EXPERIMENTS AND SIMULATIONS OF MAGNETICALLY DRIVEN IMPLOSIONS IN HIGH REPETITION RATE DENSE PLASMA FOCUS

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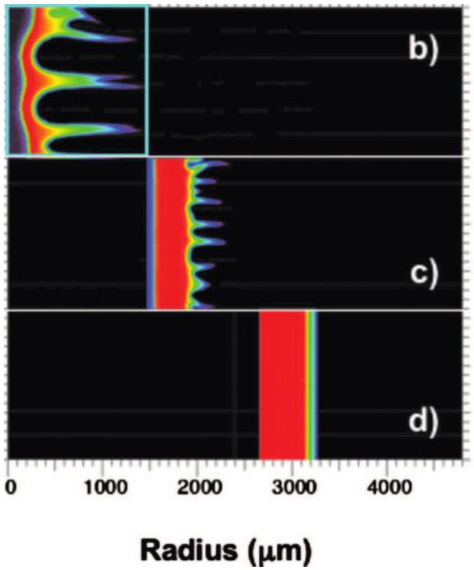
Outline

- Motivation and Goal
- Experiment
- Diagnostics and Data Recollection
- Experiments v Models
- Final Remarks

Motivation

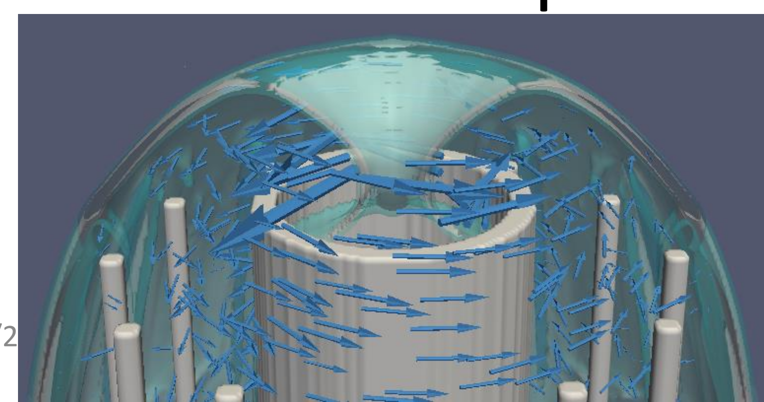
- Understand the plasma-driver coupling by study fluid instabilities at the surface of Magnetically Driven Implosions (MDI).
  - key to improve its efficiency.
- Tackled fundamental questions in physical processes relevant to Inertial Confinement Fusion (ICF) and Magnetized Liner Inertial Fusion (MagLIF).
  - instability seeding
  - fuel compression
  - heat loss

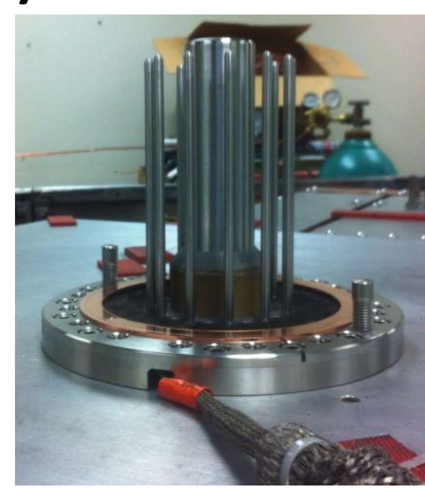


* *S Slutz et al, PoP, **17**, 056303 (2010).*

Goals

- Understand the instability growth along with the current diffusion losses, with and without the aid of external magnetic fields.
- Comparison between empirical data and theoretical models contributing to understand these phenomena.
- Have a fully 3D simulation code of a Plasma Focus with an accurate and a variety of measurable empirical parameters.



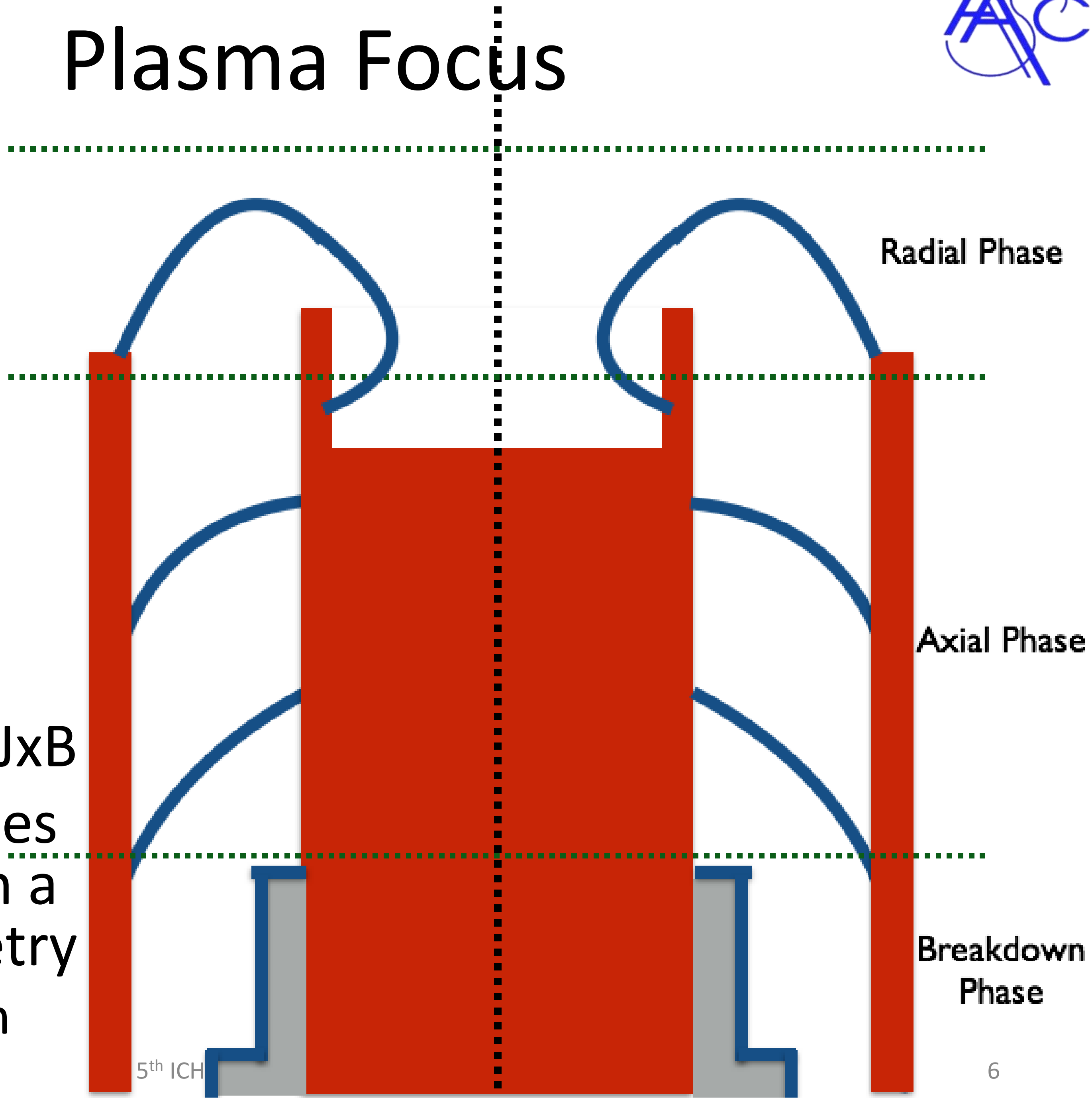


The Experimental Device

- A Dense Plasma Focus (DPF) is a medium to small size driver which works at the appropriate plasma regime to tackle the above goals.
  - well studied in terms of radiation and neutron yield over the last few decades
  - reliable and reproducible MDI source
  - rapid variation of load (i.e. gas and pressure)
  - 100s of shots per day, hence an accurate and meaningful statistical analysis to validate these fundamental physical phenomena
- DPF-3 is a Mather-type DPF based at Alameda Applied Science Corporation (AASC).
- System designed to produce 0.5J/pulse Ar SXR (3.1keV) and >10^8 n/pulse operating at <0.2Hz.
- Is a calibration tool for soft X-ray and neutron detectors for large burst situations.
- Typical operational parameters are:
  - Ne, Ar, He gas loads at 1-20 Torr
  - Current: 300-600 kA in 1.2μs rise time pulse
  - Charge Voltage: 10-20 kV
  - Stored Energy: few kJ
  - Rep. Rate: 0.1 – 10 Hz
  - # shots: 100s – 1000s per day

