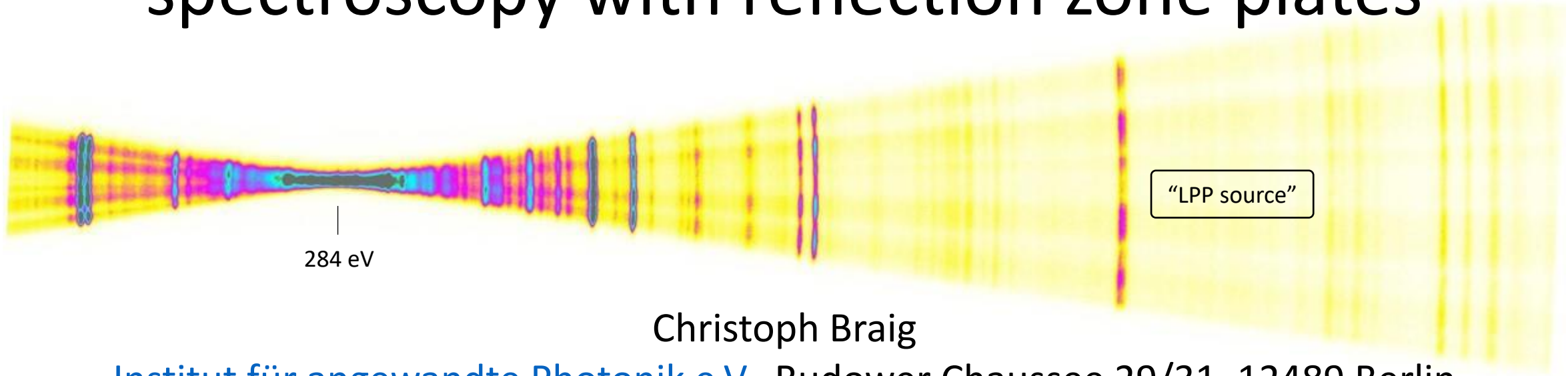
High-resolution femtosecond X-ray spectroscopy with reflection zone plates



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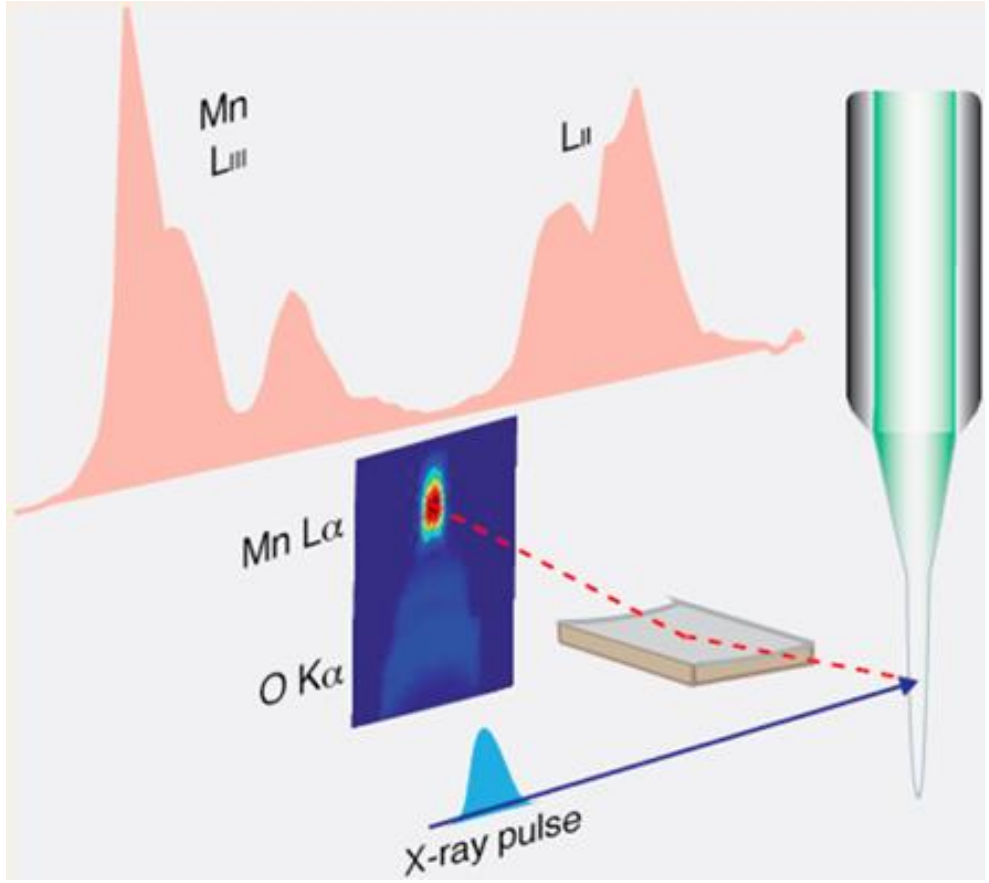
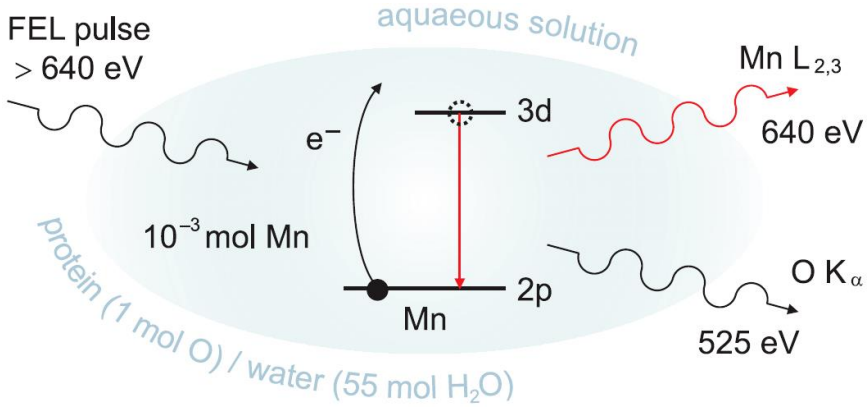
I. Mantouvalou et al., Appl. Phys. Lett. **108**, 201106 (2016).

