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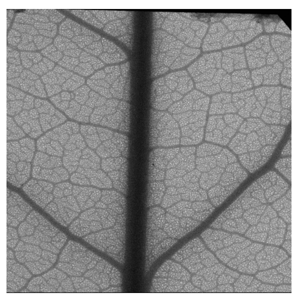
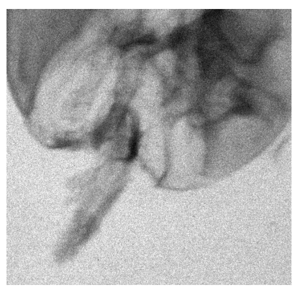
Radiations from a Water Jet Plasma Source

Wilfred Fullagar, Jens Uhlig, Monika Walczak, Sophie Canton, Claes-Göran Wahlström, Villy Sundström

Division of Chemical Physics
Division of Atomic Physics



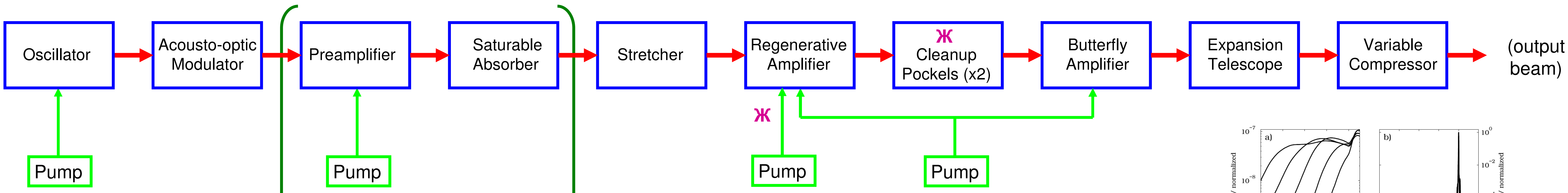
X-ray shadow image of a leaf



X-ray shadow image of a fly head

Laser system

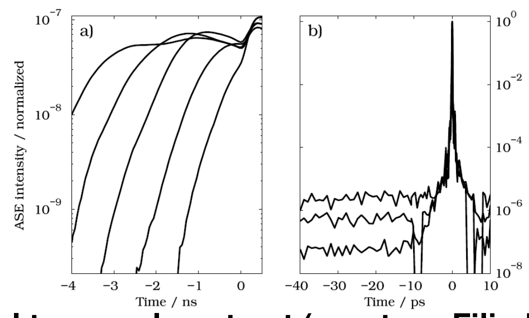
low power branch of LLC terawatt facility (June 2007)



Ж ⇒ operation critical for preplasma control

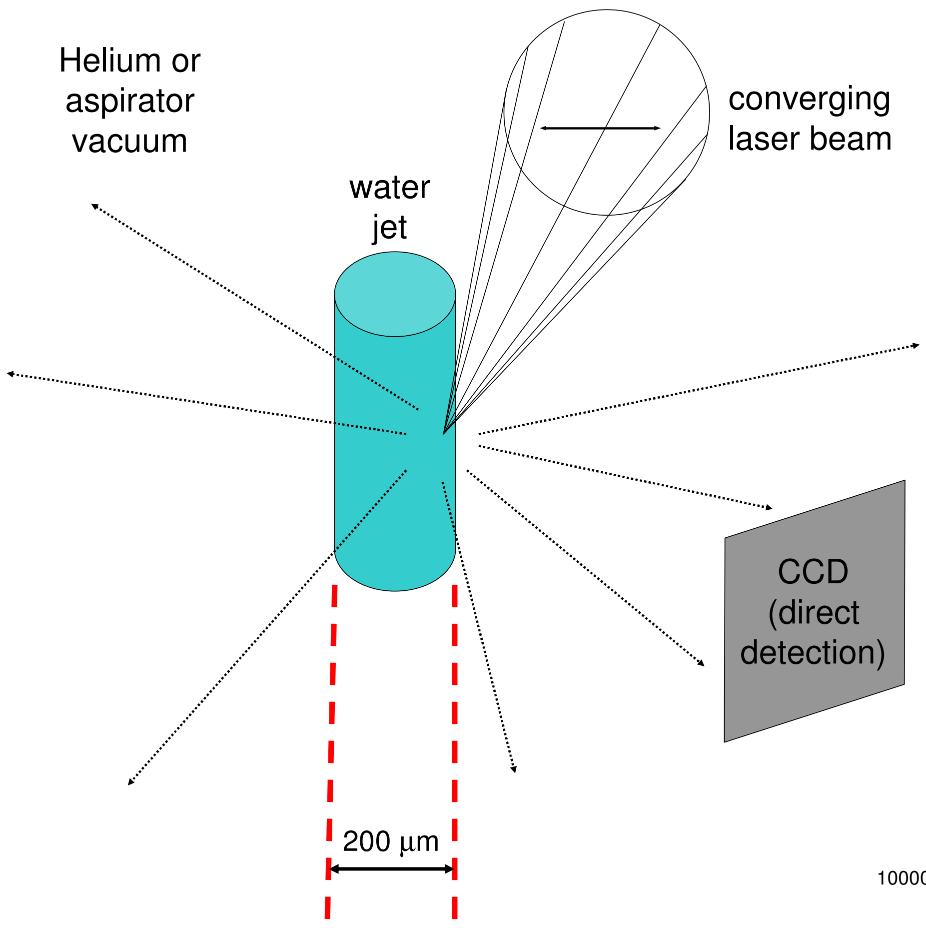
Shot-shot stability by gain saturation in butterfly amp

