ASDEX Upgrade

EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

IPP

Improved H-mode Identity Experiments at JET and ASDEX Upgrade

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Acknowledgements to

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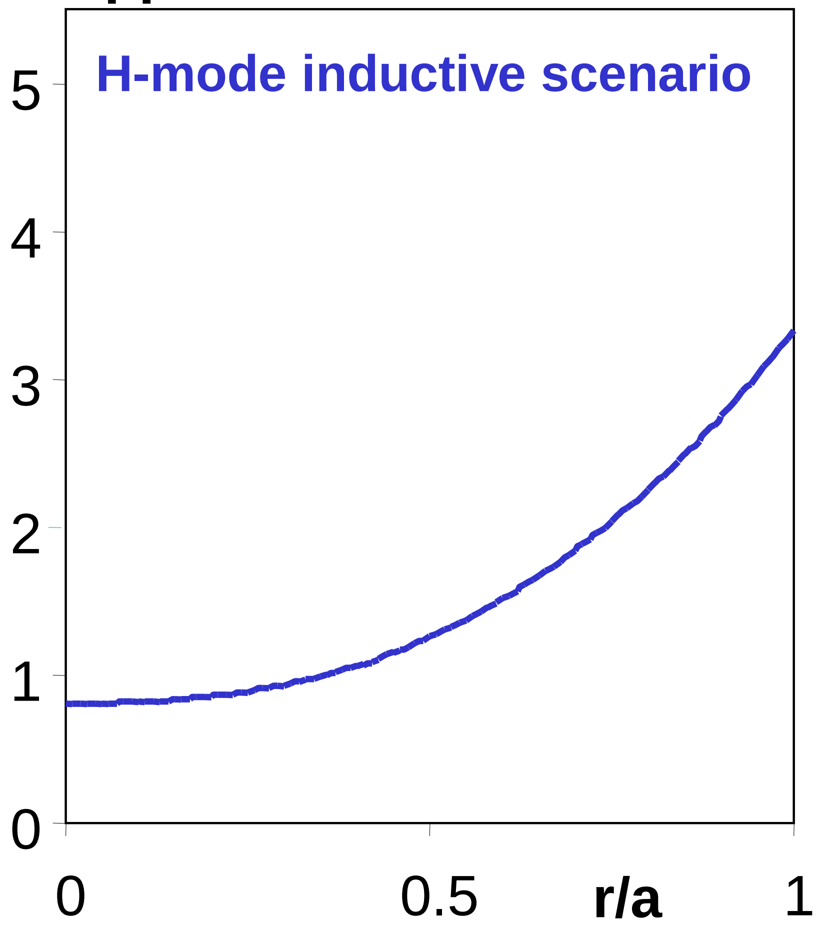
Motivation

q-profile



Requirements for ITER

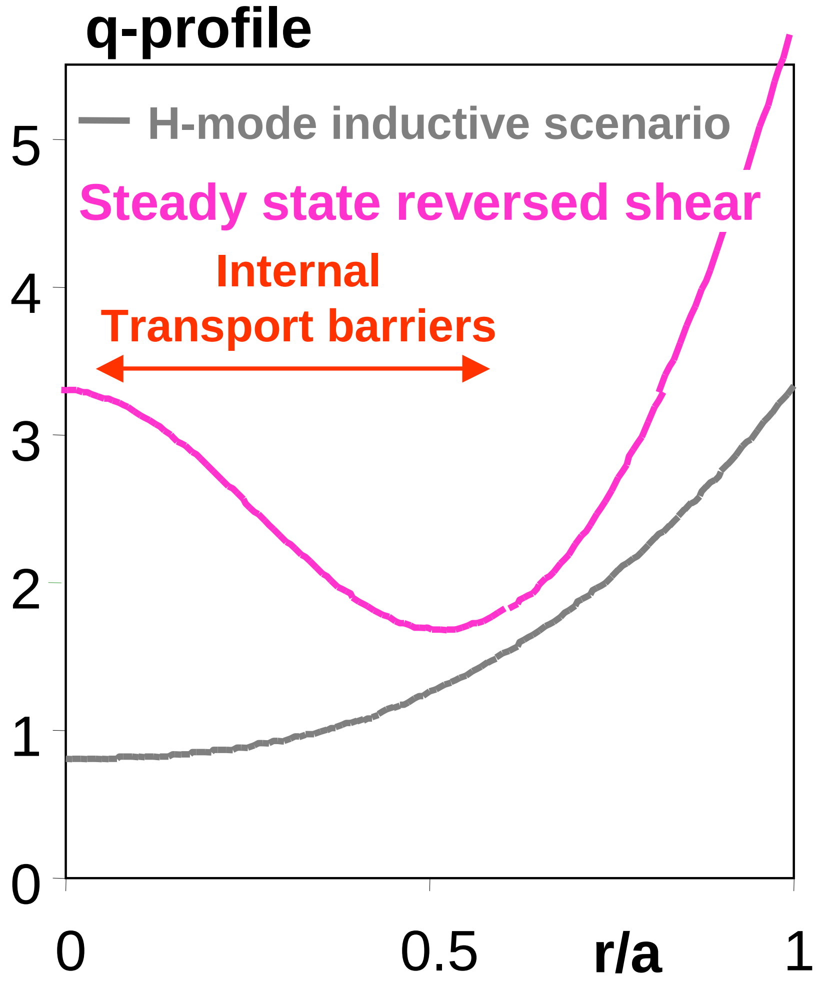
q_{95}	$H_{98}(y,2)/\beta_N$	$\langle n_e \rangle / n_{GW}$	Q
3	1.0/1.8	0.85	10 (400 s.)

q_{95} =3: Safe operation at maximum I_P.

β_N =1.8: Conservative to avoid NTM´s.

$\langle n_e \rangle / n_{GW}$ =0.85 : ITER, $n_e(r)$ assumed flat, n_{e0} to get Q=10, $n_{e,edge}$ for divertor lifetime.

