Study of ICRH and Ion Confinement in the HSX Stellarator

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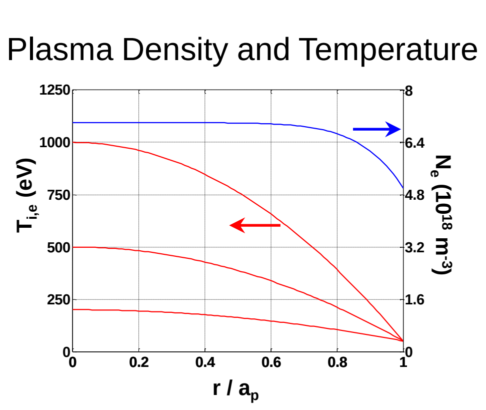
Overview

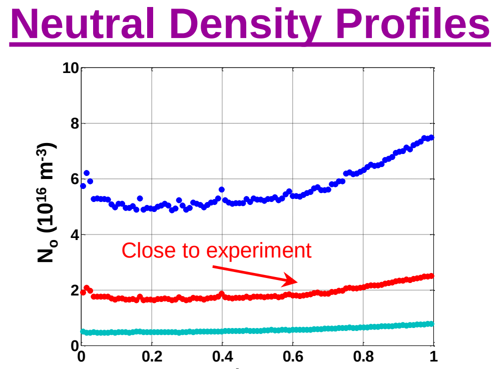
- With ECRH the ion temperature in HSX remains low (< 100 eV) compared to the electron temperature (~ 2 keV)
- With hot ions (a few hundred eV) the difference between quasi-symmetric and conventional stellarator configurations may be more pronounced
  - Ion low collisionality regime becomes accessible
  - Effect of radial electric field can be studied
- GNET code has been adapted to the HSX geometry
- The code can predict (1) efficiency of ion cyclotron resonance heating (ICRH); (2) fast ion confinement; (3) charge-exchange losses; (4) ion confinement in different magnetic configurations

Linearized Drift Kinetic Equation is solved in 5-D space

$$\frac{\partial f_{min}}{\partial t}+(\mathbf{v}_{//}+\mathbf{v}_D)\cdot\nabla f_{min}+\mathbf{a}\cdot\nabla_{\mathbf{v}} f_{min}-C(f_{min})-Q_{ICRF}(f_{min})-L_{particle}=S_{particle}$$

- 3-D equilibrium is calculated by the VMEC code
- Linear Coulomb collision operator $C(f_{min})$ is used
- $Q_{ICRF}(f_{min})$ is a heating operator based on the results of TASK/WM code for the LHD stellarator
- Particle losses $L_{particle}$ account for charge-exchange and orbits beyond the last closed flux surface
- Particle source $S_{particle}$ is determined by neutrals (AURORA code)
- Minority ion distribution function f_{min} is a convolution of a particle source and a time dependent Green's function

