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Advanced Scenarios in JT-60U Integration towards a reactor-relevant regime

M. Kikuchi for the JT-60 team

JAERI

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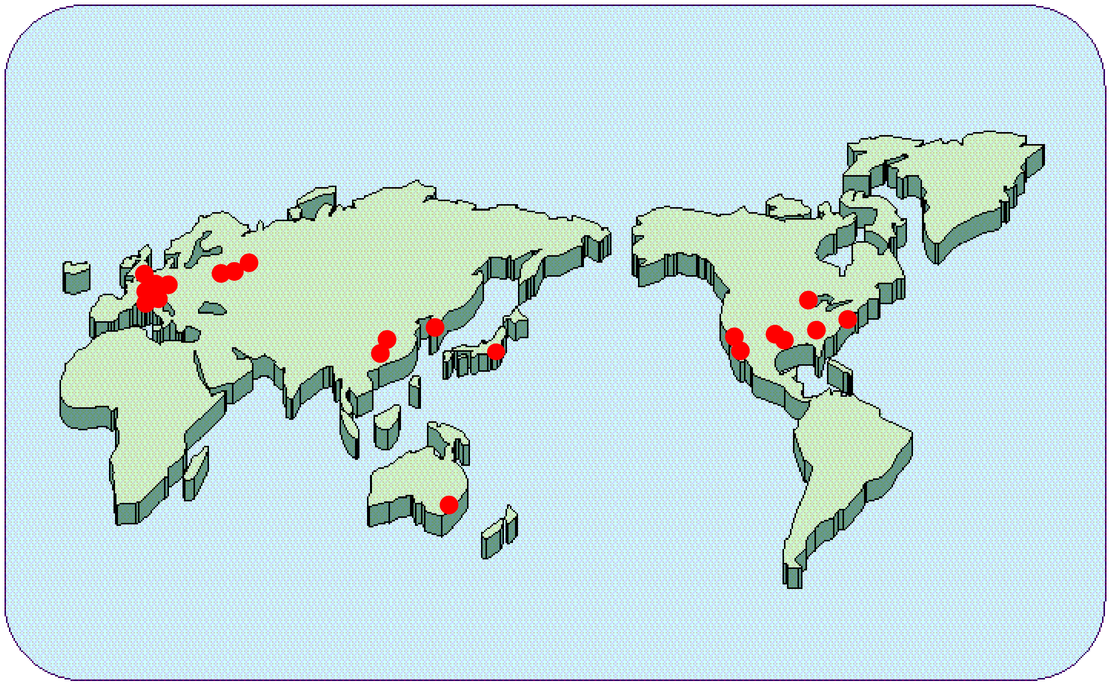
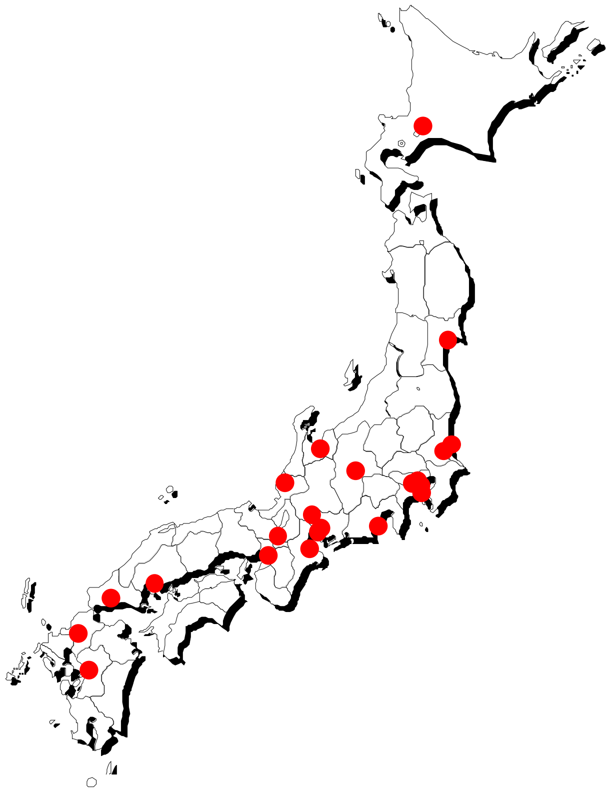




Viable tokamak reactor : high β steady-state

JT-60U

Advanced Scenario

1 . Current drive(CD)

- Bootstrap current fraction; 70–80%
- CD efficiency ; $3-5\times10^{19}$ A/m²/W
- Current profile/NTM control

2. High beta ; β_N = 3.5(SSTR)–5.5 (CREST)

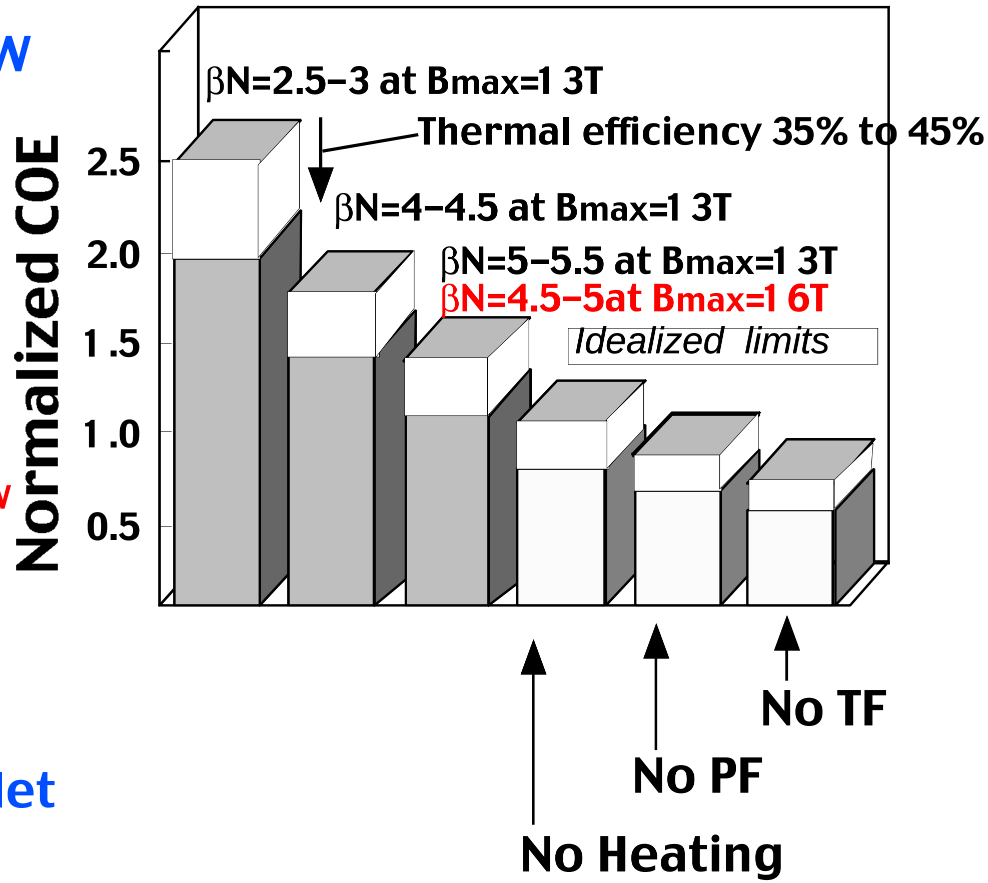
- Active control of RWM/NTM
- Simultaneous stability to AE
- Lower disruptivity & dIp/dt

3. Confinement ;1 –1 .4 xIPB98–y2 at $n_e \sim n_e^{GW}$

- Edge pedestal / profile stiffness
- Ex B shear flow, role of ITB

4. Divertor ; power and particle

- Heat : 90–95% rad., Type II ELM, killer pellet
- Particle: $\tau_{He}^*/\tau_E \sim 5$
- PSI: Metallic plasma facing component



Subcommittee for fusion development strategy May 1 7. 2000, N. Inoue et al.

