



# The PEGASUS-III Spherical Tokamak

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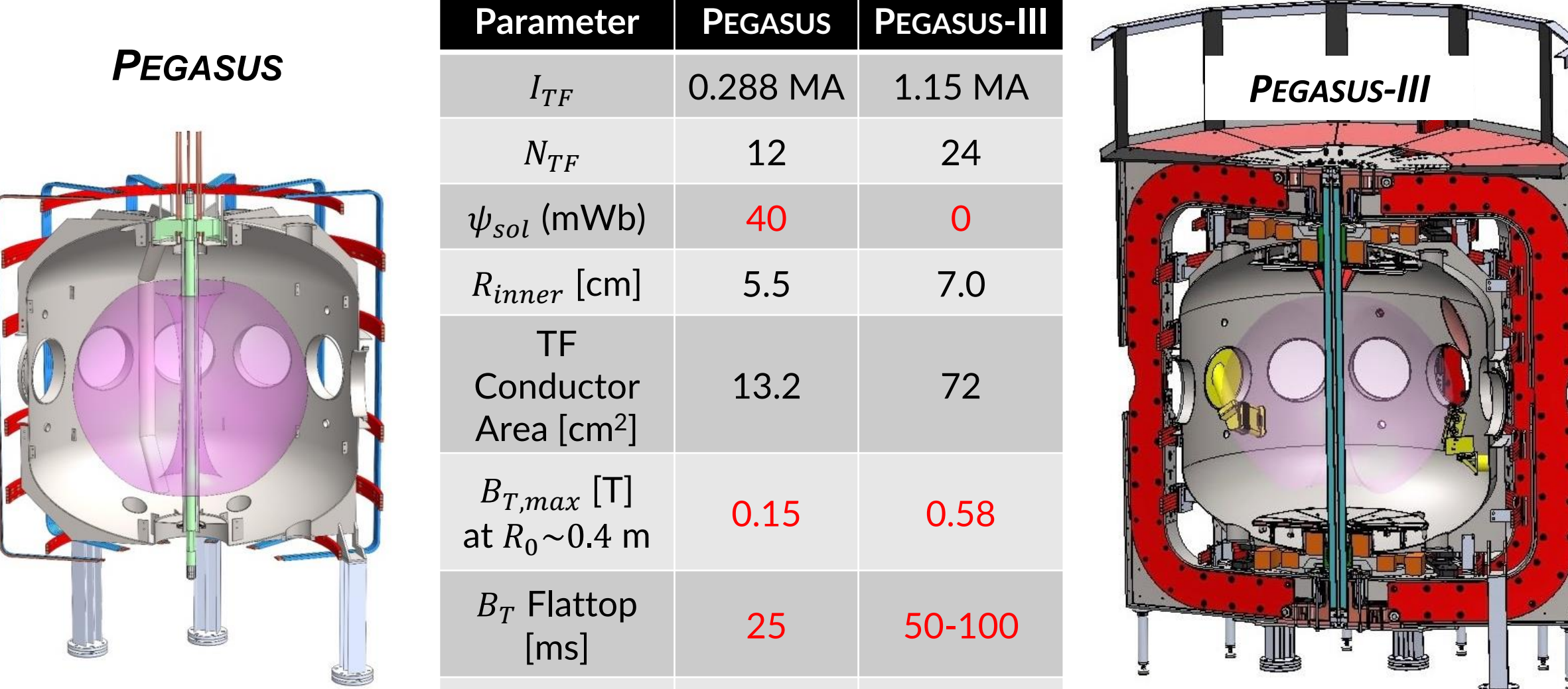
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## The PEGASUS-III Spherical Tokamak is a Dedicated US Platform for Solenoid-Free Startup Development

**PEGASUS-III Mission:** Solve the ST startup challenge by comparing, contrasting, and investigating synergistic effects of non-solenoidal current drive techniques using power plant relevant technology