Plasma Focus

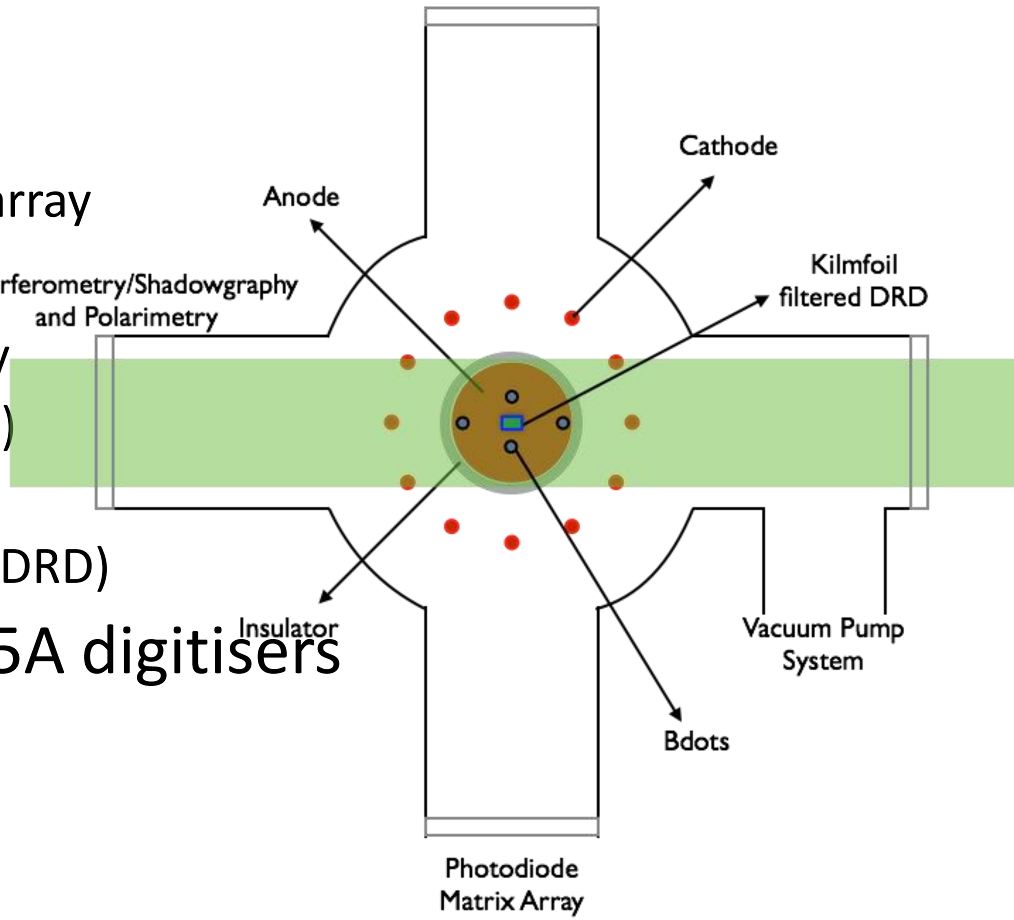
- Cylindrical Geometry
- Gas load
- Electrical discharge producing a plasma
- Plasma sheath dynamics dominated by JxB
- Plasma implodes in the centre in a Z-pinch geometry
  - Peak radiation



Diagnostics and Data Recollection

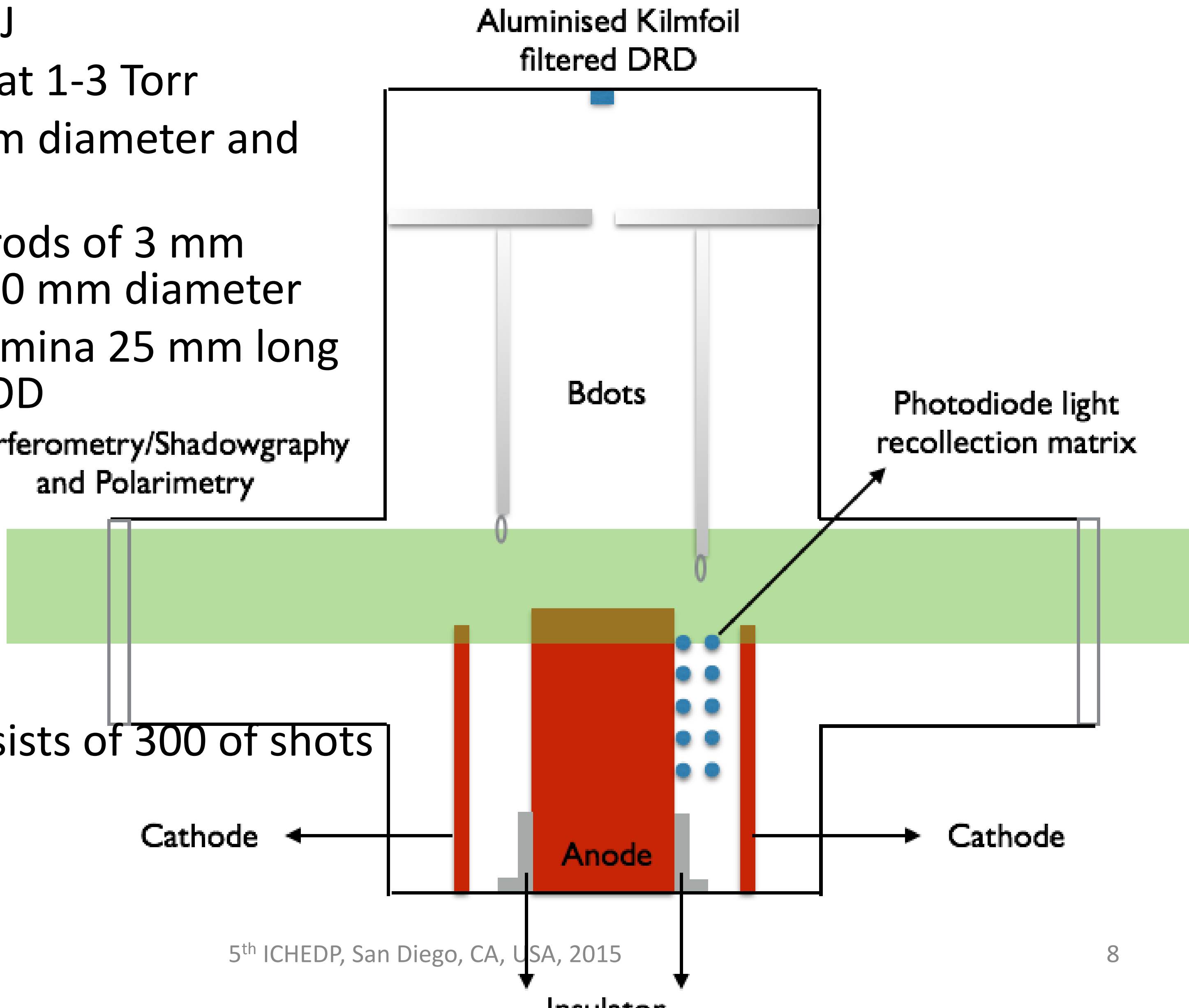
- Simultaneous, comprehensive and detailed diagnostics setup
  - Electrical Parameters
    - Rogowski coil and HV probe
  - Axial Phase
    - Non-intrusive optical system array
  - Radial Phase
    - Interferometry/shadowgraphy
    - Faraday Rotation (Polarimetry)
    - B-dots
    - Diamond Radiation Detector (DRD)
- 12 channel Tektronix TVS645A digitisers
  - 1 GHz and 5 GS/s
  - 8-bit vertical resolution