JT-60 Mission and Progress

JT-60U

[1] Original Mission :

Achievement of equivalent break-even condition ($Q_{DT}^{equ} \geq 1$) set by AEC

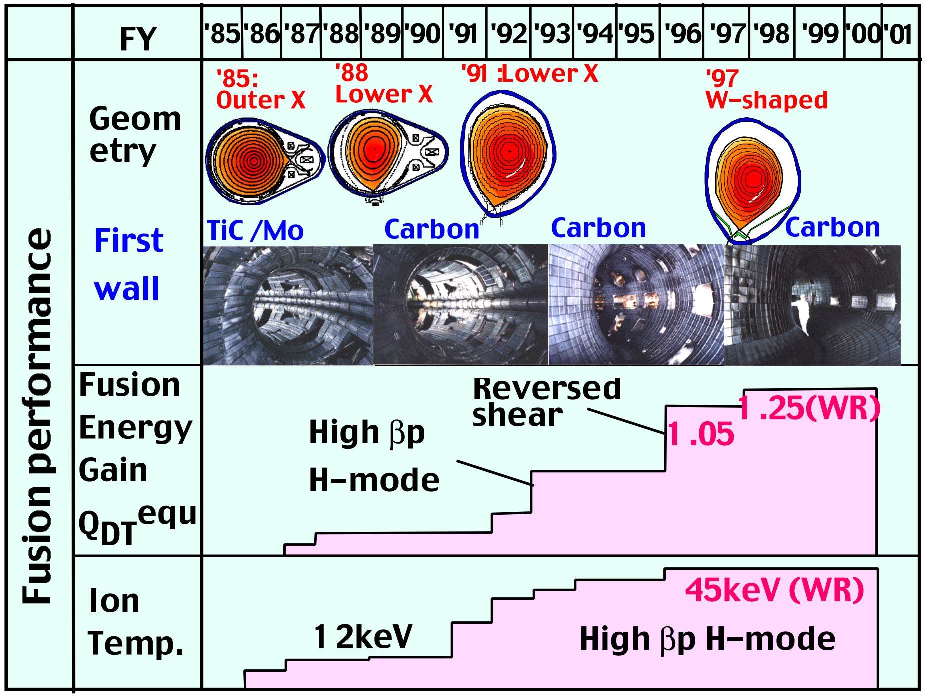
: Accomplished in FY1996

[2] New mission since 1991 :

Contribution to ITER physics R&D : contributions in all areas

Establish scientific basis of steady-state tokamak given in SSTR design.

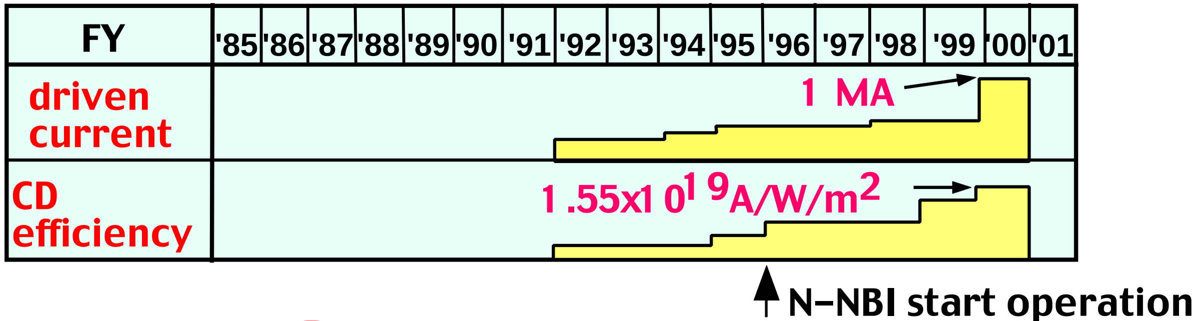
: Significant successes, still further improvement.

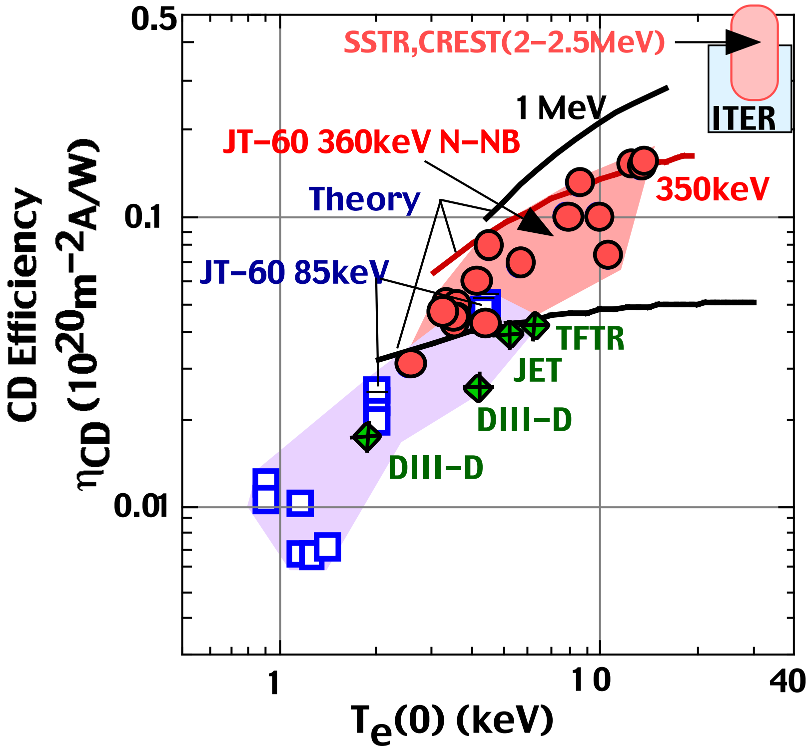


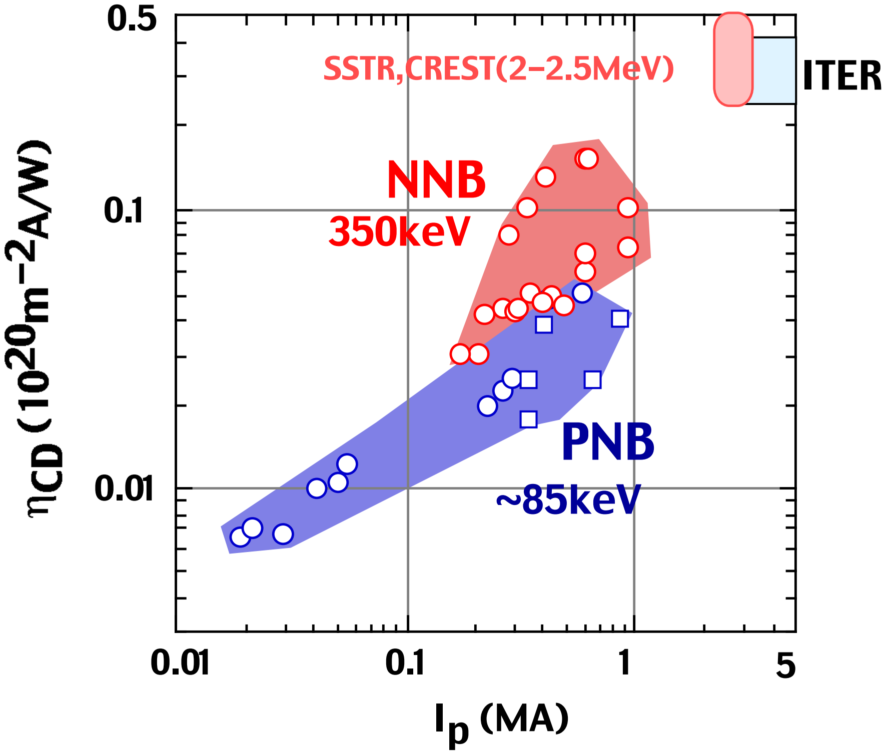
Current driver development : N-NBI

JT-60U

Improvement of N-NB CD efficiency with Te and Eb(beam energy) was demonstrated
NBCD result is consistent with neoclassical theory (T. Oikawa, this conference).



