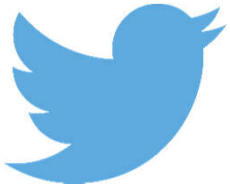

ESRF
The European Synchrotron

MHz hard X-ray imaging at the ESRF

Alexander Rack
European Synchrotron Radiation Facility, Grenoble, France



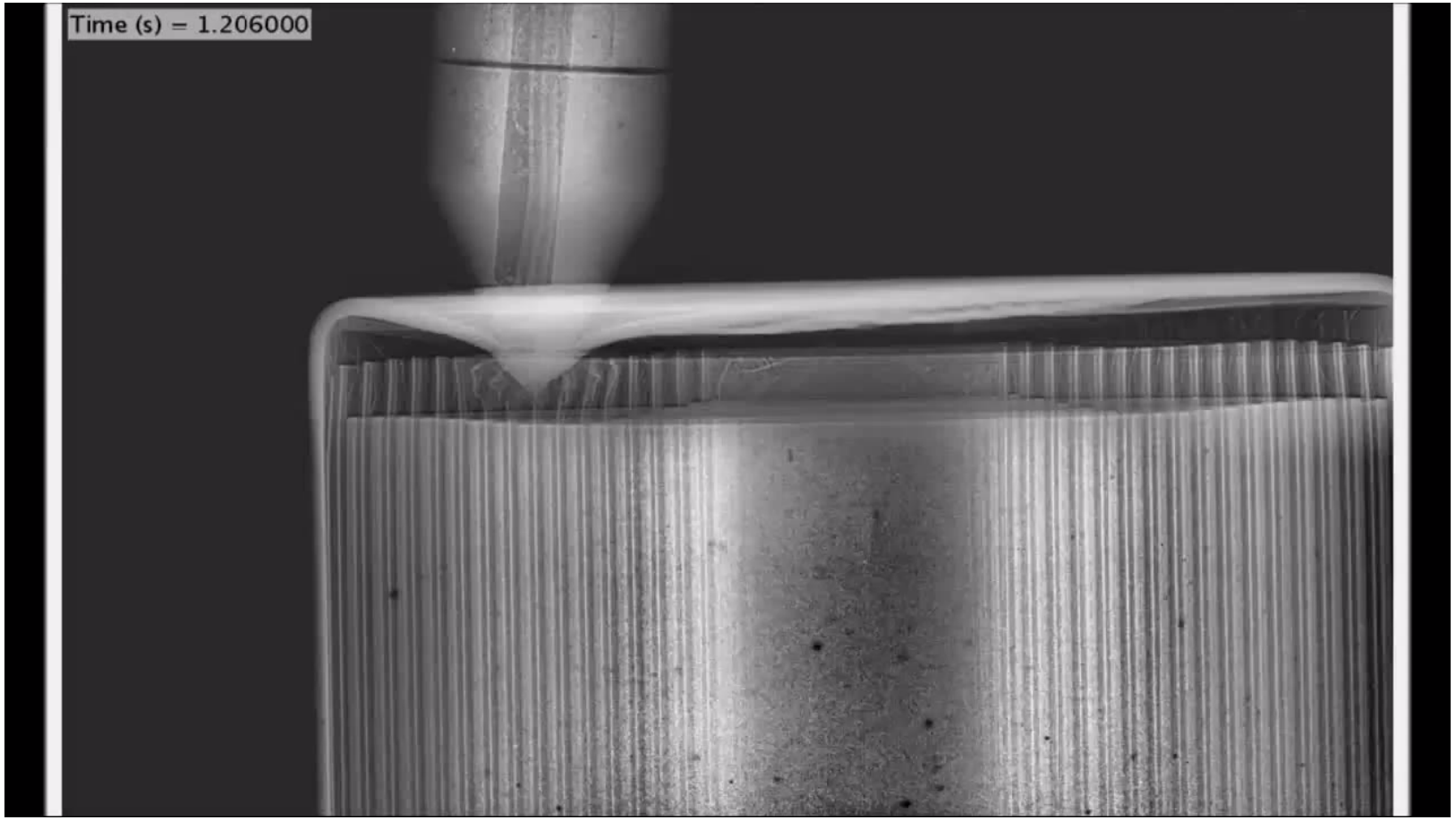
https://twitter.com/SoM_esrf

THE SCIENCE WITHIN MOVING IMAGES

1st Juli 1940, Tacoma Narrows Bridge, USA

Analysis of (non-linear) dynamics: cyclic fold bifurcation

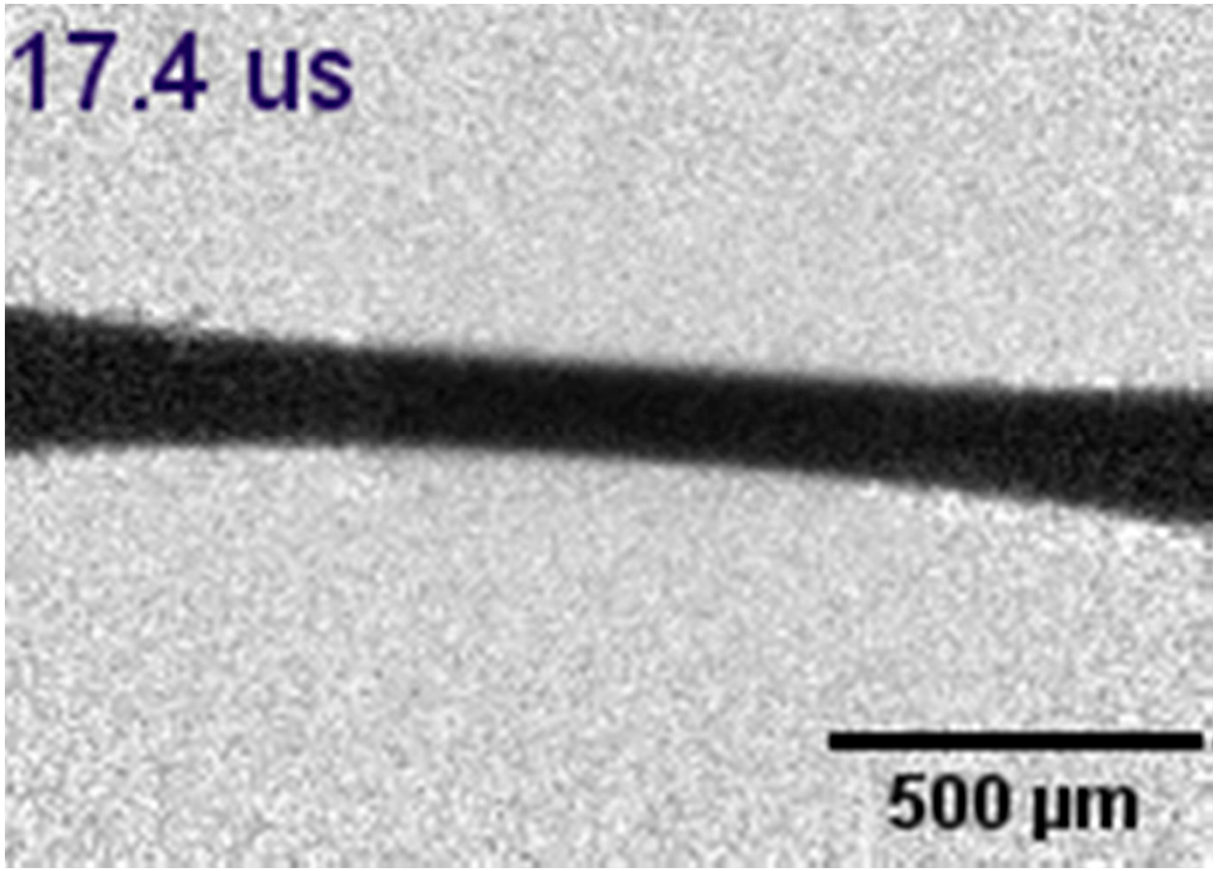
LI-ION BATTERY THERMAL RUNAWAY

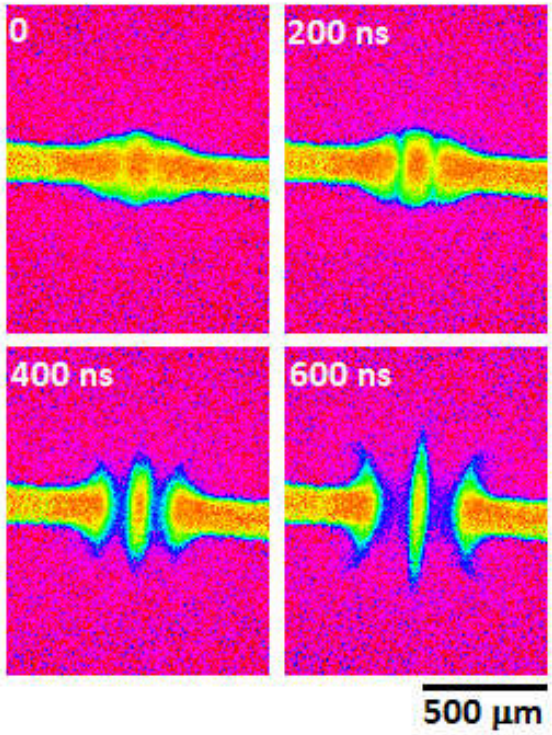


D. P. Finegan, et al, Identifying the cause of rupture of Li-ion batteries during thermal runaway Advanced Science, vol. 5, no. 1, 1700369 (2018)

polychromatic beam, peak: 75 keV, pco. dimax, 1250 fps, LuAG:Ce

ELECTRIC ARC IGNITION DURING FUSE OPERATION



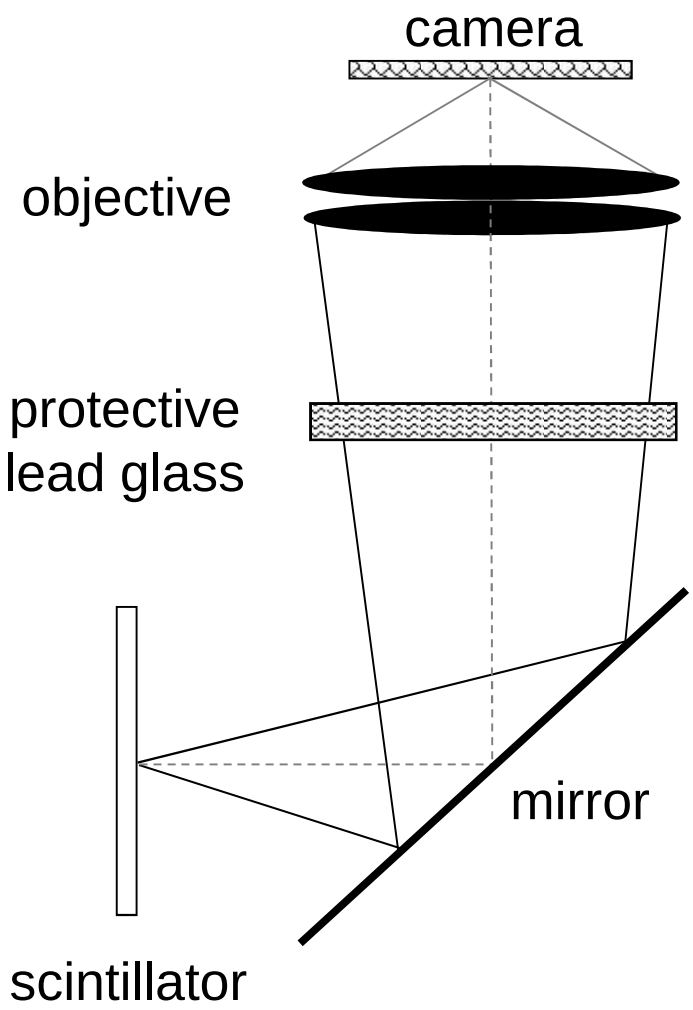


M. P. Olbinado et al, MHz frame rate hard X-ray phase-contrast imaging using synchrotron radiation, Optics Express, **25** (12), 13857-13871 (2017).

polychromatic x-ray beam, mean: 30 keV; 5 Mfps; exposure: 110 ns

Detectors, Contrast, Bunch Imaging

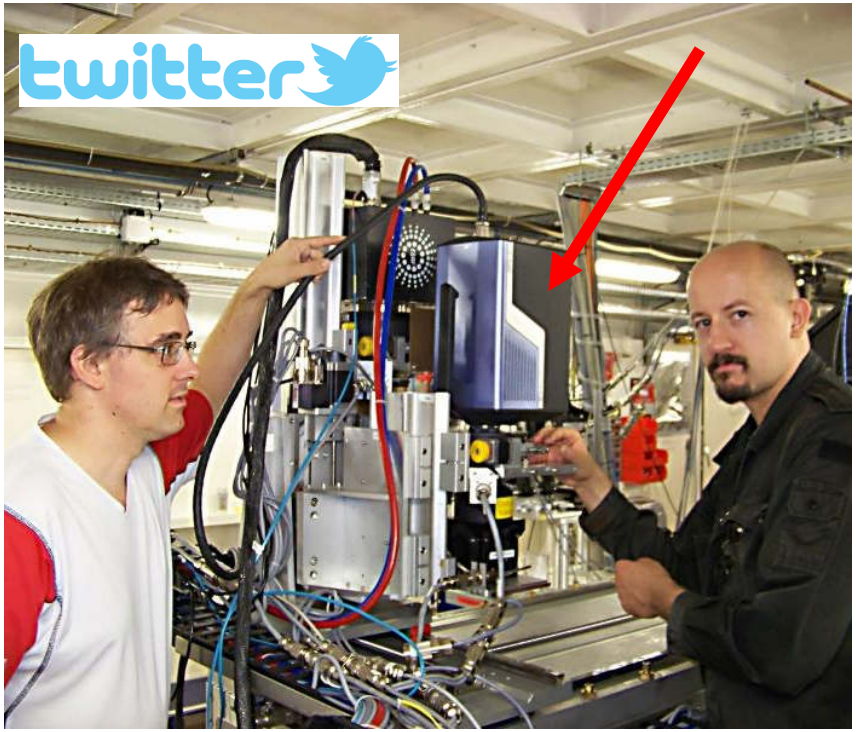
HIGH-SPEED IMAGING DETECTION SCHEME

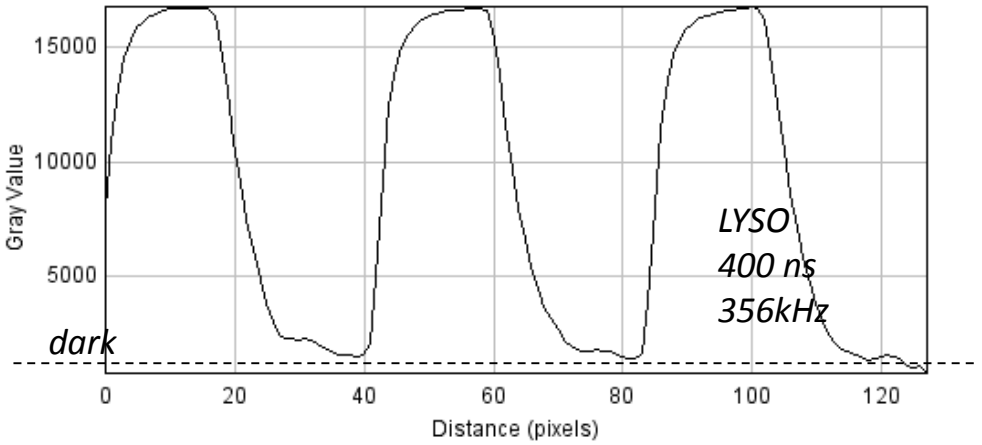


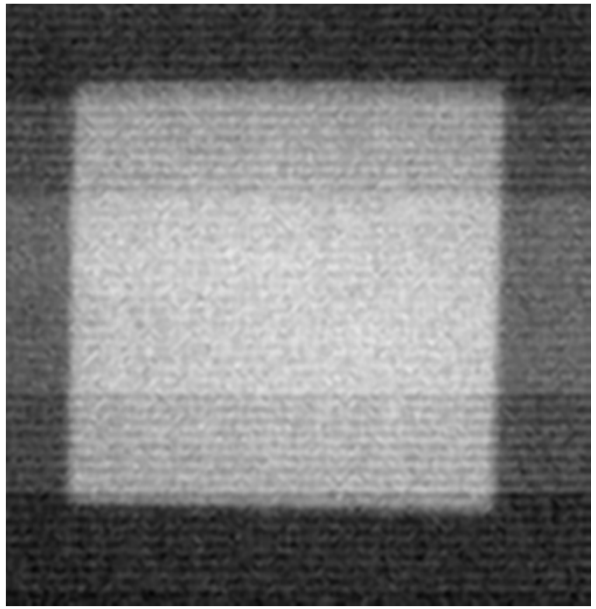
A. Koch
Nucl Instr Meth A 348 (1994)

