Summary on Technology

W. Kasparek, IPF Stuttgart

- Gyrotrons (6)
- Transmission lines and components (6)
- Vacuum windows (2)
- ITER Launchers (1)
- New ECRH systems (7)
- Discussion of future requirements

Gyrotrons: G. Denisov, 170 GHz in Russia

- **Present status: 0.65 MW / 800 s, 1.05 MW / 200 s**
  Low frequency drift, up to 60 % efficiency
  limit due to isolator,…window failure

- **New test stand 80 kV, 50 A**
  ➔ 1 MW 1000s planned this year

- **Work on higher power . $TE_{21,12}$**
  ➔ 2 MW short-pulse measured
  ➔ 1.5 MW CW design

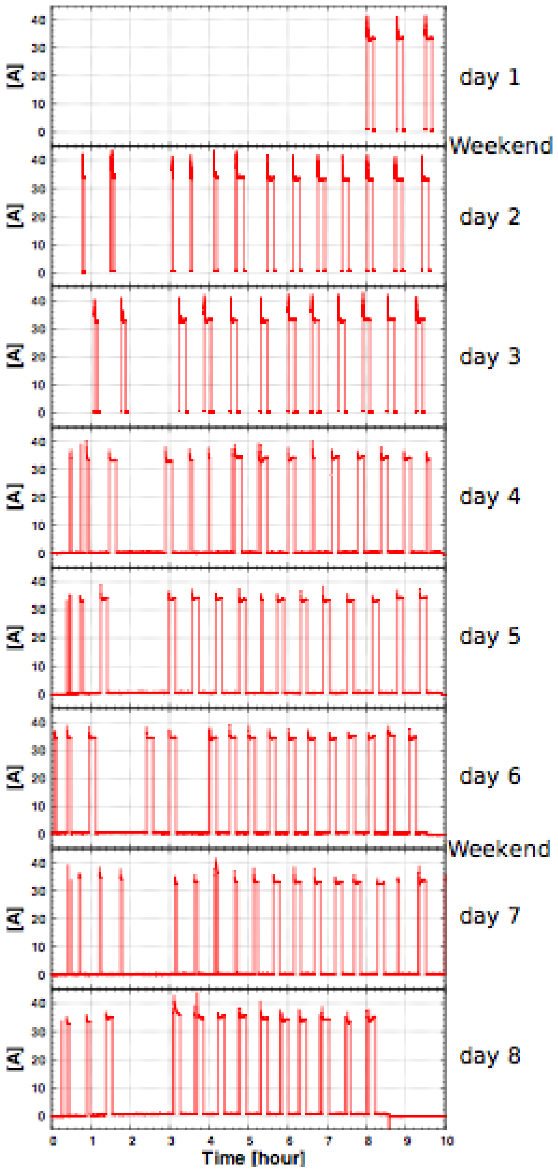
- **Multifrequency gyrotrons**: 1 MW at 50 …60 % efficiency,
  problems with windows

„ design and reliability is still and issue“

Gyrotrons: K. Sakamoto, Developments at JAEA

- **Reliability test** of 170 GHz / 1MW tube at 800 kW:
  72 o.k. out of 88 ➔ recover technology!
- **Modulation experiments** up to 5 kHz BPS + APS / APS only
  strongly reduced collector loss, increased power
- **Dual-frequency gyrotron** 170 GHz / 137 GHz, 1.5 MW design
  Short-pulse: > 1 MW, high-quality, similar beams
- 110 GHz / 1.5 MW gyrotron for JT-60 SA under test

