Recent Progress on QPS Development

J. F. Lyon, ORNL

representing the QPS Team

OFES Site Visit August 14, 2002

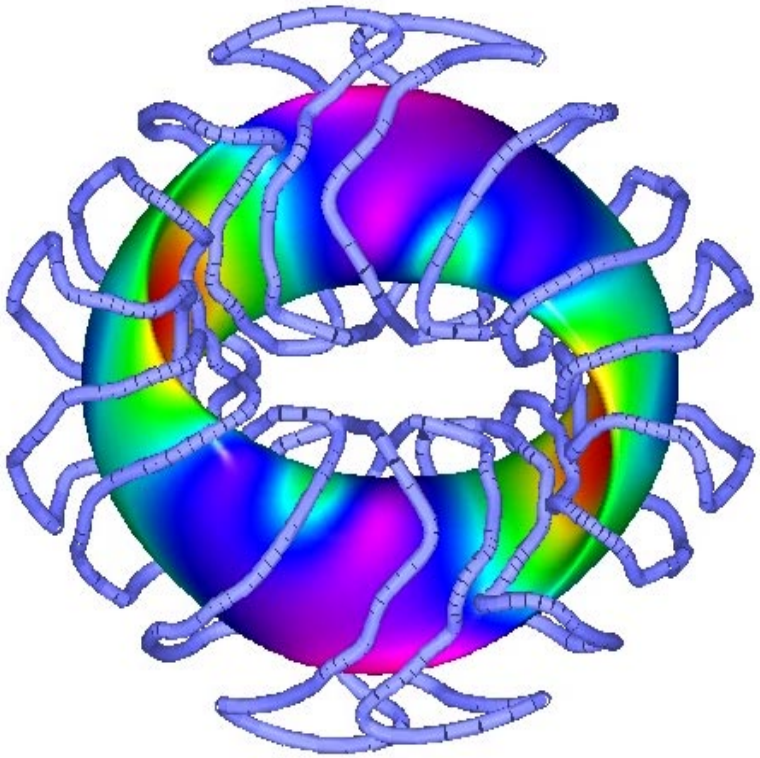
Multi-Laboratory QPS Team

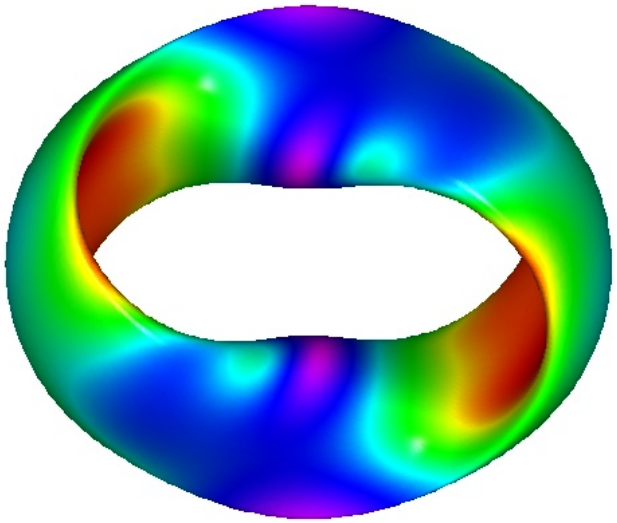
- **ORNL – D.B. Batchelor, L.A. Berry, M.J. Cole, *R.H. Fowler*, P. Goranson, E.F. Jaeger, S.P. Hirshman, J.F. Lyon, P.K. Mioduszewski, B.E. Nelson, D.A. Rasmussen, *J.A. Rome*, D.A. Spong, D.J. Strickler, J.C. Whitson, D.E. Williamson**
- **PPPL – A. Brooks, G.Y. Fu, S. Hudson, D. Mikkelsen, D.A. Monticello, N. Pomphrey**
- **U. Montana – A.S. Ware, A. Deisher, D. Heskett, *J. Hoff*, *L. Todd*, *J. Liu***
- **Universidad Carlos III de Madrid, Spain – R. Sanchez**
- **U. Tennessee – T. Shannon, *D. Irick*, *M. Madhoukar***

Progress on QPS Development

- **Magnetic Configuration**
  - neoclassical confinement improved by factor 10-20
- **QPS Capabilities**
  - can vary neoclassical confinement by factor 10
  - can vary quasi-poloidal symmetry over a large range
  - can vary ballooning beta limit by factor 2
- **Modular Coils**
  - simpler coils with larger space in middle for OH and TF coils
- **Engineering Design**
  - smaller vacuum vessel with external VF coils
- **Preparations for CDR and Beyond**
  - Outlined work and schedules

QPS Status at April 2001 PVR





colors indicate contours of constant |B|

- **Reference configuration**

  sufficient for QPS mission, but team was encouraged by PVR panel to continue pursuing improvements

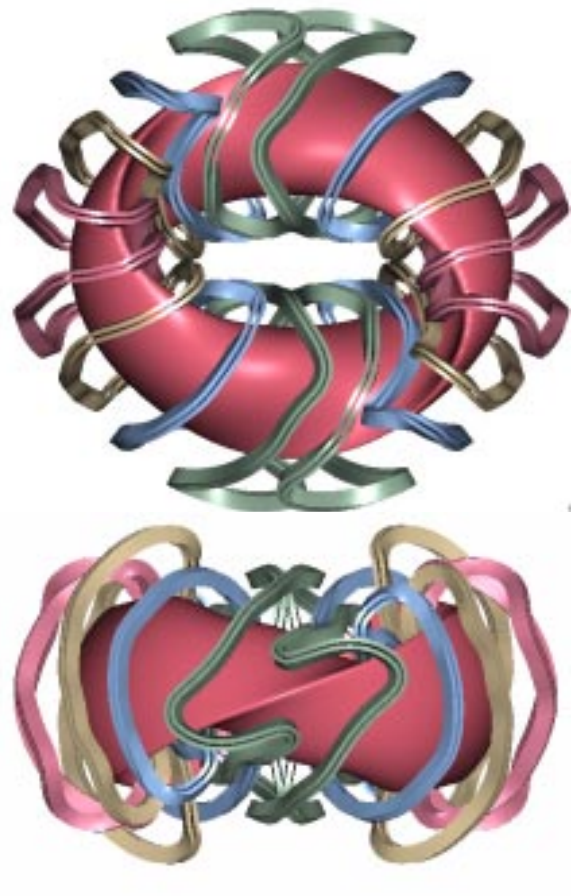
- **Improved GB5 configuration**

  1/ν transport reduced by factor of 5, BUT could not find practical coils for this configuration

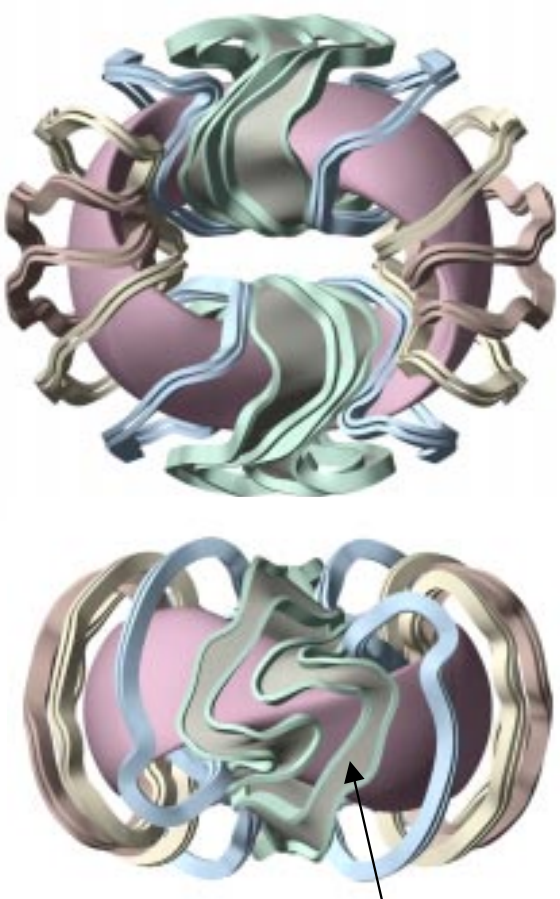
Evolution of QPS Modular Coils

- We have studied ~200 QPS plasma and coil configurations since the PVR
- The basic QPS plasma and coil configuration has not changed since last August
- The big change in QPS (and NCSX) development was to integrate the plasma and coil optimizations into one code

