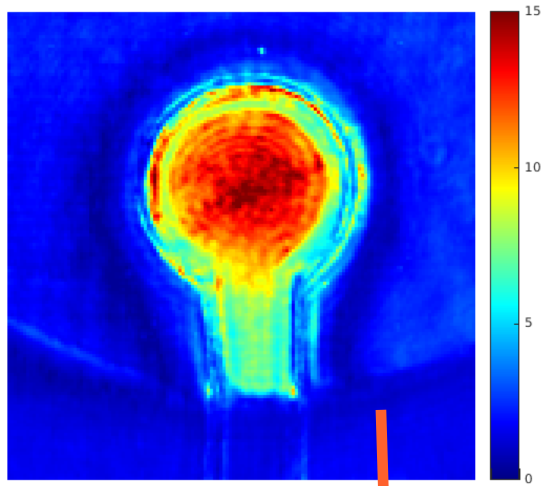

TGG boundary

Generation of sub-MG quasi-stationary magnetic field using cm scale capacitor-coil targets

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Magnetic fields for laser plasma experiments

Scientific case for magnetized experiments:

- < 40 T over ~ 1 cm³ have been used for jet collimation, MHD studies, collisionless shocks, electron heat transport
- < 15 T over ~ 0.01 cm³ have been used for ICF yield enhancement, magnetized reconnection.

→ Pulsed power systems

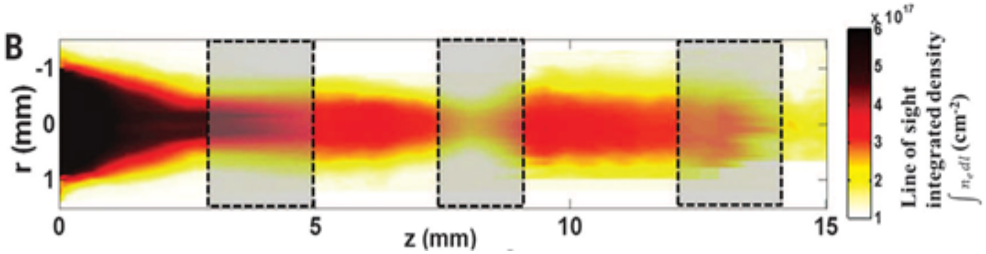
- > 100 T over < 1 mm³ can be used for charge particle lensing, low β laser plasma scenarios*

