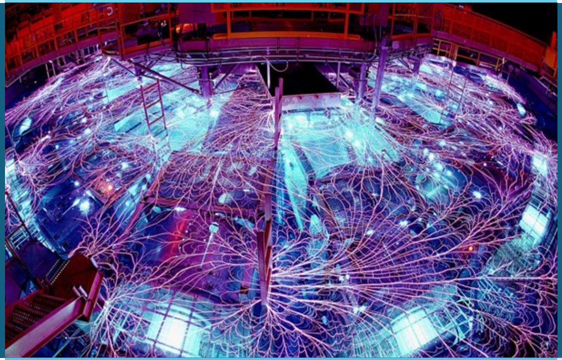
Sandia National Laboratories

SAND2020-12666C

First demonstration of an inductively driven X-pinch for diagnosing high energy density experiments on the Z Pulsed Power Facility



Project team:

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PRESENTED BY

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LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

U.S. DEPARTMENT OF ENERGY NNSA

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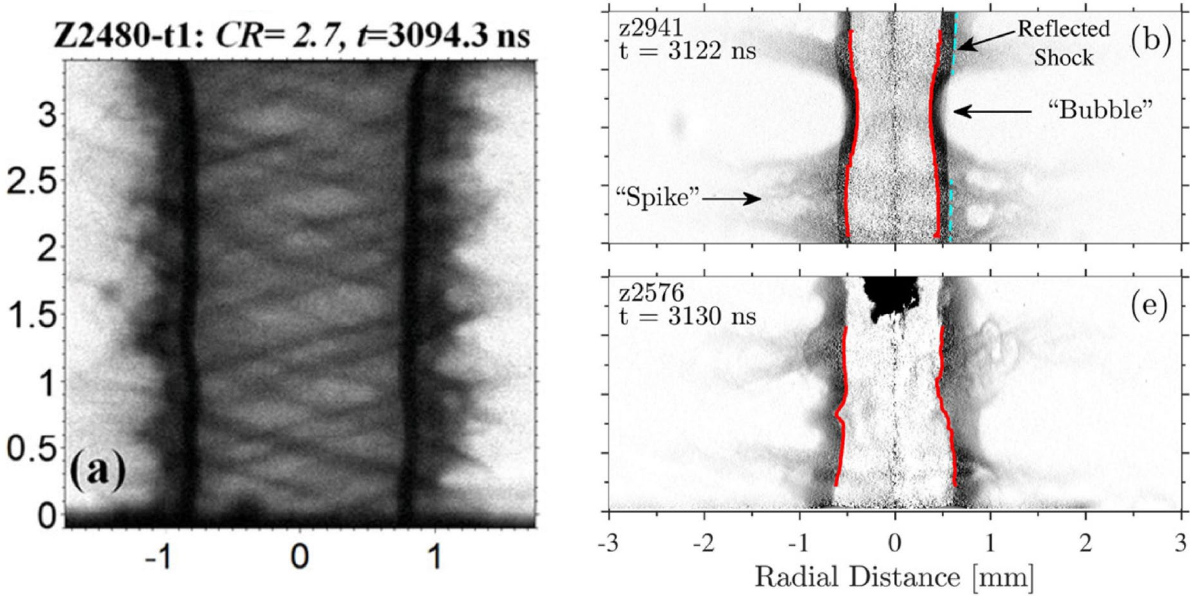
Radiography and diffraction are key diagnostics for HED experiments

Penetrating radiography is one of the only ways of directly observing Z-pinch implosions.

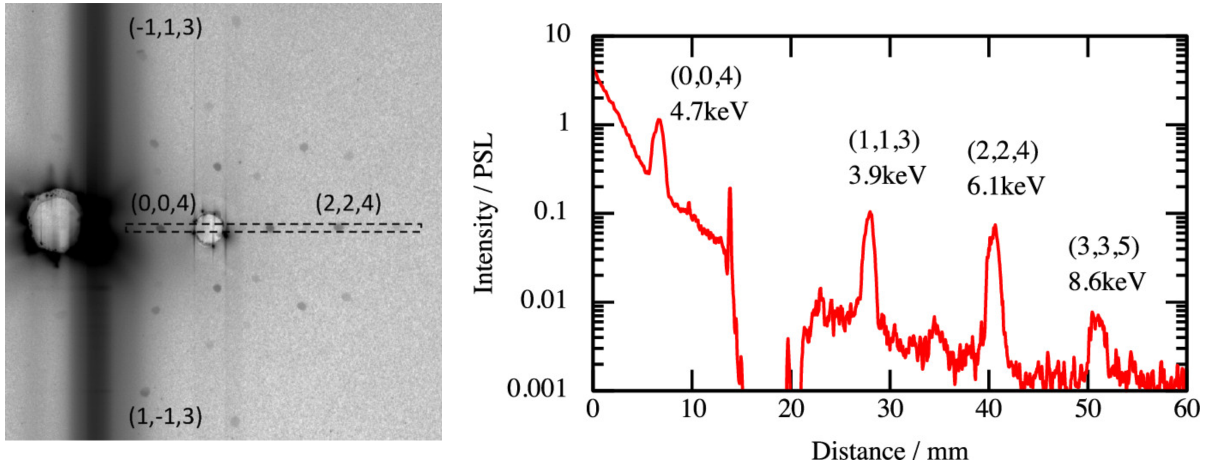
Monochromatic crystal radiography is presently provided at Z using the Z Beamlet Laser (ZBL).

ZBL radiography is limited to two frames per shot. Only available when ZBL is not blocked or being used for other purposes (e.g., MagLIF preheat).

X-ray diffraction of compressed materials is also of great interest. Presently under development at Z, again using ZBL [Ao et al. 2020].



Radiography at Z [Awe et al. 2013, Knapp et al. 2017]



Laue diffraction at JANUS [Suggit et al. 2010]

Can we develop non-perturbative pulsed-power-driven X-ray sources that will provide transformative diagnostic capabilities to Z?

In an X-pinch, very thin (~20–200 μm) wires are crossed in an X shape and driven with a large, transient electrical current (100+ kA) to produce a compact X-ray source.

A hybrid X-pinch uses conical electrodes to mock up the crossed-wire configuration. We pursue hybrid X-pinches in the project.

X-pinches are better suited to broadband point-projection radiography than monochromatic crystal radiography.

The key question is whether we can develop an X-pinch source for Z that can be fielded without perturbing the primary load.