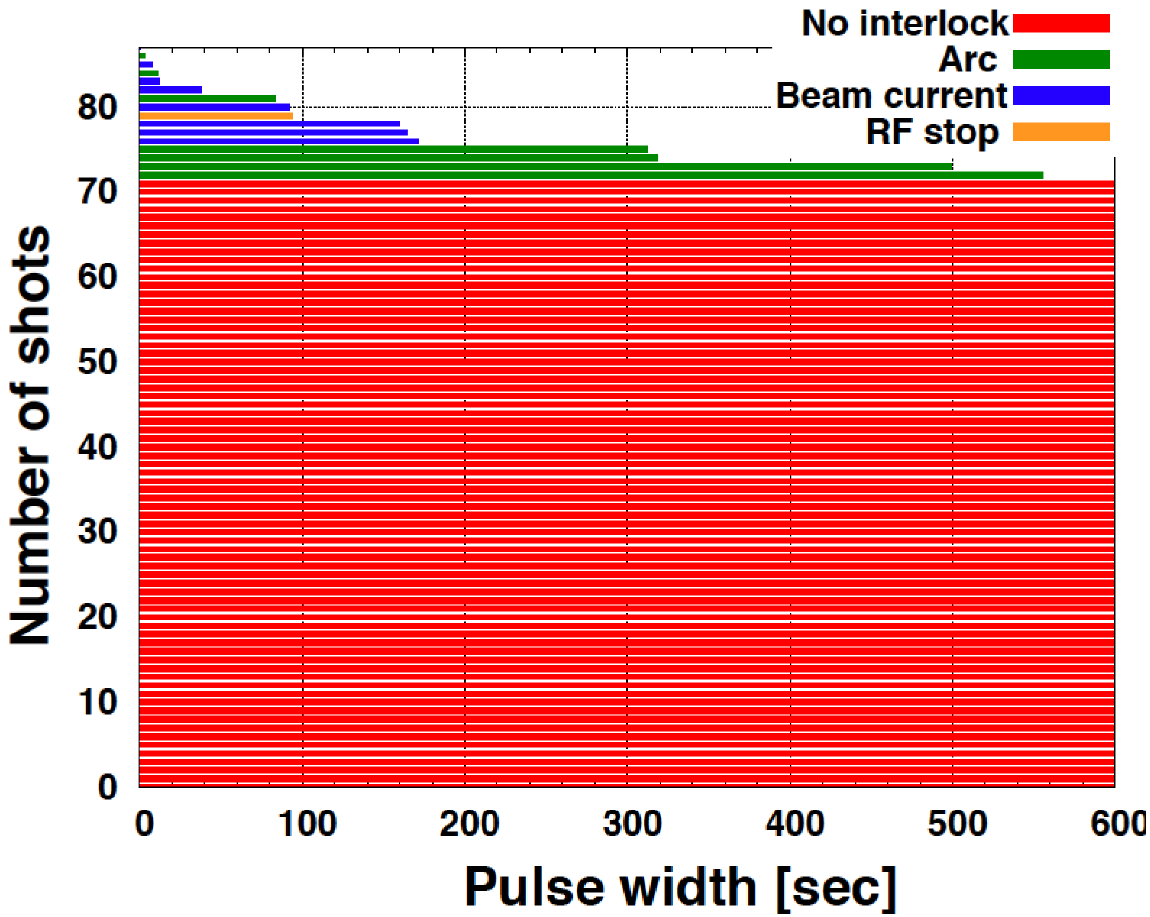
Gyrotrons



Repetitive Operation to determine reliability

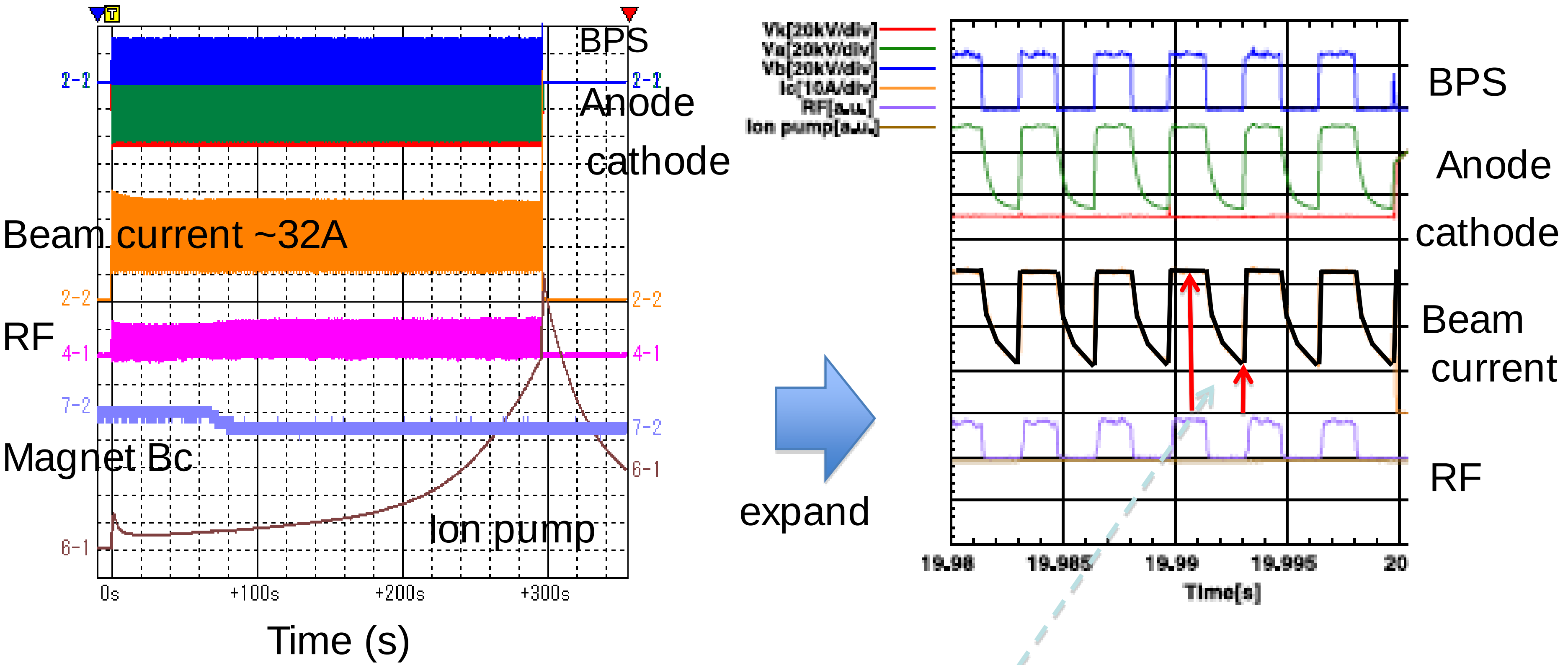
800kW/600s/every 30min/8 days

600 sec: 72 shots out of 88shots.



Gyrotrons

Long pulse Operation with 300Hz modulation



Demonstrated:

Power ~770 kW, Efficiency~50 %,
Modulation=300 Hz / Duty=46 %,
Pulse length demonstrated =5 min.

5 kHz modulation
with gun anode modulation only
Peak power 1.2 MW

Beam current→1/3 at no-oscillation phase

170 GHz Coax Gyrotron: F. Albajar, G. Gantenbein, J. Jin

- **EU: 170 GHz Coax gyrotron for ITER, Design 2 MW**
- Test of first prototype:

  ➔1.4 MW max., ➔voltages stand-off problems ➔ parasitic oscillations

- Refurbishment of tube: New beam tunnel, new q.o. converter, …..

- Test in KIT with pre-prototype tube and corrugated beam tunnel:

  ➔P = 2.2 MW short-pulse

- novel numerical method for the synthesis of launchers

  ➔ FGMC of 96.3% at the launcher aperture (10% improved)
- New synthesis of phase correcting mirrors

  ➔FGMC of 99.1% in the window plane (SURF3D-proved)

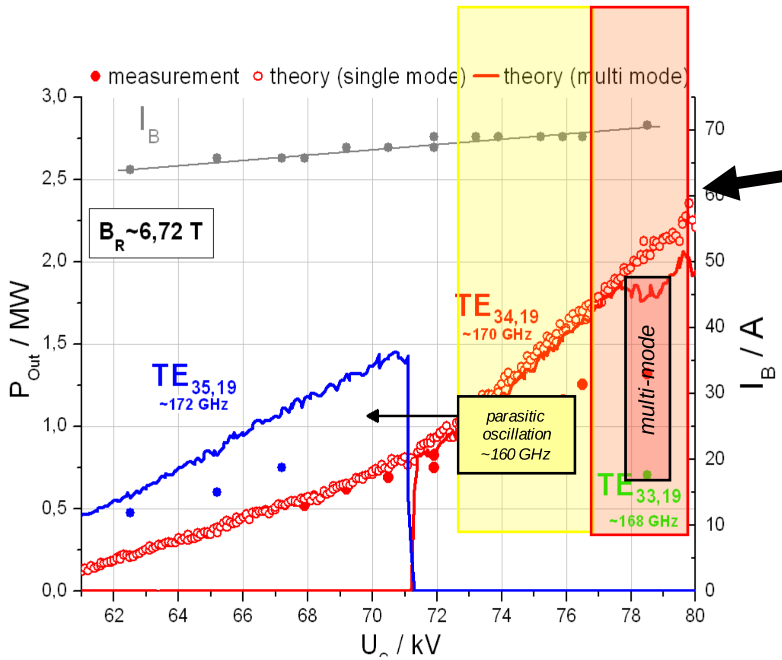
- Good prospects for refurbished tube, nevertheless:

  ➔ Plan B: conventional tube 1 MW

  ➔Risks? Time for decision coax – conv.?

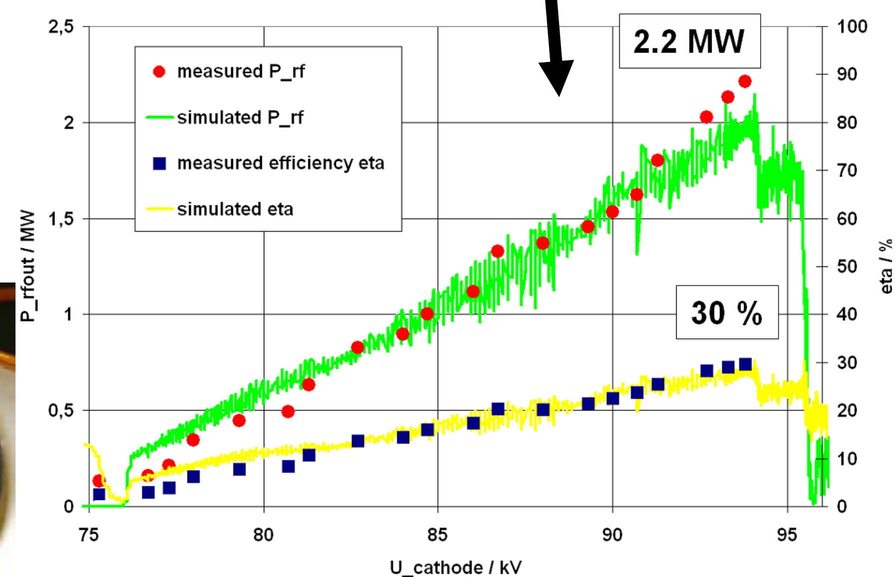
Progress in Stable Operation of High Power Gyrotrons G. Gantenbein

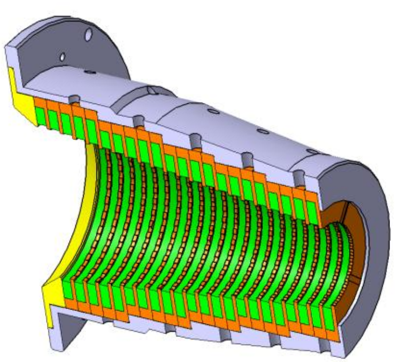
Experimental Results with the Coaxial Cavity Gyrotron (ITER Pre-Prototype)

