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NSTX

Boundary Physics Program Plan for NSTX

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NSTX PAC meeting
Princeton, NJ
Jan. 22-24, 2007

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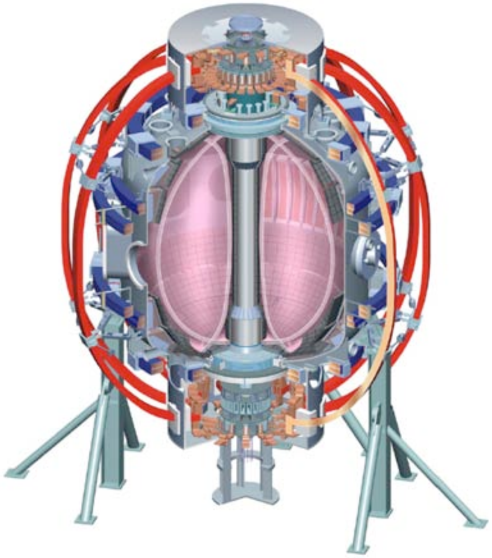

Culham Sci Ctr
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Boundary physics program in NSTX focused on next step ST design needs

- Lithium as a divertor plasma-facing component for integrated power and particle control solution
  - Near-term technique in NSTX to obtain low edge collisionality and improved confinement for more thorough and favorable extrapolation to next step STs
  - 2009 milestone - hydrogenic retention in lithium (proposed)
- SOL and divertor physics
  - Compact ST designs can lead to high divertor loading
  - 2008 milestone - heat flux control and SOL widths
- Pedestal and ELM Physics
  - Loading from large ELMs an issue for ST-CTF
  - Contributes to ITER near term design decisions (RMP coil location) as well as longer term scenarios (small ELM physics)
  - 2010 milestone: Pedestal characteristics/ELM stability (proposed)

NSTX has implemented PAC-21 boundary physics recommendations and addressed PAC-21 questions

NSTX

- ✓PAC21-16: Lithium delivery options (Kugel)
- ✓PAC21-17: continue SGI development
- ✓PAC21-18: continue blob studies - why SOL so thick?
- ✓PAC21-19: expand deuterium retention experiments
- ✓PAC21-20: adequate run time for XPs on ELM physics
- ✓PAC21-21: presentation on pedestal research program
- ✓PAC21-22: piggyback dust studies
- ✓PAC21-23: cross-machine comparisons of ELMs, bobs, SOL
- ✓PAC21-24: emphasize theory + simulation - XGC
- ✓PAC21-43: LLD compatibility with advanced ST work (Kugel)

* Further elaboration on these PAC recommendations in this talk

Outline

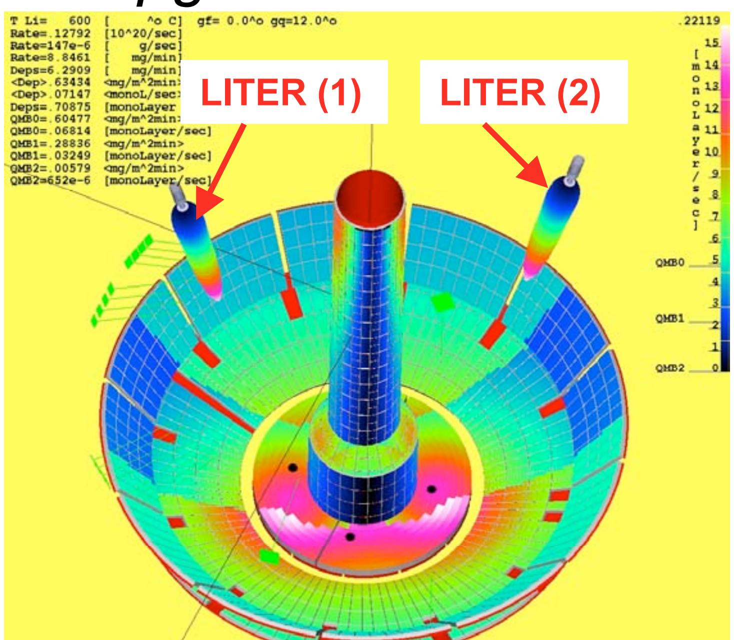
- **Lithium as a divertor plasma-facing component for integrated power and particle control solution**
  - **Density and impurity control, heat flux handling**
  - **Effect on plasma performance**

- SOL and divertor physics

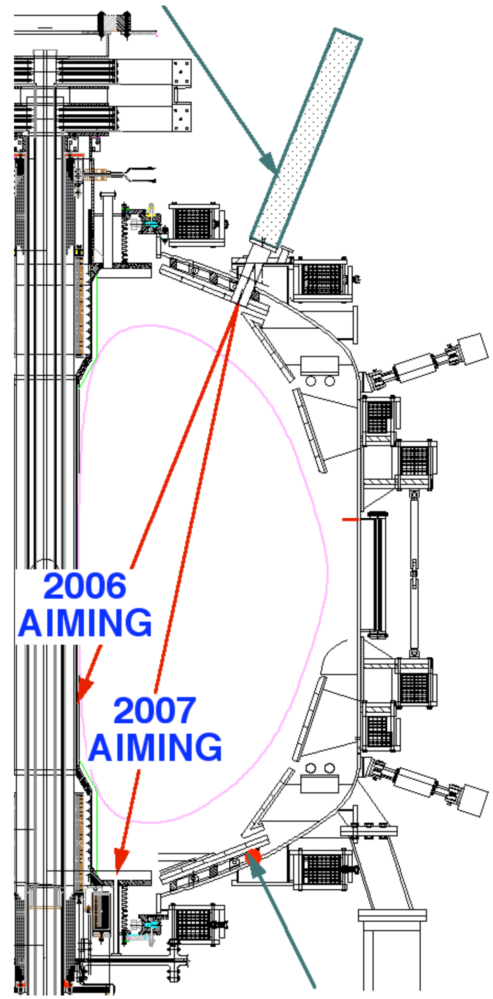
- Pedestal and ELM Physics

Lithium program in NSTX is proceeding in stages

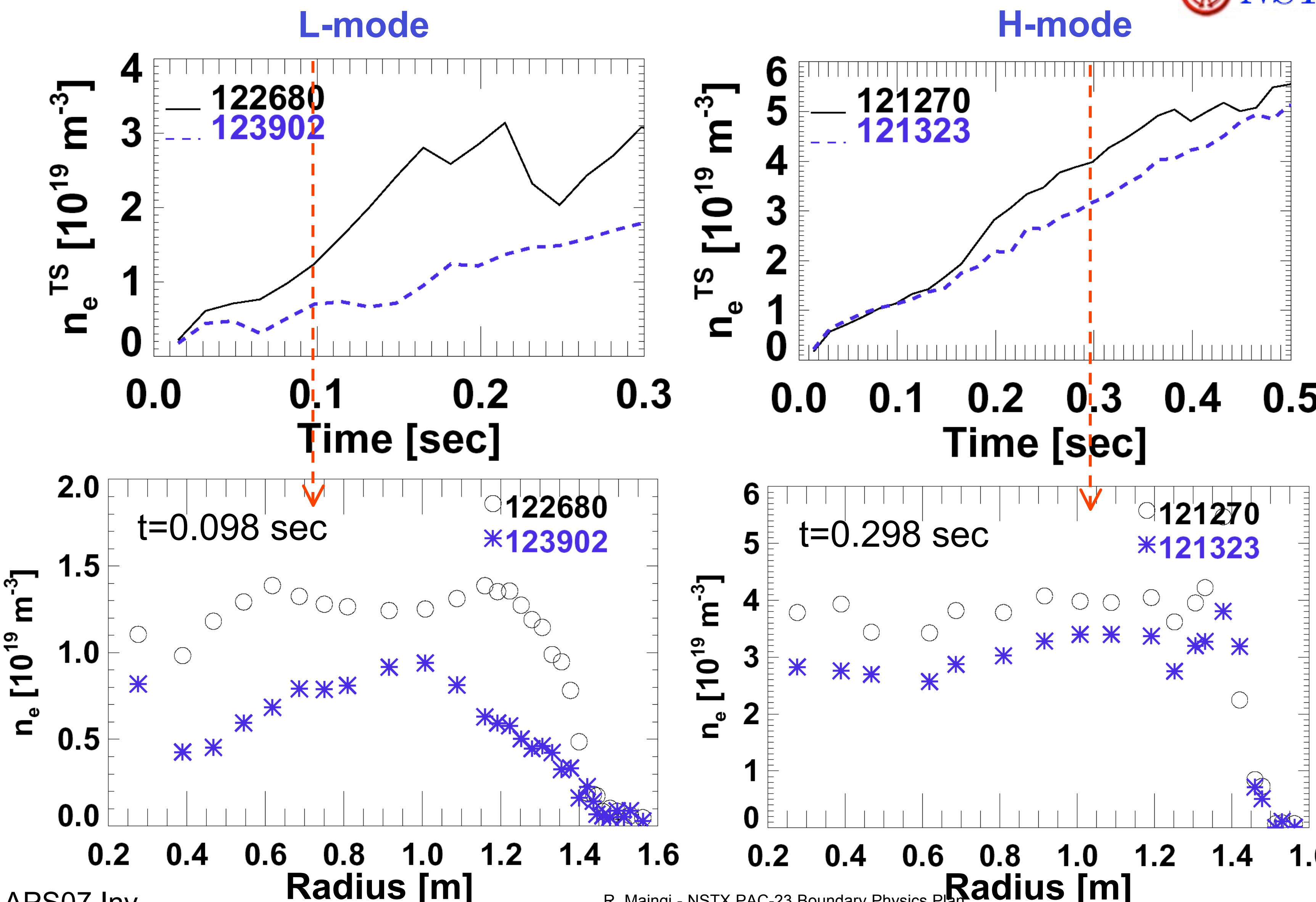
- Li pellets : FY 2005-2007
- Li evaporator (LiTER): FY 2006
- LiTER re-aimed to inner target: 2007-
- Two LiTER operation: FY 2008-
- *Liquid Li divertor (LLD): FY 2009*
- *LLD Upgrade: FY 2010*



