Performance Tests of the Photon Monochromator for Self-Seeding at FLASH

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Introduction

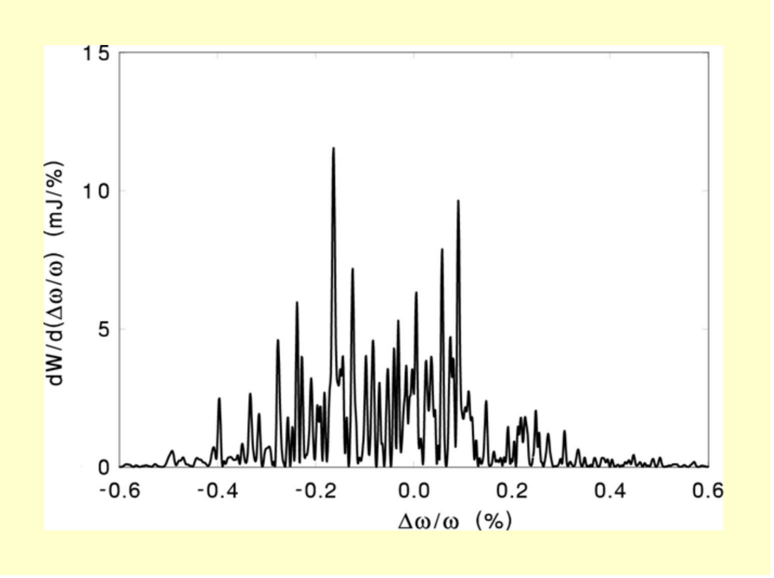
Different seeding schemes have been elaborated at DESY (Saldin, Schneidmiller, Yurkov et al.)

Seeding schemes aim to obtain either

- **full longitudinal coherence**
- **short pulses (→ few 10 femtoseconds at FLASH, or even attosecond regime for X-rays around 1Å)**
- **higher harmonics (VUV → X-rays)**

Why Self-Seeding?

A SASE FEL is a brilliant source of radiation with a high degree of transverse coherence but limited longitudinal coherence due to startup from noise.



"Spikes" in time and frequency domain are causing problems for some experiments
→ Self-Seeding is the cure

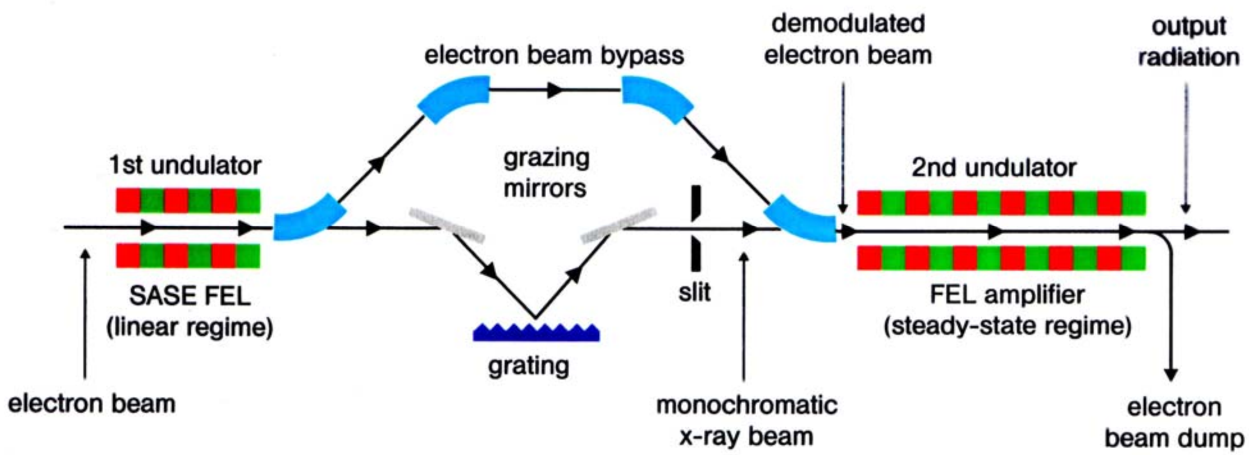
Idea: seed a SASE FEL with a fully longitudinally coherent, narrow bandwidth laser pulse

Approach: no sufficiently intense table top lasers available in the VUV and soft X-ray region

→ use monochromatized radiation from another SASE FEL as a seed

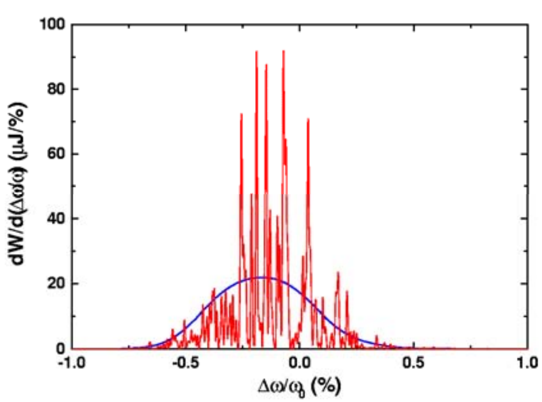
J. Feldhaus, E.L. Saldin, J.R. Schneider, E.A. Schneidmiller, and M.V. Yurkov, Opt. Comm. 140, 341 (1997)

Self - Seeding Principle

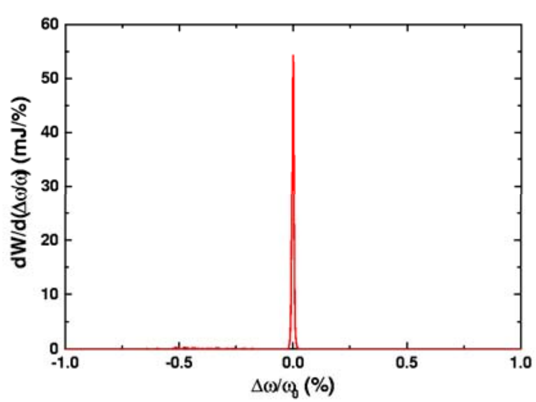


Spectral power distribution

behind 1st undulator



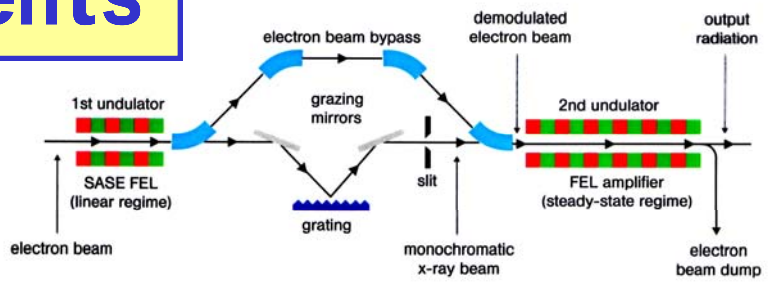
behind 2nd undulator



funded by HGF-Strategiefonds Program (01SF9935/1)

Requirements

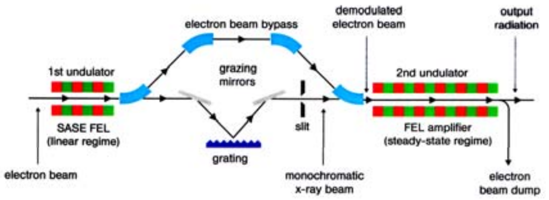
Photon Beamline:



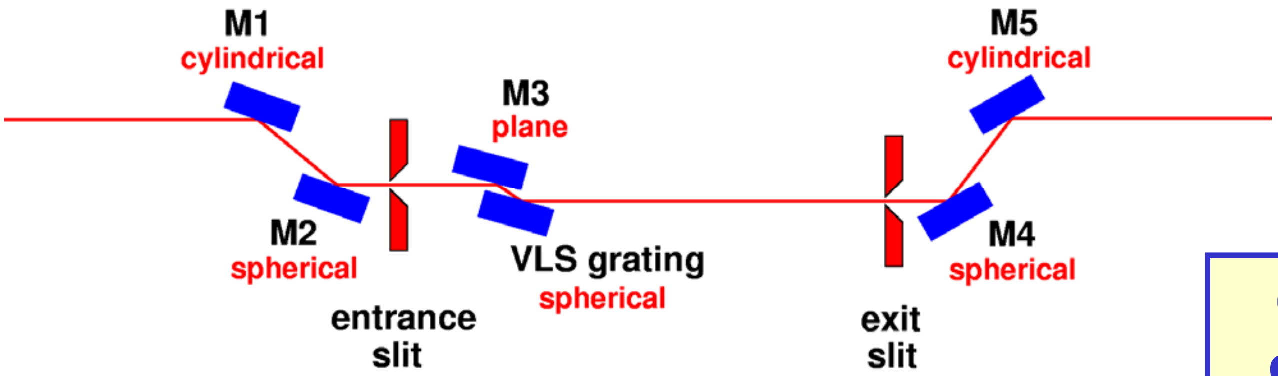
- 1:1 imaging of complex conjugated wavefront onto entrance of 2nd undulator
- monochromator resolution ≤ 20000
- overall efficiency 10%
- match pathlength of e-bypass

➔ - optimum longitudinal and transverse overlap with electron bunch in 2nd undulator
- monochromatized seed pulse dominates shot noise and is amplified to saturation
- output FEL beam possesses full longitudinal coherence and narrow bandwidth ($\Delta\lambda/\lambda \approx 10^{-4}$)

