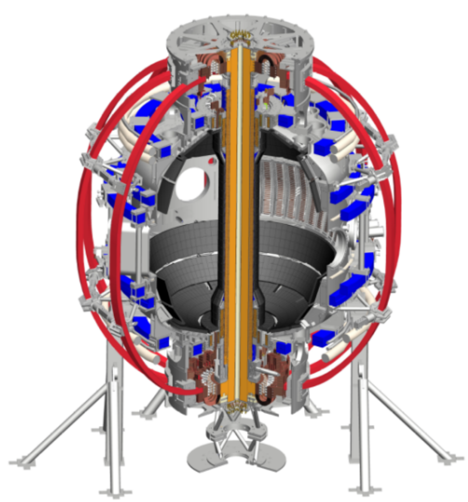
Overview of NSTX-U Collaboration Research Highlights

Jon Menard & Masa Ono

for the NSTX-U Team

July 9, 2012

Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
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JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
Seoul National U
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- NSTX-U Collaboration Program Overview
- EAST
- KSTAR
- DIII-D
- C-Mod
- MAST and other collaborations
- Lithium / PMI collaboration at PPPL / PU

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

- Transport and Turbulence
  - BES, micro-tearing w/ MAST, test TGLF code for ST profile predictions with DIII-D
- Macroscopic Stability
  - 3D δB effects, rotation damping on DIII-D, KSTAR, MAST, LHD, and RWM on DIII-D
- Energetic Particles
  - AE stability, diagnostics, reduced models for fast-ion transport on MAST, DIII-D
- Solenoid-Free Plasma Start-up
  - Develop plasma guns on Pegasus, CHI on QUEST, EBW start-up on MAST
- Wave Heating and Current Drive
  - Study/develop ICRF-only H-mode on EAST, edge & fast-ion interactions on DIII-D
- Advanced Scenarios and Control
  - Develop control of q, rotation profiles + snowflake on DIII-D
- Boundary Physics and Lithium Research
  - Study Li on EAST & LTX, assess high-Z Mo PFCs & pedestal turbulence on C-Mod

Selected Research Highlights from
NSTX-U / EAST collaboration

- Lithium research
  - Lithium granule injector for ELM triggering
  - Li pumping persistence, comparison to cryo-pumping

- First ICRF-only heated H-modes

- Gas-puff imaging of edge turbulence

- JHU Multi-Energy Soft X-Ray system

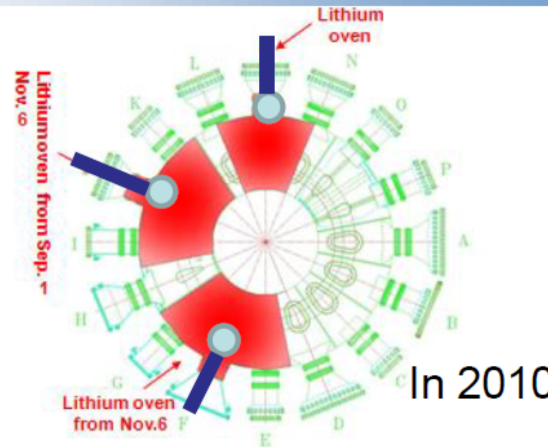
NSTX-U / EAST collaborations on Lithium

- **EAST is only other divertor H-mode facility using Li**
- NSTX Li powder dropper achieved 1st H mode on EAST and drastically reduced MHD
- Li granule injector recently installed on EAST
  - **Initial results: successfully used to trigger ELMs**
- Other recent experiments on EAST
  - Assessed lithium persistence
  - Assessed interplay between cryo-pumping and lithiumization

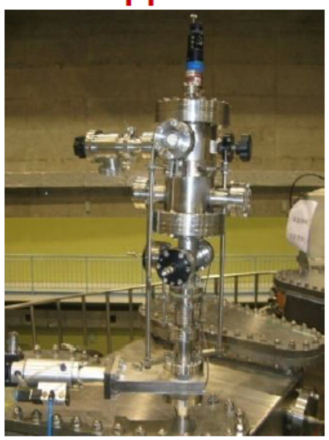
Methods of Lithium Coatings

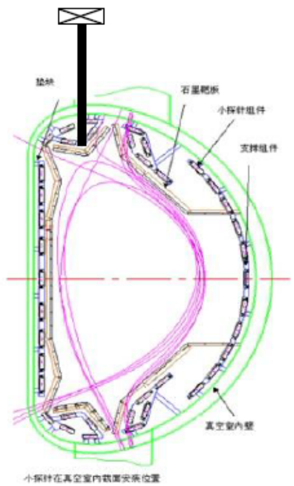
EAST

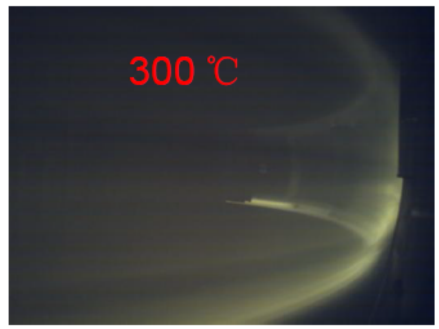
- **Li Oven Coatings :**
  - ✓ by evaporation, ionized by GDC or ICRF discharge
- **Real-time Li Coating:**
  - ✓ Lithium powder dropper used during plasma discharge

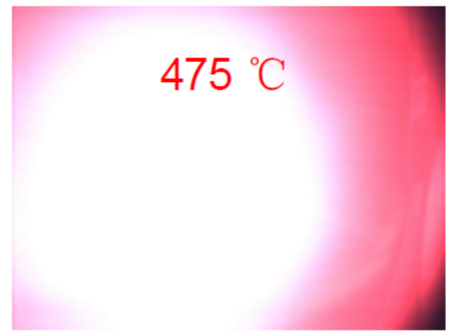


dropper









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

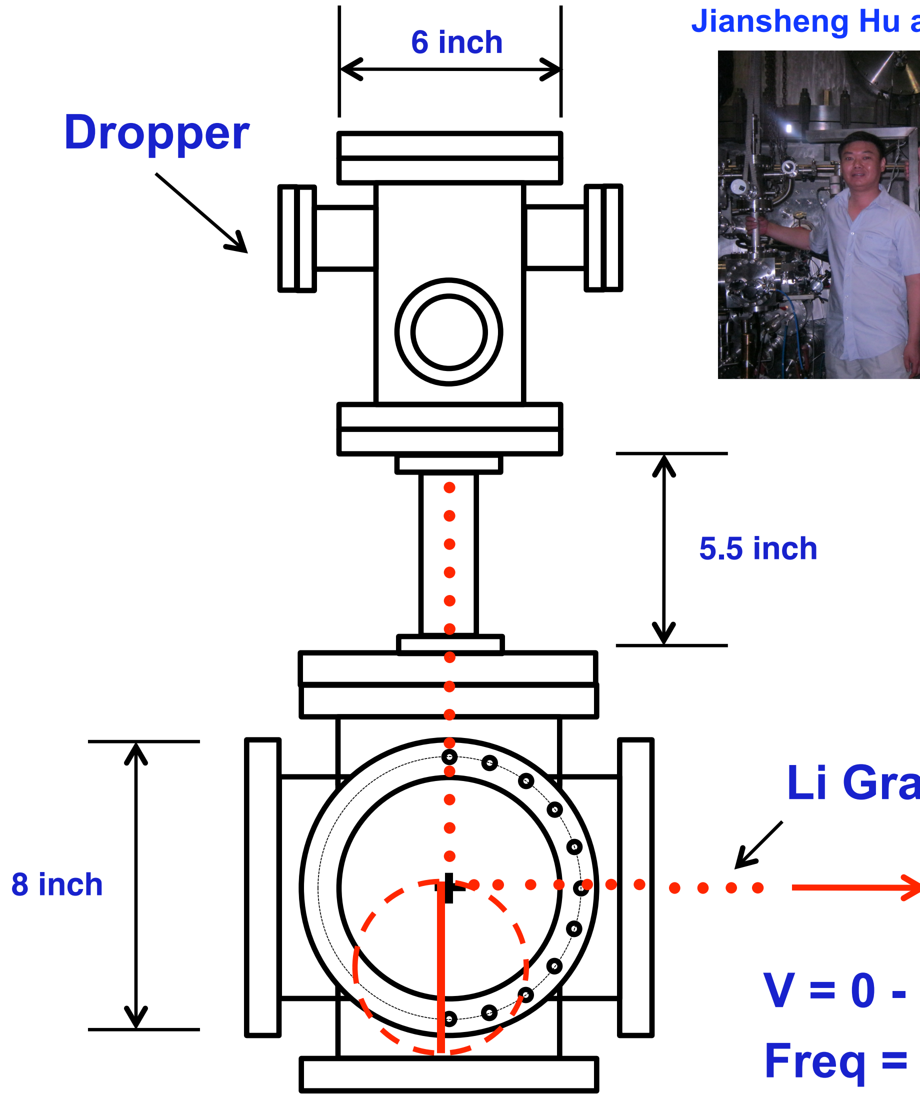
Dennis Mansfield (PPPL, retired)
Lane Roquemore (PPPL)

Independent Control:

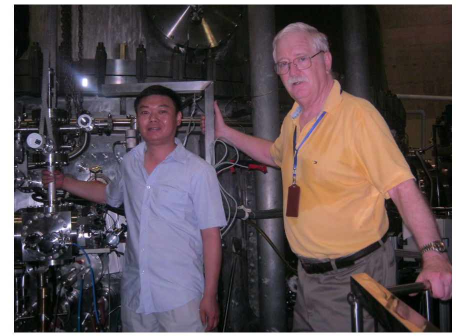
Granule Size
(change between shots)

Injection Speed
(ramp during shots)

Pacing Frequency
(ramp during shots)

