NSTX

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NSTX research collaboration strategy, expectations, and initial opportunities

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Thanks to all contributors of facility information/plans

B318 - PPPL
September 20, 2011

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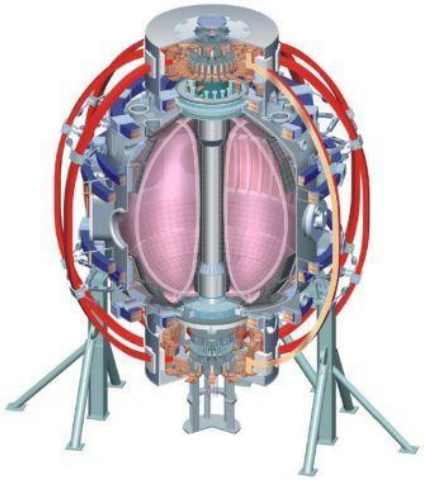


Overview

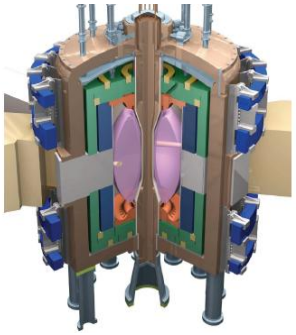
- This is the first of several/many collaboration meetings
- This meeting will focus on:
  - Goals and strategy
  - Off-site large facility plans and opportunities
- The next meeting (date TBD in October) will focus on:
  - PPPL internal/on-site opportunities
  - Off-site university and smaller-scale experiments

Outline

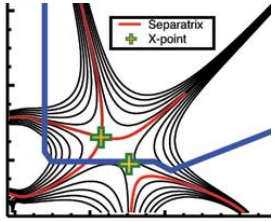
- Goals of off-site collaboration
  - For NSTX Upgrade
  - For PPPL off-site (international) research
- Expectations and logistics
- Collaboration opportunities, schedules, contacts
  - MAST
  - DIII-D
  - C-Mod
  - LHD
  - EAST
  - KSTAR
  - JET
  - C.U. plans
- Information sharing

Collaboration should aim to support NSTX-Upgrade mission elements

- Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
  - Advance non-inductive start-up, sustainment
  - Develop predictive capability for confinement, high-beta stability, and control
- Develop solutions for PMI
  - Inform NSTX-U/FNSF decisions on divertor configurations, high-Z PFCs, Li, cryo-pumping
- Advance toroidal confinement physics for ITER and beyond
  - Utilize waves/HHFW, energetic particle, 3D physics expertise in support of ITER, beyond
- Develop ST as fusion energy system
  - Integration + performance extension of above

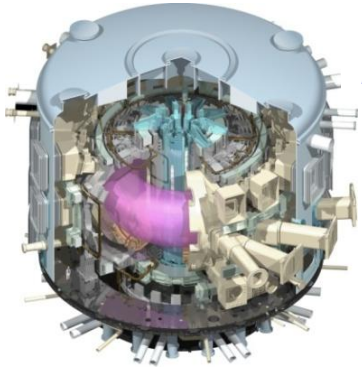


ST-FNSF

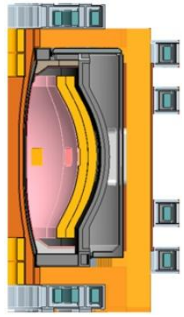


"Snowflake"

Lithium



ITER



ST Pilot Plant

PPPL/US international collaboration would greatly benefit from NSTX researcher participation

- Developing Operating Scenarios for ITER (ReNeW Theme 1)
  - A JET DT campaign could enable more accurate predictions, reduce risk for ITER operating scenarios
    - DT species effects and scaling, alpha effects
    - Compatibility with ITER-like wall and divertor
    - Test of ITER-like RMP coil system
  - Future: JT-60SA could extend high-performance ITER scenarios to steady-state
    - PPPL NNBI collaboration with JT-60SA addresses a critical ITER issue
    - (Coincidentally, ST pilot plant design assessing NNBI from JT-60SA)
- Control of Steady-State High Performance Plasma (Theme 2)
  - Understand 3D equil., limiting mechanisms in stellarators (LHD, W7-X)
  - Control of 3D, diverted, high beta plasma (W7-X)
  - Control of long-pulse AT regimes (EAST/KSTAR) w/ ECH, ICRF, LHCD
  - Apply AT understanding from U.S. tokamak work, use SC machines and U.S. tools to extend to long pulse