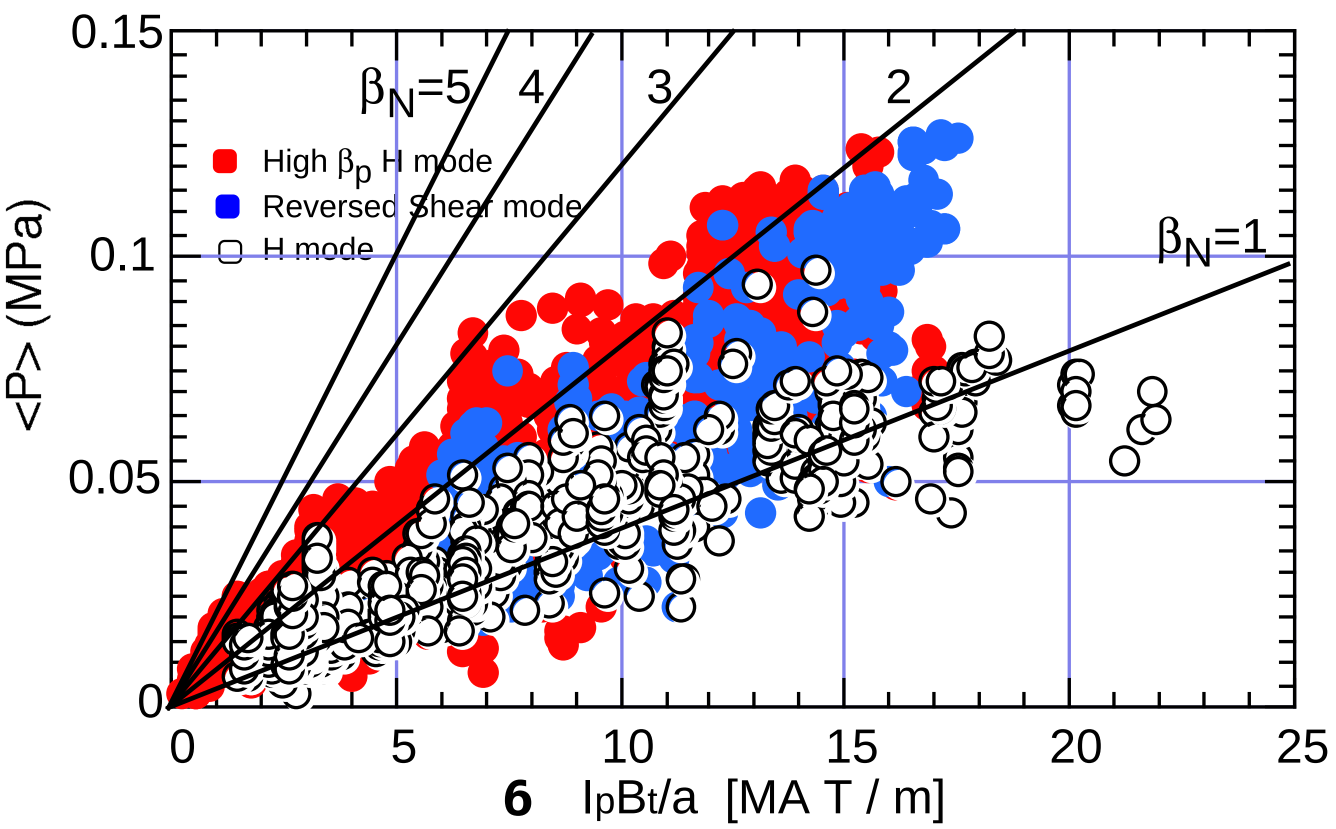




Compact reactor needs high pressure

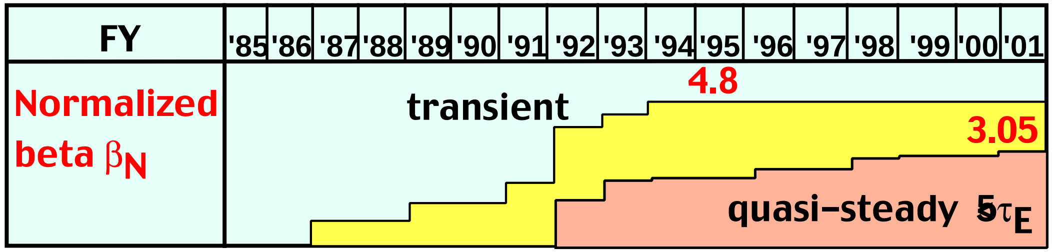
JT-60U

To realize compact DEMO, high pressure operation (~1 MPa) should be realized either by increasing IpBt/ap or β_N.
So far, high pressure ~0.1 2MPa was achieved in high β_p H and RS modes in JT-60U with heating power up to 40MW.

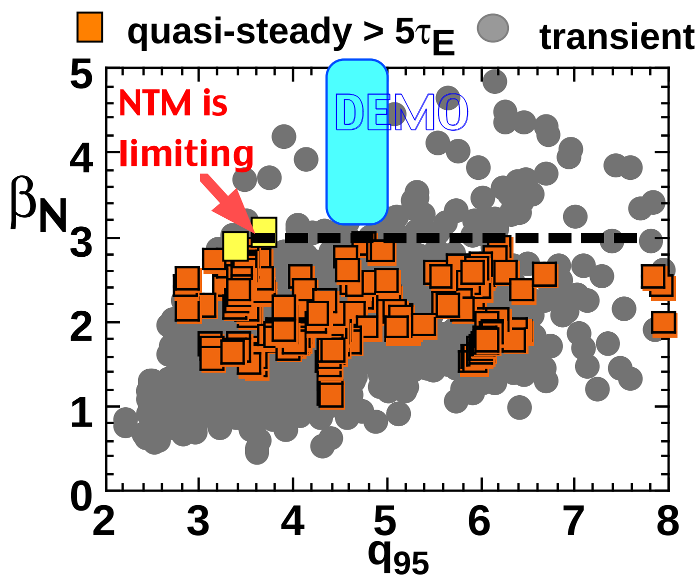


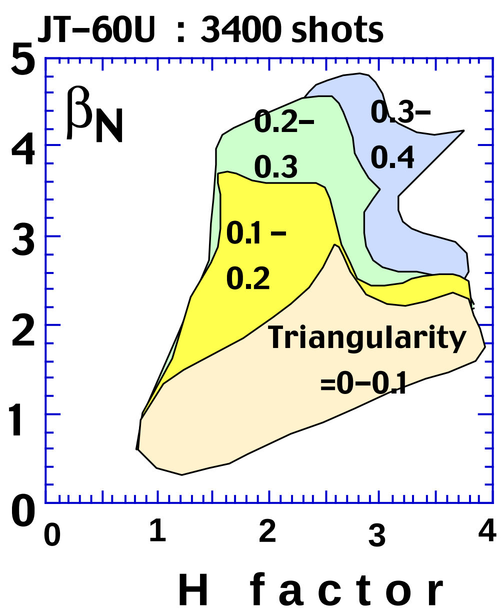
High beta research : profile control

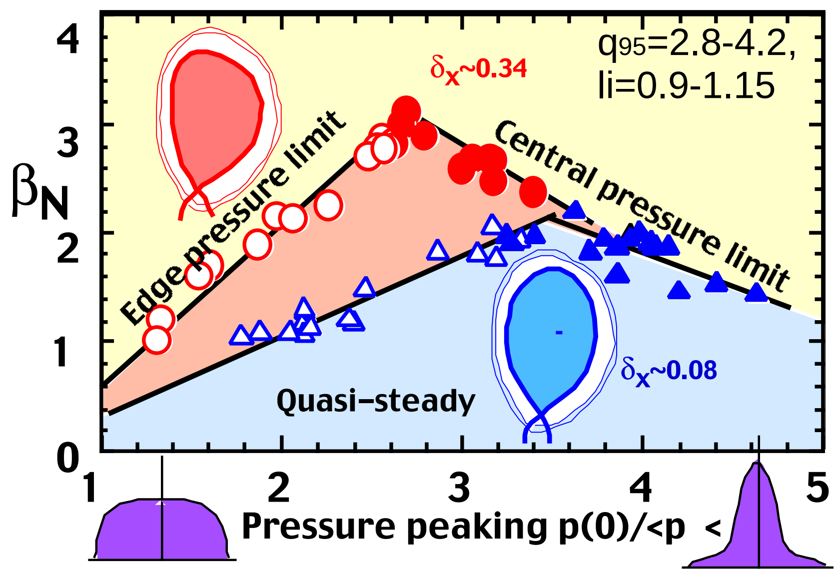
JT−60U



Shape and profile (J(r), P(r)) controls are key for higher beta (β_N) .
Higher β_N is achievable with high triangularity, broader P(r) with peaked J(r). For long sustainment, control of NTM is important.







