Max-Planck-Institut für Plasmaphysik

IPP

ASDEX Upgrade – Capabilities and Plans

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Max-Planck-Institut für Plasmaphysik

- Technical capabilities
- Mid-term (~ 2020) plans
- Opportunities for collaboration

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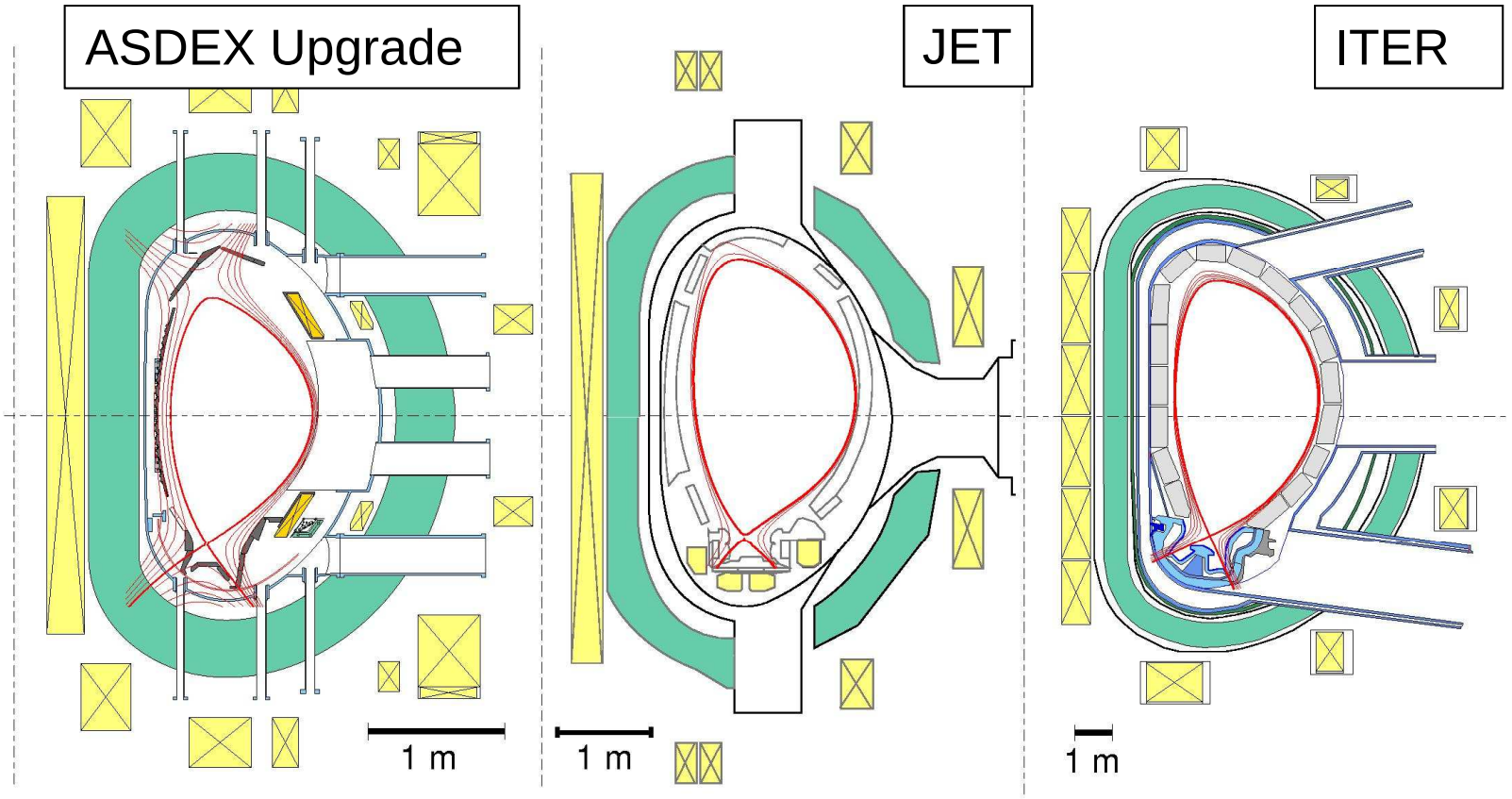
ASDEX Upgrade and JET: ‘Step ladder to ITER’



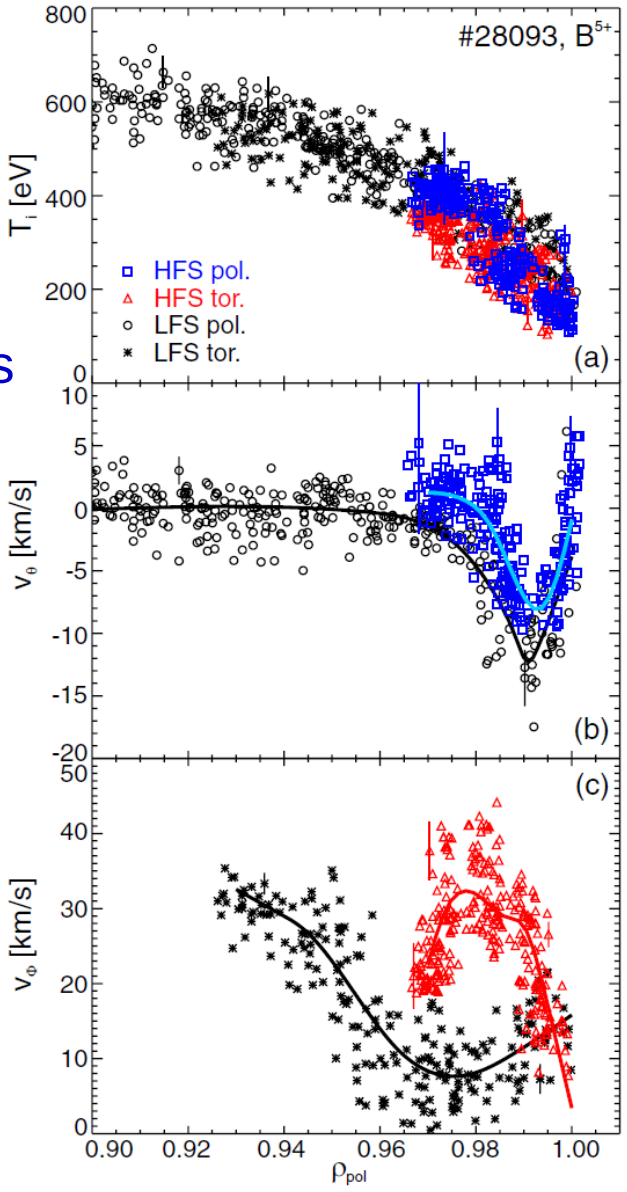
ASDEX Upgrade is part of the EU ‚step ladder‘ to ITER

