Improved operation and modeling of the Sustained Spheromak Physics eXperiment

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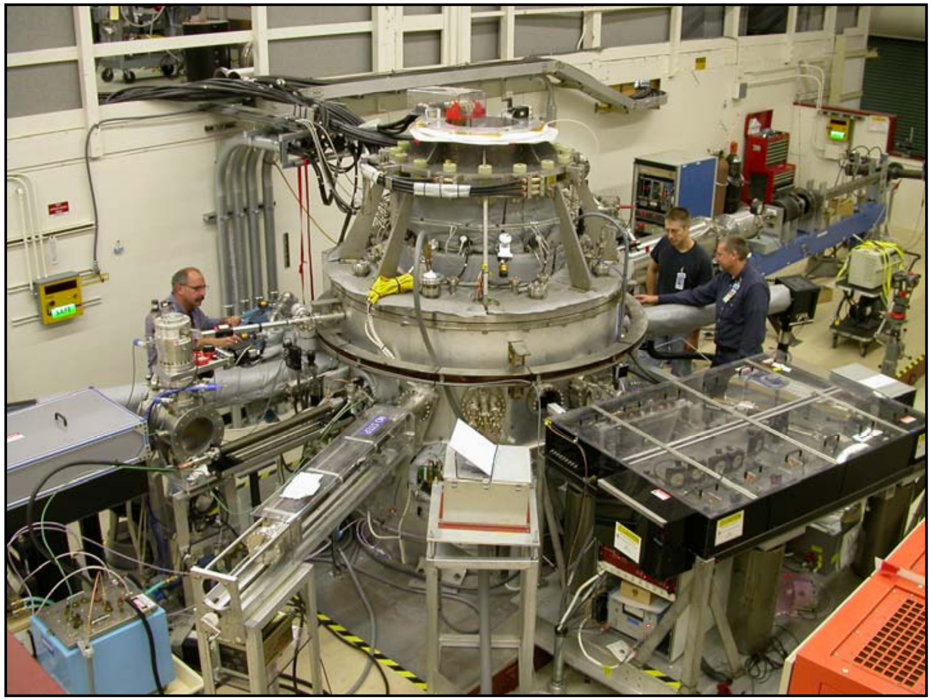
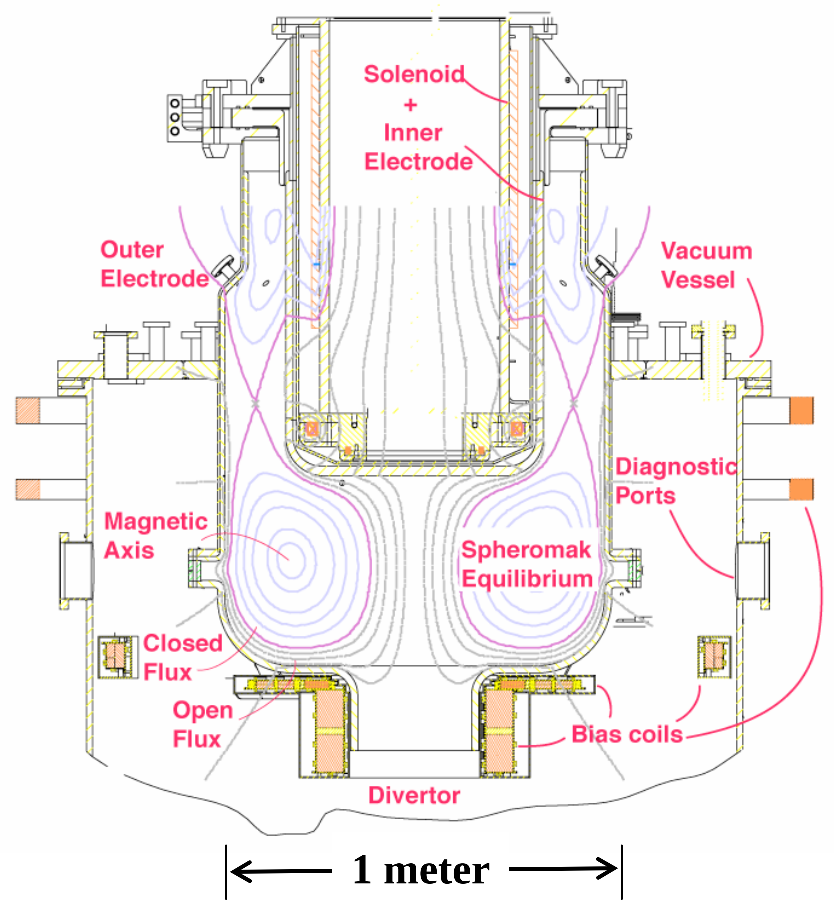


In collaboration with

Florida A&M University, Tallahassee, Fl.

