

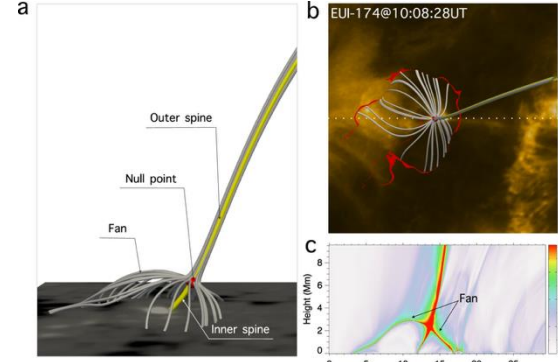
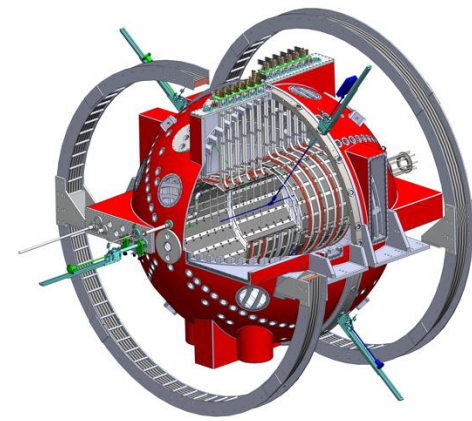
The Effects of Magnetic Pressure and Tension in Null Points Dynamics in TREX Experiment

Xinyu Yu, J. Egedal, C. Kuchta, P. Gradney, J. Schroeder, J. Olson & C.B. Forest

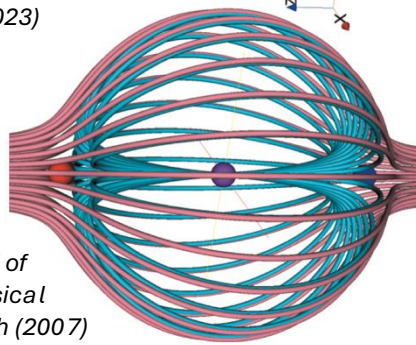
Department of Physics, University of Wisconsin - Madison



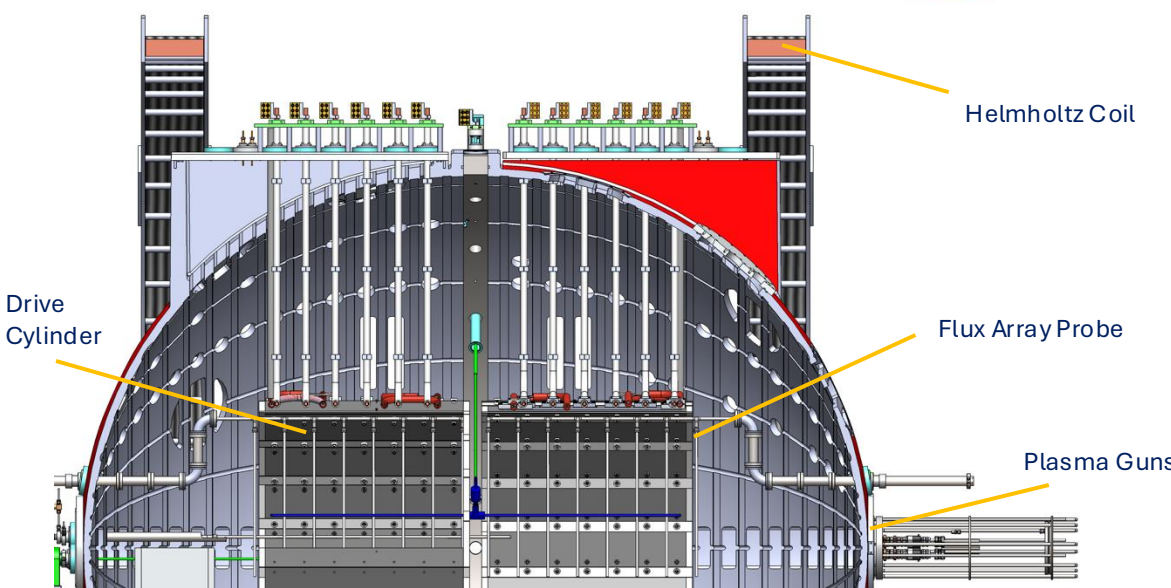
Null points [1] are created using both the **3-Coil TREX** [2] and the **TREX (The Terrestrial Reconnection Experiment) Drive Cylinder**, a thirteen-coil cylindrical magnetic field driver, housed within the Big Red Ball (BRB) [3] at the **University of Wisconsin-Madison**. Collisionless magnetic reconnection is driven in TREX Drive Cylinder [3]. As the reconnection layer advances toward the center, magnetic null points emerge. These **null points** are then driven apart by **magnetic pressure** and **tension forces**. B-dot probes and a Te Langmuir probe were used for collecting **magnetic field**, **electron temperature**, and **plasma density data**.



