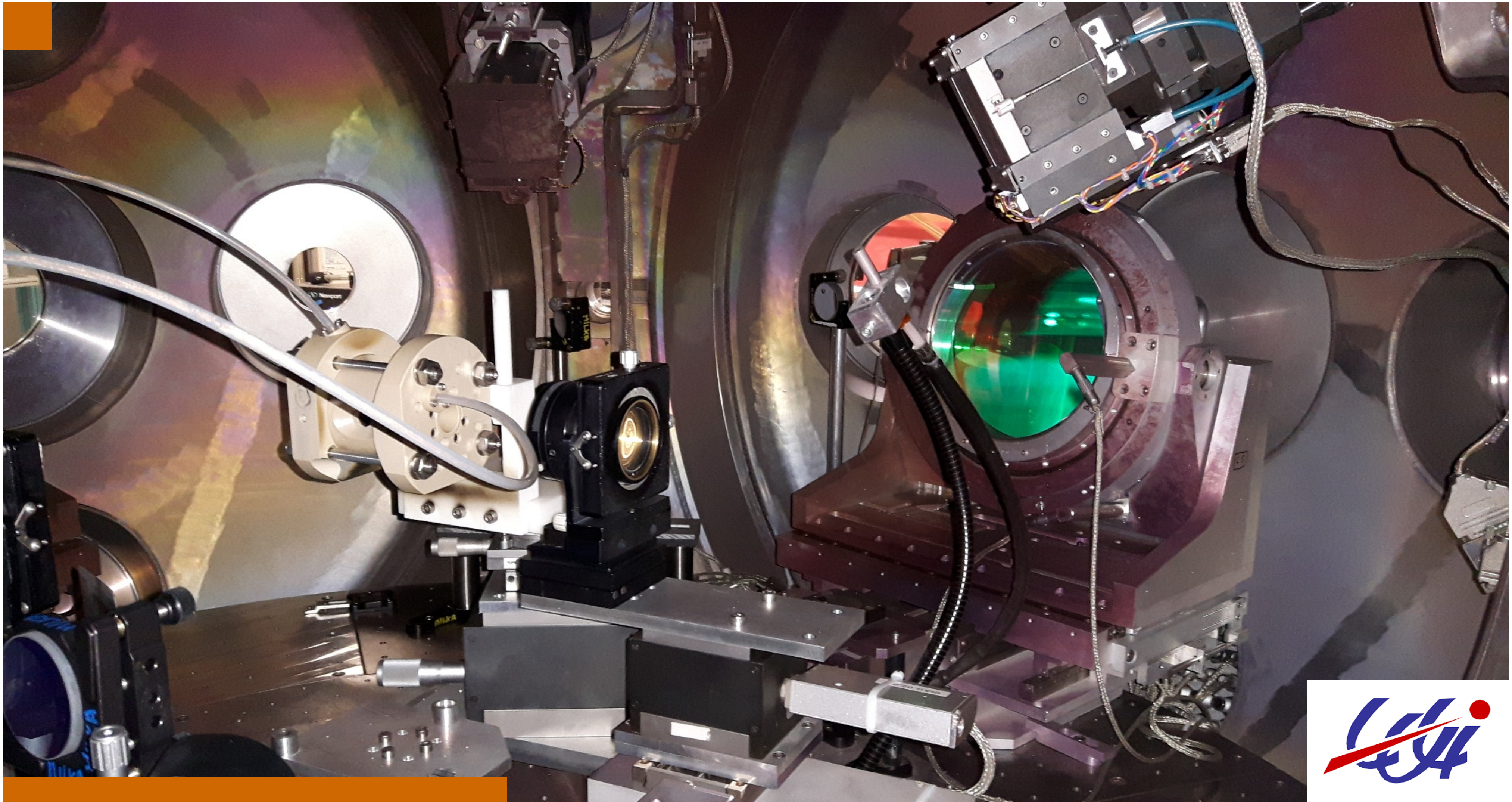


Experimental study of accretion processes in X-ray binary stars using an external magnetic field

F. Kroll[1], A. Pelka[1], B. Albertazzi[2], F. Brack[1], E. Brambrink[2], T. Cowan[1], P. Drake[3], E. Falize[4], E. Filipov[5], Y. Kuramitsu[6], C. Kuranz[3], D. Lamb[7], J. Levesque[3], C. Li[8], M. Manuel[3], T. Michel[2], T. Morita[9], N. Ozaki[10], S. Pikuz[5], A. Rigby[11], G. Rigon[2], M. Rödel[1], Y. Sakawa[10], U. Schramm[1], H. Shimogawara[10], L. Van Box Som[4] and M. Koenig[2]

[1]HZDR, Germany, [2]LULI, France, [3]University of Michigan, USA, [4]CEA-DAM-DIF, France, [5]JIHT-RAS, Russia, [6]National Central University, Taiwan, [7]Flash Center for Computational Science, USA, [8]MIT, USA, [9]Kyushu University, Japan, [10]OSaka University, Japan, [11]University of Oxford, United Kingdom

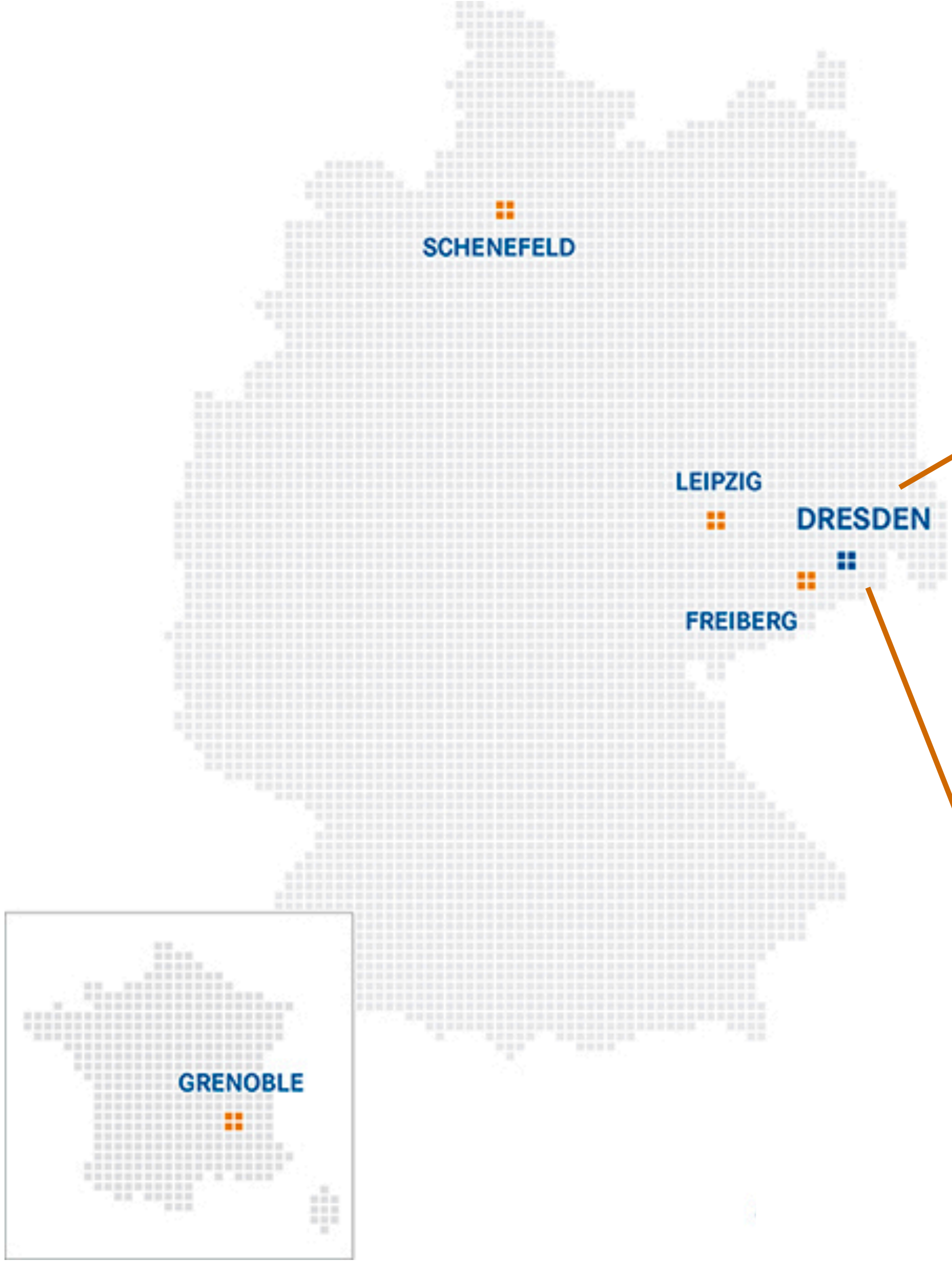
Partner von DRESDEN concept exzellenz-dresden.de

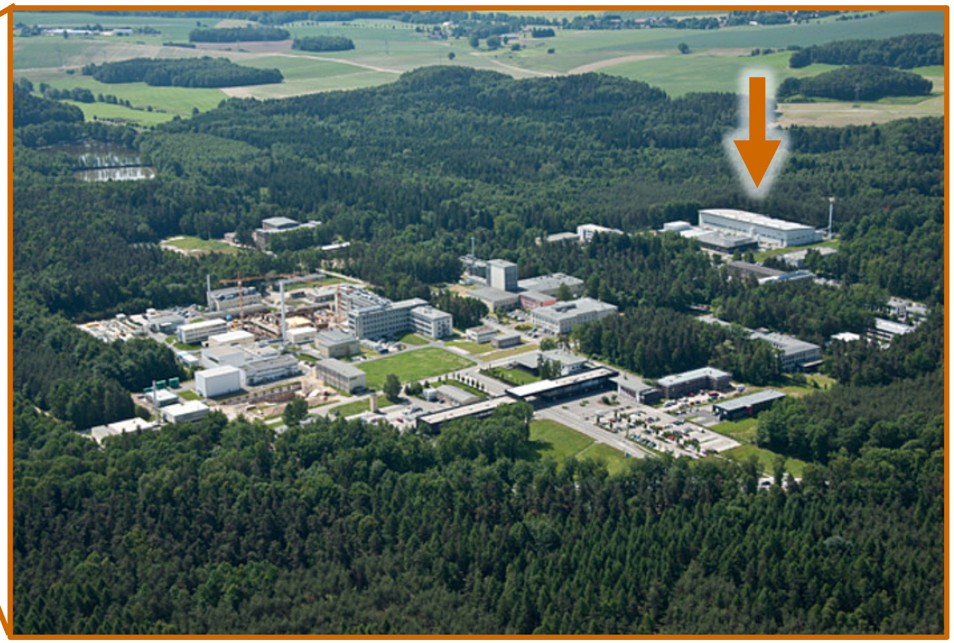
HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Hi I am Florian, but you can call me Flo!

HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

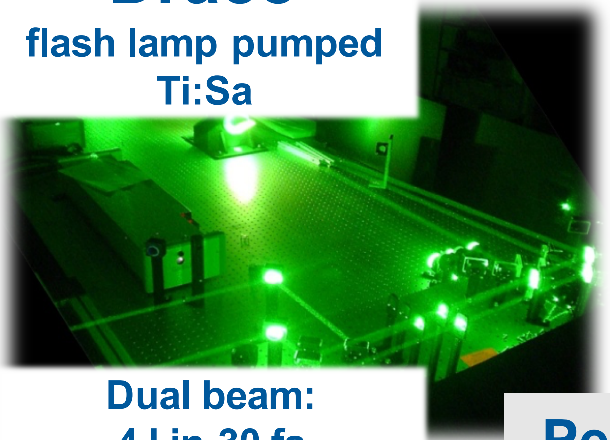




The laser particle acceleration division @ HZDR

Draco

flash lamp pumped
Ti:Sa



Dual beam:
4J in 30 fs
+ 30 J in 30 fs

Petawatt Laser Power

1 Hz repetition rate

PENELOPE

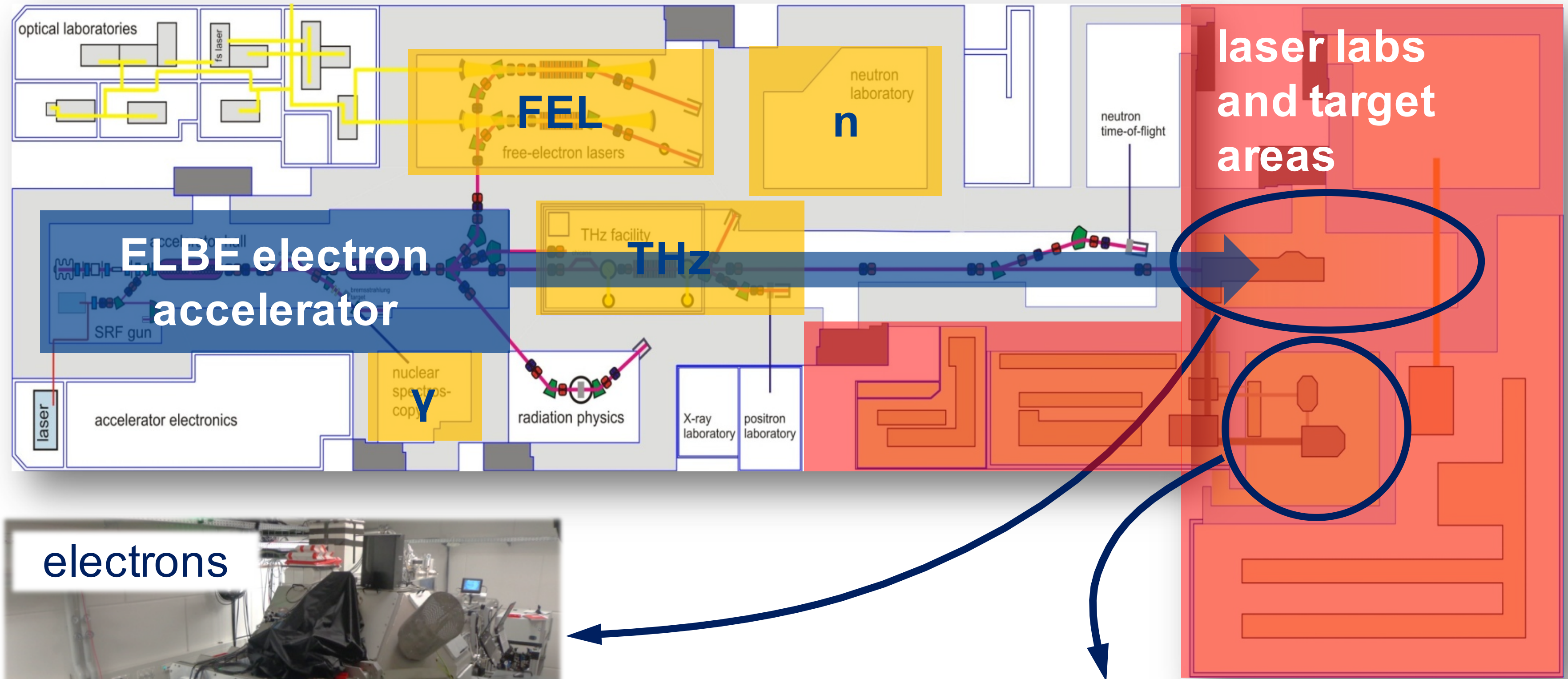
diode pumped
Yb:CaF

150 J in 150 fs

DRESDEN concept

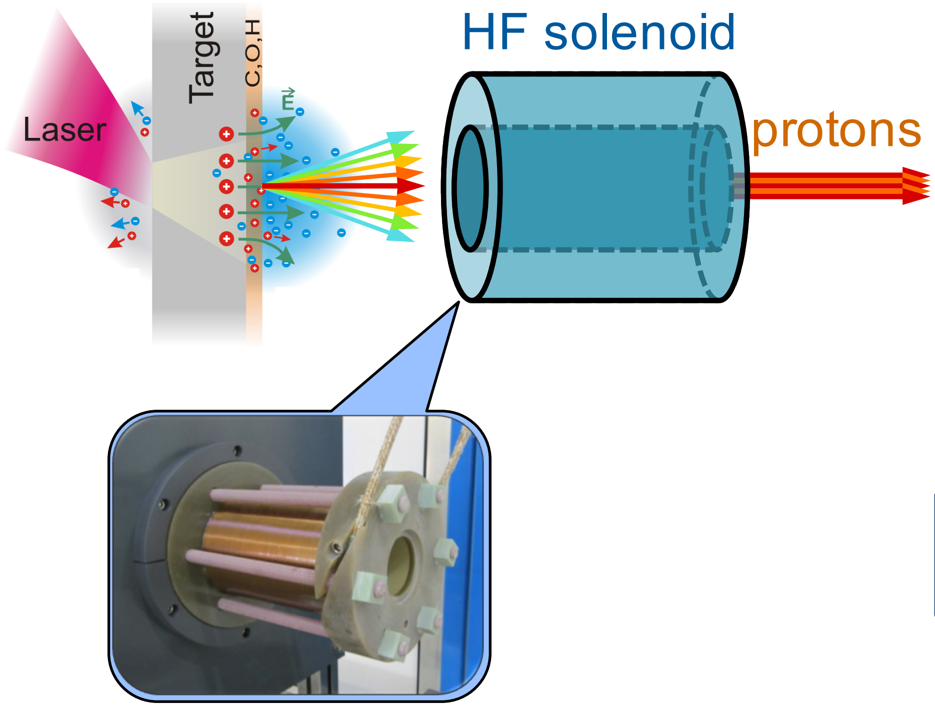
HZDR

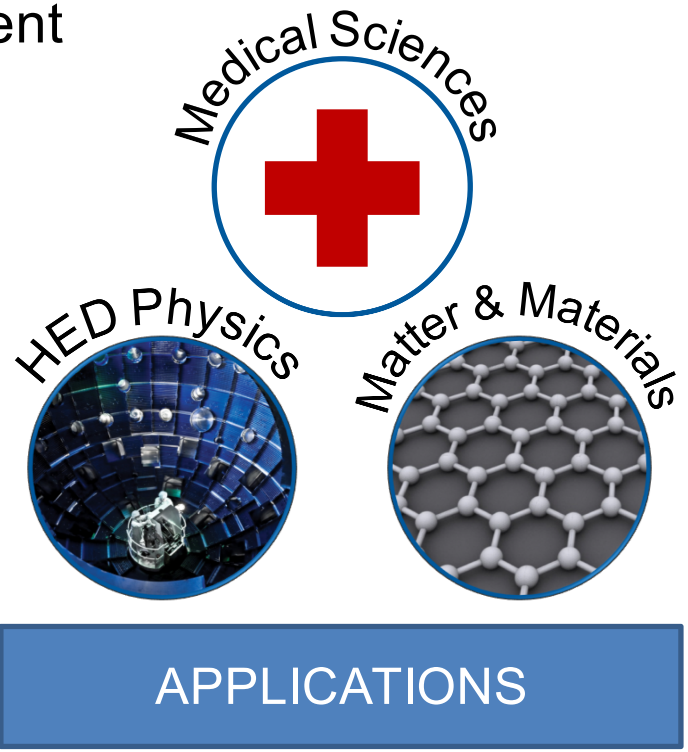
The laser particle acceleration division @ HZDR



What the heck is this guy doing here?

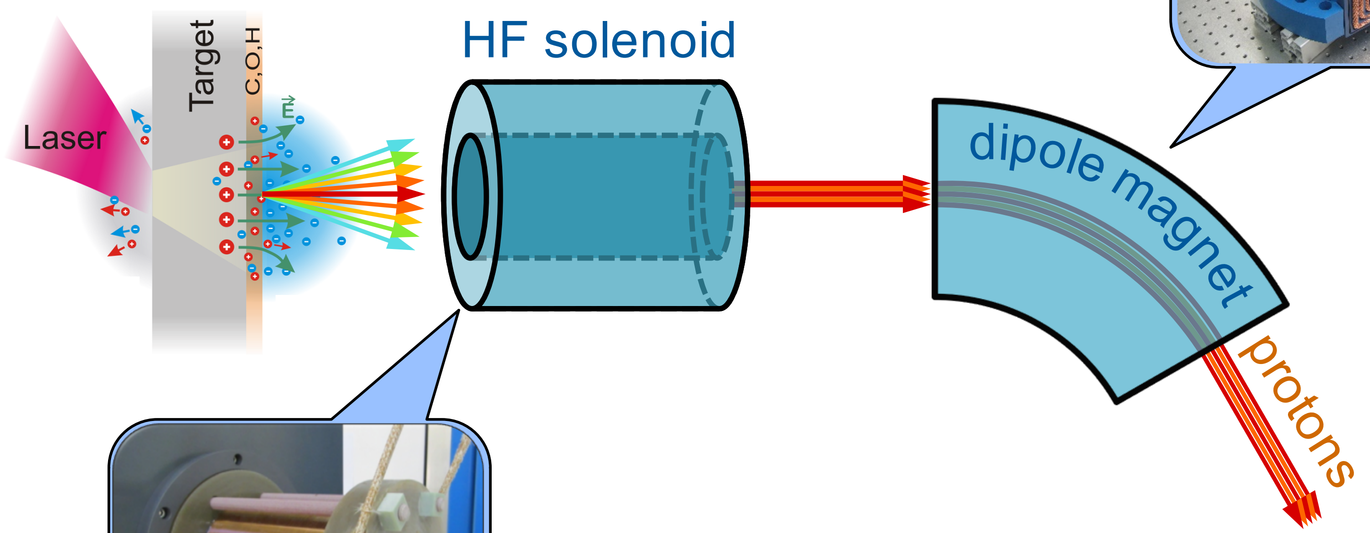
Pulsed high-field magnet development

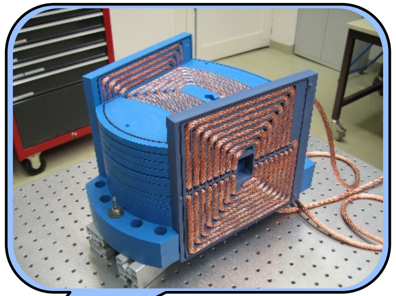


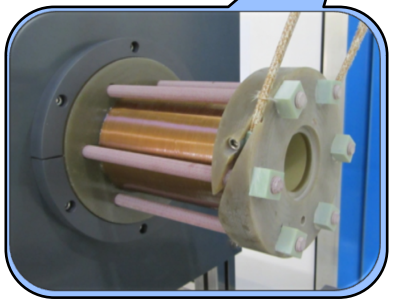


What the heck is this guy doing here?

Pulsed high-field magnet development





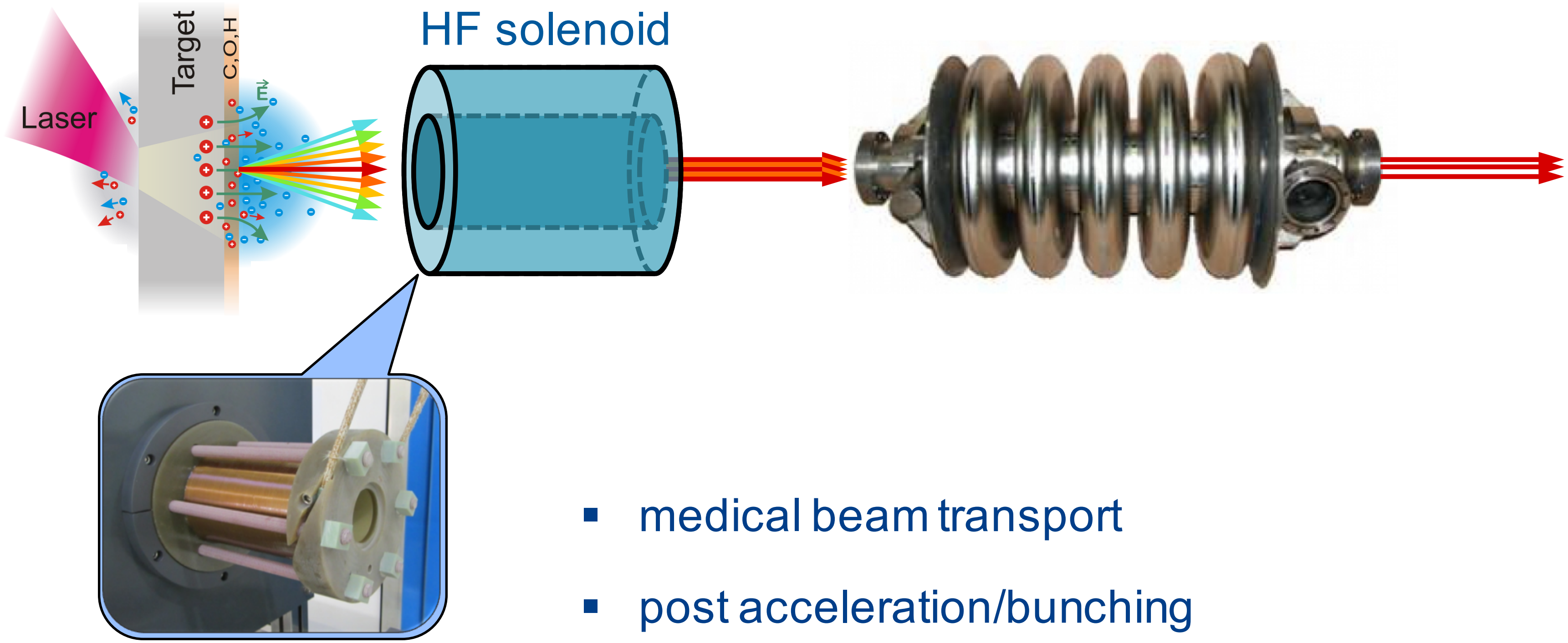


- medical beam transport

U. Masood et al., APB 117, 41-52 (2014)

What the heck is this guy doing here?

Pulsed high-field magnet development

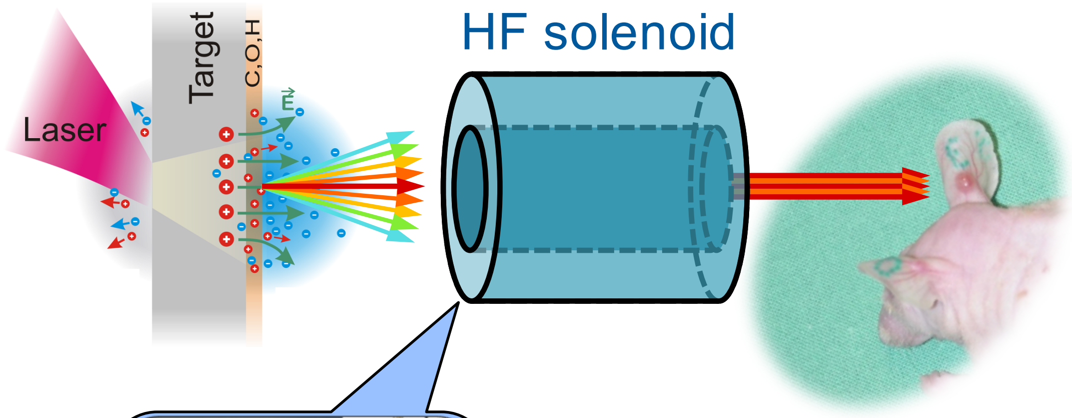


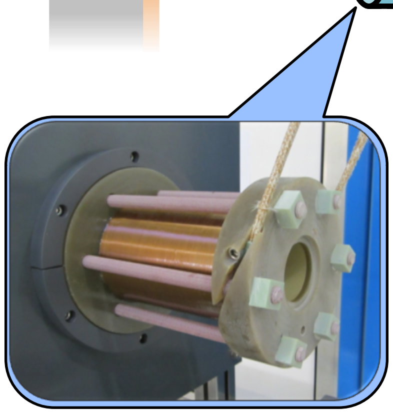
- medical beam transport
- post acceleration/bunching

S. Busold et al., PRSTAB 17, 031302 (2014)
S. Busold et al., NIM-A 740, 94-98 (2014)

What the heck is this guy doing here?

Pulsed high-field magnet development



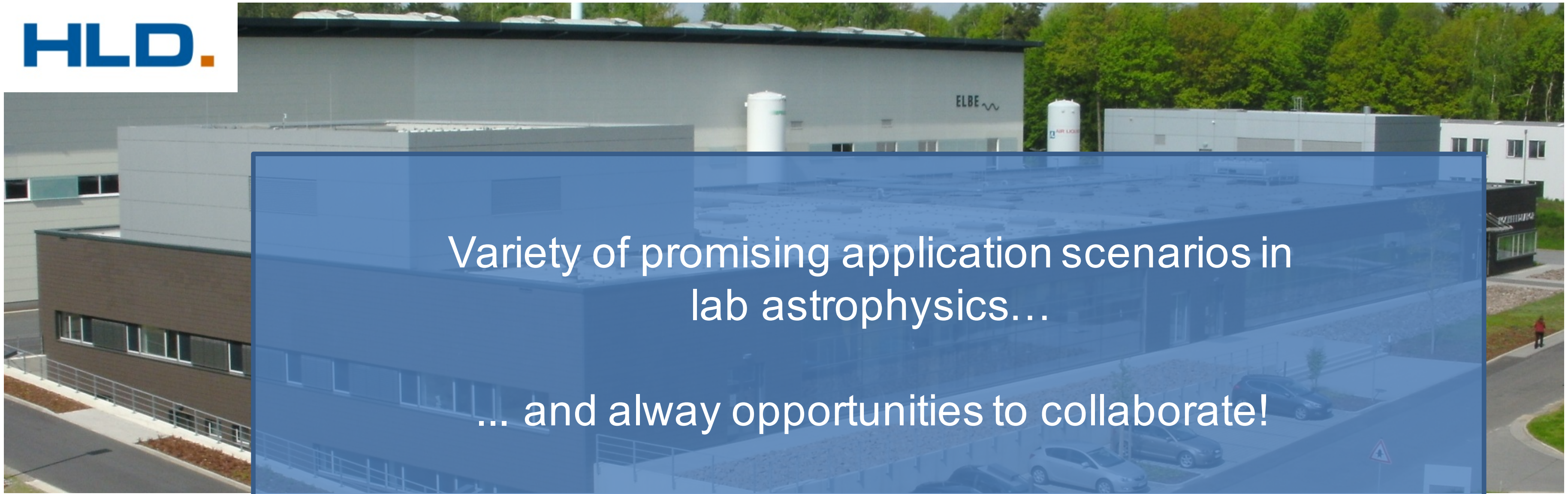


- medical beam transport
- post acceleration/bunching
- radiobiology

K. Brüchner et al., RadiatOncol, 9:57 (2014)

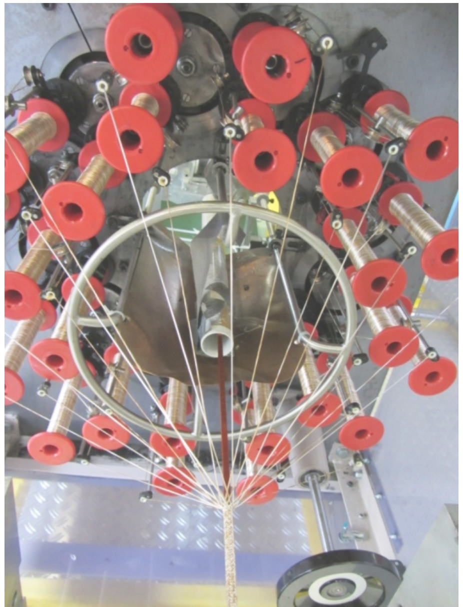
Dresden High Magnetic Field Laboratory

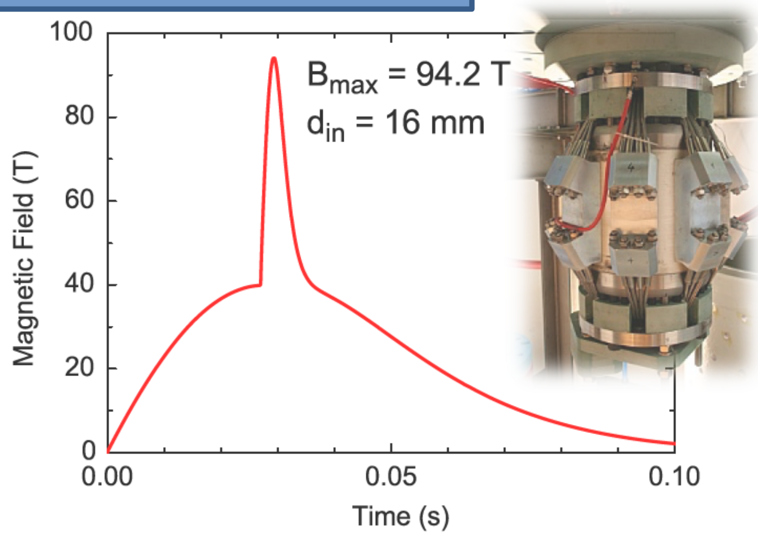
HLD.



