ISW Highlights

M. Zarnstorff 23 Oct 03

- W7X status
- High-β
- Divertors
- Sustained performance

Status of winding packages

- Five winding lines fully operational
- Winding forms with high accuracy
- Shape reproducible within < 3 mm
- 12 winding packages completed
- 10 winding packages under work
- Production time 38 -> 18 weeks

See Rißе, P.Mo20

Machining of half coil casings

Insertion of winding pack into coil casing

Welding and embedding

Status of complete coils

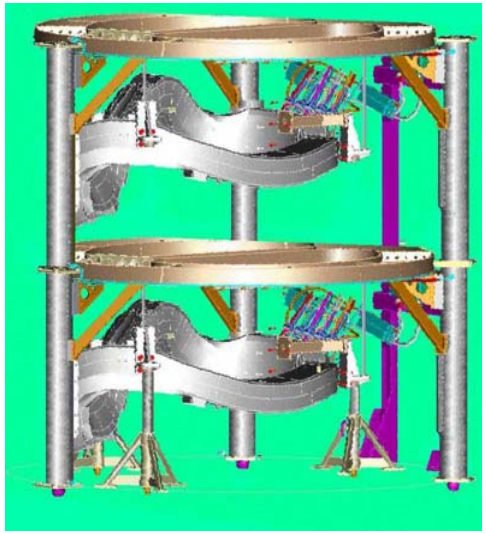
- 11 winding packages in casings
- 8 coils embedded
- 4 coils machined, 4 in progress
- machining accuracy ± 0.35 mm
- 2 coils delivered, 1 ready for delivery
- Production time 37 -> 19 weeks

Measurement after machining

Celebration of the 1st coil of type 1 at BNN at Zeitz, 16th June 2003
54 months after start of the contract

Test set-up at Saclay, 2 cryostats

Arrival of 1st coil

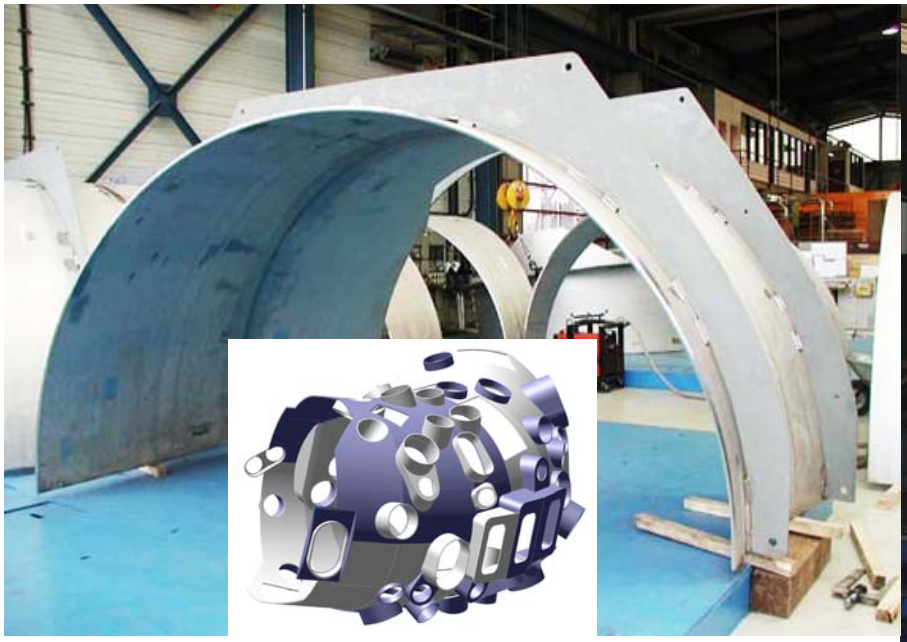


Purpose of Test

- Cool down
- Operation at nominal current
- One quench by temperature increase (margin)

Status of coil test

- 1st non-planar coil is being tested now
- 2nd non-planar coil is being installed
- Test capacity > 20 coils / y



Parts of the outer vessel and schematic model

Plasma vessel

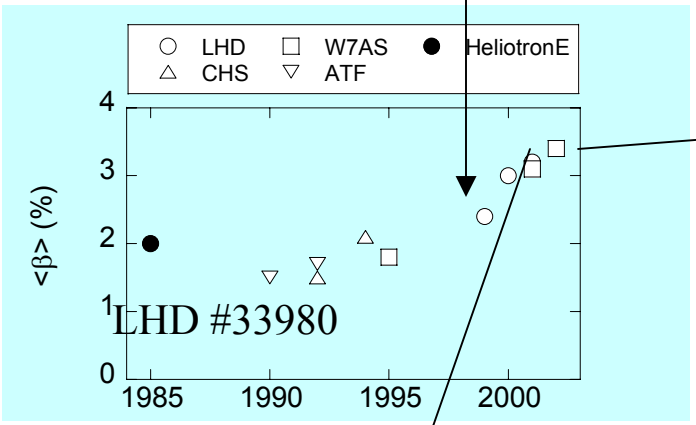
See Hein, P.Mo16

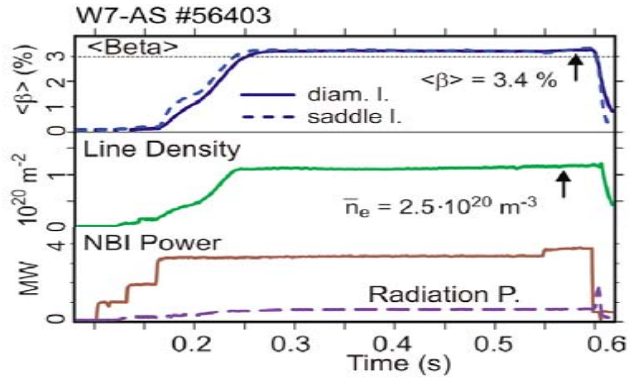
Status of vacuum vessels

- Stability calculations for openings finished
- Basic torus of outer vessel completed
- Manufacture of half shells will start soon
- 1st sector of plasma vessel will be delivered Wednesday
- In general not critical for time schedule

