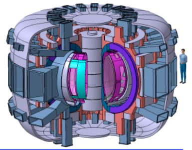


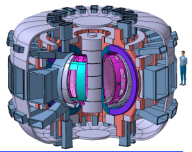
The FAST Proposal

***F**usion **A**dvanced **S**tudies **T**orus*

Presented by
Fulvio Zonca
On behalf of the FAST Physics Team

The Italian Fusion Association

Scope of the FAST proposal



- The Fusion Advanced Studies Torus (FAST) is conceived as proposal of a EU ITER-Satellite complementing capabilities and missions of JT60-SA

- The scientific basis and plasma scenarios in FAST are set for allowing integrated studies of a large number of burning plasma physics issues and operational aspects

- Ultimately: as JT60-SA, FAST is aimed at efficient exploitation of ITER, which is essential to anticipate early DEMO design & construction

Scientific basis and Rationale

FAST is designed to be capable of:

a) working in a dimensionless parameter range as close as possible to that of ITER (key for physics integration; this talk)

b) investigating, to the largest possible extent, the key ITER operational issues: ELMs, Plasma Wall Interaction, Wall Load, Heating coupling …

c) exploring innovative solutions for the first wall/divertor relevant for ITER and DEMO, such as full-tungsten plasma facing components and advanced liquid metal divertor target;

d) functioning as test bed for ITER and DEMO diagnostics

Physics Integration

FAST works in a dimensionless parameter range as close as possible to that of ITER for:

a) investigating alpha particle non linear dynamics and thermal plasma transports in burning plasmas, fast ions are produced by heating and current drive systems $\Rightarrow$ corresponds to fixing $\rho*$, β , $\tau_{SD}/\tau_{E}\sim\beta_{H}/\beta$

b) Controlling edge physics conditions, PWI and core-edge coupling in (a) $\Rightarrow$ corresponds to fixing T (and P/R)

c) exploiting advanced regimes with long pulse duration up to full non-inductive current driven (NICD) scenarios;

d) providing a framework for model and numerical code benchmarks (V&V) in ITER and DEMO relevant plasma conditions

Parameters for Physics Integration

FAST works in a dimensionless parameter range as close as possible to that of ITER for:

a) Investigating cross-scale couplings and complex behaviours in burning plasmas $\Rightarrow$ corresponds to fixing

$\rho*$, β , τ_{SD}/τ_{E}~β_{H}/β

I. $\rho*$ ($\rho_{H}*$) preserves dimensionless scales and cross scale couplings (relationship T $\Leftrightarrow T_{H}$ set by dominant electron heating through fast ion slowing down)

II. β~$(\omega_{ti}/\omega_{A})^{2}$ preserves frequency cross-couplings between meso- and micro-scales fluctuations and free energy source strength (τ_{SD}/τ_{E}~β_{H}/β)

b) Controlling edge physics conditions, PWI and core-edge coupling in (a) $\Rightarrow$ corresponds to fixing T (and P/R)

I. Heating Power is chosen to meet P/R

A new ‘weak’ similarity scaling (I)

- The similarity argument [Kadomtsev 75] is based on the existence of three dimensionless parameters in the equations governing quasi-neutral, collisional, finite-β plasmas; i.e., ρ^*, β and ν^*.
- For fixed equilibrium geometry and profiles: one free quantity to choose among B, R, n and T [Lackner 90] nR^2, $BR^{5/4}$ and $TR^{1/2}$, with R free
- Caveat for fixing T as well (PWI, Fusion Yield): Using the collection of ρ^*, β and ν^* and T, on the other hand, makes it impossible to define a non-trivial set of similarity experiments [Lackner 98].

