U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

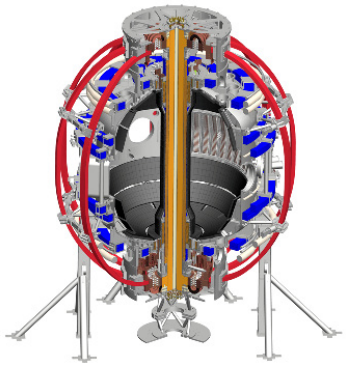
NSTX-U Project / Facility Status

Masa Ono and Jon Menard

NSTX-U FY 2015 Q3 Review Meeting

July 23, 2015

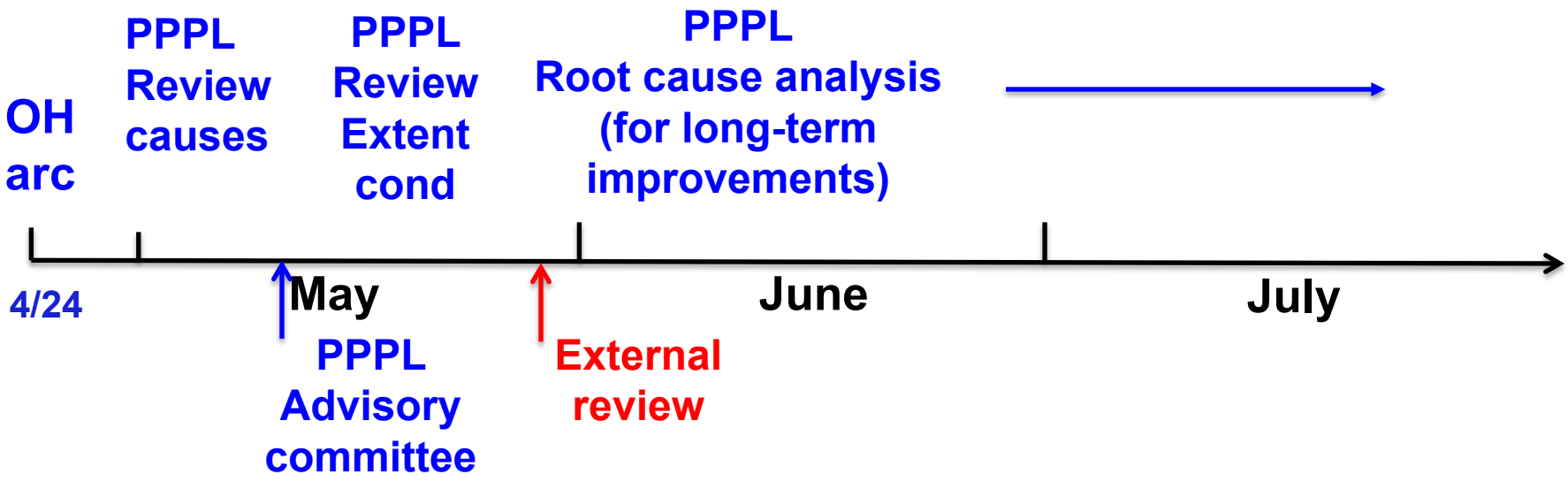
PPPL



Outline

- **OH Water Feed Arc Recovery Activities**
- **Preparation toward Operation**
- **Research Operations Plan**
- **Research facility / diagnostic enhancement activities**
- **Summary**

A number of reviews were conducted To investigate the arc incident



On causes: technical, procedural, process (April 30 – May 13)

R. Ellis (chair, ME) ,J. Delooper (best practices), J. Hosea (phys.), C. Neumeyer (EE), M. Bell (phys.)

On extent of condition (May 13 – May 22)

J. Hosea (chair, phys), R. Ellis (ME), N. Greenough (EE),D. Mueller (phys)

Root cause analysis (May 4 – July)

I. Zatz (chair, ME), J. Lacenere (EE), J. Malsbury (QA), M. Mardenfeld (ME)

NSTX-U Arc Event External Review (May 28, 2015)
External Review Committee Report

Committee Members

Arnie Kellman (Chair), General Atomics

Jim Irby, MIT Plasma Fusion Center

Brad Merrill, Idaho National Laboratory

George Ganetis, Brookhaven National Laboratory

General Comments

The committee was impressed with the thorough, high quality effort presented by the team and the larger lab personnel to address the fault event. We believe that they are addressing the right issues, both technically and procedurally. We were also impressed by the extent that they are addressing issues beyond the immediate fault and using this opportunity to improve the system.

Gave a strong endorsement of internal reviews and a vote of confidence for the team to repair and restart NSTX-U safely. Get the job done correctly and do not squeeze the research plan (MO)

OH arc recovery action activities

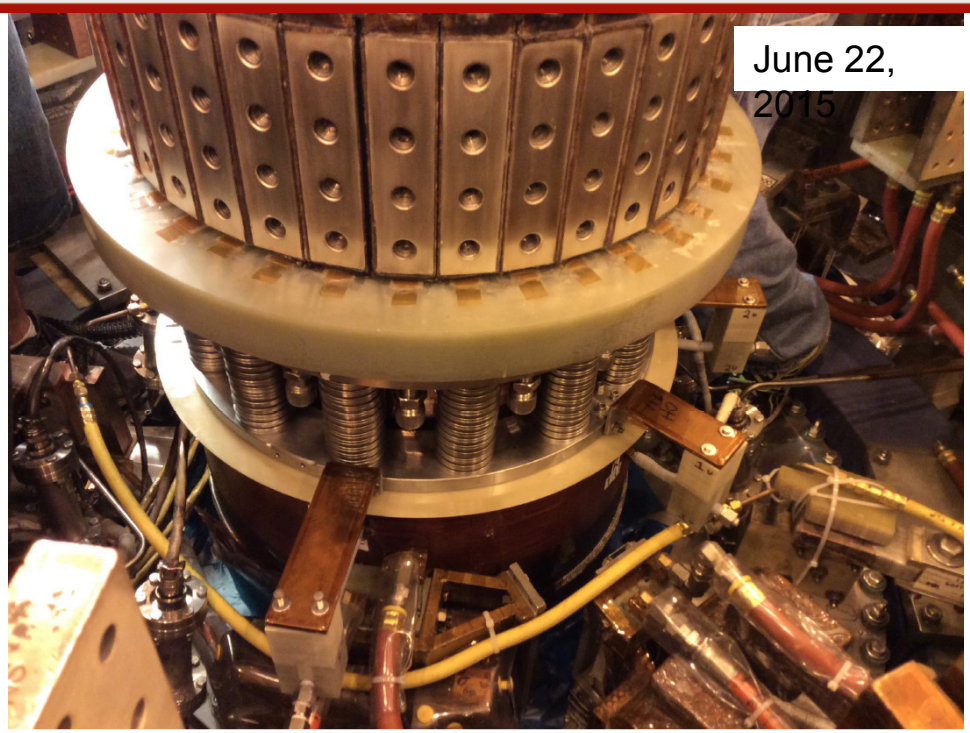
Repair/improvements completed and preparing for restart

- 73 action items suggested by the internal and external reviews
- 26 main action items combining similar ones together.
- 11 main items before CD-4 and the rest are 15 are after CD-4.
- There was a hold point (touch point with OFES) before the TF flex bus installation. DOE approval received on June 22, 2015.
- External committee recommended to have the root cause analysis feeds into ACC before CD-4. That is the present plan.
- The present schedule shows CD-4 to be mid-August. We will try our best to start as soon as possible. But we will take the necessary time to get the job done correctly.

OH Arc Recovery Status Summary

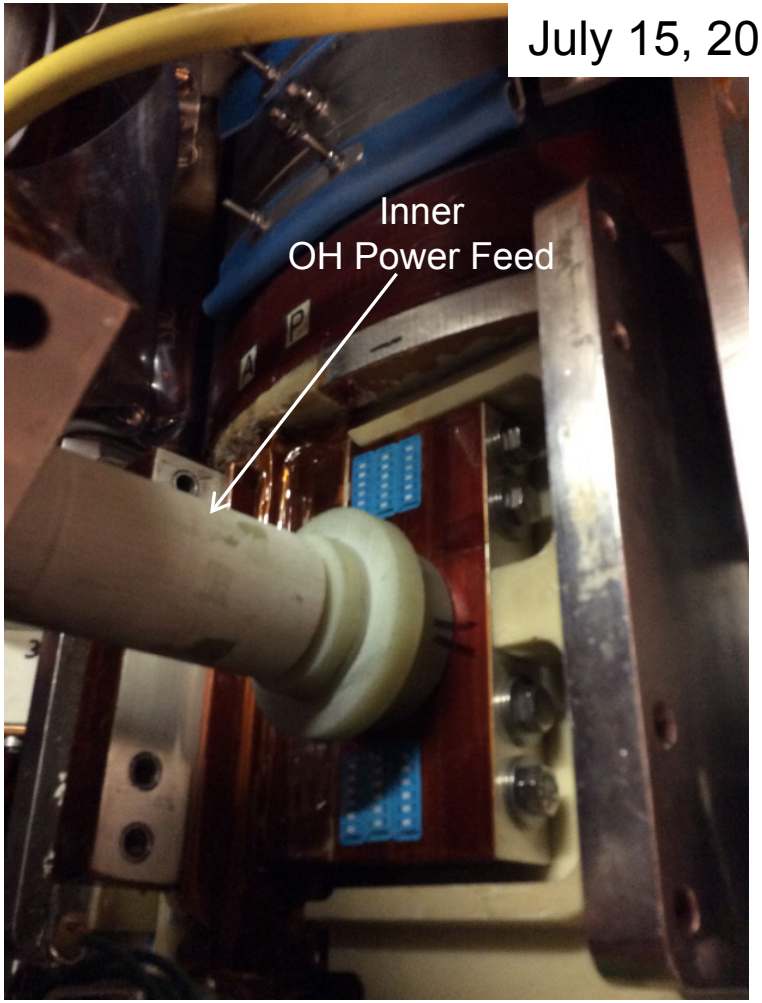
No significant damages and improvements implemented