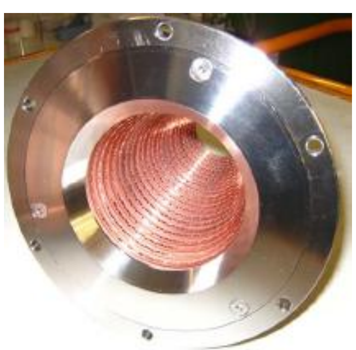


Operation with traditional beam tunnel

Operation with improved beam tunnel (and additional n.c. coil to achieve full specified mag. field):







95 GHz / 2 MW Gyrotron: S. Cauffman

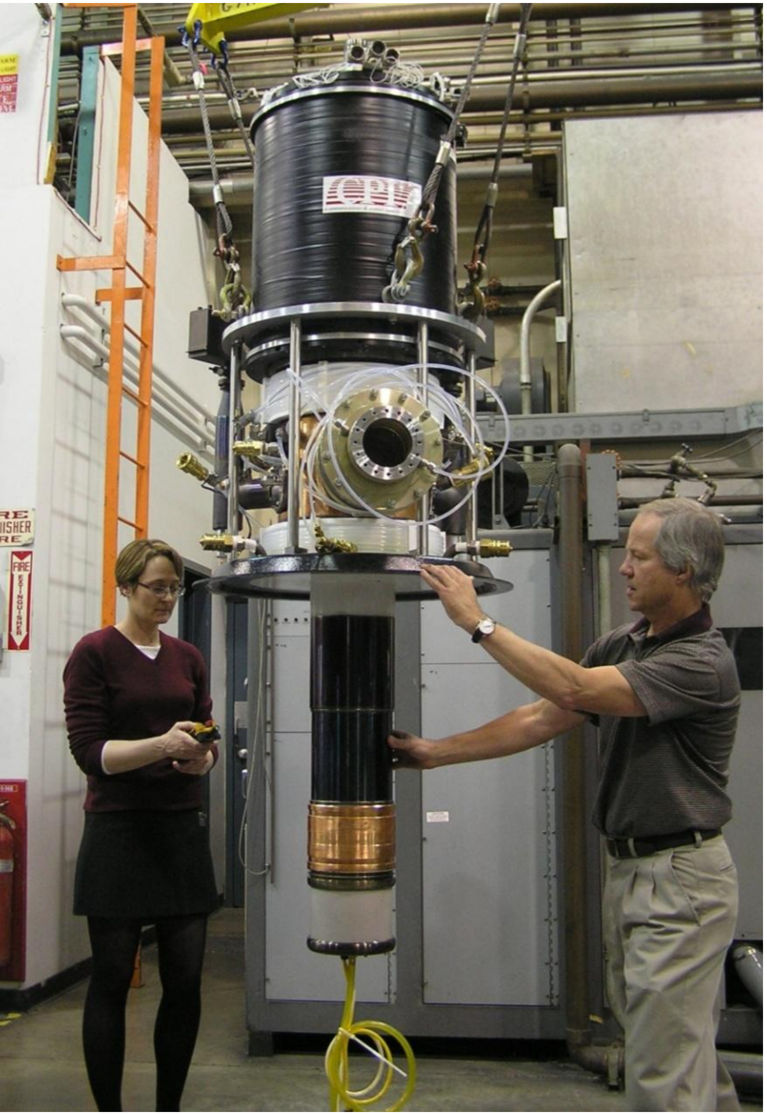
- TE22,6 gyrotron, 95 GHz, 2 MW for US. Airforce
  Goal: 55 % eff., 2 MW, weight 1.5 tons
  ➔ Lightweight design, e.g. thin collector from Glidcop

- Results:
  1. up to 1.4 MW, at 75 A, eff. = 32 %
  ➔ Parasitic oscillations in beamtunnel (cf. Coax);

  ➔ absorbers improved
  2. up to 1.4 MW, at 45 A, eff. = 51 % ….o.k.
     up to 1.7 MW, at 75 A, eff. = 33 %…..enhanced beam tunnel loss

- Further improvement of beam tunnel…..

Status of CPI 95 GHz 2 MW Gyrotron



- Testing so far has demonstrated:
  - P_{out} = 620 KW, 41% eff, 15 s, at I_b=25A
  - P_{out} = 1.40 MW, 51% eff, 5 ms, at I_b=45A ($P_{bt/cav}$=2%)
  - P_{out} = 1.72 MW, 33% eff, 5 ms, at I_b=75A ($P_{bt/cav}$=11%)
- Beam tunnel modifications have increased the threshold for onset of BT oscillation, excess BT heating, and efficiency degradation from I_b=30A to I_b=46A
- Efforts to further suppress BT oscillations at higher beam currents are underway.

Public release approval: DOD/OSR 08-S-2190. DOD/OSR 10-S-0083
Work supported by AFRL's Directed Energy Directorate under contract number FA9451-04-C-0298.

Gyrotrons

Gyrotrons have reached high power levels, however:

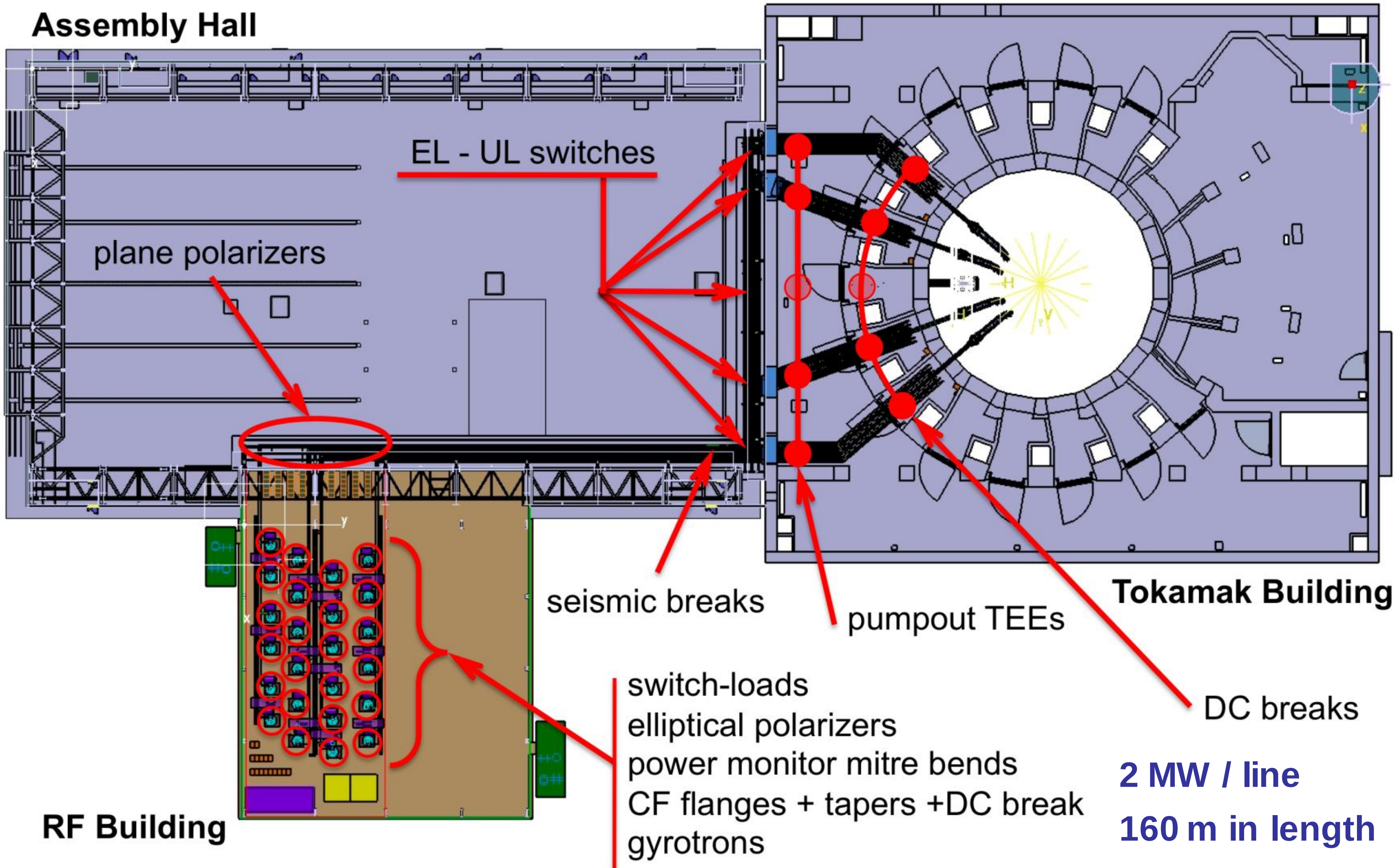
do we already have the reliable 1 MW /1000s gyrotron?

