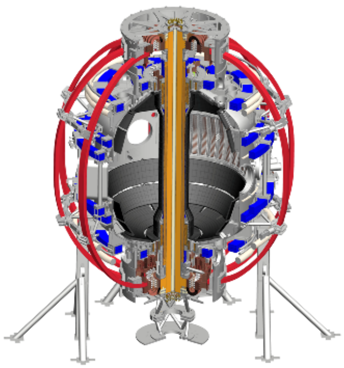
NSTX-U Facility and Diagnostic Plans for FY 2016- 2018

Masa Ono and J. Menard

FWP 2018 Budget Planning Meeting

April 13, 2016

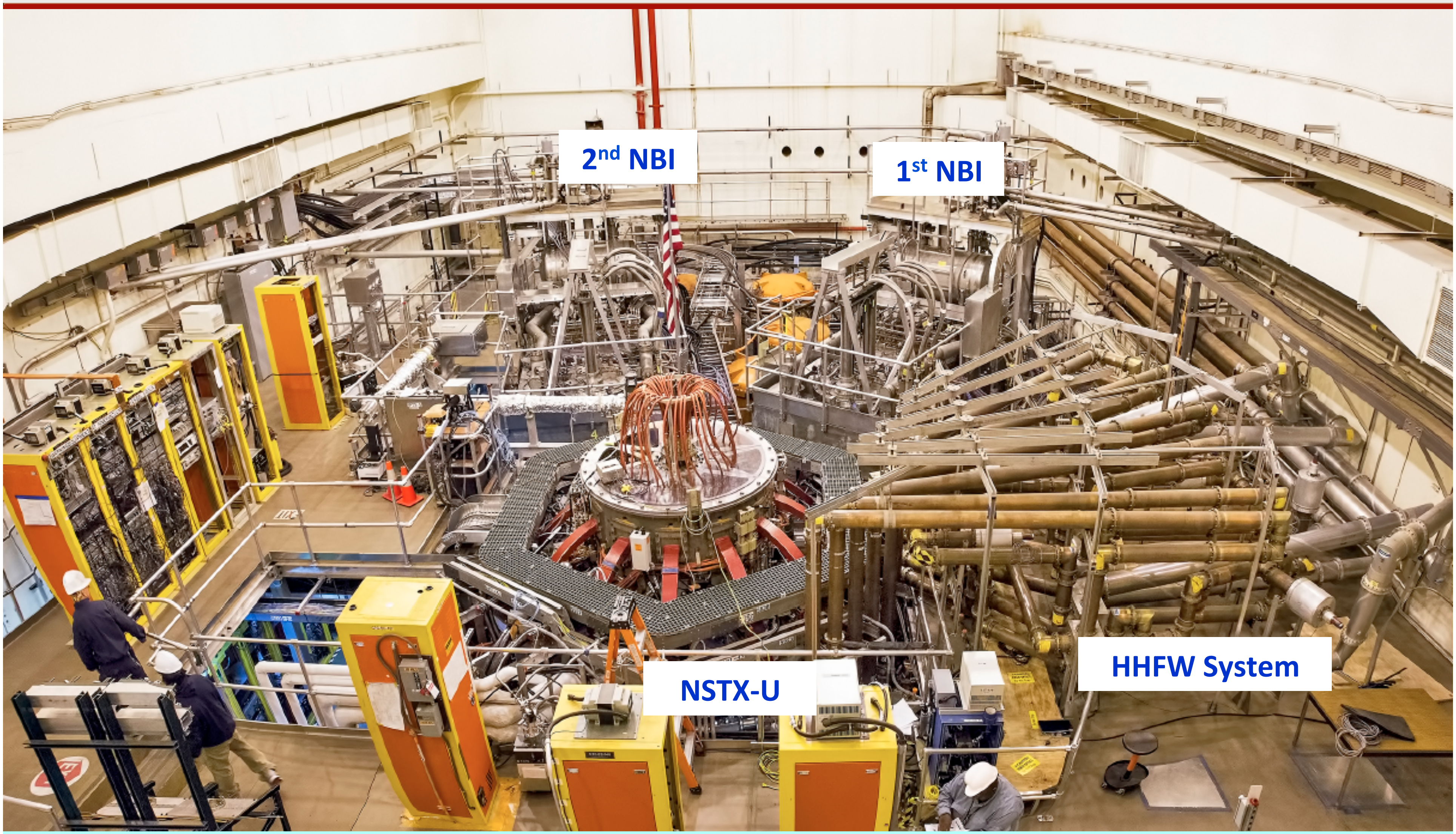


Presentation Outline

- Facility Operations Status and Plan
- Facility Enhancement Status and Plan
- Facility Milestones and Budget
- Summary

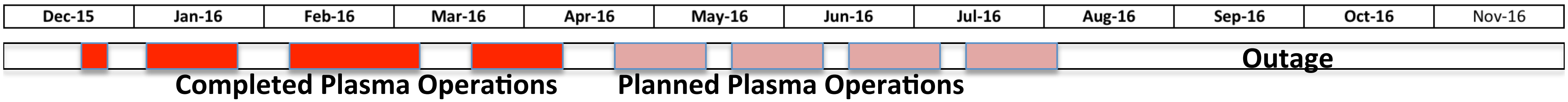
NSTX-U Facility Is Now Operational

Upgrade Project Completed on Schedule and Cost



All six NBI sources are now operational, supporting high performance H-mode experiments

Latest run plan schedule for 2016
~ 7.2 run week to date, goal is to operate 18 run weeks



➔Want as much data as possible for IAEA synopses/meeting, APS-2016

- **December 2015: 0.4 run weeks (XMP)**
- **January 2016 (3 weeks): 2 run weeks (H-mode), PAC-37**
- **Two week maintenance: NBI T-line repair, Argon purge system, LITER, Diagnostics**
- **February – March (4 weeks): 2.4 run weeks (routine H-mode)**
- **Two week maintenance: BN piece recovery, NBI Auto/transformer/T-line repair, LGI, MGI, Diagnostics**
- **March – April: (3 weeks) 2.4 run weeks (high power H-mode)**
- **Two week maintenance: BPM, NBI LHe refrigeration turbine regeneration, LGI, MGI, Diagnostics**
- **April – July 10.8 run weeks to complete FY16 run with extended run days**
- **August: Start outage: install high-k, high-Z tiles, …**
- **Resume operations winter 2017 for FY17: ~ 16 run weeks**

NSTX-U device performance progression

- **1st year:** Limit forces to ½ way between NSTX and NSTX-U, and ½ of the design-point heating of any coil
  - Presently operating at B_T ~ 0.65T
  - Increase to B_T ~ 0.8T after completing engineering analysis
- **2nd year goal:** Full field and current, coil heating to ¾ of limit
- **3rd year goal:** Full capability

Parameter	NSTX (Max.)	Year 1 NSTX-U Operations	Year 2 NSTX-U Operations	Year 3 NSTX-U Operations	NSTX-U Ultimate Goal
I_P [MA]	1.2	~1.6	2.0	2.0	2.0
B_T [T]	0.55	~0.8 (0.65)	1.0	1.0	1.0
Allowed TF I^2t [MA^2s]	7.3	80	120	160	160
I_P Flat-Top at max. allowed I^2t, I_P, and B_T [s]	~0.4	~3.5	~3	5	5

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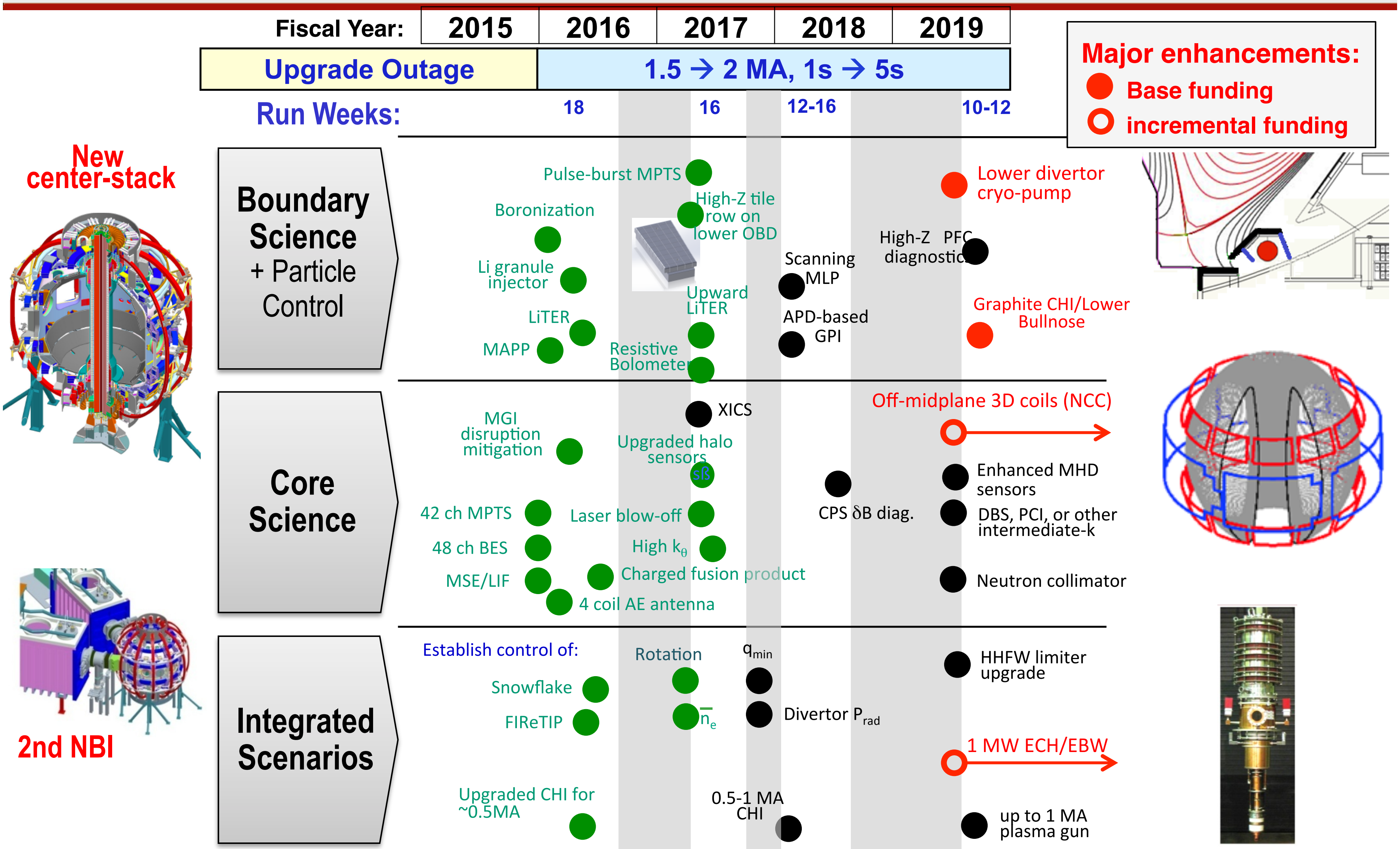
Five Year Facility Enhancement Plan (green – ongoing)

