Slow OH Formation of FRC in NSTX ?

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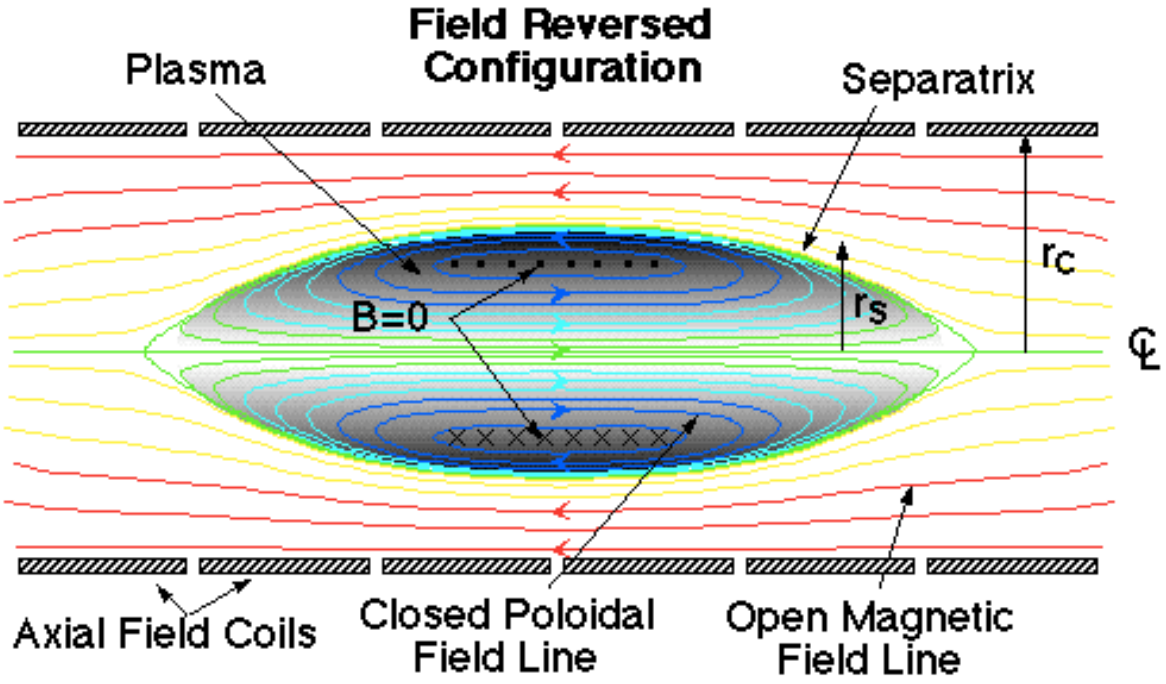
NSTX Forum '03

- Why do FRC research on NSTX ?
- Possible scenarios
- Physics issues
- First steps

Field Reversed Configuration (FRC)



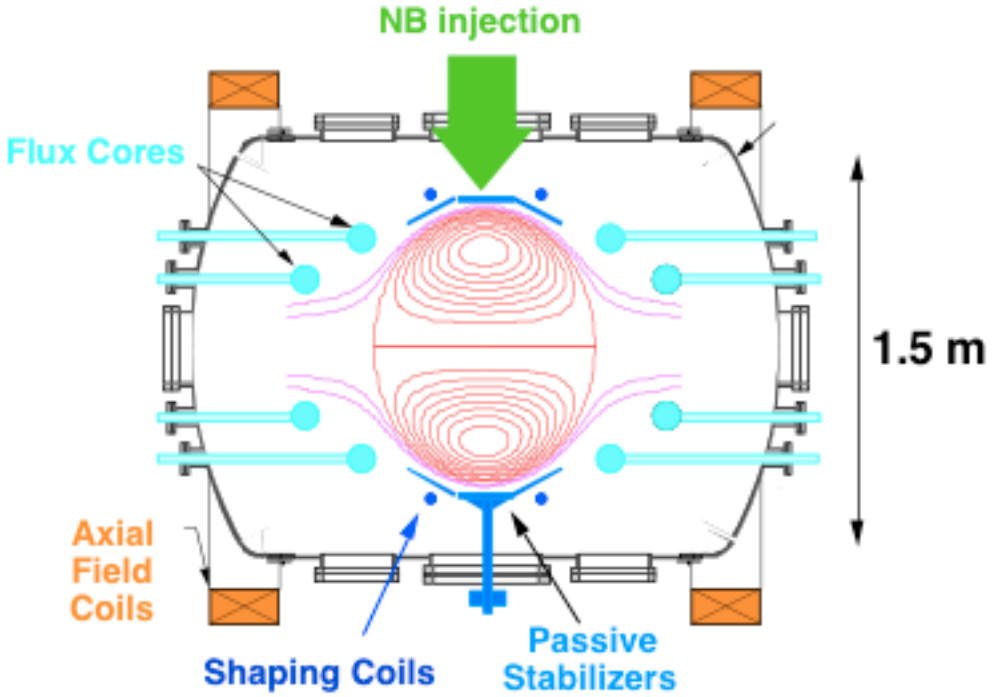
- Many experiments since 1950's (see Tuszweski NF '88)
- Difficult to create (usually needs a lot of power)
- Difficult to sustain (needs non-inductive current drive)
- Can be MHD unstable (e.g. to tilting)

