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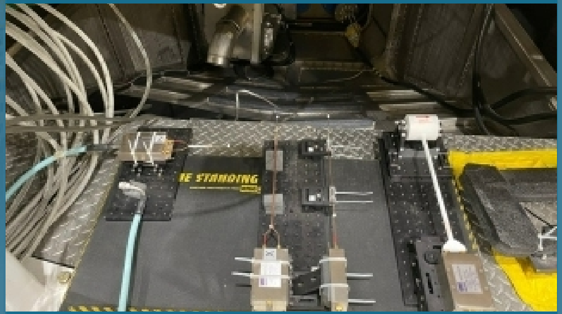
Sandia National Laboratories

Overview and status of EMI Measurement and Characterization on the Z-Machine [PH21]



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U.S. DEPARTMENT OF ENERGY NNSA

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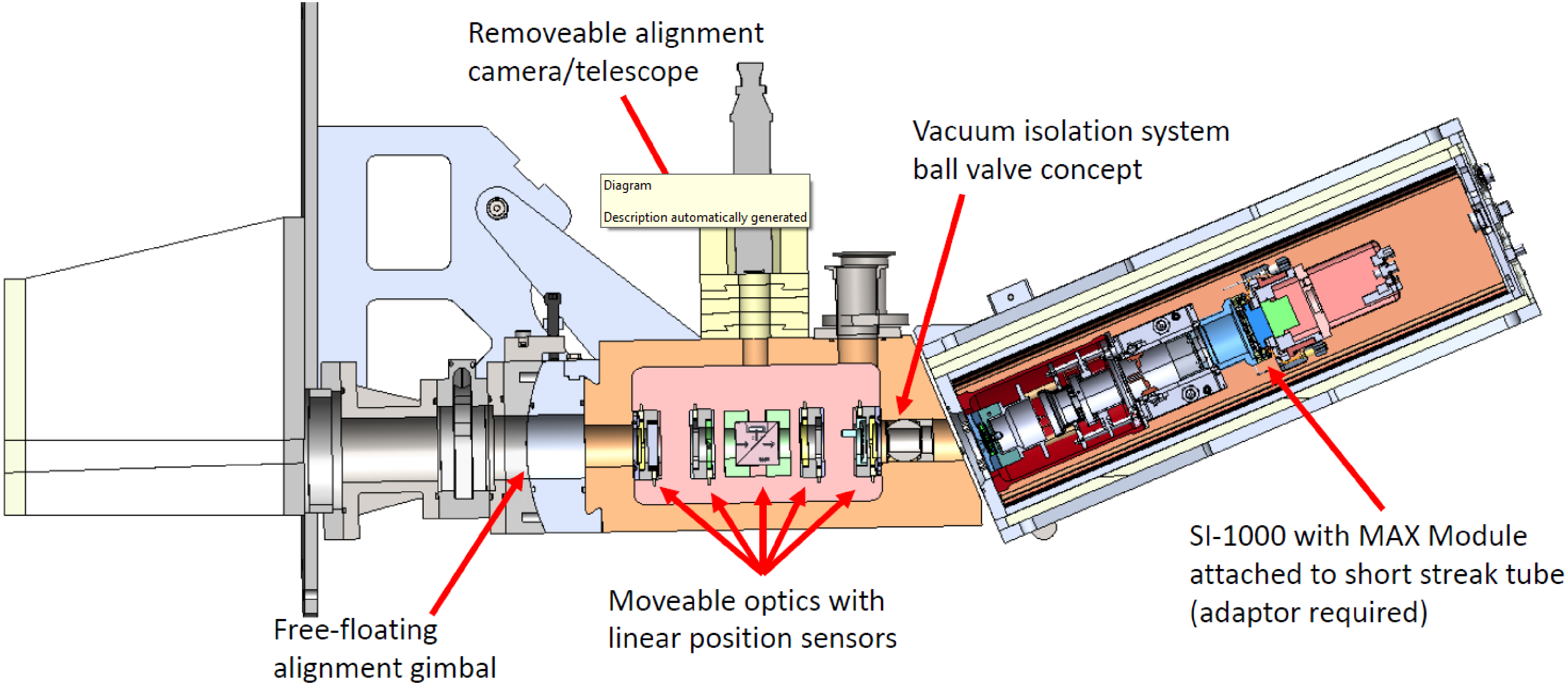
The Streak Camera Observatory with Radial and Polar Implementation on Z (SCORPIONZ)



The Streak Camera Observatory with Radial and Polar Implementation on Z (SCORPIONZ)

