INFUSE WORKSHOP

3D MHD Simulation support for Plasma-Jet Driven Magneto-Inertial Fusion (PJMIF)

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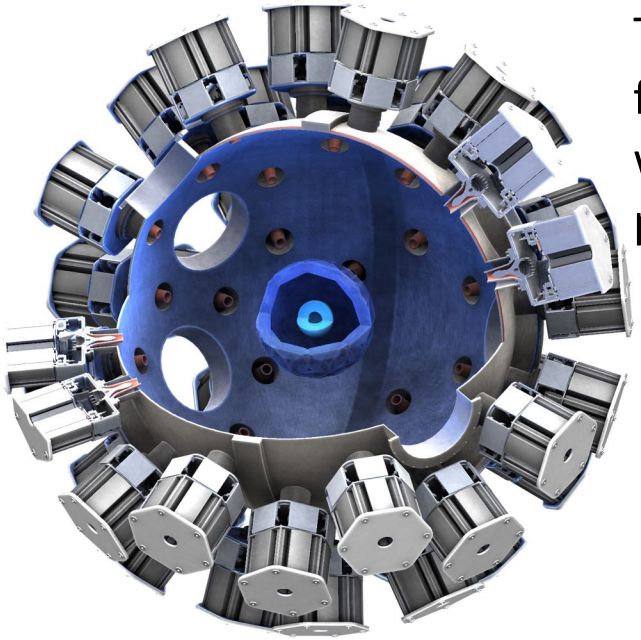
3D MHD Simulation support for Plasma-Jet Driven Magneto-Inertial Fusion (PJMIF)

- Intro to PJMIF
  - We have plasma liner guns
  - Our main current challenge is to develop a suitable magnetized target plasma
- Intro to Bethe program goals: merging multiple magnetized jets for target formation
  - Can we achieve the parameters desired?
  - Can we form a “tangled” magnetic field?
- **INFUSE ask was for Fully 3D MHD simulation capability of jet collision**
- We are working with LANL and the LA-COMPASS suite of codes – Dr. Hui Li
  - LA-COMPASS: 3D Ideal MHD, parallelized over cluster computing at LANL
  - Has had success modeling similar jet experiments conducted at Caltech in the past*

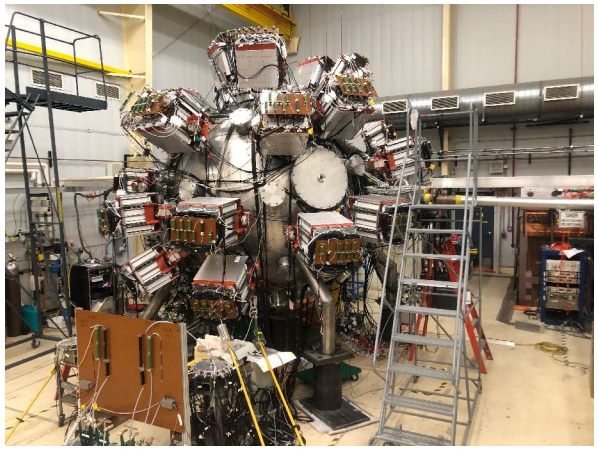
*Zhai, X., Li, H., Bellan, P. M., & Li, S. (2014). Three-dimensional MHD simulation of the Caltech plasma jet experiment: first results. The Astrophysical Journal, 791(1), 40

PLX-α program aims to demonstrate the viability of a spherically imploding plasma liner formed by merging plasma jets as a versatile MIF driver*



The Plasma Liner eXperiment (PLX) is a 9 foot dia vacuum chamber facility at LANL with 60 ports for guns plus additional larger ports for pumping and diagnostic access.

36 plasma liner guns are currently installed and under test at LANL.



Courtesy S. Langendorf, LANL

*Y. C. F. Thio et al., in *Proc. 2nd Int. Symp.–Current Trends Int.Fusion Res.*, E. Panarella, Ed. (NRC Canada, Ottawa, 1999), p. 113; S. C. Hsu et al., *IEEE Trans. Plasma Sci.* **40**, 1287 (2012).

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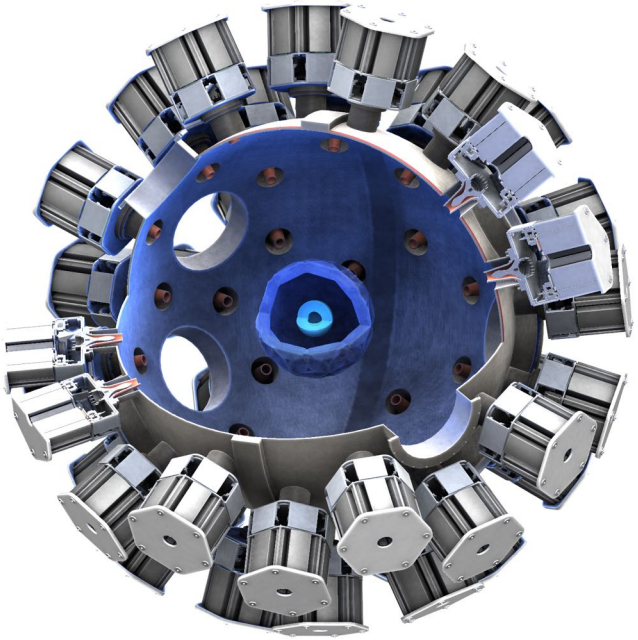
PLX

The PLX-β program aims to implode a plasma liner onto a magnetized target plasma



Plasma liner formed by the 36 PLX-α guns.

The magnetized target will be formed by up to 12 new magnetized plasma jets fired ahead of the liner guns.

Magnetized jets are variant of PLX-α guns

*Y. C. F. Thio et al., in *Proc. 2nd Int. Symp.–Current Trends Int.Fusion Res.*, E. Panarella, Ed. (NRC Canada, Ottawa, 1999), p. 113; S. C. Hsu et al., *IEEE Trans. Plasma Sci.* **40**, 1287 (2012).

