Experimental program and plans for HSX upgrade

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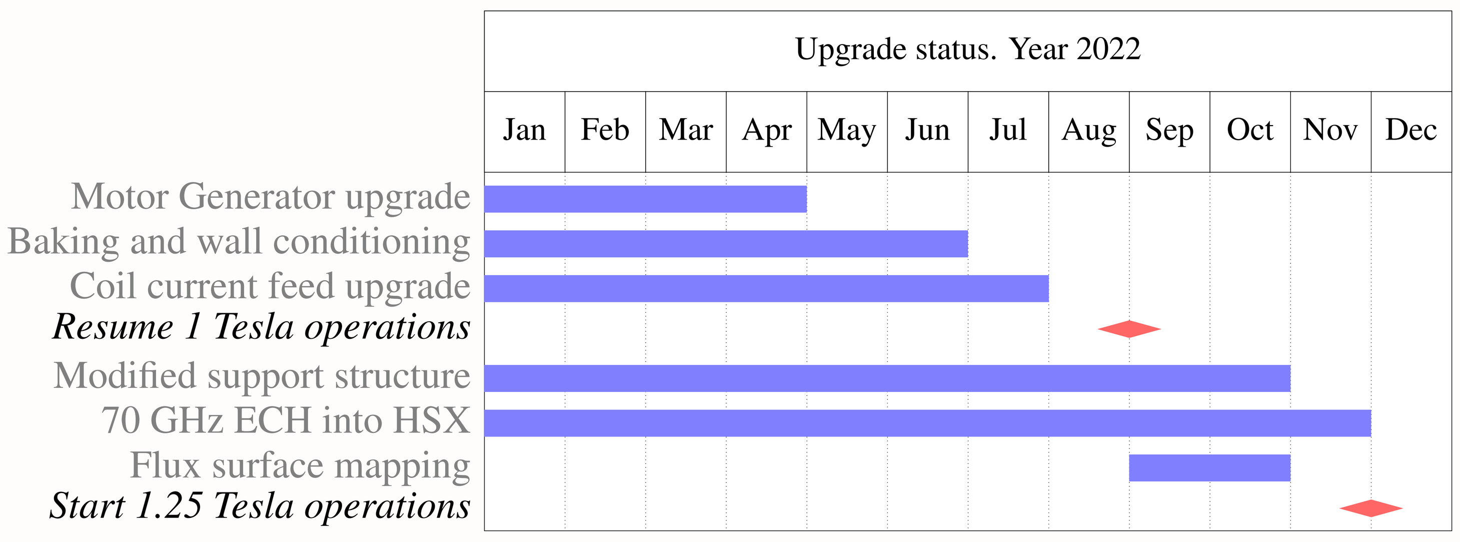
1. The HSX stellarator is currently being upgraded.

- HSX currently runs with two 28 GHz gyrotrons at fundamental ordinary at B = 1 Tesla, with a total of 100 kW of heating power.
- A new 70 GHz gyrotron will be installed that will provide up to 300 kW of power for up to 100 ms at B =1.25 Tesla.
- This upgrade will allow operation at three times higher plasma densities (up to $2.0{\times}10^{19}/m^3$) with an ECH absorption efficiency of $\sim 90\%$.
- The post-upgrade experimental program of HSX emphasizes areas that exploit these new capabilities:
  - Exploring higher ion temperature and lower neutral density regimes
  - Optimizing the magnetic geometry to vary turbulent transport
  - Measuring plasma flows and electric fields at higher ion temperatures, more negative electric fields, and lower neutral damping
  - Measuring and understanding impurity transport

2. Upgrade is expected to be completed by the end of this year.

- The gyrotron is onsite, filament and vacuum levels have been tested and found acceptable.
- The new 60 kV 20A gyrotron power supply is onsite, installed and tested.
- The main components of the transmission line have been designed and fabricated.
- The motor/generators have been refurbished and upgraded to provide the needed power.
- The structural and electrical modifications to HSX are on track.
- A PLC-controlled vessel bake-out system is being implemented to aid high density, high power discharges.
- Improvements in diagnostic and support systems are progressing rapidly.
- To ensure that no significant degradation of the magnetic field structure arises during 1.25 T operation, a flux surface mapping system is being installed.



