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NSTX

Boundary Physics Plan
FY 2004-2008

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For the NSTX National Team

DOE Review of
NSTX Five-Year Research Program Proposal
June 30 – July 2, 2003

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IPP, Garching
U Quebec

Boundary physics activities have enabling technology goals and science goals

- Enabling technology - tailor edge plasma to optimize discharges
  - NSTX needs
  - innovative solutions for integrated power and particle control

- Science goals
  - characterize edge power and particle transport regimes
  - investigate effect of ST features on boundary physics (clearest impact of low R/a at edge)
  - extend databases to low R/a

Boundary goals are linked to IPPA goals

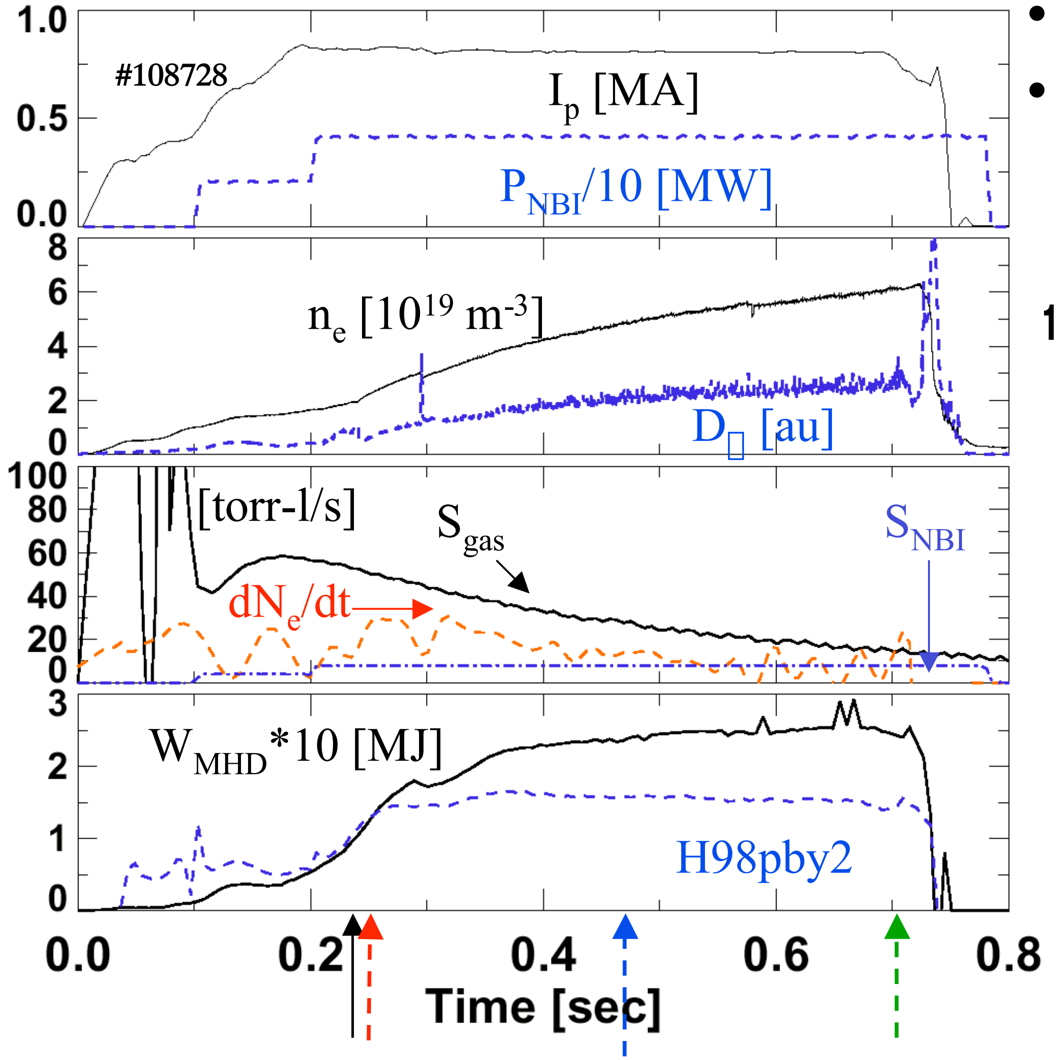
- *5-Year Objective*: Make preliminary determination of the attractiveness of the spherical torus (ST), by assessing high-β_T stability, confinement, self-consistent high bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times.

- Implementing Approach 3.2.1.5:
  - Disperse Edge Heat Flux at Acceptable Levels
  - Study ST specific effects
    - high mirror ratio
    - high flux expansion

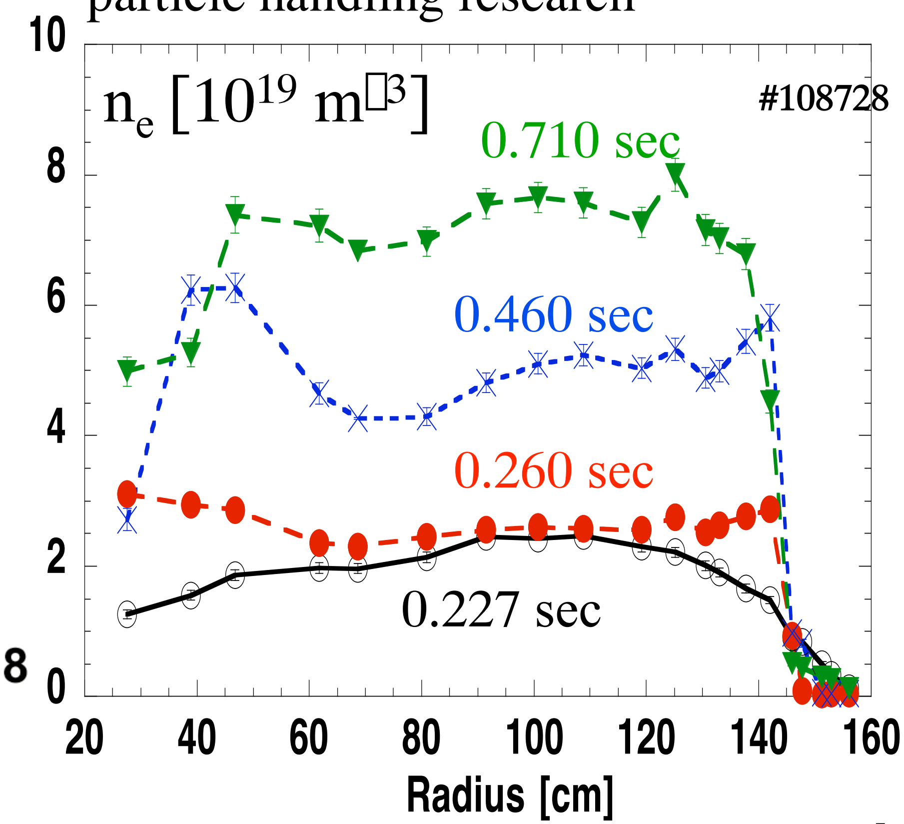
Boundary physics talk outline

- Fuel and impurity particle control
- Power handling and mitigation
- H-mode, pedestal and ELM physics
- Edge, SOL, divertor and wall conditioning physics

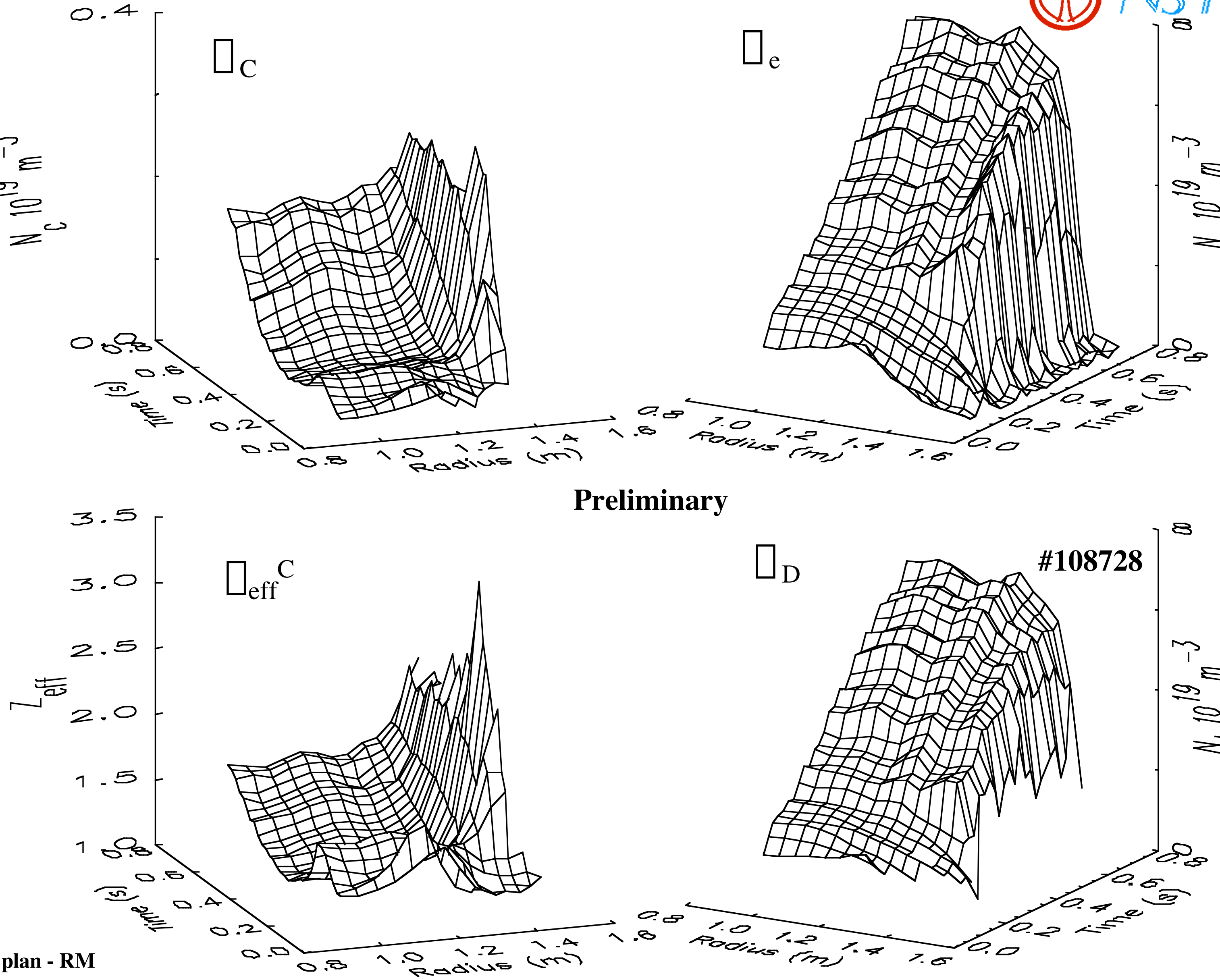
Uncontrolled (non-disruptive) density rise in long pulse H-modes points to need for particle control



