Sandia National Laboratories

Overview and status of EMI Measurement and Characterization on the Z-Machine

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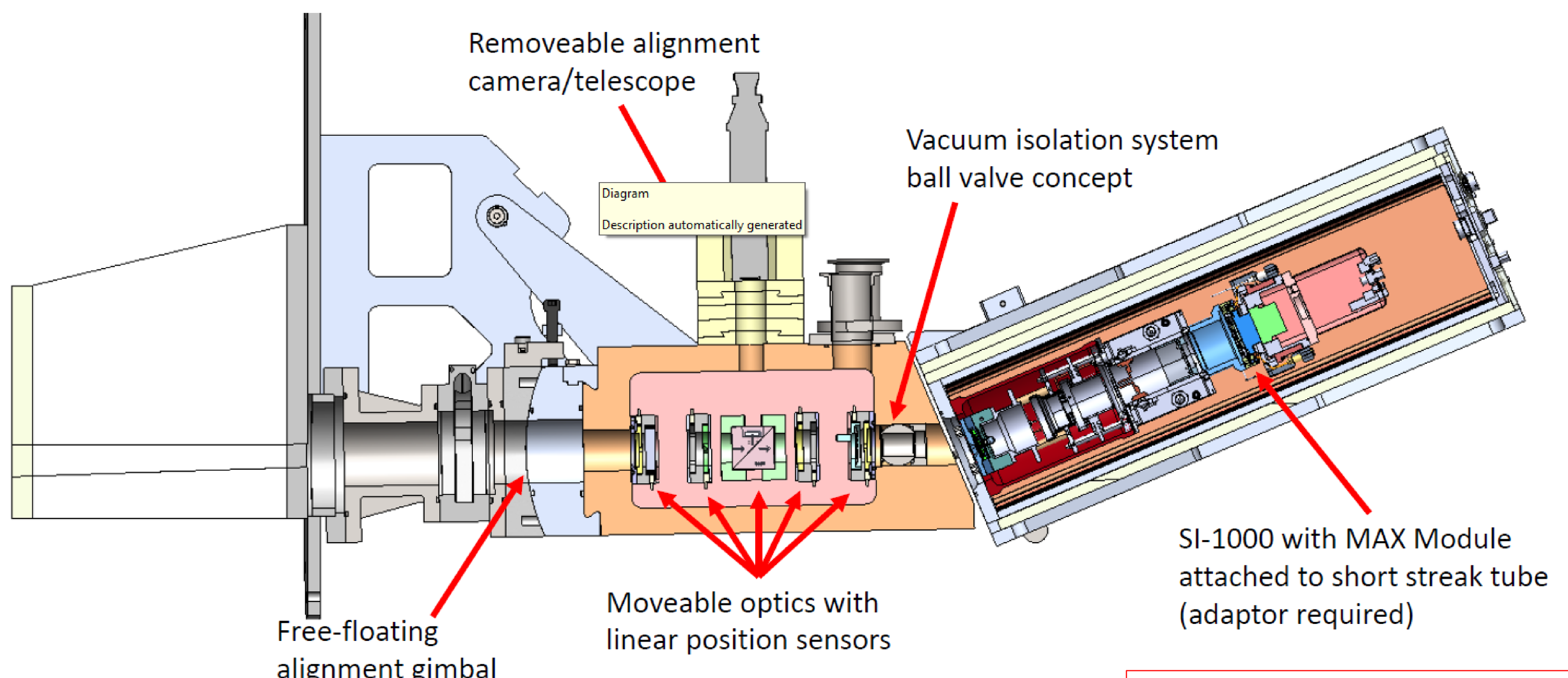
SNL and LLNL are collaborating on the development of a new X-ray streak camera for use on the Z-machine at SNL.



SCORPIONZ will build upon previous streak camera design, e.g., SPIDER and DISC on the National Ignition Facility.

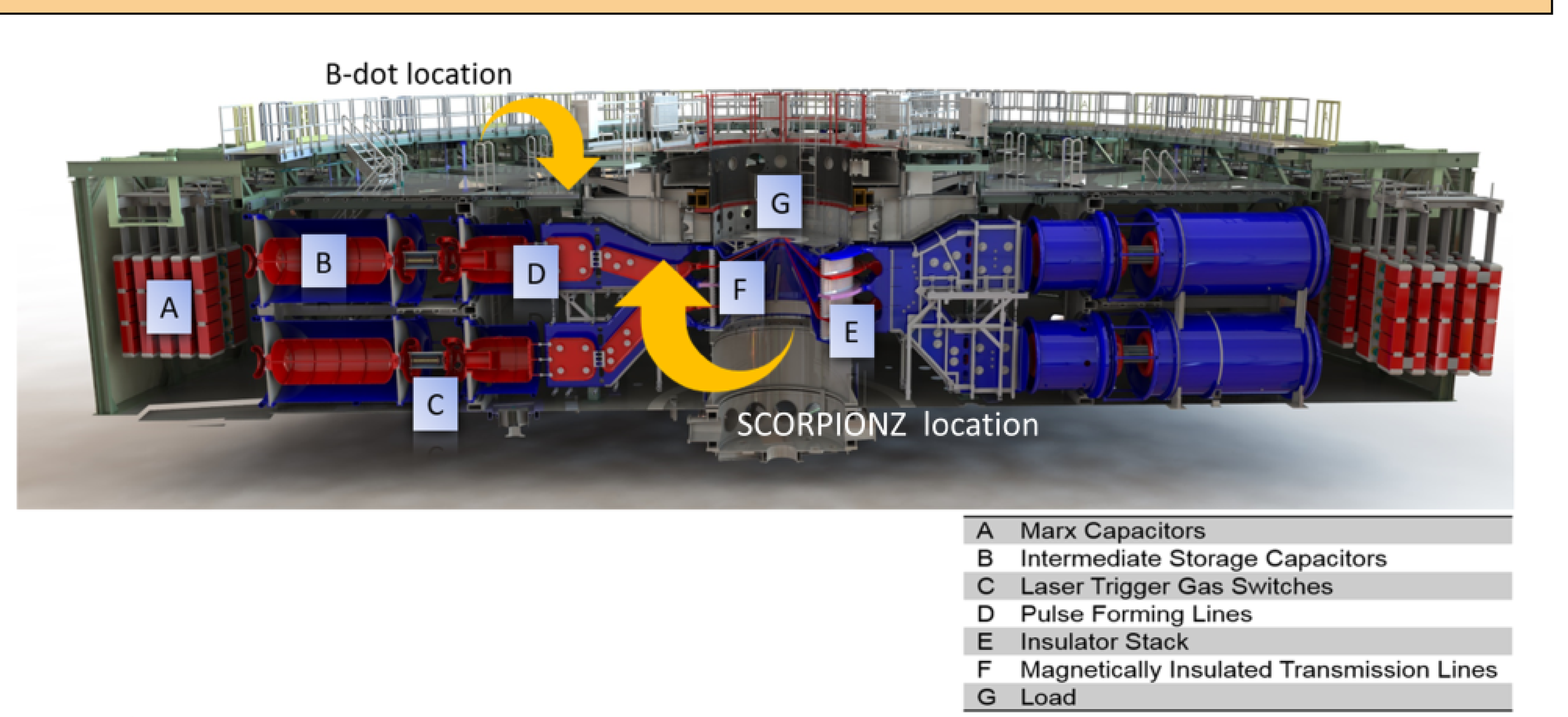
SPIDER
- Measures x-ray burn history.
- Views x-ray emission from an implosion (10keV-upper LEH).
- A version of the DISC x-ray streak camera fixed at a 7 degree viewing angle.
- Designed to run in a 5e16 neutron yield by design.

