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First Experiments in SST-1

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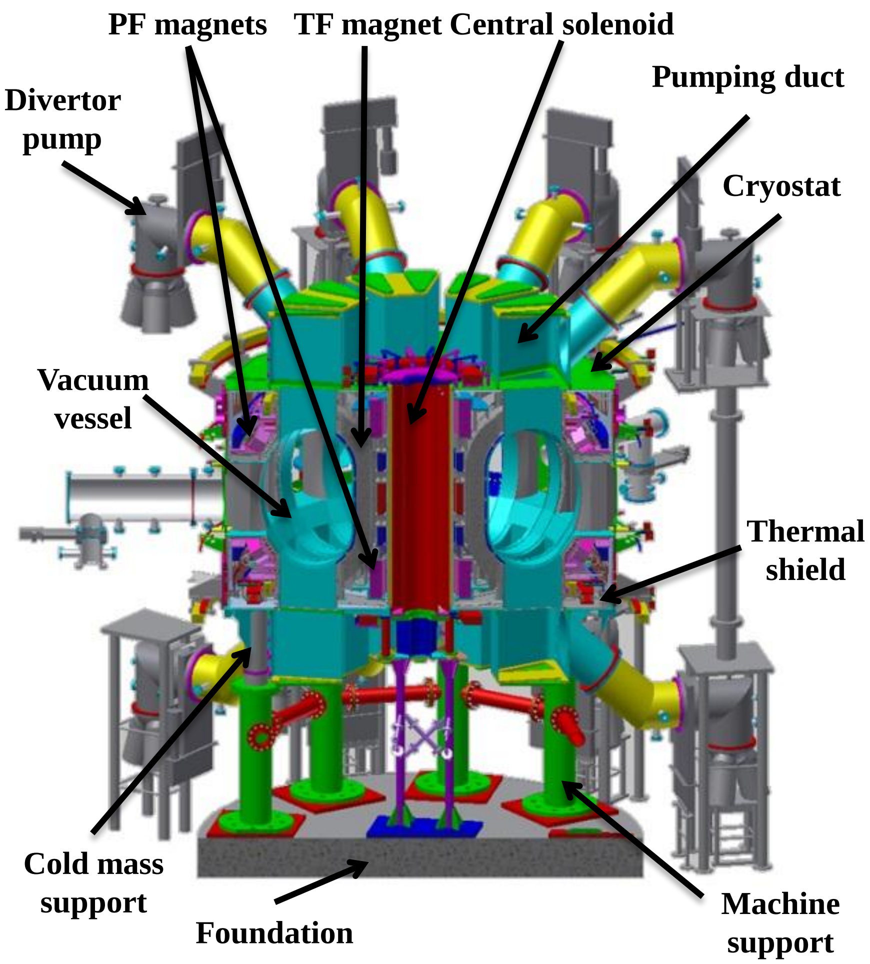
OV 5-5

Steady State Superconducting Tokamak (SST-1) at IPR

Outline

- SST-1 Parameters
- Results in SST-1 from Engineering Validations
- First Experiments in SST-1
- Significant physics results
- Significant engineering/technology results
- Future experiments & Up-gradation plans of SST-1
- Summary

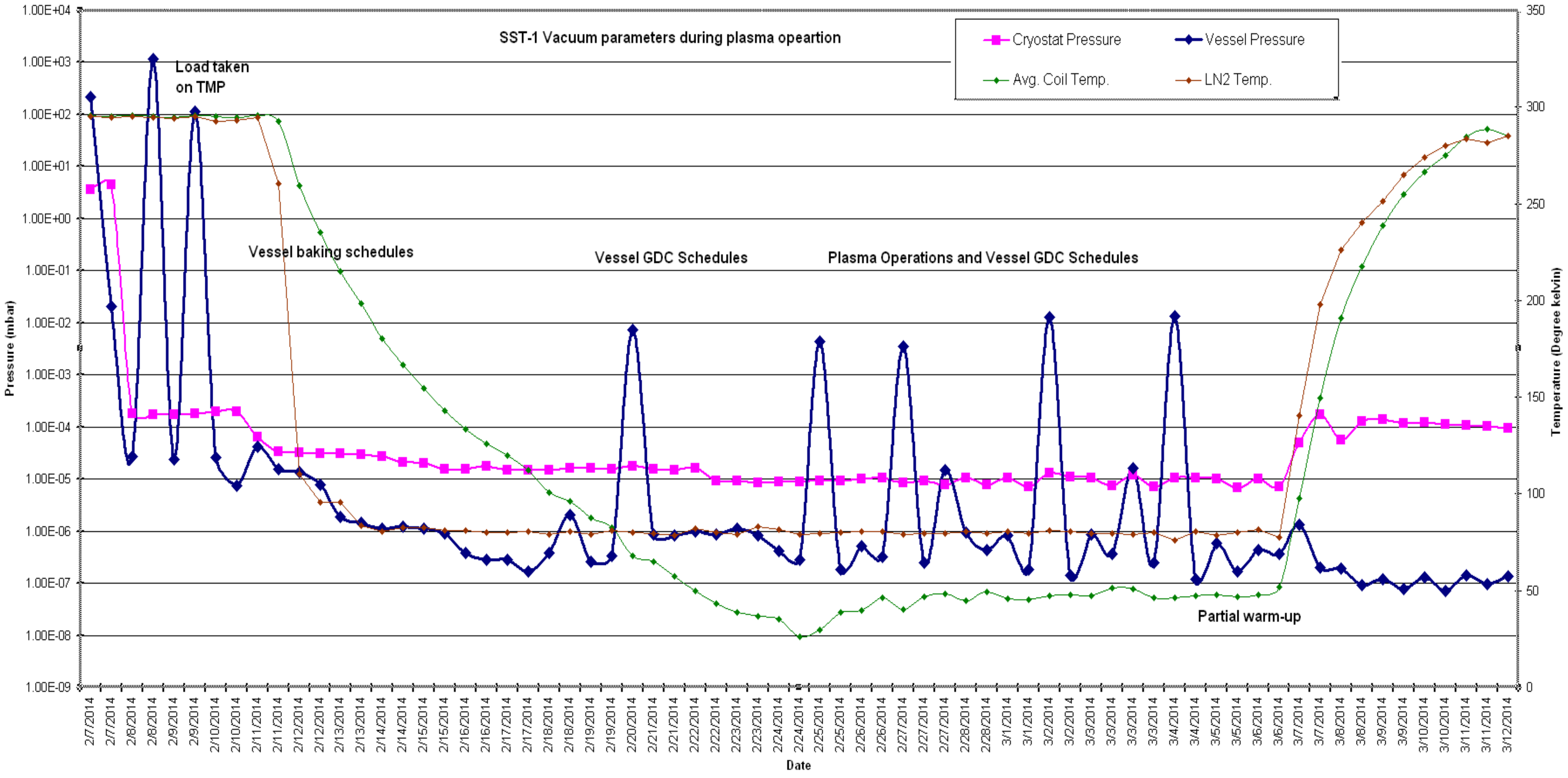
3-D Isometric View & assembled SST-1



MAJOR RADIUS	: 1.1 m
MINOR RADIUS	: 0.2 m
ELONGATION	: 1.7-2
TRIANGULARITY	: 0.4-0.7
TOROIDAL FIELD	: 3T
PLASMA CURRENT	: 220 kA.
ASPECT RATIO	: 5.2
SAFETY FACTOR	: 3
AVERAGE DENSITY	: 1.0×10^{13} cm^{-3}
AVERAGE TEMP.	: 1.5 keV
PLASMA SPECIES	: HYDROGEN
PULSE LENGTH	: 1000s
CONFIGURATION	: DOUBLE NULL
	: POLOIDAL
DIVERTER	
HEATING & CURRENT DRIVE:	
LOWER HYBRID	: 1.0 MW
NEUTRAL BEAM	: 0.8 MW
ICRH	: 1.0 MW
TOTAL INPUT POWER	: 1.0 MW
FUELLING	: GAS PUFFING

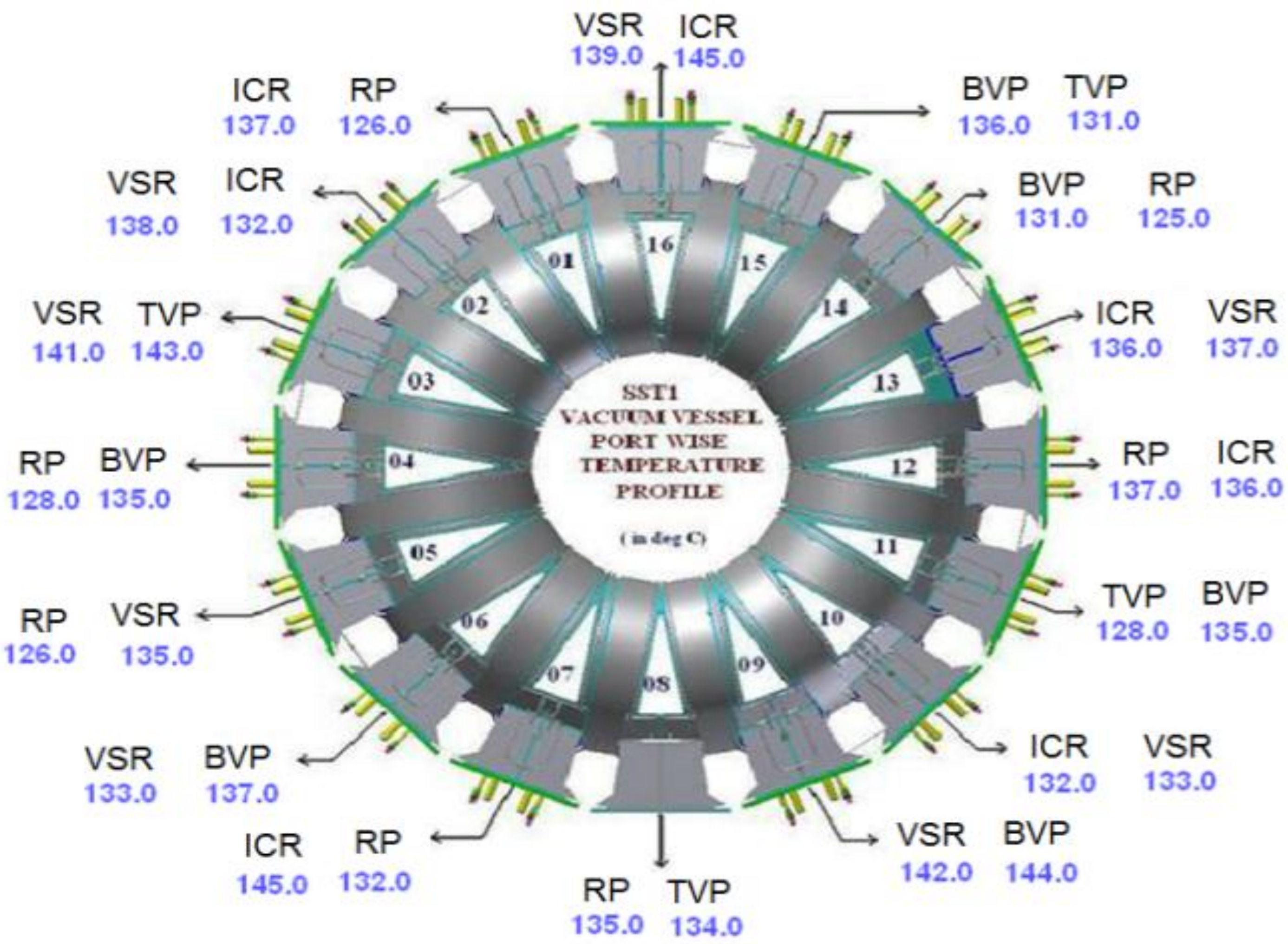
Engineering Validations of assembled SST-1 prior to `First Plasma’

Vacuum trend over long duration



Established UHV compatibility of SST-1 Vacuum Vessel, baking compatibility with 80 K shields being maintained

Temperature distribution in vacuum vessel during baking of machine (Typical)

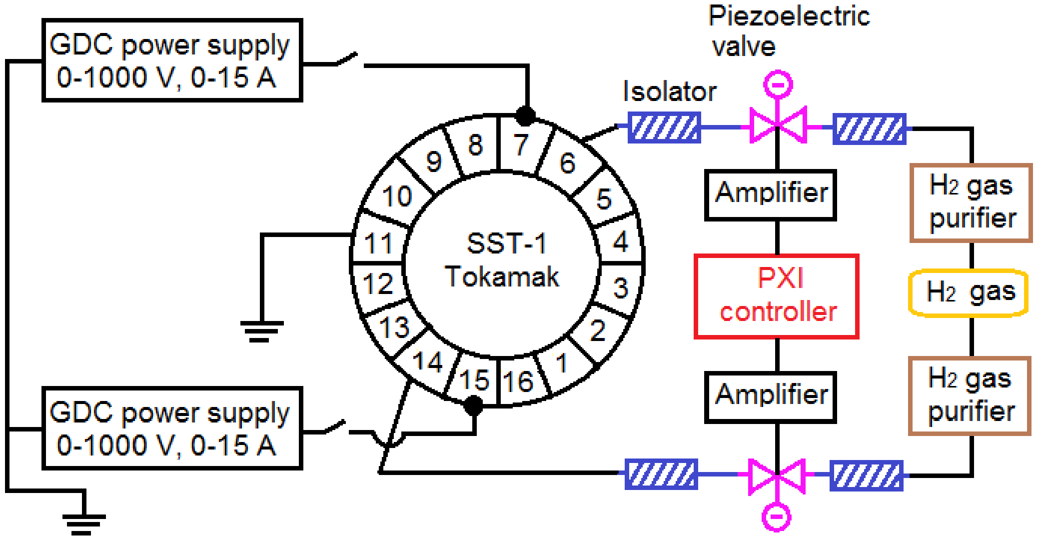


Established Stress optimized Baking with Thermal Shields being at 80 K

Temperature distribution in Limiters

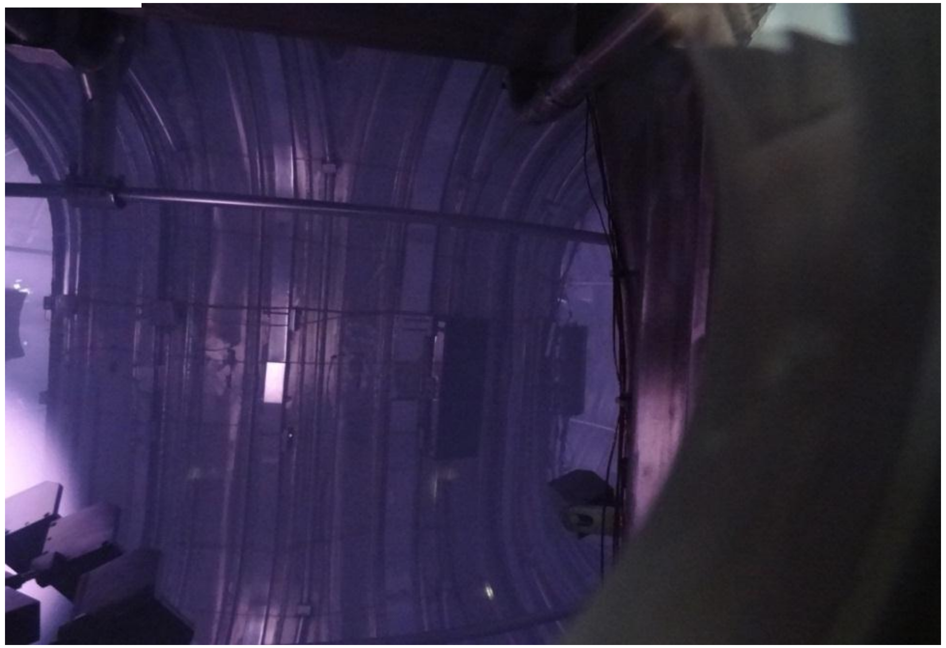
Established the Baking & UHV compatibility of Limiter system