Final Layout



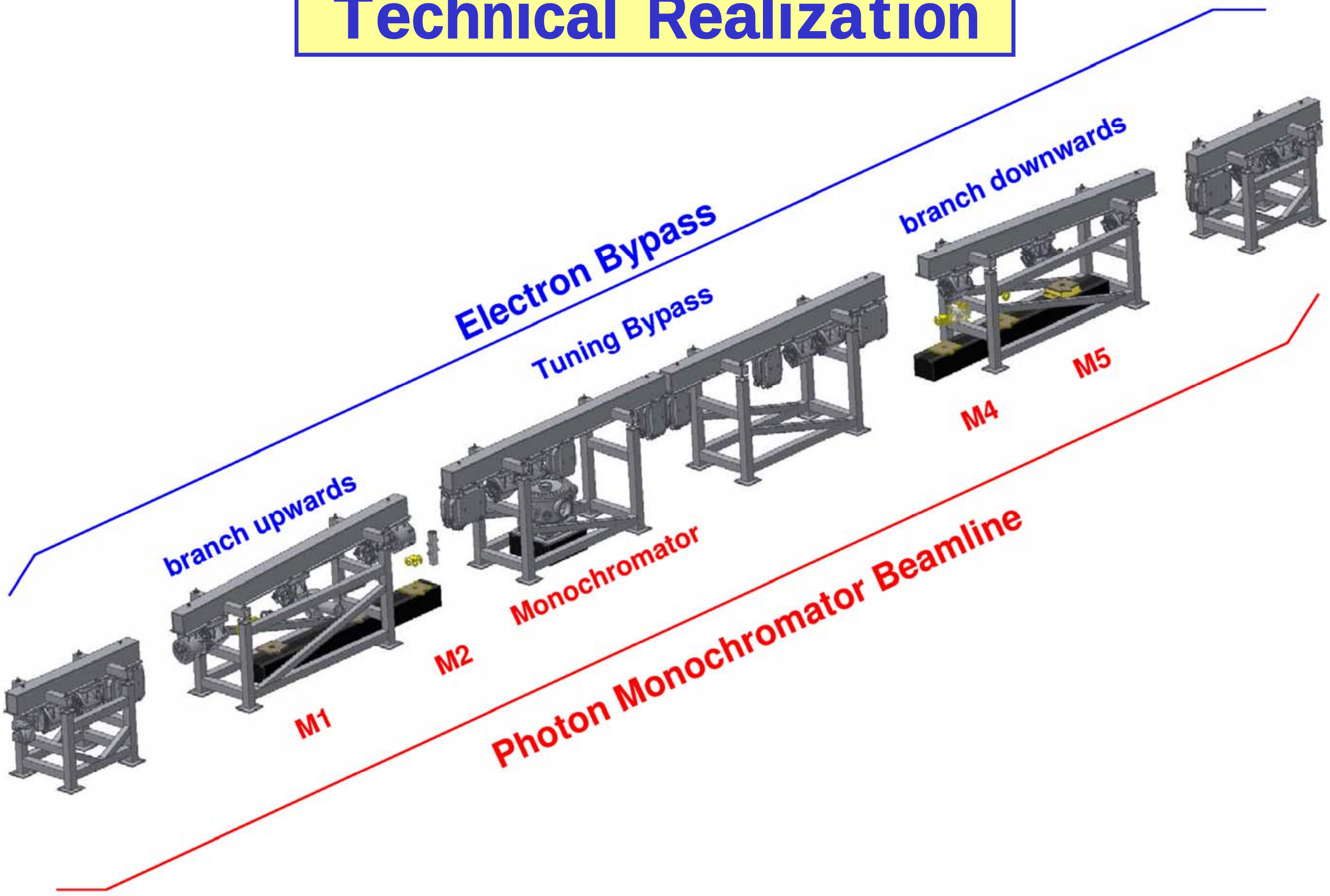
Photon Monochromator Beamline :



Total length: 22m

6 optical elements

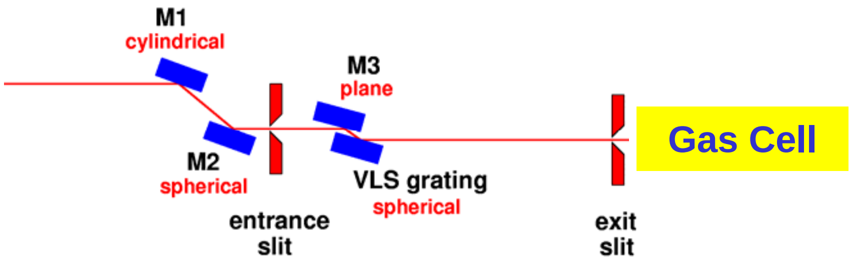
Technical Realization

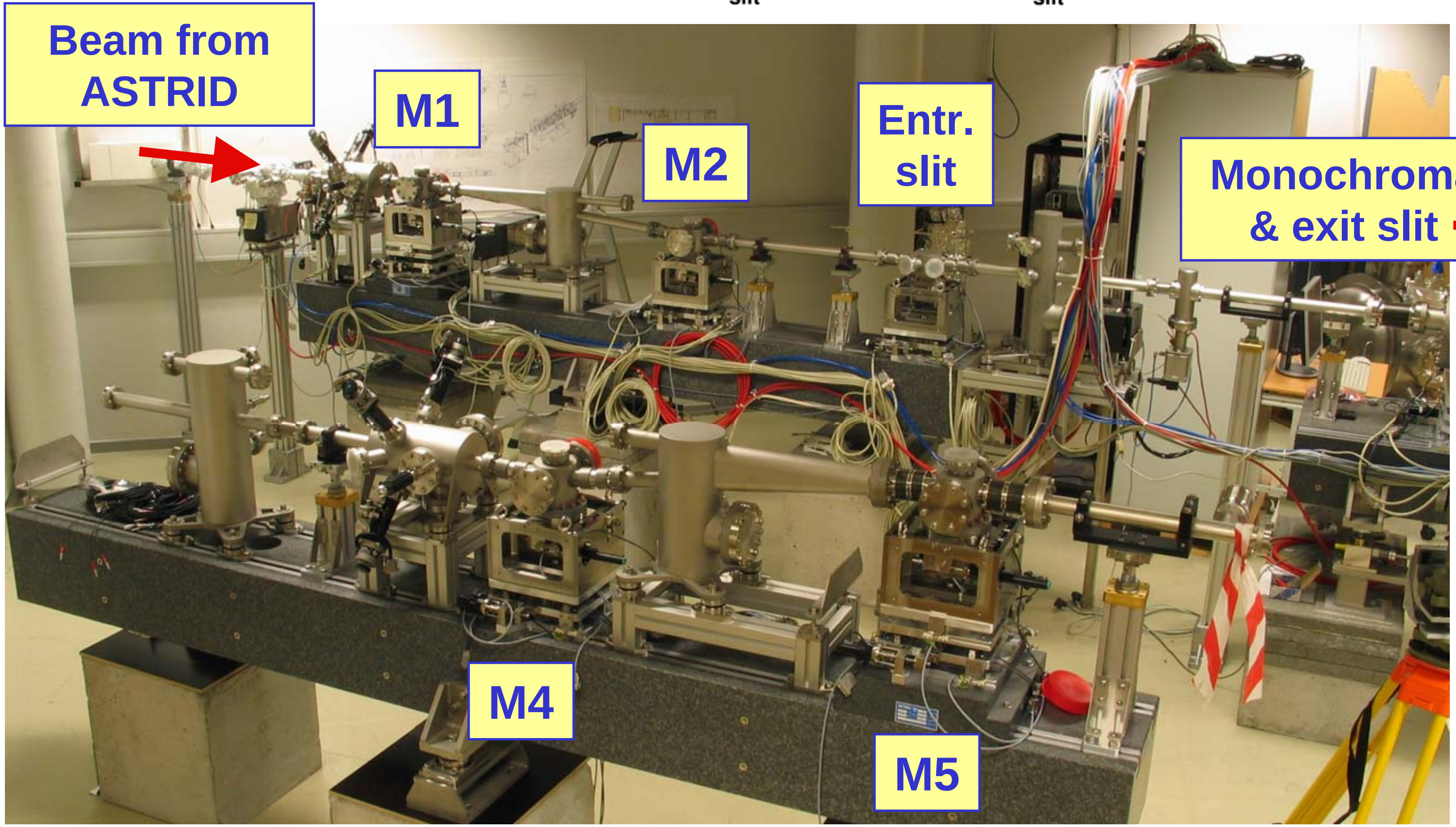


Results from photon monochromator tests at ASTRID (ISA,Aarhus,DK)

- monochromator (from M1 up to exit slit + gas cell behind) set up at bending magnet at ASTRID storage ring
- all vacuum chambers and mechanical systems (including Monochromator !) were made at IFA&ISA, Univ. Aarhus
- all mechanics succesfully tested in the lab
- monochromator performance (accuracy and in particular resolution) tested with beam on all three gratings with rare gas resonances (in particular He)