3. First set of campaigns will explore higher ion temperature and lower neutral density regimes.

- As a result of the increase in ion-electron coupling, the core ion temperature is calculated to increase from the present value of $\sim$50 eV to more than 150 eV, moving closer to a low collisionality regime. (see Fig. 1)
- Because of the very short connection lengths (the effective transform is $\sim$3) it is easier to access the low collisionality regime in HSX than any other experiment.
- The higher plasma density operation is also calculated to reduce the density of background neutrals.
- Higher density and lower charge exchange losses enable ion transport studies.
- First set of campaigns will be to understand how to lower the ion collisionality to explore whether the QHS configuration shows reduced ion neoclassical transport.

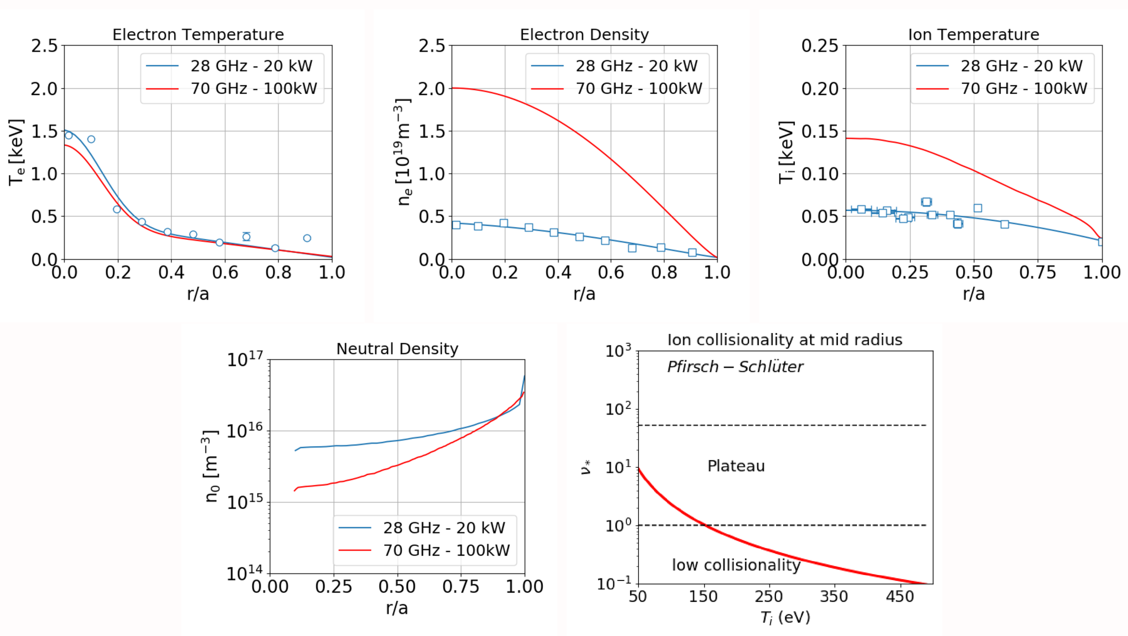


Figure 1: Calculated profiles for upgrade plasma with 70 GHz gyrotron versus old experimental data using 28 GHz gyrotron. Upgrade profiles are calculated based on ISS04 scaling of the energy confinement time. Also shown is the ion collisionality as a function of ion temperature at the mid-radius of HSX.

4. Auxiliary coils will be used to optimize the magnetic geometry to vary turbulent transport (See invited talk by M. Gerard).

- GENE simulations show that QHS configurations with increased plasma elongation provide reduced TEM growth rates.
- Several configurations with reduced growth rates are identified for experiments.

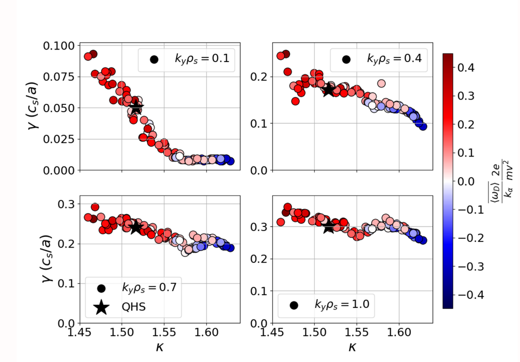


Figure 2: TEM growth rates as a function of elongation. Colorbar gives normalized precessional drift of trapped electrons.

