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# R(17-3): Identification, mitigation, and correction of intrinsic error field sources

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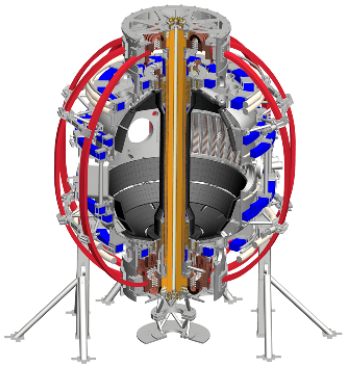
Research Milestone Status Meeting
May 25, 2017



# Milestone and Recovery Project charges

- R(17-3) Milestone:

  Identify, mitigate, and develop correction strategies for intrinsic error field sources in NSTX-U

- Recovery Project charge:

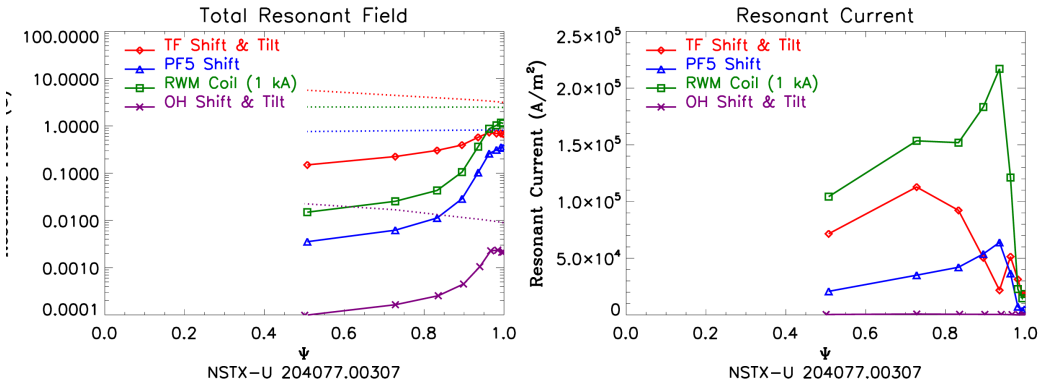
  Carry out data analysis, coil metrology, and numerical modeling of error fields to recommend a tolerance for the TF alignment upon reassembly

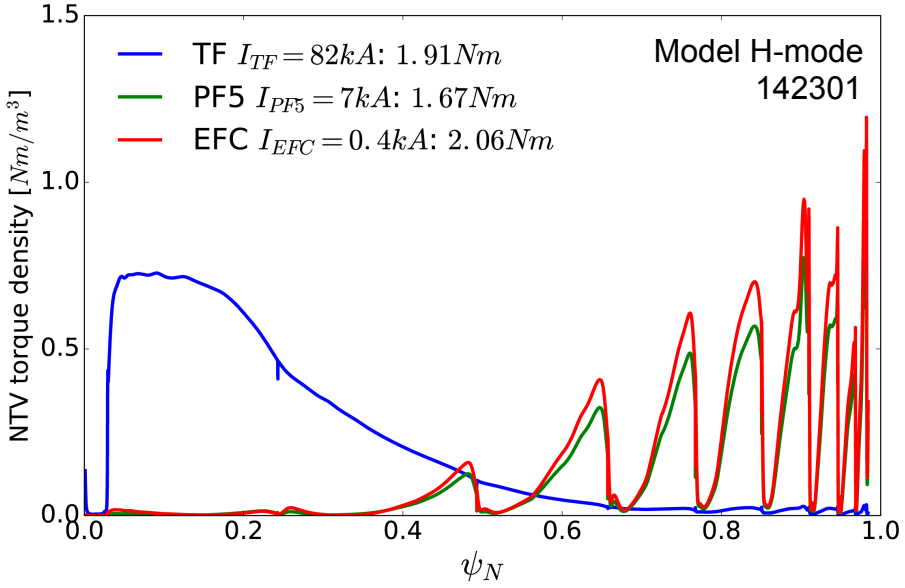
# Today's presentation

- What we presented last time (31 March 2017):
  - Experimental results from the FY16 NSTX-U campaign
  - Error field source metrology (PF5 radius and TF tilt)
  - Vacuum error field and plasma response modeling
- Error field assessment report:
  - Report issued to Recovery Project on 30 April
  - Examine effects of both resonant error fields and NTV
  - Recommended TF alignment tolerance of ≤ 2 mm (×3 reduction)
- Milestone action items:
  - Additional ex-vessel coil metrology (PF5 vertical plane, etc.)
  - Develop plan for center stack reinstallation / realignment
  - Develop plan for possible in-vessel vacuum field measurements

