# CHI Research on PEGASUS-III

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# Solenoid-free Plasma Start-up Capability Would Make an ST Reactor More Attractive as a Power Plant

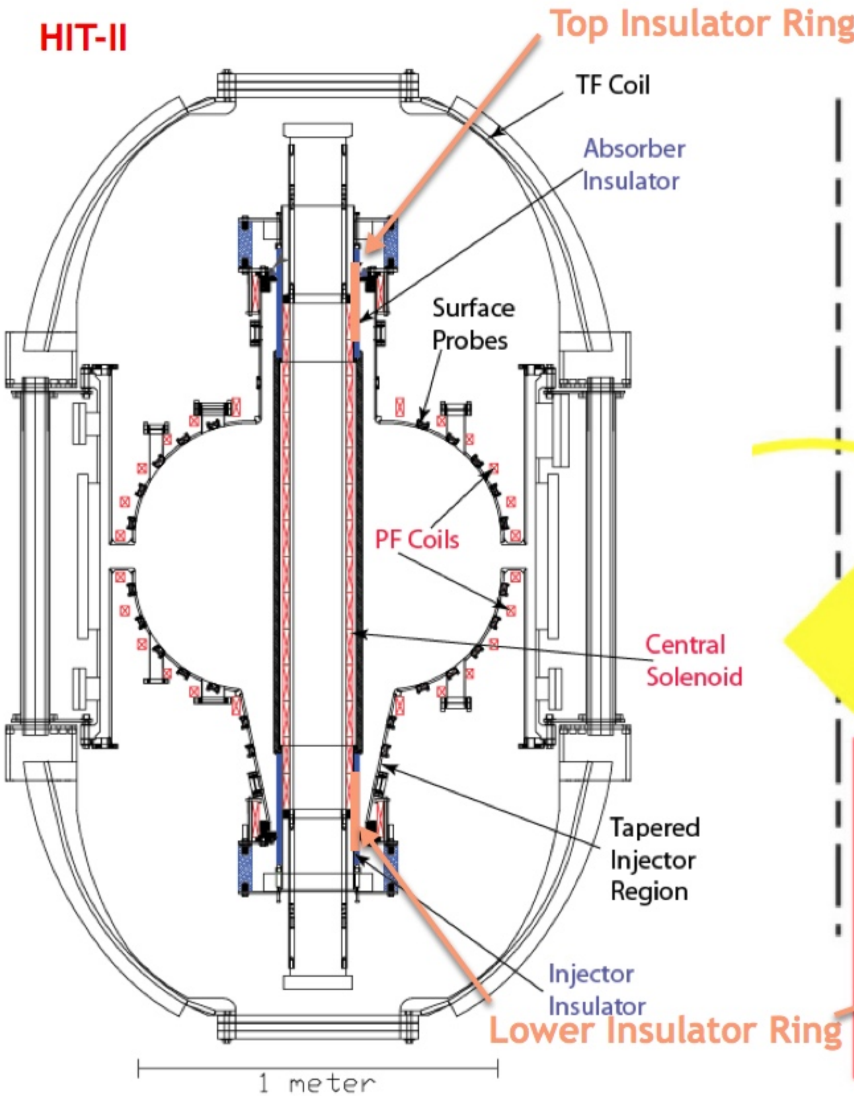
- Compared to standard aspect ratio tokamak, the ST configuration provides access to higher levels of bootstrap current drive
  - Low recirculating power & high availability important metrics for power plant
  - Small (or no) solenoid would allow the ST to operate at higher TF

- *“The singular advantage of* solenoid-free start-up *is that it allows more metal to be added to the Toroidal Field (TF) coil inboard nose region to allow the TF to support a higher peak field and higher field on axis – improving performance”* – Tom Brown (PPPL Reactor Systems Designer)

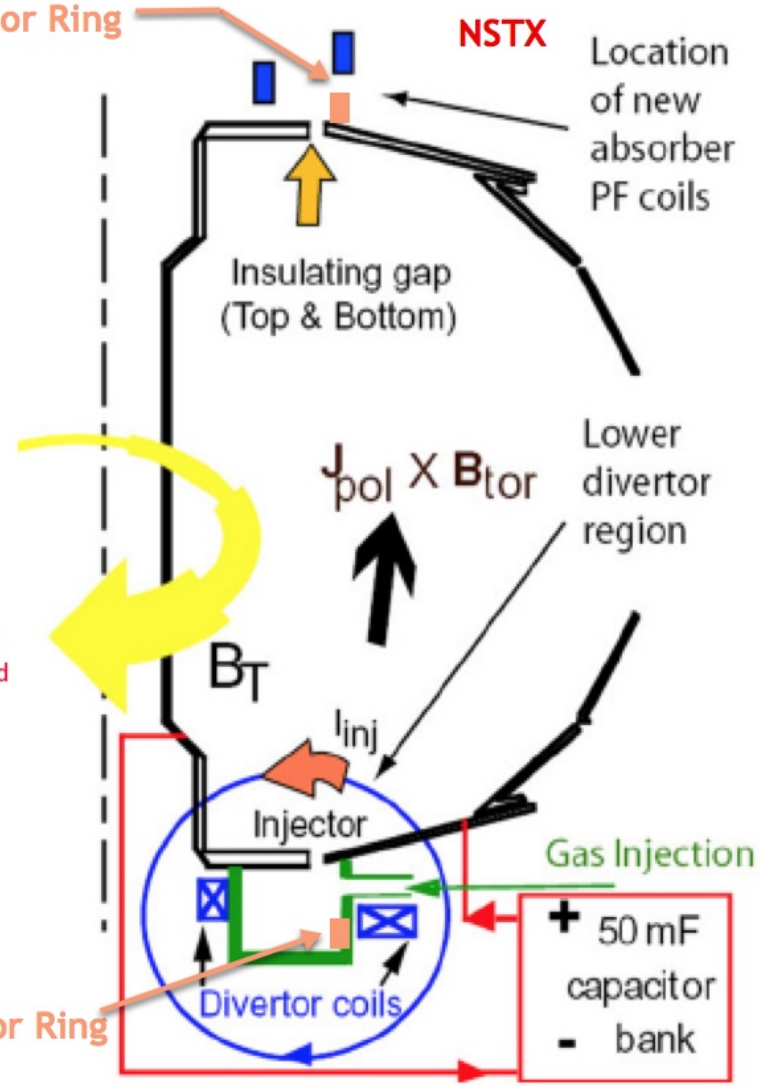
- Increased space in central core would permit installation of systems that are essential for a low recirculation power producing reactor
  - Inboard high velocity (several km/s – with no curved guide tube) pellet injection for density & pressure profile control
  - Inboard RF launchers (to eliminate NBI heating and CD)
  - Reduced OH-TF interaction forces enabling stronger TF

# T-CHI Start-up & configuration on HIT-II & NSTX

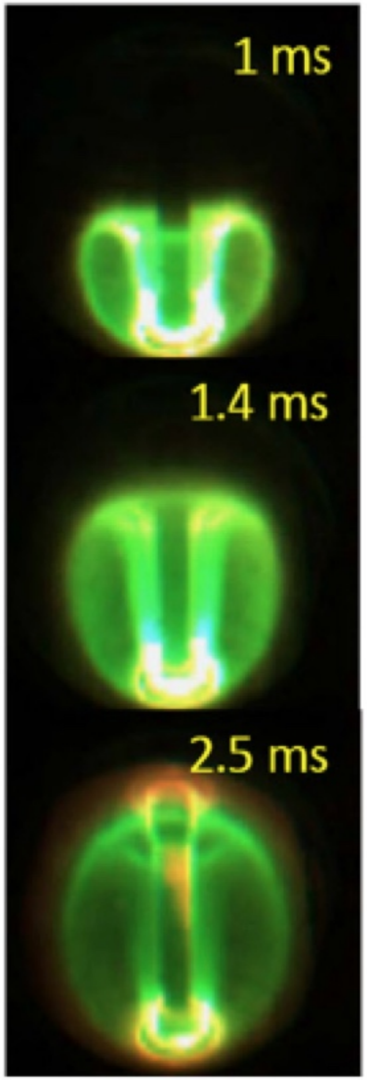
## (Insulators are a part of the vessel vacuum break)