→ Goal of this research

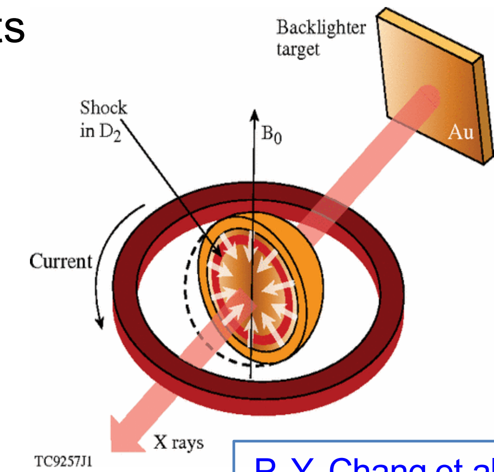
- >10⁴ T for fast ignition

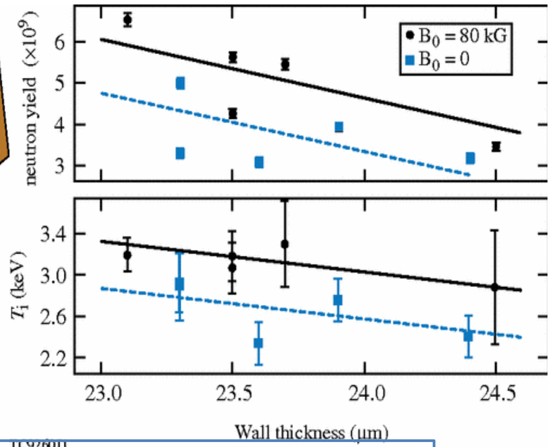
→ Long way to go

Magnetized plasma jets from ns laser experiments



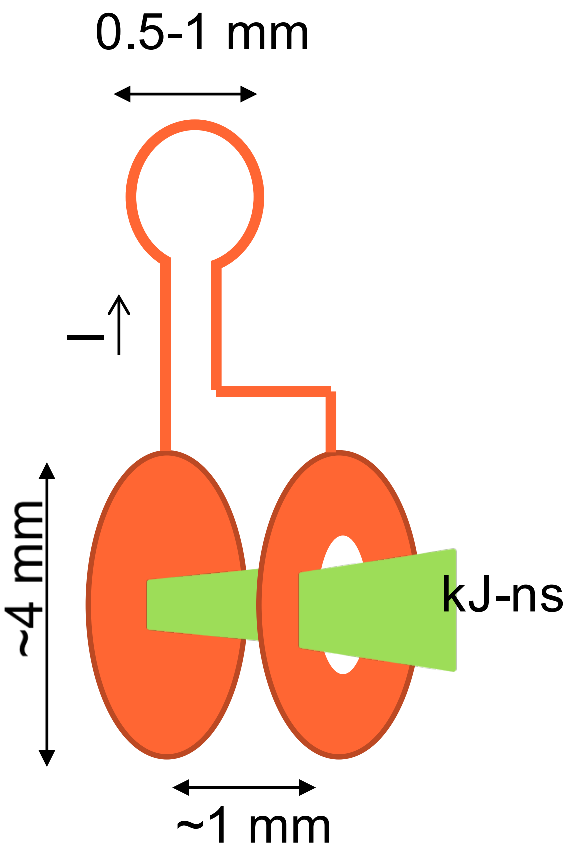
B. Albertazzi et al., Science **346**, 325 (2014)





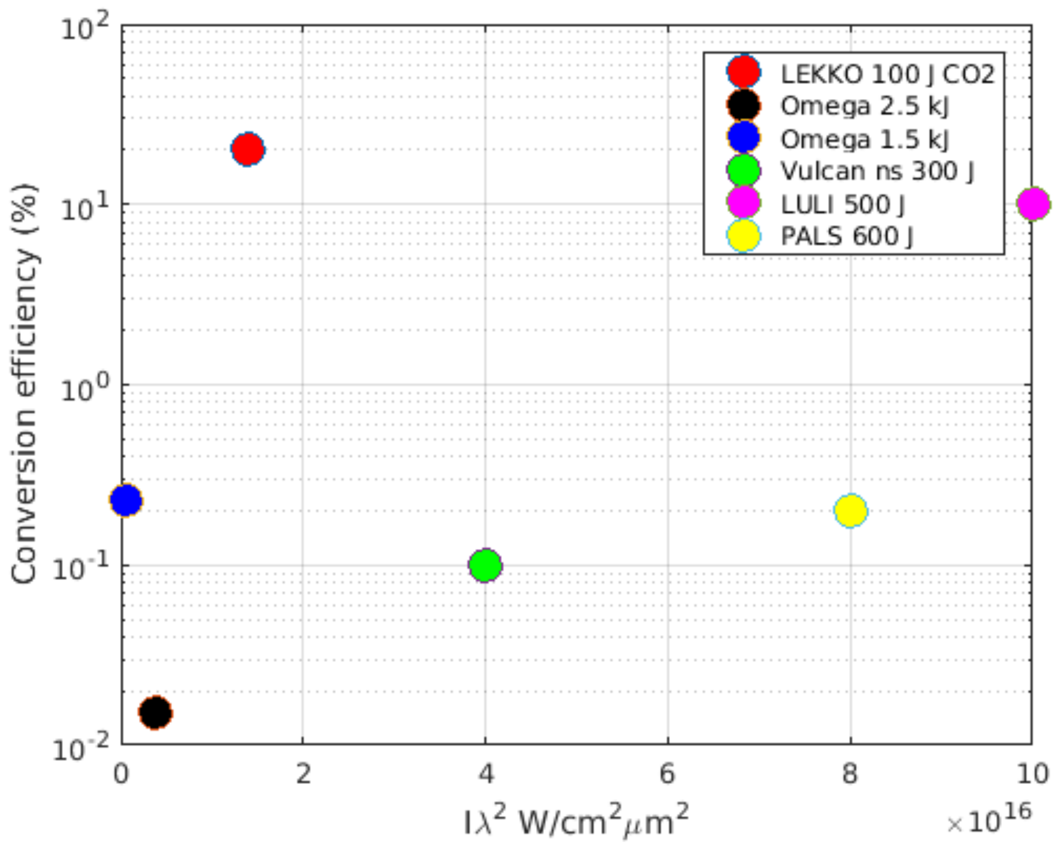
P. Y. Chang et al., PRL **107**, 035006 (2011)

Primer – capacitor coil targets



- Streaming hot electrons from the cathode (back) charge the anode (front)
- Induced voltage difference drives a current through the coil
- Current decays after bulk plasma reaches the anode and short circuits

Why revisit capacitor-coil targets?



