NSTX-U

Supported by

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National Spherical Torus Experiment Upgrade – Status and Plans*

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For the NSTX-U Team

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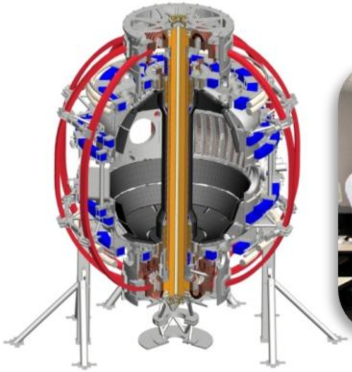


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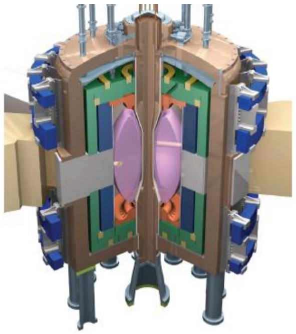
Outline

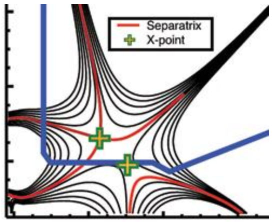
- NSTX-U Mission
- Planned NSTX Upgrade Capabilities
- Progress of Upgrade Project
- Summary

NSTX Upgrade Mission Elements

- **Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)**
- **Develop solutions for plasma-material interface**
- **Advance toroidal confinement physics predictive capability for ITER and beyond**
- **Develop ST as fusion energy system**

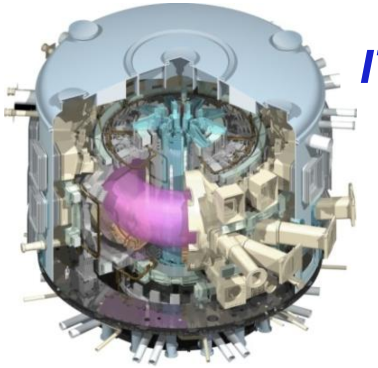


ST-FNSF



"Snowflake"

Lithium



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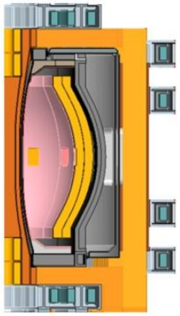
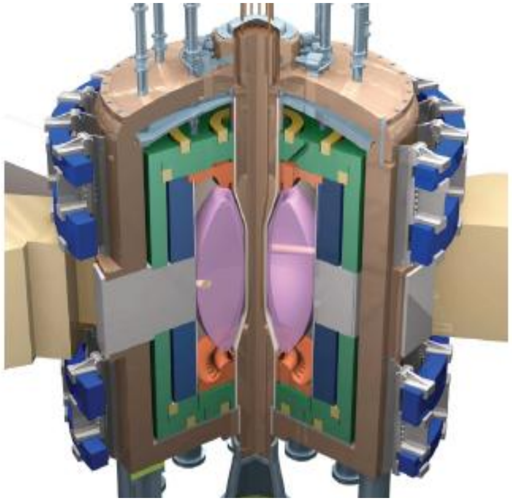


ST Pilot Plant

Mission of ST-FNSF

From M. Peng, ORNL

- **Provide a continuous fusion nuclear environment of copious neutrons to develop an experimental database on:**
  - Nuclear-nonnuclear coupling phenomena in materials in components for plasma-material interactions
  - Tritium fuel cycle
  - Power extraction



ST-FNSF

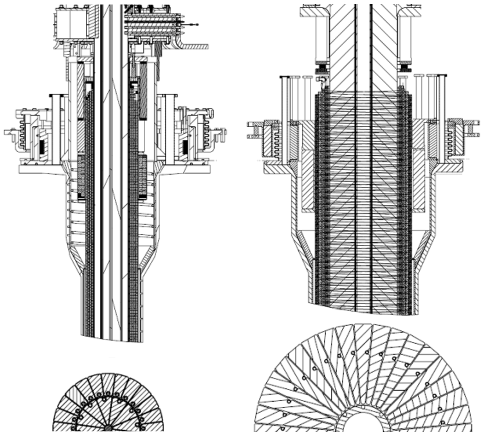
- **Complement ITER, prepare for component test facility (CTF):**

– Low Q (≤ 3):	0.3 x ITER
– Neutron flux ≤ 2 MW/m^2:	3 x
– Fluence = 1 MW-yr/m^2:	5 x
– t_{pulse} ≤ 2 wks:	1000 x
– Duty factor = 10%:	3 x

Low-aspect-ratio "spherical" tokamak (ST) is most compact embodiment of FNSF

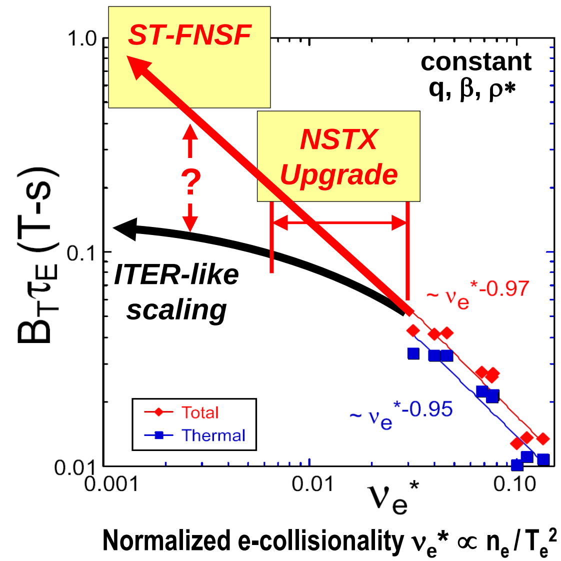
NSTX Upgrade will address critical plasma confinement and sustainment questions by exploiting 2 new capabilities

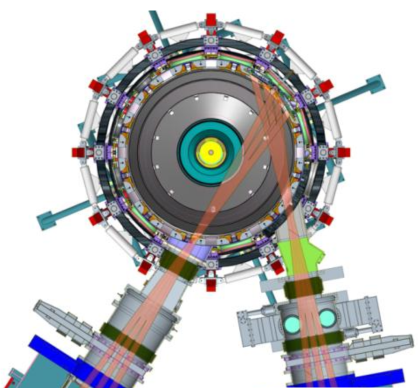
Previous center-stack | New center-stack



TF OD = 20cm | TF OD = 40cm

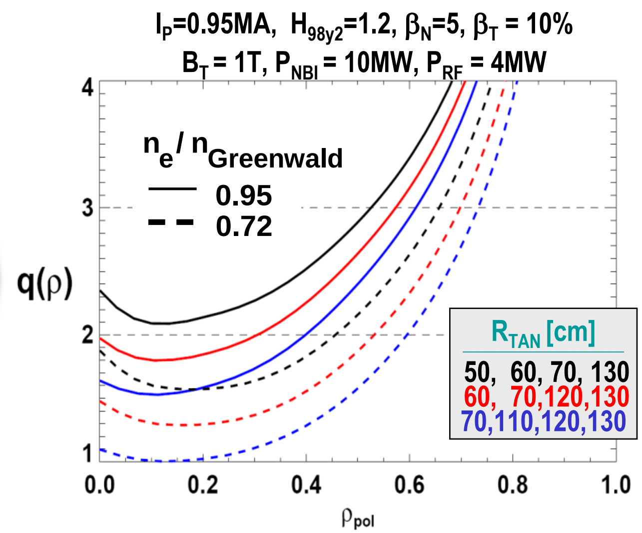
- Higher B_T and I_P increases T, reduces ν^* toward ST-FNSF to better understand confinement
- Provides 5x longer pulses for profile equilibration, NBI ramp-up





Present NBI | New 2nd NBI

- 2x higher CD efficiency from larger tangency radius R_{TAN}
- 100% non-inductive CD with q(r) profile controllable by: tangency radius, density, position

