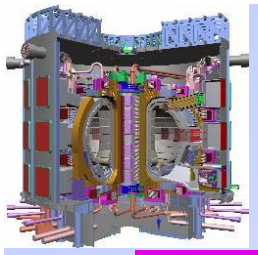
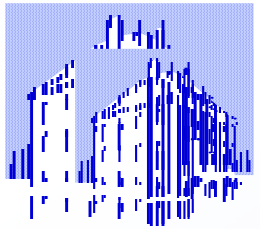


EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT

Remote Steering Launching System for ITER

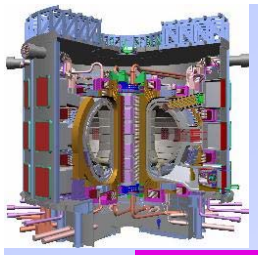
FOM-Rijnhuizen
Nieuwegein
The Netherlands



DESIGN OF THE MM-WAVE SYSTEM OF THE ITER ECRH UPPER LAUNCHER

FOM: *A.G.A. Verhoeven, W.A. Bongers , B.S.Q. Elzendoorn, M.F. Graswinckel, O.G. Kruijt, B. Lamers and D.M.S. Ronden*
FZK: *R. Heidinger, B. Piosczyk*
CNR: *A. Bruschi, S. Cirant, S. Nowak*
Stuttgart: *G. Gantenbein, B. Plaum, W. Kasparek*
EFDA: *G. Saibene*
IPP: *H. Zohm (and a team of beam-tracers)*

EC-13, Nizhny Novgorod
May 17, 2004



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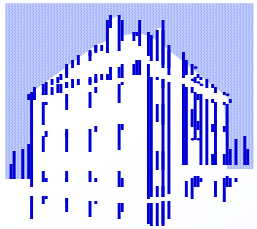
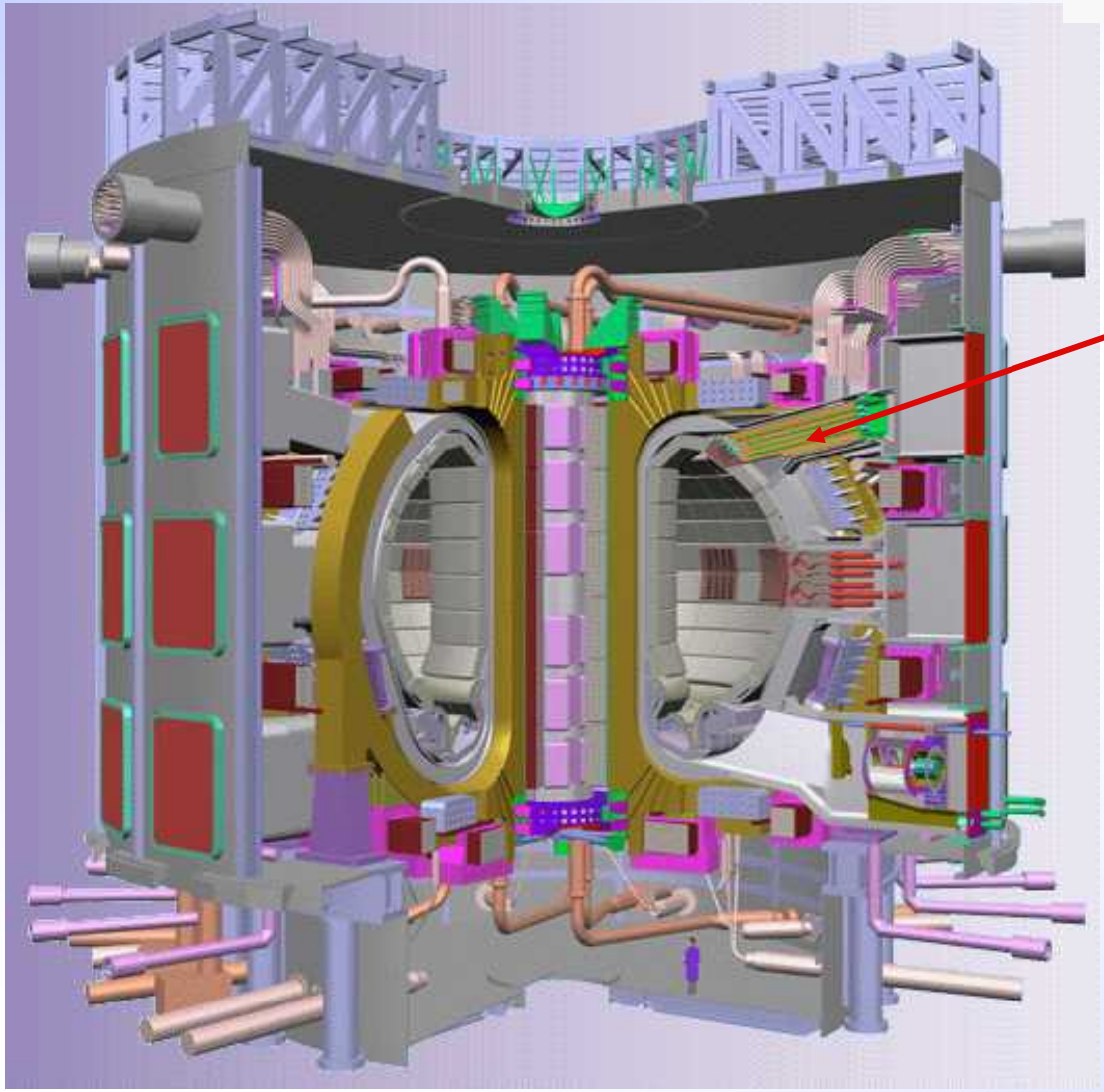
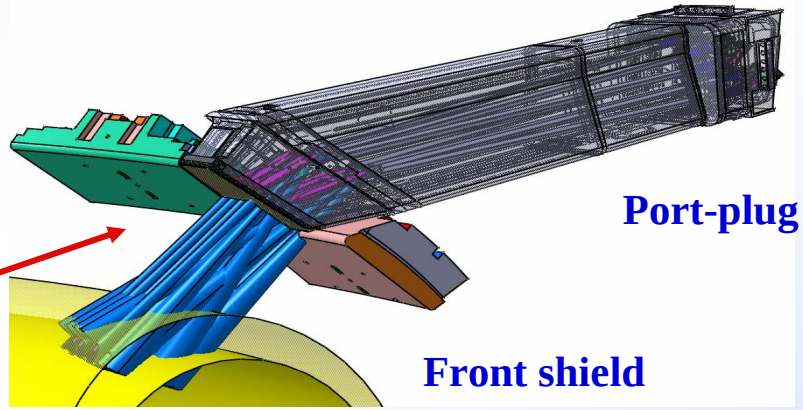
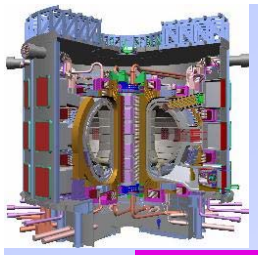


ITER upper-port





- intro remote steering
- design upper-port launcher
- arrangement of mirrors and waveguides
- CATIA CAD models
- mm-wave beam optics
- test set-up
- time schedule



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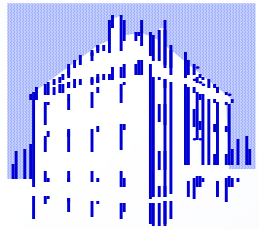
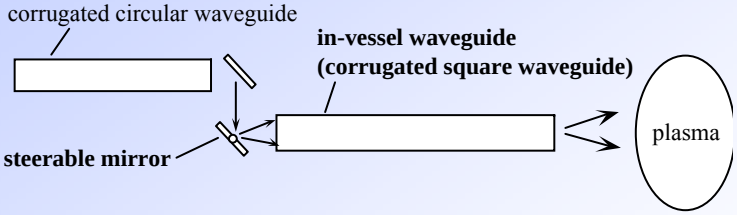
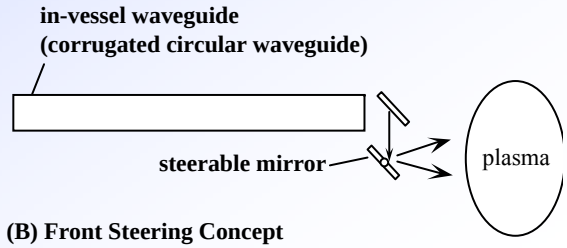


Remote Steering Launching System for ITER

Principle of remote steering

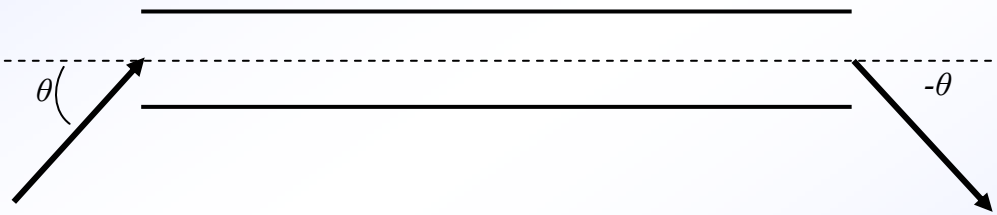


(A) Remote Steering Concept



(B) Front Steering Concept

$L \approx 4a^2/\lambda$



Based on inverse imaging character of a waveguide with the $L \approx 4a^2/\lambda$.

In: θ

Out: $-\theta$

For ITER upper launcher

Frequency: 170 GHz

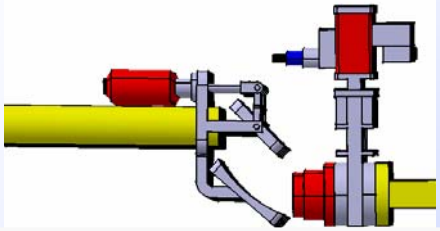
Beam scan, θ: +/- 5°

(later: +/- 12°)

Length, L = 4.4 m

Cross section, a = 44 mm

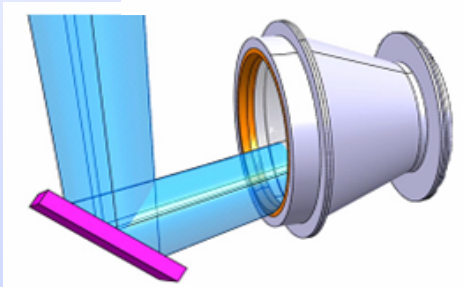
Power: 2 MW

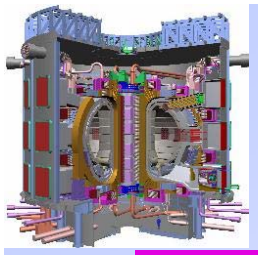


- Circular waveguide
- 2 mirrors, one rotatable, one fixed
- Window/valve/square waveguide

This effects the location of the beam on the window, as well, here shown for an angle θ of 12 degrees.

[Heidinger, later today]





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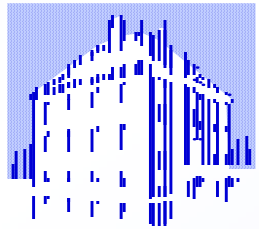
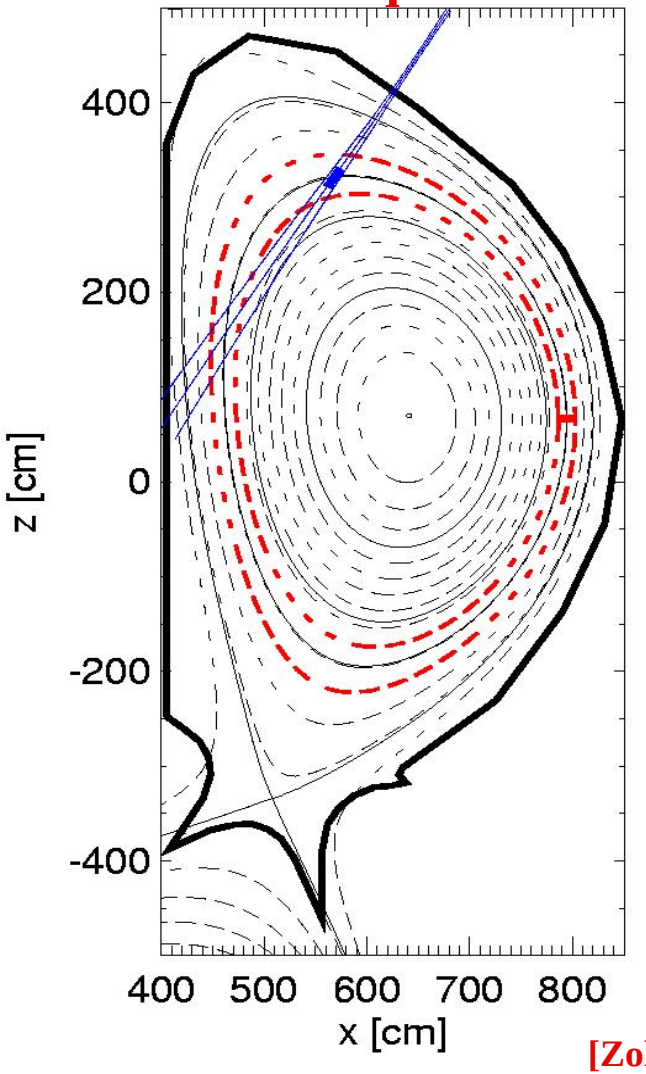


Remote Steering Launching System for ITER

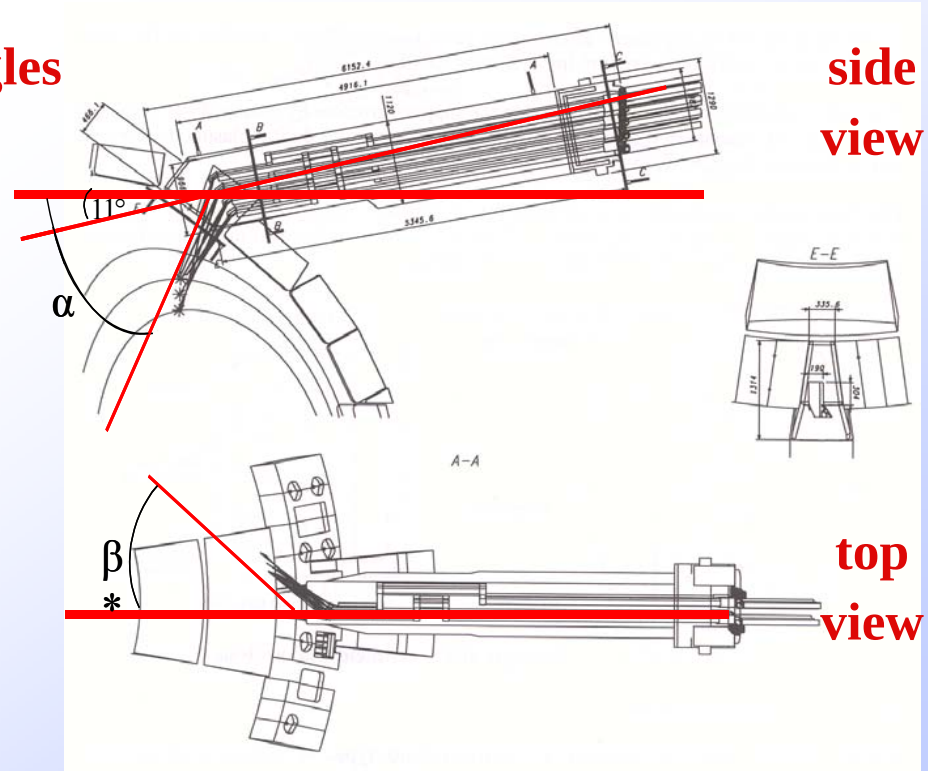
ITER q=2 surface

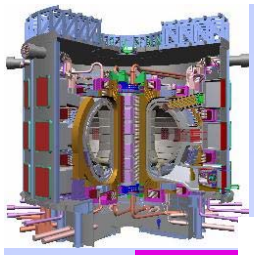


[Zohm]