- Compare, combine solenoid-free startup concepts in dedicated facility
  - Local helicity injection (LHI)
  - Coaxial helicity injection (CHI), both transient and sustained
  - RF assist and sustainment (EBW, ECH, ECCD)
  - see M.W. Bongard, CP11.00040
- Goal: develop validated physics and technology basis for MA startup

| Parameter                            | PEGASUS  | PEGASUS-III |
|--------------------------------------|----------|-------------|
| $I_{TF}$                             | 0.288 MA | 1.15 MA     |
| $N_{TF}$                             | 12       | 24          |
| $\psi_{sol}$ (mWb)                   | 40       | 0           |
| $R_{inner}$ [cm]                     | 5.5      | 7.0         |
| TF Conductor Area [cm <sup>2</sup> ] | 13.2     | 72          |
| $B_{T,max}$ [T] at $R_0 \sim 0.4$ m  | 0.15     | 0.58        |
| $B_T$ Flattop [mT]                   | 25       | 50-100      |
| A                                    | 1.15     | 1.18        |

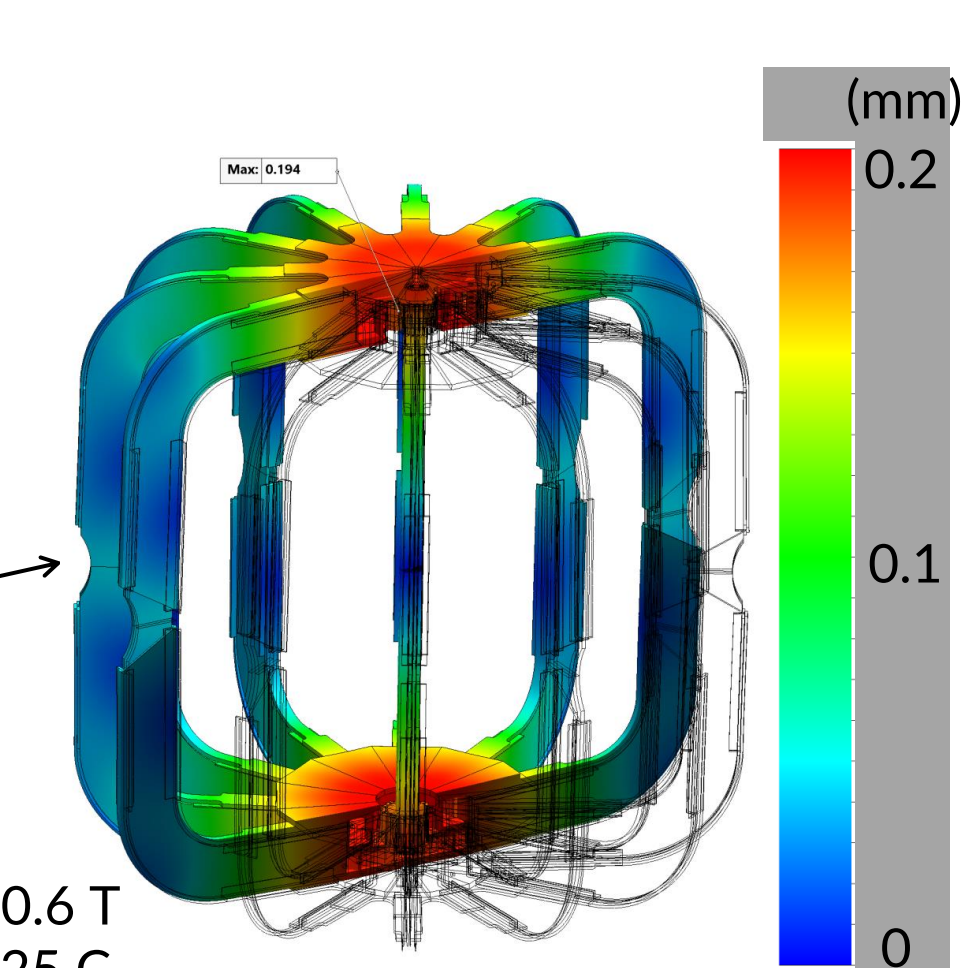


- Significant upgrades performed to provide capability for this mission
  - Ohmic solenoid removed from system
  - Upgraded TF magnet assembly capable of withstanding forces of 4x field
  - Active divertor coils
  - Upgraded/expanded power supplies and new stored energy
  - Next generation LHI, CHI, and RF capabilities
  - Expanded diagnostic set

