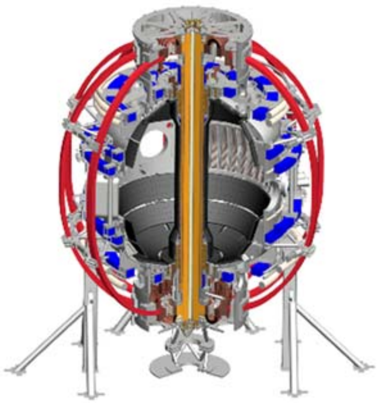
NSTX-U Project / Facility Status

Masa Ono and Jon Menard

NSTX-U FY 2015 Q4 Review Meeting

October 26, 2015



Outline

- **Post CD-4 activities**
- **Research operations plan**
- **Facility / diagnostic enhancement activities**
- **Summary**

Preparing to start FY 2016 plasma operations
Expected to run 14 – 16 run weeks in FY 2016

August 2015	September 2015	October 2015	Novembe 2015	December 2015

PTP/ISTP	R/R, Vent PF1b, dTMB	Bakeout	Post bake	ISTP	Commiss ioning	Research Plasma Operation

CD4 First Plasma (8/10)

Boronization

Dummy load testing

MPTS R&R completed

NBI 1 & 2 - Sources are being conditioned

MAPP, Fast Mirnov, X-ray, bolometer, plasma TV, VIPS, etc.

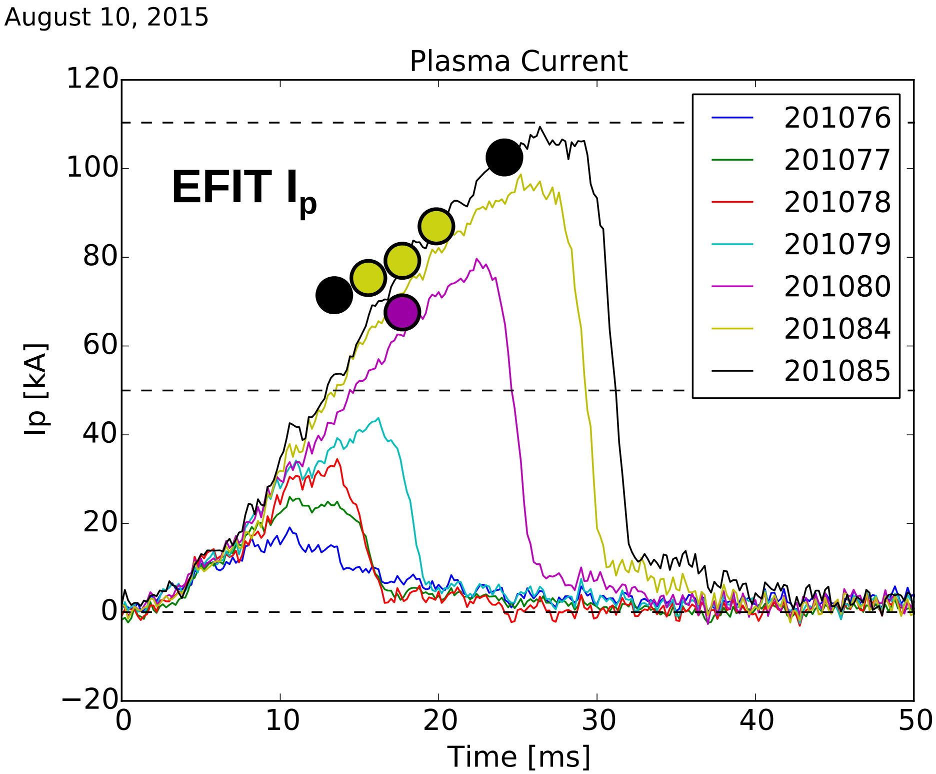
Boronization, GDCs, gas Injector-4, LITER, SGI, Divertor inj., MGI, CGI, etc.

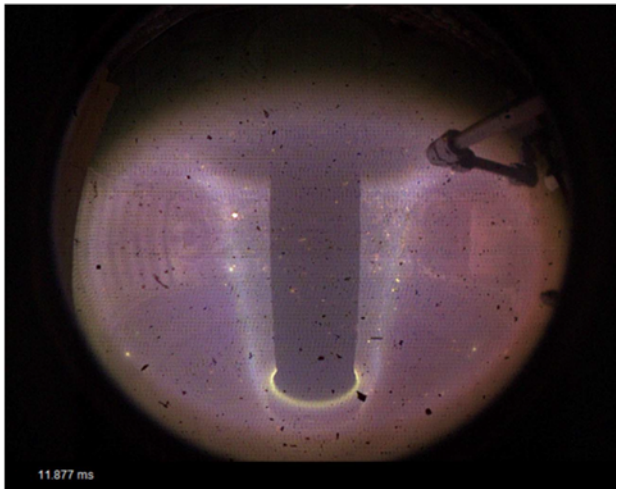
Bakeout concluded on 10/20/2015

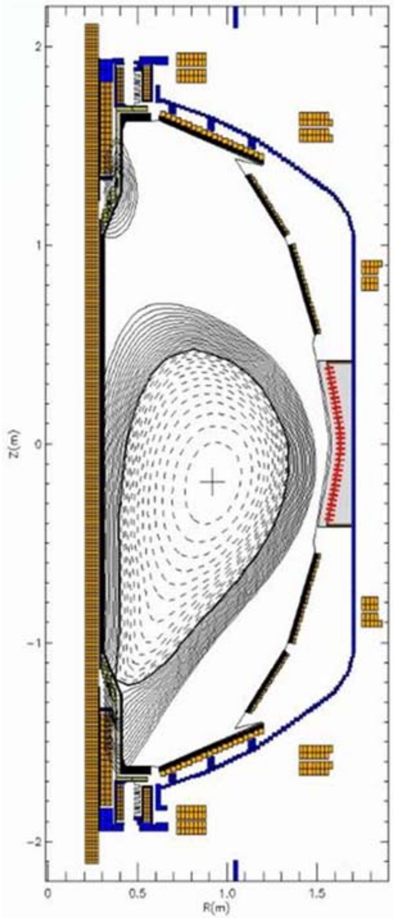
Achieved 3.8×10^{-6} Second best compared to 3.5×10^{-6} achieved in 2010

- The NBI CD-4 KPP achieved on May 11, 2015.
- The CS CD-4 KPP achieved on August 10, 2015.

CD-4 KPP #1 Plasma achieved on August 10, 2015
27 out of 29 attempts were "good" over 2 days







Shot 201085
Time: 28ms
I_p = 117 kA
B_{T0} = - 0.482 T
R_0 = 0.8 m
Z_0 = - 0.2 m
I_{wall} ~ 0.4 MA

Calibrated and compensated magnetics, EFITs plasma movie all showed consistent pictures

Bakeout Progression

Improvements identified for better reliabilty and shorter duration bake

- Started on 9/12/2015
  - Observed significant poloidal variations in the temperature.
  - Maxed of the He skip power.
- Paused on 9/18/2015
  - Had achieved ~1.4×10^{-5}, from 1×10^{-3}
  - PF-1b water heating system was improved
  - Insulation on the manifolds, plumbing was improved
- Restarted on 9/23/2015, 9/24/2015, 9/28/2015
  - Twice had to pause for leak repairs on hot He system, fix bad motor coupling on the He blower
- Blower basically failed on 9/30/2015
  - Sent to factory for rebuild on 9/30/2015, returned and reinstalled on 10/2/2015
- Bakeout restarted on 10/6/2015
  - 2 weeks at temperature projects to ending on 10/23/2015
- Bakeout concluded on 10/20/2015
  - Achieved 3.8×10^{-6} Second best compared to 3.5×10^{-6} achieved in 2010

Expected Schedule

(subject to change…including scenarios where things move earlier.)

