Stellarator
System
Studies

IPP Stellarator Reactor perspective

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O U T L I N E

- Helias Reactor concept
- Magnetic field of the Helias Reactor (HSR)
- Plasma equilibrium and stability
- Coil system and support structure
- Ignition experiment and Power Reactor
- Blanket system
- Divertor concept
- Conclusion

Helias Reactor Concept
(Basic properties)

- **Optimized magnetic field:**

good magnetic surfaces in the bulk plasmas (no major resonances, islands and stochastic regions).

magnetic islands at the edge can be utilized for divertor actions.

parallel currents are smaller than diamagnetic currents

small Safranov shift
high MHD-stability (ß = 4 - 5%)

small neoclassical losses
small bootstrap current

good alpha particle confinement

- **Steady state operation**

- **One set of modular coils**

production, maintenance etc.
large space for blanket & shield

- **Zero toroidal current :**

no OH - transformer
no need for current drive
no tearing mode instability
no transient magnetic fields
no disruptive instability

- **Low averaged neutron**

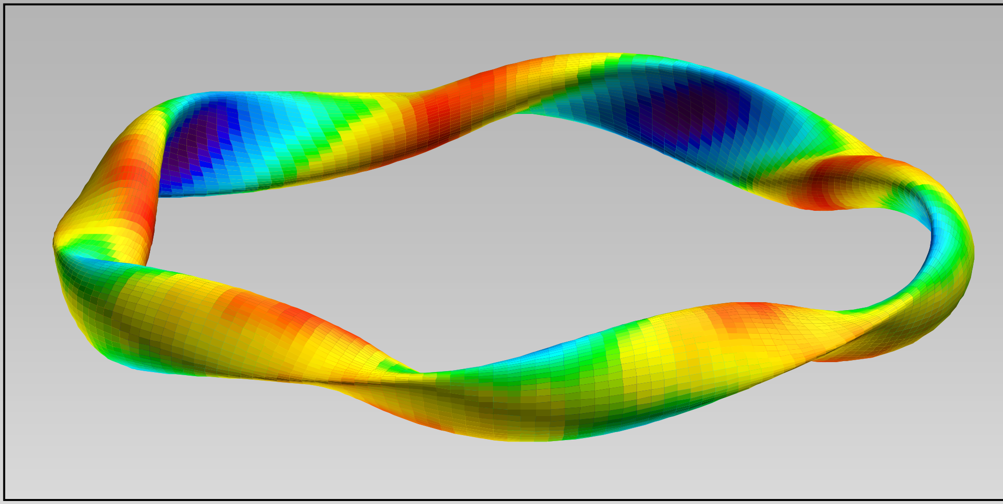
wall load about 1MW/m2

Important is to meet all these conditions in one configuration!

Design criteria of the HSR (conservative approach)

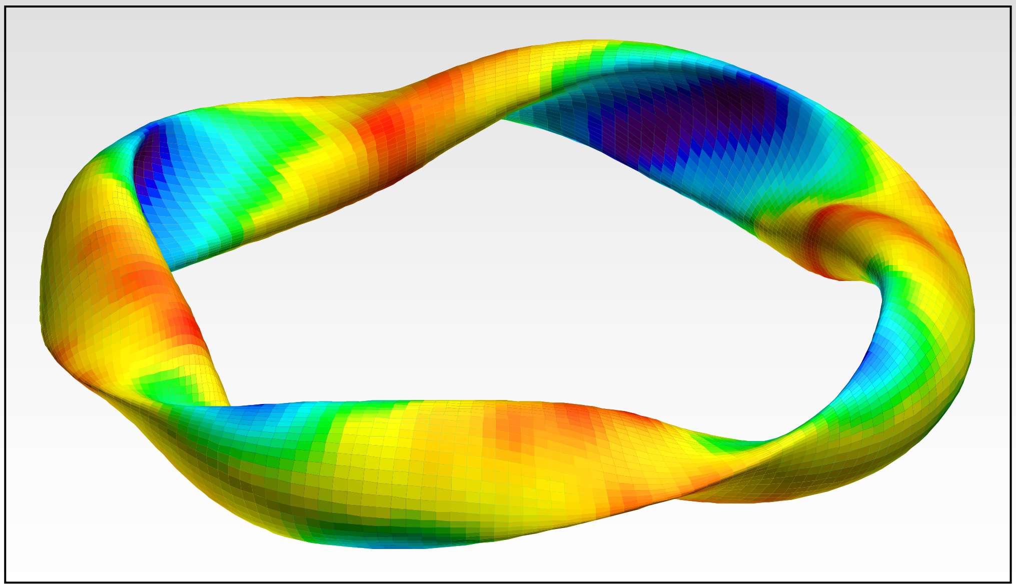
- physics within the limits known from experiments
- small B - field to facilitate mechanical problems
- NbTi or Nb_3Al superconductors
- reactor size must accommodate blanket and shield (1.3m)
- and allow for self-sustained burn within known laws τ_E
- fusion power output in the range 3000-3500 MW
- alphas well confinement (slowing down time ~ 0.1 s)
- stability of burning plasma: control of power (start up & ramp-down phase)

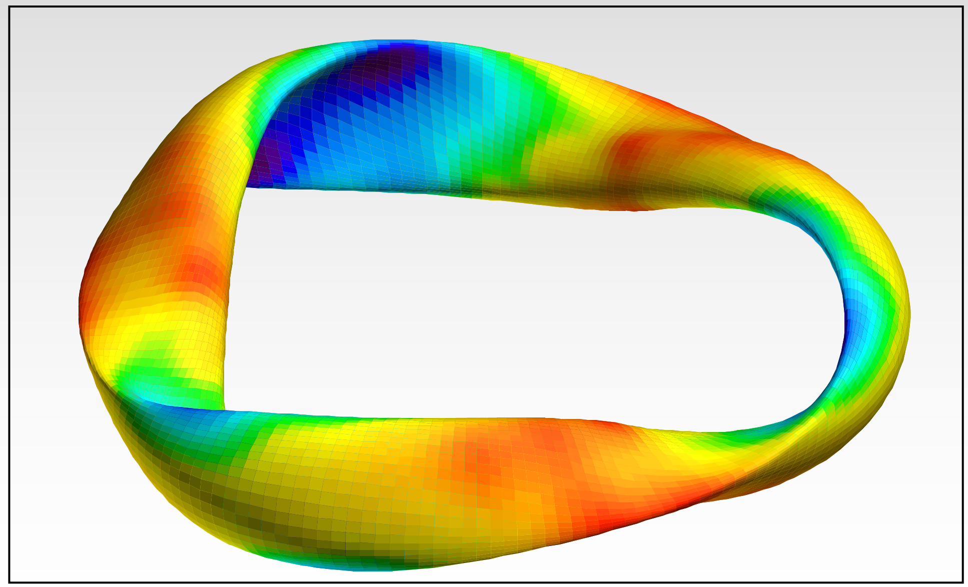
Helias Configurations (5,4,3 Periods)