$R/a = 0.3/0.2m$, $B_T = 0.5T$



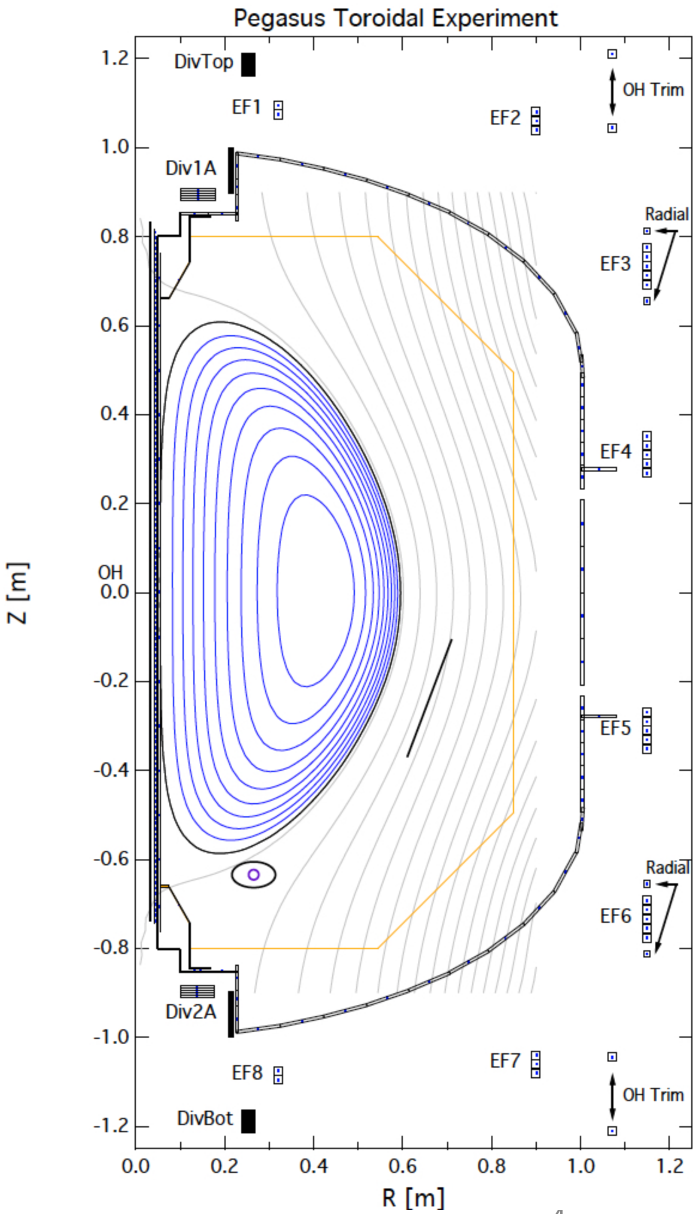

$R/a = 0.86/0.66m$, $B_T = 0.55T$




CHI discharge images

# CHI Research Plan on PEGASUS-III

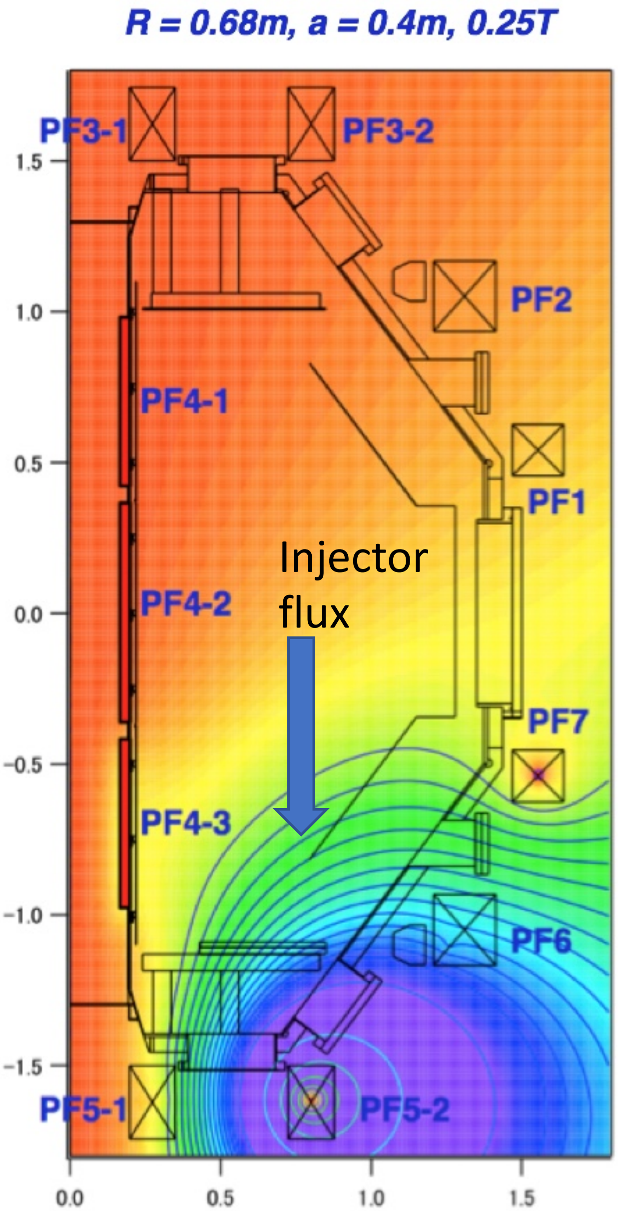
- Develop and test a double biased electrode configuration
- Initiate Transient CHI discharge and optimize it to understand requirements for implementing it on NSTX-U
  - Generate currents up to the external PF coil limits (~300kA)
  - Heat CHI plasma using ECH
- Drive a T-CHI discharge using LHI to study synergisms with LHI
- Examine potential of Steady-State (*driven*) CHI

