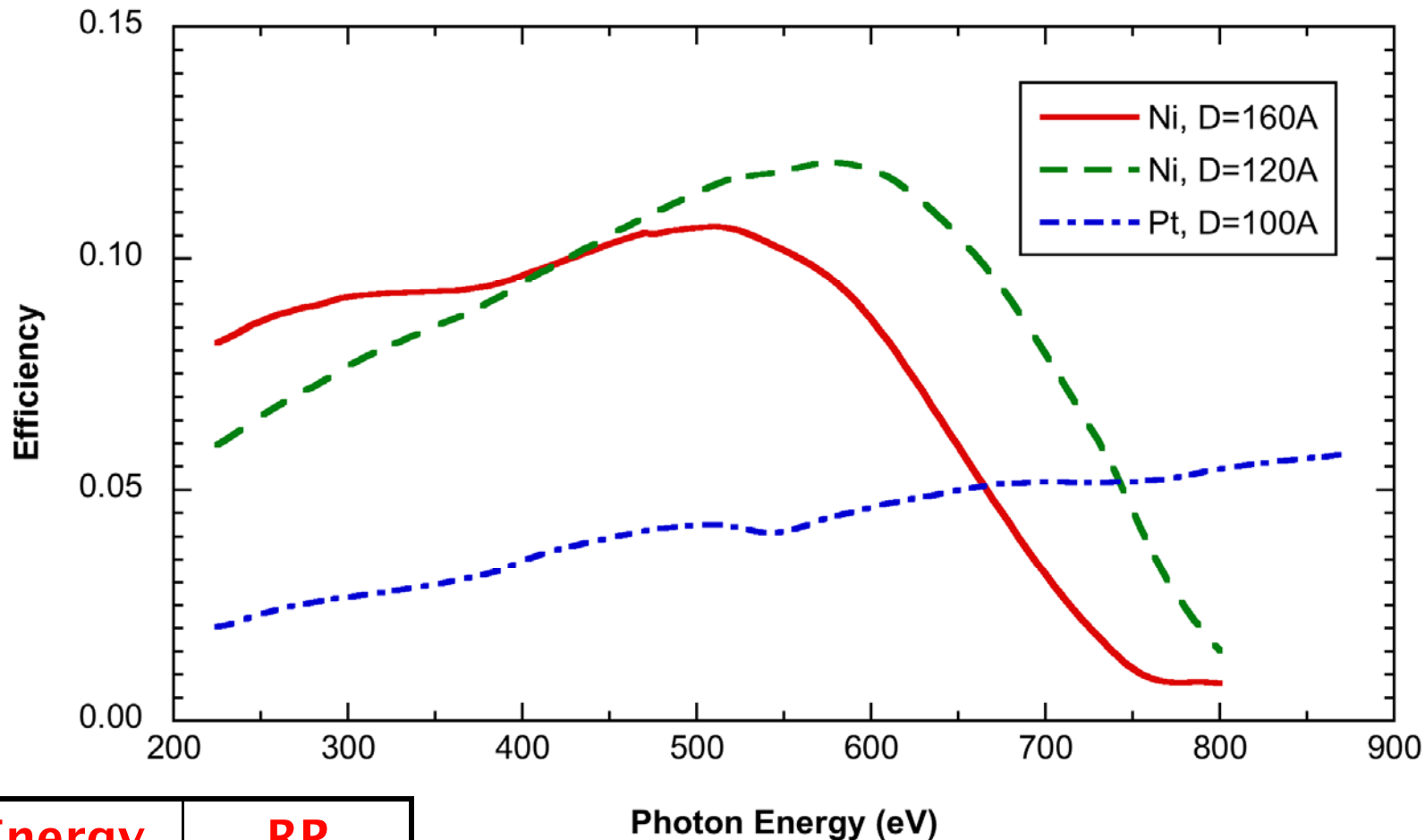
- What RP is required at say 50, 300, 550, 850 eV?
- It is assumed pulse length is not important when working in high spectral RP

## Calculated efficiency of a monochromator for FEL-2 that gives a fixed pulse stretch at all $\lambda$



NB: This is a design study only. It requires very low line density gratings that may not be manufacturable!

## Efficiency of the same monochromator when working in high spectral resolving power mode



Energy	RP
250 eV	46,000
850 eV	26,000