- Often $dN_e/dt > S_{NBI}$
- Density control needed for improved current drive efficiency, transport studies, and power and particle handling research

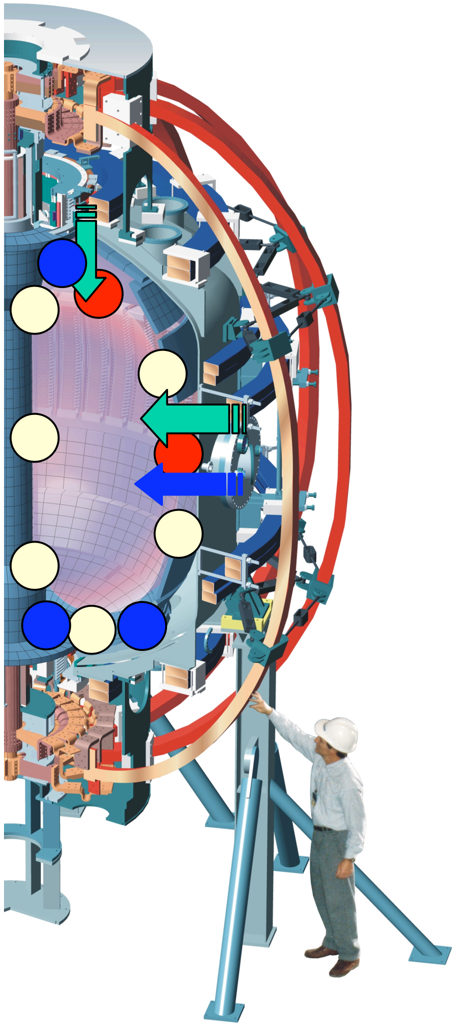


Electron and deuteron density rise both rise after L-H
Carbon and Z_{eff} low in the core

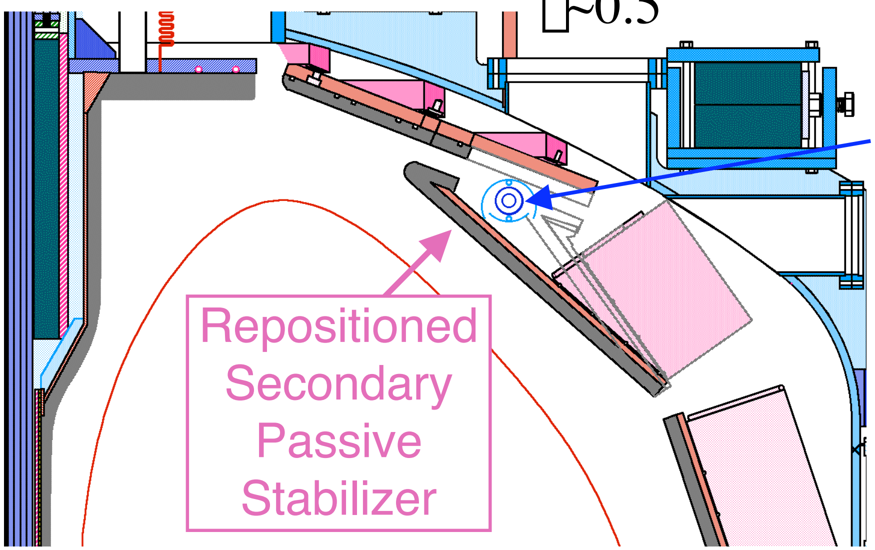


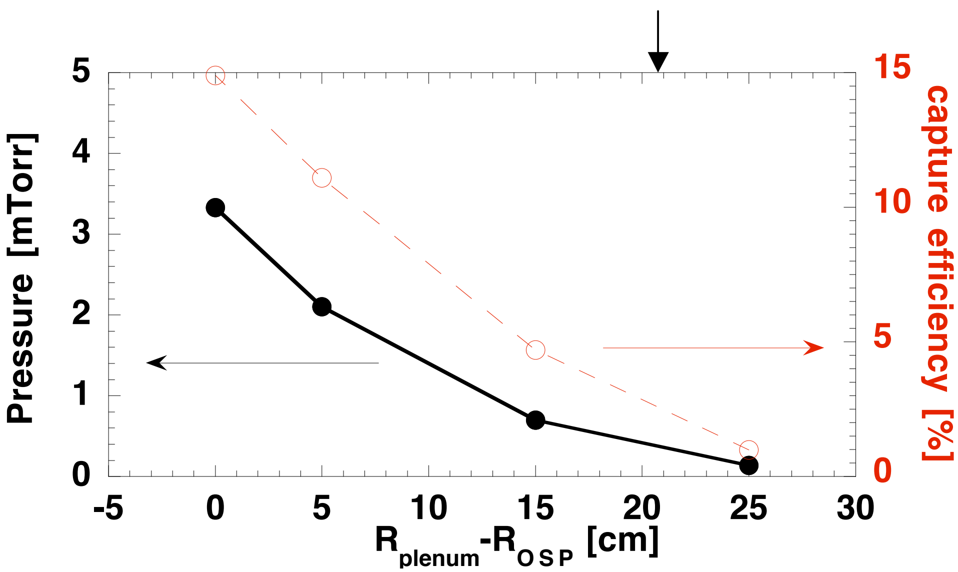
New particle control tools and diagnostics are planned

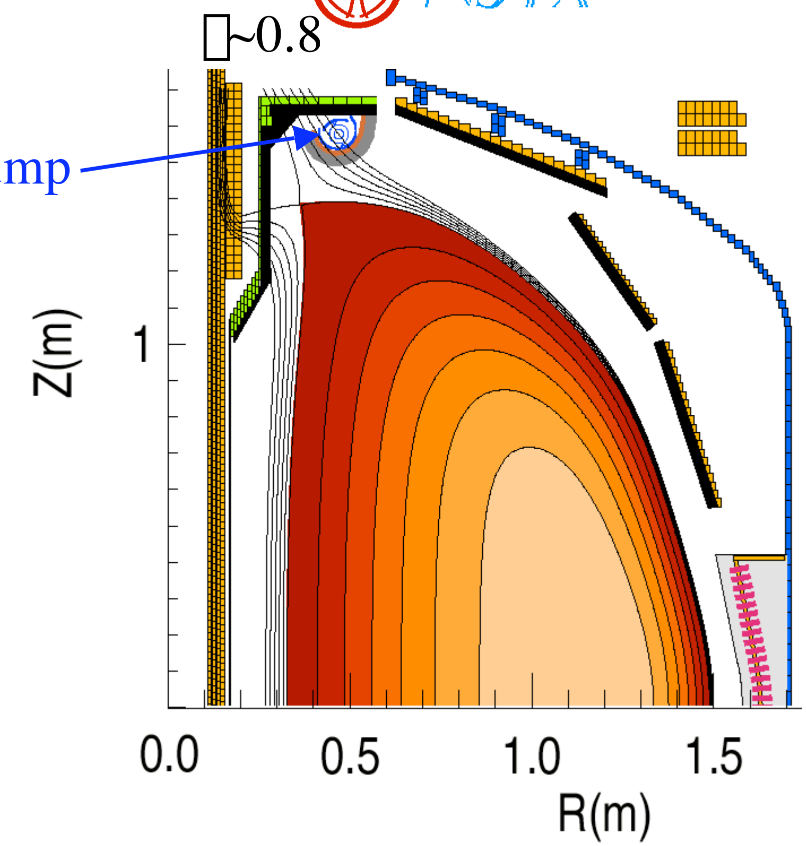
- New tools
  - more poloidal locations for gas (FY03-04)
  - supersonic gas nozzle (FY04)
  - Lithium pellets (FY04)
  - D_2 pellets (FY05)
  - improved boronization (FY04)
  - cryopumps (FY04 ? , FY06
- New diagnostics
  - $n_C(r)$ from CHERs (FY03)
  - add visible cameras for D□ + impurities (FY04-05)
  - add fast pressure gauges (FY04-05)
  - divertor Langmuir probe upgrade (FY06)
  - deuterium pellet diagnostics (FY05-06)
  - add edge Thomson chans. (FY05,07)
  - divertor SPRED (FY 07)



