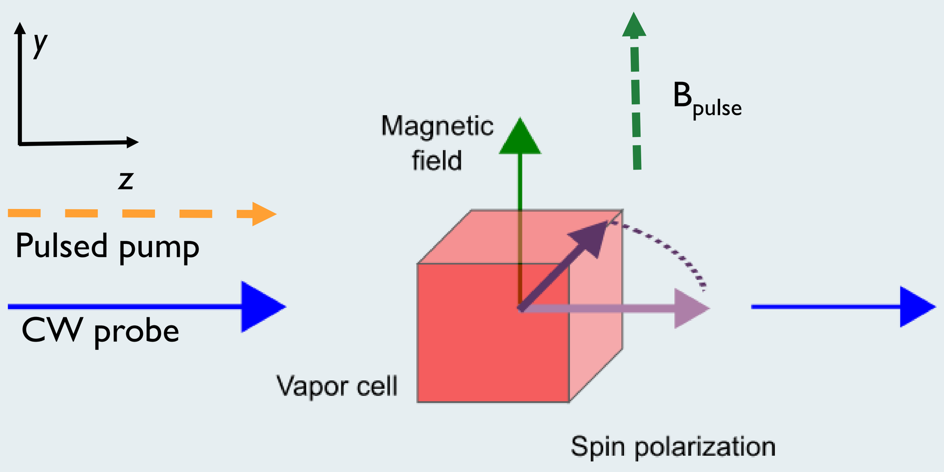
A pulsed SERF optically pumped magnetometer: Magnetic sensitivity analysis

Joonas Iivanainen[1], Kaleb Campbell[1,2], Bethany J. Little[1], Pauli Kehayias[1], Amir Borna[1], Tony R. Carter[1] and Peter D. D. Schwindt[1]
[1]Sandia National Laboratories; [2]University of New Mexico

Introduction

- We have developed a pulsed optically pumped magnetometer (OPM) operating in the spin-exchange relaxation free regime for magnetoencephalography applications [1]
- Previously we demonstrated magnetic sensitivity of 21 fT/rt-Hz
- Here, we analyze the noise mechanisms in the sensor

