DIFFER
Dutch Institute for
Fundamental Energy Research

High and low power microwaves for the stabilisation of nuclear fusion plasmas

Marco de Baar

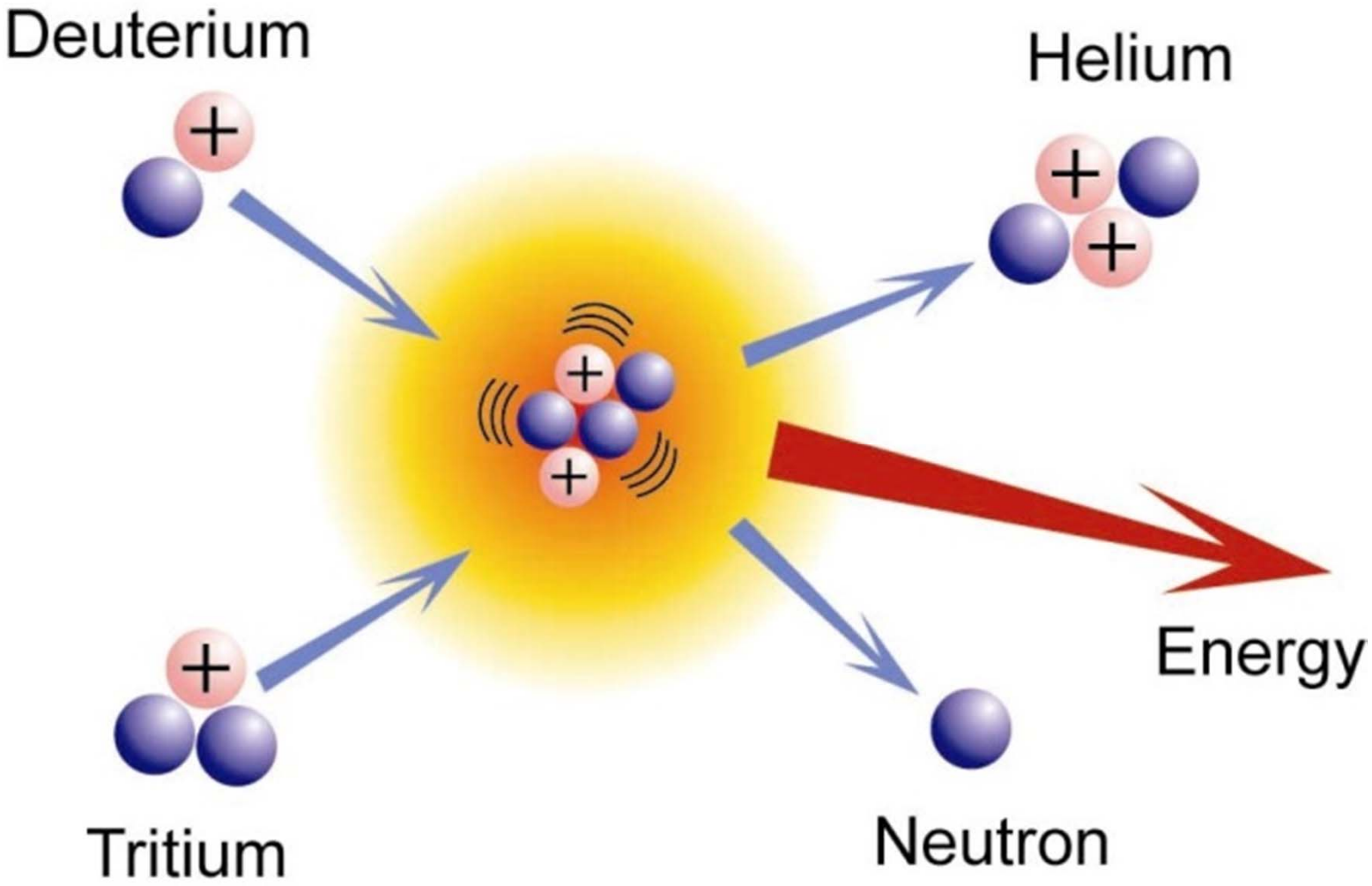
DIFFER is part of FOM and NWO

RF Technology days, Leiden, 2 April 2014

TU/e Technische Universiteit Eindhoven University of Technology

DT Reaction

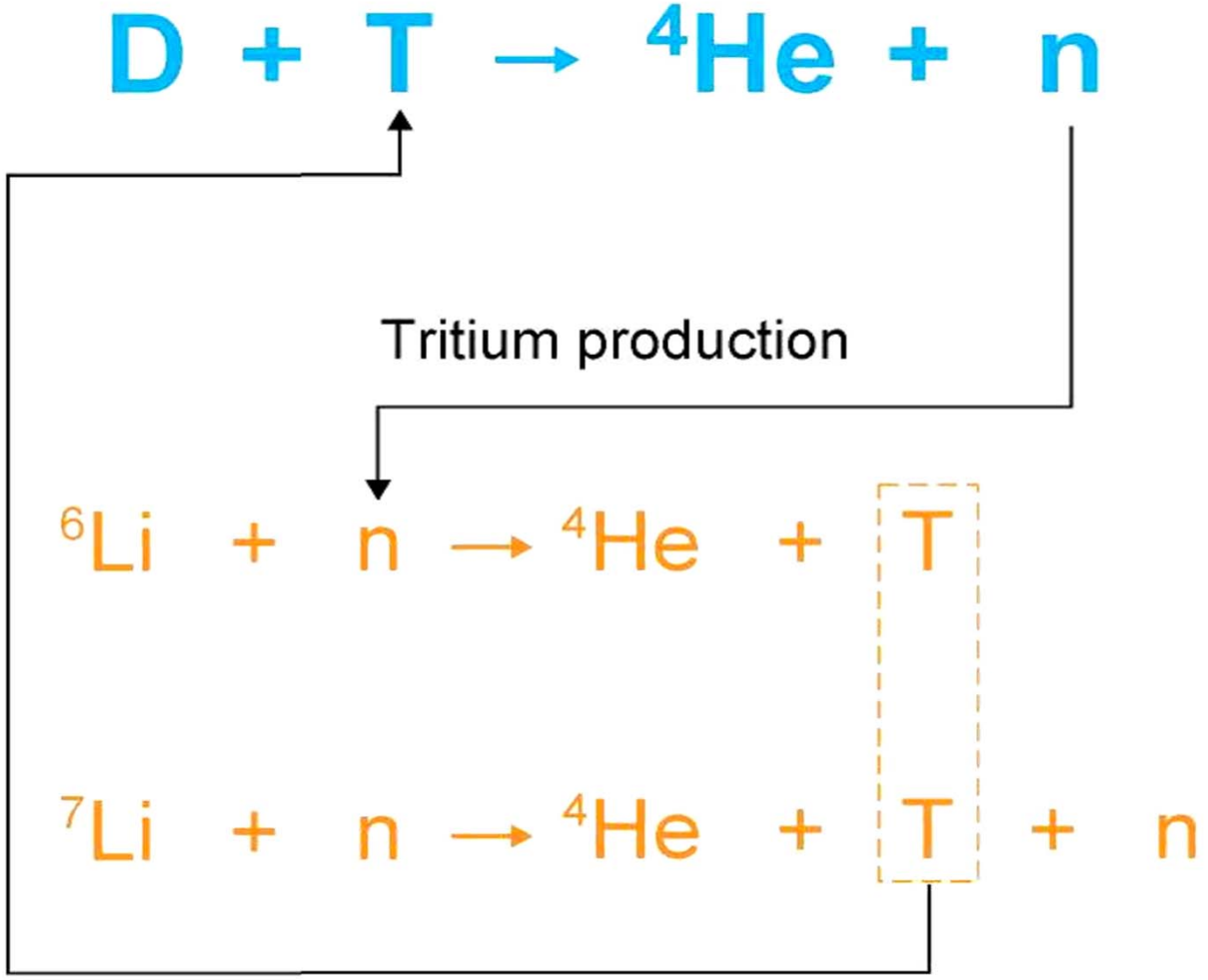
DIFFER
Dutch Institute for
Fundamental Energy Research



TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

Tritium production



TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

Top level requirements

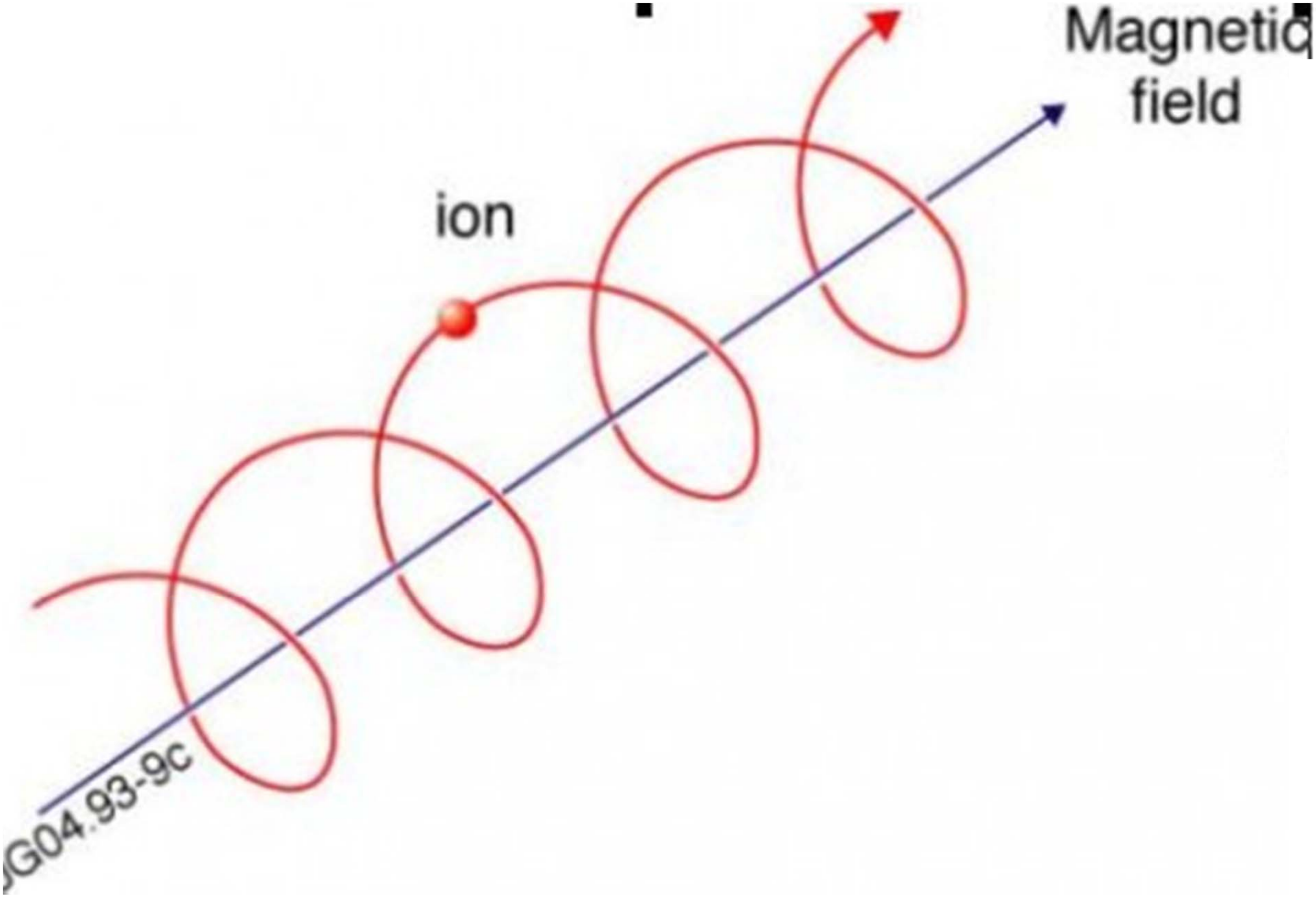
- DT temperature T ~ 200 MK
- High DT density n ~ $10^{20} m^{-3}$
- High energy confinement time τ

