LTX status and plans

R. Majeski[1]

Additional contributors: S. Avasarala[1], L. Berzak[1], E. Granstedt[1], T. Gray[1], C. Jacobson[1], R. Kaita[1], T. Kozub[1], B. P. LeBlanc[1], D. P. Lundberg[1], R. Maingi[2], S. O'Dell[3], G. V. Pereverzev[4], T. Strickler[1], D. Stotler[1], J. Timberlake[1], K. Tritz[5], and L. E. Zakharov[1]

[1] Princeton Plasma Physics Laboratory, Princeton, NJ

[2] Oak Ridge National Laboratory, Oak Ridge, TN

[3] Plasma Processes, Inc, Huntsville, AL

[4] Max-Planck-Institut Für Plasmaphysik, Garching, Germany.

[5] Johns Hopkins University, Baltimore, MD

Outline

- Introduction to LTX
- Hot, lithium coated conformal shell
  - Mechanical supports, electrical isolation, heating
  - Eddy currents in the shell and PF evolution
- Multiphase OH power supply
- Thomson scattering
- Lithium-specific engineering
- Future plans
  - Modeling of LTX performance

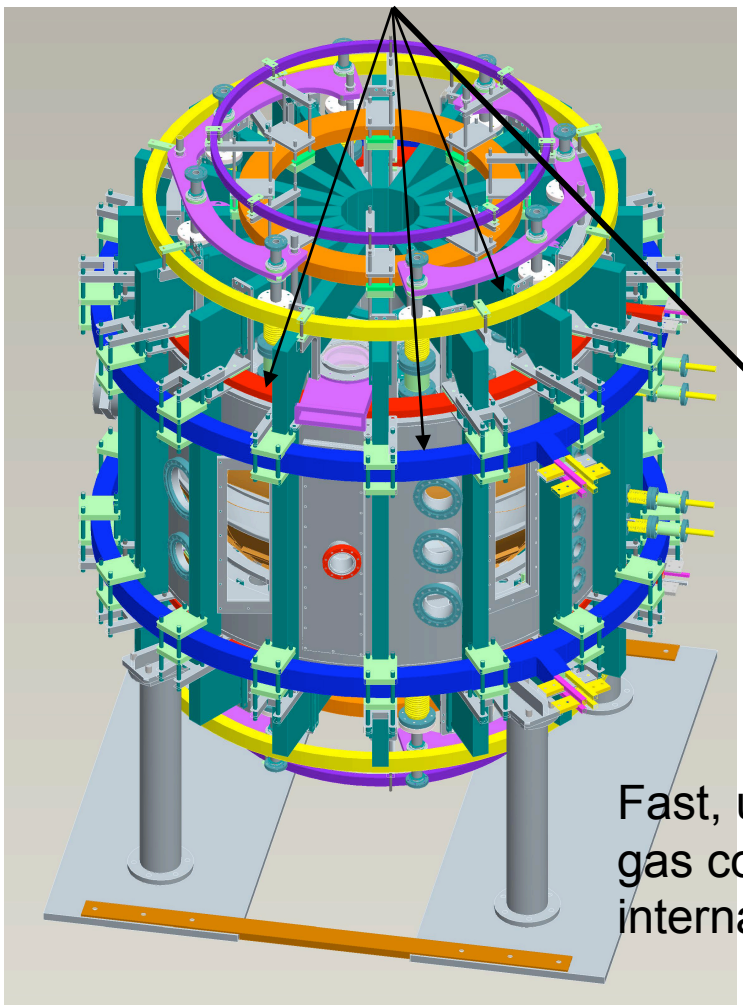
Lithium Tokamak eXperiment - LTX

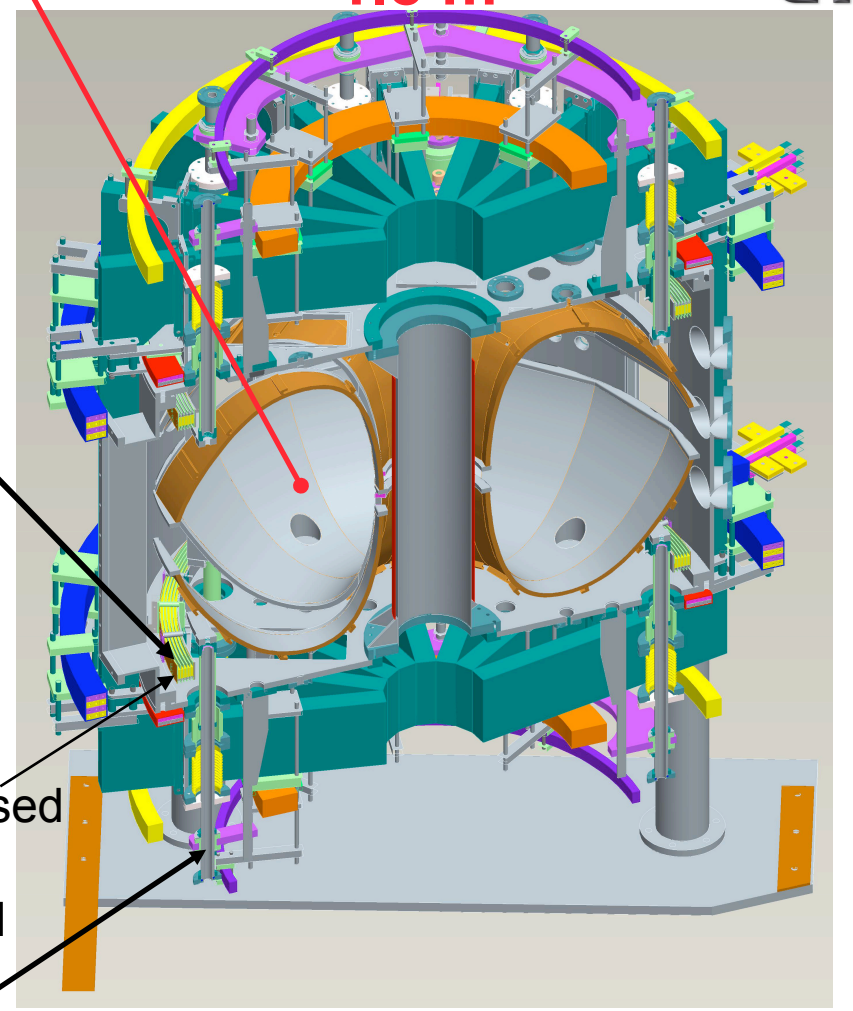
- Lithium wall technology: static, molten thin (~ 10 μ) films
  - Heated, conformal wall with small plasma-wall gap (~0.5 cm average)
    - » Explosively bonded 1.5 mm SS on 1 cm OFHC nickel plated copper
    - » Liquefied lithium film on heated metal wall
    - » Designed for 500 °C to promote wetting of SS by lithium, 300 – 350 °C during tokamak operation to limit evaporation
  - Second shell (FY11) - plasma sprayed porous molybdenum inner surface
    - » First full 500 °C high Z wall in a tokamak
- Plasma fueling with pulsed gas jets (SGI) and molecular cluster injection
  - NBI in next phase (20 keV, 5 A, full discharge duration in 2011)

Parameter	LTX
Major radius	0.4 m
Minor radius	0.26 m
Toroidal field	0.34 T
Plasma current	400 kA
Current flattop	100 ms, up to 250 msec with NBI
Ohmic flux	160 mV-s (centerstack maximum: 225 mV-s)

