

# Plans for Experimental Validation of GENE-Predicted Growth-Rate-Reduced HSX Configurations

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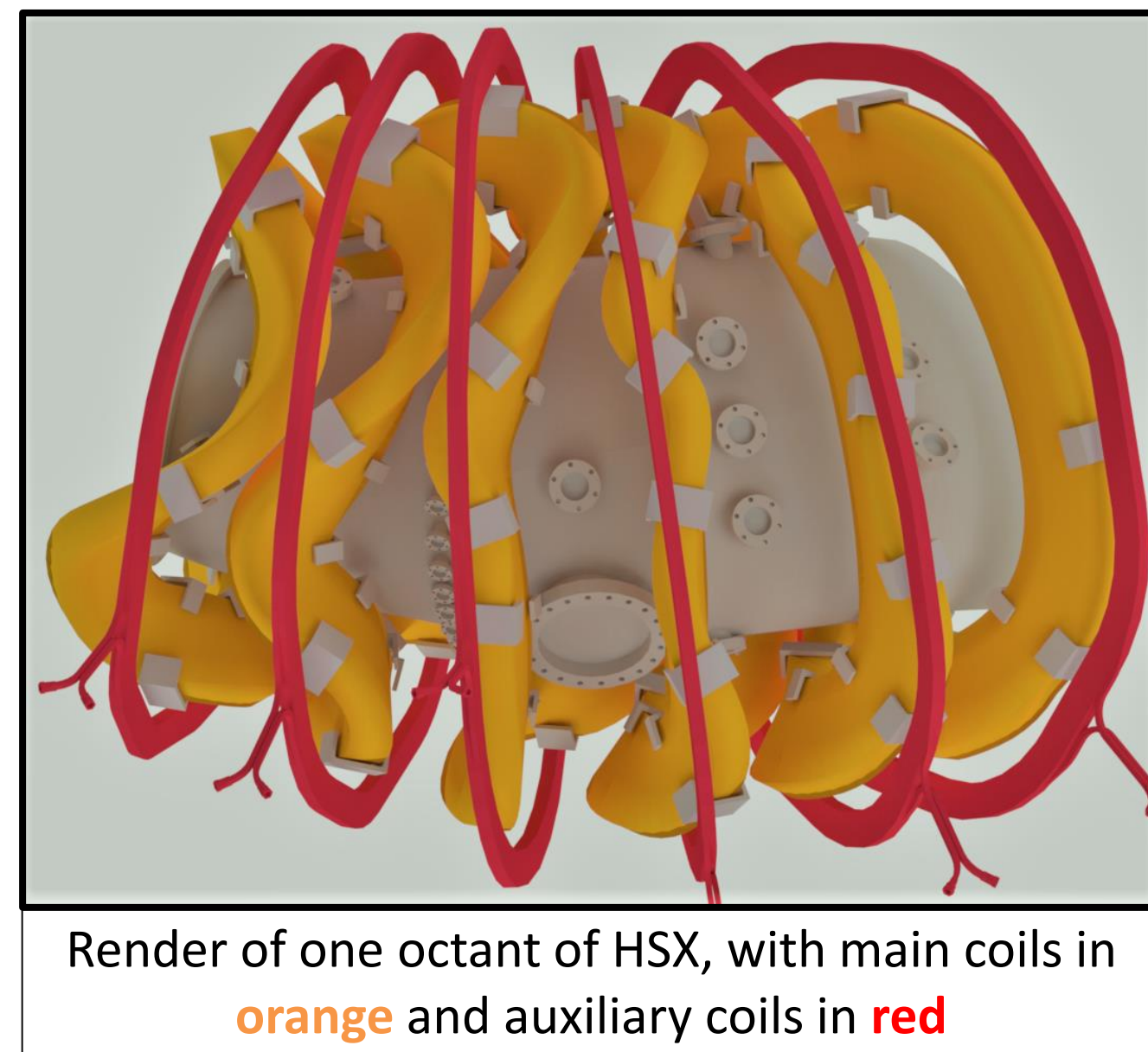
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## 1 - Motivation and HSX

### Motivation for work:

- HSX is a quasi-helically symmetric stellarator with reduced neoclassical transport [1]
- Transport in HSX dominated by anomalous transport/trapped-electron-mode turbulence [2]
- HSX has an adjustable magnetic topology, allowing for TEM-optimized configurations
- GENE simulations link increased plasma elongation and enhanced magnetic well depth configurations with reduced TEM growth rates [3]



Render of one octant of HSX, with main coils in orange and auxiliary coils in red

