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

L. S. Caballero Bendixsen, S. C. Bott-Suzuki, S. Cordaro
University of California San Diego, La Jolla, CA, USA

M. Krishnan, S. Chapman, P. Coleman*
Alameda Applied Science Corporation, San Leandro, CA, USA
**Consultant, Evergreen Hill Sciences, Philomath, OR, USA*

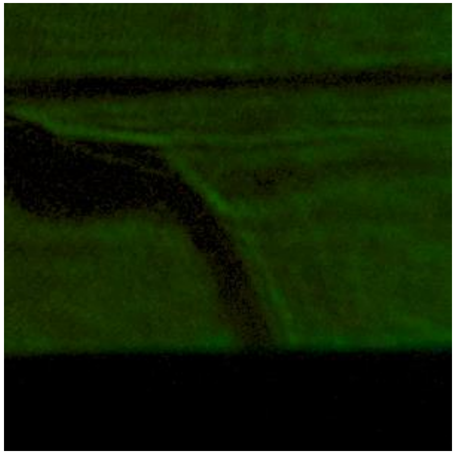
J. Chittenden

Imperial College London, South Kensington, London, UK

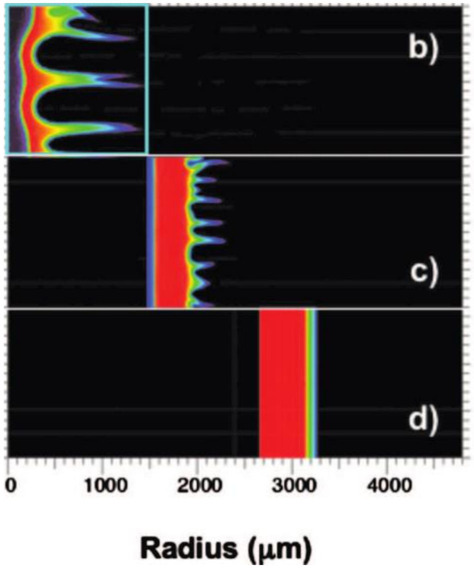
Work is funded through US Department of Energy contract DE-SC0010751

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



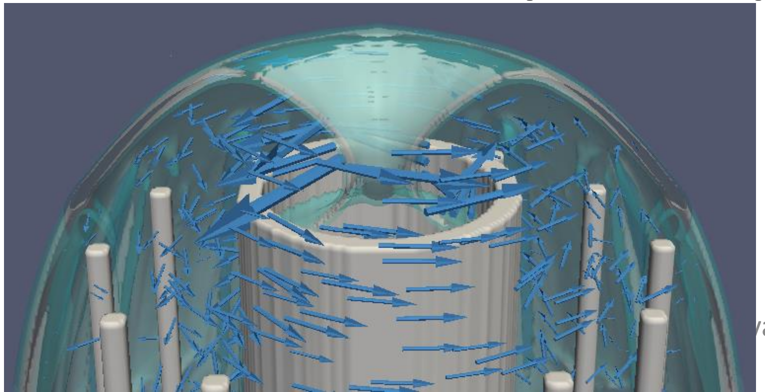
Imploding plasma sheath in our Plasma Focus

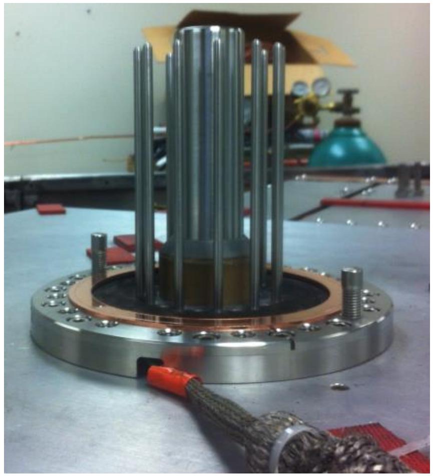


* *S Slutz et al, PoP,* ***17****, 056303 (2010).*

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.