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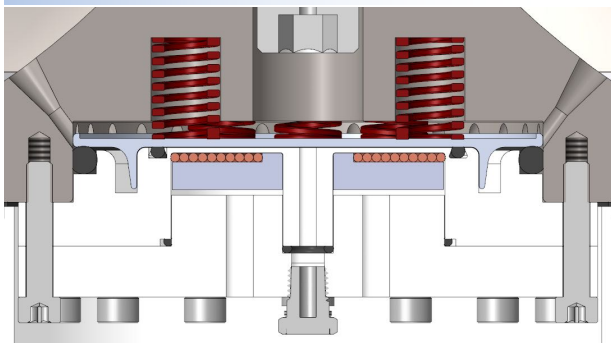
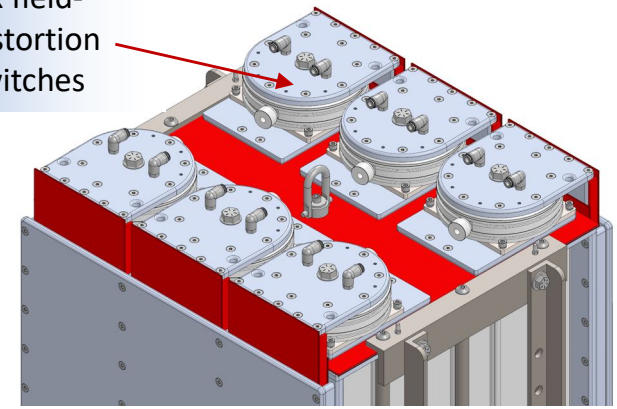
PLX

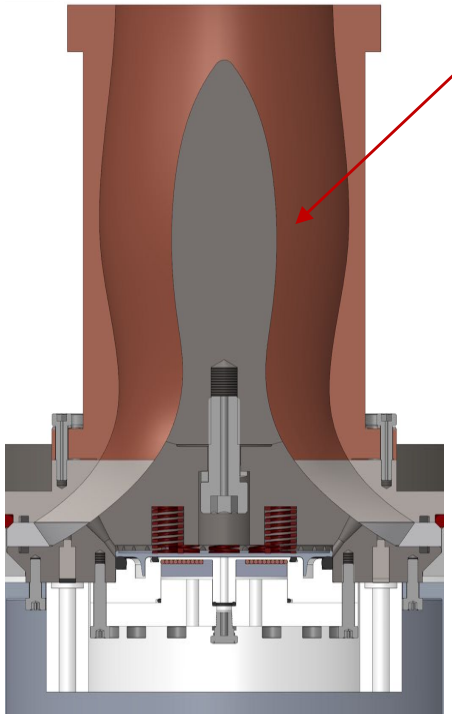
Key features of the HJ1 liner plasma gun

Ultra-fast gas valve w/ self-switched glow-like pre-ionization



Six field-distortion switches





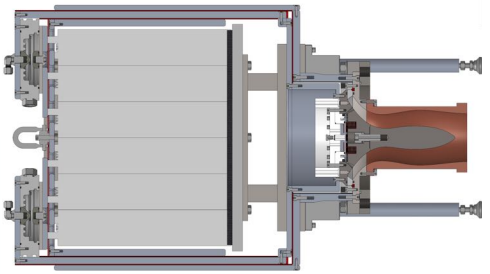
Electrode contours optimized for 600µF at 5kV and 0.5-5 mg of gas. Suppresses blowby.

Jet Parameters

Mass = 1 mg
Length = 10-30 cm
Density = 2e16 cm^{-3}
Velocity = 67 km/s

Main capacitor drive module:

- 18 custom capacitors rated for 33µF@5kV
- 7.5 kJ total bank energy
- Six groups of 3 caps in parallel
- One switch per group
- Mixed tri-plate, bi-plate and coax transmission line



Gun mounted capacitor module:

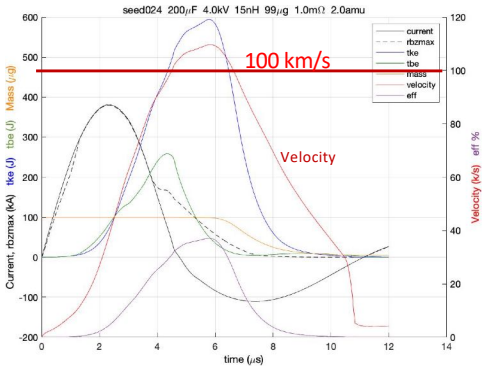
- Minimizes inductance and size
- Eliminates external cabling and racks

Mach2 modeling shows base gun can reach the target parameters for magnetized jet

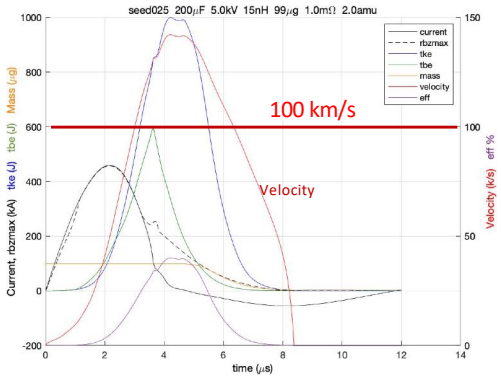
Magnetized Jet

Parameter	Goal
Velocity	>100 km/s
Density	1e14 cm^{-3}
Mass	100 µg D_2
Field in jet	1 kG