April 2001 (PVR)



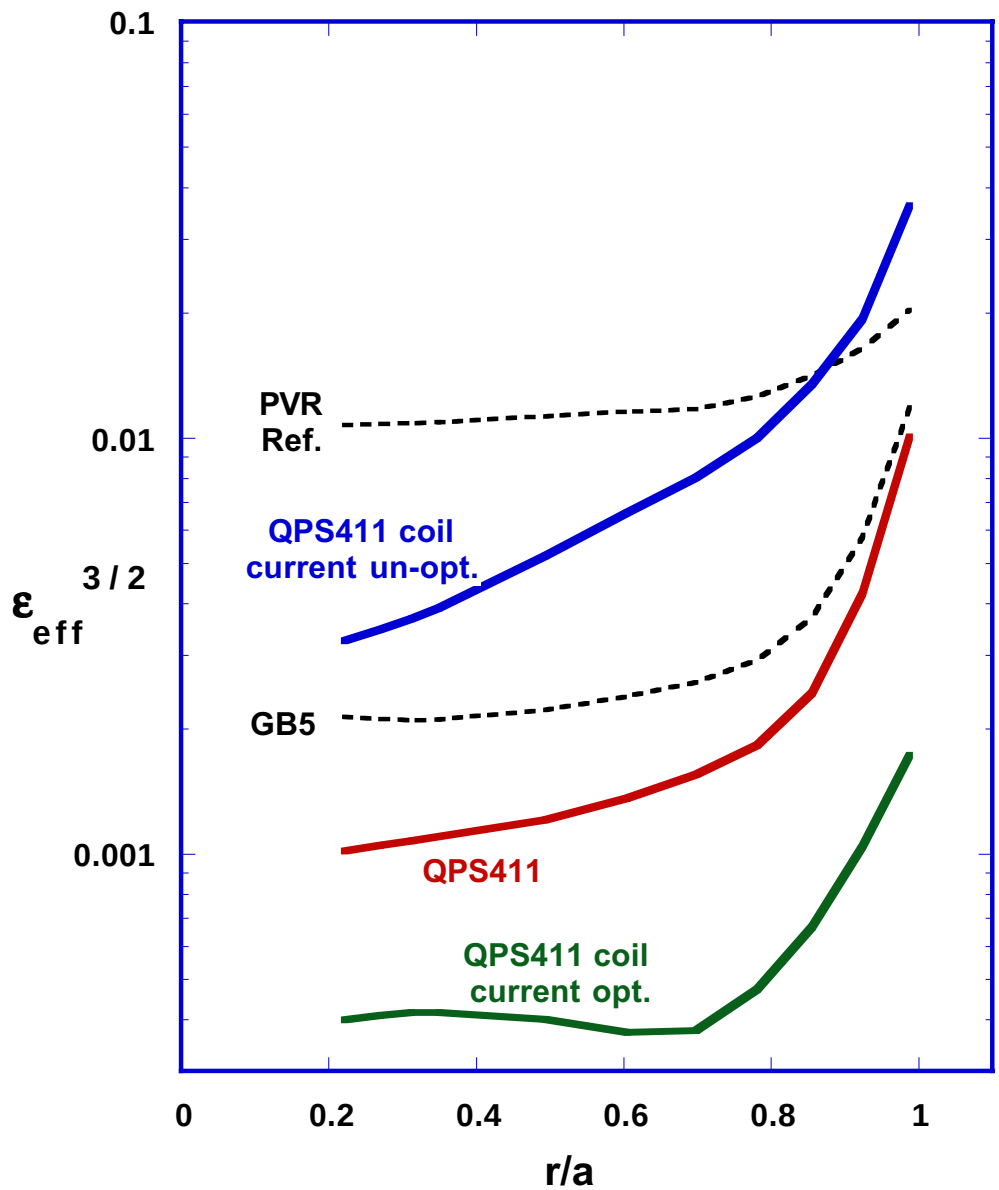
April 2002 (411)



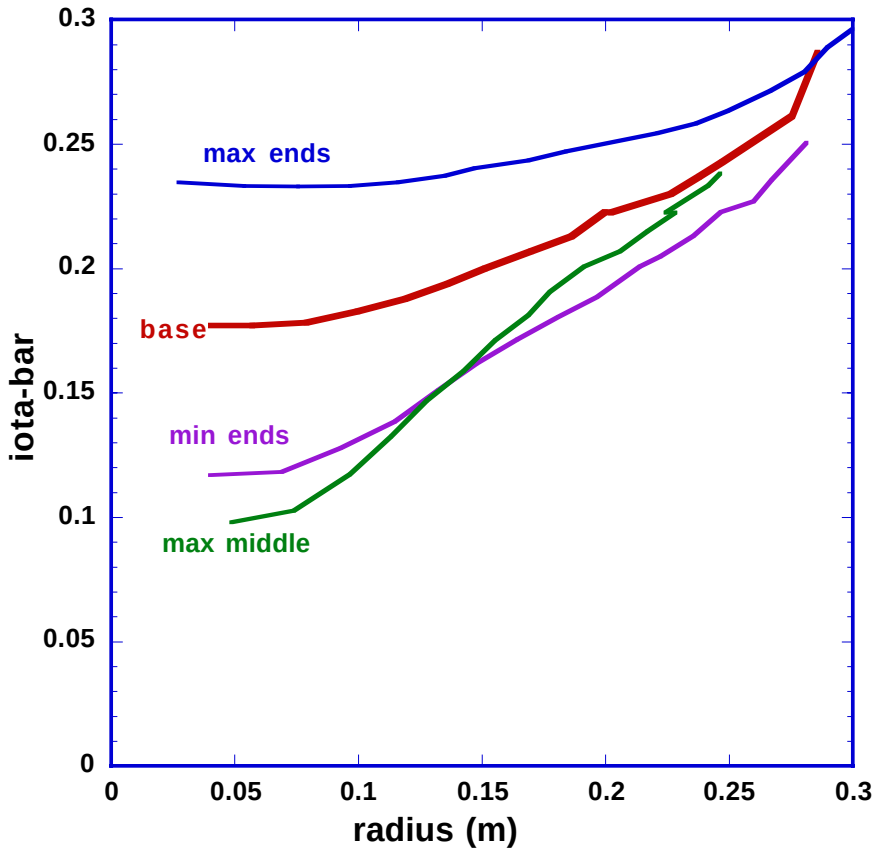
Split windings for coil type 4

411 Coil Set Improves Neoclassical Transport, Allows Tests

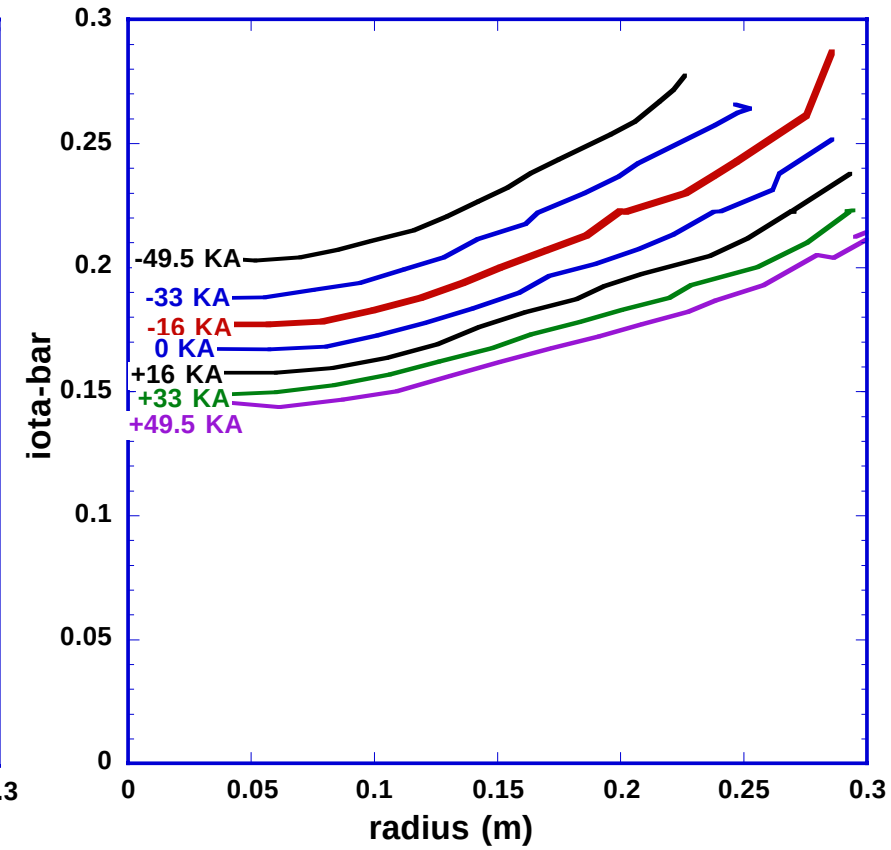
- Base QPS411 is a factor 10 better than PVR, ~ W 7-X value
- Changing currents in the QPS coils varies neoclassical transport by factor 8-20
- Can change from neoclassical being dominant over plasma core to not being significant



