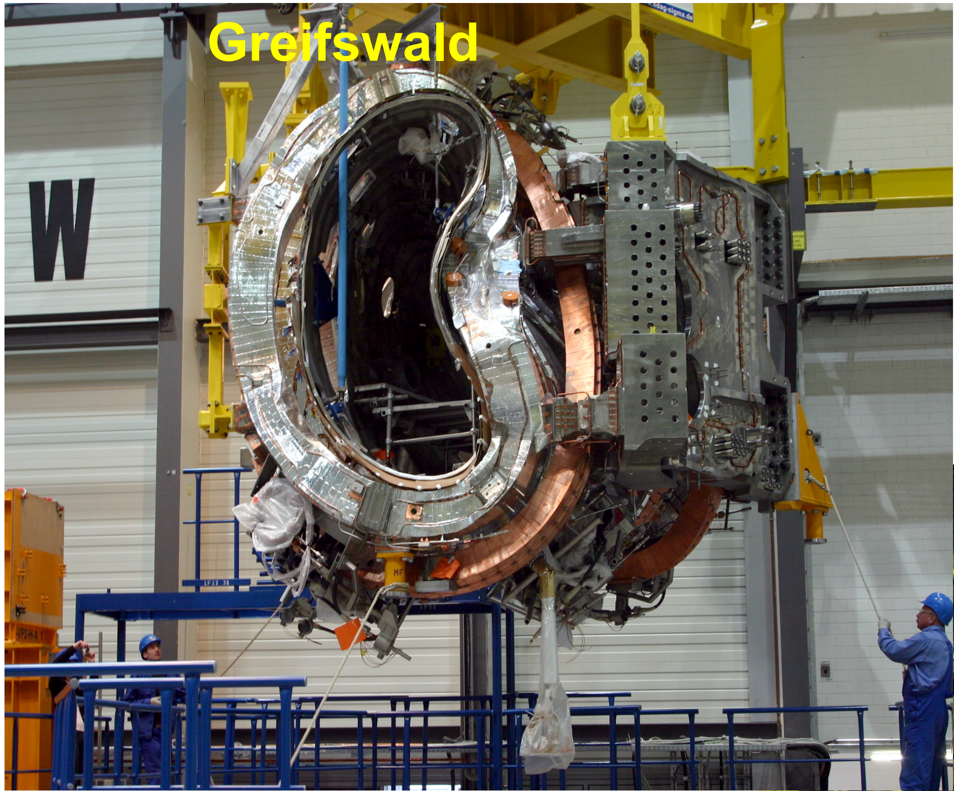
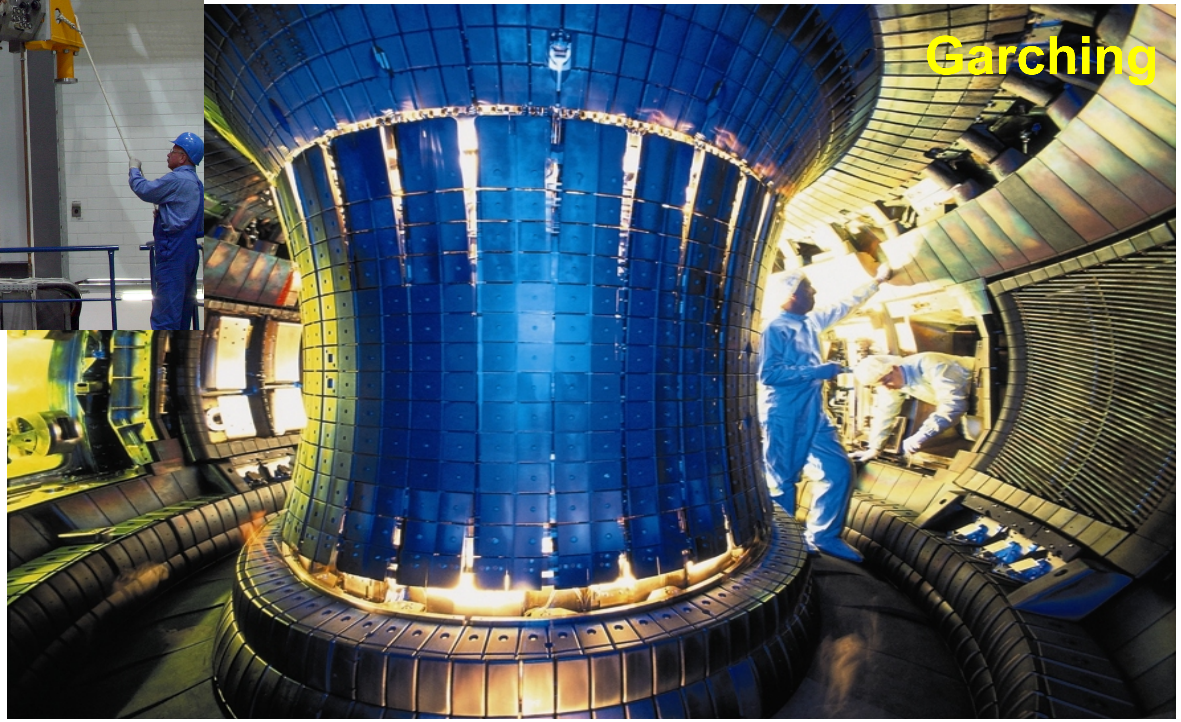
Max-Planck-Institut
für Plasmaphysik