Fusion figure of merit: $n\tau T$

TU/e Technische Universiteit Eindhoven University of Technology

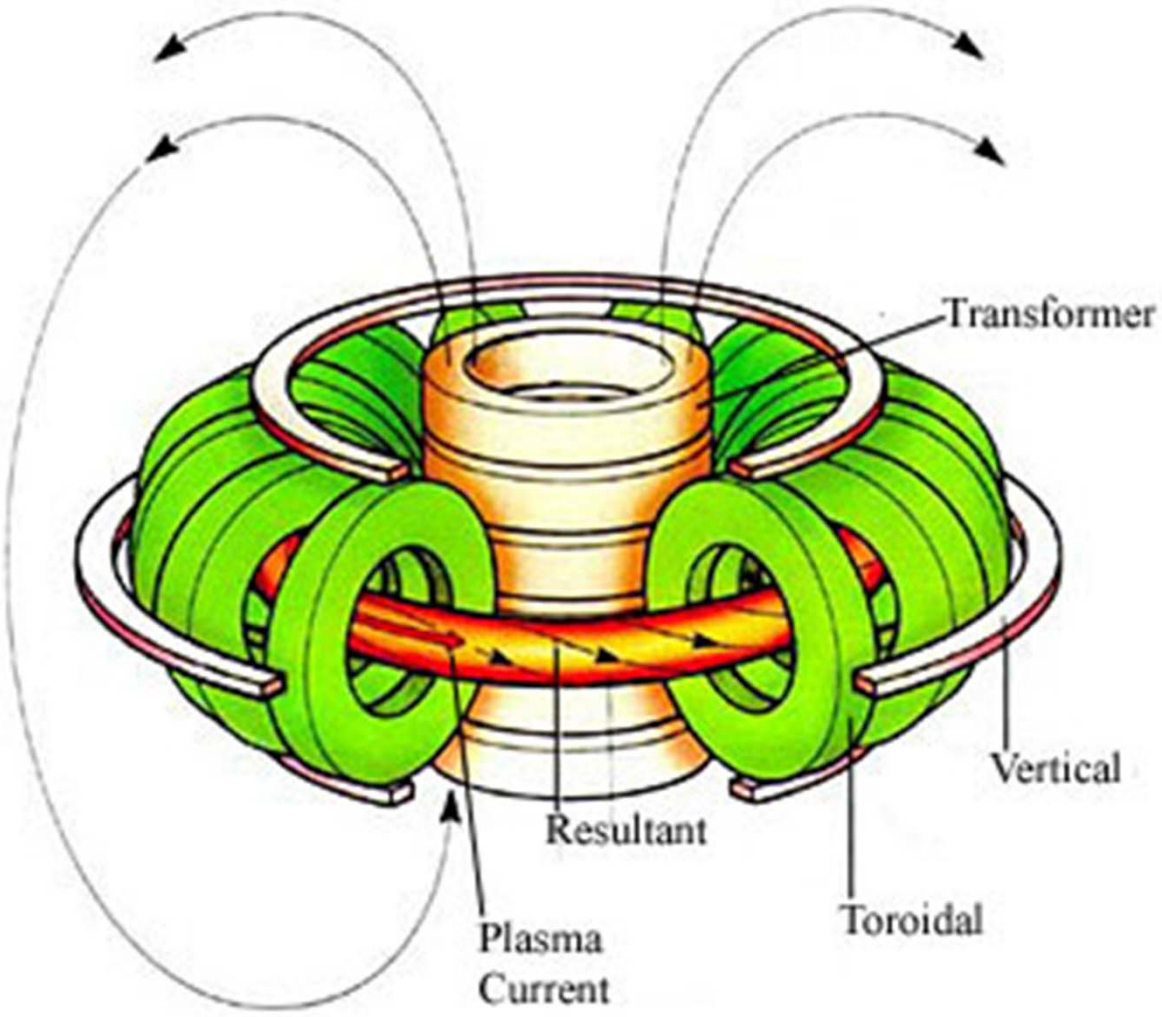
DIFFER
Dutch Institute for
Fundamental Energy Research

