U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

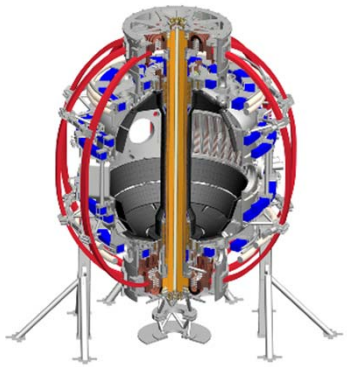
NSTX-U Project Update

Masa Ono, Jon Menard, Stefan Gerhardt

September 30, 2016

FY 2016 Q4 Review

PPPL



Outline

- Machine Recovery Status and Plan
- On-Going Facility Enhancement Status and Plan
- Summary

FY 2016 NSTX-U Run Assessment Held on Sept. 28, 2016

http://nstx.pppl.gov/DragNDrop/NSTX_Meetings/Run_Assessment/2016/

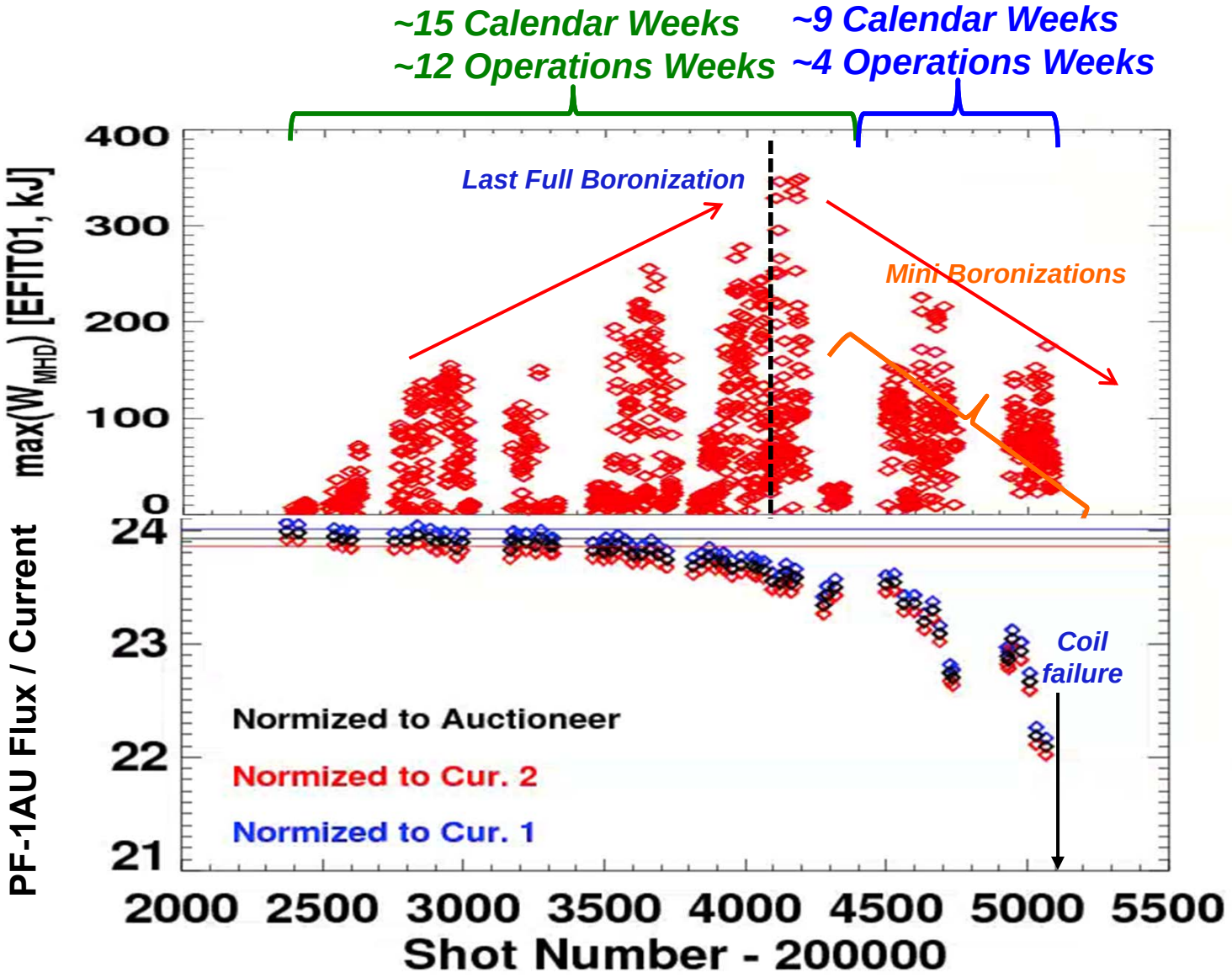
- Refrigerator Cooled: 12/2/2014
- ISTP: Started on ~11/11/2015
- First Plasma: 12/21/2015
- Last Plasma: 6/28/2016
- End of Operations Phase: 8/10/2016

27 Weeks ***39 Weeks*** ***1 ¾ Years***

- 11 declared maintenance weeks in the 27 weeks
  - And ~16 weeks where we tried to run.

- 10 full bottle boronizations and 12 mini-boronizations

Much Progress Made During the Run in Stored Energy
Apparent trending with PF-1AU coil degradation!?



Key Accomplishments During the Run: Diagnostics

Core Profile Diagnostics
- BES
- AXUV Core Bolometer
- Poloidal CHERS
- Toroidal CHERS
- ERD
- MPTS
- MSE-CIF
- MSE-LIF
- USXR Poloidal Arrays (2)
- rtVPhi
- ME-SXR

Fast Ion Diagnostics
- T-FIDA
- V-FIDA
- SNPAs (3)
- Neutron Detectors
- S-FLIP
- I-FLIP
- Fixed-f Reflectometer

Magnetics
- Operations Magnetics
- Diamagnetic Loop
- RWM sensors
- High-f and high-n arrays

Divertor
- Divertor AXUV Bolometer (LADA)
- Divertor Fast Cameras
- Divertor Intensified Cameras
- Infrared Video Bolometer
- Divertor Langmuir Probes
- U. Of Tennessee Spectrocospy
- 1D CCDs
- MAPP
- Divertor Tangential Imaging
- Wide Angle Infrared Camera
- Fast Infrared Cameras
- Divertor SPRED

Spectroscopy
- ENDD
- XEUS
- LOWEUS
- MonaLISA
- VIPS
- DIMS
- VB
- EIES (Filterscopes)
- DIBS

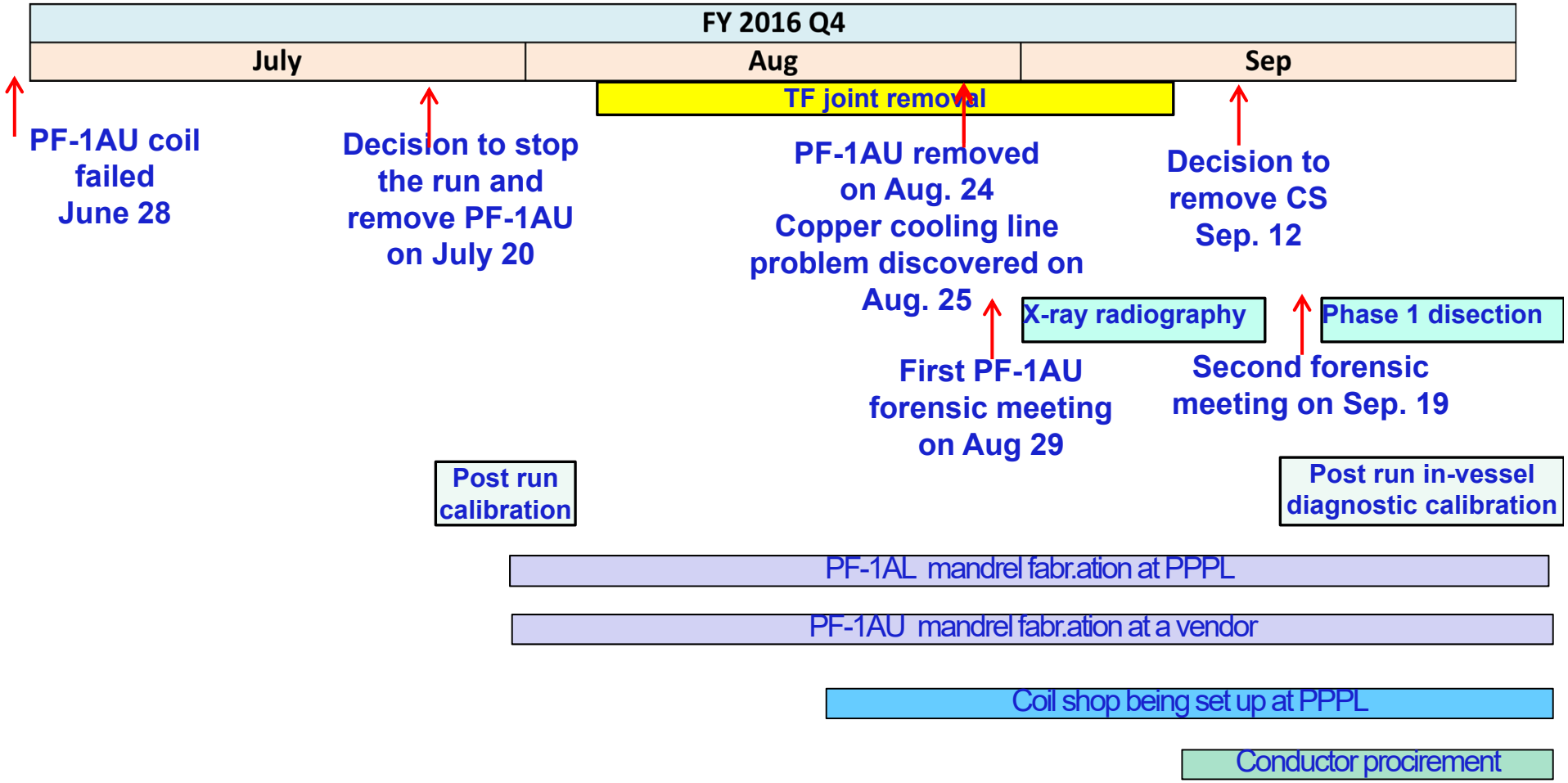
Other
- Plasma TV (2)
- Shunt Tiles
- GPI
- Penning Gauges