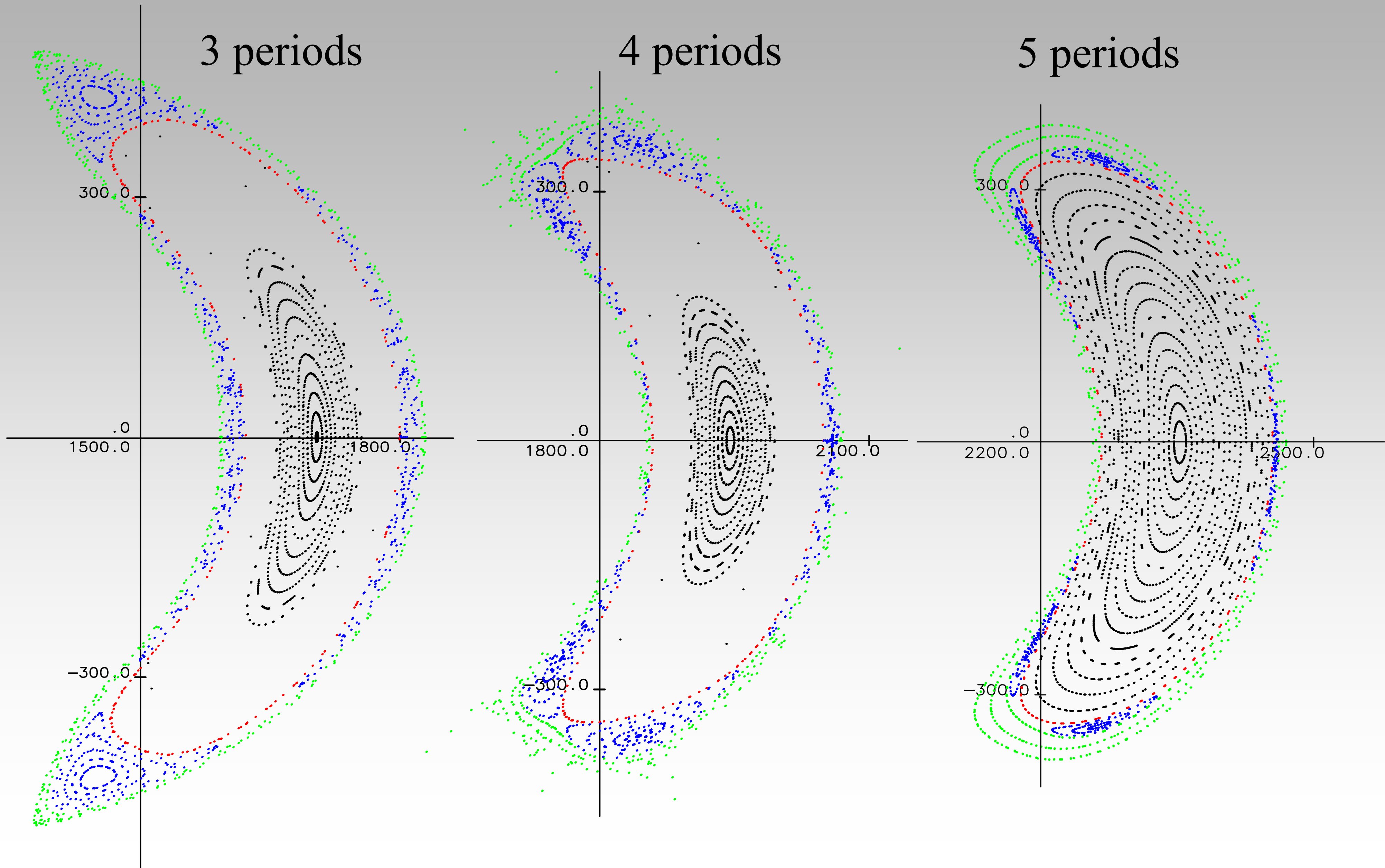
Magnetic surfaces and Mod B

Left top: 5 Field periods
Left bottom: 4 Field periods
Right bottom: 3 Field periods



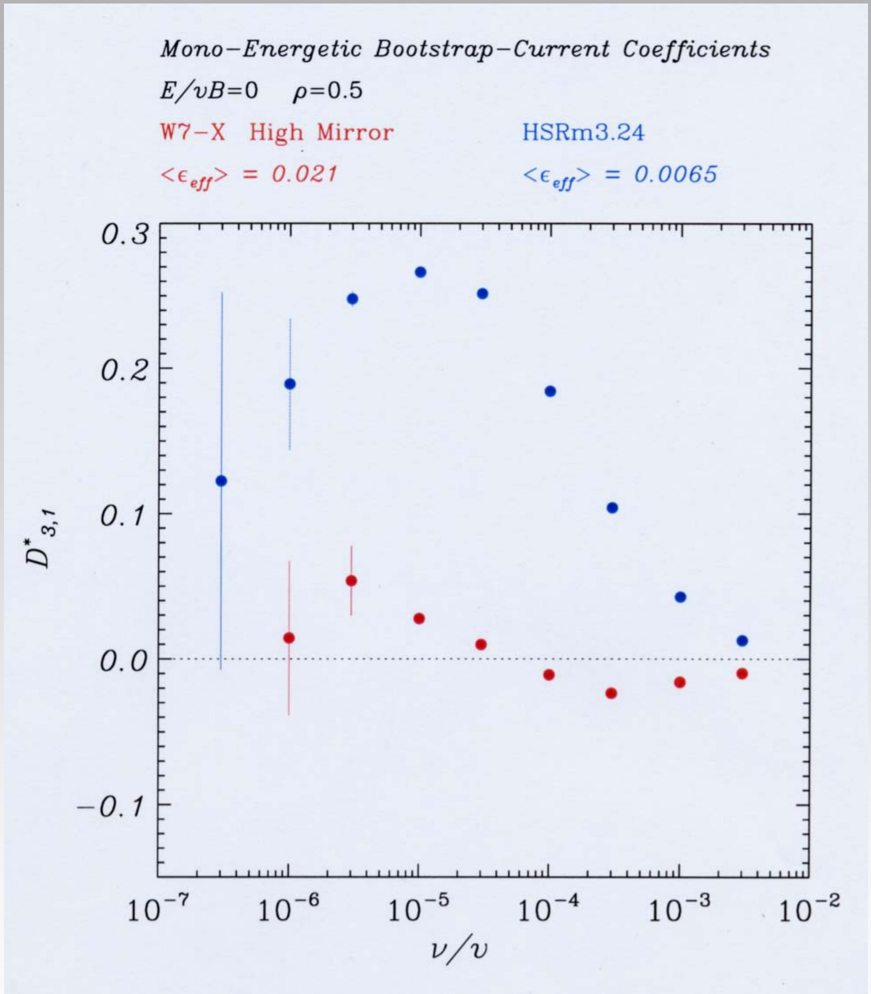


Poincare plots of magnetic surfaces at beta 4%



Bootstrap current in HSR 3/15

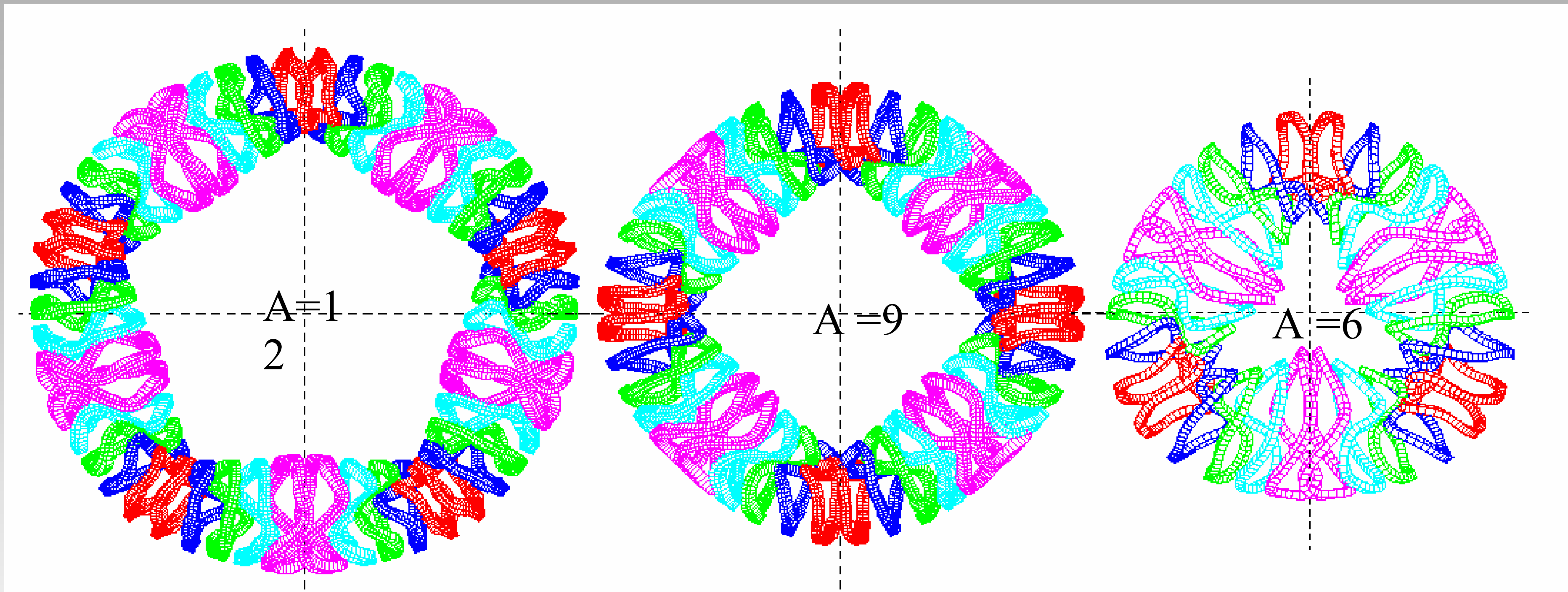
C. D. Beidler, 2003



$b_{1,1} \approx b_{1,0}$ results in significant $D^*_{3,1}$ but compatible with B_{max} limitations on NbTi superconductor