ITER ECRH upper port launcher:
Task: stabilization of NTM's
(Neo-classical Tearing Modes)
at q = 2 and q = 3/2 surfaces

Definition of launching angles α and β





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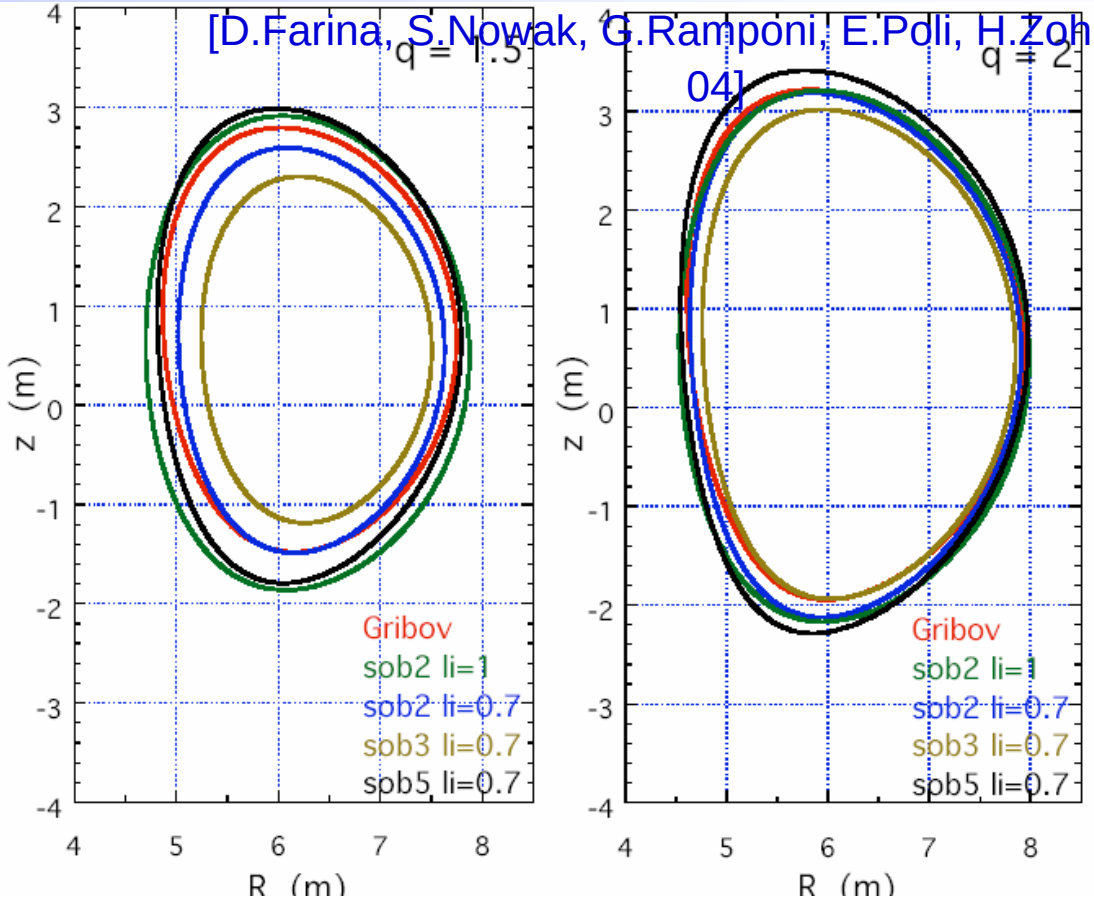
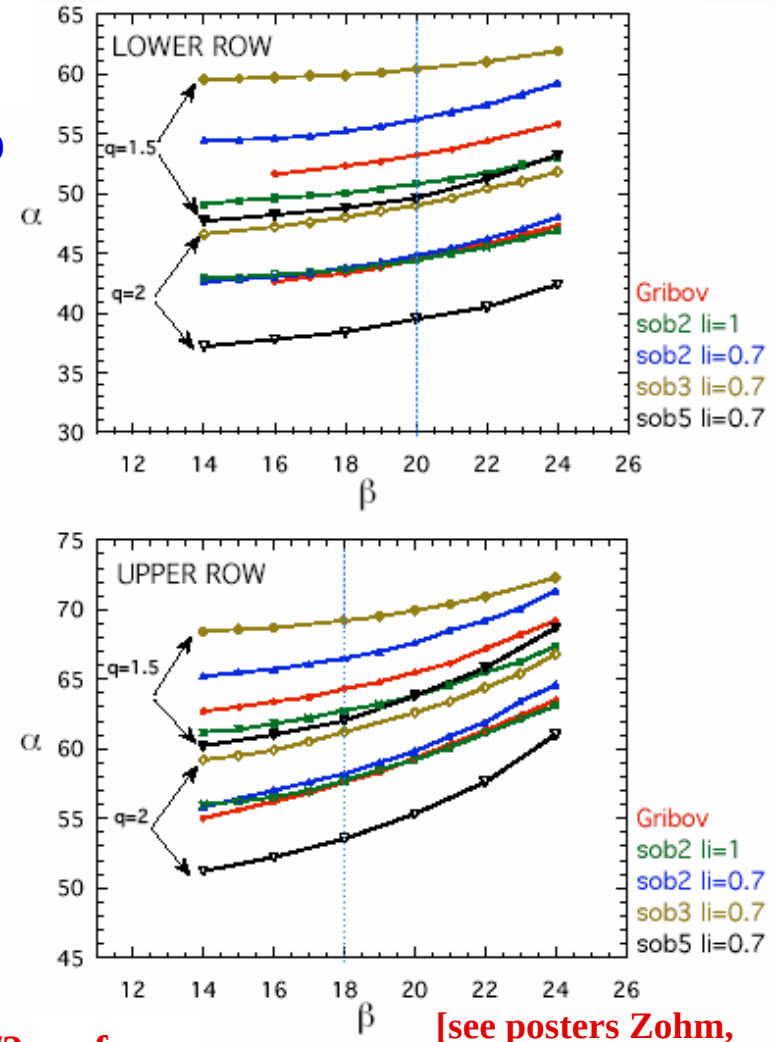
Remote Steering Launching System for ITER

Steering range requirement for Upper Launcher

[D.Farina, S.Nowak, G.Ramponi, E.Poli, H.Zohm, Feb 04]

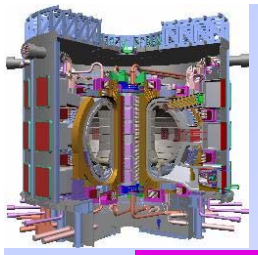




Each mirror has to be able to send the beams to both q=2 and q=3/2 surfaces

[see posters Zohm, Nowak, Volpe]

Figure 2 Solid symbols refer to q=1.5, and open symbols to q=2.



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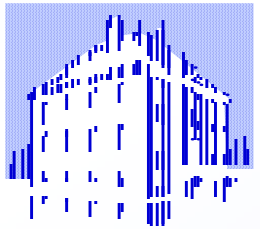


Remote Steering Launching System for ITER

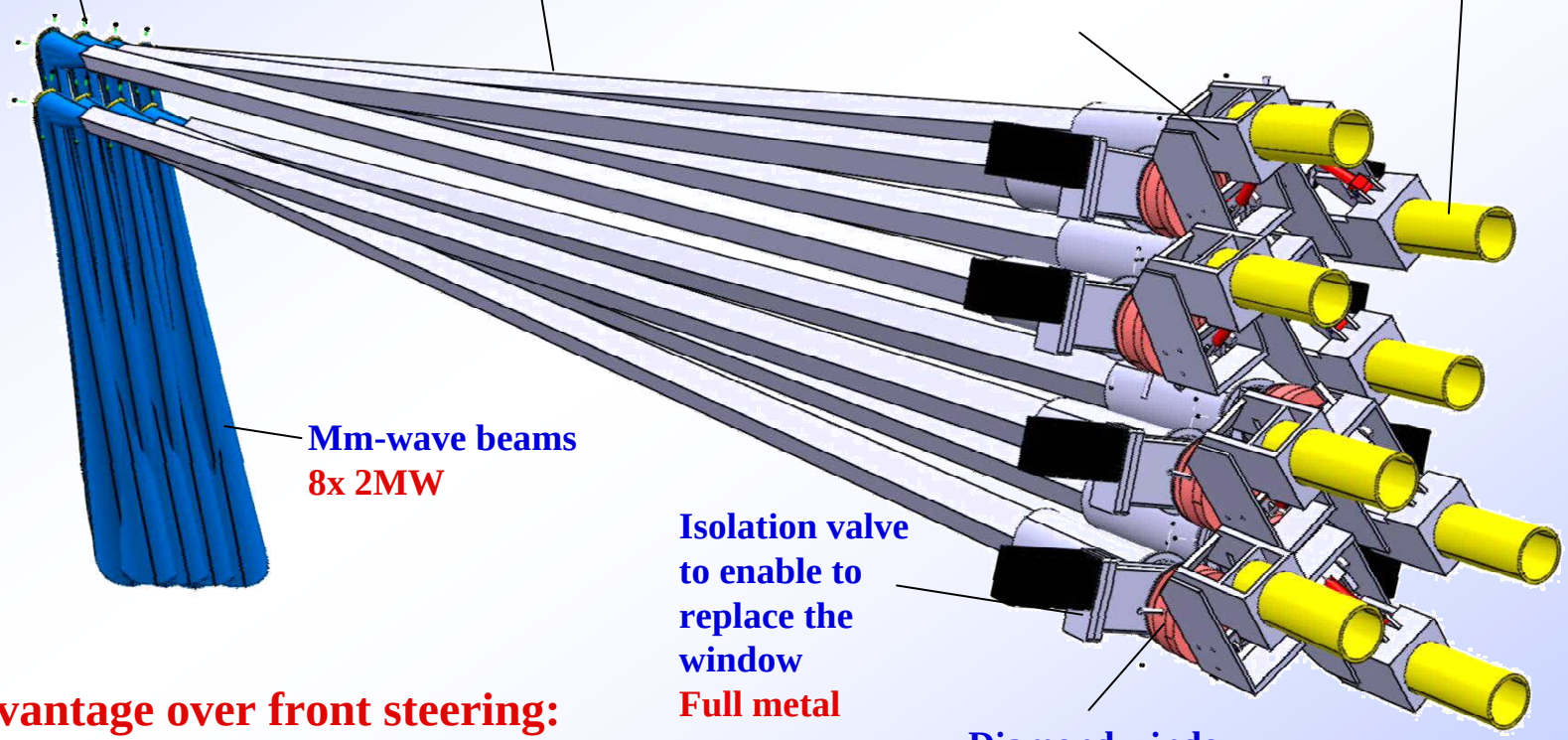
overview

Fixed mirrors to give the beams the correct angles into the plasma

Square corrugated waveguide
Corrugated
copper
dimensions 44x44x4400 mm

Steering mechanism
1 fixed mirror
1 steerable mirror
1 actuator
1 arc detector

Circular waveguide
Type HE 11
Diameter 63.5 mm
Corrugated

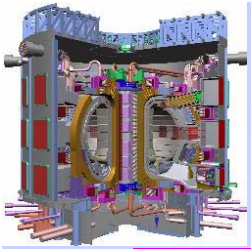


Mm-wave beams
8x 2MW

Isolation valve to enable to replace the window
Full metal

Diamond window
Single disk

Main advantage over front steering:
No moving parts near the extreme plasma environment



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Remote Steering Launching System for ITER

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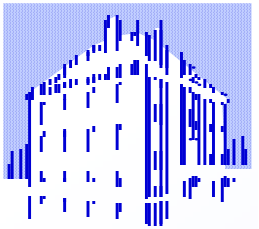
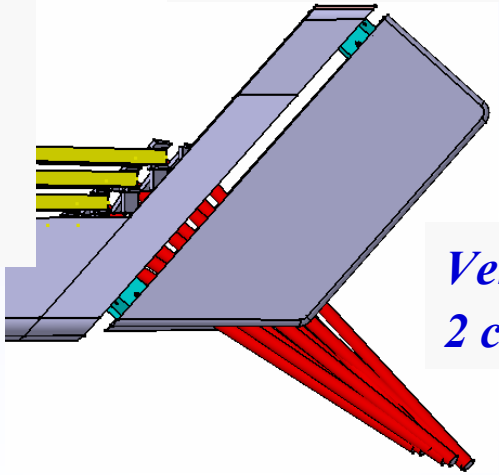


Vertical or horizontal arrangement

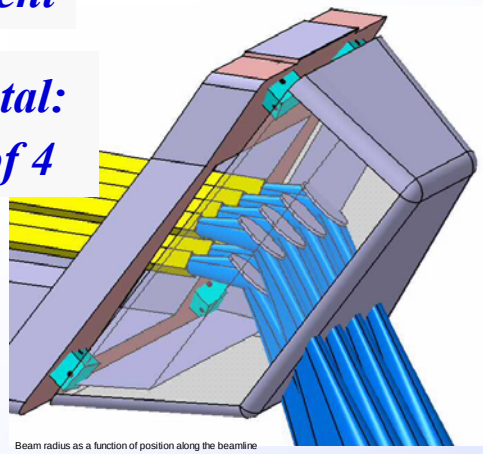
8 beams per port gives 2options for arrangement of waveguide system:
Vertical: 2 columns of 4 each,
Horizontal: 2 rows of 4

For NTM stabilization horizontal orientation is much better because of lower Z position, on average.