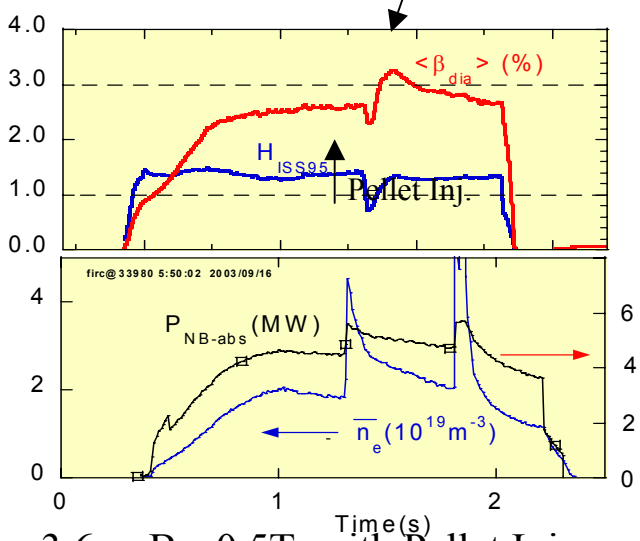
Progress of Beta Values Achieved in Stellarator/Heliotron

LHD exp. started from 1998.





(ι_a~0.5, B_0=0.9T, P_{INJ}~3.2MW)



(R_{ax}=3.6m, B_0=0.5T, with Pellet Inj.
$n_e \sim 3 \times 10^{19}$ m^{-3}, P_{abs} = 5.6 MW, $H_{DL\text{-}eff(sudo)}$~110%)

Achievement

LHD; <β>=3.2% with Pellet(2001)

<β>=3.0% (2001)

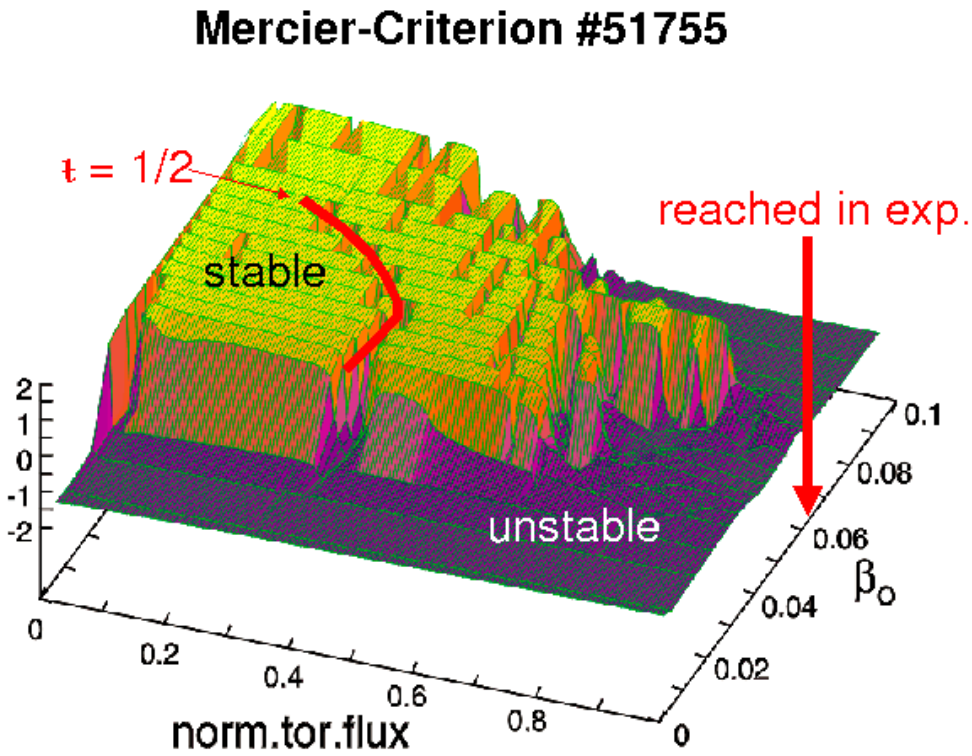
Good confinement due to mainly scale up of device size

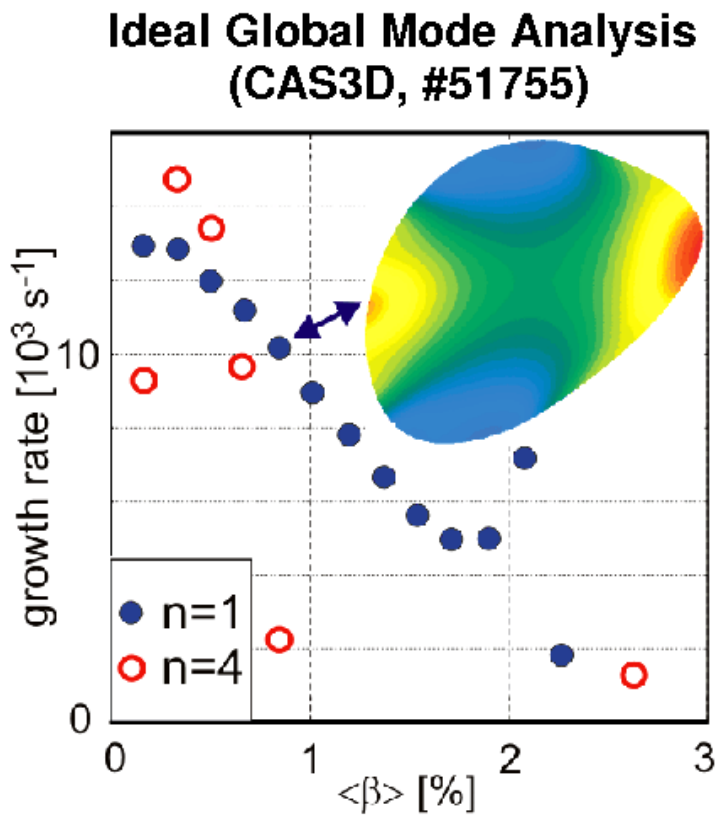
W7AS; <β>=3.4% (2002)