Output beam:
800 nm, ≥~35 fs, ≤~300 mJ/pulse, 10 Hz, ~4 cm ϕ



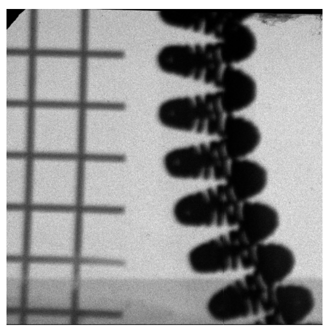
Typical temporal contrast (courtesy Filip Lindau)

X-rays

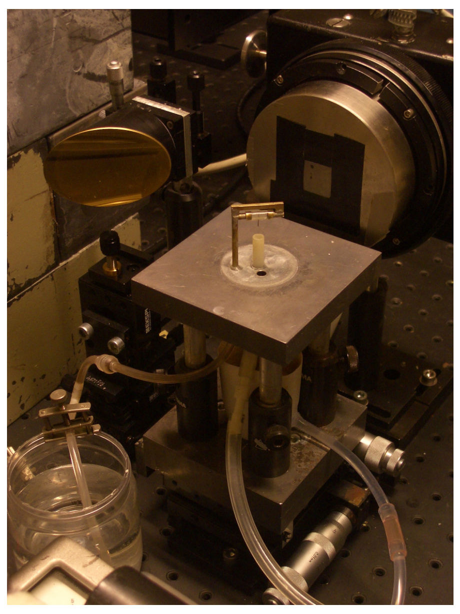


Goals:

In-house subpicosecond chemical structure dynamics, via
- pump-probe EXAFS
- pump-probe Laue crystallography