Incremental enables 5 year plan enhancements including NCC, ECH

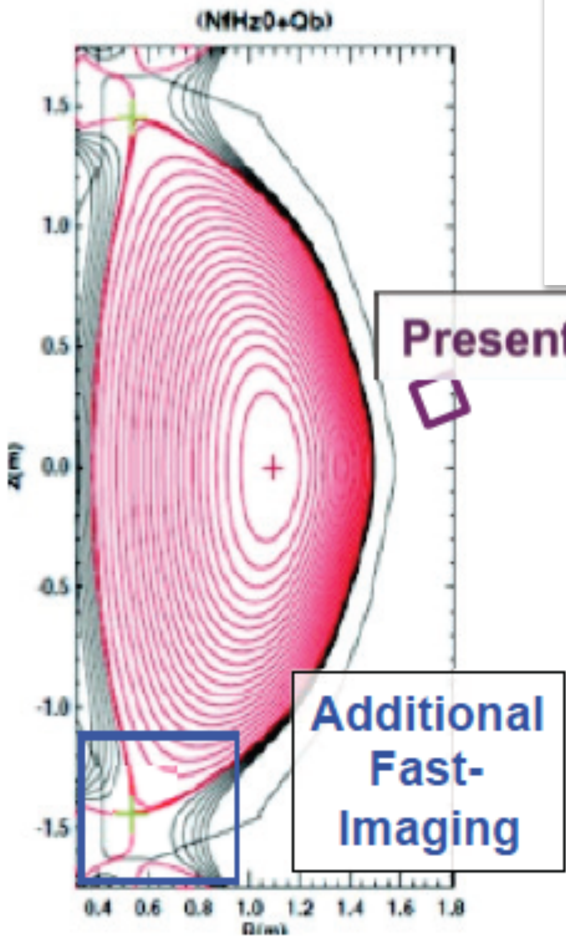


MIT PSFC Complements Well Existing NSTX-U Capabilities

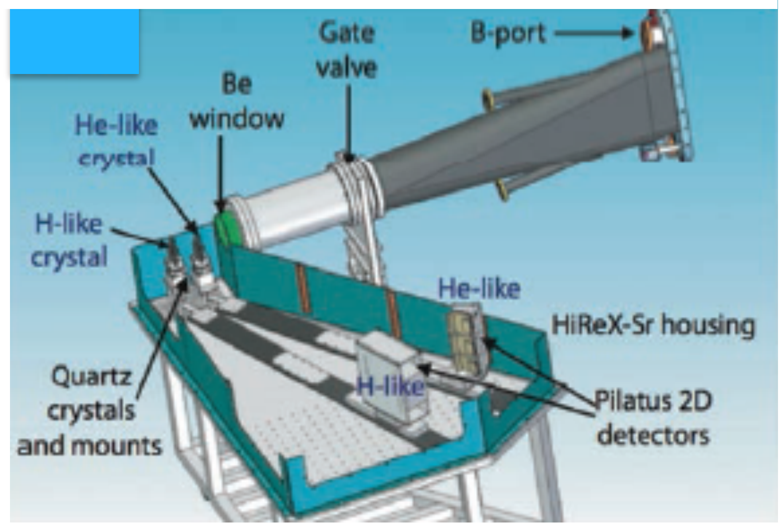
Discussions Started on Various Diagnostic Implementations

MIT will enhance NSTX-U GPI systems

Avalanche-PhotoDiode (APD)-based GPI



X-ray Imaging Crystal Spectroscopy



MIT is developing a next generation, servo-driven, compact scanning MLP system

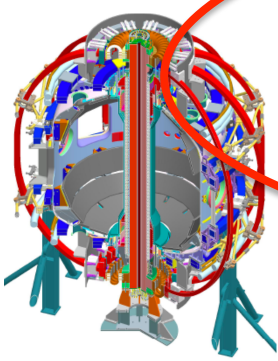
Five Year Facility Enhancement Plan (green – ongoing)

Incremental enables 5 year plan enhancements including NCC, ECH

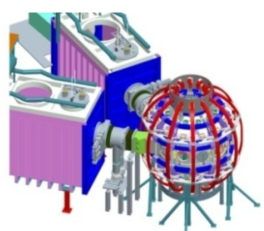
Fiscal Year:	2015	2016	2017	2018	2019
	Upgrade Outage	1.5 → 2 MA, 1s → 5s			
Run Weeks:		18	16	12-16	10-12

Major enhancements:
- ● Base funding
- ○ incremental funding

New center-stack

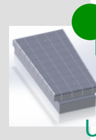


2nd NBI



Boundary Science + Particle Control

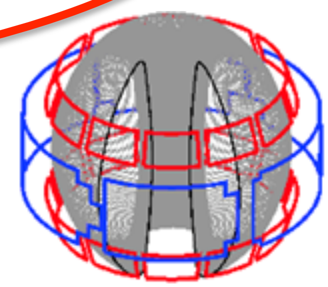
- Pulse-burst MPTS
- Boronization
- High-Z tile row on lower OBD



- Li granule injector
- Upward LiTER
- LiTER
- MAPP
- Resistive Bolometer
- Scanning MLP
- APD-based GPI
- High-Z PFC diagnostic
- Lower divertor cryo-pump
- Graphite CHI/Lower Bullnose

Core Science

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

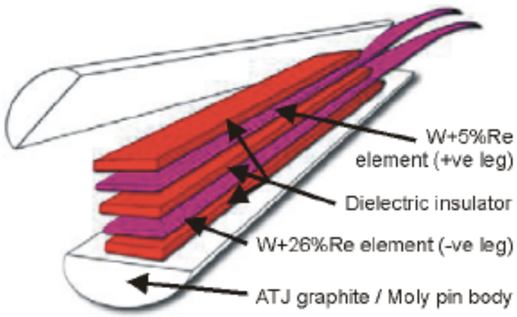


Integrated Scenarios

Establish control of:
- Snowflake
- FIReTIP
- Rotation
- $\bar{n}_e$
- q_{min}
- Divertor P_{rad}
- Upgraded CHI for ~0.5MA
- 0.5-1 MA CHI
- HHFW limiter upgrade
- 1 MW ECH/EBW →
- up to 1 MA plasma gun

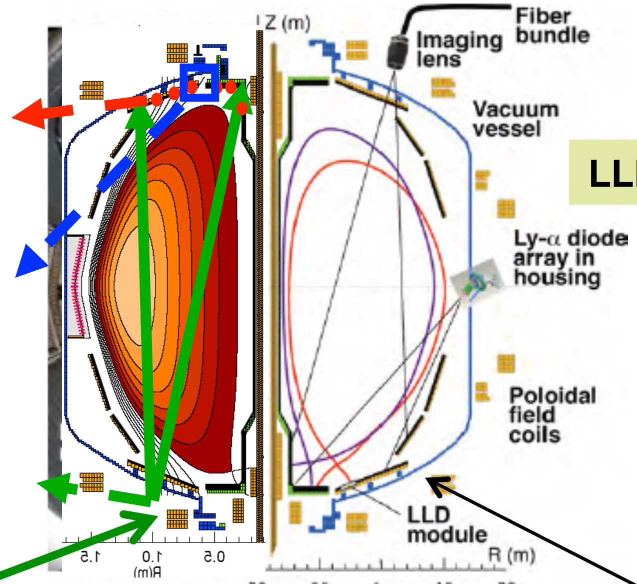
Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples



ORNL

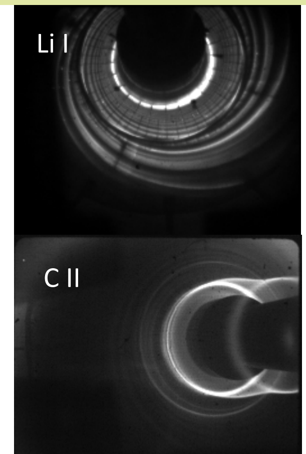
Divertor Imaging Spectrometer



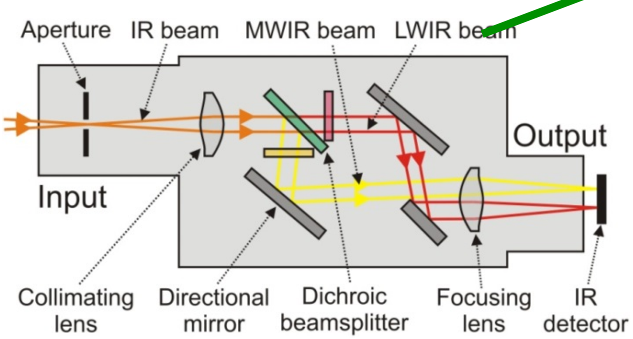
LLNL

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

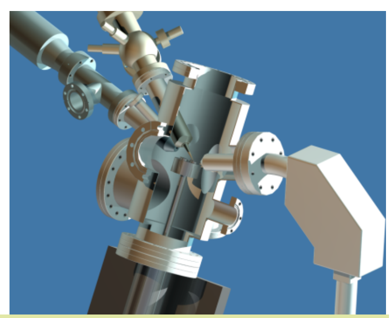
LLNL, ORNL, UT-K



Dual-band fast IR Camera



MAPP probe for between-shots surface analysis – Now taking data

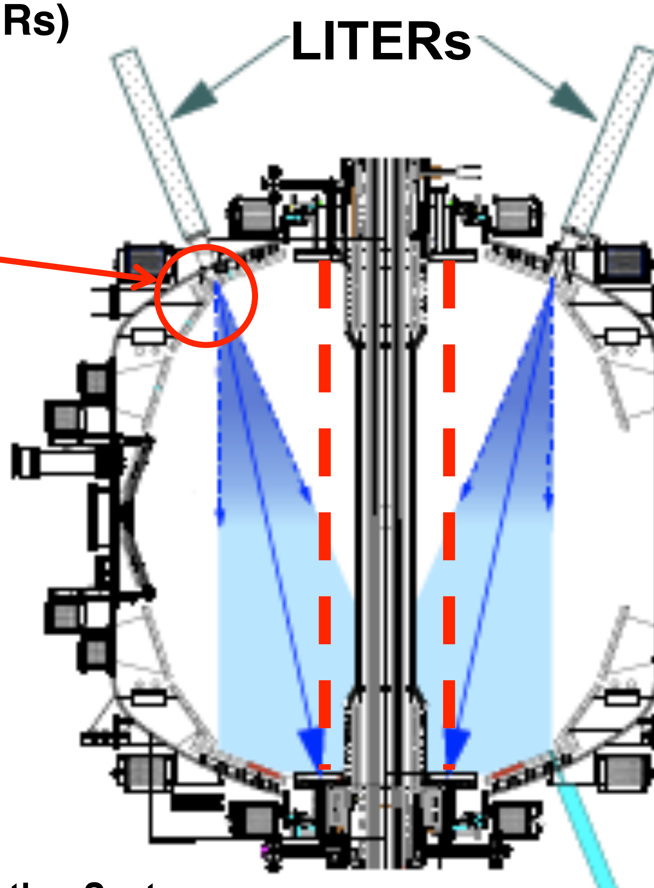


U. of Illinois, PPPL

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.
- Argon purge system implemented for Li safety, used for the quick argon vent.
- Expected to be operational in May.

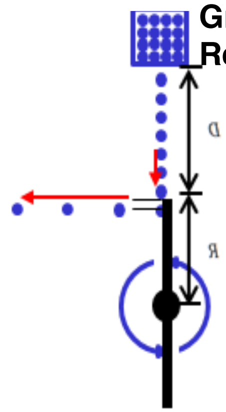
Boronization System

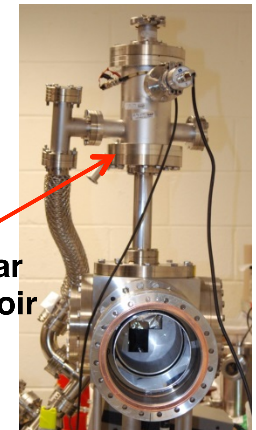
- Multiple injection and glow made more uniform boronization.
- System is working very well. Multiple # of boronization including daily ones performed. Also being used for He glow discharges.

