LTX
the Lithium Tokamak eXperiment

R. Majeski, R. Kaita, L. Zakharov (PPPL)

S. Krasheninnikov (UCSD)

with contributions from

G. Gettelfinger, H. Kugel, S. Raftopoulos, V. Soukhanovskii, J. Spaleta, D. Stotler, J. Timberlake, R. Woolley (PPPL)

T. Rognlien (LLNL)

M. Gouge, R. Maingi (ORNL)

M. Baldwin, R. Doerner, S. Luckhardt (UCSD)

D. Stutman, M. Finkenthal (JHU)

J-P Allain, D. Ruzic (U of I)

M. Ulrickson (SNL)

R. Mattas (ANL)

ALPS/APEX
4-8 November 2002
PPPL

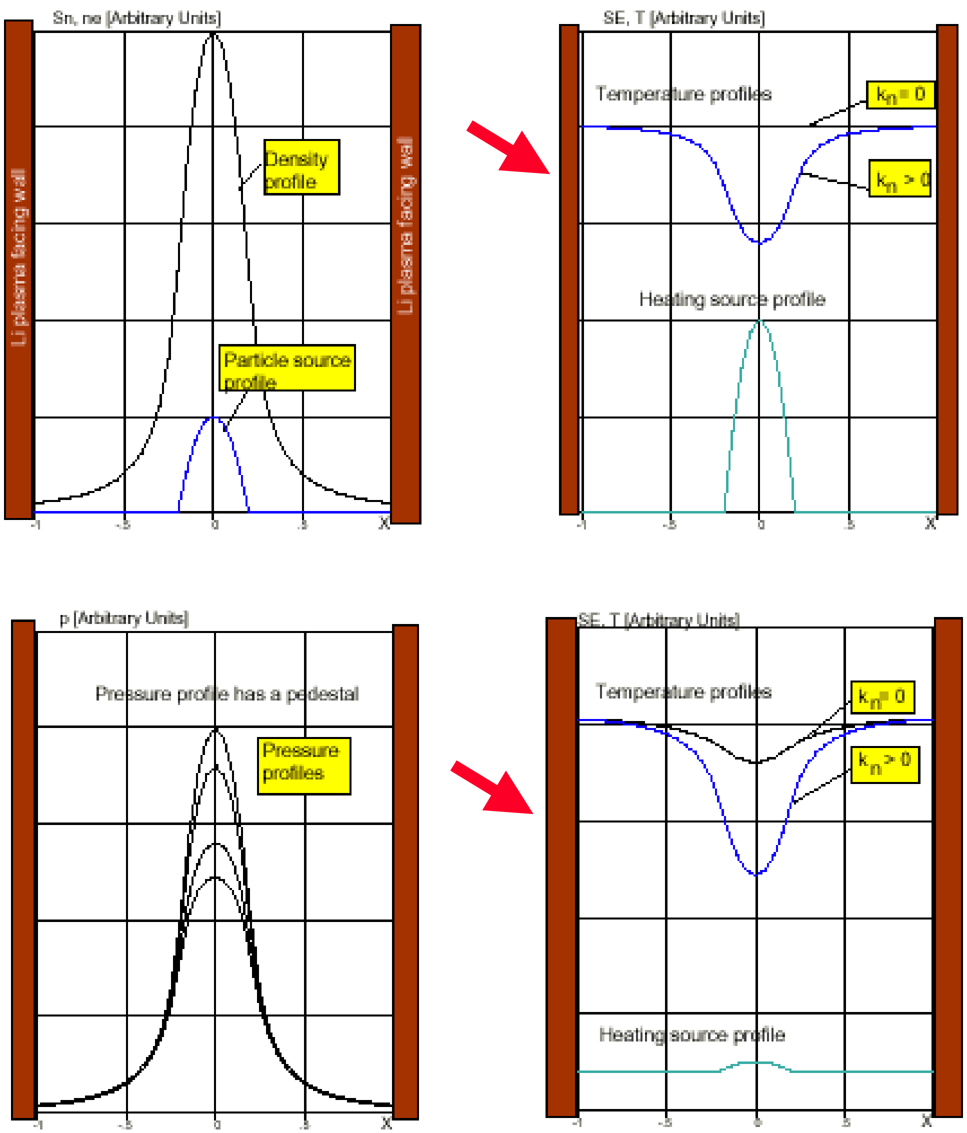
Outline

- Introduction
- Expected changes in tokamak operations with fully nonrecycling walls
  - Temperature and q-profiles
  - Stability
- Experimental configuration
  - Lithium coated shell and heat shield
  - Coating systems
  - Fueling systems
  - PF, OH system
  - Diagnostics
- Summary

Introduction

- The LTX experiment is designed to examine the consequences of liquid lithium walls on tokamak operations.
  - Primary change in PMI physics will be the elimination of recycling.
  - No magnetic confinement experiment has ever been operated with a near-zero global recycling coefficient. We don't have an experimental basis to guide us.
- Available modeling indicates that nonrecycling walls will fundamentally alter the tokamak equilibrium.
  - We cannot seriously propose a reactor with lithium walls until experiments such as this have been performed.
  - Furthermore, the predicted equilibria are very attractive.
    - » Transport and stability
- Proposal was submitted but not funded for FY03
  - Plan to resubmit

Profiles of density, temperature, pressure for nonrecycling walls (L. Zakharov, S. Krashenennikov)



Particle continuity eqn:

$$\Gamma \equiv Snv = const = (\Gamma)_a$$

Energy balance:

$$\frac{5}{2}\Gamma T - S(\kappa_T \nabla T + \kappa_n \nabla n) = \int_0^r P_E dv$$