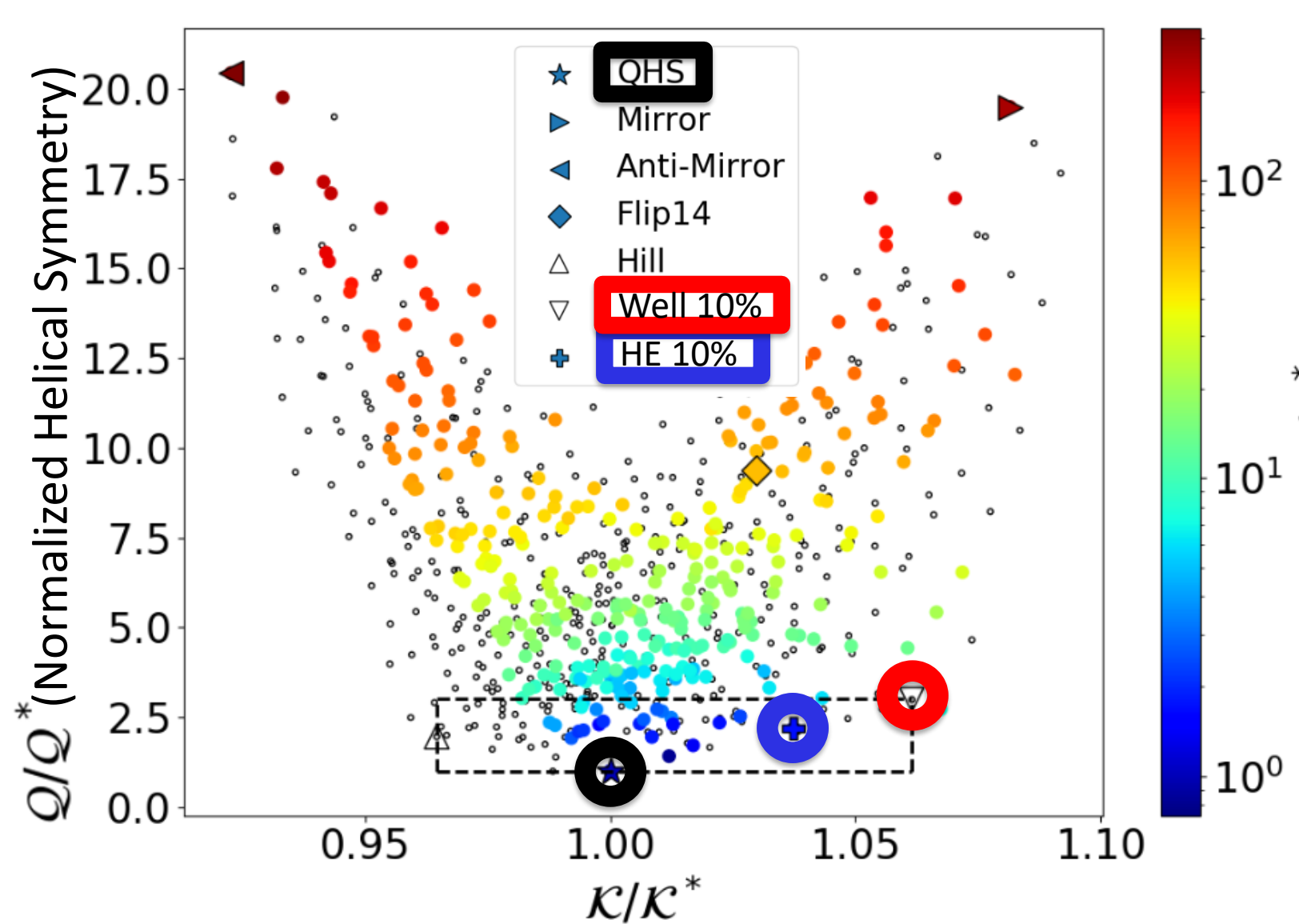
### Relevant HSX parameters:

- 1 T magnetic field
- R = 1.2m, a = 0.12m

## 2 - Turbulence Metrics

### Coil Current Scan Optimization

- Scan over coil-current configurations has been performed [3,4]
- Auxiliary coil currents denoted in percent of main coil currents
- Configurations identified with improved TEM stability metrics
  - Flux-surface elongation  $\kappa = \frac{z_{max} - z_{min}}{2a}$ , Z rotating about magnetic axis [5]
  - Magnetic well depth, defined as  $-d^2V/d\psi^2$  where  $\psi$  is toroidal flux