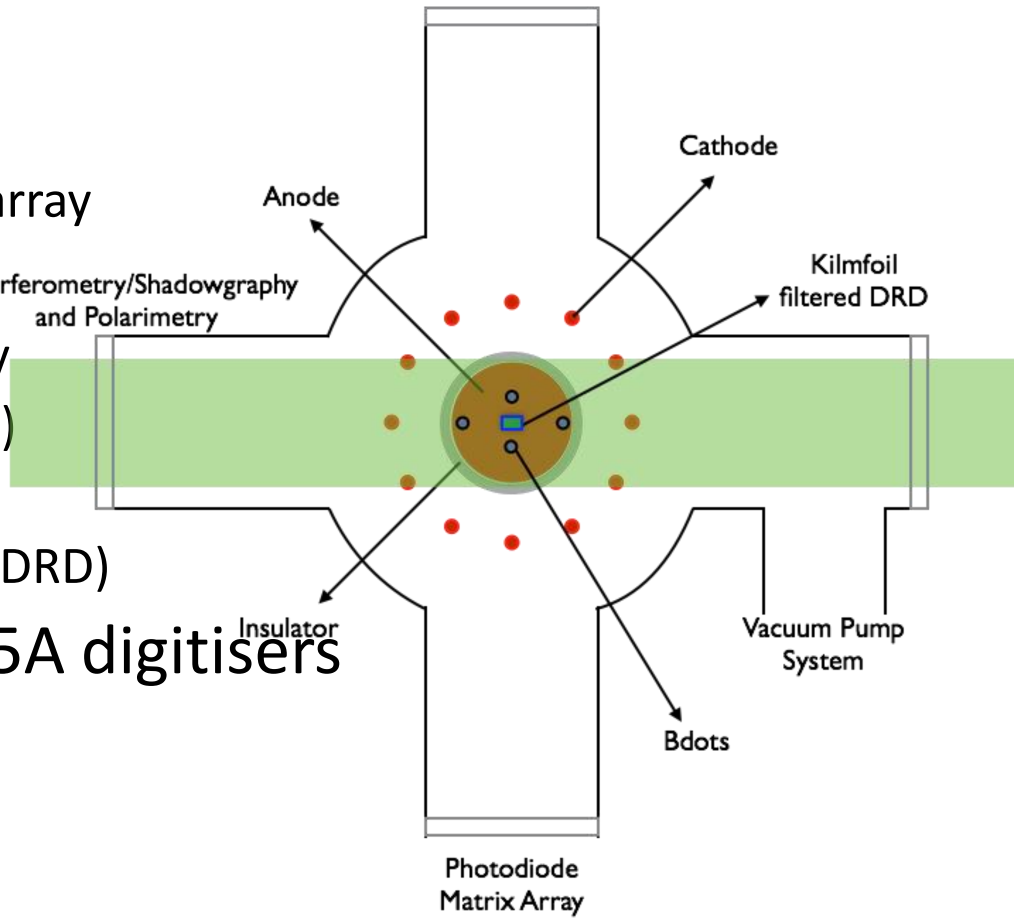
The Experimental Device

- 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

Diagnostics and Data Recollection

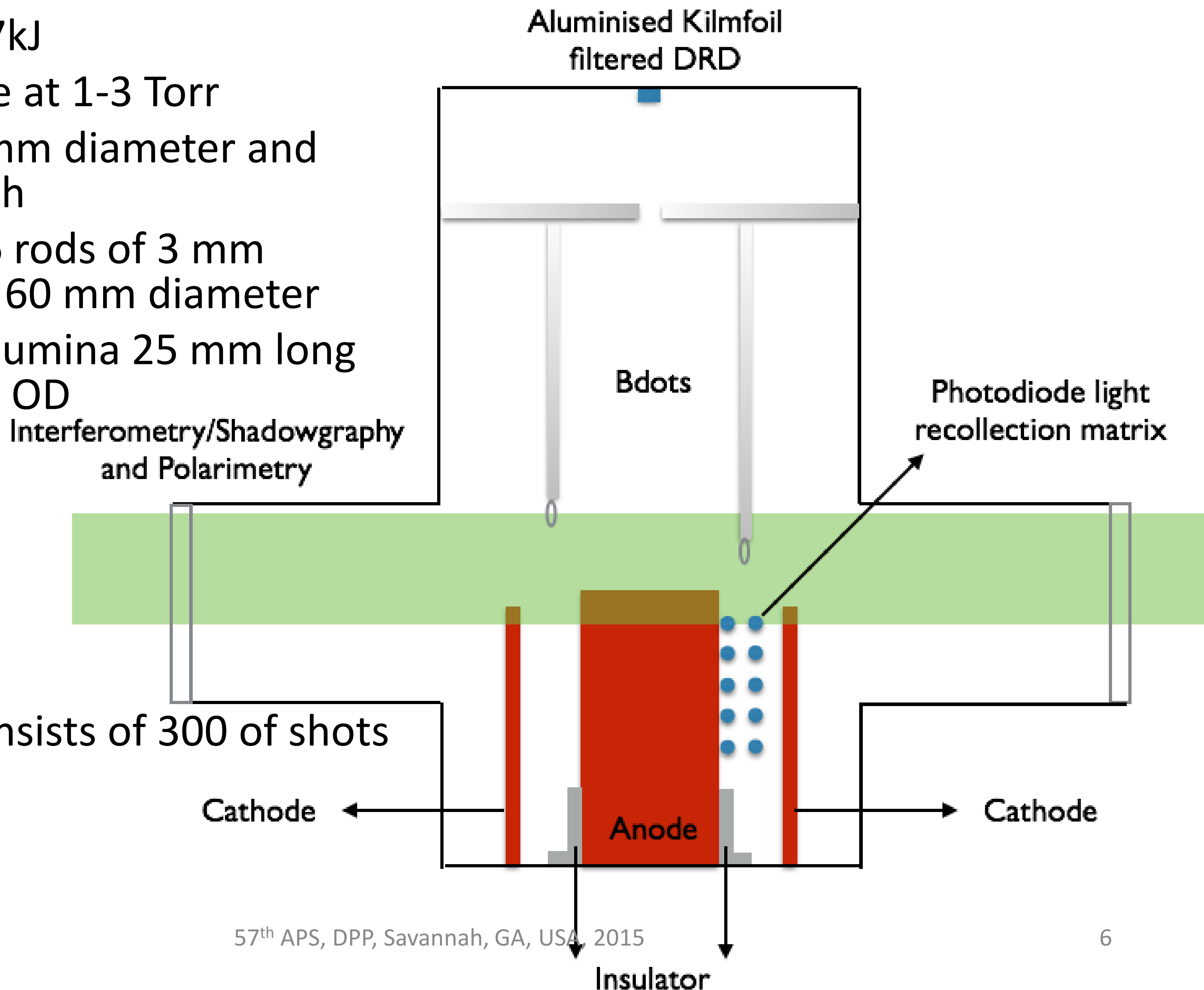
- Simultaneous, comprehensive and detailed diagnostics setup
  - Electrical Parameters
    - Rogowski coil and HV probe
  - Axial Phase
    - Non-intrusive optical system array
  - Radial Phase
    - Interferometry/shadowgraphy
    - Faraday Rotation (Polarimetry)
    - B-dots
    - Diamond Radiation 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