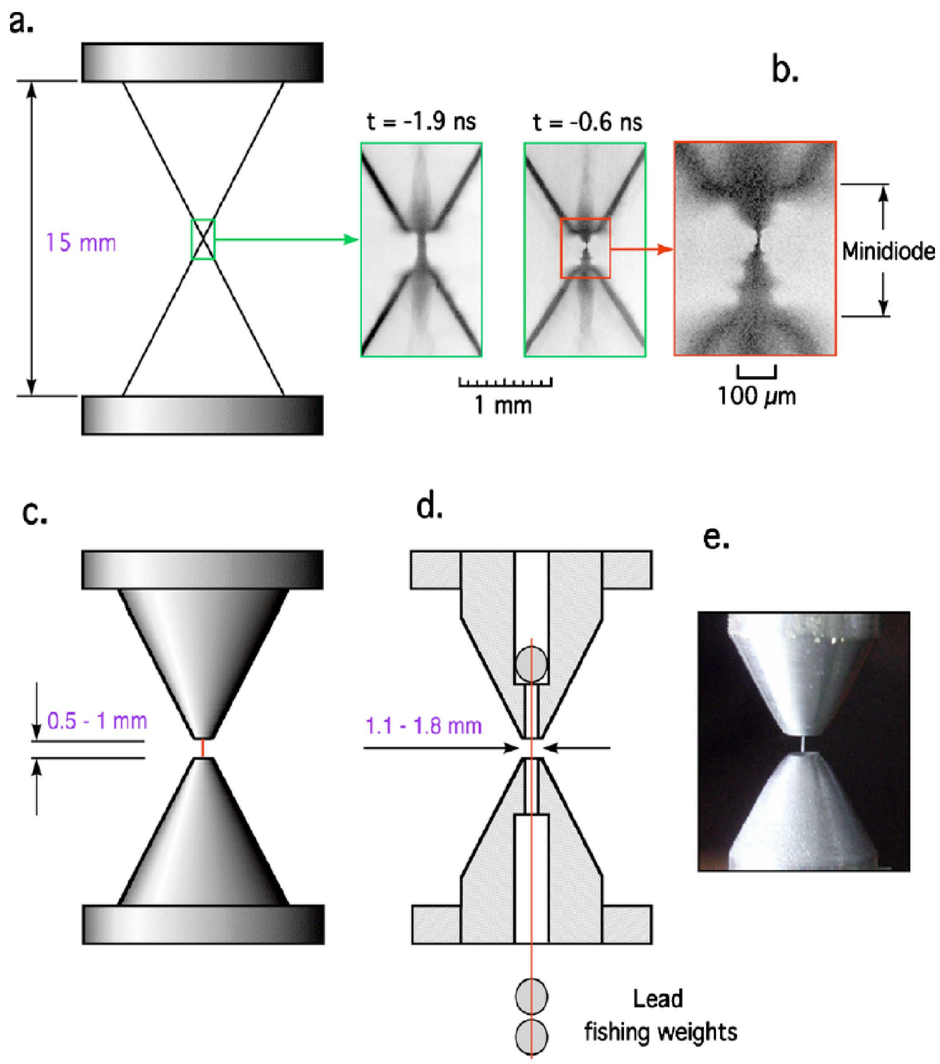
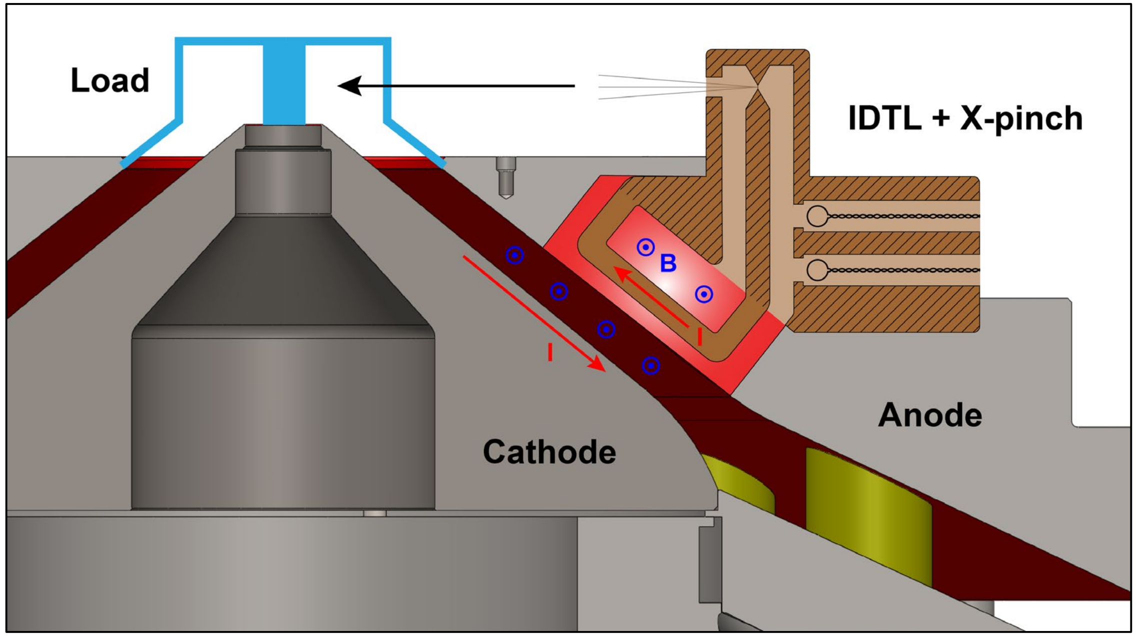


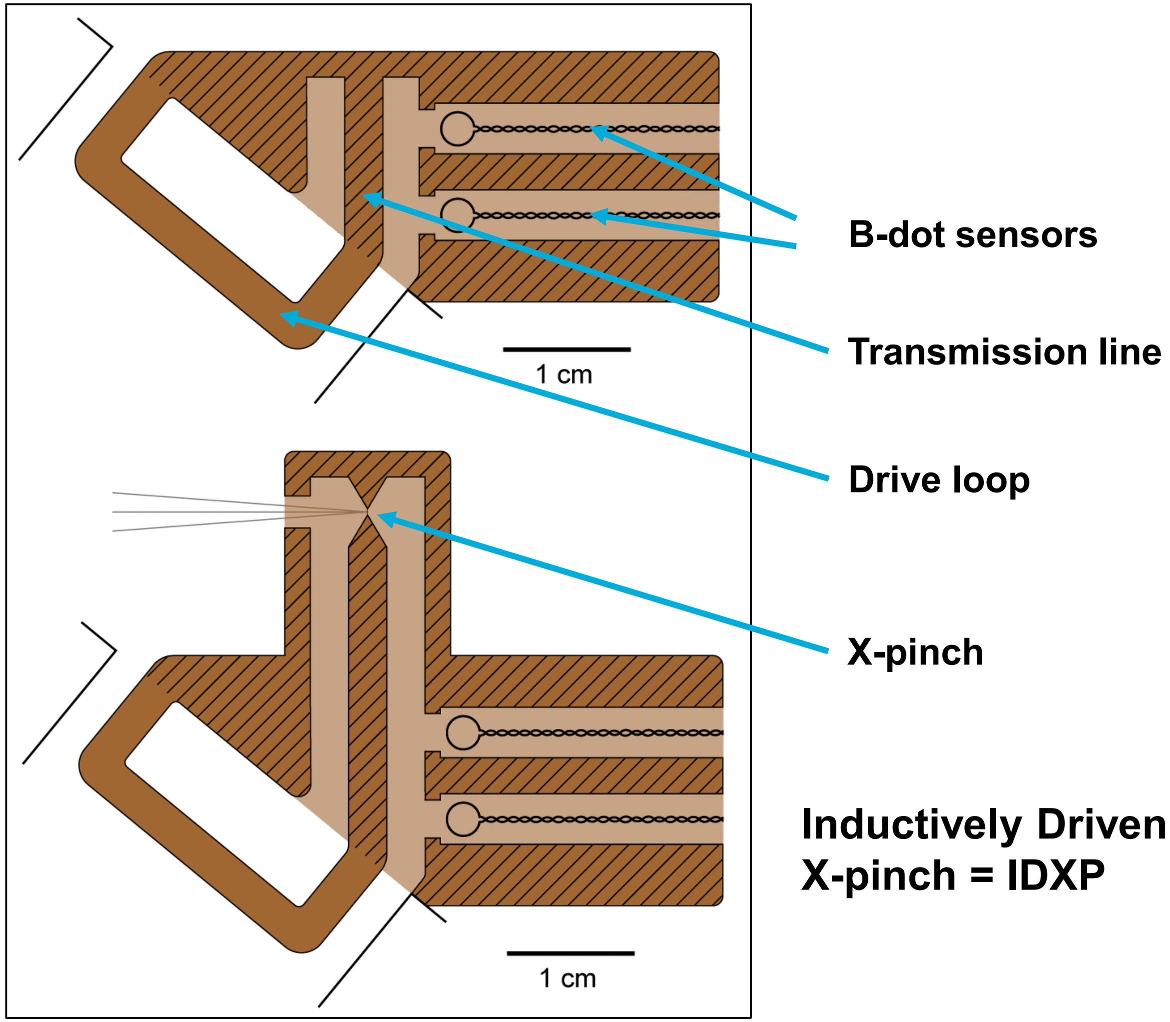
Figure from Shelkovenko et al. 2010

Attempt to drive X-pinches with inductively driven transmission lines (IDTLs) that couple to fringe magnetic fields in Z's final feed

The IDTL drive loop protrudes into a slot-shaped cavity in the top anode.

