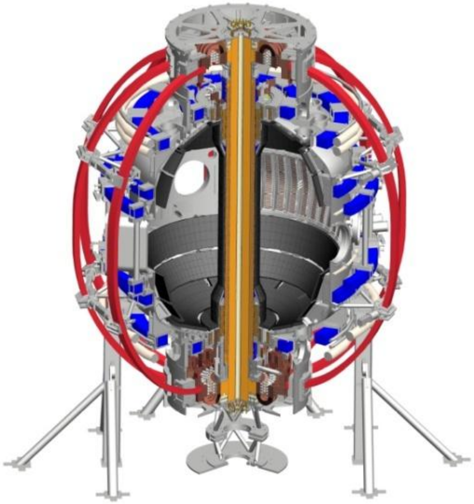
NSTX-U FY2012 3rd Quarter Review Presentation

R. Strykowski, M. Ono, J. Menard

PPPL – B233
August 7, 2012



Agenda

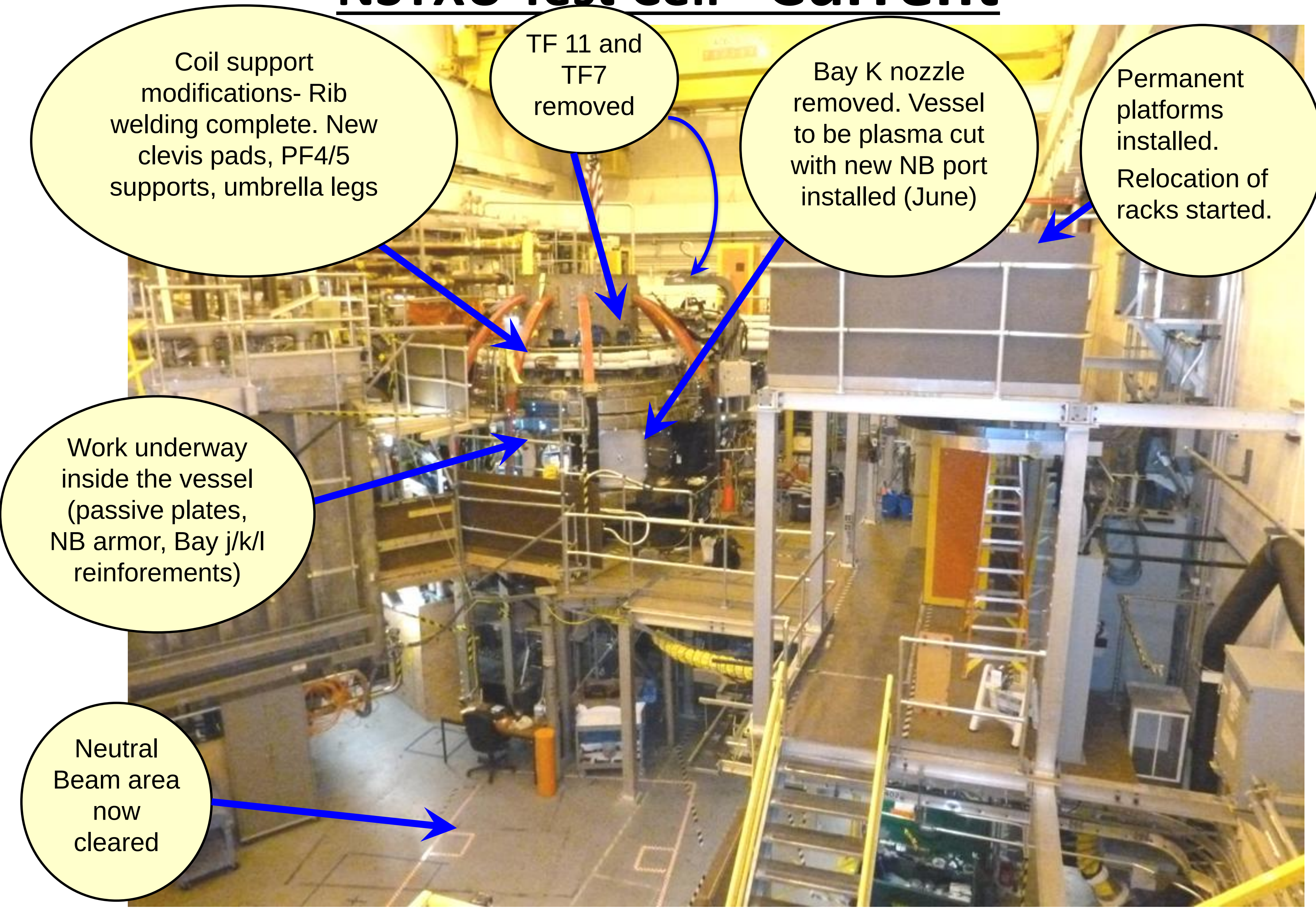
- NSTX Upgrade progress report – R. Strykowski
- NSTX-U operational highlights – M. Ono
- 5 year plan progress, collaborations – J. Menard

Recent accomplishments

Good progress across all fronts

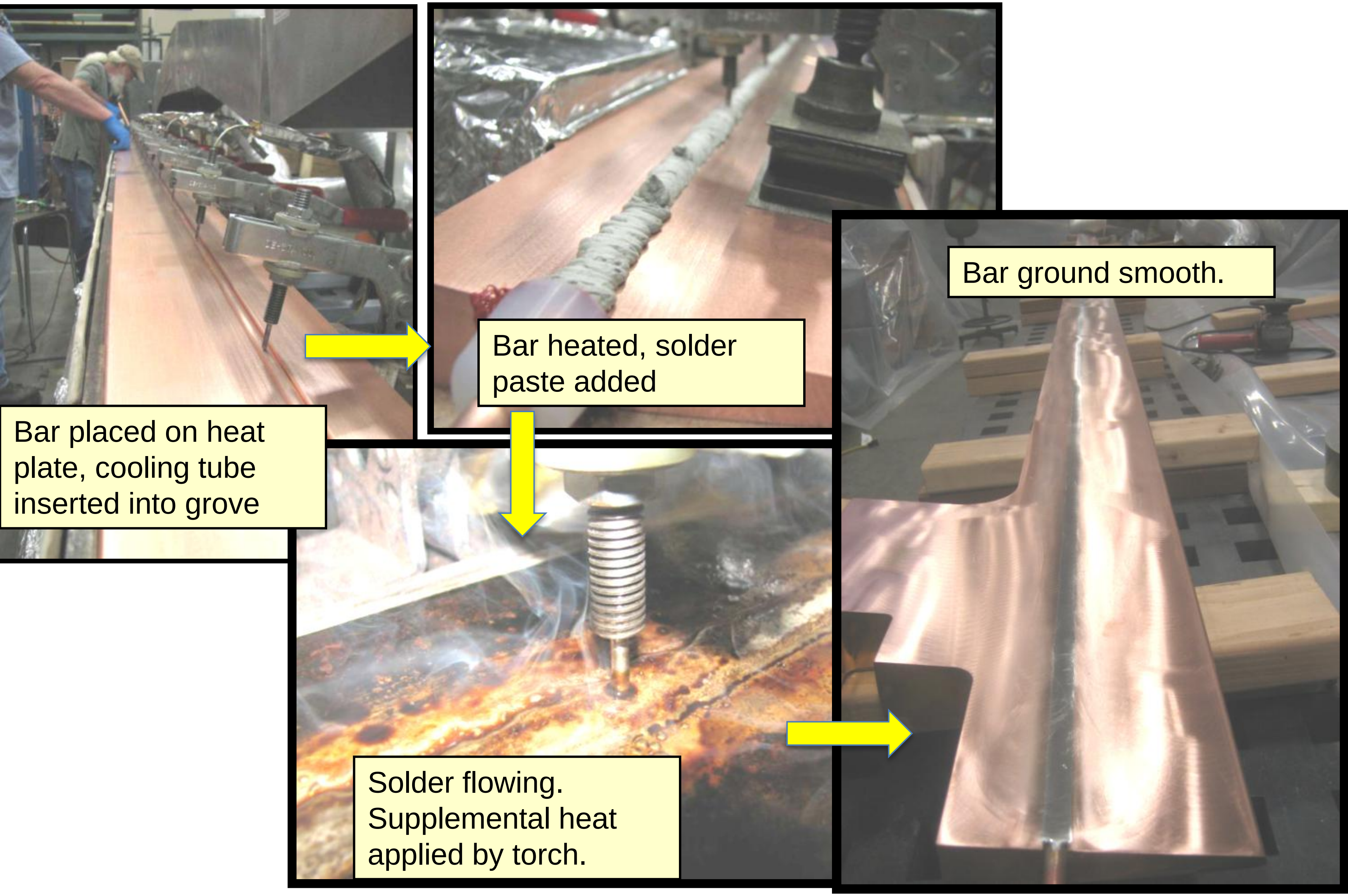
- Umbrella legs replacement underway (3 legs cut off).
- TFTR TC Lintel removed (for NB relocation).
- Neutral beam box test lift.
- NB services line installation underway .
- Outer clevis pad welding ~33% complete.
- CHI gap resolution. New tiles to be designed and installed.
- Inner TF bundle fabrication; 13 bars received, 11 soldered, 10 sandblasted/primed, 4 wrapped.
- Coil support fabrication and installation continues.
- Inner TF conductor deliveries on track

NSTXU Test Cell - Current



Center Stack - *Inner TF soldering development successful!*

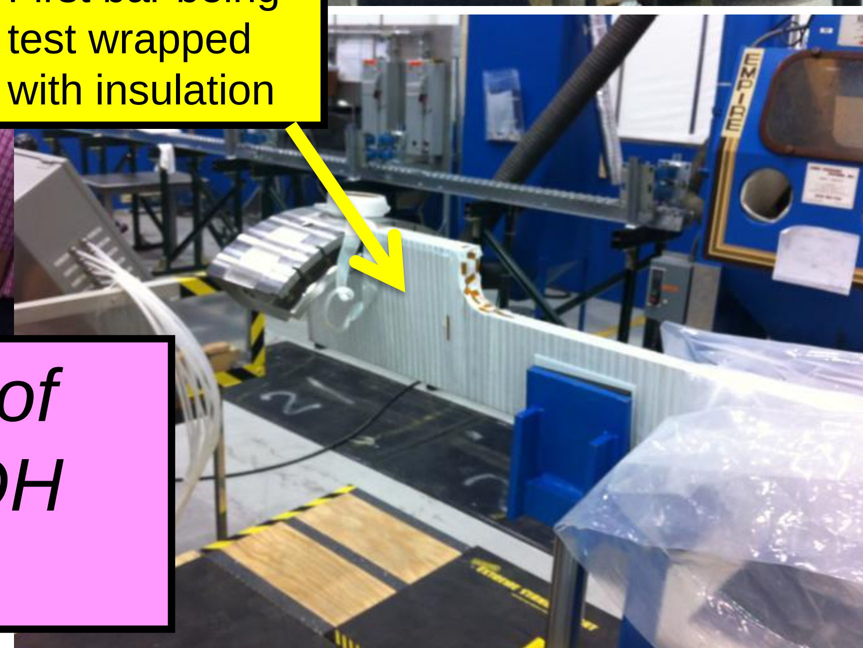
issues; solder flux, heating process, quality of final product (ie voids, trapped gases)



Center Stack - *Fabrication underway*

Conductor bar being removed from oven after post solder bake out

First bar being test wrapped with insulation



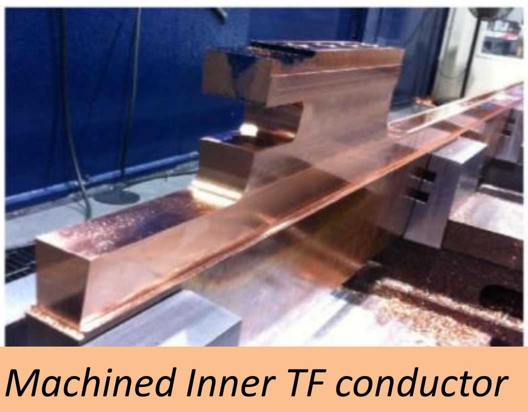
Entering the riskiest stage of the project. Inner TF and OH fabrication and VPI.

Parts and components being fabricated and delivered by industry

Center stack casing

Neutral Beam port

Umbrella structure legs



Machined Inner TF conductor

Inner TF quadrant mold

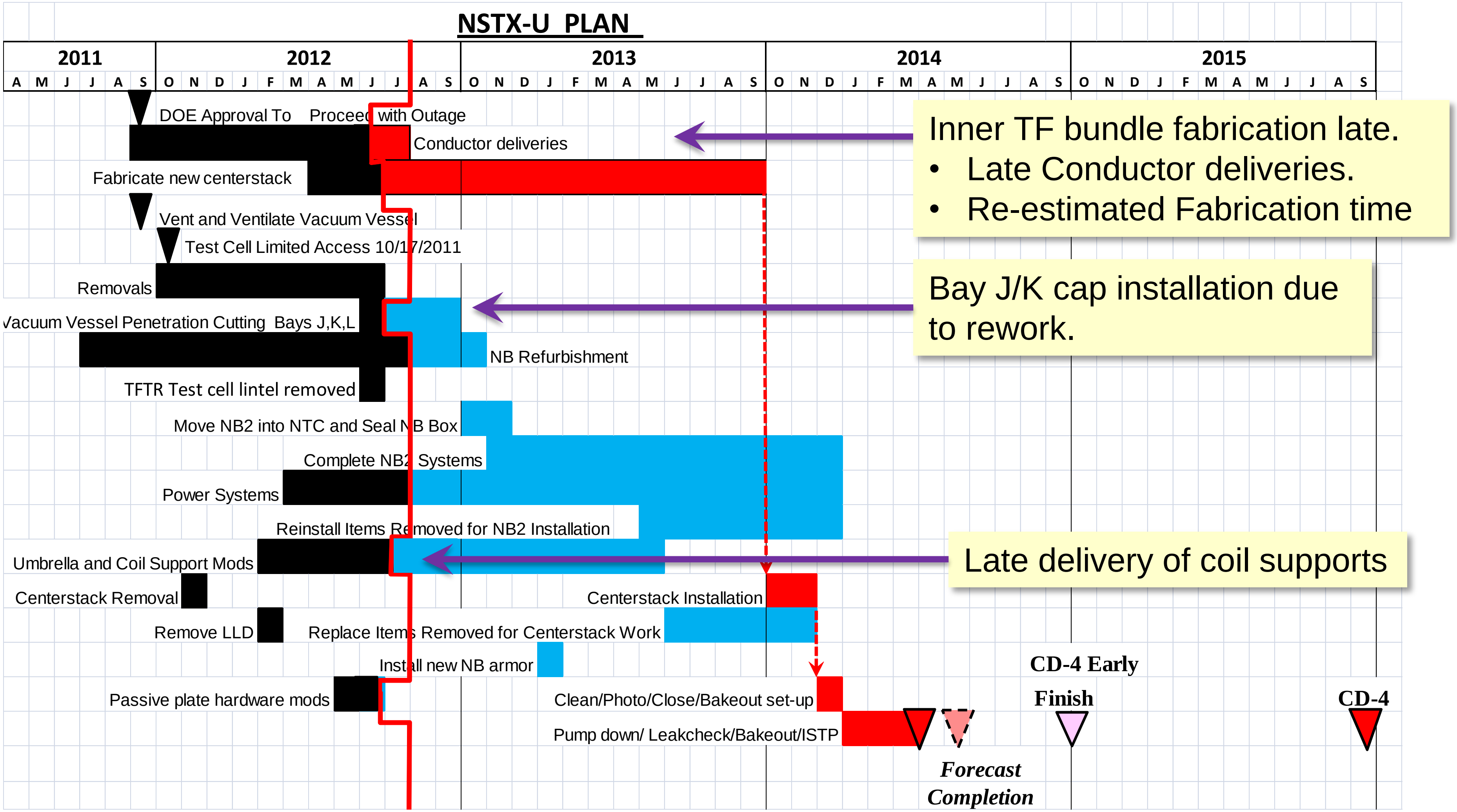
Outer TF prototype supports

Near term schedule

6/25 - 9/28	TF clevis welding
7/19 - 11/2	Umbrella legs and PF2/3 clamps
7/2 - 8/17	TF flag holes
7/23- 8/8	Repair JK cap welds
w/o 8/8	Set-up for vessel cutting at L
8/8	Leak check JK cap
w/o 8/6	Trial fit JK cap to vacuum vessel
w/o 8/13	Vessel cutting at JK
w/o 8/13	Weld JK cap onto vessel
8/8	VPI mockup trials
w/o 8/6	Penetration hole cutting (NSTX test cell into TFTR)
w/o 8/6	Modify TF quadrant mold
w/o 8/13	Begin assembling TF quadrant

<u>September</u>	VPI first TF quadrant, Relocate NB box, 36 inner TF conductors received
<u>October</u>	CS Casing delivered, all Inner TF conductor cooling tubes soldered
<u>November</u>	Install Bay MPTS port, VPI 2^{nd} TF quadrant

