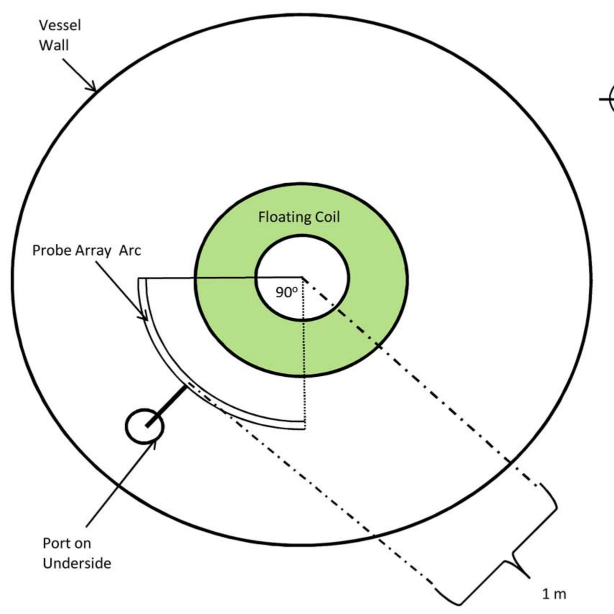
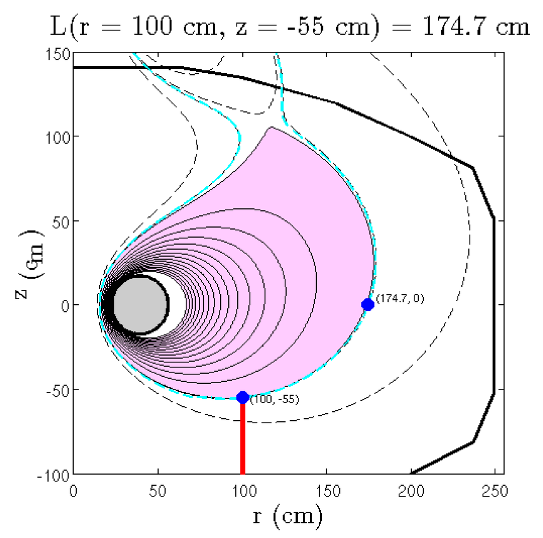
Array Design and Construction

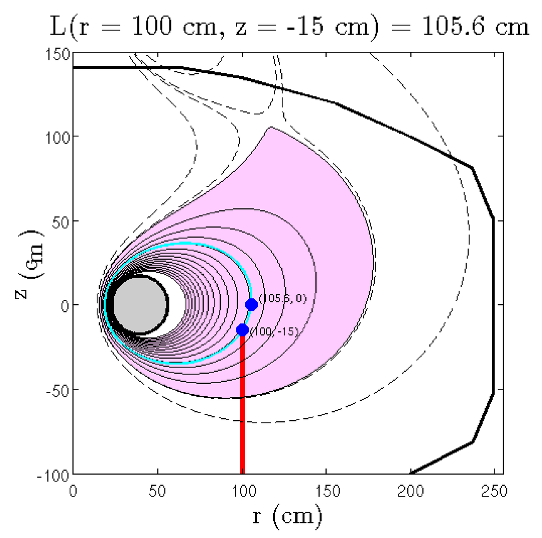
Abstract

Previous computational models using magnetic configurations similar to LDX have yielded results where convective cells transport particles without transporting energy [1], and this would prove useful in a fusion reactor since it could remove ash from the core without cooling it. A vertically adjustable electrostatic probe array has been designed to observe the previously seen low-frequency angular oscillations with better resolution and identify if they are related to expected convective cells. The array will rest one meter from the centerline and measure edge fluctuations at field lines near the separatrix that are mapped to 1.7m to 1.85m at midplane. It will cover ninety degrees angularly and have 24 probes mounted on it for total probe tip separation of 6.8cm. The probes themselves will consist of a 1cm tungsten electrode inside an alumina tube in series with a 1 mega-ohm resistor 40cm from the tip. The array can be fitted with an extension to provide radial sampling at a later date.

