Disruption modeling using TSC for ITER

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Contributors:

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Outline

- Background
  - TSC modeling for ITER over the past few years
  - Benchmarking with DINA results
  - Validation with ASDEX-UG and NSTX experiments
- Further modeling requirements using TSC/DINA
  - Model dependence on Halo current parameters
  - Further benchmarking with D3D and CMOD expts
  - Possible improvements
  - Open isssue: Are assumptions for CFC good for W?
- Conclusions

Motivation - ITER VDE/MD modeling

- **Specifications for maximum electromagnetic loads in ITER are based on major disruptions (MD) and VDEs modeling using the DINA code (Sugihara et al, NF 2007)**
- **Latest predictions for the loads:**
  - **Horizontal load : 25 MN   Vertical load : 90-108 MN**
- **Predictive modeling of MD and VDEs are difficult**
  - **benchmarked codes are 2-D (no TPF), while 3-D effects often dominate**
  - **model assumptions on various plasma parameters**
- **DINA predictions have now been validated by TSC**
- **However, predictive simulations of Disruptions are difficult, model assumptions may result in significant error bars**
- **Uncertain parameters:**
  - **Evolution of Te during TQ, W_halo and T_halo, Details of EM model**
- **Important parameters compared:**
  - **Plasma dynamics during disruptions and VDEs, Ip quench time, I_halo/Ip**

Present ITER specification based on 2D code

VDE with slow I_p quench (SVDE)

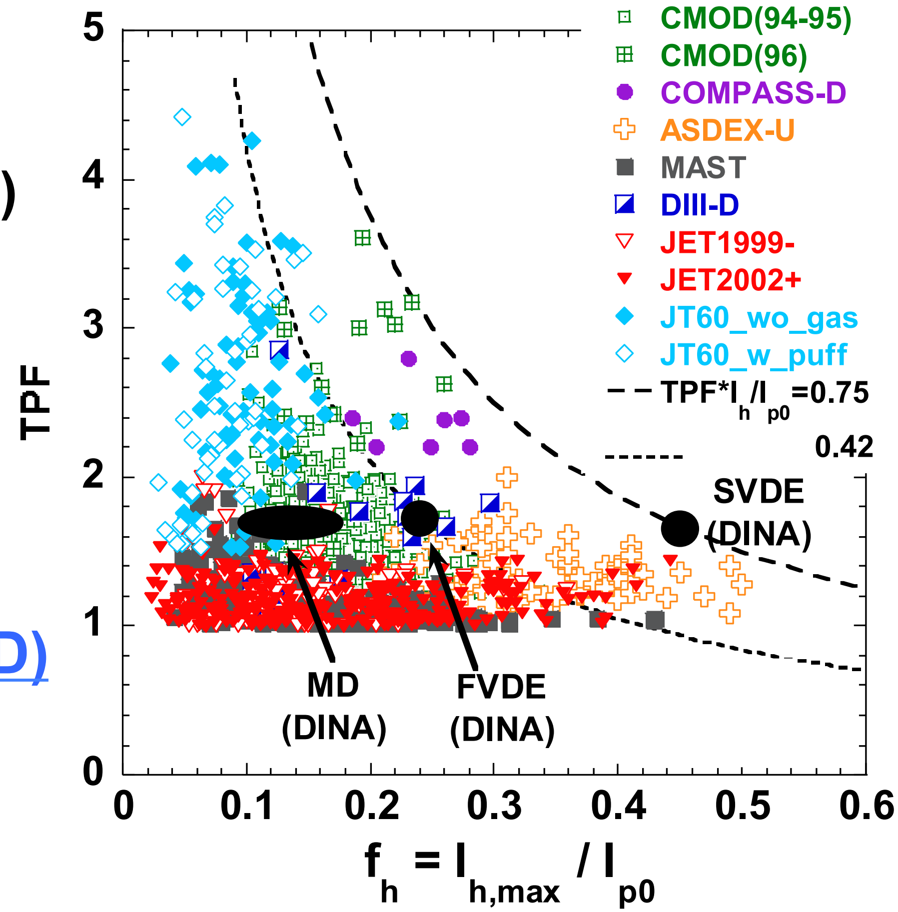
- $\langle I_{halo} \rangle_{max} / I_{p0} \approx 0.45$ (2D code)
- $TPF \times \langle I_{halo} \rangle_{max} / I_{p0} \approx 0.75$ (database)
- $TPF \approx 1.67$

VDE with fast I_p quench (FVDE)

- $TPF \approx 1.67$ (same as slow)
- $\langle I_{halo} \rangle_{max} / I_{p0} \approx 0.25$ (2D code)
- $TPF \times \langle I_{halo} \rangle_{max} / I_{p0} \approx 0.42$

Disruption with fast I_p quench (MD)

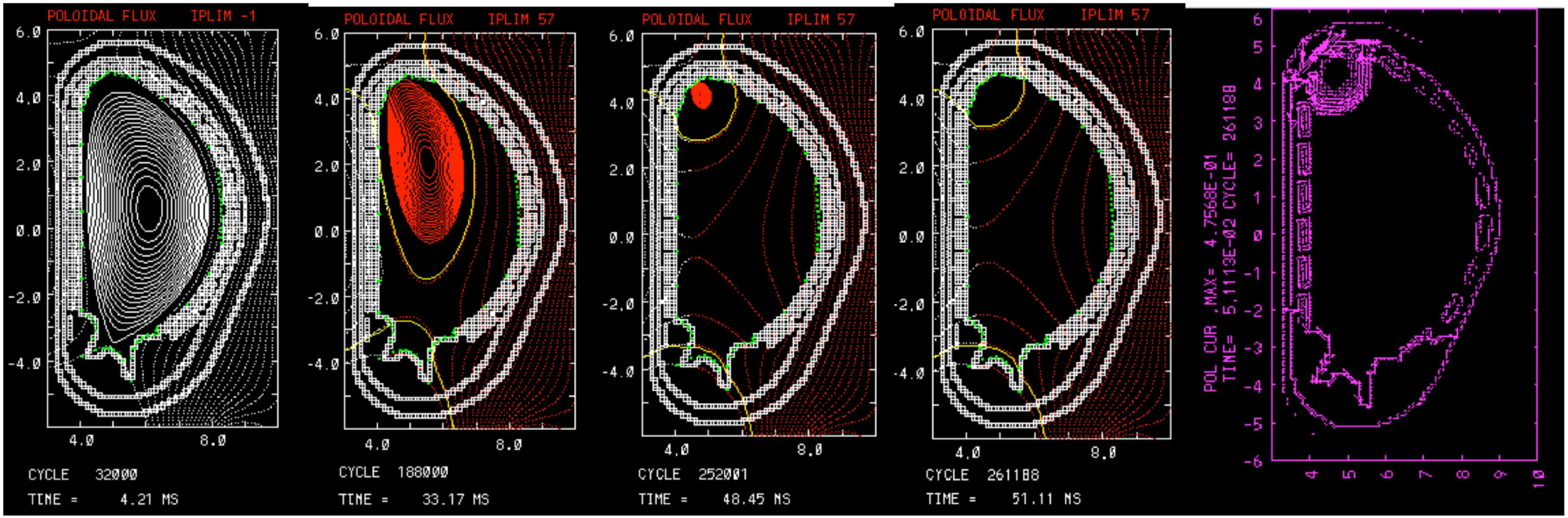
- $TPF \approx 1.67$ (same as slow)
- $\langle I_{halo} \rangle_{max} / I_{p0} \approx 0.1\text{-}0.15$ (2D code)
- $TPF \times \langle I_{halo} \rangle_{max} / I_{p0} \leq 0.25$