A new 'weak' similarity scaling (II)

- The choice underlying the FAST scientific rationale consists in fixing $\rho^* R^{\varepsilon}$, β and $\tau_{SD}/\tau_E \sim \beta_H/\beta$, with $\varepsilon = 1/2$
- Fixing T (or equivalently R) corresponds to controlling edge physics conditions and PWI
- For $\varepsilon = 0$ this argument gives back Kadomtsev/Lackner scalings at fixed ρ^*, β and ν^* and T.
- The choice of relaxing ρ^* scaling is motivated by:
  - Cross-scale coupling (micro-meso scales) is preserved for ρ^*_H/ρ^* set by T_H/T given by condition of dominant electron heating (~70% as fusion alphas in ITER)
  - Relaxing β scaling would imply relaxing the frequency ordering of meso- to micro-scale fluctuation spectra

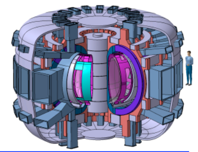
A new ‘weak’ similarity scaling (III)

- The choice of fixing $\rho^* R^{\varepsilon}$, with $\varepsilon=1/2$, β and $\tau_{SD}/\tau_E \sim \beta_H/\beta$, corresponds to the new “weak” similarity scaling proposed for FAST
- “Weak” scaling in the mathematical sense: intended as argument reproducing a general result under less stringent assumptions, which are relaxed in a controlled way and yield the original “strong” result in the appropriate limit
- The obtained “weak” scalings are

$$T \propto R^{1/3},\ \ I_p \propto R^{2/3},\ \ B \propto R^{-1/3},\ \ n/n_{GW} \propto R^{1/3},$$

$$P_{ADD}/R \propto R^{-1/6},\ \nu^* \propto R^{-2/3}\ ,\ \tau \propto R^{3/2}$$

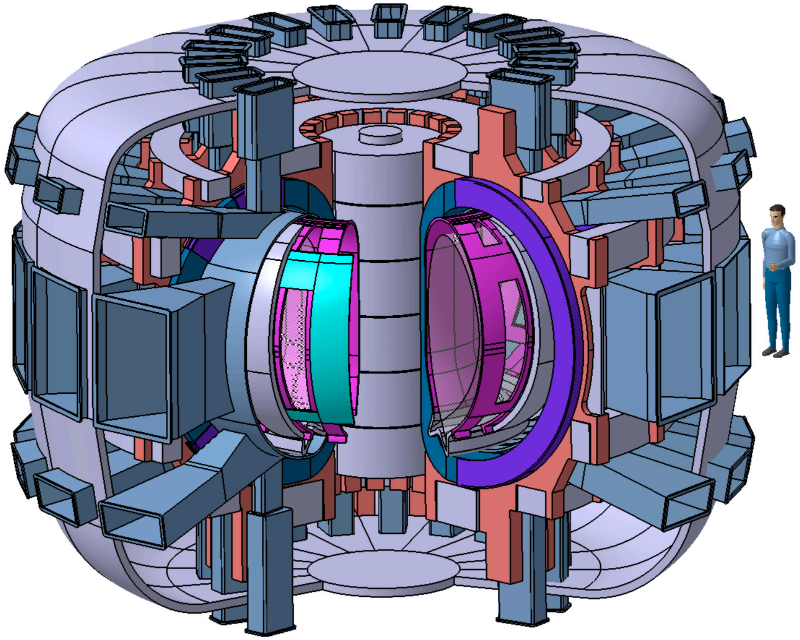
Choice of FAST parameters



- FAST is aimed at achieving its missions without technology (cost) complications of active cooling and/or superconducting magnets (complementing JT60-SA).
- Since $T \propto R^{1/3}$ and $\tau \propto R^{3/2}$ pose limitation(s) on dimensions (discharge duration) to avoid toroidal field coils heating, FAST is designed to have R=1.82m and t=170s
- Given ITER and FAST dimensions, "weak" similarity scalings would imply $T \cong 13$keV, $I_p \cong 6.8$MA, $B \cong 8$T by similarity scaling with an ITER H-mode scenario at $T \cong 20$keV, $I_p \cong 15$MA, $B \cong 5.3$T