- LEKKO: Phys. Rev. Lett. 56 (8), 846 (1986)
- Omega: Phys. Plasmas 23, 043106 (2016)
- Omega: Phys. Rev. E. 95, 033208 (2017)
- Vulcan: J. App. Phys. 98, 054913 (2005)
- LULI: NJP 17, 083051 (2015)

Capacitor coil targets
(decoupling time scales)

- Laser pulse duration: τ_L ~ 1 ns
- Plasma transition time between electrodes: d/c_s ~ 1 ns
- External circuit resonant time: $2\pi\sqrt{LC}$ ~ 0.05 ns

- Goals of the experiment
  - ➢Avoid short circuiting of the plates to investigate behavior of circuit parameters
  - ➢2-color polarimetry (spatial and temporal evolution)
  - ➢Increase access to the coil (1 mm diameter, ~ 3 cm from focus) ~~to provide in-situ measurements of magnetic field~~

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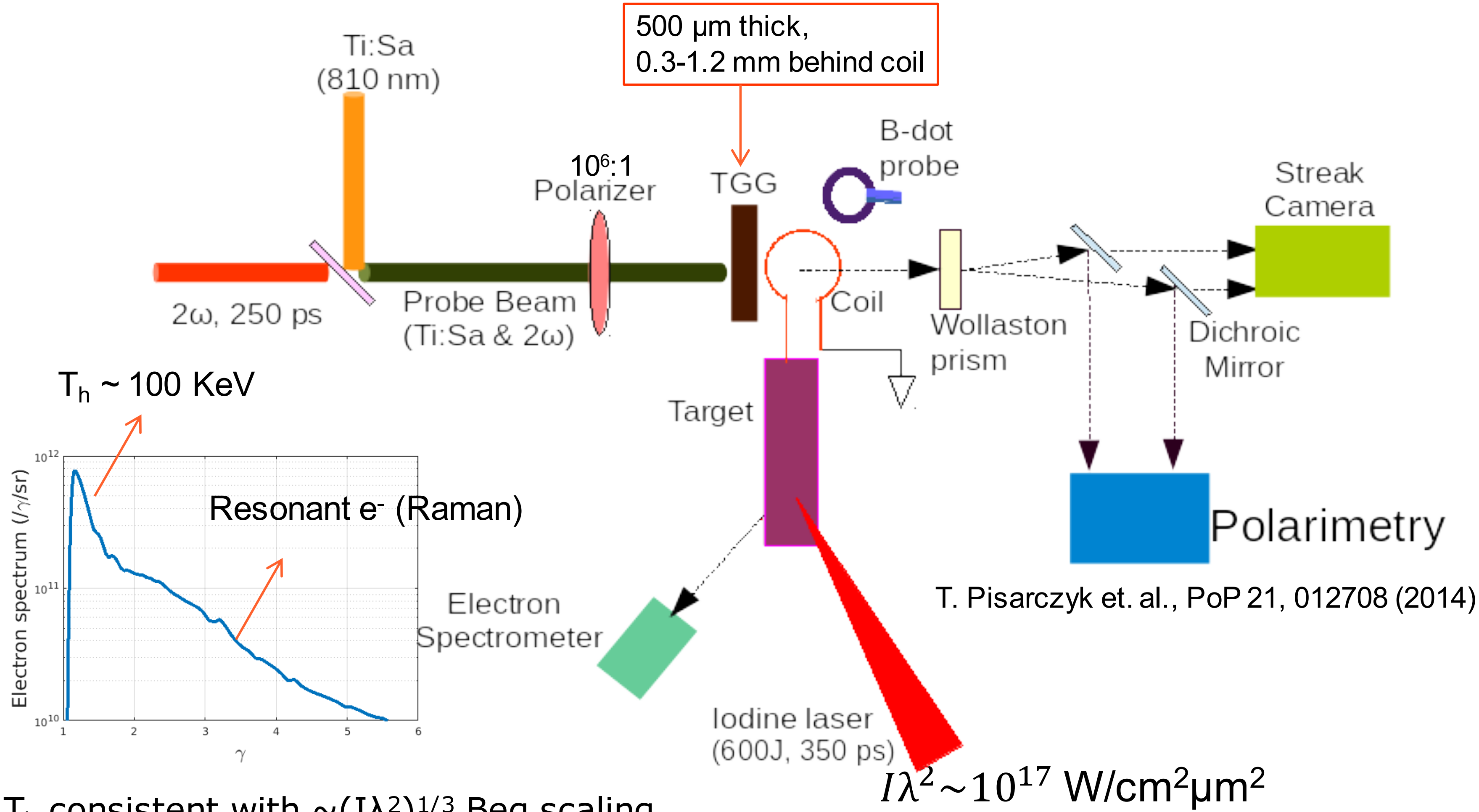
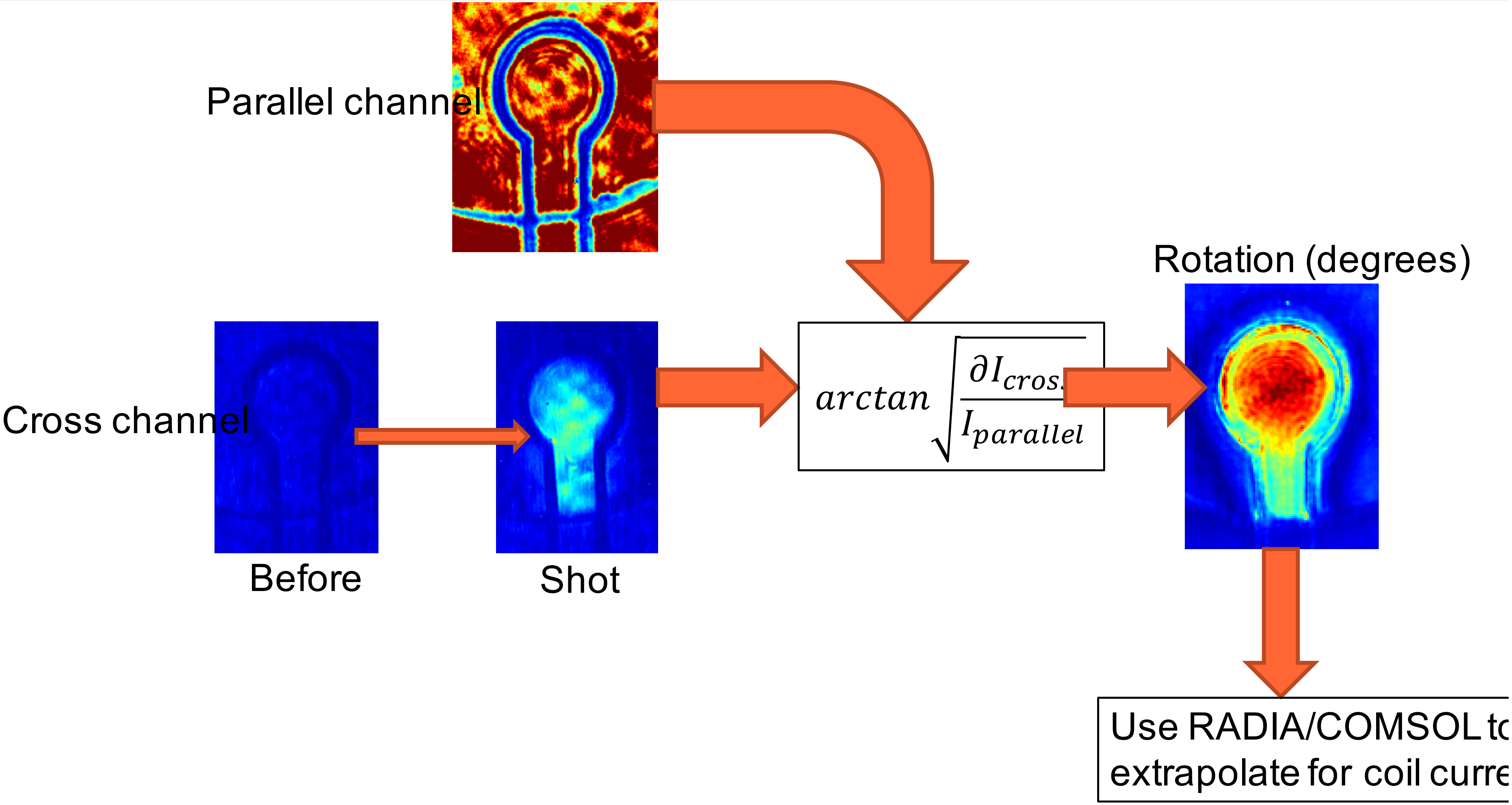
Experimental layout



