



MJOLNIR: A DPF for neutron radiography and MA experiments

ZNetUS, Albuquerque NM

August 11, 2026

9:40 AM, 25 minutes

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NSED, Plasma Engineering and Operations Group

Prepared by LLNL under Contract DE-AC52-07NA27344.

Goals for this talk

- Overview of Dense Plasma Focus (DPF) and the MegaJOuLe Neutron Imager for Radiography (MJOLNIR) Source
 - Platform for ZNetUS experiments
- Using shaped electrodes and dopants to improve DPF for radiography



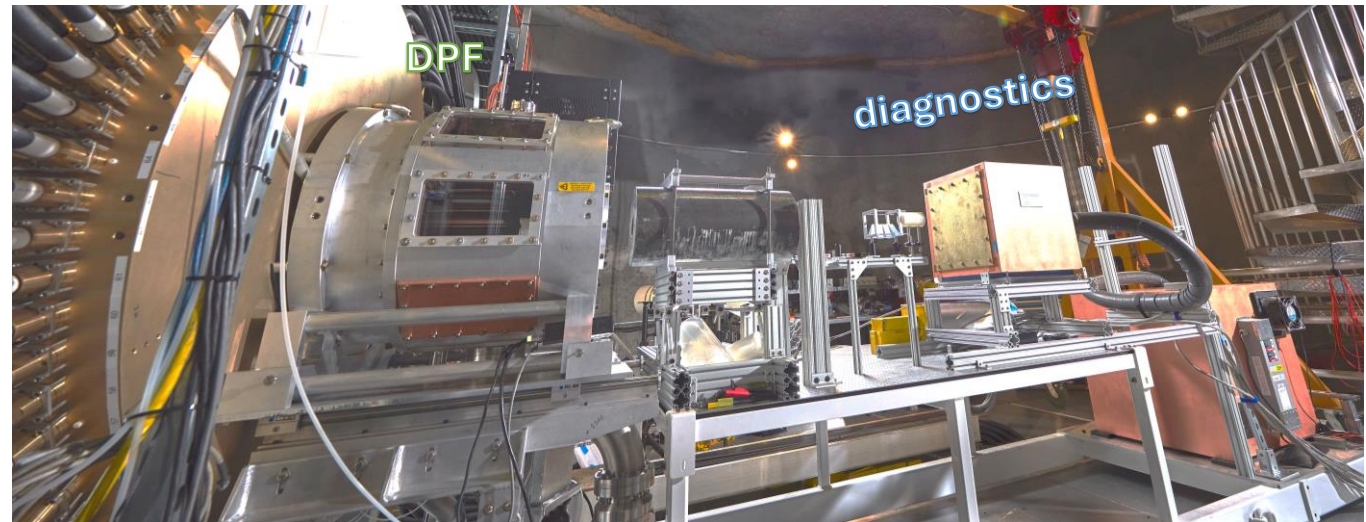
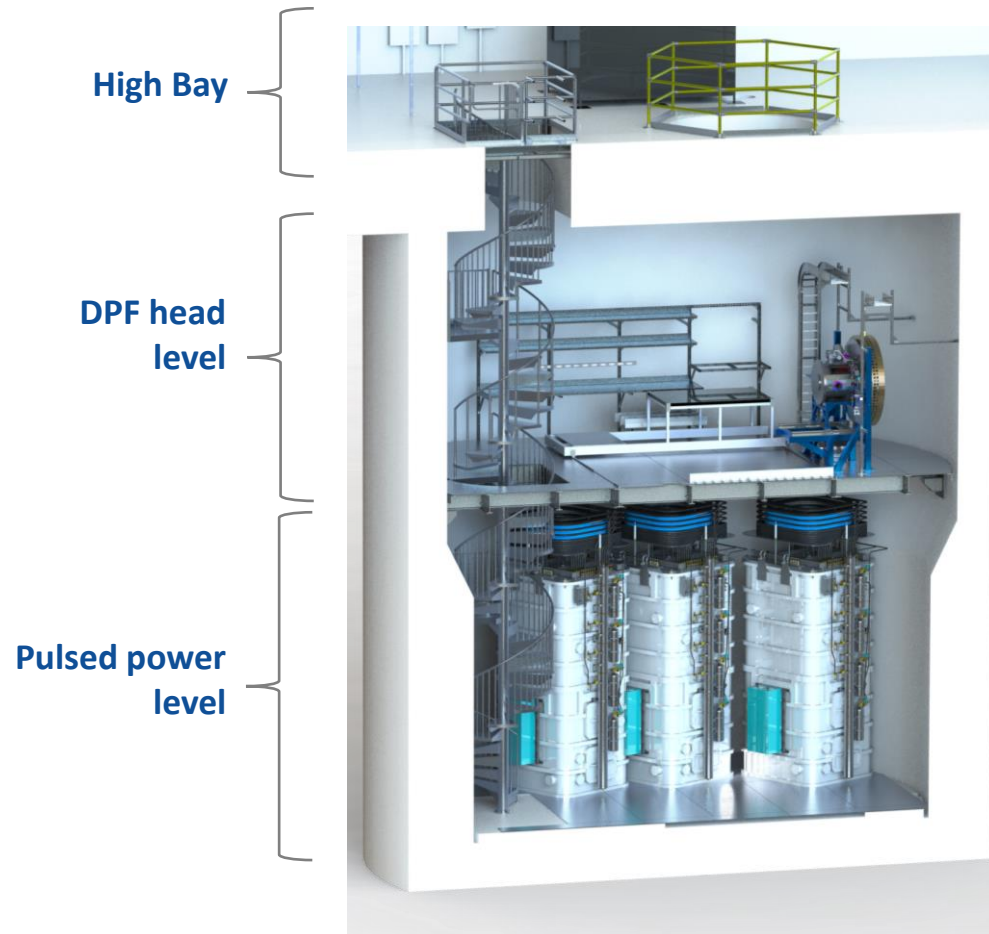
DPF Overview and MJOLNIR Capabilities

Metrics to Compare DPF-Based Neutron Radiography

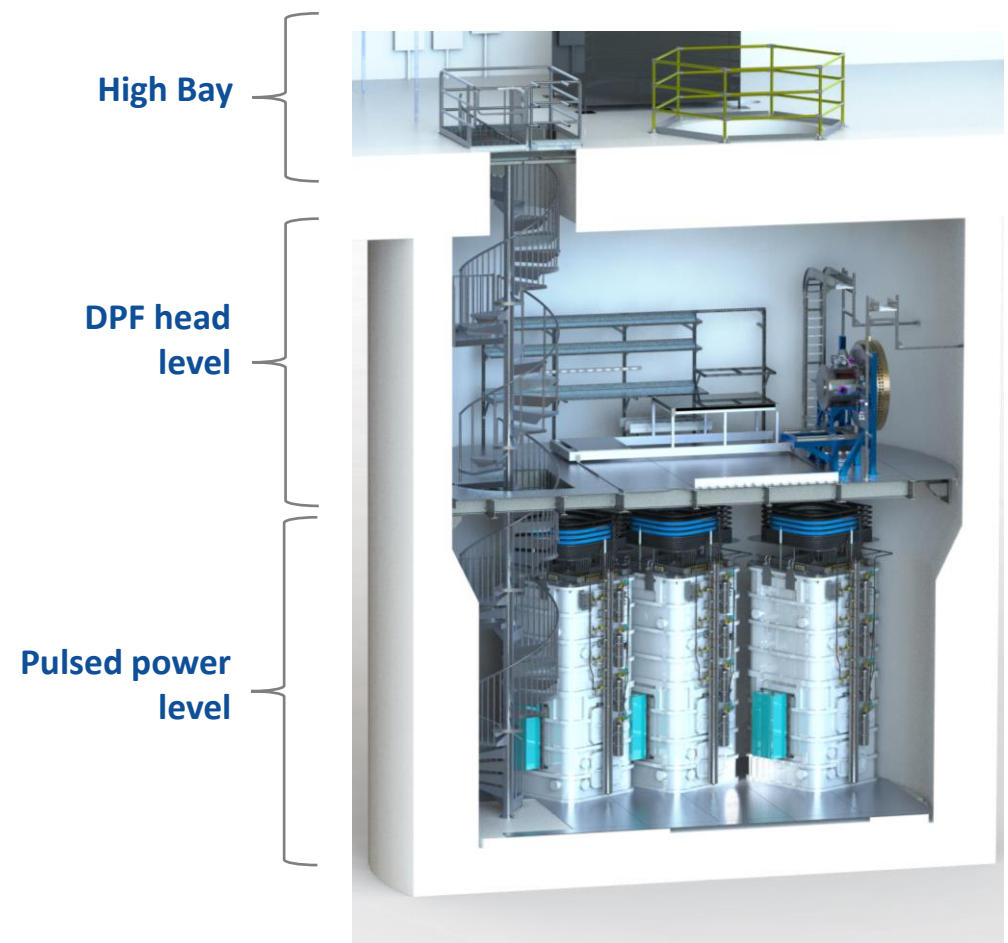
	State of the Art
Neutron Yield “signal to noise”	1.2x10 ¹² DD (MJOLNIR) 1x10 ¹³ DT (ZEUS)
Timing Jitter “reproducibility”	20 ns
Pulse Width “time resolution”	100 ns
Spot Size “spatial resolution”	4 mm