End on view of the DPF diagnostic setup



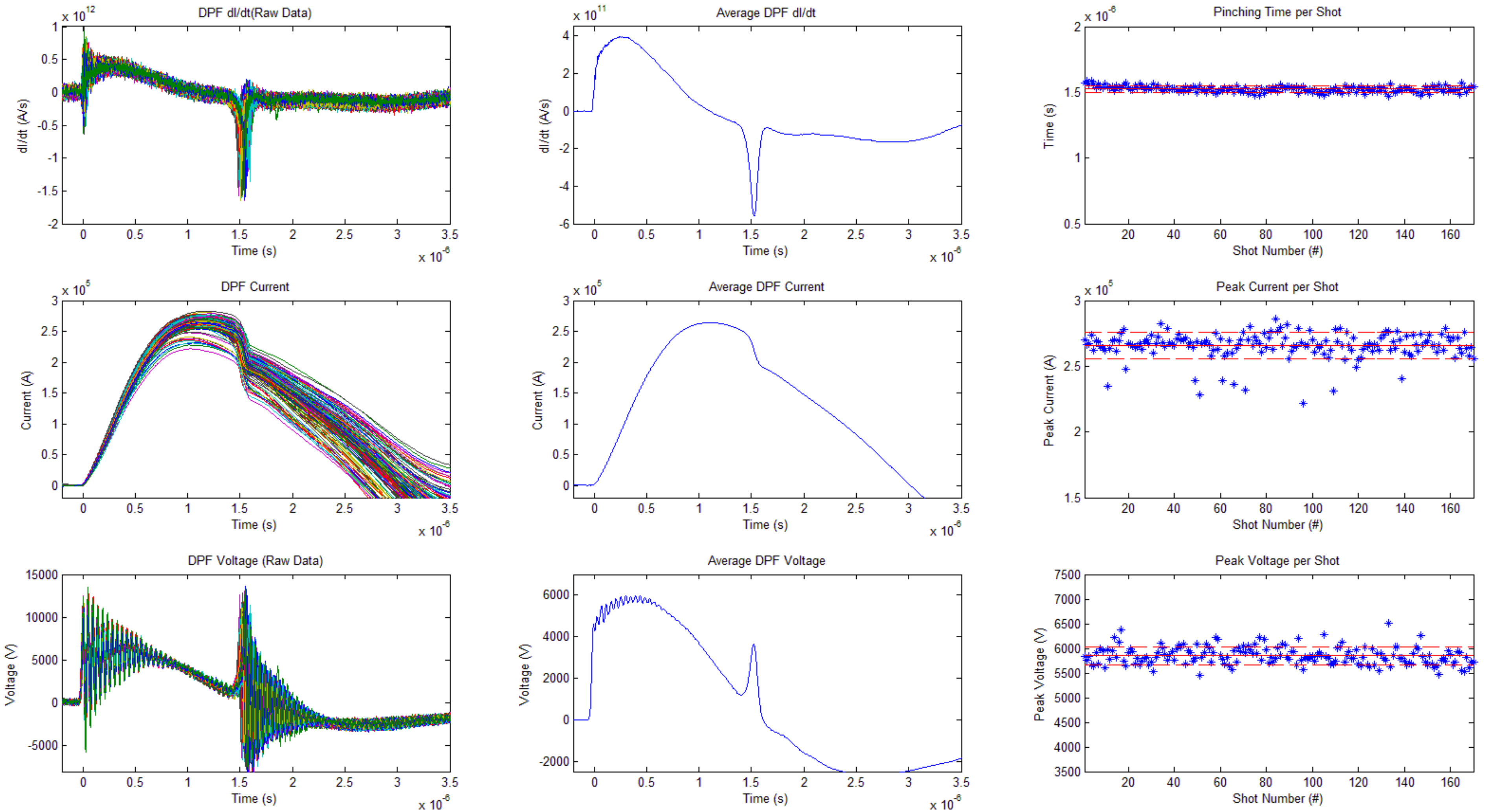
Experimental and Diagnostic Setup

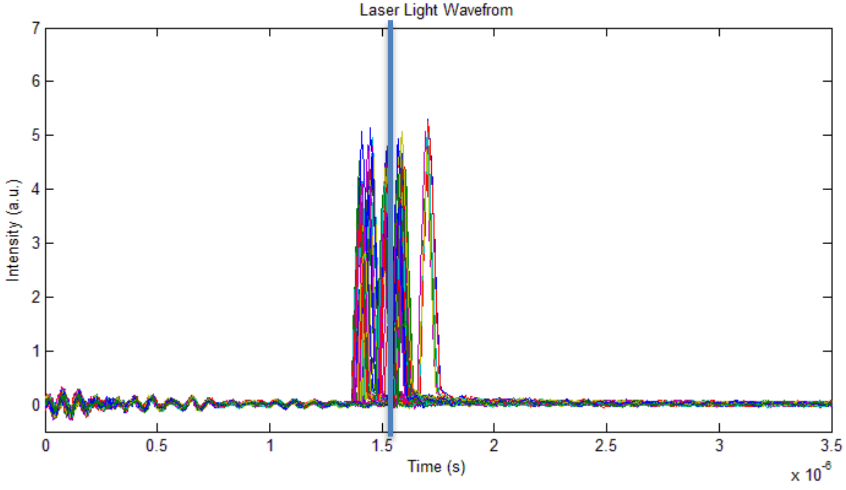
- V_c=11kV, 1.7kJ
- Gas load: Ne at 1-3 Torr
- Anode: 30 mm diameter and 85mm length
- Cathode: 16 rods of 3 mm diameter at 60 mm diameter
- Insulator: Alumina 25 mm long with 43 mm OD
- L_0= 19nH
- C_0= 28.8µF
- R_0=7mΩ



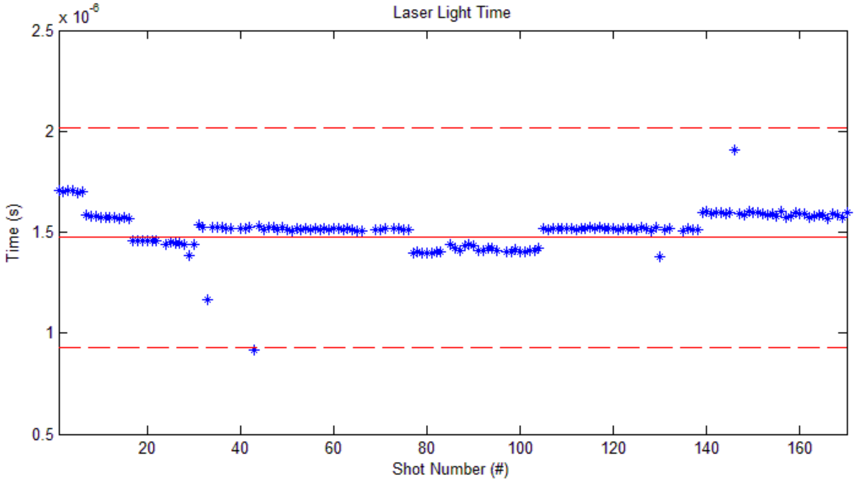
- Each run consists of 300 of shots

Data Recollection

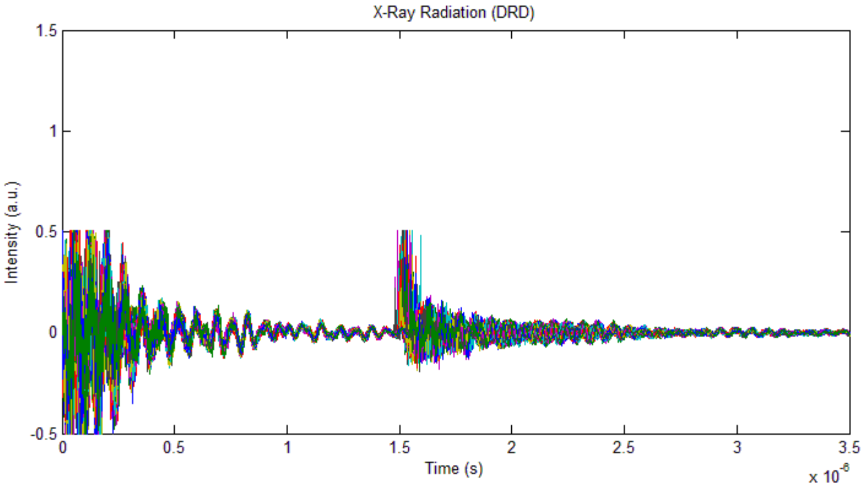




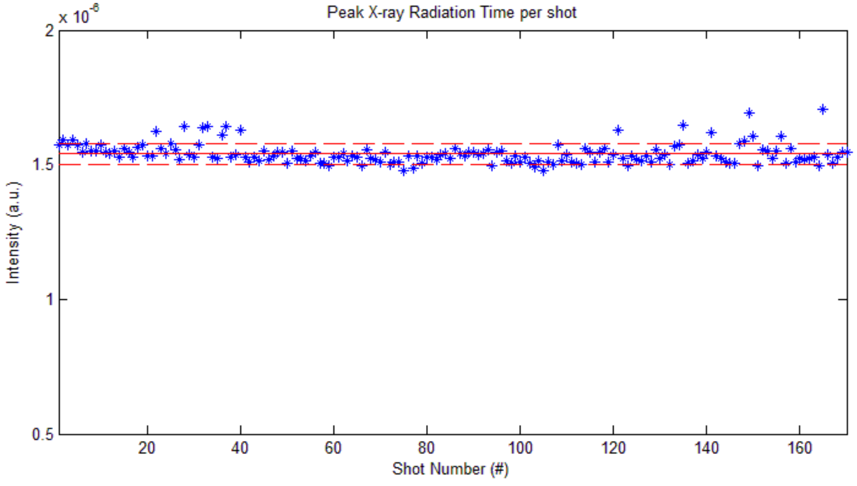
Laser Light Wavefrom
Intensity (a.u.)
Time (s)
x 10^-6



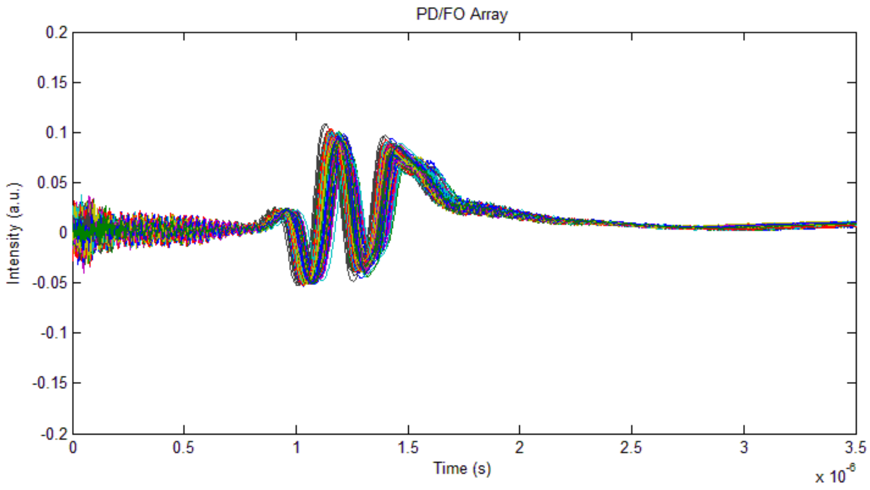
Laser Light Time
x 10^-6
Time (s)
Shot Number (#)

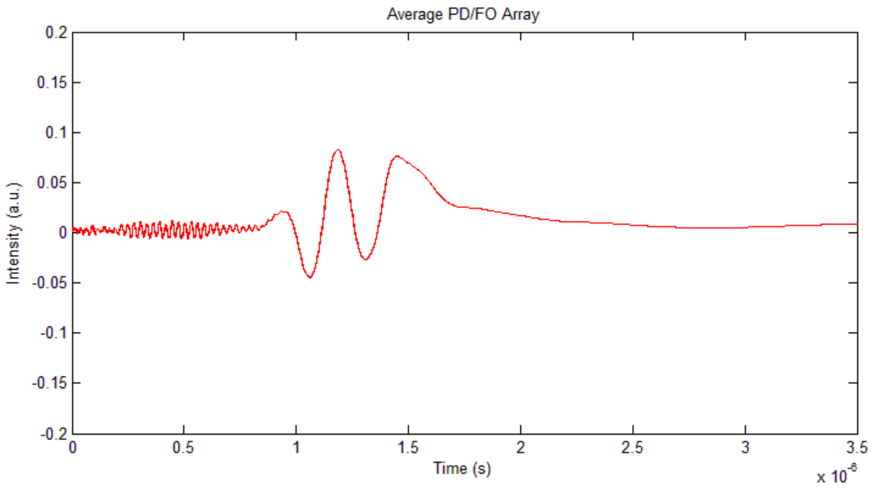


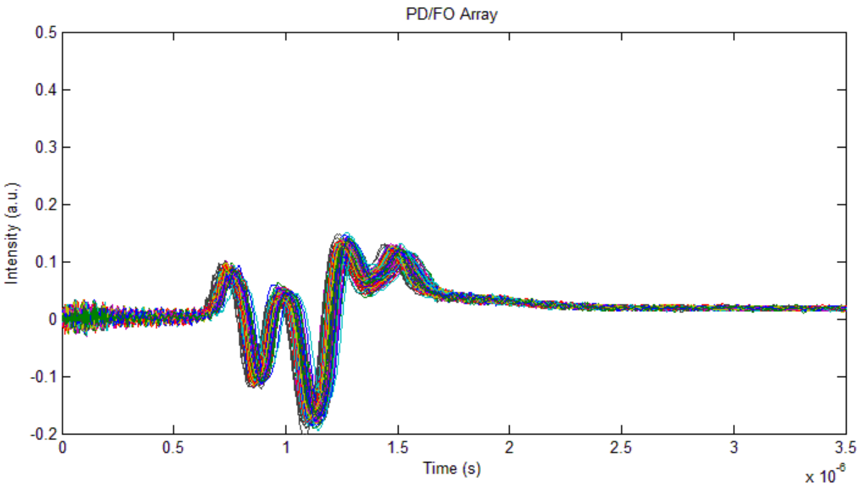
X-Ray Radiation (DRD)
Intensity (a.u.)
Time (s)
x 10^-6