[1] J. Tonge, N. Leboeuf, C. Huang, and J.M. Dawson Kinetic Simulations of the stabilityof a plasma confined by the magnetic field of a current rod. PHYSICS OF PLASMAS 10 (2003) 9.







Mechanical Design

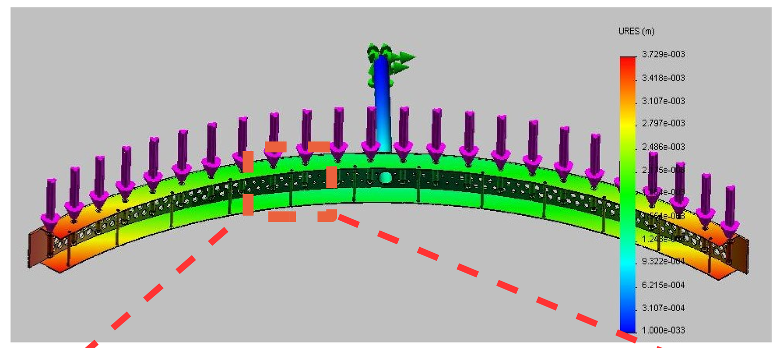
- Goals are to be rigid and light
  - Minimized flex from gravity, and keep probe tips in accurate position.
  - Use small electric motor and moderate-pitch ball screw in drive system. 25 lbs total weight.
- SolidWorks suite used to simulate flex
  - Back brace made 3/16" thick and "cheesed" out in exponentially increasing area
  - Top plates used only to hold probes, perpendicular cross section small, so made 1/16" thin.
  - Simulations predicted a maximum tip deflection of 4.5mm.
- Made of non-magnetic 316 SST

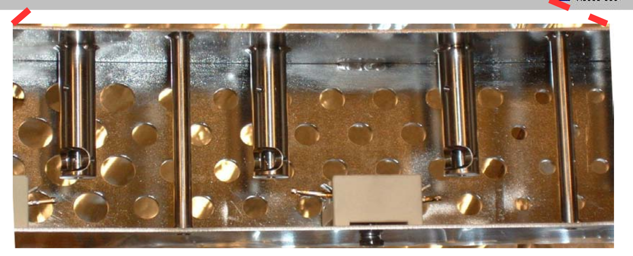
Placement

- Array placed at a constant radial position of 1m
  - lowest reach of plasma
  - largest bellows travel to plasma penetration ratio

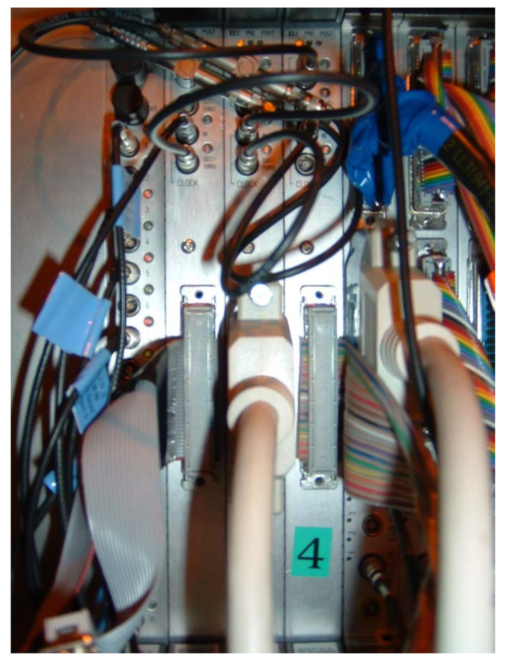
Probe Type & Number

- The array is made of a 90° arc with 24 evenly spaced floating potential probes
- Floating potential with the option of replacement with ion saturation