Cannot achieve all peak metrics with single configuration

MJOLNIR has Produced Up to 1.2×10^{12} DD Neutrons on a 3.8 MA Peak Current Discharge at LLNL

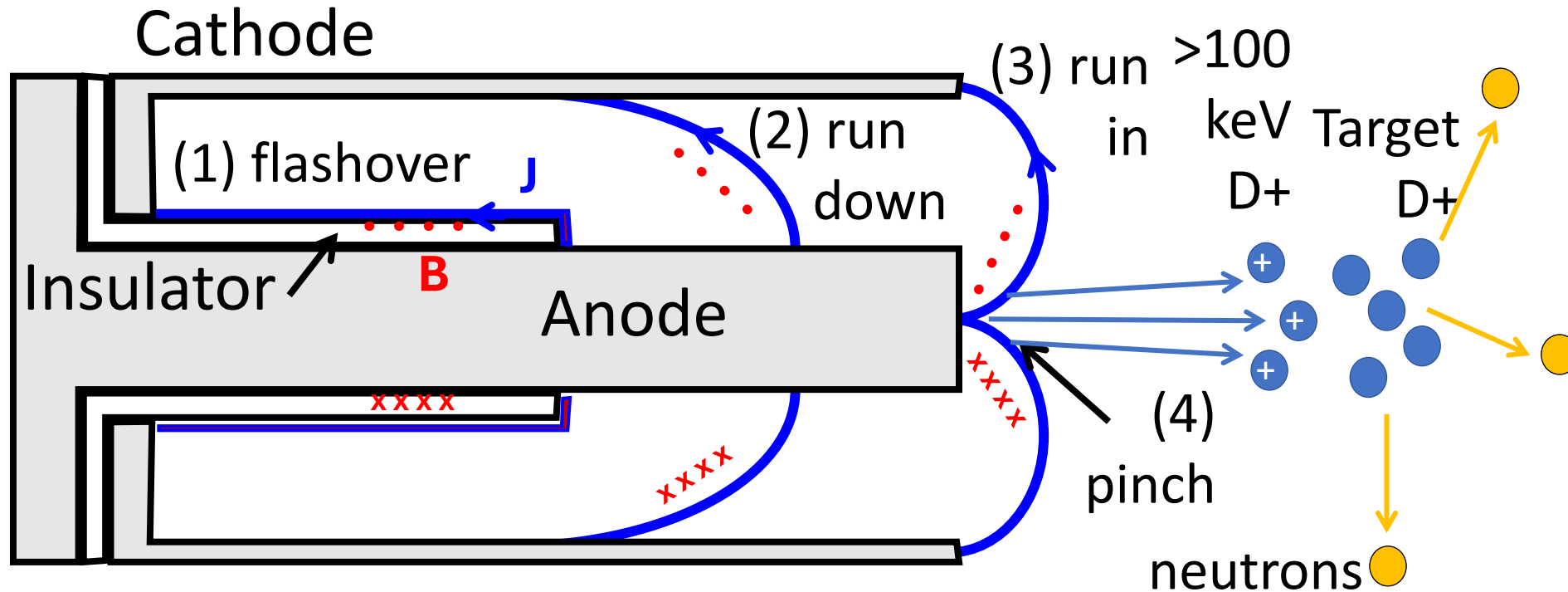


At 4.5 MA and 15 shots/day, MJOLNIR fills gap between universities and Sandia's Z-machine



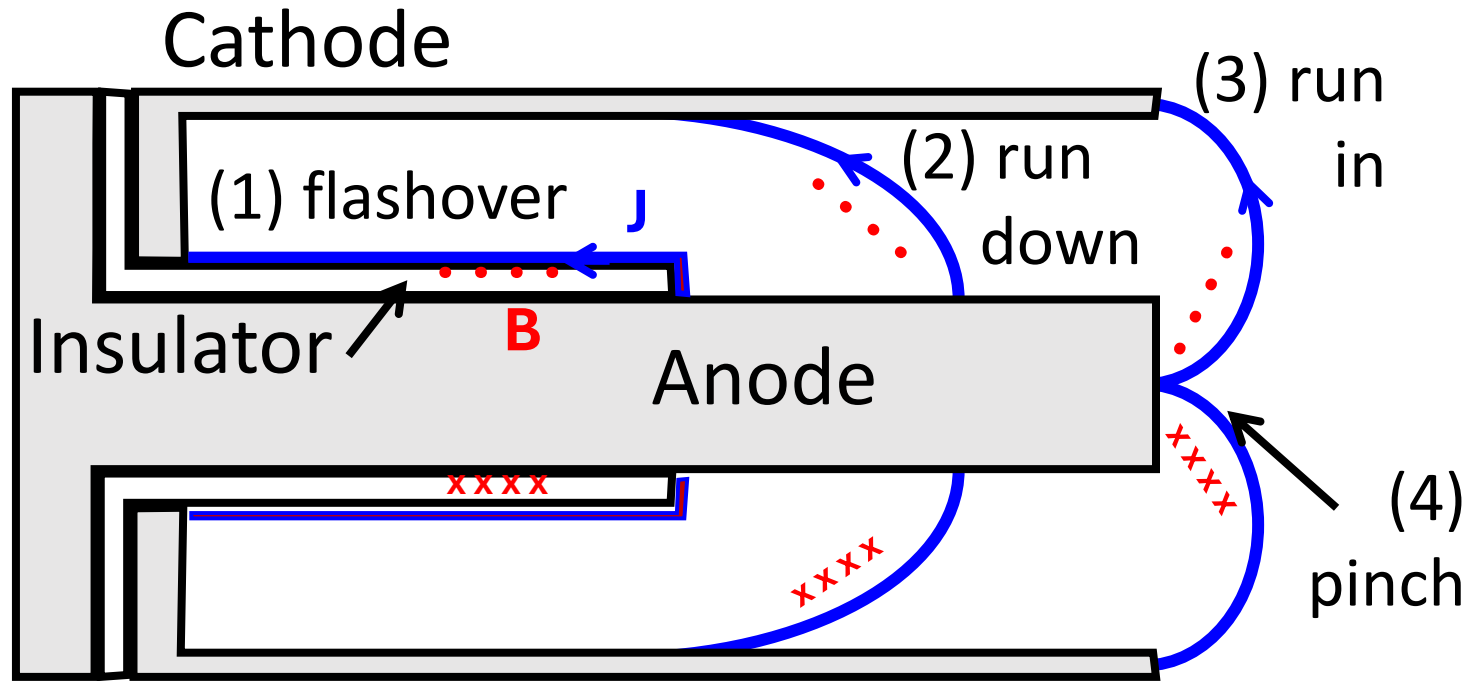
DPF Parameters	MJOLNIR values
Bank Design	24 single-stage Marx
Capacitor Number/capacitance	48/34.5 μ F
Maximum (minimum) charge voltage	$\pm$ 50 kV ($\pm$ 30 kV)
Stored Energy at full voltage	$\sim$ 2 MJ
Anode	9" diameter
AK-gap	2" (can be changed)
Electrode Material	O Free High Conductivity Cu
Insulator Material	Quartz
Fill gas	D₂ + possibility to introduce dopant
Chamber fill pressure	$\sim$ 10 Torr

MJOLNIR team characterizes all phases of a DPF with diagnostics and simulations

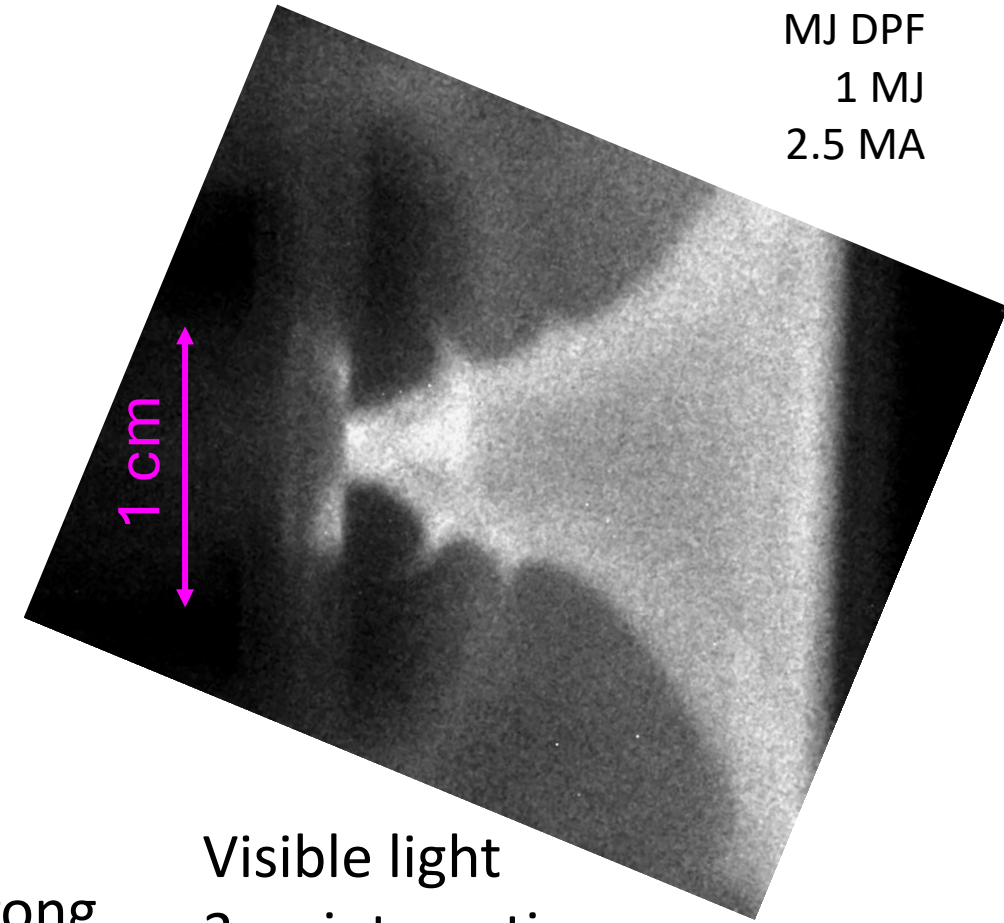


- Plasma instabilities in the pinch region producing strong electric fields which accelerate ions in the plasma sheath.