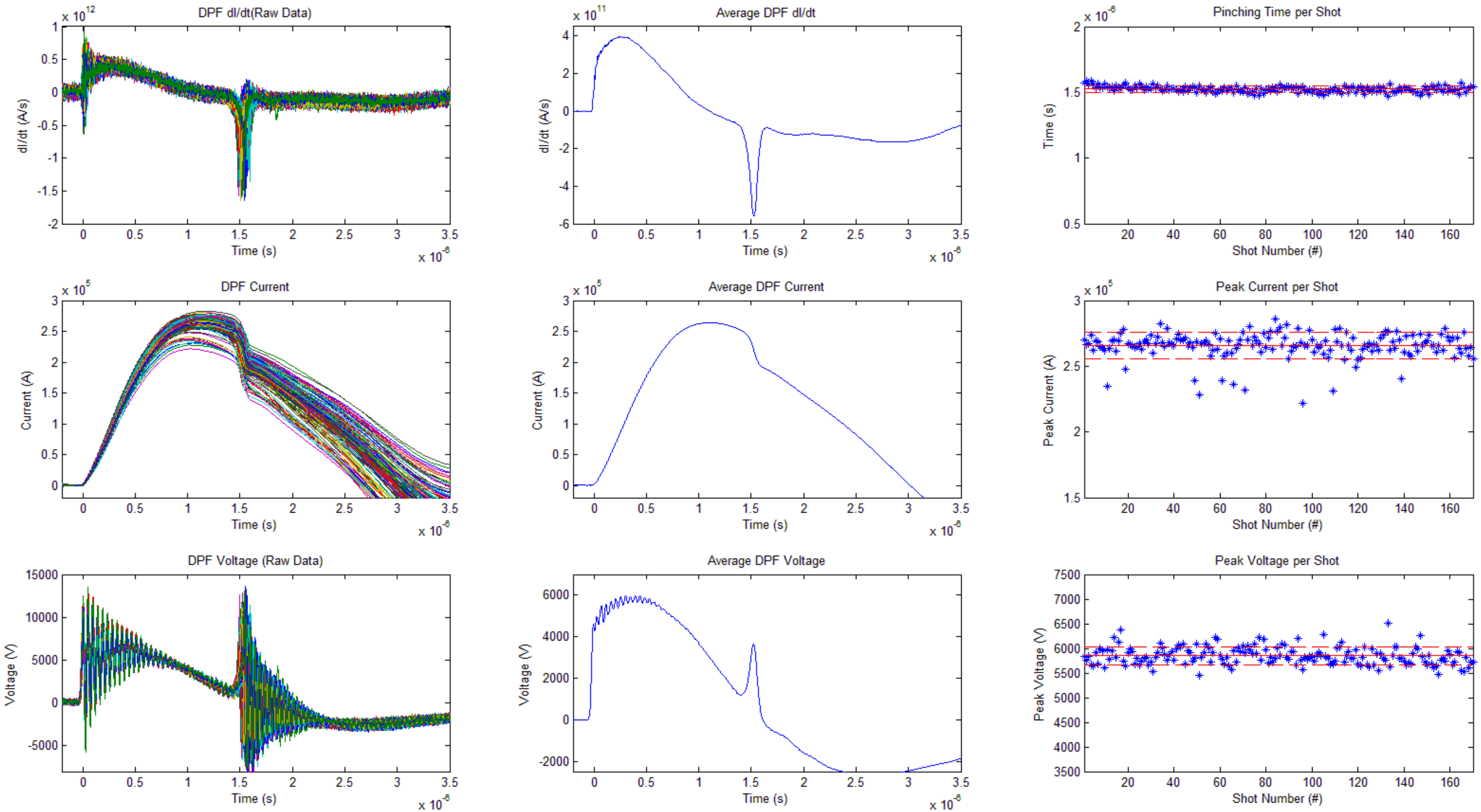


Experimental and Diagnostic Setup

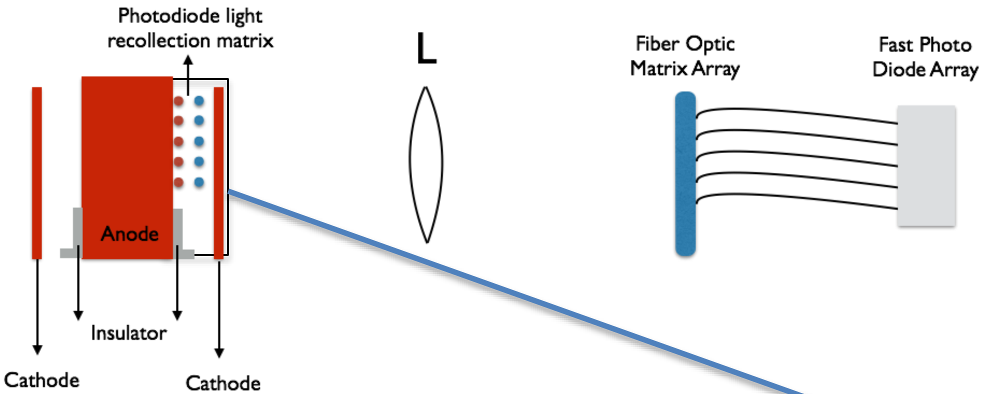
- V_c=11kV, 1.7kJ
- Gas load: Ne at 1-3 Torr
- Anode: 30 mm diameter and 85mm length
- Cathode: 16 rods of 3 mm diameter at 60 mm diameter
- Insulator: Alumina 25 mm long with 43 mm OD
- L_0= 19nH
- C_0= 28.8μF
- R_0=7mΩ
- Each run consists of 300 of shots