IPP programme till 2019

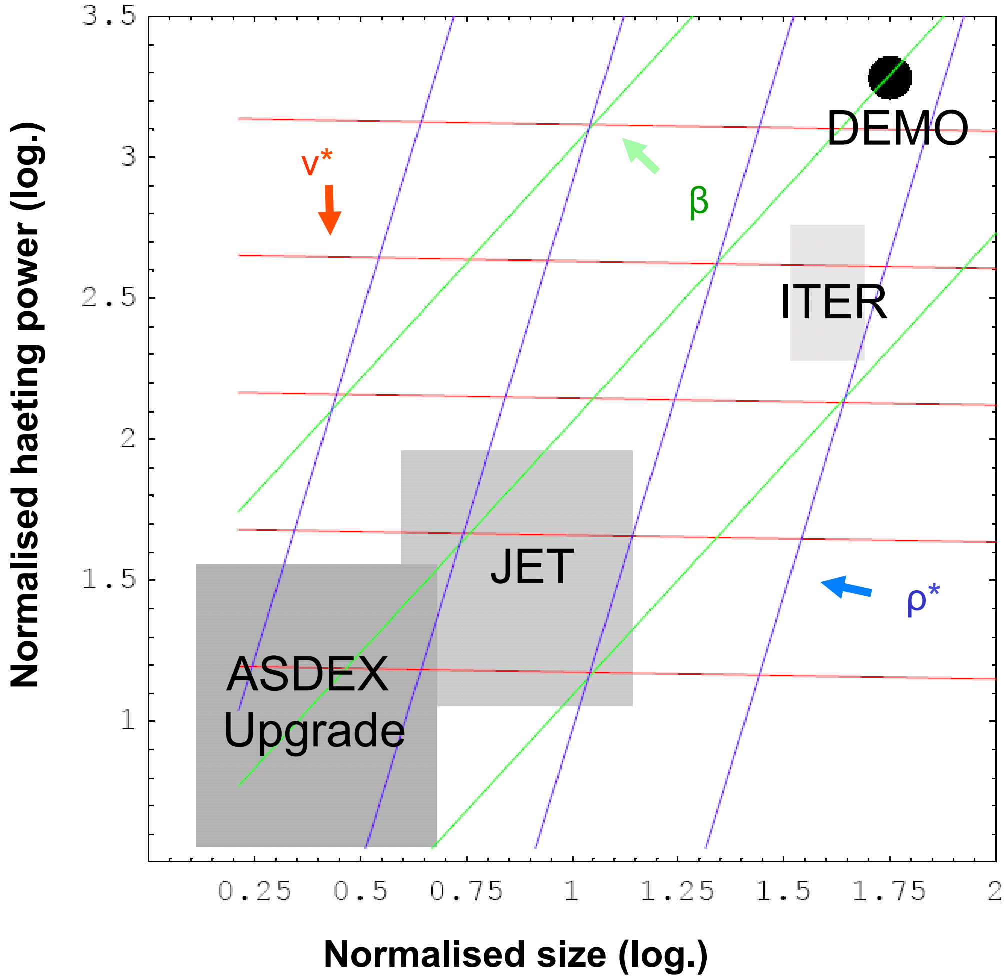
Sibylle Günter



Major projects at IPP

- Tokamak physics (AUG, JET, JT60-SA)
- Stellarator physics (W7-X)
- Plasma theory (tokamak and stellarator)
- Plasma wall interaction
- Diagnostics and heating systems for ITER
- Reactor studies

ASDEX Upgrade and JET: ‘Step ladder to ITER’

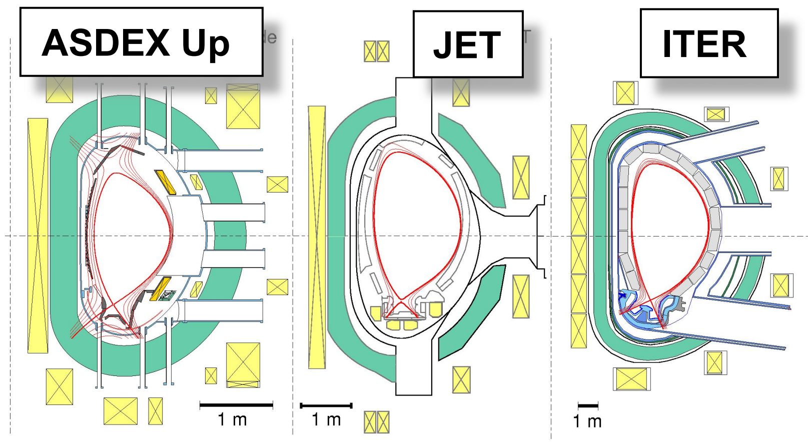


$\rho*$ = orbit effects

β = energy density

ν^* = (classical) dissipation

Pre-requisite:
geometrical similarity



Examples of AUG results with major impact on ITER

First demonstration of NTM stabilisation by ECCD

• ITER ECCD system was adapted to this task (Upper Launcher)

Discovery of ‚Improved H-mode' scenario (a.k.a. ‚hybrid')

• leads the way to longer pulses or higher fusion power in ITER

• transferred to JET by IPP scientists using ‚current overshoot' technique

Demonstration of compatibility of full-W wall with ITER scenarios

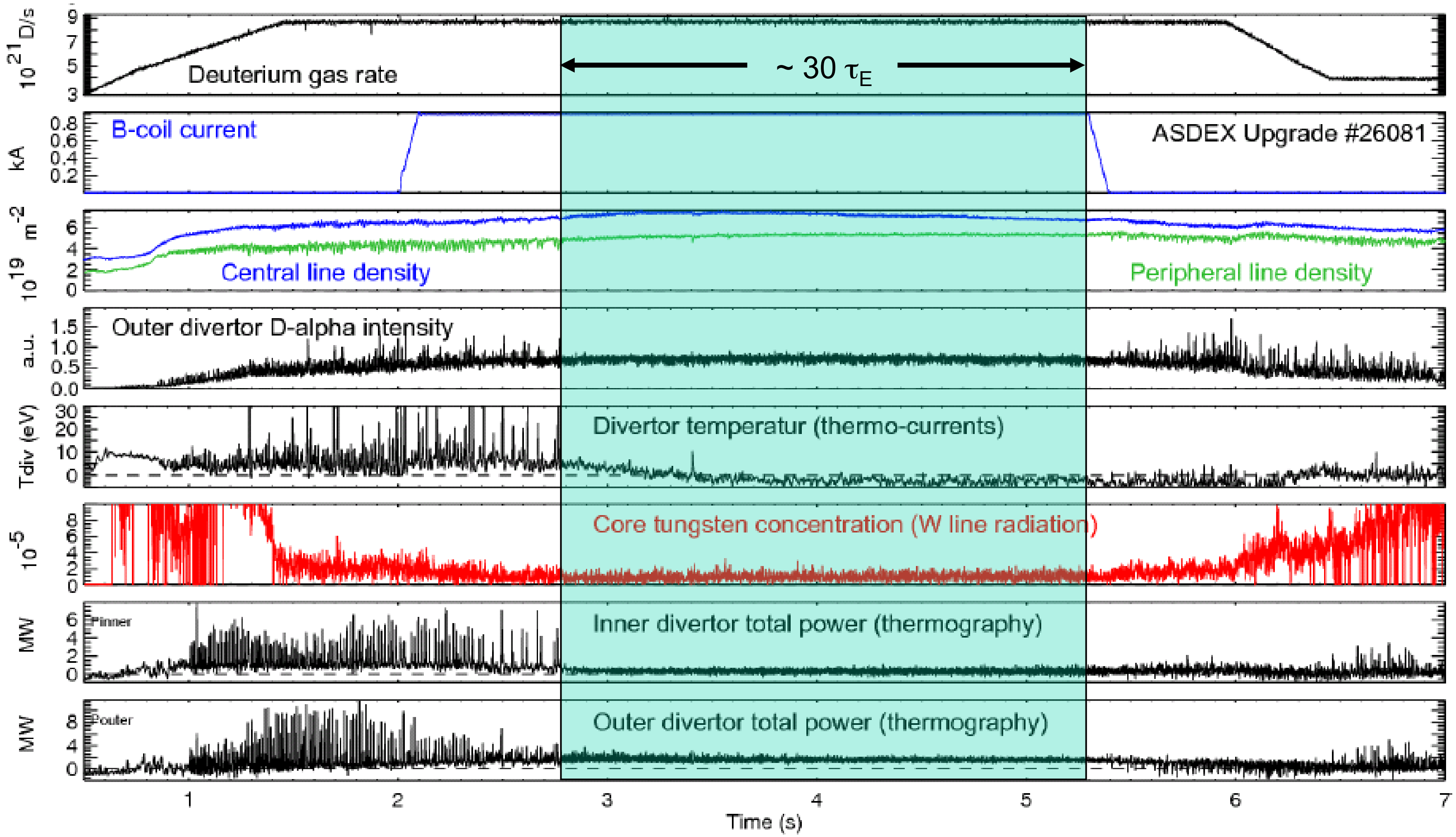
• positive result prompted a change in ITER PFC strategy (W-divertor)

