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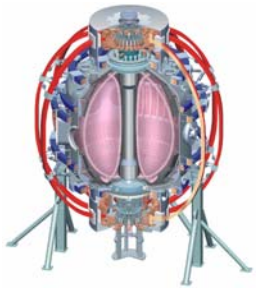

Solenoid-free Plasma Startup plans on NSTX for the 2007 to 2009 period

Roger Raman and Dennis Mueller

For the NSTX Team

NSTX Program Advisory Committee Meeting (PAC-21)

PPPL

17-19 January 2007

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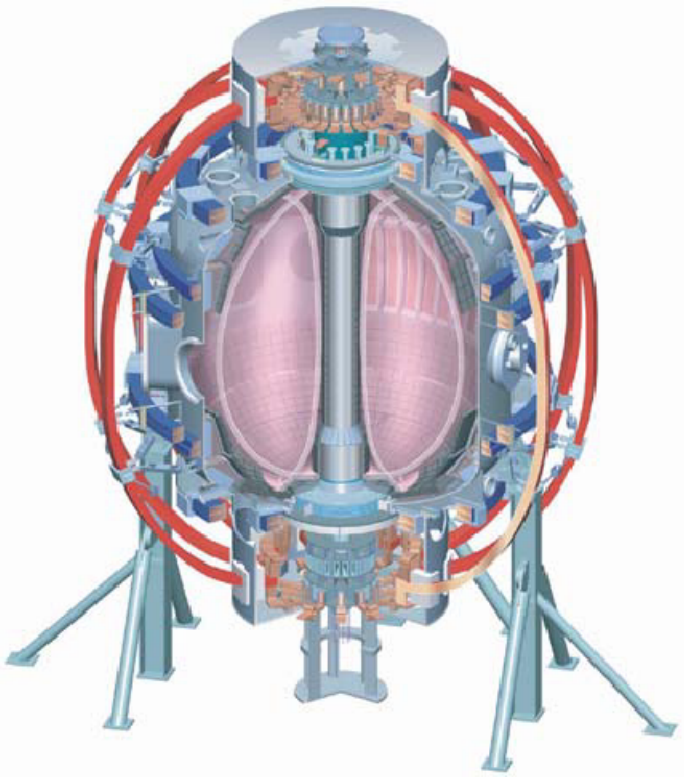
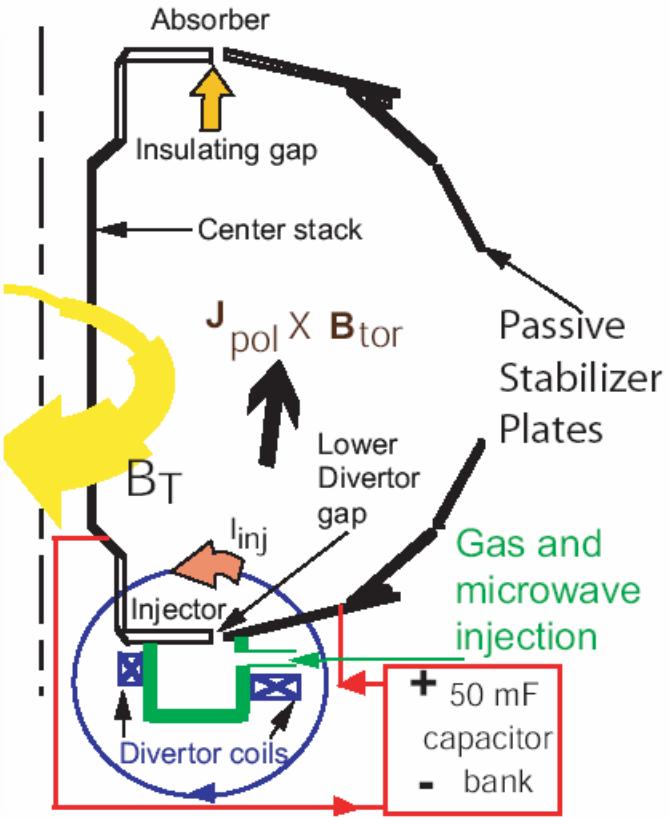
Motivations for Solenoid-free Plasma Startup Program

