Alternate PF and TF designs

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26 July 2001

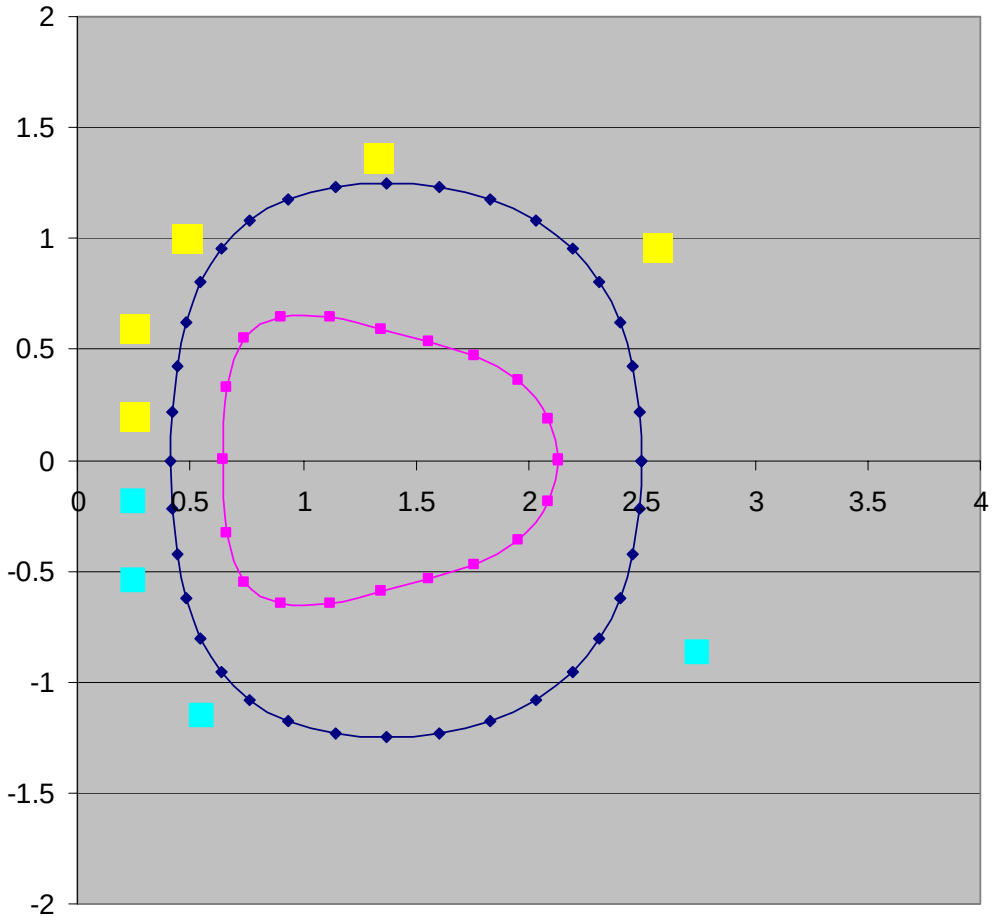
5 coil axisymmetric PF option developed

- **Feedback from Pomphrey is that 4 PF coils were inadequate, octupole not required**
- **Developed coil positions by fitting…**
  - **PF5 to minimize $B_{1,0}$ (dipole-like)**
  - **PF4 to minimize $B_{2,0}$ (quadrupole-like)**
  - **PF3 to minimize $B_{3,0}$ (hexapole-like)**
  - **PF1 and PF2 to act as solenoid coils**
    - **Provide inductive flux swing**
    - **Almost identical to existing PF1 and PF2**
- **PF coils were positioned outside reference TF coils**
  - **Positions/envelopes to be checked by ORNL**

New coil positions

	R(m)	Z(m)
PF1	0.250	0.200
PF2	0.250	0.600
PF3	0.486	1.000
PF4	1.327	1.372
PF5	2.570	0.964

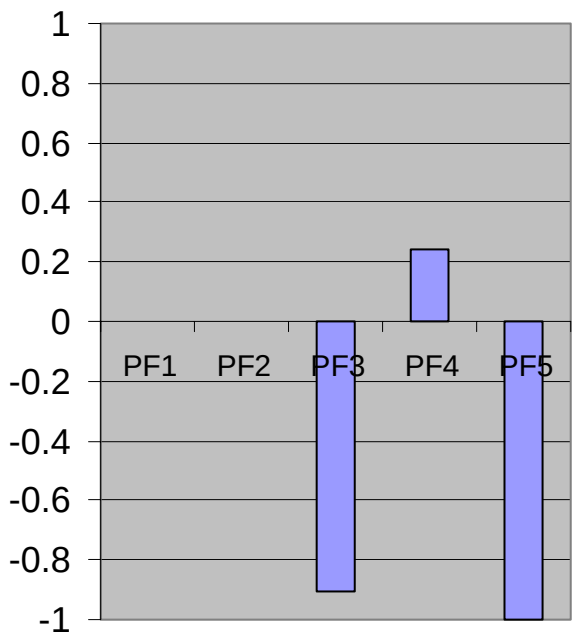
Significant difference is the addition of a PF coil at the major radius (positioned for quadrupole field)

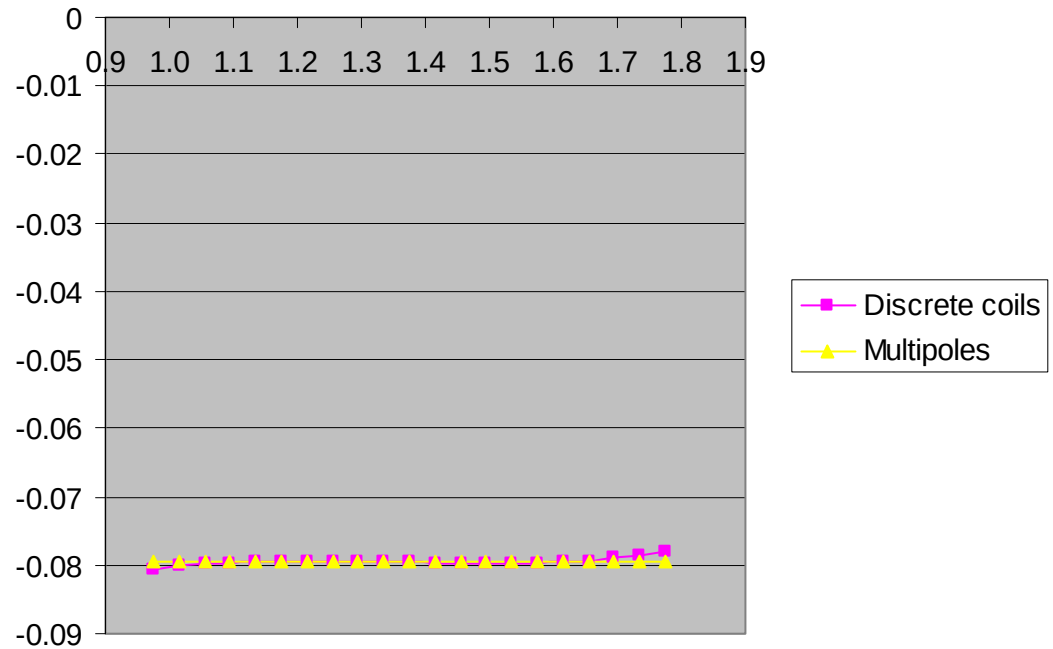


Reasonable fits found to multipole fields

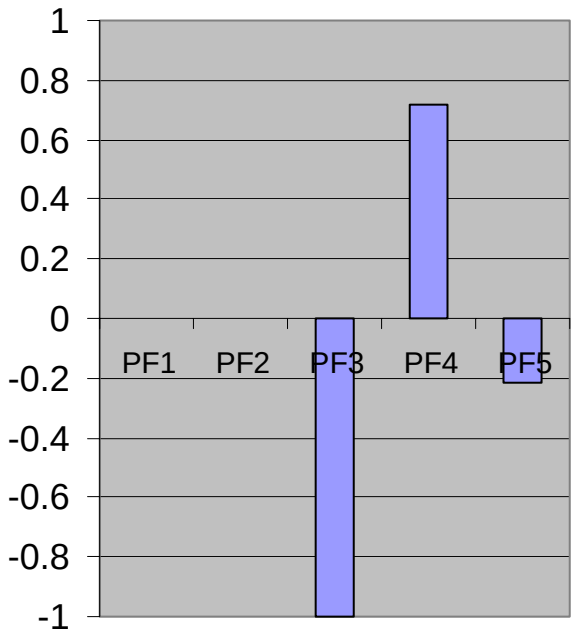
- **Good fits within ±0.3m of magnetic axis (1.075-1.675m)**
- **Better fits to lower order multipoles (dipole, quadrupole) than high order multipoles (hexapole, octupole)**
- **Better fits using all coils can be obtained**
- **Good OH distribution found**