MJOLNIR team characterizes all phases of a DPF with diagnostics and simulations



MJ DPF
1 MJ
2.5 MA

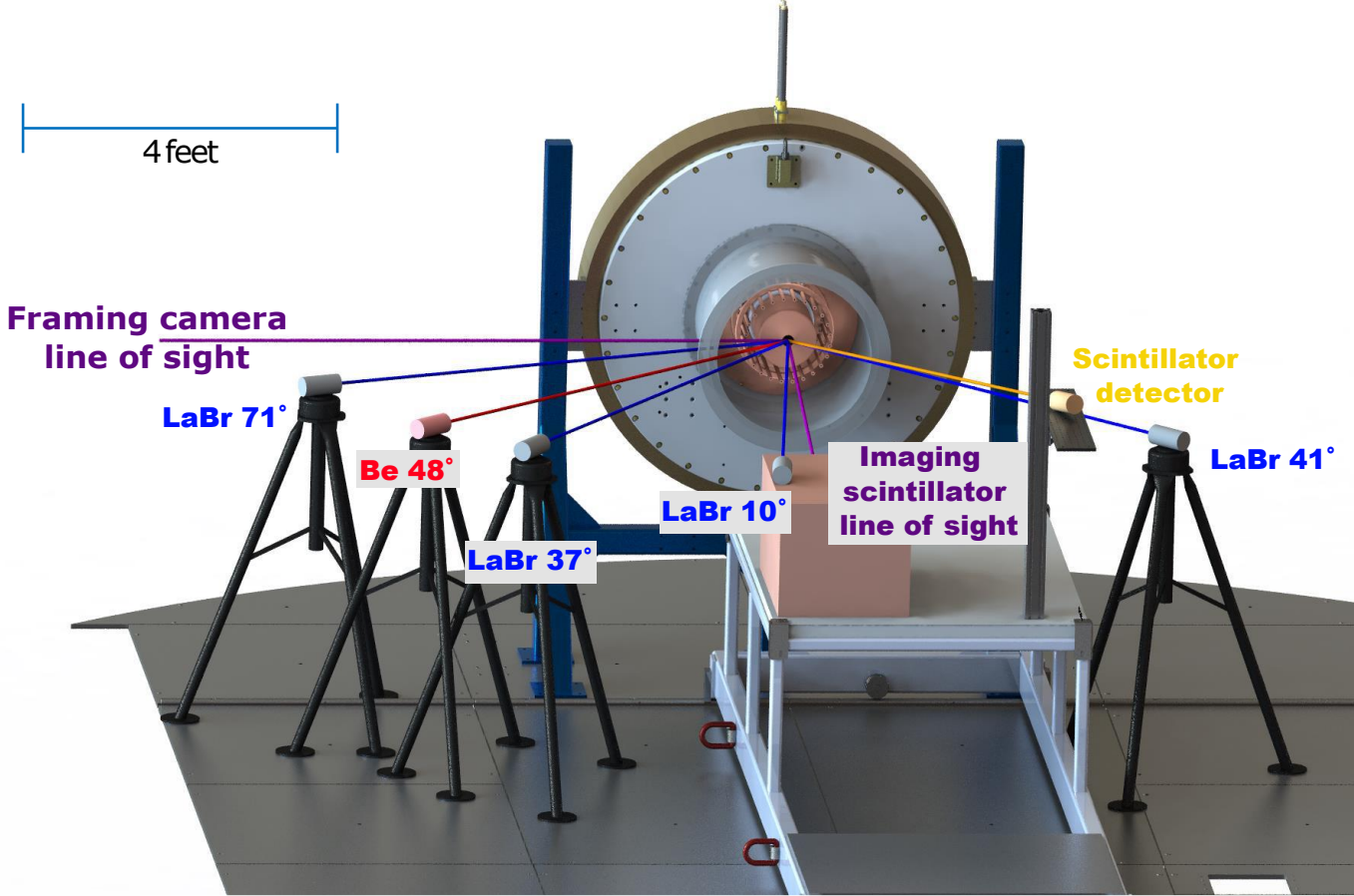


- Plasma instabilities in the pinch region producing strong electric fields which accelerate ions in the plasma sheath.

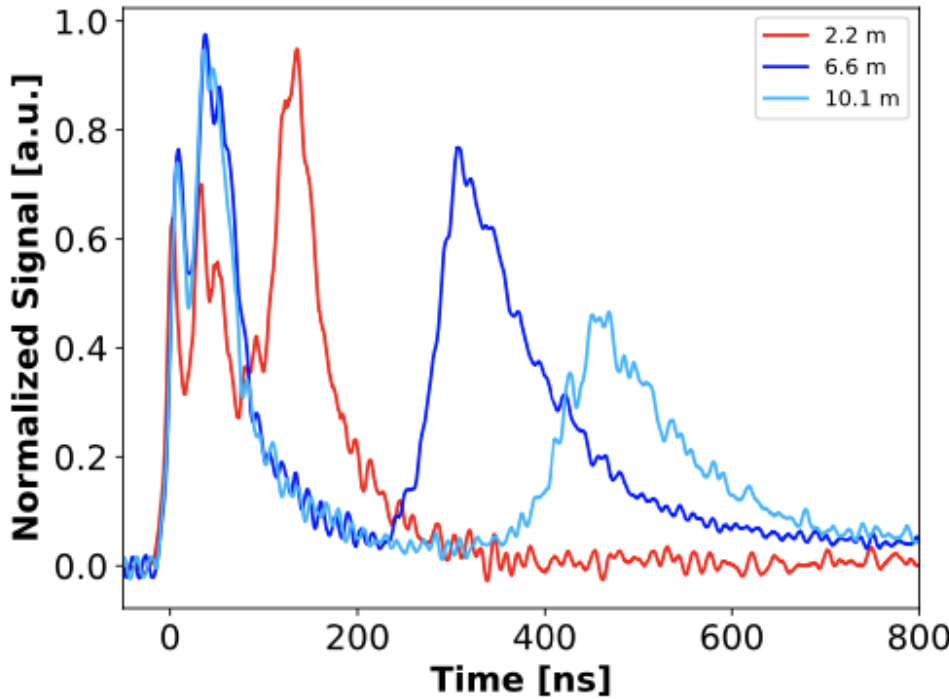
Visible light
3 ns integration
10 ns between frames

Deep understanding of plasma instabilities important to meeting mission

Comprehensive Suite of Diagnostics to Benchmark Simulations Used to Guide the DPF Design



Neutron pulse characteristics are measured using time of flight detectors



MJOLNIR employs a comprehensive suite of diagnostics



Be activation detector
Neutron yield



Neutron time-of-flight (nToF)
neutron energy spectrum



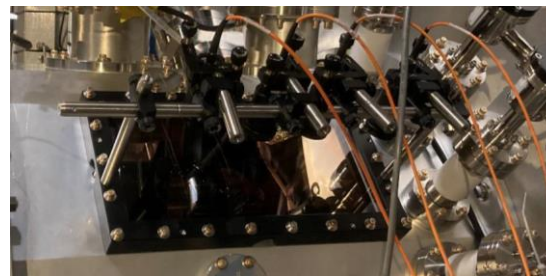
LaBr activation detector
Neutron yield/anisotropy



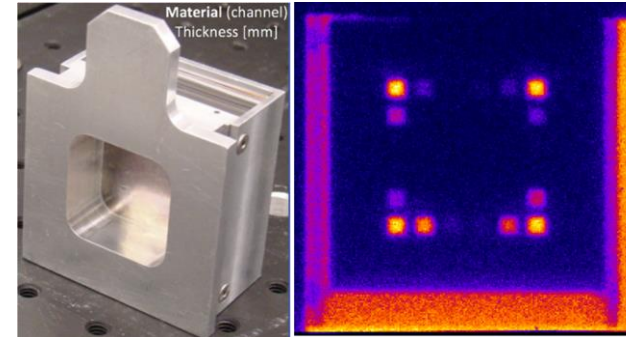
Shadowbar nToF/n energy
w/background subtraction