Motivation



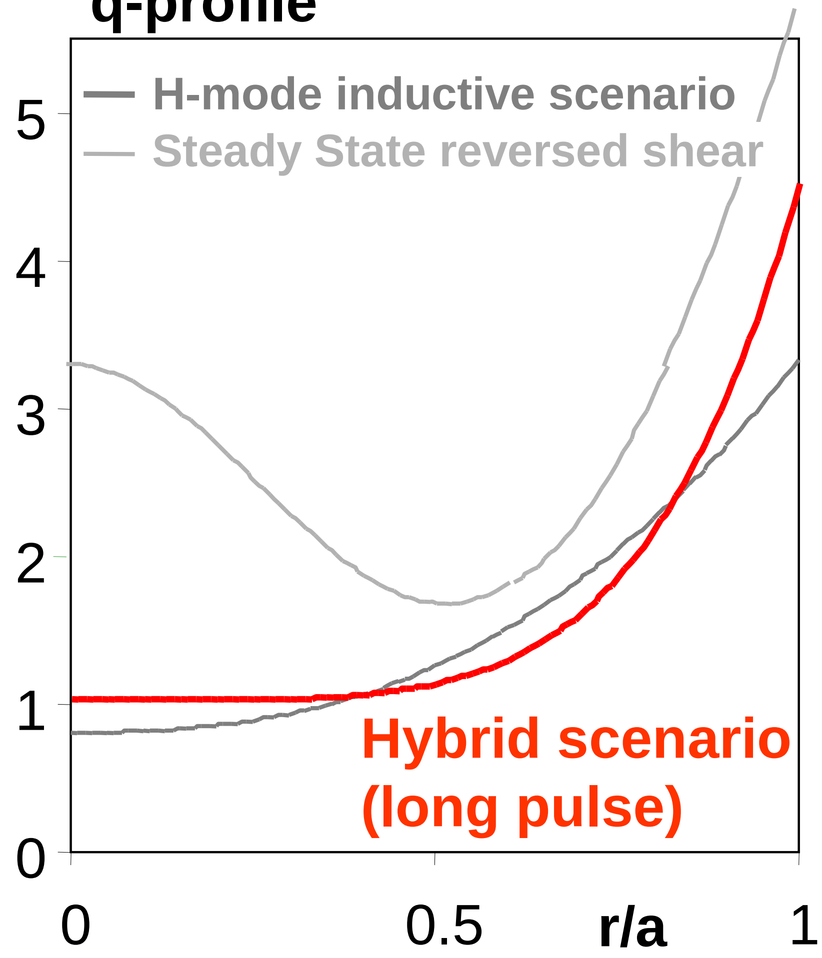
Requirements for ITER

q_{95}	$H_{98}(y,2)/\beta_N$	$<n_e>/n_{GW}$	Q
3	1.0/1.8	0.85	10 (400 s.)
5-6 [1]	2.0/3.5 [2]	> 1.2 [3]	? (SS, Q=5)

1. q-profile only sustained at low $\beta_N < 2$.
2. required $H_{98}(y,2)$ & β_N only transiently.
3. So far, no results at relevant edge n_e.

Motivation

q-profile



Low shear, q_0 ~1, stationary q(r).

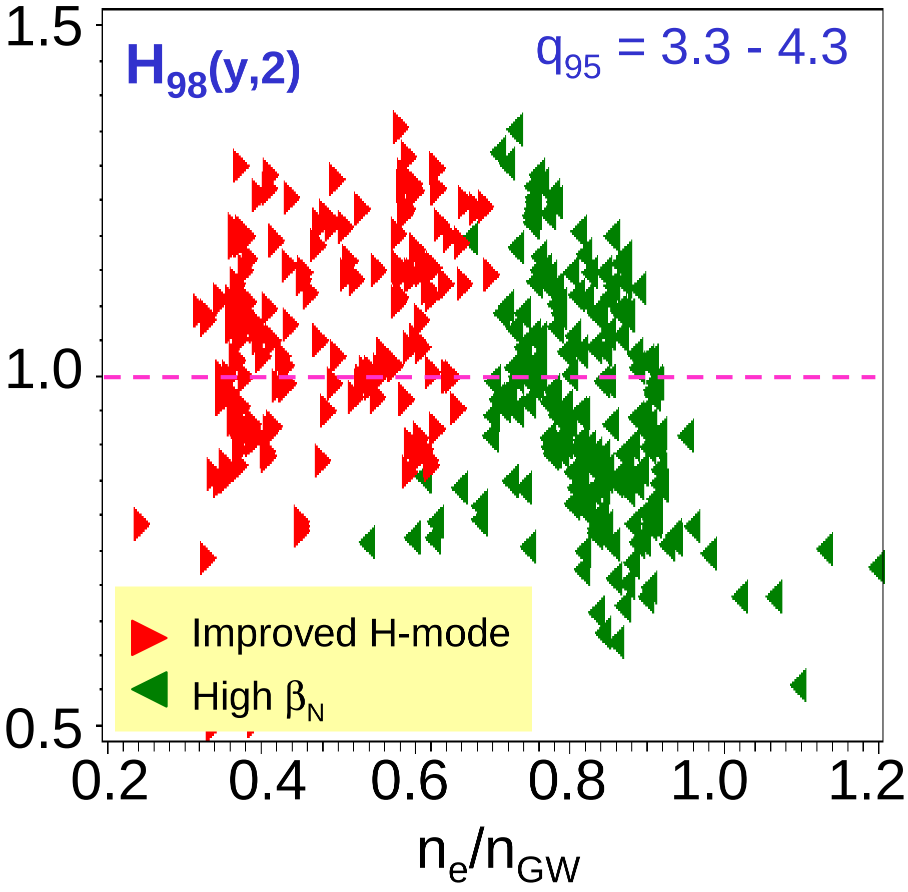
Requirements for ITER

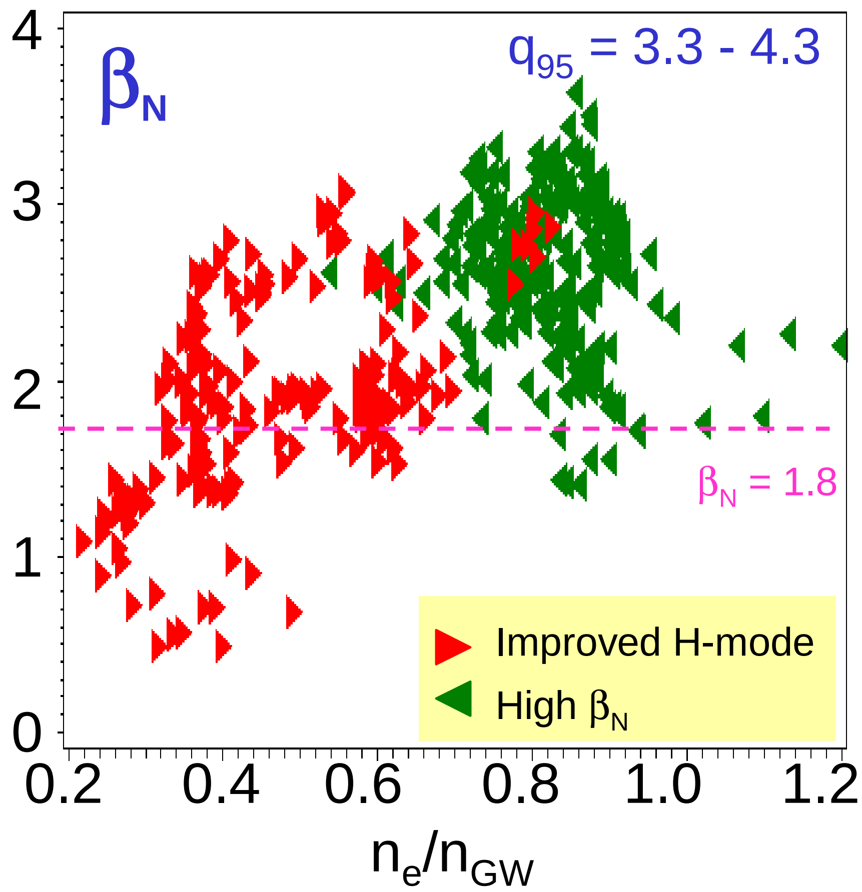
q_{95}	$H_{98}(y,2)/\beta_N$	$\langle n_e \rangle / n_{GW}$	Q
3	1.0/1.8	0.85	10 (400 s.)
5-6[1]	2.0/3.5[2]	> 1.2[3]	? (SS, Q=5)
~4	**1.3/2.5**	**~1**	**~10* (4000 s.)***

**T. Luce, P-4.42 (Friday)*

- No sawteeth, in most cases no ITB.
- Established at AUG (*Wolf, 2000*) and DIII-D (*Luce, 2001 & Wade, 2001*).

Hybrid scenarios at ASDEX Upgrade





Without gas fuelling, at $\delta \sim 0.2$: **Improved H-mode**

At $\delta \sim 0.4$, operating at high density: High β_N

Need to demonstrate this regime in more experiments !

