# Plasma formation and sustainment without a central solenoid in a Spherical Tokamak

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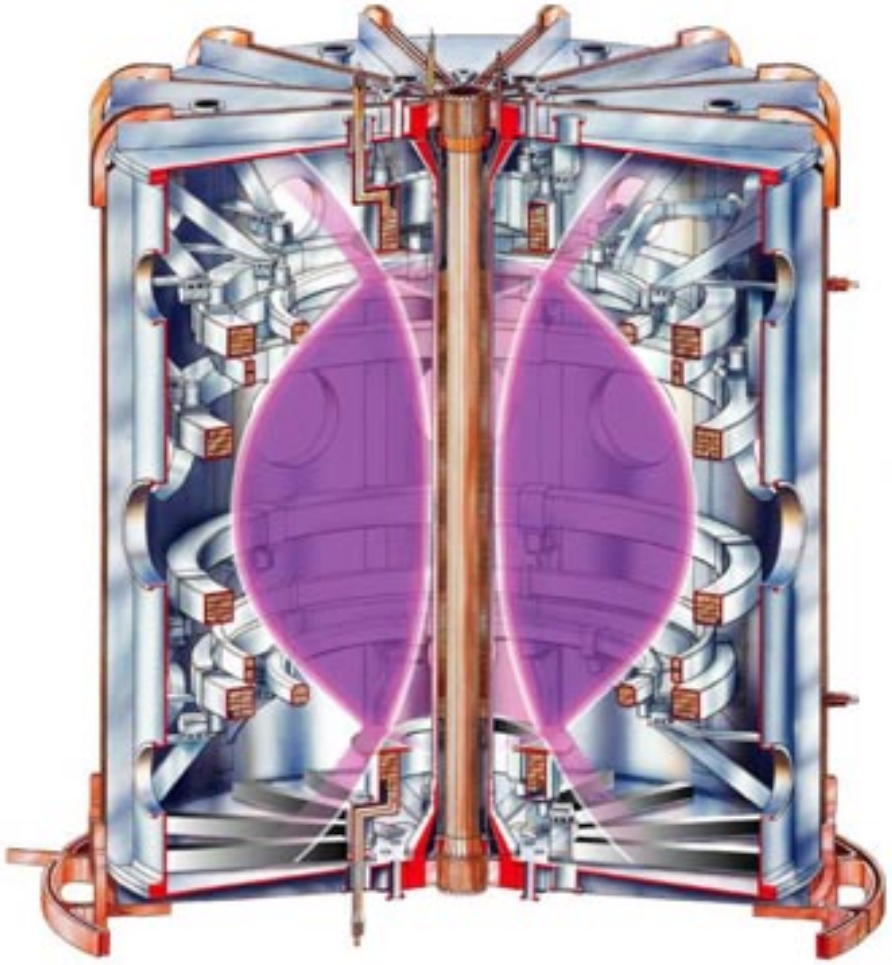
## Plasma formation without central solenoid

examples:

- Merging - Compression scheme in MAST
- CHI in NSTX / HIT

## Current ramp-up in STs

- Effectiveness of NBI
- Bv contribution
- Results from MAST



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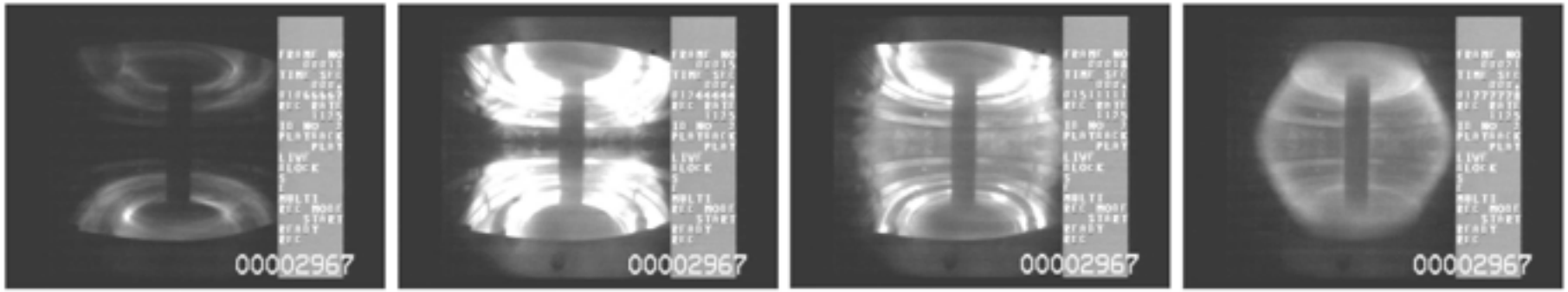
# The Merging / Compression scheme