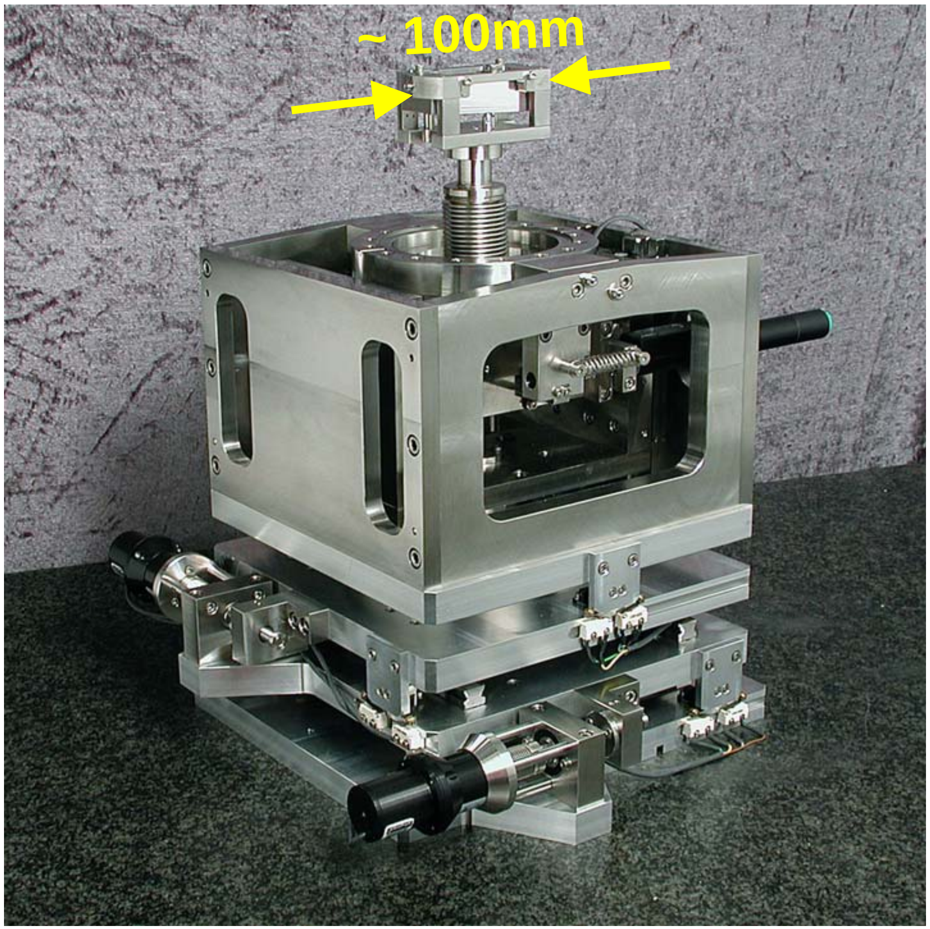
Setup

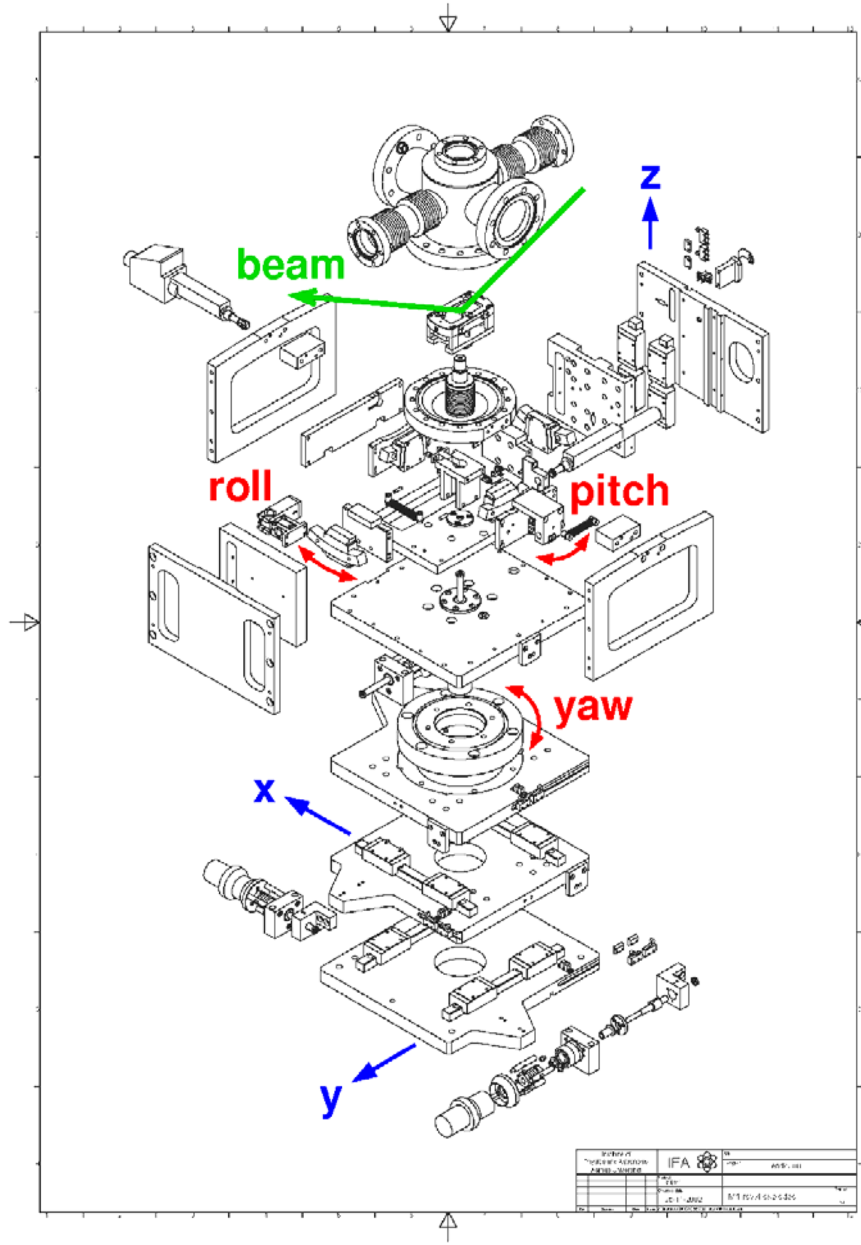




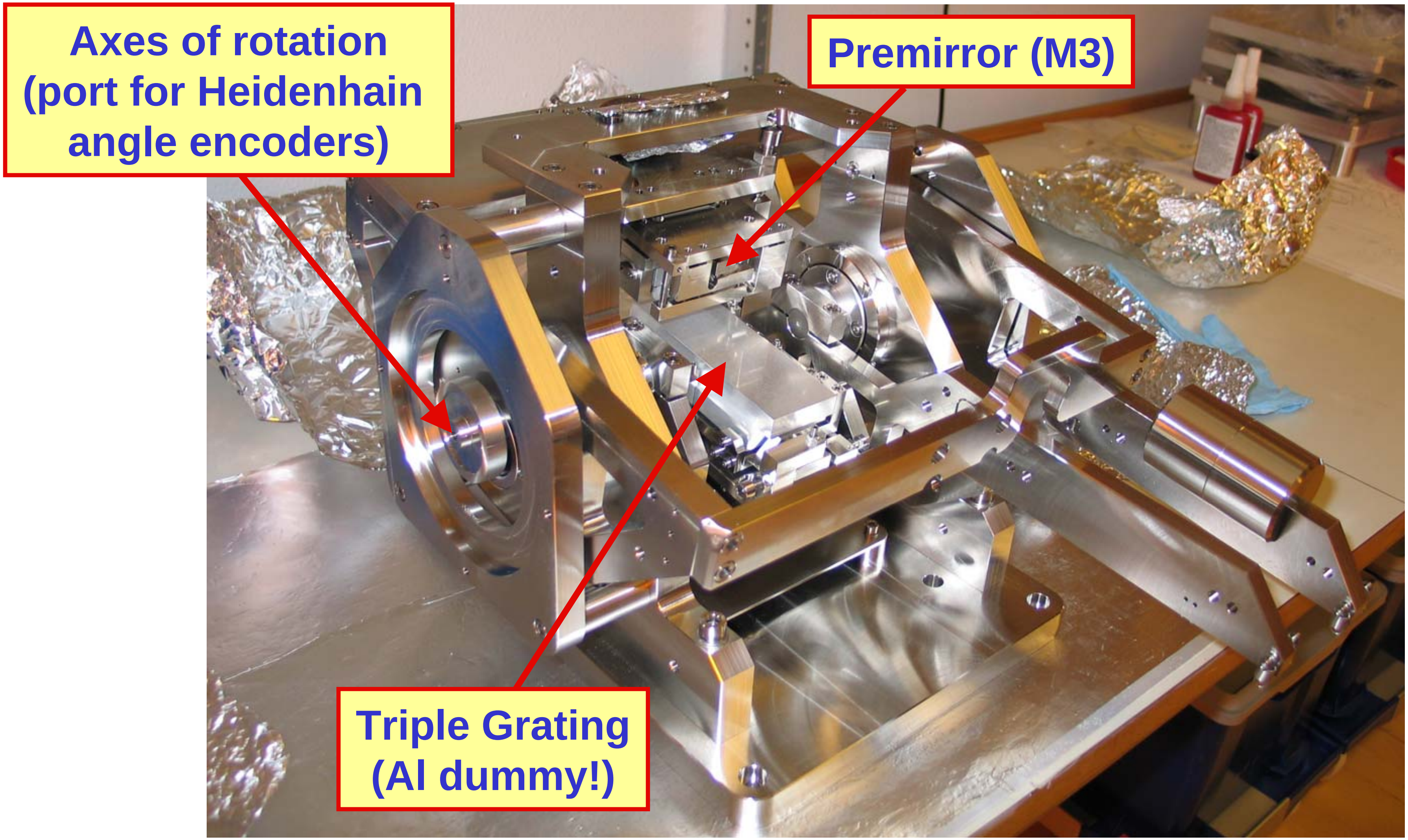
branch with M4 & M5 not used during tests, just assembled!