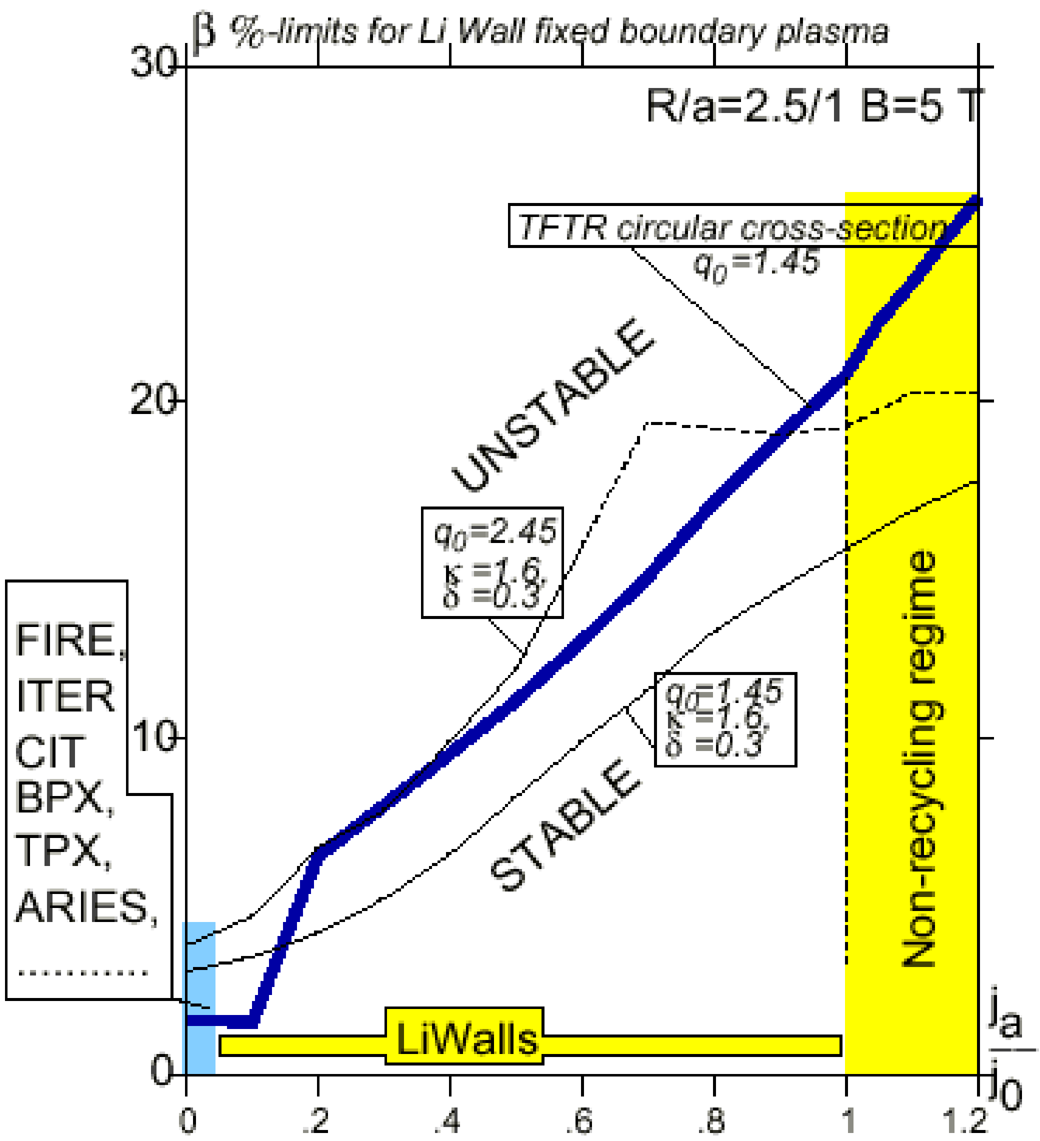
Plasma has no "information" on wall temperature

$$\left(\frac{5}{2}\Gamma T\right)_{edge} = \int_0^a P_E dv,$$

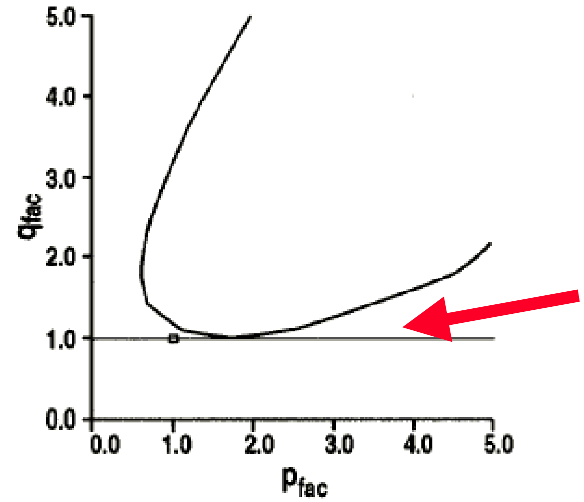
$$T_{edge} = \frac{\int_0^a P_E dv}{\frac{5}{2}\Gamma}, \qquad P_E \Rightarrow \text{heat source}$$

- Fueling profile determines density
- Edge pedestal in pressure profile
- Temperature profile will adjust to eliminate thermal conduction

Beta limits for a circular tokamak (aka TFTR)