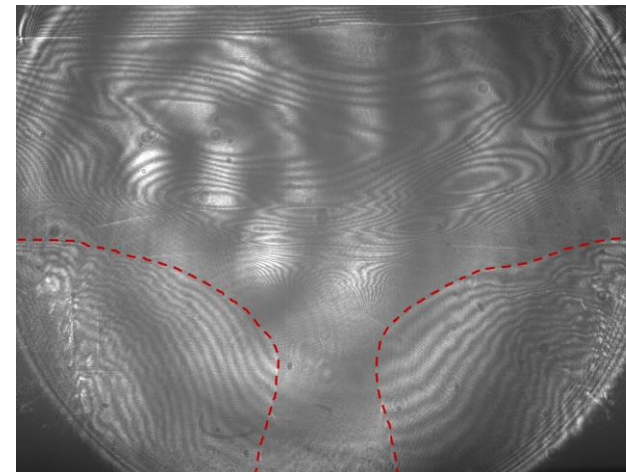
Neutron camera/n image



Optical diodes
Plasma sheath velocity

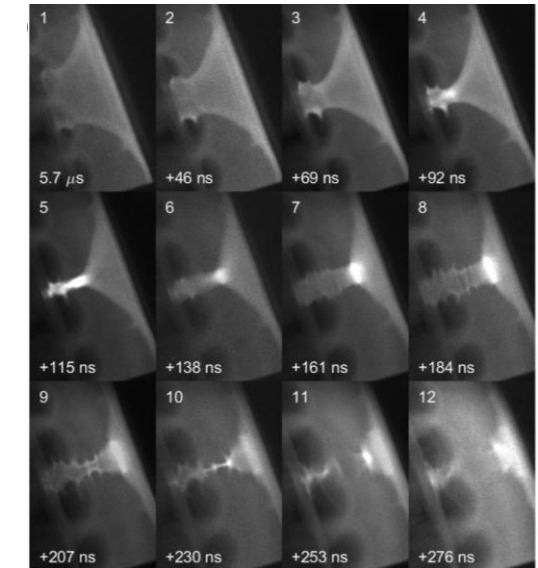


X-ray step filter array
X-ray energy spectrum



Laser interferometer
Electron density

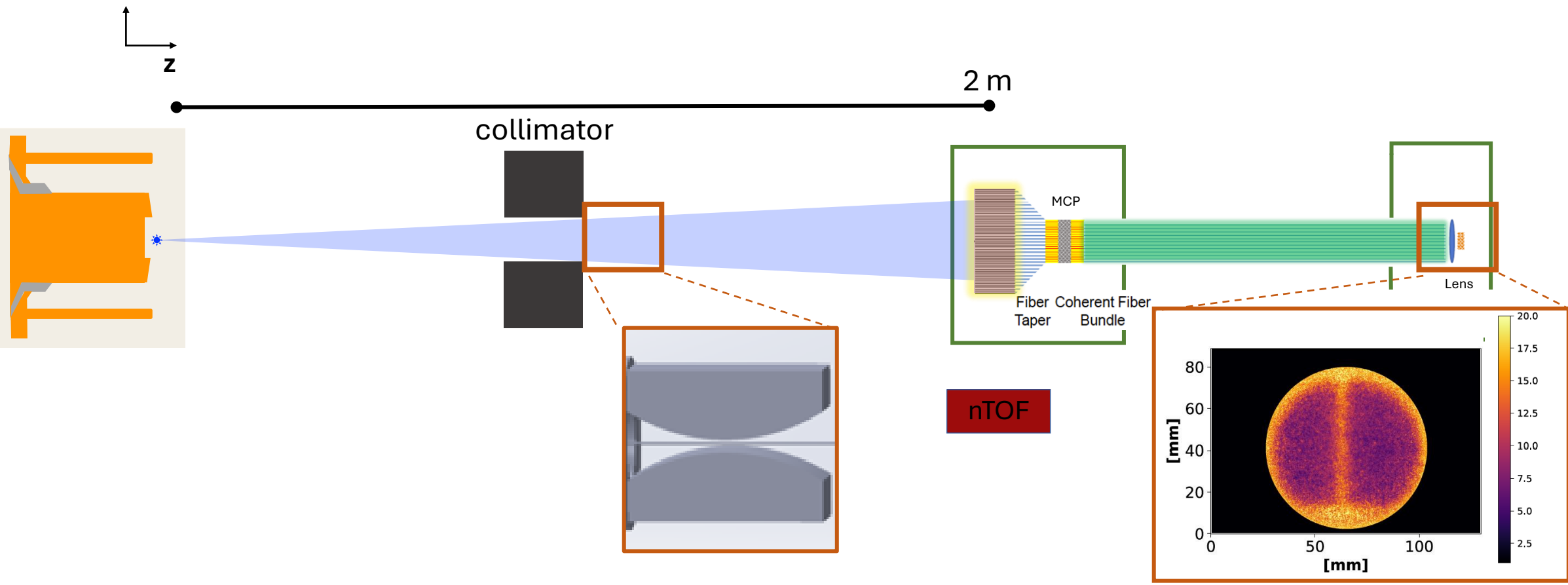
16-frame visible light



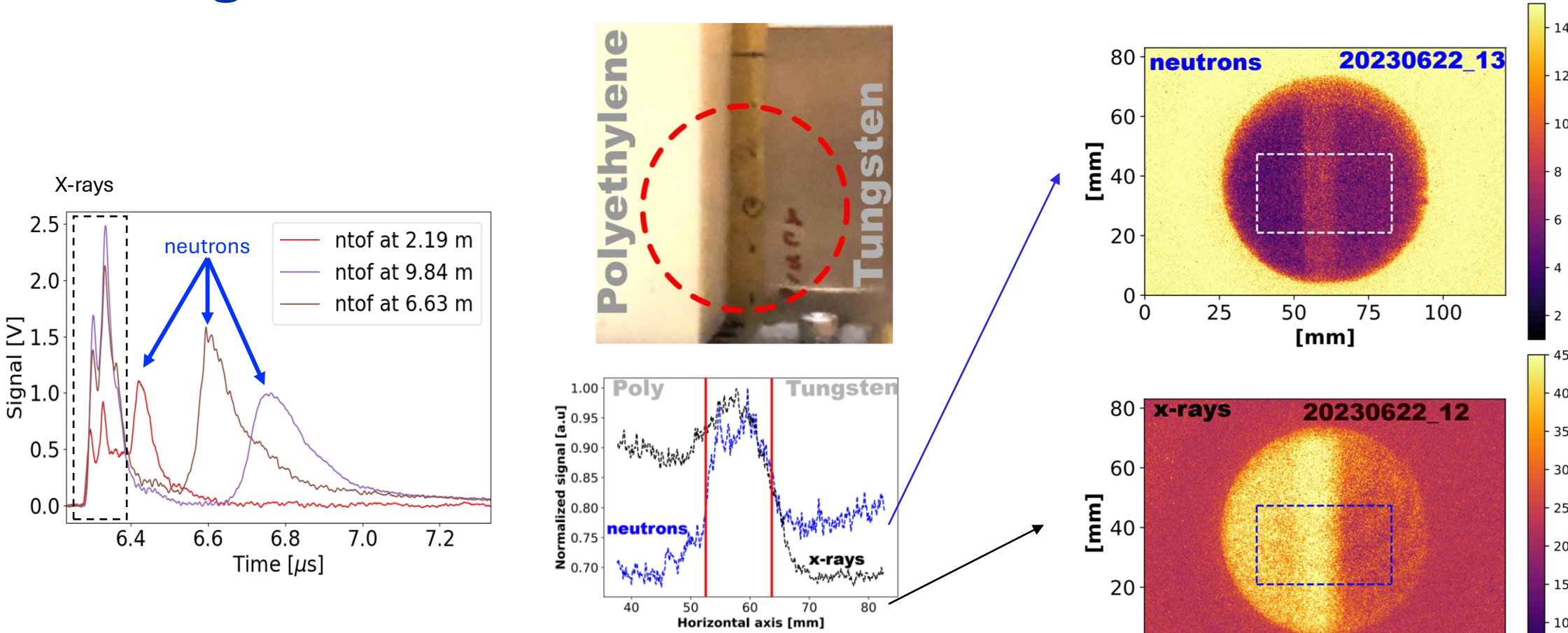
Not pictured:

- Hiden RGA
- Pulsed power monitors
- Rogowski coil
- Diamond rad detectors
- Ion spectrometer