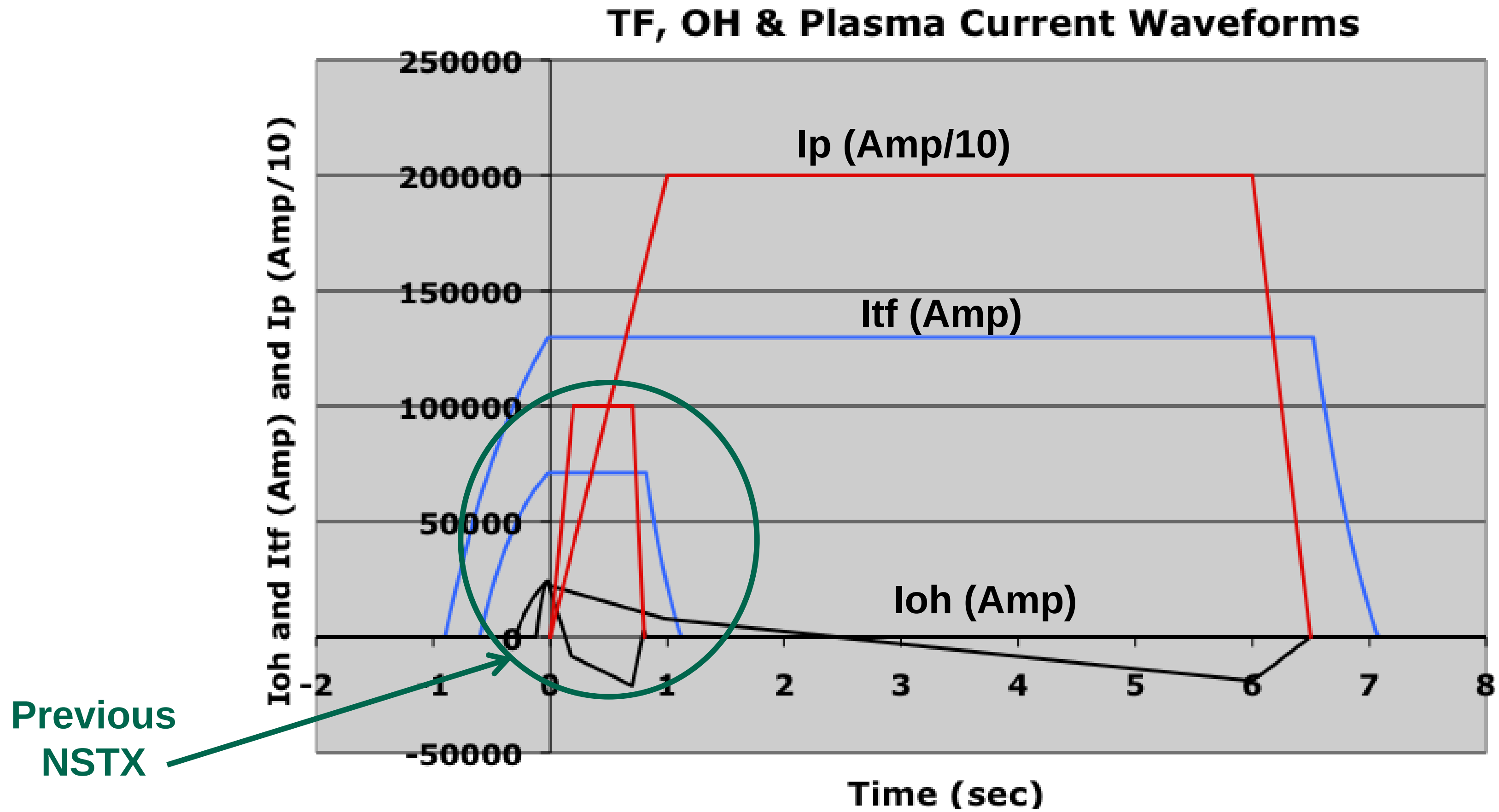


Upgrade substantially increases B_T, I_p, P_{NBI}, τ_{pulse}

Field and current will be within factor of 2 of initial operation of ST-FNSF

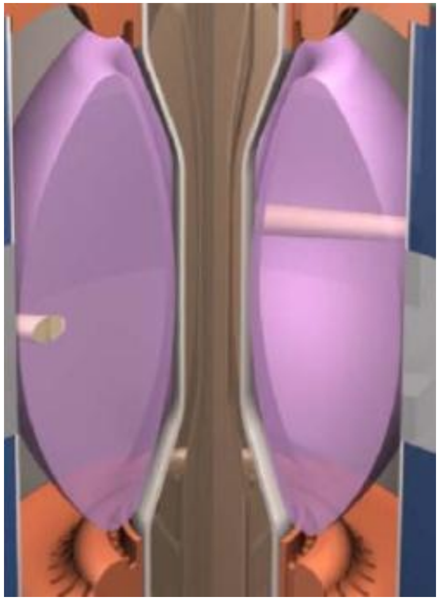
Relative performance of Upgraded NSTX vs. Base:

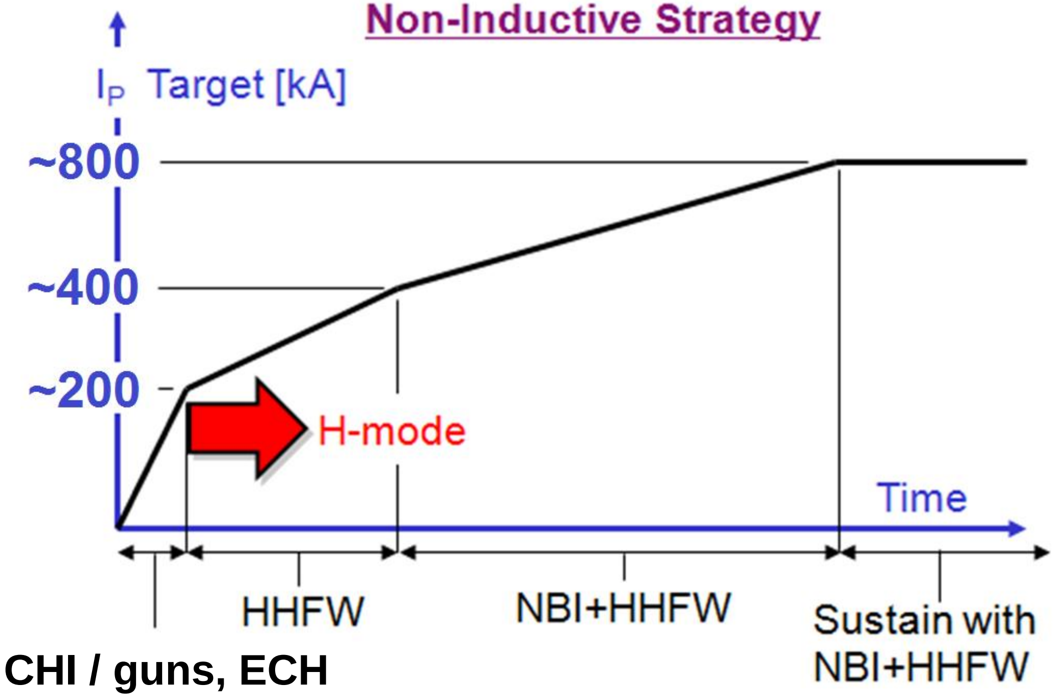
- I_P = 1 → 2MA, B_T = 0.5 → 1T (at same major radius)
- Available OH flux increased 3x, 3-5x longer flat-top
- NBI power increased 2x (5→10MW for 5s, 15MW 1.5s)
- Plasma stored energy increased up to 4x (0.25→ 1MJ)



Plasma initiation with small or no transformer is unique challenge for ST-based Fusion Nuclear Science Facility

ST-FNSF has no/small central solenoid

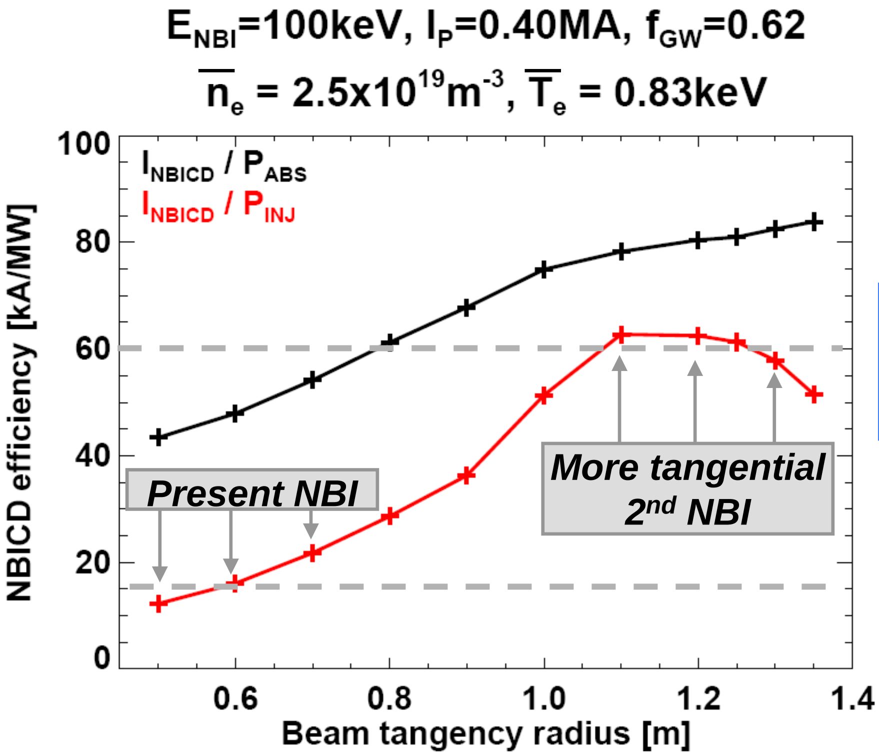


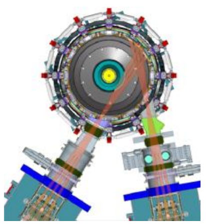


- **NSTX-U goals:**
  - Generate ~0.3-0.4MA full non-inductive start-up with helicity injection + ECH and/or fast wave heating, then ramp to ~0.8-1MA with NBI
  - Develop predictive capability for non-inductive ramp-up to high performance 100% non-inductive ST plasma → prototype FNSF

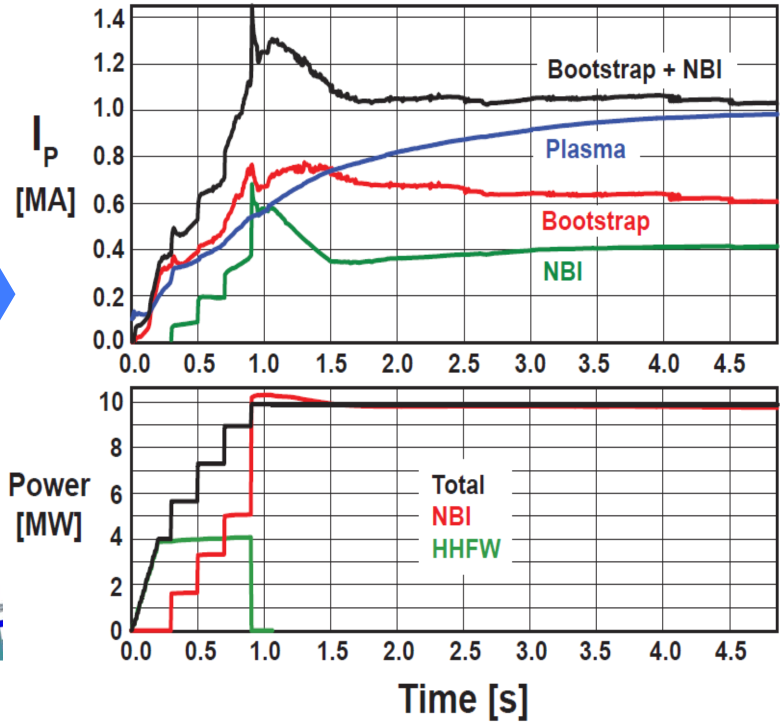
Non-inductive ramp-up from ~0.4MA to ~1MA projected to be possible with new centerstack (CS) + more tangential 2nd NBI