LTX discharges will be wall-limited on the heated, lithium-coated shell

- PF coils



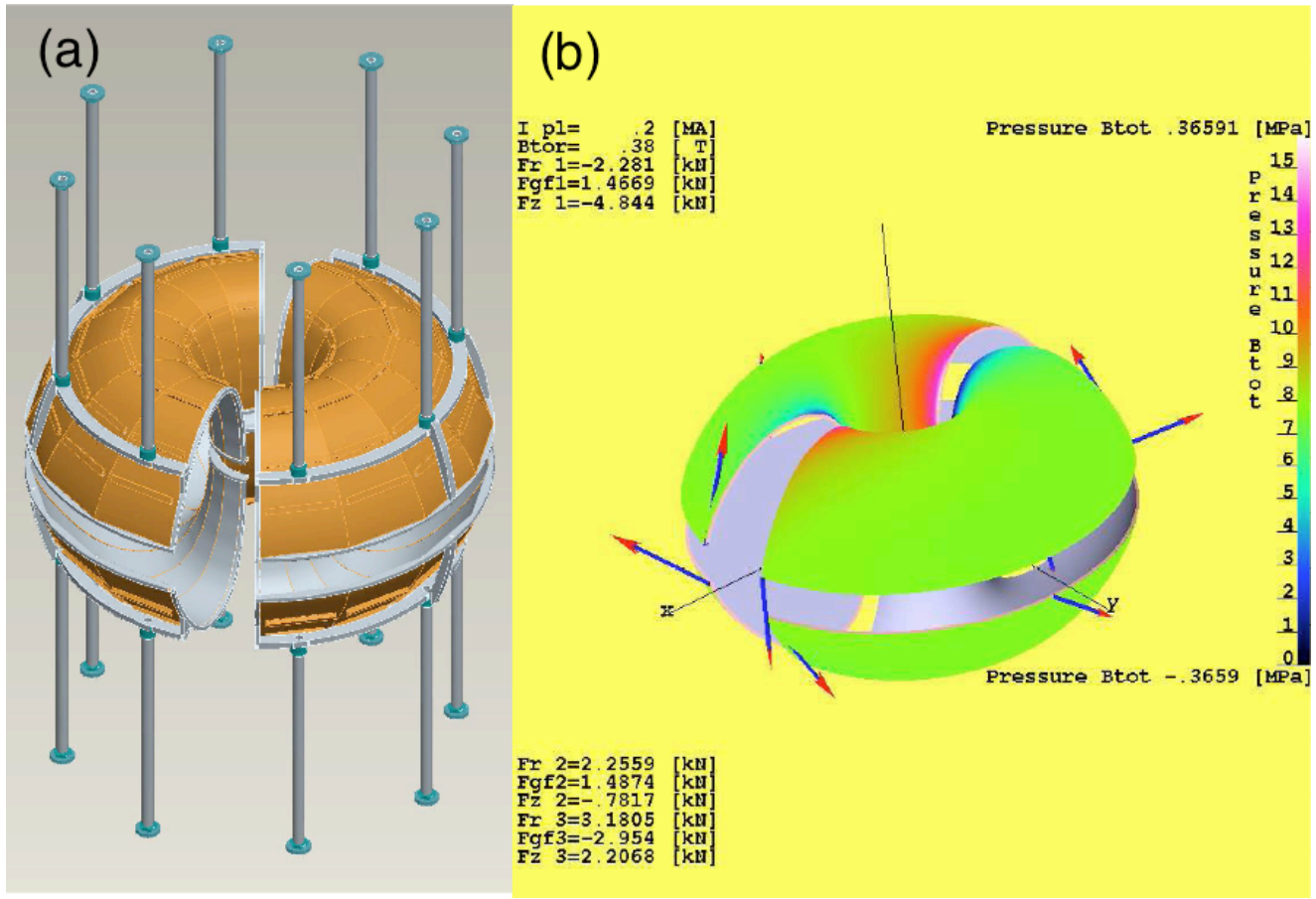


- Support structure for shell
  - Loads transferred to external supports

Shell surface will be coated by evaporation

STW2009

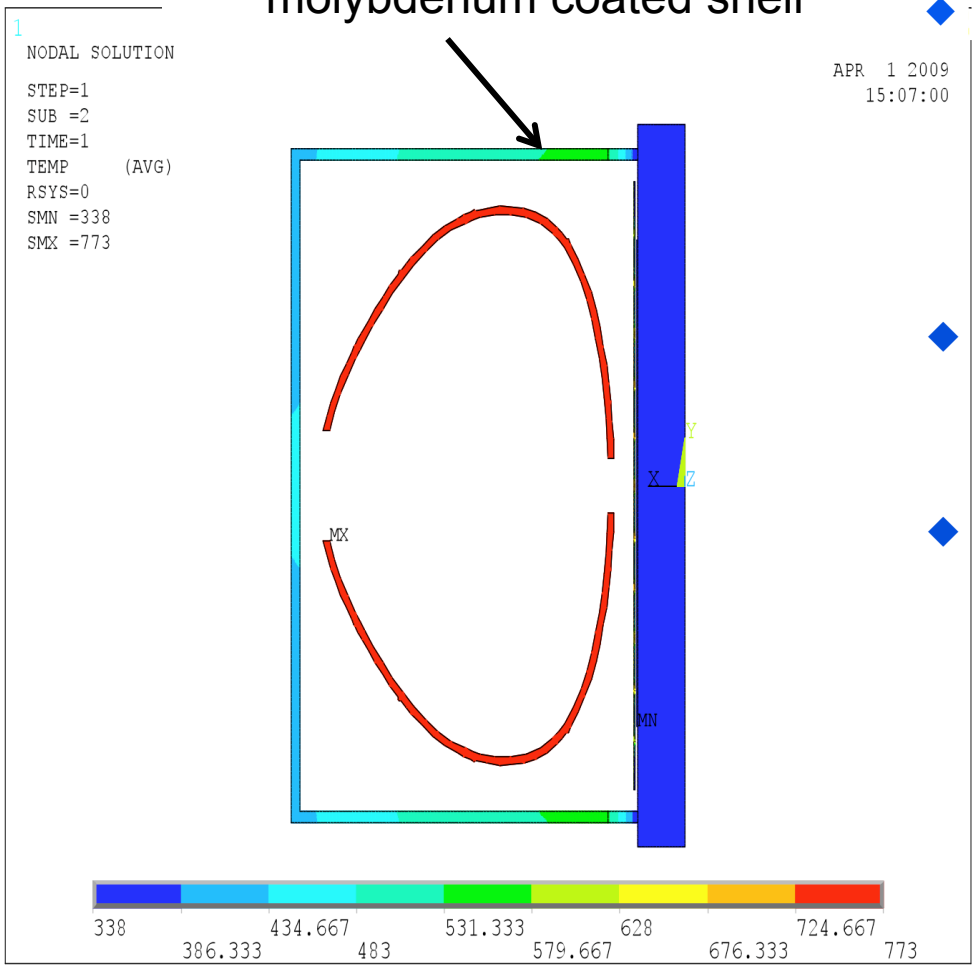
Shell support system designed to provide electrical , mechanical isolation



- Shell suspended within vacuum vessel
  - Support structure is external to the vacuum boundary
  - Bellows, ceramic breaks provide electrical, mechanical isolation
- Significant overturning moment on shells expected during disruptions
  - Supports designed to support 4× 5 kN overturning moment in disruption
  - Long “legs” allow thermal expansion

