CHI Research on PEGASUS-III

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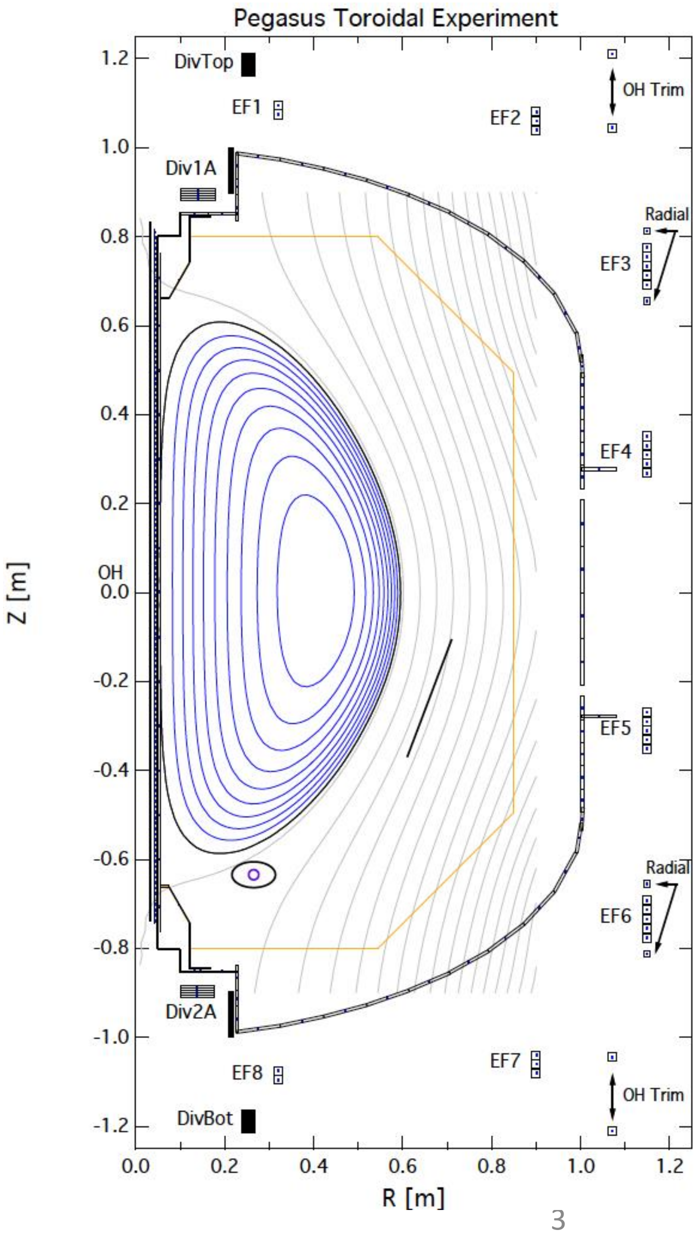
Abstract

The spherical tokamak (ST) may require and the advanced tokamak would considerably benefit from the elimination of the central solenoid. PEGASUS-III is a ST non-solenoidal startup development station under design and fabrication dedicated to solving the startup problem. On PEGASUS-III, Transient and Sustained coaxial helicity injection (T- and S-CHI) will be explored, as well as possible synergies of CHI with local helicity injection and EBW heating and current drive. T-CHI has shown promising capability on the HIT-II and NSTX STs. However, in both these machines the vacuum vessel was electrically cut. For reactor applications a simpler biased electrode configuration is required. To develop this capability a single biased electrode is being tested on QUEST, where up to 45 kA of toroidal current has been generated using CHI. URANIA will use a more advanced double biased electrode configuration with optimized injector electrodes and injector poloidal field coils that should allow the T-CHI system to generate 0.3 MA of closed flux current, the limit permitted by the equilibrium PF coils. Present design indicates that standard divertor coils will provide sufficient flux for CHI studies but may be enhanced with increased current capabilities if needed. The CHI design and the CHI research plan for URANIA will be described.

CHI Research Plan on PEGASUS-III

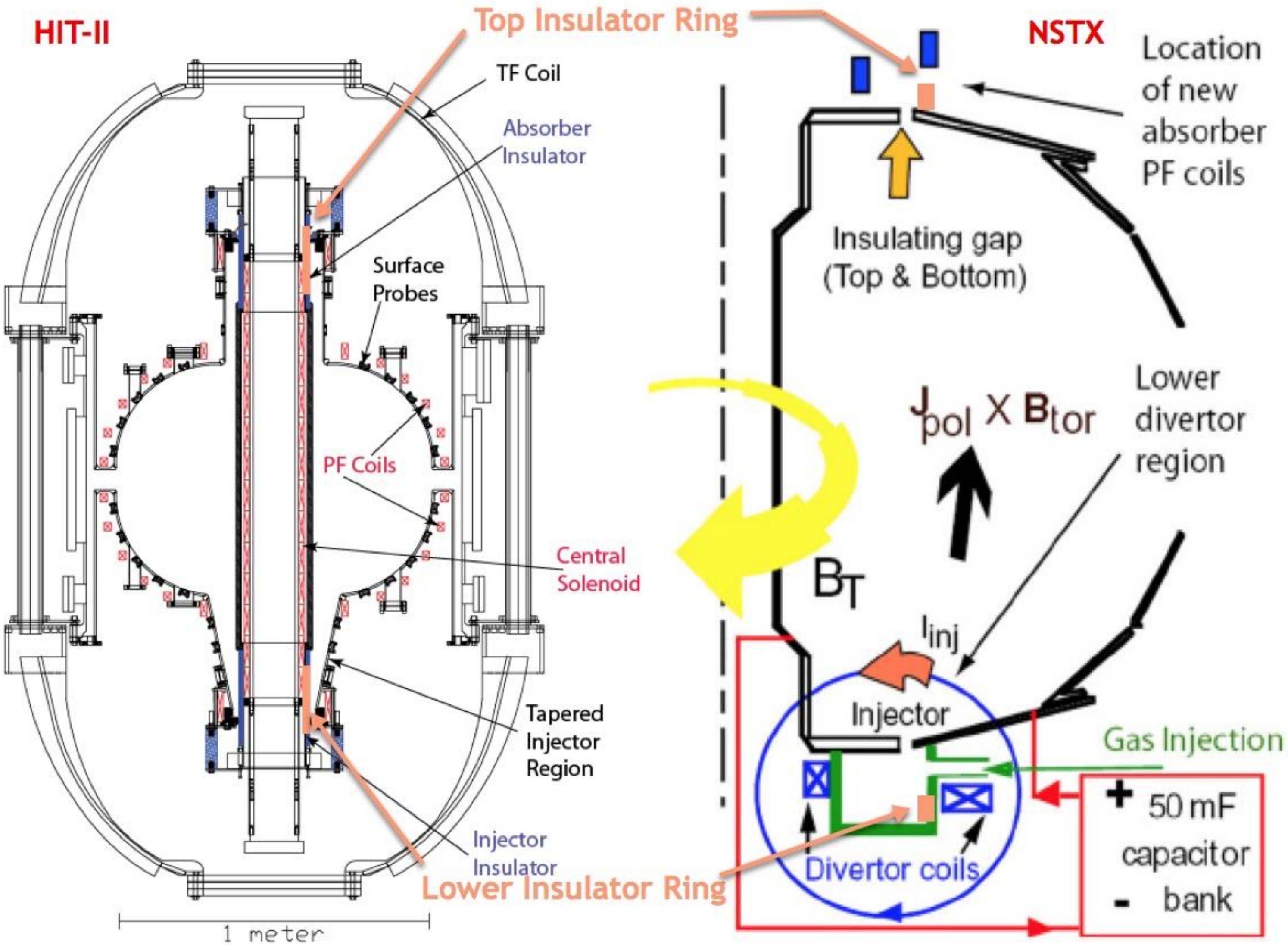
- Develop and test a double biased electrode configuration
- Initiate Transient CHI discharge and optimize it to understand requirements for implementing it on NSTX-U
  - Generate currents up to the external PF coil limits (~300kA)
  - Heat CHI plasma using ECH
- Drive a T-CHI discharge using LHI to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