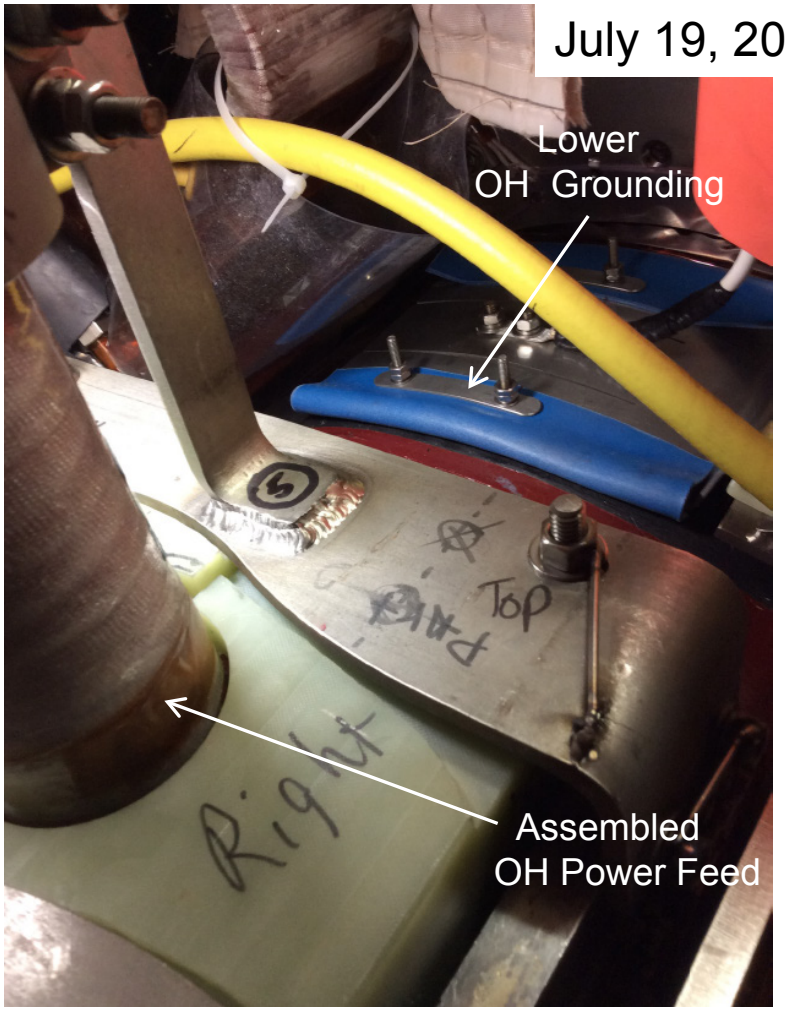
- The overall health of the NSTX-U machine appears good.
  - The damage was contained to external to OH coil (and other coils)
  - Electrical continuity/insulation and hydrostatic testing of the OH coil (and other coils nearby) indicate the coils are fine.
  - Magnetic diagnostics check out fine.
  - Bottom umbrella removed and inspected. Bottom area including support bracket improved.



- OH coil grounding loop eliminated and hose clamp improved.
- OH cooling water support bracket electrical insulation improved.
- Insulation tapes / bus supports generally improved.

A number of improvements and "Extent of Condition" issues have been identified and many were implemented.





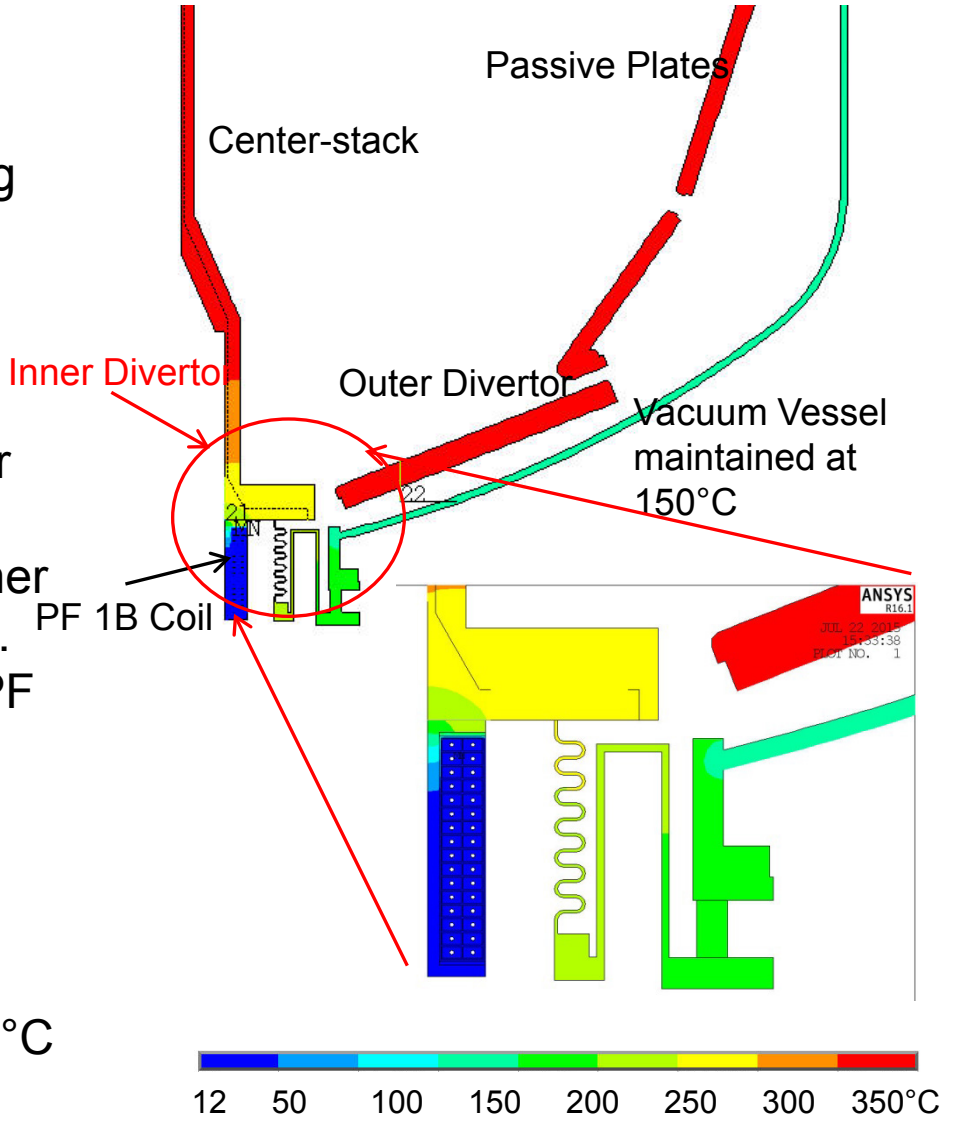
OH co-ax feed enhanced structurally with injection of epoxy.
Grounding added to the bottom to minimize fault voltage.

Inner Divertor Bake-out Issue due to PF 1B Identified

PF1b cooling hoses were replaced with high temperature ones

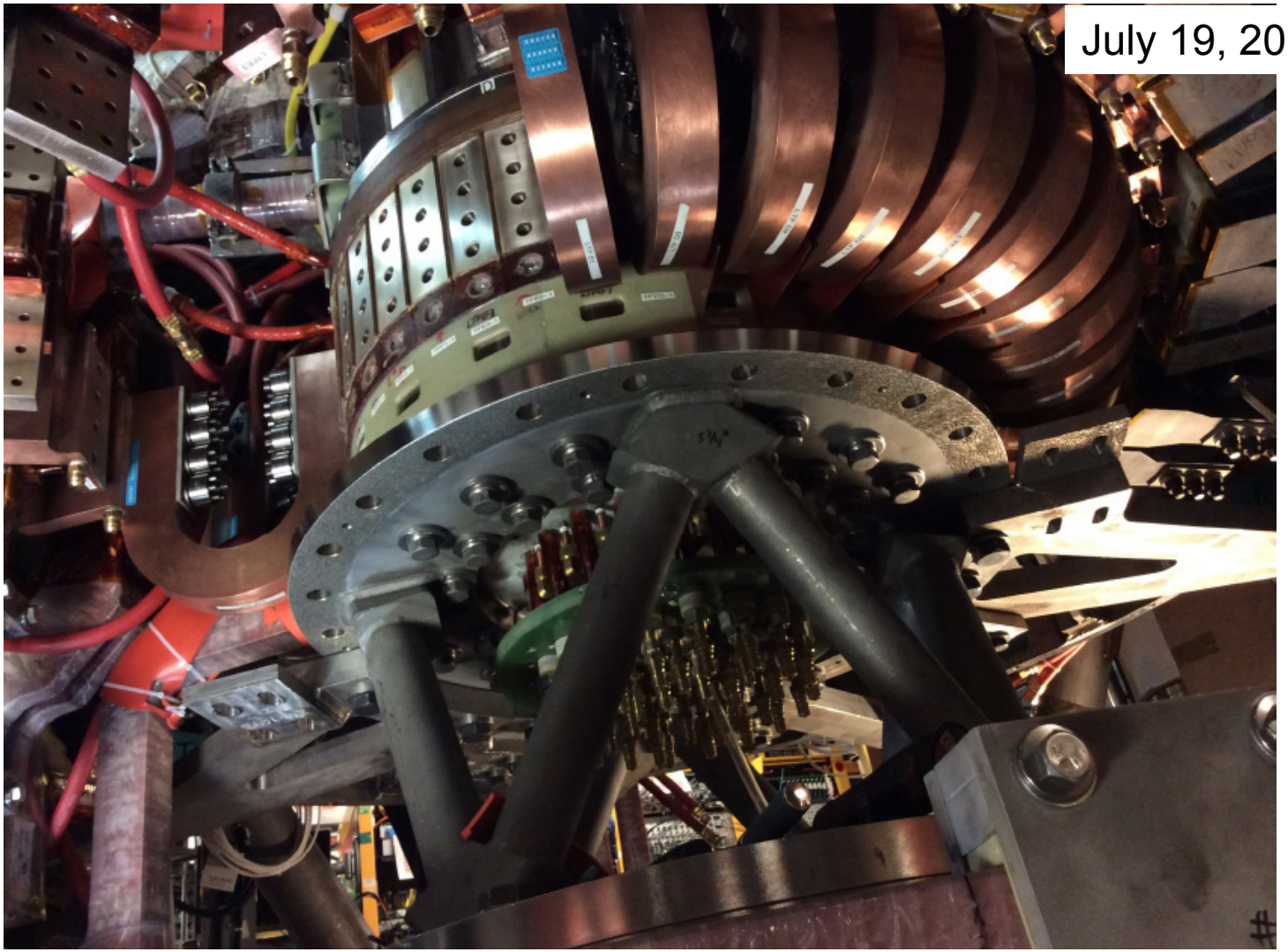
- NSTX-U bakeout system consists of 1. Hot helium gas heating passive plates and outer divertor, 2. Resistively heating the Center-stack.
- During the bakeout, all magnets are cooled by 12°C circulating water.