• also encouraged the step to the ITER-like wall on JET

Results demonstrate the path-finding role of AUG ('engine of innovation')

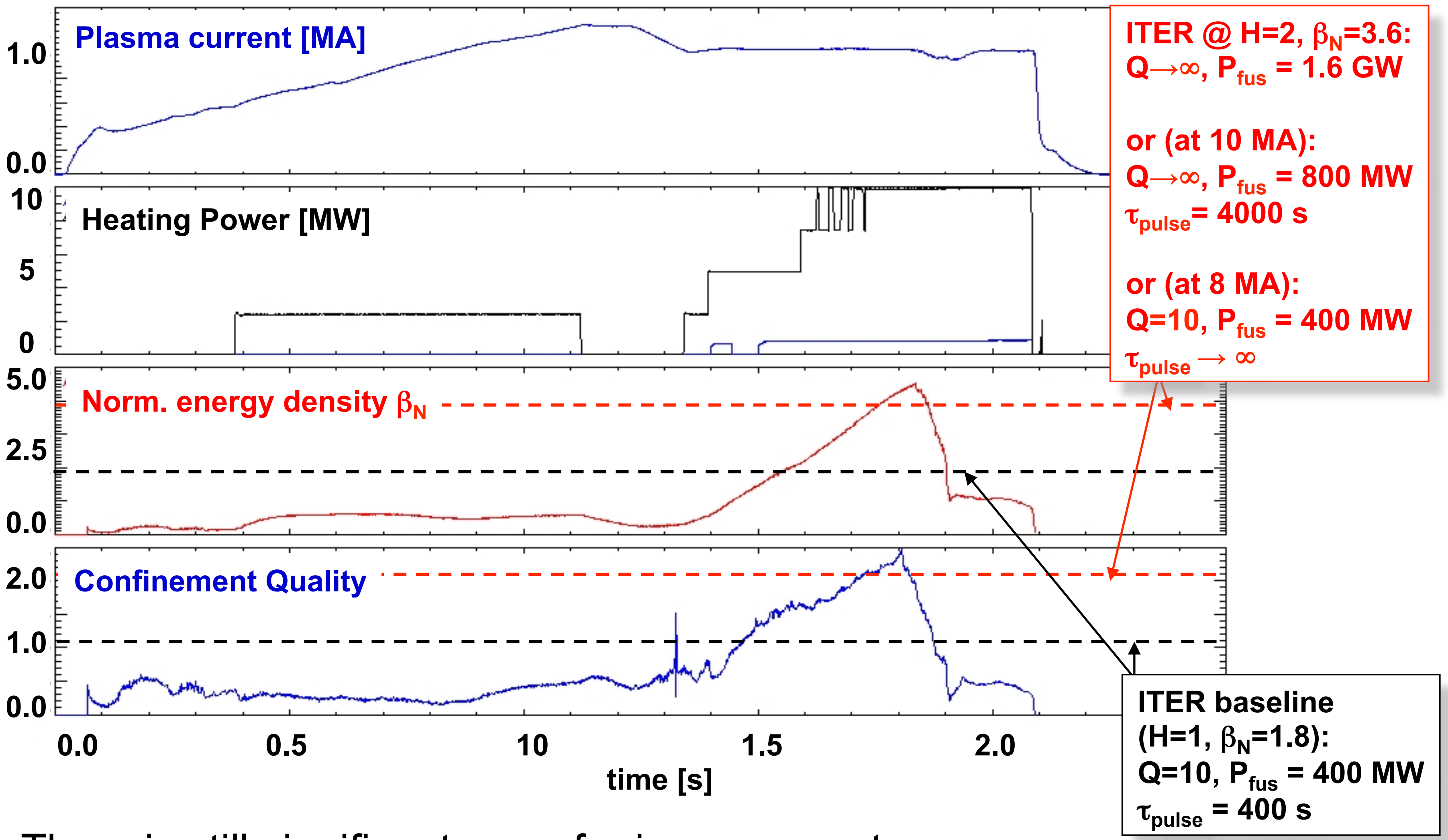
• more to come in the next years (see the following more recent examples)

ELM mitigation by RMPs in AUG



- DIII-D results readily confirmed and extended at AUG using internal coils

Operation Scenarios above ITER Baseline



There is still significant room for improvement…

- example: current overshoot in ASDEX Upgrade – stationarity possible?

AUG Programme in Preparation of ITER and DEMO

Solve immediate questions aiding the design of ITER systems

guide ITER design where input is still missing (ELMs, NTMs, first wall…)

Prepare ITER operation

Develop operation scenarios that ensure baseline operation

(Q = 10) and make possible advanced operation (Q > 10 or steady state)

Develop physics base for DEMO

-point design needs first principles understanding and thus close link to theory

-address areas that are not essential for ITER but have to be solved for DEMO (= 'DEMO physics issues')

+ Educate fusion plasma scientists and engineers (generation that will run ITER)

Future ASDEX Programme has 3 Big Blocks

Exhaust

High P/R, PWI, divertor physics…

- High P/R – use full heating power (highest P/R of present devices)
- W-wall – plans for solid W outer divertor tiles (unique capability)
- RMP coils for edge tailoring (versatile spectrum)