## Magnetic and Thermal Forces Pose Structural Challenges for PEGASUS-III TF Assembly

- FEM simulation allows load combination analysis<sup>1</sup>

Displacement of Overall Structure:



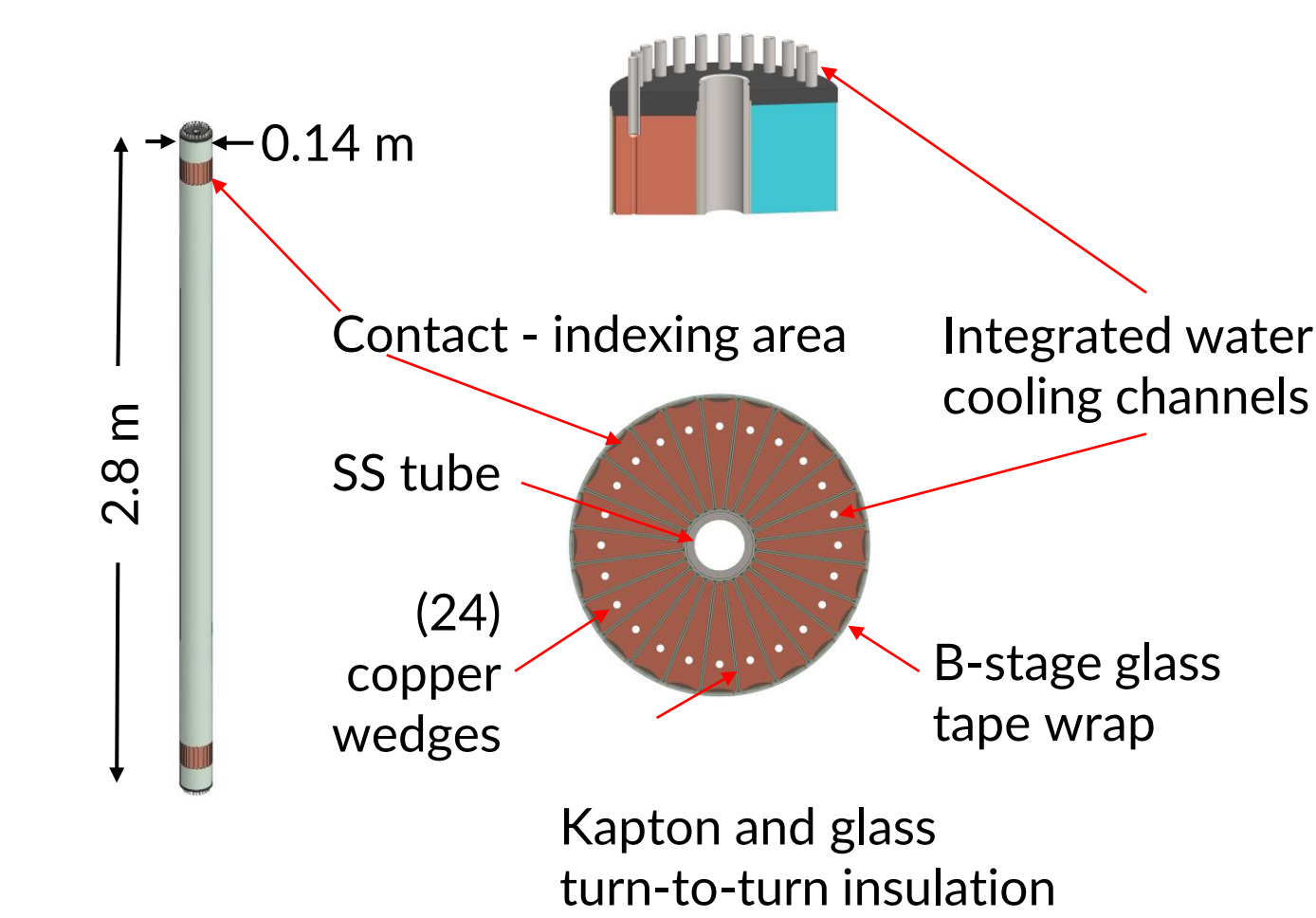
- I-Beam structure and outboard flex joint allow acceptable stress levels

