QPS Project and Diagnostic Plans

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for the QPS Team

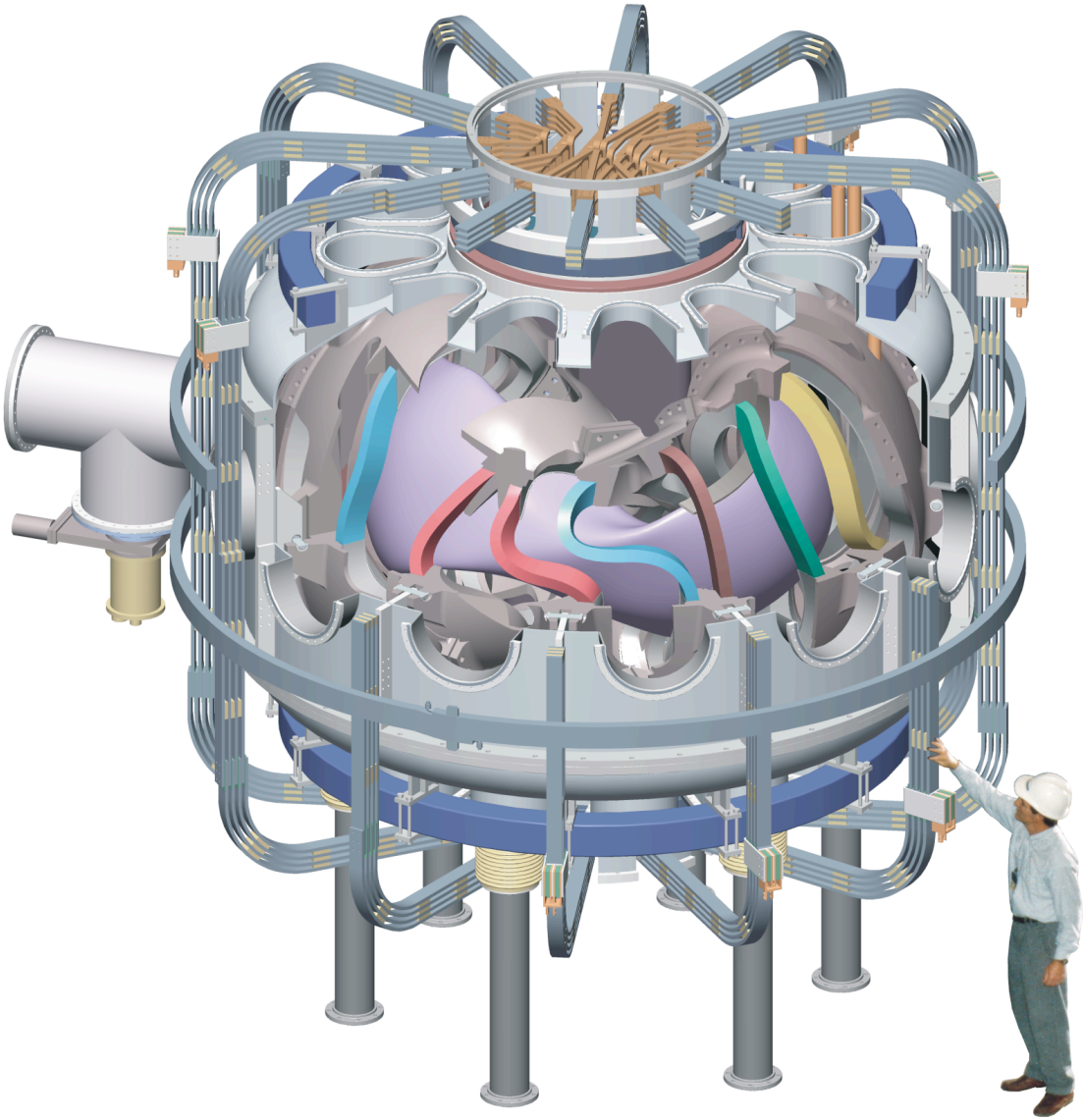
High Temperature Plasma Diagnostics Conference

San Diego April 19, 2004

Topics

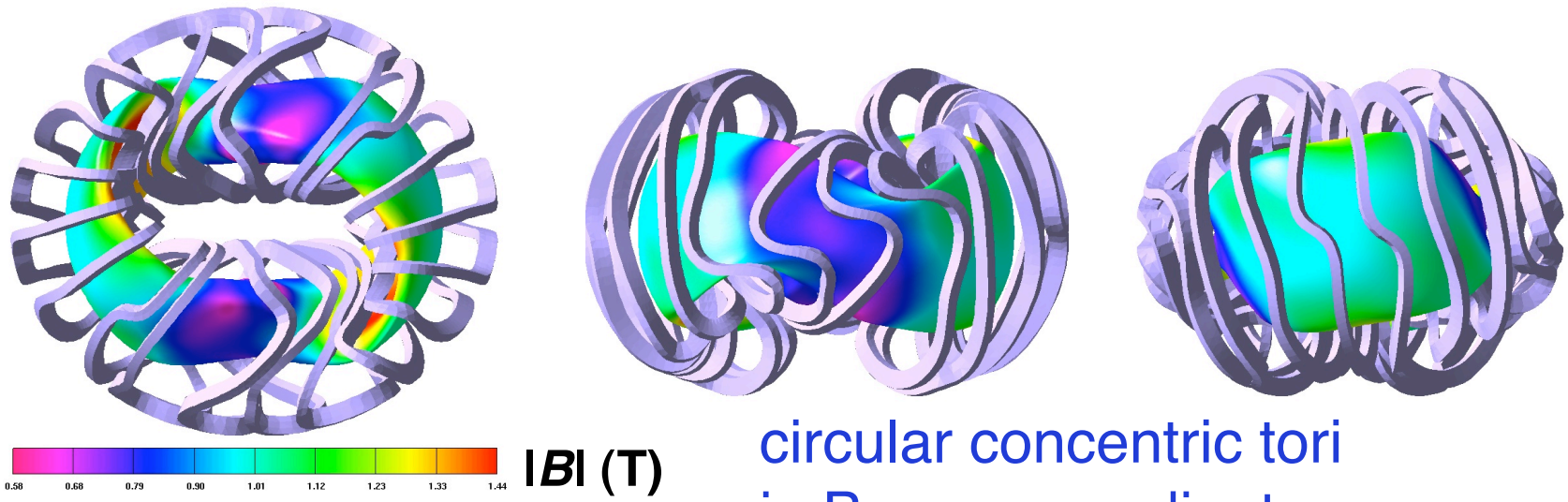
- **The QPS experiment**
  - plasma & coil geometry, configuration flexibility
  - projected performance
- **Physics Program**
  - physics program & diagnostic requirements
- **Diagnostic Access and Views**
- **Project Status**

The Quasi-Poloidal Stellarator -- QPS

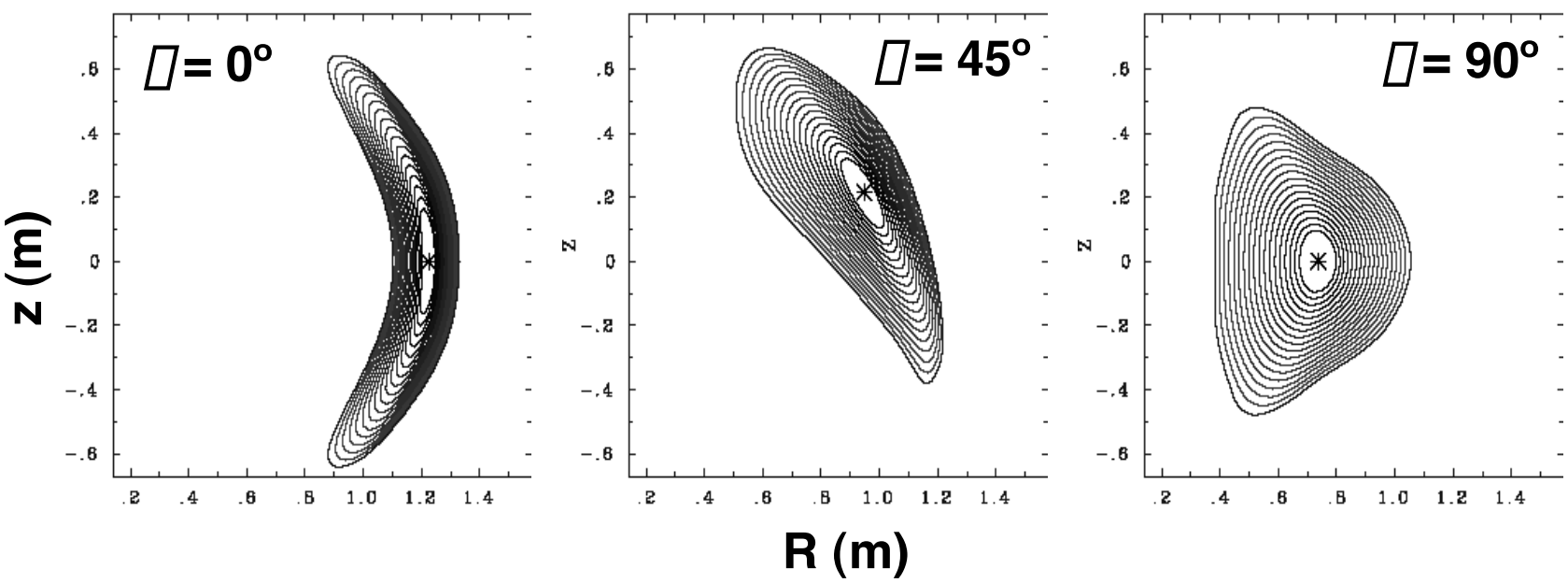


- $\langle R_{pl} \rangle$ = 0.95–1 m
- $\langle a_{pl} \rangle$ = 0.3–0.4 m
- V_{pl} = 2–3 m^3
- B_{mod} = 1 T (1.5 s)
- B_T = ± 0.15 T
- I_{plasma} < 50 kA
- P = 2–4 MW
  ECH/EBW + ICRF