QPS Coil Set Allows Variation of Rotational Transform and Shear

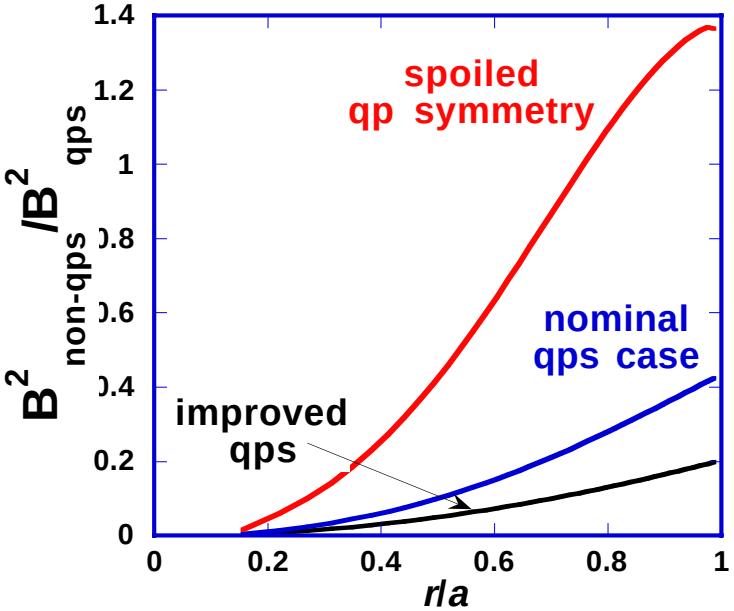


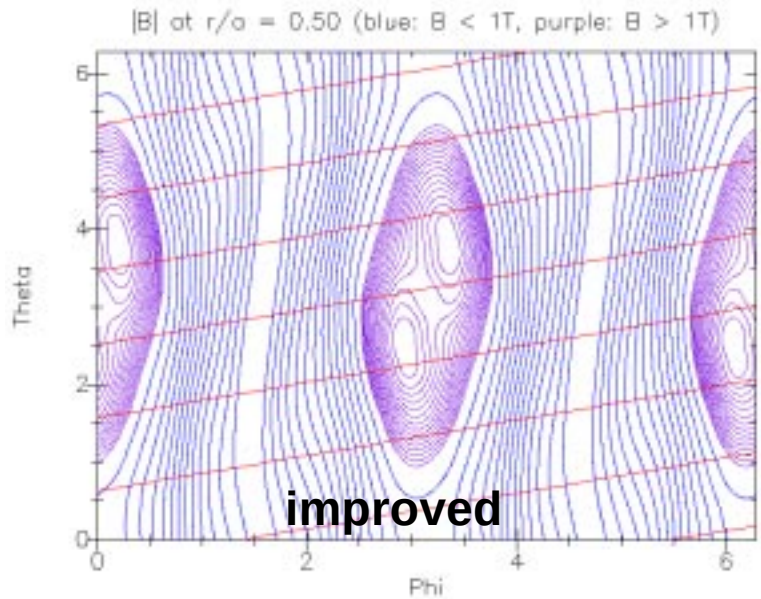
Varying currents in the modular coils

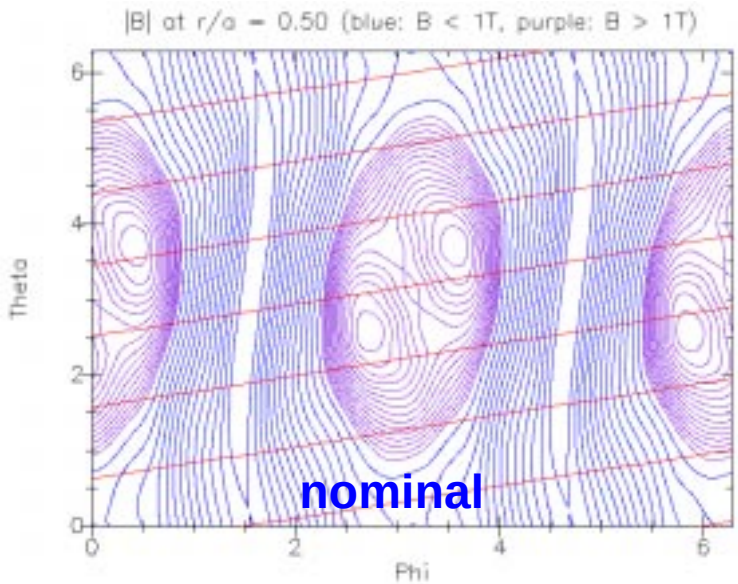


