Whole-device, resistive MHD simulations of Coaxial Helicity Injection in NSTX

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Goals for NSTX

Goals:

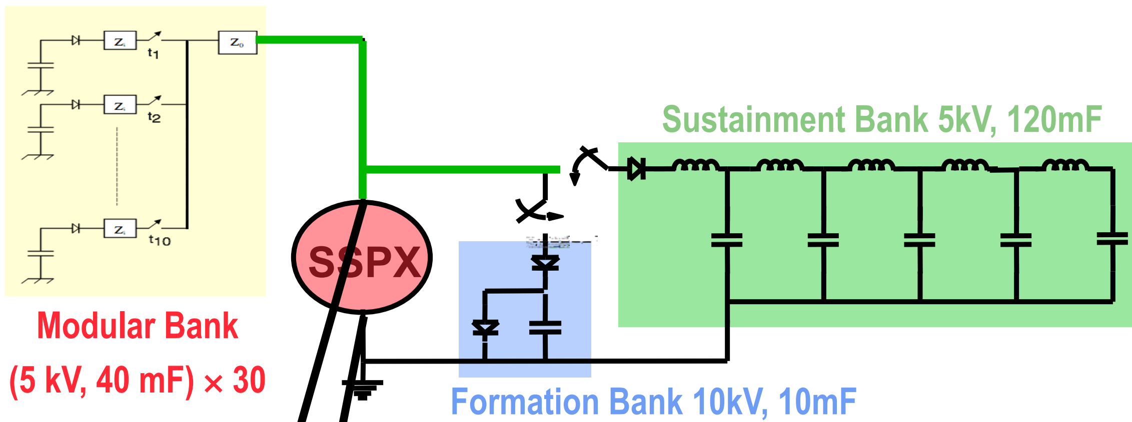
- Support the experiment by strengthening understanding of the physics in an ST
- Couple the simulations closely with the experiment
  - Validate simulations and understand their strengths and weaknesses
  - Model specific experiments and a range of data
- Help optimize CHI for startup plasmas – apply ohmic induction to simulated results

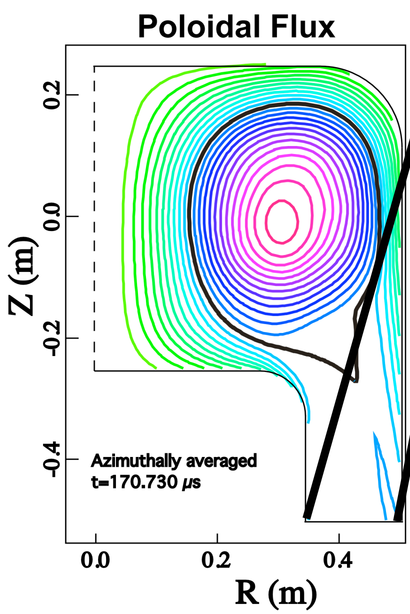
Modeling will be guided by the experimental results and needs

EXAMPLES FROM SSPX SIMULATIONS

COMPARISON WITH EXPERIMENT

Whole-device model of SSPX includes power systems and bias-coil magnets (not shown)





$$\frac{\partial n}{\partial t} + \nabla\cdot(n\mathbf{V}) = \nabla\cdot D\nabla n$$ $D \sim 2000$ m²/s to control density

$$\rho\left(\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{V}\right) = \mathbf{J}\times\mathbf{B} - \nabla p + \nabla\cdot\rho\nu\nabla\mathbf{V}$$

with isotropic numerical viscosity ν=10-2000 m²/s

$$\frac{nk_B}{\gamma-1}\left(\frac{\partial T}{\partial t} + \mathbf{V}\cdot\nabla T\right) = -\frac{p}{2}\nabla\cdot\mathbf{V}$$

$$+\nabla\cdot nk_B\left[\chi_{\|}\mathbf{bb} + \chi_{\perp}(\mathbf{I}-\mathbf{bb})\right]\cdot\nabla T + \frac{\eta \mathbf{J}^2}{2}$$