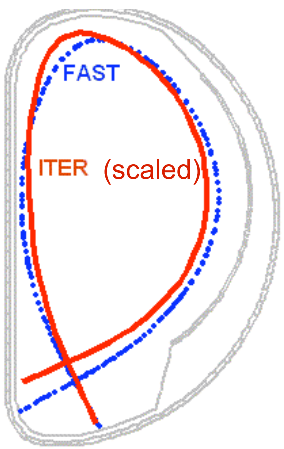
R(m)	T(keV)	B(T)	I_p(MA)	n($10^{20}m^{-3}$)	P(MW)	t(s)	Cost(M€)	Q
1.82	13	7.5	6.5	2	30	170	300	.65
2.4	14	6.8	7.8	1.5	38	260	1.9×	.85
3.0	15	6.3	9.1	1.2	45	360	3.2×	1.1

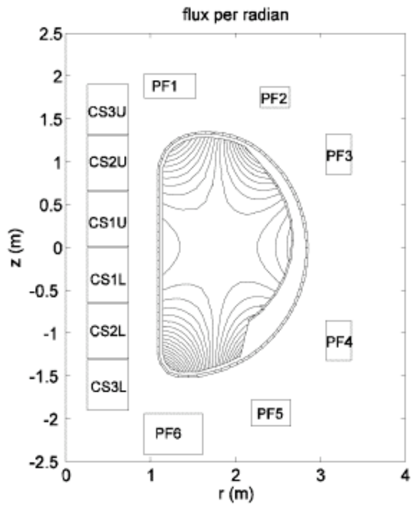
FAST Conceptual Design



FAST main parameters

Plasma Current (MA)	≤ 8
B_T (T)	≤ 8.5
Major Radius (m)	1.82
Minor Radius (m)	0.64
Elongation k_{95}	1.7
Triangularity δ_{95}	0.4
Safety Factor q_{95}	3
V_p (m^3)	23
$\langle n \rangle$(m^{-3})	$\leq 5.5 \times 10^{20}$
Flat-top B_T (s)	15 -> 170
H&CD power (MW)	40
ICRH	30 (20)
ECRH	4 (10)
LH	6 (10)
NNBI	0 (10)
P/R (MW/m)	22





Additional Heating Issues

- Coupling of high ICRH power (up to 30 MW) with full-tungsten PFC:
  - Detailed integrated antenna design (TOPICA)
  - Max ICRH power needed only for extreme LFS ($r/a \leq 0.4$) absorption for fluctuation cross scale couplings studies
  - Flexibility of additional heating mix (ICRH+LH+ECRH)
- Coupling of 10MW of NNBI at 700 keV:
  - technological challenge with positive potential impact on the physics program: it allows flexibility on shaping of fast ion radial power deposition profiles
- On both aspects, collaborative efforts are in progress with CEA and are under discussion with IPP

H-mode reference scenario (I)