$b_{1,1} \approx 2b_{1,0}$ for W7-X to obtain small values of $D^*_{3,1}$

HSR5/22 HSR4/18 HSR3/15

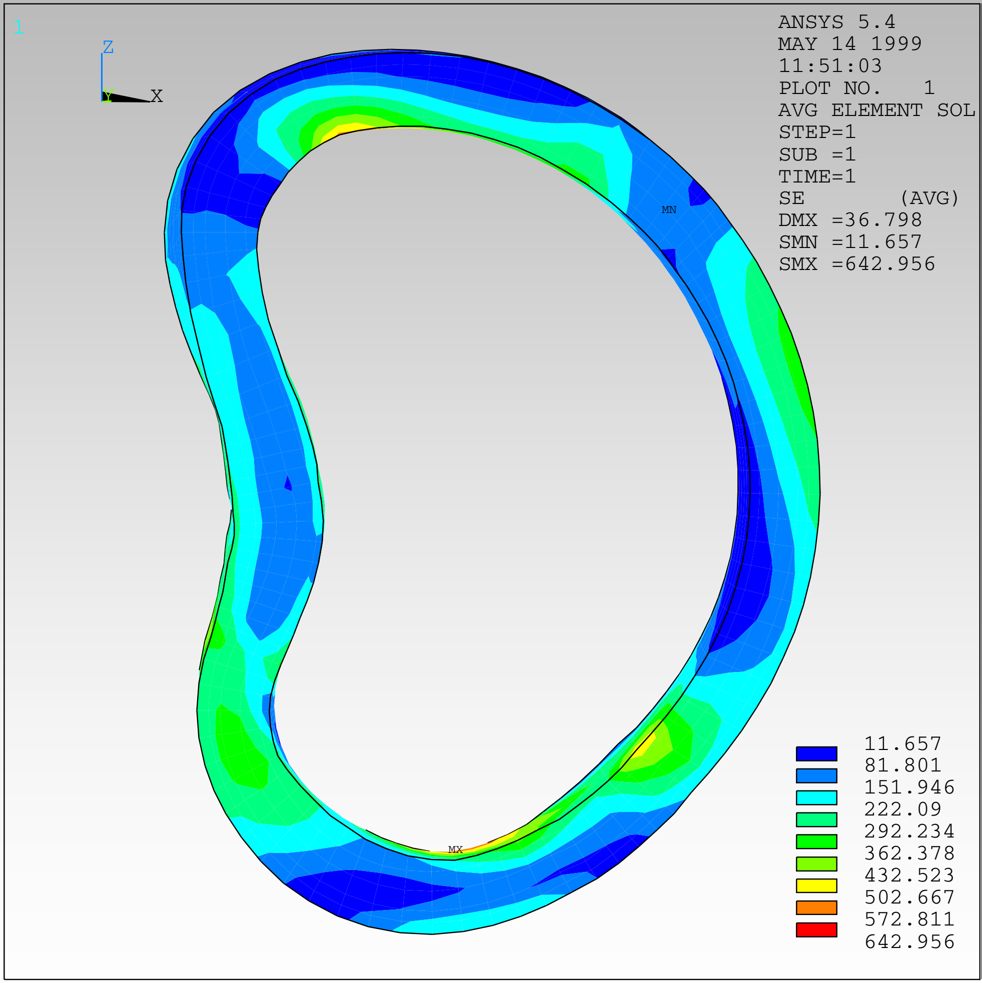


Major radius	**22 m**	**18 m**	**15 m**
Plasma radius	**1.8 m**	**2.1 m**	**2.5 m**
Plasma volume	**1410 m^3**	**1560 m^3**	**1600 m^3**
Av. field on axis	**4.75 T**	**4.4**	**4.4**
Max field	**10 T**	**8.5 T**	**8.3 T**
Number of coils	**50**	**40**	**30**
Magne energy	**100 GJ**	**76 GJ**	**72 GJ**

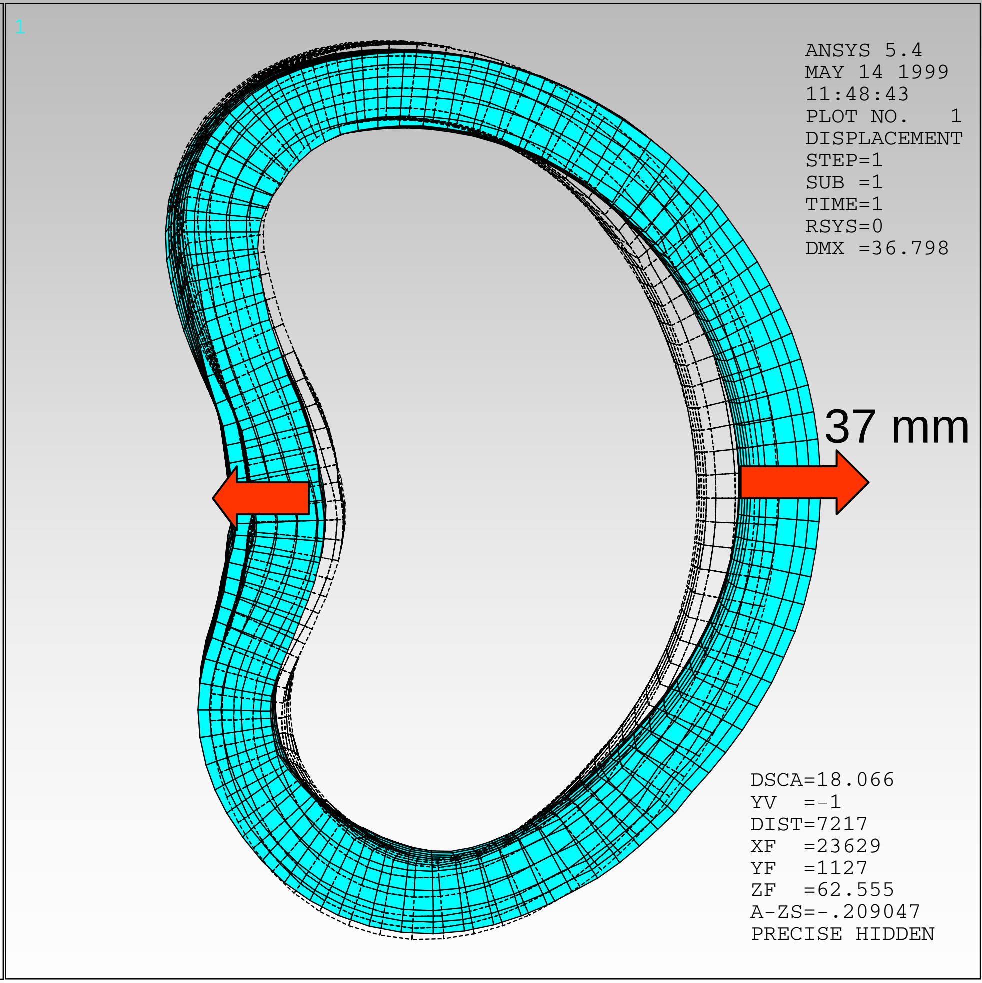
HSR optimized configurations
for 1GW elect.power

Coil1 Stress and Bending

Van Mises Stress



Deformation of coil

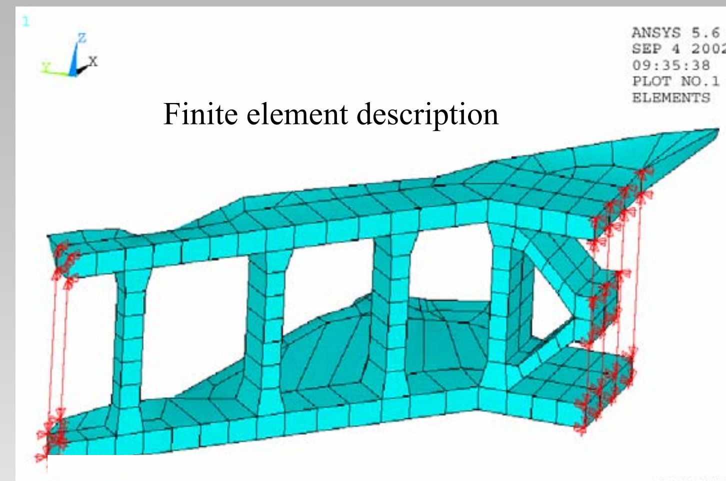


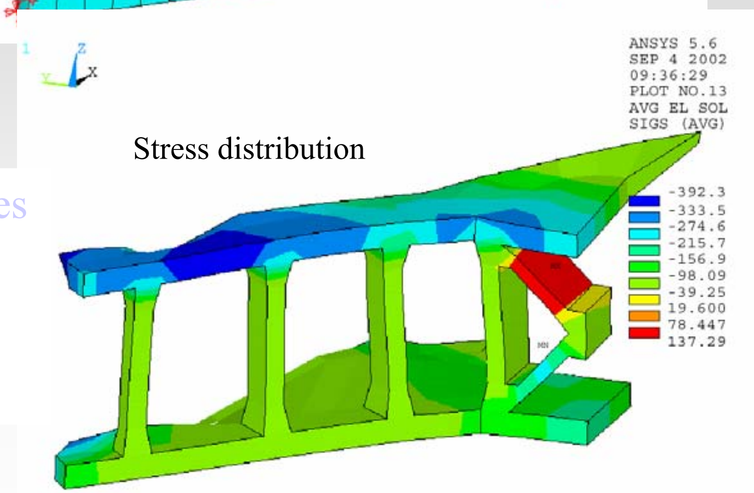
Stress distribution in the coil support structure