Magnetic confinement



DIFFER
Dutch Institute for
Fundamental Energy Research

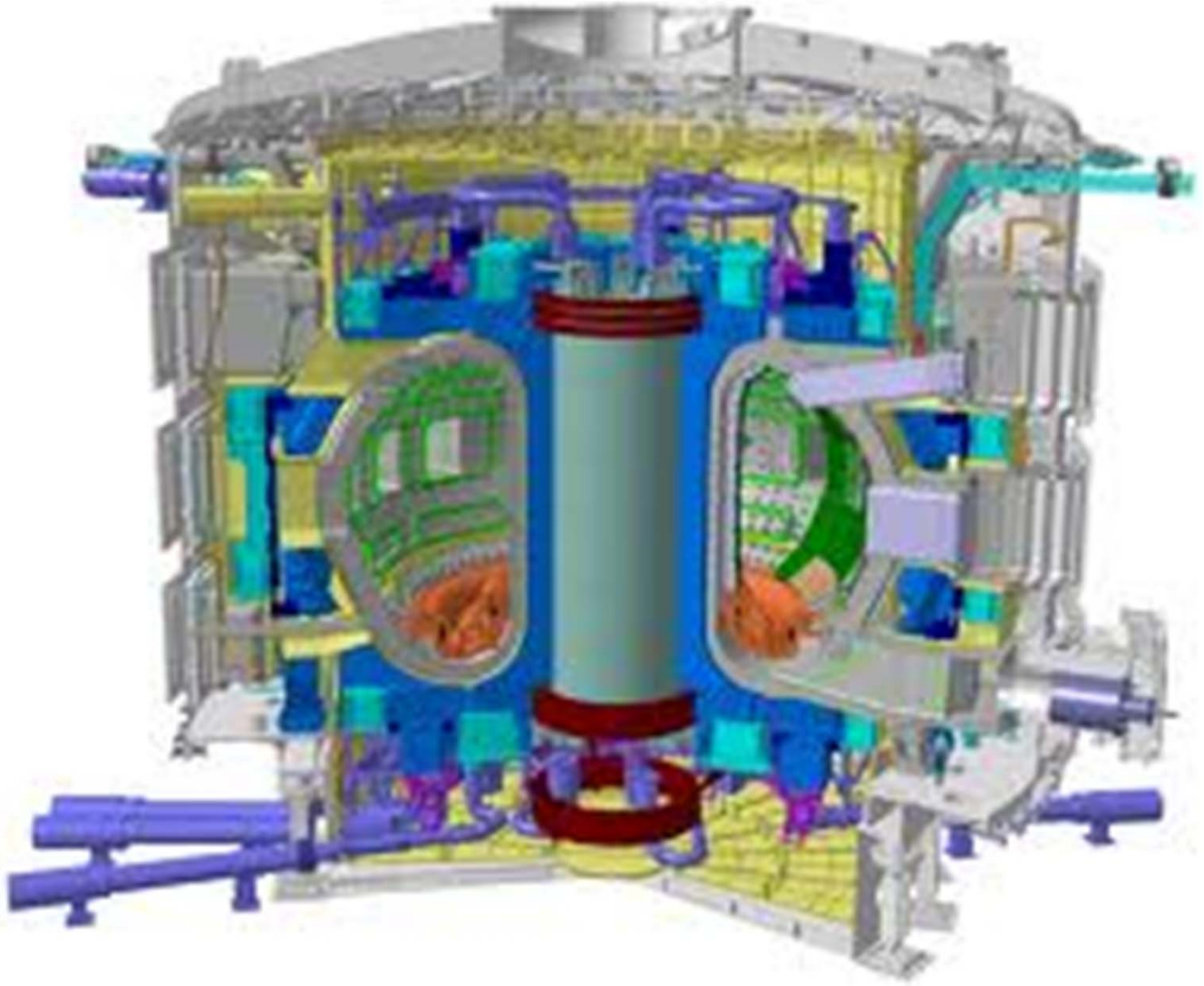
Tokamak concept



TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

Tokamak reactor ITER

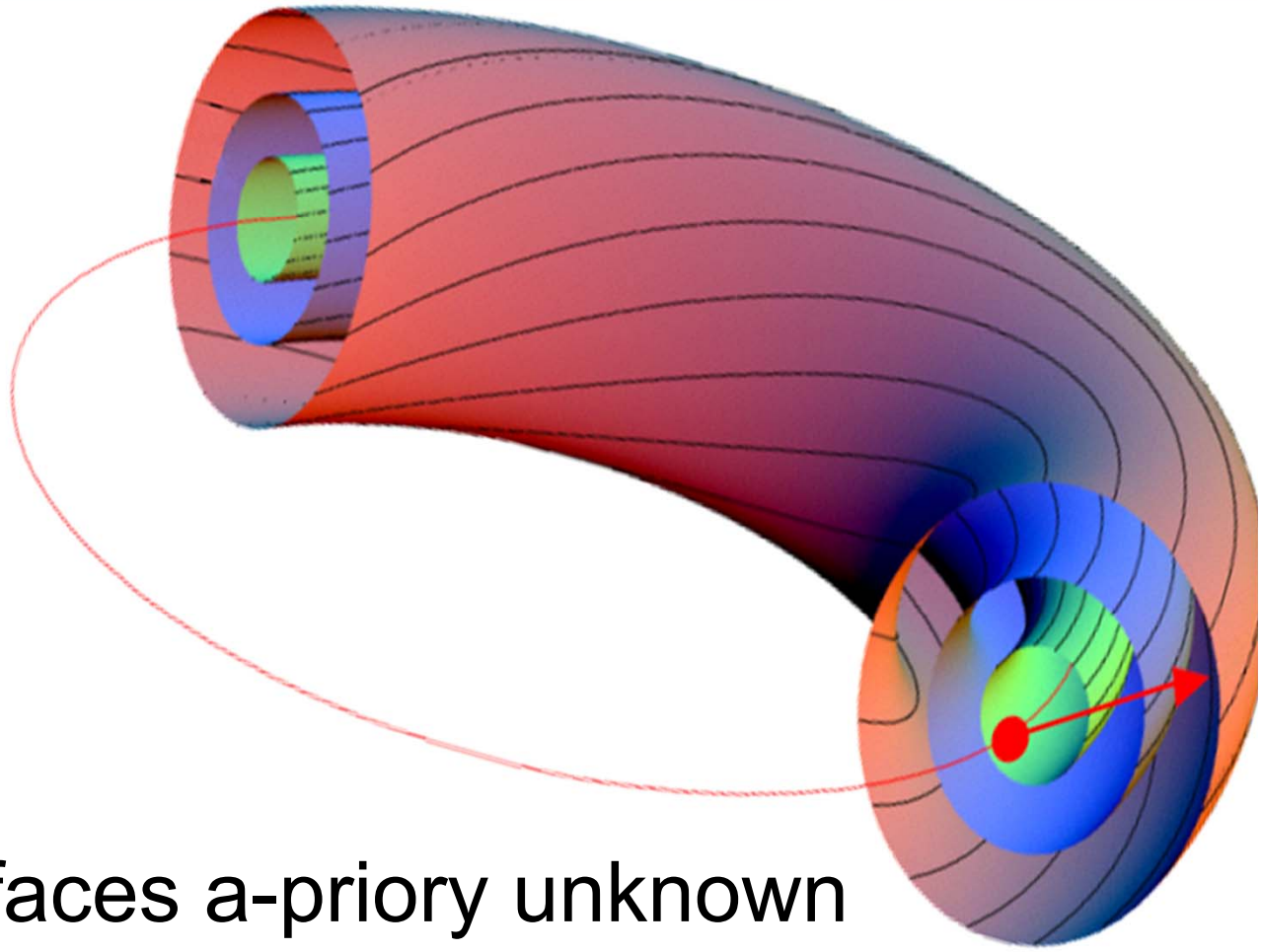


TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

Flux surfaces

- Density and temperature
- Field lines embedded



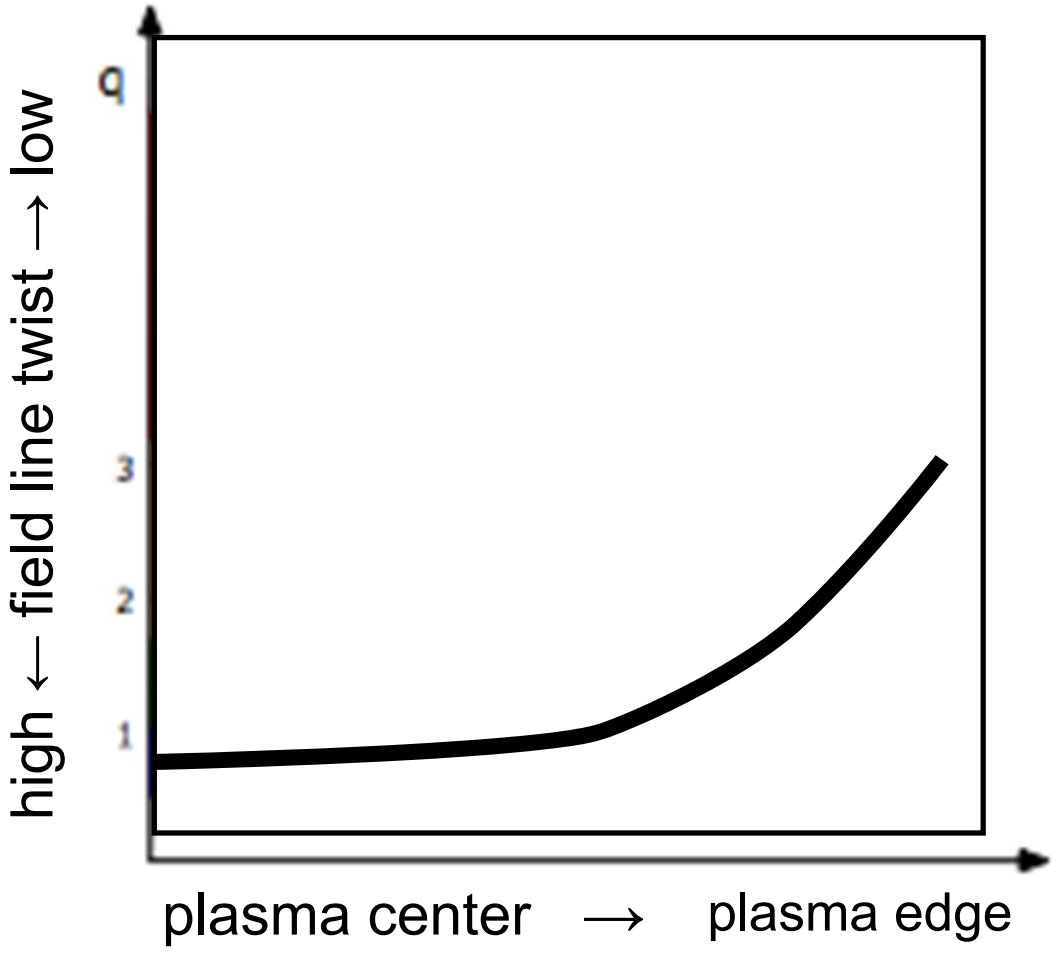
Layout flux surfaces a-priory unknown

- Current distribution in plasma (li)
- Plasma pressure (β)
- Current distribution external coils

TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

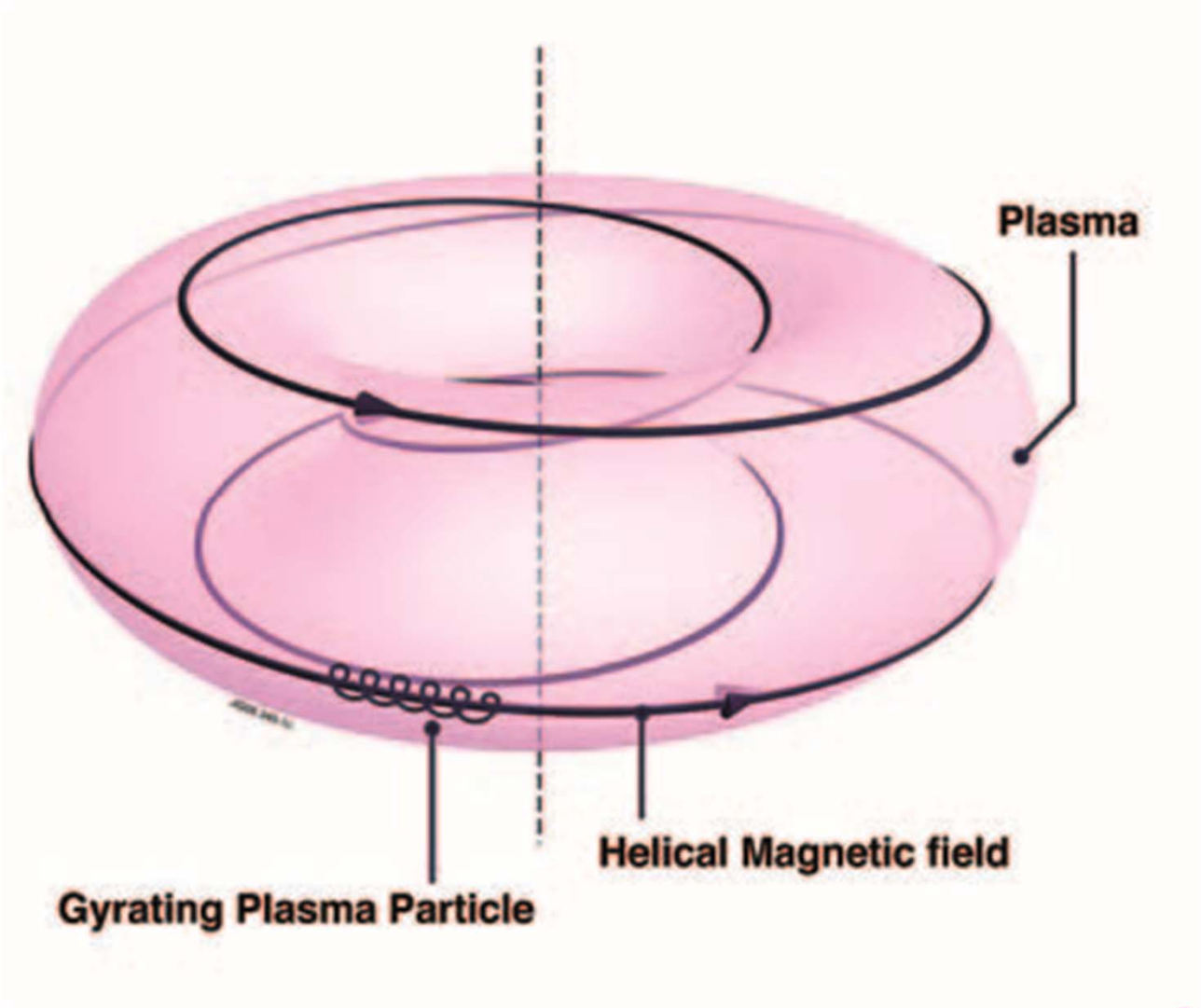
Magnetic winding number q



TU/e Technische Universiteit Eindhoven University of Technology

DIFFER
Dutch Institute for
Fundamental Energy Research

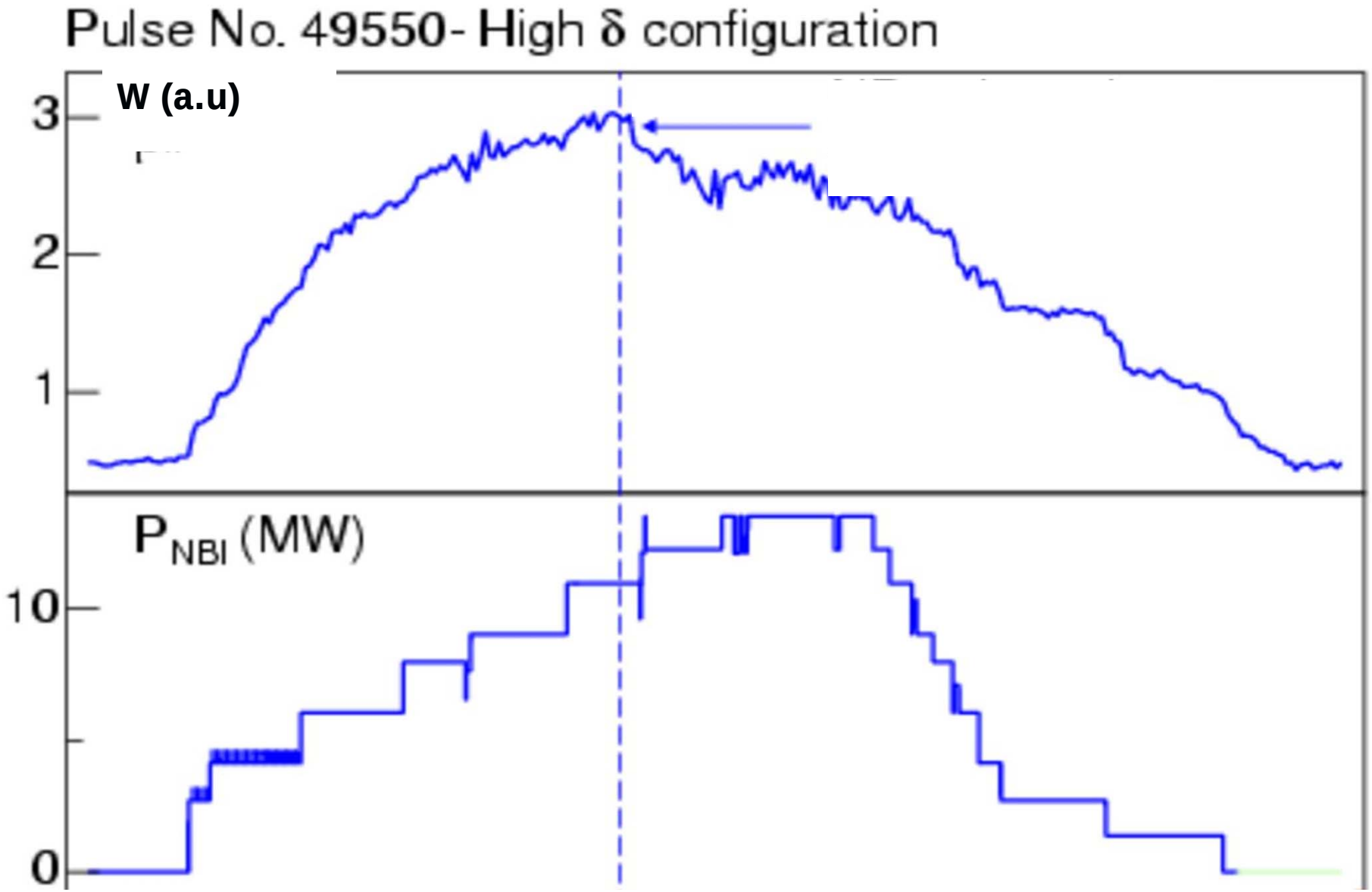
‘Rational’ field lines



TU/e Technische Universiteit Eindhoven University of Technology

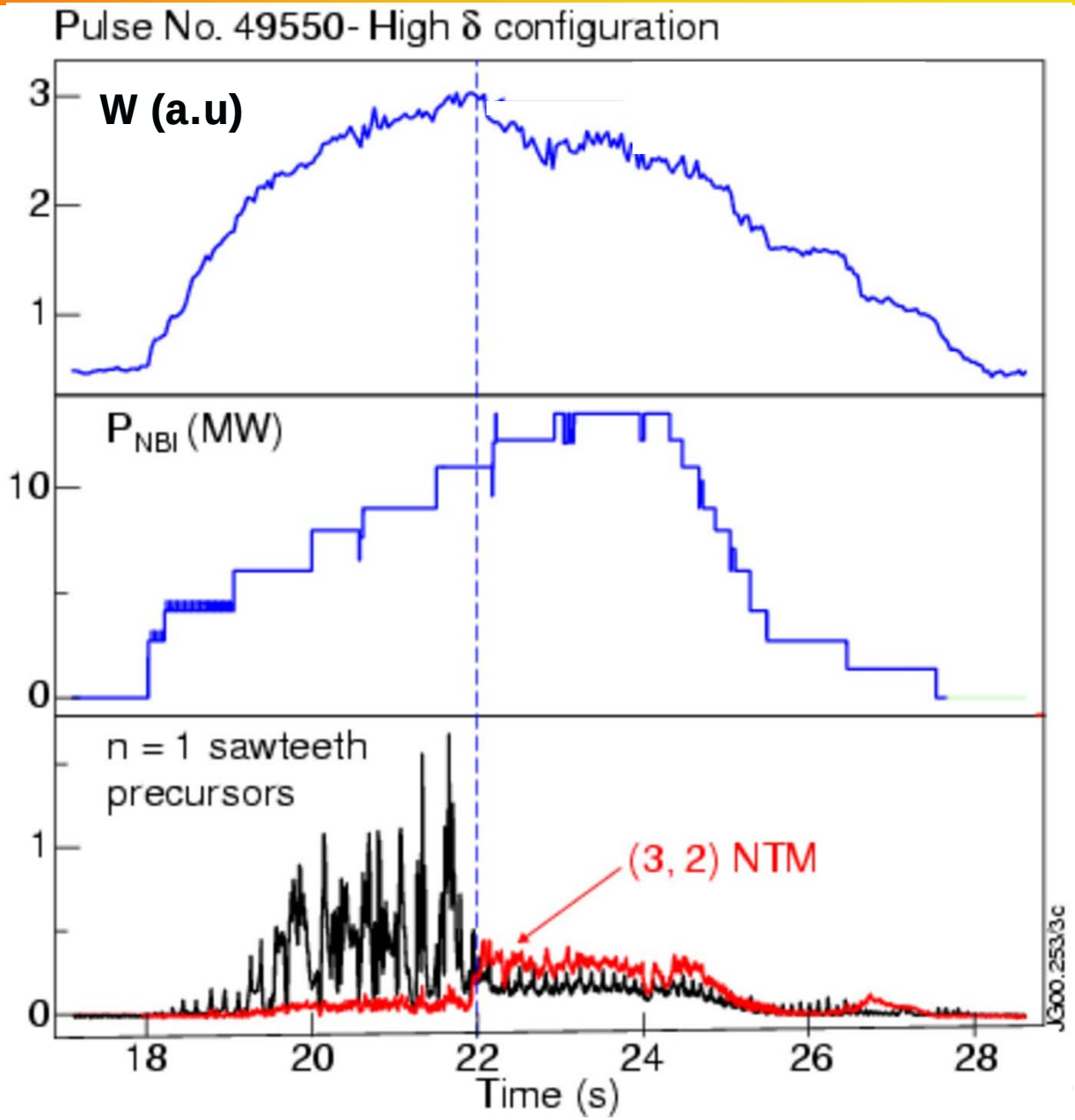
DIFFER
Dutch Institute for
Fundamental Energy Research

High nτT ?



DIFFER
Dutch Institute for
Fundamental Energy Research

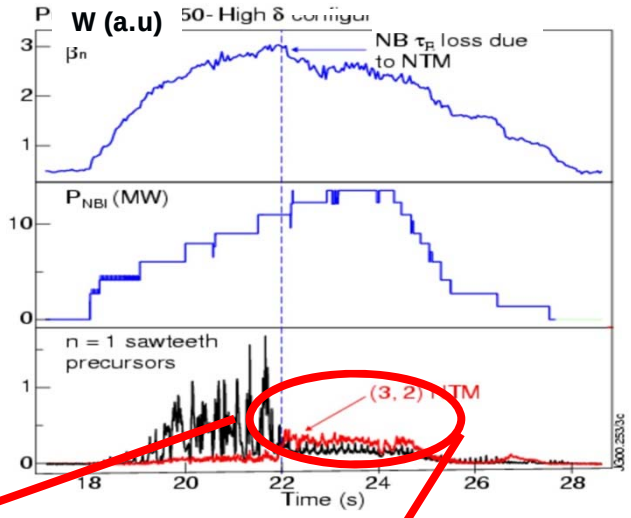
What is the resistive β limit ?

