QUEST Non-Inductive Plasma Current Ramp-up Experiments with 28 GHz Heating and a Focusing Mirror Launcher

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Report on my visit to QUEST, July 18 - 28, 2017

During my visit I collaborated with
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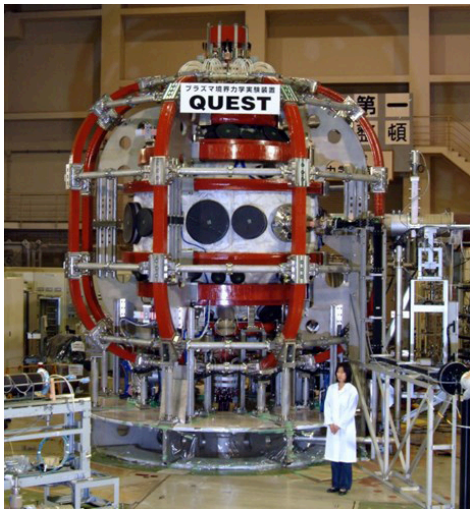
The goal of the QUEST program is generate steady-state fully non-inductive plasmas

- QUEST will ultimately use a combination of 2.45, 8.2, 8.56 and 28 GHz heating to generate steady-state, fully non-inductive plasmas with 3 MW of RF power:
  - *Present capability:*
    ~ 50 kW of 2.45 GHz
    ~ 400 kW of 8.2 GHz
    ~ 250 kW of 28 GHz
- The QUEST CHI system has been commissioned by University of Washington team and will be used with 28 GHz heating later this year

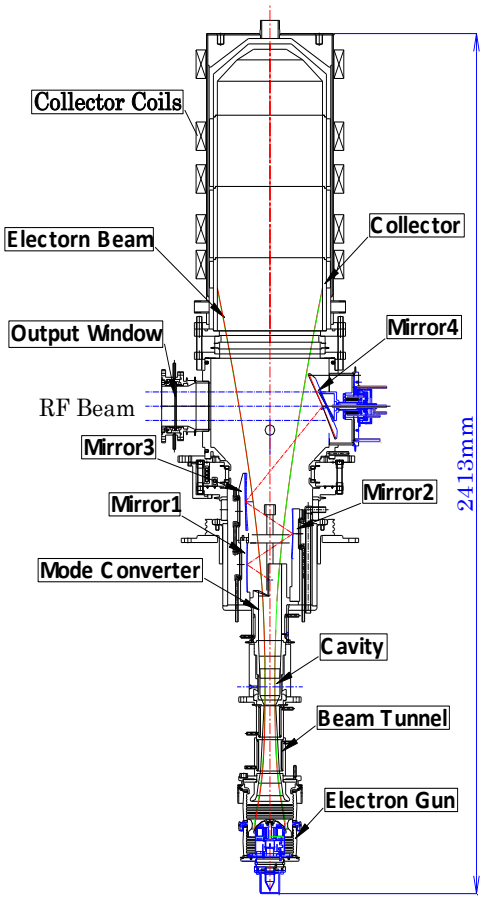


QUEST Spherical Tokamak

Major Radius	0.68 m
Minor Radius	0.40 m
Aspect Ratio	1.70
Vacuum Chamber Radius	1.4 m
Vacuum Chamber Height	2.8 m
Toroidal Magnetic Field	0.25 T (steady state), 0.5 T (pulse)
Plasma Current	100 kA (current) → 300 kA (target)
Heating Power	8.2 GHz + 8.56 GHz + 28 GHz: 3 MW (target)