Divertor cryopump concepts for medium and high triangularity discharges







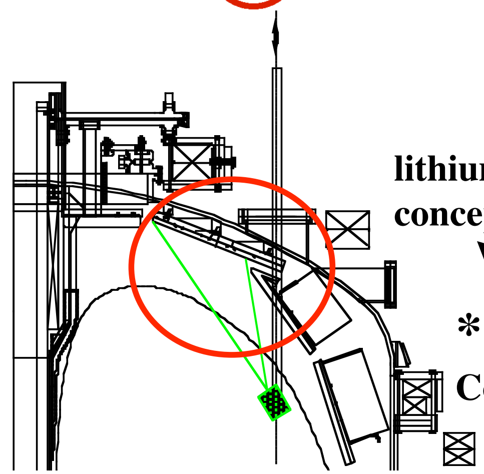
- Analytic calculations useful for scoping studies
- Physics design optimization to be done with 2-D calculations

Menon, ORNL

Innovative particle control tools will be developed

NSTX

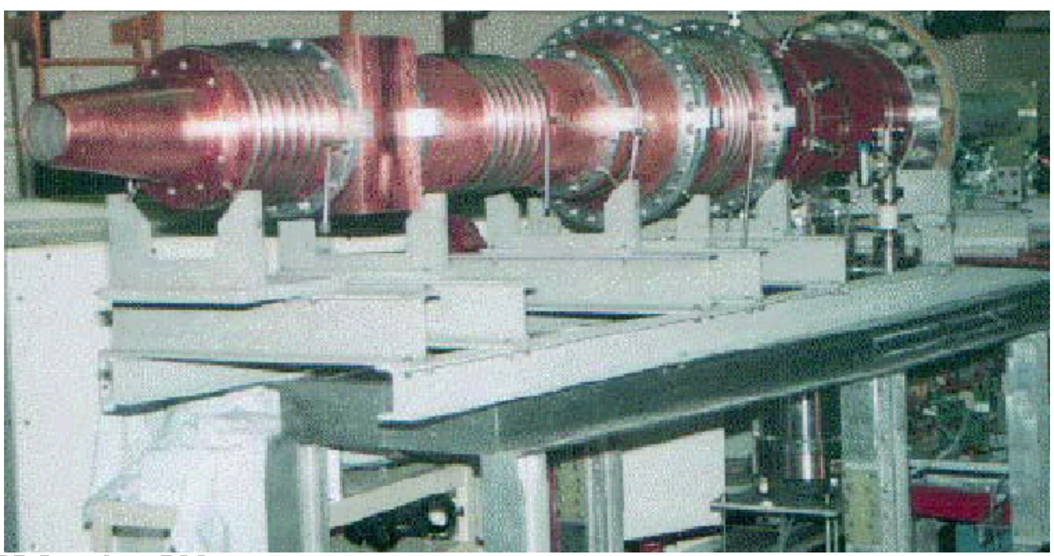
- CT injection (FY06 ◇?, FY08)
  - reactor fueling needs
- Lithium coatings (FY04-06)
  - ultra low recycling $R_{PFC} \leq 0.1$
- Lithium module (FY06 ◇?, FY09)
  - integrated power and particle control



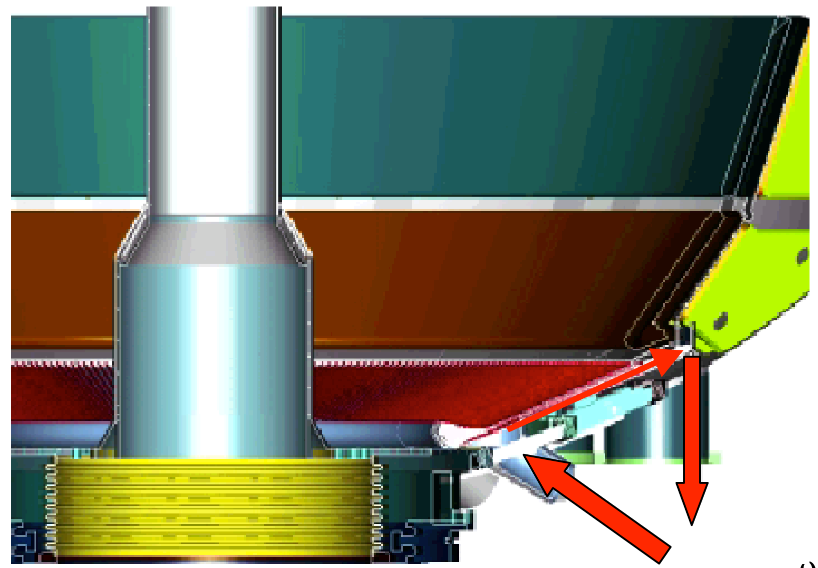
lithium coatings concept cartoon

*** VLT Collaborations**

CTF-II CT injector used on TdeV



lithium surface module cartoon



Boundary physics talk outline

- Fuel and impurity particle control
- Power handling and mitigation
- H-mode, pedestal and ELM physics
- Edge, SOL, divertor and wall conditioning physics

Power handling must be maintained for NSTX goal of several current diffusion times

NSTX

- ST's can have high heat flux because of high P_{heat}/R
  - NSTX: P_{NBI} ~ 7 MW, P_{RF} ~ 9 MW, P_{heat}/R ~ 18.8

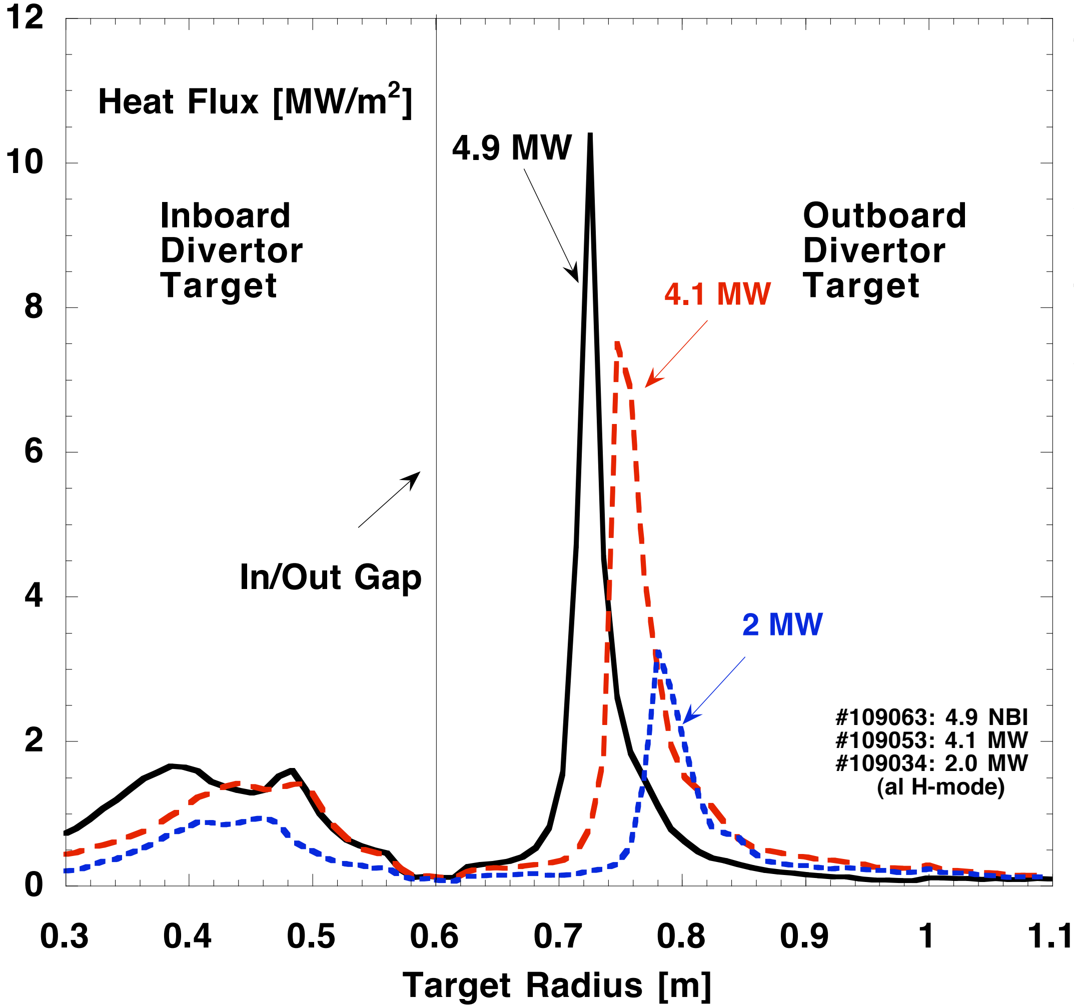
- Highest q_{peak} in NSTX ~ 10 MW/m^2
  - □T_{div} ~ 300 ^{0}C in LSN
  - extrapolates to ~ 3 sec. pulse length limit (□T_{div} ~ 1200 ^{0}C)