- 10/19/2015: End the bake
- 10/19/2015-11/8/2015: Bakeout Recovery and Final Activities
  - Leak checking and diagnostic installations, etc…
- 11/9/2015: Begin the ISTP
  - 3-5 days
- 11/16/2015: Ready for plasma operations
- ST workshop (11/2/2015-11/6/2015): Under favorable circumstances, the ISTP may overlap.
- APS week (11/16/2015-11/20/2015): No operations due to APS + DOE Conduct of Operations training

Highlights of Diagnostic Progress

- MPTS installation complete, Rayleigh-Raman scattering successfully performed, and ready to take data
- IR cameras at Bays G and H are installed and took calibration data during the bake (ORNL)
- BES fiber bundles have been run to a point close to the machine (UW)
- MAPP probe (UI) is connected to NSTX-U and leak checked
- XEUS, LoWEUS and MONA LISA EUV spectrometers are installed. Vacuum pumping manifold is being fabricated. (LLNL)
- Design for the Fusion Products diagnostic (FIU) is complete.
- Lithium Granule Injector stand has been fabricated
- SAMI rack has been installed (U. York)
- Design work is ongoing for:
  - FIReTIP interferometer (UCD)
  - Laser-blow off system (LLNL)
  - Metal foil bolometers for main plasma and divertor (ORNL)
  - Pulse Burst Laser for MPTS

Steady Progress on Magnetic Diagnostics

- Complete set of magnetics calibration shots take in August
- Plasma current, loop voltage, poloidal flux and field measurements in good shape.
  - All integrators recalibrated before bakeout started.
  - Rogowski coils fully calibrated, and pickup compensations being refined.
  - All Mirnov sensors and flux loops have had their position determinations refined based on calibration shots.
- New diamagnetic loop system is showing promise.
  - If successful, then eliminates the old TF-coil diamagnetic system.
- High-n array data acquisition is installed and functioning.
- RWM sensor calibration codes have been exercised.

Significant Progress in Plasma Control System

- **Lots of PCS success during CD-4 and ISTP activities**
  - **Pre-programmed PF control**
  - **Gas injection and pre-fill control**
  - **Pre-programmed TF and OH control**
  - **Realtime magnetic sensor calibrations**
  - **Background testing of vertical control code**
- **SPA control from PCS has been restored.**
- **New algorithms for NB control and vertical position control have been fully tested.**
- **Some older less-reliable realtime digitizers have been replaced, and a new every-shot latency measurement system is being tested.**
- **Near term PCS steps**
  - **Finish testing rtEFIT and flux-projection boundary control algorithm.**
  - **Then move on to profile control and snowflake divertor control, other code improvements,…**
- **New computer for data serving and data acquisition has been commissioned and is now supporting operations**

NBI Heating System Operations

- Both Neutral Beams are at Lhe temperatures.
- Neutral Beam #2
  - N2A Source has just started Beam conditioning at 33kV
  - N2B Source is Beam conditioning and running well at 45kV
  - N2C Source has completed Arc Conditioning and ready for High Voltage conditioning
- Neutral Beam #1
  - All three NB#1 ion sources have completed arc conditioning, and are being prepared to start High Voltage conditioning.

Physics Operators Course Was Completed
Over 25 people attended each talk.

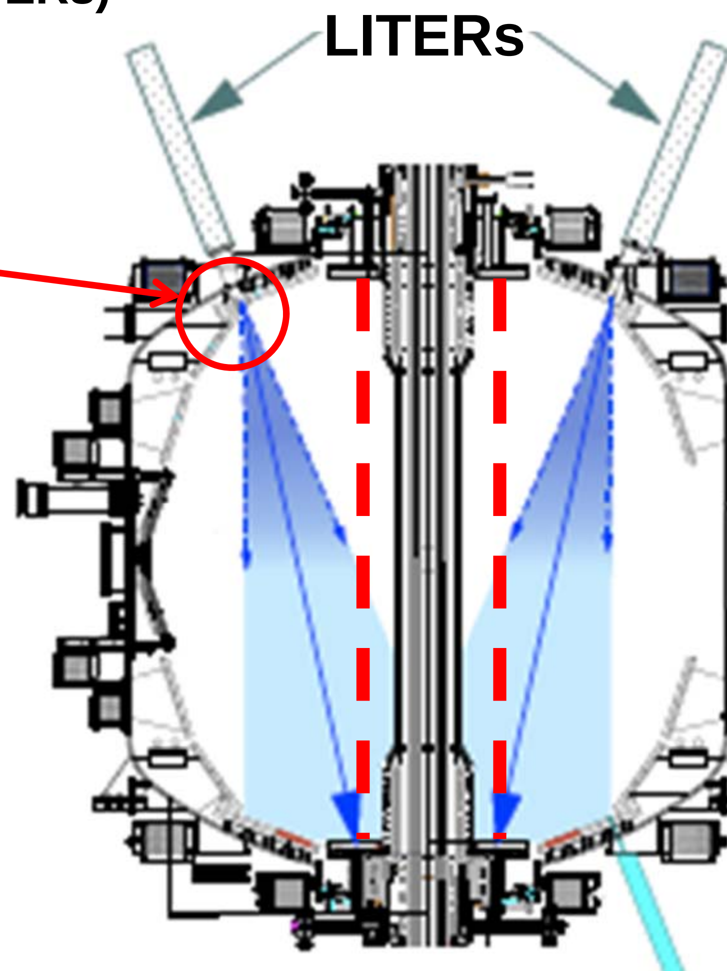
- 17 total talks, including by not limited to
  - Camp: Chief Operating Engineer role and control room responsibilities
  - Davis: IT support for physics operations
  - Gates: Intro. To PCS and Control
  - Hosea: HHFW systems on NSTX-U
  - Mueller: Breakdown and current ramp
  - Raman: Coaxial Helicity Injection
  - Stevenson: Neutral Beams
  - W. Que: NSTX-U Power systems
  - Battaglia: PCS Layout,
  - Gerhardt: Magnetic diagnostics, 3D fields, DCPS
  - Sabbagh: NSTX-U EFIT
  - E. Kolemen: Control theory
- Slides posted here or http://nstx.pppl.gov/DragNDrop/Operations/Physics_Operations_Course/
- Videos of talks posted here or http://cctest.pppl.gov/KalturaAPI.aspx?x=PPPL%3ECourses%3EPhysics%20Operators%20Training%20Course
- Three individuals interested in actually becoming physics operators, have read the required procedures, and are ready for on the job training.