- New CS provides higher TF (improves stability), 3-5s needed for J(r) equilibration
- More tangential injection provides 3-4x higher CD at low I_P:
  - 2x higher absorption (40→80%) at low I_P = 0.4MA
  - 1.5-2x higher current drive efficiency

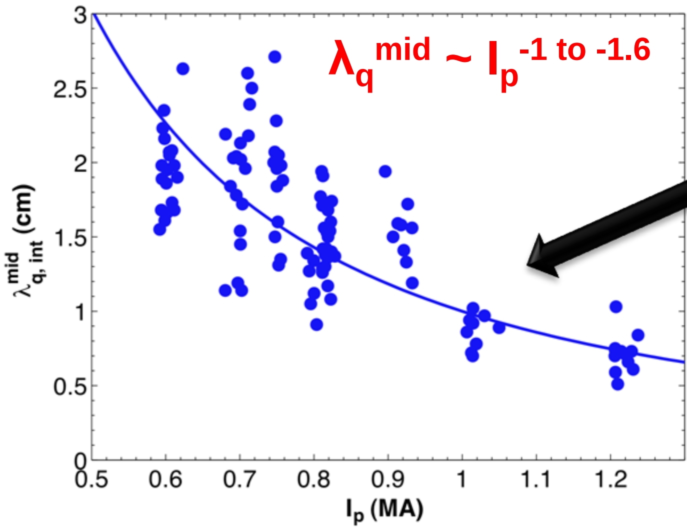




TSC simulation of non-inductive ramp-up from I_P = 0.1MA, T_e=0.5keV target at B_T=1T

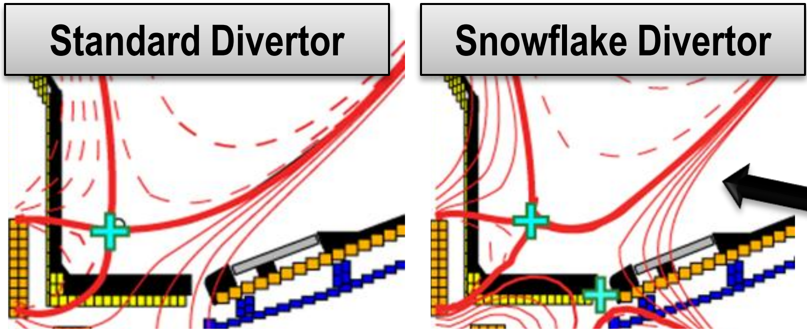


NSTX-U will investigate high flux expansion snowflake divertor + detachment for large heat-flux reduction



- Divertor heat flux width decreases with increased plasma current I_P
  - Major implications for ITER, FNSF

→ NSTX Upgrade with conventional divertor projects to very high peak heat flux up to 30-45MW/m²



- Divertor heat flux inversely proportional to flux expansion over a factor of five

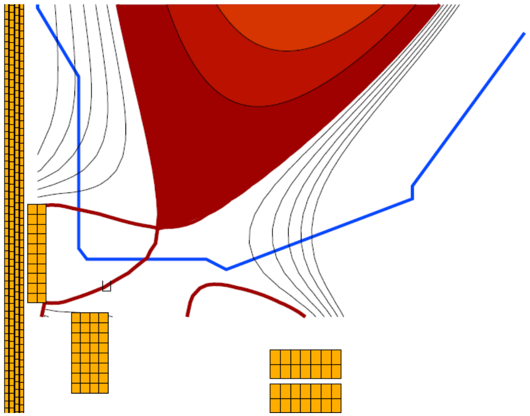
Snowflake→ high flux expansion 40-60, larger divertor volume and radiation

→U/D balanced snowflake divertor projects to acceptable heat flux < 10MW/m² in Upgrade at highest expected I_P = 2MA, P_{AUX}=10-15MW

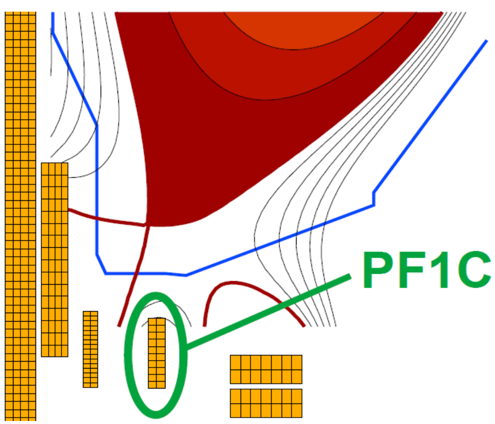
→Partial detachment → Additional ~2x reduction in NSTX

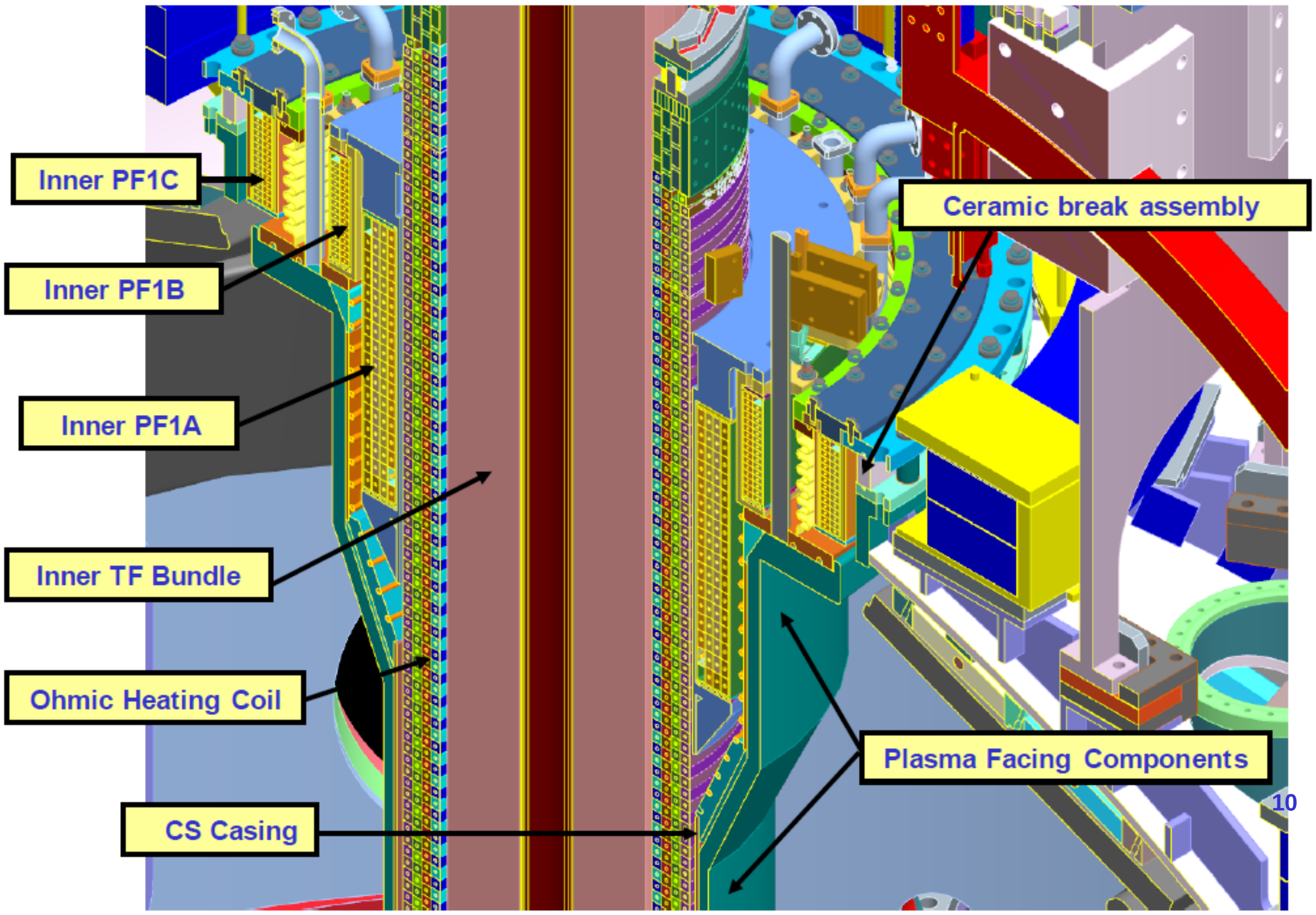
Upgrade CS design provides additional coils for flexible and controllable divertor including snowflake, and supports CHI