- Bakeout simulation shows that the inner divertor region is coolest ~ 250°C.
- PF 1B coil due to its proximity to the inner divertor is draining heat from the region.
- Analysis shows that by increasing the PF 1B cooling temperature from 12°C to 150°C, the inner divertor region temperature could be raise do ~ 300°C which also reduced weld stress.
- Hoses were replaced with higher temperature ones to accommodate 150°C cooling taking advantage of access.



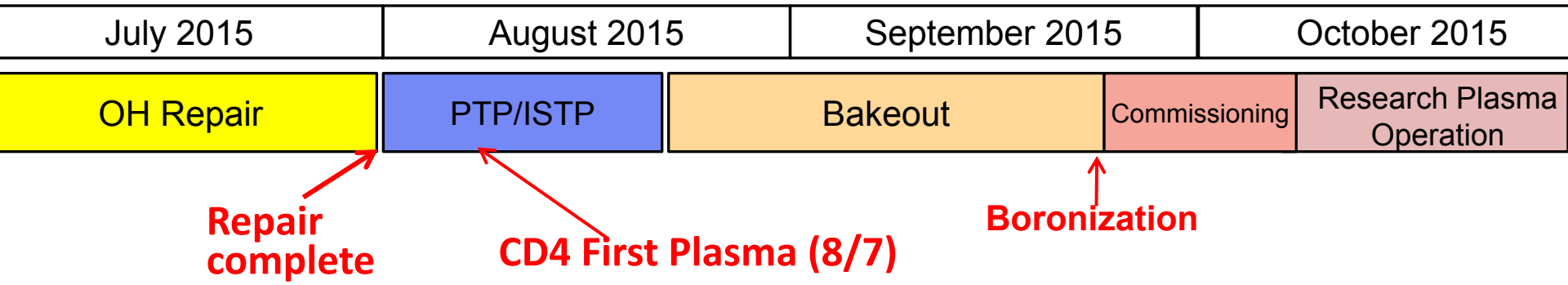
The NSTX-U Reassembly Is Going Well

Expect to complete assembly and start the scrub this week



TF / OH electrical joints individually measured and compared with model

Present Recovery Plan
Pre-CD-4 / research operation activities



Dummy load testing

MPTS R&R

NBI 1 & 2

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

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

Bakeout: June 2011- 367 hours (15 ays),
February 2010 - 472 hours (20 days)
Need 3 days to set-up and 2 days to remove

The NBI CD-4 target achieved on May 11, 2015.

The CD-4 plasmas will be used to commission diagnostics.

Five Year Facility Enhancement Plan (green – ongoing)

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

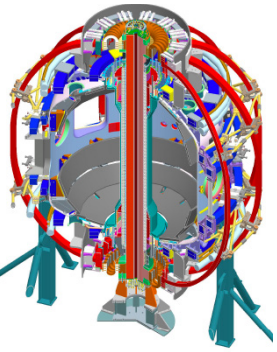
Fiscal Year: 2015 | 2016 | 2017 | 2018 | 2019

Upgrade Outage | 1.5 → 2 MA, 1s → 5s

Run Weeks: 14-16 | 16-18 | 12-16 | 10-12

Major enhancements:
- ● Base funding
- ○ +15% incremental

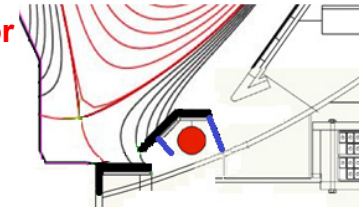
New center-stack



2nd NBI

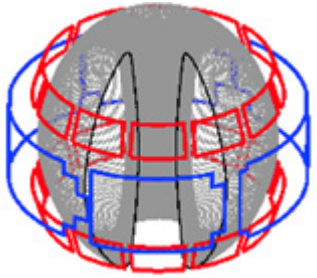
Boundary Science + Particle Control

- Pulse-burst MPTS
- Boronization
- High-Z tile row on lower OBD
- Li granule injector
- Upward LITER
- MAPP
- Lower divertor cryo-pump
- High-Z PFC diagnostics
- LLD using bakeable cryo-baffle



Core Science

- MGI disruption mitigation
- Upgraded halo sensors
- δB diag. - incremental
- Laser blow-off
- 42 ch MPTS
- High k_θ
- 48 ch BES
- Charged fusion product
- MSE/LIF
- 4 coil AE antenna
- Off-midplane 3D coils (NCC)
- Enhanced MHD sensors
- DBS, PCI, or other intermediate-k
- Neutron collimator



Integrated Scenarios

Establish control of: Rotation | q_{min}

- Snowflake
- FIReTIP
- $\bar{n}_e$
- HHFW limiter upgrade
- Divertor P_{rad}
- 1 MW ECH/EBW
- Upgraded CHI for ~0.5MA
- 0.5-1 MA CHI
- up to 1 MA plasma gun

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*

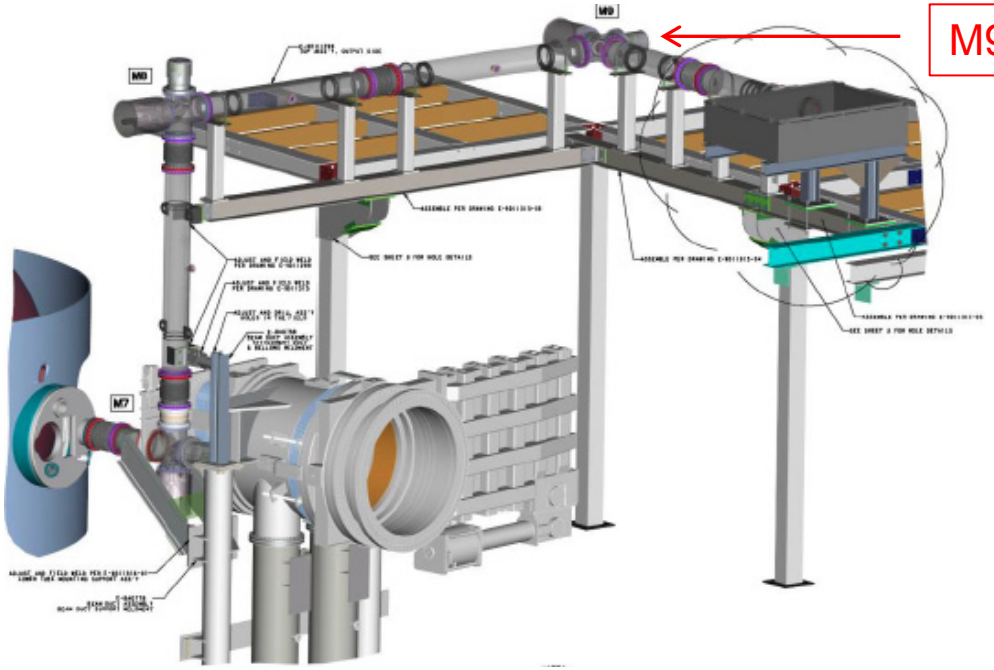
Plasma Monitoring

- 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

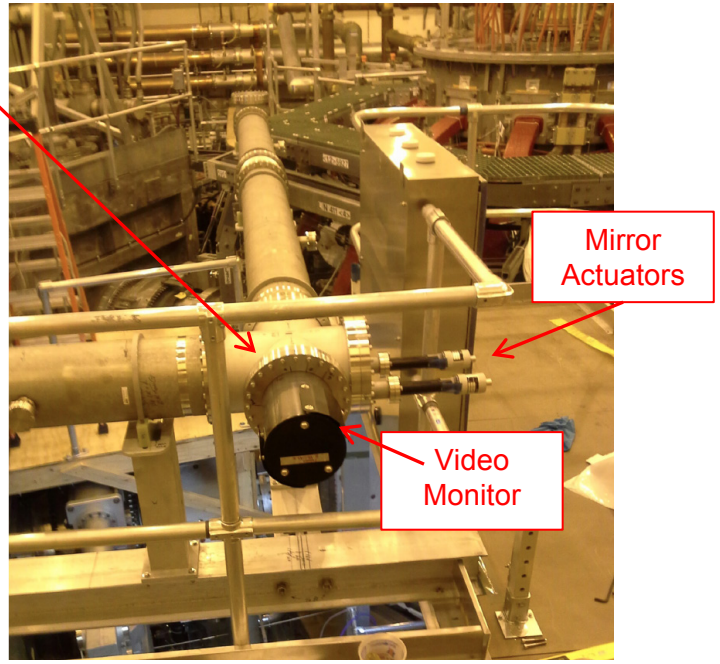
Multi-Pulse Thomson Scattering System
Nearly ready for calibration planned in August

- Realignment of MPTS nearing completion
- 42 spatial channels – improved spatial resolution in pedestal
- Alignment tasks are complete.
- Scattered light assessment this week.
- Plan to have MPTS ready for calibration in August, 2015 after CD-4