First Year Boundary Physics Tools

Boronization, Lithium Evaporators, Granule Injector

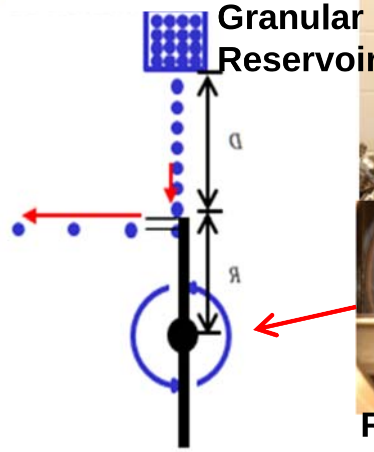
Lithium Evaporator (LITERs)

- LITERs filing set up in high bay south of NSTX-U Test Cell
- LITER software for LIFTER successfully tested
- New lithium filling procedure written and reviewed
- New procedure for remote LITER control nearly complete



Granule injector (GI) for ELM pacing

Successfully tested on EAST and DIII-D
Granules: Li, B_4C, C
f ~ up to 500 Hz



Rotating Impeller

- Remote control undergoing tests
- Stand complete
- Vacuum interlock requirements identified and implementation plan specified

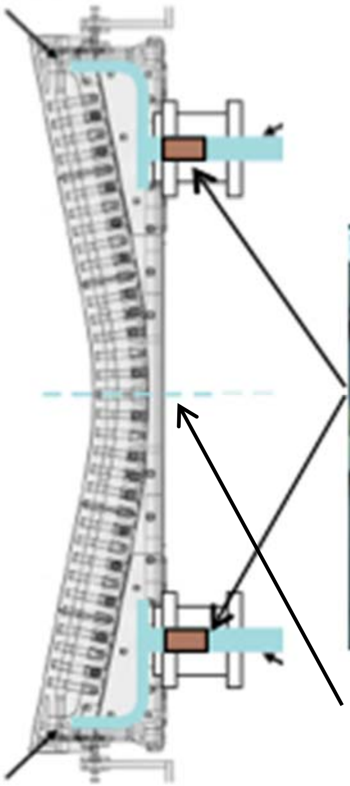
Boronization System

- PLC modifications for operation of deuterated trimethyl borane (dTMB) system complete – new software to be loaded and tested after NSTX-U bakeout ends
- System commissioning in early November

dTMB Gas Cabinet.

HHFW system preparation is going well
All sources are ready to start antenna conditioning

New Compliant Antenna Feeds
Allow HHFW antenna feedthroughs to tolerate 2 MA disruptions



Prototype electroformed compliant section

Additional ground installed

- Prototype compliant feeds tested to 46 kV in the RF test-stand. Benefit of back-plate grounding for arc prevention found.
- RF diagnostics also installed.

Antennas were re-installed with the new feeds and back-plate grounding

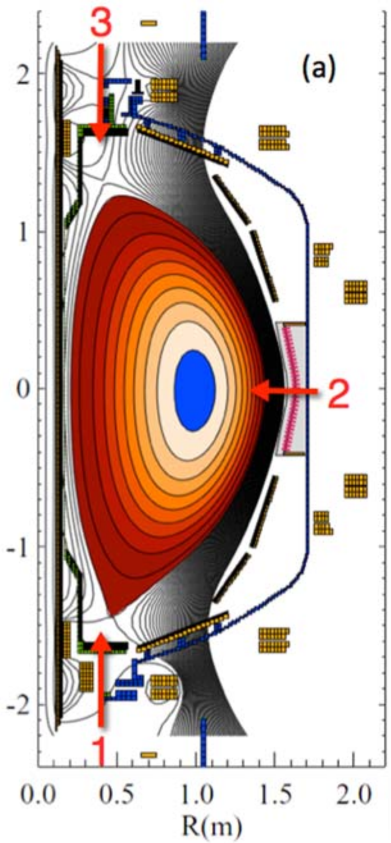
Transmission lines installed & tuned.

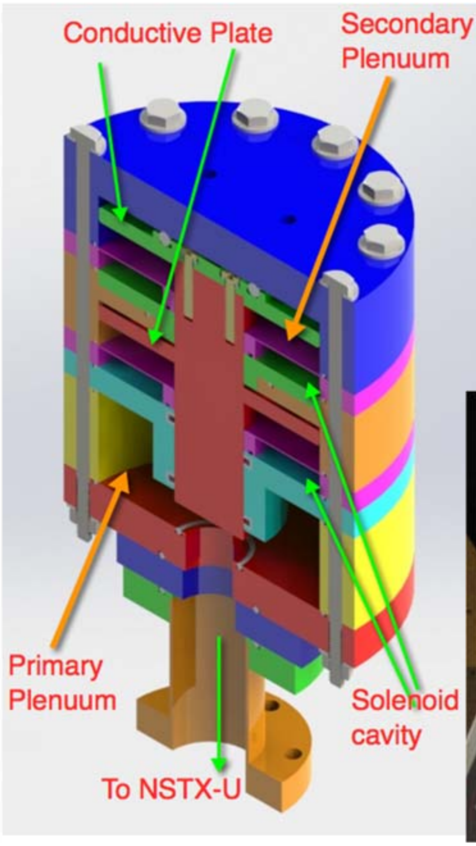
- **All sources are ready. Conditioning to start when the machine is ready for operation in early November.**

Disruption and Plasma Control Tools for NSTX-U

Massive gas injection system for disruption mitigation study

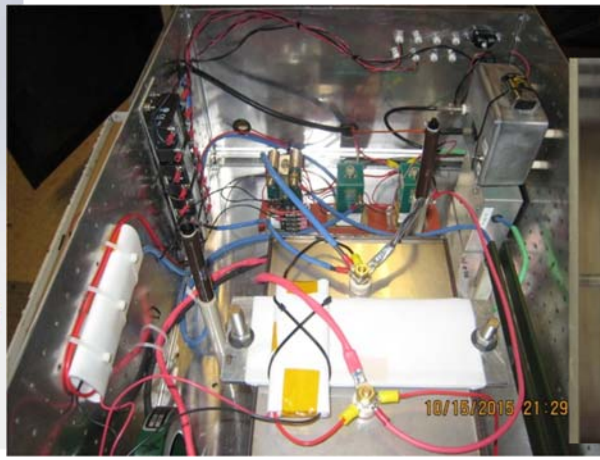
NSTX-U MGI Valve



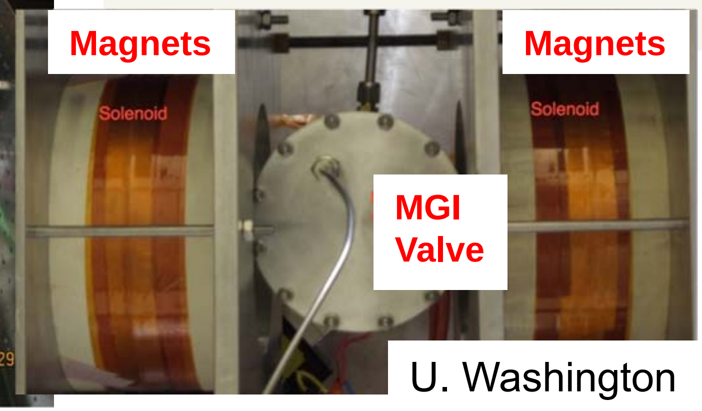


- Massive gas injector system at multi poloidal location with identical injection set-up
- Compact power supply proto-type tested at UW
- A new double solenoid MGI design (zero net J x B torque) based on the ORNL ITER MGI design

Compact MGI Power Supply for NSTX-U installation



MGI also being tested on the U. Washington test stand with magnetic field



Status:

- Conceptual Design Review of MGI system was held on October 16. Recommended changes were incorporated into the power system hardware.
- A Real-Time Velocity (RTV) diagnostic is ready for plasma test with the plasma control system for feedback control of the plasma rotation profile.