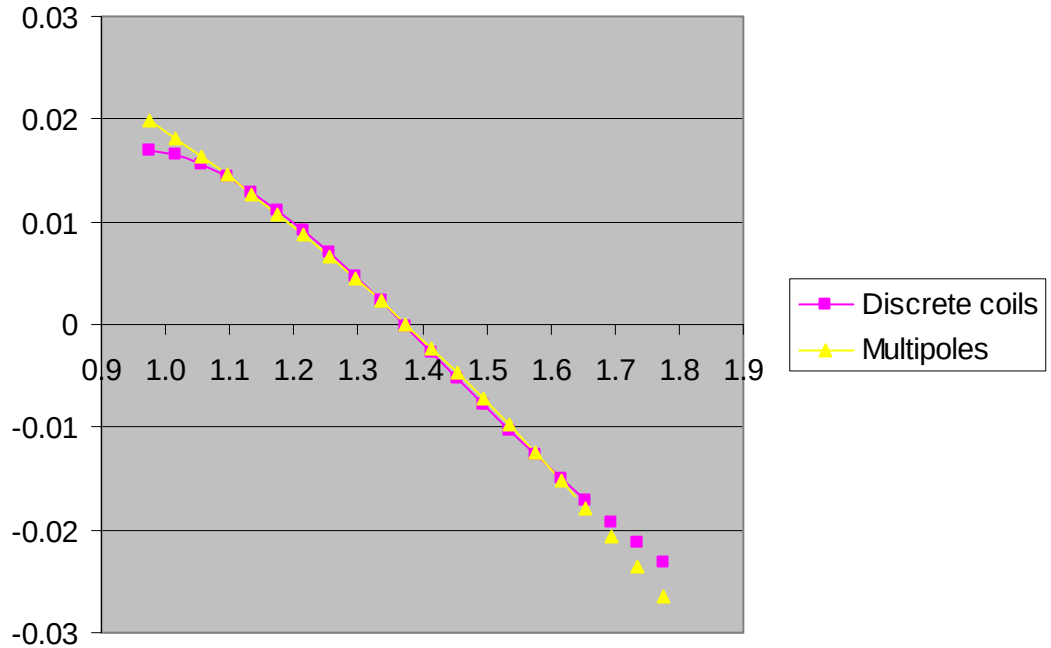
Fit to dipole field with 3 coils (PF3-5)





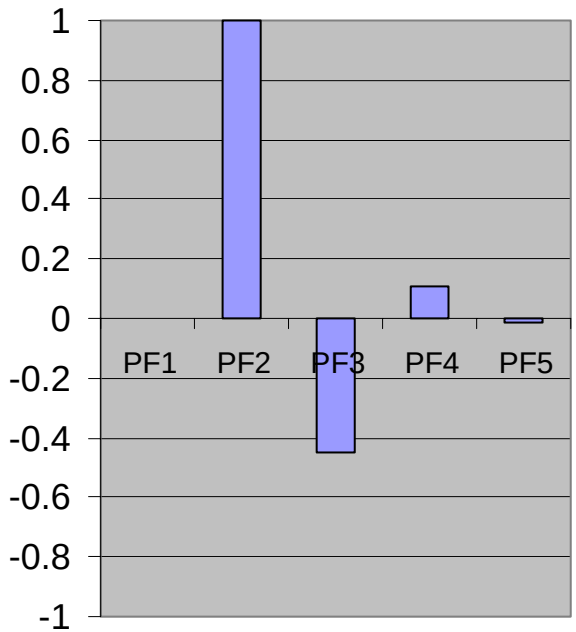
Fit to quadrupole field with 3 coils (PF3-5)

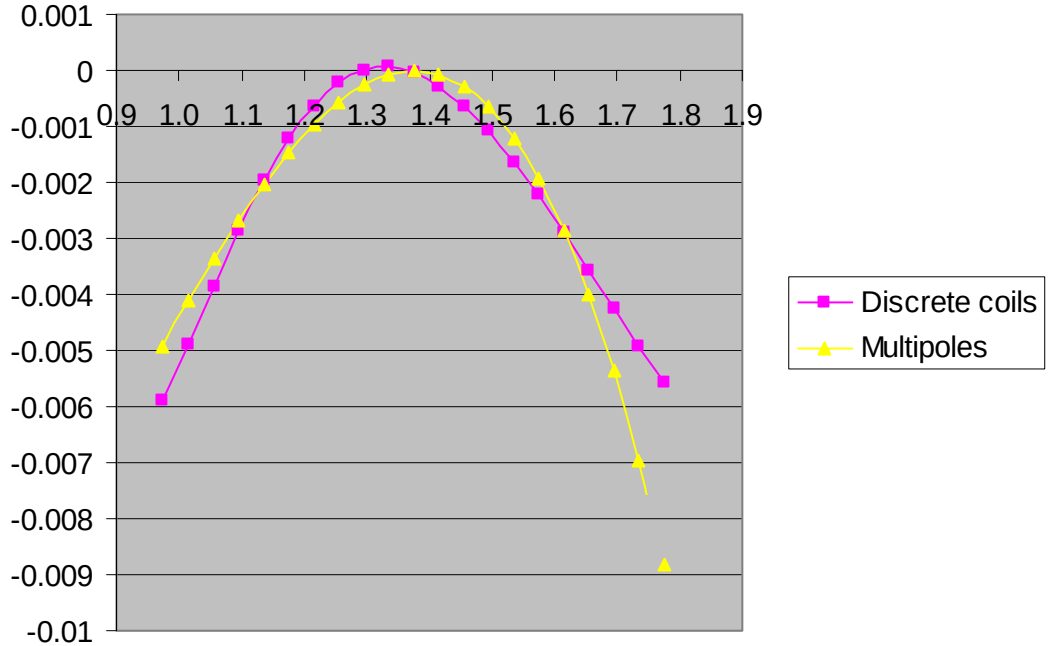




Fit to hexapole field with 4 coils (PF2-5)

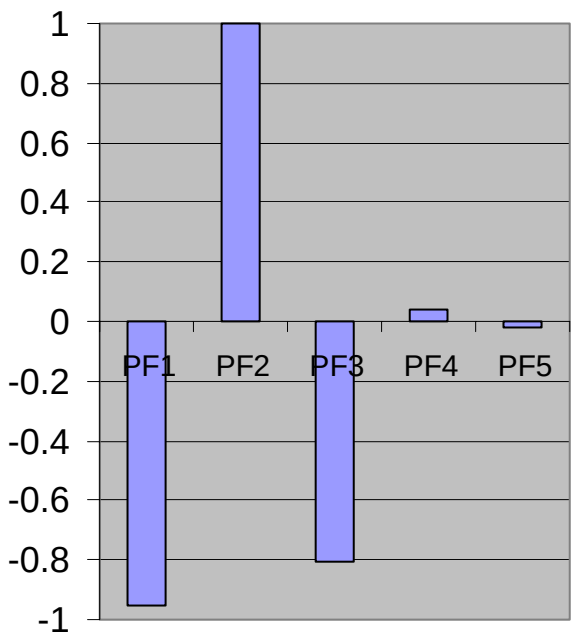
- **Better fit can be obtained using all 5 coils**