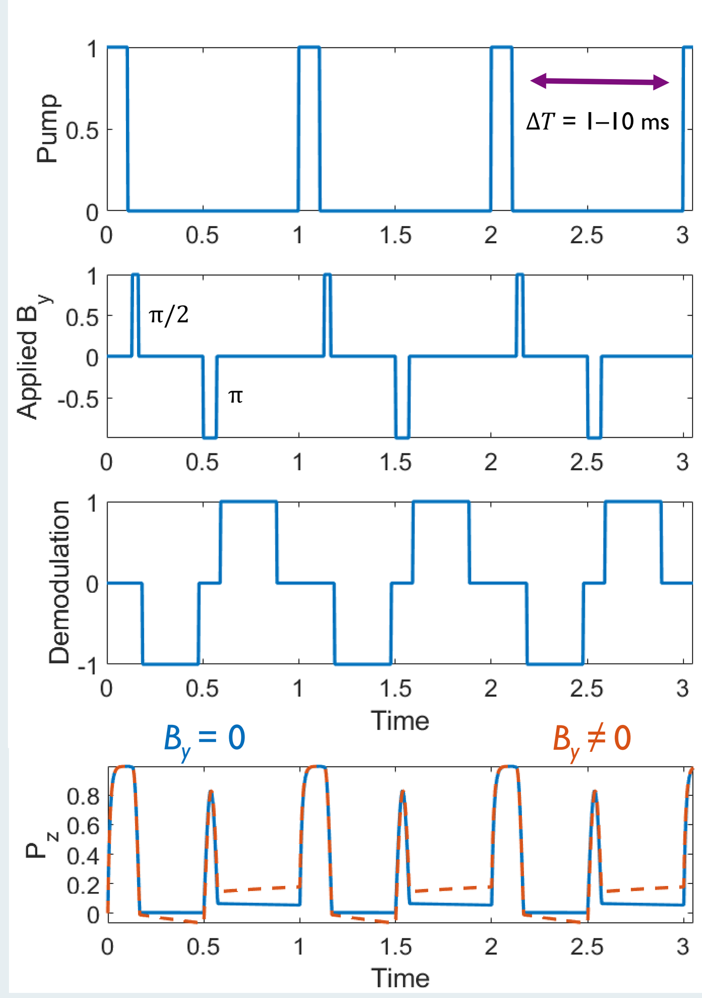


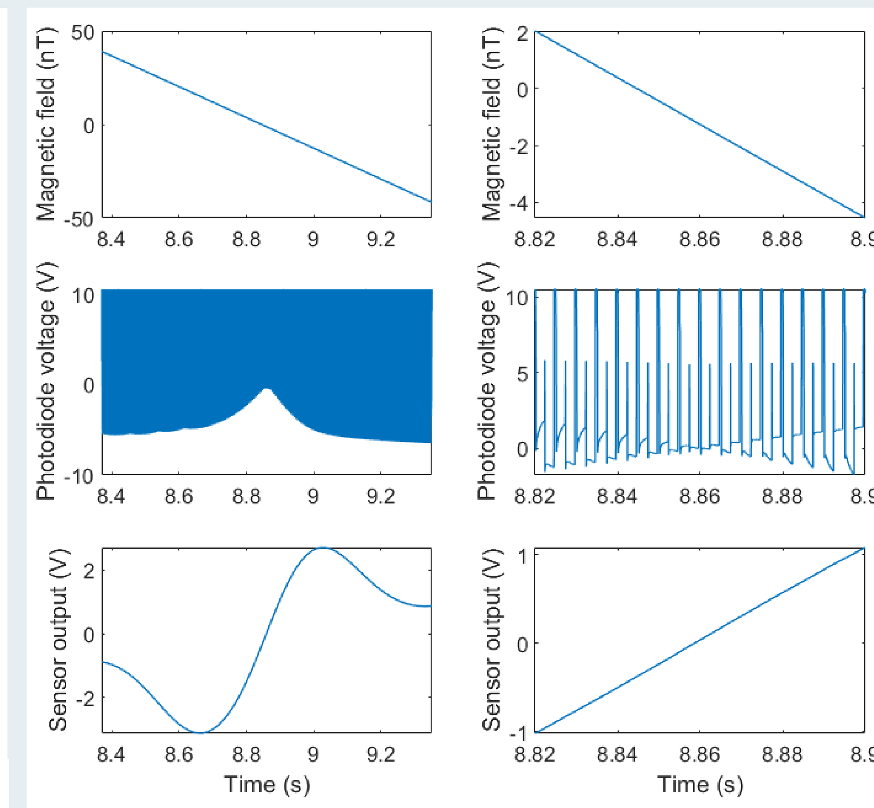
Operating principle

Pulse sequence (duration ΔT) to measure field component along *y* (collinear pump/probe along z)

1. Spin polarize hot ^{87}Rb vapor using a short pulse of 795 nm light → P_z
2. Align the spin polarization with the *x* axis using a π/2 pulse $P_z \to P_x$
3. Let P_x accrue angle in a magnetic field (B_y) → buildup of P_z
4. Use a π pulse to flip $P_z \to -P_z$
    1. Demodulation with a bi-polar waveform