Cheng. Nature Commun (2023)

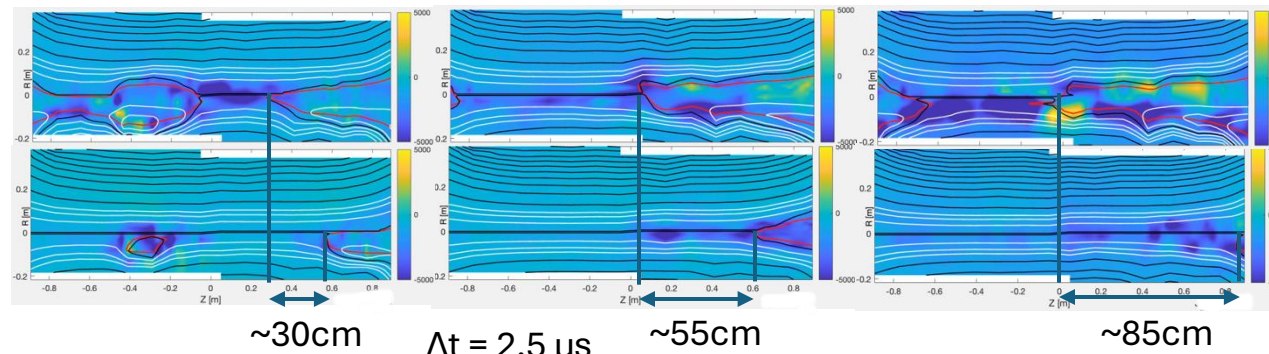


Dorelli. J of Geophysical Research (2007)



Magnetic Null Points Move Faster at Higher Drive after Reconnection in Drive Cylinder

In the Drive Cylinder experiment, the harder the drive field is driven, the faster the null points are pushed to side. By having the same background field $B_{HH} = 50G$, $I_{CT} = 6kV$ drives **120 km/s**, **7kV** drives **220 km/s**, **8kV** drives **340 km/s**.



Magnetic Pressure & Magnetic Tension Drives Nulls

Why cone shape?

- Flux contour
- Plasma follow this cone
- Pressure P is zero
- Cylindrical symmetry