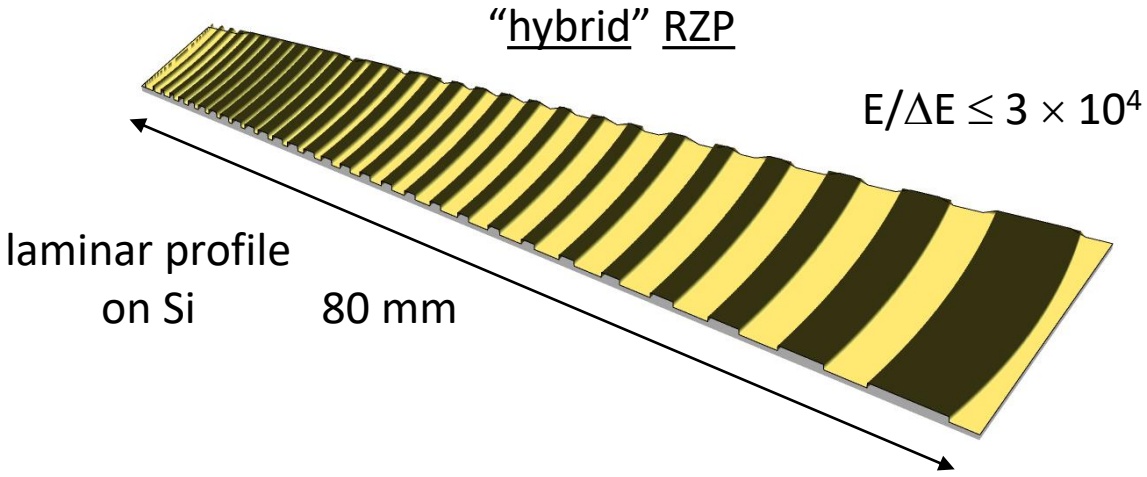
Photosystem II: Mn $L_{2,3}$ fluorescence yield