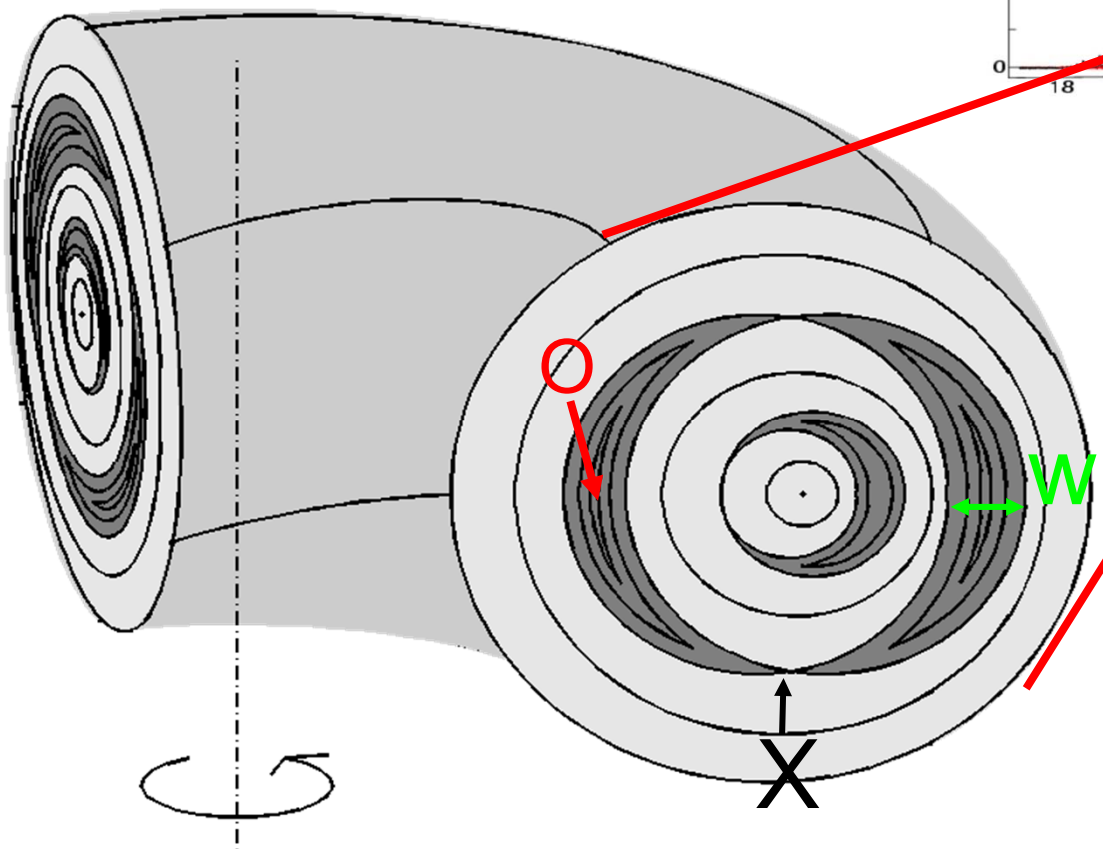


Magnetic islands

DIFFER
Dutch Institute for
Fundamental Energy Research

- Magnetic islands forms
- Plasma performance deteriorates
- Deficiency in current density in O-point

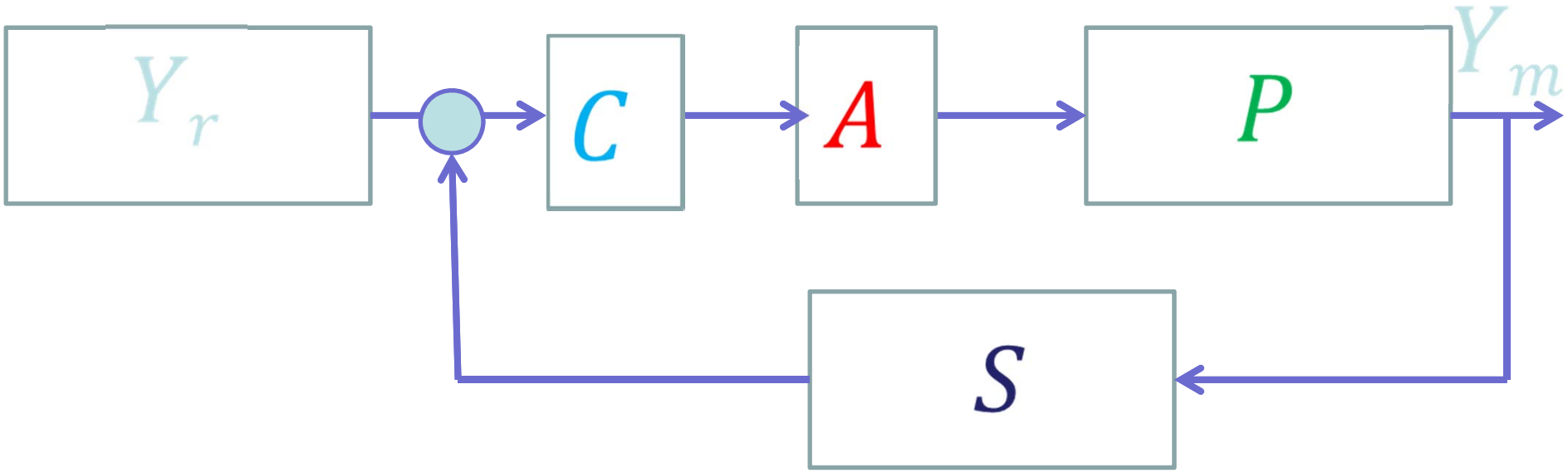




TU/e Technische Universiteit Eindhoven University of Technology

Generic closed loop control system

DIFFER
Dutch Institute for
Fundamental Energy Research



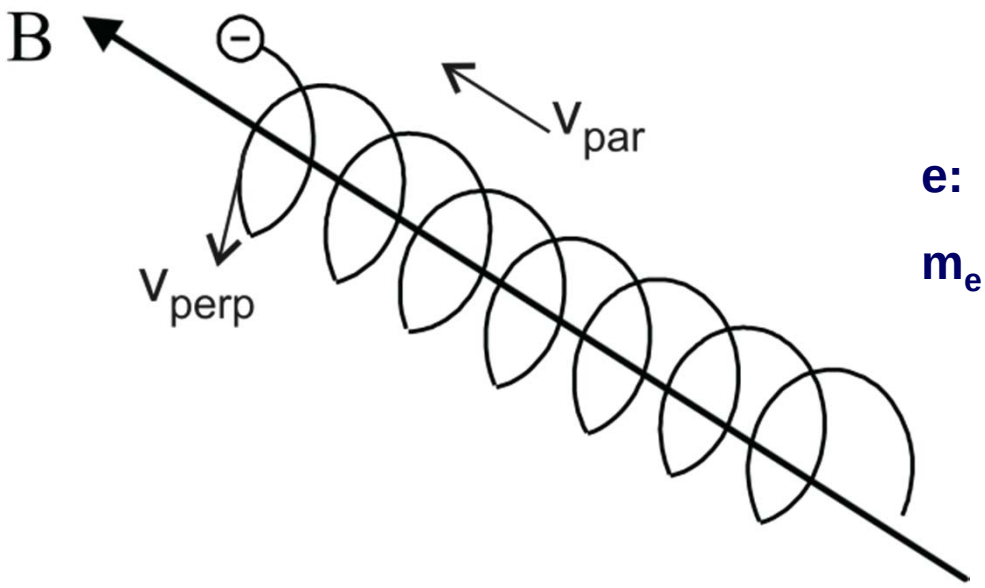
Focus on the optimisation of plasma control Systems:
Integrated optimisation of its elements

TU/e Technische Universiteit Eindhoven University of Technology

Electron Cyclotron Resonance

DIFFER
Dutch Institute for
Fundamental Energy Research

Electrons bound by magnetic field:



Cyclotron frequency for electrons:

$$\omega_c = \frac{eB}{m_e}$$

e: **electron charge**

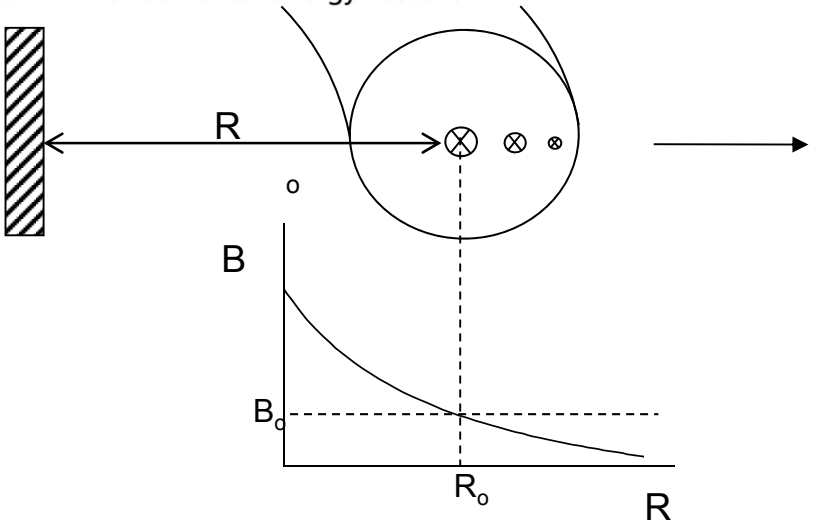
m_e: **electron rest mass.**

f_c ~ n.28 GHz / Tesla
Microwaves

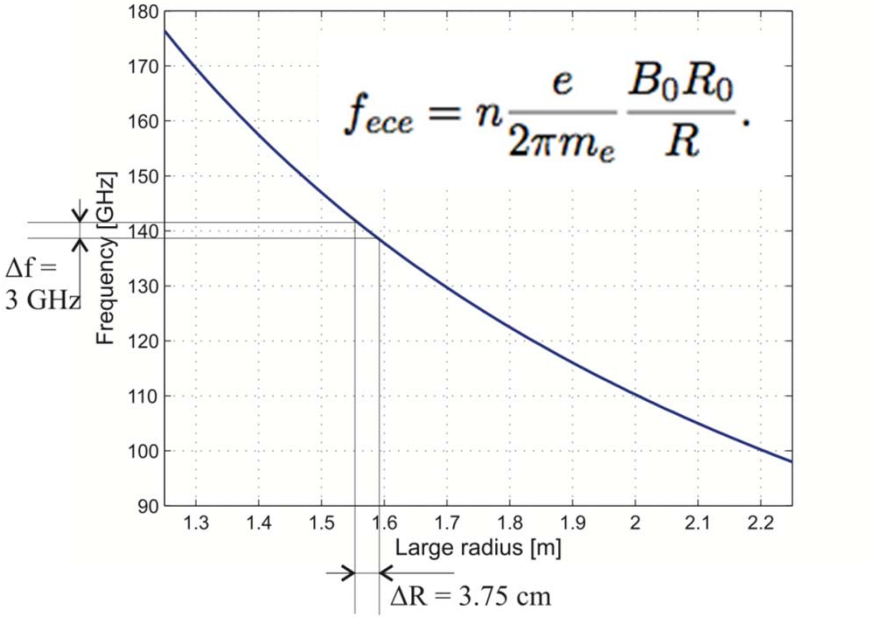
TU/e Technische Universiteit Eindhoven University of Technology