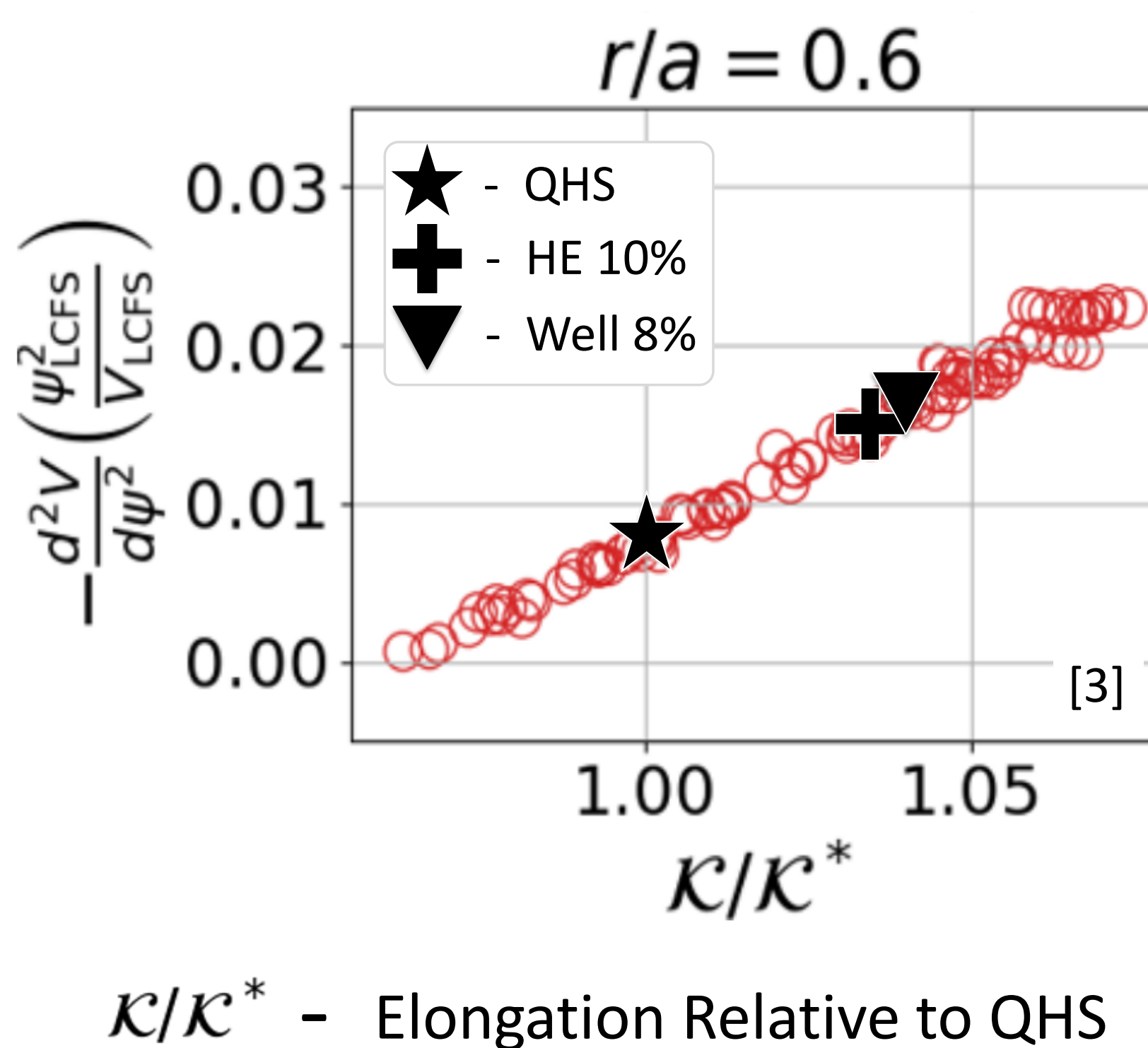


### Flux-Surface Elongation:

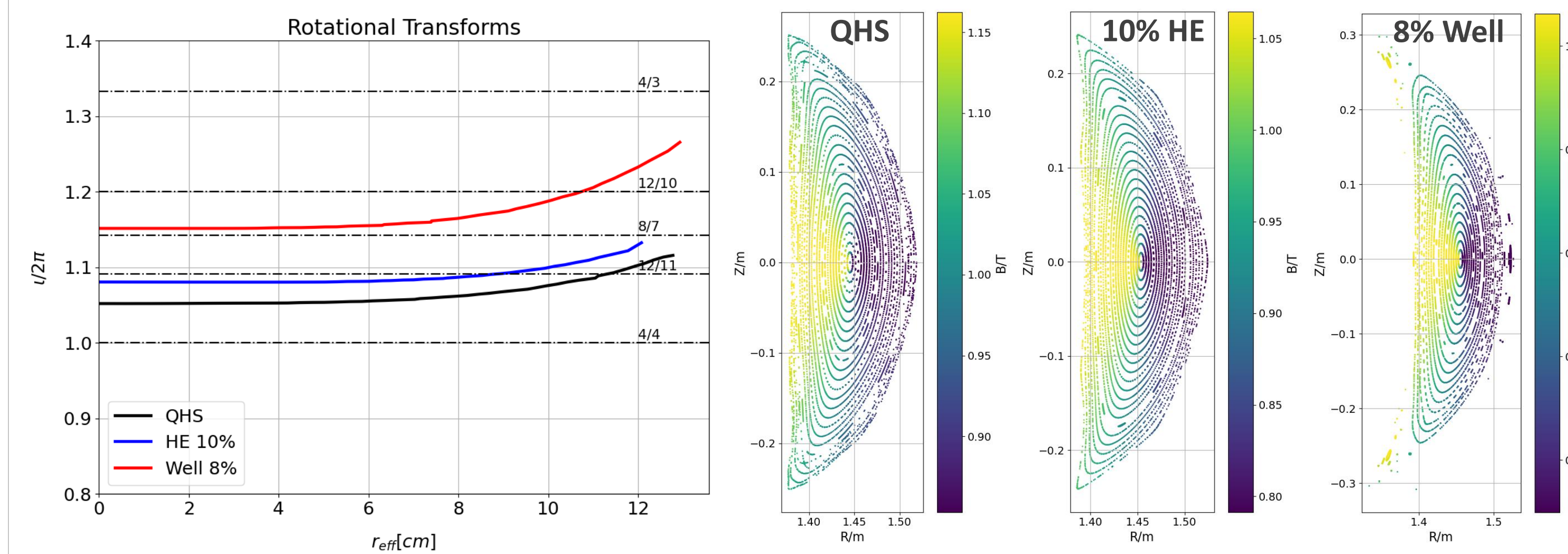
- Elongation linked to reduced linear growth rates in HSX [3]
- Correlated with TEM curvature drive metrics
- Noteworthy configurations singled out:
  - HE-QHS/HE (high elongation)
  - Enhanced magnetic well depth configurations

### Magnetic Well Depth:

- Well configuration previously established in HSX
- Well depth usually an MHD quantity, but directly correlated to flux-surface elongation
- Well depth correlated with reduced thermal diffusivity in HSX [6]
- High current well configurations promising and unexplored



## 3 - Configurations of Note



### 10% High Elongation (HE) Configuration:

- Found through coil current scan
- Aux coil currents of: [-10%, 0, -10%, -10%, 0, -10%]
- Coil current percentages up to 10% have nearly zero island formation

### 8% Well Configuration:

- Previously identified enhanced-magnetic-well-depth configuration
- Aux coils currents of -8% for every coil
- 0-3% and 8-10% configurations have minimal island formation