# Modeling results → 2 mm tolerance

- Metrology → coil shape models
  - Feed to IPEC & M3D-C1
- Resonant fields and currents:
  - TF error field is dominant
  - TF EF phase not constant
  - Difficult to correct
- Neoclassical toroidal viscosity:
  - RWM coils are poorly matched to TF NTV spectrum
- Tolerance of 2 mm:
  - Resonant fields below locking threshold without EFC
  - Reduces TF NTV by 10×



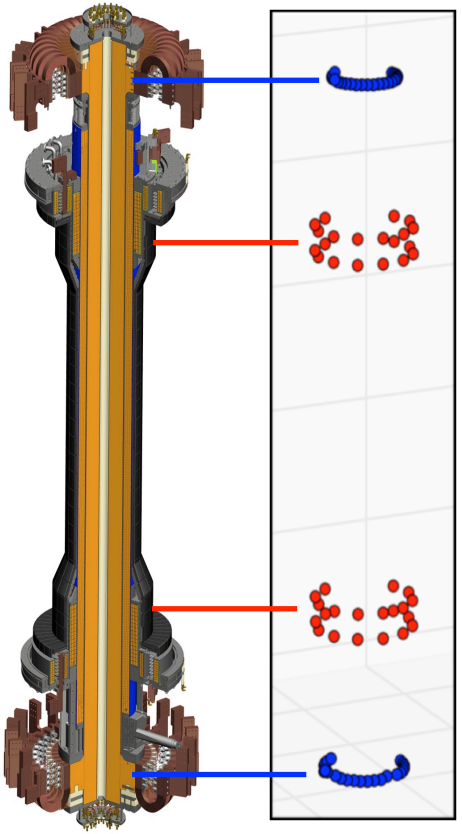



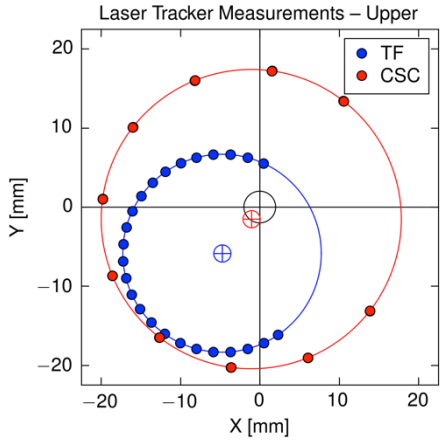
# Metrology conducted on TF bundle and CS casing

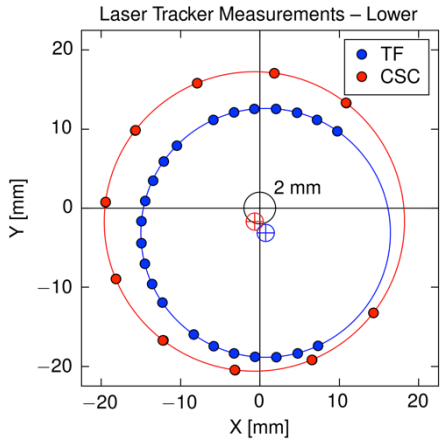
- TF bundle shift and tilt is larger than the CS casing shift and tilt
- CS casing (CSC) alignment encroaches on 2 mm tolerance
- CSC alignment will be different with new polar region hardware

| | Shift | Tilt |
|---|---|---|
| **Casing** | 1.8 mm | 0.2 mrad (~ 0.8 mm) |
| **TF bundle** | 4.9 mm | 1.2 mrad (~ 6 mm) |

Measurements of TF bundle w.r.t. casing (2016)