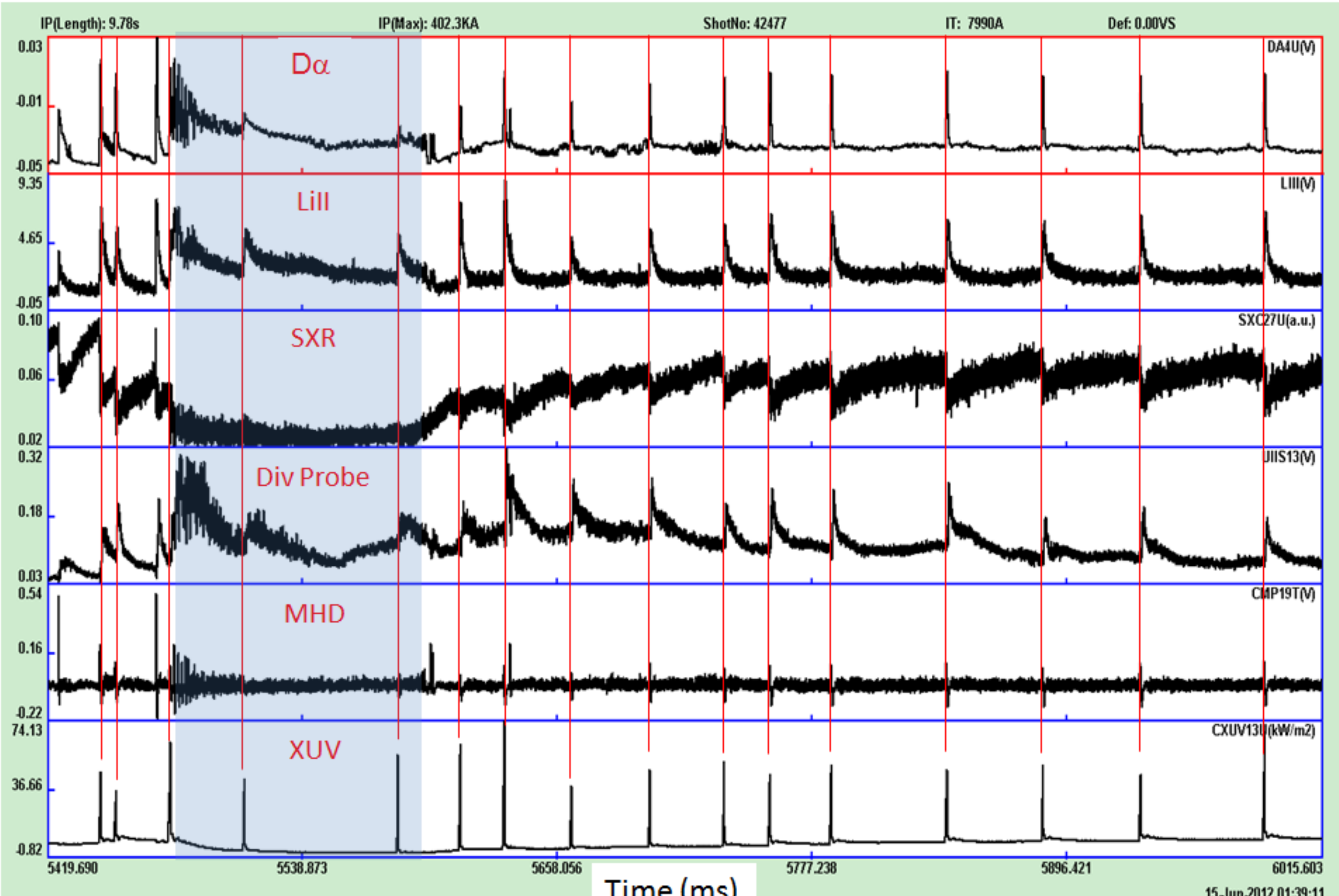


Jiansheng Hu and D. Mansfield



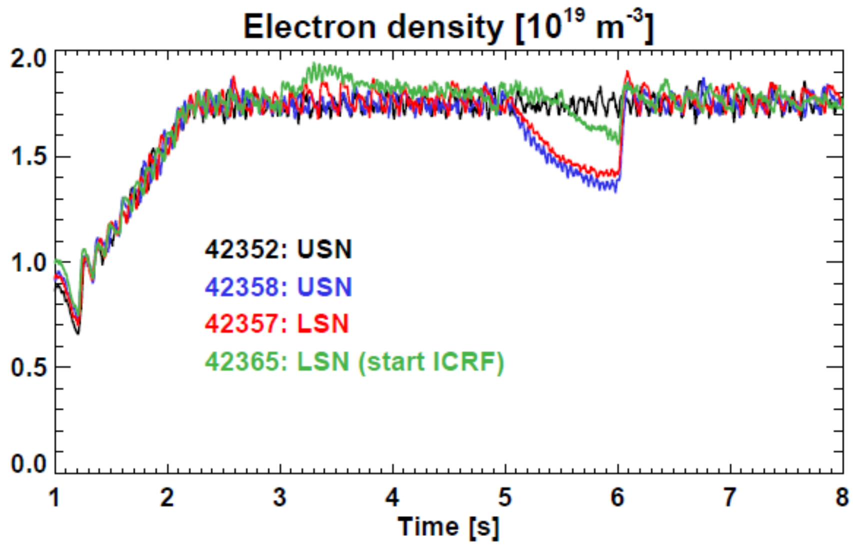
V = 0 - 100 m/s
Freq = 0 - 100 Hz

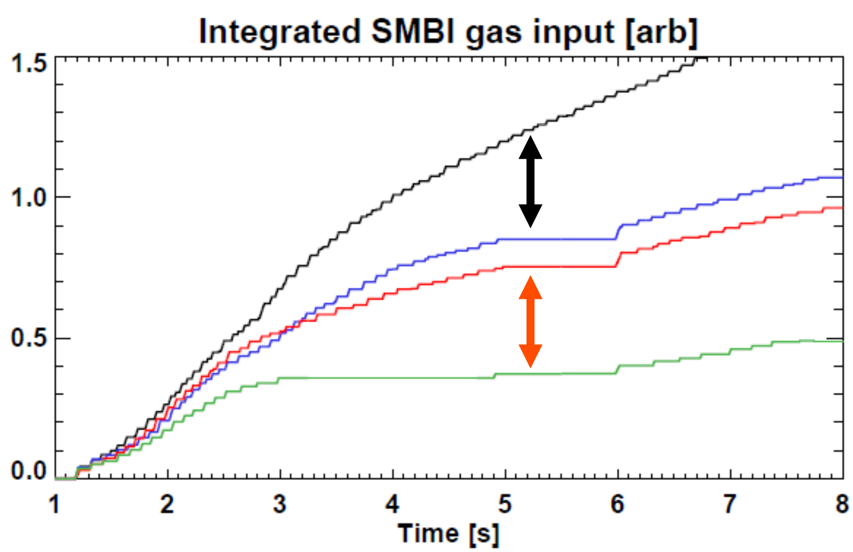
Triggered ELMs (~ 25 Hz) with 0.7 mm Li Granules @ ~ 45 m/s



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

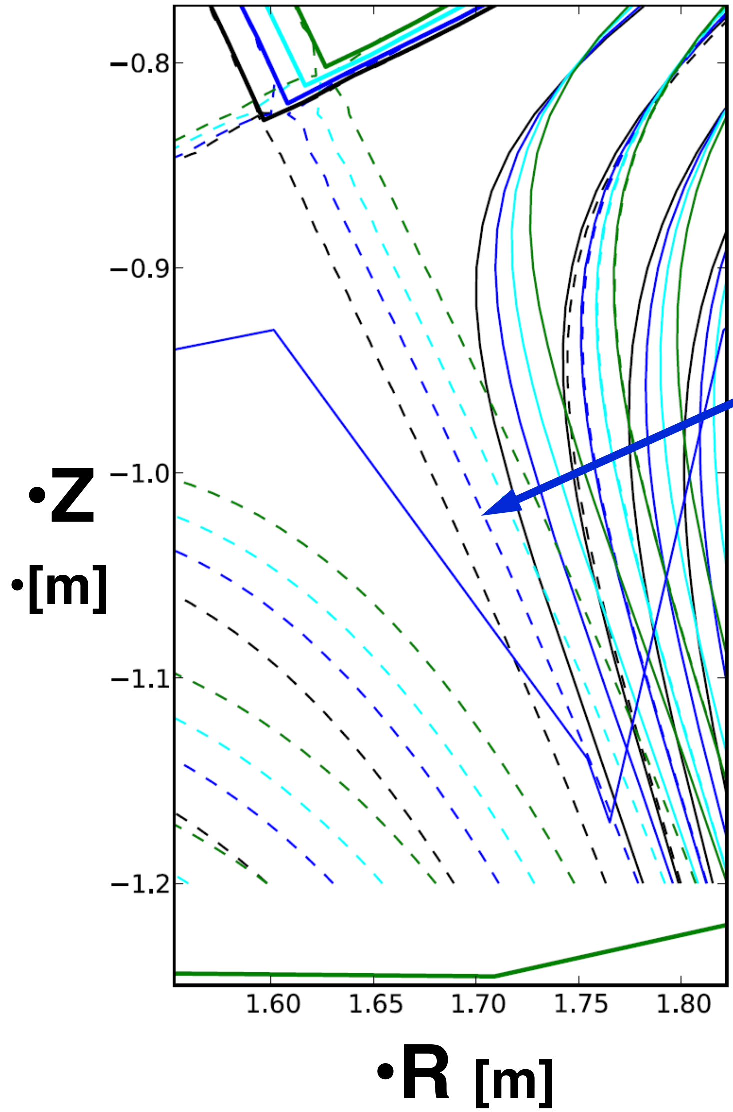
Jon Menard, Mike Jaworski et al., PPPL





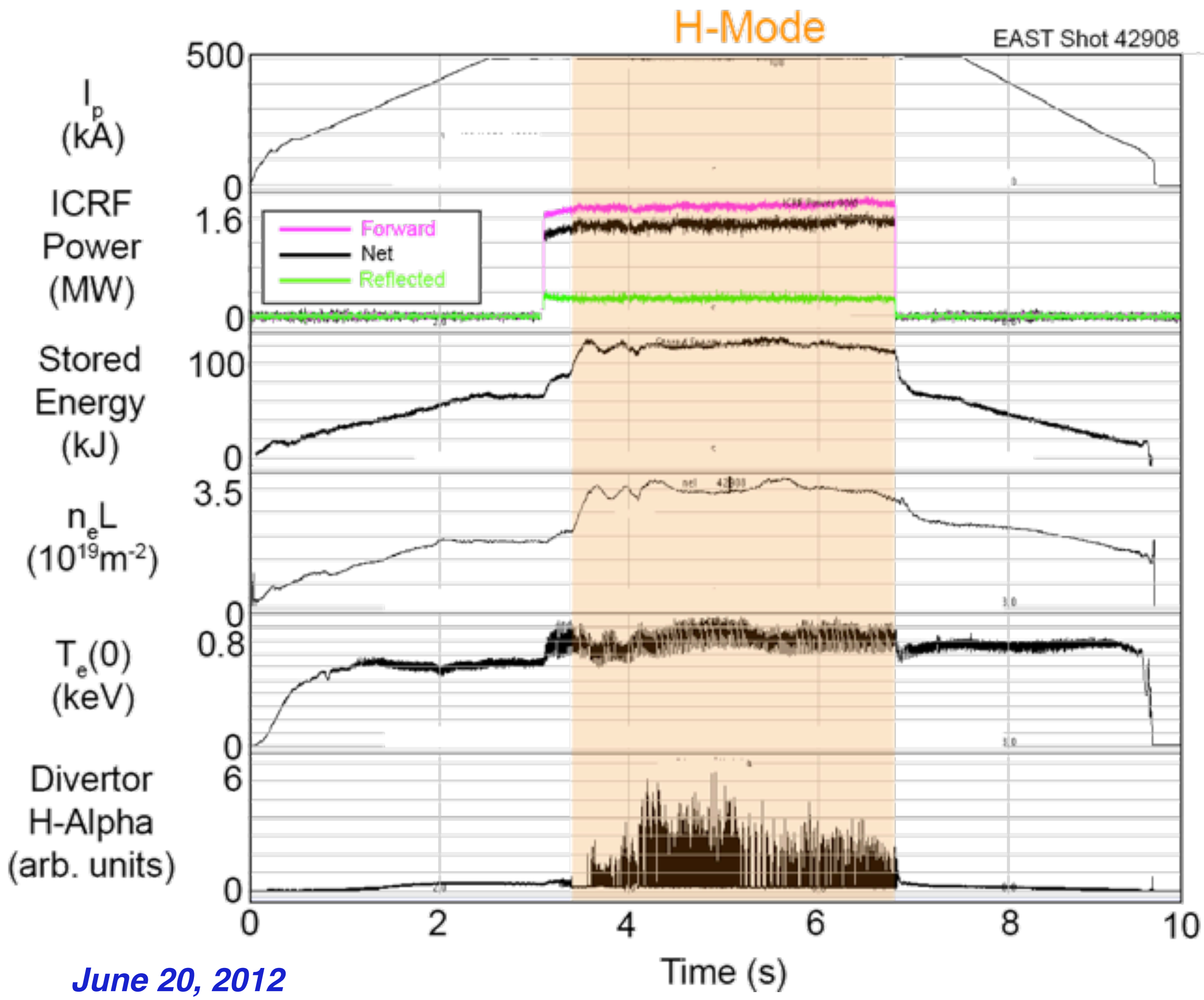
- Compared shots with same magnetic balance but similar increment in shot number
  - USN pumping stronger than LSN
- Observe 30-50% reduction in pumping after 6-8 shots
  - Each shot ~10s → 60-80 shot seconds of strong Li pumping
- Pumping decreased by factor of 2 after 20-25 shots (not shown)
  - 200-250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