NSTX Snowflake



NSTX-U Snowflake





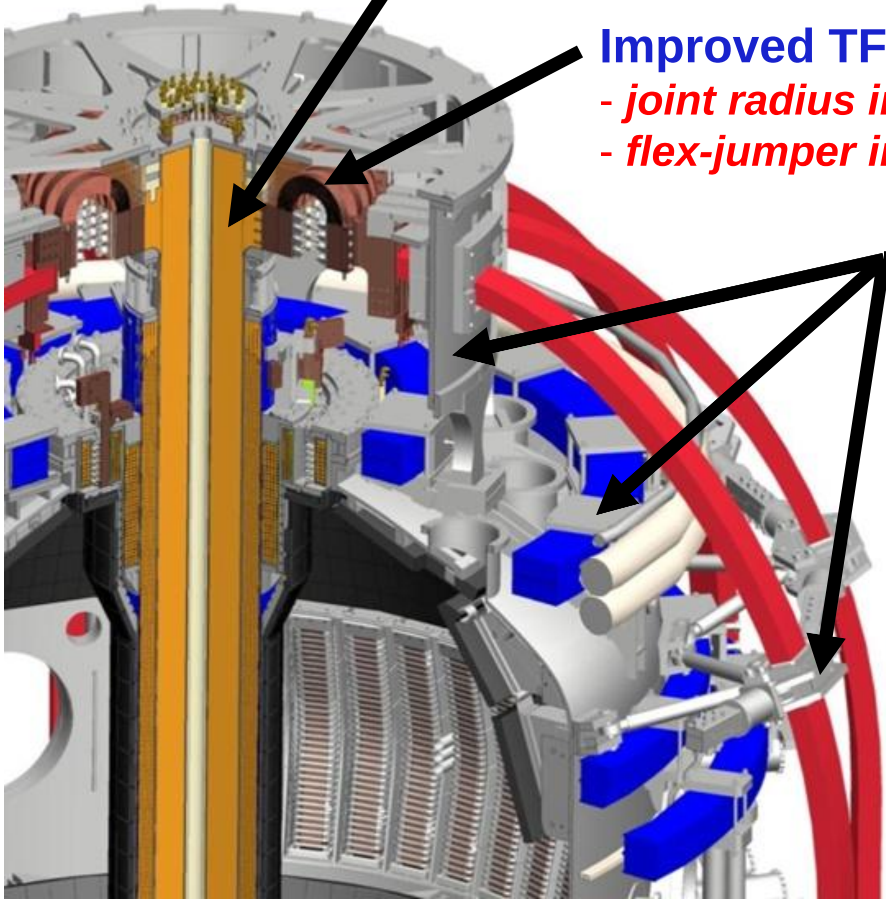
NSTX-U centerstack and vacuum vessel analysis/design are complete, component fabrication/installation has begun

B and J each increase 2x → EM forces increase 4x

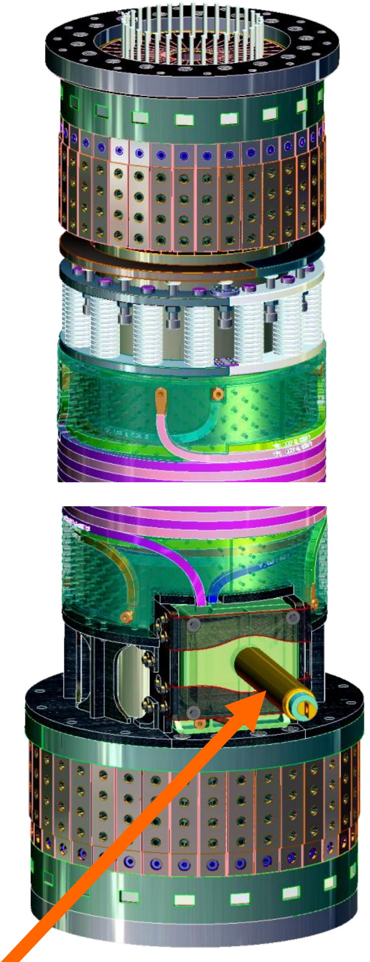
Simplified inner TF design
- single layer of TF conductors

Improved TF joint design
- joint radius increased → lower B
- flex-jumper improved

Reinforced umbrella structure and PF and TF coil supports



Upper TF/ OH Ends



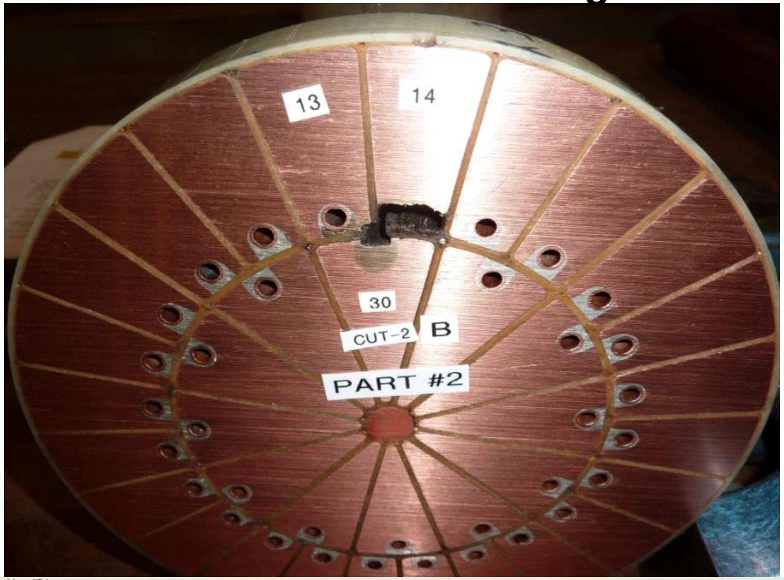
Coaxial and bottom OH lead minimizes error-fields

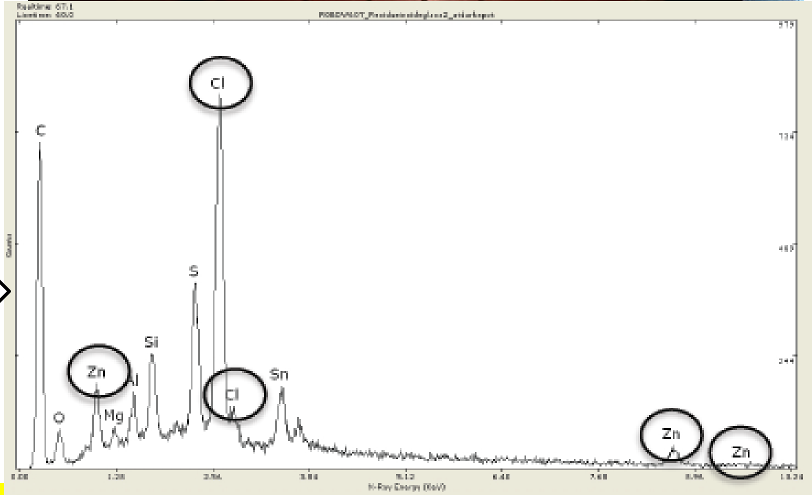
NSTX TF Fault Occurred on July 20, 2011

TF Bundle Operated for 7+ years for 20,000 shots

- TF bundle short occurred ~ 2 feet from the bottom in a relatively low mechanical stress area
- TF bundle dissection and analyses showed no sign of fatigue
- Zinc chloride based flux used for cooling water tube soldering was the cause of insulation failure.

Dissection of shorted region

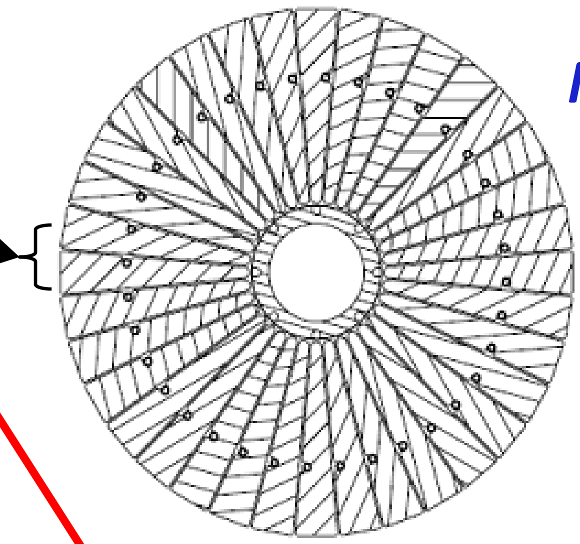




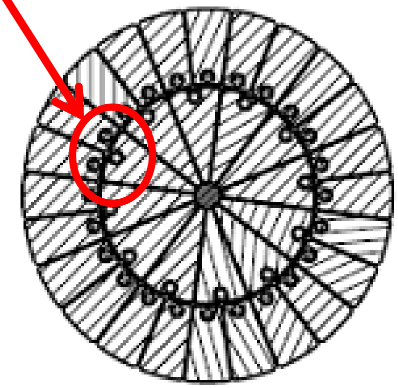
TF Upgrade will use resin flux and improved procedures for removing the flux residues

The NSTX-U center-stack design incorporates improvements that address factors contributing to NSTX center-stack failure

- Single-layer vs. double layer design
  - Reduced voltage stress between conductors (30 volts)
  - Terminal voltage (1 kV) is across quadrant segments where there is increased insulation
- VPI vs B-Stage glass resin system
  - More homogenous insulation system without voids
- Bundle manufacturing improved to address residual solder flux
  - Less corrosive flux
  - Post-soldering bakeout