- There are some concerns about the consistency between
  - Predicted maximum f_h by predictive code and
  - Experimental values

  for these representative disruption and VDE scenarios.

ITER model in TSC



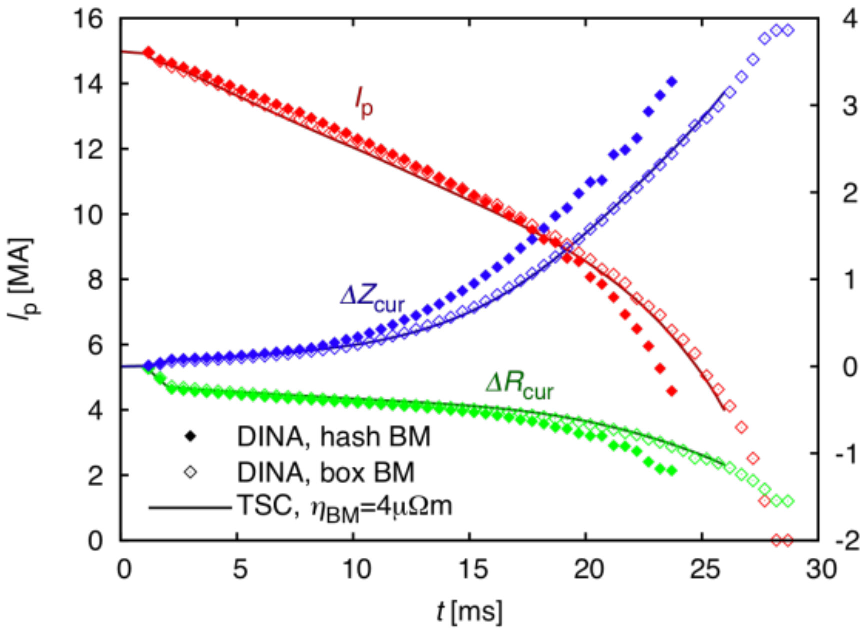
- **Detailed EM model of VV, BMs, FW/Div, Coils**
- **Initial plasma equilibrium: ITER reference scenario 2 EOB - Ip=15 MA**
- **TQ triggers MD. Post TQ Te=6eV(fast CQ) /50eV (slow CQ)**
- **For VDE, controller switched off and plasma drifts freely until q_{95} reaches 1.5, when TQ is initiated**
- **W_{halo}=0.1 of closed flux, T_{halo} =6eV**

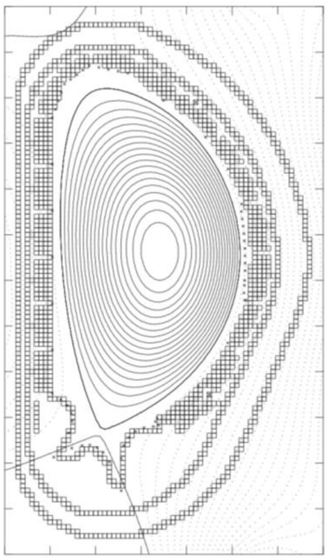
IAEA 2010

DINA and TSC benchmarking

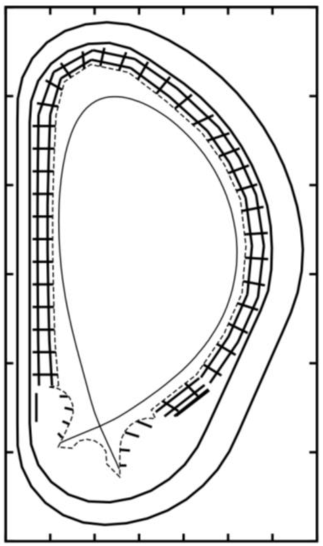
- Very detailed analysis done by Myamoto et al (NF 2014) to understand and eliminate the model differences between TSC and DINA for ITER
  - Differences in EM model, specially for blanket modules
  - Differences in plasma current density profiles near the edge
  - Halo current width and evolution
- Once the differences are removed, the models agree remarkably with each other

EM model of ITER in DINA and TSC

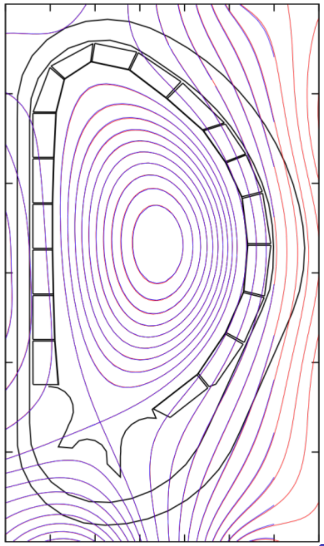




TSC



DINA (Hash)