MPTS laser exit flight tube



Exit flight tube installed

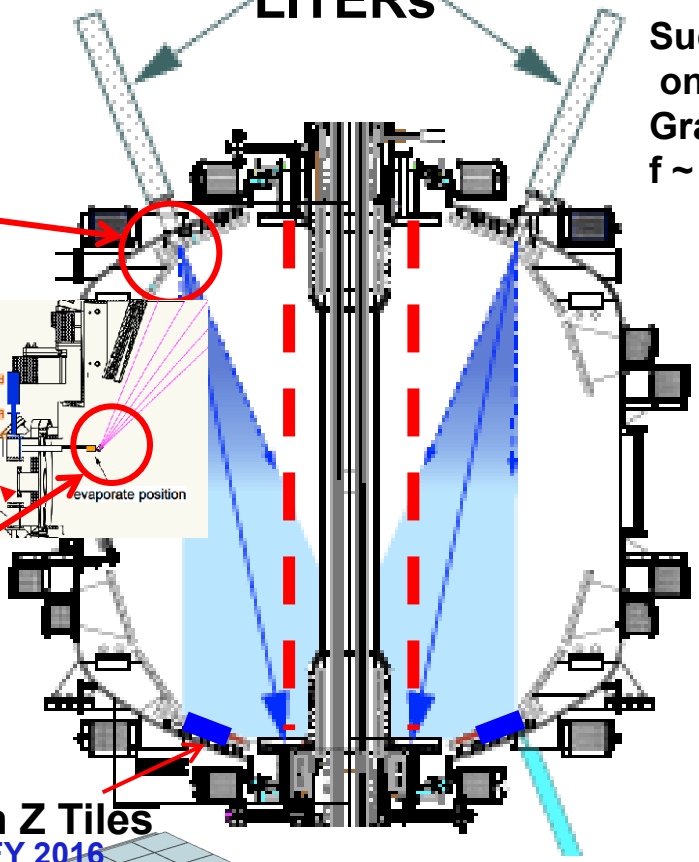


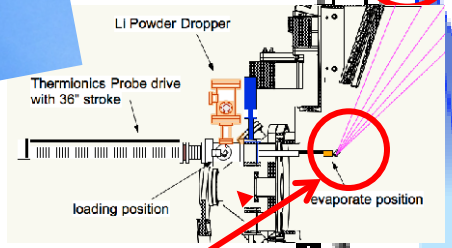
Comprehensive Boundary Physics Tools

Boronization, Lithium Evaporators, Granule Injector, High Z tiles

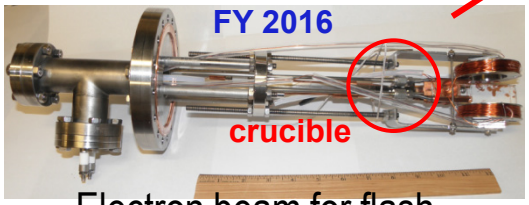
Lithium Evaporator (LITERs)

LITERs





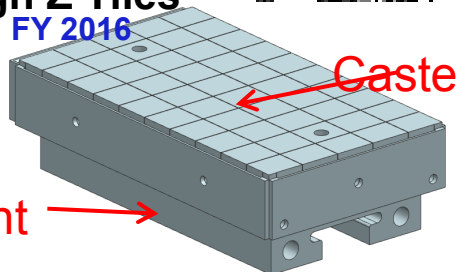
Upward Li evaporator



Electron beam for flash evaporation

High Z Tiles

FY 2016

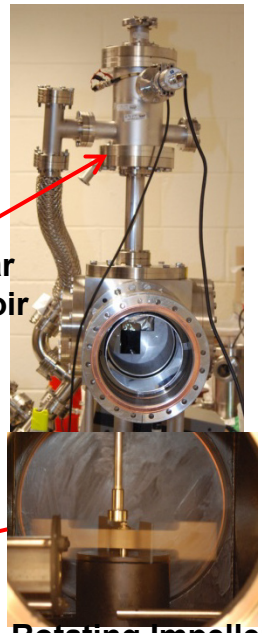


Castellations

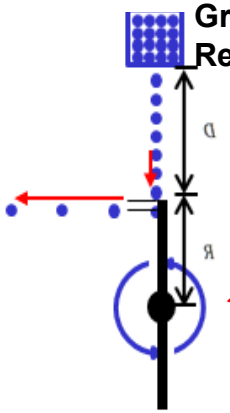
T-bar mount

Granule injector (GI) for ELM pacing

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



Granular Reservoir



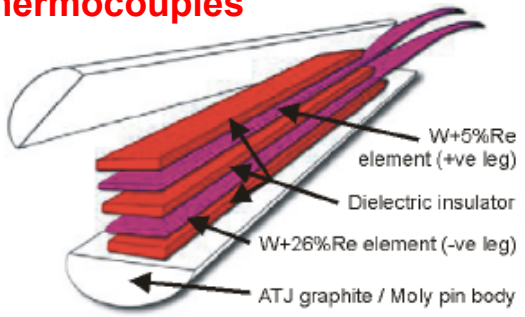
Rotating Impeller

Boronization System

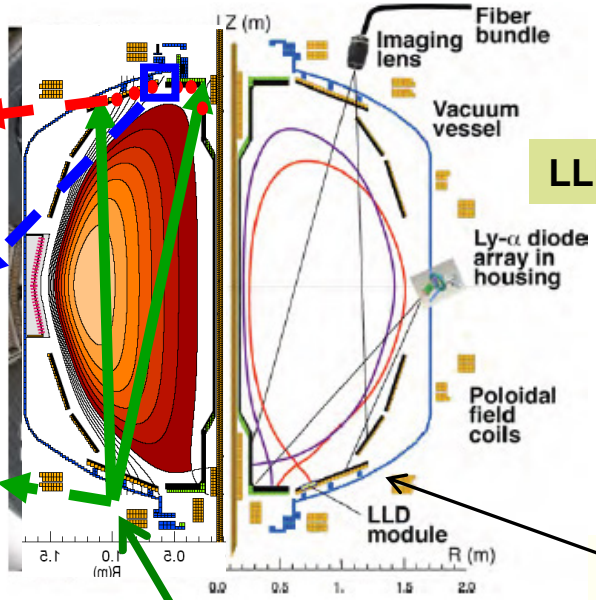
dTMB Gas Cabinet.

Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples

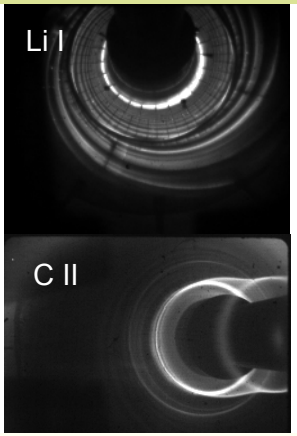


Divertor Imaging Spectrometer



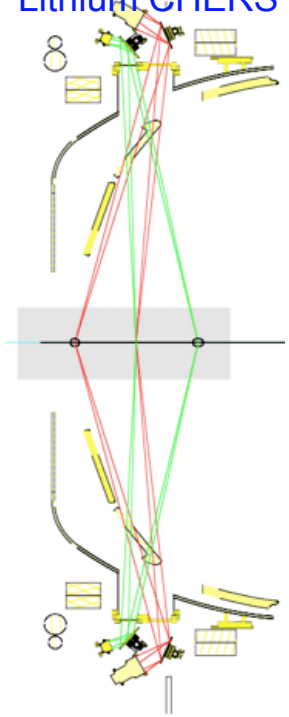
Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K



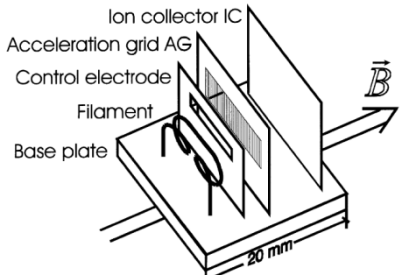
LLNL

Lithium CHERS

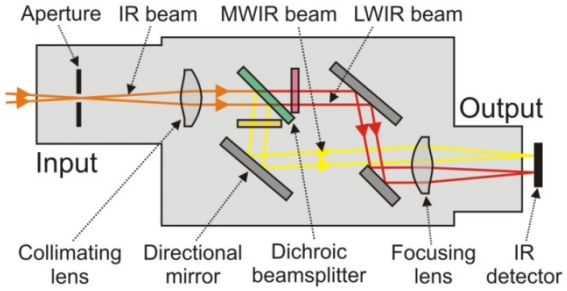


ORNL

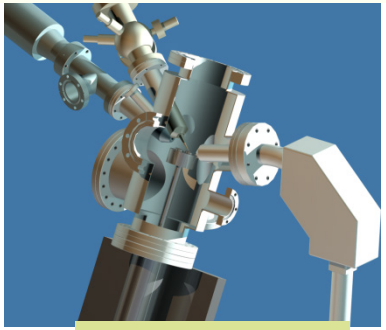
Divertor fast pressure gauges



Dual-band fast IR Camera



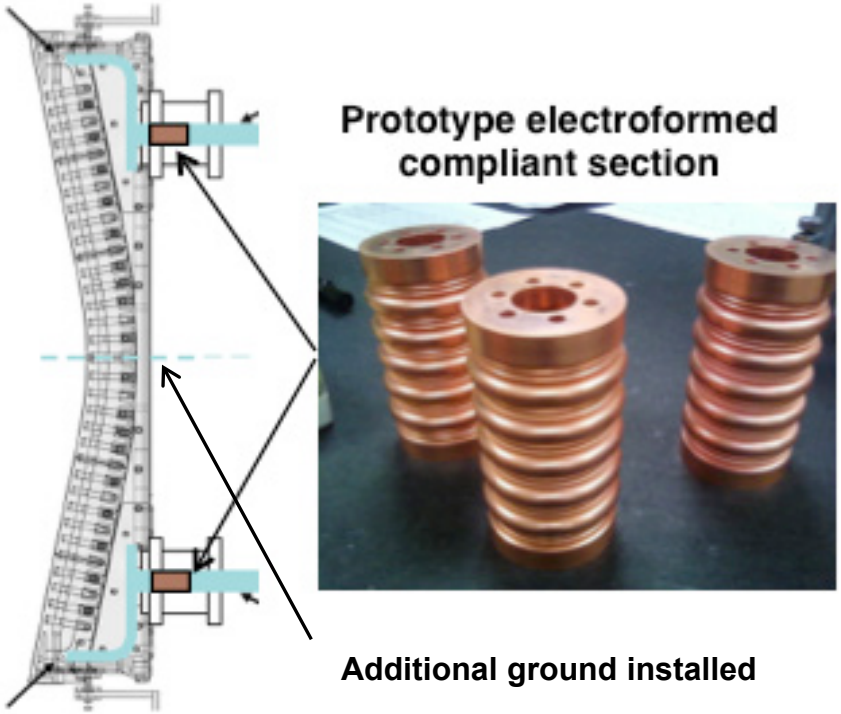
MAPP probe for between-shots surface analysis – Tested in LTX