On track for early completion

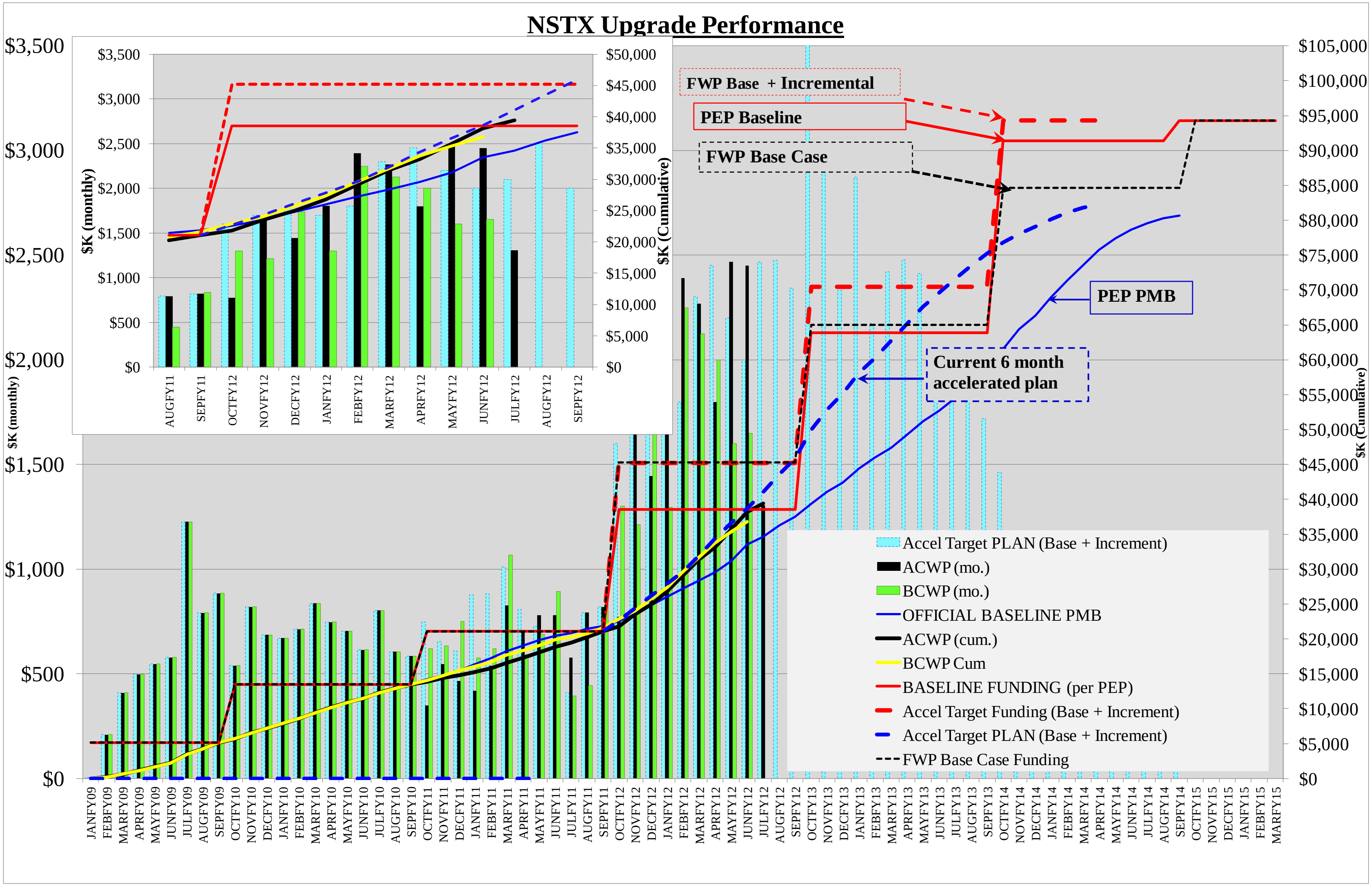


Performance metrics good

- **Cost**
  - CPI = 0.97   CV = - $1,023K
- **Schedule**
  - SPI = 1.11 *(against baseline plan)*   Total float = 6 months PLUS 12 months schedule contingency to CD-4
- **Completion**
  - Target = April 2014
  - Forecast = June 2014
  - CD-2 Baseline Early Finish = September 2014
  - CD-4 DOE Milestone (PEP) = September 2015
- BAC =$79.9 EAC= $82.8 TPC =94.3M
- Cost to date = $38.1 M 46% complete
- Risk: $2,000k retired since CD-2 Currently $4, 657 remain
- Free balance contingency 31% - 26% *($13.0M)* *(27% at CD-2)*

Cost

FY 2012
Budget= $23.25M
EAC=$22.25



Near Term Risks

COST

1. Startup/learning curve for CS winding operations
   - Mitigation plan;
     - manage staff for maximum efficiencies
     - bottoms ETC and process ECP for additional budget
2. Out year funding uncertainties. Reduced funding would increase EAC
3. Scope creep -Diligence in managing "must, needs, and wants"

TECHNICAL

1. Inner TF VPI operations (August) epoxy handling issue and TF quadrant hi-pot test.
   - Mitigation plan ;
     - Perform epoxy trials and mockup fill

SCHEDULE

1. Inner TF conductor delivery delays.
   - Mitigation plan ;
     - Continued vigilance in meeting with vendor and emphasizing criticality

Summary

- **The project continues to make good progress but as we enter the more challenging parts of the project additional cost pressures may surface.**
- **Currently, on track for early completion by mid-late FY 2014 with incremental funding.**

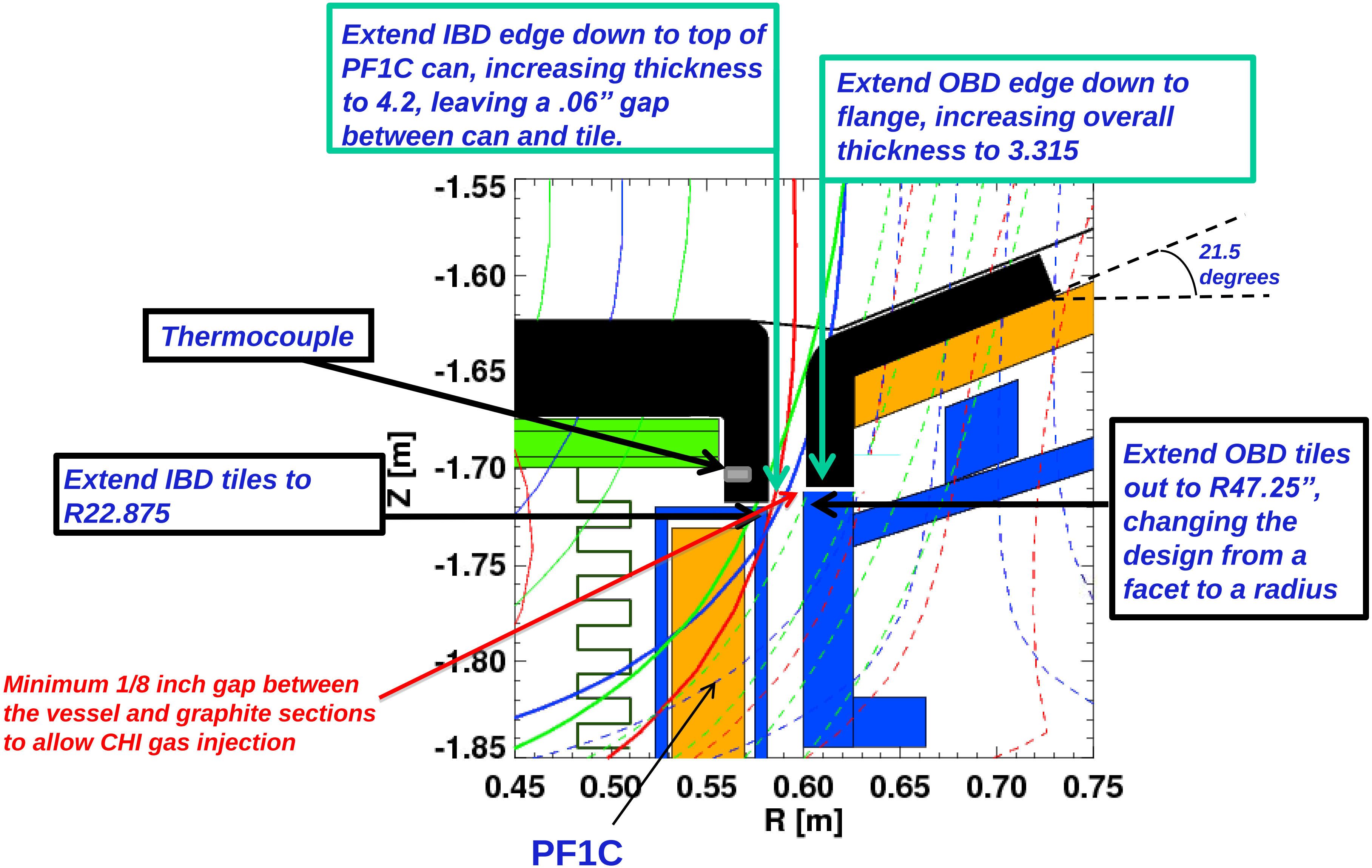
Agenda

- Status of NSTX Upgrade Project – R. Strykowski
- NSTX-U operational highlights – M. Ono
- 5 year plan progress, collaborations – J. Menard

NSTX-U Operational Highlights

- Significant research contributions are being made in diverse science areas by the NSTX research team. Summary will be presented today (see next talk), and also available on the web: http://nstx.pppl.gov/DragNDrop/Collaboration/NSTX_collaboration_highlights
- NSTX "Snowflake Divertor" team won 2012 R&D 100 Award!
- NSTX well represented at PSI, High Temperature Plasma Diagnostic, and EPS meetings.
- Expect strong presence at the fall APS and IAEA meetings.
- NSTX-U Engineering and Research Operations:
  - Rectifier firing generator production run started
  - Good CHI gap and PF1C protection design developed
  - New 32-core control computer delivered for Plasma Control System
  - NSTX-U physics operation planning started

Lower CHI Gap Protection Included in the Upgrade Scope
Need for protecting PF 1C and much greater heatload



Proposed Goals are to operate at full forces (I_PI_P, I_PB_T, B_TB_T) in 2 Years, full coil heating in 3rd year

	NSTX	Year 1 NSTX-U	Year 2 NSTX-U	Year 3 NSTX-U	Ultimate Goal
I_P [MA]	1.4	1.6	2.0	2.0	2.0
I_PI_P [MA^2]	2.0	2.5	4.0	4.0	4.0
B_T [T]	0.55	0.8	1.0	1.0	1.0
B_TB_T [T^2]	0.3	0.65	1.0	1.0	1.0
I_PB_T [MA*T]	0.61	1.3	2	2.0	2
Allowed I^2t Fraction On Any Coil	1.0	0.5	0.75	1.0	1.0
I_P Flat-Top at max. allowed I^2t, I_P, and B_T [s]	~0.7	~3.5	~3.	5	5

- Table based on assessment of physics needs for first year of operations.
- 1st year goal: operating points with forces 1/2 the way between NSTX and NSTX-U, ½ the design-point heating of any coil:
  - OH F_Z apparently requires full influence matrices for essentially ANY operations.
- 2nd year goal: Full field and current, but still limiting the coil heating.
  - Of course, will revisit year 2 parameters once year 1 data has been accumulated.
- 3rd year goal: Full capability

Making Steady Progress on FY12 Milestones
Through Data Analyses, Theory/Modeling, and Collaborations

FY 2012 Facility Joint Research Milestone (S. Kaye – NSTX-U Leader)

Understand core transport and enhance predictive capability: The 3 Q report written and submitted to FES.

FY 2012 NSTX Milestones

Research*	**Milestone Description**	**Baseline**	**Forecast**
R(12-1)	Investigate magnetic braking physics to develop toroidal rotation control at low collisionality	Sep 12	Sep 12
R(12-2)	Project deuterium pumping capabilities for NSTX-U using lithium coatings and cryo-pumping	Sep 12	Sep 12
R(12-3)	Simulate confinement, heating, and ramp-up of CHI start-up plasmas	Sep 12	Sep 12

Facility**	**Milestone Description**	**Baseline**	**Forecast**
F(12-1)	Identify possible high priority facility enhancements for the post upgrade operations	Sep 12	Sep 12

Diagnostics**	**Milestone Description**	**Baseline**	**Forecast**
D(12-1)	Identify possible high priority diagnostic enhancements for the post upgrade operations	Sep 12	Sep 12

****An important part of the next Five Year NSTX Facility Plan**

- **Diagnostic collaboration grant process was completed in Feb. 2012.**
- **Brainstorming meetings were held for both facility and diagnostic enhancements.**

Lithium Safety Assessment for NSTX-U

Liquid lithium contact with water must be prevented

Based on the discussions, it appears that because of design and engineering features and inventory limits, lithium work in LTX, NSTX and T260 does not have the potential for an explosive event similar to the one that took place at Sandia.

However, the following potential issues were raised for future lithium activities on NSTX-U:

1. **Need to consider the potential for and consequences of a major magnet arc to the NSTX vacuum vessel that could breach the vacuum boundary and possibly put in-vessel lithium in contact with water leaking/spraying from a failed coil.**
2. **Need to consider the potential for and consequences of a water leak inside an NSTX neutral beam box that might come in contact with lithium.**

Items 1 & 2 need to be addressed in the forthcoming Safety Assessment Document (SAD) for the NSTX-U and will be reviewed by the NSTX Activity Certification Committee (ACC).

- **Near term – LITER, dropper, slapper are likely to be ok due to the relatively modest inventory level.**
- **Longer term – Possible flowing liquid lithium system with significant volume will require careful safety assessment.**

NSTX-U Program Budget (June 30, 2012)

	Budget* (K$s)	Year to Date Cost (K$s)	% Costed
NSTX Science	$10,335	$7,525	72.8%
NSTX Facility Operations	$12,197	$8,843	72.5%
NSTX-Upgrade	$23,461	$17,036	72.6%
NSTX Total	**$45,993**	**$33,404**	**72.6%**

***- Budget reflects June 2012 Close plus $1,515 K additional NSTX-U Funds included in July Fin Plan and includes FY2011 carryover of $884K.**

- **No Issues to Report**

FY2012 Estimate at Completion within 3% of FY2012 Budget at FY2012 baseline rates

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Progress on 5 year plan (2014-18) preparation

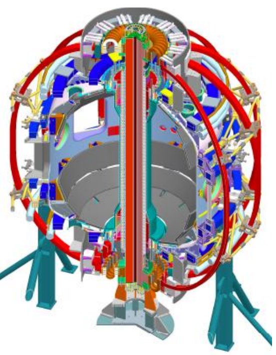
- April/May: Presented initial ideas to PAC-31, got feedback
- June-August 2012 – formulate/finalize plan elements and outline, identify/finalize authors, begin writing chapters
  - 2 weeks ago held internal topical science group review of research thrusts, proposed capabilities and timelines, chapter outlines
  - Draft outline will be shared with entire team for comment next week
  - Finalizing long-term goals, assessing budgets and achievable scope
    - Guidance: For FY2014 and beyond escalate FY2012 by 2.5% each year
    - Ok to include an over target case that is 10% higher than the baseline
- October 2012 – First drafts of plan chapters due
- Nov-Dec 2012 – Internal review/revision/editing of plan
- Jan/Feb 2013 – 5 yr plan presentation ‘dry-run’ to PAC-33
- Written report due April 1, 2013
- Plan presented to review committee and FES early May 2013

Developed comprehensive long-range plan for NSTX-U supporting ITER and FNSF – next step is to down-select based on priorities and budgets

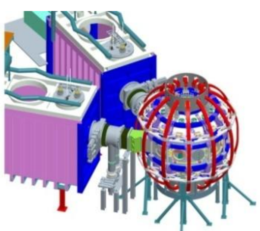
2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

Upgrade Outage | **1.5 → 2 MA, 1s → 5s** | **Advanced PFCs, 5s → 10-20s**

New center-stack



2nd NBI



Start-up and ramp-up
- 0.3-0.5 MA CHI
- 0.5-1 MA CHI
- 0.2-0.4 MA plasma gun
- up to 1 MA plasma gun
- ECH/EBW 1MW → 2 MW
- Extend NBI duration or implement 2-4 MW off-axis EBW H&CD

Boundary physics
- Divertor cryo-pump
- Divertor Thomson
- Diagnostics for high-Z wall studies

Materials and PFCs
- U or L Mo divertor
- U + L Mo divertor
- All High-Z PFCs
- Hot High-Z FW PFCs

Lithium
- Li granule injector
- Upward LiTER
- Flowing Li divertor or limiter module
- Full toroidal flowing Li divertor

MHD
- MGI disruption mitigation tests
- Enhanced RFA/RWM sensors
- NCC coils
- NCC SPA upgrade

Transport & turbulence
- High k_θ
- δB polarimetry
- DBS, PCI or other intermediate-k

Wave-particle interactions
- HHFW feedthru & limiter upgrade
- HHFW straps for EHO, *AE
- Dedicated EHO or *AE antenna

Scenarios and control
- Rotation control
- Snowflake control
- Divertor radiation control
- q_{min} control
- Control integration

U.S. FNSF conceptual design including aspect ratio and divertor optimization

NSTX researchers pursuing targeted collaboration program on fusion facilities in support of NSTX-U, ITER, FNSF

- Transport and Turbulence
- Macroscopic Stability
- Energetic Particles
- Solenoid-Free Plasma Start-up
- Wave Heating and Current Drive
- Advanced Scenarios and Control
- Boundary Physics and Lithium Research

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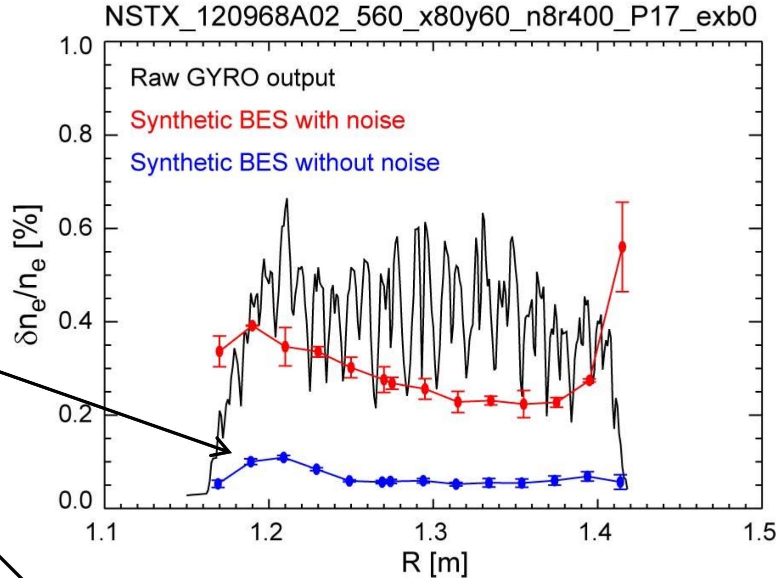
MAST-NSTX collaboration testing sensitivity of BES to microtearing turbulence through synthetic diagnostics