E.Harmeyer, J. Kiblinger, 2002

Half a field period of HSR4/18

Stresses in the toroidal support ring





Max. stress values are within the technical limits utilising this support structure

Elastomechanic analysis: Stresses in the stainless steel structure are in (MPa),

100MPa ~ 1t/cm2

Critical issues of coil system

- Cooling with super-fluid helium at 1.8 K
- Nuclear heating in winding pack
- Bending stresses in coil case
- Tensile stresses in insulator
- Modification of magnetic field by martensitic / ferritic steel

Helias reactor HSR4/18

IPP

Major radius	18 m
Av. plasma radius	2.1 m
Plasma volume	1670 m^{-3}
Magnetic field	4.4/5.0 T
Max. field	8.5/10 T
Rot. Transform	0.83 - 1.0
Magnetic energy	66/100 GJ

Coils

Av. radius [m]	5.5
Length of turns [m]	34.5
Weight of coil [t]	102
Coil system [t]	4080
Structure [t]	5000
Cryostat	
Major radius [m]	18
Minor radius [m]	8
Volume [m^3]	21476

Ignition experiment/ power reactor

HSR4/18 is smaller than HSR5/22!

Summary: ignition experiment

Stellarator ignition experiment

- The ignition experiment has the parameters:
  R= 18 m, a=2.1 m, B on axis 4.4 T
- The fusion power is 1300 -1700 MW
- Av. Density 2×10^{20} m^{-3}, T(0) = 11-14 keV, $\langle\beta\rangle$=3.6%
- The magnet system uses NbTi superconductors at 4.2 K
- Stored magnetic energy 72 GJ
- The required energy confinement is compatible with empirical scaling laws
- The net heating power for start-up is in the order of 50 MW

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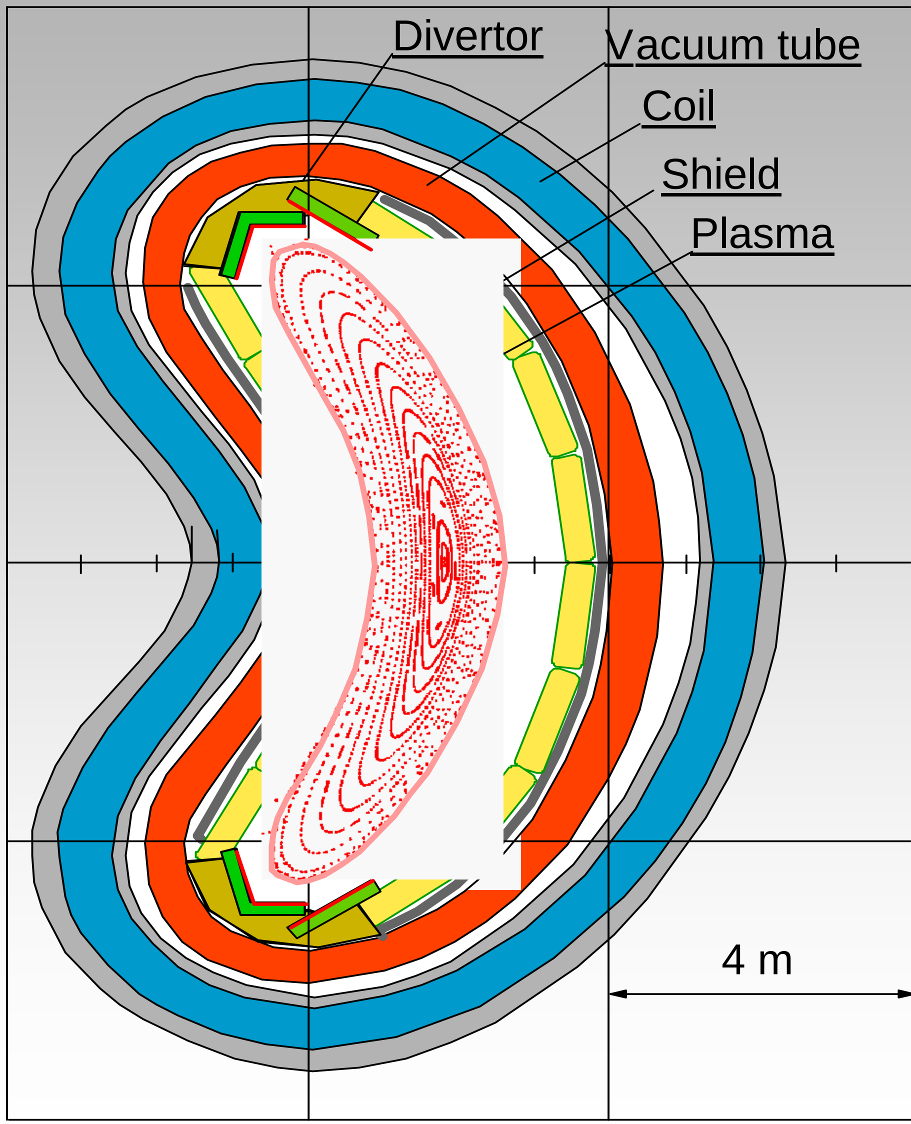
Conclusions HSR4/18

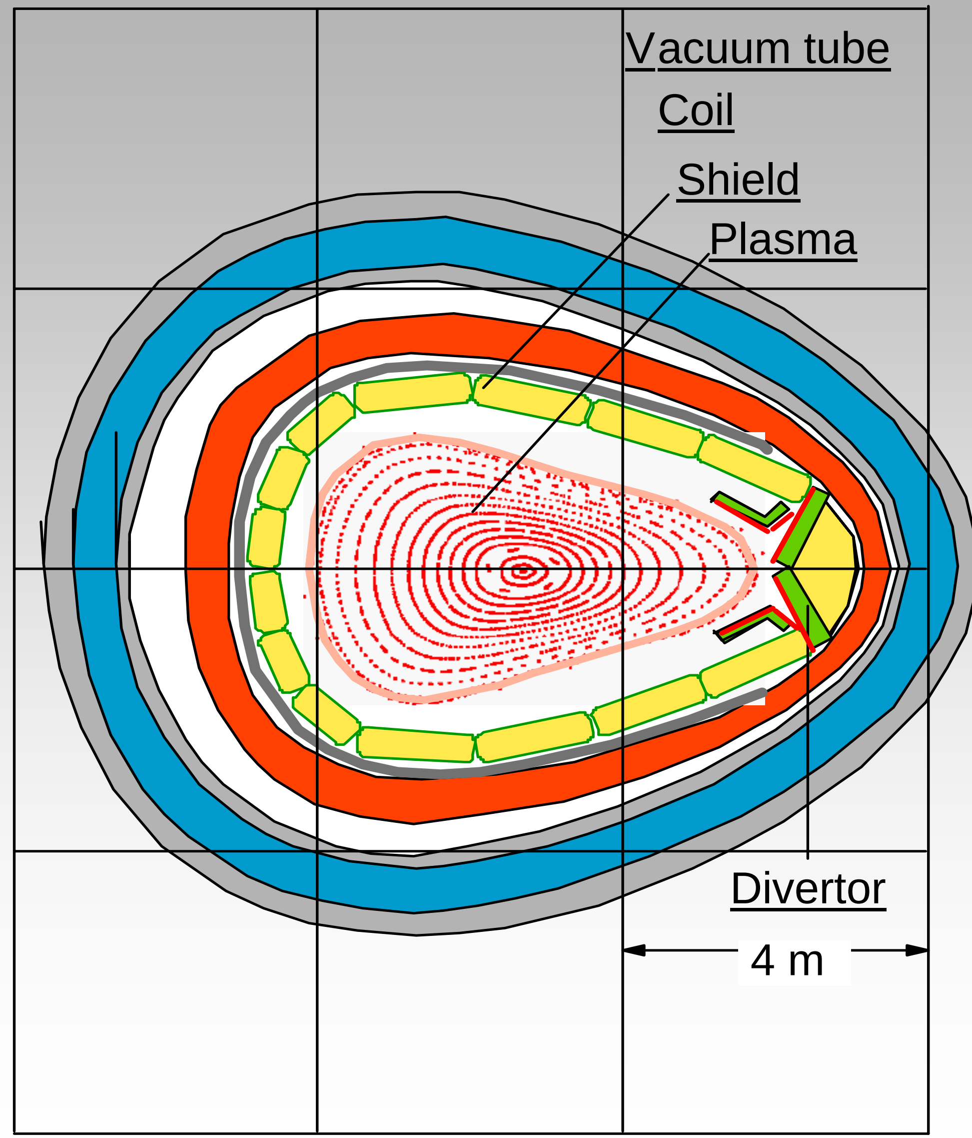
- **The power reactor has the parameters:**