Develop and test a double biased electrode configuration

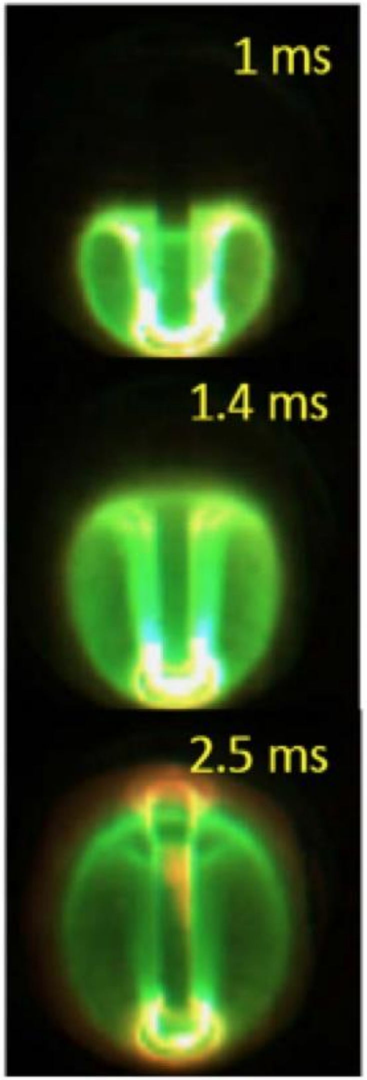
- HIT-II and NSTX used toroidal ring insulators that were part of the vessel vacuum structure
  - Difficult for reactor implementation
- QUEST is testing a single biased electrode configuration
- The externally driven injector current path is much clearly defined in a double biased configuration
  -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

CHI configuration on HIT-II & NSTX
(Insulators are a part of the vessel vacuum break)