Goals and expectations for collaboration

- For all researchers, use Upgrade outage as opportunity to:
  - Extend and improve your ongoing and future research on NSTX
  - Learn about other facilities – bring back knowledge, best practices
  - Try or learn something new – new physics, diagnostics, analysis, …
  - Make new contacts (and friends) – national and international
- Should aim to form small teams of NSTX researchers (PPPL + non-PPPL) collaborating on other facilities
  - Coordinate research plans, analysis, travel, and participation
  - Much more efficient and effective than individuals acting alone
- Expectations for (PPPL) researchers:
  - Select 1 primary and 1 secondary/backup collaboration project
  - Aim for first author paper and/or invited presentation based on collaborative research (will be noted on performance appraisal)
  - At very least, be a co-author, and utilize new results/techniques to extend/improve your NSTX research and publications/presentations
  - Present your results periodically to NSTX, PPPL research seminars

Logistics

- Highest priority now is formulating good collaboration ideas
  - Talk about it with your supervisor(s) and with us = NSTX + off-site research divisions
    - Be inclusive in the CC list: Ono, Menard + Wilson, Neilson
  - Discuss with off-site contacts, iterate to mutual agreement
  - For PPPL staff: we will try to find the resources to make collaborations happen through NSTX and/or off-site research departments
    - But, NSTX facility & travel funding very limited during Upgrade outage
  - NSTX will generally provide PPPL researcher salary, provided there is some tie-back to NSTX/toroidal physics – will treat case-by-case
    - Will require researcher discussion with, and concurrence by, NSTX + OSR
- Note for all: some international host institutions may provide housing and/or travel funds
- If you see an opportunity you want to participate in, and it is happening soon, act now. Overall, <u>be pro-active</u>

Collaboration opportunity overview

- The following slides outline facility opportunities and schedules for the next year+, and provide some contacts for additional information

- Names listed are either people already involved in collaboration, or are ideas for potential collaborators
  - These suggestions are not (yet) binding, but are meant to provoke thought, consideration, and discussion
  - If you are a PPPLer and not named, fear not – we will find you
  - If you are not a PPPLer, but are interested in a research area, discuss this with your fellow researchers and inform us too
- Note: In some cases, time is short for your integration into a research team for FY2012 experiments

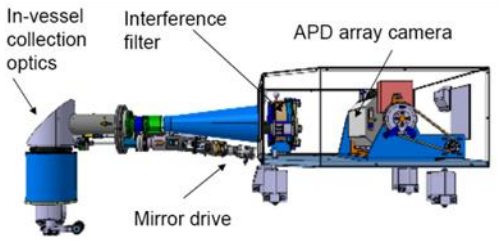
MAST collaboration opportunities

Note: MAST schedule very complementary to NSTX/NSTX-U schedule

- Operations resuming next week through mid-January 2012
  - 6 + 12 ELM coil experiments
  - NBI-CD, fast-ion redistribution, new neutron camera
  - L-H transition physics, get more/new BES data
  - ➢ There are opportunities to participate in these areas now/ASAP
- MAST research forum – April/May 2012
  - ➢ Opportunity for strong participation in forum from NSTX team
- June/July 2012 – EBW + commissioning
  - EBW start-up campaign (28GHz, 200-300kW)
  - Commissioning: vertical control, higher P_{NBI}, TAE antenna work
- Operation November 2012 thru June/July 2013
- MAST-U outage summer 2013, physics ops in fall of 2015
- Contacts:
  - I. Chapman – stability, S. Pinches – fast ion physics
  - D. McDonald – transport, W. Fundamenski – exhaust, C. Challis - scenarios

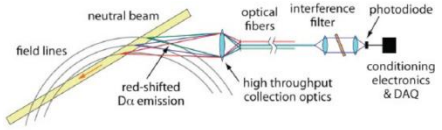
Turbulent transport has important implications for size of ST as FNSF, and for ITER, Demo