Cryo-pumping quite sensitive to strike-pt position on EAST



- 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

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



- 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

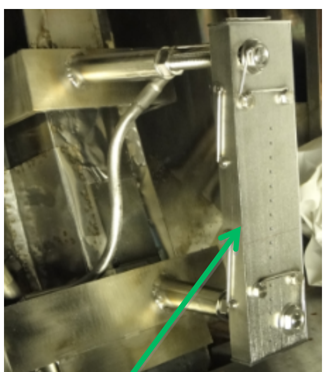
June 20, 2012

G. Taylor, et al., PPPL

Preliminary Results from EAST GPI experiments

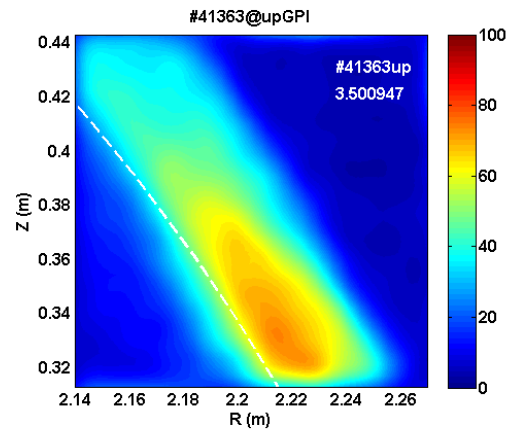
• in-vessel hardware

• Side-view
• reentrant windows

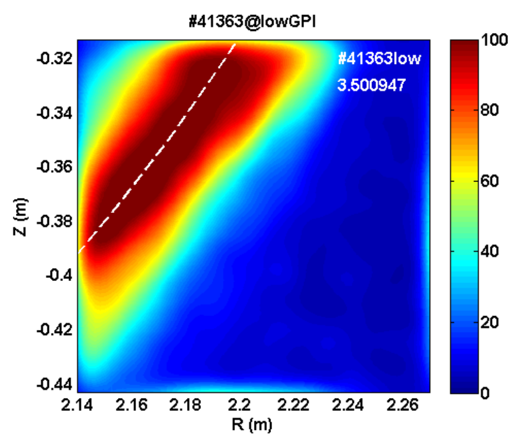


• Gas manifold

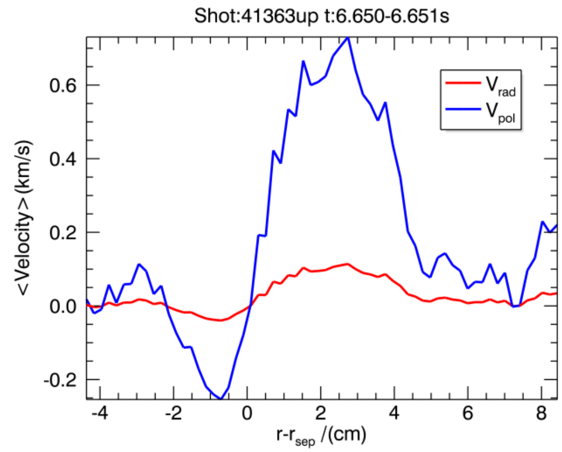
• upper GPI image

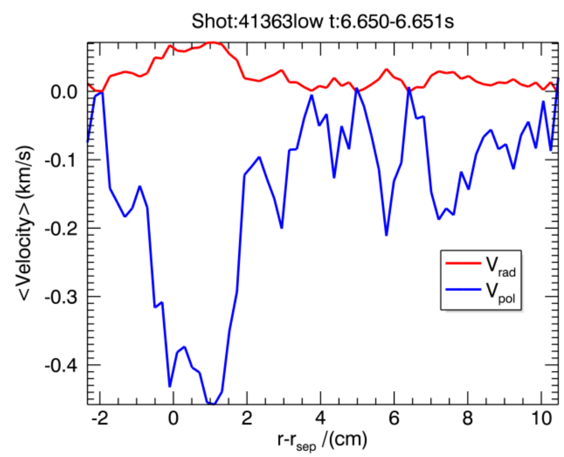


• lower GPI image



• Inferred turbulence velocities



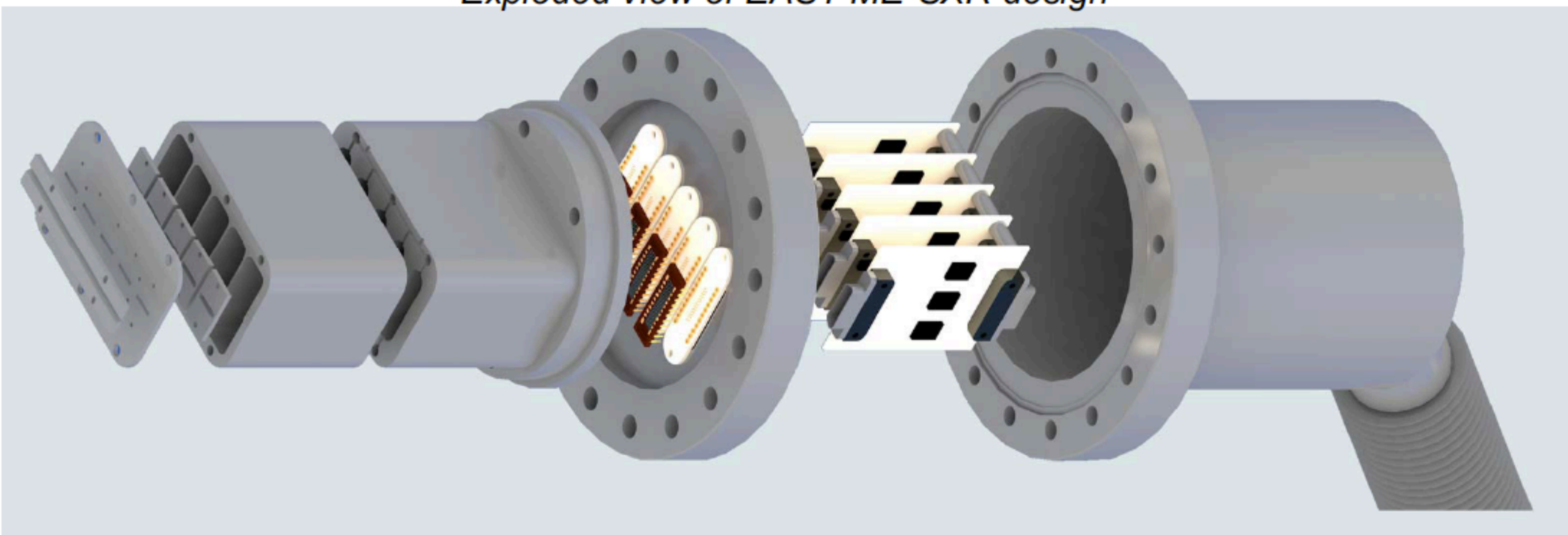


S. Zweben, et al., PPPL

JHU Multi-Energy Soft X-Ray System being implemented for EAST

- 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

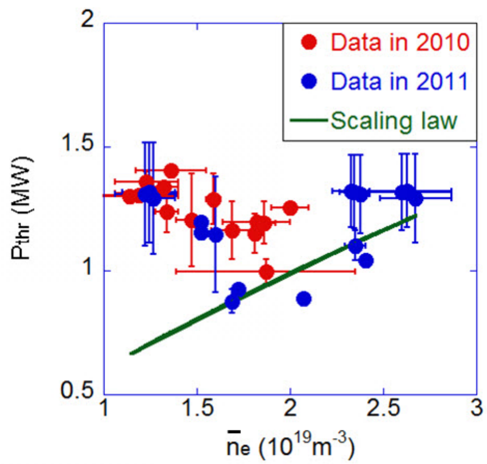
Exploded view of EAST ME-SXR design



Selected Research Highlights from
NSTX-U / KSTAR collaboration

- H-mode / ELM study
- Error Fields and Locking
- Neoclassical Toroidal Viscosity and Magnetic Braking
- High beta study
- Rotating MHD with Rotational Shear, and n = 2 NTV

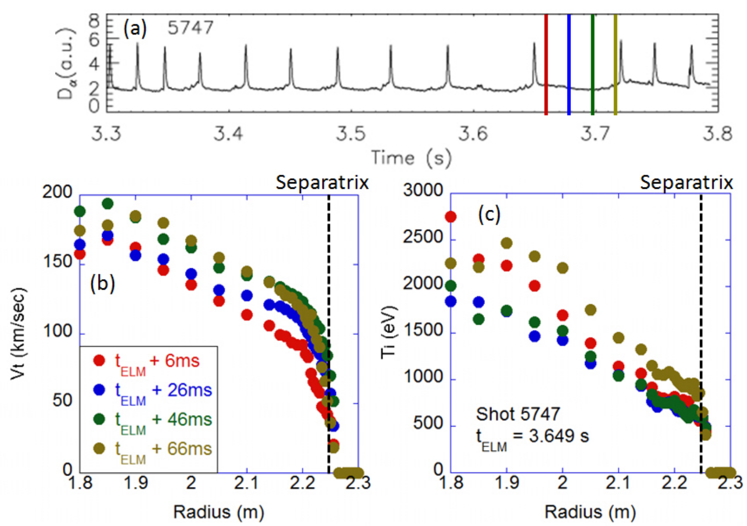
H-mode power threshold and confinement / ELM study at KSTAR



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



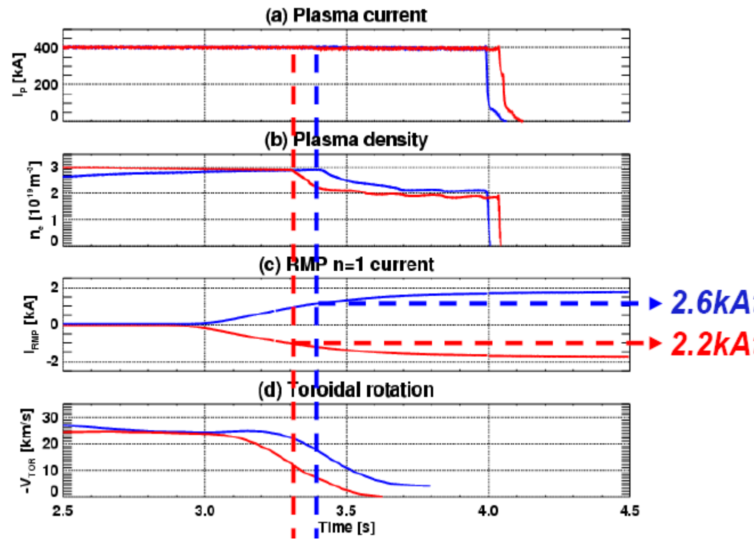
Vt and Ti profile evolution during the ELM cycle[1]

- 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.

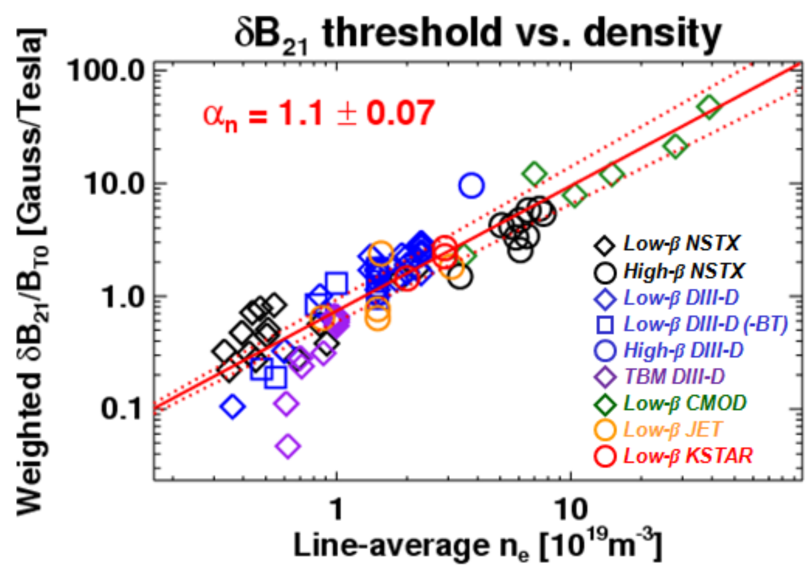
[1]J-W. Ahn, ORNL submitted to NF (2012)

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



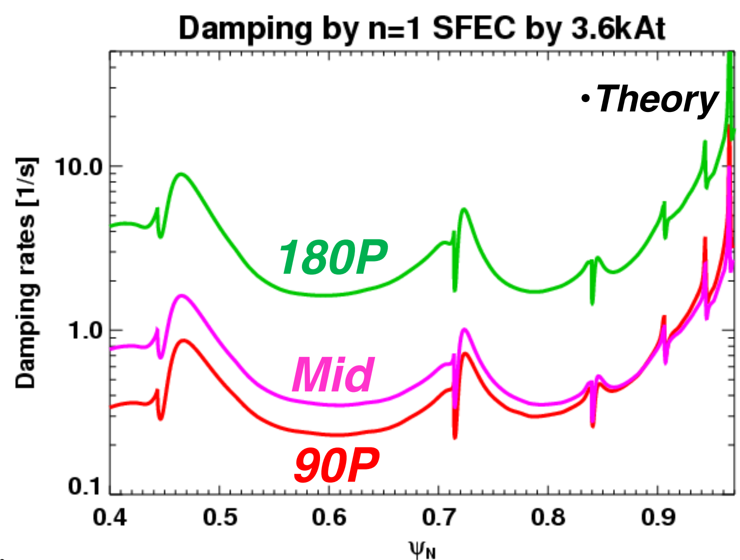
- Resonant field thresholds were analyzed by IPEC and consistently combined with locking scaling for tokamaks (ITPA activity)
- Plan for 2012: The n=1 EF study will be extended to full 4 toroidal phase scan in both resonant and non-resonant cases, and also to fully shaped L-mode and H-mode plasmas

