CONSORZIO RFX
Ricerca Formazione Innovazione

# Density limits and control in RFP's

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*ReNeW- RFP panel "break out" session*

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**Contents**

## Foreword

• Current RFP's are ohmically driven devices, with additional internal poloidal currents to generate Btor.

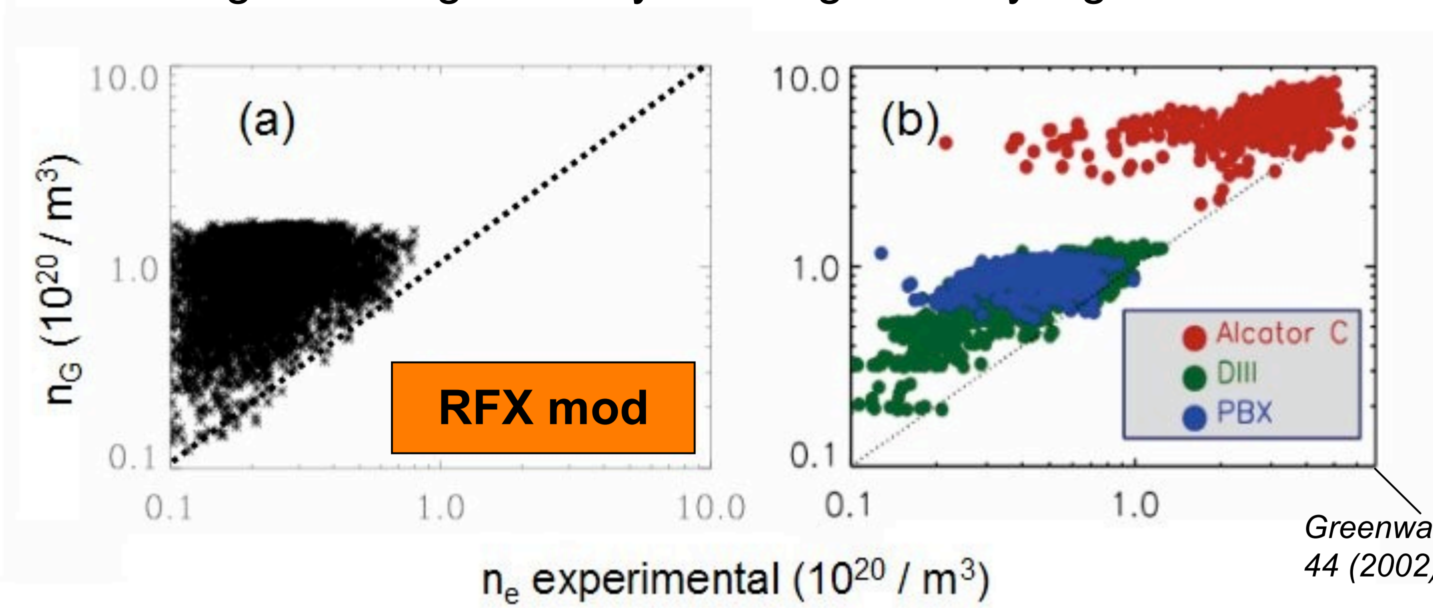
• Plasma current and density are strongly coupled

• Any transport improvement relaxes this liason by reducing loop voltage and  input power thus relaxing PWI .