R. Mitzner et al., J. Phys. Chem. Lett. **4**, 3641 – 3647 (2013).

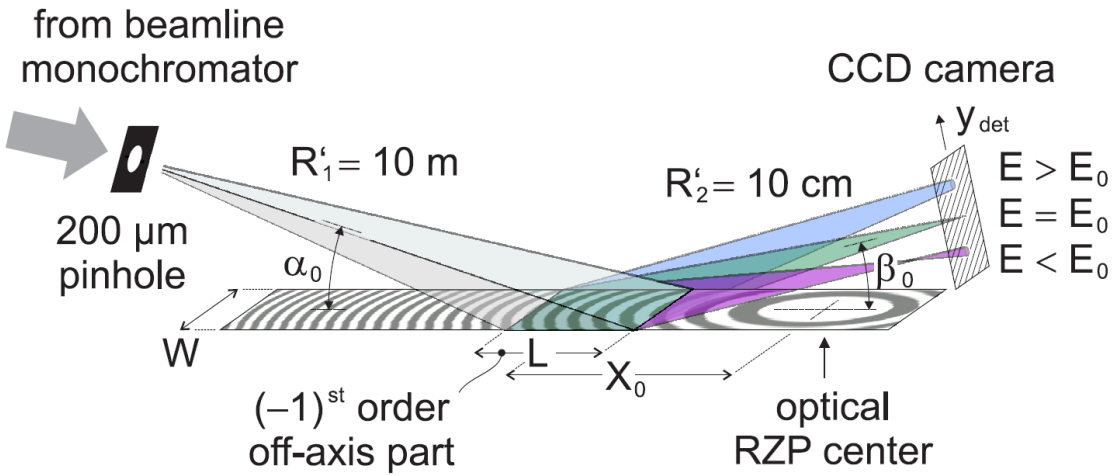


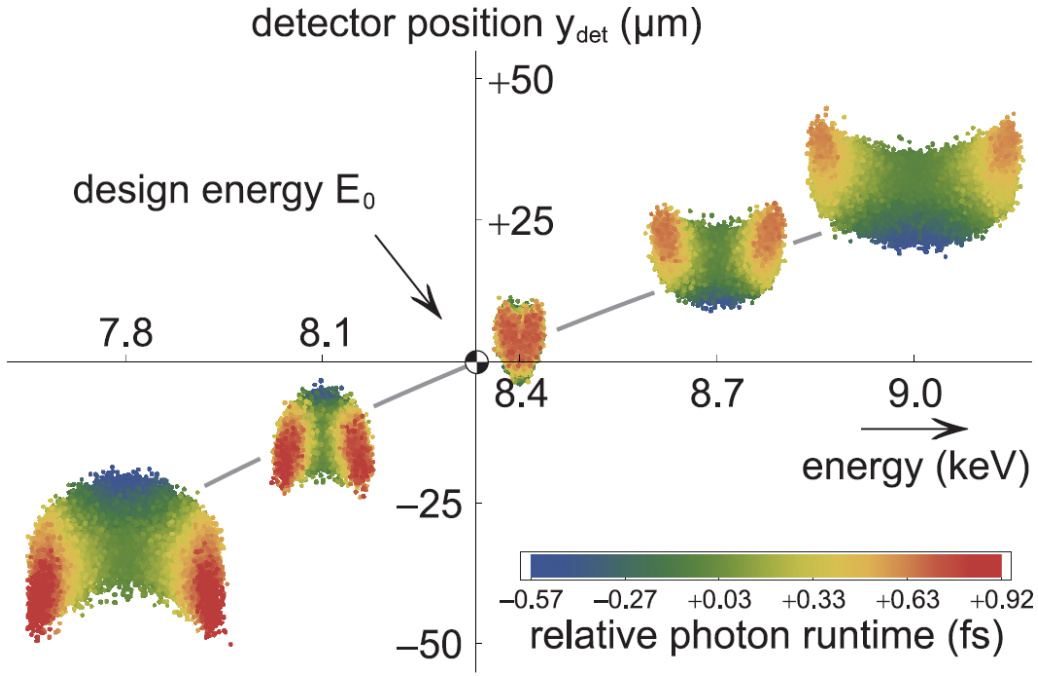
C. Braig et al., Opt. Express **22**, 12583 – 12602 (2014).



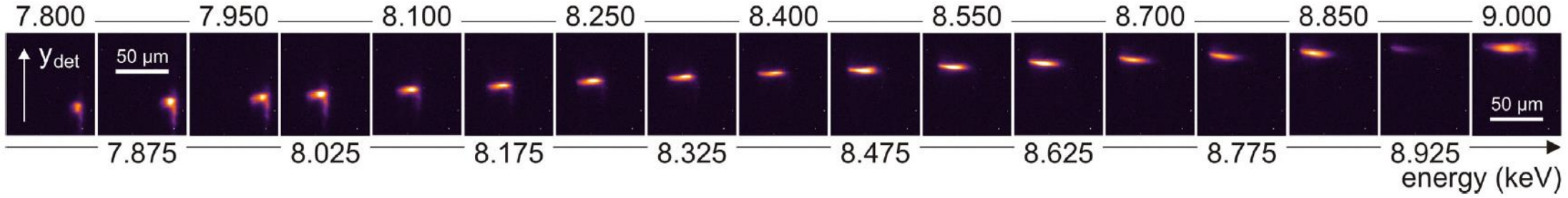
Fs hard X-ray spectroscopy at the Ni K-edge

$$\mathscr{R} \leq N \leq \frac{1}{h}(\Delta\tau \cdot E) \quad \text{with} \quad \mathscr{R} \equiv \frac{E}{\Delta E}$$