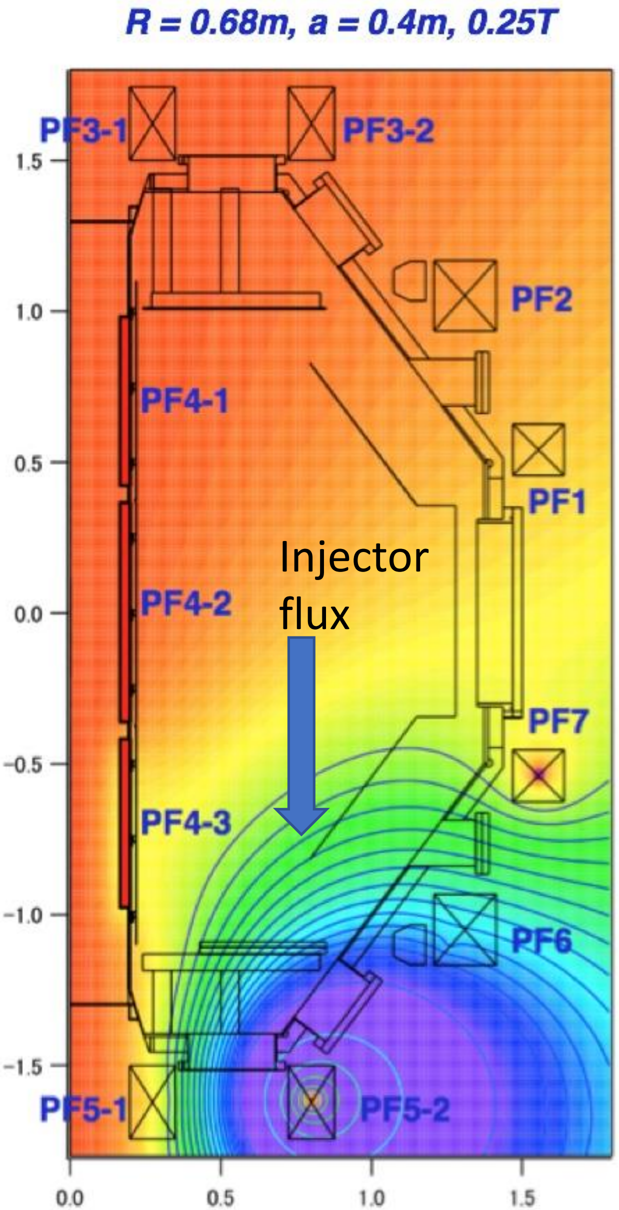
R/a = 0.3/0.2m, B_T = 0.5T

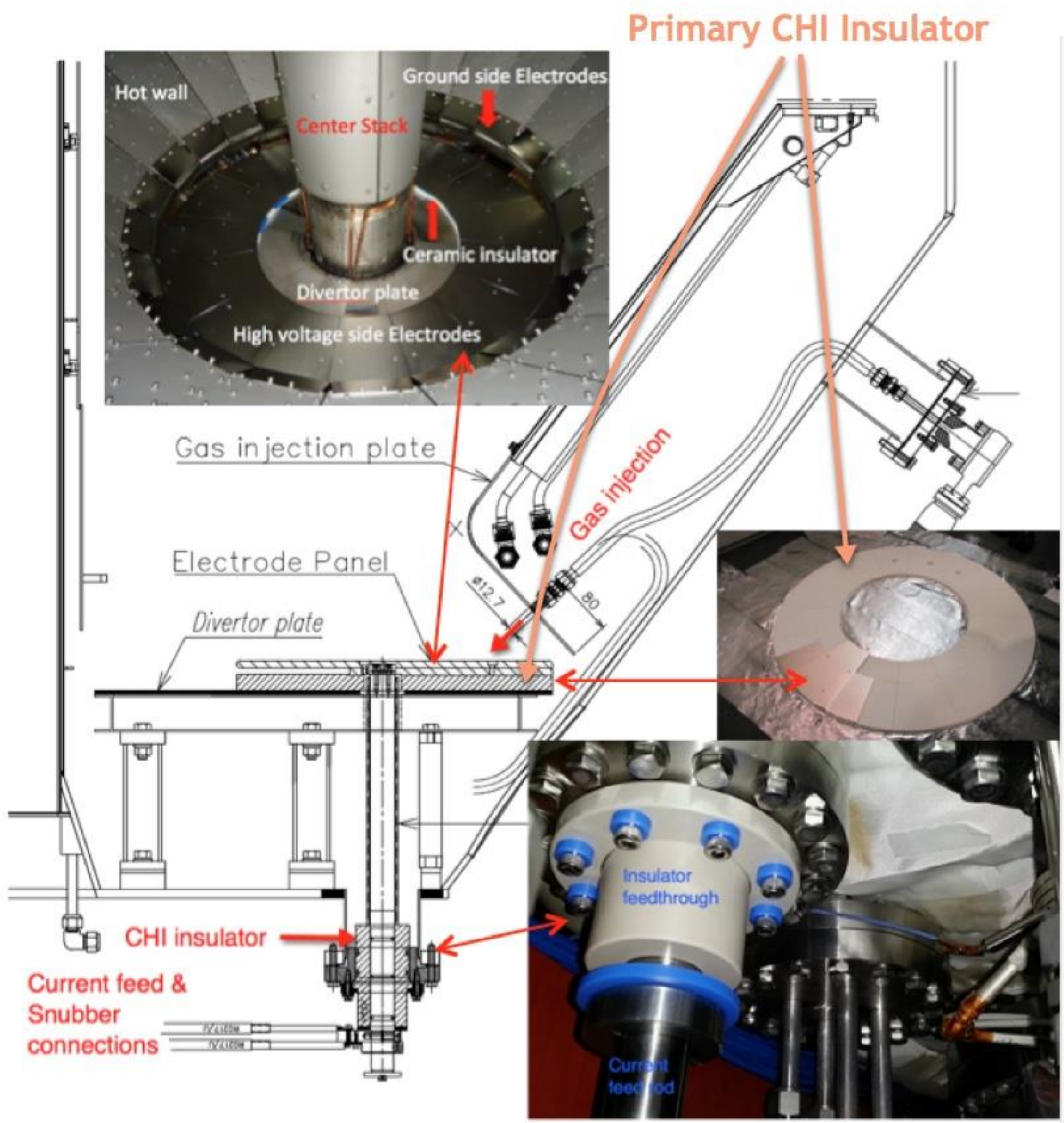
R/a = 0.86/0.66m, B_T = 0.55T



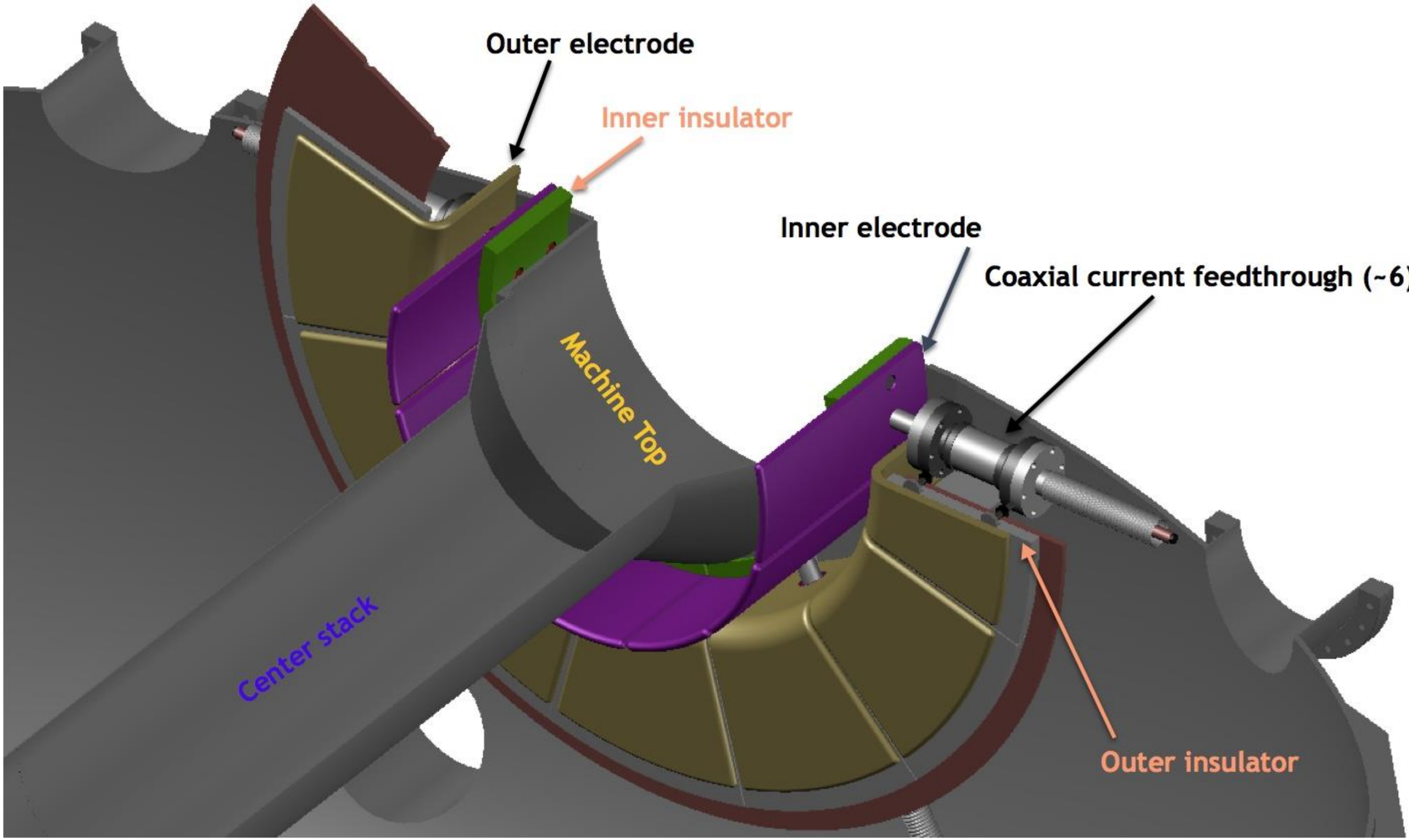
CHI discharge images

QUEST (Japan) uses a single biased electrode configuration