Aims for Experiments at JET

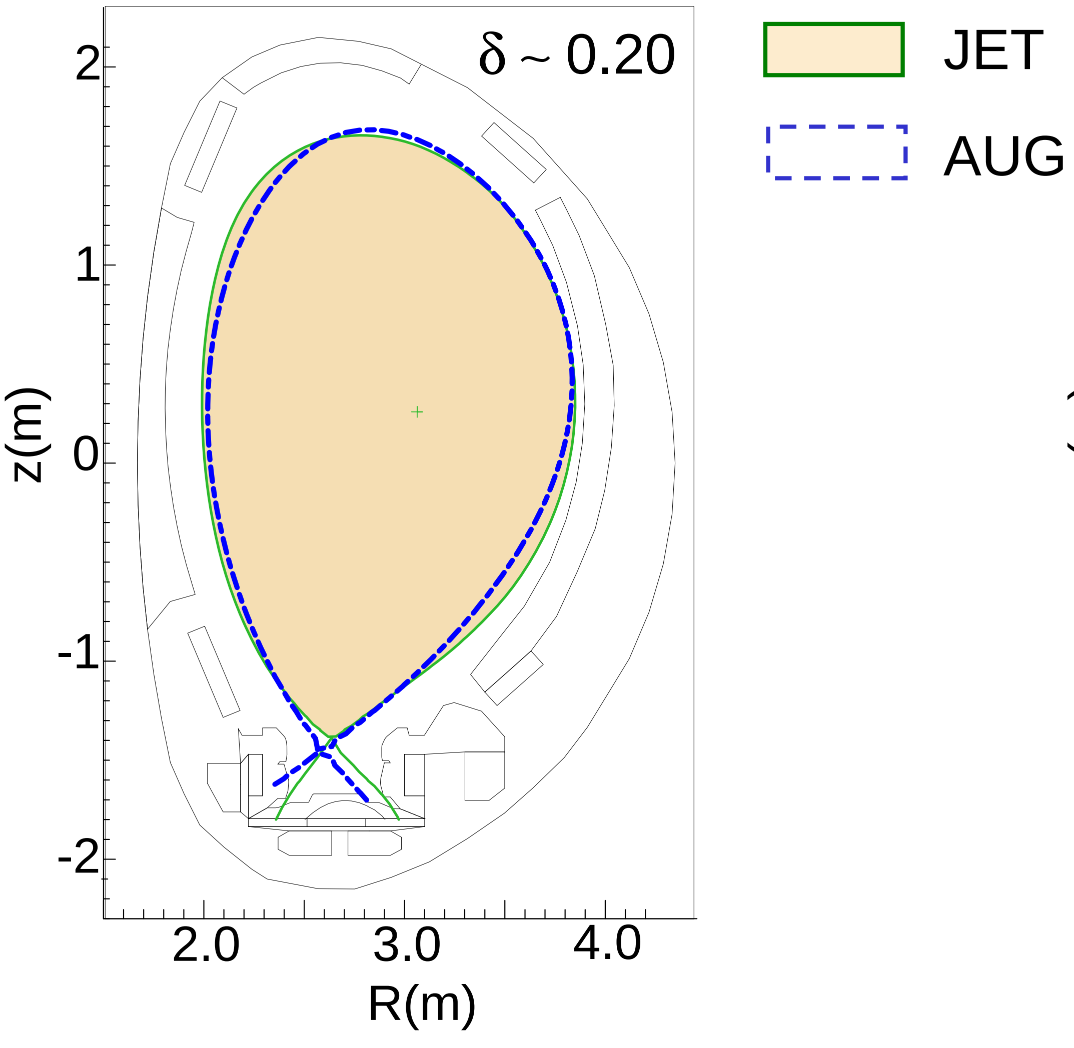
- Can the improved H-mode scenario of ASDEX Upgrade be established at JET, using a ρ^* close to ASDEX Upgrade (1.4MA/1.7T) ?
- Can stationary conditions obtained with similar q(r), $H_{98}(y,2)$, β_N and MHD activity ?
- At low δ and high δ ?
- Do we see differences at lower ρ^* (2.8MA/3.4T) ?

Need to demonstrate this regime in more experiments !

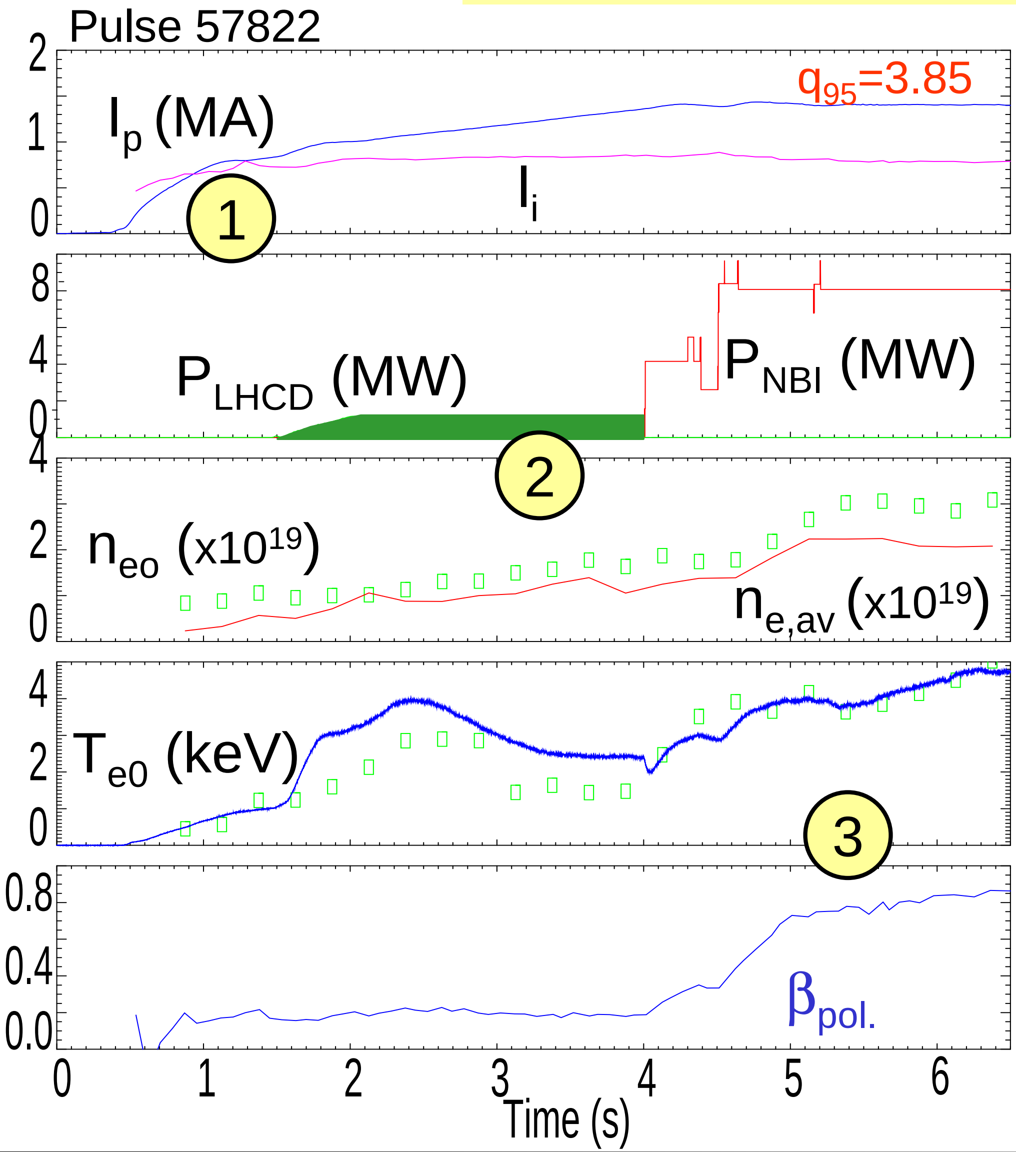
Aims for Experiments at JET

	Yes	No
• Can the improved H-mode scenario of ASDEX Upgrade be established at JET, using a ρ^* close to ASDEX Upgrade (1.4MA/1.7T) ?	■	□
• Can stationary conditions obtained with similar q(r), $H_{98}(y,2)$, β_N and MHD activity ?	■	□
• At low δ and high δ ?	■	□
• Do we see differences at lower ρ^* (2.8MA/3.4T) ?	■	□