Why Do FRC Research on NSTX ?

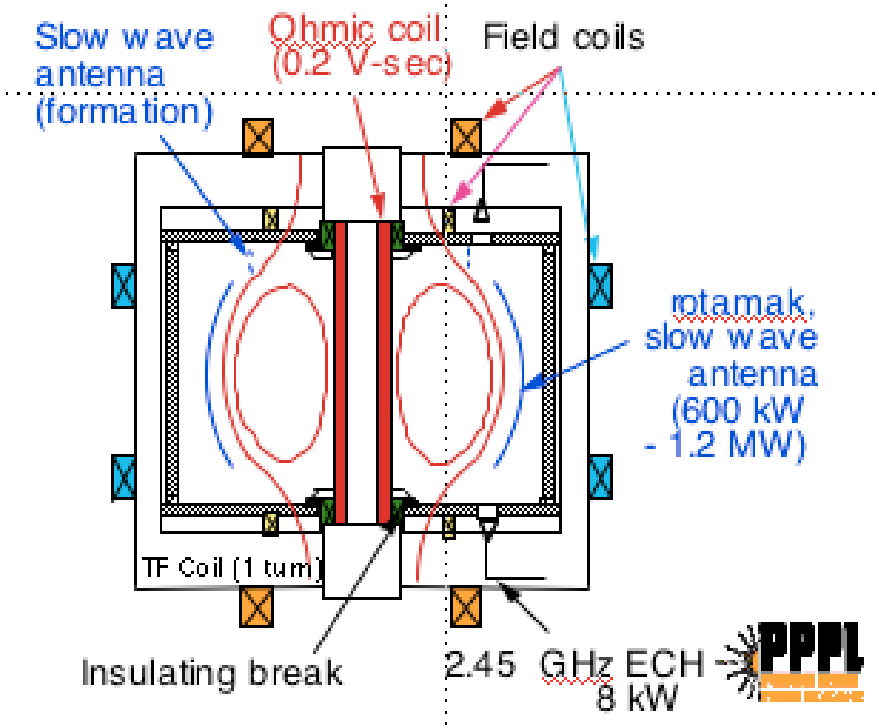
- FRC is very much like an ST (e.g. $\kappa \approx 1$), but without the annoying TF coils (which are bad for a reactor)
- If an FRC could be made in NSTX, it could become an FRC "proof-of-principal" device on the "fusion roadmap"
- FRC has interesting physics perhaps relevant to STs:
  - magnetic reconnection during formation stage
  - stabilizing effect of NBI on MHD stability
  - diamagnetic current drive from pressure gradient
  - rotamak current drive from RF antenna

Previous ST-Like FRCs at PPPL

- Can have center column for FRC physics studies
- Main difficulties are formation, stability, and current drive



SPIRIT FRC proposal
(Yamada, Ji, et al, '99)



CDX-U FRC proposal
(Majeski, Kaita, et al, '99)

Possible Scenarios for FRC Formation in NSTX

- Y. Ono proposed spheromak merging scheme (like in MRX)
  - inductively form spheromaks at top and bottom
  - merge to form FRC (strong heating @ reconnection)
  - sustain current using OH (~ TS-4) + NBI (~ SPIRIT)

- Raman proposed spheromak formation by CHI electrodes
  - polarity of top & bottom spheromaks OK for FRC
  - but present CHI electrodes not up/down symmetric

- TF rampdown from ST -> (RFP ?) -> FRC (Nagata PRL '03)

- Ohmic startup like normal in NSTX, but with little or no TF !
  (~ toroidal z-pinch, but low voltage, Sugisaki JPSJ '87)

Ohmic FRC Formation in NSTX ?