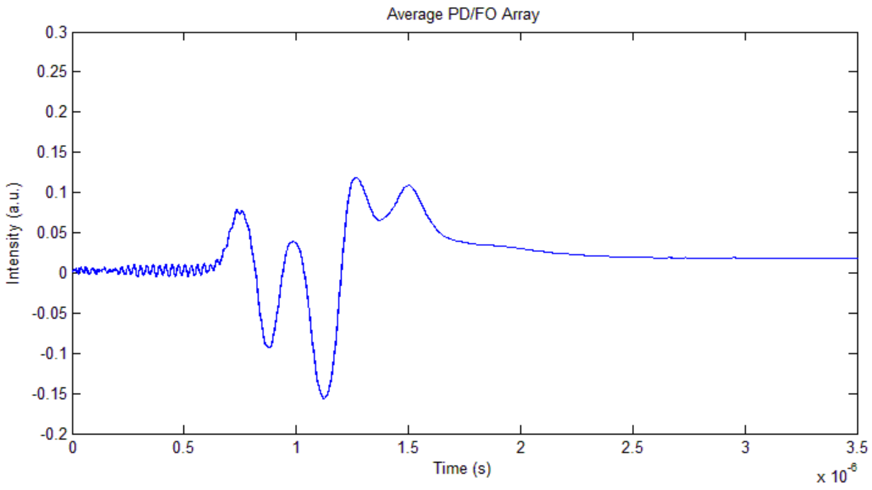


Peak X-ray Radiation Time per shot
x 10^-6
Intensity (a.u.)
Shot Number (#)