QPS Plasma and Coil Geometry

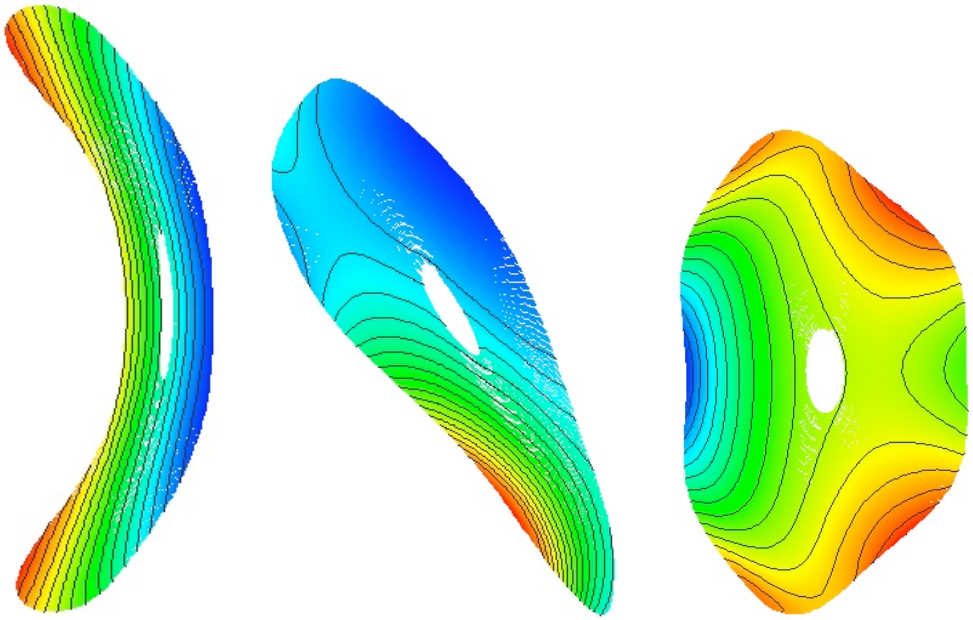


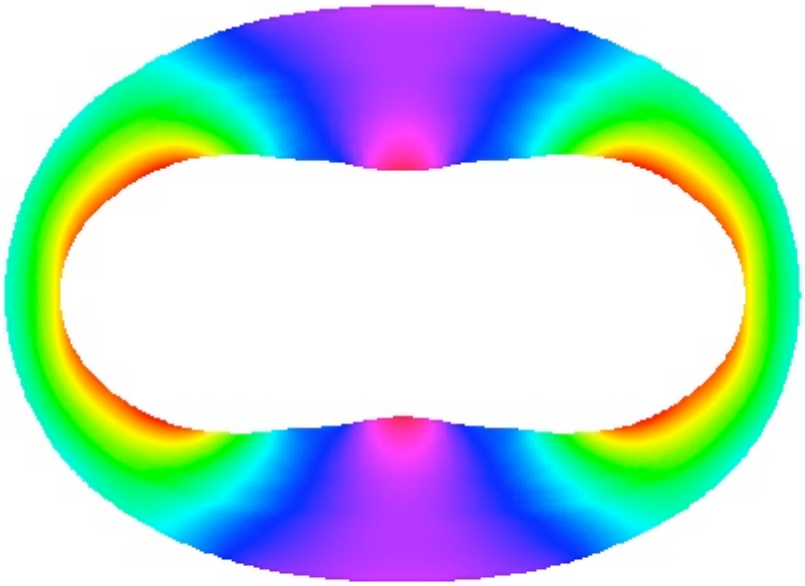
circular concentric tori
in Boozer coordinates



QPS IBI Geometry at □/□= 2%

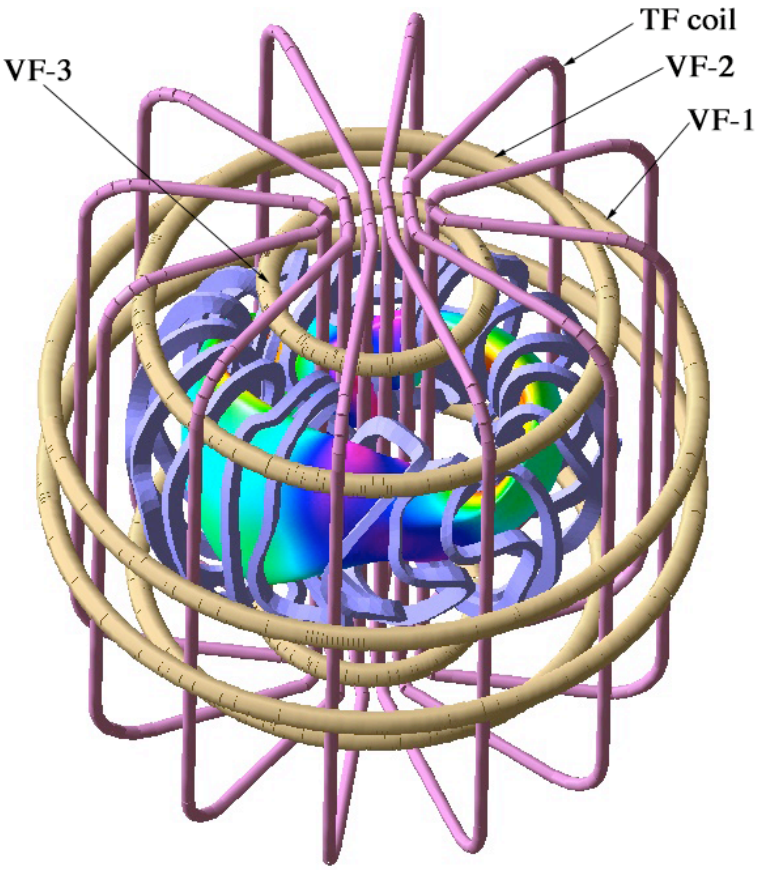
- IBI contours vary from 1/*R* (tokamak-like) in bean-shaped section to quadrupolar in the D-shaped section
  - blue low B, red high B
- High degree of poloidal symmetry in magnetic field line coordinates
- Cut in midplane illustrates 2:1 mirror ratio
  - magenta low B, red high B





QPS Allows Wide Variation in Plasma Properties

- **9 independent coil currents allow varying amount of**
  - **rotational transform (1/*q*)**
  - **stellarator or tokamak shear**
  - **helical axis excursion**
  - **magnetic field ripple**
  - **toroidal mirror ratio**
  - **helical vs. toroidal field components**
  - **plasma aspect ratio**
  - **ellipticity and triangularity**



- **This allows large variation in**
  - **neoclassical heat diffusivity (factor ~25)**
  - **degree of quasi-poloidal symmetry (factor ~10)**
  - **poloidal viscosity and flow damping (factor 5-30)**
  - **β limits (factor ~3)**

1-D Transport Calculations Indicate Possible Range of QPS Parameters

Case	Net H-ISS95	χ_{anom} (m^2/s)	$\Delta n/n$ (%)	$T_e(0)$	$T_i(0)$
1.5 MW	1	11.3	0.5	1.1	0.20
ECH	2	4.8	1.0	2.15	0.31
2×10^{19} m^{-3}	4	1.5	2.0	3.3	0.49
2 MW	1	7	1.3	0.36	0.30
EBW/ICRF	2	2.9	2.6	0.78	0.62
10^{20} m^{-3}	4	1.2	5.2	1.5	1.0
4 MW	1	10	1.7	0.53	0.38
EBW/ICRF	2	4.2	3.4	1.14	0.74
10^{20} m^{-3}	4	1.7	6.8	2.0	1.1

Requires improved confinement

QPS Program

- **Main focus of the QPS program is use of quasi-poloidal geometry to explore toroidal physics issues at low *R/a***
  - **flux surface robustness at *R/a* > 2.5 and sensitivity to β with strong toroidal/helical coupling**
  - **reduction of neoclassical and anomalous transport**
  - **variation of effective ripple, trapped particle fraction, stellarator or tokamak shear, quasi-poloidal symmetry, poloidal viscosity and poloidal flow shear, ambipolar electric field & internal transport barriers, bootstrap vs. Ohmic current, magnetic island size, magnetic beach ICRF and EBW heating**
- **A secondary component is study of β limits, second stability and the character of MHD instabilities in a very low *R/a*, quasi-poloidal stellarator**