Dispersive response as a function of B_y

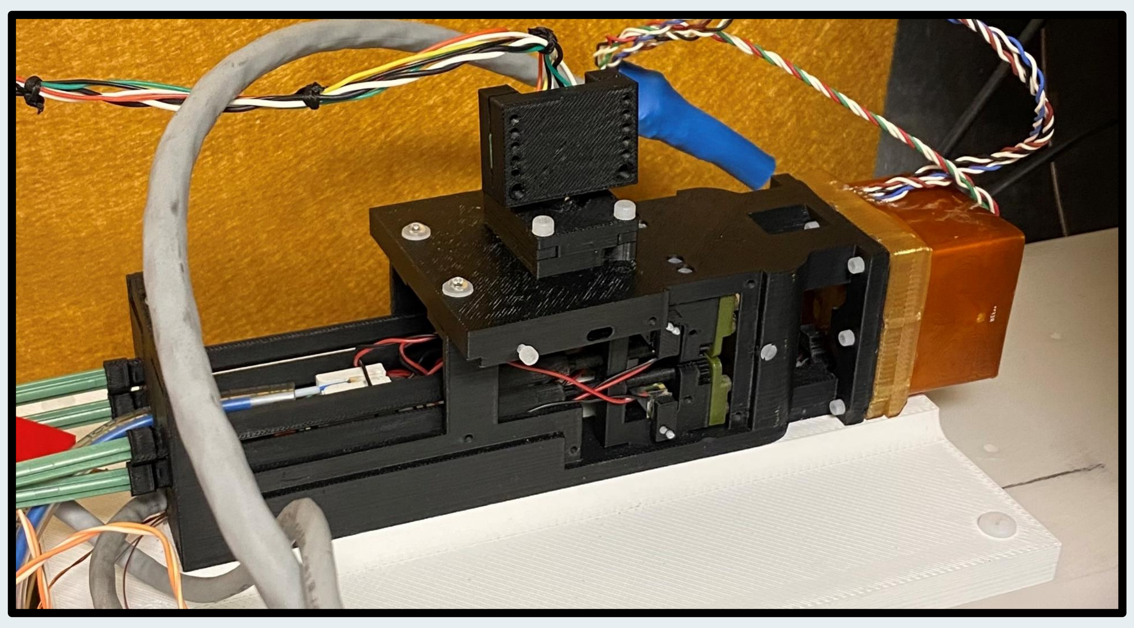


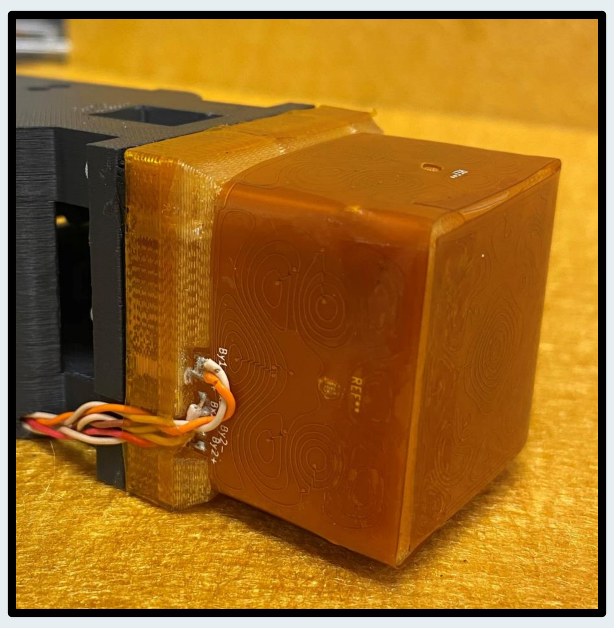


$$S = P_0 \frac{(T_2 - e^{-\frac{\Delta T}{T_2}}(T_2 + \Delta T))}{\Delta T} \frac{T_2 \gamma B_y}{(T_2 \gamma B_y)^2 + 1}$$

Pulsed sensor prototype

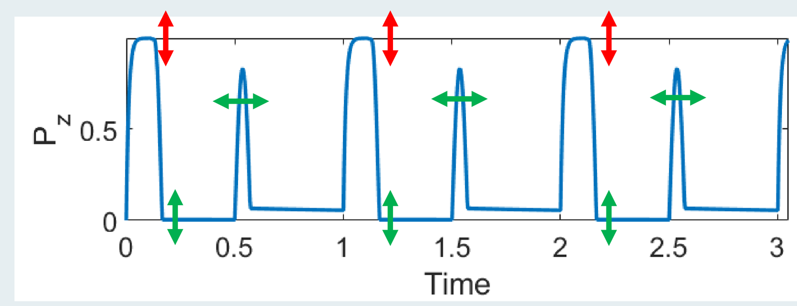
- Based on the Sandia 4-channel OPM design [2]
- High power laser diode (795 nm) integrated into the sensor head
- Distributed CW 780-nm probe
- Full H-bridge circuit to generate magnetic field pulses (4–40 µs)
- On-sensor coil design using *bfieldtools* [4]
- NI USB-6289 and PB24-100-4k-USB for data acquisition and pulse-sequence control