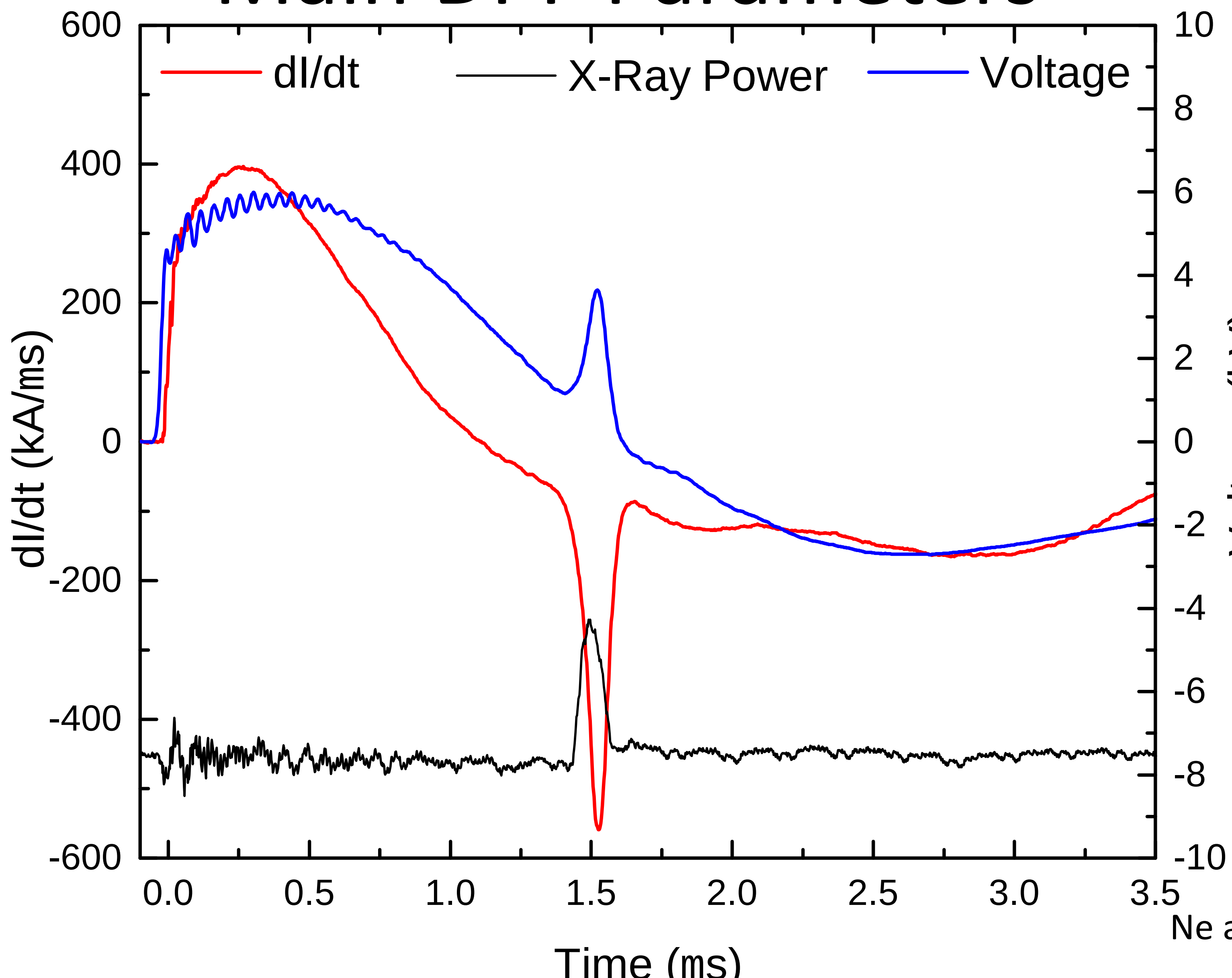

PD/FO Array
Intensity (a.u.)
Time (s)
x 10^-6


Average PD/FO Array
Intensity (a.u.)
Time (s)
x 10^-6


PD/FO Array
Intensity (a.u.)
Time (s)
x 10^-6

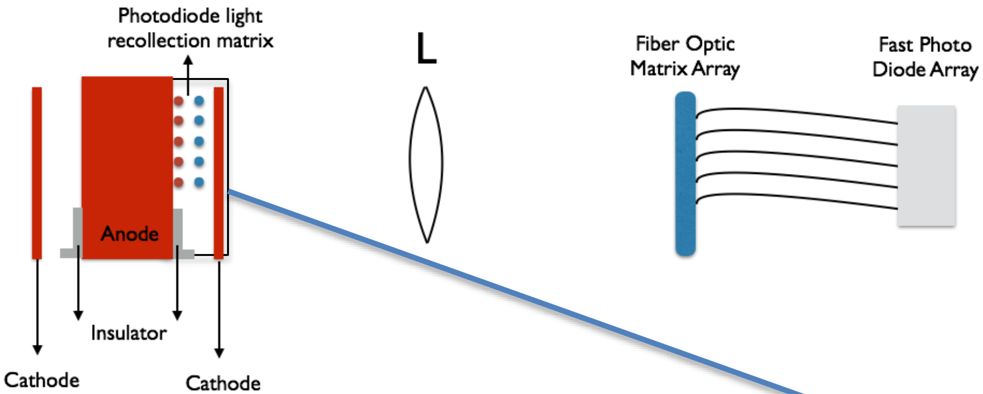

Average PD/FO Array
Intensity (a.u.)
Time (s)
x 10^-6

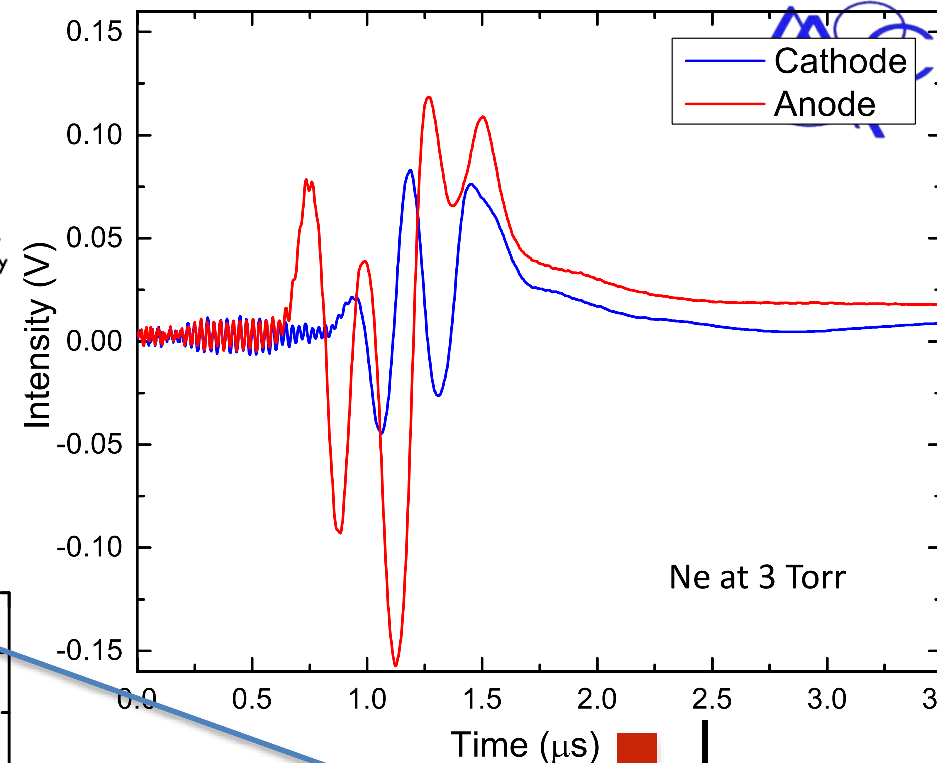
Main DPF Parameters

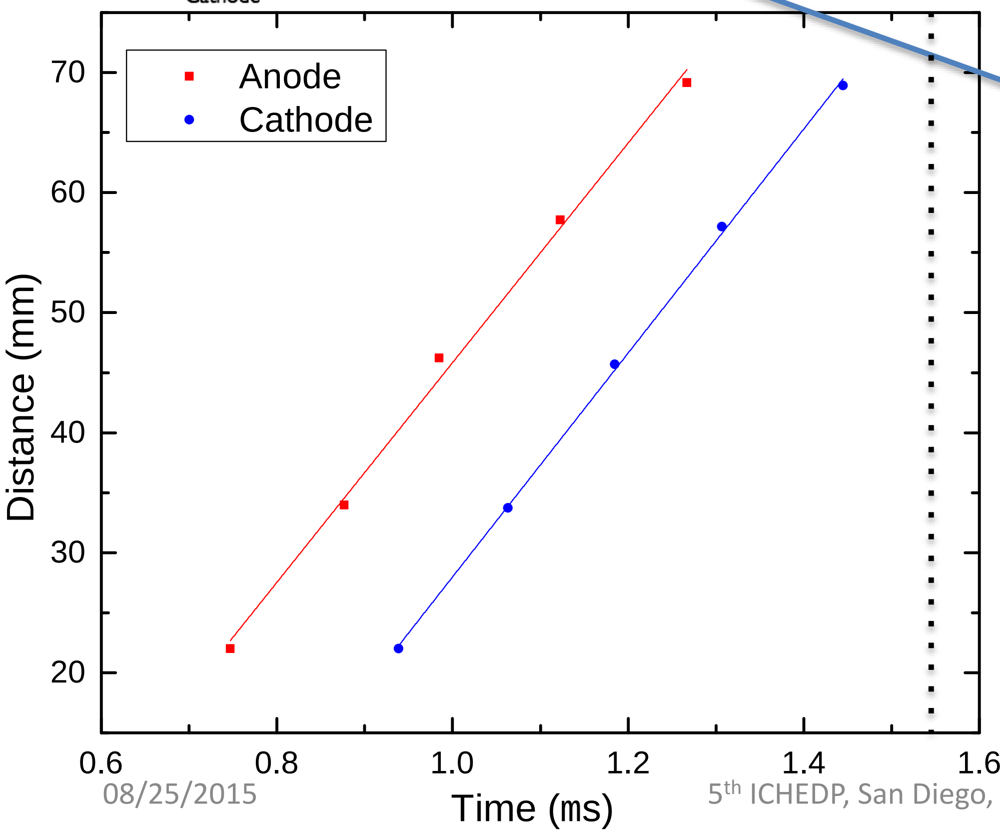


Ne at 3 Torr

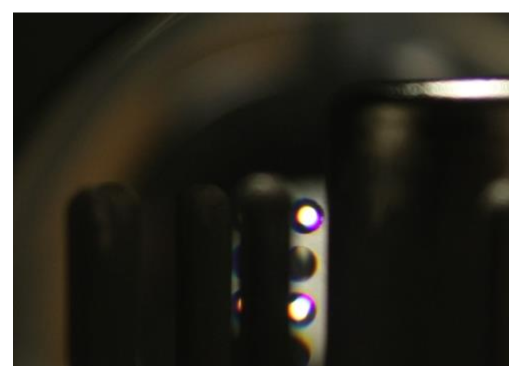
Non-intrusive optical system *

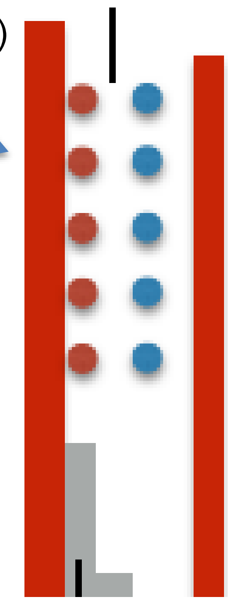






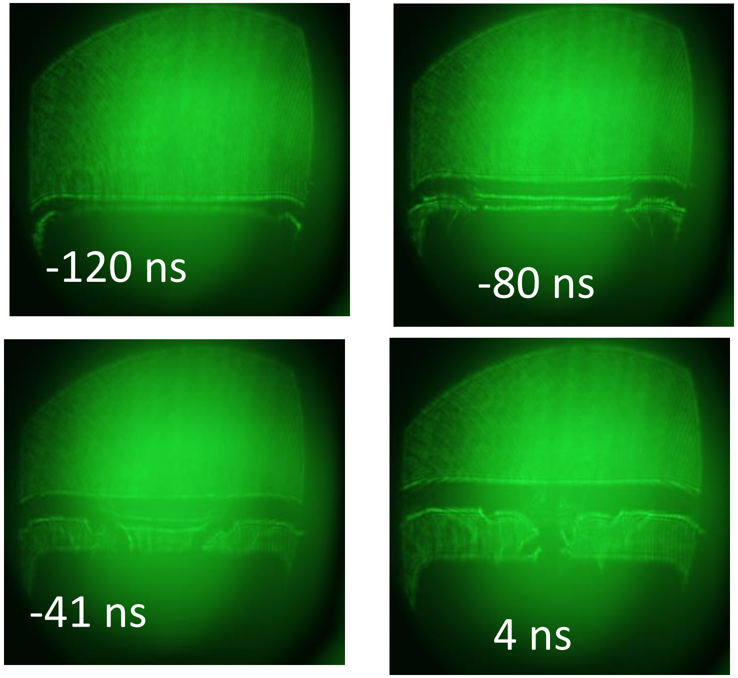
5 fast photo-diode array per column positive and negative biased