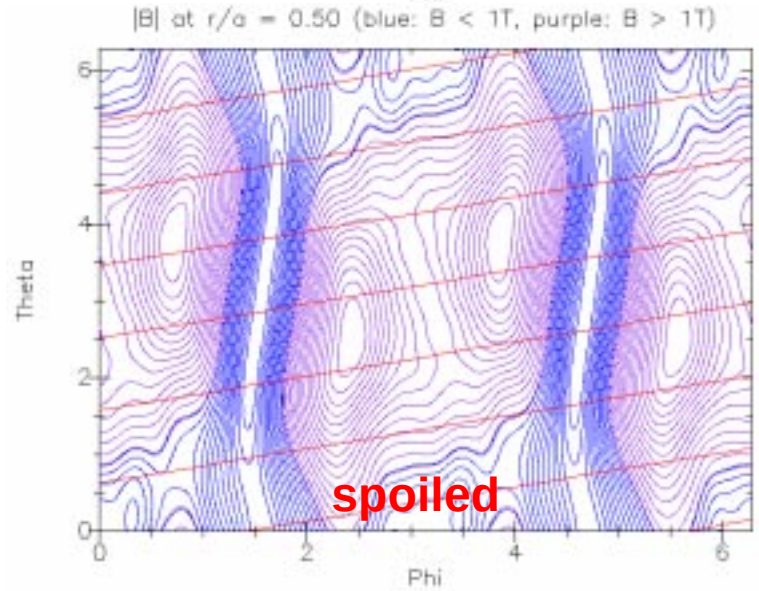
Varying currents in the TF coils

Coil Set Allows Variation of Quasi-Poloidal Symmetry



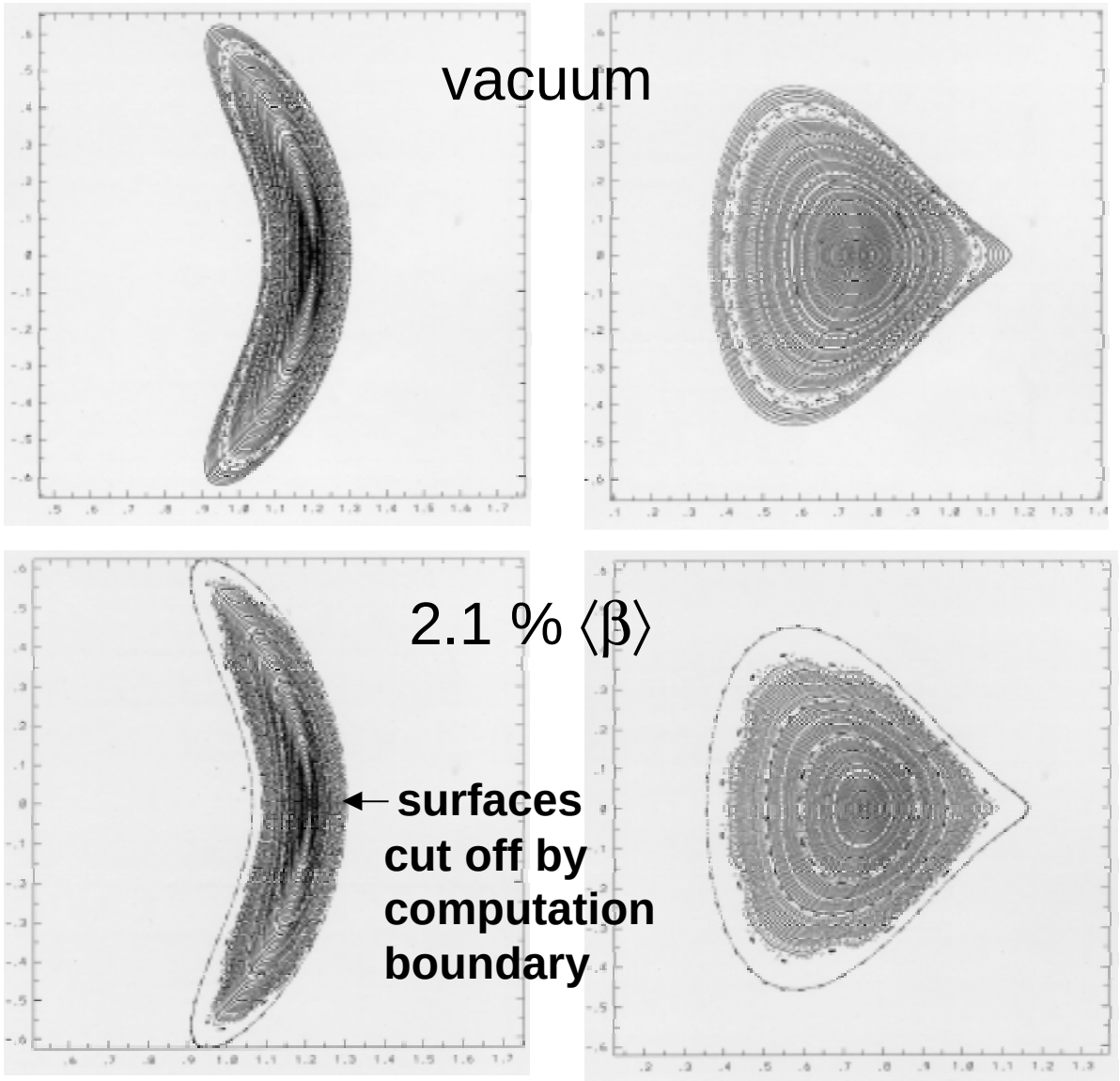






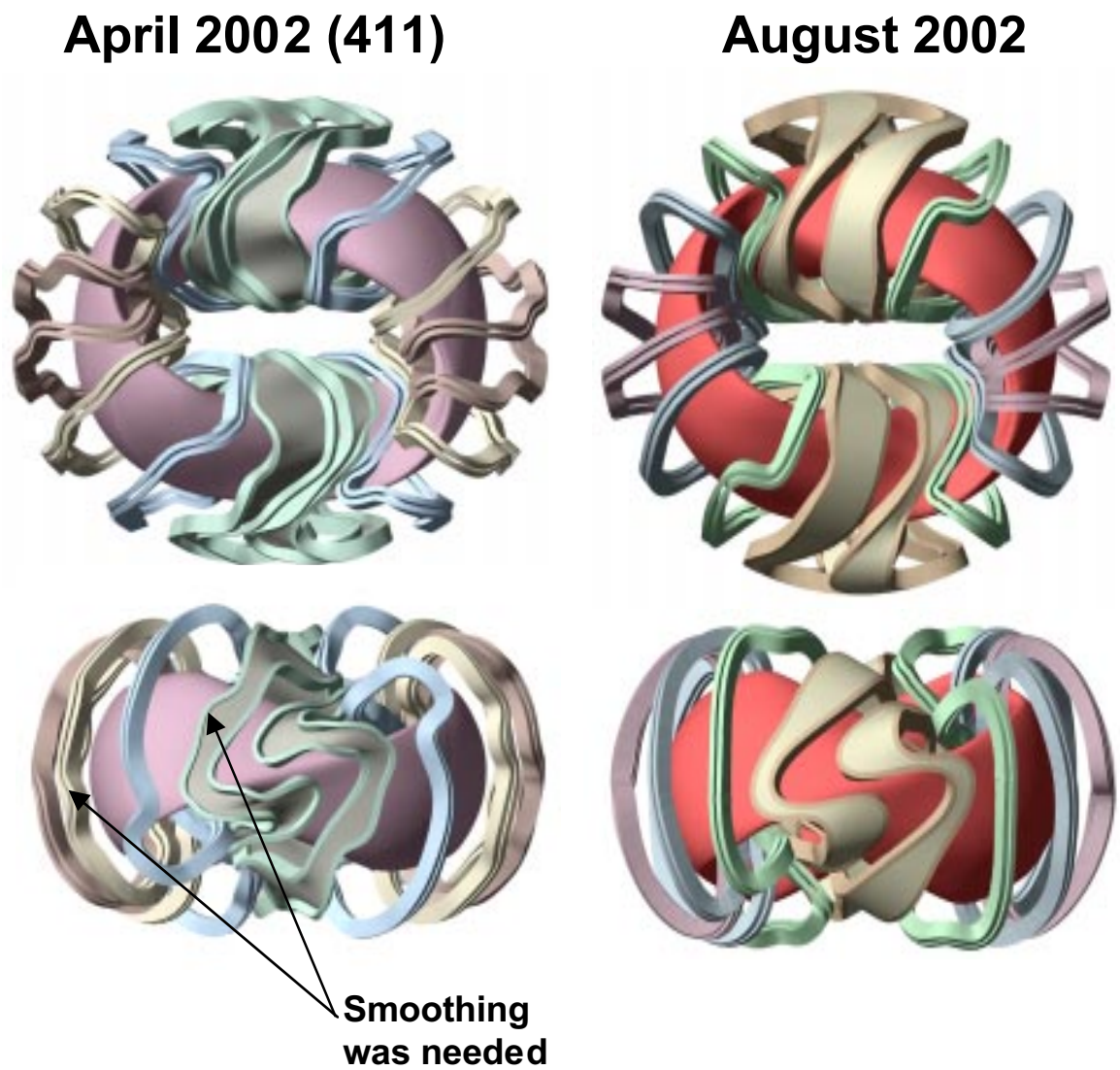
QPS Flux Surfaces Do Not Require Healing