Start-up:

1) fill chamber with normal D_2 gas pressure
2) form normal field null but with $B_T \leq 10$ Gauss !
3) preionize with RF (30 MHZ = ECRF @ 10 Gauss)
4) turn on OH and drive toroidal current
5) FRC forms when $I \approx 1$ kA ($B_p \approx 10$ Gauss)

Ramp-up / sustainment:

6) keep OH and RF on until $I \geq$ 500 kA
7) turn on NBI and sustain with current with β_p !?

Some Physics Issues

A) Optimum fields for initial breakdown

B) Density limit of ECRH preionization

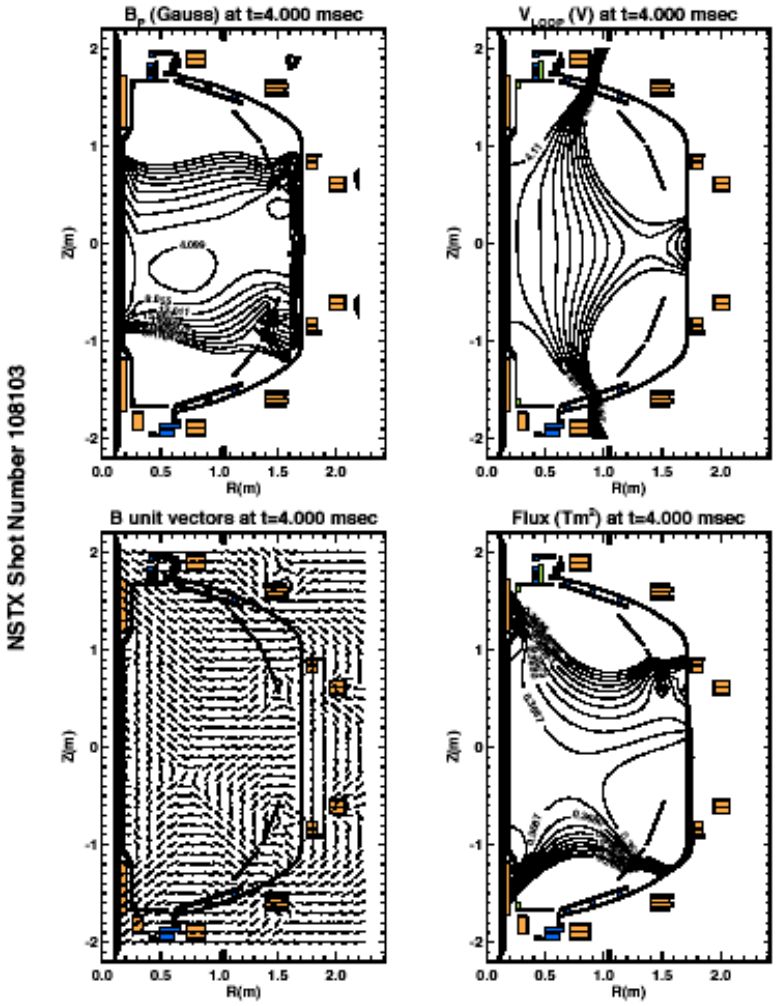
C) Ohmic current drive before FRC formation

D) Current drive and heating after FRC formation

E) MHD stability and plasma confinement

Optimum Fields for Initial Breakdown

- Want X-point for initial electron confinement @ breakdown
- Normal NSTX PF X-point ~ OK
- $B_p \leq 10$ G within z = ±50 cm
- X-point moves vs. time in R so location can be varied
- Extra fields could be added if necessary for FRC, or for stray field compensation



J. Menard

Density Limit of ECRH Preionization

- No technical reason why MW of 30 MHz ECRH can not be applied to heat at |B| ≈ 10 G in NSTX
- But cutoff of ordinary EM wave will occur at ω_{pe} or:

  $n \approx (30 \times 10^6 / 9 \times 10^3)^2 \approx 10^7\ cm^{-3}$

- It is possible that other effects may raise this limit:
  - slow waves, LH, whistler waves, helicon waves, etc.
  - near B-field effects, or E field effects on neutrals