# What is meant by vertical? → additional metrology

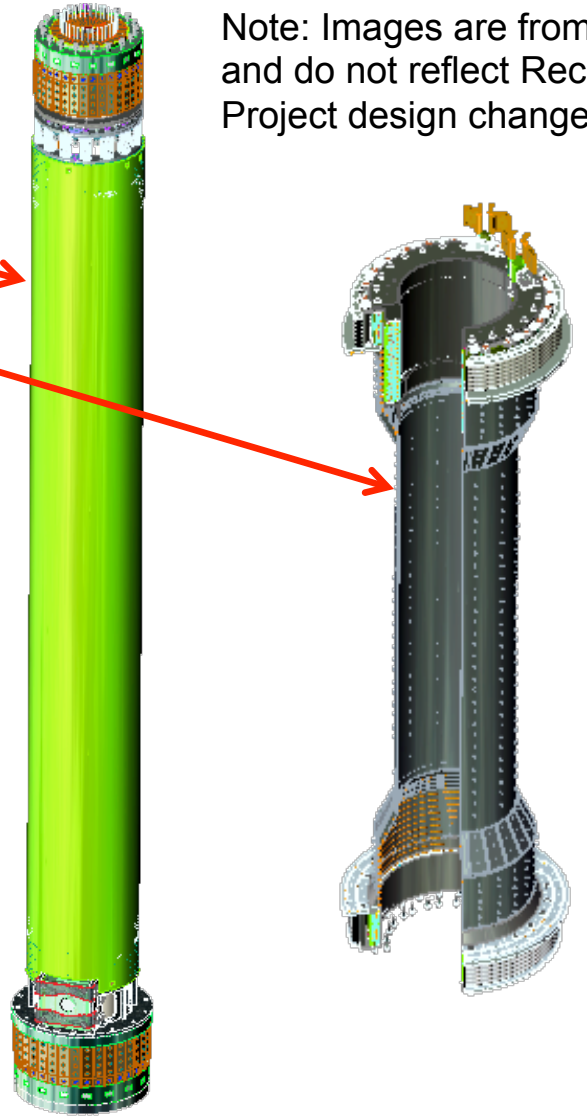
- To what vertical axis should we align the TF bundle?
  - Outer vessel axis?
    - ROMER coordinate system *z*-axis (set by monuments)
    - Axis of nozzle flanges (upper and lower)
  - PF5 coil plane normal vector? → upper or lower coil?

- Additional metrology required:
  - Reexamine existing outer vessel metrology:
    - Reference the ROMER system to gravity?
    - What is the alignment of the upper and lower outer vessel nozzles?
  - New metrology to determine the PF5U/L coil planes
    - Use laser tracker to project ROMER system out of the vessel
    - Consider shimming the PF5 coils pending these results
  - These efforts are getting underway

# Preliminary realignment / reinstallation plan

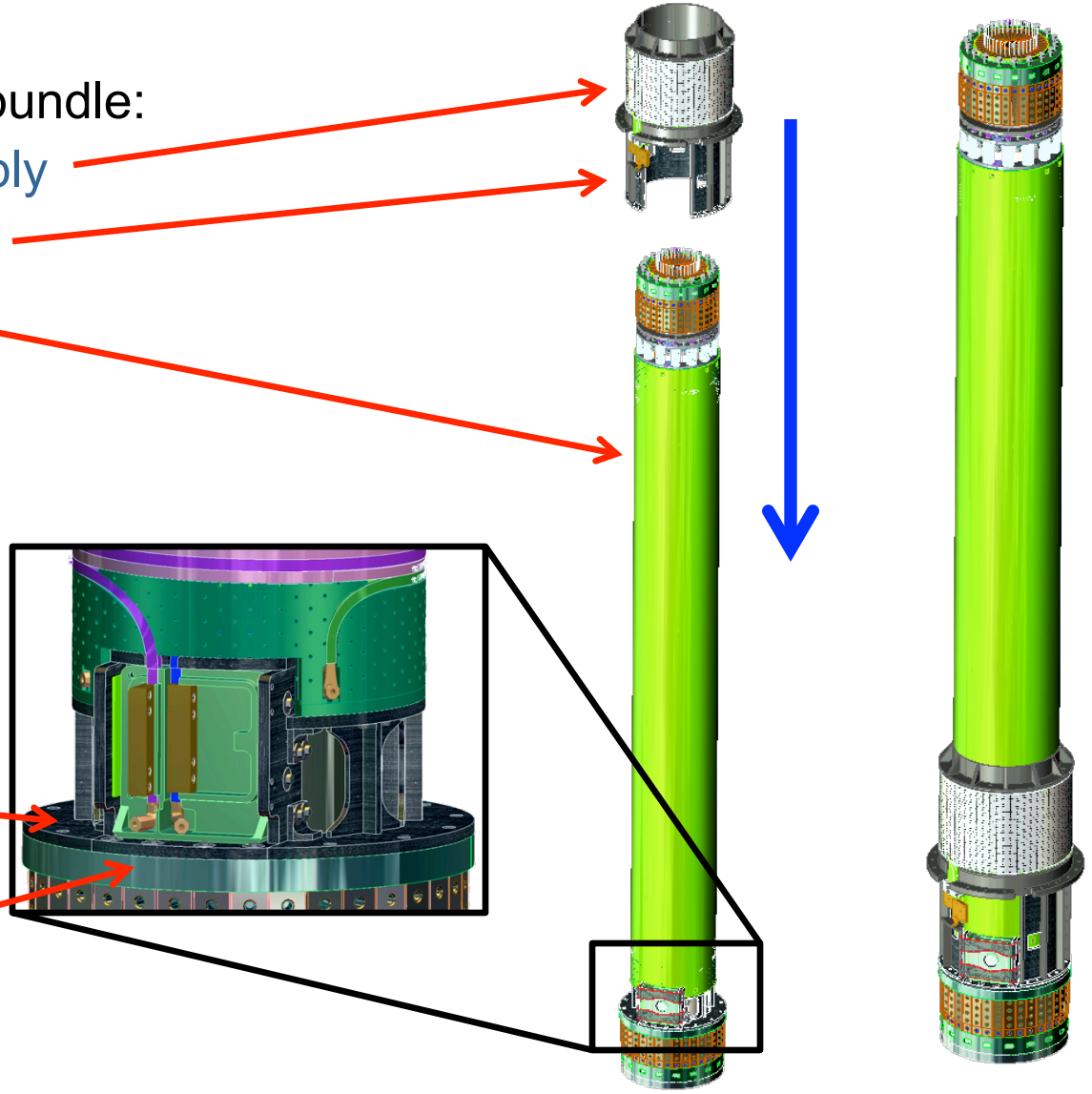
- Present configuration:
  - OH/TF bundle in SHB
  - CS casing in SHB
- Two phases of realignment and reinstallation:
  - Placement of the casing over the OH/TF bundle (South High Bay)
  - Placement of casing/bundle assembly in the machine (NTC)
- Realignment considerations:
  - Shim casing w.r.t. bundle
  - 10× lever arm ~ 0.5 mm shim
  - BUT casing mating surface will be different → polar region changes