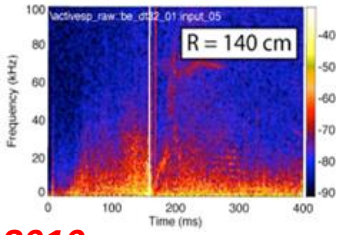
MAST



2D BES to be used 2011

NSTX



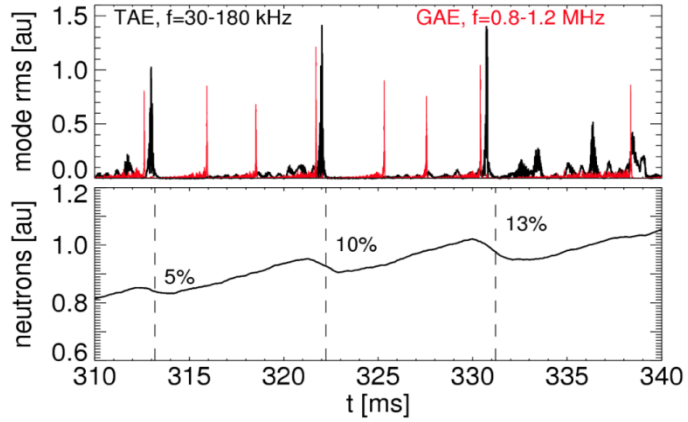


Initial 2D BES data obtained 2010
(+ existing high-k scattering)

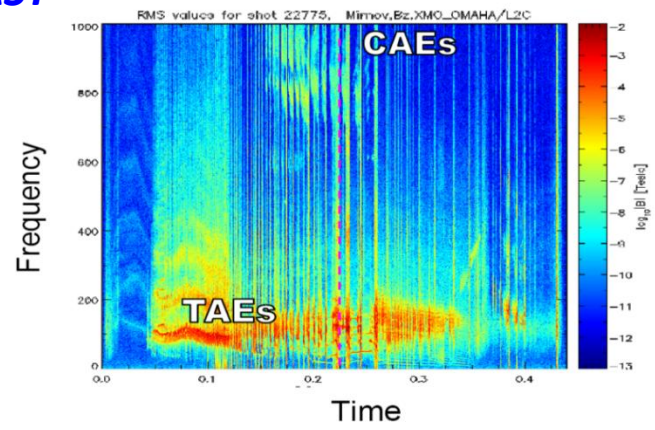
- NSTX, MAST observe similar confinement scaling that differs from conventional A – strong ~ $1/\nu^*$ scaling – what is underlying physics?
- Both devices now have similar ion turbulence diagnostics – 2D BES
- MAST expressed particular interest in PPPL/NSTX experiment-theory comparison expertise
- Potential collaborators:
  - NSTX: S. Kaye, D. Smith, Y. Ren, W. Guttenfelder
  - MAST: A. Field, C. Roach, M. Valovic
  - GK theory: G. Hammett, W. Dorland, C. Roach, A. Schekochihin, H. Wilson

Energetic particle transport has important implications for NBI-CD, alphas for FNSF, ITER BP