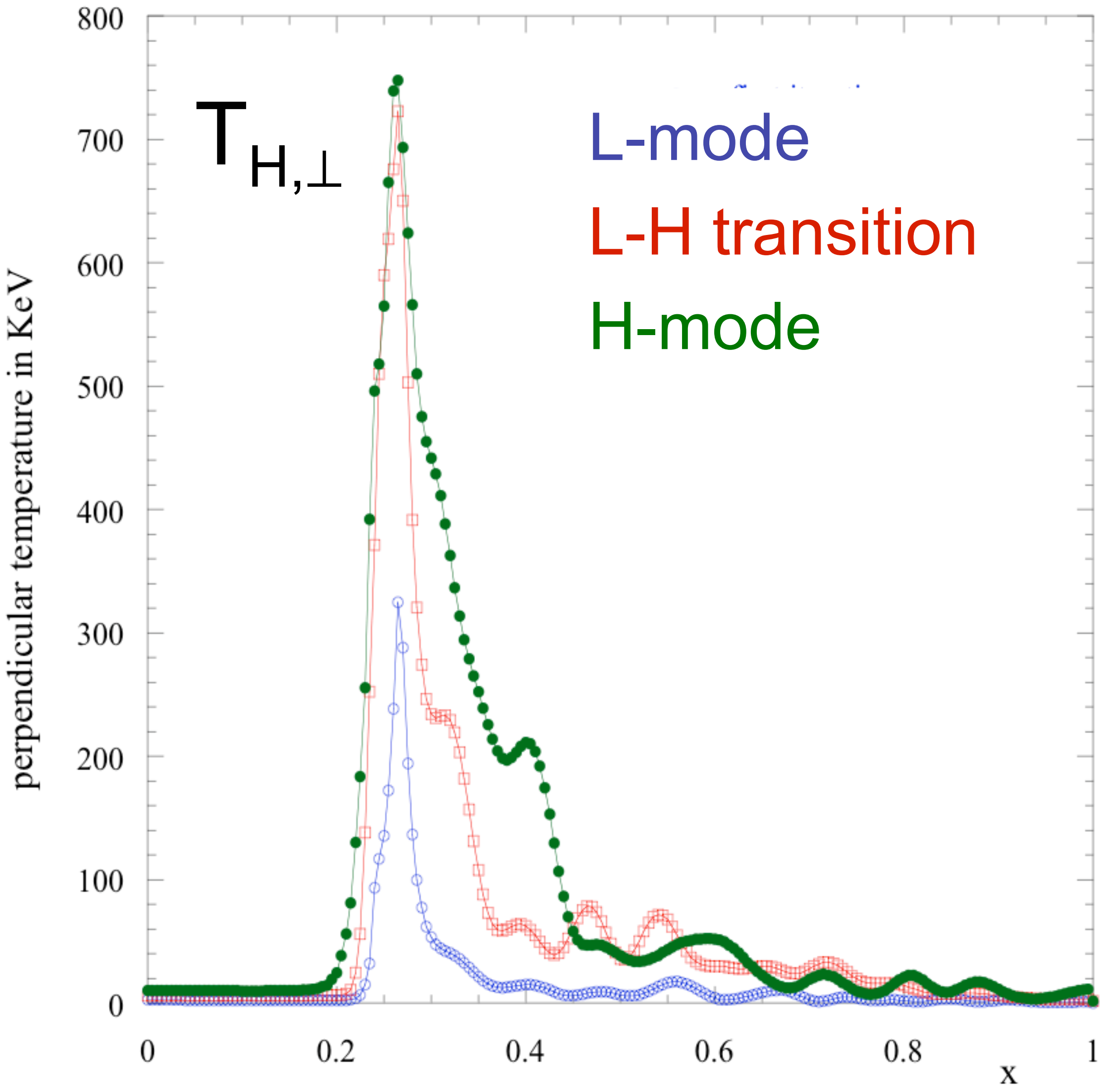
Simulation results confirm that Plasma will achieve

- T, n profiles compatible with an H mode scenario; He3 minority $n_{Hot}/\langle n\rangle \sim 5\times10^{-3}$
- $n(0) \sim 2.5\times10^{20}m^{-3}$; $n_{sep}\sim1.3\times10^{20}m^{-3}$;
- $T(0)\sim13KeV$; $\nu^* \sim 5.3\times10^{-2}$; $T_{HOT} \sim 800KeV$

	T(keV)	B(T)	I_p(MA)	n($10^{20}m^{-3}$)	$\rho_{HOT}{}^*$	β_{HOT}	ν^*
FAST	13	7.5	6.5	2.5	2.6×10^{-2}	0.7%	5.3×10^{-2}
ITER	20	5.3	15	1.0	2.5×10^{-2}	1.1%	9×10^{-2}

H-mode reference scenario (II)

- TORIC (ICRH coupling) + SSQLFP (Fokker-Planck), interfaced with JETTO: self-consistent numerical simulations of dynamic formation for H-mode reference scenario (low-field-side resonance)



