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Diagnosing Z Machine Current Loss using Anode-Side Charged Particle Diagnostics

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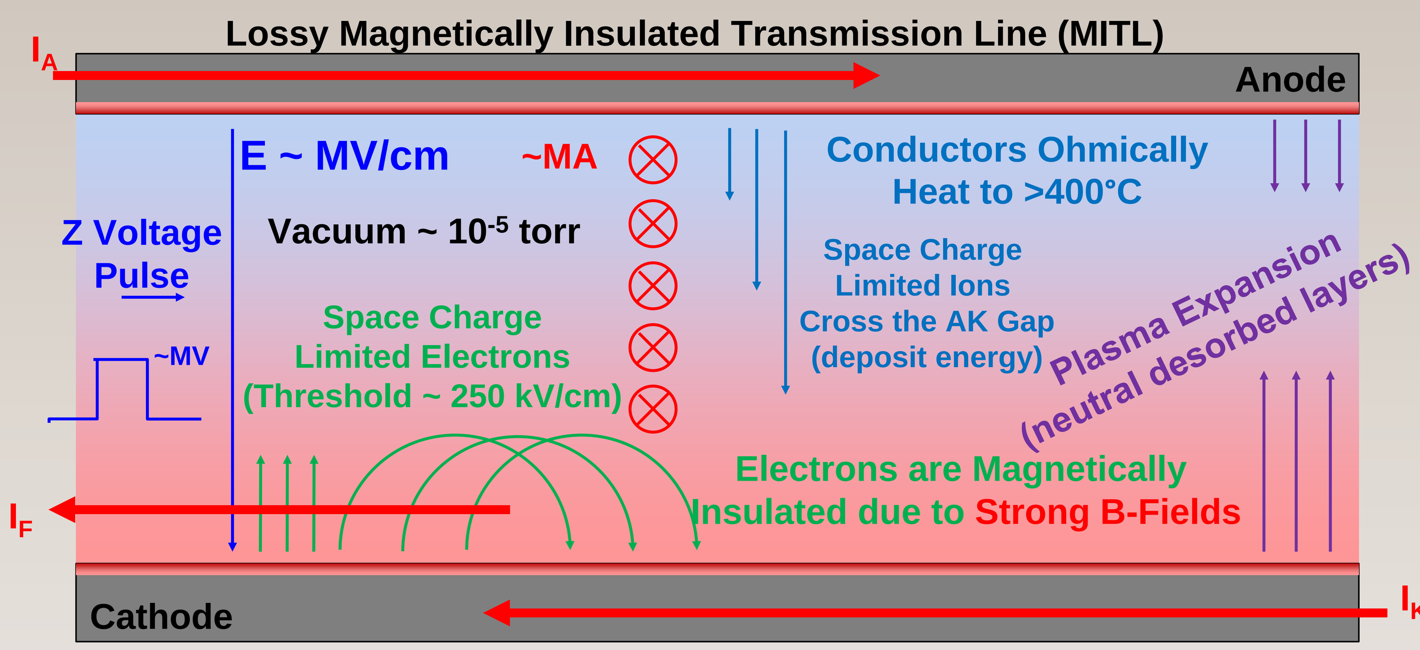
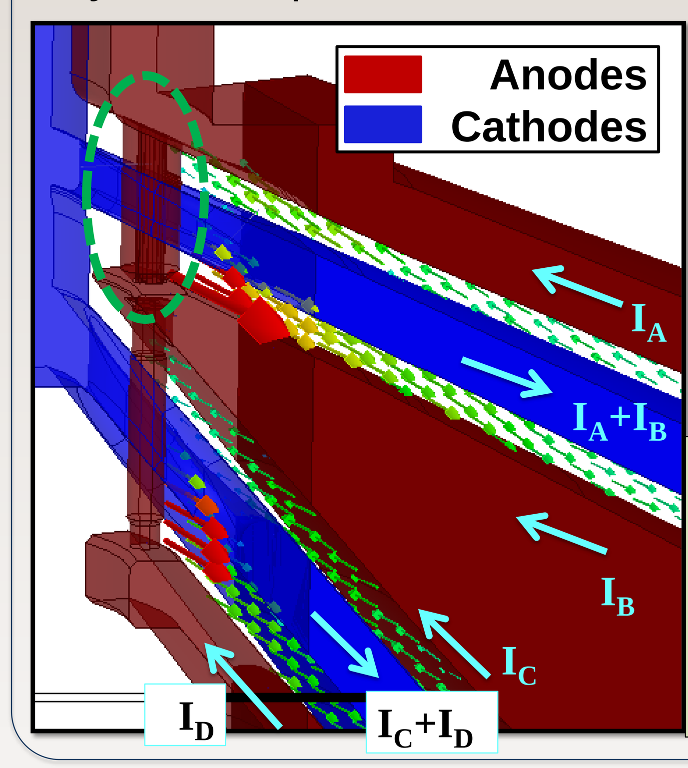
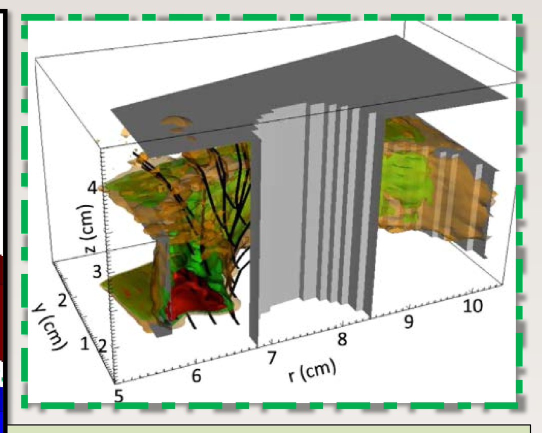
Motivation and Background - Drive current loss can limit Z performance