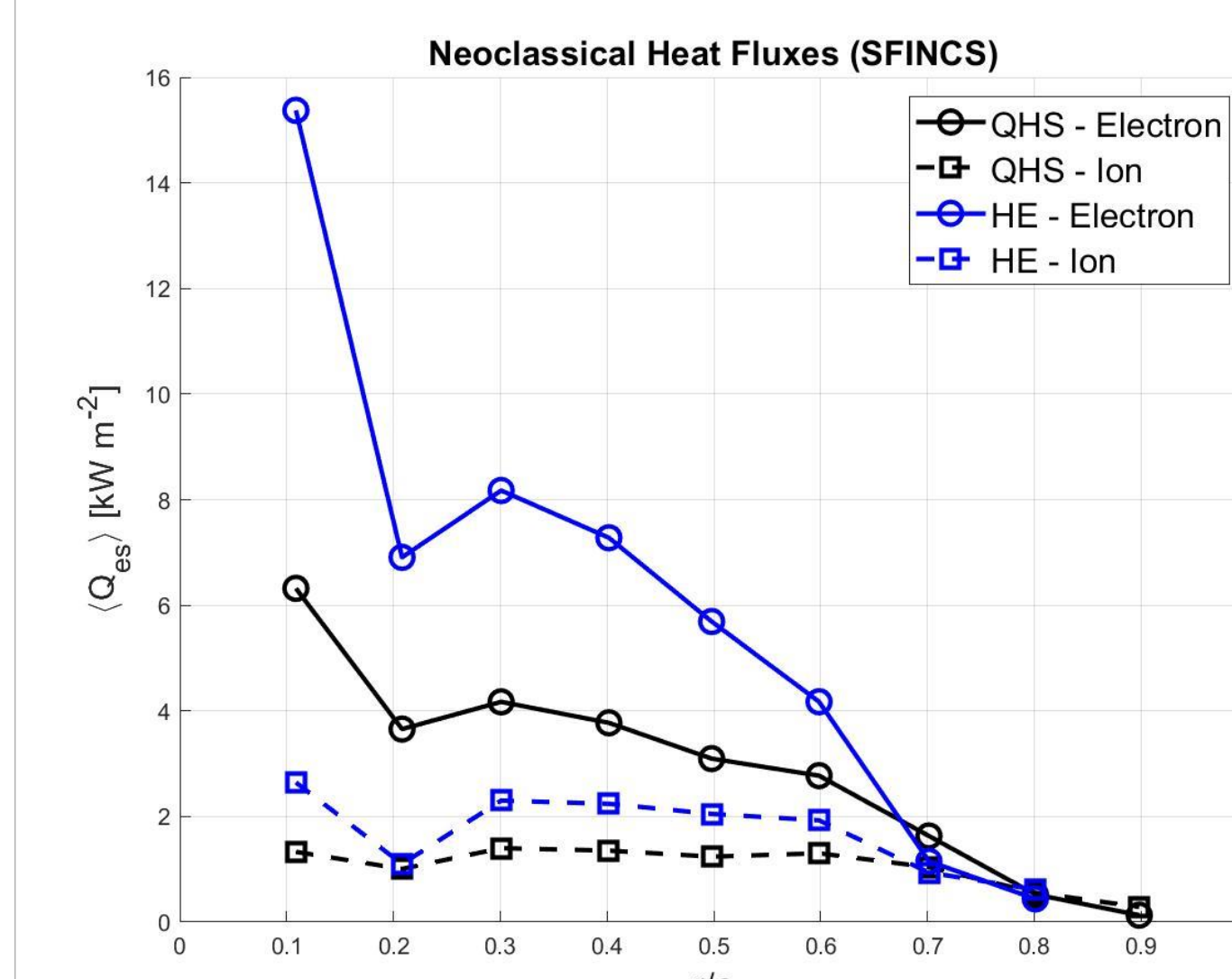
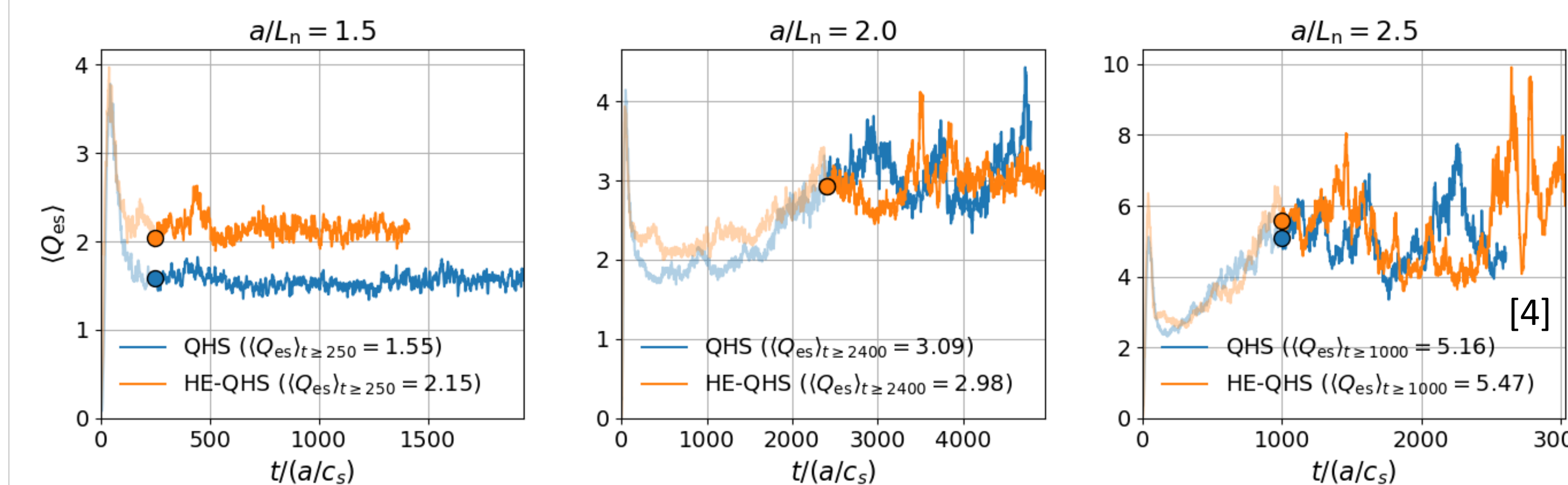