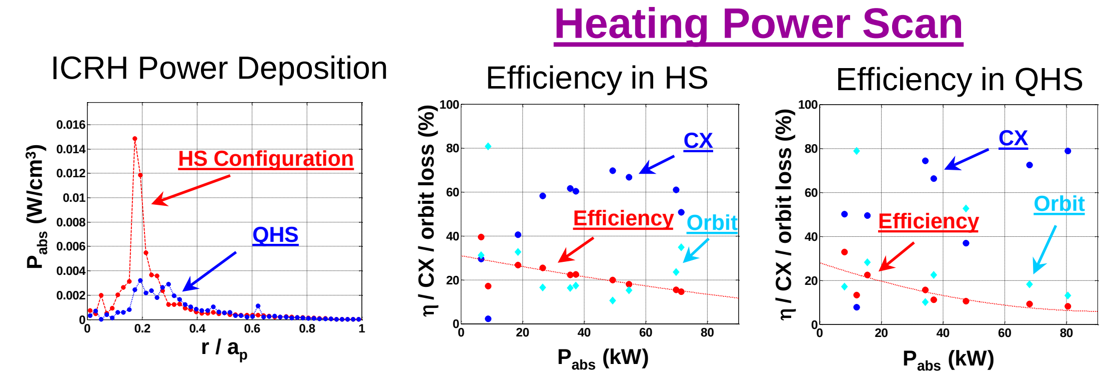




Results from GNET Code

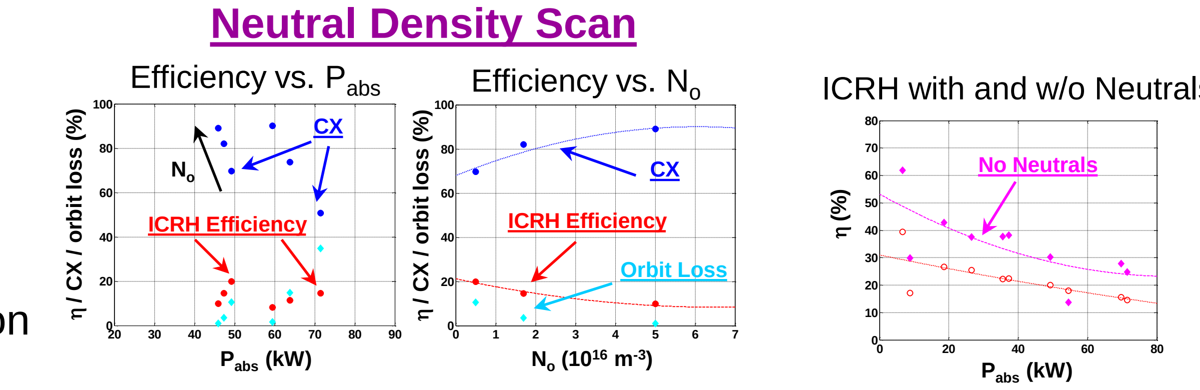
ICRH Efficiency Degrades with Heating Power and Neutral Density

Heating Power Scan



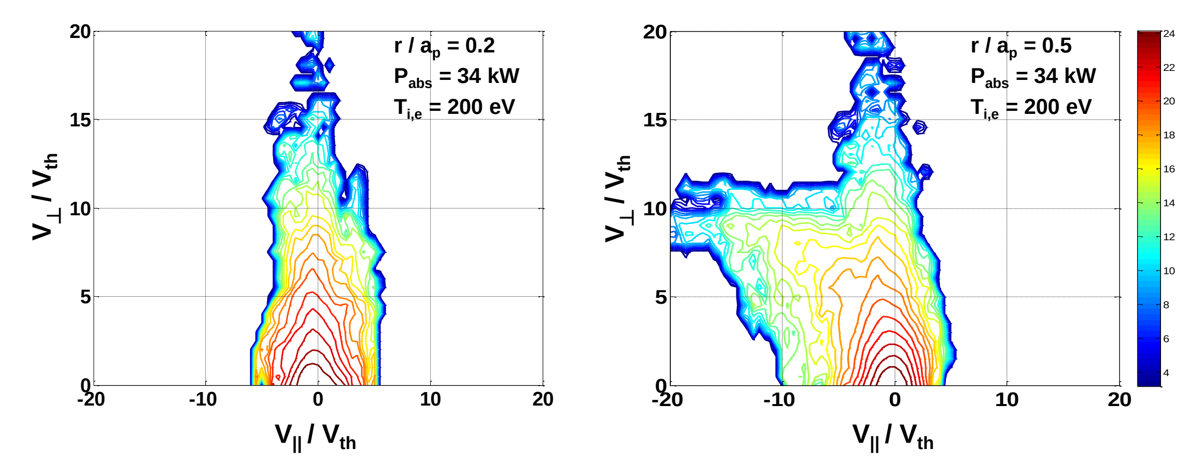
- At B_{res} = 0.975 T the power is deposited at (0.2–0.3)·r/a_p
- In helically symmetric (HS) configuration the heating is more efficient than in quasi-symmetric (QHS) mode due to a better fast ion confinement

Neutral Density Scan



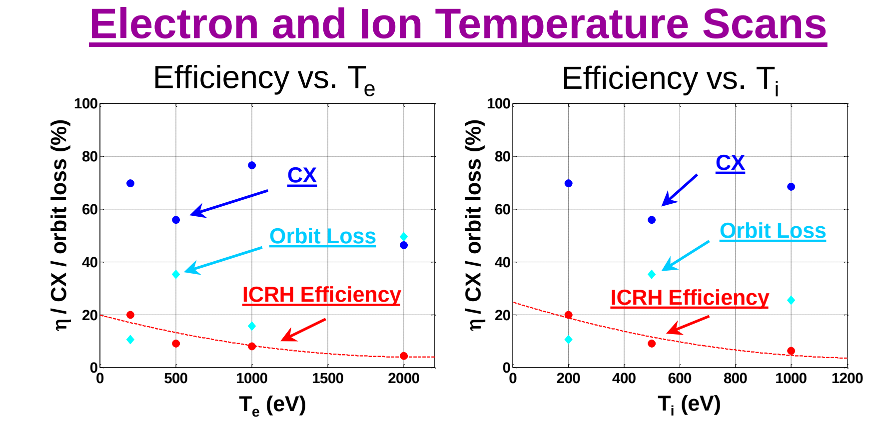
- In HSX the charge-exchange losses prevail over heating efficiency and fast ion orbit loss
- Without neutrals the heating efficiency may get up to 40%