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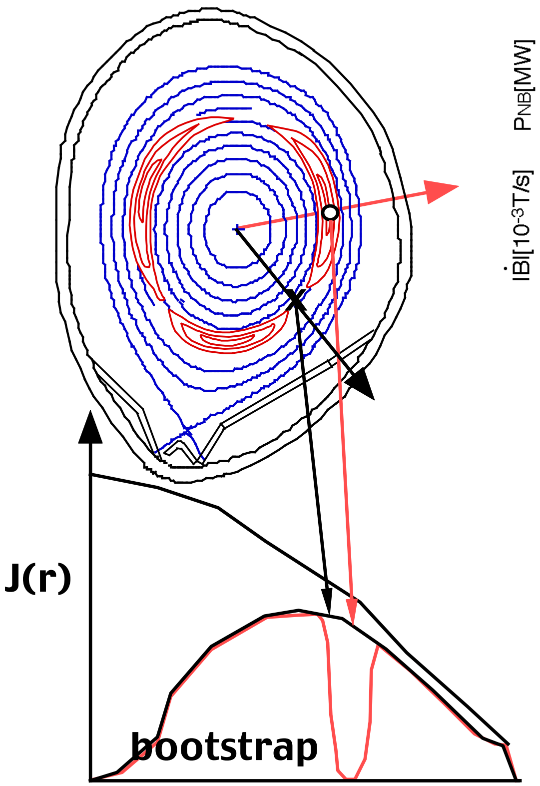
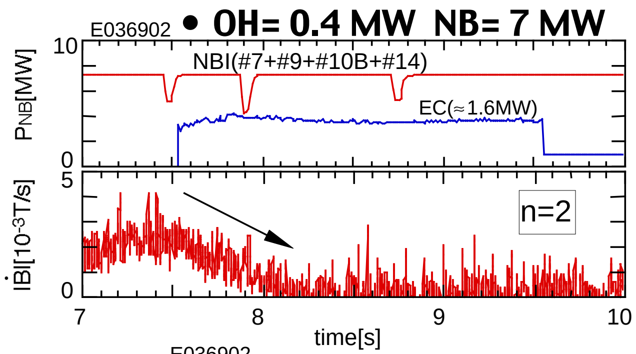
High beta research : NTM control

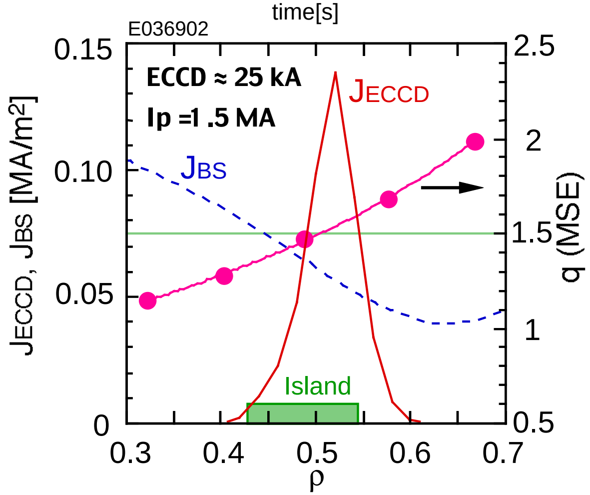
JT-60U

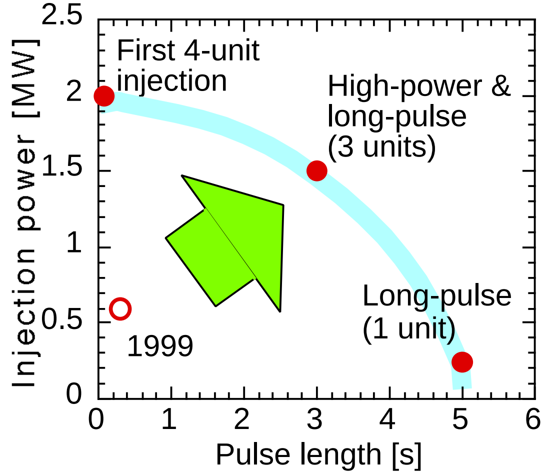
NTM is driven by the loss of b.s. curr. inside the magnetic island : Critical for SS DEMO.
Onset of NTM occurred for βp(0.7-1 .8). Once island was formed, destabilization of tearing mode due to loss of b.s. curr. persists until βp is low [quench at βp(0.2-0.4)].

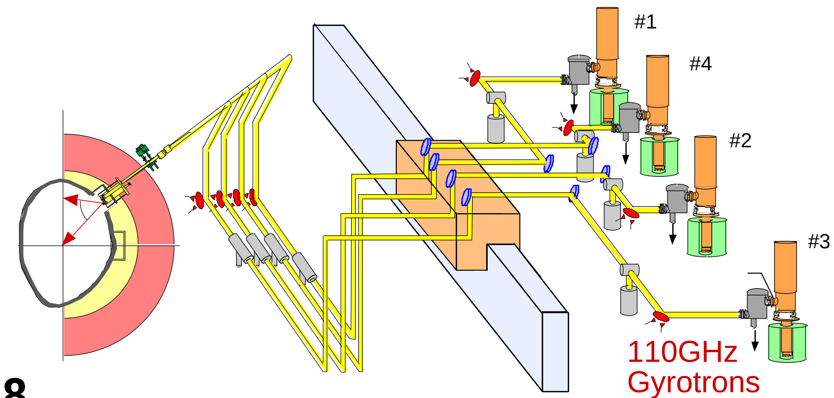
Fundamental O-mode ECCD (ITER scenario) was successfully applied to stabilize m/n=3/2 NTM.











High confinement at high ne ; Impurity seed

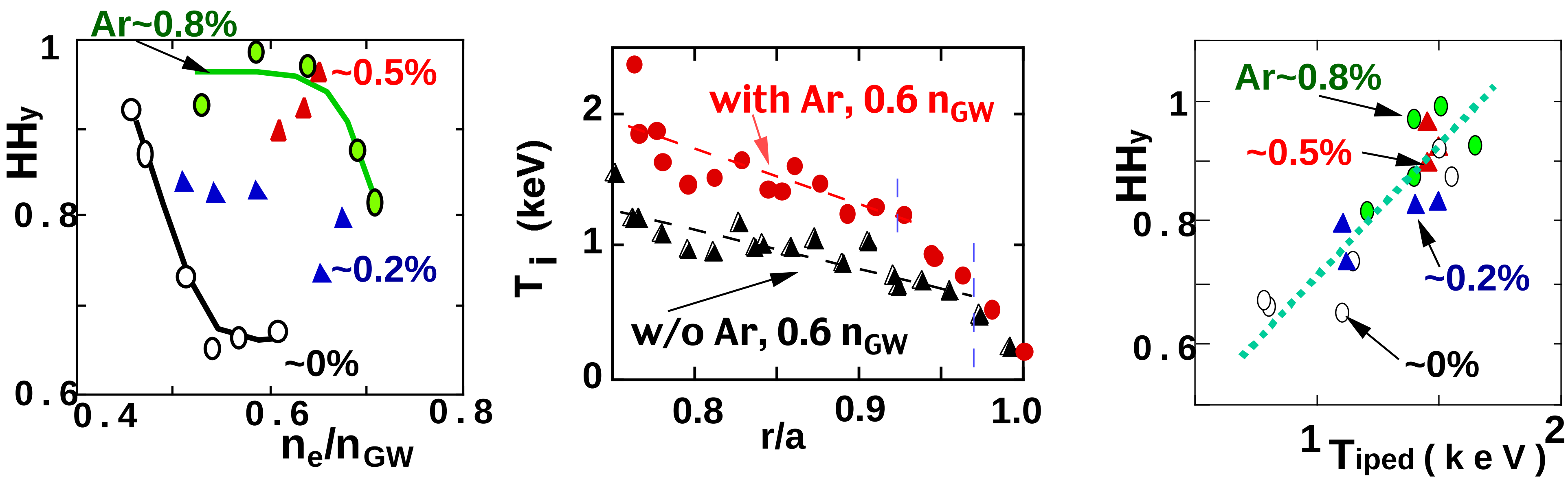
JT-60U

Ar puff into H-mode : enhanced confinement at high ne & radiation

Edge pedestal temperaure T_{iped} increased with Ar puff.

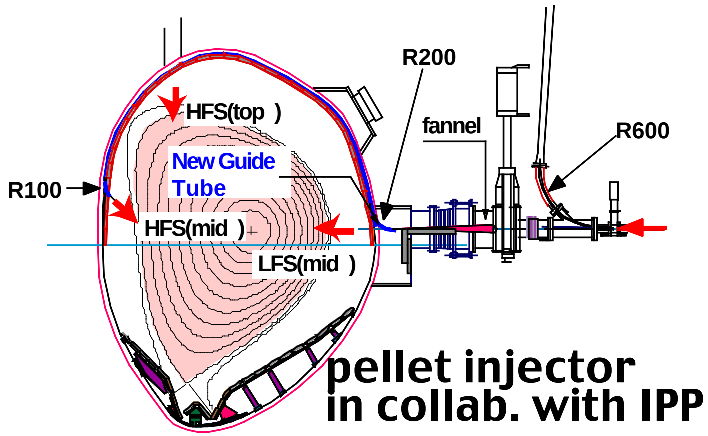
This high T_{iped} is caused by widening the pedestal width.

