Overview and New Directions in the HSX Program

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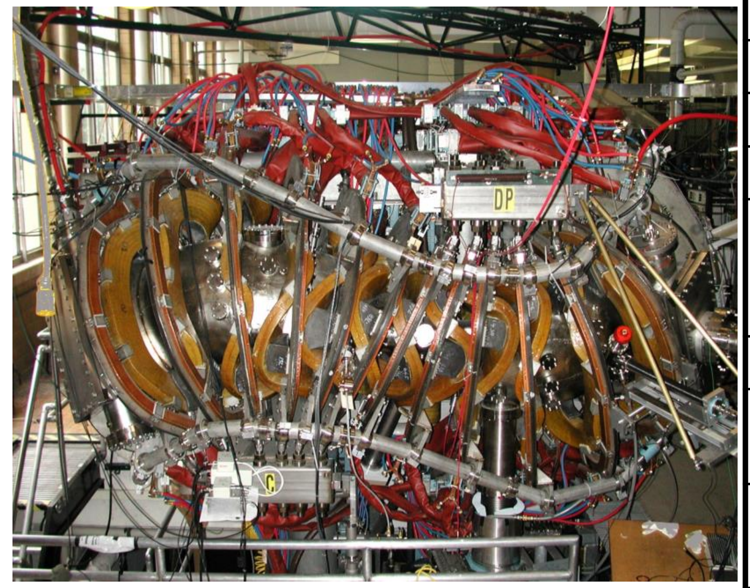
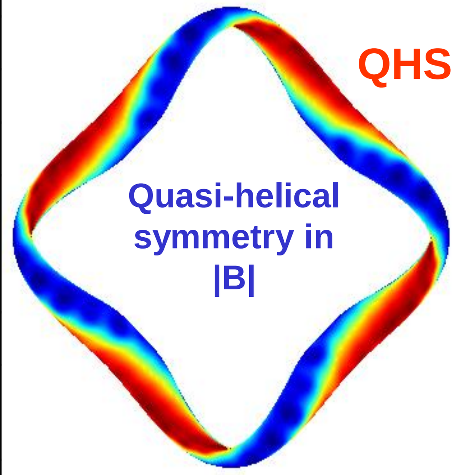
Overview

- **Neoclassical transport in qhs**
- Large intrinsic flows have been measured by CHERS in the direction of symmetry. E_r and flows modeled with PENTA which corrects DKES for momentum conservation in the collision operator.
- Impurity transport experiments have begun using laser blow-off.
- A second ECRH system with beam steering and modulation is now operational and being used for heat pulse propagation studies.
- Previous equilibrium reconstruction and fluctuation studies are being extended through optimized diagnostics.
- **Fluctuations and turbulence**
- Edge probe measurements show the Reynolds stress may play an important role in the edge poloidal momentum balance.
- Central coherent density fluctuations appear for off-axis ECRH power deposition.
- **Edges and fueling**
- Improved H-alpha diagnostics and fueling systems are being installed to better understand neutral transport. This is carried out with comparisons between DEGAS and EMC3-EIRENE.
- These codes are being applied to guide new experimental studies of the divertor structure, and divertor flows, in HSX.
- **Ion heating and particle confinement**
- The GNET 5D Fokker-Planck code is being used to study both confinement of energetic ions produced by ICRH heating, and non-Maxwellian distribution function effects on SX and ECE measurements with high power density ECRH.
- Calculations are underway to determine and possibly test elements in the magnetic structure critical for energetic particle confinement.

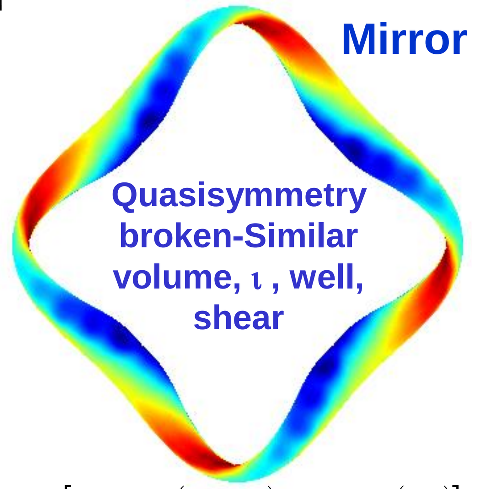
The HSX device



Major Radius	1.2 m
Minor Radius	0.12 m
# Field Periods	4
Coils/Field Period	12
Transform *Effective* transform (N- m ι)	1.05 →1.12 ~ 3
Magnetic Field	1.0 T
ECH Power (75 ms)	2 x 100kW 28 GHz
ε_{eff} at r/a = 2/3	QHS : 0.005 Mirror : 0.04



