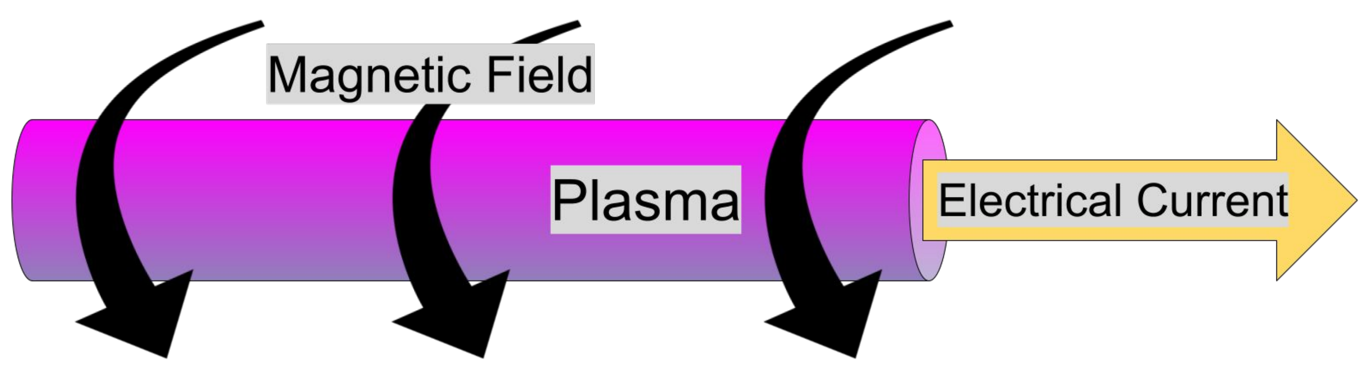
Measuring the Electron Density of Z-Pinch Plasmas on the ZaP-HD Experiment