- Using nonlinear NSTX microtearing simulations from GYRO with synthetic diagnostic for MAST BES
  - Difficult to detect MT with expected signal-to-noise ratio (uncorrelated noise dominates)
  - If S/N can be increased (e.g. significant time averaging) MT features may be measurable, such as:

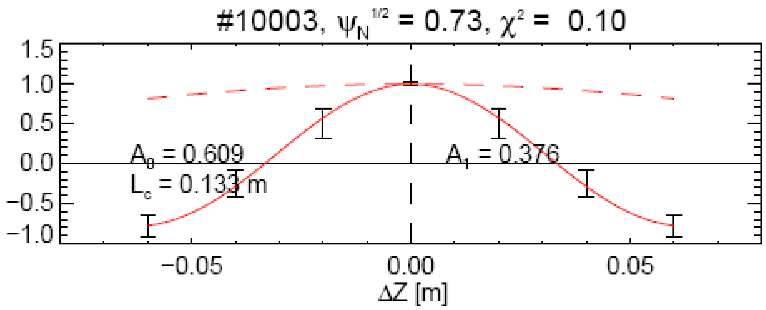
    detectable correlated fluctuation levels ($\delta n/n \sim 0.1\%$)

    large poloidal correlation lengths ($L_p \sim 15\text{-}20$ cm)

Density fluctuation (rms)



Poloidal correlation from synthetic diagnostic (without noise)



<u>Future plans:</u>

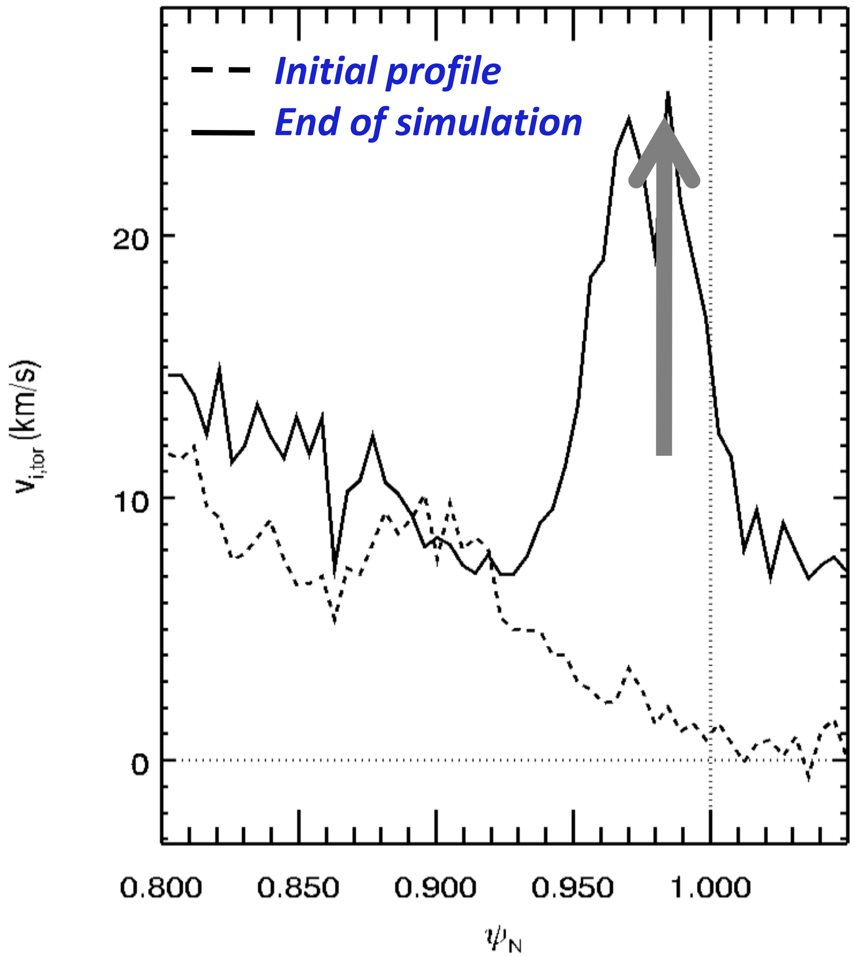
- Pursue non-linear simulations for MAST discharges with available BES data
- Propose experiments for FY13 at next MAST research forum (Dec 2012) to focus on relationship between collisionality scaling and microtearing turbulence

W. Guttenfelder, et al. PPPL

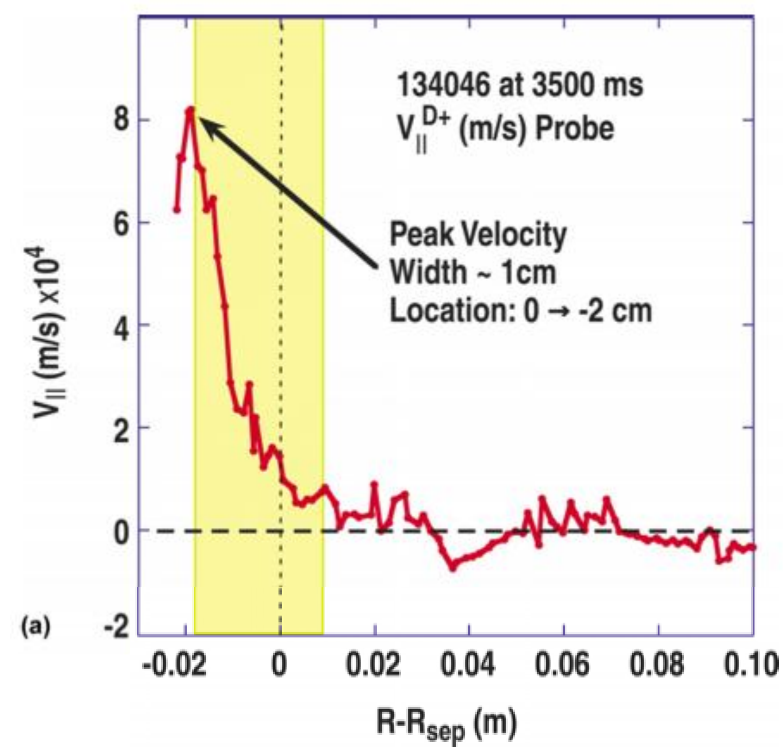
Kinetic neoclassical effects in DIII-D H-mode pedestal using XGC0

To help answer important questions on edge rotation, main-ion physics and SOL flows.

Preliminary results using XGC0 simulation of edge main-ion velocity driven by X-loss

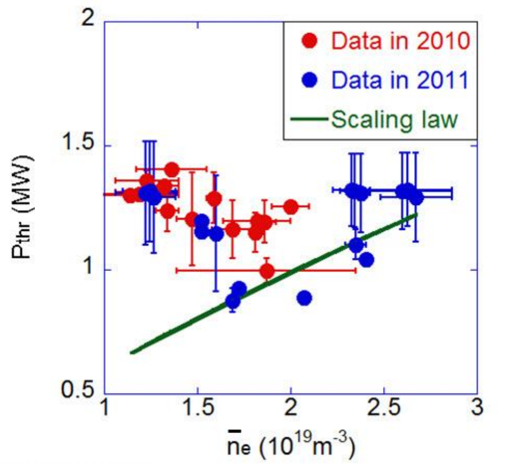


Deuterium edge velocity measured by Mach Probe
J.A. Boedo et al., PoP 18 032510 (2011)



D. Battaglia et al., (PPPL)

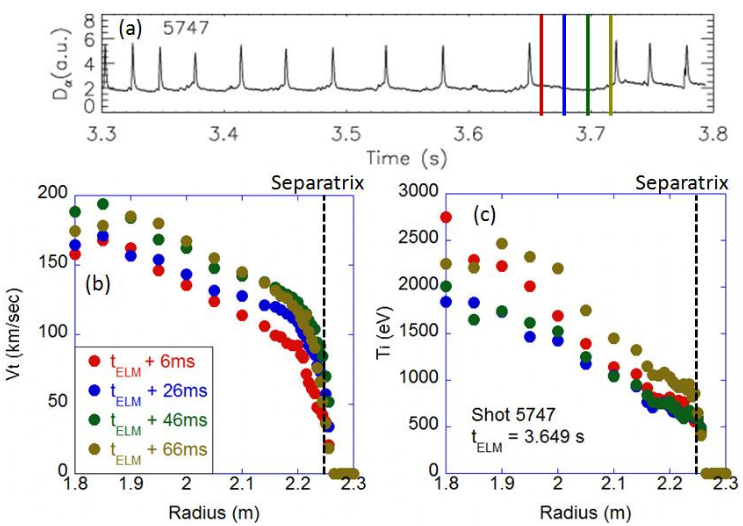
H-mode power threshold and confinement / ELM study at KSTAR



Measured L-H power threshold in low density regime[1]

- Dependence of L-H power threshold (P_{thr}) on density revealed roll-over at n_e ~ 2e19 m^{-3}, while there is no such a dependence in the present multi-machine scaling laws.

- Four types of ELMy H-mode were identified even with low NBI power (P_{NBI} = 1.5MW); (1) large type-I ELMs with H_{98}=0.8-0.9, (2) intermediate (possibly type-III) ELMs with H_{98}=0.6-0.8, (3) mixed (type-I + small) ELMs with H_{98}=0.9-1.0, and (4) small ELMs with H_{98}=0.8-0.9



Vt and Ti profile evolution during the ELM cycle[1]

Profile measurement for type-I ELMy H-mode shows that the recovery of T_i pedestal after the ELM crash only occurs at the last stage of the inter-ELM period, *i.e.* > 80 % of the ELM cycle. V_t and T_e pedestal continue to build up during the whole ELM cycle.

[1]J-W. Ahn, ORNL submitted to NF (2012)

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- Macroscopic Stability
- Energetic Particles
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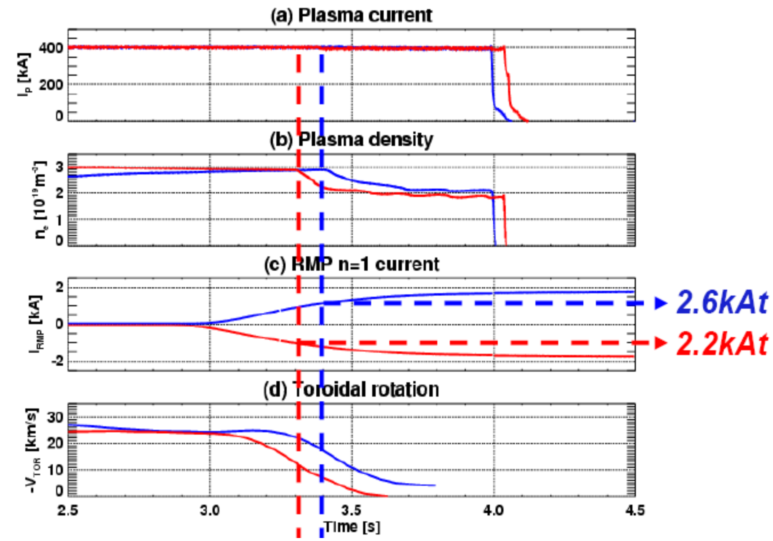
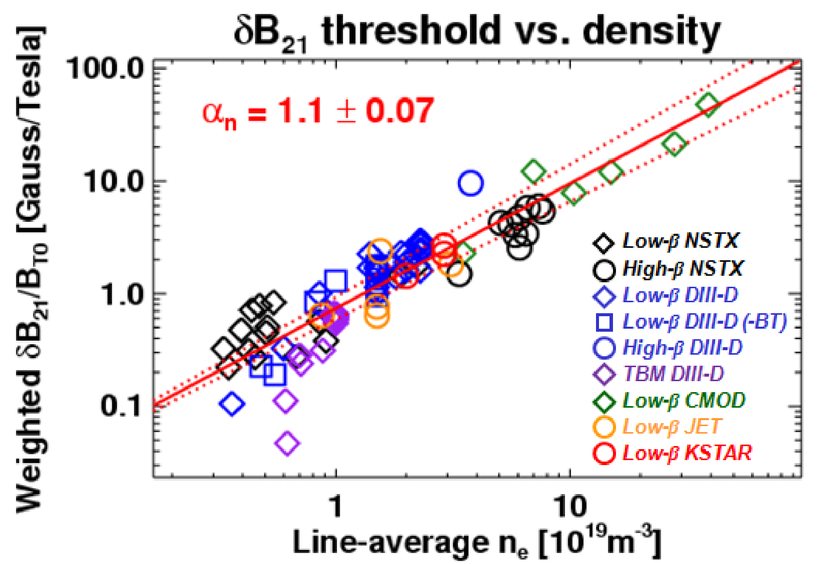
Study on Error Field and Locking in KSTAR

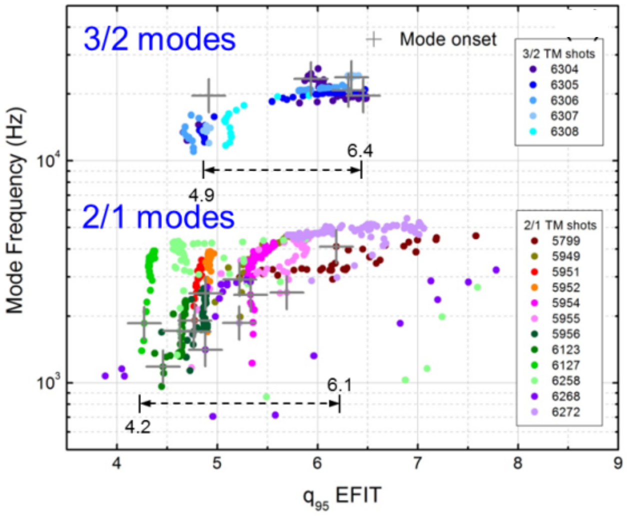
- In 2011, n=1 EF study was successfully initiated
- Non-axisymmetric plasma response was investigated with resonant (+90 phasing) and non-resonant (-90 phasing) fields, indicating the possibility of a very small intrinsic error field
- Resonant field thresholds were analyzed by IPEC and consistently combined with locking scaling for tokamaks (ITPA activity)
- Plan for 2012: The n=1 EF study will be extended to full 4 toroidal phase scan in both resonant and non-resonant cases, and also to fully shaped L-mode and H-mode plasmas



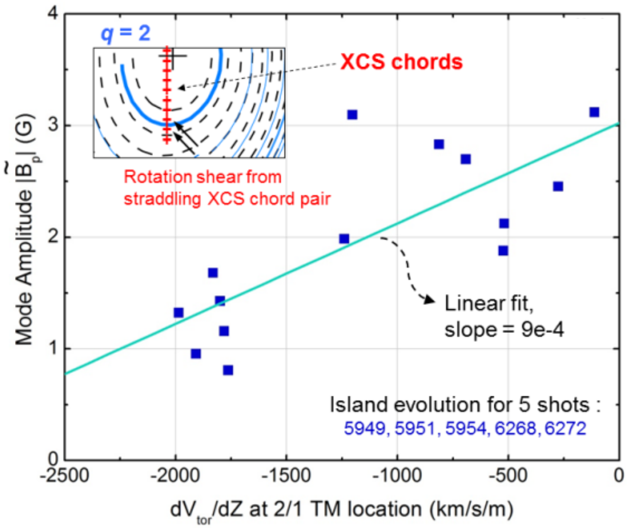


J-K Park, et al., PPPL

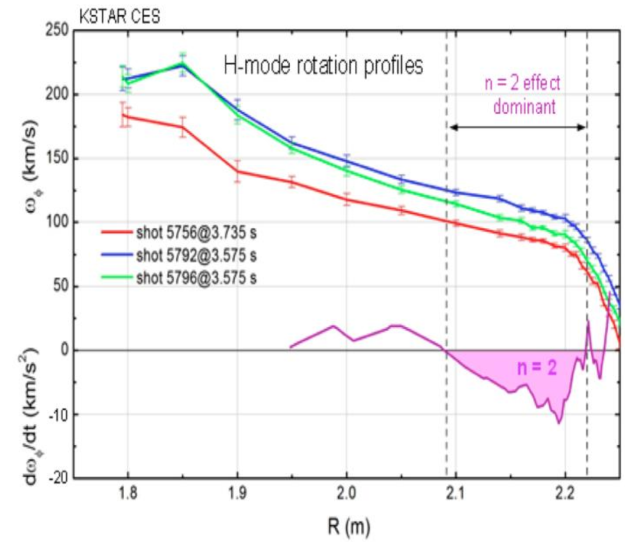
KSTAR 2/1 and 3/1 rotating MHD mode onset, and correlation with plasma rotation shear, and n=2 NTV braking profile characterized



Initial assessment of tearing mode onset (indicated by crosses) vs. q95.



Tearing mode amplitude vs. rotation shear for KSTAR plasmas.



n = 2 NTV braking profile on KSTAR using KSTAR CHERS data.