2008 - increase of Li thickness/coverage



L-mode density reduced by 50% at high evaporation rate; H-mode density reduction more modest

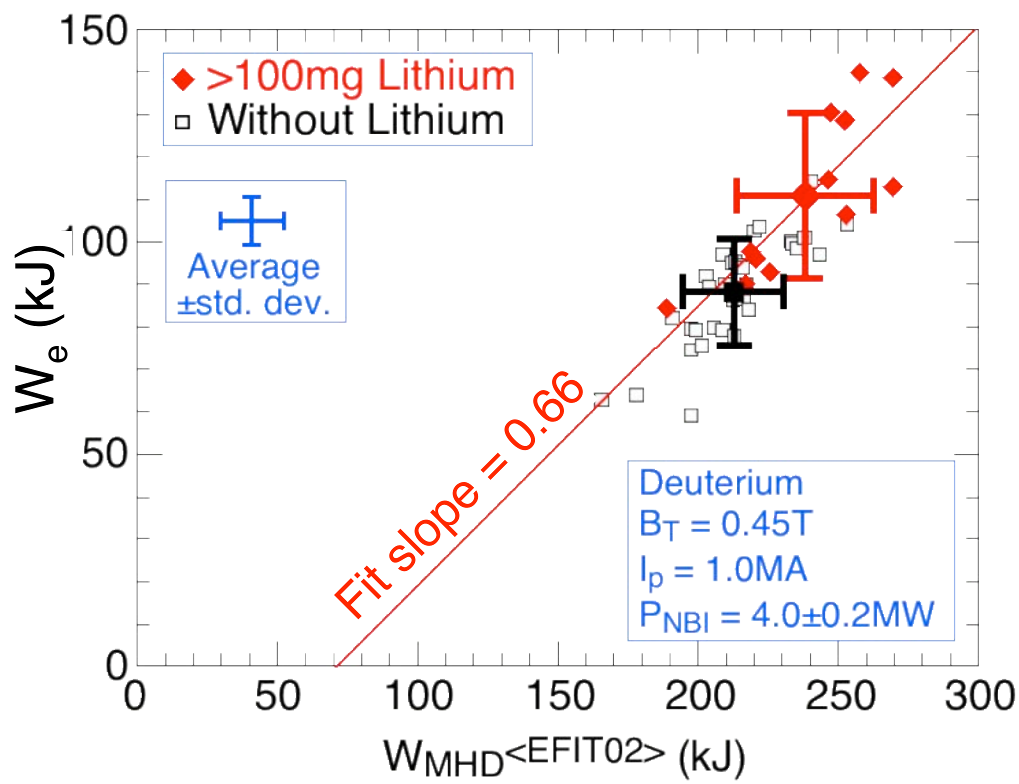


Kugel APS07 Inv.

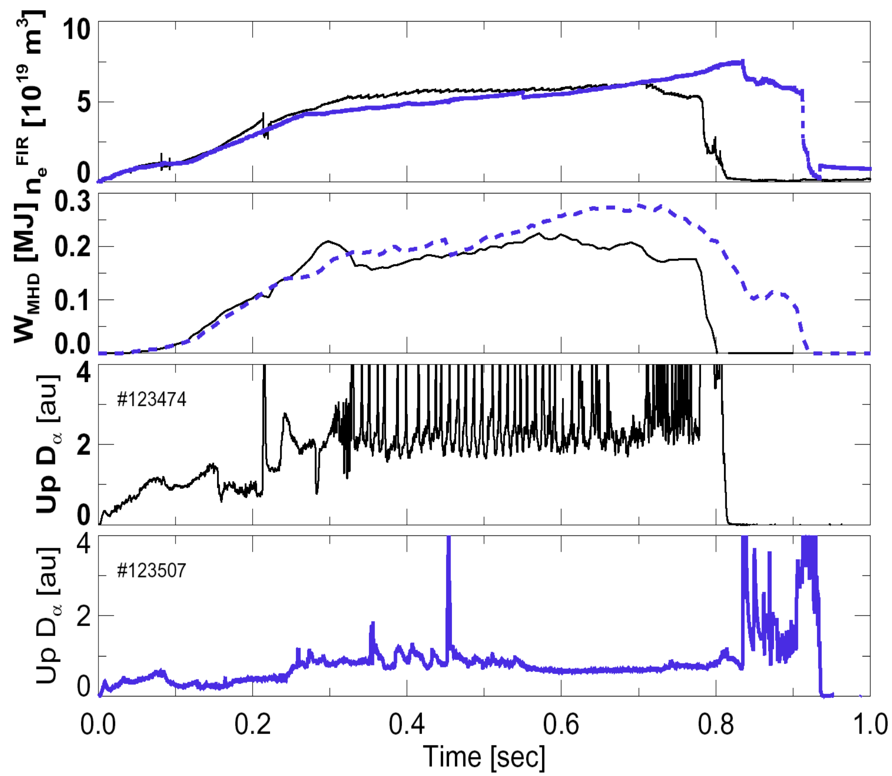
Plasma performance improved modestly and large ELMs were mitigated with lithium deposition

NSTX

W_{MHD} increase mostly from W_e

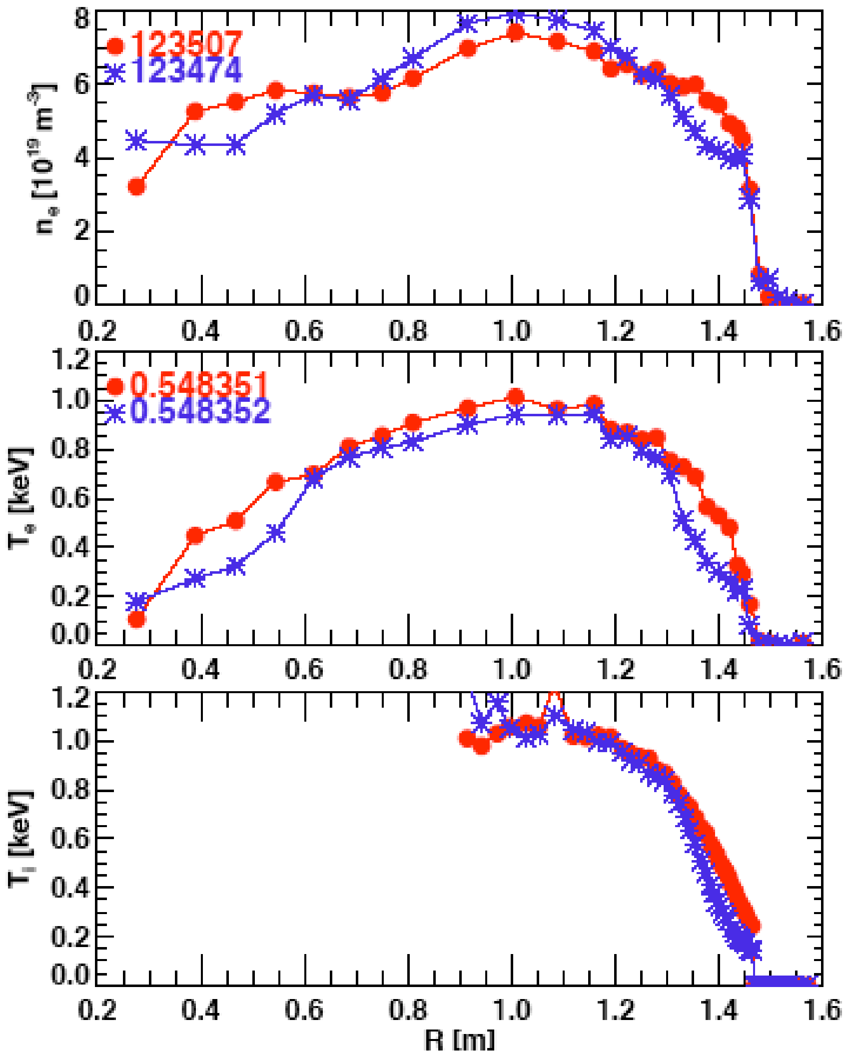


Type I ELMs almost eliminated



Kugel APS07 Inv.