- **pco.Dimax: CMOS-based camera**
- **2016 x 2016 chip, 11 µm pixel size**
- **exposure time: 1.28 µs … 40 ms**
- **36 GB fast camera memory**
- **'non-continuous' acquisition, i.e. 1.5 µs exp / 35504 FPS (28 µs)**

SINGLE-BUNCH RADIOSCOPY DEVELOPMENT: SHIMADZU HPV-X



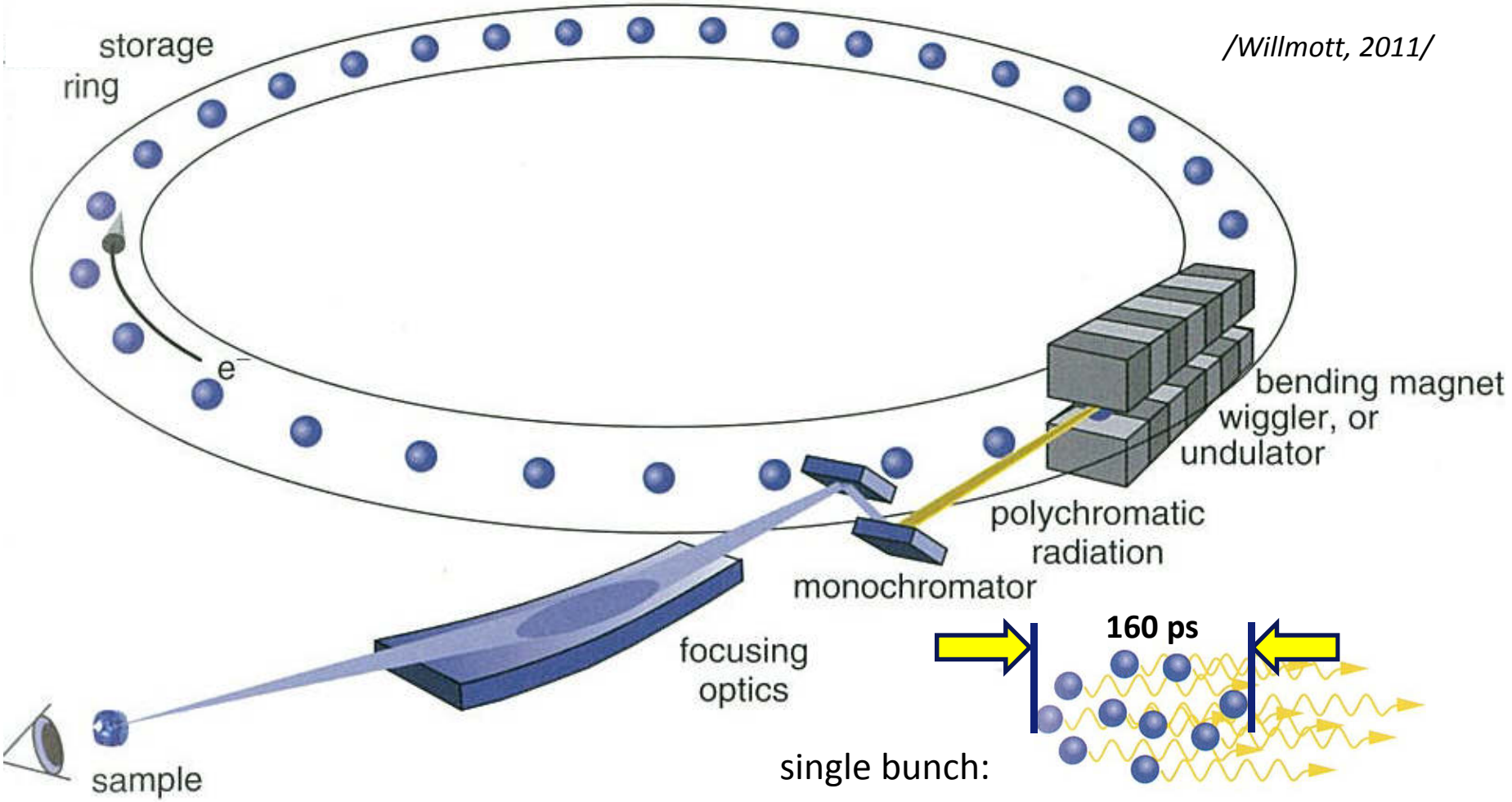




Shimadzu HPV-X2:

- 10 Mio images/second
- 128/256 ring buffer
- FrameTransfer CMOS (FTCMOS)

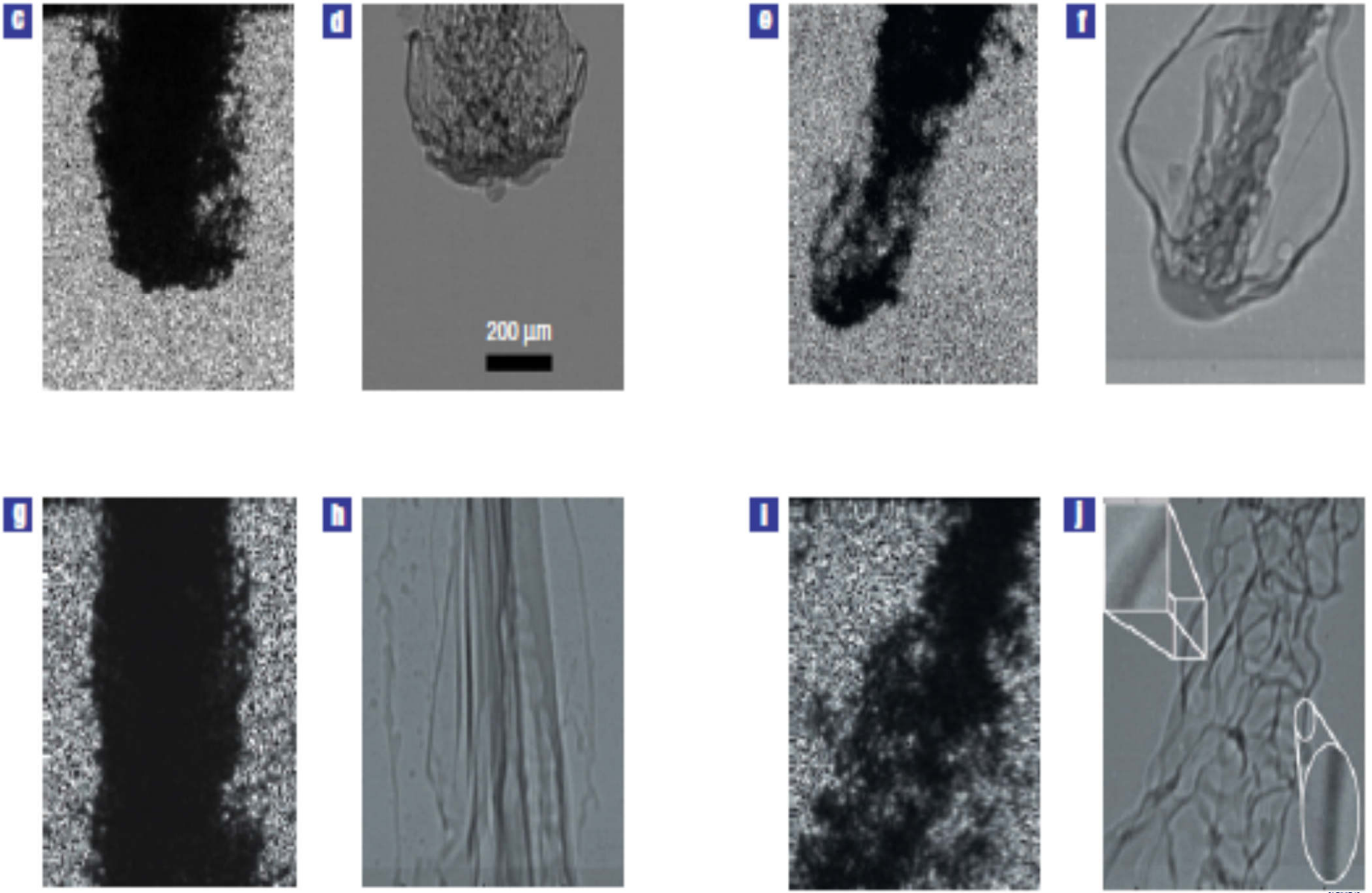
ULTRA FAST ACQUISITION: SINGLE-BUNCH IMAGING



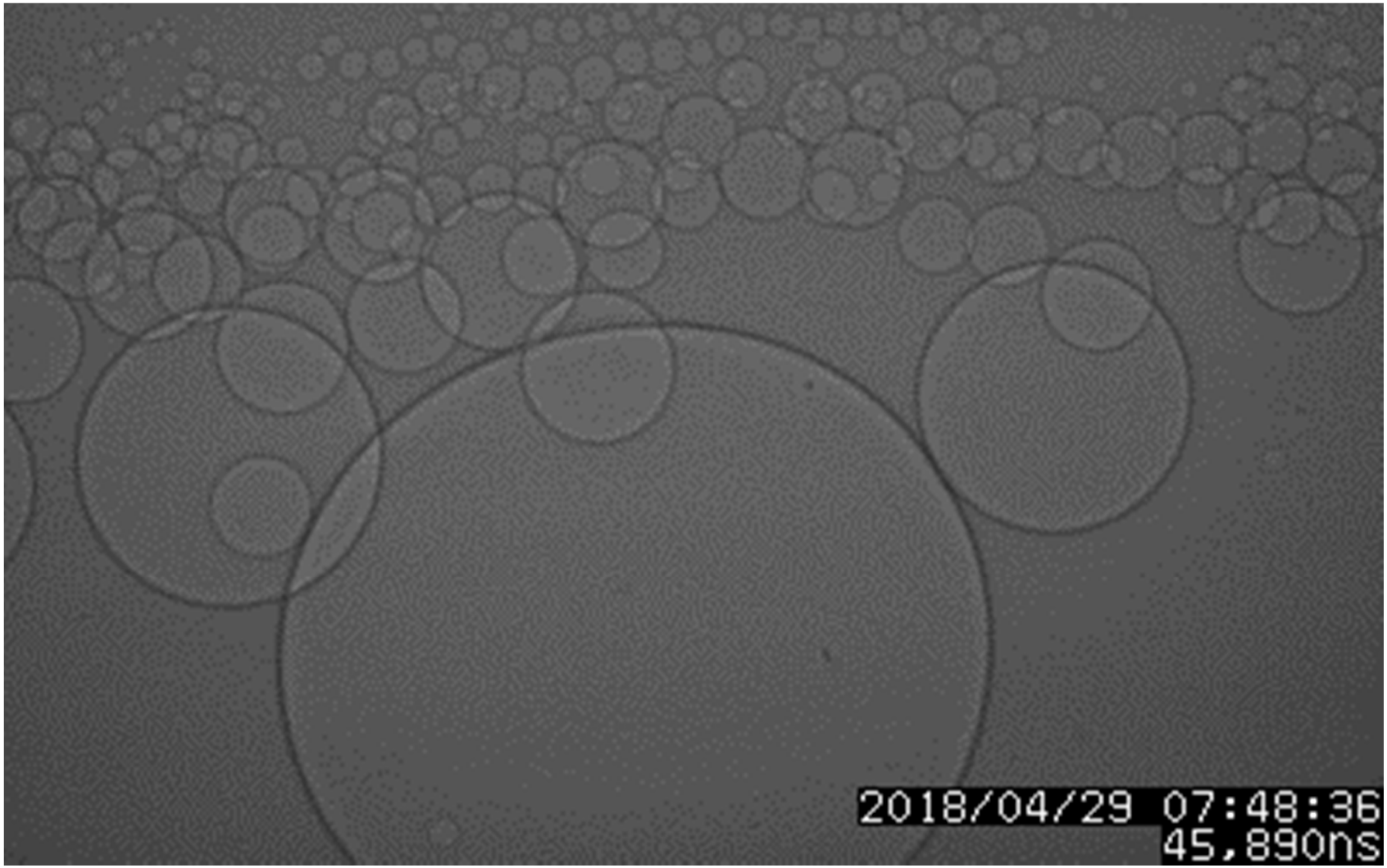
/Willmott, 2011/

- revolution 2.8 µs
- 4 bunches = 1.4 MHz frame rate
- Approx. 160 ps flash exposure