- Z can deliver to 27MA to well-matched targets (dynamic hohlraum wire arrays), but high-impedance loads (MagLIF liners, large-diam. wire arrays) lose 5-6 MA
- A majority of the loss occurs in the post-hole convolute (PHC), the 3D structure that adds the four parallel MITLs into the target's final feed
- PIC codes are used to infer loss behavior, but physics models are still being developed.
- We work to develop diagnostics to measure MITL phenomena and understand convolute power flow dynamics, provide V&V data for advanced PIC models







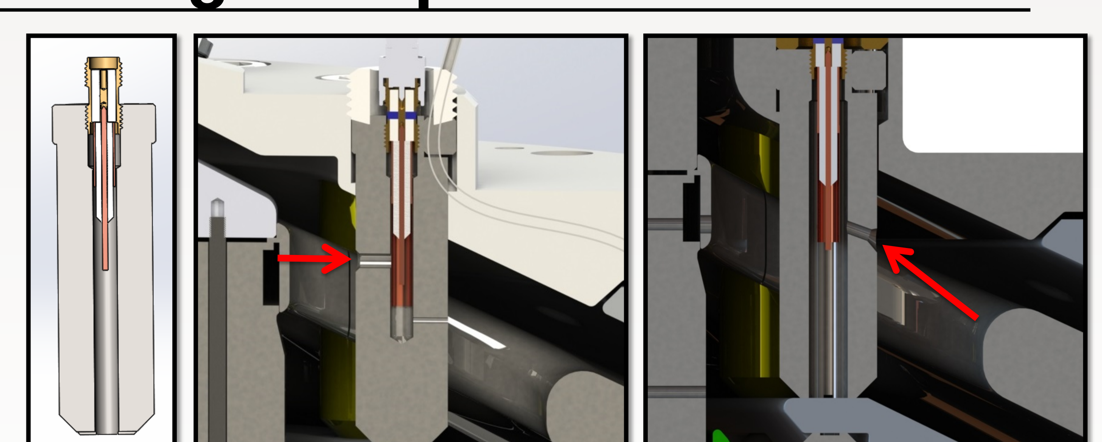
Current flow in Z MITL convolute with magnetic flux density vectors. Anode posts extend through cathode holes, region highlighted (left); LSP PIC calculation showing plasma accumulation in downstream region of convolute[1] (right)