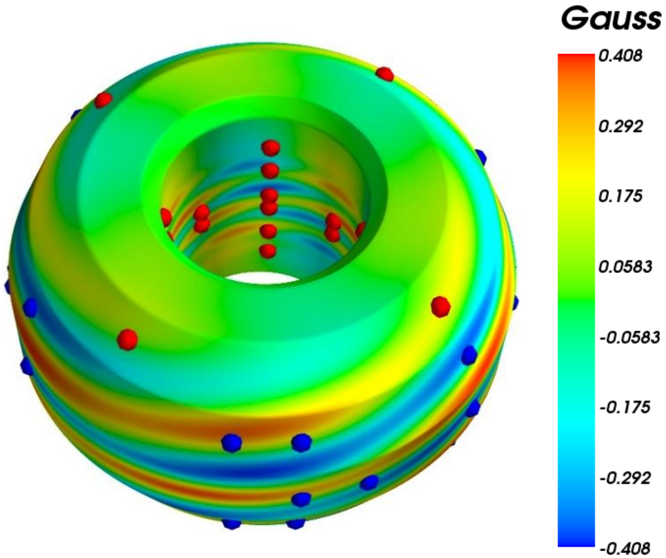
Columbia Plans for 2012

- Conduct experiment to approach/reach the n = 1 no-wall stability limit
- Characterize MHD instabilities in this regime, experimentally examine RWM stability
- Compute non-resonant NTV braking profile; examine neoclassical offset velocity and dependence on collisionality

Y.S. Park, S. Sabbagh et al., Columbia U

NSTX IPEC Graduate Thesis Collaboration with DIII-D will use expanded magnetic probe array to study E-M torque sources

- Ideal Perturbed Equilibrium Code (IPEC) applied in Physics Validation Review of 3D Magnetic Sensor Upgrade (Spring 2012)
  - New python post processor: 3D/2D visualization, synthetic diagnostics, vessel geometry, mode reconstruction, error sensitivity analysis, etc.
  - Over 100 new probes to be installed: Optimized for n ≤ 4 plasma response detection
    - High field side sensors fully redesigned for expected complex poloidal structures
  - Calibration and installation to begin this fall



Perturbed plasma field at DIII-D wall (with synthetic diagnostic locations)

Semi-automated EM torque measurement GUI completed in preparation for upgraded magnetic data for NTV and resonant breaking (spring 2012)
  - Initial application for n ≤ 2 has exposed required accuracy limits

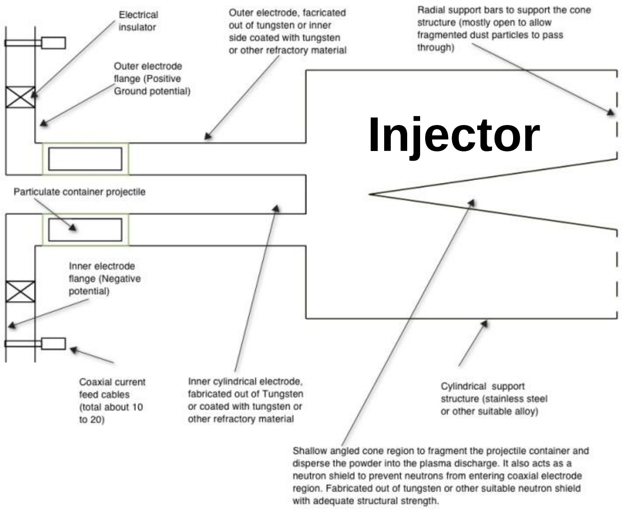
NTV torque module being built into IPEC (summer 2012)
  - Extension to non-ideal equilibrium calculation (2012-13) will be applied in support of 3D magnetics EM torque measurement experiments

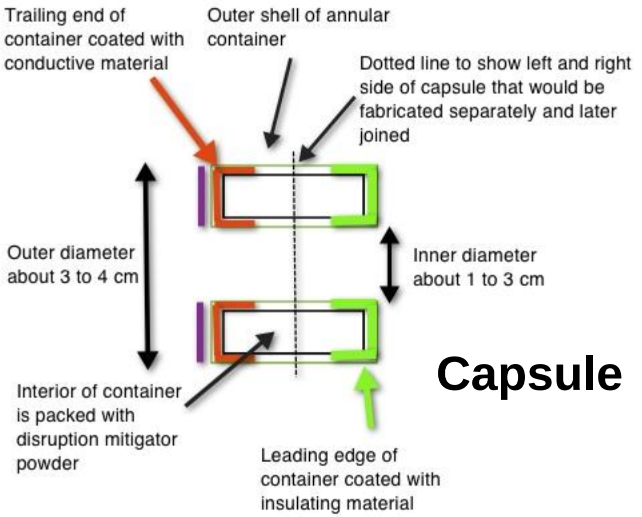
Full thesis proposal presented last week

N.C. Logan et al., (PPPL)
Advisors: J. Menard, J-K Park, T. Strait

An Electromagnetic Massive Particle Delivery System has Several Advantages over Conventional Methods for Disruption Mitigation in ITER

- Well suited for long stand-by mode operation
  - Large particle inventory
  - All particles delivered at nearly the same time
  - Particles tailored to contain multiple elements in different fractions and sizes
  - Single system for varying initial plasma parameters
    - Tailored particles fully ionized only in higher current discharges
  - Particle penetration not impeded by B-fields
- Toroidal nature and conical disperser ensures that,
  - The capsule does not enter the tokamak intact
  - The capsule will fragment symmetrically and deliver a uniform distribution of particles (or via. tapered final section)
- Coaxial Rail Gun is a fully electromagnetic system with no moving parts, so should have high reliability from long stand-by mode to operate on demand
  - Conventional gas guns will inject gas before capsule





Detailed design of a proto-type system now underway

R. Raman et al, U. Washington

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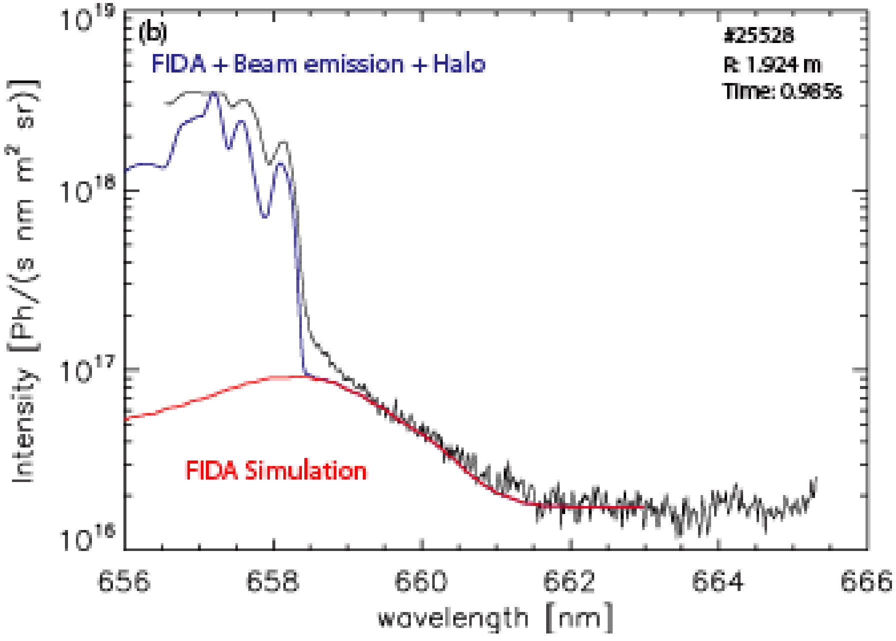
UC Irvine collaborations on Fast-ion D-alpha (FIDA) diagnostics on ASDEX-U and MAST

ASDEX-U Data



- Assisted development by Ben Geiger of ASDEX FIDA diagnostic[1]
- Geiger developed faster version of our synthetic diagnostic code FIDASIM[2]
- Assisted development by Clive Michael of MAST FIDA diagnostic
- Ongoing collaboration with Mirko Salewski (Danish Technical University) on inferring the distribution function from FIDA measurements[3]
- Advised Rob Akers (Culham) on a new fast-ion simulation code that uses graphical processing units

[1]Geiger, PPCF 53 (2011) 065010

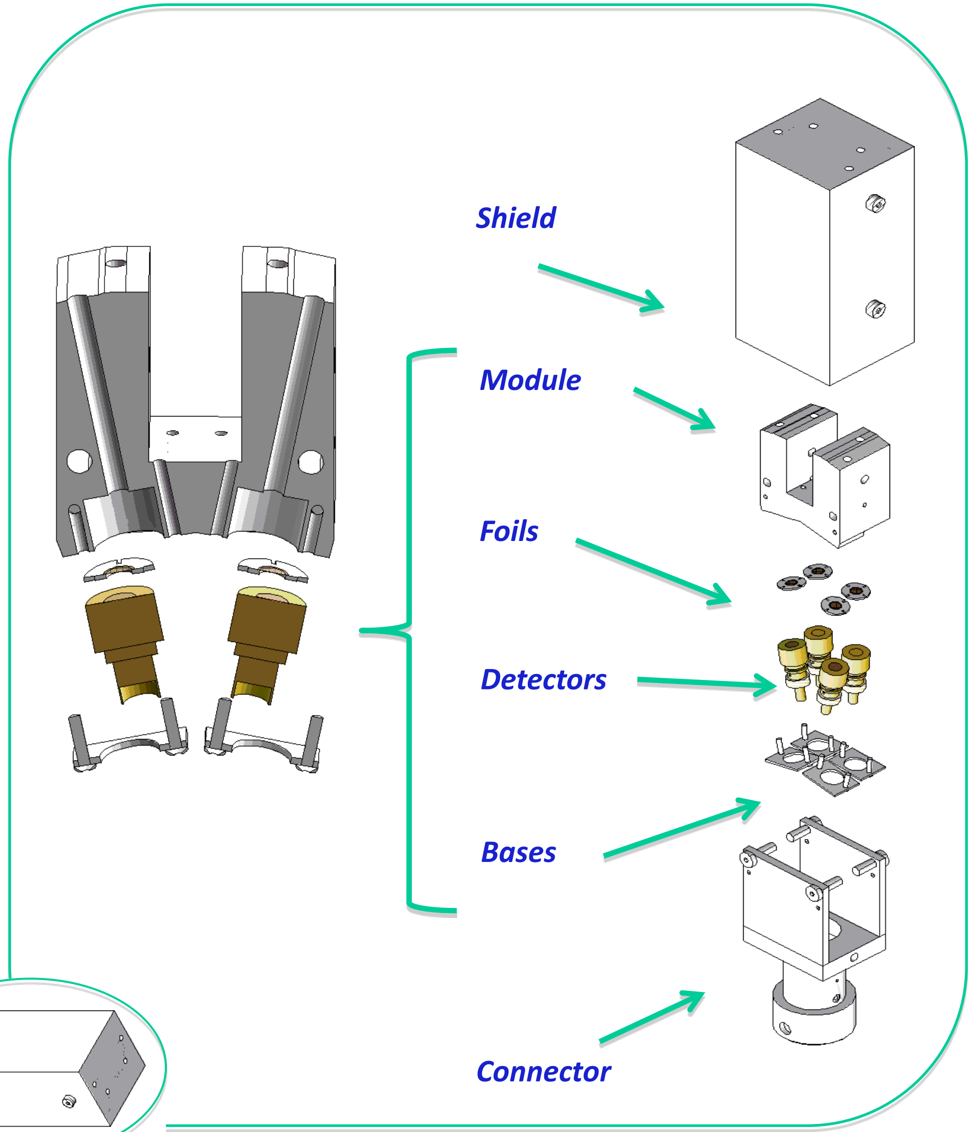
[2]Heidbrink, CiCP 10 (2011) 716

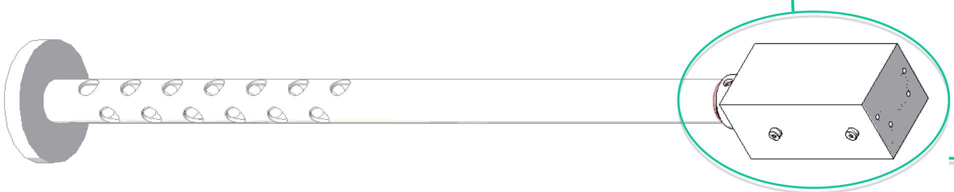
[3]Salewski, NF 52 (2012) accepted

NSTX-U Charged Fusion Products Diagnostic on MAST

Provides fusion reactivity profile due to MHD and other phernomena

- Collaborators: FIU, MAST, PPPL
- MAST Installation: November 2012
- Objective: obtain time-dependent, precise information on the d(d,p)t fusion rate profile with the goal of determining the neutral beam ion density profile as a function of R, z, and t





R. Perez et al., Florida International University

NSTX researchers pursuing targeted collaboration program on fusion facilities in support of NSTX-U, ITER, FNSF

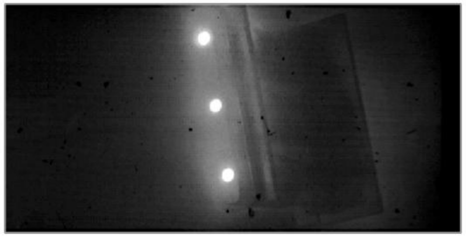
- Transport and Turbulence
- Macroscopic Stability
- Energetic Particles
- Solenoid-Free Plasma Start-up
- Wave Heating and Current Drive
- Advanced Scenarios and Control
- Boundary Physics and Lithium Research

Developments in Conceptual Design of Local Helicity Injectors for Potential NSTX-U Application

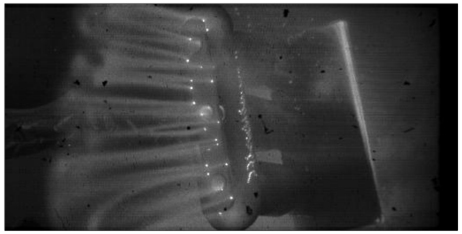
Tests on Pegasus ST experiment

- **Plasma gun current sources with integrated electrode assembly tested in Pegasus over last ¾ year.**
- **New single-gun/electrode assembly installed for testing this Summer-Fall.**
  - With integrated piezo-controlled gas valve

Three arc sources and integrated Mo electrode assembly



Arc plasma current source



Electrode current source

Framing camera images (~10 μsec) of current injectors in the scrape-off-layer region of a Pegasus discharge. I_{inj} ~ 3 kA; I_p ~ 100 kA.

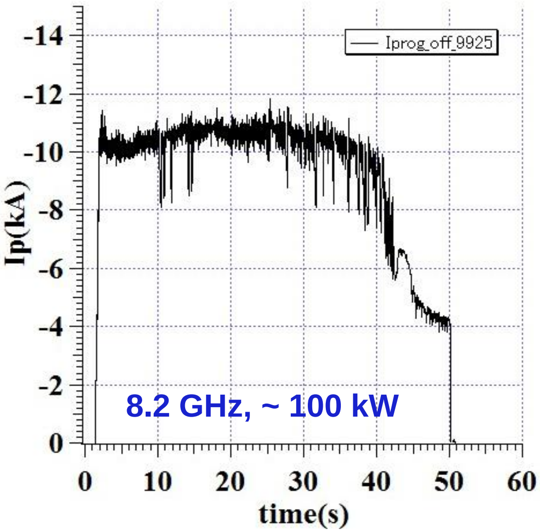
R. Fonck et al, U. Wisconsin
D. Mueller (PPPL) to collaborate with Pegasus

Collaboration with QUEST

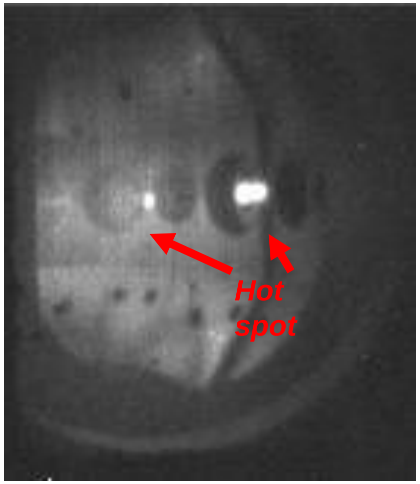
Newest ST in Japan: All metal PFCs, non-inductive long pulse

R. Raman et al, U. Washington

ECH sustained discharge



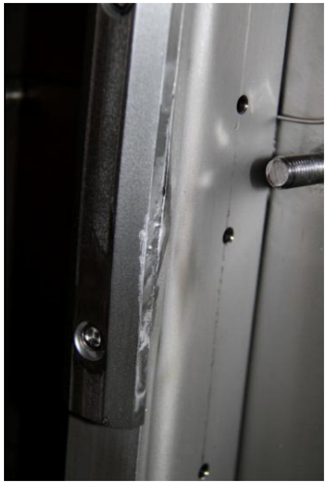
Hot spot developed



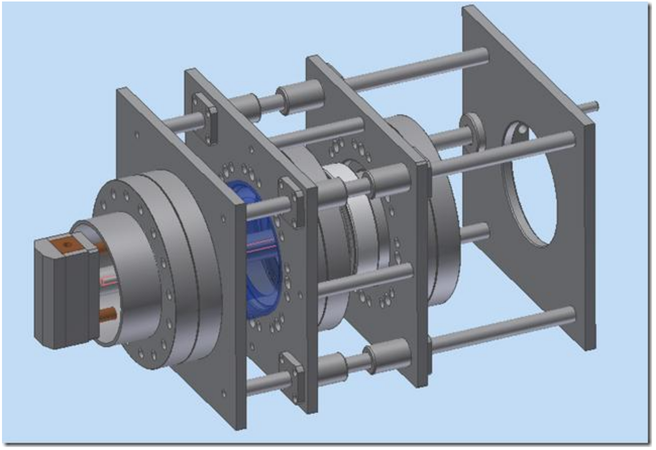
Future Direction:

- Higher power ECH (8.5 GHz, 28 GHz)
  Total power ~ 1 MW long pulse
- Hot wall for particle control
- All metal CHI being considered
  U. Washington / NSTX collaboration