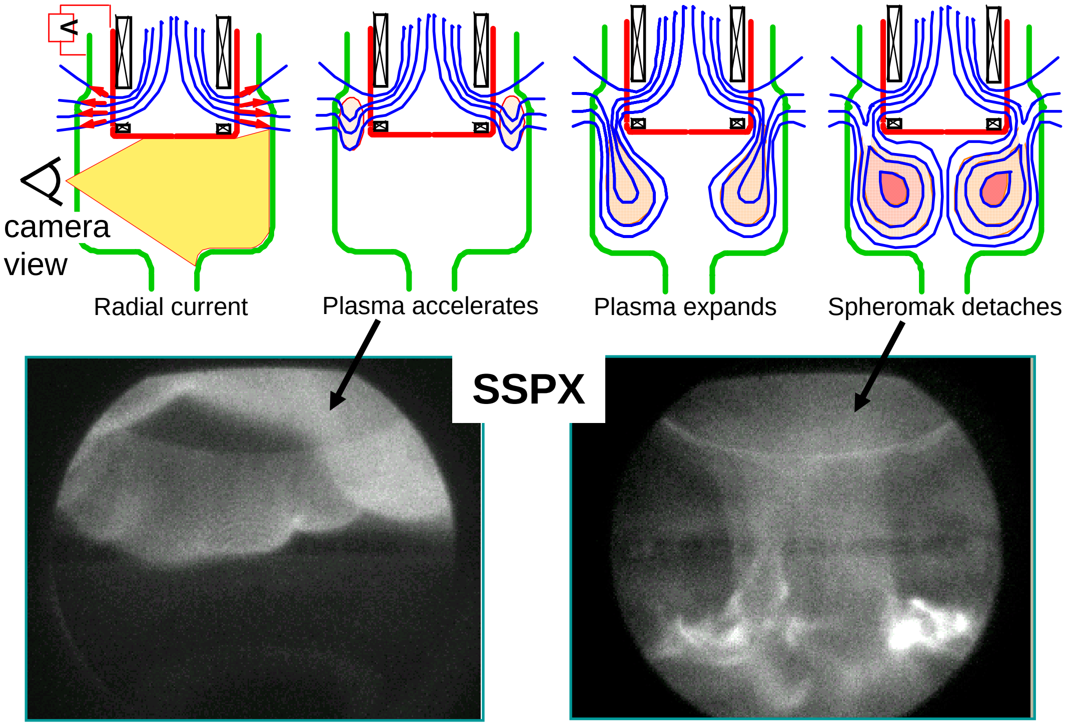
California Institute of Technology, Pasadena, Ca.

SSPX was built to examine energy confinement and field generation



- SSPX Operations:
  - –The best confinement in SSPX (χ_E~10m^2/s) is obtained with controlled decay.
  - –Peak temperature of >200 eV (peak β_e ~5-10%) observed when magnetic fluctuations are small (< 1%).
  - –Slow formation and double-formation-pulse discharges yield the highest magnetic field in SSPX.
- NIMROD simulations
  - –Show good closed nested flux surfaces
  - –Electron temperatures similar to experiment

Formation: In SSPX, spheromak formation does not show a strongly kinked central column



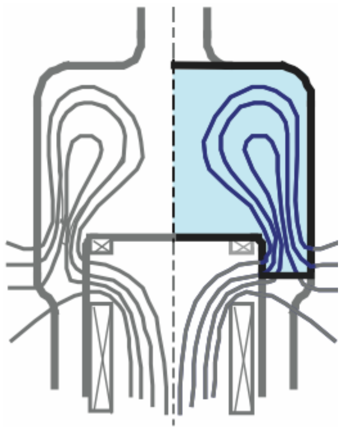
- **Formation approximately axisymmetric with reconnection near coaxial gun region**
- **Fast (4μsec) camera images show:**
  - **Current sheet extending into flux conserver**
  - **Formation with a central column that is not strongly kinked**
- **In SSPX, the flux conserver constrains the amplitude of the n=1 mode**