where $p \equiv 2nkT = nk(T_i + T_e),\ T_i \equiv T_e,$

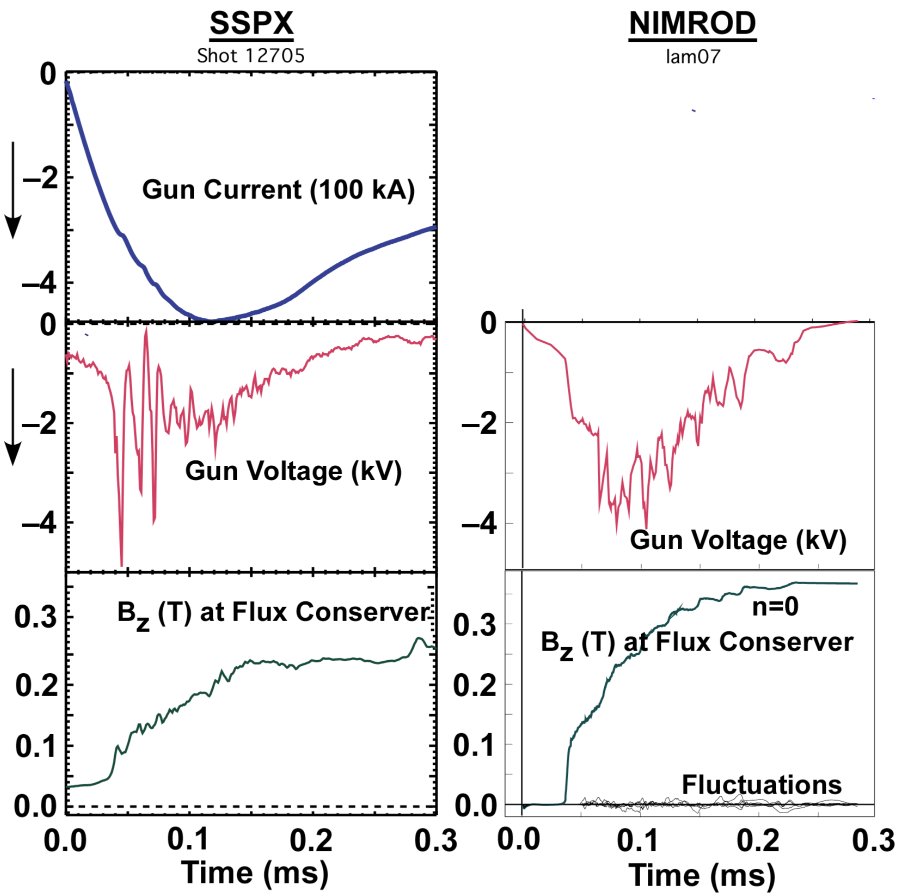
$\chi_{\|} = 387\,T^{5/2}$ m²/s and $\chi_{\perp} = 0.50\,T^{-1/2}B^{-2}$ m²/s (B in Tesla) or const.

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla\times(\mathbf{V}\times\mathbf{B} - \eta\mathbf{J}) \qquad \mu_0\mathbf{J} = \nabla\times\mathbf{B}$$

with $\eta/\mu_0 = 411\left(1\ \mathrm{eV}/\langle T\rangle\right)^{3/2}$ m²/s,

Experiment and NIMROD —

Voltage spikes occur in both and have the same effect on building and sustaining the plasma