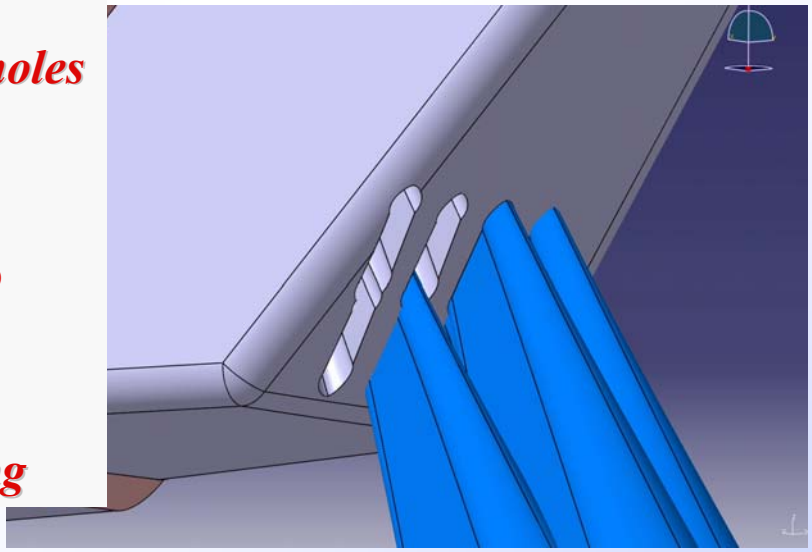


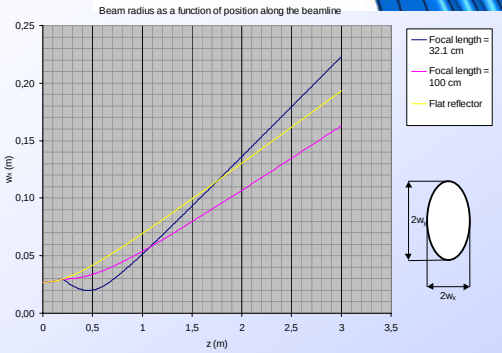
Vertical:
2 columns

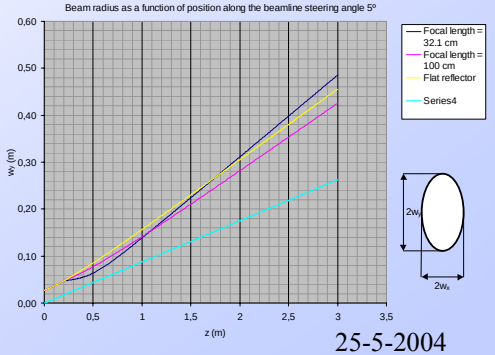
Horizontal:
2 rows of 4

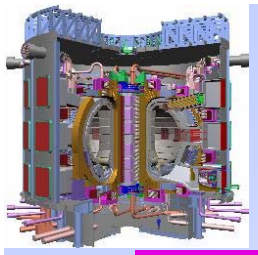


Two beams on top of each other can use partly same holes and so minimize holes and leave side rims in place.
poloidal plane:
scan + 5° to - 5°
no focusing
toroidal plane:
optimized focusing









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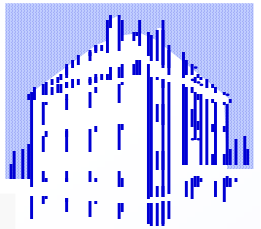
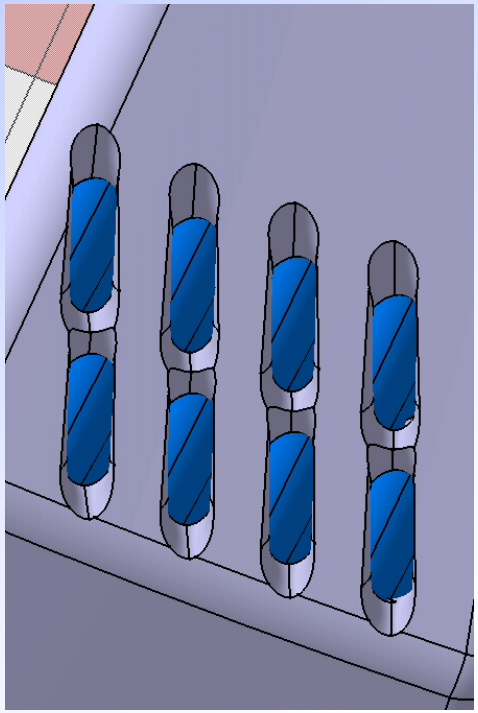
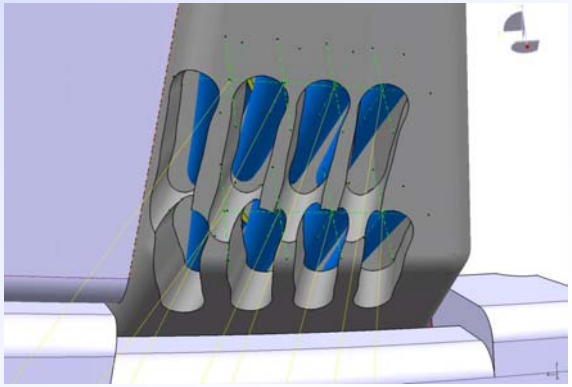


Remote Steering Launching System for ITER

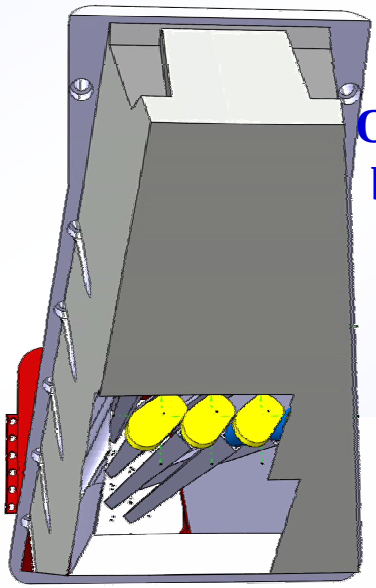
Three front shield options



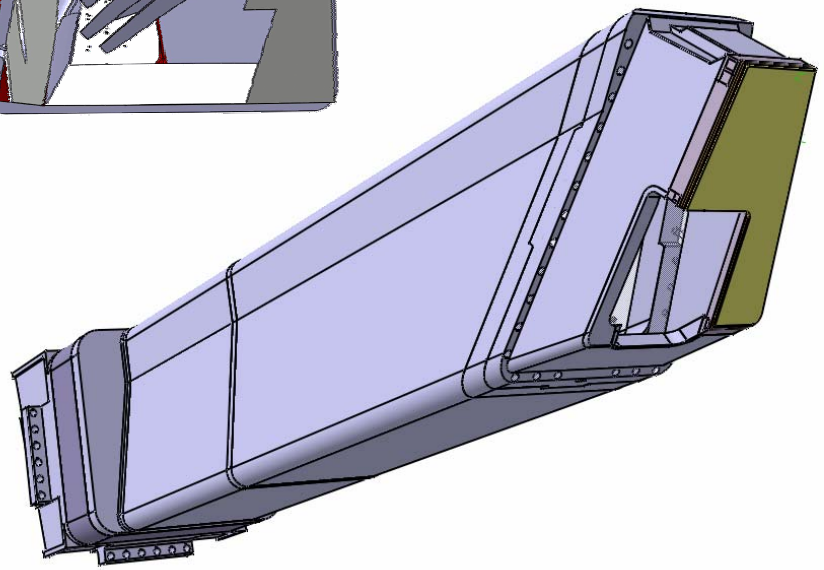
Optimized for the best neutron shielding



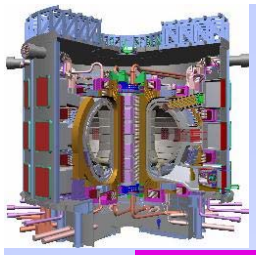
Optimized for the smallest beam spot in the plasma: Difficult cooling arrangements



Optimized for the smallest beam spot in the plasma: Larger hole



Now cooling channels have been incorporated by FZK
[Heidinger, later today]



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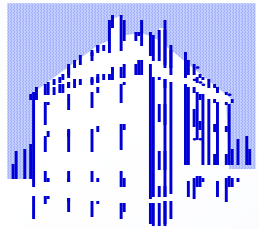
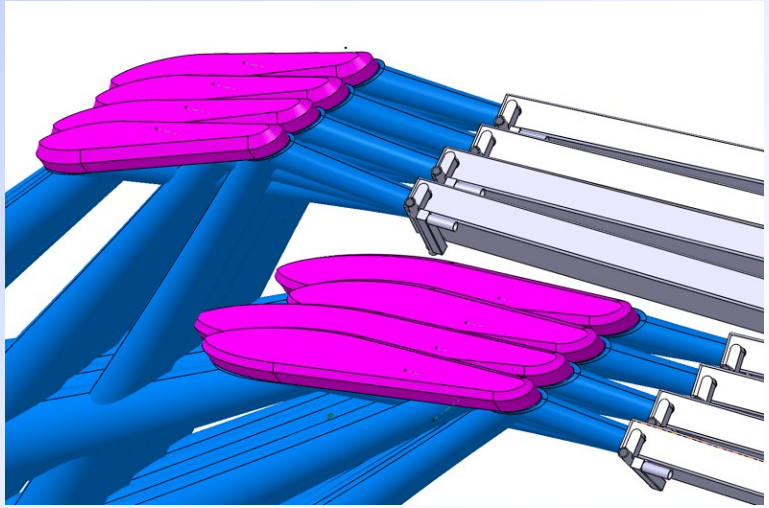


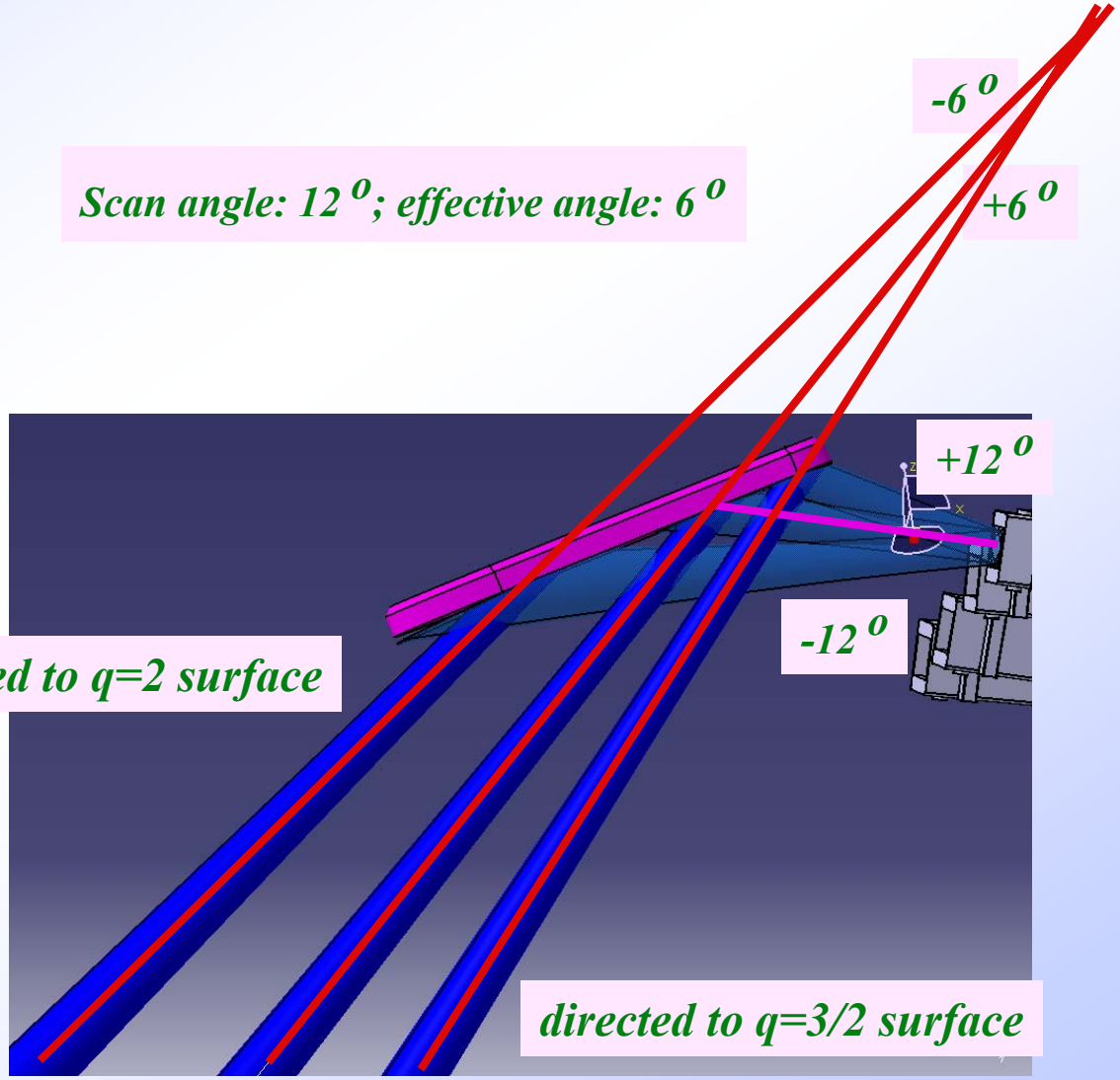
Virtual rotation point



Scan angle: 12 ^{o}; effective angle: 6 ^{o}

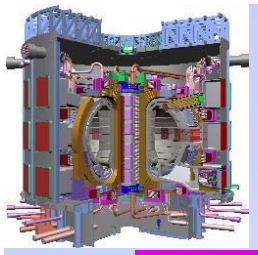
-6 ^{o}

+6 ^{o}



shown here are incoming angles of:
+ 12° , 0° and - 12°
and reflected angles of:
+ 6° , 0° and - 6°

Mirror surface not flat but curved in both directions in order to get the smallest beam in the plasma



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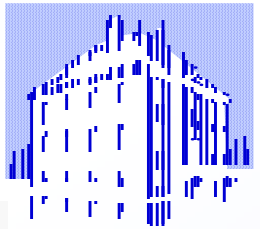
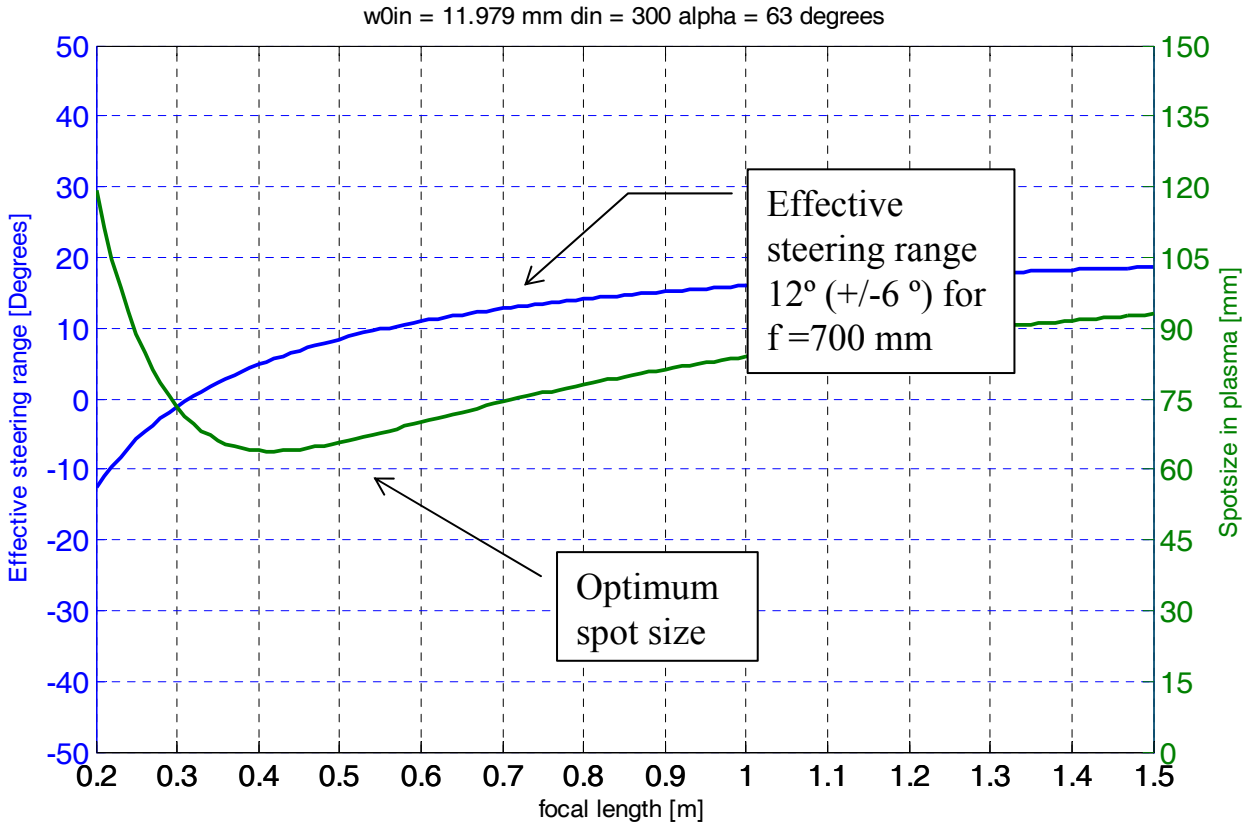
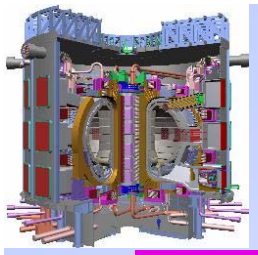