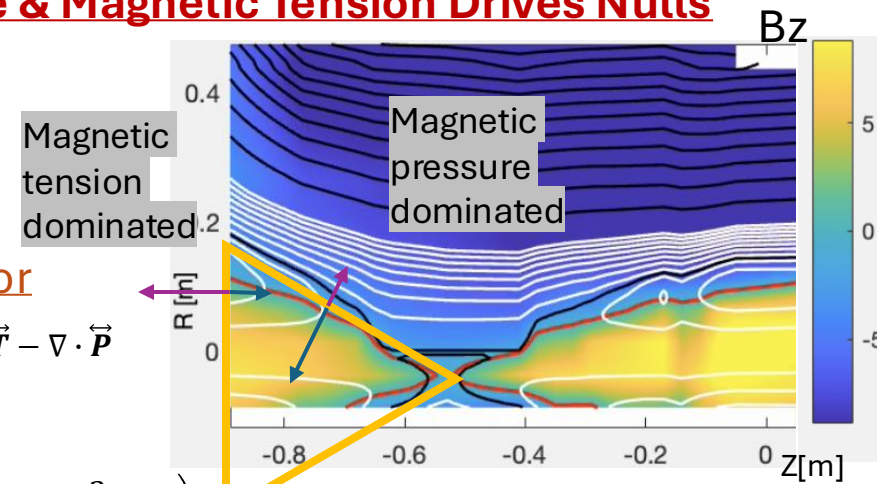
Maxwell Stress Tensor

$$m_i n \frac{d}{dt} \mathbf{v} = \mathbf{J} \times \mathbf{B} - \nabla \cdot \mathbf{P} = \nabla \cdot \mathbf{T} - \nabla \cdot \mathbf{P}$$

$$\mathbf{T} = -\frac{B^2}{2\mu_0} \mathbf{I} + \frac{B^2}{\mu_0} \hat{\mathbf{b}}\hat{\mathbf{b}}$$

$$\mathbf{T} = \frac{B^2}{2\mu_0} \begin{pmatrix} -1 + 2rr & 2r\phi & 2rz \\ 2\phi r & -1 + 2\phi\phi & 2\phi z \\ 2zr & 2z\phi & -1 + 2zz \end{pmatrix}$$

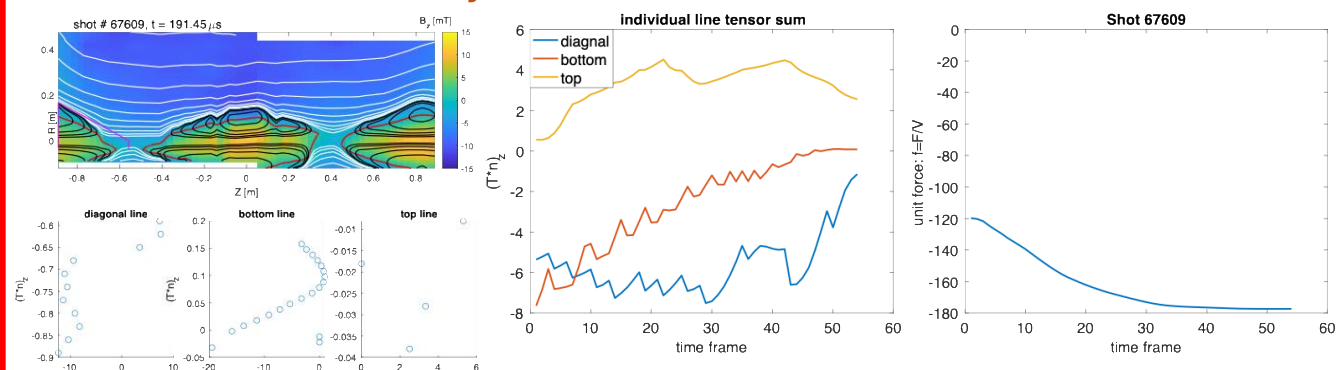
$$\mathbf{F} = \iiint \nabla \cdot \mathbf{T} dx^3 = \iint \mathbf{T} \cdot \hat{\mathbf{n}} da$$



Diagonal surface: magnetic pressure > magnetic tension
Bottom surface: magnetic pressure < magnetic tension
By integrating over, only F_z leaves for both surfaces.