The voltage induced on the drive loop drives substantial current up a vertical transmission line.





Inductively Driven X-pinch = IDXP

Can inductively driven X-pinches (IDXPs) serve as the first Z-compatible pulsed-power-driven diagnostic X-ray sources?

YES 1. Can 100+ kA of current be reproducibly and non-perturbatively driven in short-circuit inductively driven transmission line (IDTL) experiments on Z?

YES 2. Can the same 100+ kA of current be driven in Z-surrogate short-circuit IDTLs on the 1-MA Mykonos facility?

YES 3. Can the Z-surrogate IDTLs on Mykonos drive X-pinches that generate radiography-quality X-ray bursts?

TBD 4. Are the IDXP X-ray sources sufficiently reproducible and do they generate enough X-ray fluence to be used for radiography and diffraction on Z?

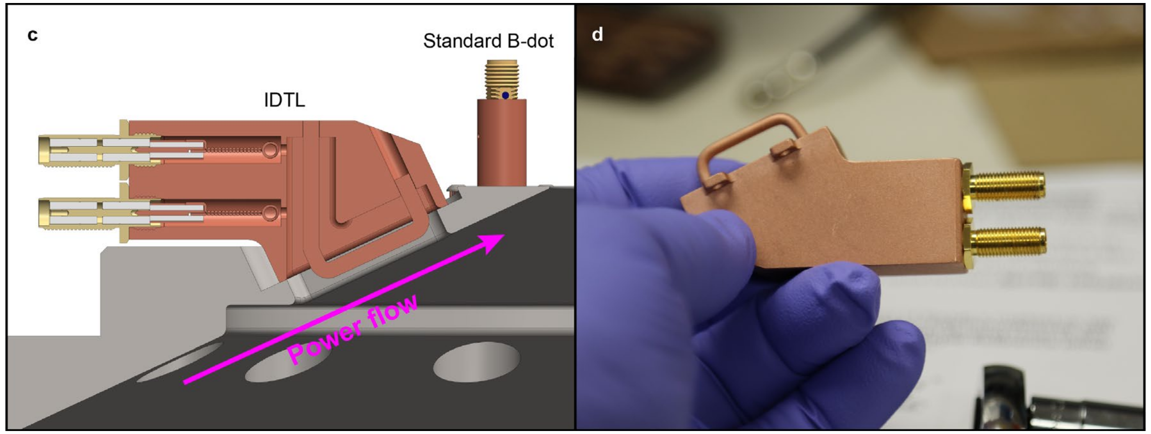
Short-circuit IDTLs on Z can non-perturbatively draw 200+ kA of current

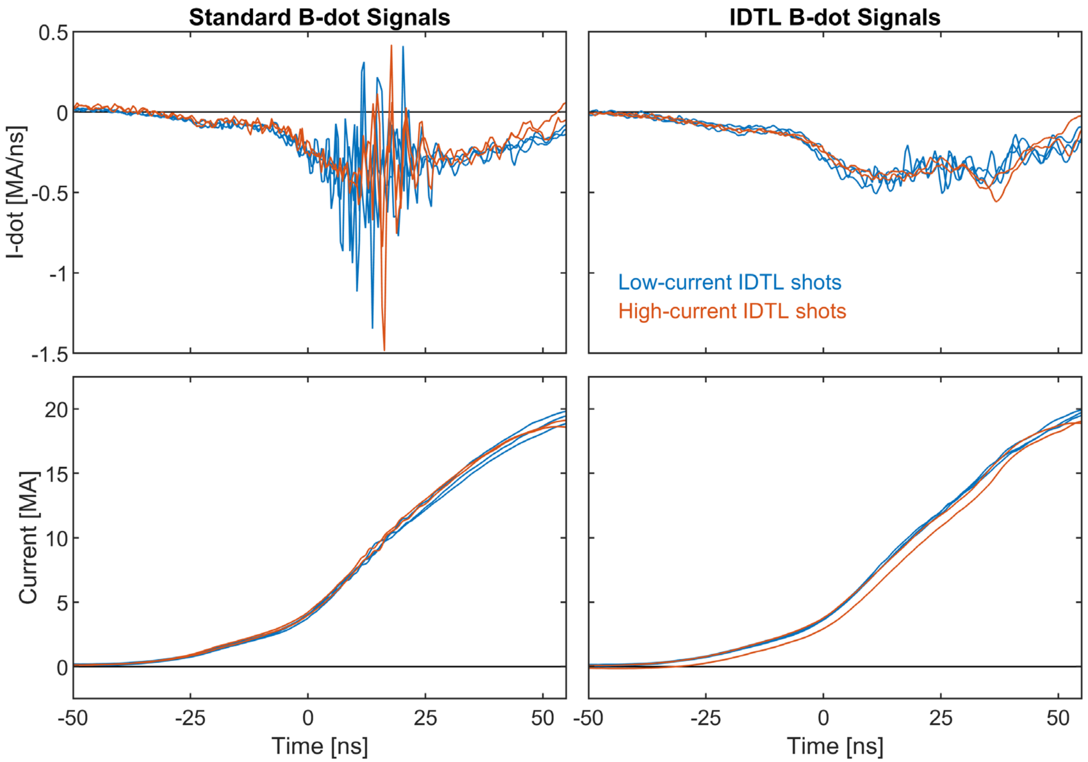
High-current short-circuit IDTLs (200+ kA) were fielded on two identical Z experiments.

Expected IDTL currents are calculated using ANSYS Maxwell or HFSS. Measured B-dot sensor voltages (not shown) confirm the modeling results.

The IDTL B-dots follow the standard B-dot currents to better than 10%, indicating nearly full current coupling in the IDTLs.