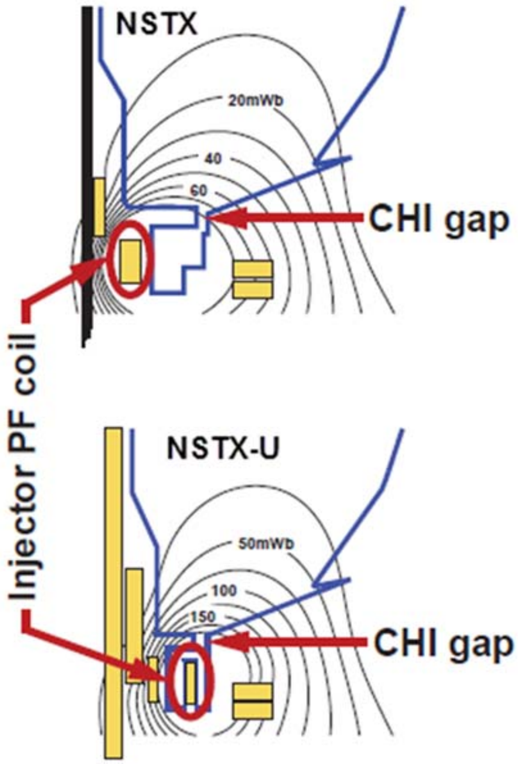
Solenoid-free start-up in support of ST-FNSF

NSTX-U CHI configuration permits ~ 400 kA level start-up

CHI Start-Up in NSTX-U

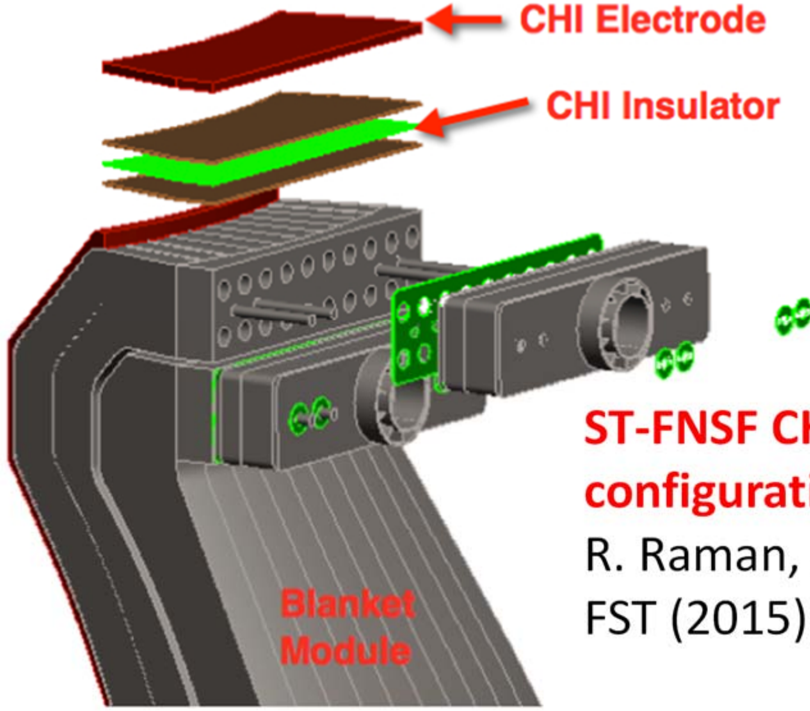
- Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX
- NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation

U. Washington



- CHI will start with the present 2 kV capability then enhanced to higher voltage as needed.
- Control system updates for the CHI cap bank have been completed, and the system is ready for remote testing.
- The CHI control room procedure has been updated.

QUEST CHI Experiment



ST-FNSF CHI configuration

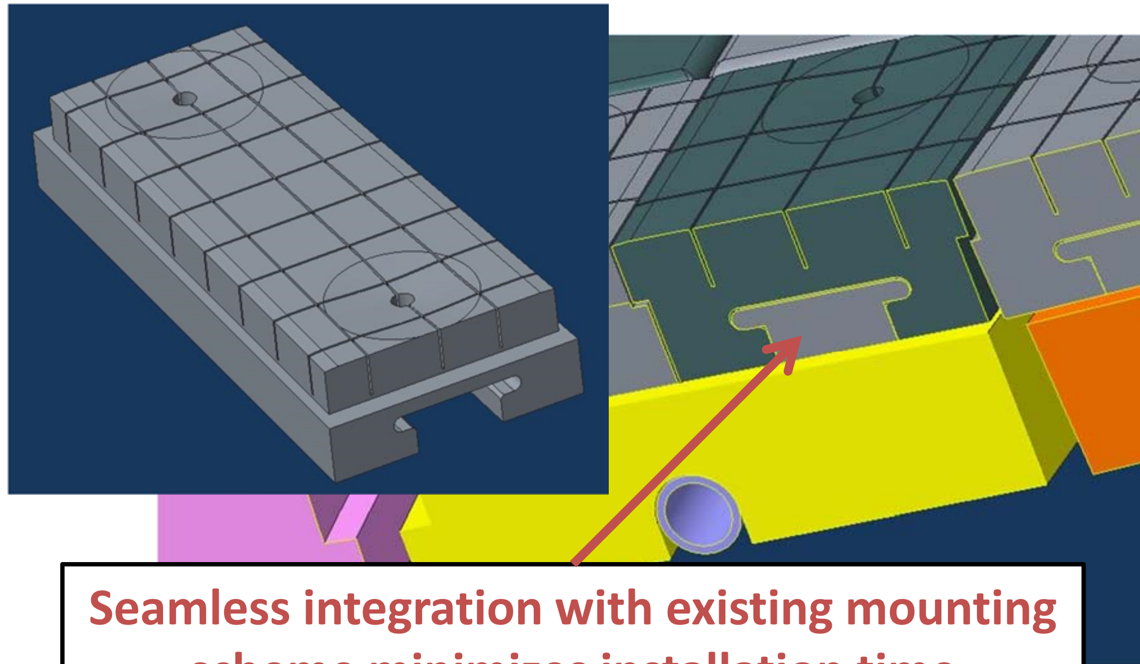
R. Raman, et al., FST (2015)

- An ST-FNSF like CHI configuration will undergo plasma tests on QUEST after FY 2016 NSTX-U operation
- CHI electrodes installed in QUEST, CHI power supply and gas injection system fabricated at U-Washington

High-Z Tile Design Progressing

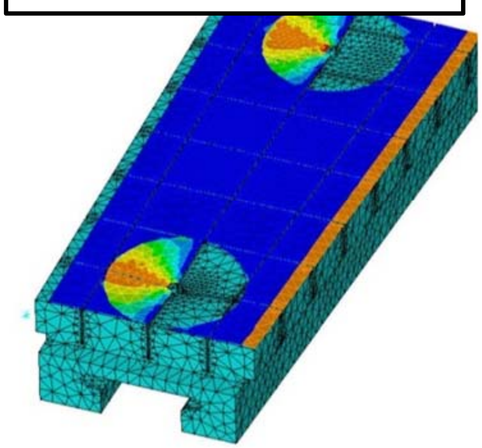
(plan to be ready by the 2016 outage ~ June 2016)

- **Successful CDR held in June**
  - 75% of Chits resolved PDR planned for early Nov.
  - Raw material procurement underway
- **2nd design iteration analysis nearly complete**
  - Installation flexibility introduced to accommodate “as built” vessel tolerances
  - Edge and access-way chamfers introduced to reduce heat-flux peaking
- **Thermal analysis of new leading edge geometry indicates ~30% reduction in peak temperature**
  - 1000 °C lower peak surface temperature vs. graphite reference design

