

Solenoidless Startup Research Thrusts for Tokamaks

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- Current and proposed tokamaks (ITER/DEMO) all have central solenoids
- **Outer PF coil inductive startup (solenoidless) plus current drive could reduce or possibly eliminate the central solenoid => reducing size/cost**
- Here we explore research thrusts aimed at utilizing existing and expected machine components to reduce (eliminate) solenoidal flux requirements.
- We neglect other means (CHI, plasma gun, ...) and concentrate on hardware envisioned for DEMO.

OUTLINE

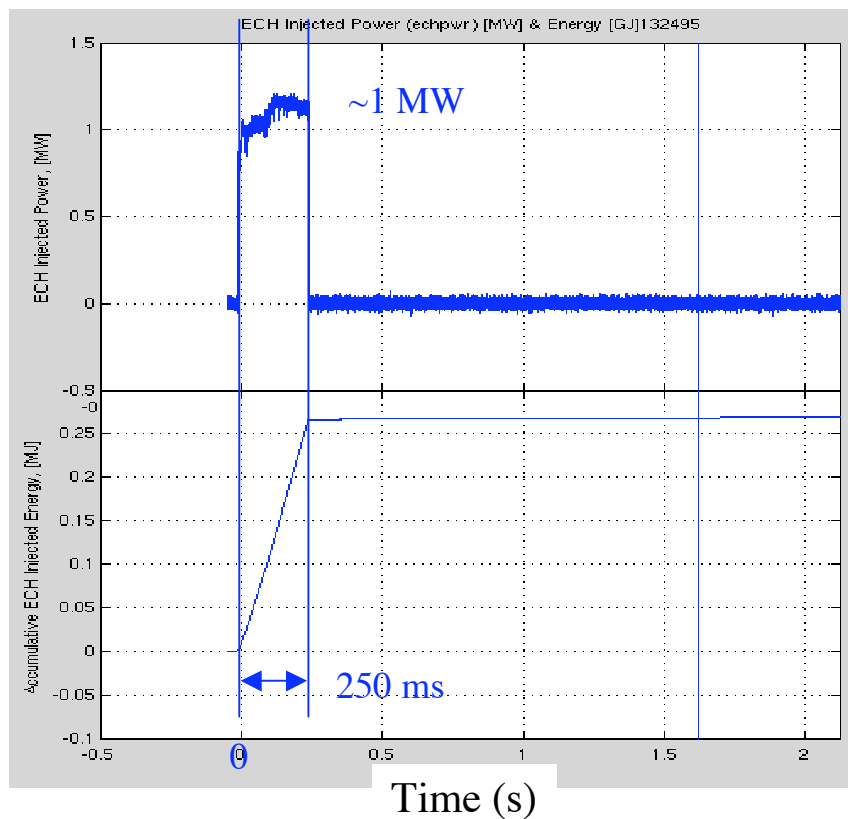
- Objective/Issues/Needs
- Simple DIII-D Flux savings example
- Historical experiments (just snapshot)
- Thrusts

Objective/Issues/Needs

- Objective: Reduce/eliminate need for PF solenoid
- Outside coil plasma initiation:
 - Low field (Null) required for initial EM configuration
 - ECH essential for breakdown / burn-through
 - Stability issues ultimately limit I_p generation
- Current Drive (CD):
 - ECCD, NBI, LHCD ...
 - CD efficiencies poorly understood during I_p ramp
 - CD methods require different plasma parameters (i.e. density)
 - CD requires high power input which leads to MHD/disruptions
 - Achieving high bootstrap current important, but little understood
- Needs:
 - Dedicated ramp-up experiments aimed at inductive flux reduction
 - Theoretical understanding of ramp-up including CD phenomena