Physics Program Determines Diagnostic Needs

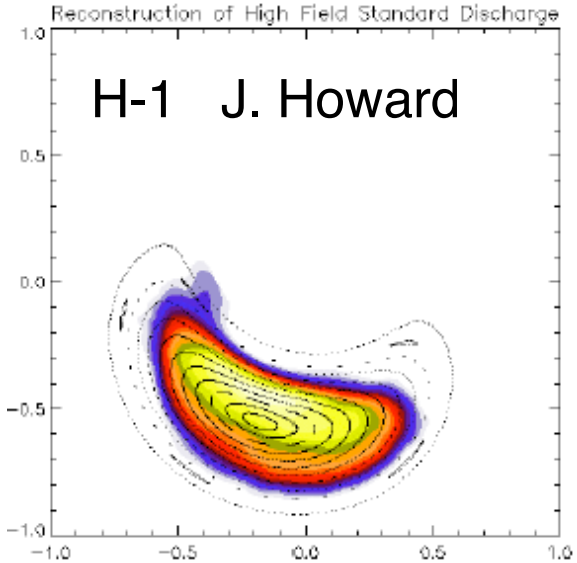
PROGRAM AREA	PHYSICS ISSUES/FEATURES	DIAGNOSTIC
MAGNETIC GEOMETRY, FLEXIBILITY	low beta geometry: flux surface geometry, ergodic regions, islands, aspect ratio, ellipticity, triangularity, helical axis, etc.	electron beam with fluorescent screen or rods and CCD camera: low energy -- flux surfaces; high energy -- non-symmetric IBI components and energetic orbit confinement
MHD EQUILIBRIUM, ROBUSTNESS OF FLUX SURFACES	higher-beta geometry: flux surfaces, magnetic axis shift, interior ergodic regions and magnetic islands	magnetic loop arrays, soft X-ray diode arrays visible ion emission tomography YAG Thomson scattering
BOOTSTRAP CURRENT	variation (reduction) with coil currents, effect on magnetic islands, ergodization of flux surfaces, and tearing modes	Rogowski coils, magnetic loops, polarimeter
MHD INSTABILITY	frequency spectrum, mode structure, correlations	high frequency magnetic probes soft X-ray array

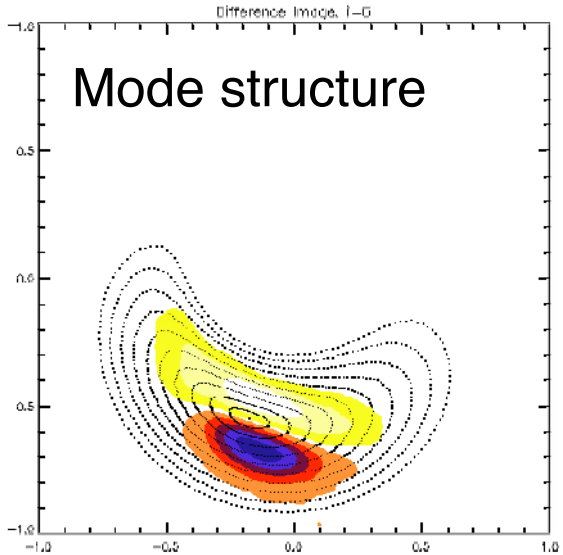
Physics Program Determines Diagnostic Needs

PROGRAM AREA	PHYSICS ISSUES/FEATURES	DIAGNOSTIC
POWER BALANCE	power deposition power losses	fast diamagnetic loop, Thomson scattering, reflectometer bolometer array, spectroscopy, filterscope fast ion loss cups, IR camera
TRANSPORT	electron density profile electron temperature profile ion temperature profile electric field	2-mm/FIR multi-channel interferometer ECE, Thomson scattering, EBW emission spectroscopy, charge-exchange probes, spectroscopy, HIBP
PLASMA EDGE, DIVERTOR GEOMETRY	limiting aspect ratio, edge magnetic structure and islands, diverted flux bundle	Langmuir probes, filtered CCD cameras, edge interferometer, IR camera, bias on divertor plates, divertor probes

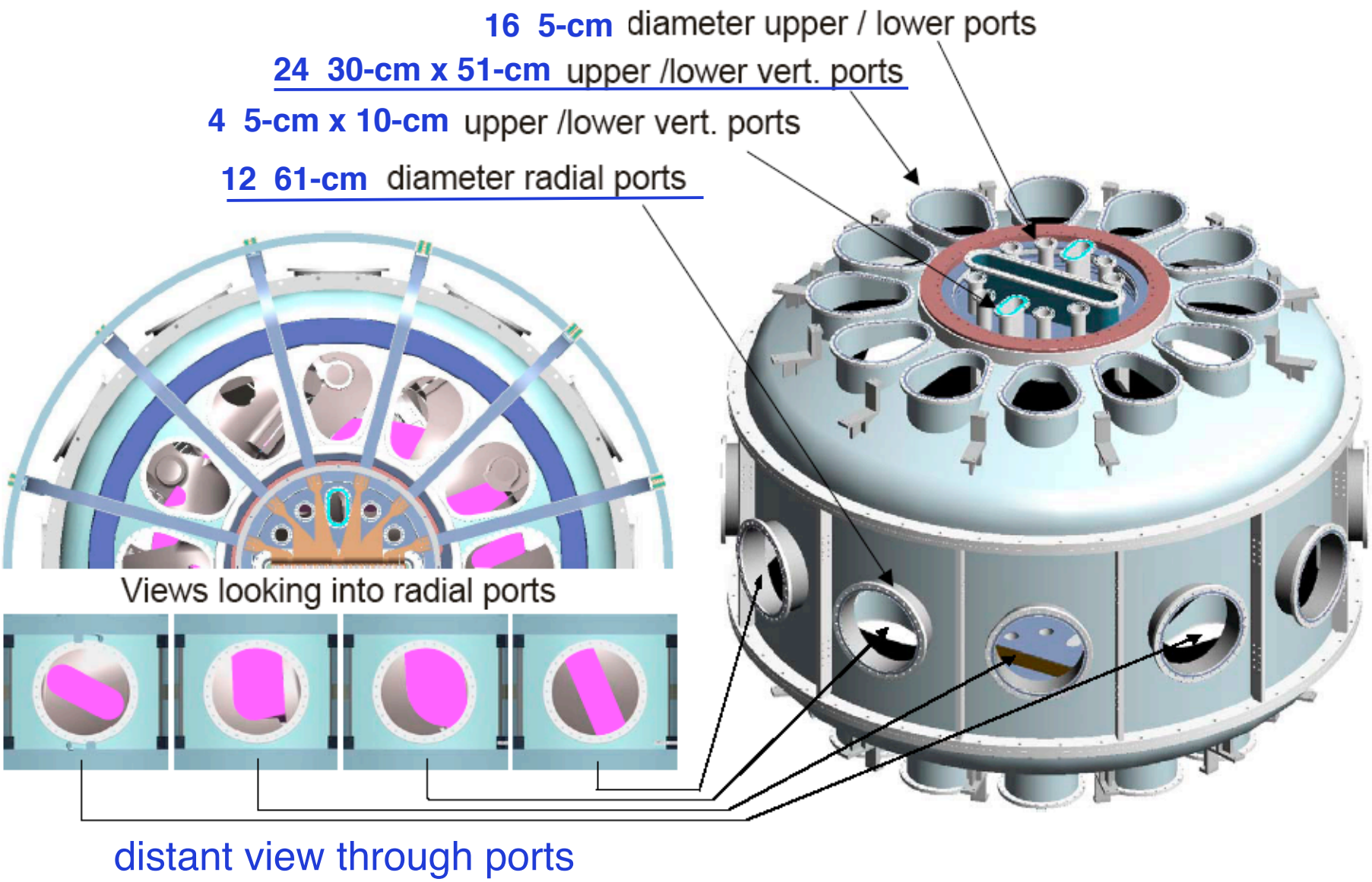
Best Way to Measure Important Features?

- **Flux surface geometry and magnetic islands**
  - ion emission or soft x-ray tomography ==>
  - magnetic loop arrays
- **Poloidal rotation**
  - spectroscopy array
  - need DNB for CXRS
- **Electric field radial profile**
  - HIBP or spectroscopy
  - scanning Langmuir probes