NSTX



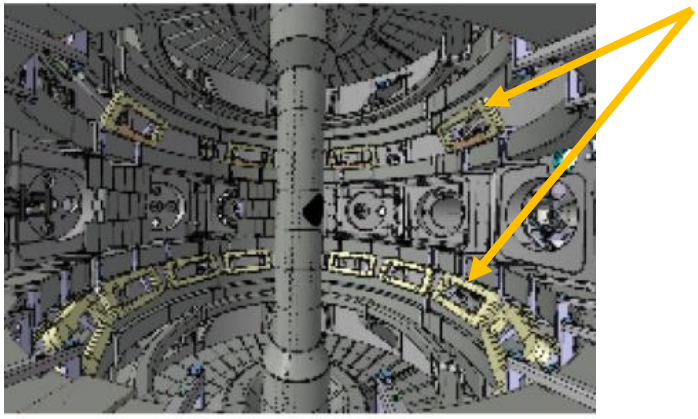
MAST



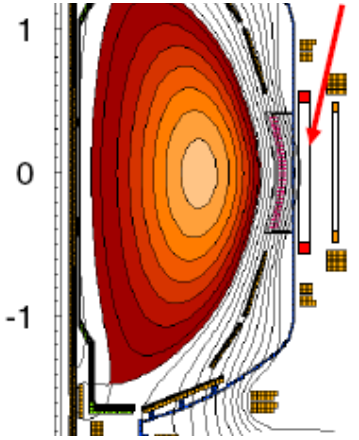
- NSTX, MAST observe multi-mode *AE, fast-ion transport
- NSTX has FIDA, NPA, … MAST has neutron collimator
  - Both also have BES for *AE eigen-function measurement
- MAST using *AE antenna, NSTX-U will test prototype antenna
- MAST expressed particular interest in improving models for “anomalous diffusion” from *AE (for TRANSP analysis)
- Darrow/Boeglin exploring use of NSTX fusion product detector on MAST
- Potential collaborators:
  - NSTX: D. Darrow, M. Podestà, E. Fredrickson, N. Gorelenkov, G. Fu, S. Gerhardt
  - MAST: R. Akers, S. Pinches, M. Turnyanskiy

Improved 3D plasma response models needed to understand RMP ELM suppression for ITER, FNSF

MAST – in-vessel off-midplane RMP coils



NSTX – ex-vessel mid-plane RMP coils

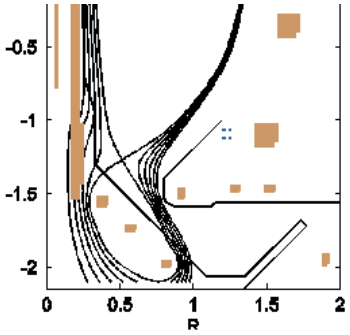


- MAST, NSTX modify edge transport and ELMs with 3D fields
  - Have not yet suppressed ELMs with 3D fields
  - Both observe transport/plasma response to 3D fields sensitive to q_{95}
- MAST, NSTX have complementary 3D coil capabilities
- Collaboration initiated on perturbed equilibria, NTV rotation damping
  - US: DCON, IPEC codes → resistive DCON, GPEC code, UK: MARS, T7
- Collaborators:
  - U.S.: J.-K. Park + A. Glasser (visited Culham late Sept 2010), A. Boozer, S. Sabbagh
  - Culham/UK: I. Chapman, Y. Liu, C. Gimblett, H. Wilson

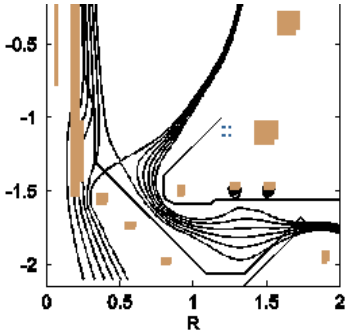
Advanced divertors will be needed for heat flux mitigation in Upgrades, FNSF, Demo

MAST Upgrade

Conventional

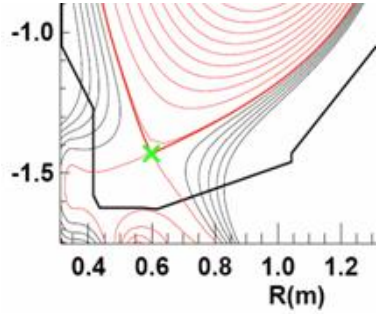


Super-X

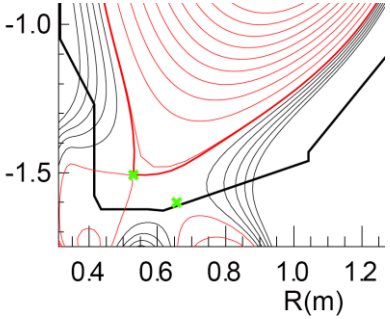


NSTX, NSTX Upgrade

Conventional



Snowflake



- MAST: effect of line-length on H-mode, NSTX: snowflake, LLD
- MAST-U: Super-X + cryos, NSTX-U: snowflake + Li pumping
  - Both will access substantial flux expansion, variation of line-length, pumping
  - Complementary: open vs. closed divertor, different pumping techniques
  - Will need advanced boundary control (example: control of multiple X-points)
- Potential collaborators:
  - NSTX: V. Soukhanovskii, R. Maingi, J. Canik, D. Stotler, E. Kolemen
  - MAST: G. Fishpool, A. Kirk, H. Meyer, G. Cunningham