QUEST Parameters

QUEST uses a 28 GHz Gyrotron developed by Tsukuba University

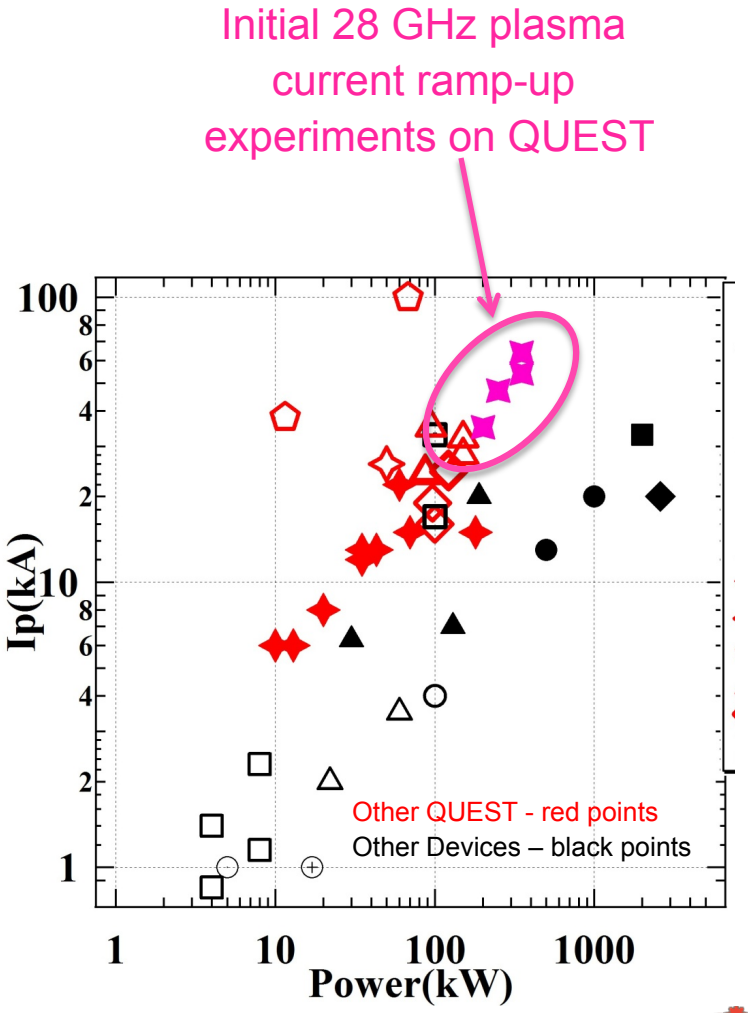


- 28 GHz gyrotron had been developed for Gamma-10/PDX projects at Tsukuba University

28 GHz Gyrotron Design Parameters	
Frequency	28GHz
Output Power	1 MW
Pulse Width	1 s
Output Efficiency	35% (W/O CPD)
Beam Voltage	80 kV
Beam Current	40 A
Cavity Oscillation mode	$TE_{8,3}$
Output mode	Gaussian like
Output Window	Sapphire Single Disk
Aperture diameter	112 mm