- Discharge will be in the "low shear" 2nd stability regime



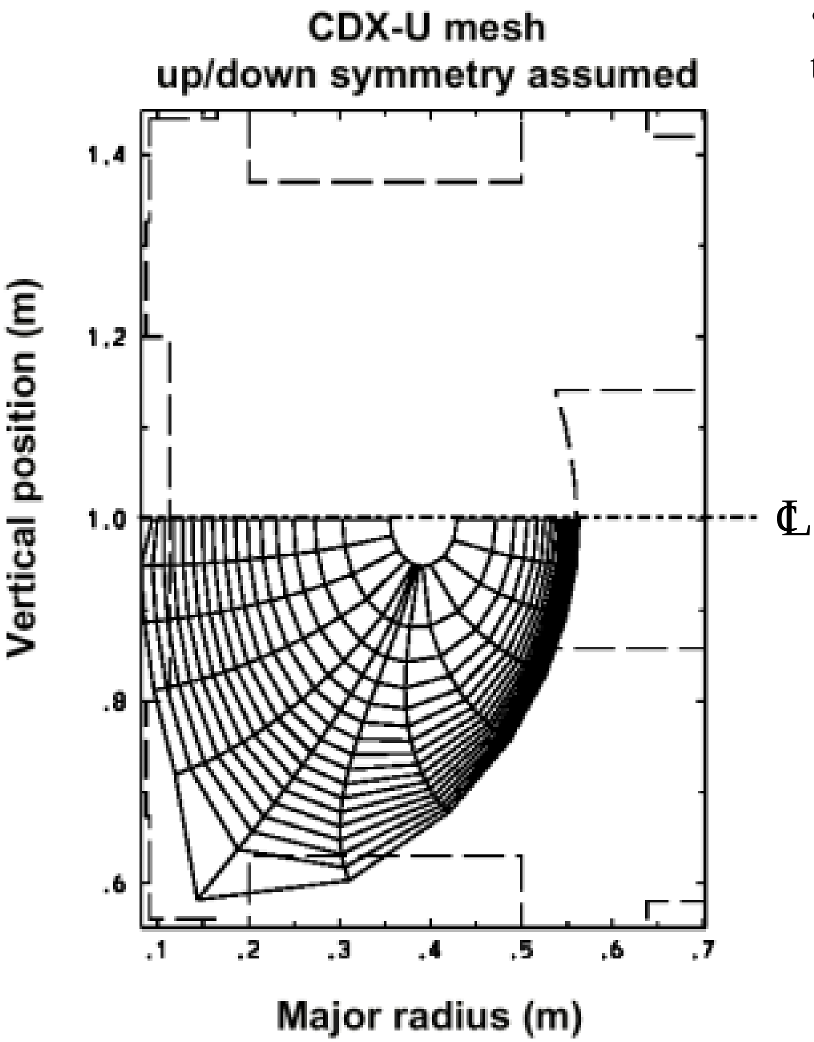
- Beta limits are greatly enhanced for circular, conventional aspect ratio devices. *Less so for a high κ ST*
- Results for n=1,2,3,… ballooning modes (DCON, PEST-2, BALLON)
- Current profile with edge pedestal:

$$j_{\|} = j_a + (j_0 - j_a)\left(1 - \frac{r^2}{a^2}\right)$$

Modeling of the LTX equilibrium

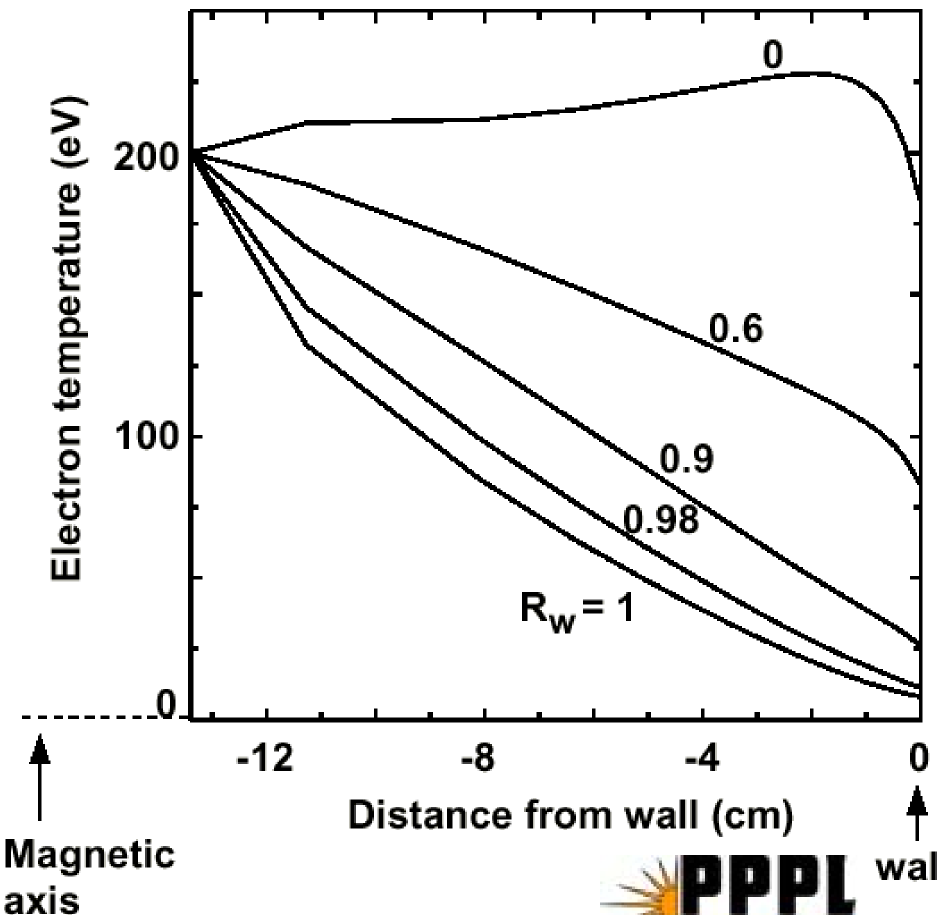
- How many of these effects could we expect to see in a small experiment (like LTX)?
  - Flat to hollow T_e profiles
  - Reversed shear q-profiles
  - Modified beta limits
    - » Requires auxiliary heating (second phase?)
- Modeling of LTX equilibria has been performed with:
  - UEDGE
  - ASTRA
  - ESC
- We will also benefit from a new initiative to use CDX-U as a benchmark system under the SciDAC initiative
  - Through CEMM - Center for Extended MHD Modeling