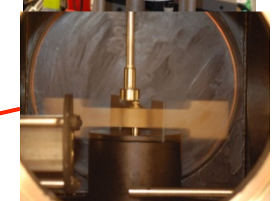
dTMB Gas Cabinet for safety

Granule injector (GI) for ELM pacing

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







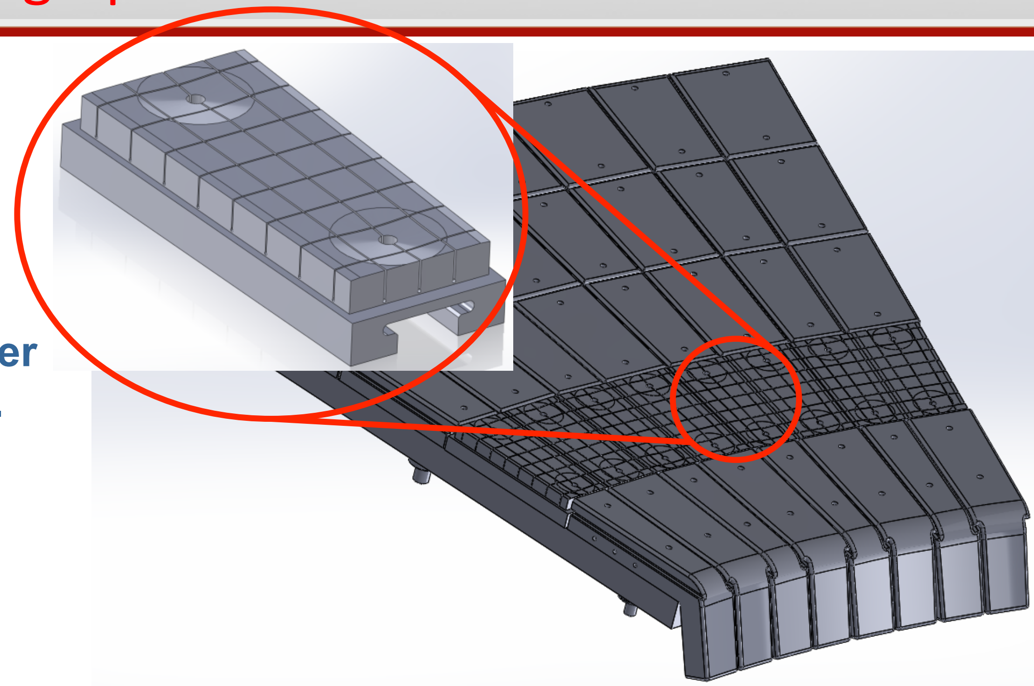
Rotating Impeller

- Granule injector installed on NSTX-U.
- Undergoing commissioning and initial injection during the next plasma operation.

High-Z Tile to be installed for FY 2017 run

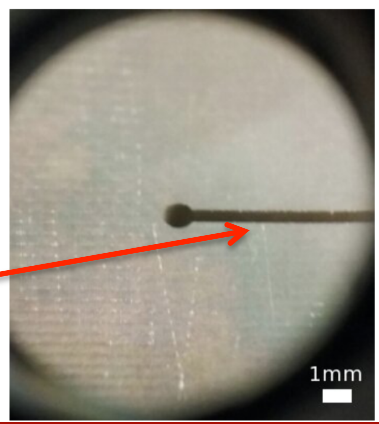
Design to replace a row of the graphite tiles in lower outer divertor

- **Successful FDR held in February**
  - 82% of raw materials on-site
  - Fabrication contract placed
  - Schedule to be delivered in September in time for the installation in NSTX-U.

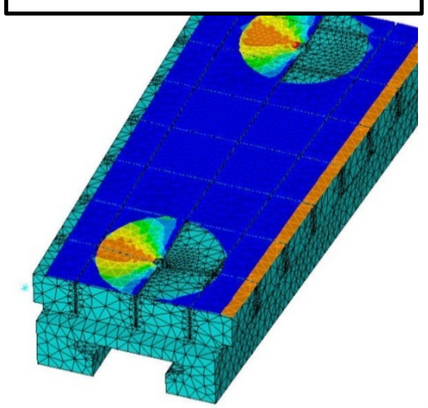


- **Final design rated to 10 MW/m² for 1s heat flux for 1000s of cycles**
  - Installation flexibility introduced to accommodate "as built" vessel tolerances
  - Edge and access-way chamfers introduced to reduce heat-flux peaking

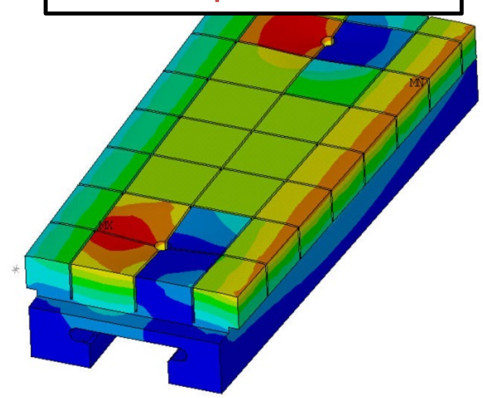
Test cut from one of the castellations performed



Surface heat flux

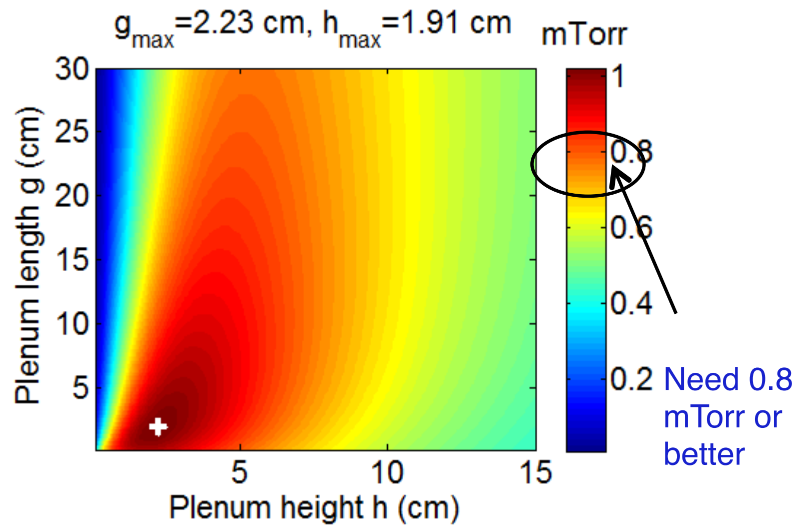


Temperature

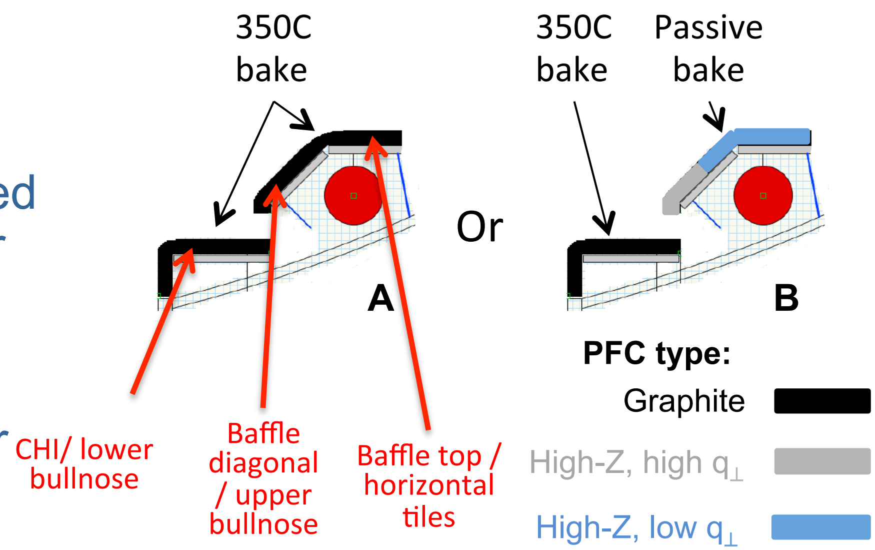


Lower Divertor Cryo-pump to Provide Pumping over a Wide Range of Divertor Geometries and Core Densities

- Physics design completed in collaboration with ORNL.
  - Defined the geometry, plenum sizes, ability to pump various geometries.
- Conceptual design process has been initiated:
  - Draft GRD has been formulated.
  - Initial designer sketches of in-vessel implementation completed.
  - Two types of PFCs being investigated.
  - CHI/lower bullnose section may be pursued as separate job as it may be enhanced for high Z and flowing Li in the future.
  - Goal is to to have the system ready for installation in the 2018-2019 outage under base funding.