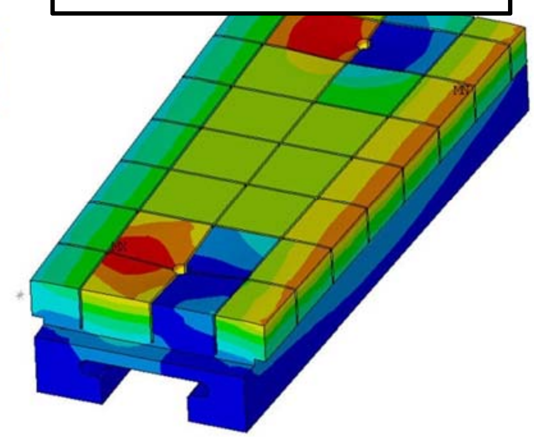


Seamless integration with existing mounting scheme minimizes installation time

Surface heat flux



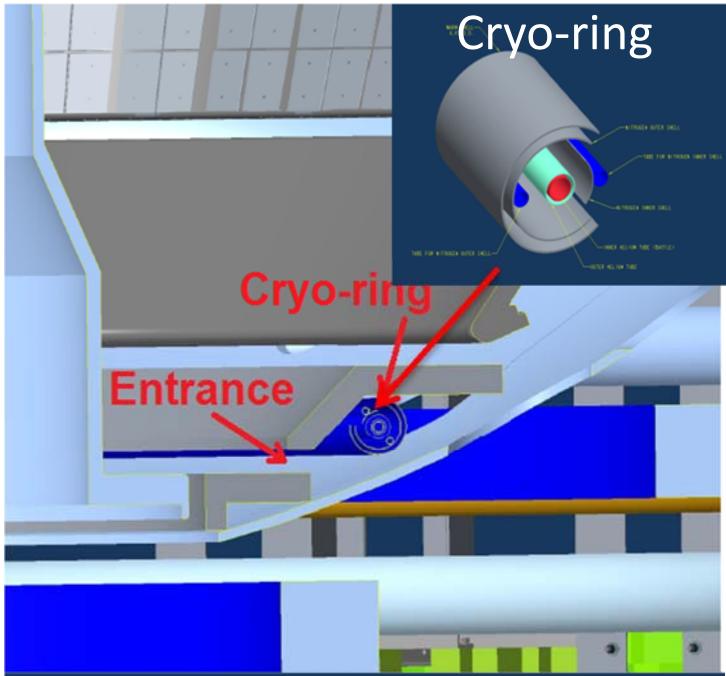
Temperature

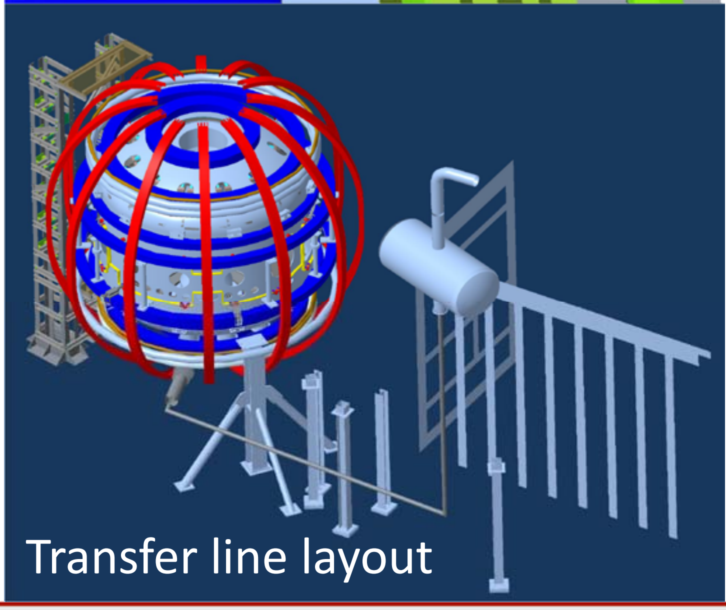


Divertor Cryo-pump Physics Design Activities Started

Develop engineering design and cost/schedule this year

- **Scoping work for the modified divertor & tiles has started**
  - Engineer assigned to this task.
  - Requirements are being formulated
- **Cost & Schedule continues to be developed**
  - Working on scoping estimate to get through CDR
  - Will generate WAF when definition of job elements matures.
- **PPPL & MIT are working on a agreement to fund MIT/PSFC staff to work on the in-vessel LHe pump design.**
- **Working on system integration.**
  - a working group that will look at the impact of the new pump/divertor on the lower diagnostics will start meeting in October
- **CDR - Q1 CY'16**

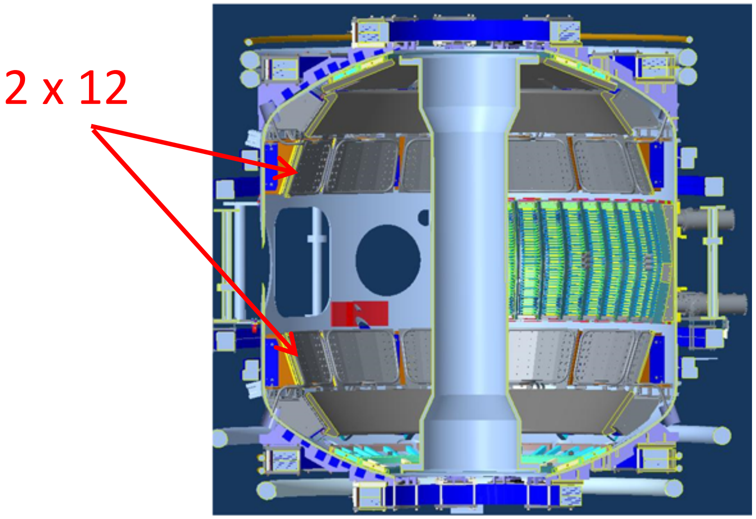


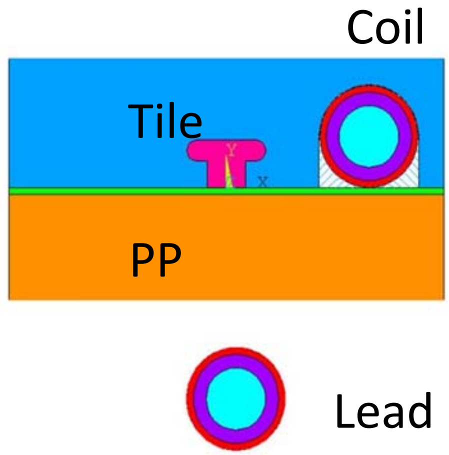


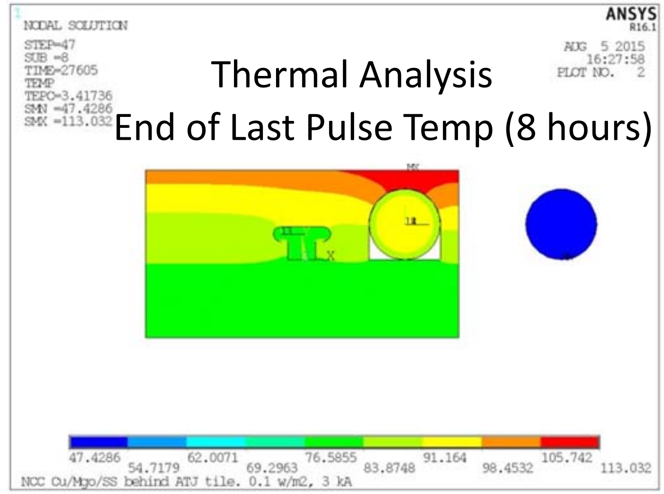
NCC Coils Design Activity Made Significant Progress