- used on START and MAST
- can produce an initial ST plasma of 500kA on MAST




*Plasma rings form* *- merge -* *take up ST configuration*

*all in 10ms*

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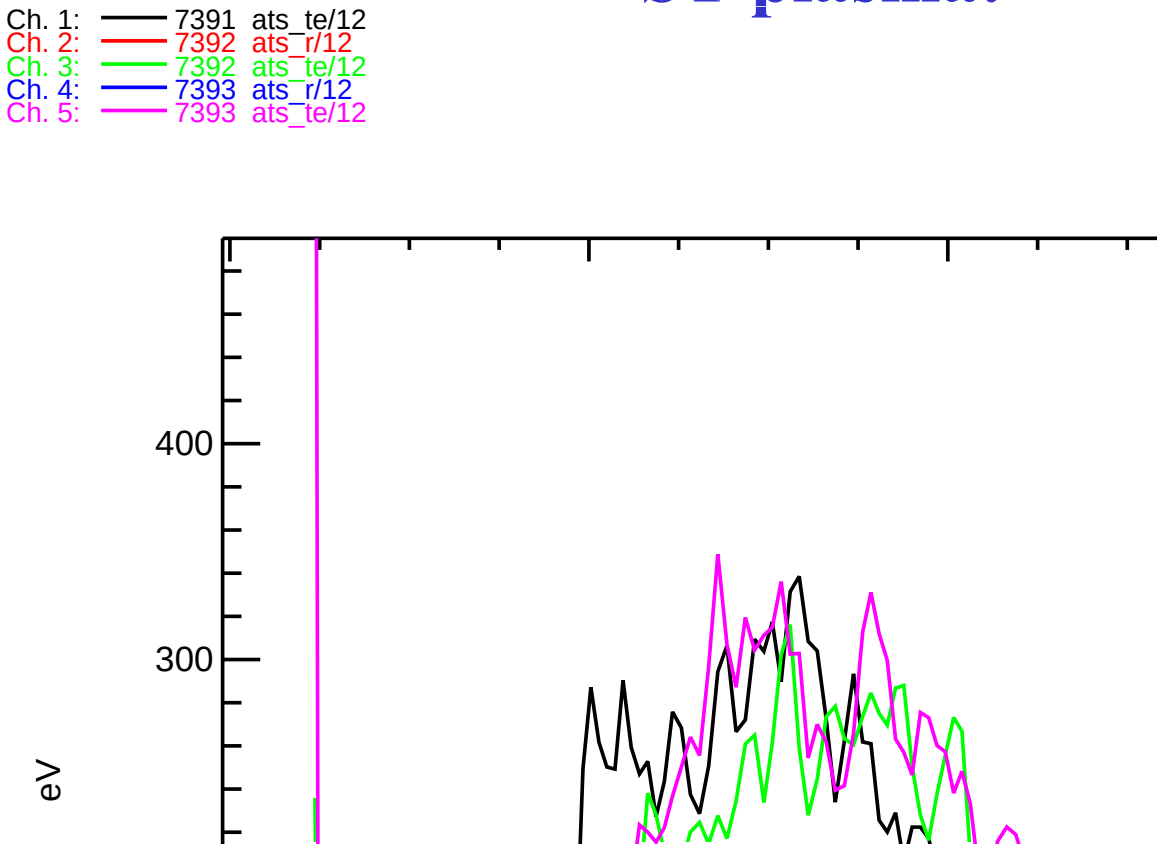
# Merging-Compression produces a relatively hot ST plasma:

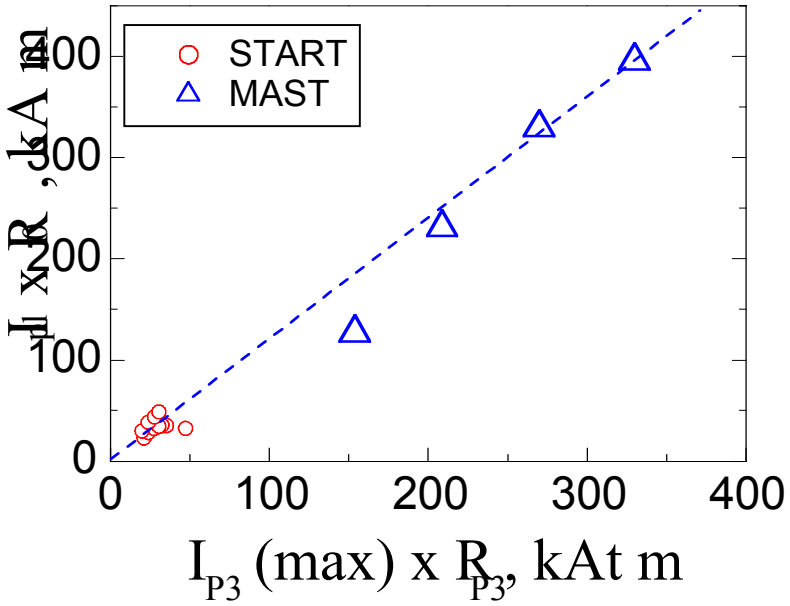


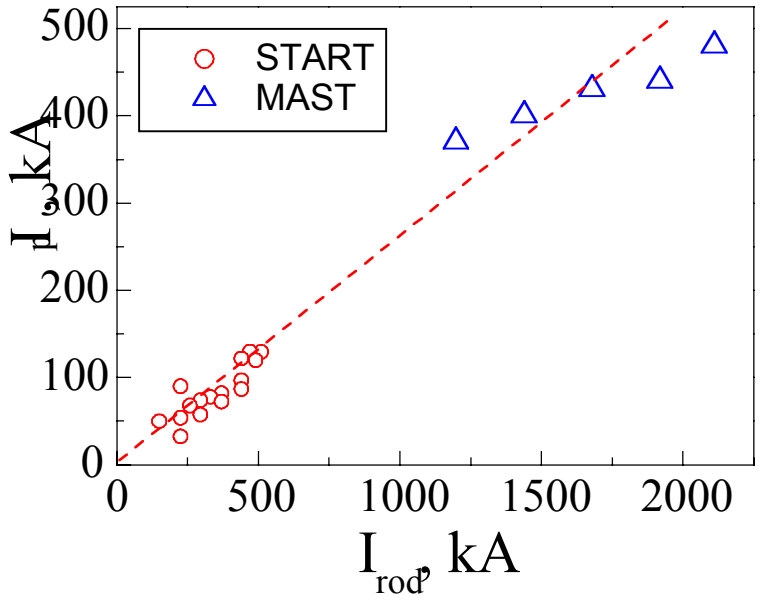

*Te profiles from TS at time 12ms, for the TF scan.*

**Plasma current scales with I(P3) (induction coil current); plasma thermal content scales as $I(P3)^2$**

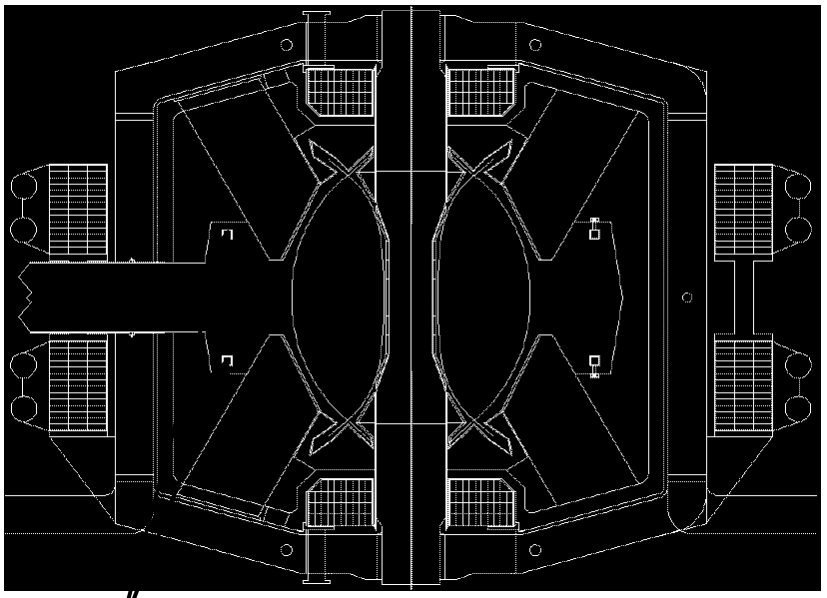
**a 33% increase in I(P3) is planned for 2003**