The DPF Source is Imaged Using a Rolled Edge Slit with the Neutron Imager



X-rays or Neutrons Measured at Different Times Along the Radiation Emission

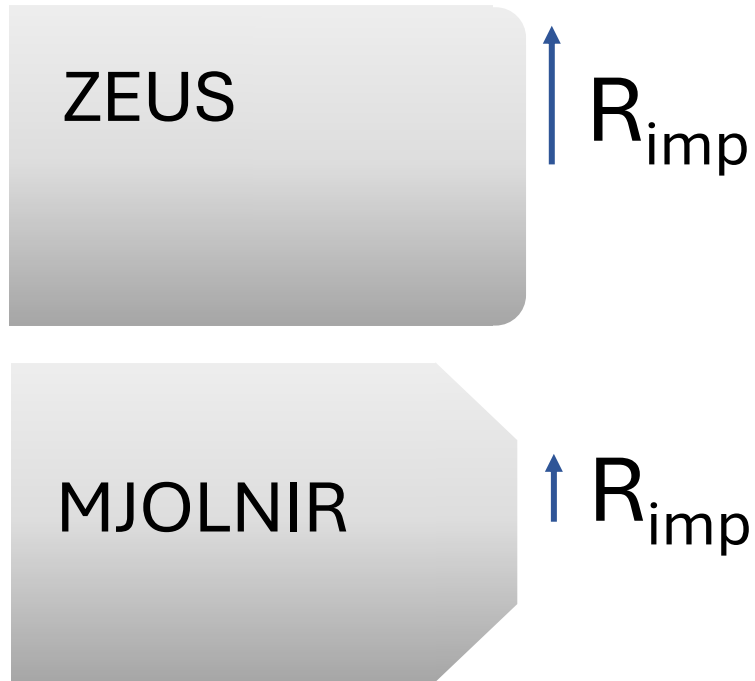


Camera can be triggered off system, light gates, or x-rays to ensure timing

Manipulating electrodes

- Smaller anode radius can raise pinch temperature, yield
- Smaller anode radius can narrow pulse width
- Smaller anode radius can lower spot size

Implosion radius sets the total mass swept into the pinch, and the timing of various implosion events



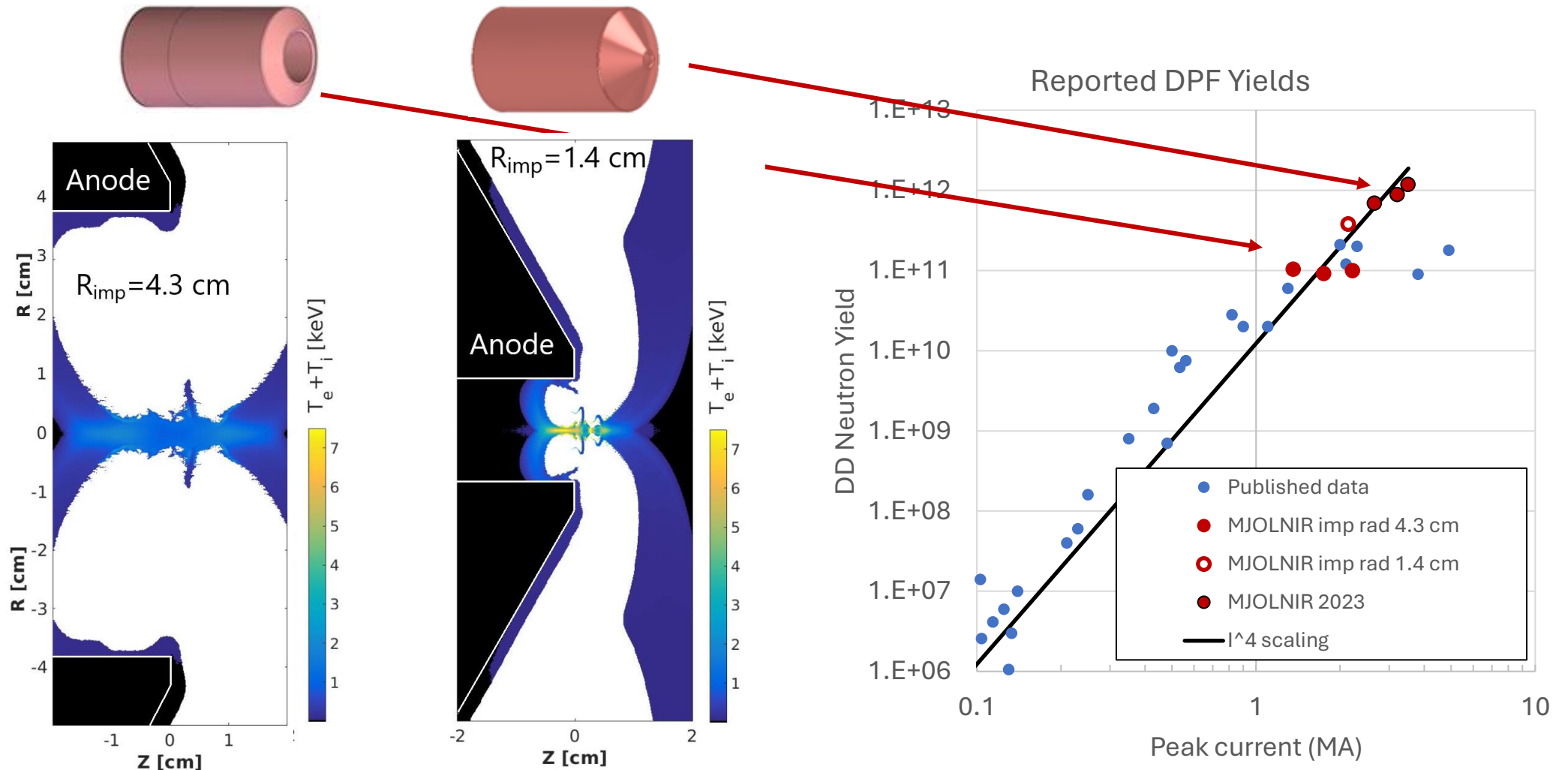
Angus, Phys. Plasmas 27, 012108 (2020)



- Only gas within the taper is swept into pinch
- The plasma column is narrower
- The timescales are faster

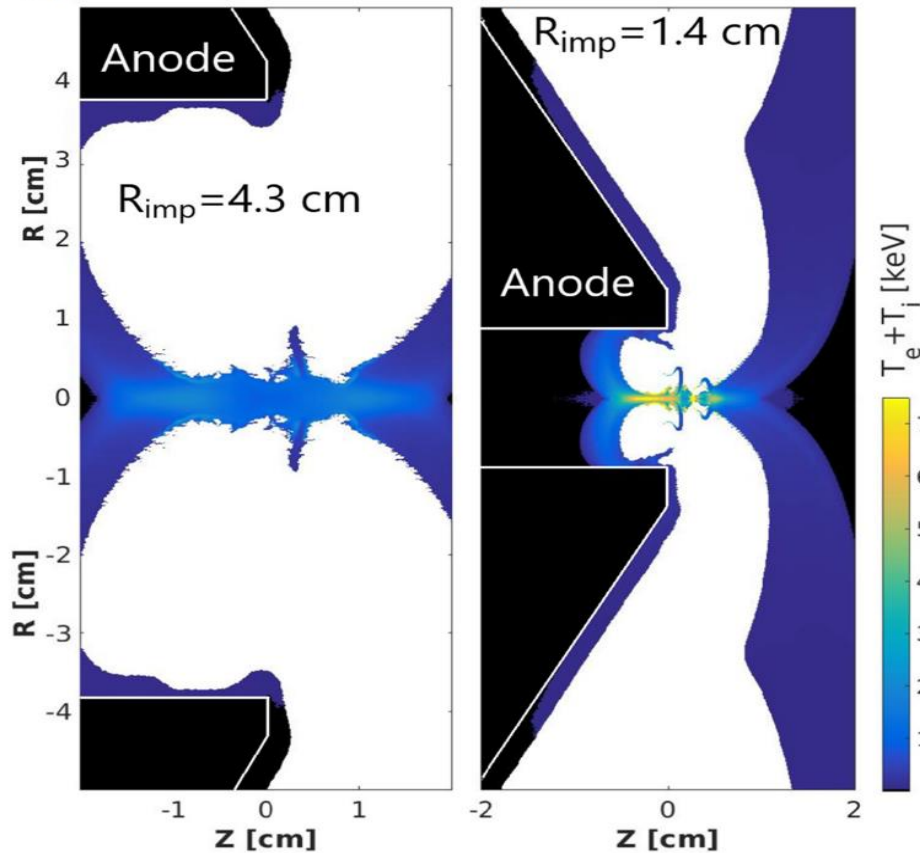
We originally used smaller implosion radius to increase yield and decrease spot size, but it has the side-benefit of shortening the neutron pulse

Maintaining > 3 MA operations requires optimization of anode radius, gas pressure, and length for fixed driver