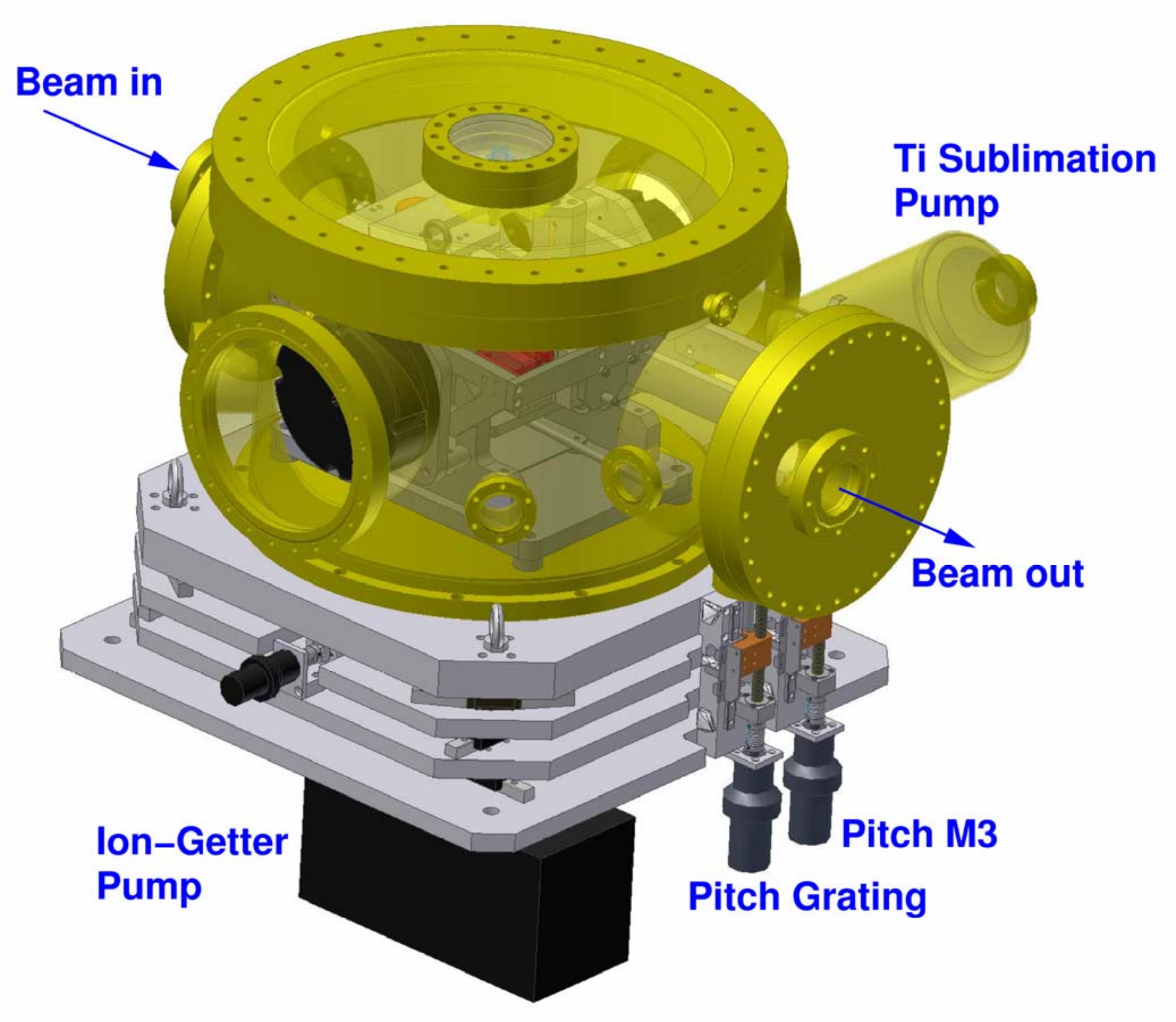
Mirror mechanics



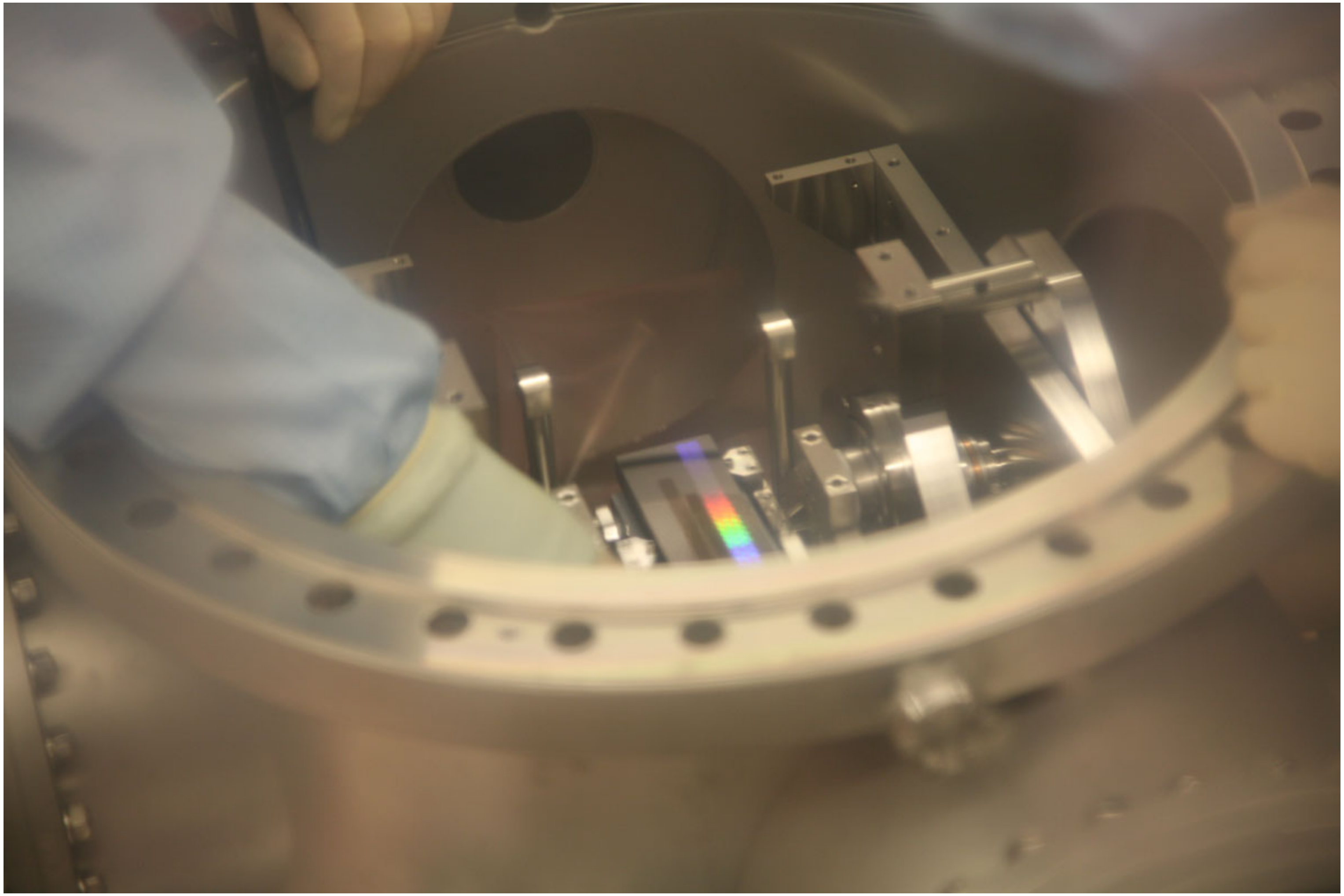


Monochromator mechanics

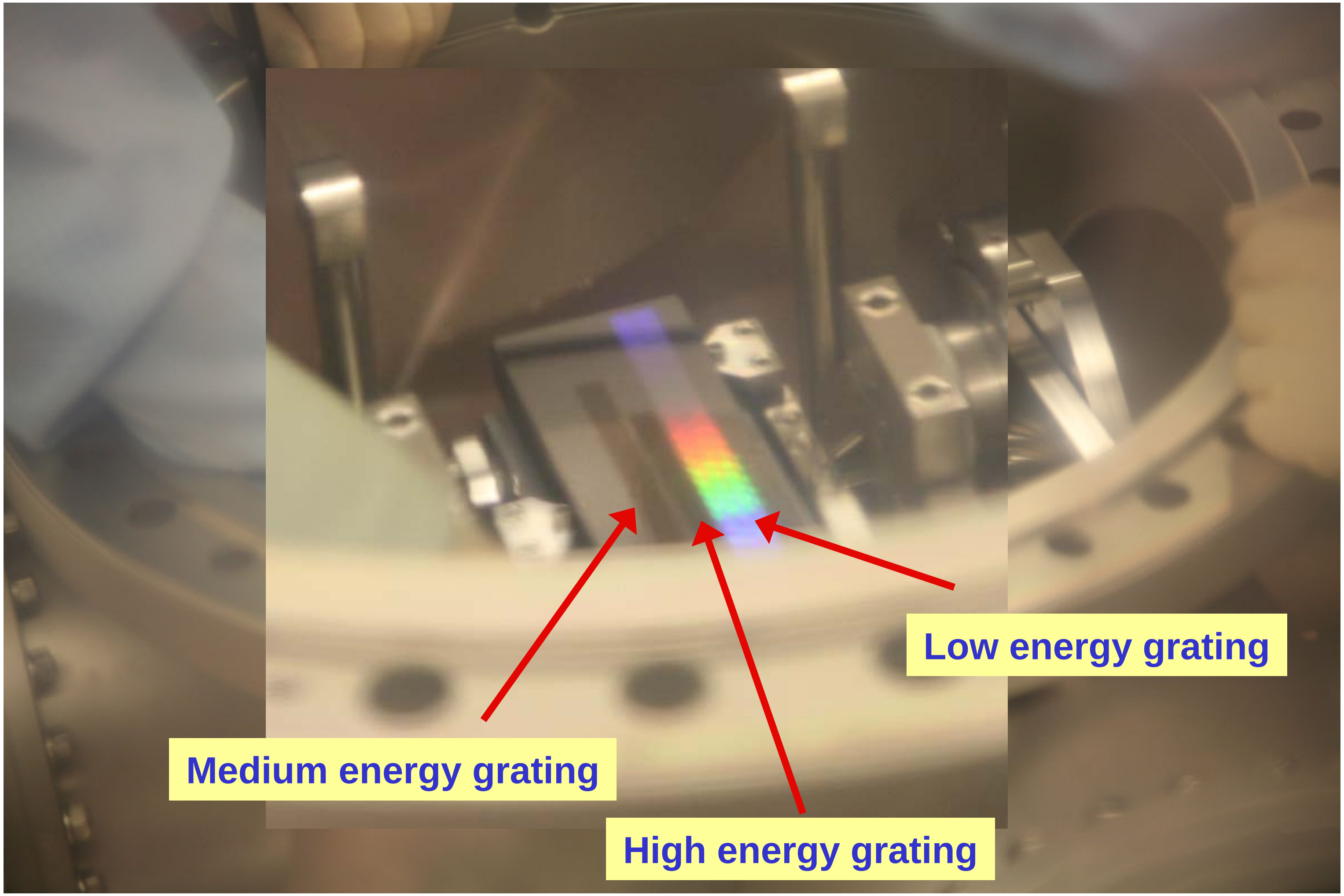



Beam in
Ti Sublimation Pump
Beam out
Ion–Getter Pump
Pitch M3
Pitch Grating

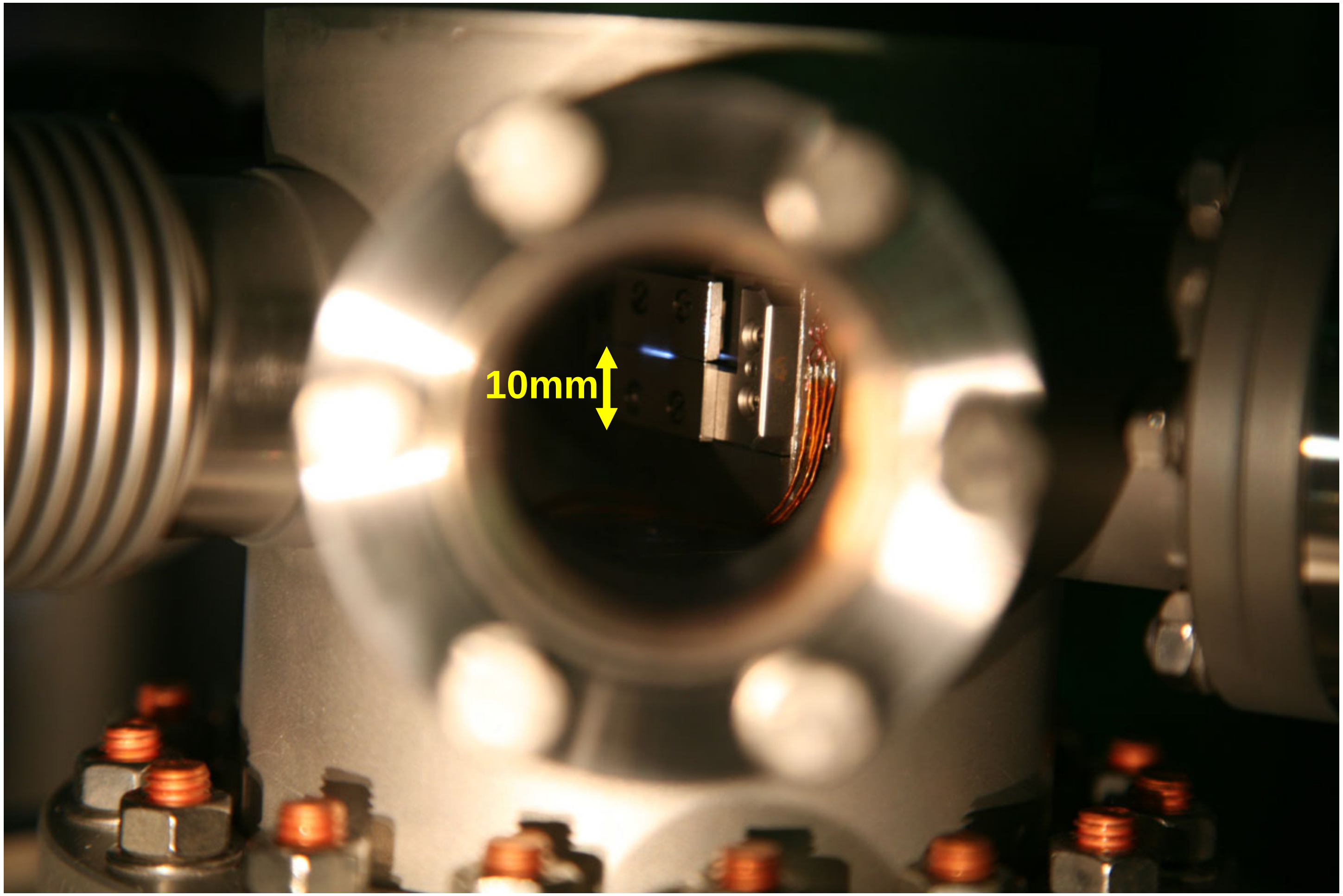
View onto triple grating in monochromator