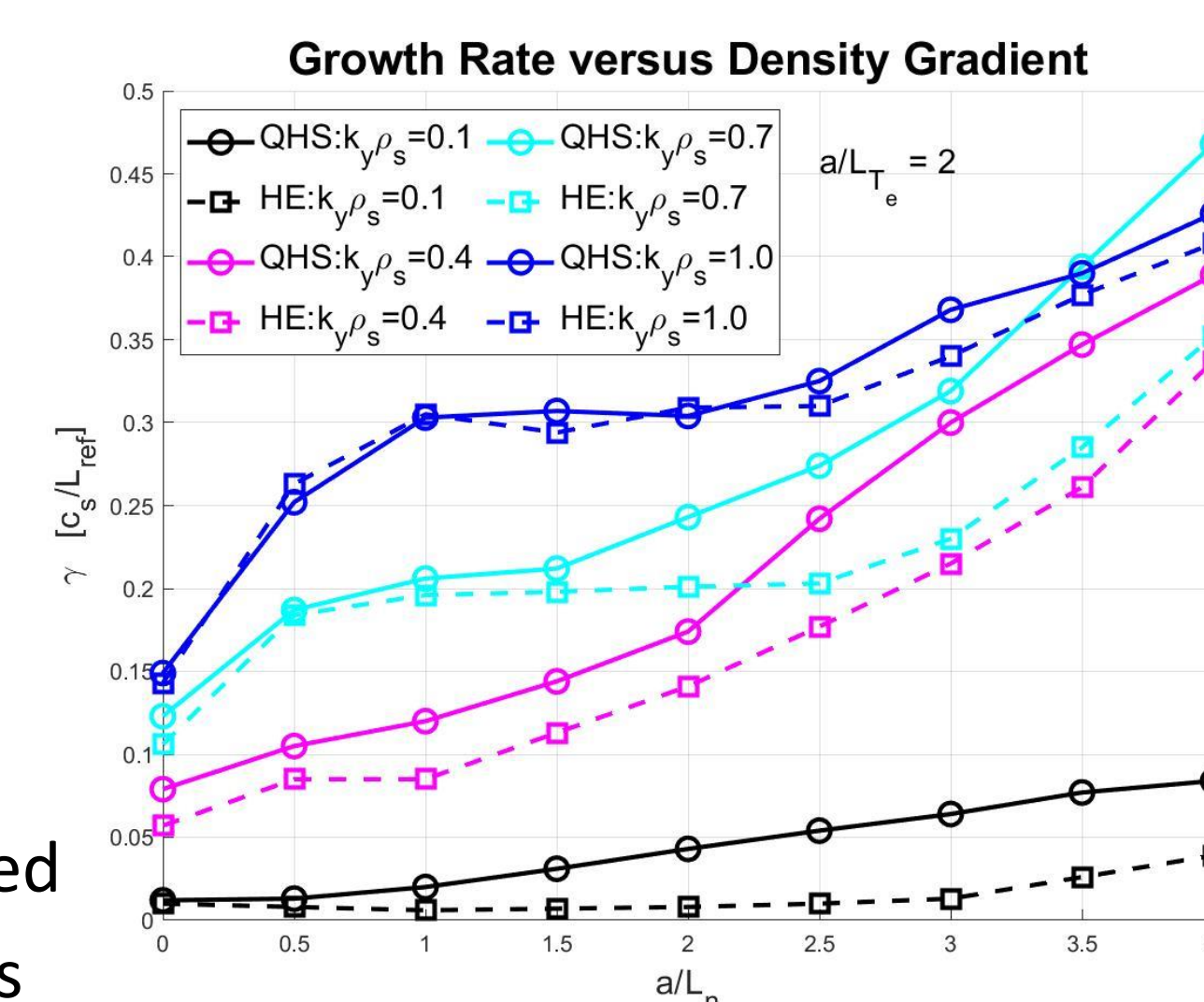
## 4 - Transport Predictions

