



STATUS OF THE NEW ECRH SYSTEM FOR ASDEX UPGRADE

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Planned system parameters:

power: 4 MW, provided by 4 gyrotrons

pulse length: 10 sec

frequency: 105 / 140 GHz as a 2-f-gyrotron
105 to 140 GHz as a step tunable gyrotron

launcher: feedback controlled deposition

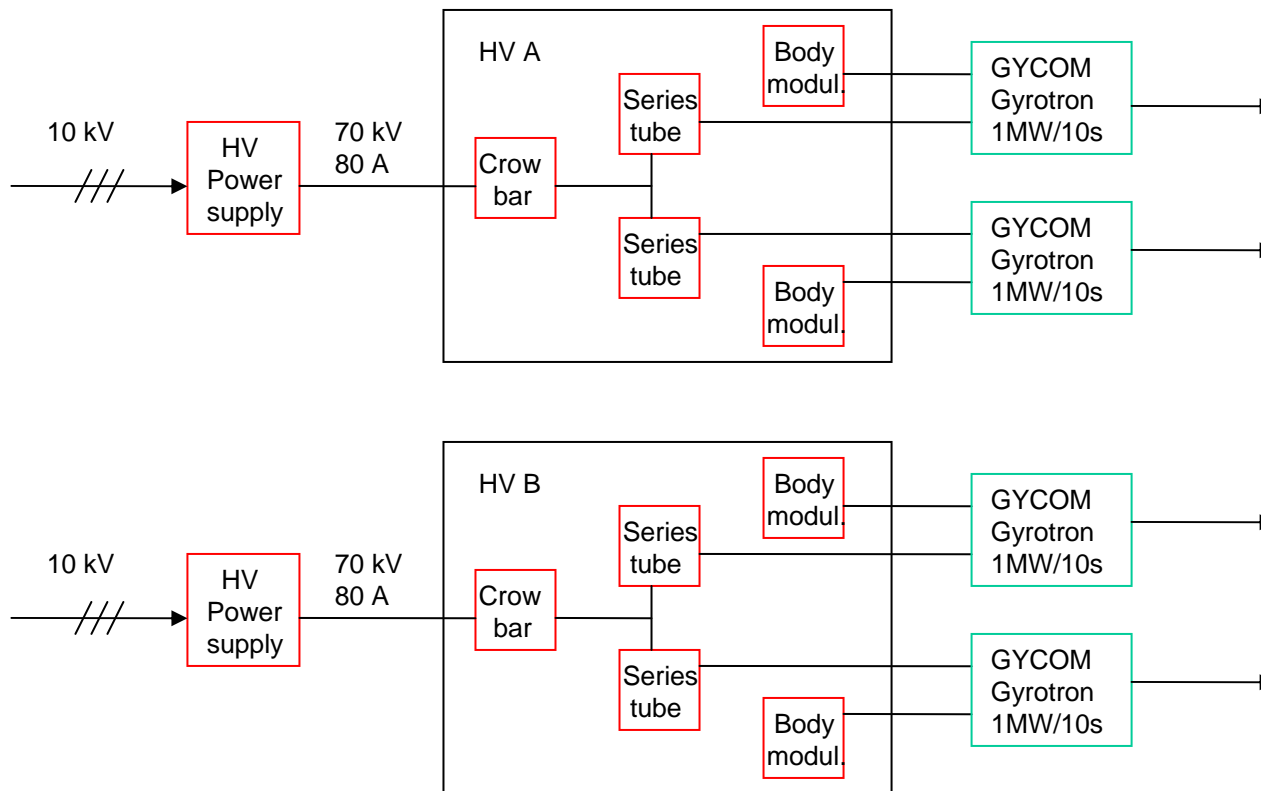
physics aims: heating and current drive, in particular for studies of
advanced tokamak regime
suppression of tearing modes
control of transport and pressure profile

The project is supported in part by Helmholtz Gemeinschaft HGF
via a cooperation between IPP, FZK and FZJ

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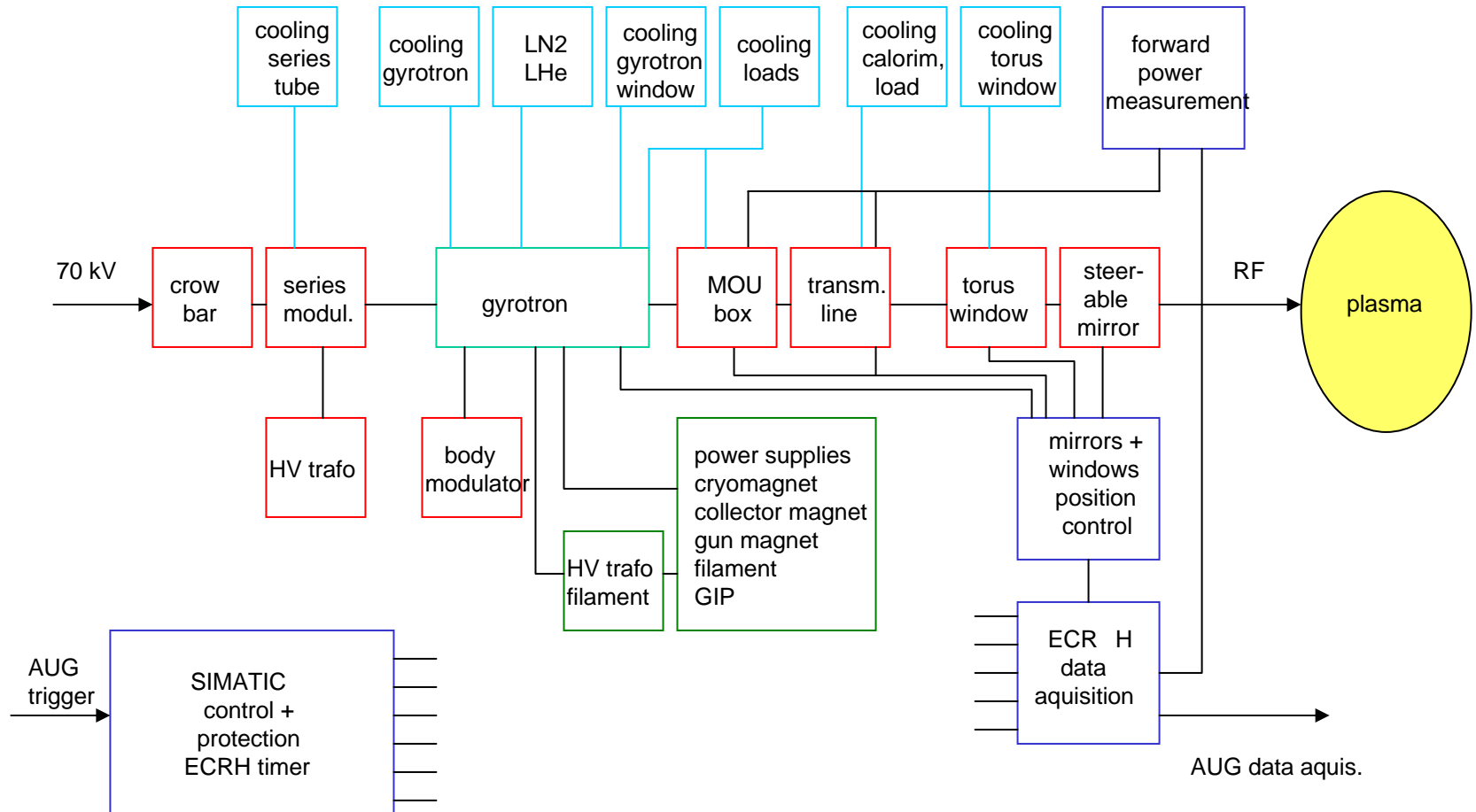
4 gyrotrons, 105 - 140 GHz, 1 MW, 10 sec



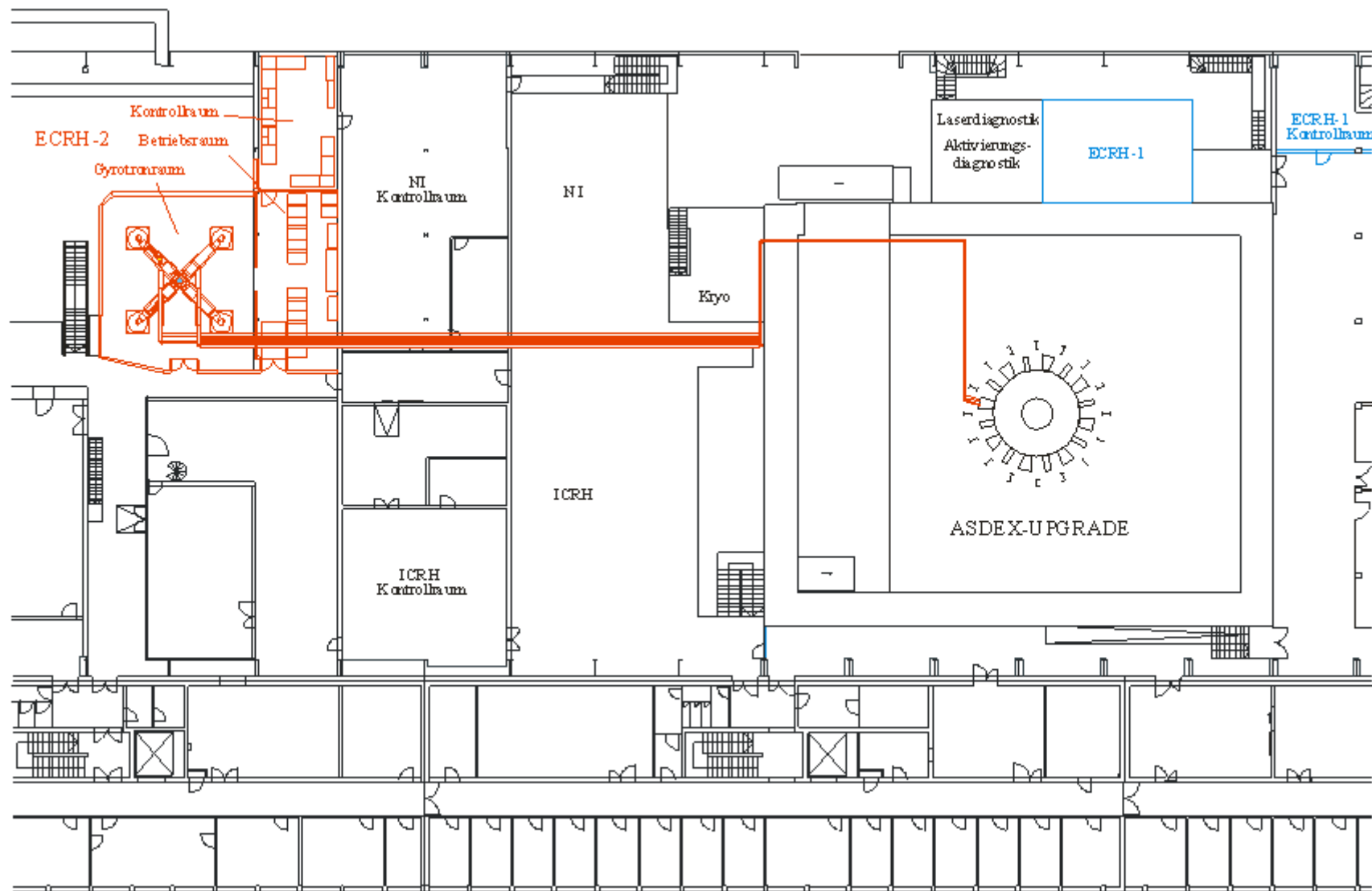
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4 gyrotrons, 105 - 140 GHz, 1 MW, 10 sec