Plasma shapes used in JET compared to ASDEX Upgrade



JET, experiments at 1.4MA/1.7 T

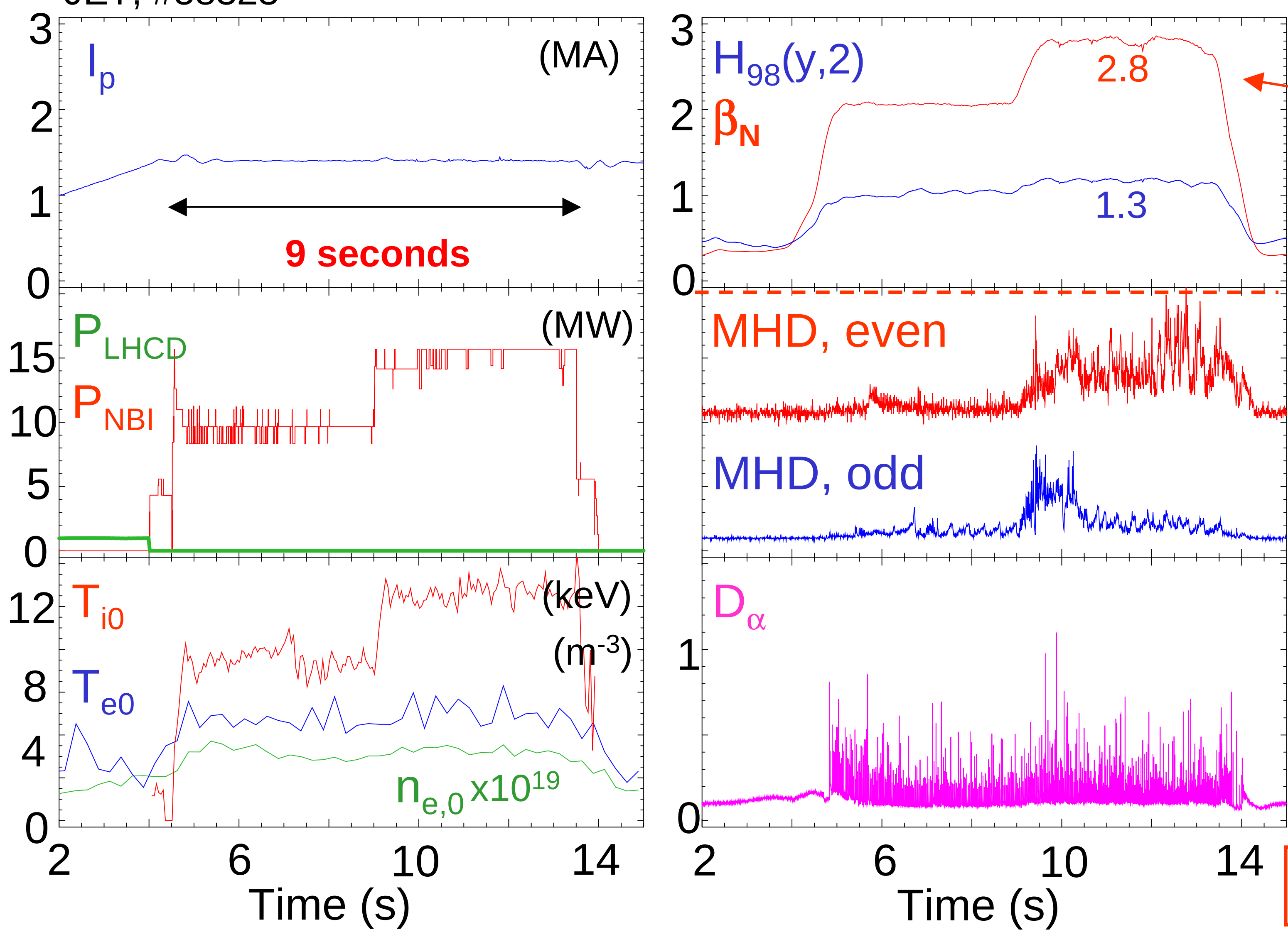


1. Current rise optimised for low inductance, however not reversed q-profiles.

2. Timing of the heating and LHCD (1.5 MW) tuned to avoid sawteeth.

3. Enough power (beta) is required to keep sawteeth away.