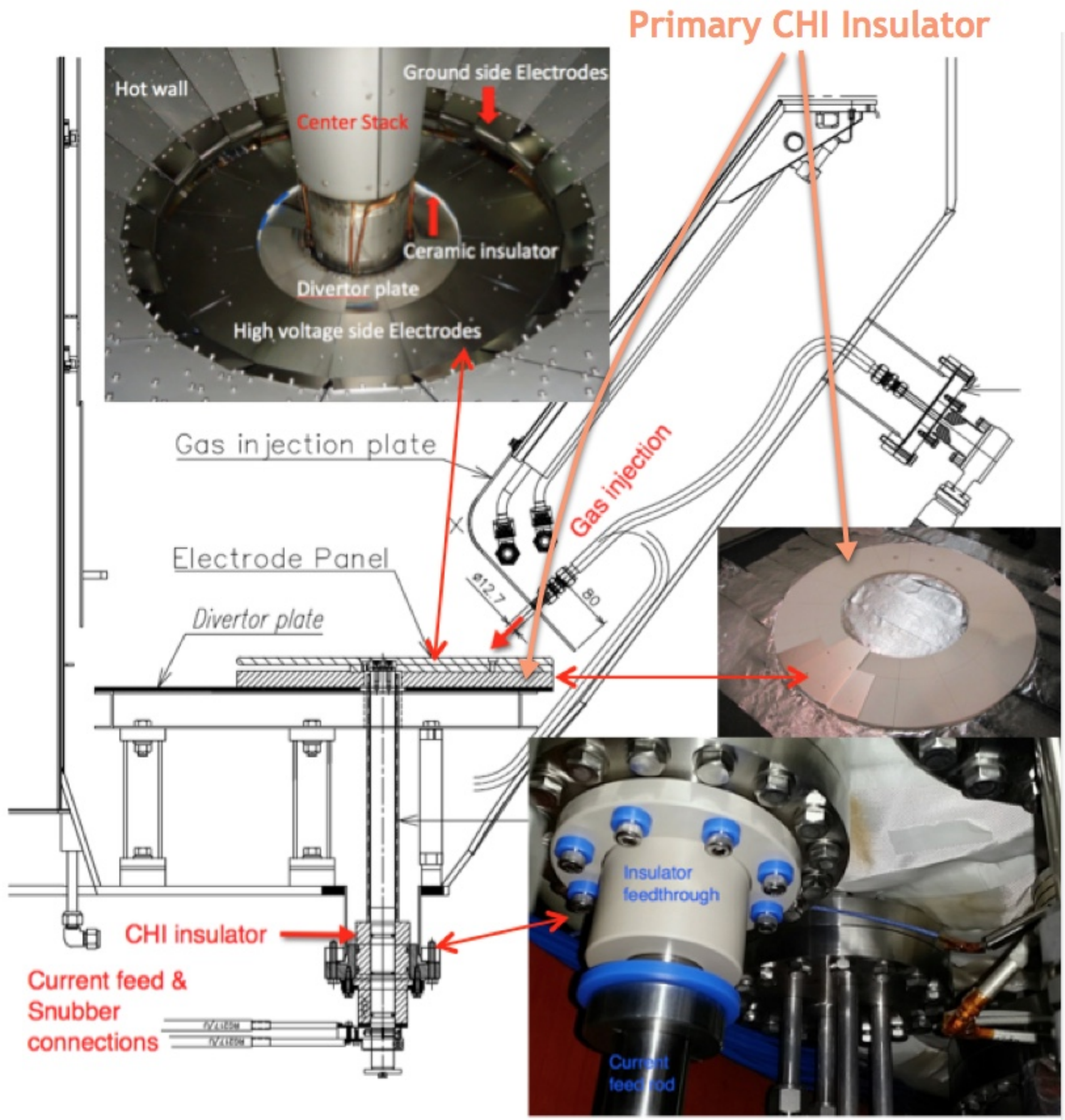


# Develop and test a double biased electrode configuration

- HIT-II and NSTX used toroidal ring insulators that were part of the vessel vacuum structure
  - Difficult for reactor implementation
- QUEST is testing a single biased electrode configuration
- The externally driven injector current path is much clearly defined in a double biased configuration
  - Much more difficult for spurious arcs to occur
  - Much better suited for long-pulse driven CHI studies

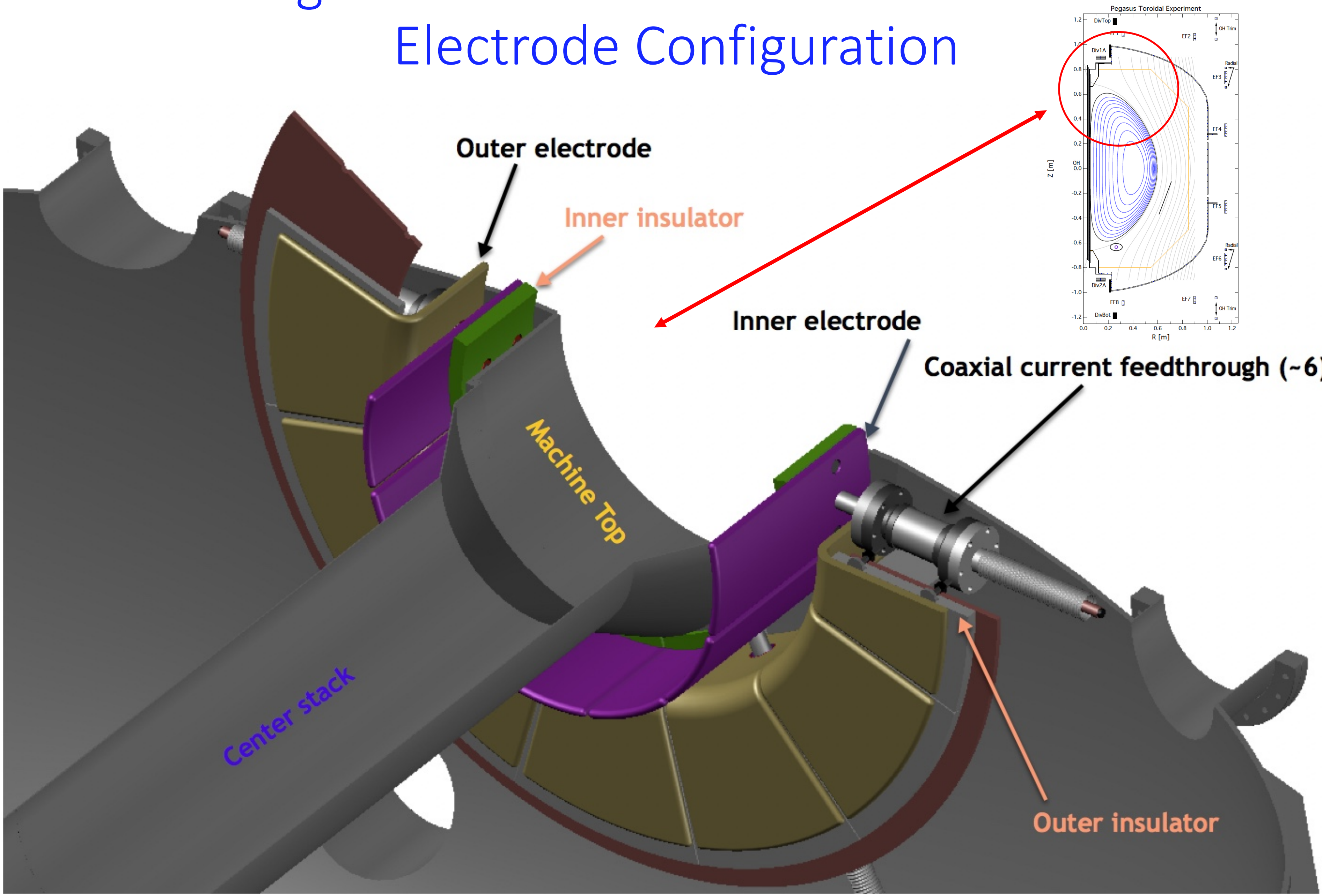
# QUEST (Japan) uses a single biased electrode configuration