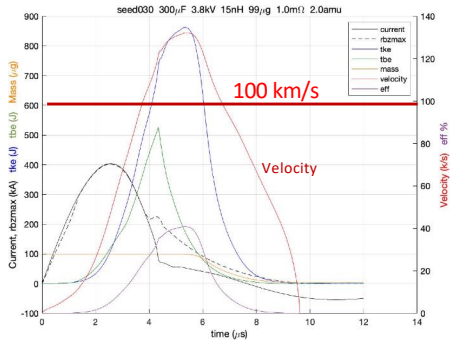
200 µF at 4.0 kV

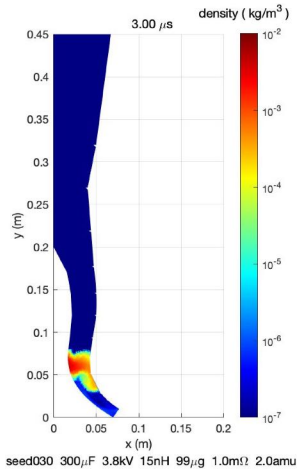


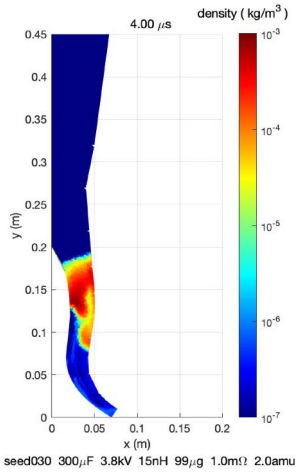
200 µF at 5.0 kV

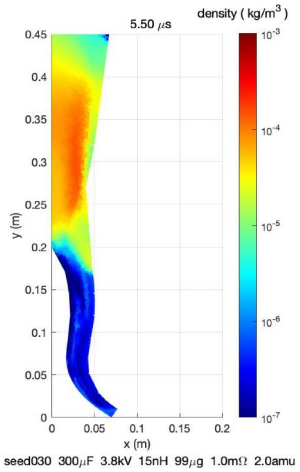


300 µF at 3.8 kV









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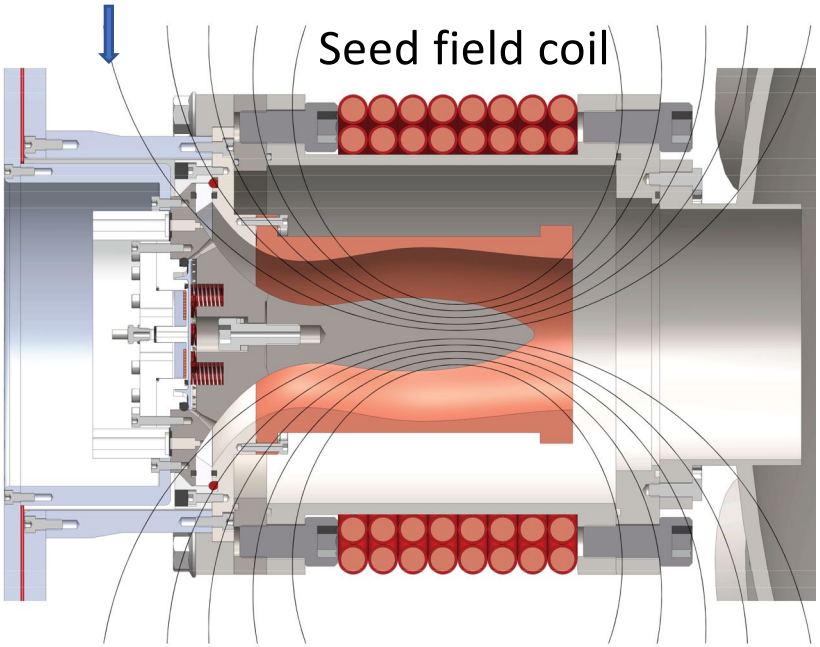
PLX

We are developing the magnetized gun by adding an external coil to generate flux in the HJ1 breech

Coil moved to here



Original concept called for coil around vacuum port. Avoids HV vacuum penetrations on PLX!!

The spheromak is a minimum-energy state towards which any initial magnetized plasma configuration will relax, as demonstrated by the diversity of methods used to produce them

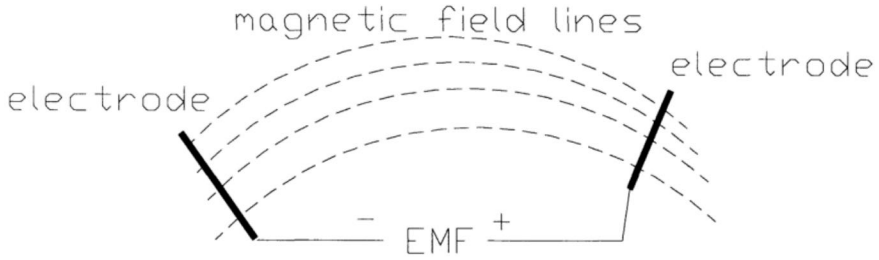
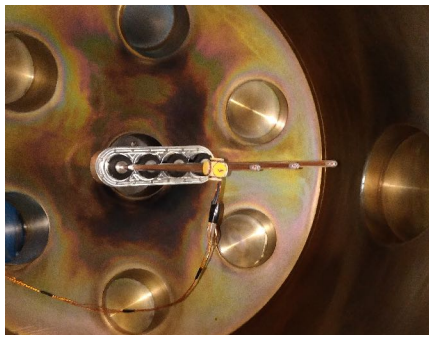


Fig. 7.1 Generic spheromak formation scheme: An EMF applied along field lines drives field-aligned current, or equivalently, injects magnetic helicity. When the ratio of field-aligned current to intercepted flux exceeds a threshold, closed field lines are formed, i.e., a spheromak-like configuration is created.

Ref: Paul M. Bellan, *Spheromaks*, Ch. 7, World Scientific, 2000

Modular B-dot fork system for single jet tests

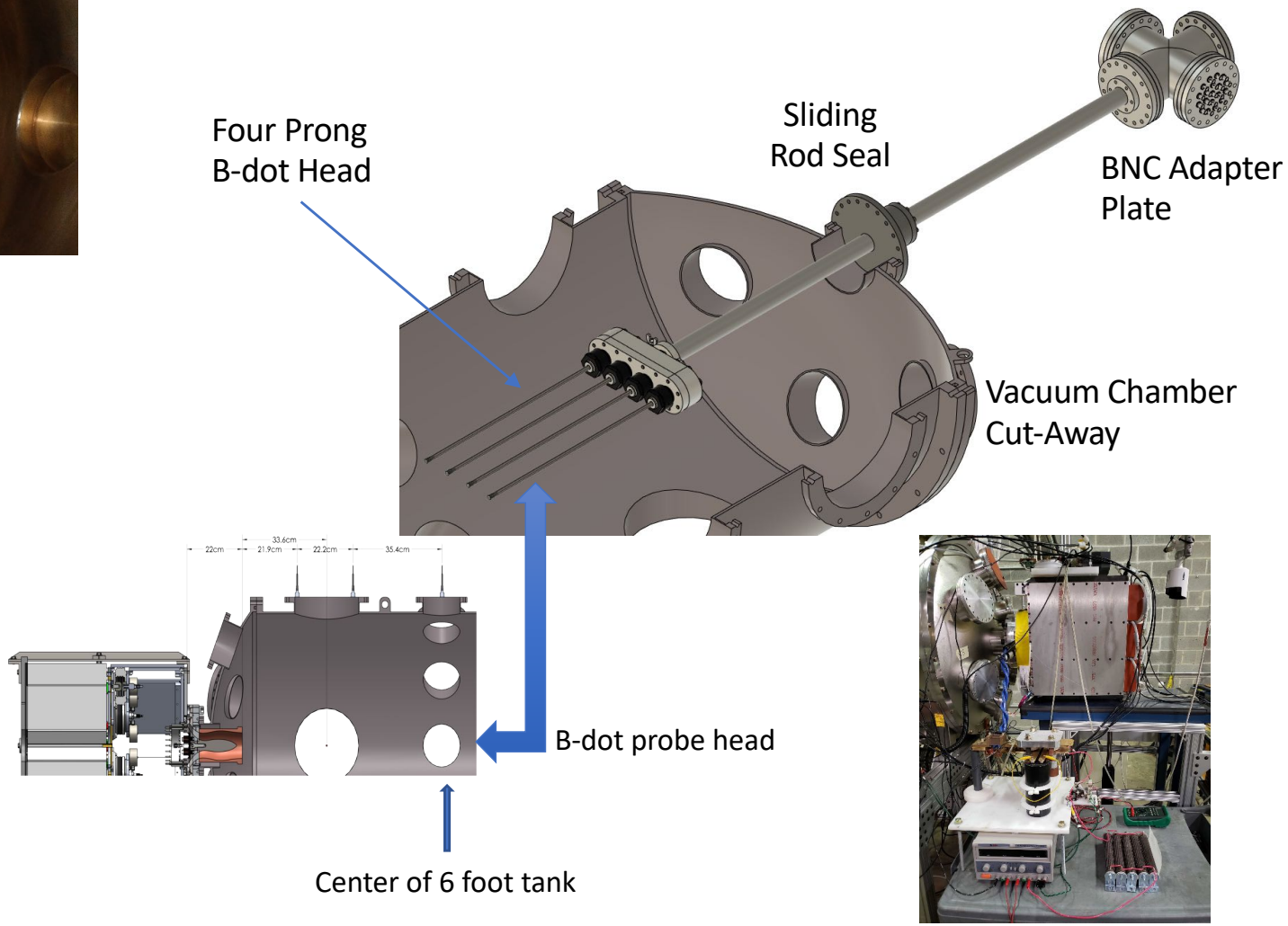


Three main components:

1) Bdot head assembly
2) Rod seal assembly
3) Back-end assembly

Modular head/effector for future diagnostic purposes.