Note: Images are from 2011 FDR and do not reflect Recovery Project design changes.

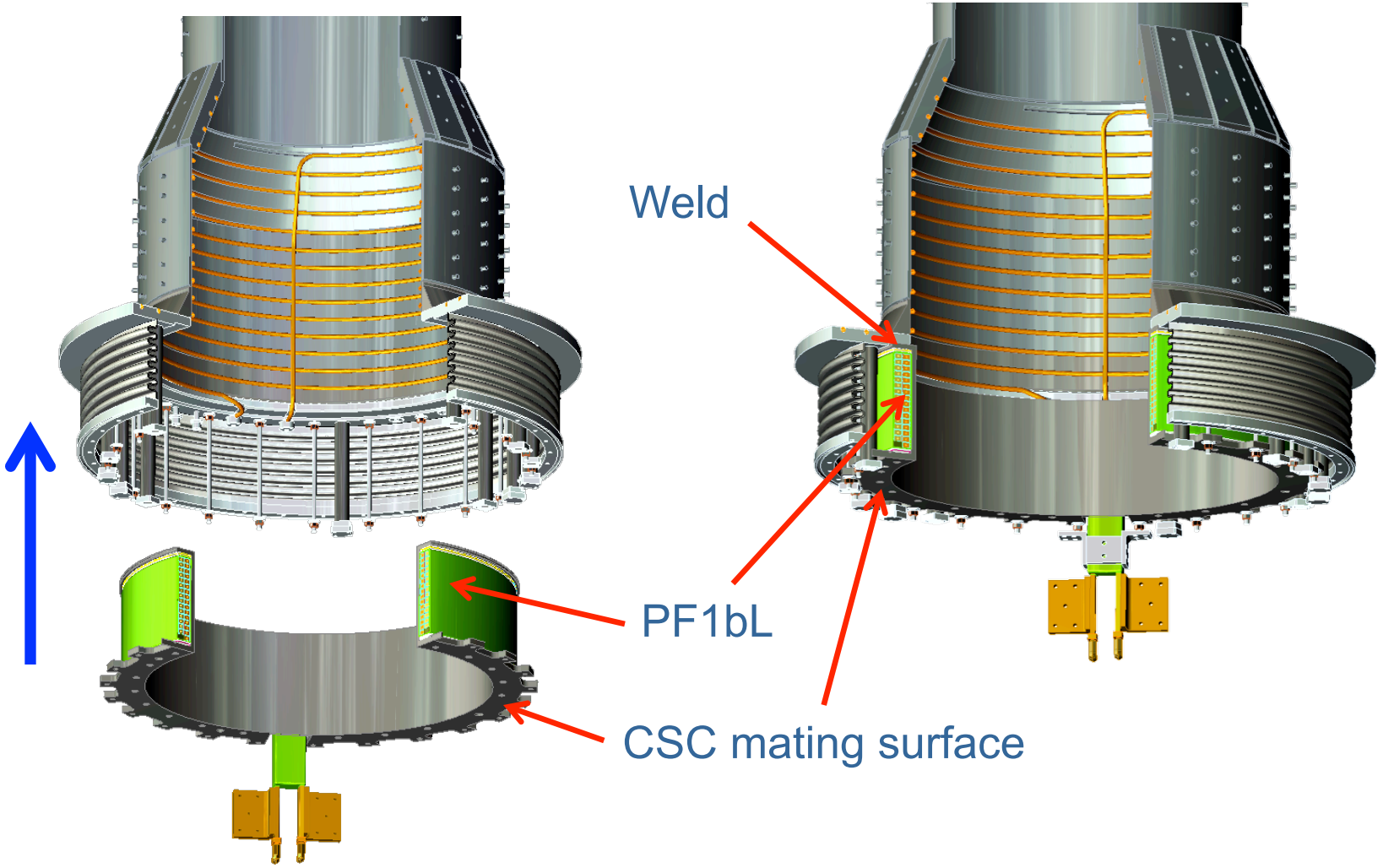


# First shimming opportunity: PF1aL coil installation

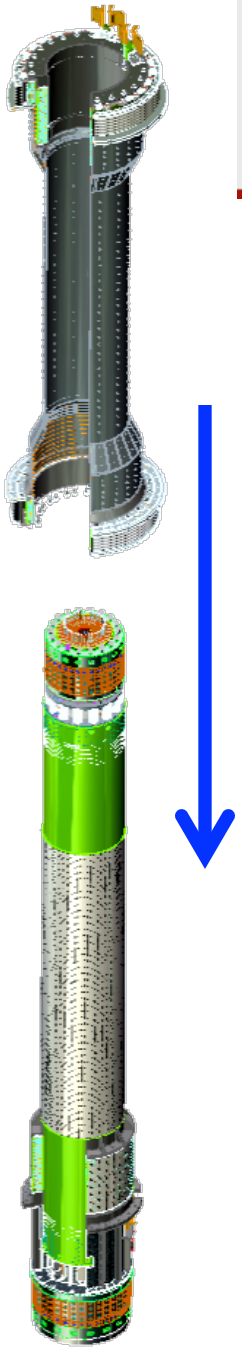