- **In SSPX the *n*=1 mode is**
  - **Always observed during formation**
  - **Converts injected toroidal flux into poloidal flux**
  - **~10% ($\delta B_p/B_p$) effect at the midplane edge**

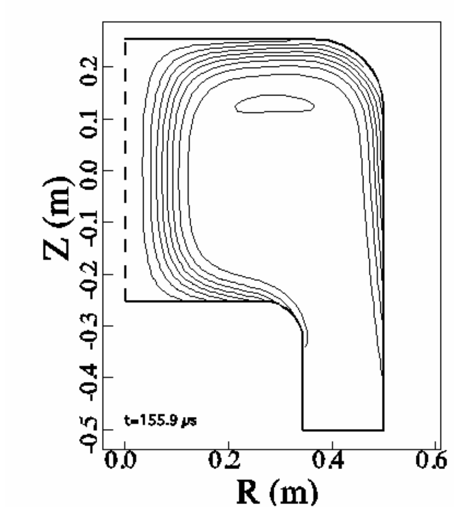
SSPX Photos
C. Romero-Talamas
Caltech

Formation: simulation of spheromak shows the change in field topology is due to reconnection processes

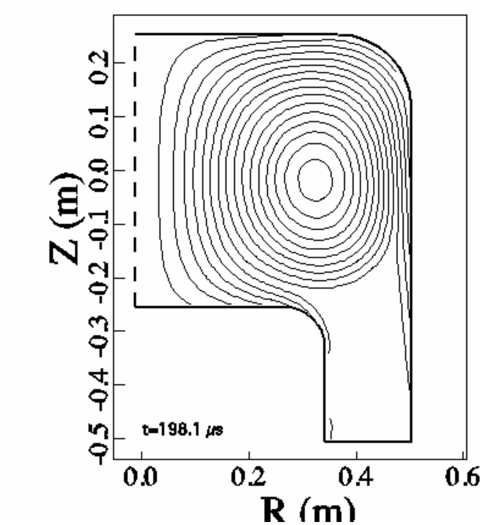
Inverted

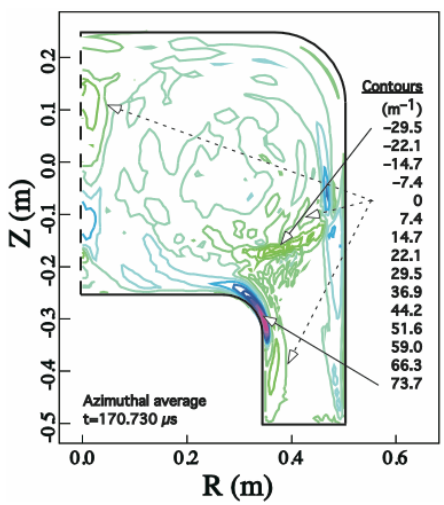


Before reconnection