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.[4]

DISC

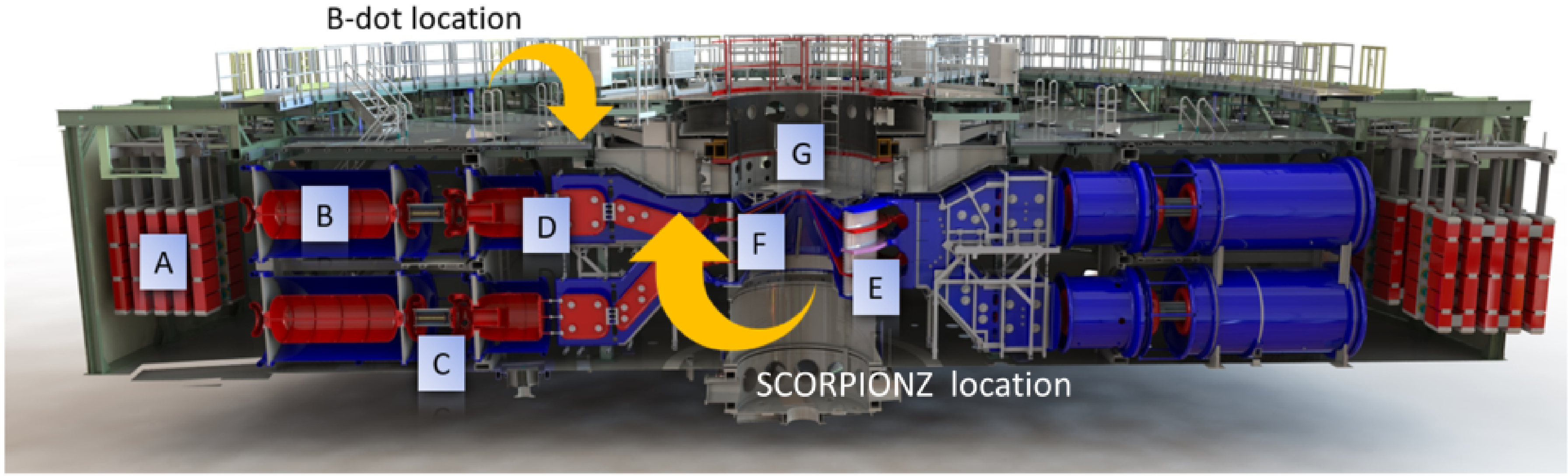
- Measures time-dependent x-ray emission from a variety of targets.
- Commonly used in experiments involving backlighting (i.e. for ignition implosion experiments, used to measure the trajectory and width of the imploding shell).[1,2,3]

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).