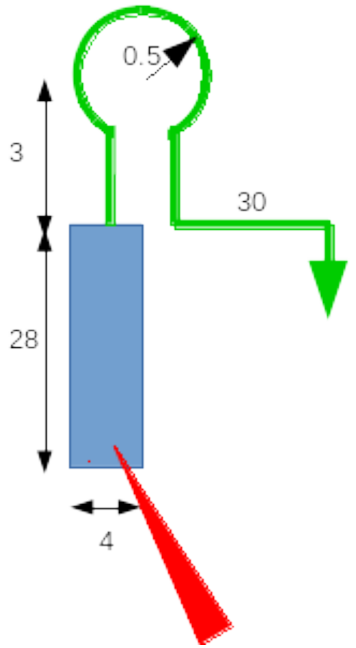
T_h consistent with $\sim(I\lambda^2)^{1/3}$ Beg scaling

n_h 1-2 orders smaller than measured charge

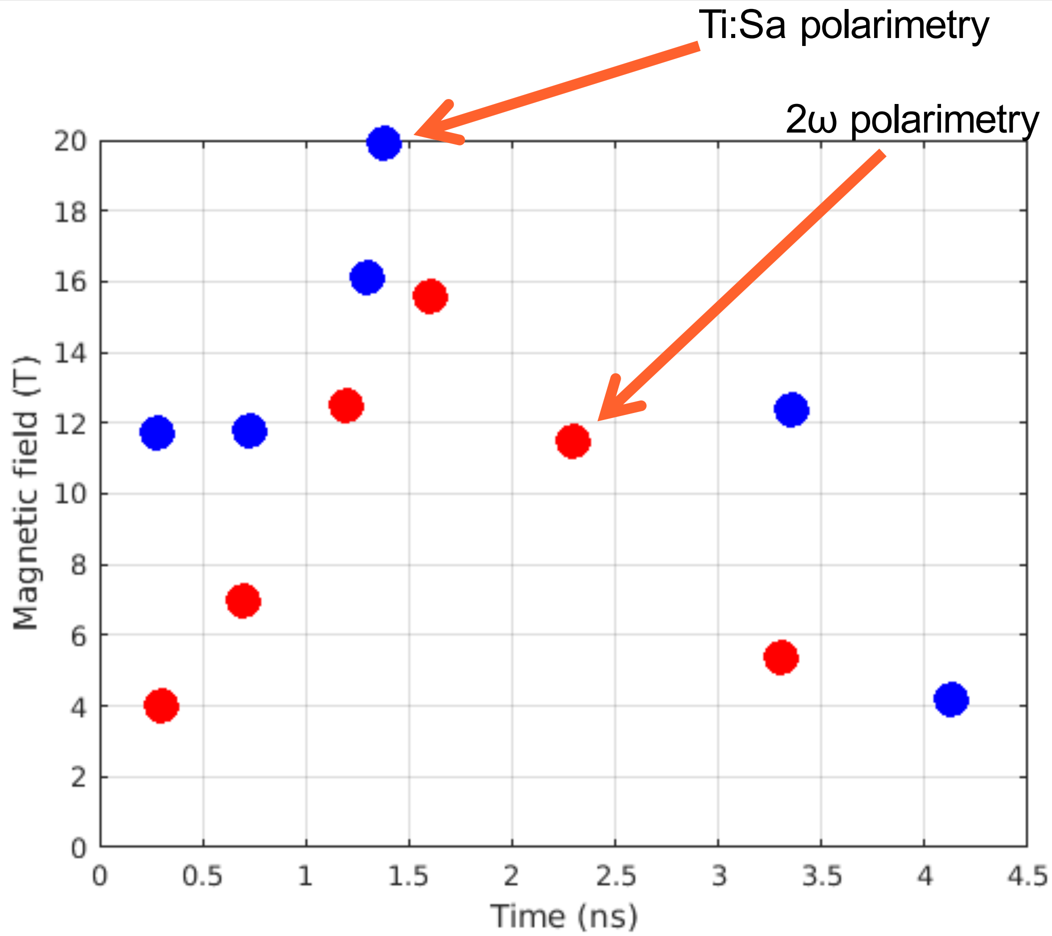