- ➔ Reliability tests…..800 kW
- ➔ Designs of 1.5 MW………..safe operation at > 1 MW level
- ➔ Coax gyrotron …..too late?

ITER ECRH system, M.Henderson, F. Gandini

- Administration, time schedule, in-kind purchasing….
- Broad range of EC applications, overlap of EL and UL
  ……….X2 mode operation at half field, X3 ?
  ……….increase of currend drive at mid-radius?
  127GHz start-up tubes exchanged by170 GHz
- System design still ongoing,
  Space problems in RF hall (24 / 26 tubes)
  Launcher concept. design essentially frozen
  Optimization of components……mode purity…hot ideas…
- Flexibility for future power upgrade needed

Generic TL description – 1MW EU sources option

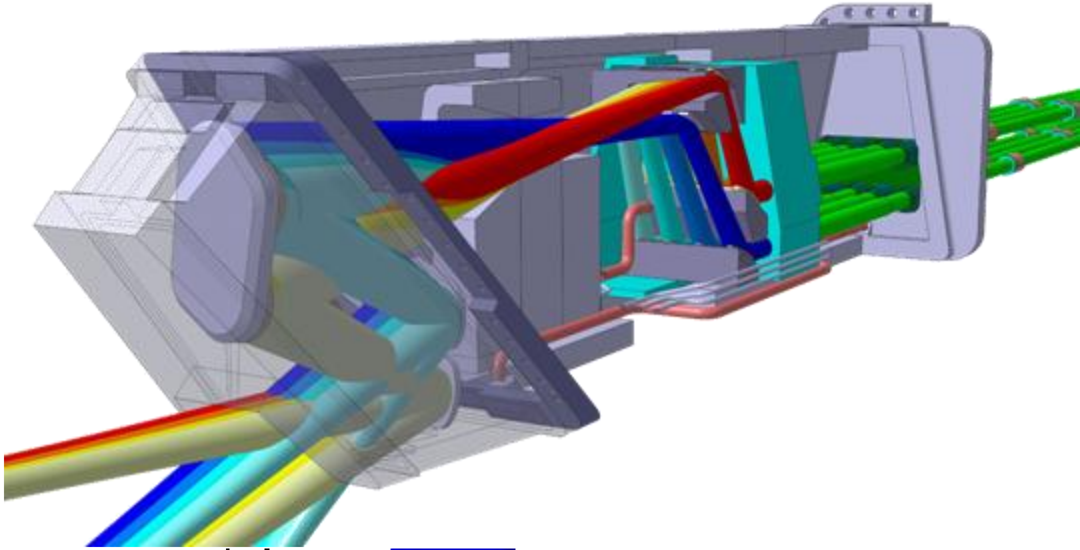


2 MW / line

160 m in length

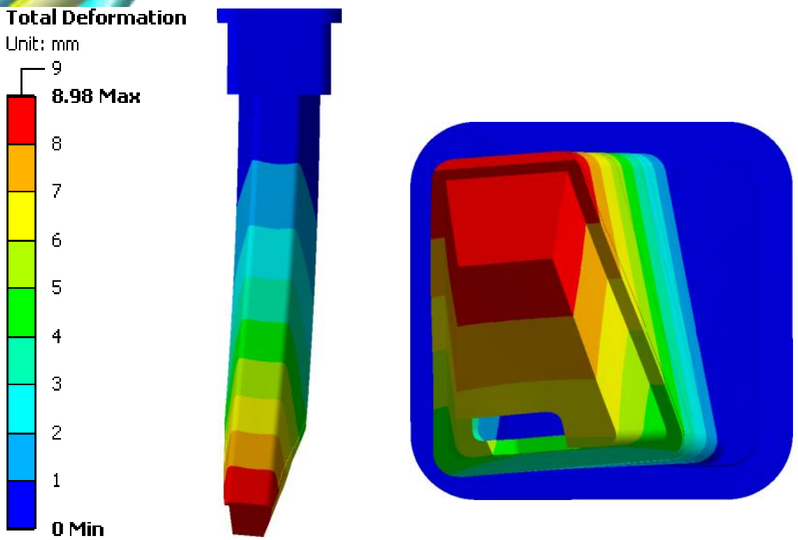
Efficiency ≤ 92%

Deflection of ITER Upper Launcher, D. Strauß,



Optimization results:

- Maximum plug deflection 9.0 mm.
- Maximum port + plug deflection 11.6 mm (< 13 mm required).
- Dynamic amplification low (10 %).



Is 13 mm spacing enough for

- tolerances,

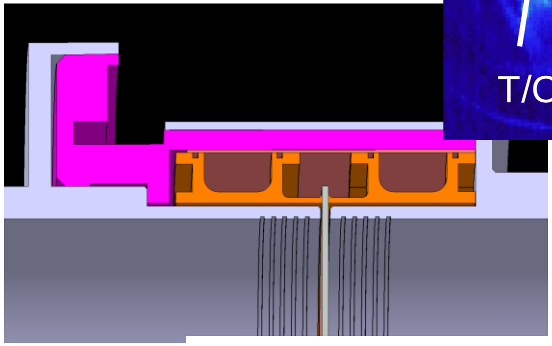
- safe operation,

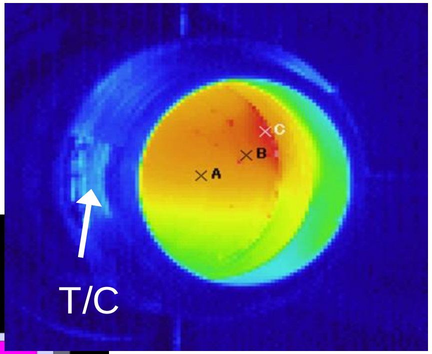
- remote handling ?