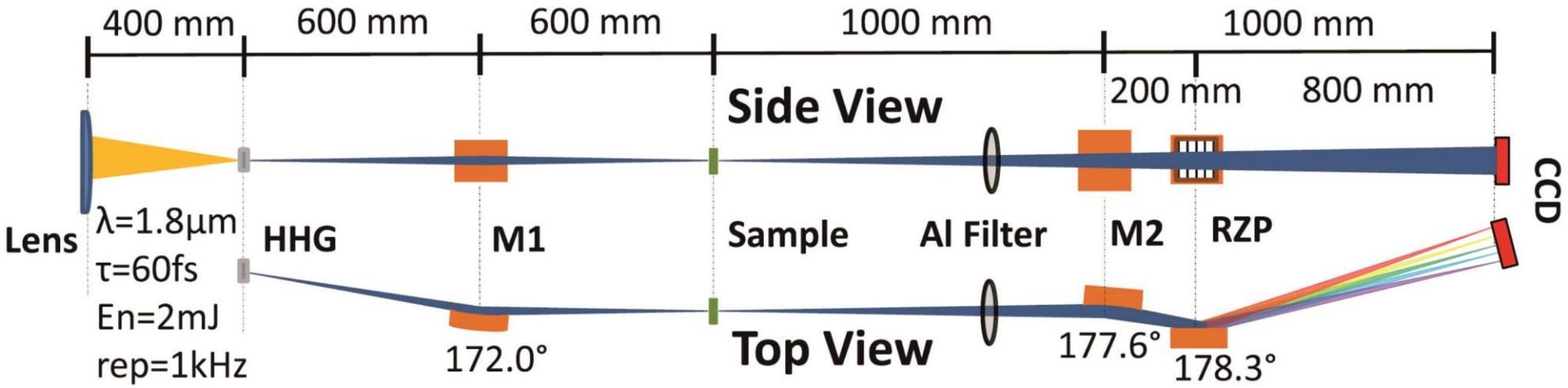




H. Löchel et al., Opt. Express **23**, 8788 – 8799 (2015).



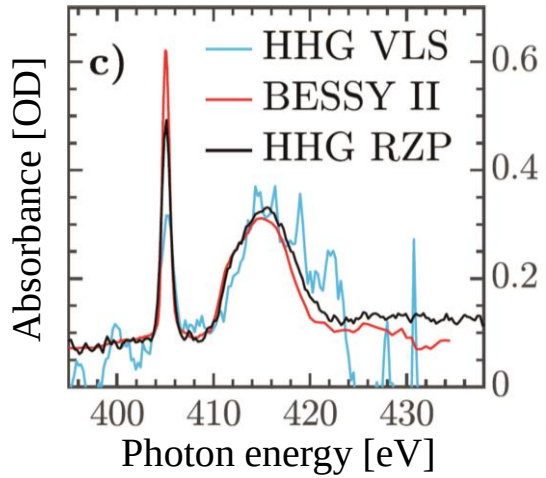
E.g., transient absorption in the water window