Noise in the sensor

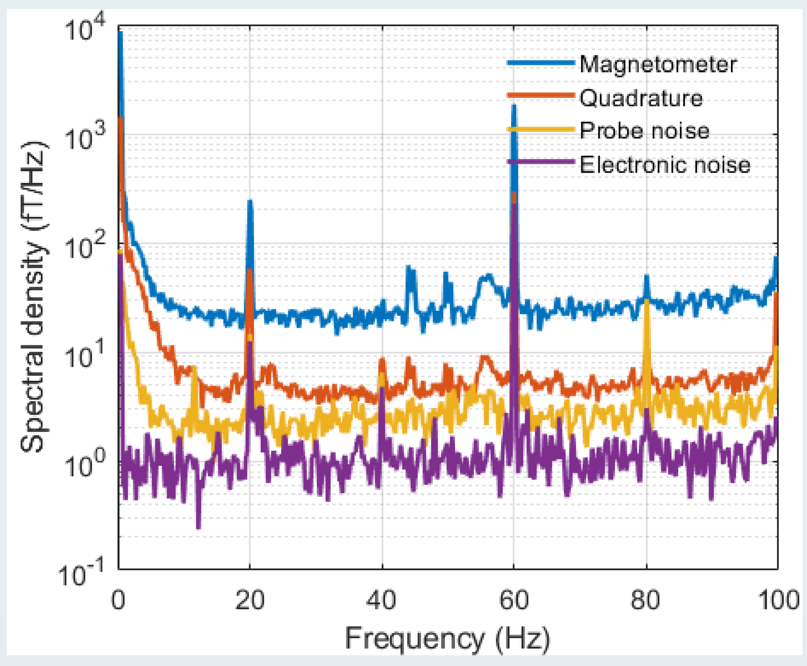
- Pump laser pulses → shot-to-shot fluctuations of spin polarization
    - Pump laser, pulse circuit
- Magnetic field pulses
    - Current noise, timing jitter



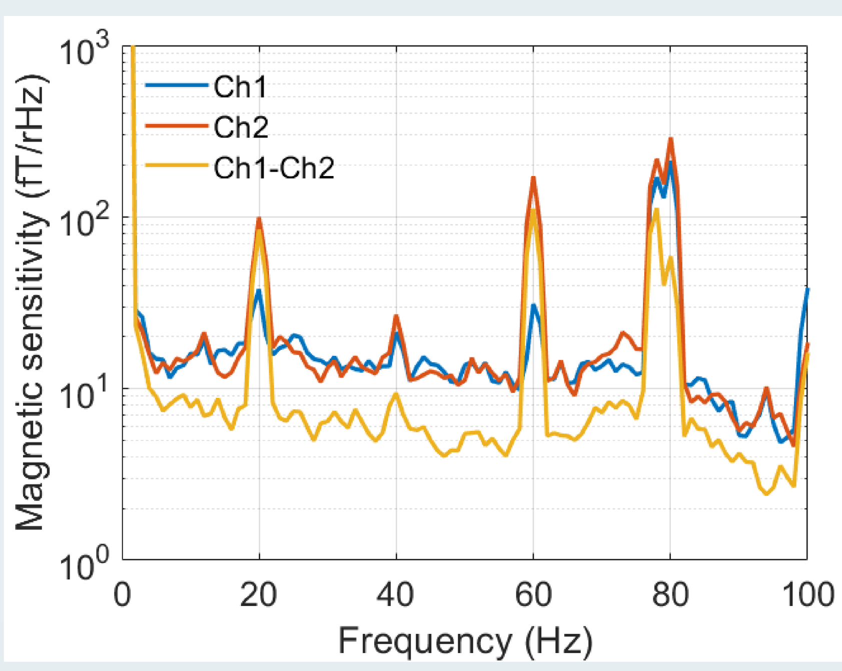
Pump pulse noise

- Magnetic sensitivity of the sensor was limited to ~21 fT/rt-Hz for unknown reasons
- To assess the noise due to the integrated pump laser, we used the MEG system pump laser [5] for optical pumping
    - Chop the laser with an acousto-optic modulator (AOM)
- We achieved
    - magnetic (gradiometric) sensitivity of 14 fT/rt-Hz (6 fT/rt-Hz)

