NSTX-U Facility and Diagnostics Status

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X Science LLC

Masa Ono

for the NSTX-U Team

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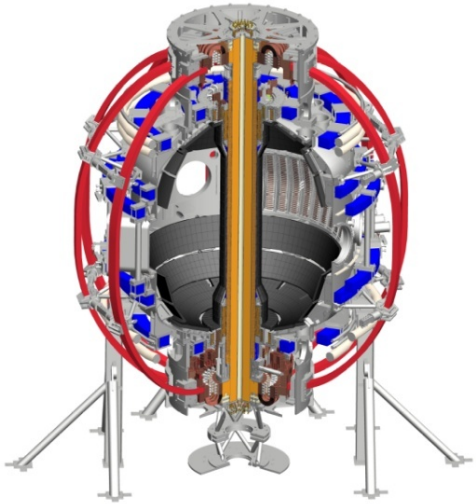
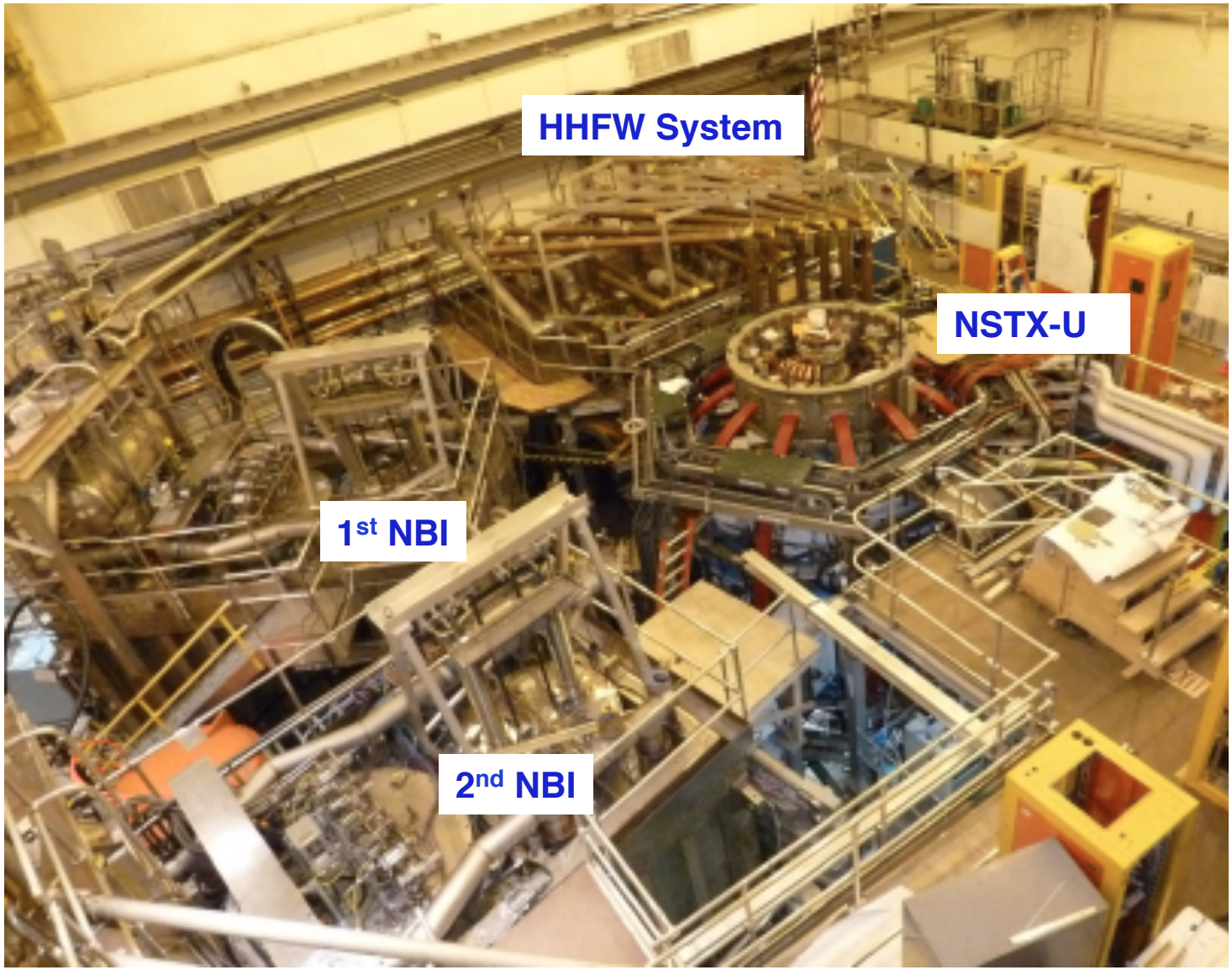
NSTX-U Research Forum
February 24 - 27, 2015



Talk Outline

- NSTX Upgrade Project Commissioning
- Preparation toward research operation
- Day 1 Facility / Diagnostic Status
- Summary

NSTX Upgrade Project Is Nearly Complete
Recent aerial view of NSTX-U Test Cell (February, 2015)



NSTX-U In-Vessel Photo Prior to Pump-down (Dec. 2014)

Remaining Construction Work in NSTX-U Test Cell CD-4 date depends on how well ISTP goes

- Pumpdown - *Started in December*
- Leak check - *On-going*
- Install bus inside umbrella and back to racks *November - January*
- Install new TF lead extensions *January-February*
- Install TF flex bus *January-February*
- Install new umbrella lids - *February*
- Install umbrella lid support rings - *February*
- Bakeout *March*
- ISTP - *March*

Status of Power & Control Systems

MG#1 has been fully restored to operation.

- Considering similar MG#2 weld crack repair.

Rectifier reactivation (open circuit testing) is complete

Rectifier Dummy Load testing is on-going.

- Will concentrate on systems needed for the CD4 plasma (TF, OH, PF3U/L, PF5)

Dummy load testing will also test many systems needed for operations.

- Clock systems, EPICS control, MDS+ databases.
- Realtime control hardware, including realtime data acquisition systems.
- "Backstop" digital coil protection system (that in the Junction Area).

We are doing the final commissioning of the "first line" digital coil protection system (DCPS).

Expect to be ready to start ISTP-001 in late March.

Both neutral beams should be available for research operations

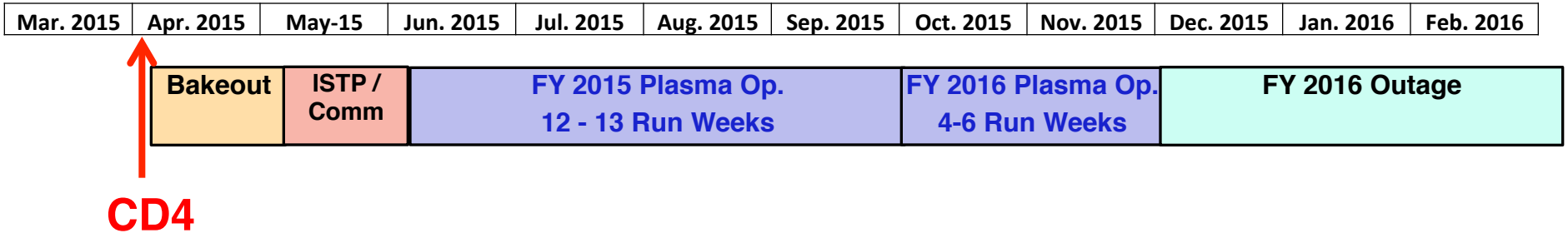
NB2 is preparing for the CD4 milestone in March, 2015.

- NB2 is under vacuum and ion sources are installed
- The He refrigerator is operating and making liquid
- Expect to be ready to cool down NB2 in late Feb.
- Low level ion source conditioning in early March, followed by beam conditioning and CD4 injection (late March as test cell access allows).

NB1 should be ready for the research operation.