$CaNO_3$ in H_2O

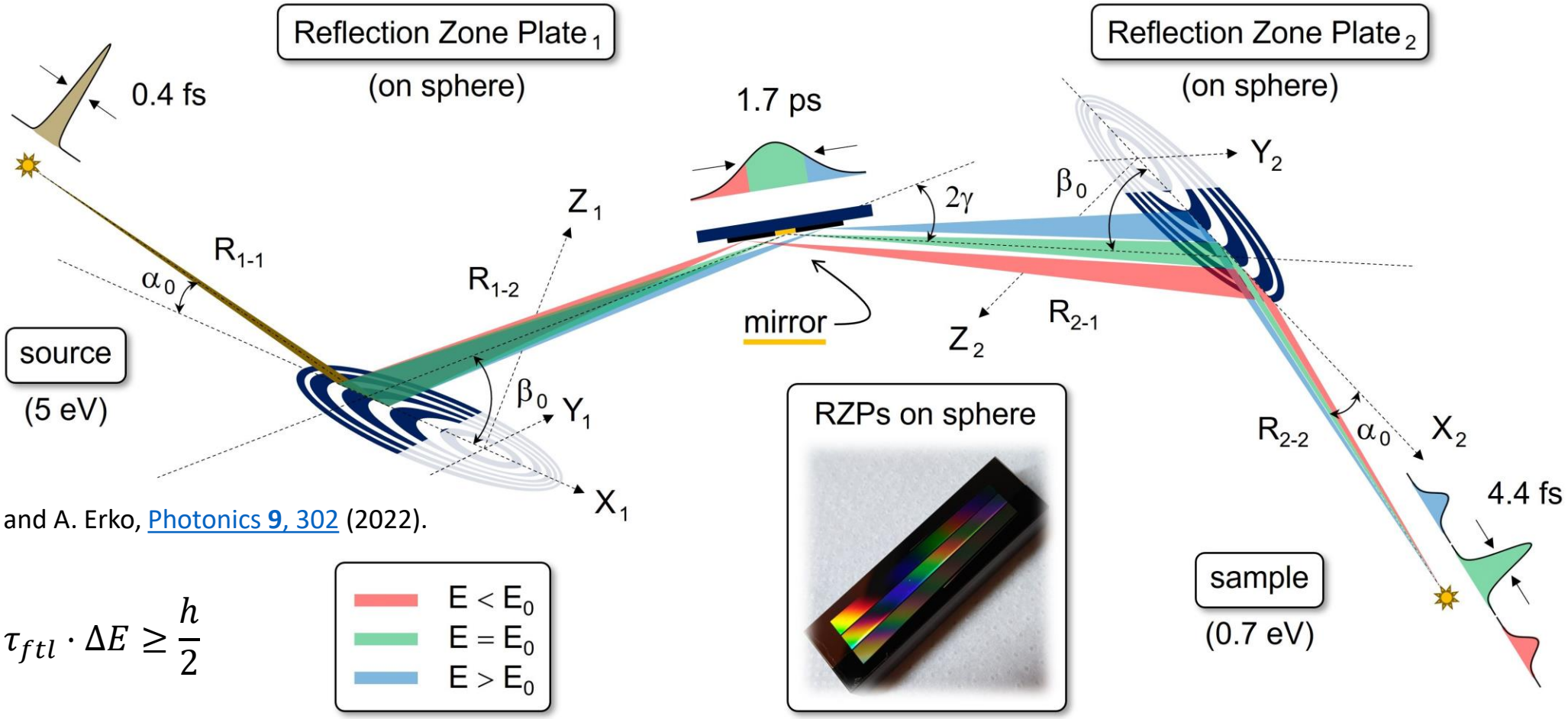
cylindrical mirror (M2) + planar RZP

@ 410 eV: $E/\Delta E \leq 9 \times 10^2$ | diffraction efficiency = 12 %