HH_{y2} ~1 at n_e/n_{GW} ~ 0.65, P_{rad}/P_{abs}~80%, detached div., n_D reduction due to Ar~10%



High confinement at high n_e ; Pellet fuelling

JT-60U

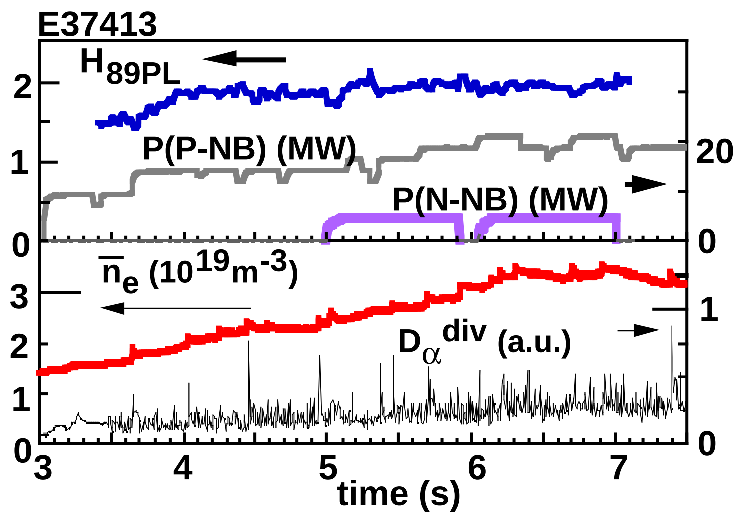


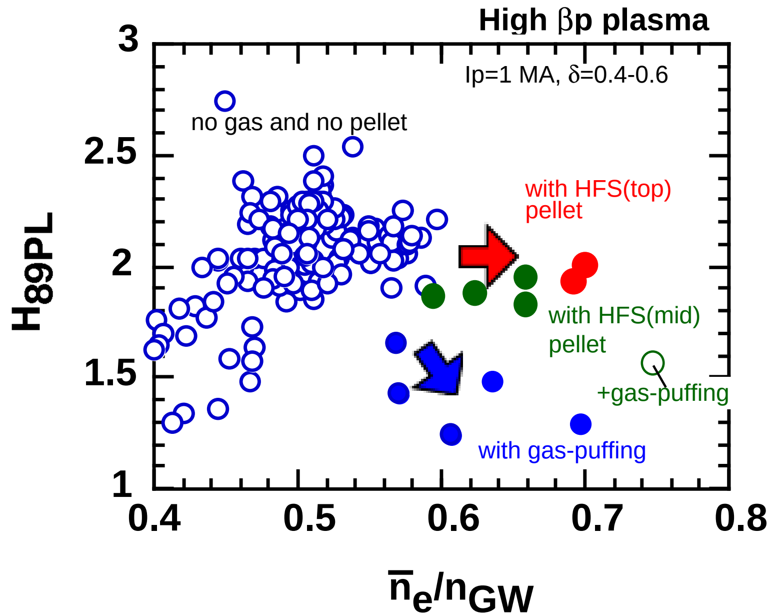
High βp ELMy H-mode 1 MA/ 3.6T ,
NNB (360keV: ~4MW)

at $\bar{n}_e/n_{GW}$=0.7, HH_{y2}=1 .05, H_{89PL}=1 .94, β_N=2.2

bootstrap~59%, NBCD~25%

P_{rad}/P_{abs} ~60%





High confinement at high n_e ; RS Full CD

JT-60U

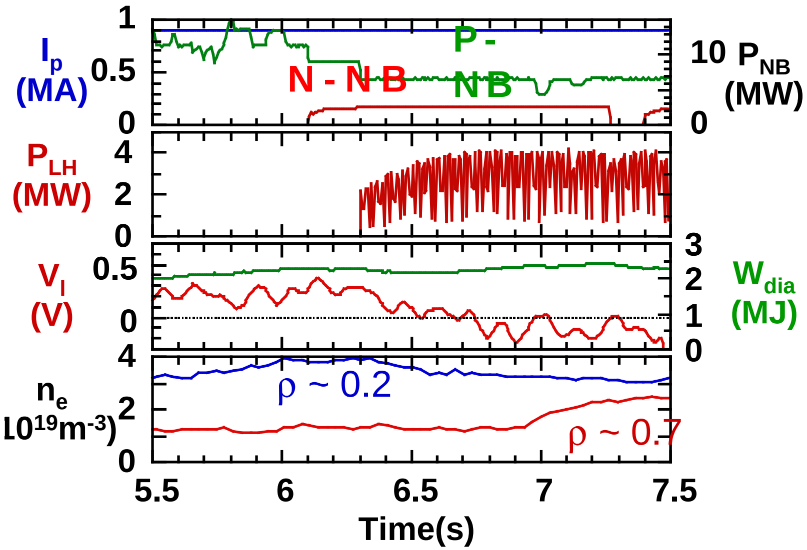
Full current drive : bootstrap =55−60% of Ip

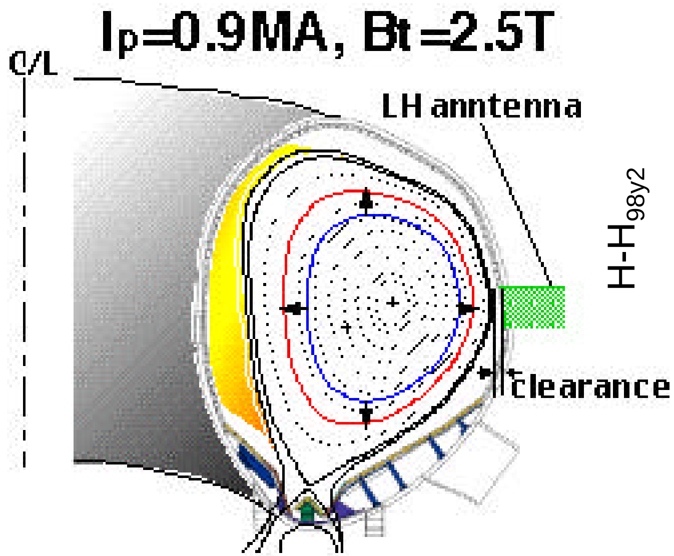
others by LHCD (3.6MW; CD at edge)

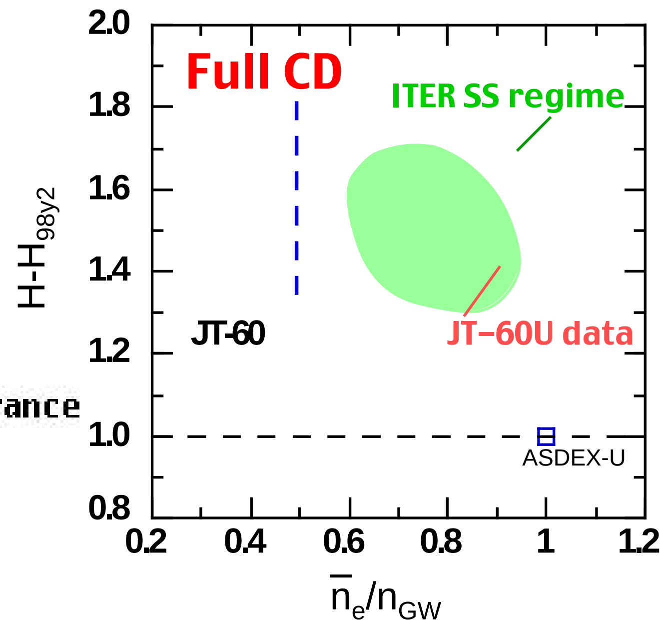
& N-NBCD(2.4MW;CD at core)

$n_e(0.7a)$ increases with widening ITB by LHCD.