A phenomenological description of Z current loss

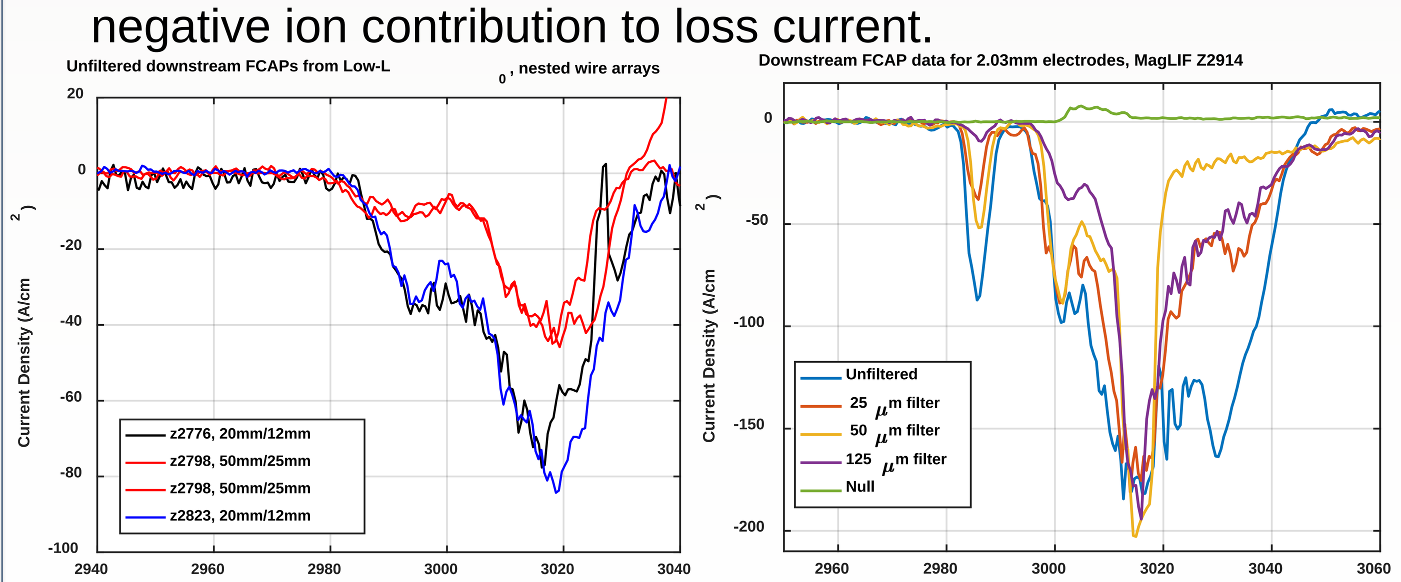
- Early-time convolute voltage exceeds 250kV/cm threshold for explosive emission from cathode surface
- Bound anode current plus electron and negative ion bombardment quickly heat anode surfaces to >400°C
- Desorbed gases from anode ionize, form surface plasma that source positive ions across MITL gap.
- Distribution of insulated e^- in MITL vacuum gap partially neutralize space charge, enhance positive ion flow across gap above bipolar space-charge limit (η ~10-25).
- Convolute 3D field topology further perturbs this model.

Faraday-Cup Anode Posts (FCAPs) measure negative particle flux

- Electrodes inside convolute anode posts measure negative particle fluence (electrons and negative ions) incident on anode surface.
- We use thin copper filters to block ion species and neutrals, and isolate high-energy electrons for collection by electrode.
- 2mm Cu and W electrodes are now used to provide sufficient stopping power for 2-3MV+ electrons.
- Numerical subtraction of filtered from unfiltered signals infers negative ion contribution to loss current.