C. Kleine et al., Struct. Dynamics **8**, 034302 (2021).

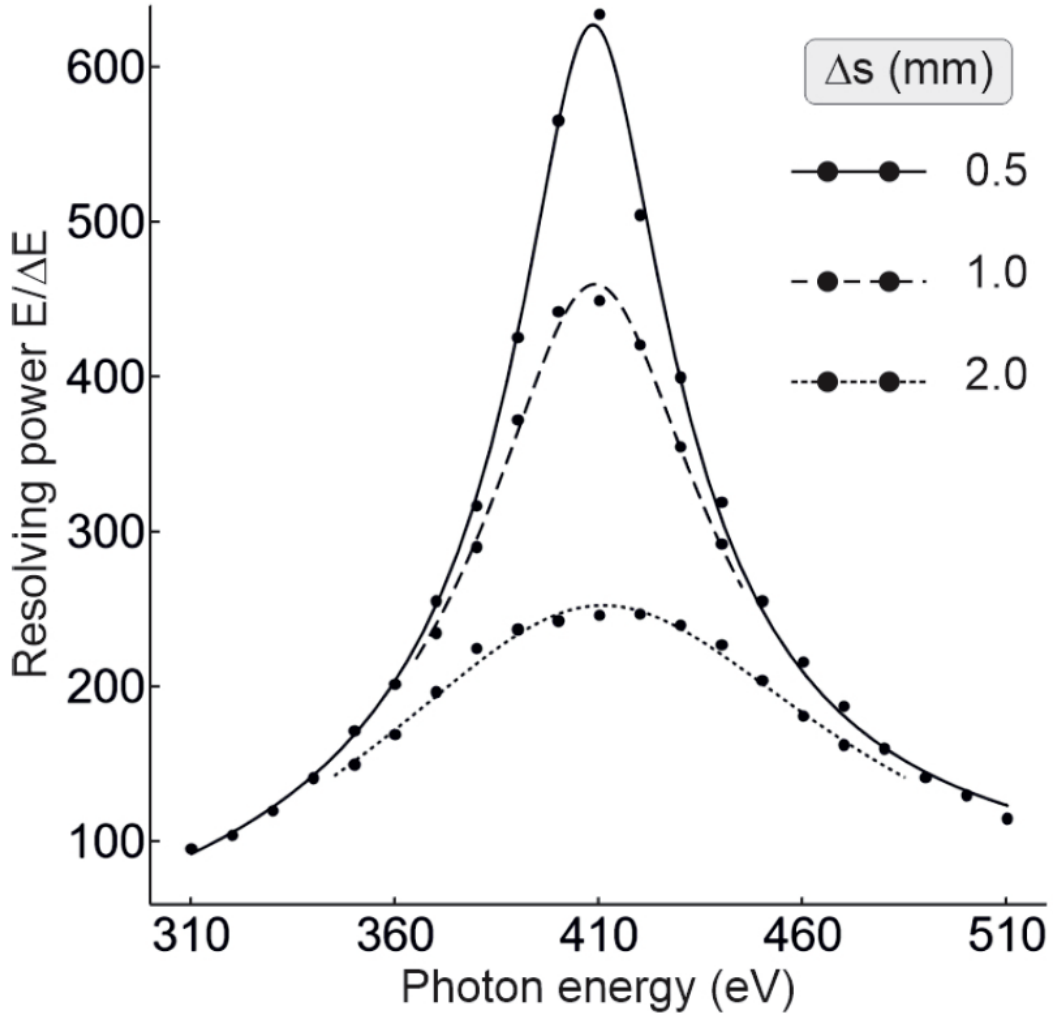
Time-delay compensated monochromatization