JET, performance at 1.4MA/1.7 T



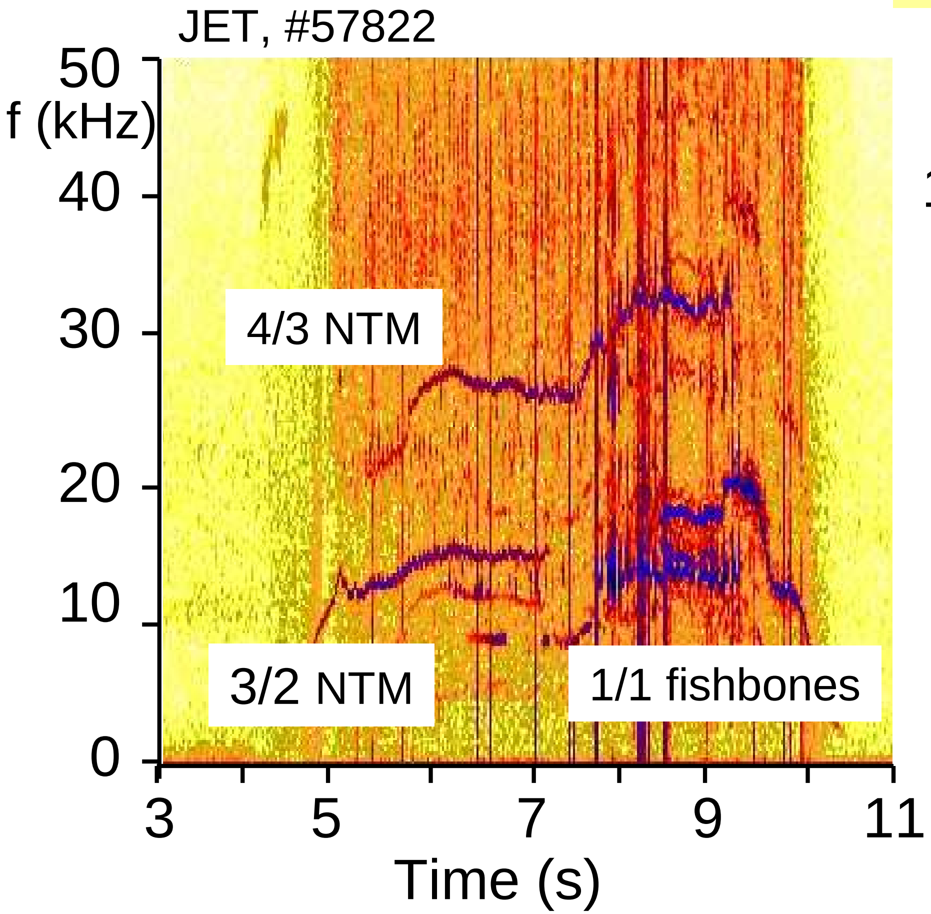
Real-time Control of β_N

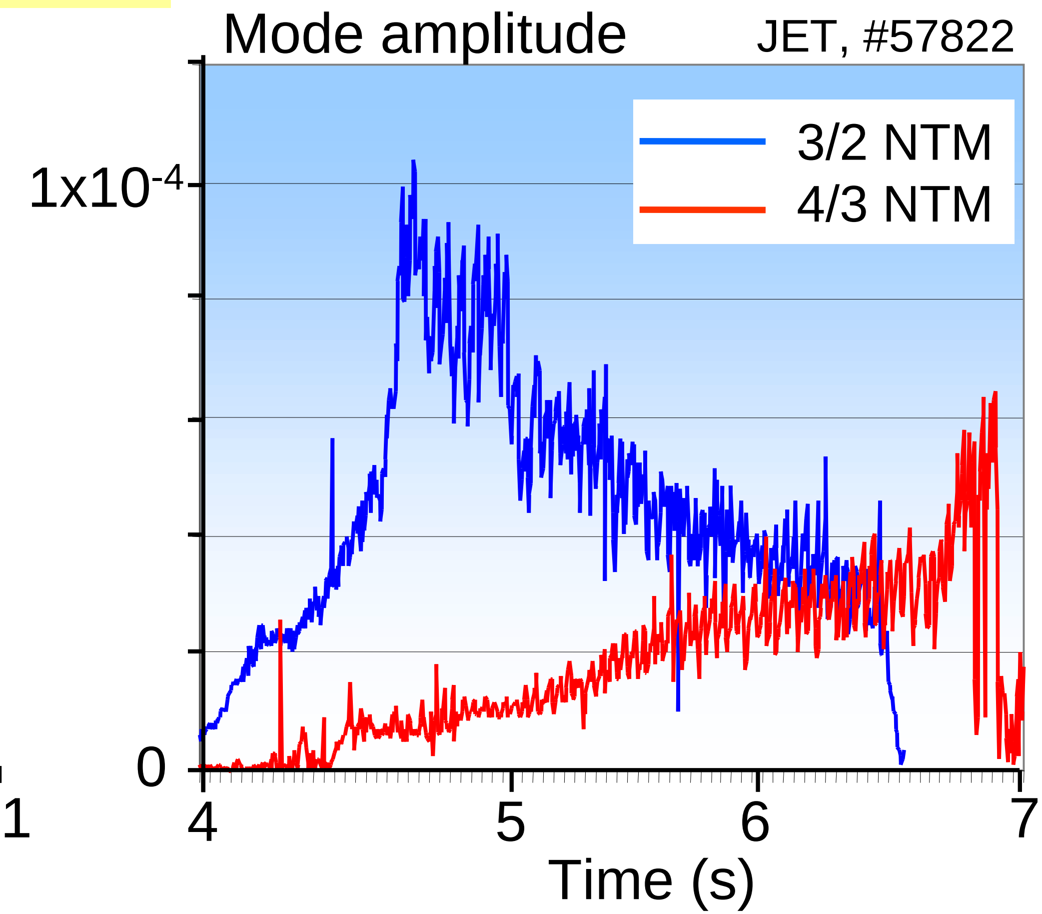
Joffrin, I-4.6 (Thursday)

$\rho^* = 6\text{-}7 \times 10^{-3}$

S.D Pinches, P-1.93, Monday

MHD





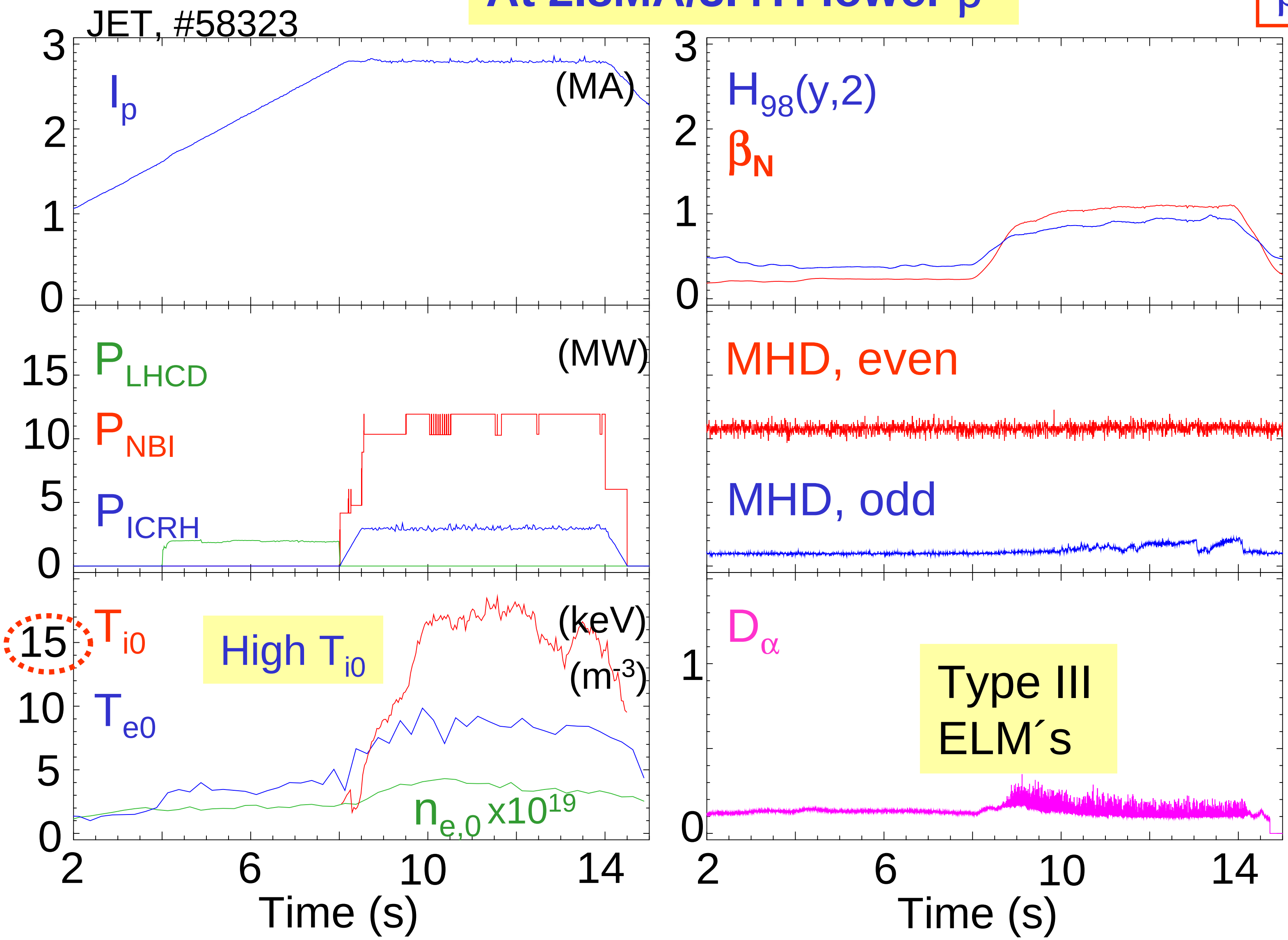
ALL of these small enough !!!