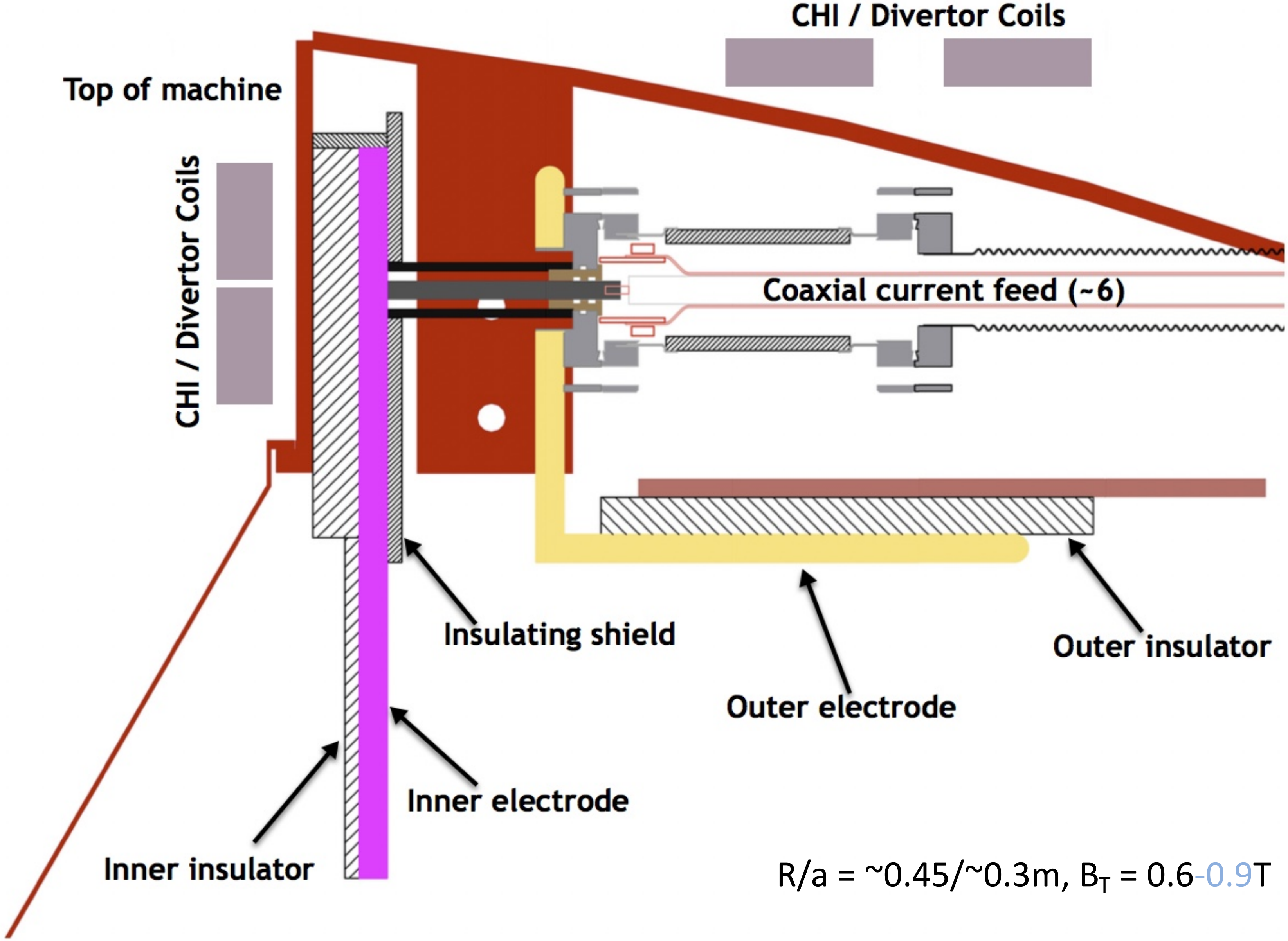




See K. Kuroda (poster) for details & CHI plan on QUEST

# CHI Design for PEGASUS-III uses a Double-Biased Electrode Configuration



# PEGASUS-III: Divertor Coils / CHI Electrode locations to be finalized (soon) after finalizing Toroidal Field Coil design

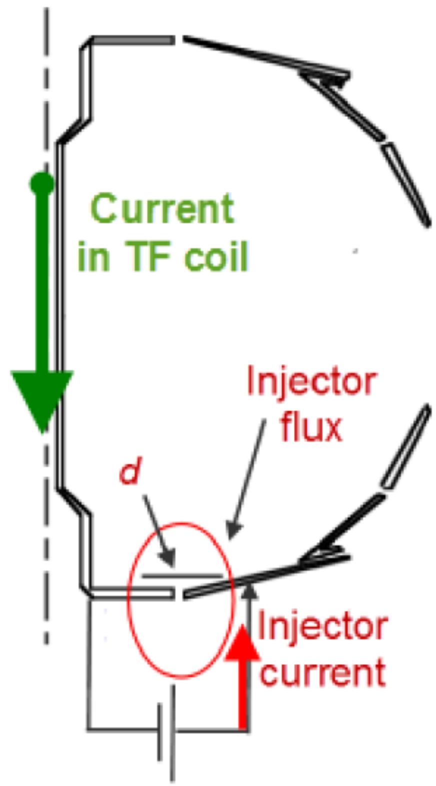



R/a = ~0.45/~0.3m, $B_T$ = 0.6-0.9T

# Scaling relations for Transient CHI based on experimental results from HIT-II, NSTX, and from TSC simulations

- Capacity to generate plasma current $I_p$ is proportional to $\psi_{inj}$
- Toroidal current* generation is proportional to the ratio of toroidal flux $\psi_{tor}$ to injector flux $\psi_{inj}$
- Injector current* $I_{inj}$ must meet *bubble-burst condition* for plasma to expand from injector to main vessel

$$I_{\rm p} = \frac{2\psi_{\rm pol}}{\mu_0 R_{\rm maj} l_i} \qquad \psi_{\rm pol} \le \psi_{\rm inj}$$

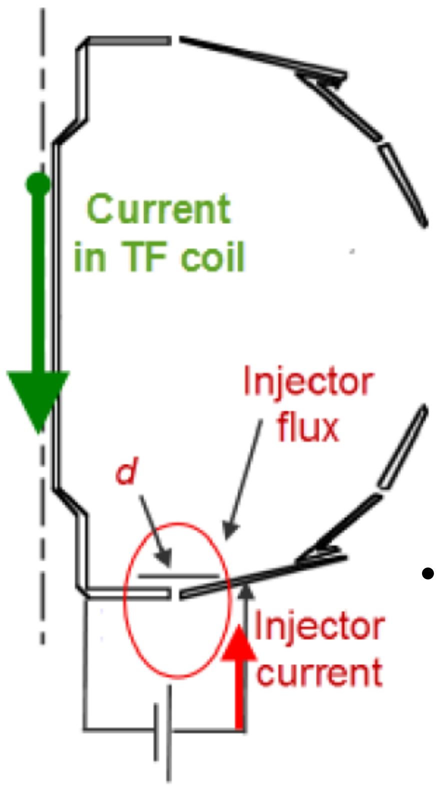



$$I_{\rm p} \le I_{\rm inj} \frac{\psi_{\rm tor}}{\psi_{\rm inj}}$$

$$I_{\rm inj} \ge \frac{2\psi_{\rm inj}^2}{\mu_0^2 d^2 I_{\rm TF}}$$

* T.R. Jarboe, Fusion Tech. 15, 7 (1989)

# Studies on PEGASUS-III will optimize CHI by improved quantification of scaling parameters in support of future studies on NSTX-U




$$I_{\text{inj}} \geq \frac{2\psi_{\text{inj}}^2}{\mu_0^2 d^2 I_{\text{TF}}}$$

Parameter 'd' the injector flux footprint width strongly determines required injector current and needs improved characterization

$$I_{\text{p}} = \frac{2\psi_{\text{pol}}}{\mu_0 R_{\text{maj}} l_i} \qquad \psi_{\text{pol}} \leq \psi_{\text{inj}}$$

- The attained plasma current is depends on the plasma internal inductance, which is controlled by the edge current carrying open flux during CHI discharge initiation
- External flux shaping coils will control the parameter 'd' and the width of the edge current channel
- Close positioning of the divertor coils to the CHI electrodes would permit these important parameters to be studied on PEGASUS-III