Finding confinement improvement close to density limit

Make sure that the achieved beta values (~2%) was not limited by MHD phenomena before LHD.

Interchange Stability of High-β-Configurations

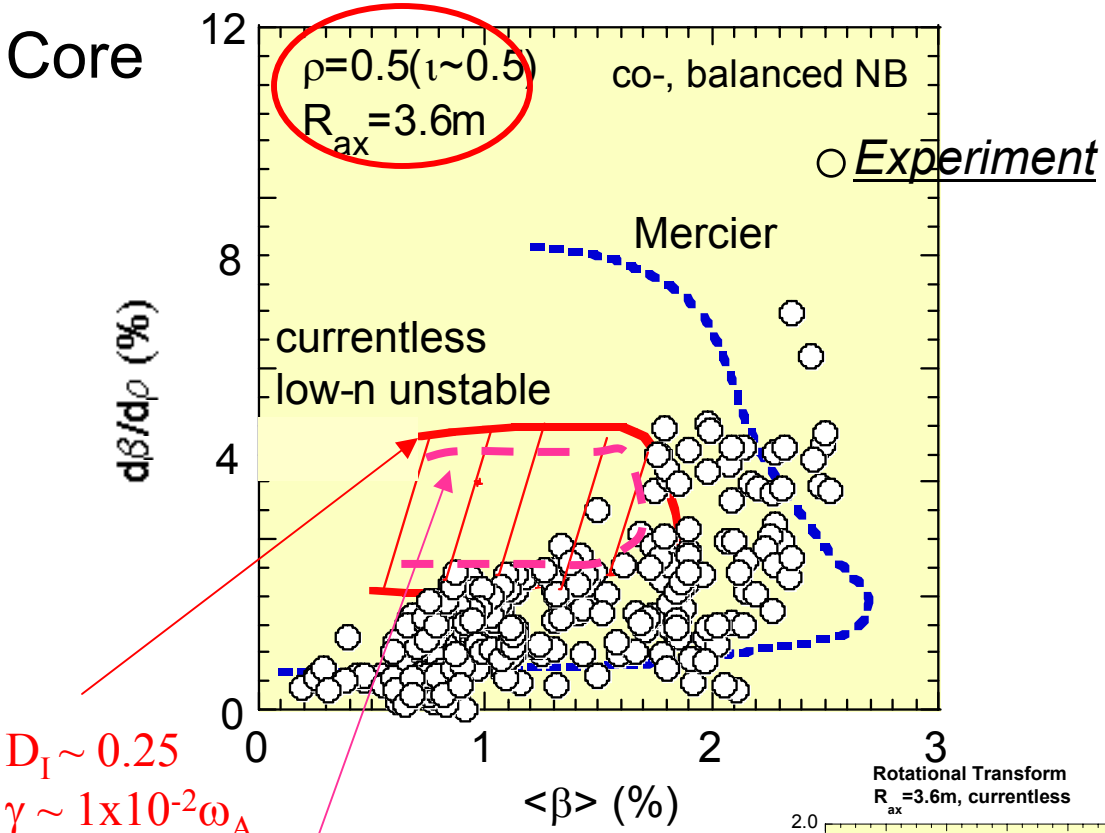




- Discharges start in Mercier-unstable region (magnetic well reduced by inward shift)
- Stable region develops, local and global stability improves with increasing β
- No global modes for ⟨β⟩ > 2.7 % (increased magnetic well, change of iota-profile)

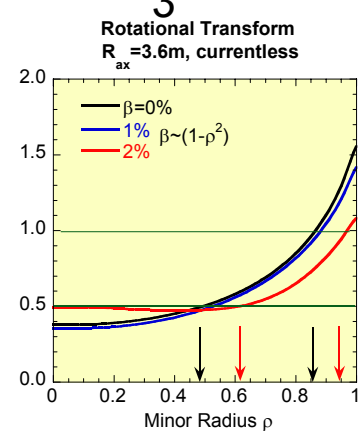
Role of Ideal MHD Mode in Core (R_{ax}=3.6m)

Compare between observed pressure gradient and low-n unstable region based on ***linear ideal MHD mode analysis*** by TERPSHICORE code in dβ/dρ-β diagram