Remote Steering Launching System for ITER

scan range vs. focusing



Tradeoff between effective steering range and the amount of focusing in the beam plane. Steering angle is sum of + and -



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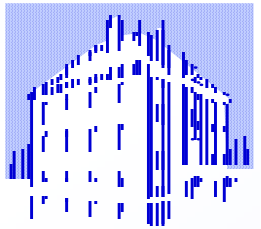
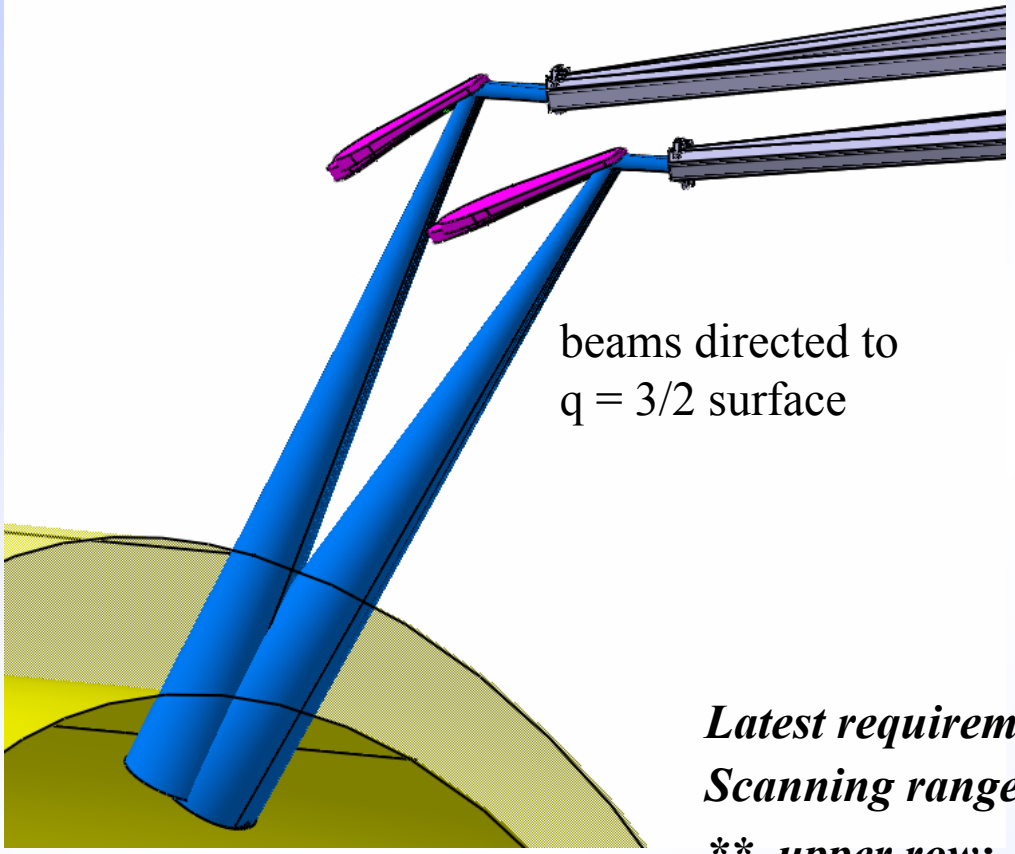
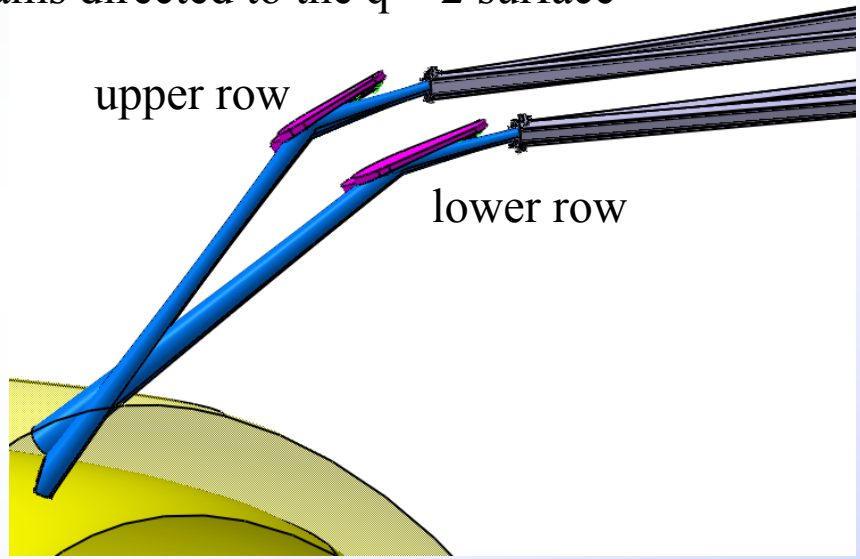


Remote Steering Launching System for ITER

April 2004 model



Beams directed to the q = 2 surface



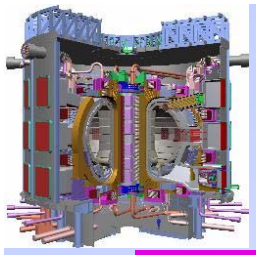
Latest requirements from beam tracers are taken into account:

Scanning range:

** ***upper row:*** ***+/- 8 °*** $\alpha_{nom} = -61.3°$ $\beta = -18°$

** ***lower row:*** ***+/- 10.5 °*** $\alpha_{nom} = -50°$ $\beta = -20°$

β ***is slightly varying for optimal*** η_{cd} ***and geometry***



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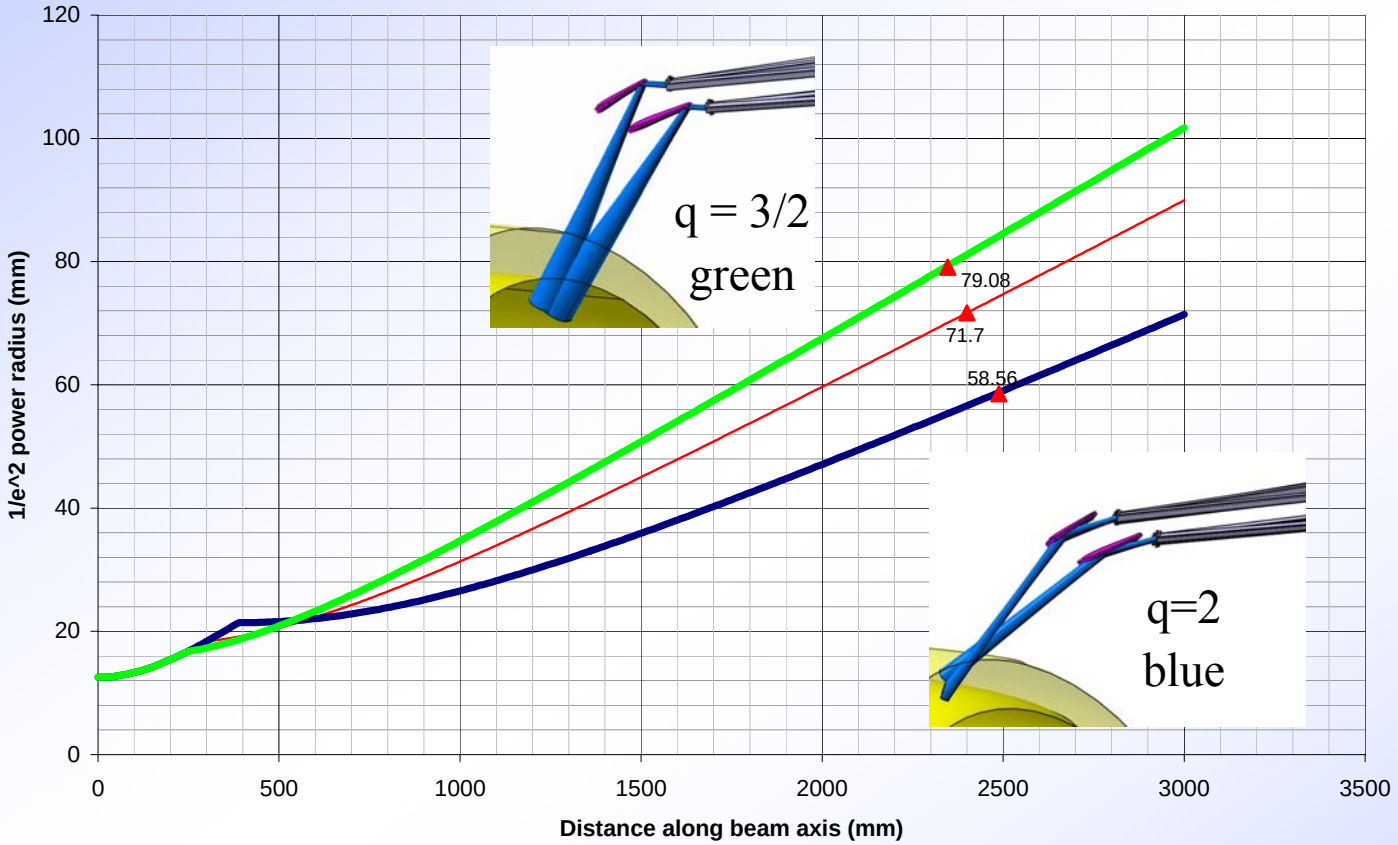
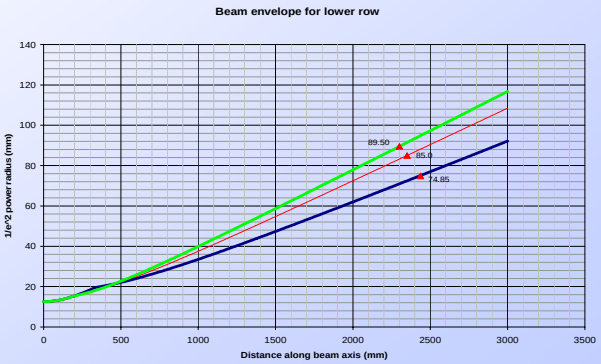
Remote Steering Launching System for ITER

April 2004 model

Beam envelope in upper row

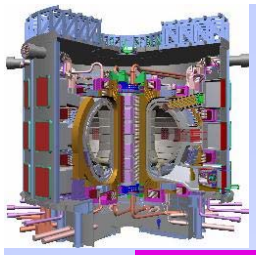


Beam envelopes for upper row showing:
q = 3/2,
nominal
q = 3/2



New model in 3-D Catia

Beam envelopes for lower row



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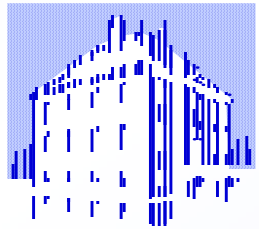
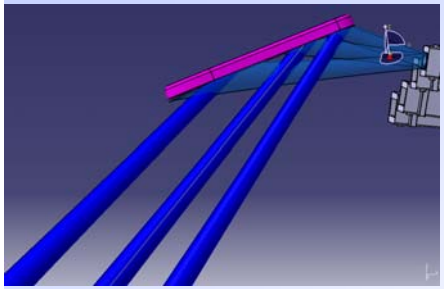
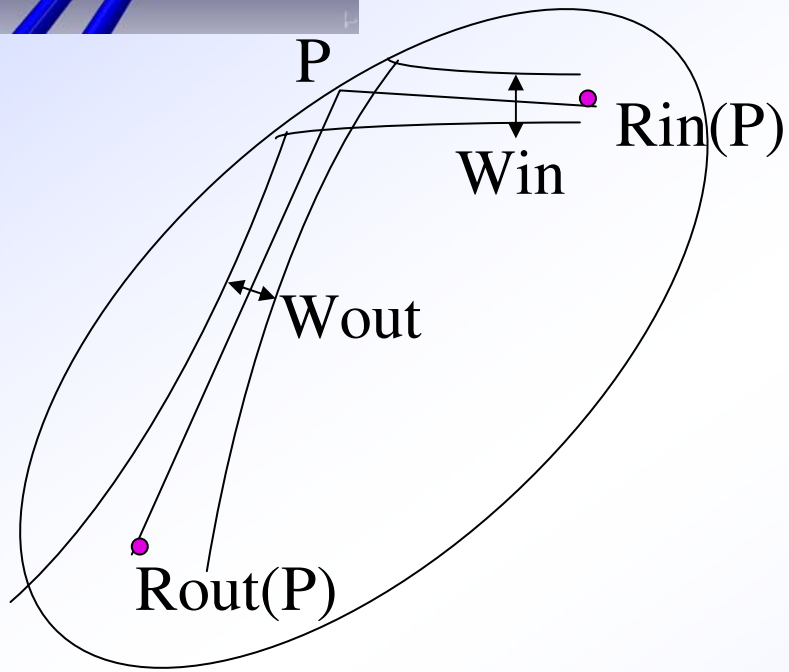
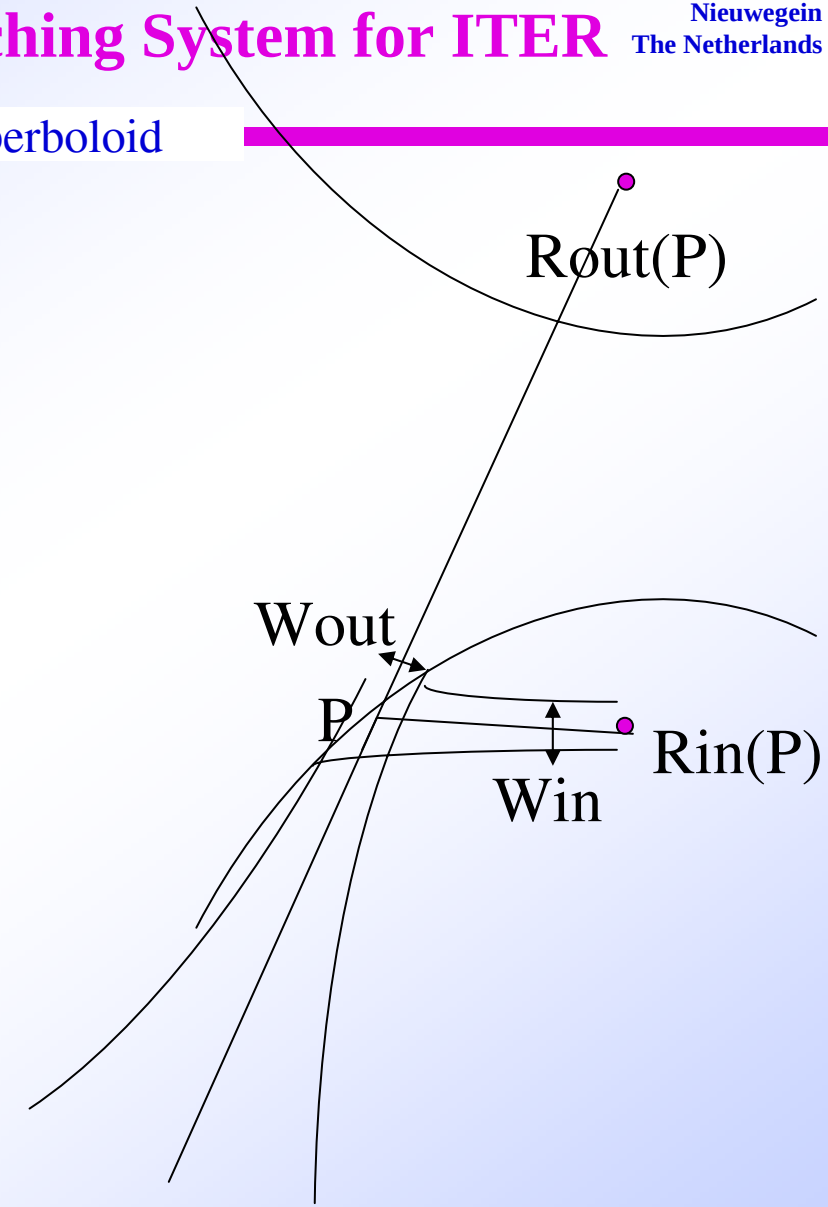