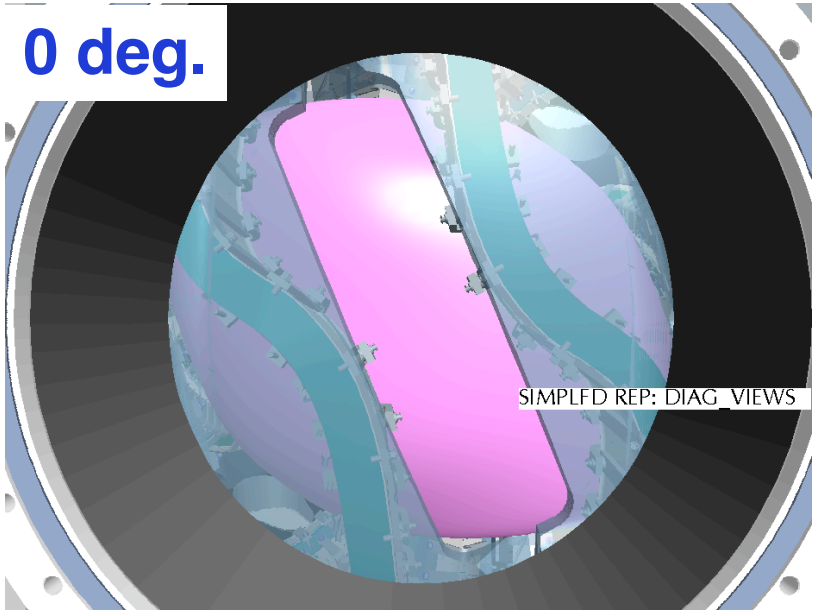


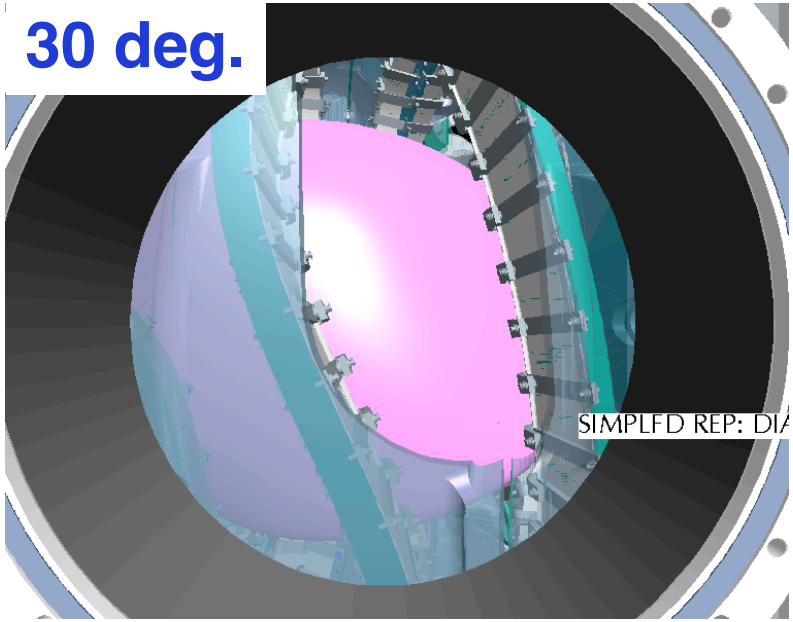


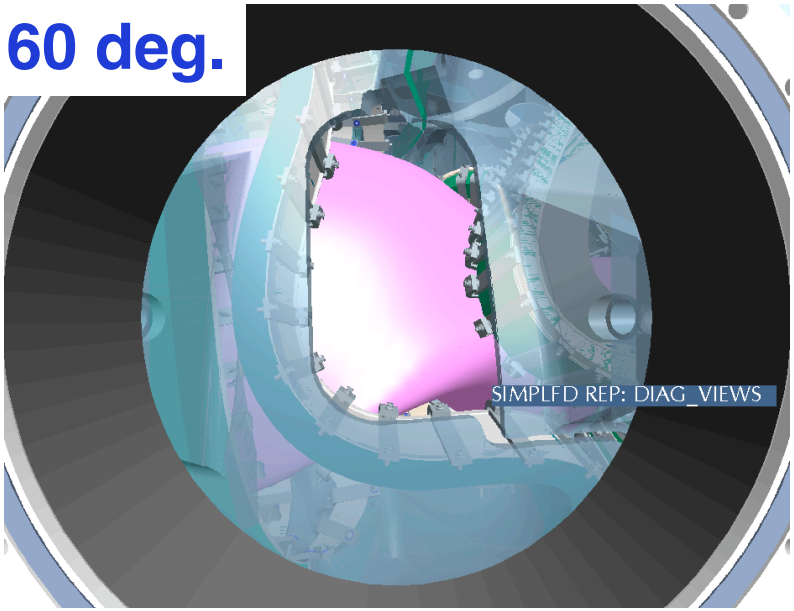
QPS Has Excellent Diagnostic Access

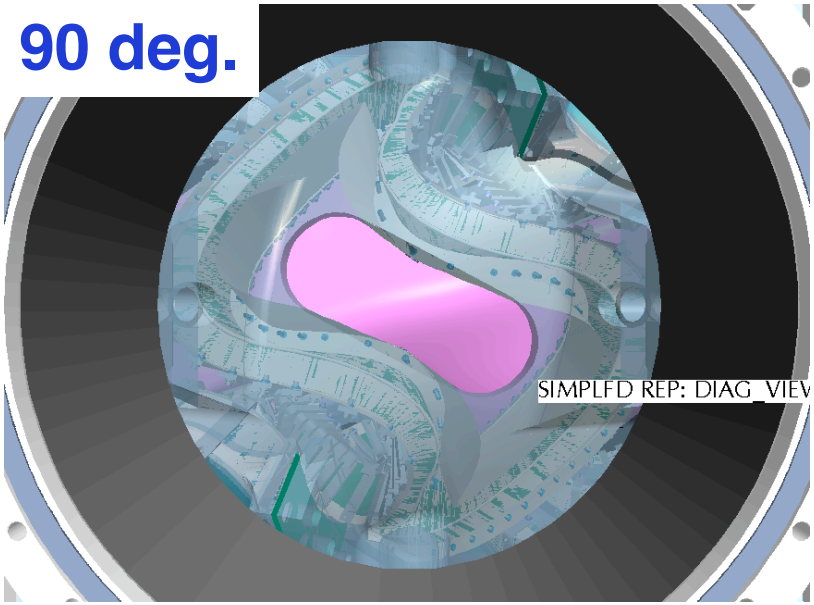


View 30 cm outside Side Ports



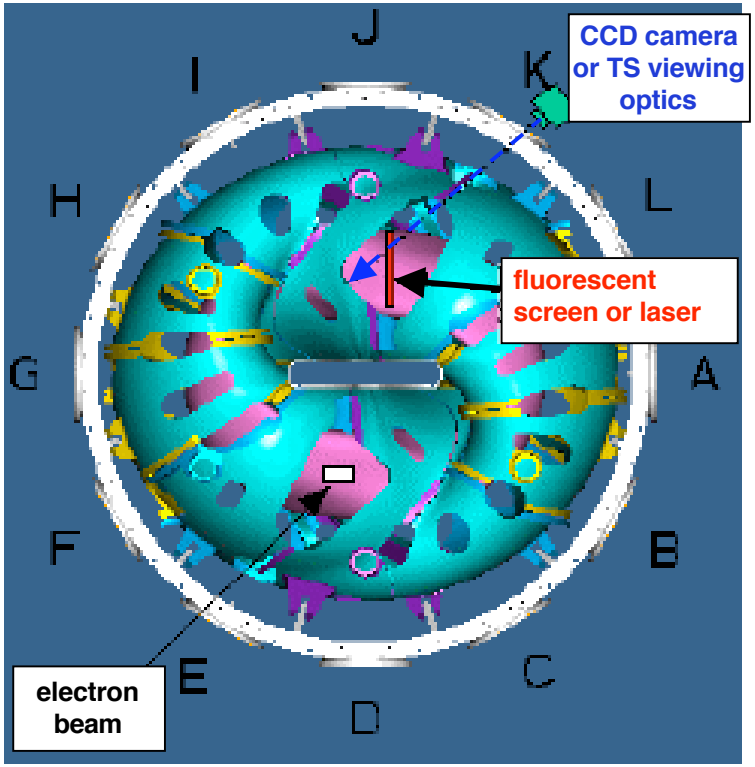


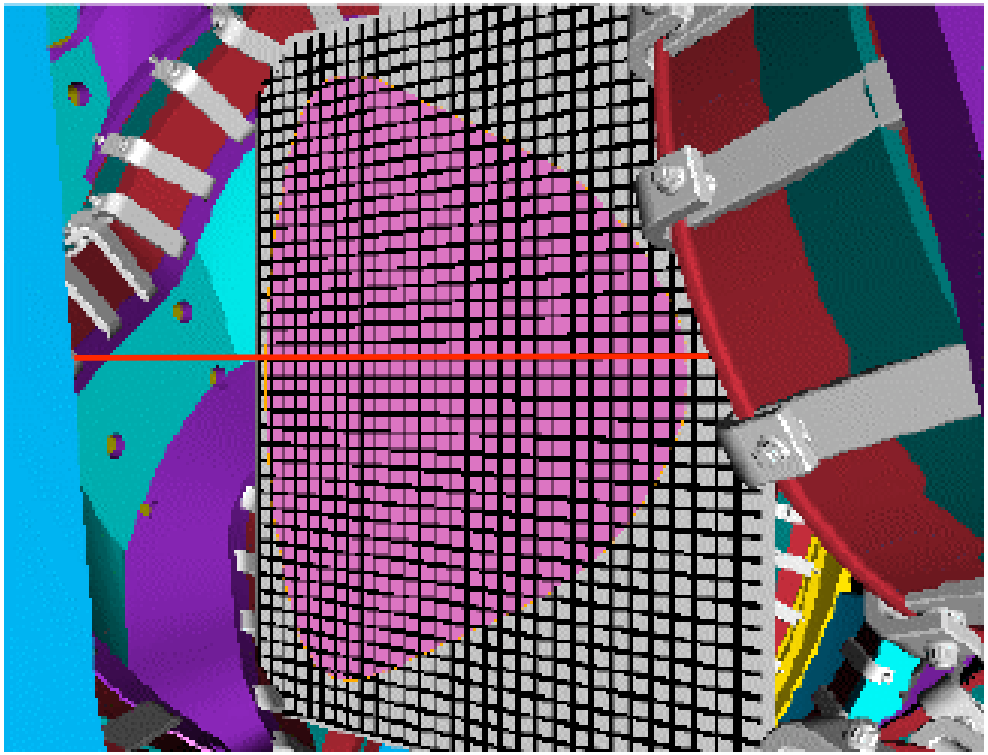




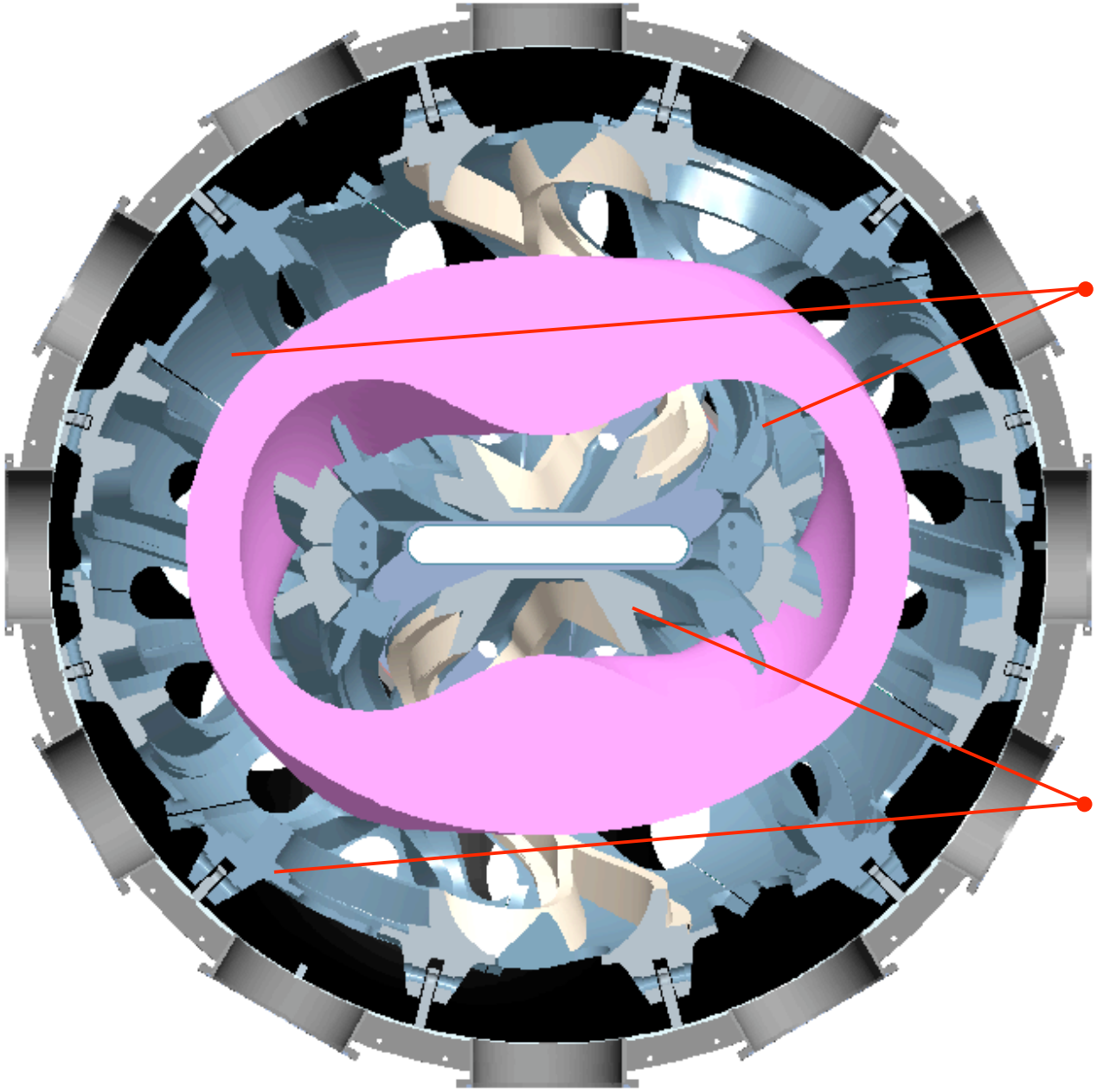
Good Access to D-Shaped Cross Section

- **Two examples: electron beam mapping and Thomson scattering**