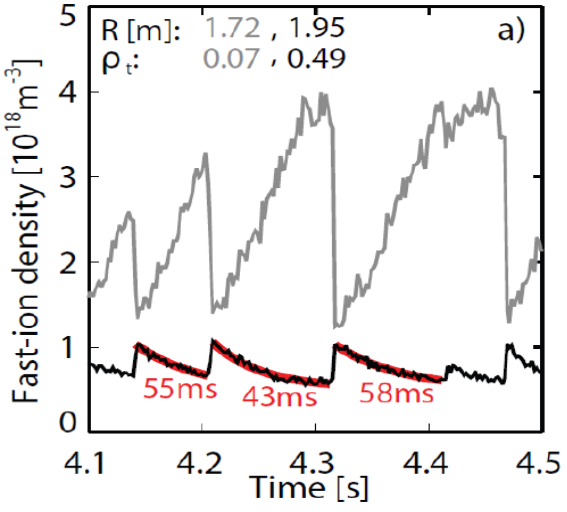
- plasma shape, aspect ratio similar to JET, ITER
- smallest device on step-ladder is the most flexible
- note: ASDEX Upgrade coil set DEMO-relevant (re. blanket)

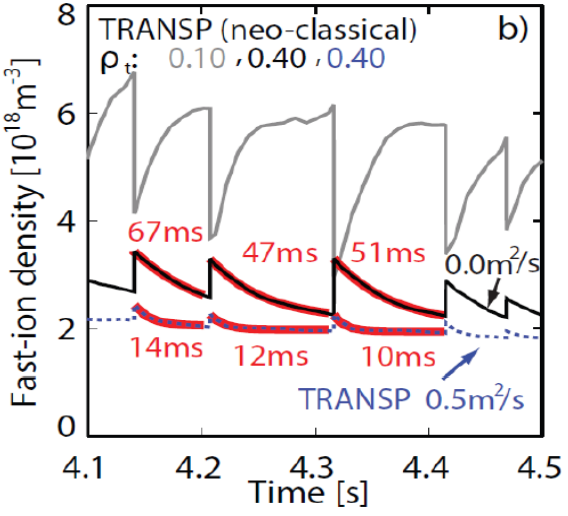
ASDEX Upgrade diagnostic set

Over the last ~20 years, we have developed a world-class diagnostic set

- comprehensive diagnostic set with high radial and temporal resolution
- examples for (physics driven) special emphasis
  - pedestal
  - fast ions
  - …