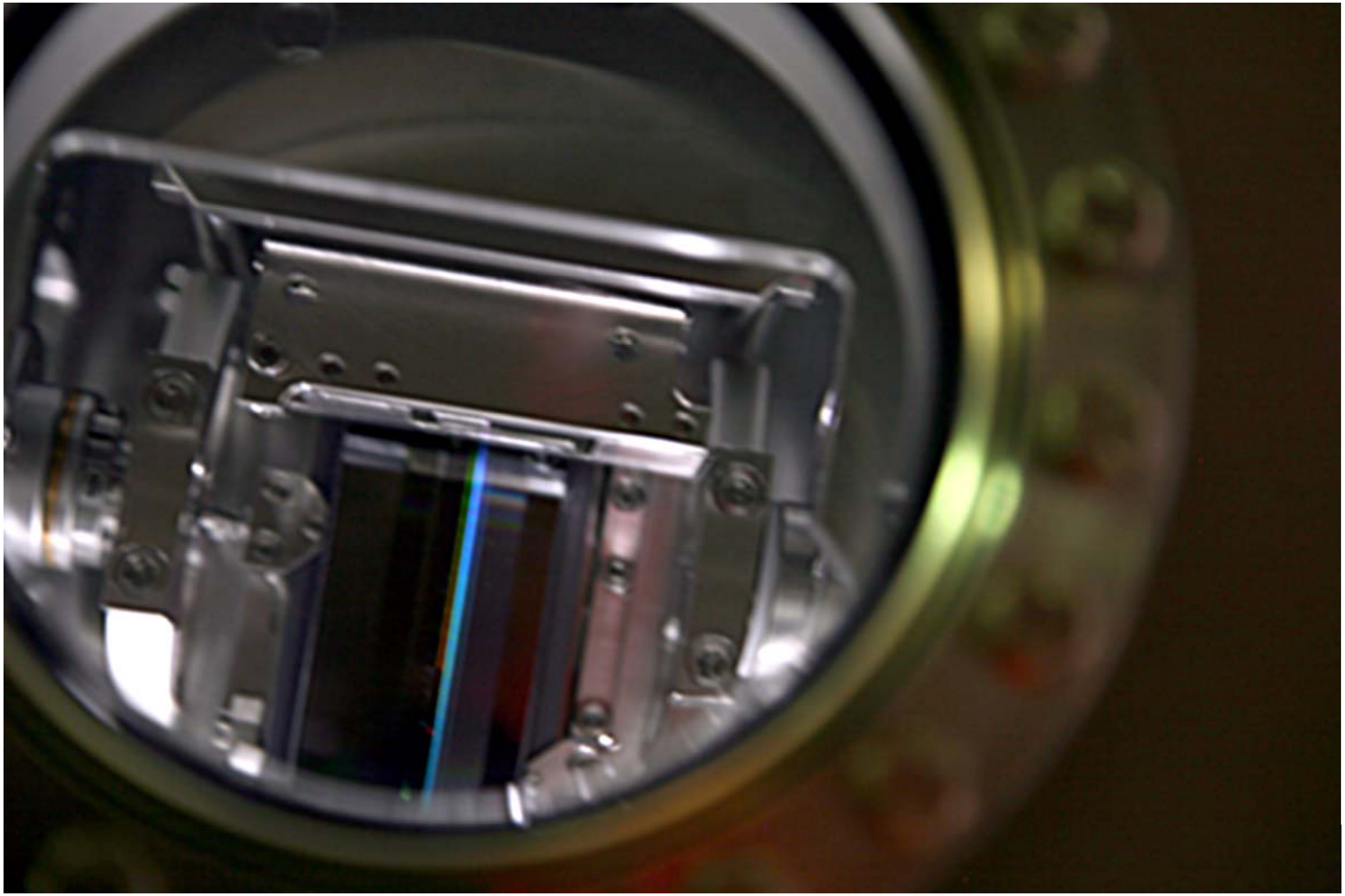
View onto triple grating in monochromator