Operational
In Progress

NSTX-U Post-Run Recovery Update
NSTX-U is making steady progress in all front

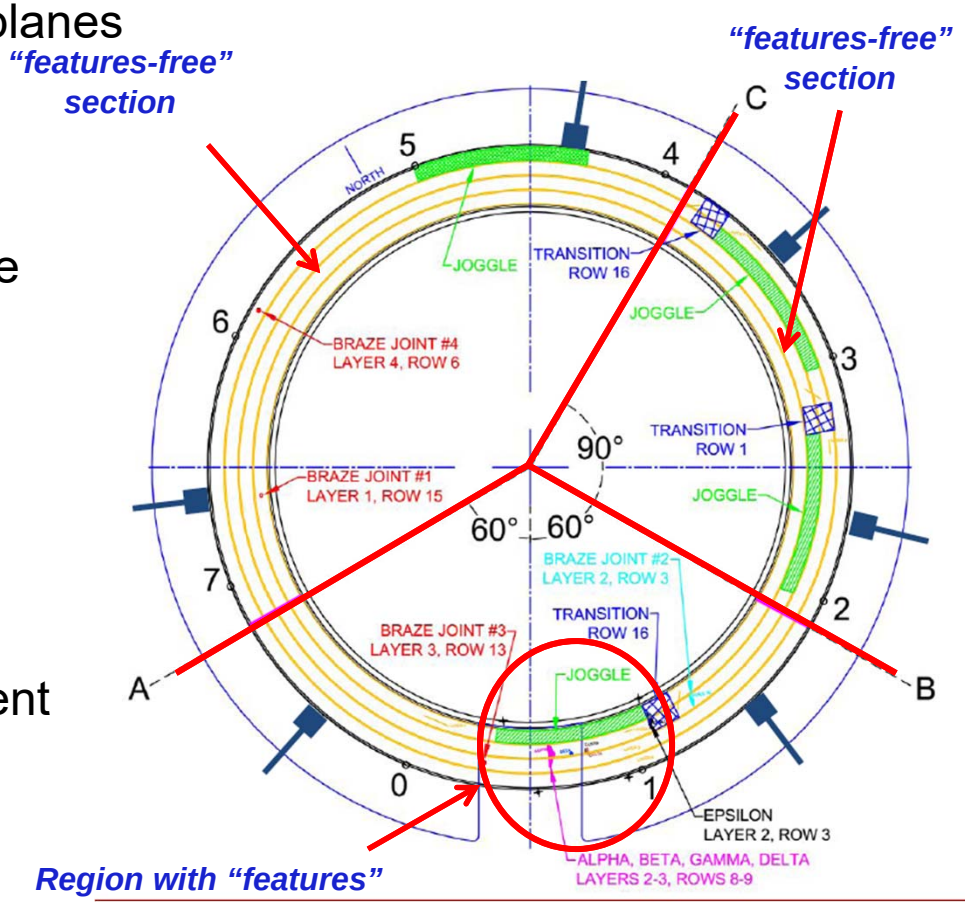
- With support of FES and PPPL management, decision was made to remove the center-stack to replace the damaged copper divertor cooling tubes. This will also give the opportunity to replace PF-1AL.
- PF-1AU x-ray radiology was complete and a PF-1AU forensic meeting was held on September 19. The radiology results were reviewed and the phase I destructive test (the coil sectional cuts) plan was discussed.
- Preparation for PF-1AU fabrication is continuing including the coil shop preparation, coil mandrel fabrication, coil conductor procurement, and procurement of coil fabrication parts.
- After in-vessel inspection, in-vessel post run diagnostic calibrations is being performed in preparation for IAEA and APS. Plan to complete the calibration on October 7.
- Results review meeting was held on Sept. 21-22 with 54 presentations.
- Device components are being removed in preparation of the CS removal planned in mid-October around the time of IAEA.
- C. Neumeyer has joined the NSTX-U directorate to oversee the engineering recovery activities.

FY 2016 Q4 Facility Activity Summary



Moving into Phase I Destructive Testing
Carefully thought through plan being developed

- Preserve all existing evidence of coil damage contributing factors – Section coil pack into three portions in feature-free areas
- Verify the locations of anomalies and braze joints identified in radiographs – Borescope cooling paths from section planes
- Identify the locations of cooling path blockages – Borescope
- Visually inspect the anomalies and braze joints – Borescope
- Verify cooling path integrity – Vacuum & Helium Leak Testing
- Verify braze joint integrity – Vacuum, Helium Leak, & Hydrostatic Testing
- Electrical testing of each coil turn segment
- Identify & test coil pack disassembly methods for Phase II DT



2D Radiography of PF-1AU Complete

A meeting of phase-1 destructive testing held on Sept. 19

- 2D Radiography identified two principal areas of interest and four braze joints
- Cutting methods were evaluated for Phase I DT. A milling operation was selected – based on careful considerations – Facility available at PPPL – Aiming to start next week.
- Optimal sectioning planes were identified
- Procedural documentation was developed including:
- Schedules, NEPA form, JHA, Procedure, and Fixture
- Required drawings and drawing changes to be complete
- 3D Computed Tomography would augment 2D findings. Sandia Lab can perform CT in mid-October. Will consider sending a section once cooling line inspection/test is complete.

Aiming to complete forensic activities by the end of October

PF-1AU coil fabrication status

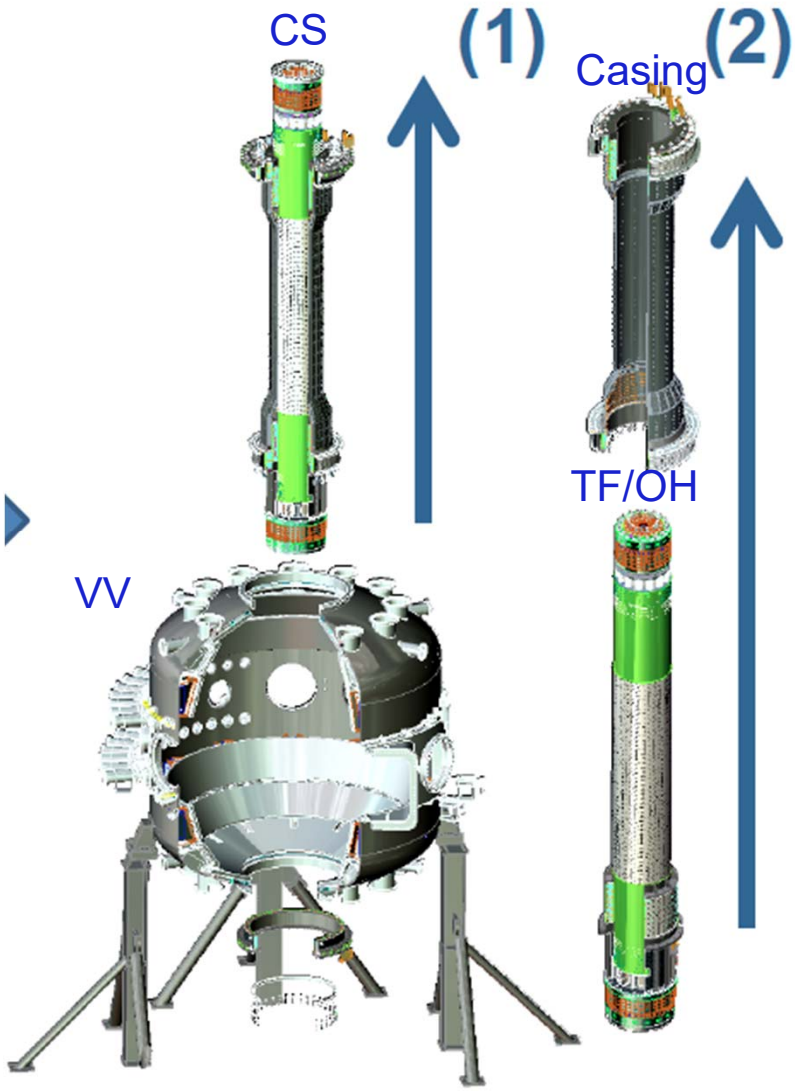
- 2 upper mandrels being fabricated at vendor. We heard that the weld by a subcontractor was not satisfactory so we will request the remedy for it.
- 1 lower mandrel being fabricated at PPPL. We can decide to fabricated another lower mandrel.
- A partial order (enough for three coils) for Cu conductor with sufficient length placed. Another vendor order was placed for the another three coils.
- A coil shop is being set up at PPPL where the NSTX-U TF and OH coils were fabricated.
- Four design improvements were identified :
  - Eliminate joggles (ease winding and reduce stresses during cool down)
  - Double insulation thickness (increase insulation margin)
  - Use softer copper and control hardness (ease winding)
  - Use continuous conductor, eliminate in-line joints (avoid potential leaks)

Making the joggle with the conductor long way was particularly challenging

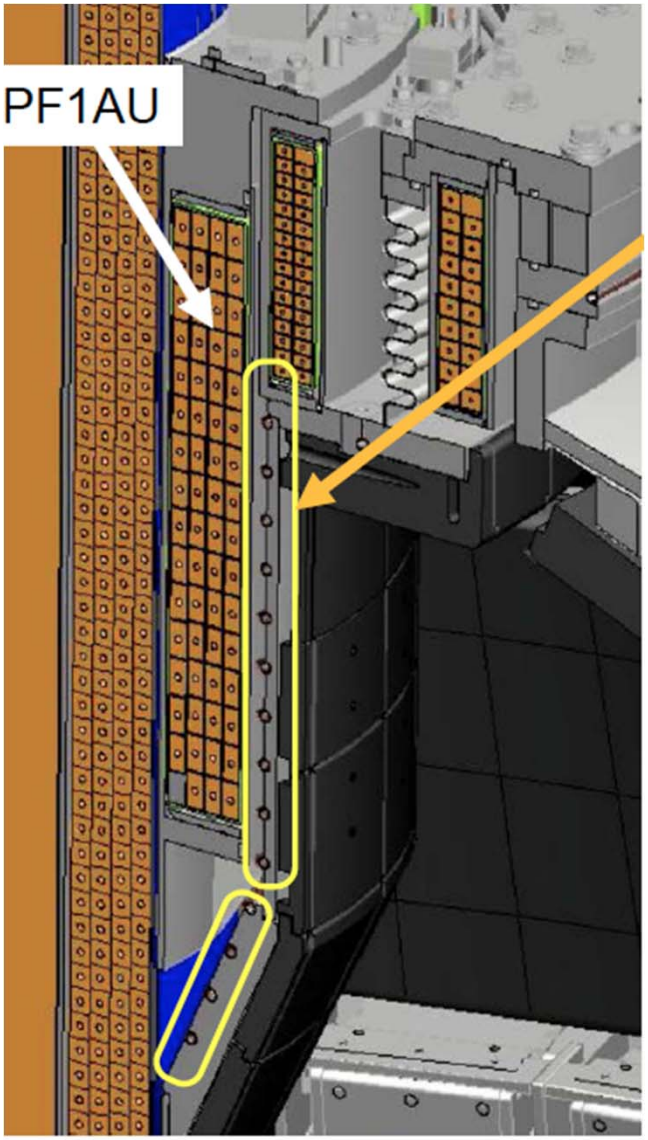
Recent findings motivate decision to remove center-stack

With cooling tubing replacement, the critical path is now defined

- Due to up-down symmetry, we expect similar cooling tube damage in the lower divertor area. Lower cooling tube does not hold any air pressure.
- With damaged cooling tubes, the divertor area cannot be cooled between long-pulse higher power NSTX-U operations.
- Copper tubes if left in CS maybe degraded further. They should be replaced with SS tubes at this time.
- Tubes can be only accessed by:
  1. Removing CS from VV.
  2. Pulling CS casing from OH-TF bundle
- The damaged cooling The cooling tubing installation schedule is similar to the new PF-1AL and –U installation schedule so they can be performed in parallel with no significant schedule hit.



NSTX-U CS Divertor Cooper Cooling Tube Replacement options being considered

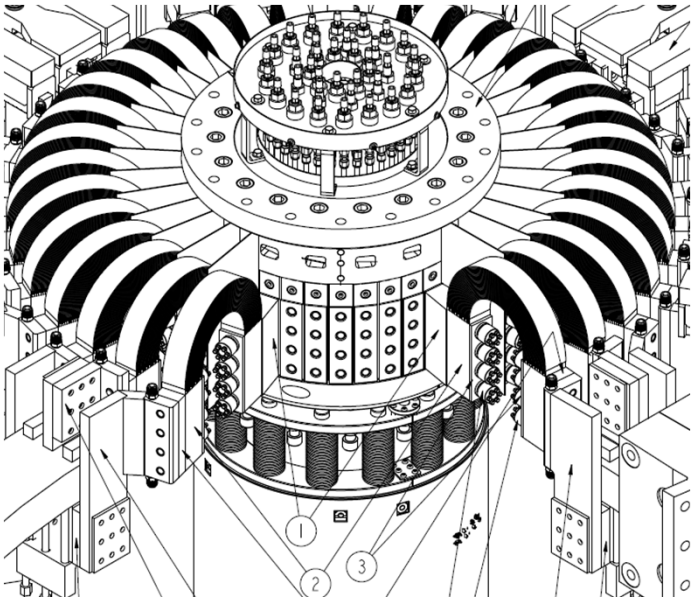


- Two meetings were held on the cooling tube design on Sept. 16 and Sept. 29.
- Number of action items generated.
- Helium heating and cooling being considered.