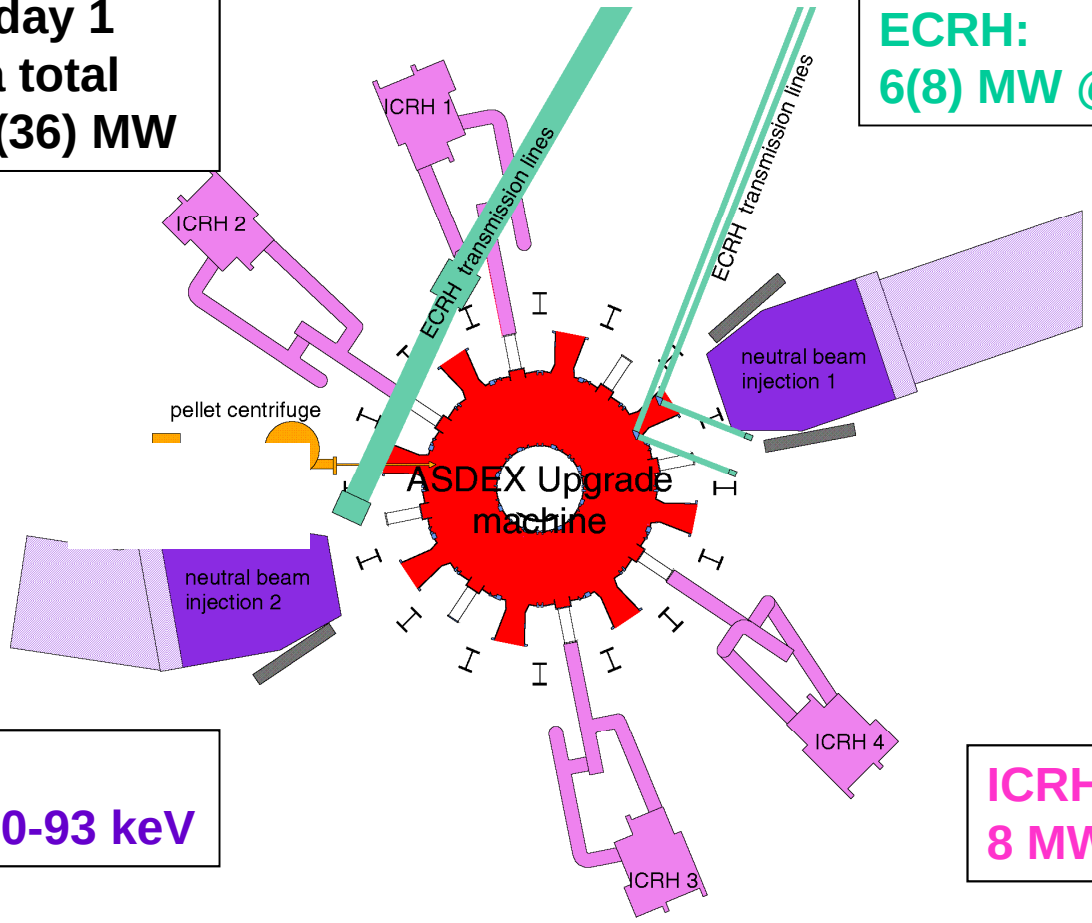






ASDEX Upgrade H&CD systems

All three ITER day 1 systems with a total of $P_{installed}$ ~ 34(36) MW



ECRH:
6(8) MW @ 140/105 GHz

NBI:
20 MW @ 60-93 keV

ICRH:
8 MW @ 30-60 MHz

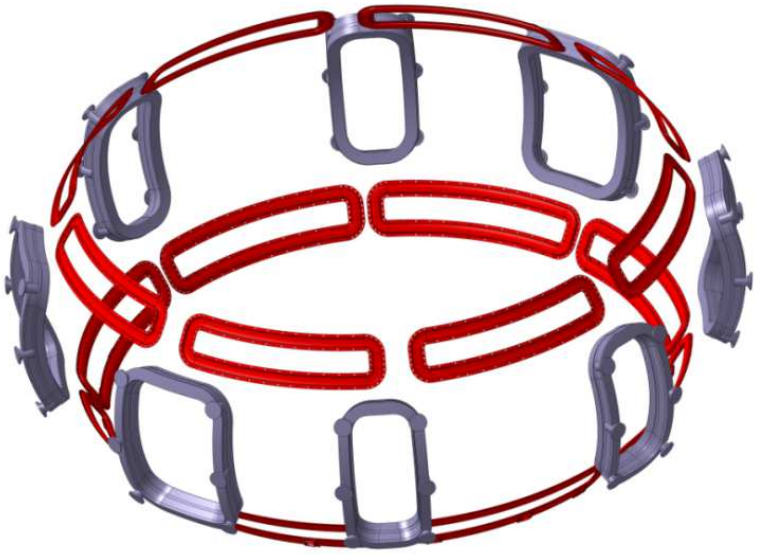
- allows to achieve ITER/DEMO relevant values of P_{sep}/R
- ongoing enhancements aim at capability for τ_{pulse}=10 s at full power

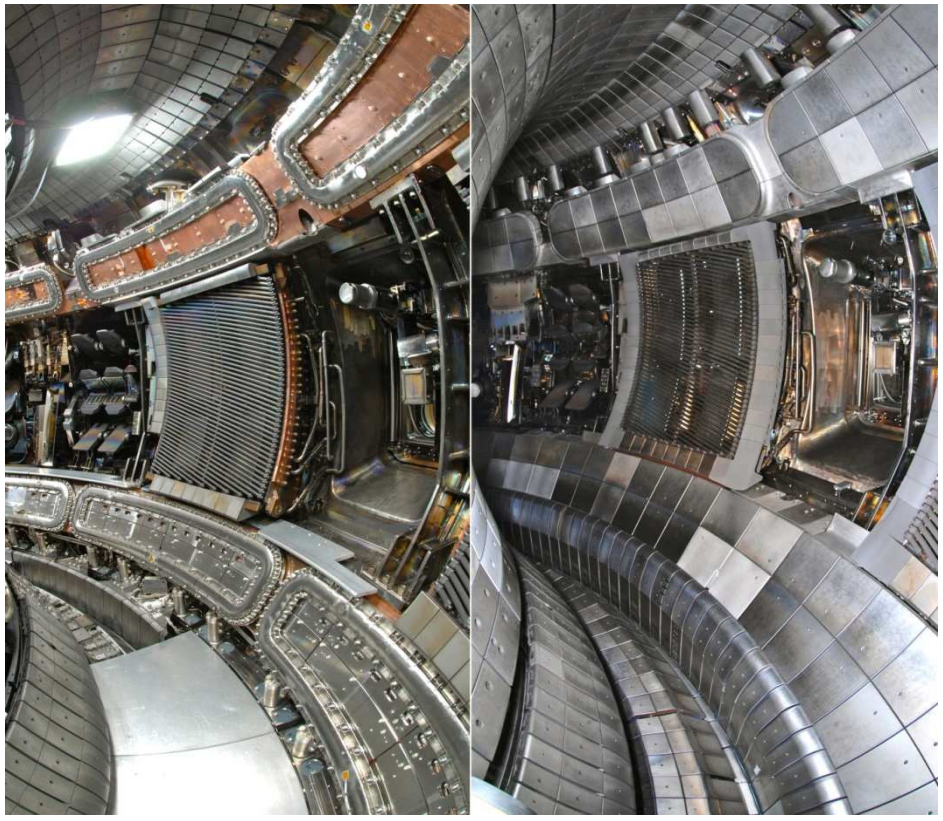
ASDEX Upgrade is equipped with a full-W wall

ASDEX Upgrade has pioneered modern tokamak operation with W-wall

- decisive input (together with JET) to ITER divertor strategy decision
- since 2014 equipped with solid W-divertor tiles in high power area
- innovative divertor manipulate allows to test large samples in situ