Maxwell stress tensor analysis of a cone shape

flux surface in Drive Cylinder

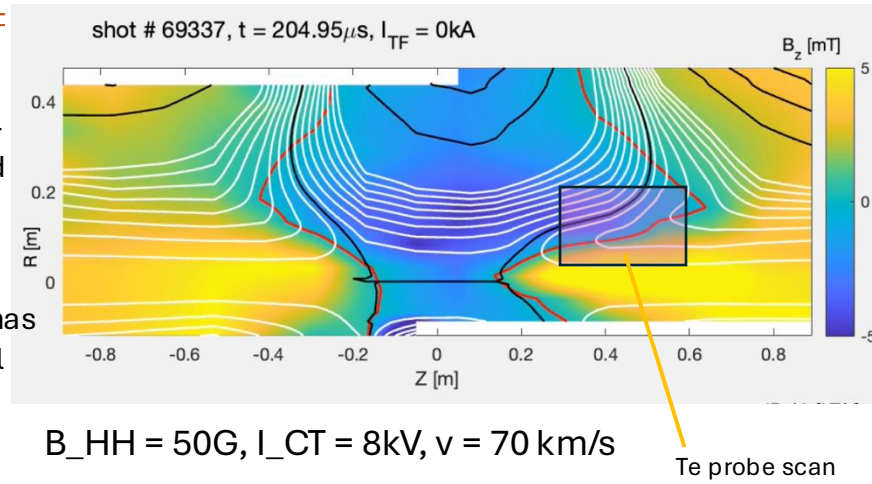


The total force from magnetic pressure and magnetic tension rises by time. Negative values means the direction of force is towards $-Z$.

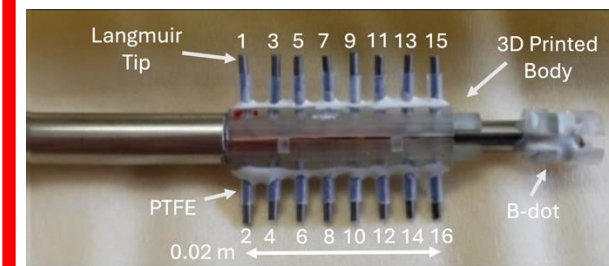
3-Coil TREX Deforms the Magnetic Structure of Nulls

What's the difference of 3-Coil compared to Drive Cylinder?

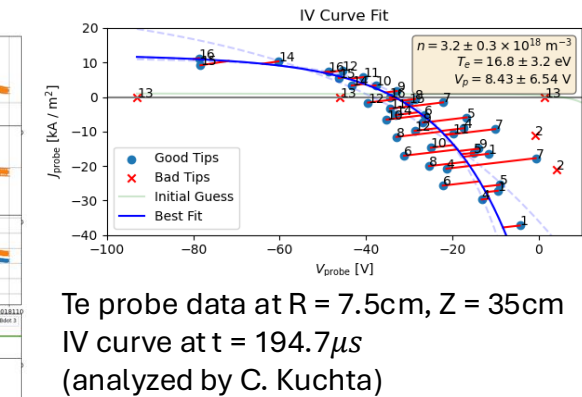
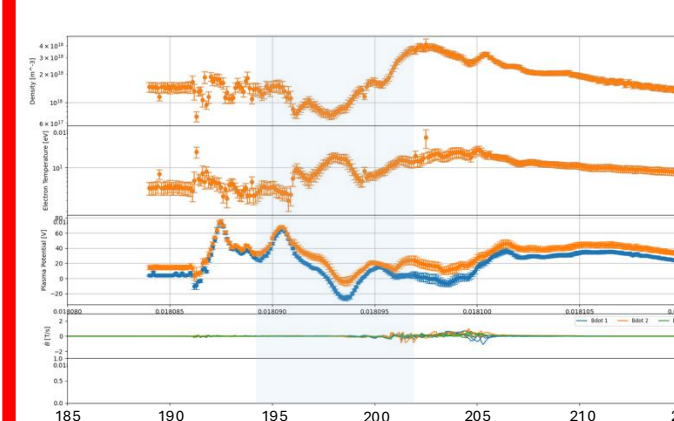
- Smaller loop voltage - weaker magnetic field
- Fatter cone shape - weaker tension at bottom
- Shorter length - null has less distance to travel
- More re-producible