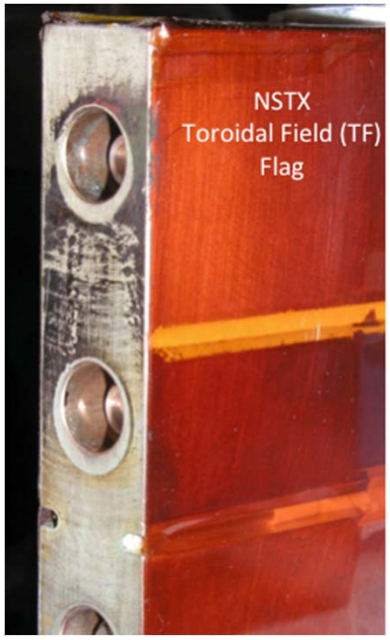
Heat transfer panel concept (used in Tore Supre) is being explored because of the radially thin design.

TF Joint Measurement and Examination Were Fine
Flex joints and lead extension were also fine

- In FY 2016, NSTX-U operated mostly at B_T ~ 6.5 kG up to ~ 2.2 s flat top for well over 1000 shots.
- The TF joint measurement were performed as the TF joints were disassembled.
- All measured joints are nominal based on design, installation procedure, modeling data, bench measurements, and in-situ measurements.
- Joint surfaces look very good.



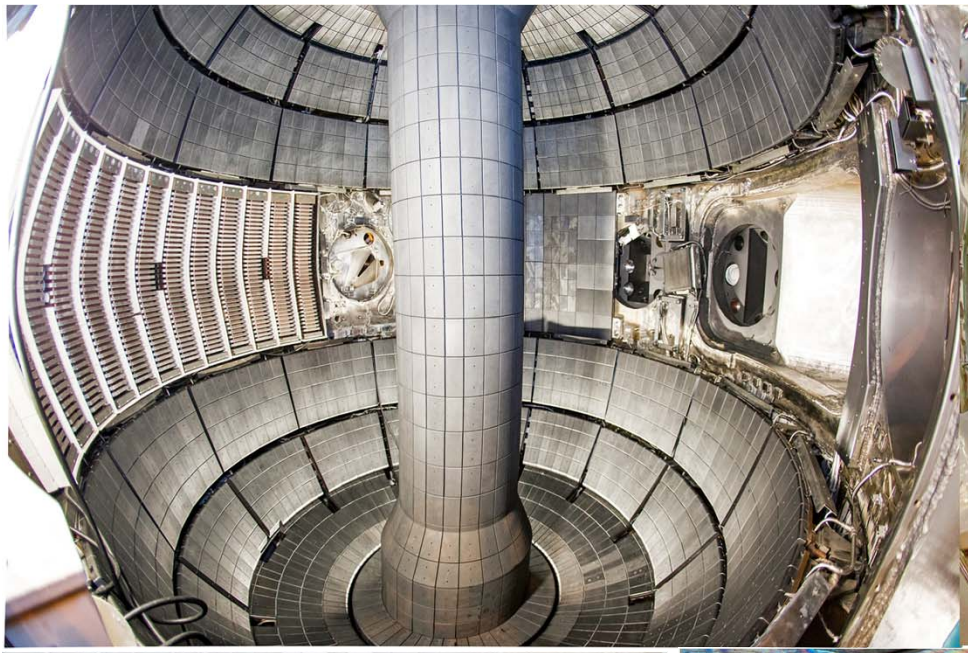
Joint surfaces degraded in NSTX due to lift-off

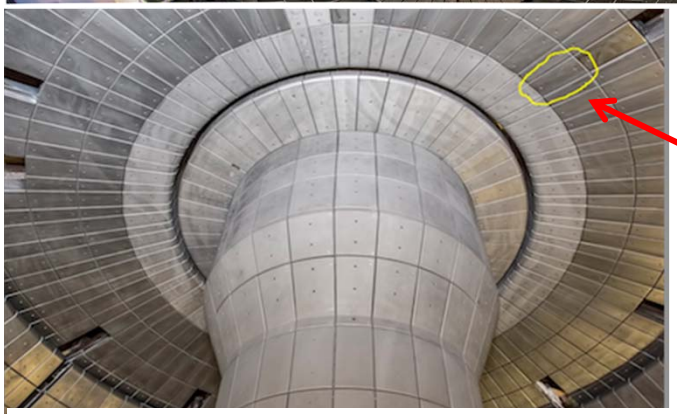


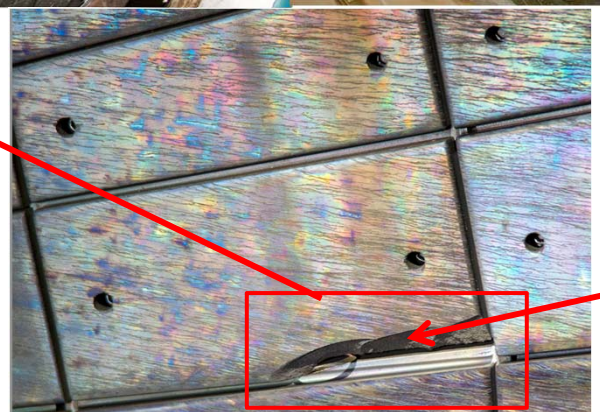
Initial Inspection of NSTX-U Vacuum Vessel Interior
Lower divertor looks fine, one cracked tile in upper divertor

Before campaign 12/05/2014

After campaign 09/19/2016







http://nstx.pppl.gov/DragNDrop/Operations/In_vessel_inspections/Post_run_2016/

F. Scotti (LLNL)

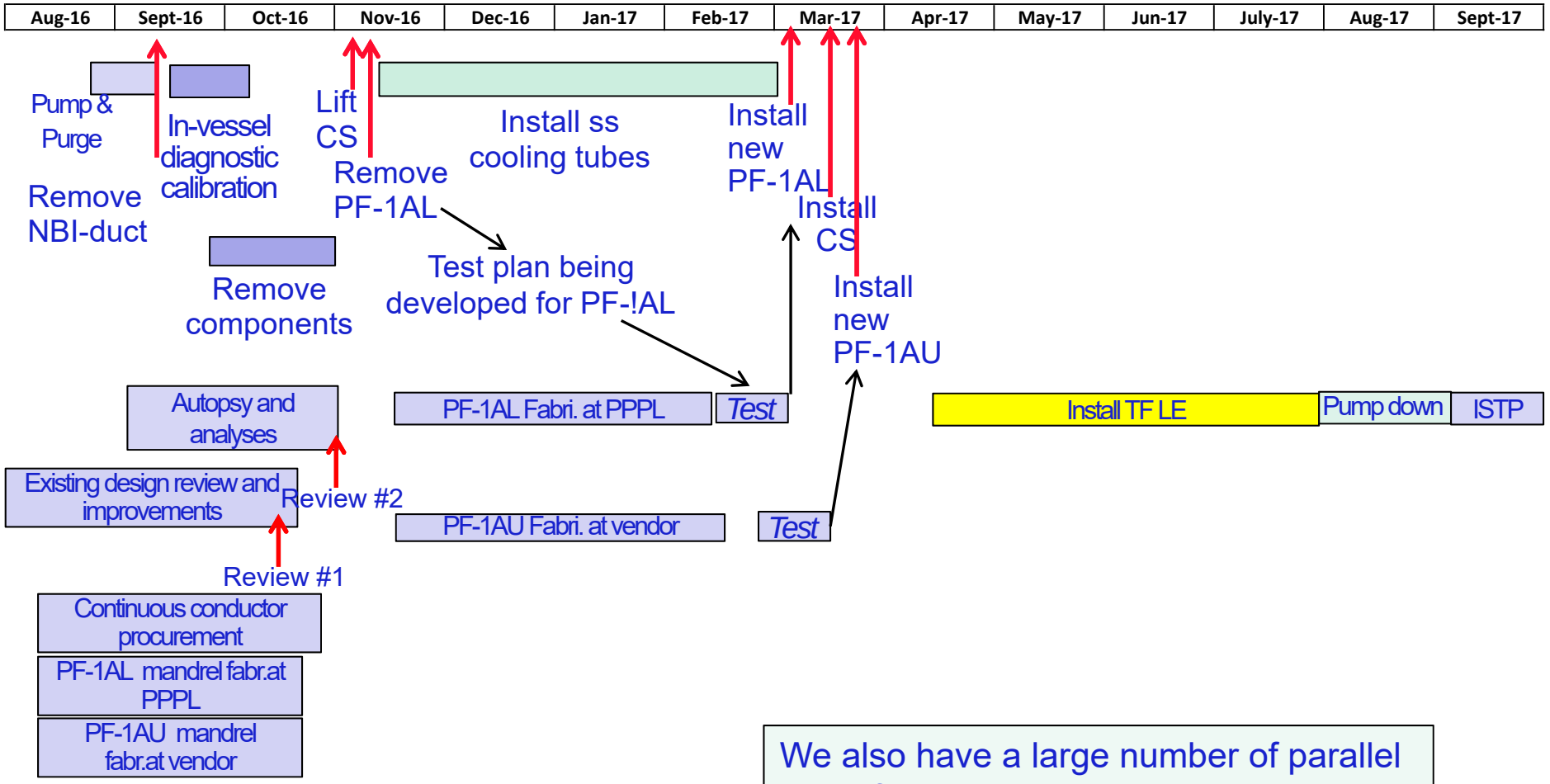
NBI System Secured and Refurbishment Activity Begun

- NBI system locked and tagged and prepared for maintenance and repairs. Some spares for the next run period will be procured.
- NBI calorimeters will be removed in October for repairs and maintenance in the TFTR Test Cell.
- Preparations to remove the NB Armor are underway to repair a known water leak in vacuum.
- Negative pressure system in the Decon Room Source shop refurbishments requires a repair.
- Two new items that are planned: an update to fiber optics telemetry and an update to PLC controls. This long outage is an opportune time to address soon to be obsolete equipment.

Three Helium refrigerator compressors were removed and prepared for shipment to go out for full rebuilds.

Most Recent Draft Schedule

Cooling tube replacement can be done in parallel with PF-1A fabrication



NBI related repair and maintenance: armor leak, calorimeters, source 1-A isolation valve, compressor rebuild, etc.

We also have a large number of parallel tasks for diagnostics, research tools, and engineering projects including OH water heater, high Z tiles, etc.