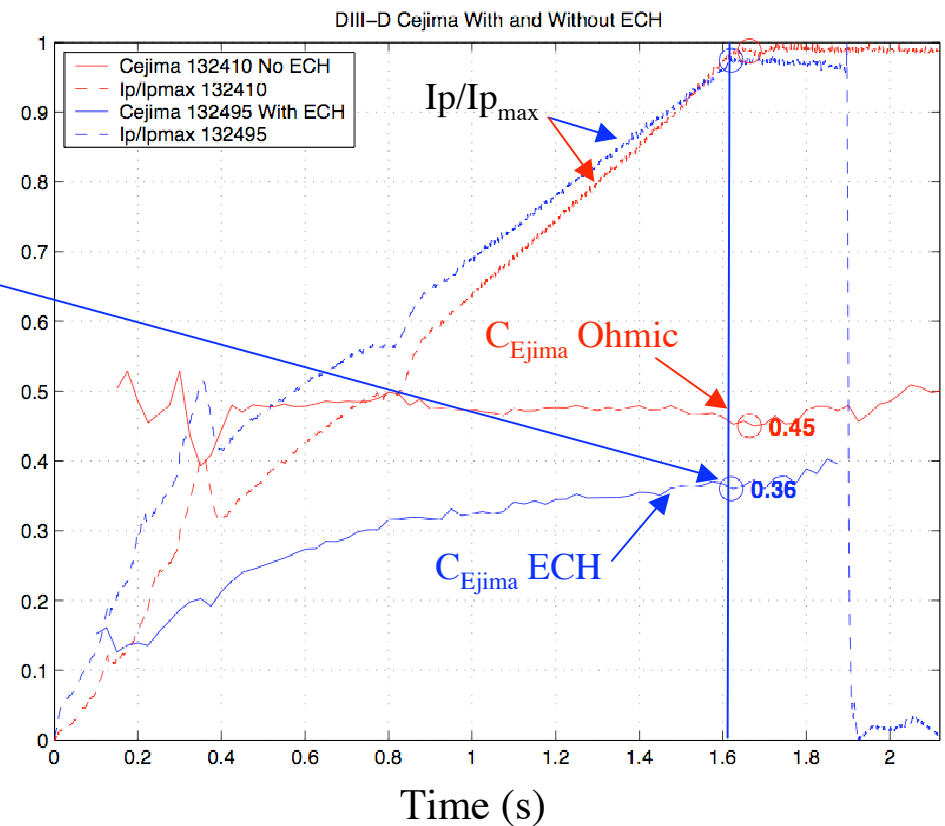
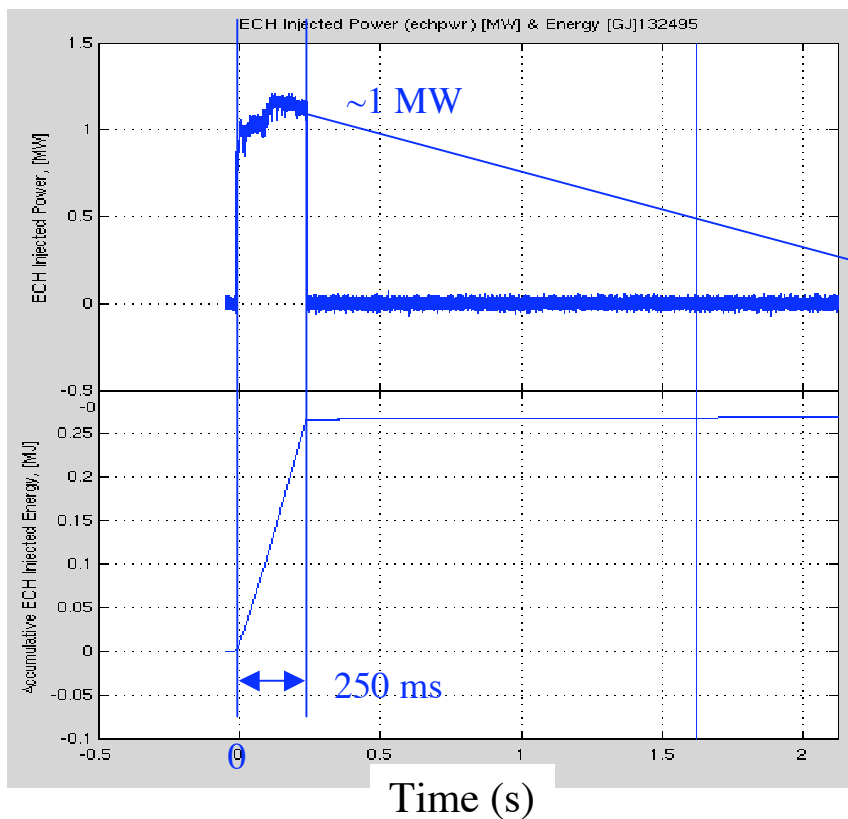
Early ECH in DIII-D => Reduced Flux Consumption

- Early 250ms of 1MW ECH greatly reduces resistive losses



Early ECH in DIII-D => Reduced Flux Consumption

- Early 250ms of 1MW ECH greatly reduces resistive losses
- Resistive loss reduction at flattop is 20% with just 0.25MJ ECH
- Scaled to ITER this would produce 130s extra burn time