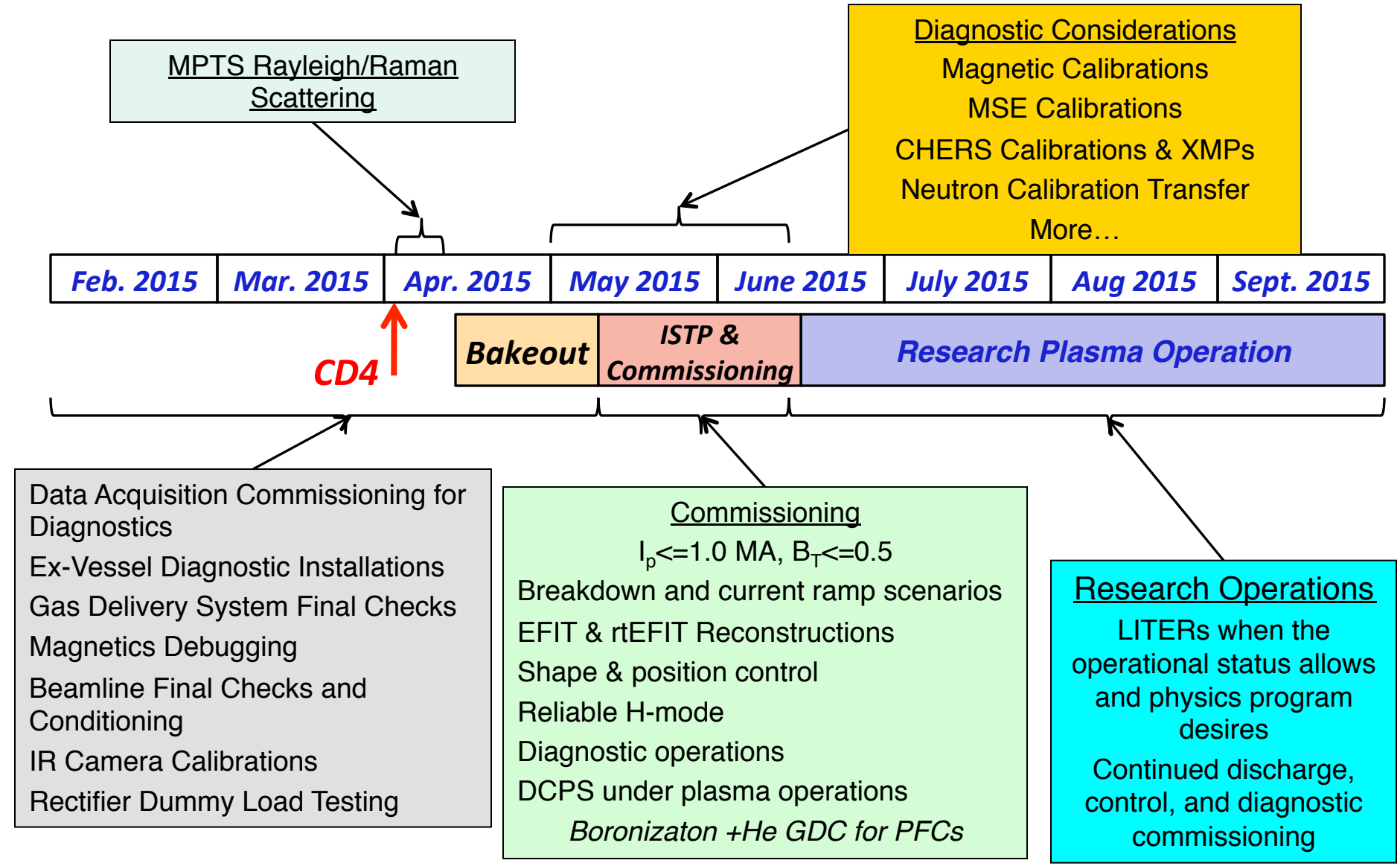
- NB1 is under vacuum and ion sources are installed
- Plan to cool down NB1 in parallel with NB2
- Expect to condition the NB1 ion sources during the vessel bake

Nominal NSTX-U run schedule for FY2015

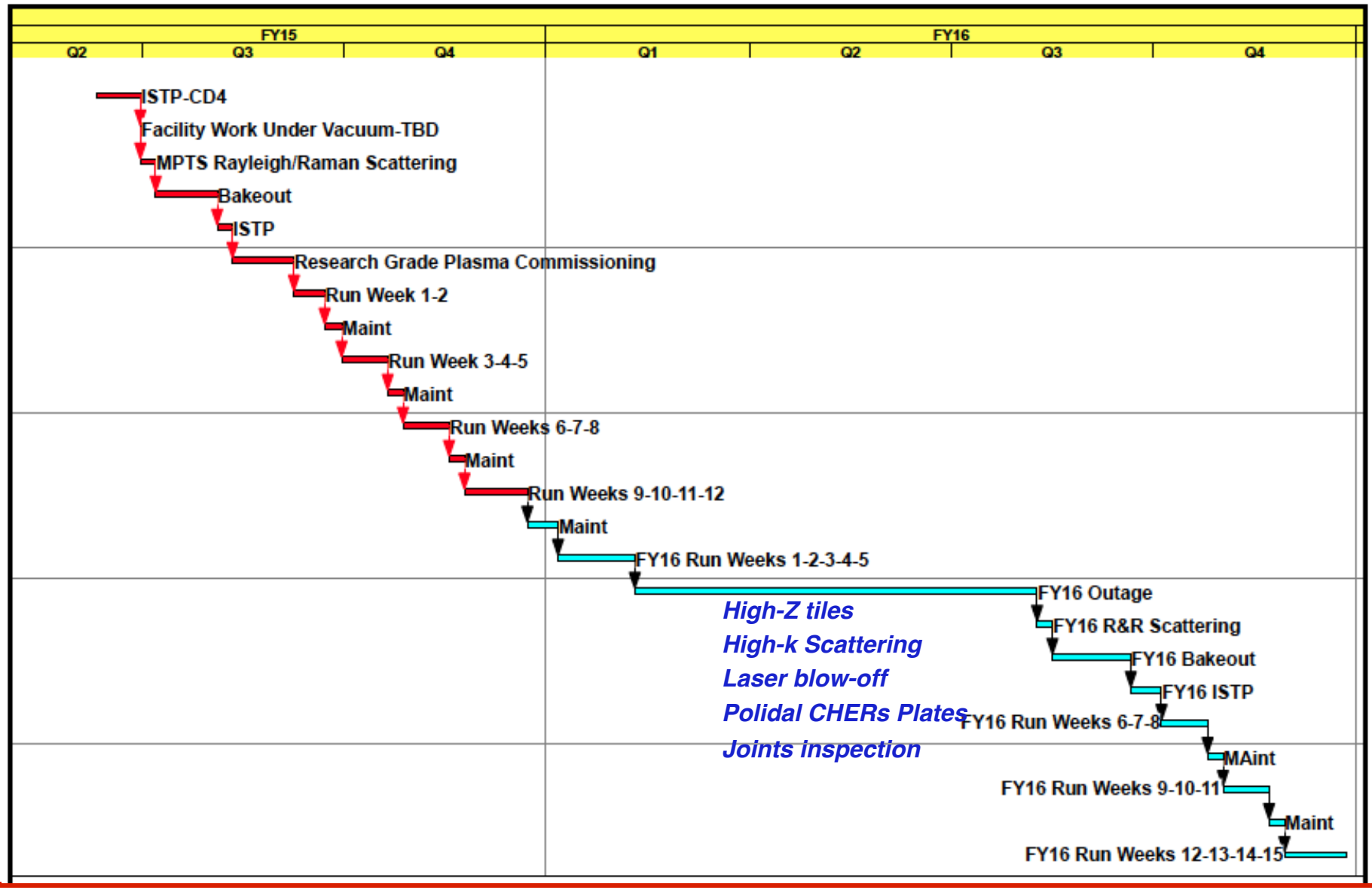


- CD-4 is now projected to be in late March, 2015.
- ~ 2 month period allocated between CD-4 and research plasma operations → Research ops begin in late-May
- Plan: ~12 - 13 run weeks (assumes 1 maintenance week / month)
- If machine is running well at end of FY15, may run into early FY16
  - Provide additional data for APS 2015 and IAEA synopses for 2016
- FY16 outage tasks include high-Z tile, high-k scattering, laser blow-off system installation and full field/current operation preparation.

Provisional Schedule for the 2015 Research Campaign More Details!



Provisional NSTX-U run schedule for FY2015 – 2016 (primavera form)



Strategy for Achieving Full NSTX-U Parameters

After CD-4, the plasma operation could quickly access new ST regimes

	NSTX (Max.)	FY 2015 NSTX-U Operations	FY 2016 NSTX-U Operations	FY 2017 NSTX-U Operations	Ultimate Goal
I_P [MA]	1.2	~1.6	2.0	2.0	2.0
B_T [T]	0.55	~0.8	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

- 1st year goal: operating points with forces up to ½ the way between NSTX and NSTX-U, ½ the design-point heating of any coil
  - Will permit up to ~5 second operation at B_T~0.65
- 2nd year goal: Full field and current, but still limiting the coil heating
  - Will revisit year 2 parameters once year 1 data has been accumulated
- 3rd year goal: Full capability

January 28 - Operations / Diagnostics / Software Support status update

The goal of Jan 28 presentations was to provide materials for team members to use in writing XMP/XPs prior to the forum - in particular estimates of which NSTX-U capabilities will be available and when.