UEDGE modeling from T. Rognlien

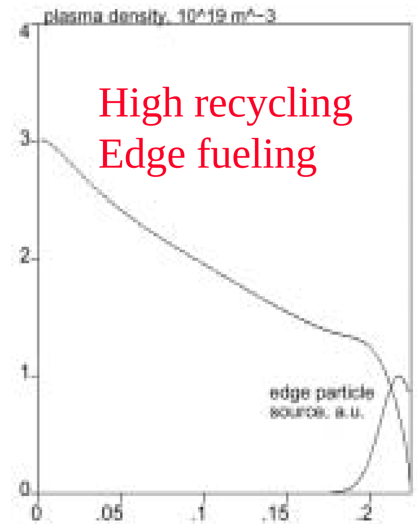


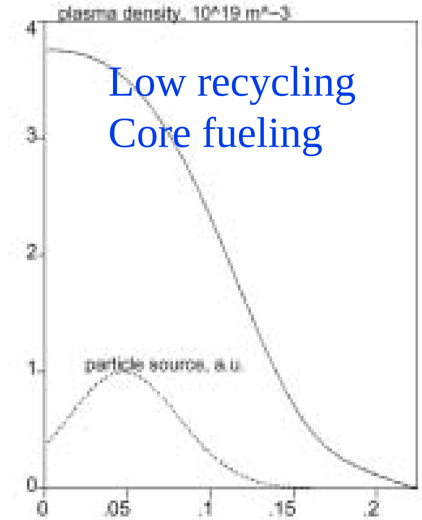
•Electron temperature at the wall approaches the core temperature as recycling coeff. (R_w) → 0

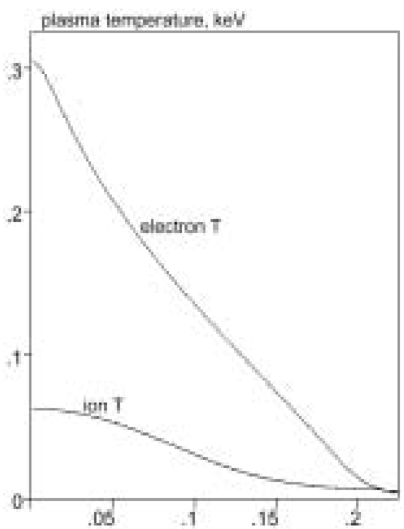
•Boundary conditions, assumptions may differ from Zakharov, Krashenennikov

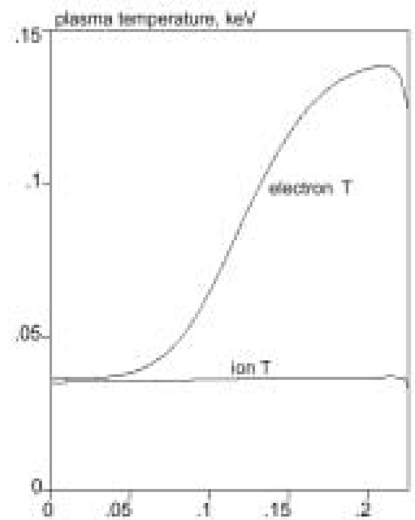


Astra modeling (Krashnenninikov and Zakharov





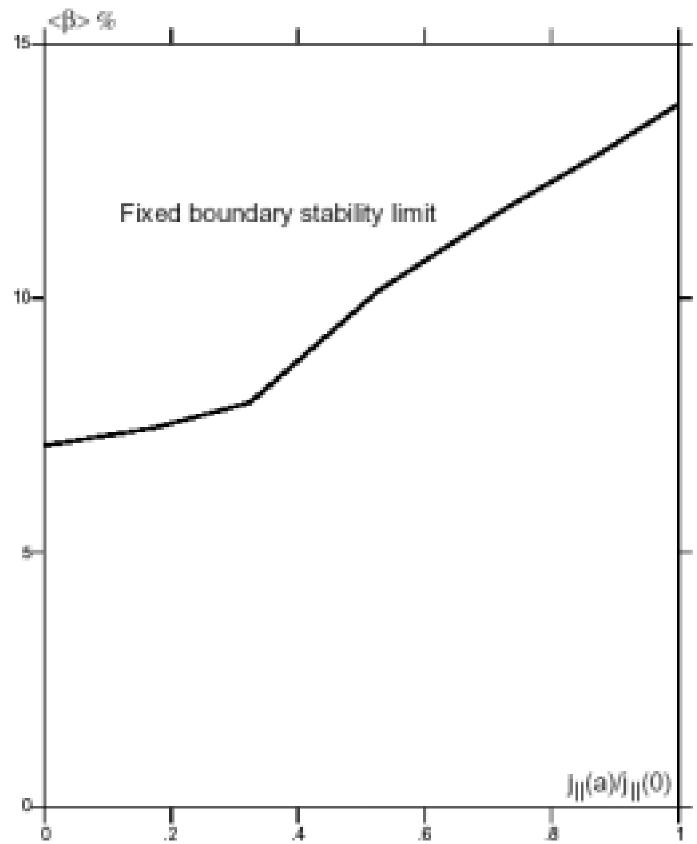




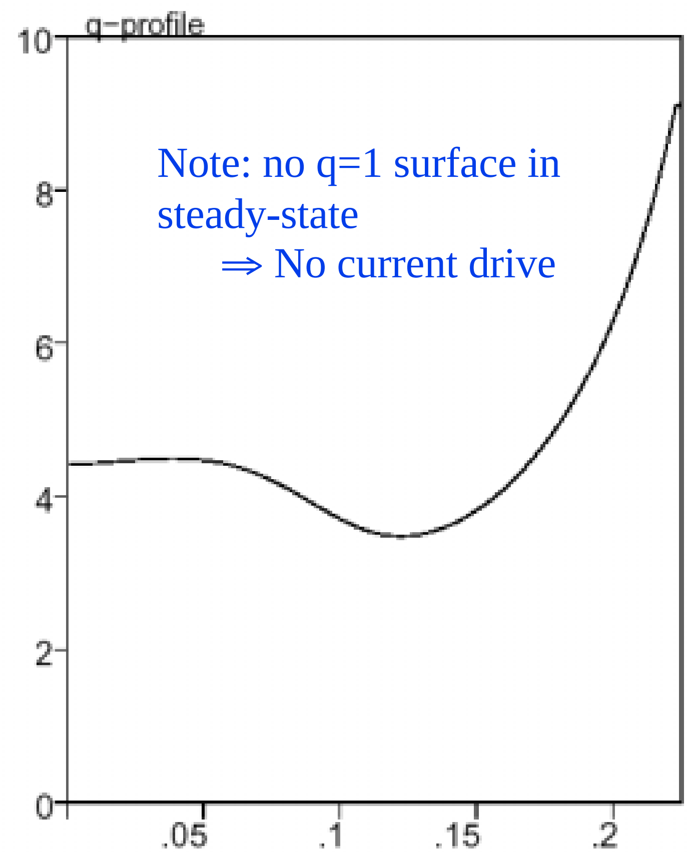
- ASTRA is a 1.5D transport package extensively utilized in the European fusion program
- Includes plasma (energy, particle, current) transport
- MHD stability and island formation
- Neutral particle transport (gas, pellets)
- Various models for cross-field transport
- Results are highly dependent on the particle transport model
  - Particle transport in this regime is not well understood
  - Model is pessimistic