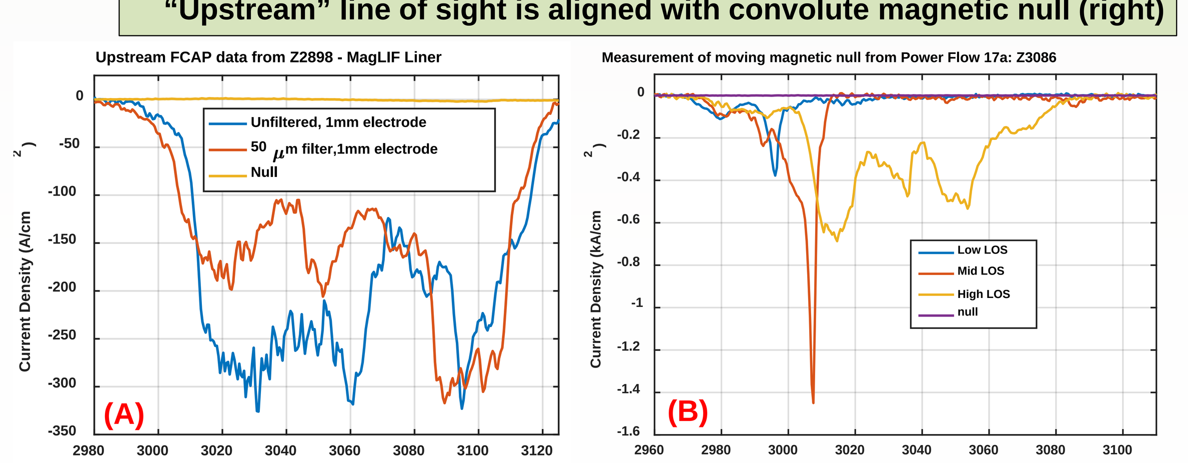


FCAP null measurement (left); "downstream" line of sight (center); "Upstream" line of sight is aligned with convolute magnetic null (right)

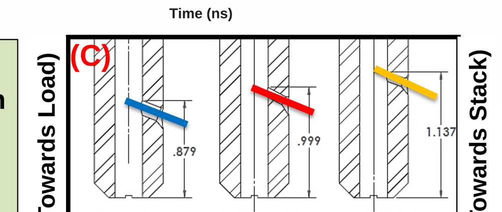


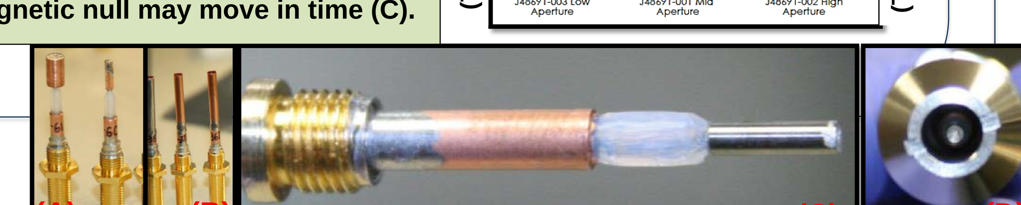
Unfiltered downstream FCAPs show repeatable convolute behavior for low-L_0 wire arrays (left). High-L_0 MagLIF loads (right) present higher current densities; varying filter responses suggest either convolute asymmetry or significant low-energy electrons.

- Downstream measurements show particle flux to anode after magnetic insulation in DPHC is thought to be established.



Unfiltered upstream FCAPs measure magnetic null currents for duration of pulse with 1mm Cu (A), 2mm W (B) electrodes. Electrons exceeding 1.25MeV range through 1mm copper in (A) but are collected by 2mm tungsten in (B). Z3086 used three LOS views to show magnetic null may move in time (C).