SINGLE-BUNCH IMAGING @ ADVANCED PHOTON SOURCE

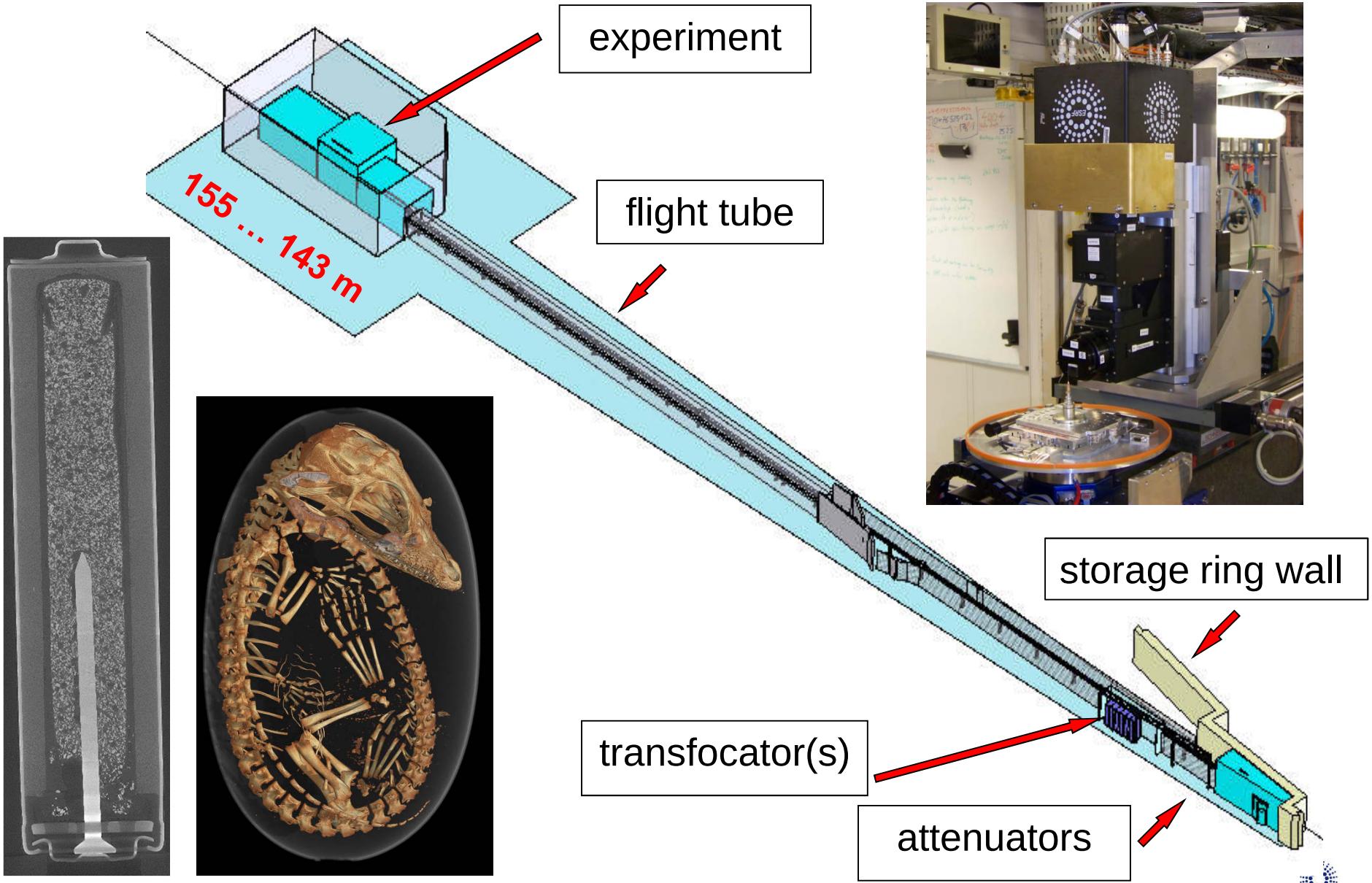


CONTRAST - LASER-INDUCED BUBBLE COLLAPSE



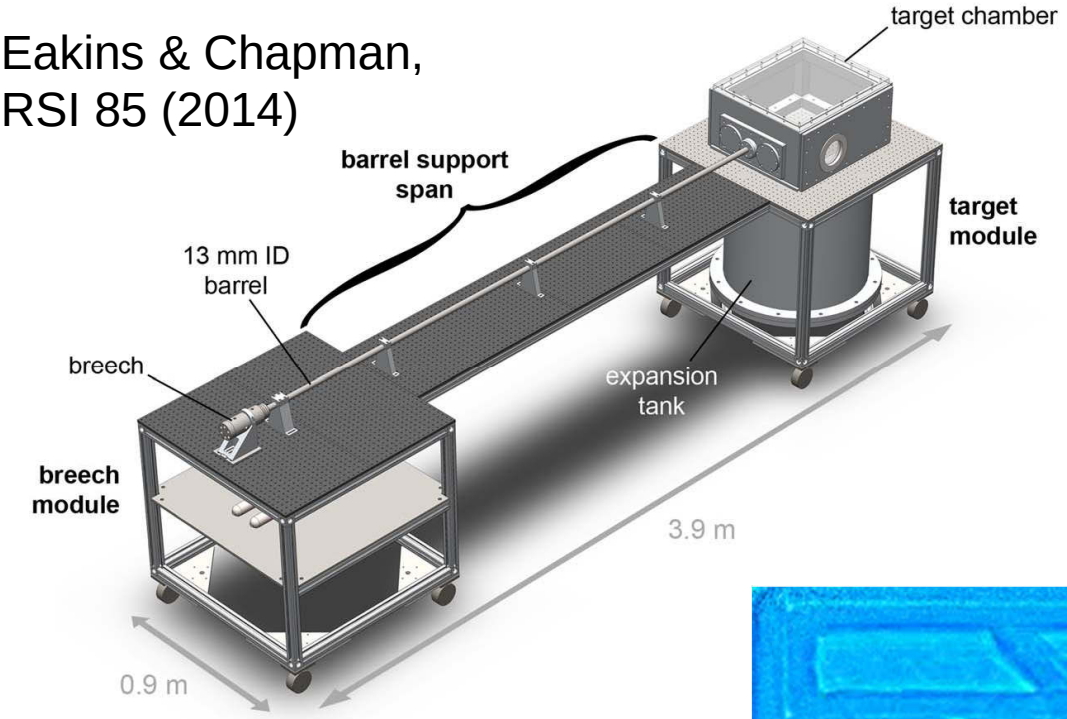
Examples

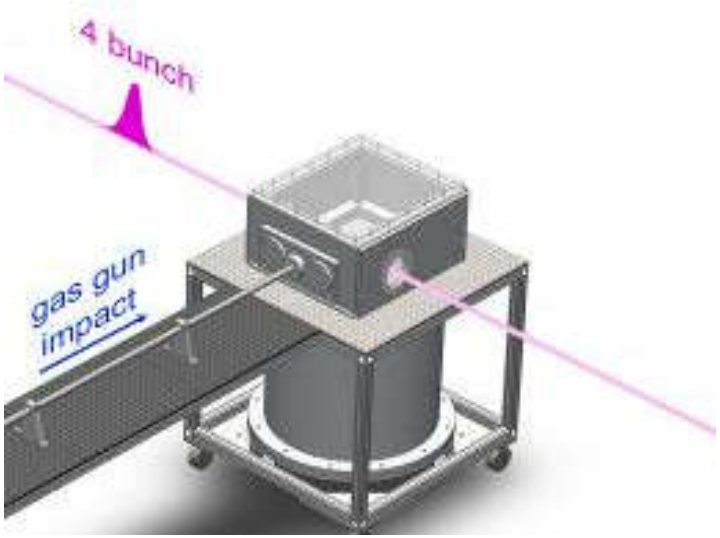
FULL-FIELD HARD X-RAY IMAGING BEAMLINE ID19 @ ESRF

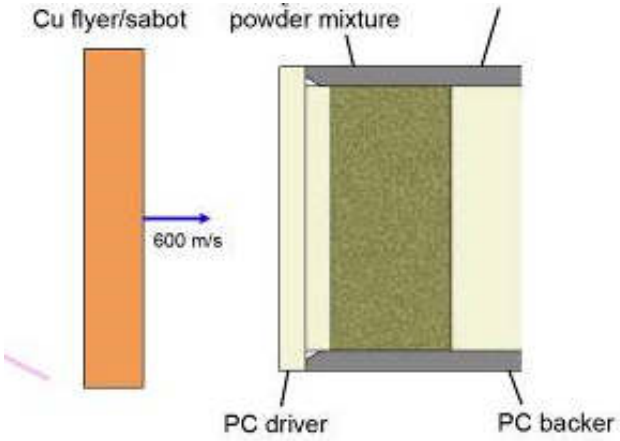


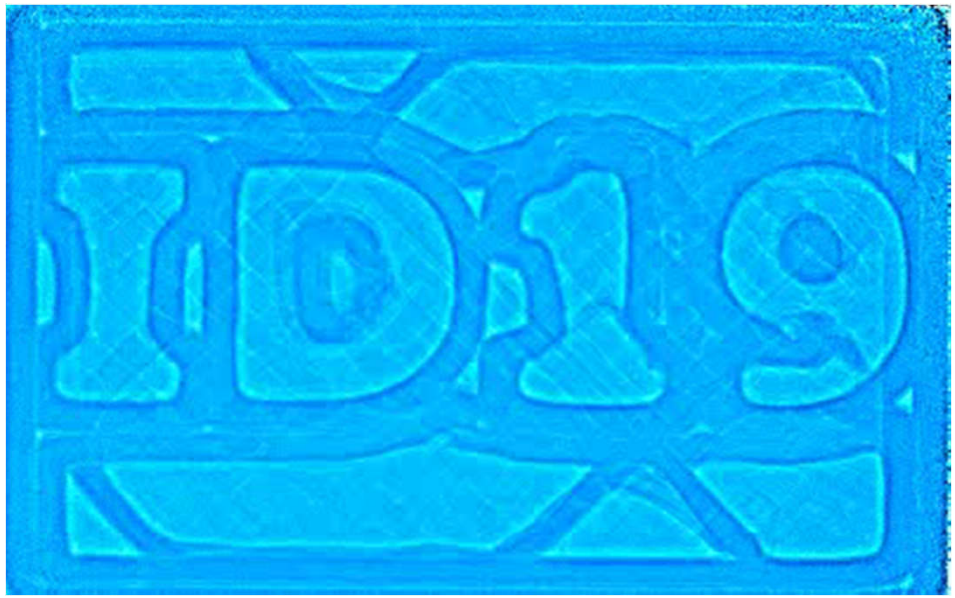
IMPACT STUDIES WITH GAS GUN AND MHZ HARD X-RAY RADIOSCOPY

Eakins & Chapman,
RSI 85 (2014)



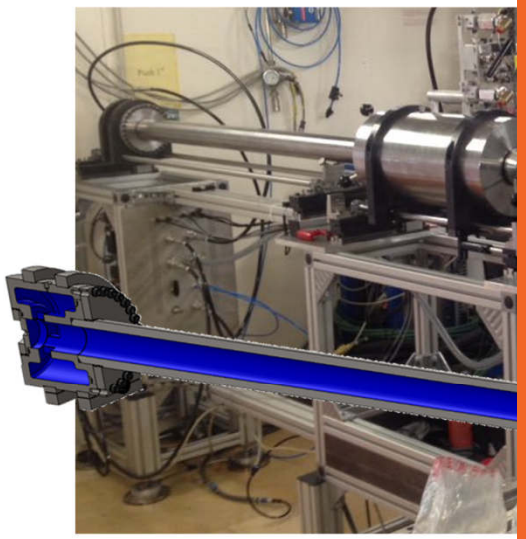


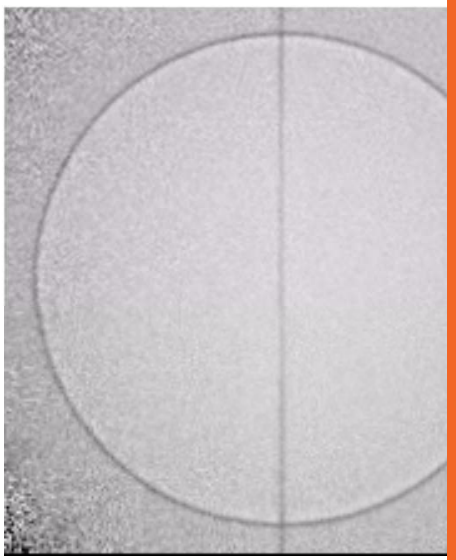




Oxford University, Imperial London

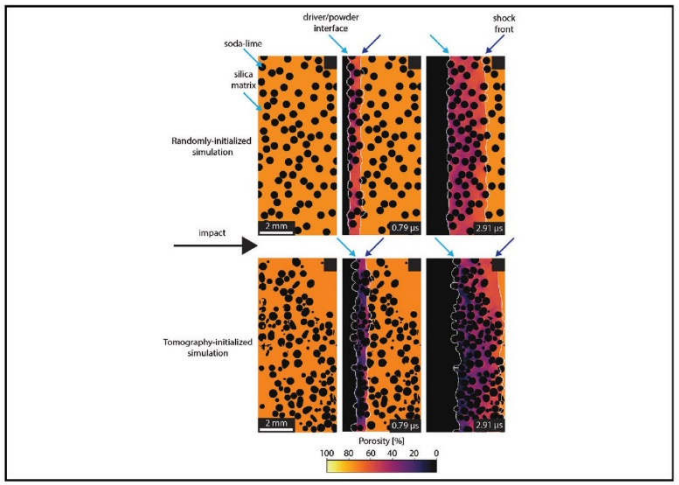
2-STAGE GAS GUN @ 3.8 MHz





Journal of Applied Physics

scitation.org/journal/jap



Volume 125, Issue 1, 7 Jan. 2019

Insights into local shockwave behavior and thermodynamics in granular materials from tomography-initialized mesoscale simulations

J. Appl. Phys. **125,** 015902 (2019); doi.org/10.1063/1.5048591

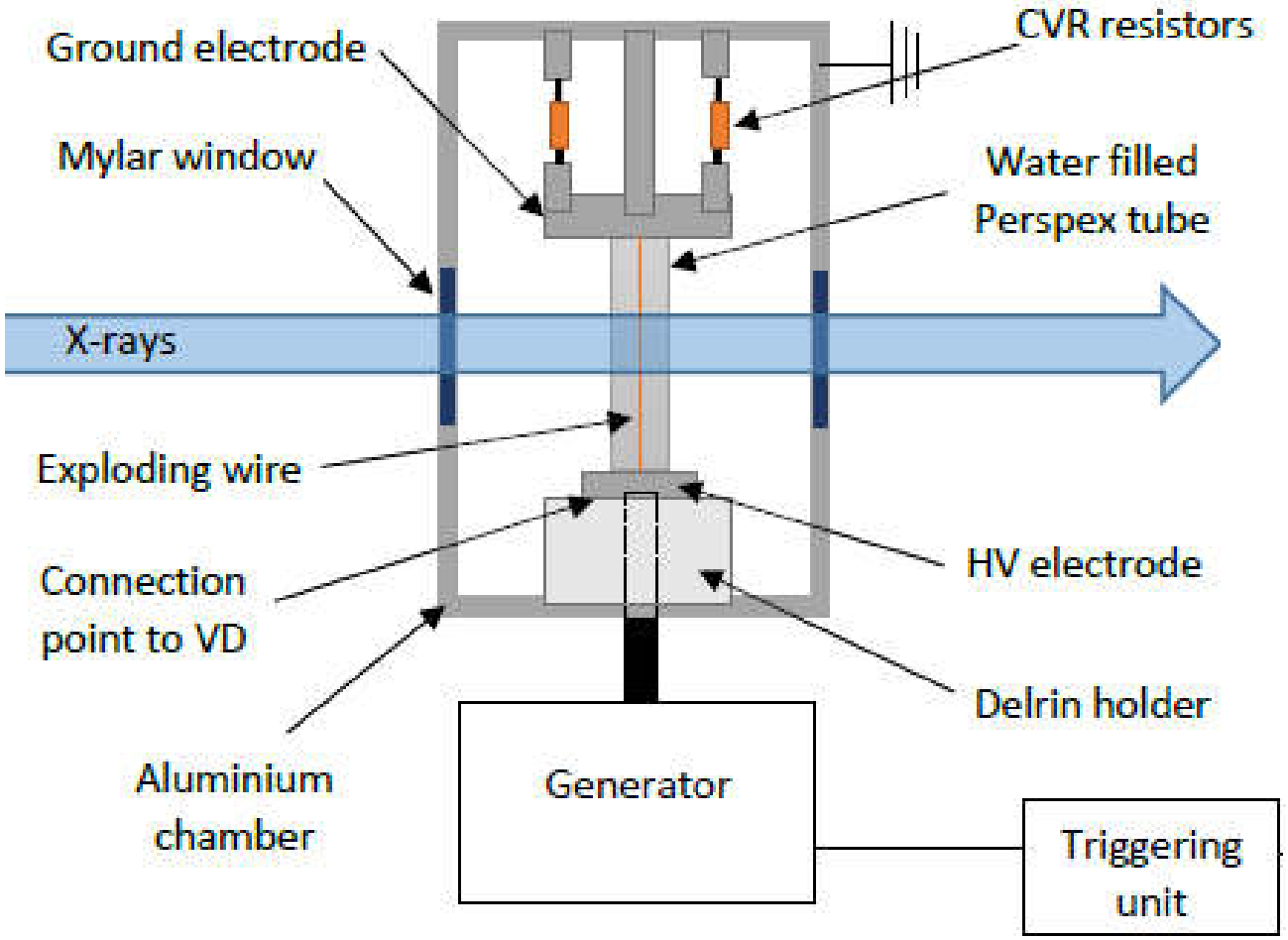
M. E. Rutherford, J. G. Derrick, D. J. Chapman, G. S. Collins, *et al*