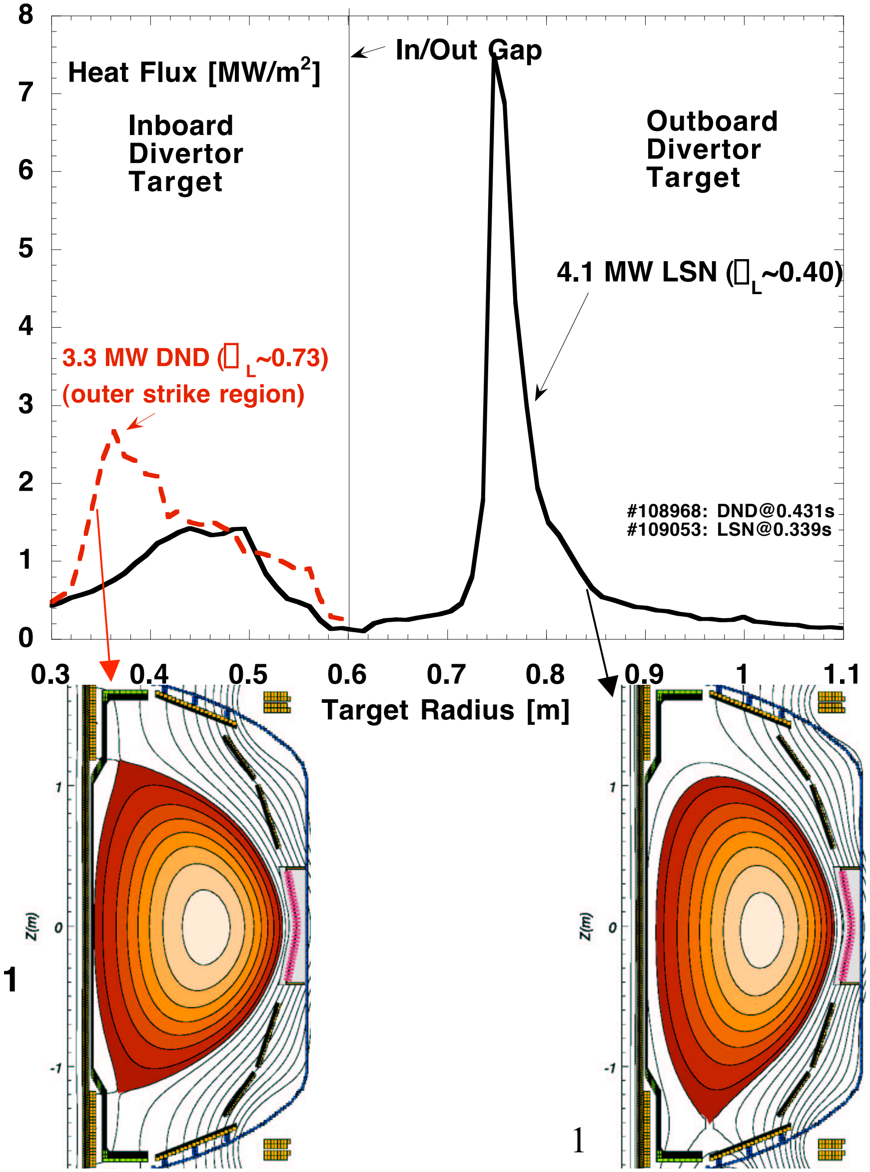
  ⇒ OK for projected current diffusion times < 0.5 sec

- Goal: assess power balance and survey heat flux in many scenarios (vs. shape, input parameters, etc.)

- Staged plan
  - quasi-steady power balance in near term; transient events in future
  - evaluate PFCs heating; upgrade if needed (FY05 ?)
  - develop innovative liquid lithium solution to heat flux problem

Peak heat flux increased with NBI power in LSN and was reduced in DND relative to LSN





Power handling and mitigation plan

- Experimental plan
  - Power balance studies (FY02+)
    - divertor heat flux vs core and divertor radiation
    - parallel vs perpendicular transport
  - Detailed comparison between single-nulls and double-nulls (FY04+)
  - Heat flux reduction studies (FY04+) [PFC upgrade ◇? end FY05]
  - Impact of fast events, e.g. ELMs, IREs, and disruptions (FY05+)
  - Liquid lithium solution to heat flux issues (FY06 ◇?, FY09)

- New Diagnostics
  - Cross-calibrate core bolometry with platinum-foils (FY04)
  - Add and optimize divertor bolometer channels (FY04-05)
  - Add one slow and one fast infrared cameras (FY04, FY05)
  - Lithium surface module diagnostics (FY09)

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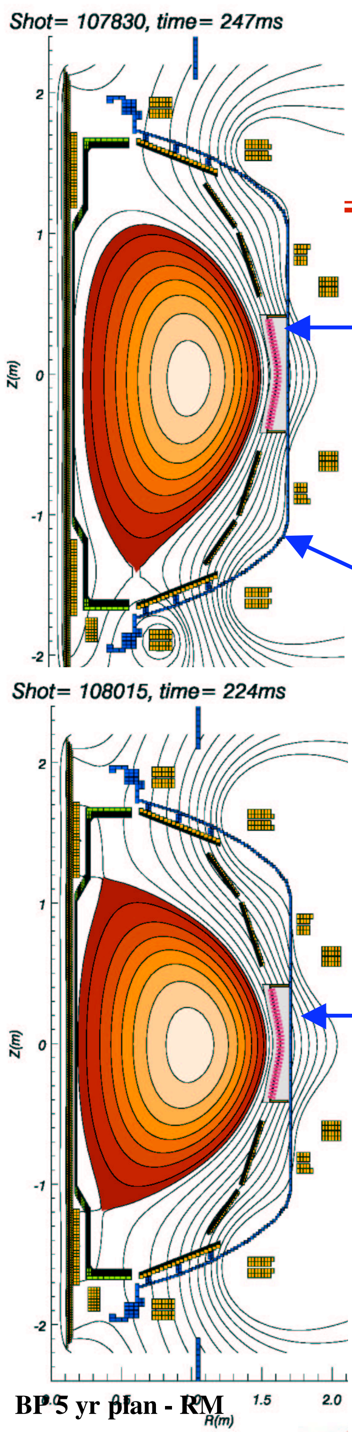
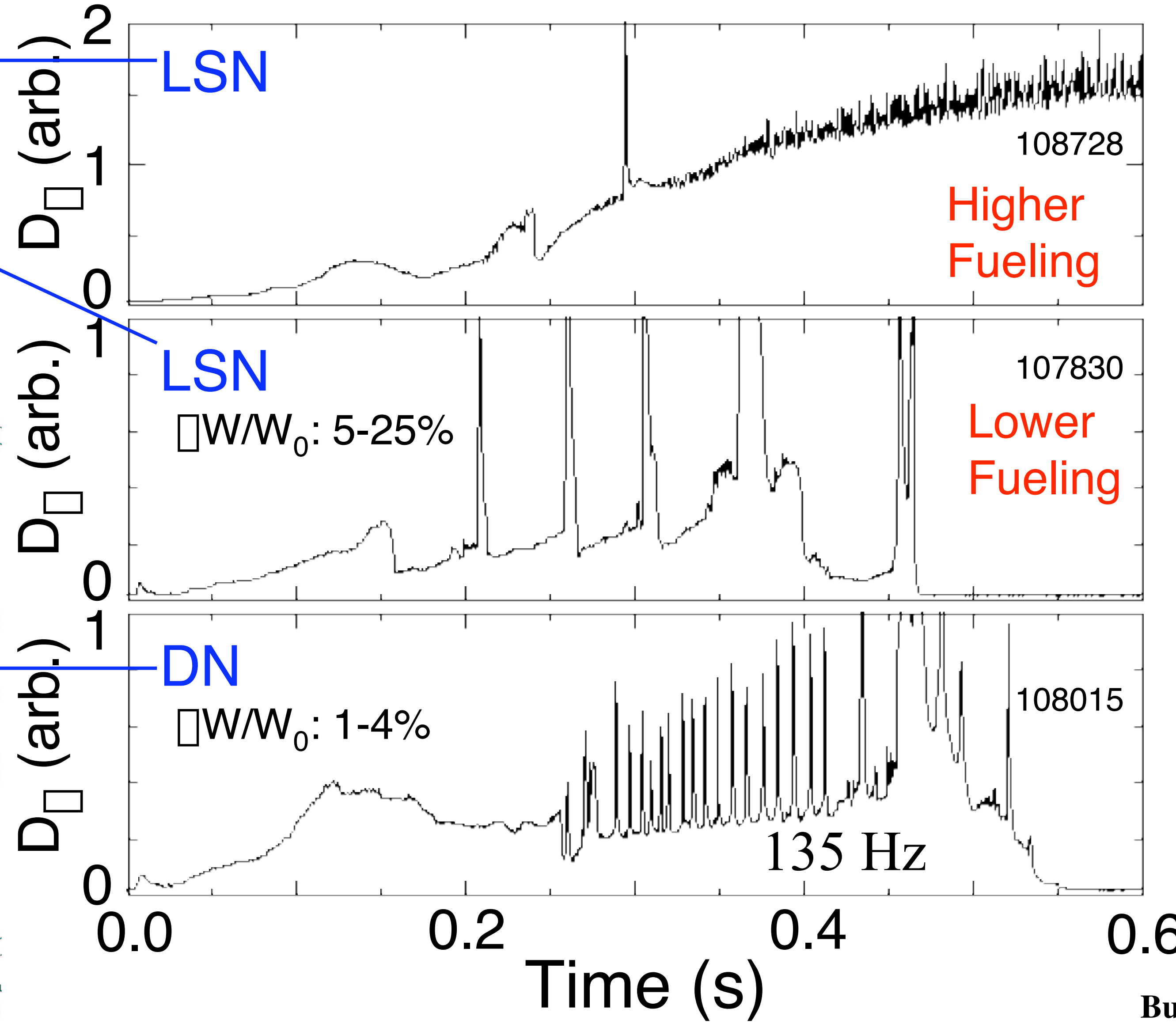
H-mode, pedestal and ELM physics background