**References:** [1] Sontag, et al., IEEE Trans. Plasma. Sci. (2022); doi: 10.1109/TPS.2022.3184626  
[2] Reusch et al., IEEE Trans. Plasma. Sci. (2022); doi: 10.1109/TPS.2022.3171510;  
[3] Bongard, et al., IEEE Trans. Plasma. Sci. (2022); doi: 10.1109/TPS.2022.3165694

## All Major PEGASUS-III Upgrade Sub-Assemblies are Nearing Completion

### TF bundle

- 24 conductor, water cooled copper
- Utilize solenoid space for more conductor



TF bundle installed in vacuum wall



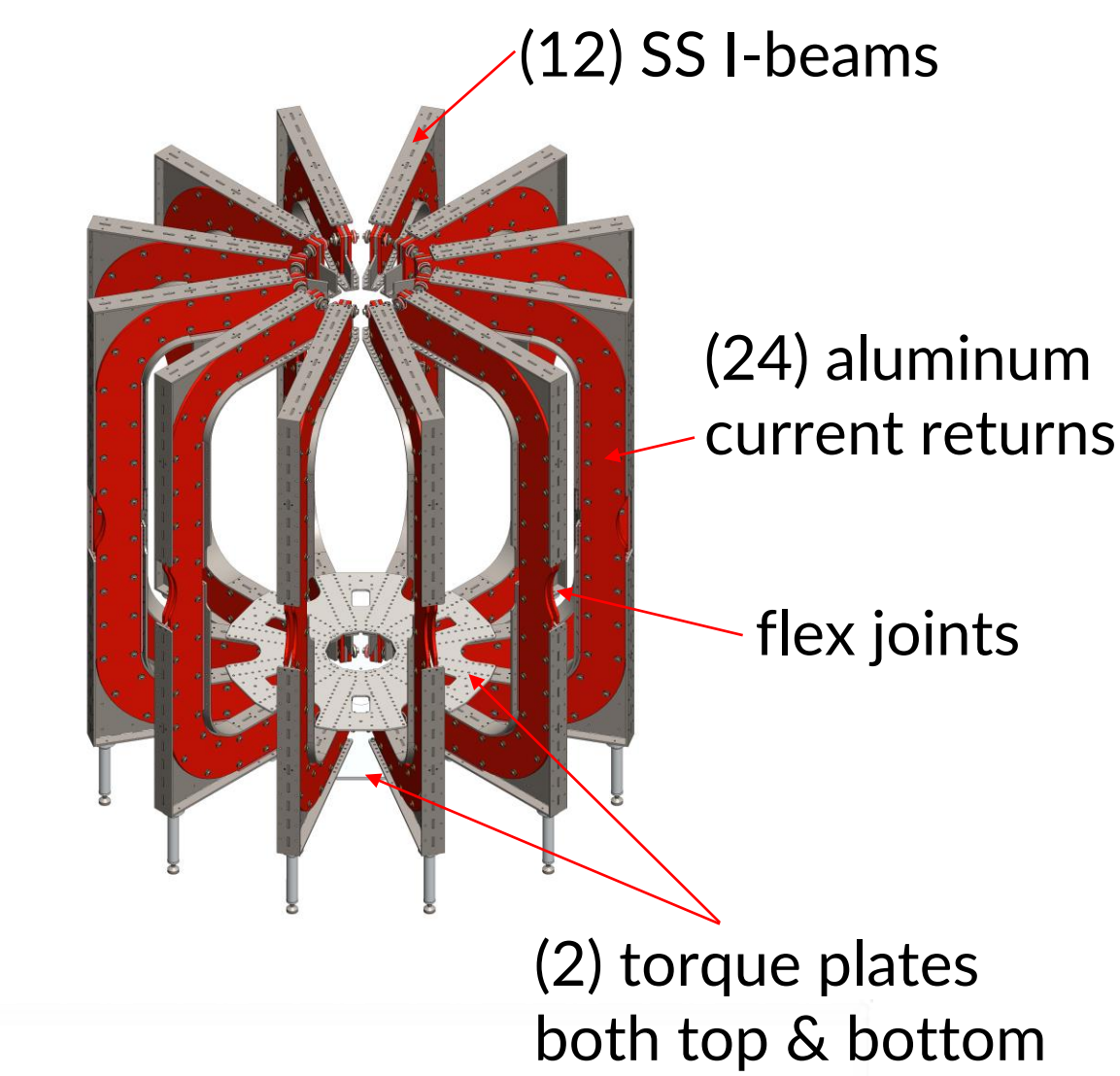
Contact - indexing area

Interior of vacuum vessel showing new vacuum wall covered in core armor and new LHI hardware