- **PIES show only small islands which plasma would cure**



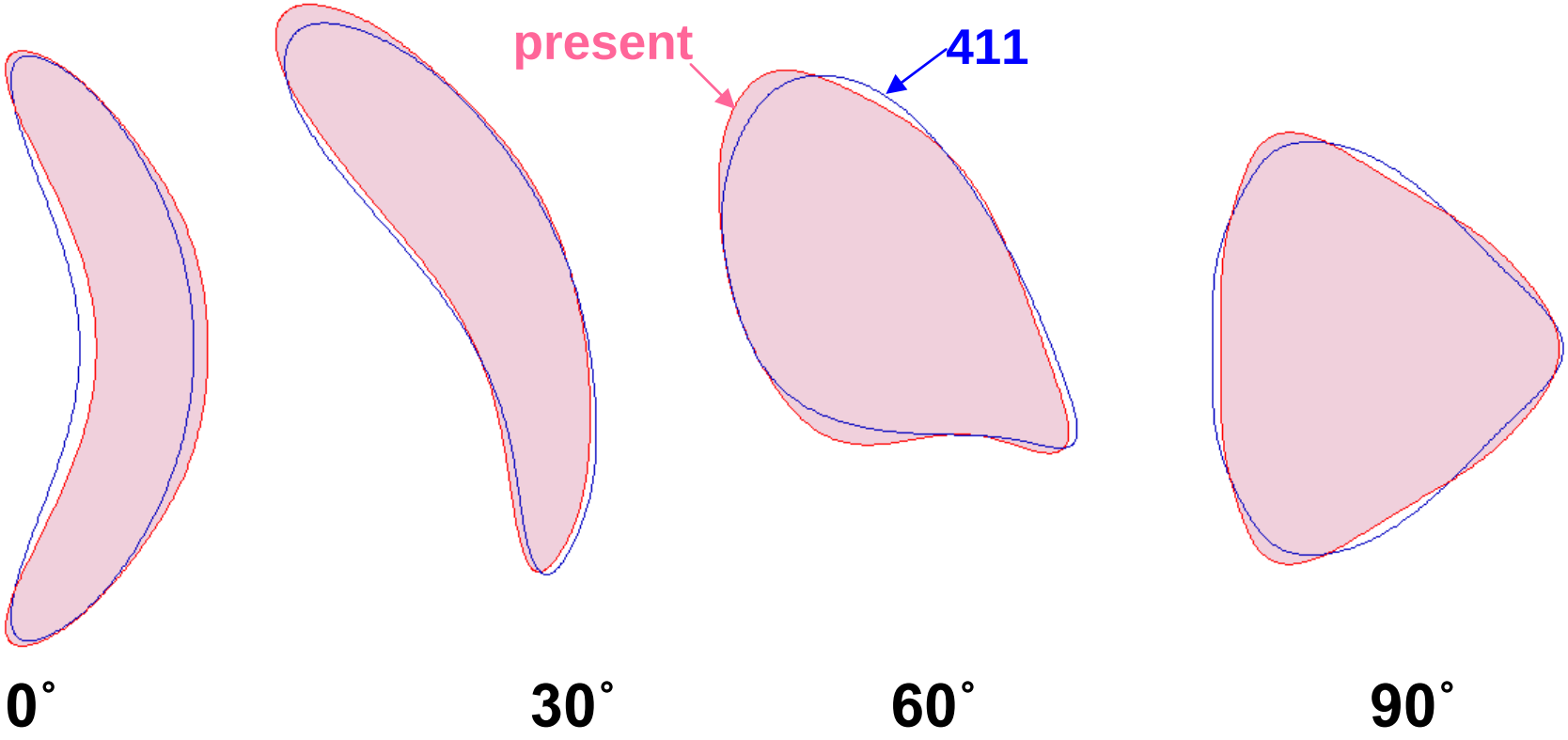
We Have Been Improving the QPS Modular coils

- New coils are smoother, easier to fabricate and measure
- Coil winding surface is smoother, simplifying the coil support structure



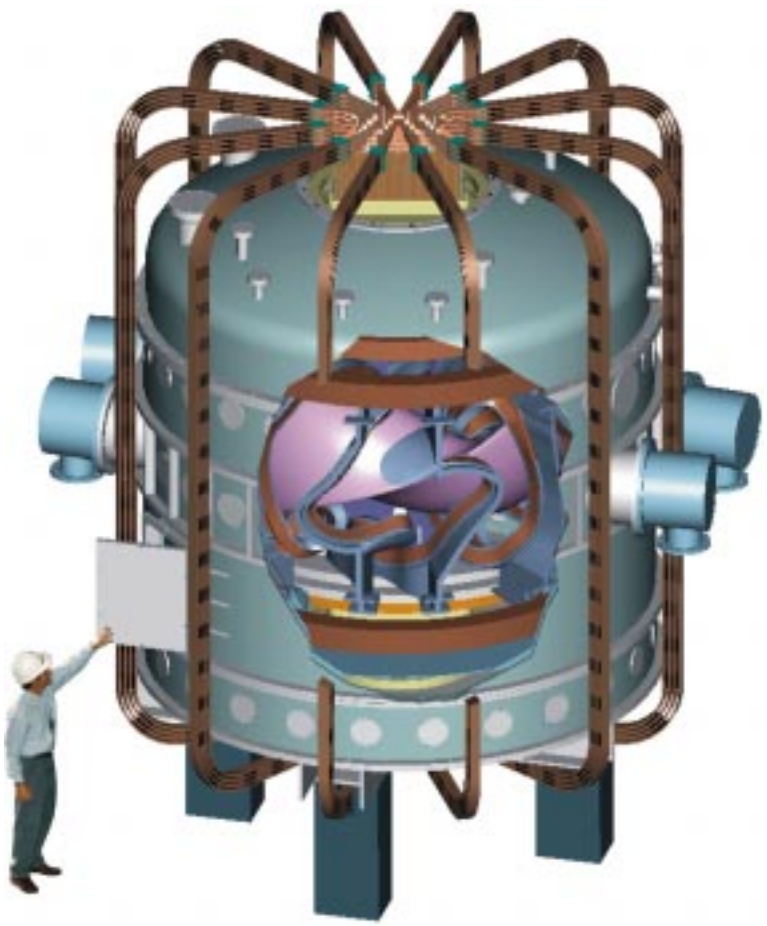
Present QPS Configuration Is Close to 411Case

- **Plasma cross sections at different toroidal angles**



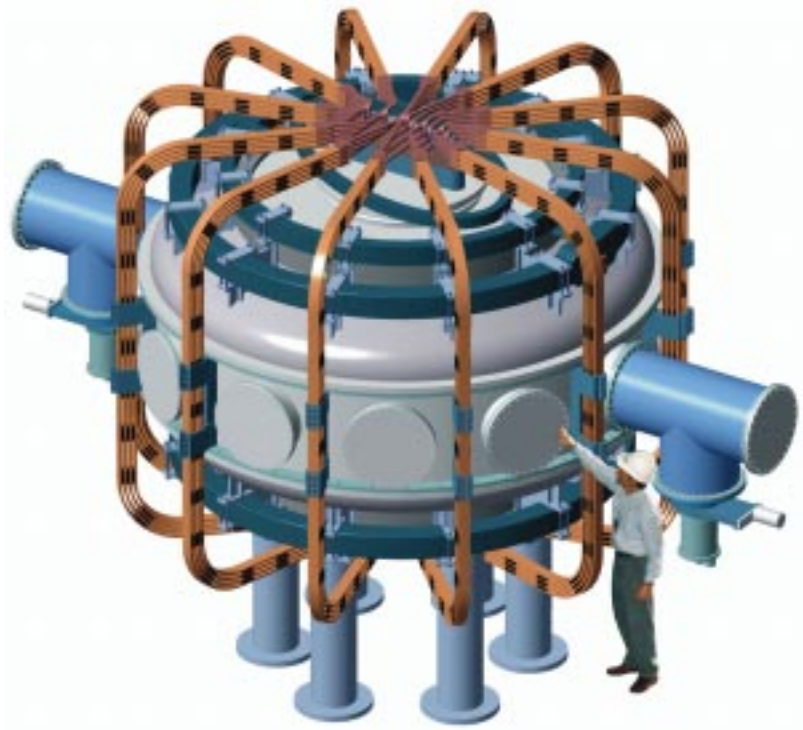
Significant Progress Has Also Been Made in QPS Engineering