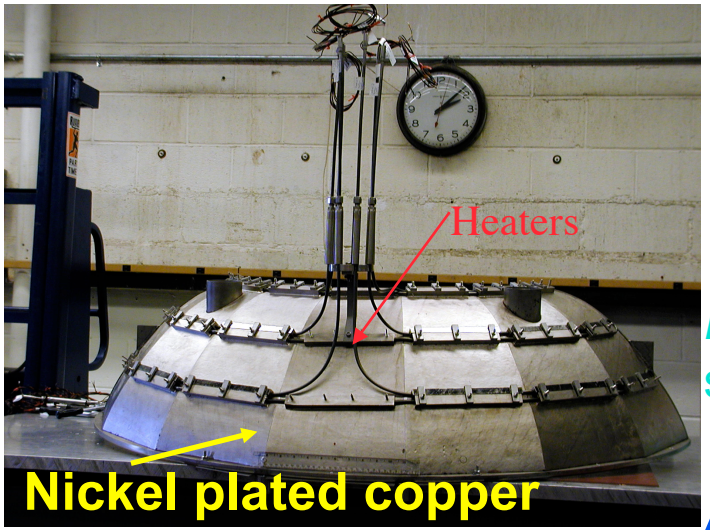
Shell was designed for 500 °C operation to promote wetting of the SS surface by lithium

Passive heat shielding for upper, lower vessel with installation of molybdenum coated shell



- ANSYS modeling for 500 °C operation
- Shell radiating into the vacuum chamber
  - 29 kW heater power required
  - Centerstack, vessel wall water cooled
- Centerstack is fitted with heat shield
  - Passive; polished stainless steel over silicon-bonded mica
- Shell tested to 200 °C
  - Vacuum vessel did not require water cooling; $\Delta T < 30$ °C
  - Centerstack surface $\Delta T < 2$ °C
  - Required ~10% of heater power
  - Projected *continuous* temperature limit: ⇒560 °C

Shell support structure and heaters



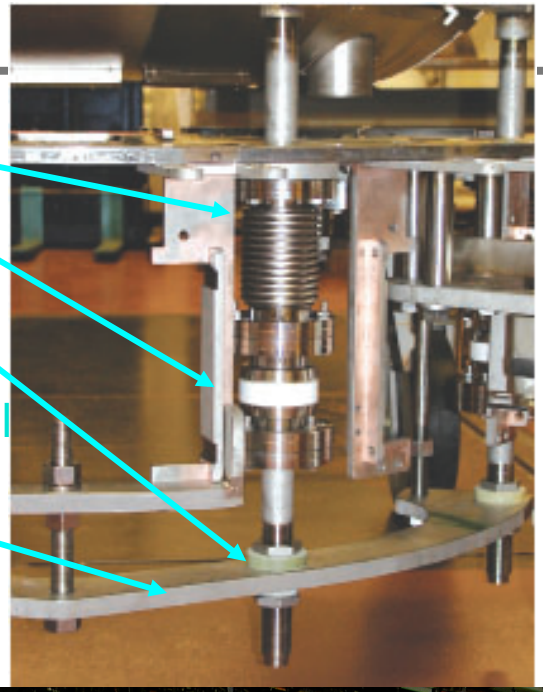
Bellows

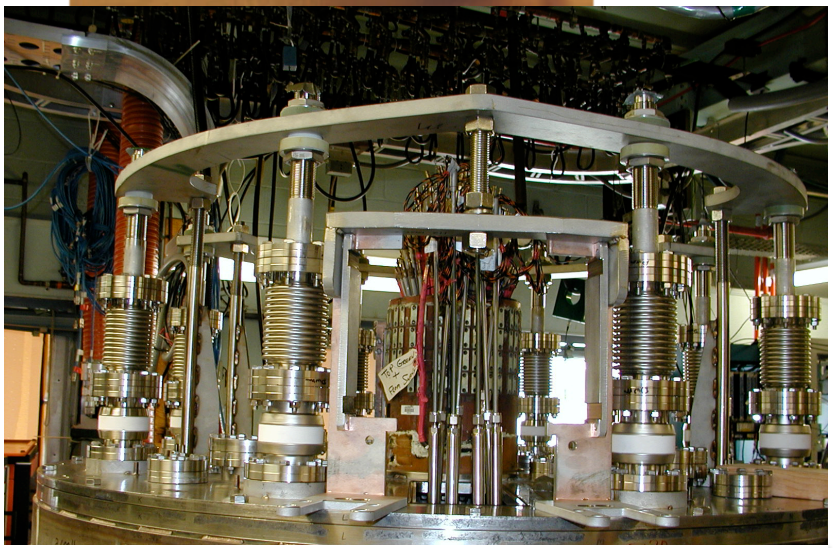
Ceramic break

G10 bushing

External mechanical support structure

Surface coated by evaporation.

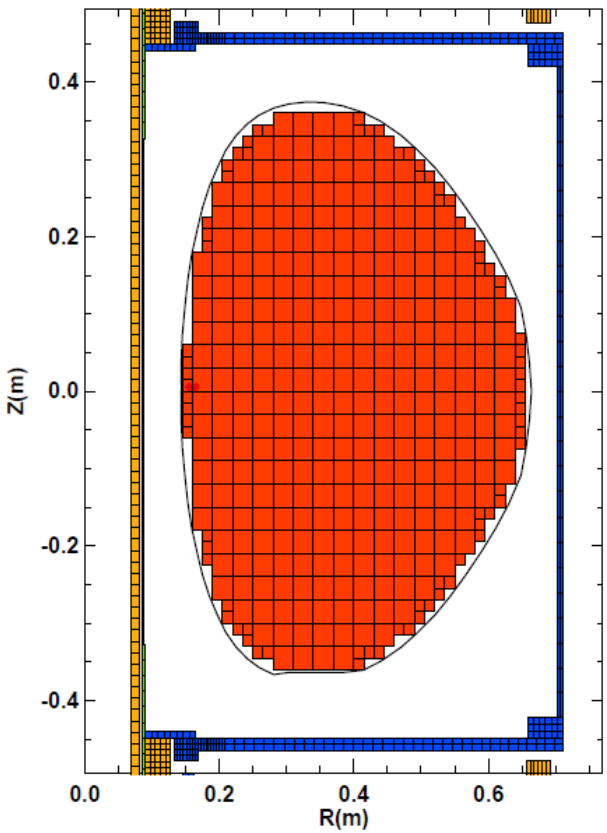


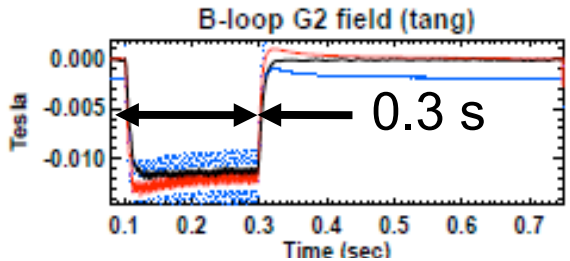


- Detail of full shell support structure

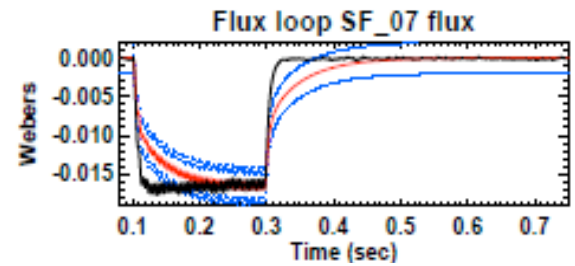
1 cm thick conformal copper shell strongly affects poloidal field evolution, equilibrium reconstruction