5. Upgrade enables measurement of plasma flows and electric fields at higher ion temperatures, more negative electric fields, and lower neutral damping.

- Due to the reduced flow damping from the neutrals, there should be higher flows in the direction of symmetry, as well as the parallel flow.
- The neoclassical radial electric field is calculated to be more negative in the core. Ambipolar solution is away from the ion resonance. (See Fig. 3).
- Measurements of intrinsic ion parallel flow and radial electric field will continue, using CXRS.
- Biased electrode experiments will continue.
  - To determine whether there are damping terms in addition to parallel viscosity and neutral drag.
  - To demonstrate the effect of the parallel flow on the ion resonant electric field (see Fig. 4)
- Collaboration with Kyoto University will continue on modeling and experiments to understand the mechanism of toroidal flow generation by ECH driven currents.

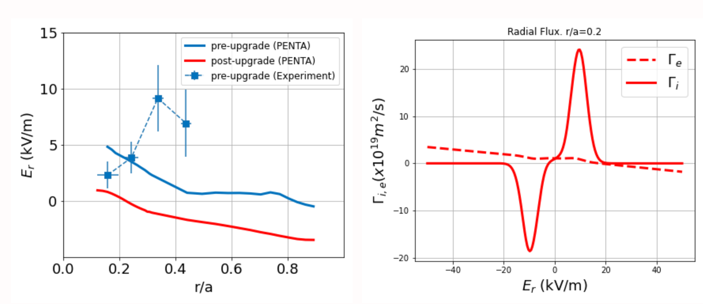


Figure 3: [Left] Neoclassical E_r calculated by PENTA for pre and post upgrade plasma parameters. Also shown experimental E_r for the pre-upgrade measured using CXRS. [Right] Radial particle flux at r/a=0.2

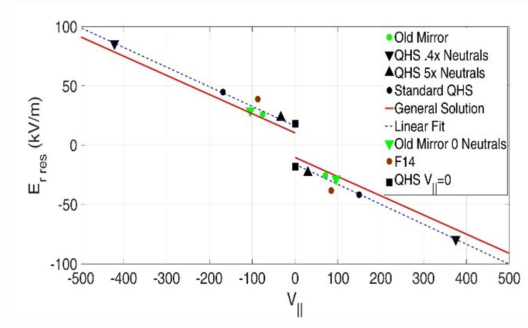


Figure 4: The resonant electric field as a function of the parallel flow for three different magnetic configurations and three different neutral densities. The red line is the analytic expression and the data points are the steady-state solutions to the momentum balance equations.

6. Impurity transport experiments with Laser Blow-off (LBO) will continue.

- LBO injection experiments in the present 1 Tesla operation showed very strong diffusive, turbulent transport of impurities (Fig. 5). This might, however, change during high density operation with negative radial electric fields and possible reduced levels of turbulence.
- We will explore the impurity transport in the turbulence optimized configurations to compare with the measurements already made in the QHS configuration.
- While previous experiments employed only aluminum injections, additional impurities such as boron will be used for the upgrade.
- Using a biased electrode, we will investigate how the convective velocity corresponds to the radial electric field.

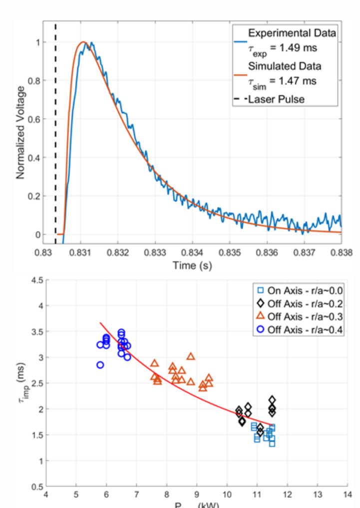


Figure 5: [Top]The experimental photodiode signals and STRAHL simulated signals are plotted as a function of time. [Bottom] Impurity decay time as a function of the absorbed power. The red line represents $\tau \sim P^{-1.1}$.

Acknowledgements

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