Gas puff system and H2 GDC of machine

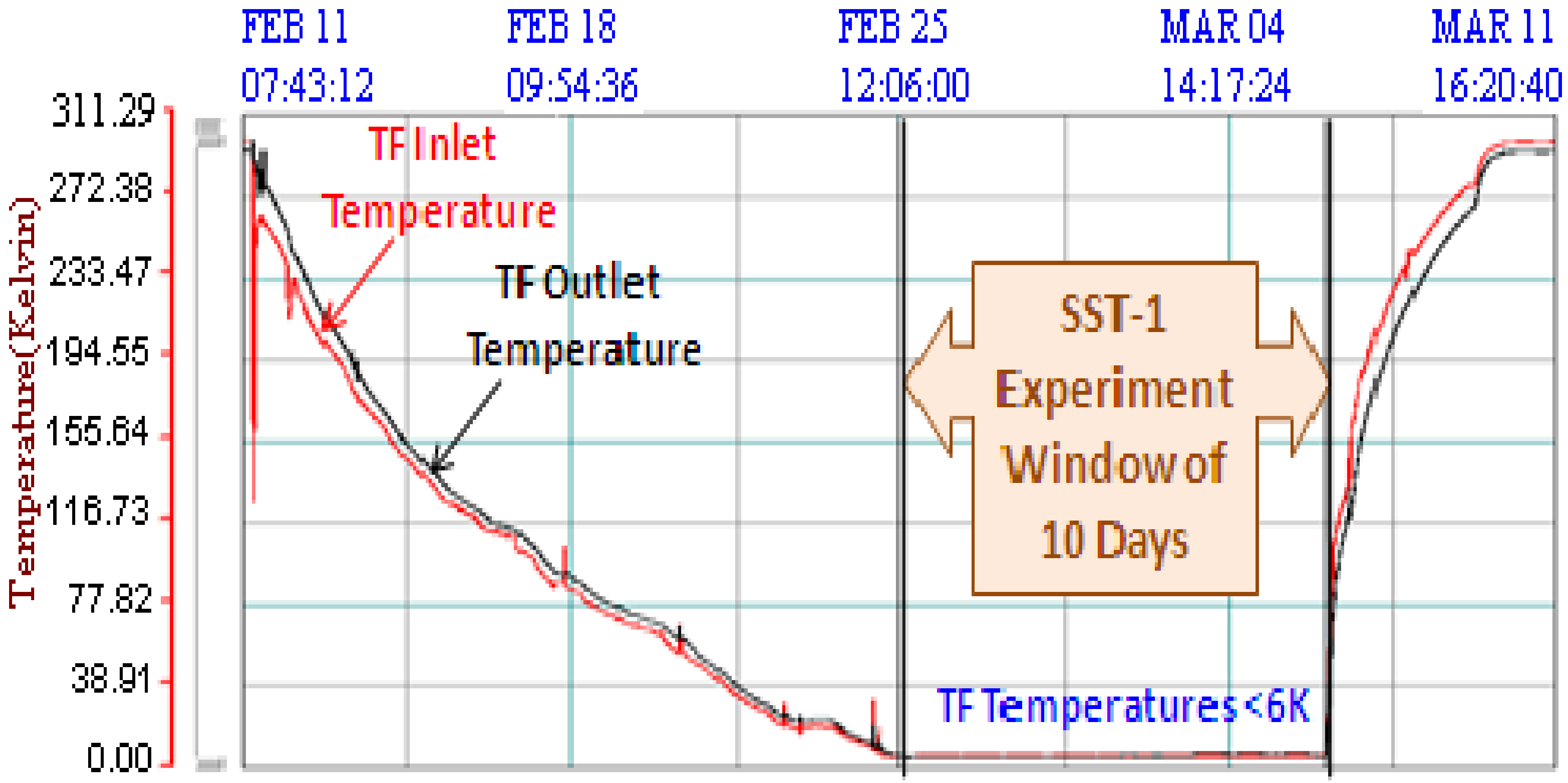


Established appropriate Pre-filling of pressure towards break-down

Established appropriate Glow Discharge Cleaning procedure aimed at reducing impurities

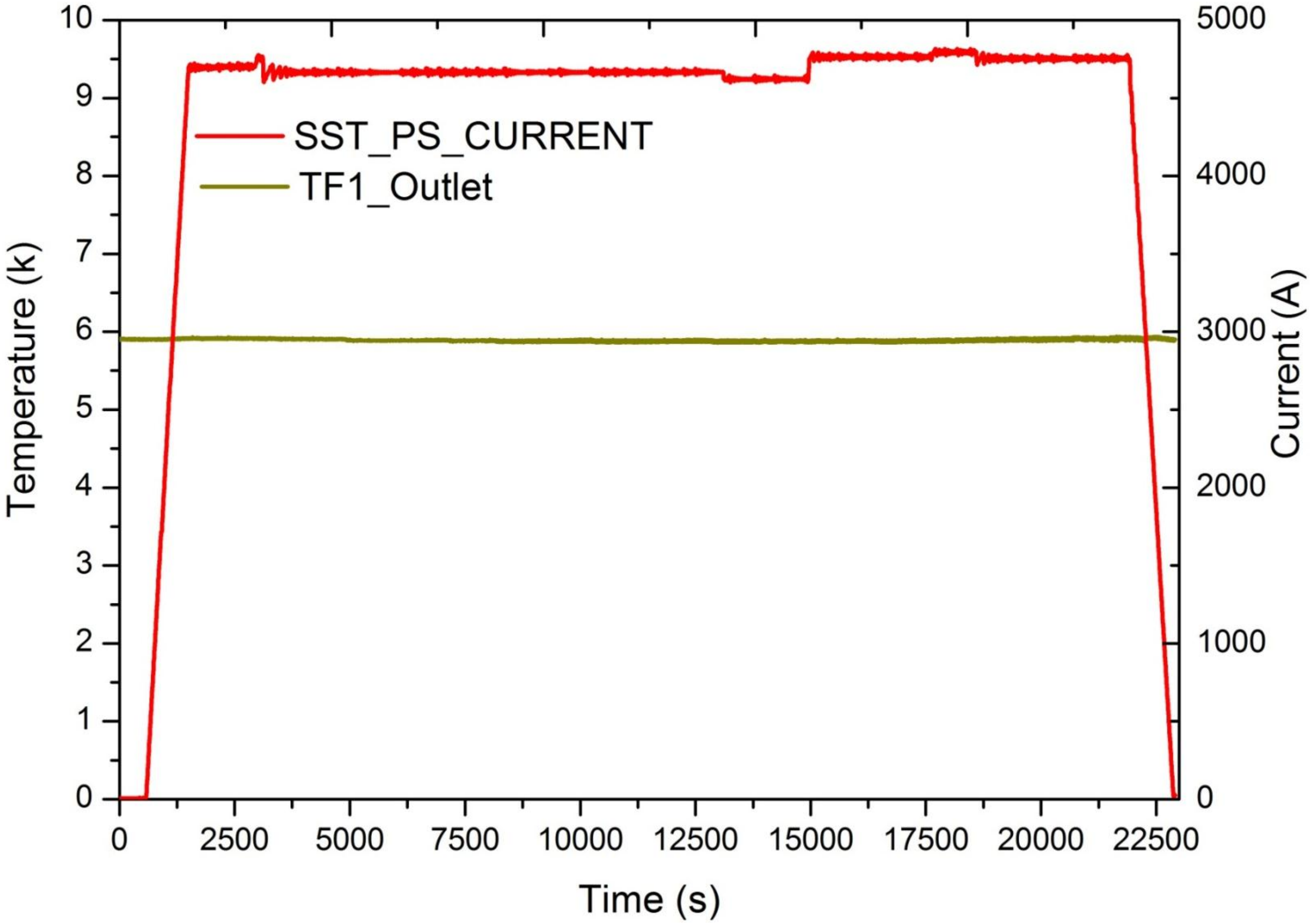


Controlled cooling of TF coils



Established the appropriateness of helium refrigerator towards thermal stress optimized cooling down of the cold mass

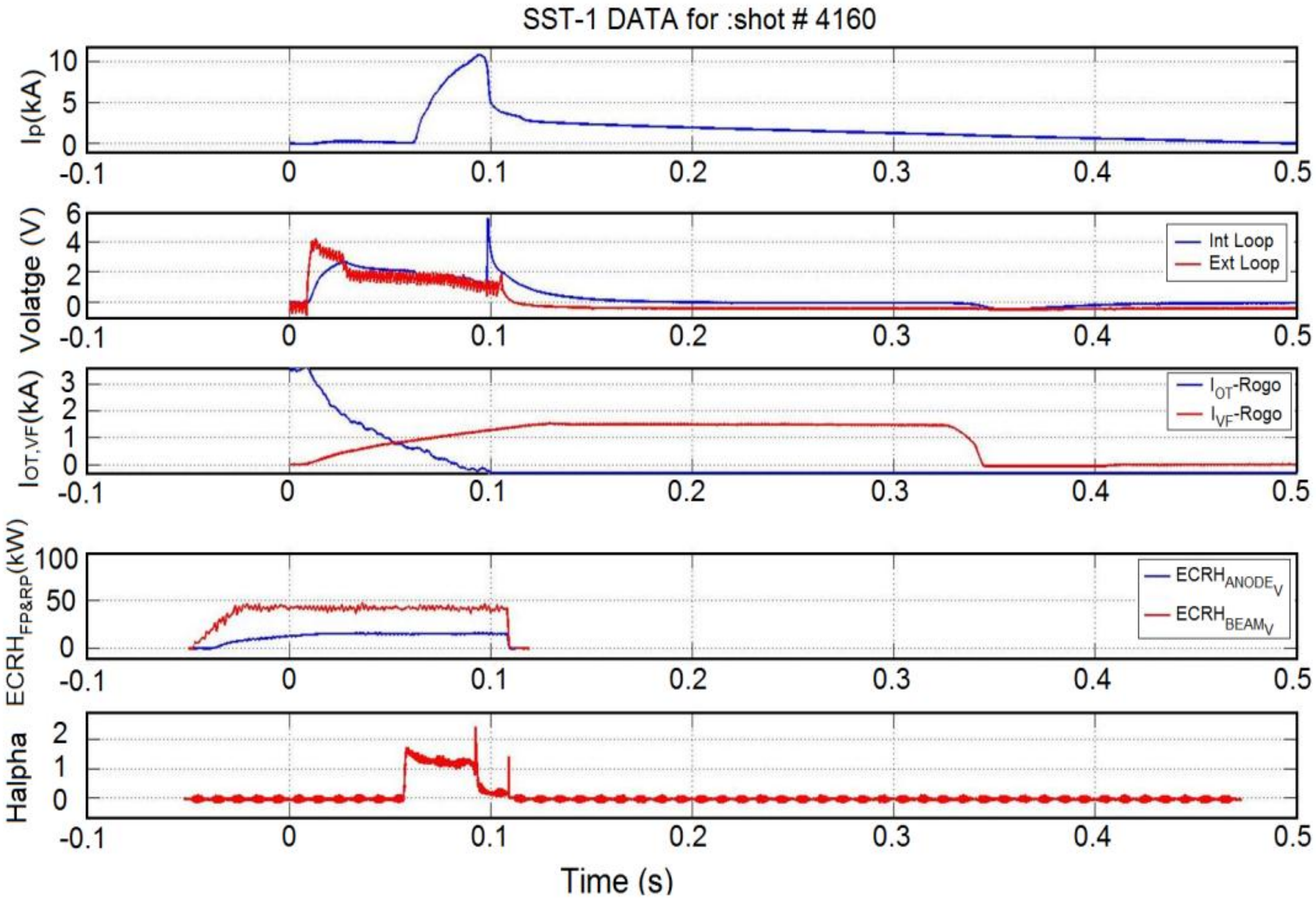
Temperature stability with Longer duration TF current charging