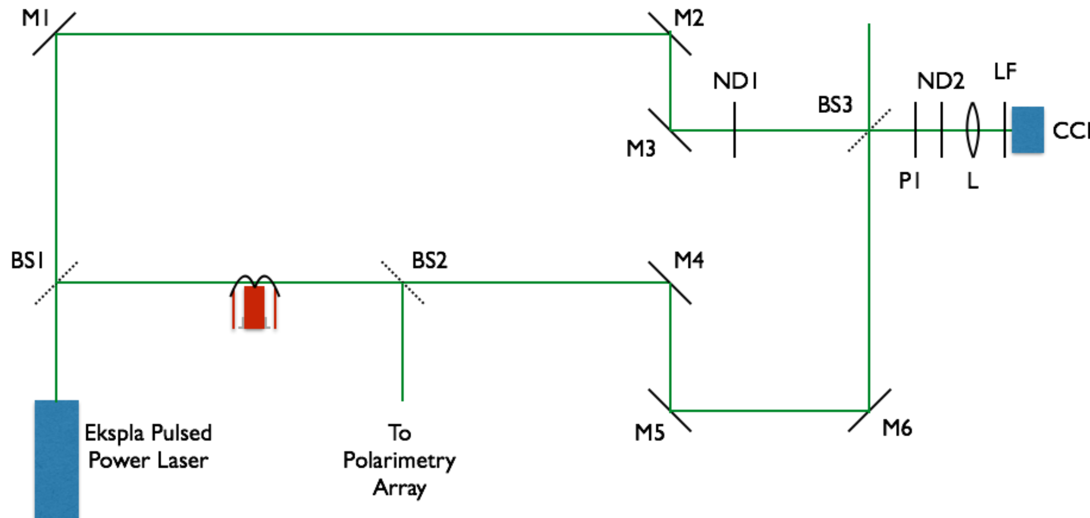


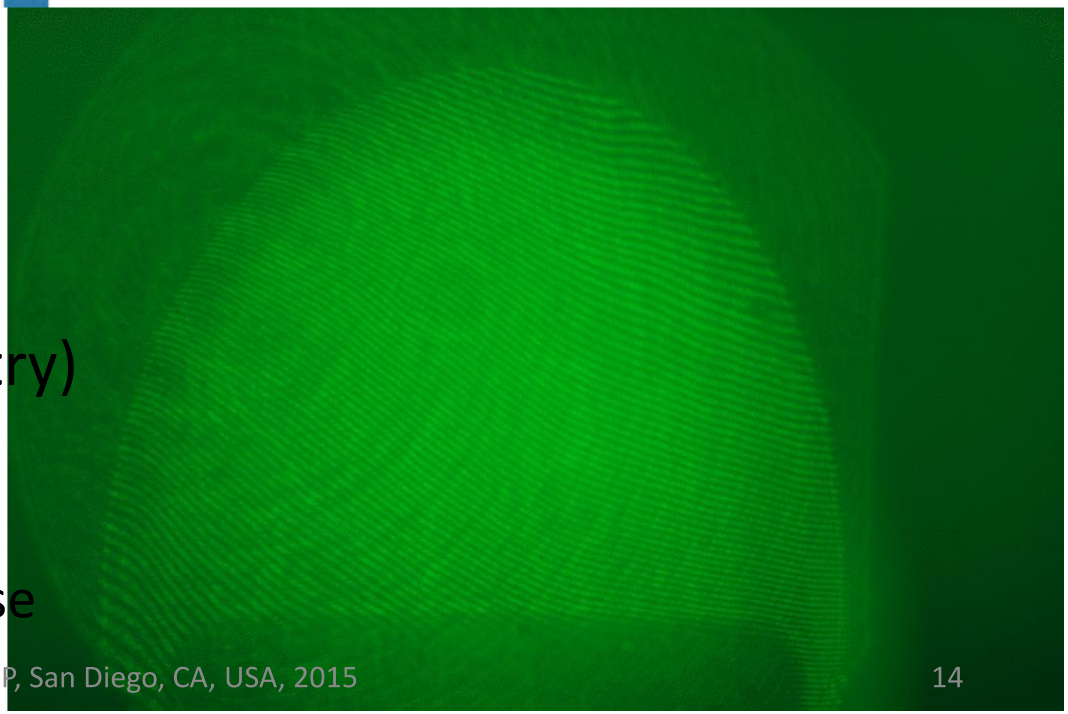


* *F Veloso et. al.* Meas. Sci. Technol. **23** (2012) 087002

Refractive Diagnostics

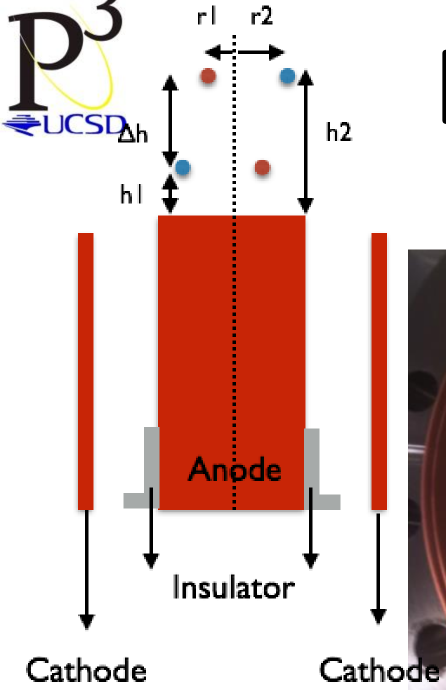


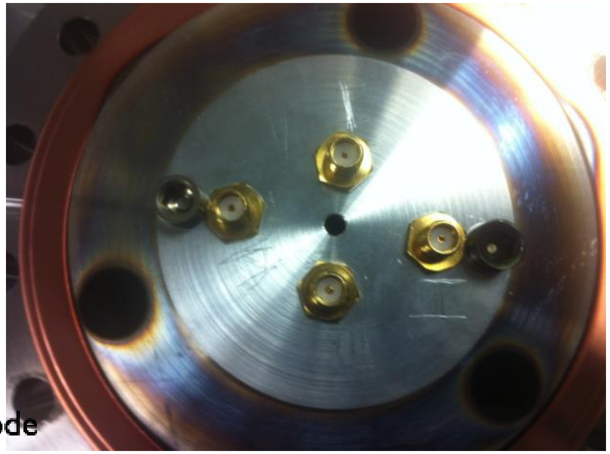


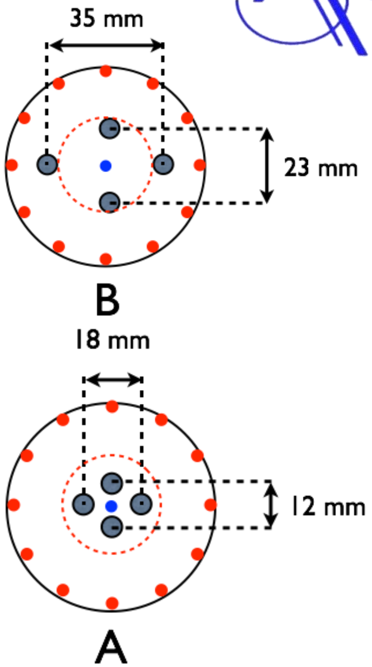


- Interferometry
- Shadowgraphy
- Faraday Rotation (Polarimetry)
- Ekspla SL312 #14 Laser
- 120 mJ, 532 nm, 150 ps
  - scan through the radial phase of the experiment

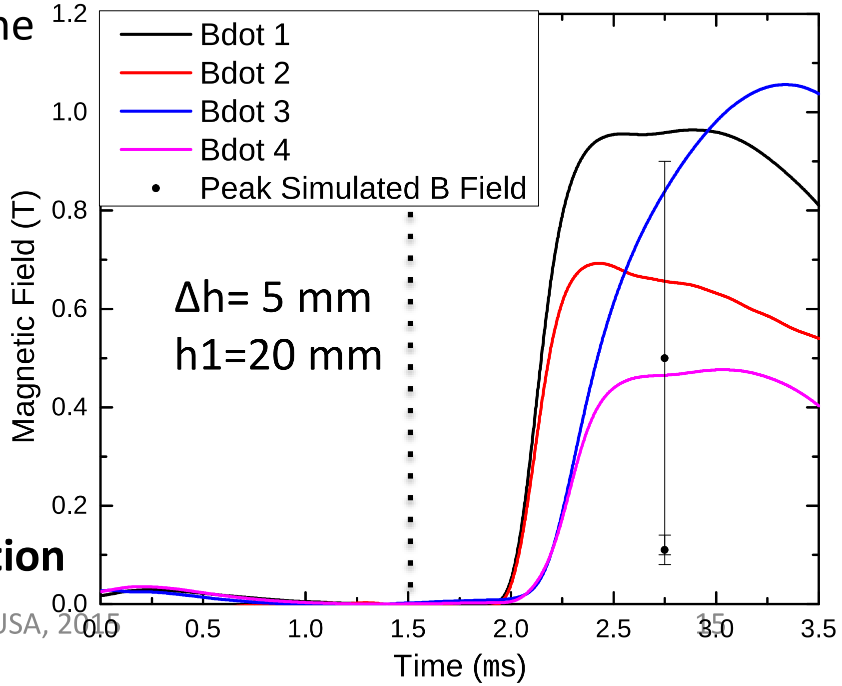
B-dots Measurements





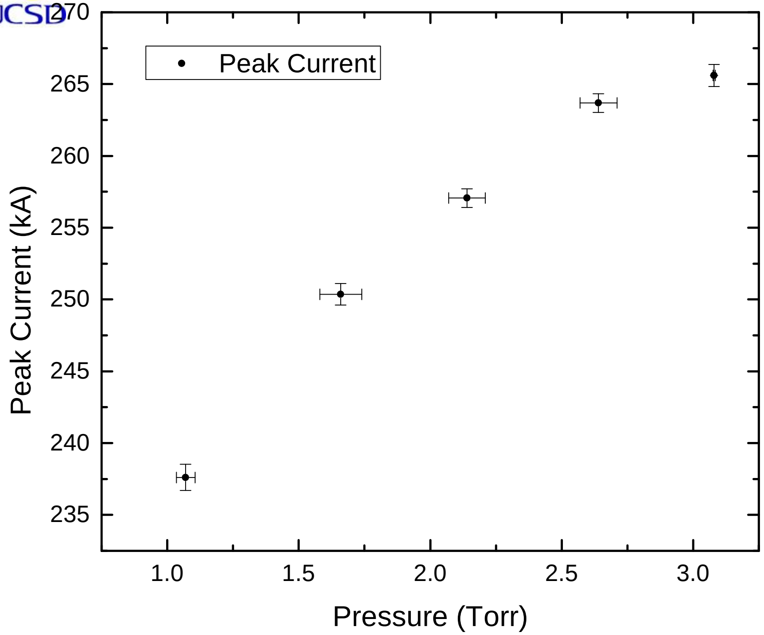


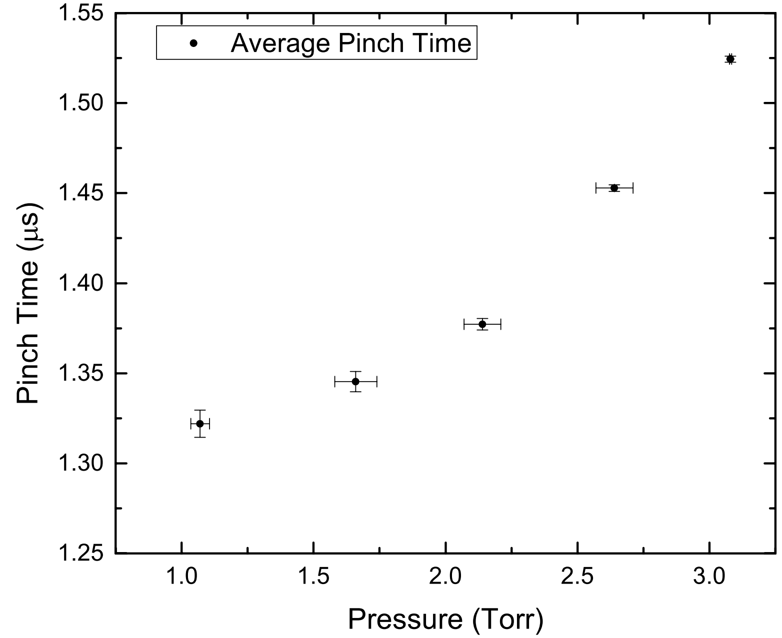
- 4 B-dots to map the B field above the anode volume
- Home made B-dots
  - Semi-rigid 50 Ω coax. cable
  - Sensor area ~ 1 mm^2
  - Two different lengths
  - Typical calibration factor: ~ 10^6 T/V
  - 2 brackets with 4 different radii
- Life span : 500+ shots