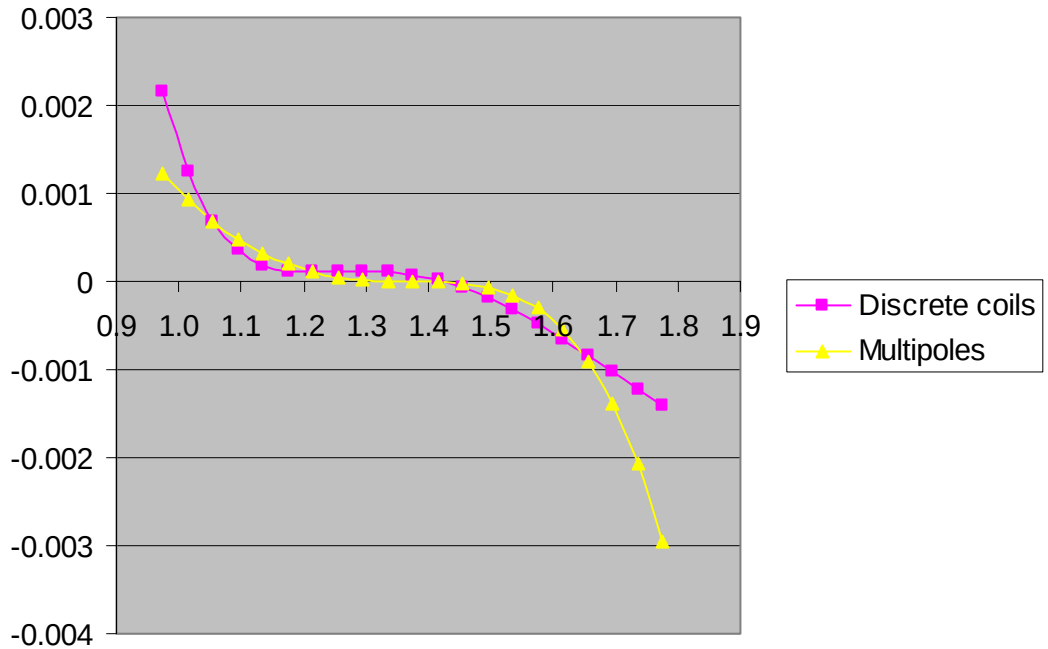




Fit to octupole using all coils

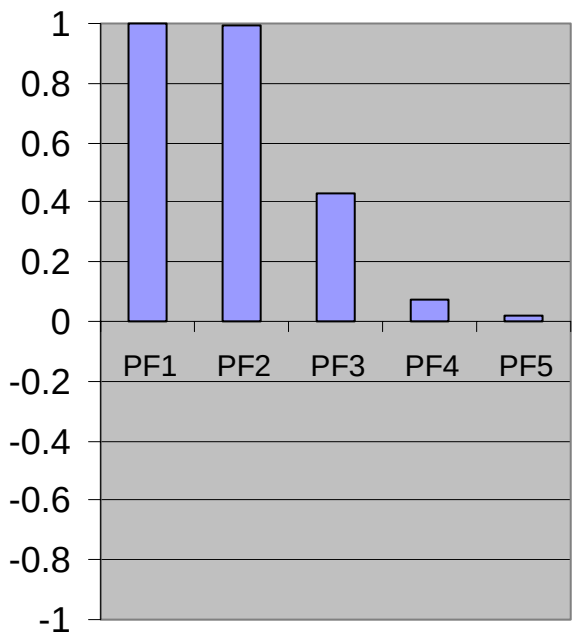
- **Fit gets rough for R<1.05 and R>1.65**

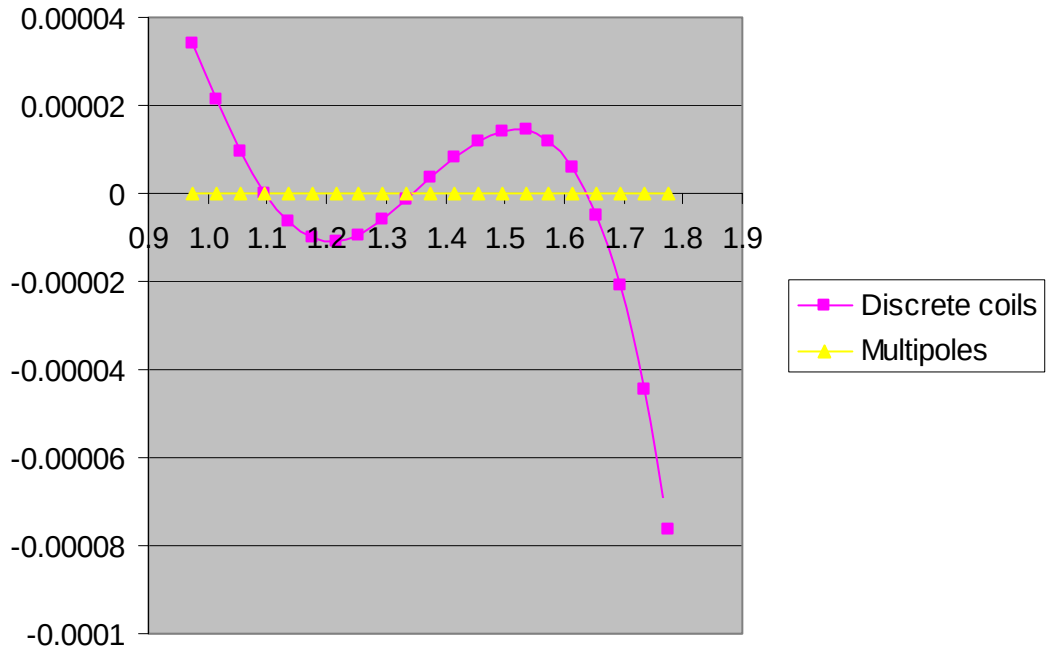




1 Vs OH distribution

- **$|B_p|$ less than 0.2 gauss between 1.0-1.7m**





Alternate PF substantially improves OH and quadrupole fits

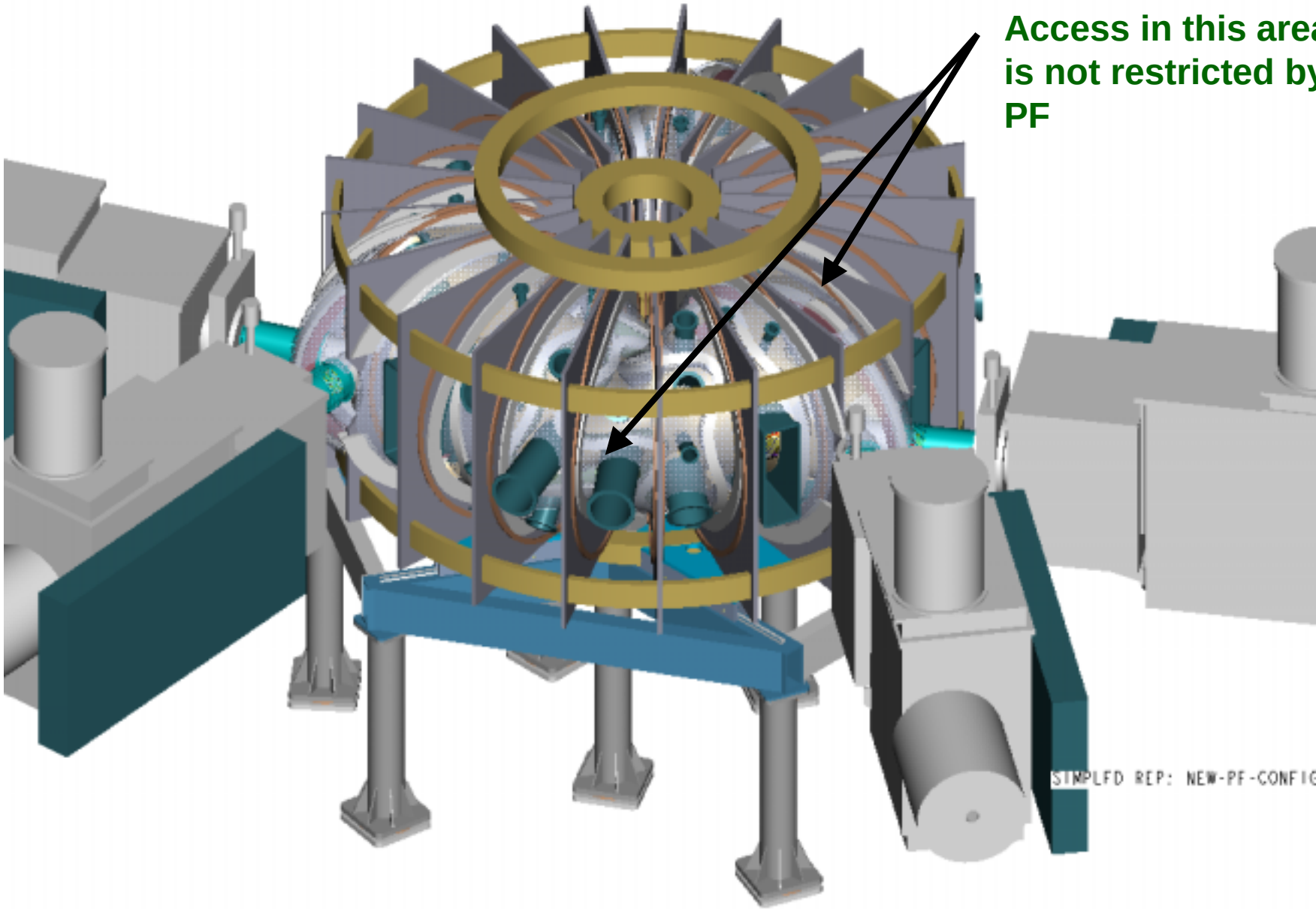
- **Deficiencies in reference PF attributable to lack of "quadrupole" coil**