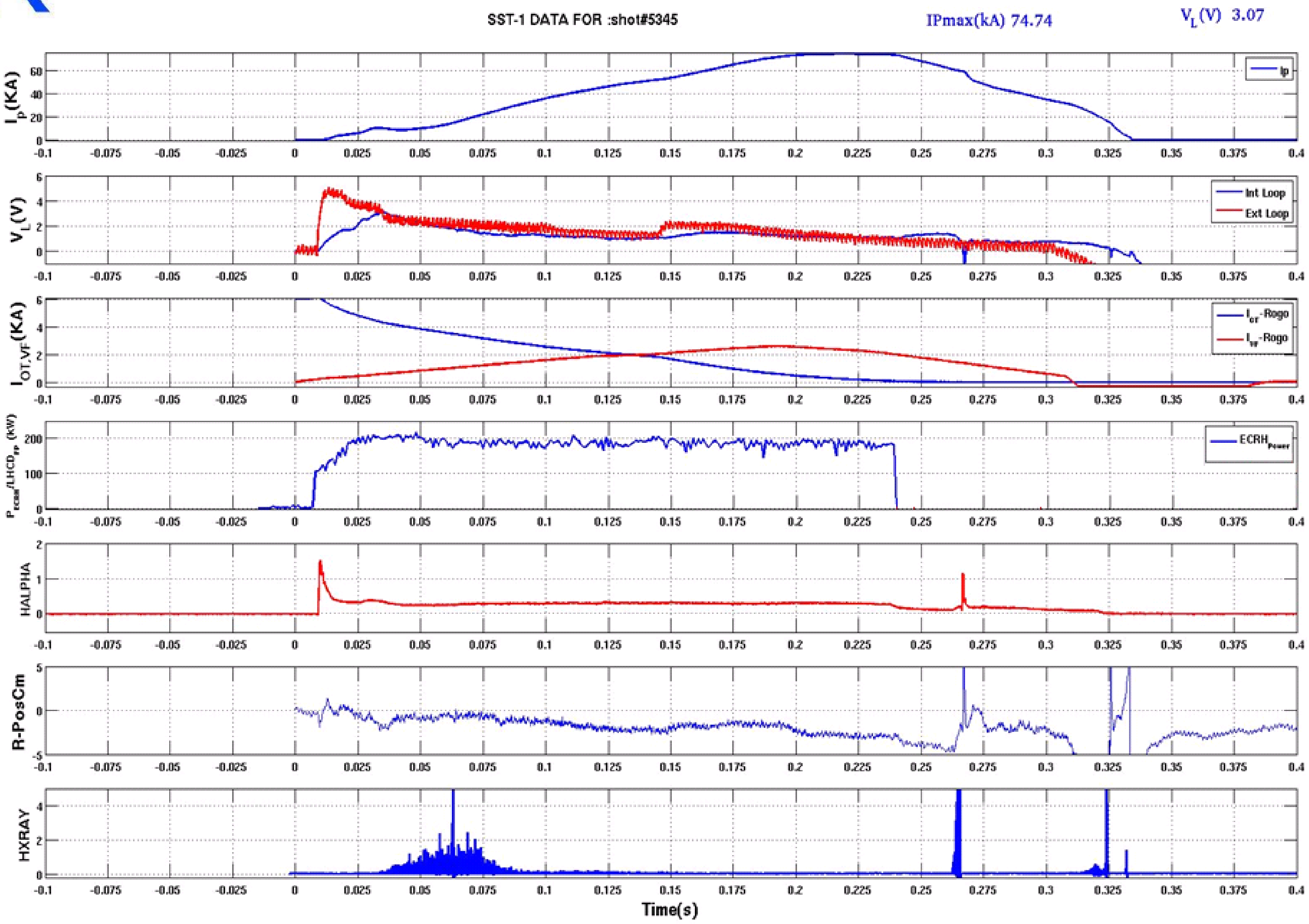
Established long duration Superconducting Magnet operational scenarios

Post `Engineering Validations', a systematic physical Experimental program began: **First Experimental Results**

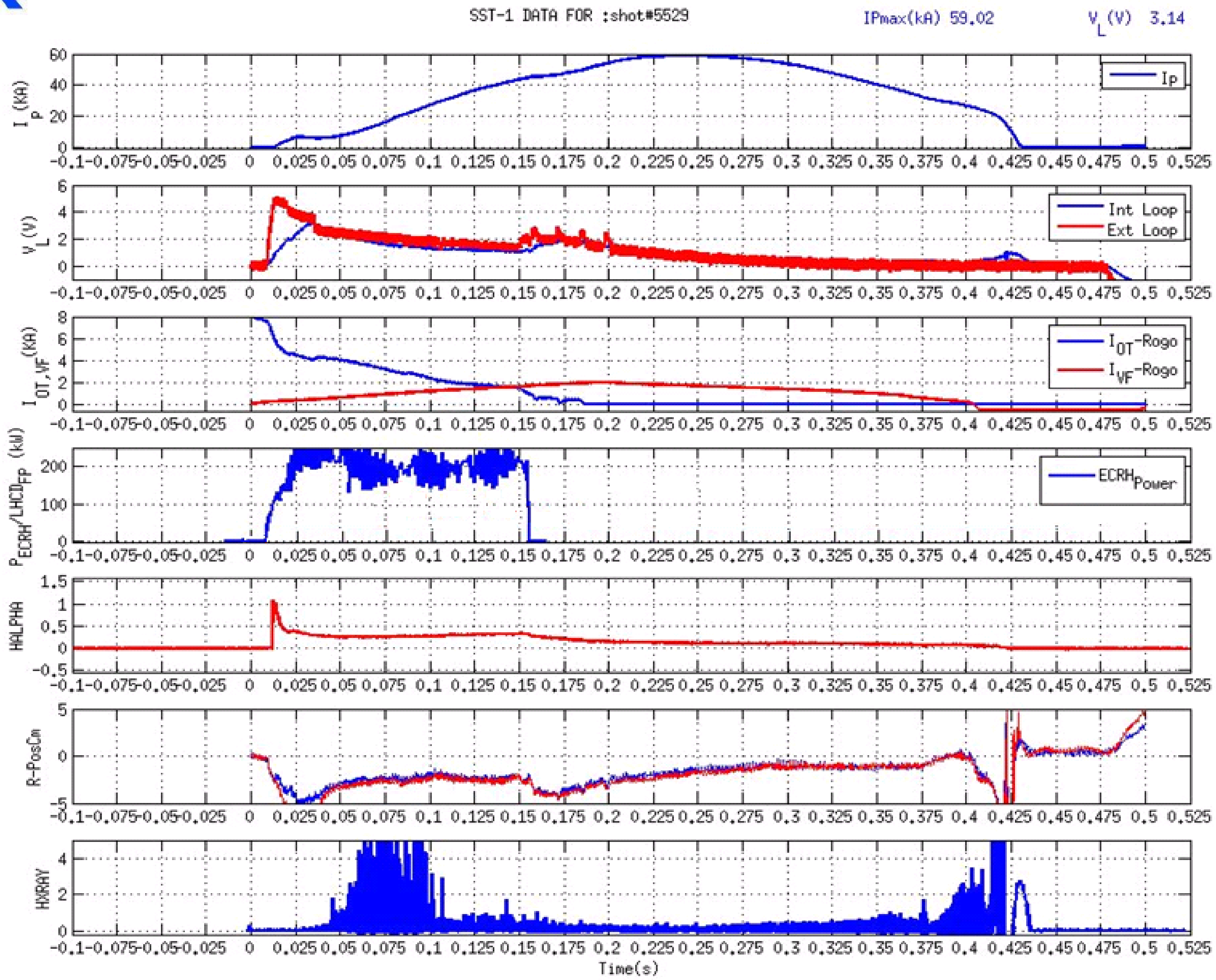
SST-1 first plasma (June 20, 2013)



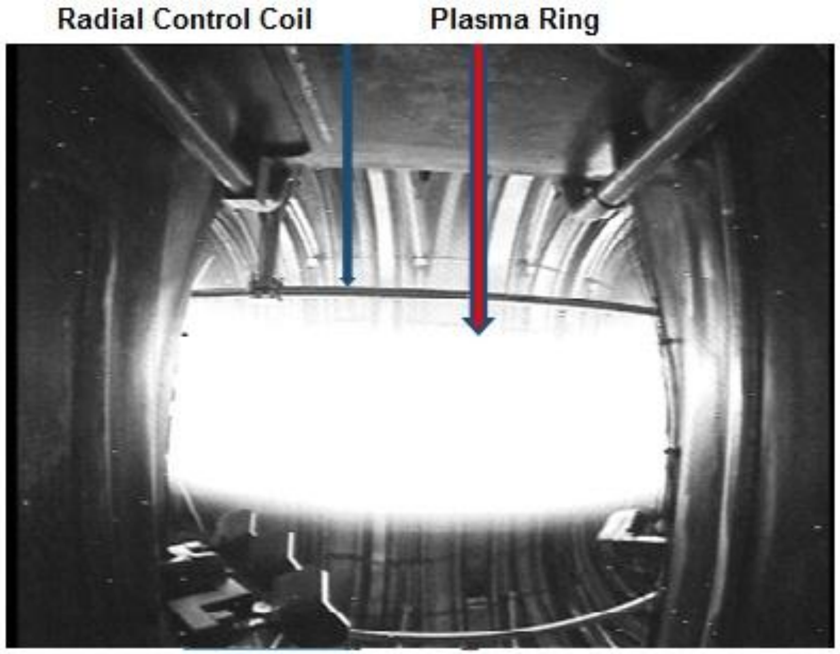
Typical SST-1 discharges at 1.5 T (ECH Pre-ionization)

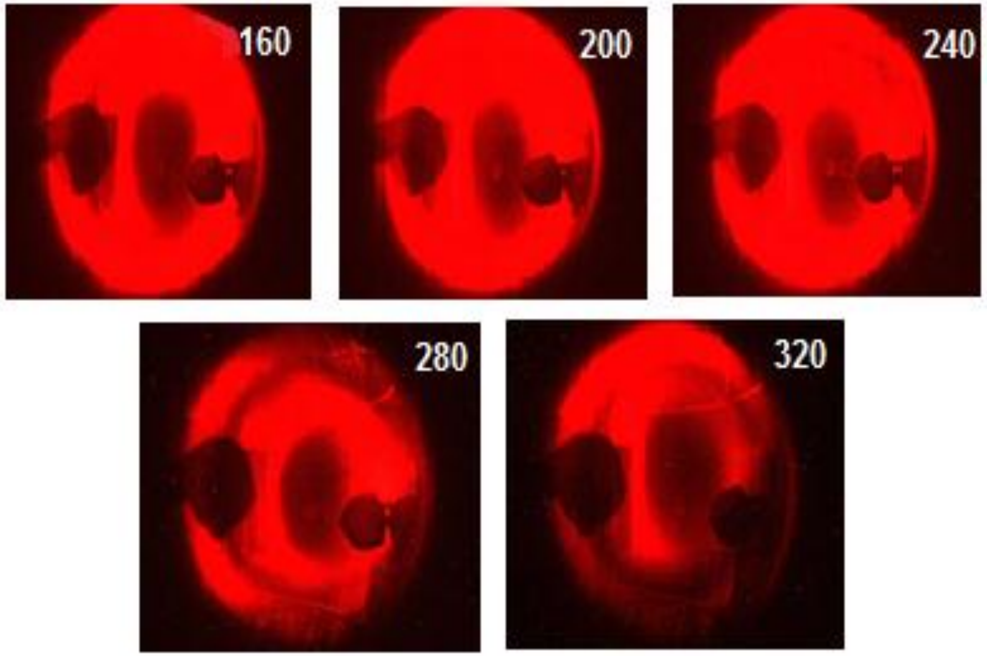


Typical SST-1 discharges (largely Ohmic driven), Density ~ 5-8 x 10^12, Core Temperature ~ 300 eV, E < 0.4 V/m



Imaging of SST-1 Plasma

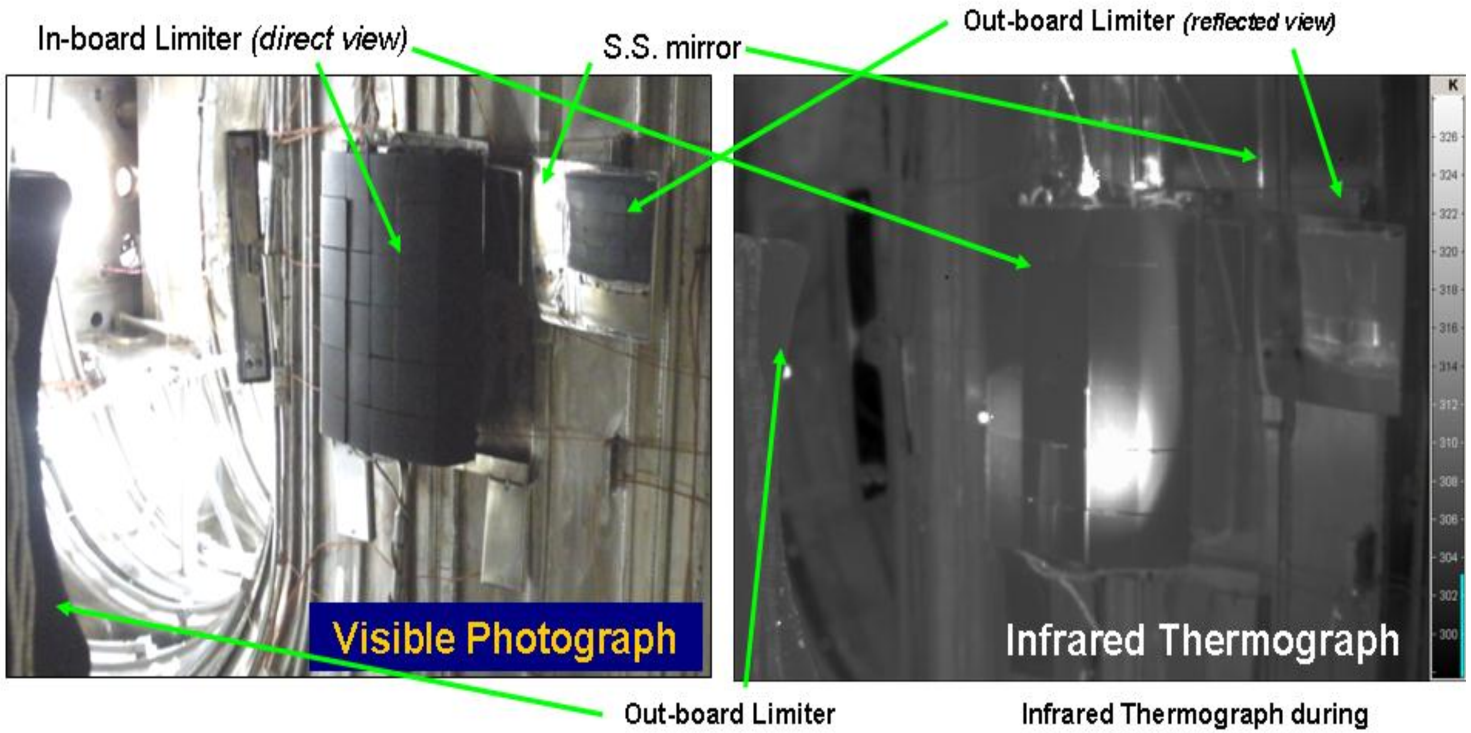




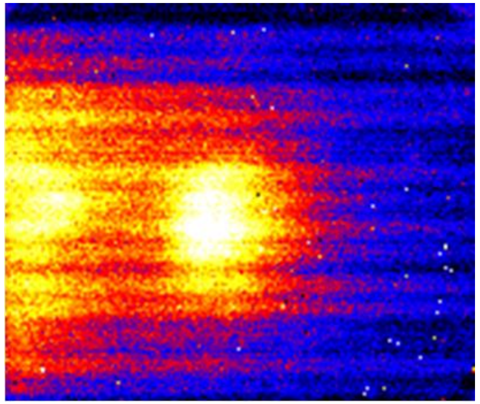
Near Axi-symmetric toroidal plasma ring

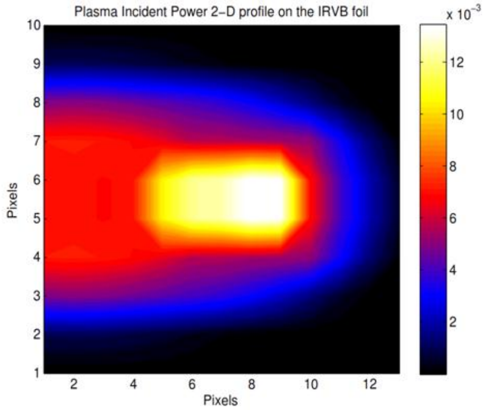
Plasma evolution snap shots (time in msec)