Edge χ_e and core χ_i decrease after lithium deposition



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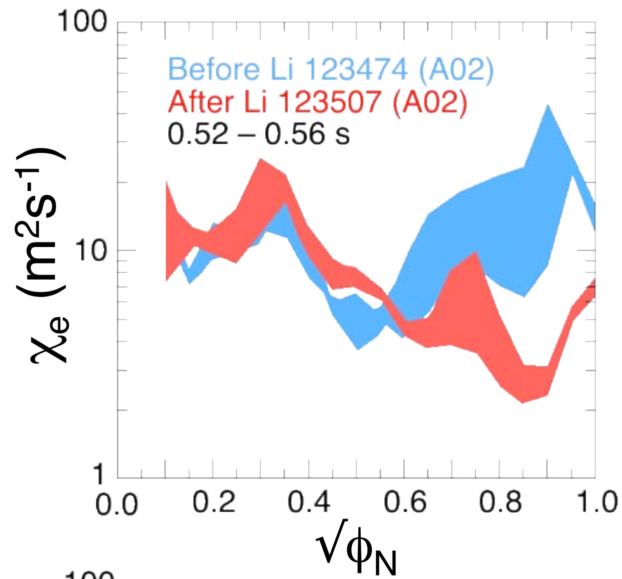
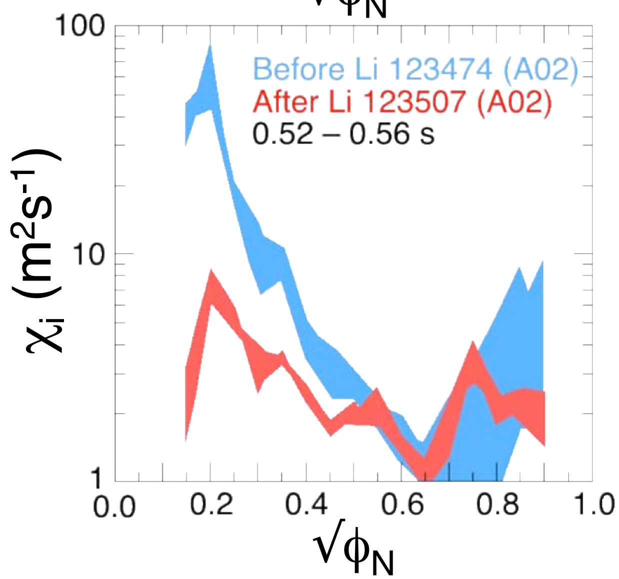


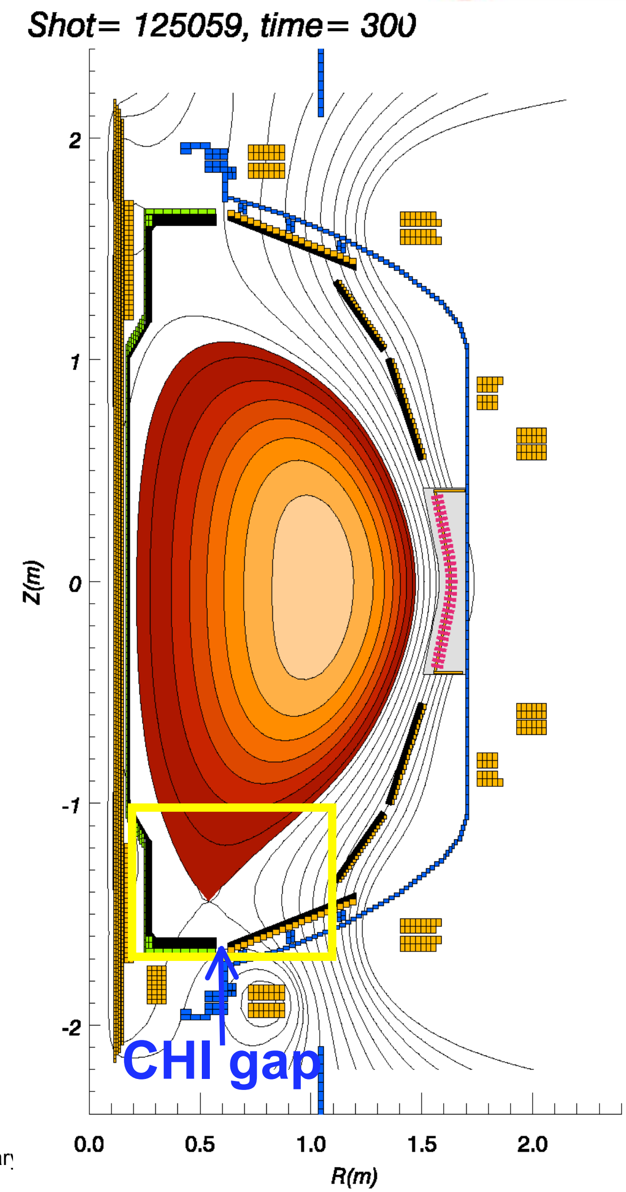


Kugel APS07 Inv.

Liquid lithium divertor design projections indicate density control in both low and high triangularity shapes

NSTX

- Goals
  - **Low δ : reduce n_e by 50-60%**
  - **High δ : reduce n_e by 25-30%**
- Features
  - About 15 cm wide
  - 5 cm outboard of CHI gap
  - Desired $T_{surface}$ ~ 200-400 °C
- Installation in summer 2008
- Upgrade in 2009