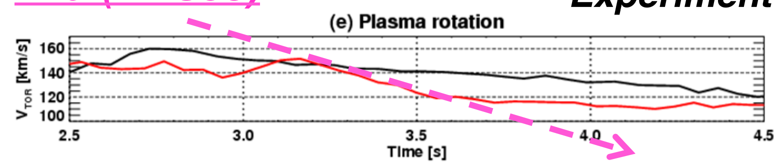


J-K Park, et al., PPPL

Study on Neoclassical Toroidal Viscosity and Magnetic Braking in KSTAR

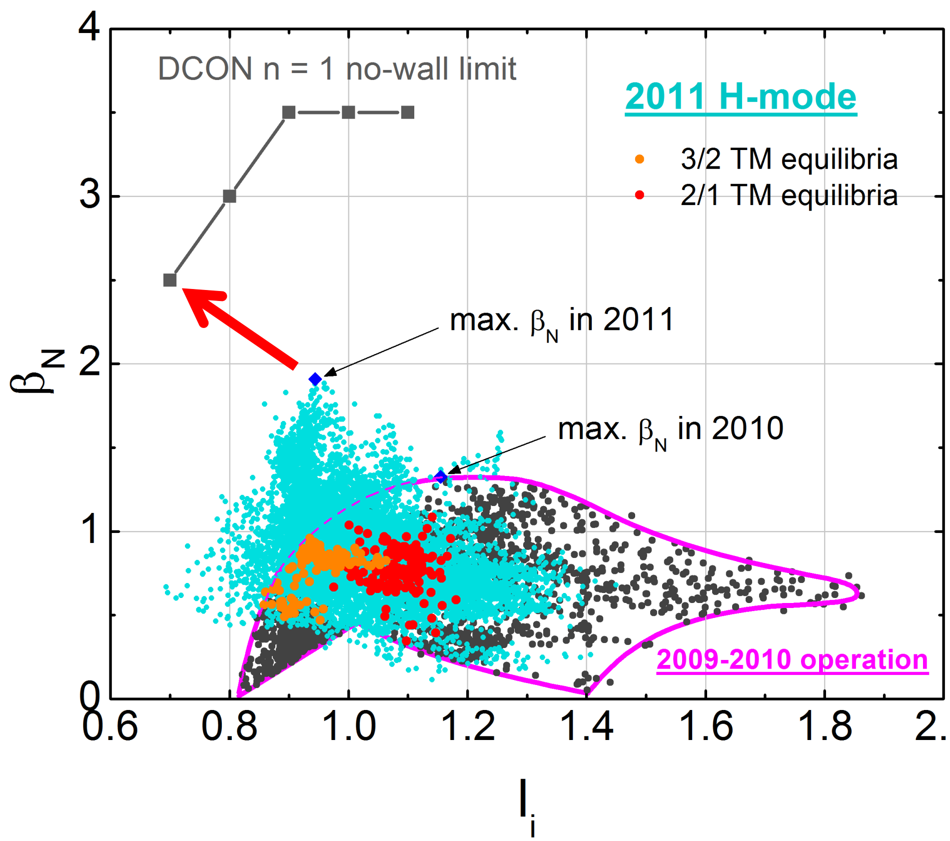
- **In 2011, n=1 resonant magnetic perturbations were successfully used to modify ELMs, under strong collaborations with PPPL**
- **Magnetic braking of rotation was also observed and analyzed by combined NTV theory**
- **Combined NTV theory predicted +180 phasing>midplane alone>+90 phasing for NTV, consistently 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**



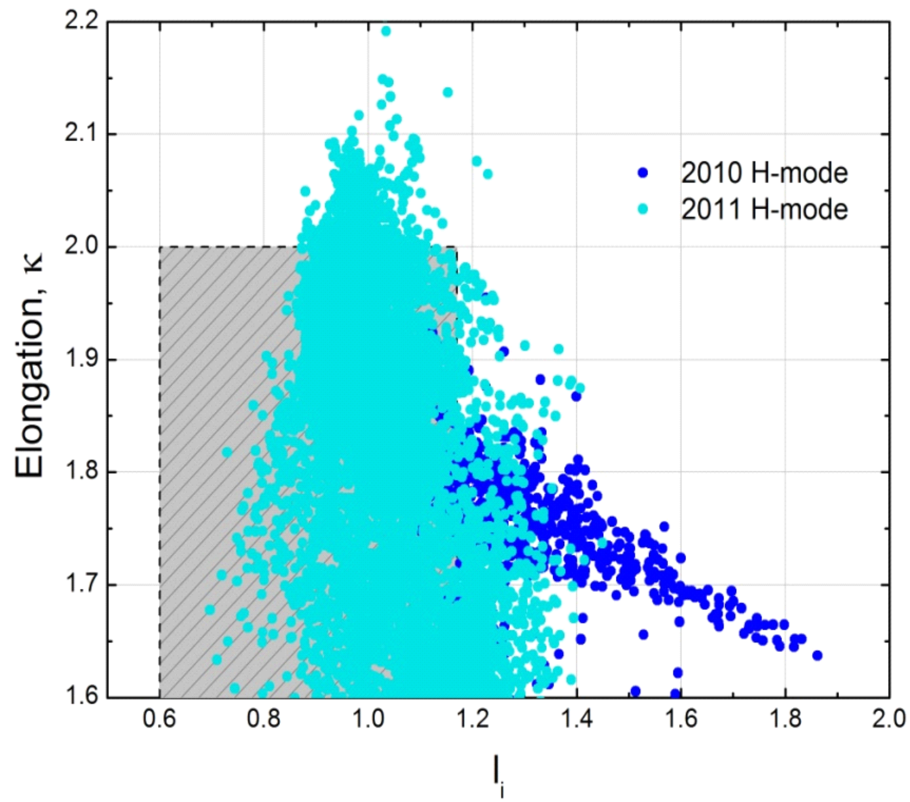


J-K Park, et al., PPPL

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



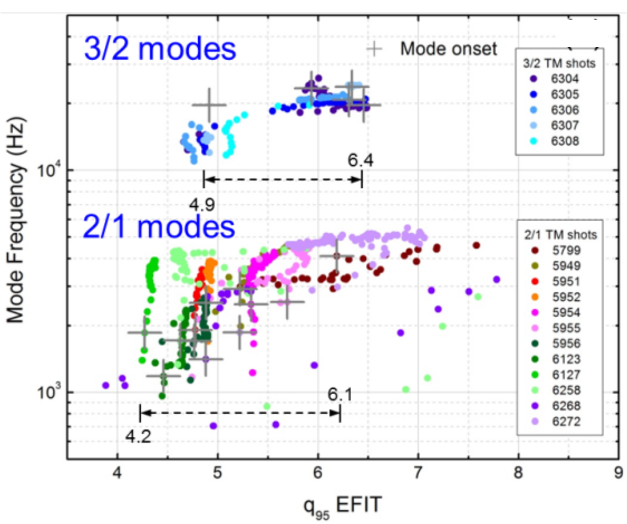
Standard (l_i, b_N) operational stability space diagram for KSTAR through the year 2011 along with the static ideal n = 1 MHD no-wall for H-mode pressure profiles. The red arrow indicates the primary direction targeted for plasmas in this experiment.



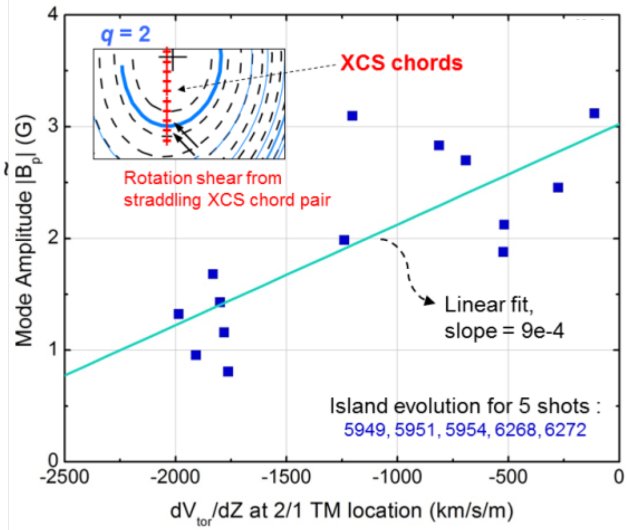
(l_i, k) operational stability diagrams for the present KSTAR database. The grey area represents the design target region.

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

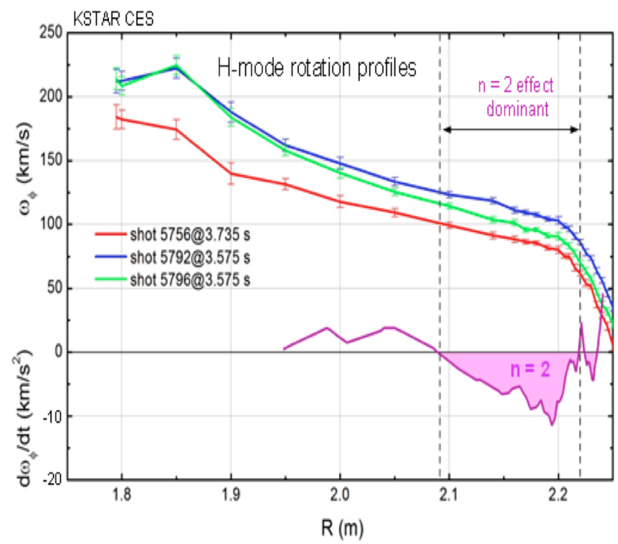
KSTAR 2/1 and 3/1 rotating MHD mode onset, and correlation with plasma rotation shear, and n=2 NTV braking profile characterized



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

Selected Research Highlights from

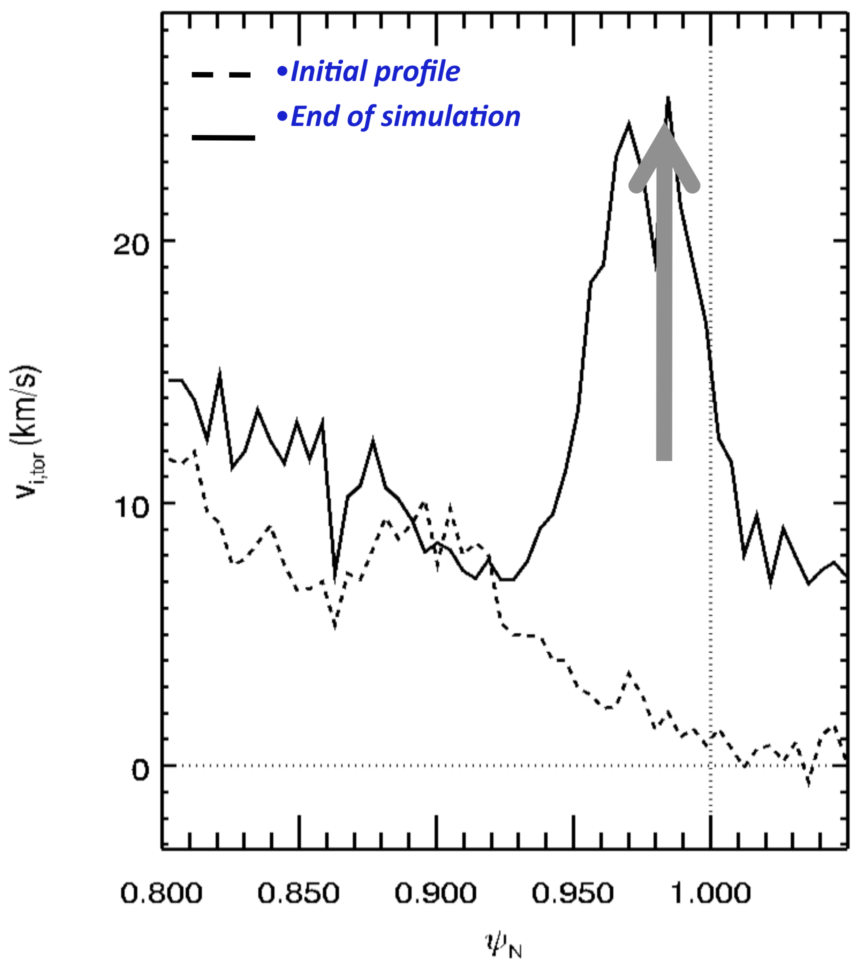
NSTX-U / DIII-D collaboration

- H-mode pedestal
- Neoclassical Tearing Stabilization Control
- IPEC MHD simulation
- Snow-flakes