Agenda:

- S. Gerhardt (Research Operation)
- A. von Halle (Engineering Operations)
- D. Mueller (Physics Operations)
- R. Kaita (Boundary Physics Operations)
- B. Stratton (Diagnostic Operations)
- J. Hosea (RF Operations)
- W. Davis (Software and Analysis Tools Overview)

- http://nstx-u.pppl.gov/research-forum/nstx-u-research-forum-2015/pre-forum-meetings

NSTX-U diagnostics to be installed during first two years

All except high-k should be operational during the first year

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

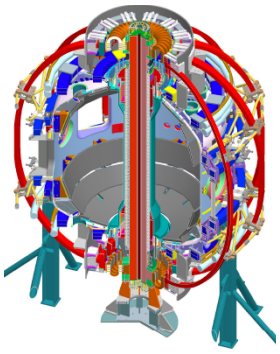
- FIReTIP interferometer
- Fast visible cameras
- Visible bremsstrahlung radiometer
- *Visible and UV survey spectrometers*
- *VUV transmission grating spectrometer*
- *Visible filterscopes (hydrogen & impurity lines)*
- Wall coupon analysis

Five Year Facility Enhancement Plan (green – ongoing)

Engineering design for ECH, Cryo-Pump and NCC performed in 2015 (red)

2014	2015	2016	2017	2018
Upgrade Outage	1.5 → 2 MA, 1s → 5s			
Run Weeks:	12	4	10	12	12

New center-stack



2nd NBI

Boundary Science + Particle Control

- Pulse-burst MPTS
- Boronization
- Downward LITER
- Li granule injector
- MAPP
- Upward LiTER
- High-Z tile row on lower OBD
- 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
- 48 ch BES
- High k_θ
- MSE/LIF
- Charged fusion product
- FIDAs
- 4 coil AE antenna
- Partial (maybe full) NCC
- Enhanced MHD sensors
- DBS, PCI, or other intermediate-k
- Neutron collimator

Integrated Scenarios

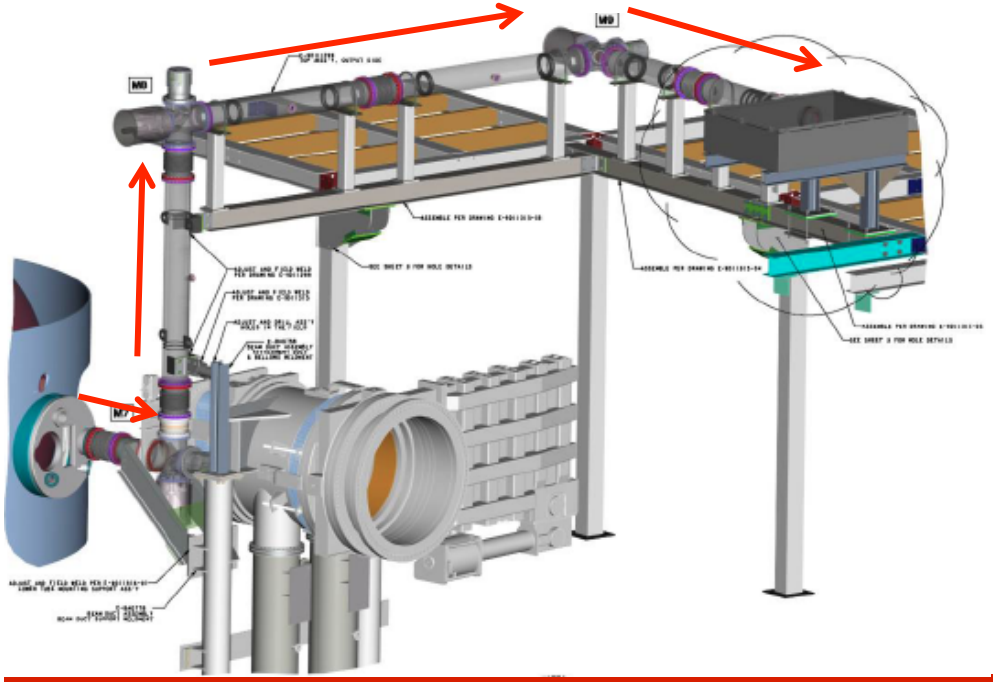
Establish control of:

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

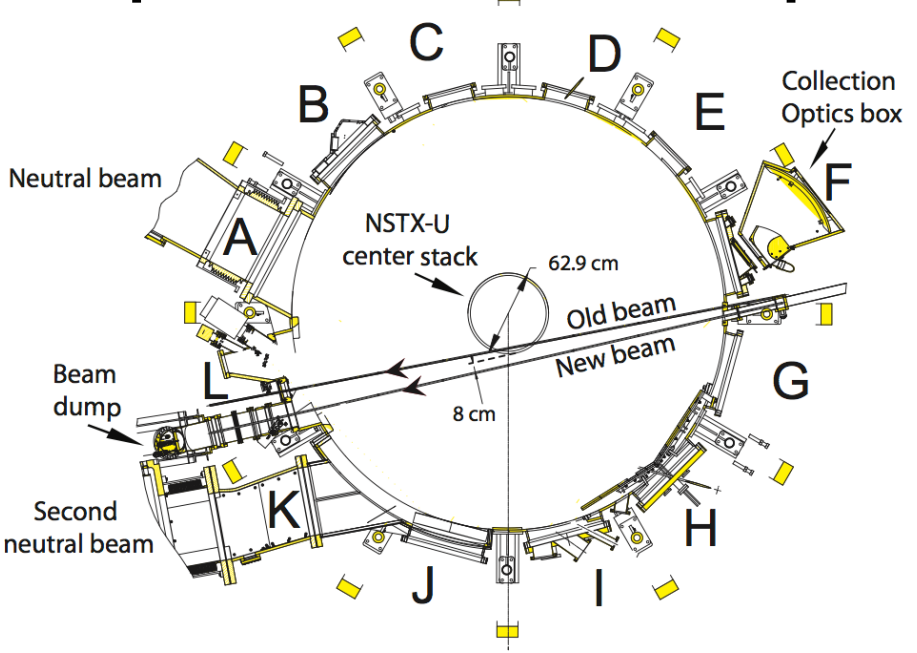
Multi-Pulse Thomson Scattering System
Laser exit flight tube being installed

- Installation of remainder of exit flight tube will start soon
- 42 spatial channels – improved spatial resolution in pedestal
- Plan to have system ready for calibration in April
- M. Coury will join MPTS group hired under A. Diallo's Early Career Award of pulse burst MPTS

MPTS laser exit flight tube



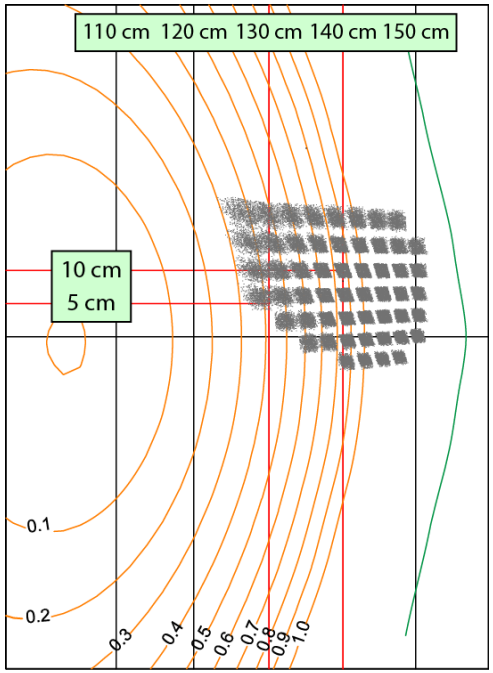
Top view of MPTS laser path



Other diagnostic highlights

Motional Stark Effect Diagnostics (Nova Photonics)

- MSE/CIF: B-field pitch, q(R) with reconstruction, 18 spatial channels
- MSE/LIF: B-field pitch, |**B**|, q(R) with reconstruction, pressure profile, 10 spatial channels to be expanded to 32 over time
- MSE/CIF & MSE/LIF: $E_r(R)$
- Both systems re-installed and spatial calibrations performed
- Y. Sechrest will join Nova Photonics MSE group



Beam Emission Spectroscopy (U. Wisconsin)

- New 2-D fiber holder will provide better radial and poloidal coverage of r/a~0.4-SOL region
  - Fibers will be installed in April
- 48 detector channels

Operations Team Continuing to Make Progress in Boundary Physics Operations to Prepare the Facility for Research

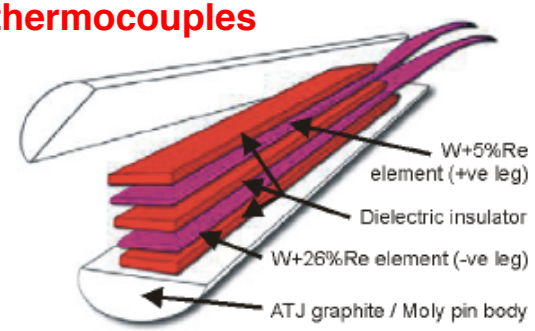
Massive Gas Injection	• Installation procedures for MGI valves have been released. • Critical valve components delivered to PPPL (from U. Washington), and support brackets fabricated. • Being installed in parallel with the inner-PF bus work.