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

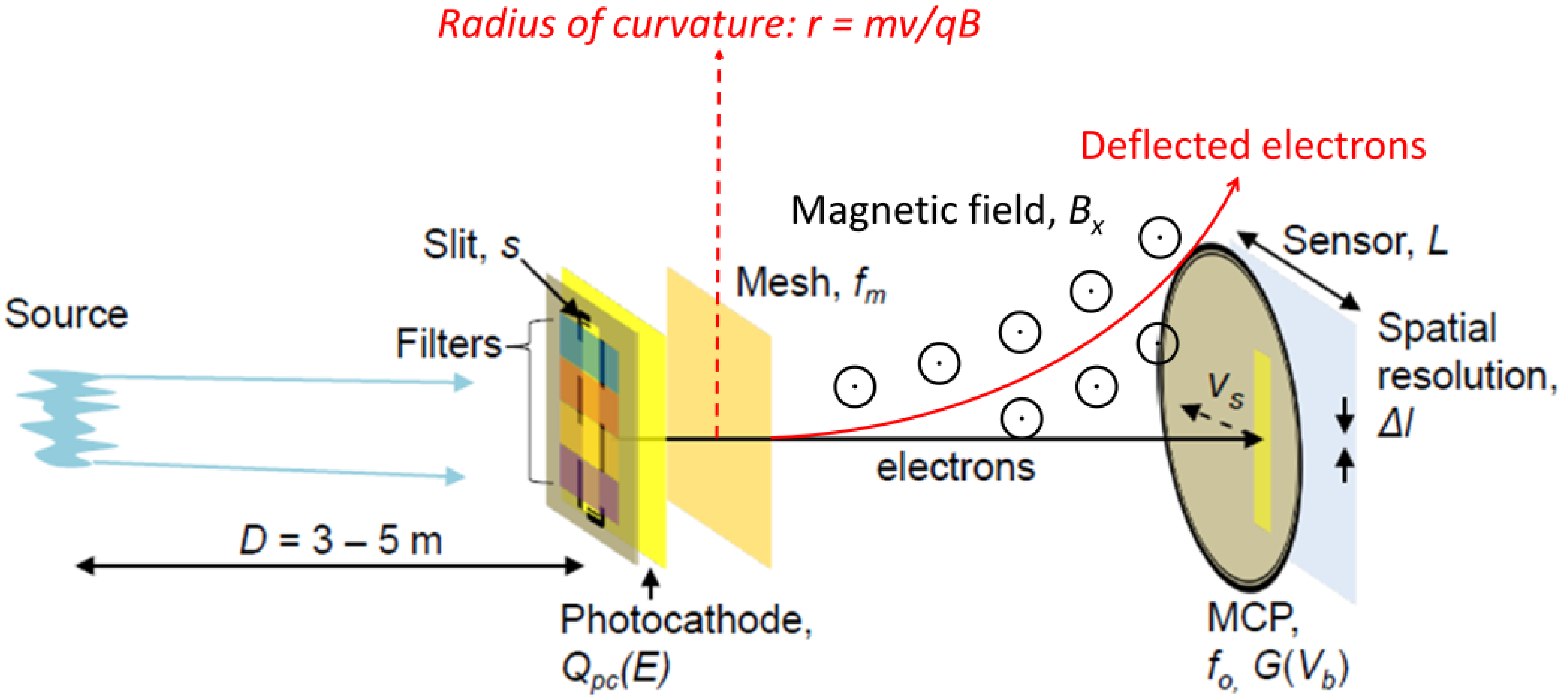
SCORPIONZ must be designed to operate in the harsh Z-Machine environment that includes significant debris, mechanical shock, and large electromagnetic impulses (EMI) that result from the > 10MA currents delivered to physics targets

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.



A	Marx Capacitors
B	Intermediate Storage Capacitors
C	Laser Trigger Gas Switches
D	Pulse Forming Lines
E	Insulator Stack
F	Magnetically Insulated Transmission Lines
G	Load

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



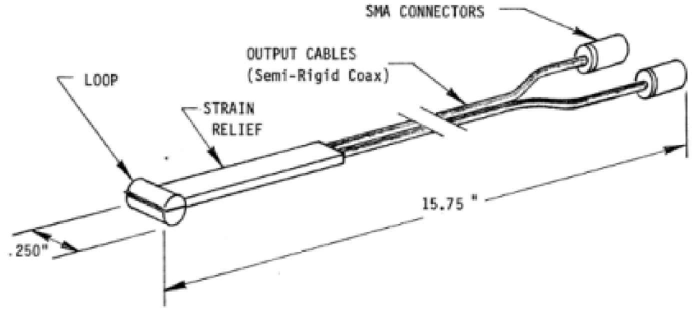
Deflections caused by the time-varying magnetic fields produced can significantly warp streak records beyond usability.

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

ELECTRICAL SPECIFICATIONS

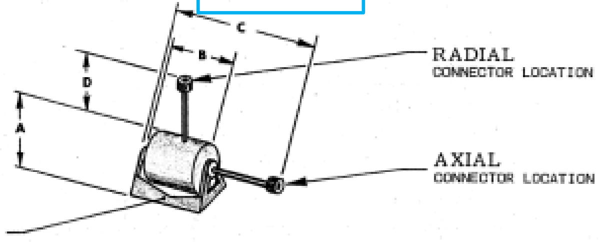
Equivalent Area (A_{eq}, Differential) . . . . 9 x 10^{-6}
Frequency Response (3dB point). . . . .~8.5GH$_z$
Risetime (t_r, 10-90) . . . .~.041 NS
Maximum Output (peak) . . . . ±500v
Output Connectors . . . . SMA (Male)