ESC and ASTRA modeling (low recycling)

- Beta limit increases as the edge current density increases



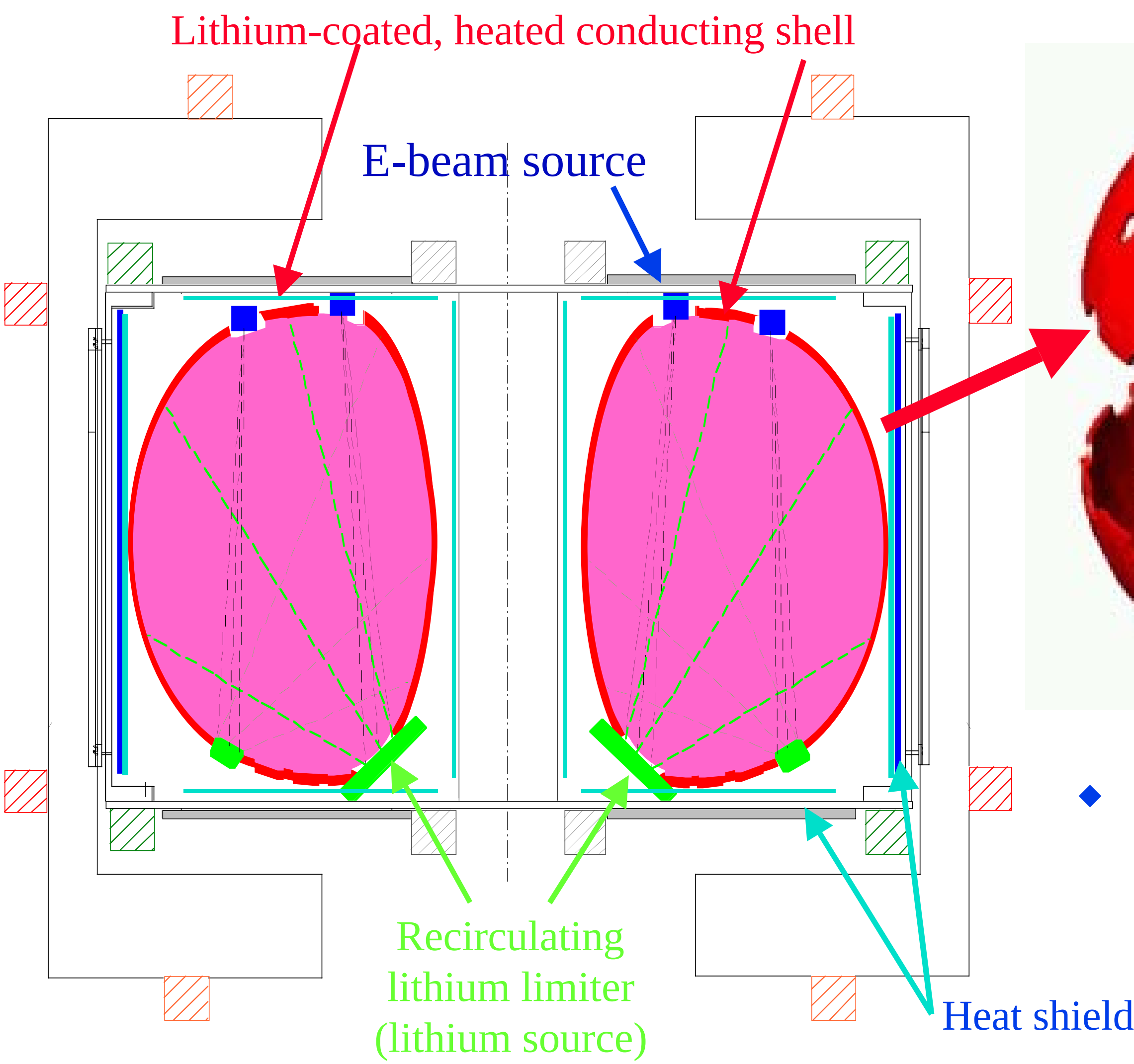
- High edge current density results in a "naturally" inverted q-profile

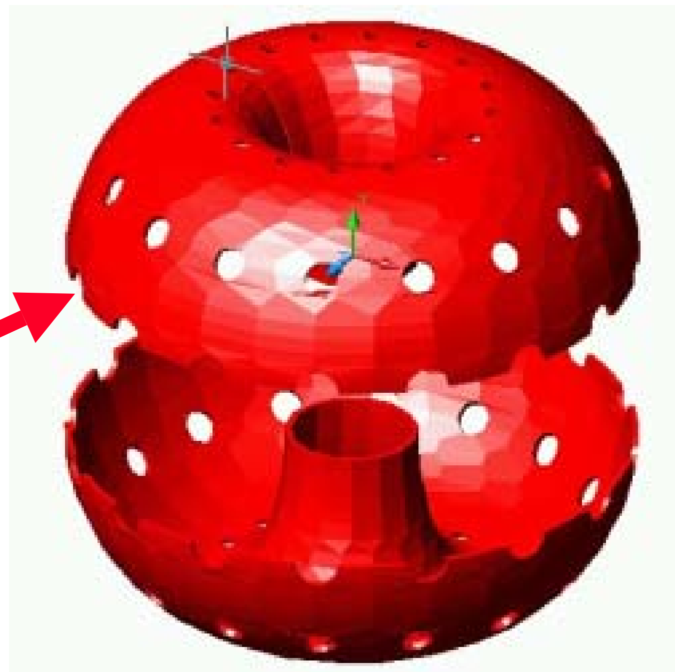


Experimental configuration for LTX

- Start with CDX-U
- Install a resistively heated conformal copper shell ~1 cm thick
  - Lined with plasma sprayed molybdenum
  - Electron-beam deposition system for rapid lithium coating of the liner
- Retain recirculating lithium limiter
  - Primary plasma limiter, lithium source for coatings
- Introduce core fueling via high field side fast gas jets and pellets
- Longer pulse, higher toroidal field and plasma current operation
  - Pulse length several L/R times to allow current profile relaxation
  - Longer particle confinement time to enable pellet fueling
  - No auxiliary heating planned (during initial phase)