Vacuum Barrier Windows, T.Scherer, A. Vaccaro, J. Stober

ITER ECRH torus window upgrades:

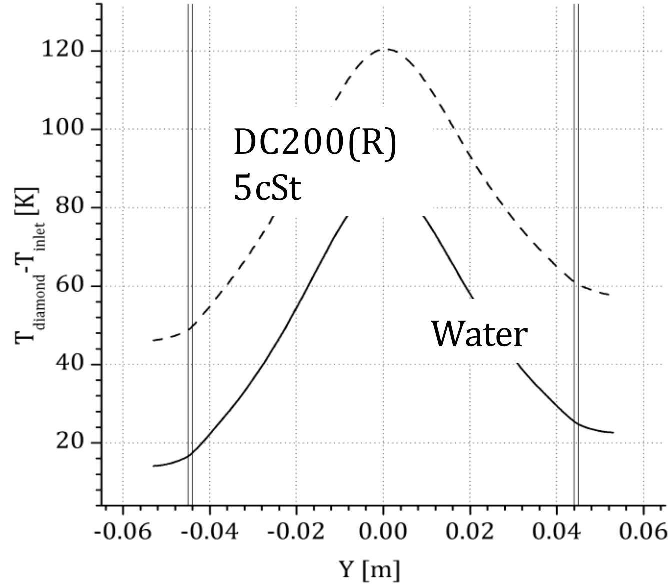
- Corrugated inserts up to diamond disc avoids excessive loss
- Material investigations.
  Goal: remove surface loss
  ➔ bulk loss tanδ = $2 \cdot 10^{-6}$





Brazing in contact with cooling:
➔ Corrosion! (W7-X)

- low viscosity silicone oil is a good alternative to water



Windows for multi-freq. gyrotrons:

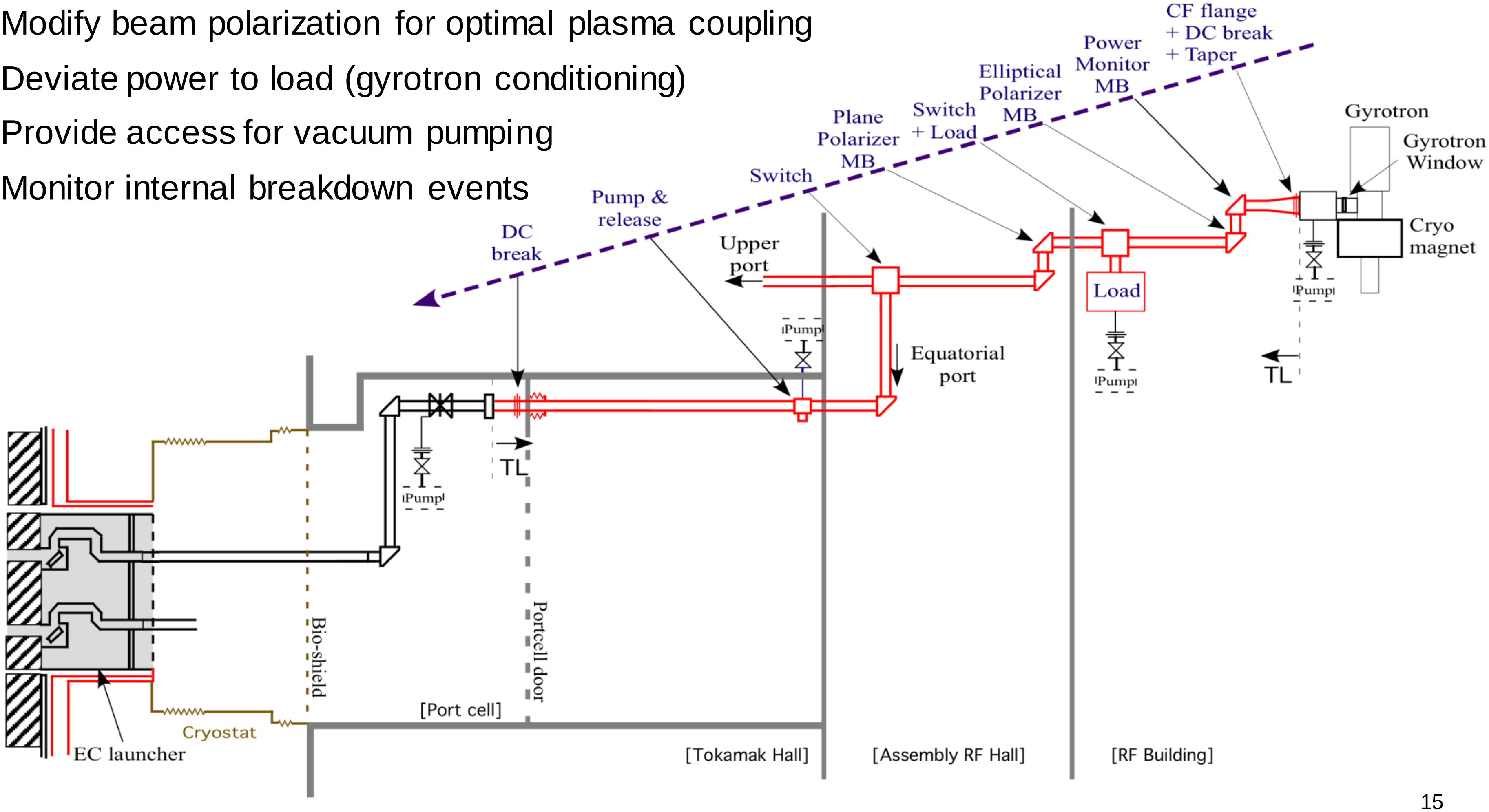
- Double-disc tunable window?
- Single-disc Brewster window?
- Single disc with anti-reflection corrugation?

ITER ECRH System, M. Henderson, F. Gandini

The TL also has the following functions:

- ✓Provide DC isolation at gyrotron and tokamak
- ✓Monitor forward and reflected power
- ✓Modify beam polarization for optimal plasma coupling
- ✓Deviate power to load (gyrotron conditioning)
- ✓Provide access for vacuum pumping
- ✓Monitor internal breakdown events

- ✓ **Rated for 2 MW transmission**
- ✓ **Roughly 160 m in length**
- ✓ **Transmission efficiency ≤ 92%**



ITER Transmission line: Components, R. Olstad, D. Rasmussen

Complete set of components available,1 MW approved (cw?)

Present development issues:

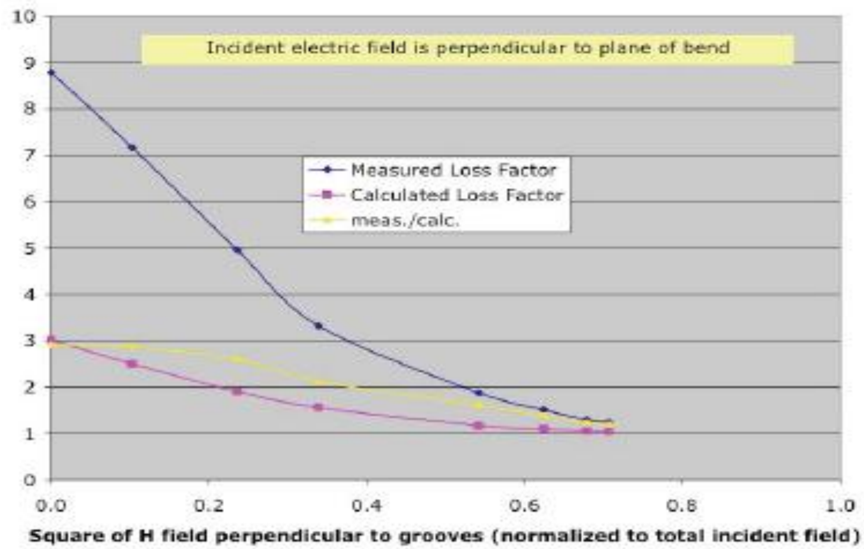
- Design / cooling for 2 MW (polarizers, switch)

  ➔ optimization of groove profile!