PHYSICAL SPECIFICATIONS



Specifications

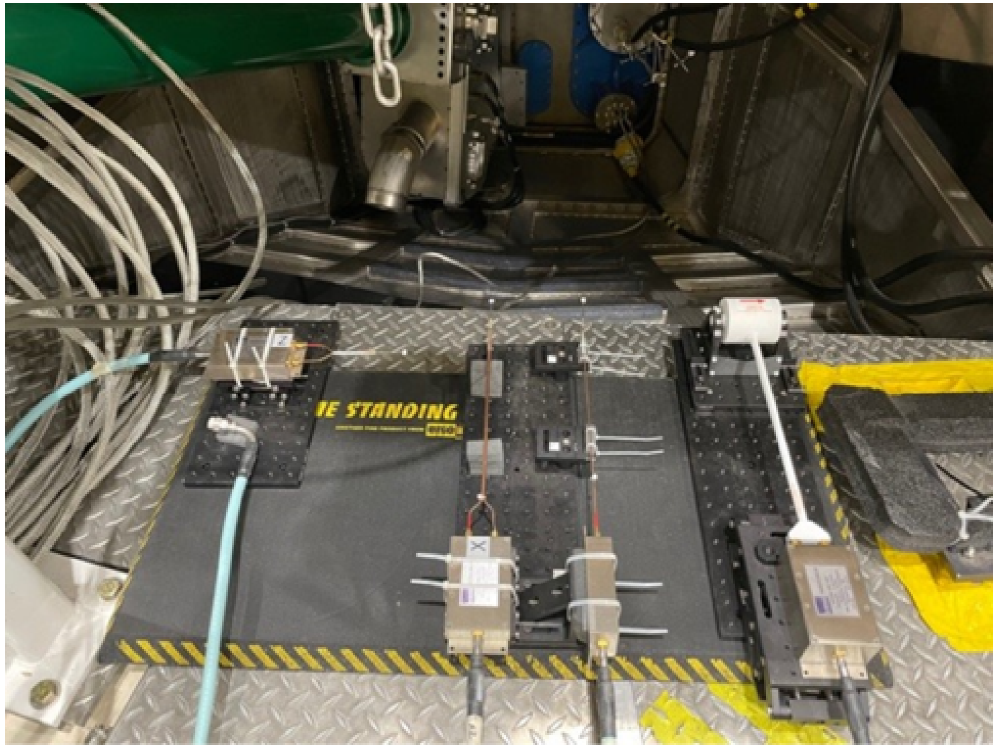
ELECTRICAL	B-10 (*) (***)	B-20 (*) (***)	B-60 (*) (***)	B-90 (R)	B-100 (*) (***)
Equiv. Area (Aeq)	1 x 10^{-1} m²	1 x 10^{-2} m²	1 x 10^{-3} m²	2 x 10^{-5} m²	1 x 10^{-4} m²
Freq Resp (3dB Point)	>120 MHz	>300 MHz	>840 MHz	~ 10 GHz	> 2.6 GHz
Risetime (tr10-90)	< 3.0 ns	< 1.2 ns	< .42 ns	≤ .035 ns	< .13 ns
MaxOutput (peak)	± 5 kV	± 5 kV	± 2 kV	± 150 v	± 1.5 kV
Output Connector	100 ohmTwinax (modified GR-874)**	100 ohm Twinax (modified GR-874)**	2 SMA male **	2 SMA male	2 SMA male
PHYSICAL					
Mass	36 kg	3.74 kg	550 g	28 g	32 g
Dimen. B (cm)	54.61	18.80	6.99	1.02	2.54
Dimen. A (cm)	53.85	18.10	6.35	.95	2.39
Dimen. C (cm)	85.09	67.56	41.59	N/A	18.42
Dimen. D (cm)	30.48	34.54	30.00	20.80	15.88



Note: Typical configuration. Please see outline drawings for more detail.

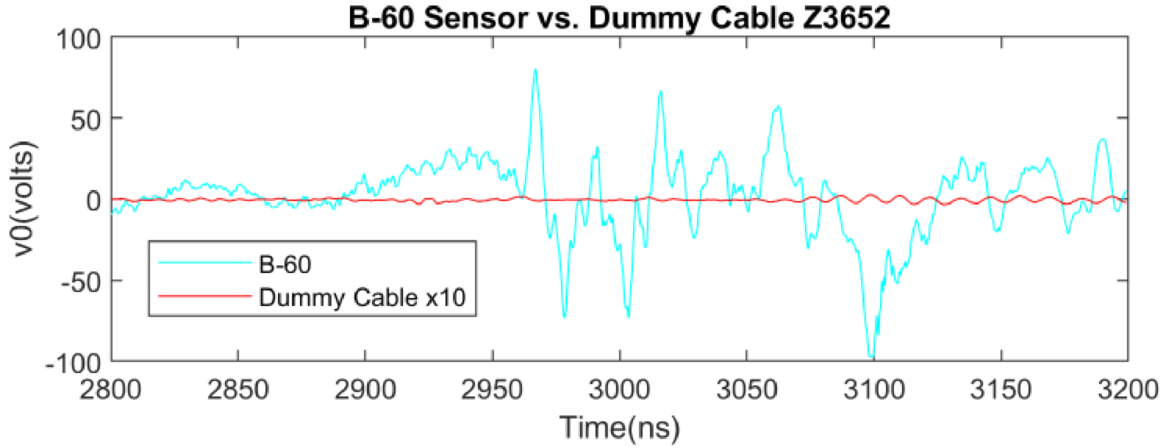
* Customer to specify axial (A) or radial (R) version
** Other connector types and output configurations are available. Please consult factory for details.
*** These sensors are equipped with a dielectric holding cradle. Dimensions available upon request.