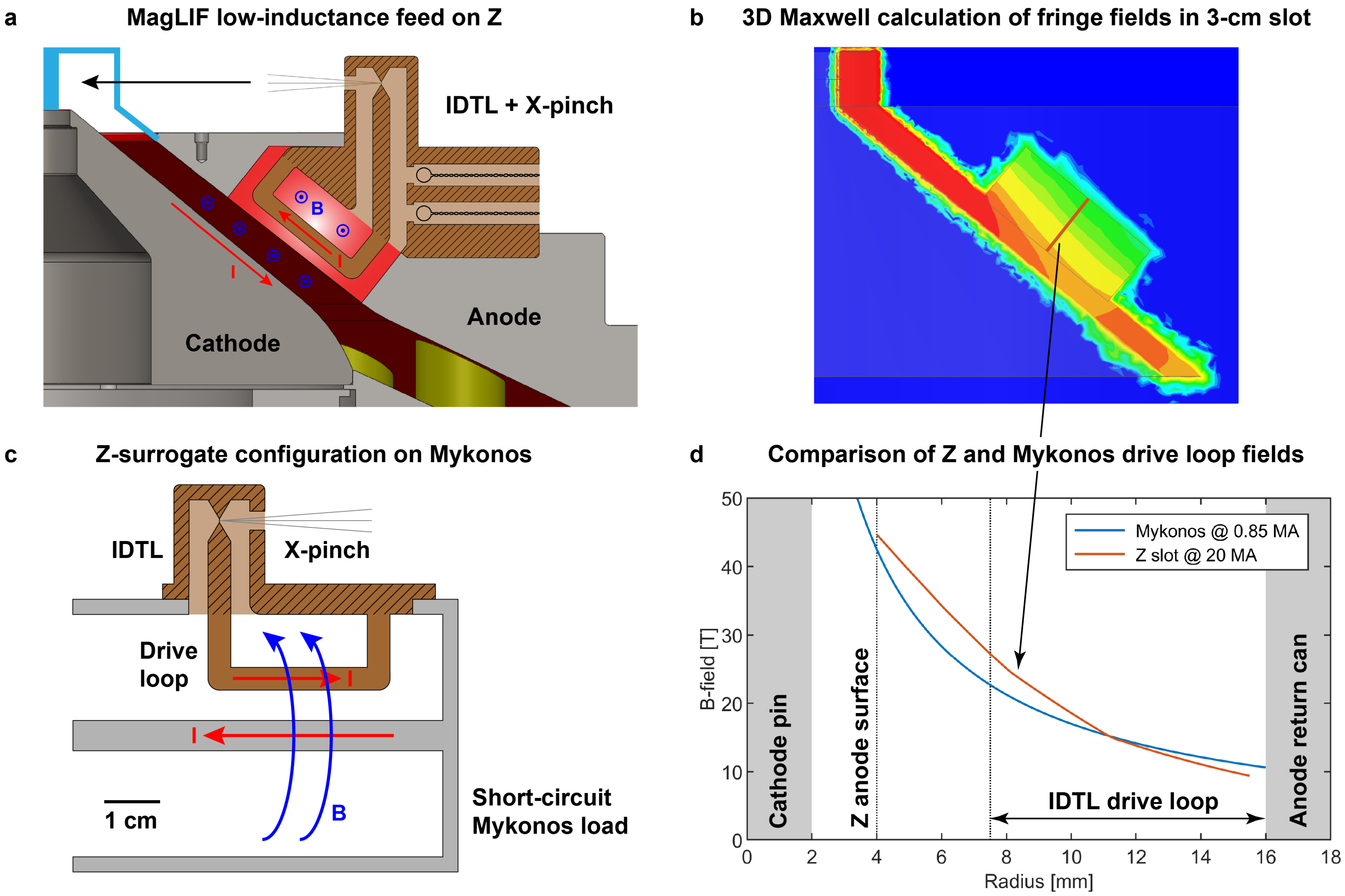
In each case, the primary experiments performed nominally according to both driver-target coupling diagnostics and other metrics.





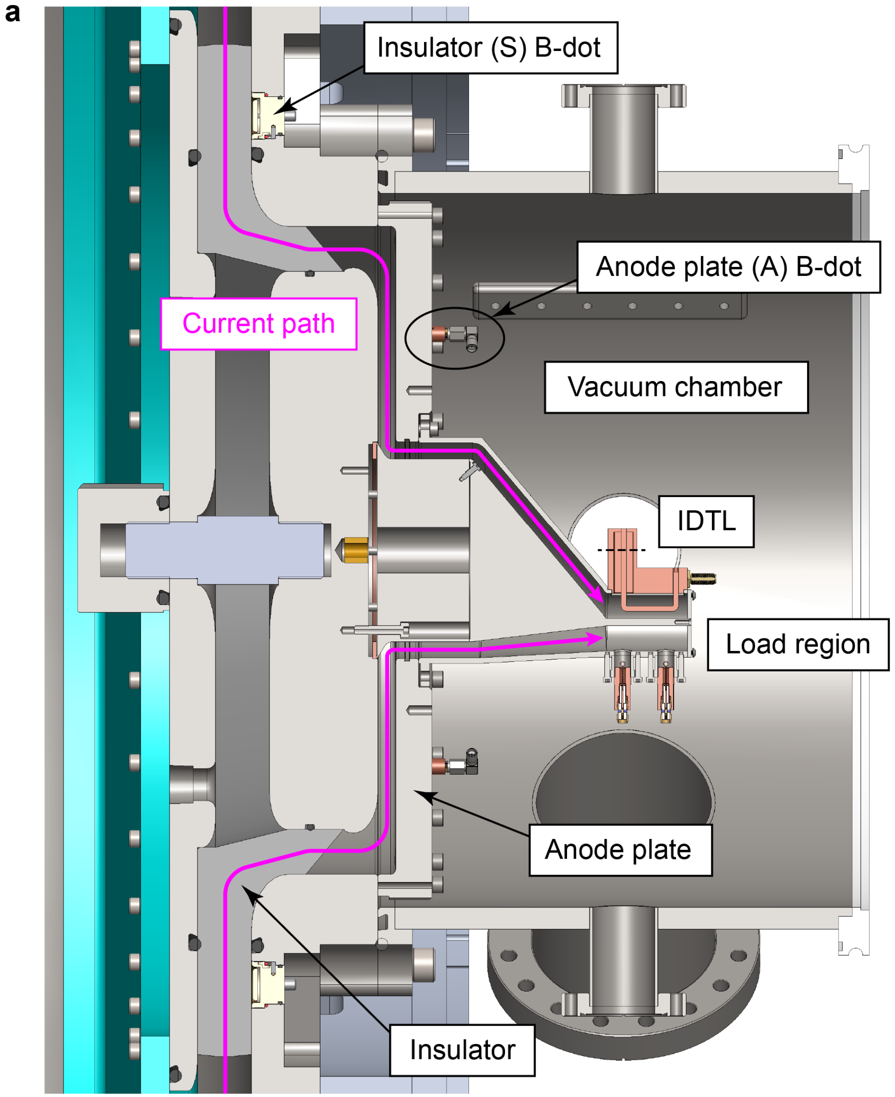
Q1

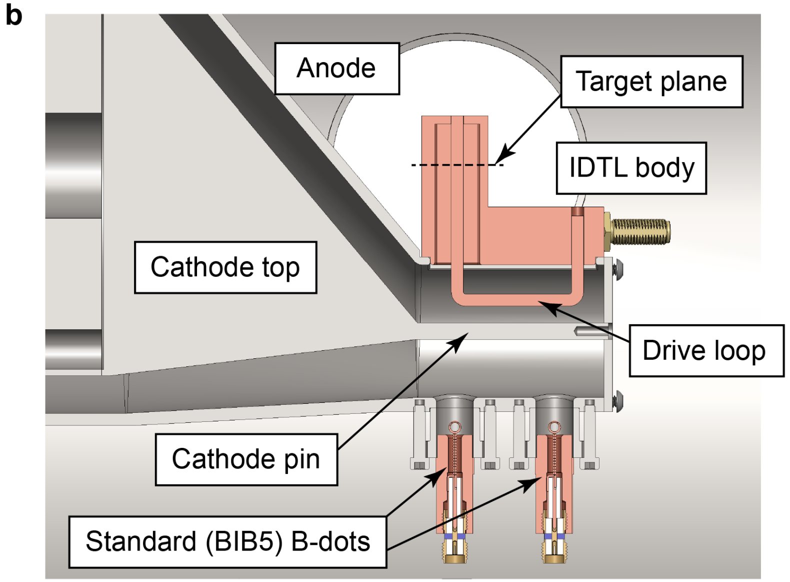
Mykonos can generate comparable magnetic fields at the IDTL drive loop