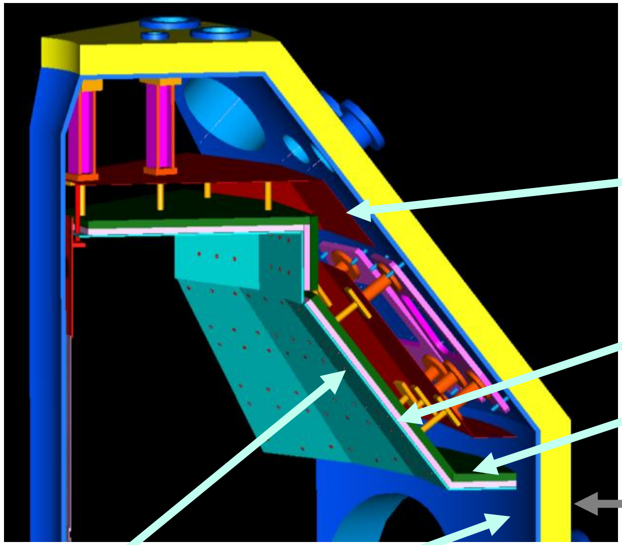
Melted moly limiter



Water cooled tungsten movable limiter



Hot wall (up to 500 °C) planned for 2014



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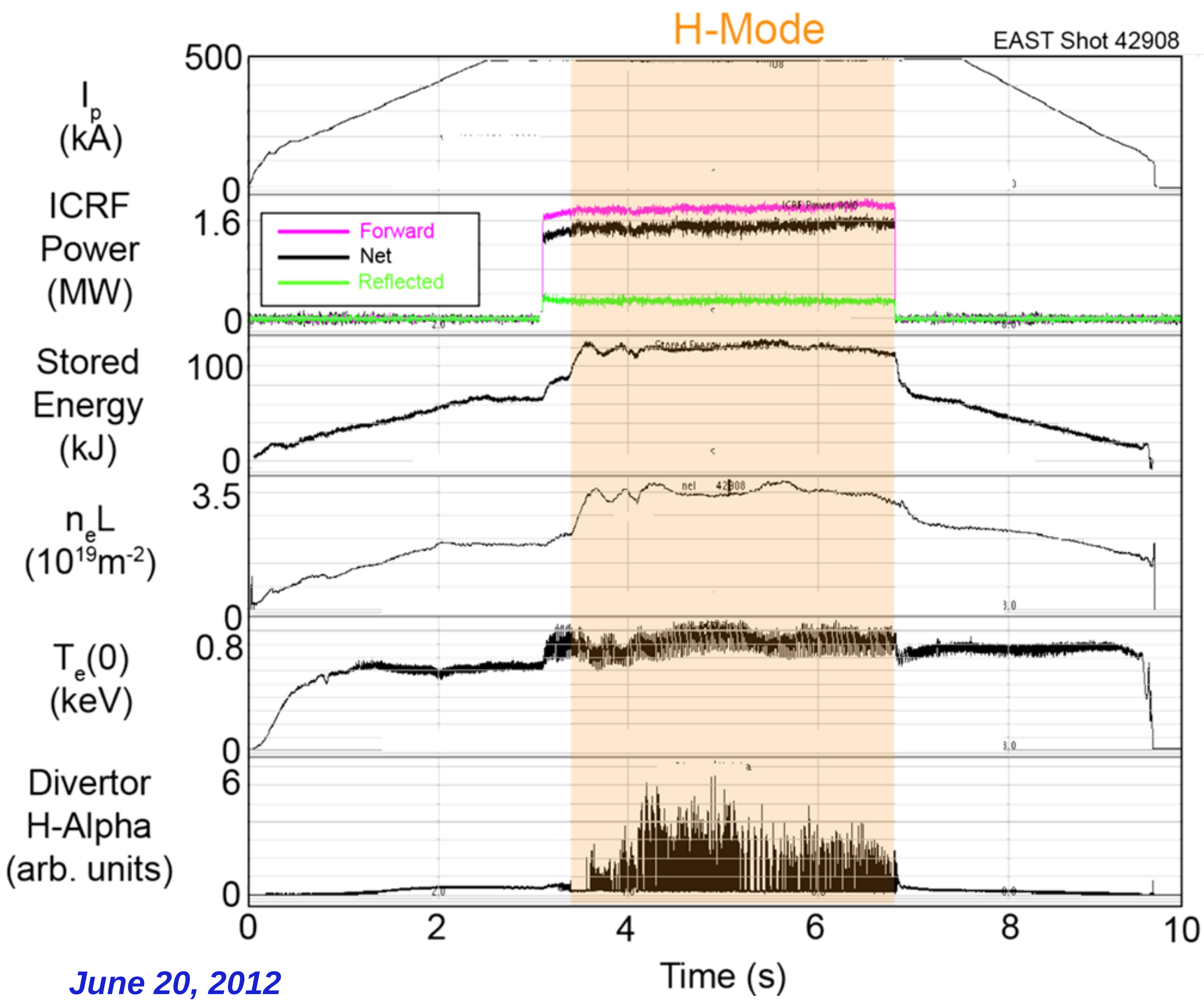
EAST: Achieved 3.5 s duration ICRF-generated H-mode on Terminated only when ICRF power was turned off



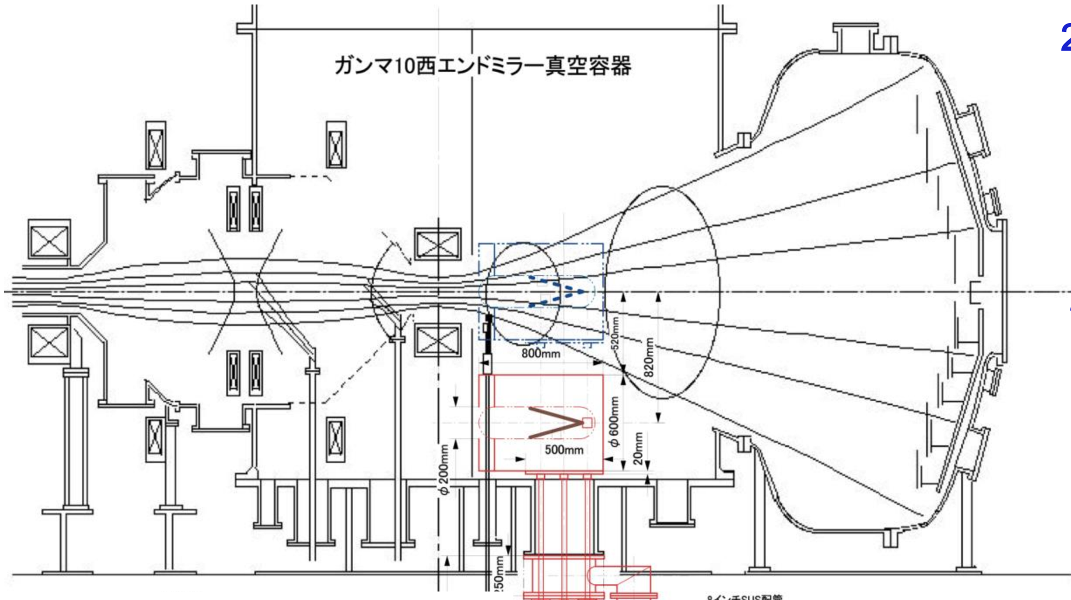
June 20, 2012

- 200 ms ELM-free period after L→H Transition
- Followed by "Grassy" ELMing until H→L back transition
- ELM frequency 150 - 500 Hz
- Measured core electron heating
- 30% increase in stored energy at L→H transition

G. Taylor, et al., PPPL

Collaboration with Gamma-10 Group

New PMI research direction and 28 GHz Gyrotron R&D



28GHz Gyrotron is required in GAMMA10

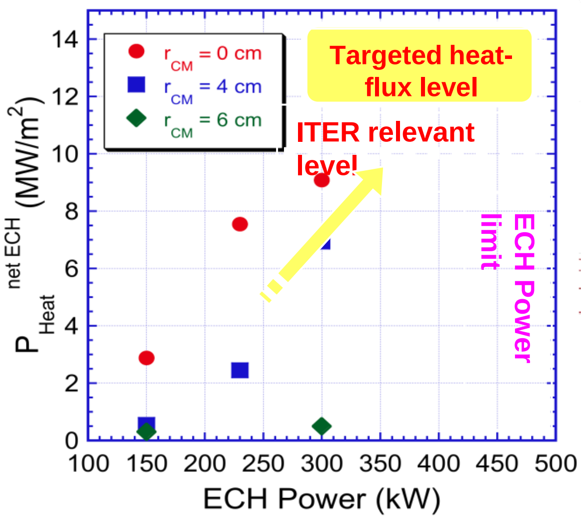
This Gyrotron will be used to achieve higher plasma performance.

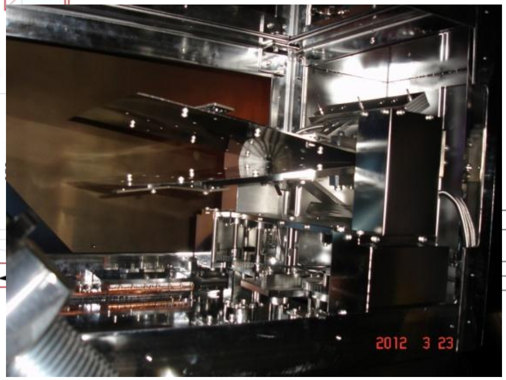
Ex) axial ion confining potential, heats electrons, heat flux

28GHz Gyrotrons are required in some plasma experimental devices.

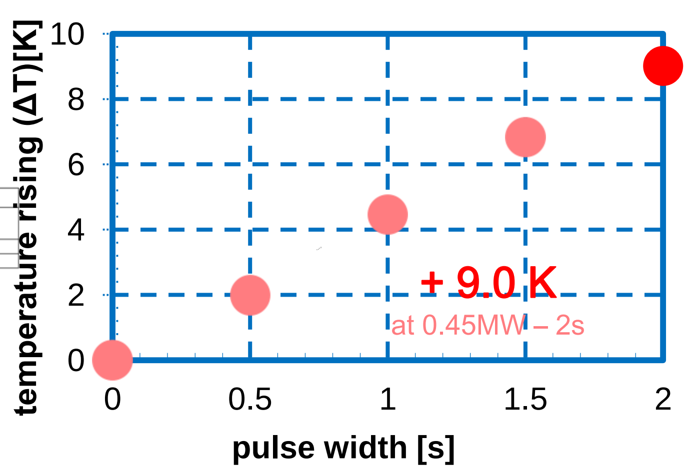
- NSTX (Princeton University):
  2MW – several seconds
  Ex) ECH, ECCD, EBW experiment etc.

Improved design of 28GHz 1MW Gyrotron for development of 2MW Gyrotron





Sapphire window (single disk)



M. Ono et al, PPPL

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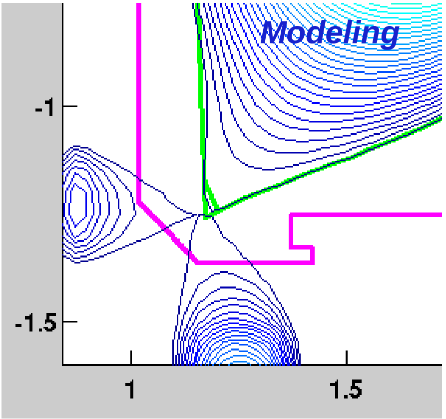
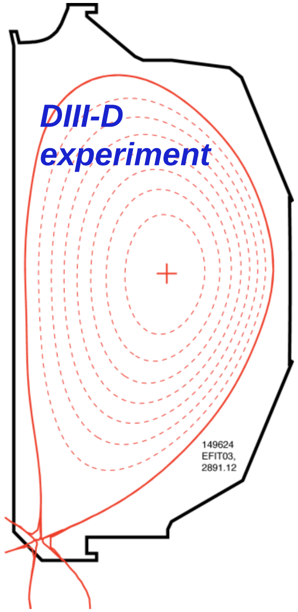
Snowflake divertor studies started at DIII-D

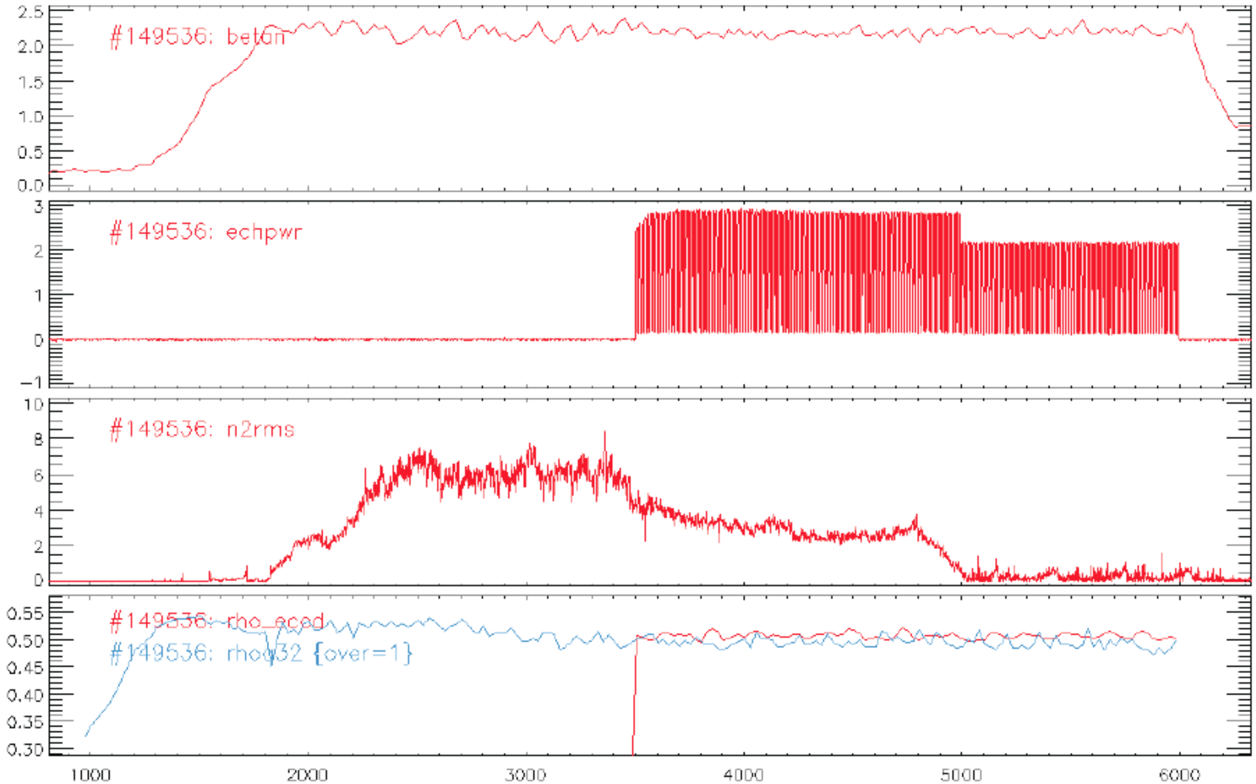
- LLNL collaboration with PPPL and GA on magnetic control development on-going
  - Successfully implemented snowflake divertor scenario at DIII-D enabling the initial physics experiment
- DIII-D: Evaluation of snowflake geometry on pedestal stability, steady-state and ELM divertor heat flux, radiation, and cryo-pump operation
  - ✓ Ran a ½ run day snowflake divertor experiment in July 2012
  - ✓ Demonstrated steady-state (2-3 s) snowflake-minus and plus configurations at $\sigma = d_{X\text{-}X}/a_{minor}$=0.15-0.20
  - ✓ Demonstrated beneficial magnetic geometry properties
  - ✓ Demonstrated significant (x4-8) steady-state peak divertor heat flux reduction via geometry compatible with good confinement
  - ✓ Demonstrated radiative detachment at 0.6-0.75 x n/n_G with large radiation fraction and slight confinement degrardation





V. Soukhanovskii (LLNL) and E. Kolemen (PPPL) et al.,

Successful NTM suppression with feed-back on q-surface with real-time steerable mirror – important for ITER, extend to NSTX-U EBW-CD?



Real-time steerable mirror control of the EC deposition location

- Faster NTM suppression
- Capability to run experiments consistently in high beta.
- Possibility to control NTMs with lower EC power.
- Suppress multiple islands at the same time

- Calculate the q-surface location corresponding the NTM mode (3/2, 2/1).
- Request the mirror to move to follow the angle that correspond to intersection of the q-surface with the 2fce using Ray tracing.
- Control designed for tracking performance using Relay-Feedback.
- Great performance with <<1 cm error.

E. Kolemen et al., (PPPL)

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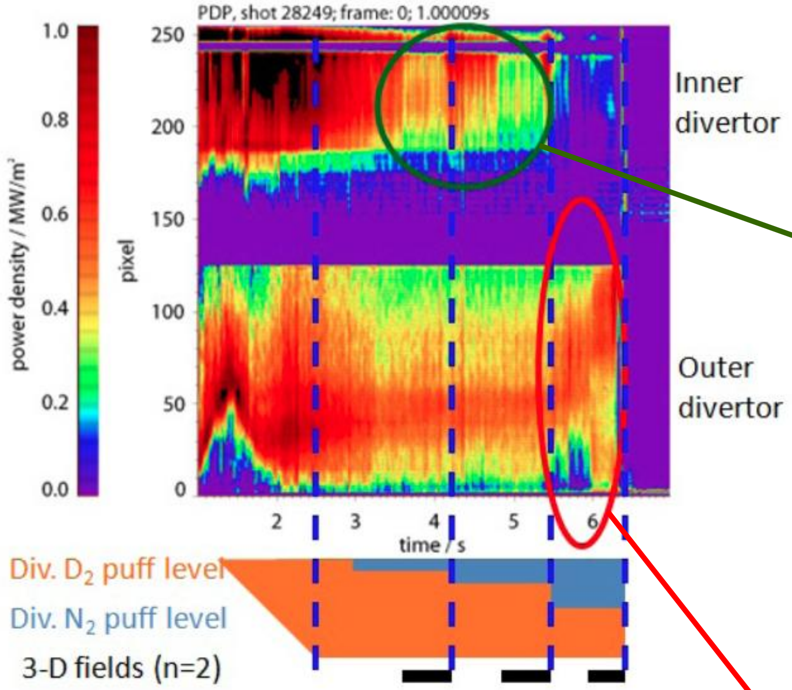
3-D Field Effects on Divertor Detachment Explored in ASDEX-U

Temporal evolution of divertor heat flux profile during the divertor gas puff and 3-D field application



- Deuterium gas puffing induced power detachment at outer divertor but particle detachment was only produced by additional nitrogen puffing
- 3-D fields (n=2) application reduced the inner divertor power density but there was no change at the outer divertor.
- Applied 3-D fields reduced particle detachment at the outer divertor, which is consistent with the NSTX result.