- Long (3.5 m) waveguide with helical corrugations (cheaper..)
- **2 MW test facility** foreseen with 170 GHz gyrotron and ring resonator

- Mode analyzer
- Robust directional coupler (…AUG, W7-X)

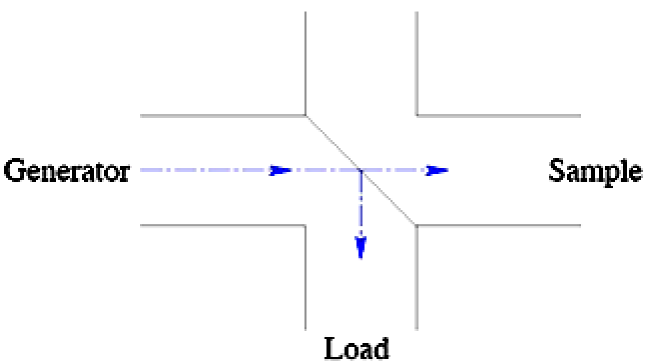
ITER Transmission line: Components, R. Olstad, D. Rasmussen

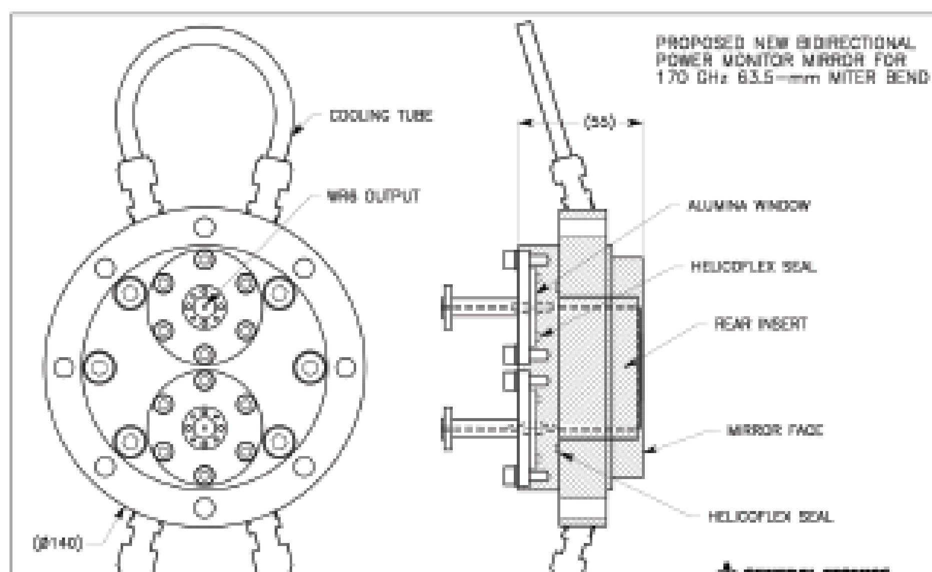


Polarization rotator loss

Extremely high
due to fabrication method
and groove profile?

Mode analyzer



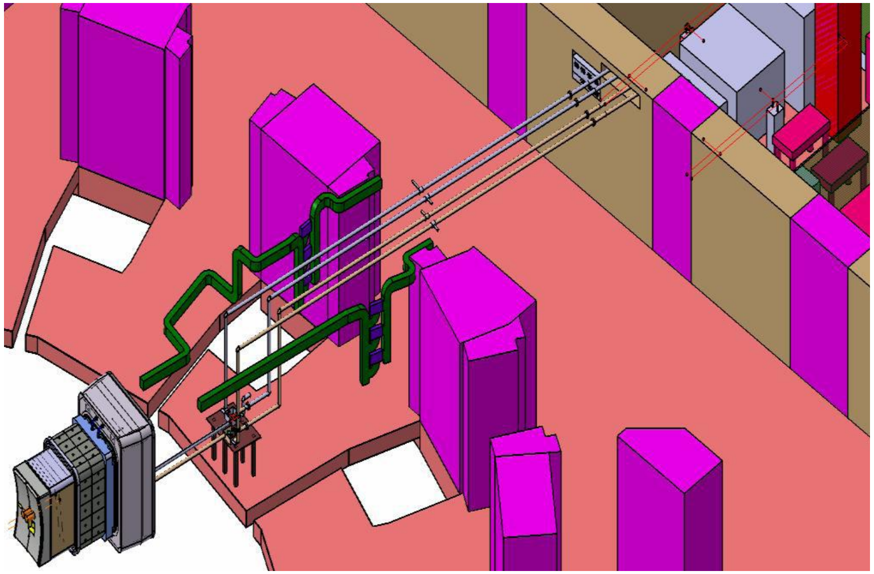


Directional coupler

ITER ECE Transmission components, H. Pandya

Requirements for transmission lines for ITER ECE:

- Bandwidth 70 GHz ………….1000 GHz !!
- Low-loss, stable transmission
- 40 m long, mitre bends, switch,



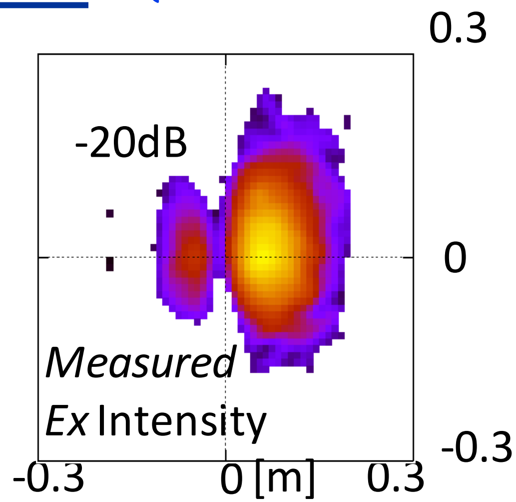
Proposal:

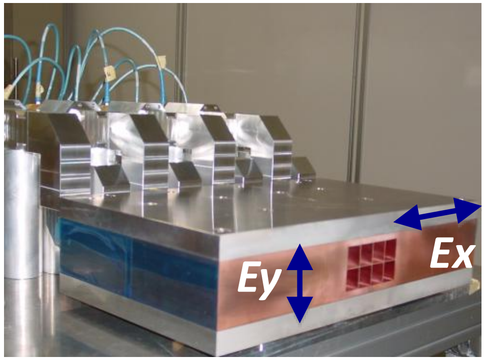
- Windows with grooved anti-reflection layer and corrugation
- HE11 mode for transmission
- corrugated waveguide
  Dm. 63. 5 mm with p = 0.45 mm

Can corrugated waveguide be used above Bragg-limit (ca. 300 MHz)?
Alternatives, like dielectric or dielectrically coated waveguides?

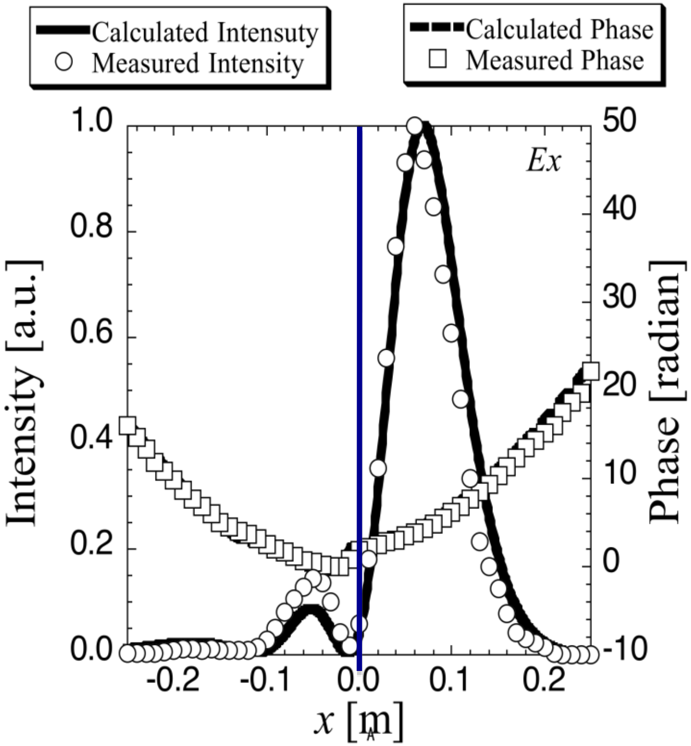
Phased Array Antenna for EBWH/CD on QUEST, H. Idei