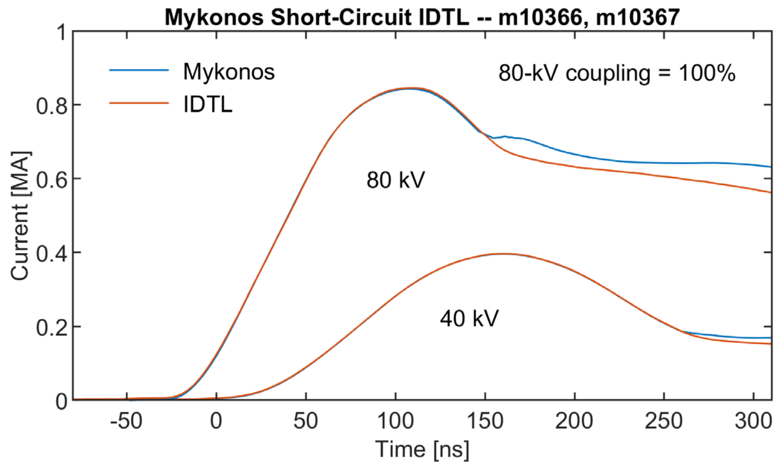


Q2

We developed a skewed conical feed to allow diagnostic access to the IDTL







Short-circuit IDTLs draw 150+ kA with >90% coupling

Q2

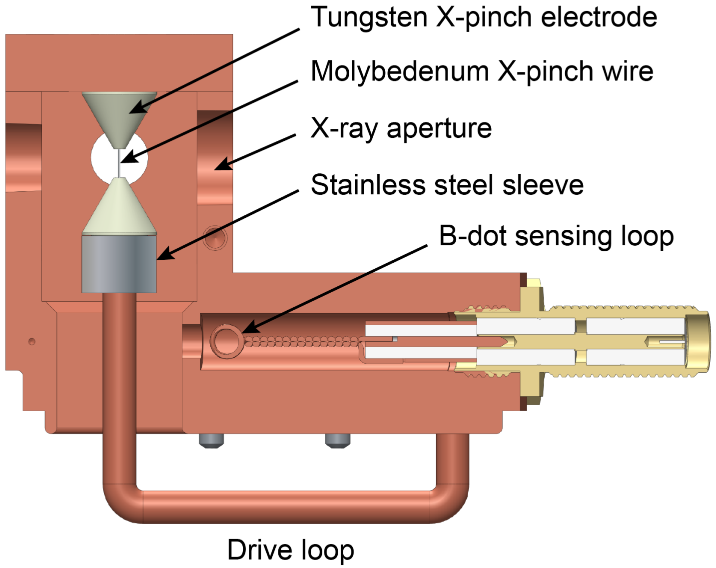
The IDTL cavity is expanded to accommodate a hybrid X-pinch

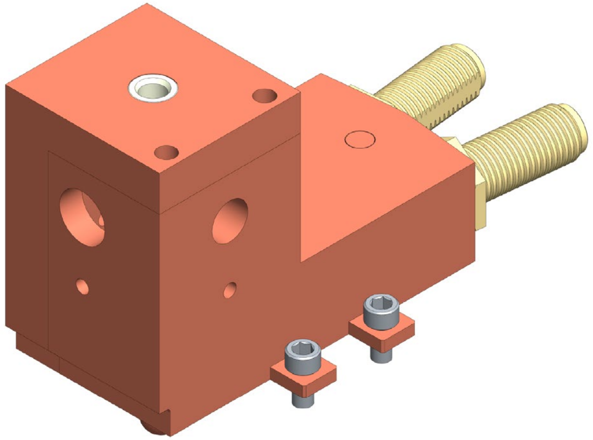
Two conical tungsten electrodes are spanned by a 15-μm molybdenum X-pinch wire.

The empirically determined optimum electrode gap is wider than expected (2–2.5 mm vs. 0.8 mm).

The IDXP body has an L-shaped removable lid that provides access to the inner chamber for building up the hybrid X-pinch assembly.

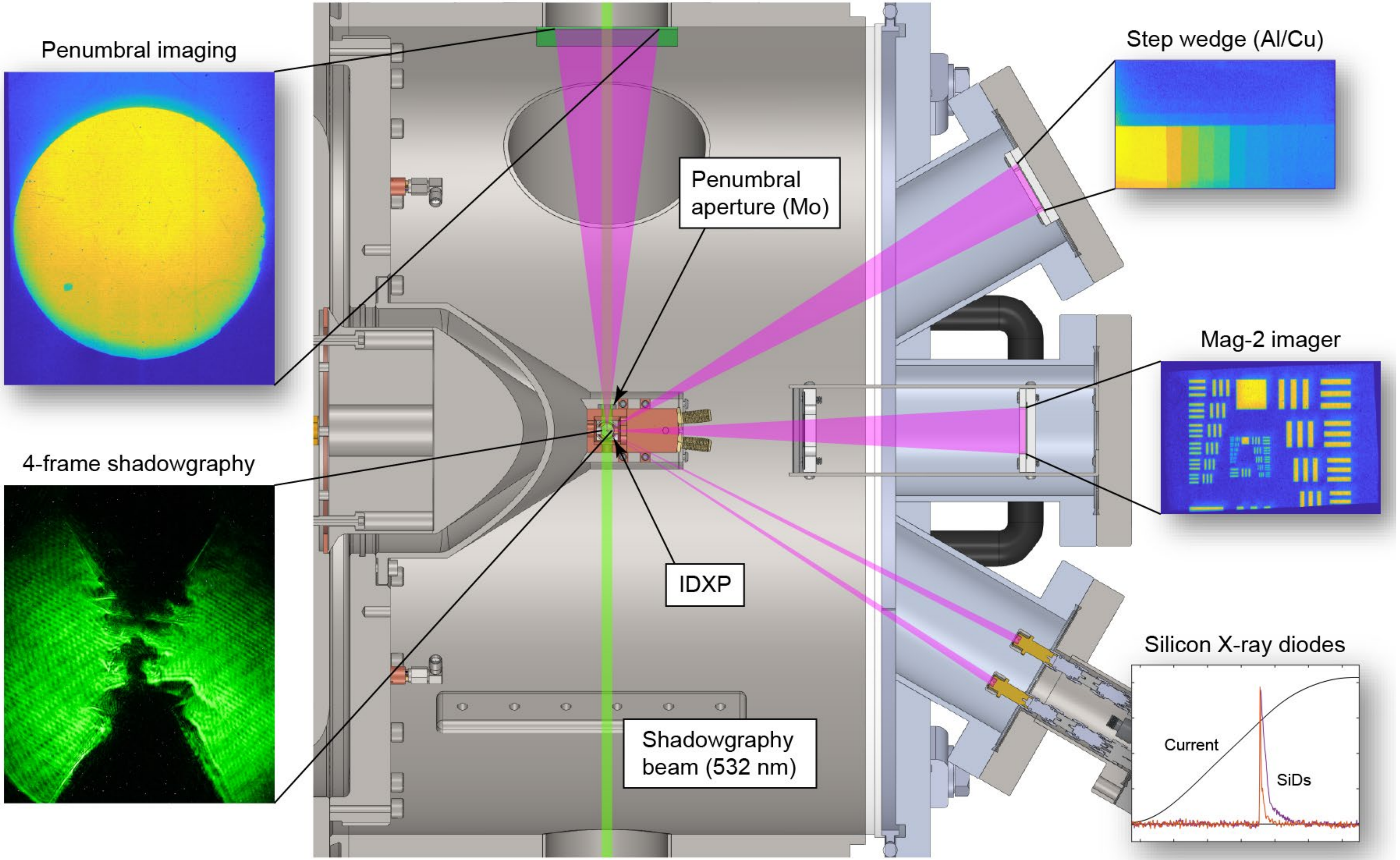
The IDXP bodies and the electrodes (along with the skewed Mykonos anodes) are thankfully reusable, though refurbishment by a machinist is required.