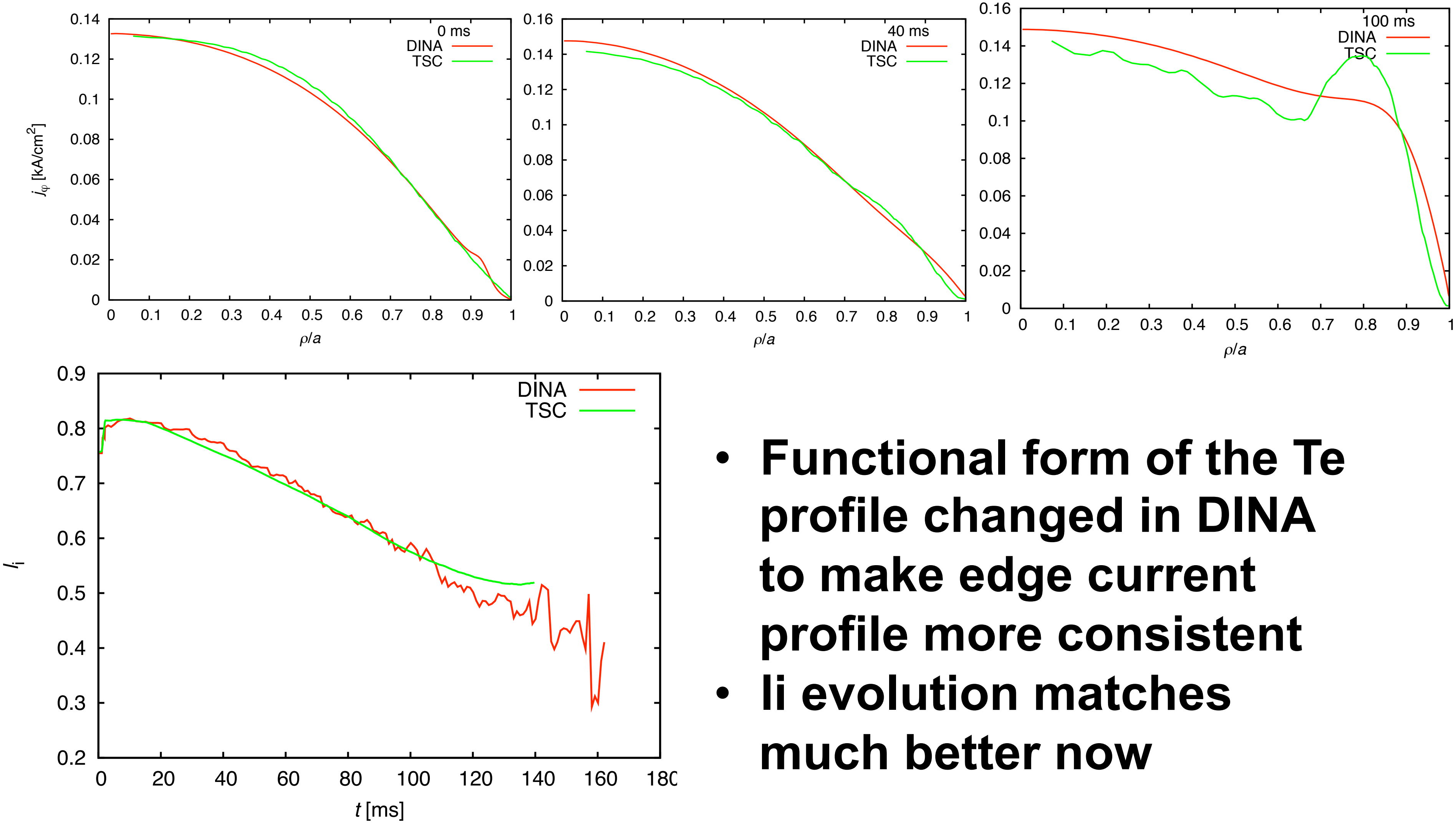


DINA (Box)

Comparison of DINA simulation results with the box type BM (open diamonds) model and those with the hash type BM (solid diamonds) model. TSC results are also shown for ηBM= 4 μΩm, with which time constants are the same order as DINA's ones.

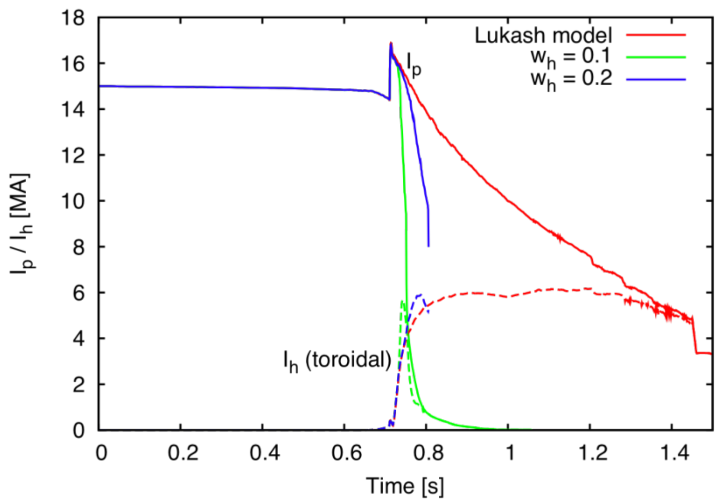
Miyamoto et al NF 2014

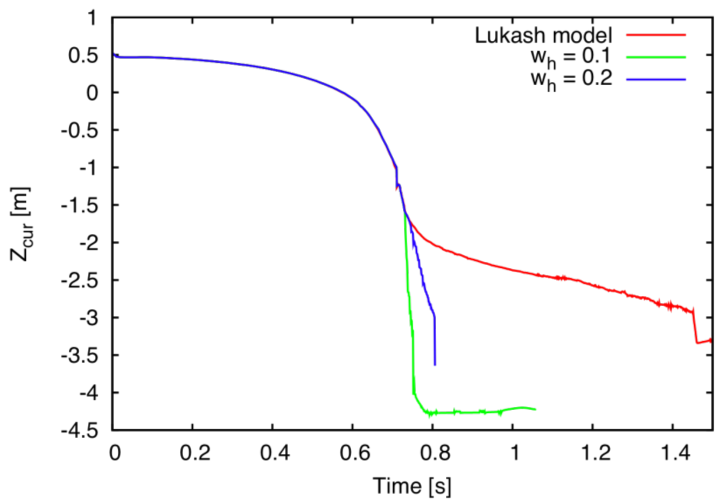
j_Φ profile discrepancy resolved

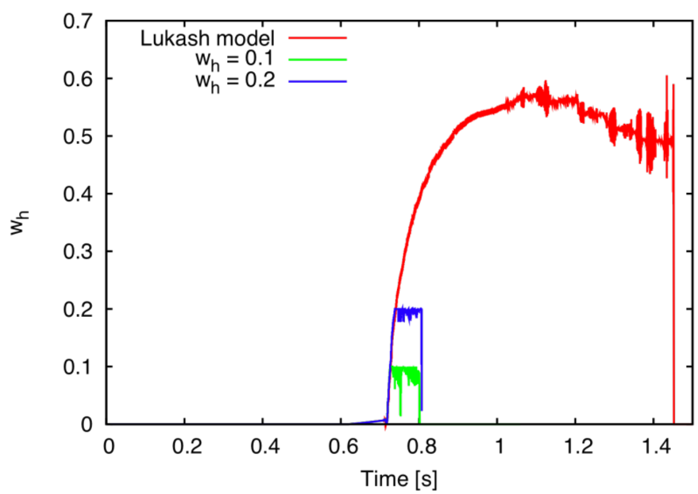


- **Functional form of the Te profile changed in DINA to make edge current profile more consistent**
- **li evolution matches much better now**