	Relative Error	Relative Jmax	Relative Amp-m	Comments
Alternate PF				
Dipole	**20**	1.13	1.10	**3 coils (alternate) v. 4 coils (reference)**
Quadrupole	**0.30**	**0.08**	**0.54**	
Hexapole	0.74	0.74	**0.51**	
Octupole	**1.30**	0.73	0.92	
Nullapole	**0.002**	0.87	0.98	**|B|<0.2 gauss for 1.1<R<1.7m (v. 5 gauss for the reference PF)**
Reference PF with 5th coil added				
Quadrupole	**0.18**	**0.07**	**0.54**	
Nullapole	**0.002**	1.12	1	**|B|<0.3 gauss for 1.1<R<1.7m**

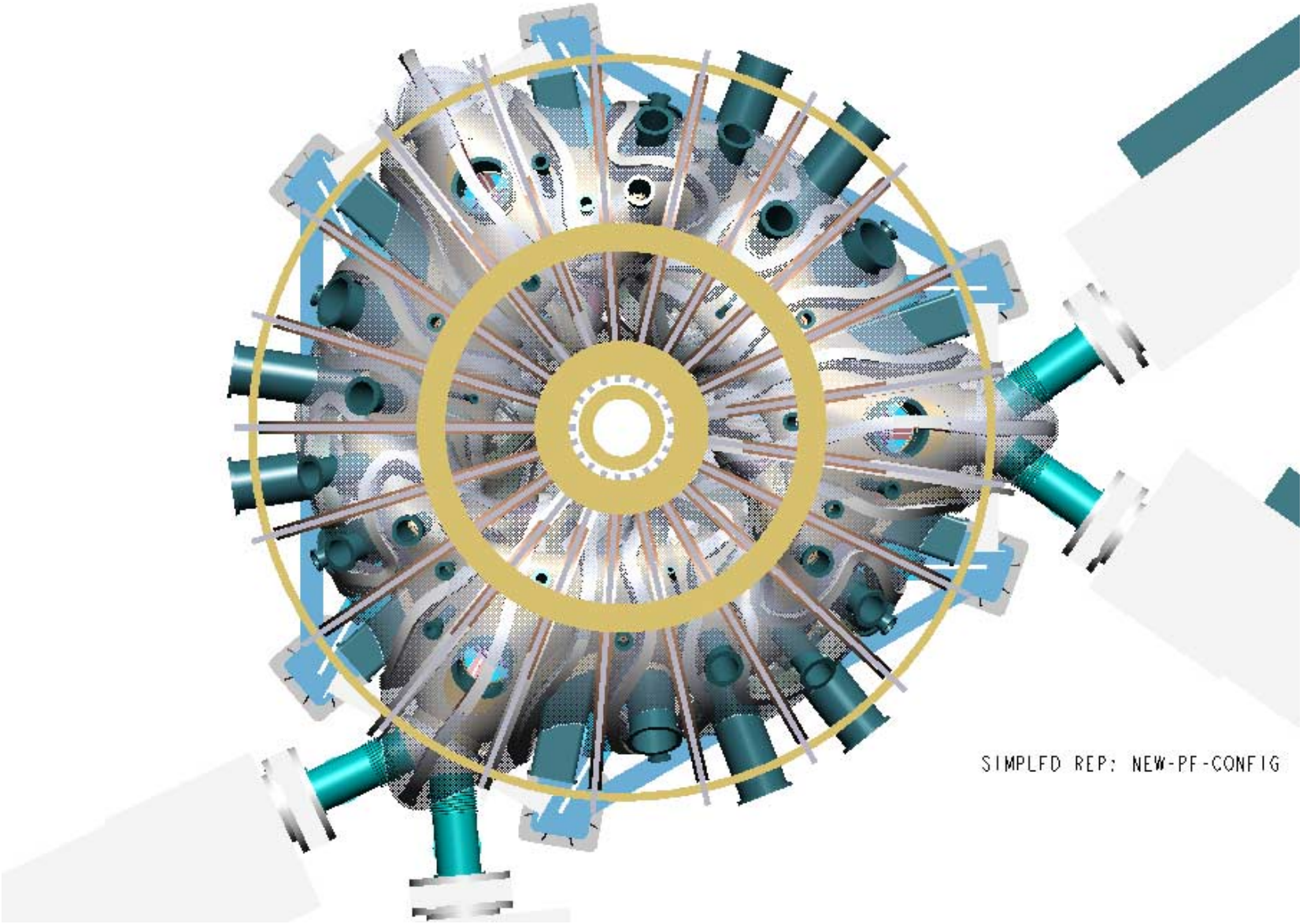
ORNL moved the coils slightly to avoid interferences, checked access

	Rc	Zc	dR	dZ
PF1	0.25	0.2	0.1	0.36
PF2	0.25	0.6	0.1	0.36
PF3	0.486	1.075	0.24	0.24
PF4	1.327	1.379	0.2	0.2
PF5	2.57	0.964	0.06	0.24

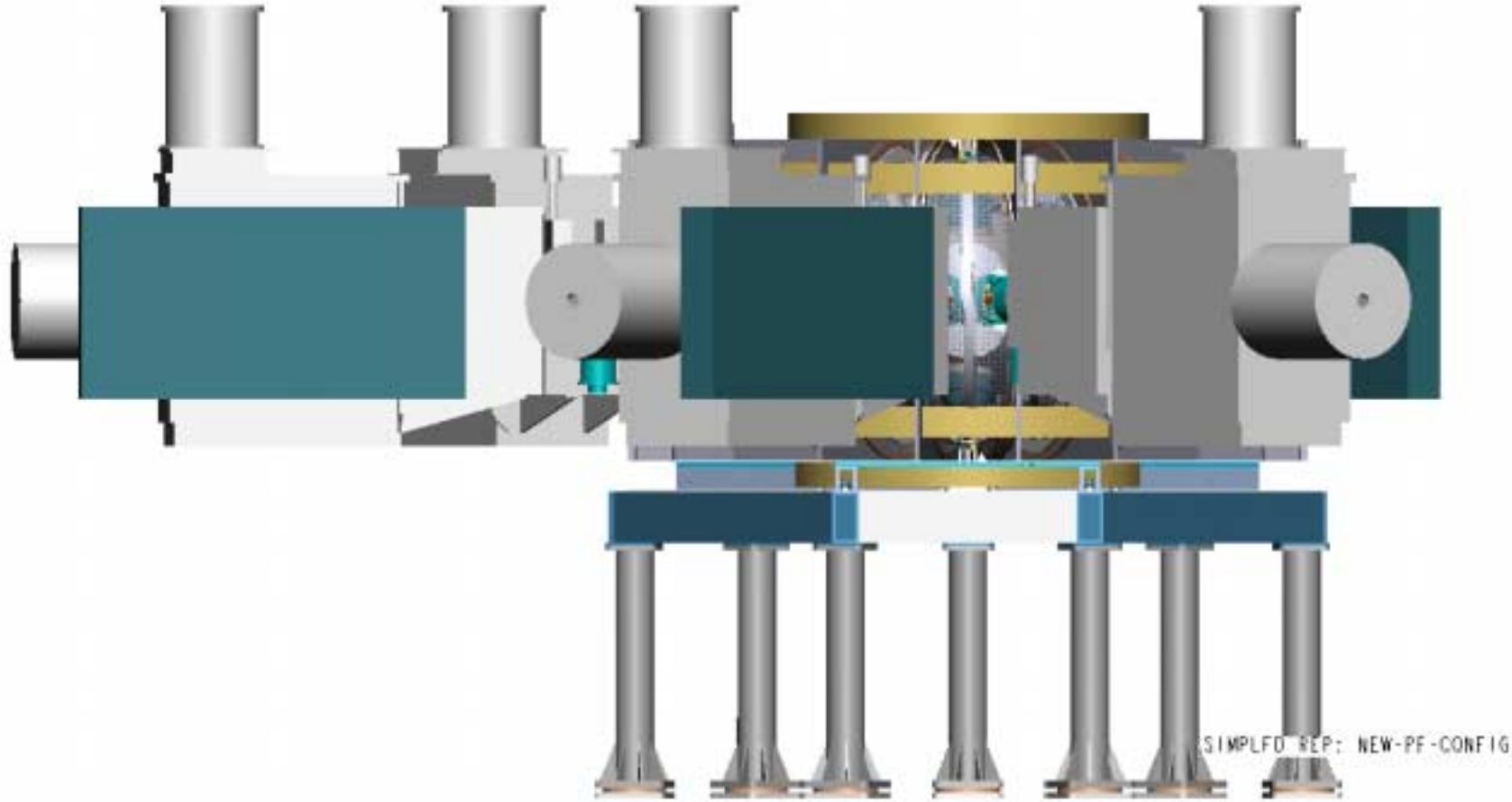
Alternate 5 coil PF configuration added to PVR machine configuration