Sensor: EC Emission

DIFFER
Dutch Institute for
Fundamental Energy Research



Radiometer: I_{ECE} in receiving antenna



$$T = P_{ec} / k_b B_w$$

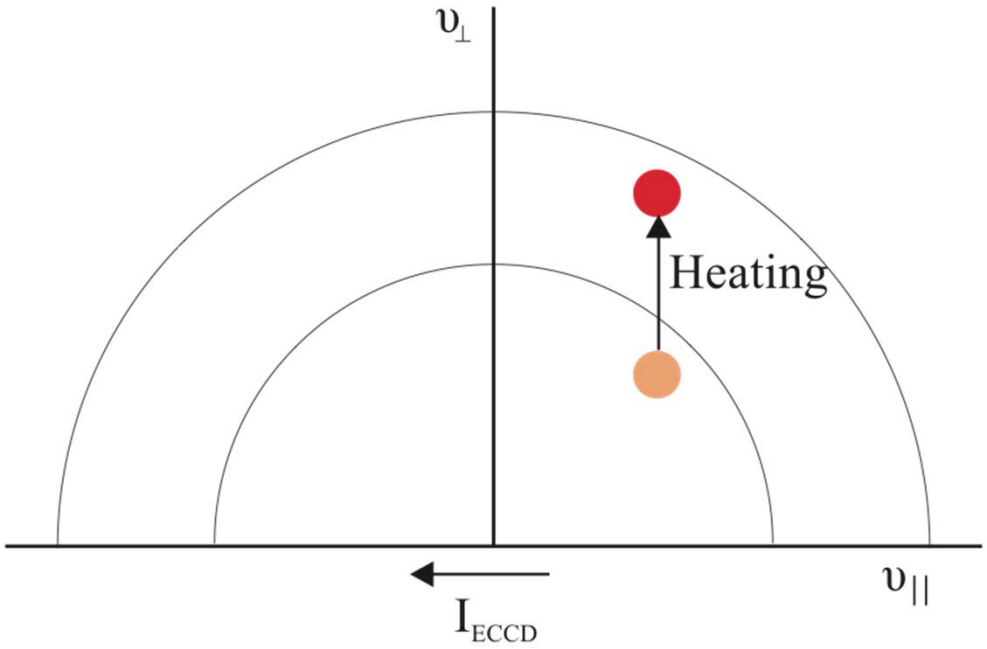
Technische Universiteit Eindhoven University of Technology

Actuator: EC Current Drive

DIFFER
Dutch Institute for
Fundamental Energy Research

ECCD: Injection of high power microwaves at the cyclotron frequency under a toroidal angle.

Direct local current drive to optimise or 'repair' the plasma

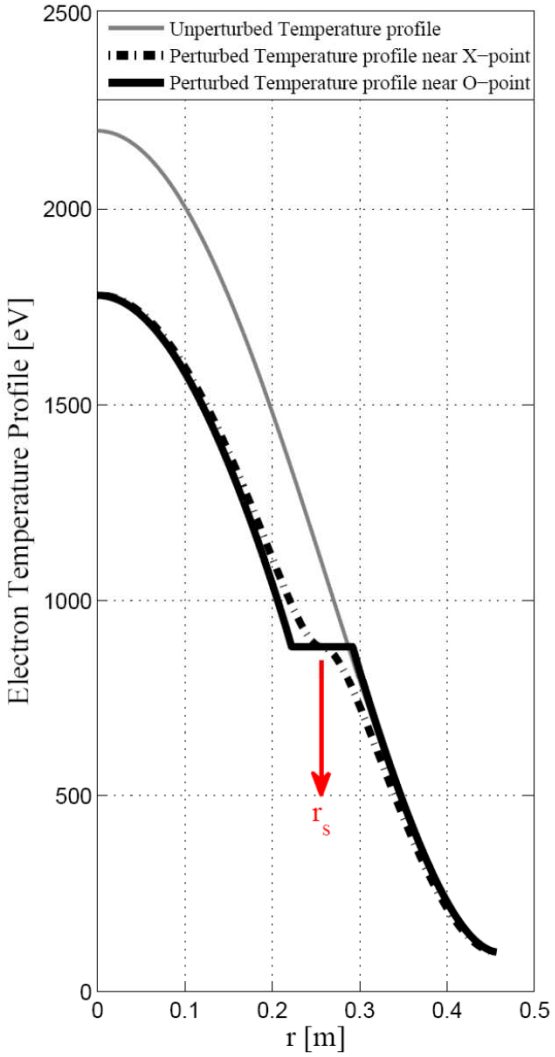


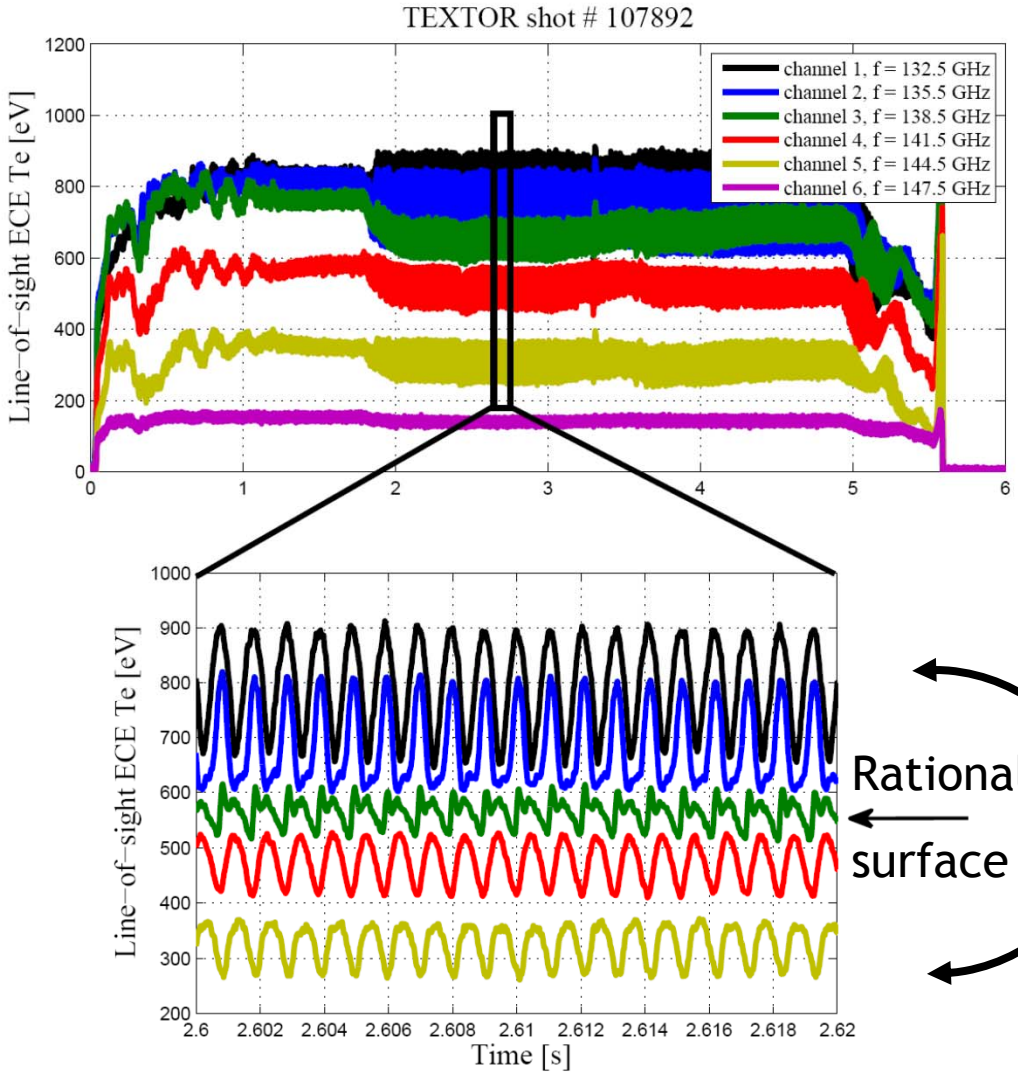
$$\omega = \frac{n\omega_c}{\gamma} + k_{par} v_{par}$$

Heating of selected v_{par}
Absorbed energy mainly to v_{per}
Reduces collisionality population
Increased current