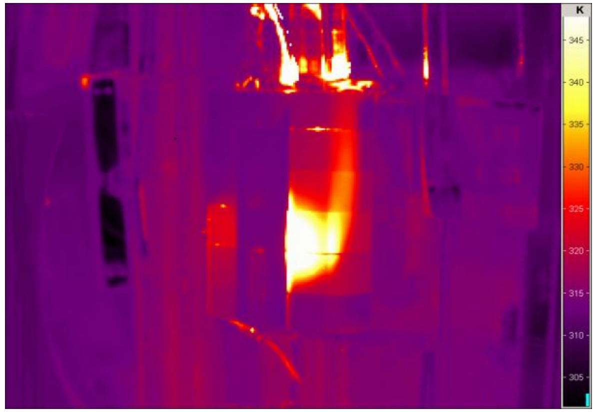
IR imaging of inboard and outboard limiters, Plasma position & evolutions (experimental & simulated)



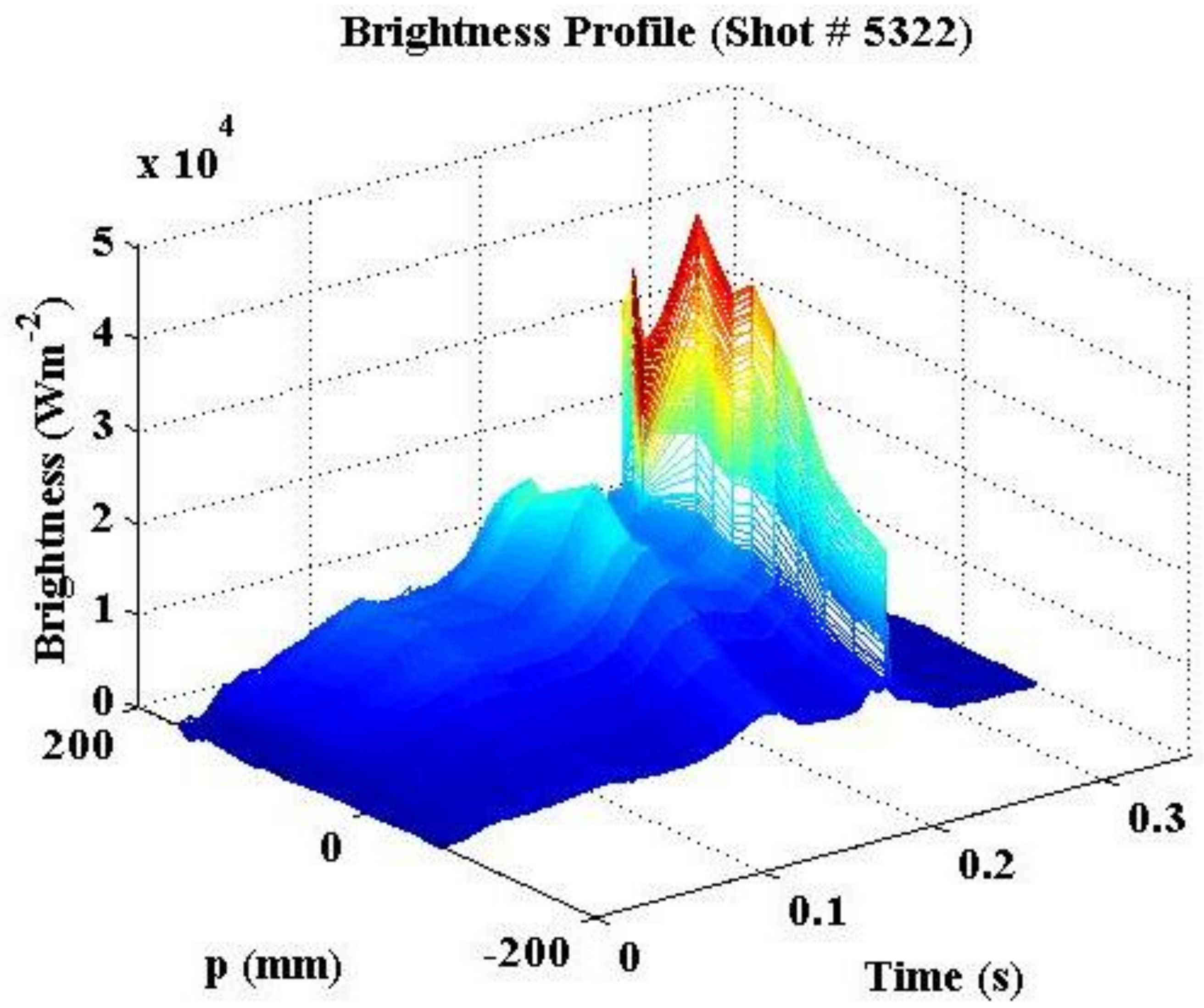
Infrared Thermograph during plasma#5533 at 100ms