AIP Publishing

.kins, Chapman,
ıarte et al.
perial College
ndon & Oxford
ıiversity

r: impact 4 km/s
kwave-driven
rmation
= ~2 x impact
ɔver-ridden,
v regime
2x 1.9 MHz
'daniel_eakins/

PULSED-POWER-DRIVEN WIRE EXPLOSIONS IN WATER

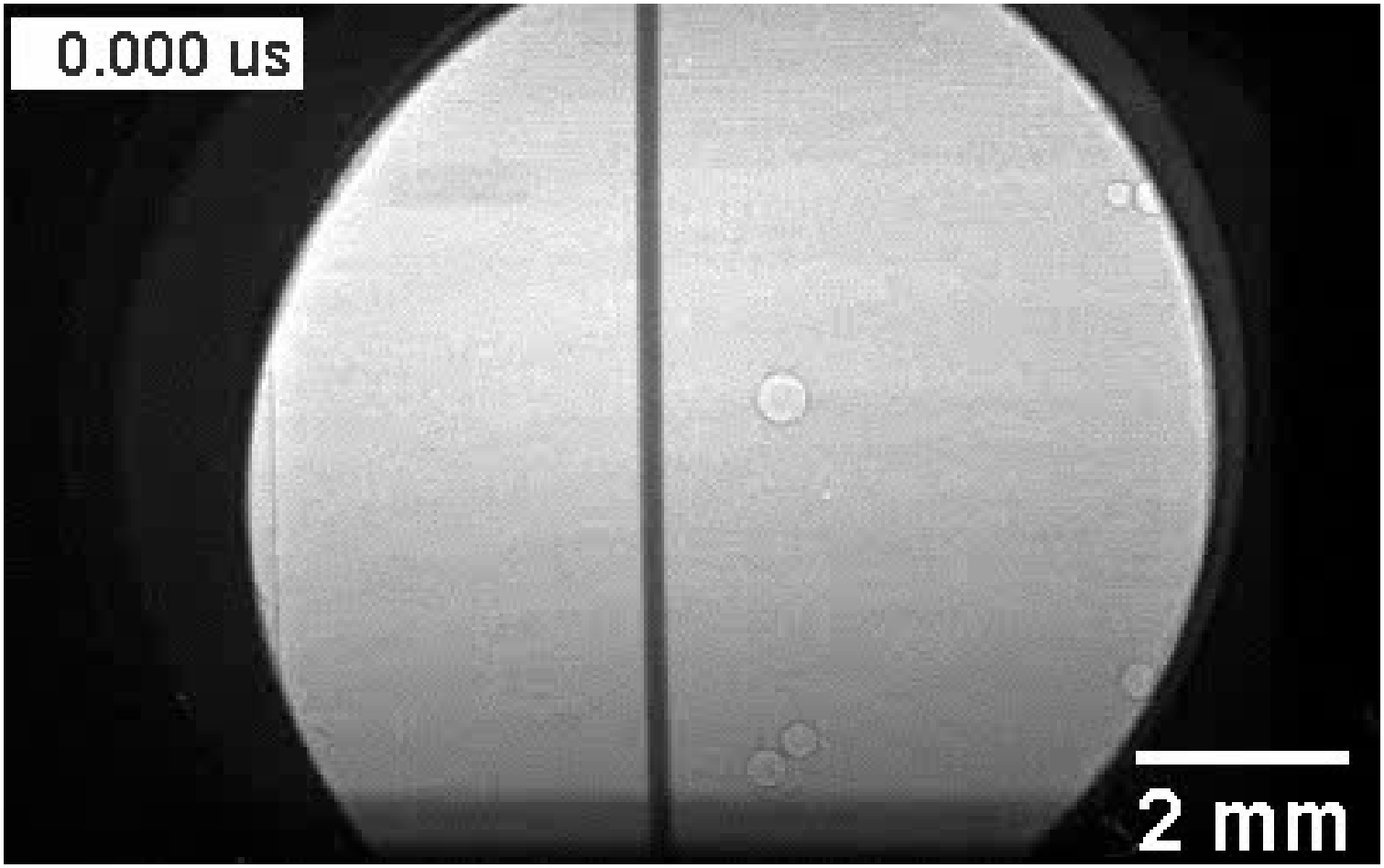


Imperial College London

In collaboration with S. Bland, D. Yanuka, A. Rasoshek, S. Theocharous, Y. E. Krasik (Imperial College London, UK)

D. Yanuka et al, J. Appl. Phys., vol. 124, 153301 (2018).
S. Theocharous, et al Rev. Sci. Instrum., vol. 90, 013504 (2019).
D. Yanuka et al, Physics of Plasma, submitted (2019).

PULSED-POWER-DRIVEN WIRE EXPLOSIONS IN WATER

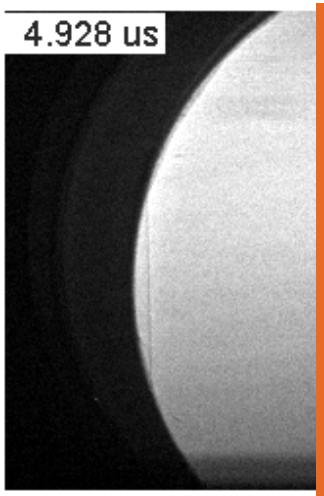


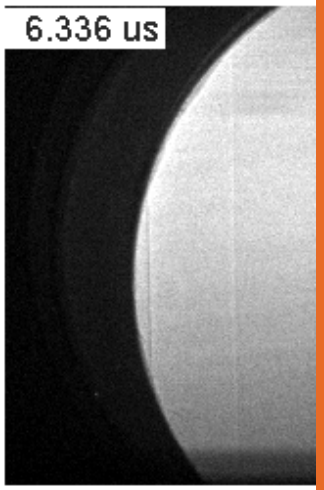
4-bunch filling mode (176 ns); polychromatic x-ray beam, mean 30 keV; 1.4 Mfps; exposure: 200 ns

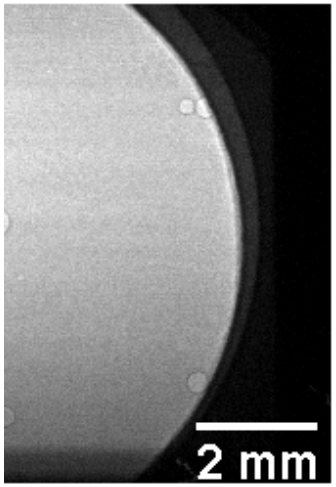
Imperial College London

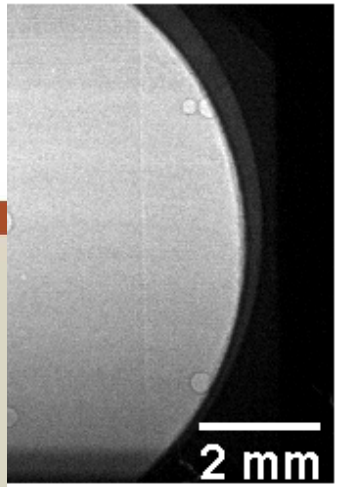
In collaboration with S. Bland, D. Yanuka, A. Rasoshek, S. Theocharous, Y. E. Krasik (Imperial College London, UK)

PULSED-POWER-DRIVEN WIRE EXPLOSIONS IN WATER





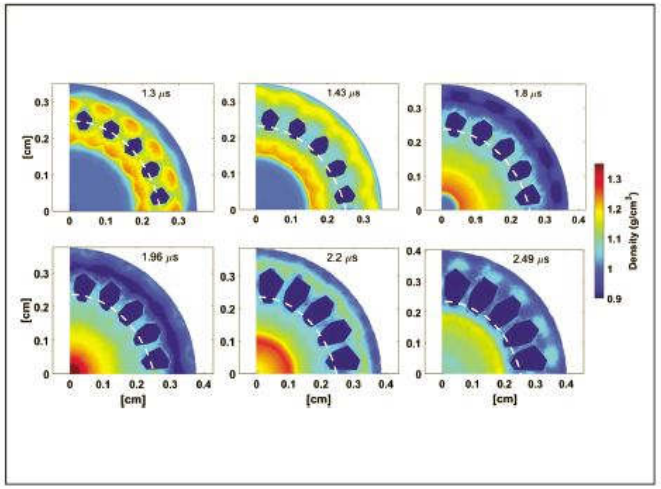




Journal of Applied Physics

AIP Publishing

scitation.org/journal/jap



Volume 125, Issue 9, 7 Mar. 2019

Synchrotron based X-ray radiography of convergent shock waves driven by underwater electrical explosion of a cylindrical wire array