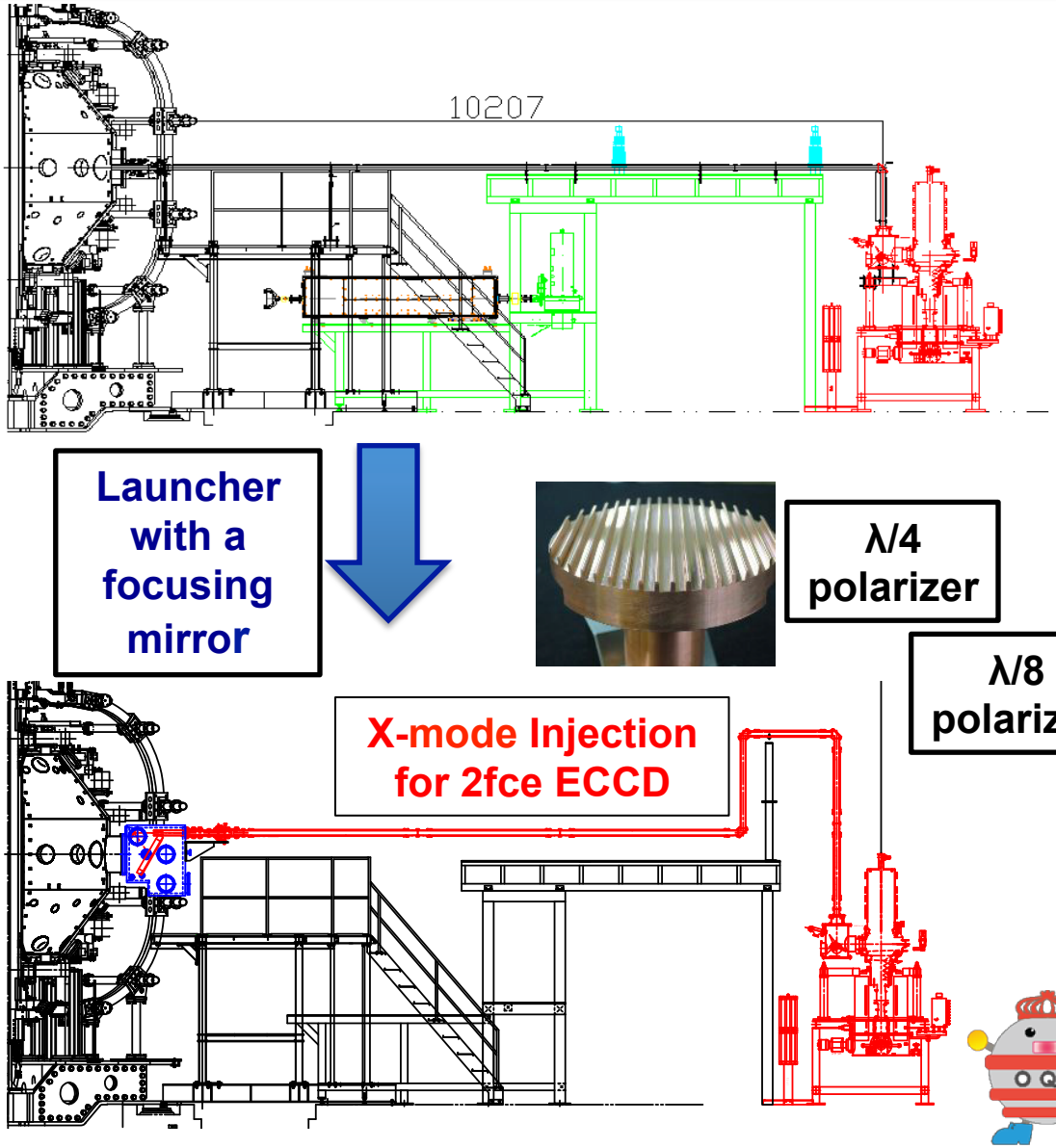
28 GHz gyrotron system was initially configured with an open ended waveguide launcher

- Initial QUEST 28 GHz heating experiments used an open ended waveguide launcher and there was no polarization rotator
- At QUEST toroidal field, $B_T(0) = 0.25$ T, the 2nd harmonic EC resonance is just 10 cm from the center stack, so the beam size was large at the resonance
- Nevertheless up to 66 kA of non-inductive current was generated with 270 kW of 28 GHz power



28 GHz gyrotron system has been upgraded with a focusing mirror launcher and polarizer

- Added quasi-optical polarization control to provide the desired X-mode polarization to obtain good single pass absorption
- Added focusing mirror launcher to obtain a narrow beam
- This new 28 GHz transmission line was commissioned in July