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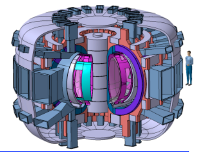

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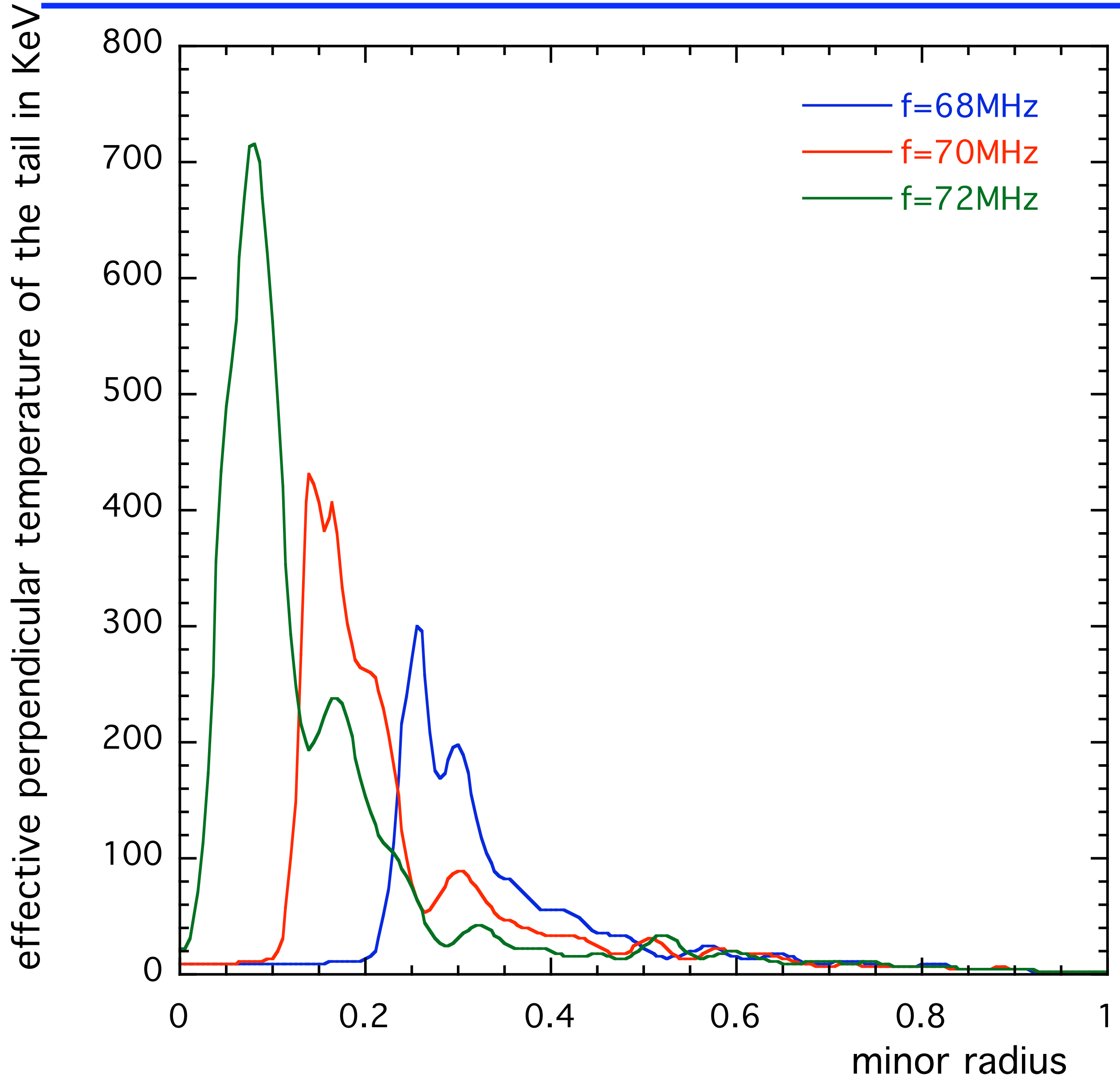
- Efficient ICRH coupling from LFS to HFS shows flexibility in studying cross scale coupling of DWT with collective modes excited by fast particles for $r/a\leq0.4$.
- Note that, just for fast particle generation/studies, 10 MW of ICRH could be sufficient