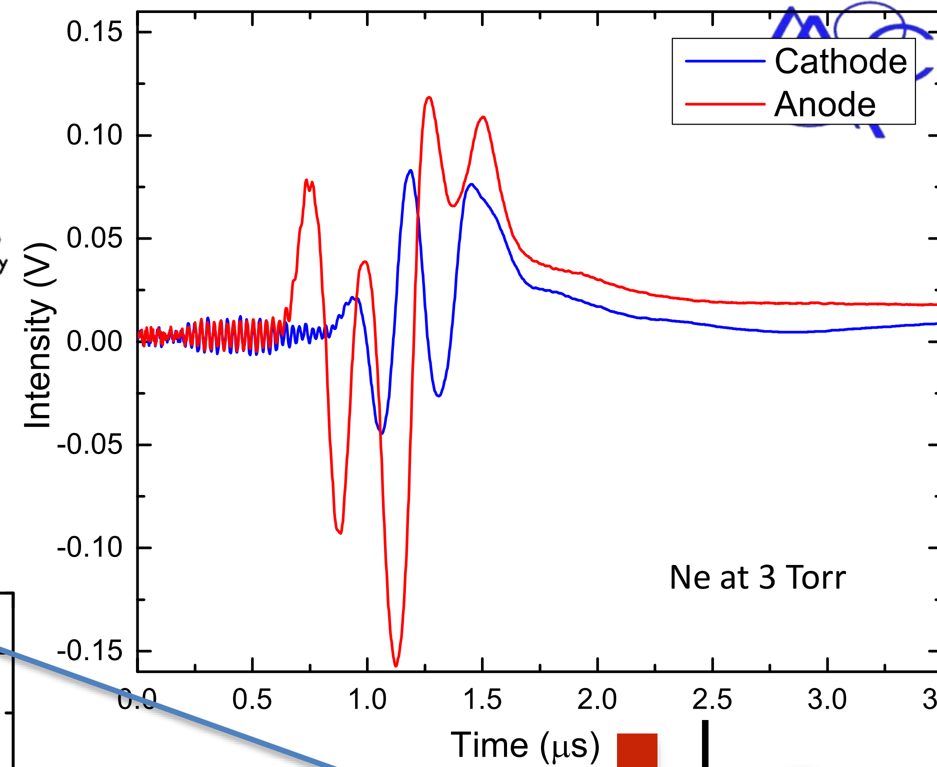


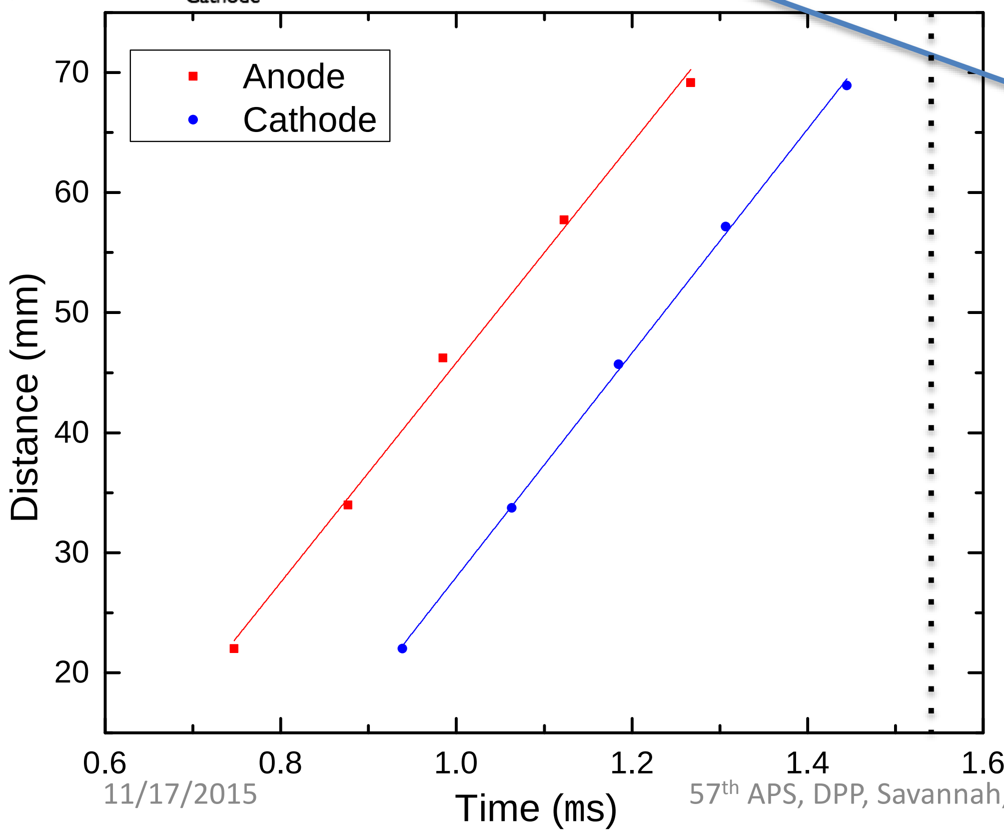
Data Recollection

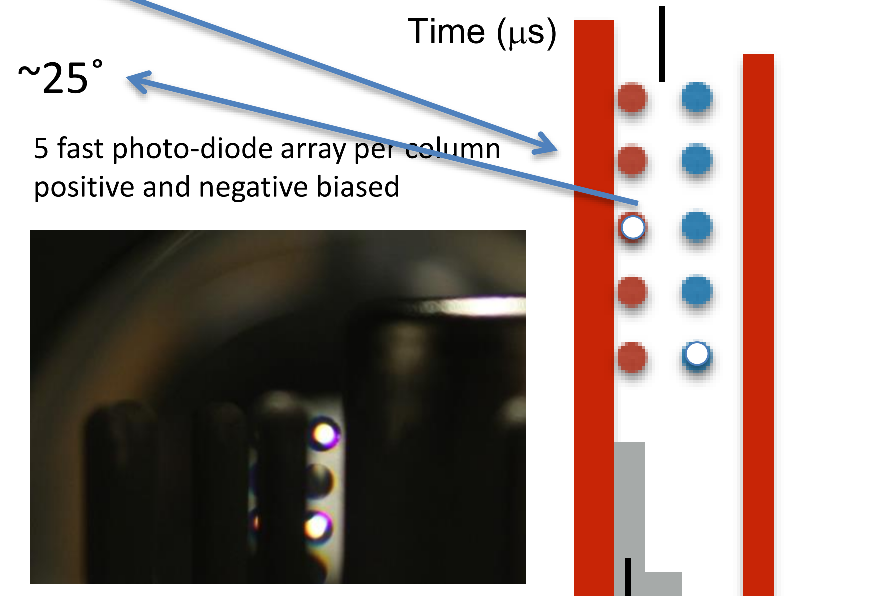


Non-intrusive optical system *



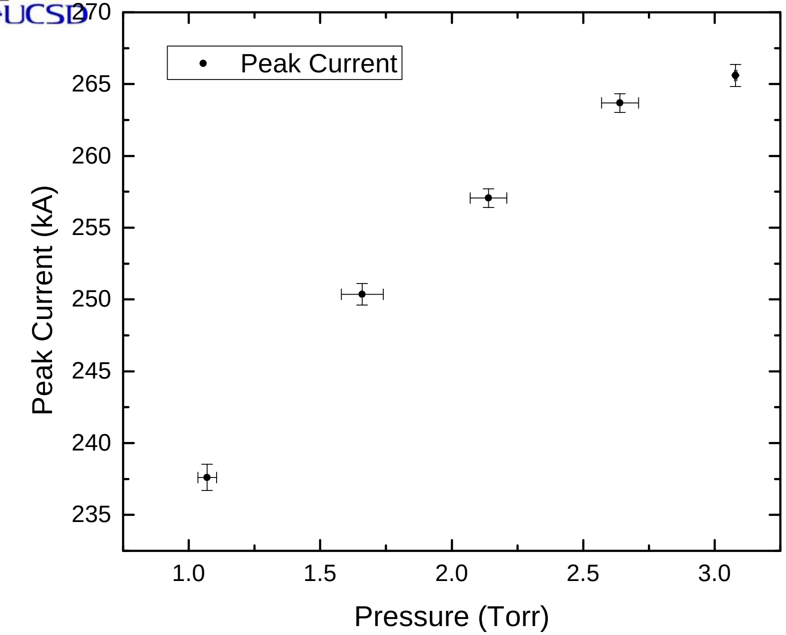


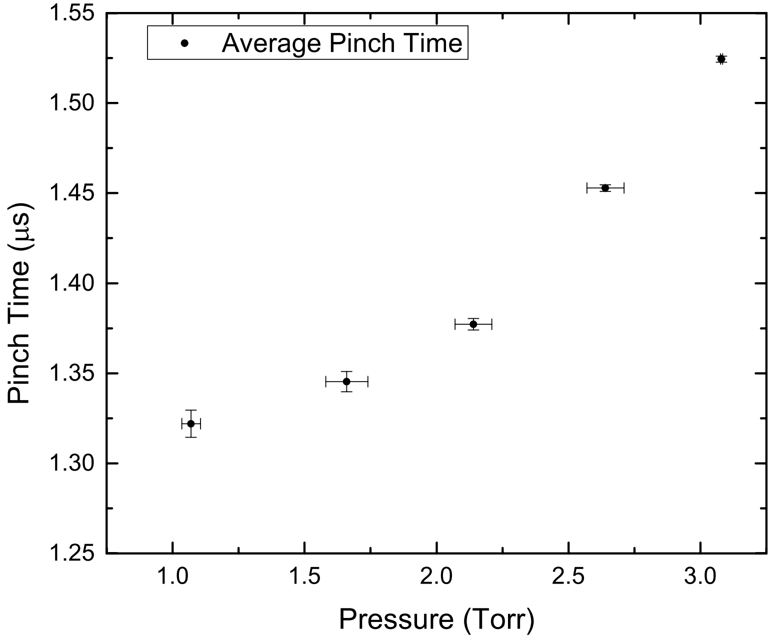


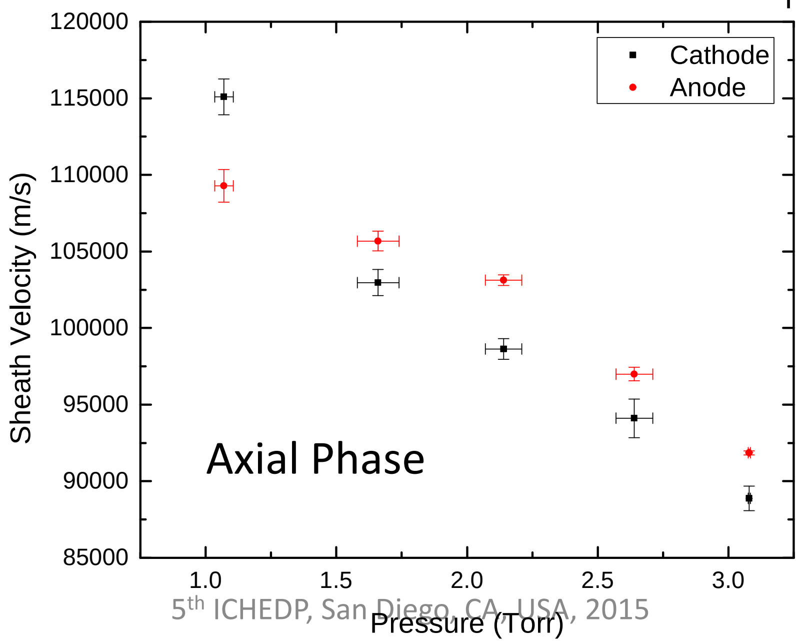