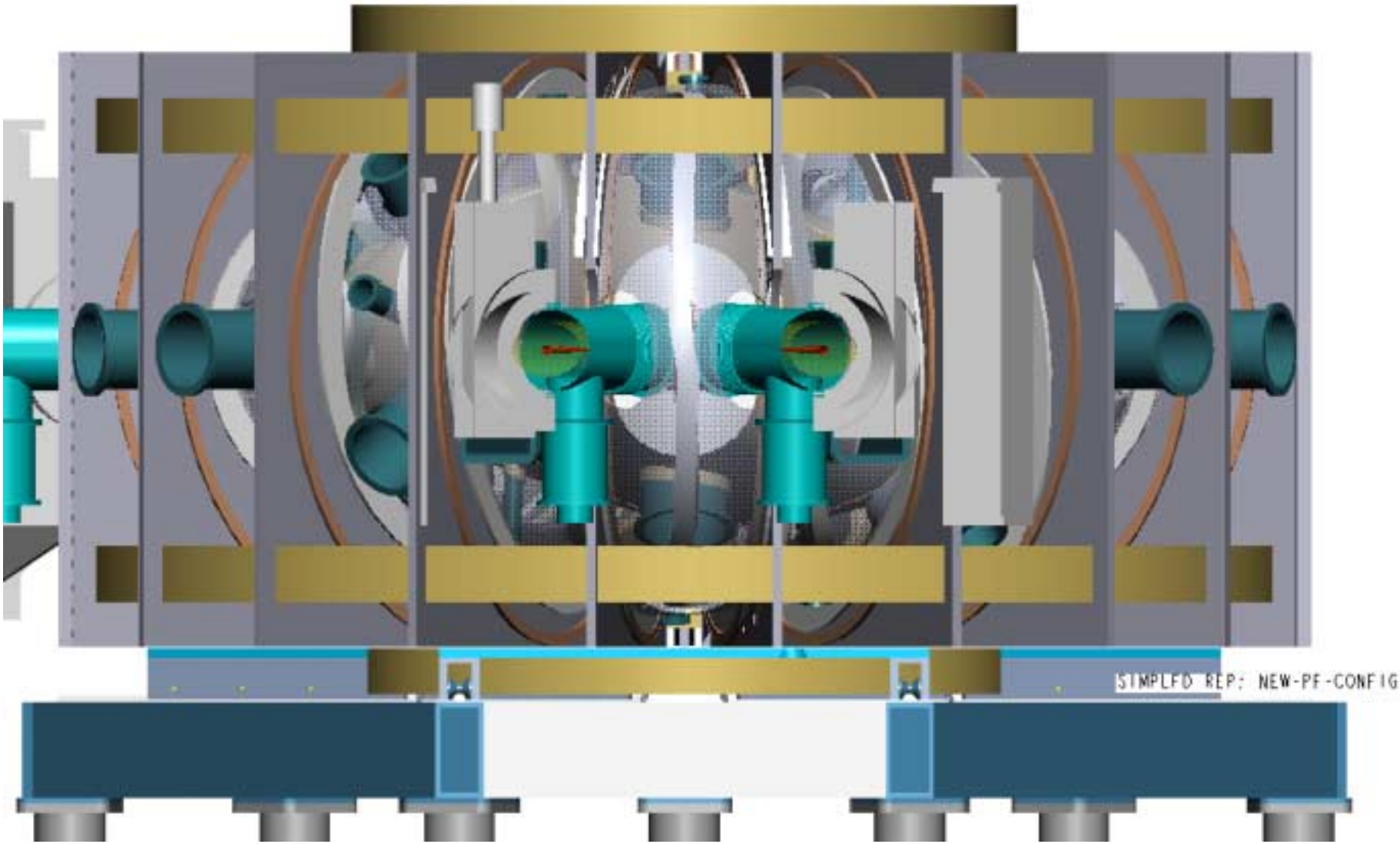
Top view – Access from top appears to be unrestricted by PF



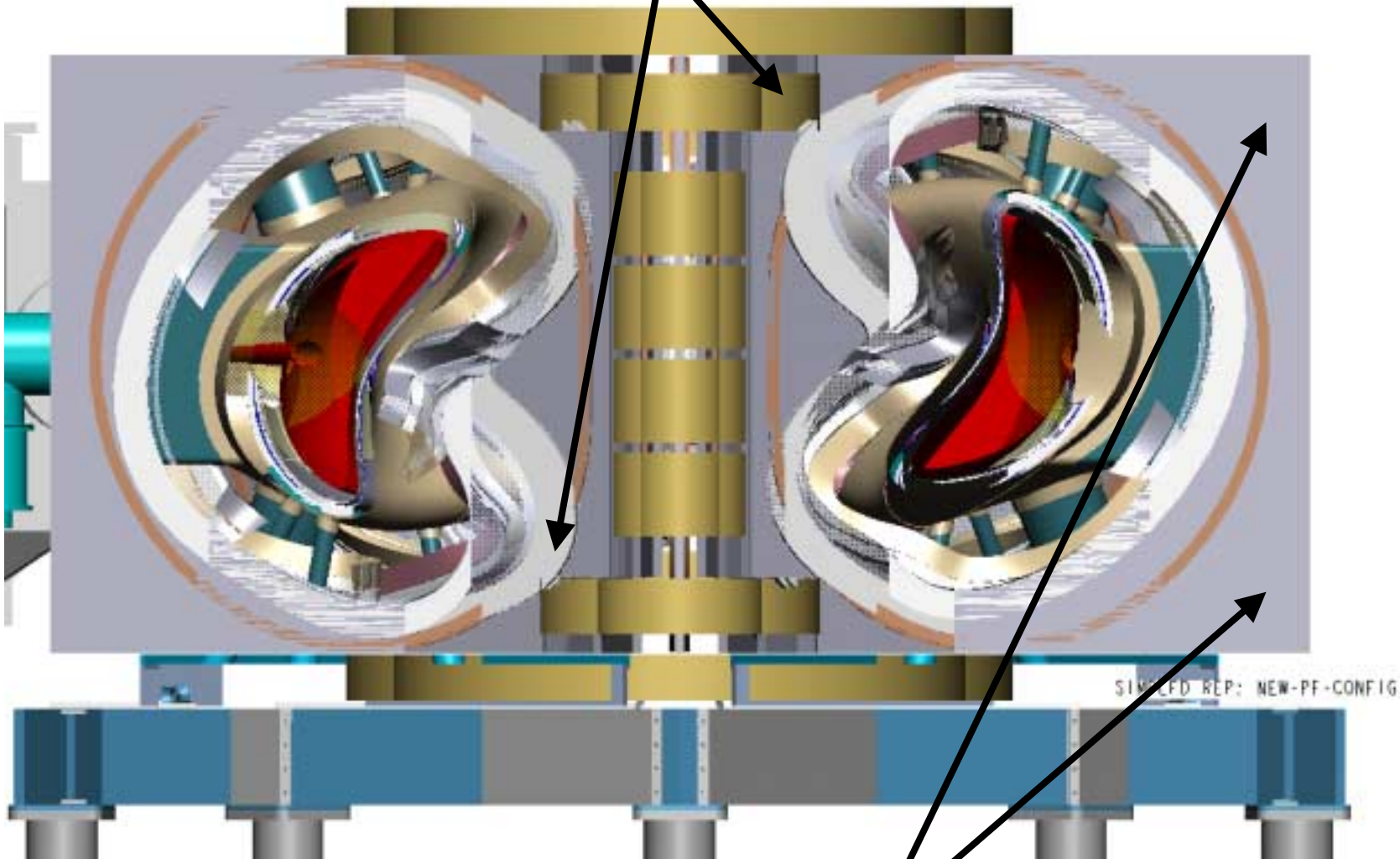
Right view – The next 2 slides show cut-away views from this position



Neutral Beam boxes removed. Access in this area is good.