- L-H transition physics (common with transport group)
  - P_{LH} higher than scalings
  - I_p and maybe B_t dependence of P_{LH} appears different
  - Fueling location can affect P_{LH}
- Pedestal physics
  - n_e pedestal $\leq$ 0.9 n_{GW}; T_e, T_i pedestal $\leq$ 500 eV
  - Pedestal stored energy below tokamak scaling predictions
- ELMs
  - Tokamak-like ELMs in double-null
  - Usually ELM-free or very large events in single-null
  - Fueling rate strongly affects ELM size(type?)

- Plan: characterization studies over next few years and optimization studies over longer term

ELM behavior depends on operating conditions





H-mode, pedestal and ELM physics plan

- Continue L-H mode transition parametric studies
  - importance of high trapped particle fraction and neutrals
  - extend tests of L-H theories to low R/a
- Pedestal studies
  - relative importance of gyro-radius, MHD and fueling effects on heights, widths, and gradients
- ELM studies
  - effect of shape and fueling on size and frequency
  - optimization for density and impurity control
- New Diagnostics
  - extra edge Thomson channels (FY05, FY07)
  - edge Helium line ratio (FY06)
  - improved time resolution in edge passive spectroscopy (FY08)

Boundary physics talk outline

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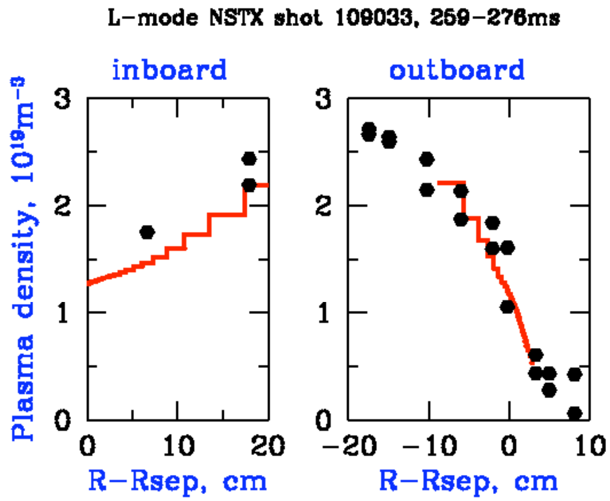
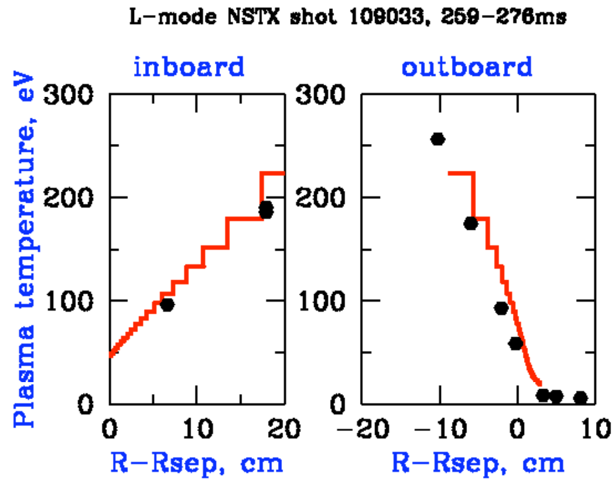
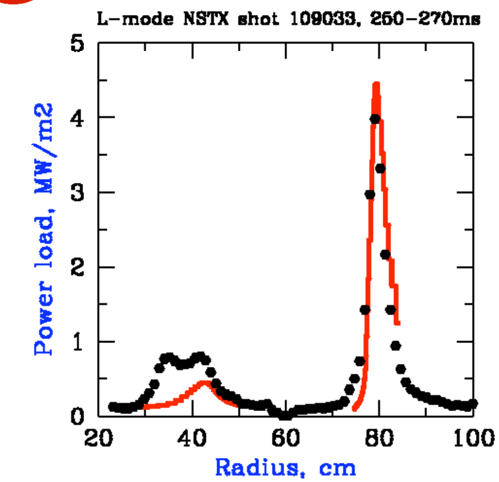
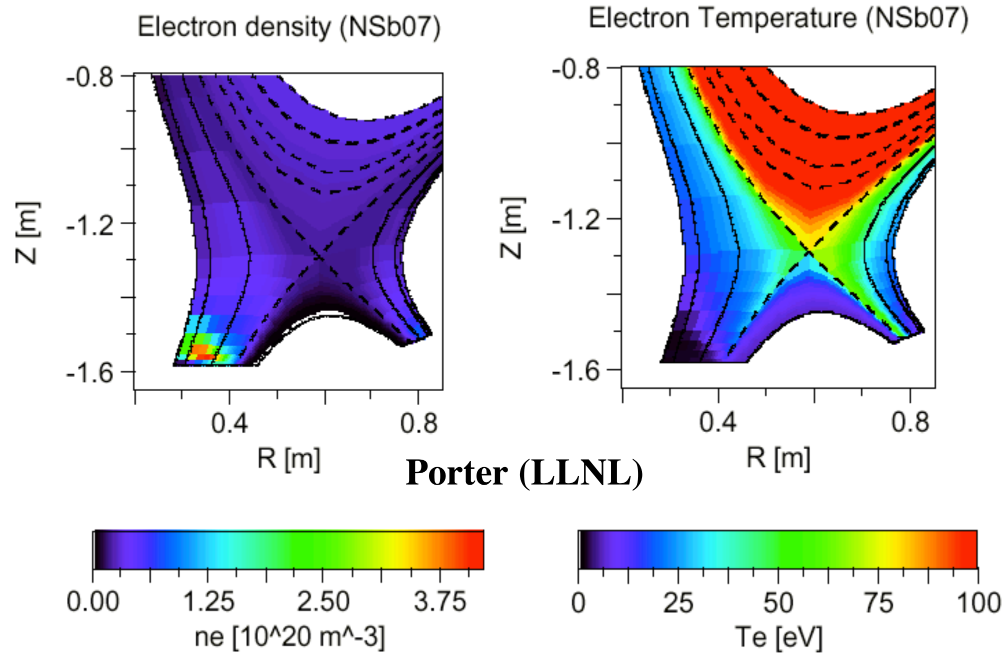
UEDGE modeling used to estimate transport coefficients/flux







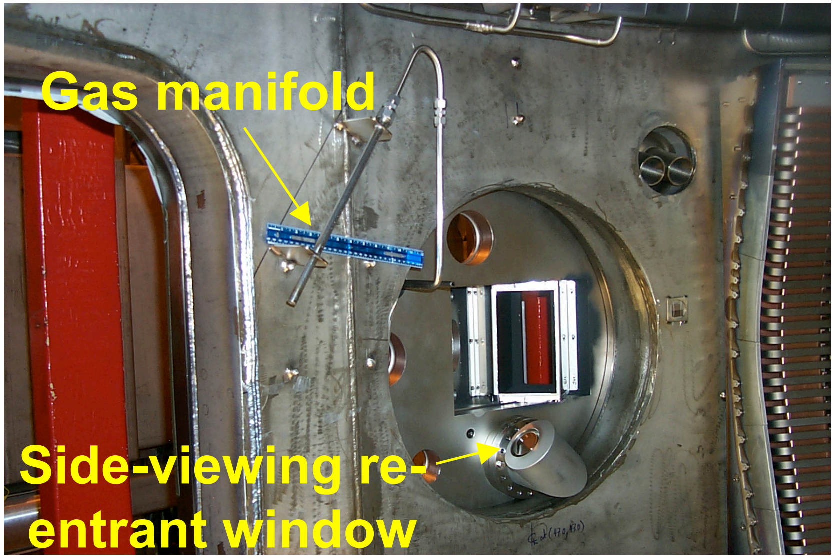
Pigarov (UCSD)