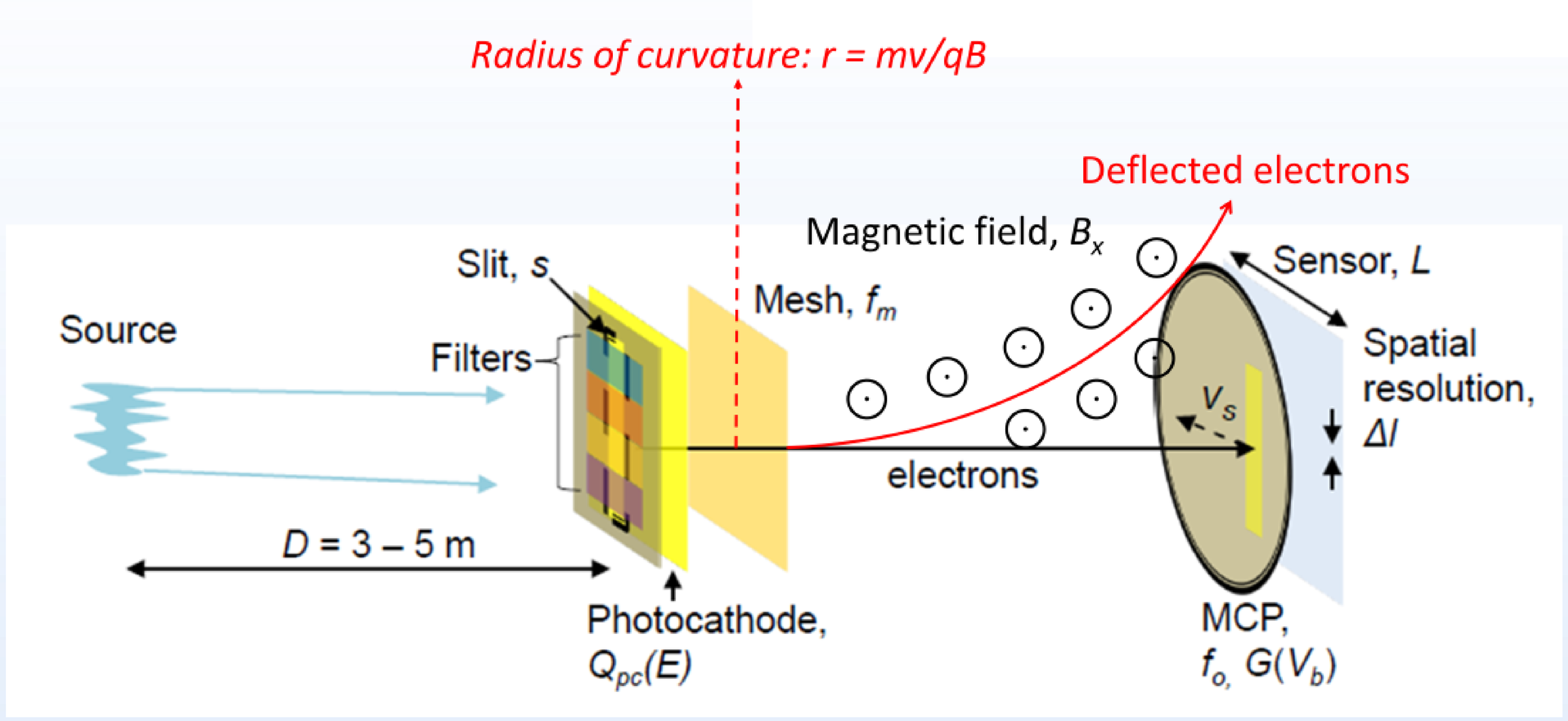
DISC
- Measures time-dependent x-ray emission from a variety of targets.
- Commonly used in experiments involving backlighting (i.e. for ignition implosion experiments, used to measure the trajectory and width of the imploding shell).

SCORPIONZ must be designed to operate in the harsh Z-Machine environment that includes significant debris, mechanical shock, and large electromagnetic impulses (EMI) that result from the > 10MA currents delivered to physics targets.