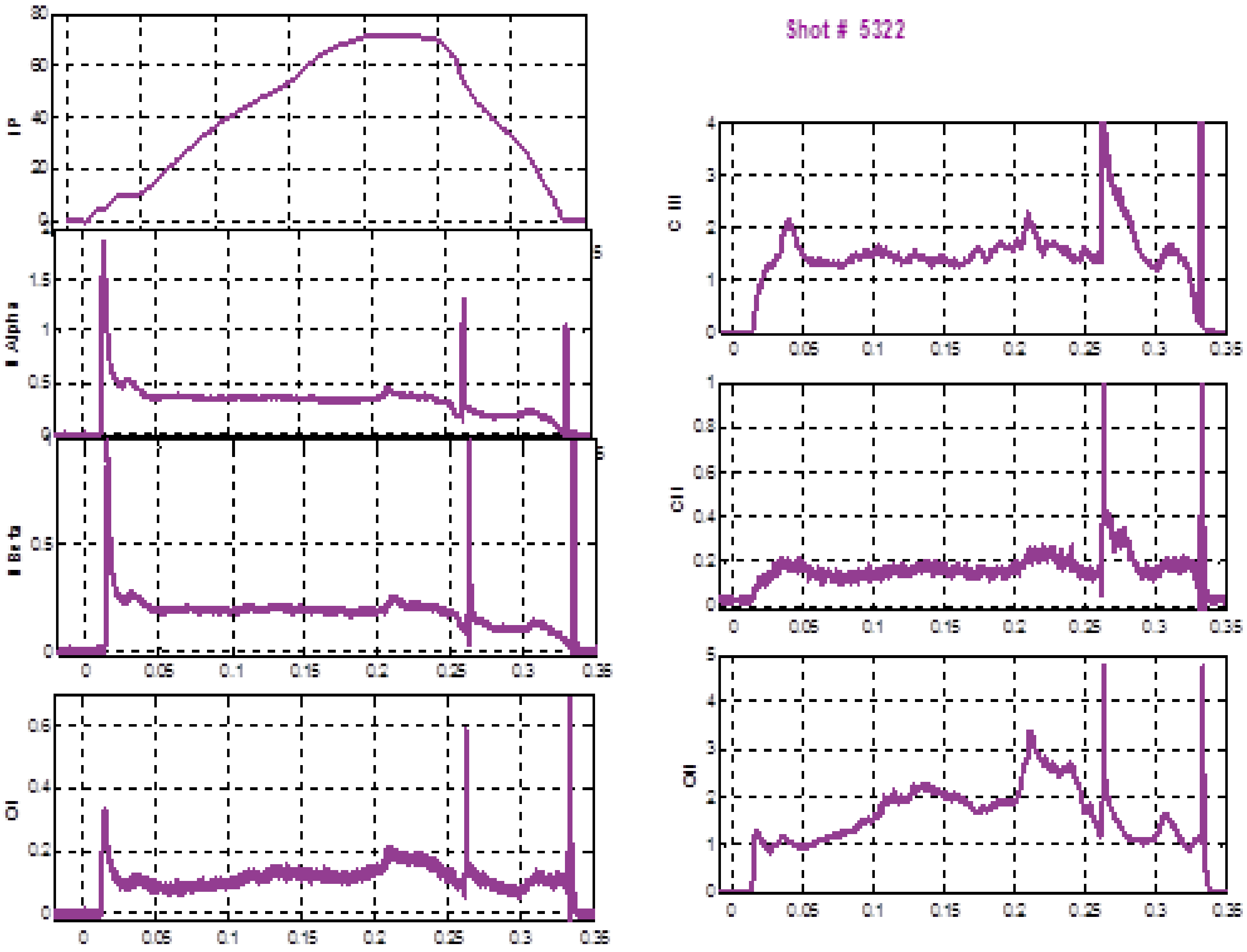




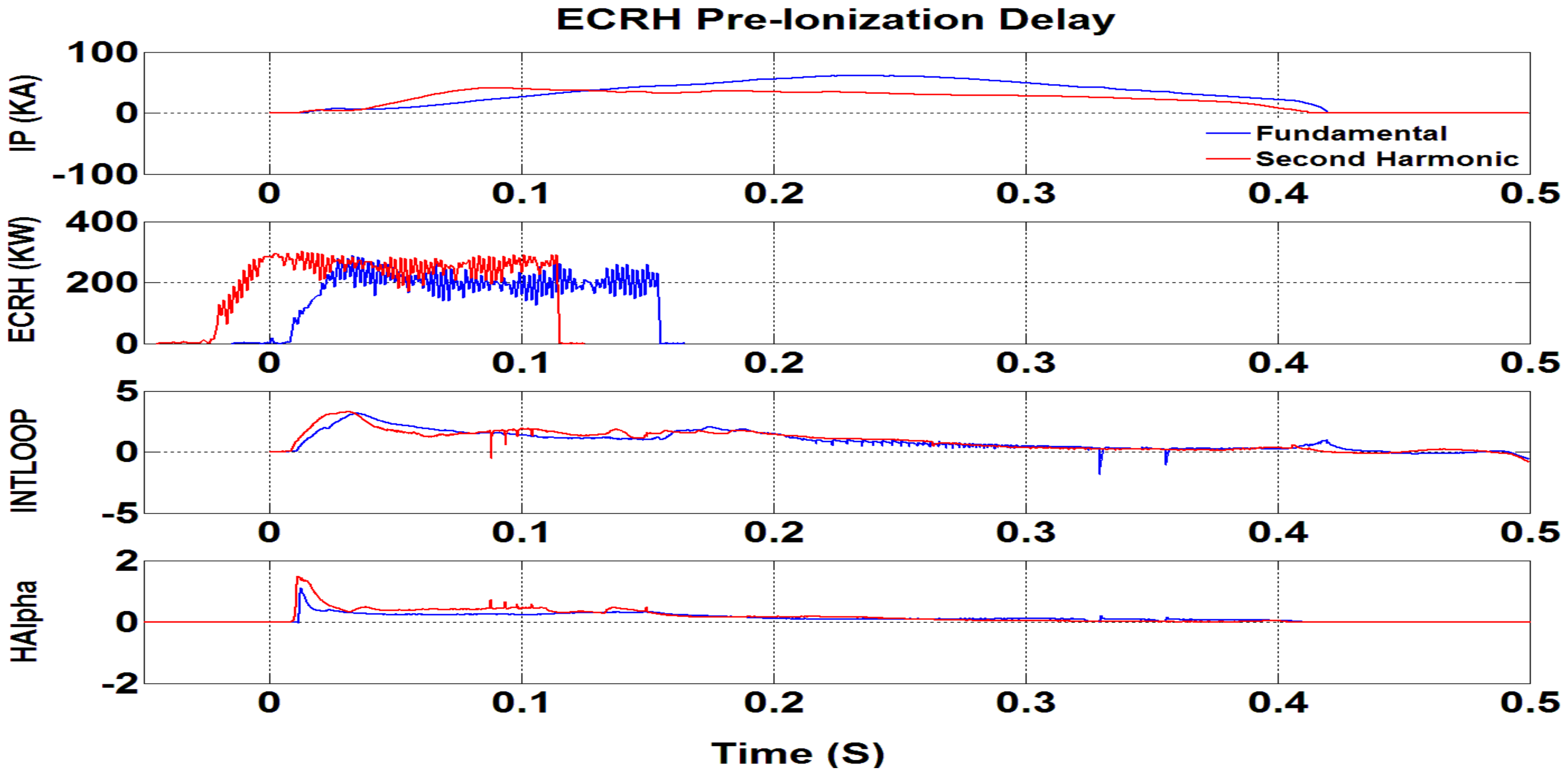
Plasma brightness in time



Carbon impurities evolution signifying plasma-limiter interaction in SST-1

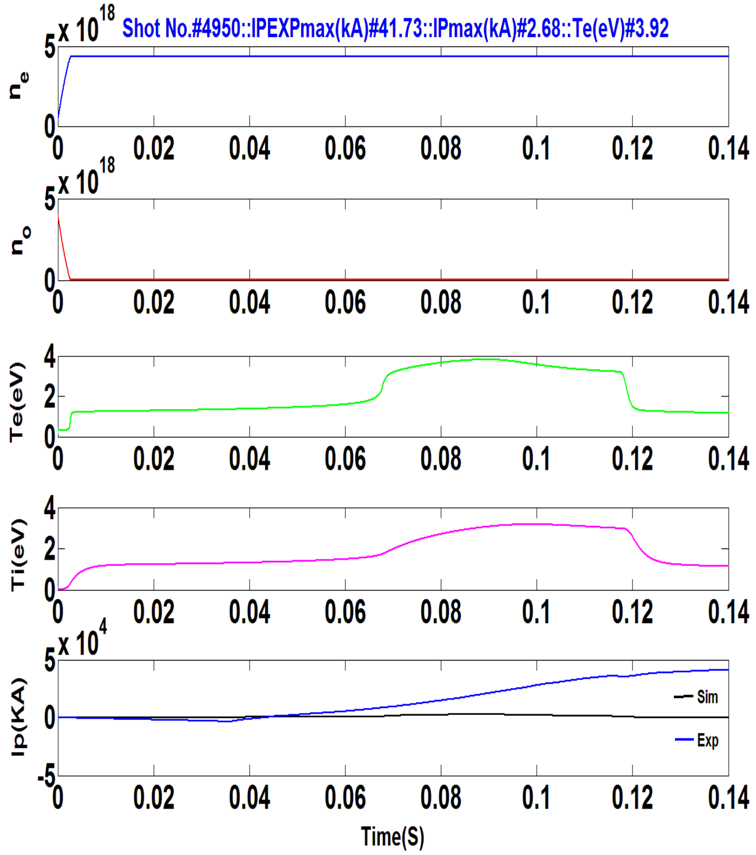


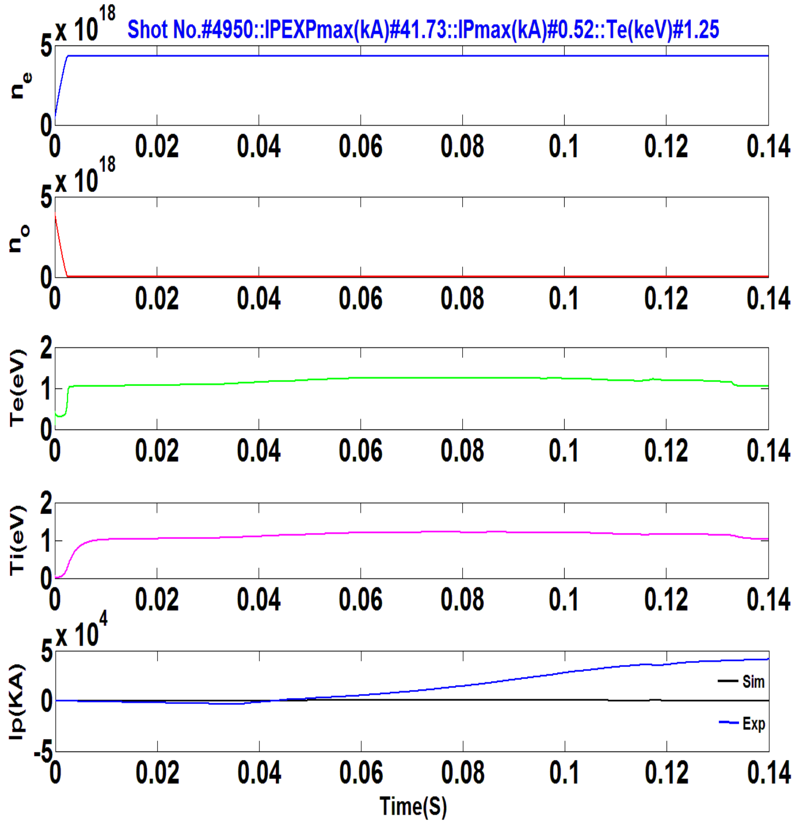
Delay in Plasma discharges with ECH pre-ionized plasmas in fundamental &second harmonics



SST-1 operates successfully with both fundamental and second harmonic ECH pre-ionization with loop voltages ~ 3 V

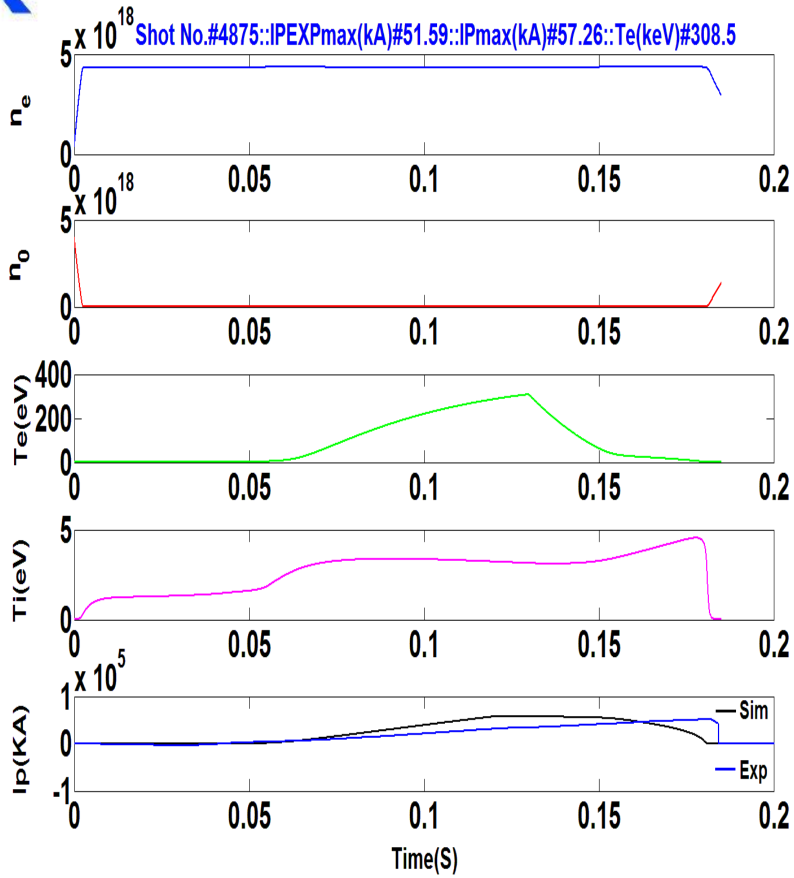
Plasma Start-up: experimental results vs simulated

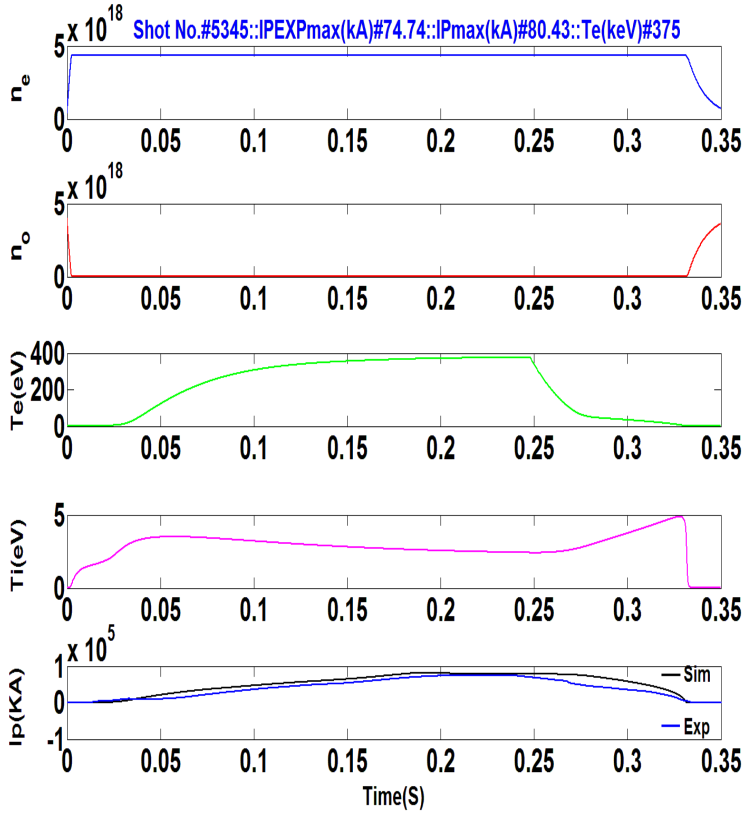




P_{ECRH} Threshold when P_{ECRH} < 200kW Field Error effect when B_{err} > 0.5mT

Plasma Start-up: experimental results vs simulated

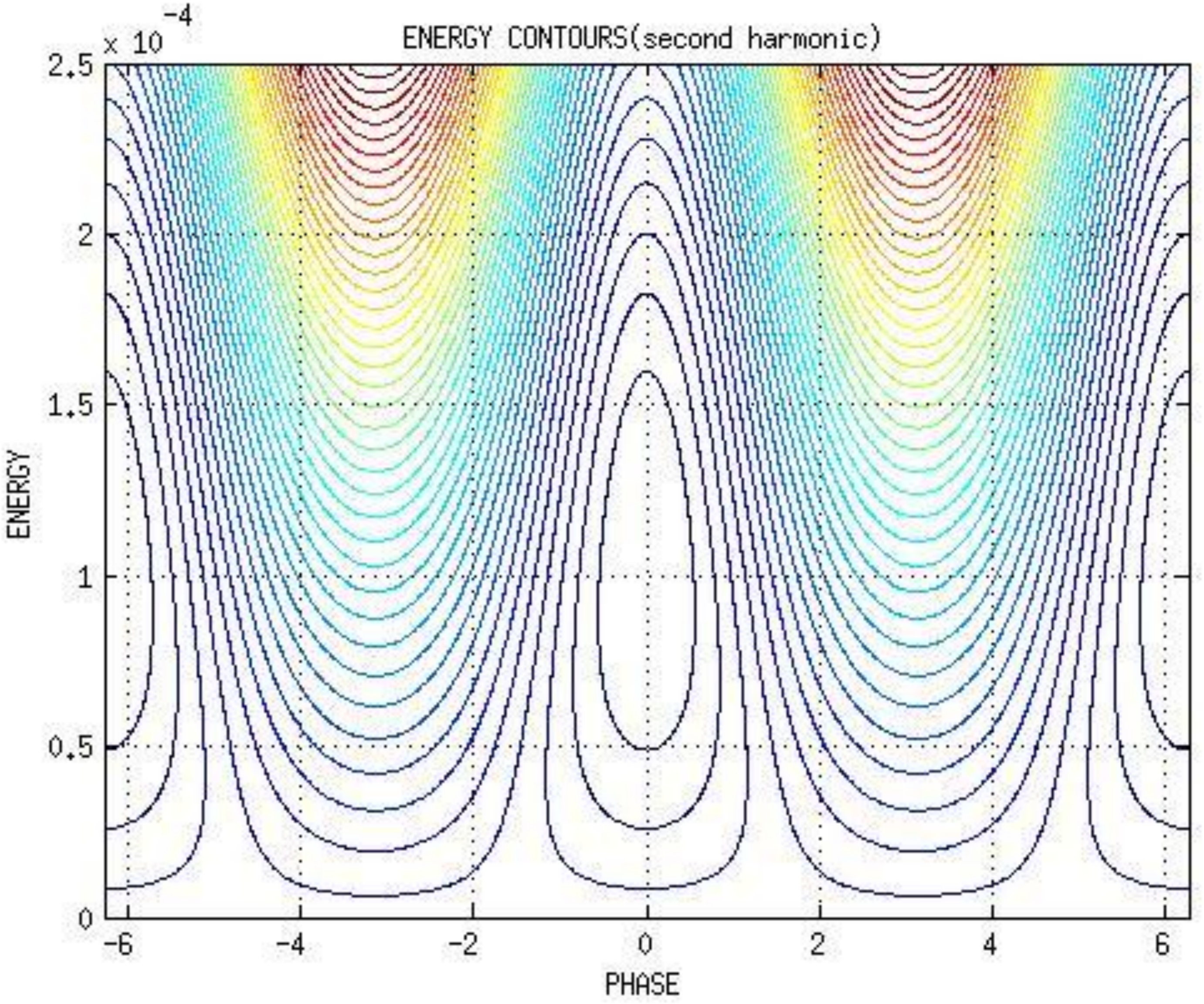




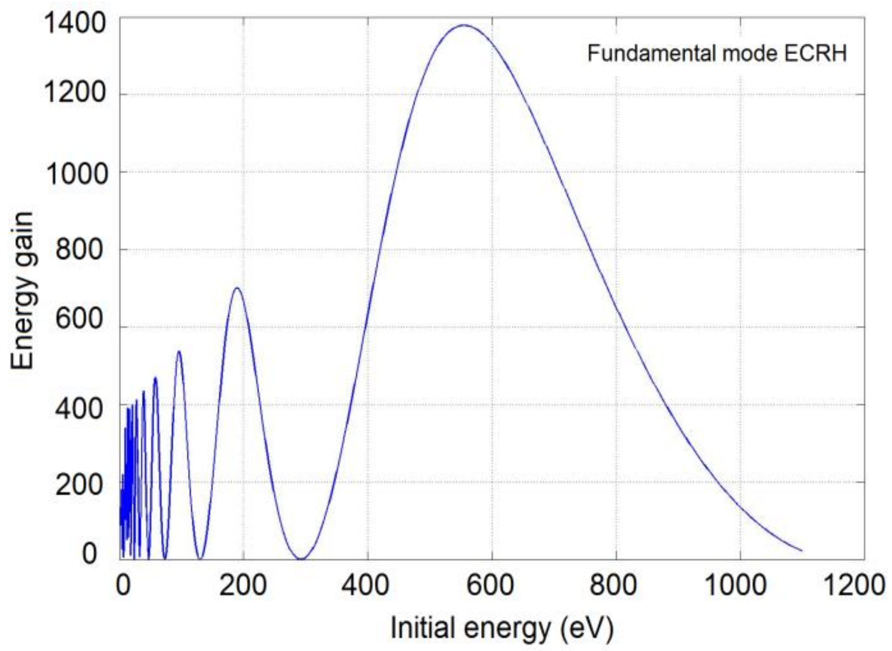
Validated result for second harmonic ECH