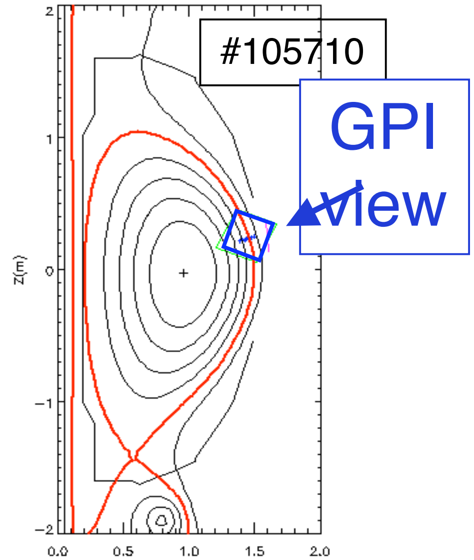


Porter (LLNL)

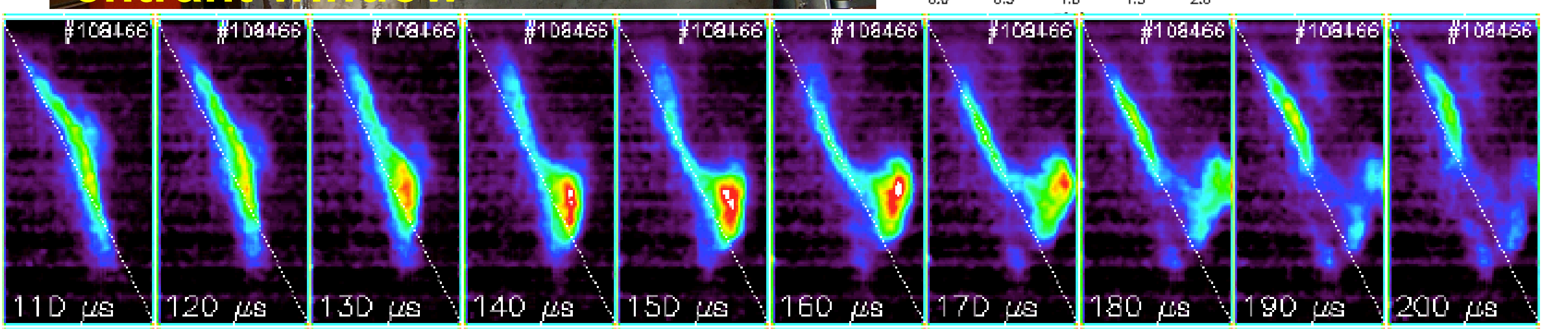
- LLNL using diffusive cross-field transport
- UCSD examining convective cross-field transport

Intermittent plasma objects observed with gas puff imaging diagnostic

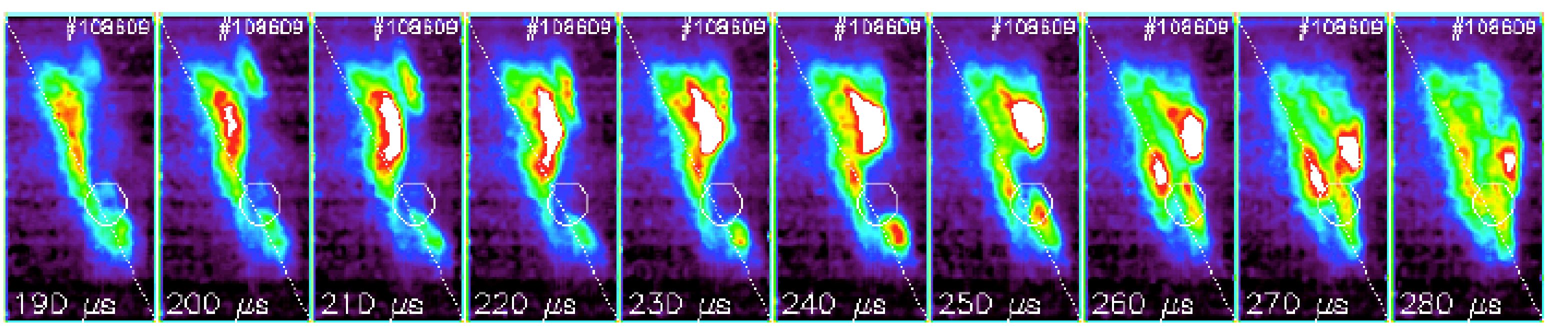




Reflectometers (UCLA, ORNL) and edge reciprocating probe (UCSD) also observe intermittency



H-mode



L-mode

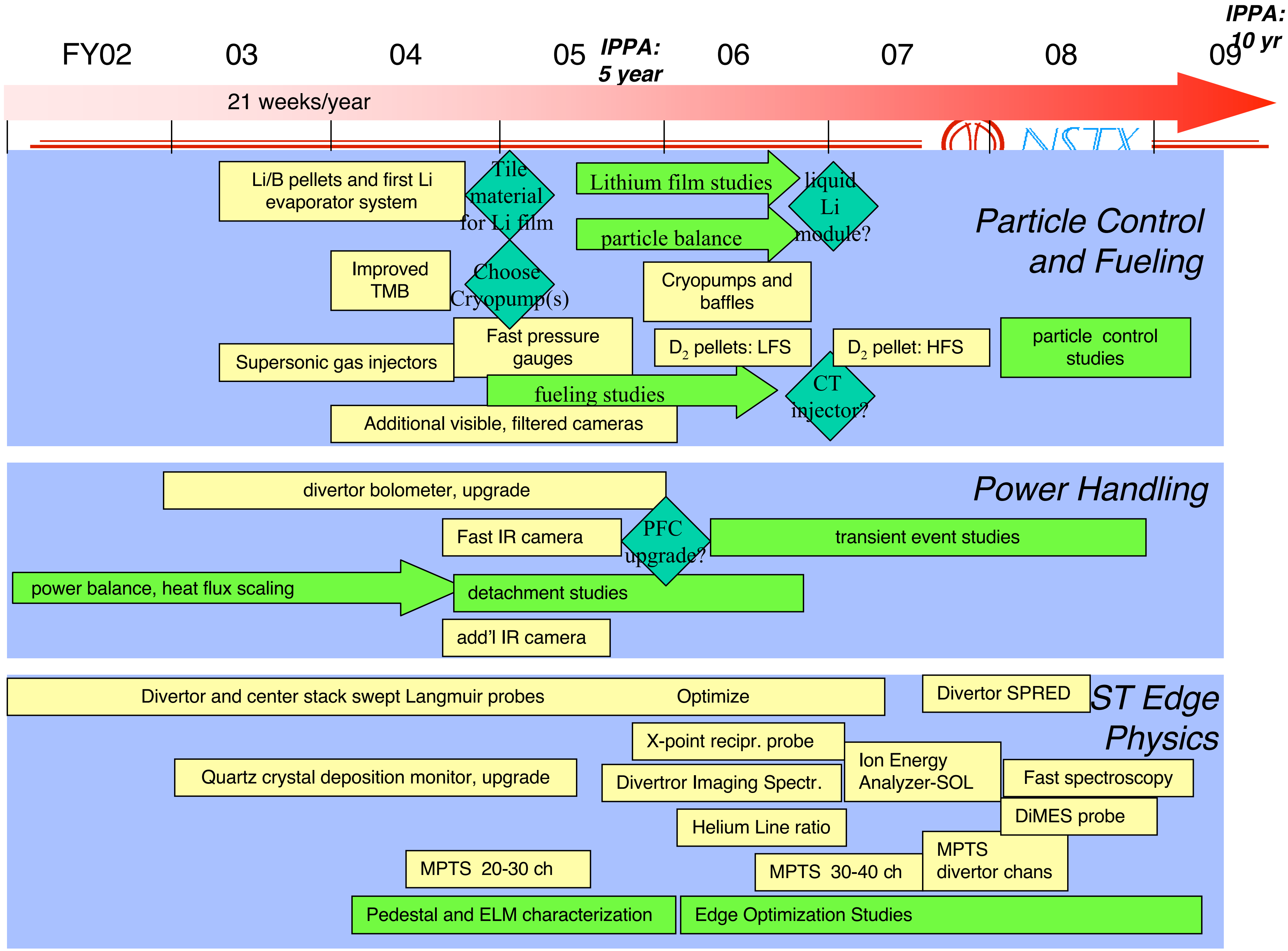
Zweben (PPPL)
Maqueda (LANL)

Edge, SOL, and divertor plasma transport plan

- Classical divertor heat flow regimes (conduction-limited, sheath-limited, detached) applicable? (FY03-04)
  - outer divertor likely attached; inner likely detached
  - UEDGE simulations for interpretation
- Cross-field transport: diffusive vs. intermittent (FY04+)
  - intermittent transport appears strong in both L and H-modes
  - simulation and coupling with theory crucial (e.g. BOUT, DEGAS-2)
- Cross-field transport and SOL scaling with mid-plane reciprocating probe (FY04+)
- New Diagnostics
  - divertor Langmuir probe array with improved spatial resolution (FY06)
  - imaging spectrometer (FY06)
  - X-point reciprocating probe (FY06)
  - divertor Thomson scattering (FY08)