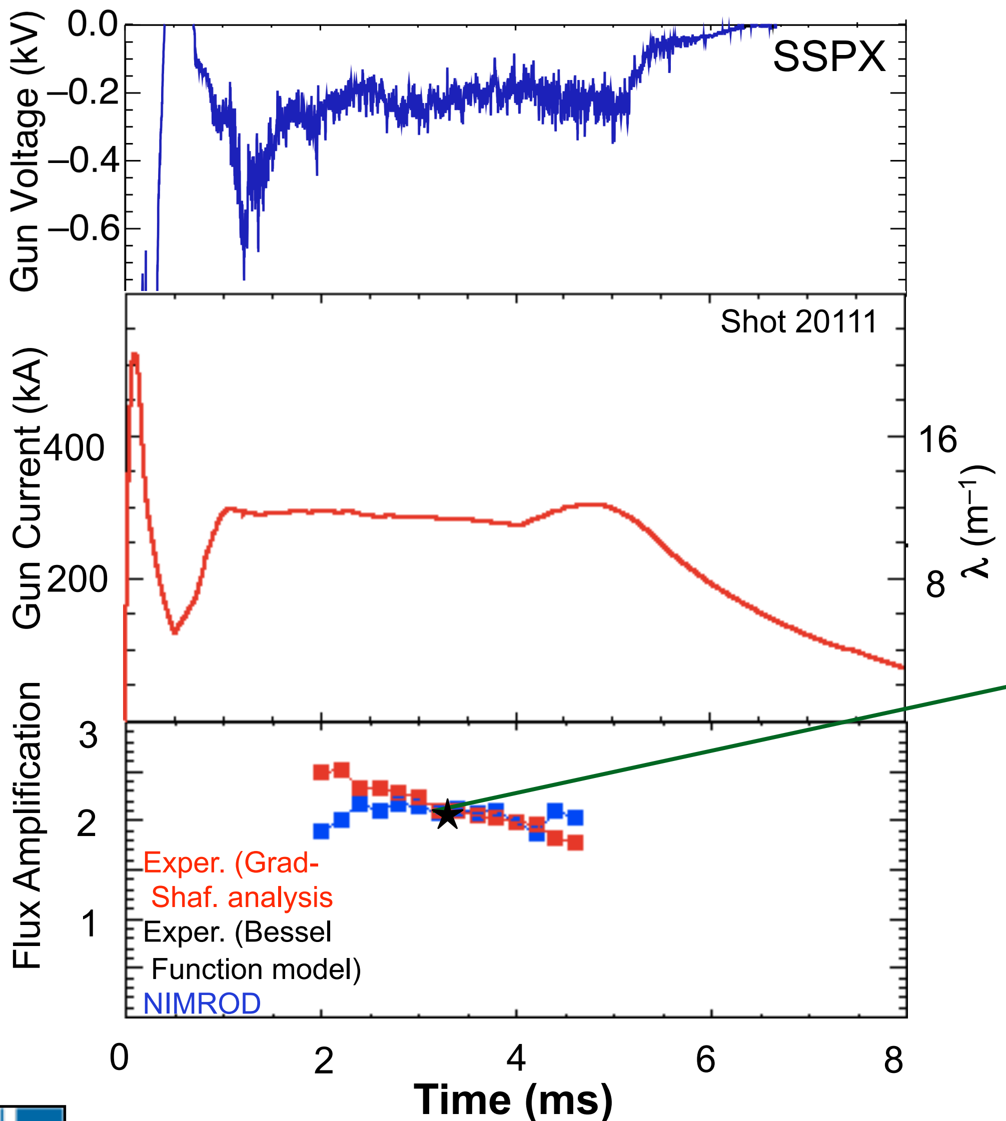
Compared are SSPX and NIMROD for identical gun currents

The "bubble-burst" of plasma from the gun is followed by voltage spikes

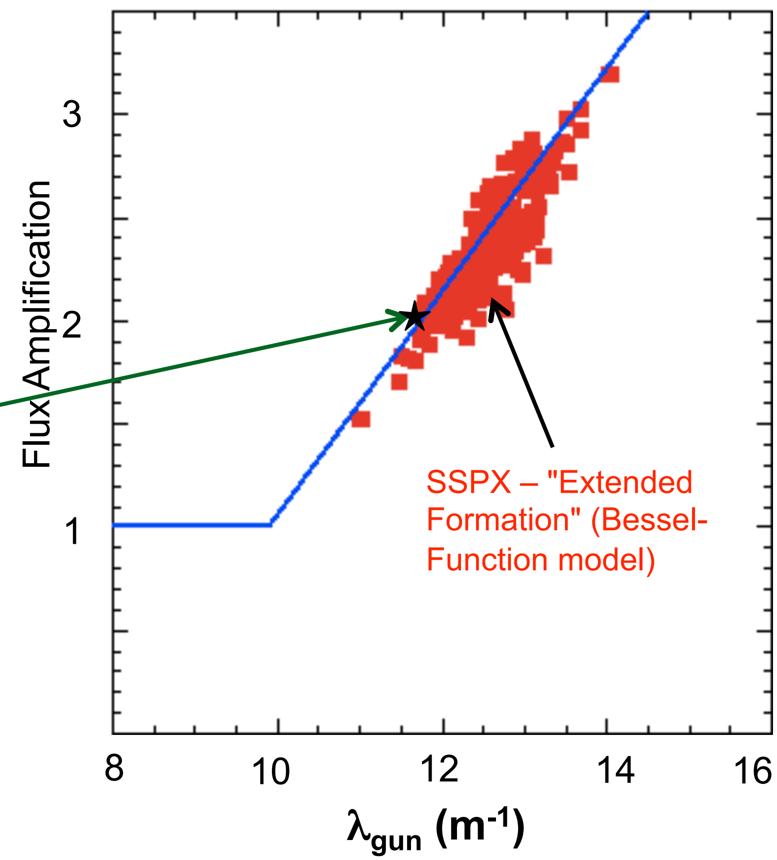
Toroidal flux is converted into poloidal flux at each spike — Reconnection