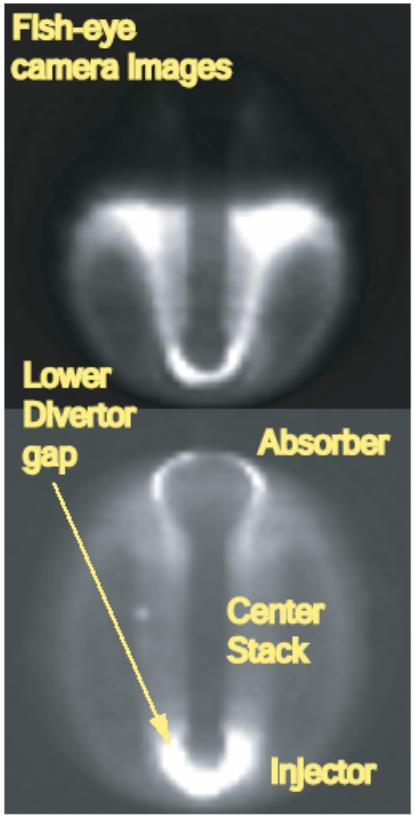
- The development of methods for solenoid-free current initiation will improve the prospects of the ST as a fusion reactor
- Could result in a more compact tokamak
- Of the three large machines in the US (DIII-D, NSTX, C-Mod) only NSTX is engaged in solenoid-free plasma startup research
- NSTX is exploring CHI and Outer PF Startup as methods for plasma current initiation

Goal: Initiate solenoid-free plasma currents, couple to non-inductive CD methods and ramp-up to high beta, high bootstrap current fraction discharges

NSTX Incorporates Toroidal Insulation Breaks to Enable CHI Operation







Transient CHI: Axisymmetric reconnection leads to formation of closed flux surfaces.

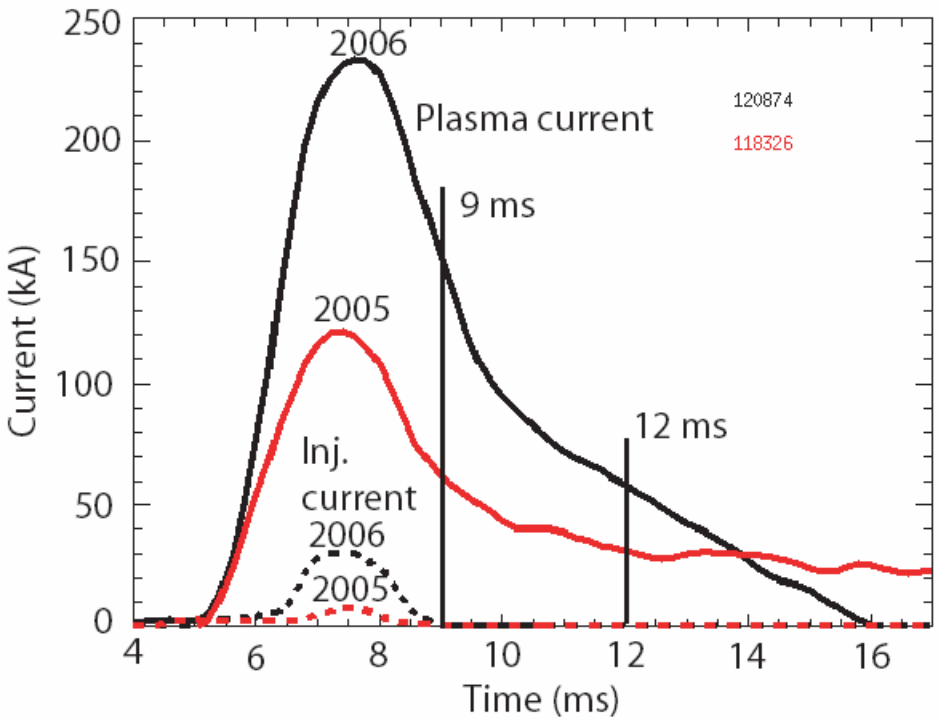
*CHI for an ST: T.R. Jarboe, Fusion Technology, **15** (1989) 7*