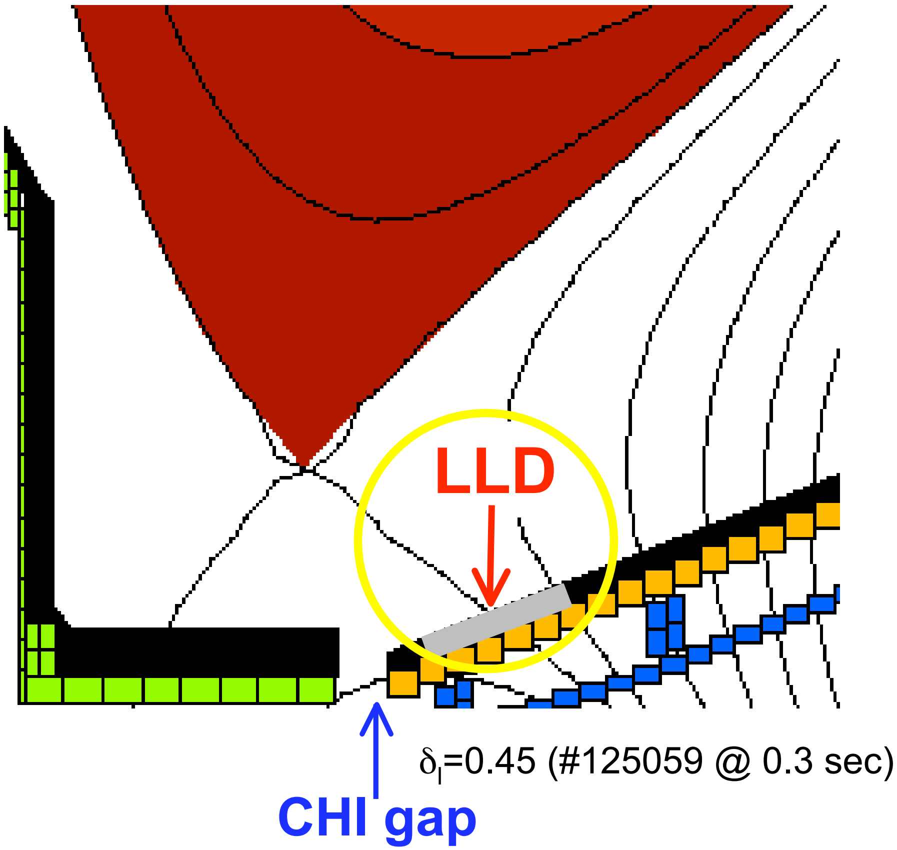


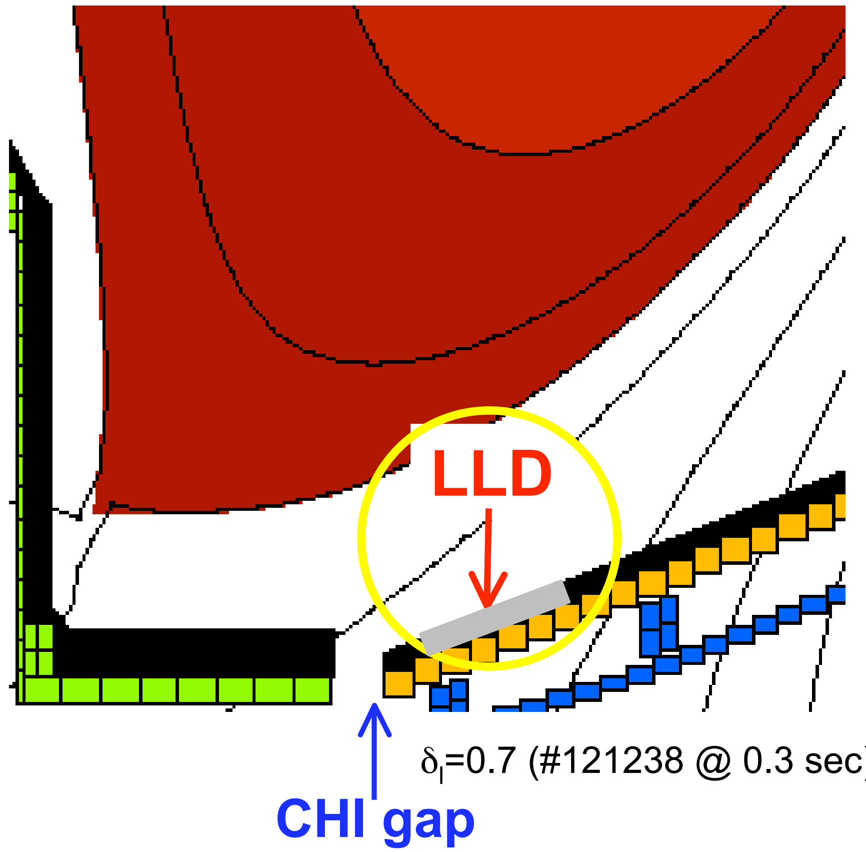
Density reduction will depend on proximity of outer strike point to LLD module

NSTX

Low δ : reduce n_e by 50-60%

High δ : reduce n_e by 25-30%





Lithium program plan

2008-2010

- Install and characterize double-LiTER operation, followed by plate-based Liquid Lithium divertor (LLD-I) module operation, and then possibly a mesh-based LLD upgrade (LLD-II)
- Perform hydrogen retention and pumping efficiency studies PAC21-19
- Optimize efficiency of gas injector fueling

New tools: LLD + diagnostics, Penning gauge near pumps, upgraded supersonic gas injector, programmable center stack gas injector

- *Limiting NSTX operation to 2008-2009 will prevent the LLD-II, which will likely be needed for optimization to obtain a complete answer on the use of lithium as a divertor PFC*

2011-2013

- Utilize core fueling (Pellets, Compact toroids) for long pulse

New tools: Long pulse divertor (LLD-III), new divertor diagnostics

Outline

- Lithium as a divertor plasma-facing component

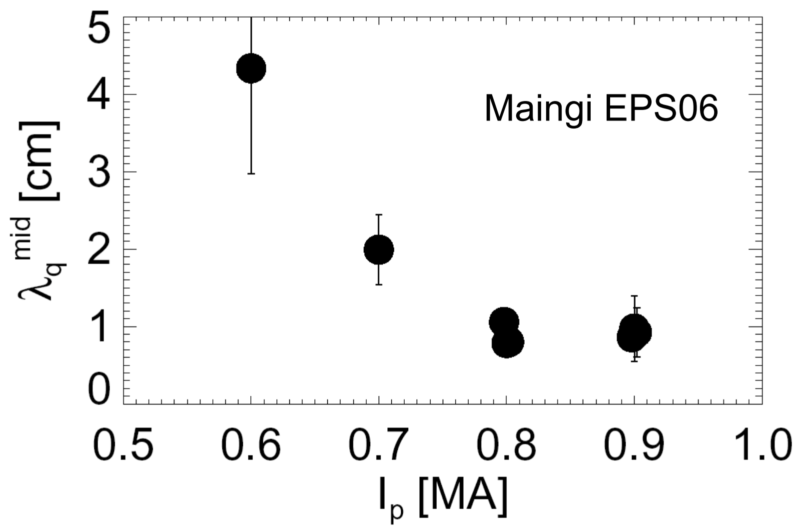
- **SOL and divertor physics for prediction of plasma-wall interaction footprint with theory-based cross-field transport**
  - **Edge transport and turbulence ⇔ SOL width**
    - **World-class SOL turbulence measurements and program**
  - **Divertor heat and particle flux optimization**

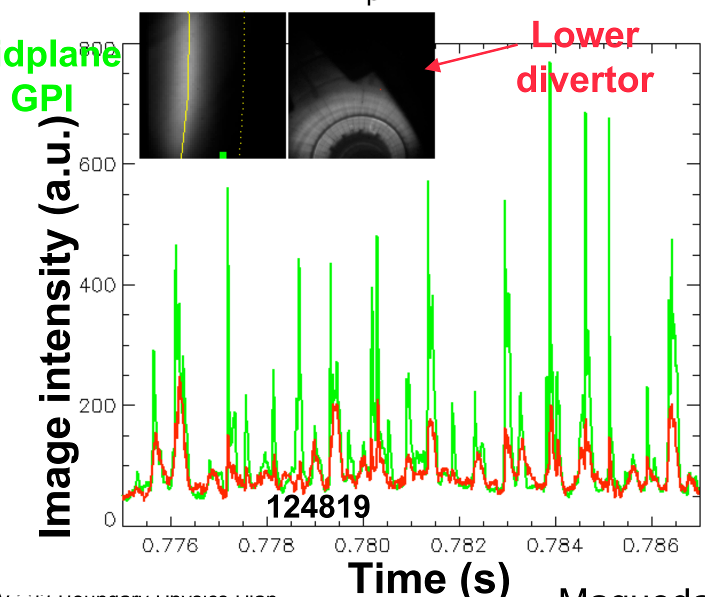
- Pedestal and ELM Physics

Edge T & T studies will focus on connection between measured turbulence characteristics and SOL widths

PAC21-18

- Motivated by the high divertor and first-wall heat loads in NHTX, ST-CTF, *and* ITER
  - Peak heat flux in NSTX ≥ 10 MW/m^2 (NHTX q_{peak} ~ 40 MW/m^2)
- Dependence of heat flux width (λ_q^{mid}) not well understood in tokamaks
  - λ_q^{mid} larger in NSTX than high aspect ratio tokamak analytic scalings
  - Strong I_P dependence of NSTX λ_q^{mid}, but magnitude at high I_p overlaps with tokamak database
- Turbulence modeling already connecting to analytic theory of blob formation
  - Recent capability to measure X-point turbulence for correlation w/midplane





Edge T & T Physics Plan

2008-2010

- Comparison of midplane and div. turbulence characteristics with models
- Scaling of midplane λ_n, λ_T, λ_Γ, λ_q with major parameters
  - Comparison with SOL width models
  - Comparison with turbulence characteristics
- Edge biasing with local electrodes and probes for SOL width control

New tools: fast IR camera

- *Limiting NSTX operation to 2008-2009 will mainly reduce the run time available to resolve the science issues*

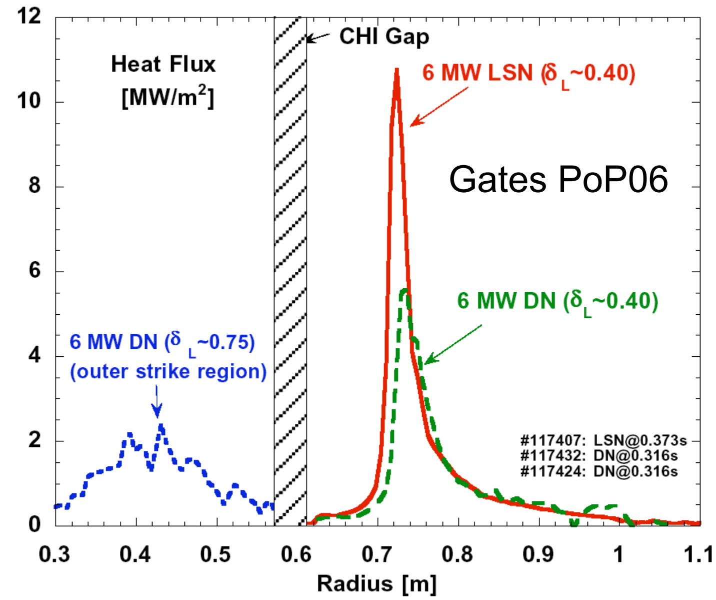
2011-2013

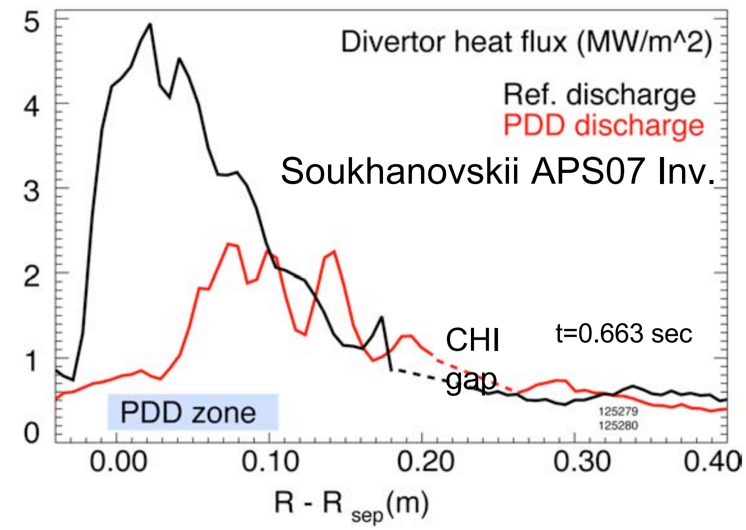
- Upgraded biasing capability, if warranted
- Divertor turbulence with X-point probe (+10% scenario)
- SOL turbulence and widths with higher input power (+10% scenario)