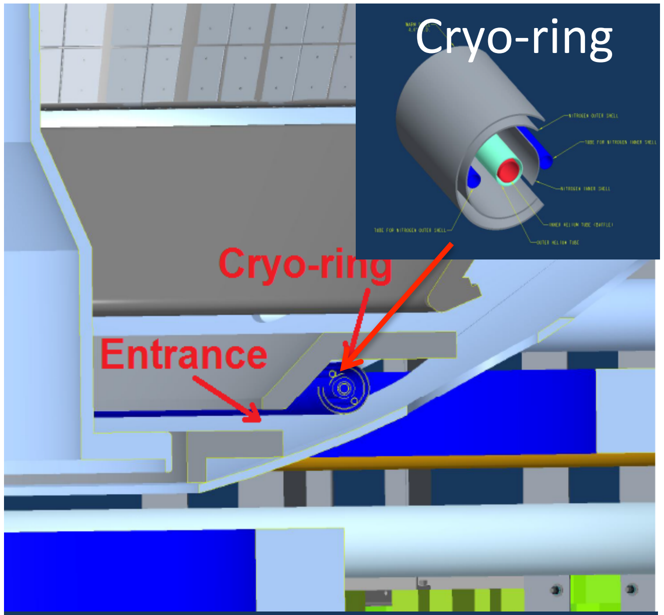
Two PFC Options for CDR

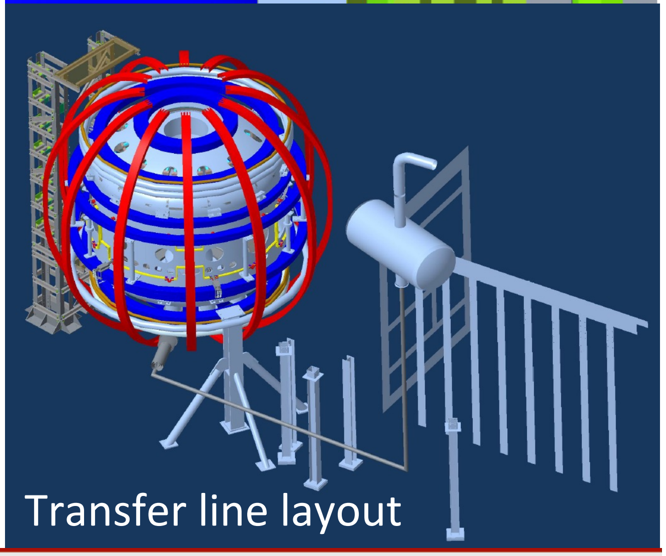


Divertor Cryo-pump Design Activities Started

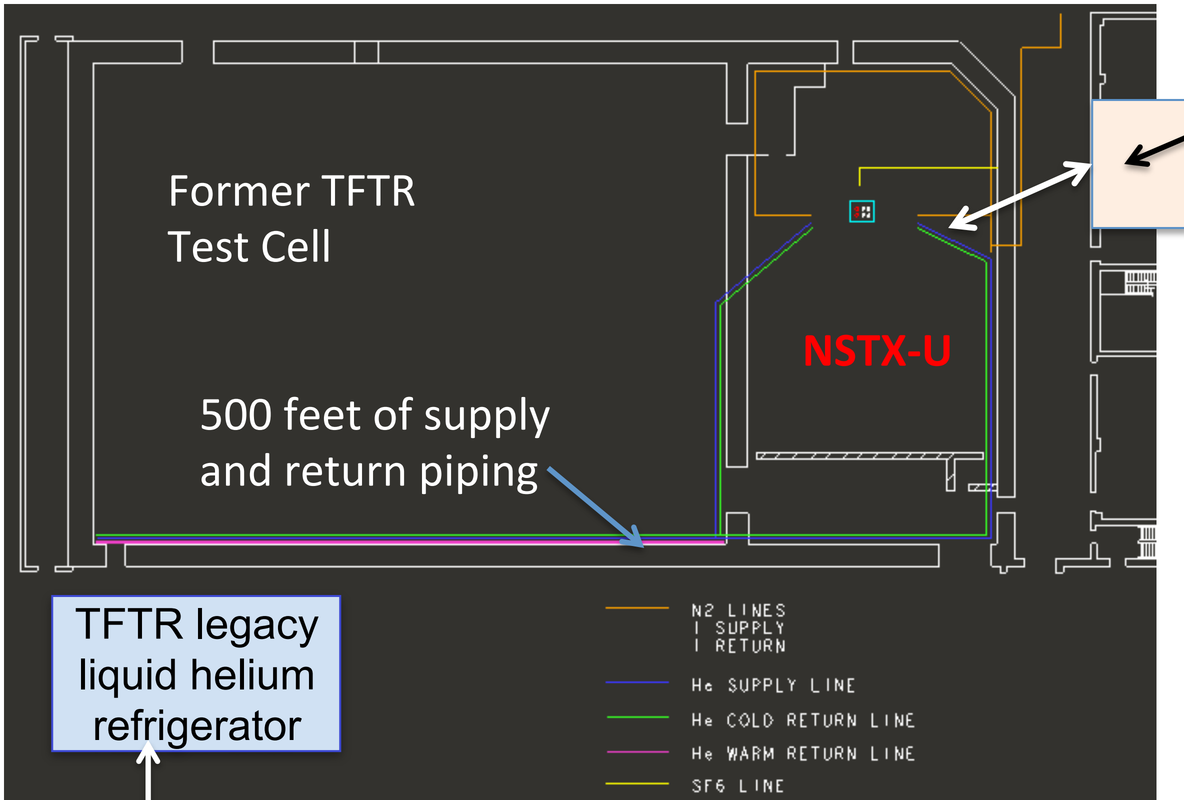
Design also includes appropriate PFCs and L-He refrigerator

- Initial in-vessel geometry has been laid out. MIT will design 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 at CDR.
  - Diagnostic access and cryo-ring maintainability are major design consideration.
  - Two PFC options (Graphite or high Z) are pursued for CDR.
- A 400W liquid He refrigerator considered to reduce NBI operational risk and operational cost savings.
  - A room adjacent to NSTX-U has been identified for energy efficient location with utilities already available.
  - Replaces the outdated TFTR-era L-He refrigerator reducing risks to the NBI operations.





A new efficient 400 W liquid helium (L-He) refrigerator to minimize down time risk and reduce operating cost



- 36 years old 800 W refrigerator for NBI #1 and 2 operating at near capacity due to long piping causes significant heat loss – also quite expensive to operate and maintain.
- If a cold box failure occurs, the repair will require reverse engineering and loss of several months will severely impact NSTX-U operations.

- To be located in the Cryogenics Compressor Room near NSTX-U, accommodates all envisioned loads by benefit of greatly reduced piping and heat loss (x 3-4).
- The unit would reuse power and space previously used for a 225 Watt refrigerator with all the utilities and compressors available.
- Benefit:
  - Remove down time risk
  - Increase available L-He for NSTX-U including NBI and Divertor Cryo-pump.
  - Reduced operating and maintenance cost

Implement Divertor Cryo-Pump with base funding

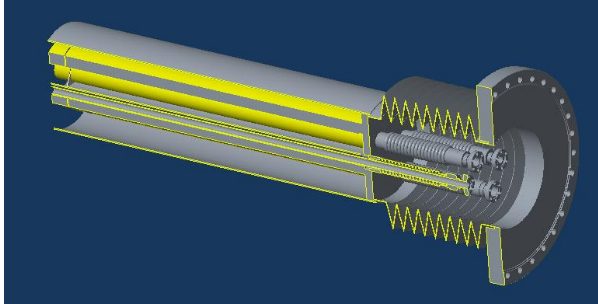
Exploring various options to minimize cost for timely completion

Schedule for Cryo-pump and PFCs:

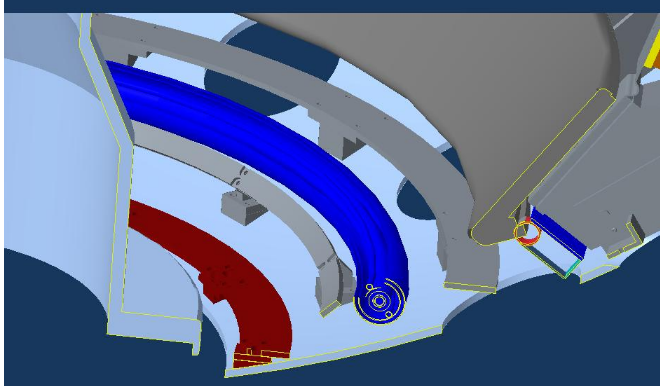
- Start formal design collaboration with MIT in Feb 2016.
- CDR – planned in July 2016 with cost and schedule developed
- PDR – planned in Nov. 2016
- FDR – planned in March 2017
- Complete fabrication of in-vessel components – May 2018
- Complete installation of in-vessel and ex-vessel components – Feb. 2019

Schedule for L-He refrigerator:

- PDR in June 2016 with external reviewers
- Start procurement – Sep. 2016.
- Start installation – June 2017
- Commission – Oct. 2017



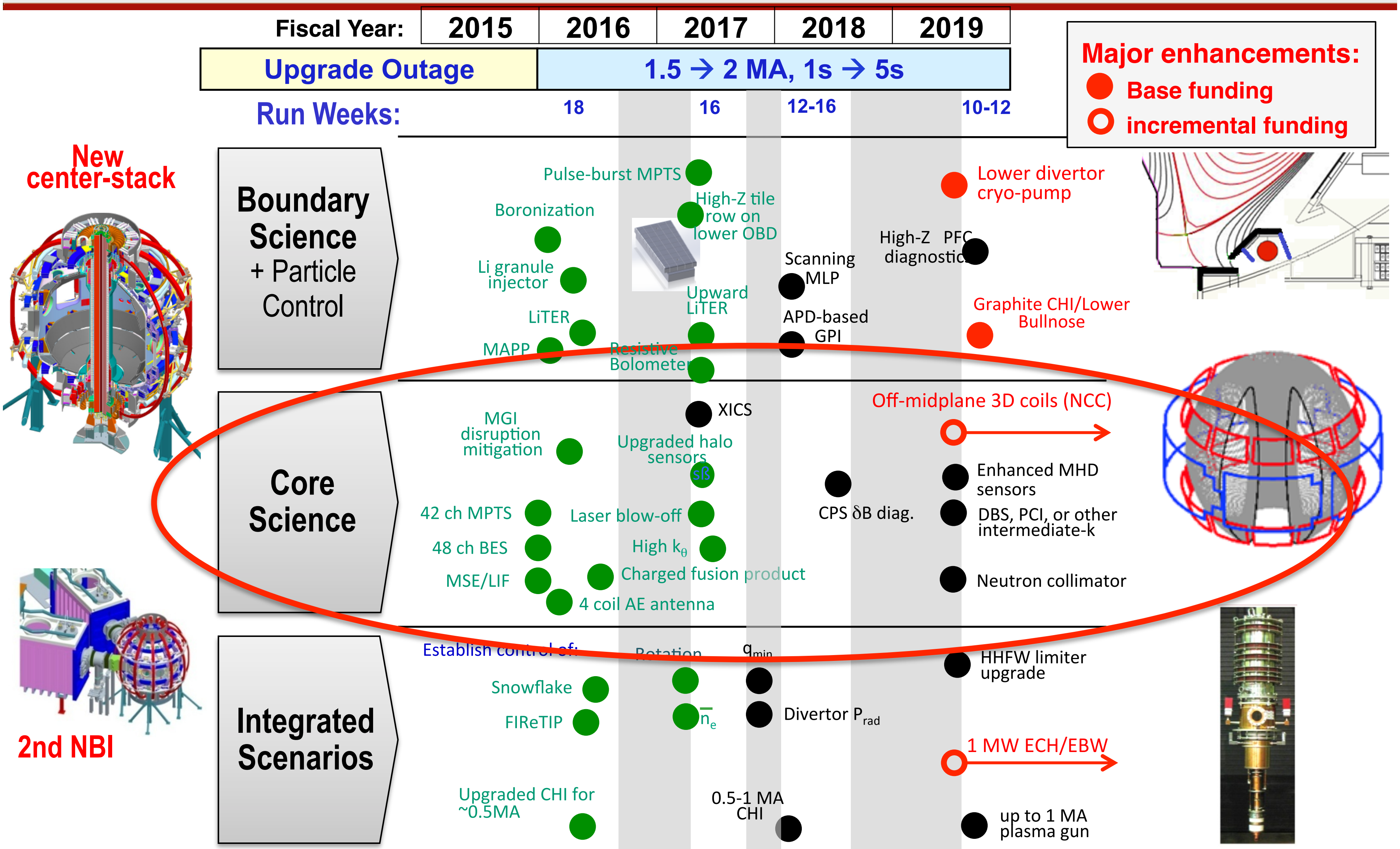
Cryogenic vacuum feedthrough concept.



Cryopump with redesigned divertor support structures

Five Year Facility Enhancement Plan (green – ongoing)

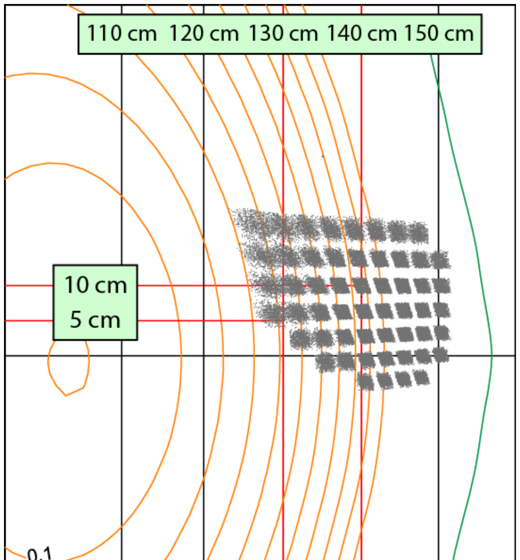
Incremental enables 5 year plan enhancements including NCC, ECH

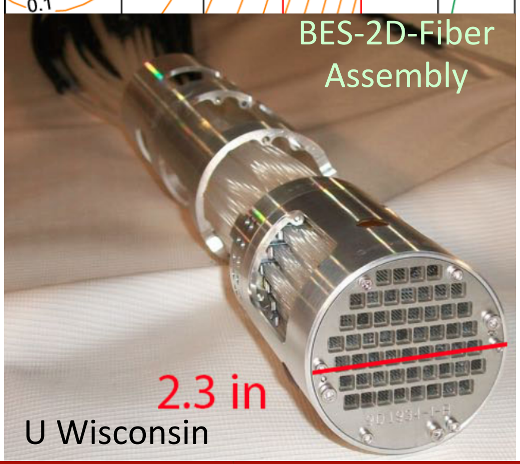


Microturbulence Diagnostics Being Enhanced

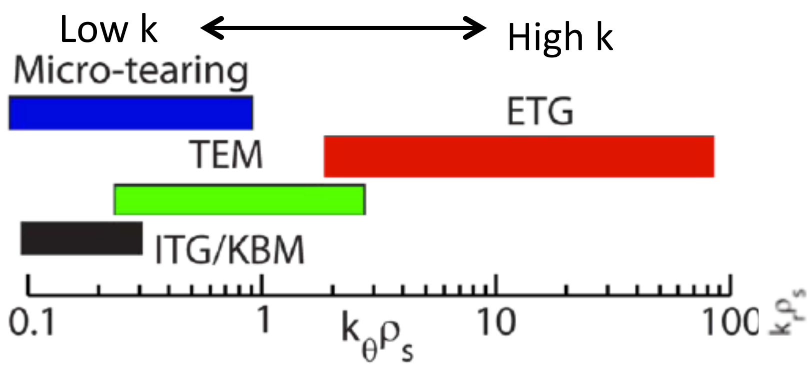
To measure ion to electron gyro-scale, magnetic fluctuations