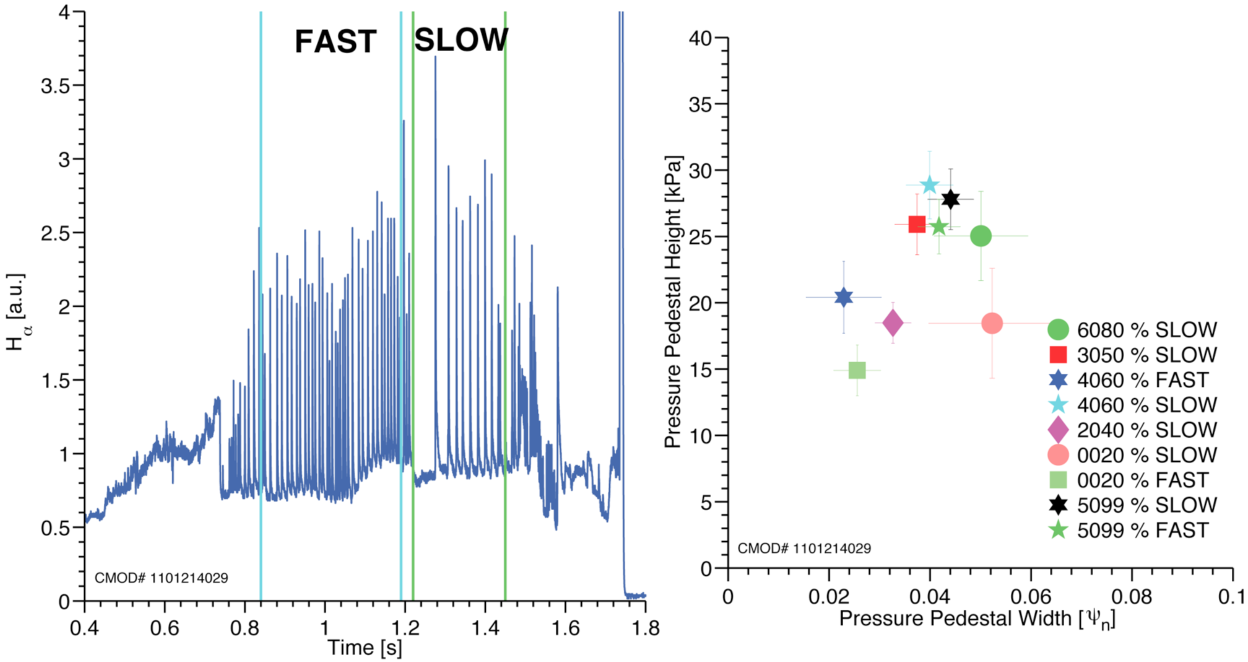
3-D fields brought the outer divertor heat zone back in, closer to the strike point (sign of power re-attachment, similar to the observation in NSTX) although the particle detachment was becoming stronger. This data suggests that there is a possibility of a de-coupling of the power and particle detachments.

J-W. Ahn et al. ORNL

Pedestal Width and Height Scalings in C-Mod

Profile analyses of the density and temperature between ELMs performed

- Profile analyses of the density and temperature between ELMs performed to characterize the pedestal width and height scalings.
- These characterizations motivated the design and planning of future C-Mod experiments targeting the inter-ELM fluctuations characterizations and comparison with EDA- H mode fluctuations.
- This experiment has been approved, awaiting scheduling for its execution.



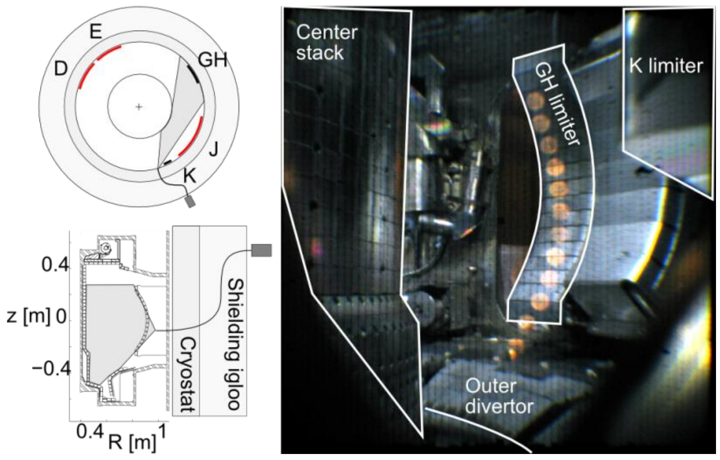
Left: Dalpha time trace showing the fast and slow ELMs. Right: Trends of the pedestal height and width during the various parts of the ELM cycle.

A. Diallo et al., PPPL

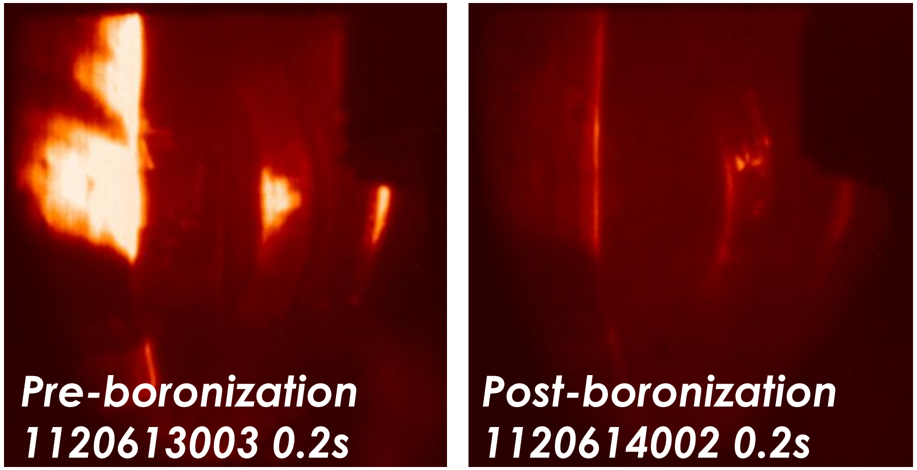
Material erosion studies at C-Mod
(high-Z wall and low-Z coatings)

- **LLNL postdoc on-site at Alcator C-Mod tokamak**
- **Novel LLNL intensified camera diagnostic for molybdenum and boron erosion studies**
  - **Camera installed and calibrated, contributing to physics operations**
  - **Improving techniques for accounting for continuum and Plank emissions**
  - **Analyzing moly and boron limiter erosion and core moly penetration factors including RF, inner-wall startup, and boronization effects**
- **Collaboration with ADAS consortium on improved Mo I and Mo II atomic physics calculations for gross and net erosion measurements**

Vlad Soukhanovskii et al., LLNL



LLNL moly camera viewing geometry



Mo I emission pre- and post-boronization in C-Mod

NSTX Dust Detector Demonstrated on Tore Supra

- Real-time dust measurement is necessary to safely manage dust in tokamak fusion reactors.
- A novel electrostatic dust detector was developed at PPPL and demonstrated on NSTX

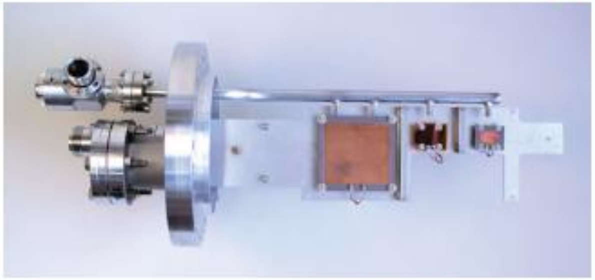
  see: 'First real-time detection of surface dust in a tokamak' C. H. Skinner et al., Rev. Sci. Instrum., 81 (2010) 10E102.

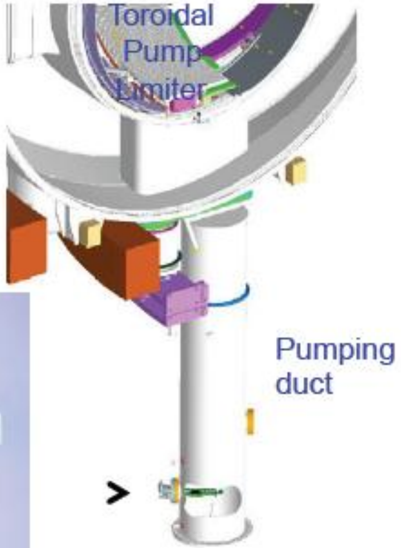
- Dust detection technology was successfully transferred to Tore Supra and used to correlate dust production with plasma events.
- 82% of the dust particles detected were due to disruptions

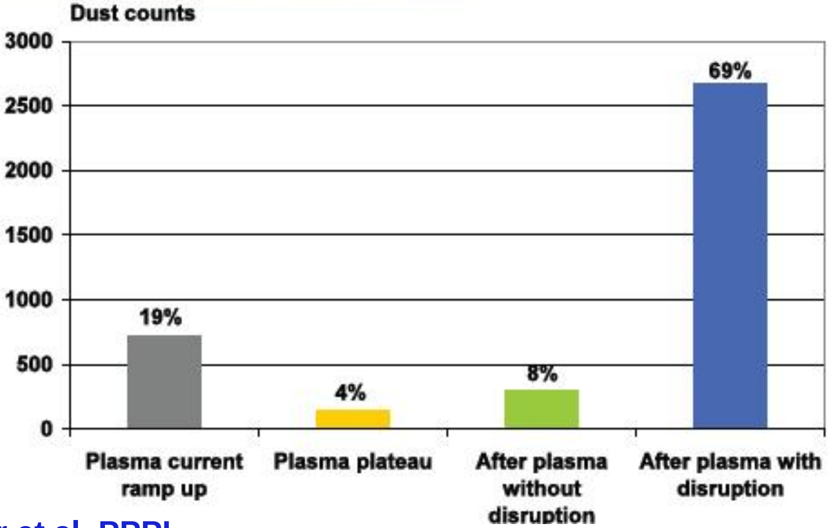
  (including 13% detected during plasma current ramp up, following a shot with disruption).

  For complete results see 'First results from dust detection during plasma discharges on Tore Supra' H. Roche et al., Phys. Scr. T145 (2011) 014022.

A set of 3 electrostatic detectors from PPPL





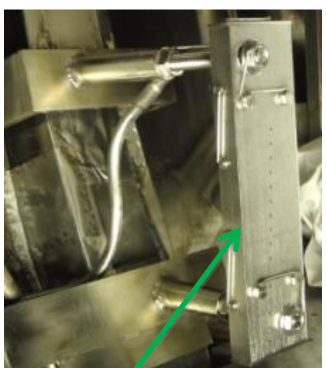


C. Skinner et al, PPPL

Preliminary results from EAST GPI experiments
Interested in developing similar multi-view capabilities for NSTX-U

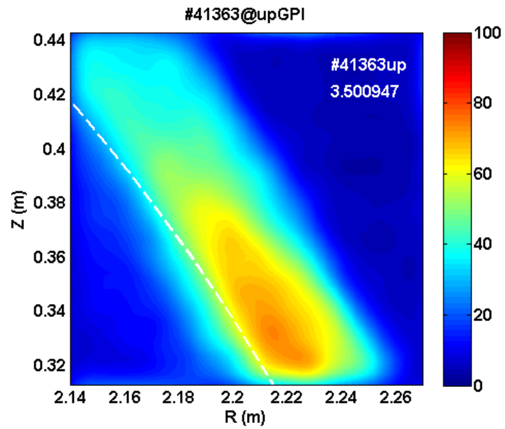
in-vessel hardware

Side-view reentrant windows

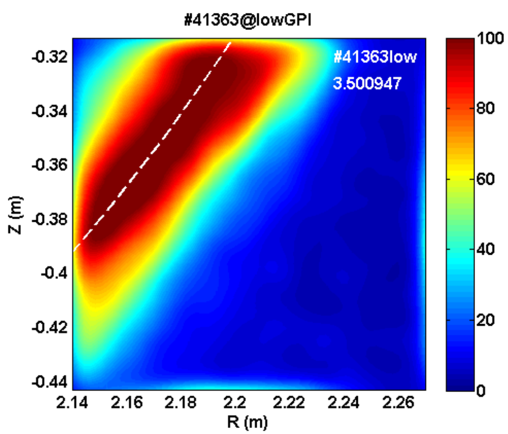


Gas manifold

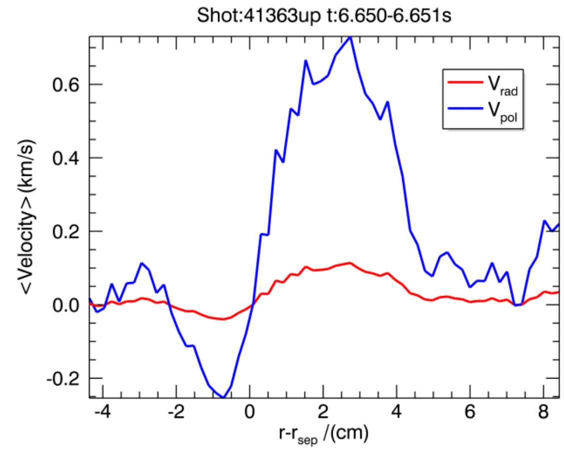
upper GPI image

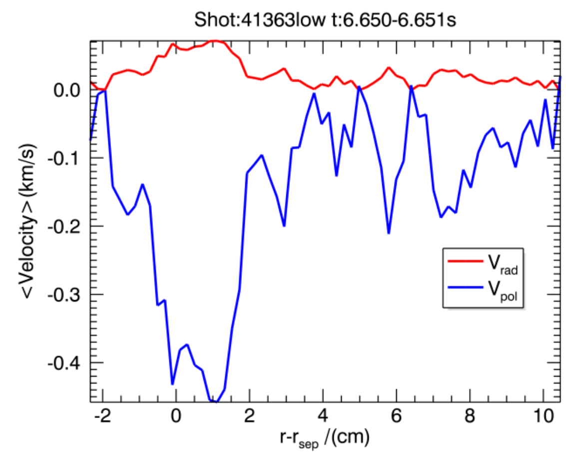


lower GPI image



Inferred turbulence velocities



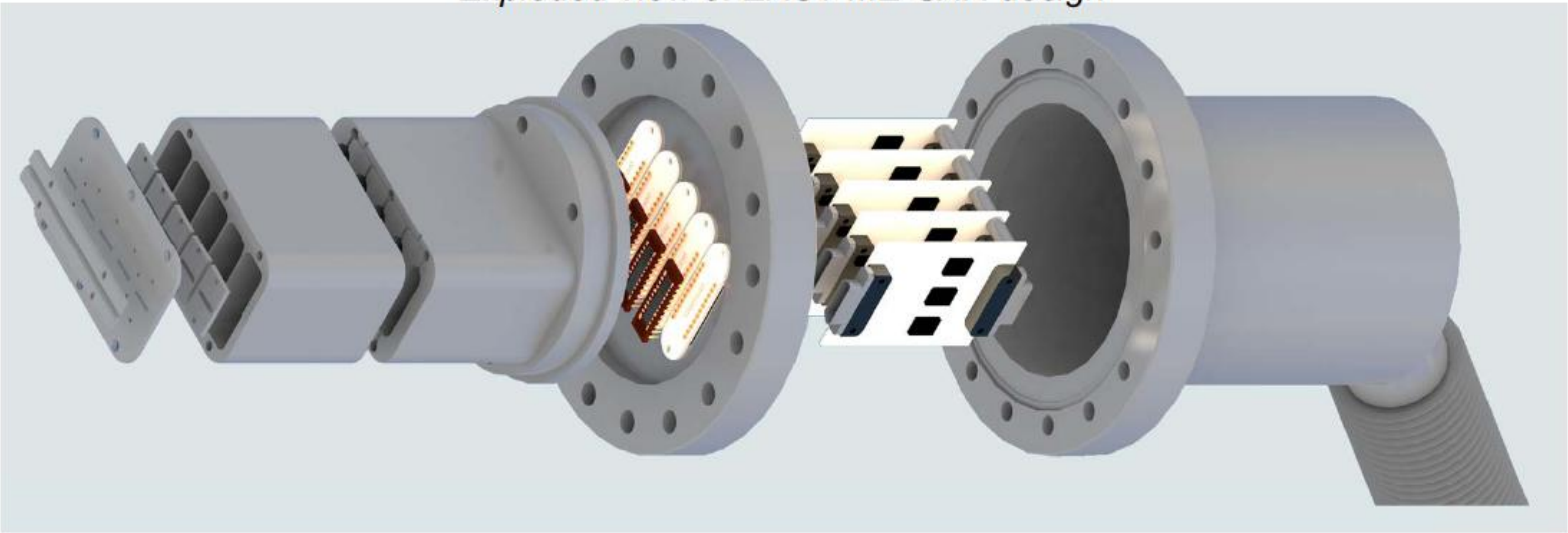


S. Zweben, et al., PPPL

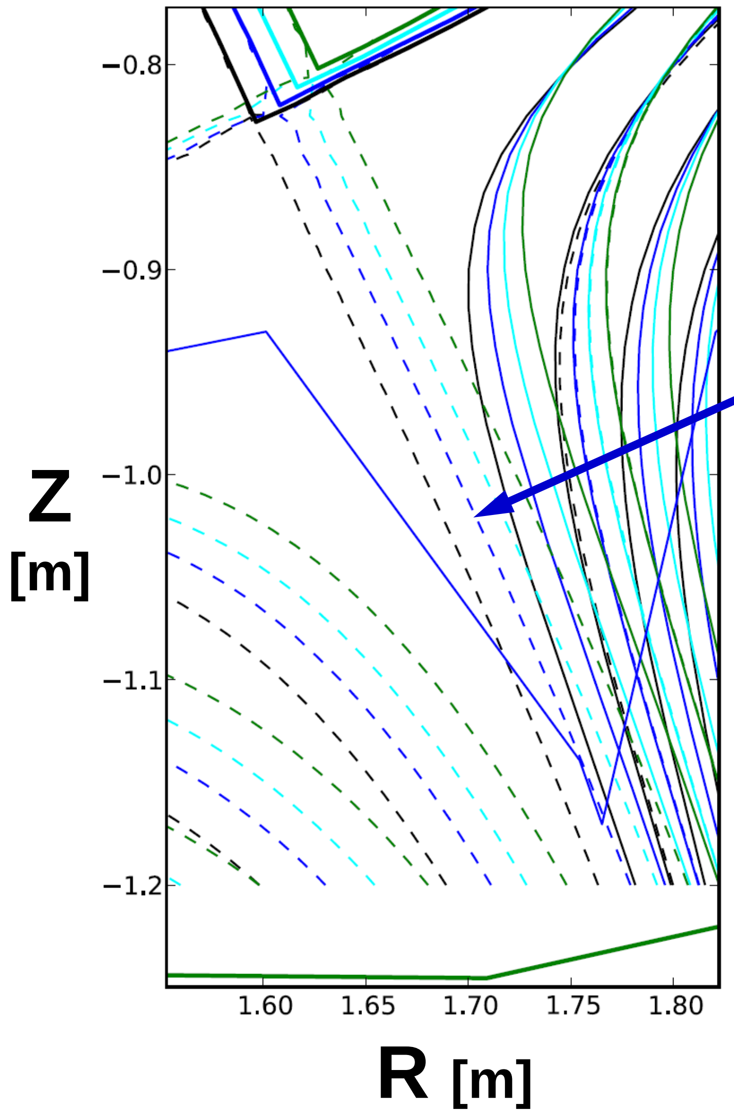
JHU Multi-Energy Soft X-Ray System being implemented for EAST – will serve as prototype for NSTX-U