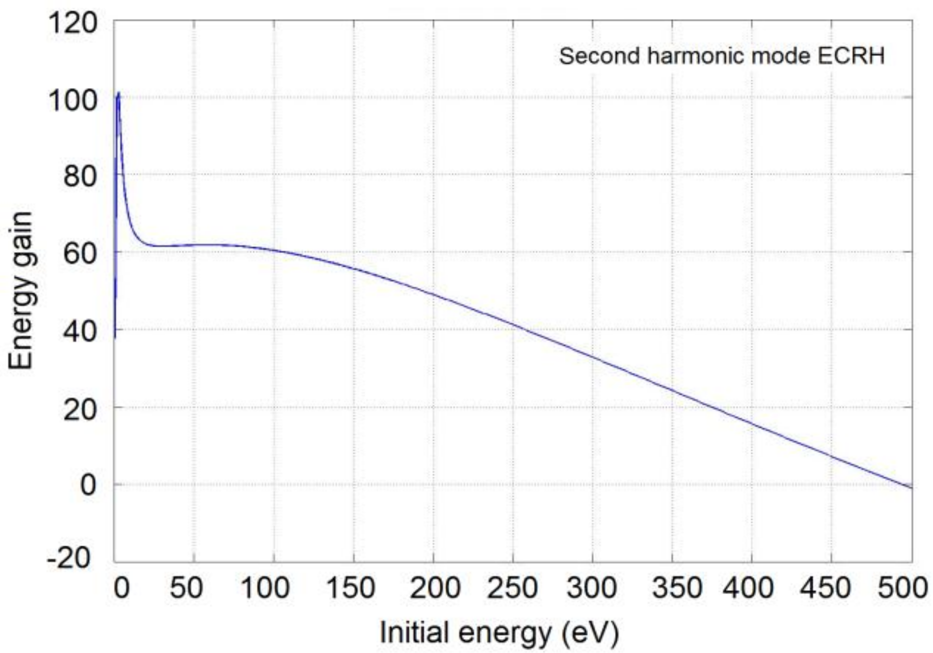
Validated result for fundamental ECH

Electron dynamics in SST-1 ECH MW field



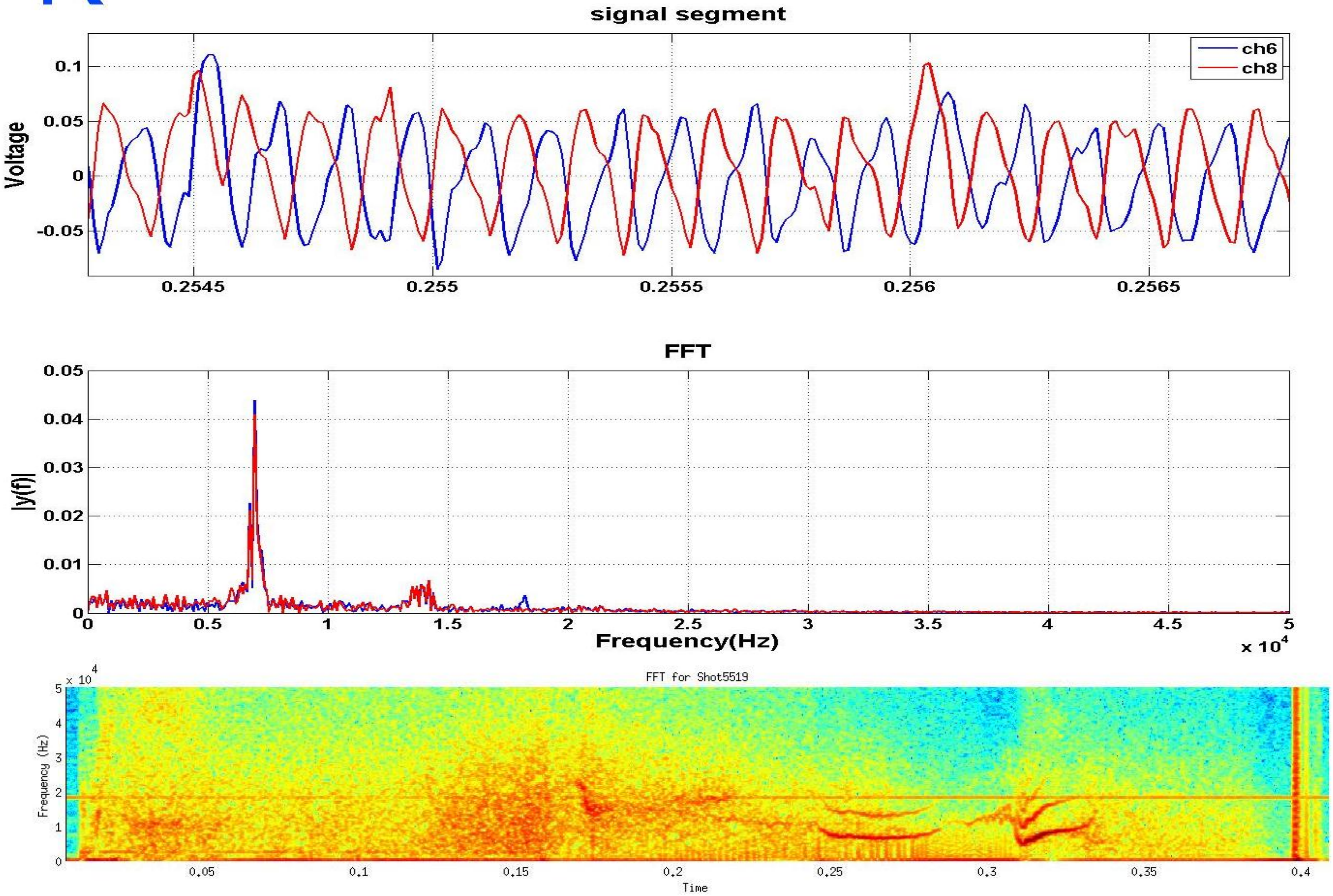
Energy gain of electrons in fundamental and second harmonics assisted ECH break-down



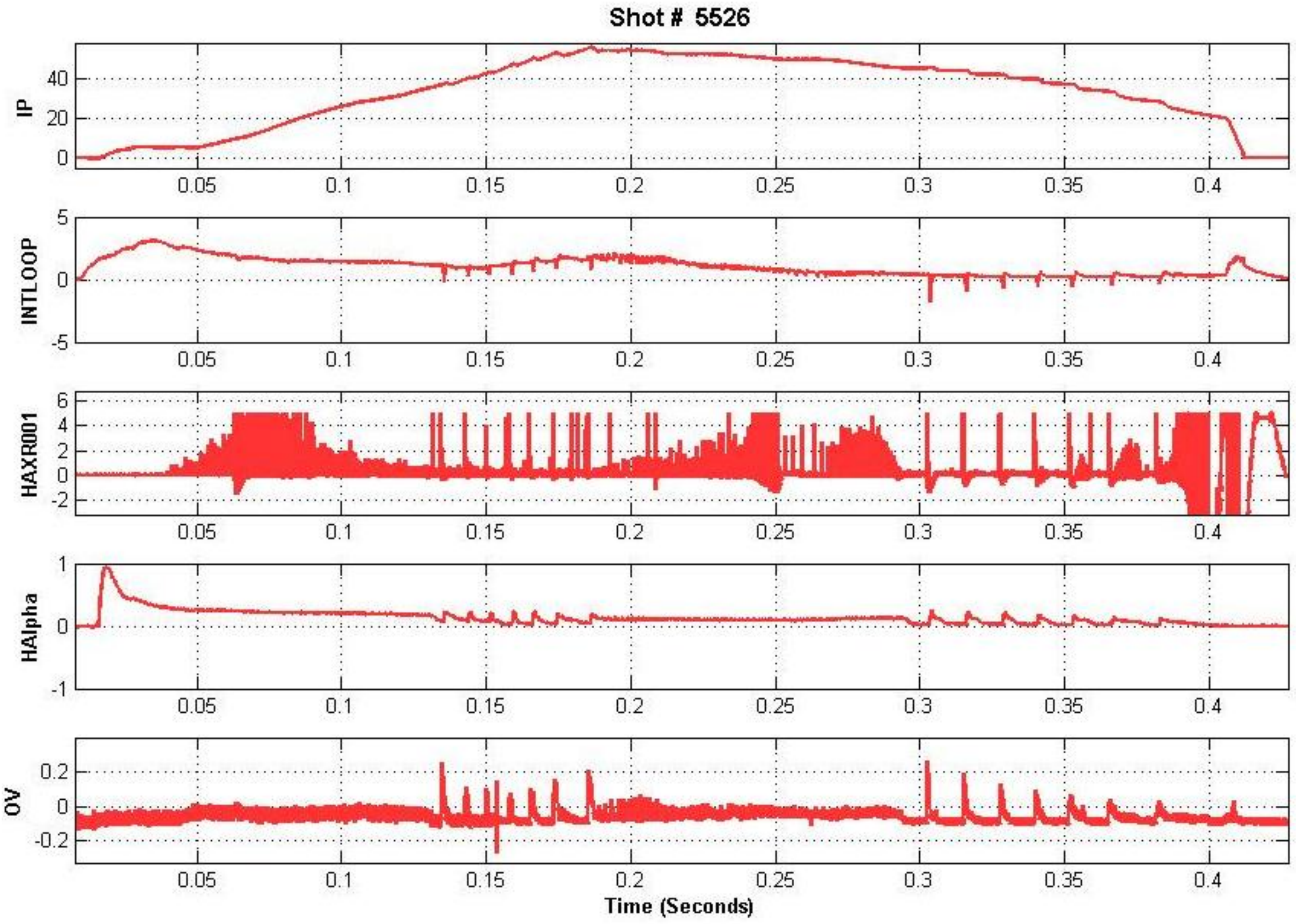


These simulations explains the delay in the break down

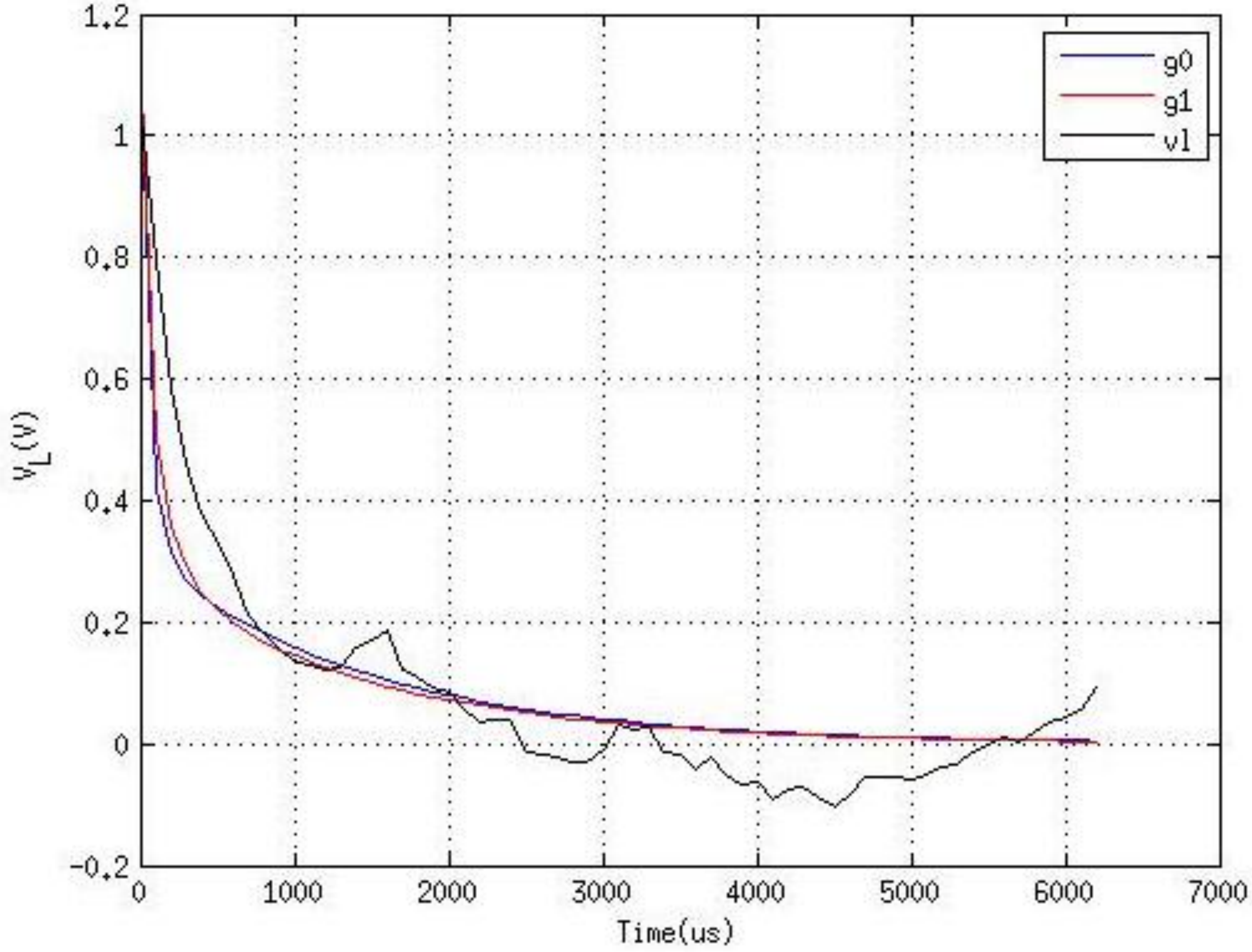
MHD signatures in SST-1 discharges



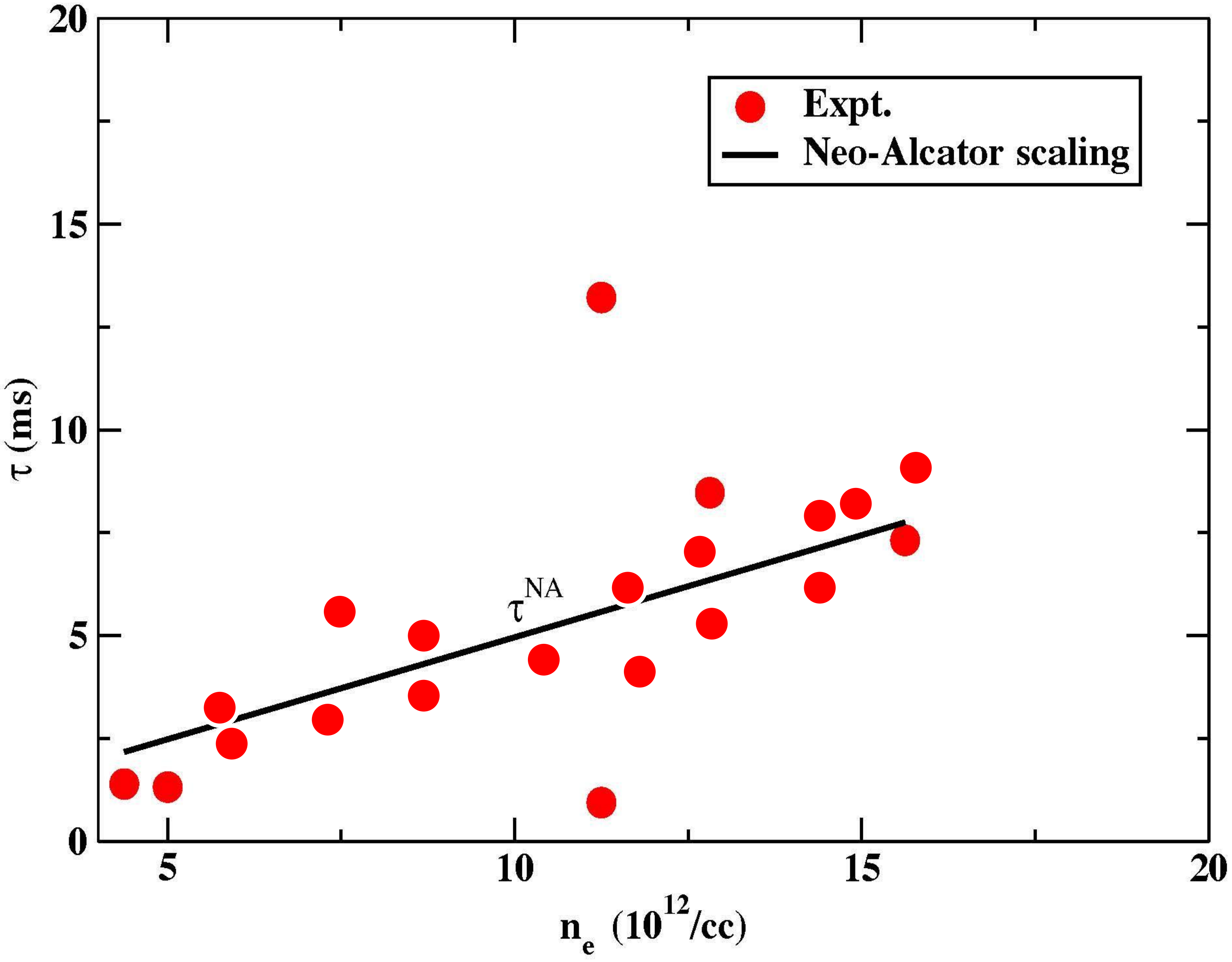
Some discharges showing Toroidal Plasma-Supra-thermal electron interaction