Each probe has three 10 turn pickup loops, one each for B_x, B_y, and B_z.

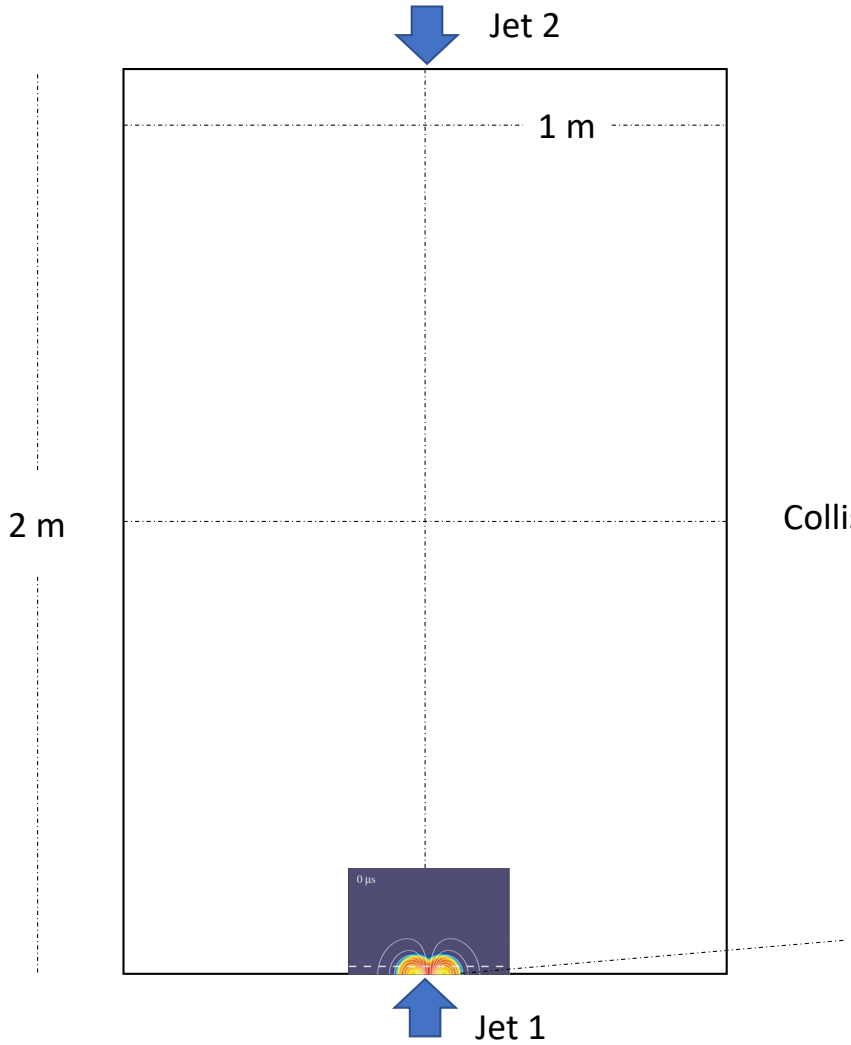


Setup for LANL 3D Simulations

Full size of HyperJet Vacuum chamber and target formation experiments

LANL Cluster

Badger CTS-1
Intel Xeon Broadwell
Linux
660 nodes
36 cores/node
23,760 total cores
128GB / 84.5 TiB
798 TFlops/s
23.5 PB storage



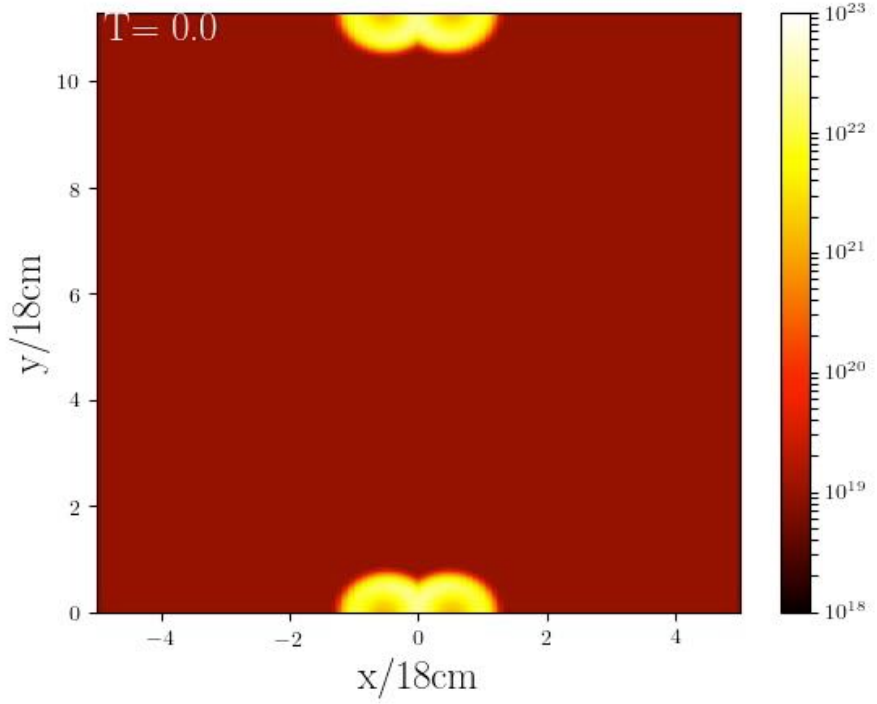
Goal post-collision parameters:
Hydrogen plasma
Te ~= 50 eV
B ~= 500 gauss
Ne ~= 3 x 10^{14} cm^{-3}
Leading to:
Beta ~= 1
Electron Hall Param. ~= 100

Grid resolution 3.6 mm
Grid size 500 x 500 x 880
Uses 1100 processors to ~20 us
10 hour runs
High res runs need 14 x cpu time