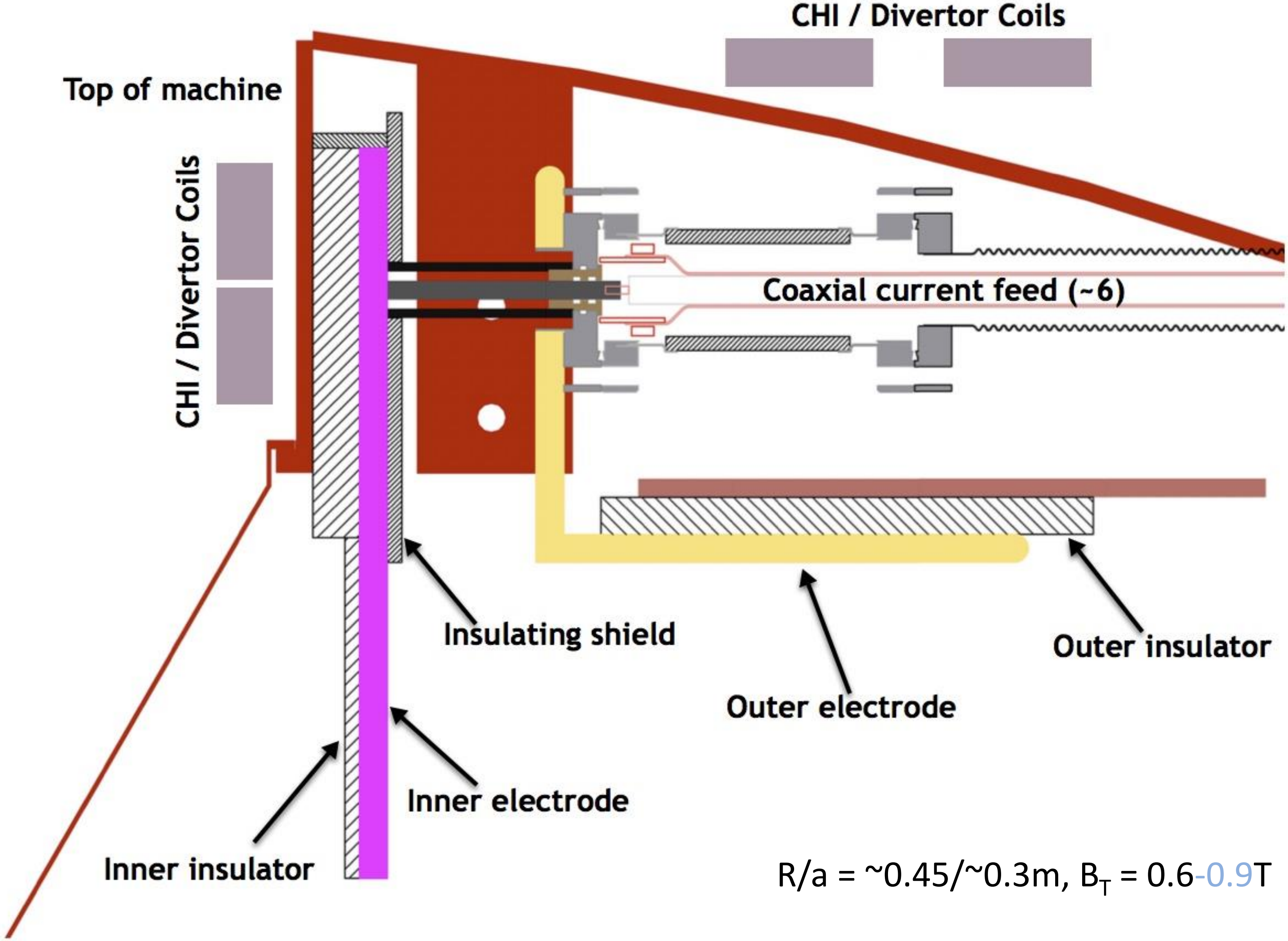




CHI Design for PEGASUS-III uses a Double-Biased Electrode Configuration



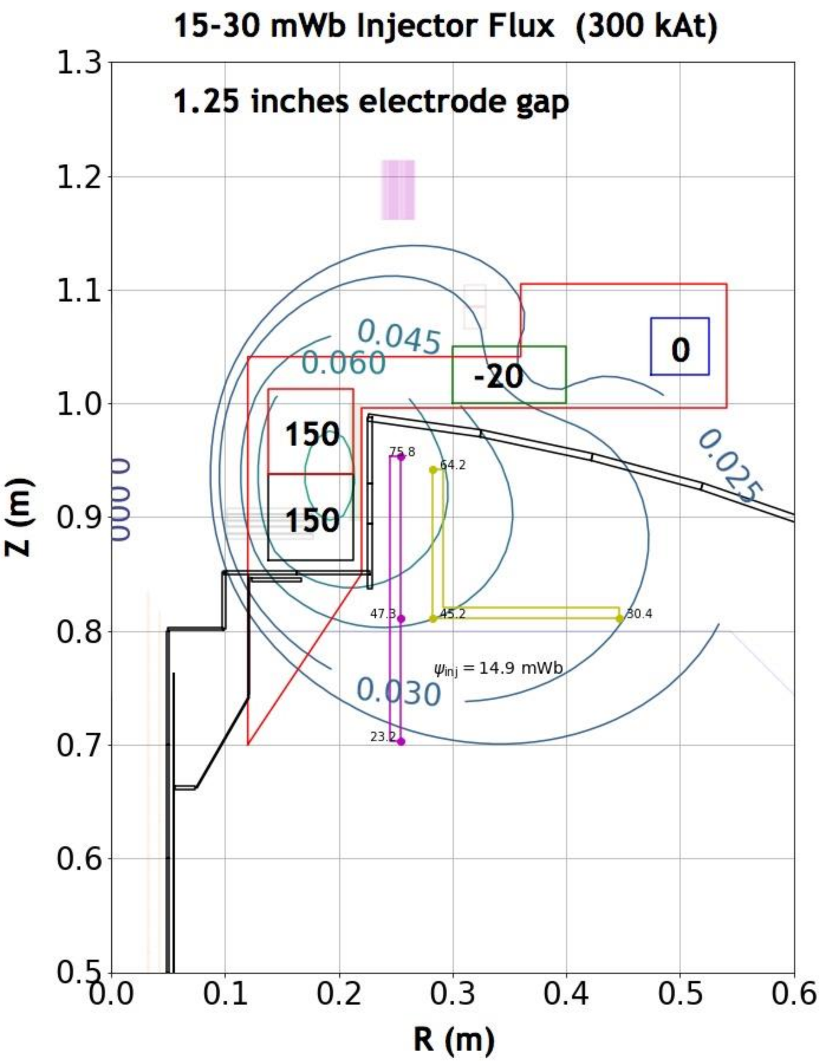
PEGASUS-III: Divertor Coils / CHI Electrode locations to be finalized (soon) after finalizing Toroidal Field Coil design