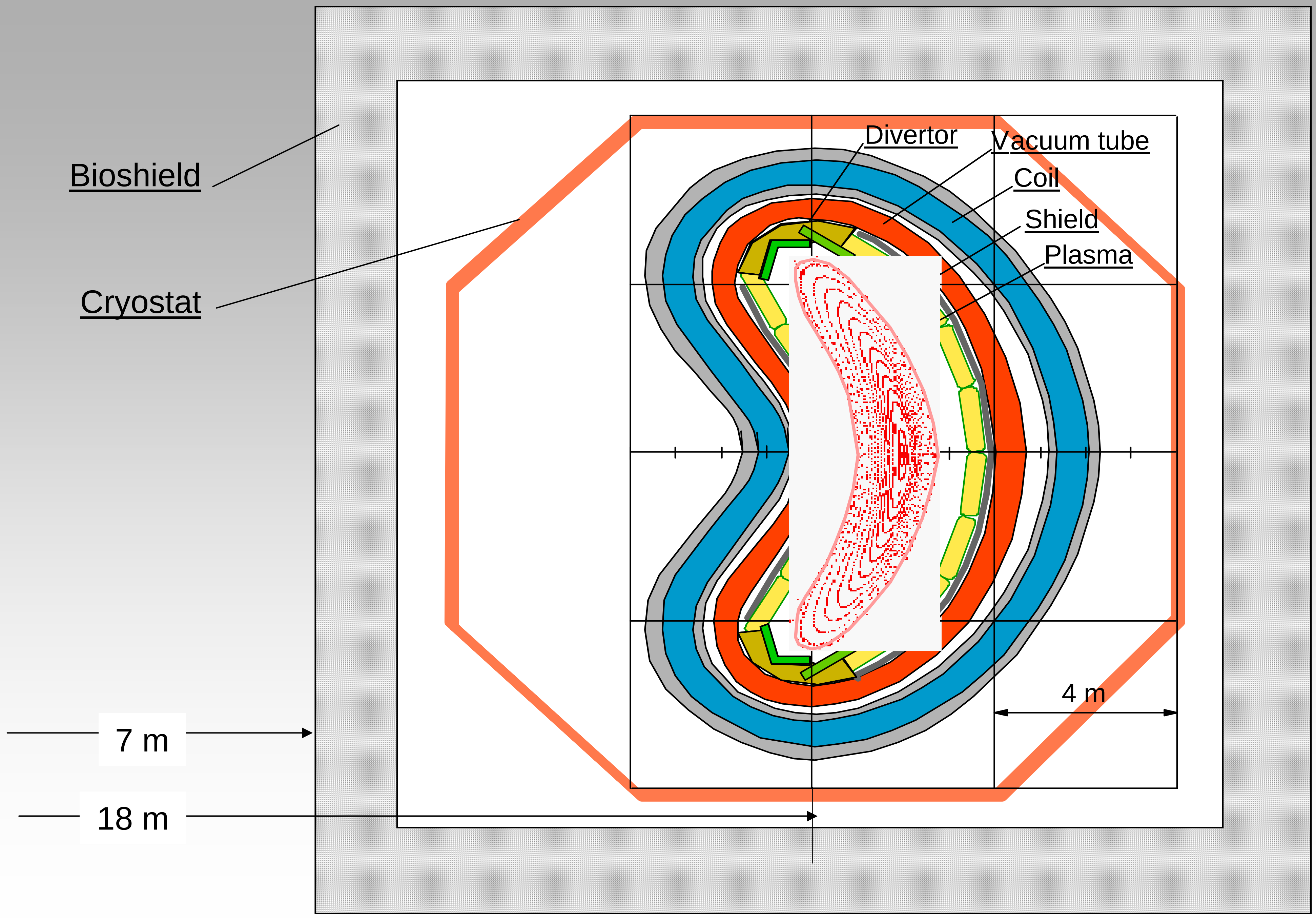
  R= 18 m, a=2.1 m, B on axis 5.0 T, Bmax about 10 T
- **The fusion power is 3000 MW**
- **Av. Density 2-3x10^{20} m^{-3}, T<=15 keV**
- **HSR4/18 is stable against global modes at <ß> ≤ 3.5%**

  (increase by profile shaping possible)
- **Small neoclassical transport is (ε_{eff} <0.6%)**
- **Good confinement of alpha-particles (2.5% energy loss)**
- **The magnet system uses NbTi superconductors at 1.8 K**
- **The required energy confinement is compatible with empirical scaling laws**
- **The net heating power for start-up is of the order of 50 MW**
- **Cost analysis (Cook, Ward). Comparable to tokamak reactor**