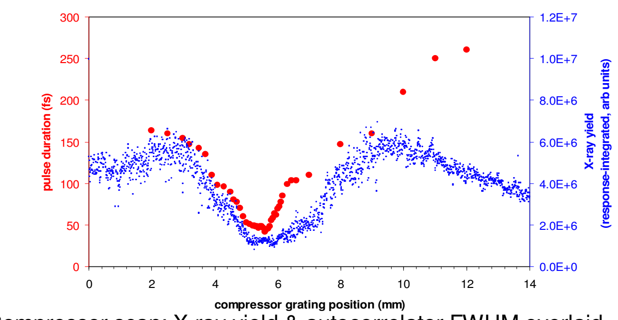


Shadow of ightbulb filament & 250μm Cu grid
Blurring ⇒ source ~30 μm

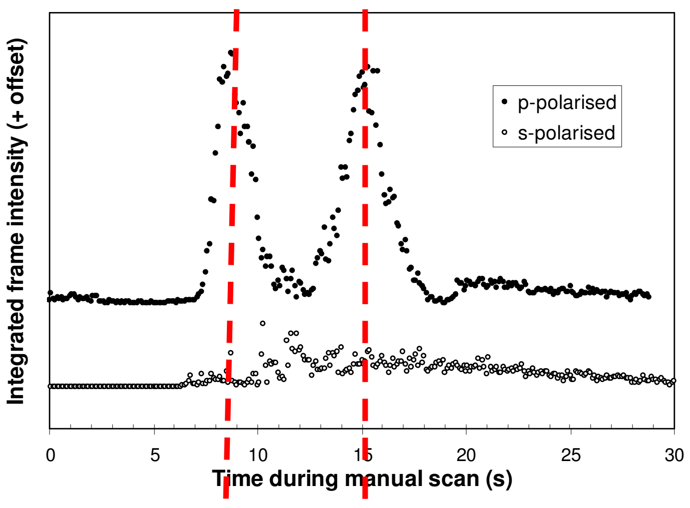


A typical setup, shield chamber removed

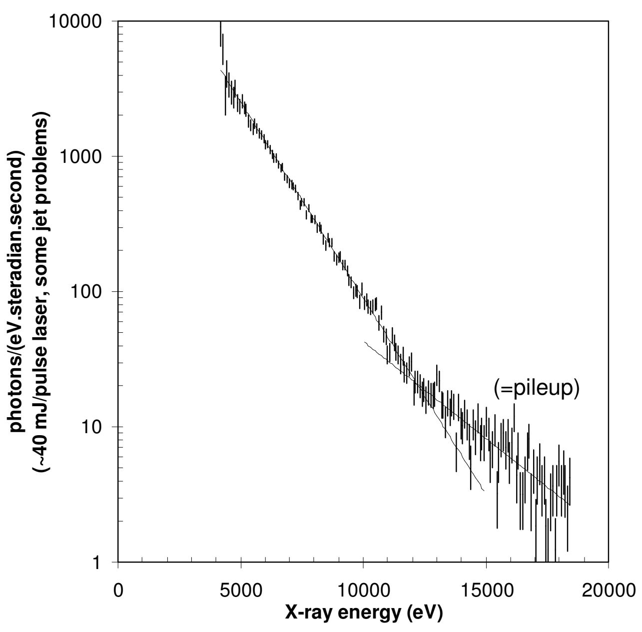
Source ambitions:	This source:
* Everyday local development access	Yes (LLC collaboration)
* Simplicity → in-house development & maintenance	Yes
* Broadband radiation	Yes (Maxwellian, T = 10-50 x10⁶ K)
* Sub-picosecond burst	Expected (believed limited by (jet ϕ)/(e⁻ velocity), or laser pulse)
* No emission lines (→ detection & mechanism issues)	Yes (oxygen Kα too soft for typical filter transmission)
* Adequate X-ray flux	Yes (EXAFS) but requires detection development
* jitter-free laser synchronisation	Yes
* Collimation	No (needed for Laue xtlgrphy; see electron beams, below)
* Small source size	Yes (multi-shot images ⇒ ~30 μm in target plane)



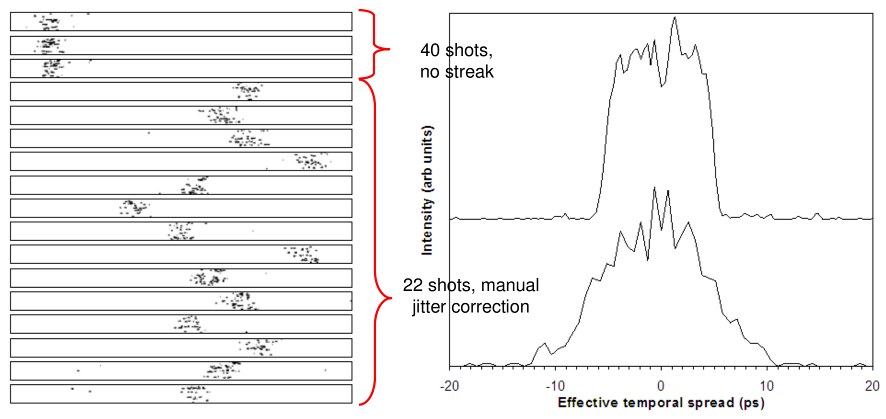
Compressor scan: X-ray yield & autocorrelator FWHM overlaid



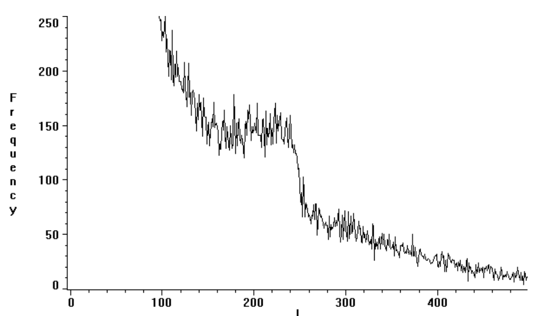
Manual scan of jet through focus



A typical mono-temperature spectrum & fit (table at right)