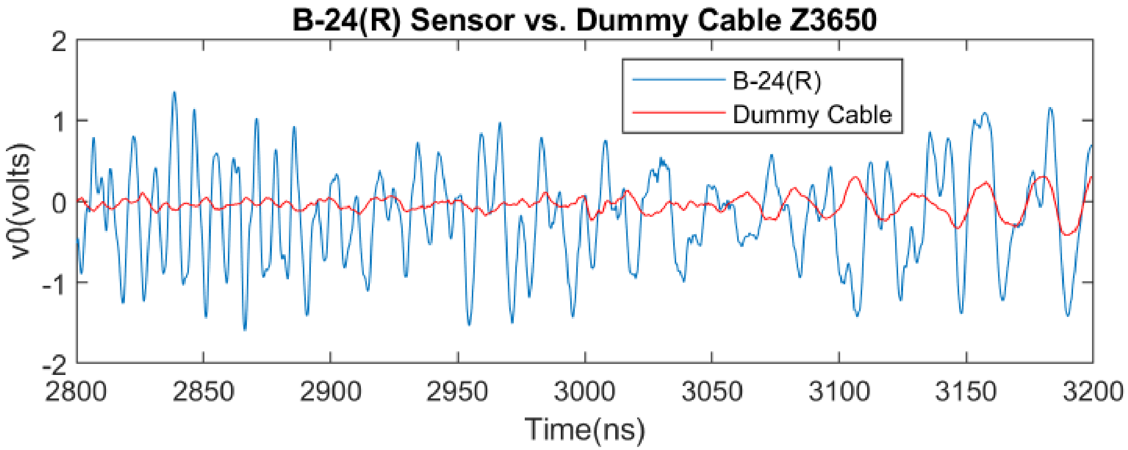
- The PRODYN B-24(R) and B-60 sensors were both fielded to look at low and high frequency interference.
- All sensors were fielded through a balun to combine and average the 2 signals of the differential sensors.
- Sensors were fielded in multiple orientations to determine field strengths along different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