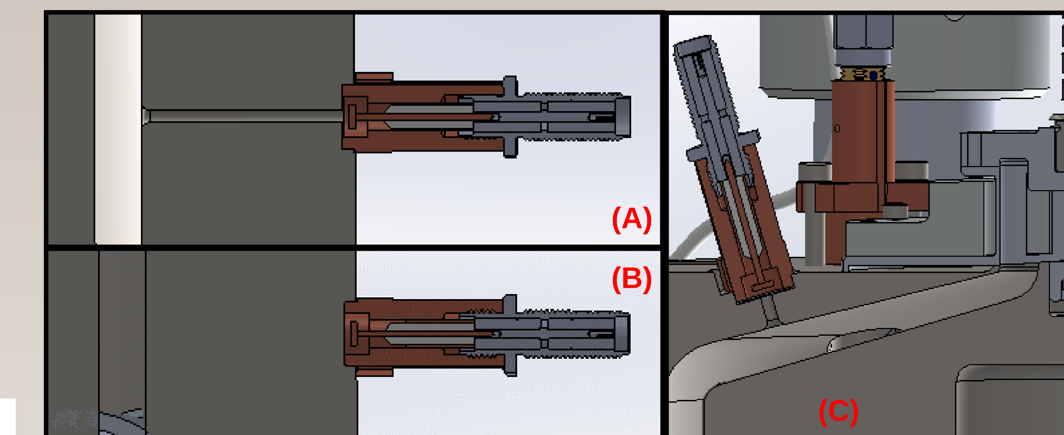




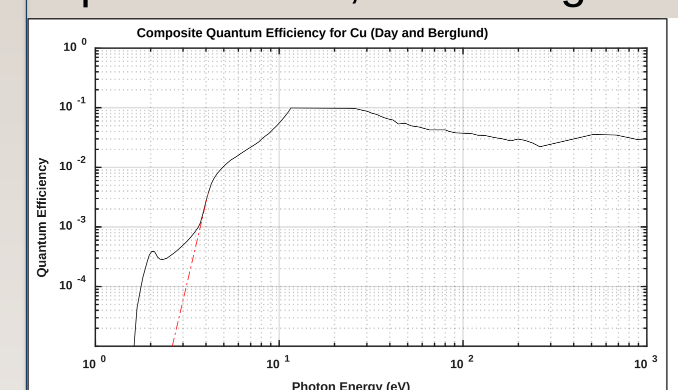
A) Faraday cups of various electrode diameters. B) cups with filter. C) tungsten electrode cup. D) FCAP bottom view.

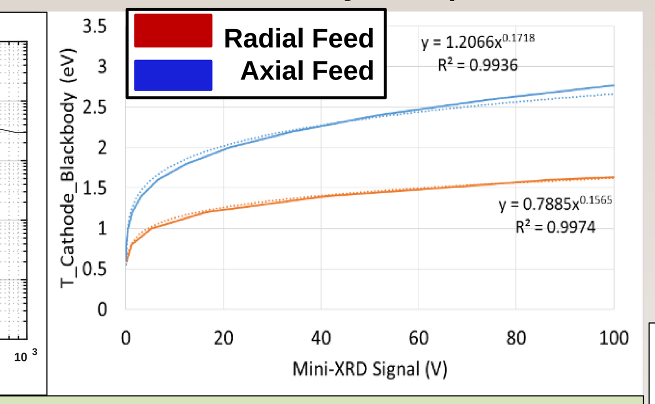
MiniXRDs used to infer cathode plasma blackbody temperature

- A MiniXRD is a negatively-biased collector with line-of-sight to cathode electrode via 1.5mm aperture.
- Bound current and anode ions quickly heat cathode electrode plasma to >1eV temperatures, which is assumed to radiate as a blackbody.
- Incident photons on MiniXRD electrode produce photocurrent, whose signal is measured by acquisition.