Harry Furey-Soper - Presenting for SURP on 8/19/2022

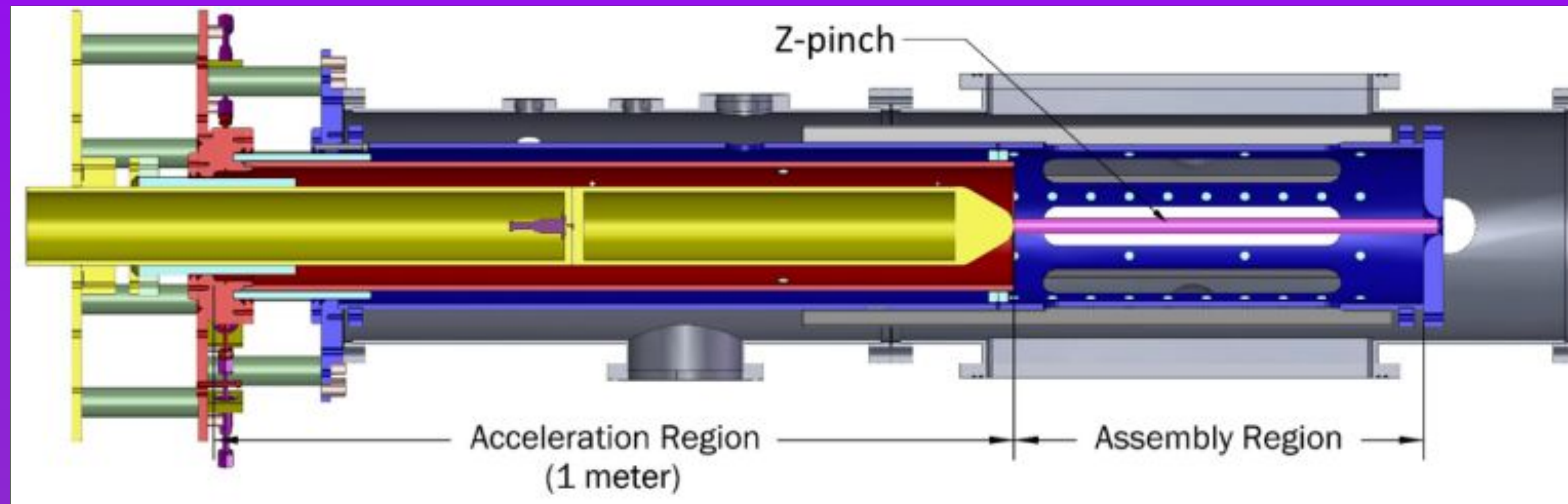
Fusion: a Clean Nuclear Power

Today's nuclear reactors use a reaction known as **fission**, which splits large atoms such as uranium into smaller atoms. This produces **radioactive waste**, which remains hazardous for **hundreds of thousands of years**. The reactors of tomorrow, however, will use a reaction known as **fusion**. This is the same process that powers stars, such as our sun, and acts as the **opposite of fission**. Instead of splitting large atoms, small atoms like hydrogen are "fused" together into larger atoms, releasing energy. Fusion is not a chain reaction, which means it poses **no risk of meltdown**.



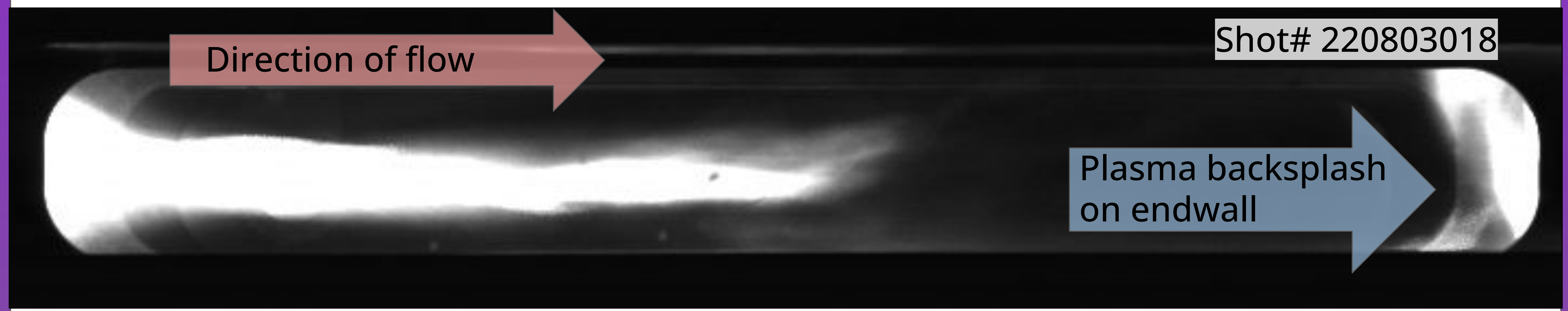
Advantages of Z-Pinch Fusion

All fusion experiments follow the same basic idea: **heat and compress plasma** as much as possible for as long as possible. In a Z-pinch, an **electric current** is sent through plasma, which creates a magnetic field that **"pinches"** the plasma into a column. This is what makes the Z-pinch so interesting: it requires **no externally applied magnetic fields**, as it is completely **self-confining**. This provides several advantages over other fusion models like tokamaks and spheromaks. Without the need for heavy permanent magnets or complex conductor coils, a Z-pinch reactor can be made far **lighter and cheaper** than alternative models, with more favorable design simplicity. Additionally, the linear formation of the Z-pinch is ideal for application in a fusion-drive space propulsion device. However, despite the theoretical advantages, the typical static Z-pinch is highly susceptible to instabilities.