$HH_{y,2} = 1.4$, $n_e^{ave}/n_{GW} = 0.8$, $q_{95} = 6.9$, $\delta_x=0.45$, $\beta_N = 2.2$

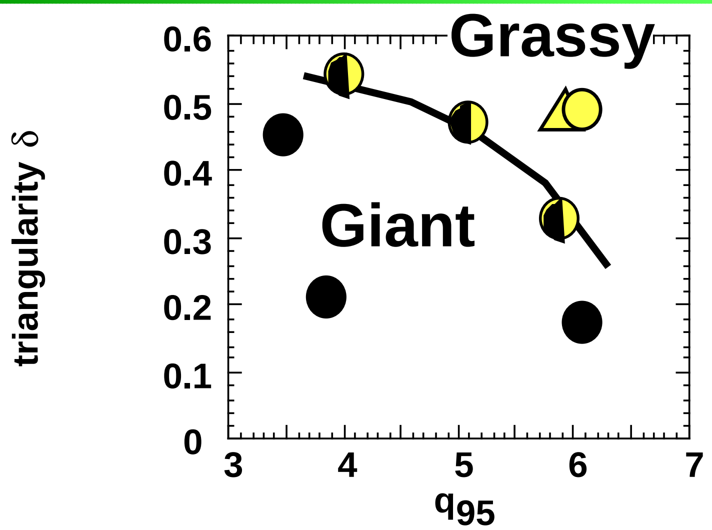


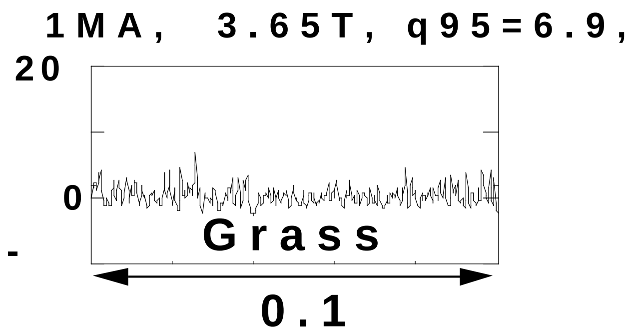


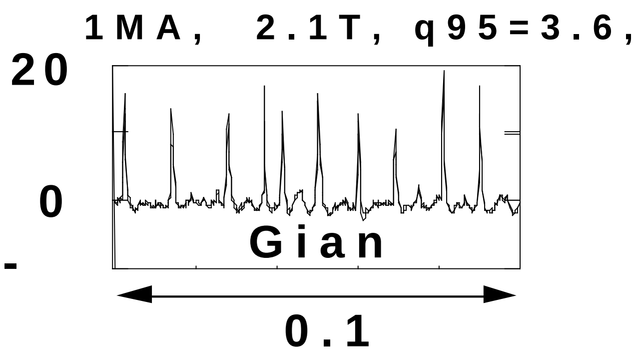


Divertor control : ELM control

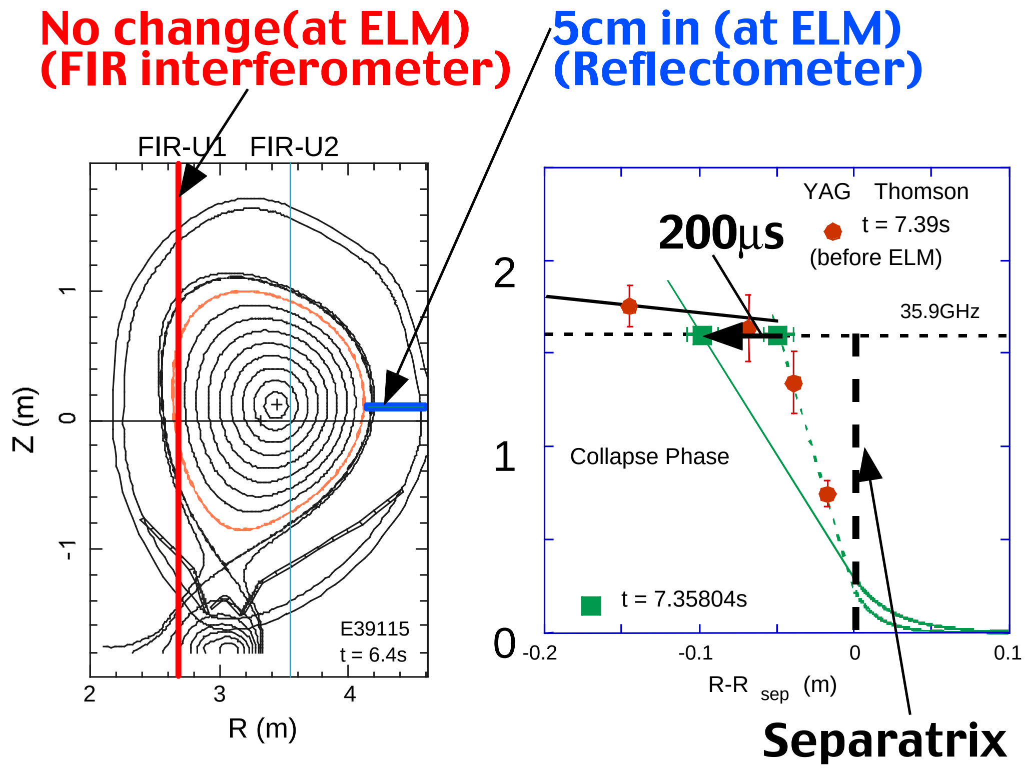
JT-60U







ELM is localized at bad curvature



N. Ohyama (H-mode WS,2001)

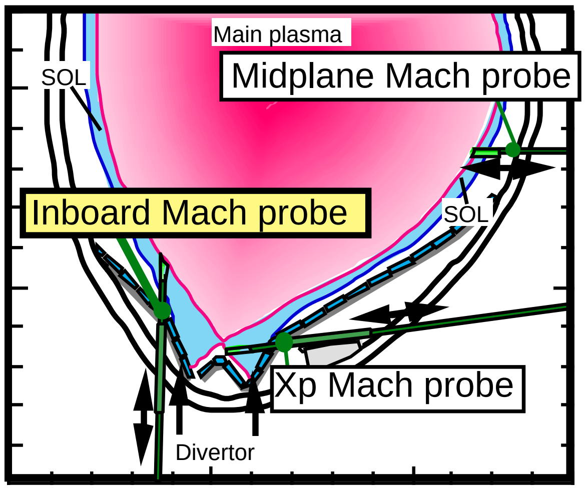
Divertor control : SOL flow

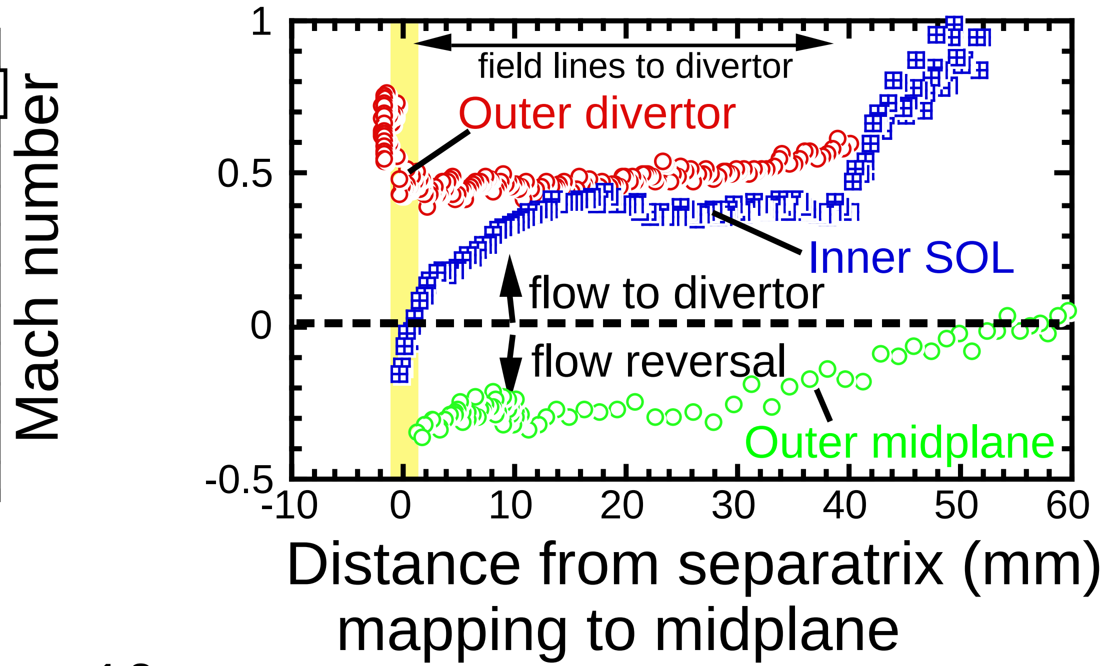
JT-60U

High-field-side SOL plasma was measured, for the first time, with new Inner reciprocating Mach probe:

SOL profile and flow pattern are investigated at 3 locations (Inner, Xp and outer midplane)

Flow reversal at outer midplane SOL (low field side), Asakura et al., Phys. Rev. Lett 84 (2000) 3093.