ST unique features and wall conditioning plan

- Impact of “unique” ST features (FY06+)
  - high SOL mirror ratio, short connection length, high flux expansion -> distorted SOL ion energy distribution?
  - in/out B_t ratio and target; E X B flows
- Wall conditioning: boronization optimization (FY04)
  - does every morning or between shots improve things?
  - does hot boronization help?
- New Diagnostics
  - quartz crystal real time flux monitor (FY03, upgrade FY05)
  - imaging spectrometer (FY06)
  - X-point reciprocating probe (FY06)
  - SOL ion energy analyzer for $T_i^{\parallel}$ and $T_i^{\perp}$ (FY07)
  - divertor Thomson scattering (FY08)
  - DiMES material testing probe (FY08)

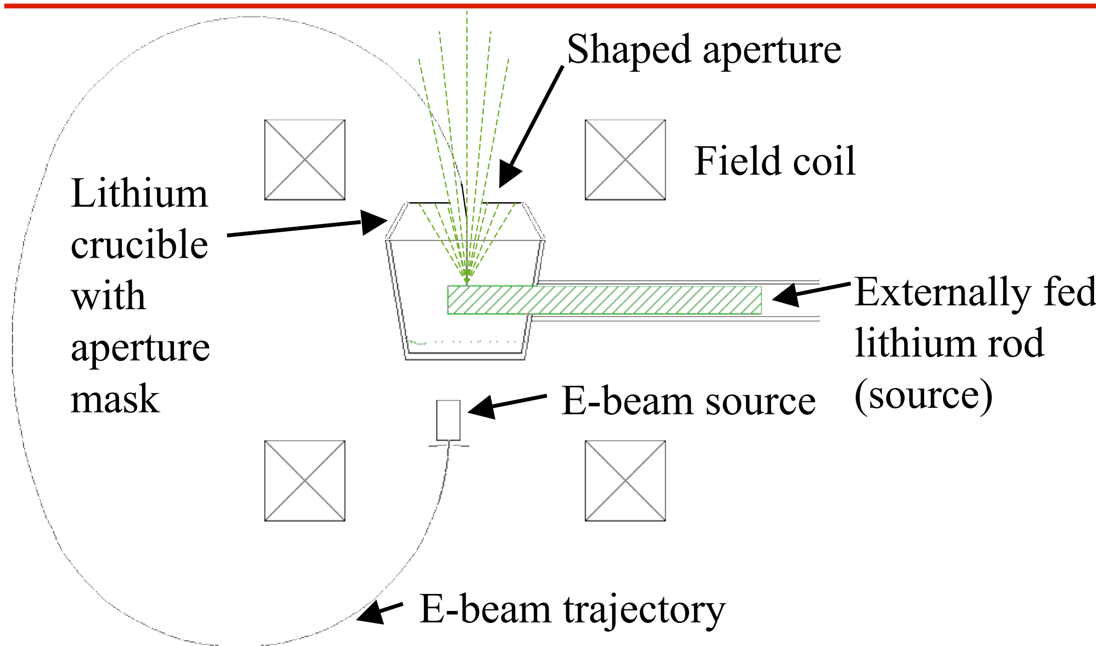

FY02
03
04
05
IPPA:
5 year
06
07
08
09
IPPA:
10 yr
21 weeks/year
NSTX
Particle Control and Fueling
Li/B pellets and first Li evaporator system
Tile material for Li film
Lithium film studies
liquid Li module?
particle balance
Improved TMB
Choose Cryopump(s)
Cryopumps and baffles
Fast pressure gauges
Supersonic gas injectors
D$_2$ pellets: LFS
D$_2$ pellet: HFS
particle control studies
fueling studies
CT injector?
Additional visible, filtered cameras
Power Handling
divertor bolometer, upgrade
Fast IR camera
PFC upgrade?
transient event studies
power balance, heat flux scaling
detachment studies
add'l IR camera
ST Edge Physics
Divertor and center stack swept Langmuir probes
Optimize
Divertor SPRED
X-point recipr. probe
Quartz crystal deposition monitor, upgrade
Divertror Imaging Spectr.
Ion Energy Analyzer-SOL
Fast spectroscopy
DiMES probe
Helium Line ratio
MPTS 20-30 ch
MPTS 30-40 ch
MPTS divertor chans
Pedestal and ELM characterization
Edge Optimization Studies

Boundary physics plan addresses NSTX program needs and contributes to ST physics

- Improved source and sink control to achieve ultra-low recycling regimes
  - conventional and innovative tools
- Power balance studies for NSTX PFC needs and next step ST and/or reactor needs
  - integrated power and particle flux solutions
- Dependence of H-mode, pedestal and ELM physics on R/a
  - ST features facilitate theory testing and development
- Edge, SOL, divertor and wall conditioning physics
  - nature of “classical” parallel transport and cross-field transport
  - ST kinetic effects in SOL

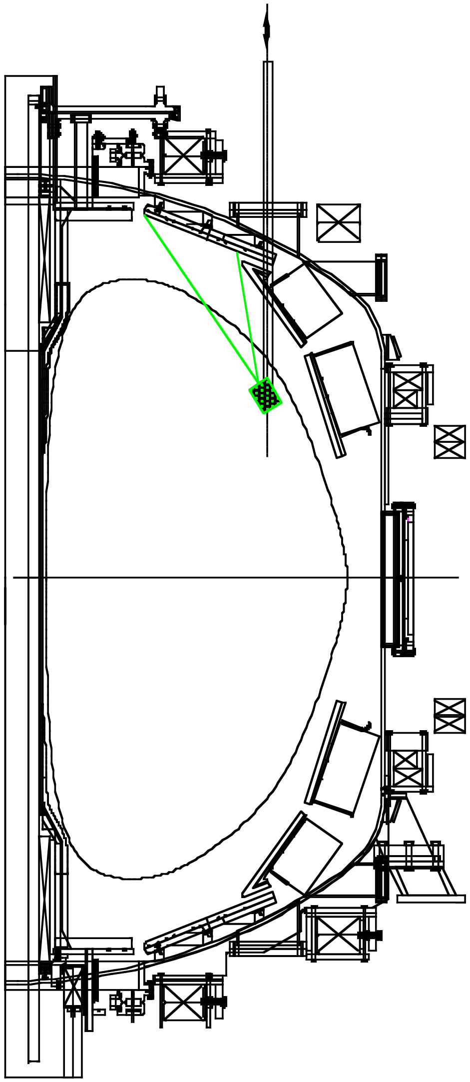
Backup

Self-contained deposition source is under development



- Electromagnetic version of commercial (permanent magnet) source now in use
  - Allows adjustment of power density by varying ratio of coil currents
- Beam power densities of 250 MW/m^2 attainable
- Shroud crucible or physically scan source to produce desired deposition pattern
  - Defocussed beam can heat/clean aperture