Beam on entrance slit

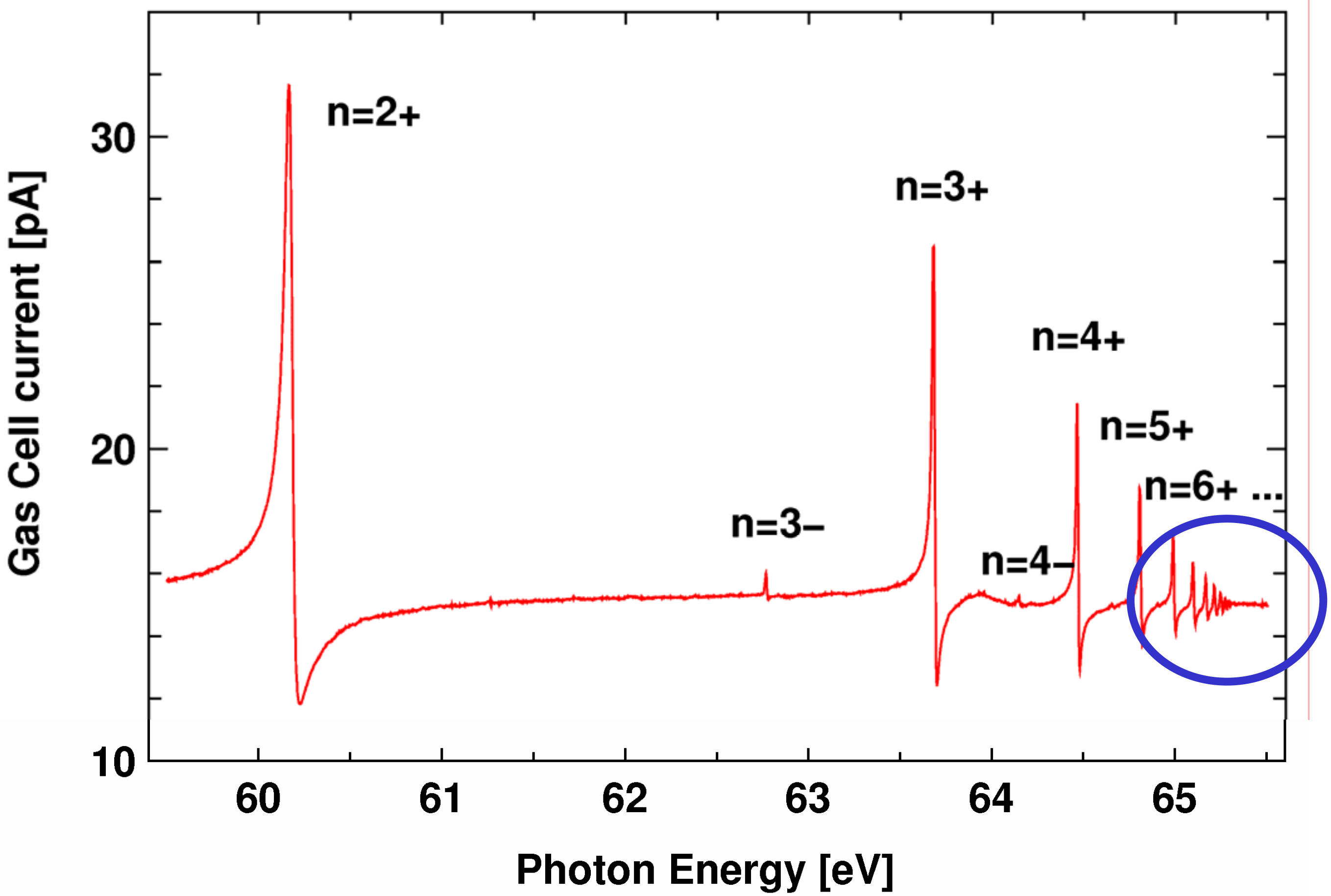


Beam on grating



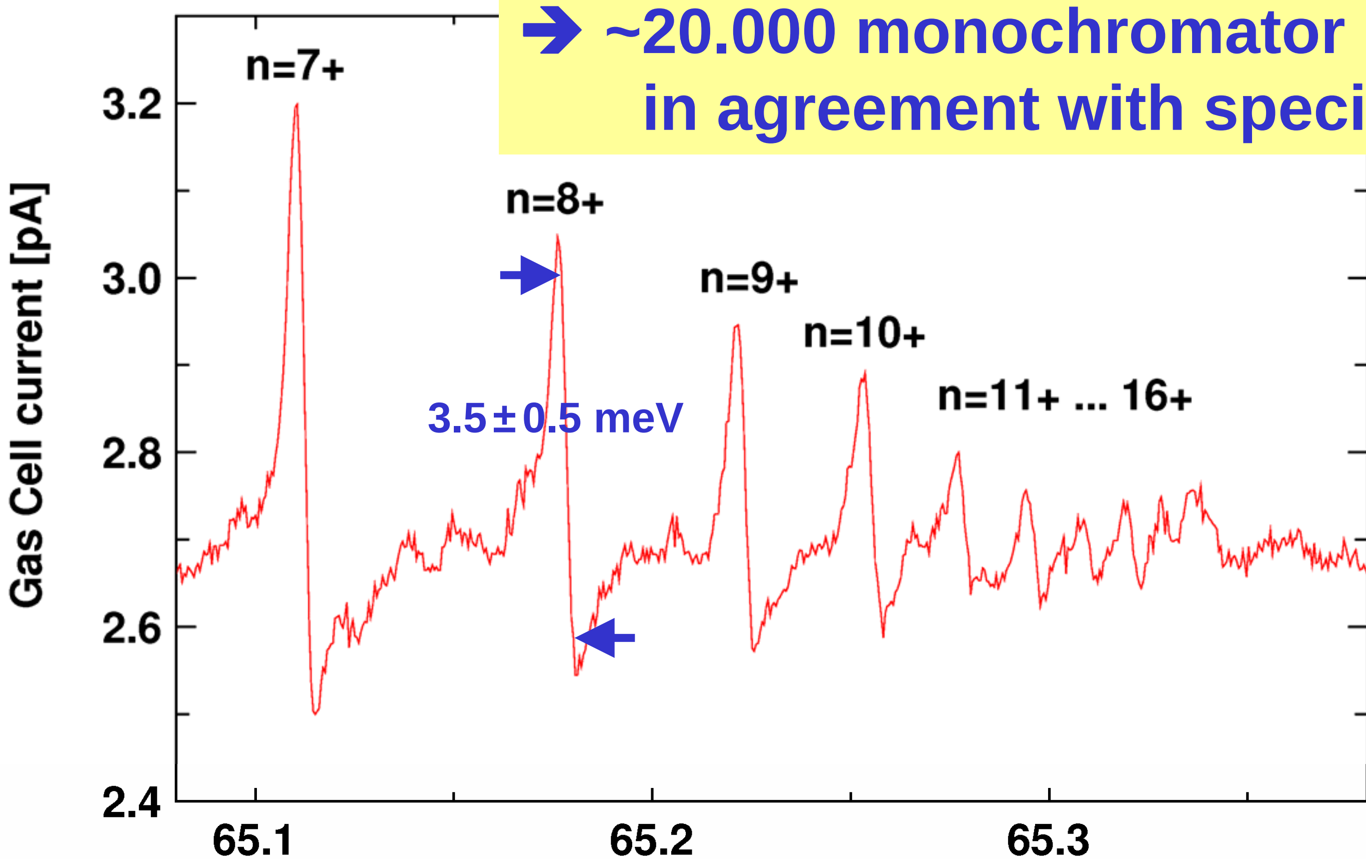
Results: resonance spectra

1) He $^1P^0$ double-excitation states around 60eV



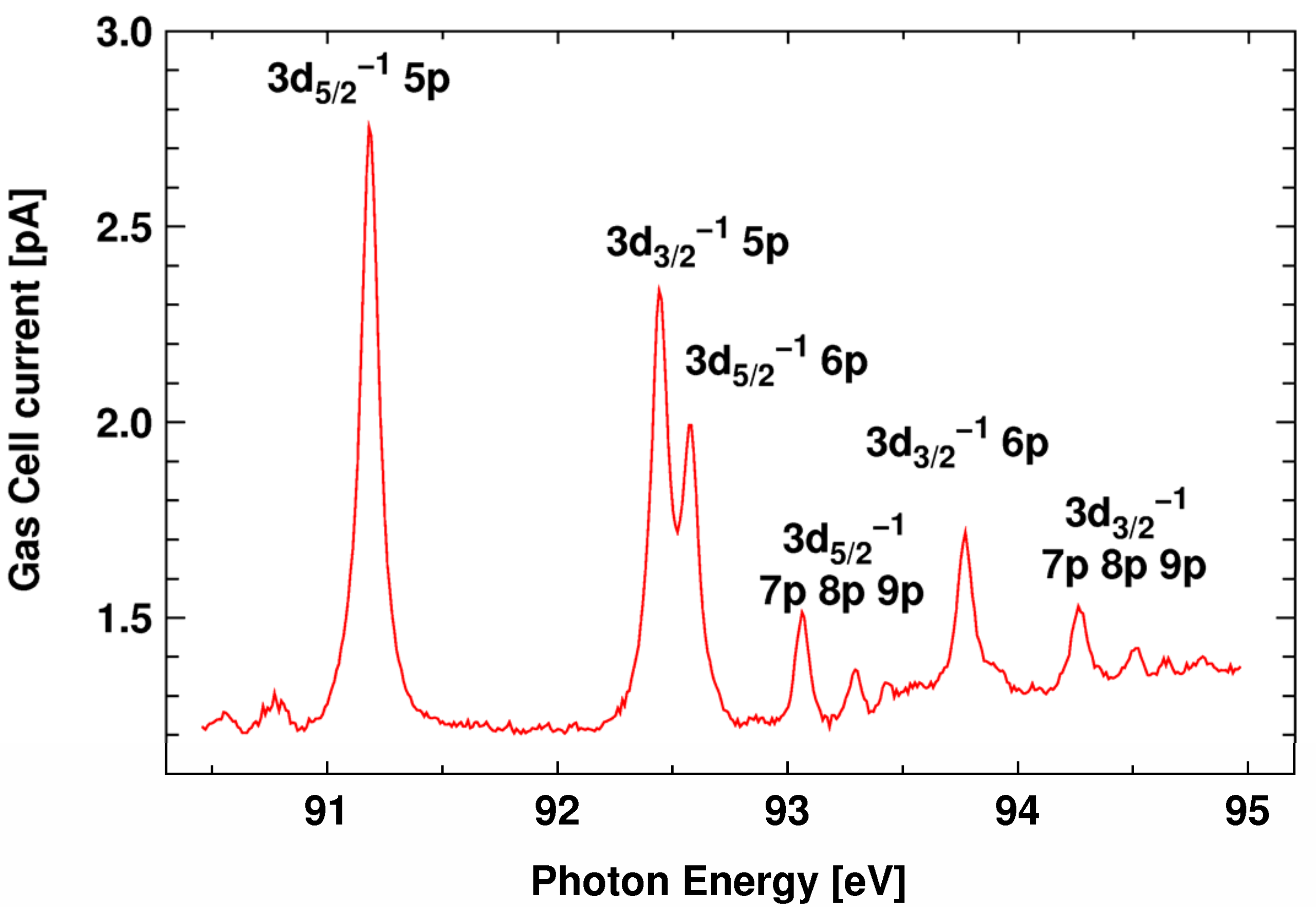
Helium $^1P^0$: zoom onto n=7+ to continuum high energy grating (HEG)

➔ ~20.000 monochromator resolution, in agreement with specifications!



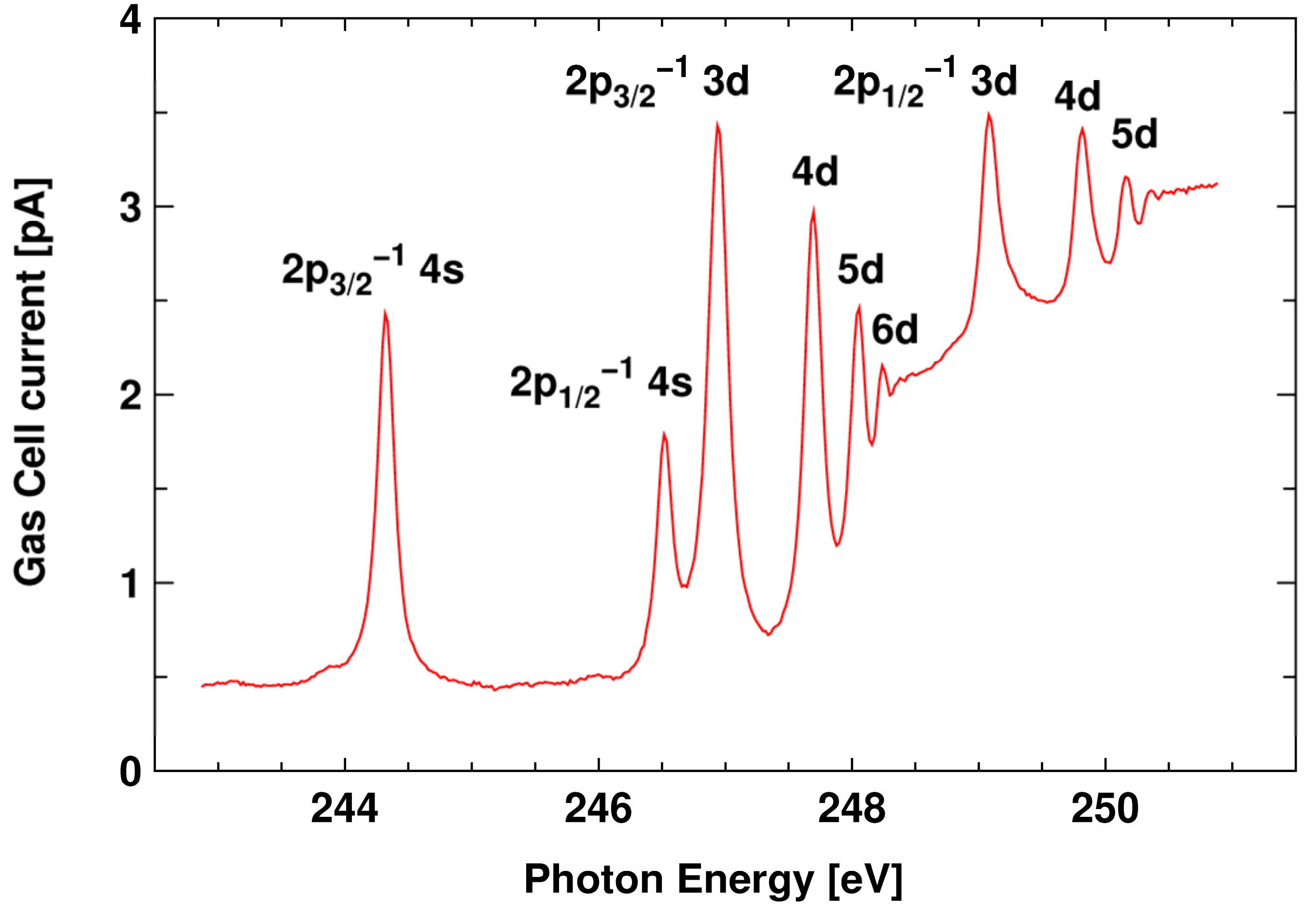
Changing from MEG to HEG, energies were only 13 meV (0.2‰) off !!

Kr 3d → np, HEG



Coming from calibrated MEG, energies were only 40 meV (0.45‰) off !!

Ar 3p → ns,nd, HEG



Coming from calibrated MEG, energies were only 123 meV (0.5‰) off !!

Resolving Power

Energy [eV]	Gas	LEG	MEG	HEG
~24	He	~ 8000 [8000] (3 meV)		
60-65	He	~ 5000 [5000] (13meV)	11000 - 16000 [15000] (4-6meV)	16000 - 22000 [22000] (3-4meV)
91-95	Kr			≥ 4000 (≤ 25/60 meV) conservative estimate, limited by natural linewidth and data quality
244-250	Ar			

blue: 40 micron slits, red: 20 micron slits, [ ] : ray tracing values

Summary

- Self-Seeding will deliver FEL beam with almost full coherence, both transverse and longitudinal
- Narrow bandwidth → ≈ 50x higher peak brilliance with pulse energies comparable to usual SASE FEL
- Wavelength range at FLASH from about 60 - 6.4 nm
- Jitter free synchronization between seed pulse and electron bunch
- Monochromator performs according to specs !

Acknowledgements

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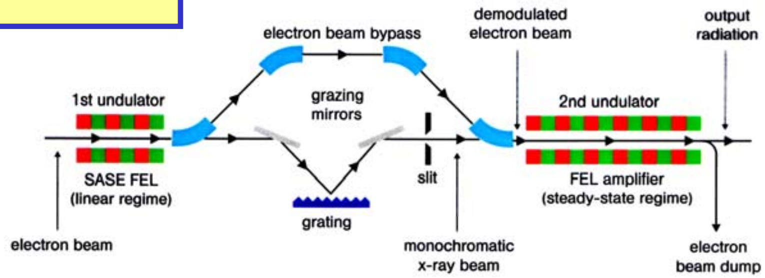
Ruben Reininger

Special thanks for perfect support:

ISA/IFA workshops
DESY/HASYLAB Exp.Control and Vacuum Groups

Supplementary Transparencies

Requirements

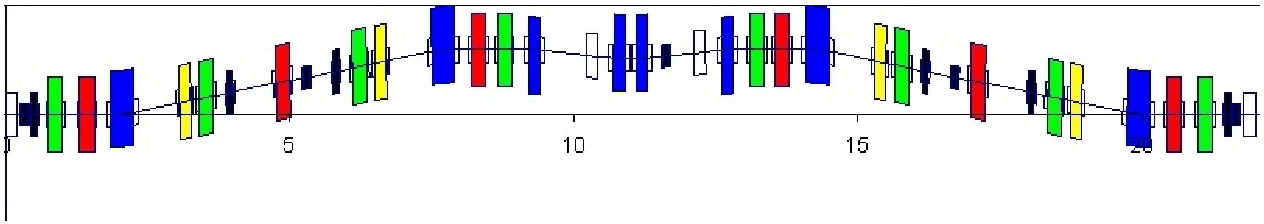


Electron Bypass:

- **some dispersion needed to remove the microbunching, but avoid too large increase of total bunch length**
- **minimize deterioration of beam quality caused by coherent synchrotron radiation (CSR) in the dipoles (tolerable limit of about 10 % growth of the slice emittance)**
- **small central "tuning bypass" to vary the electron beam pathlength by about 1 mm is necessary to cope with the changes in photon beam pathlength introduced by changing the monochromator energy**