# Scaling of plasma current with Induction Coil current and Toroidal Field



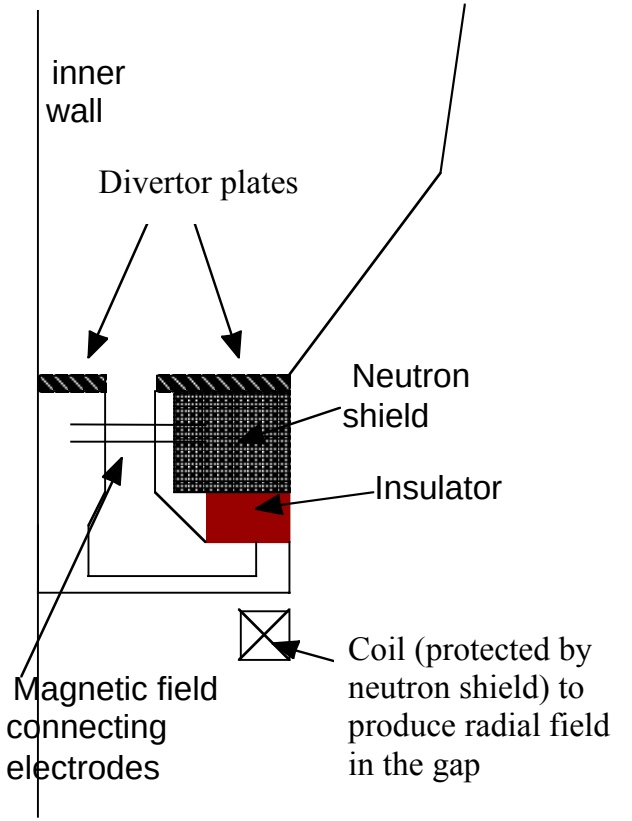



# The Merging/Compression and CHI schemes could be used to initiate a large ST device, e.g. CTF (Component Test Facility)



Induction coils

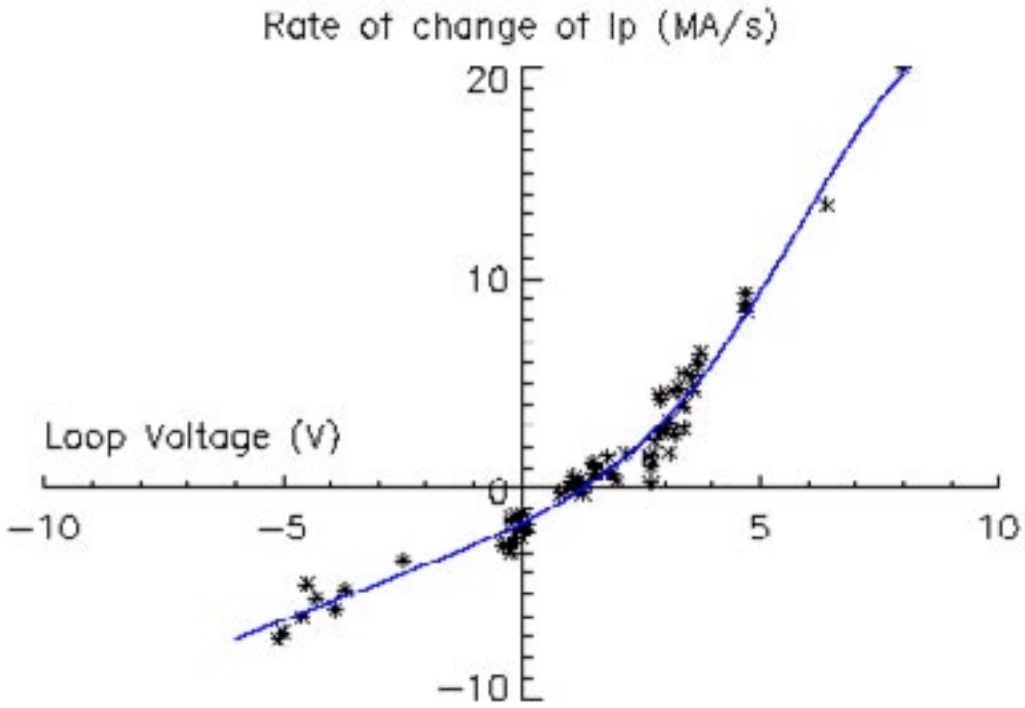
(T C Hender, Culham)