- PF1aL lowered onto bundle:
  - PF1aL coil assembly
  - OH skirt assembly
  - OH/TF bundle



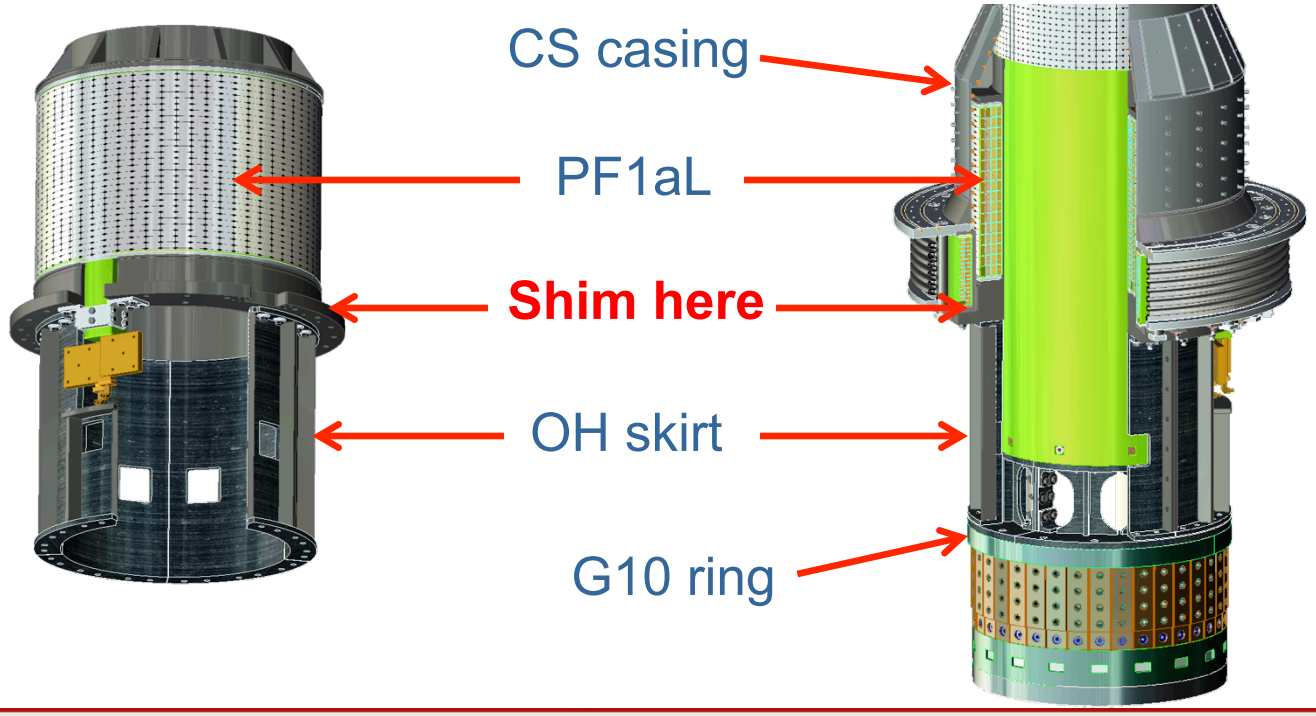
# Present design: PF1bL provides CSC mating surface