The magnetic oscillations (esp. n=1) – driven by the gun current – grow between voltage spikes and relax at the reconnection event

NIMROD Simulations Agree with Flux Amplification in SSPX



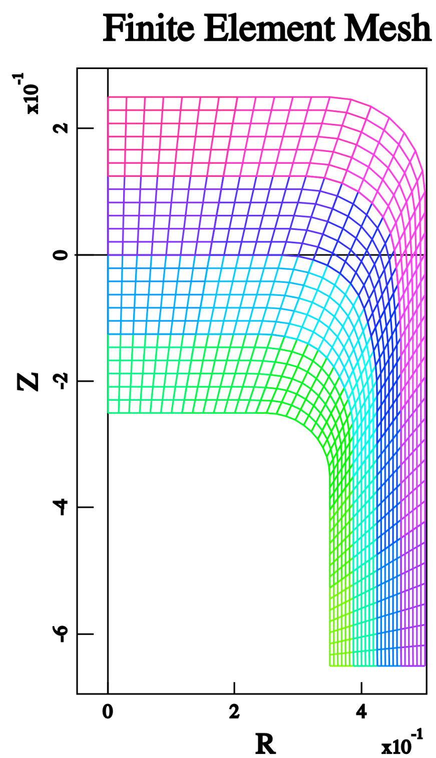
- NIMROD predicts the flux amplification in SSPX for current ≈ constant
- Extended formation discharges scale with $\lambda_{gun}=\mu_0 I_{gun}/\psi_{gun}$ as predicted by NIMROD.



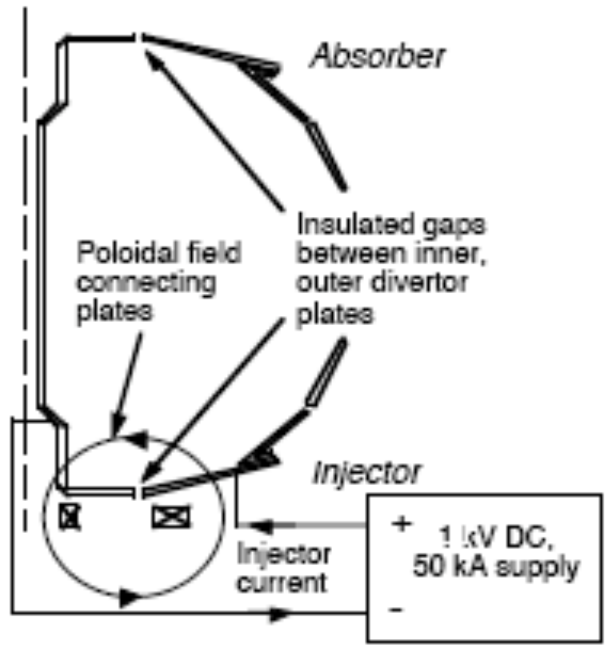
Note: For strong drive the agreement broke down. The reasons are not well understood