Fuelling and Density Control	• All gas valves will be under PCS control
	  • Allowing SGI to be used for density feedback
	  • Divertor injectors for radiation control

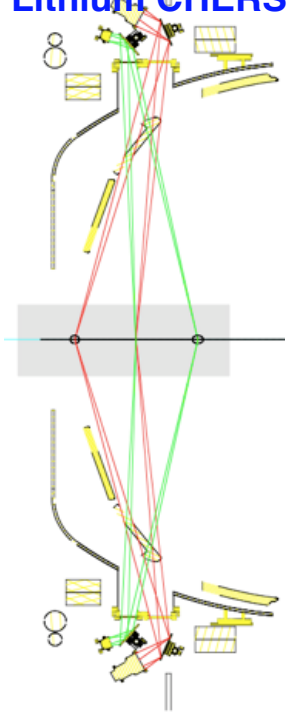
Boronization	• New engineer with extensive experience in hazardous gas handling completed design for trimethyl borane system • Components have been ordered with goal of availability of system for start of research operations
Lithium Evaporators (LITERs)	• Fume hood installation and other upgrades complete for laboratory for LITER filling and maintenance • Lithium handling procedures being updated – engineer responsible for boronization system involved
Granule Injectors for NSTX	• New injector expected to be available for plasma operations – new postdoc responsible for system • Lithium granules to be manufactured by UIUC

Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples

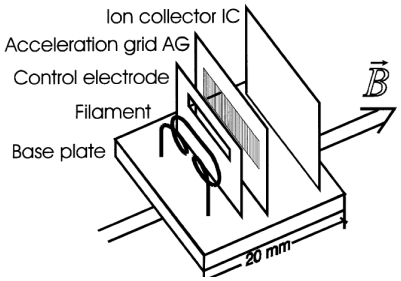


Lithium CHERS

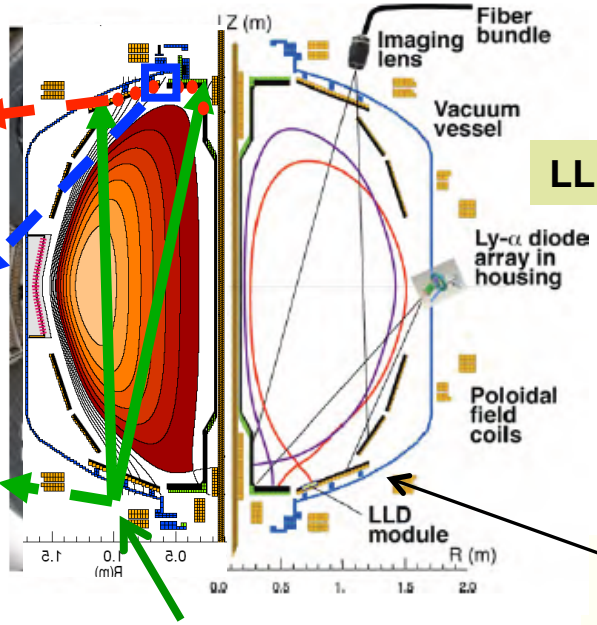


ORNL

Divertor fast pressure gauges

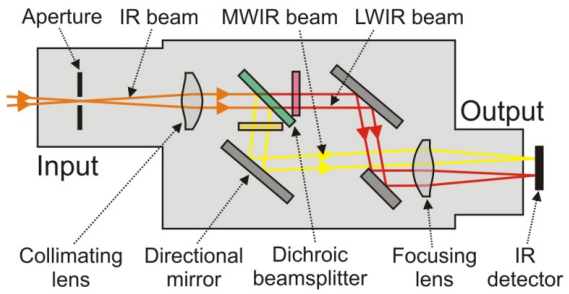


Divertor Imaging Spectrometer



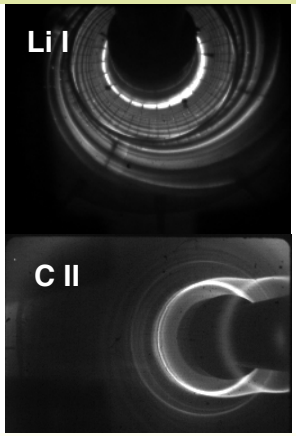
LLNL

Dual-band fast IR Camera

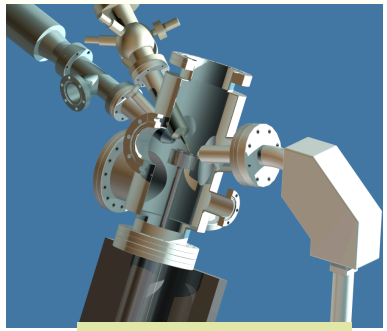


Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K



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



U. of Illinois

HHFW system commissioning schedule for Research Operations

Complete transmission and matching hookups:

- **Feb** Finish loops
- **Feb - Mar** Hookup to loops, set decouplers,
- **Mar** Match vacuum from RFE

Complete source assembly and testing

- **Feb - Mar** Complete source assembly and test into dummy load
- **March** Labview updates for power/phase, EPICs system control

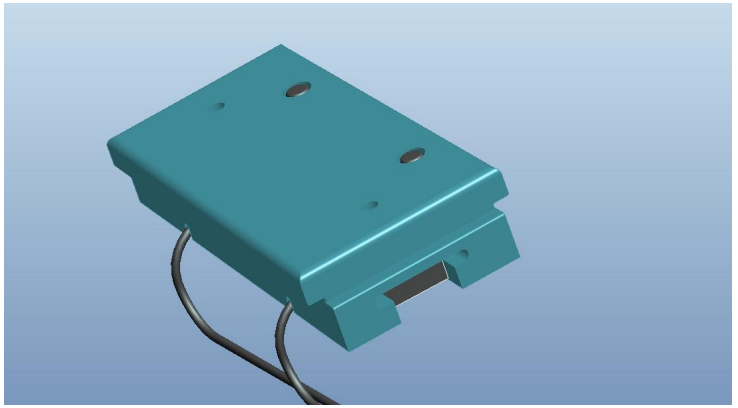
NSTX-U TC & RFE diagnostics re-commissioning

- **Feb - March** Into MDSplus

Prepare diagnostics for supporting HHFW studies

- **May** Complete coaxial Langmuir probe electronic hookups and connections to central computer (MDS plus)
- **May** IR camera commissioning
- **May** ORNL Reflectometer, probe, etc. reactivation
- **May** RF probes at Bay J installation, hookup, commissioning

Resonant loop connections to top/bottom antenna element feeds



Coax connected Langmuir probes at Bay J top and bottom, Two probes per tile in rows 2, 3, and 4

NSTX-U Plasma Operation Preparation Going Well
Many activities are on the critical paths!

- With NSTX upgrade schedule to complete CD-4 in April 2015, and the research operation in being prepared to start in June 2015.
- Many activities are going on in parallel! Aiming to minimize the period for research prep and maximize research operations.
- Last vacuum diagnostic interfaces are being installed this week. This may be the last chance for vacuum opening until FY 2016.
- Dummy load testing of rectifiers are on-going along with many PTPs.
- Both NBIs should be available from Day 1.
- MPTS and TMBs (boronization) should be available for Day 1 but schedule is tight.
- Plan to run 12 – 13 weeks in FY 2015. Continue running for 4-5 weeks in FY 2016, then ~ 6 months outage before restart in May, 2016. Plan to complete 14 run weeks in FY 2016.

Let us work together to make the 2015 NSTX-U Run the best it can be!