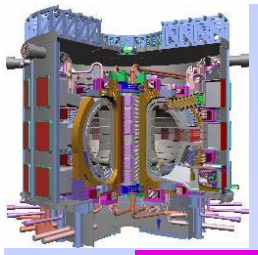
Remote Steering Launching System for ITER

Mirror surface: ellipsoid vs. hyperboloid









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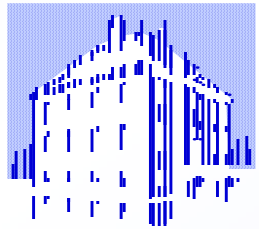
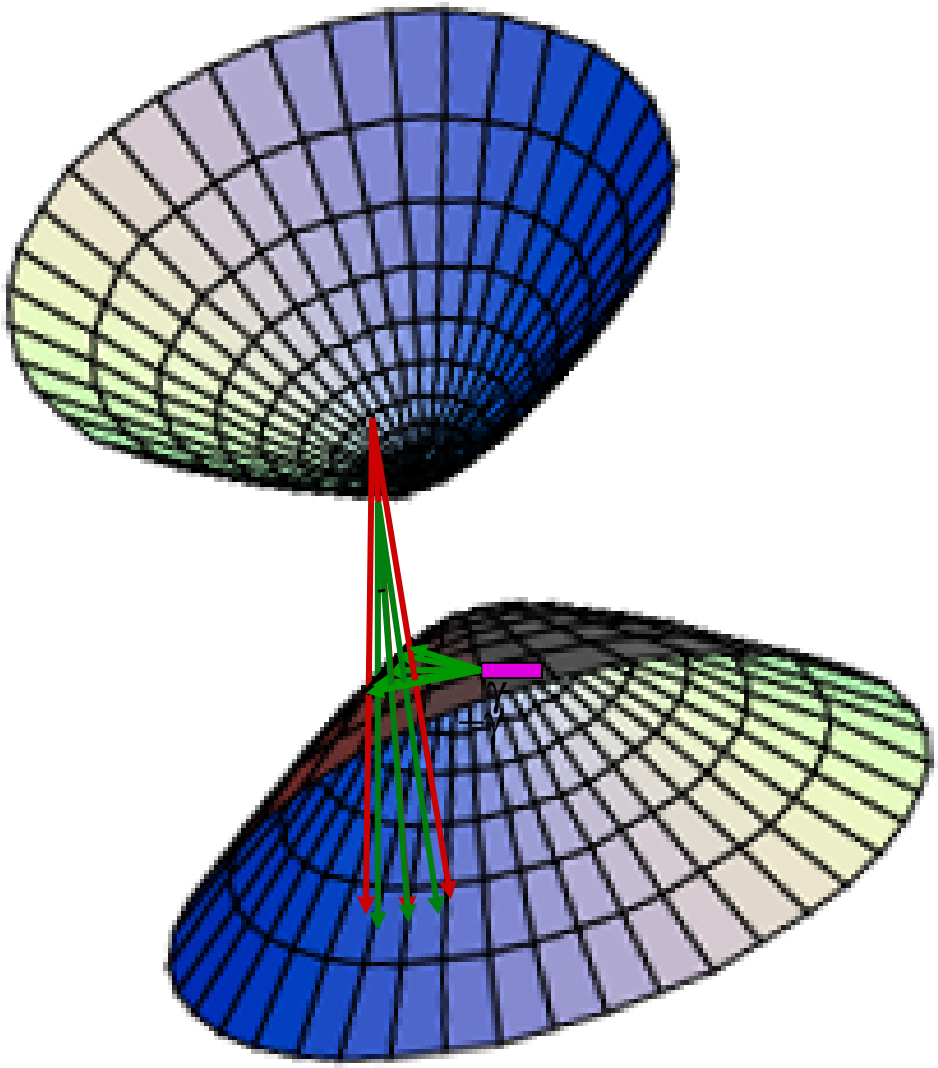
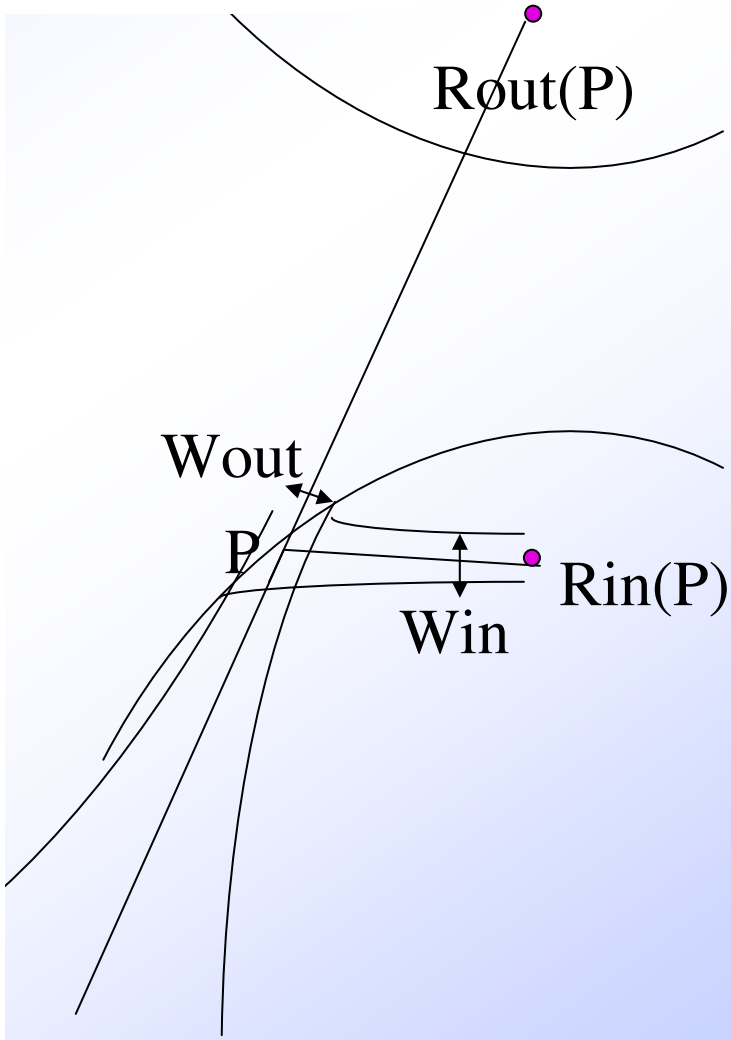
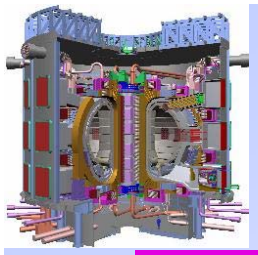


Mirror surface: hyperboloid







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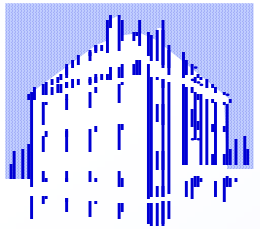
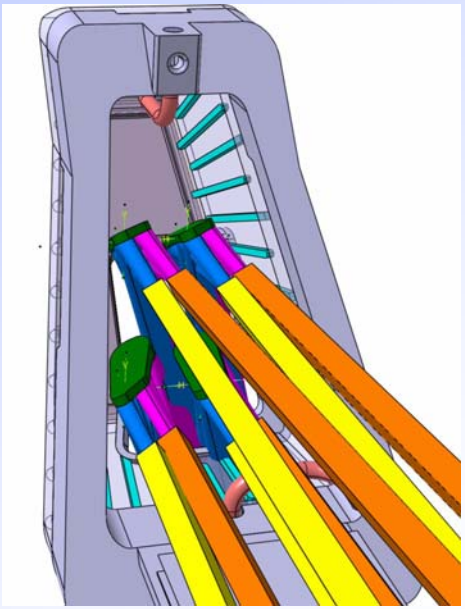


Remote Steering Launching System for ITER

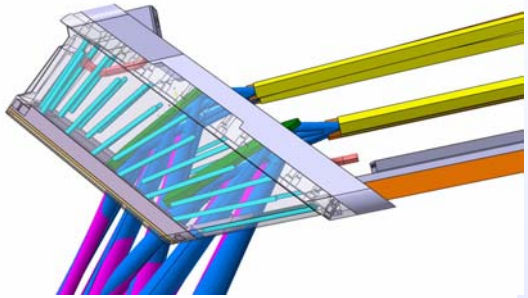
2 beams per mirror

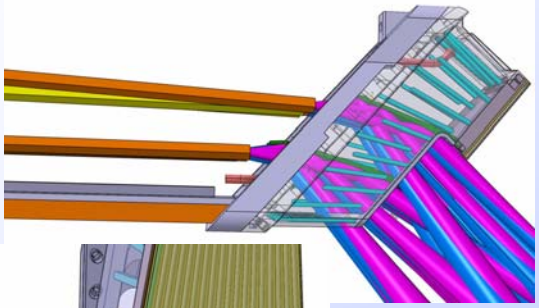


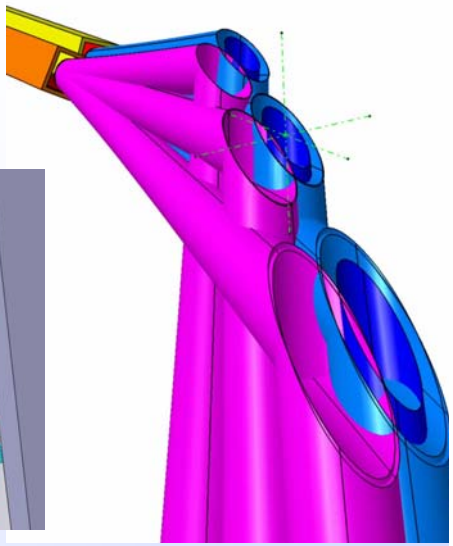
Most recent concept: 2 beams per end-mirror

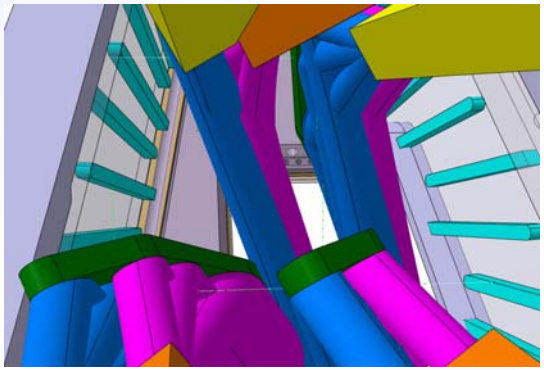
- Allows to have larger D_{in}
- Larger beams on mirror
  - Lower wall loading
- Smaller beams in plasma

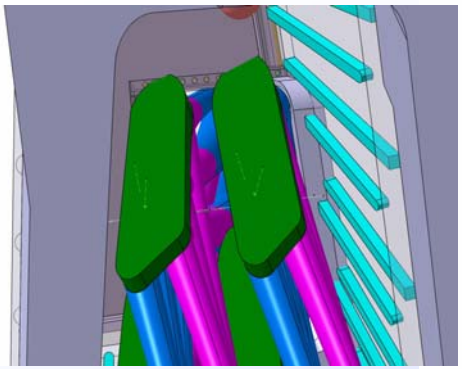
- Toroidal effect can be compensated by poloidal adjustment (scan angle)

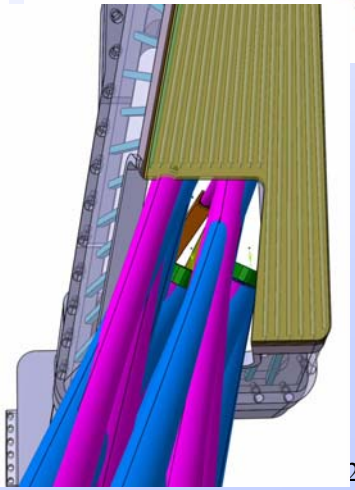


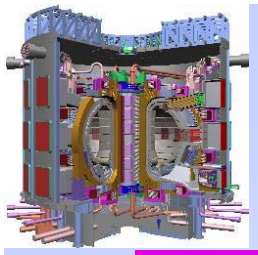












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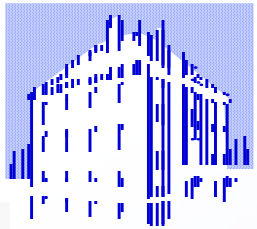
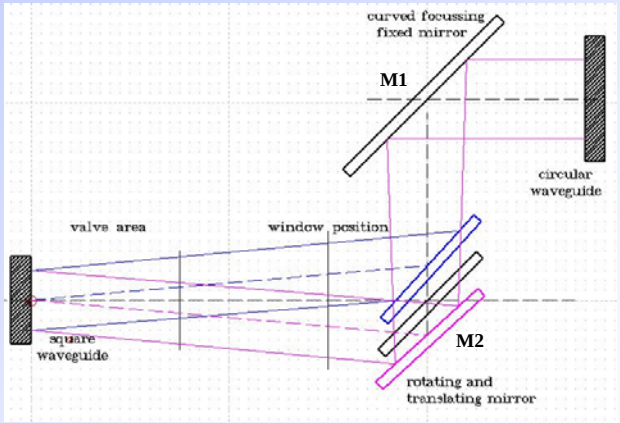
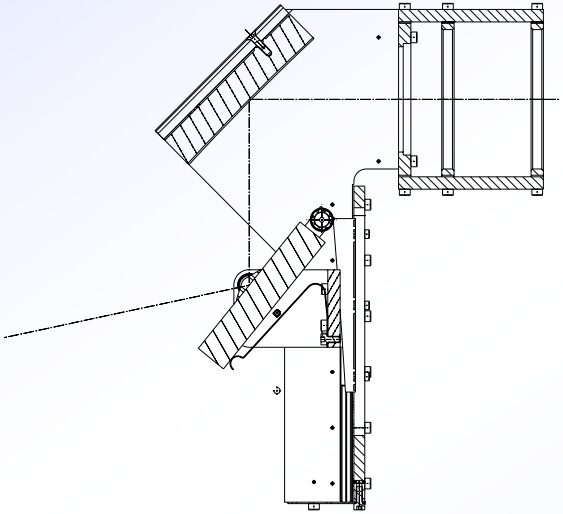
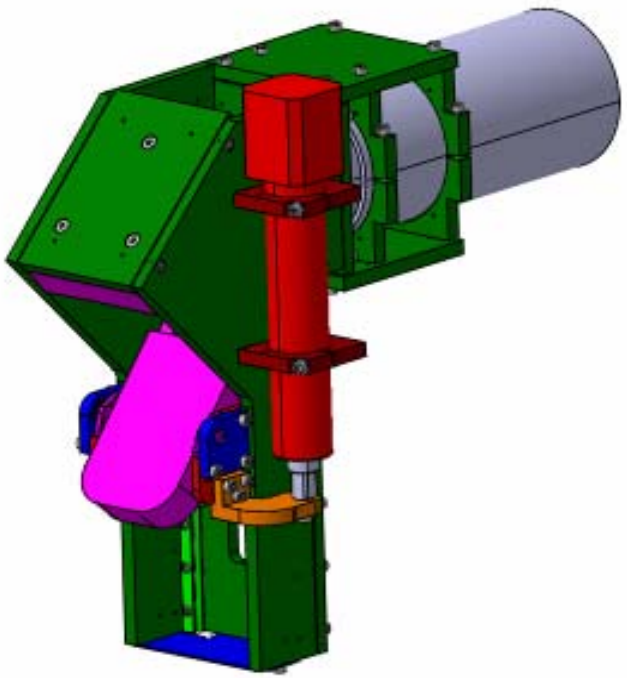