$B = B_0\left[1 + \varepsilon_h \cos(N - m\iota)\phi\right]$



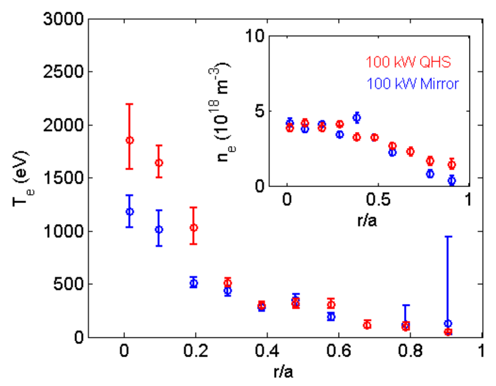
$B = B_0\left[1 + \varepsilon_h \cos(N - m\iota)\phi + \varepsilon_M \cos(N\phi)\right]$

HSX has a helical axis of symmetry in |B|, low magnetic field ripple, high effective transform, and very low toroidal curvature

- Reduction of direct loss orbits
- Improved neoclassical transport

For experimental flexibility, the quasi-helical symmetry can be broken by adding a mirror field.

Basic plasma profiles for ECH plasmas

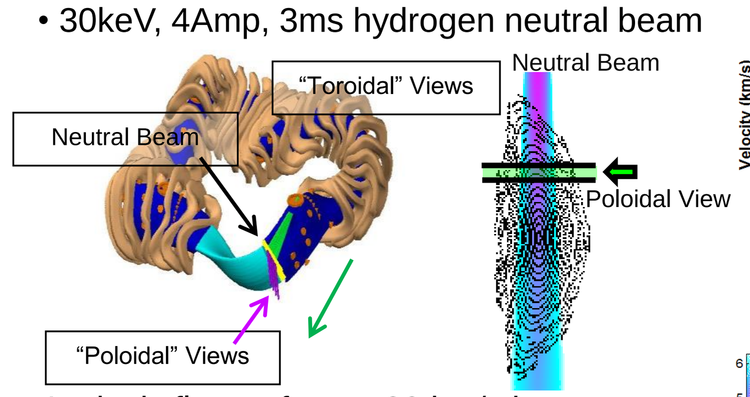


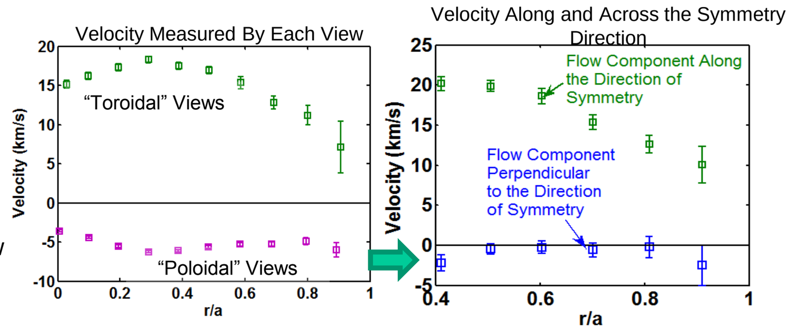
Intrinsic flow measurements and neoclassical modeling

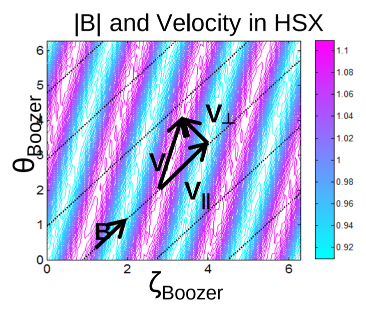
(invited talk by A. Briesemeister)

CHERS diagnostic

- 30keV, 4Amp, 3ms hydrogen neutral beam







$$\vec{V}_i = \underbrace{\left(\frac{\vec{E}_r \times \vec{B}}{B^2} - \frac{\nabla p_i \times \vec{B}}{n_i Z_i e B^2}\right)}_{\vec{V}_\perp} + \underbrace{V_{PS}\hat{b} + \frac{\langle V_\parallel B\rangle}{\langle B^2\rangle}\vec{B}}_{\vec{V}_\parallel}$$

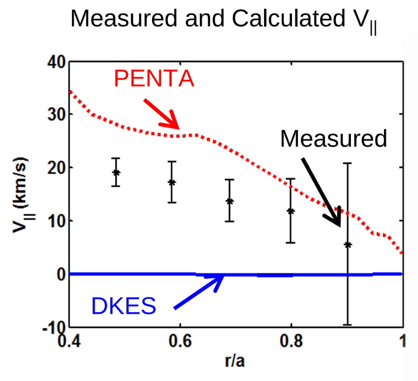
$V_\perp$ driven by ExB and diamagnetic flows.
$V_\parallel$ proportional to $V_\perp$ will arise to cause the total flow to move along helical direction of symmetry.