Electronics



Amplifiers

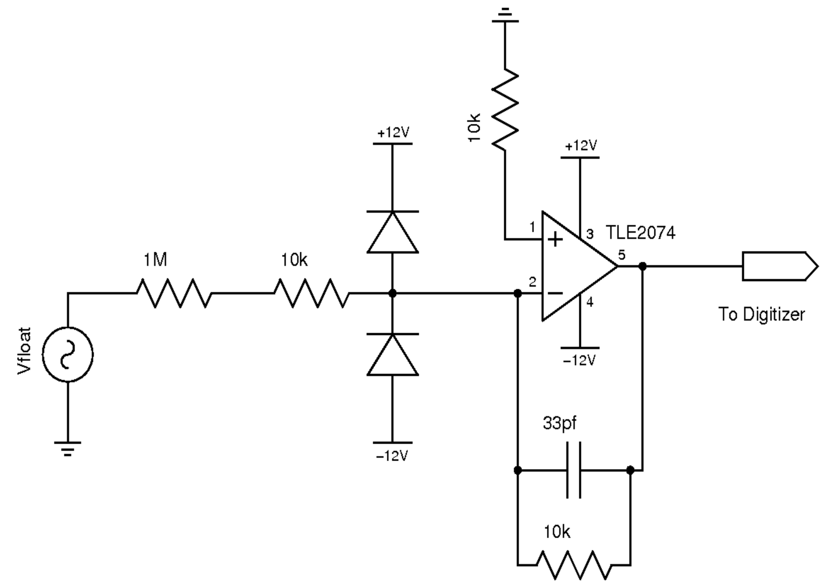
- Use the TI TLE2074 high-speed, low noise quad JFET opamp
  - 10Mhz bandwidth-gain
  - Configured for -3db knee at 480Khz and -0.01 gain
- High-Impedance circuits
  - low opamp bias current to minimize error – 20 pA
  - high opamp input impedance – 1 TΩ
- Voltage spike protection
  - Schottkey Diodes referenced to power rails keep differential input less than the rails
  - small on-board input resistor protects against arcs side the vessel

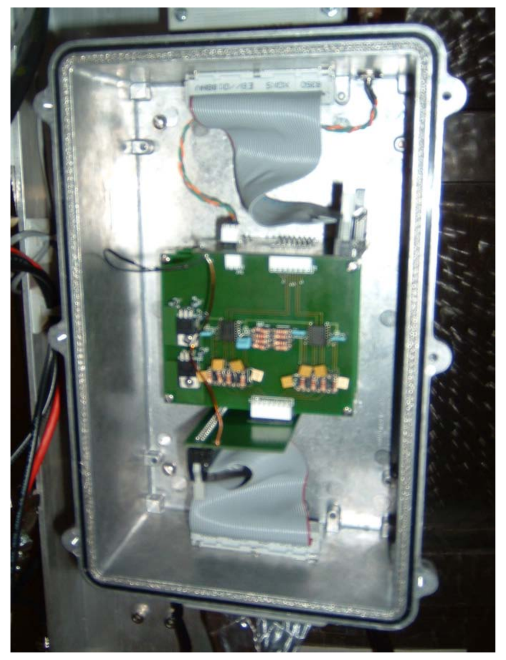
DAQ

- INCAA Computers
- 16 Inputs per board
- 800k input resistance
- 80Khz digitization (up to 125Khz)
- 16 bits resolution over ±10V