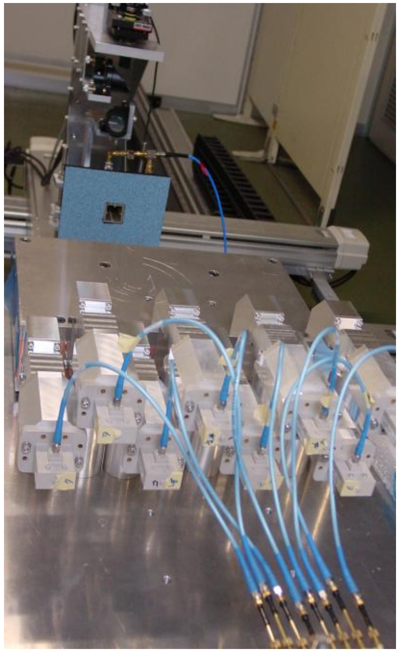
QUEST Advanced Fusion Research Center





- **Phased array antenna 8.2 GHz**, 8 elements, arbitrary polarization, up to 200 kW cw
  ➔ beam steering over large ang. range w/o mechanics
- EBW CD on QUEST of 10 kA with 30 kW shown,
- Application for diagnostics
- For low frequencies, monomode waveguide technology is still useful



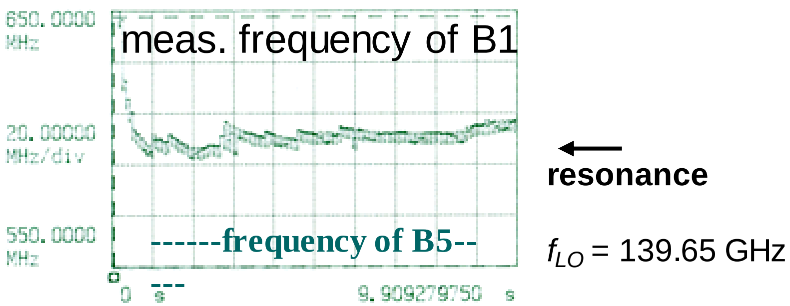


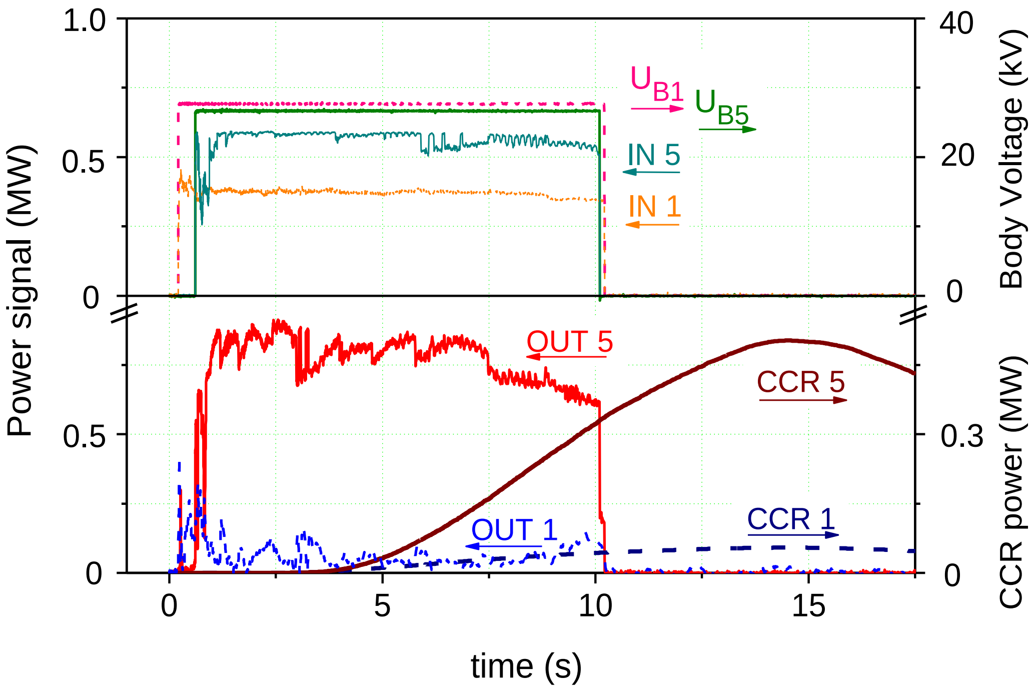
High-power diplexers, W. Kasparek

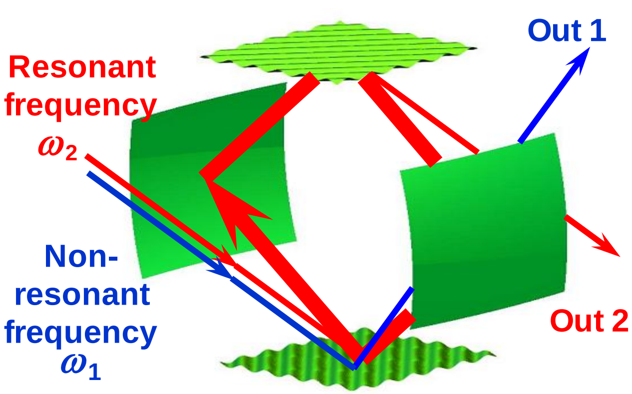
proof-of-principle of
power combination,
fast and slow switching
in high-power experiment

Frequency stability of the gyrotrons ?

Option for reliable component in an ECRH system?







New systems: ECRH for KSTAR, M.Joung, T. Seo

Commissioning and operation of 110 GHz system in KSTAR

- Fast installation (Gycom) of loaned (D III-D) 110 GHz gyrotron
- Efficient MOU
- 250 kW injected, showing X2 and O2 preionization, optimized with gas-puffing

2.8-MVA Power supply system for KSTAR ECH:

- Main power supply 80 kV 25 A

  IGBT-Inverter / Transformer+rectifier / Filterdeck /

  HV switch +crowbar / snubber / gyrotron
- Body power supply

  HV DC supply with IGBT modulator

New systems: Feasibility of an ECRH system for JET

C. Sozzi, M. Lennholm, Garaviglia, H. Braune (G.Giruzzi, D. Farina, S. Novak…. ECRH Exp.)

Key technological issues:

- **12 tubes , 170 GHz, 1 MW, 20 s**
- Ready for operation in 2015 !!!

- **Power supplies:**

  8 refurbished power supplies (4 x 180 kV ➔ 8 x 90 kV)

  4 new Pulse step modulators

- **Transmission system** mostly similar to ITER

  ➔ could act as kind of test facility for ITER transmission system

- **Launcher:** 12 beams have to fit in one port

  Two-axes steering for 2 x 6 beams

  Use of ITER Front-steering unit

- **At present: conceptual design ongoing**

  ➔ Gyrotrons supplied in kind by Russia?

  ➔ early decision is needed to cope with time schedules !