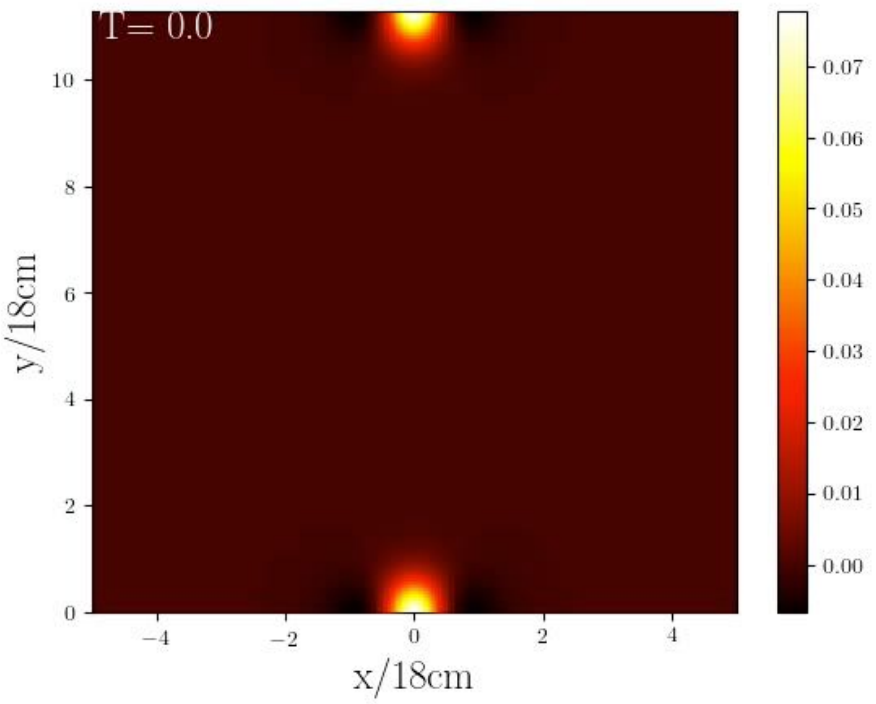
A test was done with lower "background pressure" in chamber, with minimal effect on results, confirming that this is not a significant problem in the comparison.

Initial simulation results show possibility for m=1 kink instability forming in jet

(Density)



(Bz)



- Could be a good thing, instability leading to a more “tangled” field !
- This 3D instability was not captured by our previous models (2d axisymmetric)

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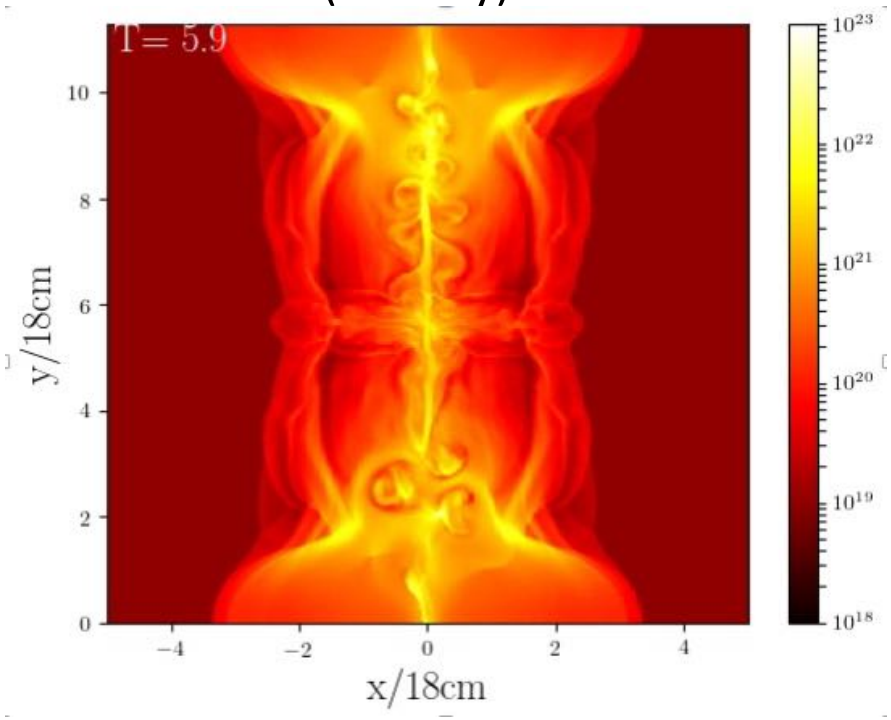

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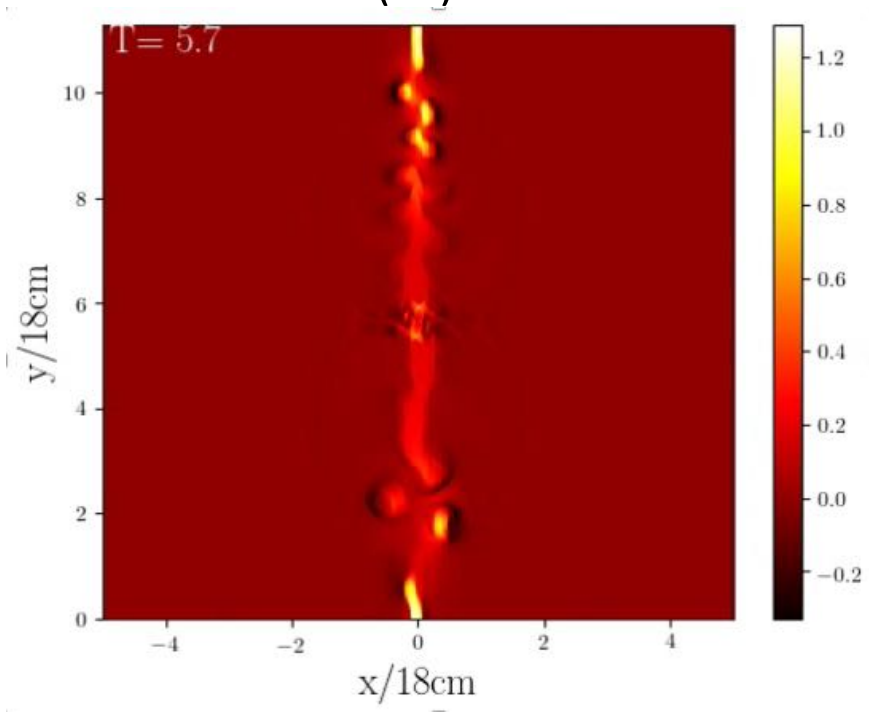