- 2-D LRDFIT model, **without** conducting shell
- Time evolution of some magnetic sensor signals not fully modeled

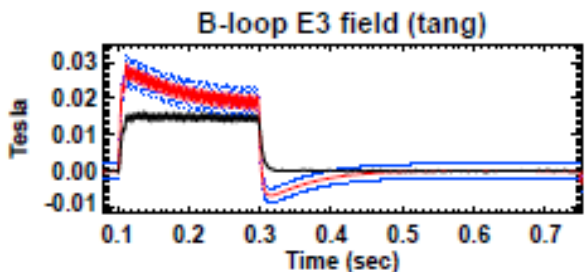




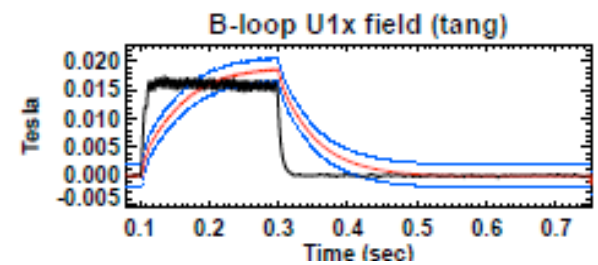
G2 is an inboard Mirnov coil, in a toroidal shell gap



SF_07 is an outboard shell flux loop



E3 is a Mirnov coil on shell exterior

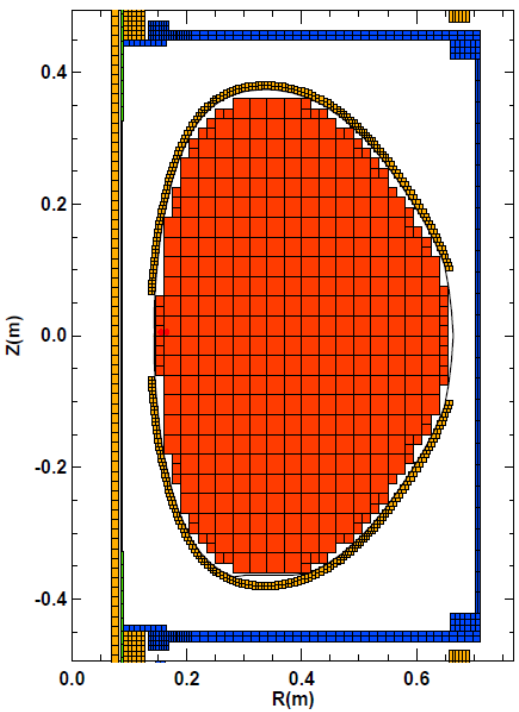


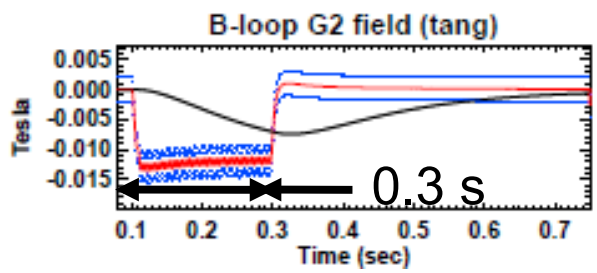
U1x is a in-shell Mirnov

Red trace is measured signal; blue traces indicate error bars; black is simulated signal (L. Berzak, developed with J. Menard)

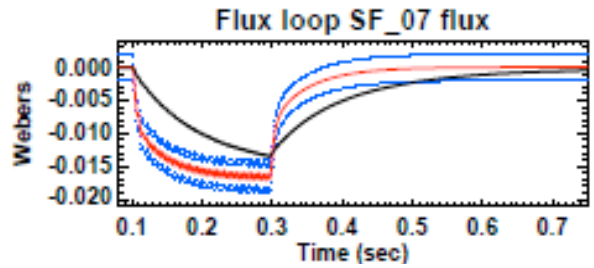
2-D (axisymmetric) model of shell improves modeling of sensor response

- Response of poloidal sensor arrays in shell gaps not fully captured
  - Sensors mounted on shell are overshielded in model
  - Misses response when sensor is in shell gap

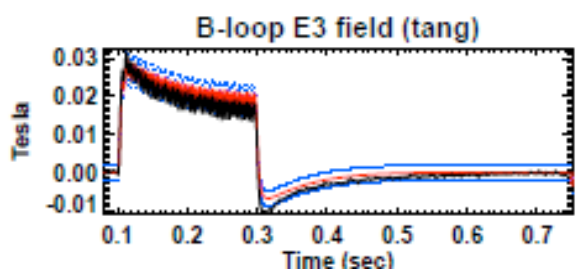




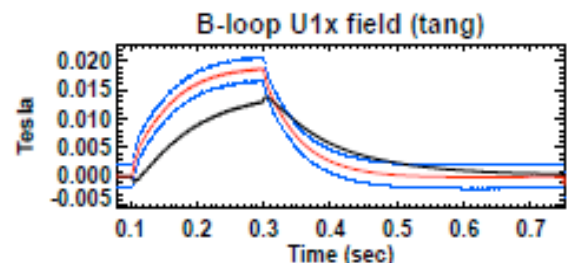
Simulated G2 signal overshielded – sensor in toroidal shell gap