Beam Emission Spectroscopy
for low k turbulence
48 chs being readied

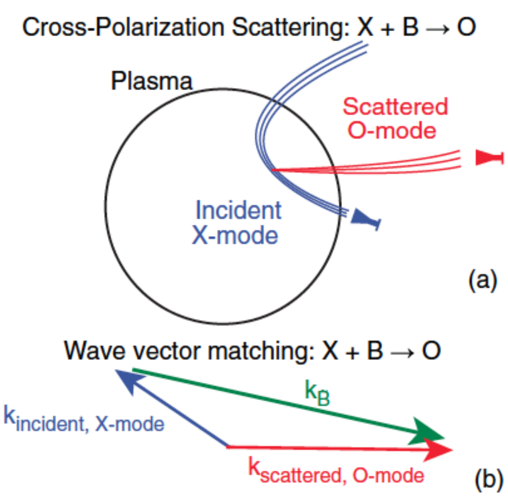




U Wisconsin

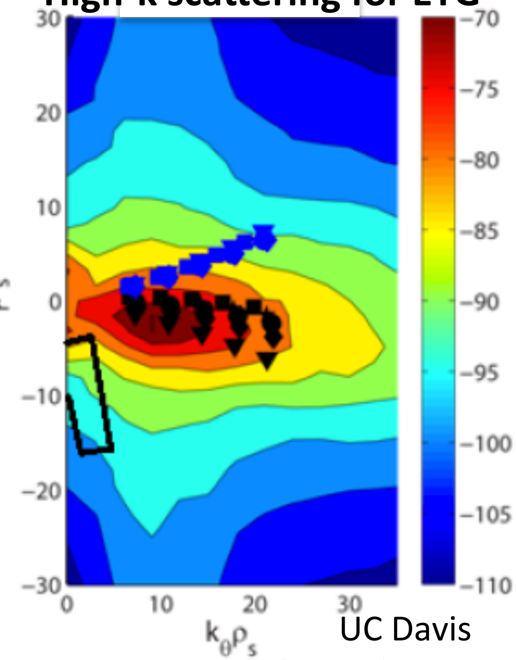


Cross-Polarization Scattering for magnetic fluctuations being developed in collaboration with DIII-D and MAST



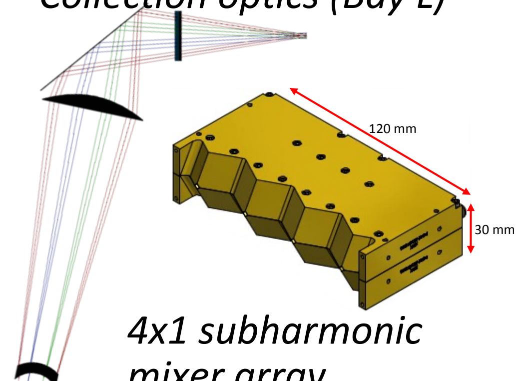
4–channel CPS system in 2017 UCLA

High-k scattering for ETG



UC Davis

Collection optics (Bay L)



4x1 subharmonic mixer array

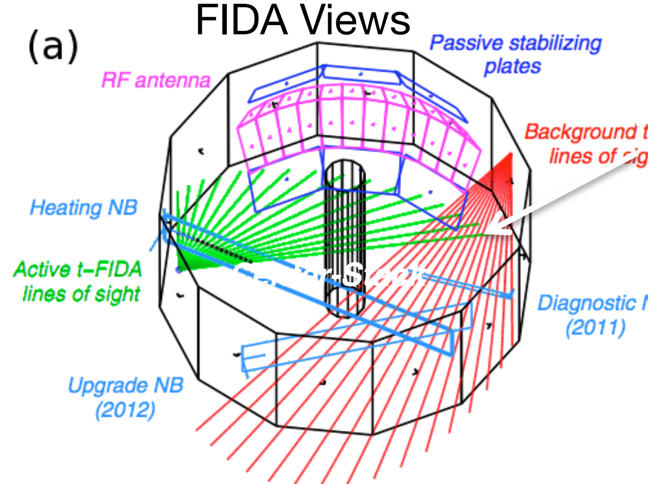
Available for FY 17

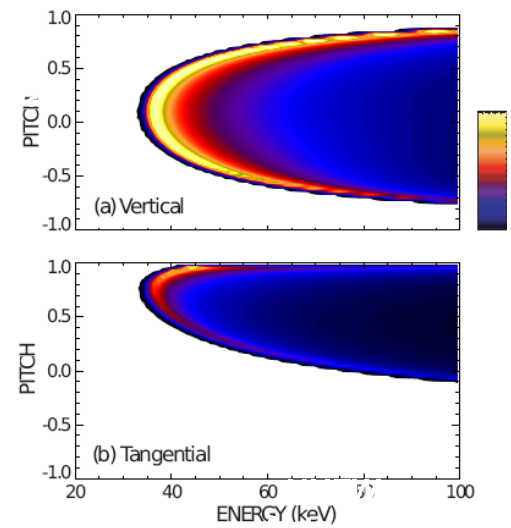
Enhanced FIDA will measure NBI distribution function
For NBI fast ion transport and current drive physics

Fast Ion D-Alpha Diagnostics
Taking data 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.**

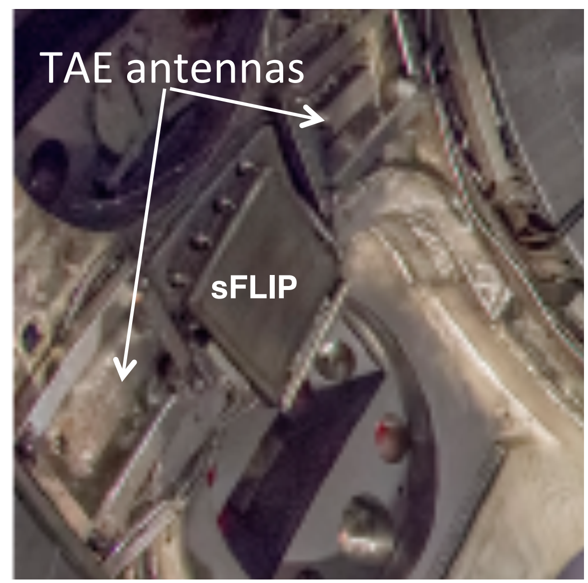
FIDA Views





FY 2016 - 2017 Energetic Particle Conceptual Design and Diagnostic Upgrade

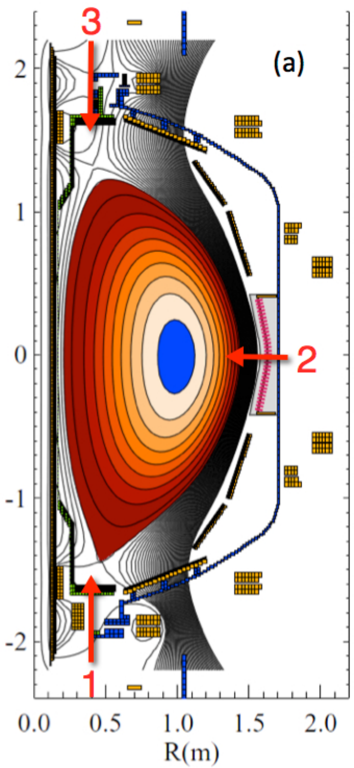
- SS-NPA installed and taking data. UCI
- sFLIP installed for lost ion measurements
- Active 2 X 2 TAE antennas installed. Initially passive spectroscopy then active excitation at few kW level.
- Proto-type charged fusion product (CFP) profile diagnostic is being prepared to be installed. FIU
- 8+8 reflectometry array available for AEs. UCLA

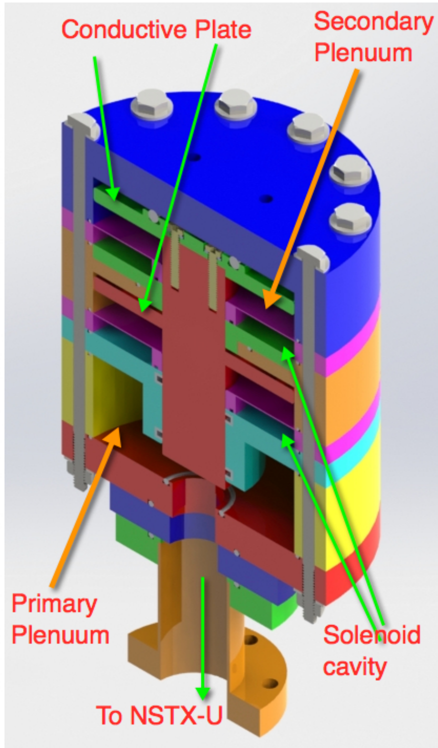


Disruption Mitigation System for NSTX-U

Massive gas injection system at multiple poloidal positions

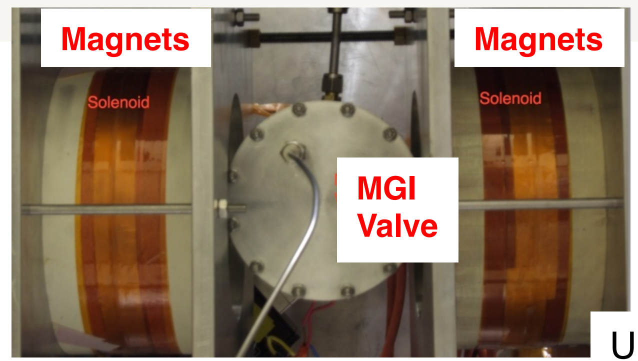
NSTX-U MGI Valve





- 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

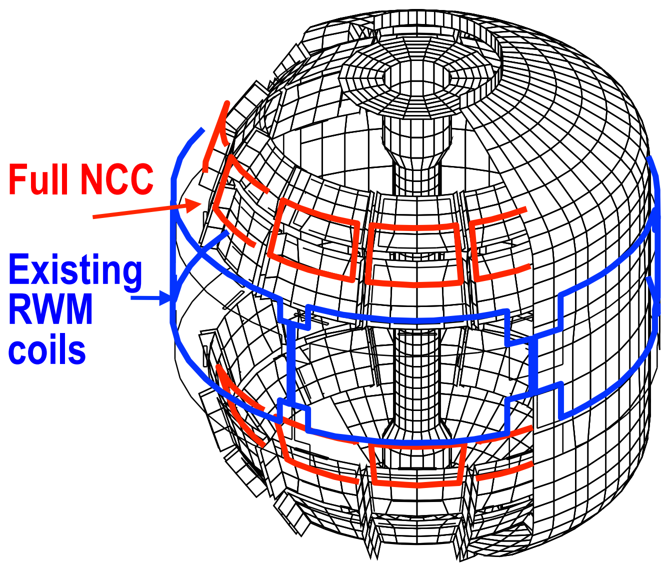
- **Successful final Design Review of MGI system was held on February 18, 2016.**
- **All the MGI components including MGI valves were delivered to PPPL from U. Washington and being installed on NSTX-U.**
- **Preliminary MGI test is planned in May, 2016 for the initial gas pulses into NSTX-U.**