### TF Return Structure & Torque Assembly

- TF return structure
  - 12 stainless steel I-beams supporting 2 aluminum conductors each
  - Two plates connect all beams, top & bottom
- Torque assembly
  - Plates indexed to vessel
  - Allowed to travel vertically on pins
  - Support divertor coils as well as finger assembly
  - Vessel domes reinforced with ribs & gusset plates



Test fit of "C's" returns on vessel

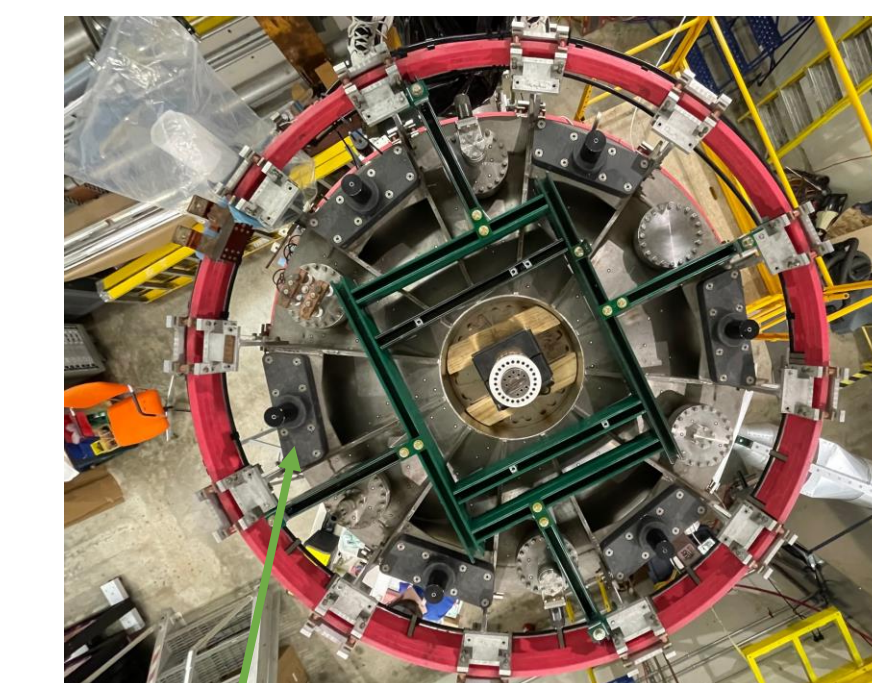


### Return assembly (the C's)

### TF bundle

### Torque assembly

Six pin blocks and pins installed on vessel (top shown here)