Optimisation of tokamak scenarios

Asses steady state operation with dominant e-heating, low momentum input

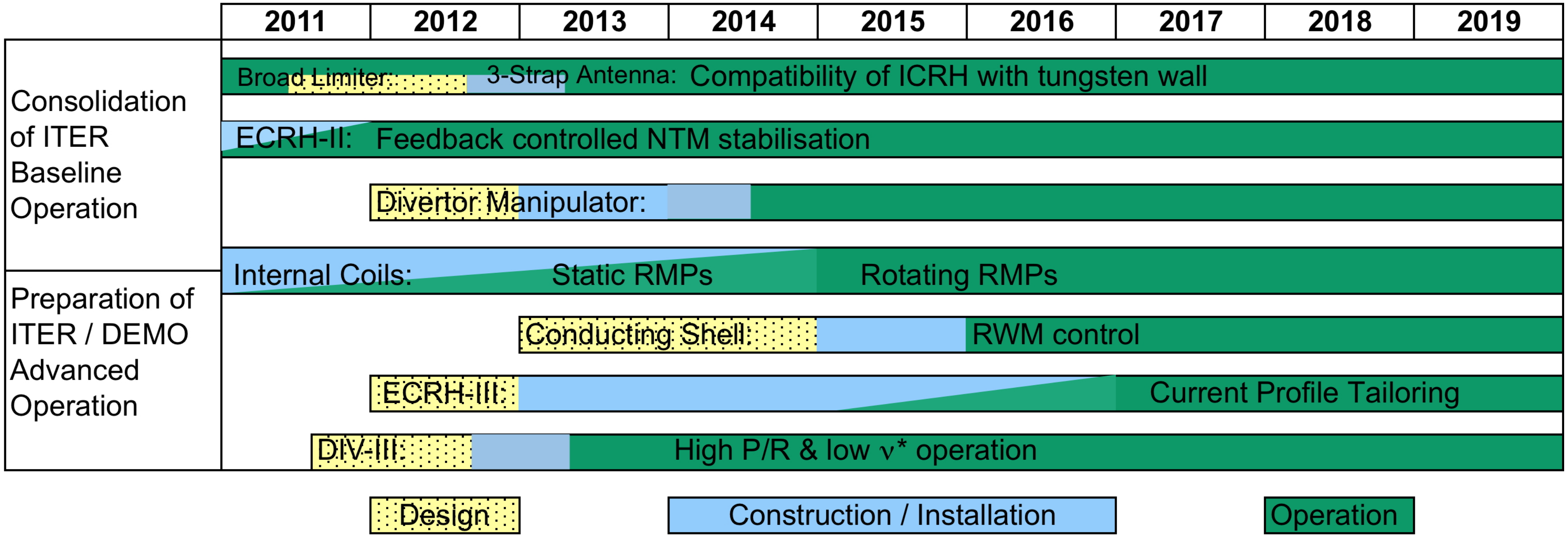
- ECCD upgrade to 8 MW (ability to replace major fraction of NBI power)
- LHCD with PAM grill (on hold – would be unique)
- RWM stabilisation using full RMP coil set and conducting shell

Advancing Fusion Plasma Physics

fast ion physics, L-H transition, pedestal, turbulent transport...

This block will continue our work in many areas that need better understanding

ASDEX Upgrade programme schedule and Upgrades



Proposed extensions allow to study the relevant plasma physics to prepare ITER and DEMO in the EU programme at least until the start of ITER

Operation as a EU satellite in the 1 MA class in parallel to ITER is envisaged

‚Europeanisation ‘ of the AUG Programme

In 2001, we formally opened the ASDEX Upgrade programme to the EU Associations

- remote access and communication
- established the ‚International ASDEX Upgrade Programme Committee ‘ that decides on mid term (~ 1 year) programme

  21 members (12 EU-Associations, 9 IPP members)

Has become a success story:

- 20-30% of the programme proposals, but also AUG conference contributions and refereed publications come from the EU Associations
- Mainly manpower contributions, but also diagnostics-hardware (PT,NL, DK, HU,GR)

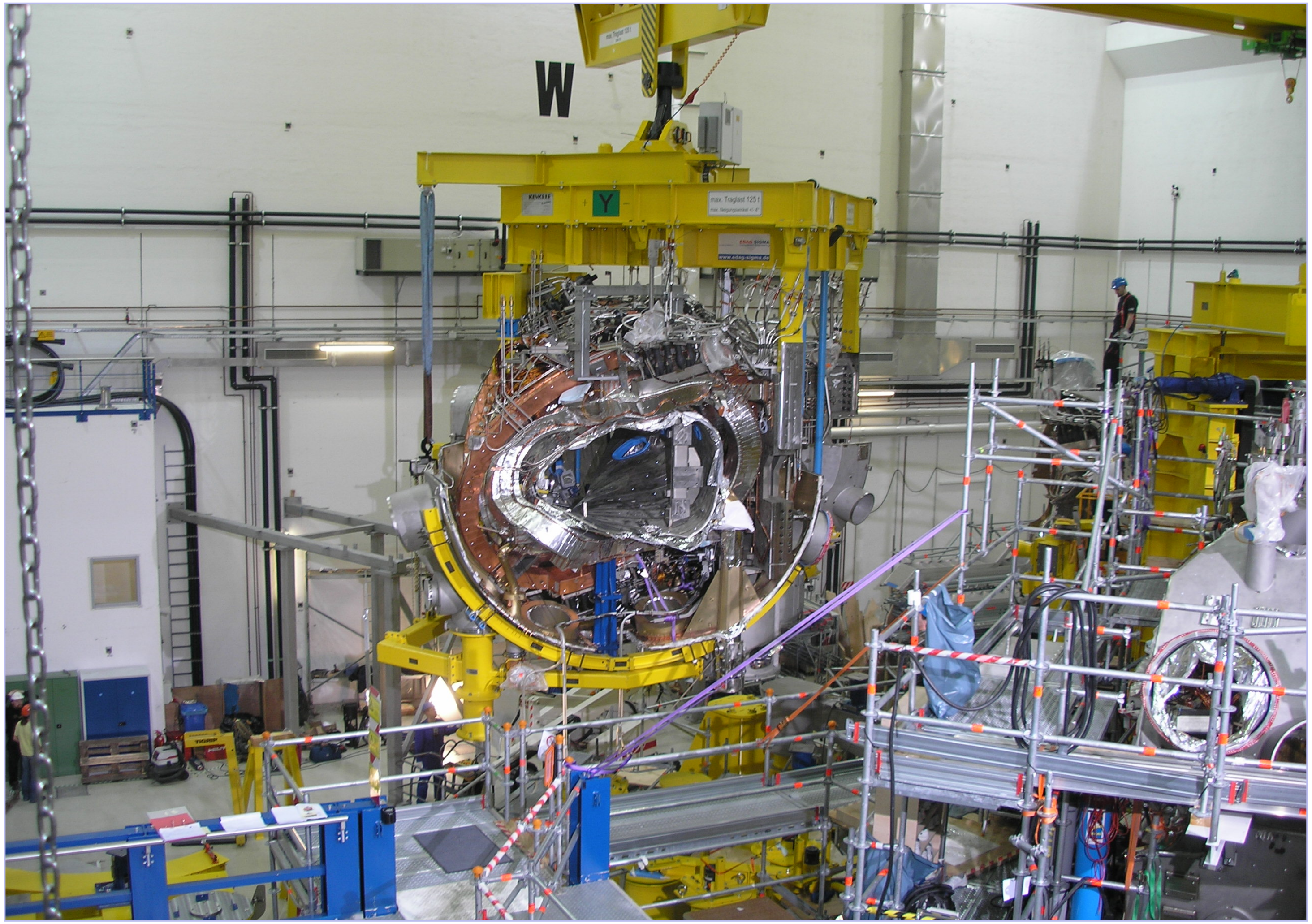
Open to the Associations also in the future!

The step ladder approach ...