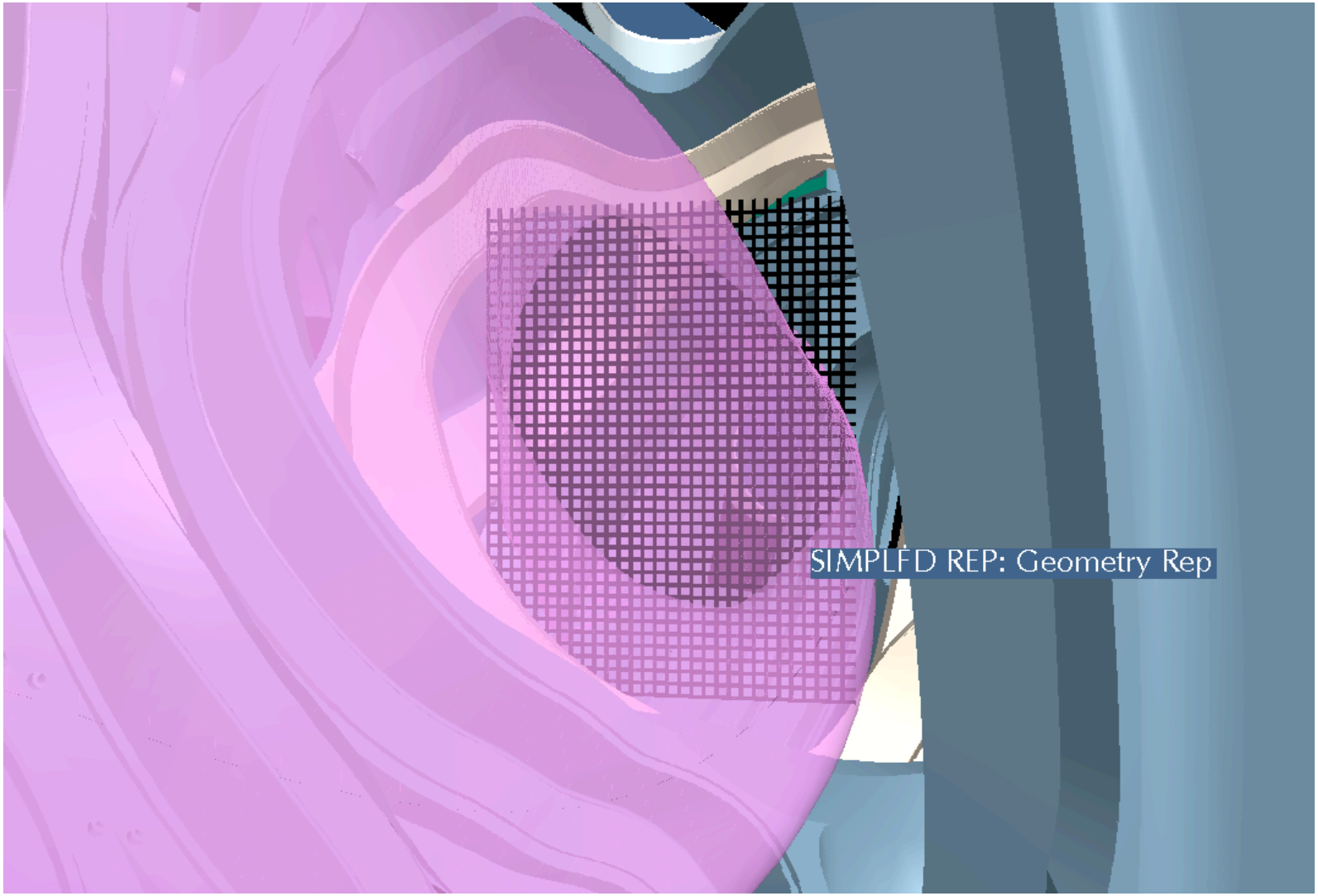


Midplane Cut through QPS

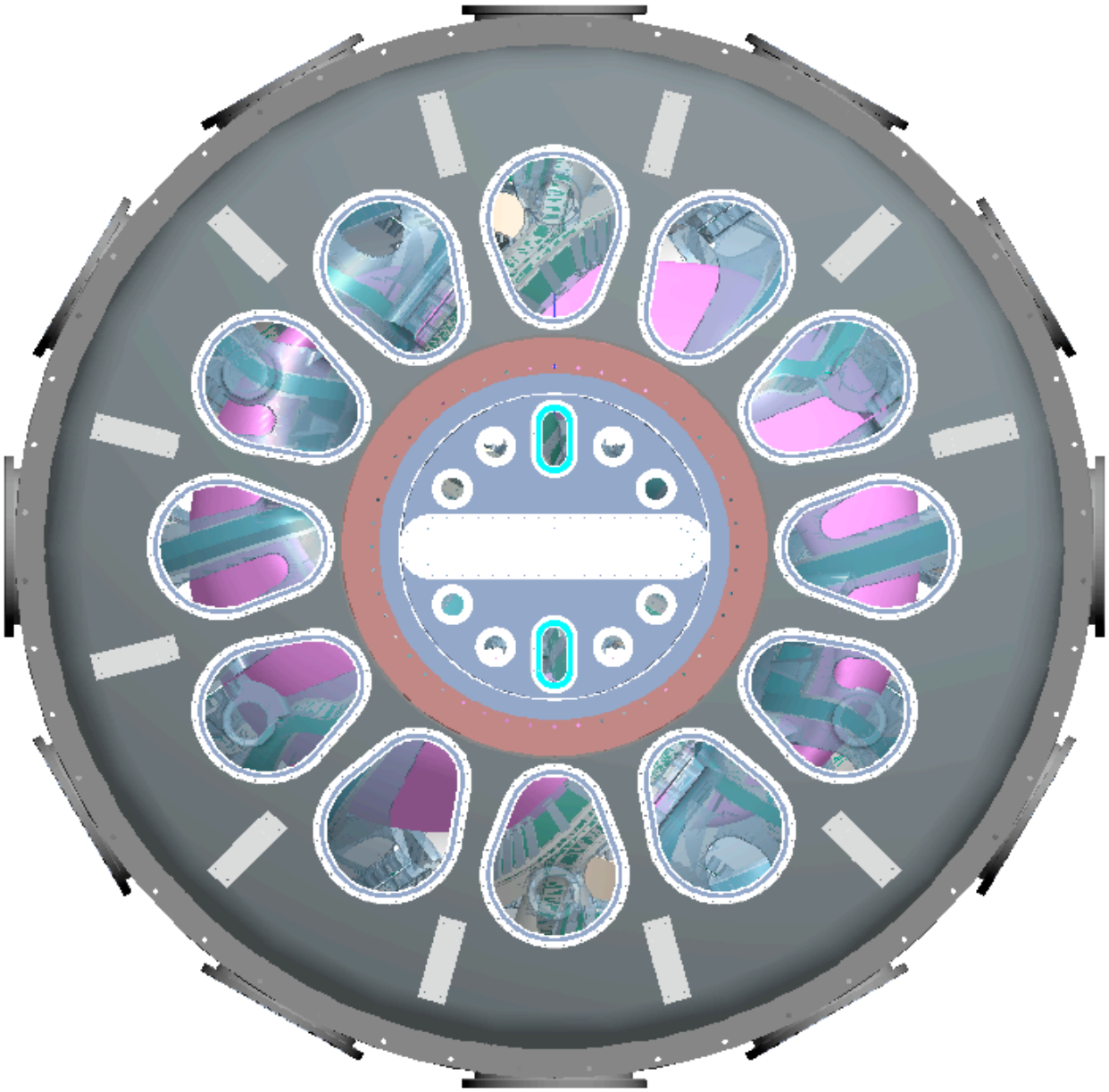


also good tangential diagnostic access

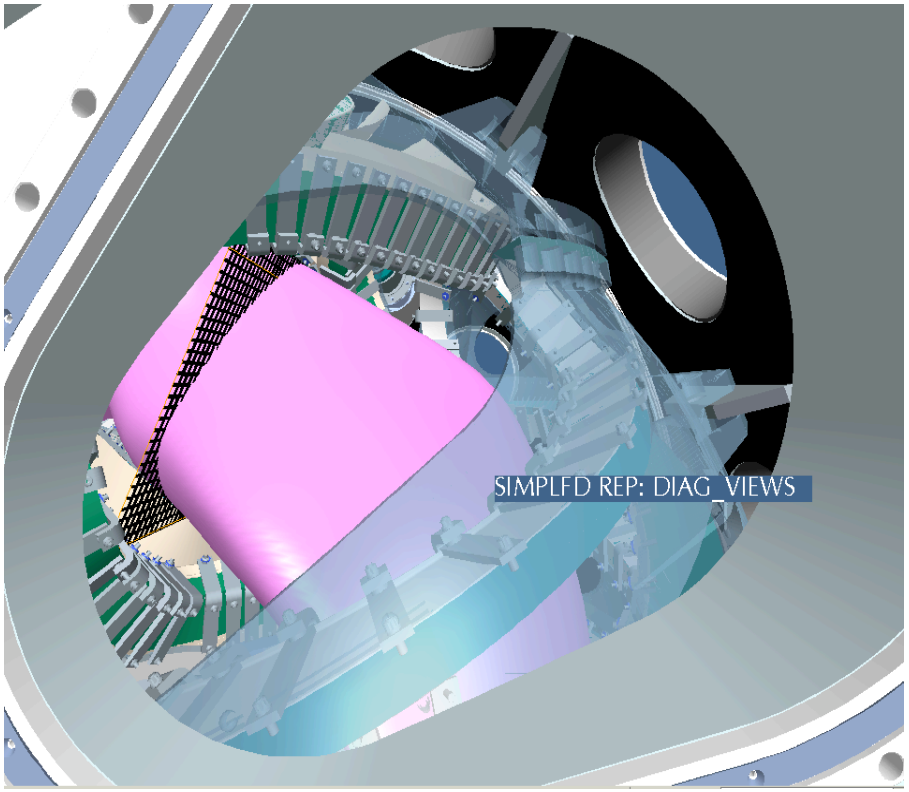
Tangential Midplane View

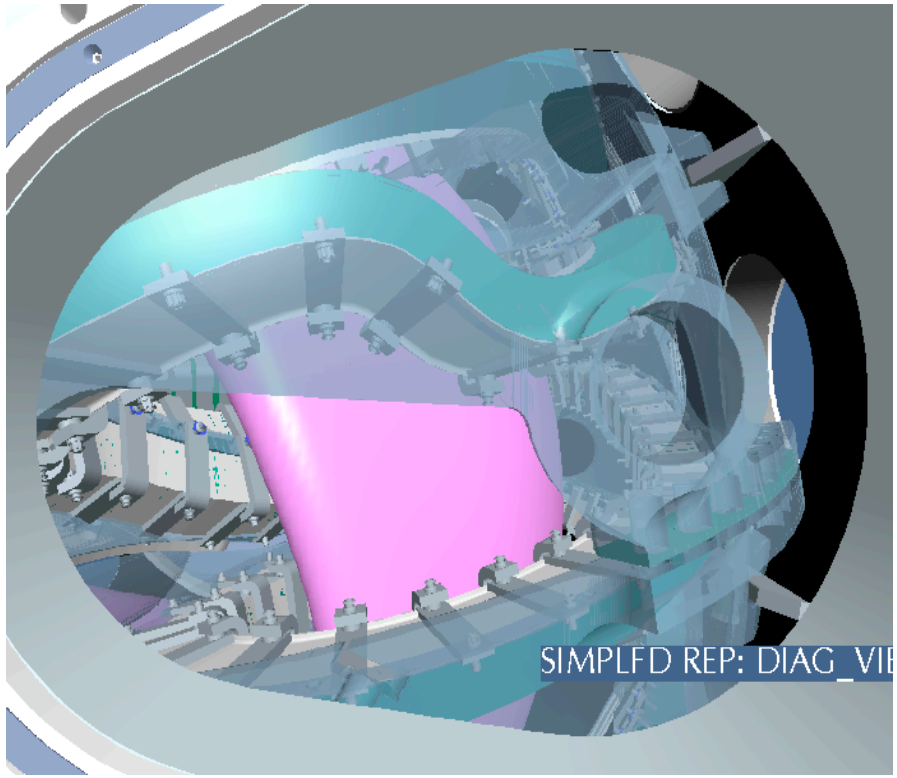


Distant View Through Top/Bottom Ports

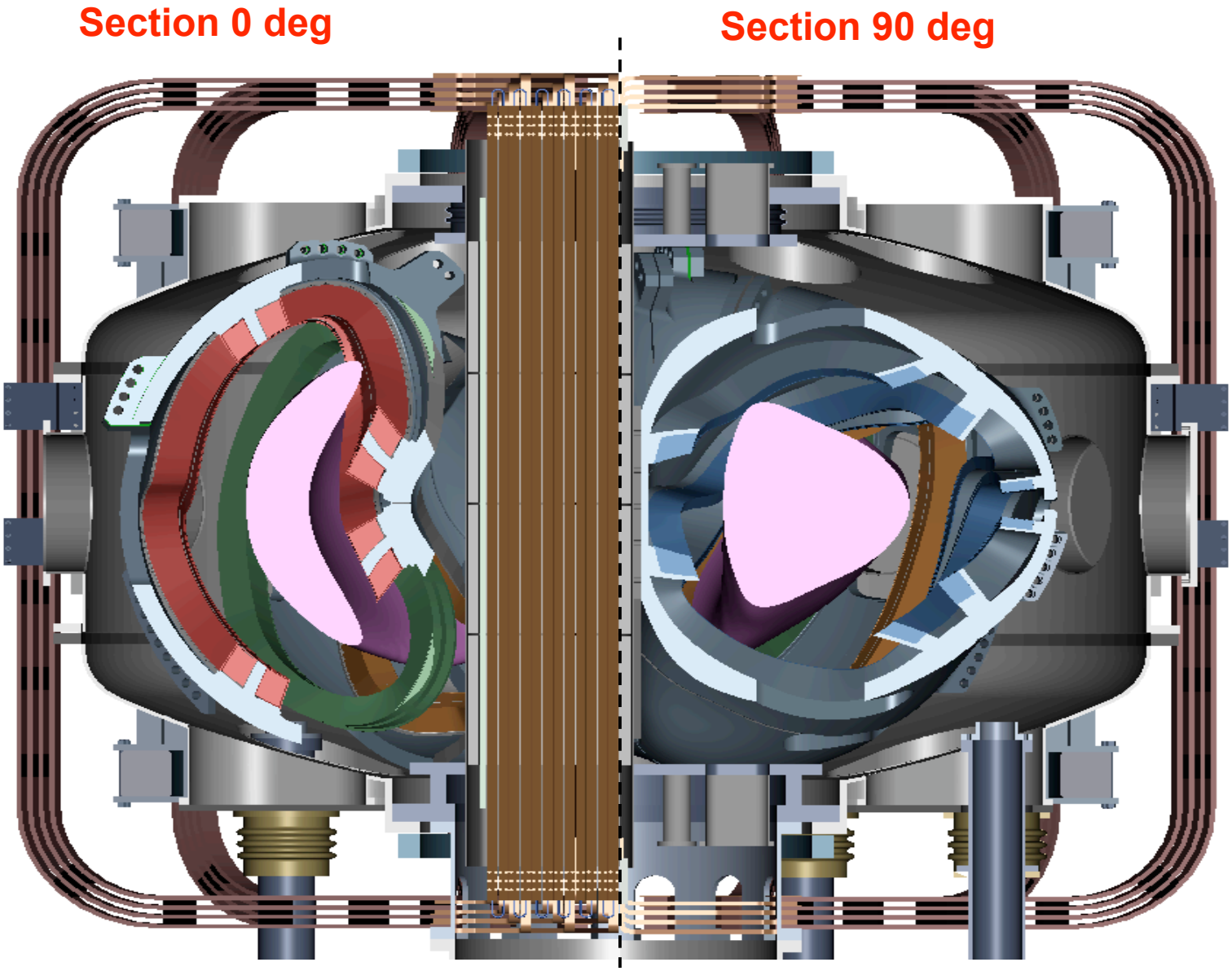


Views 30 cm from Top/Bottom Ports

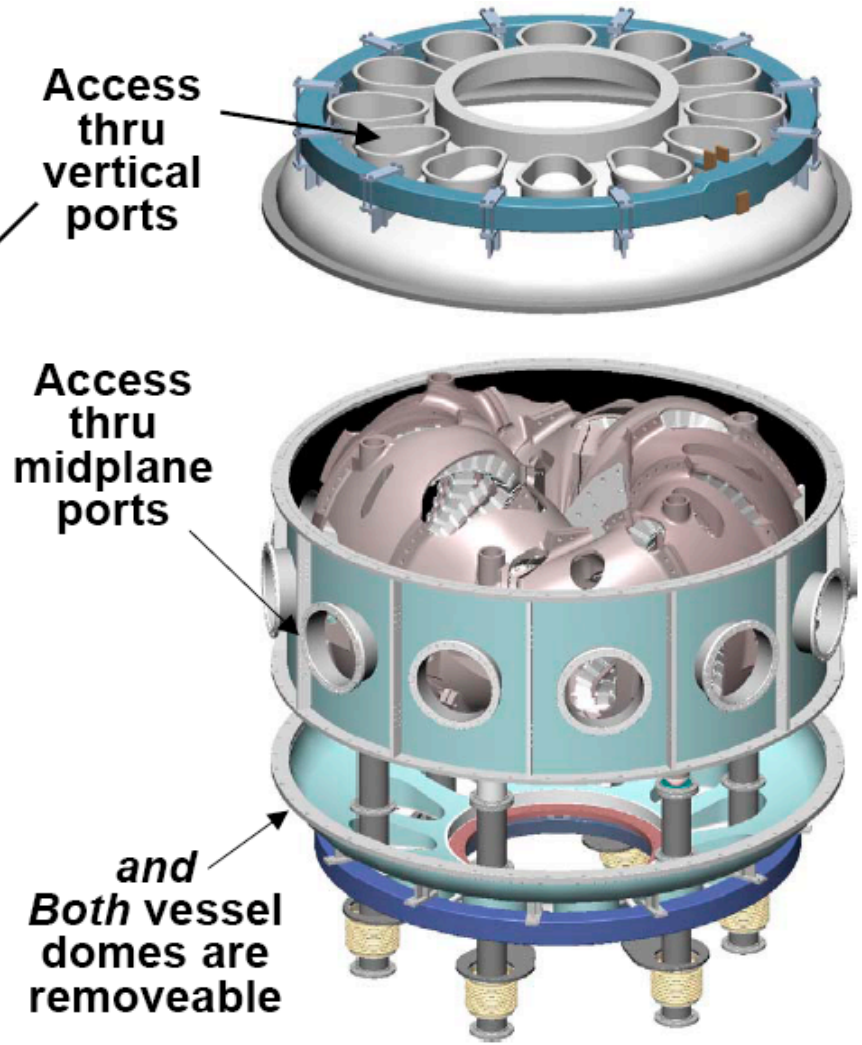