DINA with TSC-like W_{halo}

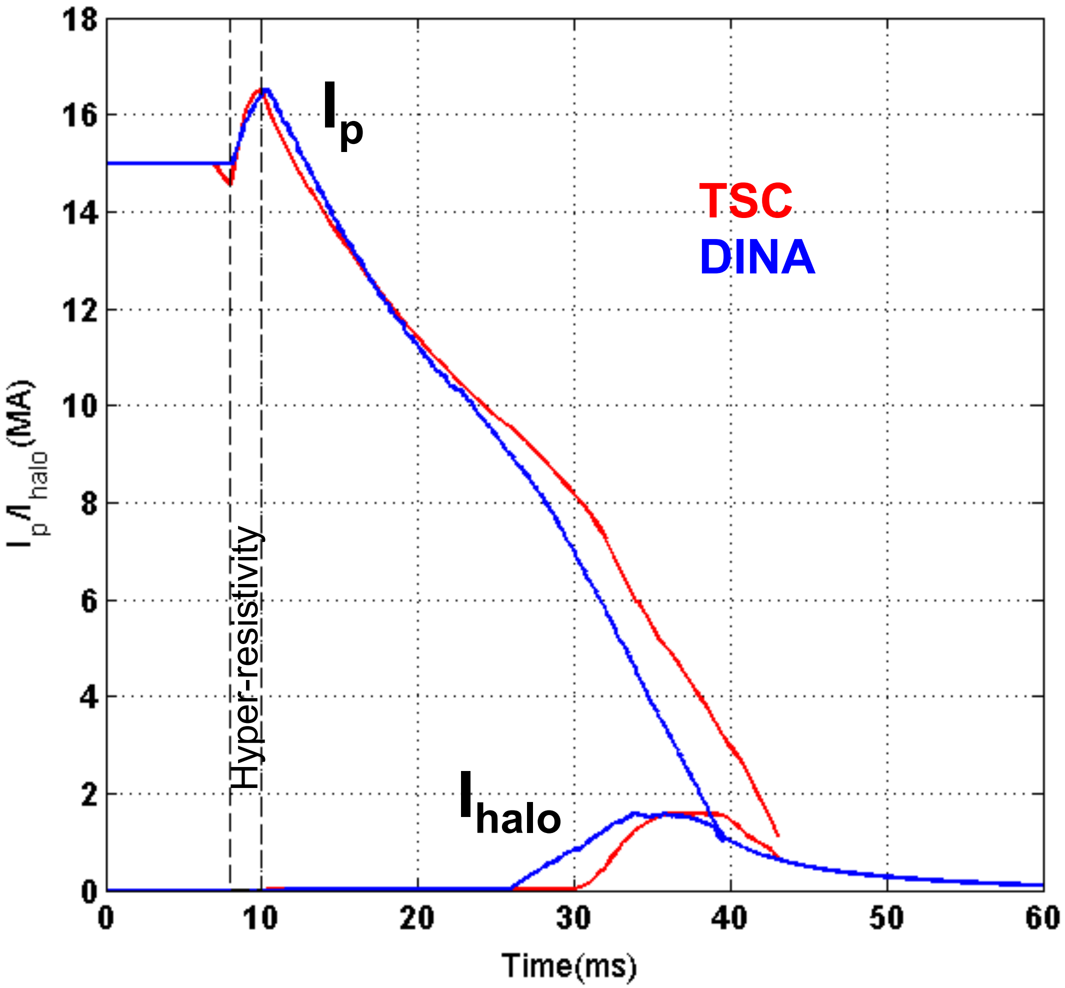






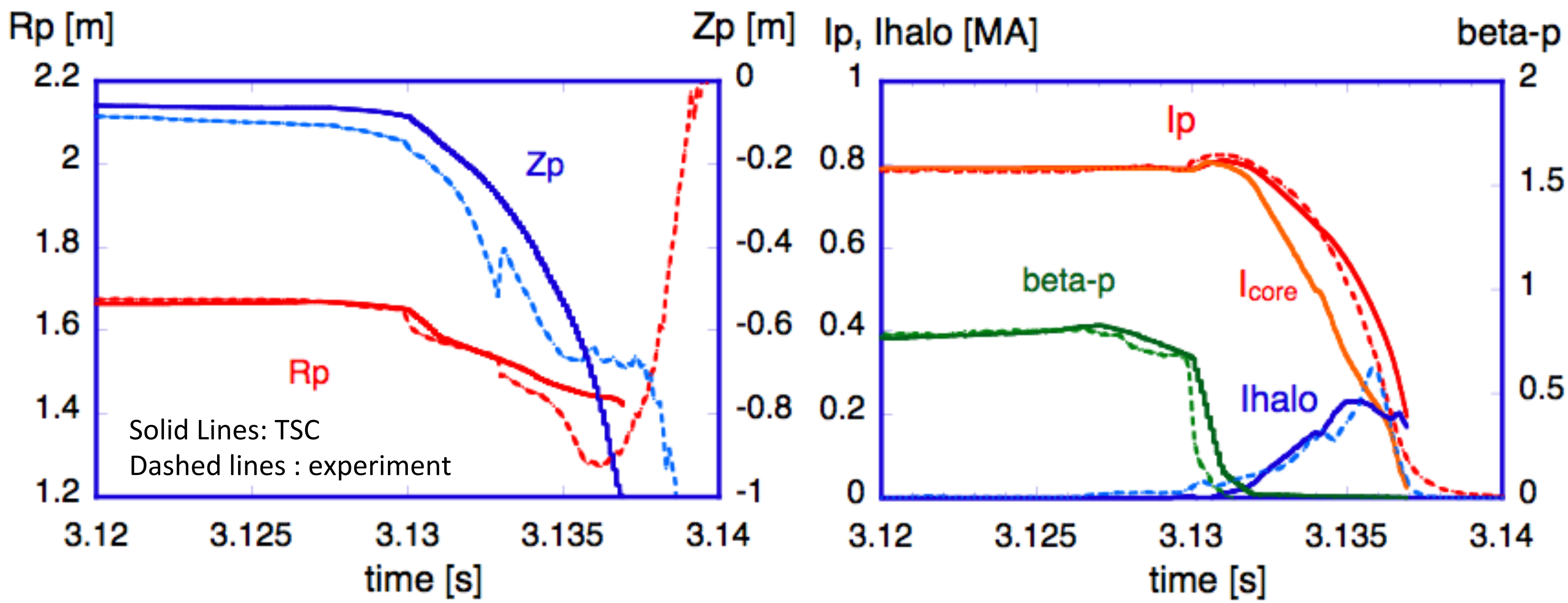
- **DINA slow DN VDE case uses an unusually large W_{halo}.**
- **DINA runs with TSC like W_{halo} gives much faster Ip quench**