### Linear Gyrokinetics:

- HE observed to have shifted critical density gradient for  $k_y \rho_s = 0.1$
- HE configuration has reduced growth rates vs QHS for  $k_y \rho_s$  below 1, improved TEM stability
- Elongation generally linked to improved TEM stability if sufficiently quasi-symmetric [3,4]

### Nonlinear Gyrokinetics:

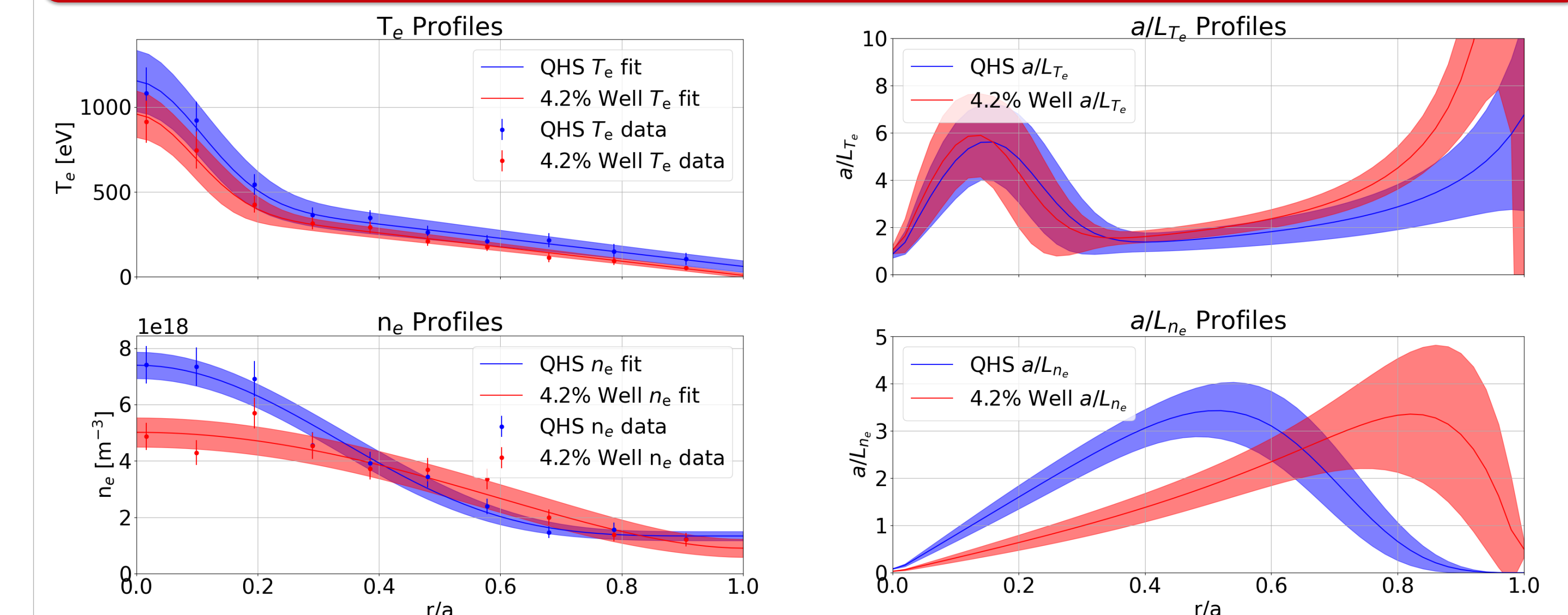
- HE and QHS configurations nonlinearly converged
- Both simulated at  $k_{ymin} = 0.05$  for all gradients
- Predicted to have similar transport, electrostatic electron heat flux very close to QHS, with late-onset, low- $k_y$ -dominated heat flux



### Neoclassical Predictions:

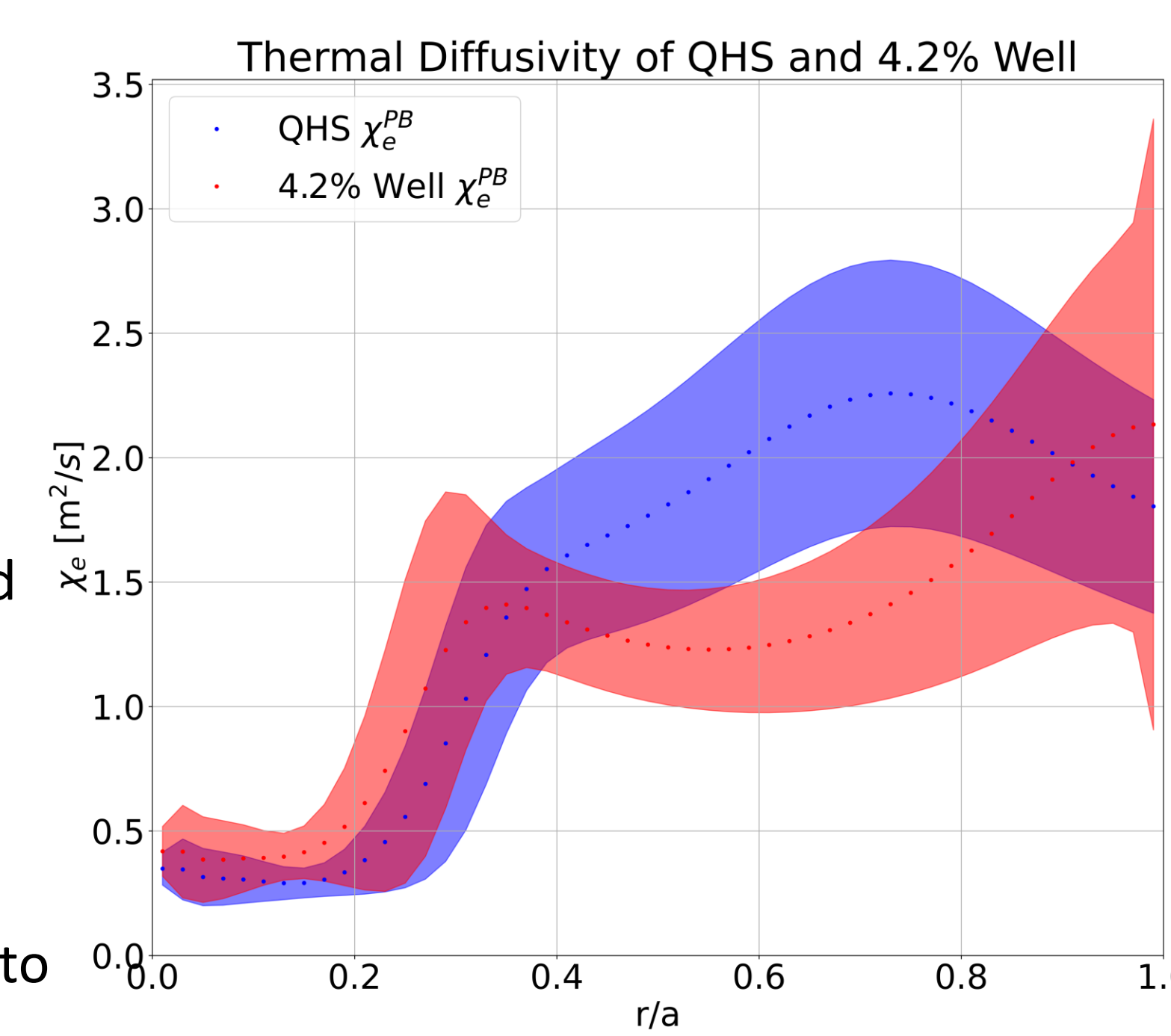
- SFINCS simulations done for HE and QHS
- Predicted to have similar/moderately worse neoclassical transport to QHS
- Outer radius behavior matches fairly well with QHS, indicates low transport
- Near-core behavior likely due to proximity to resonant electric field, may be a numerical artifact in SFINCS