Simulated SF_07 signal is overshielded

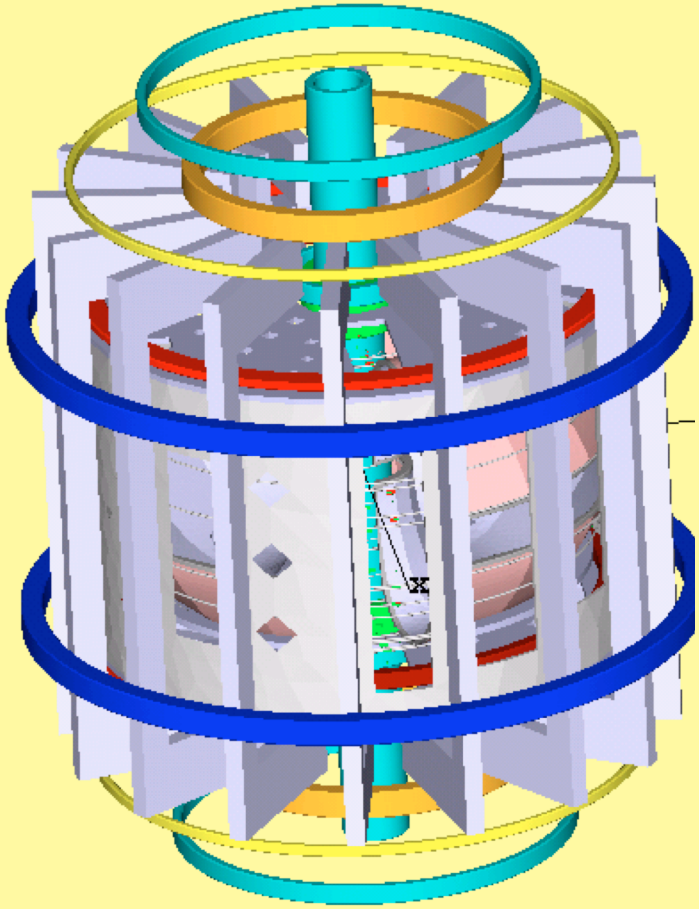


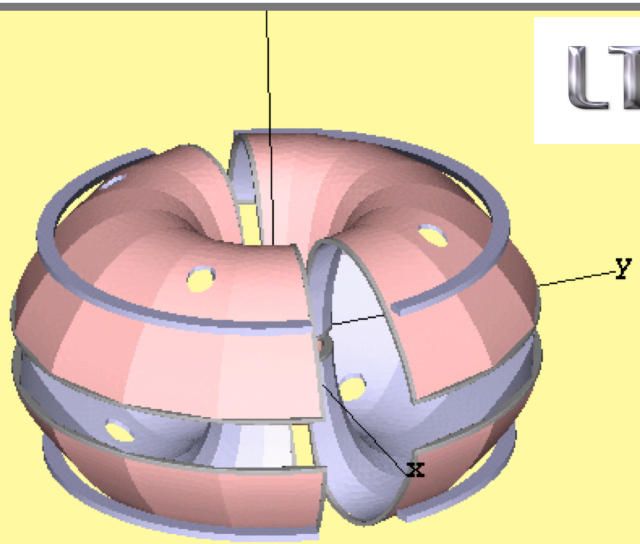
Shell code captures behavior of E3 sensor



Shell code captures behavior of U1x sensor with small amount of overshielding

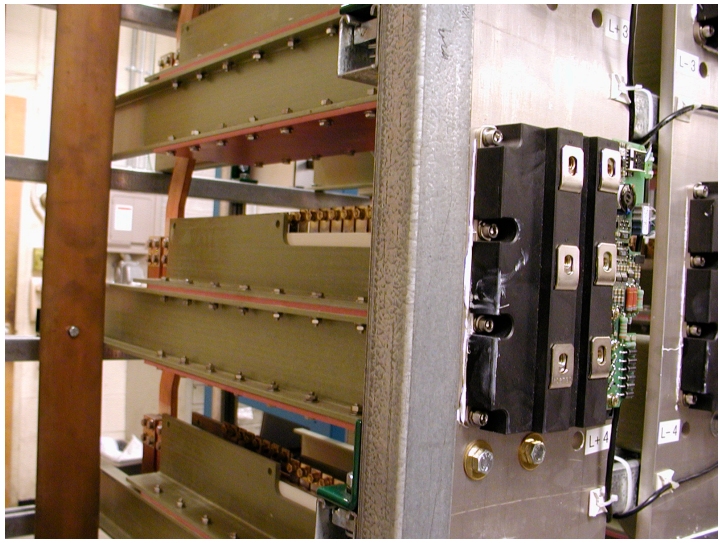
Fully 3-D electromagnetic shell model developed



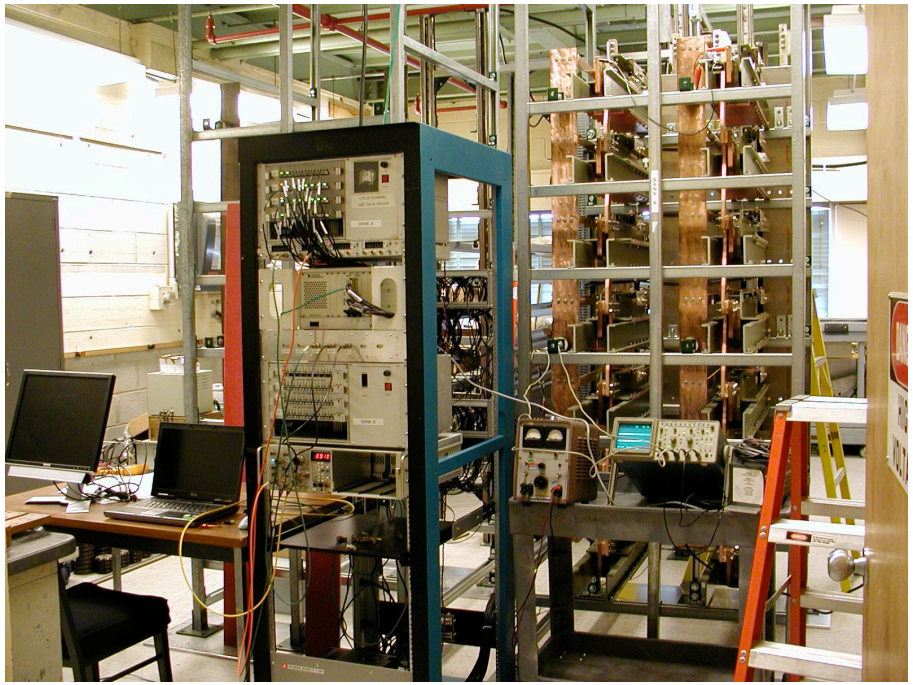


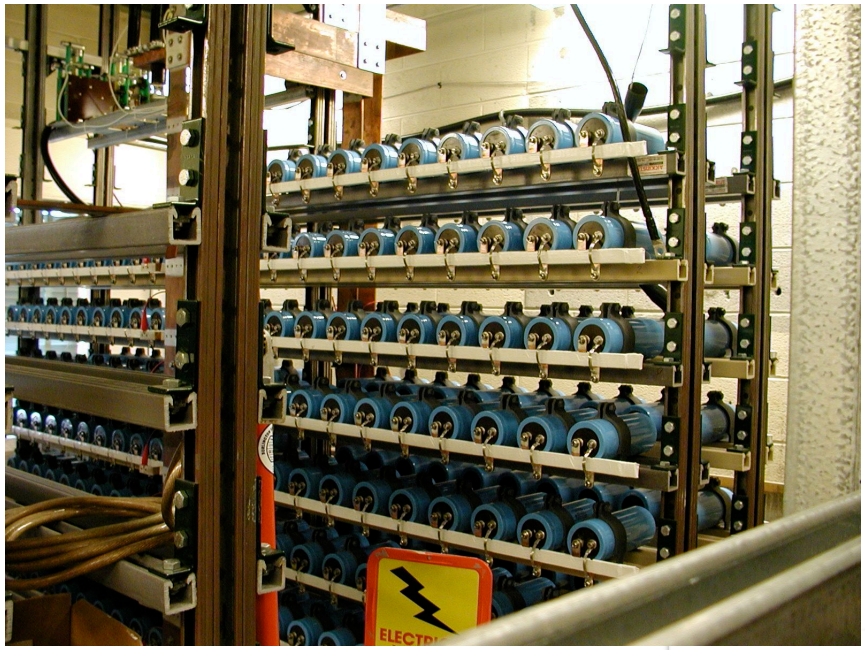
- 3-D model (L. Zakharov, being implemented) includes details of shell, vacuum vessel
  - Triangular solid mesh, NOT a wireframe model
- Integrates PF coils, magnetic sensors, equilibrium reconstruction

First stage of new multiphase OH supply entering test phase



- Compensation transformers permit staggered firing of IGBTs
  - Multiphase operation
  - Accurate response to control signals
- OH capacitor bank to be expanded 4× to 1.3 MJ
  - I_p up to 400 kA, 250 msec
- LTX presently operating with simple capacitor bank