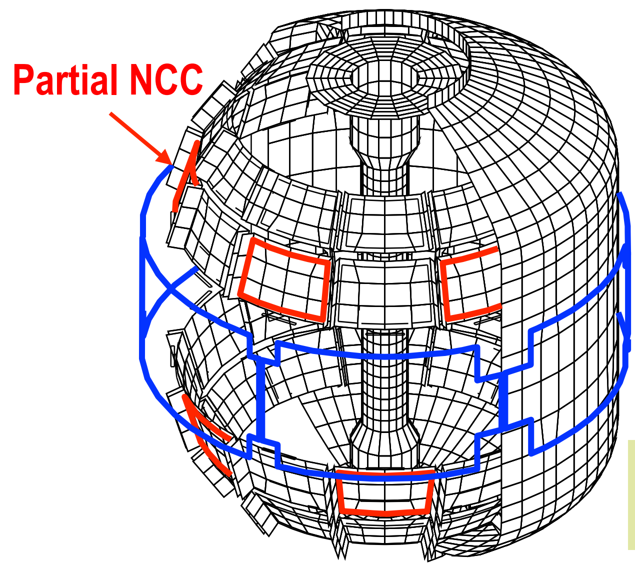
Flexible Mid-Plane Feedback Coils for MHD Studies

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

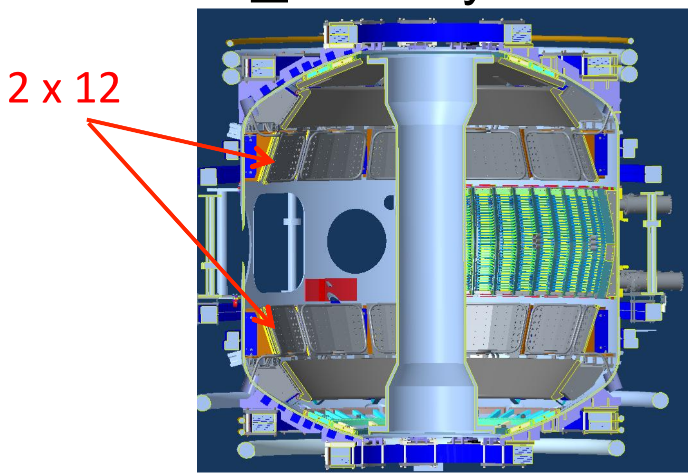
- 6-channel Switching Power Amplifier (SPA) powers independent currents in existing EFC/ RWM Coils supporting experiments
- NCC (a facility enhancement) can provide various NTV, RMP, RWM, and EF selectivity with flexibility of field spectrum (n ≤ 6 for full and n≤ 3 for partial)

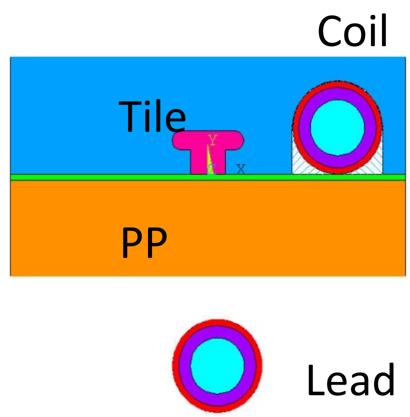
Base Budget – NCC engineering conceptual design work to develop reliable cost and schedule is being concluded to focus engineering resources to divertor cryo-pump design.

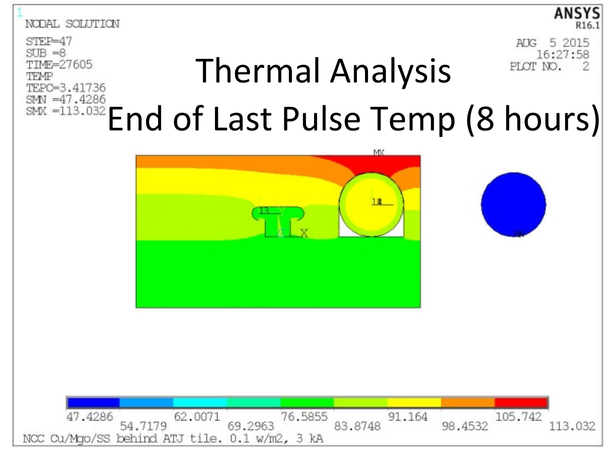
Incremental Budget – Enables continued design, development, and installation of NCC.

NCC Coils Design Activity Made Significant Progress
Test area prepared to perform conductor sample R&D

NCC = Non-axisymmetric Control Coil

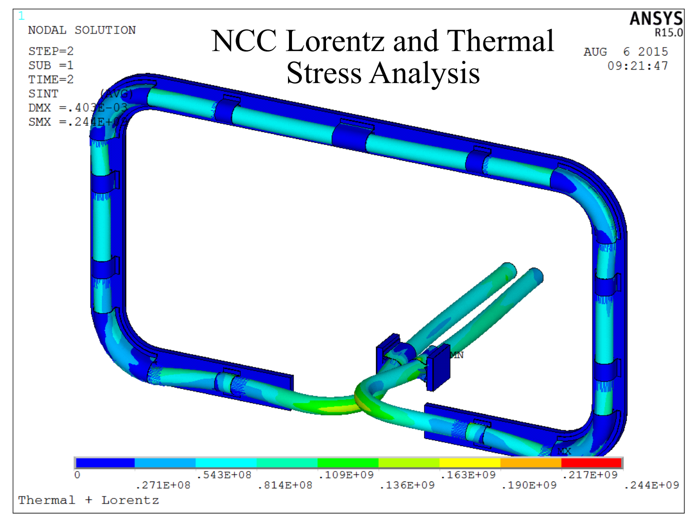






3 kA,0.1 MW/m2 Plasma Heating,5s pulse,1200 s reprate

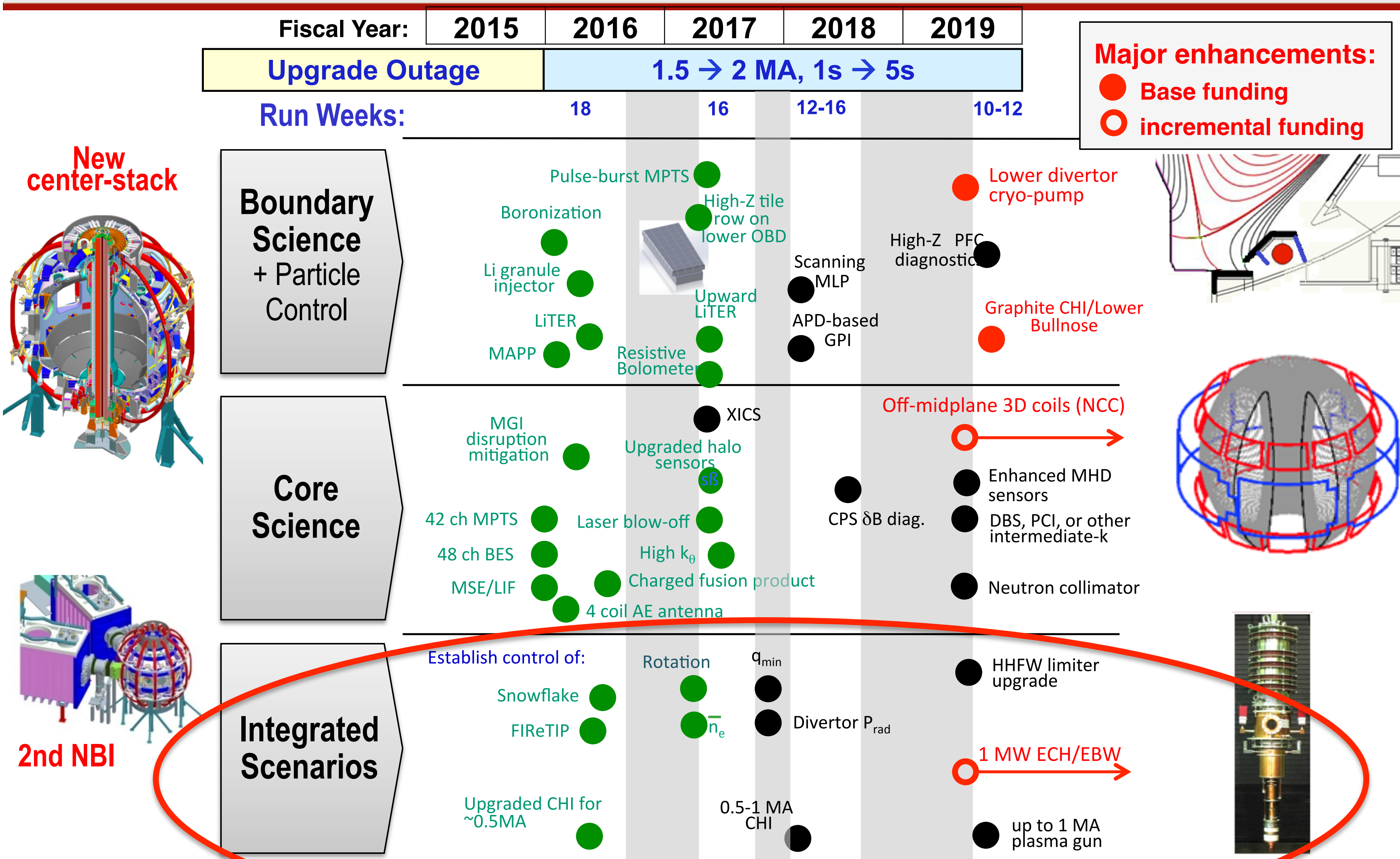
- **Candidate conductor for test sample received for R&D.**
- **R&D facility prepared and test being conducted.**
- **The R&D selection criteria include thermal capability, manufacturability, impact on interfacing objects, fabrication lead time and cost.**
- **Cost and schedule will be prepared as part of the CDR which is targeted for May, 2016.**



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

Five Year Facility Enhancement Plan (green – ongoing)

Incremental enables 5 year plan enhancements including NCC, ECH



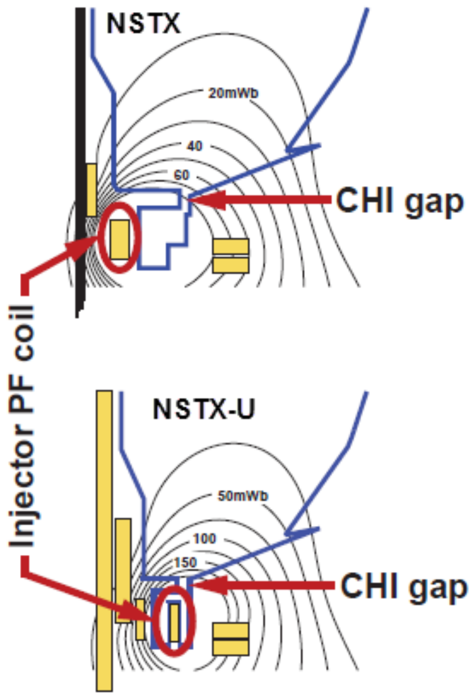
Solenoid-free start-up in support of ST-FNSF