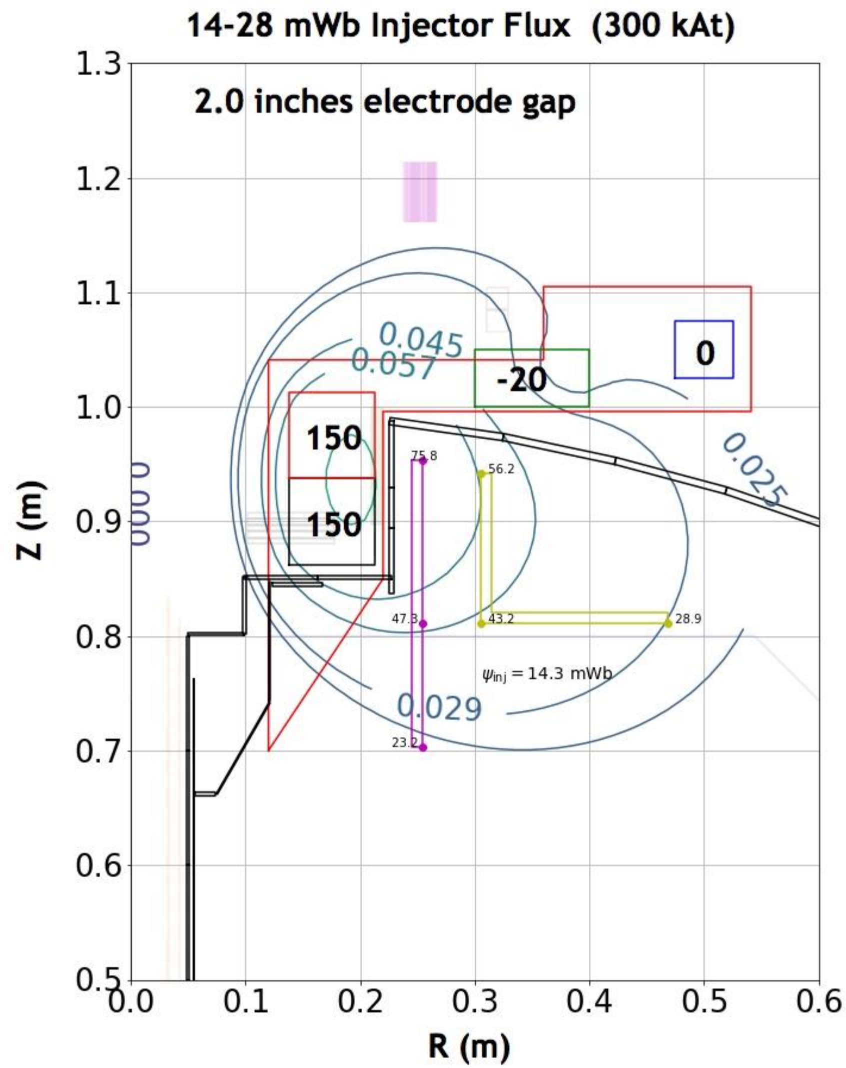


R/a = ~0.45/~0.3m, B_T = 0.6-0.9T

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

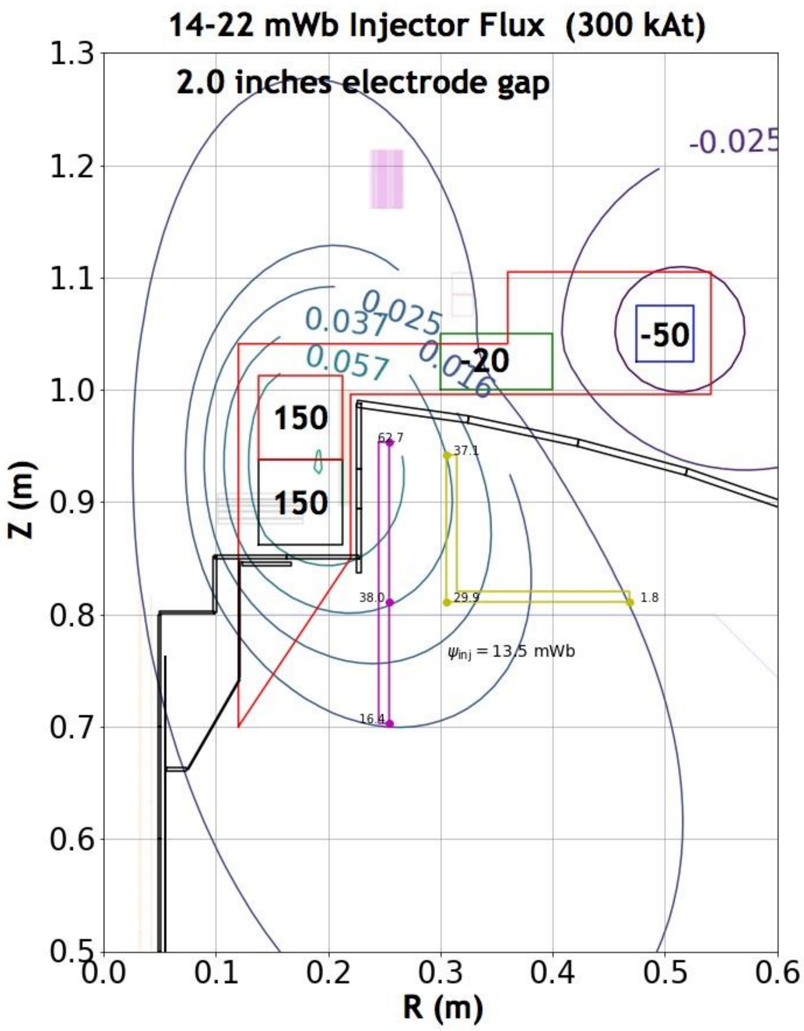
(Coil current in kA.turns)

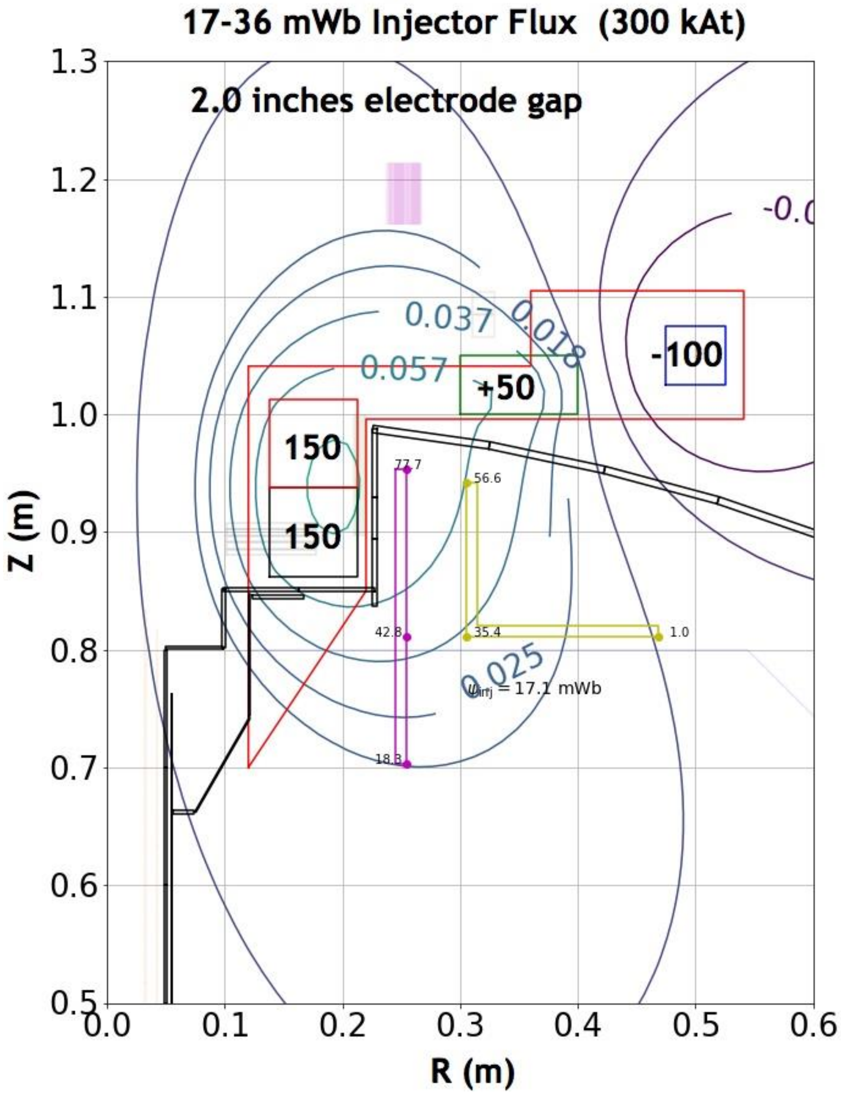




Bi-polar Outboard coils provide flux shaping capability

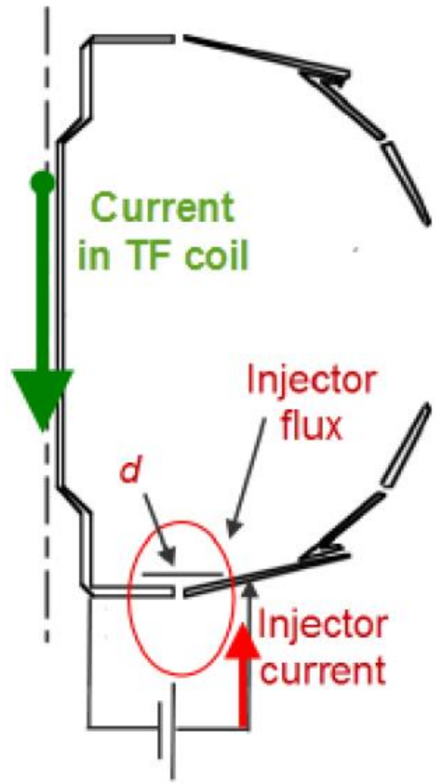
(Coil current in kA.turns)