Fast MD Simulations



- Improved model removed earlier mismatches
- Ip quench time matches well in the two models
- After the halo onset, the Ip quench in TSC is still somewhat slower
- Halo current predictions from both models almost same

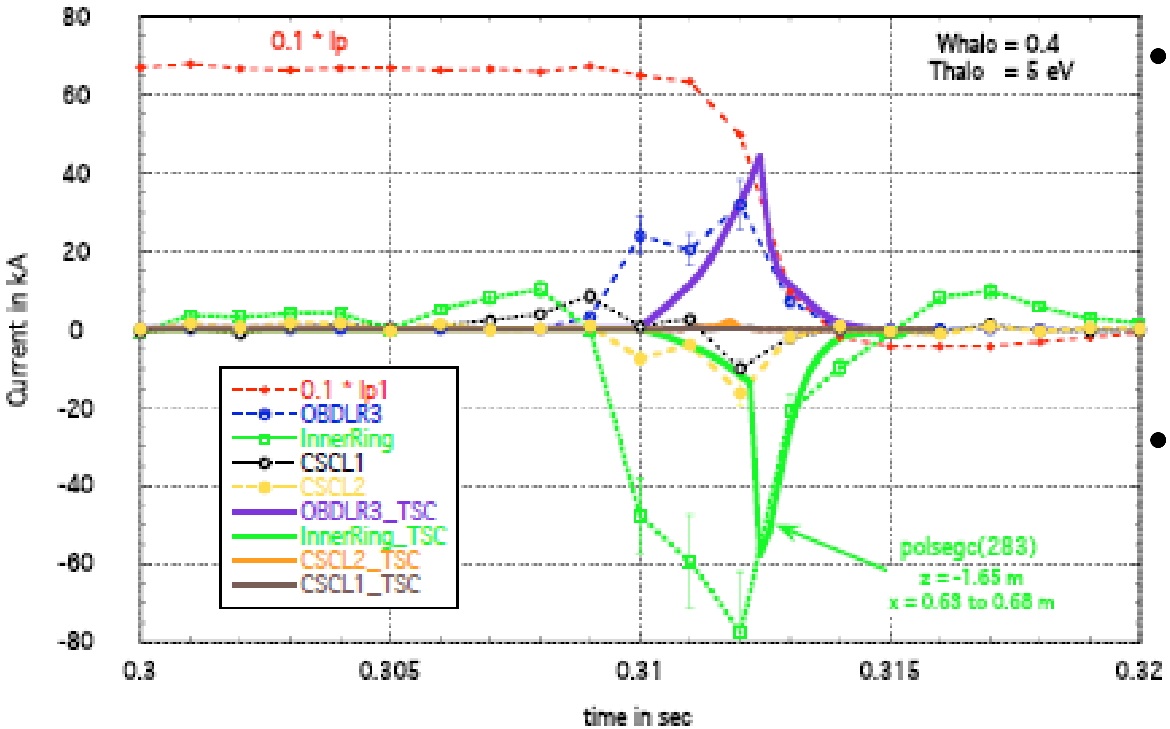
TSC benchmarking of ASDEX-UG



- ASDEX-UG shot #25000. I_p ~ 791 kA, l_i ~ 0.71, β_p ~ 0.74, κ ~ 1.8, initial R_p = 1.67 m, Z_p = -3.5 cm
- Assumptions:
  - T_{halo}=12eV, W_{halo} up to 40% of closed flux