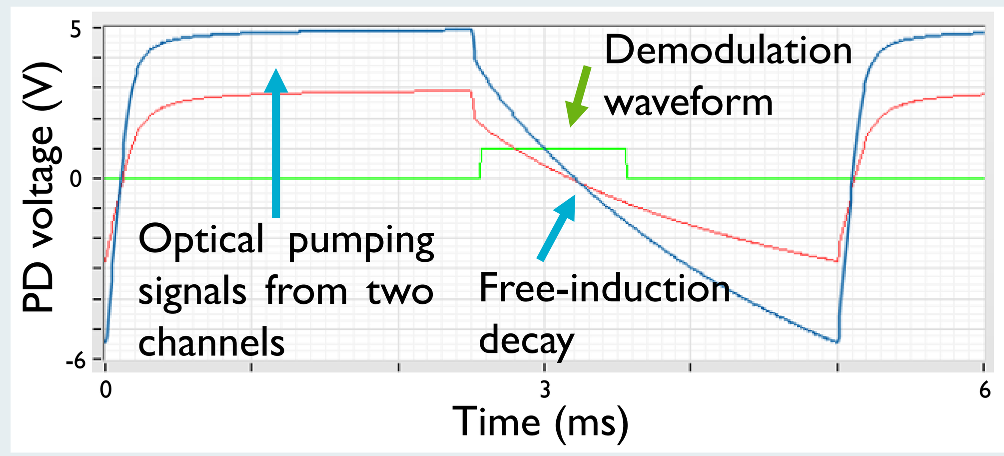
Integrated laser



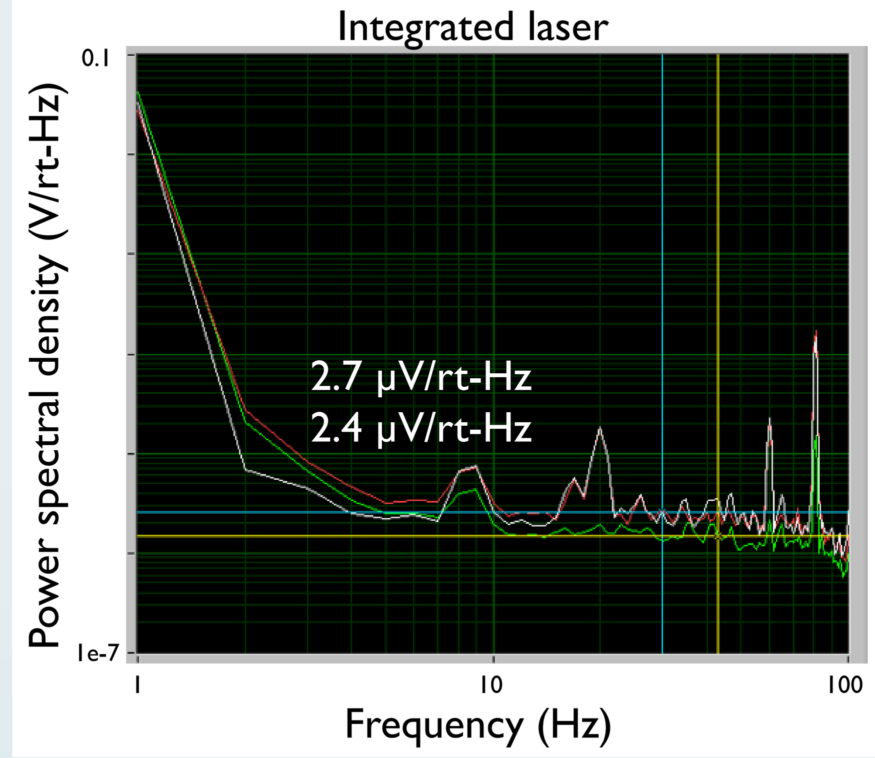
AOM



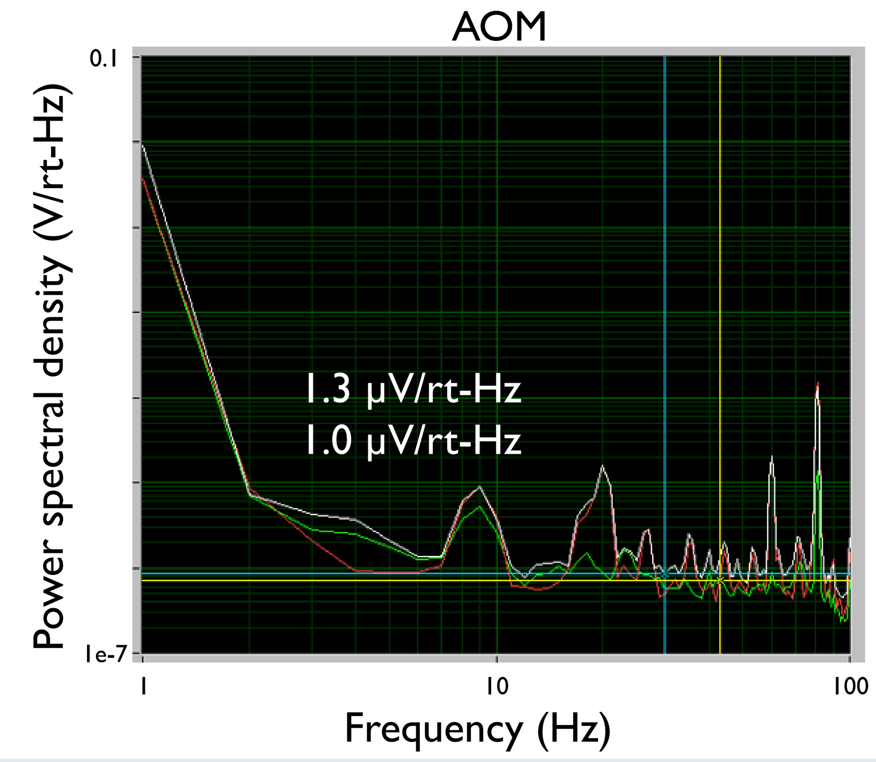
- To assess the noise due to the pump laser, we investigated fluctuations of the spin polarization
- Amplitude fluctuation of the initial free-induction decay signal
- Fluctuations with the integrated laser are 2–2.5 times larger