LTX

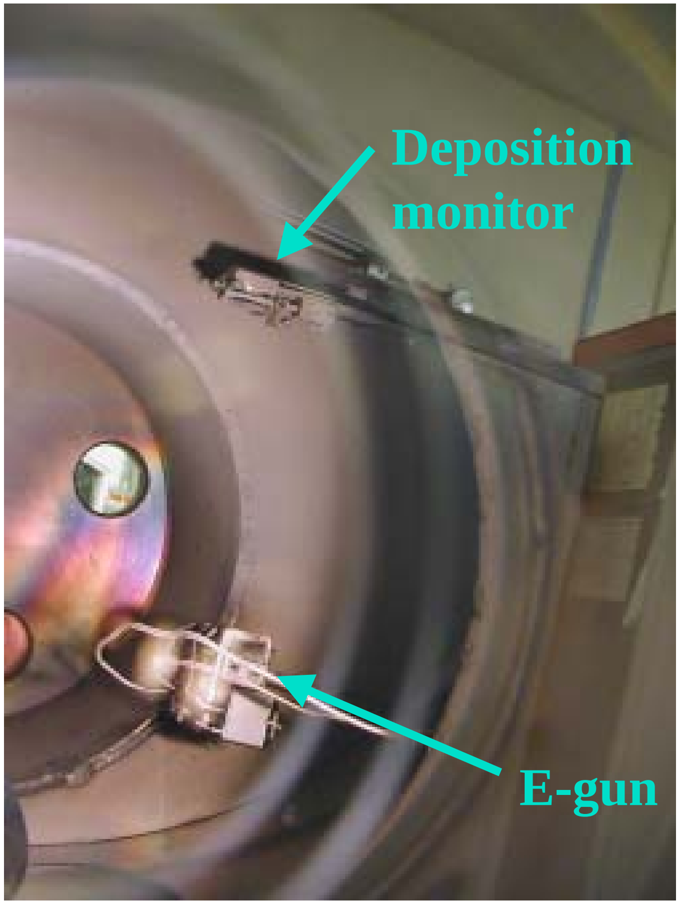




- Shell will be ~1 cm thick copper plasma-sprayed with molybdenum on inner surface

E-beam coating system is under development

- 3 kW Thermionics e-beam system and Leybold Heraeus deposition monitor installed in a test chamber, operational.
- Deposition rates up to 400 Å/sec on a quartz crystal deposition monitor 25 cm from the lithium source have been achieved.
  - Scales to 1000 Å /40sec. at 1 m radius
  - Higher deposition rates clearly feasible
- Plan to test deposition and adhesion of lithium films on samples of the LTX shell