Variety of promising application scenarios in lab astrophysics…

... and alway opportunities to collaborate!





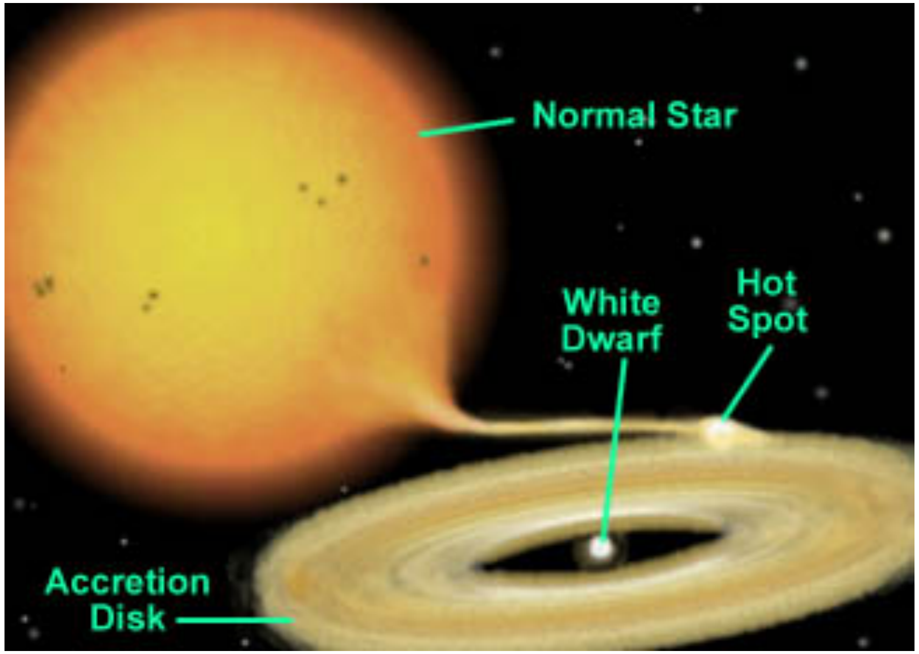
Binary star systems

What is a cataclysmic variable star?

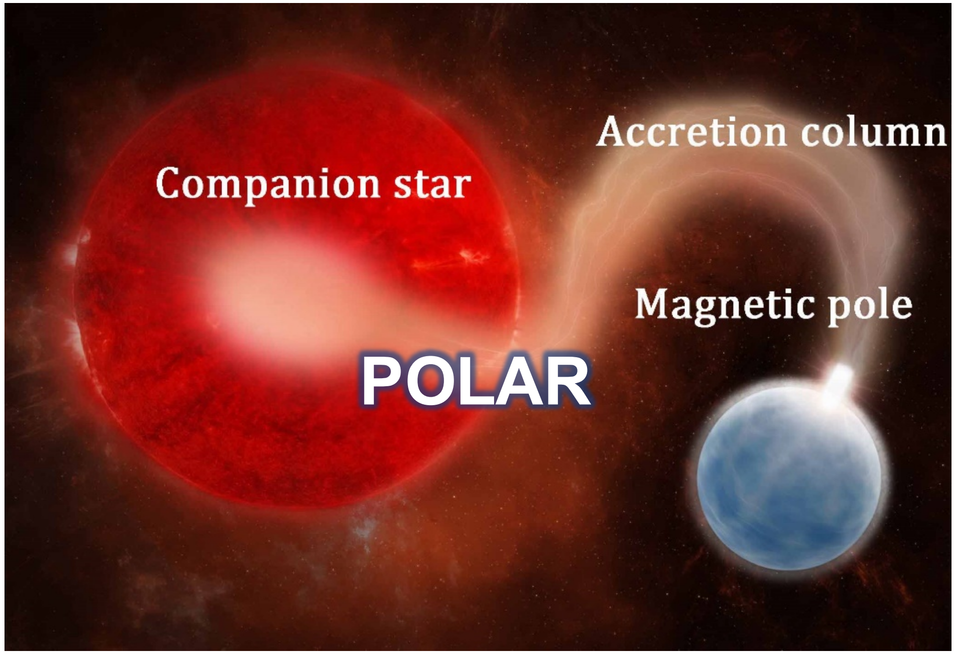
=

A binary system composed of a white dwarf accreting matter from a sun-like star

Two types of CVs:

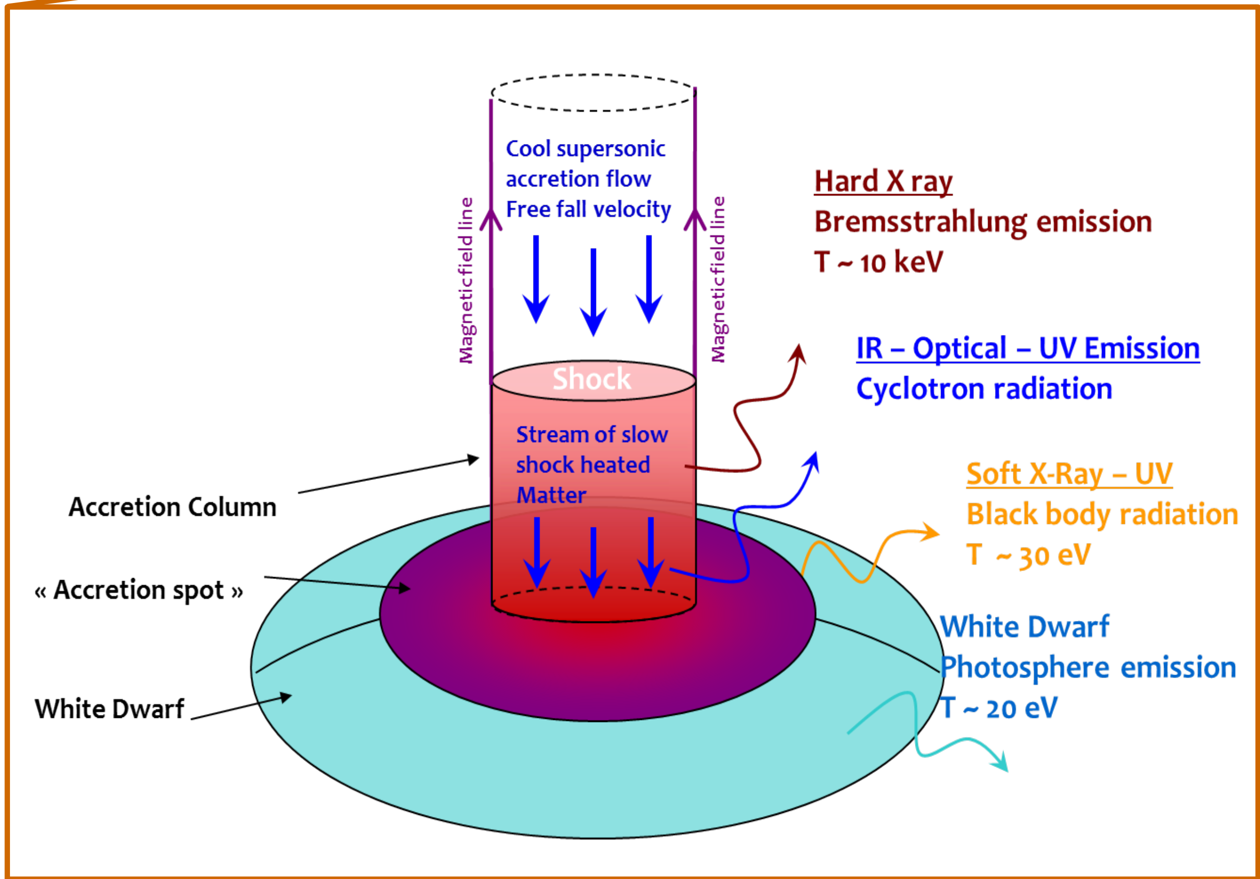


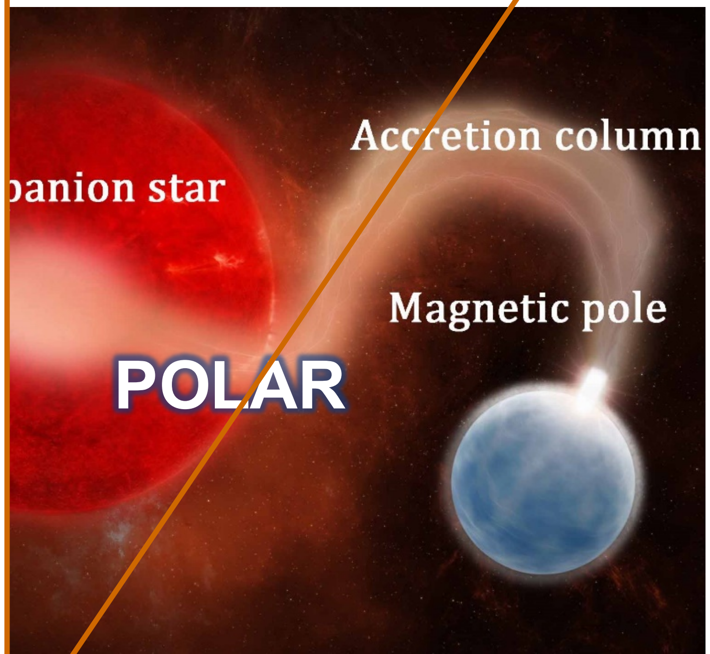
B-field < 1 MG: accretion disk



B-field > 10 MG: no accretion disk

Binary star systems

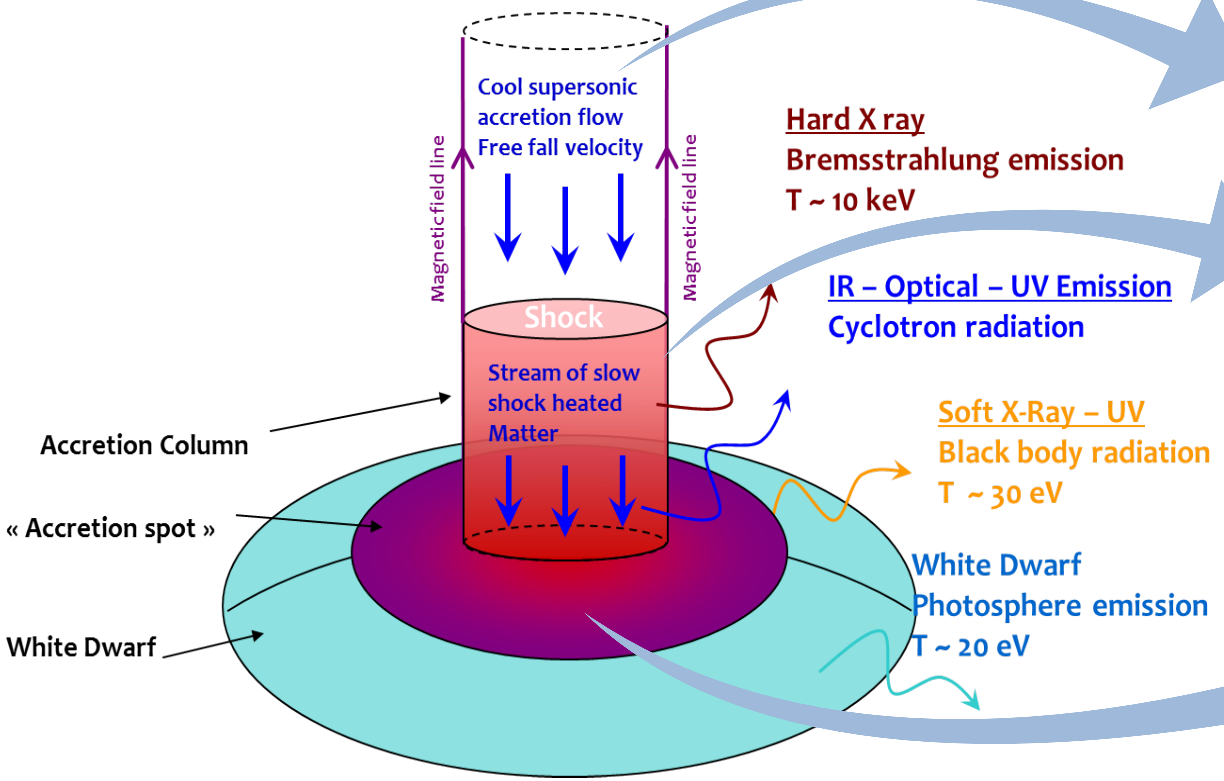




> 10 MG: no accretion disk

Binary star systems in the lab?

Astrophysical scenario:



Experiment:

Reproduce a plasma flow:
laser-target interaction

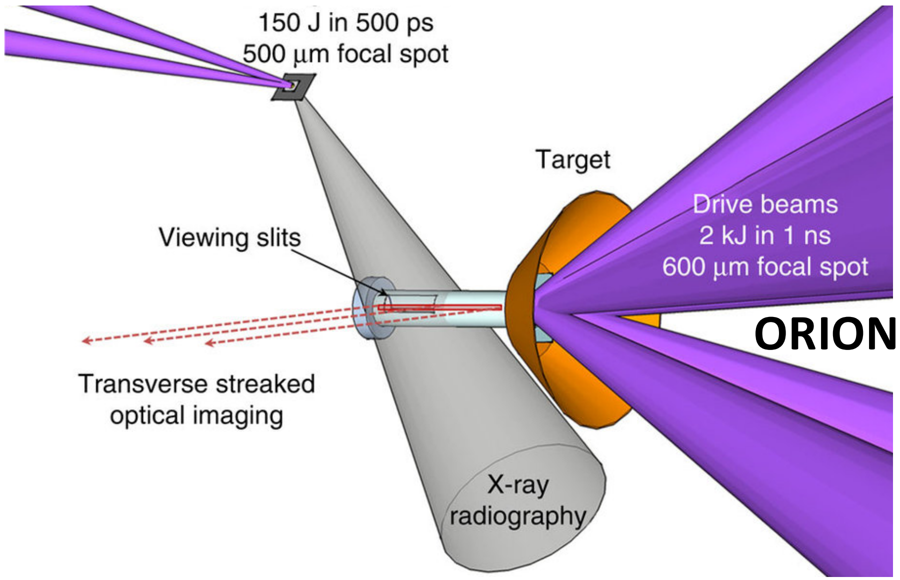
Collimate the plasma flow:
???