Sources of EMI on Z are a potential problem for implementing an x-ray streak camera on Z

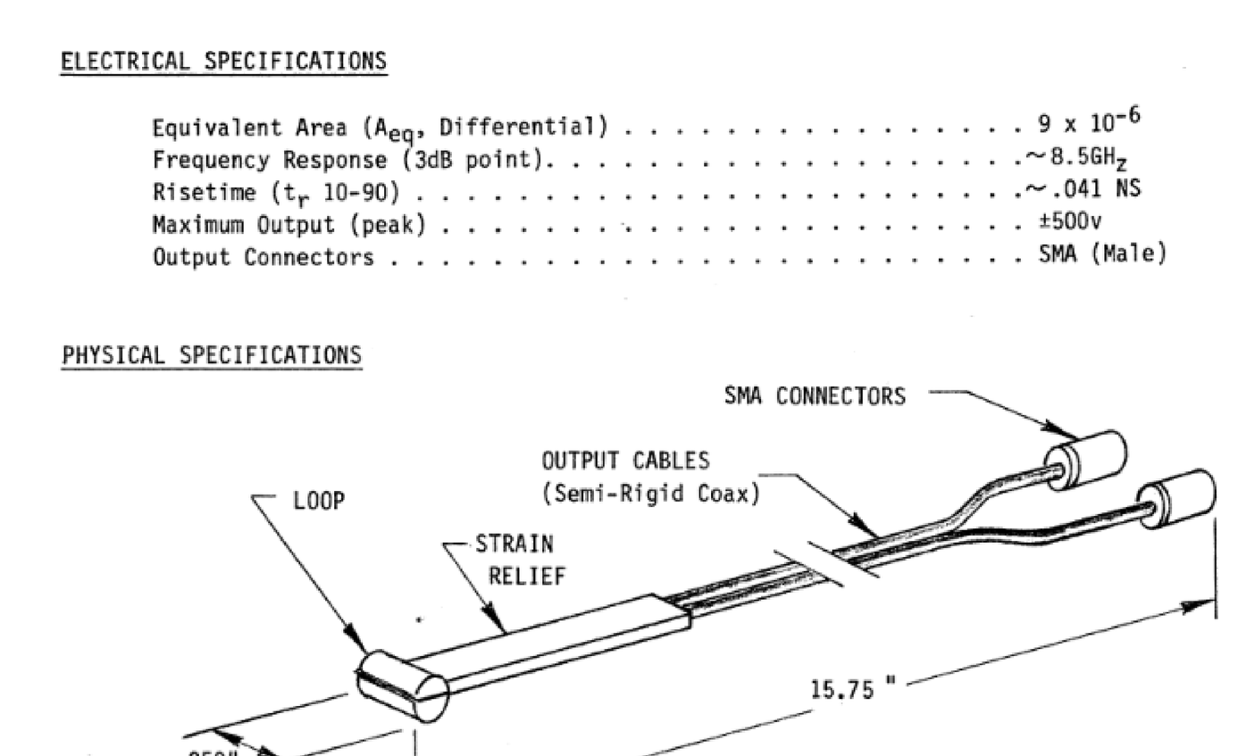
The Z-Machine Pulse forming and energy storage sections are responsible for delivering current to the target, but can simultaneously be detrimental to electron optics in streak tubes.