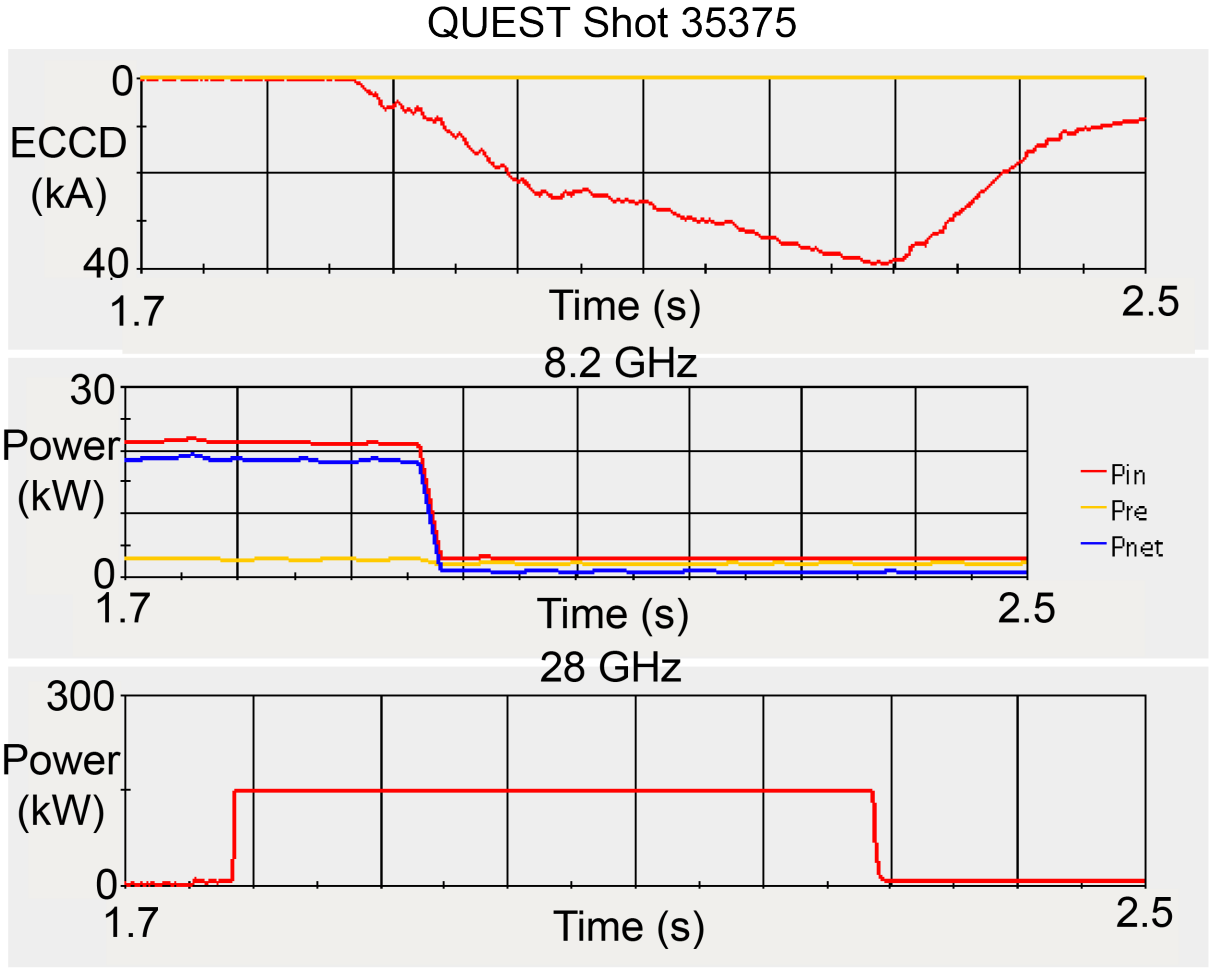


The upgraded 28 GHz heating system was commissioned during the period July 18 - 30

- There was no coupling of 28 GHz power into QUEST plasmas during the first week of my visit (July 18 - 21)
- The water-cooled dummy load can now be switched remotely into the transmission line, previously the transmission line had to be disconnected from the machine and connected to the dummy load
- After fixing some water leaks on the dummy load we spent July 19-20 firing 75 ms 150-200 kW pulses into the dummy load while they discharge cleaned QUEST with 10 kW of 2.45 GHz power
- Power was initially limited to ~ 150 kW by arcs in the dummy load
- By the end of the first week of my visit we were conditioning into the dummy load at a power level ~ 200 kW, we were still getting arcs in the transmission line above that power
- On Monday, July 24 there was no gyrotron operation