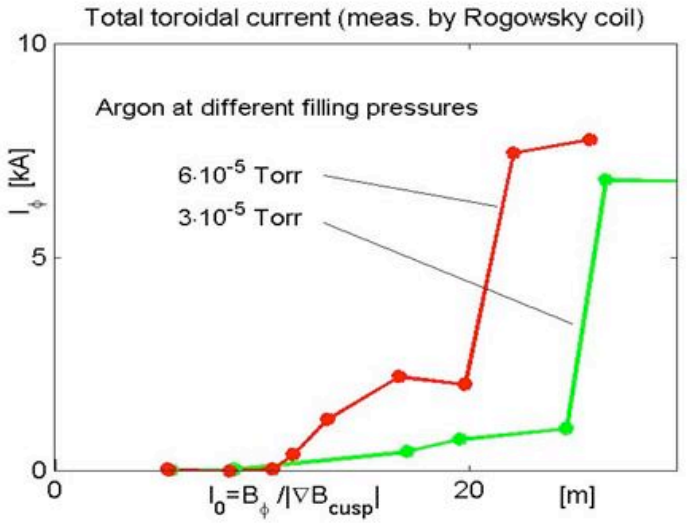
=> need to try and see what density can be obtained

Ohmic Current Drive Before FRC Formation

- If B_T=0, toroidal conductivity □ B should be *half of* Spitzer if collisionality is high enough (this would be very good)
- But if E = V x B + □□j, then main effect of OH may be to drive $V_r \geq 10^5$ cm/sec @ B_p=10 G
- Egedal found high torodial current only when $L_o = B_T/\square B_p \geq 10$ m

=> may want $B_T \approx 10$ G, $B_p \approx 0.5$ G ?

Measured plasma current



- For $l_0 < 1$m : $I_p < 5$ A (the cases shown so far)
- For $10\text{m} < l_0 < 20\text{m}$: $I_p \sim 0$ - 2 kA
- For $l_0 > 20$m : $I_p \sim 8$ kA

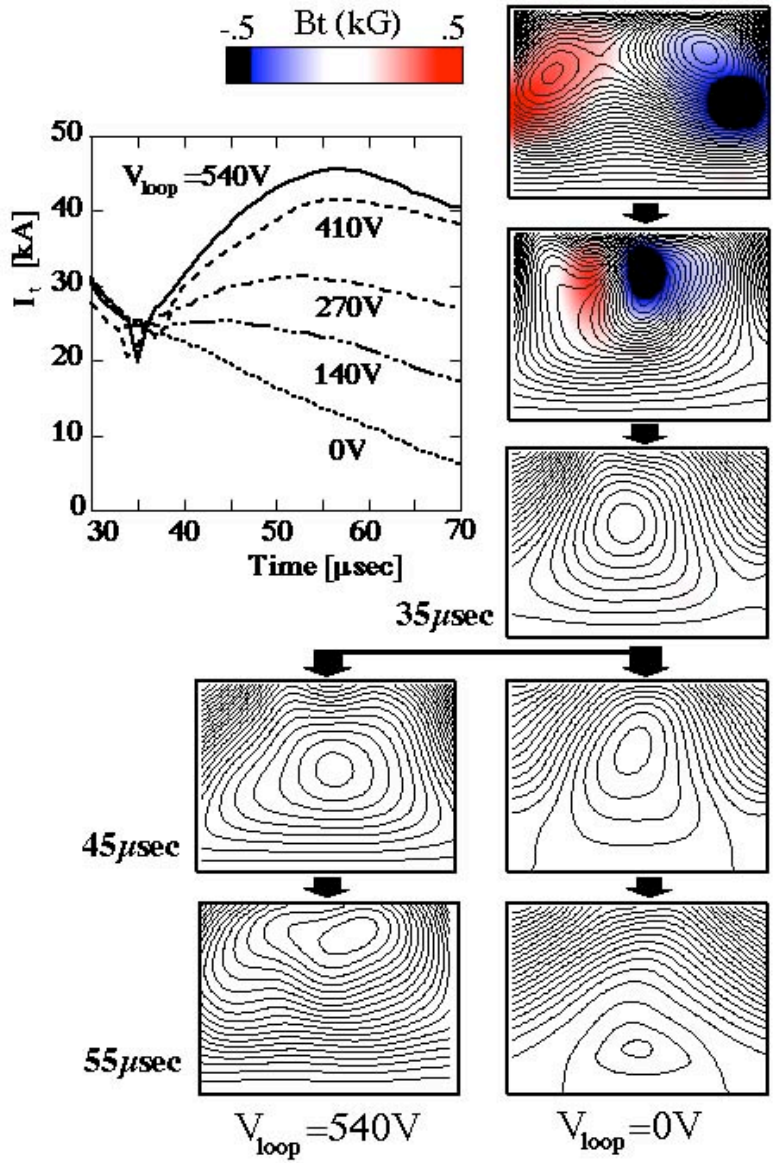
VTF, Egedal (PRL '03)

Current Drive and Heating After FRC

- FRC current should be sustainable by pressure gradient $\nabla p = j_T \times B_p$, just driven by external heating power
- Best FRCs so far have poloidal flux of ≈ 0.01 Wb, which is small compared with typical NSTX flux of ≥ 0.5 Wb
- Can a better FRC be made with existing NSTX systems ?
  - OH can drive additional current in FRC (TS-3,4)
  - NBI can drive current above I ≈ 100 kA or so
  - RF might drive current with fast wave or rotamak ?