Q3

We developed numerous line-of-sight X-pinch diagnostics for Mykonos



Q3

X-ray diodes, B-dots, and the Mag-2 imager show that IDXPs work!

A silicon diode (**red**) captures a sharp X-ray burst emanating from the IDXP.

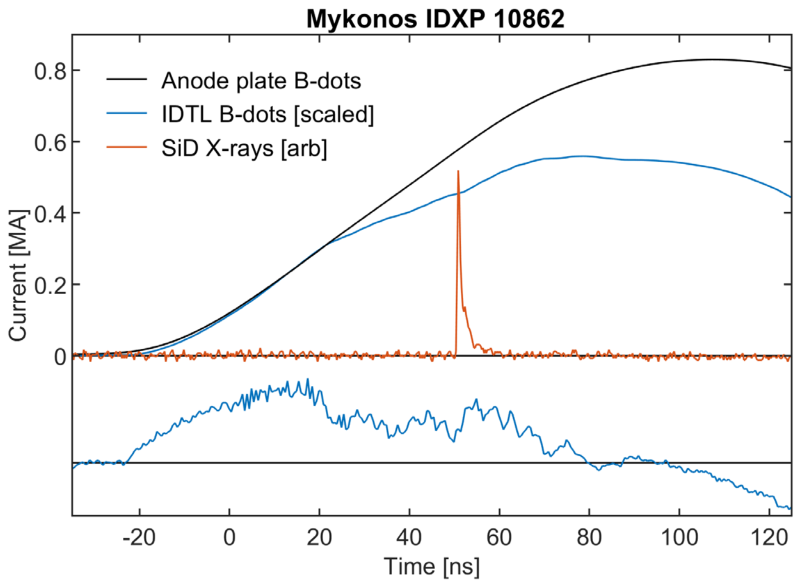
The B-dot sensors embedded in the IDXP (**blue**) show a sharp inductive dip that correlates with the X-ray burst.

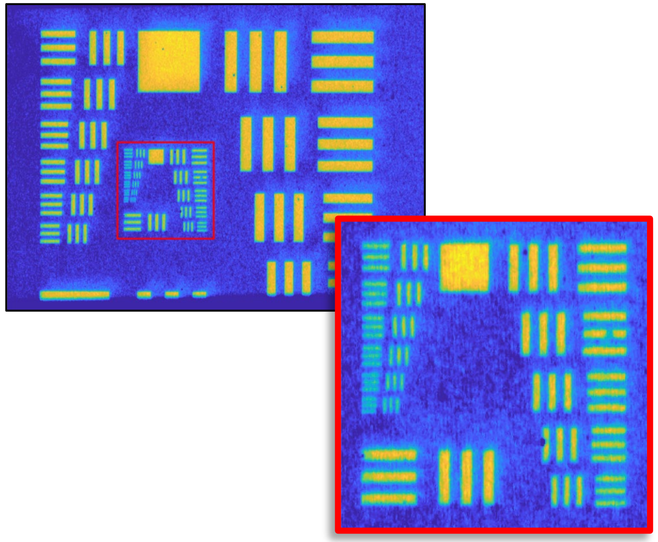
A USAF 1951 clear path resolution target is fielded in the Mag-2 imager.

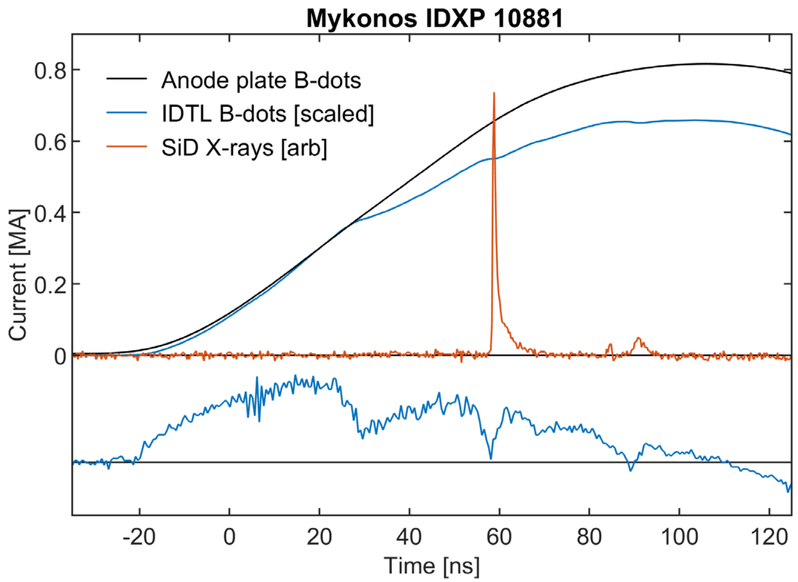
The X-pinch backlighter resolves the smallest elements in the resolution target (35 μm or 14.25 LP/mm).

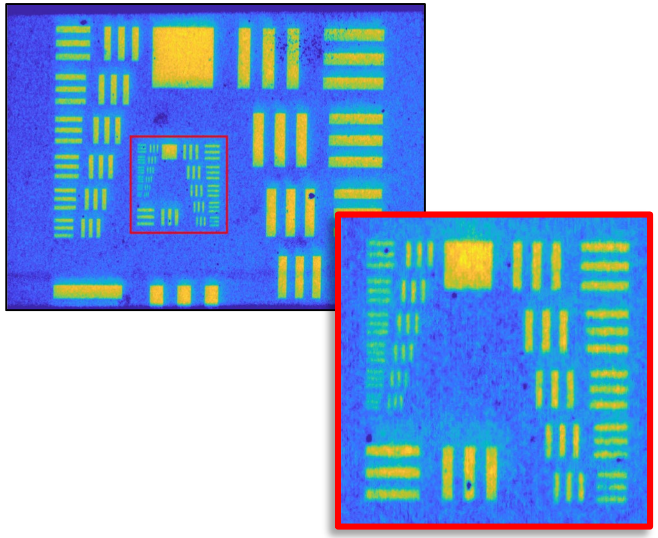
Penumbral imaging constrains the source size to smaller than ~10 μm.

Diodes constrain the source duration to less than ~750 ps (FWHM).