H-mode reference scenario (III)

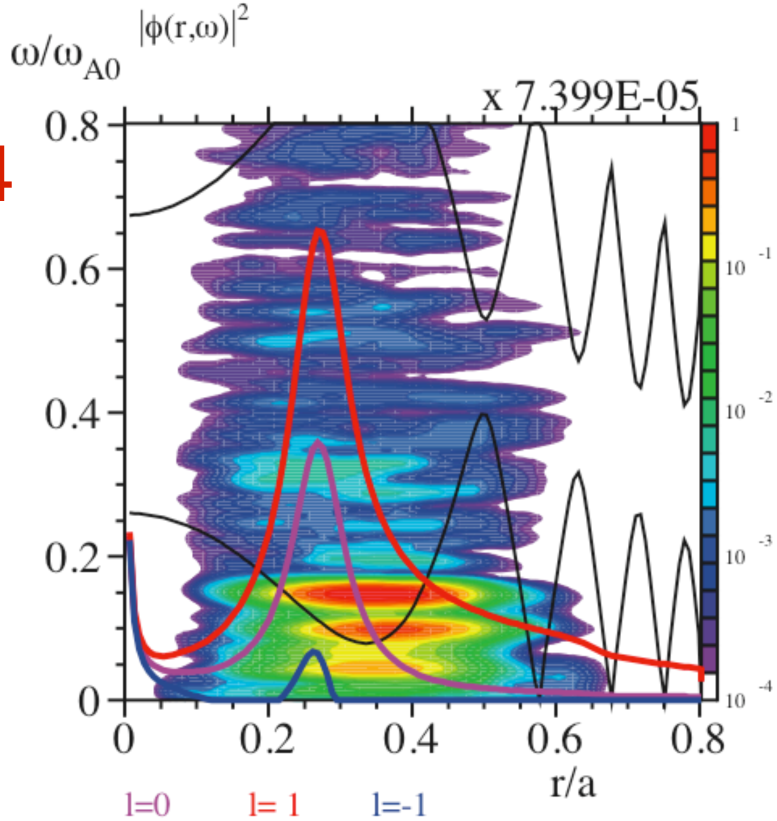


- Fixed freq. scan P_{ICRH}=10MW
- Constant β_H~1% at n_H~ $5\times10^{-3}\langle n\rangle$
- Flexibility on additional power mix. P=30MW from ICRH + LH + ECRH