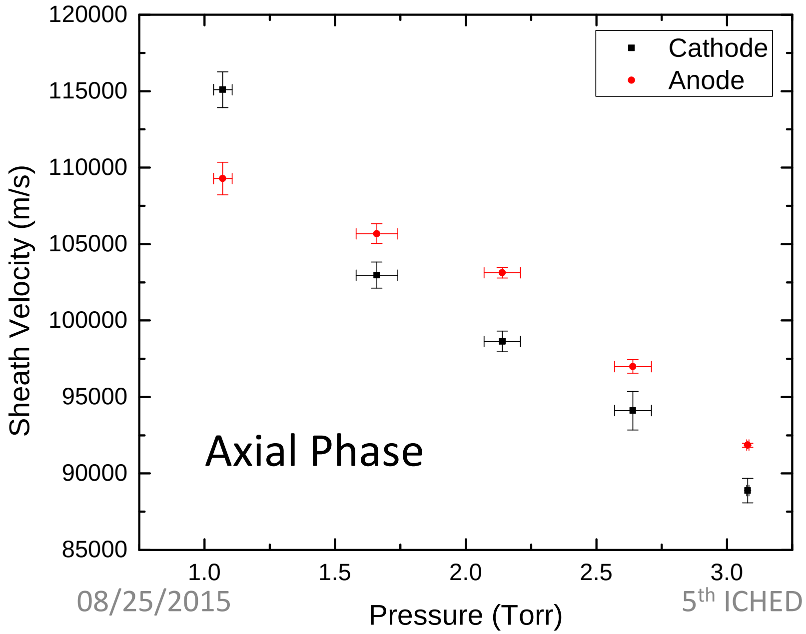


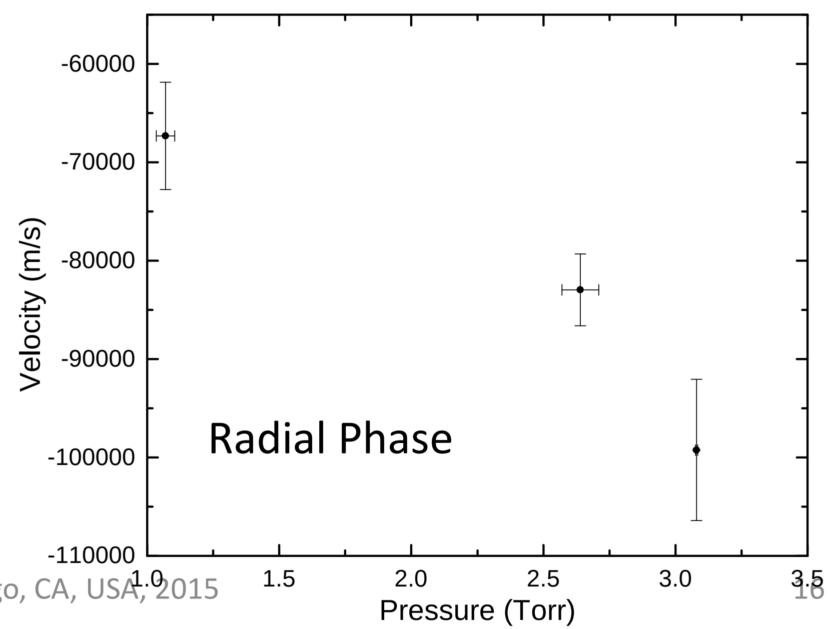
"Far away" from the anode to avoid sheath perturbation

Data Summary

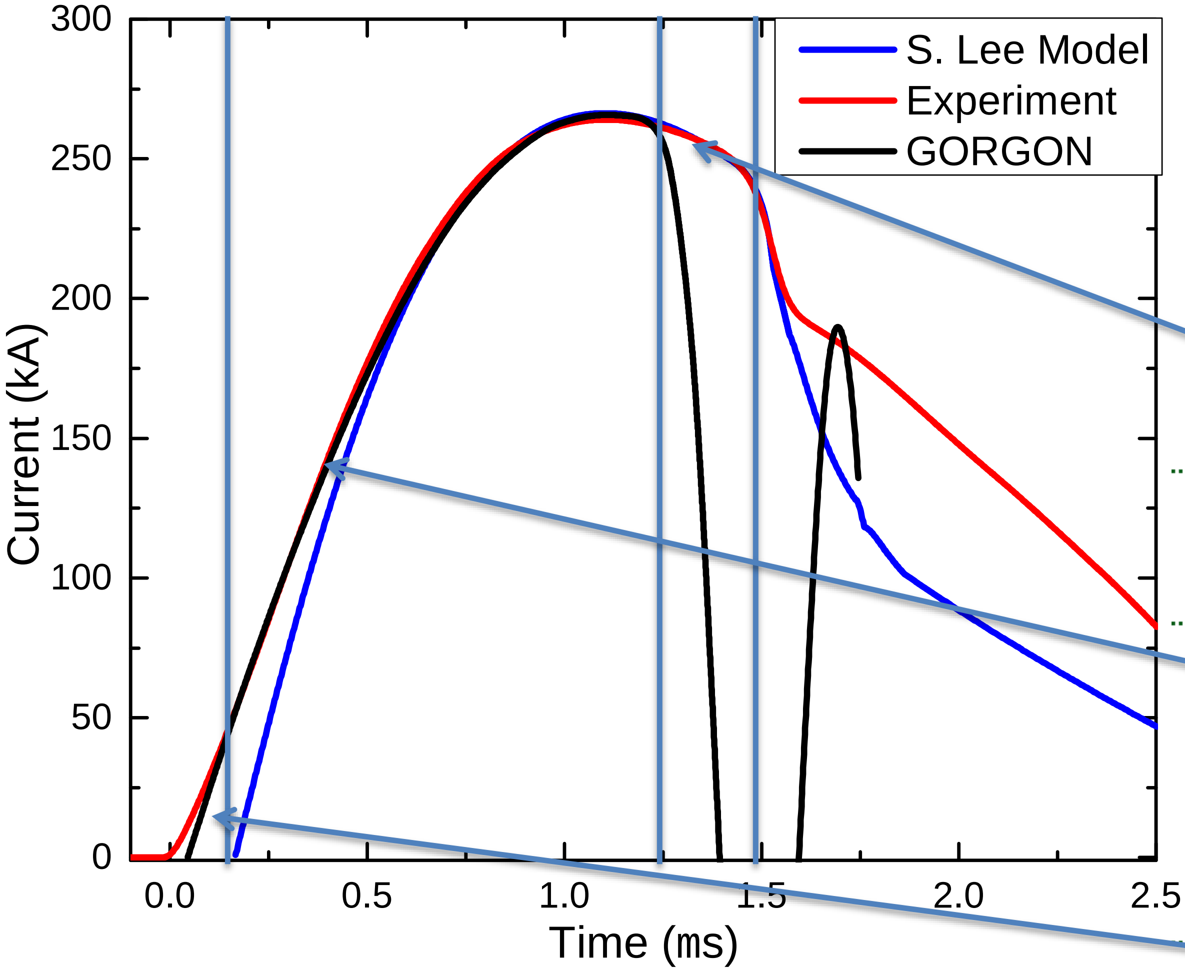




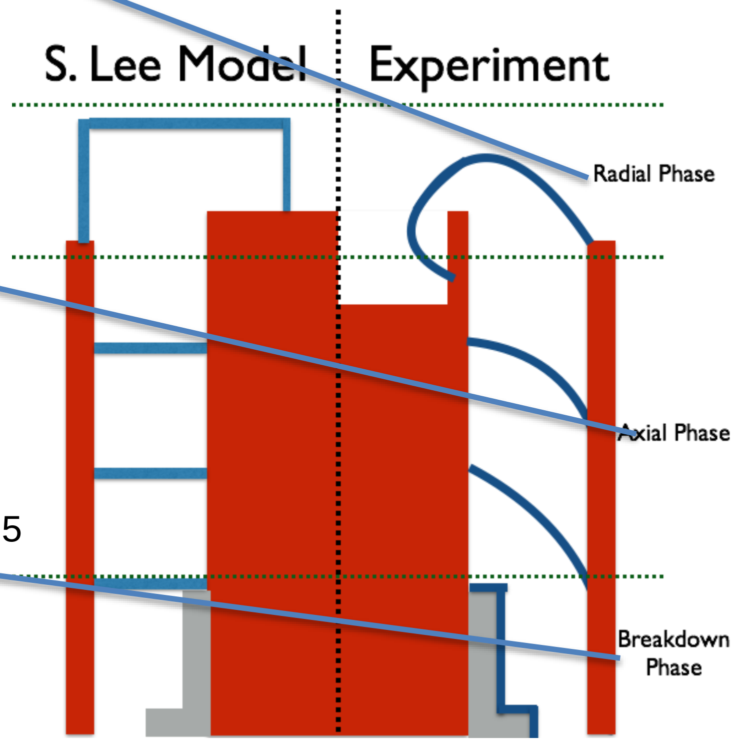




Models v Experiment



- An effort is being made to compare empirical data with S. Lee* and Gorgon** models
- S. Lee model better matches the end of the axial phase and the radial phase
- Gorgon with a circuit model matches better the axial phase



* *S Lee, J Fusion* Energy, Vol. 33, Issue 4, 319 (2014)

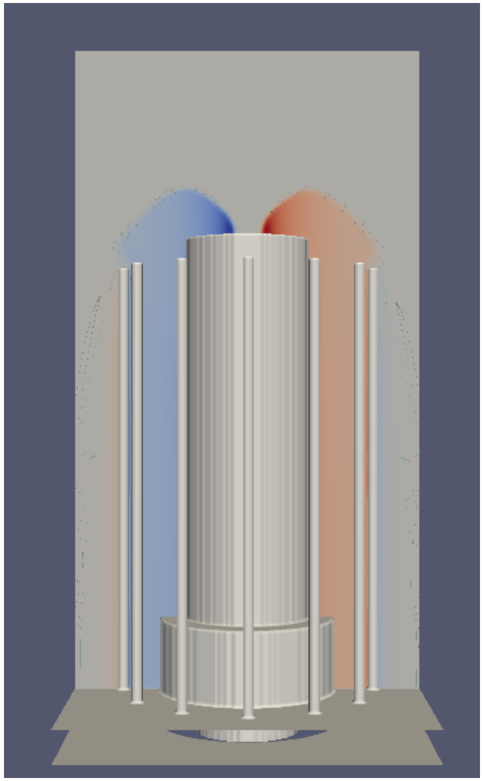
** *J. Chittenden, Plasma Phys. Control. Fusion 46 (2004) B457–B476*

- Often experiments do not recover details of both the axial and radial phases simultaneously.
- Here we are trying to provide strong constraints on the simulation to help guide and optimize the initiation conditions which then set the parameters in the axial and radial phases.
- The advantage we have is the amount of reproducible shots, hence a meaningful statistics
- Different loads (He, Ne, Ar), hence different mass, ionization states etc…