- Active participation in the JET and JT60-SA programme, in particular: transfer of knowledge and developed operational scenarios

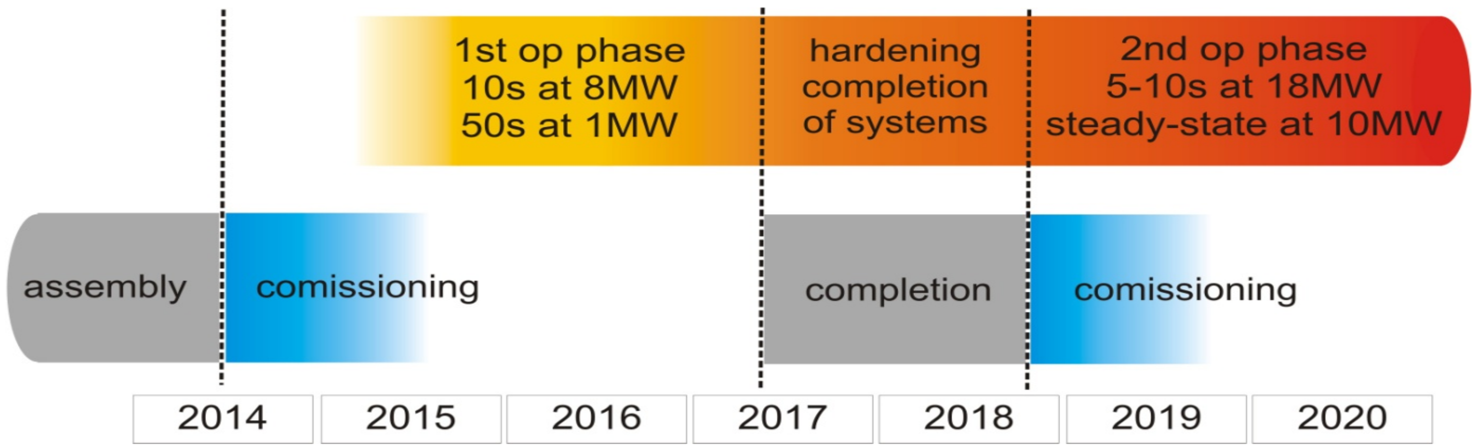
- Collaboration with other European tokamaks, in particular those with similar geometry (TCV, MAST)

W7-X: Assembly according to plan



No delays expected: finished mid 2014

W7-X: Major Milestones



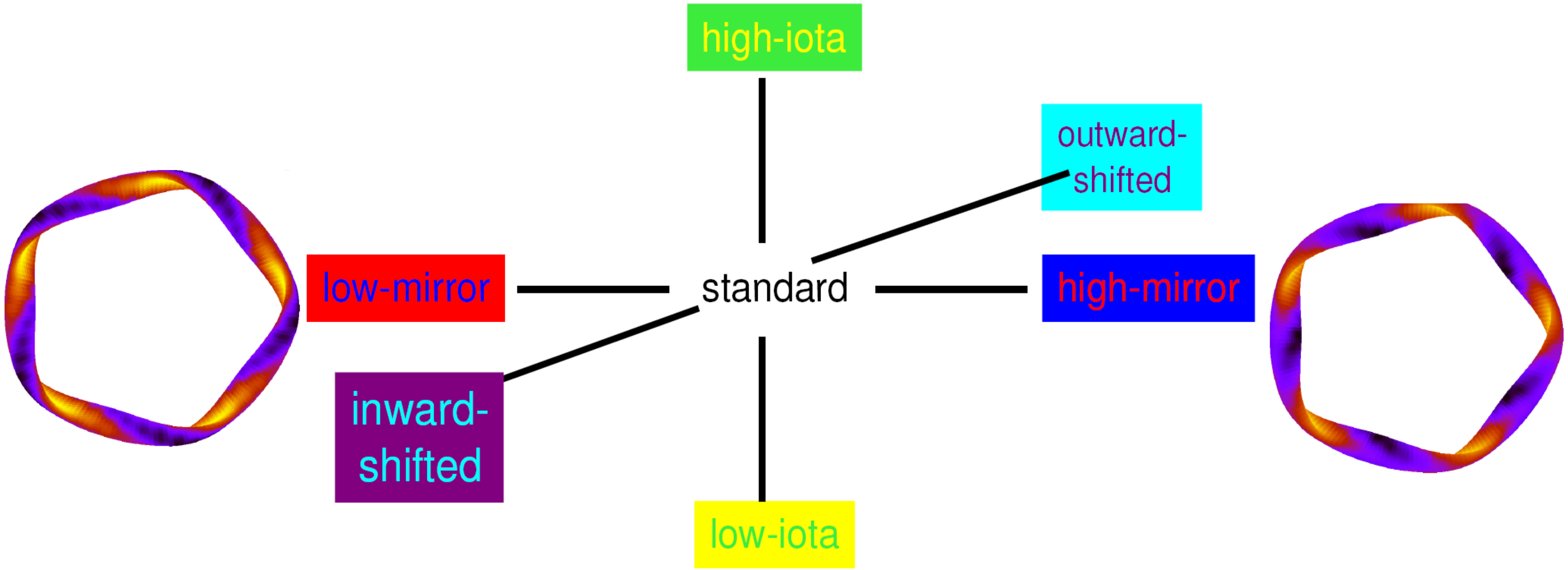
During first campaign:

- 8MW ECRH and 7 MW NBI (thanks to Polish association!)
- Diagnostics set probably sufficient to conduct the initial program
- Test divertor unit to study operation limits and divertor physics

Completion:

- Steady state divertor
- Increase in heating power, ICRH
- Diagnostic completion

Confinement studies at moderate β



- variation of the toroidal mirror component over $0.0 \ldots 0.1$ varies χ_e
- verification of reduced $1/\nu$ transport
- confinement scaling and comparison to ISS04

Density limits and Impurity control studies

Stellarators have a soft density limit with the scaling $n_{DL} = 1.46\ (P/V)^{0.48}\ B^{0.54} \leftarrow$ verify