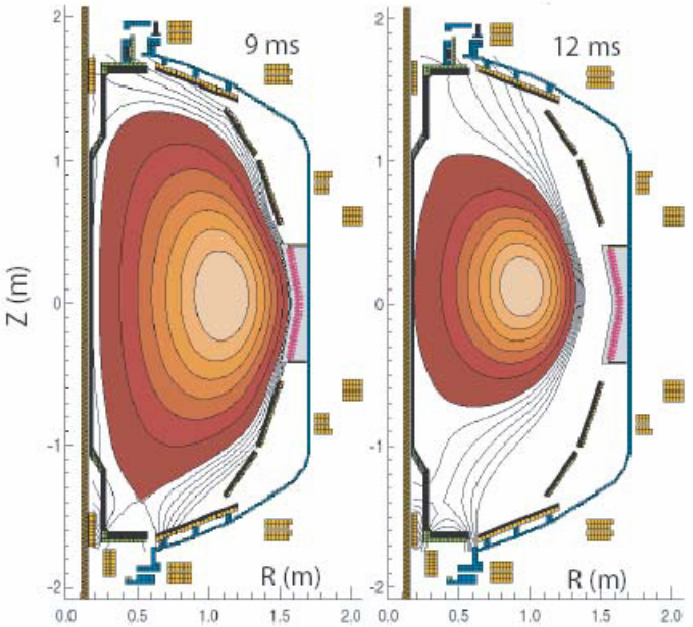
*Transient CHI: R. Raman, T.R. Jarboe, B.A. Nelson, et al., PRL **90**, (2003) 075005-1*

Upgrades Enabled Progress in Transient CHI

- Improved upper divertor insulator design
- Replaced rectifier power supply with capacitor bank
- Added Metal Oxide Varistors and capacitor snubber
  - Reduce transient voltages across insulators
- Added gas & ECPI injection from lower divertor region
- Added “crowbar” resistor across capacitor bank
- Improved voltage monitoring (for FY 07)
- MOV current monitoring (for FY 07)