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

CHI Start-Up in NSTX-U

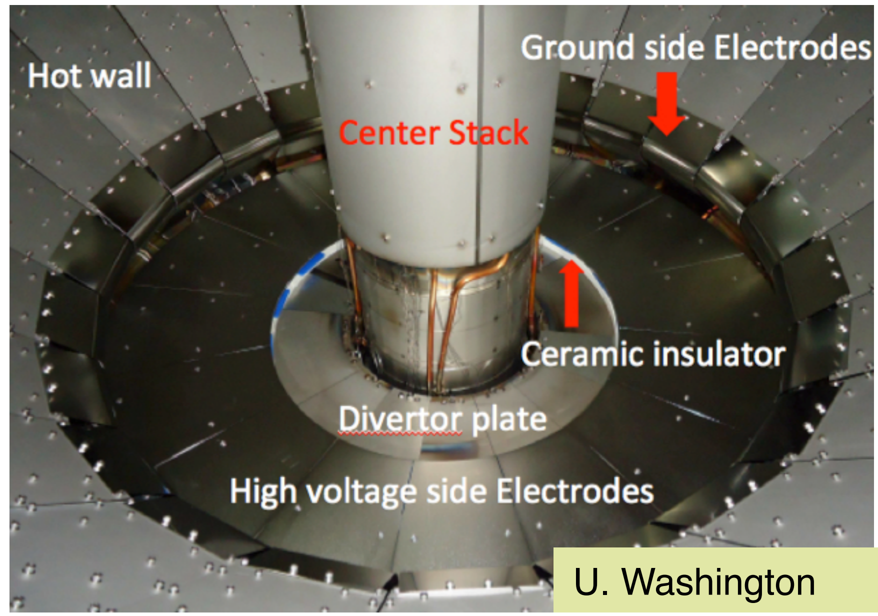
- **Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX**
- **NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation**

U. Washington



- **The resistive voltage divider network was made functional, and many of the components related to a fast voltage monitoring system were installed.**
- **All of the connections of the gas lines to the CHI gas injection systems have been completed.**
- **Initial testing of the CHI system into a plasma load will begin in the near future.**

QUEST CHI Experiment to test high-Z electrode operation

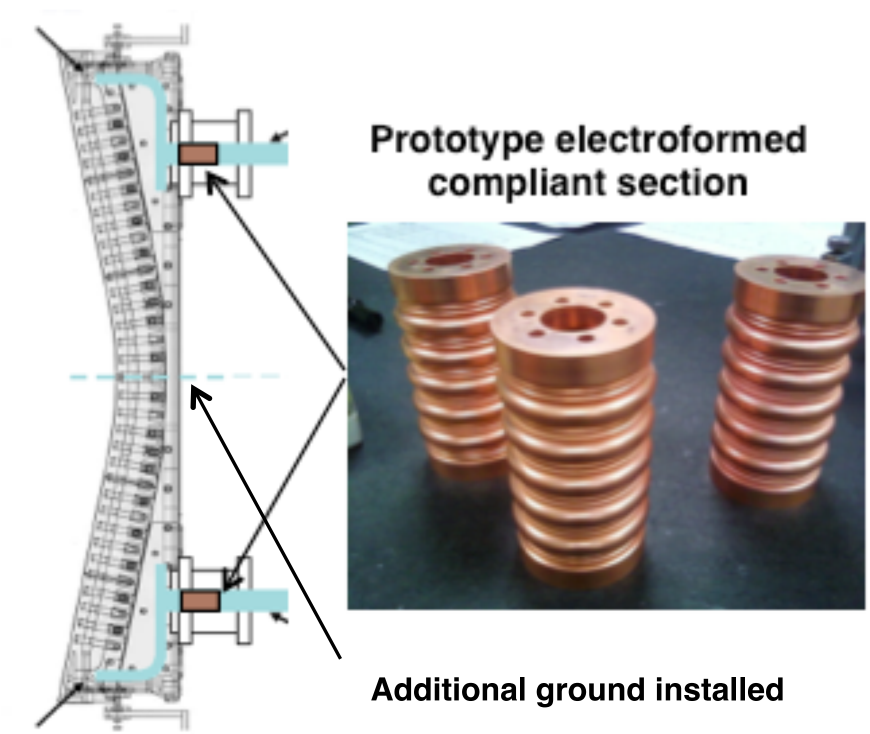


U. Washington

- **An ST-FNSF like CHI configuration will undergo plasma tests on QUEST after FY 2016 NSTX-U operation (after July 2016).**
- **All metal (high-Z) CHI electrodes provide valuable information for NSTX-U (presently graphite electrodes)**

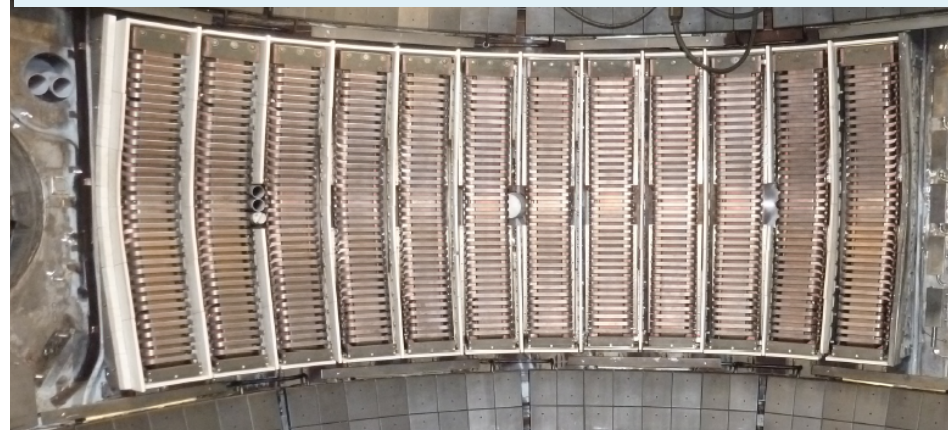
HHFW system will be ready for operation
Antenna plasma conditioning to start in April

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.

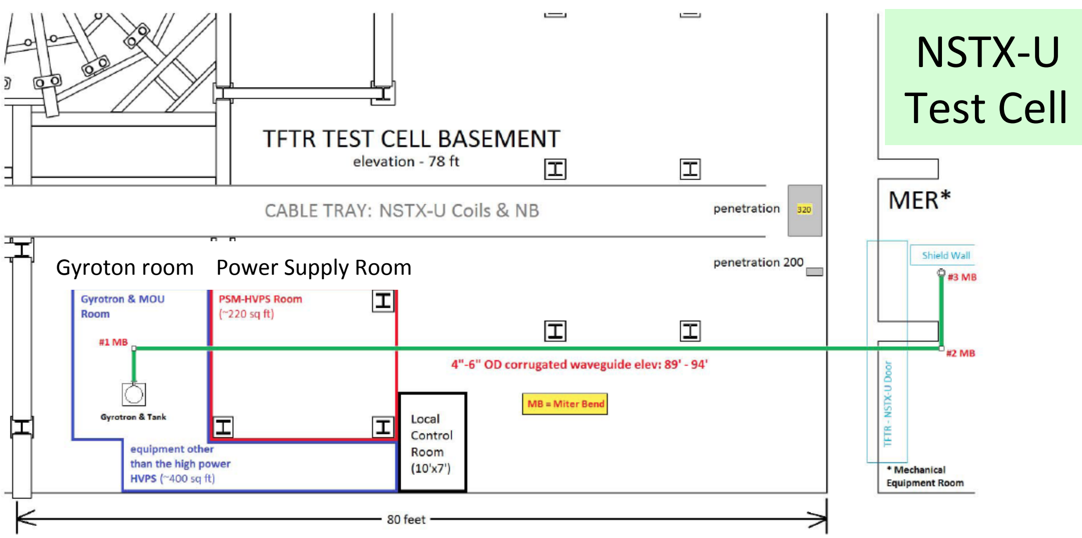
- **All sources will be ready to support HHFW operation in April.**

28 GHz ECH System Design Progressing Well

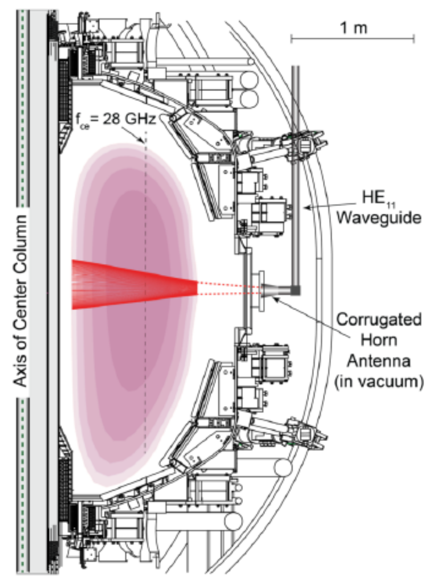
Complete conceptual design and cost/schedule this year

- 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.

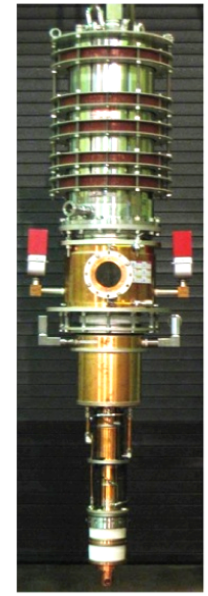
28 GHz Gyrotron Room



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. (See back-up slide). Power test to start in May.
- Incremental budget enables continued design and procurement of the ECH system.

Presentation Outline

- Facility Operations Status and Plan
- Facility Enhancement Status and Plan
- Facility Milestones and Budget
- Summary

Base NSTX-U Facility/Diagnostic Milestones

To complete Cryo-pump, NCC, and ECH/EBW Engineering Designs in FY 2016

Facility	Base Milestone Description	Baseline
F(16-1)	Complete 18 run week research operation	Sep 16
F(16-2)	Complete high-Z tile fabrication and prepare for installation	Sep 16
F(16-3)	Complete electron cyclotron heating / electron Bernstein wave (ECH/EBW) system conceptual design	Sep 16
F(16-4)	Complete divertor cryo-pump conceptual design	Sep 16
F(16-5)	Complete non-axisymmetric control coil (NCC) conceptual design	Sep 16
F(17-1)	Complete 16 run week research operation	Sep 17
F(17-2)	Complete divertor cryo-pump preliminary engineering design and begin long term procurement	Sep 17
F(17-3)	Complete lower outer divertor PFC preliminary engineering design and begin long term procurement	Sep 17
F(18-1)	Complete 12 run week research operation	Sep 18
F(18-2)	Complete cryo-pump engineering procurement of components for installation	Sep 18
F(18-3)	Complete lower outer divertor PFC procurement of components for installation	Sep 18

Diagnostics	Base Milestone Description	Baseline
D(16-1)	Complete fabrication of divertor resistive bolometers and prepare for installation	Sep 16
D(17-1)	Install and commission high k_q diagnostic system	May 17
D(17-2)	Install and commission pulse –burst MPTS	May 17
D(18-1)	Install and commission δB diagnostic system	Sep 18