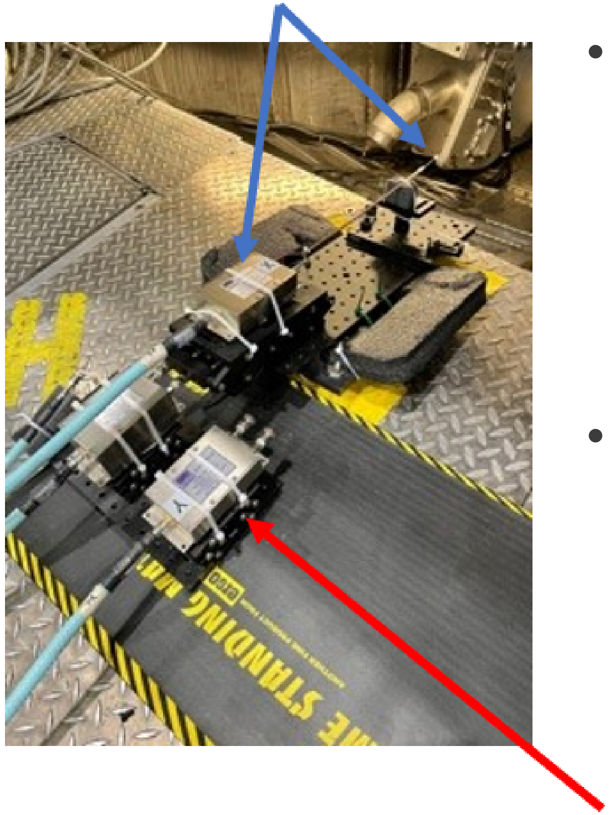
Data Collection Set Up Z3633-Z3638

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





Balun and Sensor



Balun for measuring background

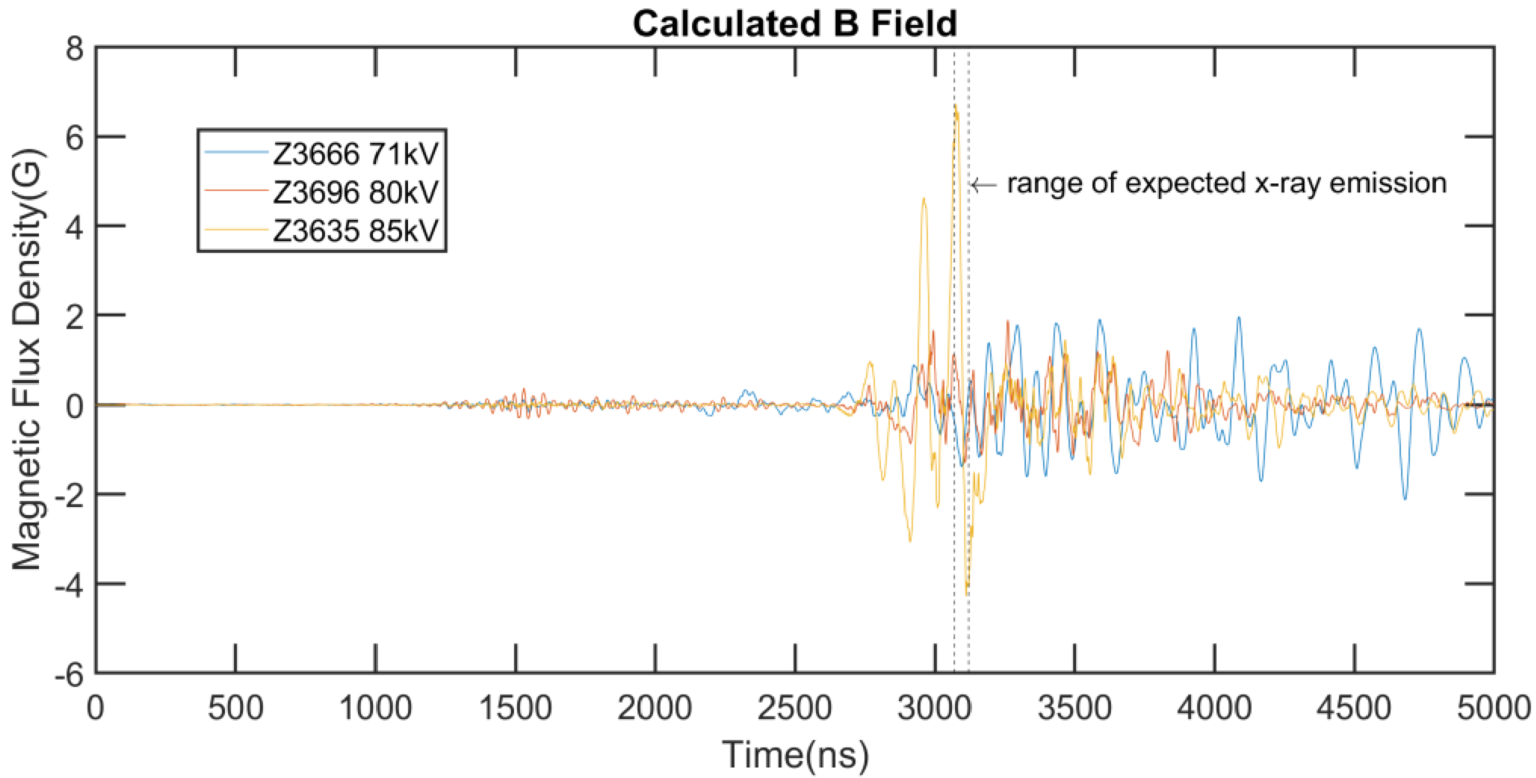
- A “dummy cable” connected to a capped balun was fielded along side B-dot sensors to compare sensor signal data to noise levels.
- Signal data from both types of sensors appear significantly above noise.