U. of Illinois

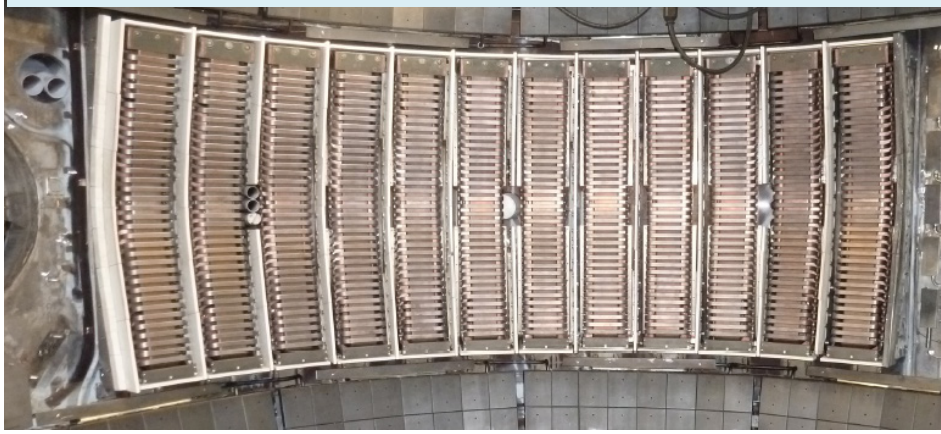
HHFW system preparation is going well
Ready to start conditioning in August

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



- 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

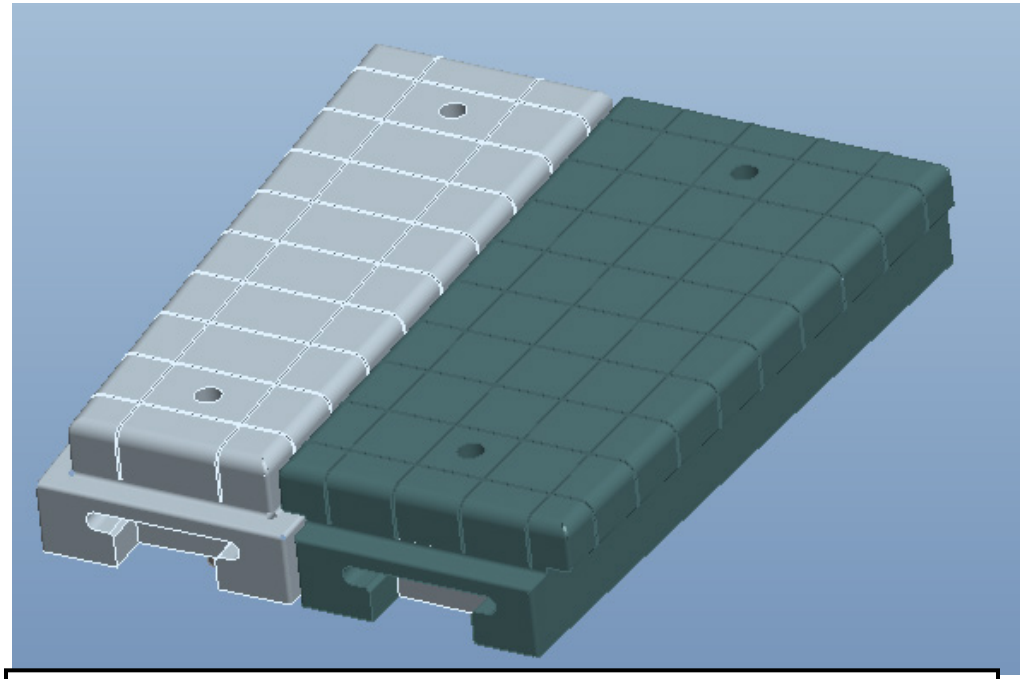


Transmission lines installed & tuned.

- **Source 3-6 are ready. Sources 1 & 2 are being readied. Conditioning to start when the machine is ready.**

High-Z Tile Design Progressing
(plan to be ready by the 2016 outage ~ April 2016)

- **WAF (work authorization form) is complete,**
- **WP (work package) Form is complete**
- **System Design Document (SDD) 1st draft is complete, a review meeting held in May.**
- **Initial tile analysis is complete**
  - **Thermal, EM & Structural, Combined Load Case**
  - **Produced a calculation sheet.**
- **A successful Conceptual Design Review (CDR) was held in June.**



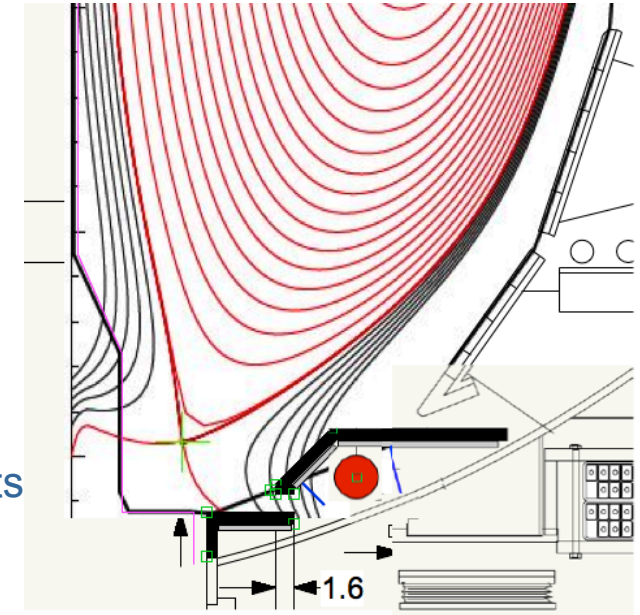
Simplest example of new tiles, 1st Iteration

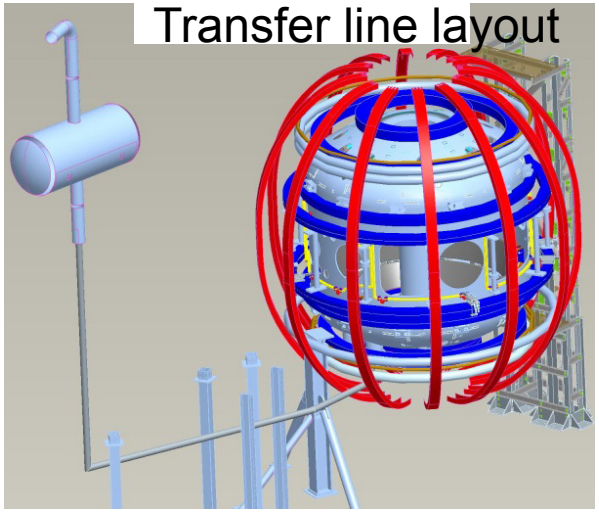
Tiles in assembly, designed to be seamlessly integrated with other OBD tiles.

Divertor Cryo-pump Physics Design Activities Started

Develop engineering design and cost/schedule this year

- Several options for the cryo feed line considered and made some key decisions:
  - The size of the liquefier determined.
  - Bay“D” bottom port identified as the candidate access port for the LN/LH feedthrough, which allows us to finalize the route for the transfer lines.
  - Designs for the ring, heat loads, design for electrical breaks were examined. Also began listing requirements for the Helium refrigerator and evaluating the layout as much as possible for routing to the machine, penetrations through thevacuum vessel, and clearances inside the vacuum vessel for support structures.
- Design review schedule to follow this outline:
  - System level CDR soon.
  - Break out PDRs and FDRs for the other elements as needed to support procurements and installations (cost and schedule).
  - Liquid He system is identified as a long lead item ~ 18 months.