# In RFX mod: 3 types of operational density thresholds

***1) ne/nG < 1 The Greenwald density Limit***

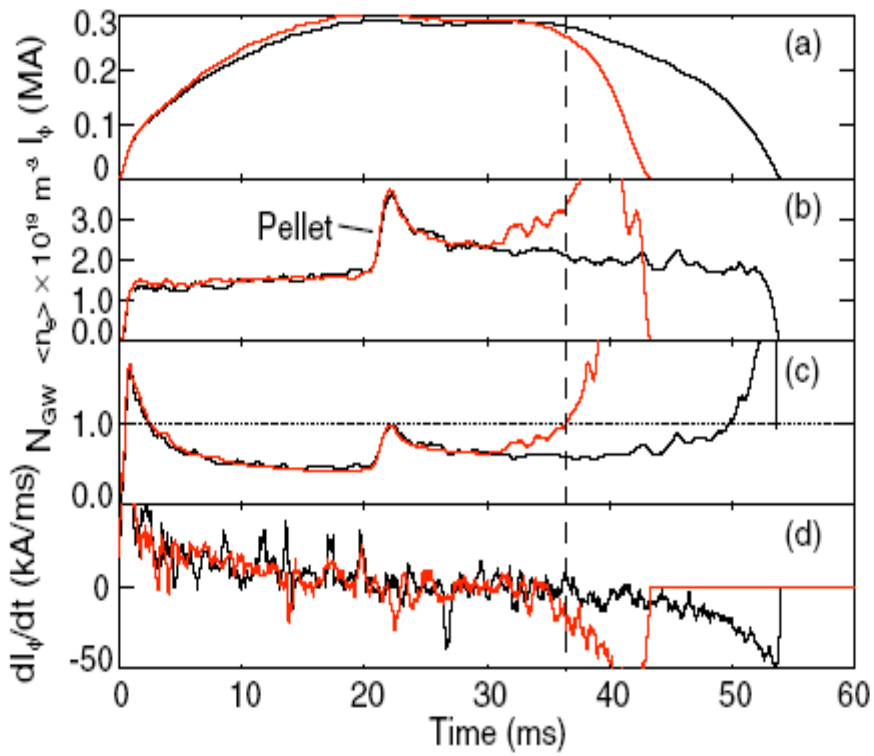
Similar to Tokamak but lower that Sudo scaling in Stellarators
The Sudo scaling is an edge density limit significantly higher than Greenwald's.




*Greenwald et al. PPCF 44 (2002) R27-R80*

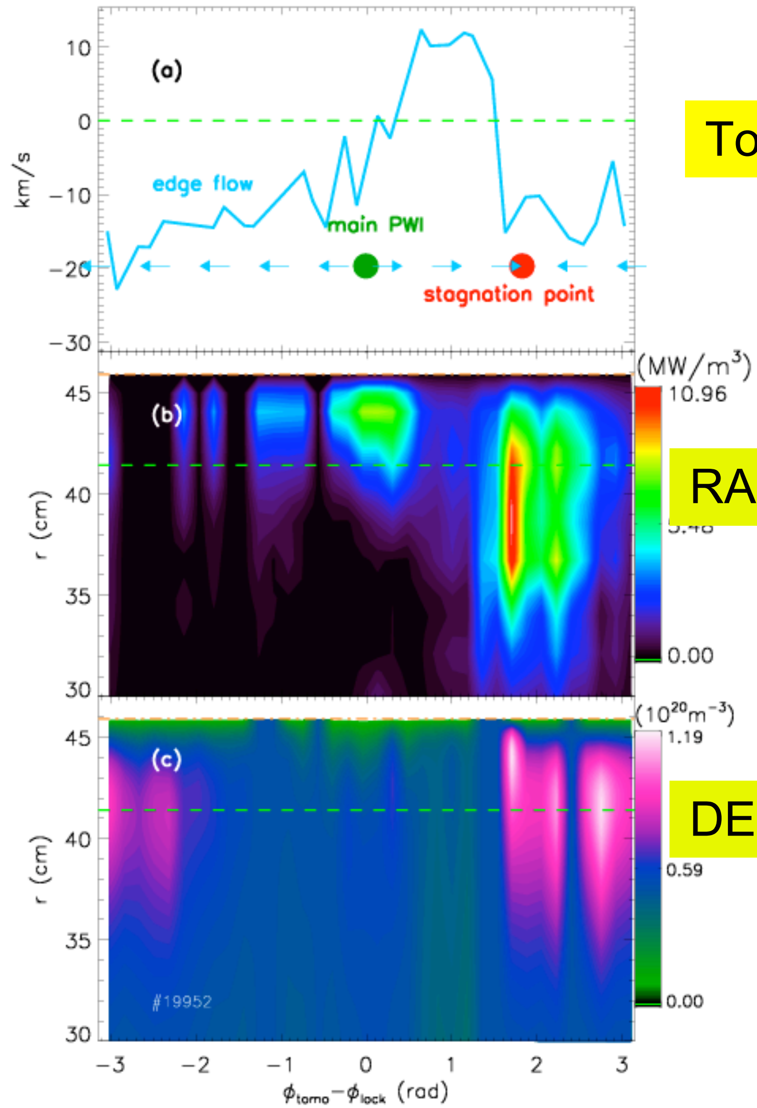
On MST and RFX-mod the Greenwald limit transiently overcome with PELLETS or during Ramp up/ ramp down

Nucl. Fusion 49 (2009) 015003 Wyman et al.