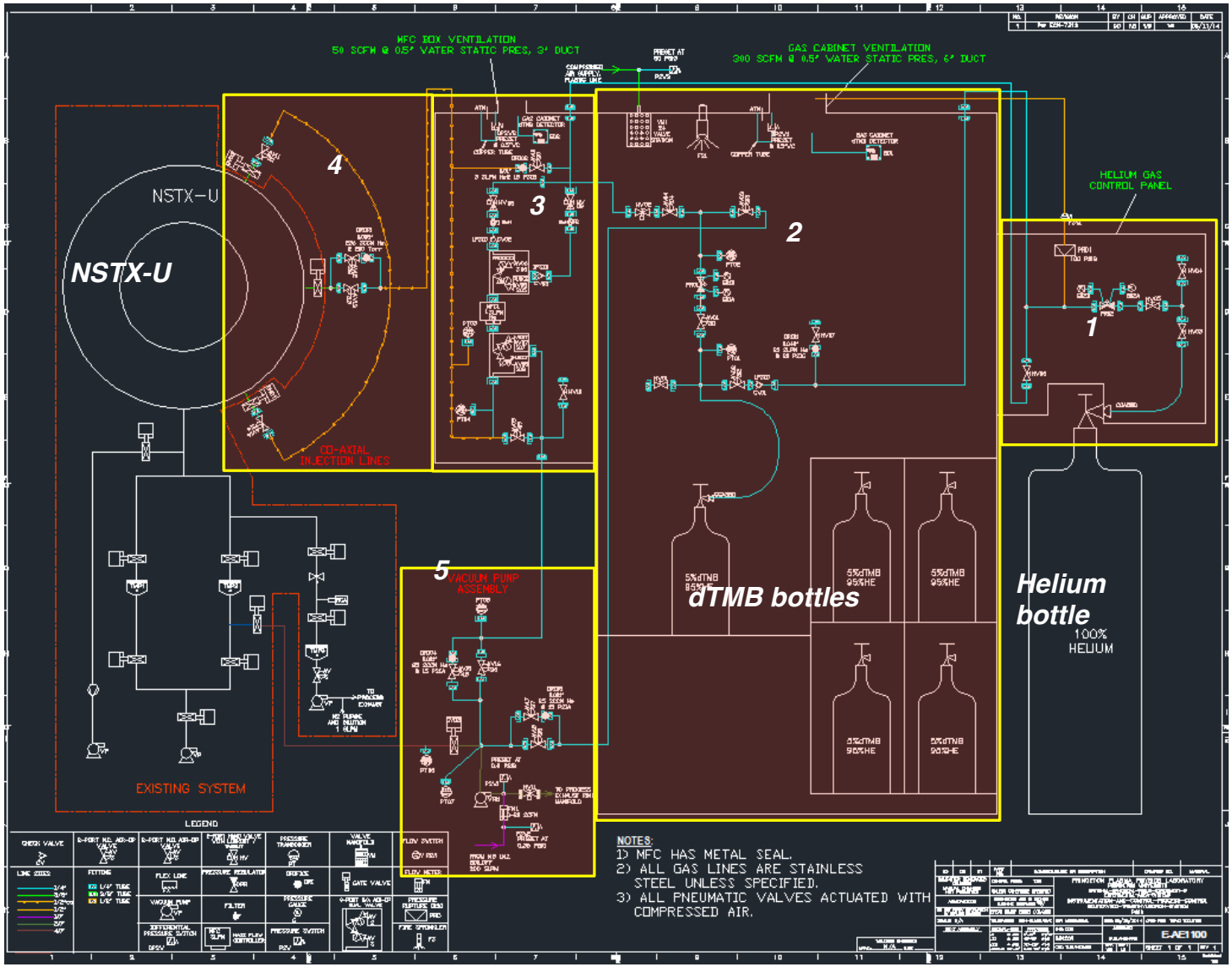
Backup Slides

New boronization system being implemented
(Significantly enhanced due to industrial safety requirements)

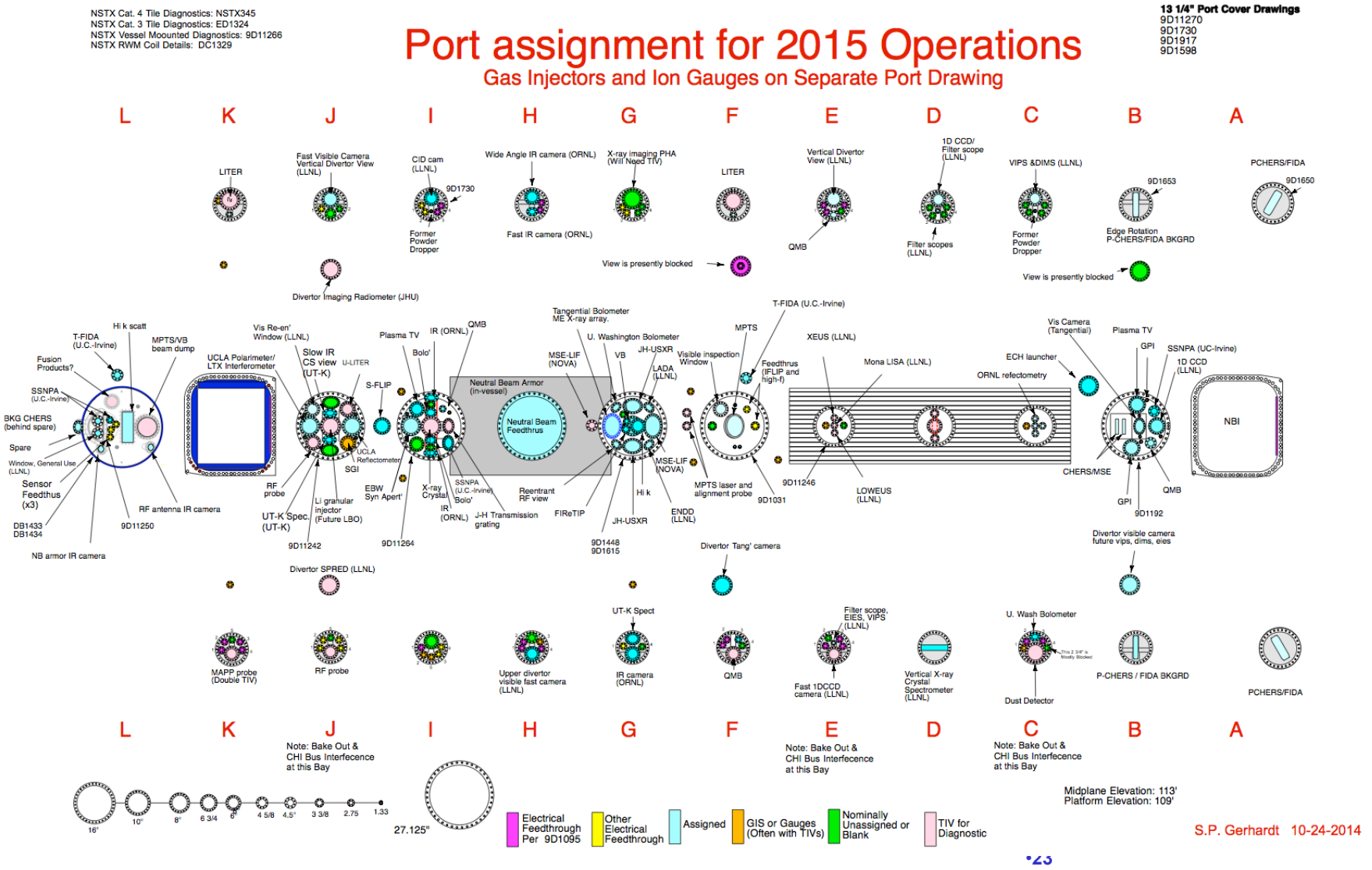
Five major sub-assemblies:

1. Helium control panel
2. dTMB gas cabinet
3. Master *Flow Control* (MFC) box
4. Coaxial injection lines
5. Vacuum pumping assemblies