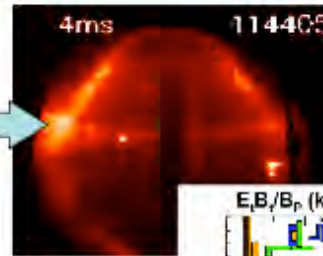


2004 NSTX (Menard)

Solenoid-free tokamak formation in NSTX



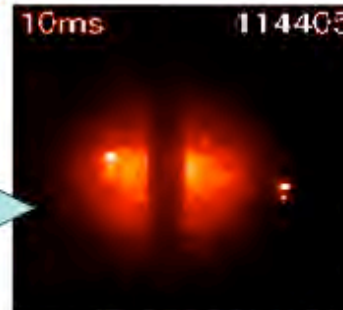
1. Pre-ionize plasma near RF antenna with ECH + 400kW HHFW, $n_{D_2} = 1-2 \times 10^{-5}$ Torr



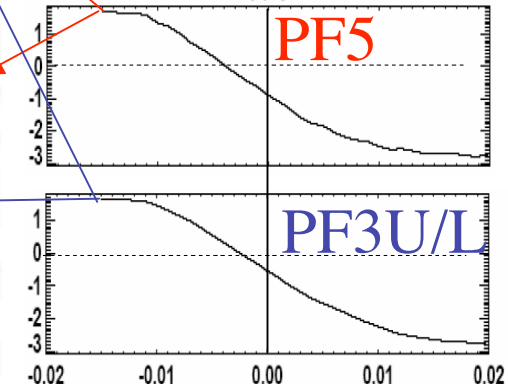
2. Create high-quality field-null with 5-15 loop-volts at antenna - So far, *require* $E_{\phi} B_{\phi} / B_p > 0.1 \text{ kV/m}$ over *substantial plasma volume*