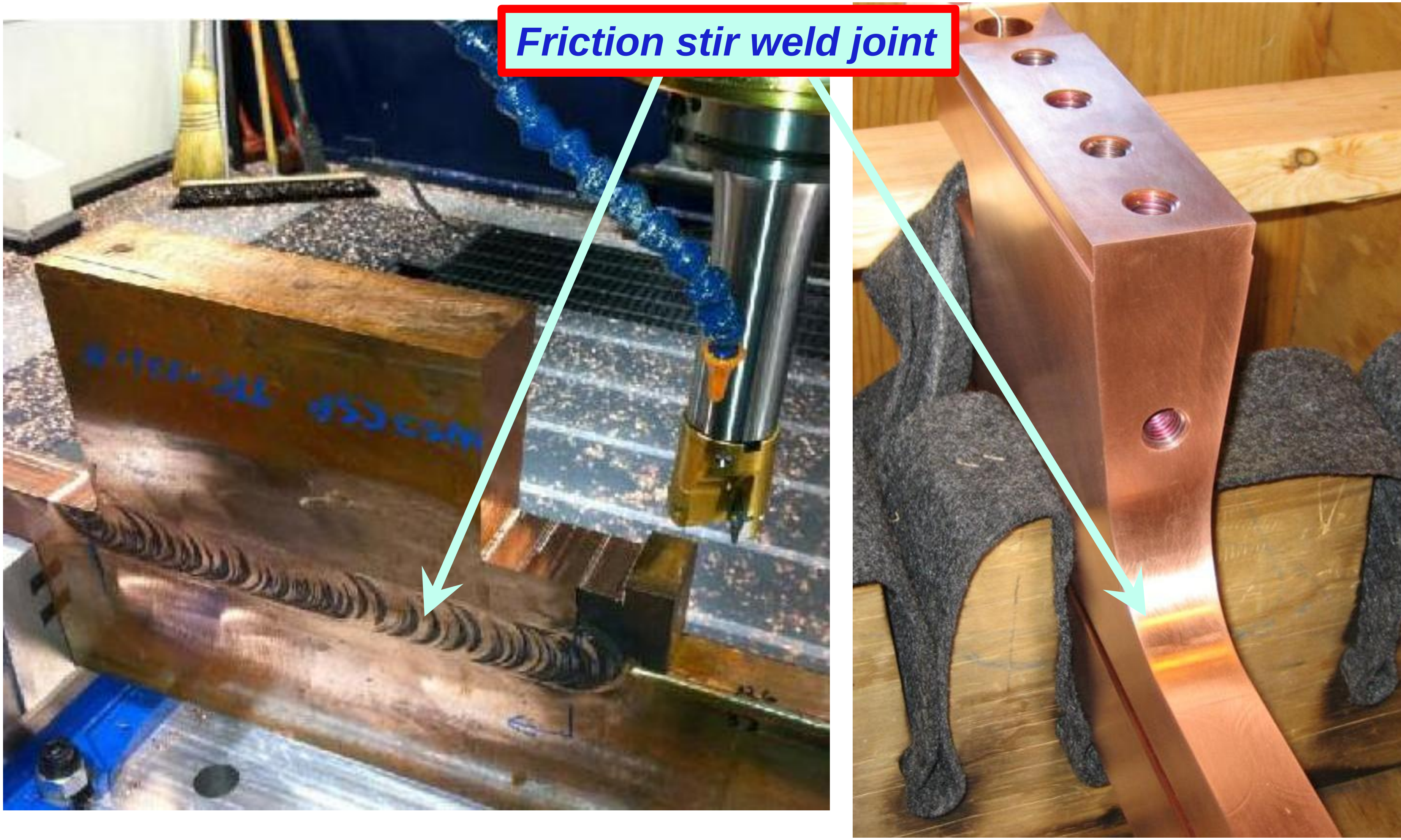


New



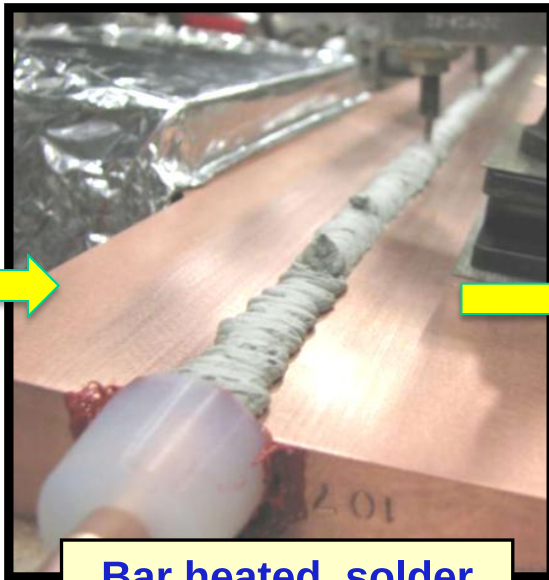
Old

Friction stir welding of TF flags to vertical TF conductors is producing high-quality joints



Improved soldering and flux removal process for TF cooling tubes has also been developed

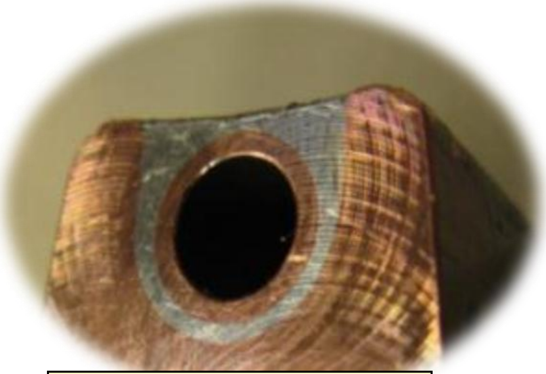
Bar placed on heat plate, cooling tube inserted into grove



Bar heated, solder paste added

Solder flowing. Supplemental heat applied by torch

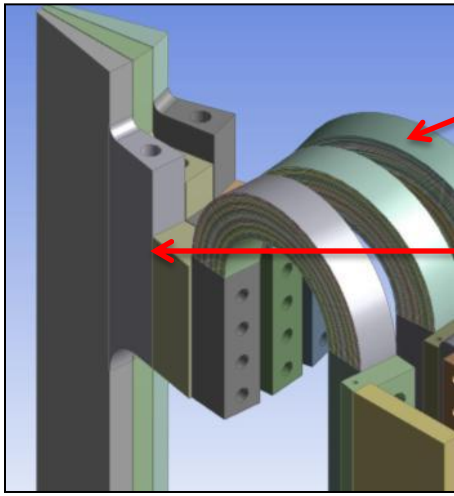
Bar ground smooth



Close up views of solder joint

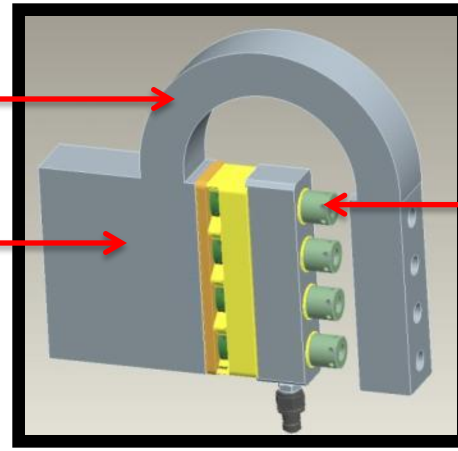
Good wetting of both the tube and copper bar, indicating effectiveness of flux

Features of TF inner/outer flex strap connector

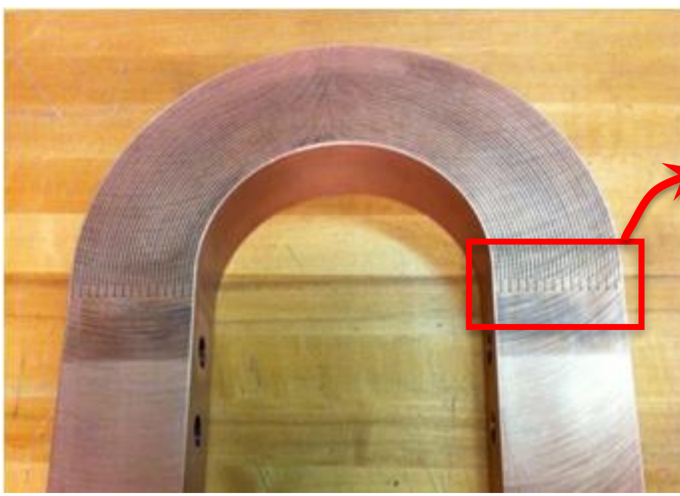


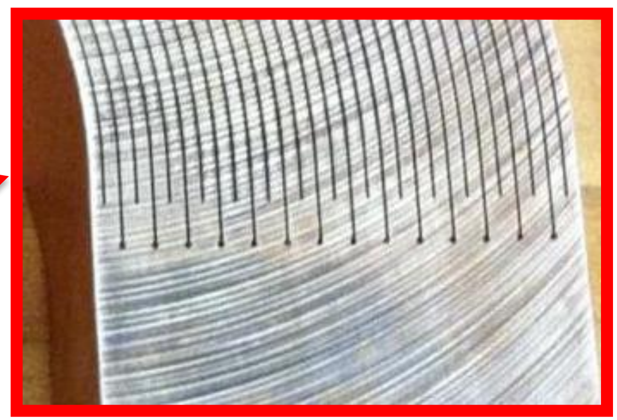
Flex strap

Inner TF

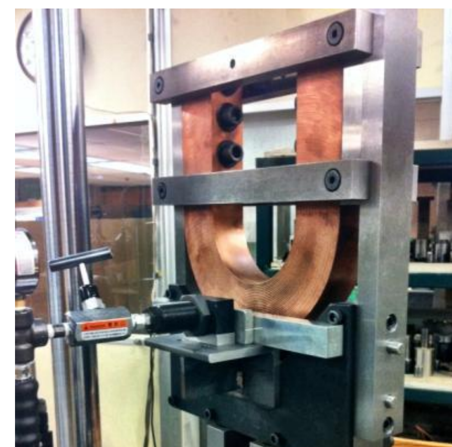


Supernuts® to be used to facilitate assembly





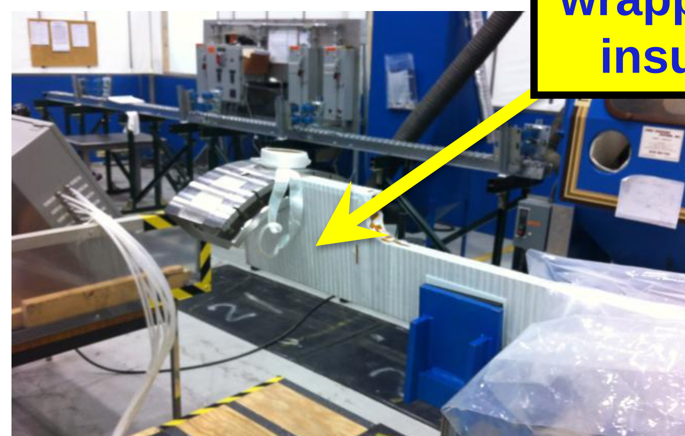
Wire EDM instead of laminated build



Testing (60,000 cycles)