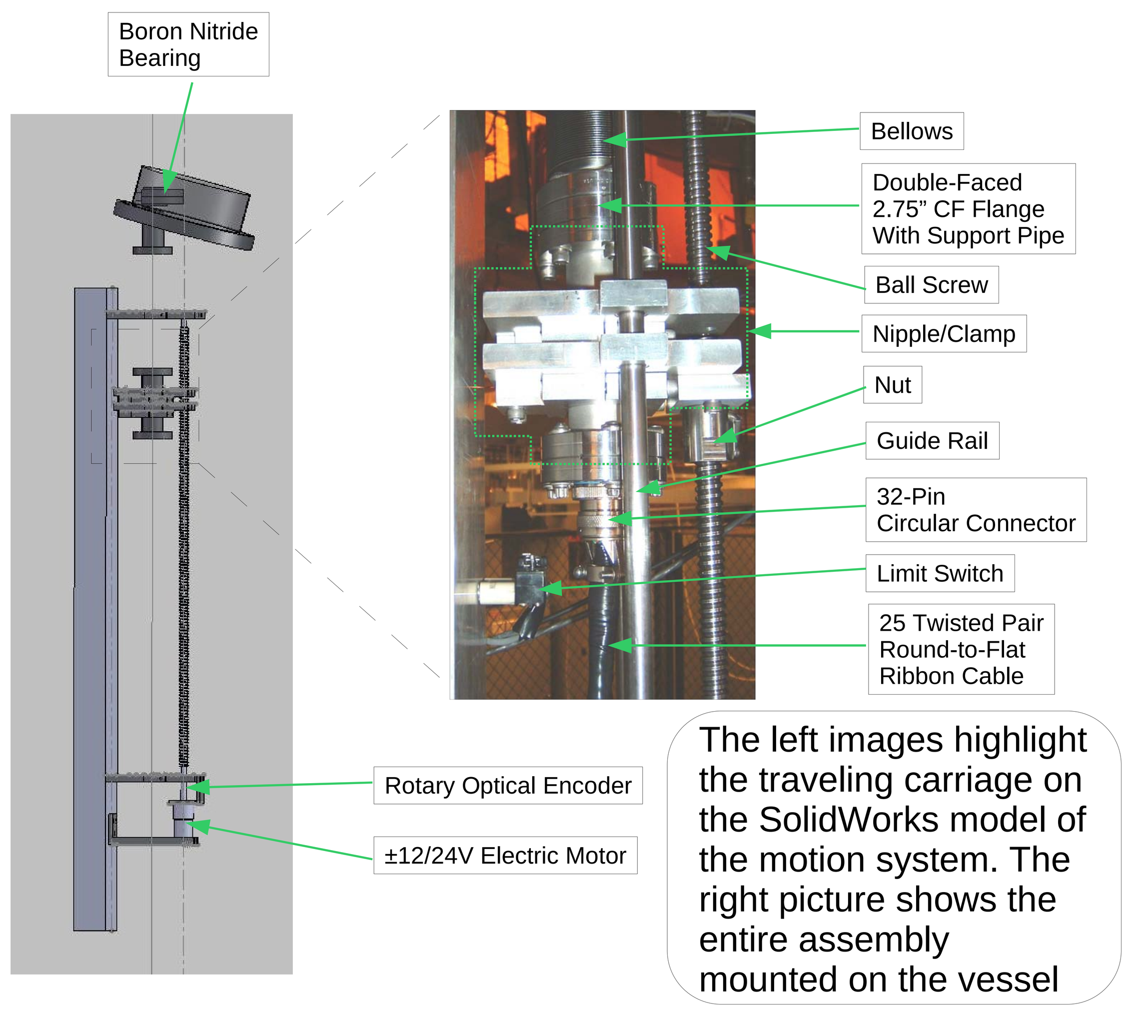
Cabling

- 25 twisted pair, round-to-flat ribbon cable
- 100% foil shielded
- Terminated with 50 position D Sub connectors
- Enclosure has wire mesh gasket for EMI/RF protection