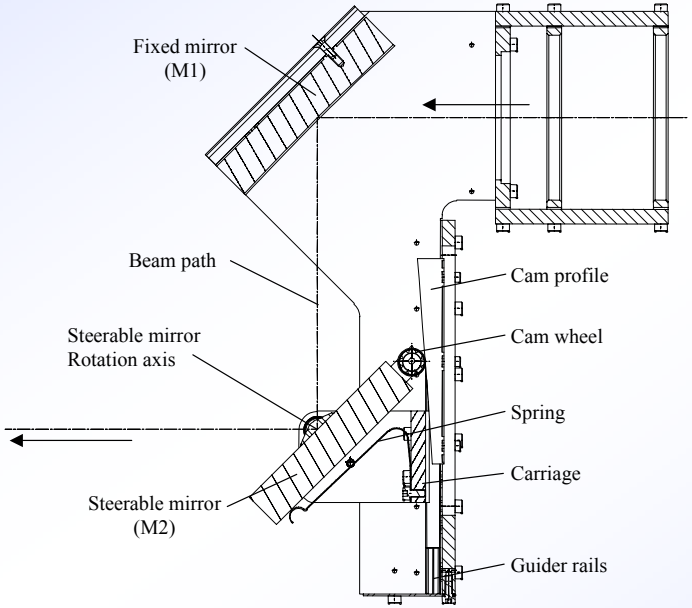
Remote Steering Launching System for ITER

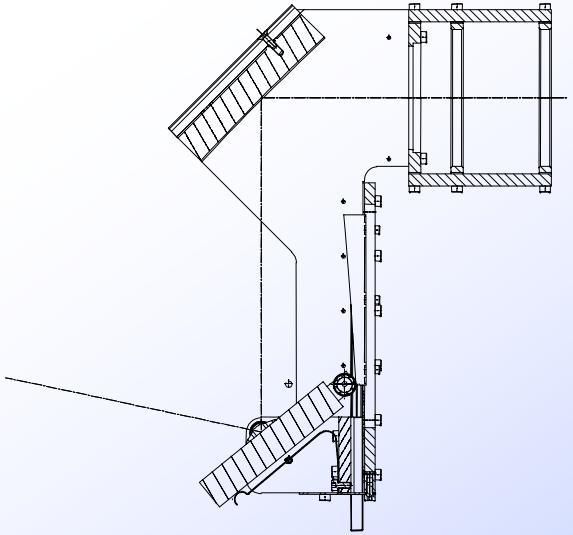
steerable mirror



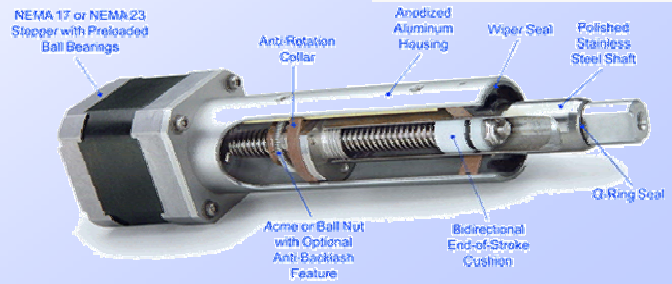


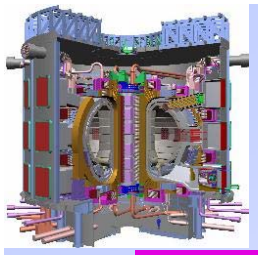






actuator





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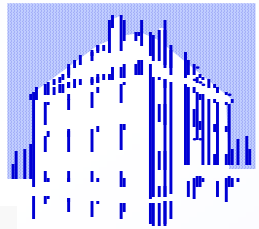

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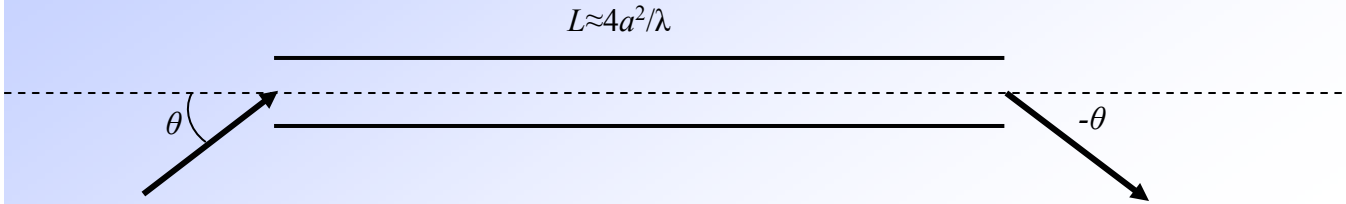
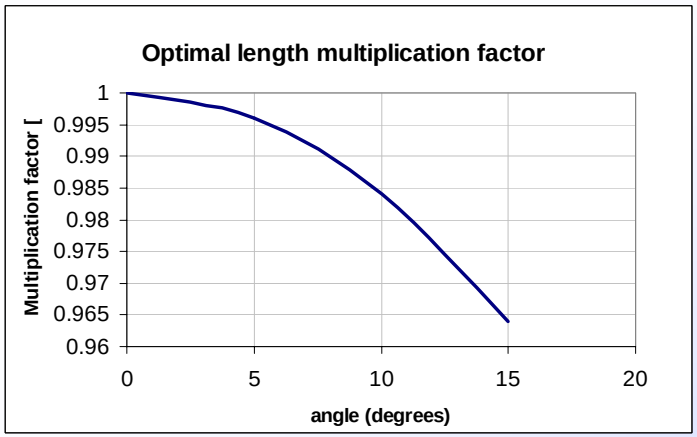
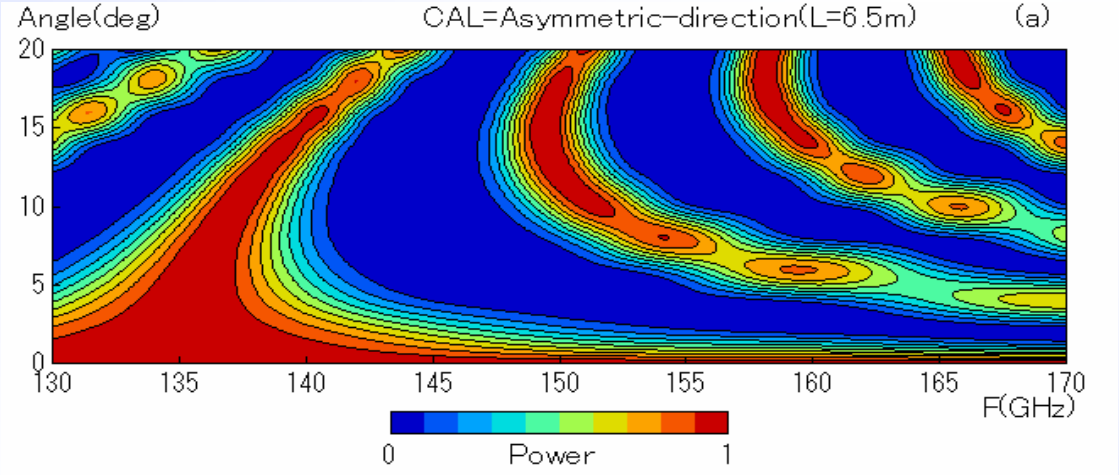
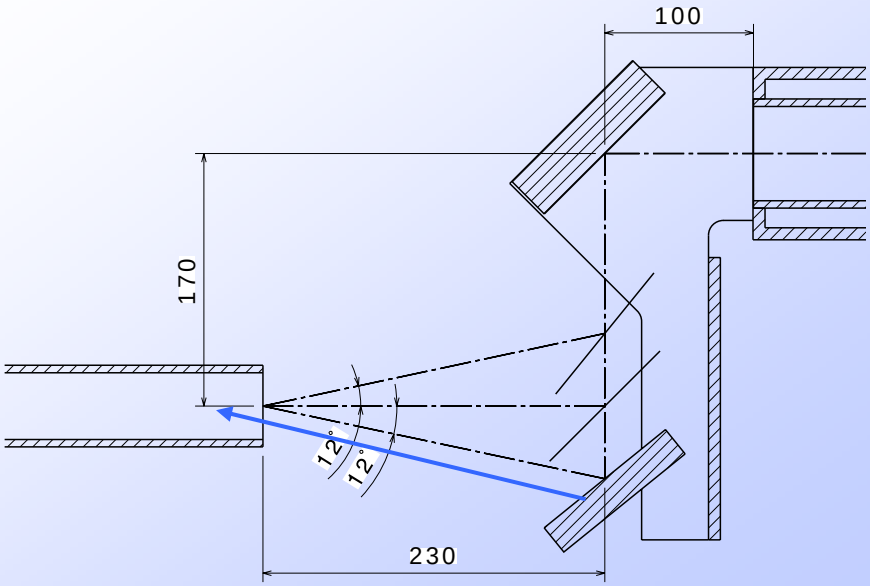
Optimal length depends on θ

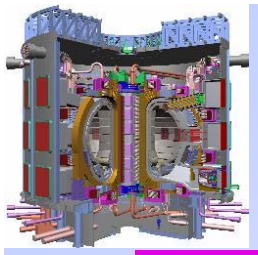








[K. Ohkubo, W. Kasparek, et al.]



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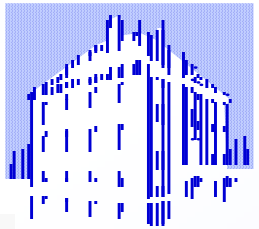
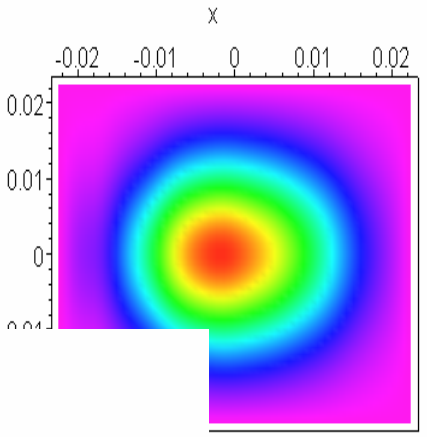
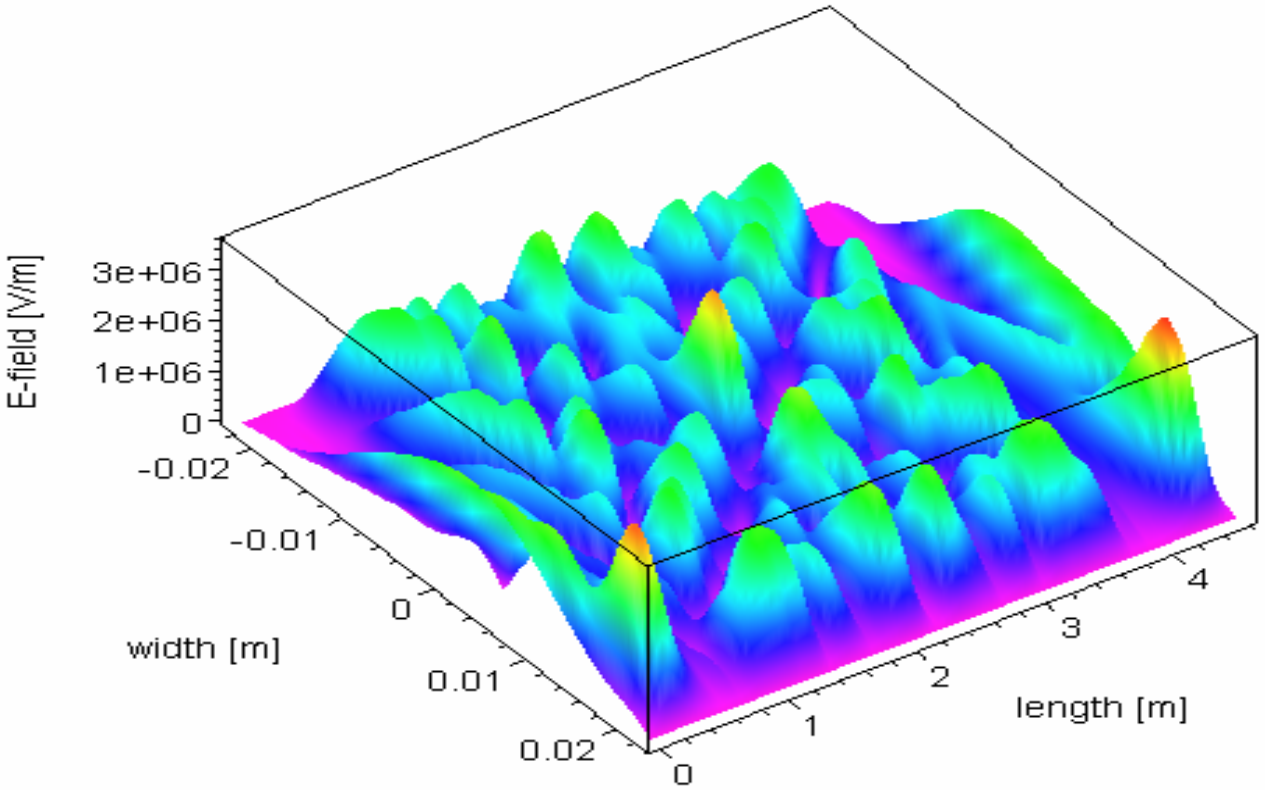
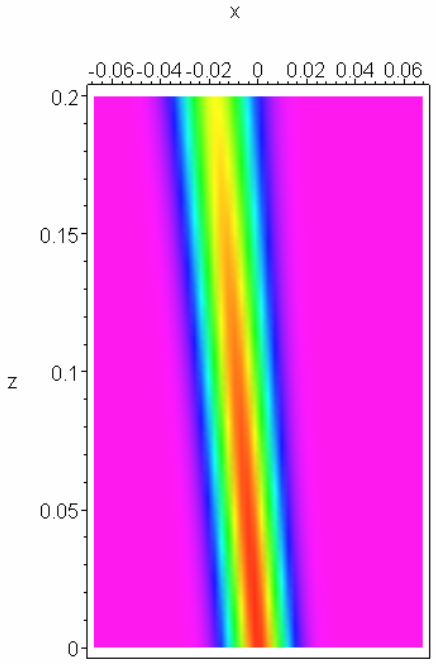


The result of a three dimensional mode decomposition simulation is calculated, for use at 170 GHz and 5° steering angle. In the simulation we couple the output field to Hermite-Gaussian modes to be able to calculate further propagation, the lowest order Gaussian mode is a measure for the beam quality.