(T Jarboe, Univ. Washington)

# Current ramp-up in MAST (1)

Current ramp rate vs. Vloop from solenoid, over typical set of early MAST discharges, **low power (<1MW) NBI.**



# Current ramp-up in MAST (2)

**<u>High power NBI helps in 4 ways:</u>**

- hotter plasma ⇒ less resistive loss
- NBI Current Drive
- high $\beta_p$ ⇒ high bootstrap fraction
- **increasing plasma energy ⇒ increasing Bv ⇒ additional flux**

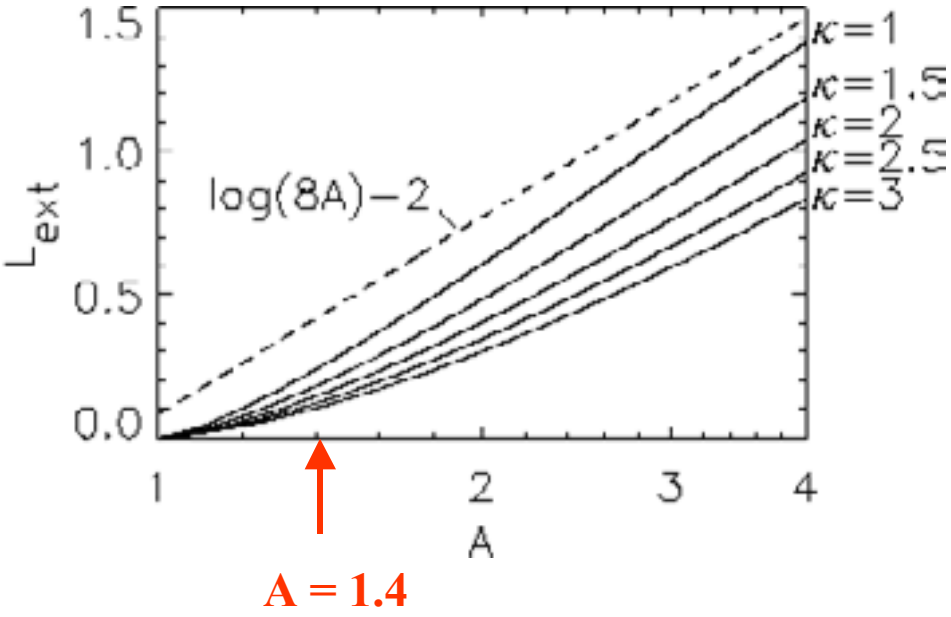
# Flux from Bv coils is especially important at low A

Compare two tokamaks of similar plasma area and current, assuming typical values li=1, $\beta_p = 1$:

| | A | k | R(m) | Ip (MA) | LI (Vs) Associated (1) | Vs Provided by Bv (2) | Vs From solenoid |
|---|---|---|---|---|---|---|---|
| MAST | 1.4 | 2 | 0.85 | 1.0 | 0.68 | 0.47 | 1 |
| TFTR | 3.5 | 1 | 2.5 | 1.0 | 5.5 | 2.5 | 12.5 |