at PVR



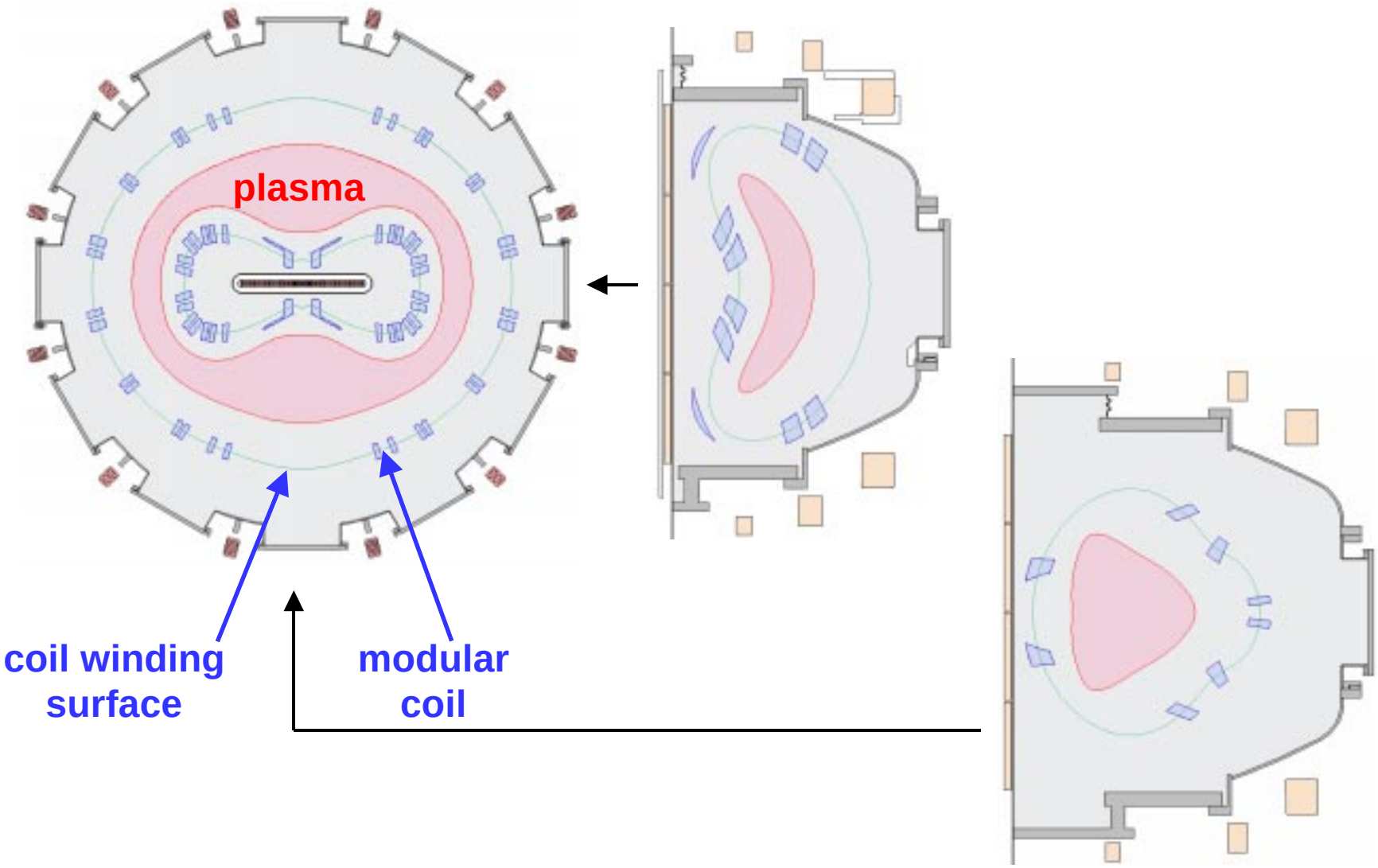
Present

VF coils and Ti gettering outside the vacuum vessel, new ports on top and bottom



Design Preserves Good Access between Coils

- No interior vacuum vessel, twelve 2-foot diameter ports

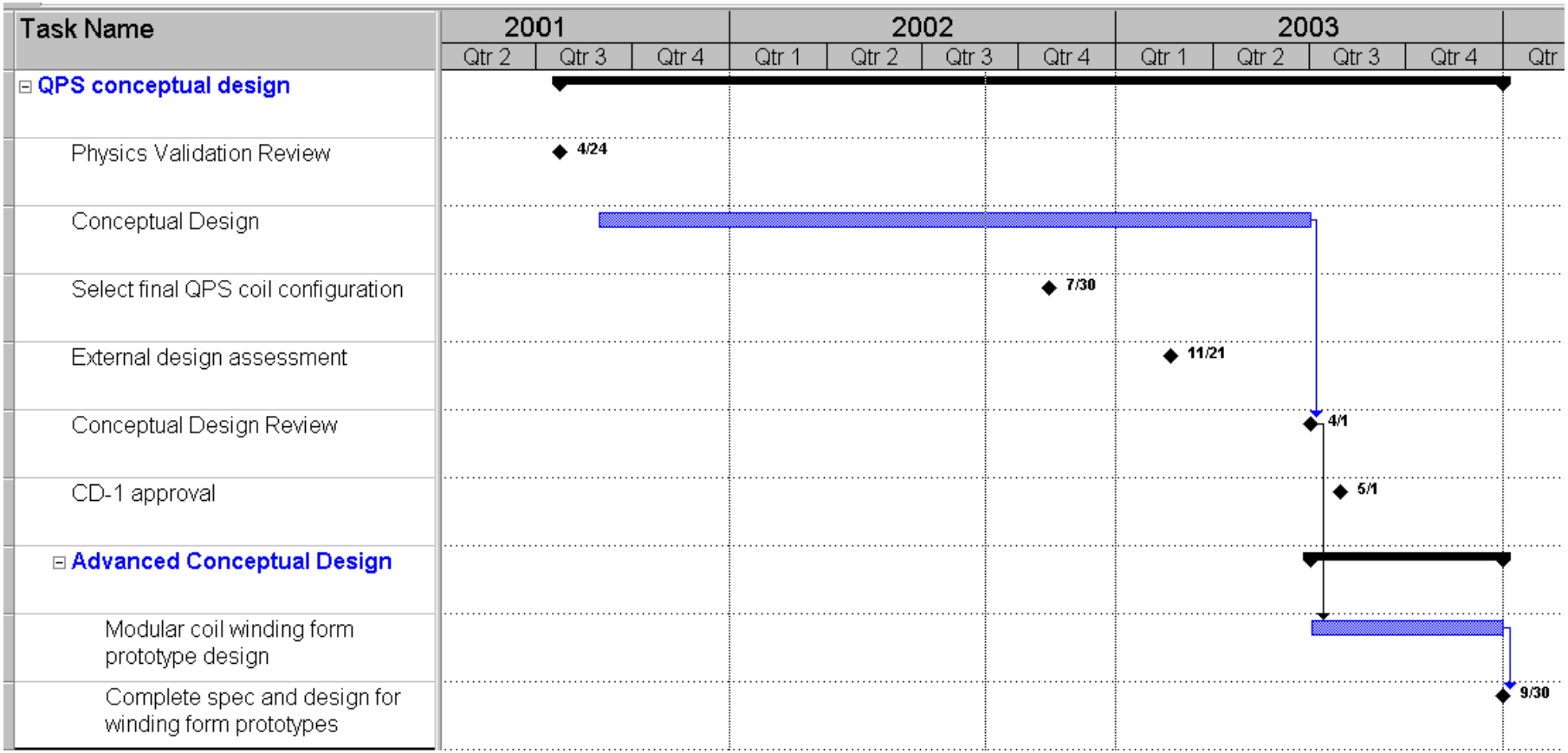


We Have Addressed Issues Raised by the PVR Panel

- **Flux Surfaces Quality -- only small islands, no healing needed**
- **Confinement Issues -- QPS coil set allows large variation in neoclassical transport and beta limits**
- **Vacuum Issues -- smaller vacuum vessel with hard seals and baking**
- **Coils -- same measurement procedure as for NCSX**
- **Diagnostics -- port configuration allows good access to the plasma**
- **High Beta -- startup scenarios from vacuum to 2% β and second stability region examined**
- **RF Heating -- W 7-AS has demonstrated EBW heating and NSTX has demonstrated HHFW heating**
- **Personnel and Management -- more mid-career people will be brought into the QPS project as funding permits**

QPS Work through FY03

- **Update design and physics assessments, fine tune plasma and coils, hold external design assessment**
- **Update cost estimate and schedule, hold CDR**
- **Prepare for modular coil R&D**