# Second shimming opportunity: casing support

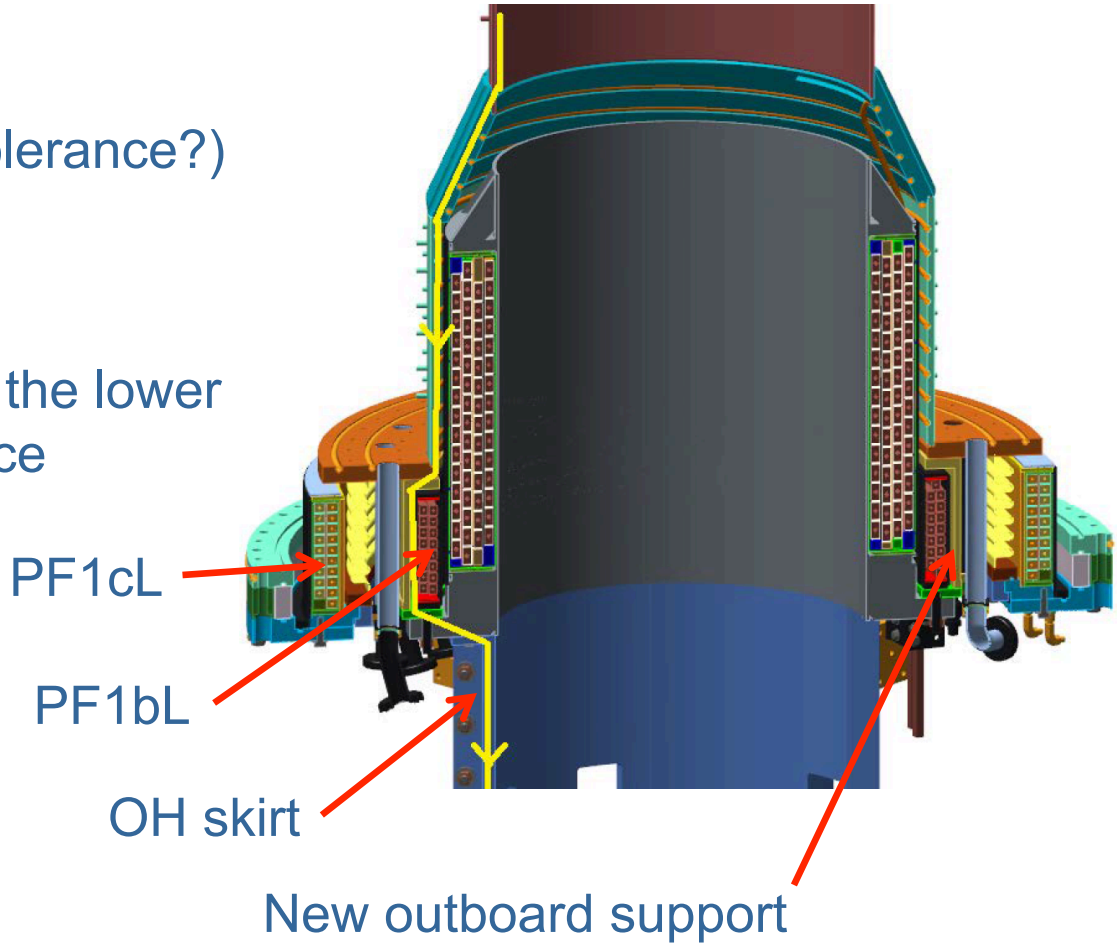


- Lower the casing over the bundle (left)
- CSC rests on top of OH skirt
  - At present PF1bL provides the mating surface
  - Second opportunity for shimming
- Repeat CSC ←→ TF metrology to verify alignment



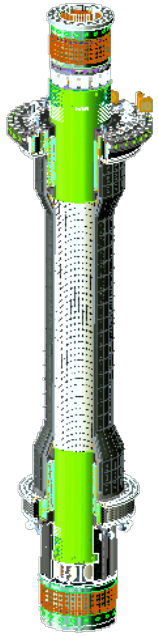
# Consider post-machining new CSC mating surface