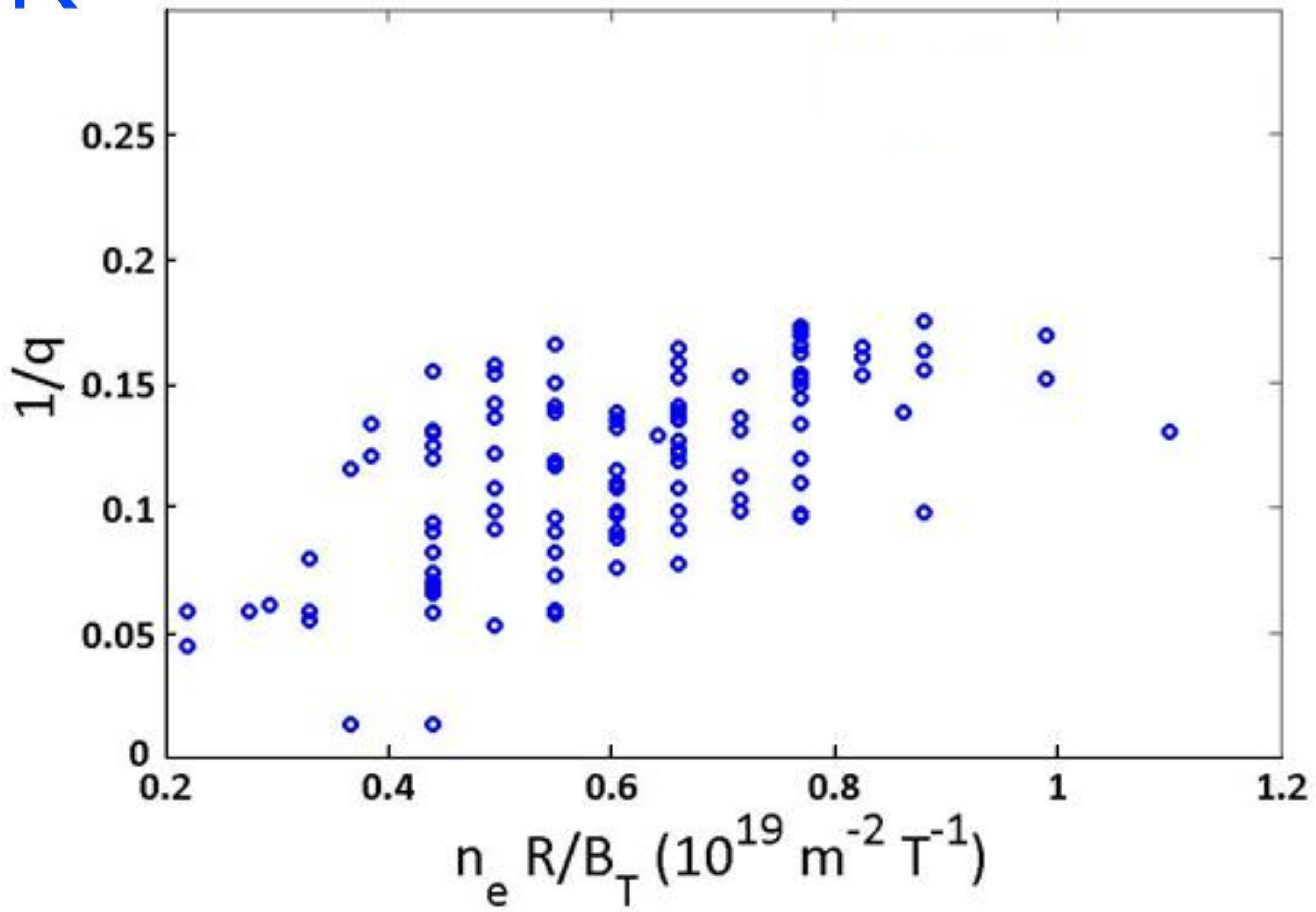
Experimental V_loop with simulated (electron –supra-thermal beam interaction



Confinement Scaling in SST-1



The Hugill in SST-1 in early discharges



Near-term experimental plan (2014-2015)

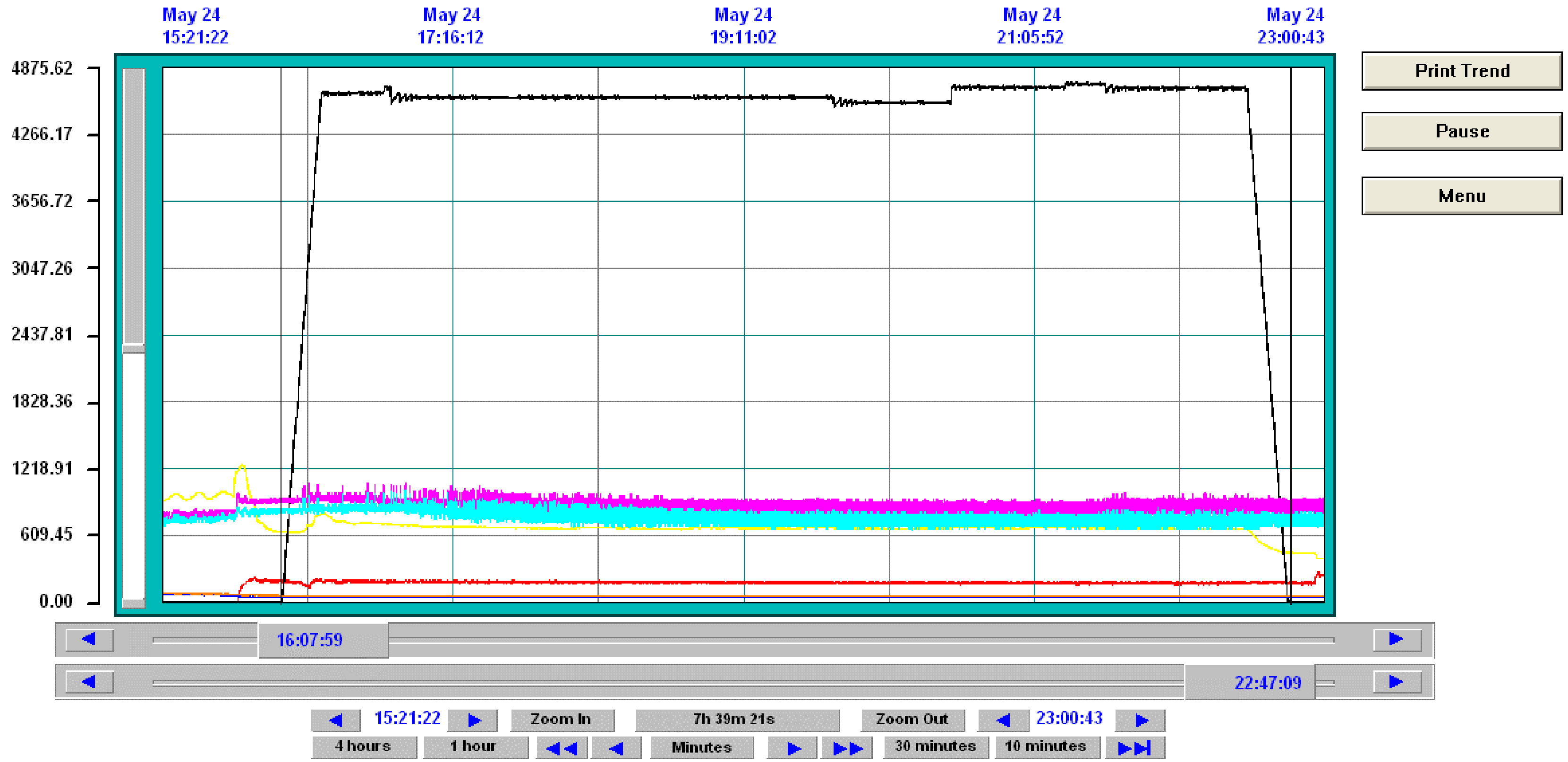
	Oct 2013-Sep 2014	Mar 2014-Dec 2015
Experimental Goals	• First plasma start-up • Fundamental & 2nd Harmonic ECH pre-ionization	• Startup stabilization • LHCD coupling • Elongated plasma
Target Operation Parameters	• B_T ~ 0.75 T/1.5 T • I_P > 0.05MA • t_P > 0.1 s • Te > 0.3 keV • Ti ~ 0 keV • Flux ~ 0.2 Wb • Shape ~ Circular • Gas : H_2	• B_T ~ 1.5 T • I_P > 0.1 MA • t_P > 1s • Te > 0.3 keV • Ti ~ 0.3 keV • Flux ~ 0.4 Wb • Shape ~ Circular & slight elongation • Gas : $H_{2,}$
PFC & Wall conditioning	• Inboard limiter (movable) • Gas puff	• Inboard limiter & some FW • Wall conditioning
Magnetic control	• TF : 0.75/1.5 T	• TF : up to 1.5 T
Heating operation	• ECH(42G): 0.5MW, 0.5s • ICRF: 0.2 MW, 0.2 s • LHCD: 0.2 MW, 0.2 s	• ECH(42G): 0.5MW, 0.5s • ICRF: 0.2 MW, 0.2 s • LHCD: 0.2 MW, 0.2 s
Diagnostics	• Visual Imaging • Hα & O2,C impurity lines • MW • ECE • Reflectometry • EM diagnostics • Bolometry • Soft X-ray Largely Achieved	• Visual Imaging • Hα & O2,C impurity lines • MW • ECE • Reflectometry • EM diagnostics • Bolometry • Soft X-ray • FIR • TS Campaign due: Feb 2015

Near Future Physics Studies would focus on

- The ECH assisted discharges feasible with $E < 0.4$ V/m.
- Carrying out experiments with high aspect ratio toroidal plasmas in both circular & elongated configurations.
- Exploring regimes in ohmic plasma (and possible LHCD coupled plasma) interacting with supra-thermal electron beams.
- ECCD regimes in SST-1 plasmas.

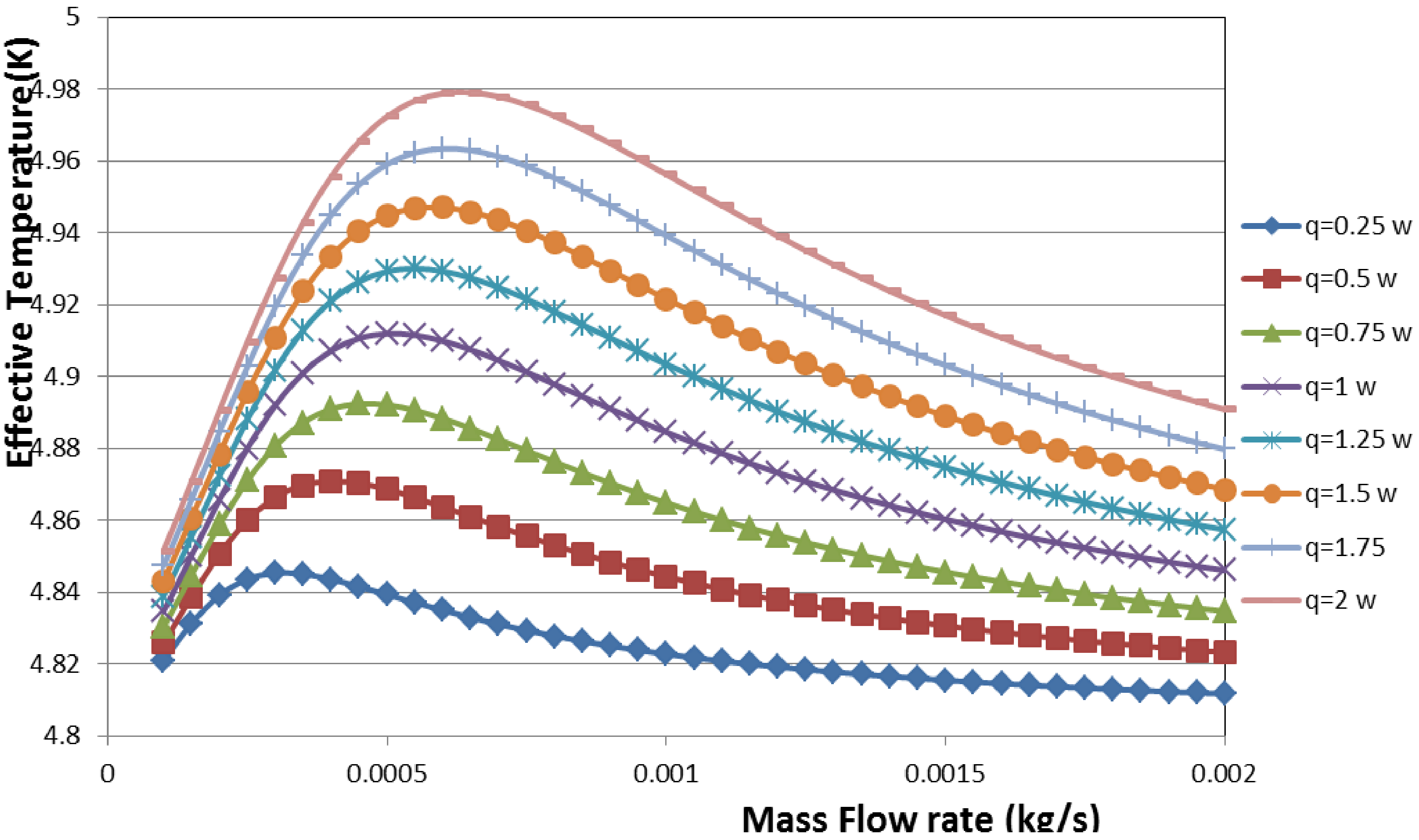
New & Unique Technology attributes in SST-1, thus far