ASDEX Upgrade equipped with an n=4 RMP system

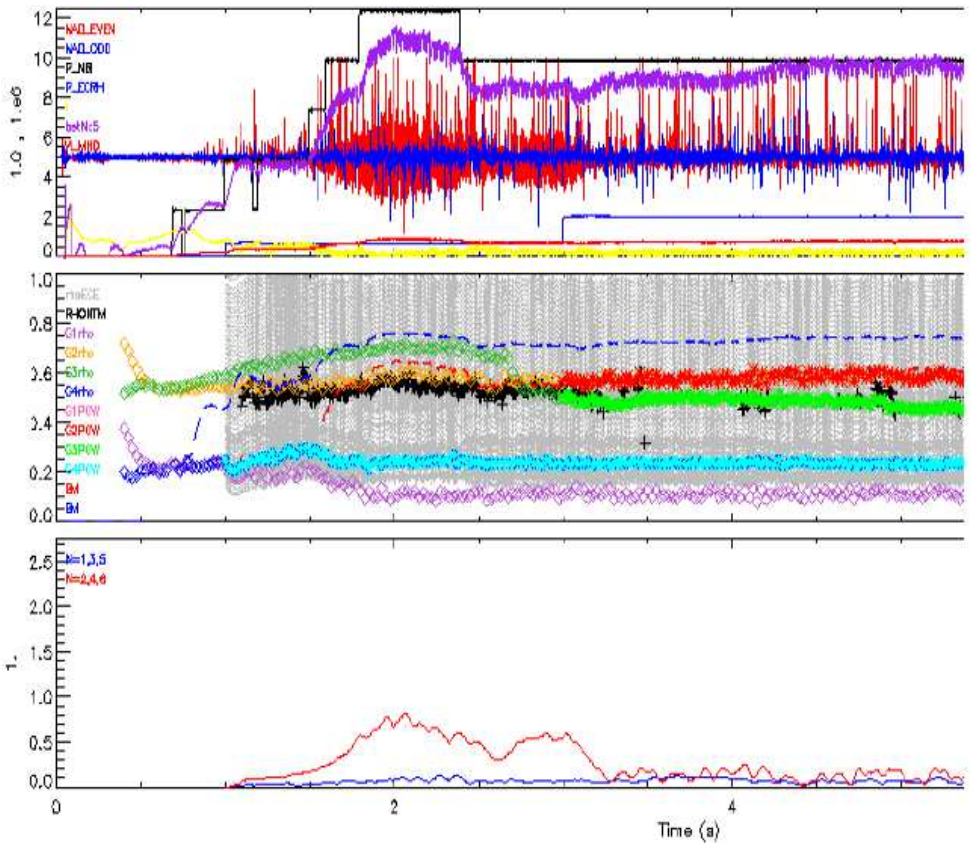




Flexible in-vessel coil system that allows n=1-4 perturbation fields

- ELM suppression in different collisionality regimes, MHD mode studies…
- general 3-d physics studies of vital interest for IPP ☺
- upgrade to provide rotating fields up to 500 Hz (RFA) just under way

ASDEX Upgrade: feedback control of discharges



mode activity
NBI power
ECRH power
stored energy

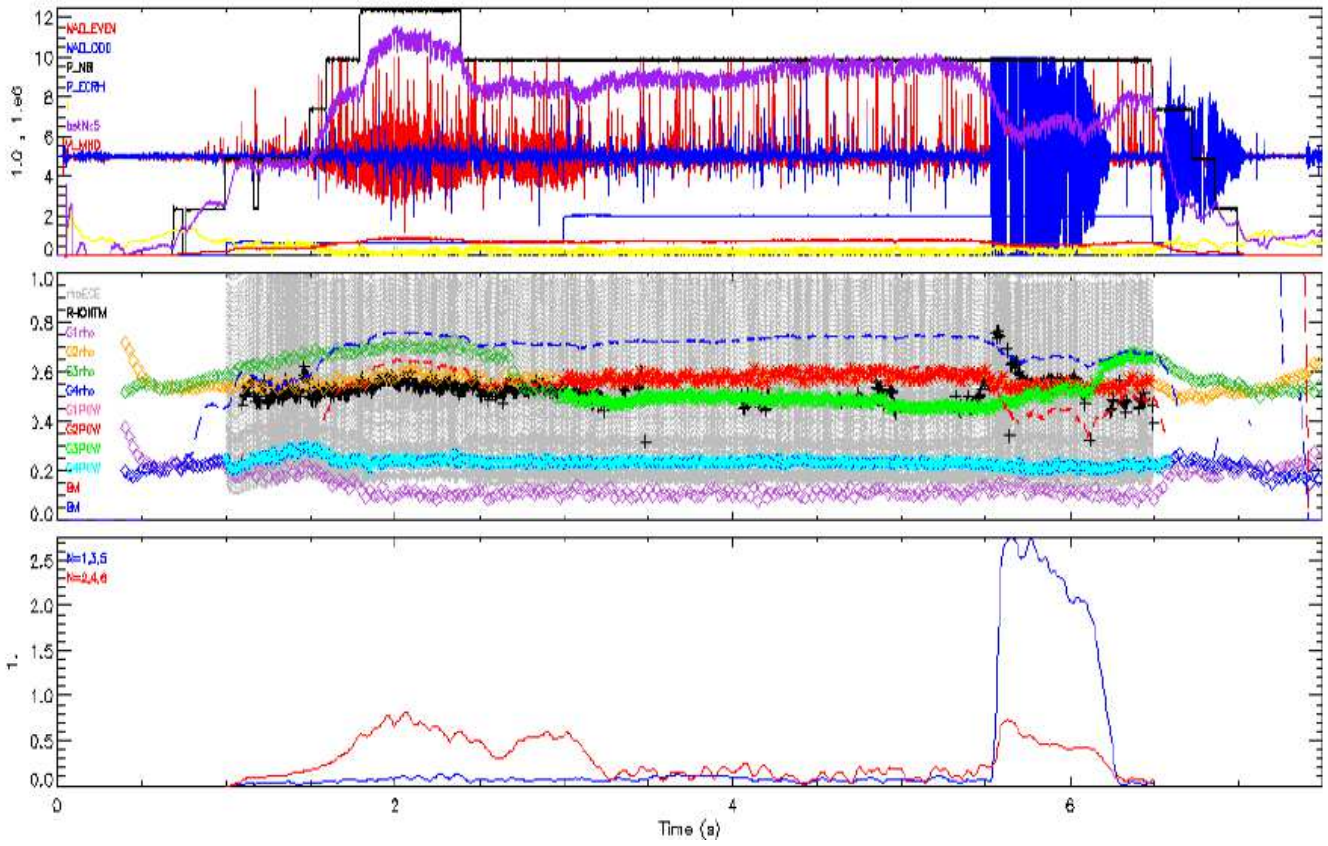
3/2 location
2/1 location
actual
deposition

(2,1) amplitude
(3,2) amplitude

ASDEX Upgrade digital control system can be extended in a modular way

- number of real time sensors and actuators steadily increasing
- ‚performance control' is becoming more and more sophisticated
- control group strongly involved in design of ITER system (collab. w/ GA)

ASDEX Upgrade: feedback control of discharges



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- Technical capabilities
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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

Prepare ITER operation

- develop operation scenarios that ensure baseline operation (Q = 10) and make possible 'advanced' operation (Q > 10 or steady state)