3. Have created 20kA plasmas that terminate near center-stack

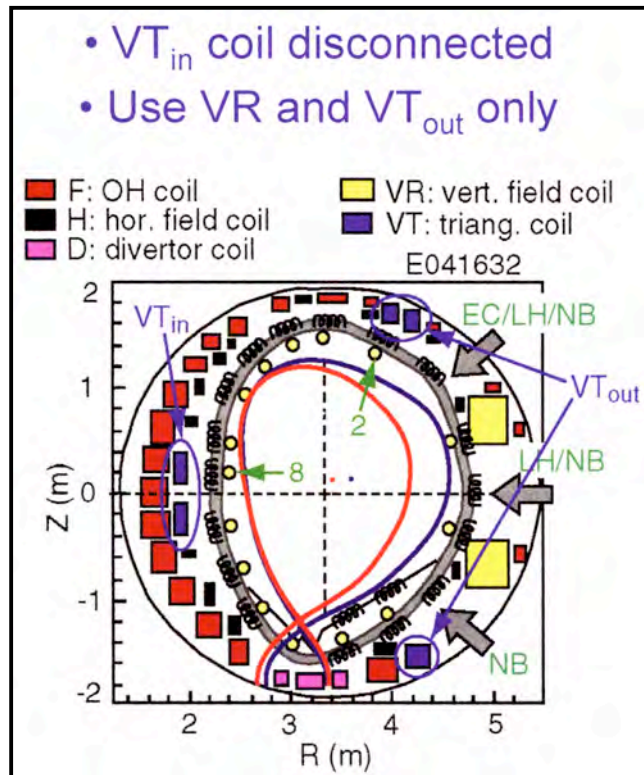


- Outer PF only
- ECH+HHFW
- 20KA/6ms center-stack collapse



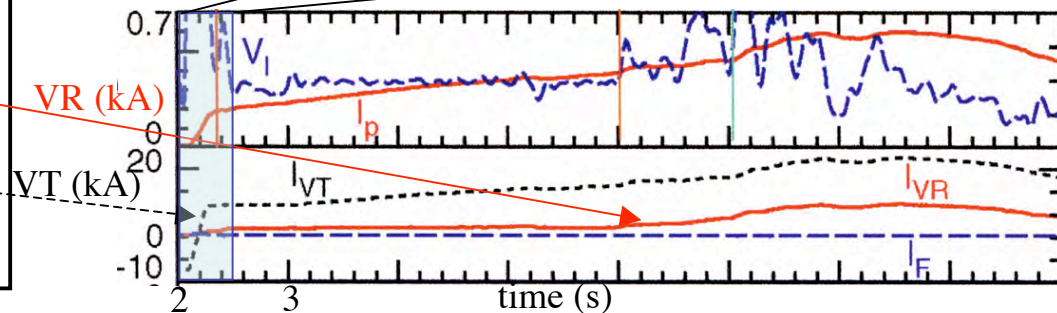
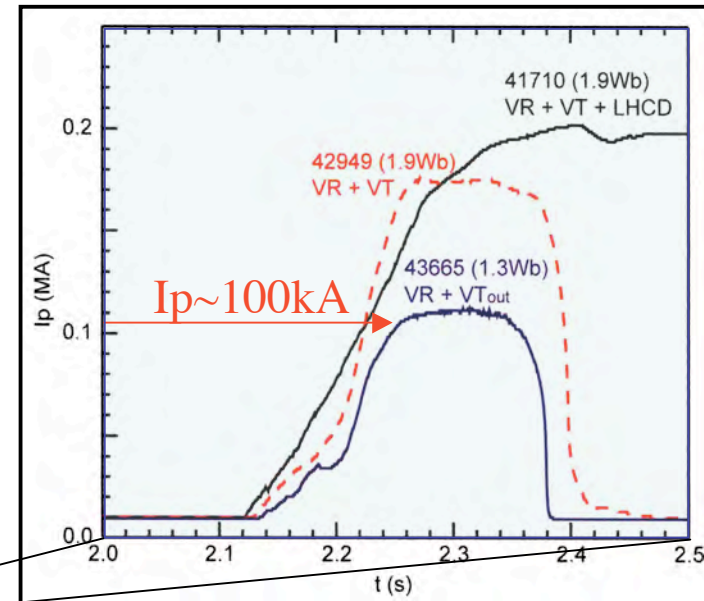
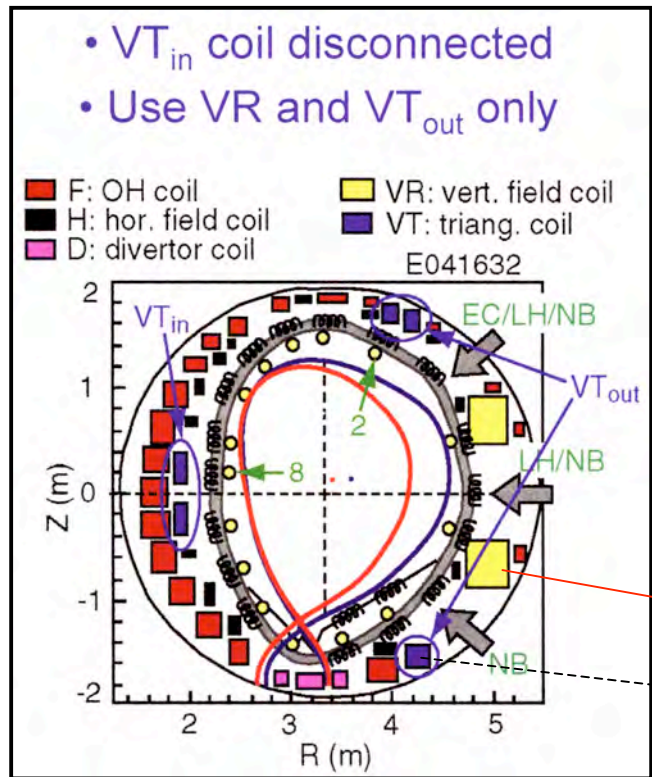
2006 JT60 (Ushigome)

- Outer PF only, 1MW EC generated



2006 JT60 (Ushigome)

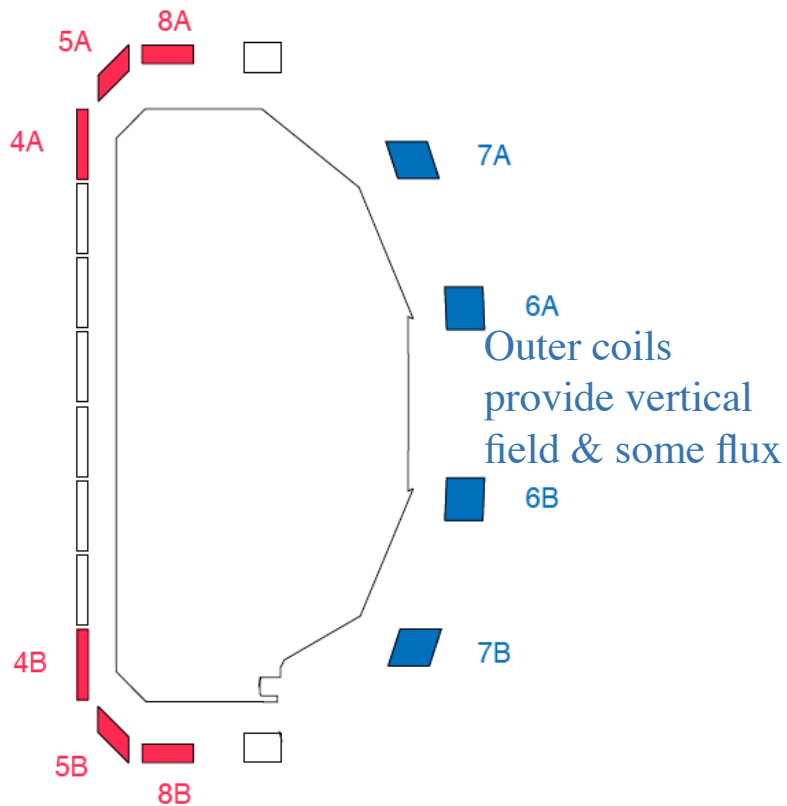
- Outer PF only, 1MW EC generated $\sim 100\text{kA}$
- Null not necessary with ECH, but preferred
- LHCD effective