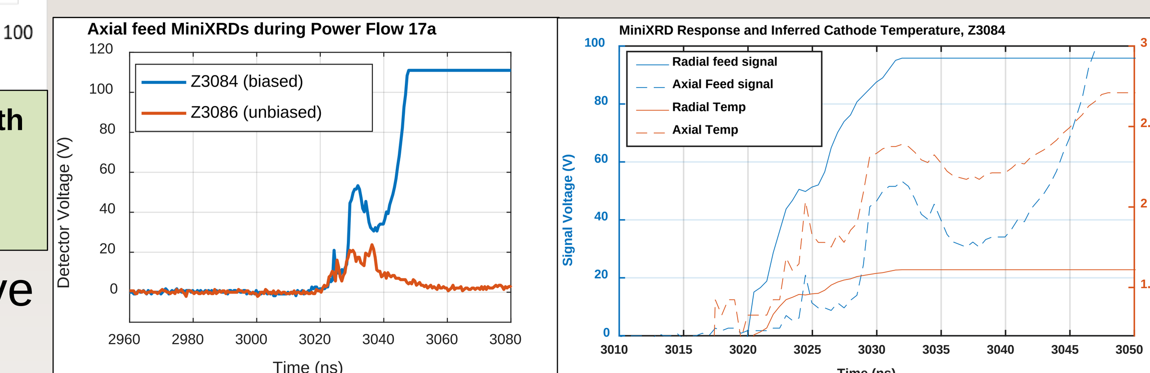
MiniXRD with ~1" drift tube observed no negative-particle fluence (A). A null was fielded to confirm noise immunity (B). MiniXRD electrodes with short drift lengths observe particles prior to insulation (C).





Computed blackbody spectral intensity, with geometric effects, is convolved with copper photoelectron quantum efficiency (left, from Day[2] and Berglund[3]) to determine detector current. MiniXRD voltage measurements scale to effective observed blackbody temperature (right).

- MiniXRDs have been fielded on three shots. We are adjusting expected signal response to prevent clipping.



Biased and unbiased MiniXRD electrodes for Z3084 and Z3086 (left) show photoelectron production. Processed cathode temperatures on shot Z3084 for radial and axial feed MiniXRDs (right) suggest axial MITL cathode surface is hotter than final power feed cathode.

- MiniXRDs with short drift lengths also observe negative particle fluence. Current densities averaging ~30-40A/cm² are observed in final (radial) power feed.
- Negative particles and photoelectric currents produce competing voltage components, confusing interpretation.

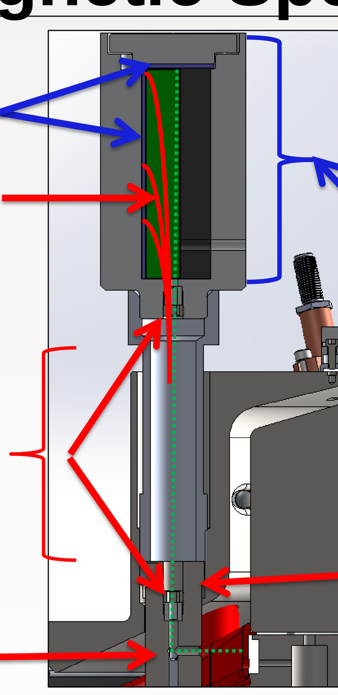
In-Post Magnetic Spectrometer (MagSpec) to observe H^-

CR-39 plastic records tracks of time-integrated, energy resolved negative ion flux