NSTX-U device performance progression plan

Will utilize this outage to prepare for full capability

- FY 2016: Limit forces to ½ way between NSTX and NSTX-U, and ½ of the design-point heating of any coil
  - Operated at B_T ~ 0.65T for ~ 2 sec for over 1000 shots. All joints came out clean and nominal.
- FY 2017 goal: Implement repair/enhancements needed to achieve full capability
  - Replace TF joint lead extension pieces, PF-1AU and –L, divertor cooling tubes
  - Replace poloidal CHERs passive plates and enhance passive plates as needed
  - Test plan being developed for PF-1A and -1C coils.
  - Install and test instrumentation to monitor coils and passive plates to full capability
- FY 2018 goal: Full capability

Parameter	NSTX (Max.)	FY 2016 NSTX-U Operations Achieved	FY 2017 NSTX-U Preparation	Year 3 NSTX-U Operations	NSTX-U Ultimate Goal
I_P [MA]	1.2	~1.1	2.0	2.0	2.0
B_T [T]	0.55	~0.65	1.0	1.0	1.0
Max Pulse length (s)	~ 1	~ 2	5	5	5

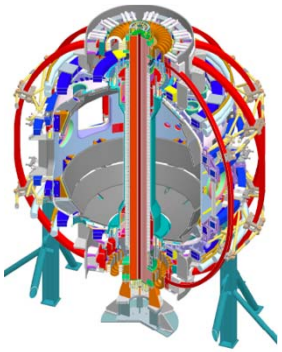
Five Year Facility Enhancement Plan (green – ongoing)

Incremental enables 5 year plan enhancements including DCP, NCC, ECH

Fiscal Year:	2016	2017	2018	2019	2020
	0.5 T → 1T, 1.5 → 2 MA, 1s → 5s				
Run Weeks:	10		20		20

Major enhancements:
- ● Base funding
- ○ incremental funding

New center-stack



2nd NBI

Boundary Science + Particle Control

- Boronization
- Li granule injector
- LiTER
- MAPP
- Pulse-burst MPTS
- High-Z tile row on IOBD
- Scanning MLP
- Upward LiTER
- Resistive *Bolometers*
- Lower divertor cryo-pump
- *Graphite CHI/Lower Bullnose*
- APD-based GPI

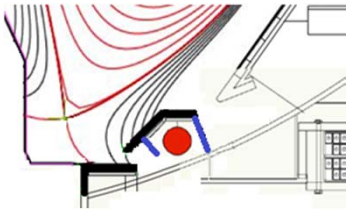
Core Science

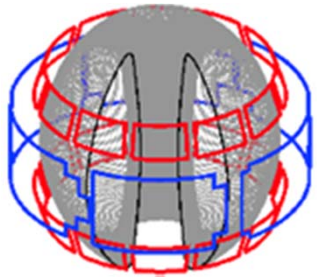
- MGI disruption mitigation
- MPTS
- BES
- MSE/LIF
- AE antenna
- XICS
- Upgraded halo sensors
- sß
- Laser blow off
- High k_θ
- *CPS* δB dia
- Charged fusion product
- Off-midplane 3D coils (NCC)
- Enhanced MHD sensors
- DBS, PCI, or other intermediate-k
- Neutron collimator

Integrated Scenarios

Establish control of:

- Rotation
- $\overline{n}_e$
- Snowflake
- FIReTIP
- P_{rad} Divertor
- HHFW limiter upgrade
- 1 MW ECH/EBW





Outline

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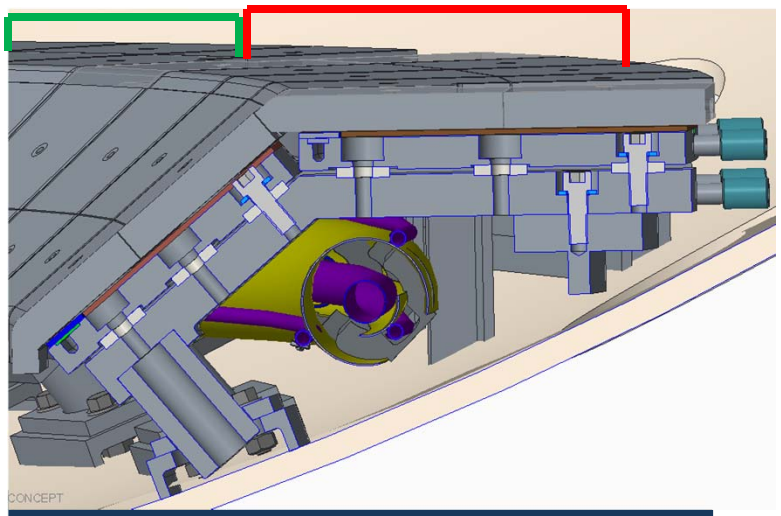
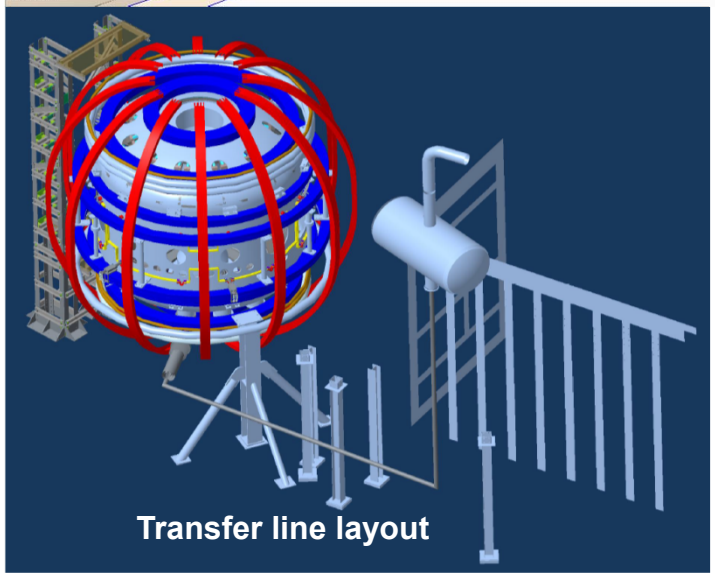
Divertor Cryo-pump Design *Making Good Progress*
Successful CDR was held on August 3, 2016

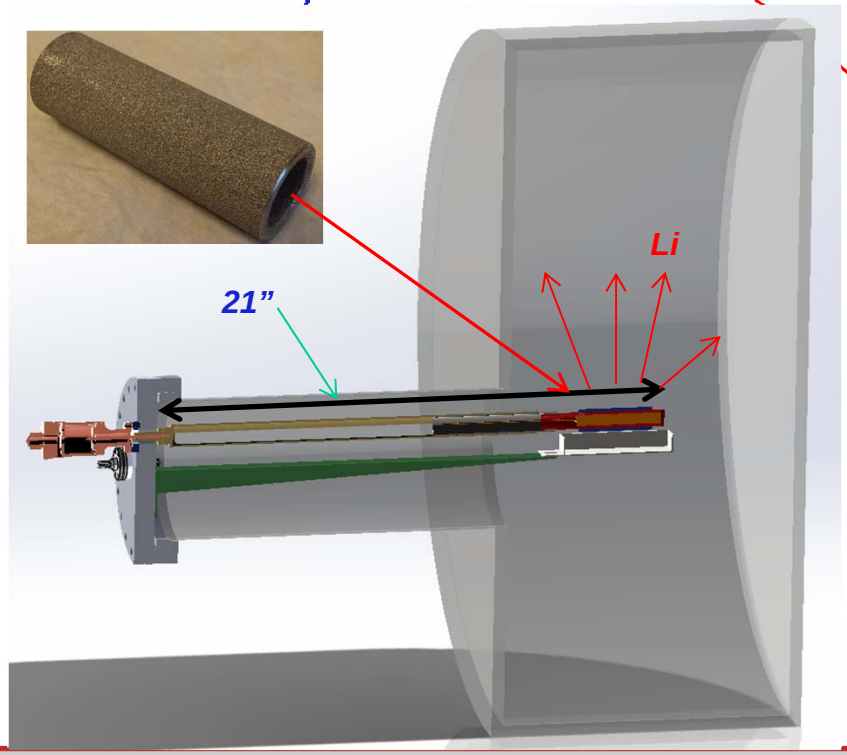
- Initial in-vessel geometry has been laid out.
- MIT designed the cryo-ring.
  - Pump radius, throat dimensions taken from the modeling.
  - The entire lower outer divertor region to be reduild.
- Cryo-baffle design to be finalized.
  - Diagnostic access and cryo-ring maintainability were assessed.
  - Graphite PFC with bake-out capability considered.
- A cost/schedule review of the design/installation plans of the new Cryo-pump Divertor (CPD) was held in Sept. 23.

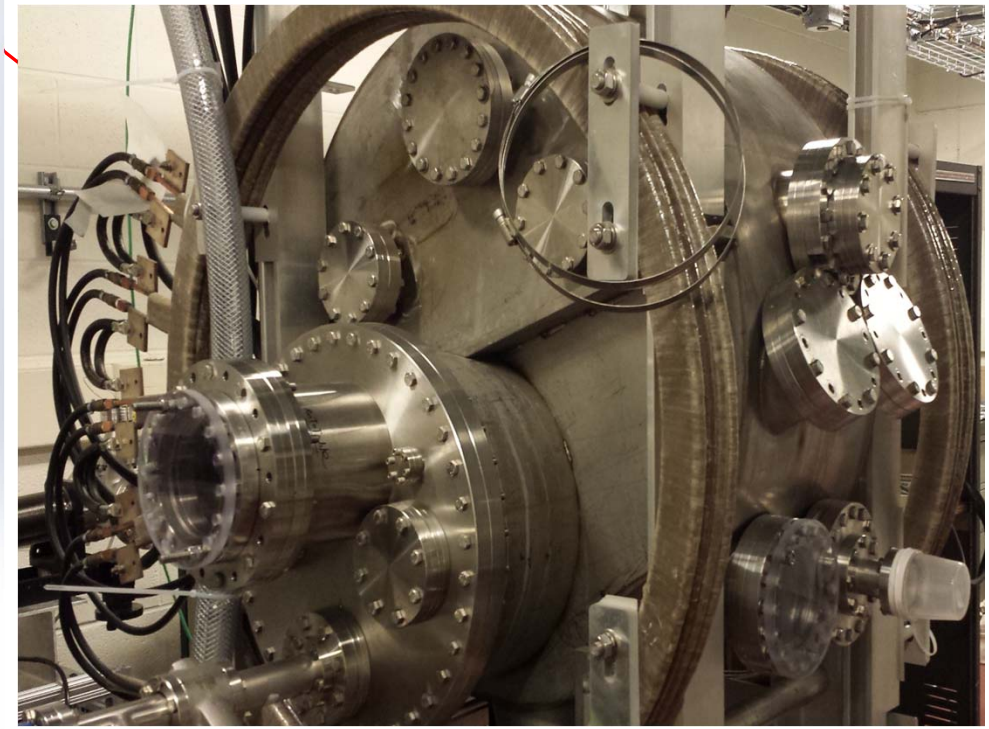




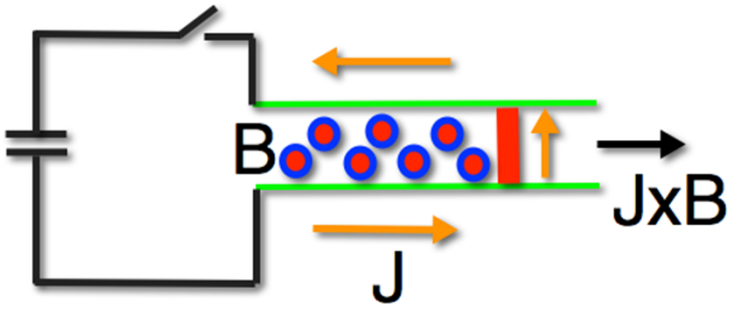
Upward Lithium Evaporator R&D Being Performed
Fast evaporation with much less lithium

- WAF completed for ULITER prototype development
- Based on resistive heating of lithium in porous stainless steel medium for fast evaporation
- Prototype can be used on NSTX-U if installed using power supply with remote control
- Evaluation of porous medium to absorb liquid lithium in progress