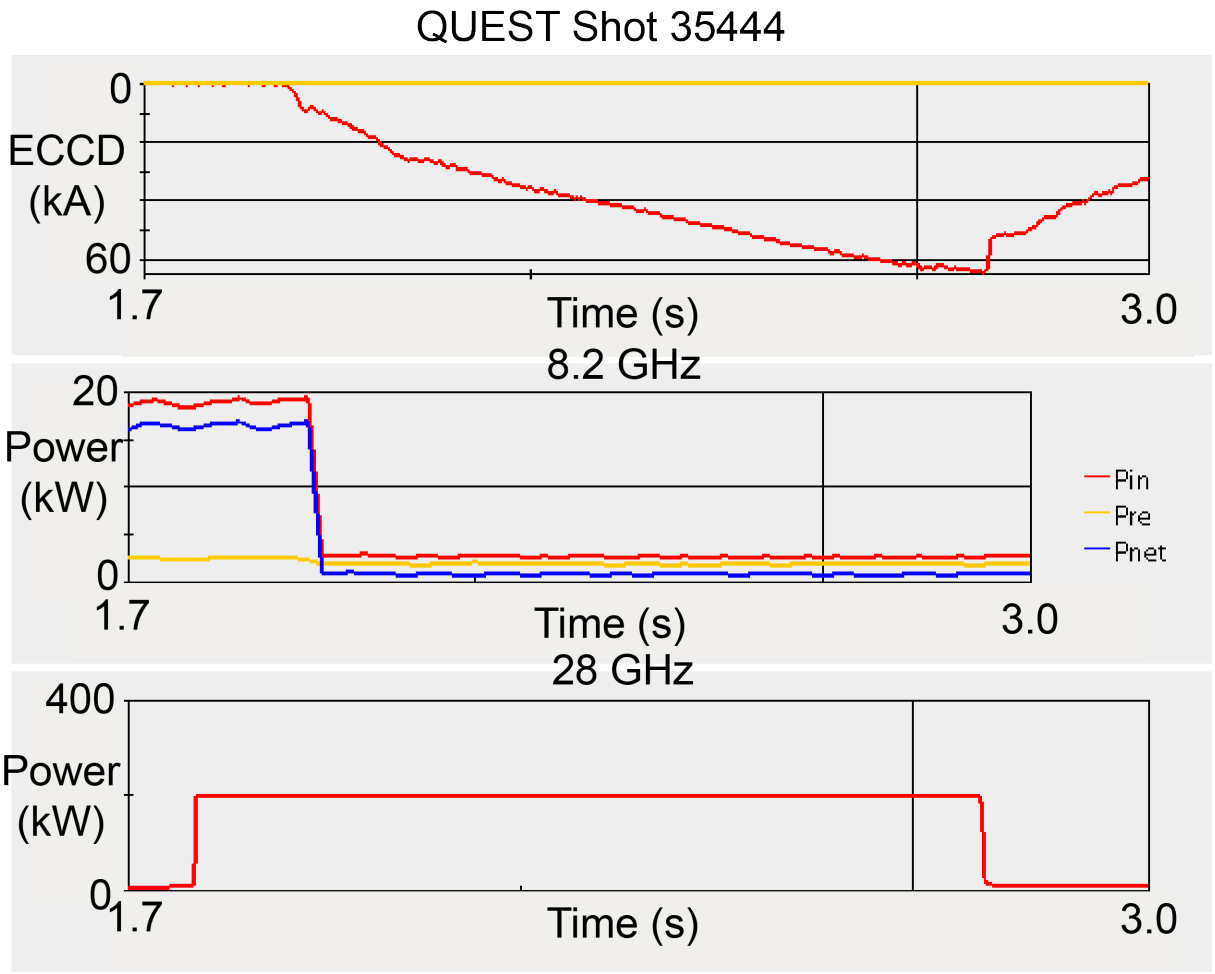
We began injecting 28 GHz power into the QUEST plasma on July 25

- By the end of the day on July 25 we were injecting 500 ms, 150 kW pulses into the QUEST plasma and driving 40 kA of ECCD