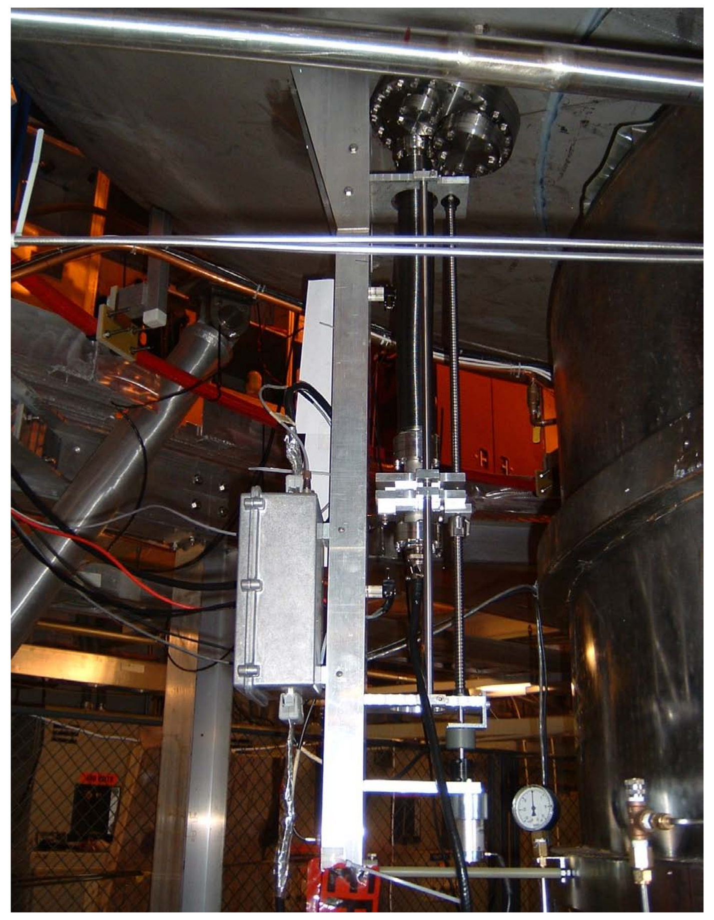
Motion System



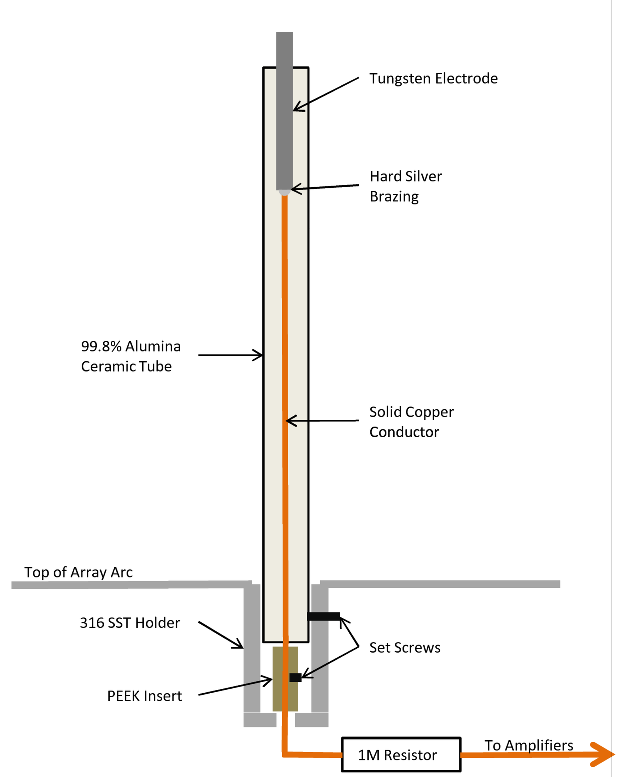
The left images highlight the traveling carriage on the SolidWorks model of the motion system. The right picture shows the entire assembly mounted on the vessel

Specifications

- 50cm travel edge-welded bellows terminated in 2.75" CF flanges
- Electric motor driven
  - Fully steel – shielded from C-coil
  - ±12/24V
  - -45 oz-in max continuous torque
- Ball screw drive mechanism
  - 0.631" diameter
  - 0.2" pitch
  - nut attached to a clamp which holds a nipple attached to a CF flange that has the array support pipe welded to it.
  - Two side rails keep the clamp horizontal, clamp rides on sleeve bearings
- Rotary optical encoder
  - 1000 counts per revolution
  - used to automate probe positioning