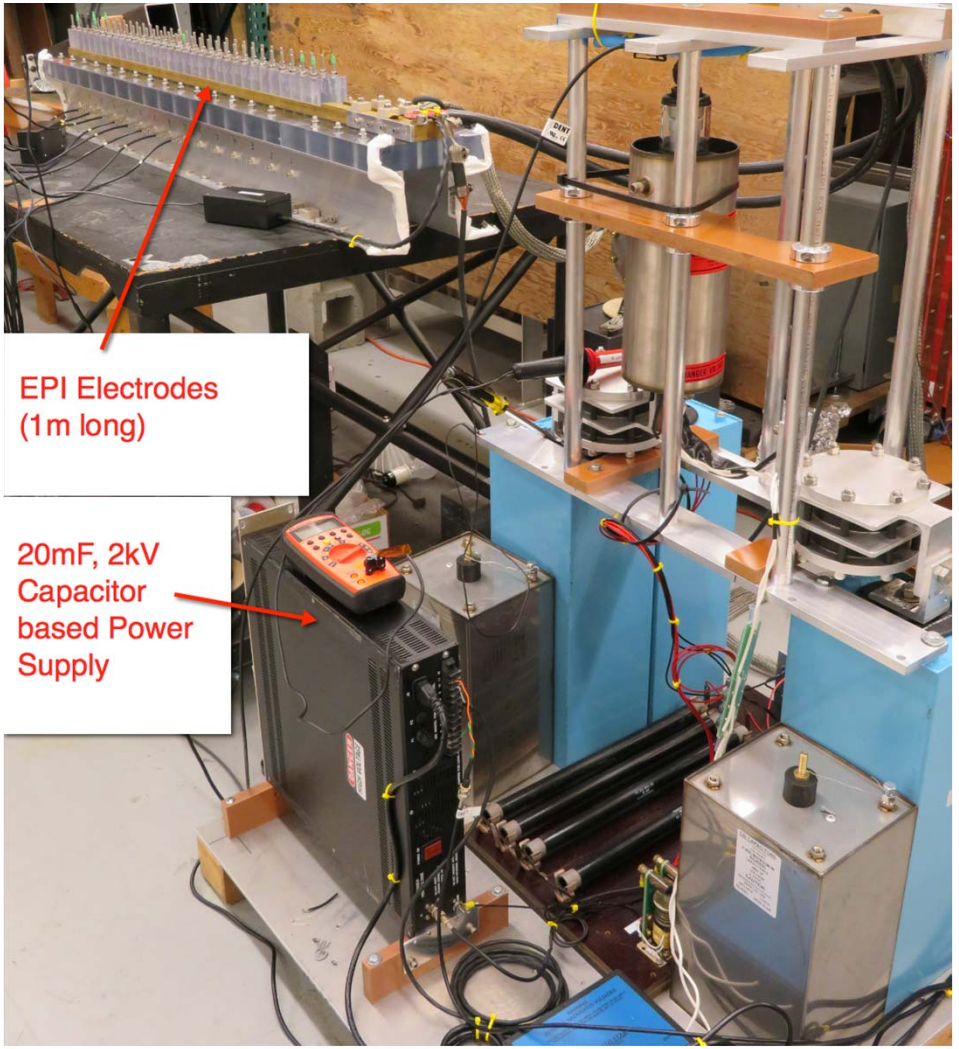


Electromagnetic Particle Injector is Especially Well Suited for Operation in High-Ambient Magnetic Fields (R. Raman, UW)



- An important advantage of a linear rail gun is that the ambient magnetic field in ITER can be used to increase the gun efficiency
- Injector can to be positioned very close to the vessel, which further improves the system response time and efficiency
- Commissioning tests are being conducted at UW and will be reported during IAEA FEC 2016

EPI-V1 designed, fabricated, and assembled for NSTX-U EPI system prototype testing

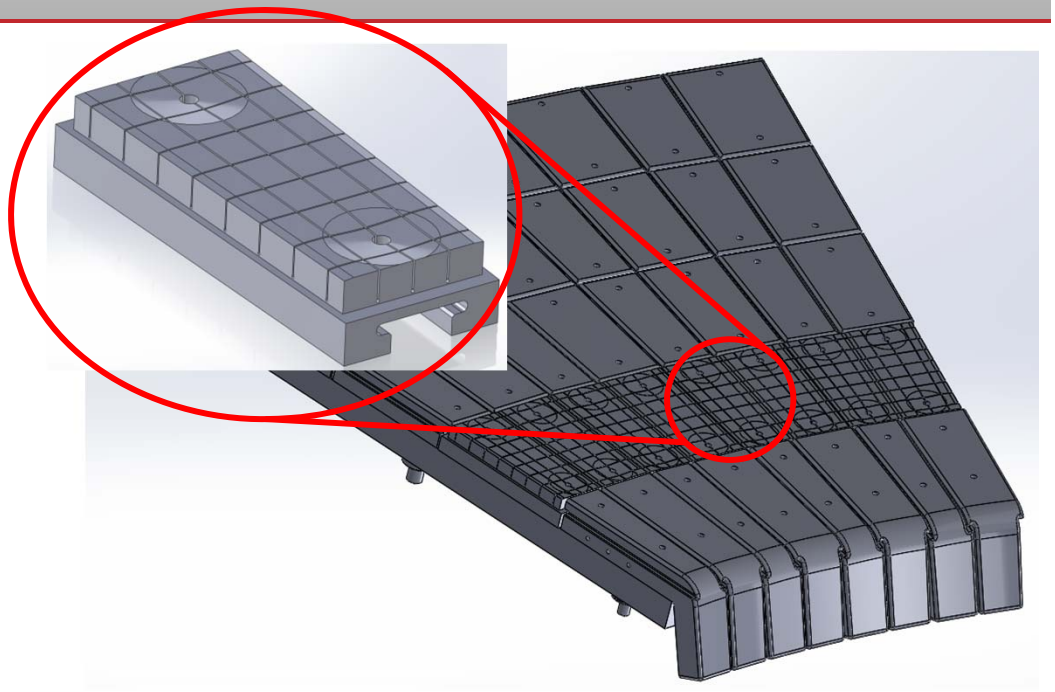


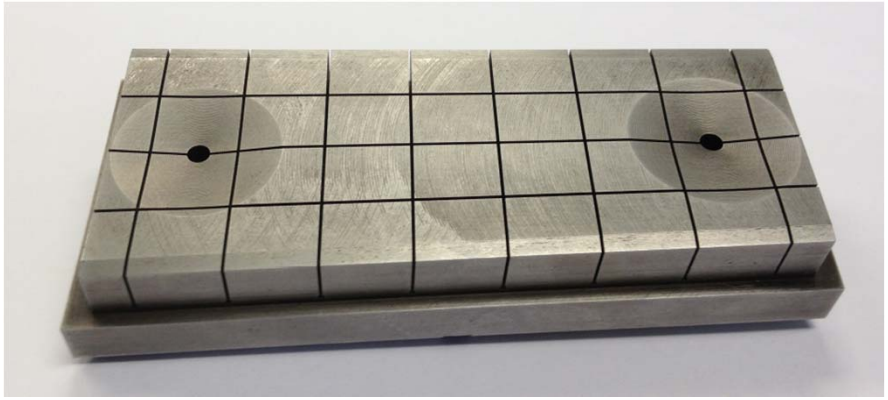
Being assessed to install High-Z Tile for FY 2017 run

Design to replace a row of the graphite tiles in lower outer divertor

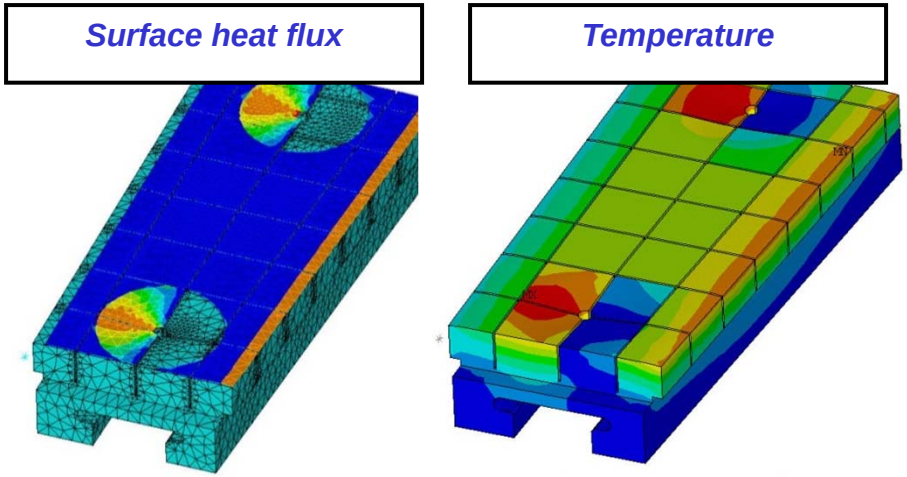
Vendor Fabrication Complete

- High-Z tiles were delivered to PPPL in September on schedule .
- While high-Z tiles are available, whether to install the at this outage will be decided by the programmatic needs.





First fabricated high-Z tile



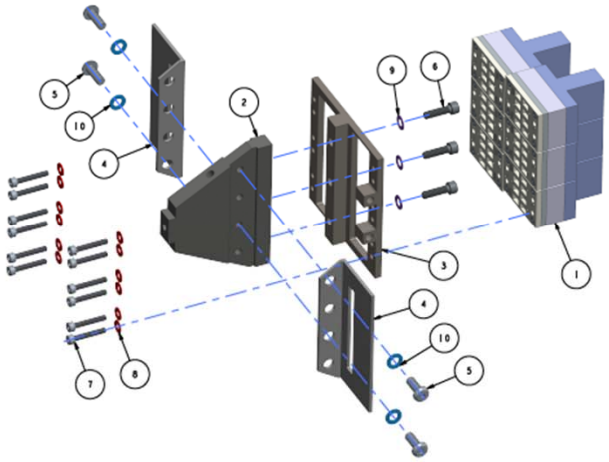
Status of NSTX-U NBI LHe Refrigerator Bids in October followed by PDR

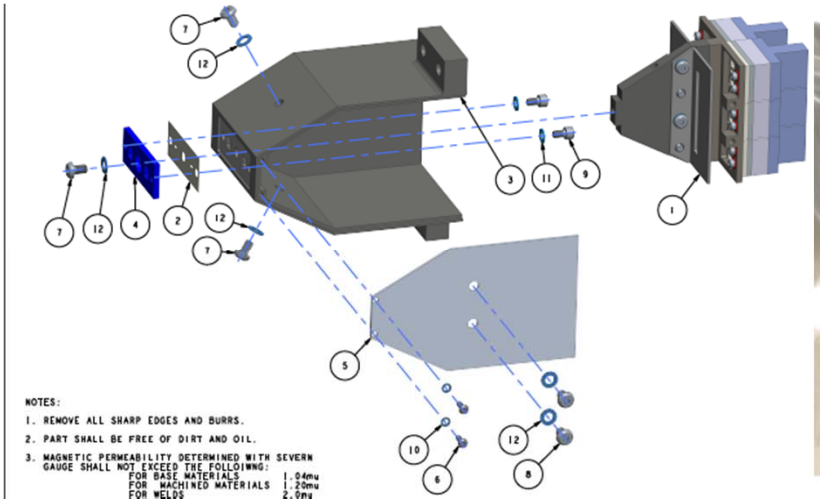
- The project to replace the refrigerator continues with a requisition and specification in Procurement.
- After several cycles of review by Procurement, ESH, QA, and Engineering, the spec is ready for approvals again and is in Procurement.
- We plan for request for bids in October with a PDR to follow.
- In parallel, a second spec will be prepared in case we need to go out for bid on a full replacement refrigerator system.