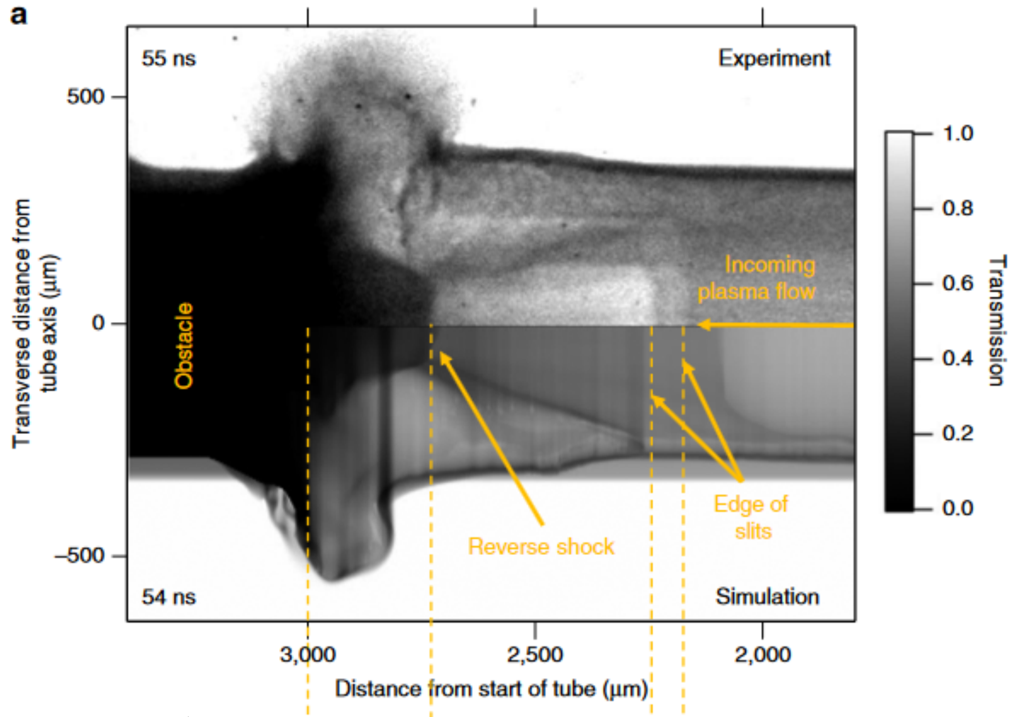
Simulate WD photosphere:
obstacle

Plasma collimation via tube

J. Cross et al., Nat Commun, 7:11899 (2016)

ORION + LULI2000 (2012, 2014)



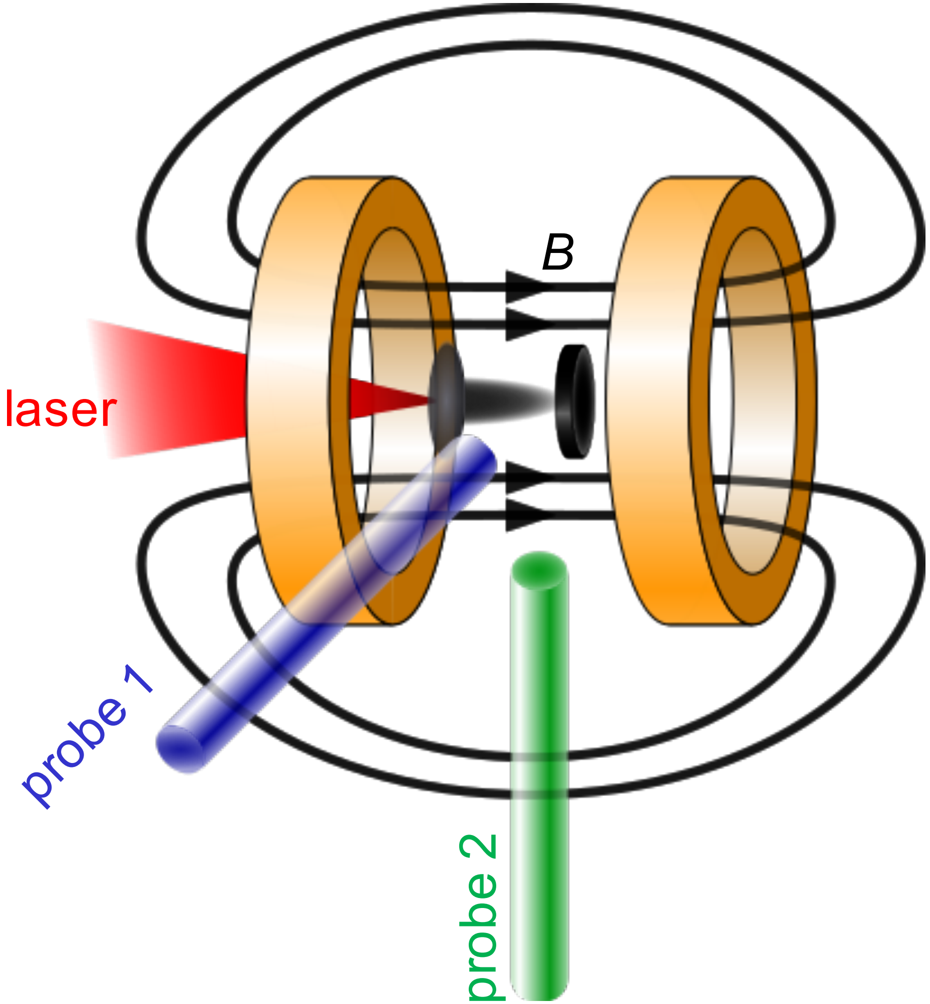


- simulations and experiment in good agreement
- **Tube strongly influences plasma dynamics**

Can we accomplish the same with a magnetic field and still study the jet expansion and shock physics?

cf. B. Albertazzi, Science, 346, 325-328 (2014)

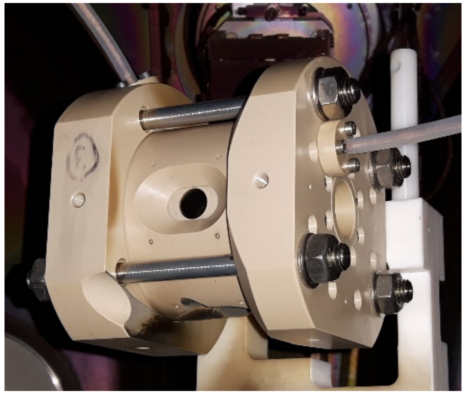
Experimental setup

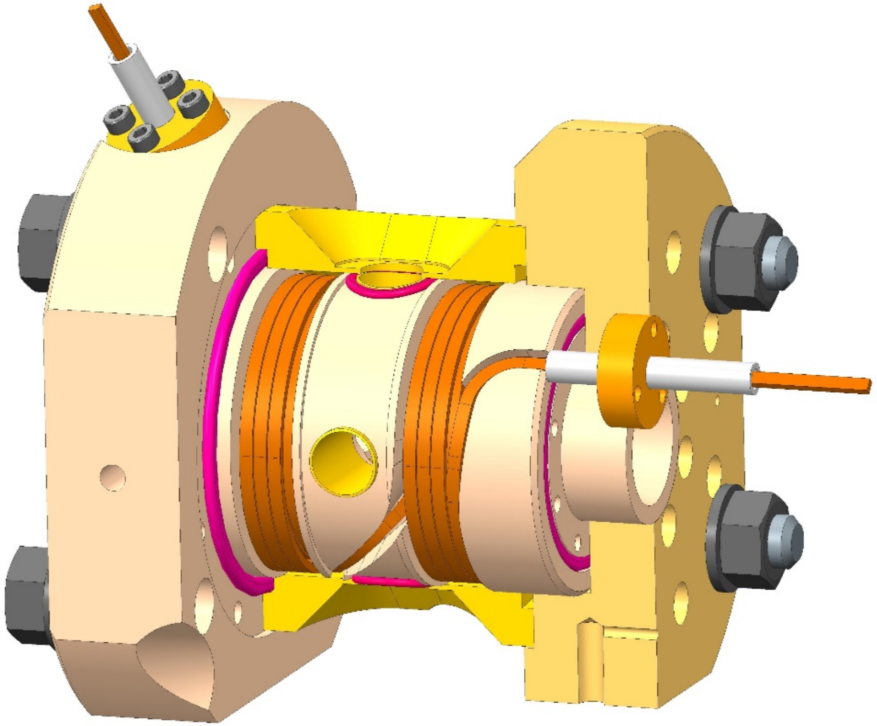


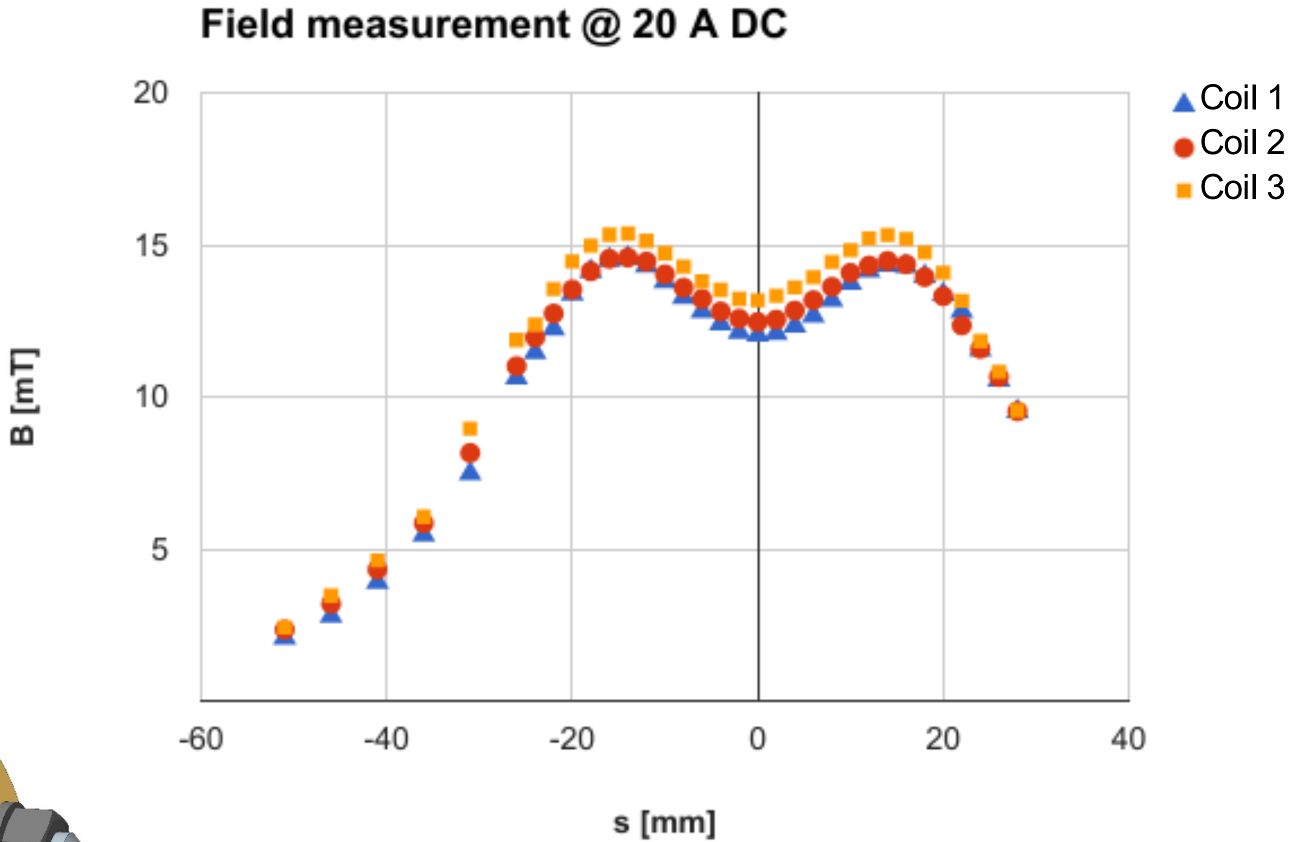
Challenges:

- High field (~ 20 T) generation + optical access to gap
  - → Strong attracting forces
  - → High mechanical stress
- Vacuum compatible materials (~10^{-5} mbar)
- Compact housing to prevent coil from outgassing
  - → Flash over protection

Magnet prototype

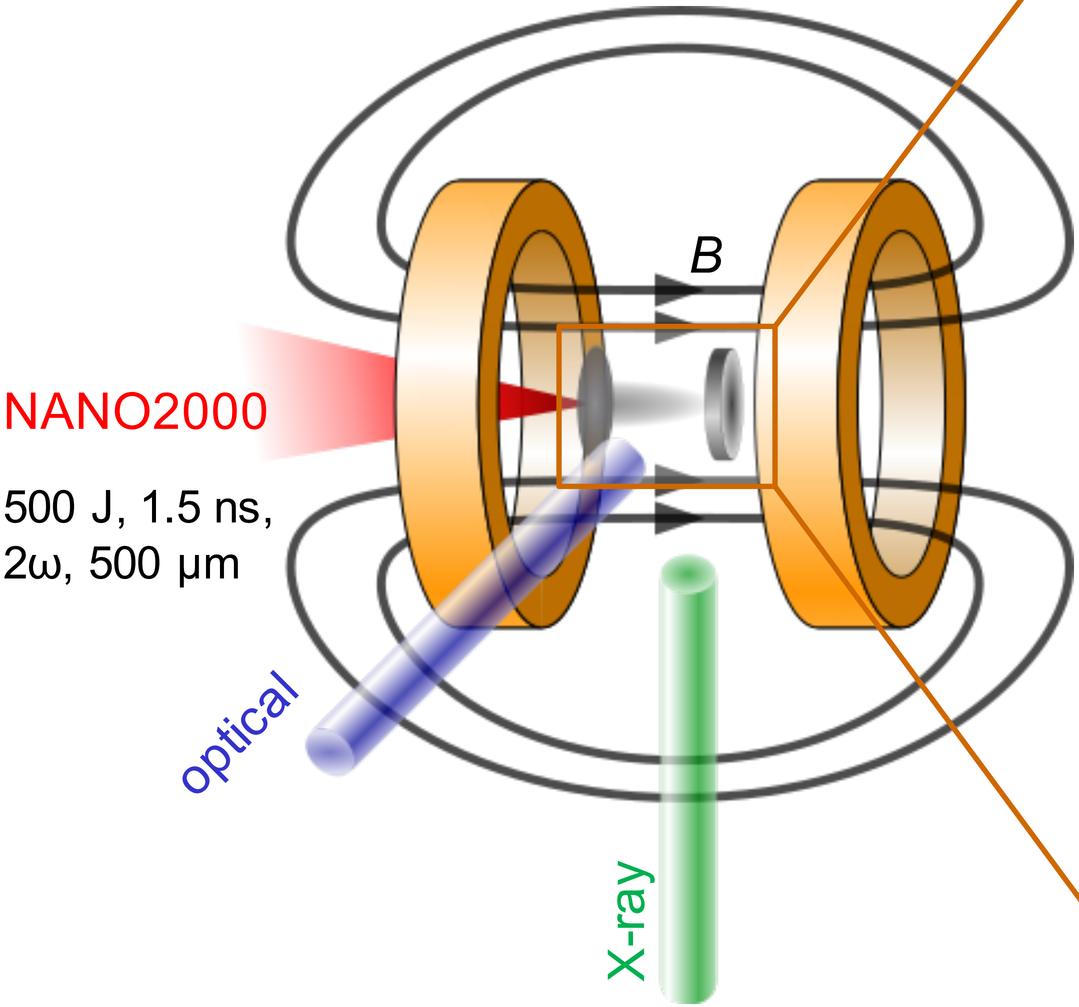




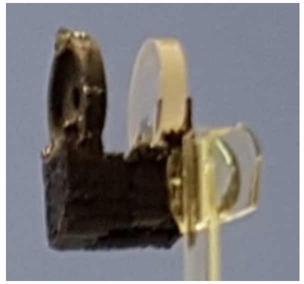


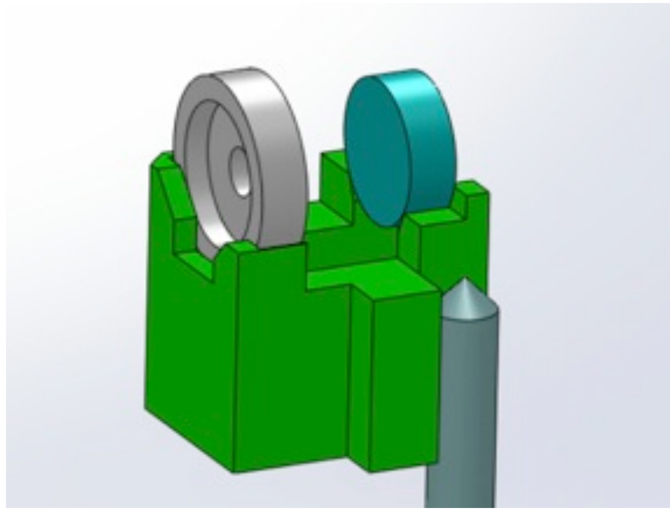
Successfully commissioned
for **15 T** operation

Experimental setup @ LULI2000



Target





Laser targets:

$Al_{0.2µm}$-$CH_{10µm}$-$Au_{1.5µm}$-$Ti_{6µm}$

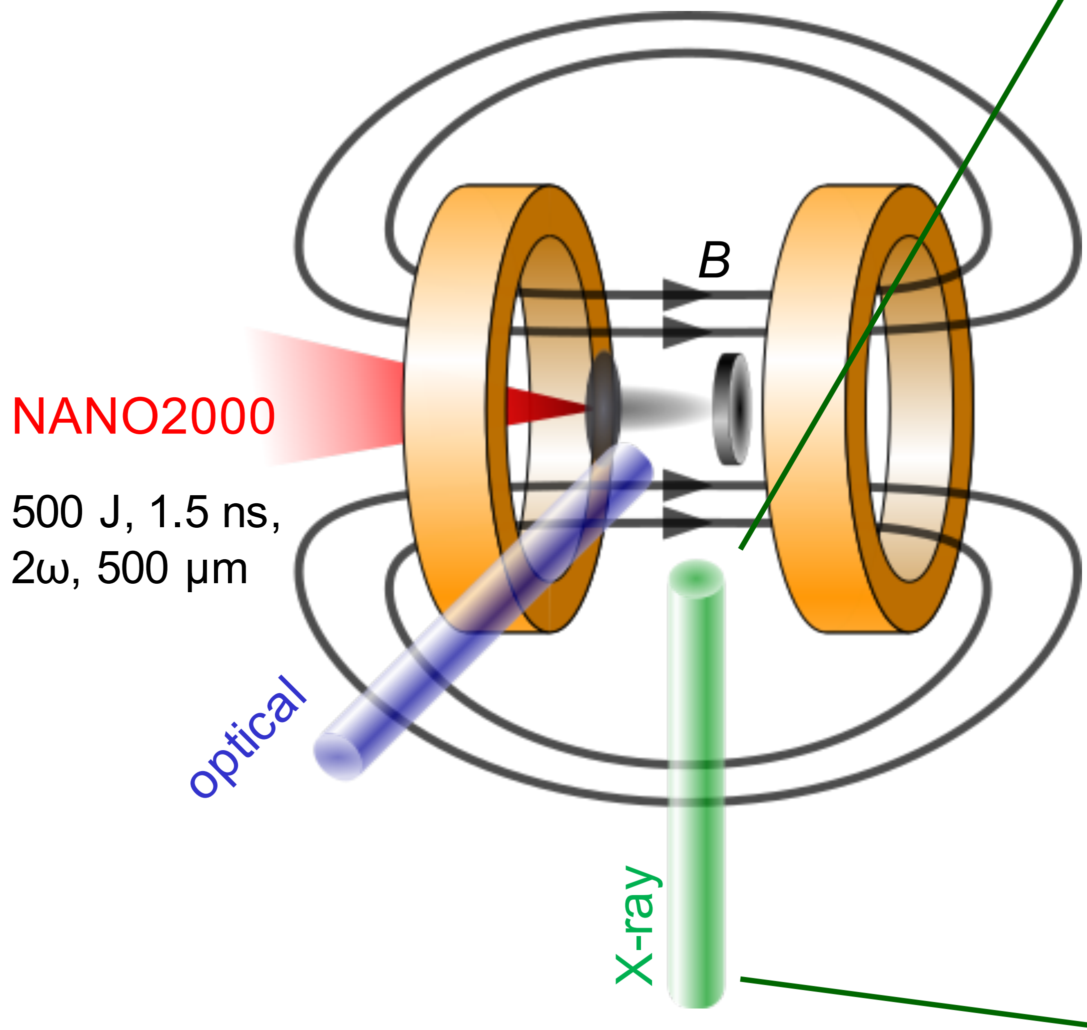
$CH_{25µm}$-$Sn_{6µm}$-$CH_{25µm}$

$CH_{25µm}$-$Sn_{6µm}$

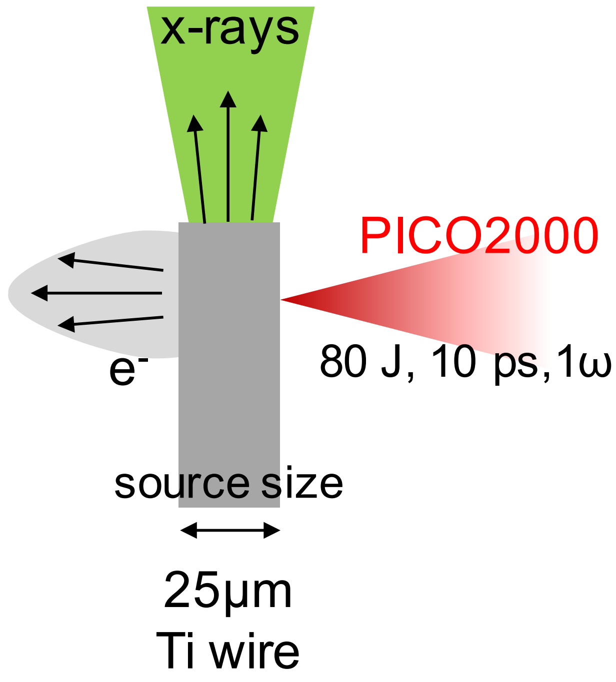
Obstacle:

GGG

Experimental setup @ LULI2000

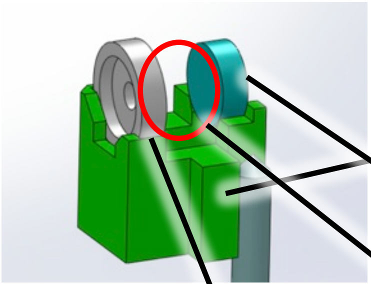


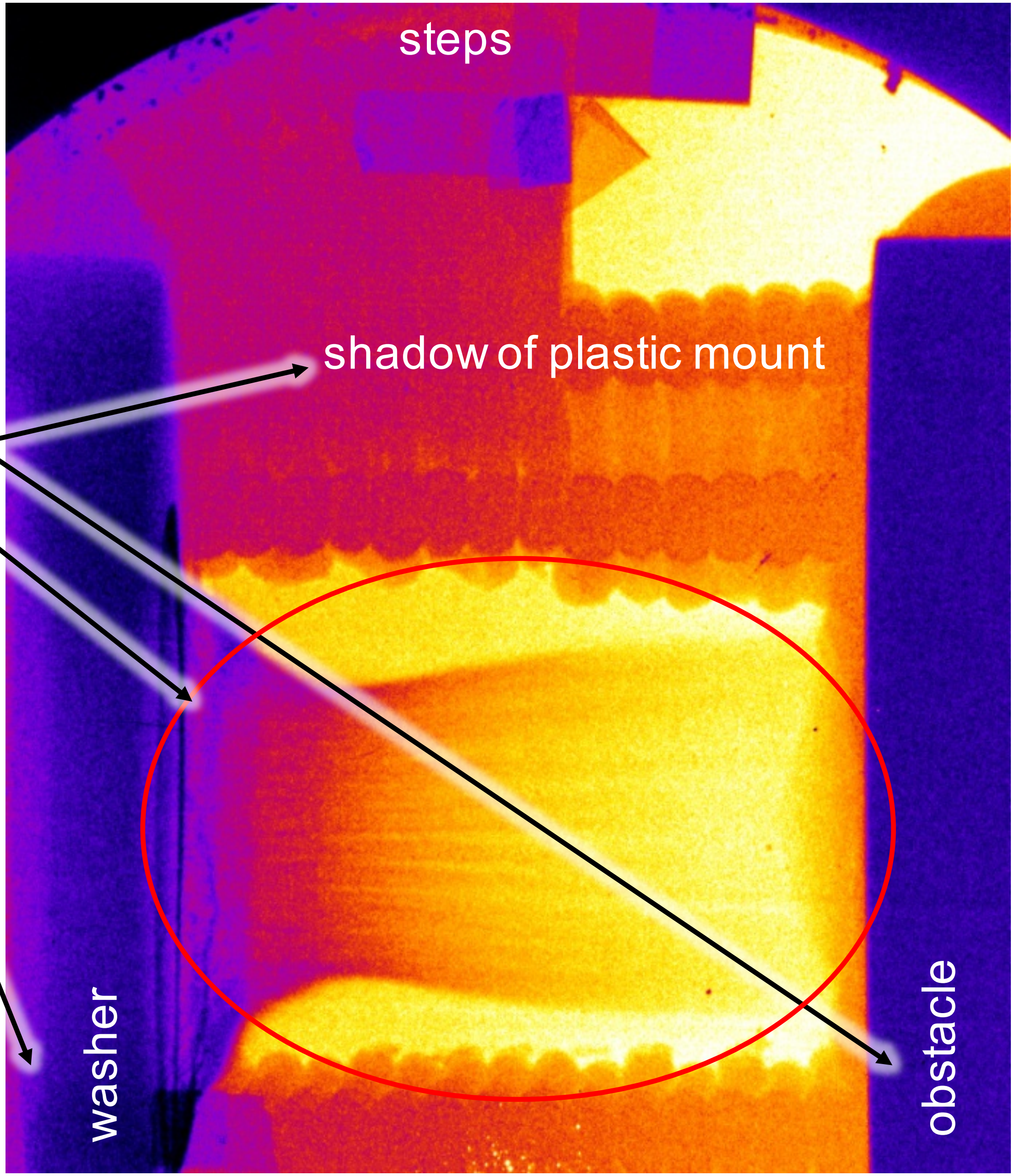
X-ray generation



- X-rays detected by IP
- spectrally characterized
- ~ 20 × magnification
- 1.443 μm/px
- 1000 lines/inch resolvable