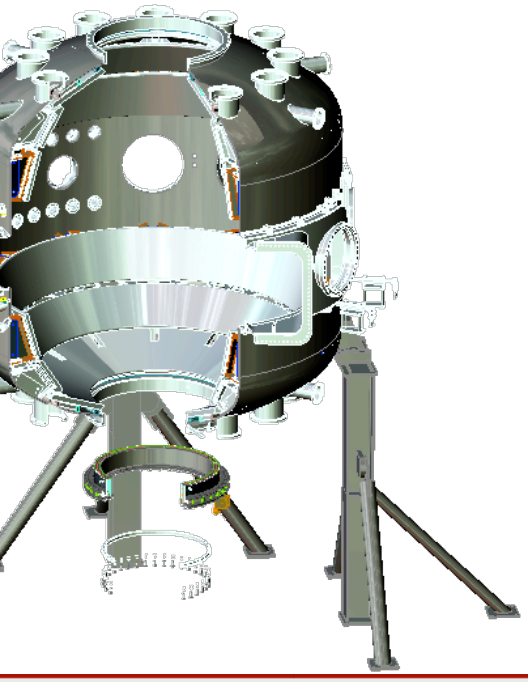
- Present configuration:
  - PF1bL sits on OH skirt
  - PF1bL welded to CSC (tolerance?)
- New configuration:
  - Outboard support
  - Consider post-machining the lower surface to ensure tolerance