Final Layout

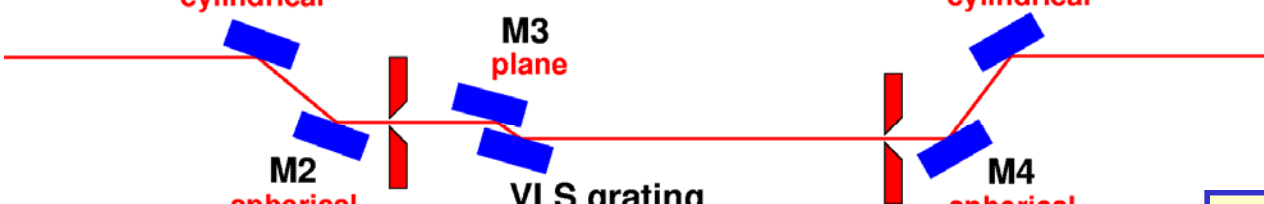
Electron Bypass :



11 steerers, 8 dipoles, 8 quadrupoles (vert. foc.), 6 quadrupoles (hor. foc.), 4 sextupoles

37 magnets total

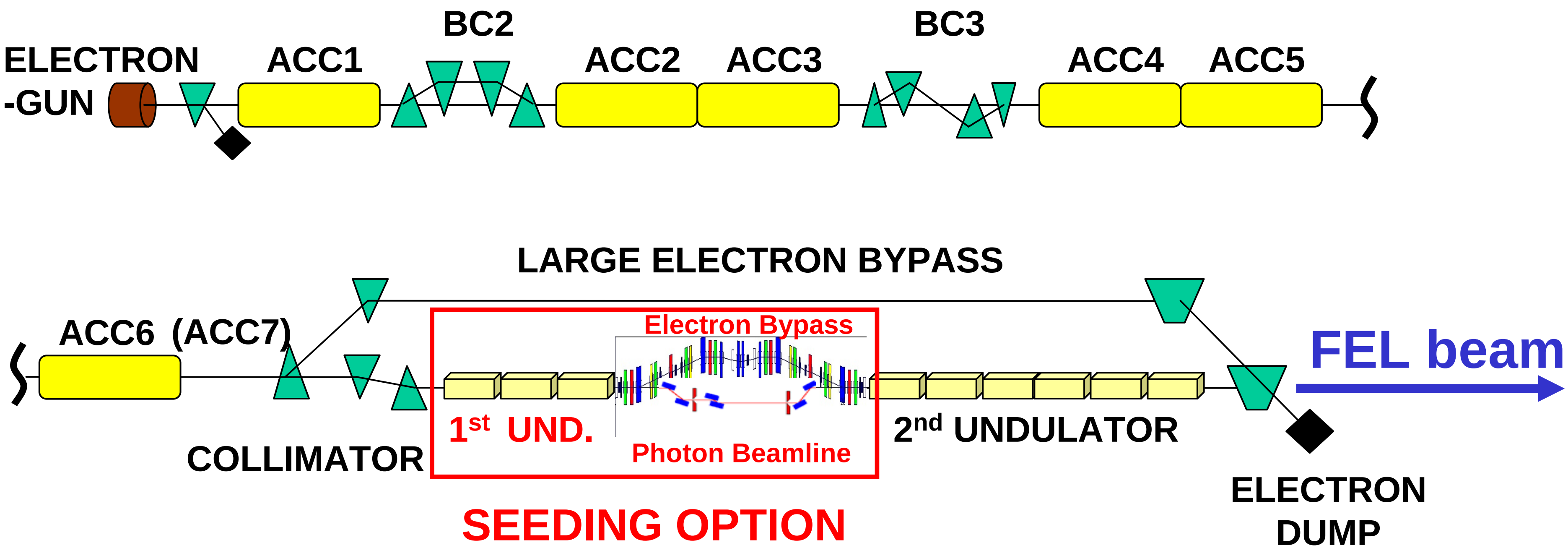
Photon Monochromator Beamline :