Sheared-Flow Stabilization: the ZaP-HD Device

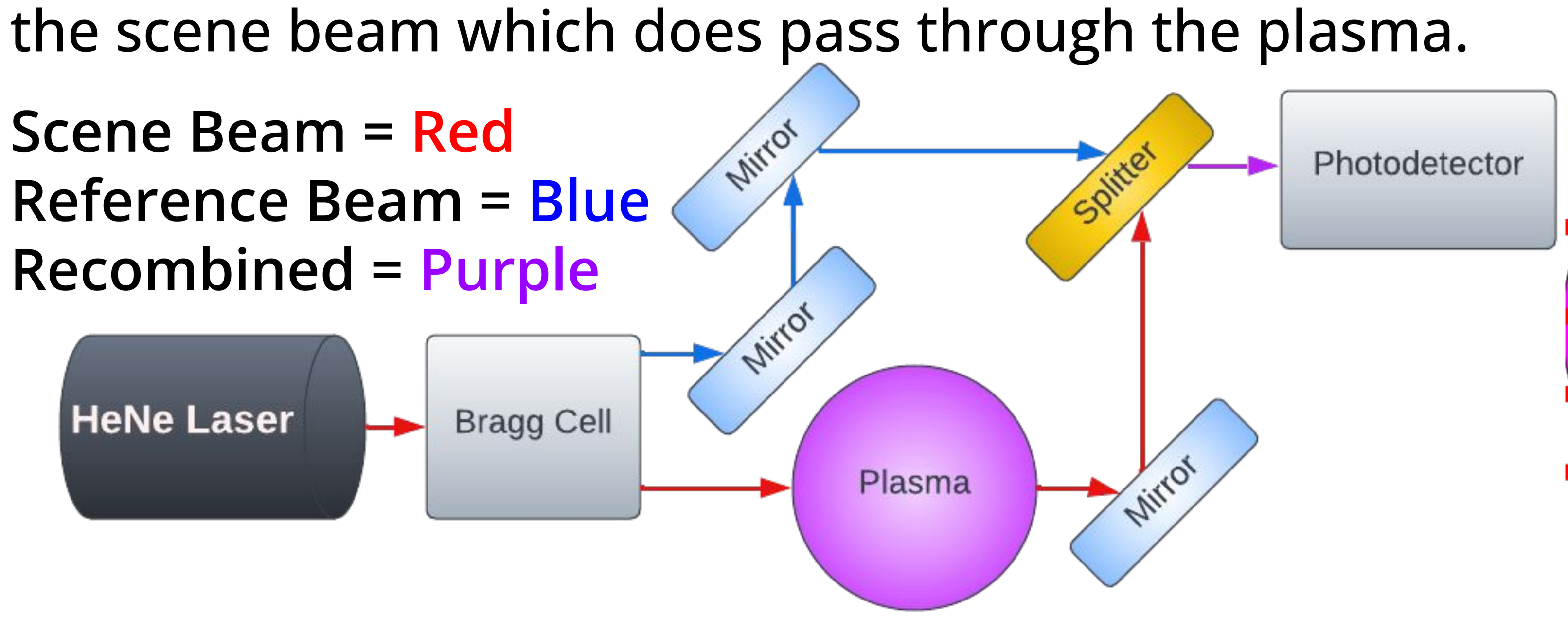
Z-pinch instabilities are reduced by giving plasma a **sheared axial flow** before initiating the pinch [1]. The ZaP-HD device pictured above injects gas into the acceleration region, where it is **ionized and accelerated** into the assembly region, where it is compressed into a Z-pinch [2]. Pictured below is an **image of a ZaP-HD Z-pinch**, taken by a high speed camera on August 3rd, 2022.