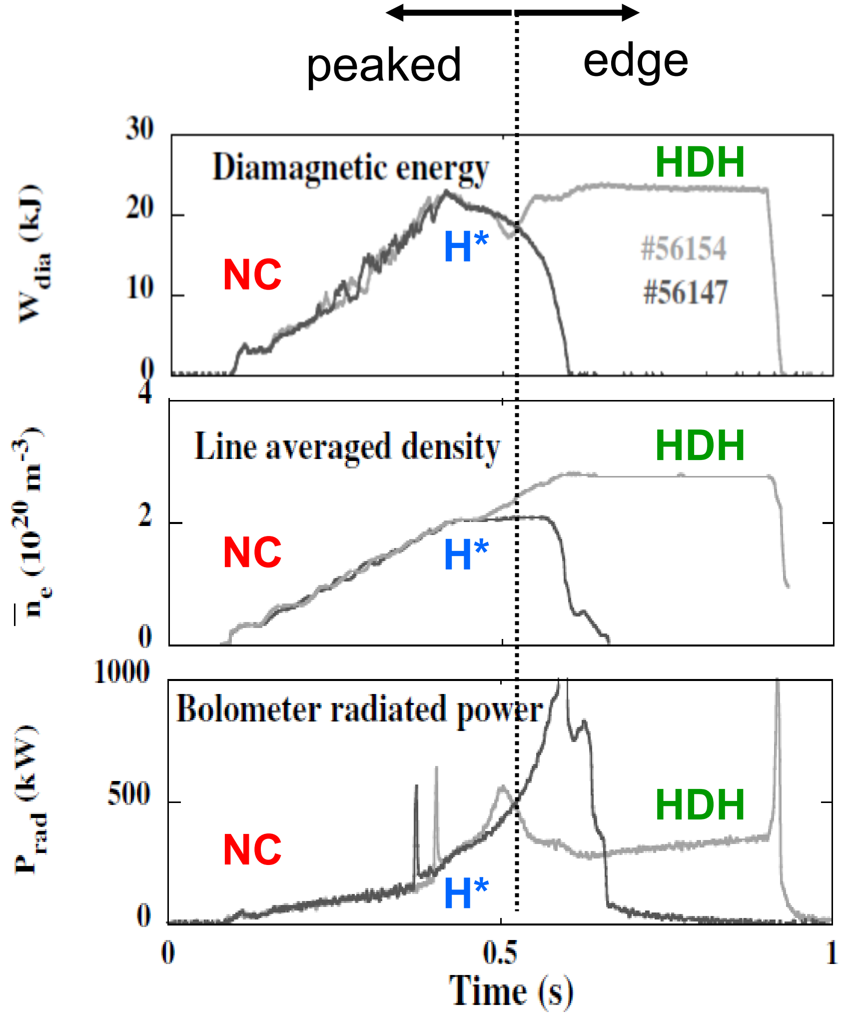
(and try to understand difference to tokamaks)

Impurity accumulation at high densities?

... the aim is stationary plasma with $P_{rad} < 50\%\ P_{heat}$

Temperature screening does not occur in stellarators!