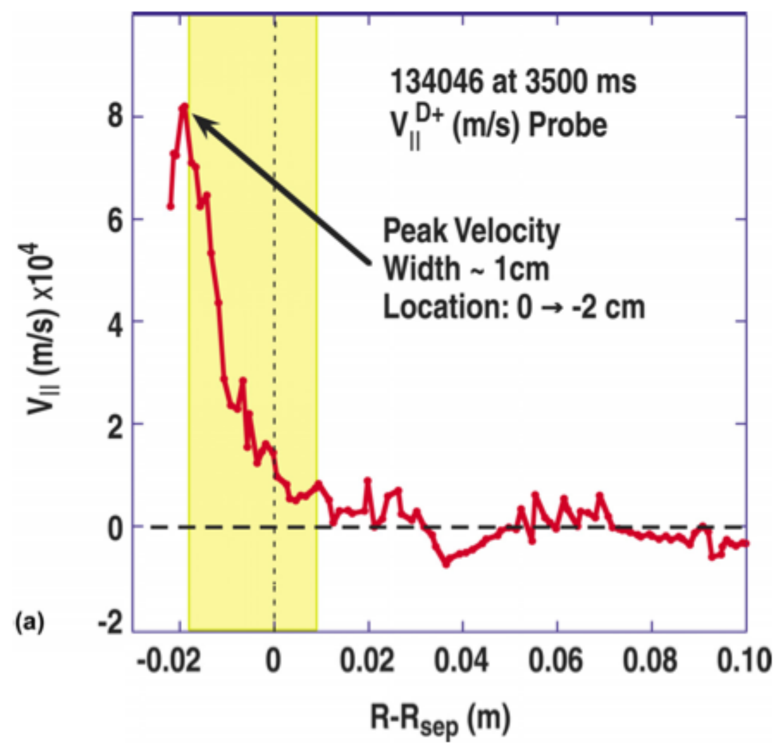
Kinetic neoclassical effects in DIII-D H-mode pedestal using XGC0

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)

Successful NTM Suppression with Feed-back on q-surface with Real-time Steerable Mirror

Real-time steerable mirror control of the EC deposition location

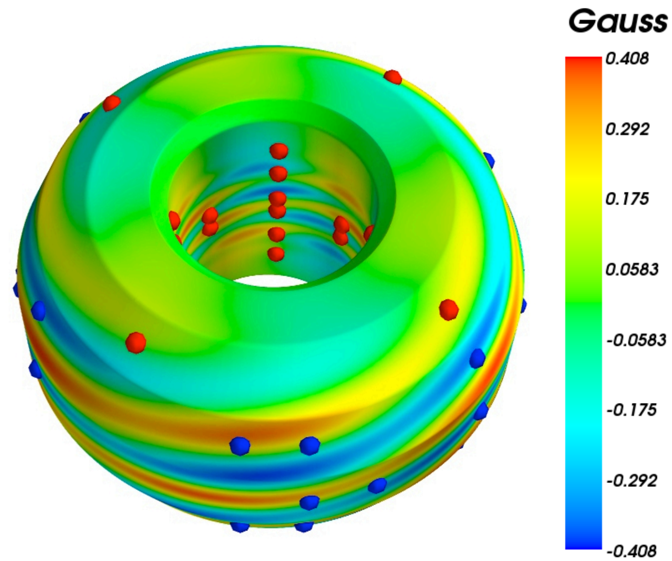
- **Faster NTM suppression**
- **Capability to run experiments consistently in high beta.**
- **Possibility to control NTMs with lower EC power.**
- **Suppress multiple islands at the same time**

- **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)

NSTX IPEC Graduate Thesis Collaboration with DIII-D

- 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 $n \leq 4$ plasma response detection
    - High field side sensors fully redesigned for expected complex poloidal structures
  - Calibration and installation to begin this fall



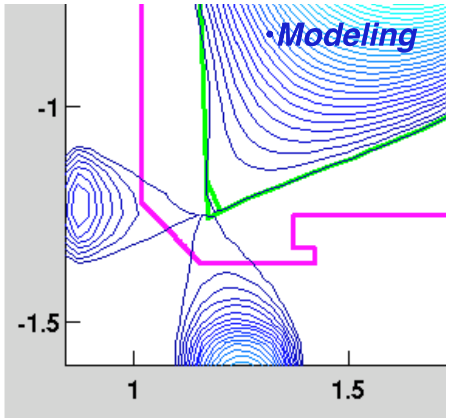
•*Perturbed plasma field at DIII-D wall (with synthetic diagnostic locations)*

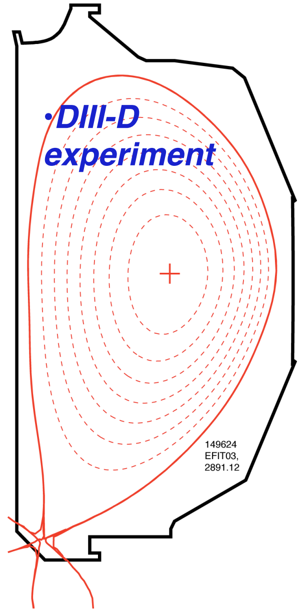
- Semi-automated EM torque measurement GUI completed in preparation for upgraded magnetic data for NTV and resonant breaking (spring 2012)
  - Initial application for $n \leq 2$ has exposed required accuracy limits
- NTV torque module being built into IPEC (summer 2012)
  - Extension to non-ideal equilibrium calculation (2012-13) will be applied in support of 3D magnetics EM torque measurement experiments
- Full thesis proposal being presented soon!

N.C. Logan et al., (PPPL)

Snowflake divertor geometry 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.,

Selected Research Highlights from
NSTX-U / C-Mod collaboration

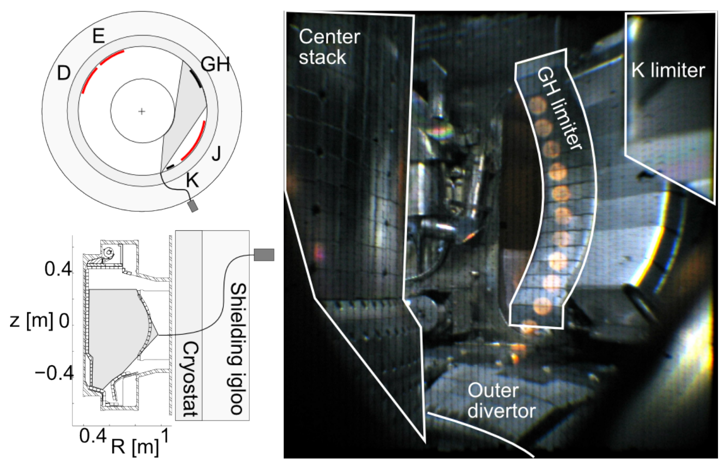
- Molybdenum PFC Spectroscopy Study

- H-mode Pedestal Scaling Study

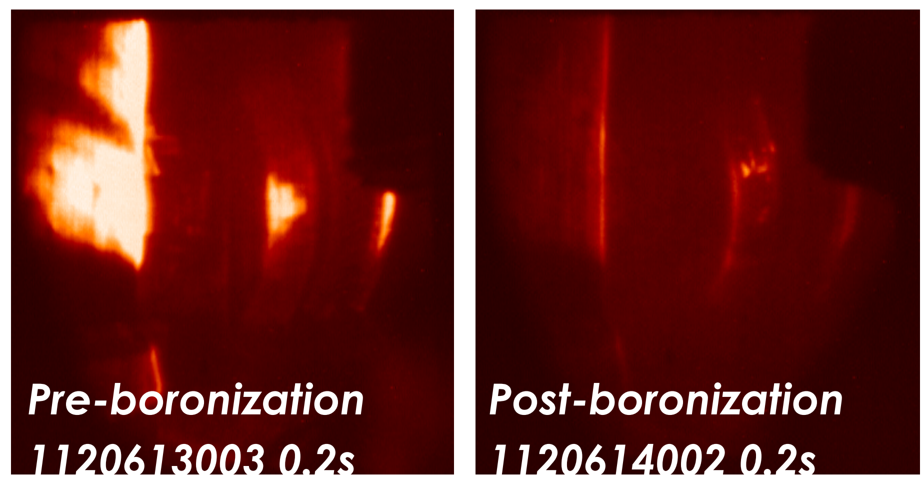
Material erosion studies at C-Mod (high-Z wall and low-Z coatings)

- **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

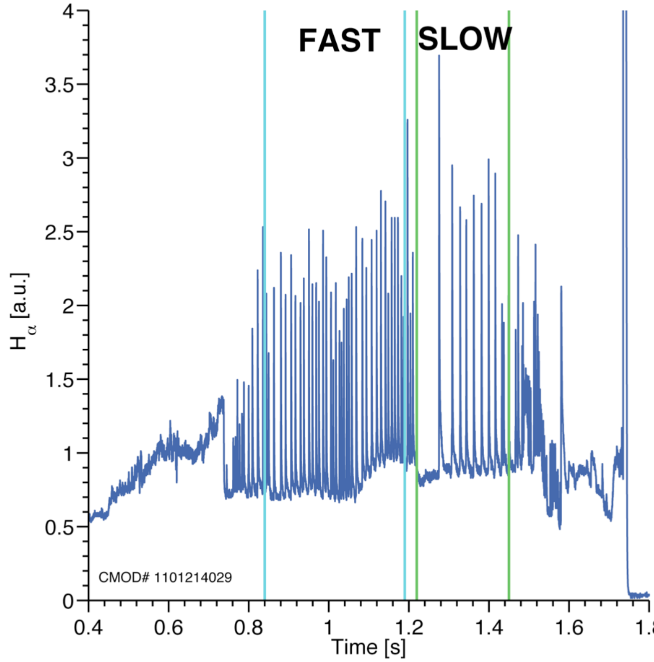


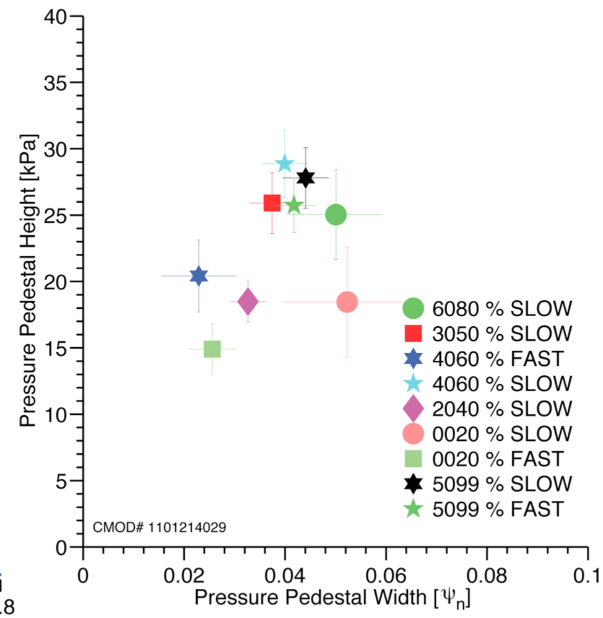
Mo I emission pre- and post-boronization in C-Mod

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 and is 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.