Blanket system for HSR4/18i,

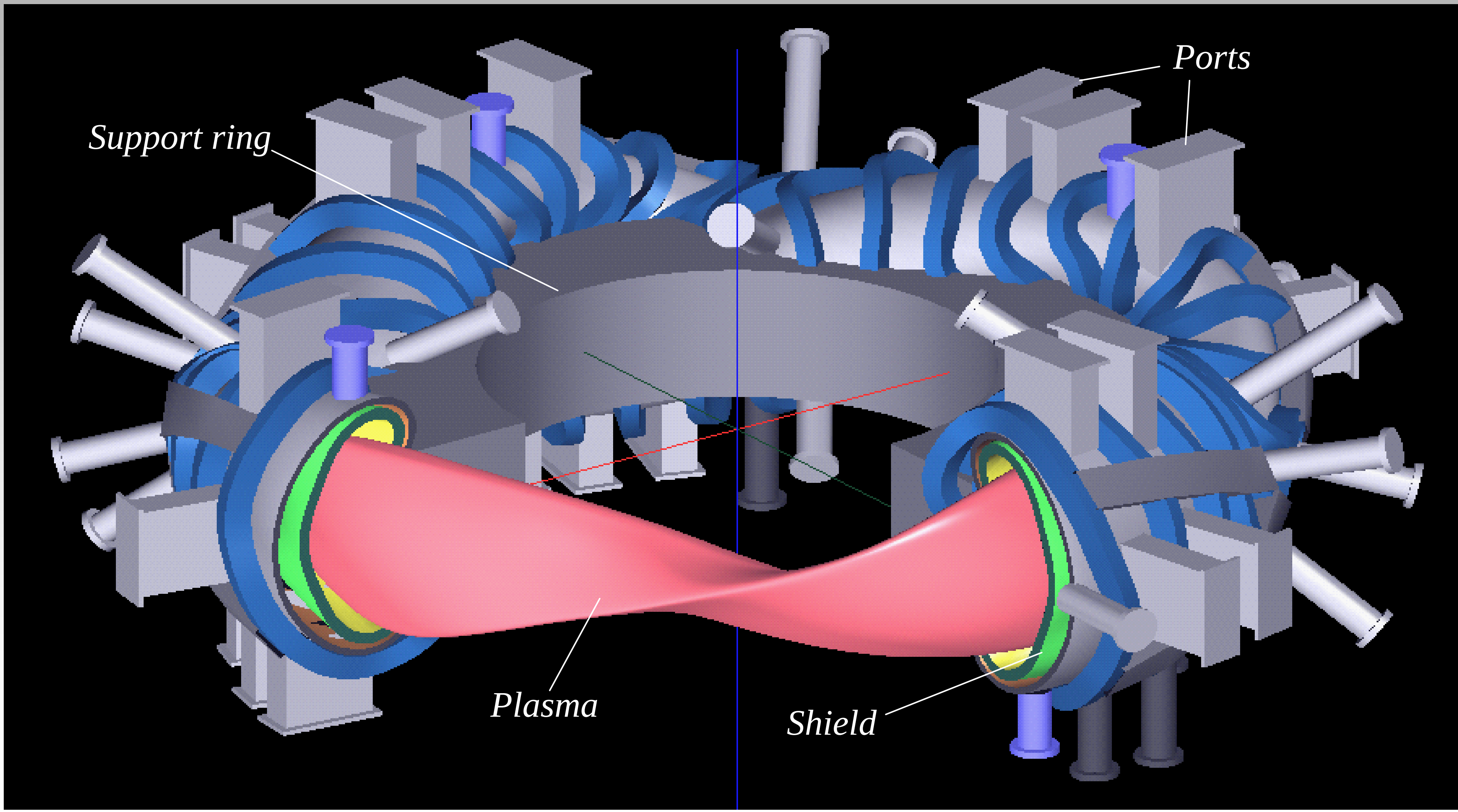




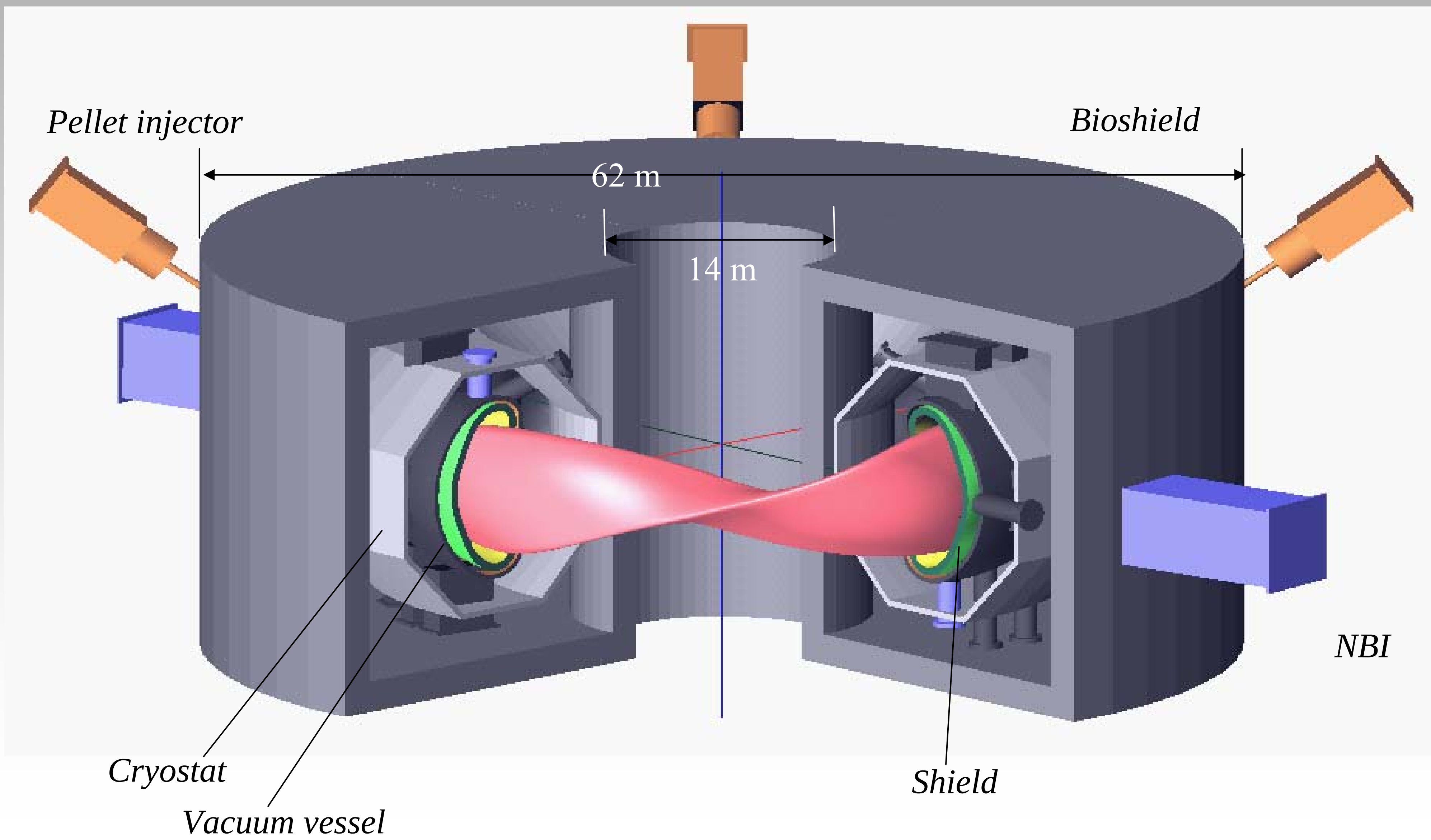


Bioshield
Cryostat
Divertor
Vacuum tube
Coil
Shield
Plasma
4 m
7 m
18 m

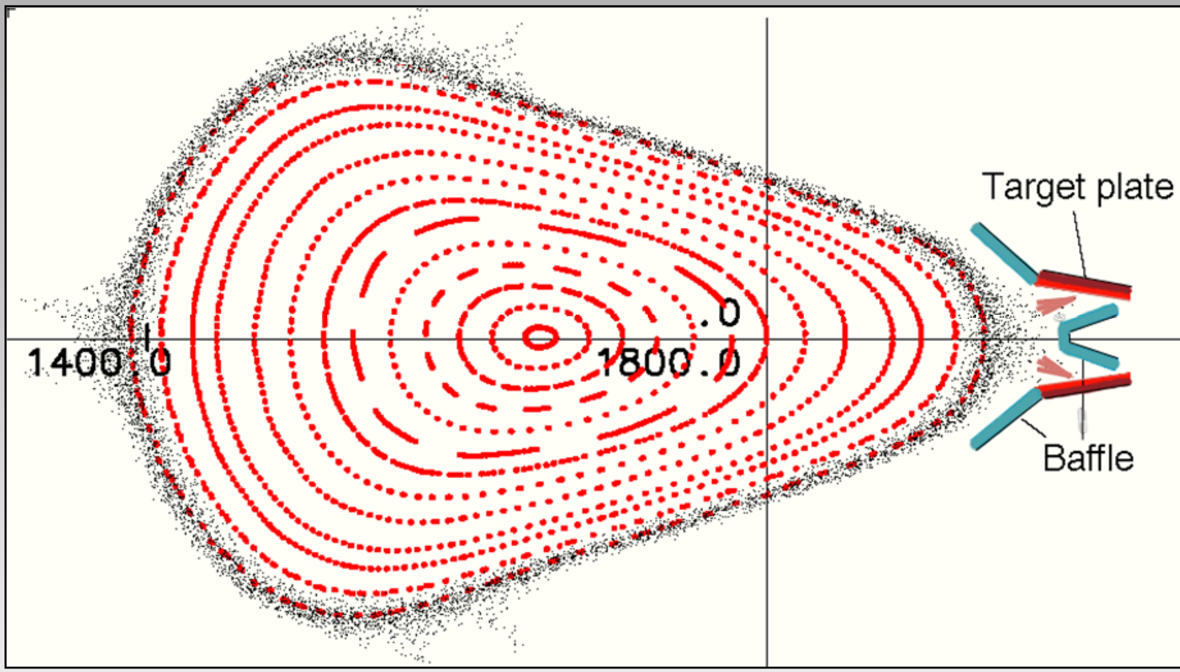
HSR4/18: Coils, support system, vacuum vessel, blanket