* *F Veloso et. al.* Meas. Sci. Technol. **23** (2012) 087002

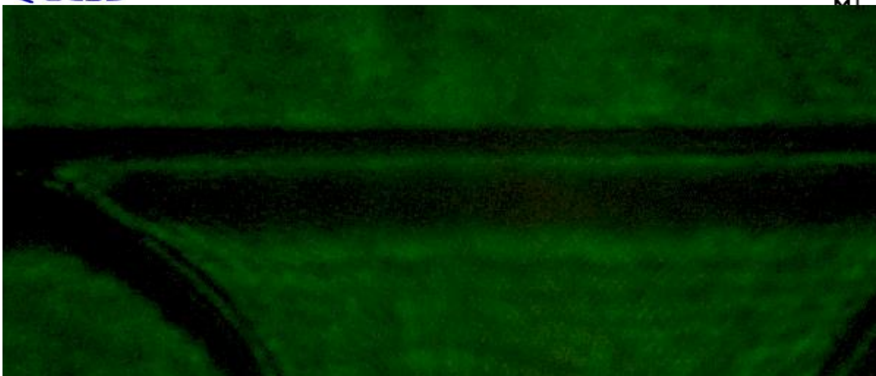
Data Summary

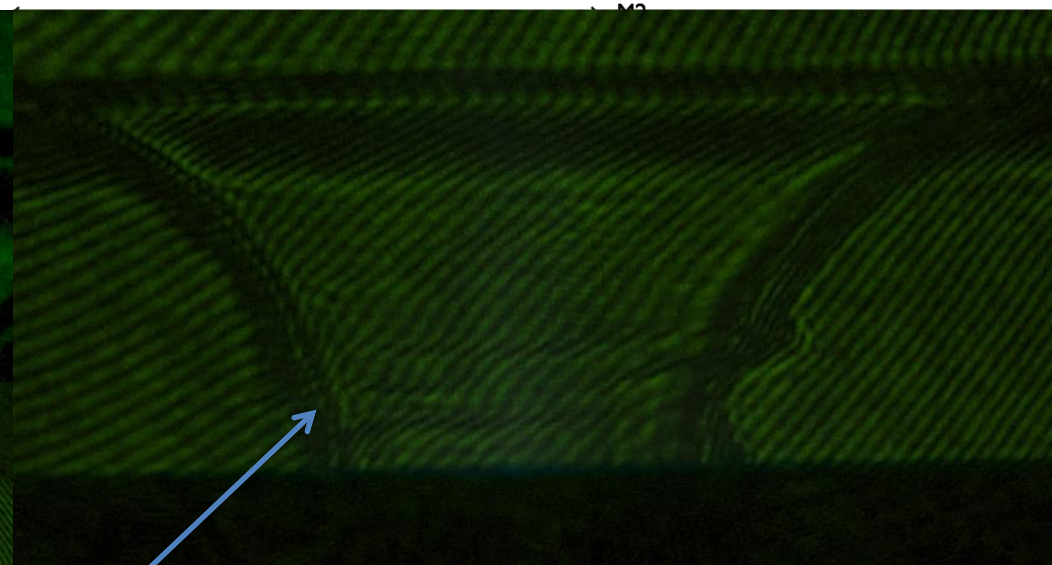


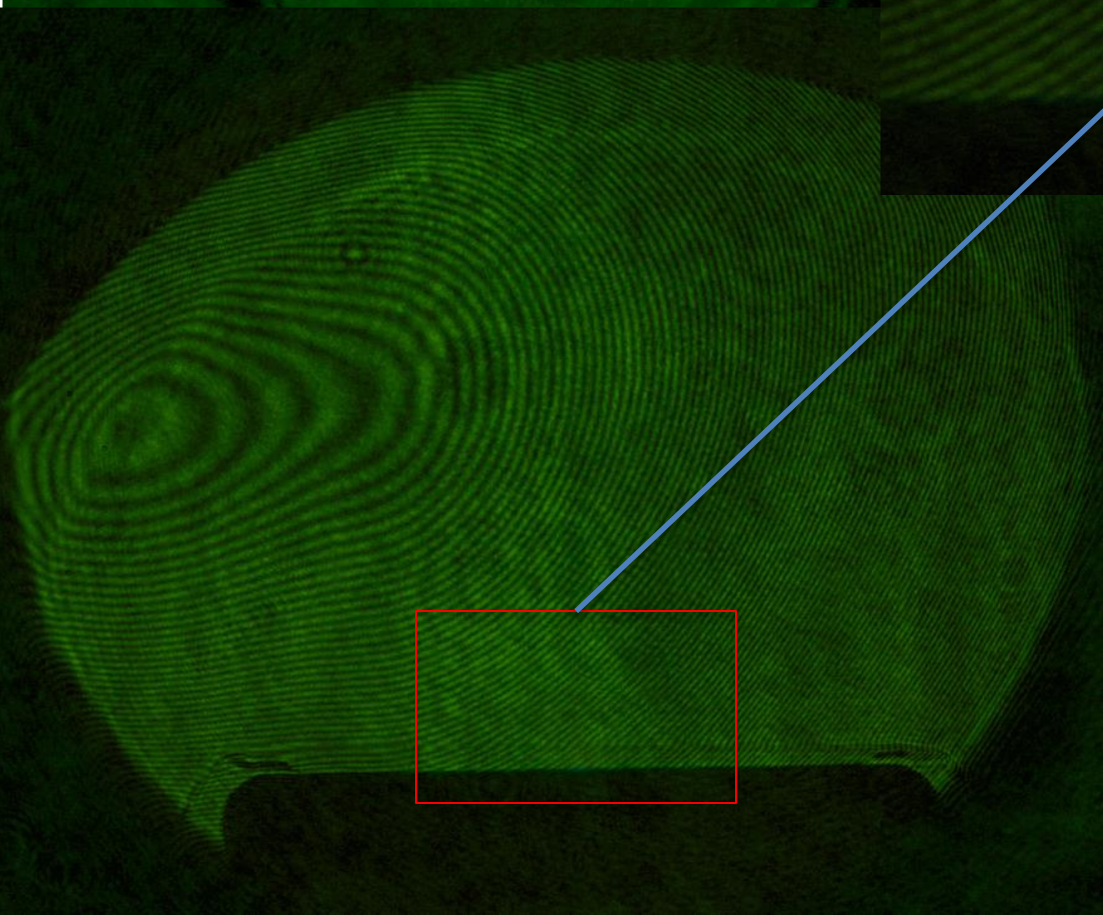


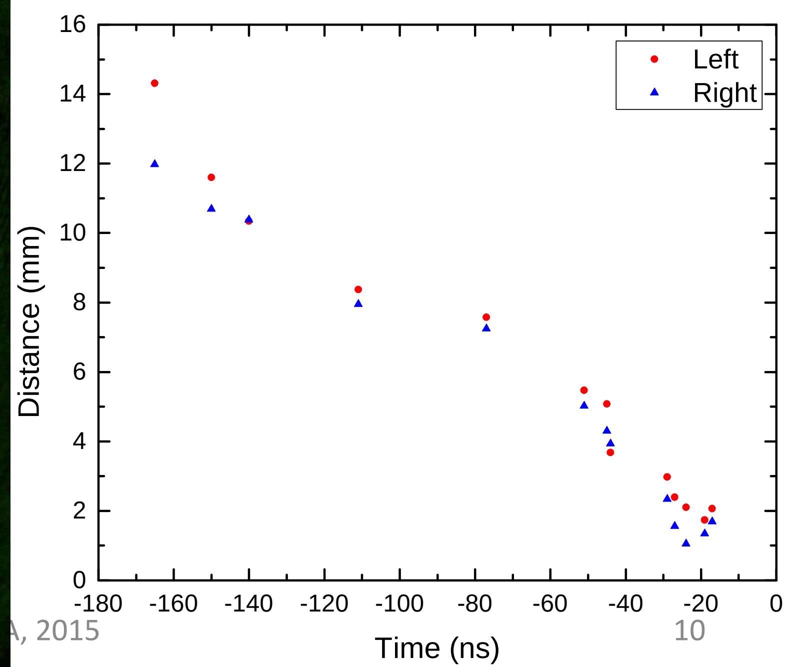


Refractive Diagnostics

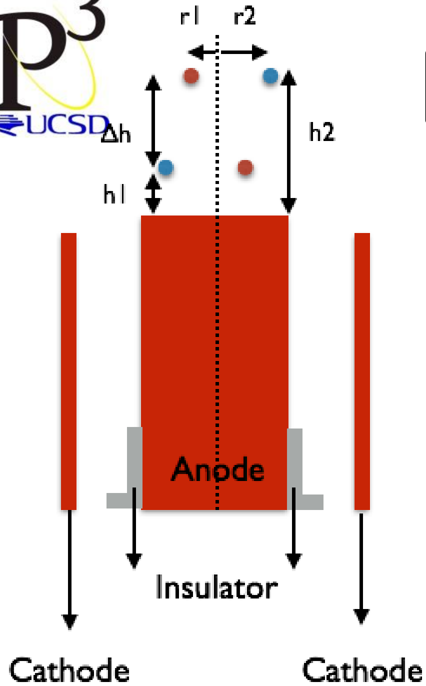


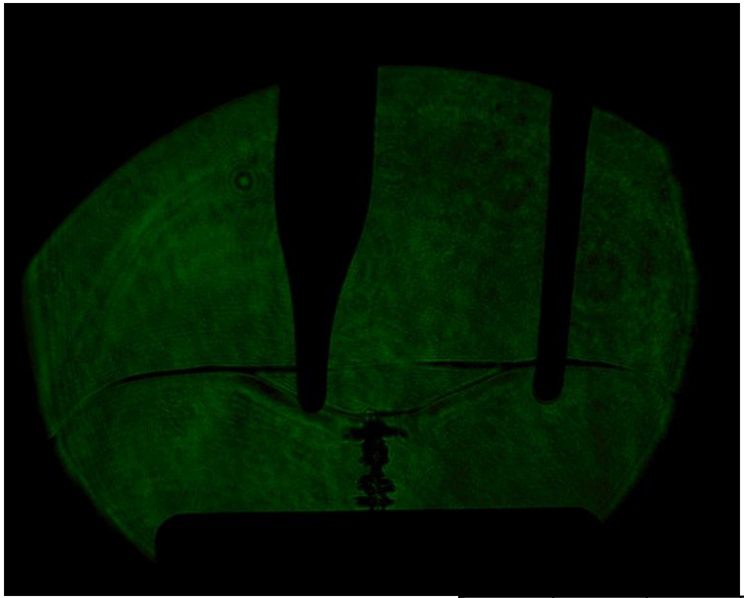