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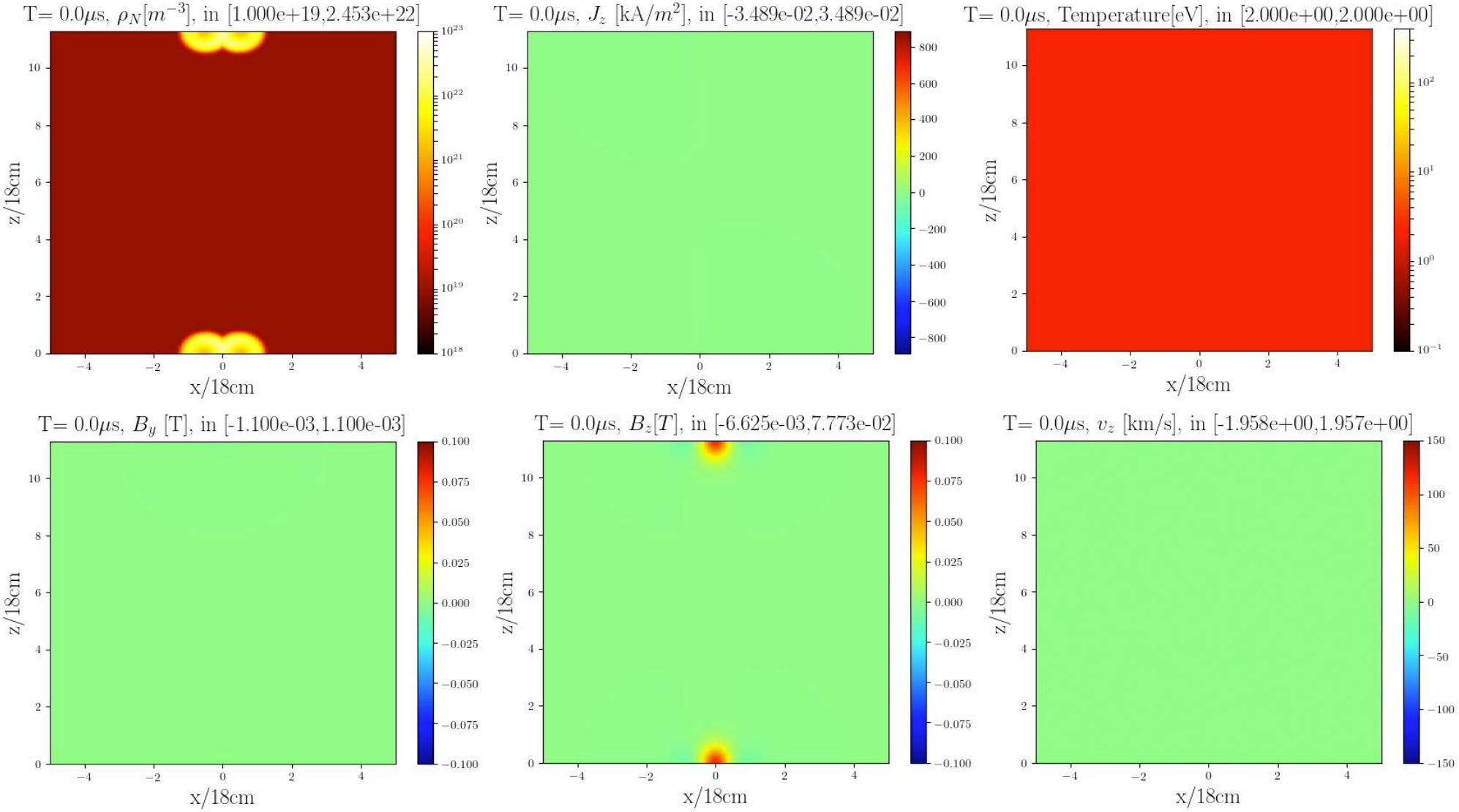
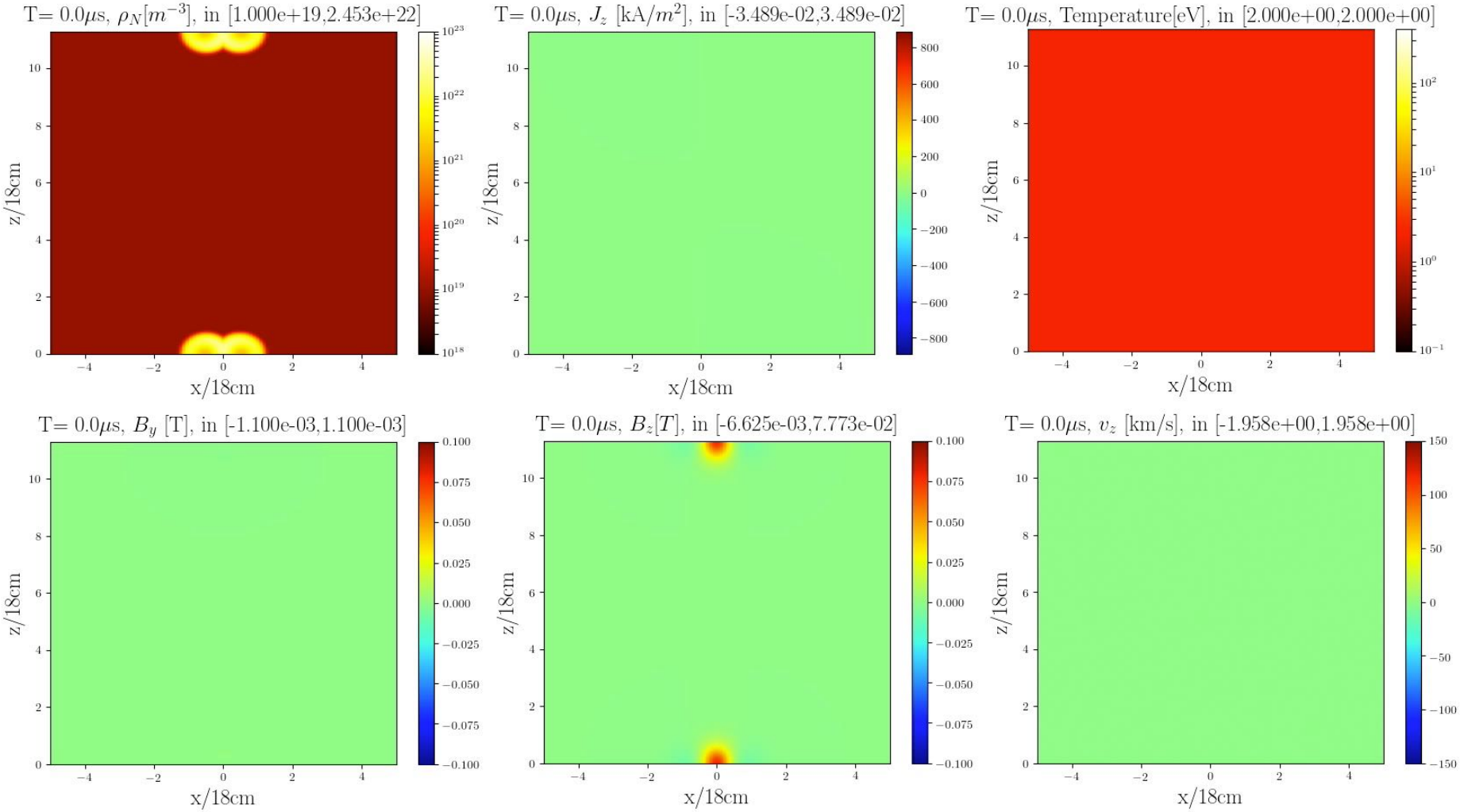
Lower current leads to more stable jet, but still can form tangles on collision



Instability is only excited at high current, low field range of experimental parameters



- Ultimately, prediction is that the instability may only be weak / not form on our scale
- Plasma parameters predicted on collision look good for BETHE program goals