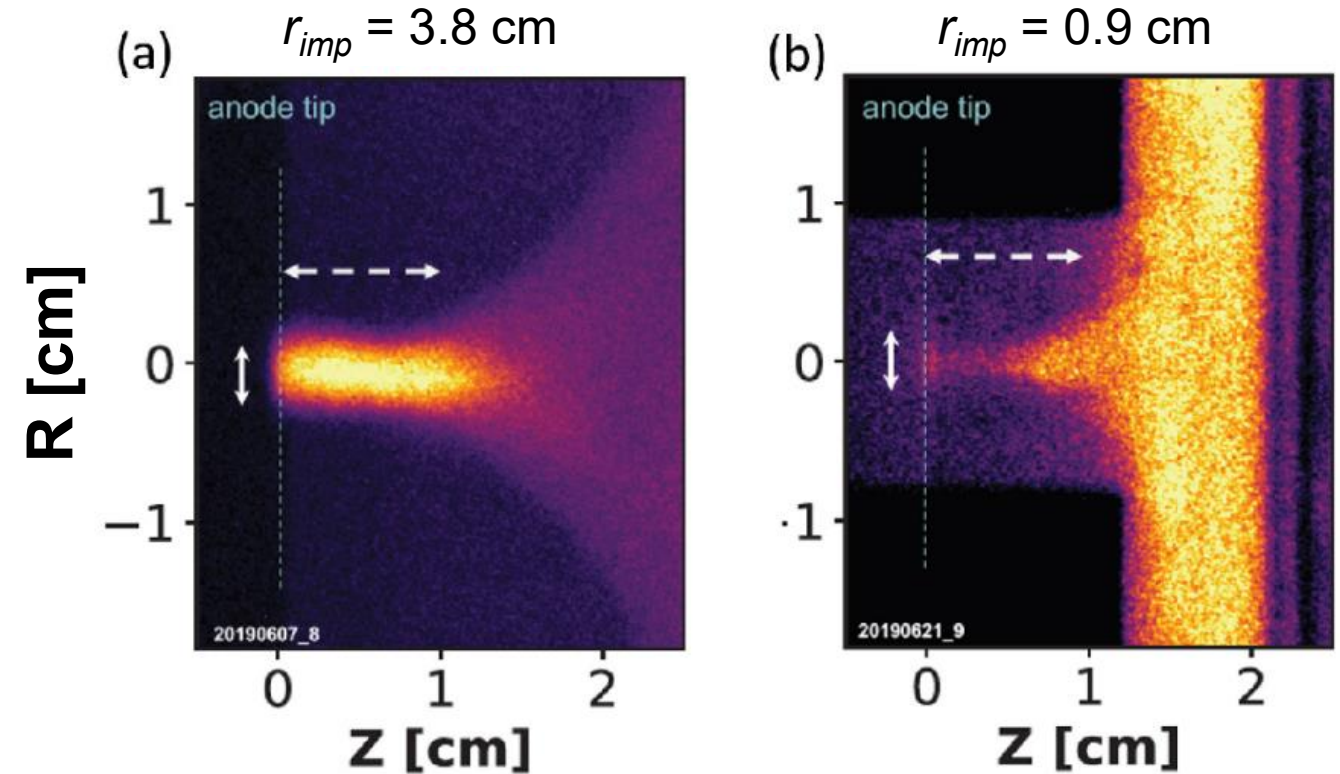


Experimental Measurements Corroborate the Smaller Stagnation Column Predicted in Simulations

Target temperature modeled using MHD-kinetic

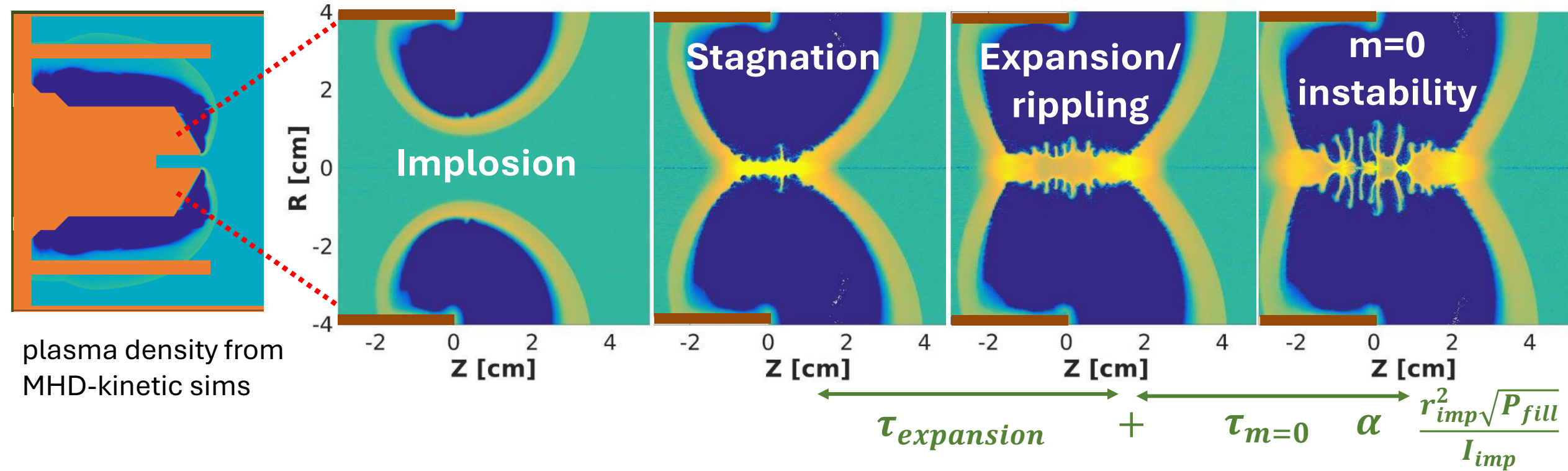


Experimental measurements of optical emission



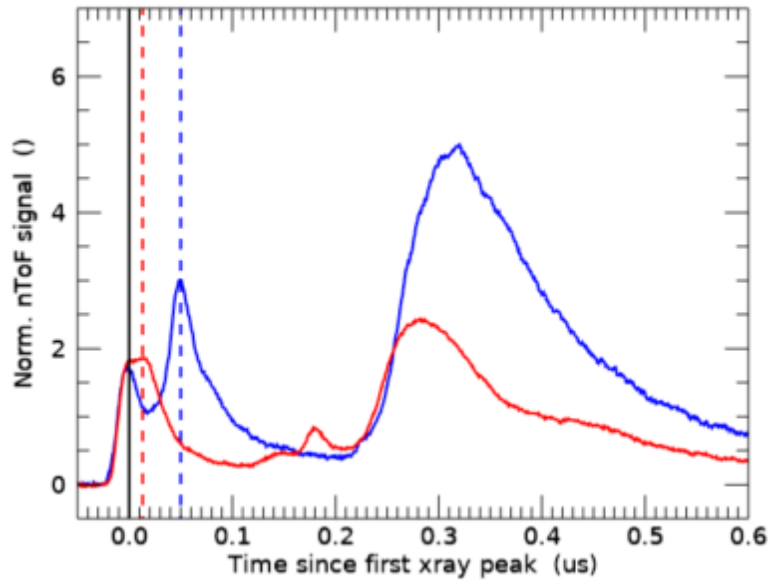
The smaller stagnation radius may lead to a smaller neutron spot size

Simulation show neutrons emitted during two of the four pinch stages: Stagnation and m=0 instability



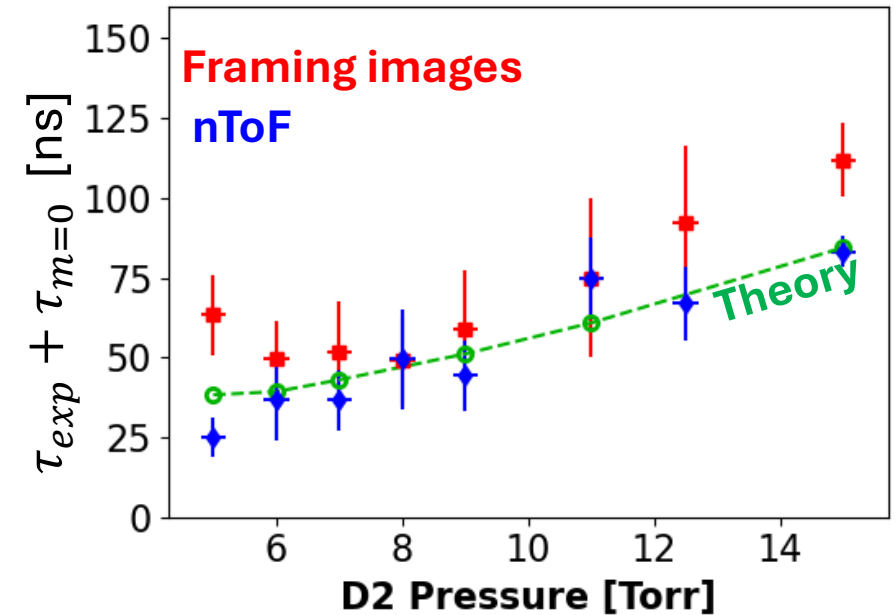
[Goyon 2025]