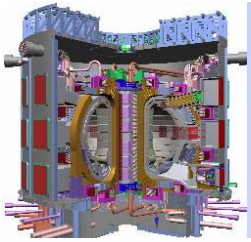


5º steering angle (99.2 %) fundamental mode gaussian beam.





Propagated beam exiting waveguide at 5º



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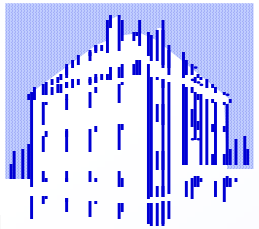
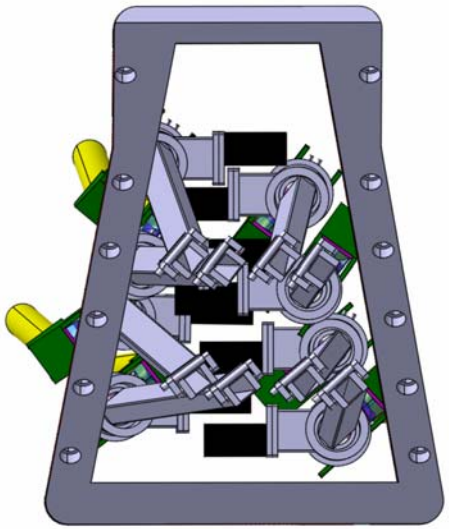
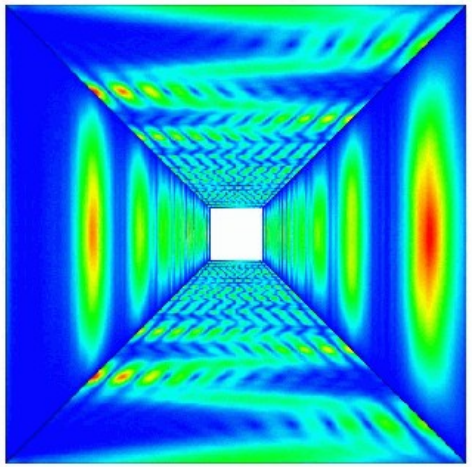


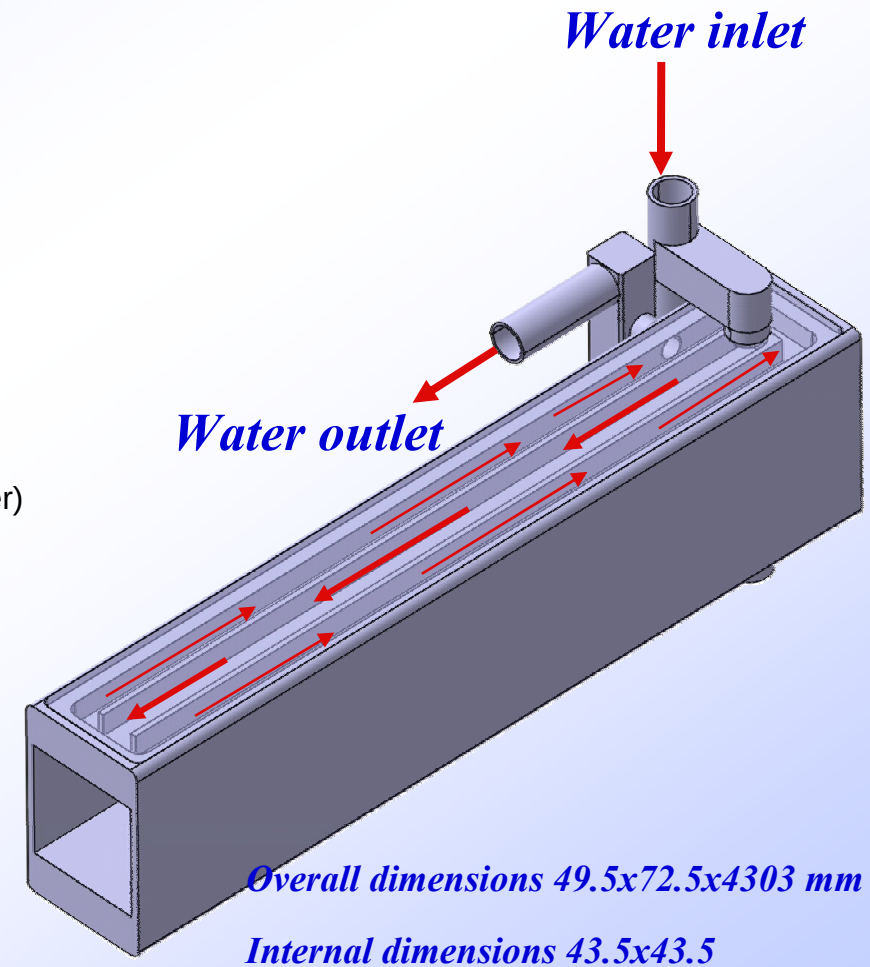
square waveguide with water cooling





(Scale on non-steering walls 10^-5 lower)

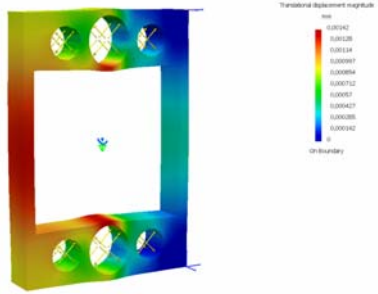
[Plaum, Kasparek]



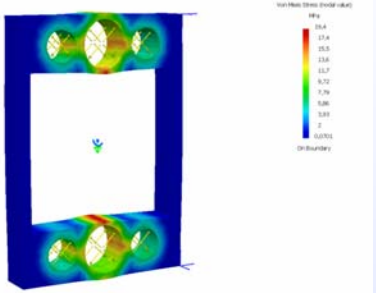
Overall dimensions 49.5x72.5x4303 mm

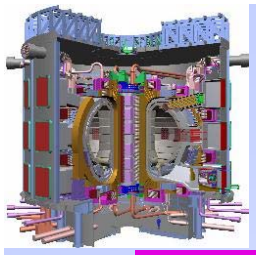
Internal dimensions 43.5x43.5

Displacement 0.0014 mm



Mechanical stress 19.4 MPa





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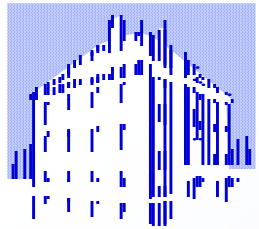
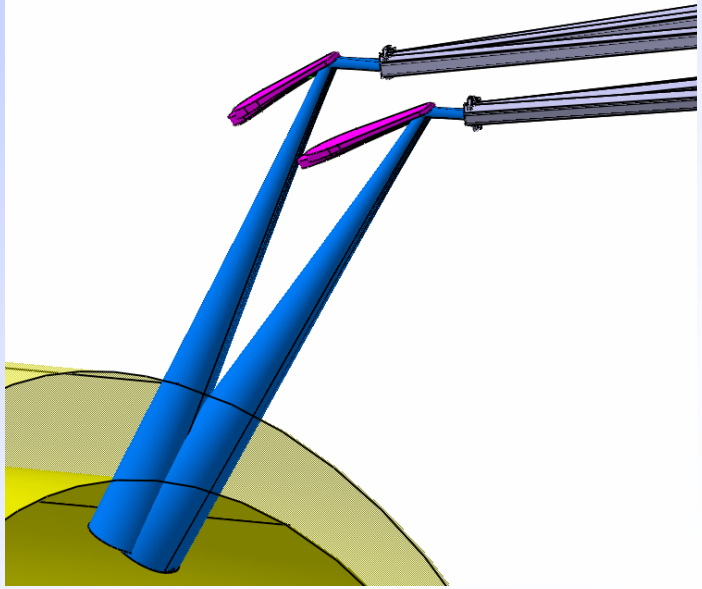
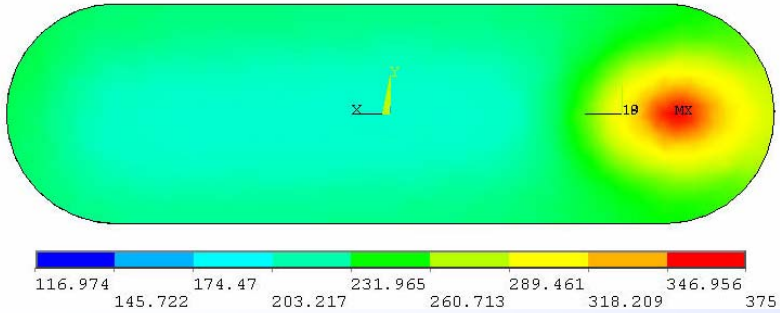


Remote Steering Launching System for ITER

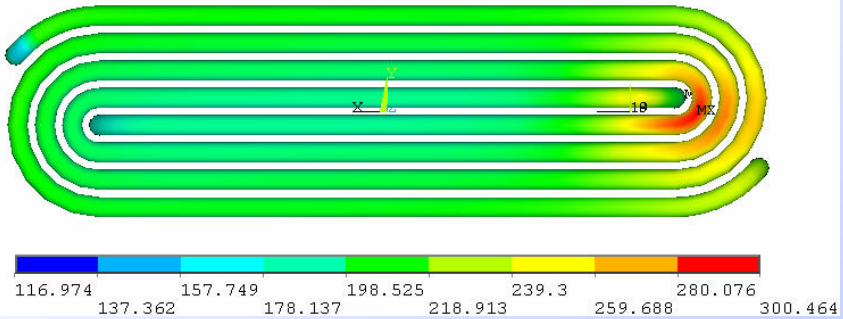
Thermal-hydraulics analysis of end-mirror



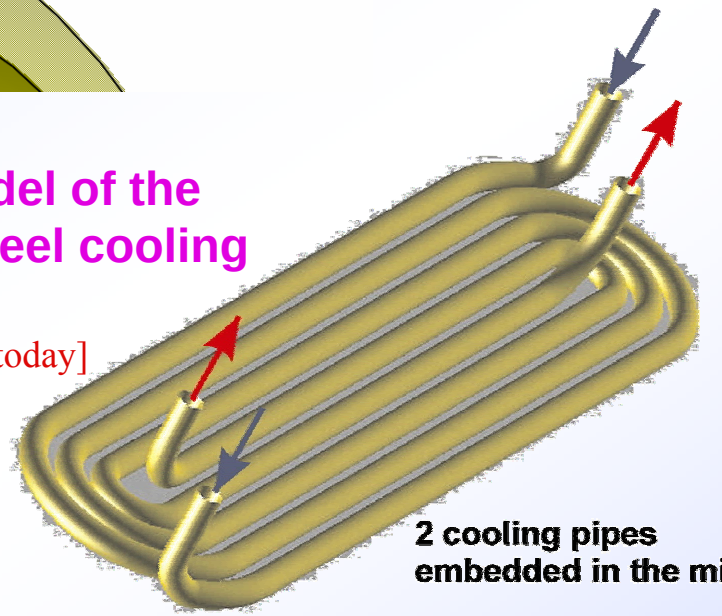
Surface temperature of Cu block



Temperature at SS316 pipe surface

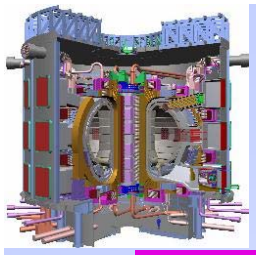


ANSYS model of the stainless steel cooling pipes [FZK]
[Heidinger, later today]



2 cooling pipes embedded in the mirror

2 beams on 1mirror could lower the peak heat load



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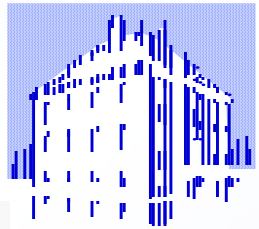
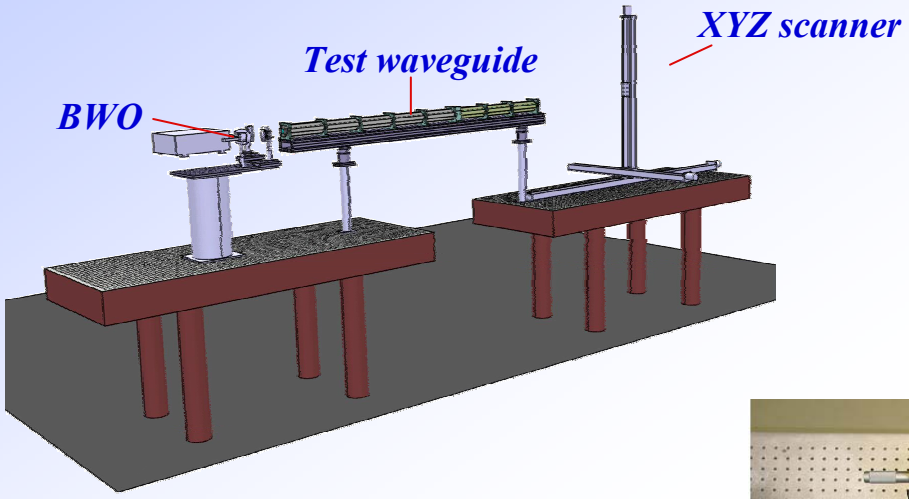
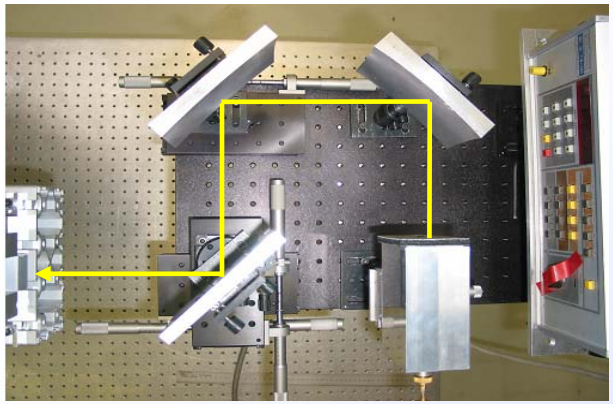


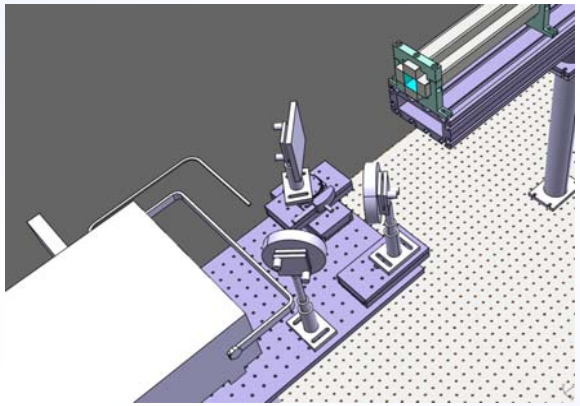
Remote Steering Launching System for ITER