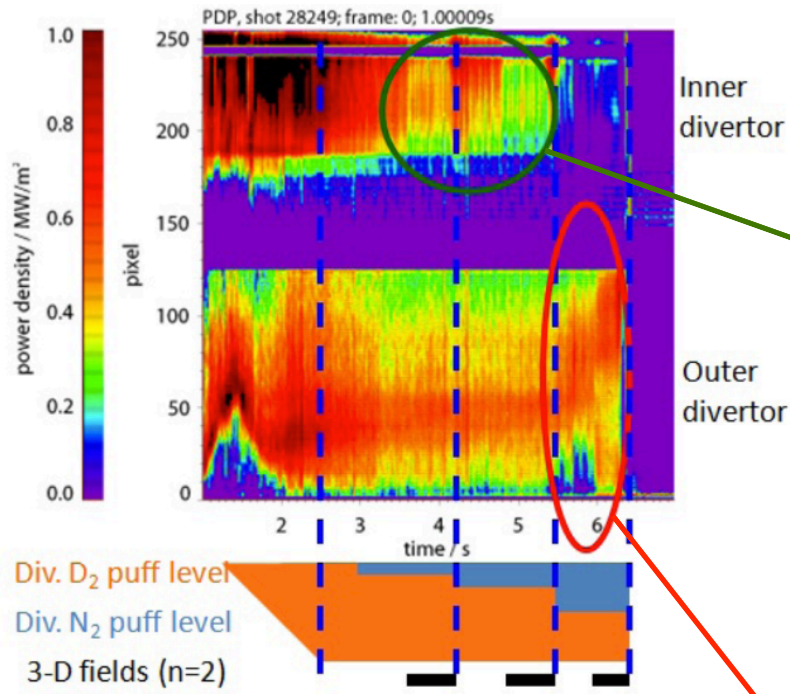
A. Diallo et al., PPPL

Selected Research Highlights from
NSTX-U / Other Collaborations

- ASDEX-U 3-D Fields Divertor Detachment Study
- Fast-ion D-alpha diagnostic on ASDEX-U and MAST
- MAST BES Micro-Tearing Synthetic Diagnostic and Charge Fusion Product Diagnostic
- Magnum-PSI Lithium Study
- PRGASUS Gun Start-up
- QUEST CHI/PMI/Start-up
- GAMMA-10 PMI/ECH Development
- Disruption Mitigation System for ITER

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

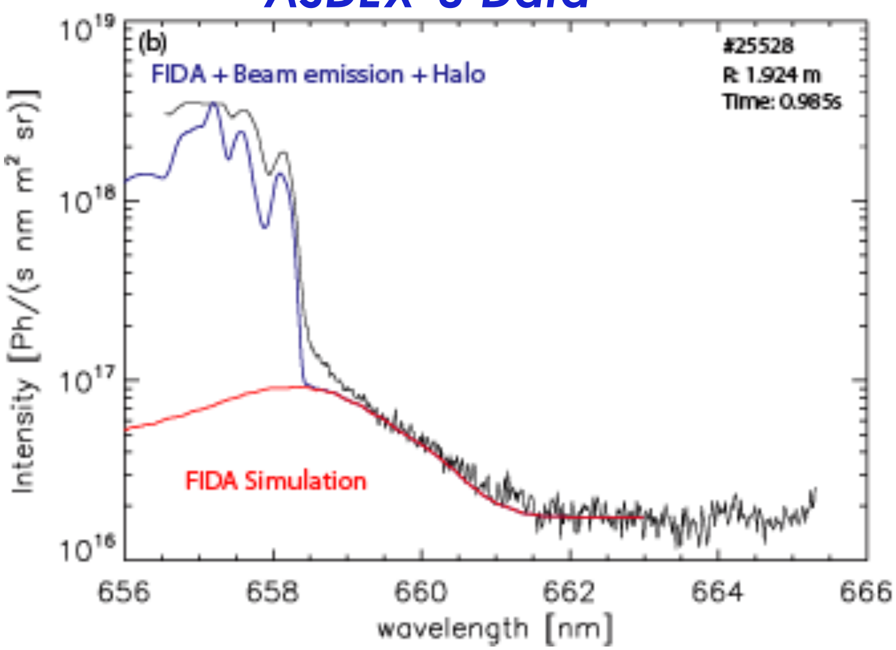


- Deuterium gas puffing induced power detachment at outer divertor but particle detachment was only produced by additional nitrogen puffing
- 3-D fields (n=2) application reduced the inner divertor power density but there was no change at the outer divertor.
- Applied 3-D fields reduced particle detachment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

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

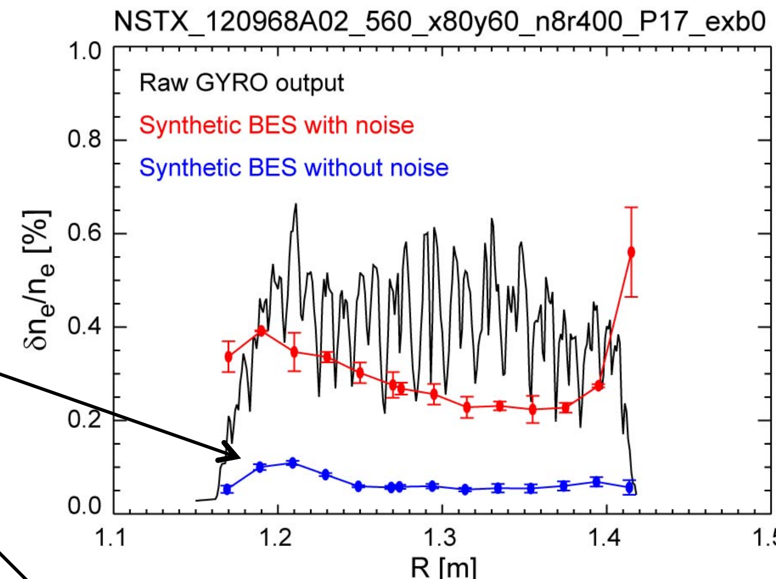
MAST-NSTX collaboration testing sensitivity of BES to microtearing turbulence through synthetic diagnostics

- 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:

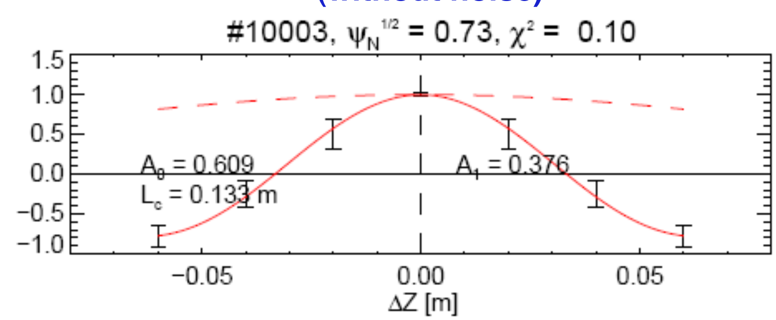
    detectable correlated fluctuation levels ($\delta n/n \sim 0.1\%$)

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

Density fluctuation (rms)



Poloidal correlation from synthetic diagnostic (without noise)



<u>Future plans:</u>

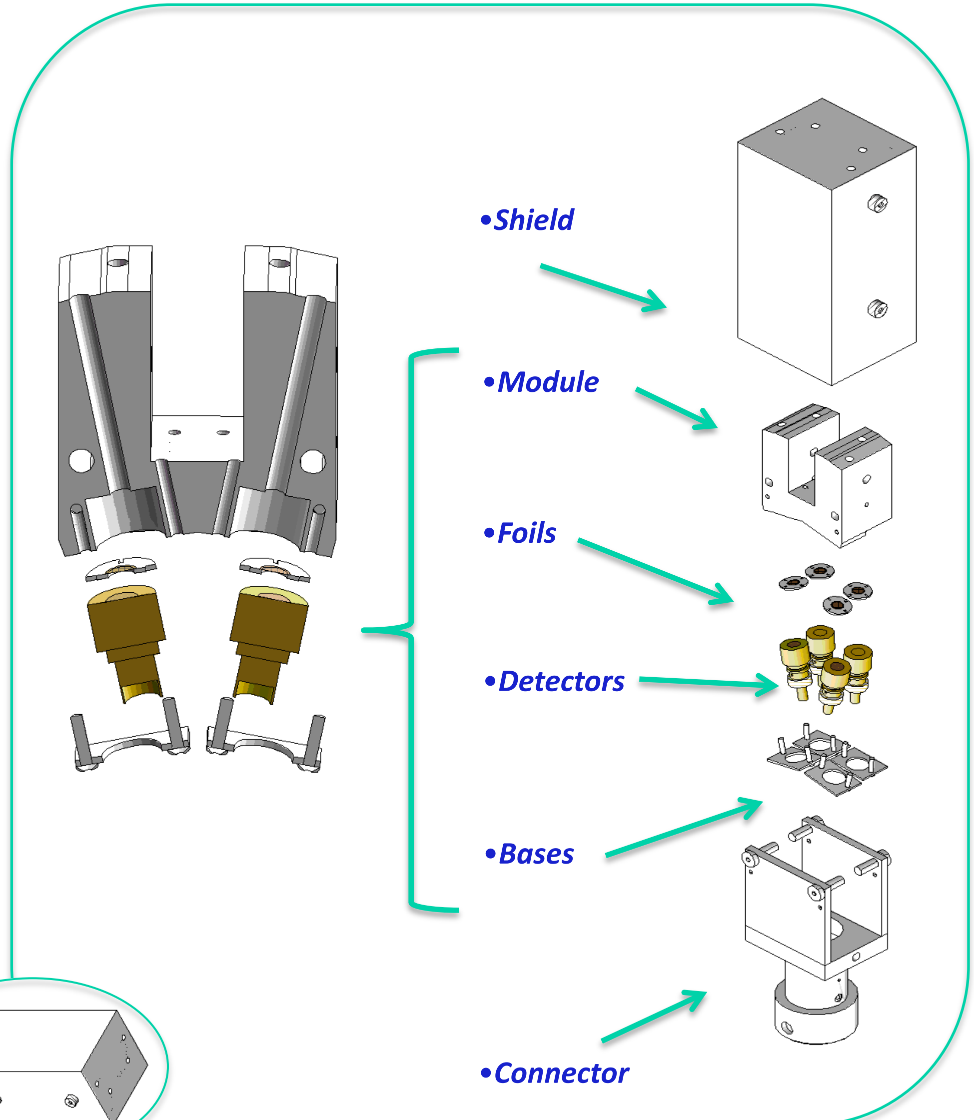
- Pursue non-linear simulations for MAST discharges with available BES data
- Propose experiments for FY13 at next MAST research forum (Dec 2012) to focus on relationship between collisionality scaling and microtearing turbulence

W. Guttenfelder, et al. PPPL

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

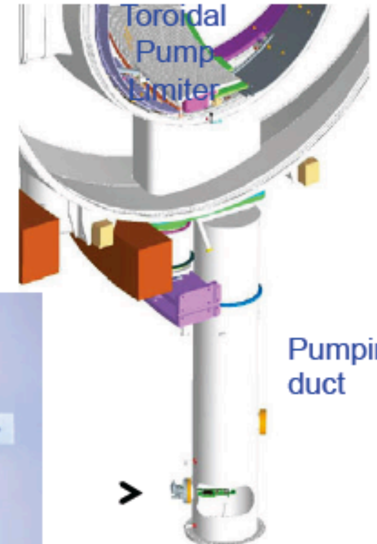


R. Perez et al., Florida International University

NSTX Dust Detector Demonstrated on Tore Supra

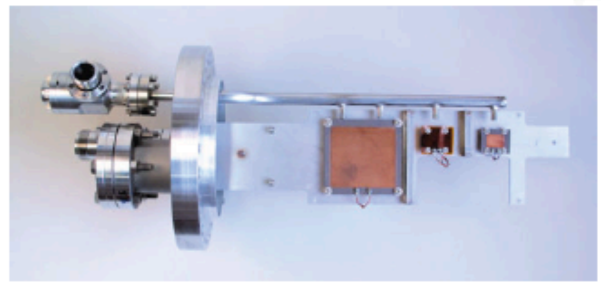
- Real-time dust measurement is necessary to safely manage dust in tokamak fusion reactors.
- A novel electrostatic dust detector was developed at PPPL and demonstrated on NSTX
  see: 'First real-time detection of surface dust in a tokamak' C. H. Skinner et al., Rev. Sci. Instrum., 81 (2010) 10E102.