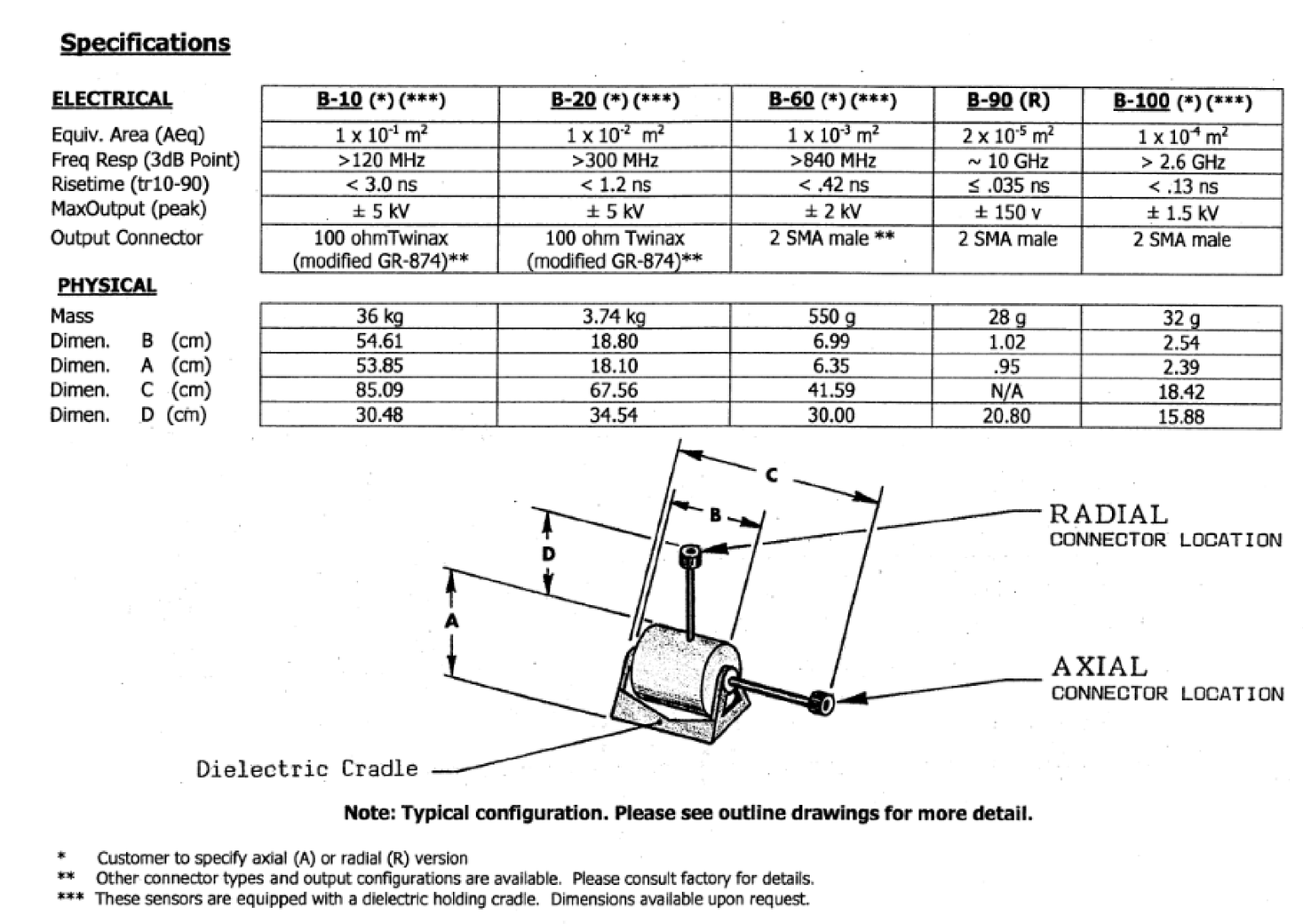




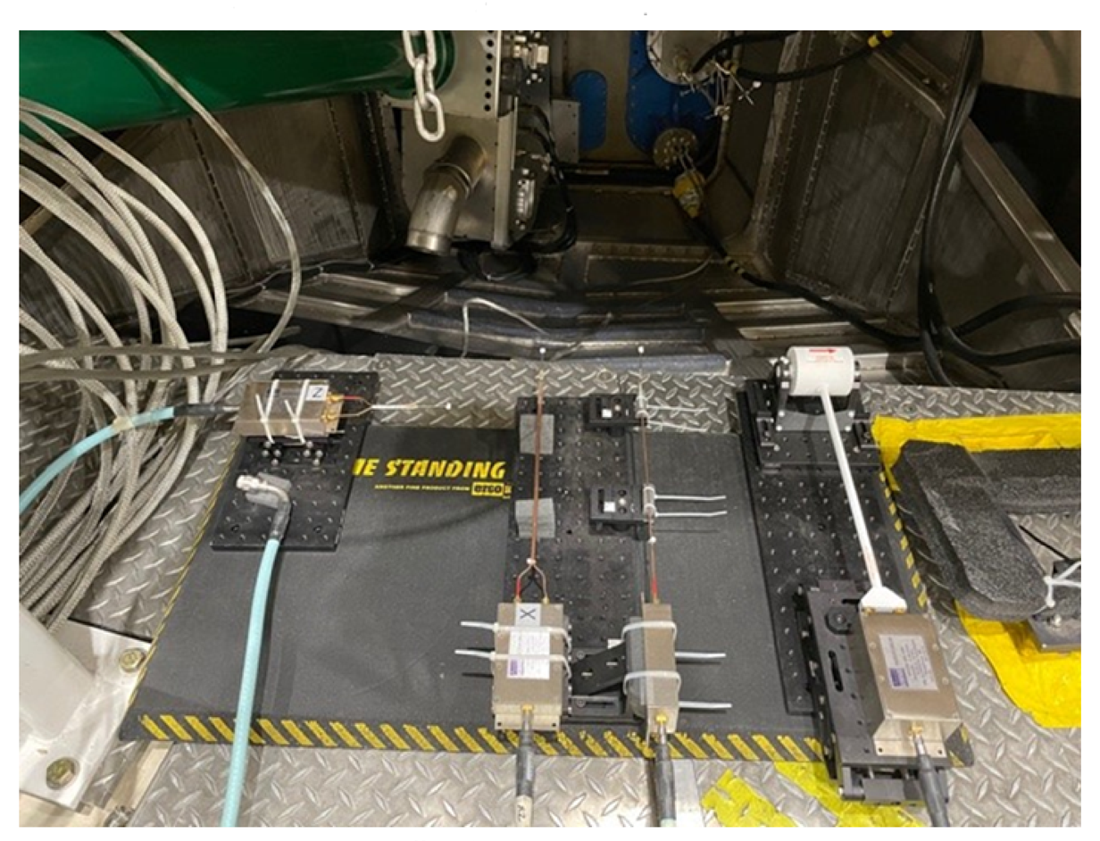
Deflections caused by the time-varying magnetic fields produced can significantly warp streak records beyond usability.

Multi-gap and free-field sensors fielded on Z to measure magnetic field near SCORPIONZ installation area