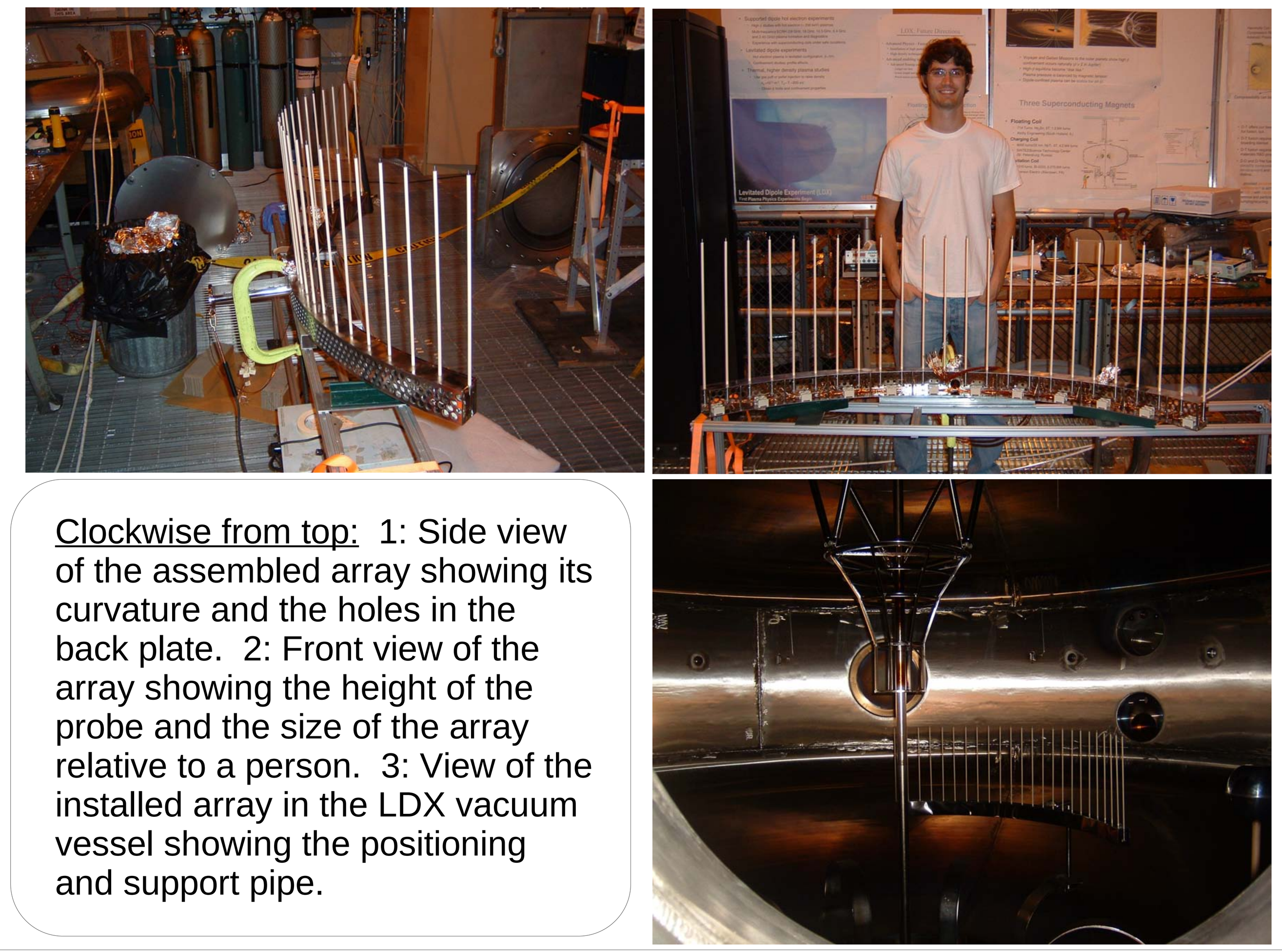


Probes



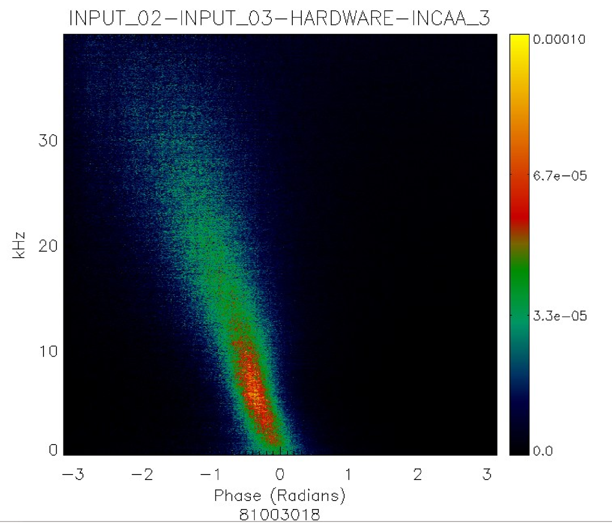
Specifications

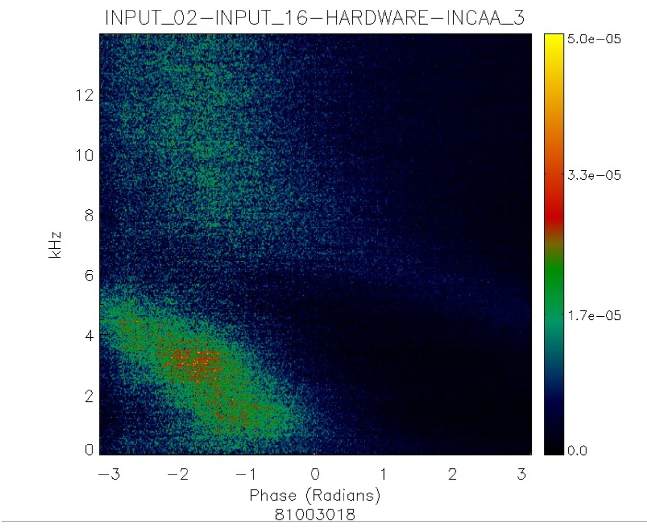
- 1 Megaohm resistor in series
  - Keep floating potential close to plasma potential, high sheath resistance
  - Close to the tip to reduce effective capacitance and keep the RC time low
- 16 inches exposed length
  - Probe sits atop a PEEK insert that holds the copper conductor and tip in position and insulates it from the steel probe holder.