## 5 - Experimental Analysis Example

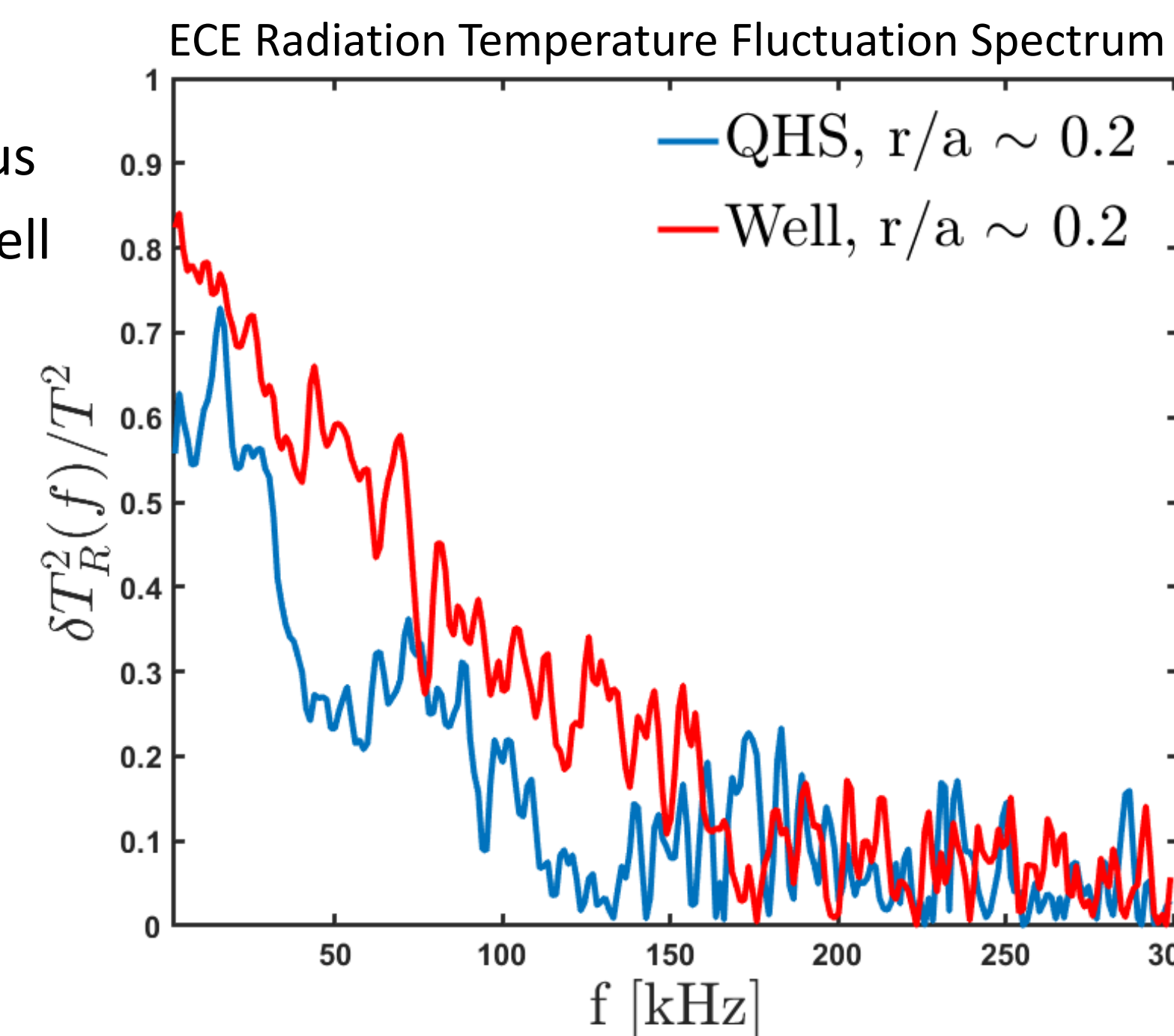
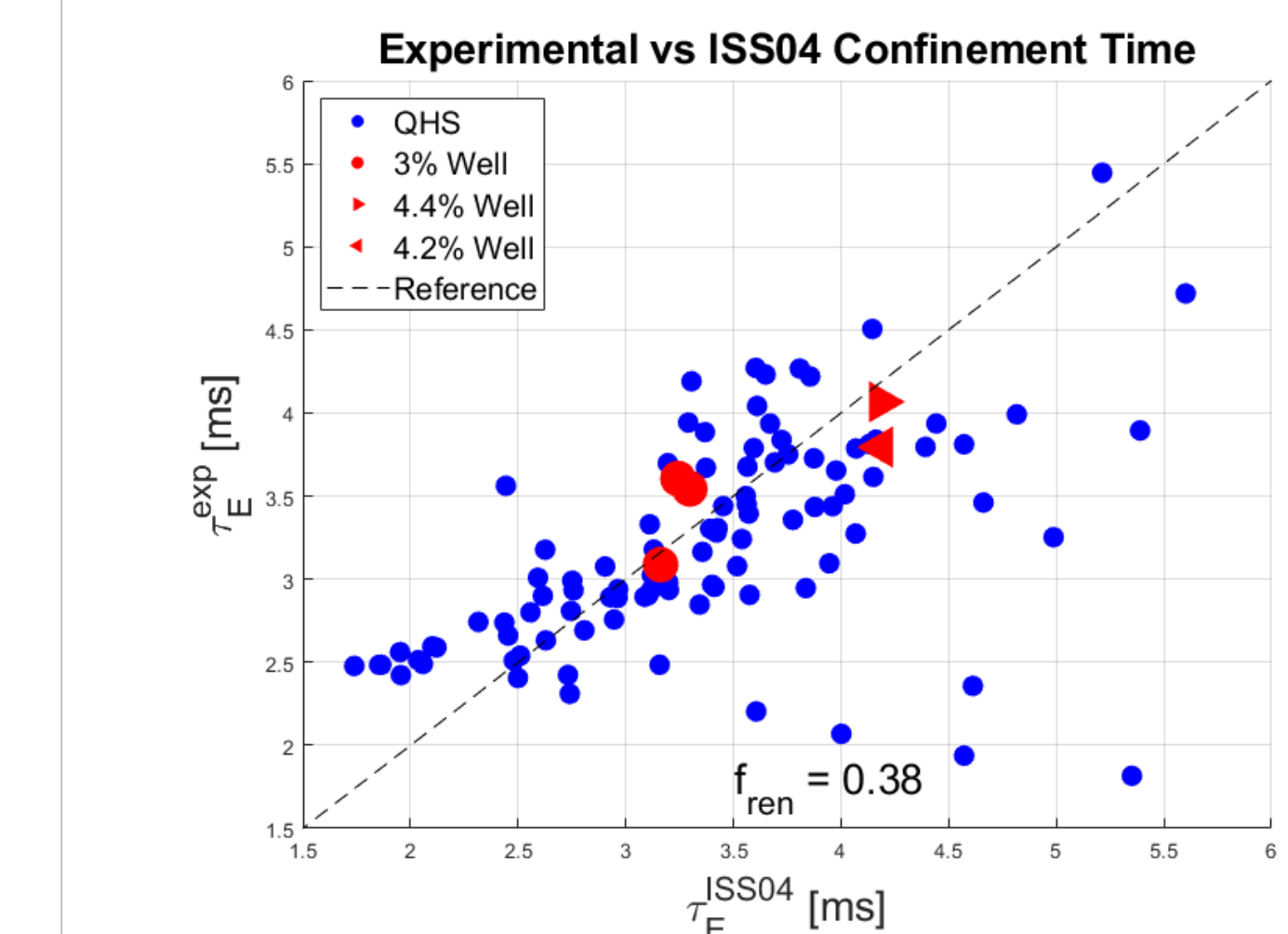