Center-stack fabrication is now underway

Conductor bar being removed from oven after post-solder bake out



Bar being wrapped with insulation

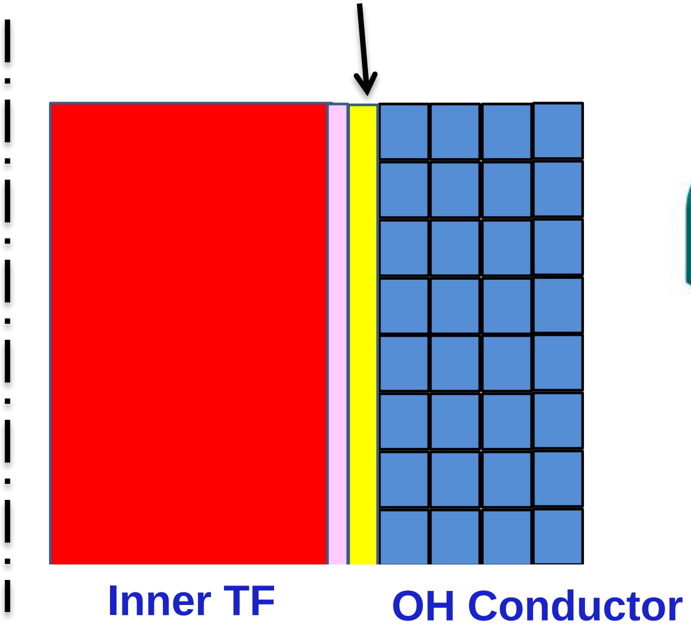
Now entering the riskiest stage of project → inner TF and OH fabrication and VPI – will VPI 1st quadrant in Sept/Oct

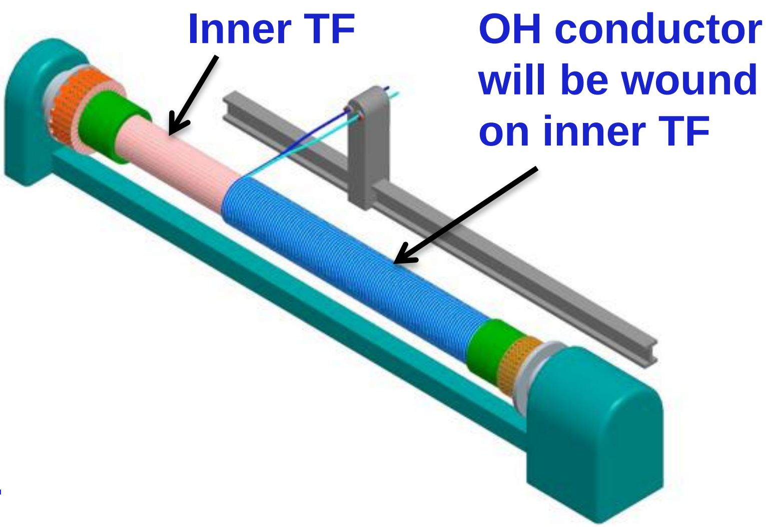
Fabrication techniques for the TF and OH coils

- Epoxy VPI (CTD-425: special cyanate-ester blend) required for shear strength will be used for the inner TF assembly

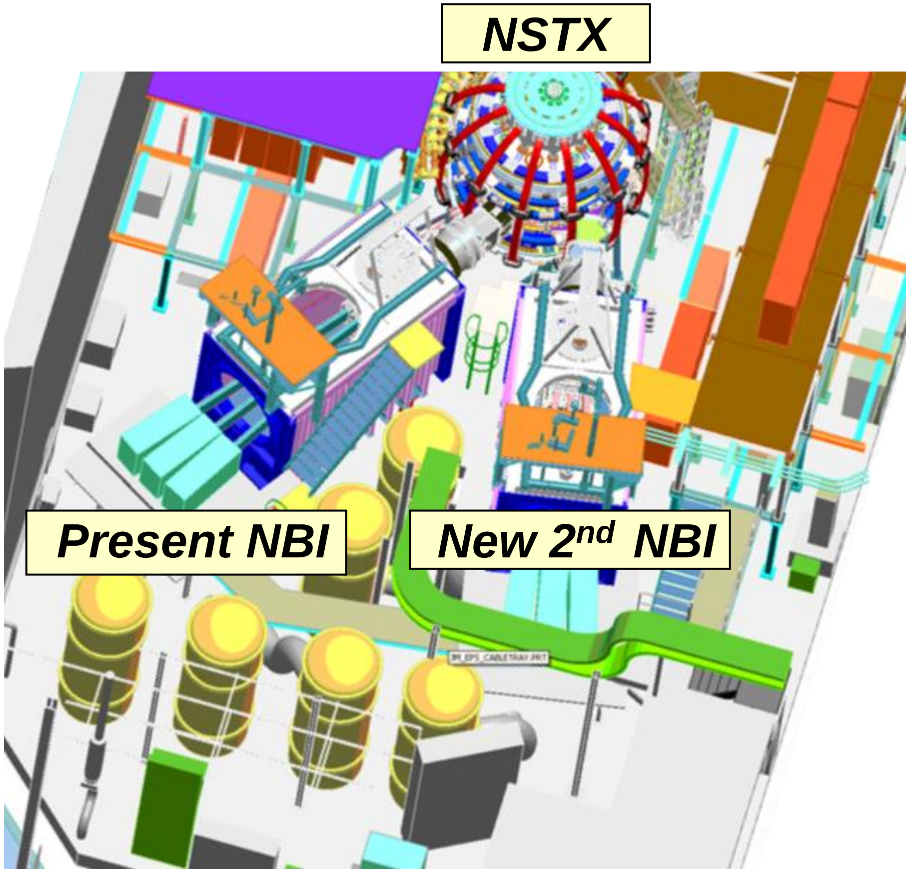
Recent successful VPI trials

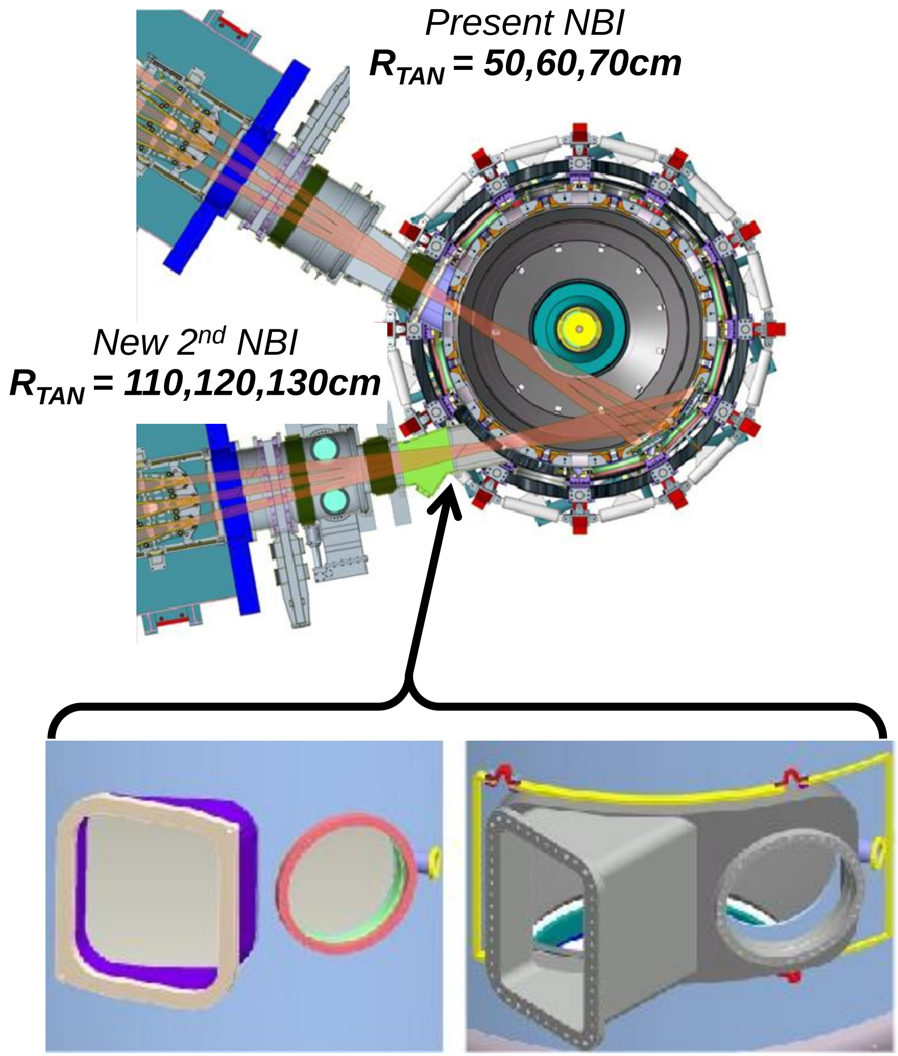
- Aquapour™ will be used as a temporary winding mandrel material to maintain gap between inner TF and OH of 0.1"





2nd NBI requires relocation of a TFTR NBI system to NSTX, diagnostic relocations, new port for more tangential NBI