New tools: new divertor diagnostics, 2nd NBI, X-point probe width

Divertor physics and detachment physics program needed for NHTX and ST-CTF design

- ST effects: low $\ell_{||}$, small R, low in/out power split make outer detachment difficult
  - *Power management through flux expansion and detachment may be required for heat dissipation in high power ST's*
  - *ST effects above allow broader test of detachment physics in 2-D codes*
- Heat flux management through plasma shaping (upper left) and detachment with good confinement (lower left) shows promise in NSTX





Divertor and detachment Physics Plan

2008-2010

- Lower divertor power accountability and transient loading studies
- Improved detachment control for long pulse discharges
- Divertor performance dependence on geometry
- MARFE characterization studies

New tools: Fast IR camera(09), div. bolometer(08) + upgrade(09)

- *Limiting NSTX operation to 2008-2009 will require new tools to produce convincing results in first year of implementation (2009)*

2011-2013

- Private flux region physics studies
- Effect of high m,n RMP on heat flux spreading
- Detachment physics at higher P/R (2nd NBI)

New tools: X-point probe, divertor imaging spectrometer, divertor Thomson, 2nd NBI, Xpoint probe and Edge SXR (+10%)

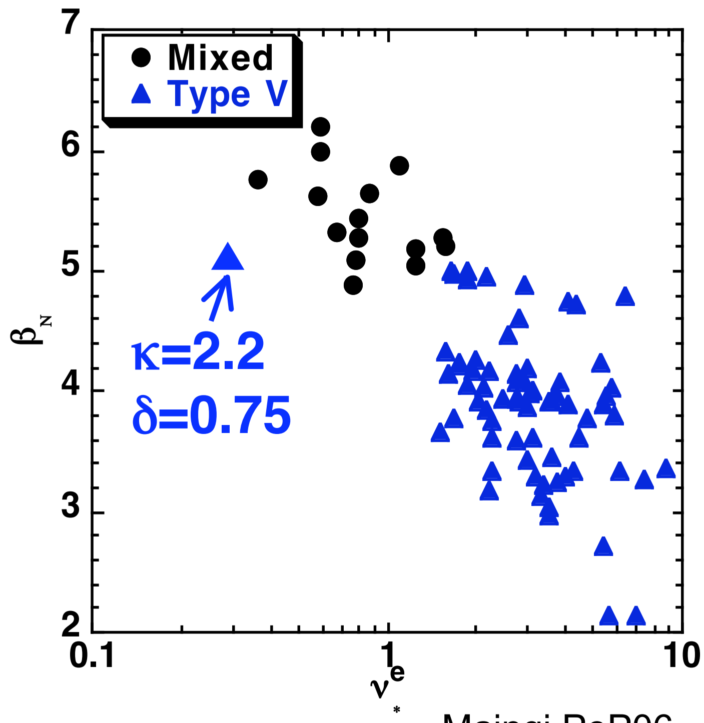
Outline

NSTX

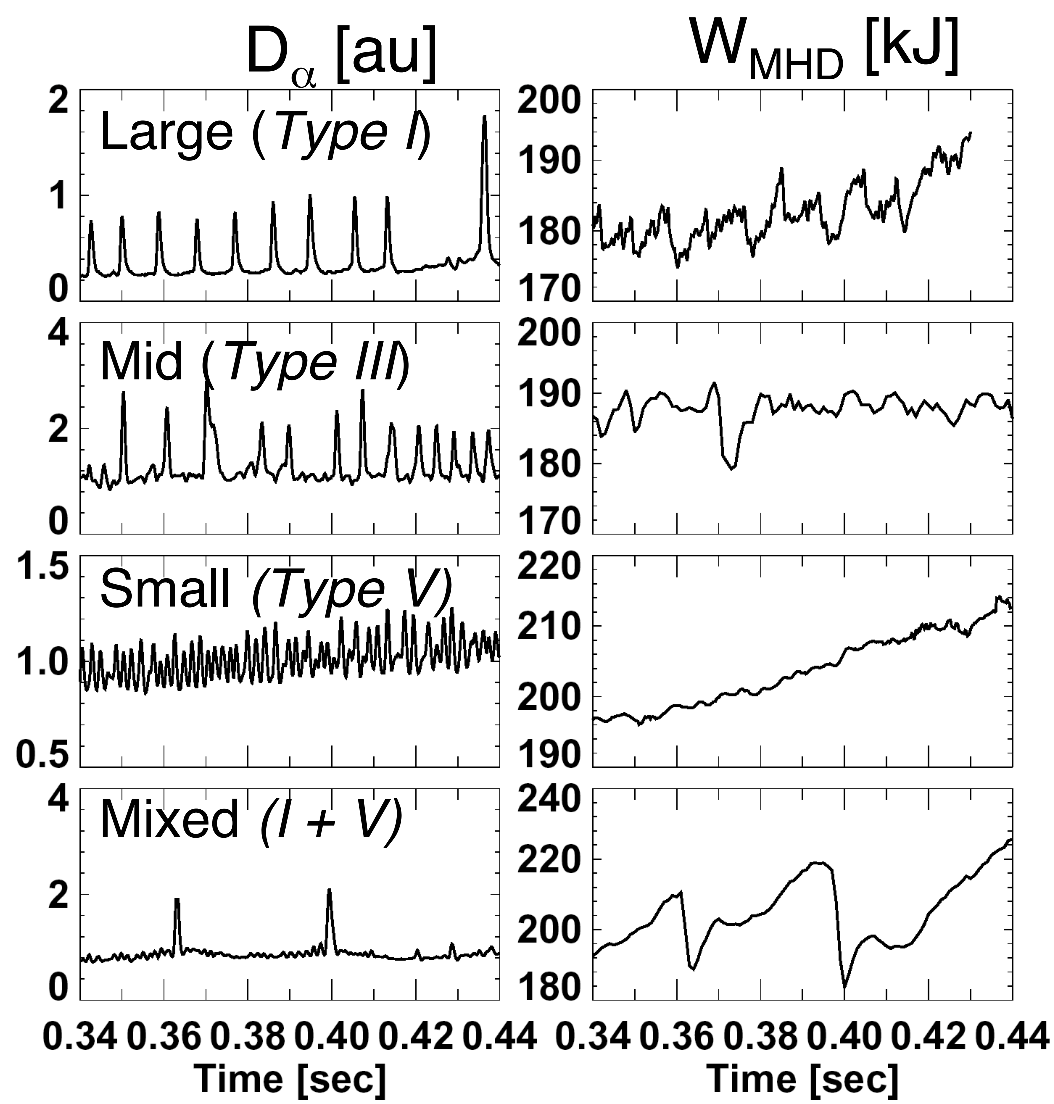
- Lithium as a divertor plasma-facing component
- SOL and divertor physics
- **Pedestal and ELM Physics toward pedestal width prediction and improved understanding of ELM suppression** PAC21-21
  - **Characterization and theory comparison at low R/a**
  - **Active control with resonant magnetic perturbations**

ELM and Pedestal studies motivated partly by occurrence of giant ELMS at low collisionality

- Many ELM types observed in NSTX, including promising small ELM regime
  - Do small ELMs in different devices have common physics?