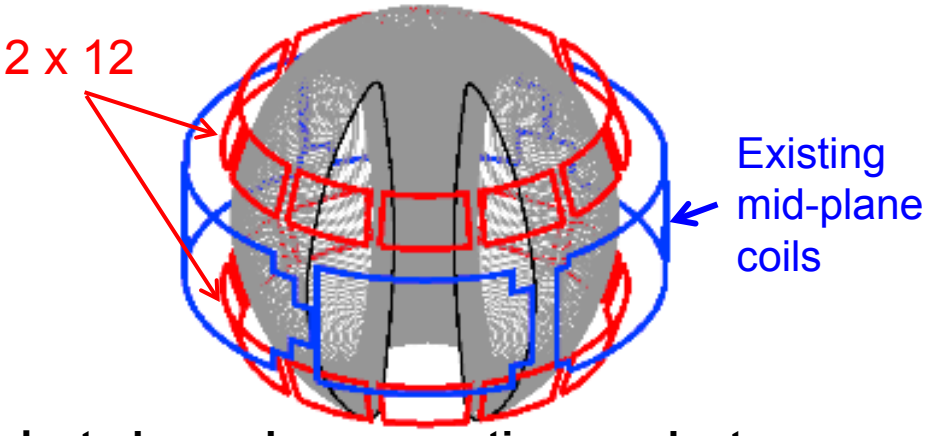


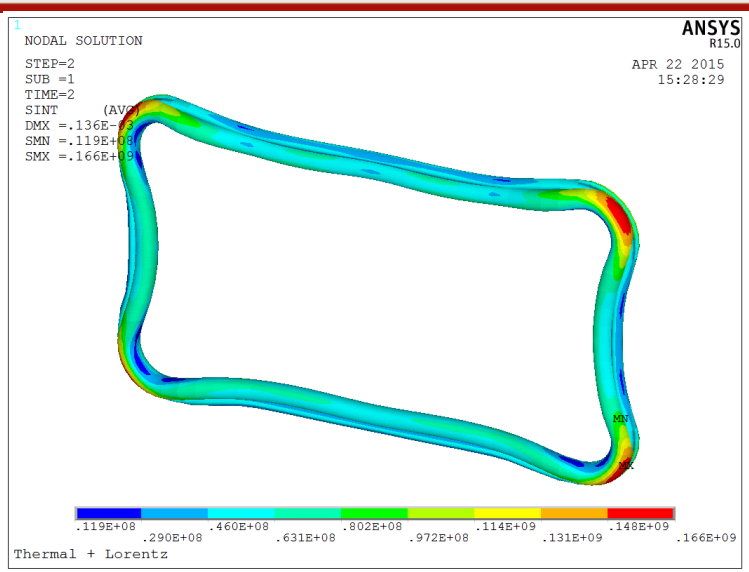


NCC Coils Design Activity Made Significant Progress

Develop engineering design and cost/schedule this year

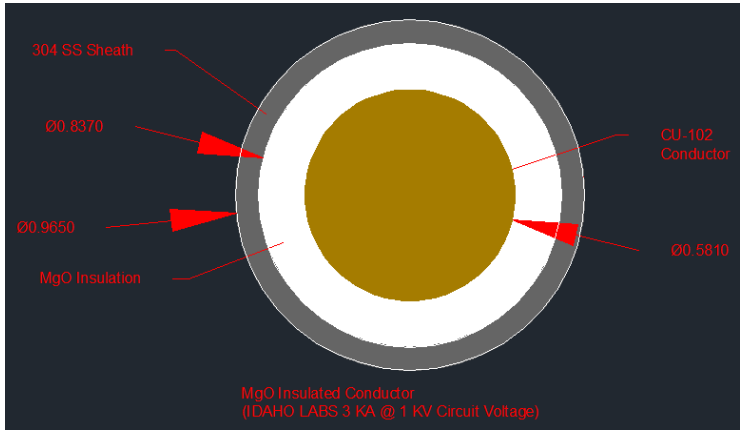
NCC = Non-axisymmetric Control Coil





- **Selected round cross-section conductor. Procurement of test sample is underway:**
  - Dia. 0.965, Conductor Dia. 0.58, Length 20 feet is 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 September 2015.

Round cross-section conductor

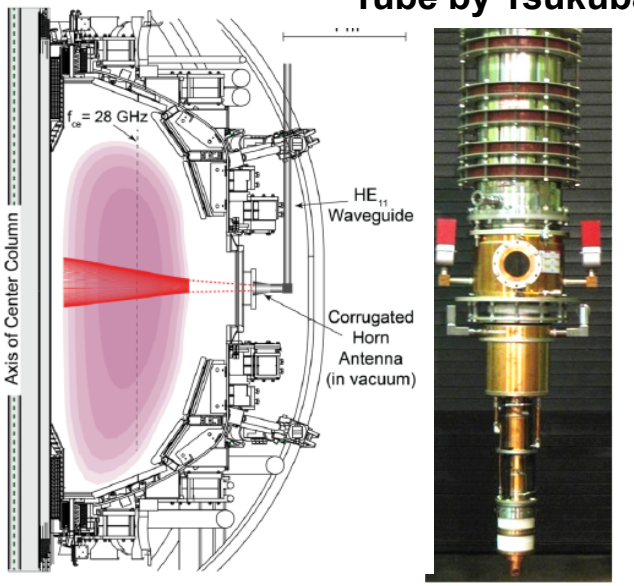


28 GHz ECH System Design Progressing Well

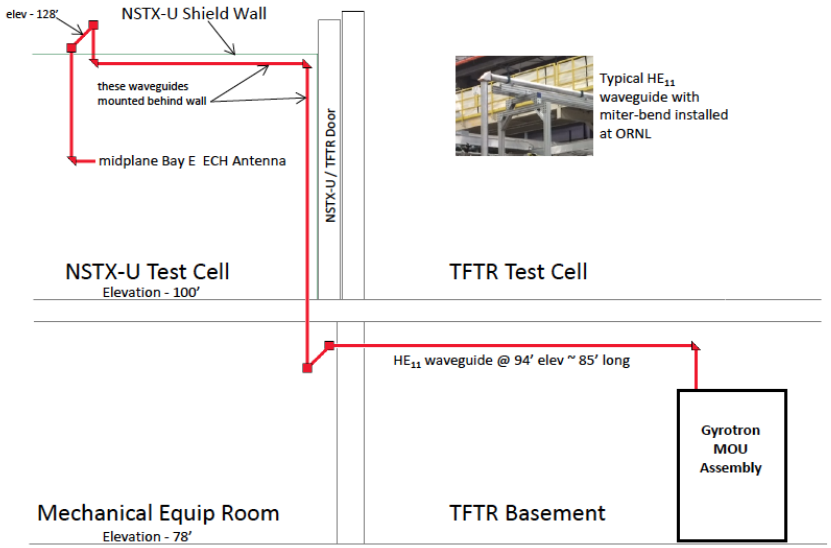
Develop engineering design and cost/schedule this year

- **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 2018 run with 15% incremental funding.**

28 GHz 1 MW Tube by Tsukuba



Schematic of waveguide run from NSTX-U Test Cell to Gyrotron in TFTR Test Cell Basement



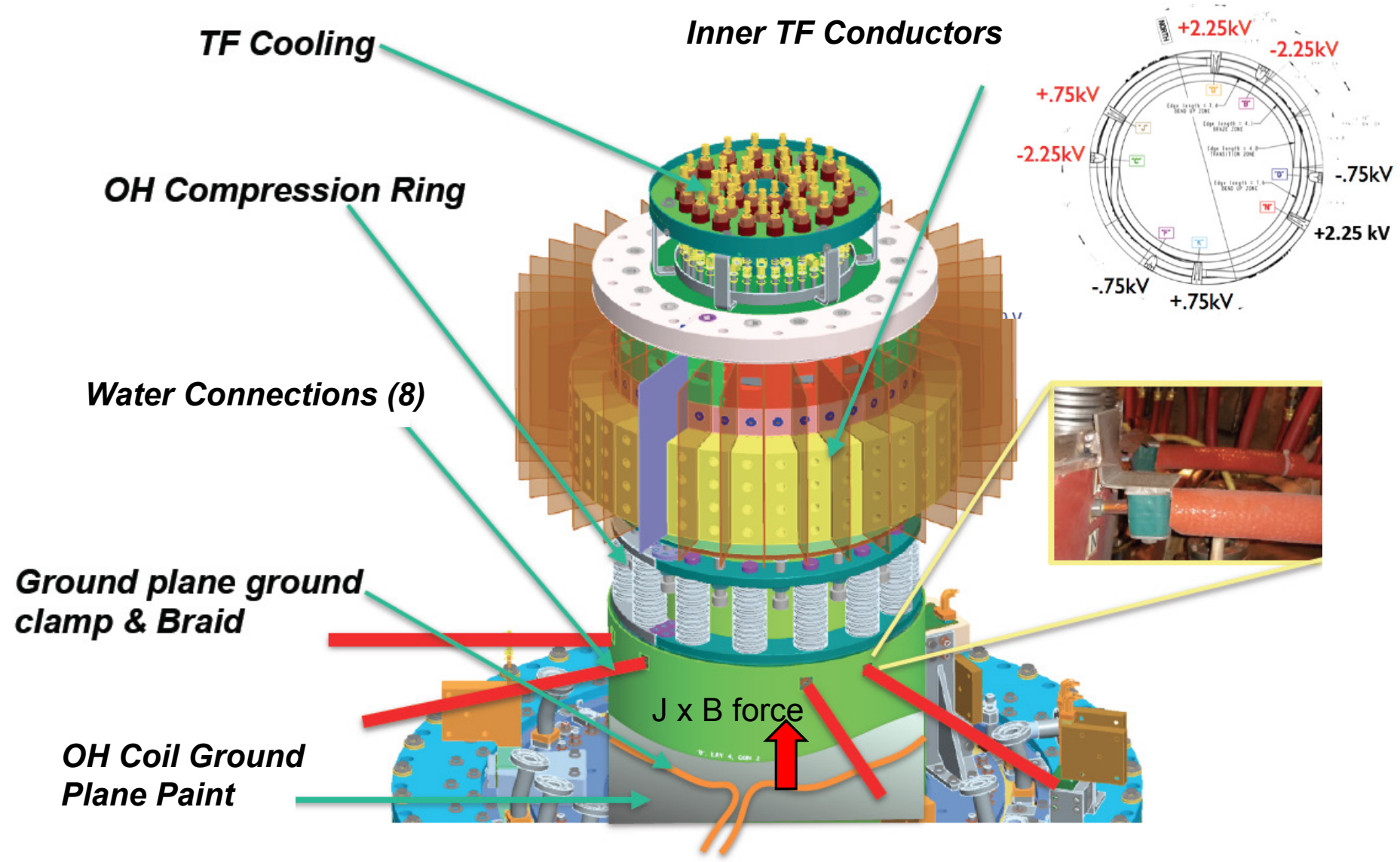
Typical HE_{11} waveguide with miter-bend installed at ORNL

- **Gyrotron will be located in the TFTR basement. Stray magnetic fields will be measured during ISTP.**
- **A commercial waveguide manufacturer was contacted and expect be able to complete the list of the components we need for our NSTX-U 1+ MW ECH waveguide system.**

Summary of Facility and Diagnostics
The OH arc recovery effort is nearly complete

- **A number of reviews were performed for the OH arc event. The cause of the arc was quickly identified and rectified with design improvements.**
- **Extensive re-examinations of the NSTX-U device/design (extent of condition review) revealed a number of areas for improvement and they are being implemented.**
- **The OH arc event recovery effort is nearly complete. The CD-4 is scheduled in early August. The NBI part of CD-4 was successfully completed on May 11, 2015.**
- **Research preparation progressed well during the OH arc recovery period. All of the planned diagnostics and research tools should be available during the first year of plasma operations.**
- **Research operation schedule / commissioning – Presently planning to start research plasma operation in October, 2015.**
- **Engineering design work started for the major facility enhancements: high-Z tiles, divertor cryo-pump, ECH, and NCC.**