Proposed 400 *W* L-He Linde LR-140 *refrigerator*

Status of Res. Bolometer Diagnostics
(FY 2016 Diagnostic milestone – M. Reinke, ORNL)

- Long-lead time procurements are complete
  - x6 4-ch sensors (below) w/ in-vessel ex-vessel cabling
  - 48-ch FPGA-based analyzers, MDS+ integration demonstrated
- FDR of 16-ch divertor viewing pinhole cameras complete
  - drawings w/ vendors being quoted for fabrication
- Final drawings for 24-ch mid-plane camera complete

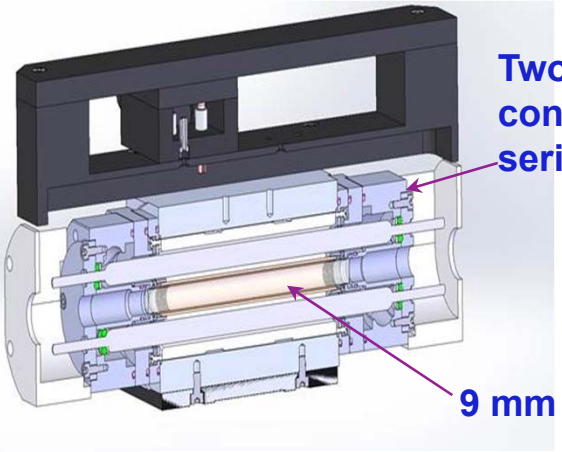




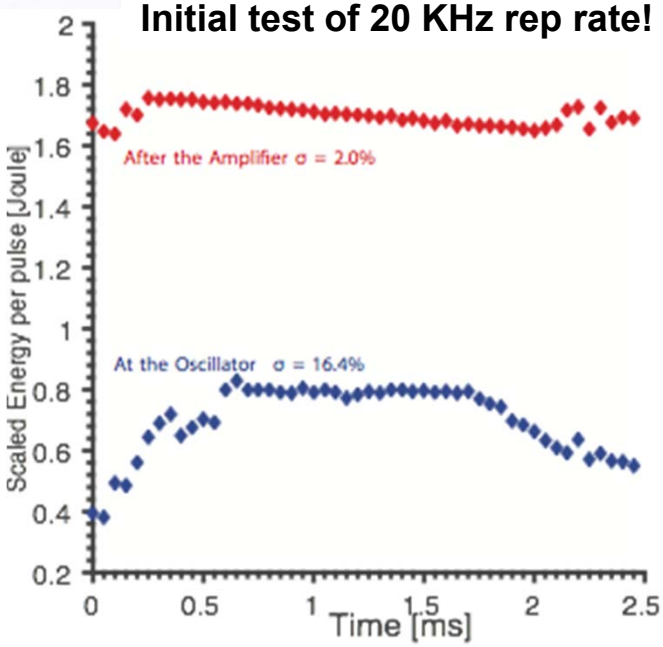
Status of Pulse Burst Laser System (PBLS)
for edge pedestal structure control by A. Diallo's ECRP

- PBLS met all its design specifications and more!:
  - Pulse energy ⇛ 1.5 J per pulse
  - Pulse width ⇛ 10 ns (FWHM)
  - Beam diameter ⇛ 10 mm @ 0.5 mrad
  - Three modes of operation:
    - Base mode @ 30 Hz to be compatible with the current NSTX-U rep rate
    - Slow burst mode: 1 kHz rep rate for 50 ms
    - Fast burst mode: 10 kHz rep rate for 5 ms.PBLS test activities are on schedule
- Control system for the laser system was developed and tested at PSL, U Wisconsin.
- PBLS was packed and shipped on Sept 23rd 2016 and received on Sept 26th at PPPL.
- The support structures for the power supplies are being finalized.
- The laser support in the mezzanine is being fabricated and slated for delivery mid-October.
- PBLS will be installed in two phases: Power supplies and then laser head in FY 17.

Cut of the pumping chamber



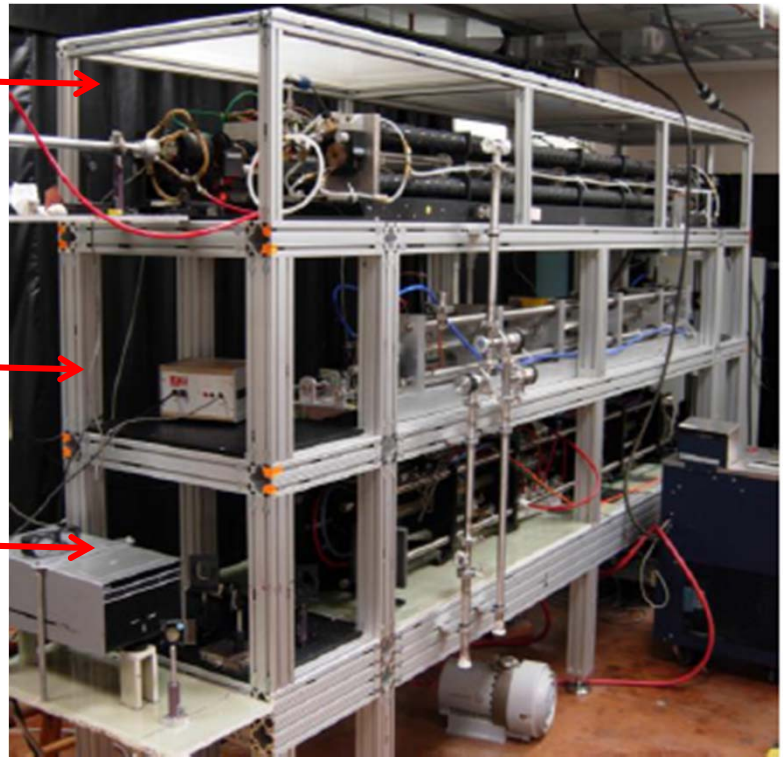
Initial test of 20 KHz rep rate!



FIR and mm-Wave Density Monitoring, Feedback Control and Fluctuation Diagnostics for NSTX-U (UCD)

- Structure for lasers set up in gallery cage and preparations in progress for testing
- Enclosure for launch optics complete and ready for installation on NSTX-U
- Vibration measurements of NSTX-U vacuum vessel made with new compact accelerometer to be used by UC Davis graduate student (E. Scott) for thesis on real-time vibration compensation for FIReTIP

Three level FIReTIP / High-K Table Installed

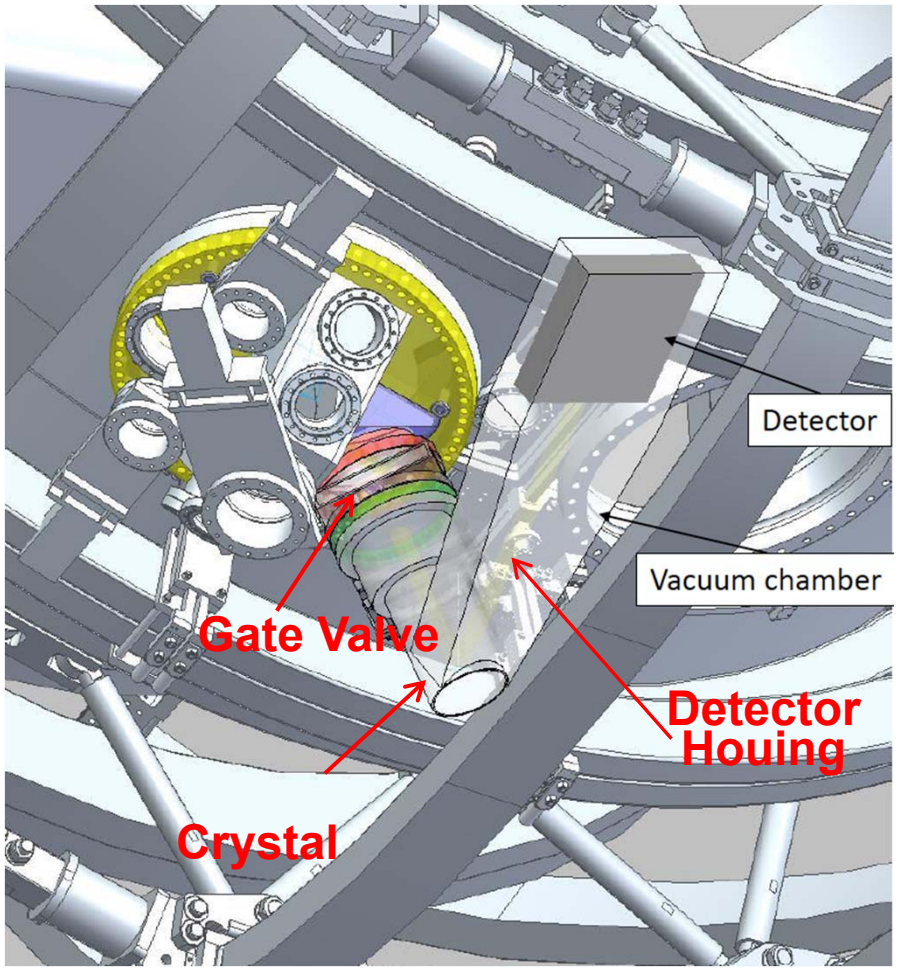


Three diagnostics for complete coverage of transport physics

- FIReTIP, low-k turbulence from edge channels
- High-k Scattering, high-k turbulence from core to edge
- MIR, MHD activities and low-k turbulence (L-mode core and H-mode pedestal)

Successful X-Ray Image Crystal Spectrometer (XICS) Conceptual Design Review conducted on July 29, 2016

- PSFC/PPPL collaboration work. J port Horizontal Modifications for installation of the XICS
- Proceed with the detailed design of the bay J port cover, which enable implementation of tangential x-ray PHA and a TIV for later installation of the XICS.
- But other work on XICS is now on hold.



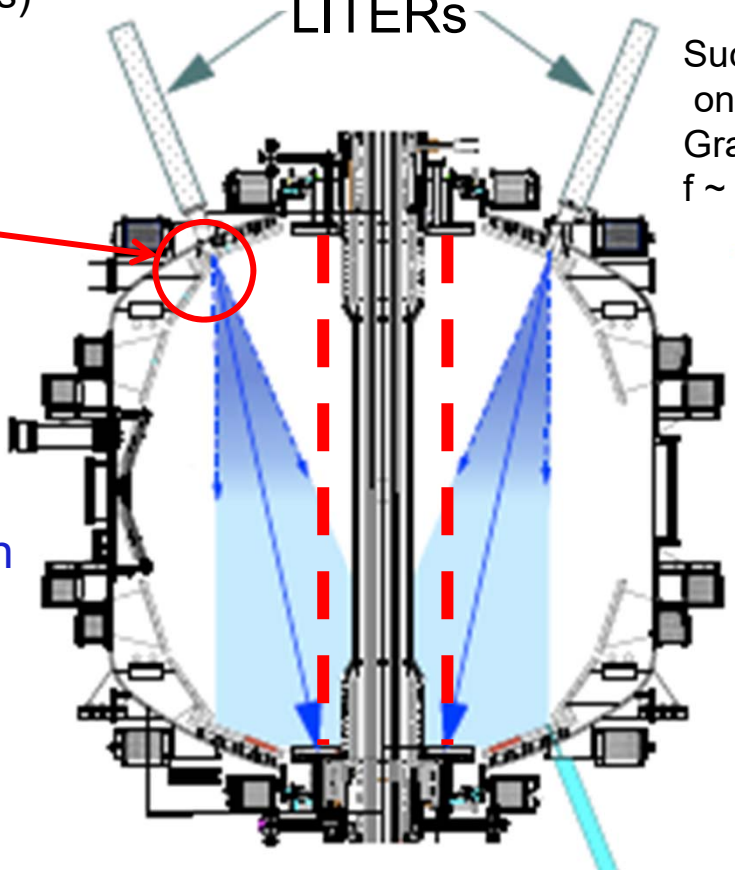
Summary of Facility and Diagnostics

- NSTX-U plasma operation ended on July 20, 2016 due to the PF-1AU coil failure. The facility achieved 10.03 run weeks (18 run weeks target) with 1066 plasma shots.
- PF-1AU coil was lifted out of NSTX-U on August 24. Upper CS divertor copper cooling water line damage discovered. After consultation with FES and PPPL management, decision to lift the CS was made on Sept 12. This will enable replacing PF-1AL without significantly impacting the schedule.
- PF-1AU forensic investigation is on going. Radiography is complete and the Phase 1 of the destructive testing is being prepared. The actual cutting will likely next week.
- A new PF-1A coil fabrication preparation is progressing. A coil shop is set up in the C-site, the same area as the NSTX-U TF/OH shop Mandrels are being fabricated and the coil conductors ordered. Other coil related material are also being procured. .
- Good progress were made on post run calibrations and a number of near term and longer term enhancements.
- Successful CDR for the divertor cryo-pump CDR conducted on Aug. 3, 2016.