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:

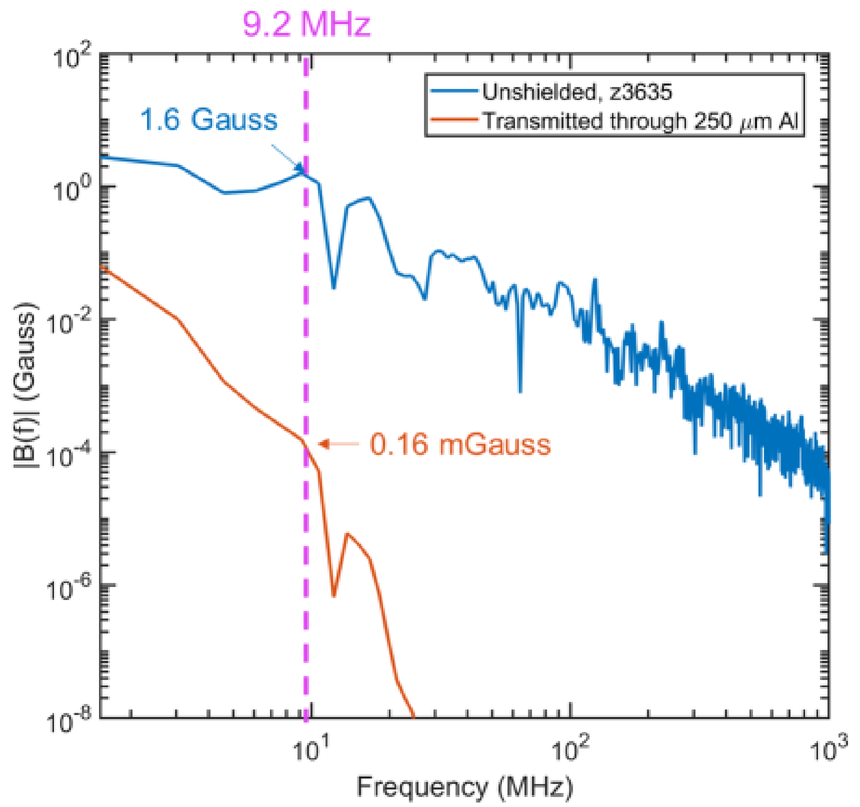
$$V(t) = -\frac{d\Phi}{dt} = -A\frac{dB}{dt}$$

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



Using EMI measurements to guide shielding strategies in new diagnostic design

We can calculate the expected electron deflections for field strengths at the most prominent frequencies in the magnetic-field spectrum.



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

μ_r: 1.000022

ρ: 2.65 x 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.

Skin depth is used to calculate the transmission of the B-fields through the aluminum layer. The plot above shows that 250μm of Al can reduce the B-field by a factor of 104 at a frequency of ~9MHz.