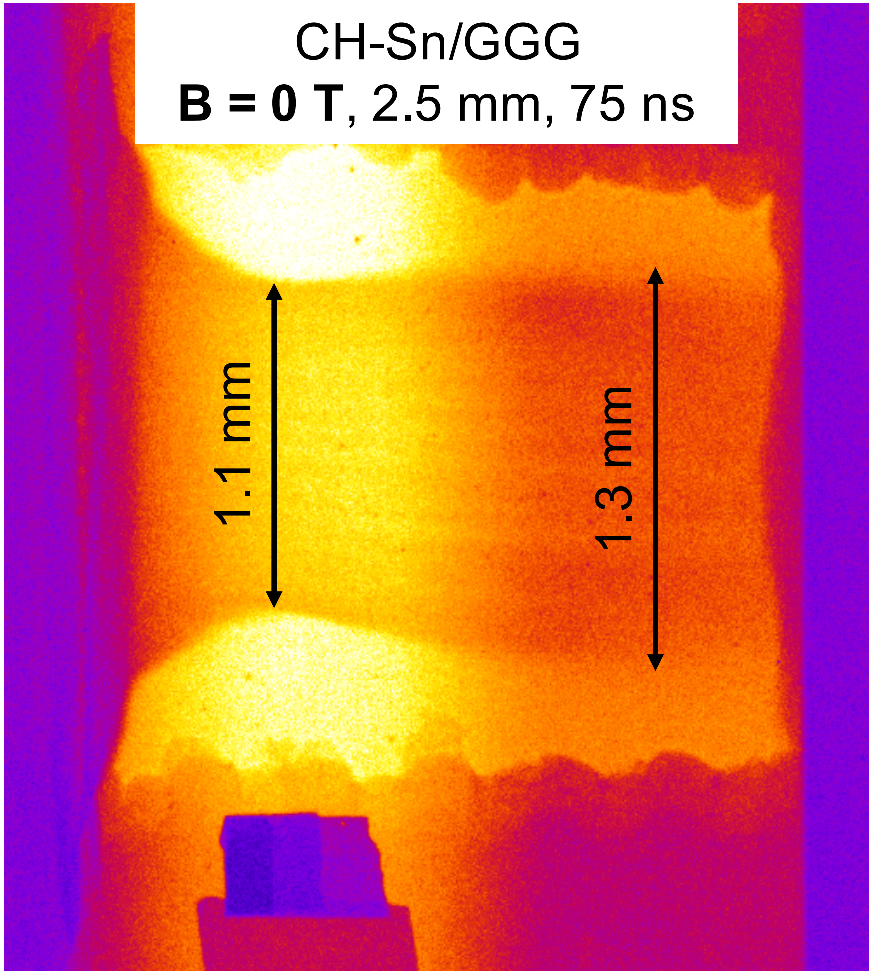
X-ray radiographs

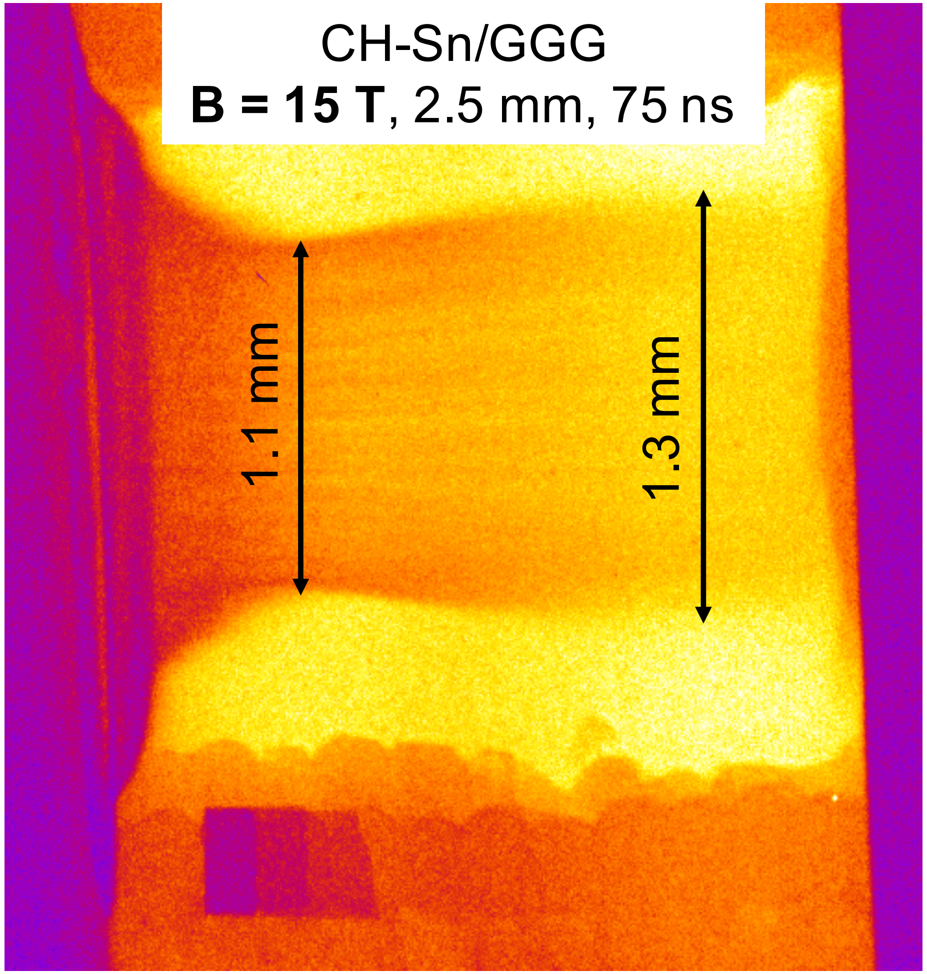




Magnetic field: 15 T,
Distance W to O: 3 mm,
Delay NANO-PICO: 120 ns

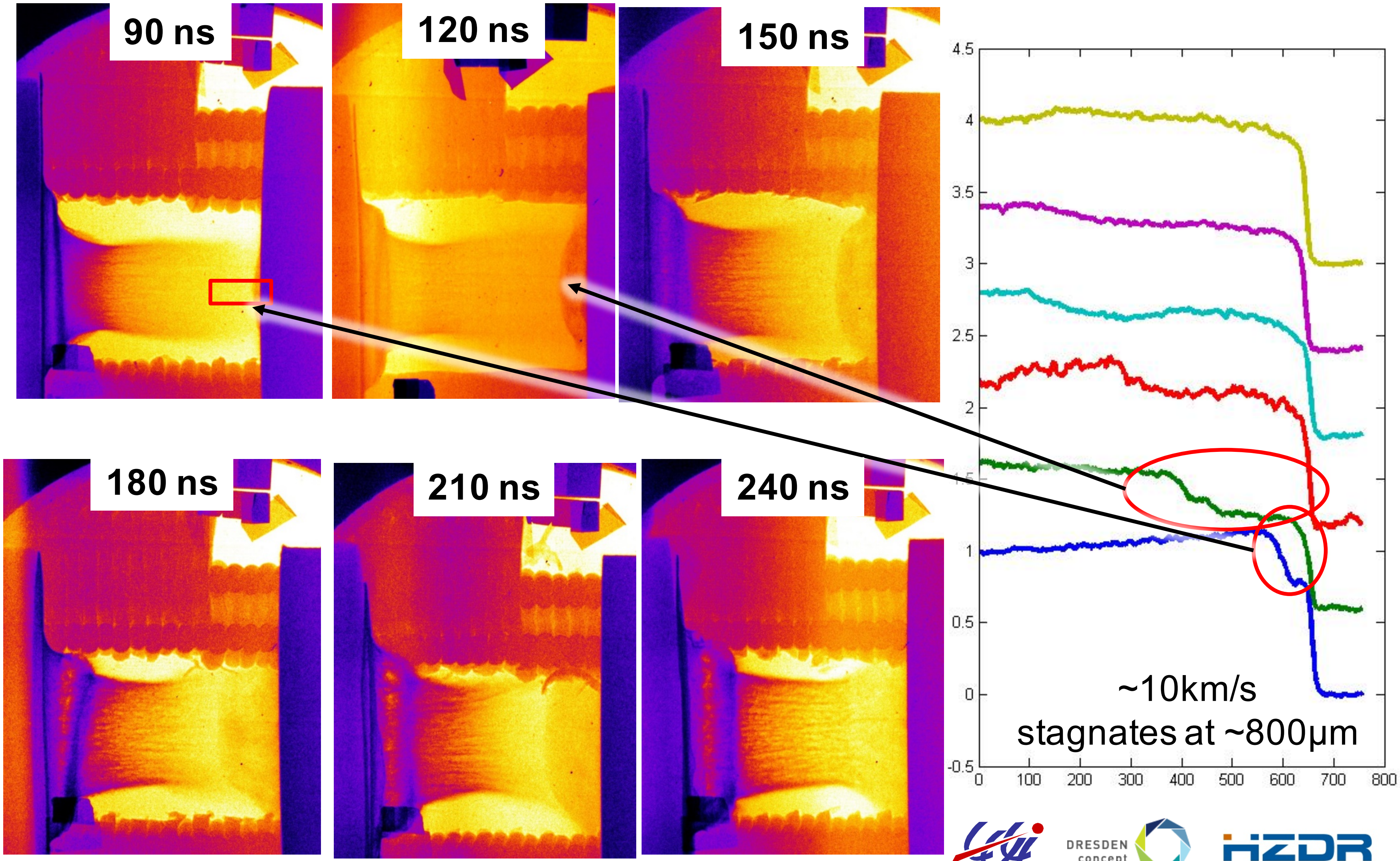
w/o B-field vs. w/ B-field



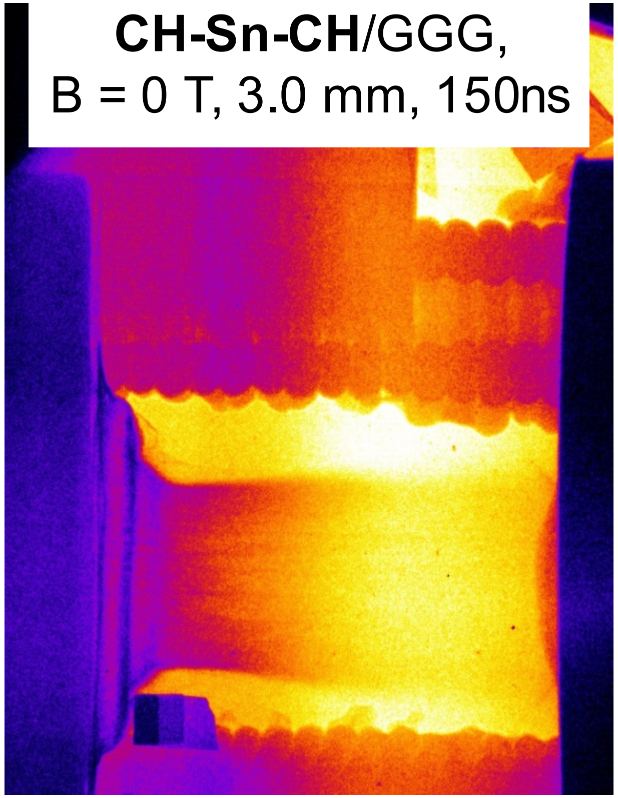


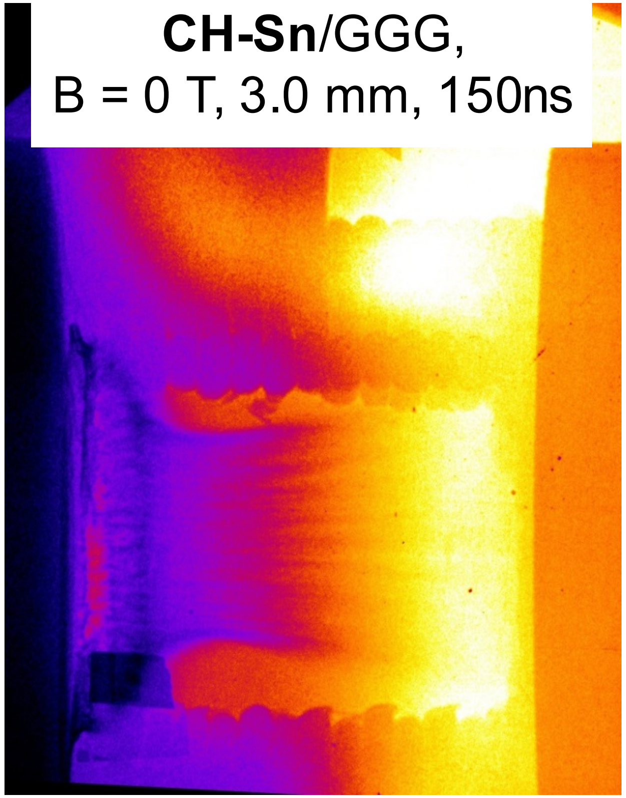
Magnetic field has only little influence on high density region