B field calculation from polarimetry



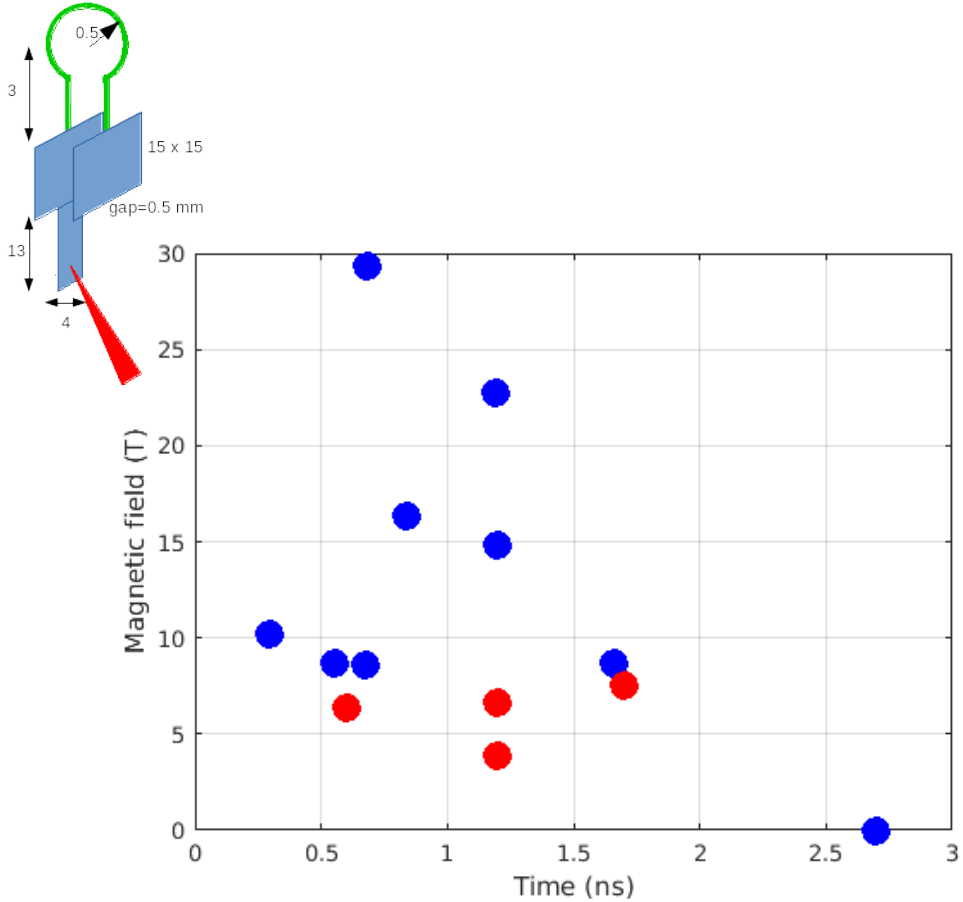
Target #1: Single foil with coil



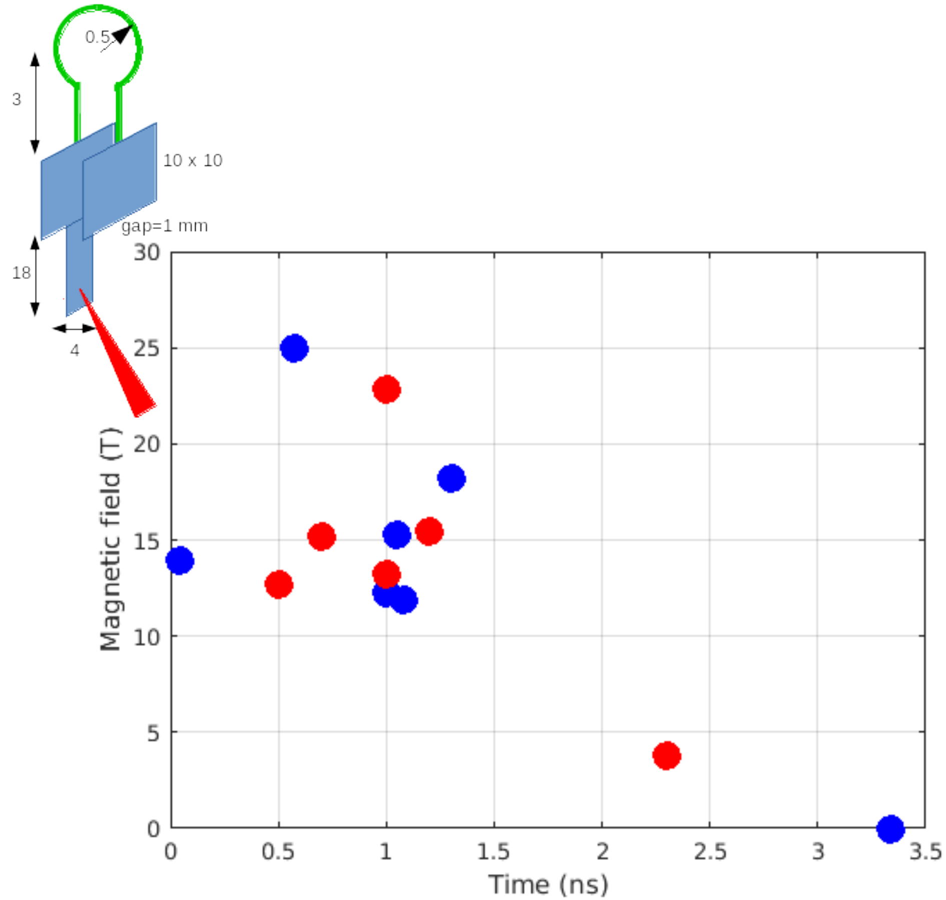
- L~ 40nH, C~0.2 pF
- $2\pi\sqrt{LC}$ ~ 0.5 ns
- η~0.1%