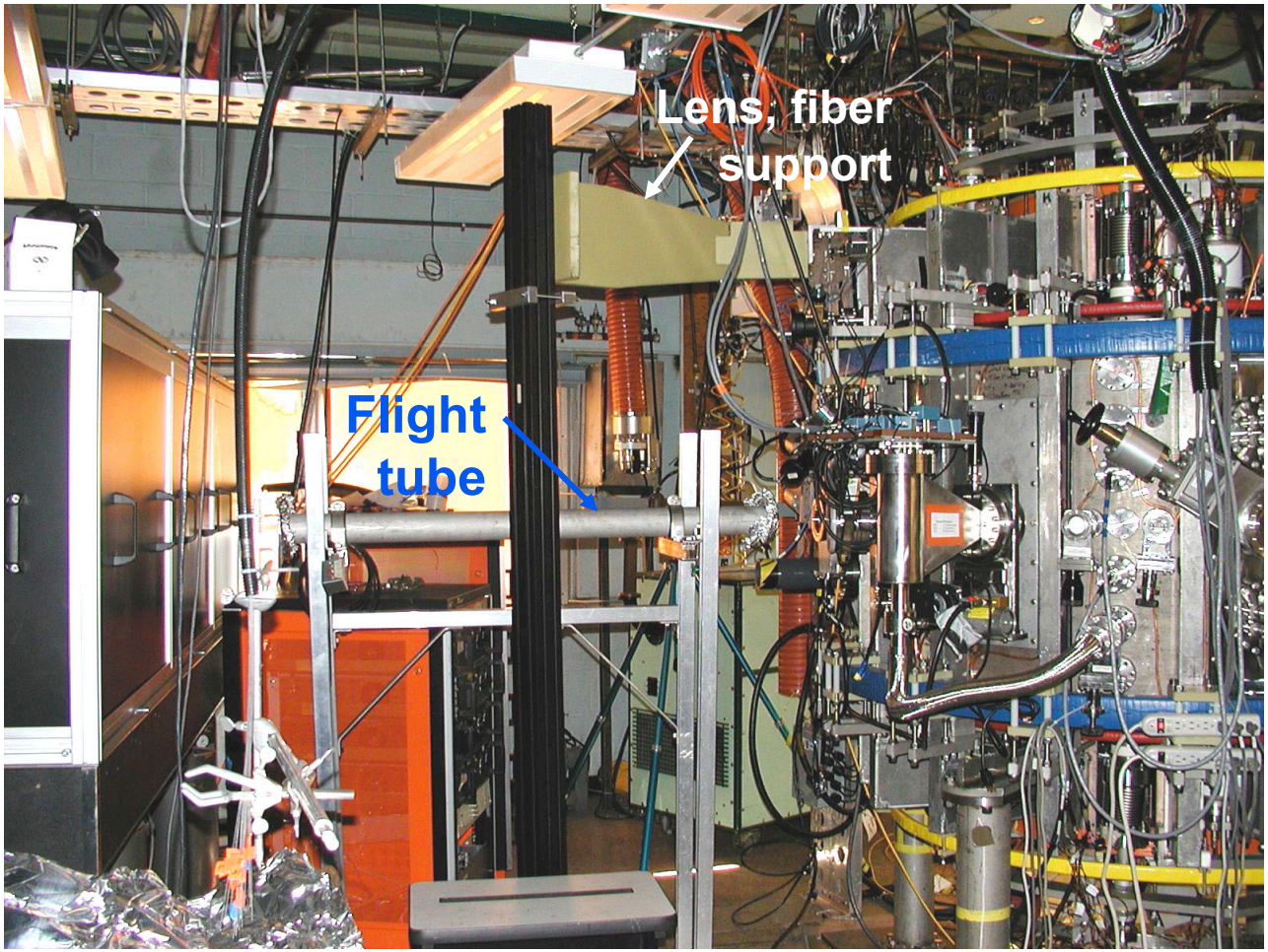




Thomson scattering system to be operational at the beginning of 2010

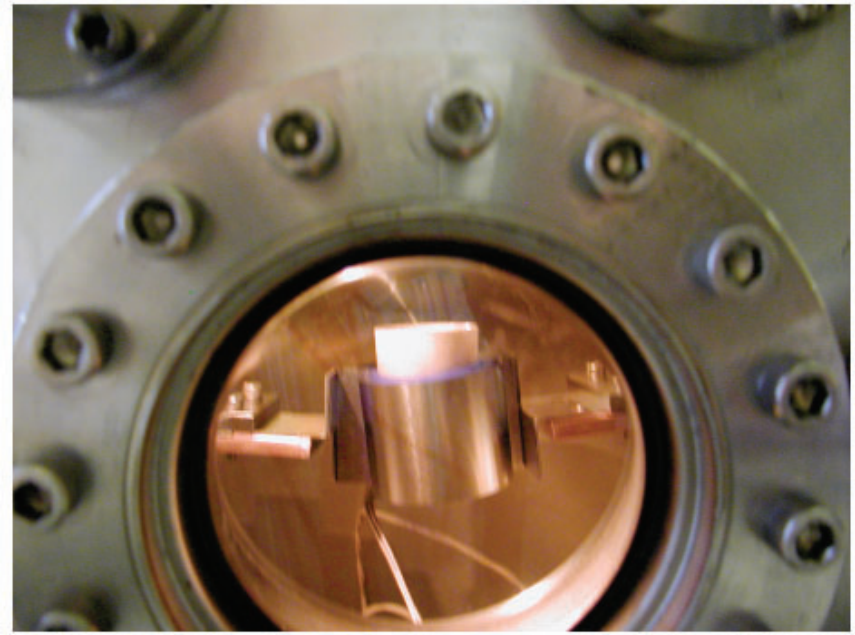
- 16 core spatial points, 15 J ruby laser, single pulse
- Add 5 edge points in 2011
  - ~1-2 mm spatial resolution

Laser enclosure



Other lithium-specific design features of LTX

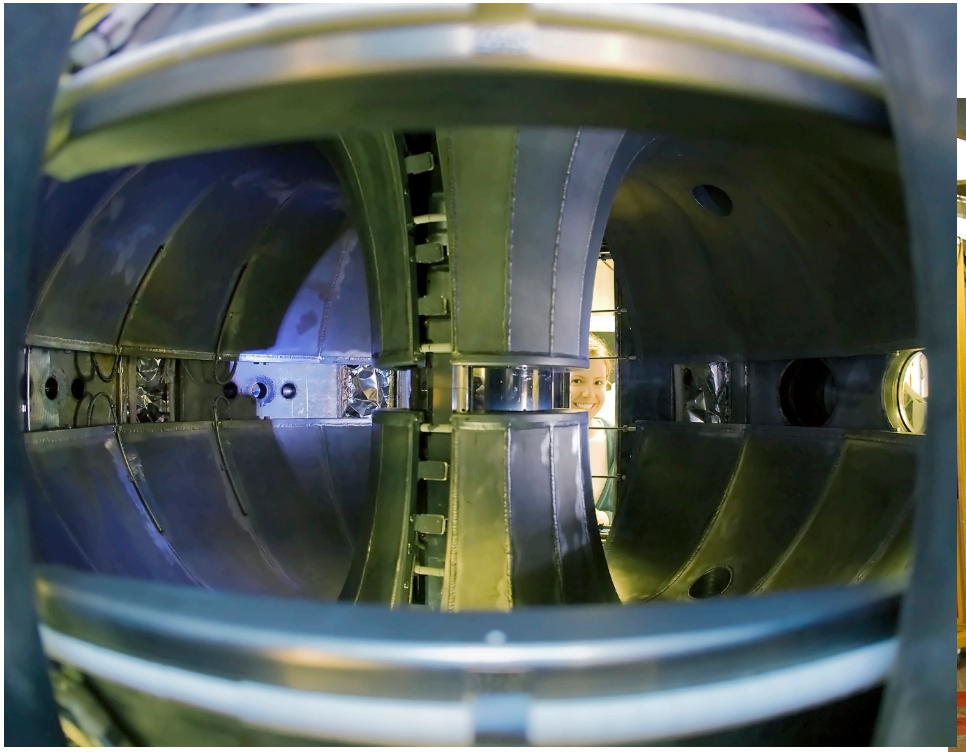
- Internal conducting shell designed to operate at >500 ºC
  - Intermittent high temperature operation to produce wetting
  - Routine operation at 300 - 350 ºC
- Shell electrically isolated to 1 kV
- Y_2O_3 - stabilized MgO ceramic insulation
  - Tested for lithium resistance to 400 ºC
- Ceramic yttria crucibles for initial evaporative coating of shell interior
  - Tested to 600 ºC with lithium fill
- Tungsten-sprayed lithium "stop zones"
- All windows are gate-valve mounted, for removal and cleaning
  - Thomson scattering viewing window also shuttered