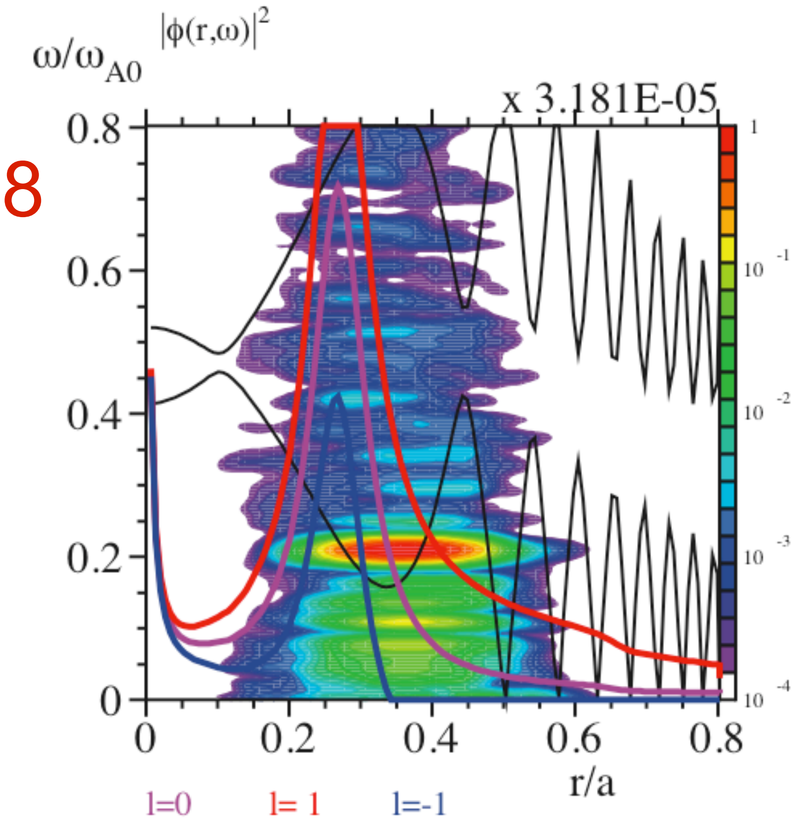
H-mode reference scenario (IV)

- Alfvén fluctuation spectrum dominated by a dense spectrum of modes (L. Chen IAEA 06 TH-OV).

n=4



n=8



- Hybrid MHD-GK simulations with HMGC code

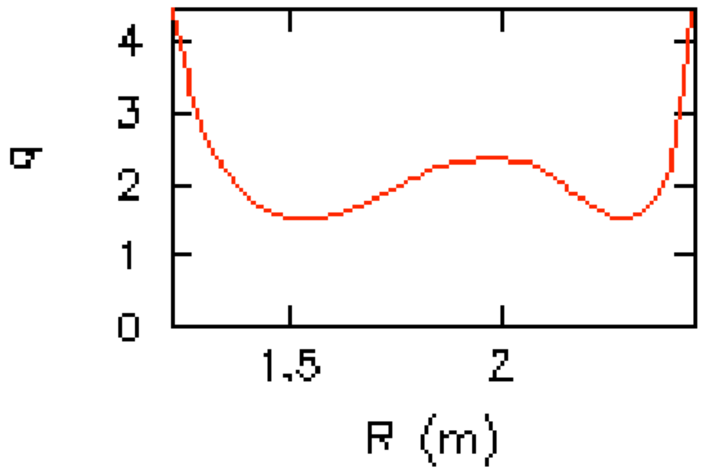
  (S.Briguglio, G.Vlad, G. Fogaccia et al.)

Long Pulse NICD Scenario

FAST	AT	AT2	Full NICD
I_p (MA)	3	3	2
q_{95}	5	3	5
B_T (T)	6	3.5	3.5
H_{98}	1.5	1.5	1.5
$\langle n_{20} \rangle$ (m^{-3})	1.2	1.1	1
P_{th_H} (MW)	8.5 ÷ 12	5 ÷ 7	5 ÷ 7
β_N	1.9	3.2	3.4
τ_E (s)	0.25	0.18	0.13
τ_{res} (s)	3	5 ÷ 6	2 ÷ 5
T_0 (keV)	13	13	7.5
Q	0.19	0.14	0.06
$t_{discharge}$ (s)	70	170	170
$t_{flat-top}$ (s)	60	160	160
I_{NI}/I_p (%)	60	80	>100
P_{ADD}(MW)	30	40	40

Three different scenarios proposed for Advanced Tokamak Studies

All of them assume a slightly reverse q profile and an improved H_{98} (=1.5)



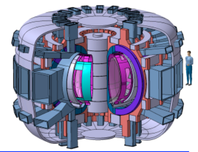
6MW of LHCD at 3.7 GHz assumed for CD and profile control for AT&AT2