For the ST, Bv flux is a bigger fraction

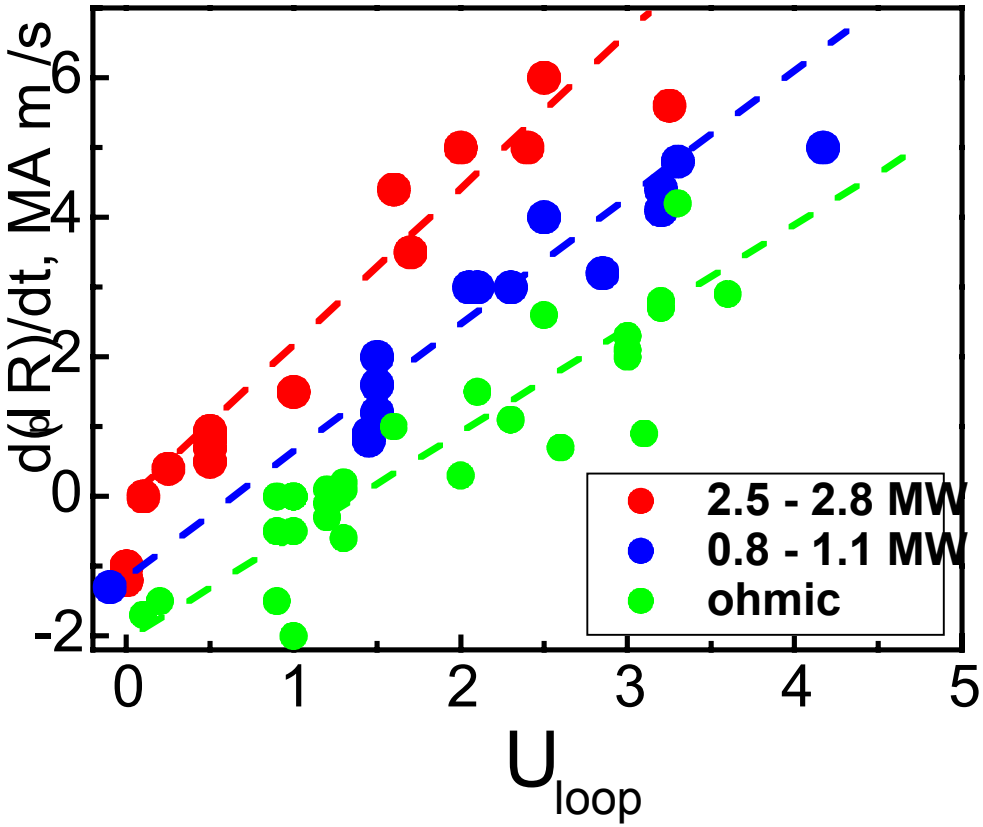
AND of a scarcer resource




(1) S P Hirshman & G H Nielson, Phys Fluids **29** (1986) p790

(2) O. Mitarai & Y Takase, Fusion Science & Technology, Nov 2002

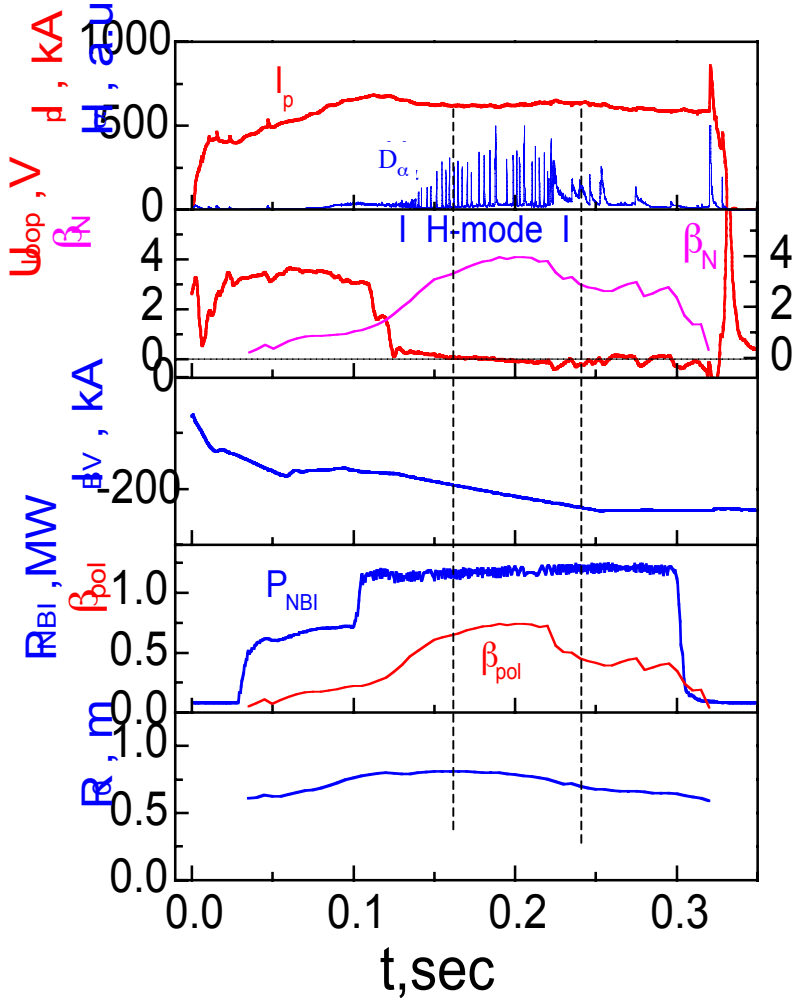
# Current Ramp in MAST (3)




*Current ramp rate is increased under strong NBI heating.*

These results suggest that future experiments at PNBI ≥ 3MW should exhibit positive current ramp at zero solenoid loop voltage.