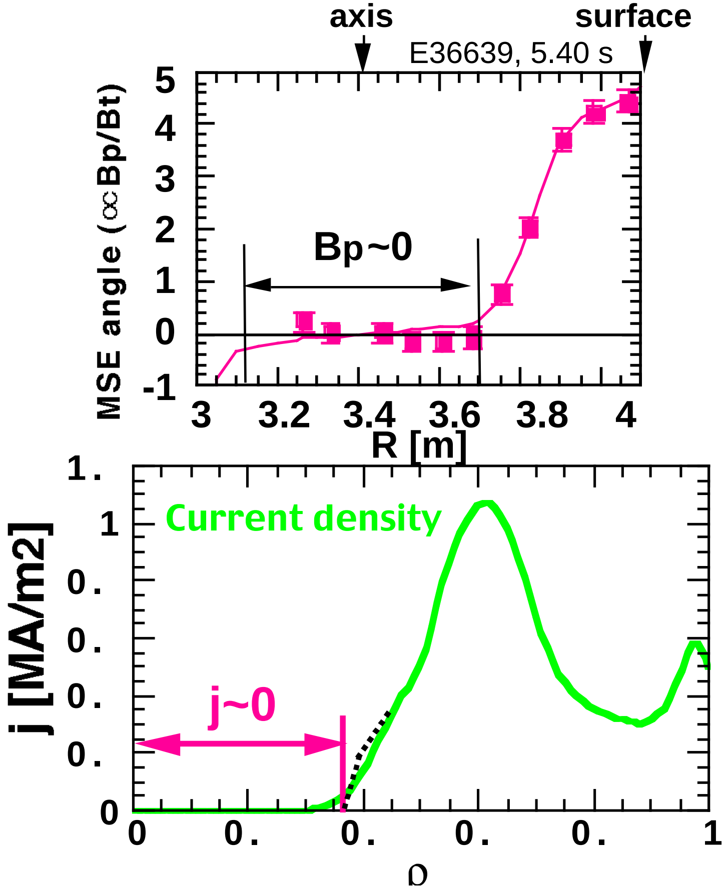


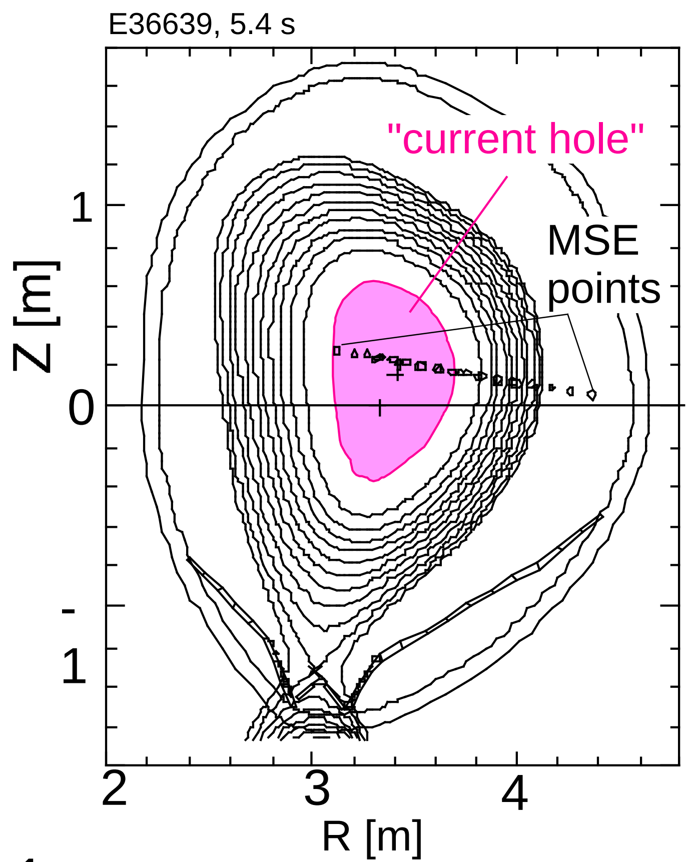
New observation : Current Hole

JT-60U

T. Fujita , to be published

For strongly reversed shear discharges, we observed a region of J~0, "Current Hole".