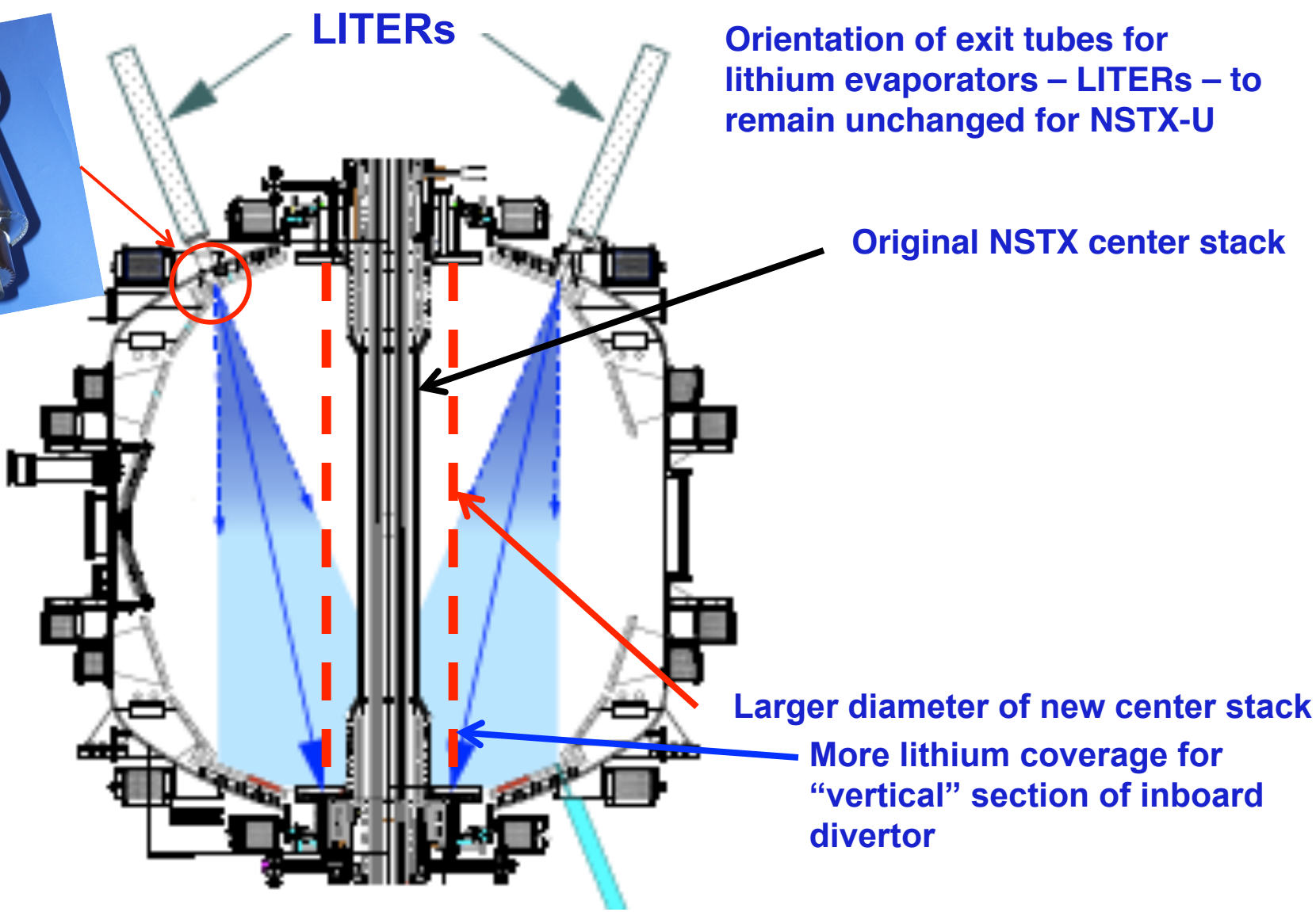
To be available for research operation



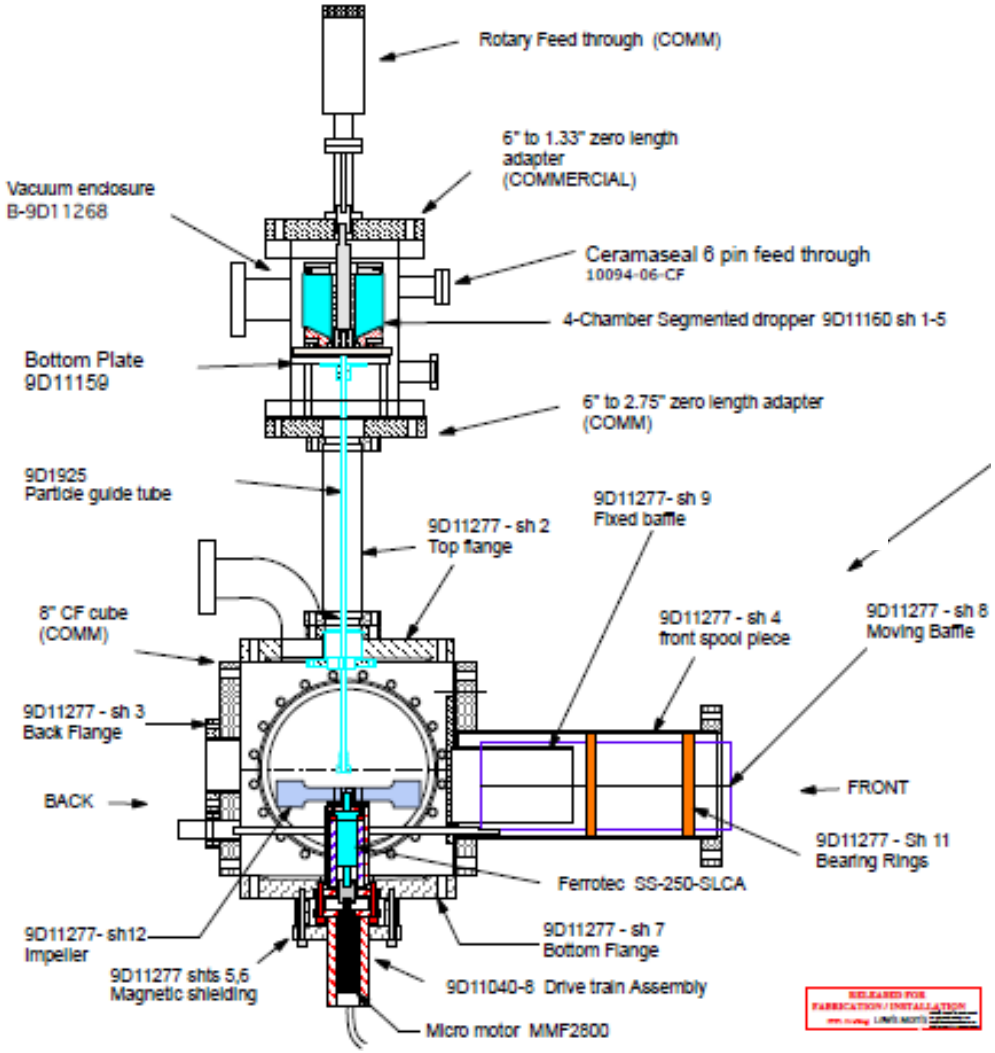
Diagnostic Port Map (Ports Fully Allocated)



LIThium EvaporatoRs – LITERs
Using same exit ducts as used on NSTX



Lithium Granule Injector – LGI – identical to system presently in use for inducing ELMs in EAST and DIII-D plasmas



Available pellet sizes (approximate)
900μm, 700μm

Proposed Pellet Composition
Lithium, Boron Carbide*, Graphite*

Pellet Injection Velocity
50 – 150 m/sec

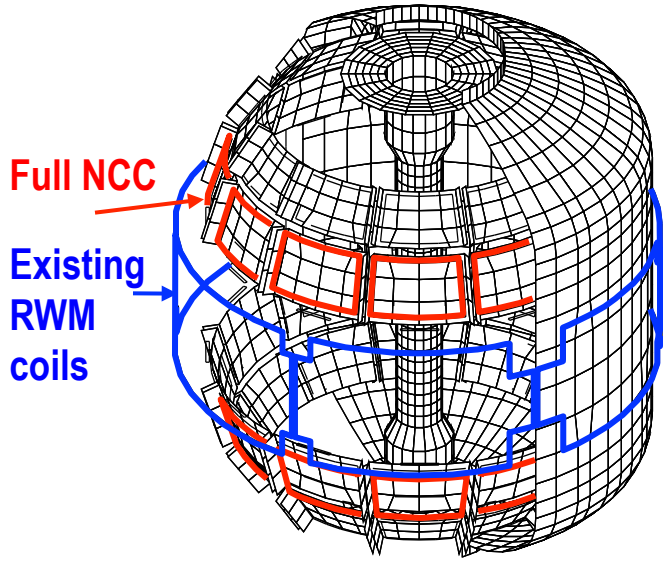
Pellet to Pellet Injection Frequency
100 – 500 Hz

Granule supply arrangements being negotiated for fabrication at the University of Illinois

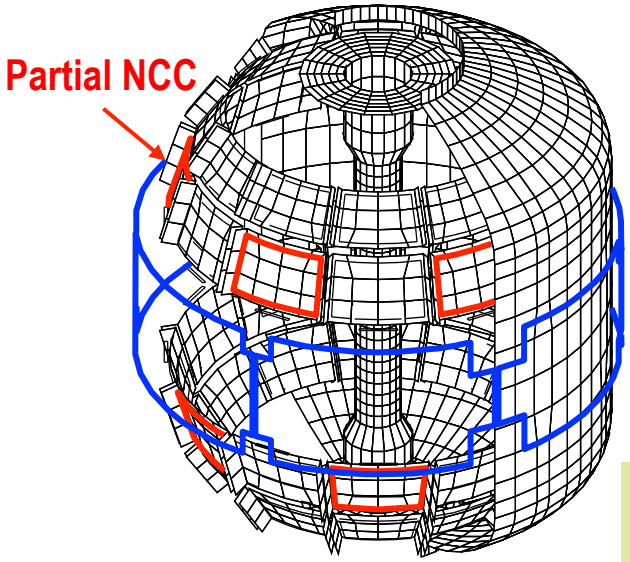
NCC will greatly enhance MHD physics studies and control

Range of off-midplane NCC coil configurations is assessed

Full toroidal NCC array (2 x 12)



Partial toroidal NCC array (2 x 6)