HSR4/18i: Bioshield, cryostat, vacuum vessel, blanket



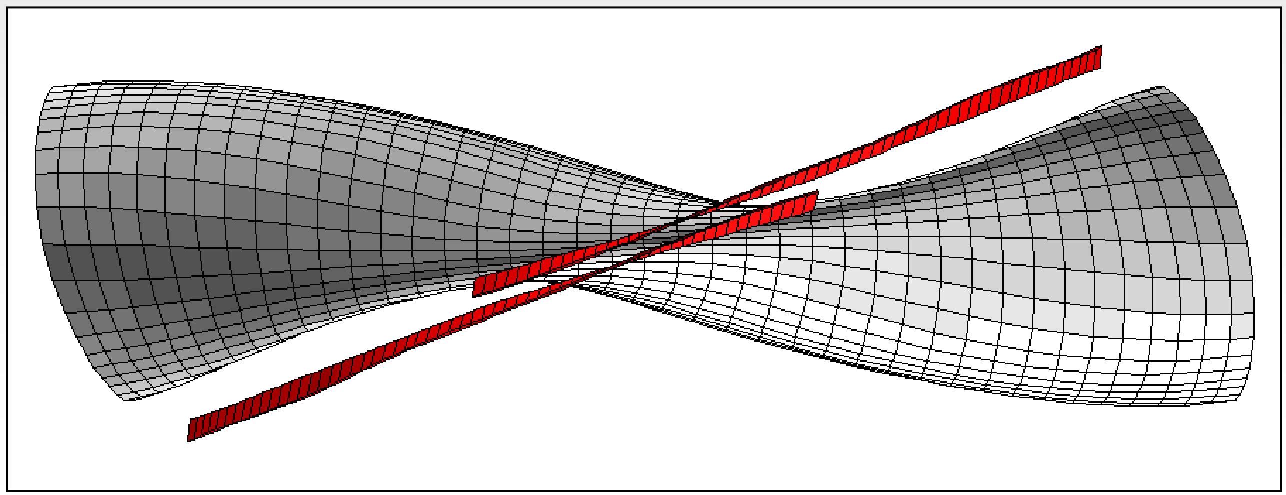
HSR4/18 Divertor

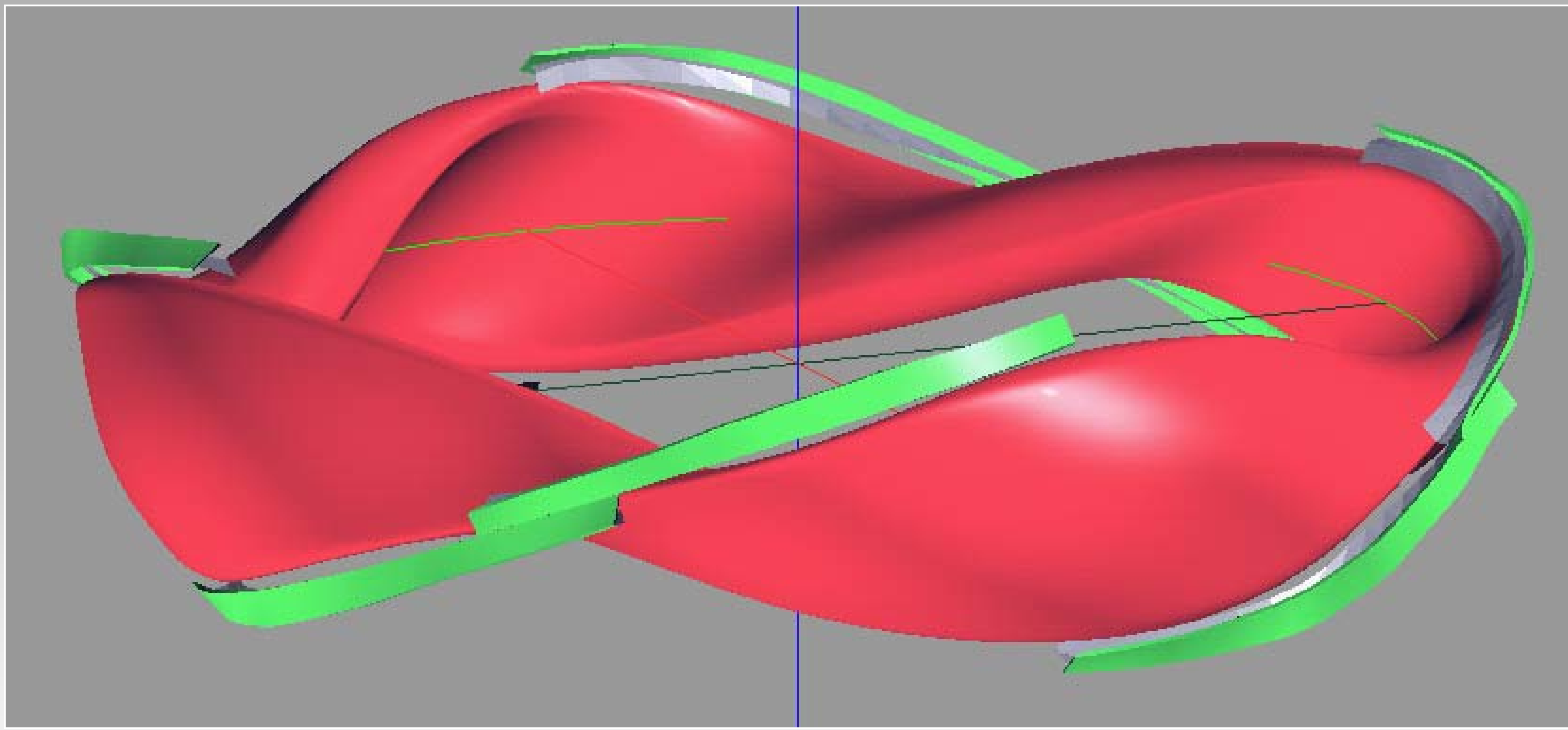


The last magnetic surface is enclosed by a stochastic region.

Remnants of 4/4 islands are utilized for divertor action

8 Target plates
Length 15 m
Width 1m
Segment length 2 m
Wetted area 40 m^2





8 Target plates
Length 15 m
Width 1m
Segment length 2 m
Wetted area 40 m^2

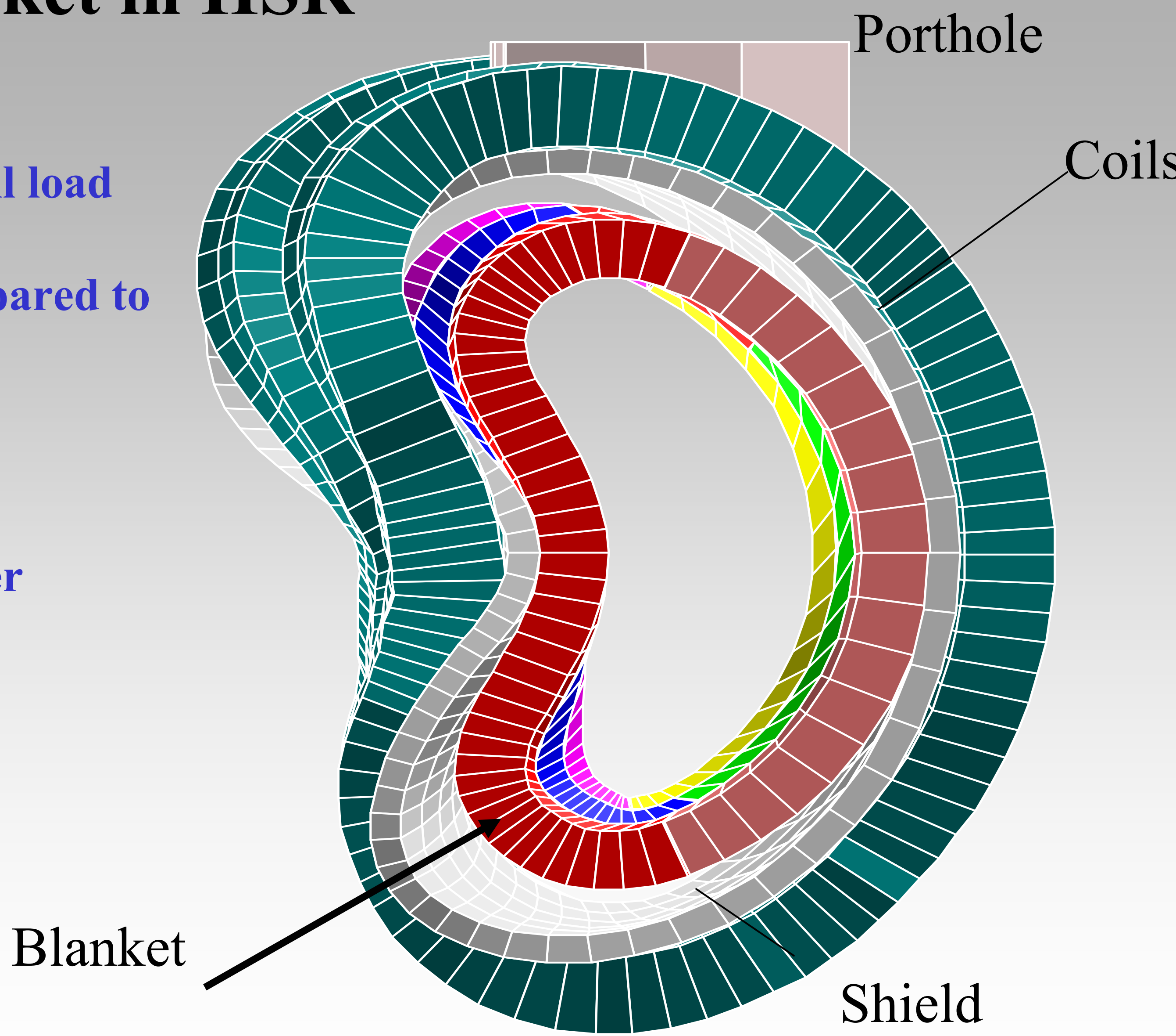
Coils and Blanket in HSR

- Low average neutron wall load

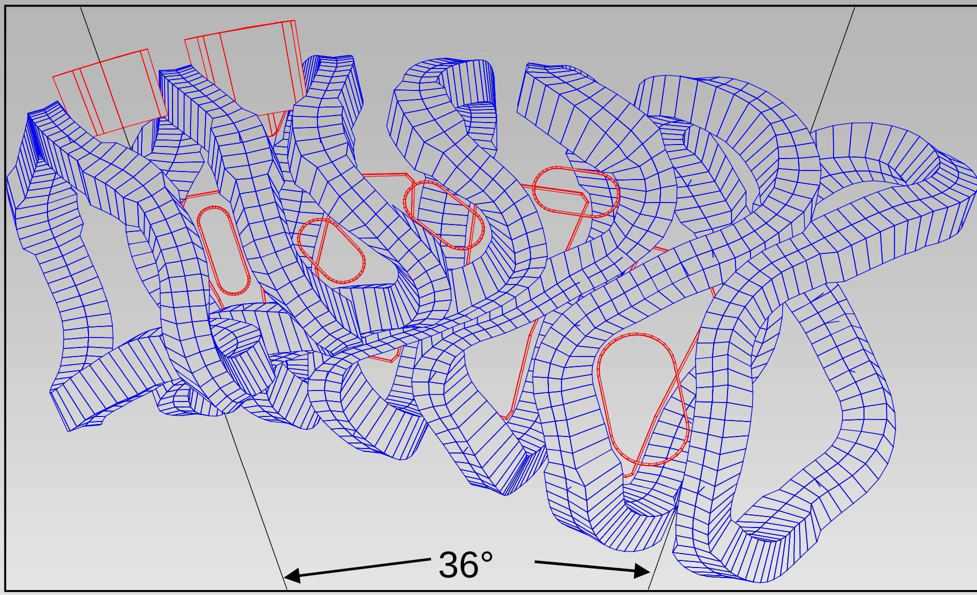
- Complex geometry (compared to tokamaks)