See also Wyman et al.
Phys. Plasmas 15, 010701 2008

Outermost radius ( cm )




Tor. FLOW

RADIATION

DENSITY

(Puatti et al. PoP 2009)

RFX-mod : at high density m0-like structures (poloidal symmetric)
define toroidally localized dense and higly radiating belts, corresponding to stagnation points of the edge toroidal flow. Main PWI is elsewhere

Analogy with MARFES observed in Tokamaks with toroidal symmetry

Important difference: in RFP's the instability is not disruptive

Stellarators may instead recover from a temperature collapse

Note: in Ultra Low q discharges ( q positive every where non resonant m=0)
Greenwald is easily achieved

R&D

1) Extend density limit studies and comparison with Tokamak and Stellarators, and possibly extend operation beyond the limit

2) Understand the role of m=0 islands in the density limit

3) Understand the role of recycling in the RFP density limit

Tokamaks aim at operation close to the Greenwald limit. Is the RFP bound to have the same target?

Unlike Tokamaks, in fact, the RFP plasma current is not limited by stability constraints but rather by engineering limits. So in case of a lower density $n\tau T$ could be compensated by a higher current

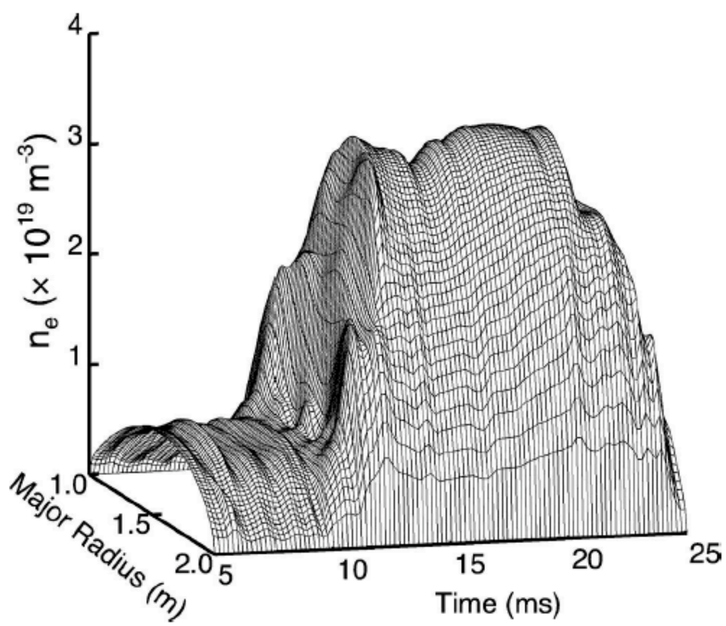
What the impact on an RFP reactor ?