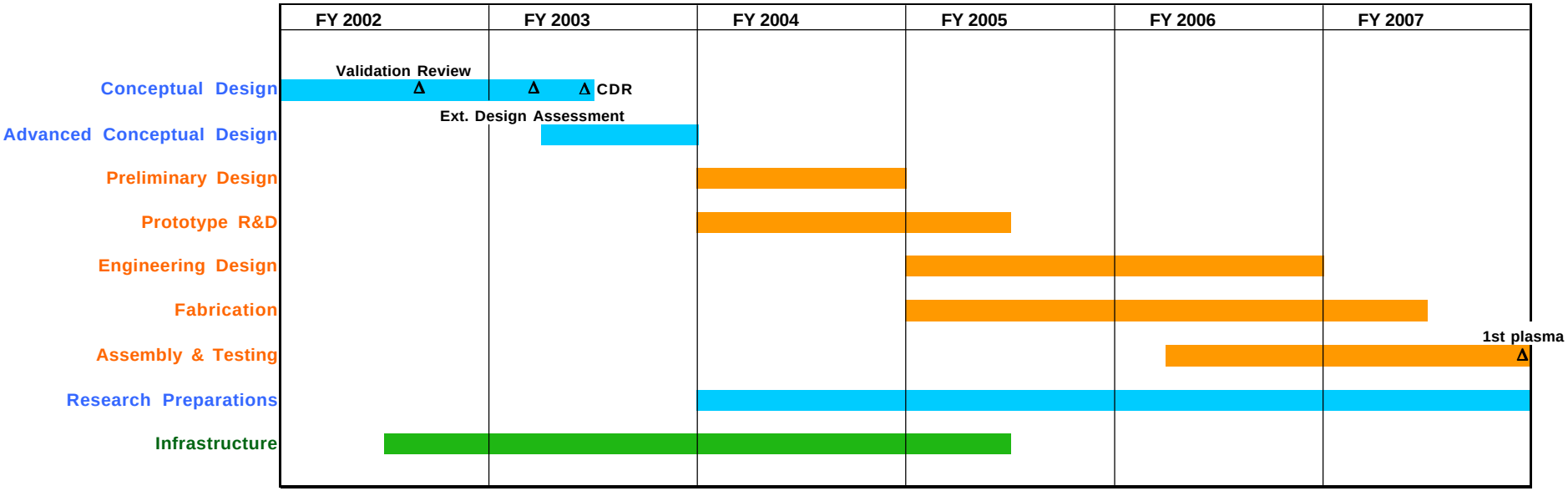


QPS Effort FYs 2004-7

- **2004**
  - Complete modular coil detailed design
  - Modular coil R&D
  - Begin TF and PF coil design
- **2005**
  - Procure full set of modular coil winding forms and begin winding modular coils
  - Begin detailed design of vessel, structures, and ancillary systems
  - Begin fabrication of PF, TF and Centerstack assembly
- **2006**
  - Complete fabrication of modular coil set and vacuum vessel
  - Complete fabrication of OH coils, elliptical PF coils, TF coils, center-stack assembly, diagnostics, heating system hardware
  - Begin pre-assembly of stellarator core field periods, set base
- **2007**
  - Complete fabrication of all systems
  - Complete on-site assembly
  - Complete integrated systems testing
  - **First plasma in Sept. 07**

QPS Schedule

- Nov. 2002: external design assessment
- April 2003: Design, Cost & Schedule Review
- 2003-2007: R&D, design and construction
- Sept. 2007: first plasma



QPS Cost Reduction Measures

- Feedback from industry on the cost of the NCSX modular coils is also a concern for QPS

⇒ We are taking steps to reduce modular coil costs

  - Simplifying the shape of the coils and the winding surface
  - Reducing the length of the modular coils
  - Planning manufacturing studies with industry to estimate QPS coil costs and ways to reduce it
  - Examining alternative ways to fabricate coils

- We have already reduced size of the vacuum vessel and moved VF coils and Ti gettering regions outside the vacuum tank

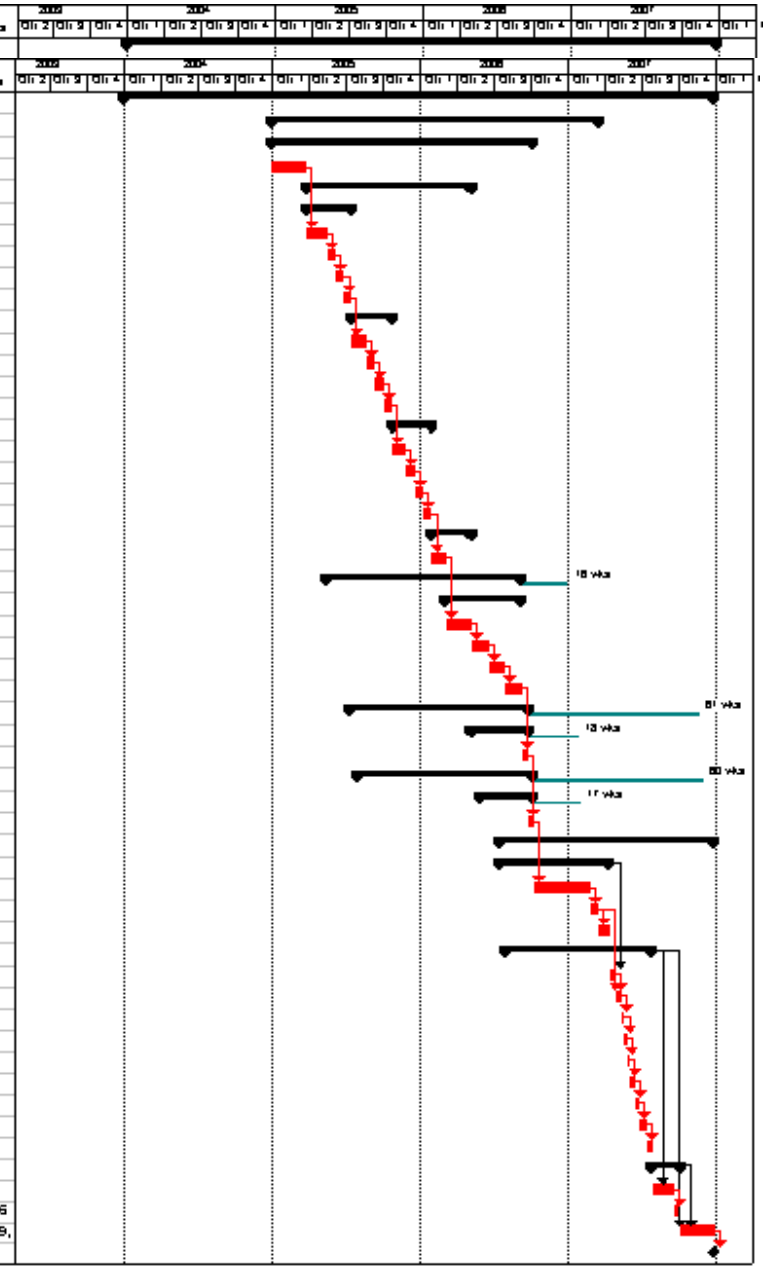
Summary

- Substantial progress has been made in QPS plasma and coil development since last year
- Merged optimizer has produced the plasma and coil configuration that we need
- Engineering design has been simplified
- Disposition of PVR comments is mostly complete
- Plans have been developed for FY's 2002–2003
- Steps needed for the QPS project have been outlined for FY's 2004–2007