IAEA 2010

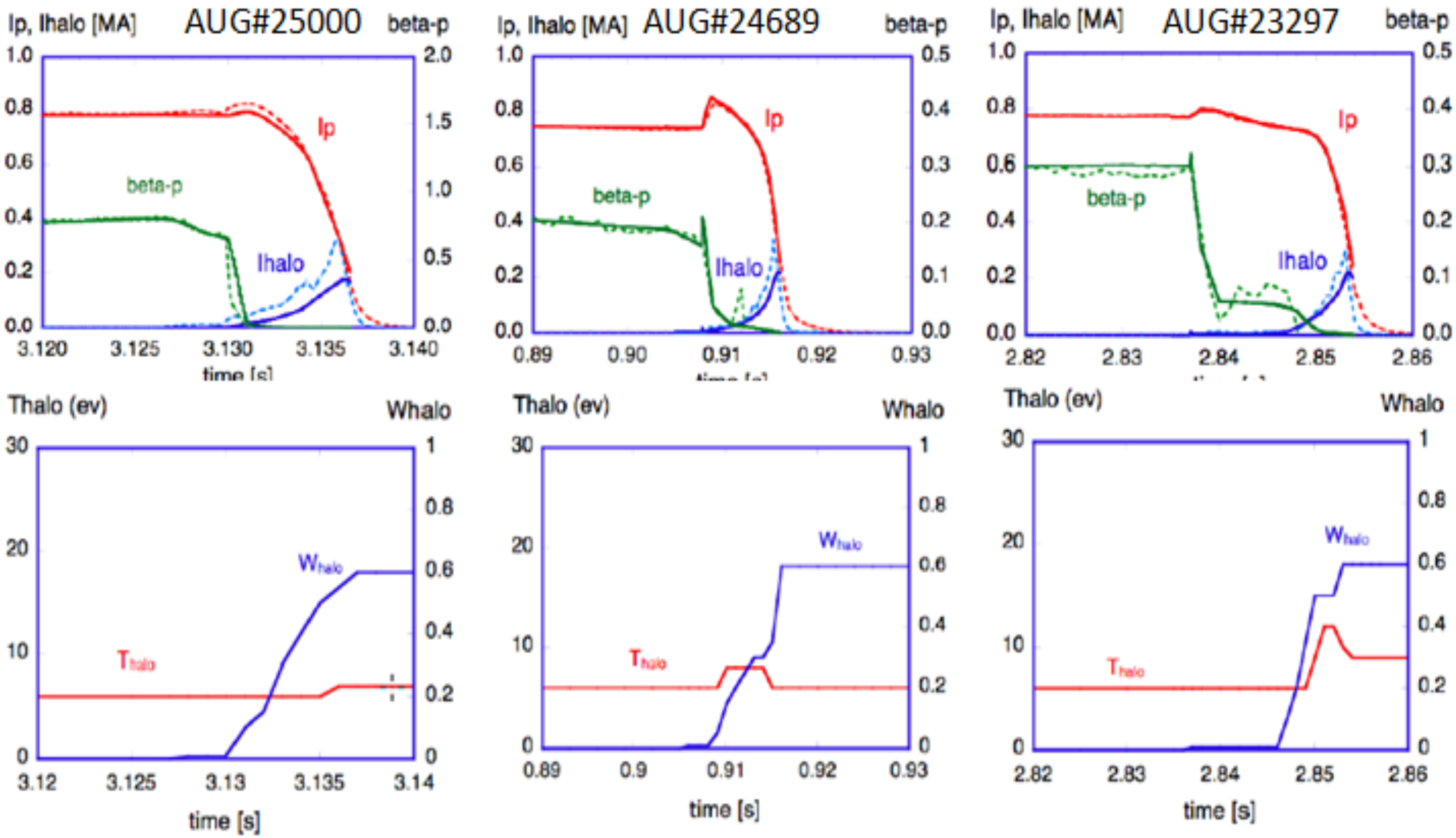
TSC benchmarking of NSTX



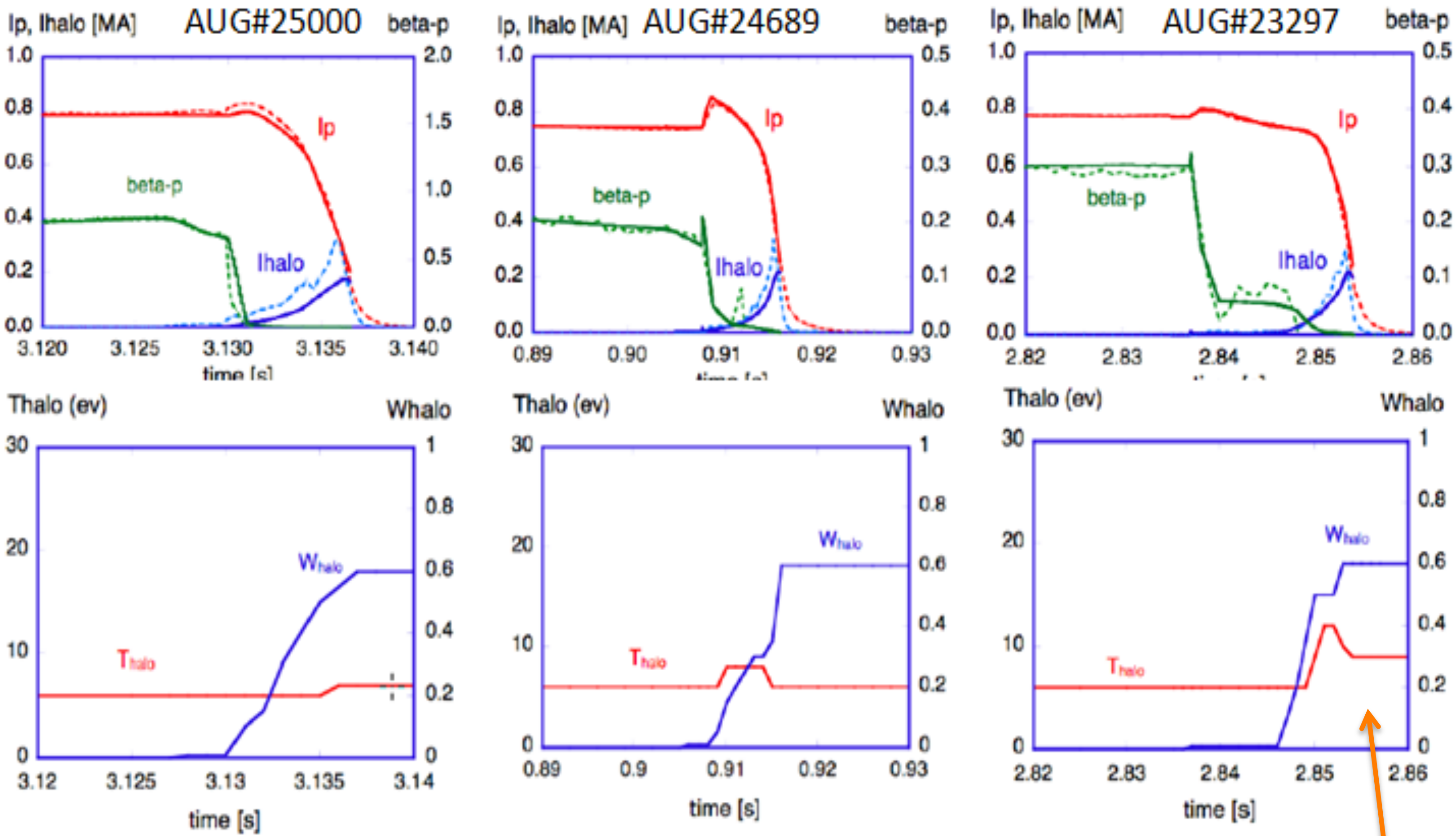
- **Comparison of Experimental data of NSTX discharge 132859 and TSC simulations**
- **Assumptions:**
  - **T_{halo}=5eV, W_{halo} up to 40% of closed flux**