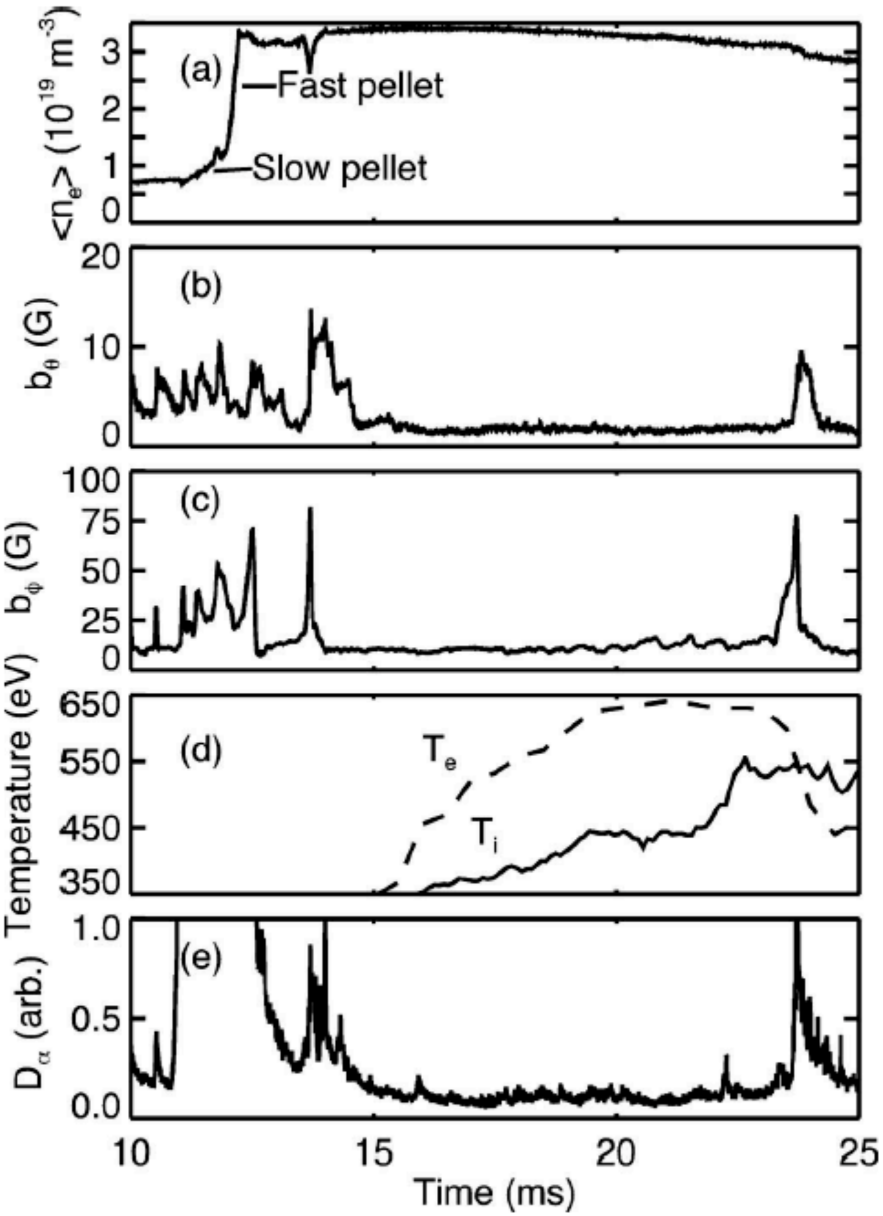
R&D

4) Extrapolate present scaling and understanding to a conceptual RFP reactor to identify plausible operational scenarios within e
and plasma wall loading

Obviously high density regimes are appealing:

On MST with Pellet: achieved $\beta$=26%






Improved confinement in MST after pellet injection

**2)** ***ne/nG <0.5  Beyond: difficult to sustain Ip.***
***This  worsens as IP is increased.***

Apparently a recycling issue (more ne increases resistivity that increases P_Ohm that increases PWI and particle influxes in an unstable way )

RFX-mod scaling: $T \propto I^{0.93}(n/n_g)^{-0.35}$ $P = VI \propto I^{0.6}(n/n_g)^{0.5}$

RFX-mod has an all graphite wall. Recycling can be >1.

R&D:
5) explore new materials . RFX-mod is going to test Lithisation(pellets and limiters)
6) If successful this would require efficient fuelling tecniques (pellets ,supersonic gas, plasma guns)

Is there another reason for the limit #2? (perhaps intrinsic to the fields topology)?

R&D
7) Selfconsistent RFP code to simulate high density RFP's

MORE on 2) ***ne/nG <0.5 limit***

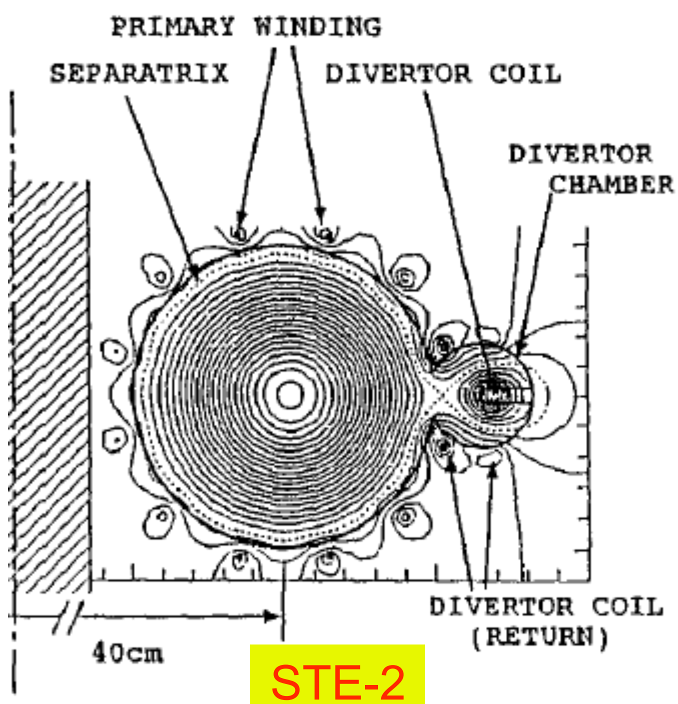
Efficient current drive or NBI power with momentum input reduce the Ip and ne coupling, and also improve transport.