Manipulating the plasma physics during run in can modify the timing of the pulse



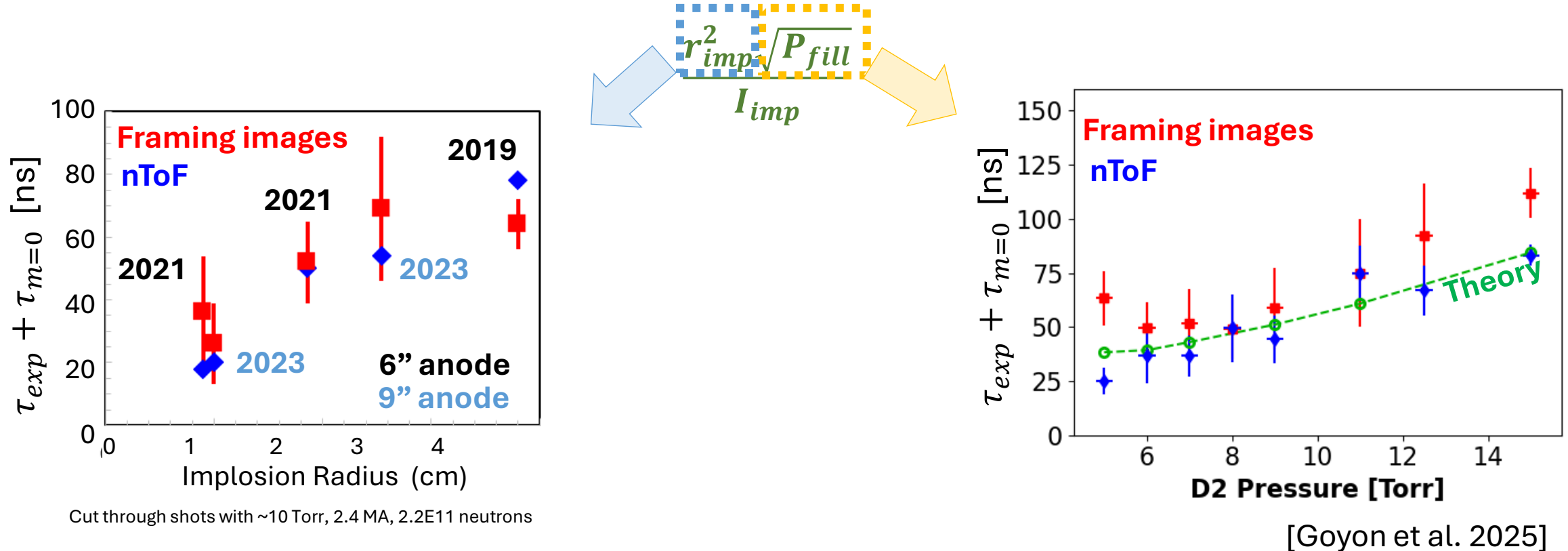
1.9 cm rad (blue)
0.9 cm rad (red) is :faster:

$$\frac{r_{imp}^2 \sqrt{P_{fill}}}{I_{imp}}$$



[Goyon et al. 2025]

Manipulating the plasma physics during run in can modify the timing of the pulse



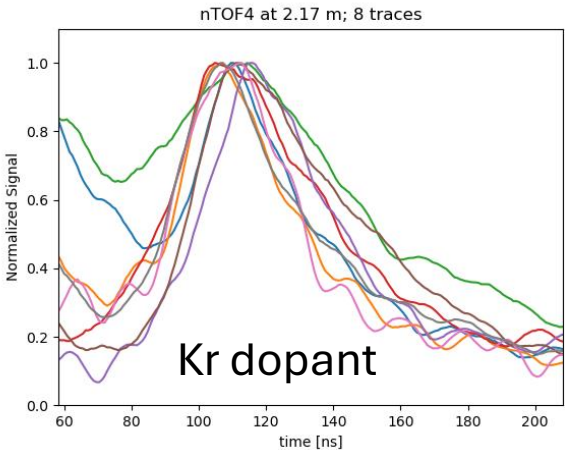
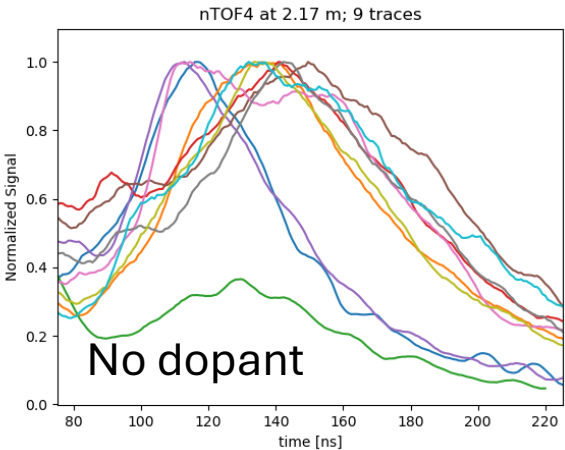
MJONLIR developed theory and data could help meet multiple requirements

Adding dopants

- Dopants can lower neutron jitter
- Dopants can lower neutron pulse width
- Too much dopant lowers neutron yield
- Xe reduces neutron spot size

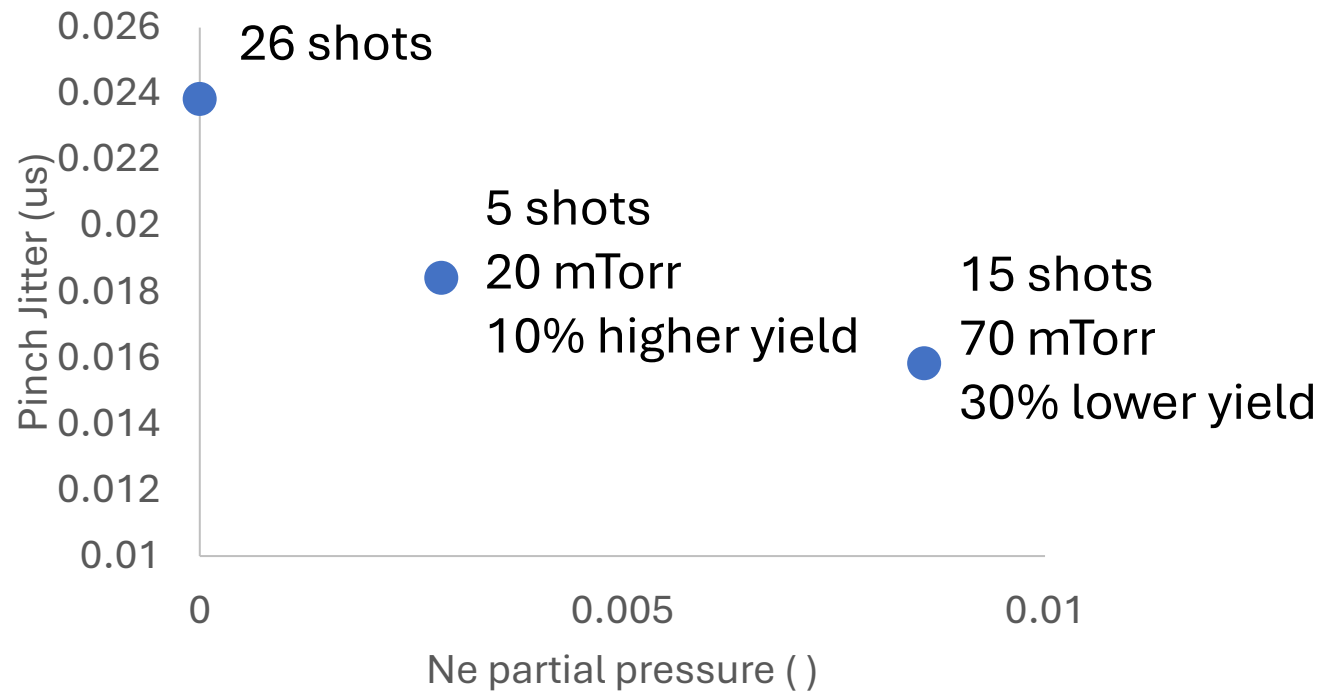
Experiments demonstrate that a small quantity of dopant improves timing reproducibility

- After adding small amounts of dopant:
 - More consistent peak time
 - Faster disassembly of plasma column



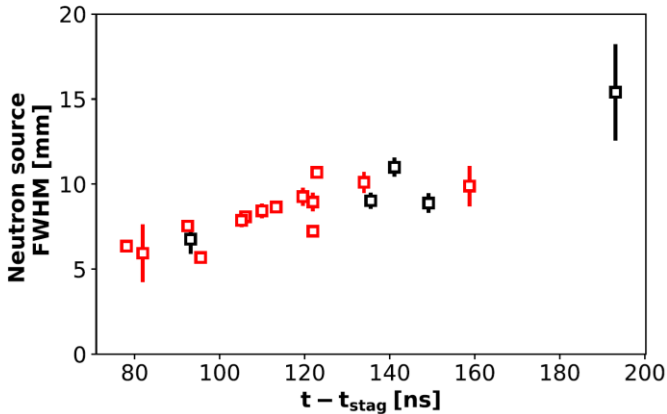
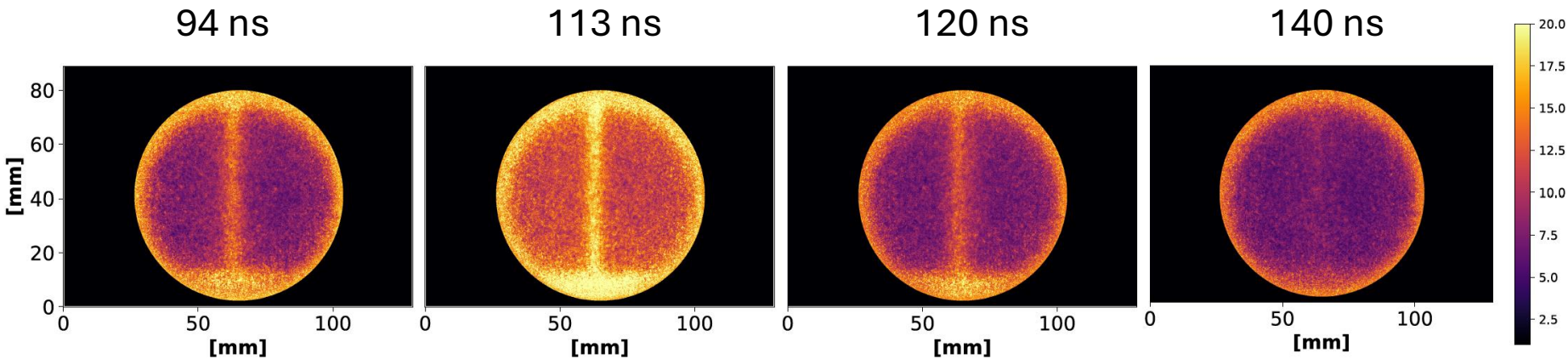
Time of peak neutron signal relative to start of x-ray signal		
	Only D ₂	With Kr dopant
A-15 10 torr 60 kV	74 shots: 153.09 +/- 95.13 ns	6 shots: 110.40 +/- 8.98 ns
A-45 14 torr 80 kV	9 shots: 130.93 +/- 12.53 ns	8 shots: 110.30 +/- 3.74 ns
A-45 12 torr 60 kV	25 shots: 190.78 +/- 139.20 ns	4 shots: 110.60 +/- 8.62 ns
A-15 6 torr 60 kV	22 shots: 119.49 +/- 14.57 ns	4 shots: 104.00 +/- 3.20 ns