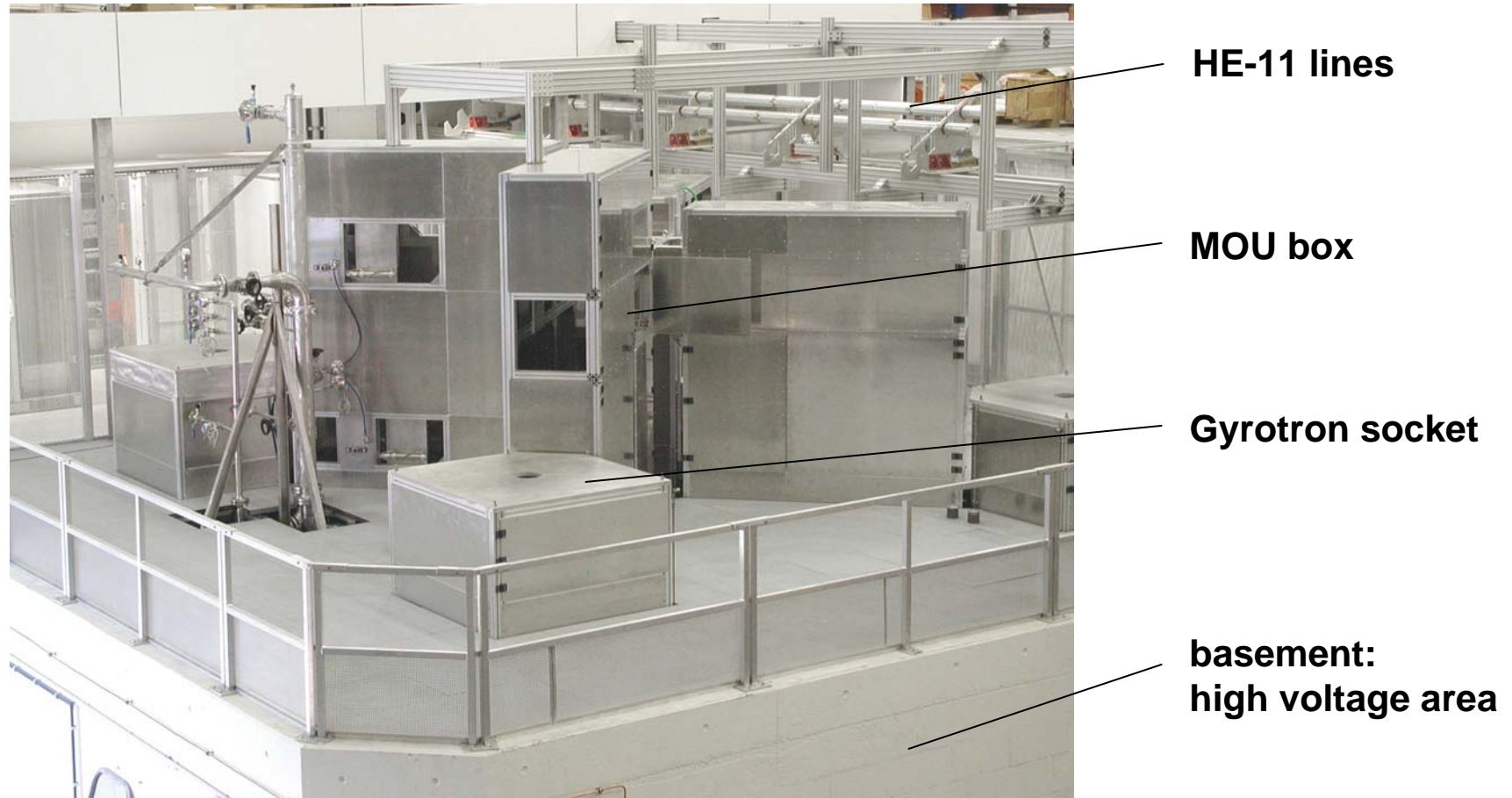
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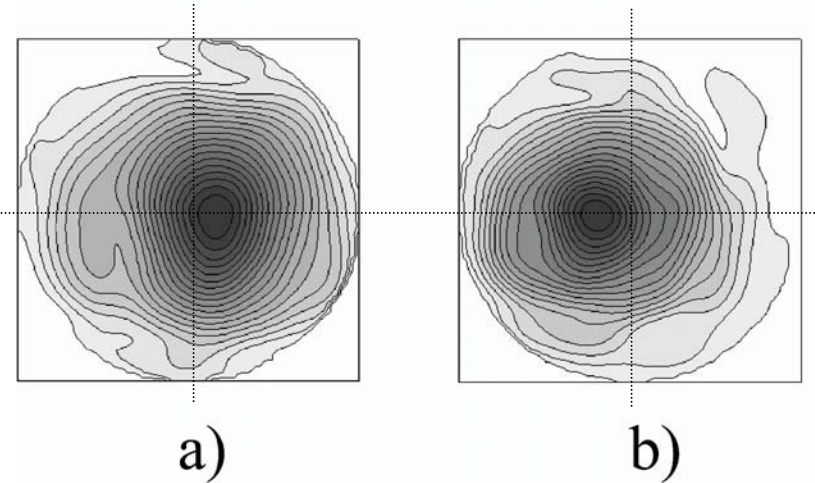
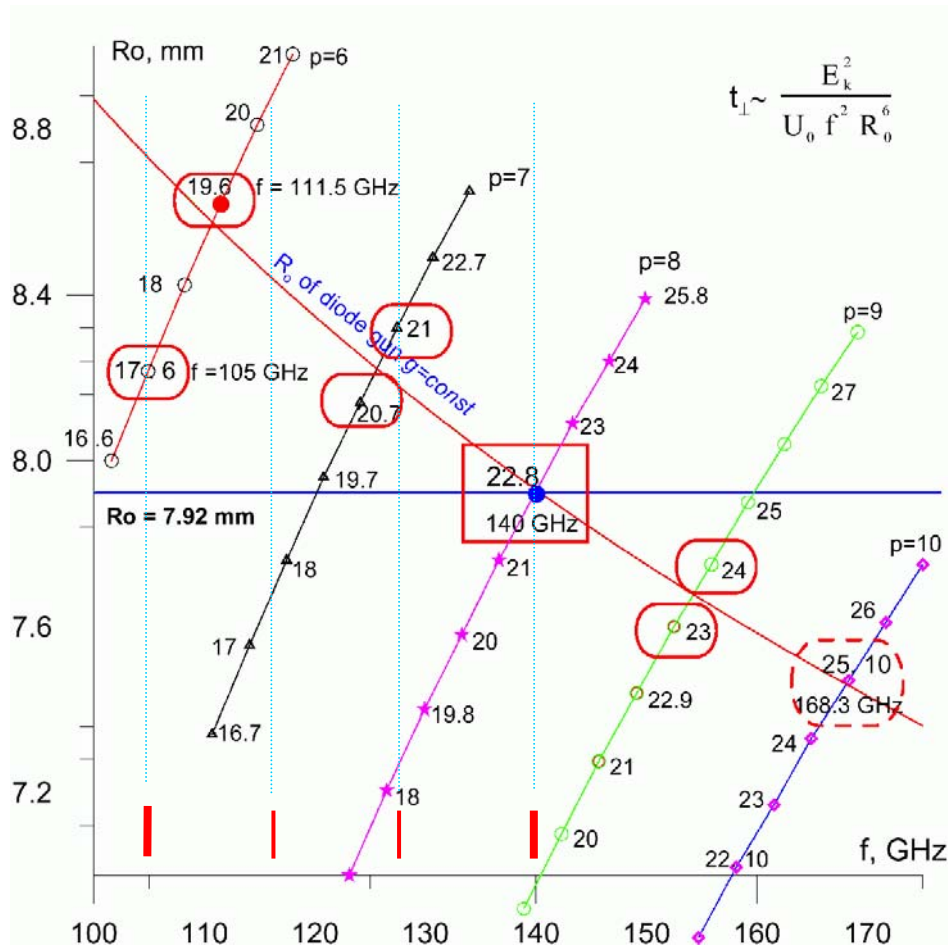
Gyrotron hall



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- **Electron beam radii and caustics for operating modes (Zapevalov et al.)**