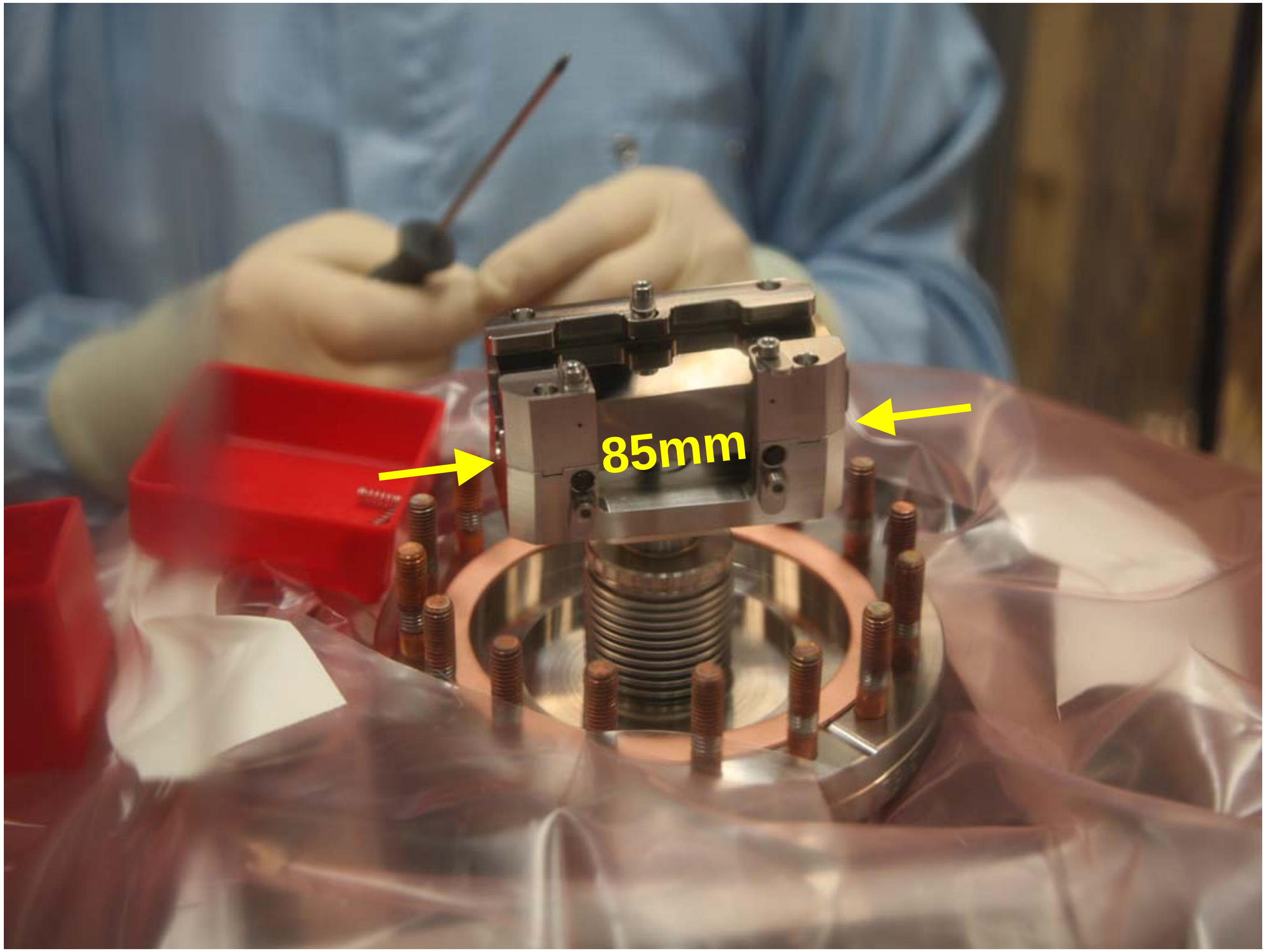
6 optical elements

Total length: 22m

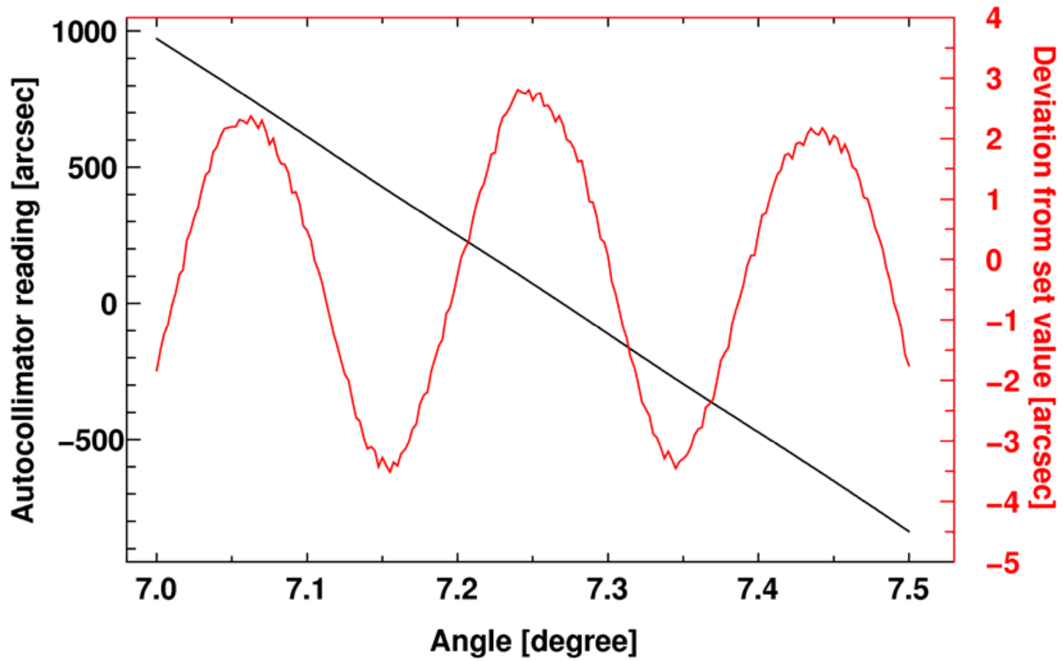
FLASH with Seeding Option



Mirror M2 in holder



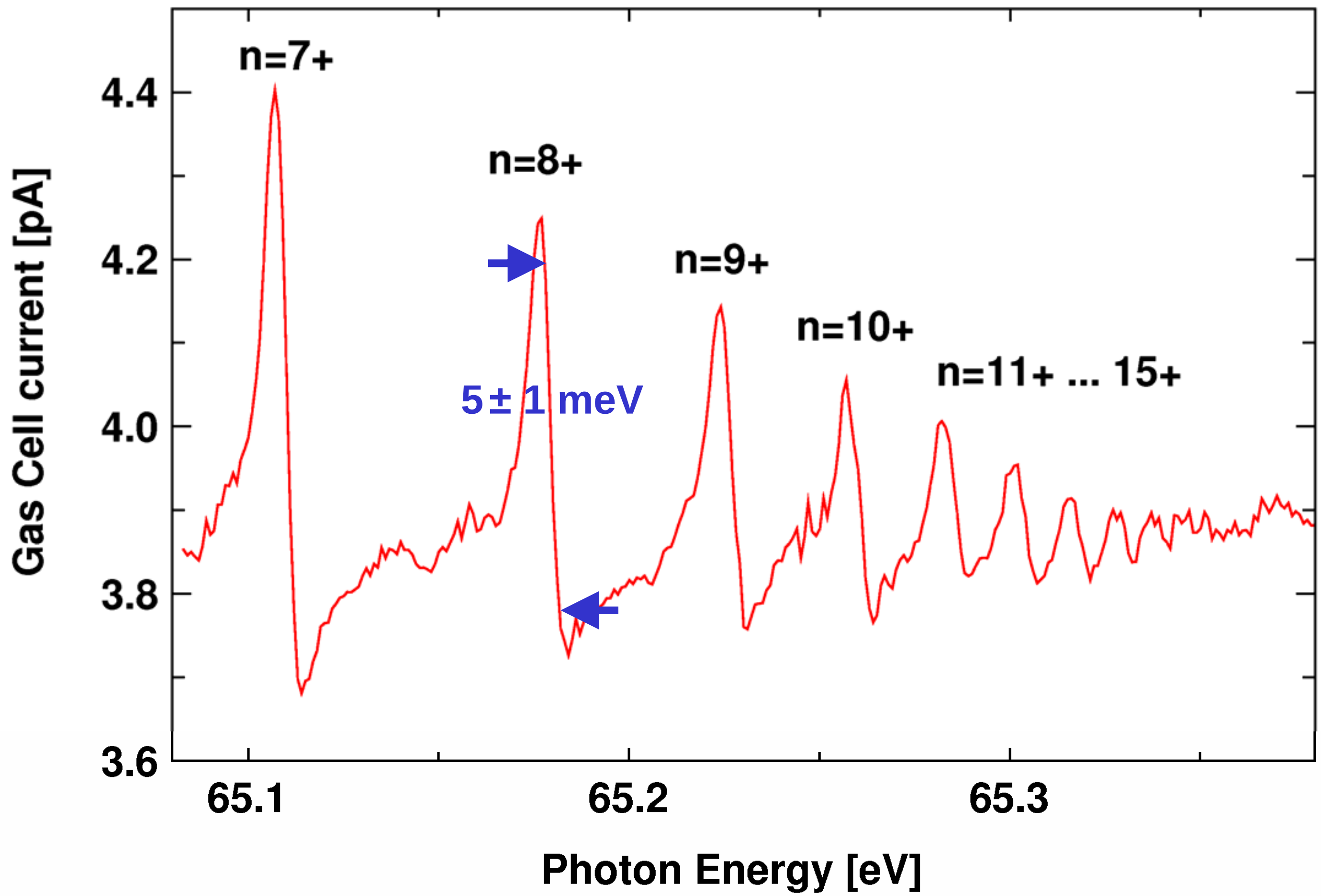
Accuracy of grating/premirror drive



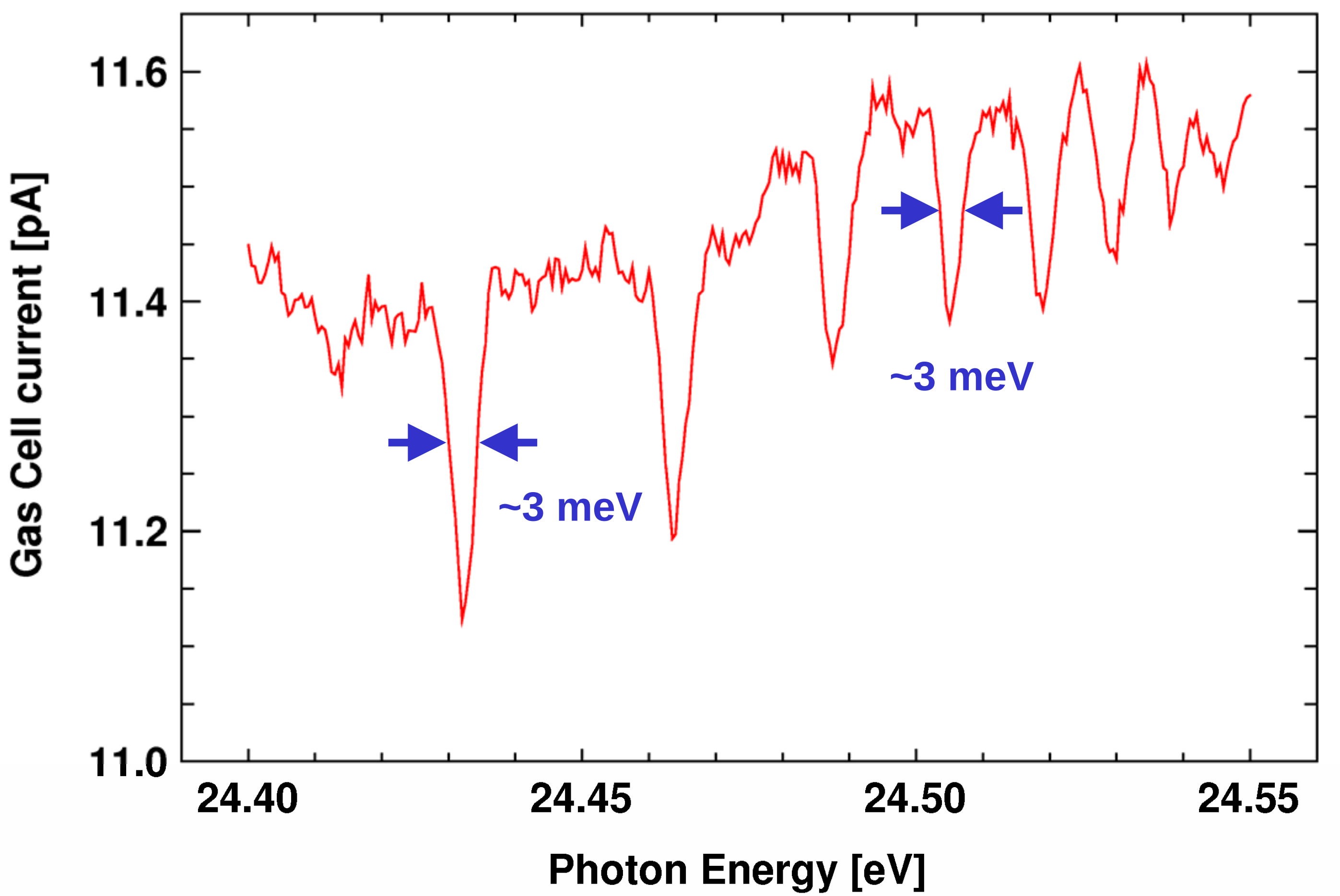
±3" per 0.2degree or
±4.5 µm per 1mm (= one turn)
due to spindle reeling/wobbling

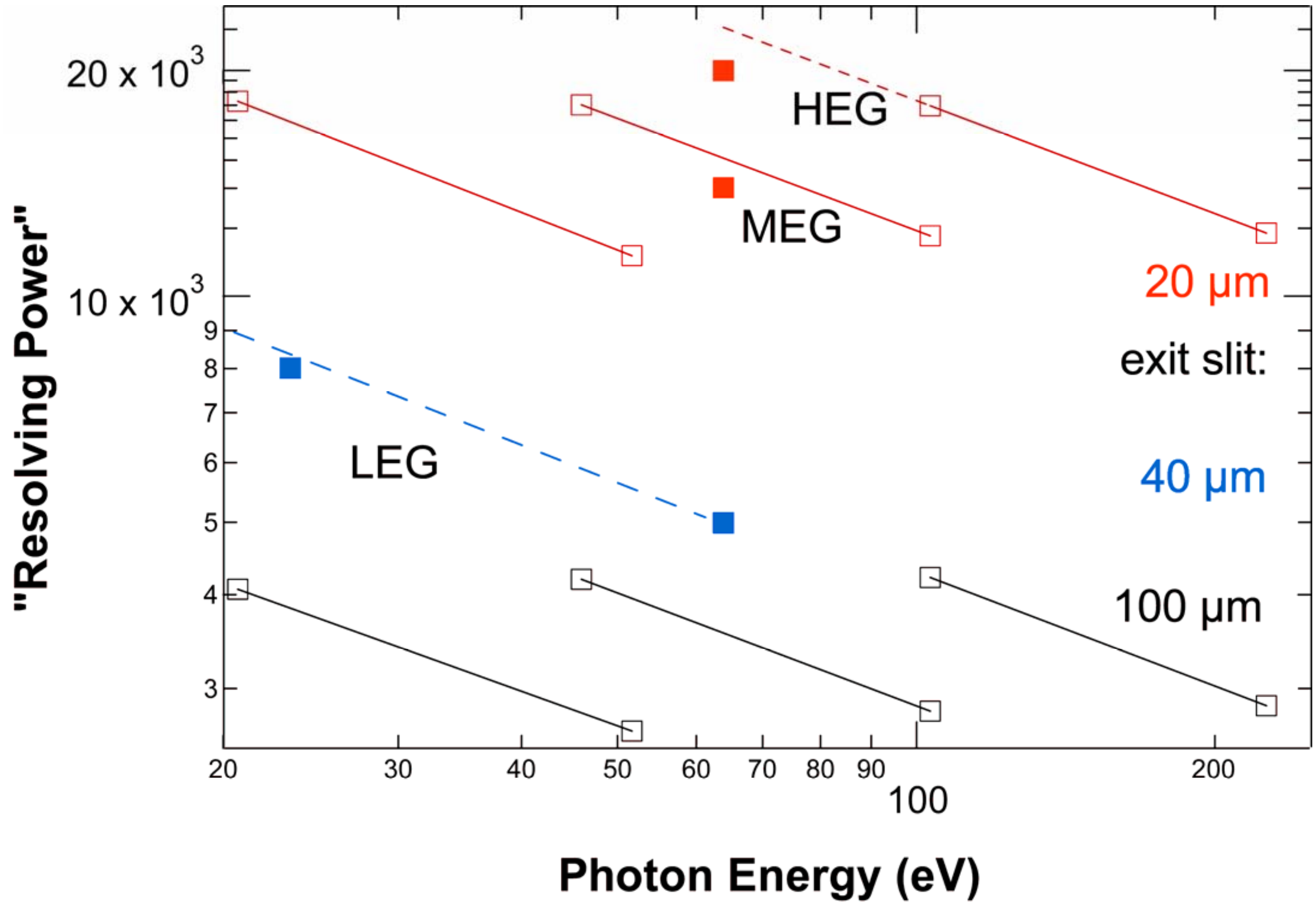
Locally (within few eV) energy scale error up to ~ 1% (some 10 meV), but globally better than 0.5‰, even upon grating change!
Can/will be improved but is not crucial since we will use feedback from Heidenhain rotary encoders (RON 905 UHV, accuracy +/- 0.2", can be even interpolated to better accuracy)

Helium $^1P^0$: zoom onto n=7+ to continuum, medium energy grating (MEG)



Helium I around 24 eV, low energy grating (LEG)





■,■ : measurements

□,□ : ray-tracing results (R.Reininger)