Back-Up Slides

First Year Boundary Physics Tools Operational
Boronization, Lithium Evaporators, Granule Injector

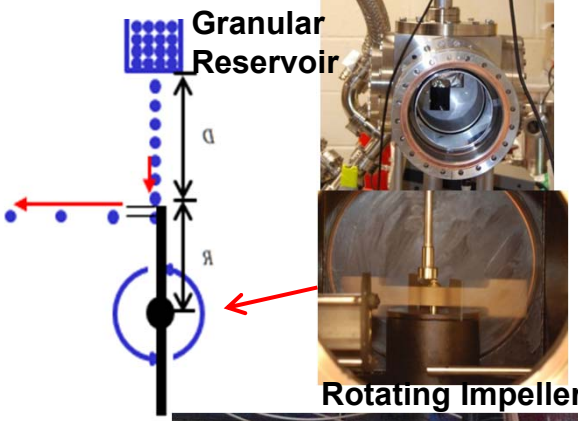
Lithium Evaporator (LITERs)



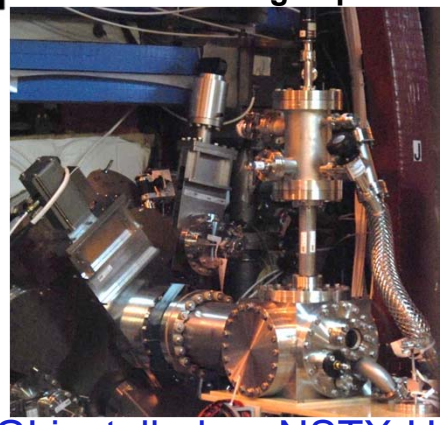
- LITERs filing set up in high bay south of NSTX-U Test Cell.
- Argon purge system implemented for Li safety, used for the quick argon vent.
- Ready to support the run.

Granule injector (GI) for ELM pacing

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



- GI is now operational.

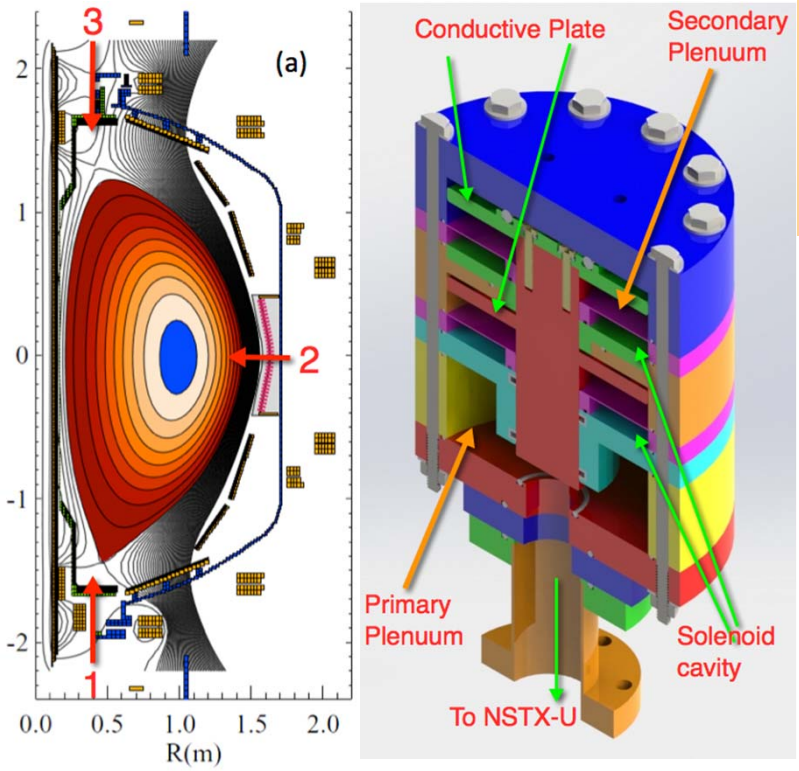


GI installed on NSTX-U

Disruption Mitigation System for NSTX-U

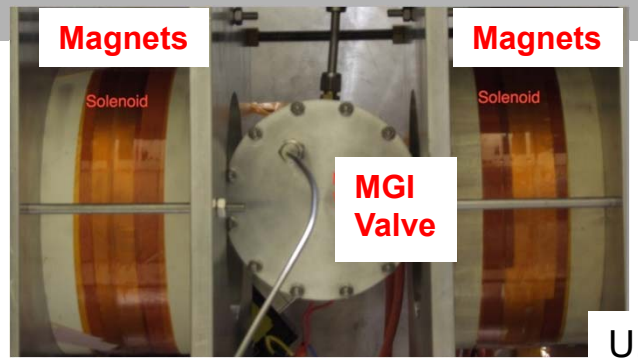
Massive gas injection system at multiple poloidal positions

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

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



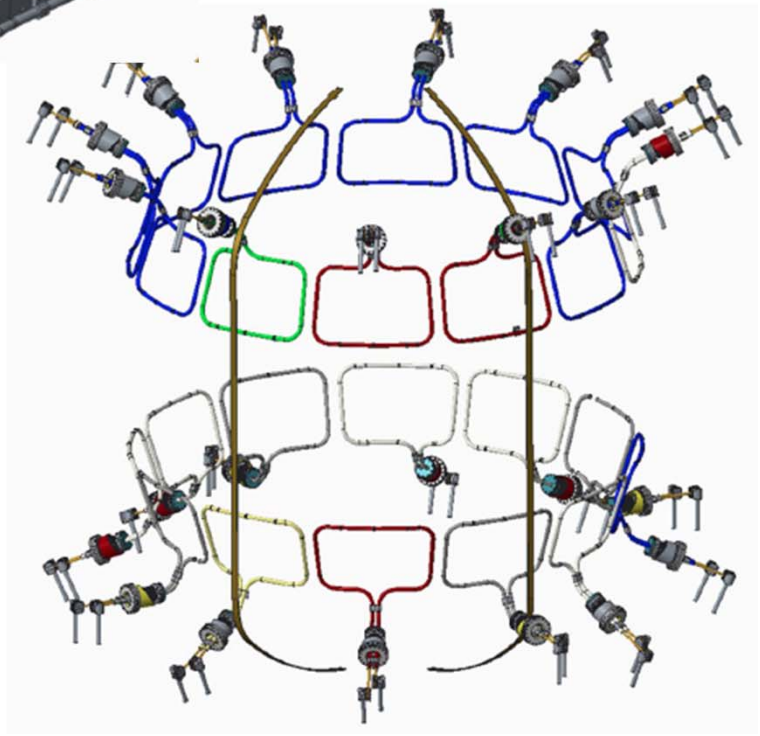
U. Washington

- Successful final Design Review of MGI system was held on February 18, 2016.
- All the MGI components were installed on NSTX-U and the control is being installed.
- Initial gas pulses into NSTX-U were performed and it is ready to support the operations.

NCC Coils Conceptual Design Successfully Completed

NCC = Non-axisymmetric Control Coil

- CDR design includes selection criteria include thermal capability, manufacturability, impact on interfacing objects, fabrication lead time and cost.
- Cost and schedule were prepared as part of the CDR which is completed on May 13, 2016.



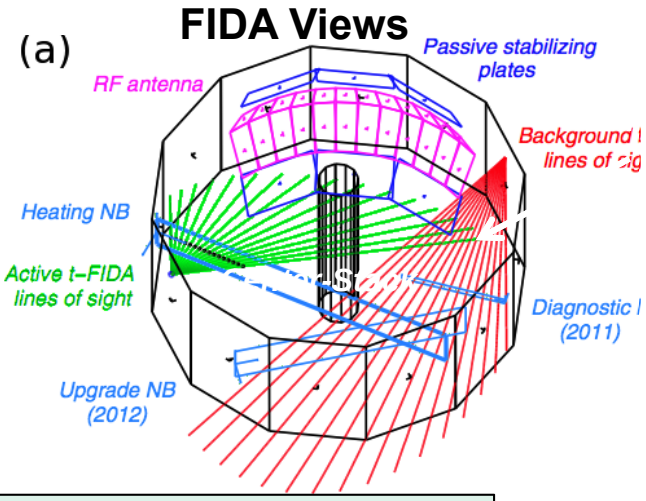
Prototype testing of joint design conducted

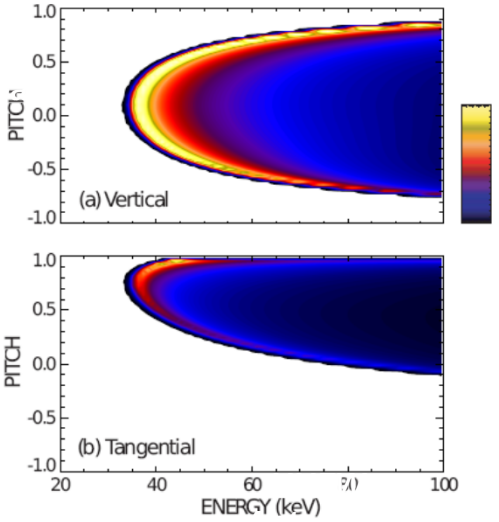
Enhanced FIDA measured NBI distribution function
For NBI fast ion transport and current drive physics

Fast Ion D-Alpha Diagnostics

Supported number of experiments on NSTX-U

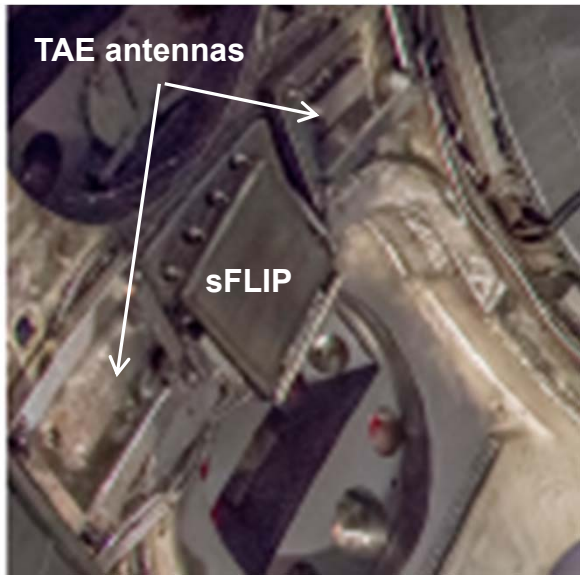
- Both vertical (perpendicular) and new tangential (parallel) FIDA systems are ready.
- Both FIDA systems have 10 ms, 5 cm, ≈ 10 keV resolutions.





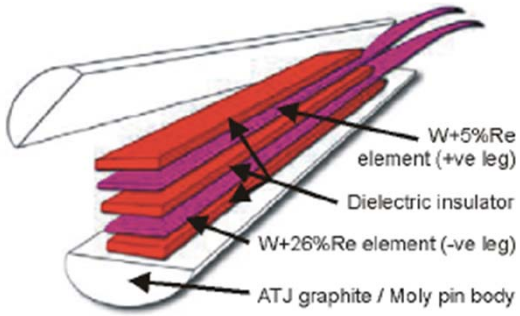
FY 2016 - 2017 Energetic Particle Conceptual Design and Diagnostic Upgrade

- SS-NPA installed and taking data. UCI
- sFLIP installed for lost ion measurements
- 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 being complete. FIU
- 8+8 reflectometry array available for AEs. UCLA



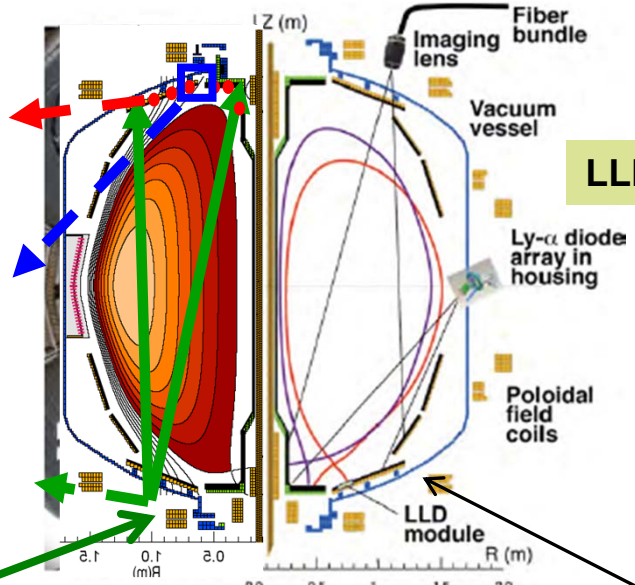
Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples