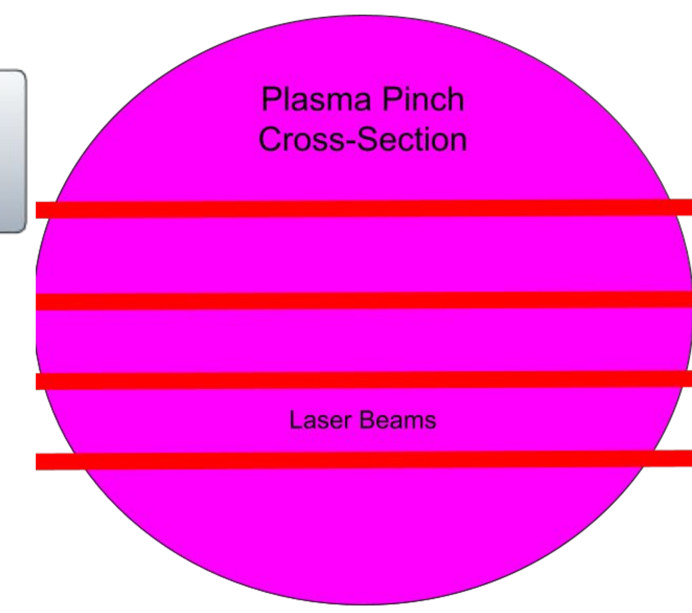


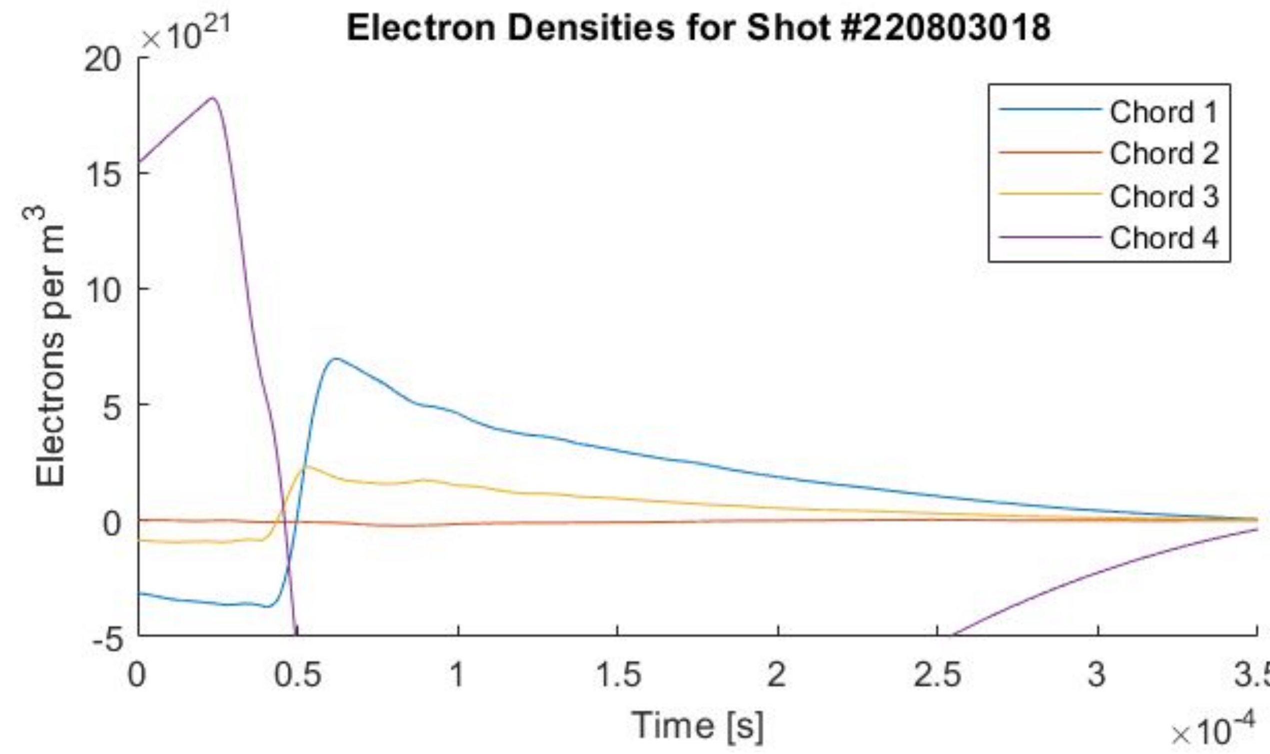
Helium Neon Interferometry

Time-resolved electron density measurements are taken with a 4-chord Mach-Zehnder interferometer. Four parallel HeNe laser beams are directed through the plasma flow, and the interference experienced by the laser beams is used to calculate the **index of refraction** of the plasma, which is proportional to the **electron density**. Pictured below are a diagram of the full setup for one chord (left) and a close-up cross section perspective of the beam passage (right). For each measuring beam, a corresponding reference beam is passed through the air over the device to provide a signal with no plasma for comparison with the scene beam which does pass through the plasma.

Scene Beam = Red
Reference Beam = Blue
Recombined = Purple







Current Task: Data Analysis

Plotted above is density data for the same shot shown in the high-speed camera image. This data has noticeable flaws. Density curves dip into the negatives, which is physically impossible. Chord 2 shows lower densities than chord 1 despite being aligned closer to the pinch center. The highest density shown is roughly 2E22 electrons per cubic meter, while previous HeNe IF studies suggest measurements an order of magnitude higher should be expected [3]. I am currently working on troubleshooting hardware and programming issues to solve these errors.

Acknowledgements

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References

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2. Forbes, Eleanor. *Diagnostic development and plasma-material interaction studies on the ZaP-HD device*. University of Washington, 2020.
3. Lloyd, Timothy. *Comparison of Diagnostics for Determining Z Pinch Centroid in the ZaP-HD Experiment*. Diss. University of Washington, 2022.