OH current drive in TS-3 FRC (Y. Ono et al, IAEA '96)

The OH current drive amplifies the toroidal current of FRC by factor 2.



Time evolutions of toroidal currents for five loop voltages applied to the FRCs and correponding contours of poloidal flux and Bt.

MHD Stability and Plasma Confinement

- These are the most interesting physics issue to study
- Sophisticated FRC simulations available at PPPL

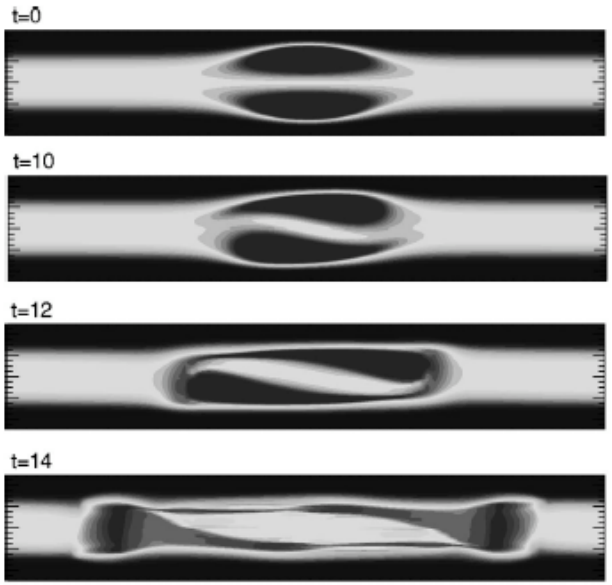
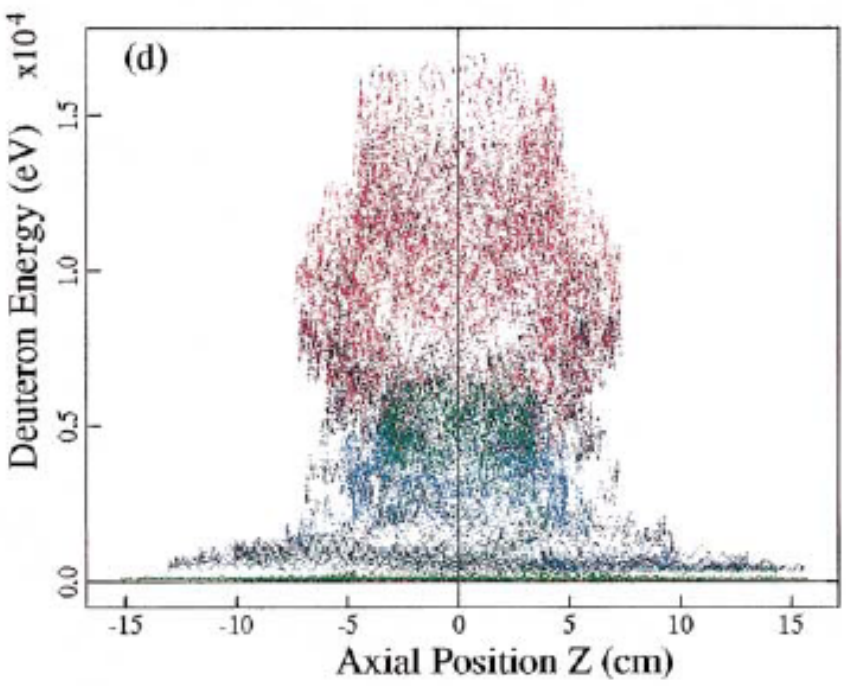


FIG. 2. The pressure contours in the poloidal plane at $t=0$, $10t_A$, $12t_A$, and $14t_A$ for the case of $E=4$, elliptic separatrix.

Belova et al, PoP '00



Cohen and Glasser PRL '00

First Steps

- Test RF loading at B ≈ 10-100 Gauss during RF conditioning shots, or at the very end of normal NSTX discharges
- Once low B plasma has been formed, add OH voltage
- Vary conditions and look for maximum current or density:
  - shape and size of B_p and B_T fields
  - timing between RF and OH
  - filling pressure, etc.
- Coordinate with other experiments (TS-4, HIT-II, VTF, etc)
- Try to simulate NSTX FRC formation and ramp-up (Belova)