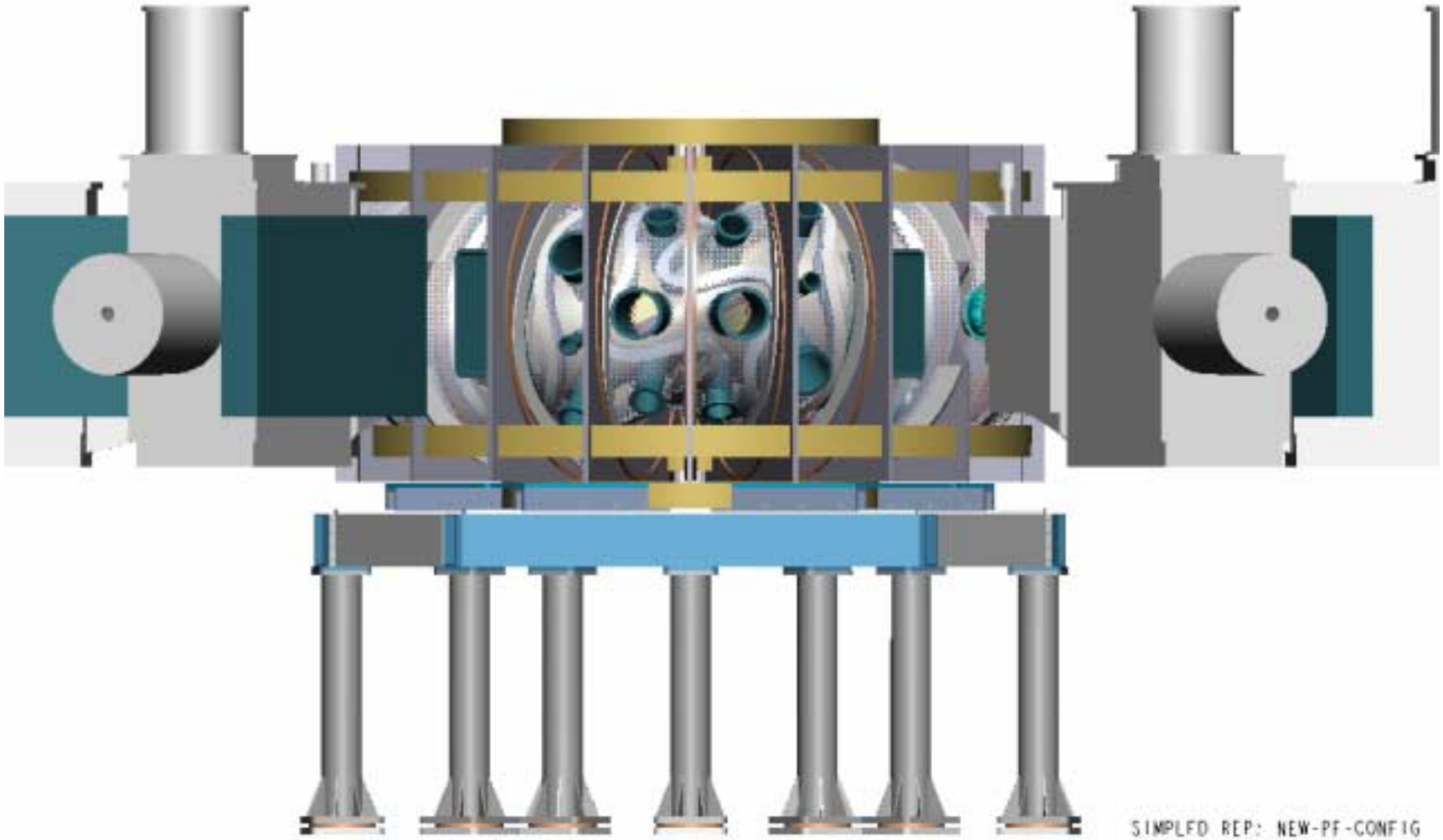


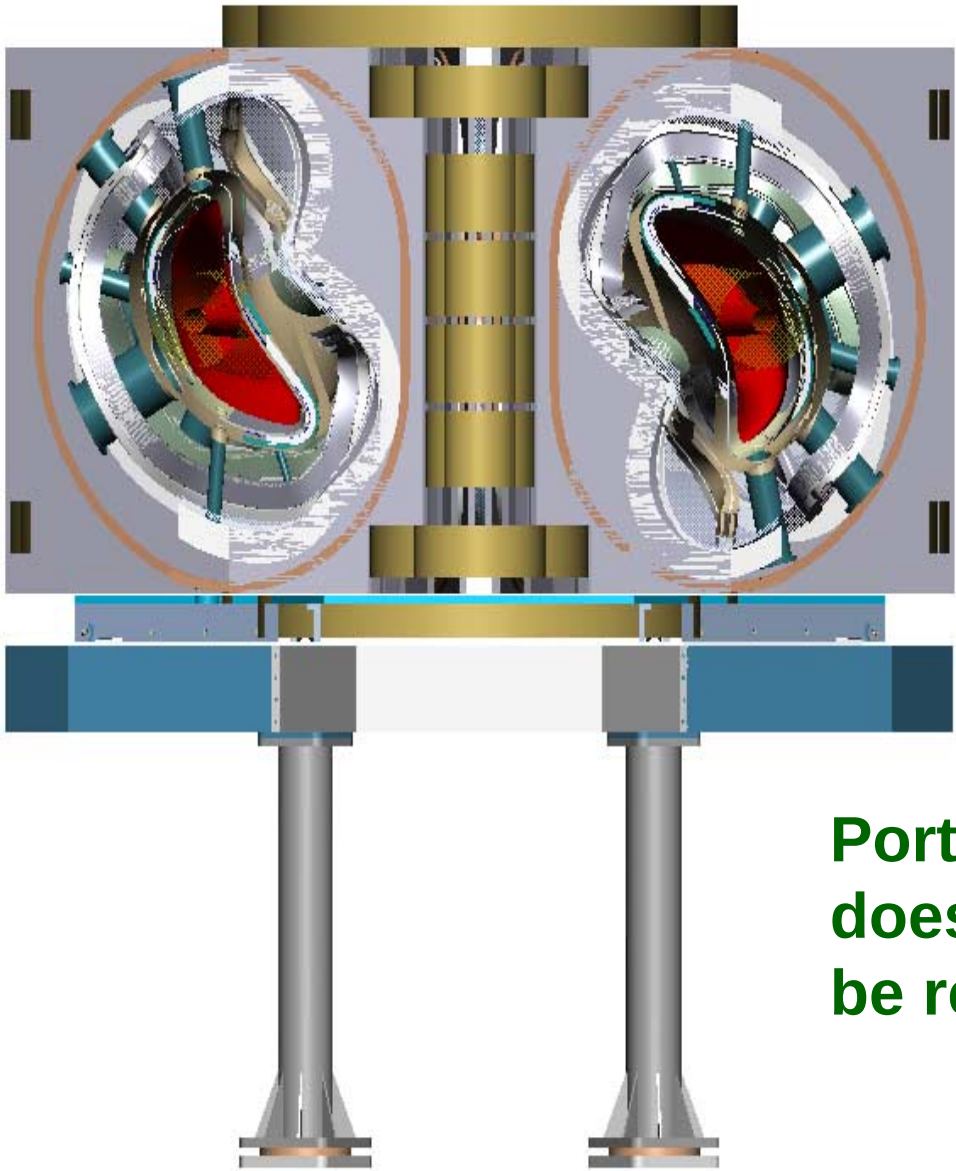
Access is not restricted in this view but an interference with PF3 and the modular coil is shown.



PF5 is not shown in this view.

View looking into the oblate section. The next slide is viewed from this orientation.





Port configuration does not appear to be restricted by PF.