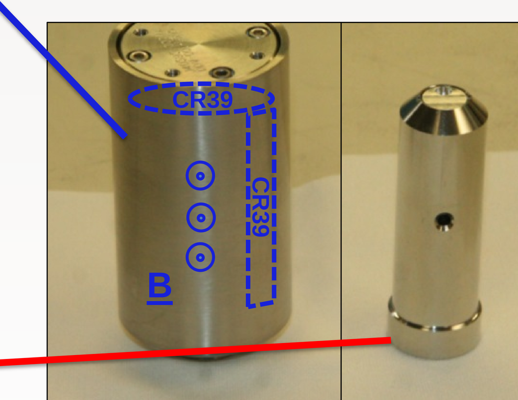
Permanent magnets (B~0.7T) steer scattered H^- into CR39

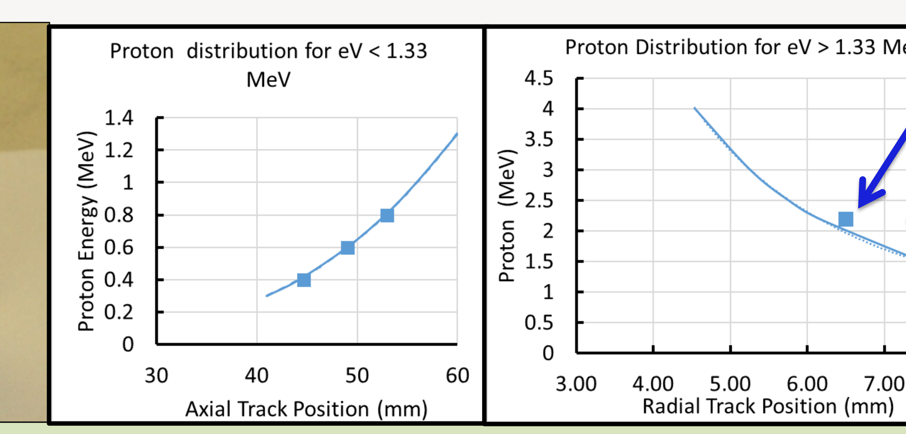
2ea. ~1mm apertures, drift tube collimate scattered ion fluence

Au-coated polyimide film Rutherford-scatters ions from downstream FCAP LOS



- Diagnostic uses permanent magnets to steer ions into detector
- CR-39 detector is recovered post-shot, etched, and tracks counted
- Diagnostic will provide time-integrated, energy-resolved H^- fluence





Sandia Ion Beam Lab (IBL) calibration points

In-post MagSpec has been designed (left); measured proton deflection in nominal 0.7 T field resolves H^- ions < 1.33MeV (center) on vertical CR39, >1.33MeV on horizontal CR39 (right)

Summary and Future Work

- We have developed three new particle diagnostics for diagnosing power feed plasma dynamics on Z.
- We plan FCAP experiments to understand effects of line-of-sight aperture (e.g. hole closure, effective area), azimuthal symmetry of convolute dynamics, and collocated measurements of ion and electron species.
- The MiniXRD needs to decouple particle response from photon fluence. We are incorporating longer drift tubes to evaluate signal scaling compared to blackbody.

  Our first attempt to field an in-post MagSpec will be Nov 2017. Our objective is to recover the CR39, etch it, and evaluate the efficacy of the measurement technique.
- Variations of upstream FCAP LOS will be used to quantify loss current in convolute magnetic nulls, eliminate aperture effects from reported current density.
- These anode-based particle diagnostics will be fielded on upcoming dedicated 3-shot campaign whose primary objective is to provide a platform to mature understanding of power flow diagnostics:
  - 9-11 FCAPs, 8 MiniXRDs, 2 MagSpecs per shot!
- Data collected with these diagnostics will play a ***critical role*** in providing ***validation data*** for ***next-generation particle-in-cell codes*** currently in development

References

[1] *D. Rose, et al.*, Phys. Rev. Accel. Beams 18, 030402 (2015)
[2] Day, *et al.*, J. Appl. Phys., 52, 6965 (1981)
[3] Berglund, Stanford Electronics Laboratories, Tech Report No. 5205-1 (1964)

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