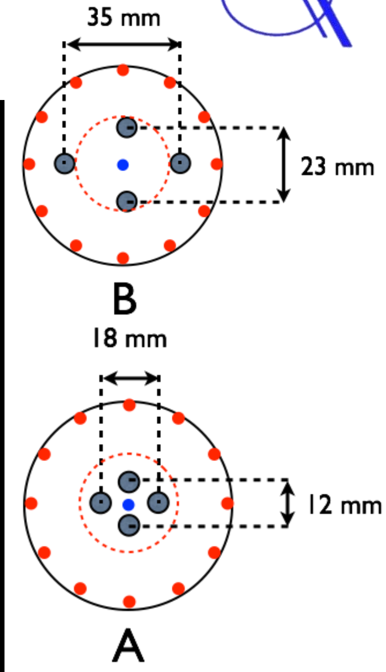




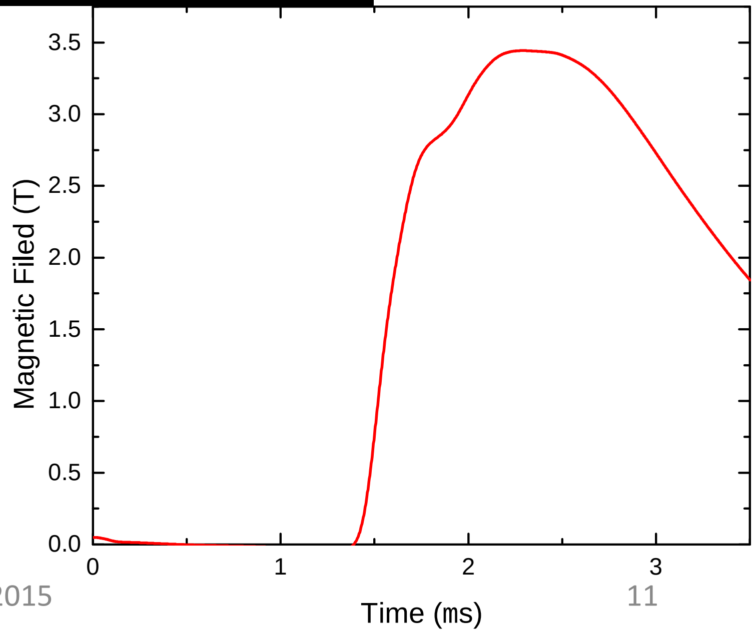
B-dots Measurements





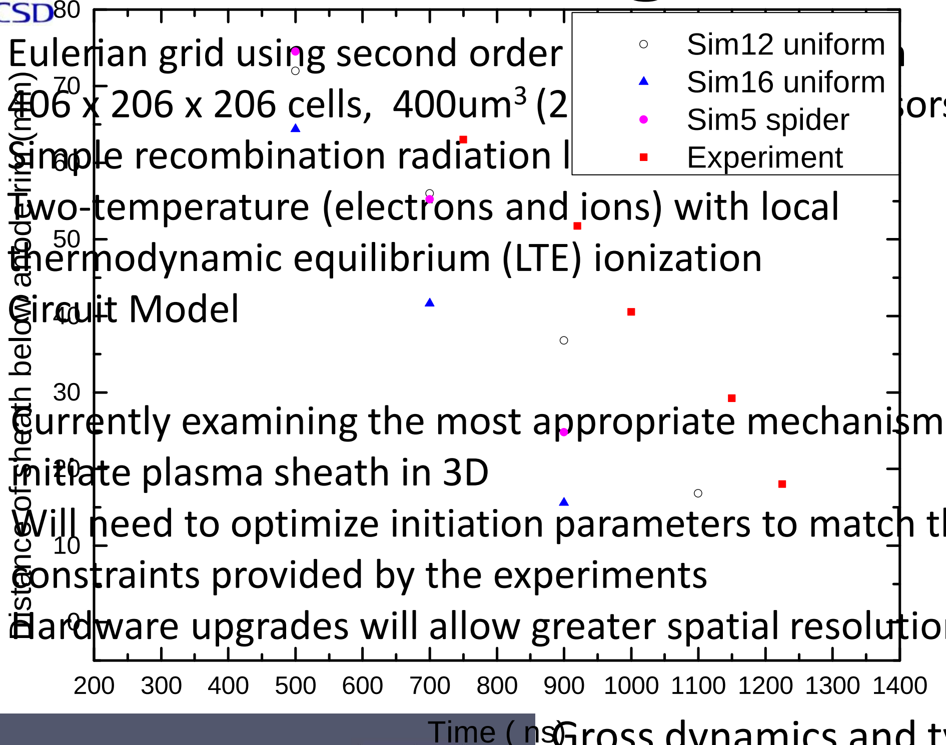


- Home made B-dots
  - Semi-rigid 50 Ω coax. cable with 0.52 mm OD
  - Sensor area ~ 1 mm^2
  - Typical calibration factor: ~ 10^6 T/V
- Life span : 1500+ shots