  - held to holder with set screws
- 1cm exposed tungsten tip
  - 3.5"total tungsten length for heat capacity
  - Hard silver brazed to copper conductor

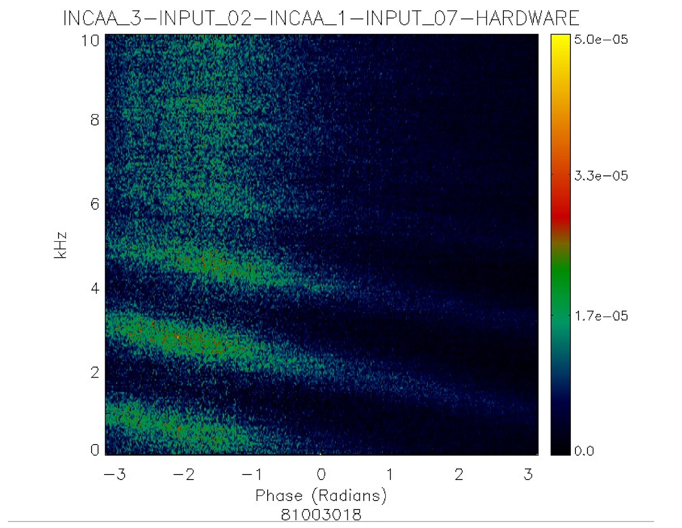


Clockwise from top: 1: Side view of the assembled array showing its curvature and the holes in the back plate. 2: Front view of the array showing the height of the probe and the size of the array relative to a person. 3: View of the installed array in the LDX vacuum vessel showing the positioning and support pipe.