DIII-D near-term collaboration opportunities

- Operations October 10-28 – act NOW if interested
  - QH mode with co-NBI, NTV, high beta
  - Off-axis NBI for steady-state scenarios - longer duration (Kolemen)
  - Long-pulse ITER baseline scenarios – try to get stationary J profile
  - TBM simulation experiments (last week Oct) (Park, Kramer, Sabbagh)
  - Runaway electron ramp-down control – test for ITER (Kolemen)
  - Pellet pacing for ELM control (3 ORNL pellet injectors, 10Hz each)
  - ➢ Contacts: QH - Garofalo+Burrell, off-axis NBI - Luce, ITER - Strait, TBM - Schaffer, RE - Humphreys, pacing - Fenstermacher
- DIII-D research opportunities forum – first week of Jan 2012
  - ➢ Opportunity for strong participation in forum from NSTX team
  - Contact area leaders to initiate dialog/participation by December, 2011
  - January-March: Interact with DIII-D, organize participation/analysis
    - participate in group meetings, arrange travel, design and plan experiments
- Finalize run plans in Feb/Mar 2012, operate April – July 2012

DIII-D longer-term collaboration opportunities

- Areas of emphasis suggested by DIII-D would also be very beneficial to preparation for NSTX-U:
  - Effects of 3D on plasma, diagnostics/magnetics – improved measurements, improved modeling
  - Disruptions – additional analysis and modeling, control development
  - Transport modeling – in particular for projecting performance to steady-state ops for ITER and next-steps (UCLA/polarimetry, Guttenfelder)
  - Non-inductive plasma start-up – would get run time if new/compelling experiment identified - clearly important ST (Raman, Mueller?)
- DIII-D PCS algorithm development and/or plasma operations also beneficial to DIII-D, NSTX Upgrade prep (Mueller)
- M. Wade is working with DIII-D team now to identify key additional areas like those listed above
- Mickey will visit PPPL mid-October to discuss w/ NSTX team
- Contact R. Nazikian for local/PPPL information on DIII-D

Collaboration opportunities on C-Mod (1)

(underline indicates areas of particular NSTX-U relevance)

- Transport - Focus on 2012 JRT, development of fluctuations measurements, exploration of origin and impact of self-generated rotation, exploitation of RF tools to control transport through modification of current or rotation profiles
  - Mode-conversion ICRF or minority heating at low density – both provide strong e-heating
  - (temporary) addition of more TS core channels to improve spatial resolution
  - Help with reflectometry – particularly modeling
  - Analysis of BES system
- Edge/SOL - SOL turbulence and transport, their relation to divertor heat loads, impurity sources and transport, impurity seeding to reduce divertor heat flux, PWI for refractory metal walls.
  - Impurity spectroscopy
  - Infrared measurements of divertor heat flux – need design of new viewing optics
- Pedestal - Structure of the pedestal, H- and I-mode access, non/small ELM regimes, influence of coherent and non-coherent fluctuations on particle and energy transport in pedestal
  - MHD and gyrokinetic modeling of edge profiles and neutral source modeling.
  - Upgrades to edge/SOL Thomson scattering measurements.
  - Preliminary work for 2013 JRT

Collaboration opportunities on C-Mod (2)

- ICRF – Commission new, tilted-strap antenna. ICRF flow and current drive, RF model validation, impurity generation, creation of RF sheaths, SOL modification
  - Fast ion physics – lost particle detectors, stability analysis, sawtooth modification
  - Edge/SOL interactions, parasitic losses
- MHD - Disruption characterization+ mitigation, fast particle modes, tearing modes
- LHCD - Validation of current drive models – particularly at high density, transport in flat/reversed shear plasmas, development of steady-state scenarios
  - Help with operations, modeling and analysis, SOL Diagnostics (particularly RF probes)
  - Help with design of new LH launcher
- Scenarios - development and optimization of integrated scenarios mainly in support of ITER and other next-step devices including control strategies + validation or qualification of modeling tools
  - Scenario modeling, addition of new LH code + CQL3D into TRANSP
- Operations - additional physics operators, plasma control, advanced algorithms
- Diagnostics - analysis/exploitation of CXRS, bolometry, Lyman_alpha, ECE (esp. non-thermal emission), Thomson (TS-ECE discrepancy issue), VB
  - Help with DNB ops, analysis/upgrades of BES, reflectometry upgrades/modeling/analysis