- Monitor the volume above the anode

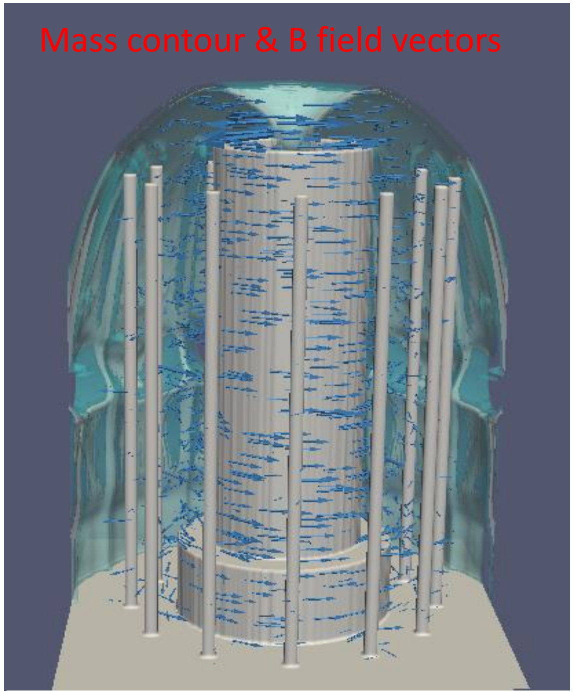


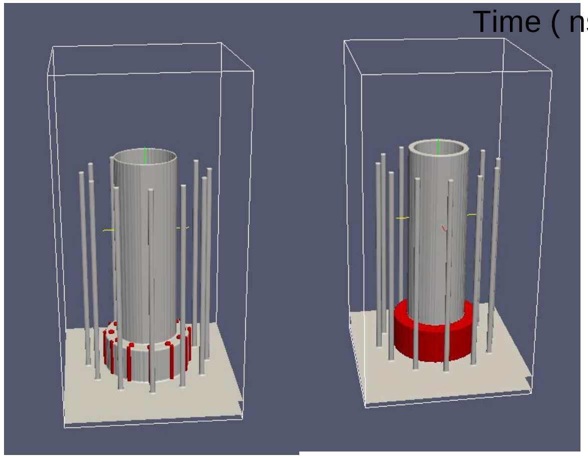
Gorgon Simulations

- Eulerian grid using second order
- 406 x 206 x 206 cells, 400um^3 (2 ors)
- Simple recombination radiation l
- 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