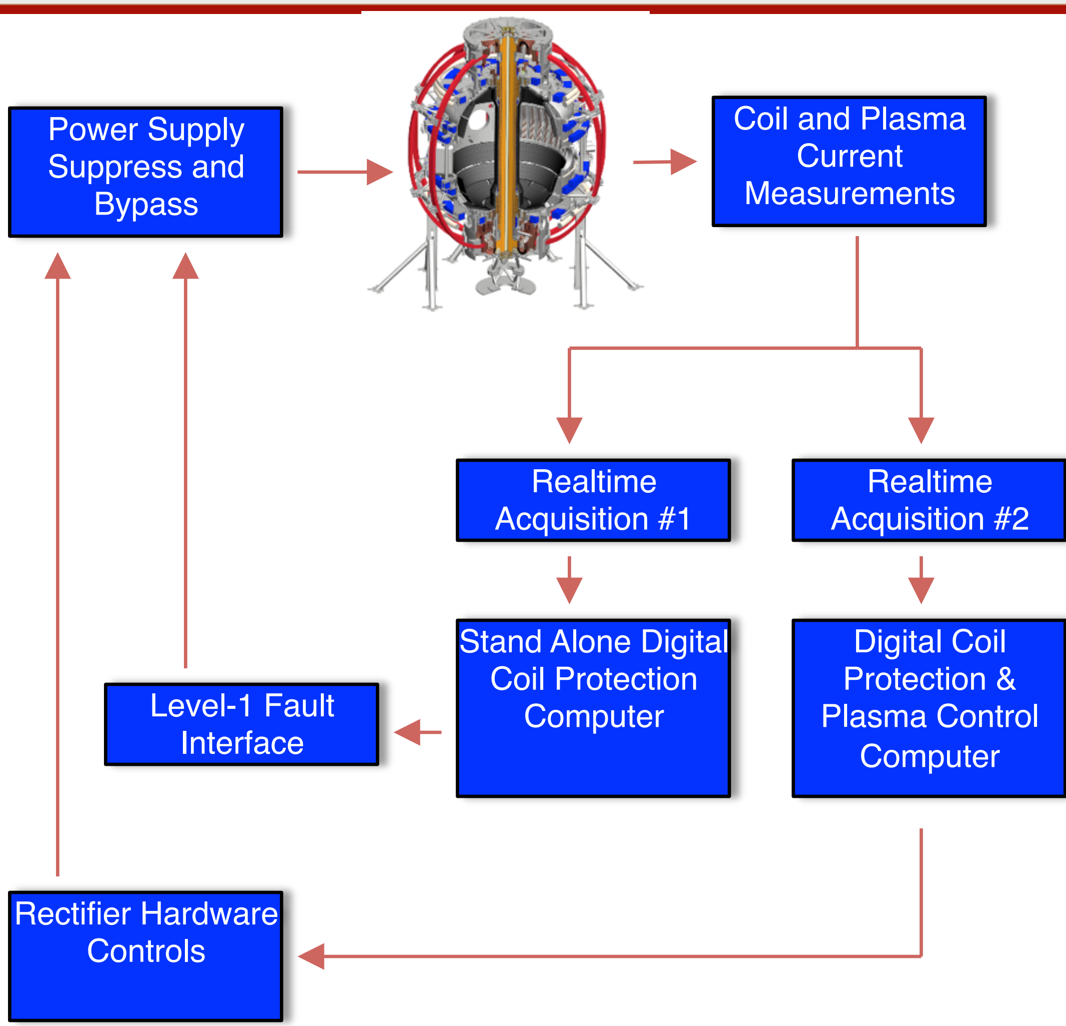
Summary of Facility and Diagnostics
Research operations successfully started

- Research operation started on December 18, 2015. With 7.23 run weeks achieved thus far we are at 40% of 18 run week target.
- The commissioning phase is nearly complete and the plasma operation is now becoming routine and the availability increasing to 90 – 100% range.
- NBI and boronization are now supporting operations with routine H-mode access.
- Very good progress on the plasma control system, quickly achieving H-mode and high performance discharges comparable to the best NSTX plasma parameters.
- A number of enhancements are being implemented to support the NSTX-U research plan. installation of high-Z tiles and complete conceptual engineering design for divertor cryo-pump, NCC, and ECH this year.
- Divertor cryo-pump, outer lower divertor PFCs will be implemented in the base plan.

Back-Up slides

Digital System Provides Electromechanical Coil Protection

DCPS supporting the research operation very nicely



Protects the NSTX-U coils and mechanical structure against electromagnetic loads

Computes forces and stresses in realtime based on reduced models of the full mechanical structure

Redundant systems

Full commissioning of the system went very well; DCPS is now routinely supporting operations.

Discussions on going with ITER for collaboration

NSTX-U Operations Encountered # of Issues
All the issues were resolved

- TF Water Fitting Repair – Cracked brass fitting –two out of 72 fittings - traced to possible stress during tightening. Made adjustment to procedure to minimize stress.
- Gas Injection System - Traced to a pressure gauge in the high field side gas injection system – broke down due to changing gas line pressure - "Paschen" curve. Moved the pressure gauge to the high pressure side.
- Water leaks in power supply room – changed hoses and components – this one could occur in the future because of the vast number of hoses and components.
- Protection system related – DCPS and other protection systems – adjusted the protection systems after confirming safe operation.
- Water leak in flow meter – broken plastic side wall - replaced all the meters of similar age (~ 16 years)

No significant loss of operations time due to motor generator nor NBI

Heating System Operations

- **Both Neutral Beams are still at LHe temperatures. Routine panel regens. Cold box regen this maintenance period after 15 months operation. NBI supporting experiments daily.**
- **Neutral Beam #2**
  - **N2A Source has operated to 86 kV.**
  - **N2B Source has operated to 80 kV.**
    - **High voltage crowbars under investigation this maintenance period.**
  - **N2C Source has operated 80 kV.**
- **Neutral Beam #1**
  - **N1A Source has operated up to 76 kV.**
  - **N1B Source has operated up to 70 kV 1 MW.**
  - **N1C Source had operated up to 90 kV 2 MW.**
- **HHFW Systems – Recovery Corrective Action Plan (CAP) activities to resume operations:**
  - **HHFW #1-4 Recovery CAP completed. Awaiting AC Power to start conditioning.**
  - **HHFW #5-6 testing done & CAP nearly completed. Awaiting AC Power to condition.**

Excellent Progress on Magnetic Diagnostics

- **Plasma current, loop voltage, poloidal flux and field measurements in good shape supporting EFIT.**
  - All integrators recalibrated
  - Rogowski coils fully calibrated, and pickup compensations established
  - All Mirnov sensors and flux loops have had their position determinations refined based on calibration shots.
- **New diamagnetic loop system is now operational also supporting EFIT.**
  - Based on using the Rogowski return loop as a diamagnetic loop.
  - Successfully implemented and eliminated the old TF-coil diamagnetic system.
- **High-n and high-f array is taking data.**
  - Used for detecting rotating Kink/Tearing modes, *AE modes.
- **RWM sensors are writing mode fit data to the tree.**
  - Realtime RWM sensor codes have also been upgraded, now in testing.

Significant Progress in Plasma Control System
Now supporting the research operations

- **PCS has been supporting plasma operations.**
  - **Pre-programmed PF control & simple radial and vertical position control, I_P control.**
  - **Gas injection and pre-fill control**
  - **Real-time magnetic sensor calibrations**
  - **Beam control from PCS**
  - **Automatic discharge shutdown following disruption detection.**
  - **rtEFIT running in the background on the control machines**
  - **RWM/EF coil current control from PCS has been restored.**
- **Some older less-reliable real-time digitizers have been replaced, and a new every-shot latency measurement system has been implemented.**
- **Near term PCS steps**
  - **Finish testing rtEFIT and begin to use ISOFLUX shape control**
  - **Finish the recommissioning of the RWM/EF control algorithms**
  - **Then move on to profile control and snowflake divertor control.**

NSTX-U diagnostics commissioned or being prepared
More than half are led by collaborators

Ready now/commissioning

Magnetics for equilibrium reconstruction
Halo current detectors
High-n and high-frequency Mirnov arrays
RWM / Locked-mode sensors
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)
Edge Rotation Diagnostics (T_i, V_ϕ, V_{pol})
Beam Emission Spectroscopy (48 ch)
Midplane ME-SXR (200 ch)
SAMI edge field pitch diagnoistc
Midplane tangential AXUV bolometer array (40 ch)
Ultra-soft x-ray arrays – multi-color
Fast Ion D_α profile measurement (perp + tang)
Solid-State neutral particle analyzer
Neutron measurements
Charged Fusion Product
Fast IR camera (two color)
Material Analysis and Particle Probe
AXUV-based Divertor Bolometer
Tile temperature thermocouple array
Fast visible cameras
Visible bremsstrahlung radiometer
Visible and UV survey spectrometers
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis
1-D CCD H_α cameras (divertor, midplane)
2-D divertor fast visible cameras (4)
Two-color intensified 2D cameras TWICE (2)
Edge neutral density diagnostic ENDD
IR cameras (30Hz) (3)
Dust detector
Edge Deposition Monitors
Scrape-off layer reflectometer
Edge neutral pressure gauges

Ready by mid-run

Fast lost-ion probe (energy/pitch angle resolving)
Microwave Reflectometer
MSE-CIF (18 ch)
MSE-LIF (20 ch)
Divertor VUV Spectrometer (SPRED)
Gas-puff Imaging (500kHz)
Langmuir probe array
Divertor fast eroding thermocouple

Ready by end of run

FIReTIP interferometer

Ready next run year

Laser blow-off system
Poloidal FIR high-k scattering
Midplane metal foil bolometer
Metal foil divertor bolometer

New capability,
Enhanced capability

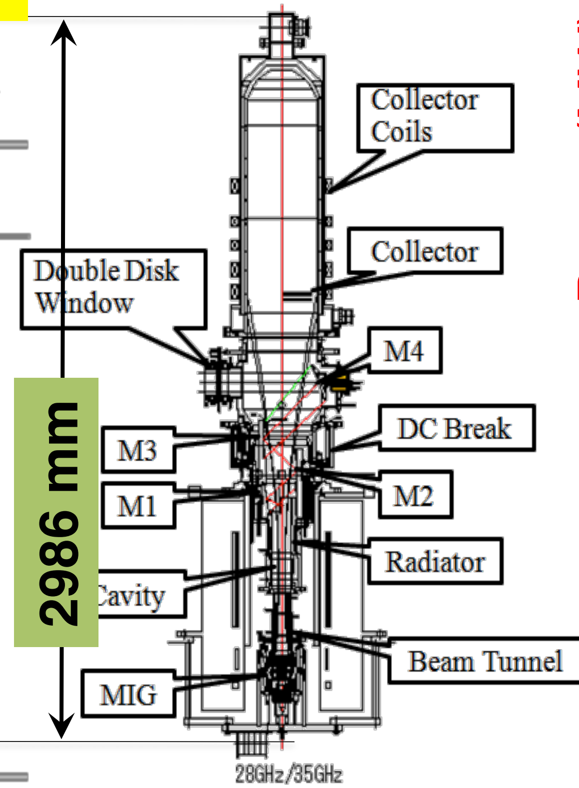
Tsukuba University is developing Prototype 28 / 35 GHz Gyrotron for NSTX-U & G-10/PDX

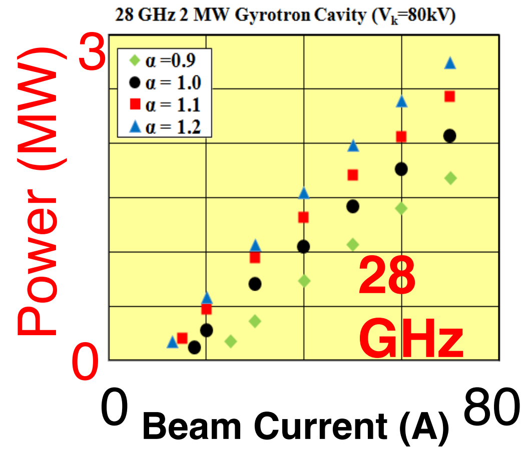
→ New design of cathode, cavity and mode converter for 1.5 – 2 MW

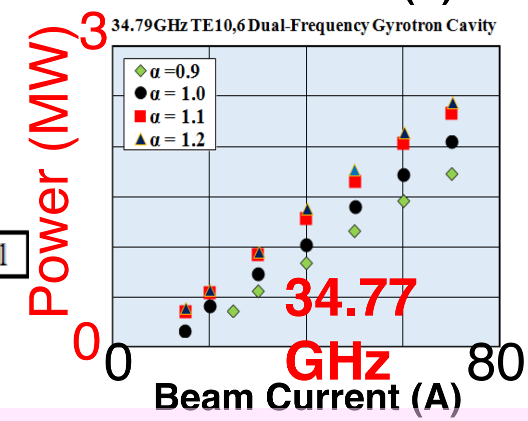
●Design Parameters of New Tube

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 this summer.