R&D 8) ….Both MST and RFX are working on NBI and RF

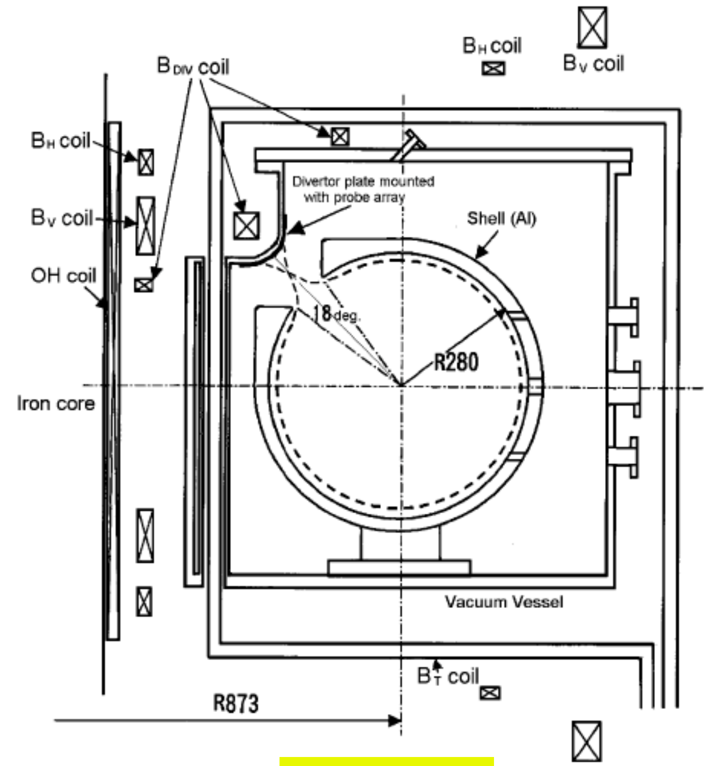
## MORE on 2) ***ne/nG <0.5 limit***

Now that the feasibility of virtual shell has been demonstrated , a divertor based RFP becomes realistic.

In the past a divertor was experimentd on STE-2 (Masamune et al J.of Nucl.Mat 241-243-(1997) 1002) and TPE-2M(Hayase et al J.of Nucl.Mat 313–316 (2003) 230)




STE-2




TPE-2M

R&D 9) study divertor solutions for an RFP with clean magnetic boundary

**3) *ne/nG < 0.3 : Beyond, no access to spontaneous QSH and its improved transport***

However, QSH persistence and duration increase with Lundquist's number S RFX-mod scaling:

$$S \propto BT^{3/2} \qquad S \propto I^{2.35}(n/n_g)^{-0.525}$$

Therefore, if such Te scaling presists, around I=2.3 MA it will be possible to get at n/ng=1 the high S values that presently allow the access to the QSH regime.

This means that above I=2.3 this soft limit should disappear.

At higher current, as mentioned above, higher power loading is to be expected as well. Radiative shield at the edge?

R&D
10) Explore high Ip regimes > 2 MA

11) Explore the feasibility of a radiation shield

## More on *ne/nG < 0.3 limit*

Someone may read the limit as a difficulty to feed the QSH region, surrounded by a transport barrier. On RFX-mod some examples of pellet feeded QSH structures that last few ms have been found.

R&D
12) Improve pellet injection tecnique to feed the QSH

## Summary

Upper density operational limits appear to be of three types.

**Immediate research should seek**:
- better understanding of the impact of reclycling on confinement
+ techniques to control it (lithisation etc.).
- Impact of boundary control on recycling itself
-Role of m=0 in the Greenwald density limit to try to overcome it
+ strict comparison with Tokamaks and Stellarators cases
- Improve  our present fuelling capability

**Future research targets**
Extrapolate to  reactor regimes present scaling to work out sustainable scenarios i.e. with reasonable Ip and wall loading
- Increase Ip beyond 2 MA to probe QSH high density scenarios
- Conceive a divertor RFP for better density control