Develop engineering design and cost/schedule

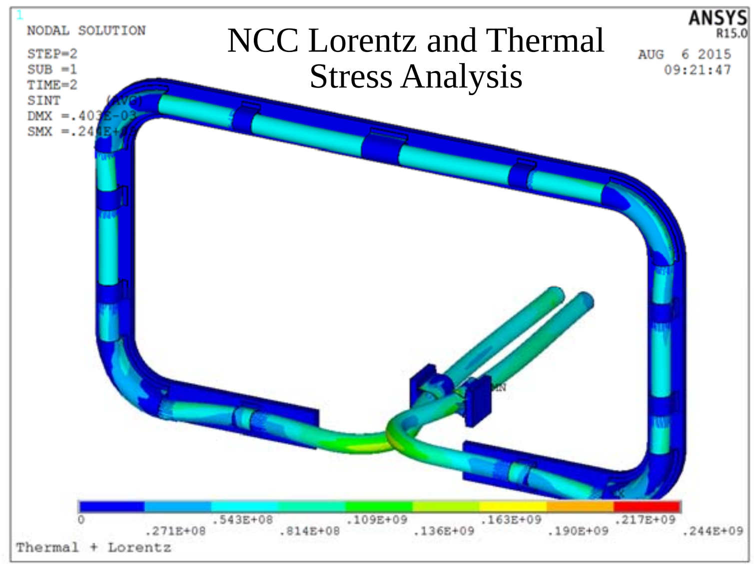
NCC = Non-axisymmetric Control Coil







3 kA,0.1 MW/m2 Plasma Heating,5s pulse,1200 s reprate



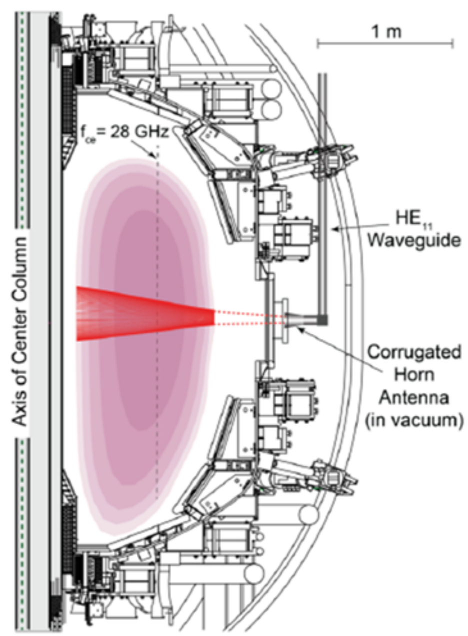
With Lead Clamp, 50 C Heat-up, 3kA+ Background Field

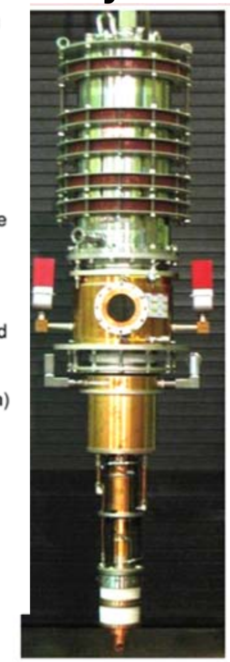
- **Selected round cross-section conductor. Order of test sample is placed: Dia. 0.965, Conductor Dia. 0.58, Length 20 feets are considered. The selection criteria include thermal capability, manufacturability, impact on interfacing objects, fabrication lead time and cost.**
- **Helium cooling system or no direct cooling options will be quantified.**
- **A WAF estimate (cost and schedule) will be prepared as part of the CDR which is targeted for May, 2016.**

28 GHz ECH System Design Progressing Well
Develop engineering design and cost/schedule this year

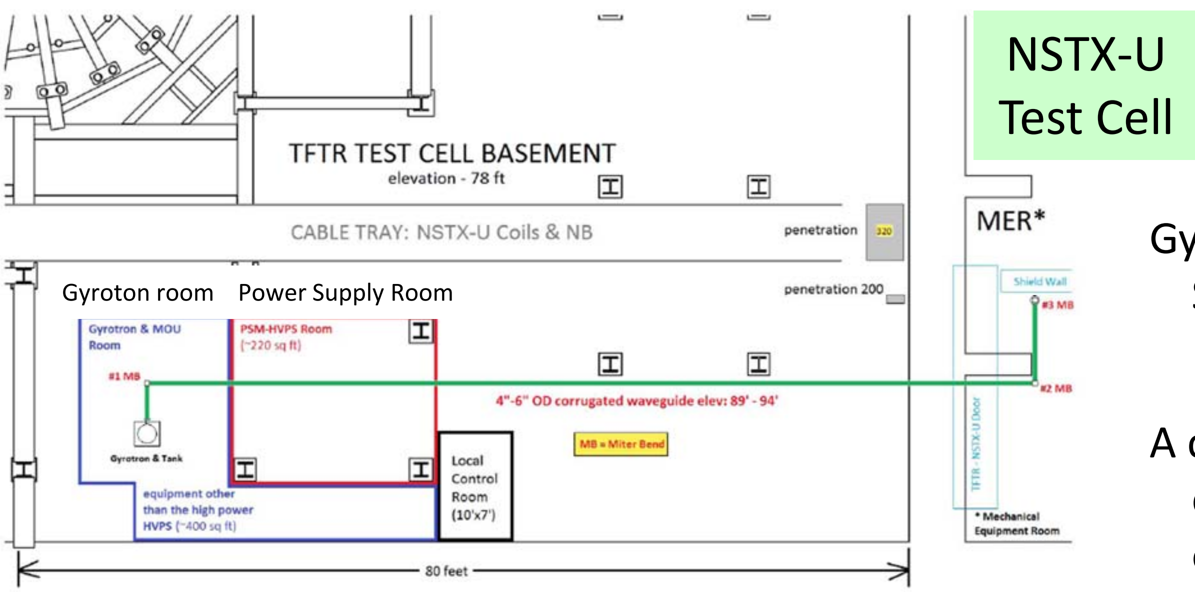
- **CHI can form a 200-400 kA seed plasma, but it is too cold for HHFW absorption.**
- **Use of ECH can "bridge the T_e gap" to where HHFW and then NB current drive can support the ramp and sustain the current – crucial for OH solenoid-free compact STs.**
  - **Good first pass absorption predicted.**
- **Goal of first ECH power in 2019 run with 15% incremental funding.**

28 GHz 1 MW
be by Tsukuba





28 GHz Gyrotron Room



Gyrotron will be located in the TFTR basement. Stray magnetic fields was measured to be negligible.

A commercial waveguide manufacturer was contacted and expect be able to complete the li of the components we need for our NSTX-U 1+ MW ECH waveguide system.

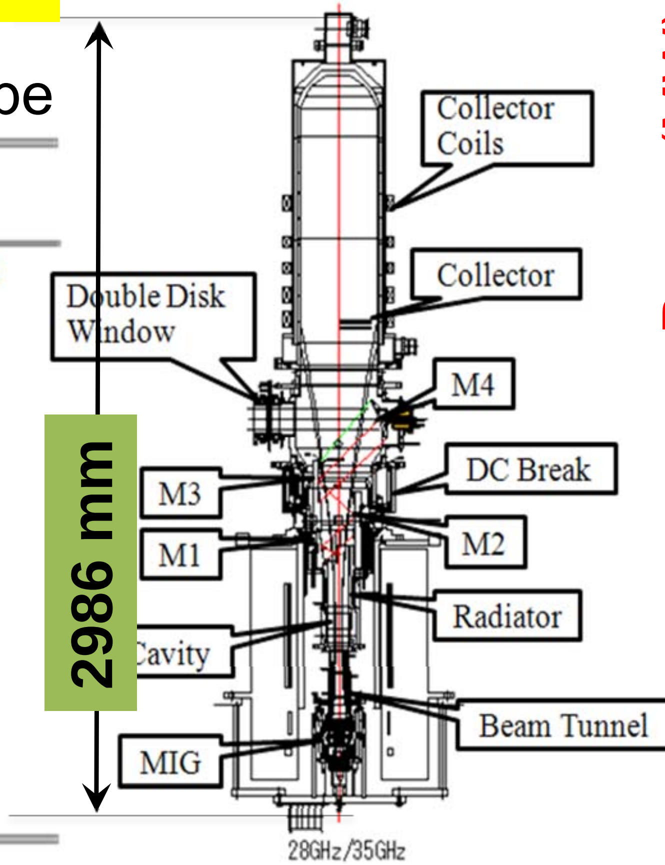
Tsukuba University is developing Prototype 28 / 35 GHz Gyrotron for NSTX-U & G-10/PDX