Using EMI measurements to guide shielding strategies in new diagnostic design

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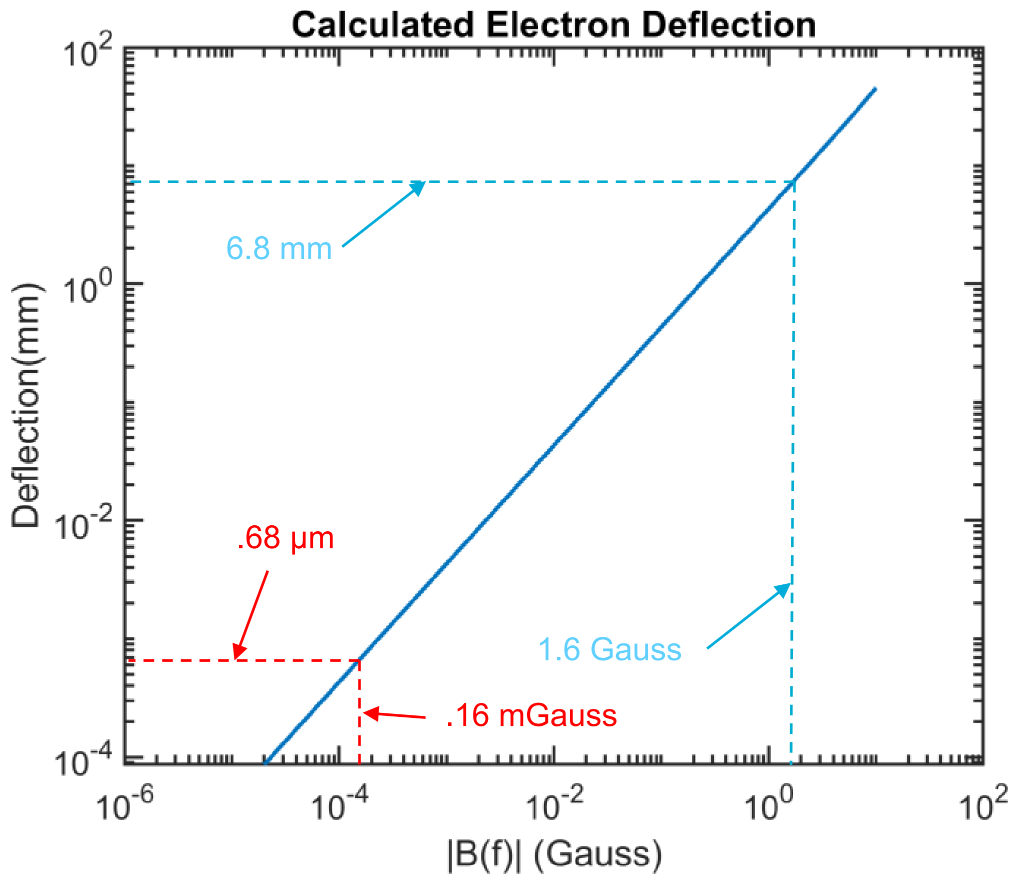
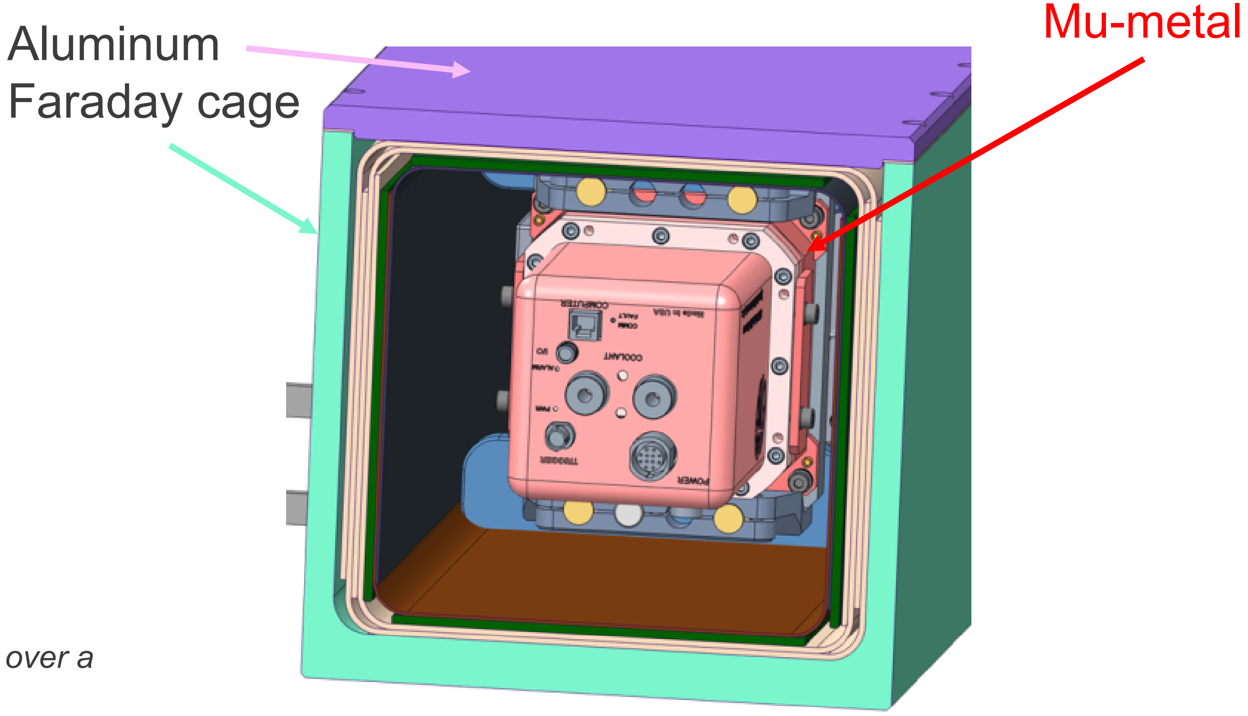


(note) This calculation assumes a 14kV voltage accelerating electrons over a distance of 186mm between anode and microchannel plate.

These findings have guided SCORPIONZ shielding design. Aluminum Faraday cage has been shown to be more than sufficient.

Rear of streak camera



Conclusions

- Successful fielding of the SCORPIONZ x-ray streak camera on Z required validation of proposed EMI shielding designs for the sensitive electron optics
- B-field measurements were taken with B-dot probes in SCORPIONZ fielding locations across a multitude of Z shots of different target loads, pulsed power configurations, and shot charge voltages.
- EMI measurements help confirm that the SCORPIONZ electron optics will be adequately shielded from time-varying magnetic fields in the MHz-GHz range
- These types of measurements will continue to guide design of future EMI-sensitive diagnostics on Z