Q3

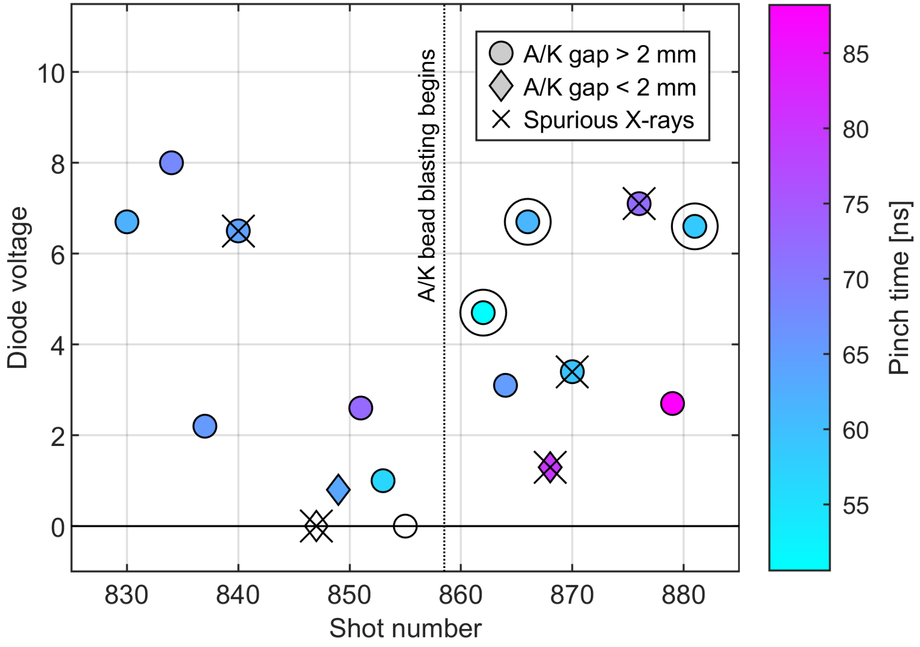
IDXP reliability is a challenge; Electrode conditioning is key

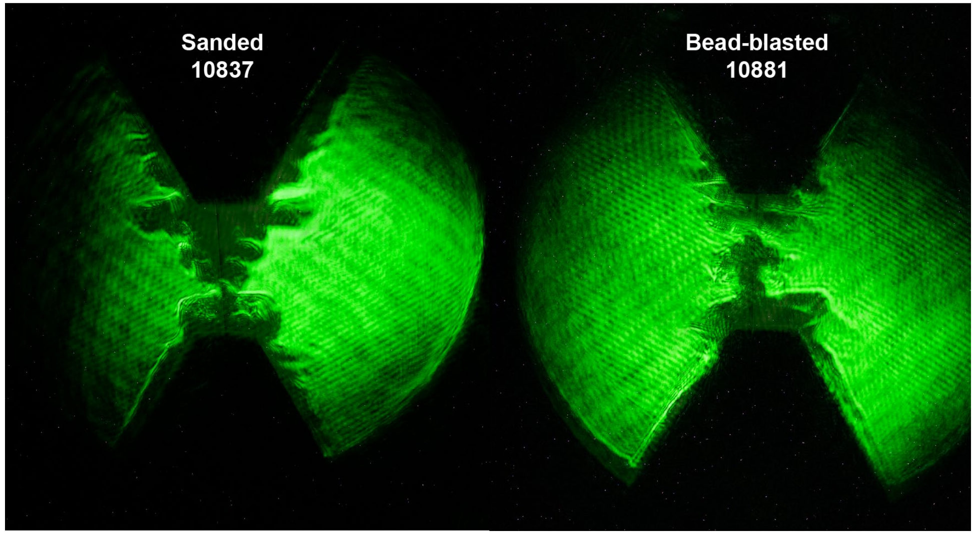
A total of 17 Mykonos IDXP experiments were conducted with 15-μm Mo wire. Initially promising results tapered off into a series of poorly performing experiments.

We switched from sanding to bead blasting the electrodes between shots, which resulted in better reproducibility and all three of our highest quality X-pinch radiographs.

A qualitative comparison of shadowgraphs appears to show reduced electrode plasma formation in the bead-blasted case.

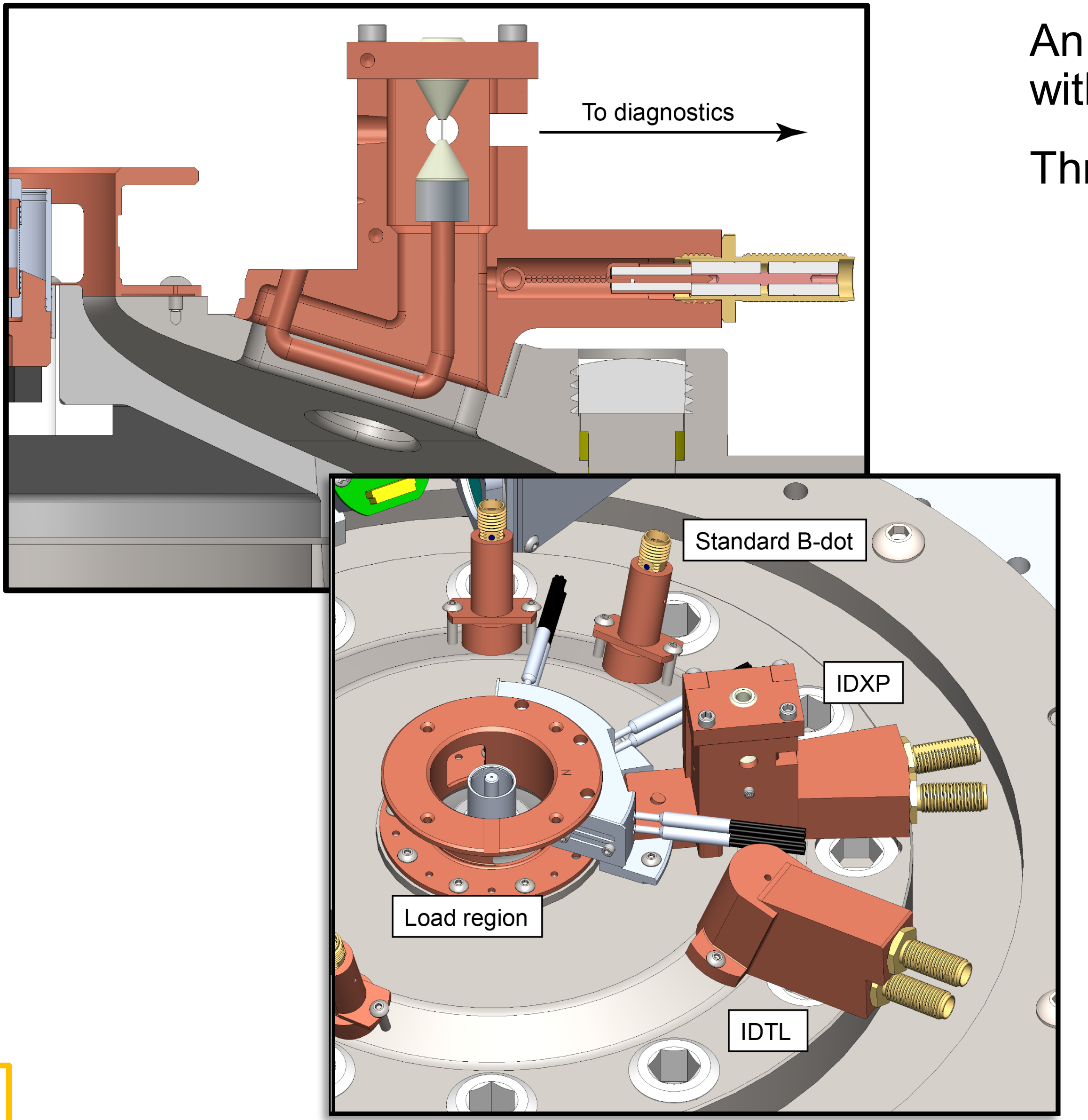
Reproducibility remains a challenge, however, and could potentially be improved with additional conditioning (e.g., plasma cleaning).