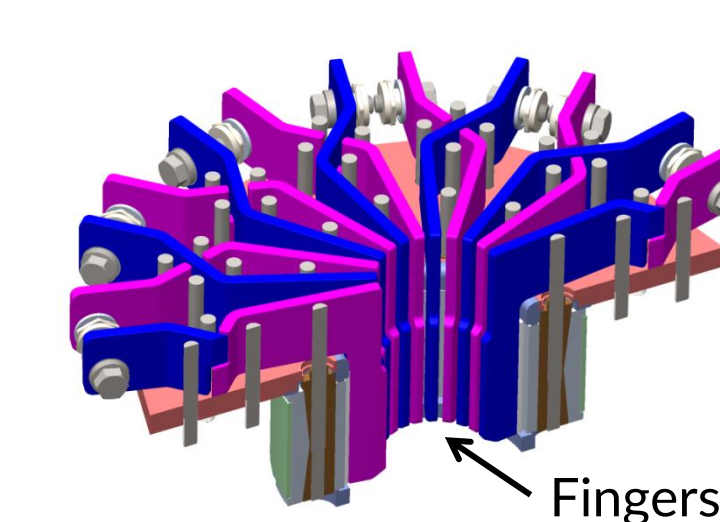
- Pin block with pin attached to gusset plate reinforced ribs

### Finger assembly

### Divertor coils

- see M.D. Nornberg, CP11.00046 for diagnostics
- see A.C. Sontag, CP11.00045 for LHI

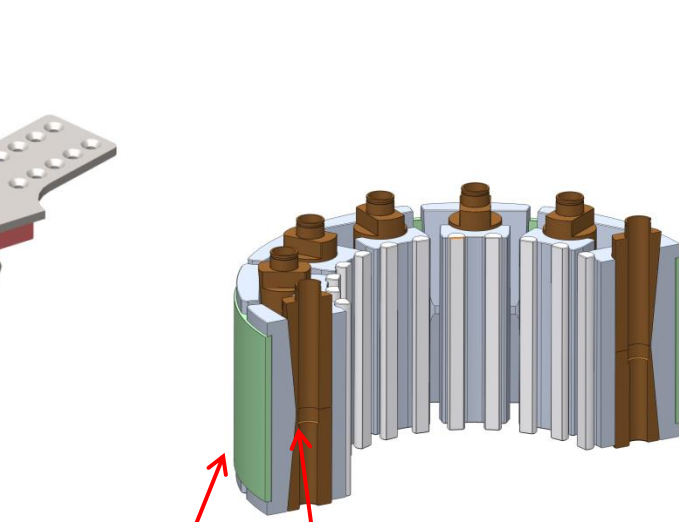
### Finger Assembly



- Fingers are electrical connection between return structure (C's) and center bundle

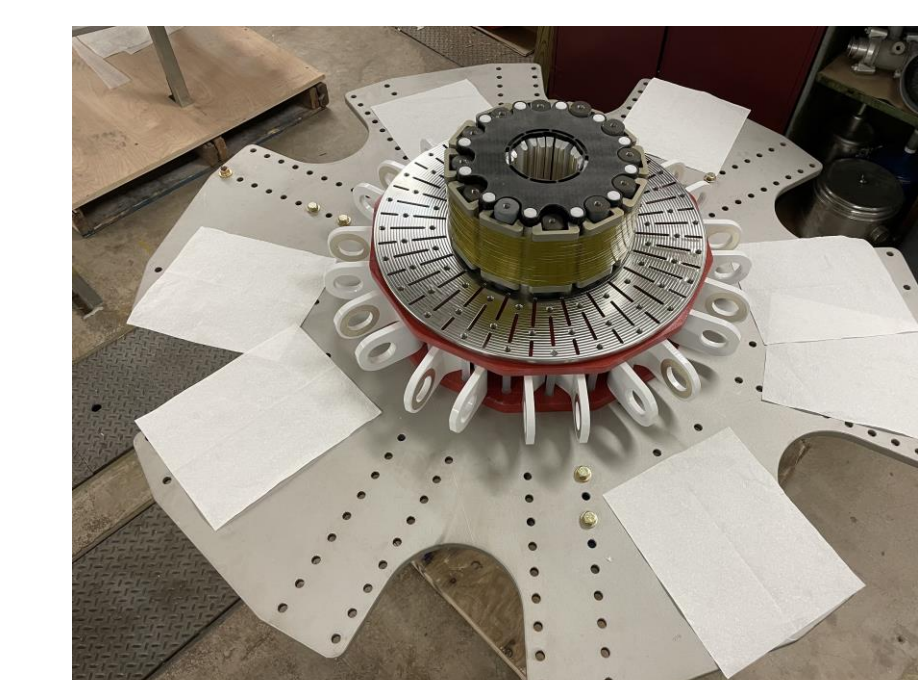
- Adjacent conductor cross-over eliminates back-winding