### Example of 4.2% Well vs QHS (2014 data):

- Profile matched experiments
- Power balance and thermal diffusivity
  - Use kinetic profiles, configuration geometry, absorbed power, approximate energy losses
- Stored energy and confinement time
  - Diamagnetic loop measurements used to back out stored energy, absorbed power, and energy confinement time
- Temperature and density fluctuations
  - Electron cyclotron emission (ECE) spectroscopy and reflectometry used to measure local fluctuations



- Preliminary results show 4.2% Well has improved thermal diffusivity at mid-radius
- ECE shows higher fluctuations in 4.2% Well



## 6 - Experiment Plan and Future Work

### Experimental Plan:

- HSX 1T operation slated for early 2024
- HE and Well configurations will be experimentally implemented
- Coil current scans, working gas changes, and profile-matching experiments
- Stored energy, energy confinement time, and power balance analysis for each configuration
- Electron temperature and density fluctuation measurements using ECE and reflectometry

### GENE Simulations:

- Fully converged linear and nonlinear GENE simulations for each configuration
- Linear growth rates for Hill (opposite of Well) and potentially a low elongation configuration
- Nonlinear gradient scans for all configurations
- GENE3D global simulations for QHS and other configurations of note
- Profile prediction using Tango, KNOSOS and GENE

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## References

[1] J.M. Canik et al., Phys. Rev. Lett. 98, 085002 (2007) [5] T.C. Luce, Plas. Phys. Contr. Fus. 55, 095009 (2013)  
 [2] B. Faber et al., Phys. of Plasmas 22, 072305 (2015) [6] E.M. Shilling et al., 60th APS DPP Poster, (2018)  
 [3] M.J. Gerard et al., Nucl. Fusion 63, 056004 (2023)  
 [4] M.J. Gerard et al., 65th APS DPP Talk - Friday (2023)