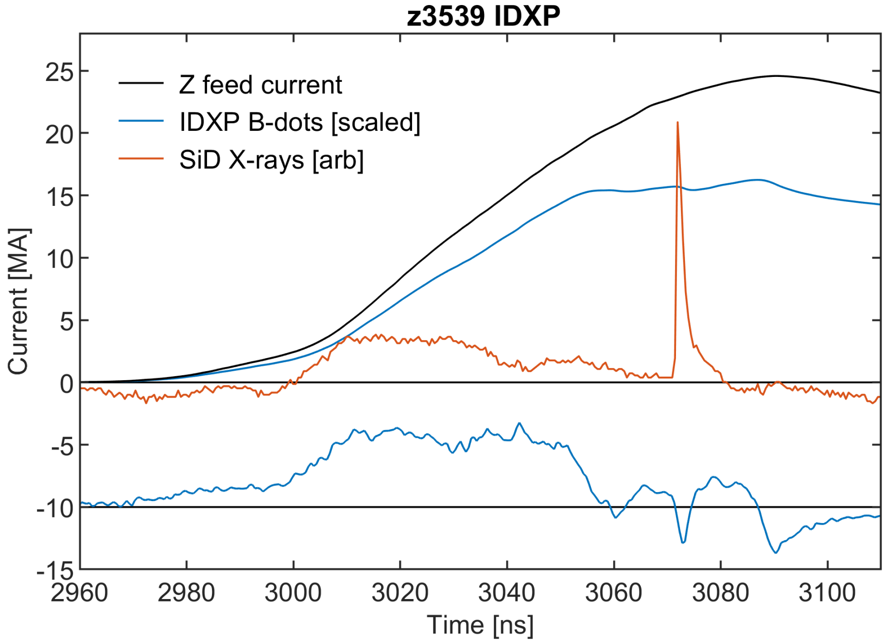
Q4

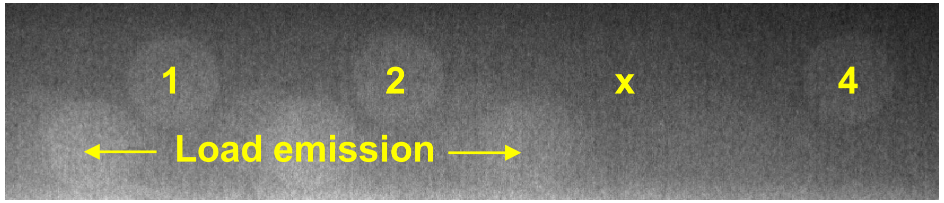
We recently successfully fielded the first-ever diagnostic X-pinch on Z!



An inductive dip and X-ray burst were observed with ~20 MA in the final feed!

Three apertures were projected onto image plate.





Time-integrated pinhole camera (TIPC)

Q4

We have developed and demonstrated the first Z-compatible X-pinch for use as a diagnostic X-ray source.

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TBD 4. Are the IDXP X-ray sources sufficiently reproducible and do they generate enough X-ray fluence to be used for radiography and diffraction on Z?

We are actively developing a point-projection X-pinch radiography capability at Z.

BACKUP

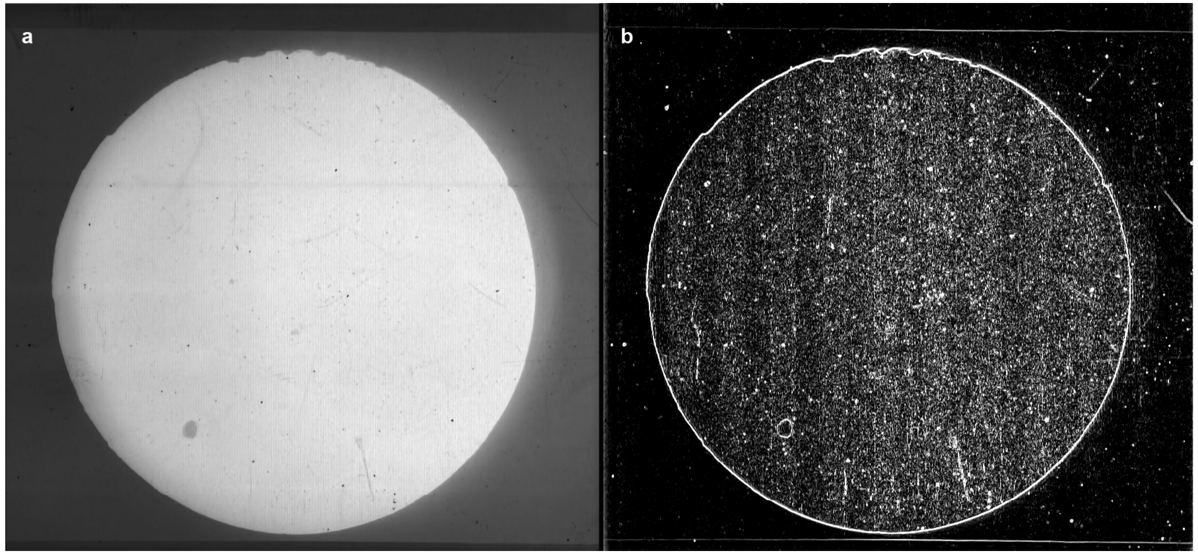
High-mag penumbral imaging indicates the IDXP source is <10 μm in size

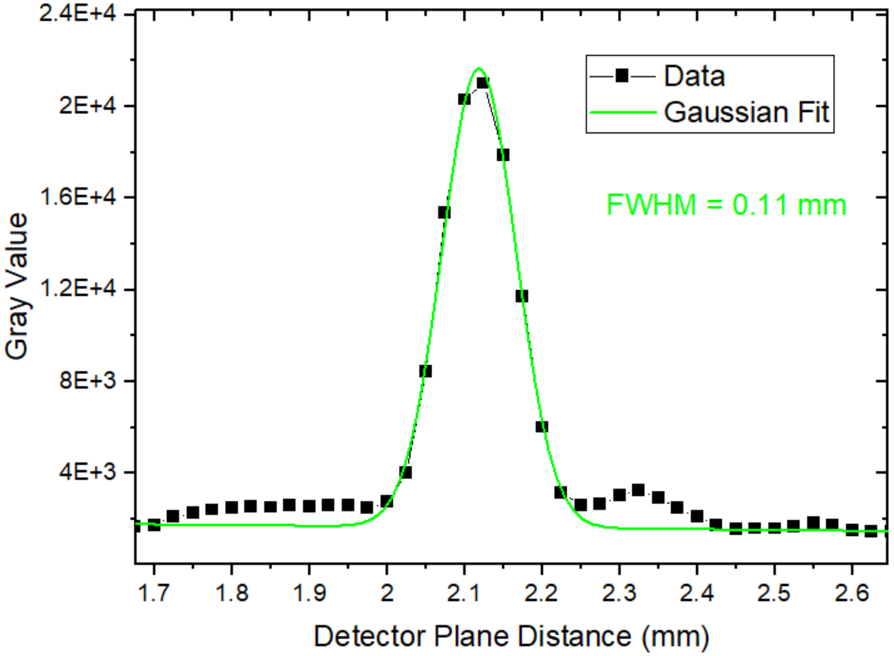
A molybdenum aperture (0.125" diameter) is projected onto an image plate at high magnification (17.6x).

The resulting circular image can be processed (Sobel filtered) to identify the line spread function (LSF) at the edge of the aperture.

Contact radiographs (not shown) indicate that an LSF FHWM of ~100 μm at the detector is the limit of this measurement. This corresponds to a ~6 μm source.

The best IDXP sources generate LSF FHWMs at the detector limit (see right), so we conclude conservatively that the IDXP source is <10 μm in size. This is highly desirable for radiography.





Q3