$D_I \sim 0.25$
$\gamma \sim 1\times10^{-2}\omega_A$

$D_I \sim 0.3$
$\gamma \sim 1.5\times10^{-2}\omega_A$



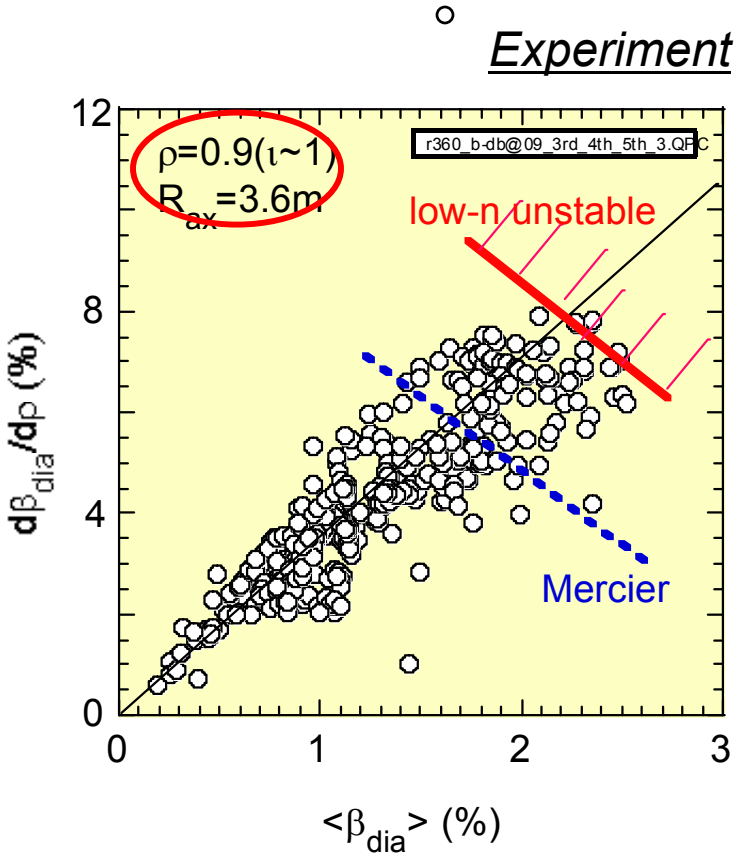
Core region
Gradient seems to avoid low-n unstable region.

 # Gradient does not care Mercier unstable region in both core and edge regions!!

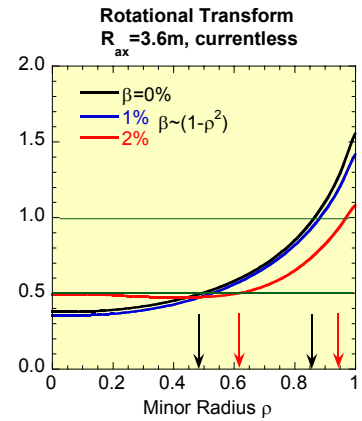
One final goal of this work is to obtain a criterion (parameter) that low-n mode is effective by using on D_I or γ.

Role of Ideal MHD Mode in Edge (R_{ax}=3.6m)

Compare between observed pressure gradient and low-n unstable region based on ***linear ideal MHD mode analysis*** by TERPSHICORE code in dβ/dρ-β diagram



Edge



Edge region

The b-gradients are in low-n marginal region

 # Gradient does not care Mercier unstable region in both core and edge regions!!

But: in reality walls are 3d and even have holes

Present tokamak theory approaches:

- approximate wall by 2d closed (Bondeson)
- 3d wall coupled to 2d linear MHD code (Bialek, Boozer), i.e. no change in MHD mode structure possible

Here: Generalisation of CAS3D (P. Merkel, C. Nührenberg)

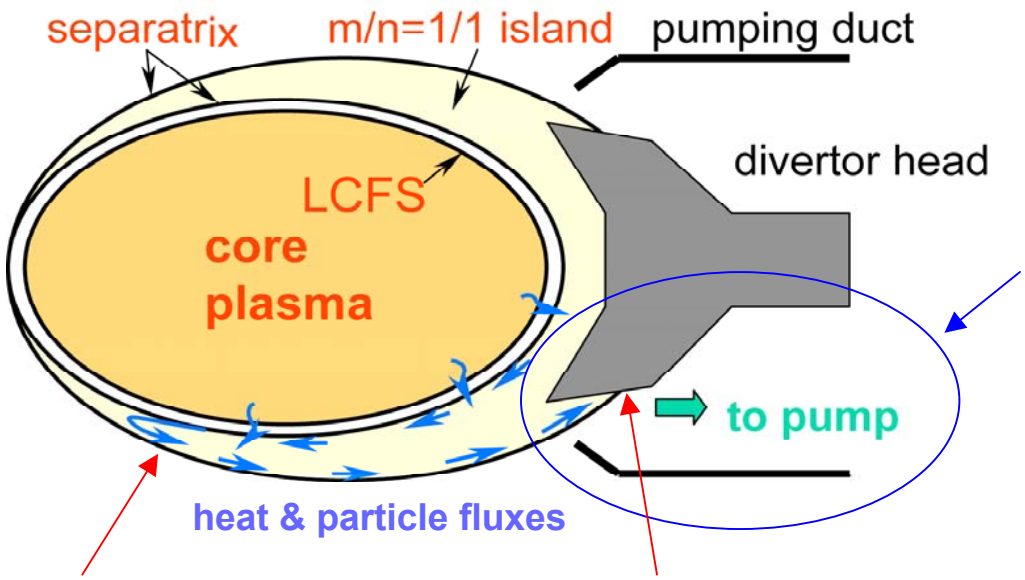
- vacuum solution with ideal walls:
  - no constraints on wall configuration
  - finite element method

- generalisation on up- down asymmetric equilibria (VMEC, CAS3D)

details: TM: P. Merkel (Monday)

Principle of LID

LID is a divertor that uses an *m/n* = 1/1 island.



Closed geometry

High pumping efficiency of ≥ 30%.

⇩

Highly efficient pumping, combined with core fueling, is the key to realizing a few keV divertor plasma, leading to a significant energy confinement improvement.