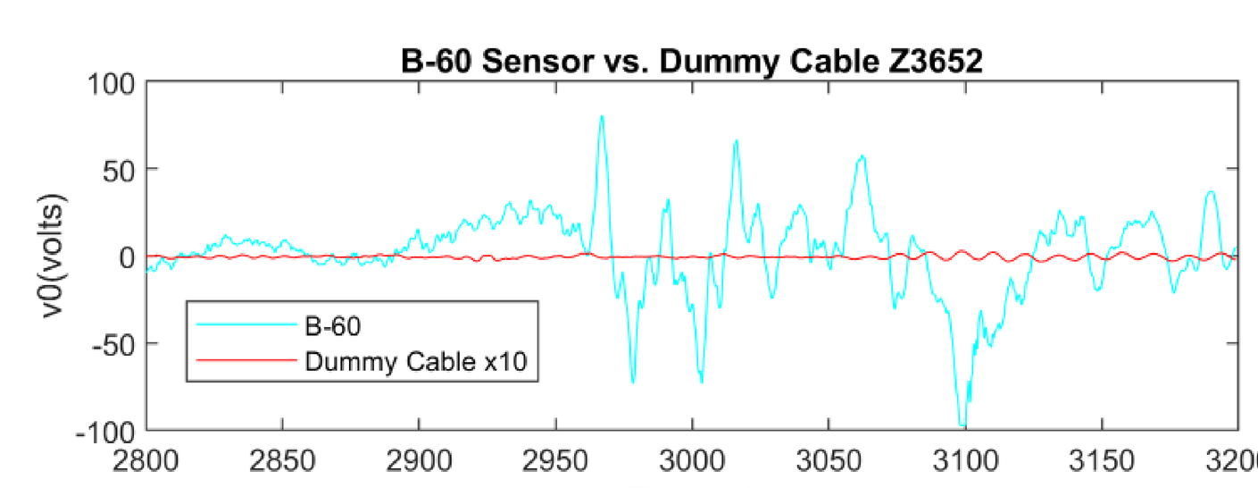


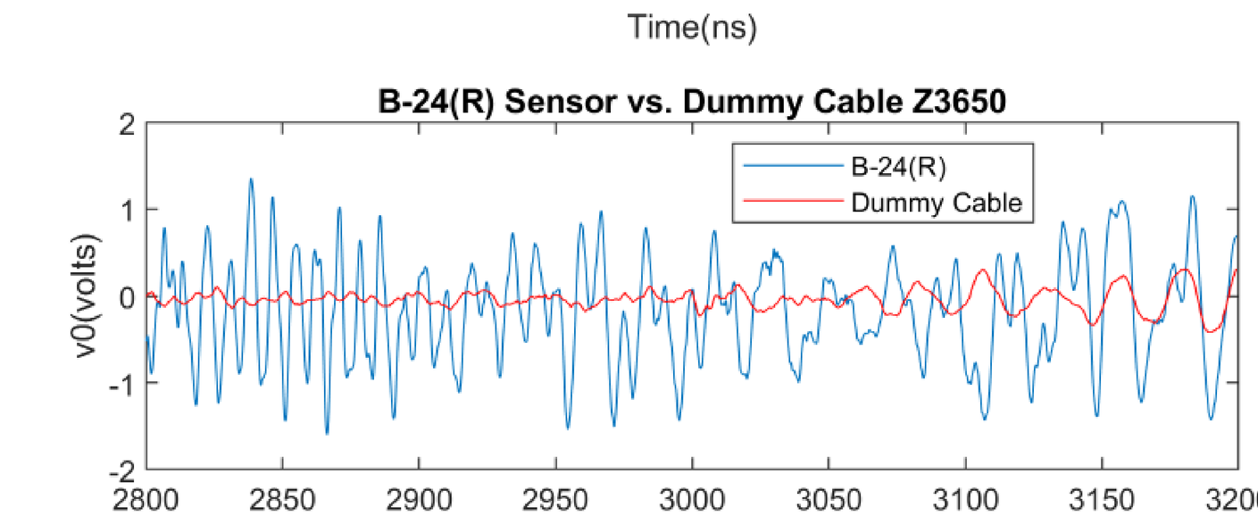


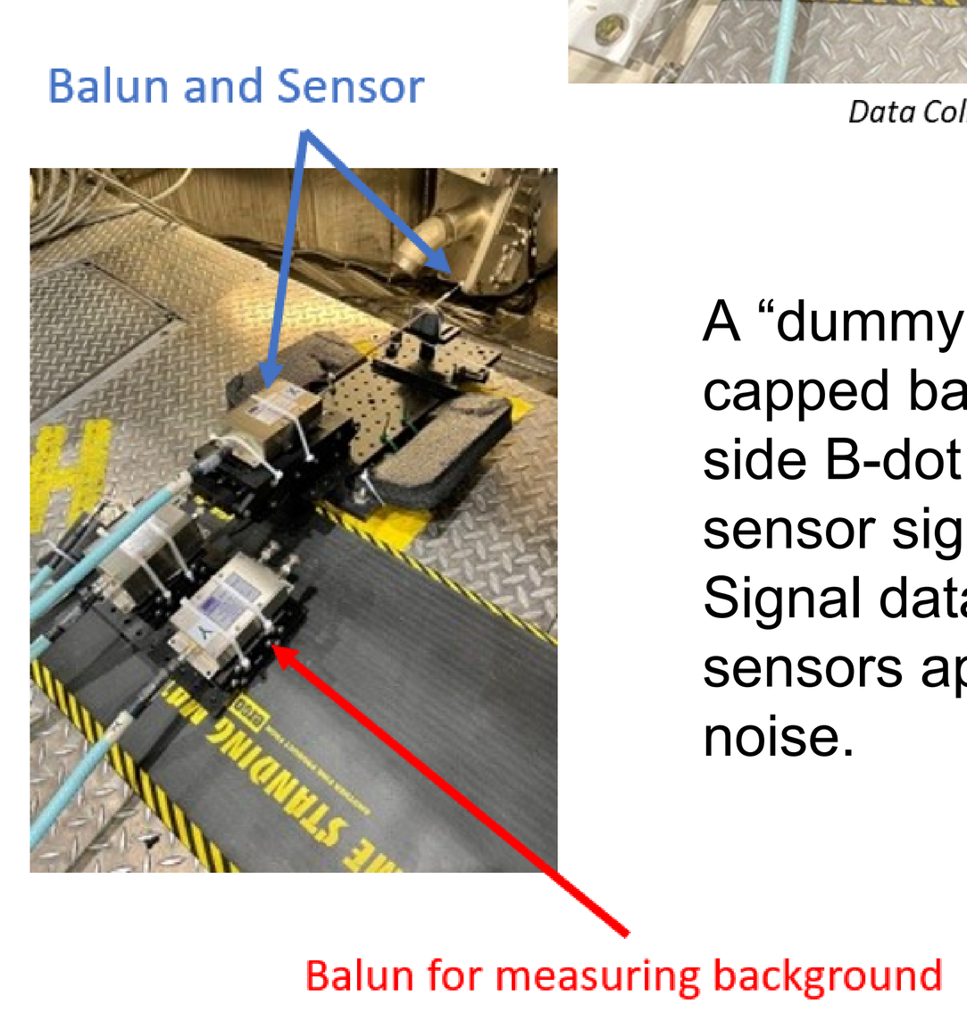
- The PRODYN B-24(R) and B-60 sensors were both fielded to look at low and high frequency interference.
- All sensors were fielded through a balun to combine and average the 2 signals of the differential sensors.
- Sensors were fielded in multiple orientations to determine field strengths along different axes.