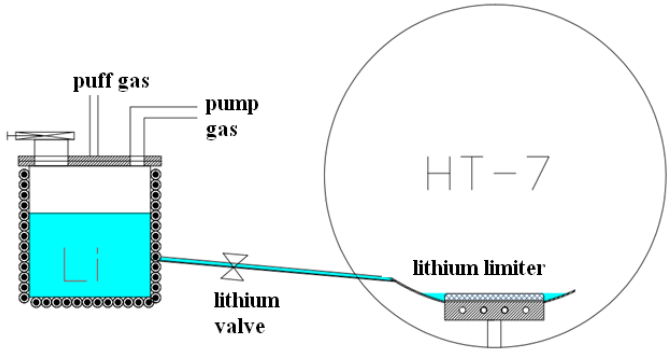
➢ **Operations: October → spring 2012 – generally open to new XP ideas**

Collaboration opportunities on LHD

- LHD materials discussed at Sept 6 meeting w/ Prof. Yamada:
  - ftp://ftp.pppl.gov/pub/hneilson/20110906%20Presentations%20w.%20Prof.%20Yamada/
- Ongoing/potential research areas for collaboration
  - Equilibrium reconstr., β limit expts (Lazerson, Gates, PPPL theory)
  - X-ray Imaging Crystal Spectroscopy (Pablant, Bitter, Hill)
  - Comparative study with a gyro-kinetic simulation and experimental observation of turbulence (Mikkelsen)
  - Study on neoclassical toroidal viscosity, error fields (J-K Park)
  - Study on dynamics and quantification of dusts (Skinner)
  - Fission chamber calibration for neutron yields (Darrow, Roquemore)
  - Study on stochastic magnetic field in the edge, closed divertor
- Info for collaborators:
  - Formal proposals submitted in January 2012, selected in March, schedule made in May, operate in summer 2012
  - Contact H. Neilson, D. Gates for additional (local) information

Collaboration opportunities on EAST/HT-7

- NSTX Li droppers → EAST H-mode
- HT-7 being used as test-bed for Li system development for EAST
- EAST converting to all high-Z PFCs (Mo/W/C) in 2012, (Mo/W) by 2013
  - Possibly flowing Li divertor after 2014



- Lithium re-filling from ex-vessel
- CPS structure (SS foam)
- Will also test UICU LiMIT concept

- ASIPP collaboration can inform NSTX Upgrade decisions on:
  - PFC material (high-Z vs. graphite)
  - Cryo-pumping requirements, design choices
  - Design of next-generation Liquid Lithium Divertor (LLD)
- J. Menard visiting ASIPP in 2 weeks to get further information
  - Near-term: Li/PFC/RF/diagnostics, longer-term: AT/MHD/3D coils
  - Preceded by extensive discussion, visits by Zarnstorff/Neilson in June

ASIPP collaboration can address key questions for Li research program for NSTX-U

- What is role of Li pumping in H/D particle control in H-modes?
  - Are cryo-pumps needed for particle control w/ Li? (Mueller, Menard)
- What is transport and turbulence response to Li-PFCs?
  - Similar to NSTX experience? What are differences?
  - SOL/divertor – GPI (Zweben), core - GS2 (Ren), pedestal – MPTS (Diallo)
- Long-pulse ELM-free H-mode w/ Li on EAST – is this possible?
  - Does short-pulse (~1s) NSTX ped. structure change at long-pulse (10-100s)?
- What is best long-pulse/steady-state Li delivery system?
  - Assess dropper, slapper (Mansfield), CPS and LiMIT (Jaworski)
- How much can Li assist RF performance, advanced scenarios?
  - Reductions in H, low-Z impurities, edge density, increases in e-confinement
  - ICRF/ECH/LHCD assessment (Hosea, Taylor), spectroscopy (Skinner, Battaglia)
- How do high-Z (Mo) PFCs perform with and w/o Li? (all)
- What is assessment of performance of any static/flowing liquid-Li PFCs on HT-7, EAST? (Jaworski, Menard, Maingi, Kaita, Kugel)

Collaboration opportunities on KSTAR (1)