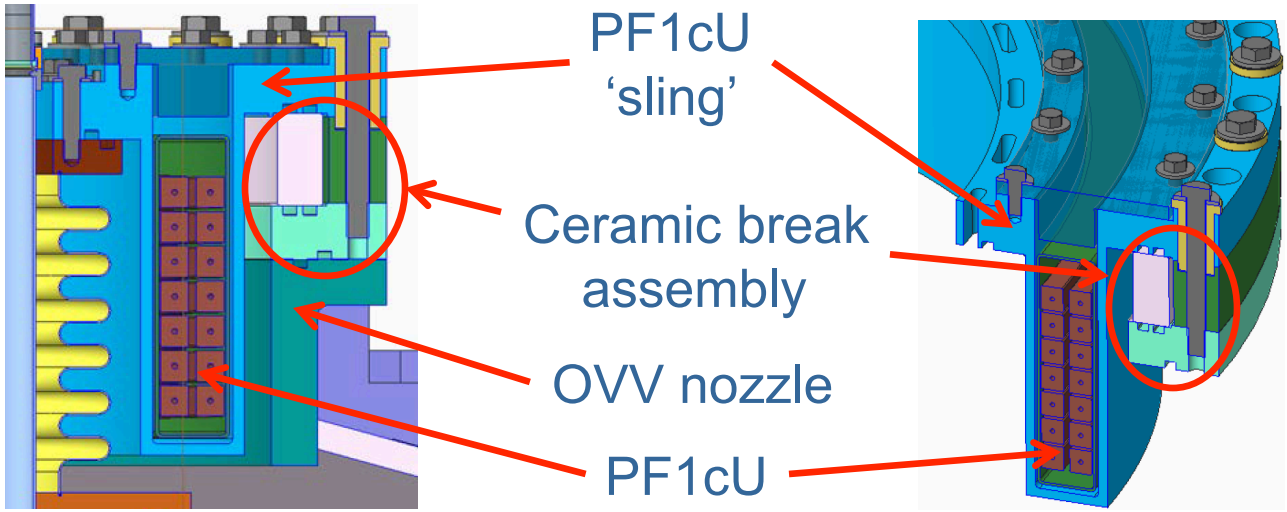

M. Sibilia – Polar region integration review

# Casing must align to outer vessel → affects TF





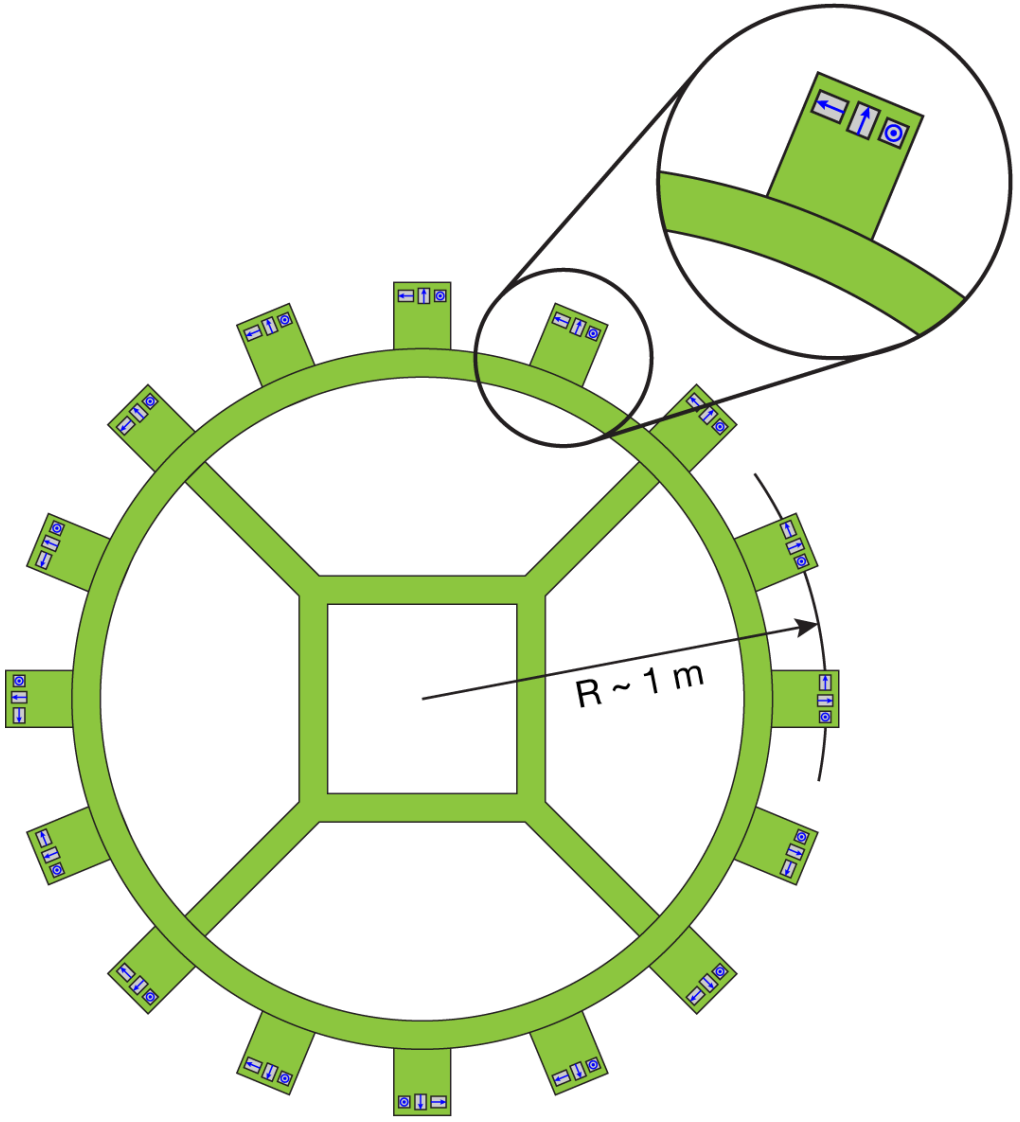
- Alignment dictated by the casing mating to the outer vessel nozzles → TF along for the ride
- Exploring whether engineers can provide a few millimeters of flexibility in the new -1c sling assembly
- Use ROMER arm to assess CS alignment upon reinstallation




M. Sibilia – Polar region integration review

# In-vessel magnetic measurements

- Deploy in-vessel magnetics rig during possible coil validation testing of outer PF coils:
  - Directly measure error fields from each coil (DC, AC)
- Tentative specifications:
  - 48 sensors (16×3 $B_Z$, $B_R$, $B_T$)
  - Difference opposing sensors
  - Requires 24 new integrators
  - Calibrate each set of sensors on bench with Helmholtz coils
  - Position with ROMER arm
  - Move rig vertically in vessel → multiple horizontal planes



# R(17-3) milestone summary

- Error field assessment report:
  - Report issued to Recovery Project on 30 April
  - Recommended TF alignment tolerance of ≤ 2 mm (×3 reduction)
- Additional metrology and magnetic measurements:
  - Ex-vessel metrology of PF5 coils → coil plane w.r.t. ROMER system
  - Define the vertical axis to which the TF should be aligned
  - In-vessel magnetic measurements during outer PF validation testing
- Reinstallation and realignment planning:
  - Shim and/or post-machine CS casing to ensure TF bundle is centered
  - Repeat CSC / TF metrology to verify alignment
  - Design mm's of flexibility into -1c slings to facilitate CS alignment (?)
  - Use ROMER arm to quantify CS alignment upon installation