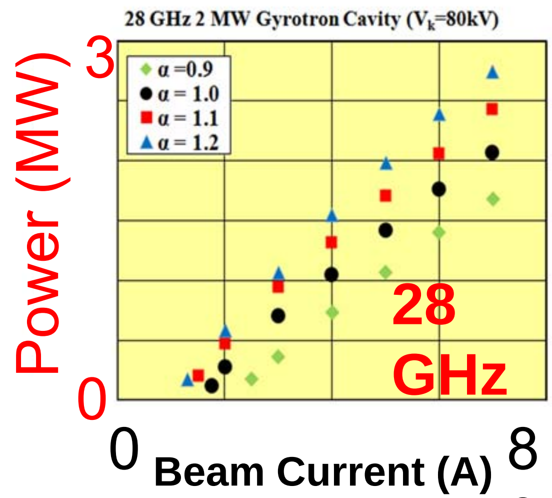
→ New design of cathode, cavity and mode converter for 1.5 – 2 MW

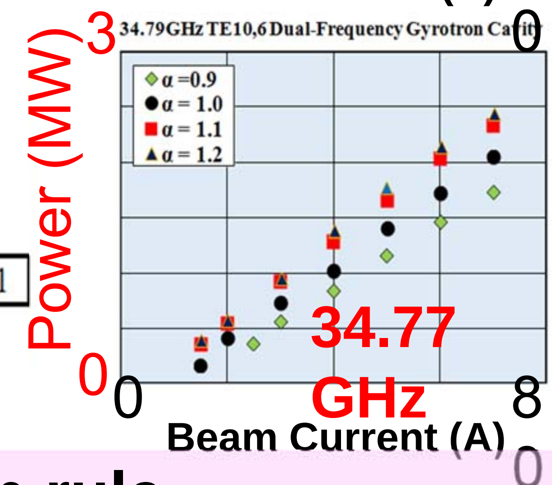
● Design Parameters of New Tube

28 GHz 2 MW Dual-frequency Gyrotron for GAMMA 10/PDX, QUEST, NSTX-U

Frequency	28 GHz		34.77 GHz
Output Power	2 MW	0.4 MW	1 MW
Pulse Width	3 s	CW	3 s
Output Efficiency	50% (with CPD)		
Beam Voltage	80 kV	70 kV	80 kV
Beam Current	70 A	20 A	40 A
MIG		triode	
Cavity mode	$TE_{8,5}$		$TE_{10,6}$
Output mode	Gaussian like		
Output Window	Sapphire Double Disk		
Collector	Depressed Collector		
	Sweeping coils		







$TE_{8,5}$ (28 GHz) & $TE_{10,6}$ (35 GHz) by the selection rule

- **2 MW calculated outputs at both 28 & 35 GHz are obtained.**
- We (Tsukuba) started its fabrication and it will be tested in FY 2016.

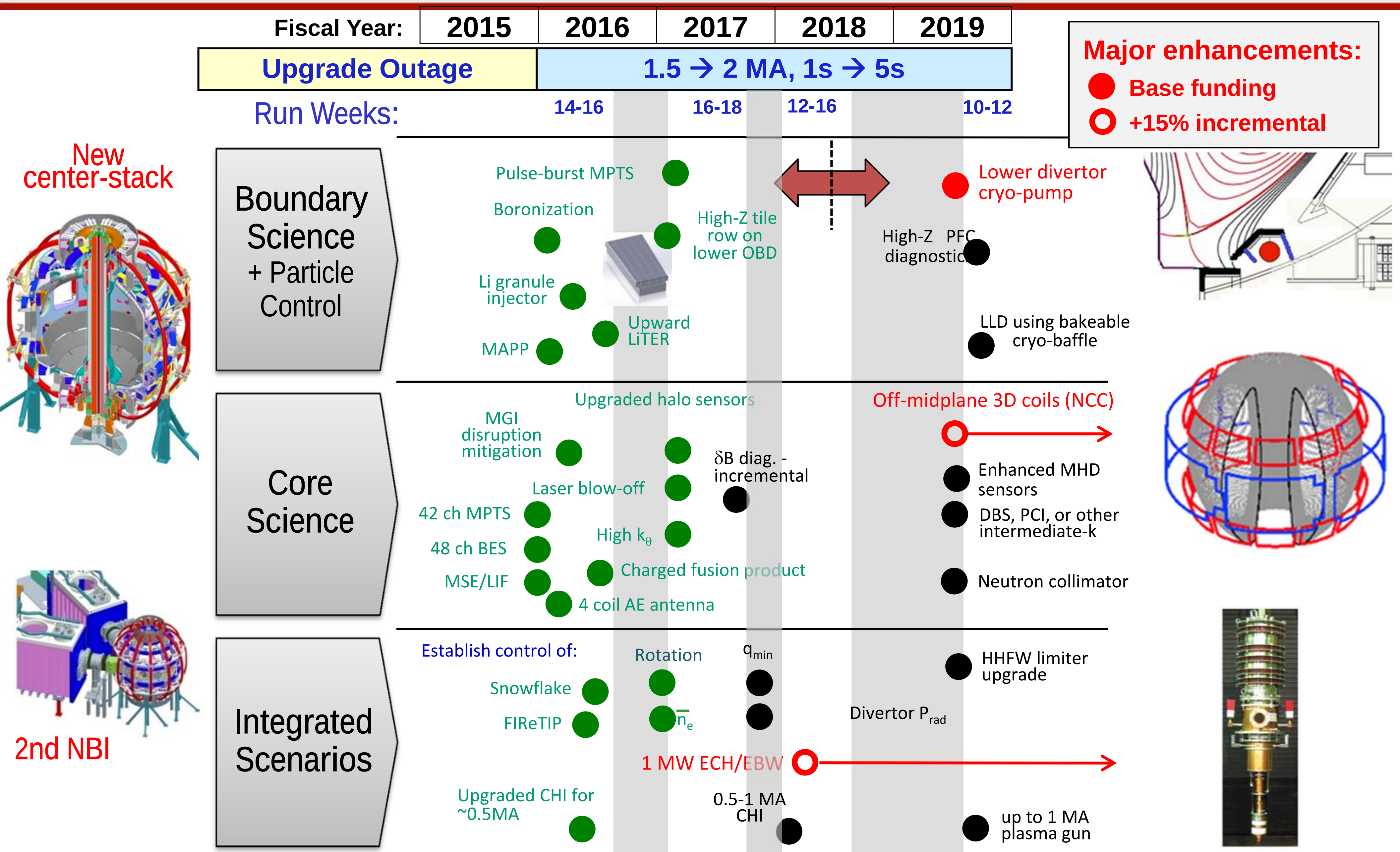
Summary of Facility and Diagnostics
Team is preparing for research operations

- CD-4 KPP#1 Plasma successfully achieved on August 10, 2015. The upgrade project was concluded in September 2015.
- Bake-out has concluded on October 20, 2015.
- Research preparation progressing well. All of the planned diagnostics and research tools should be available during the first year of plasma operations.
- Vacuum leak check is on going and diagnostics are being installed.
- ISTP should start in November followed by commissioning.
- Research operation should start in early December 2015.
- Engineering design work continuing for the major facility enhancements: high-Z tiles, divertor cryo-pump, ECH, and NCC.