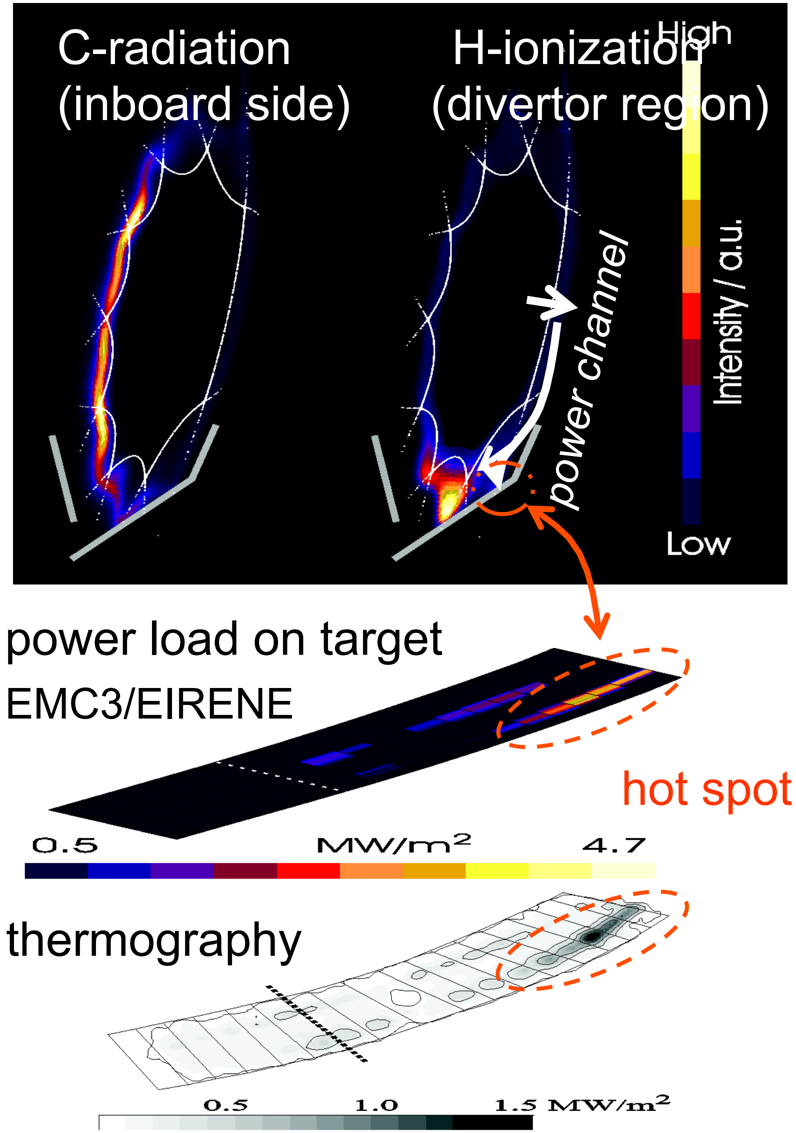
radiation profiles



experience with W7-AS

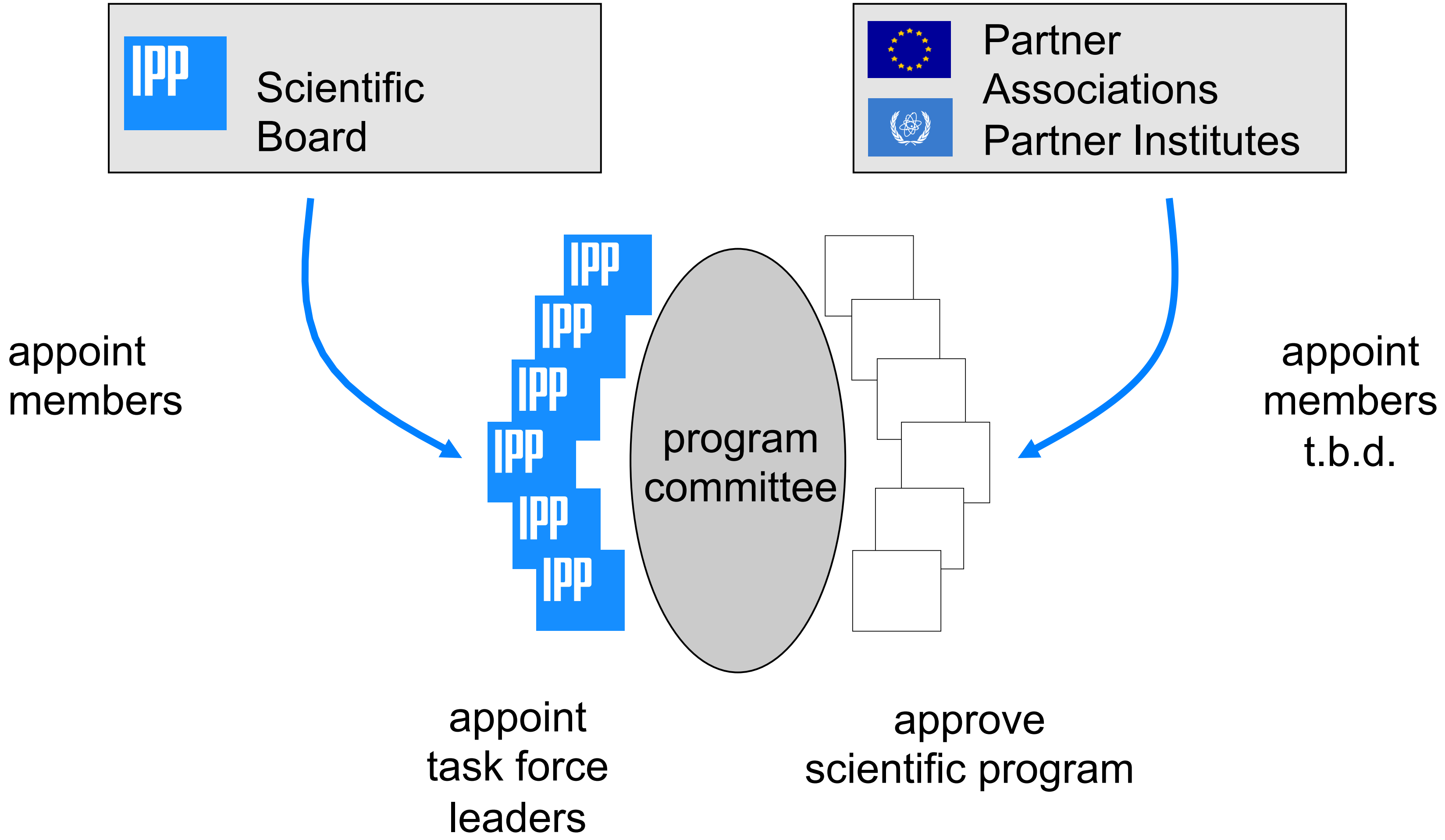
Initial divertor load studies

- experience with W7-AS island divertor
- good modelling capabilities with EMC3/ EIRENE



Power load distribution in line with the planned steady state divertor?

European (international) exploitation



We greatfully ackowledge the important contributions by PL, HUN, CEA, PPPL, CIEMAT (also KIT and FZJ)

IPP Theory: vision and grand challenges

quantitative understanding
of **confinement, stability, heating and exhaust** for both **tokamaks and stellarators** from **first principles**

Tokamaks

H-mode barrier

density limit

current driven instabilities

current & rotation profile effects on turbulence

S&T common

turbulent transport modelling

elements of SOL physics

pressure driven instabilities

fast particle driven instabilities

effects of perturbation fields

Stellarators

configuration optimisation

3-d configuration effects on turbulence

stellarator divertor physics

wave heating in stellarator geometry

IPP Theory: our particular strengths

previous achievements (GENE, GEM, TORIC, LIGKA, CAS3D, stellarator optimisation …)

network of organized collaborations (CRPP,CCFE,CEA)

stellarator-tokamak synergies

grand challenges & critical issues; ITER, DEMO prediction

institutional links to Computational Science community: MPG-RZG & joint Chair with TU Munich

close interaction with experiments

international composition of staff *) => drive of informal collaborations

*) e.g.60% of permanent TOK-scientific staff non-German

Core Turbulence (collaboration CRPP, ITM)

Present status	2014	2019
Global, full physics tokamak codes (GENE, ORB) local stellarator codes	Full JET global simulations, global stellarator codes	ITER full discharges on transport time scale

Edge Turbulence (collaboration DK, Austria)

Present status	2014	2019
Gyrofluid, close to separatrix, first GK (GEM, FEFI)	Full-f GK, extension to separatrix	all physics for H-mode

Heating (collaboration ITM, MIT)

Present status	2014	2019
ICRH (TORIC) 3d ECRH (TRAVIS)	3d ECRH/ECCD real time control	ICRH for stellarators

Present status | 2014 | 2019

SOL and divertor modelling (collaboration ITM, FZJ)

Present status	2014	2019
2d: fluid (drifts), impurities (SOLPS) 3d: divertor fluid model (EMC3)	Kinetic electrons, improved turb. transport, integrate core-edge	Direct link to turbulent transport models

Fast particle driven modes (collaboration CCFE, CRPP, ITM)

Present status	2014	2019
Linear GK full orbit in 2d (LIGKA) and in 3d	Non-linear hybrid, GK mode structure	Fully non-linear, Fast particle losses for ITER/ DEMO

Non-linear MHD (collaboration CEA, CRPP, ITM)

Present status	2014	2019
JOREK (3d walls) XTOR 2-fluid (reconnection)	Extension of physics model (jointly)	Applications to ITER (jointly)

Present status 2014 2019

Plasma-facing Materials and Components

PWI programme in support of fusion devices and fundamental understanding from laboratory studies

Tokamaks, laboratory plasmas and ion beams

- Material transport in fusion devices; development of modelling tools
- PMI investigation on W (H inventory, neutron damage, …)
- Be-containing mixed materials in support of ITER & participation in JET ILW

Programme related to material development

- PMI investigation and development of novel W alloys for DEMO
- Component analysis in GLADIS: Test of W7-X divertor elements until 2014; then free for ITER tests

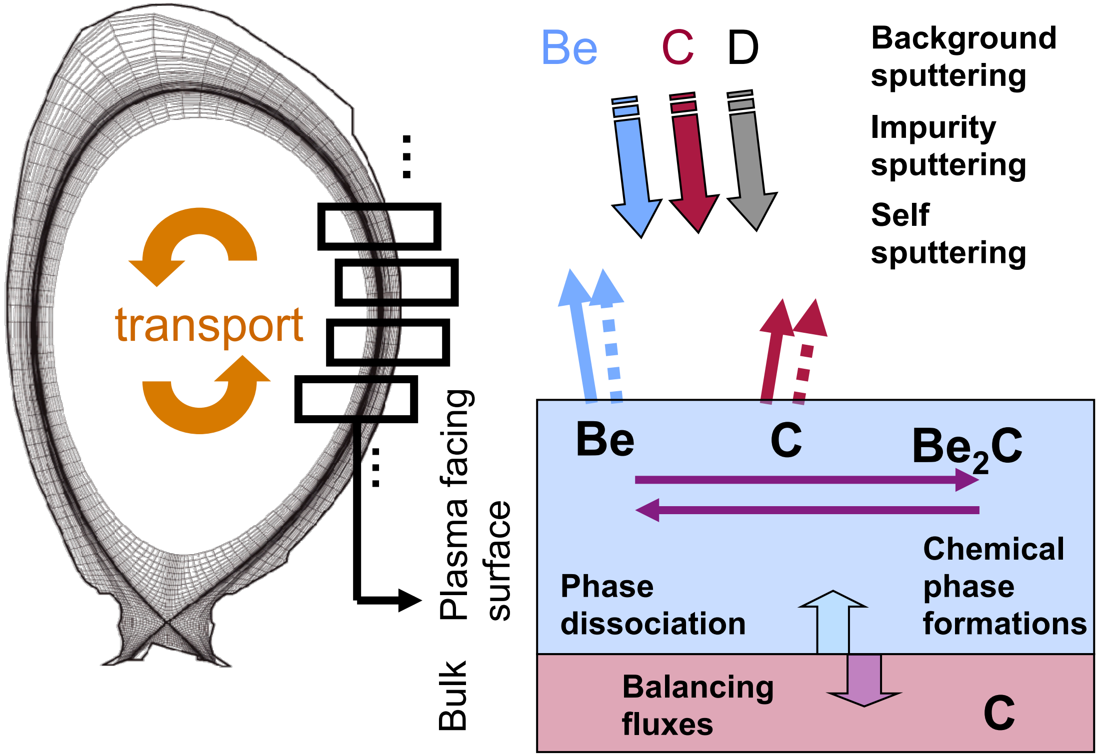
unique particle high heat flux test bed under realistic loading conditions (ions)