Minority Ion Distribution Function in QHS Configuration

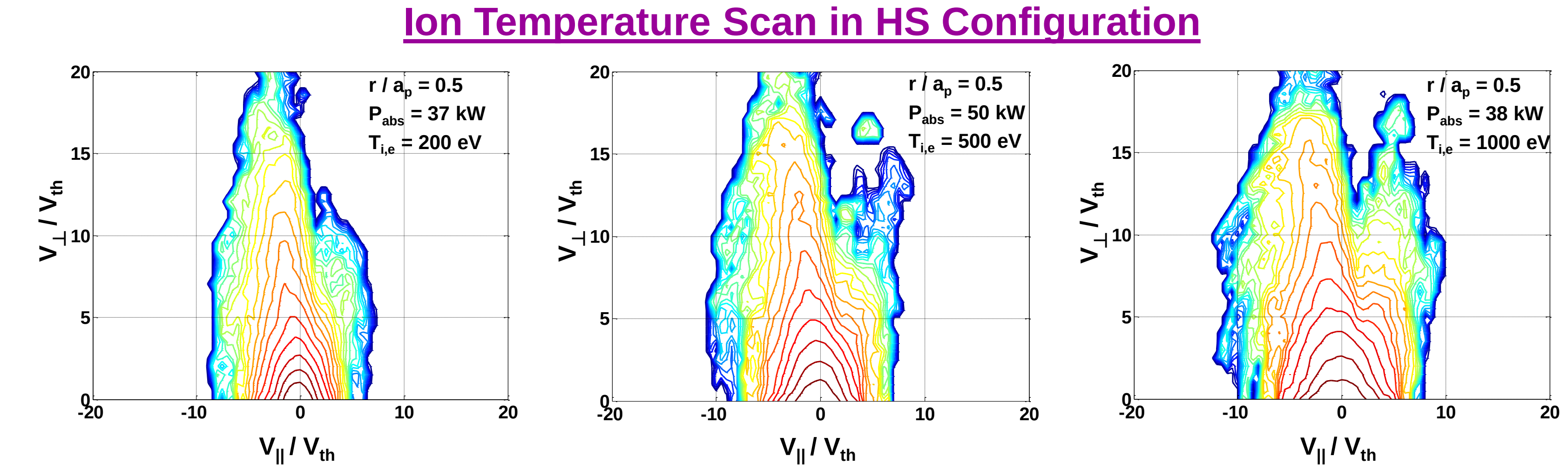


- There is a large $V_\perp$ distortion of the distribution function inside the resonance region
- High energy (> 5 keV) ions are predicted in both configurations
- In QHS a distortion is more pronounced than in HS

Electron and Ion Temperature Scans

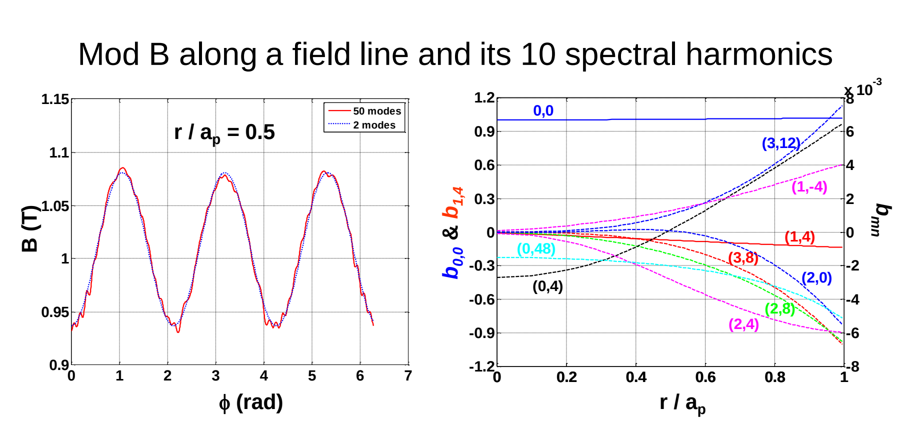


Ion Temperature Scan in HS Configuration



- At high plasma temperature the heating efficiency drops drastically
- Distortion of the ion distribution function increases with plasma temperature due to a poor confinement of high energy ions at a such low magnetic field
- As high as 20% of heating power is estimated to go directly to the ions
- Up to 80% of absorbed power will be lost through charge-exchange process and ions leaving the confinement volume

Helically Symmetric and Quasi-Symmetric Magnetic Configurations



$$B=\sum_{m,n} b_{mn}\cos(m\theta-n\phi)$$

- Helically symmetric (HS) configuration has two main terms (0,0) & (1,4) in its magnetic field spectrum
- In the quasi-helically symmetric (QHS) configuration there are non-symmetric harmonics as well
- Due to the symmetry-breaking terms the fast ions drift out from the confinement volume in a short period of time

Summary

- A new parallel version of the code has been installed on the NERSC Cray computer and benchmarked against the runs on the computer at Kyoto University
- At 1 T the heating efficiency is less than 20%
- In HSX the GNET code predicts rather high charge-exchange loss (> 60%)

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