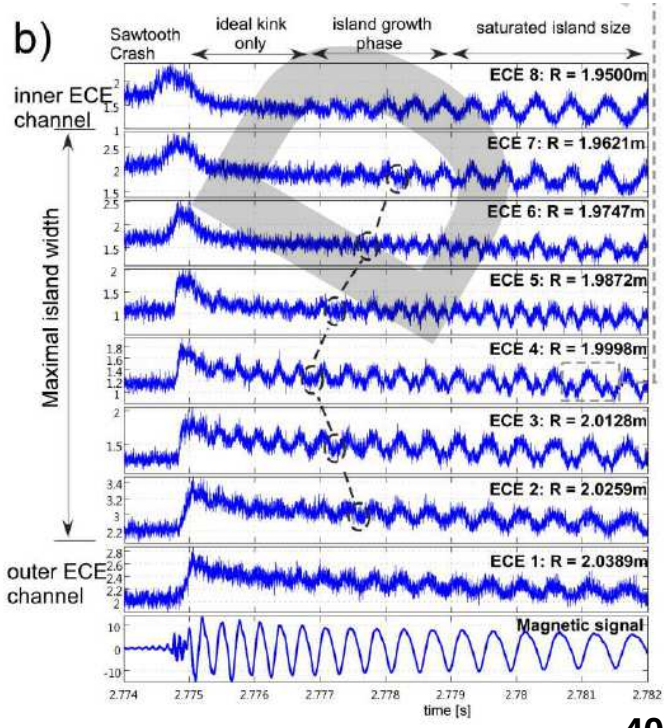
Develop and improve the physics base for DEMO (point design needs first principles understanding – strong interaction with theory)

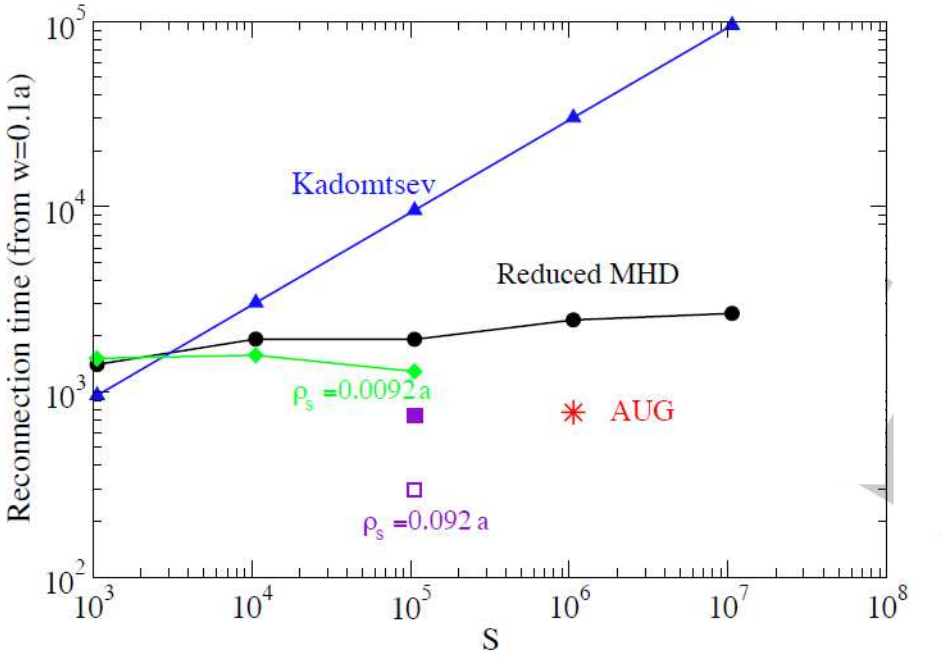
- address areas that are not essential for ITER reaching its goals but have to be solved for DEMO (= 'DEMO physics issues')