Instrumental resolution on X-ray streak camera



Single shot Ti K_α XAS edge spectrum (5 μm Ti foil)

Adaptable to typical kHz laser

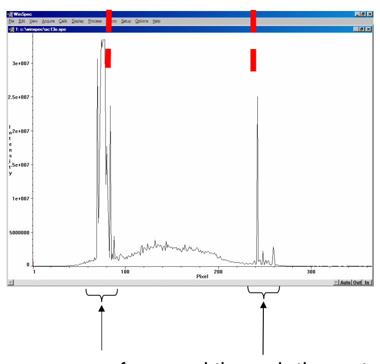
Selected relevant literature:
* R.J. Tompkins et al, Rev.Sci. Inst 69(9), 3113 (1998)
* K. Eidmann *et al, Europhys Lett.*, 55(3) 334 (2001)

Handy bunch of numbers (corresp. 10 Hz , 1 atm He operation)

Energy/pulse (mJ)	optical pulse duration	N_0 (ph/[eV.sr.sec])	T (K)
40	~200 fs (optimum)	71500	17.4×10^6
1.6	~200 fs (optimum)	14702	12.7×10^6
40	~40 fs (shortest)	29200	11.5×10^6

Electrons

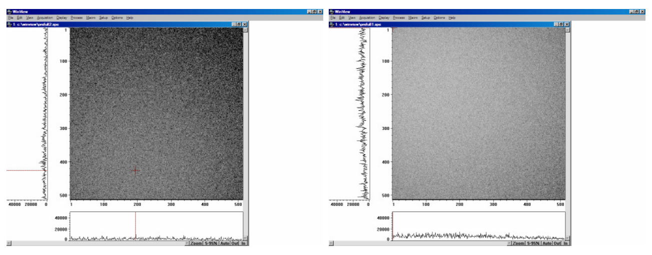
Add s-pol prepulse, several 10s ps early, 1:1 pwr ratio
⇒ X-ray-free, controllable preplasma (vast parameter space)



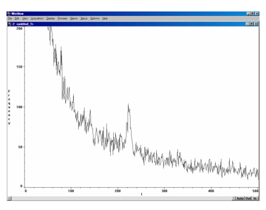
Electron beams away from and through the water jet

Also! : dramatic change of interaction geometry for continuum X-rays (typical literature ⇒ 30° - 60° incidence for assorted K_α)

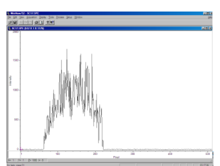
Clear flashes on GdOS screen after ~1cm air
⇒ observe strong scatter by 50 μm Be window



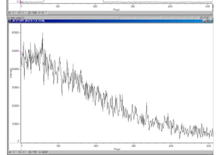
Collimated:
including strong filter scatter & assoc 2ndary radiation <10° FWHM



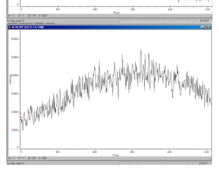
Generates 5.9keV Kα emission line through 5 mm Ti X-ray attenuation foil.



No prepulse
X-ray pinhole shadow.
(magnet present)

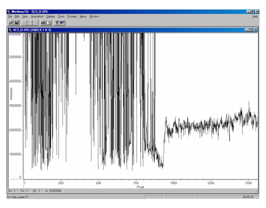


With prepulse
B-field pointing up
(NB lots scatter, vert rescale)

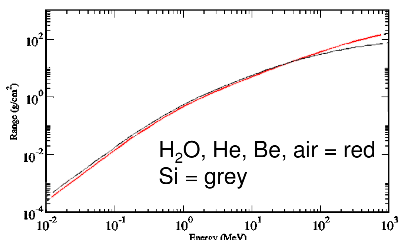


With prepulse
B-field pointing down
(NB lots scatter, vert rescale)

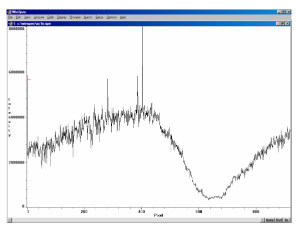
Deflects like electron in magnetic field (detector view from source)



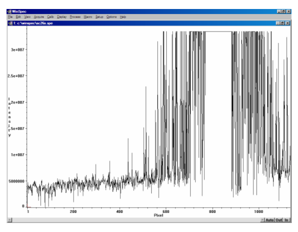
Prepulse delay scan through t=0. l→r ≡~2ns.
⇒ e-beam requires p-polarised pulse in preplasma.