- 30N/mm<sup>2</sup> compressive pressure provided by finger assembly
  - Minimizes electrical resistance
  - Prevents slipping of finger at TF bundle interface



- Wedge tightening stretches filament belt to produce radial compression force

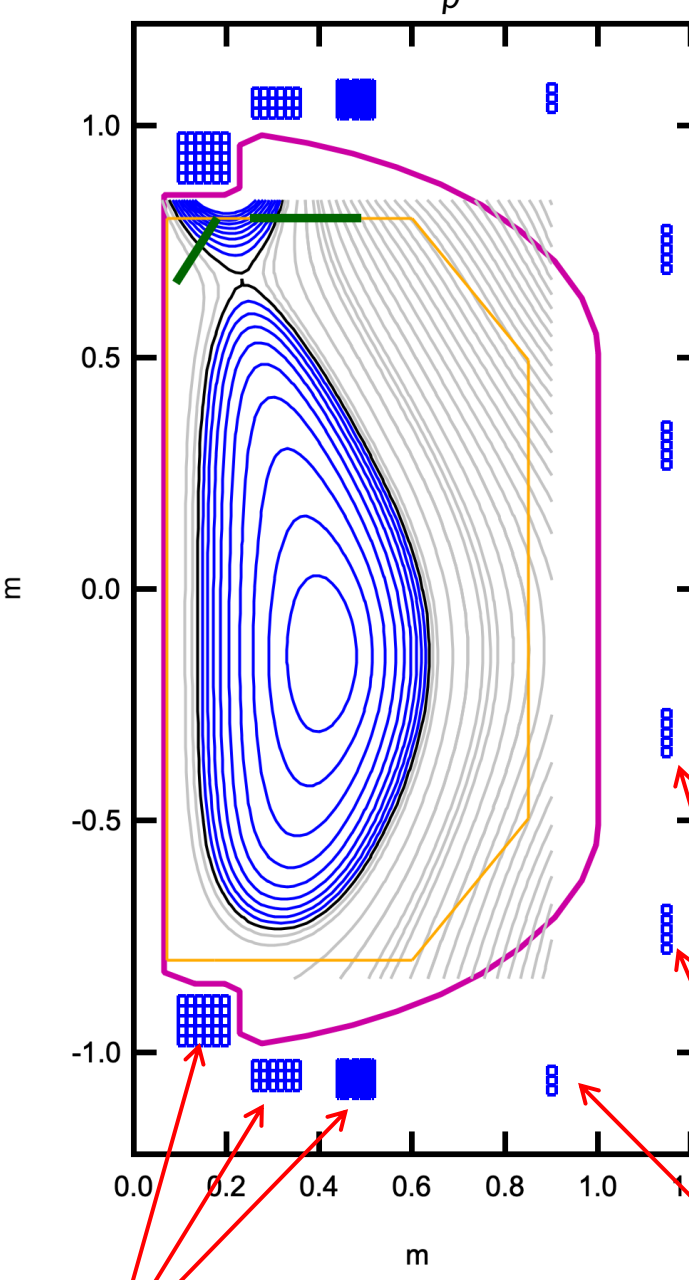
Test fit of finger assembly on torque plate & finger assembly compression check



### Divertor Coils

- New divertor coil triplet, both upper and lower, allows CHI operation<sup>2</sup>
  - 30/18/14-turn coil set from inner to outer R
  - 480/288/224 kA-turn capability
  - Coils tapped at 1/3, 2/3 ratio for flexibility
- see J.A. Reusch, CP11.00044

