NSTX

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XP-901: Exploration of Fast Shut-Down Using Coaxial-Helicity Injection

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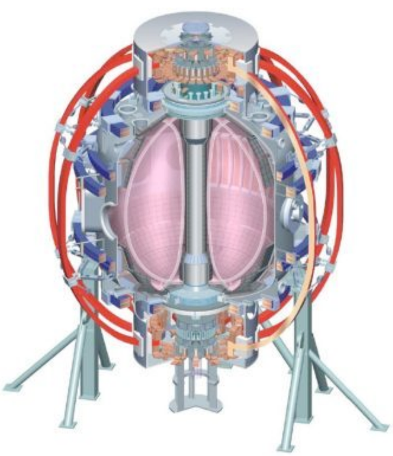
MHD Group Review

1: Motivation and Goal for XP
2: Some Technical Considerations
3: Shot Plan



Disruptions Are a Problem For Tokamak Reactors

- Eddy Currents Driven by the Current Quench
  - Cause overturning moment on conducting components inside the vessel.
- Halo Currents During Vertical Motion
  - Vertical position typically lost after β-collapse or thermal quench.
  - Large current (10-30% of I_P) flow between plasma and PFCs/VV, causing large forces of those items.
- Impulsive Heat Loading
  - Entire thermal energy of plasma lost in <1ms.
  - If it all goes to divertor, can exceed melting/ablation threshold (~40 $MJ/m^2s^{1/2}$).
- Runaway Electron Beam Formation
  - Three mechanisms can drive runaway formation. (Dreicer, "Hot-Tail', Rosenbluth)
  - All can be mitigated if the runaway loss rate is increased.
  - Runaway beam can result in very localized damage to PFCs and/or VV.
- Often Little Warning of Imminent Disruption
  - Especially true of ITB ∇p disruptions (uncommon/unknown (?) in NSTX).
  - Only very short time to initiate shutdown before disruption starts.

CHI-Based Fast Shutdown Scheme Might Help Alleviate Many of These Concerns

- Thermal Quench Heat Loading :
  - CHI plasma can bring impurity gas into main discharge.
  - Thermal energy is then radiated away, instead of conducted to the divertor.
  - Impurity gas is toroidally distributed, so that, in contrast to MGI, there is no toroidally localized radiation burst.
- Halo Currents :
  - If shutdown is sufficiently fast, the VDE motion cannot occur before shutdown is done…no possibility for halo currents.
- Runaway Formation:
  - It is believed that stochastic fields can prevent runaway formation (see Granetz APS contributed oral).
  - Flowing CHI currents could assist in making fields stochastic.
- Look Ahead Time:
  - Impurities are electromagnetically forced into the main plasma, potentially reducing the time to shutdown compared to gas flowing down a tube.

If an ST reactor has a CHI system for startup, then it is useful to explore the capabilities of the system for shutdown as well.