J. Appl. Phys. 125, 017909 (2019); doi.org/10.1063/1.5089011

D. Yanuka, S. Theocharous, S. Efimov, S. N. Bland, *et al*

D. Yanuka et al, J. A

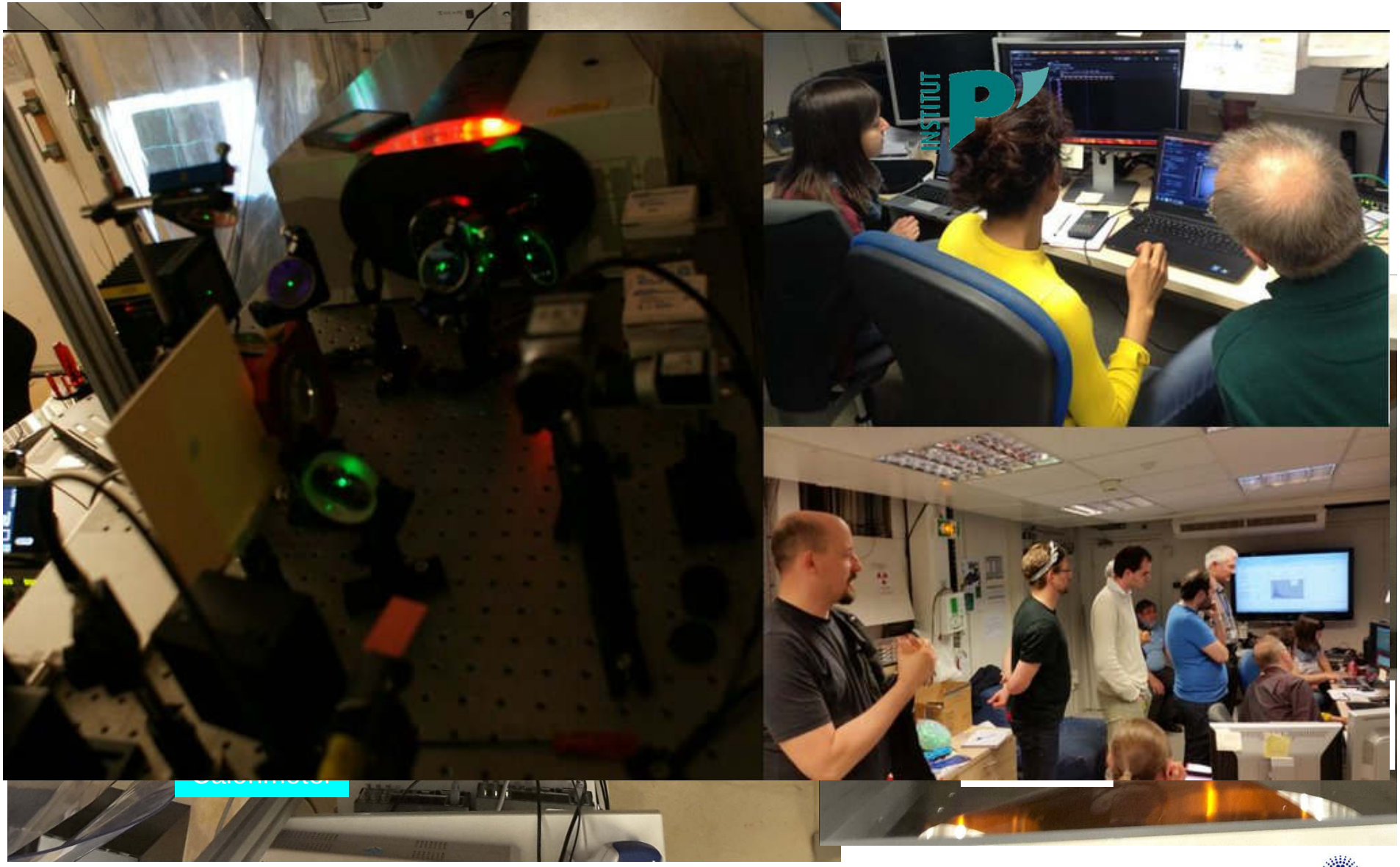
S. Theocharous, et

D. Yanuka et al, Phy

Imperial College London

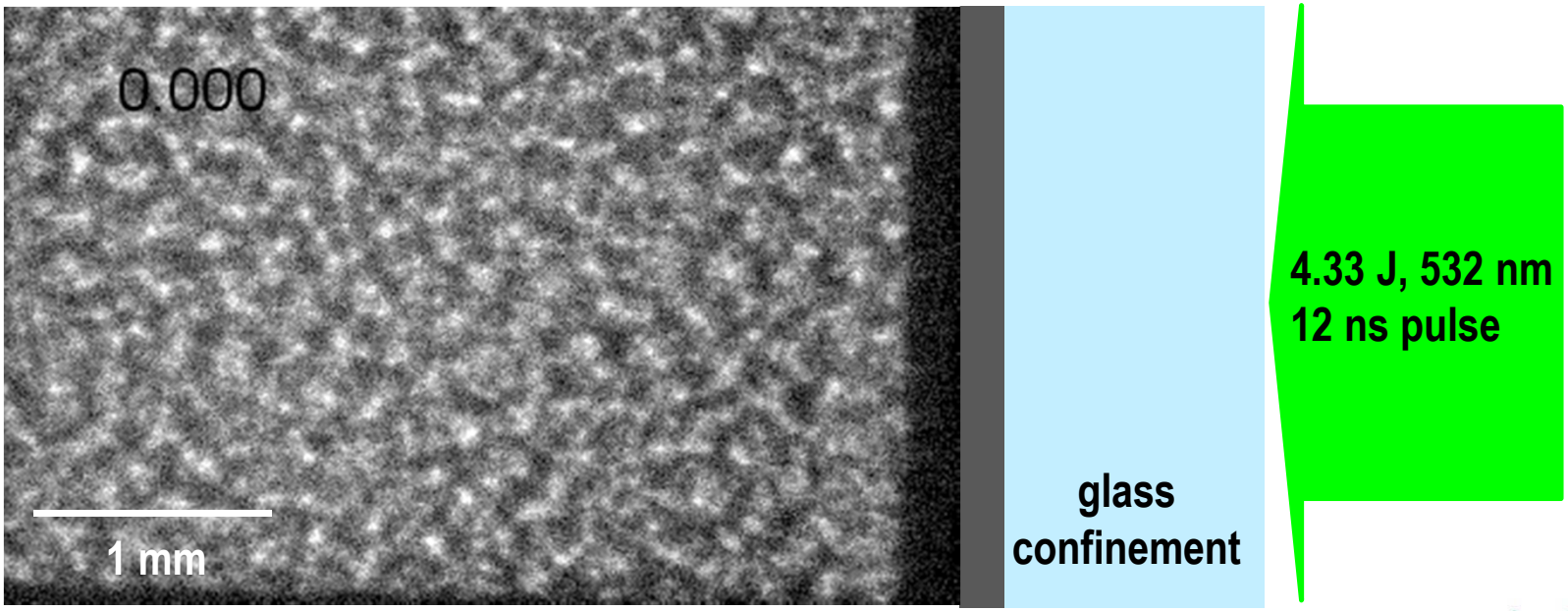
The European Synchrotron | ESRF

MEGAFRAME-RATE RADIOSCOPY – LASER-INDUCED PROCESSES



LASER-SHOCK-COMPRESSION IN POLYMERIC FOAM

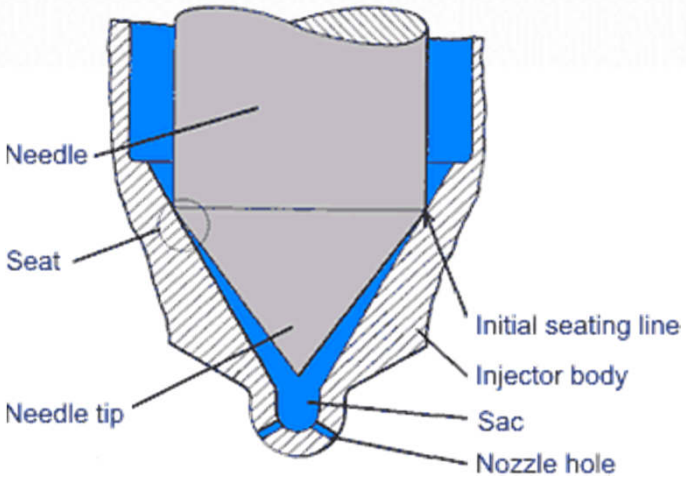
4-bunch filling mode (704 ns); polychromatic x-ray beam, mean 30 keV; 709 kfps; exposure: 600 ns

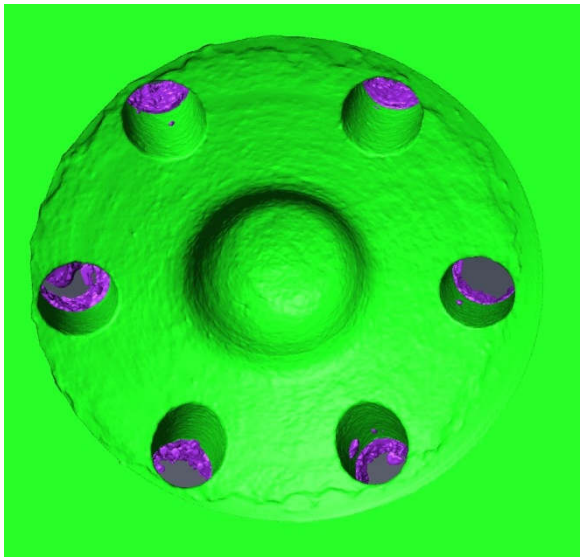


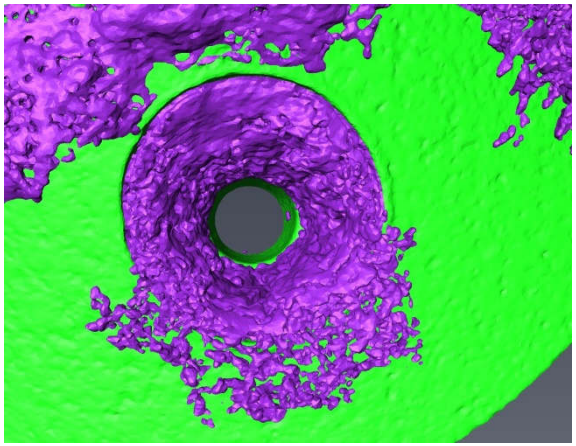
In collaboration with P. Pradel, T. de Resseguier (CNRS, FR), A. Pelka, M. Roedel, I. Prencipe, J. Grenzer, T. Cowan (HZDR, D)

M. P. Olbinado, et al. Ultra high-speed X-ray imaging of laser-driven shock compression using synchrotron light, Journal of Physics D: Applied Physics, vol. 51, no. 5, 055601 (2018).

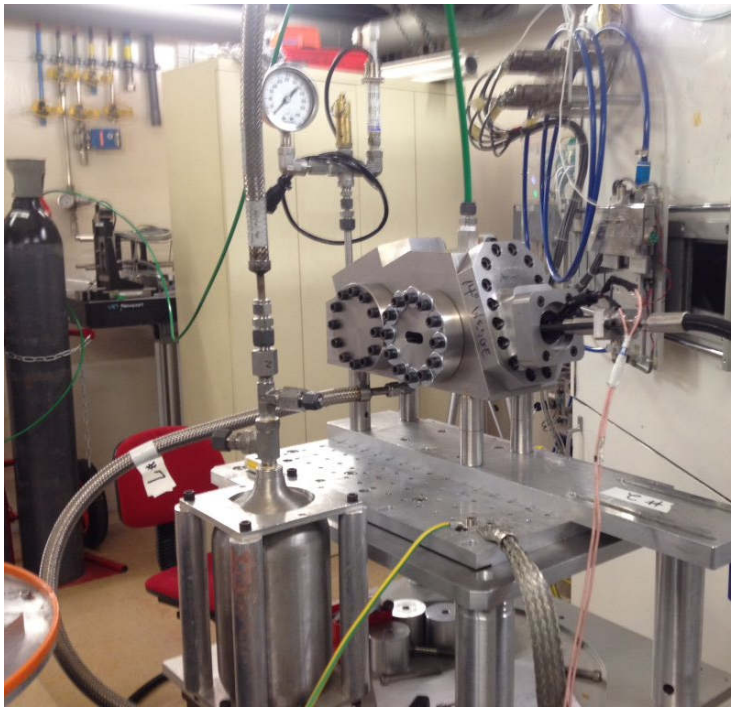
MEGAFRAME-RATE RADIOSCOPY - FUEL INJECTION



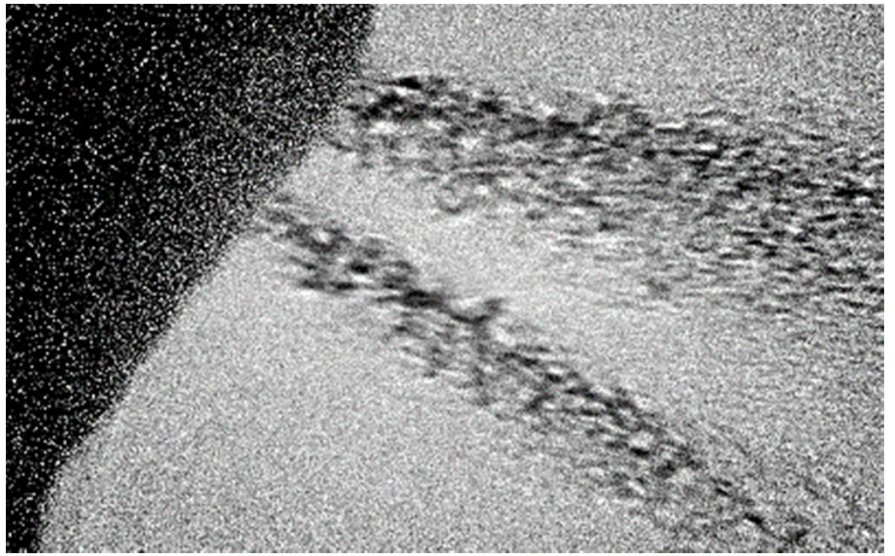




MEGAFRAME-RATE RADIOSCOPY – FUEL INJECTION



Detector	
Scintillator	250 µm LuAG:Ce
Camera	Shimadzu HPV-X2
Rate	500 ns / frame
Exposure	200 ns

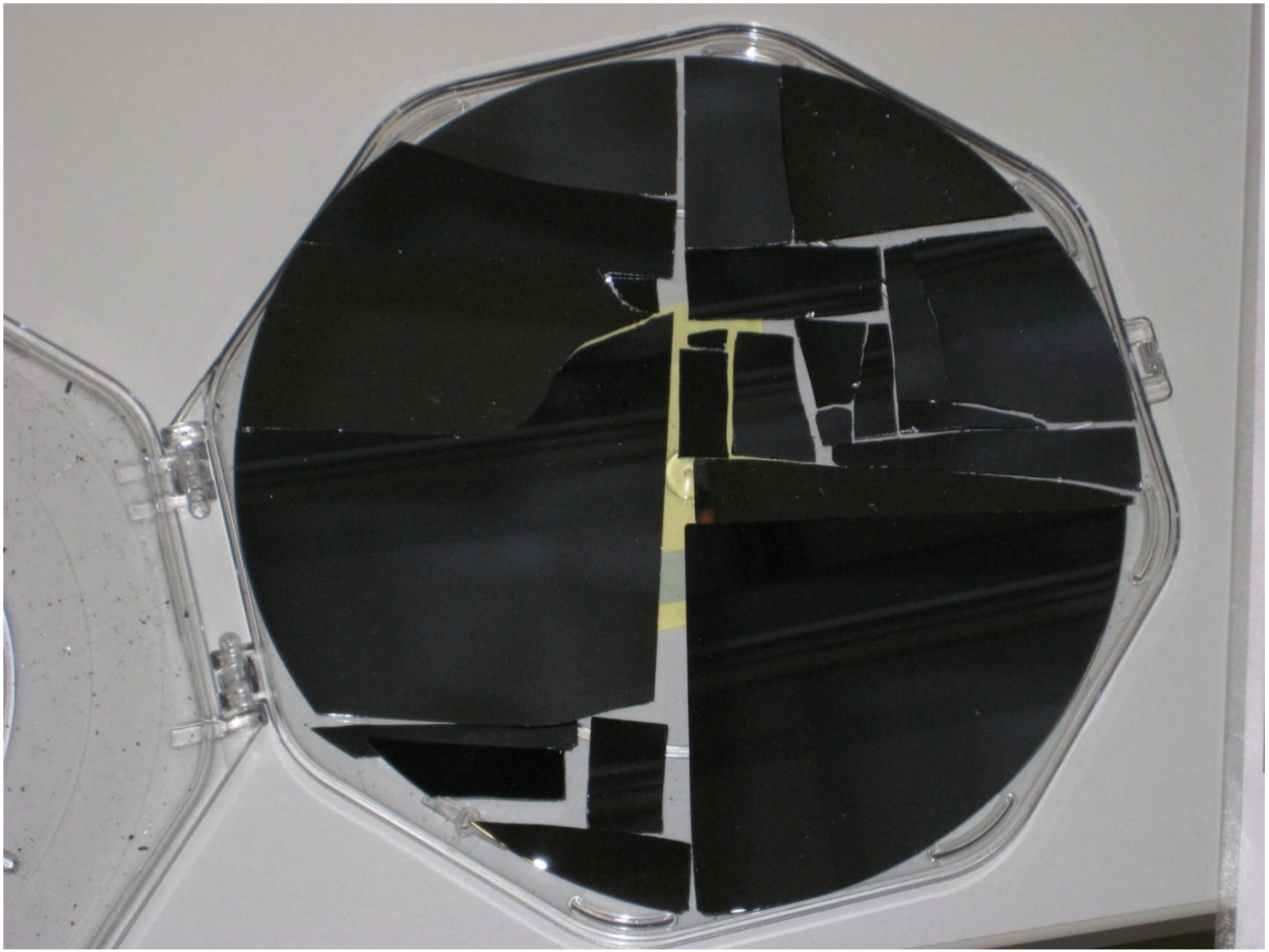


Olbinado et al., Imaging & Microscopy, vol. 20 (2018)

200 mA uniform fill

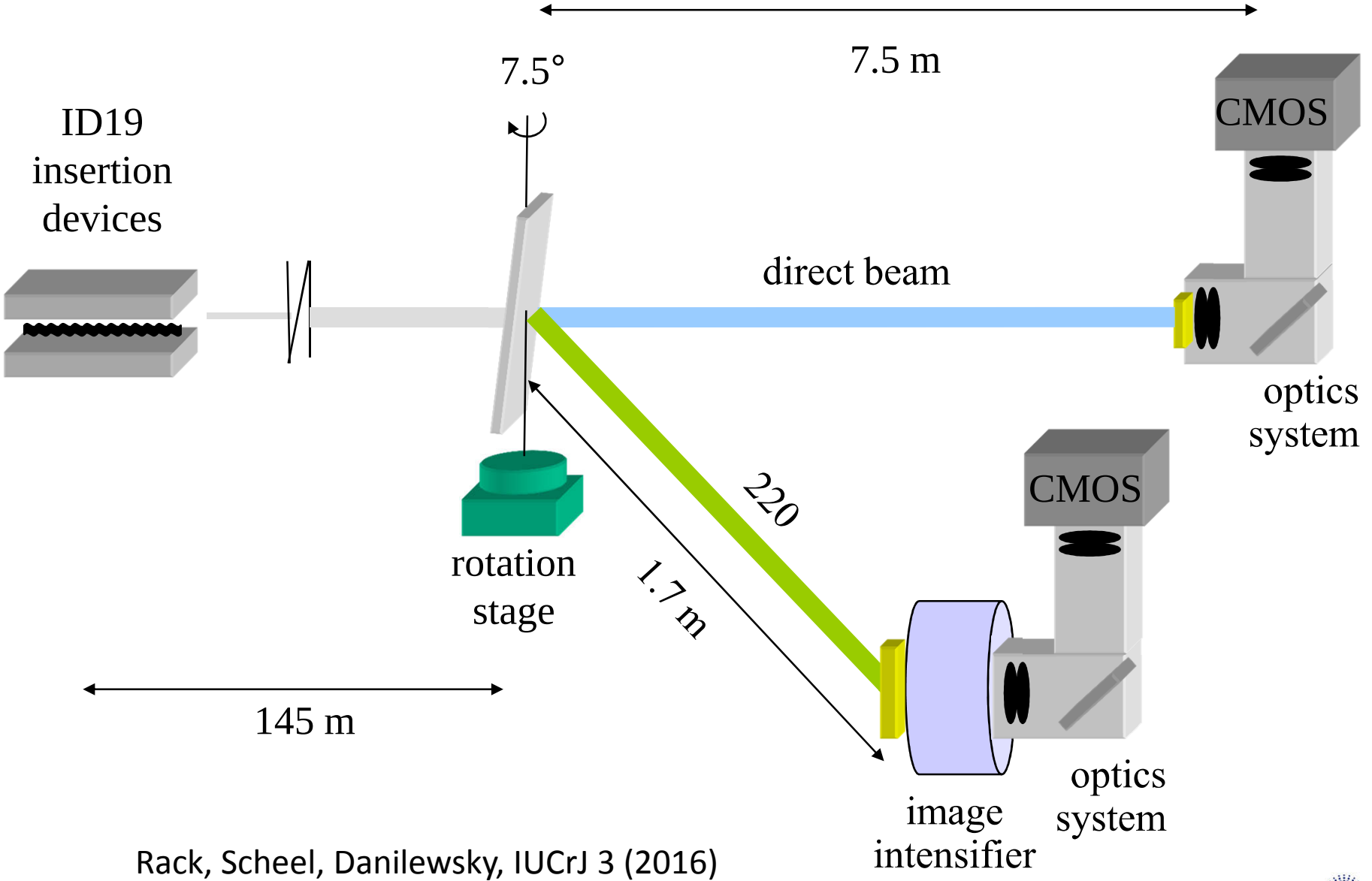
Need for MHz Imaging XFEL
(E > 50keV)