Integrated laser



AOM



Magnetic field pulse noise

H-bridge power supply, current noise

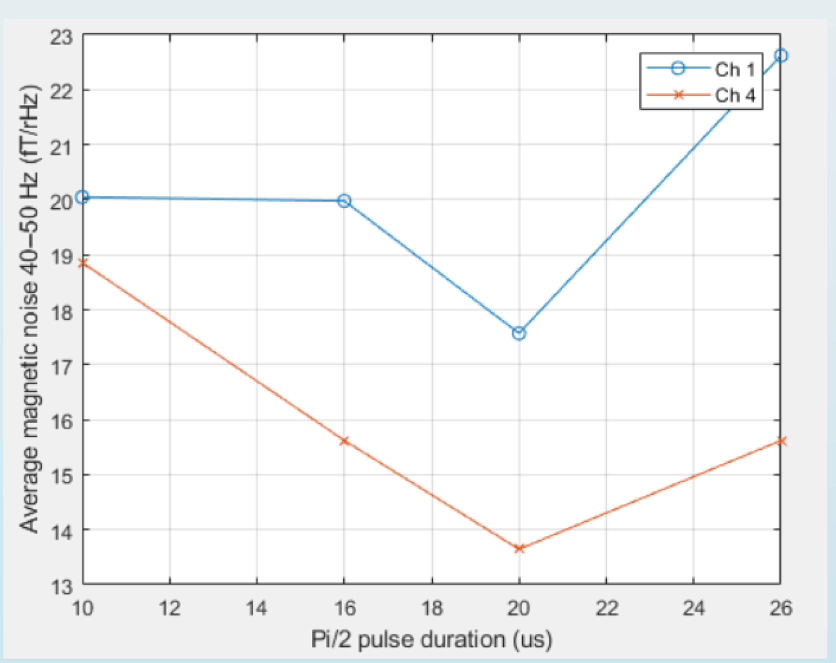
- Battery gave better noise performance than the DC power supply (HP6237B)

Pulse timing jitter

- NI USB-6289 vs. PulseBlaster PB24-100-4k-USB
- No difference in noise

π/2 and π pulse duration

- No clear trend on noise



Conclusions

- The sensitivity of the pulsed OPM was limited by spin polarization fluctuations due to the optical pumping by the integrated high-power laser
- Pulsed OPM is feasible if low noise pump laser with enough power for fast pumping of the atoms is available
    - Minimize power requirements by sensor design
- Possible to measure two or three components of the field simultaneously

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ____________

Research reported here was supported by the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health, under award number U01EB028656. This poster describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the poster do not necessarily represent the views of the U.S. Department of Energy, the United States Government, or the National Institutes of Health. The content is solely the responsibility of the authors.

[1] J. Iivanainen, *et al.*, WOPM (2021)
[2] A. P. Colombo, *et al.*, Optics Express, **24**, 15403 (2016)
[3] E. Zhivun, *et al.*, Phys Rev Appl, **11**, 034040 (2019)
[4] *https://bfieldtools.github.io/*
[5] A. Borna, *et al.*, Phys Med Biol, **62**, 8909 (2017)

Sandia National Laboratories