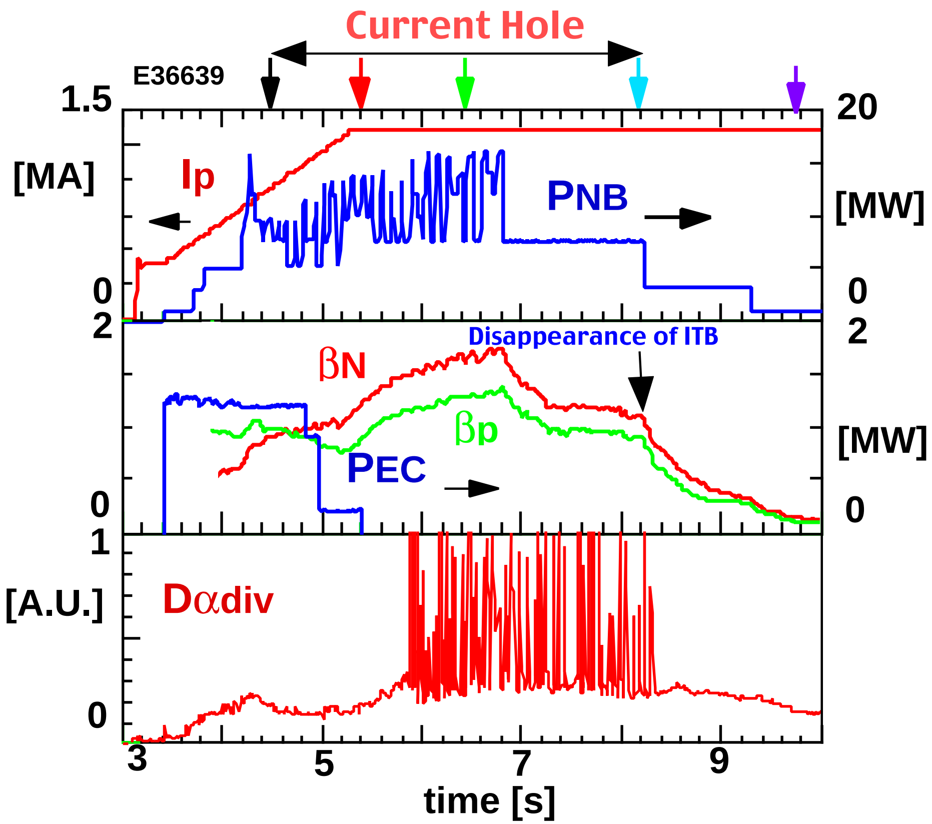


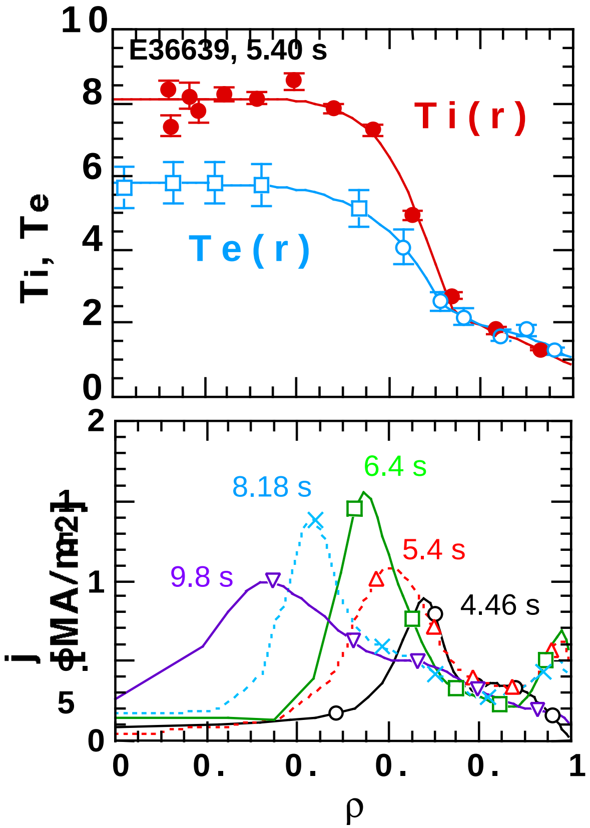


Current Hole is a long-lived state

JT-60U

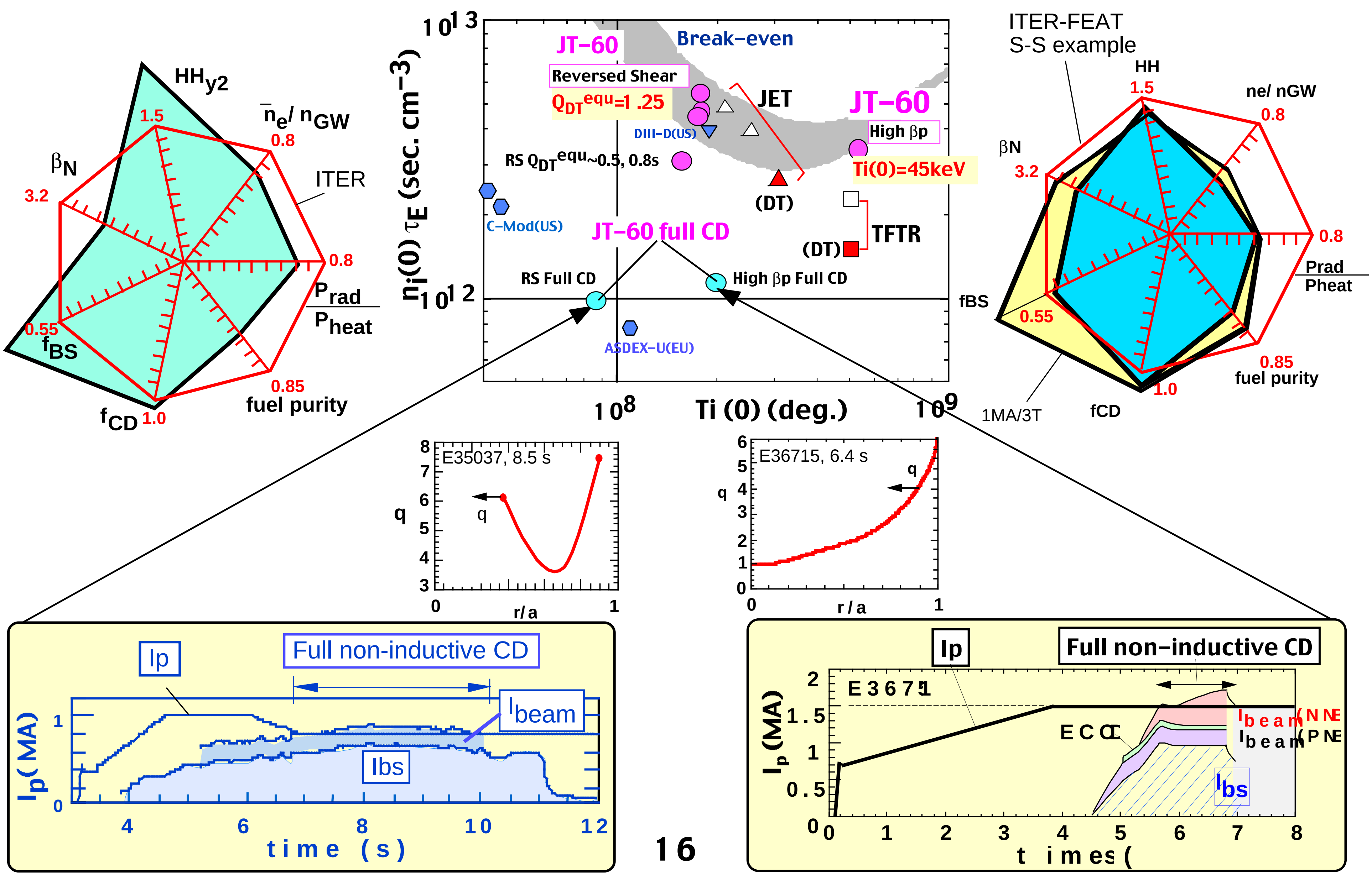
Observation of flat temperature inside current hole is consistent with a loss of confining field.





Integrated Demonstration : RS and high βp

JT-60U

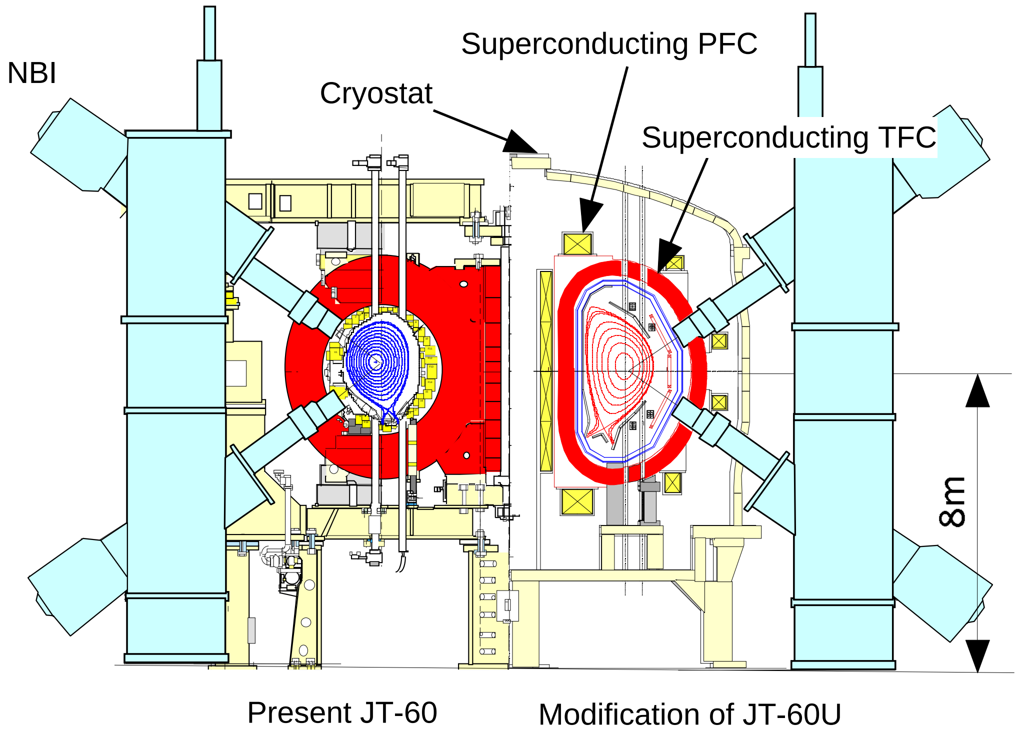


Future program ; JT–60 modification

JT–60U

[1] Further improved understanding of physics elements

[2] Full demonstration of advanced scenairos for DEMO



Parameter	JT-60U	JT-60SC	ITER-FEAT Pulse	ITER-FEAT Steady-State
Pulse length	15 s	100 s	400 s	Steady
Maximum input power	40 MW (10 s)	40 MW (10 s) ≥10MW (100 s)	73 MW	73 MW
Plasma current I_p	3-5 MA	4 MA	15 MA	7.8 MA
Toroidal field B_t	4 T	3.8 T (R_p=2.8 m)	5.3 T	4.98 T
Major radius R_p	3.4 m	2.8 -3 m (2.8 m*)	6.2 m	6.6 m
Minor radius a_p	0.9 m	0.7-0.9 m (0.85*)	2.0 m	1.6 m
Elongation κ_{95}	1.8 (δ_{95}=0.06)	≲1.9 (1.7*)	1.7	2.0
Triangularity δ_{95}	0.4 (κ_{95}=1.33)	≲0.45 (0.35*)	0.35	0.35

* Nominal

Summary

JT-60U

[1] JT-60 have achieved original objective of achieving equivalent break-even condition in 1996.

[2] Since 1991, we have made significant efforts to extend plasma regime, in confinement, MHD stability , heating and current drive, divertor, energetic particle confinement as necessary conditions for ITER and DEMO such as SSTR.

[3] We have developed two kinds of steady-state operation scenarios. Integrated demonstration was successfully made.
But it still needs further improvements.