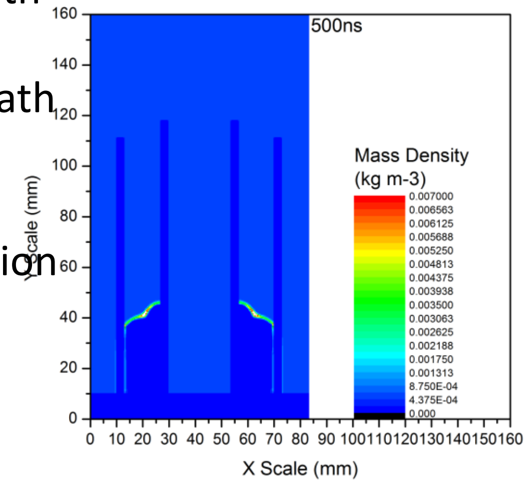




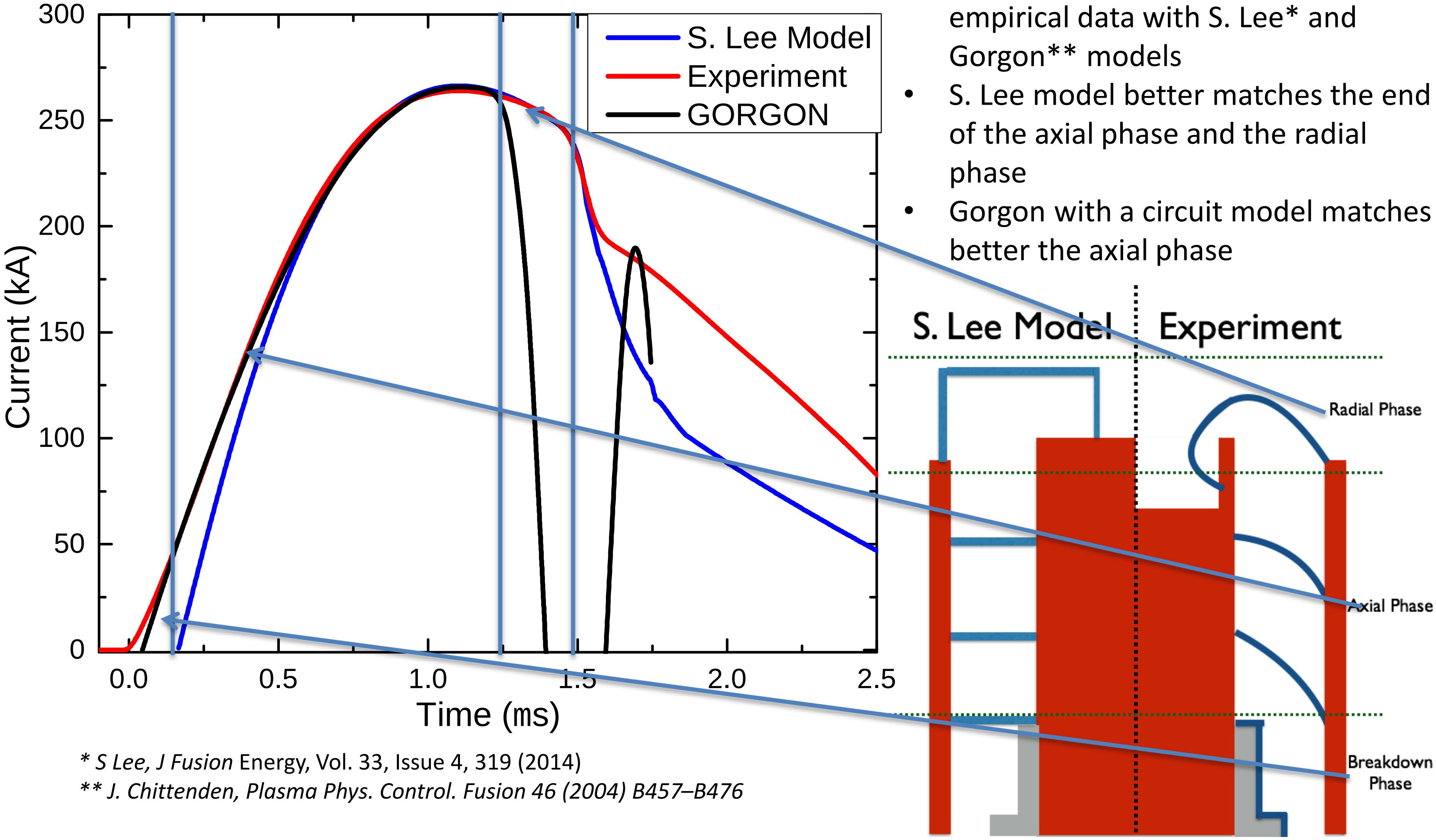
Gross dynamics and typical sheath thicknesses are recovered

Issues remain in the current sheath details

- trailing mass %
- absolute timings and position
- velocities of the sheath
- pinch time



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*

Final Remarks

- We run our DPF with more than 200 reproducible shots per load, hence accurate and meaningful statistics.
- Recover details of both the axial and radial phases simultaneously.
- We have implemented 7 diagnostics to recover key plasma parameters including magnetic filed, X-ray radiation, particle density, plasma sheath dynamics, instability growth.
- We are providing strong empirical constrains to improve the simulations. In particular guiding and optimizing the initiation conditions which then set the parameters in the axial and radial phases.
- Work in progress
  - Density profile
  - Instability growth
  - Radial phase dynamics
- Future work
  - Different gas loads (He and Ar) will be tested in future campaigns. We will have different mass, ionization states, radiation loss etc.
  - Add an axial constant magnetic field to address the instability growth the aid of this field.

Thank your for your attention

Questions?