# Initial Studies to Focus on ~15 mWb Flux Injection

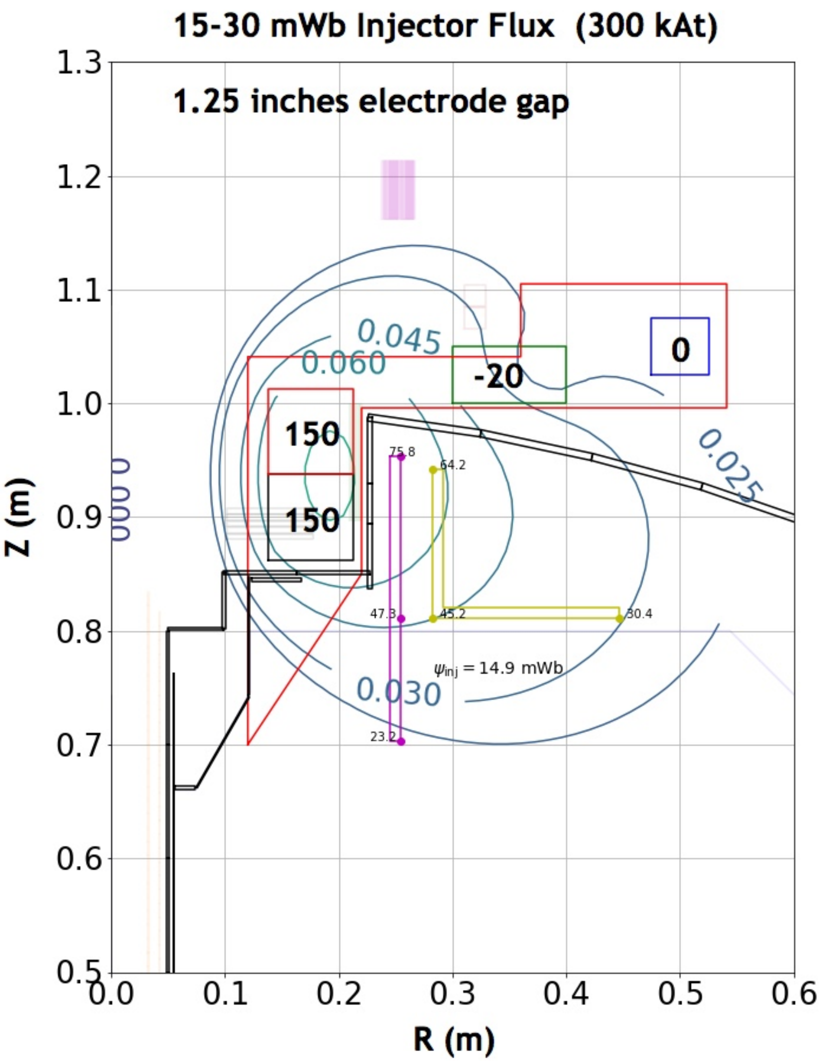
| | |
|---|---|
| Ip (kA): | 150.00 |
| Rm (m): | 0.45 |
| Bt (T): | 0.51 |
| Bt @ CHI location (T): | 0.82 |
| Bt multiplier factor: | 1.61 |
| li – Plas normalized Induct: | 0.30 |
| | |
| Enclosed Polo flux (mWb): | 12.72 |
| Flux conversion efficieny: | 0.70 |
| Injector flux (mWb): | 18.18 |
| | |
| Itf (kA): | 1152.00 |
| footprint width – (cm): | 10.00 |
| Inj Curr (kA) | 22.60 |
| | |
| Plasma Inductance (μH): | 0.08 |
| Plas inductive energy (kJ): | 0.95 |

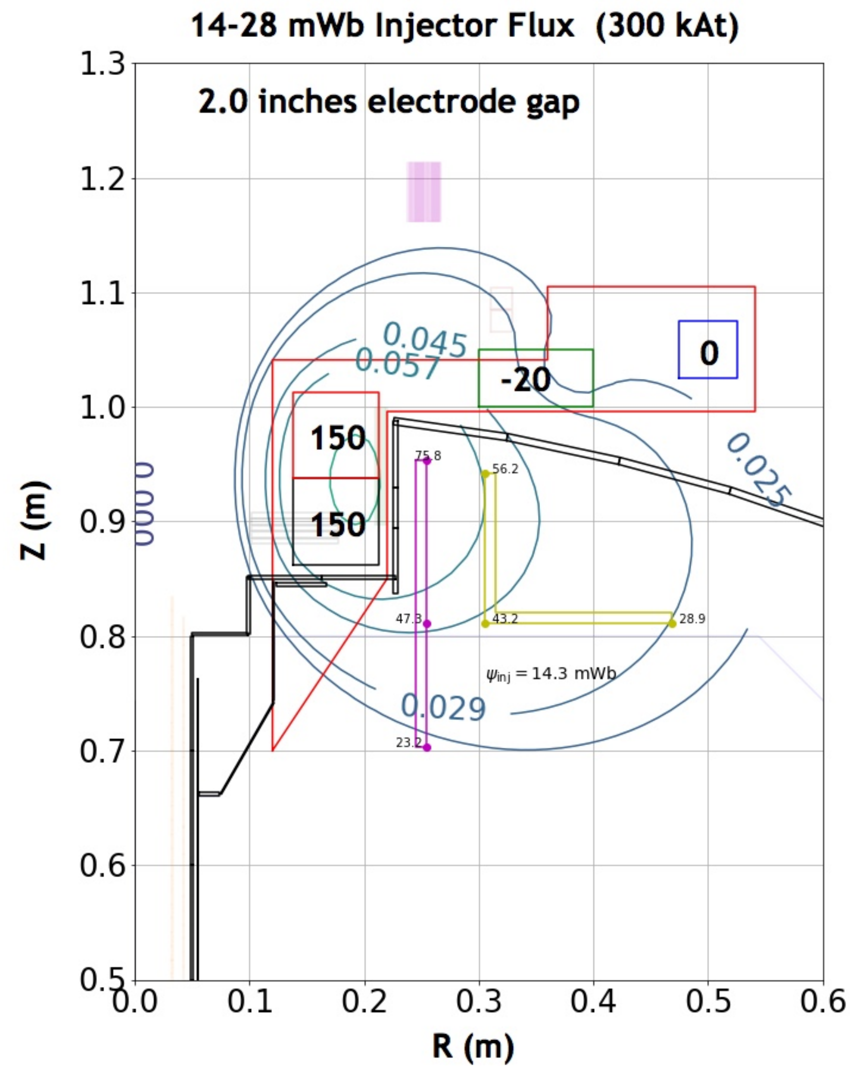
For d = 15cm, 36 mWb = 300kA, I_inj = 40kA

Optimization/scaling studies to be used to improve 'd'

# ~ 300kAt (total) needed in inboard coils to generate 15-30 mWb Injector Flux

(Coil current in kA.turns)