Data Analysis







2-Point Cross Correlation

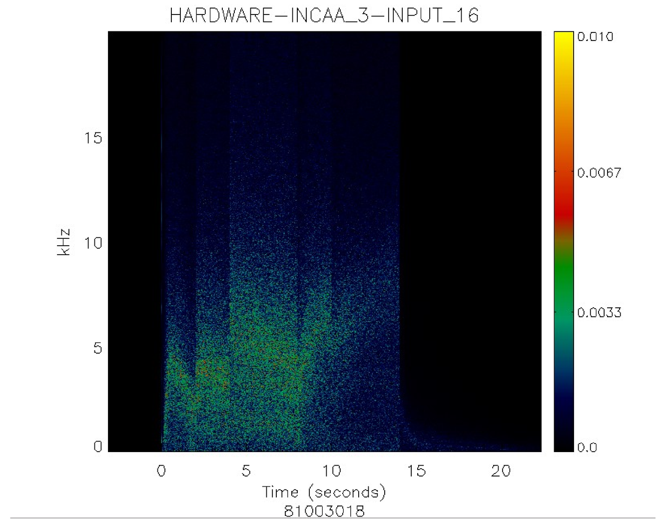
- Linear relationship between phase and frequency of potential fluctuations
- Slope of line can be used to find rotation velocity if the potential profile is assumed to be fixed in the plasma:

$$v = 2\pi R\theta \frac{df}{d\phi}$$

- These plots show analysis between adjacent, close, and distance probes on the same shot for the same time interval.
- Multiple lines on the more distance shots are from the shorter correlation lengths

Future Work

- Calculate the azimuthal electric field distribution
- Use the electric field to determine ExB drift velocities and rates

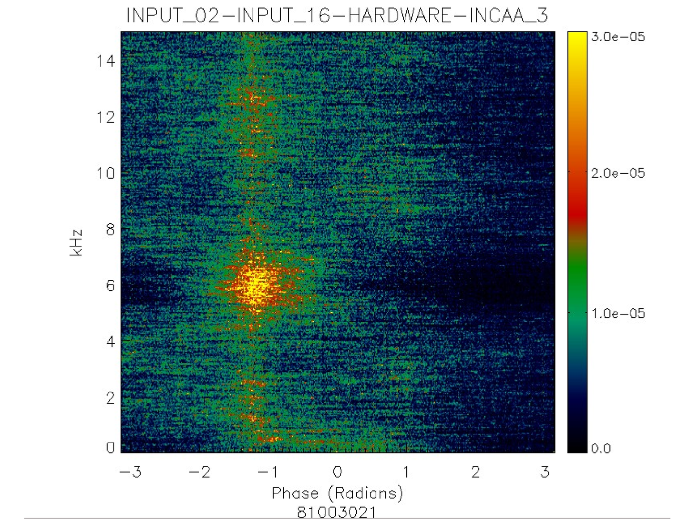


Spectrograph

- Relationship of signal frequency spectrum with time
- This shows the same shot (81003018) as the above 2-point cross correlation plots

"Spot" 2-Point Cross Correlation

- Shot 81003021 – very low density
- Shows one dominant frequency
- The fluctuation rotates with constant velocity



"Stripey" Plot

- Amplitude plot of probe array data with the signal time mean subtracted out of each channel
- Clearly shows a moving fluctuation
- Calculated velocity consistent with that determined with the 2-point cross-correlation plots, on the order of 100 km/s

$$v = R\frac{d\theta}{dt}$$

- Useful in picking out patterns