CHI driven:  $I_p = 375$  kA



- New divertor coils

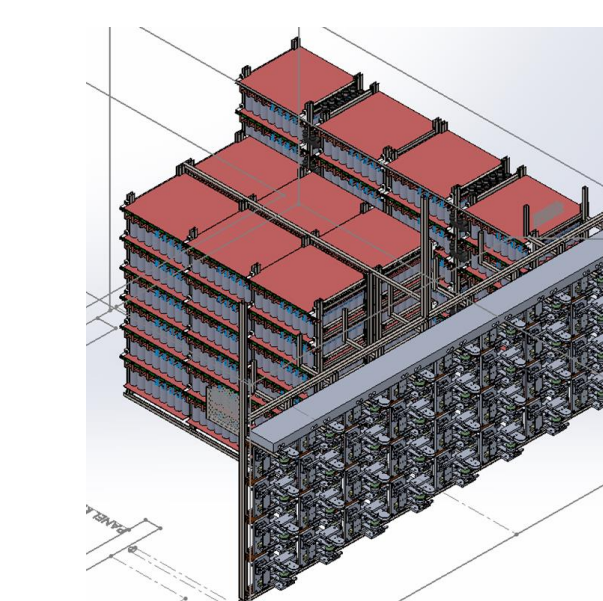
Test fit and alignment of upper divertor coils



- Existing PF coils

## Multiple Power Systems Support PEGASUS-III Physics Mission

- 175 MVA of switching power amplifiers deployed for PEGASUS-III electromagnets and LHI systems<sup>3</sup>
  - Reallocation of legacy PEGASUS systems
  - New TF bridge configuration
- Multi-level buck converter for advanced LHI  $V_{inj}(t)$
- Zero voltage switching resonant converters for diagnostic beam and RF sources
  - Successful tests at low power; scaling to high voltage and reduced ripple
- Distributed energy storage and control systems developed
  - 8.5 MJ stored energy commissioned
- Digital control and protection systems implemented
  - Real-time computing and FPGA programmable hardware
  - 16 digital feedback controllers



Switchyard built for LHI power supplies

Designed and as built switchyard for TF and PF power supplies

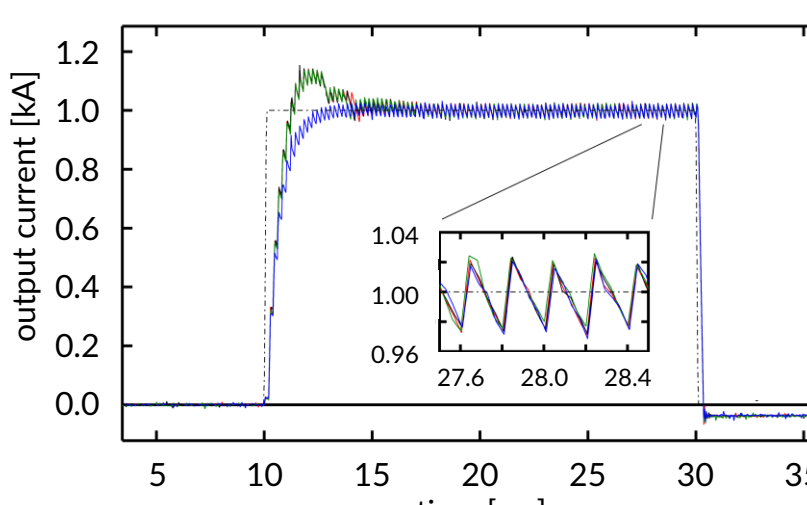


Zero voltage switching resonant converter being constructed



### Status of Power Systems

- TF, PF, and LHI supplies constructed
  - Buck converters for TF and PF
  - Multi-level buck converter for LHI bias
- 8.5 MJ of stored energy installed and conditioned
  - Charge/dump circuitry functional
- Individual switch testing ongoing
  - Low-power certification complete
  - Dummy load testing
  - DPWM / control tests demonstrated



## Status of PEGASUS-III

- Commissioning of PEGASUS-III has begun
  - Testing power supplies
  - In-vessel diagnostics installed
- Magnet assembly and testing to finish in late 2022
- Conditioning vacuum vessel and LHI injectors in late 2022
- Plasma operations to commence in early 2023

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