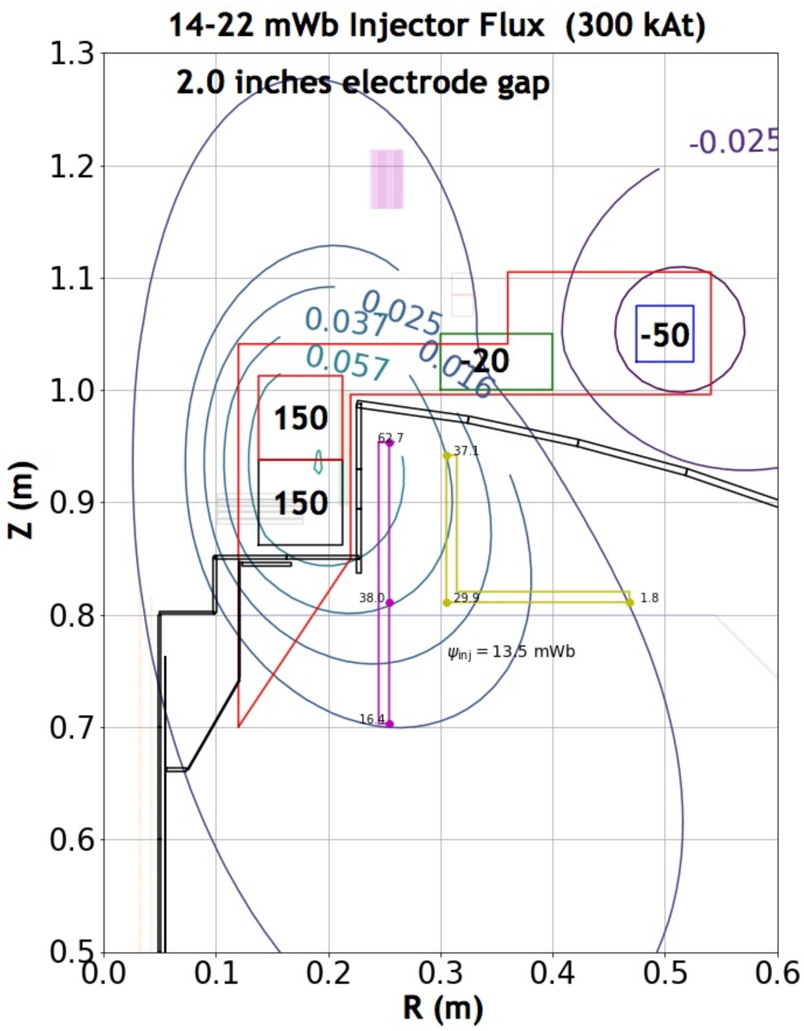



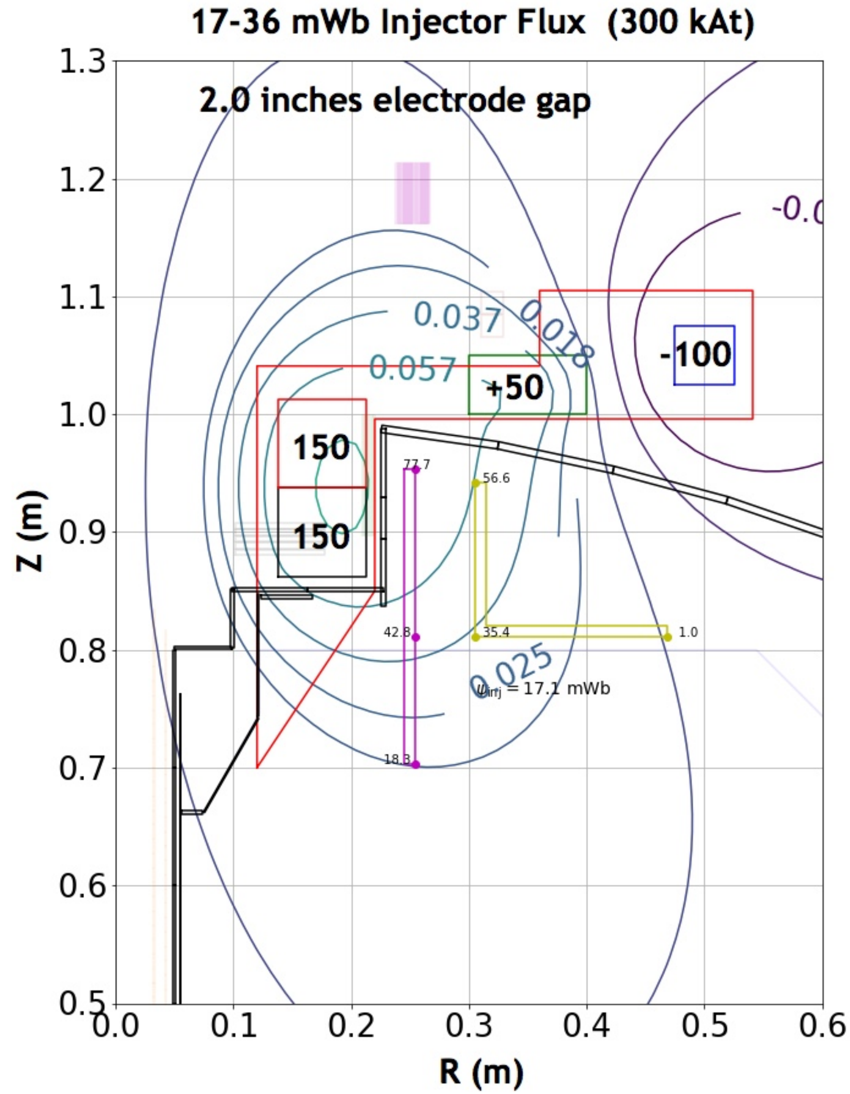



It would be useful to study electrode gap variation in future

# Bi-polar Outboard coils provide flux shaping capability

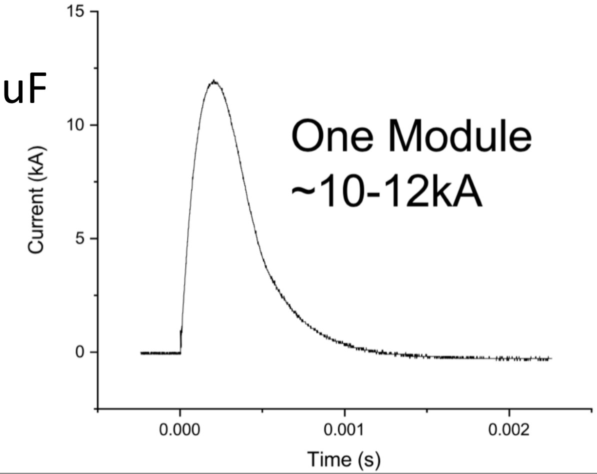
(Coil current in kA.turns)