TU/e Technische Universiteit Eindhoven University of Technology

Radial location tearing mode

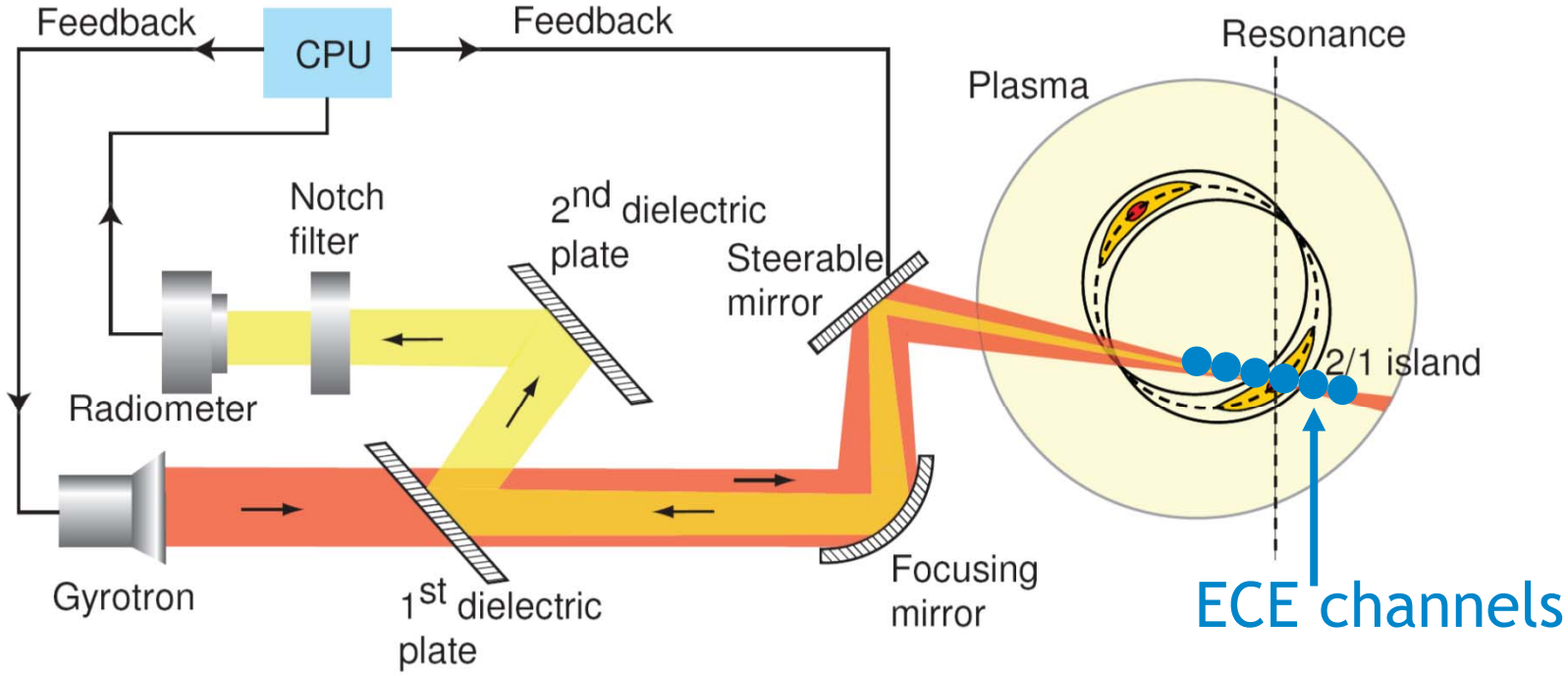




Rational surface r_s

180°

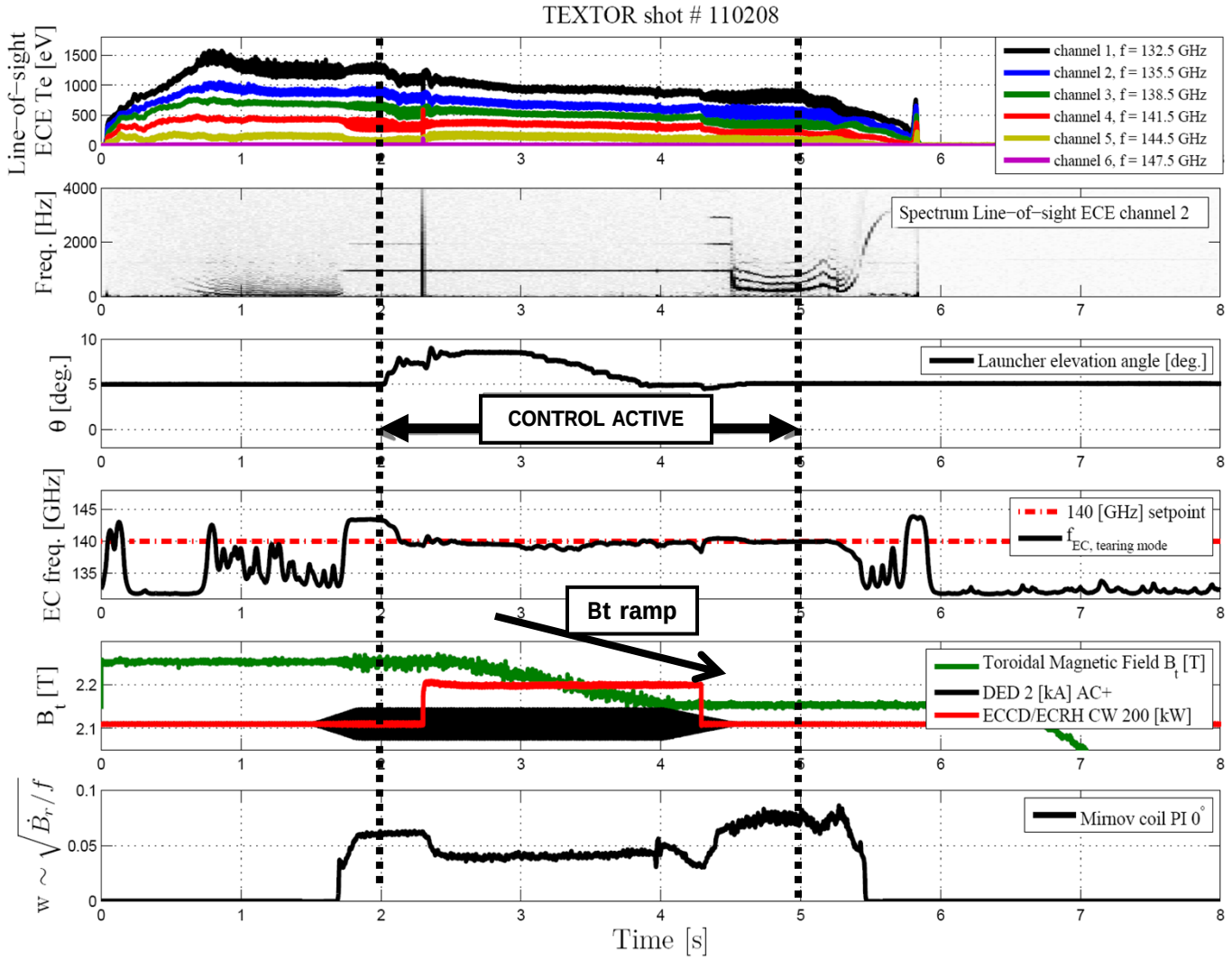
In-line ECE for mode location



- Advantages:
  - No beam tracing and equilibrium reconstruction required
  - Guarantees alignment even when launcher orientation is perturbed or calibration is lost

Robust island tracking

DIFFER
Dutch Institute for



- $\theta_{initial}$ = 5°
- B_t = 2.25-2.15 T
- I_p = 300 kA

- Continuous ECRH/ECCD 200 kW, t = 2.3-4.3 sec.
- DED triggered

  m/n = 2/1 mode

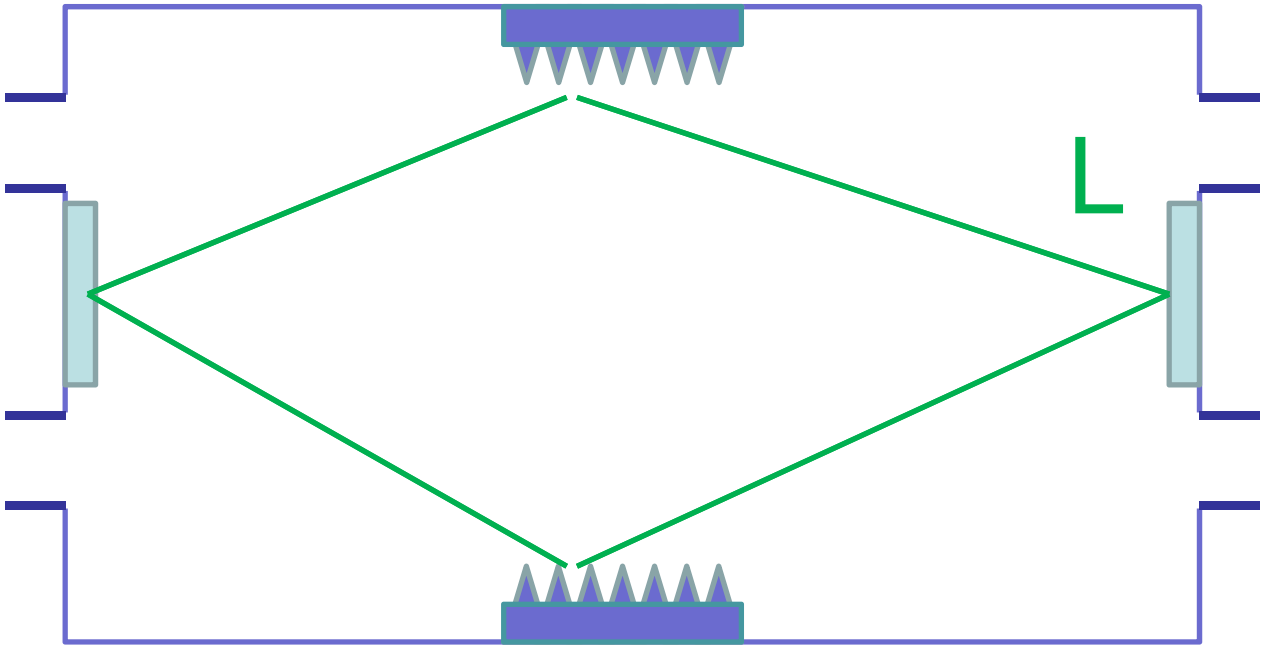
- Controller active from t = 2-5 sec.
- Alignment maintained during Bt ramp

PLL for Phase tracking of island successfully applied

DIFFER μ-wave cavity FADIS

Dutch Institute for Fundamental Energy Research

Textor results proof of principle. But how to implement with
-Corrogated wave guides?
-CW?



$$T_1 = h(f, g, L)$$

$$T_2 = k(f, g, L)$$

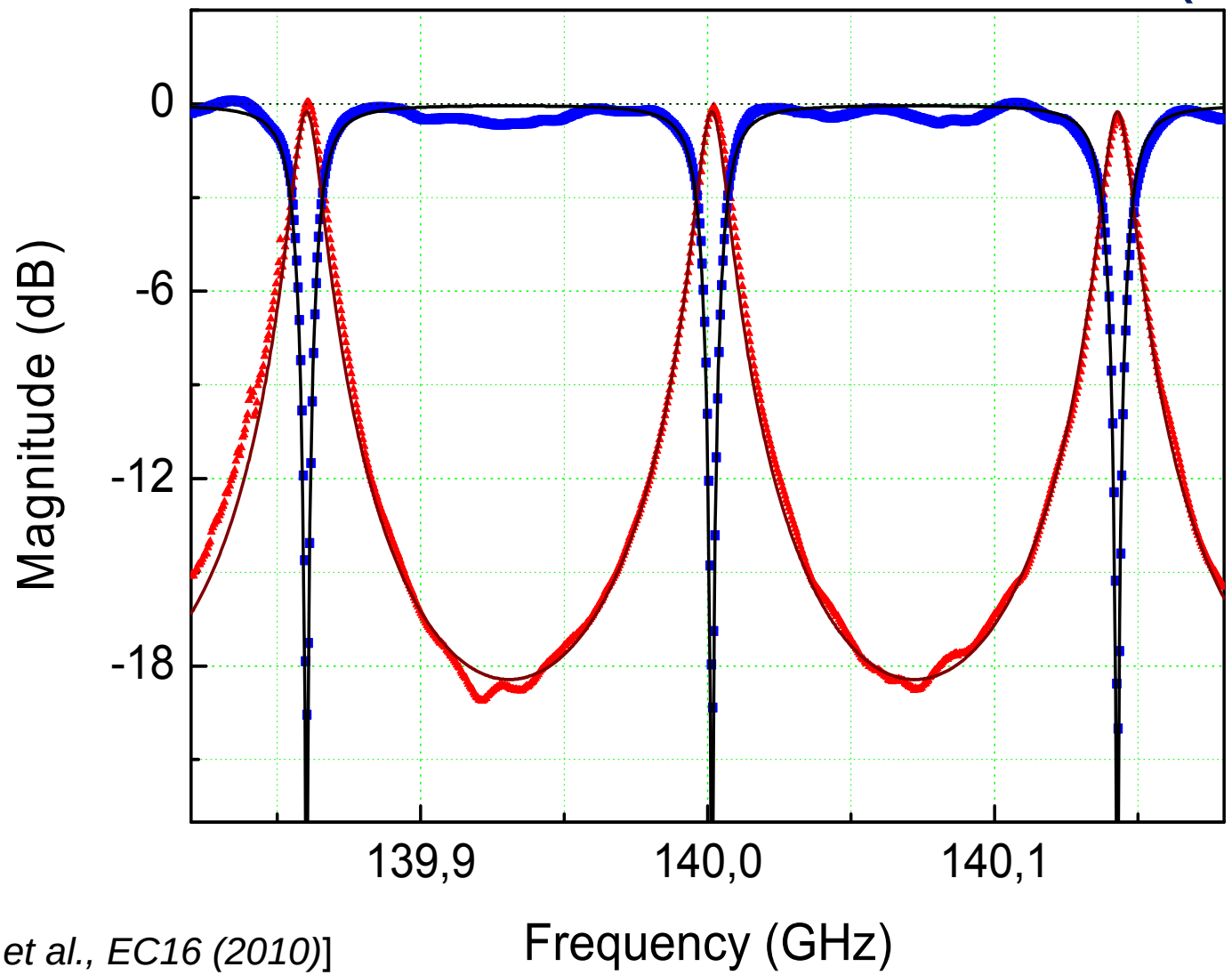
Kasparek et al., IFP Stuttgart

TU/e Technische Universiteit Eindhoven University of Technology

FADIS for in-Line ECE isolation

FADIS Transmission:

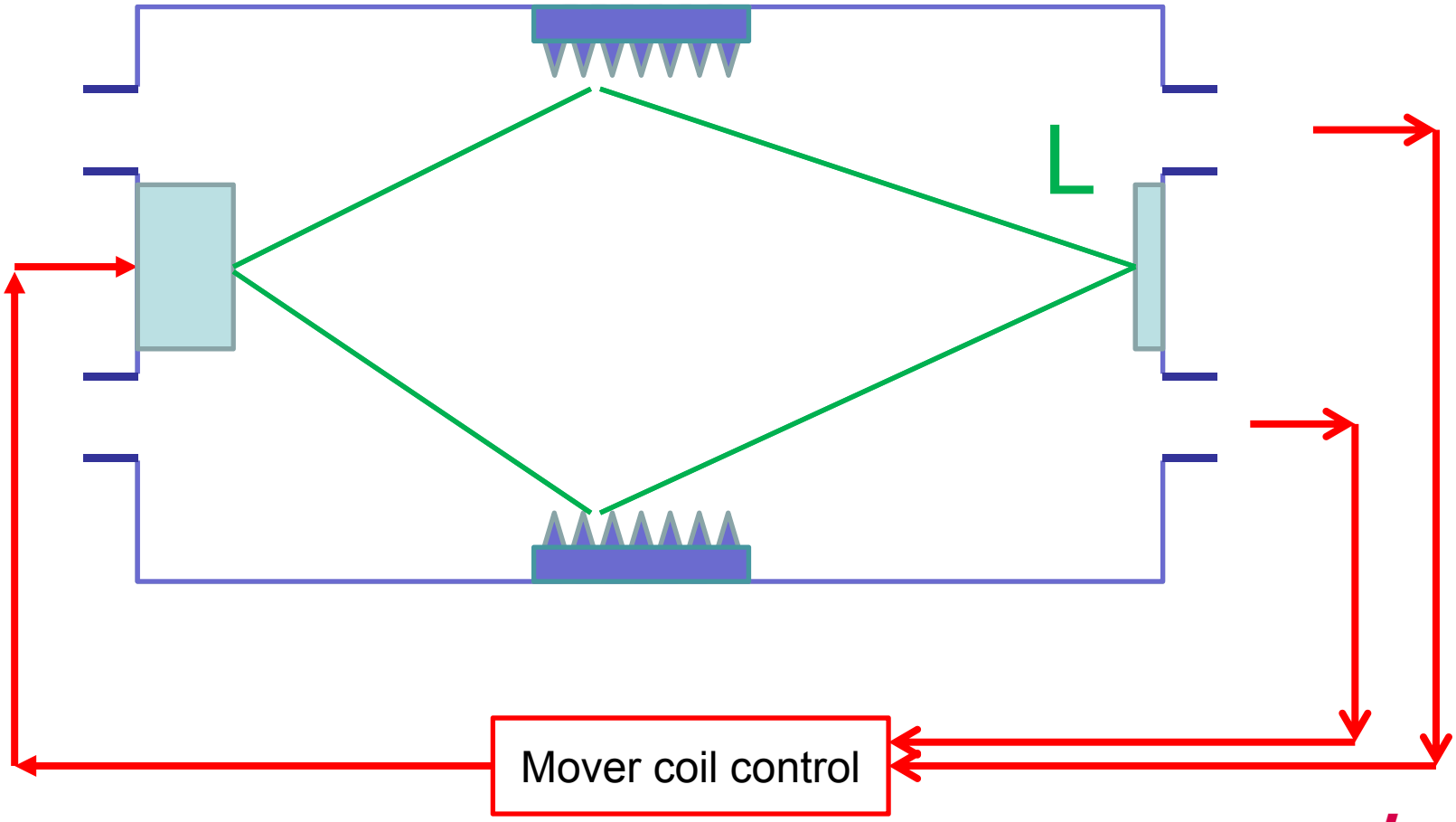
➢Mk IIa with matched HE11: **non-resonant channel (blue)**



[*Kasparek et al., EC16 (2010)*]

FADIS: Active, RT, Tunable Cavity

DIFFER
Dutch Institute for Fundamental Energy Research

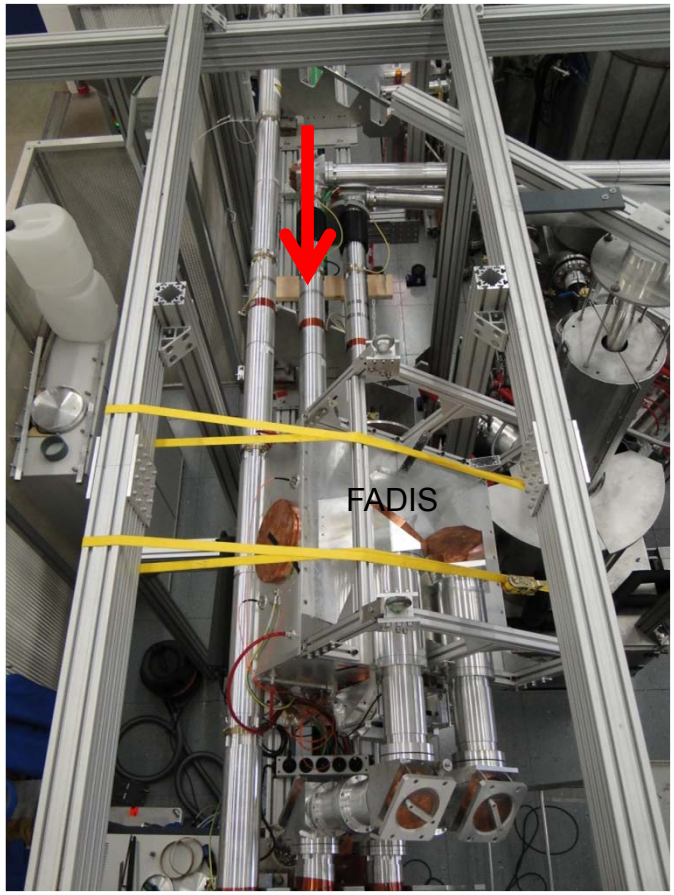


Kasparek et al., IFP Stuttgart, DE and Doelman et al. TNO Delft, NL

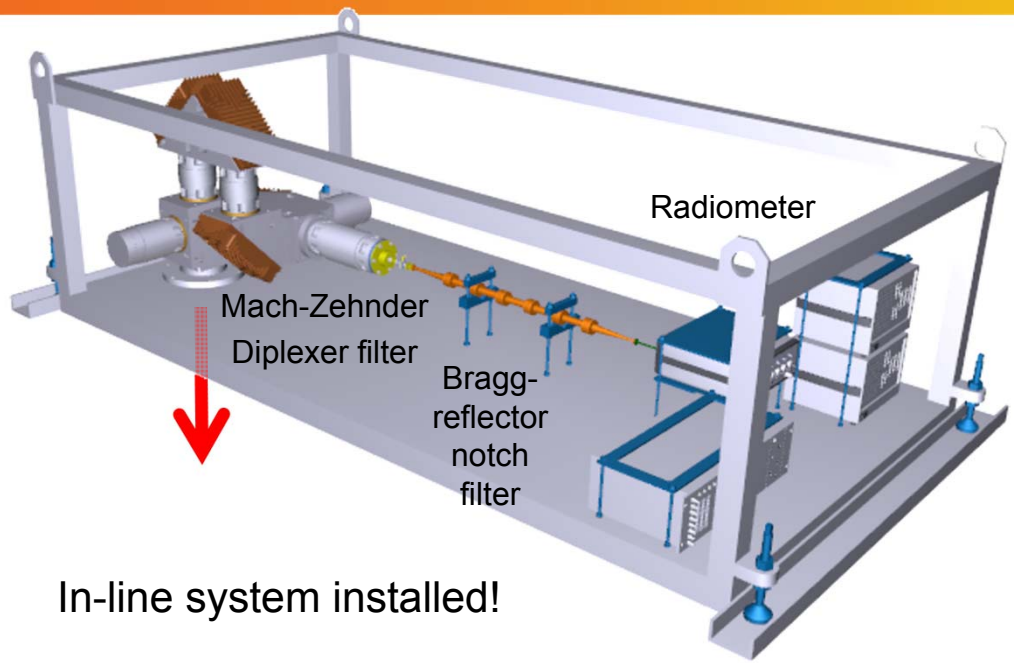
TU/e Technische Universiteit Eindhoven University of Technology

AUG inline ECE setup

From Gyrotrons



To Tokamak



In-line system installed!

Conclusions

DIFFER
Dutch Institute for
Fundamental Energy Research

- High and low power μ-waves for plasma stabilisation

- High power:Local current drive inside island (ECCD)
- Low power: Local measurement island position (ECE)

- In-Line ECE: Integration ECE-ECCD in transmission line.

- High quality notch at gyrotron frequency
  - Quasi-optical (TEXTOR)
  - CW, waveguides (AUG)

TU/e Technische Universiteit Eindhoven University of Technology