6MW of LHCD at 5 GHz assumed for CD and profile control for NICD

LHCD and bootstrap well aligned with the q profile

4MW of ECRH assumed for central electron Heating and/or MHD control

FAST: theory and modeling



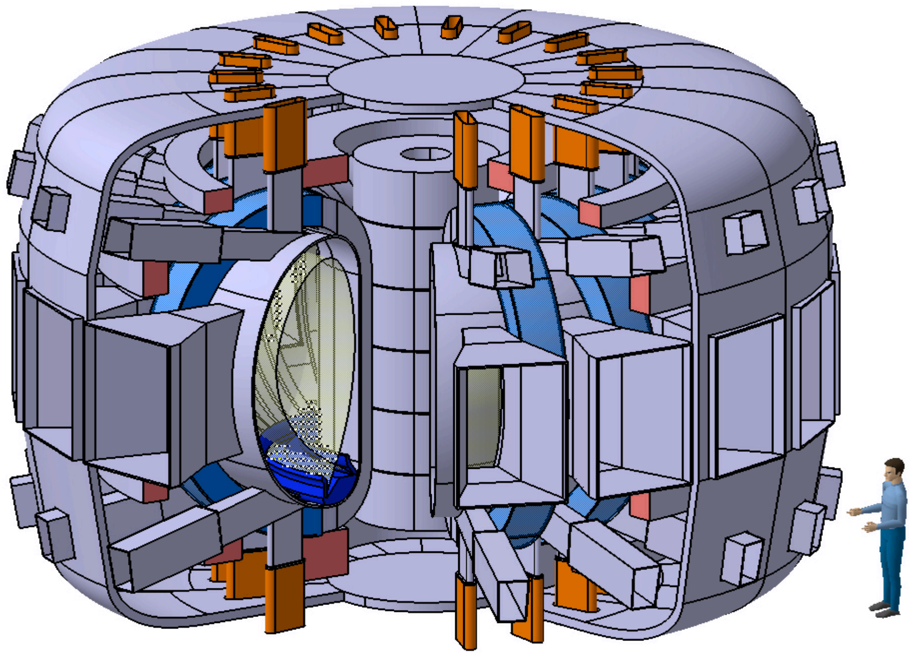
- FAST is a conceptual design of a EU ITER Satellite, thus it has strong Theory&Modeling support
- The scientific case and its main input is to stimulate discussions: reference scenarios will be made (**some are**) available for integrated numerical simulations (via EFDA ITM-TF framework and Gateway: your contribution is welcome)
- FAST can help responding to the need of “providing a suitable framework for model and numerical code benchmarks, as well as V&V, in ITER and DEMO relevant plasma conditions”.

FAST Load Assembly

FAST Load Assembly, consists of 18 TFCs, 6 CSs coils, 6 External Poloidal coils, the Vacuum Vessel (VV) and its internal components, including active control coils, and mechanical structure

Resistive coils, adiabatically heated during the plasma pulse, are cooled down at cryogenic temperatures (30 K) by helium gas (4 kg/s) max duty cycle 45 min.

The entire machine is enclosed by a vacuum metallic cryostat.



FAST Load Assembly

FAST: Cost & Manpower

Costs & manpower:

- Investment cost: < 300 M€
- Project Team: 120 PPY
- Operation Team: 150 PPY
- Operation cost: ~ 14 M€/y+personnel

FAST can be ready to operate in 2018 (6yrs construction +1yr commissioning) well in advance with respect ITER DT phase

In summary FAST …

- FAST is intrinsically "multi-dimensional" → ideal for "non-linear" physics with many time scales and threshold phenomena
- Is flexible and integrates many physics issues, so far only addressed separately
- Can provide a unique opportunity to explore unexpected physics issues thus helping in avoiding long and costly scenario development in ITER
- Is an ideal test bed to exploit advanced divertor materials and configurations (W. Liquid Lithium) suitable for DEMO
- Can be a key facility for international collaboration, training of young scientists in a ITER-class device for integrated physics and development of new diagnostics
- FAST and JT60-SA, being complementary satellites, can serve as strong and thorough basis and support for ITER