160 kA Closed Flux Current Produced in NSTX



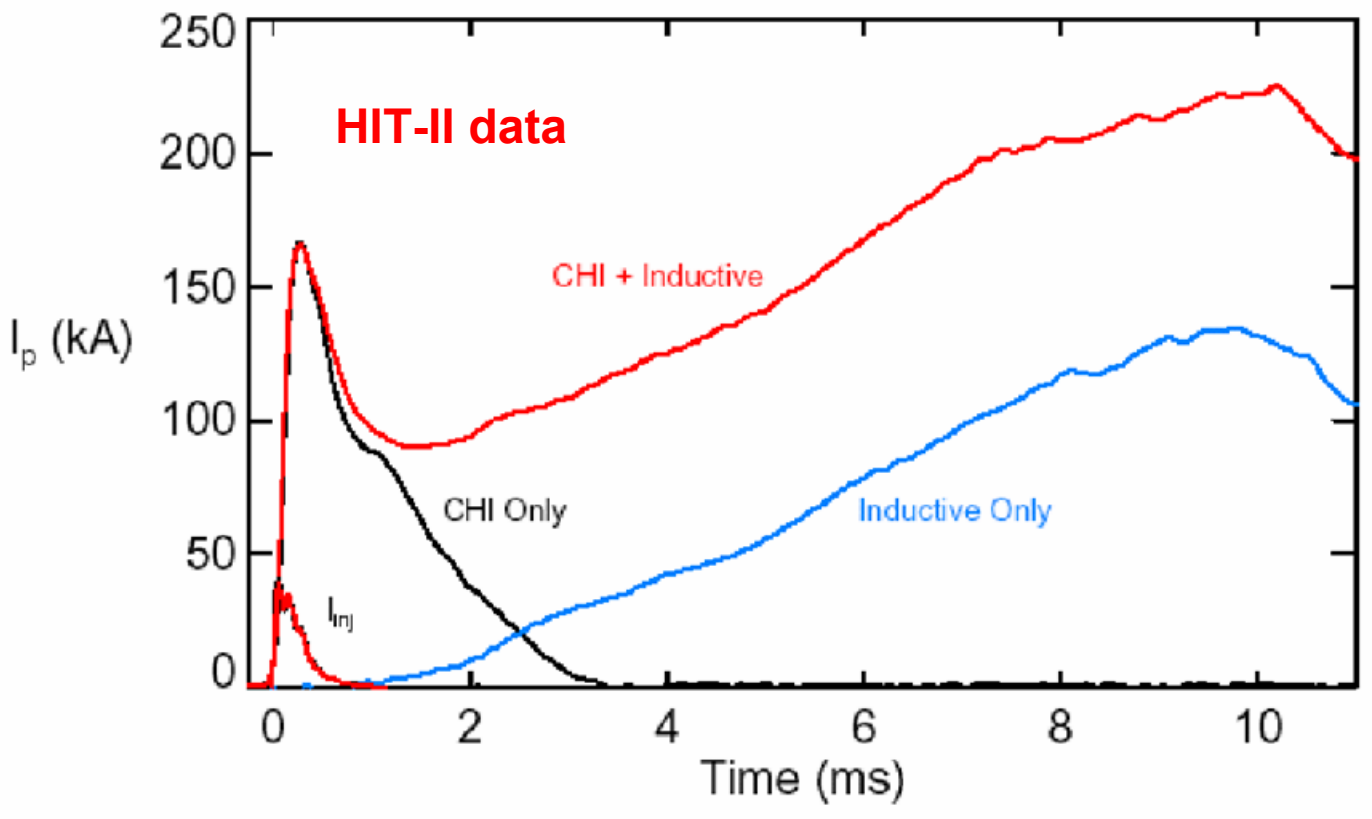


- 2006 discharges operated at higher toroidal field and injector flux
- EFIT analysis possible when no injector current is present
- Magnetic sensors and flux loops used in reconstruction

*R. Raman, B.A. Nelson, M.G. Bell et al., PRL **97**, 175002 (2006)*

FY 08 Milestone: Couple Induction to CHI Initiated Discharge

Results from HIT-II show nearly all CHI-produced closed flux current is retained in the subsequent inductive ramp



Both discharges have identical loop voltage programming

*R. Raman, T.R. Jarboe, R.G. O'Neill, et al., NF **45** (2005) L15-L19*

Research Forum Prioritization of FY 07 CHI Experiments

Experiment	5-Day Run Plan	10-Day Run Plan
Transient CHI – Startup optimization	2	3
Transient CHI – Couple to induction	3	5
Heat OH plasmas with HHFW	0	1-2
Heat CHI plasmas with HHFW	Piggyback	0.5-1
Dynamo Probe studies	Piggyback	Piggyback