SIMPLFD REP: NEW-PF-CONFIG

Summary of alternate 5-coil PF design

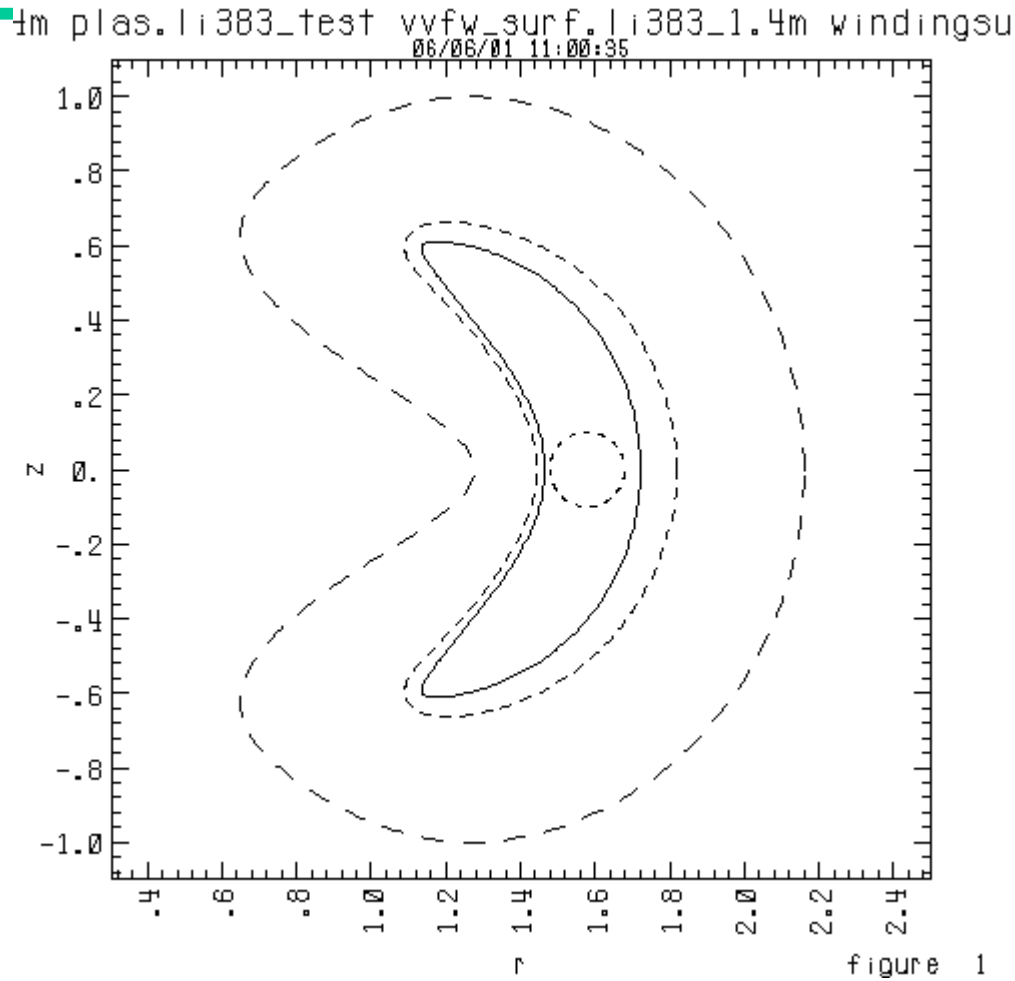
- **An alternate 5 coil PF design has been developed**
- **ORNL tweaked the coil locations (rc, zc) to avoid interferences and established envelope sizes**
- **Physics (Pomphrey) will assess physics performance relative to the reference 4 coil PF design**
- **Reiersen will develop a 5 coil non-circular PF design for comparison with this 5 coil circular option**

Non-1/R TF options

- A 1/R background toroidal field has been used in studies to date, primarily for flexibility
  - May be a good match to magnetic axis in traditional (large A, many field period) stellarators
  - Not so for small A, few field periods
- NCSX magnetic axis is non-circular, non-planar
  - R = 1.47 ± 0.10 m
  - Z = ± 0.06 m
- Improve core quasi-symmetry with non-1/R background field? Improve access with fewer coils?

Methodology

- **Described at June 10 project meeting**
- **Place 10cm radius surface around magnetic axis**
- **Place TF outside winding surface for modular coils**
- **Design TF to minimize B_n**
- **Compare flexibility and access**



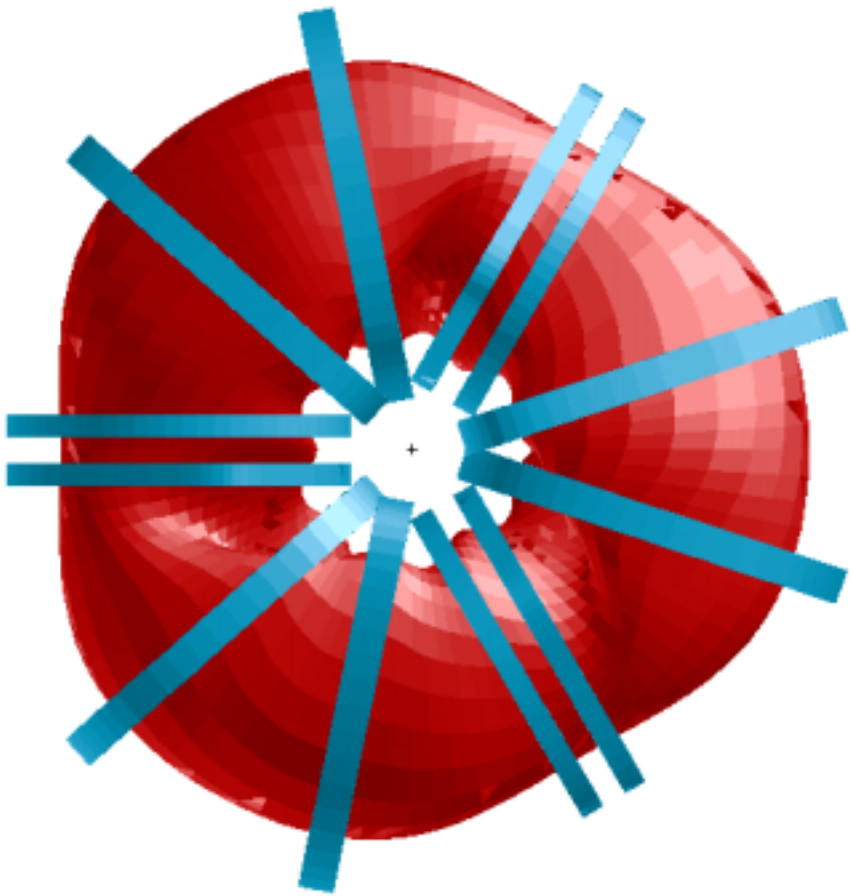
Options

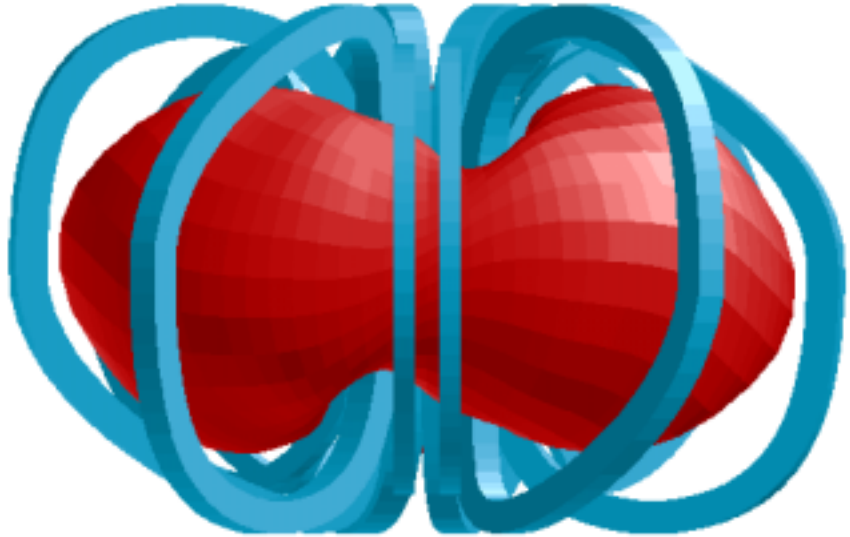
- Reference 21-coil TF
  - Closely approximates 1/R field
  - Blocks access at v=0.5
- 12-coil TF
  - Access at v=0.5 provided via split coil
  - Additional coil at v=0.14 (optimally positioned)
  - Vertical, planar TF coils offset from modular coil winding surface
  - Twist [z-rotation] allowed by optimum appears to be near zero
- 18-coil TF
  - Coil at v=0.14 replaced with coils at v=0.07, 0.21 to preserve machine segmentation for 18 and 21 modular coil options (ref. Williamson presentation today)