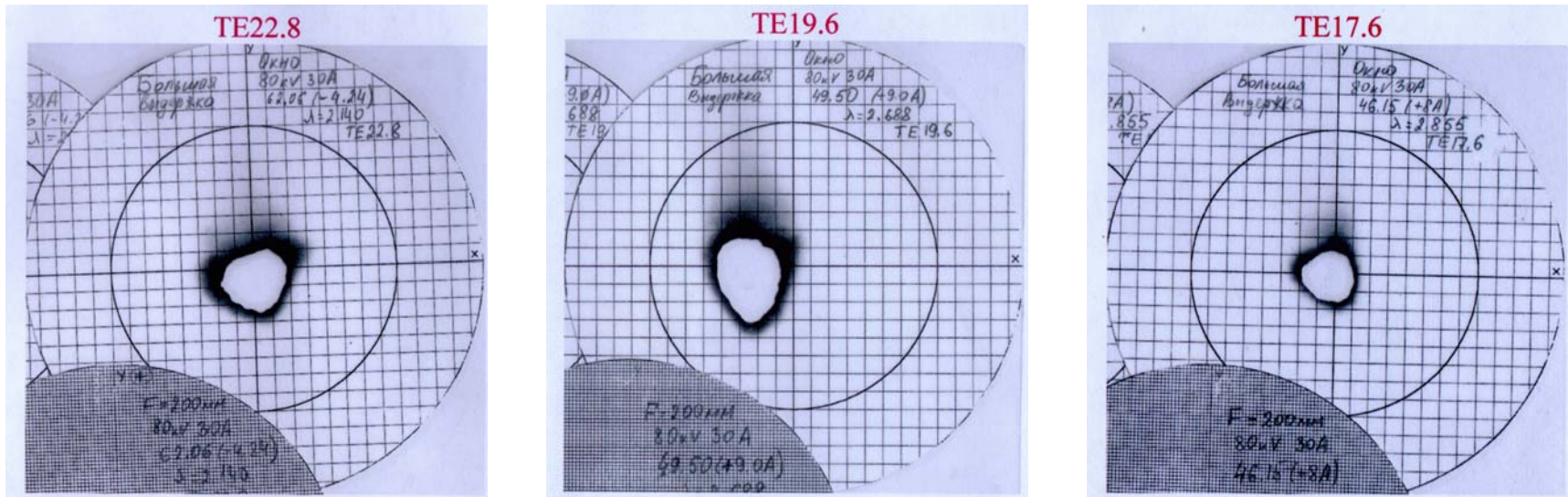
- **Calculated field amplitude patterns at the gyrotron window $\varnothing 80\text{mm}$**



- a.) $f=111.6 \text{ GHz}$, Gaussian mode content $\eta_G=95\%$
 b.) $f=140 \text{ GHz}$, $\eta_G=96\%$

We will choose 4 frequencies as our main operating modes

Measured beam at the output window (Zapevalov et al.)



- For each frequency the beam leaves the gyrotron in a slightly different direction
- This has to be corrected in the first two mirrors of the matching optics unit

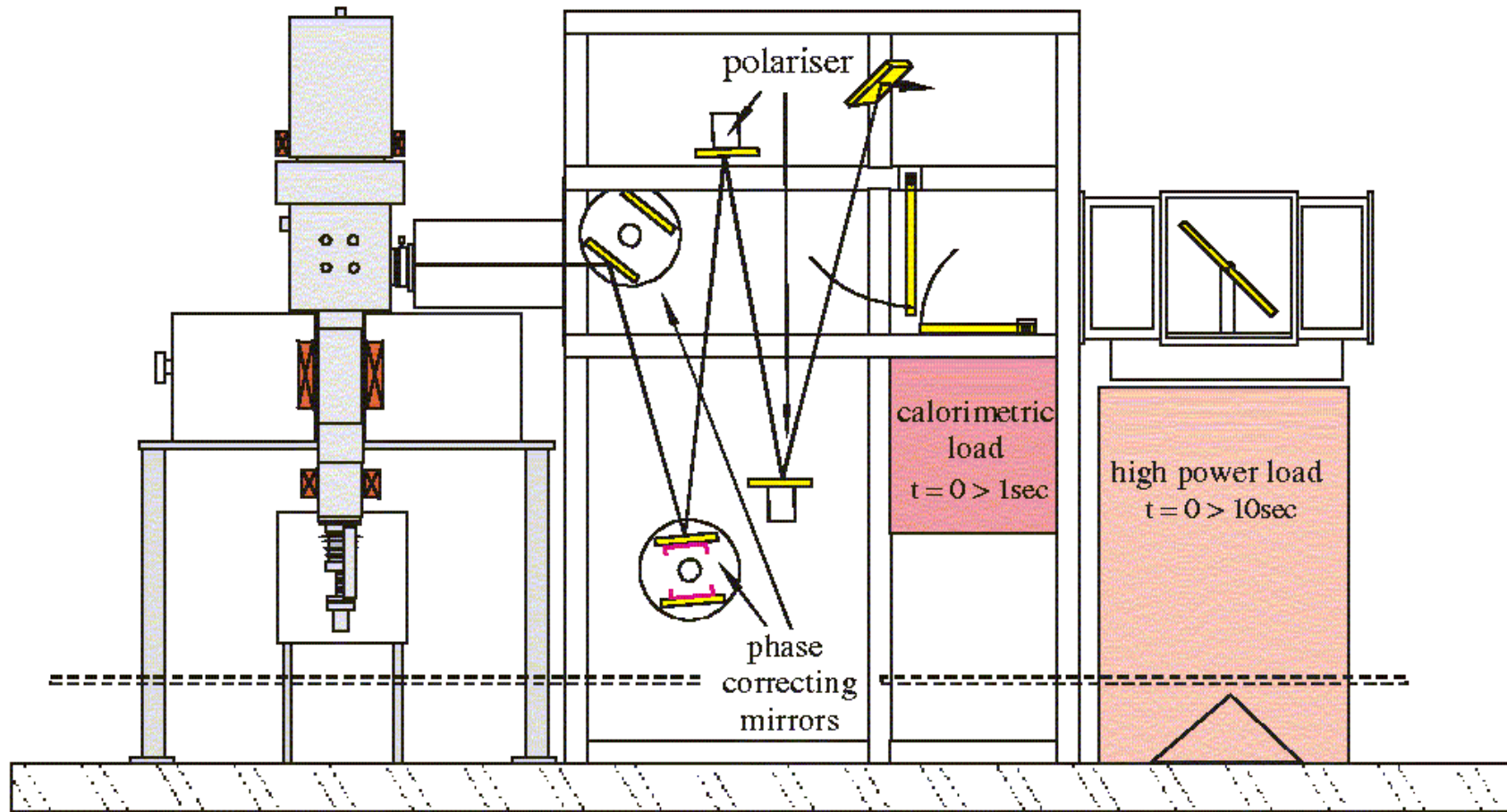
Matching optics unit:

- **two phase correcting mirrors, the second one with integrated directional coupler (one pair of mirrors for each frequency)**
- **two broad band polariser mirrors**
- **mirror for coupling into the HE11-line**
- **switchable mirror for coupling into the central 1 MW / 10 sec load**
- **switchable mirror for coupling into a 1 MW / 0.5 sec calorimeter load**

The mirrors are made of 40 mm thick copper without forced cooling

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gyrotron GYCOM N.N.



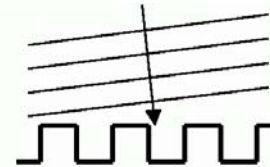
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Polarizer mirrors must provide the desired polarization in the frequency range 105-140 GHz for the required angular range in ASDEX Upgrade experiments ($\approx \pm 35^\circ$ in poloidal and toroidal direction)

BROADBAND POLARIZERS

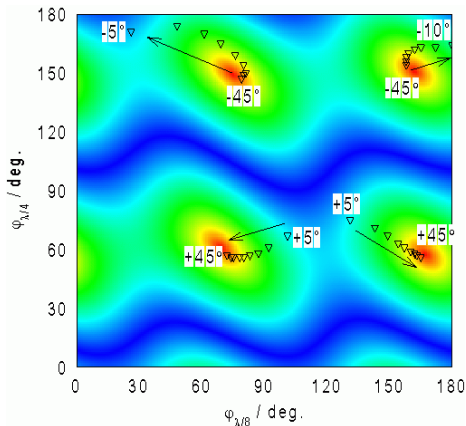
incident angle = 17.25°
toroidal scan, $\Phi_{\text{pol}} = \text{const.} = 10^\circ$
 $B_t = -2.4\text{T}$
 $I_p = 800\text{kA}$, x mode



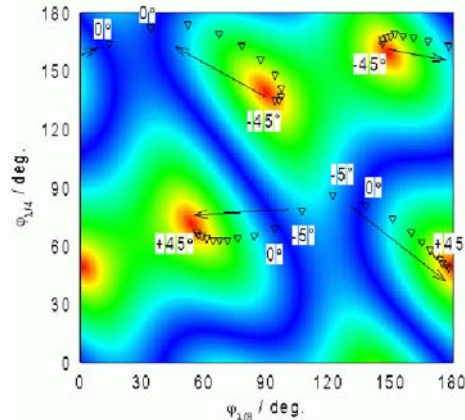
new polarizer
 $h = 0.44/0.6\text{ mm}$

ellipticity:

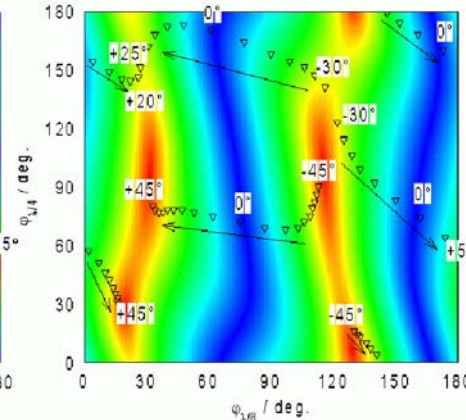
87.5 GHz



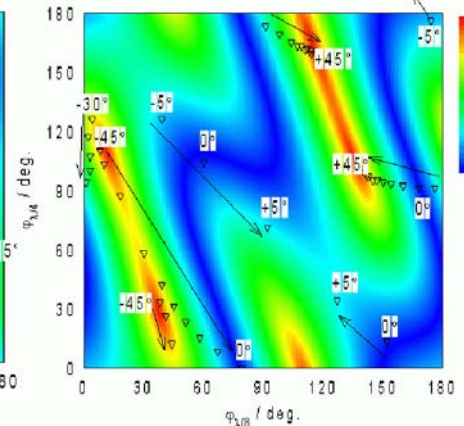
105 GHz



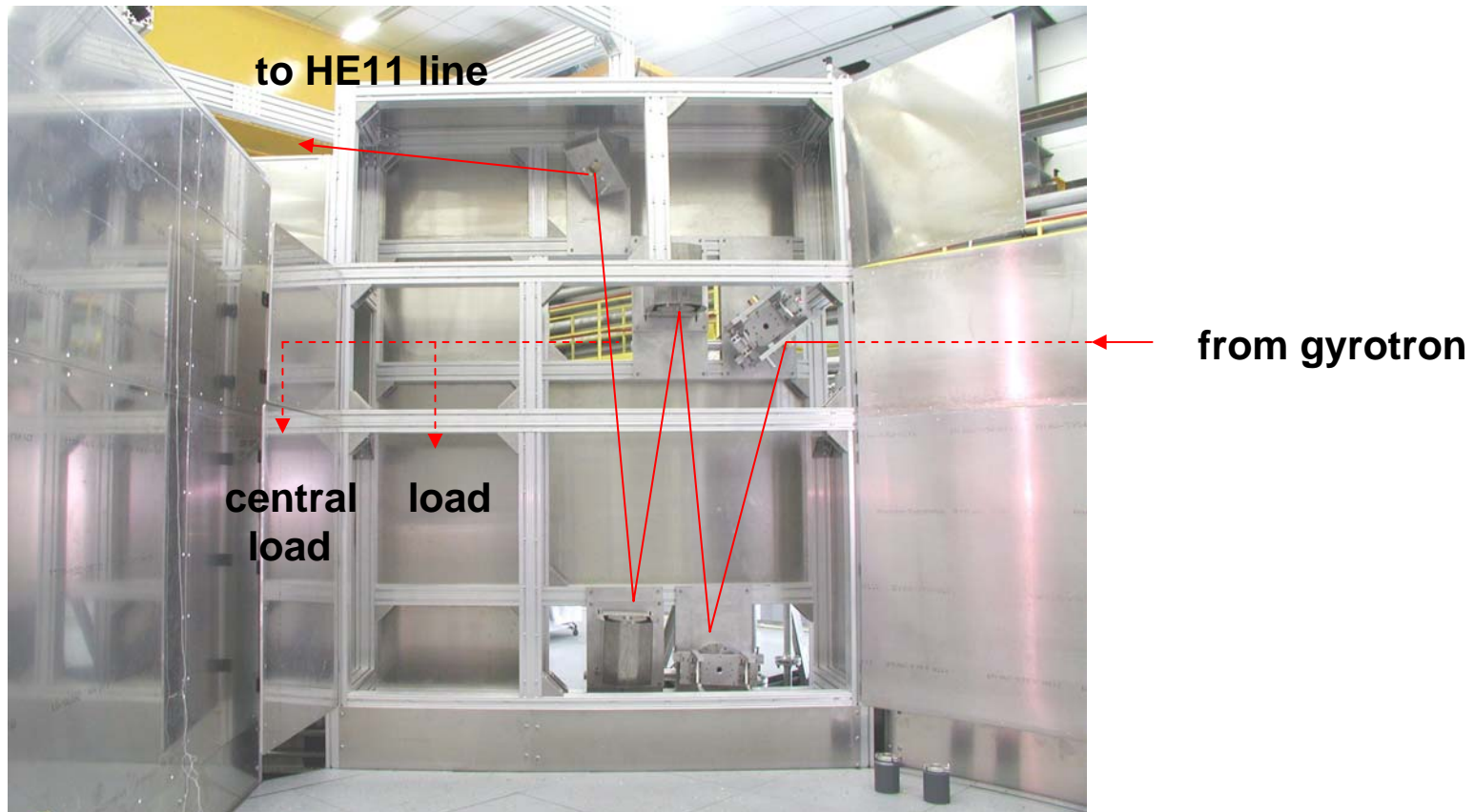
122.5 GHz



140 GHz



Matching optics unit



HE11 transmission lines



**87 mm i.d.
broadband corrugated
waveguide line**

at normal air pressure

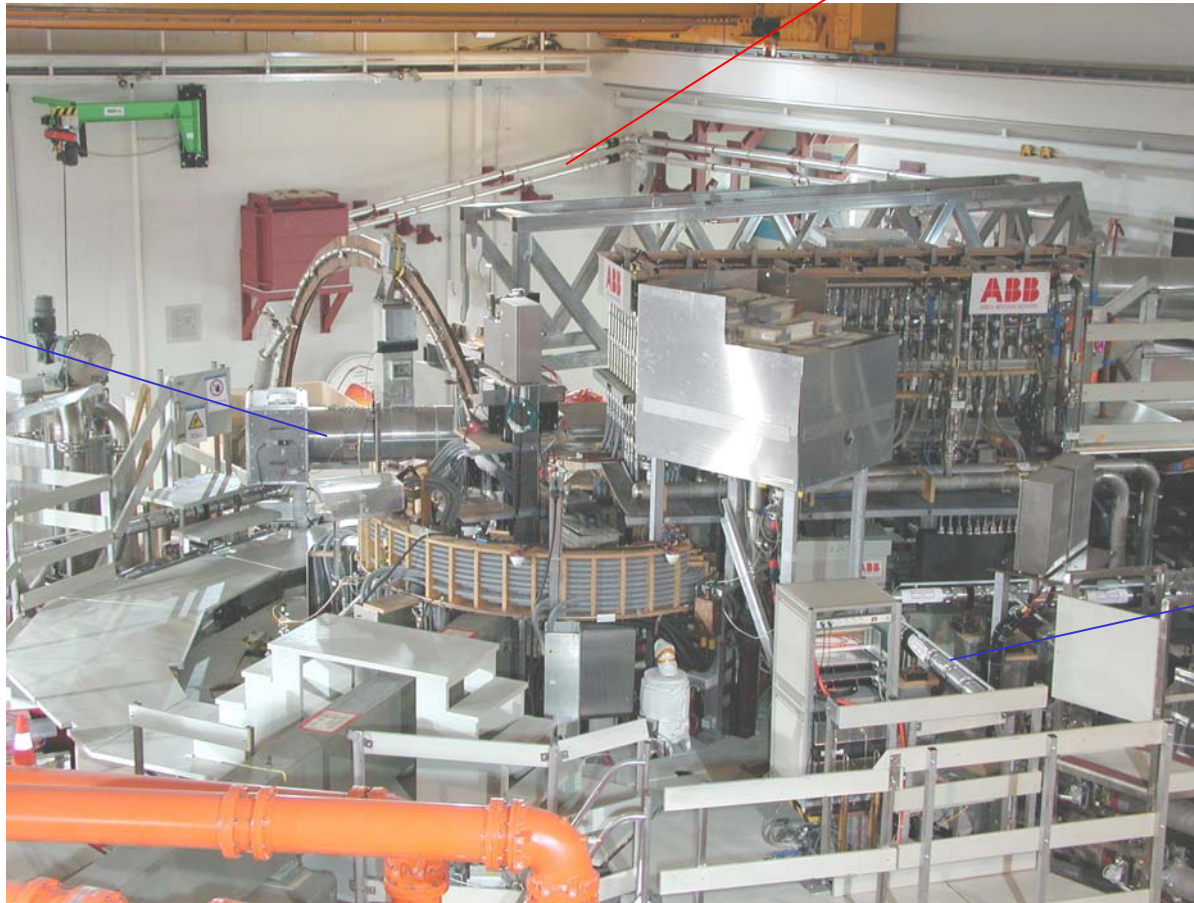
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ASDEX Upgrade torus hall (on top of the torus)