CATASTROPHIC WAFER BREAKAGE



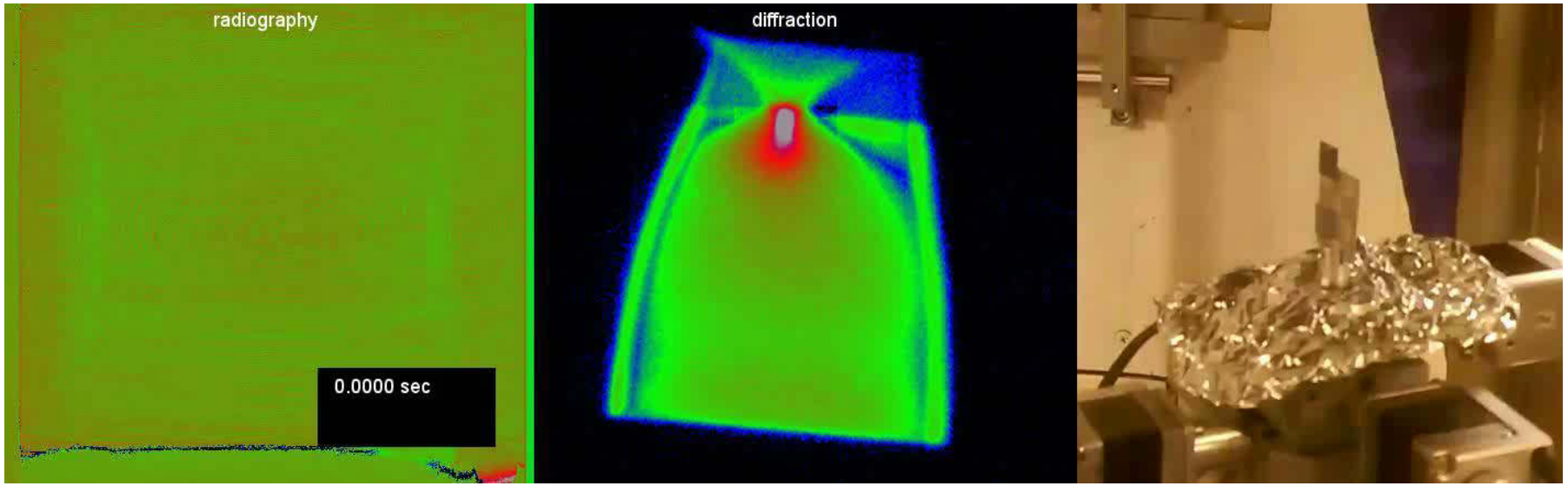
Brian Tanner, IUCrJ 3 (2016)

CRACK PROPAGATION IN SILICON WAFERS



Rack, Scheel, Danilewsky, IUCrJ 3 (2016)

LASER DRILLING: SI WAFER



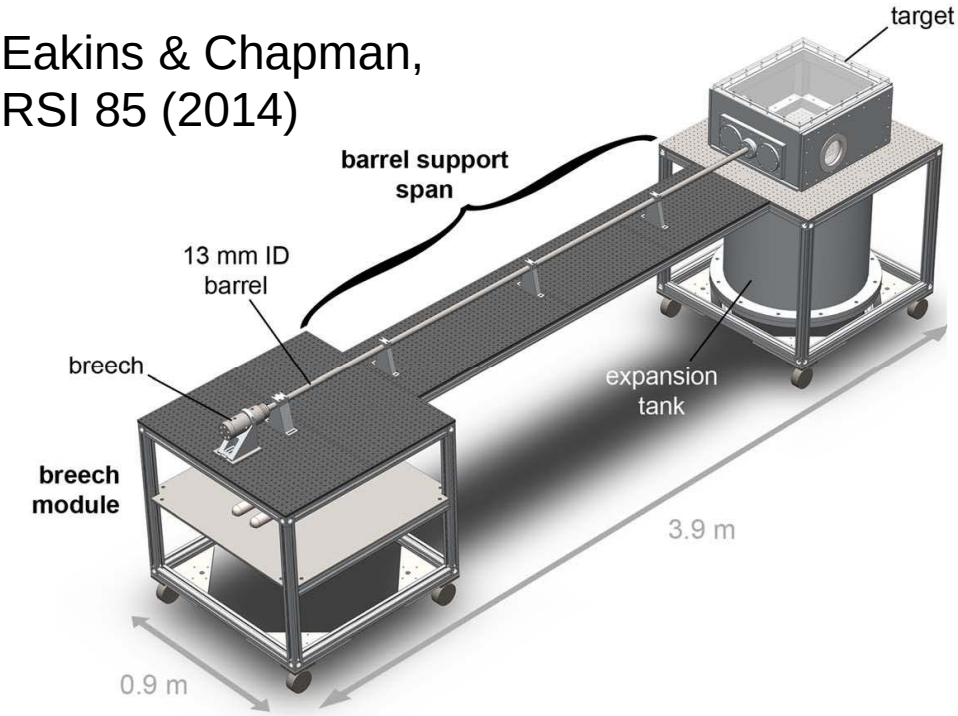
radiograph

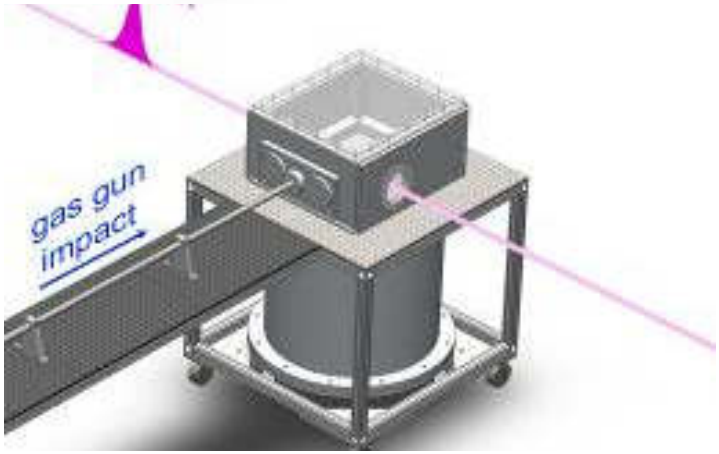
diffraction image

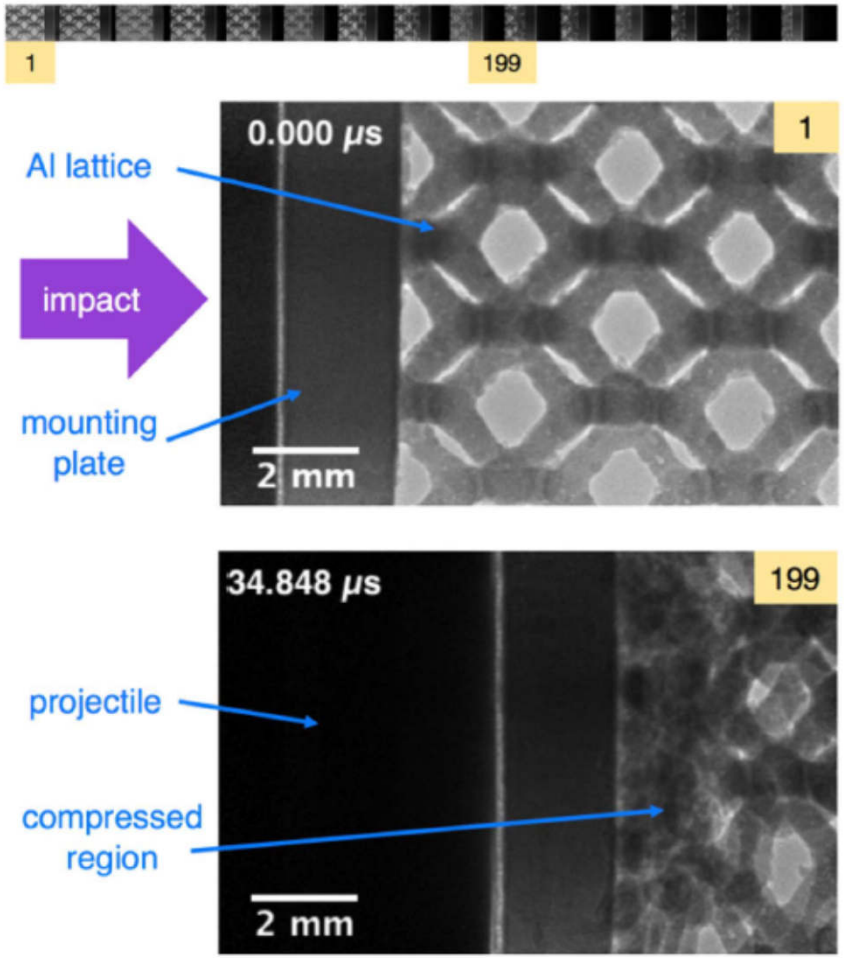
M. P. Olbinado, et al. Advances in indirect detector systems for ultra high-speed hard X-ray imaging with synchrotron light, Journal of Instrumentation, vol. 13, no. 4, C04004 (2018).

IMPACT STUDIES: ADDITIVE MANUFACTURED SAMPLES (BEYOND ALUMINUM)

Eakins & Chapman,
RSI 85 (2014)







E. M. Escauriza et al.,
Applied Optics, 57(18), 5004-5010 (2018).

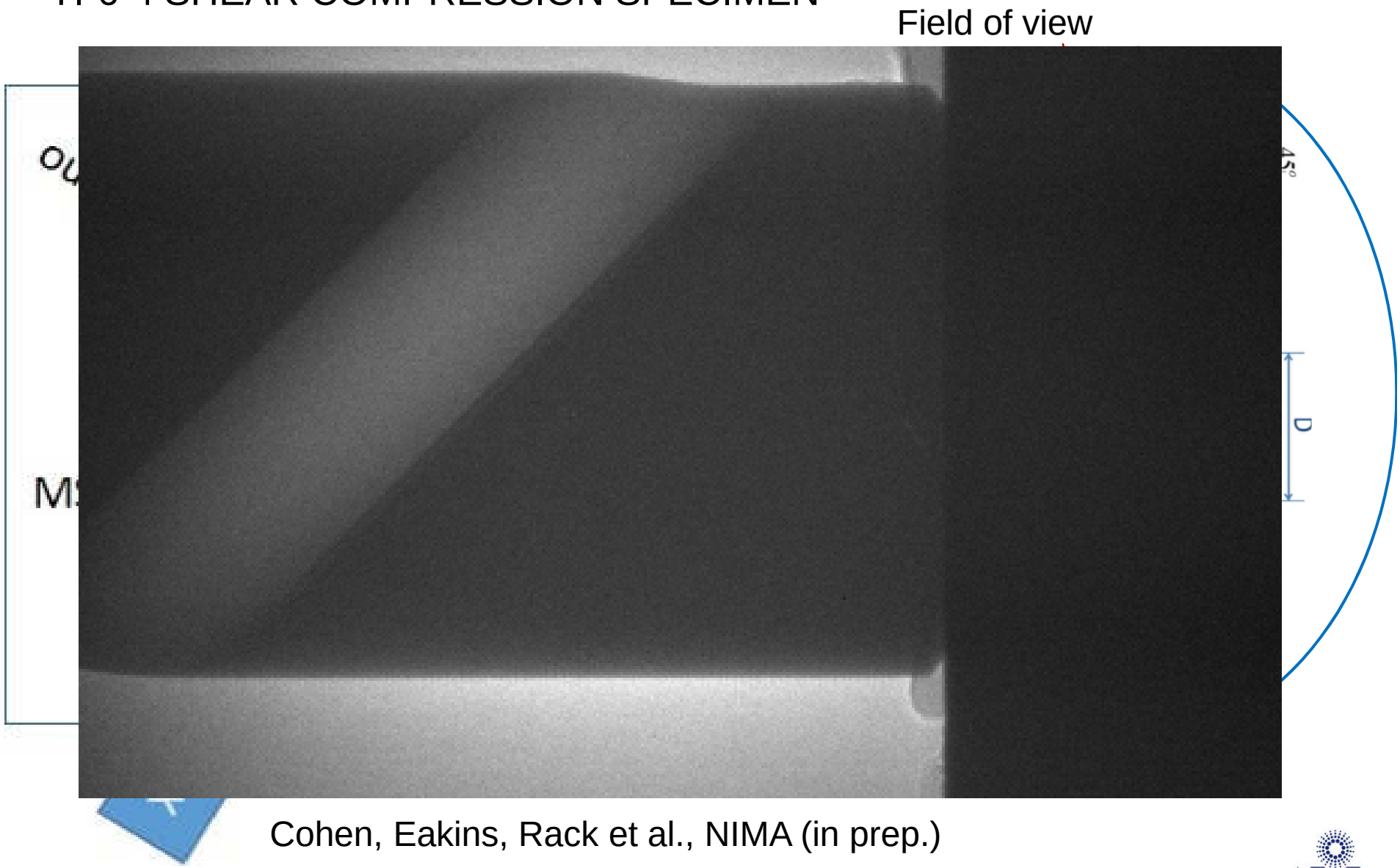
Oxford University, Imperial London

SPLIT HOPKINSON PRESSURE BAR

Amitay Cohen, LH "MP1252 Eakins et al. (Imperial/Oxford)

SPLIT HOPKINSON PRESSURE BAR

TI-6-4 SHEAR COMPRESSION SPECIMEN

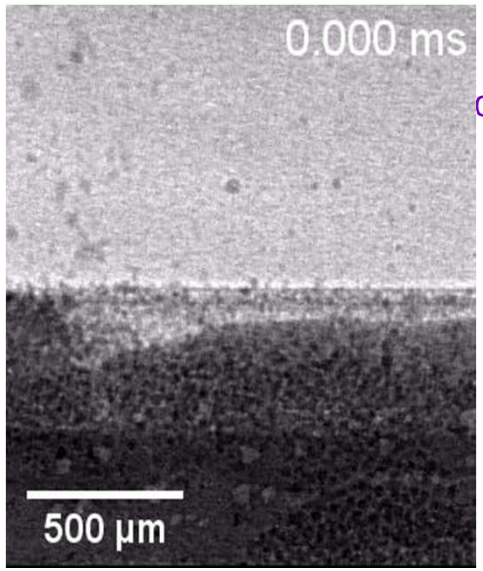


Cohen, Eakins, Rack et al., NIMA (in prep.)