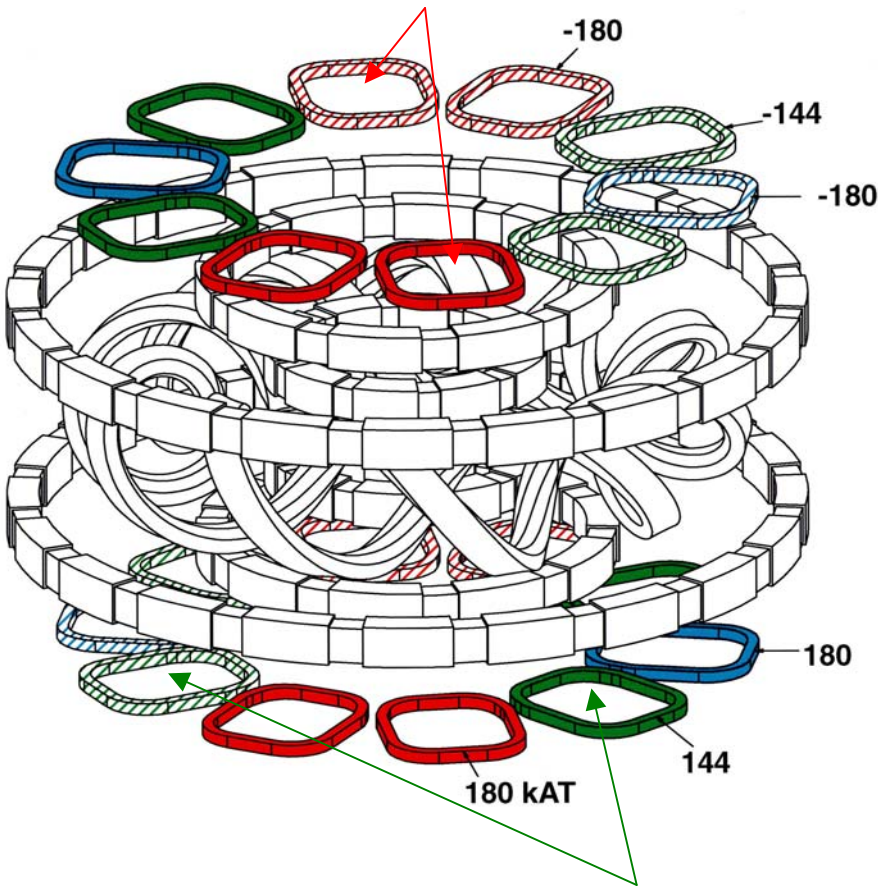
Outward heat and particle fluxes crossing island separatrix flow along field lines to backside of the island.

Particles recycled on the divertor head are pumped out by a pumping system.

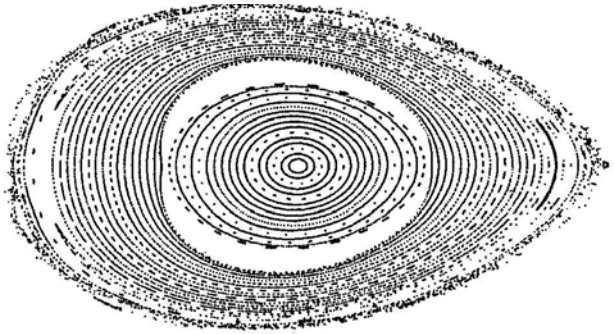
A temperature pedestal must be realized, whose value and gradient are larger and steeper than those observed up to now, respectively.

Perturbation coils form only 1/1 island

Red coils generate an *m*/*n* = 1/1 and 2/1 islands.



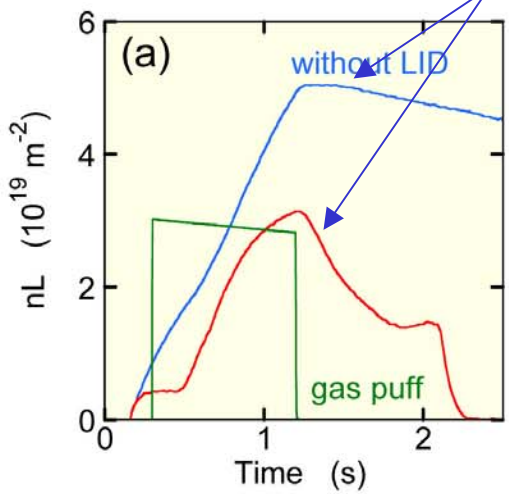
***m*/*n* = 1/1 island required for LID**

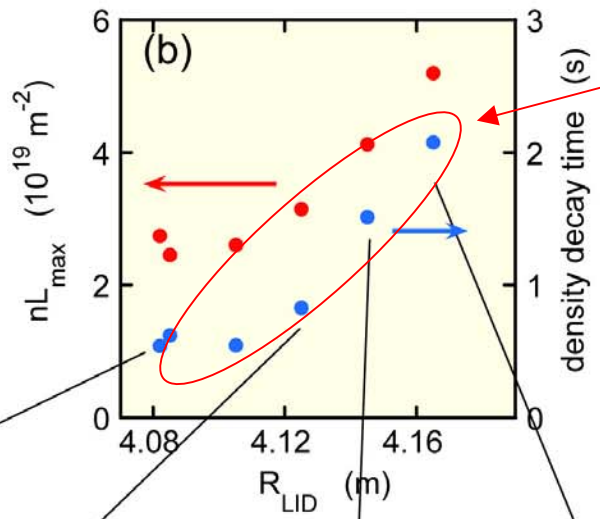


Green and blue coils generate *m*/*n* = 2/1 islands.