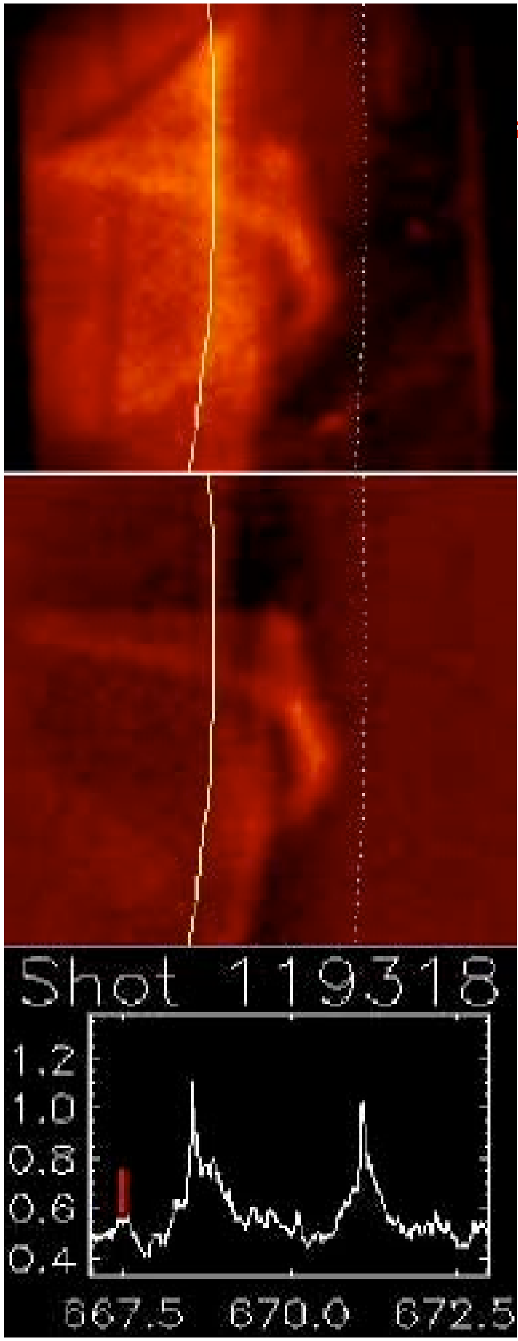


Maingi PoP06



NSTX

ITPA comparison studies with MAST and C-MOD have shown clear differences in small ELM structure



MAST

This movie shows up properly on a PC

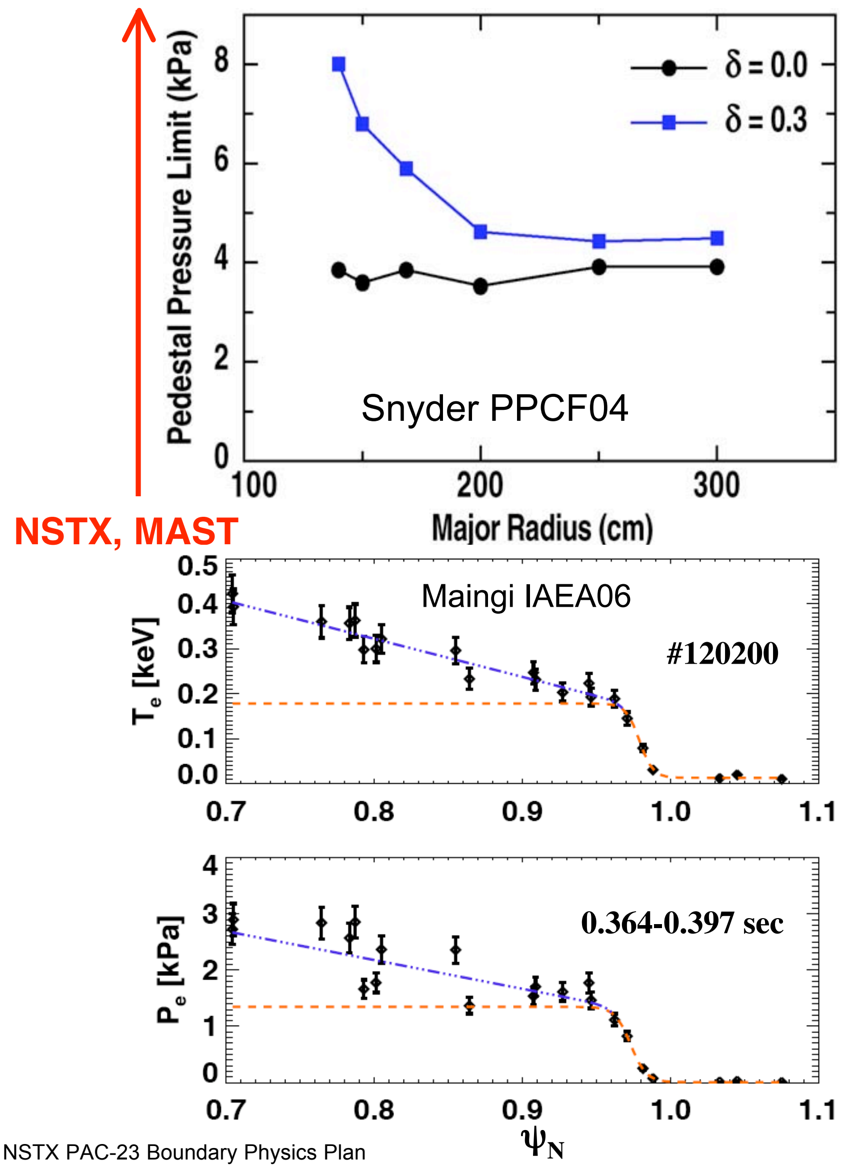
Maqueda

A. Kirk - UKAEA

Studies of R/a pedestal dependencies aim to determine the range of applicability of edge stability models

NSTX

- ELITE calculations suggest existence of high P_{ped} at low R/a and constant pedestal width
  - Requires low ν^* -> high T_{ped}
- NSTX data show $T_e^{ped} \leq 250$ eV, in agreement with certain models (e.g. Guzdar PoP 2005)
  - Unfavorable scaling for next step ST
- Pedestal dependence on R/a investigated in NSTX, DIII-D, and MAST through ITPA
  - No clear evidence of larger pressure gradients at low R/a
    - Predicted regime accessible?
    - Collisionality too high?



ELM and Pedestal Physics plan: 2008-2010

NSTX

2008-2010

- Assess edge stability of different ELM types and impact of aspect ratio on pedestal gradients and widths PAC21-23
- Compare small ELM regimes with other devices
- Identify shape dependencies and effect of lithium on ELM regimes
- Assess effects of RMP on edge stability
- Compare pedestal parameters with XGC-0

PAC21-24

New tools: LLD, five extra edge Thomson channels (+10%)

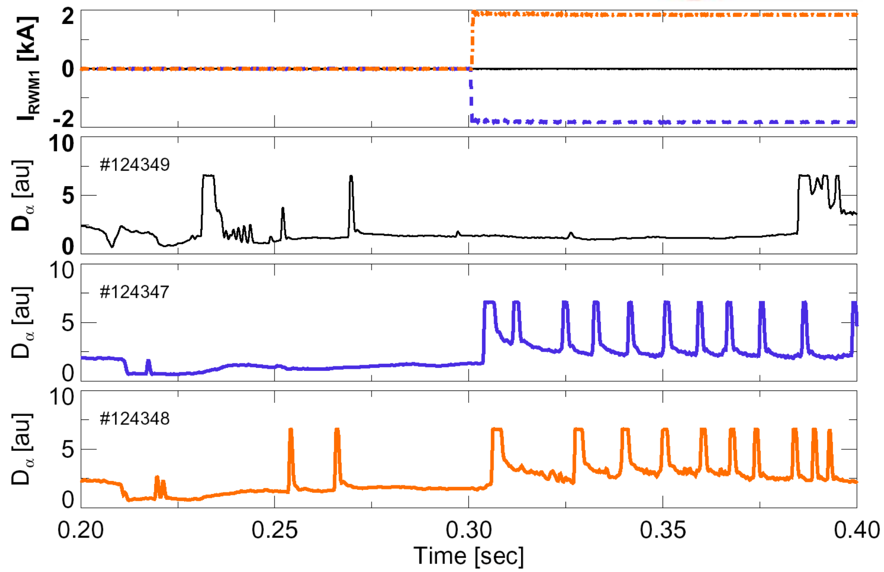
- *Limiting NSTX operation to 2008-2009 will prevent investigation with higher resolution TS, and will jeopardize the completion of multi-machine ITPA experiments*

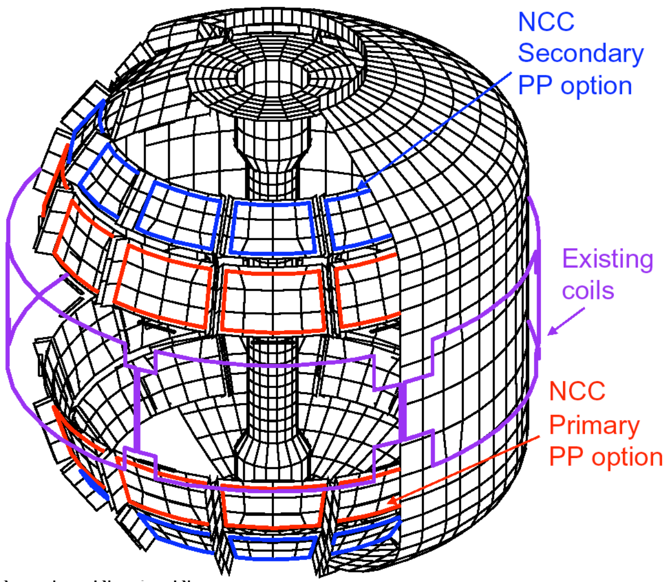
ELM and Pedestal Physics plan: 2011-2013