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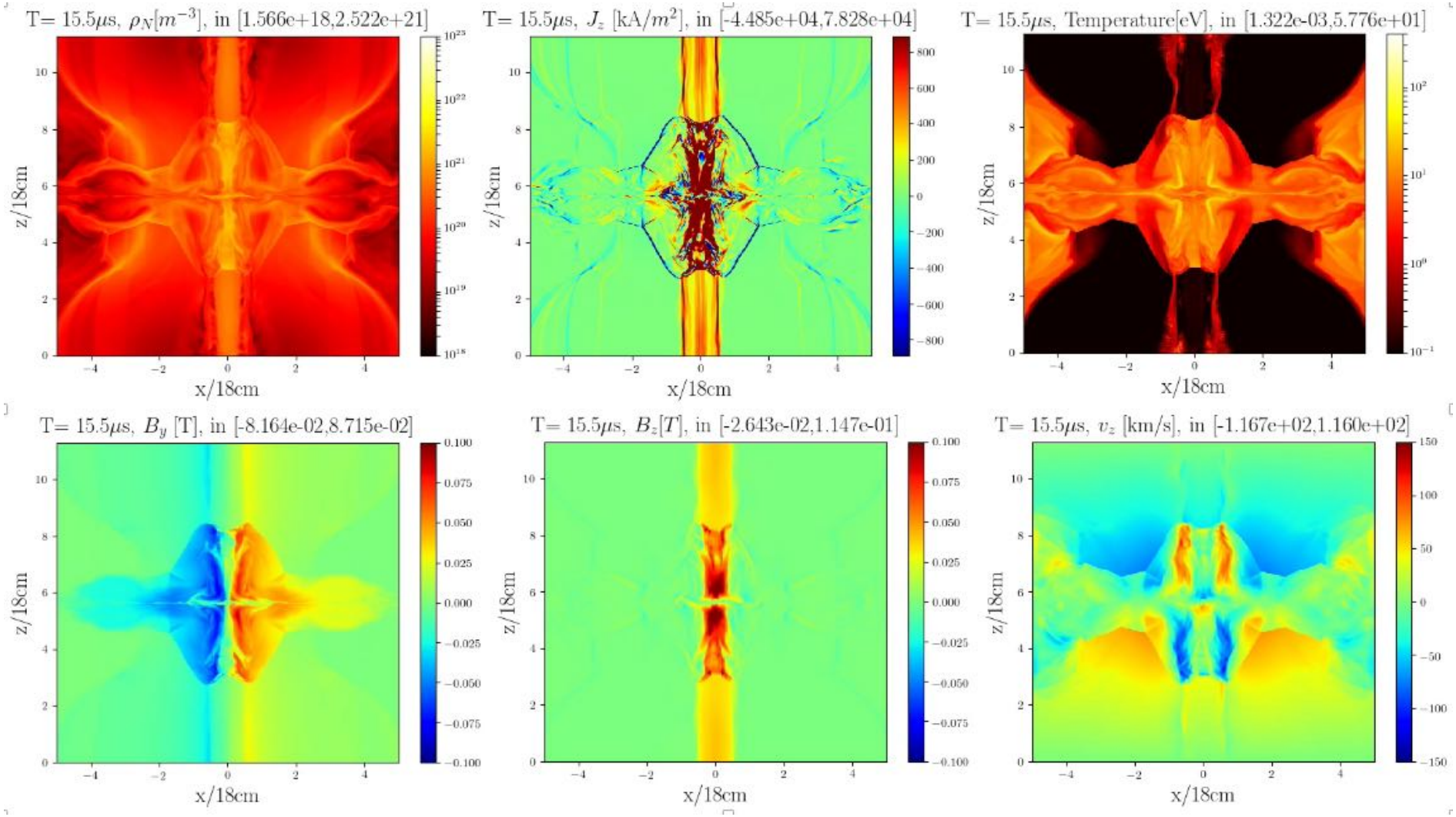
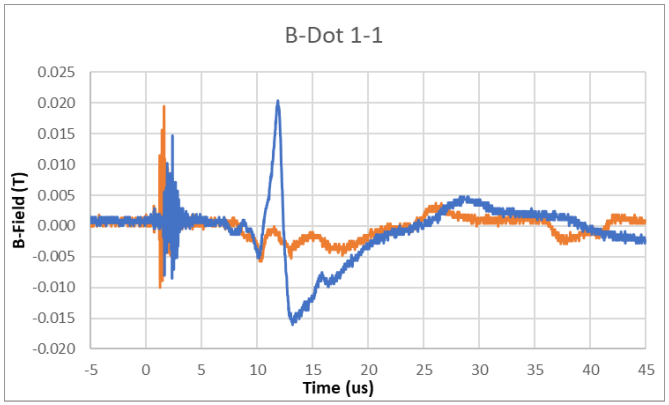
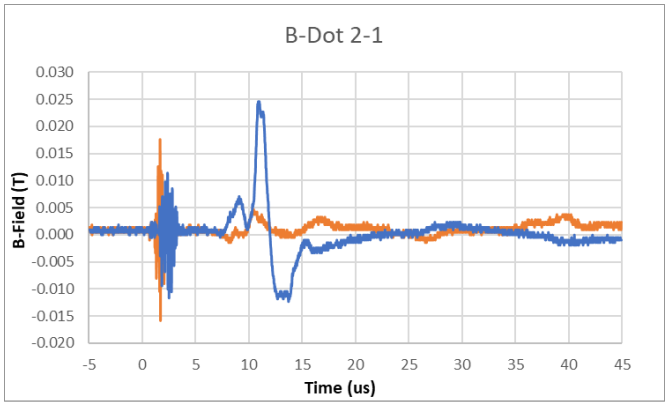


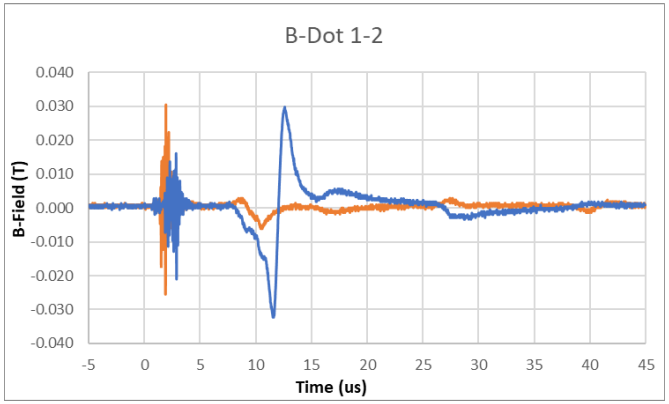
- Ultimately, prediction is that the instability may only be weak / not form on our scale
- Plasma parameters predicted on collision look good for BETHE program goals