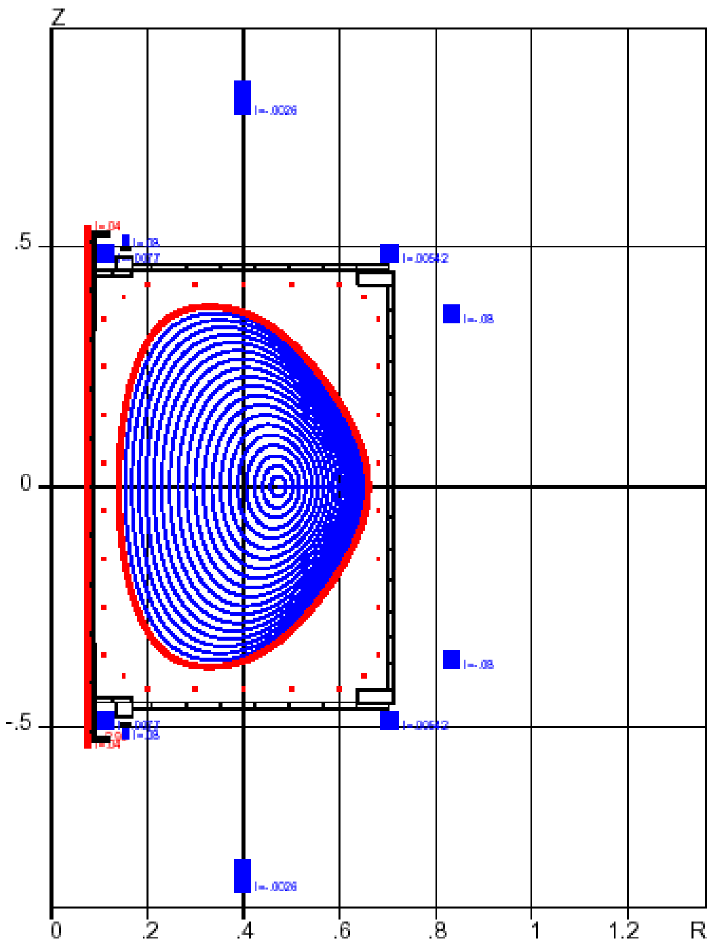


Core fueling

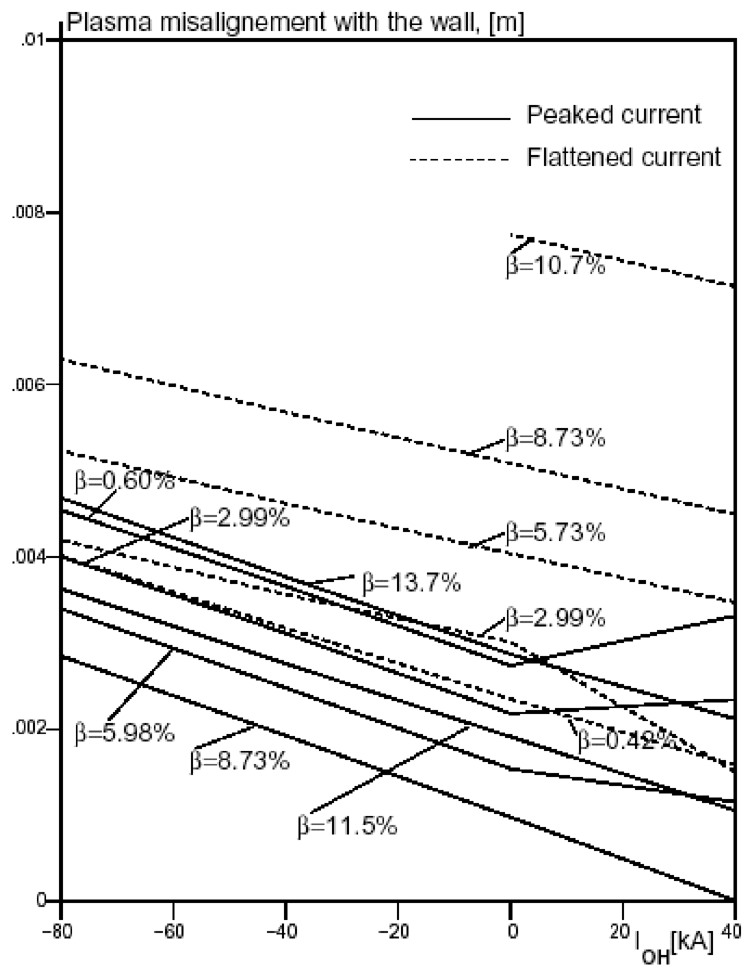
- Core fueling is required to produce flat temperature profiles
- LTX would utilize two methods:
  - Pellets
  - Very fast gas jets
- ORNL would refurbish the PBX-M 8 pellet injector
  - Smaller guide tubes, thermoelectric refrigerator
  - High field side injection would be used
- Supersonic gas jet fueling would also be implemented
  - Fast gas jets are under joint development with NSTX now.
  - Goal is a Mach 12-15 jet.