<u>2011-13</u>

- High m,n RMP impact on ELMs and heat flux
  - Upper panel: n=3 RMP shown to de-stabilize ELMS in certain discharges ($\kappa \leq 2$)
- Triggering of localized transport barriers with localized rotation control by RMP
- Develop quasi-steady small ELM scenarios with higher input power

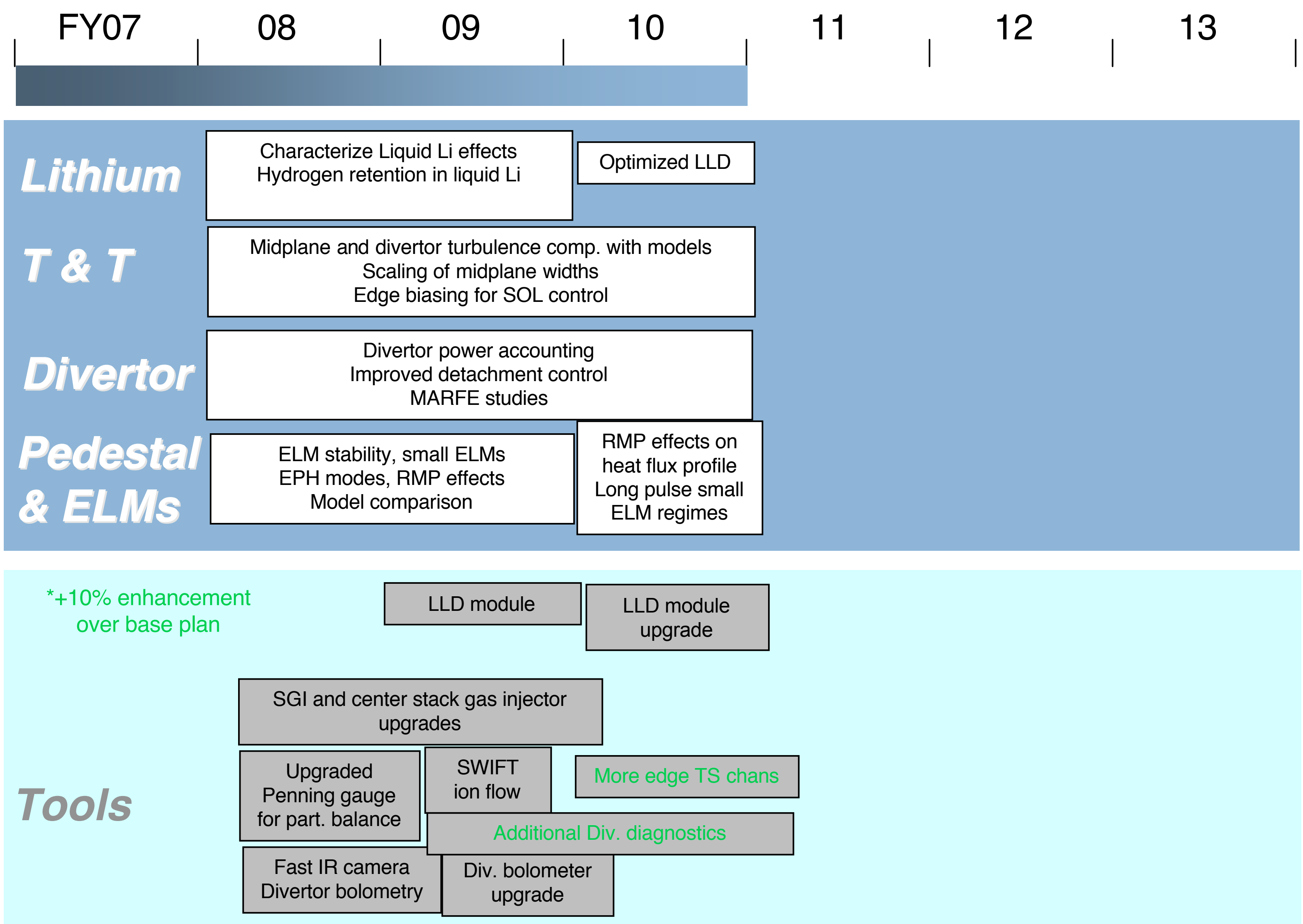
New tools: Internal Non-axisymmetric Control Coils (NCC), new divertor diagnostics, 2nd NBI (+10%)





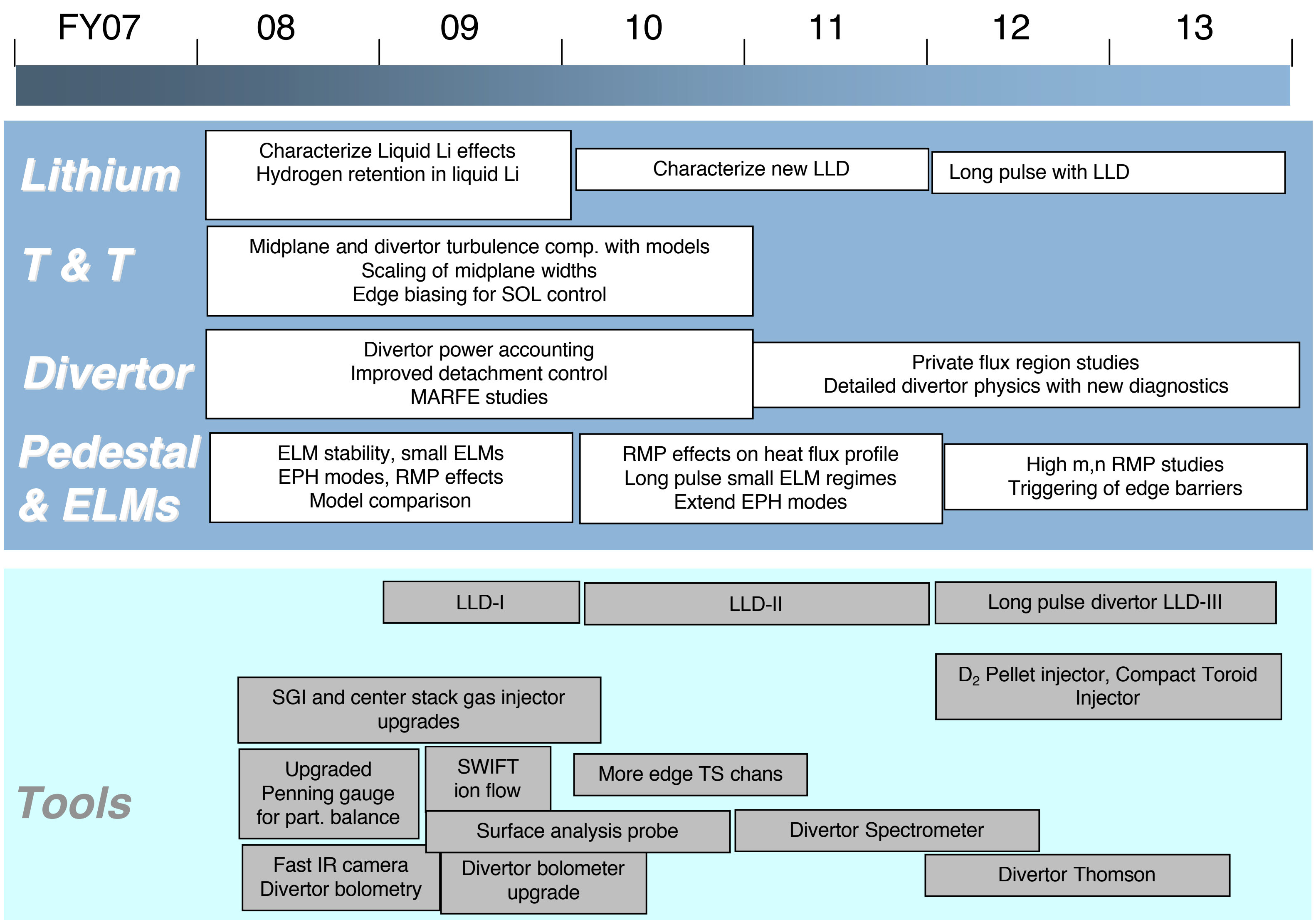
Boundary physics program time line FY08-FY10
Flat (+10%) funding profile