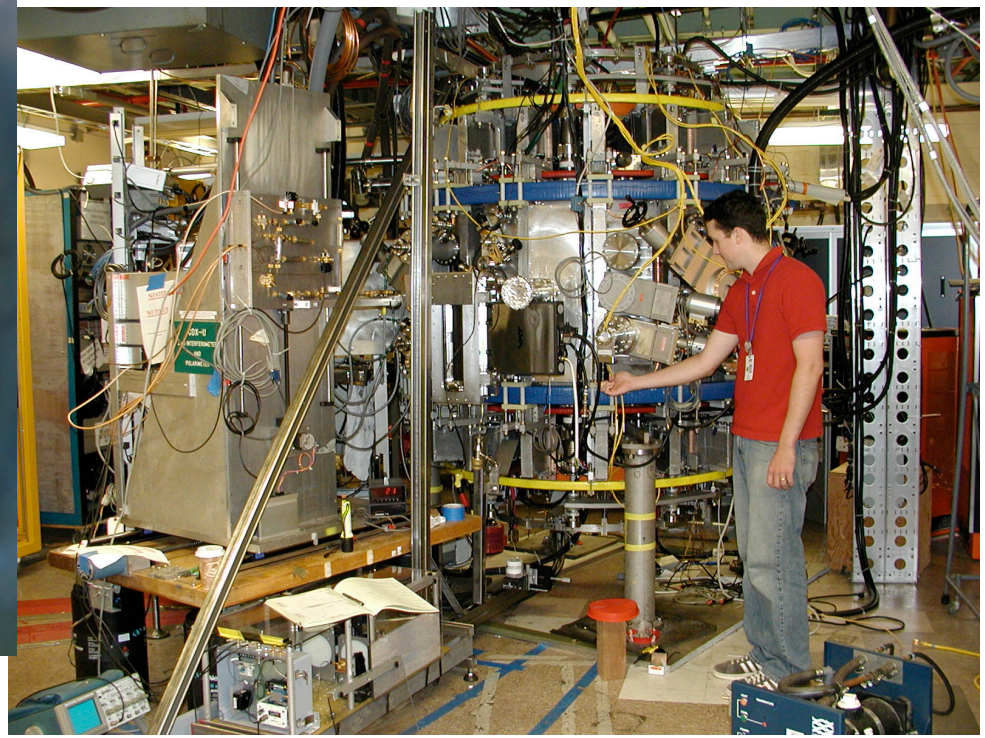


Y_2O_3 crucible, Ta heater tested successfully to 700 °C with 13 g lithium, as an evaporator

- Second shell will be vacuum plasma sprayed with porous molybdenum
- First shell removed, tungsten sprayed
- 500 - 600 °C high-Z first wall

LTX is now operating
Lithium operations commence in 2010

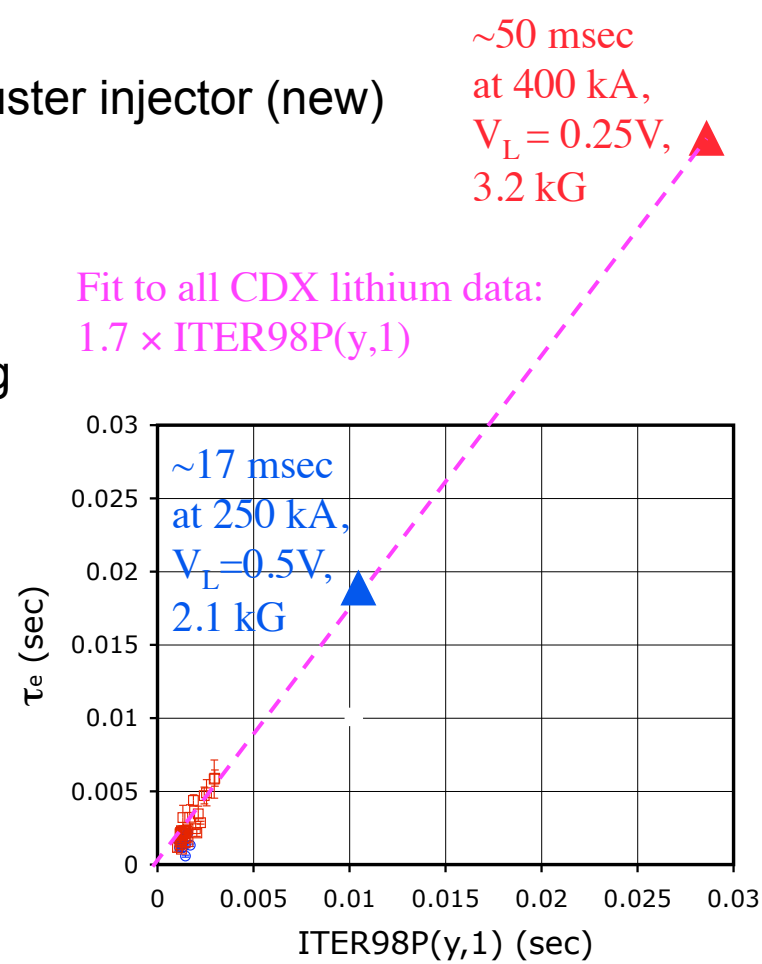




- Wide angle view of vessel interior during recent vent
  - Shell, inner gap showing centerstack heat shield
- LTX assembled, first plasma Oct. 2008
  - Employed temporary OH power supply
  - New, multiphase IGBT supply now completed, entering testing

LTX research program for FY10-11

- Introduce lithium - 20g (coatings) ⇒ 100-200g (pool in lower shell)
- Spherical tokamak equilibria with a very low recycling coefficient and pulsed gas fueling
  - Fuel with SGI (existing) and a molecular cluster injector (new)
- Employ 140 channel magnetics system, Thomson scattering
  - Global confinement, T_e profile
- Employ 2 channel interferometer, pulsed fueling
  - Particle transport
  - Add digital holography (δn_e) in FY10-11
- New capabilities to be added in 2010 - 2011
  - Edge Thomson for near-wall T_e gradient
  - Full toroidal field (3.5 kG)
  - 100 kW NBI for ion heating, CHERS
  - Complete full OH power supply
    - 400 kA