Upper OH Coil Arrangement

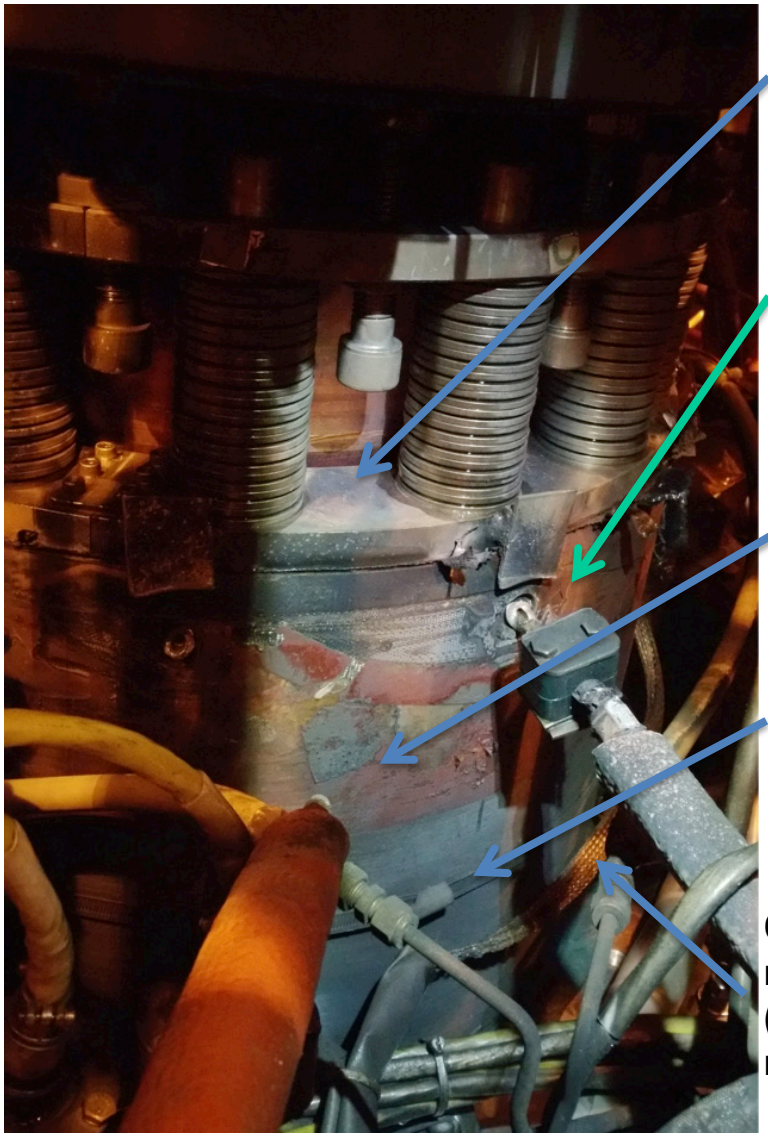


Activities leading up to the OH arc on April 24th

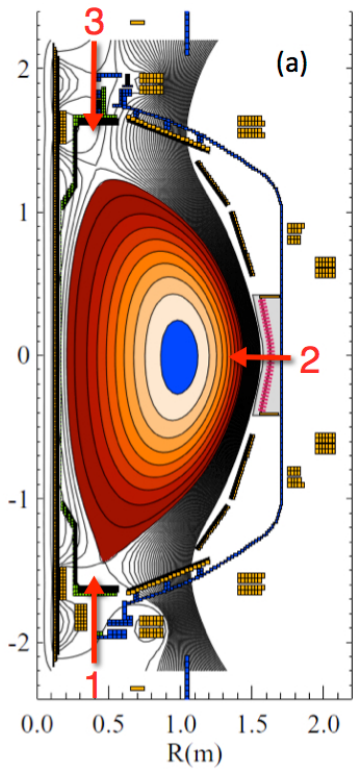
- We had successfully completed the NSTX-U machine Integrated System Test Procedure (ISTP) on April 21, 2015.
- On Friday, April 24, 2015, we were performing test shots in preparation for the CD-4 KPP attempt when an arc occurred.
  - 200183, 200184: Successful 8% and 50% test shots
  - 200185 (100% test shot): First OH Ground Current Trip
    - Machine inspections found no water leaks.
    - Did a low-pot of the OH coil from rectifier room.
  - 200187: Second Trip
    - Discussion, increased the threshold on the instantaneous ground fault relay from 50 mA to 100 mA
  - 200189: Trip again
    - Discussion, noted the previous good low-pot and lack of water leaks.
    - OH Instantaneous ground fault relays were taken out of circuit.
  - 200190: Shot with the damaging arc

Direct Causes of Arc: Summary

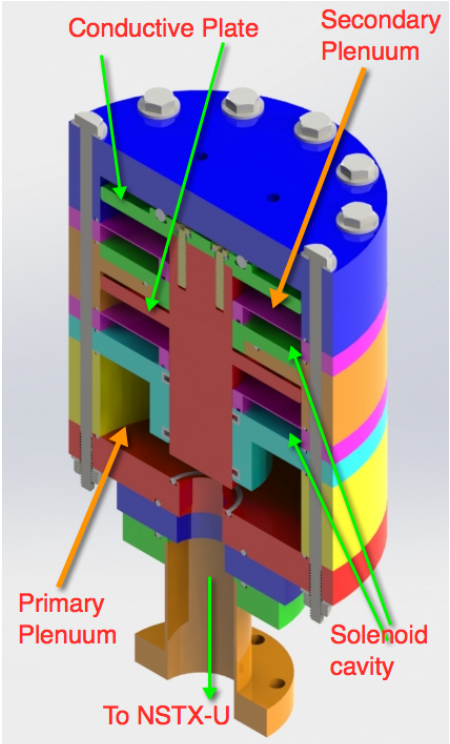
- **The OH ground plane braid had a continuous toroidal loop.**
  - **Currents induced by OH coil flux swing during the shot.**
  - **Experienced a JxB force that pushed it up into the exposed coil cooling water fittings *during the shot*.**
- **The Belleville washer stack assembly was not grounded.**
  - **Communication between OH coil and assembly could not be detected by high-pots or ground fault interlocks.**



Disruption and Plasma Control Tools for NSTX-U
Massive gas injection system for disruption mitigation study

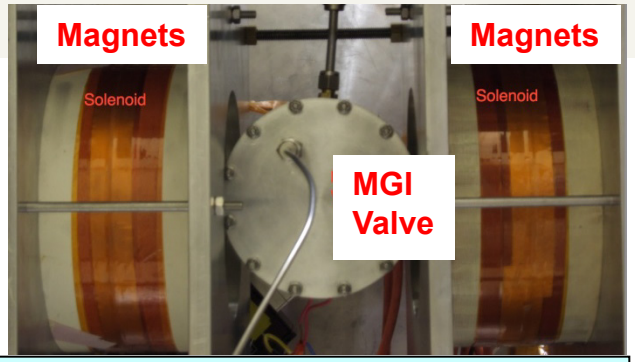


NSTX-U MGI Valve



- **Massive gas injector system installed at multi-poloidal location with identical injection set-up.**
- **A new double solenoid MGI design (zero net J x B torque) based on the ORNL ITER MGI design.**

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



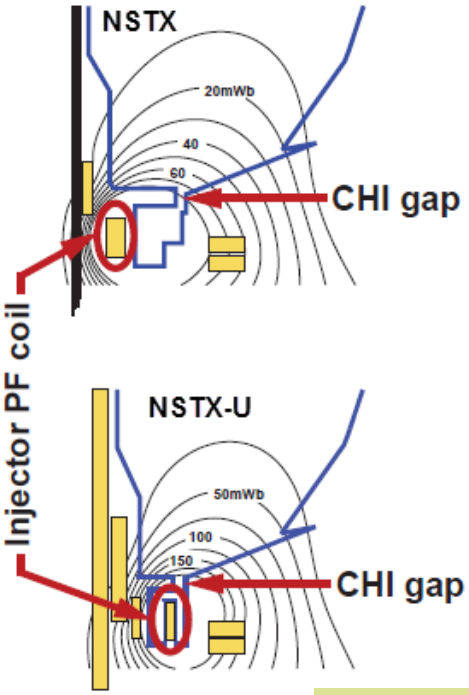
- A peer review MGI meeting was held at PPPL on July 15, 2015 to discuss the details of assembly of the capacitor based power supply to power the MGI valves and the logic to be used to control the valves. All of the long lead-time items have been ordered and most of them have been delivered.
- A Real-Time Velocity (RTV) diagnostic will be incorporated into the plasma control system for feedback control of the plasma rotation profile.

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

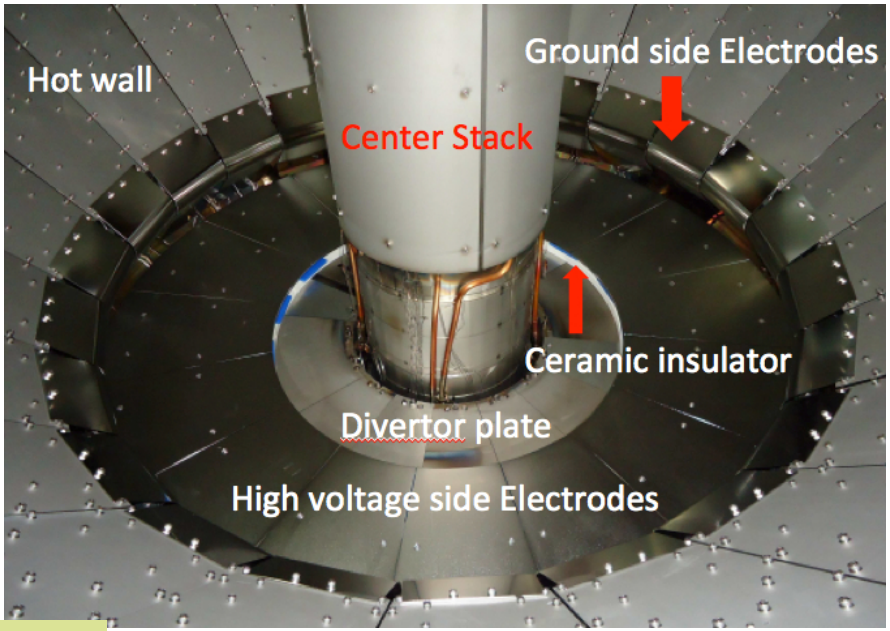
NSTX-U CHI configuration permits ~ 400 kA level start-up