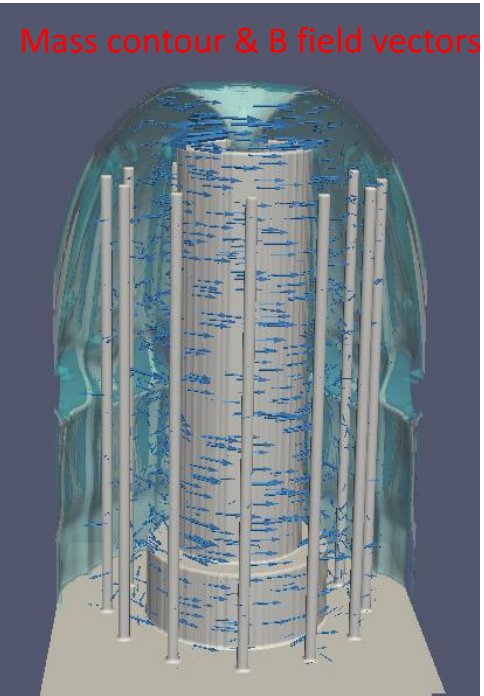
Gorgon

- Eulerian grid using second order Van-Leer advection
- 406 x 206 x 206 cells, 400um^3 (2 days on 92 processors)
- Simple recombination radiation loss model
- Two-temperature (electrons and ions) with local thermodynamic equilibrium (LTE) ionization
- Circuit Model

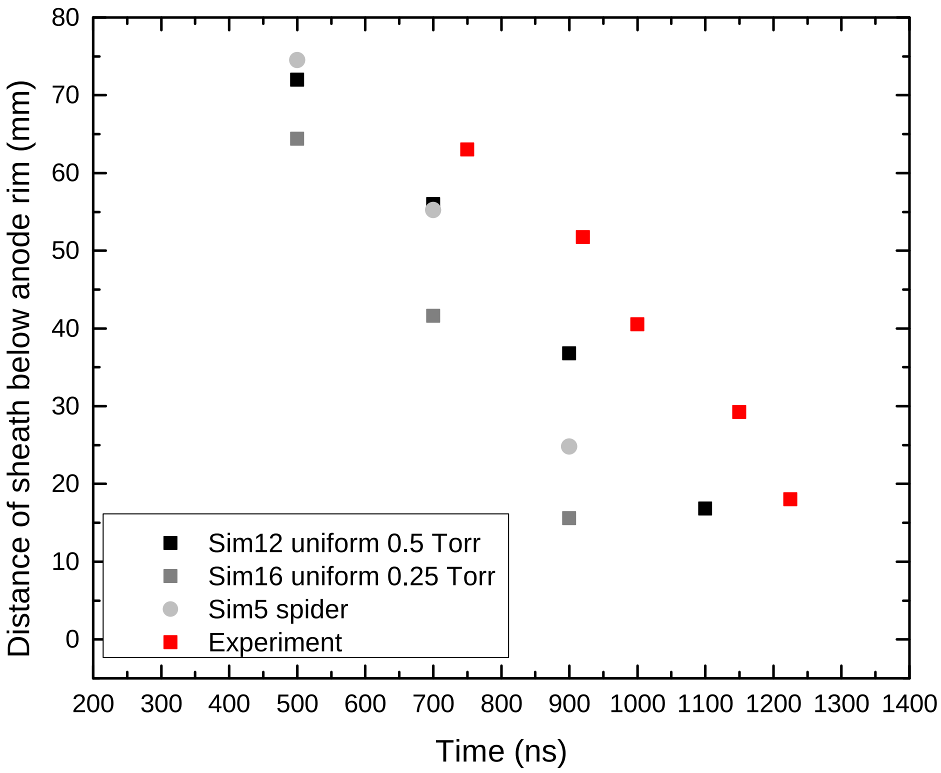
- Currently examining the most appropriate mechanism to initiate plasma sheath in 3D
- Will need to optimize initiation parameters to match the constraints provided by the experiments
- Hardware upgrades will allow greater spatial resolution

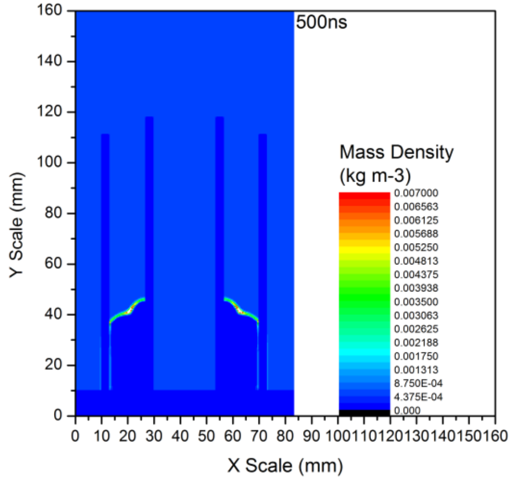


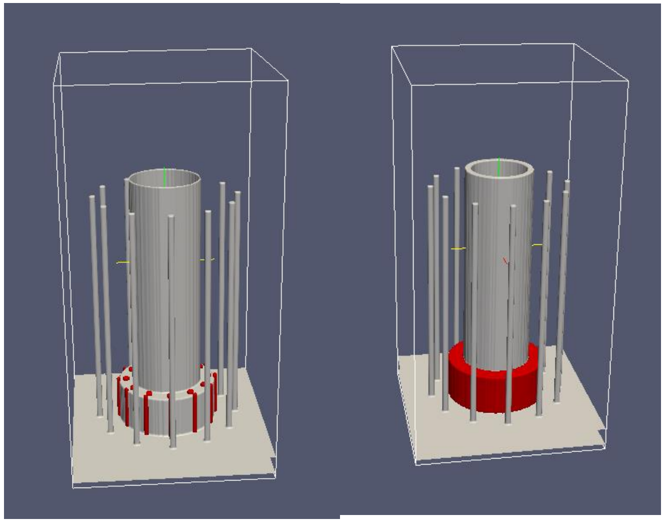
Simulated Magnetic field



- Gross dynamics as well as typical sheath thicknesses are recovered
- Issues remain in the current sheath details
    - trailing mass %
    - absolute timings and position
    - velocities of the sheath
    - pinch time







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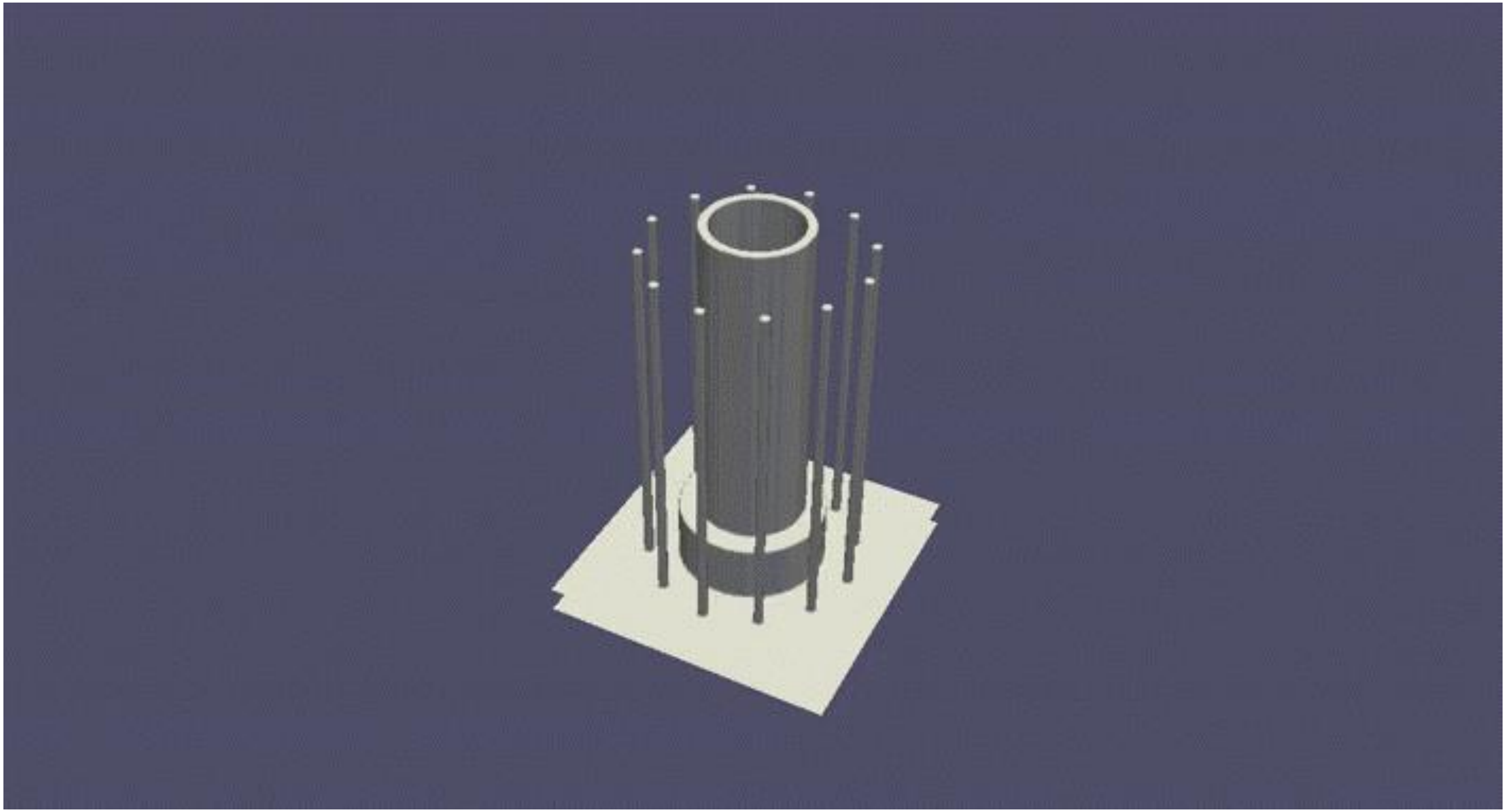
3D Simulation



Final Remarks

- We have implemented 7 diagnostics to simultaneous characterize our DPF including B, X-ray radiation, particle density, plasma sheath dynamics, instability growth. Key plasma parameters.
- More than 200 shots per load are run, hence an accurate and meaningful statistics.
- Pinch times of 1.3-1.55 μs increasing with load pressure.
- Axial plasma sheath moves faster closer to the anode. The sheath moves with a velocity ~10^5 diminishing with load pressure as more mass is dragged.
- B field of a about a Tesla at 20-25 mm above the anode
- Work in progress
  - Density profile
  - Instability growth
  - Radial Phase dynamics

Thank your for your attention

Questions?