Large Distance between Plasma and Coils for Diagnostic Access



QPS Design Allows Later Installation of In-Vessel Diagnostics



QPS Project Status

- **Successful DOE reviews completed**
  - physics validation review ==> DOE mission need approval (CD-0), May 2001
  - project validation reviews, May 2001 and June 2002
  - conceptual design review June 2003 ==> DOE alternative selection and cost range approval (CD-1) this Spring
- **The next steps are R&D and further design**
  - casting a stainless steel winding form this year
  - plan to wind, vacuum can, and pot a prototype modular coil next year

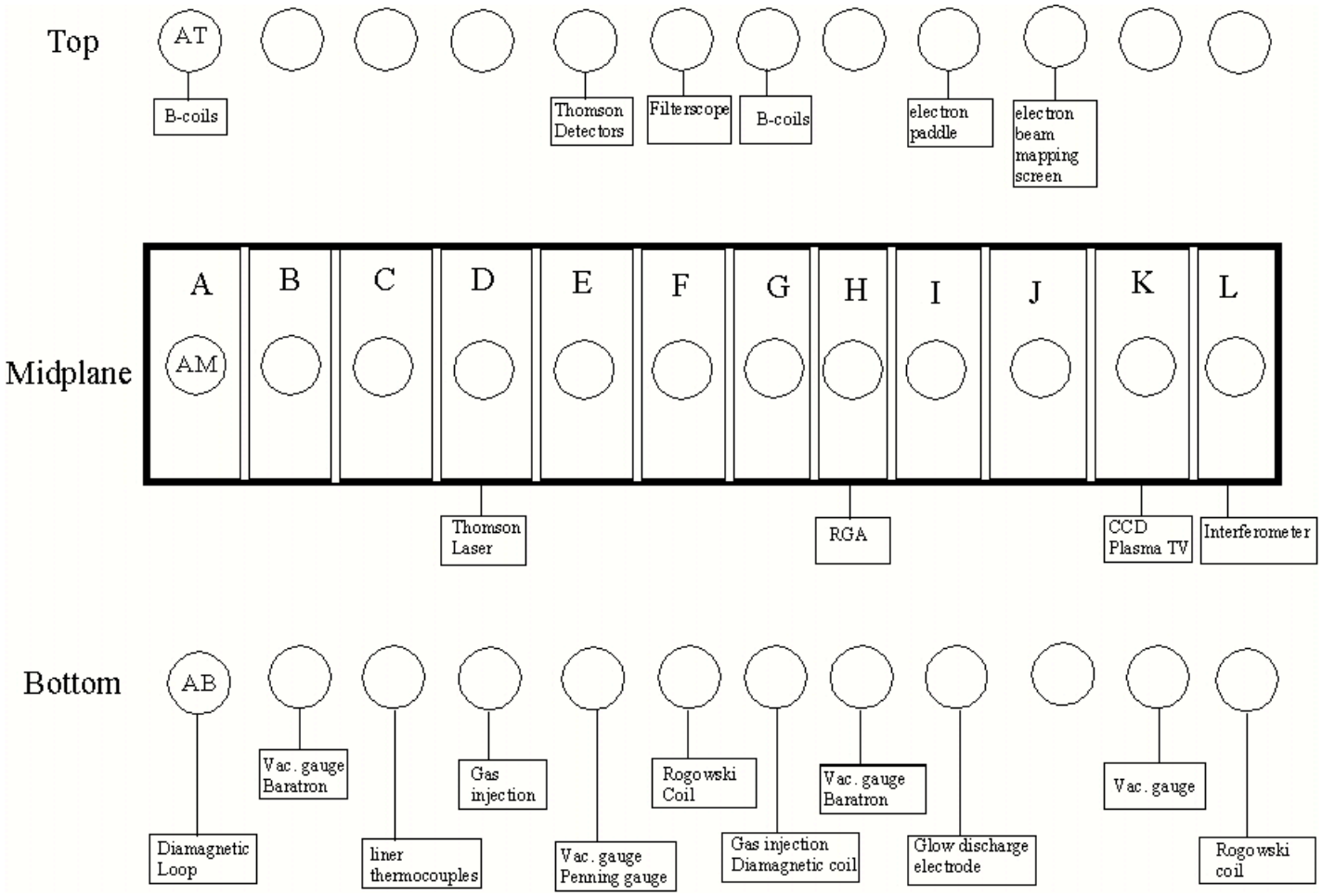
QPS Program Approach

- Focus on unique contributions of quasi-poloidal stellarator to toroidal confinement understanding
- International Program Advisory Committee and Research Forums
- Team approach to experimental program
- ~1/2 physics funding for collaborators, post docs, students, etc.