ORNL

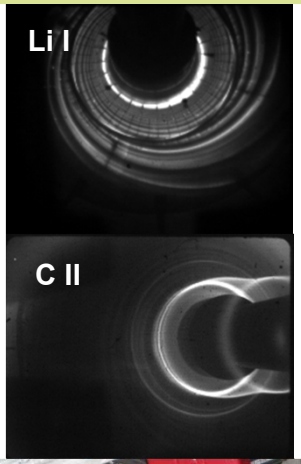
Divertor Imaging Spectrometer



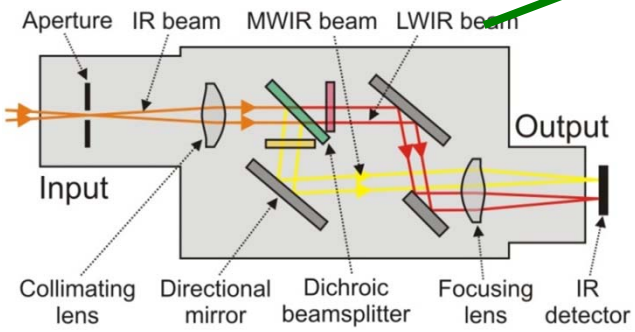
LLNL

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

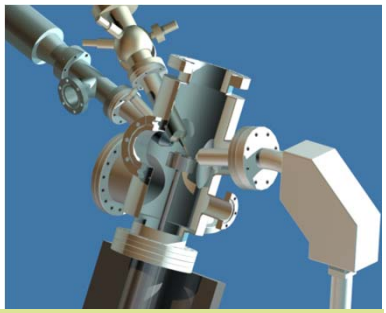
LLNL, ORNL, UT-K



Dual-band fast IR Camera



MAPP probe for between-shots surface analysis – took data

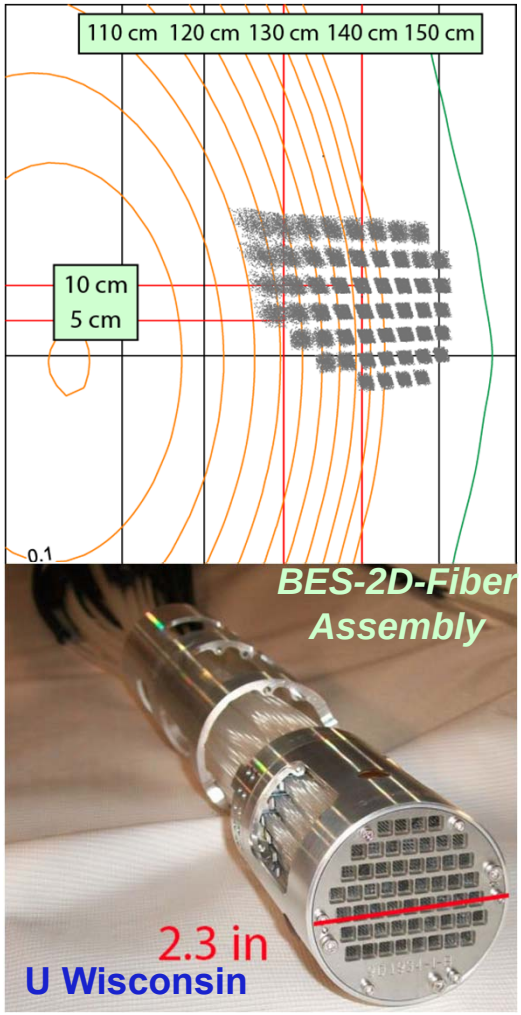


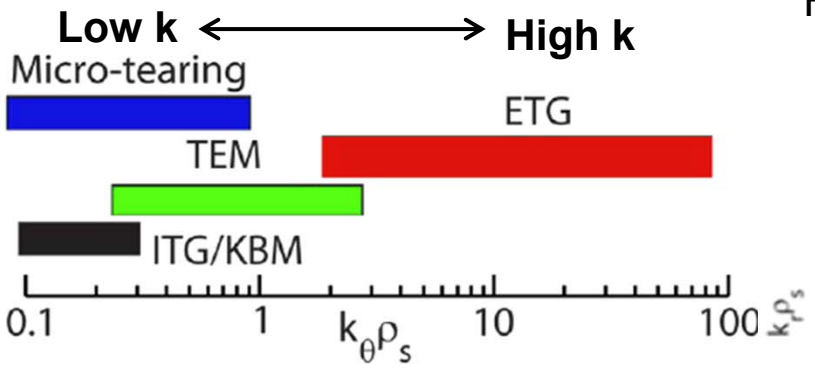
U. of Illinois, PPPL

Microturbulence Diagnostics Being Enhanced

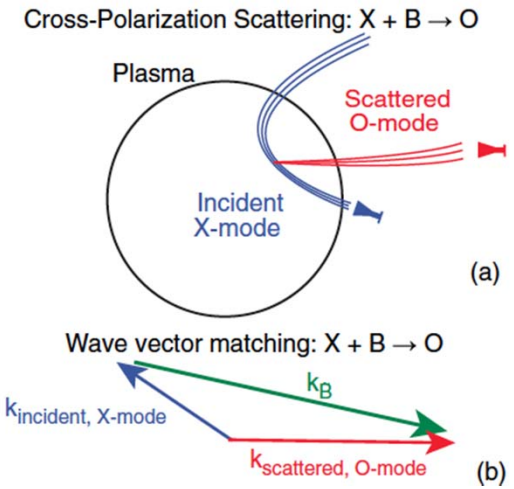
To measure ion to electron gyro-scale, magnetic fluctuations

Beam Emission Spectroscopy
for low k turbulence
Supported experiments



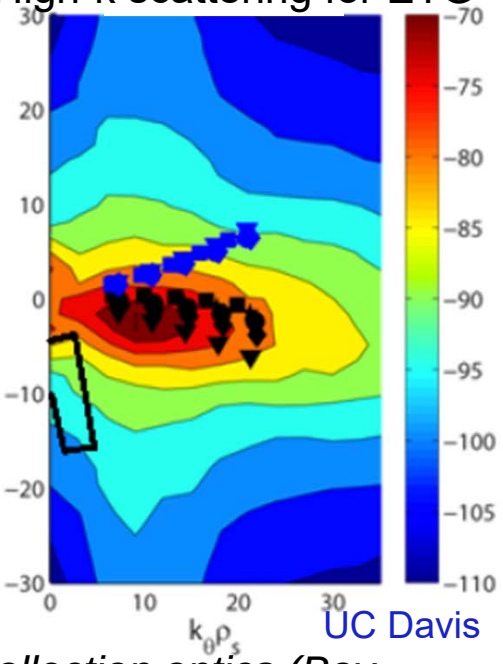


Cross-Polarization Scattering for magnetic fluctuations being developed in collaboration with DIII-D and MAST



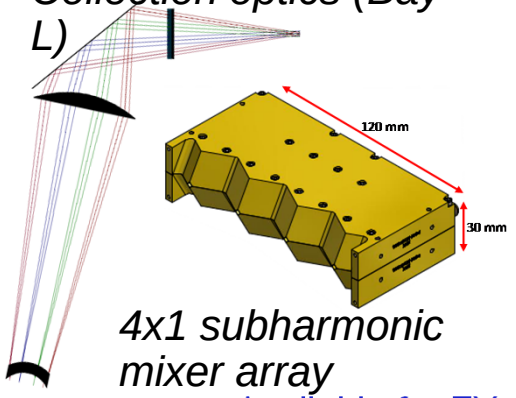
4–channel CPS system in 2017 UCLA

High-k scattering for ETG



UC Davis

Collection optics (Bay L)



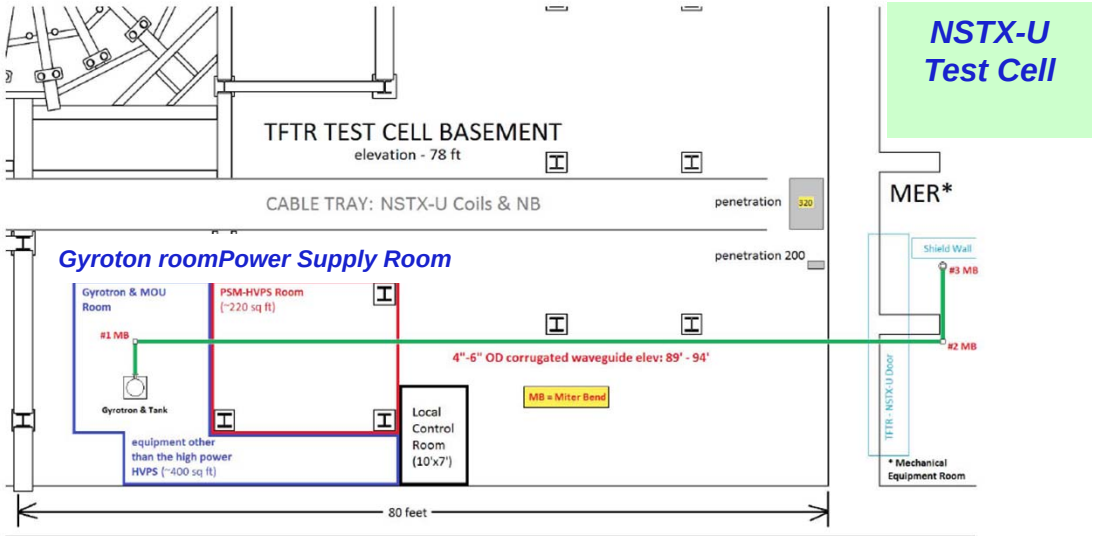
4x1 subharmonic mixer array

Available for FY 17

28 GHz ECH System Design
Completed conceptual design and cost/schedule

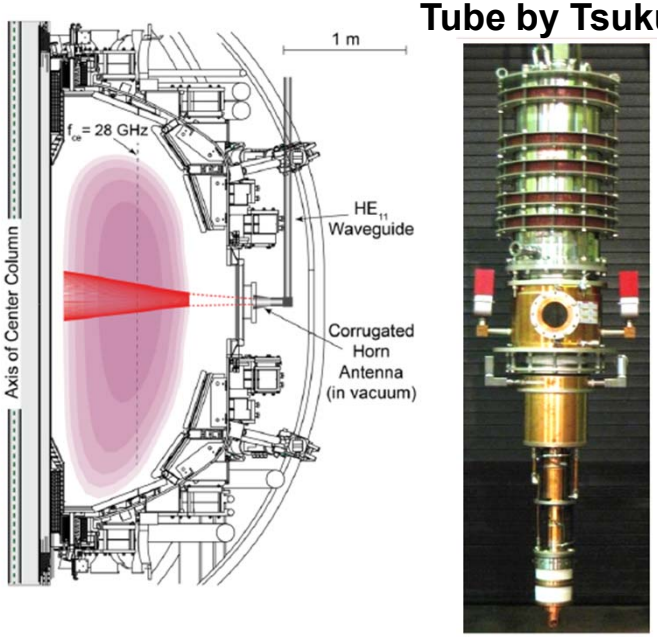
- CHI can form a 200-400 kA seed plasma, but it is too cold for HHFW absorption.
- Use of ECH can "bridge the T_e gap" to where HHFW and then NB current drive can support the ramp and sustain the current – crucial for OH solenoid-free compact STs
  - Good first pass absorption predicted.
- Goal of first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

28 GHz Gyrotron Room



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

28 GHz 1 MW Tube by Tsukuba



<u>28 GHz Gyrotron Development</u>

- 2nd generation 1.5 MW 28/35 GHz gyroton being developed at Tsukuba University.
- The tube was delivered to Tsukuba and the preliminary power test looks promising for 1.5 MW operations.