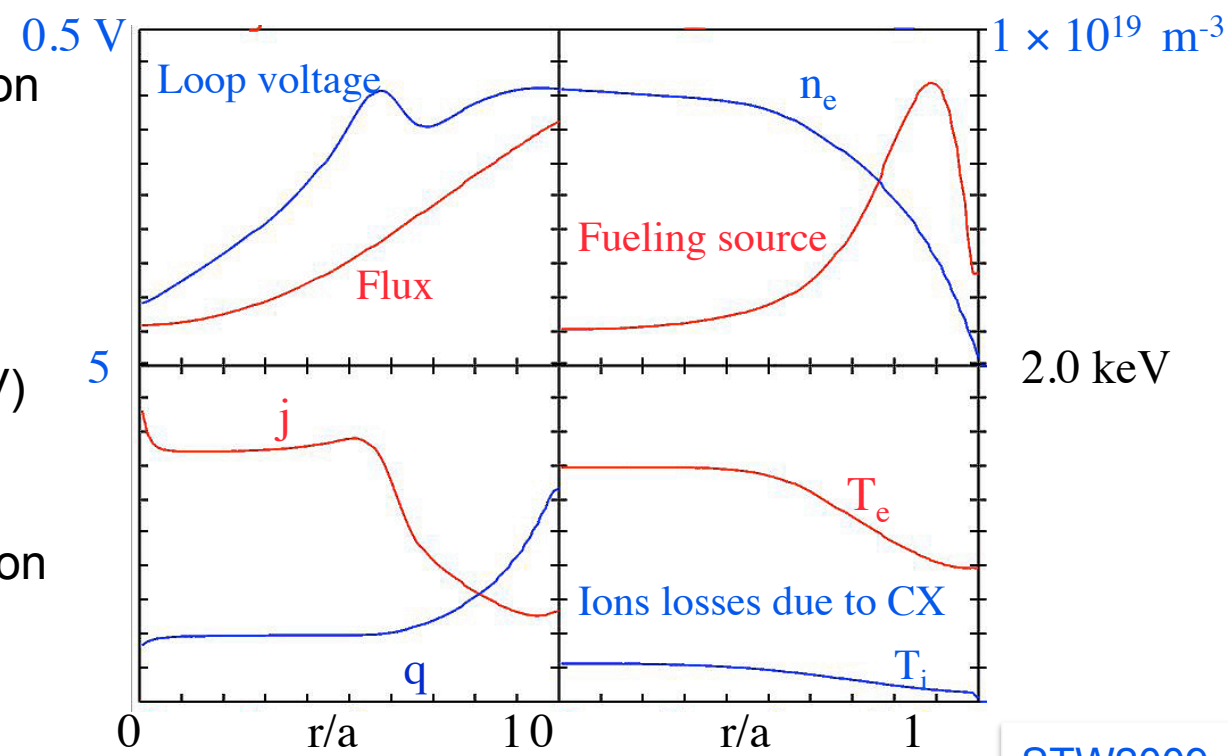


STW2009

First research focus: Electron transport studies with lithium walls

- What are the limits of low recycling with fresh lithium walls?
  - Can we approach the theoretical limit imposed by direct reflection?
  - ⇒Extensive Lyman-α arrays
- What is the effect of recycling coefficient on T_e profiles?
  - Core, edge Thomson scattering

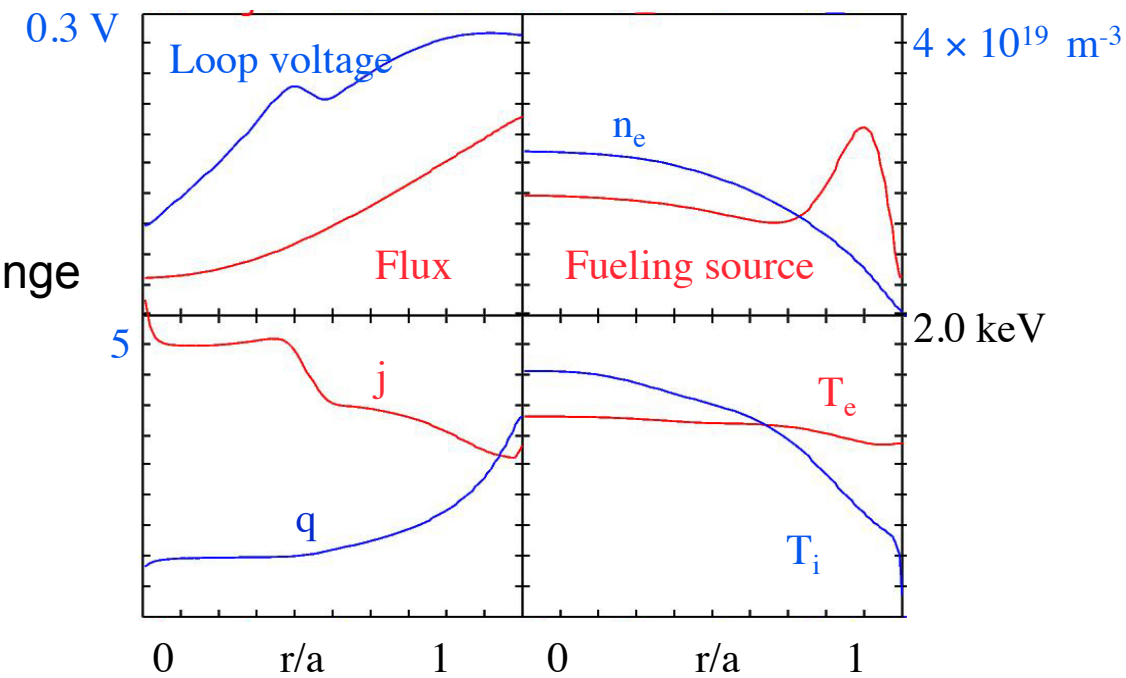
- ASTRA results (Zakharov - PPPL, Pereverzev - IPP-Garching) for initial operation
  - Ohmic + gas puffing
- Model predicts broad T_e profiles, hot edge
  - ($T_e(0)/\langle T_e \rangle = 1.26$)
  - Low loop voltage (0.4 V)
  - $\tau_E \sim 25$ ms
- Transient or pulsed gas puffing to allow edge electron temperature to approach core between "puffs"



STW2009

Present plan is to implement NBI starting in FY11

- NCSX diagnostic beam (downrated to 15 - 20 keV, 5A, 1 sec)
  - Provide CHERS, initial ion heating results
  - Small beam footprint, compact system for installation in present test cell
- Install in combination with moly coated shell (SBIR - funded effort)
- ASTRA modeling shown for 100 kW NBI
  - Requires gas puffing to sustain density
- V_{loop} decreases to 0.25 V
- $T_i(0)$ increases to 1.6 keV
  - $T_i \sim T_e$
  - τ_E to 60 ms (ASTRA)
- Wider accessible parameter range
  - υ^* reduced to 0.01 - 0.1
  - Higher density operation
    - » Combine with molecular cluster injection



LTX – summary of plans for 2010 - 11

- Detailed investigation of PMI with liquid lithium walls
- PMI investigations with a hot high-Z wall
  - Proposed collaboration with Purdue University
  - Performed after installation of moly coated wall, before lithium
  - LTX will have first full, 500 °C, high Z wall
- Joint NSTX, LTX experiments:
  - Plasma-material interactions
    - » H retention, recycling
    - » Sputtering, thermal (evaporative) limits
  - Confinement with low recycling walls
  - Electron transport
  - ➔ Determine, with NSTX, the optimum global recycling coefficient for tokamaks
- Move to core fueling, heating with NBI in LTX
  - 100 kW (20 keV, 1 sec) in 2011
    - » Transport with $T_i \sim T_e$
  - *Full* fueling possible with two 8-12 keV, 15A, 500 msec beams
- Stability with conducting wall at r~1.02a