Educate fusion plasma scientists and engineers

- train and educate the generation that will run ITER

Future programme block 1: fusion plasma physics



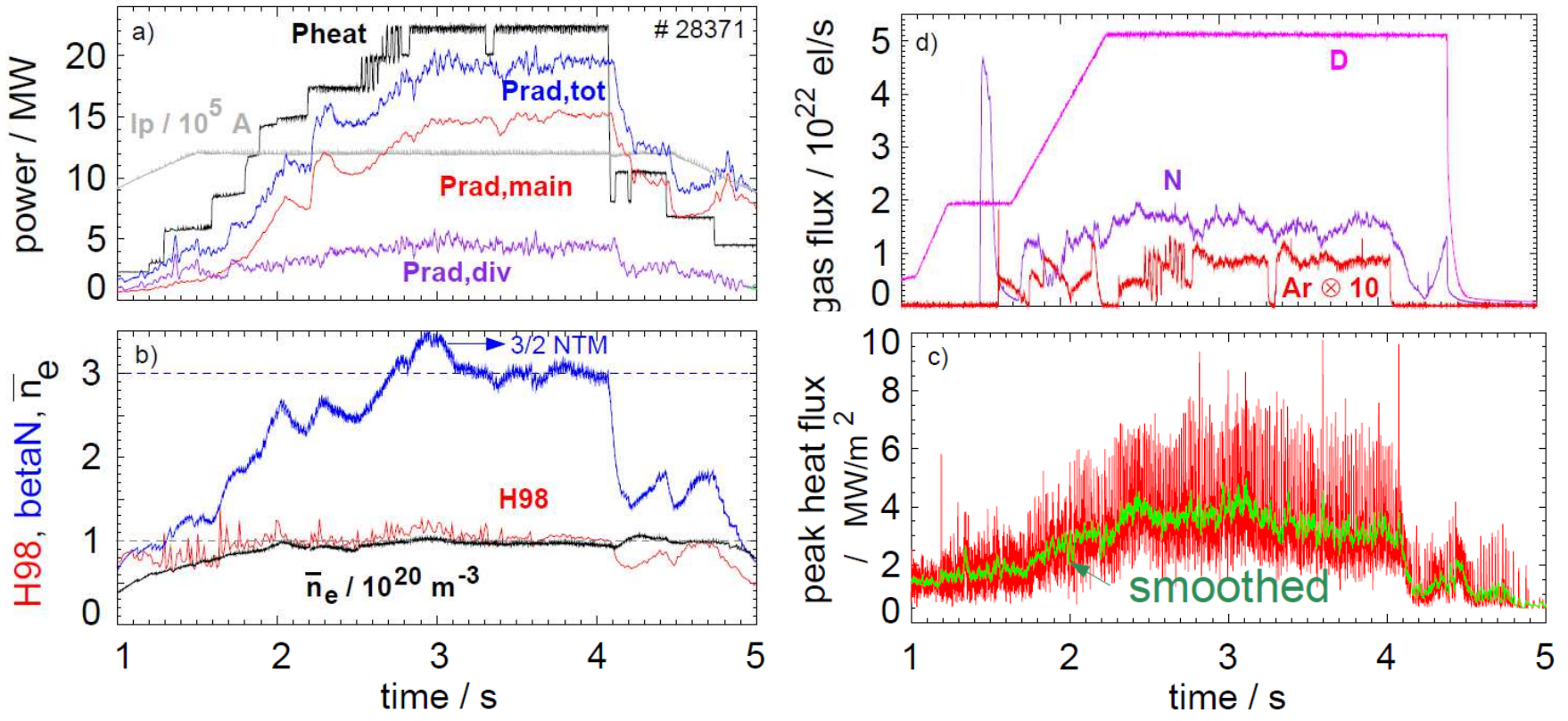


40 years after von Goeler and Kadomtsev… (PPPL collaboration)

Fusion plasma physics offers many opportunities for curiosity driven research

- often aligned with path to fusion reactor (collisionless plasmas are fun!)
- programmatically, this part provides the basis for sound extrapolation
- in this area, diagnostics extensions play a key role (as does theory)
- in future, IPP will have benefit of running in parallel tokamak and stellarator

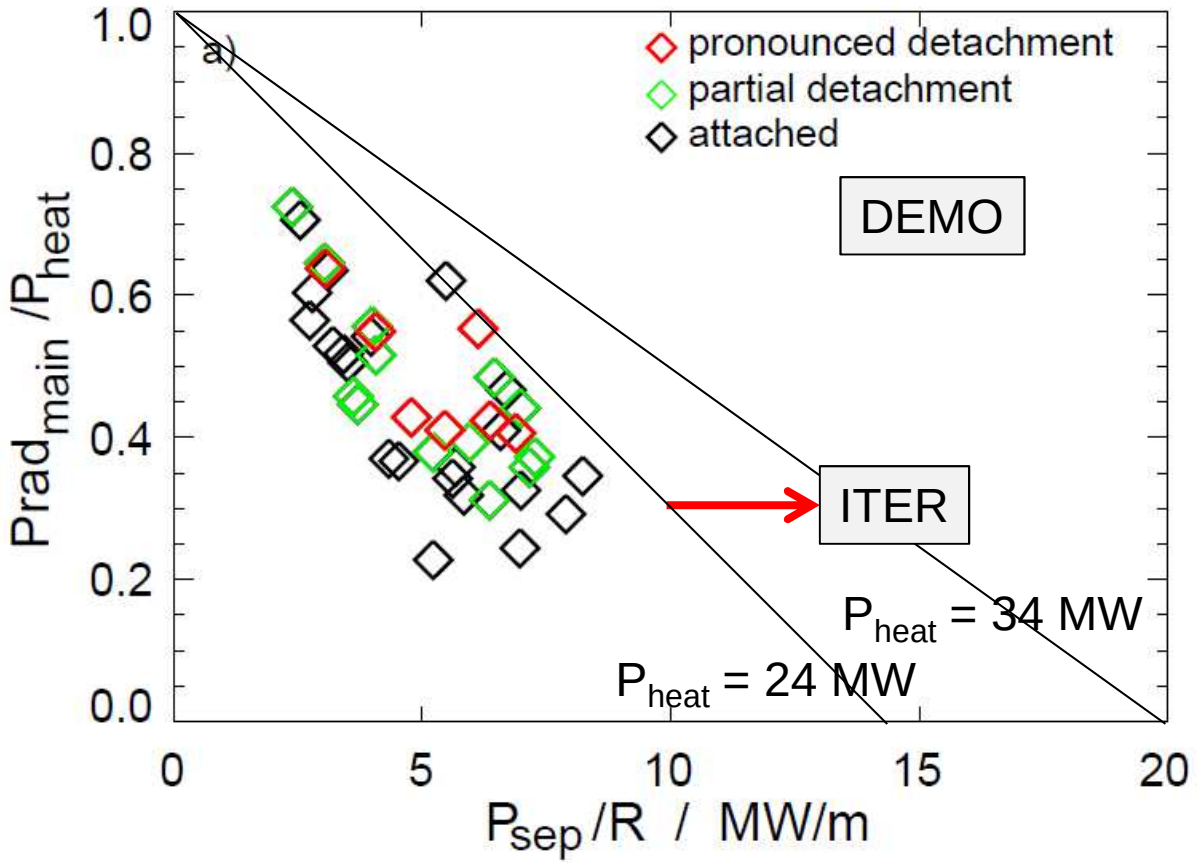
Future programme block 2: exhaust



Exhaust will be a crucial area for future fusion reactors

- ASDEX Upgrade aims at optimisation of conventional divertor configuration
- experiments need to show both high $P_{rad,core}/P_{tot}$ and high P_{sep}/R
- example: high core radiation using double seed impurity feedback