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

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



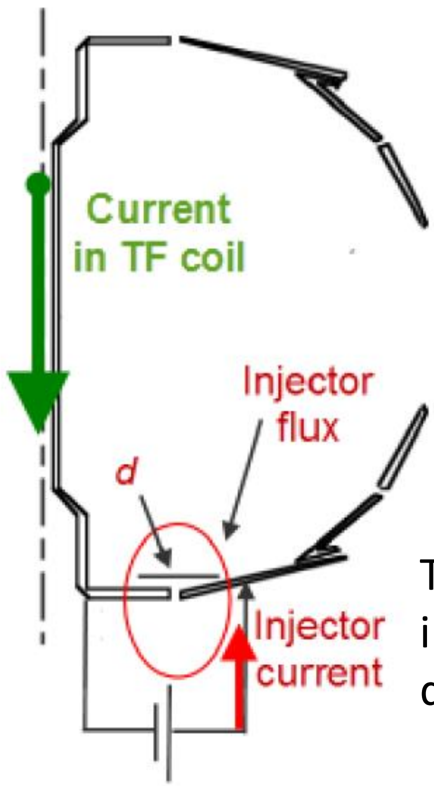
$$I_{\rm inj} \geq \frac{2\psi_{\rm inj}^2}{\mu_0^2 d^2 I_{\rm TF}}$$

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

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

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

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



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

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

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

The attained plasma current is dependent 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

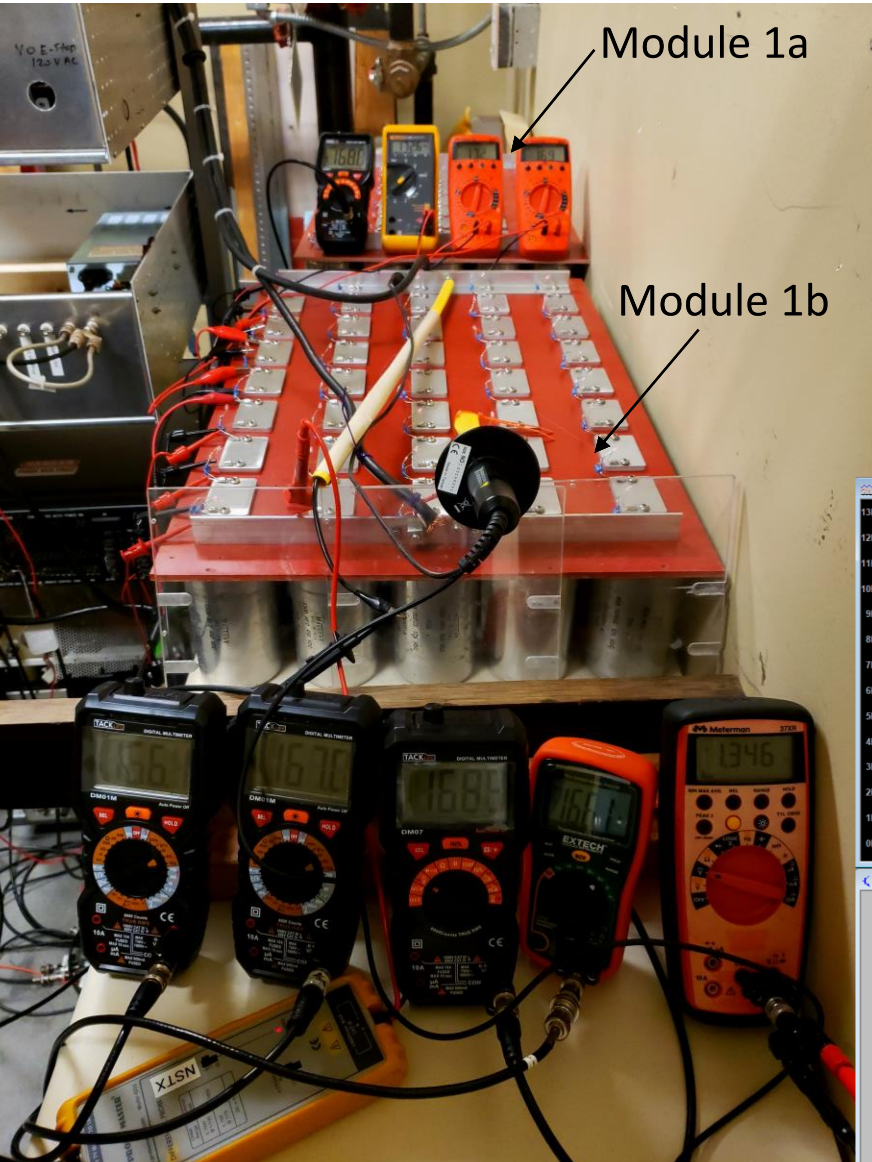
Close positioning of the divertor coils to the CHI electrodes would permit these important parameters to be studied on PEGASUS-III

Initial Studies to Focus on ~15 mWb Flux Injection

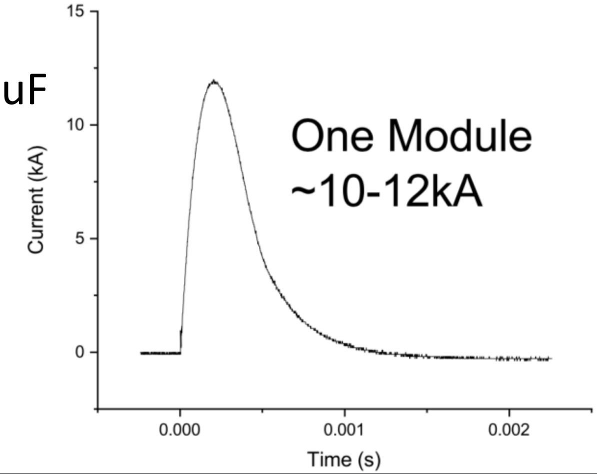
Ip (kA):	150.00
Rm (m):	0.45
Bt (T):	0.51
Bt @ CHI location (T):	0.82
Bt multiplier factor:	1.61
li - Plas normalized Induct:	0.30
Enclosed Polo flux (mWb):	12.72
Flux conversion efficieny:	0.70
Injector flux (mWb):	18.18
Itf (kA):	1152.00
footprint width - (cm):	10.00
Inj Curr (kA)	22.60
Plasma Inductance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

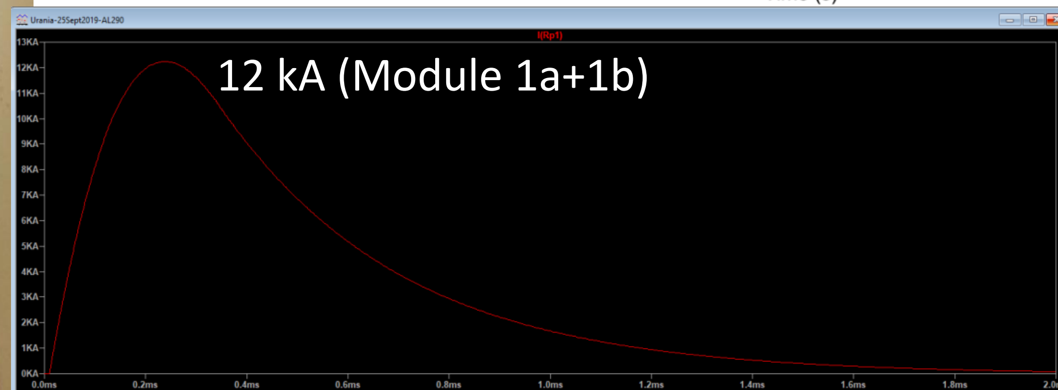
For d = 15cm, 36 mWb = 300kA, I_inj = 40kA
Optimization/scaling studies to be used to measure ‘d’