After/during reconnection

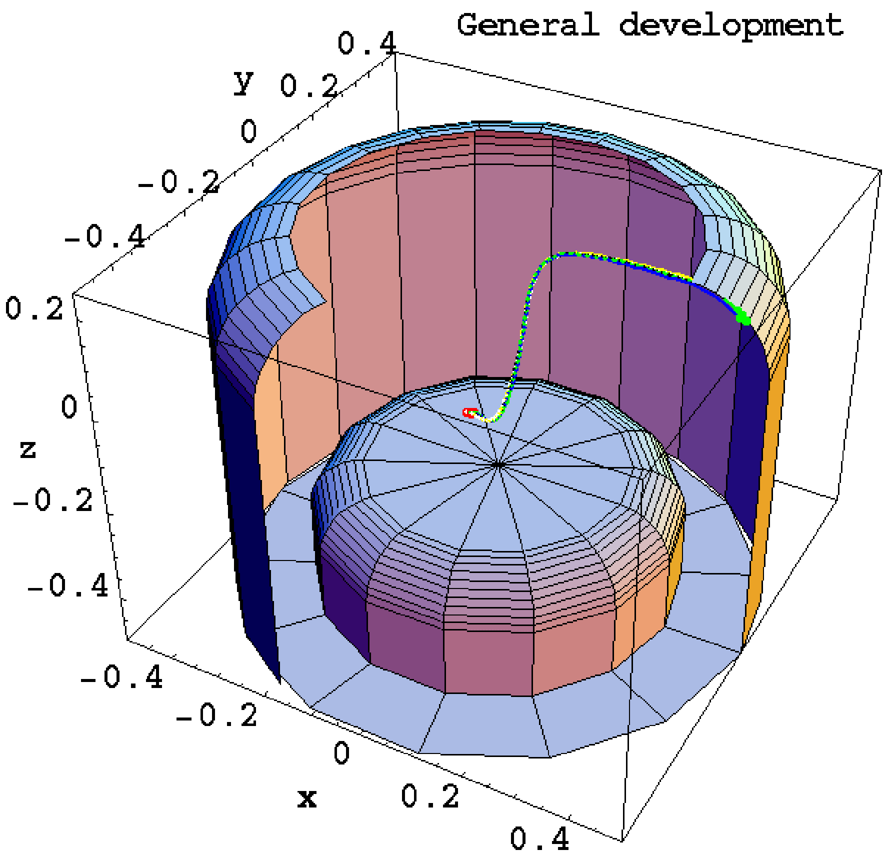


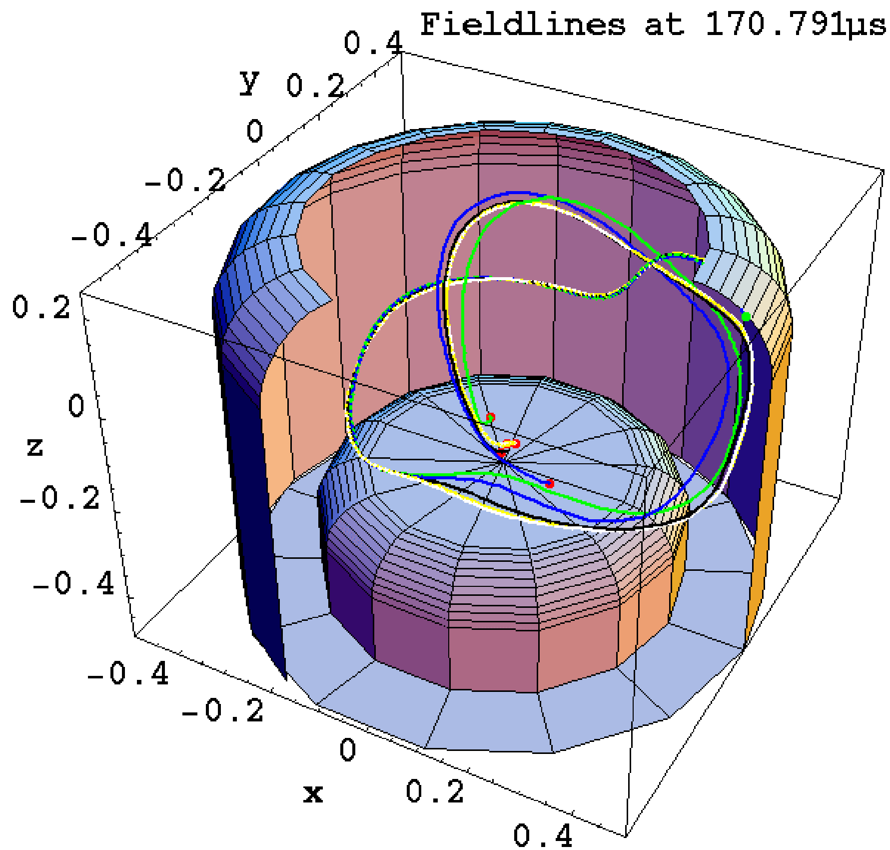


- **Magnetic reconnection converts toroidal flux into poloidal flux in both isolated events and a "steady" burbling**
- **Examination of the isolated events shows a change in field topology in the growth of mean-field flux contours**
- **Reconnection is generated by current sheets with negative $\lambda = \mu_0 j \bullet B/B^2$ –– These are strongest near the X-point of the mean-field spheromak**