ECRH-2
HE11-
transm. lines

ECRH-1
quasi optical
transm. lines

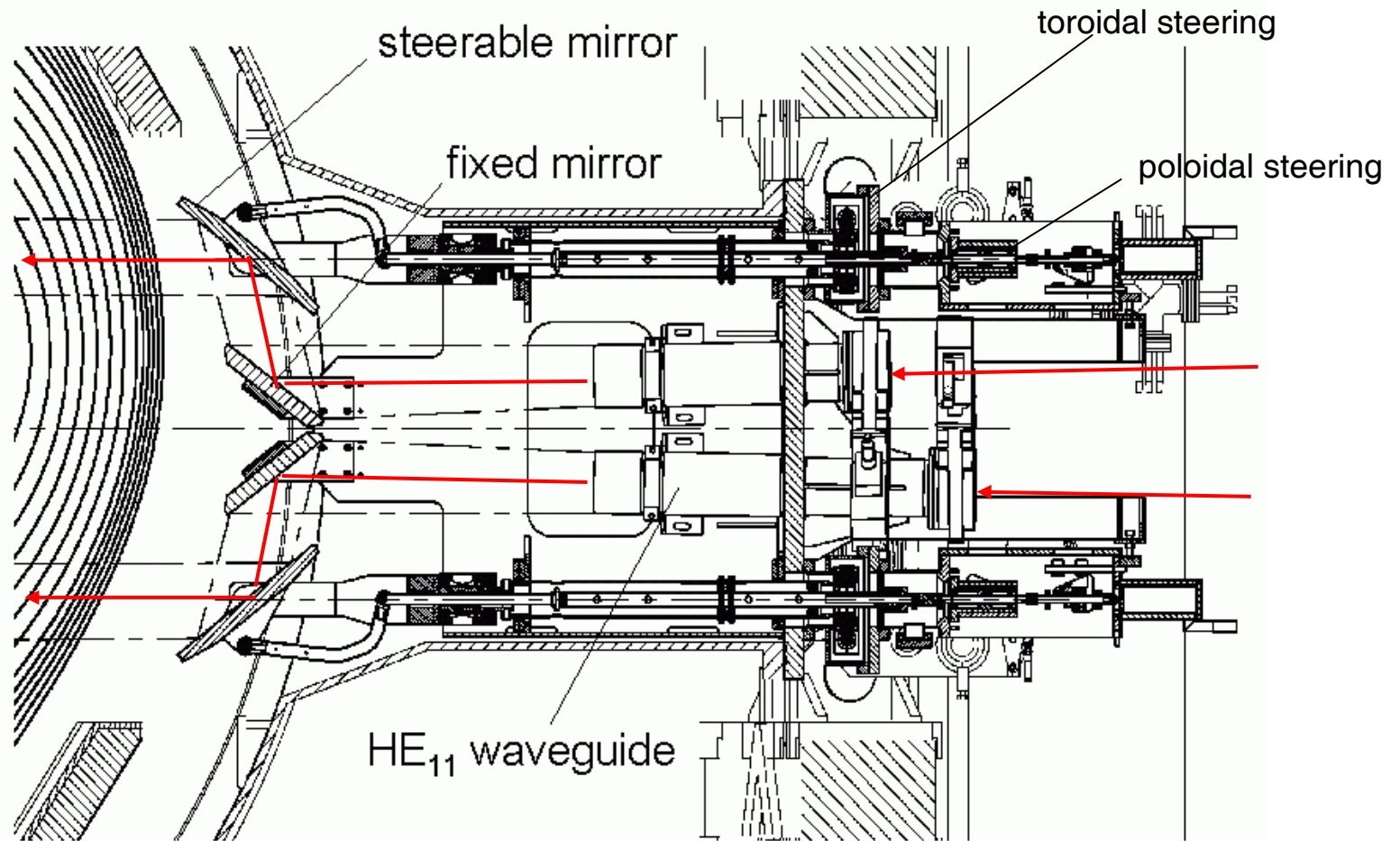


ECRH-1
HE11-
transm. lines

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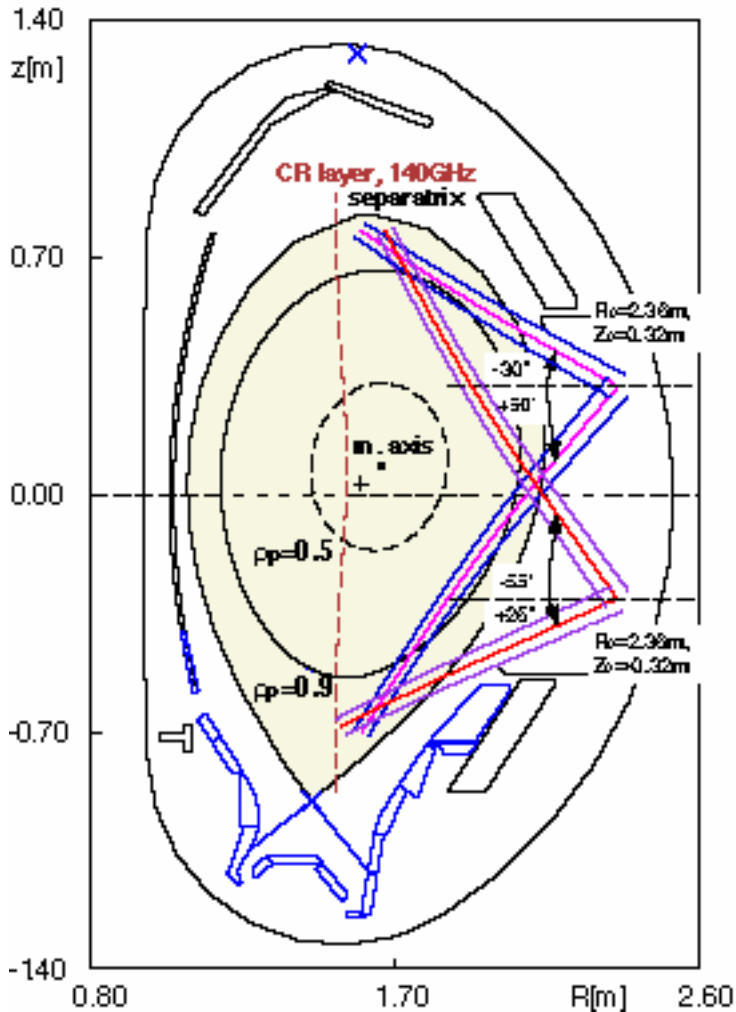
AUG - sector 5 , ECRH launcher plug-in



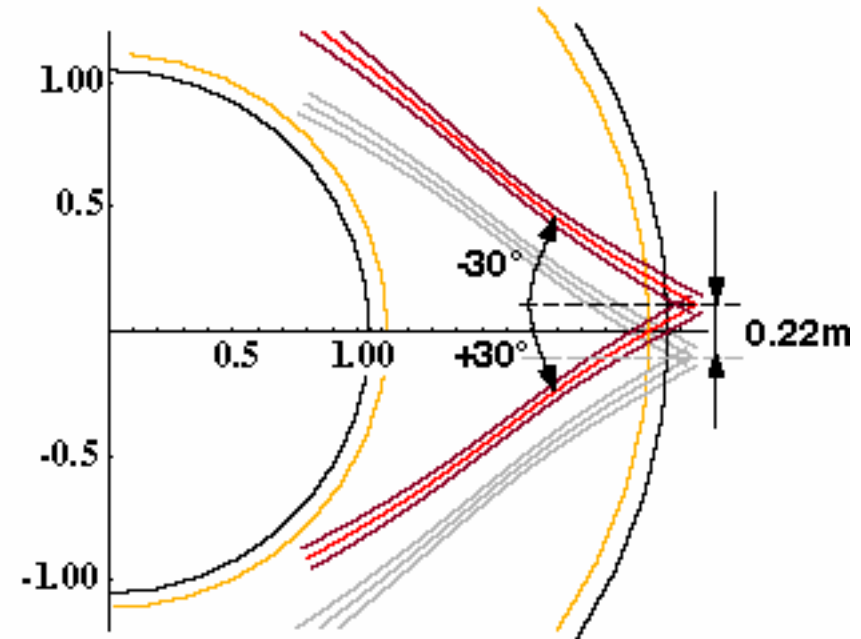
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Poloidal scanning range

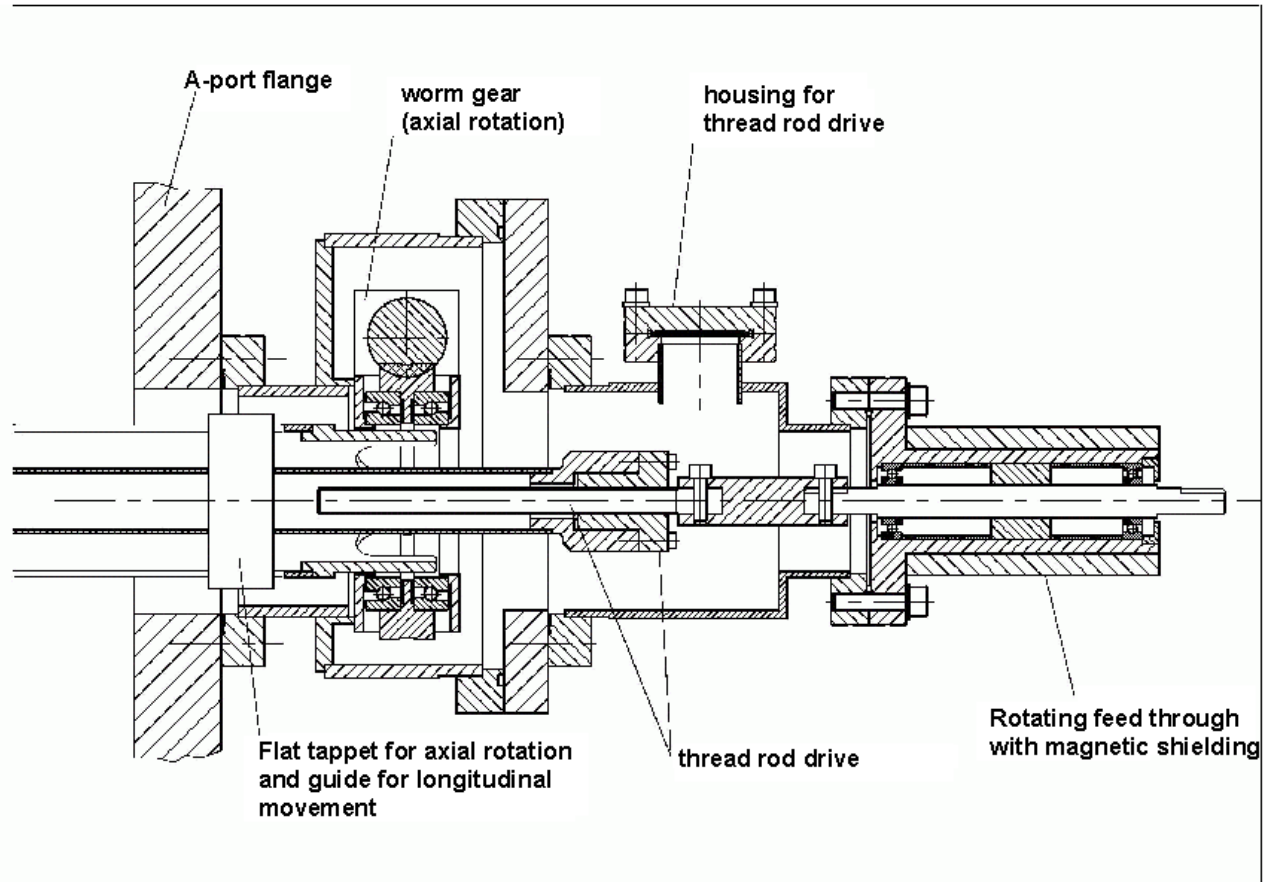
AUG #15907, $t=3.000$ [s], -2.3 [T], 0.8 [MA]



Toroidal scanning range



ECRH launcher drive concept: push rod drive



target: mirror positioning 10° in 100 msec

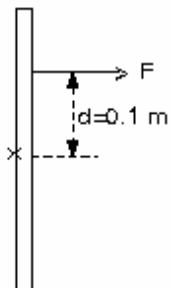
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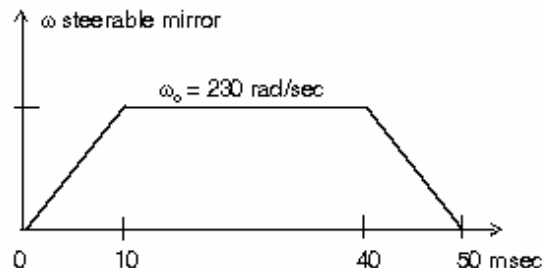
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Dynamical considerations