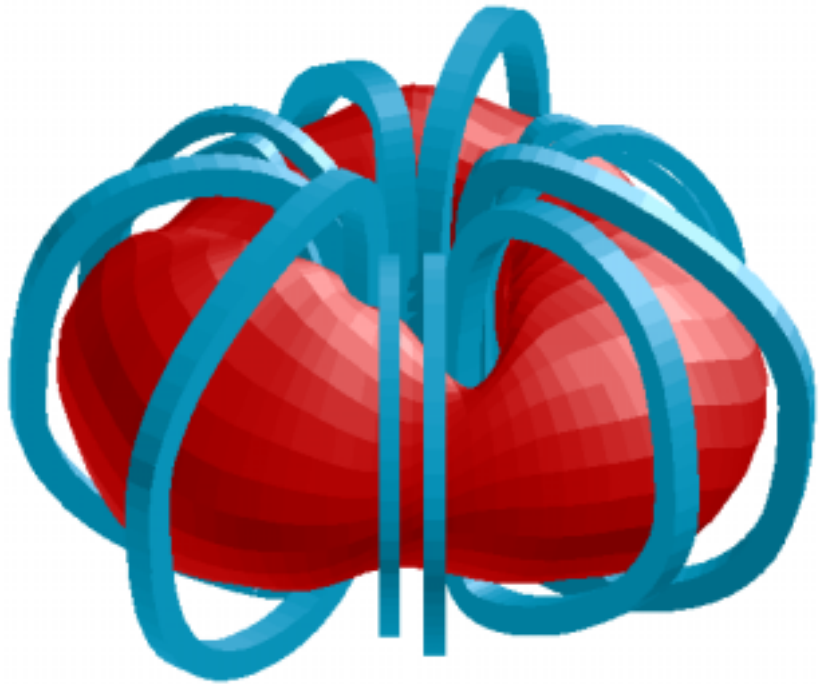
Fit comparison

Description	Bavg (Rel.)	Bmax (Rel.)	Amp-m (Rel.)
1/R background field	**2.3%**	**4.9%**	**-**
Ref. 21-coil TF design (equal size, equal spacing, equal currents)	**2.3% (1.00)**	**4.9% (1.00)**	**22.5 (1.00)**
Ref. 21-coil TF design (optimized currents peak at v=0.5, 0.07, zero in between)	**2.1% (0.91)**	**4.8% (0.98)**	**22.5 (1.00)**
Ref. 21-coil TF design (optimized currents, not constrained to be positive)	**1.8% (0.78)**	**4.8% (0.98)**	48.1 **(2.14)**
12-coil TF design (1 pair straddles v=0.5 and 1 pair located at v=0.14)	1.6% **(0.70)**	**4.1% (0.84)**	**24.1 (1.07)**
18-coil TF design (1 pair straddles v=0.5; additional pairs at v=0.07 and v=0.21)	1.6% **(0.70)**	**4.2% (0.86)**	**23.4 (1.04)**

12-coil TF option



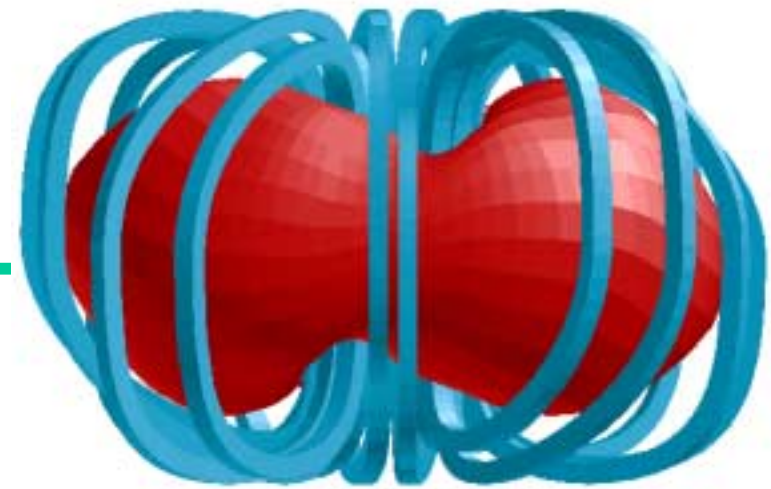


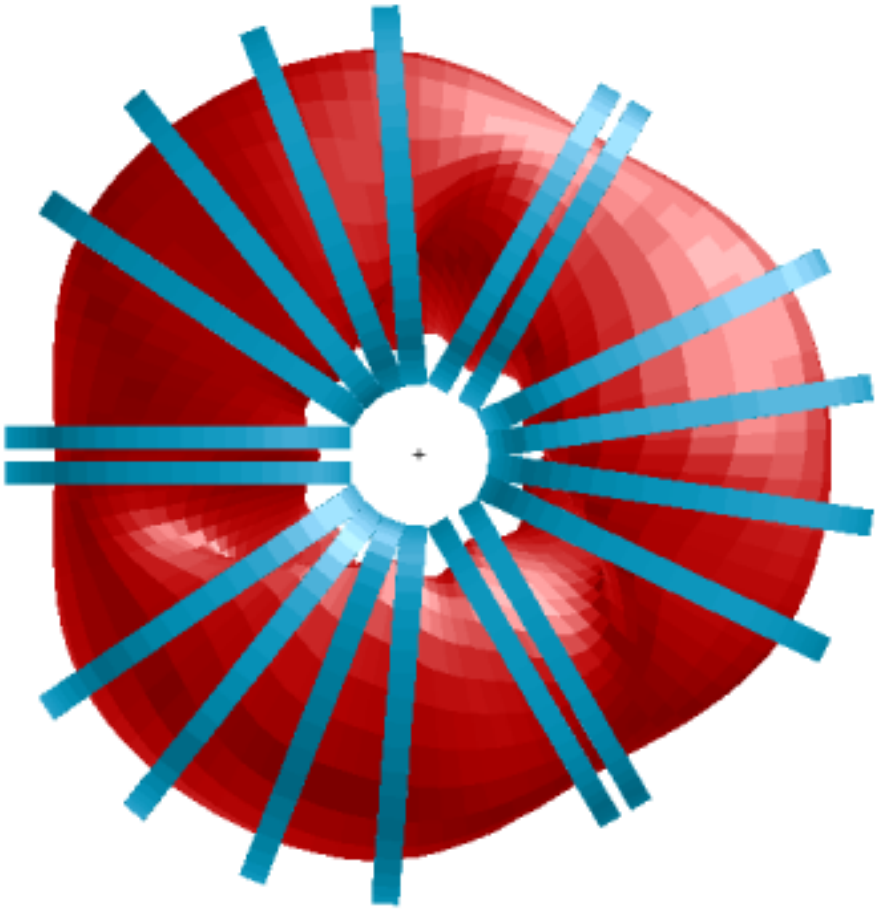


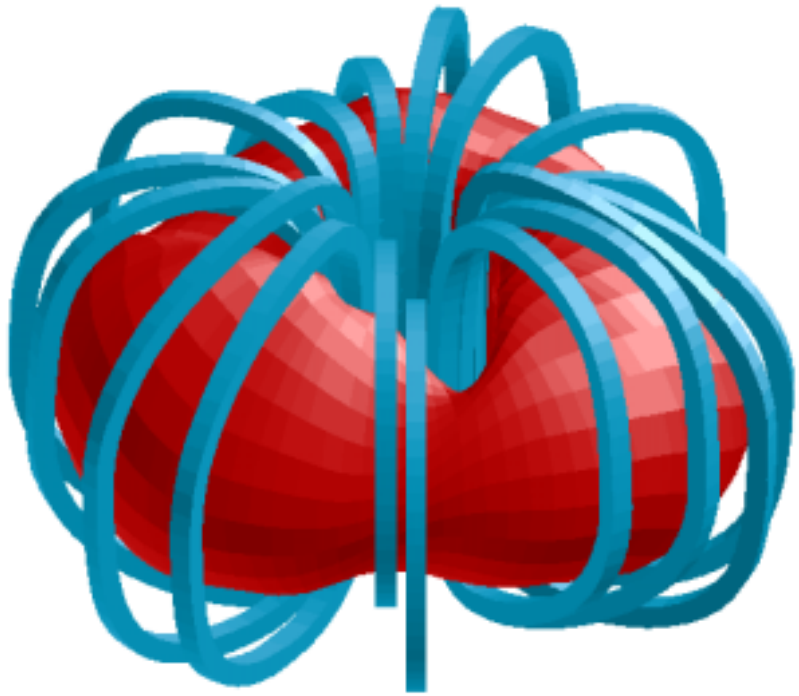
Pros and cons of 12-coil option

- Better fit to magnetic axis (Bavg down by 30%), improved quasi-symmetry in core**, possibly worse in edge**
- Diagnostic access provided at v=0.5
- Fewer coils (effectively, 9) may provide better access than with 21
- **May be run in single circuit on Day One (with a turn ratio of 3:7), just like reference TF**
- **Reduced cost (2 coil types, 12 coils total)**
- **Fewer circuits (2 v. 4) simplify control, reduce power supply cost but maybe with loss of flexibility**
- V=0.14 location inconsistent with present segmentation scheme (?)
- **Taller coils (1.54m v. 1.27m) may negatively impact PF performance**

18-coil TF option







Pros and cons of 18-coil option

- Consistent with segmentation scheme in reference TF design (v=0.35 coil is missing)
- Better fit to magnetic axis (Bavg down by 30%), improved quasi-symmetry in core**, possibly worse in edge**
- Diagnostic access provided at v=0.5
- Fewer coils (effectively, 15) may provide better access than 21
- **Fewer circuits (3 v. 4) simplify control, reduce power supply costs**
- More difficult to run in single circuit on Day One (awkward turn ratios required)
- **Probably no significant cost saving (3 coil types, 18 coils)**
- **Taller coils (1.53m v. 1.27m) may negatively impact PF performance**

Next steps for non-1/R TF options

- **Check impacts on access and segmentation for 12 and 18-coil options, propose improvements for 18-coil (e.g. 0628) and 21-coil (e.g.1017) options [ORNL]**

- **Check flexibility against 1/R (1-circuit) and 4-circuit options using reference TF coils [NP]**