IAEA 2010

TSC modeling of ASDEX-UG shots



TSC modeling of ASDEX-UG shots

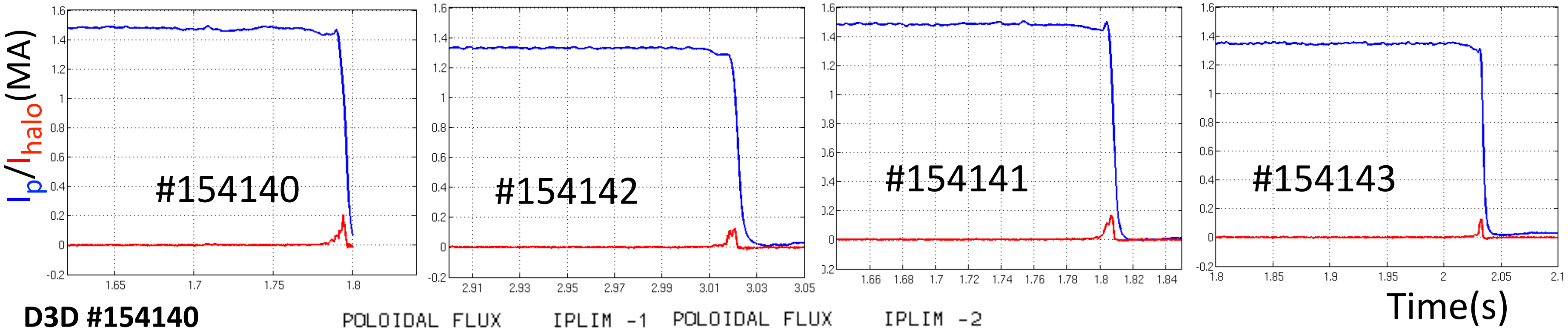


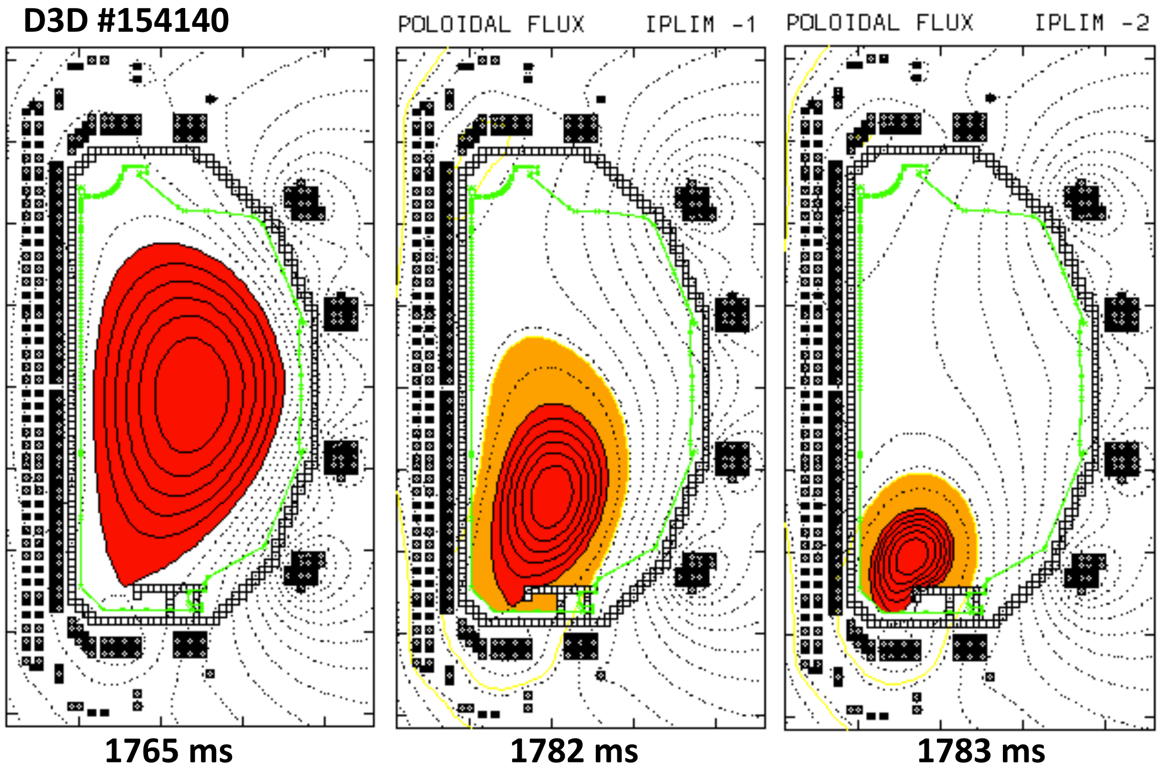
Adjustment of T_{halo} and W_{halo}

ITPA MHD WG-10 plan for 2014

- **Multi machine benchmarking of evolution of Ip quench and halo current**
  - **DIII-D and CMOD VDE/MD shots (~4-5 shots in each) to be modeled**
  - **W_{halo} and T_{halo} to be tailored and fixed against one representative discharge in each machine.**
  - **For rest of the shots, more or less predictive modeling with only initial equilibrium at the beginning of the thermal quench as input to modeling**
  - **The variations of modeled and experimental peak I_{halo} to be used as a measure of error bar in predictive modeling**