Target #2: Parallel plate ~~capacitor~~ target

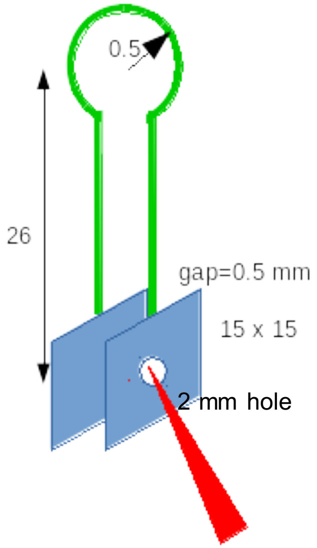


- 2 coils in parallel generated half the field each
- L~ 4nH, C~4 pF
- $2\pi\sqrt{LC}$ ~0.8 ns
- η~0.2%

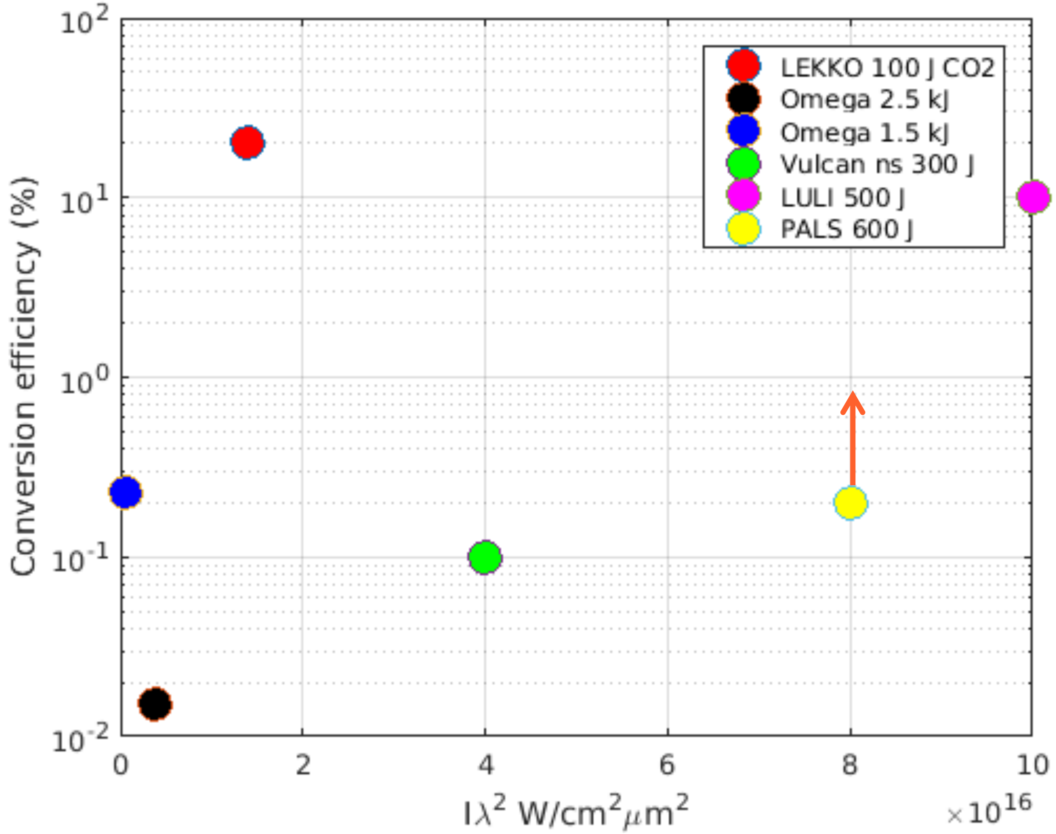


- L~ 4nH, C~1 pF
- τ~0.4 ns
- η~0.1%

Target #4: ~~Capacitor~~ target with a hole



Refer



- Saturated signal corresponds to > 60 T field at 1ns delay

Discussion

- Lumped circuit analysis
  - Previous experiments: $\tau_{res} = 0.05\, ns \leftrightarrow L_{res} = 1.5\, cm \leftrightarrow 3\times target\ size$
  - PALS experiment: $\tau_{res} = 0.4\ - 0.8\, ns \leftrightarrow L_{res} = 12 - 24\, cm \leftrightarrow 3 - 8\times target\ size$
- Total charge
  - Electron spectrometer measures 50 x smaller charge. Low energy electrons responsible for most of target current
- Energy balance
  - $\int_{vol} B^2/2\mu_0 \sim 0.1 - 0.2\%$, however $\int Q^2/2C \sim 50\%$
  - How do we account for dissipation?
  - Coil resistance can increase 10 fold (still not enough)
  - Under estimating target capacitance by a factor of ~ 100
- Implications of higher capacitance