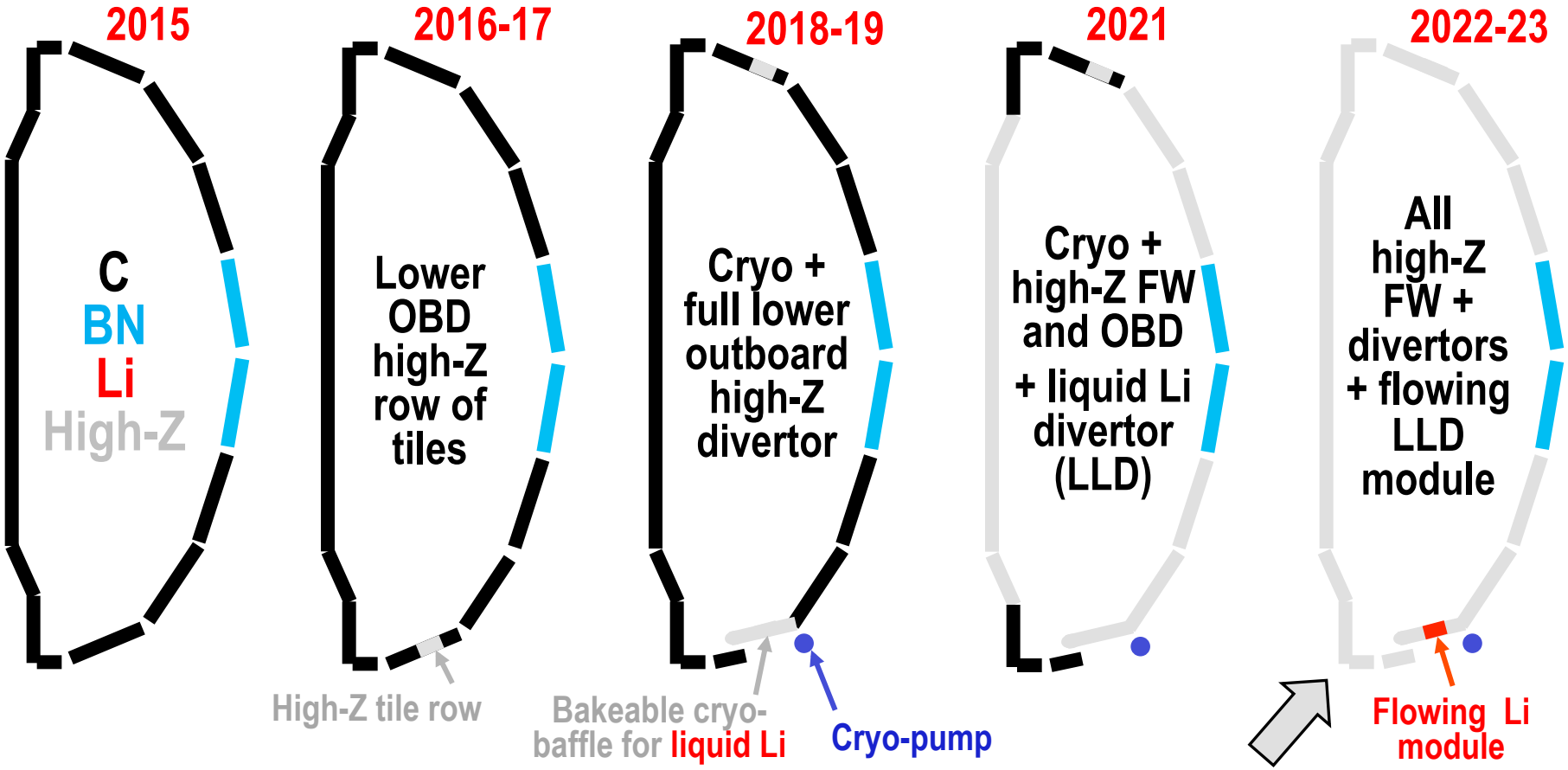
Columbia U
General Atomics

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

Base – Engineering design work on NCC to be performed in 2015. Incremental funding will enable start of procurement in FY 2016 and installation in FY 2017 to be available in FY 2018.

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

Nominal 2014-18 5 year plan steps for implementation of cryo-pump + high-Z PFCs + LLD



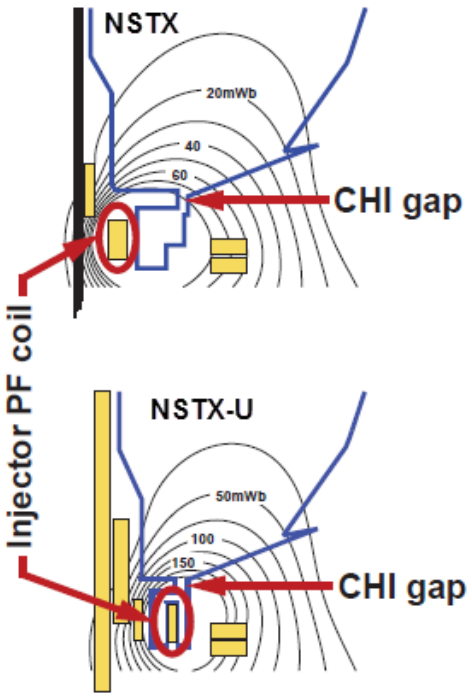
Increased funding / priority could accelerate full high-Z by ~2 years

Solenoid-free Start-up
High priority goal for NSTX-U in support of FNSF

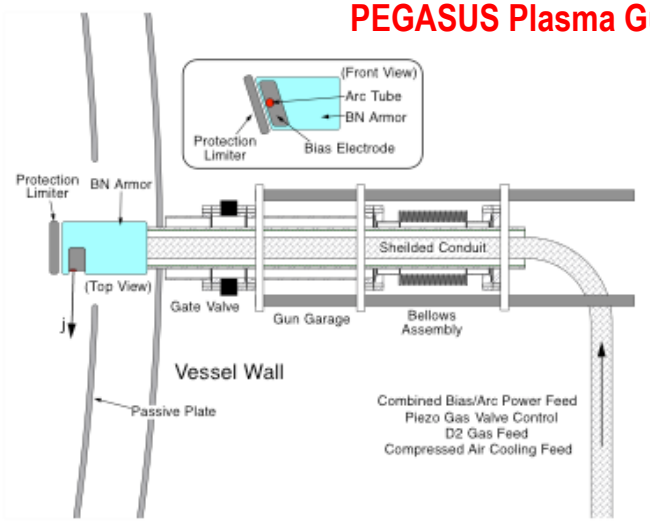
CHI Start-Up

- 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

U. Washington



Point Source Being Developed



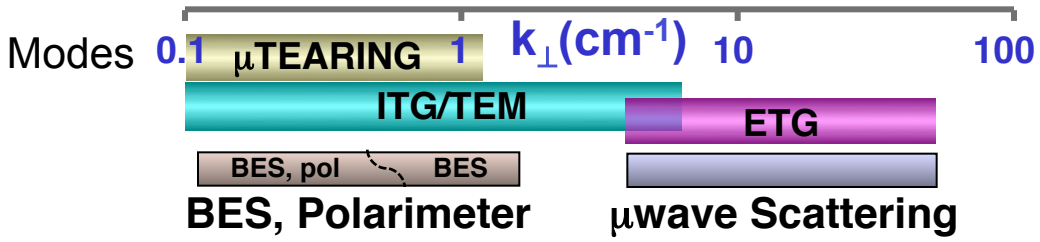
U. Wisconsin

FY 2015-16 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

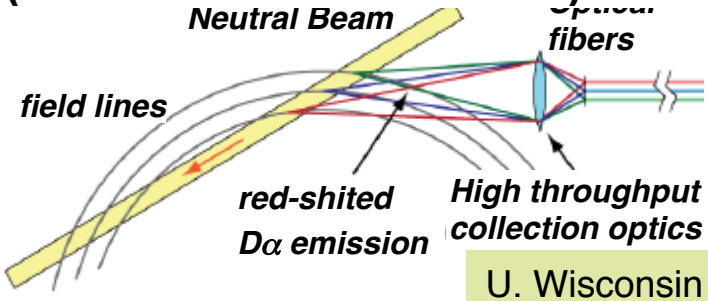
- CHI will start with the present 2 kV capability then enhanced to ~ 3 kV higher voltage as needed.
- PEGASUS gun start-up producing exciting results Ip ~ 160 kA. The PEGASUS gun concept is technically flexible to implement on NSTX once fully developed. High voltage gun for the NSTX-U will be developed utilizing the PEGASUS facility in collaboration with University of Wisconsin.