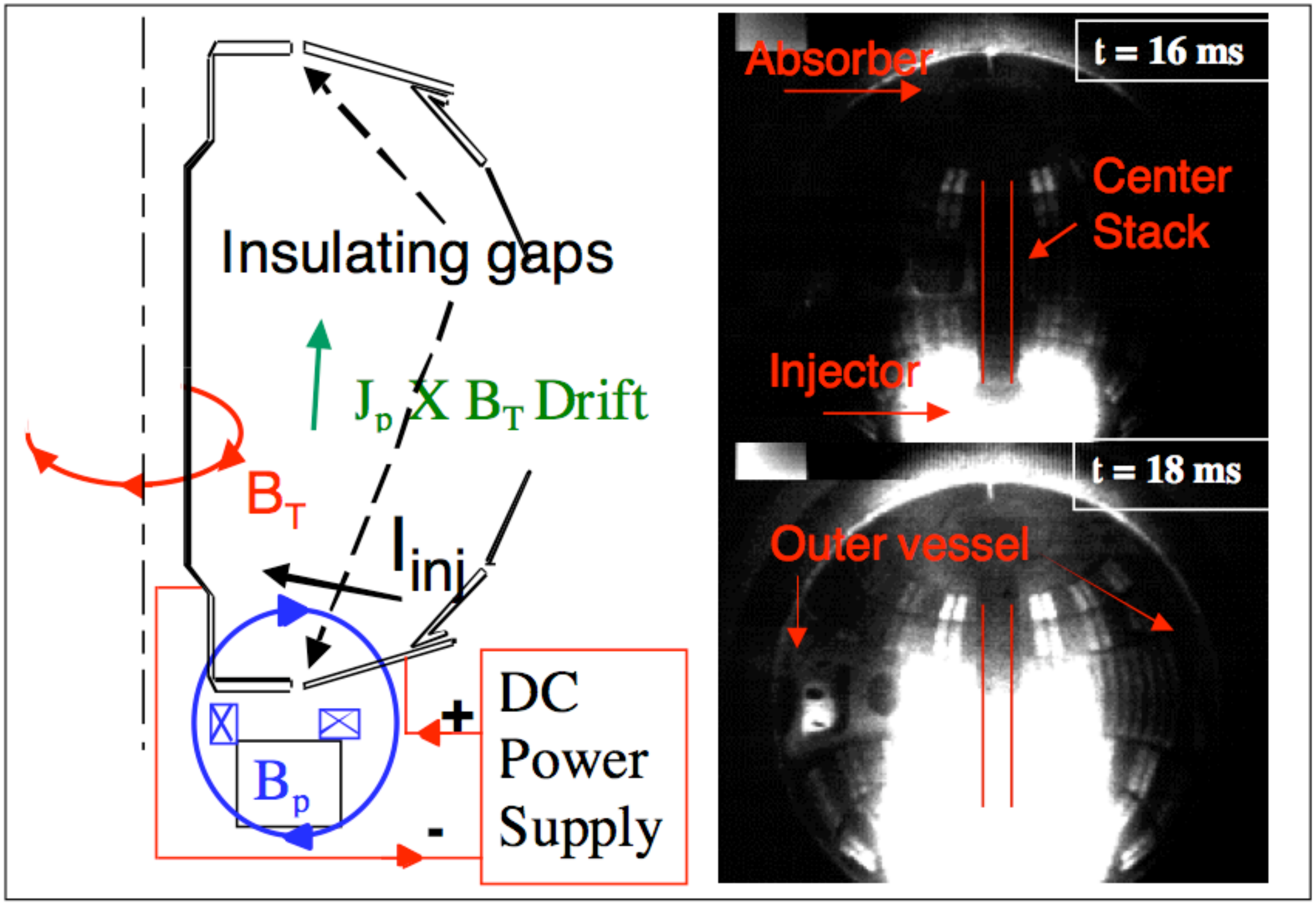
Three Questions to Explore in a First XP in NSTX

- Can CHI injection in NB heated plasma lead to fast shutdown?
  - Can VDE motion be avoided? *(Highest Priority Question)*
  - What is the time delay between CHI initiation and plasma shutdown?
  - How much gas is required? Which LDGIS Plenum is best? What gas is best?
  - How does the CHI bank energy influence the shutdown.

- If successful, does the shut down require CHI?
  - LDGIS system can inject a lot of gas, so verify that the electromagnetic effects are important (and that it is not simply fancy MGI)?

- Does the lower divertor magnetic topology modify the effectiveness?
  - Different divertor geometries link the LOBD and LIBD in different ways (or not at all), allowing different current paths.
  - Which geometries are optimal for disruption mitigation.

Schematic of CHI System



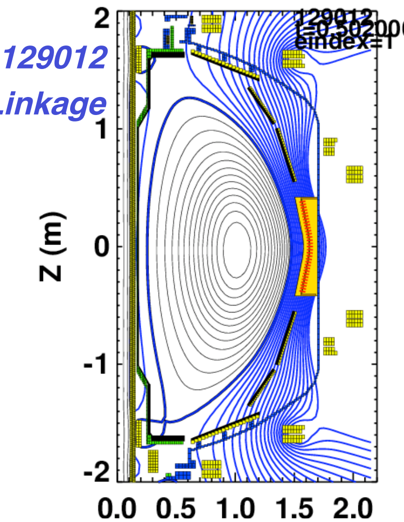
- PF-2 flux links IBD & OBD, allowing current to flow between them
- J_P x B_T force drives plasma into the main chamber.

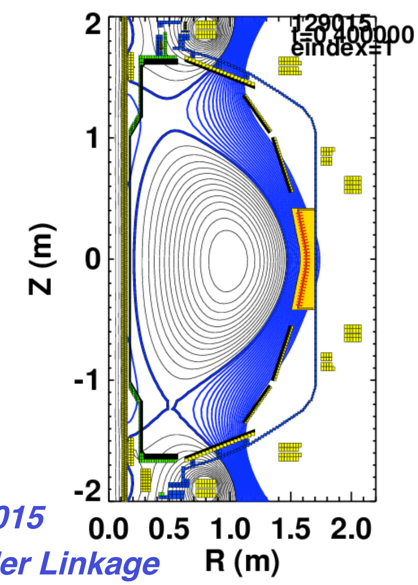
Possible Targets With Difference Field Line Characteristics Linking Lower Divertor, Different Control Capabilities