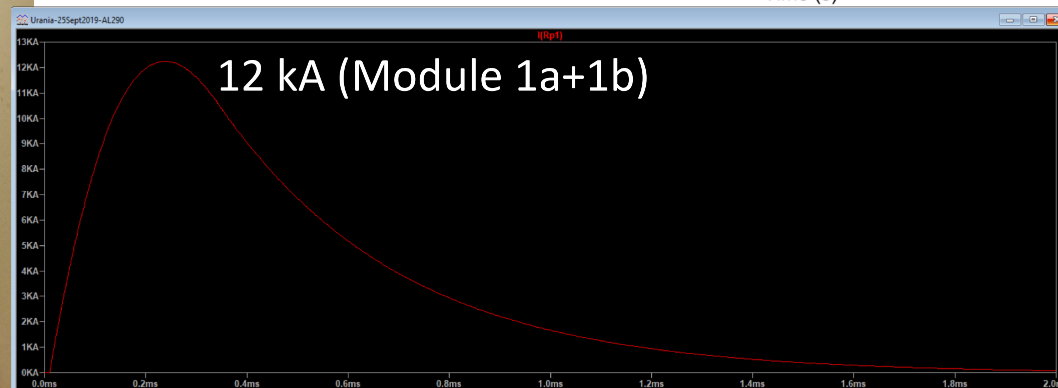


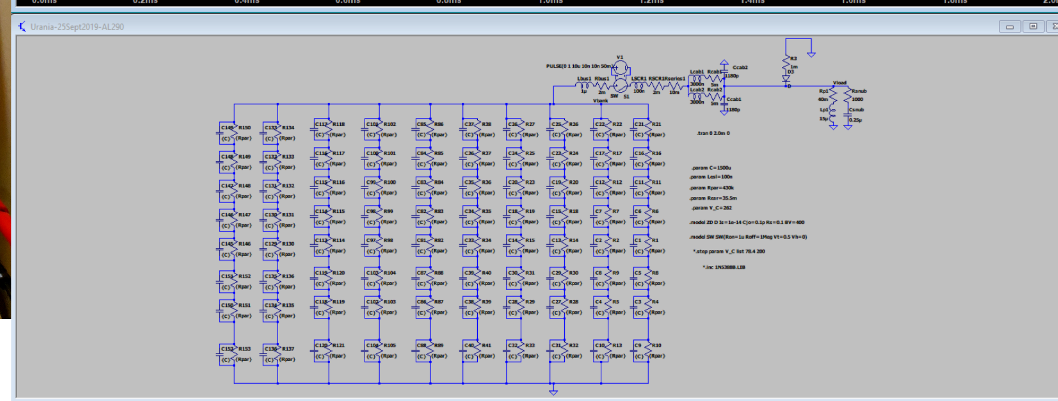



# CHI Power Supply will use electrolytic capacitor bank for driving the injector current (22-30 kA for initial studies using 4-modules)

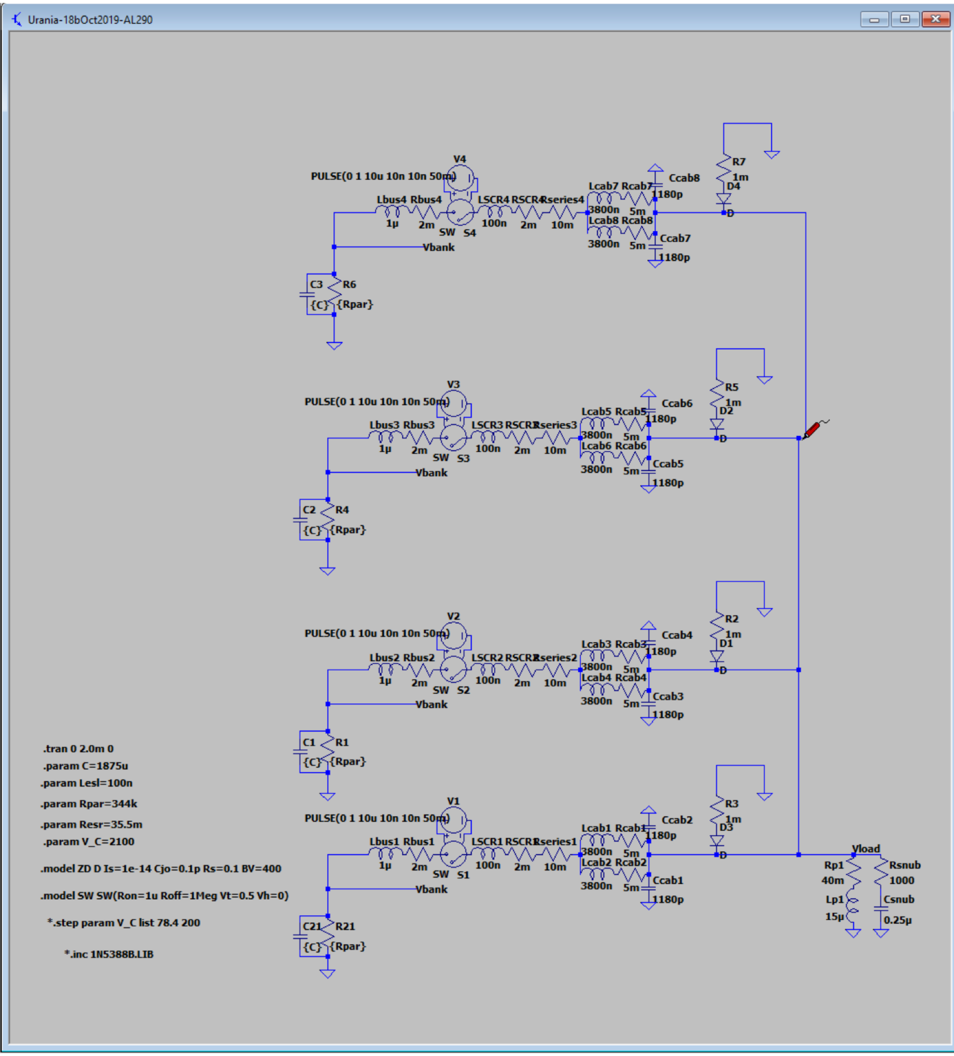

Module 1a+1b
80 Capacitors x 1500uF
8 (450V) in Series
10 in parallel
2100 V total
262 V/cap
R = 55.5 mOhm
L = 18 µH