- Ongoing research areas for collaboration
  - 3D field RMP for ELM suppression (J.Park, ..)
  - RWM physics and EFIT reconstruction (S. Sabbagh, Y.Park, ..)
  - H-mode parameter scan & filterscope (J. Ahn, ..)
  - Plasma control (D. Mueller, ..)
  - 170 GHz ECH launcher (R. Ellis, Hosea, ..)
  - NBI Operation (L. Grisham, ..)
  - TRANSP & codes (Theory Group)

- Planned KSTAR upgrade for 2012 operation:
  - Heating: additional NB (2MW) + LHCD (5GHz, 0.5MW)
  - Diagnostics : Thomson laser (5J, 100Hz) + IR on divertor
  - PCS : IRC

Collaboration opportunities on KSTAR (2)

- Extended joint research for experiments
  - Long pulse (over 10sec.) H-mode in 1MA
  - ELM mitigation at various methods (RMP, ECCD, SMBI..)
  - Plasma shaping control (Iso-flux)
  - Diagnostics improvements (Thomson, Probe, BES, IR, RBA)
- Collaboration on diagnostics and others
  - Utilizing the NSTX diagnostic systems in KSTAR for several years (The possible items will be discussed afterward)
  - Collaboration in data analysis of existing diagnostics
  - New diagnostic design and development - (MSE, etc.)
- Info for collaborators:
  - Formal proposals submitted in Feb 2012, selected in March, schedule made in May, operate in Sep. 2012
  - Contact: Woong Kim for additional information (also J.-K. Park)

Collaboration opportunities on JET

- Energetic particles:
  - JET strongly supportive of PPPL participation in this research area
    - Encourage interested NSTX collaborators to participate also
    - NOTE that MAST and JET are next-door – participate in both!
  - Planning for D. Darrow to be on-site for next ~2 years (+ Gorelenkov)
  - JET will identify gaps in EP modeling and diagnostics
- JET recently resumed operation, now with the ITER-like wall
- Next DT campaign is planned for 2015
- ILW and EP physics with DT very ITER/BP relevant
  - Tritium retention & removal (ILW qualification)
  - Alpha particle physics:
    - At low/modest performance: Alpha transport and loss channels (MHD)
    - At high P_{fus} and Q: Alpha heating, impact of MHD, and alpha particle
    - Interaction with TAE's and EPM's

Upcoming FES international collaboration solicitation
(information courtesy H. Neilson – subject to change…)

- Solicitation to be issued in December, funding to be distributed in June
  - Likely proposal deadline will be ~February
- Entire portfolio will be put up for competition, except the W7-X collaboration (since it is new and is mostly hardware commitments at this time)
- Existing collaborations will be funded for 3/4 of a year; funding after that will depend on results of the solicitation
- Preferred model is national partnership led by a national lab, with university participants included
- FES has not decided yet if the solicitation will be targeted, either topic-wise or facility-wise

Collaboration information sharing - will benefit you and the entire team

Example:

- Columbia U. NSTX research/analysis during outage (outline)
  - RWM passive stabilization physics
  - RWM active control and stabilization physics
  - Neoclassical toroidal viscosity physics and rotation control support
  - ELM stabilization physics
  - Equilibrium reconstruction support and development
- C.U. will also be collaborating with DIII-D, KSTAR, and MAST on these research areas
- We encourage all NSTX team-members to work together on collaborations wherever/whenever possible
  - More effective collaboration, helps maintain NSTX team

Collaboration Information Sharing

- NSTX management gathered/formulated preliminary collaboration information (facility, topic, time allocation) from PPPL NSTX researchers in late spring of 2011
- We also gathered information on expected diagnostic, engineering, and operational activities needed to prepare for NSTX Upgrade operation
- This information is very important for planning
- In light of the change in NSTX Upgrade outage schedule, we need to update this information, and would also like to gather input from collaborators (i.e. entire NSTX team)
- Try Google docs shared editing of collaborations file – URL:

https://docs.google.com/spreadsheet/ccc?key=0AiTk18lxrtYodE5OQTJkeVFsdU42eWN0alVnaHFyWUE&hl=en_US

  - Please give feedback on above sharing method, including protections
  - PPPL converting to GMAIL/Google apps at end of October