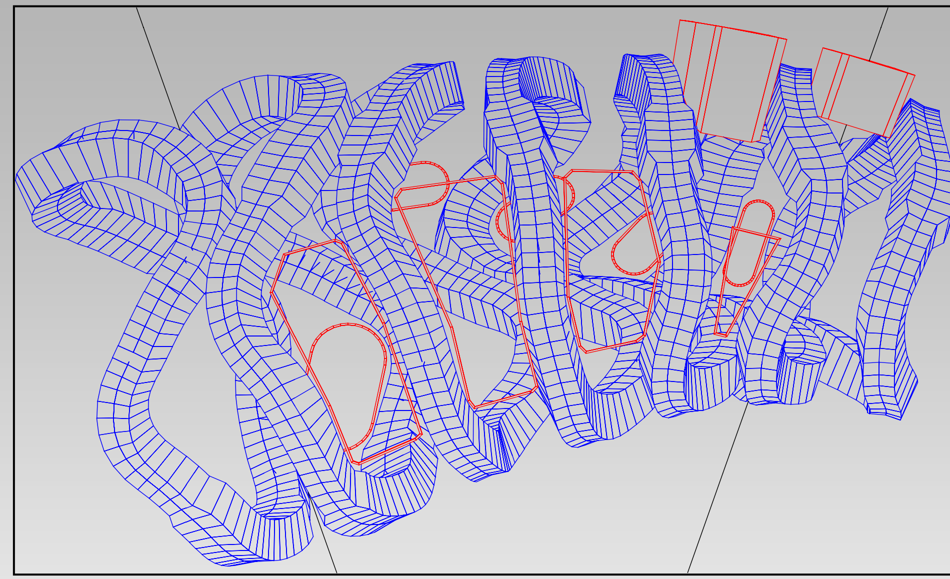
- Problem of maintenance

- Comparison LiPb-breeder /Ceramic breeder



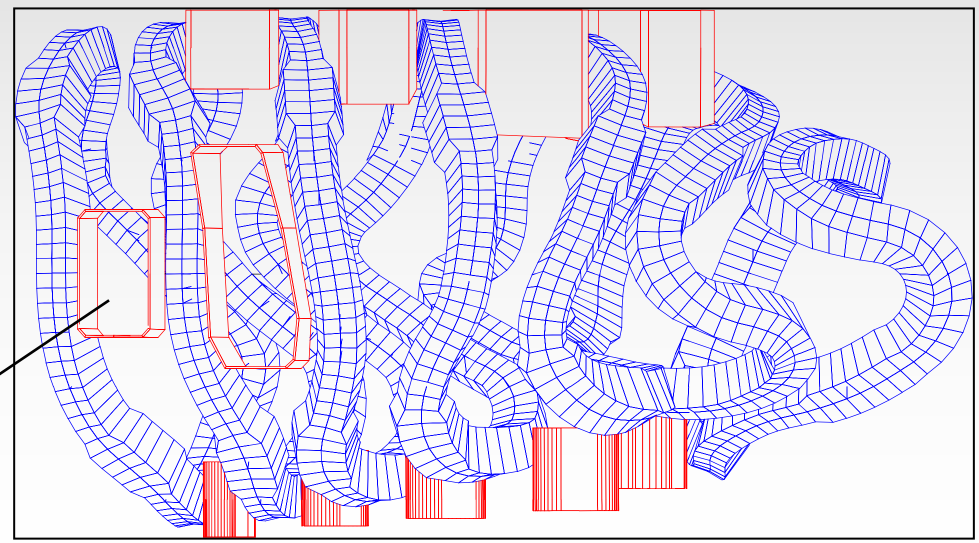
HSR Portholes in a period



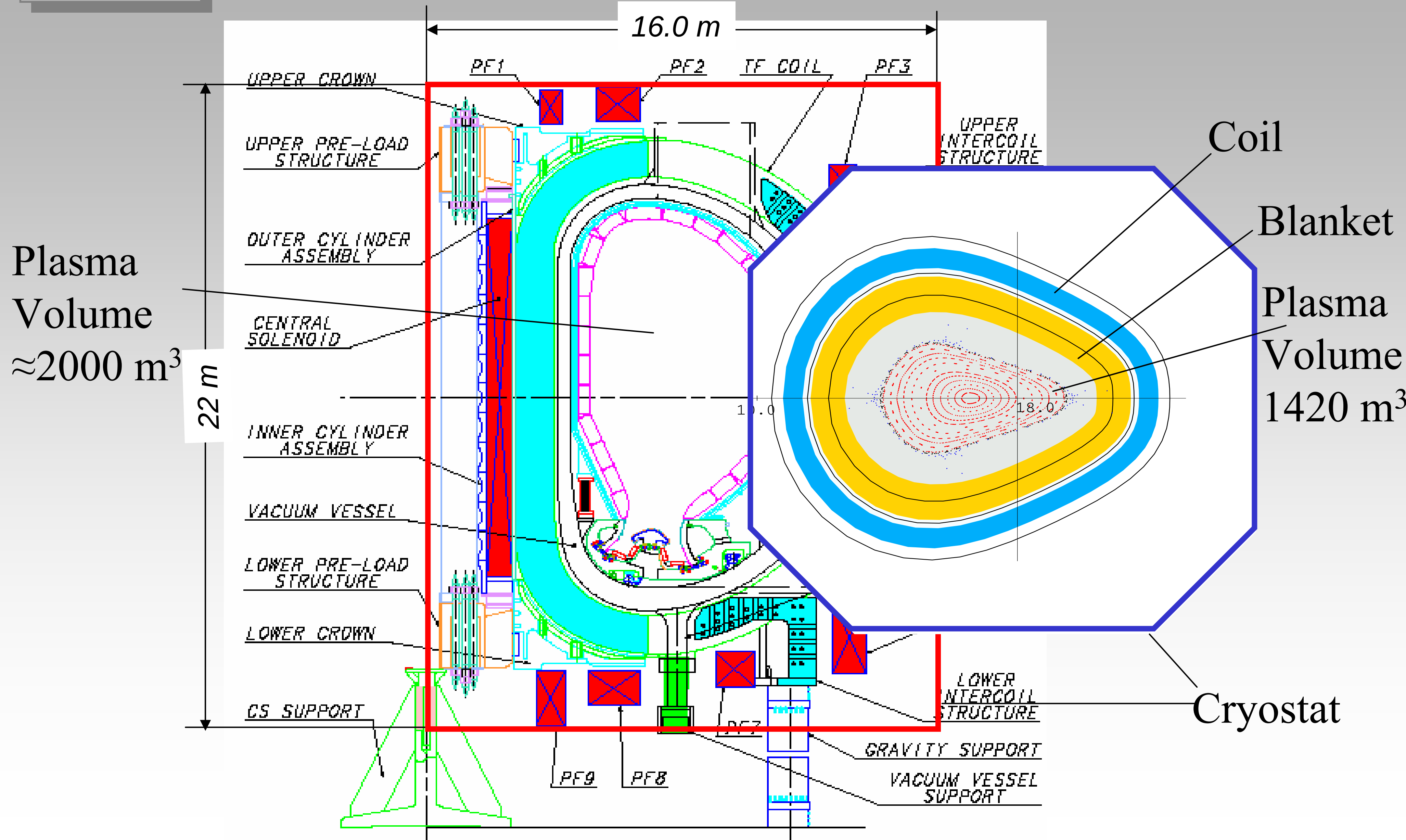


Portholes in a field period
Top-left: view from below
Top-right: view from above
Right : view radially in z=0 plane

Poertholes are indicated in red



ITER/FDR and HSR 4/18



Conclusions

- **HSR4/18 is the most reliable option**

  B=5 T, $\langle\beta\rangle = 3.6$ %, $\tau_E = 1.5$ s, $P_{fus} = 3.1$ GW

- **HSR4/18 can be used as an ignition experiment**

  B=4.4T, P_{fus} =1-1.5 GW, SC NbTi at 4K

- **HSR3/15 is the most compact but has a large bootstrap current.**

The End