- 10/2011 - visit to EAST to discuss initiation of a diagnostic collaboration involving an initial multi-energy soft X-ray system (ME-SXR)
- 04/2012 - received DoE supplement to begin work on ME-SXR for EAST which will provide design optimization and operational test-bed for funded NSTX-U system
- 06/2012 - visit to EAST for review of completed preliminary design for EAST ME-SXR, with discussion further tasks, schedule, and proposed installation in summer/fall 2013
- 07/2012 - initial discussion with EAST regarding the use of non-magnetic sensors for long pulse boundary feedback and control, potential solution to integrator drift issues

Exploded view of EAST ME-SXR design



Cryo-pumping quite sensitive to strike-pt position on EAST and results will help inform NSTX-U cryo-design



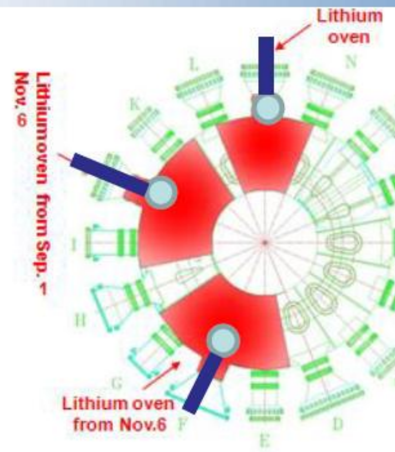
- Only case with increased density pump-out places strike-point directly at divertor corner (plenum entrance)
- Other nearby shapes with +/- 1-2cm x-point height change do not show significant pumping
  - Implies precise strike-point control likely needed for particle control with cryo
- Potentially important for density control in long-pulse H-mode
  - Topic for future EAST collaboration, and for NSTX-U cryo-pump design

J. Menard, M. Jaworski et al., PPPL

Methods of Lithium Coatings

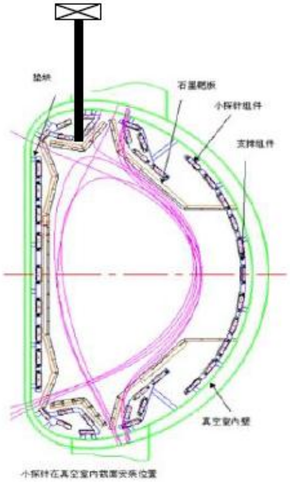
EAST

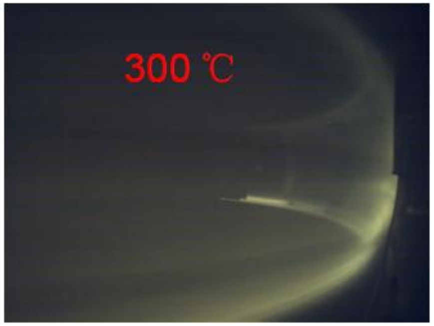
- **Li Oven Coatings :**
  - ✓ by evaporation, ionized by GDC or ICRF discharge
- **Real-time Li Coating:**
  - ✓ Lithium powder dropper used during plasma discharge



In 2010

dropper





ICRF lithium coating

➢ICRF Li coatings seem better than GDC or evaporation only:

- ✓ **More Li atoms were ionized by ICRF plasma with larger symmetric flux of energetic ions than that by GDC or Li evaporation only**
- ✓ **More uniform Li distribution along toroidal direction**

8

From G. Z. Zuo – "Lithium Coating for H-Mode and High Performance Plasmas on EAST in ASIPP" – PSI2012

PPPL Lithium Granule Injector Tested on EAST

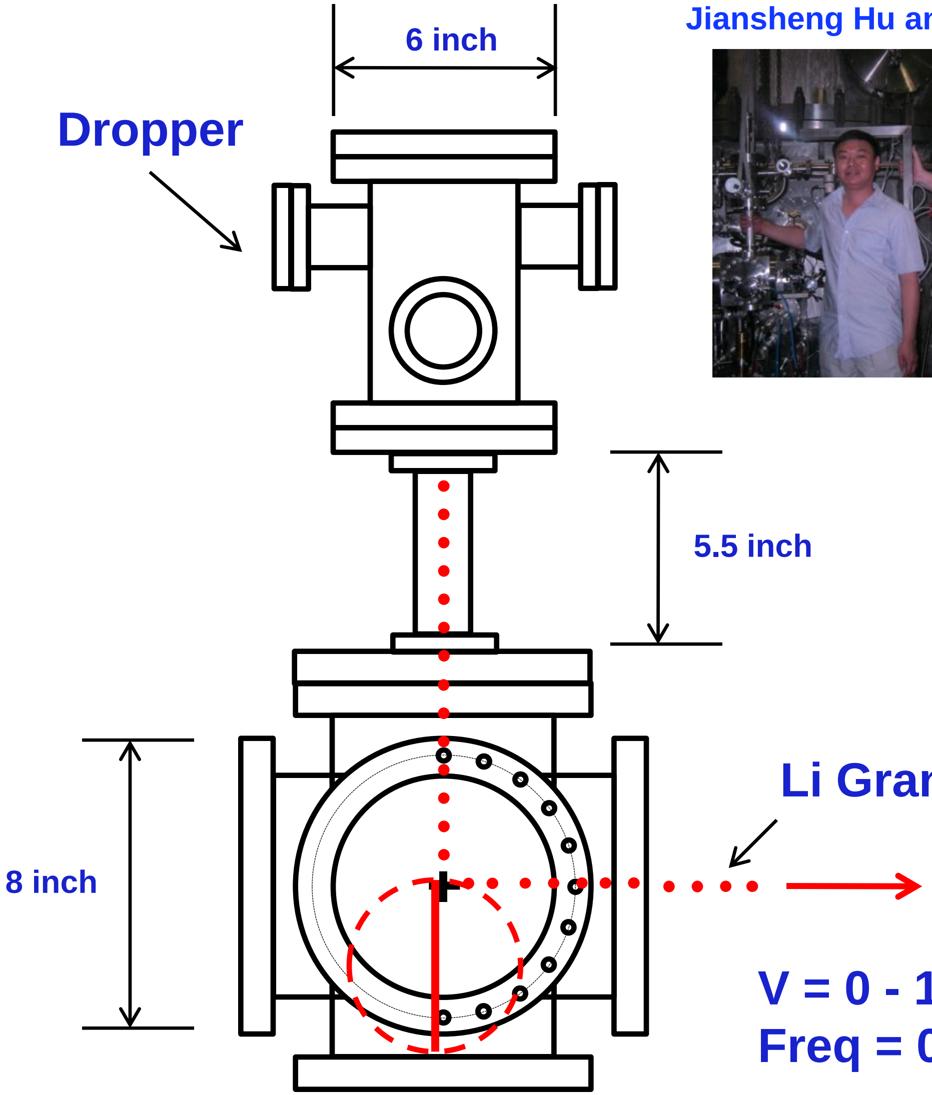
Dennis Mansfield (PPPL, retired)
Lane Roquemore (PPPL)

Independent Control:

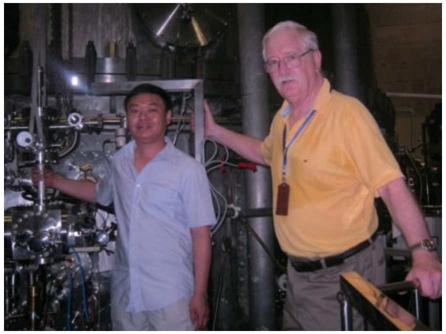
Granule Size
(change between shots)

Injection Speed
(ramp during shots)

Pacing Frequency
(ramp during shots)



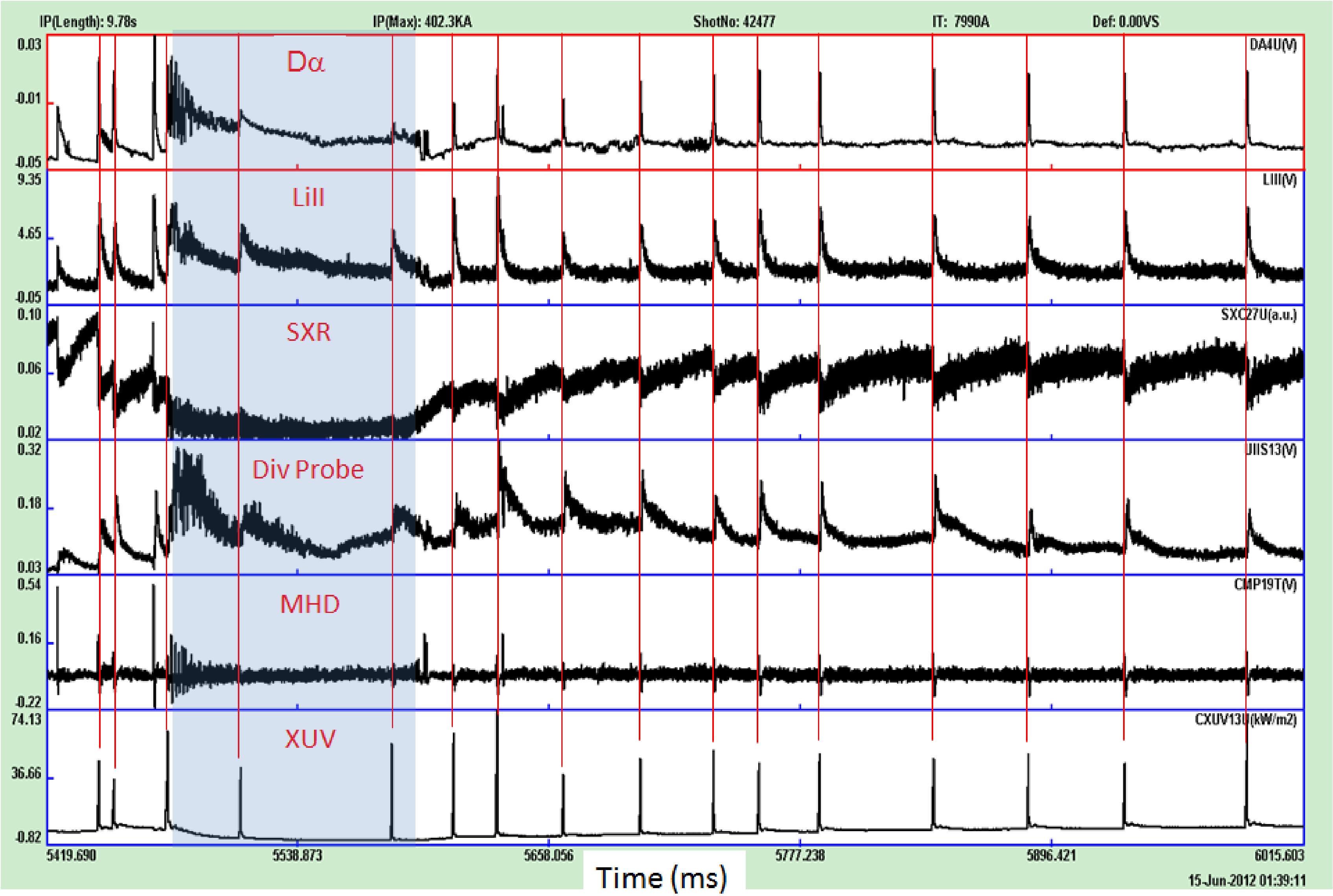
Jiansheng Hu and D. Mansfield



V = 0 - 100 m/s
Freq = 0 - 100 Hz

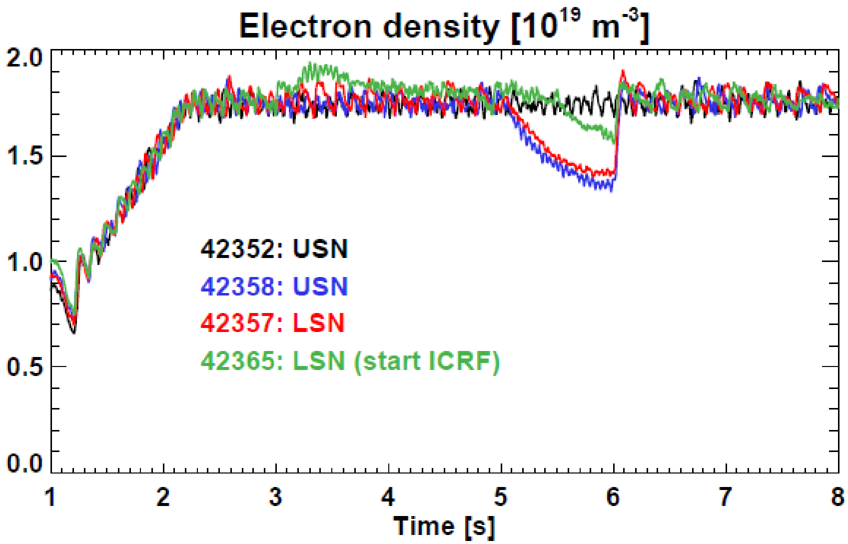
Triggered ELMs (~ 25 Hz) with 0.7 mm Li Granules @ ~ 45 m/s

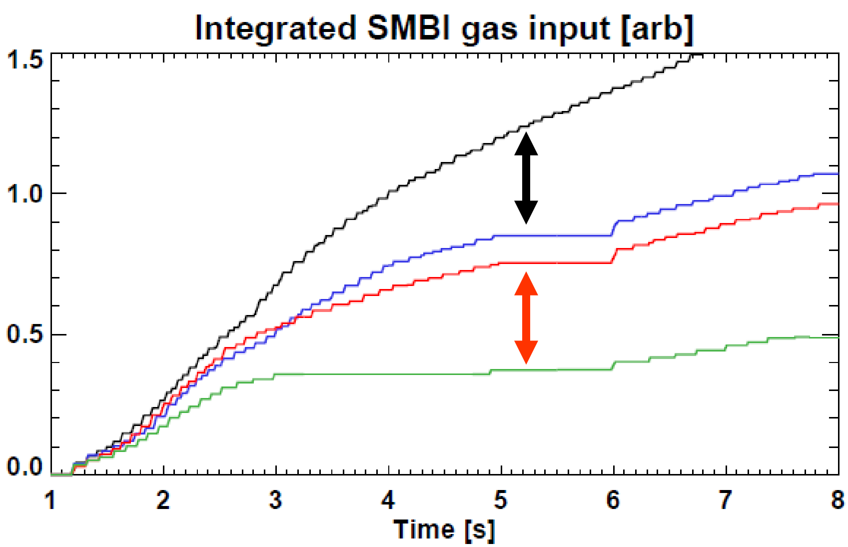
→ could be very useful for triggering ELMs in Li-ELM free H-modes in NSTX-U



Measured lithium pumping trends on EAST versus integrated shot time + shaping parameters (June 2012)

J. Menard, M. Jaworski et al., PPPL

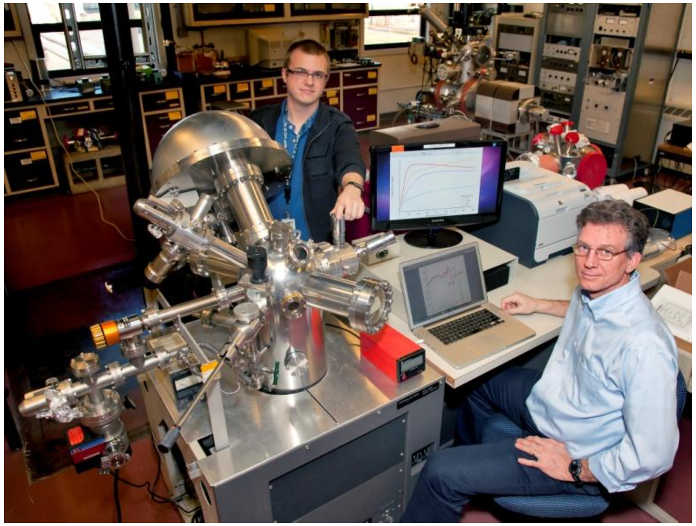




- Compared shots with same magnetic balance but similar increment in shot number
  - USN pumping stronger than LSN
- Observe 30-50% reduction in pumping after 6-8 shots
  - Each shot ~10s → 60-80 shot seconds of strong Li pumping
- Pumping decreased by factor of 2 after 20-25 shots (not shown)
  - 200-250 shot seconds
  - **significant Li passivation**