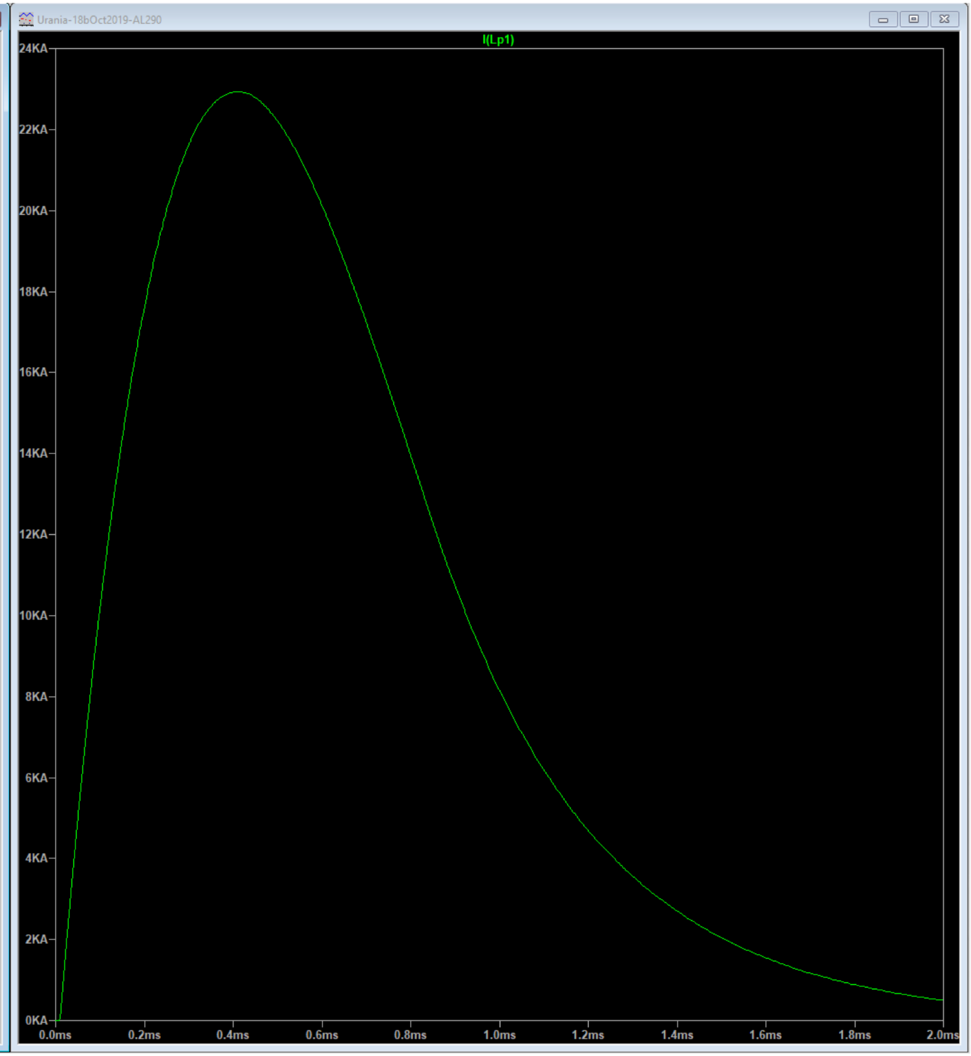


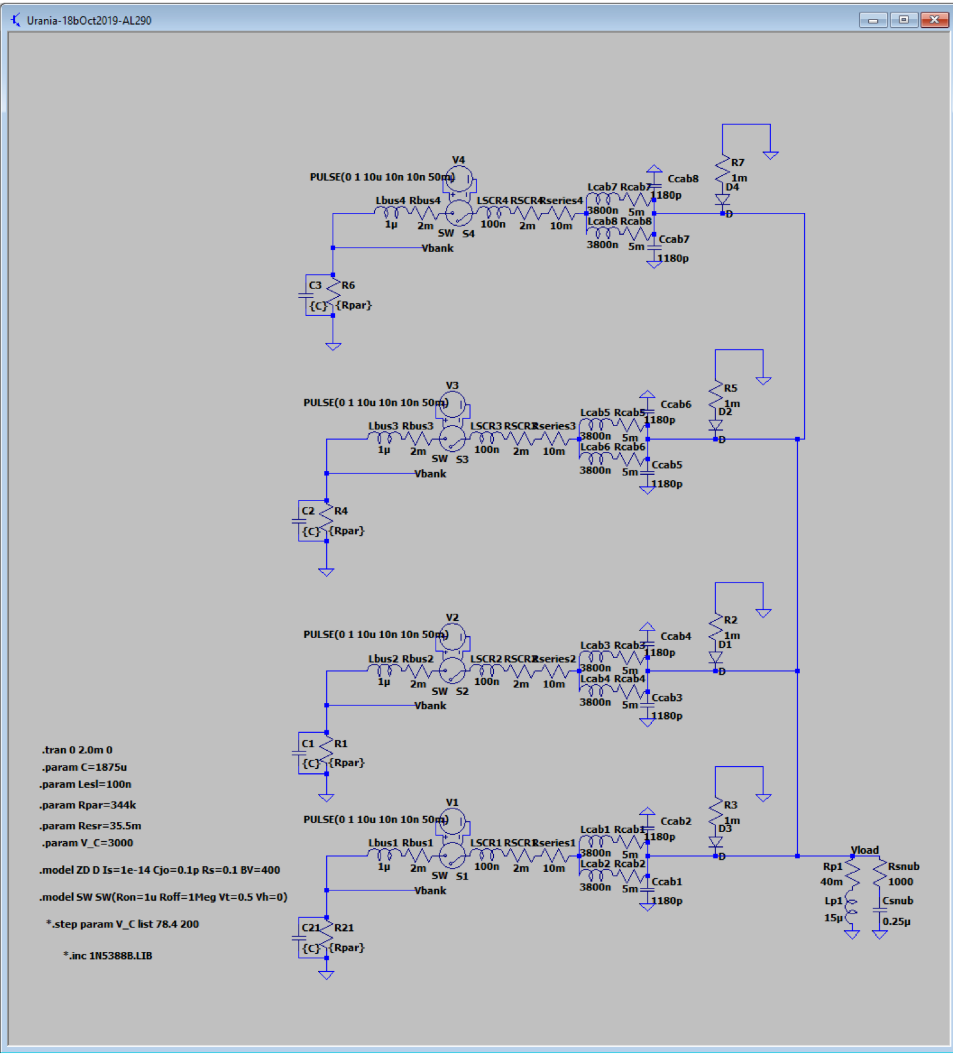



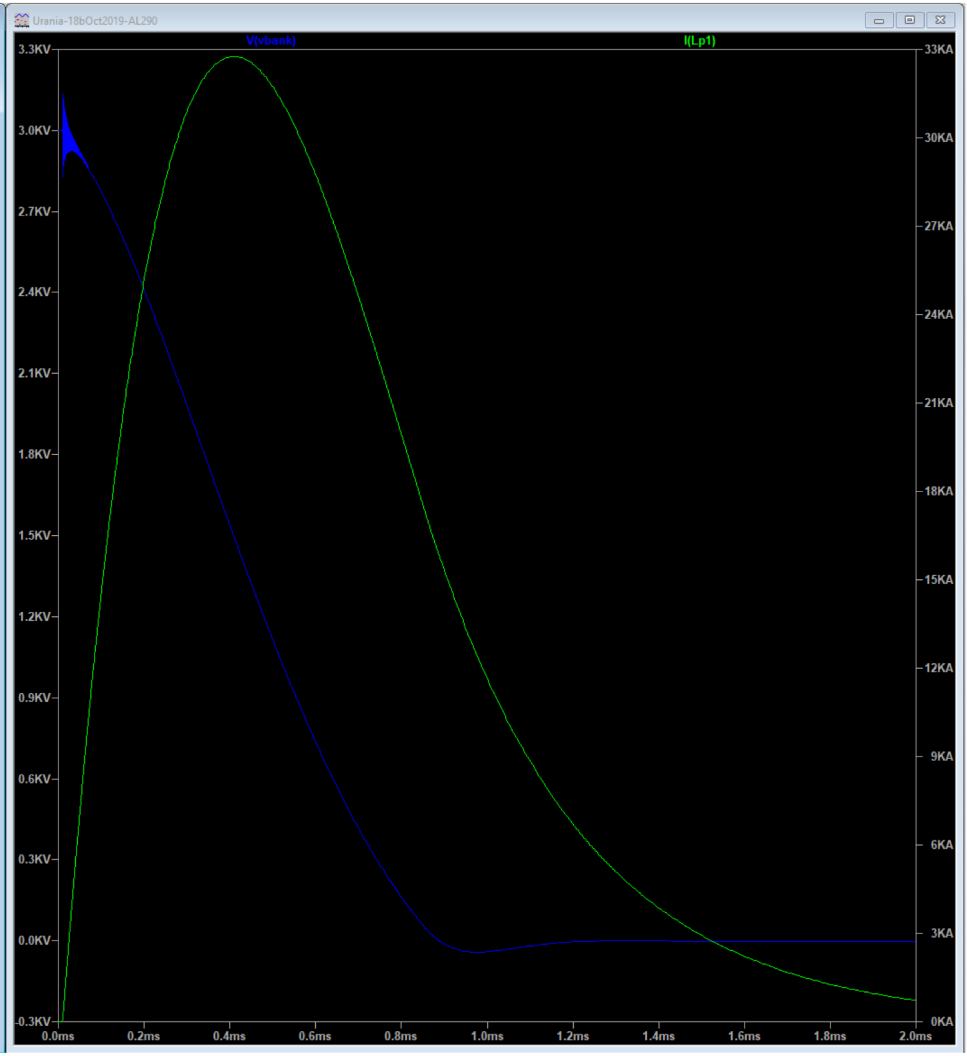
# 4 – Modules @ 2100V (262V/can): 22kA



# 4 – Modules @ 3000V (375V/can): 33kA





# Transient CHI studies on PEGASUS-III will Optimize and Improve our Understanding of the CHI Scaling Parameters in support of a future CHI deployment on the NSTX-U upper divertor using QUEST/PEGASUS-III –like electrodes

- Develop and test a double biased electrode configuration
- Initiate Transient CHI discharge and optimize
  - Generate currents up to the external PF coil limits (~150kA initially, up to 300kA eventually)
  - Quantify the parameter ‘d’ and flux shaping effects on the plasma internal inductance
  - Heat CHI plasma using ECH
- Drive a T-CHI discharge using LHI to study synergisms with LHI
- Examine potential of Steady-State (*driven*) CHI