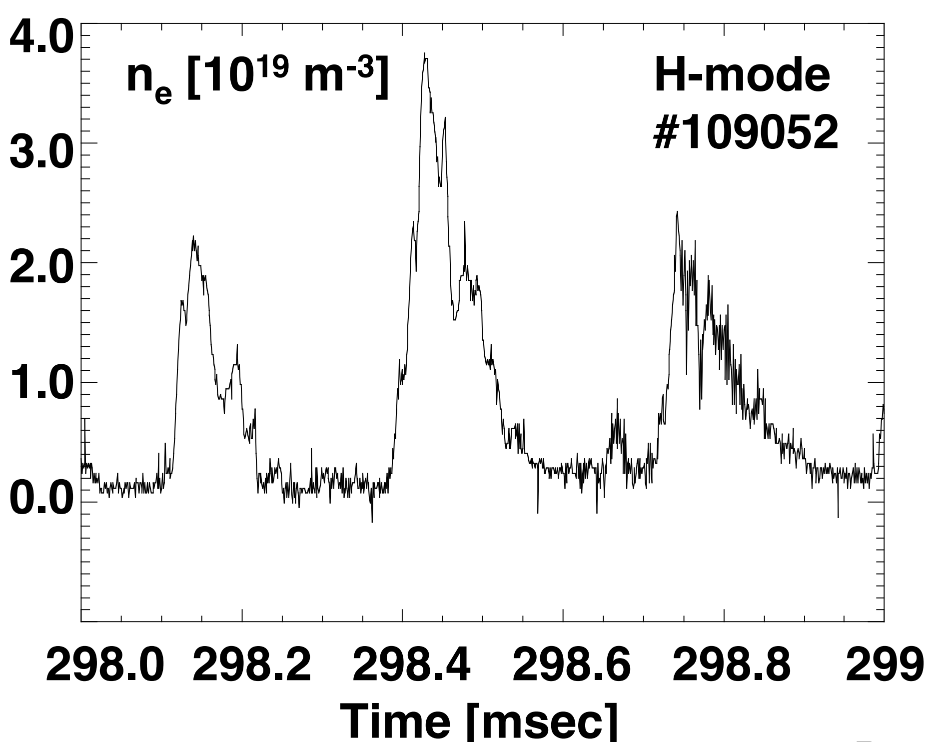
NSTX implementation

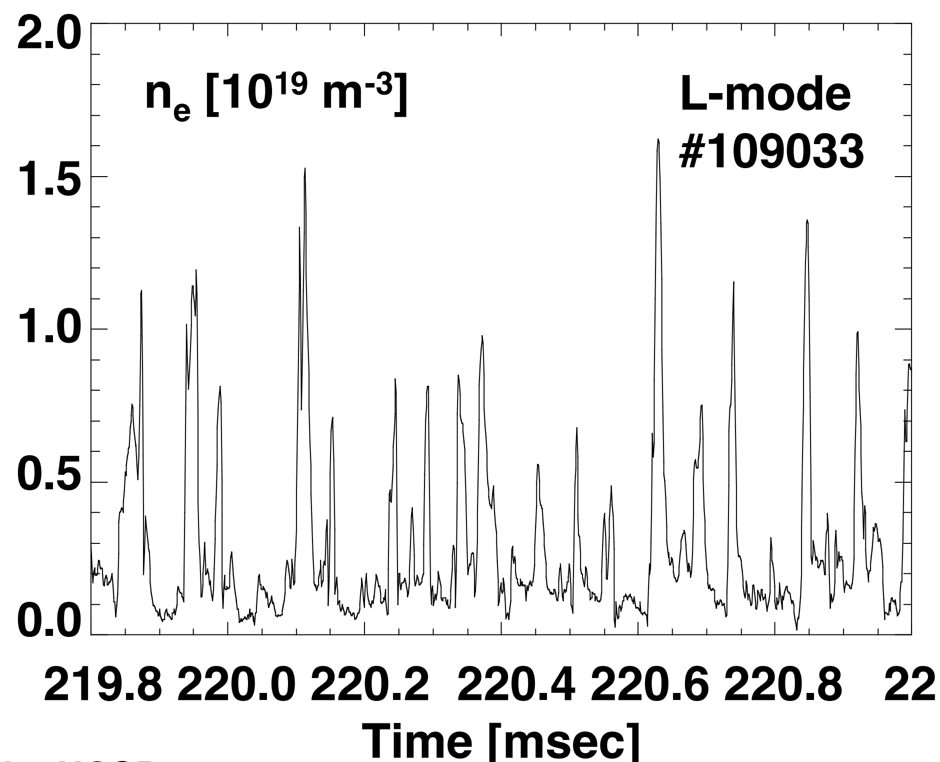


- Replace one of the passive stabilizing plates with a new plate, faced with plasma sprayed tungsten or moly
- Install an insertable e-beam system which can be scanned over the stabilizing plate
- Deposit 1000Å of lithium and withdraw the e-beam system
  - Similar to the insertable getters used in PLT, PBX
  - But time scale is different
    - Few 10's of seconds for 1000Å coating
    - Cycle time is dominated by insertion/removal of e-beam.
- Coat before *every shot*
  - 1000 shots 0.1 mm accumulation
    - Accumulation may be limited by evaporation

Intermittent behavior observed in L and H-mode

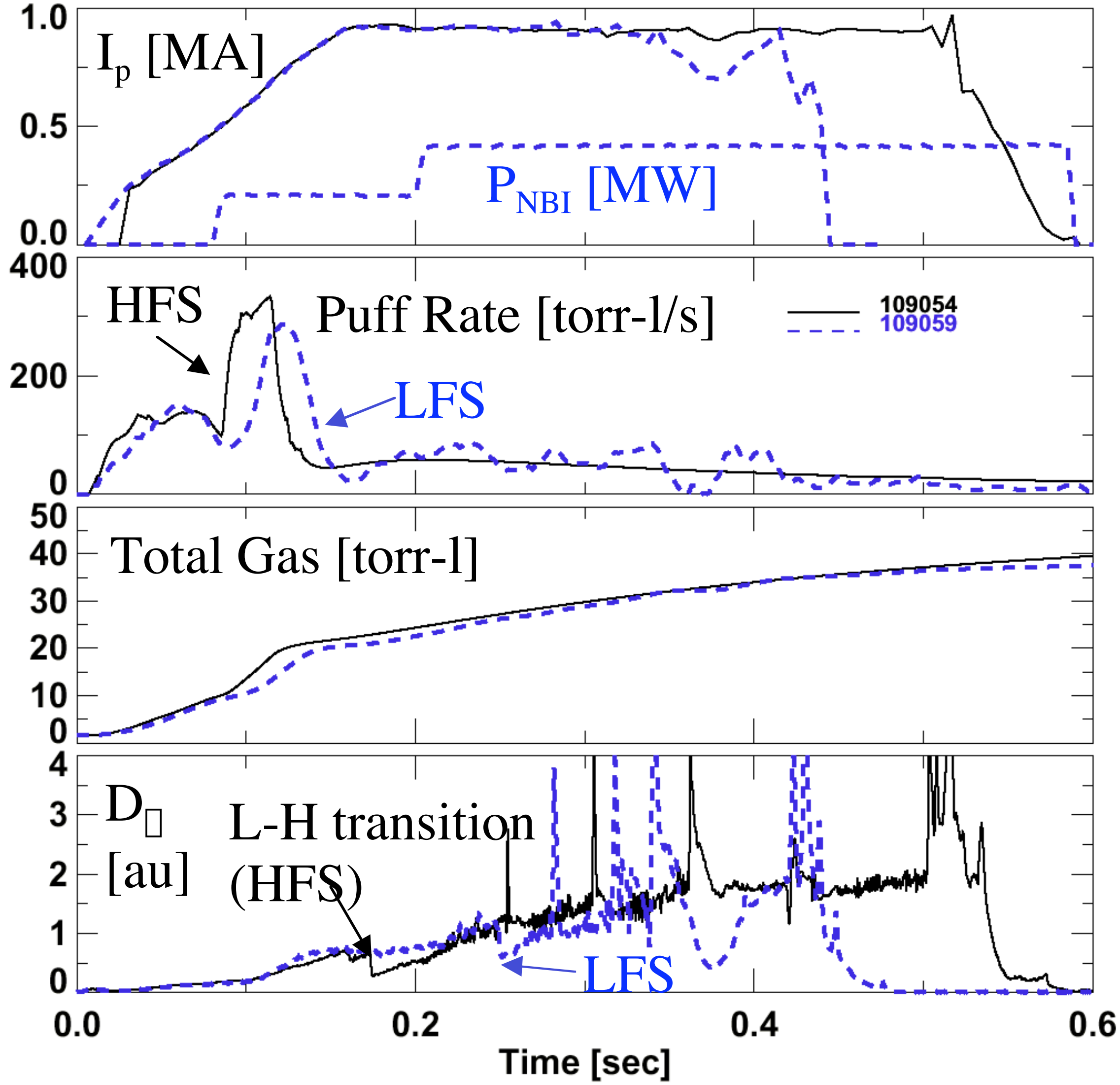
- Density is intermittent
- Rate of bursts is 2E3
- Poloidal field is much less intermittent
- Instantaneous particle flux ~10^{19} $m^{-2}s^{-1}$





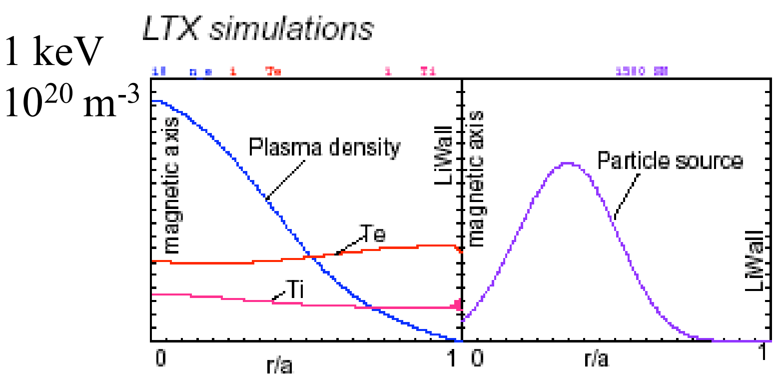
High-Field Side Gas Injector Fueling Allows Early L-H Transition and Longer H-mode Duration

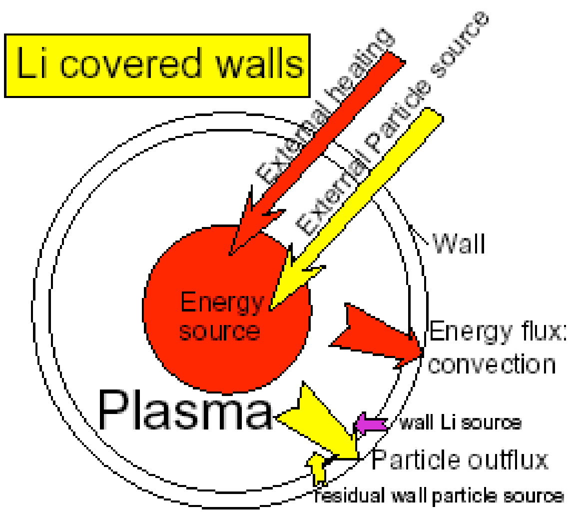
NSTX



Flat T_e will have profound effects on transport, MHD

Core fueling + Li absorbing wall offers enhanced edge temperature.





Flatten temperature

- no ITG turbulence,
- convection is a loss channel for particles and energy,
- no sawtooth oscillations,
- second stability regime (no Troyon limit),

LiWalls add more:

- wall stabilized plasma,
- high-β,
- high bootstrap current,
- outflux of impurities,
- . . .