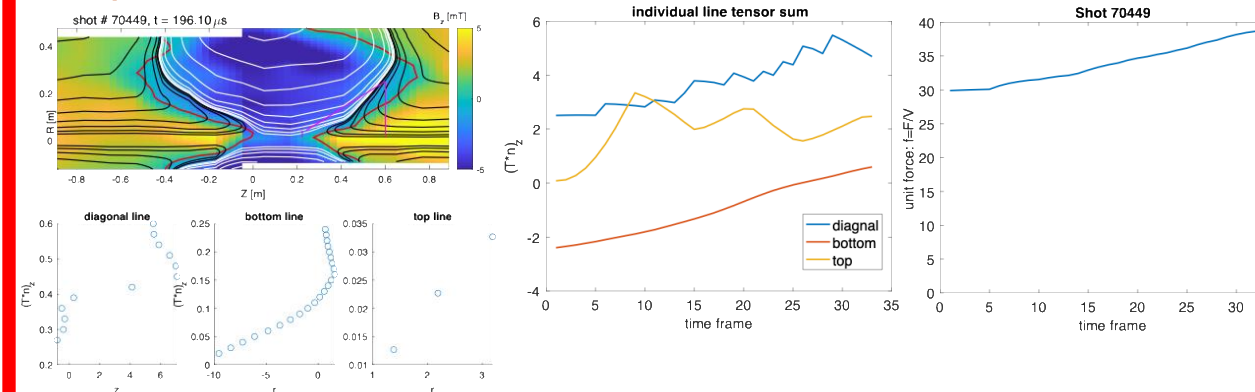
Te Probe



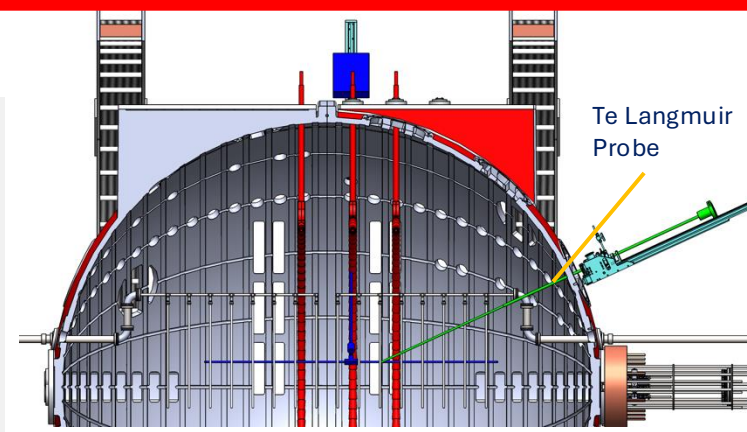
- 16-tip Langmuir probe
- Each tip has different bias voltage
- Fitting all working tips generates IV curve for each time
- 3 pick-up B-dot loops for x, y, z



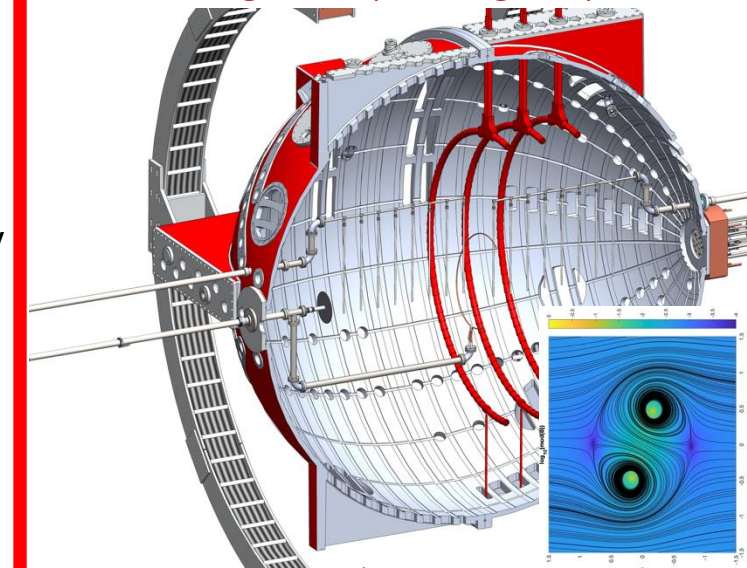
Maxwell stress tensor analysis of a cone shape flux surface in 3-Coil TREX



The total force also increases by time. However, the cone shape is fatter than that of D.C. Force from tension pulling to $+Z$ is not strong enough to oppose pressure from bottom. Positive values means the direction of force is towards $+Z$.