Return shock @ different (long) delays, B = 15 T



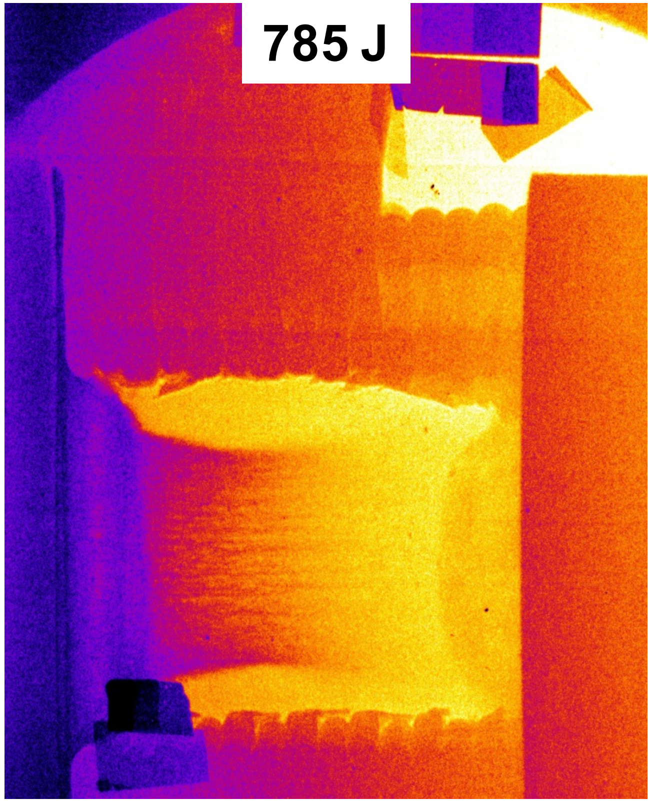
Different main targets



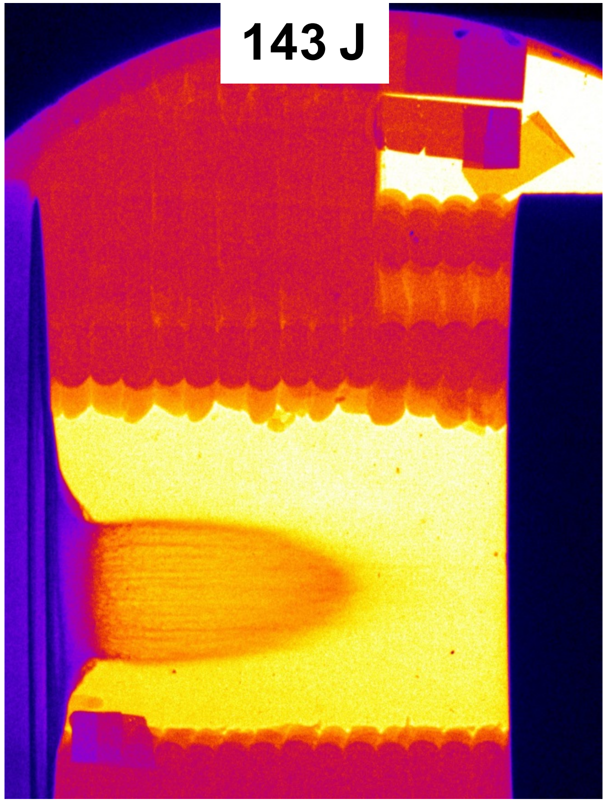


Analysis ongoing…

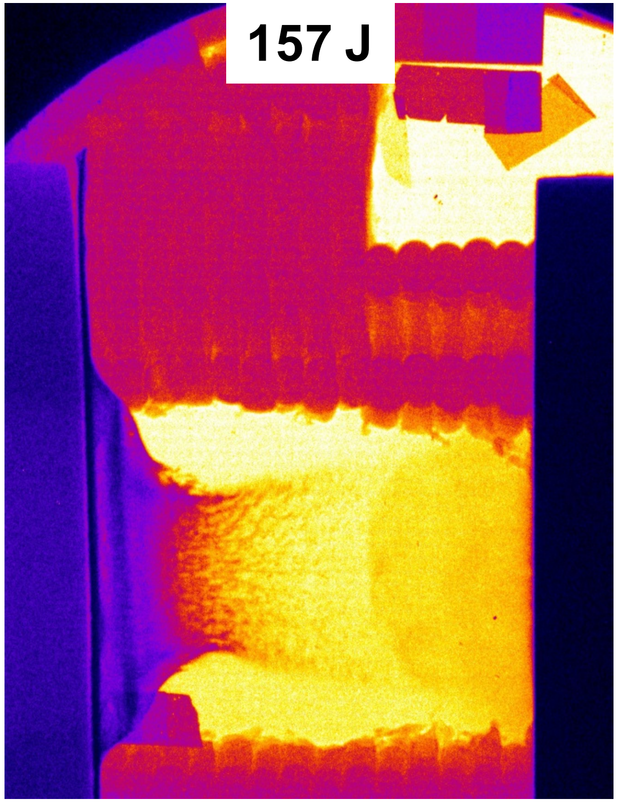
Reduced laser energy, B = 15 T



Al-CH-Au-Ti , 3 mm,
150 ns



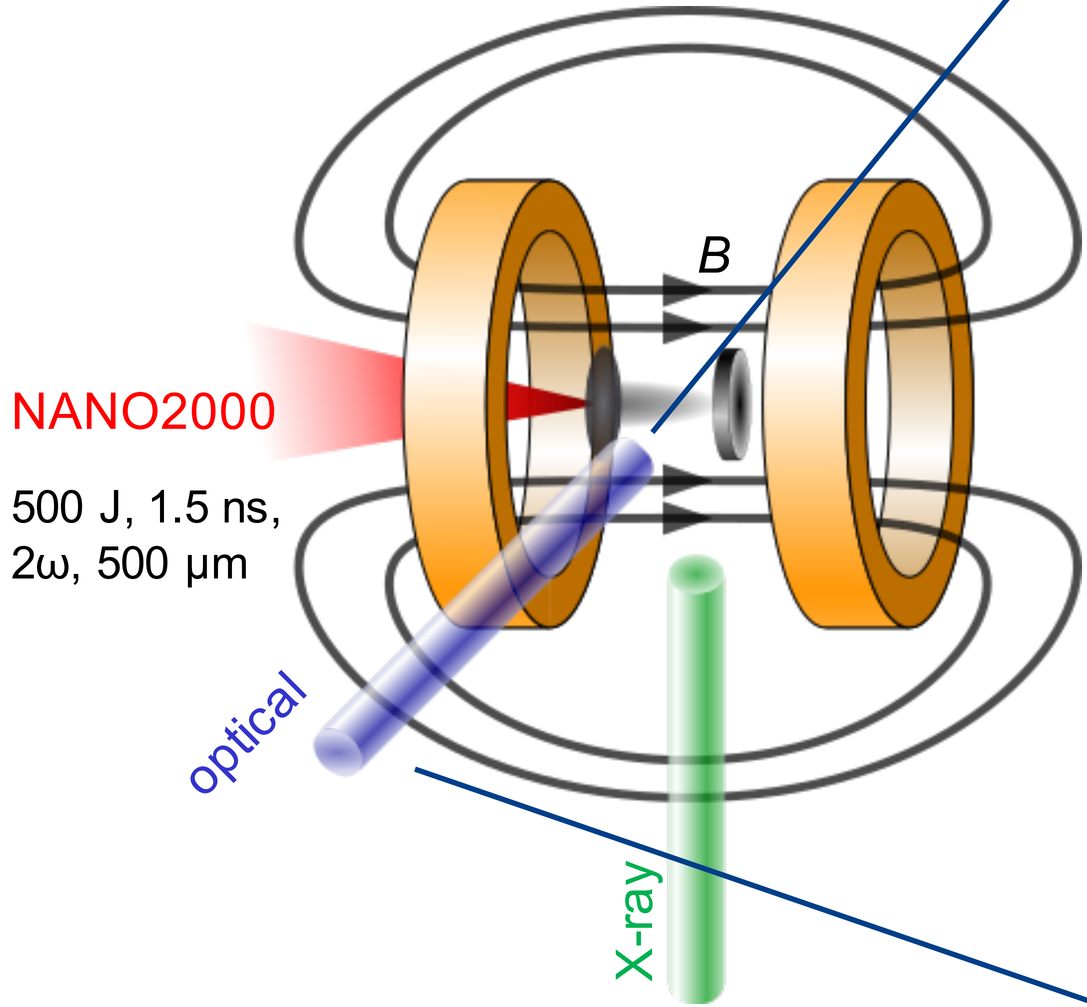
Al-CH-Au-Ti, 3 mm,
145 ns



Al-CH-Au-Ti, 3 mm,
395 ns

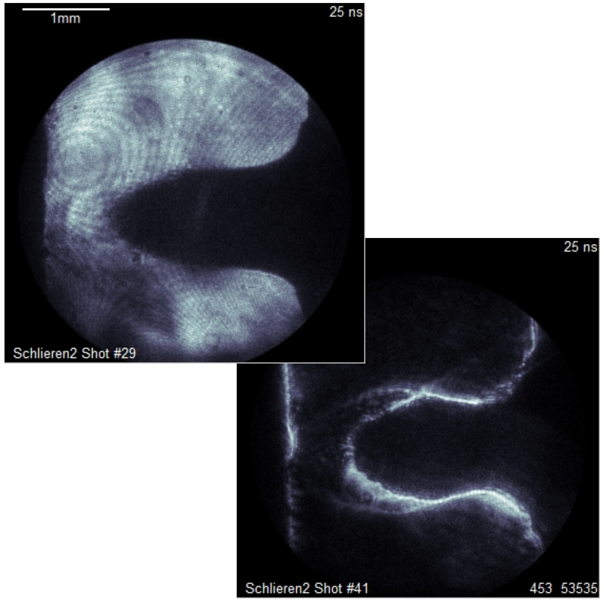
Analysis ongoing…

Experimental setup @ LULI2000



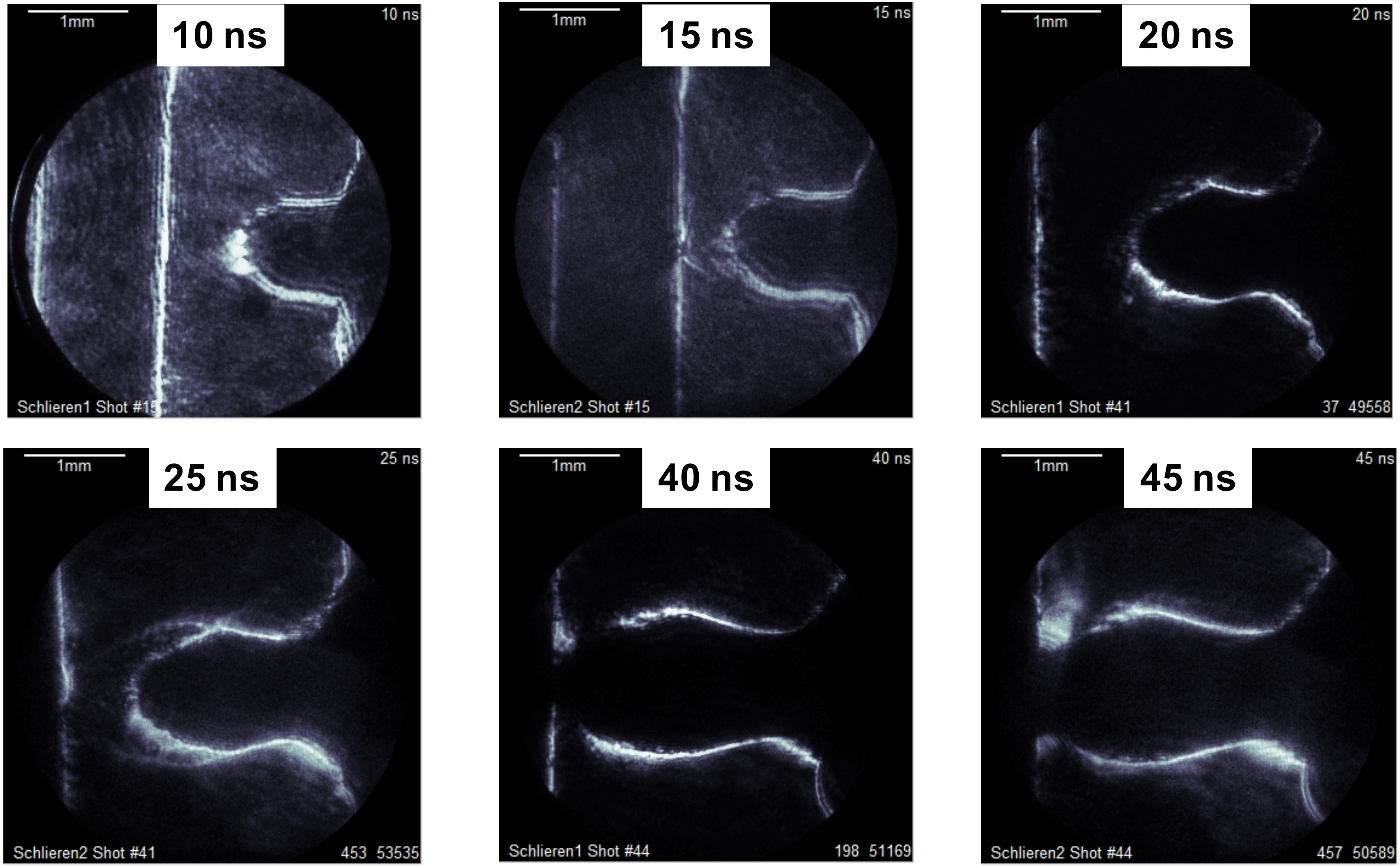
transverse optical diagnostics

shadowgraphy / schlieren



- 2 × schlieren imaging
- very sensitive to gradients in low density plasma
- difficult to quantitatively analyze

Plasma expansion in Schlieren diagnostic

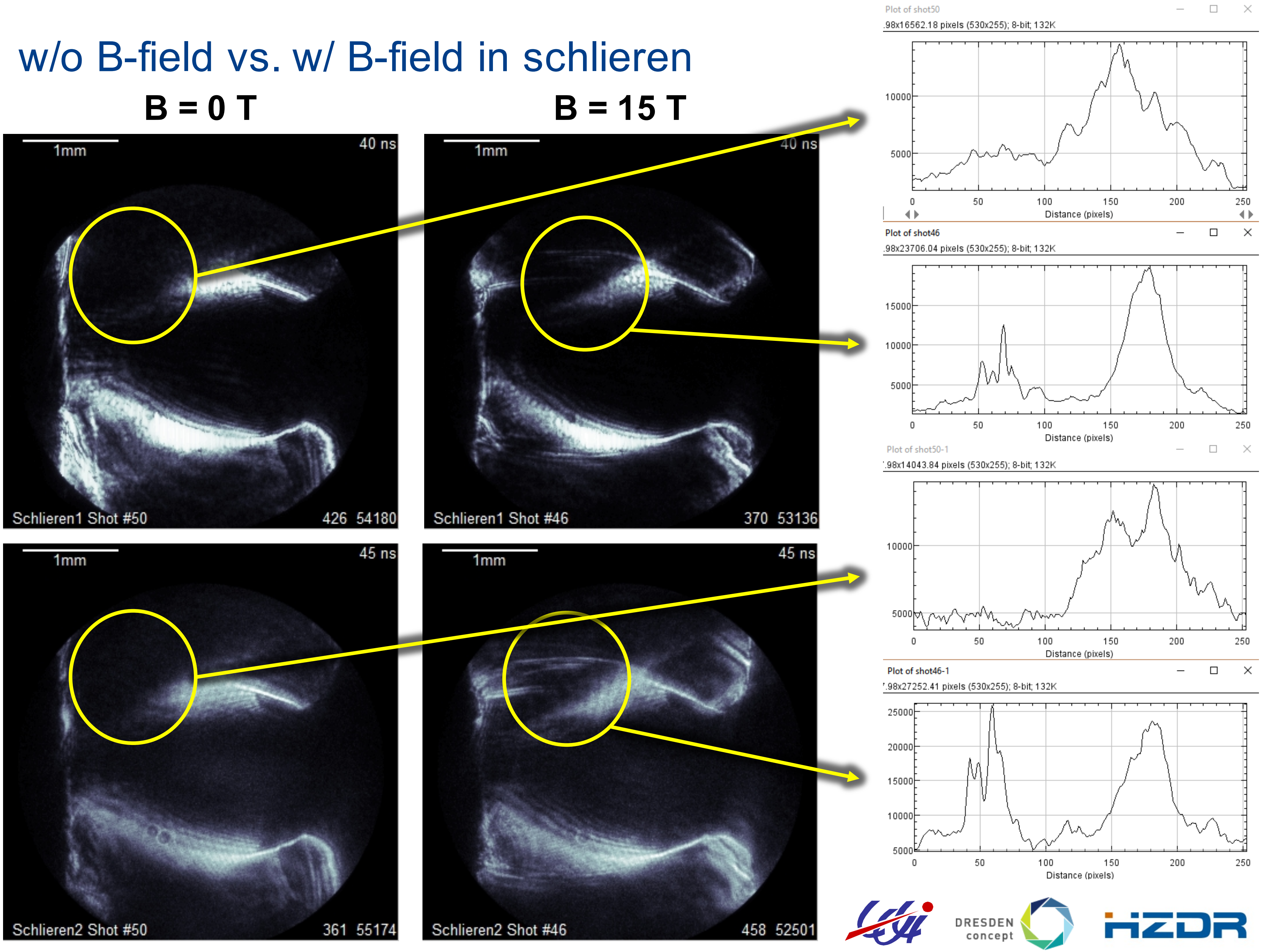


Collision of low density plasma with obstacle at ~40ns

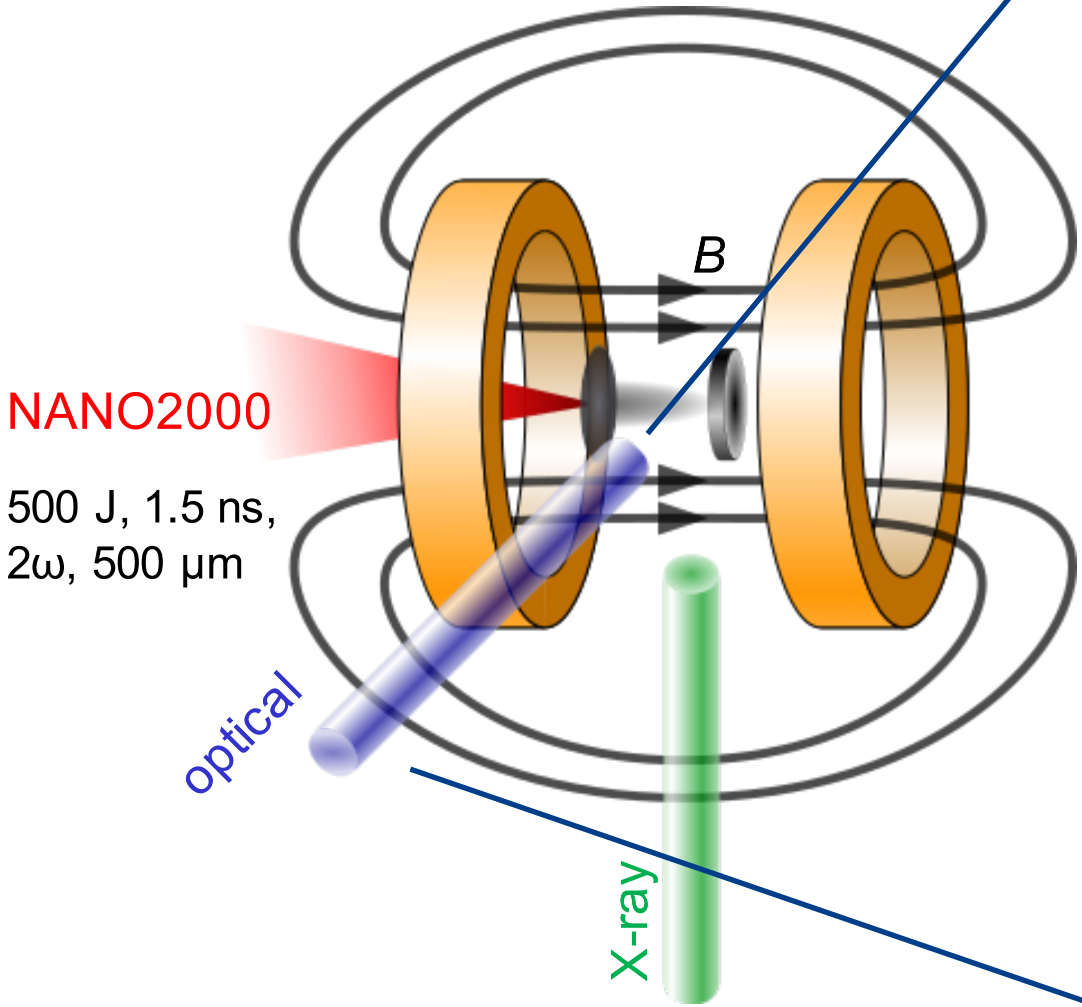
DRESDEN concept

HZDR

w/o B-field vs. w/ B-field in schlieren

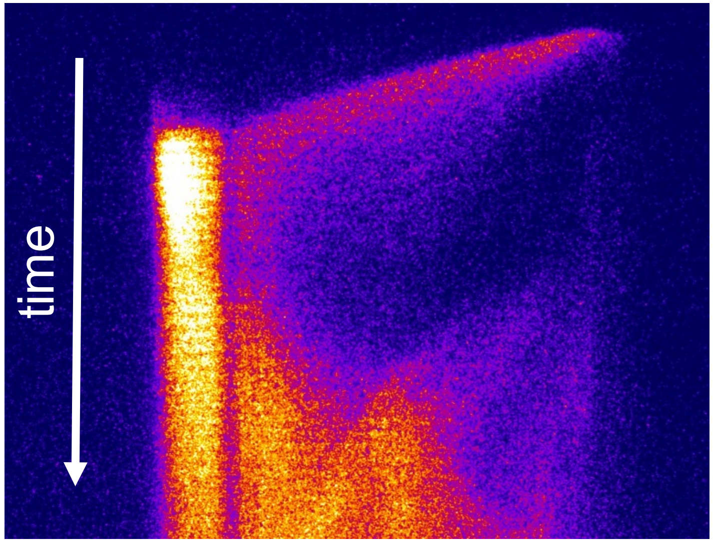


Experimental setup @ LULI2000



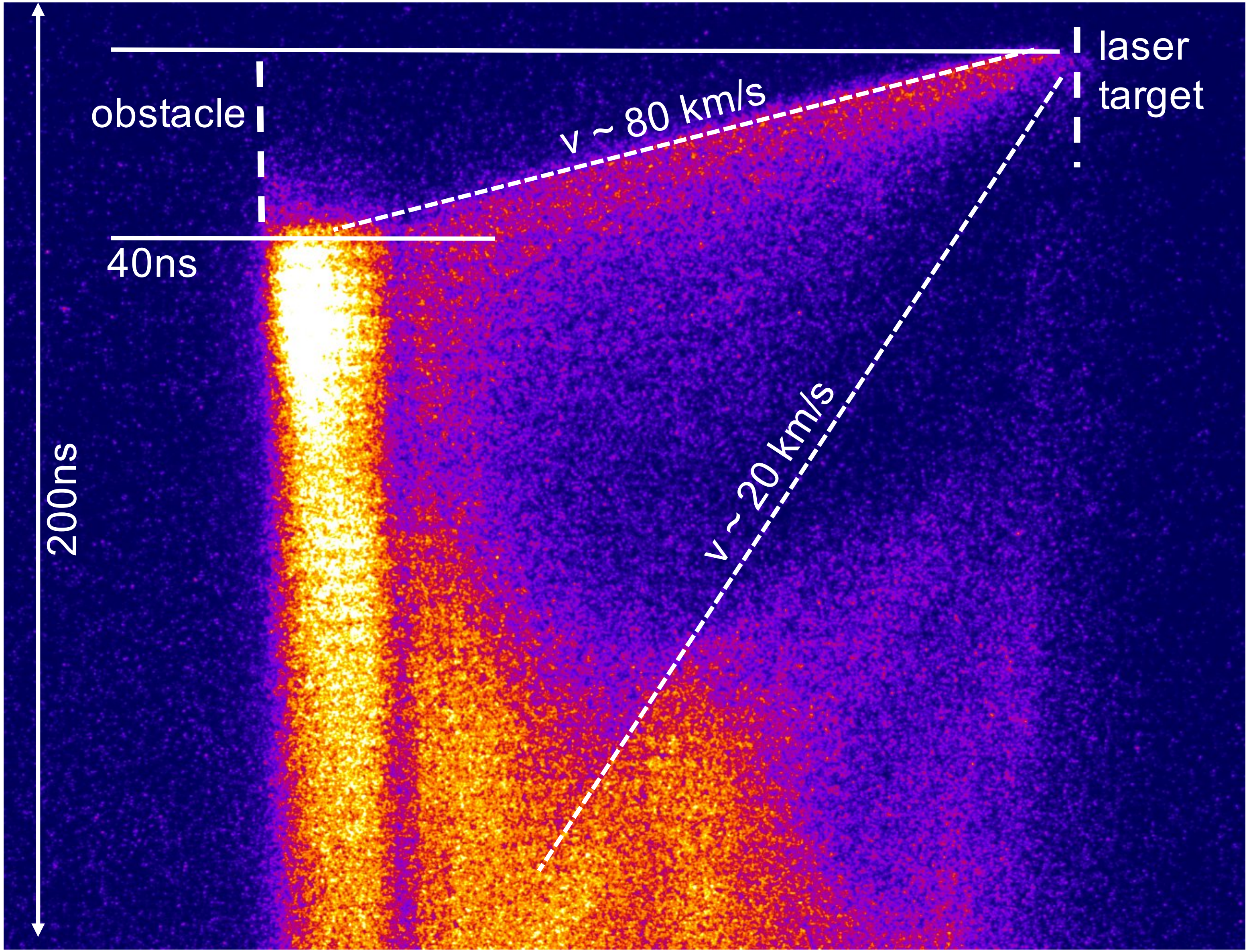
transverse optical diagnostics

Streaked optical pyrometry (SOP)