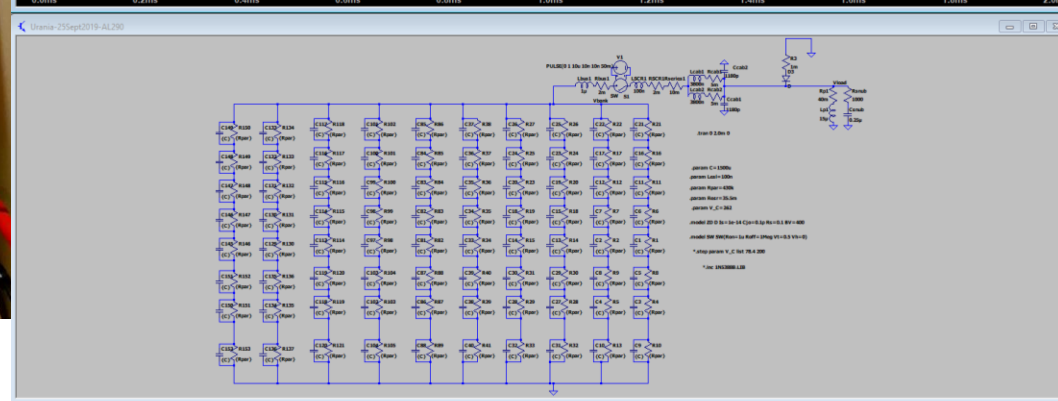
CHI Power Supply will use electrolytic capacitor bank for driving the injector current (22-30 kA for initial studies using 4-modules)



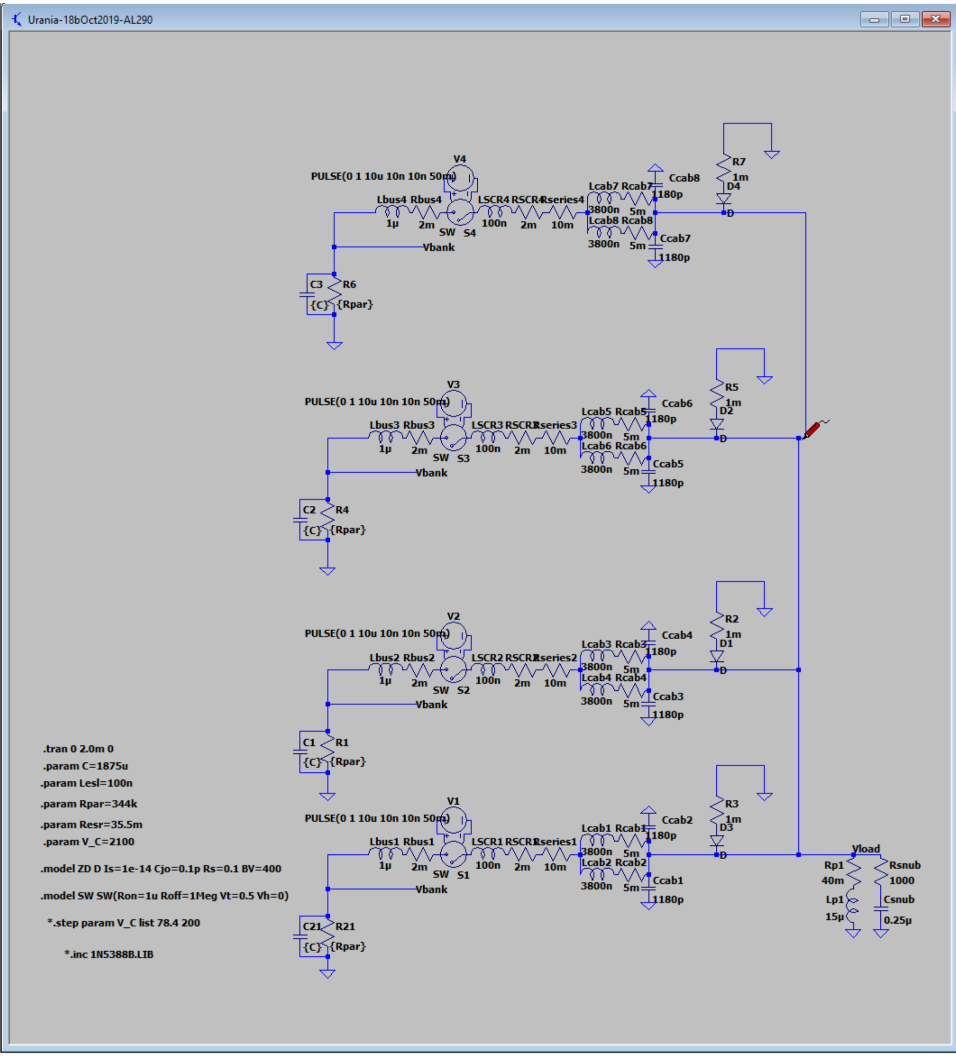
Module 1a+1b
80 Capacitors x 1500uF
8 (450V) in Series
10 in parallel
2100 V total
262 V/cap
R = 55.5 mOhm
L = 18 µH