Electron ranges (CSDA, ESTAR, NIST). ρ⁻¹ (cm³/g):
H_2O = 1; He = 5590, Be = 0.541, air = 769, Si = 0.429
Suggests observed beams are 20 – 200 keV.



Chirp scan, no prepulse
No electrons
X-rays only, as above

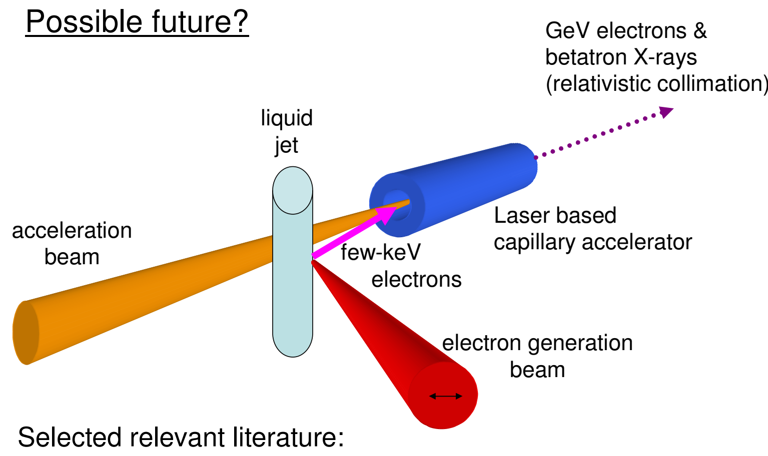


Repeat, with prepulse
e⁻ beams at shortest pulses
Note rescale to include saturation

Strong e⁻ generation when s- & p- pulses briefest. Suggests:
* proton motion during p-pulse unimportant
* e⁻ beam emission = non-resonant phenomenon
* e- beam pulse duration ← energy range, distance from src

Selected literature precedents:
* S. Bastiani *et al, Phys. Rev. E*, 56(6), 7179 (1997)
* X.-Y. Peng *et al, Chin. Phys. Lett.*, 21(4), 693 (2004)

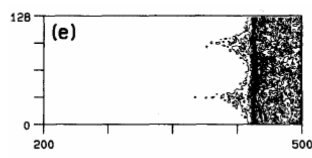
Possible future?



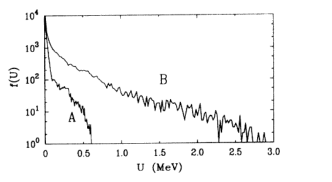
Selected relevant literature:
* A. Rousse et al, Phys. Rev. Lett., 93(13), 135005 (2004)
* W.P. Leemans *et al, Nature Physics,* October(2), 696 (2006)

Protons??

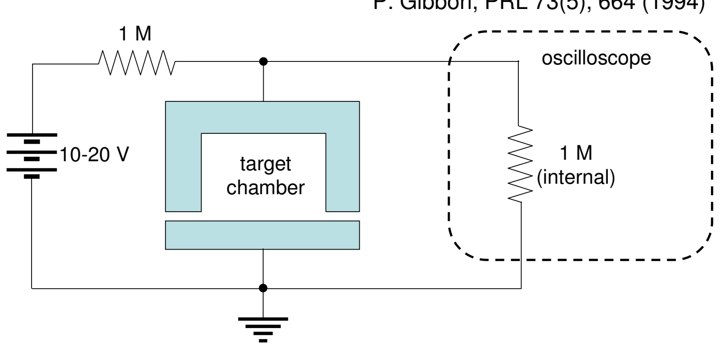
H⁺ emission conceivable with long pulses, high NA focus
For example:



H⁺ jets moving to left, PIC simulation
F. Brunel, Phys. Fluids, 31(9) 2716 (1988)



Simulated electron spectra
with & without mobile H⁺
P. Gibbon, PRL 73(5), 664 (1994)



Circuit observes all ionization in chamber → strong signal when hitting jet.
But! : only partial correlation with X-ray yield.... ***why?***

Protons stopped in chamber by He (→ ionisation) : see below
However : 524 eV oxygen K_α (1/e in He → 12 cm), & possible other contibutions

Proton range in He (p-STAR, NIST)
ρ⁻¹ = 5990 cm³/g
⇒ H⁺ < ~1 MeV stopped in chamber