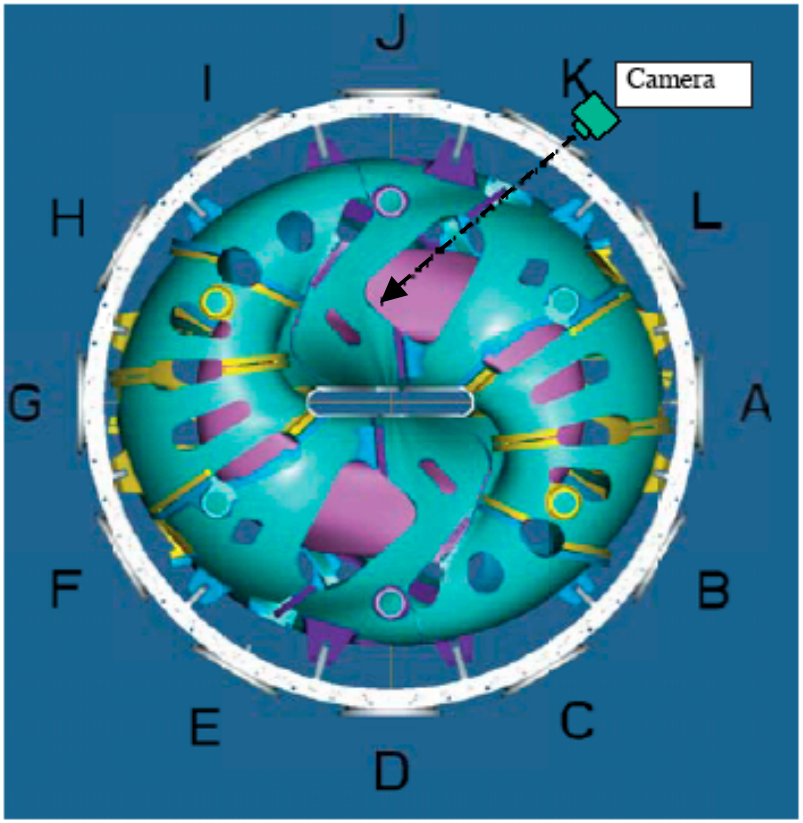
Summary

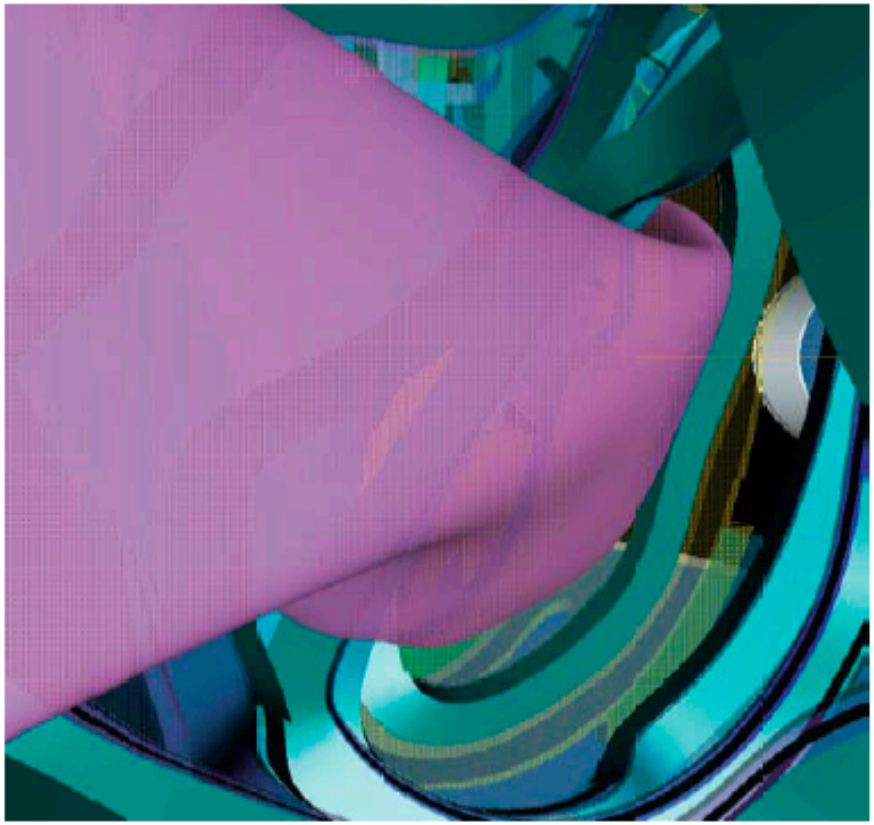
- **The QPS experiment**
  - non-circular, non-axisymmetric plasma & coil geometry,
  - dominant feature is quasi-poloidal symmetry
  - large range in configuration properties available
- **Physics Program**
  - physics program focuses on optimization of stellarator confinement at very low aspect ratio
  - diagnostic requirements determined by physics program
- **Diagnostic Challenges**
  - illuminating unique quasi-poloidal physics
  - complex 3-D geometry, large external vacuum tank, but excellent access for diagnostics from multiple viewpoints

Preliminary Layout of QPS Ports



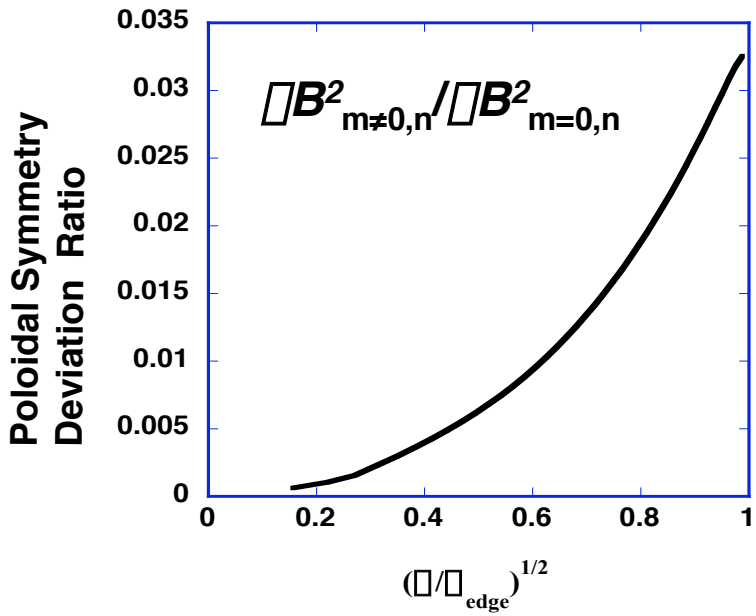
CCD Camera View

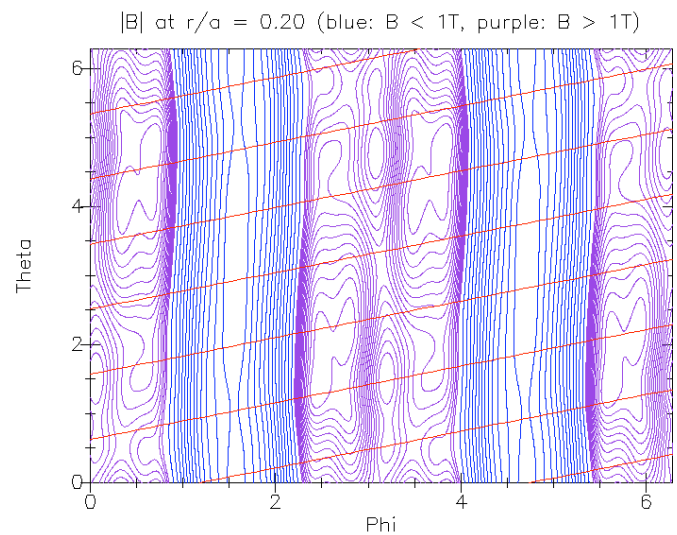
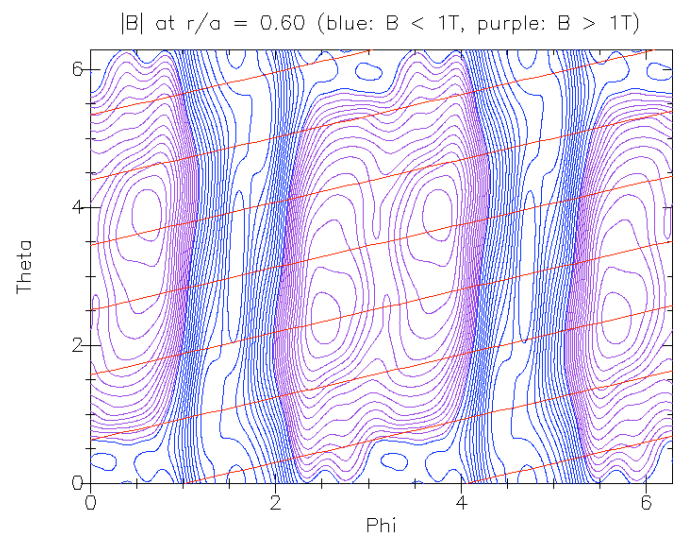




Quasi-Poloidal Symmetry

- **Reduces neoclassical transport, poloidal flow damping, bootstrap current, sensitivity to β, second stability threshold**





- **Electron beam mapping measures deviation from QP symmetry**