Supression of 3/2 NTM by 4/3 NTM

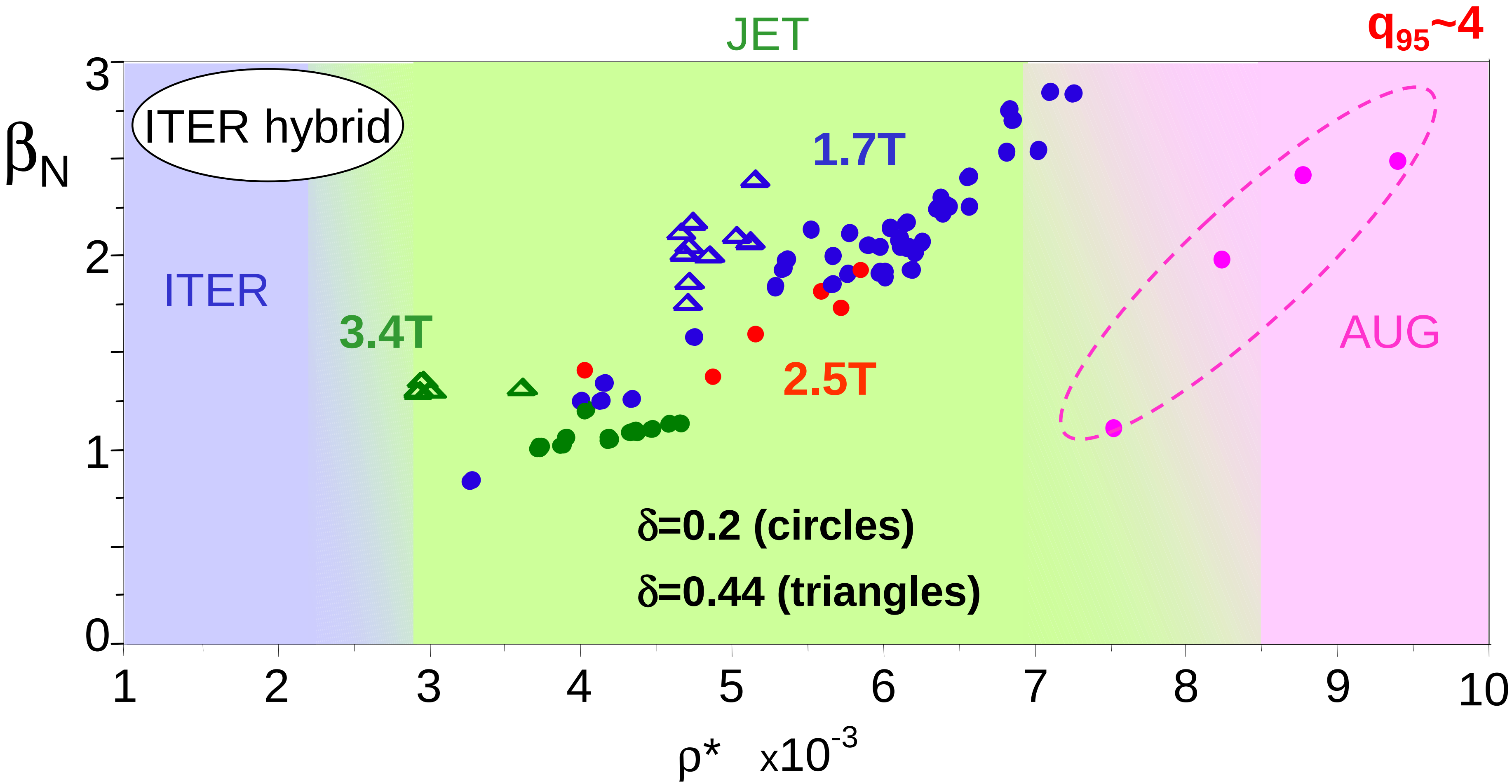
With sawteeth, 3/2 and 2/1 NTM are triggered, → beta collapse for β_N **< 2.5**