Back-Up slides

Five Year Facility Enhancement Plan (green – ongoing)

2015: Engineering design for high-Z tiles, Cryo-Pump, NCC, ECH



High Priority NTC Activities Following the Bake

- Shutter and TIV connections to the PLC
- Diagnostic installation
- Boronization system commissioning
- I_P Calculator Tuning
- RWM coil high-pots, resistance checks, polarity checks
- Ground loop cleanup on diagnostics

NSTX-U diagnostics to be installed during first year

All center stack sensors mounted & ex-vessel terminations completed

MHD/Magnetics/Reconstruction

Magnetics for equilibrium reconstruction
Halo current detectors
High-n and high-frequency Mirnov arrays
Locked-mode detectors
RWM sensors

Profile Diagnostics

MPTS (42 ch, 60 Hz)
T-CHERS: $T_i(R)$, $V_\phi(r)$, $n_C(R)$, $n_{Li}(R)$, (51 ch)
P-CHERS: $V_\theta(r)$ (71 ch)
MSE-CIF (18 ch)
MSE-LIF (20 ch)
ME-SXR (40 ch)
Midplane tangential bolometer array (16 ch)

Turbulence/Modes Diagnostics

Poloidal FIR high-k scattering (installed in 2016)
Beam Emission Spectroscopy (48 ch)
Microwave Reflectometer,
Microwave Interferometer
Ultra-soft x-ray arrays – multi-color

Energetic Particle Diagnostics

Fast Ion D_α profile measurement (perp + tang)
Solid-State neutral particle analyzer
Fast lost-ion probe (energy/pitch angle resolving)
Neutron measurements
Charged Fusion Product

New capability,
Enhanced capability

Edge Divertor Physics

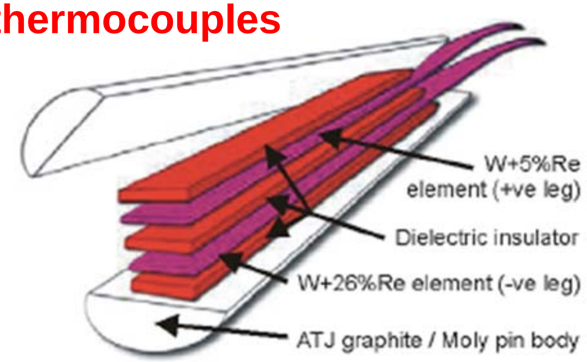
Gas-puff Imaging (500kHz)
Langmuir probe array
Edge Rotation Diagnostics (T_i, V_ϕ, V_{pol})
1-D CCD H_α cameras (divertor, midplane)
2-D divertor fast visible camera
Metal foil divertor bolometer
AXUV-based Divertor Bolometer
IR cameras (30Hz) (3)
Fast IR camera (two color)
Tile temperature thermocouple array
Divertor fast eroding thermocouple
Dust detector
Edge Deposition Monitors
Scrape-off layer reflectometer
Edge neutral pressure gauges
Material Analysis and Particle Probe
Divertor VUV Spectrometer

Plasma Monitoring

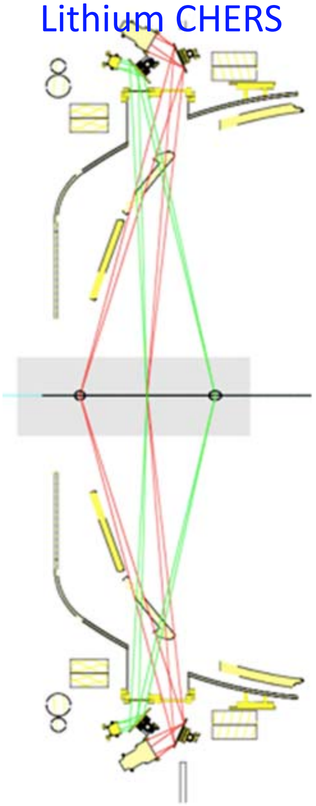
FIReTIP interferometer
Fast visible cameras
Visible bremsstrahlung radiometer
Visible and UV survey spectrometers
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis

Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples

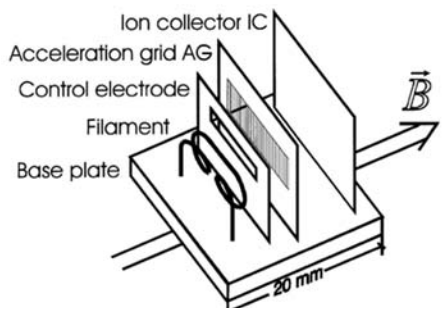


Lithium CHERS

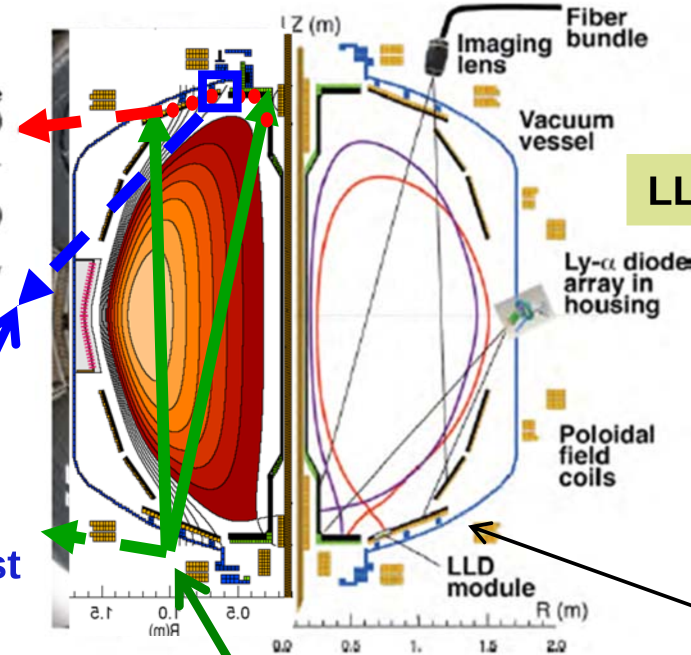


ORNL

Divertor fast pressure gauges

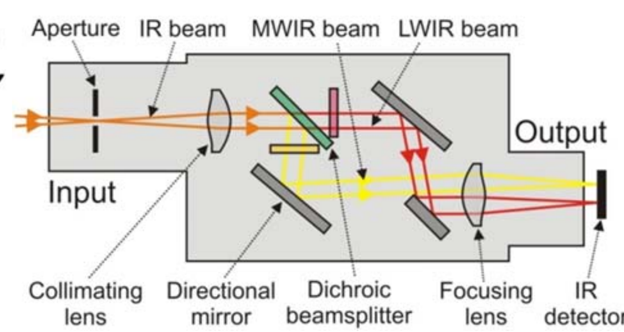


Divertor Imaging Spectrometer



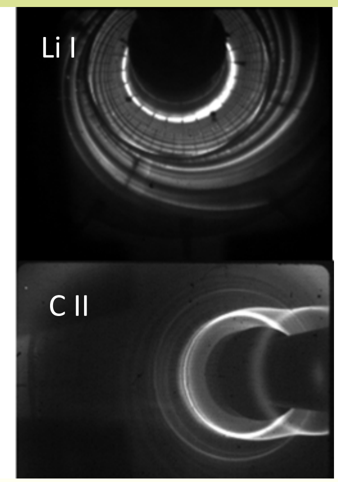
LLNL

Dual-band fast IR Camera

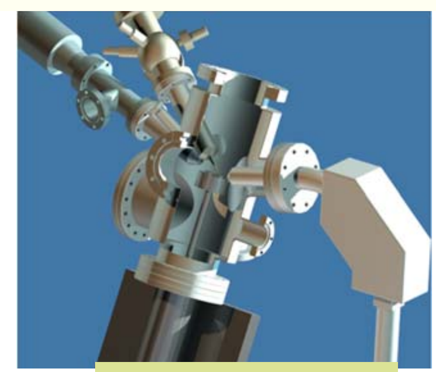


Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K



MAPP probe for between-shots surface analysis – Tested in LTX



U. of Illinois