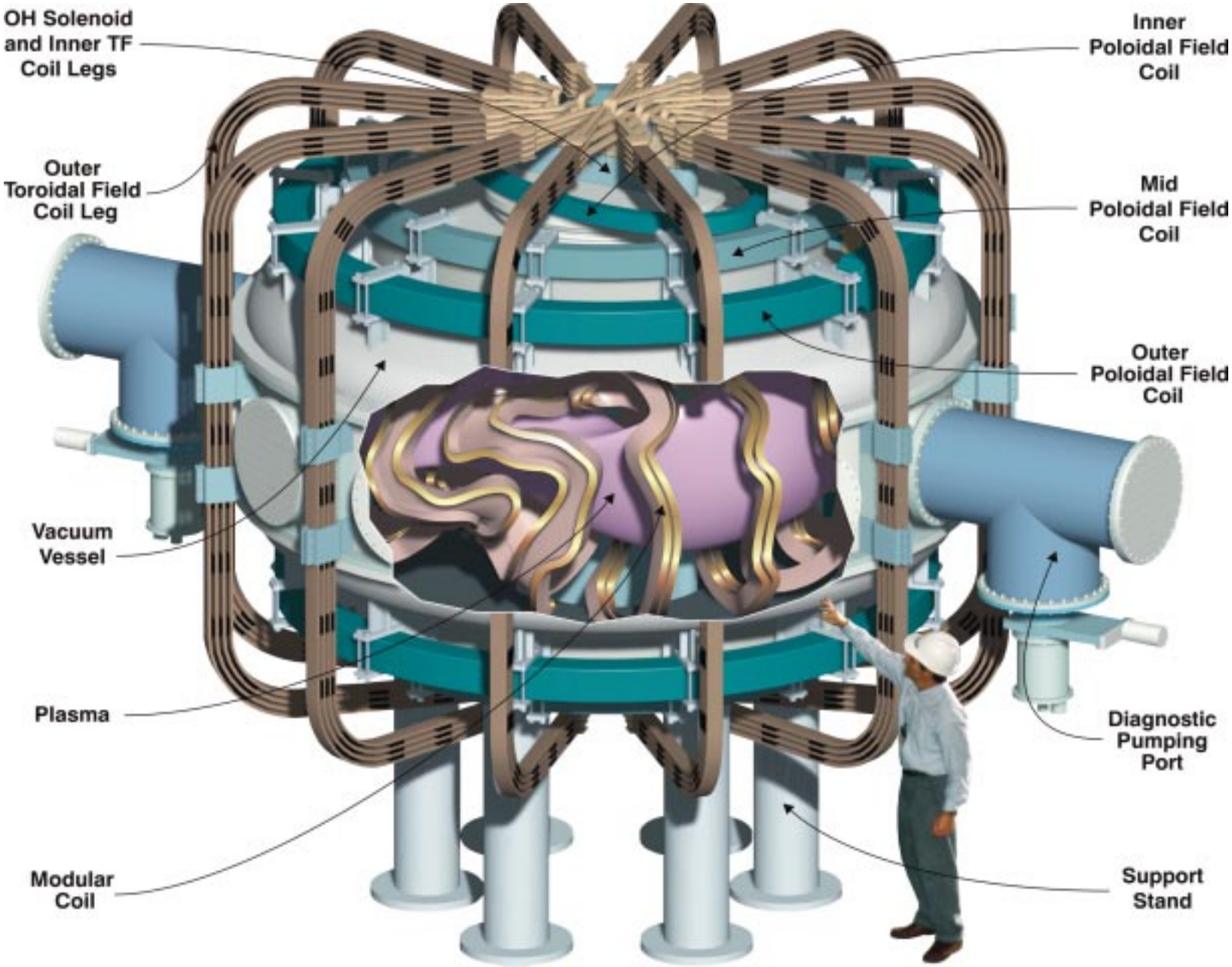
⇒ On track for November design assessment and April CDR

QPS Critical Path Schedule

ID		Task Name	Duration	Start	Finish	Predecessors
12		QPS project	203.4 days	Wed 10/1/03	Thu 9/27/07	
12		QPS project	203.4 days	Wed 10/1/03	Thu 9/27/07	
13		Fabrication	116.2 days	Fri 10/1/04	Fri 12/16/06	
25		Modular Coils	82 days	Fri 10/1/04	Thu 7/6/06	
26		bid contract for mod coils	12 wks	Fri 10/1/04	Thu 12/23/04	19
33		Winding form casting and machining	68 days	Fri 12/24/04	Thu 2/2/06	
89		Coil type 1	18 days	Fri 12/24/04	Thu 4/14/05	
90		Coil 1-1	7 wks	Fri 12/24/04	Thu 2/10/05	86
91		Coil 1-2	3 wks	Fri 2/11/05	Thu 3/3/05	90
92		Coil 1-3	3 wks	Fri 3/4/05	Thu 3/24/05	91
93		Coil 1-4	3 wks	Fri 3/25/05	Thu 4/14/05	92
94		Coil type 2	14 days	Fri 4/15/05	Thu 7/21/05	
95		Coil 2-1	5 wks	Fri 4/15/05	Thu 5/19/05	93
96		Coil 2-2	3 wks	Fri 5/20/05	Thu 6/9/05	95
97		Coil 2-3	3 wks	Fri 6/10/05	Thu 6/30/05	96
98		Coil 2-4	3 wks	Fri 7/1/05	Thu 7/21/05	97
99		Coil type 3	14 days	Fri 7/22/05	Thu 10/27/05	
100		Coil 3-1	5 wks	Fri 7/22/05	Thu 8/25/05	98
101		Coil 3-2	3 wks	Fri 8/26/05	Thu 9/15/05	100
102		Coil 3-3	3 wks	Fri 9/16/05	Thu 10/6/05	101
103		Coil 3-4	3 wks	Fri 10/7/05	Thu 10/27/05	102
104		Coil type 4	14 days	Fri 10/28/05	Thu 2/2/06	
105		Coil 4-1	5 wks	Fri 10/28/05	Thu 12/1/05	103
106		Conductor winding	88 days	Fri 2/11/06	Thu 6/8/06	
125		Coil type 4	27 days	Fri 12/2/06	Thu 6/8/06	
126		Coil 4-1	5 wks	Fri 12/2/05	Thu 2/2/06	105,119
127		Coil 4-2	6 wks	Fri 2/3/06	Thu 3/16/06	106,126
128		Coil 4-3	6 wks	Fri 3/17/06	Thu 4/27/06	107,127
129		Coil 4-4	6 wks	Fri 4/28/06	Thu 6/8/06	108,128
130		Can welding and leak checking	82 days	Fri 4/8/06	Thu 8/22/06	
148		Coil type 4	20 days	Fri 2/8/06	Thu 8/22/06	
150		Coil 4-4	2 wks	Fri 6/9/06	Thu 6/22/06	129
151		Vacuum Pressure Impregnation	82 days	Fri 4/28/06	Thu 7/6/06	
167		Coil type 4	18 days	Fri 2/24/06	Thu 7/6/06	
171		Coil 4-4	2 wks	Fri 6/23/06	Thu 7/6/06	150
203		Final Assembly / Test	78 days	Fri 4/14/06	Thu 9/27/07	
204		Core assembly, off-site	38 days	Fri 4/14/06	Thu 1/11/07	
206		assemble second field period	20 wks	Fri 7/7/06	Thu 11/23/06	171
207		pre-assemble field periods around centerstack	3 wks	Fri 11/24/06	Thu 12/14/06	206,176
208		disassemble and ship	4 wks	Fri 12/15/06	Thu 1/11/07	207
209		Core Assembly, on-site	62 days	Fri 4/28/06	Thu 4/26/07	
212		Install centerstack assembly	2 wks	Fri 1/12/07	Thu 1/25/07	204,210
213		Install Coil field period assemblies	2 wks	Fri 1/26/07	Thu 2/8/07	207,212
214		Install vessel spool piece	1 wk	Fri 2/9/07	Thu 2/15/07	213
215		Install upper VV lid with PF coils	1 wk	Fri 2/16/07	Thu 2/22/07	214
216		Install vacuum seals around modular coil leads	1 wk	Fri 2/23/07	Thu 3/1/07	215
217		Install blank port covers	2 wks	Fri 3/2/07	Thu 3/15/07	216
218		leak check vessel	1 wk	Fri 3/16/07	Thu 3/22/07	217
219		Install TF coil outer legs	3 wks	Fri 3/23/07	Thu 4/12/07	218
221		Install PF/TF leads, connect to building buswork	2 wks	Fri 4/13/07	Thu 4/26/07	219
225		Diagnostics	10 days	Fri 4/27/07	Thu 7/6/07	
226		Install day 1 diagnostics on machine	8 wks	Fri 4/27/07	Thu 6/21/07	197,209
227		Run cables to control room	2 wks	Fri 6/22/07	Thu 7/5/07	223,224,226
229		Startup and Integrated Systems Testing	12 wks	Fri 7/6/07	Thu 9/27/07	225,222,209,
234		First Plasma	0 days	Thu 9/27/07	Thu 9/27/07	233



QPS


OH Solenoid and Inner TF Coil Legs
Outer Toroidal Field Coil Leg
Vacuum Vessel
Plasma
Modular Coil
Inner Poloidal Field Coil
Mid Poloidal Field Coil
Outer Poloidal Field Coil
Diagnostic Pumping Port
Support Stand