Data Collection Set Up Z3633-Z3638

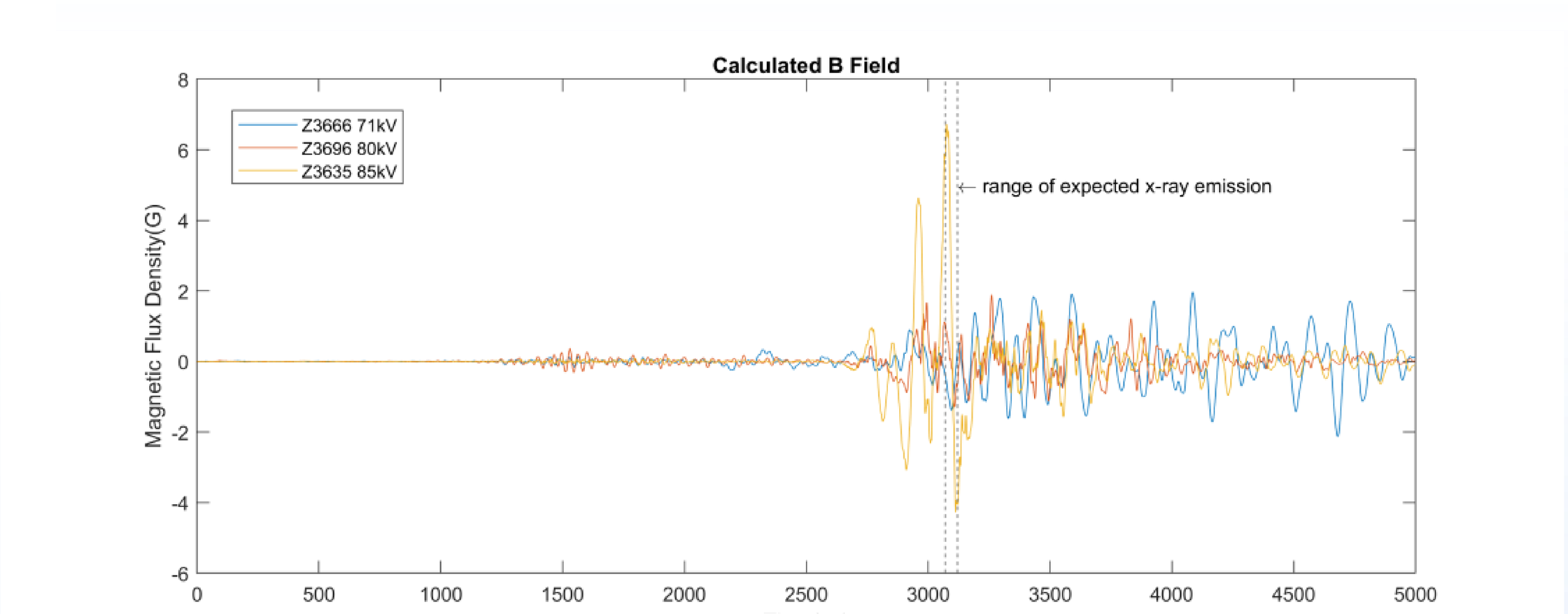






A "dummy cable" connected to a capped balun was fielded along side B-dot sensors to compare sensor signal data to noise levels. Signal data from both types of sensors appear significantly above noise.

Measured time-varying B-fields range from ~1 – 10 Gauss, and depend on Z Machine pulsed power configuration



Magnetic field is calculated from measured voltage using Lenz's law:

$$V(t) = -\frac{d\Phi}{dt} = -A\frac{dB}{dt}$$

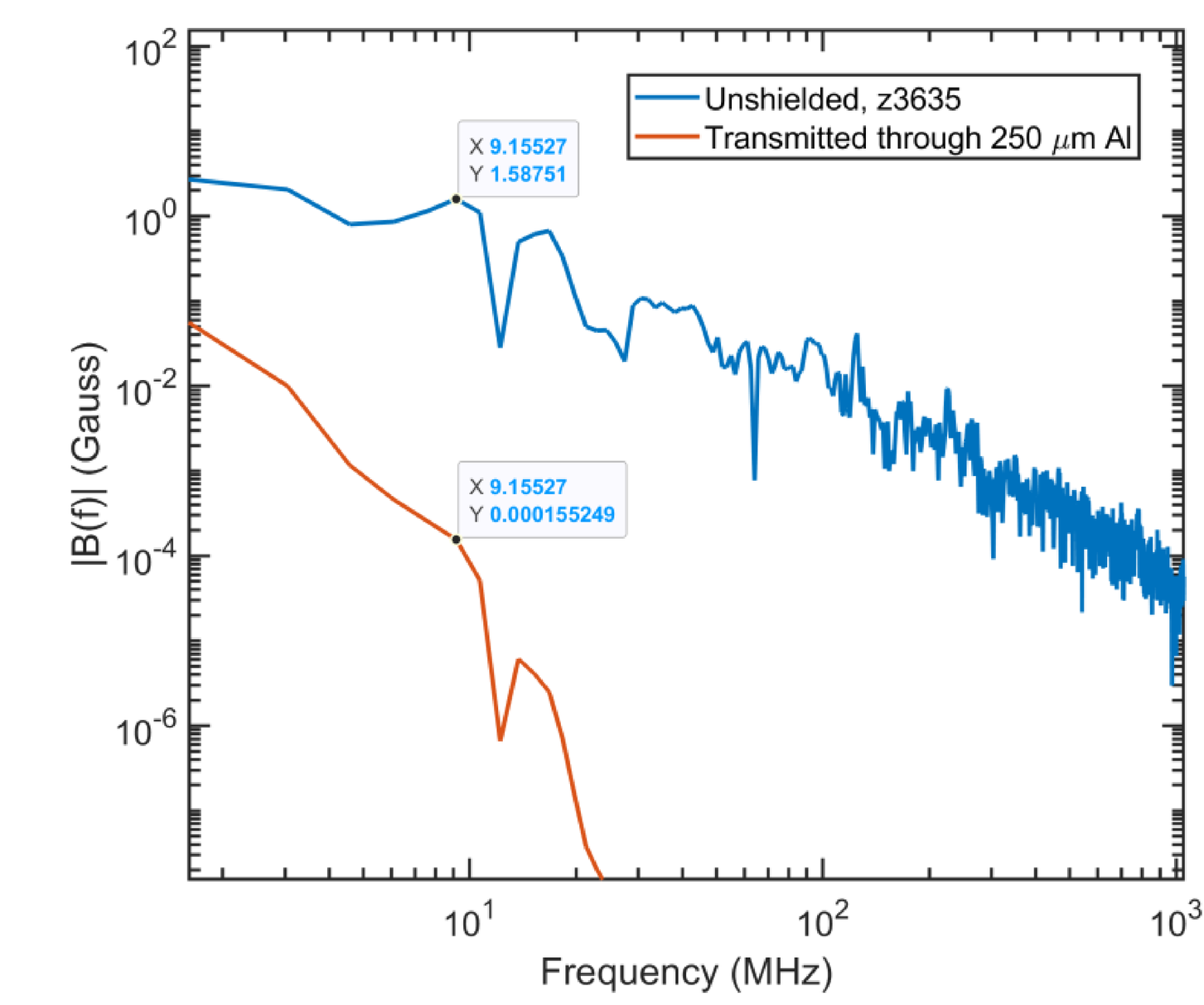
- Measured magnetic field strength increases with charge voltage
- B-fields are strongest around x-ray production time

References

1. J. R. Kimbrough el at., "National Ignition Facility core x-ray streak camera." Rev. Sci. Instrum. 72, 748 (2001)
2. D. H. Kalantar el at., "Optimizing data recording for the NIF core diagnostic x-ray streak camera." Rev. Sci. Instrum. 72, 751 (2001)
3. J.R. Kimbrough et al., "Standard design for National Ignition Facility x-ray streak and framing cameras," Rev. Sci. Instrum. 81, 10E530 (2010).
4. S.F. Khan et al., "Measuring x-ray burn history with the Streaked Polar Instrumentation for Diagnosing Energetic Radiation (SPIDER) at the National Ignition Facility," Proc. SPIE 8505 (2012).

Using EMI measurements to guide shielding strategies in new diagnostic design

By looking at B field data in frequency space we can calculate the expected electron deflections for field strengths at the most prominent frequencies in the spectrum.