Intense international collaboration

- EU TF PWI. TF ITM. TG Materials. ExtreMat. FEMaS.

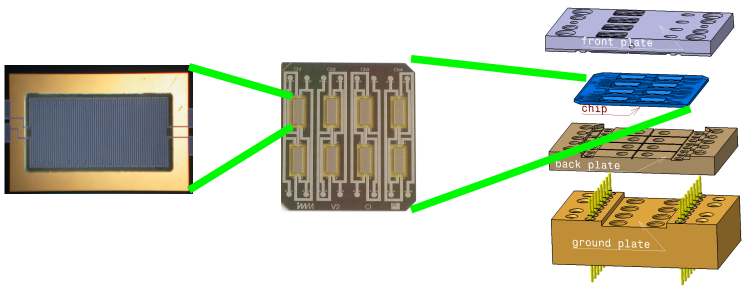
Coupling of plasma transport and wall processes

- Numerical model for **long term** and **global** material migration including dynamic surface
- Based on fundamental processes investigated in well-defined laboratory experiments
- Validation by dedicated tokamak experiments (JET, ASDEX Upgrade)
- Prediction of material transport for ITER



Development of the ITER diagnostics

ITER Bolometer



Done in close collaboration with ITERBolo consortium (**IPP**, RMKI, KIT)

Possible further Diagnostic systems

- Pressure gauges for ITER
  - The reference detector for the ITER divertor has been developed at IPP
- Dust monitoring
  - Long years of experience in dust investigations at ASDEX Upgrade

RF driven negative hydrogen ion source development for the ITER NBI system

IPP RF source is the reference source for ITER

Future Work:

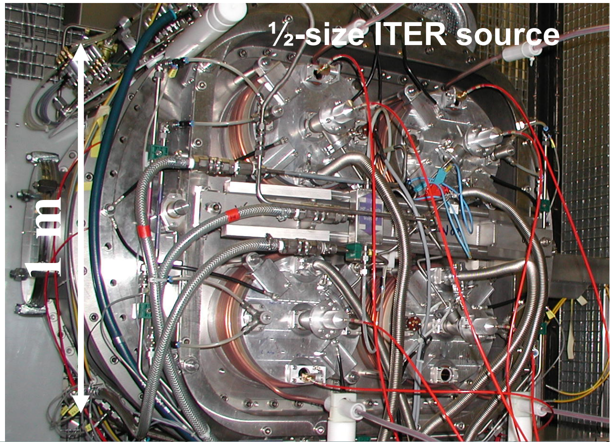
- ITER NNBI Design & Technology

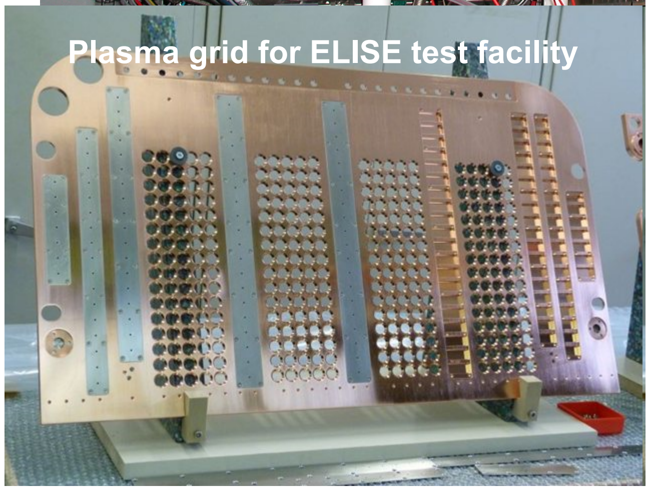
  main test facilities: **ELISE (IPP, >2012)**, SPIDER (RFX, >2014), MITICA (RFX, >2016)

- DEMO NNBI Design & Technology

  improve plug-in efficiency to 0.6 → Laser Neutralizer

  improve reliability → Cs free ion source



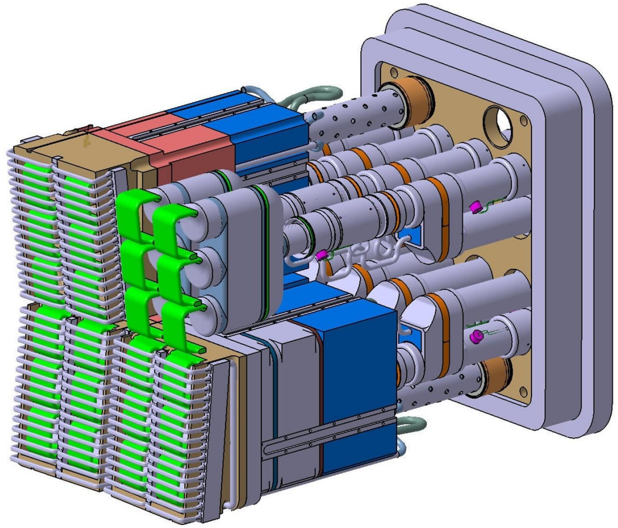


done in close collaboration with other associations (RFX, CCFE, KIT, CIEMAT)

Further heating systems

- ICRF
  - IPP is part of the CYCLE consortium

  → development of the ITER ICRF antenna design
  - Application of ICRF in all metal machine



- ECRH
  - IPP is part of the ECHUL consortium

  → coordination of the physics analysis

Increased activities in reactor studies

In the framework of EFDA (PPPT)

- both for tokamaks and stellarators
- Involve physicists and engineers
- Materials (use of test facilities, AUG)
- Heating systems (NNBI, ICRH)
- Theory: Improved system code

Education and Training

Joint appointments with universities:

- TU München (physics, mathematics, engineering)
- LMU München
- EMAU Greifswald
- TU Berlin

honorary professorships at several universities

- Engineers (W7-X construction!)
- Operators (in sheets only session leaders given)
- Physicists (Theory and Experiment)