DIII-D shots to be modelled

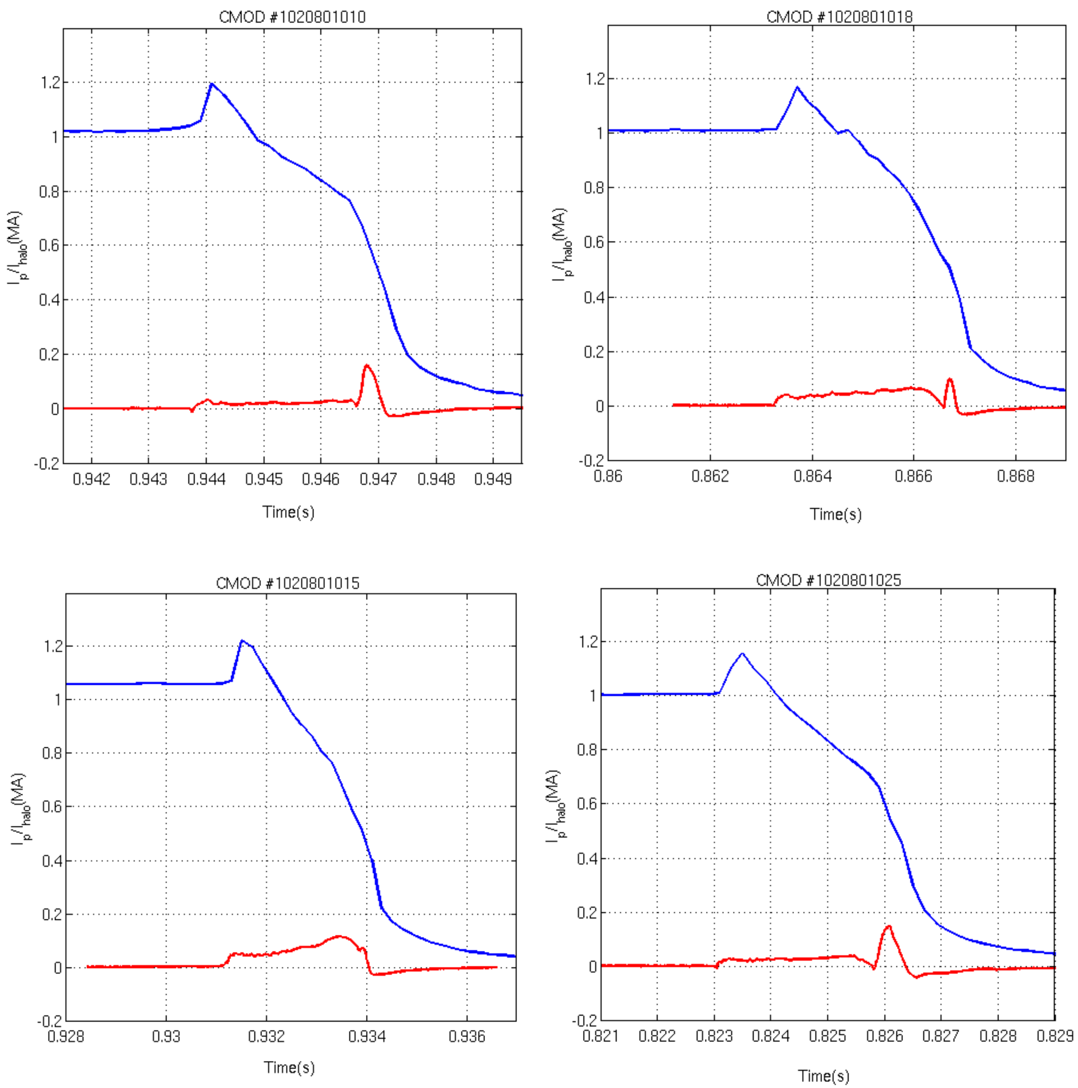




4 shots selected
Ip~1.3-1.5MA
Ihalo~100-200kA
All DW VDE cases

Halo parameters to be fitted against #154140

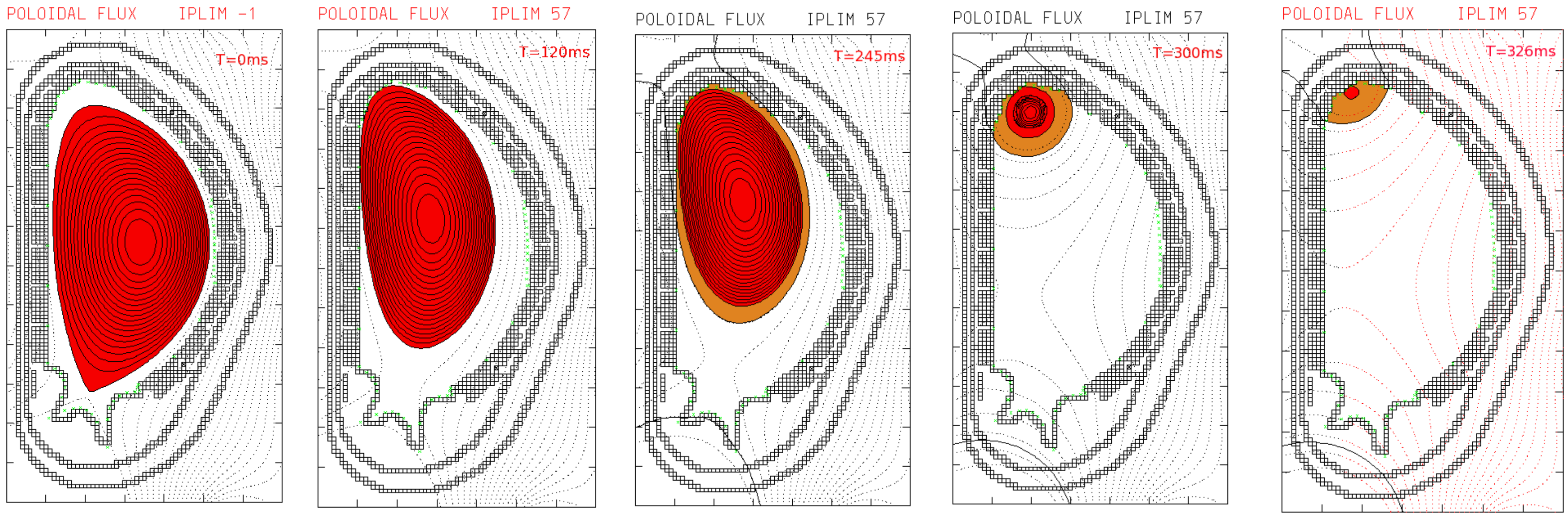
CMOD shots to be modelled

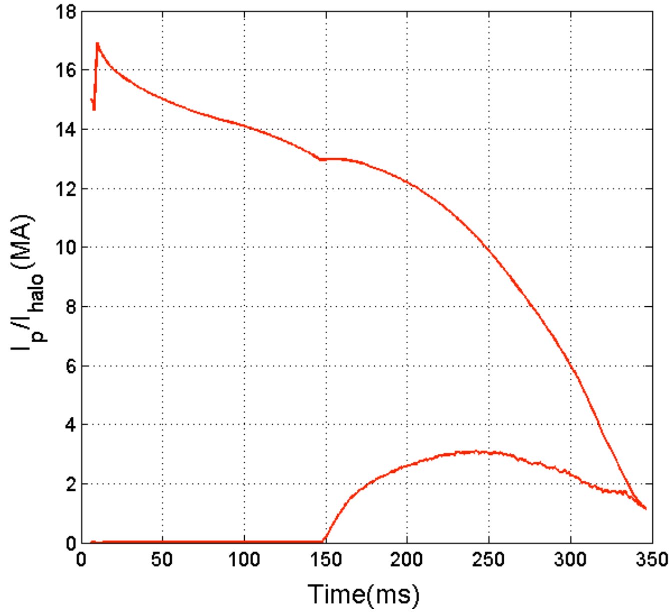


4 shots selected
Ip~1.0MA
Ihalo~112-168kA
All DW VDE cases

Halo parameters to be fitted against #1020801010

ITER Disruptions slow Ip quench





- **Post TQ Te=50eV in slow CQ**
- **Poloidal halo current of ~3MA can flow for >200msec!**

(Note: TPF=1.67 absent in 2D)

- **Concern for W/Be Wall?**

Conclusions

- **TSC and DINA code differences have been analysed in detail**
  - **The code predictions for ITER match very well when the model differences are eliminated/minimised**
- **TSC has been benchmarked extensively with disruption shots in various machines**
- **However, uncertainties still exist for predictive modeling for ITER, especially in parameters of the halo region (mainly W_{halo} and T_{halo}), which critically determine Ip quench time, peak halo current and duration**
- **Further TSC modeling with D3D and CMOD discharges currently underway under ITPA MHD WG to estimate error bars in halo currents for predictive modeling**