Outside Coil Plasma Initiation Limitations

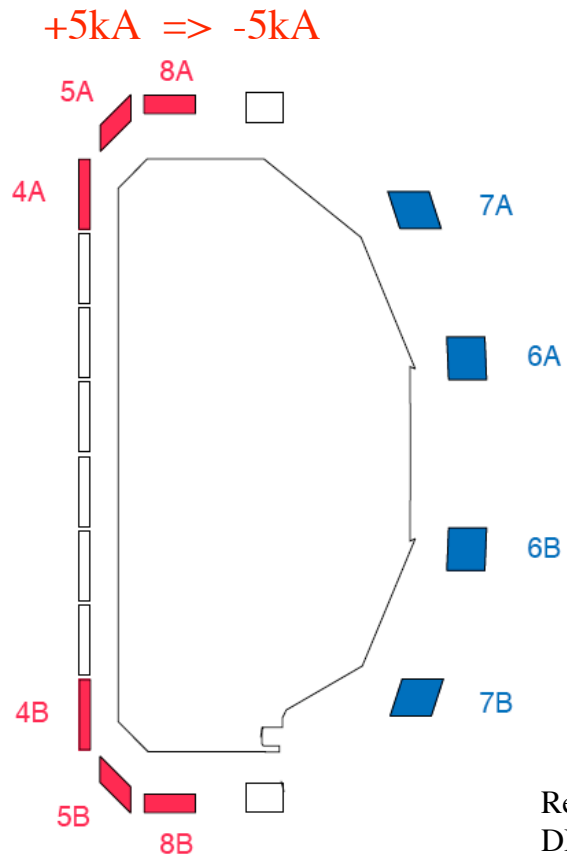
- Plasma current and shape are integrally coupled

Divertor coils
produce plasma
 $+5\text{kA} \Rightarrow -5\text{kA}$

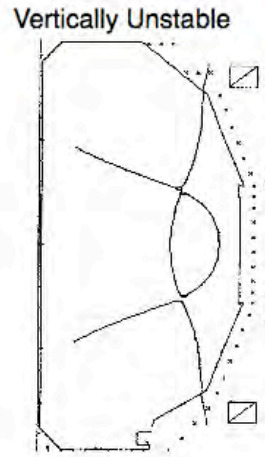


Outside Coil Plasma Initiation Limitations

- Plasma current and shape are integrally coupled
- Stability issues limit shape at ramp start/end ==> Limits I_p generation

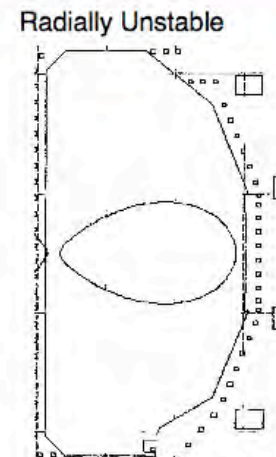


High positive currents in divertor coils $I_p = 20\text{kA}$



Start of Discharge

High negative currents in divertor coils $I_p = 160\text{kA}$



End of Discharge

Ref: W.P. West, R. Khayrutdinov, ... "Modeling of plasma initiation & current rampup on DIII-D using only the divertor and outer poloidal field coils, ST workshop, Russia, Sept '97

Thrusts Based on Present Devices

- Modeling
 - Inductive aspects easily modeled, CD much more difficult
 - TSC, Corsica, DINA, PTRANSP, ...
- NSTX
 - Good coil geometry
 - Needs ECH
- DIII-D (solenoidless campaign under way)
 - Good coil geometry - lots of ECH
 - Needs upgraded shaping coil supplies (4-quadrant)
- Other
 - EAST - Good coil geometry - Needs ECH
 - KSTAR - Good coil geometry - 2010 campaign