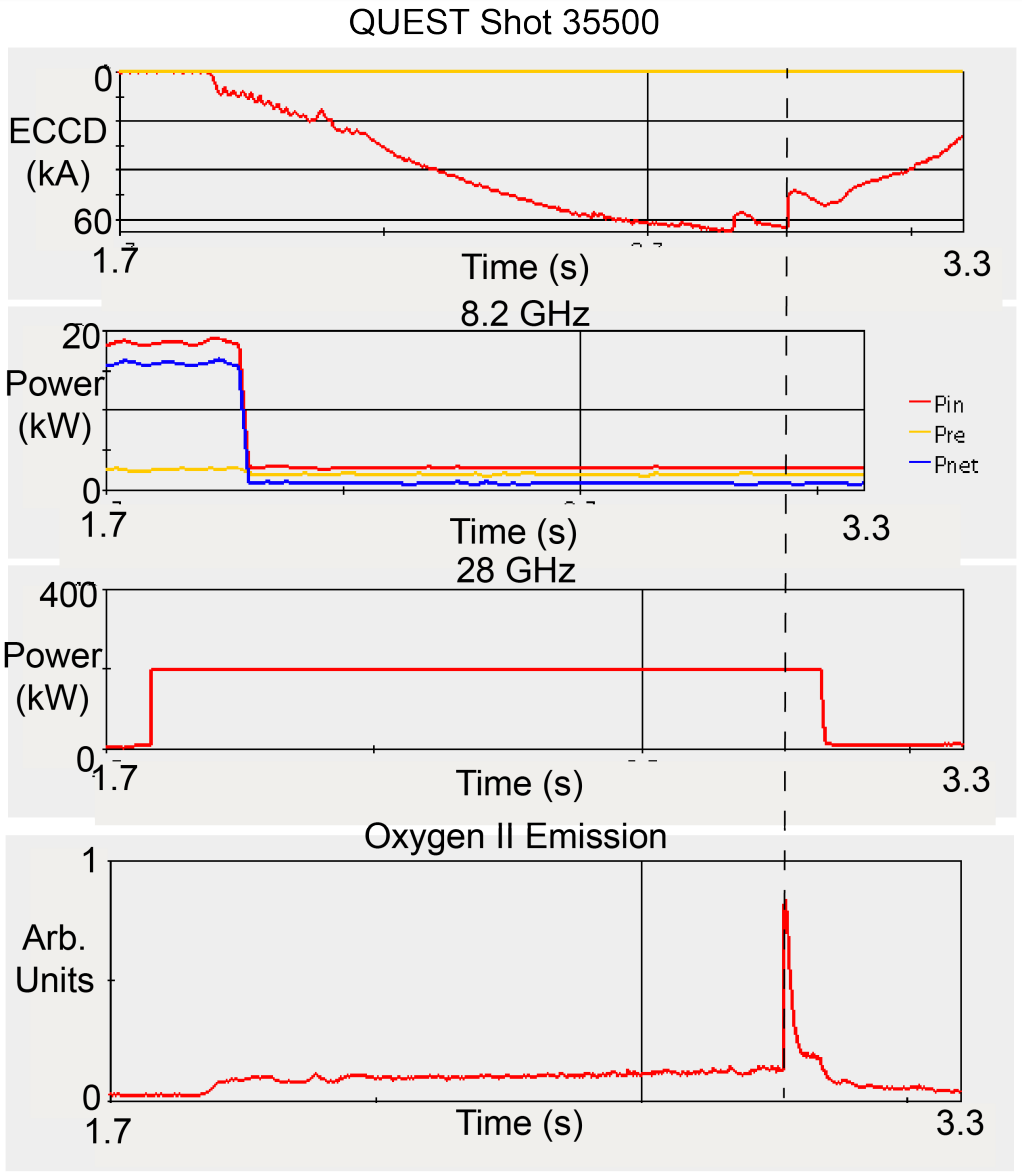
On July 26 we increased the power to 200 kW for one second, generating up to 65 kA of ECCD

- Current ramped up throughout the RF pulse, so we hoped to generate more current by stretching the pulse and raising the power