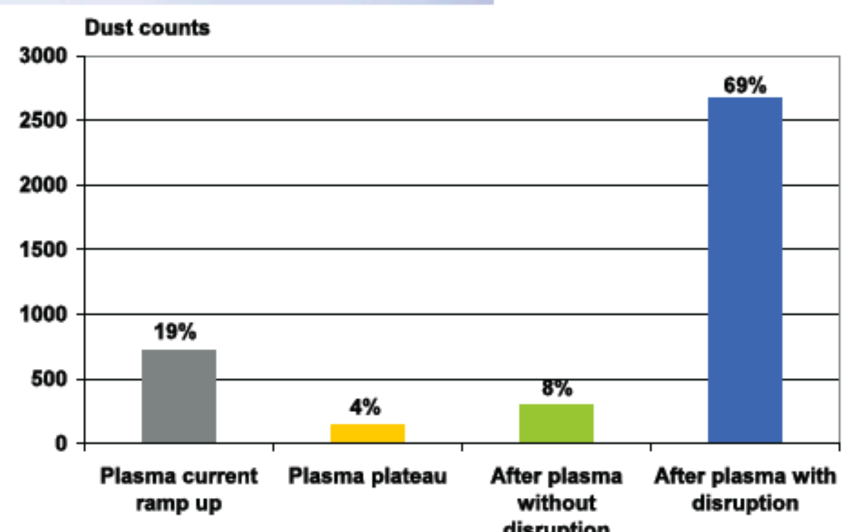
- Dust detection technology was successfully transferred to Tore Supra and used to correlate dust production with plasma events.
- 82% of the dust particles detected were due to disruptions
  (including 13% detected during plasma current ramp up, following a shot with disruption).
  For complete results see 'First results from dust detection during plasma discharges on Tore Supra' H. Roche et al., Phys. Scr. T145 (2011) 014022.



Pumping duct

A set of 3 electrostatic detectors from PPPL

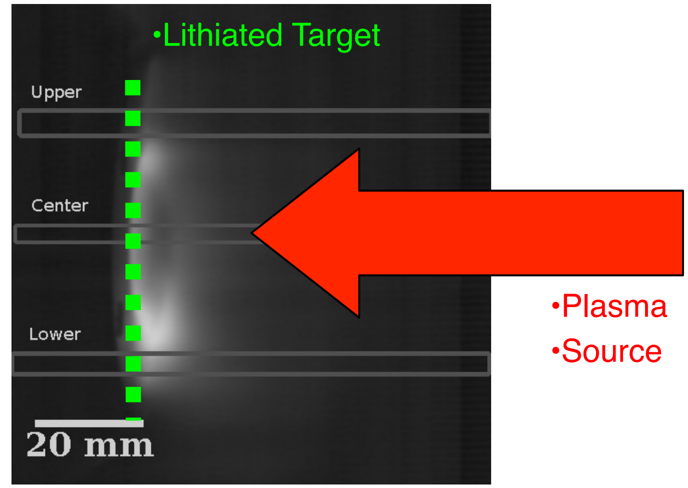




C. Skinner et al, PPPL

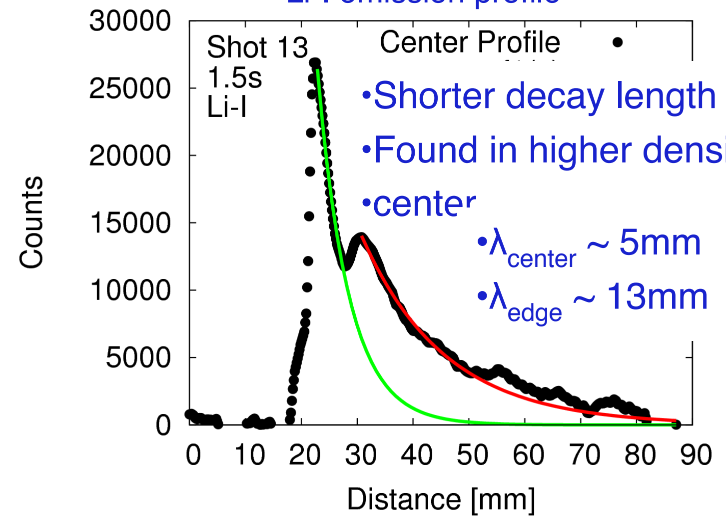
Lithium transport near divertor target being studied with Magnum-PSI linear test stand

- 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

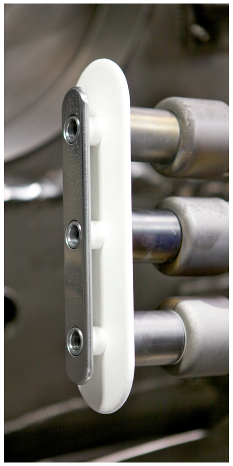


M. Jaworski et al, PPPL

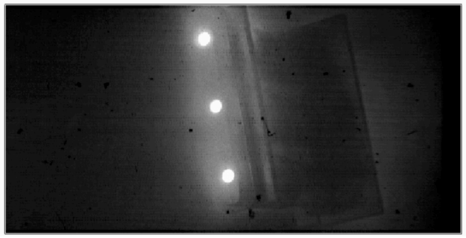
Developments in Conceptual Design of Local Helicity Injectors for Potential NSTX-U Application

Tests on Pegasus ST experiment

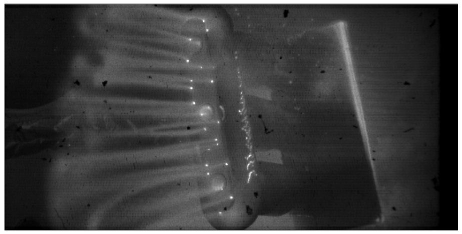
- **Plasma gun current sources with integrated electrode assembly tested in Pegasus over last ¾ year.**
- **New single-gun/electrode assembly installed for testing this Summer-Fall.**
  - With integrated piezo-controlled gas valve



Three arc sources and integrated Mo electrode assembly



Arc plasma current source



Electrode current source

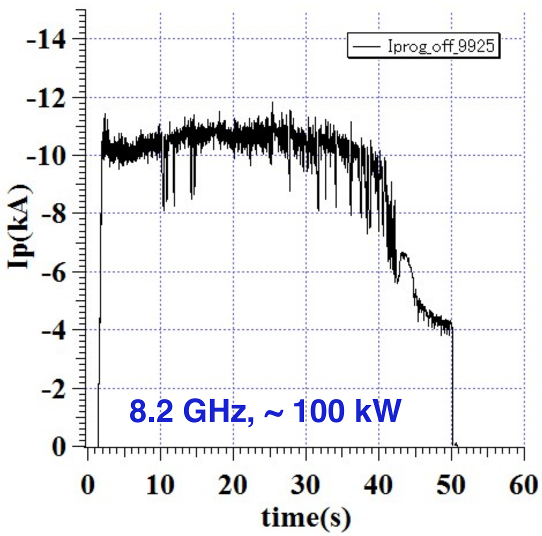
Framing camera images (~10 μsec) of current injectors in the scrape-off-layer region of a Pegasus discharge. I_{inj} ~ 3 kA; I_p ~ 100 kA.

R. Fonck et al, U. Wisconsin

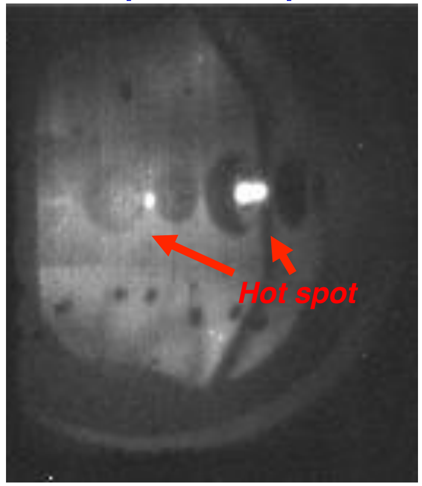
Collaboration with QUEST

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

ECH sustained discharge



Hot spot developed

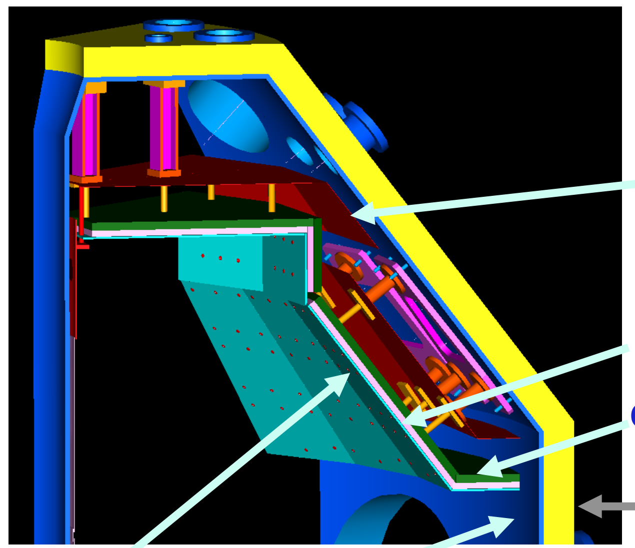


R. Ramen et al, U. Washington

Future Direction:

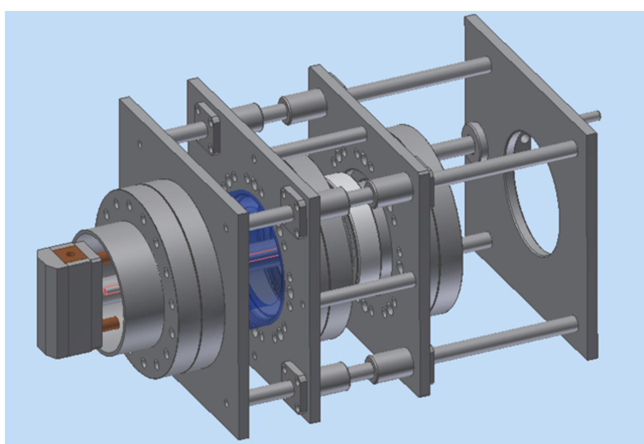
- Higher power ECH (8.5 GHz, 28 GHz)
  Total power ~ 1 MW long pulse
- Hot wall for particle control
- All metal CHI being considered
  U. Washington / NSTX collaboration

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



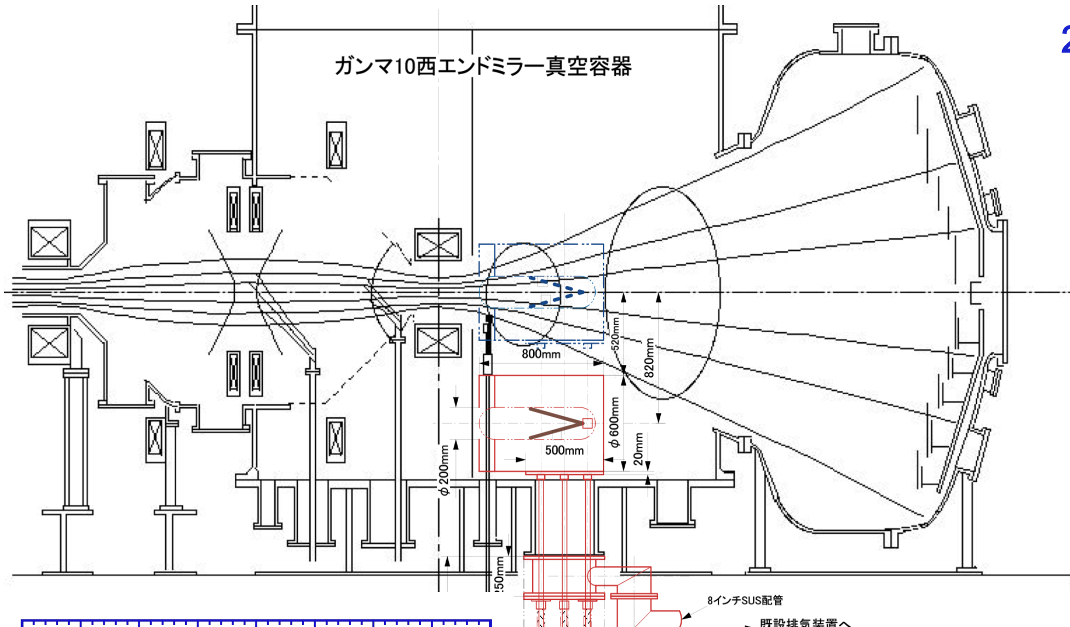
Melted moly limiter

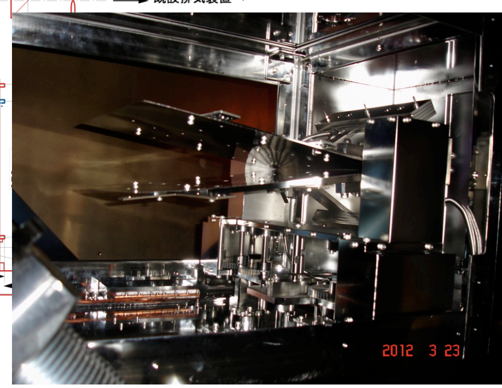
Water cooled tungsten movable limiter

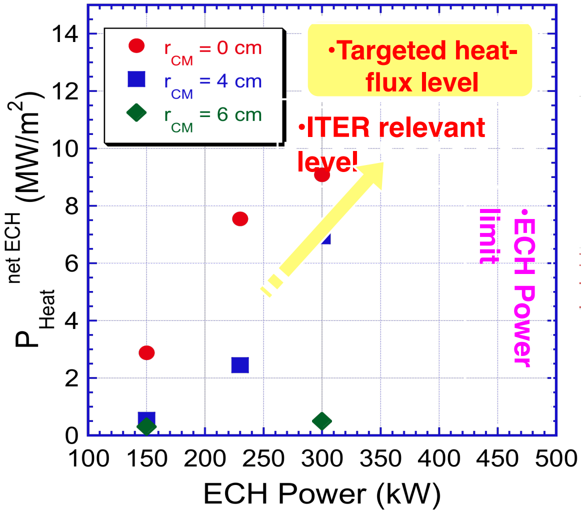


Collaboration with Gamma-10 Group

New PMI research direction and 28 GHz Gyrotron R&D







28GHz Gyrotron is required in GAMM10

This Gyrotron will be used to achieve higher plasma performance.