Neon dopant reduced pinch jitter by 9 ns (30%)



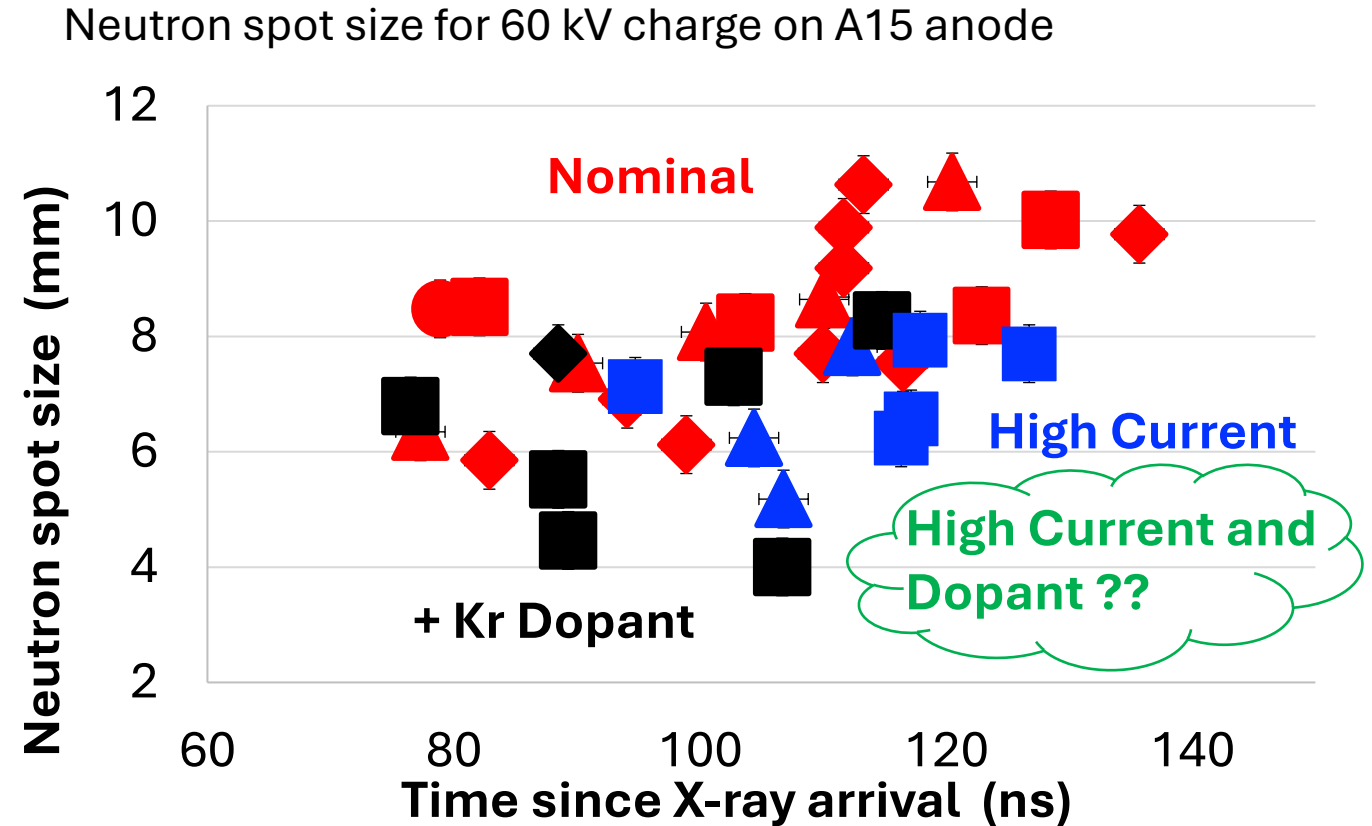
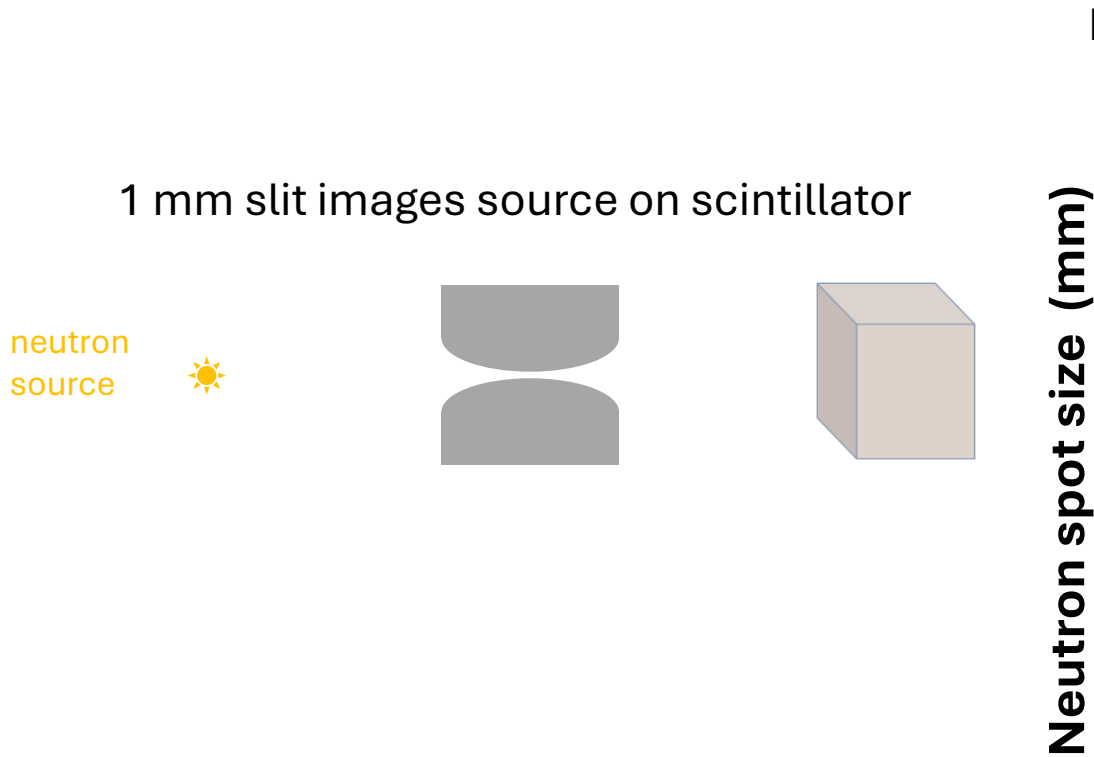
Tradeoff between timing and yield for some dopants types and partial pressure

Imaging a dynamic plasma implosion shows source size increase over the neutron emission time scale



C. Goyon, et al; Neutron generation dynamics inside a MA-class dense plasma focus Z-pinch. *Phys. Plasmas* 1 March 2025; 32 (3): 033105.
<https://doi.org/10.1063/5.0253547>

New MJOLNIR analysis technique with high temporal resolution can isolate time dependent effects



Recent data indicates 0.1% Kr can improve DPF spot size

Collaborative Research at MJOLNIR with a Current User Facility Pilot Program

- Prompt Diagnostic Development: Test readiness program with M. May and D. Bower
- Source collaboration for NDSE (Neutron Diagnosed Subcritical Experiments): D. Lowe
- Thin coded apertures for neutron source size reconstruction: M. Selwood, D. Fittinghoff
- Cross calibration for activation detectors for fusion companies: Helion, Zap, Realta
- Optical spectroscopy of pinch: J. Young and P. Gourdain
- Neutron resonance transmission analysis: E. Klein and C. Cooper
- X-ray filter array measurements (DSTI fellowship): A. Jibodu and M. Cappelli
- Effects of thin wire array on pinch stability (ZNetUS): Cornell University
- 2 color laser absorption for temperature and density measurements (ZNetUS): Stanford
- Calibration of fiber-coupled scintillator detectors (ZnetUS): U. Michigan



Z pinch physics

- MJOLNIR is a versatile, well diagnosed pulsed-power platform for HED and DPF physics available through ZNetUS
 - Please reach out for collaborations
- Shaped anodes can improve pulse width, yield, and spot size
- Gas dopants can improve timing, pulse width and spot size

Combining multiple new techniques will allow simultaneous meeting of source requirements

Thank you,
Any Questions?