At 2.8MA/3.4T: lower ρ*

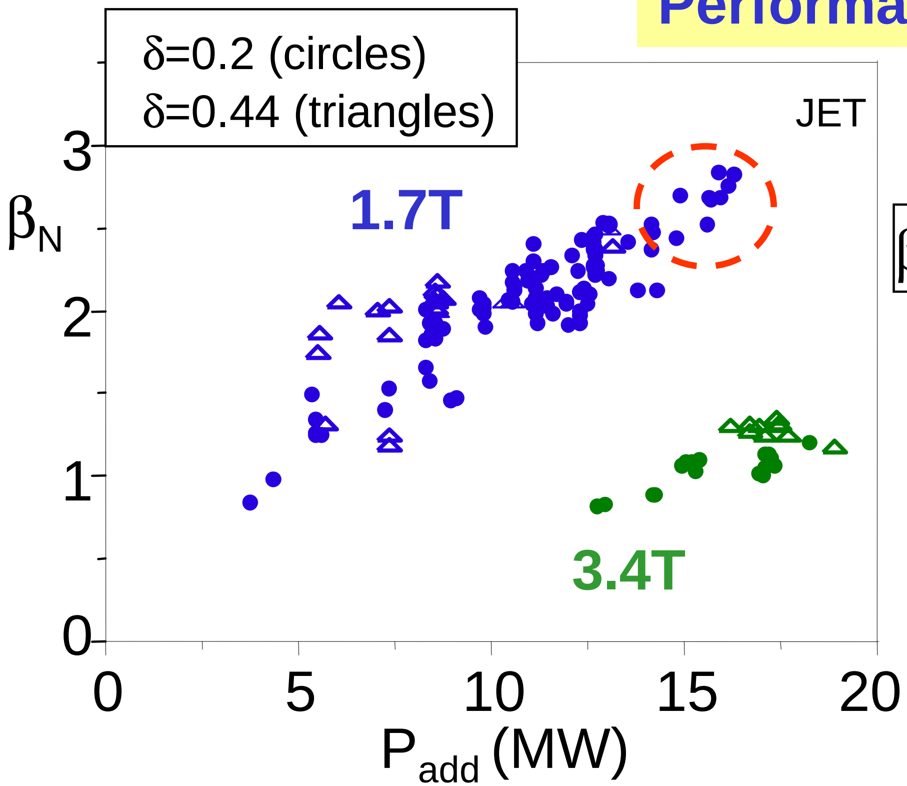
$\rho^* = 3.5\text{-}4\times10^{-3}$

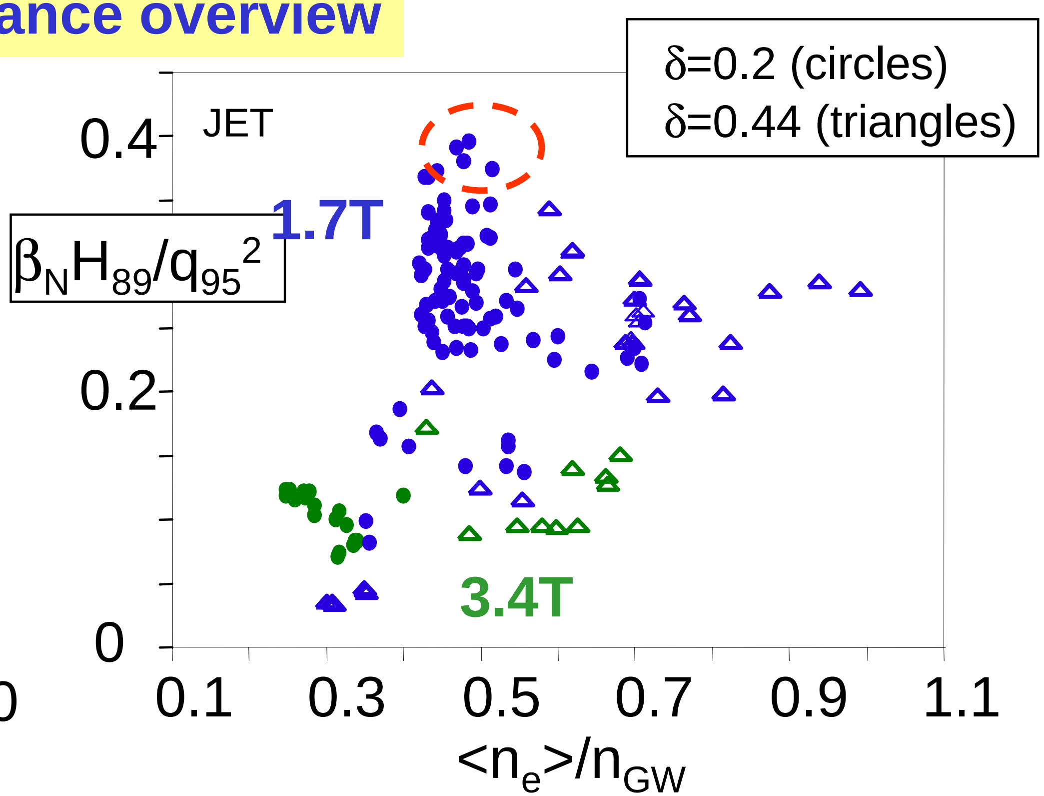


Normalised parameter range



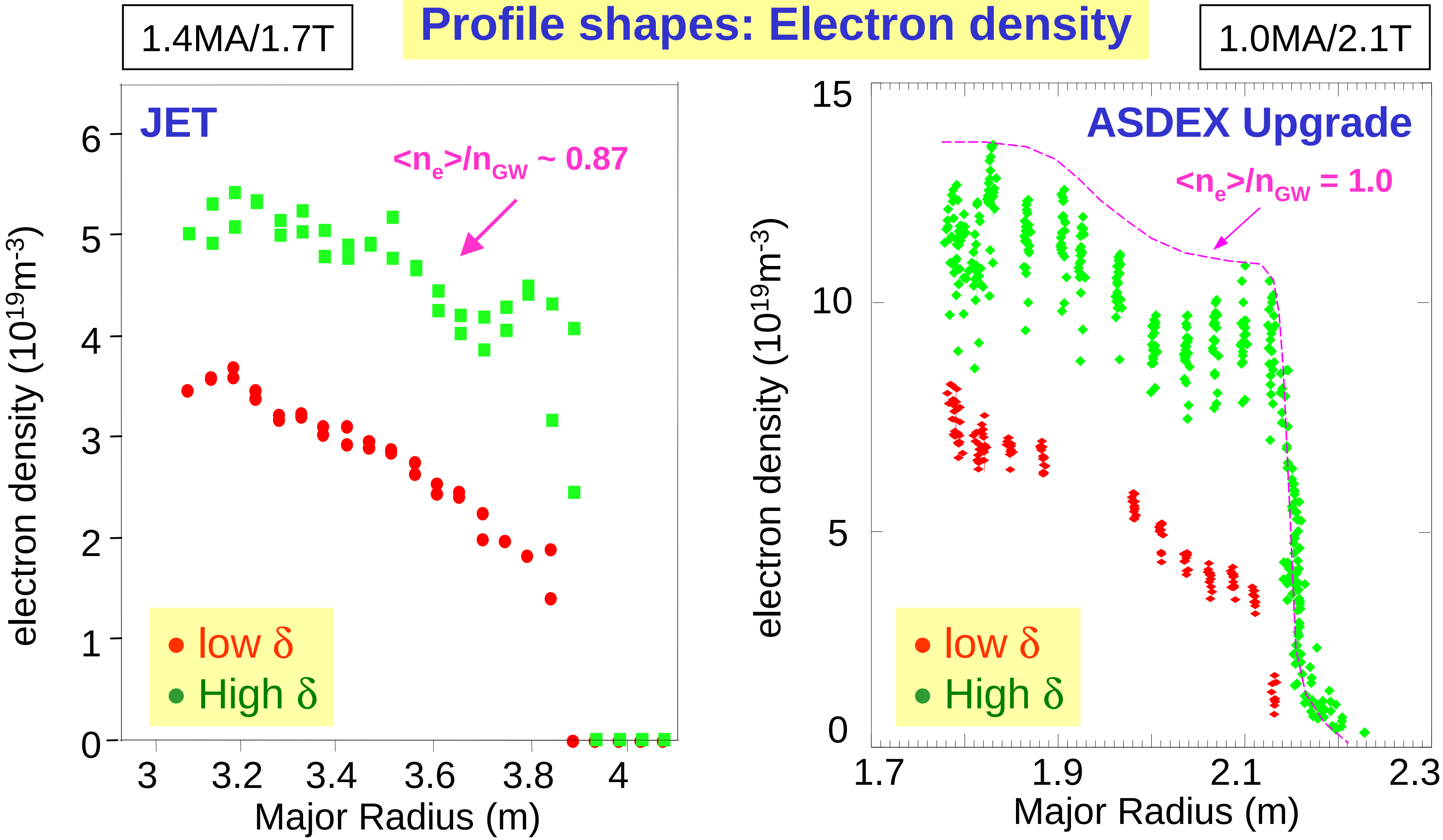
Performance overview





- At higher power, the H-factor improves, beta increases ~ linearly.
- Still no hard NTM limit found, need more input power.
- At $\langle n_e \rangle / n_{GW} < 0.6$, substantial fast particle content (30 %) !
- $\beta_N H_{89}/q_{95}^2$ reaches values required for ITER.