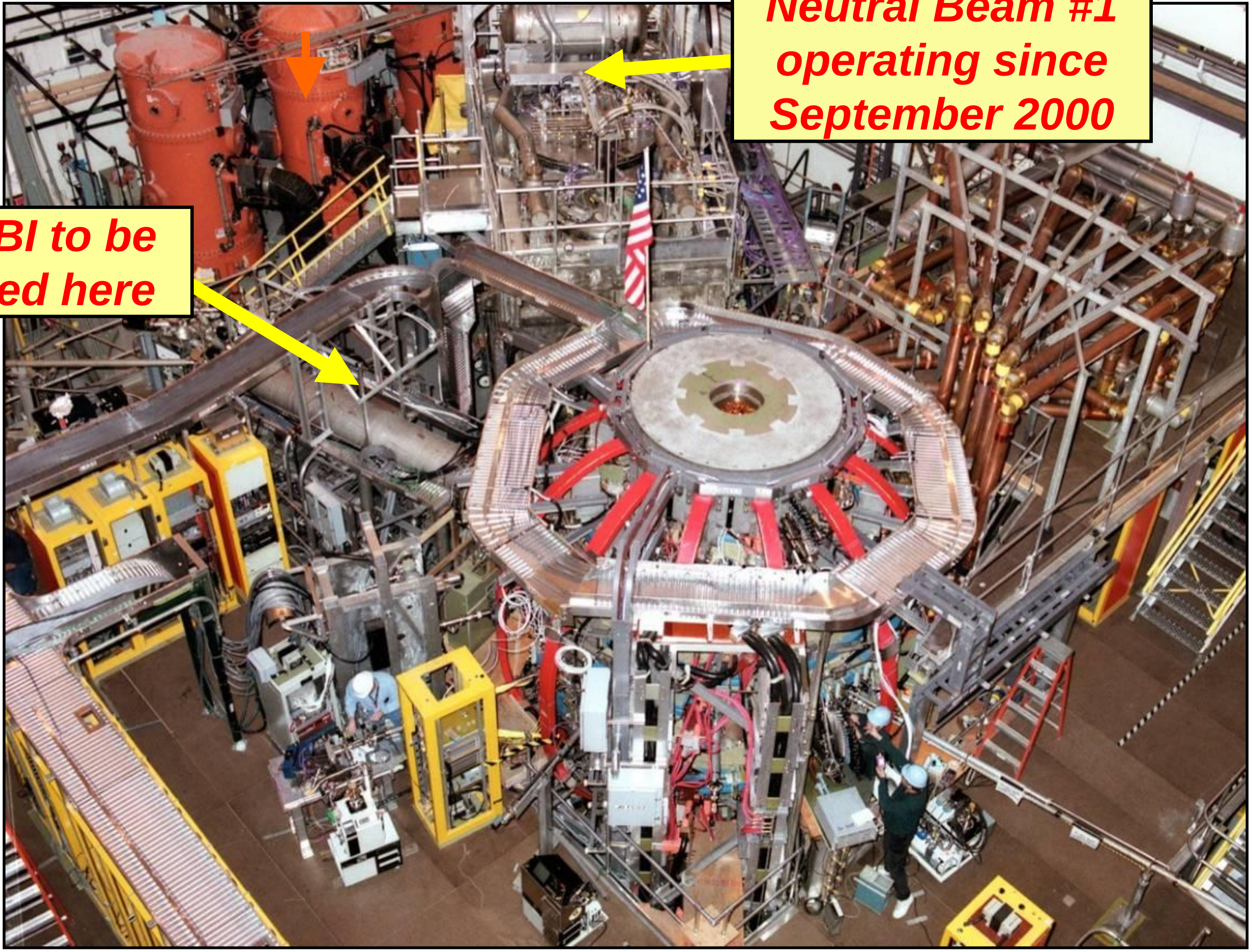




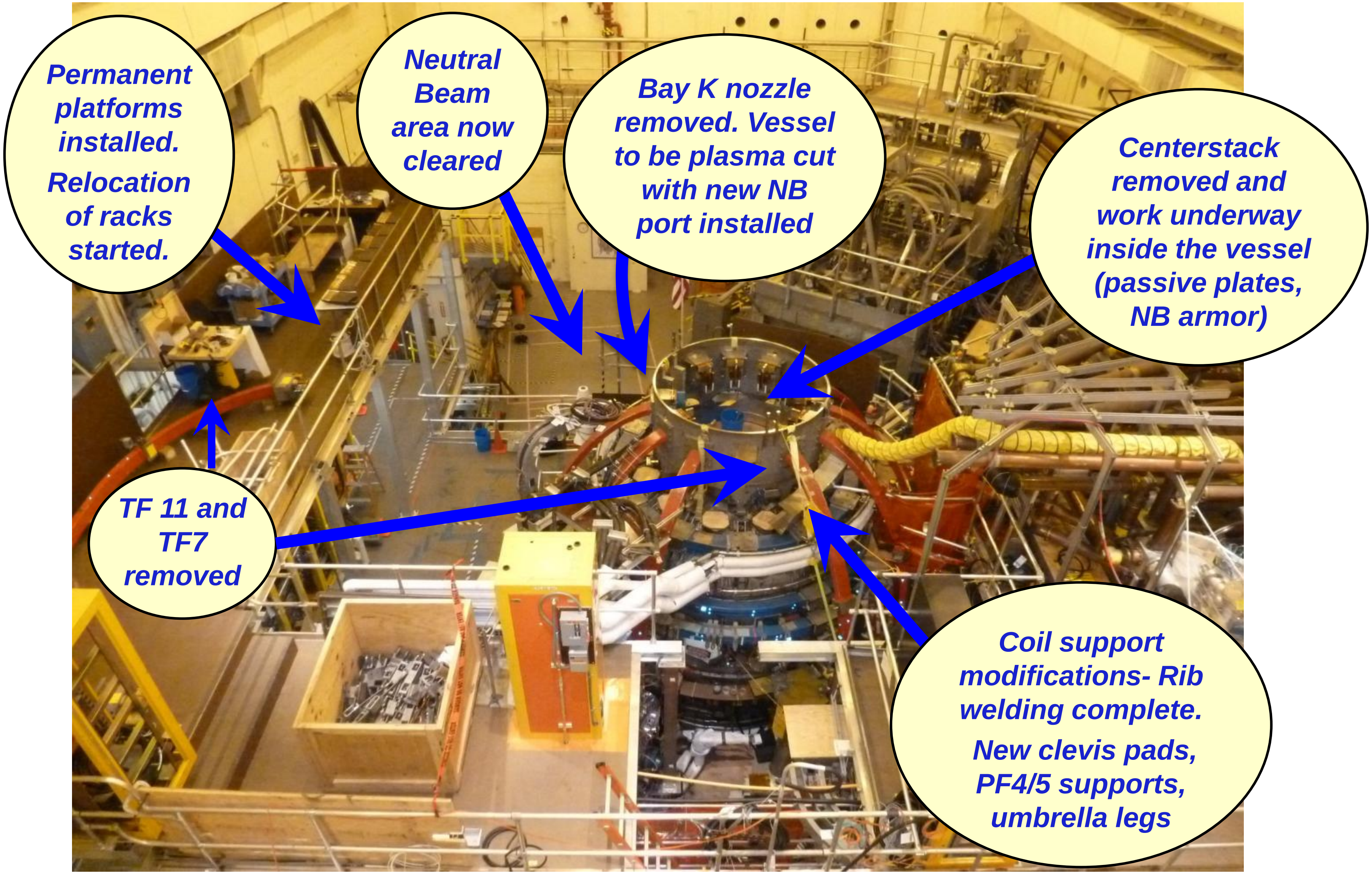
Original NBI Port *New NBI Port*

- Decontamination of 2nd Beam line successfully completed in 2010

NSTX circa 2010

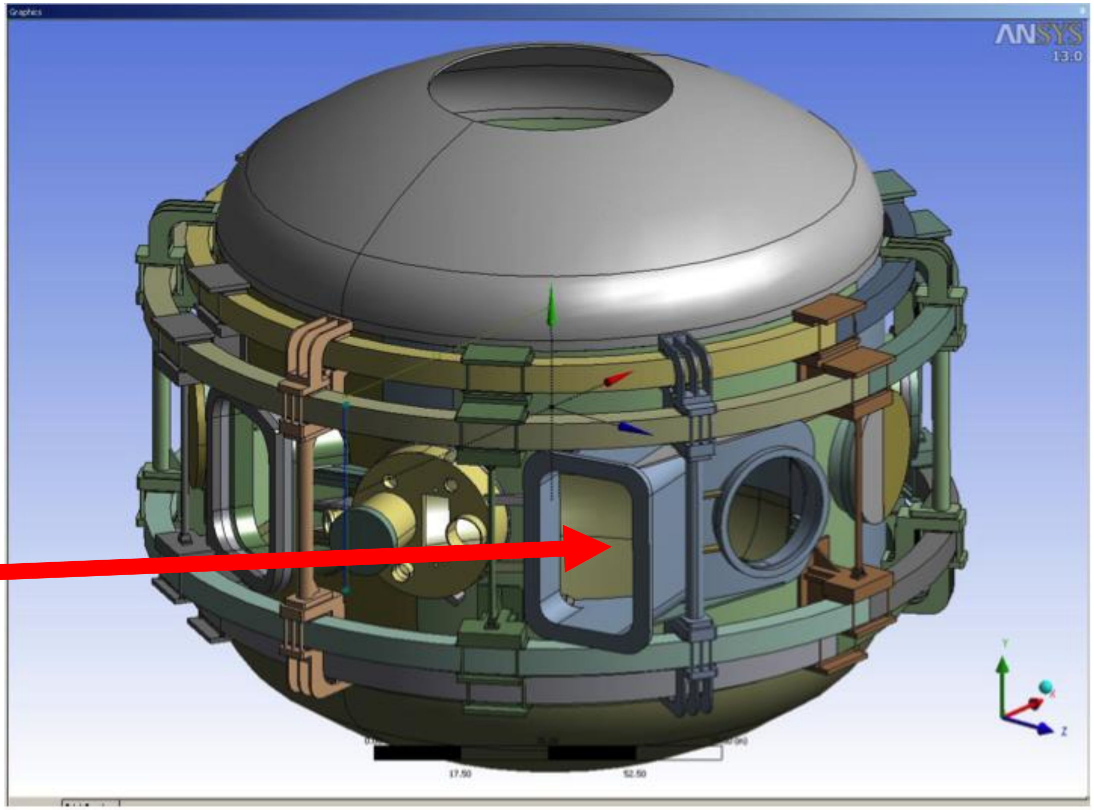


Test-cell progress since September 2011

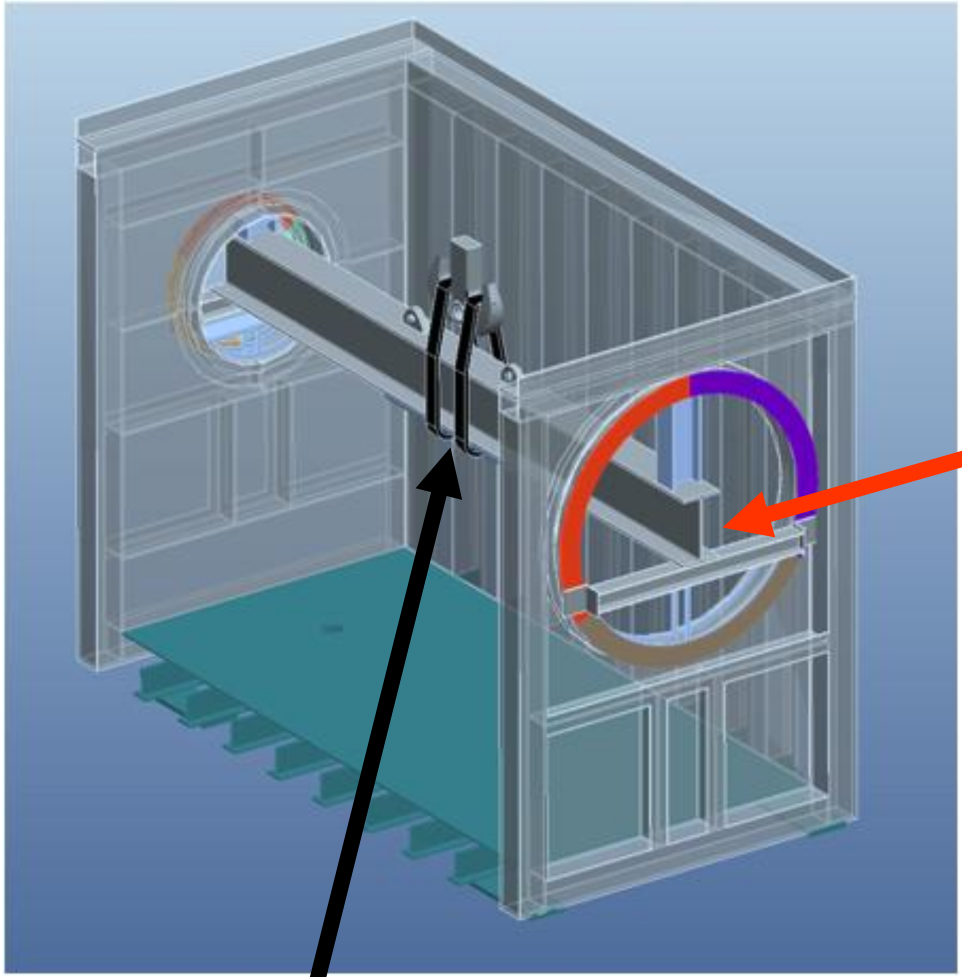


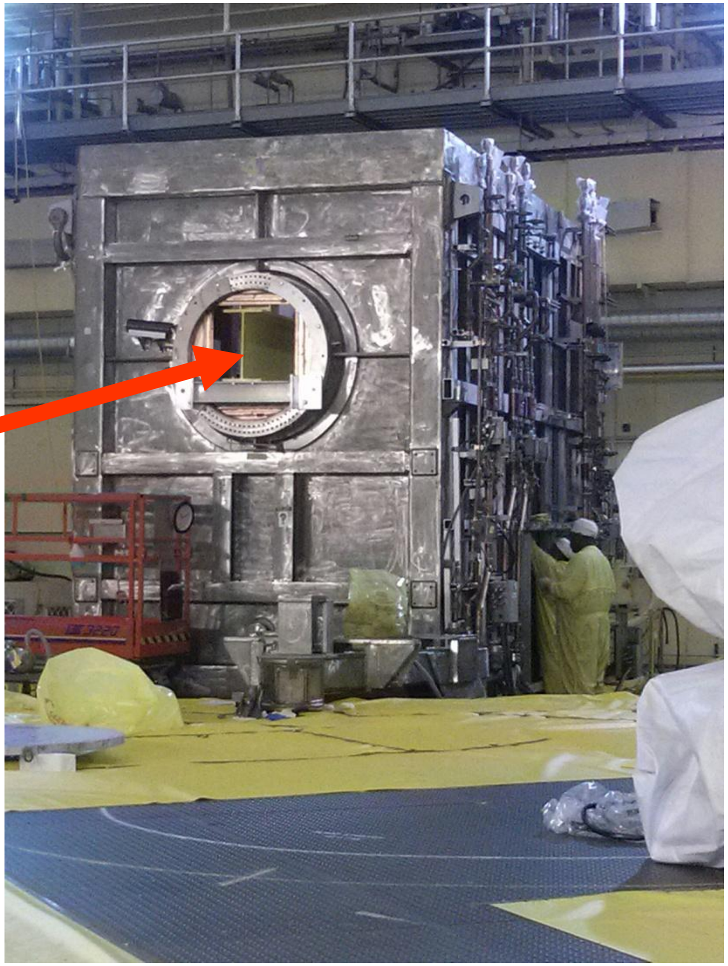
New NBI port-cap has been received

- **Materials, machining meet spec (but welds being re-worked)**
- **Preparing to plasma-cut hole in vessel for cap installation**



2nd NBI to move to NSTX-U test-cell in Sept/Oct

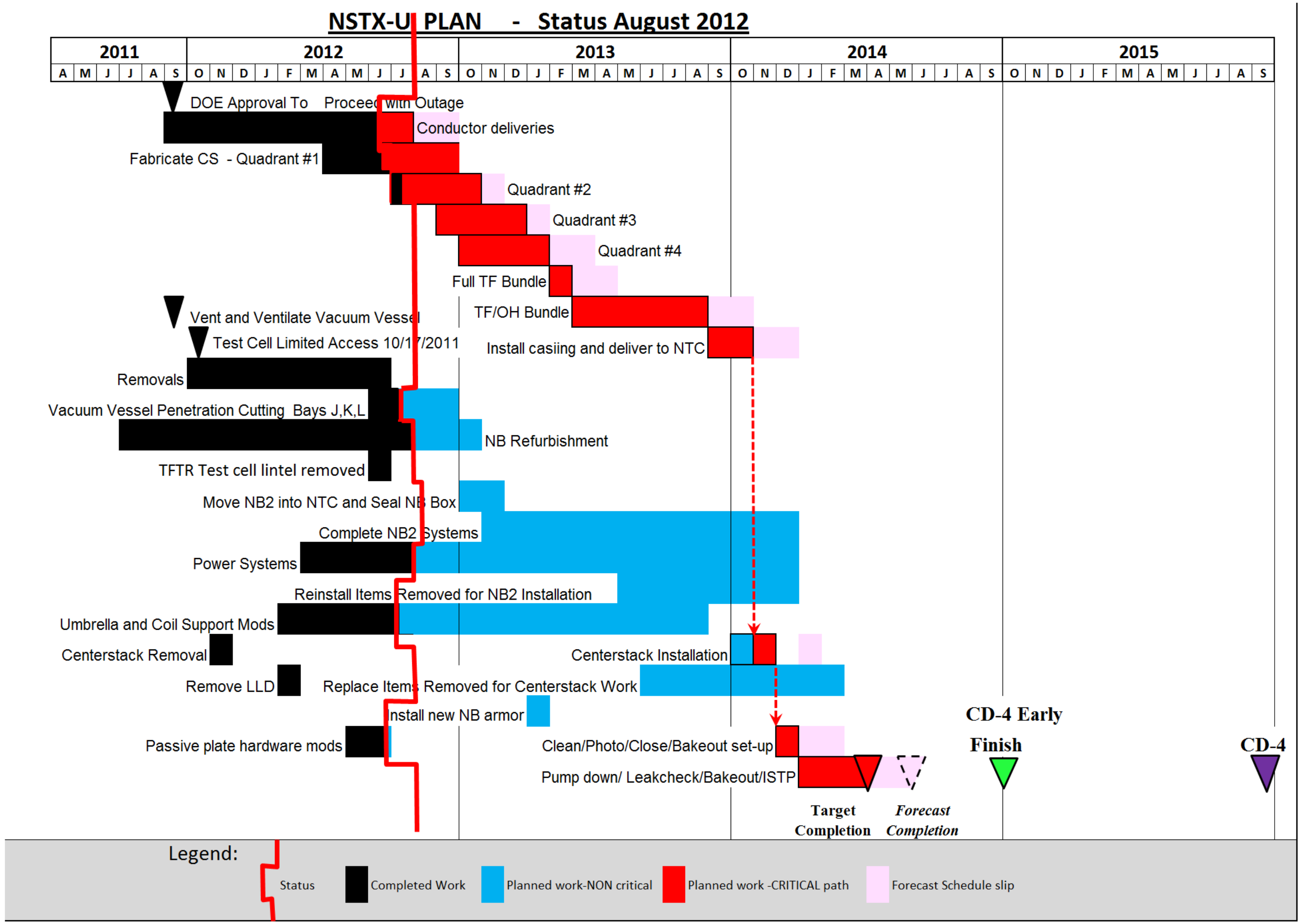




Reentrant hook lift fixture designed to increase clearance over NSTX test-cell wall

Lift fixture installed, tested, and ready to go…

Project on-track for (early) completion: Apr-Jun 2014



President's budget for FY2013 would delay completion by ~1 year

Summary

- NSTX-U device and research will narrow many performance and understanding gaps to next-steps
- The Upgrade Project has made good progress in overcoming key design challenges
- The Project is on schedule and budget
- NSTX-U team now formulating next 5 year plan (2014-18) to access new ST regimes including follow-on staged and prioritized upgrades