New PF coil set will provide good boundary control

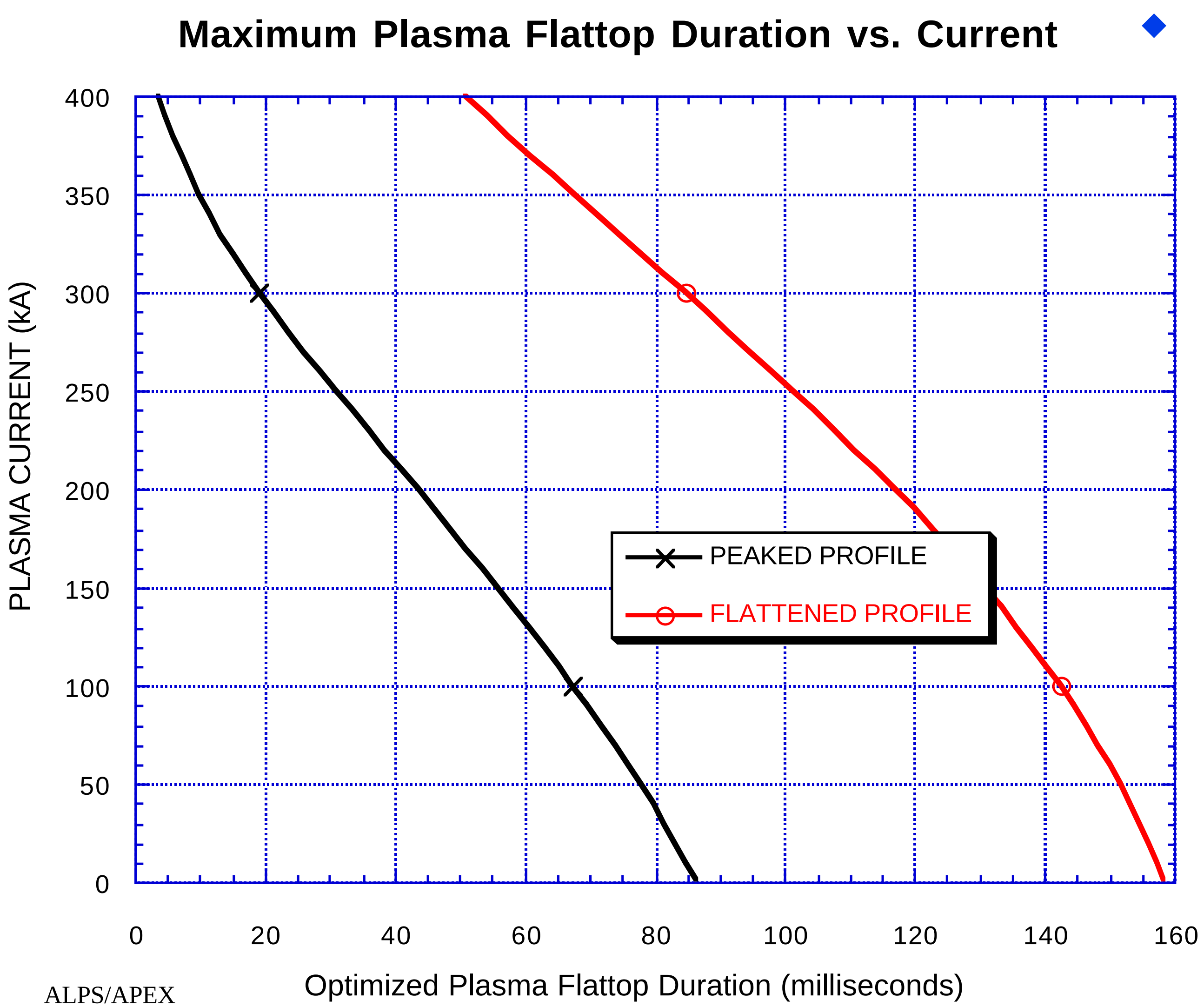
Coil set with ESC equilibrium



Misalignment for peaked, flat current profiles

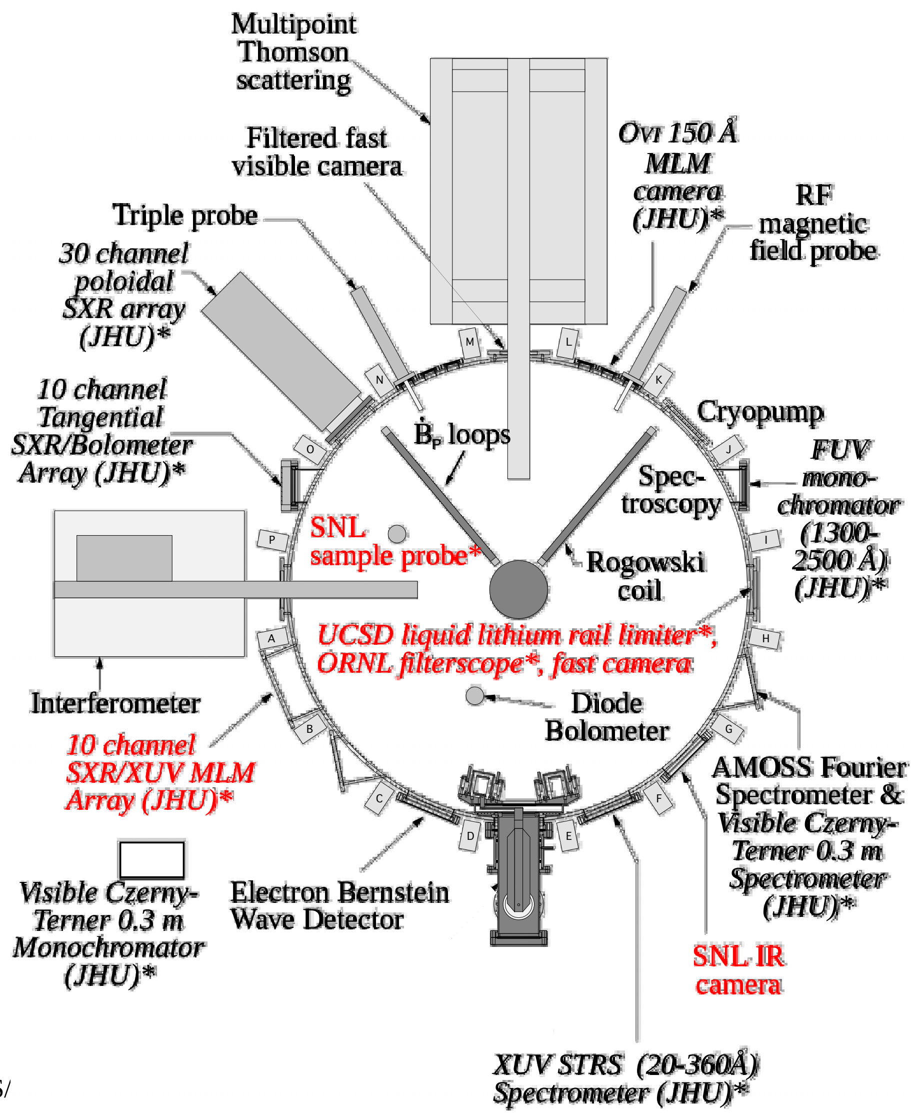


OH system will permit flattops of ~100 msec



- System modeling by Bob Woolley for upgraded OH system
  - Flux consumption based on CDX-U experimental values
  - Flattop limited by temperature rise in water-cooled OH coil

Diagnostics for LTX



Present (CDX-U) set includes:

- 10 channel soft x-ray array for lithium density profiles (JHU)
- IR camera (SNL) (not available for tray run)
- Fast (10,000 fps) visible camera
  - Upgrade to 30,000 fps this spring
- 2 filterscopes for neutral deuterium (D_α) radiation, oxygen, carbon, boron (ORNL)
  - Views of lithium tray limiter and centerstack
- Silicon sample wafer to diagnose wall flux (SNL)

Add for LTX:

- Additional magnetics (current profile)
- Upgraded Thomson scattering (YAG system)
- Edge interferometer channels (edge density)
- Time-of-flight ion energy analyzer

Discussion

- For LTX the whole nine yards is:
  - Near zero recycling leads to flat T_e, T_i profiles, suppression of all ∇T drive instabilities, fantastic τ_E
  - $N_e(r)$ ~ fueling profile. Very low particle transport.
  - I_p (r) flat; high edge current.
    - » "Natural" reversed shear with q(0)>1, no sawteeth, other MHD is wall-stabilized.
  - He ash implantation in flowing LM (assisted w/ ICRH?) demonstrated separately (reactor issue).
    - » Primary driver for a divertor eliminated
- Resulting reactor concept is very attractive
- If: particle confinement is unimproved $\Rightarrow$ edge power flow becomes a problem
  - Would indicate other LM systems with moderate - high recycling (Sn, SnLi, Ga) are more reactor-relevant
- LTX would still yield unique physics, wall technology data

Summary

- The LTX is designed to access an entirely new regime for MFE
  - Innovative Confinement Concept-level experiment is needed to determine if this regime will be as attractive as predicted
  - *Very* difficult to implement full liquid lithium walls in NSTX!
- Flat or inverted temperature profiles would provide a significant test of our understanding of transport
  - Energy *and* particle
- Application to larger devices with pulse lengths of up to a few seconds would be a straightforward (though expensive) extension
  - Longer pulse lengths would require flowing metal
- Key enabling concept originated with the Fusion Technology program
  - Innovative concept which was “born” with a reactor embodiment