CHI Start-Up

- **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**



CHI Implementation on Quest showing installed electrodes

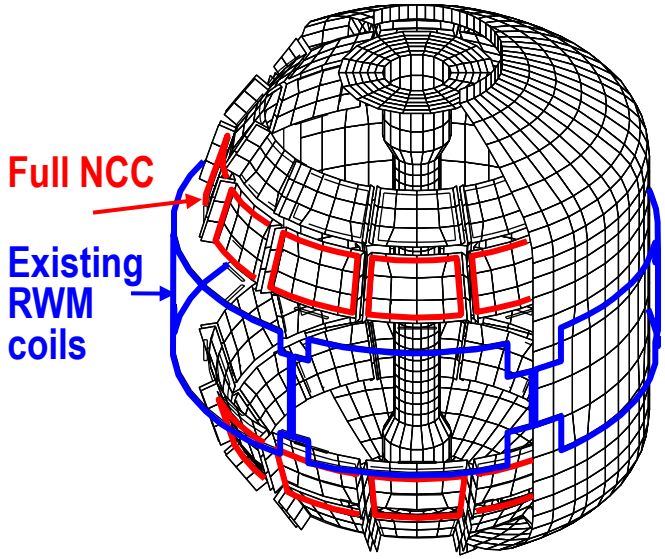


U. Washington

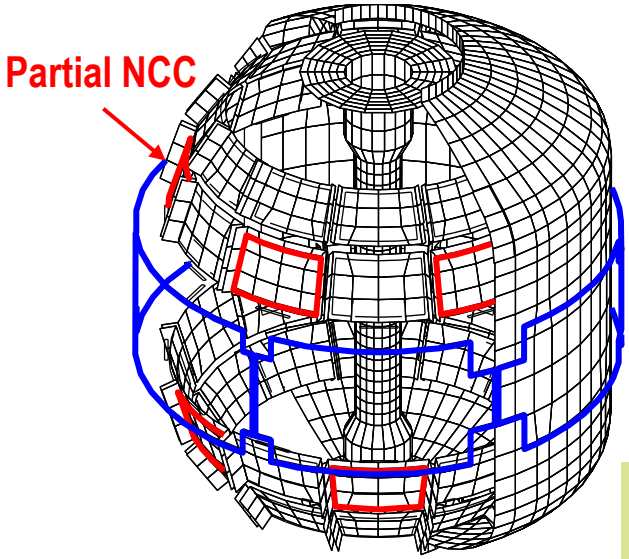
- Refurbishment of CHI Cap Bank completed.
- Fabrication of the CHI gas injection system and operation procedure for the QUEST ST experiment in Japan completed.
- Fabrication of the CHI capacitor bank for QUEST is nearing completion.

Flexible Mid-Plane Feedback Coils for MHD Studoes
NCC will greatly enhance MHD physics studies and control

Full toroidal NCC array (2 x 12)



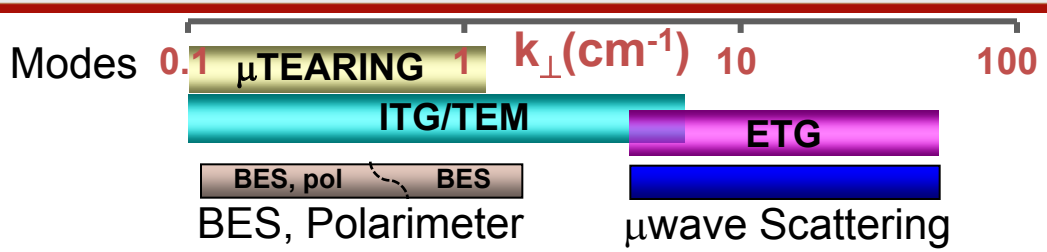
Partial toroidal NCC array (2 x 6)



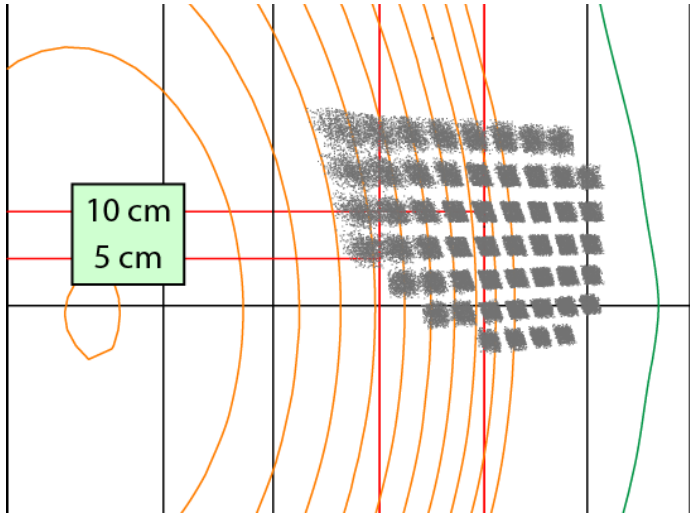
Columbia U
General Atomics

- 6-channel Switching Power Amplifier (SPA) powers independent currents in existing EFC/RWM and NCC coils. SPA testing is planned before the research operations.
- NCC (a facility enhancement) can provide various NTV, RMP, and EF selectivity with flexibility of field spectrum ($n \leq 6$ for full and $n \leq 3$ for partial)

Enhanced turbulence diagnostics will give comprehensive view
MSE-CIF and MSE-LIF will provide Er information



48 ch BES available for NSTX-U (24 ch BES available in 2011)

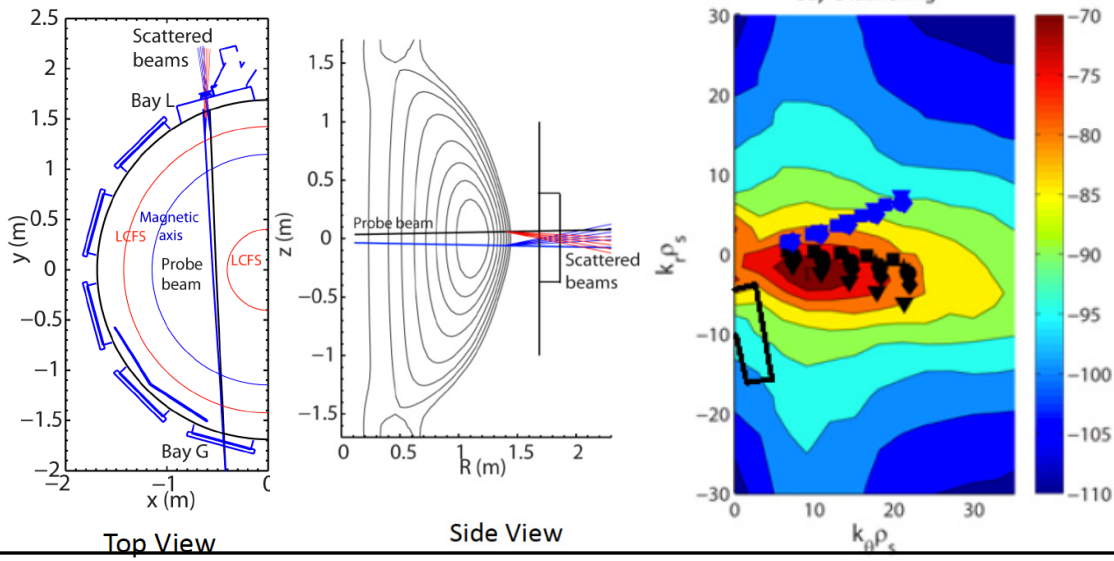


New 2-D fiber holder will provide better radial and poloidal coverage of r/a~0.4-SOL region

U. Wisconsin

New high-k scattering system for allowing 2-D k spectrum in FY 2016

UCD



Preliminary magnetic fluctuation measurement concept under development at DIII-D; also initial tests performed on MAST. Proto-type on NSTX-U.

UCLA

Enhanced FIDA will measure NBI distribution function

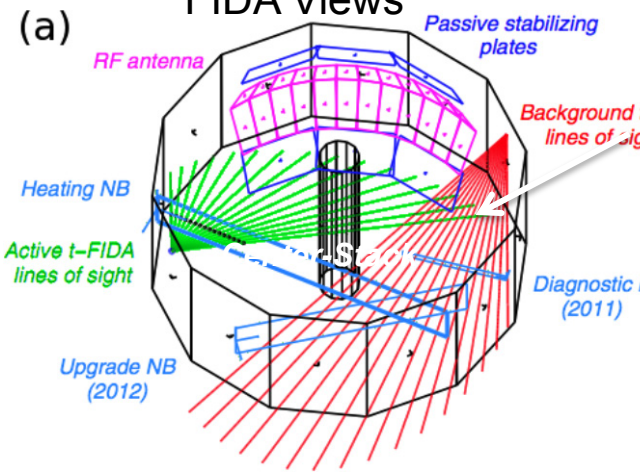
For NBI fast ion transport and current drive physics

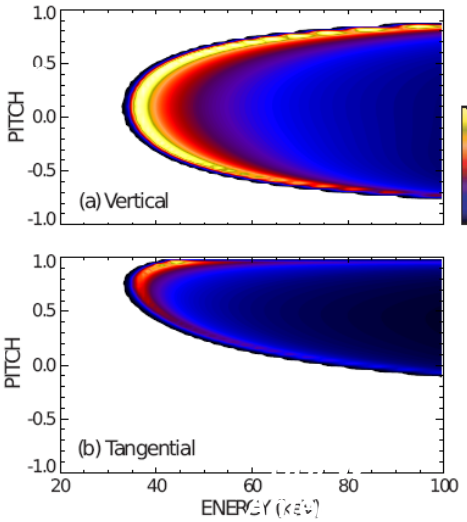
Fast Ion D-Alpha Diagnostics

- **Both vertical (perpendicular) and new tangential (parallel) FIDA systems are improved and ready for operation.**
- **Both FIDA systems have 10 ms, 5 cm, ≈ 10 keV resolutions.**

UCI

FIDA Views





- SS-NPA (solid state neutral particle analyzer) installed and ready to be tested in August. UCI
- sFLIP is installed for lost ion measurements
- Neuton detectors calibrated and ready for operation.
- Active 2 X 2 TAE antennas installed. Initially passive spectroscopy then active excitation at few kW level.
- Proto-type charged fusion product (CFP) profile diagnostic design has started. FIU