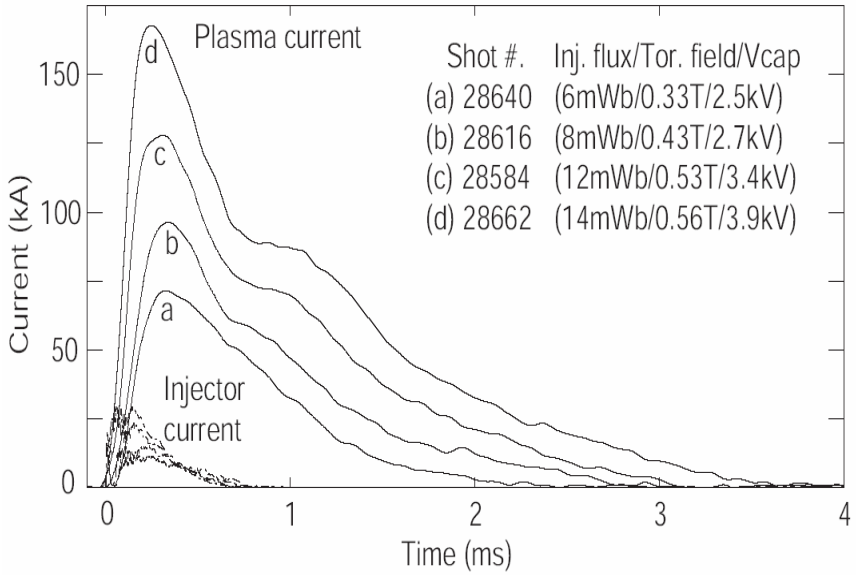
FY 07 Plans for CHI

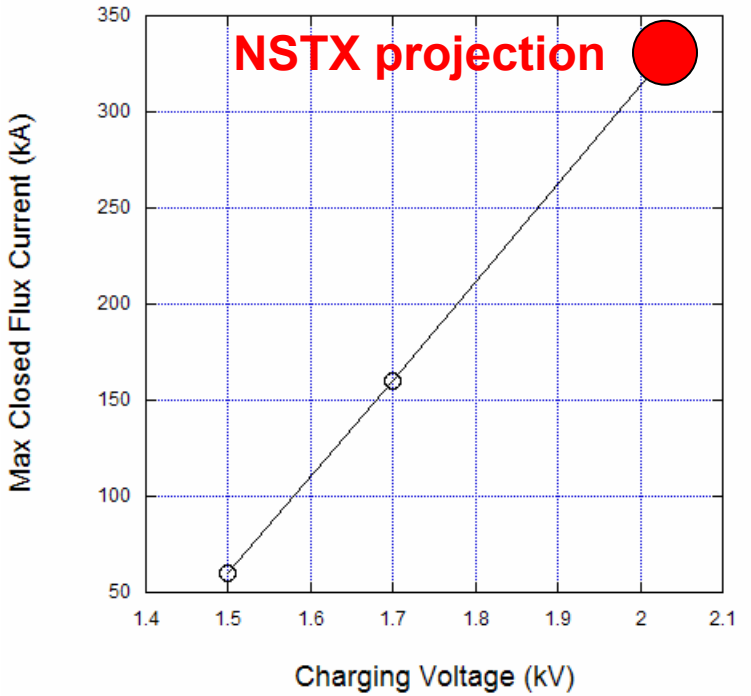
- Optimize high current CHI discharges
  - Use fewer capacitors
    - Reduce potential for absorber arcs which affect main discharge
  - Increase capacitor bank voltage to 1.85kV (new charging supply and improved voltage monitoring)
  - Operate at higher values of TF (if available voltage permits)
- Couple to induction
  - Measure flux saving
  - Initially ramp OH solenoid unidirectionally from zero current
  - Later investigate using small amount of solenoid pre-charge
    - Increases available flux and initial inductive loop voltage
    - Investigate effects of solenoid fringing field on formation and equilibrium
- Test HHFW heating of CHI+OH plasmas
  - Determine effectiveness of HHFW at low current

NSTX & HIT-II Results Indicate Further Improvement to CHI Target Possible

- Results indicate 300kA should be possible in NSTX at 2kV
  - Planned for 2008

Closed-flux current increased with capacitor charging voltage in HIT-II





- Present CHI discharges in NSTX should couple to induction
  - Plasmas reach 10 – 20 eV and radiate ~100kW
- 100 – 200 kW of ECH could increase T_e to ~100eV in NSTX
  - Expect adequate HHFW absorption at this temperature

HIT-II data: *R. Raman et al., Nucl. Fusion, **45**, L15-L19 (2005), Phys. Plasmas **11** (2004) 2565*

FY 08 Plans for CHI

- Increase CHI capacitor bank voltage to 2kV
  - If necessary install new surge suppressors
  - Increase CHI produced current magnitude to ~300kA
  - Improve coupling to induction **(Milestone guided by PAC 19)**
  - Produce a standard CHI-initiated discharge for use by other experiments
- Use CHI for edge current drive in a pre-formed inductive discharge
  - Diagnose using the Dynamo Probe

FY 09 Plans for CHI

- Apply ECH and HHFW heating to CHI plasma
  - Use outer PF for additional volt-seconds
  - Optimize solenoid-free current fraction
- Measure edge current penetration in CHI edge current drive experiments
  - Use MSE diagnostic
  - Determine effect on plasma edge stability

Plasma Startup Using Outer Poloidal Field Coils

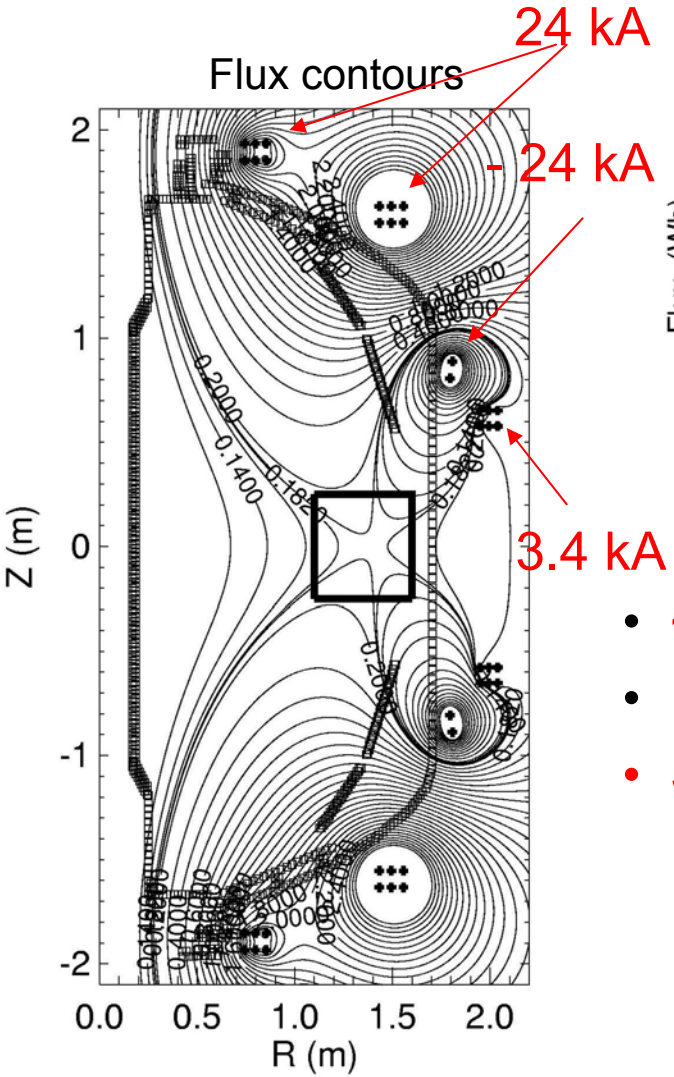
Outer PFs has been used to startup the plasma:

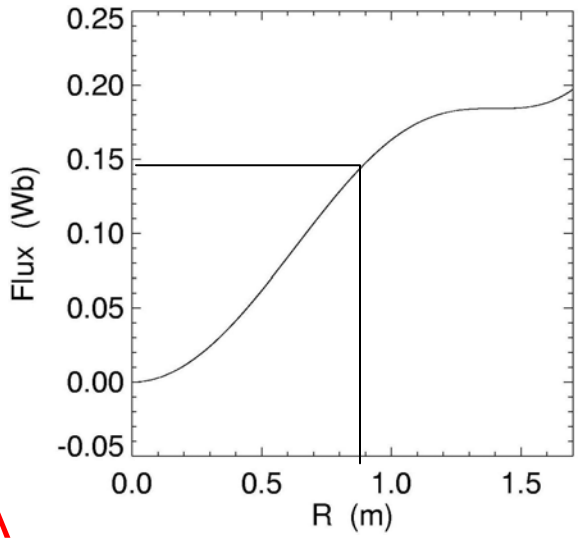
- MAST (START) - poloidal field coils + radial compression
- JT-60U - Aggressive application of RF heating and current drive

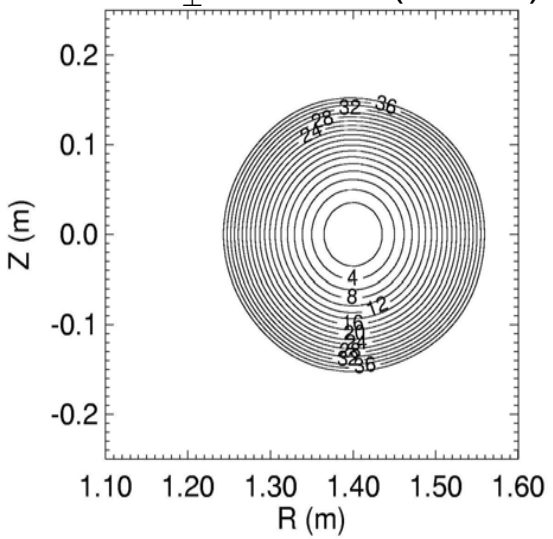
Three important conditions for "Inductive" plasma startup:

1. Satisfy the "Lloyd condition" for plasma startup. With strong ECH (in DIII-D), $E_T \cdot B_T / B_P \geq 0.12$ kV/m.
2. The field null must be maintained for a sufficient duration 2 – 3 ms in the presence of wall eddy currents.
3. Sufficient available flux for subsequent current ramp up to ~ 500 kA.

Creation of High-Quality Field-Null with Significant Poloidal Flux is Possible with NSTX PF Coils







- ~0.15 Vs available on NSTX
- 1 MA achieved with ~0.3 Vs from solenoid
- Sugggests possibility of ~ 500 kA in NSTX
  - ~20 kA produced in FY 2005
  - Improvements to pre-ionization are needed
    - e.g. plasma injectors, ECH

*W. Choe, J. Kim and M. Ono, NF **45** (2005) 1463*

CHI and Outside PF Induction Could be Used Synergistically to Increase Startup Current

- Transient CHI works well
  - Successful initial development on HIT-II
  - Produced record non-inductive initial current in NSTX
  - Scaling to larger machines is attractive
- Next goal is to couple CHI to induction (FY 08 Milestone)
- Heat CHI plasma with ECH and HHFW (FY 09)
- Test plasma startup using outside PF induction (FY 09)
  - Potential to produce MA level startup currents in large STs
- NSTX is the only large machine is the US studying these
  - CHI is unique to NSTX
  - Edge current drive has potential for edge current profile control & modification of SOL flows