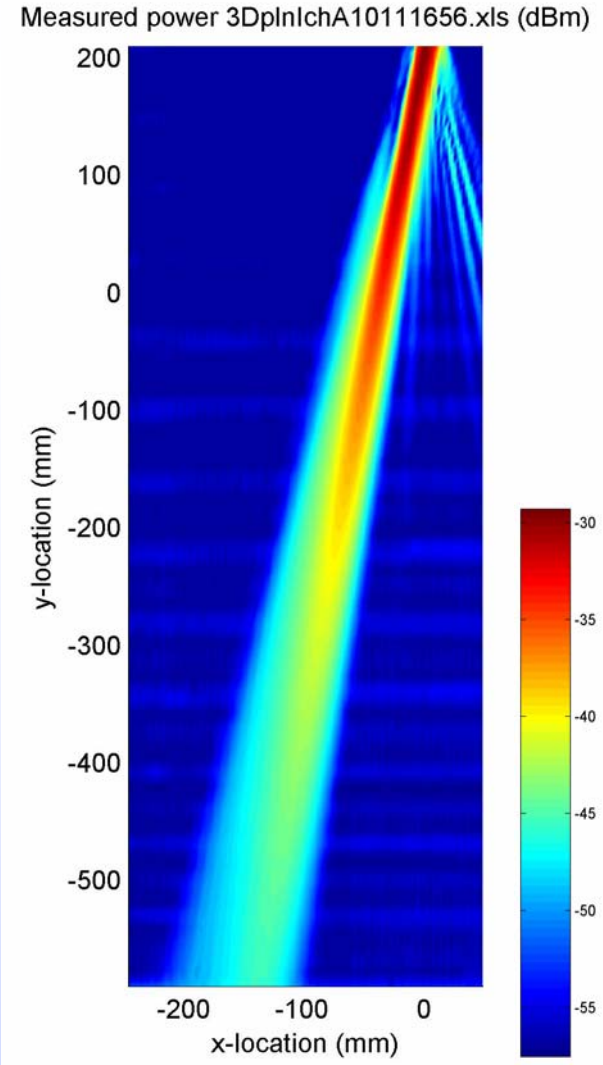
Preliminary set-up for low power tests at Rijnhuizen

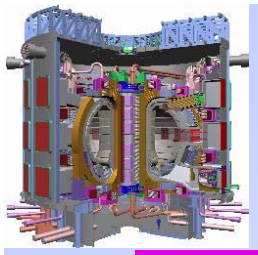


Conditions:
- **Frequency 170 GHz**
- **Power 10 mW CW**
- **Dimensions square corrugated waveguide 32x32x2300mm**









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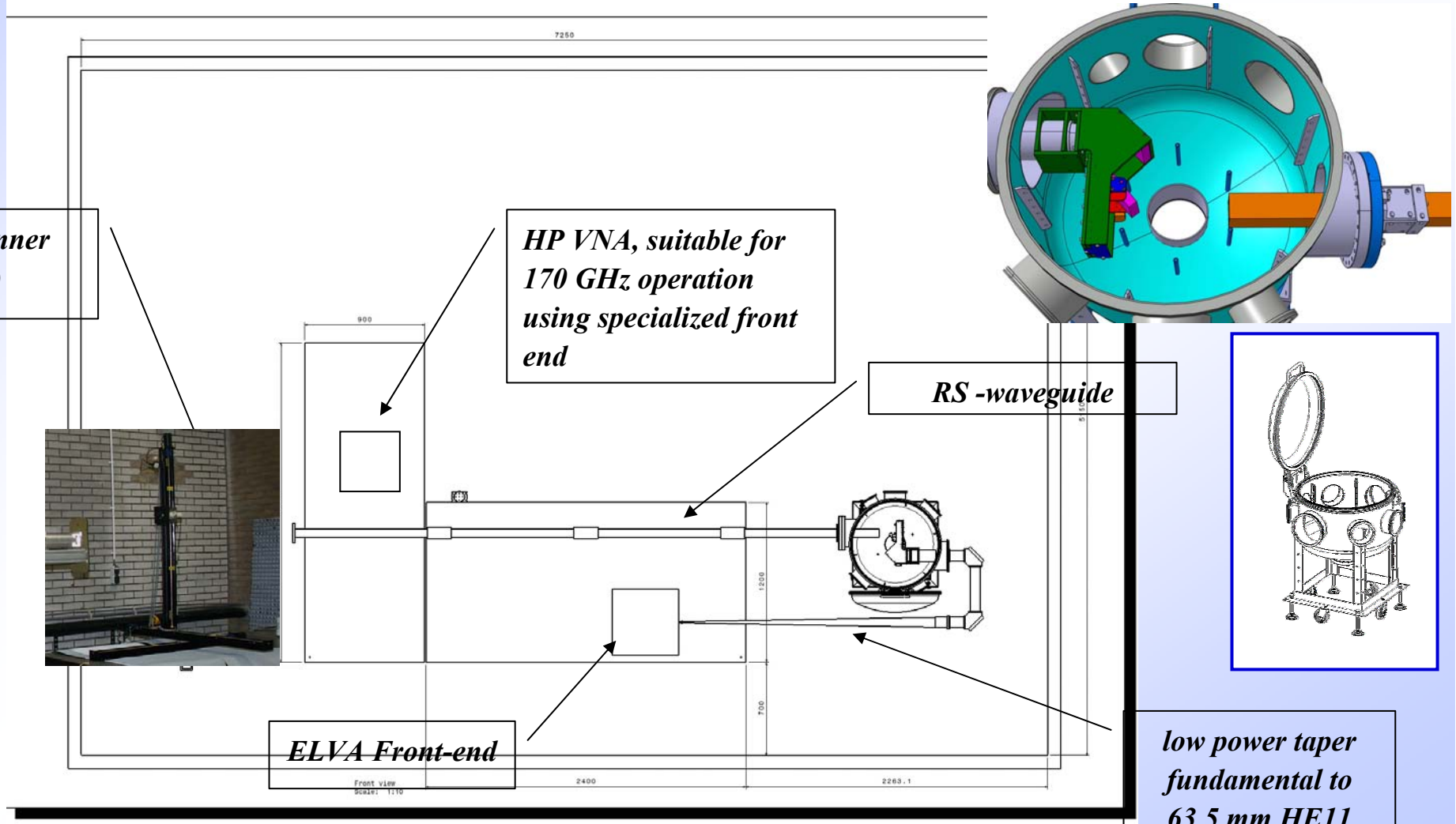
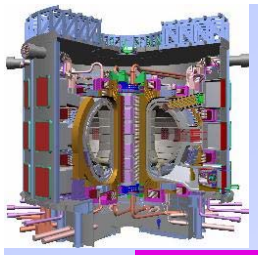
Low-power test set-up at 170 GHz; Rijnhuizen





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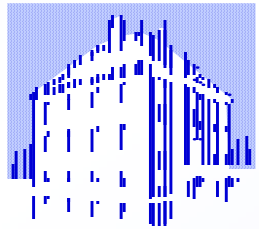


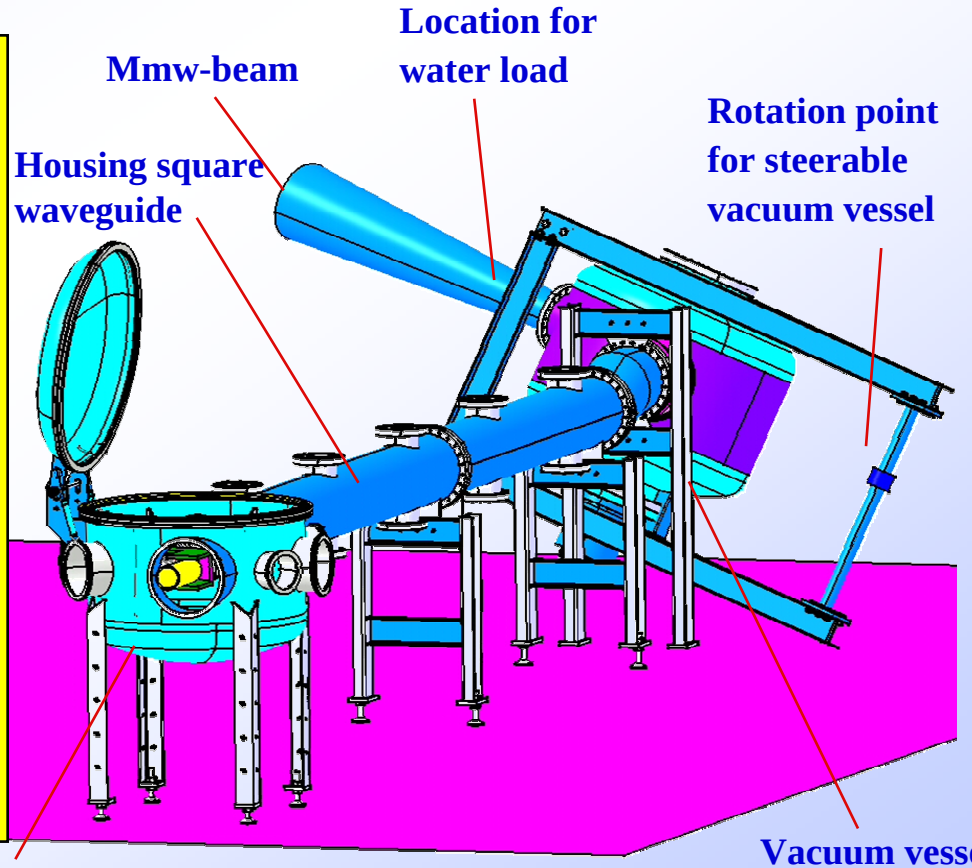
Mock-up tests under ITER operational conditions

Time schedule:

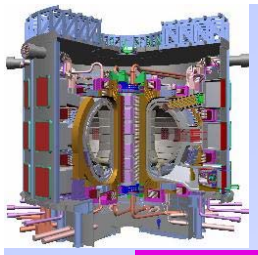
- Rijnhuizen end of 2004 low power (10 mW CW)
- Karlsruhe 2005 high power low energy tests (1.5 MW 10ms)
- Lausanne 2006 high energy CW (2MW CW)

Simulate ITER operational conditions:

- Maximum coolant temperature 250 ^{o}C;
- Operational temperature primary vacuum 180 ^{o}C;
- Operational temperature secondary vacuum 100 ^{o}C;
- Primary vacuum UHV 10^{-7} mbar and 10^{-4} mbar;
- Secondary vacuum HV 10^{-5} mbar.



New model in 3-D Catia



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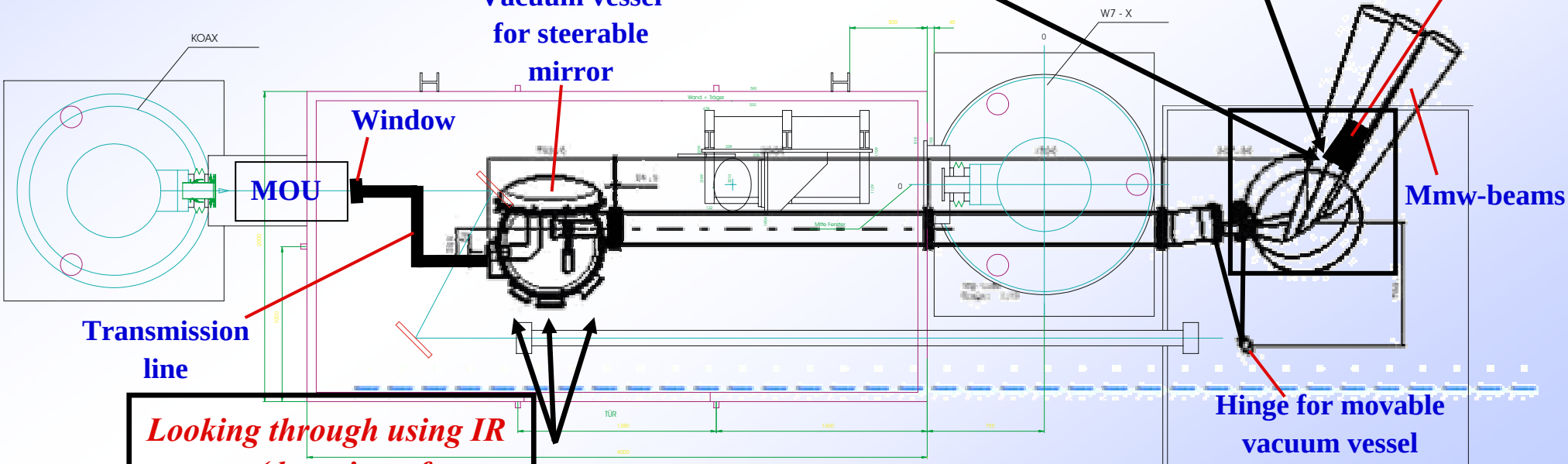
Mock-up in FZK test facility

Mm-wave diagnostics on the 170 GHz test facility

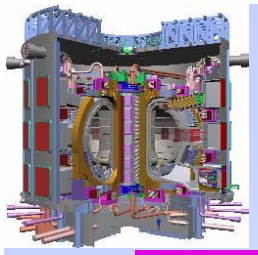
Checking polarization using rotating probe. Can be done directly in the beam or using a foil

Beam profiling using IR camera



Looking through using IR camera (detection of hotspots)

top view



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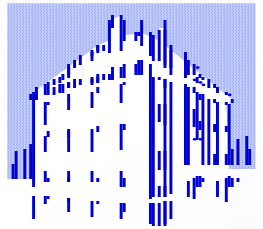


Time schedule

2003-2004 Detailed design, analysis and manufacture of a prototype ITER launcher with all the details.

2004 Test full mmw prototype at FOM, mechanical, low-power mmw 170 GHz

2005 Test full mmw prototype at FZK: 1.5 MW, 10 ms, 170 GHz

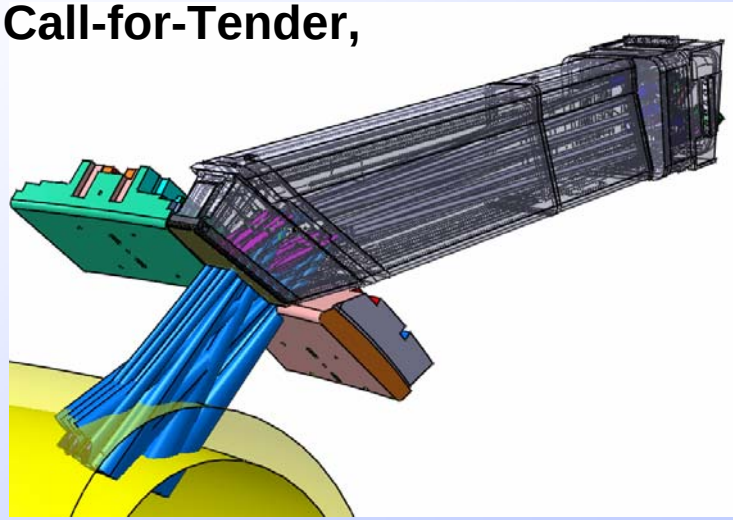
2006 Test at CRPP: 2 MW, few s, 170 GHz

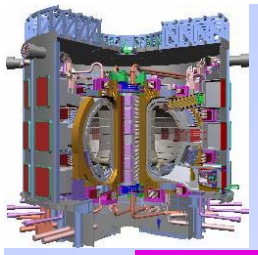
2007 longer pulses: 2 MW, cw, 170 GHz

2008-2009 ITER launcher: design, specifications Call-for-Tender, follow-up, factory tests

2010-2012 Installation, commissioning and test full ITER launcher: 2 MW, cw

2013 Start ITER plasmas with full ECRH system





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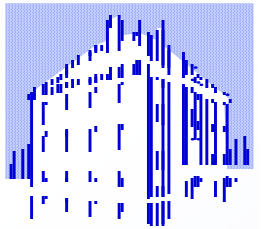

Conclusions

Feasibility study for remote steering for ITER shows:

- **No show-stoppers**
- **Conceptual design for key components ready**
- **Important advantage of remote steering:**
  - **no moving parts near plasma**
- **Mitre bends can (hopefully) be avoided**
- **Now recent physics wishes included**
  - **smaller beams in plasma**
  - **larger steering range**
  - **trade-offs being discussed**

Detailed design for high-power test set-up finalized
Detailed design of port-plug system ongoing

Time schedule in accordance with ITER procurement