First step for NSTX — develop grid

SSPX



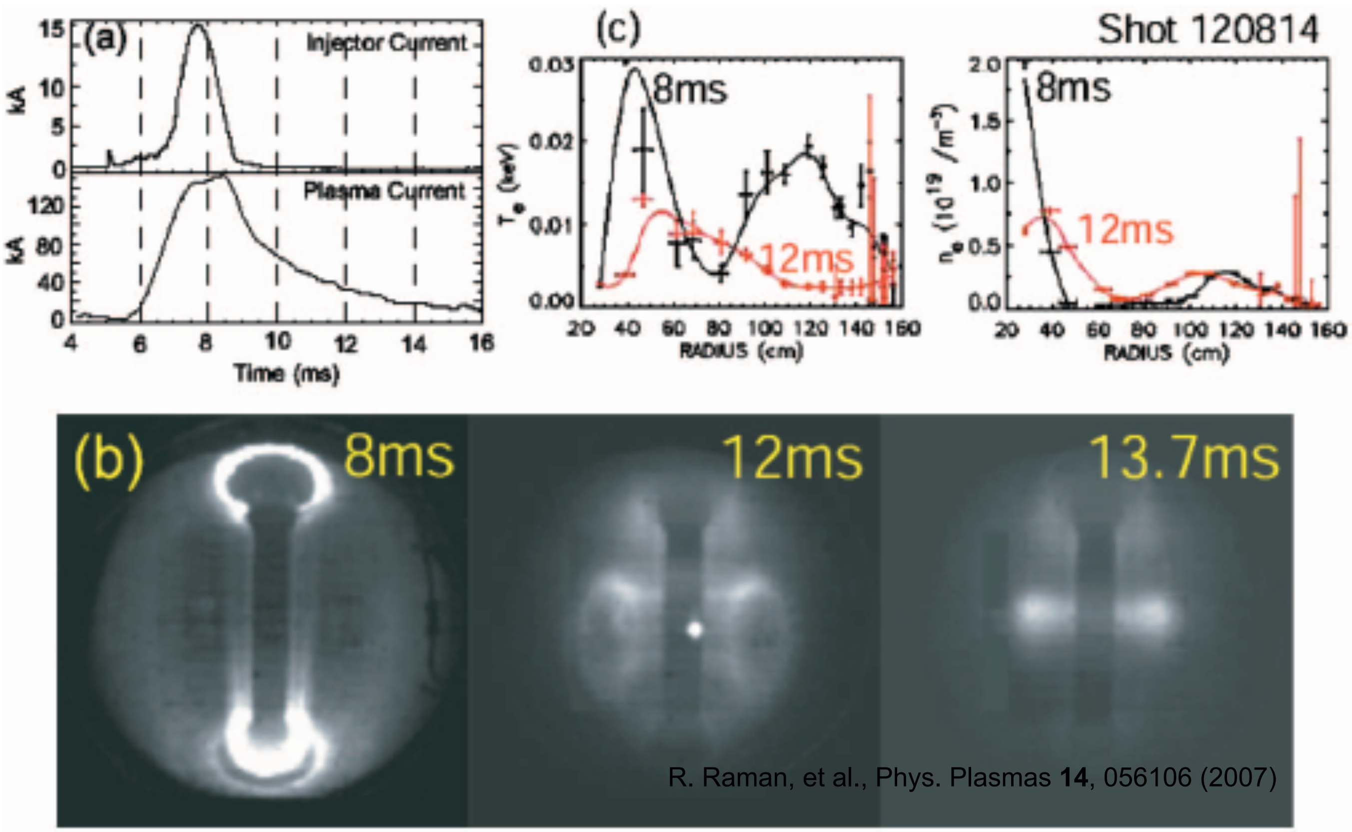
NSTX



The SSPX grid efficiently mapped the "gun" region into the spheromak volume

- The small size of the insulating gaps and localized ionization region in NSTX may make this more difficult
- It will probably be necessary to test and iterate the NSTX grid several times to optimize the grid for studying CHI

Second step — Model a simple startup shot



R. Raman, et al., Phys. Plasmas **14**, 056106 (2007)

Summary

Simulation of a specific discharge will allow comparison of current and voltage, plasma behavior near the insulating gaps, plasma evolution, etc.

- Success will provide a basis for exploring detailed physics in the ST geometry. The physics of interest includes:
  - The CHI discharge formation
  - Current and flux amplification
  - The reconnection processes associated with expansion into the NSTX volume
  - Plasma behavior following reconnection
- Modeling will be closely coupled to the experiment and focus on the most immediate needs and interests