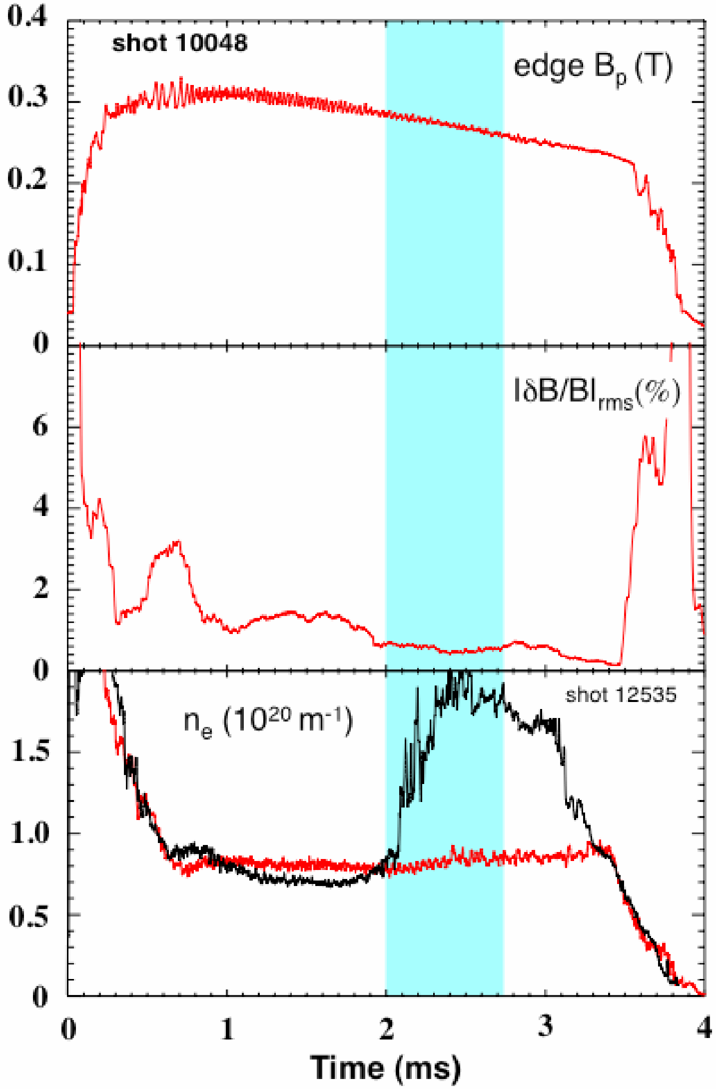
Magnetic fieldline topology changes as azimuthally-averaged poloidal flux is generated

- **During “bubble blowing”, fieldlines bend and rotate toroidally without a change in topology**
- **Reconnection changes fieldline topology – shown are knotted lines resulting from breaking and attaching to other lines**

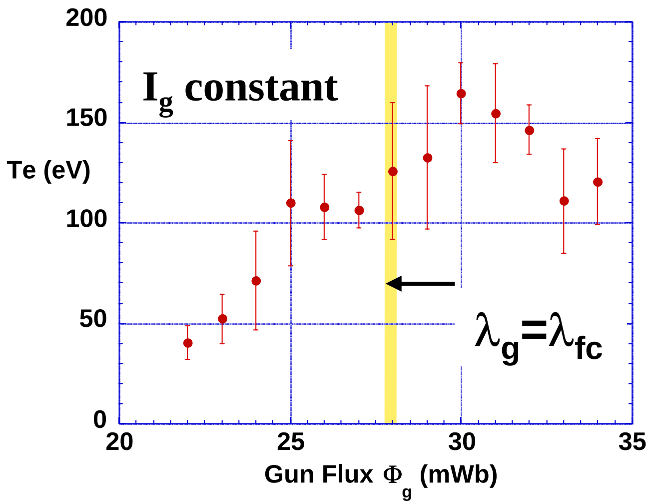




Improved confinement obtained with increased time to heat and reduced fluctuations (controlled decay)



- Ohmic heating to higher T_e made possible by longer pulses
- Optimizing edge current relative to injector flux reduces fluctuations (<1%); maintain edge current to keep current profile flat to slightly peaked