# Example




In MAST #4571, the discharge is maintained (approx. constant Ip, Ro) for ~100ms at zero solenoid loop voltage, using ~1.3MW of NBI

Estimates: at t=200ms,

j(NBCD) ~ 65kA (10%)

j(boot) ~ 160kA (26%)

# SUMMARY

without central solenoid:

•an initial plasma can be produced using M/C or CHI (and possibly ECRH/EBW?)

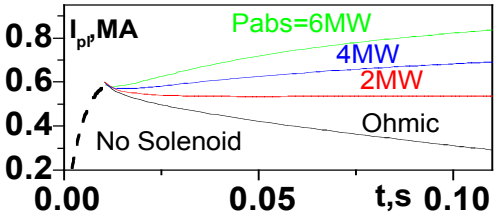
•On MAST, plasma current can be maintained using NBI heating/CD

# QUESTIONS

without central solenoid:

•Can we demonstrate plasma current increase at higher power NBI ?

•Can we 'handover' from initial plasma to a plasma ramp-up?




SIMULATION
using ASTRA

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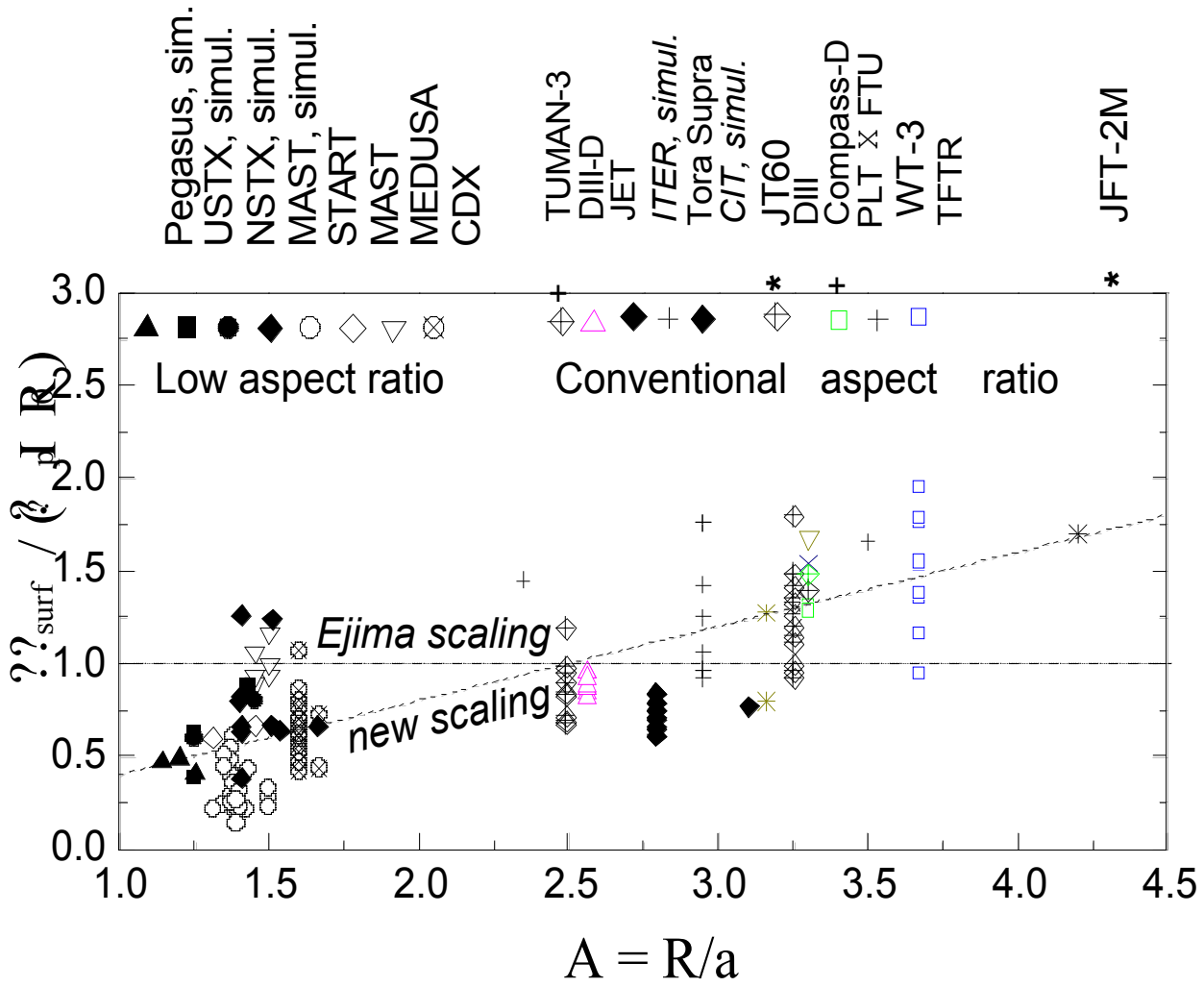
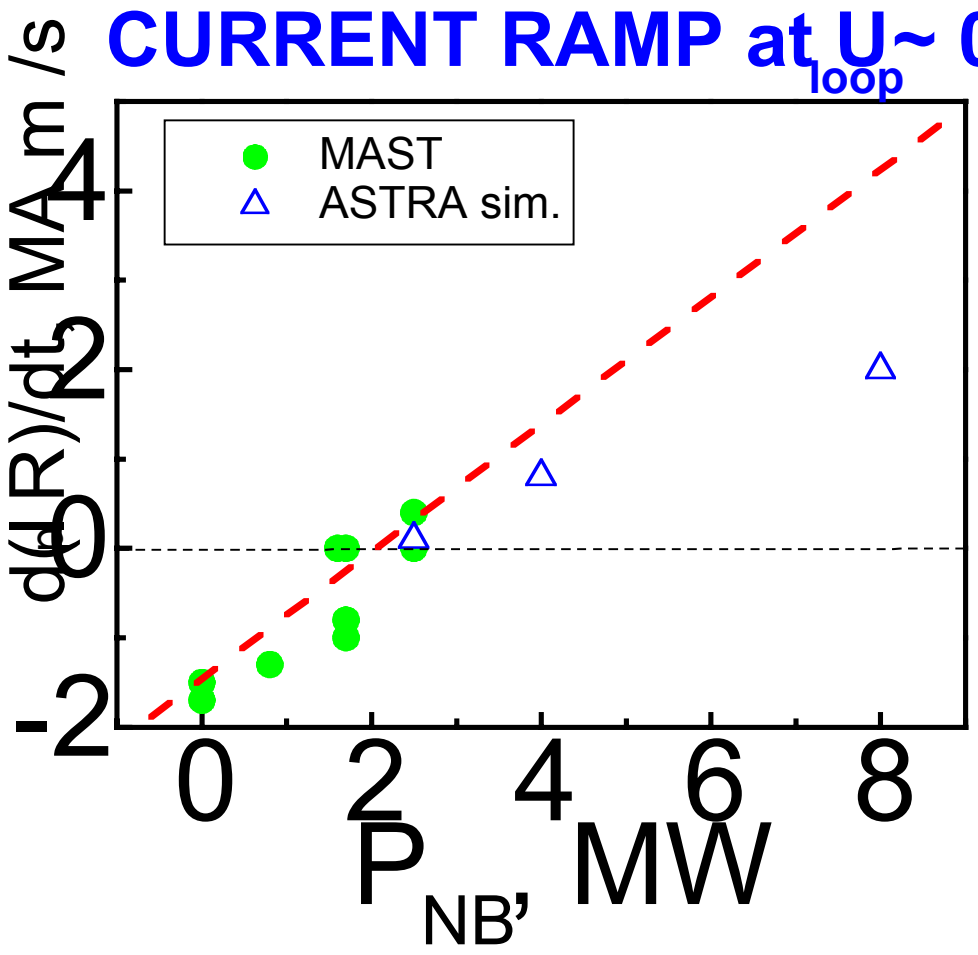
# Ejima scaling, modified by Gryaznevich




**Ejima-Wesley:** $\Delta\psi_{surf} = C_{EW}\,\mu_o\,I_{pl}\,R_0$ , where $C_{EW} \sim 1$

**Gryaznevich:** $\Delta\psi_{surf} = 0.4\,(R/a)\,\mu_o\,I_{pl}\,R_0$


CURRENT RAMP at U~ 0
loop
MAST
ASTRA sim.
d(LR)/dt MA m /s
4
2
0
-2
0
2
4
6
8
P NB' MW