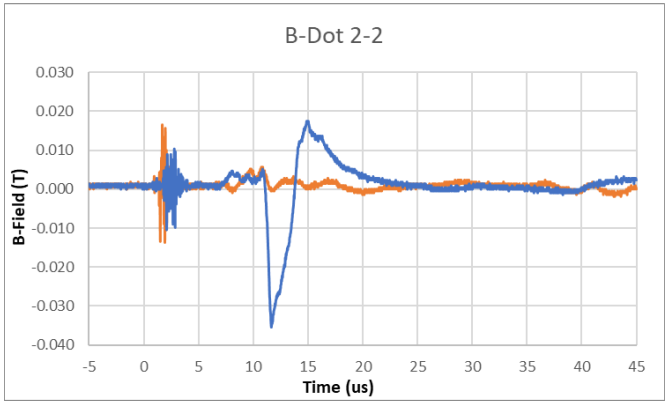
First experimental results with one magnetized jet (no collision)

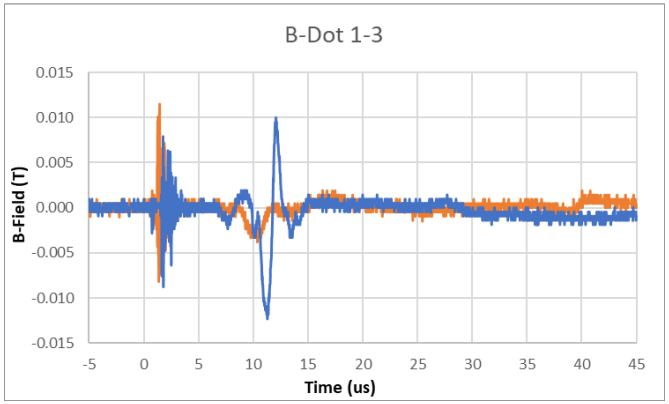
- Bdot probes near the chamber centerline recorded field components in first low-field test.
- Field seems stable rather than highly fluctuating, but shows rotation / reversal, possibly in agreement with the simulated structure.
- More analysis ongoing for detailed conclusions to be drawn.

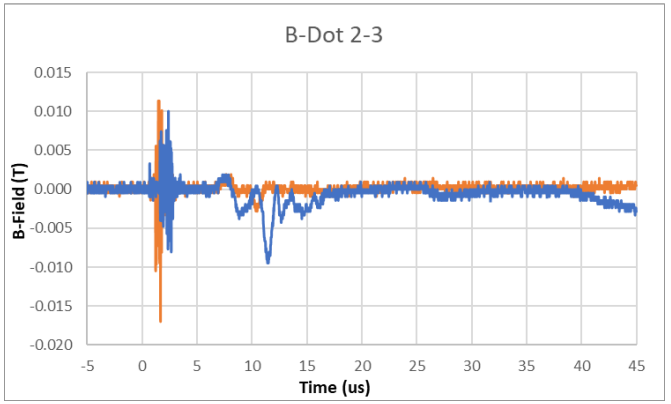






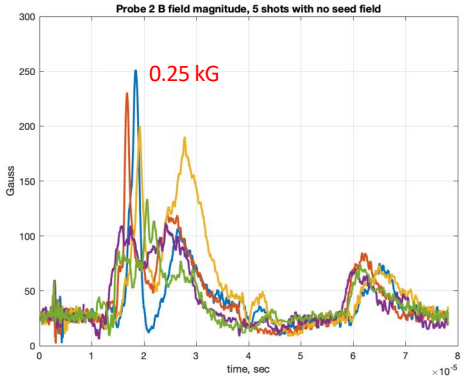


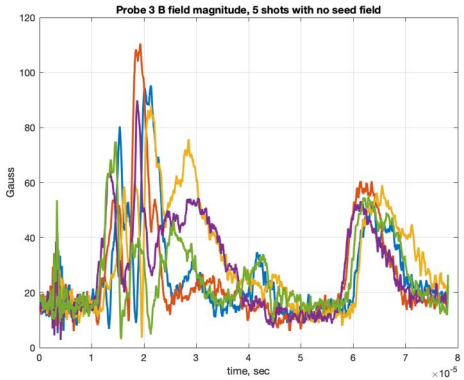




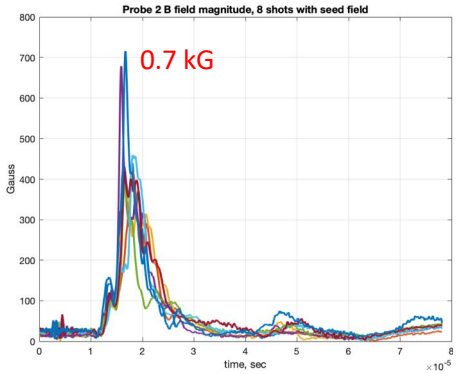
We observe nicely magnetized jets close to 1 kG for seeded cases with 8 turn coil

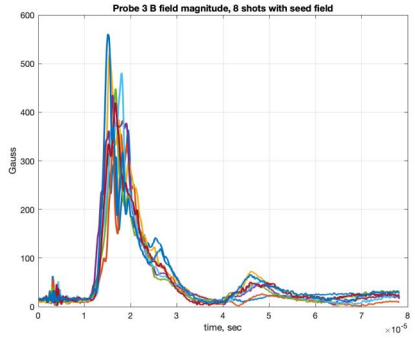
5 He shots no Seed field



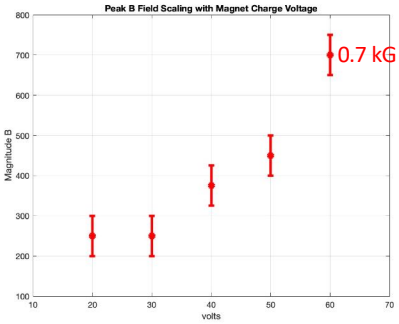


8 He shots with Seed field



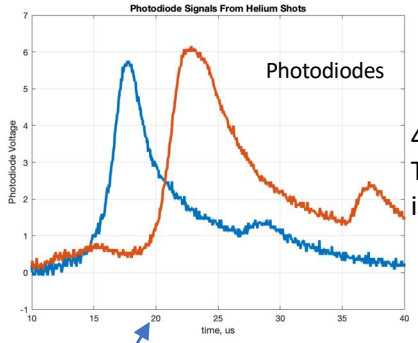


Peak B_{jet} scales with voltage (i.e. B_{seed})

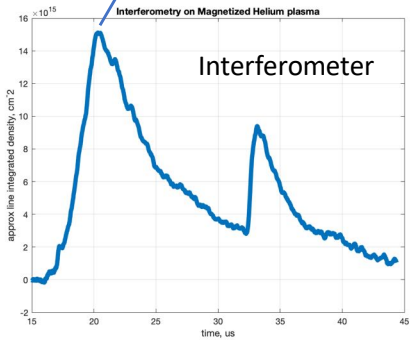


Magnet charge voltage

Initial test results



40 km/s
Total mass is too large!



Density on track

Some recent tests indicate 90-110 km/s as we reduce mass.

We are currently installing 30 turn coil to produce larger fields

Conclusions

- Simulations are providing useful insight for upcoming planned colliding jet experiments
- Instabilities in jet could help generate “tangled” field
- Two colliding magnetized jet experiments are planned for 2021
- INFUSE is definitely a useful program!