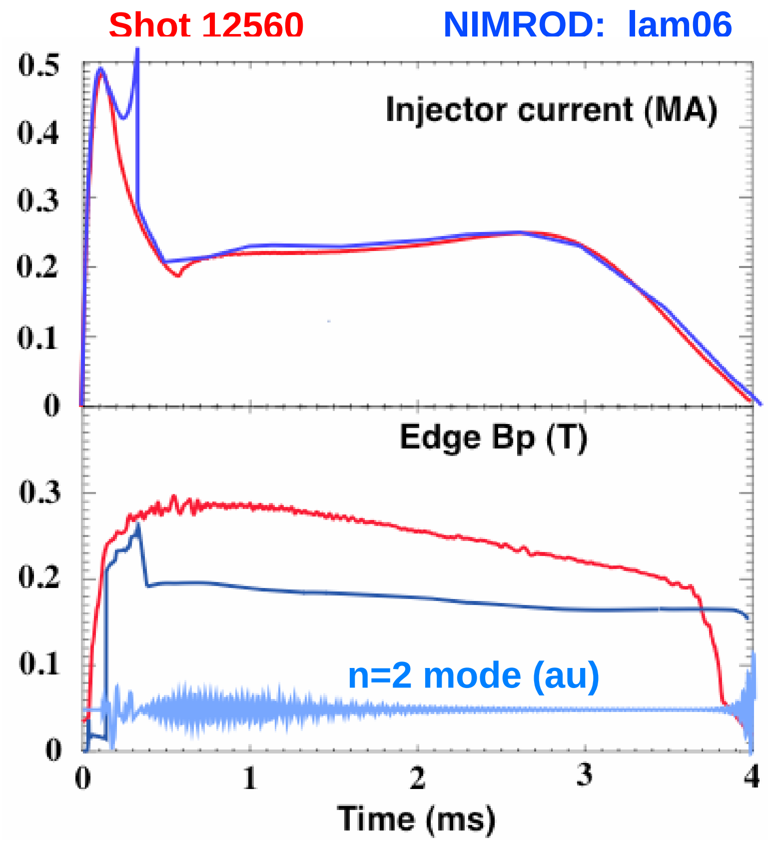


$\lambda_g=\mu_0 I_g/\Phi_g$

(normalized current density)

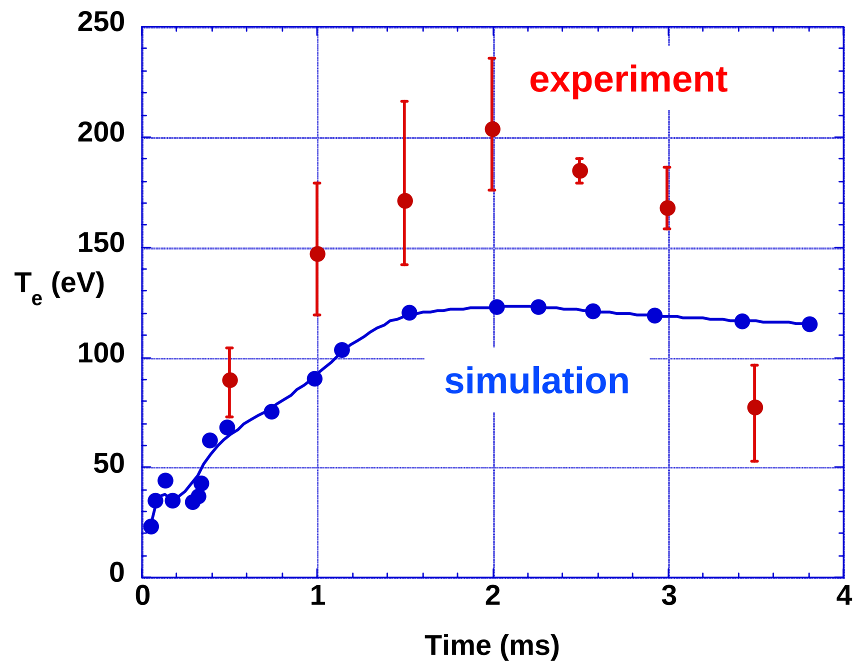
- Improved wall conditioning lowers density; essential to high temperature