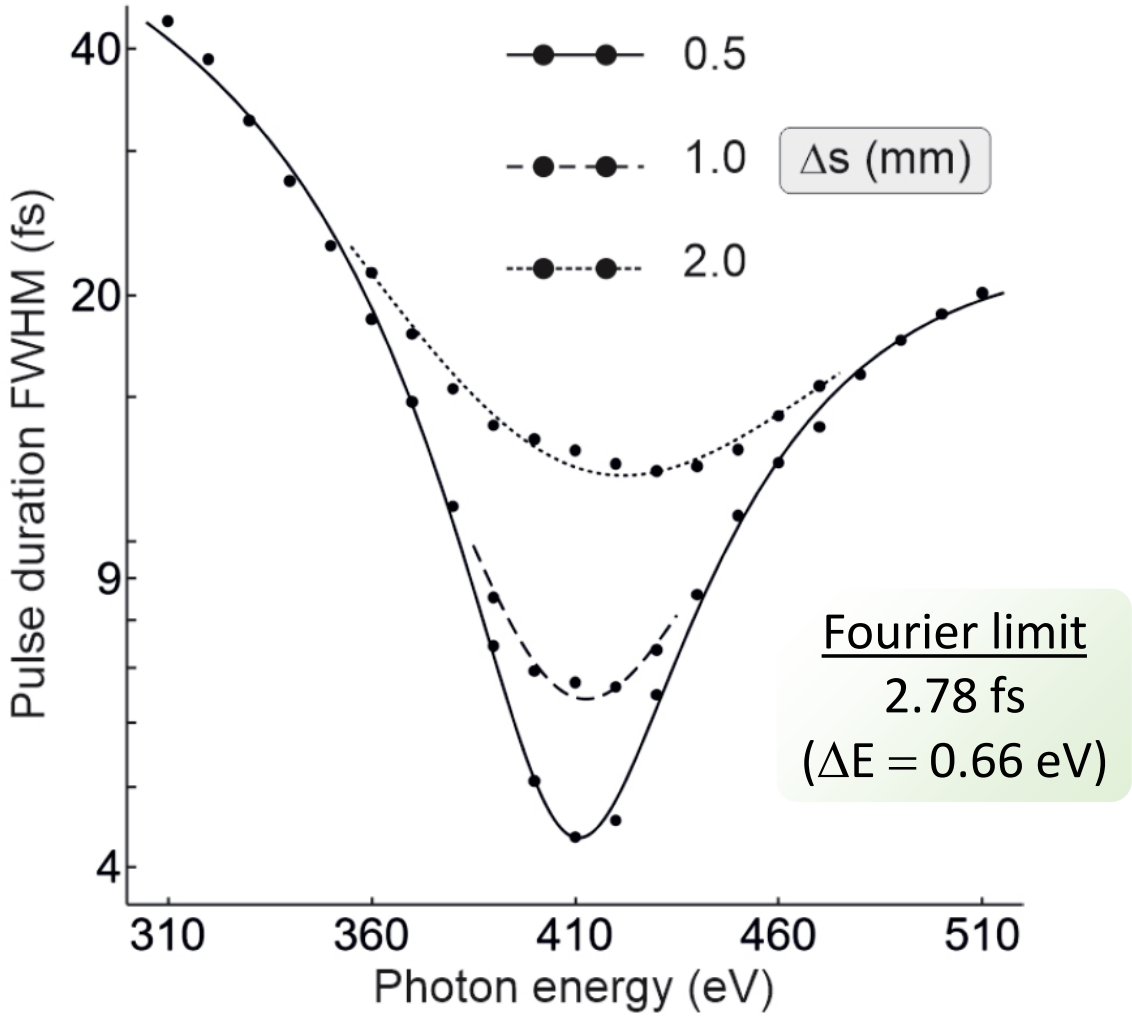


C. Braig and A. Erko, Photonics **9**, 302 (2022).

$$\tau_{ftl} \cdot \Delta E \geq \frac{h}{2}$$

Broad-band performance using curved RZPs

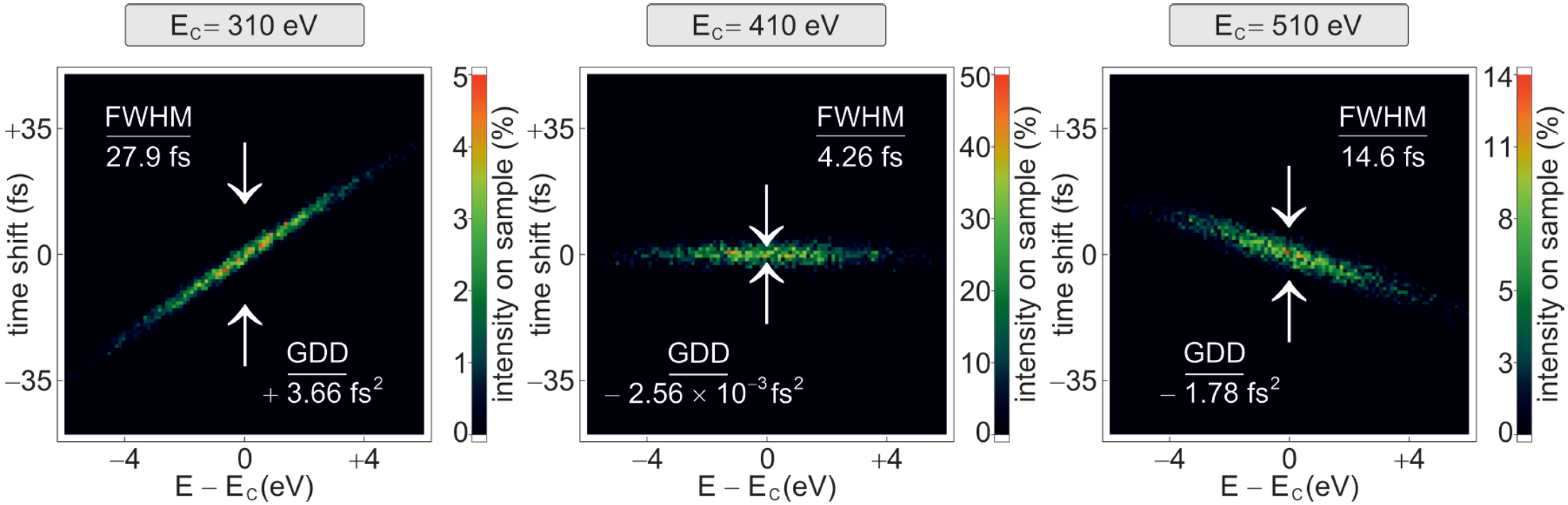




Fourier limit
2.78 fs
($\Delta E = 0.66$ eV)