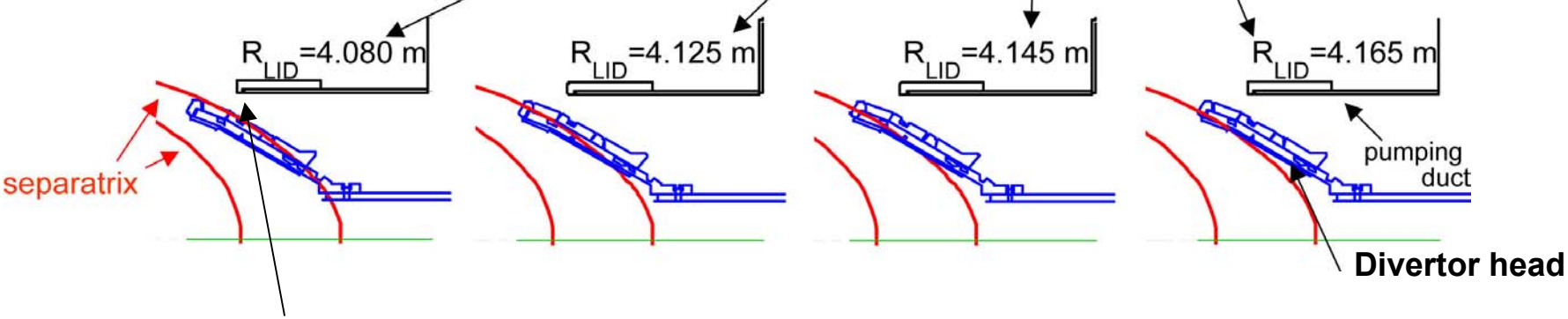
Recycling rate is low in the standard LID configuration

With LID, the decay time of line density is shorter than that without LID. ⇨ **Recycling rate, R_p, is low [$\tau^*_p = \tau_p /(1 - R_p)$].**



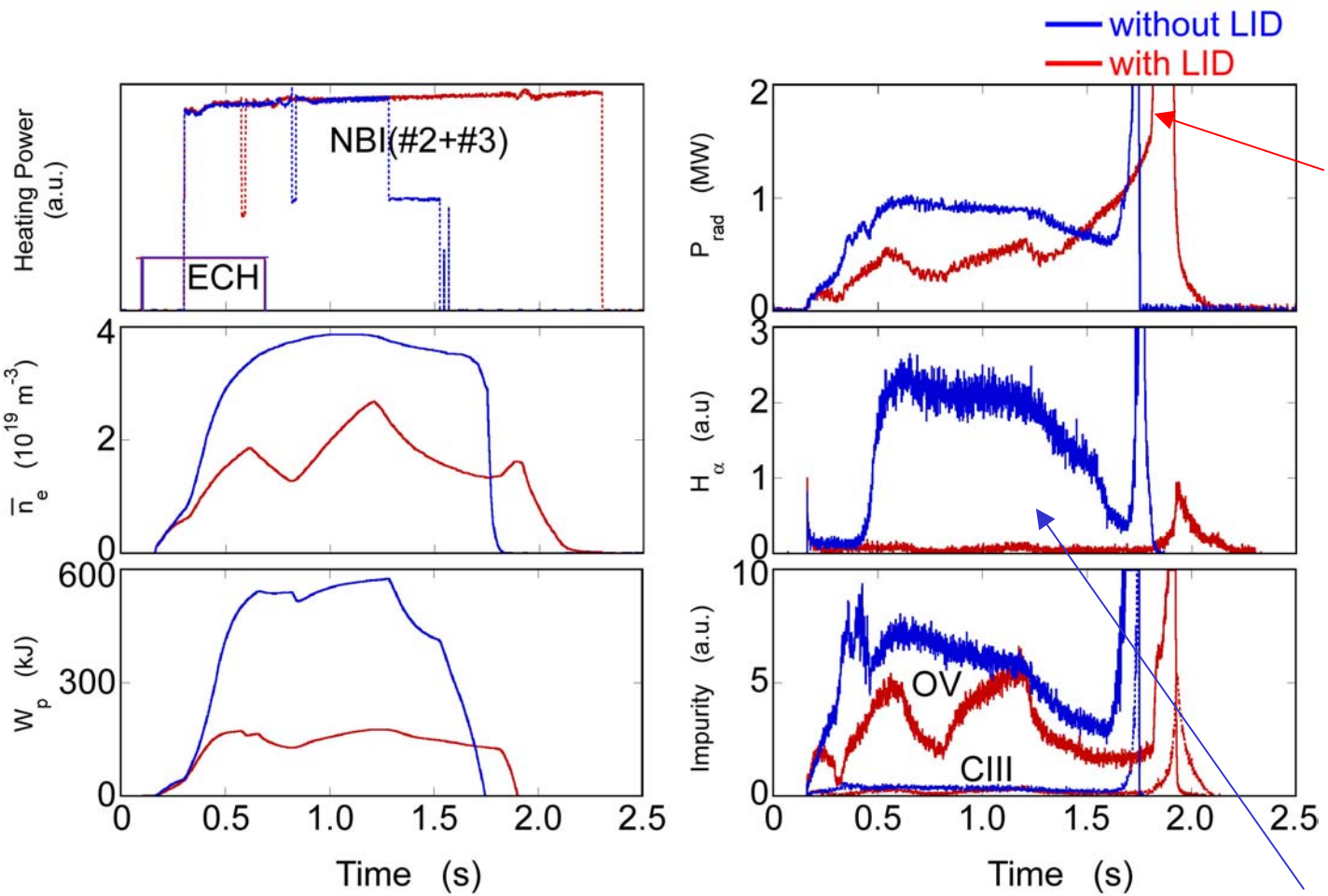


The decay time of line density decreases monotonously, as the divertor head moves into the island.