NIMROD simulations close to matching experiment

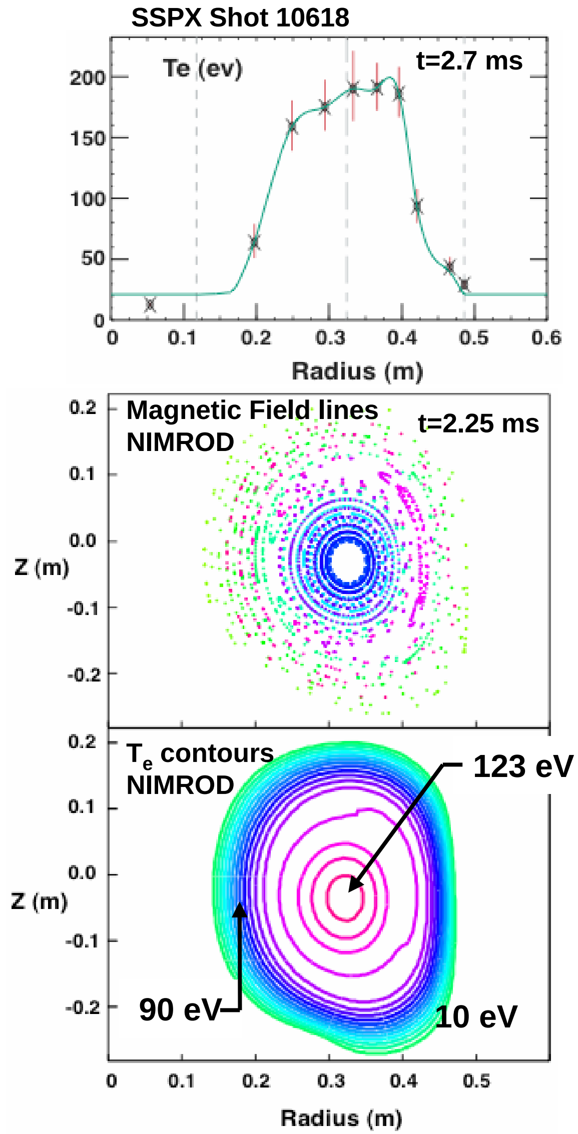


- Fluctuations are lower during sustainment
- As current ramps down at the end of the shot, a large amplitude *n*=2 mode observed in both experiment and simulation

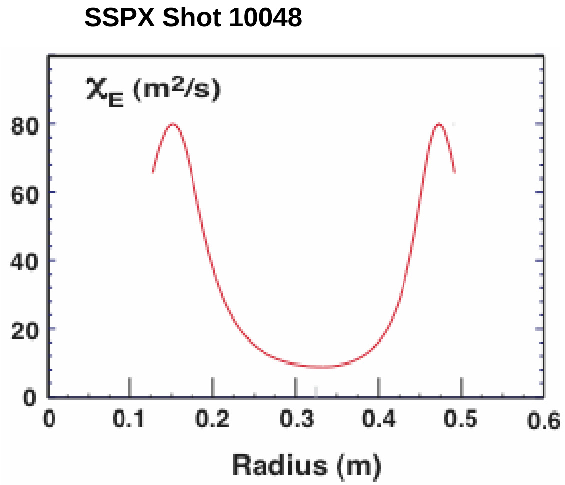
- Improved NIMROD simulations with
  - Spitzer-Braginski resistivity and parallel thermal conduction
  - more detailed representation of gun geometry
  - matching current-drive time history with experiment



NIMROD simulations show regions of closed flux surfaces and T_e profiles consistent with experiment



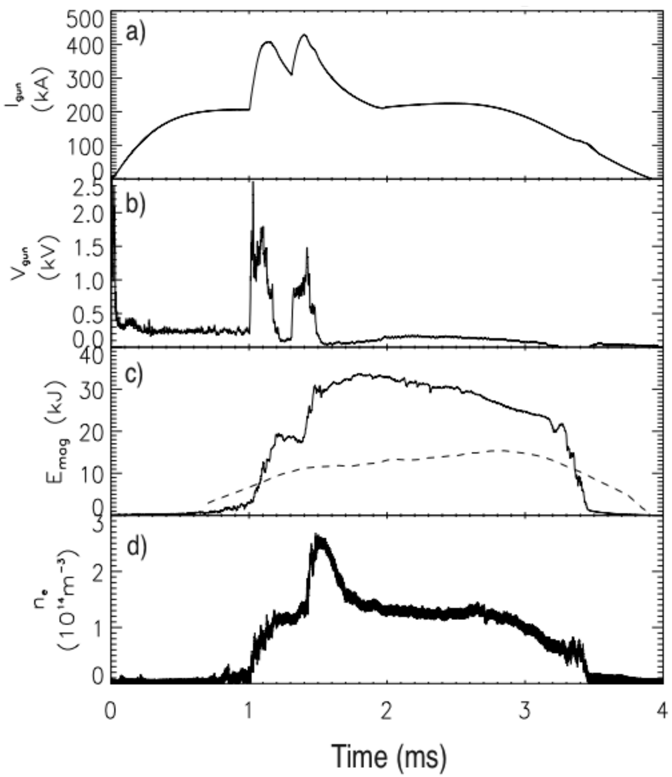
- Steep gradients in measured electron temperature profile are observed during sustainment
- NIMROD simulations show regions of good confinement surrounded by islands and confined chaotic lines and then open field lines.
- With parallel heat conductivity >> perpendicular heat conductivity, the electron temperature contours tend to align with the magnetic field lines.