Near Fourier-limited chirped pulse compression

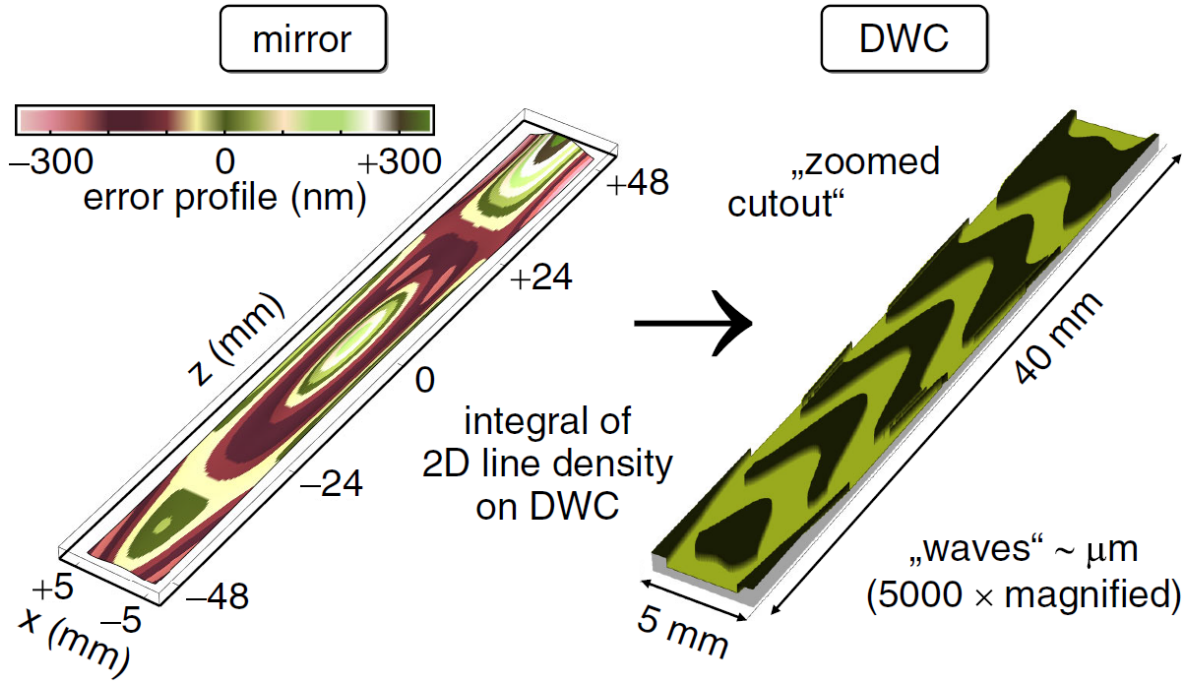
source: $\Delta E = 5$ eV, $\tau_{in} = 38$ fs $\rightarrow$ time-bandwidth product exceeds Fourier limit by a factor of 10^2



compression ratio (τ_{in}/τ_{out}) ≥ 4.5 within $\pm$ 32.5 eV (FWHM) around the design energy (410 eV)

Outlook, references and acknowledgments

diffractive wavefront correction



prediction: $E/\Delta E \sim 4 \times 10^4$ @ Ti $L\beta_{1,6}$ (coherent source)

further literature

[1] Y. Pertot, C. Schmidt, M. Matthews, A. Chauvet, M. Huppert, V. Svoboda, A. von Conta, A. Tehlar, D. Baykusheva, J.-P. Wolf, and H. J. Wörner, “Time-resolved x-ray absorption spectroscopy with a water window high-harmonic source,” Science **355**, 264 – 267 (2017).

[2] Y. Fu, K. Nishimura, R. Shao, A. Suda, K. Midorikawa, P. Lan, and E. J. Takahashi, “High efficiency ultrafast water-window harmonic generation for single-shot soft X-ray spectroscopy,” Commun. Phys. **3**, 92 (2020).

[3] Z. Yin, Y.-P. Chang, T. Balčiūnas, Y. Shakya, G. Gaulier, G. Fazio, R. Santra, L. Inhester, J.-P. Wolf, and H. J. Wörner, “Femtosecond proton transfer in urea solutions probed by X-ray spectroscopy,” Nature **619**, 749 – 754 (2023).

[4] J. Probst, C. Braig, E. Langlotz, I. Rahneberg, M. Kühnel, T. Zeschke, F. Siewert, T. Krist, and A. Erko, “Conception of diffractive wavefront correction for XUV and soft x-ray spectroscopy,” Appl. Opt. **59**, 2580 – 2590 (2020).

Thank you!