The shortest decay time of line density, that is, the lowest recycling rate is obtained when the outer separatrix of the island is located between the divertor head and pumping duct, which is the standard geometrical configuration of LID.

Temporal evolutions of plasma parameters with and without LID

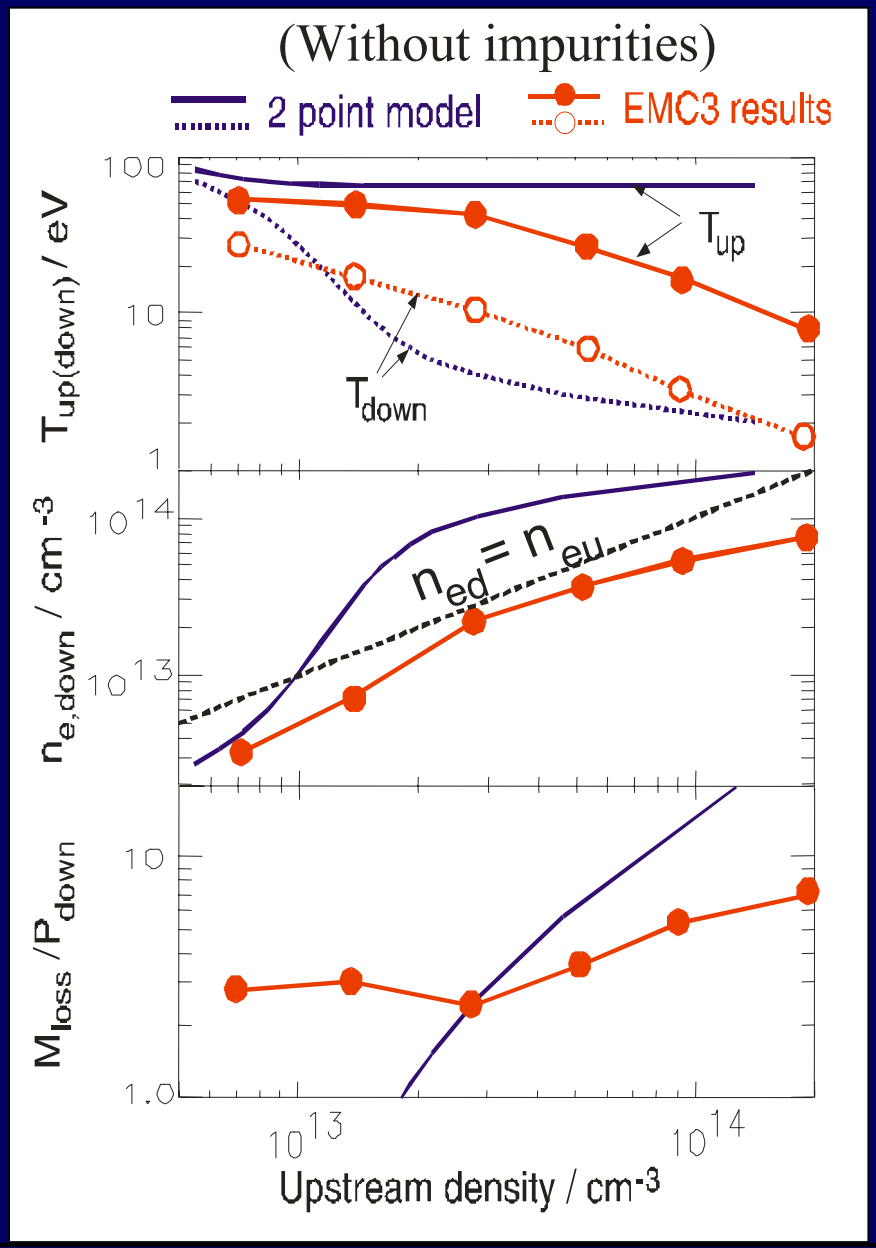


Radiation collapse always occurred at the end of LID discharges.

Plasma parameters were, however, found to change in LID discharges before the collapse.

Especially, the reduction of the Hα intensity is remarkable, suggesting that vague plasmas disappear, which exist outside the last closed flux surface (LCFS).

Transport: island divertor vs. tokamak divertor



Code results

- Drop of T_{up} (cross-B heat conduction)
- Downstream density never exceeds upstream density, no high recycling
- Momentum loss at low densities, high temperatures (cross-B diffusion)

confirmed by experiment

Conclusions

- EMC3-EIRENE treats self-consistently the plasma, impurities and neutral gas transports in 3D ergodic and non-ergodic edges including realistic divertor plates, baffles and wall. The code has been implemented on W7-X and TEXTOR-DED.
- The main differences in physics between the W7-AS island divertor and a tokamak divertor are the geometry-related momentum loss, the absence of the high-recycling regime, the high separatrix density required for detachment transition (and for an effective pumping) and the weak efficiency of neutral gas screening.
- Detachment stability depends on island geometry
  * Stable detachment only possible for sufficiently large island and field-line pitch