  - Lumped circuit model valid
  - Macroscopic targets should be used for such targets

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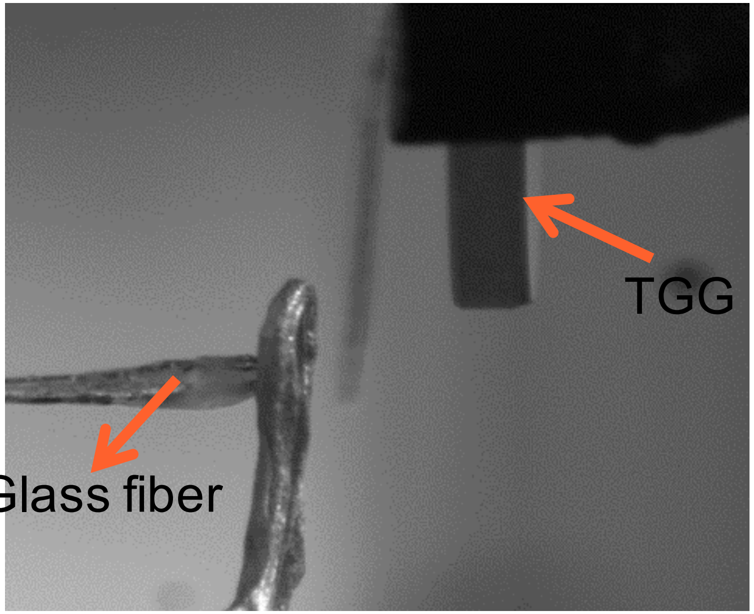
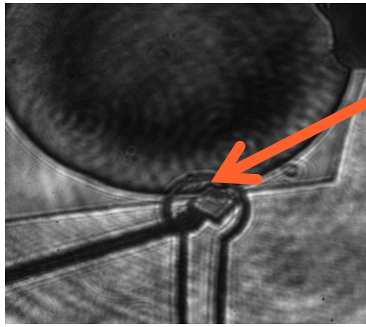
Conclusion

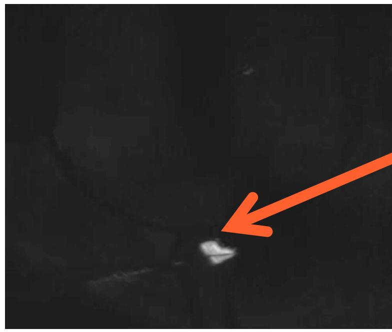
- At PALS, we were able to generate ~ 20 T fields with 1 mm diameter coils with just a grounded foil.
- Increasing the target capacitance tends to increase the field strengths. We measured ~ 30 T.
  - Note: this is without collecting the hot electrons from the plasma.
- Increasing the distance of the focus from the coil does not seem to have any adverse effects.
- For targets with the hole in front plate, ~ 100 T fields seem likely at PALS.
- Macroscopic targets can provide similar performance while still shielding the coil from the plasma

In-situ magnetic field measurement by fused silica

- Fused silica crystals (500 um x 500 um, 100/300 um thick) placed within the coil
- The crystals introduced a polarization change (~ 2^{o}), and thus were not usable.







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