- Best measured confinement:

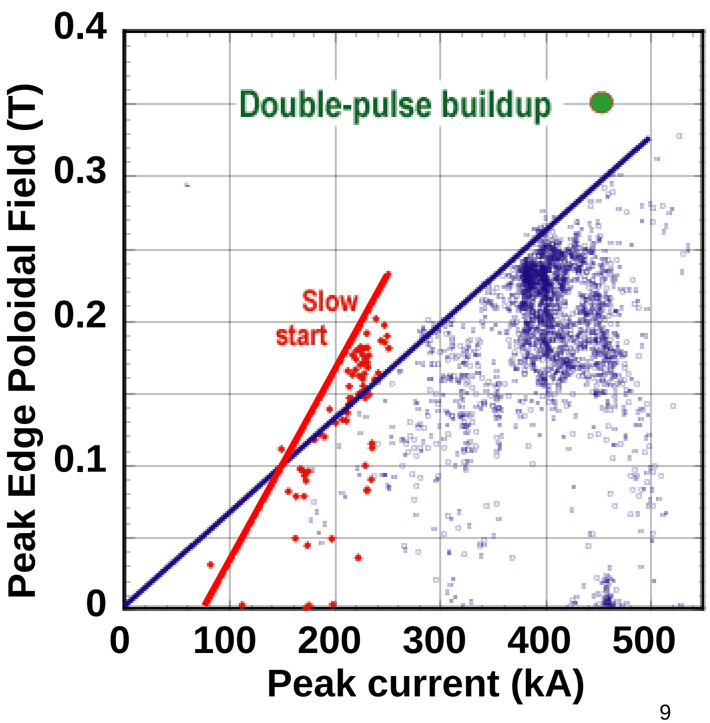
$$\chi_E \sim 10 \text{ m}^2/\text{s}$$

In SSPX, efficient magnetic field build-up is a key element to higher temperatures



- Double-pulse and slow formation discharges obtain higher magnetic field per unit current than fast formation

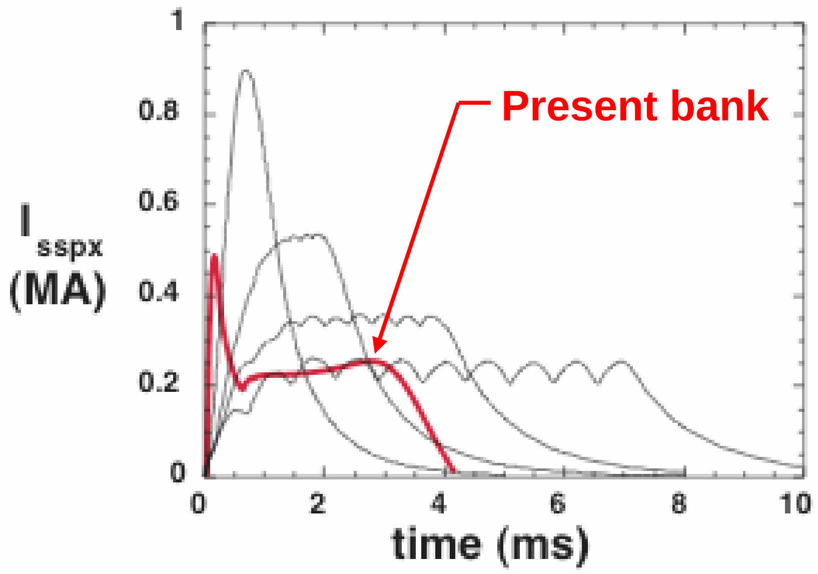
- Standard fast formation followed by sustainment yields maximum B/I_{gun}~0.65 T/MA.



- Slow–start formation has steadily growing B with B/I_{gun}= 0.75 T/MA.

- Double-pulse also produces highest fields of 0.78 T/MA

Future work includes modifying the capacitor bank to explore magnetic field build up



- **Modification of bank will provide three important conditions:**
  - **Better control of operation near threshold (operation near threshold produces lowest fluctuations and highest T_e)**
  - **Multiple pulse experiments.**
  - **A way to increase total pulse length incrementally.**

Summary

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  - –Peak temperature of >200 eV (peak β_e ~5-10%) observed when magnetic fluctuations are small (< 1%).
  - –Slow formation and double-formation-pulse discharges yield the highest magnetic field in SSPX.
- NIMROD simulations
  - –In good agreement with experiment
  - –Multi-pulse simulations underway
  - –Will be used to further explore spheromak physics and gun geometries