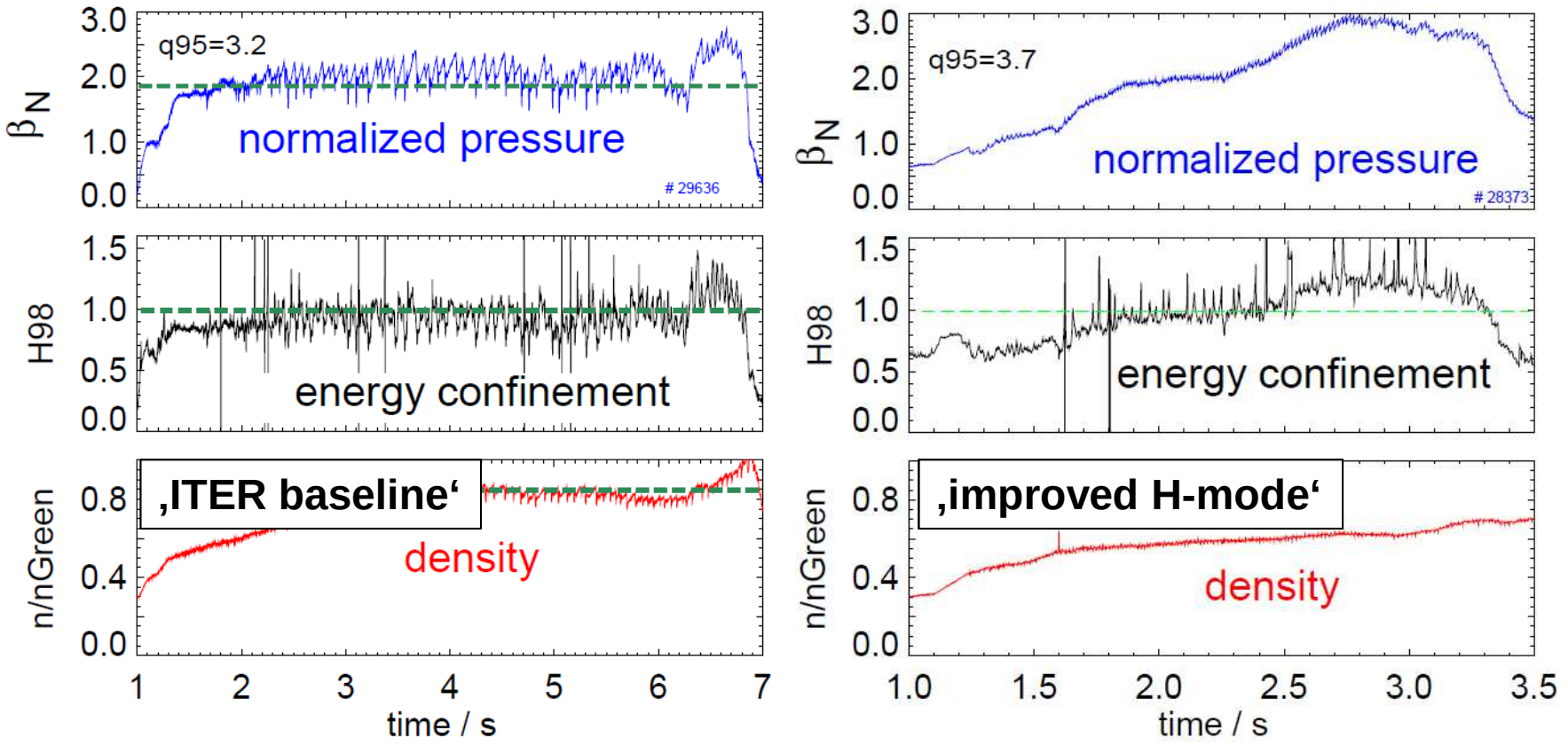
Future programme block 2: exhaust



Enhancement of capabilities aims at demonstrating ITER / DEMO solutions

- heating power and pulse length extension leads to ITER P_{sep}/R-values
- sophisticated feedback schemes to address detachment control

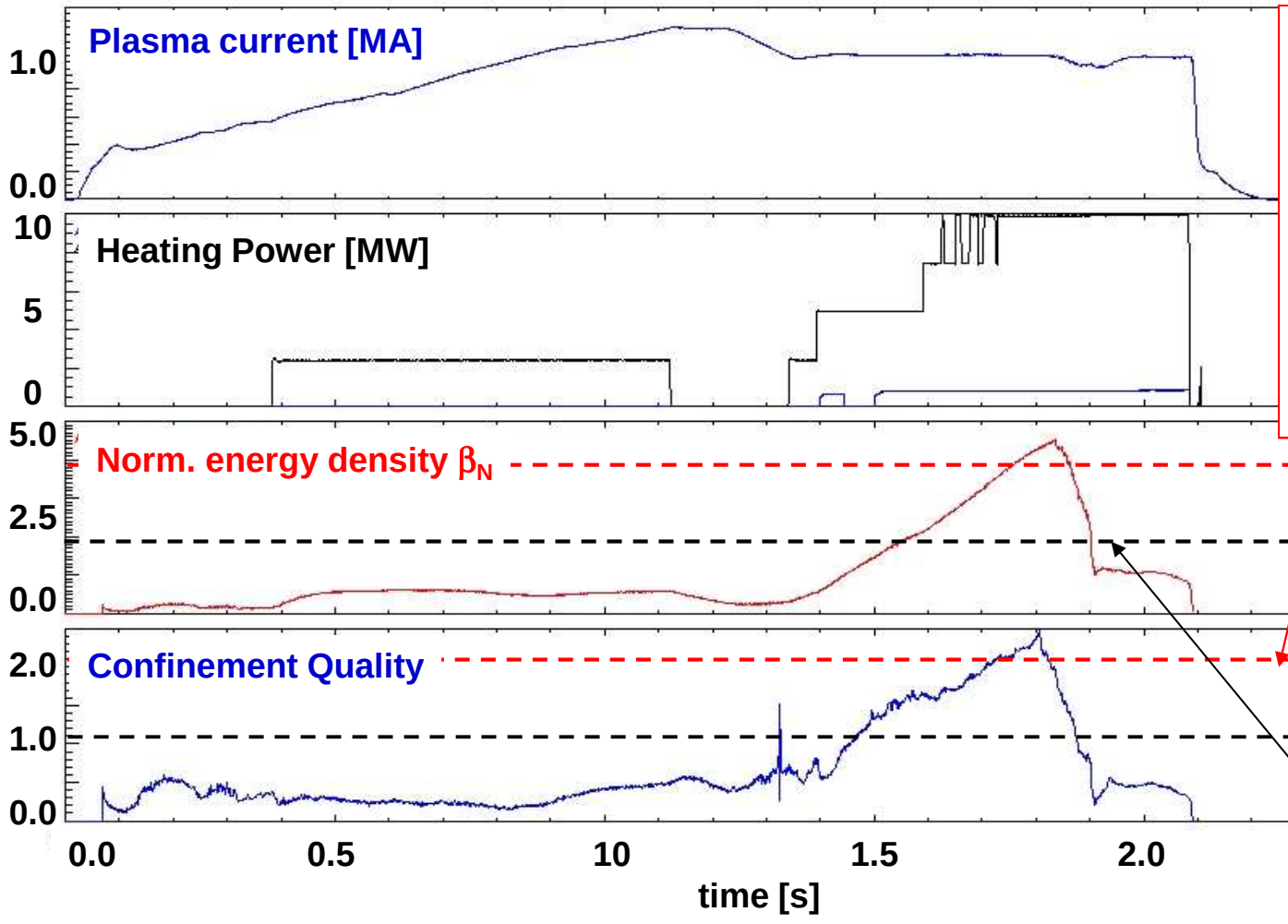
Future programme block 3: scenario integration