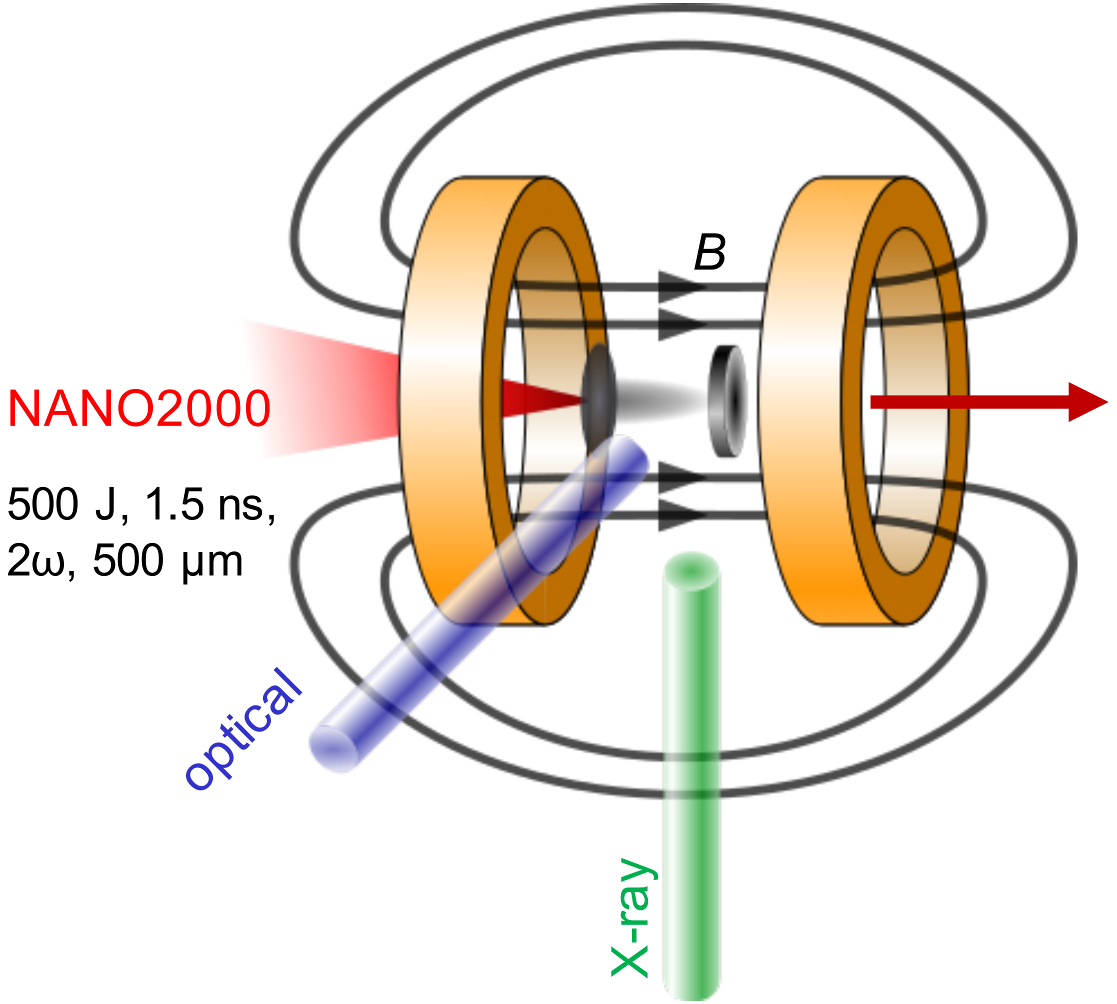
- collison time measurement
- determine plasma / reverse shock velocity

Transverse SOP



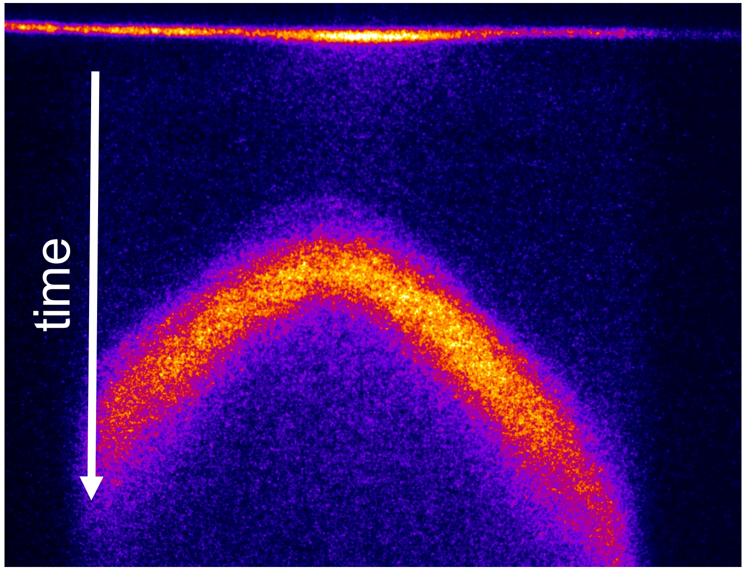
Collision time of 40 ns consistent with Schlieren

Experimental setup @ LULI2000

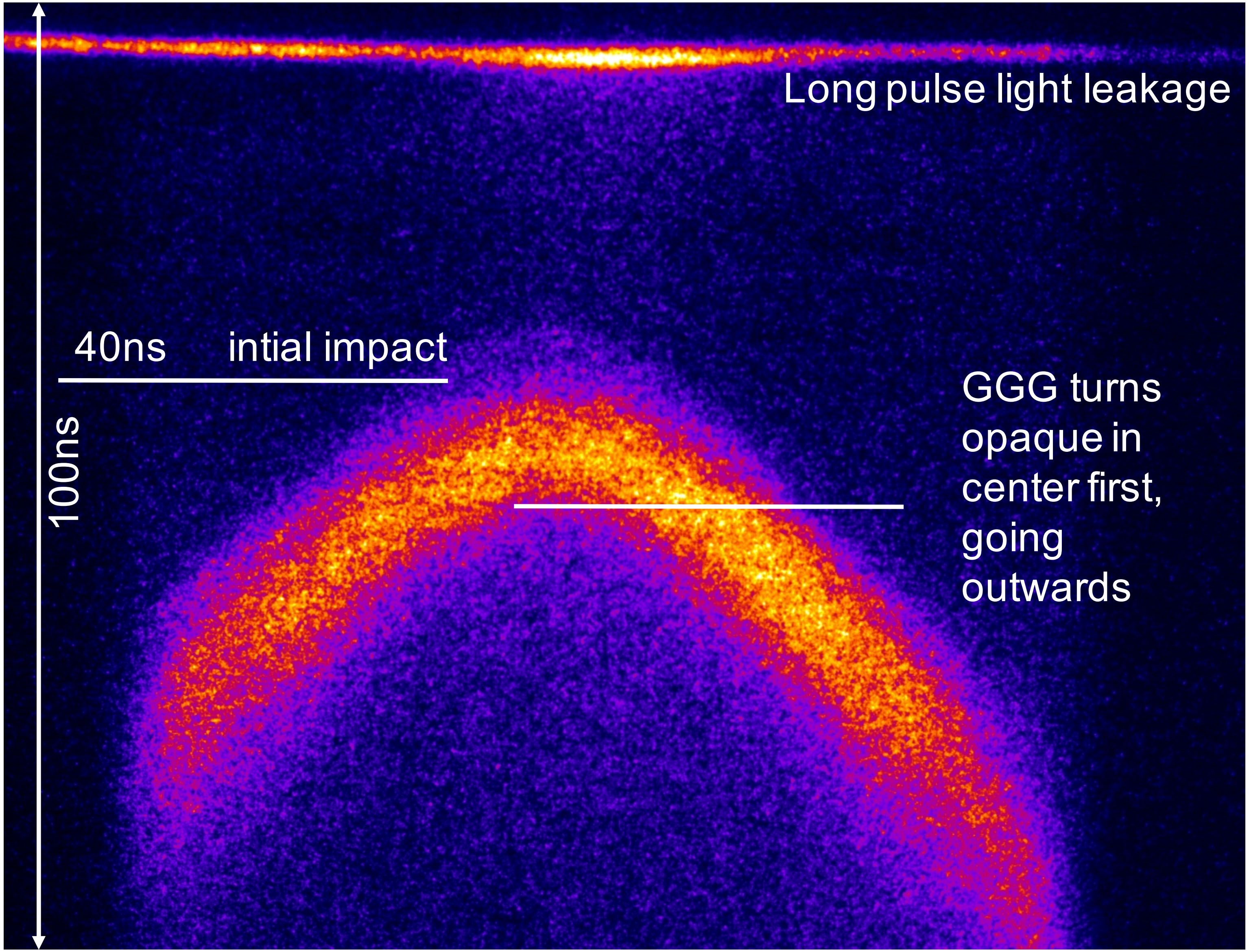


transmitted light diagnostics

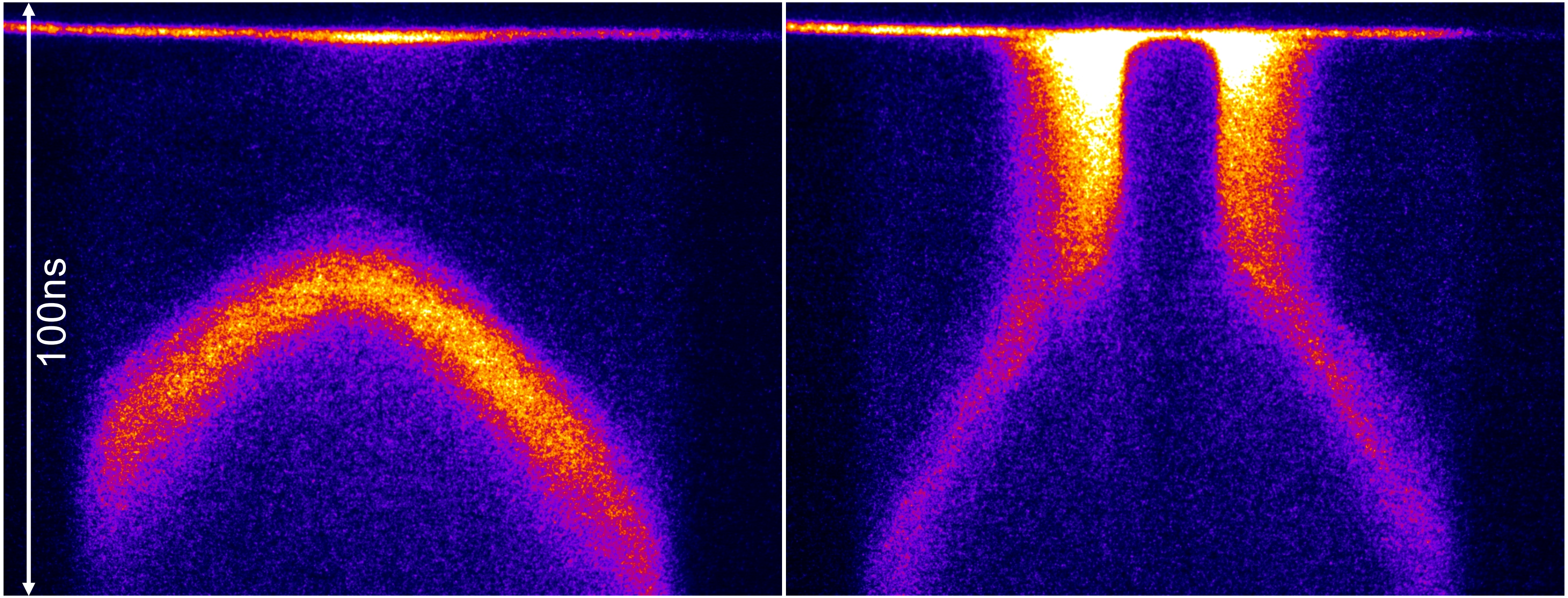
Rear side SOP



Rear side SOP w/o B-field

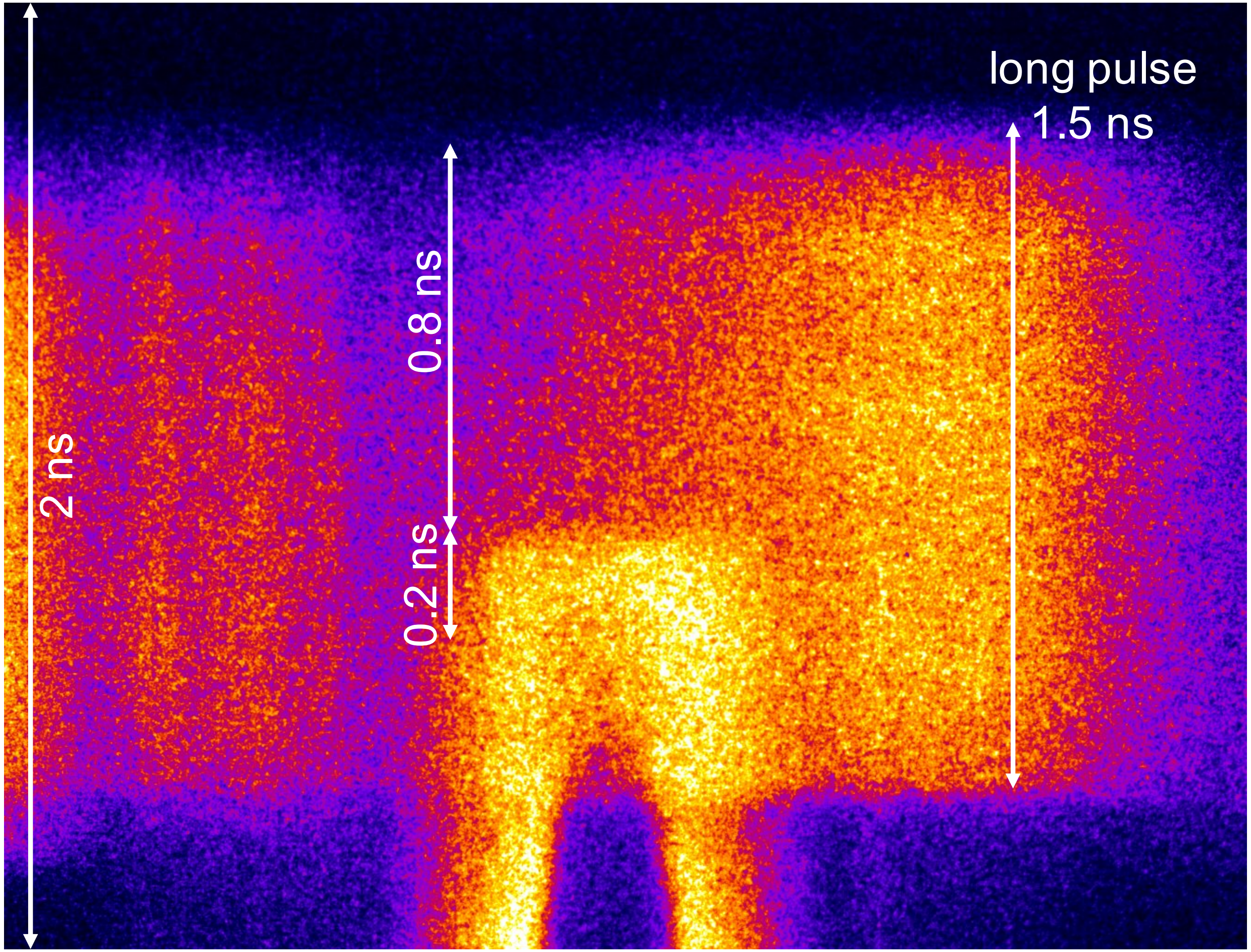


Rear side SOP w/o B-field vs. w/ B-field



- GGG turns opaque very fast due to electrons locked to B-field
- Plasma outflow radiates stronger, but return shock collision shines weaker

Rear side SOP w/ B-field – shorter time window



- shock breakout @~0.8ns
- GGG turns opaque @~1ns after long pulse onset
- quantitative analysis needed to determine if e^- or other effect

Summary

- Successful combination of pulsed coil with a longpulse/shortpulse laser facility
- generated laser-driven plasmaflows within the magnet
- diagnosed the plasmaflow both in the high density regime using laser-generated x-ray radiography and the low-density regime using various optical diagnostics
- generated and radiographed a return shock from the collision on hard obstacles

Next steps:

- complete analysis of collected data
- next experiment: low-density, high-Z plasmaflows (foams), stronger magnet
- Lab-astro experiments at XFEL?