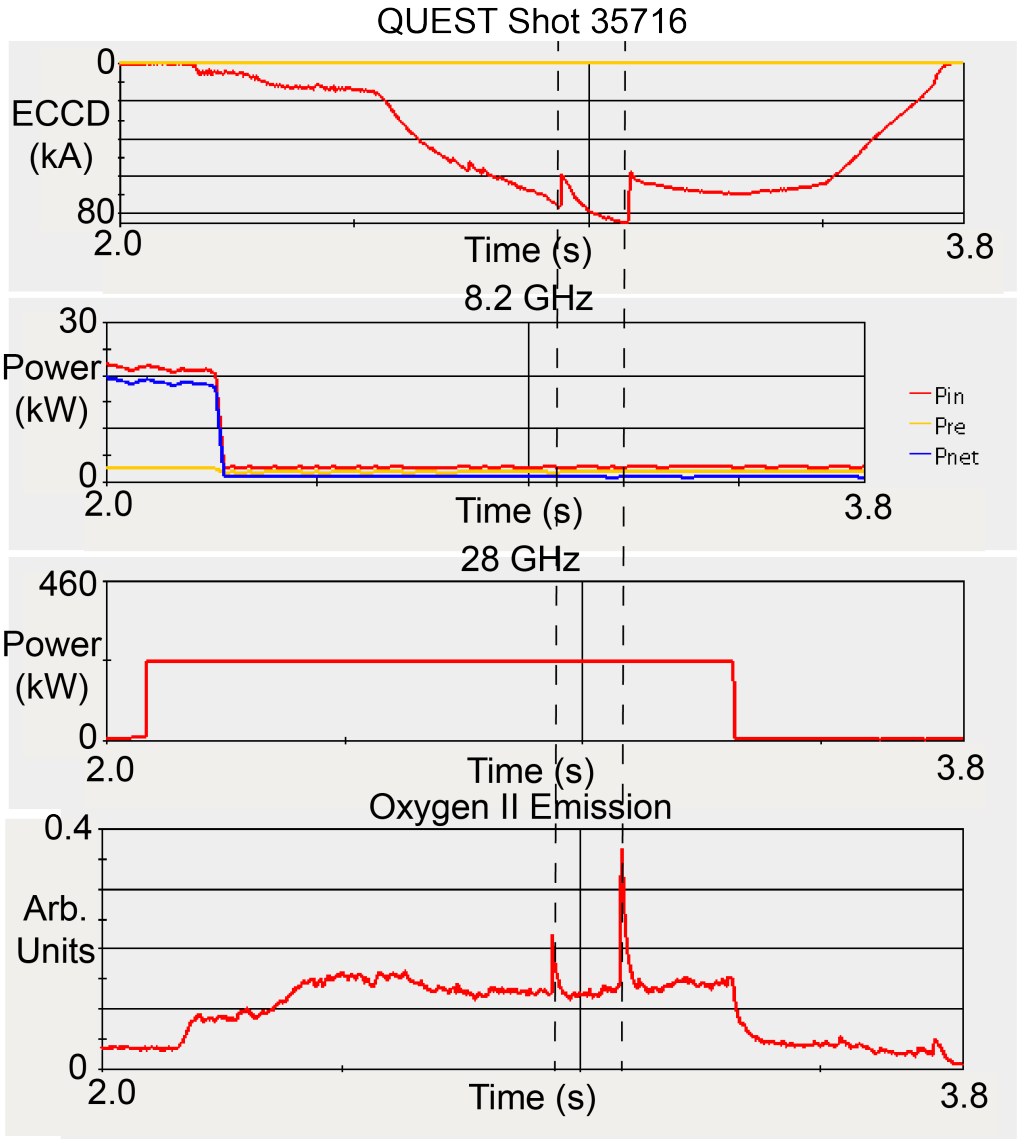
On July 27 we injected 210 kW for 1.25s but generated current was limited to 65 kA

- Stretching the pulse to 1.25 s did not increase the non-inductive current beyond 65 kA
- Non-inductive current dropped several times during the last 200 ms of the RF pulse
- Burst in Oxygen-II emission coincident with the last current drop



Experiments continued July 28-30, eventually generating up to 85 kA with 230 kW

- We made no progress on July 28
- July 29 I returned to the US, experiments continued July 29-30
- Eventually they generated 85 kA with 230 kW, but there were several large drops in generated current, once again coincident with bursts in the Oxygen-II emission



Upgrades to the QUEST 28 GHz heating system resulted in improved ECCD performance

- Generated more current (85 kA) with less 28 GHz power (230 kW) compared to earlier experiments that used an open ended waveguide and no polarizer, that generated up to 66 kA with 270 kW
- There were sudden drops in the ECCD that limited the rise in current when we increased the power and pulse length, these drops were often associated with bursts of Oxygen II emission
- Sudden drops in generated current may result from an instability driven by the non-thermal electrons created by the ECCD, but this is still under investigation
- 28 GHz experiments, focused on combining 28 GHz heating with CHI, will resume during the QUEST October – December campaign:
  - *It is unlikely the 8.56 GHz system will be commissioned by then*