Development of realistic advanced scenarios remains a challenge

- H&CD extension will provide CD capabilities to optimise q-profile
- higher heating power + solif W-divertor allows to access lower ν^*
- integrated control will be key also in this area (link to exhaust!)

Future programme block 3: scenario integration



ITER @ H=2, β_N=3.6:
$Q \rightarrow \infty$, P_{fus} = 1.6 GW

or (at 10 MA):
$Q \rightarrow \infty$, P_{fus} = 800 MW
τ_{pulse}= 4000 s

or (at 8 MA):
Q=10, P_{fus} = 400 MW
$\tau_{pulse} \rightarrow \infty$

ITER baseline
(H=1, β_N=1.8):
Q=10, P_{fus} = 400 MW
τ_{pulse} = 400 s

There is still significant room for improvement…

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

- Technical capabilities
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Collaborations on ASDEX Upgrade dominated by EU

Direct financing of experimental time under ‚Medium Size Tokamak' programme of the EUROfusion consortium

- roughly 40 % of the programme is executed in EU collaboration
- limits the capacity for international co-operation

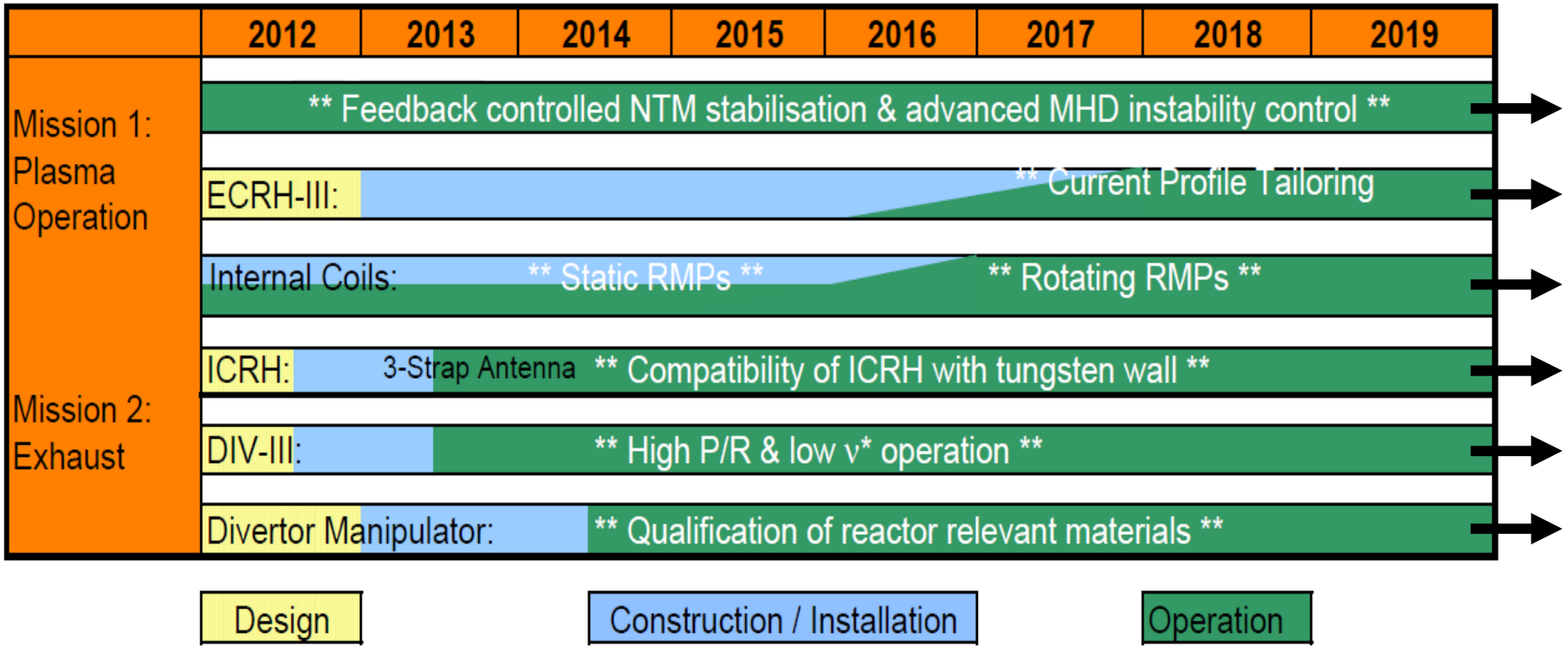
Traditionally, collaboration with US on specific topics very successful

- GA collaboration on MHD stability wins 2 APS awards in 2014 ☺
- C-Mod collaboration in boundary has been area quite successful
- collaboration with PPPL has largely been on theory side

While existing US collaborations will certainly continue, new collaboration projects should be a 'win-win' situation e.g. centered around hardware

- example MIT (A. White et al.) – turbulence studies on ASDEX Upgrade
- possible example U Madison (D. Demers et al.) - HIBP
- example W7-X – DoE collaboration: trim coils

Summary and outlook: time schedule



ASDEX Upgrade is an essential part of the EU H2020 funding period

- financing of upgrades and experimental programme secured until 2020
- after that ASDEX Upgrade can still play a major role preparing and then accompanying ITER operation while at the same time preapring DEMO