Plasma Current Flow through a Twisted Single Coil (Building now)



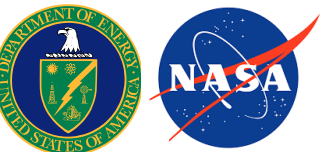
- Molybdenum plate biases plasma guns
- A single coil with 10 or 20 degree tilting
- Helmholtz field as background
- Drive the single coil fast on to change the magnetic field structure, 2 nulls show up
- Plasma current is forced to change path
- Finish 3D scan of magnetic data by rotating the coil

References

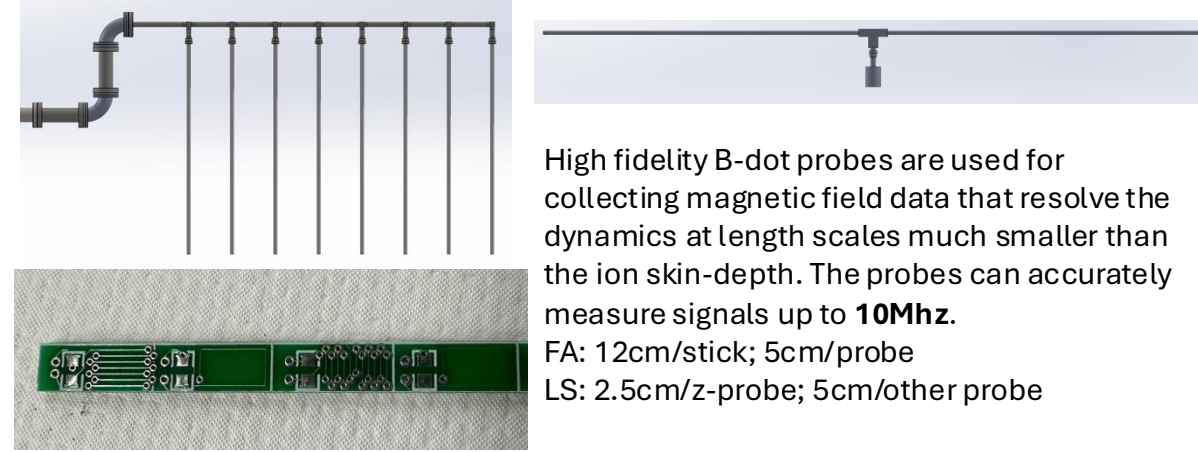
[1] Priest E, Forbes T. *Magnetic Reconnection: MHD Theory and Applications*. Cambridge University Press. 2000. <https://doi.org/10.1017/CBO9780511525087>
 [2] Olson, J., Egedal, J., Clark, M., Endrizzi, D. A., Greess, S., Millet-Ayala, A., Myers, R., Peterson, E., Wallace, J., Forest, C. B. (2021). Regulation of the normalized rate of driven magnetic reconnection through shocked flux pileup. *Journal of Plasma Physics*, 87. <http://dx.doi.org/10.1017/S0022377821000659>
 [3] Gradney, P., Egedal, J., Barnhill, I., Flores-García, R., Greess, S., Kuchta, C., Olson, J., Wallace, J., Yu, X., & Forest, C. (2023). Implementation of a drive cylinder for low collisional experiments on magnetic reconnection. *Review of Scientific Instruments*, 94(12), 123503. <https://doi.org/10.1063/5.0175812>

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Flux Array B-dot Probe & Light-Saber B-dot Probe



High fidelity B-dot probes are used for collecting magnetic field data that resolve the dynamics at length scales much smaller than the ion skin-depth. The probes can accurately measure signals up to **10Mhz**.
 FA: 12cm/stick; 5cm/probe
 LS: 2.5cm/z-probe; 5cm/other probe