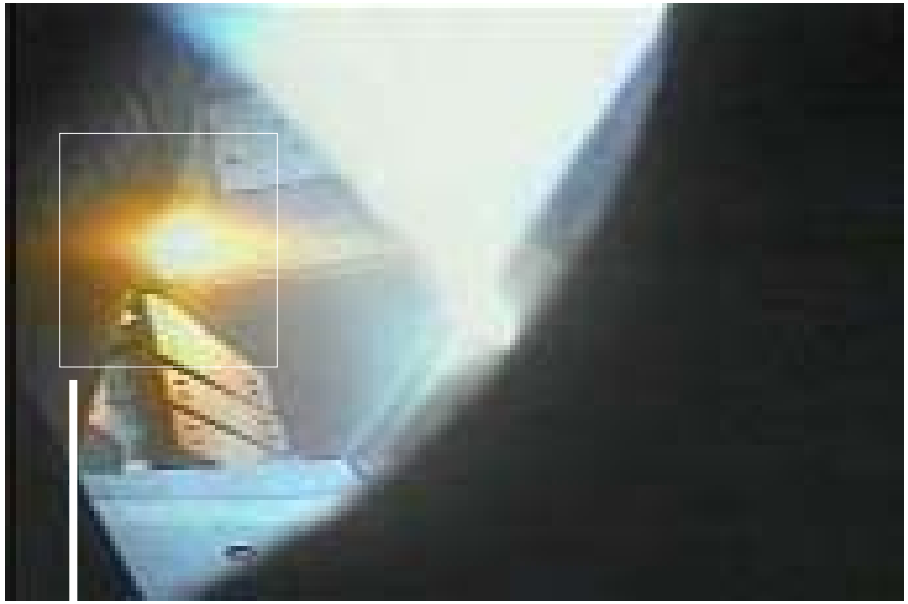
Code results:

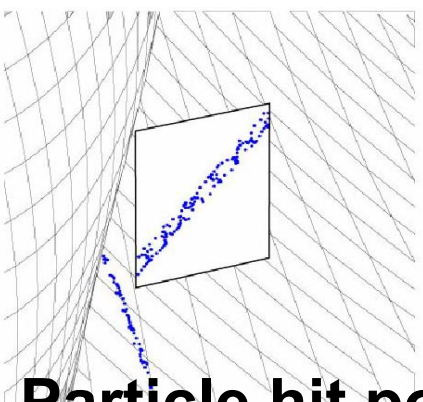
* Only two typical radiation patterns
  - inboard side radiation (large islands and field-line pitch)
  - divertor radiation (small islands or field line pitch)
* Evolution of radiation through detachment similar to that of MARFEs in tokamaks
* Divertor radiation → cold islands → poor neutral screening
* Loss of neutral screening responsible for detachment instability
* Stabilization by decreasing n_{es}

Summary of Long Pulse ICRF Operation

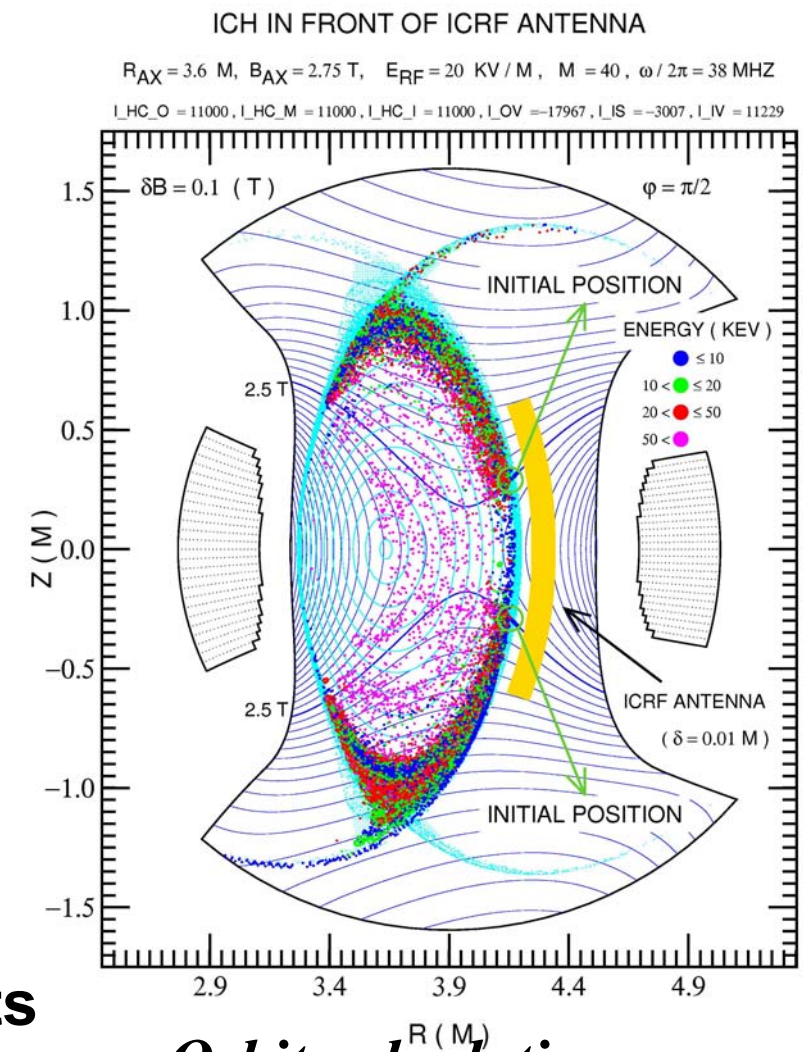
1. By the improving ICRF hardware, operation time has been elongated to 150 sec.
2. Arcing problem at the vacuum chamber was solved by adding grounding plates.
3. Last long pulse operation was terminated by plasma density increase over the ICRF density limit.
4. Local heating of divertor carbon plate may cause an excess hydrogen outgas flux.
5. Particle acceleration in front of the antenna and direct loss may lead local heating of divertor plates.
6. For the next operation (in 2004), several operation techniques are proposed for longer duration.
   - -- antenna position change
   - -- higher density operation
   - -- use of multi antennas by turns

A Divertor carbon plate was locally heated by ICRF accelerated particles. Hot spot pattern was well reproduced by the particle orbit calculation. (by T. Watanabe).





Particle hit points by calculation



Orbit calculation by T.Watanabe