LASER Additive manufacturing offers the unique opportunity to directly manufacture complex, high value added components for aerospace applications like these AM built Ti-alloy aerofoils in a Trent XWB-97k test bed engine. However, the process is poorly understood, and the models limited.

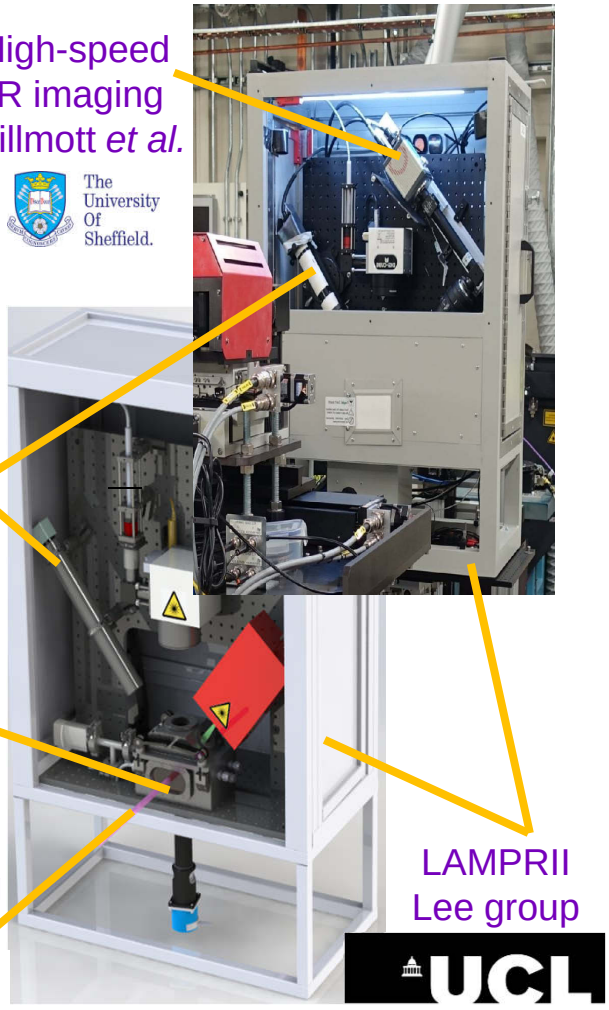
Goal: Coupling an *in situ* and operando laser powder bed additive manufacturing process replicator with ultra-fast (>50kHz) synchrotron imaging to understand:

- **Laser melt pool dynamics**
- **Defect formation**
- **Process optimisation & control**
- **Capture phase transformations**
- **Design new alloys / processes**



EPSRC

Research Complex at Harwell

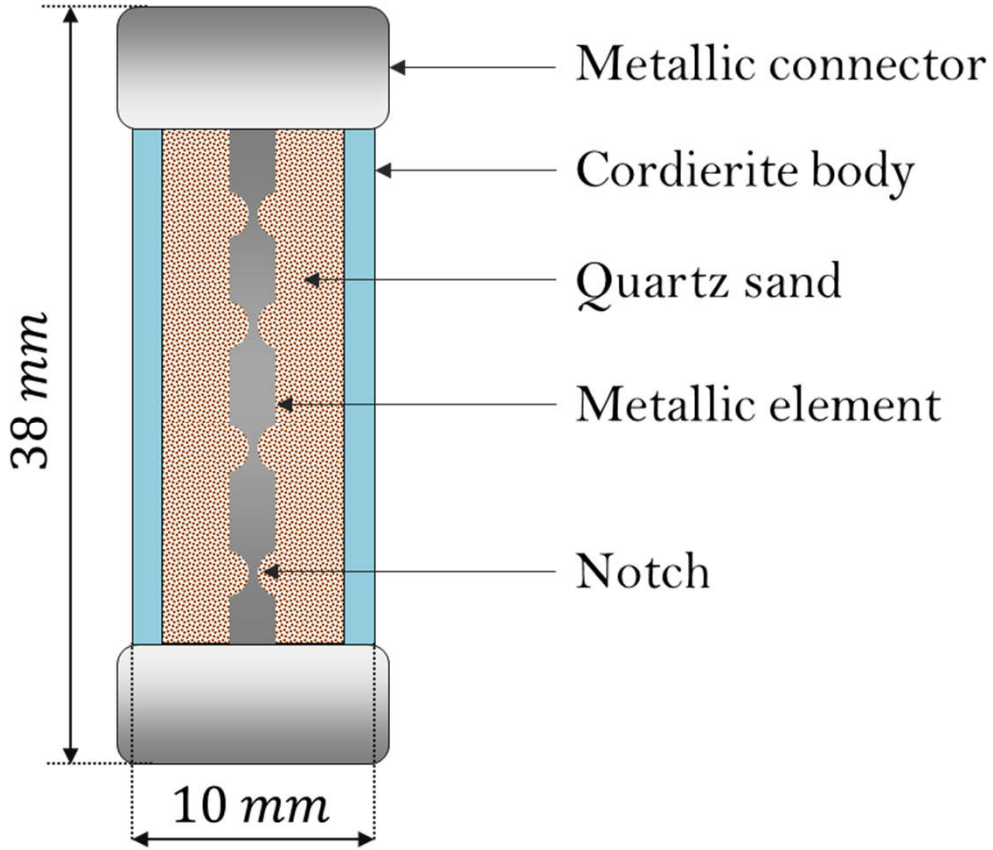


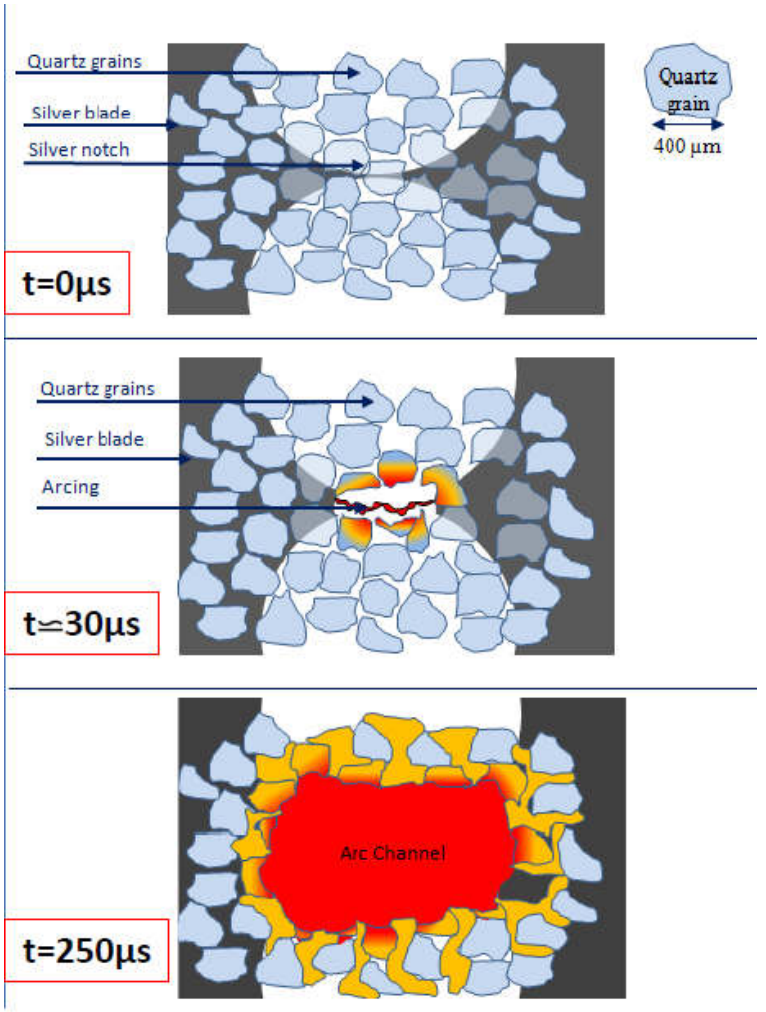
Alex Leung, Sebastian Marussi, Sam Clark, Yunhui Chen, Lorna Sinclair, Alexander Rack & Margie Olbinado (ESRF), Mike Towrie (CLF), Robert Atwood (DLS), Iain Todd & Jon Willmott (Sheff.), Peter D. Lee (peter.lee@ucl.ac.uk)

Thanks for your attention!

(EBS restart early 2020: 2× PostDoc, 1× Scientist)

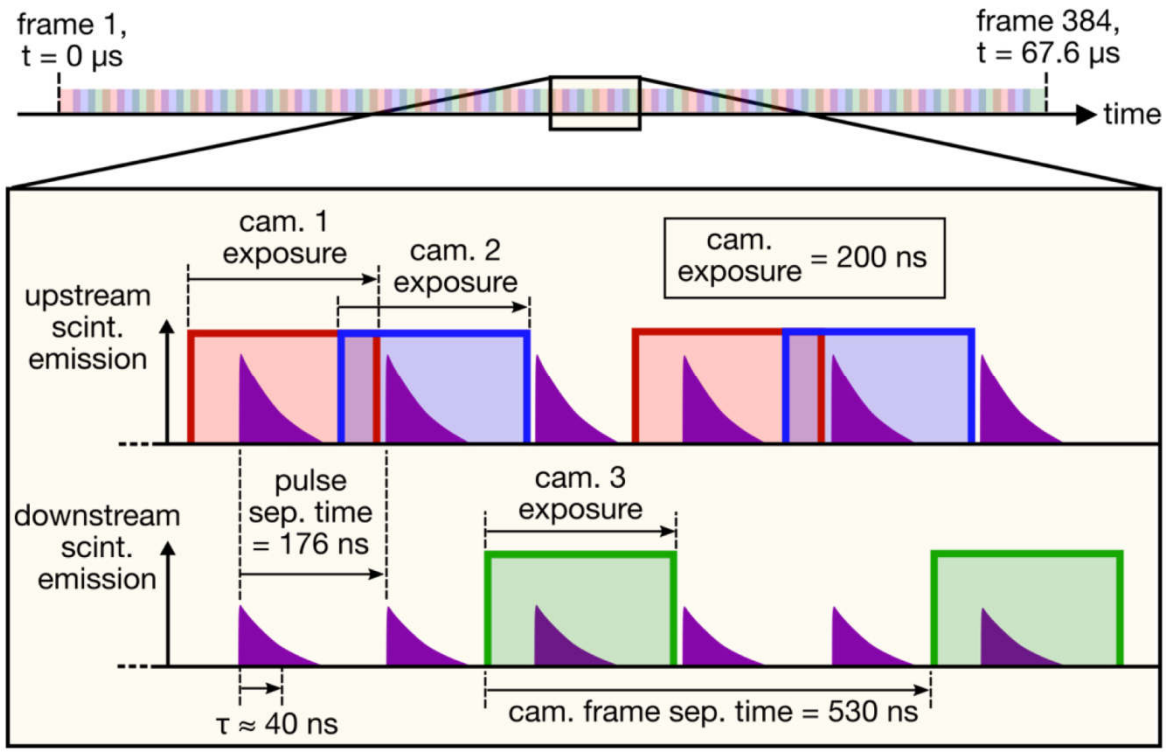
HIGH-SPEED ELECTRICAL FUSE BREAKING





X. Just, P. Lhuissier, J.-M. Chaix (SIMAP), J.-L. Gelet, F. Balboni, M. Morati (Mersen)

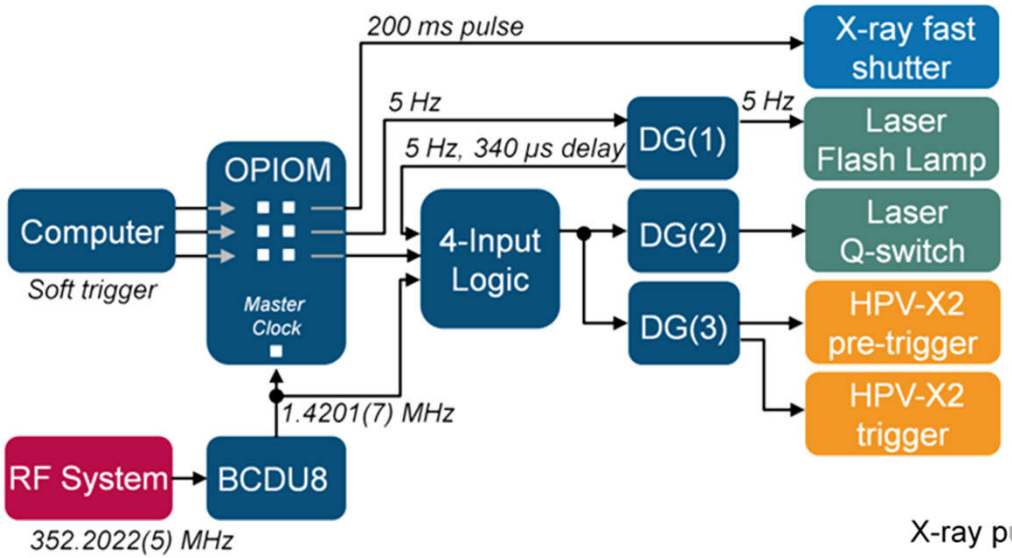
Camera synchronization with the x-ray pulses

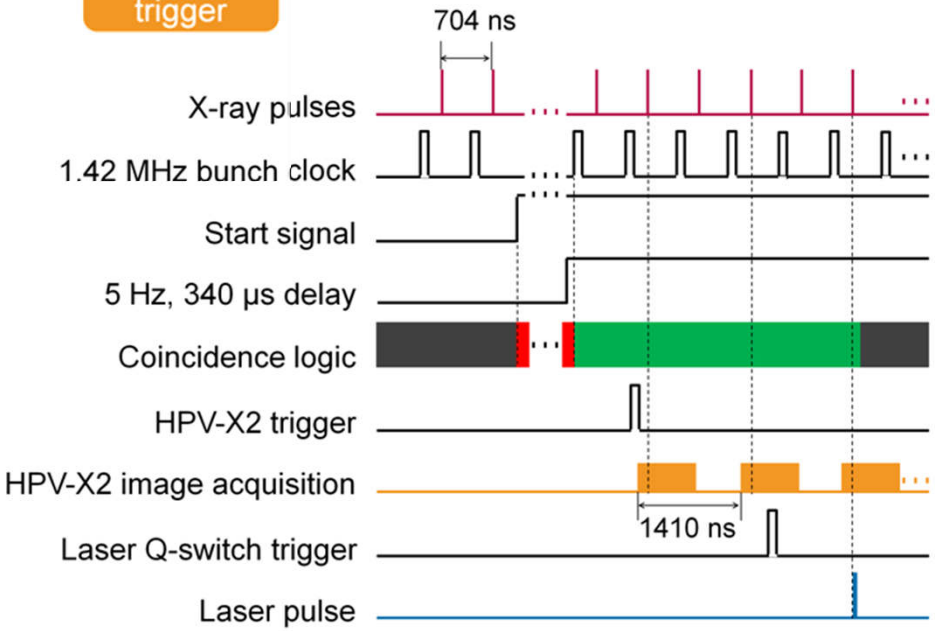


3 cameras to achieve 5.6 Mfps single-bunch imaging

E. M. Escauriza et al, Ultra high-speed indirect X-ray imaging system with versatile spatio-temporal sampling capabilities, Applied Optics, 57(18), 5004-5010 (2018).