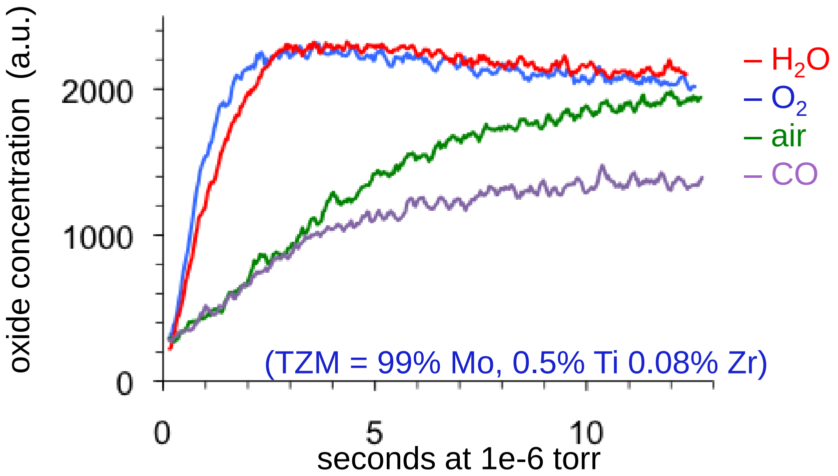
NSTX/PPPL/PU collaboration shows lithium reacts quickly with residual gases

New Surface Analysis Labs at PPPL

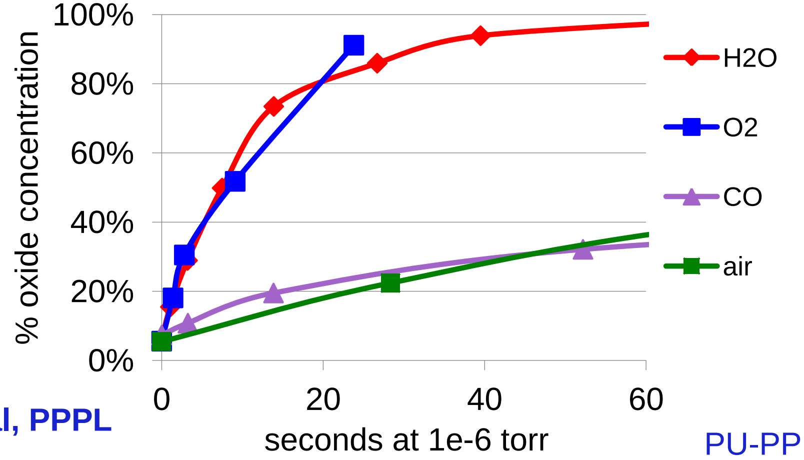


Li surface oxidation time

1 monolayer of lithium on TZM Mo (AES O 1s)



Solid lithium (XPS Li 1s))



PU-PPPL

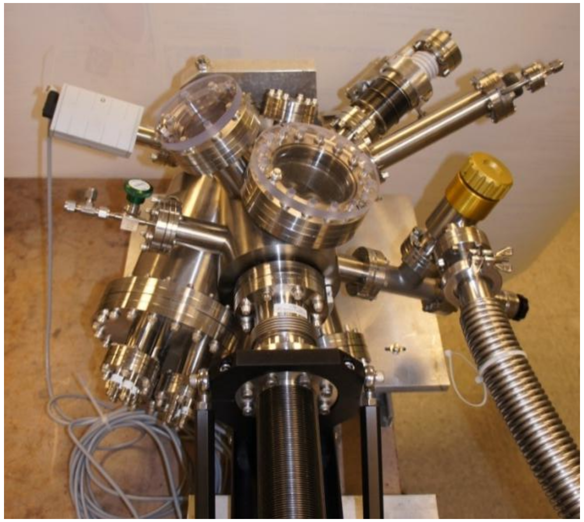
- Surface analysis experiments show PFC oxide coverage is expected in 10s of seconds from residual H_2O at typical NSTX intershot pressures ~1e-7 torr.
- Plasma facing surface after Li evaporation is a mixed material rather than 'lithium coating'.
- **Short reaction times motivate flowing Li PFCs**

C. Skinner et al, PPPL

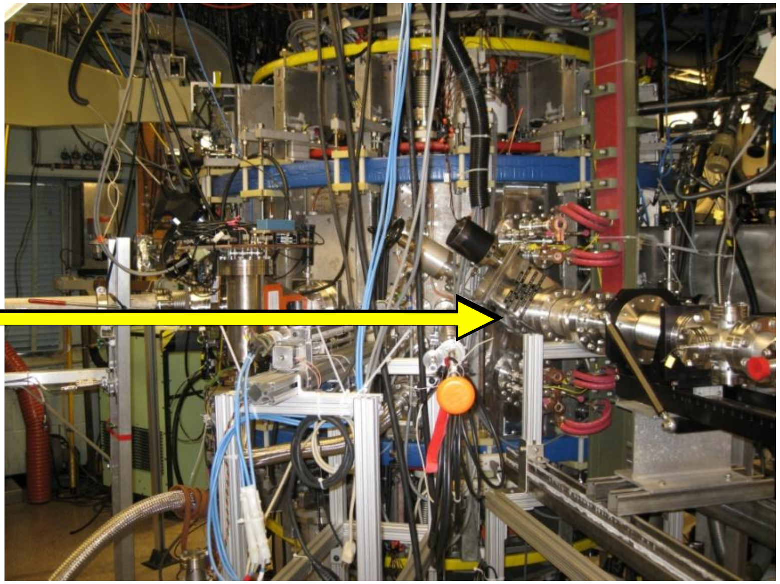
NSTX MAPP System is being installed on LTX in support of NSTX milestone R(13-2) in collaboration with Purdue U.

- Lithium Tokamak Experiment has: 1. 120 cm^2 Li-filled dendritic W limiter heatable ≤ 500 C
  2. Thick (>100 micron) evaporated Li films on 3,000 – 5,000 cm^2 upper heated liner
  3. Few hundred cm^3 pool of liquid Li in the lower shells (total ≤ 85% of plasma surface)
  - Will investigate plasma-surface interactions, Li influx vs. temp., confinement, Te profile, liquid metal flows in B fields up to 0.3T
- Materials Analysis and Particle Probe (MAPP) will be used first on LTX in support of NSTX milestone R(13-2): "*Investigate relationship between lithium-conditioned surface composition and plasma behavior*" and transferred to NSTX-U later.
- MAPP's innovative design enables sample exposure to plasma and inter-shot surface analysis.

MAPP

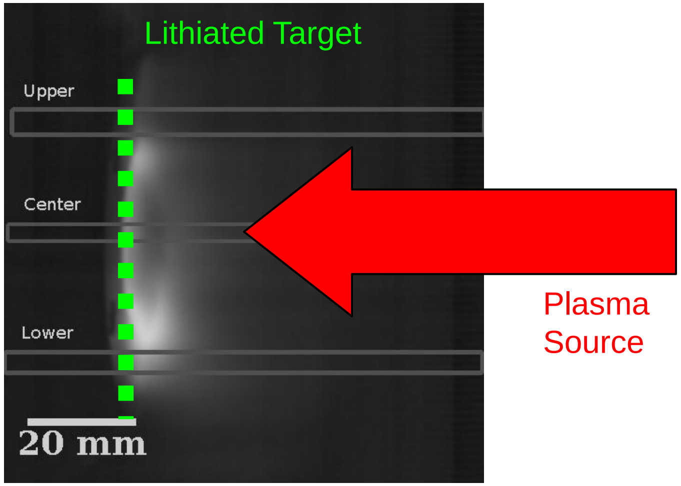


MAPP will be installed on midplane LTX port



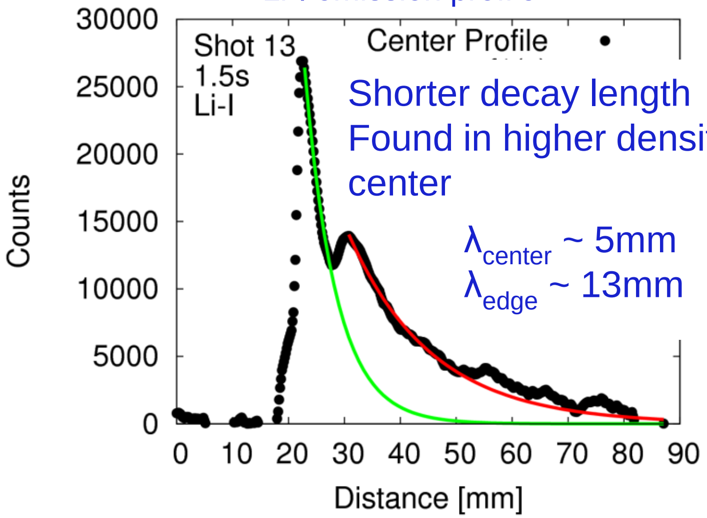
Lithium transport near divertor target being studied with Magnum-PSI linear test stand

- Transport of eroded lithium needed for plasma modeling and PFC development
  - Heat flux reduction via lithium radiation in the SOL – how does it get there?
  - Control of lithium inventory critical to reactors to avoid tritium codeposition and build-up
- Magnum-PSI reproduces divertor plasmas on target
  - Lithiated TZM example shown
  - Emission profiles in known background plasma provide basis for testing transport models



Li-I emission during exposure

Li-I emission profile



M. Jaworski et al, PPPL

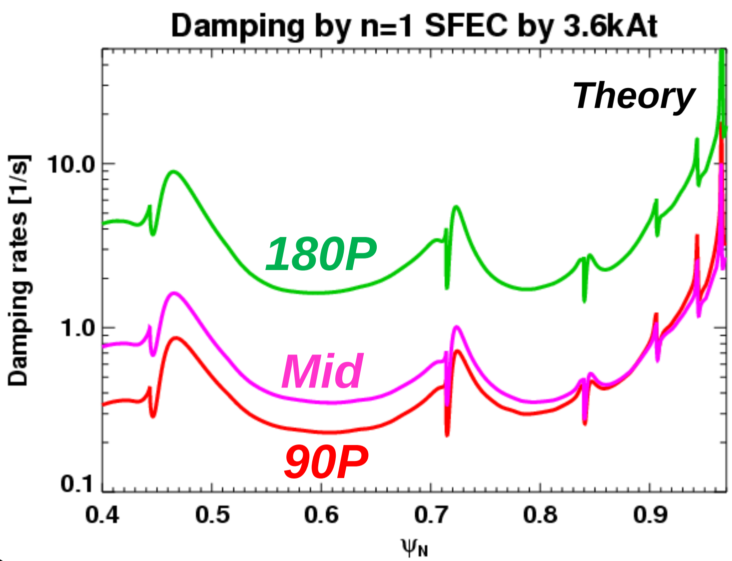
Summary

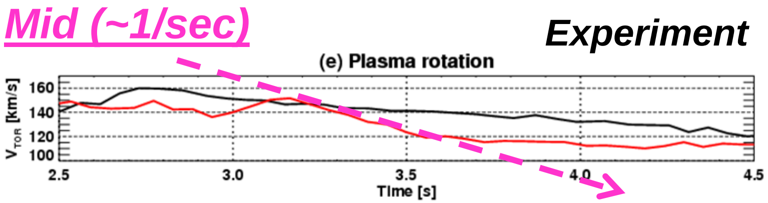
- NSTX Upgrade Project on-track, proceeding well
- Good progress in preparing for NSTX-U operations
- 5 year plan development underway
- Team strongly engaged in collaborations supporting NSTX-U, ITER, FNSF → broad scientific impact

Backup

Study on Neoclassical Toroidal Viscosity and Magnetic Braking in KSTAR – extends results from NSTX, DIII-D

- In 2011, n=1 resonant magnetic perturbations were successfully used to modify ELMs, under strong collaborations with PPPL
- Magnetic braking of rotation was also observed and analyzed by combined NTV theory
- Combined NTV theory predicted +180 phasing>midplane alone>+90 phasing for NTV, consistently with observed magnetic braking and rotation damping →
- Plan for 2012: NTV braking experiments, focused on bounce-harmonic and superbanana-plateau resonances, will be performed, and PPPL support on computations will be continued





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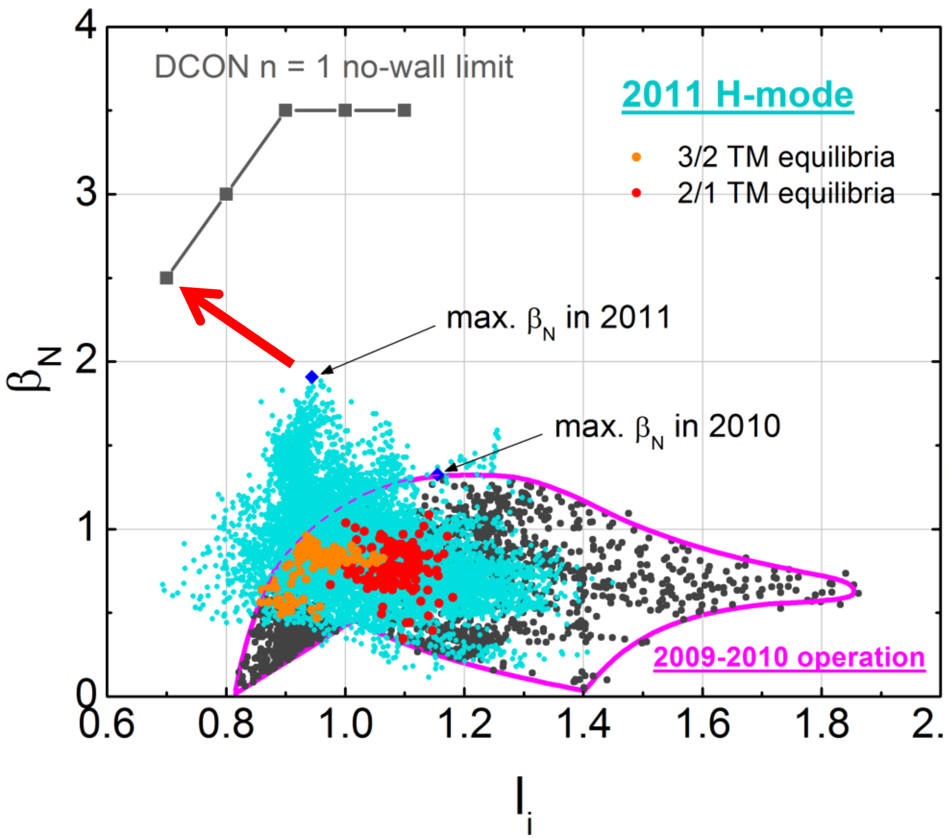
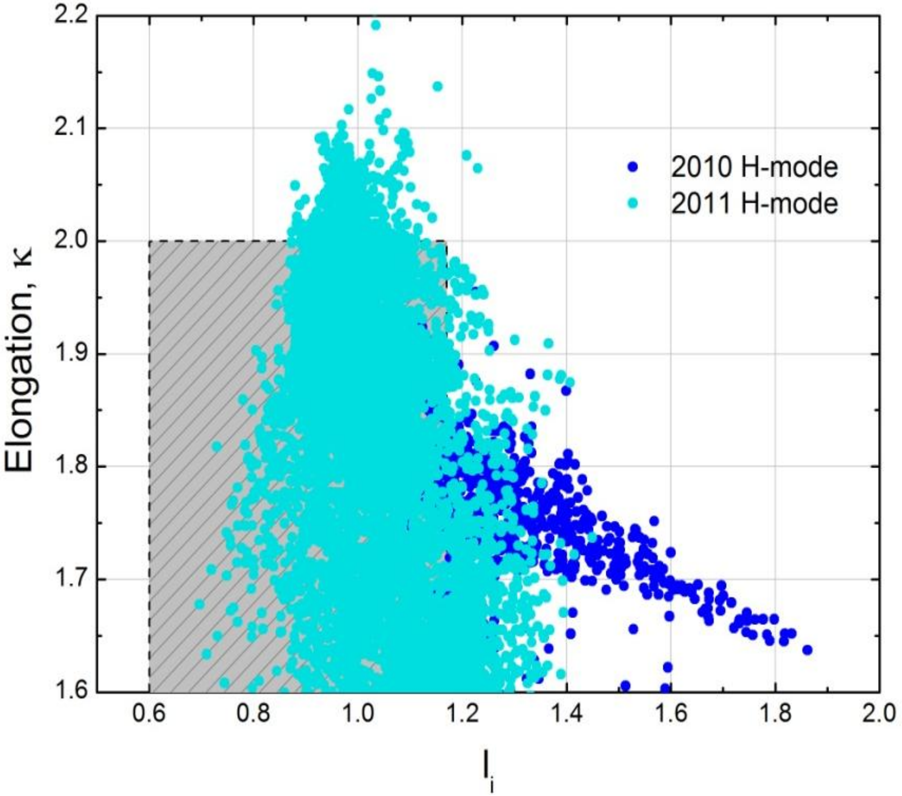
KSTAR equilibrium operation space compared to n = 1 ideal no-wall MHD stability limit demonstrating KSTAR plasma approach toward this limit.



Standard (l_i, β_N) operational stability space diagram for KSTAR through the year 2011 along with the static ideal n = 1 MHD no-wall for H-mode pressure profiles. The red arrow indicates the primary direction targeted for plasmas in this experiment.



(l_i, κ) operational stability diagrams for the present KSTAR database. The grey area represents the design target region.

Y.S. Park, S. Sabbagh et al., Columbia U

Lab-based R&D on liquid metal technology will inform long term PFC decisions:

Pre-NSTX-U restart R&D initiated by PPPL:

Laboratory studies of D uptake as a function of Li dose, C/Mo substrate, surface oxidation, wetting…

Tests of prototype of scalable flowing liquid lithium system (FliLi) at PPPL and on HT7

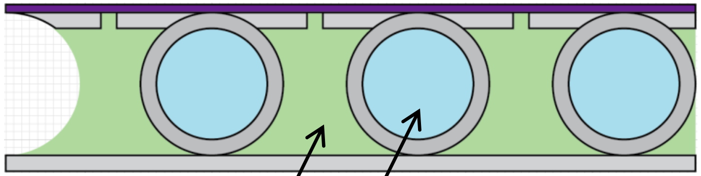
Basic liquid lithium flow loop on textured surfaces

Analysis and design of actively-cooled PFCs with Li flows due to capillary action and thermoelectric MHD

Magnum-PSI tests begin June 2012

Thin flowing Li film in FLiLi (Zakharov)

Soaker hose capillary porous system concept (Goldston)



Four proposals on Li-PFCs submitted to OFES Materials Solicitation to extend above work.

Preparing for upcoming international collaboration solicitation, which will include possible tests of Li PFCs on HT-7 and EAST

R. Kaita et al, PPPL