NSTX

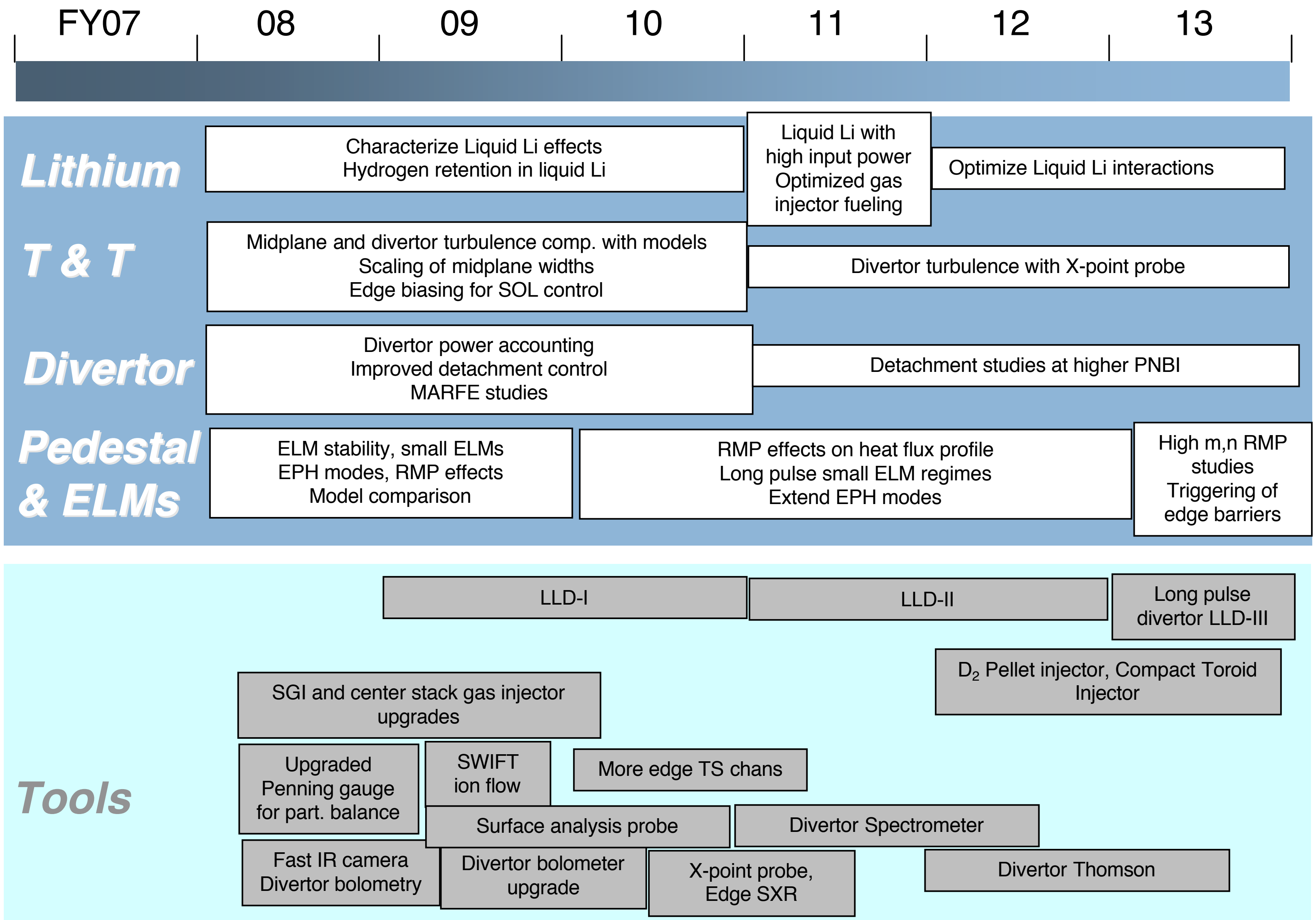


Boundary physics program time line FY08-FY13
Flat funding profile

NSTX



Boundary physics program time line FY08-FY13
+10% budget increment



* 2nd NBI comes earlier and 2nd LLD and new RMP coils delayed

NSTX boundary physics plan vital for next step ST design needs

- NSTX has an exciting plan which addresses several key areas needed for projection to next step STs
  - Lithium as a divertor plasma-facing component for integrated power and particle control solution
  - SOL and divertor physics
  - Pedestal and ELM Physics
- *Limiting NSTX operation to 2008-2009 will increase risk that the Lithium and pedestal physics program would provide only preliminary answers, making projection more difficult*
- *Running NSTX to 2013 will enable substantial progress in SOL and divertor physics, which require diagnostic enhancements in 2010-2011 time frame*

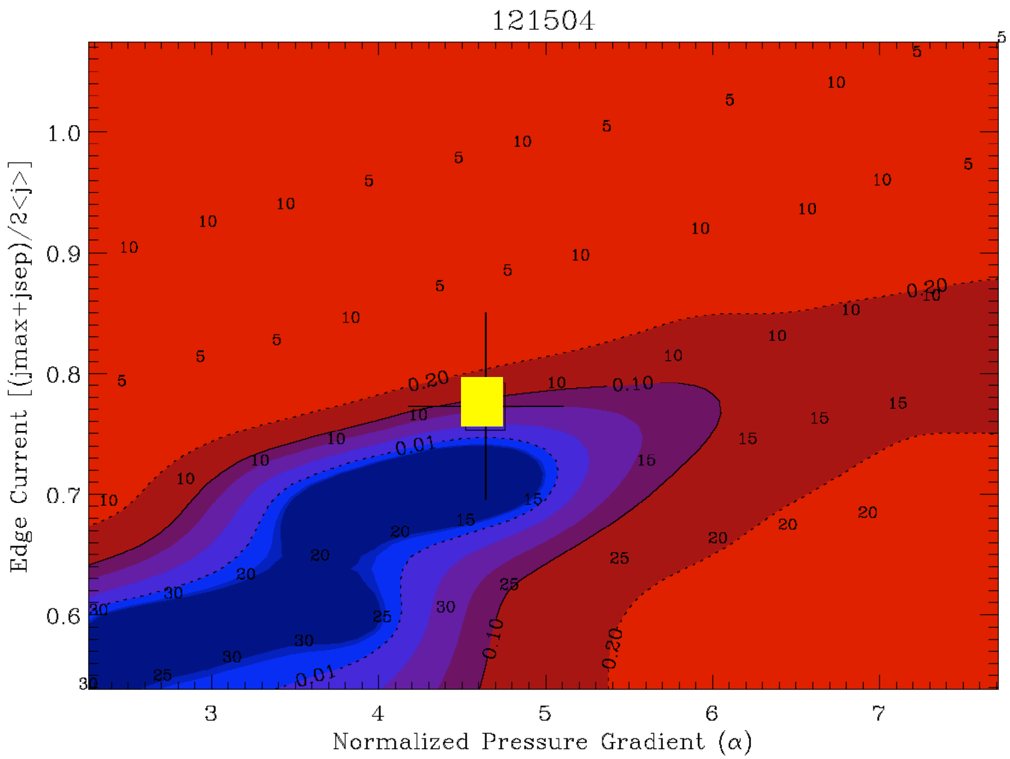
Backup

DIII-D and MAST pedestals both at peeling/ballooning boundary at matched pedestal top ρ^* and ν_e^*

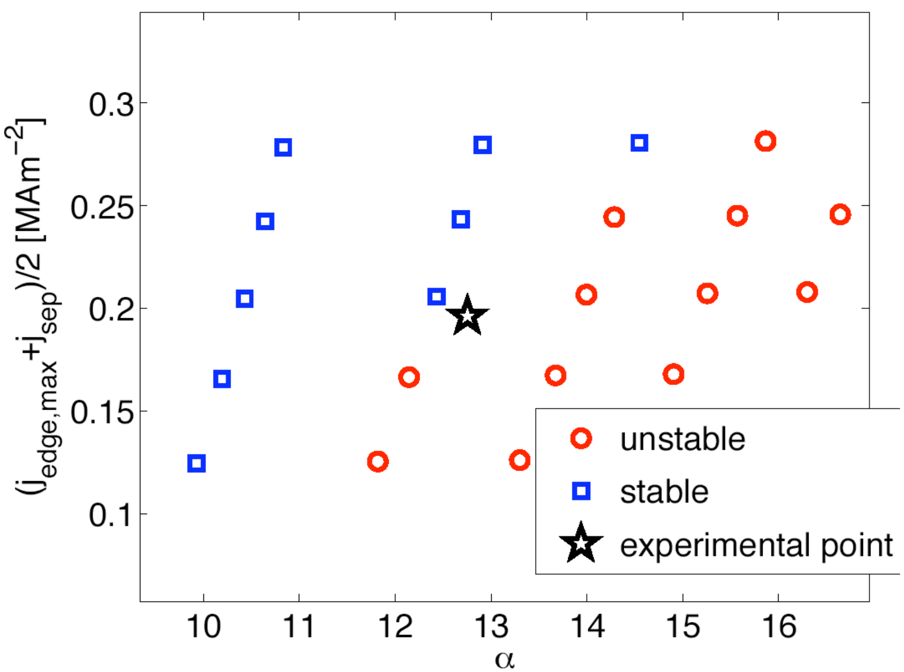
NSTX

- NSTX needs more data close to the ELM onset

DIII-D



MAST



T. Osborne, P. Snyder

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