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

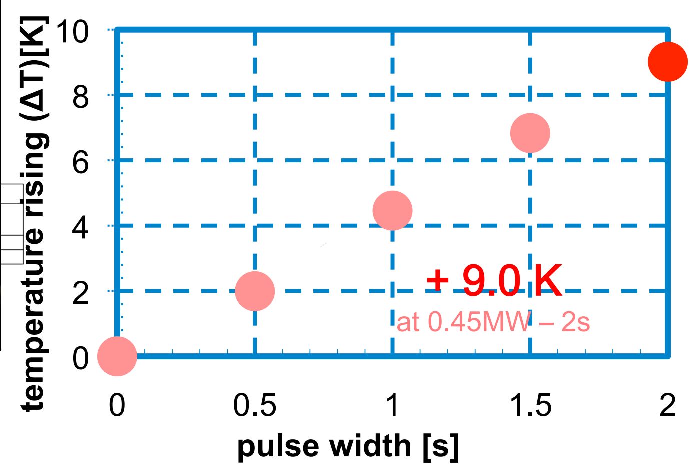
28GHz Gyrotrons are required in some plasma experimental devices.

- NSTX (Princeton University) : 2MW – several seconds

Ex) ECH, ECCD, EBW experiment etc.

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

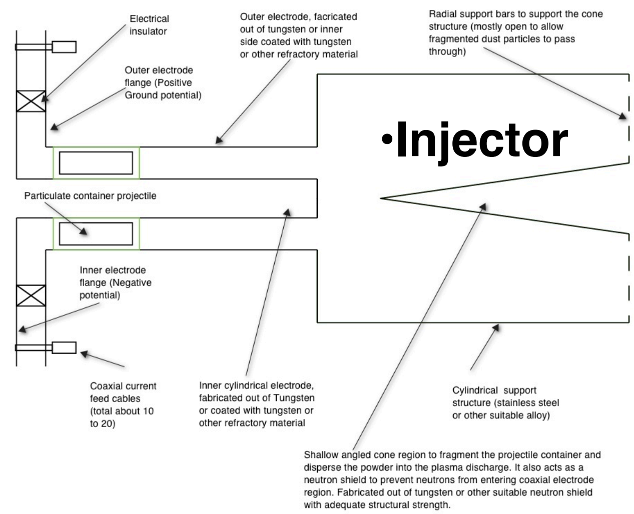
Sapphire window (single disk)

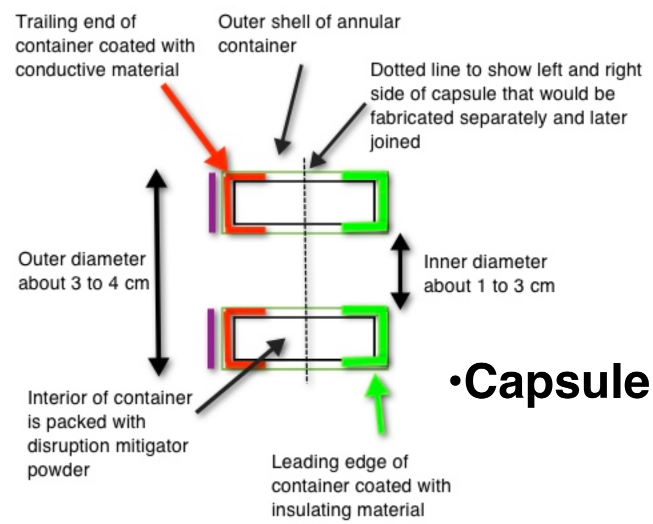


M. Ono et al, PPPL

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. Ramen et al, U. Washington

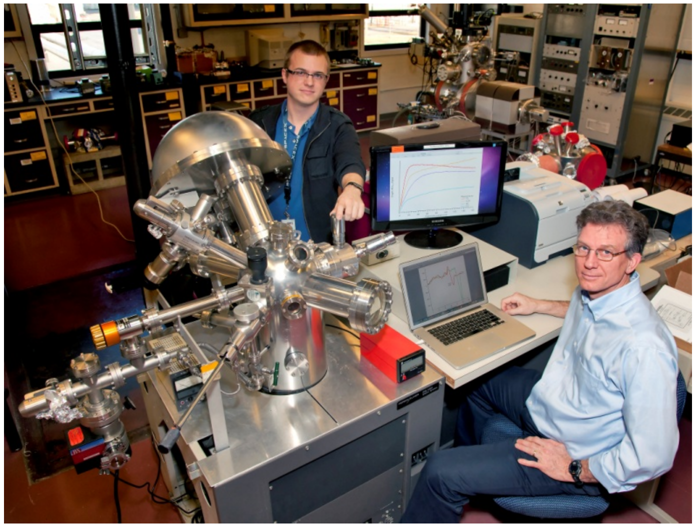
Selected Research Highlights from

NSTX-U / PPPL-PU Collaborations

- New Surface Analysis Lab at PPPL with PU
- MAPP on LTX
- Liquid Lithium PFC R&D

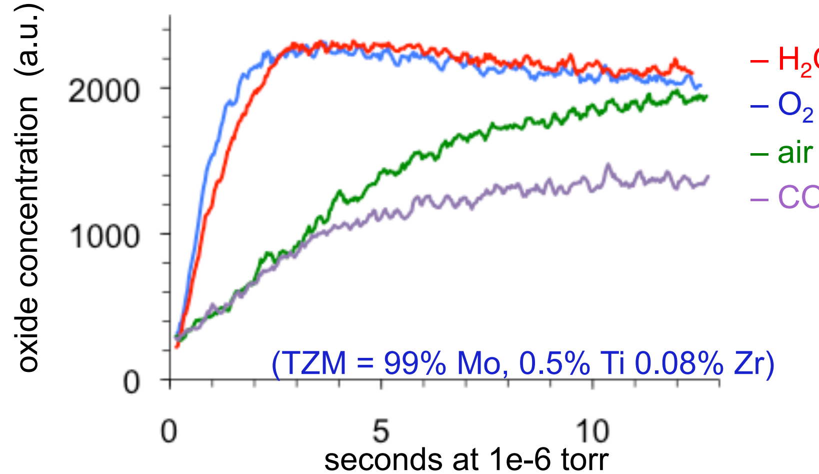
NSTX/PPPL/PU collaboration shows lithium reacts quickly with residual gases

New Surface Analysis Labs at PPPL

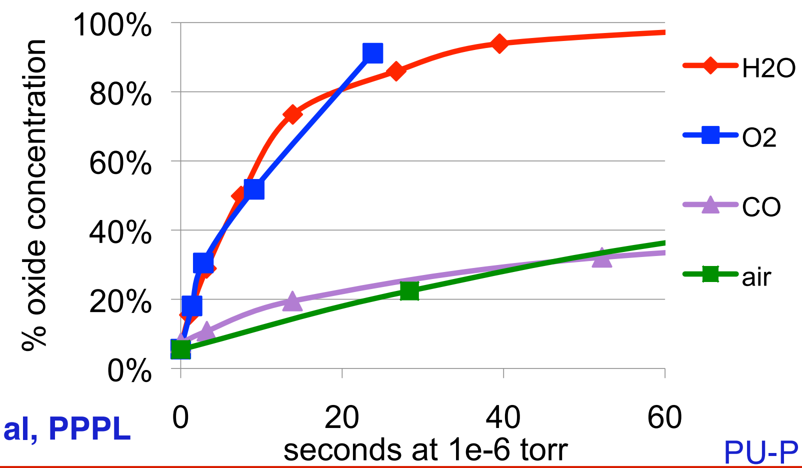


Li surface oxidation time

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



Solid lithium (XPS Li 1s))



- 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**

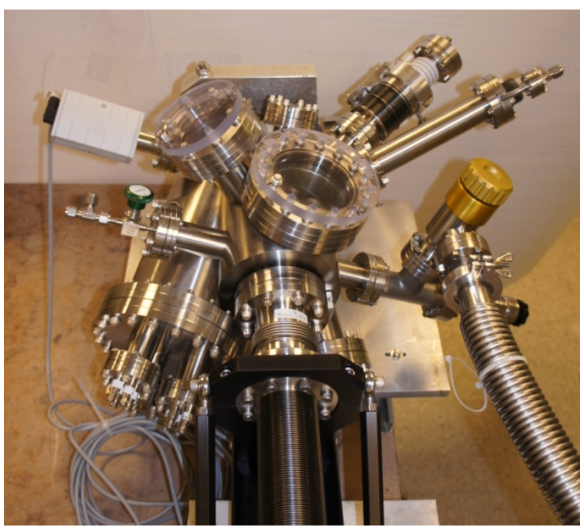
C. Skinner et al, PPPL

PU-PPPL

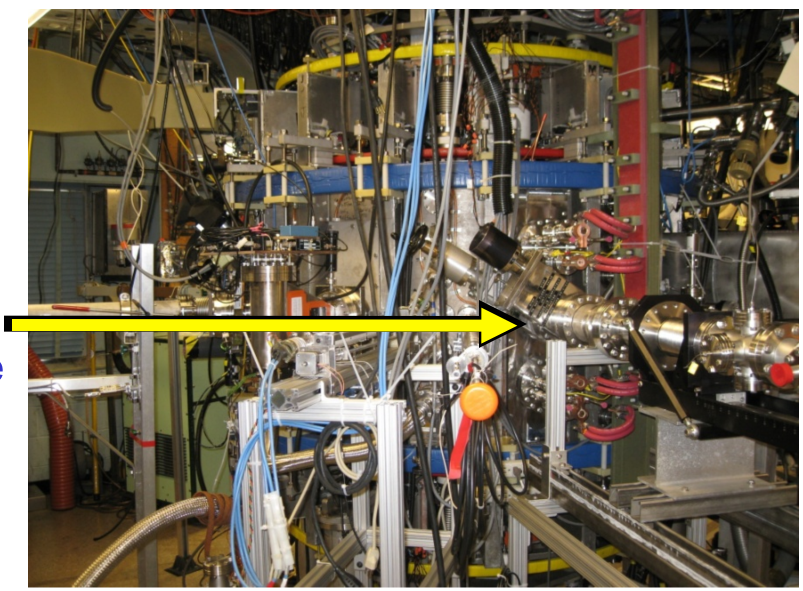
NSTX MAPP System is being installed on LTX in support of NSTX milestone R(13-2) in collaboration with Purdue U.

- 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



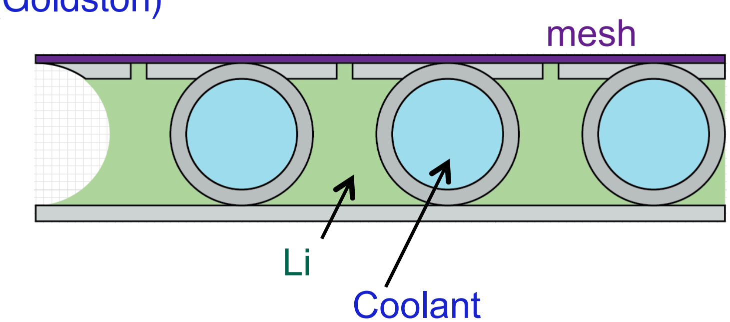
Lab-based R&D on liquid metal technology will inform long term PFC decisions:

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)



(He, supercritical CO_2, Na heatpipe…)

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