Two phase cooled SST-1 TF operations (the only Tokamak to operate)



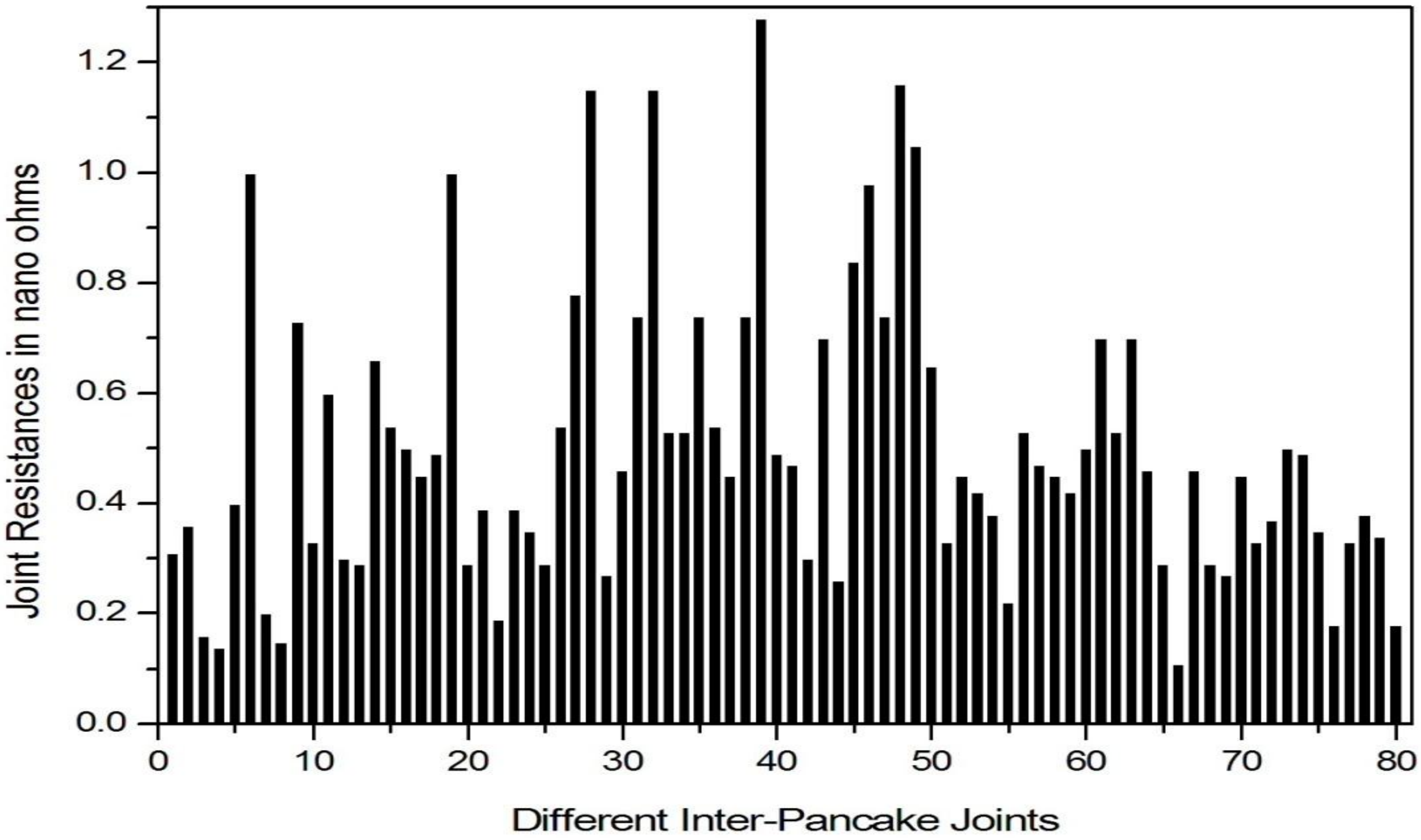
Tag Variable	Max	Min	Average	Max Range	Min Range	Value at Left Slide	Value at Right Slide	Rate (K/Hr.)
TF_N_T2	30.20	18.50	25.68	325.00	4.00	24.60	18.55	-0.909
LHE_HDR_L	21.40	12.80	18.18	1016.00	0.00	19.10	18.30	-0.120
TF_N_T2	30.20	18.50	25.68	325.00	4.00	24.60	18.55	-0.909
CFS_CURRENT	4761.00	1.00	4447.99	10000.00	0.00	2.50	1.00	-0.225
TF_N_T4	5.60	5.30	5.49	325.00	4.00	5.53	5.43	-0.015
TF_N_FT	0.76	0.53	0.61	7.00	0.00	0.65	0.59	-0.009
TF_P_FT	0.72	0.46	0.54	7.00	0.00	0.59	0.51	-0.013
TF_P_T4	5.90	5.60	5.75	325.00	4.00	5.85	5.75	-0.015

Effective Temperature variance at different heat load & mass flow

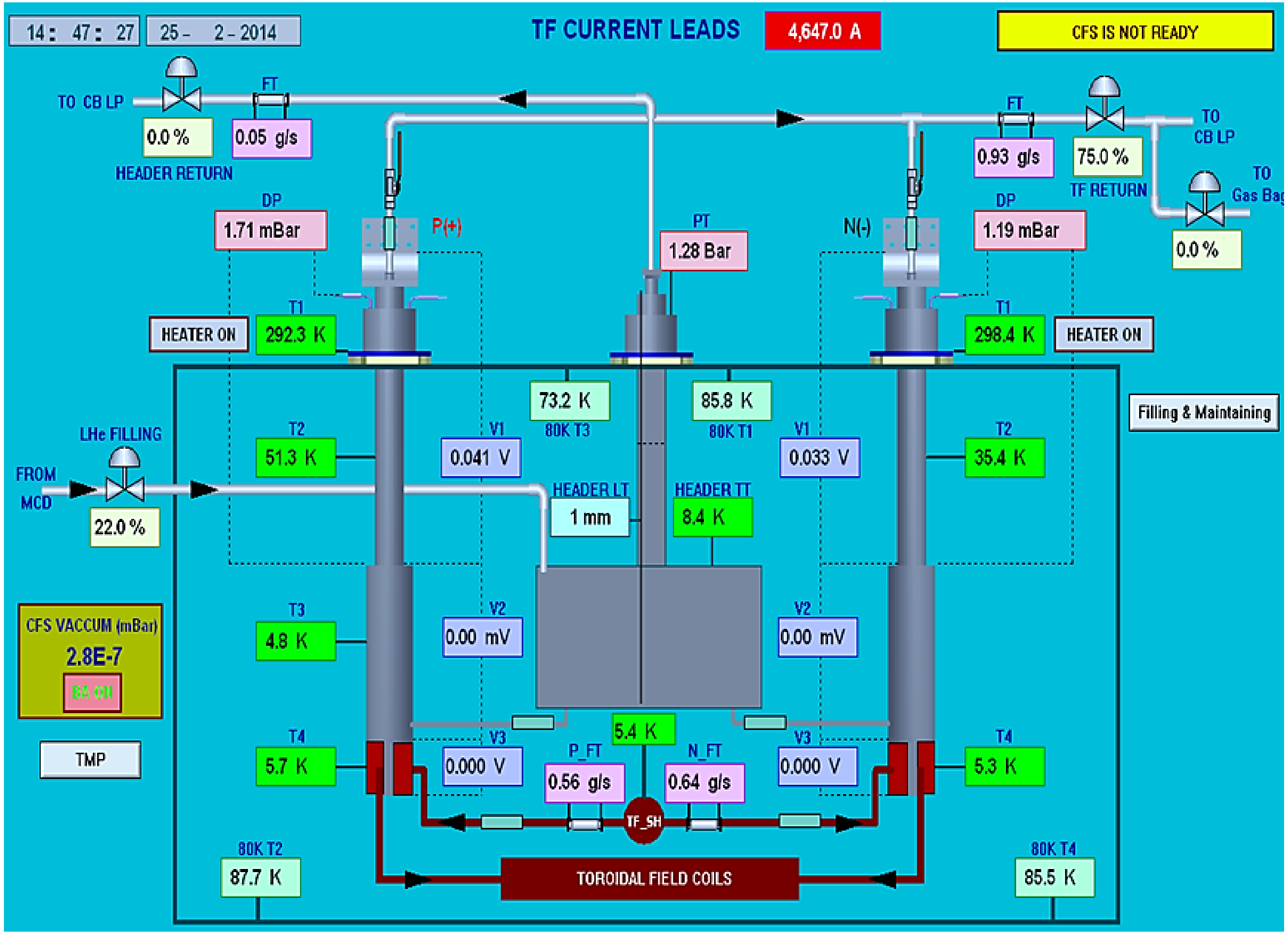


A probable new parameter regime

Sub n-ohm joint resistance in SST-1 Winding packs



Cold He Gas Cooled Current Leads in 1.5 T operation

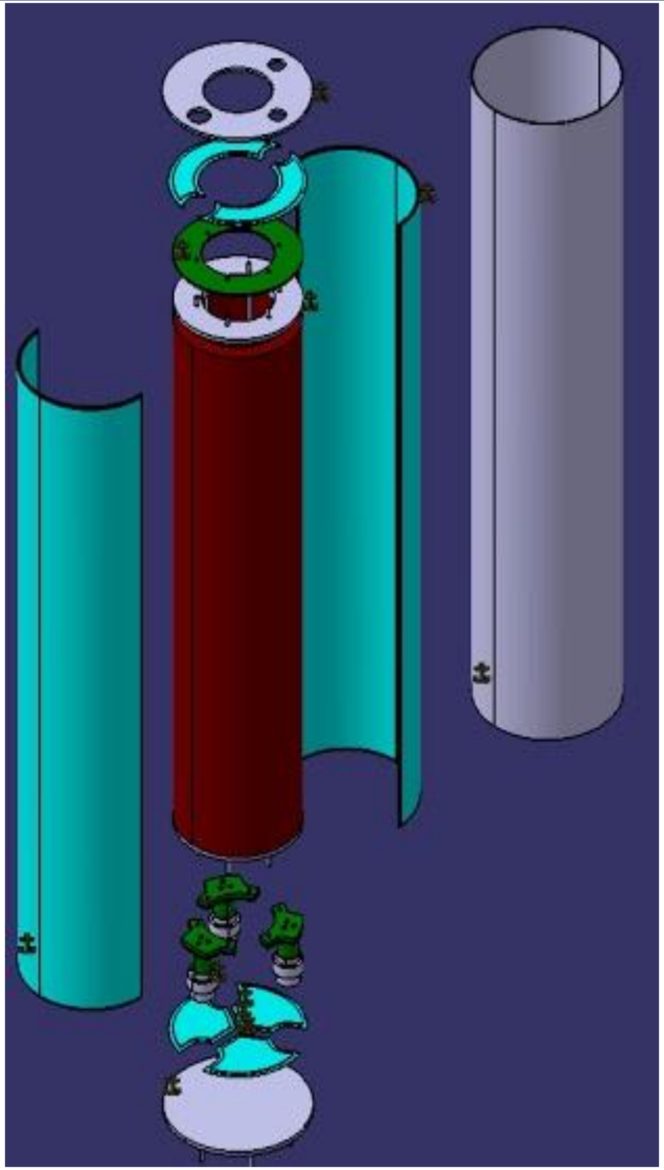


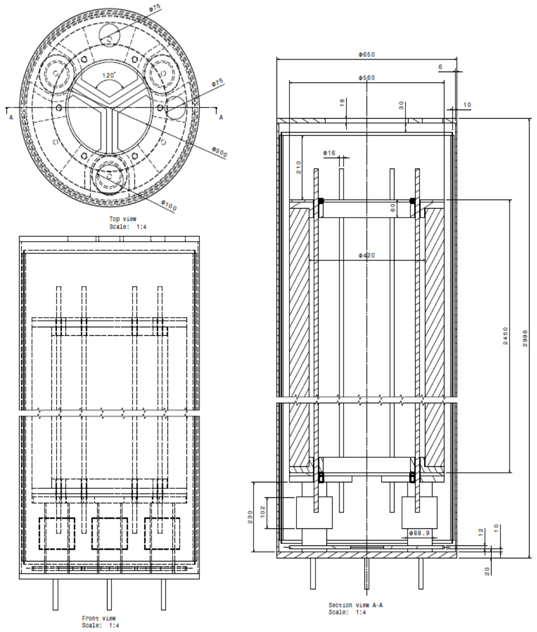
Near future Up-gradation in SST-1

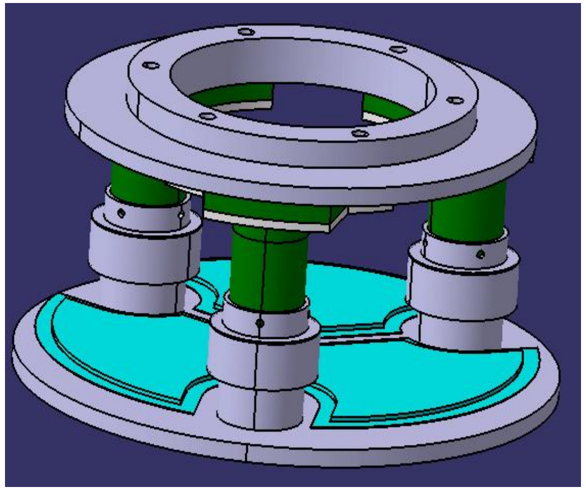
- First Wall Components getting installed
- The central solenoid is getting superconducting
- LHCD take-over experiments have been initiated
- NBI and other heating systems would get integrated soon.

Prototyping & ground Assembly of PFCs of SST-1

Nb_3Sn based Central Solenoid (CS) Development







Thanking You All

Jai Hind

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