- Goal: Avoid Shot Development
- Gap Control Algorithm
  - Feedback control only the vertical position, R_0, gaps (bad).
  - Has capability for freezing of vertical position control (good).
- Isoflux (SPG prefers to use these, save deliberates VDE studies for next year)
  - Control above + κ (through squareness), dr_{sep} (good)
  - No vertical position freeze. (bad)

Liter Day 1&2, Isoflux

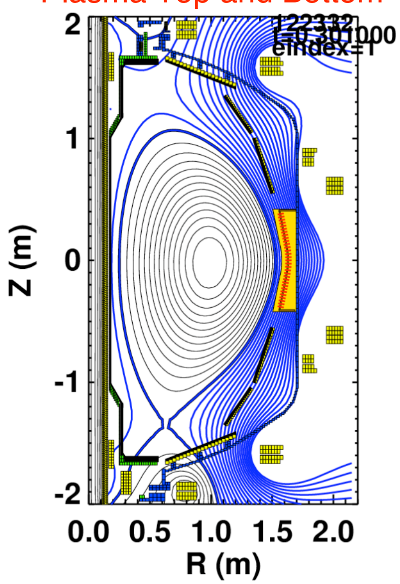
129012
No Linkage





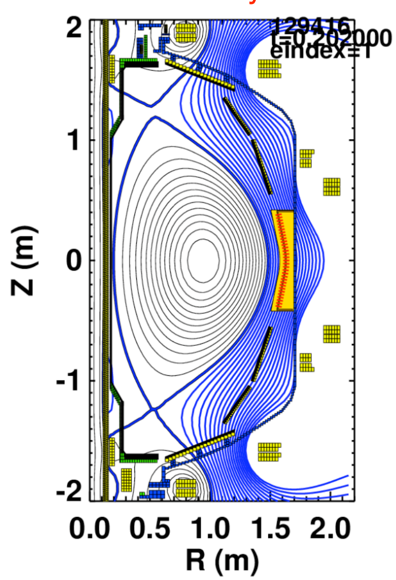
129015
Under Linkage

122332, Gap Control
Used in XMP-48
IBD and OBD Linked Over Plasma Top and Bottom



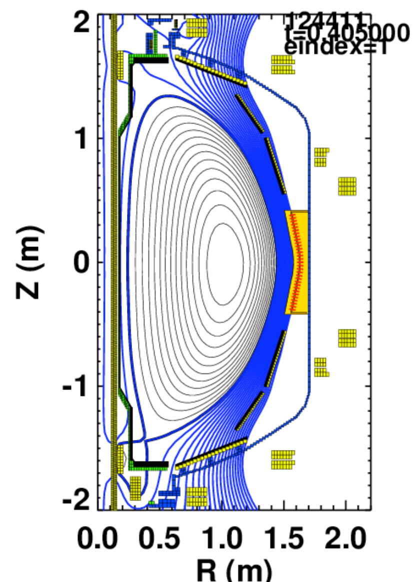
Over/Under Linkage

129415, Gap Control
Used in Δz_{max} XP, 2008
IBD Linked to OBD at Bottom Only



Under Linkage

124411, Gap Control
High-κ, high-δ
JEM Shot last used 2007
No IBD/OBD Linkage



No Linkage

NSTX Device Configuration

Important Note

Split this XP over a few days, mixed with other CHI experiments.

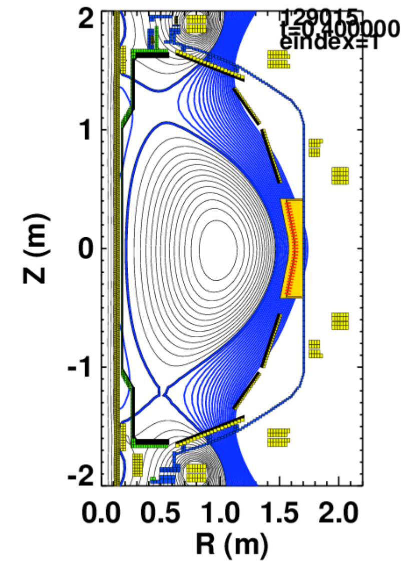
Hardware and experimental design should be consistent with this type of scheduling.