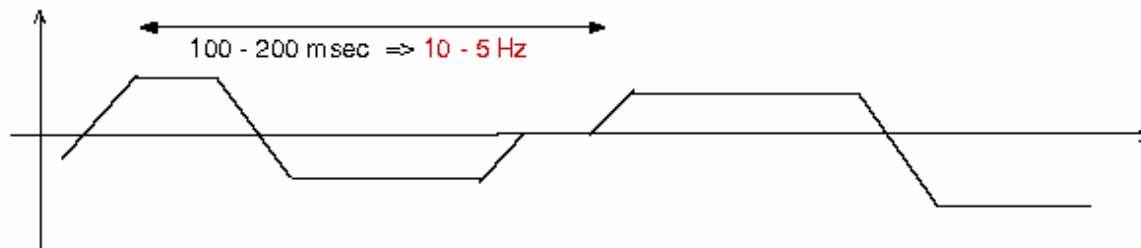
target: scan of 5° in 50 msec



mirror material	Cu	CrNi	Graphite	AlN
accel. force, N	280	255	55	100

+ additional acceleration force of the drive system

operation in feedback mode:

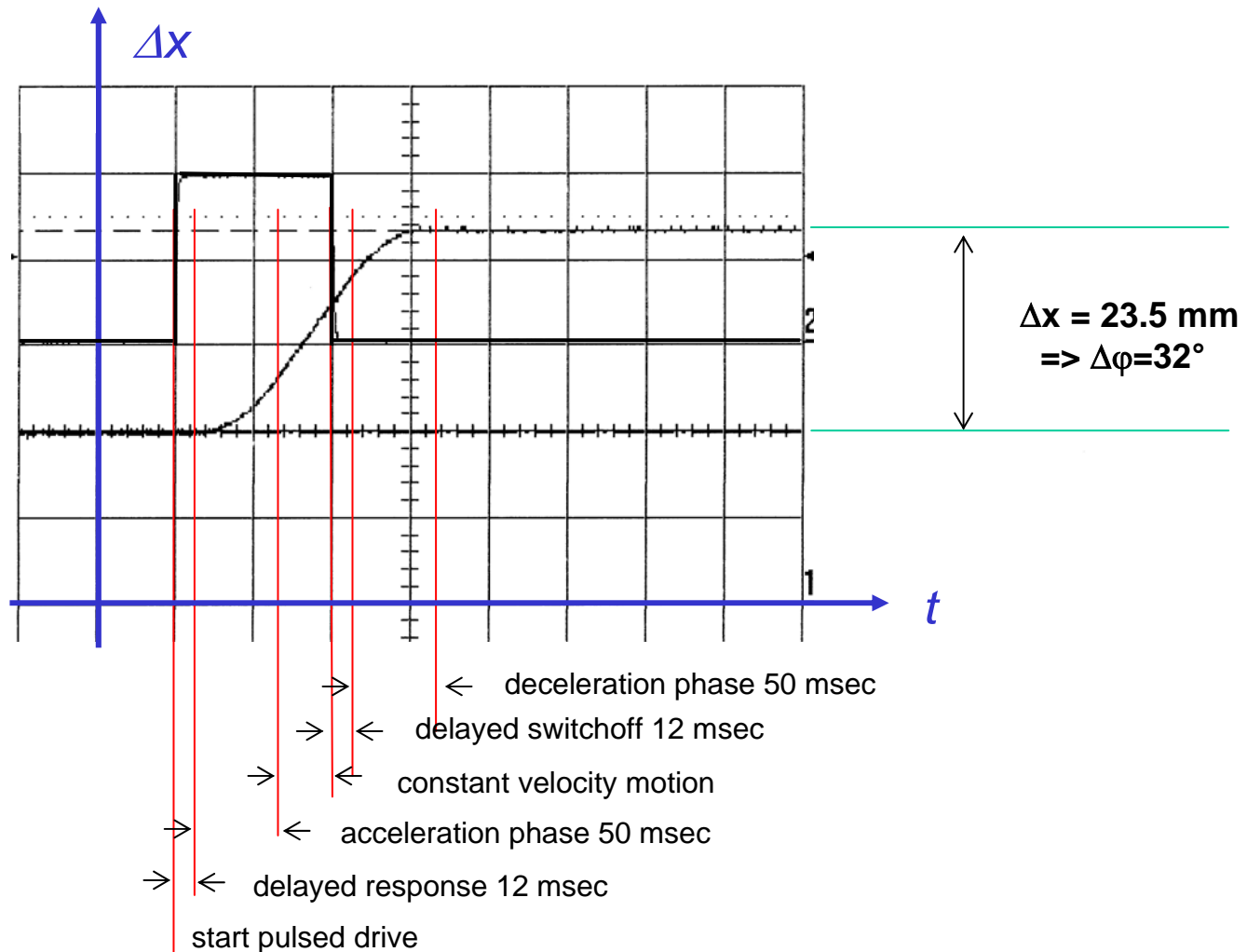


⇒ use low mass mirrors and drive system

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A poloidal angle variation of 10° in 100 msec has been achieved



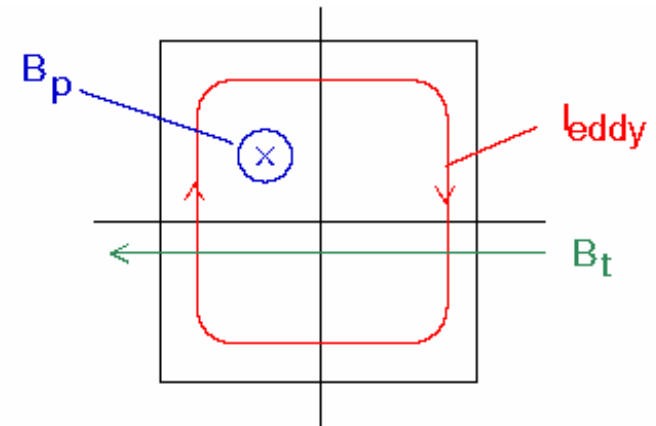
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Estimation of disruption forces

Assumptions: $B_p(r=a) = 0.1 \text{ T}$
 $\tau = 3 \text{ msec}$ } $\Rightarrow \dot{B}_p = 33 \text{ T/sec}$
 $B_t(r=a) = 2.2 \text{ T}$
 mirror $\perp B_p$, $320 \times 160 \times 30 \text{ mm}$

Force: $F = I_{\text{eddy}} \times B_t$



Results:

Mirror material	Cu	SS	Graphite
mass, kg	14	13	3
torque, Nm	8400	200	8
accel. ω , rad/sec ²	$29 \cdot 10^4$	$0.75 \cdot 10^4$	$0.14 \cdot 10^4$
$\Delta\phi$ in 3 msec	75°	2°	0.4°
ΔE in 3 msec, Joule	1100	7	0.05

\Rightarrow we need low conductivity material or low eddy current construction

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Estimation of thermal loading of the mirrors

Assumptions: beam $w = 33.1$ mm (field)
lost power 2.8 kW
perpendicular incidence
circular mirror $r = 130$ mm
thickness 30 mm

Inputs: $\lambda = \lambda(T)$ = heat conductivity
 $c = c(T)$ = heat capacity
 $\rho = \rho(T)$ = electr. resistivity

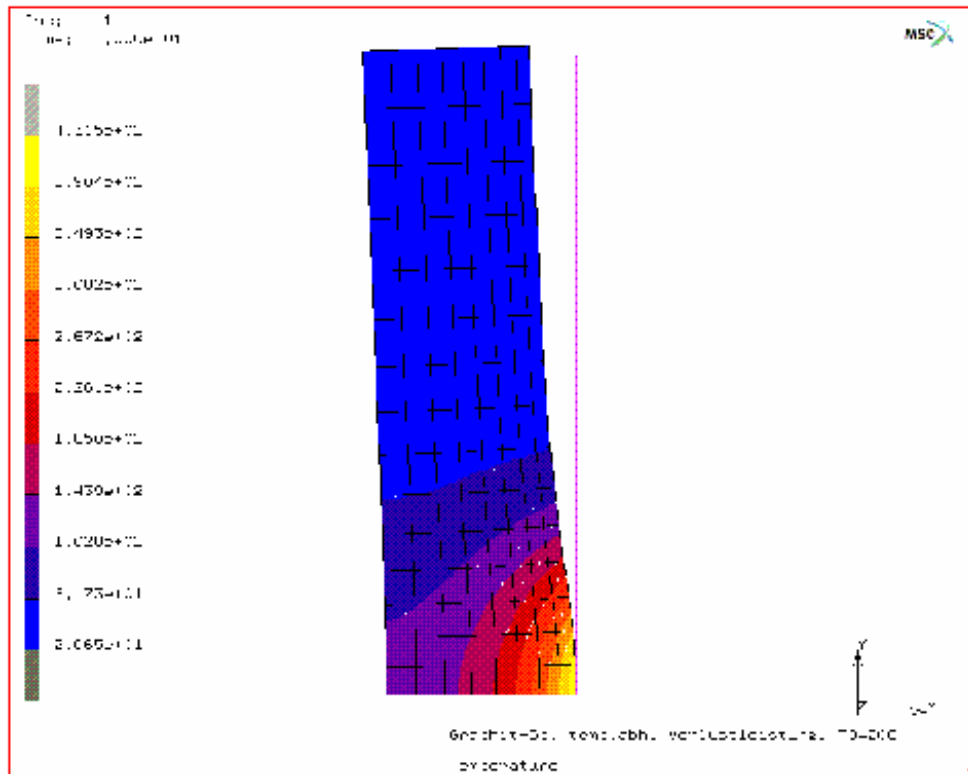
Results for central surface temperature after a 10 sec pulse, in °C:

Mirror material	Cu	CrNi	Graphite	AlN	BeO	SiC
		< - Cu coated - >				
T, surface, T(0)= 20°	104°		430°			
T, surface, T(0)=200°	308°	1970°	760°	540°	450°	1495°

Cooling of fast steerable mirror: only radiation cooling from the rear surface
equilibrium temperature with 1 pulse every 10 min: 230°C

⇒ use material with high heat conductivity and heat capacity

Temperature distribution after a 10 sec pulse



assumptions:

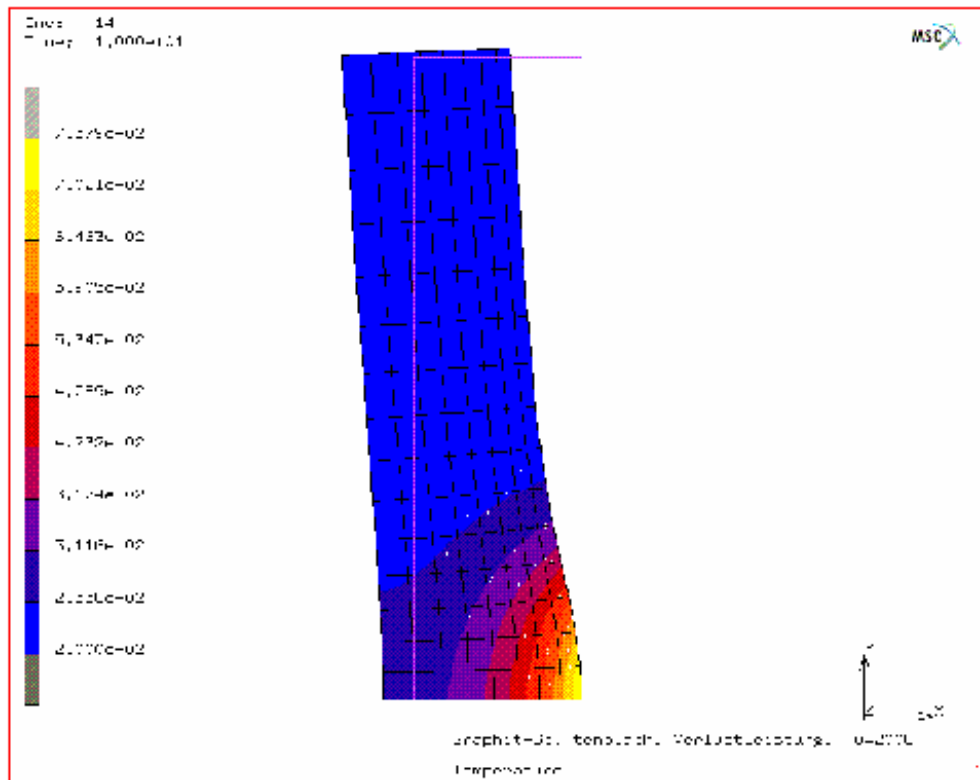
beam $w = 33.1$ mm (field)
lost power 2.8 kW
perpendicular incidence
circular mirror $r = 130$ mm
thickness 30 mm

Material: Graphite EK 98

$T(t=0) = 20^\circ\text{C}$

$\Rightarrow T(10 \text{ sec}) = 430^\circ\text{C}$

Temperature distribution after a 10 sec pulse



assumptions:

beam $w = 33.1$ mm (field)
lost power 2.8 kW
perpendicular incidence
circular mirror $r = 130$ mm
thickness 30 mm

Material: Graphite EK 98

$T(t=0) = 200^\circ\text{C}$

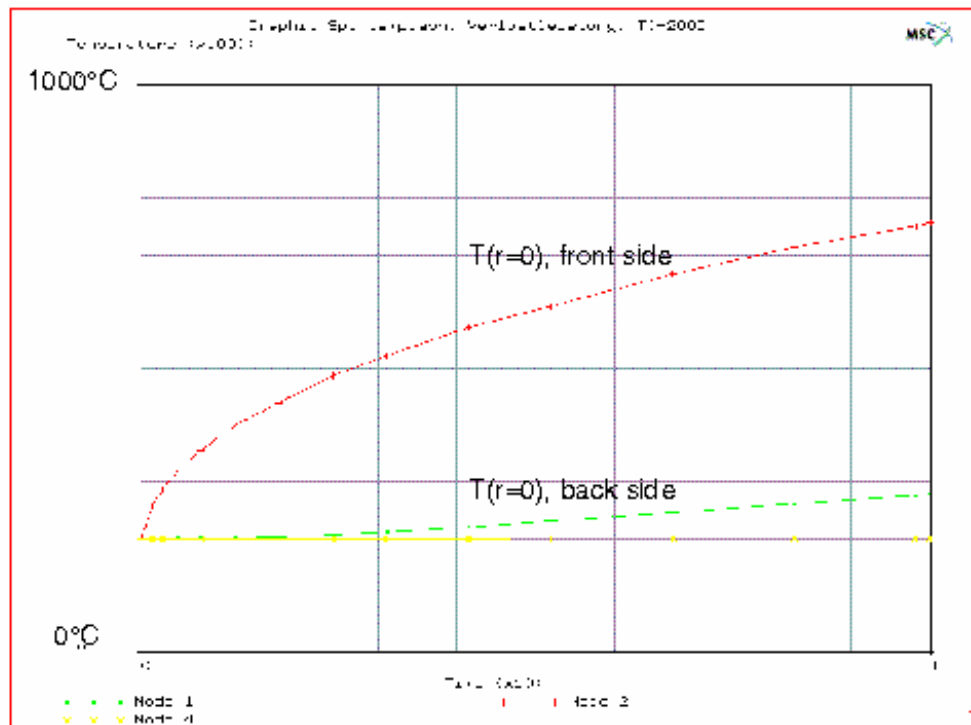
$\Rightarrow T(10 \text{ sec}) = 760^\circ\text{C}$

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Graphit mirror, Cu coated,

Temperature evolution, starting temp. 200°C



assumptions:

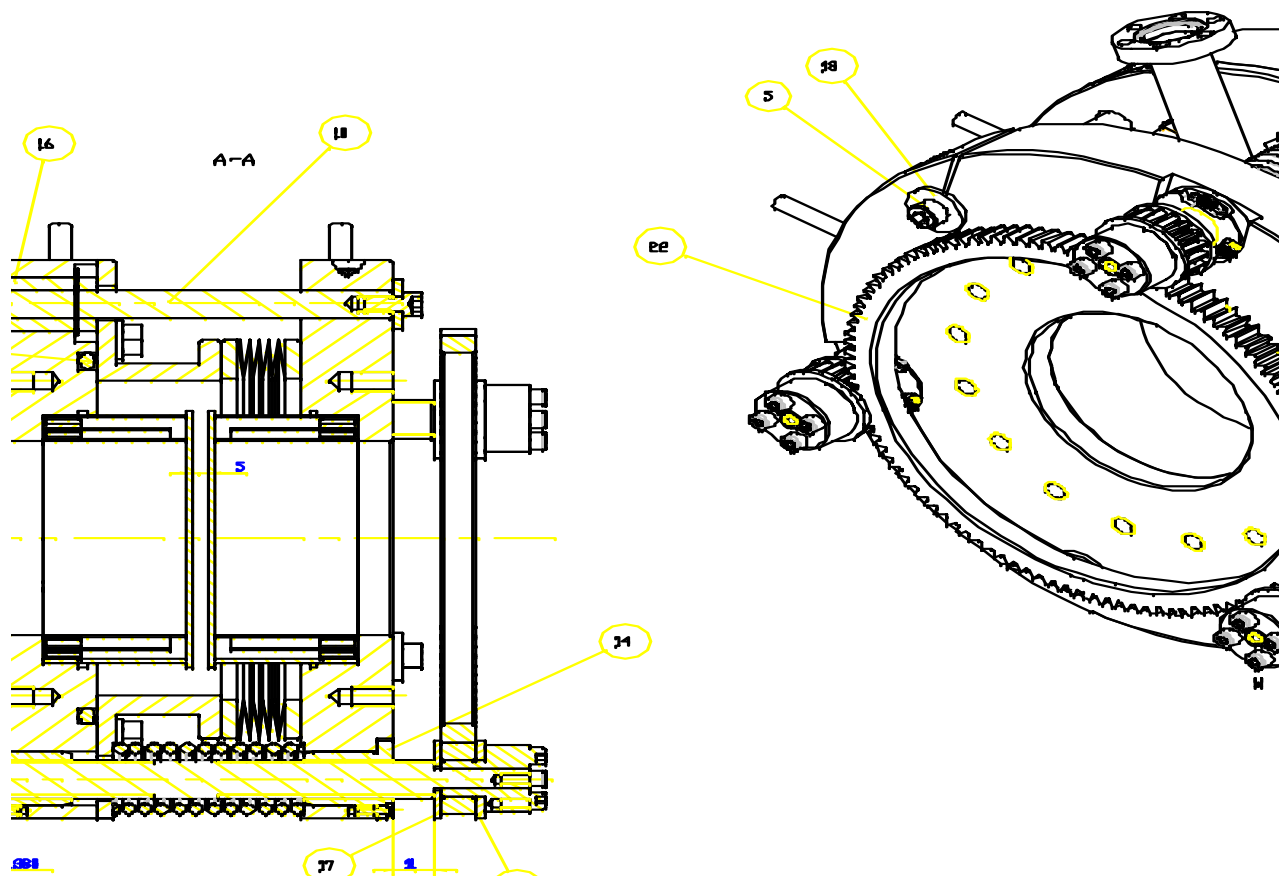
beam $w = 33.1$ mm (field)
lost power 2.8 kW
perpendicular incidence
circular mirror $r = 130$ mm
thickness 30 mm

Material: Graphite EK 98

$T(t=0) = 200^\circ\text{C}$

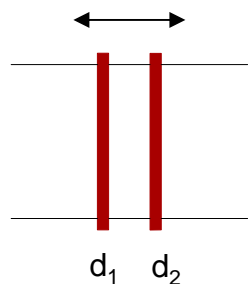
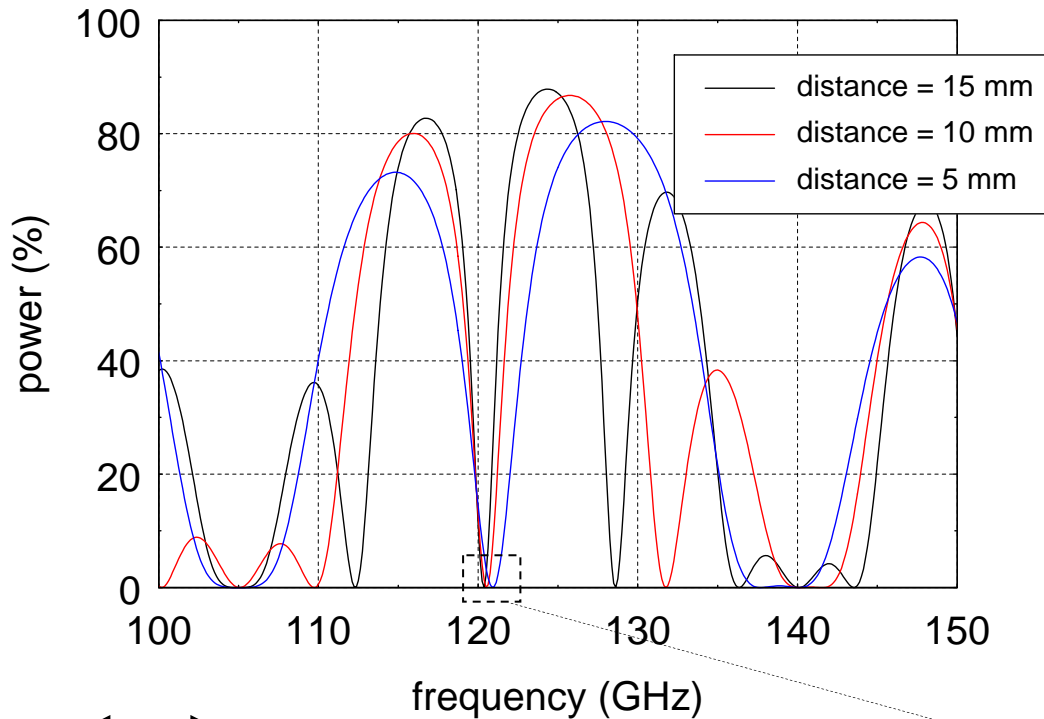
$\Rightarrow T(10 \text{ sec}) = 760^\circ\text{C}$