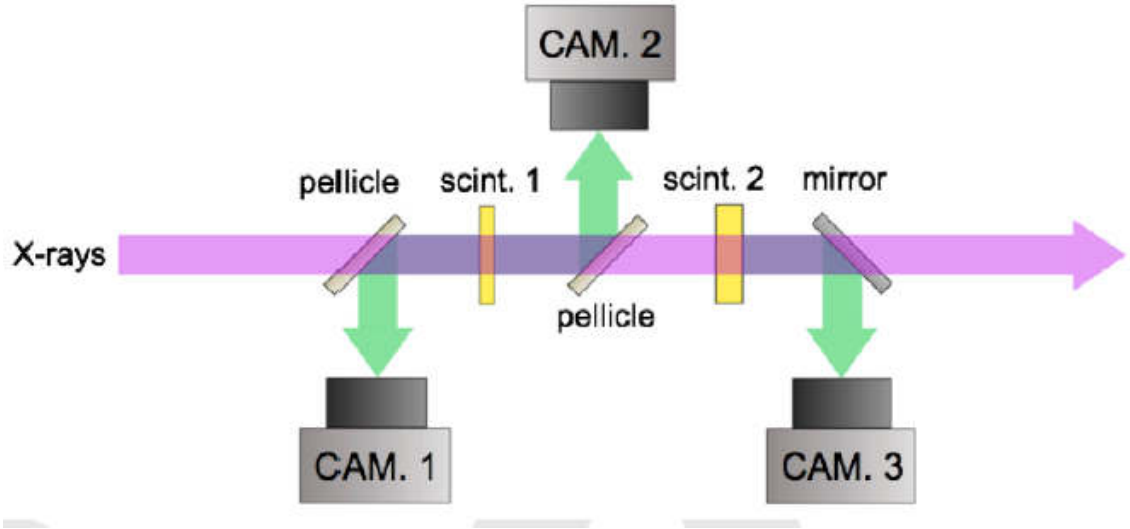
TIMING AND SYNCHRONIZATION





M. P. Olbinado, et al Ultra high-speed X-ray imaging of laser-driven shock compression using synchrotron light, Journal of Physics D: Applied Physics, vol. 51, no. 5, 055601 (2018).

Synchronization with the x-ray pulses

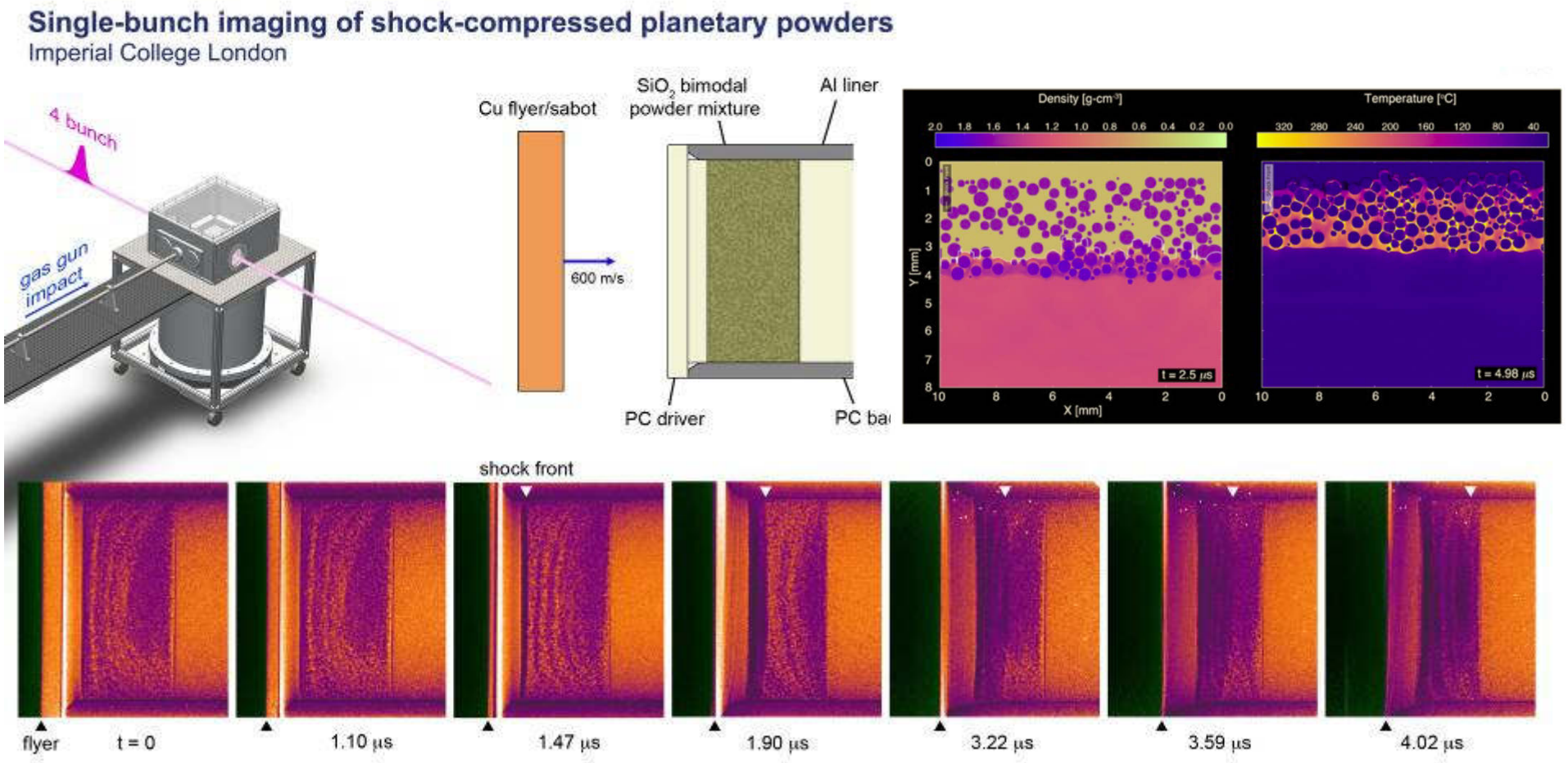


3 cameras to achieve 5.6 Mfps single-bunch imaging

E. M. Escauriza et al, Ultra high-speed indirect X-ray imaging system with versatile spatio-temporal sampling capabilities, Applied Optics, 57(18), 5004-5010 (2018).

SHOCK WAVE PROPAGATION (BIMODAL POWDER BED)

MI-1224 - Eakins, Chapman et al., Imperial College London

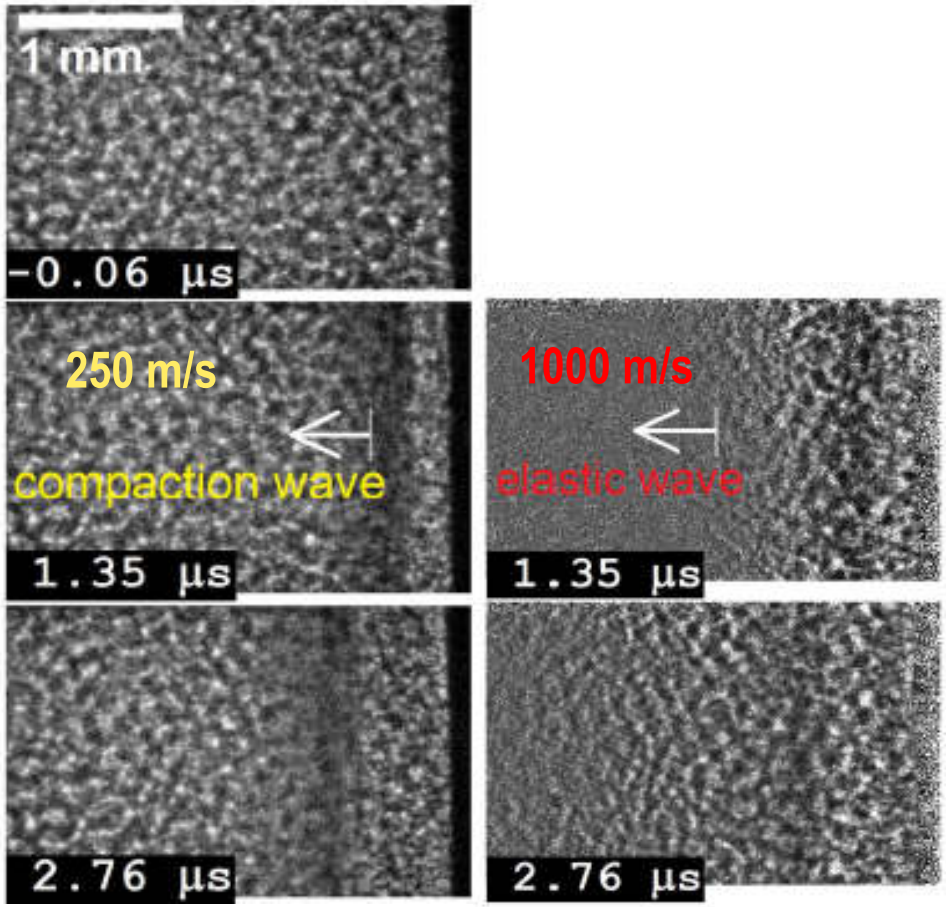


M. E. Rutherford, D. J. Chapman, J. R. W. Patten, D. E. Eakins, J. G. Derrick, G. S. Collins, A. Rack, P. A. Bland
Probing the early stages of shock-induced chondritic meteorite formation at the mesoscale
Scientific Reports, **7**, 45206 (2017)

GAS GUN: INSTALLATION AT ID19 (8 h during Machine Day)

Laser-shock-compression in polymeric foam

4-bunch filling mode (704 ns); polychromatic x-ray beam, mean 30 keV;
709 kfps; exposure: 600 ns

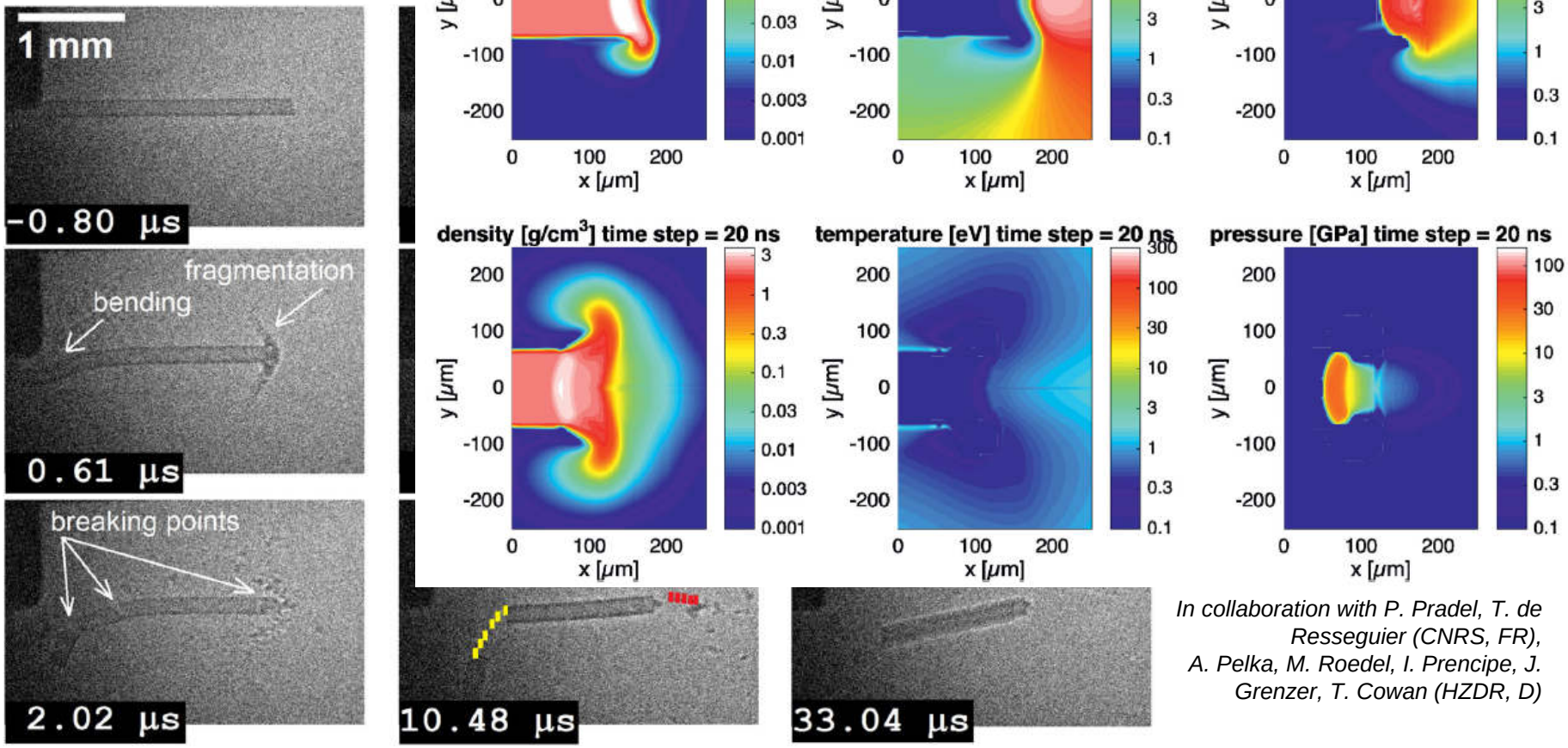


In collaboration with P. Pradel, T. de Resseguier (CNRS, FR), A. Pelka, M. Roedel, I. Prencipe, J. Grenzer, T. Cowan (HZDR, D)

M. P. Olbinado, et al Ultra high-speed X-ray imaging of laser-driven shock compression using synchrotron light, Journal of Physics D: Applied Physics, vol. 51, no. 5, 055601 (2018).

LASER-SHOCK-COMPRESSION CARBON ROD

4-bunch filling mode (7
709 kfps; exposure: 60



In collaboration with P. Pradel, T. de Resseguier (CNRS, FR), A. Pelka, M. Roedel, I. Prencipe, J. Grenzer, T. Cowan (HZDR, D)

M. P. Olbinado, et al. Ultra high-speed X-ray imaging of laser-driven shock compression using synchrotron light, Journal of Physics D: Applied Physics, vol. 51, no. 5, 055601 (2018).