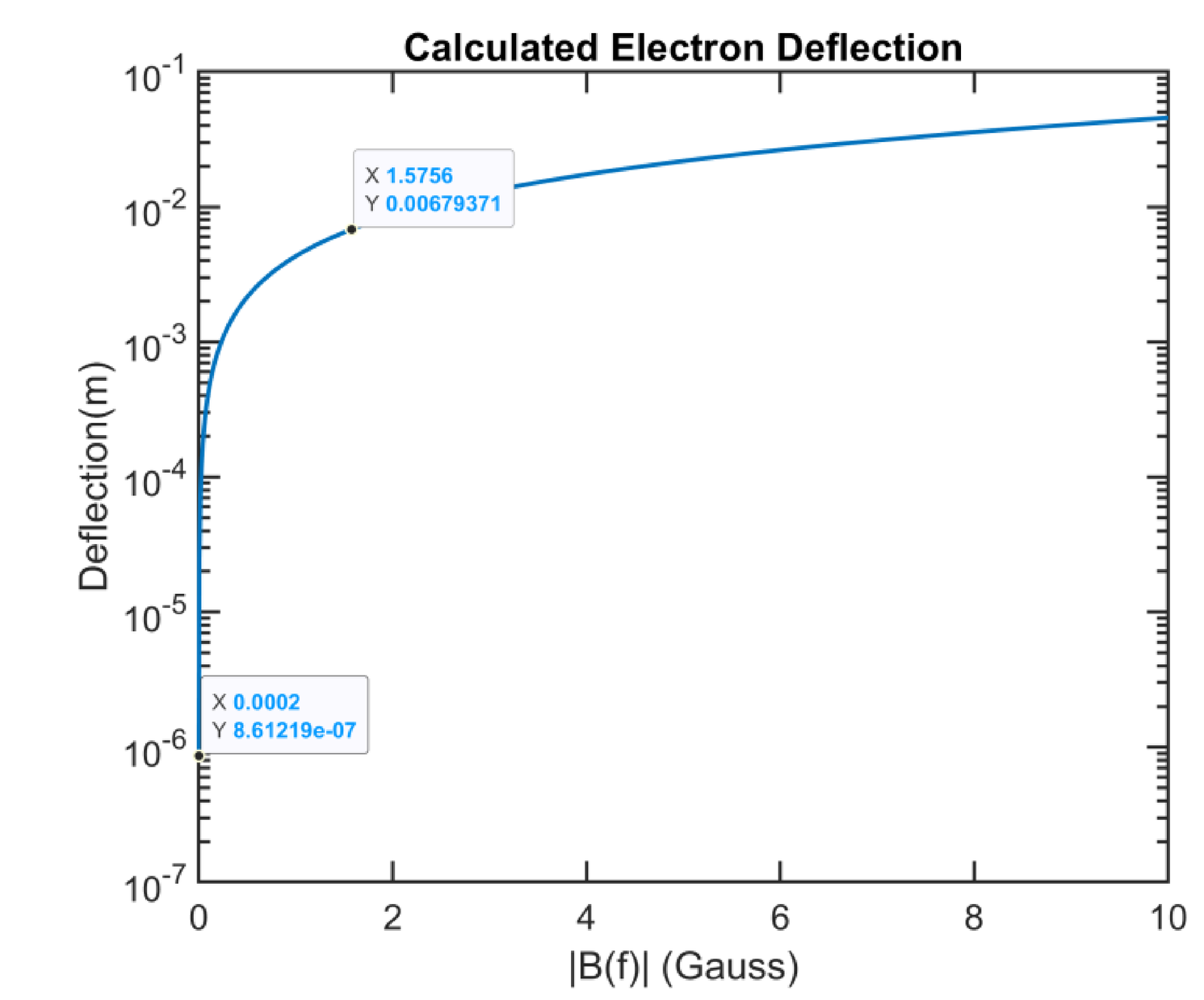


Skin depth [m]
$$\delta = \frac{1}{\alpha} = \sqrt{\frac{2\rho}{(2\pi f)(\mu_0\mu_r)}} = \frac{1}{\sqrt{\pi f \mu \sigma}} \approx 503\sqrt{\frac{\rho}{\mu_r f}} \approx 503\frac{1}{\sqrt{\mu_r f \sigma}},$$

1.000022; 2.65×10^{-8} Ωm; For Aluminum

At high frequencies the skin depth for good conductors becomes very small. The skin depths for Aluminum in the MHz range becomes a fraction of a millimeter.

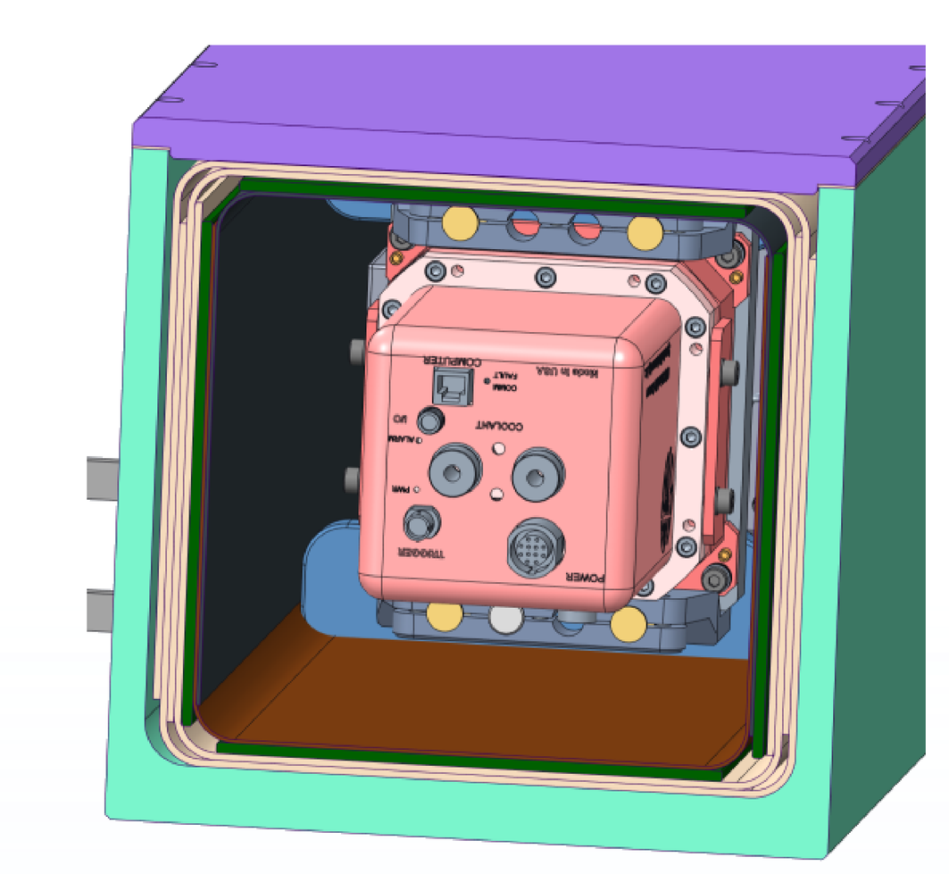
From the skin depth calculations a transmission curve can be derived. The plot above shows with the introduction of 250μm of Al the B field for a frequency of ~9MHz there is a 10,000% reduction in magnetic field.



The plot to the left shows how drastic of a reduction in electron deflection is achieved through only minimal shielding

(note) This calculation assumes a 14kV voltage accelerating electrons over a distance of 186mm between anode and MCP.

These findings have guided SCORPIONZ design. Aluminum Faraday cage (green and purple) has been shown to be more than sufficient. While Mu-Metal (red) shielding is included for lower frequency shielding although at a thinner layer due to all fields measuring < 10 Gauss.



See poster PH26 by Toby Miller

Conclusions/Future Directions

- It was important to first develop measurement techniques to determine the strength of magnetic fields created in the Z diagnostic boats. From these measurements the following resulted:
  - A data set across a multitude of Z shots of different target loads, pulsed power configurations, and shot charge voltages.
  - An initial understanding of the sources of magnetic fields observed.
  - Data collection that will continue to guide future EMI sensitive Z diagnostic design.
- From the data collected it has been possible to quantitatively demonstrate that for higher frequency B fields (in the MHz-GHz range) the addition of aluminum shielding will be sufficient to reduce EMI to a level that won't warp streak records SCORPIONZ when fielded on Z experiments.

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