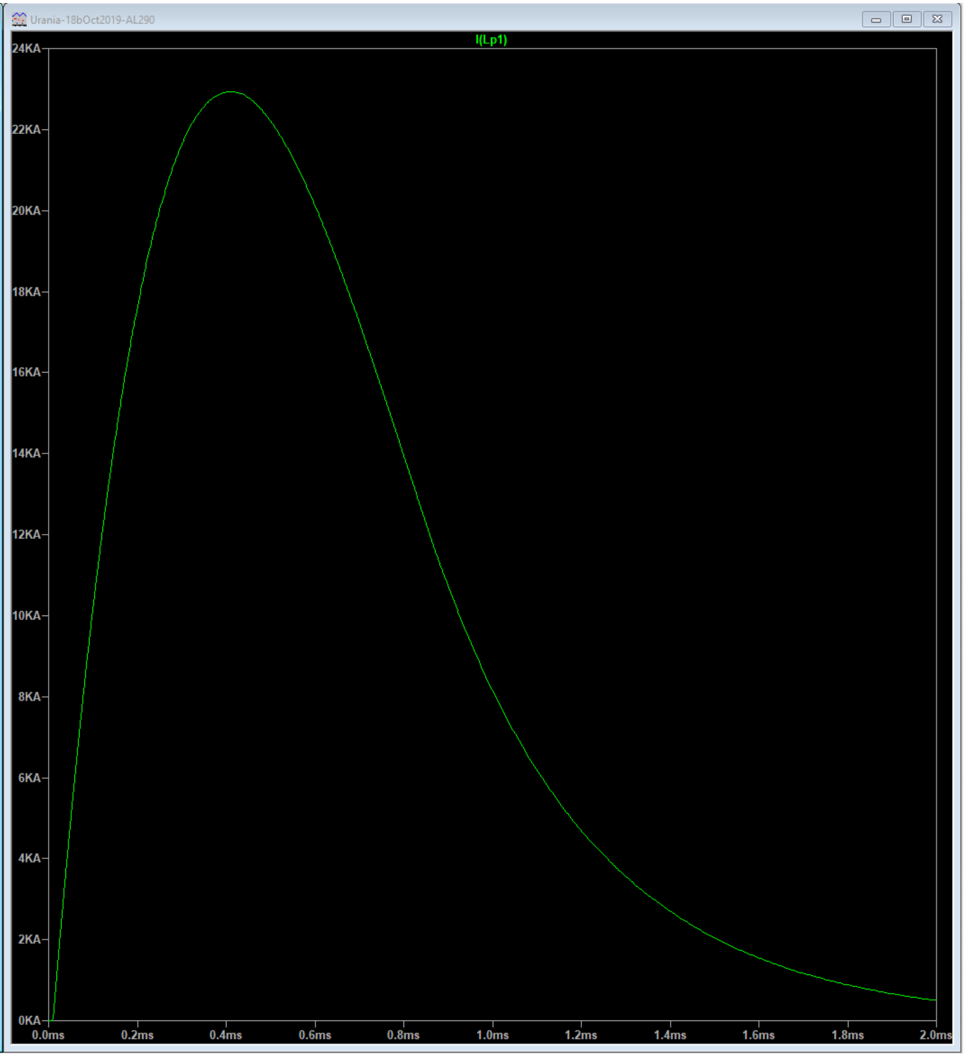




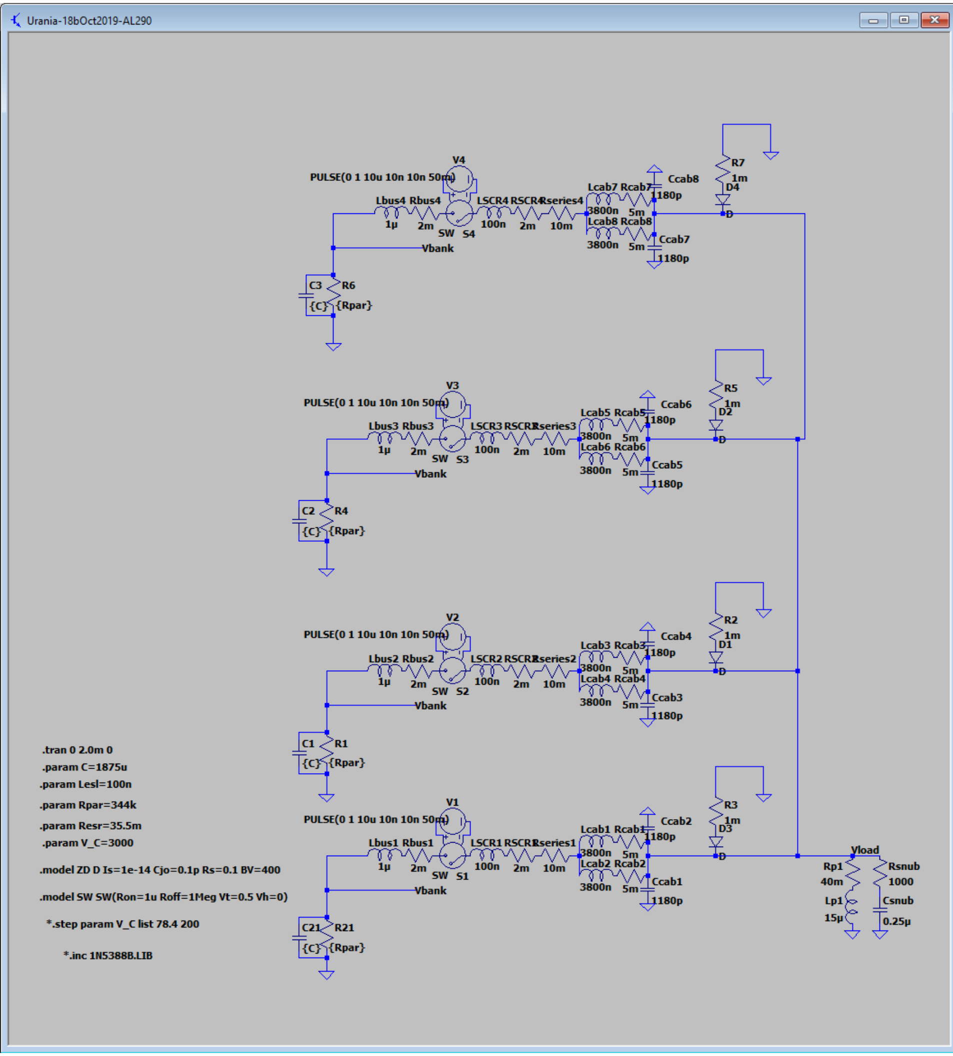


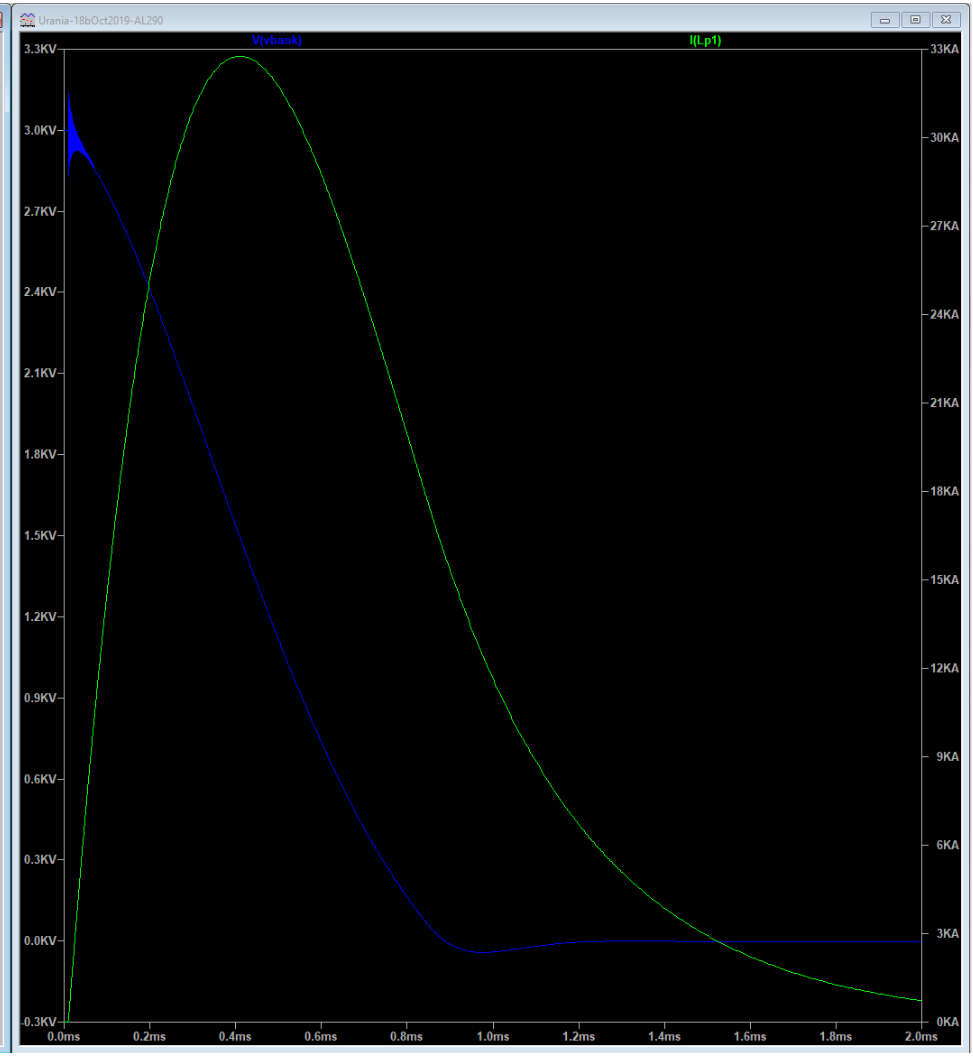
4 – Modules @ 2100V (262V/can): 22kA





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 CHI Deployment on NSTX-U

- 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