Tunable double disc window

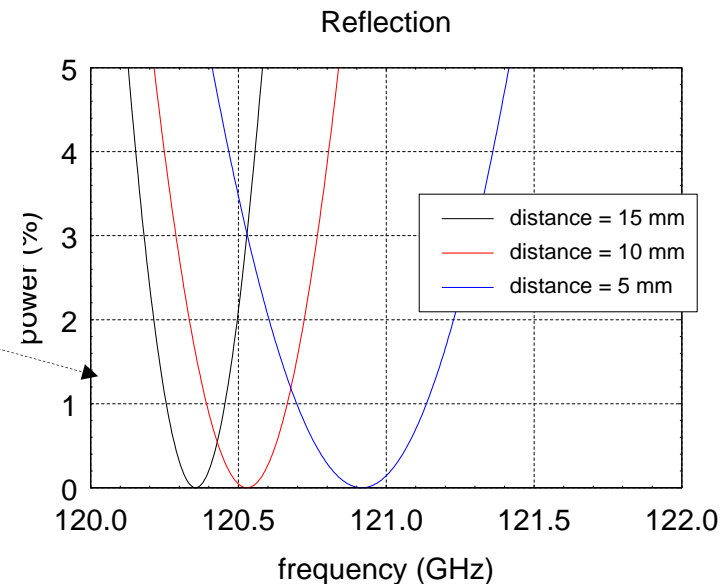


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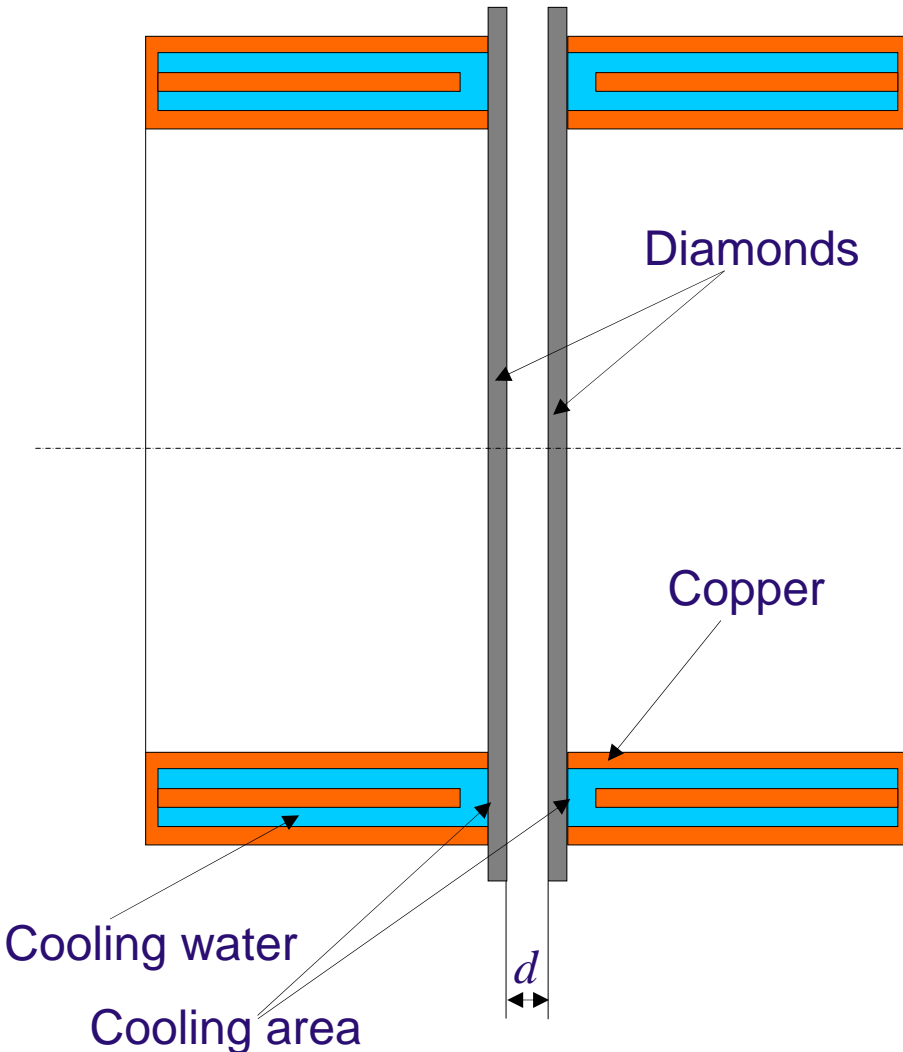
Reflection, $d_1=d_2= 1.797$ mm



- minimum Window reflection required
- Fabry-Perot resonances must be broad enough to include the frequency drift of the gyrotron
- **maximum allowed distance** between discs

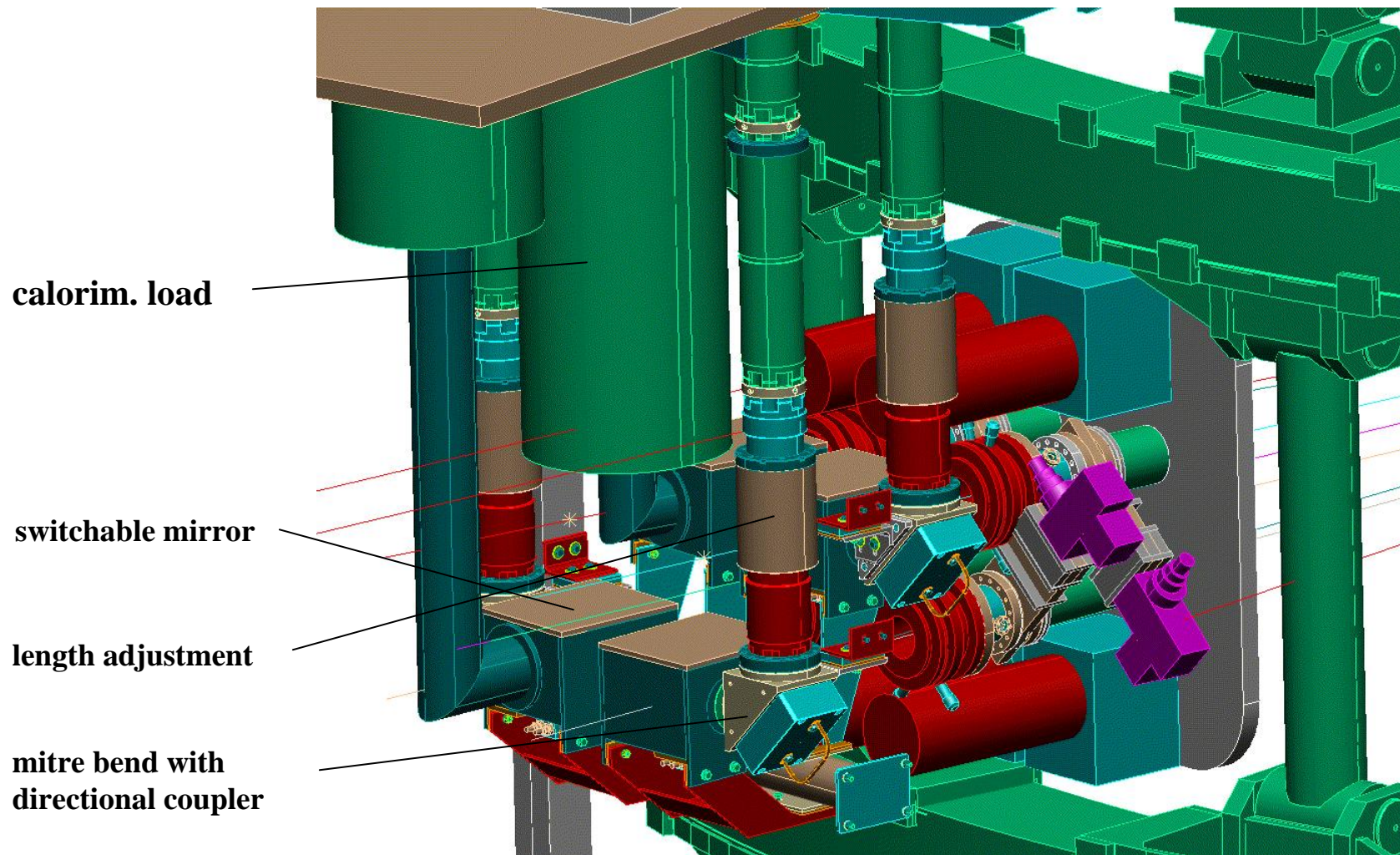


New concept: *direct* cooling of *one* side of the disk



- Effective cooling area is big
- Distance d between diamond disks could be sufficiently reduced

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Time planning

2003 **new launchers installed into the torus**

main parts of the transmission line mounted

2004 **first set of two modulators installed and tested**

2004 **delivery and commissioning of 2 - f - gyrotron**

+ 1 month calibrations

delivery and commissioning of step tunable gyrotron

+ 2 months calibrations