Transport and Turbulence

BES together with high-k to provide comprehensive turbulence diagnostic



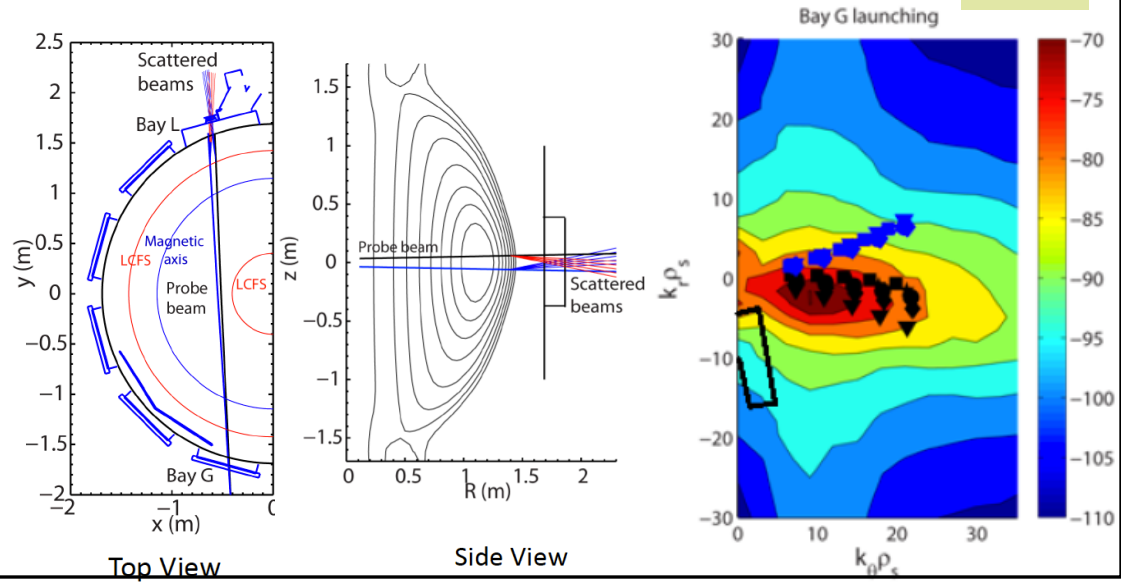
48 ch BES available for NSTX-U (24 ch BES available in 2011)



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

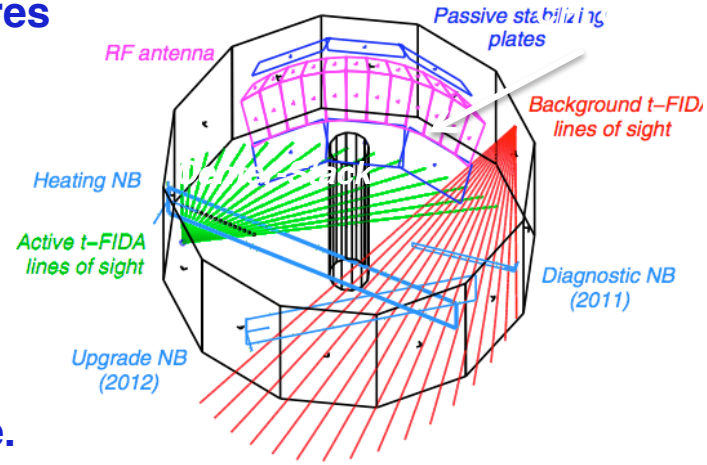
Energetic Particle Research Capabilities
For NBI fast ion transport and current drive physics

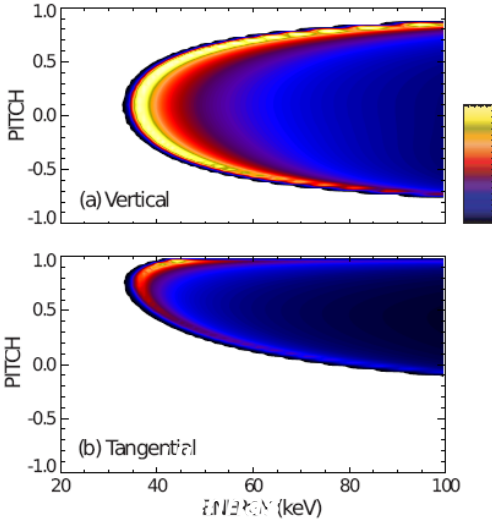
Fast Ion D-Alpha Diagnostics

UCI

- A vertical FIDA system measures fast ions with small pitch, corresponding to trapped or barely passing (co-going) particles.
- A new tangential FIDA system measures co-passing fast ions with pitch ~0.4 at the magnetic axis up to 1 at the plasma edge.
- Both FIDA systems have time resolution of 10 ms, spatial resolution ≈5 cm and energy resolution ≈10 keV.

FIDA Views



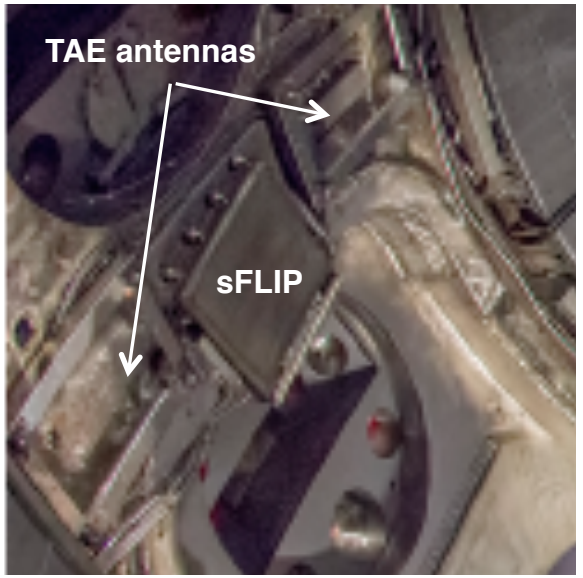


FY 2014 - 15 Energetic Particle Conceptual Design and Diagnostic Upgrade

- SS-NPA enhancement due to removal of scanning NPA

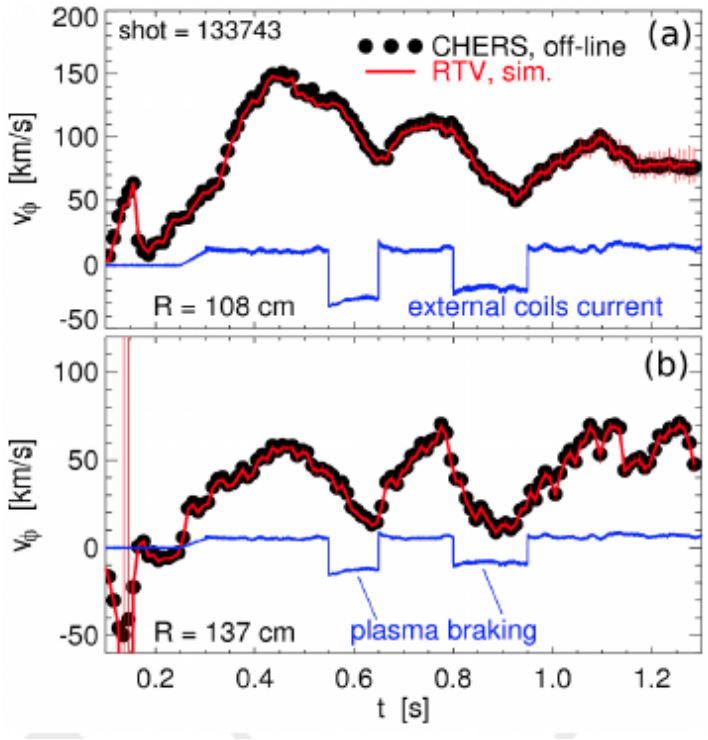
UCI

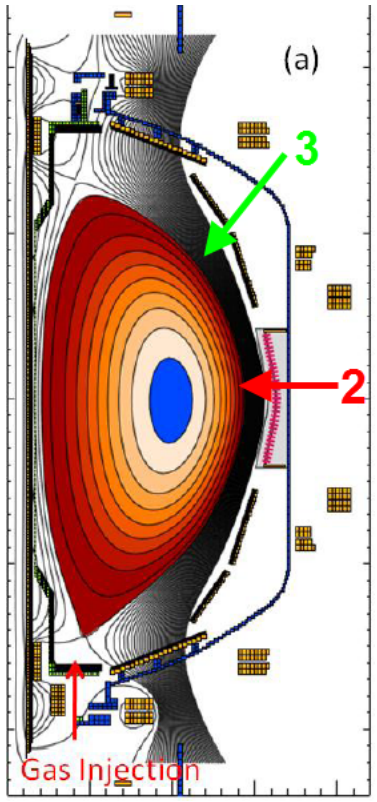
- Active 2 X 2 TAE antennas and sFLIP



Advanced Scenario and Plasma Control Tools for NSTX-U
Real time rotation control and disruption mitigation

RTV fitting vs off-line CHERS data





Massive gas injector system at multi-poloidal location

U. Washington

FY 2015-16:

- **A Real-Time Velocity (RTV) diagnostic will be incorporated into the plasma control system for feedback control of the plasma rotation profile.**
- **Multi-poloidal location massive gas injector system for disruption mitigation will be implemented to test the efficiency vs location.**