- CHI Bank Connections:
  - Bank 1: 1 Capacitors
  - Bank 2: 2 Capacitors
  - Bank 3: 5 Capacitors
- LDGIS configured in “puff” mode at 2400 T D_2/He. Use both large and small LDGIS plenums in XP.
  - First D_2 OH, then NB-heated plasmas, with D_2 or He injected for mitigation.
  - In the future, mix some Ar or Ne?
- RWM Coils/SPAs in odd configuration for “standard” n=1+3 EF correction, if necessary (but pick configurations where high-β physics isn’t too important).
- OH configured for 4kV operation:
  - Standard is 6kV, so maximum breakdown loop voltage limited to (4kV/6kV)*7=4.7 V
  - With proper shot selection and machine conditions should be OK (125329 had 3.5 V, 129012 had 3.6V, 122332 had 5.1, 129415 in He had 3.4, 129015 had 3.0 V, all measured at breakdown & early I_P ramp).

Diagnostics / Analysis

- **Halo Current Detection.**
  - Both magnetic detection and new instrumented tile array.
  - Hope not to measure anything…suppression of VDE and HCs.
- **USXR Measurements**
  - Htop in bolometry, h-bottom in 10 μm, vtop in 10μm
  - Should allow a measurement of the cooling time.
- **Thomson Scattering**
  - May vary the Thomson scattering trigger time, for instance to be +0.5, +1 and +1.5ms after CHI trigger time in a case that we wish to document well.
  - Be wary of background light issues during shutdown.
- **Phantom Cameras.**
  - One viewing toriodally into X-point region, for details of interaction.
  - One viewing from top.
- **Fast Equilibrium Reconstruction.**
  - 1 msec EFITs between shots.
- **IR Thermography.**
  - New fast camera viewing lower divertor. New capability for 2009. Use if possible but don't wait for it.
  - Slow cameras viewing upper and lower divertor, for up-down imbalance of total divertor energy deposition.
- **Hard X-rays**
  - Look for formation of runaways.

Plan, Step 1: Safety Check & Ohmic Plasma Shutdown



- Goal: NSTX Safety Assessment
  - ~1/3 of a run day, following standard CHI startup experiments
  - Use low energy/low current plasmas
- Target: 600 kA Ohmic Plasma D_2, “Under Linkage”
  - RT-EFIT Version: 129015 (LITER Day-2 Shape)
  - Gap-Control Version: 129415 (Δz_{max} measurement)
  - RF shot?
- Shot List: D_2 in LDGIS
  1. Reproduce target plasma (2 shot)
  2. Use 3 capacitors (1.7kV), 2400 Torr in Branch 5 (T_{gas}=T_{CHI}-13ms) (2 shots)
  3. Use 9-10 capacitors, 2400 Torr in Branch 5 [~3 Torr.L] (2 shots)
  4. Repeat both above with no capacitors (gas only) (2 shots)
  5. Use 9-10 capacitors, 500, 1000, 2000 Torr in LDGIS (4 plenums) [~18-72 Torr.L] (4 shots)
  6. Repeat optimal case(s) from 5 with no capacitors (gas only) (2 shots)

CHI may force the plasma upward

May be necessary to energize the PF3U coil to push plasma down.

Plan, Step 2: NB Heated Plasma Shutdown

Note: Extended Plan, Probably Divided Over Multiple Days, & Likely Modified as a Result of Step 1

1: Re-establish 600 kA D_2 target, same as Step 1 Experiments (2 shots)

2: Repeat "optimal" configuration from Step 1 with *He* CHI, both with and without voltage (3 shots)

3: Establish a 4MW, 900kA "Under-Linkage" Target (129015, 129415?) (2 shots)

4: Test CHI shut-down, bank 3 @ 1.8kV, 2400 T He in 1cc plenum, during I_p flat-top (2 shots)
- If successful (centered rapid shutdown), then repeat with same gas, but no voltage.

5: Test CHI shut-down, bank 3 @ 1.8kV, 2400 T He in 4 plenums, during I_p flat-top (5 shots)
- If successful (centered rapid shutdown), then repeat with same gas, but no voltage.
- Do small scan of plenum pressure (2000T, 1600T)

6: Scan of capacitance (bank energy) at optimal plenum configuration (size, fill pressure) from 2 & 3. (4 shots)
- Repeat with bank 2 only. (3 capacitors)
- Repeat with banks 2+3. (8 capacitors)

Here is a Good Break Point

7: Repeat optimal CHI configuration from 1-4 with an "Over/Under Linkage" target (122332, 130328) (4 shots)
- Do gas-only as well.

8: Repeat optimal CHI configuration from 1-4 "No Linkage" target (124411 or fiducial shape). (4 shots)
- Do gas-only as well.