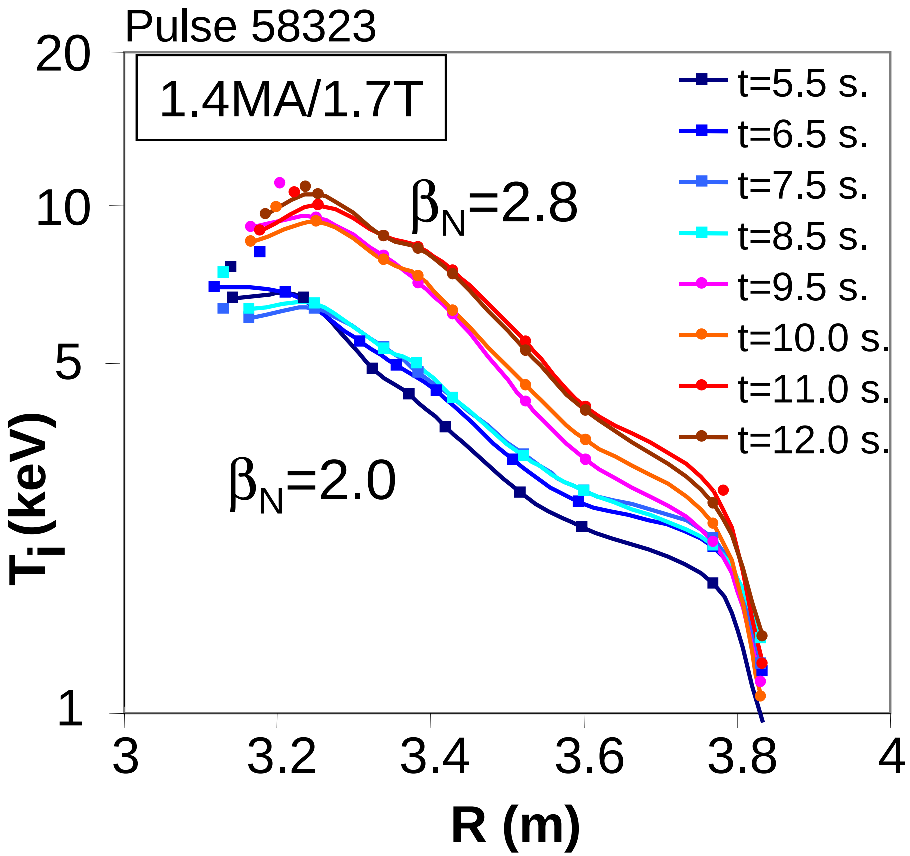
Profile shapes: Electron density

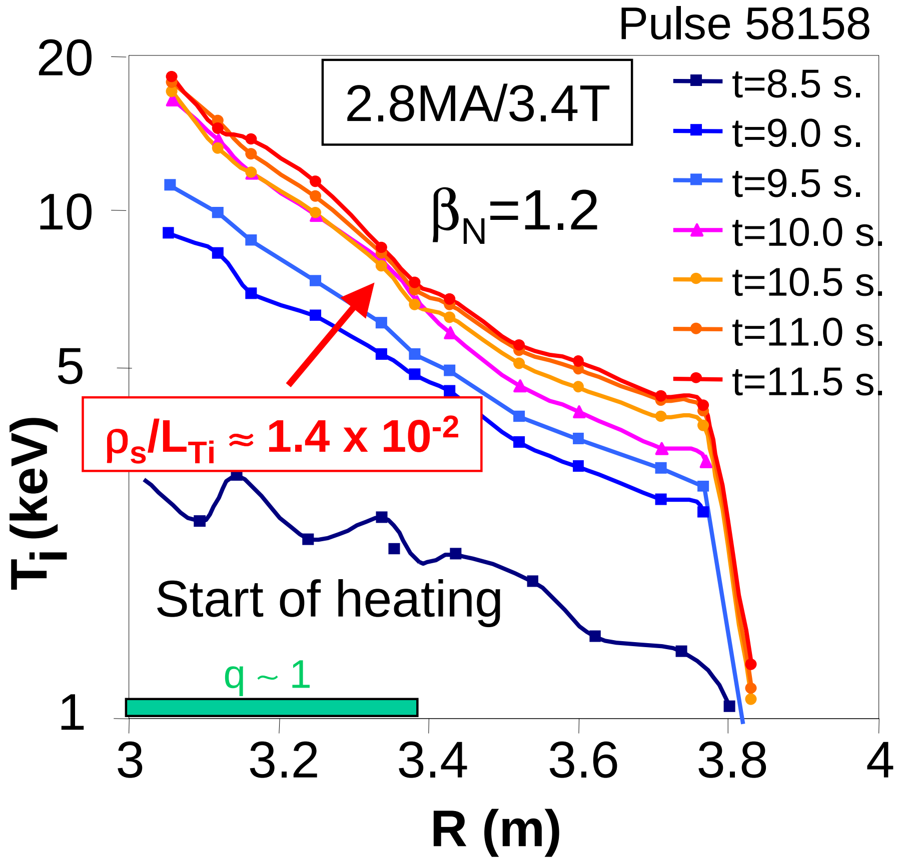


At JET density profile has same peaking factor $n_{e0}/\langle n_e \rangle \sim 1.3$.

No impurity accumulation: Avoided by central heating.

Profile shapes: Ion temperature

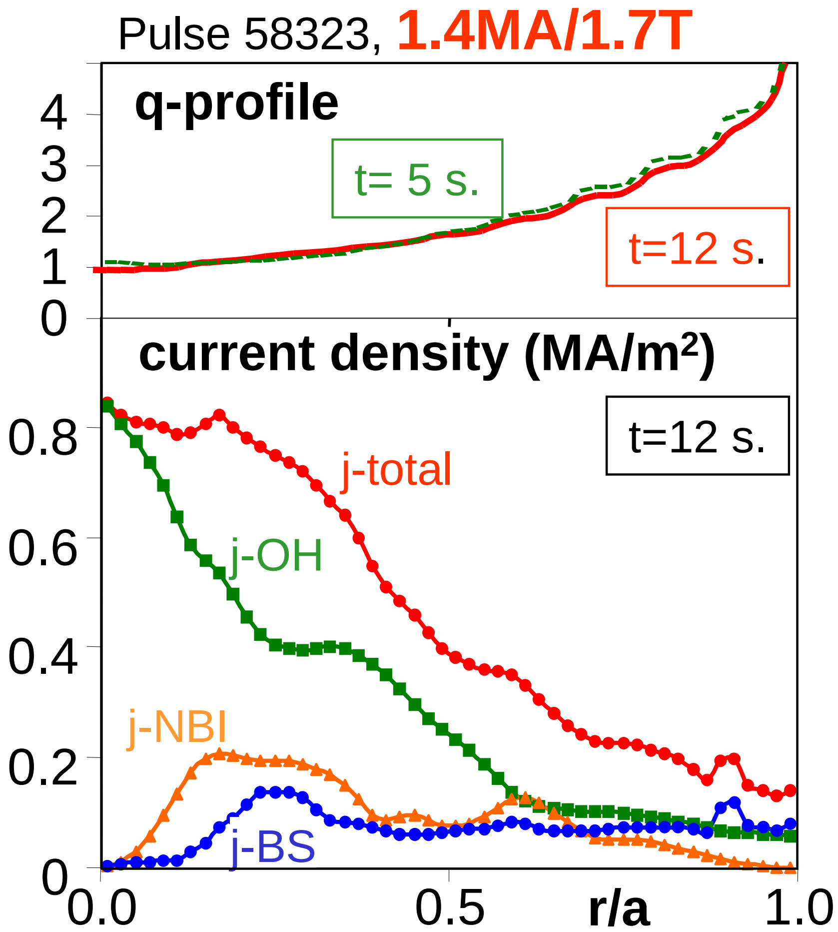




- Similar to ASDEX Upgrade.
- Temperature profiles are stiff.

- ITB within q=1, for $\langle n_e \rangle / n_{GW} \leq 0.3$ *(similar as reported by Joffrin, 2002).*
- TRANSP: reduced transport.

Current density profiles



TRANSP code results

At end of heating phase, q(r) stationary.
Also confirmed by ASTRA calculations.

	1.4MA/1.7T	2.8MA/3.4T
I_{CD}/I_p	45%	13%
I_{OH}	0.75 MA	2.35 MA
I_{NBI}	0.33 MA	0.12 MA
I_{BS}	0.32 MA*	0.25 MA

*: Off axis to sustain low shear near q=1.

Summary and Conclusions

- By matching plasma shape, q-profile and ρ*, an improved H-mode scenario has been obtained at JET (1.4MA/1.7T).
- In stationary conditions, small NTM and fishbone activity in the core.
- With similar β_N, H-factor, MHD and profiles as at ASDEX Upgrade.
- At lowest ρ*, ITB formation at low density, no Type I ELM´s. Not enough heating power to establish improved H-mode ?

More experiments:

Document the beta limit at JET at 1.4MA/1.7T.

More experiments at $\delta \sim 0.44$ (higher density).

Assess the lowest ρ* with maximum input power.