New systems: Feasibility of an ECRH system for JET

C. Sozzi, M. Lennholm, Garaviglia, H. Braune (G.Giruzzi, D. Farina, S. Novak…. ECRH Exp.)

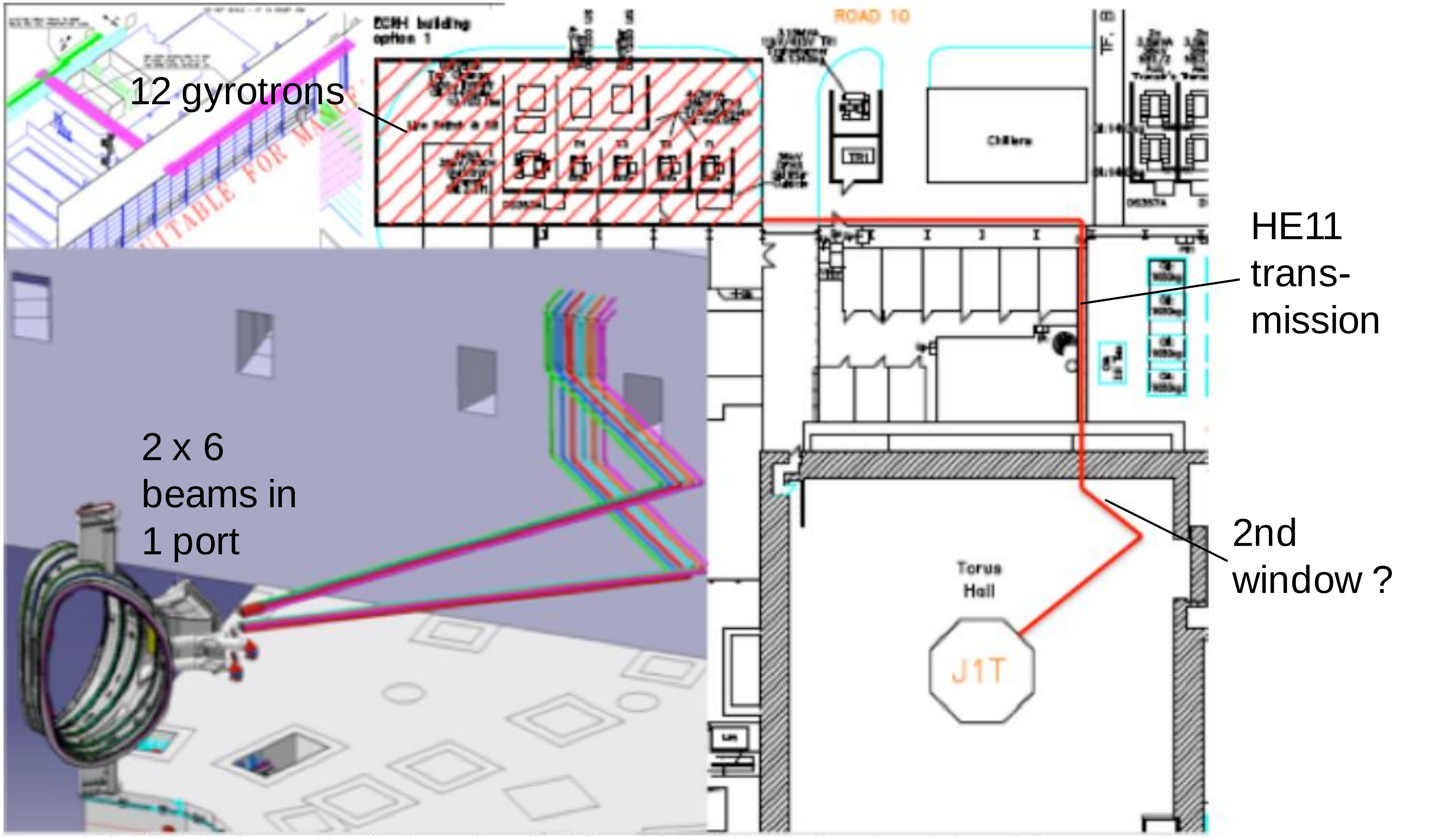
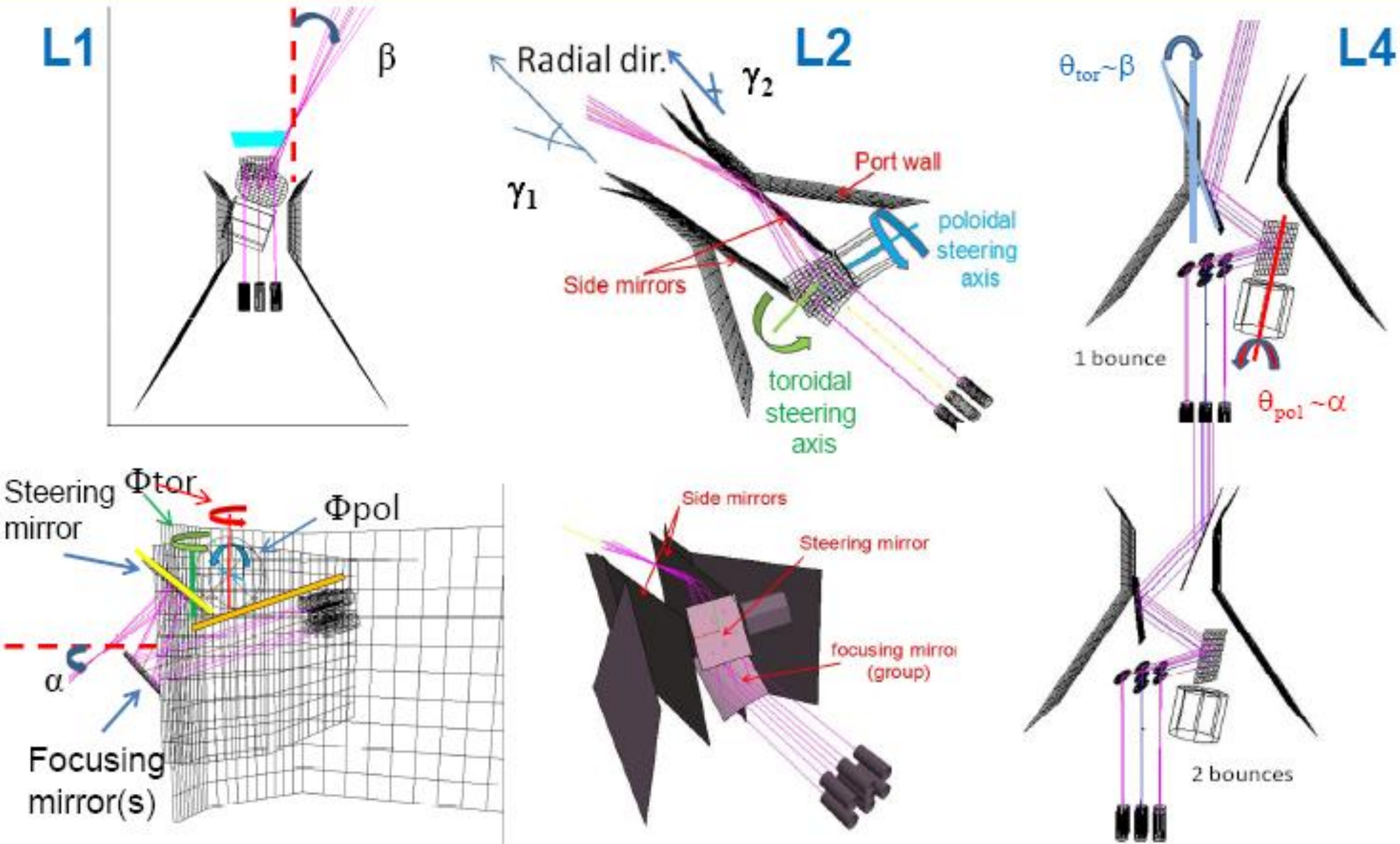


Figure 1.) (Right) The suggested gyrotron building (the shadowed rectangle) and the approximate Transmission Line routing (red line). (Left): the route outside and through the J1H building (up) and the routing in the Torus Hall (down).

New systems: Feasibility of an ECRH system for JET

C. Sozzi, M. Lennholm, Garaviglia, H. Braune (G.Giruzzi, D. Farina, S. Novak…. ECRH Exp.)

Options



Requirements for DEMO, (G. Giruzzi, J. Lohr,) M. Henderson….

Overall efficiency > 50 %
Reliability: lifetime, restart after problem, automated operation

Simplicity!
control issues, overall system design

Supplies:
HV 97 %, but cooling efficiency, other support systems

Gyrotrons:
200 GHz cw efficiency high (multistage CPD?) 2 MW o.k.
Optimism supported by continuous progress
Single frequency?

Transmission:
2 MW, simple, high mode purity, efficient > 92 %!

Launcher :
Hole! (Remote) steering required?