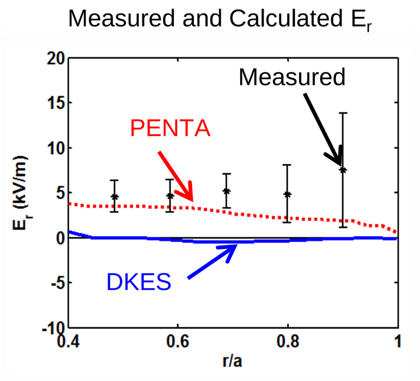
Intrinsic flows of up to 20 km/s have been observed.

These flows are in the direction of symmetry of the quasisymmetric field.

PENTA corrects **DKES** for momentum conservation in collision operator

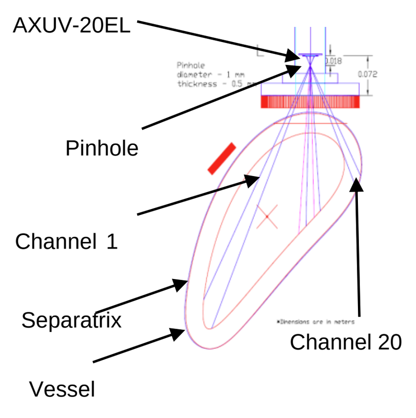
- Applicable to symmetric (quasi-symmetric stellarator and tokamak) through non-symmetric (classical stellarator) devices
- E_r is found by enforcing ambipolarity
- Differences between the E_r from PENTA and DKES become significant when there are multiple ion species in the calculation
- Momentum conservation is required for modeling to predict flows of this level

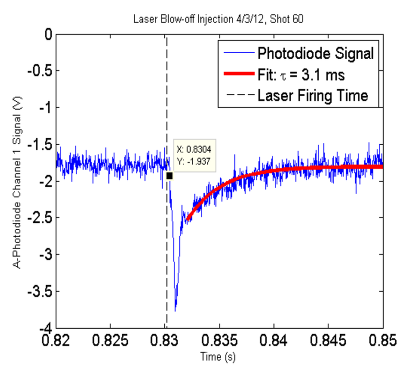


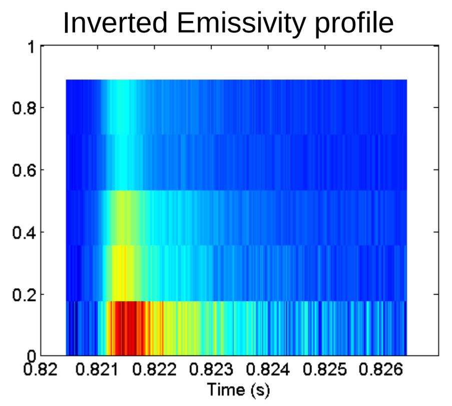


Impurity transport through laser blow-off (poster by C. Clark)

- Impurity radiation detected with full spectrum and AXUV photodiode arrays
  - Two arrays installed on HSX, 5 under construction
- The transport code STRAHL solves the 1-D continuity equation for each impurity charge state, including the source and sink terms due to ionization and recombination from adjacent charge states
- STRAHL, in conjunction with a nonlinear optimization routine, will be used to determine the impurity convective velocity and diffusivity from the time dependent emissivity profiles



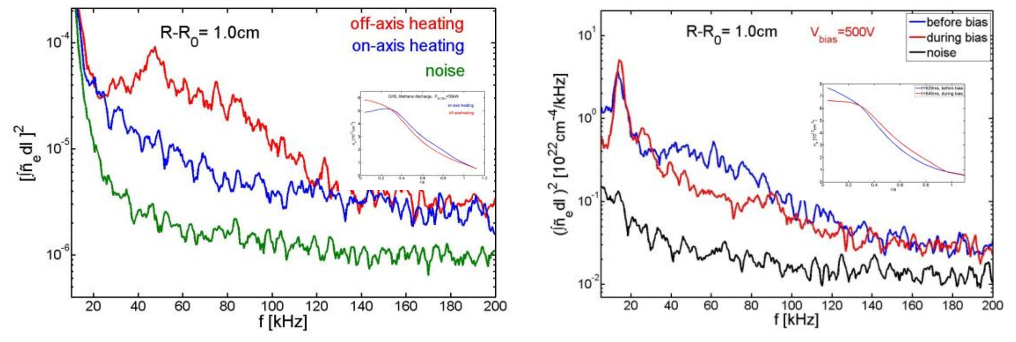




Fluctuation studies (poster by C. Deng)

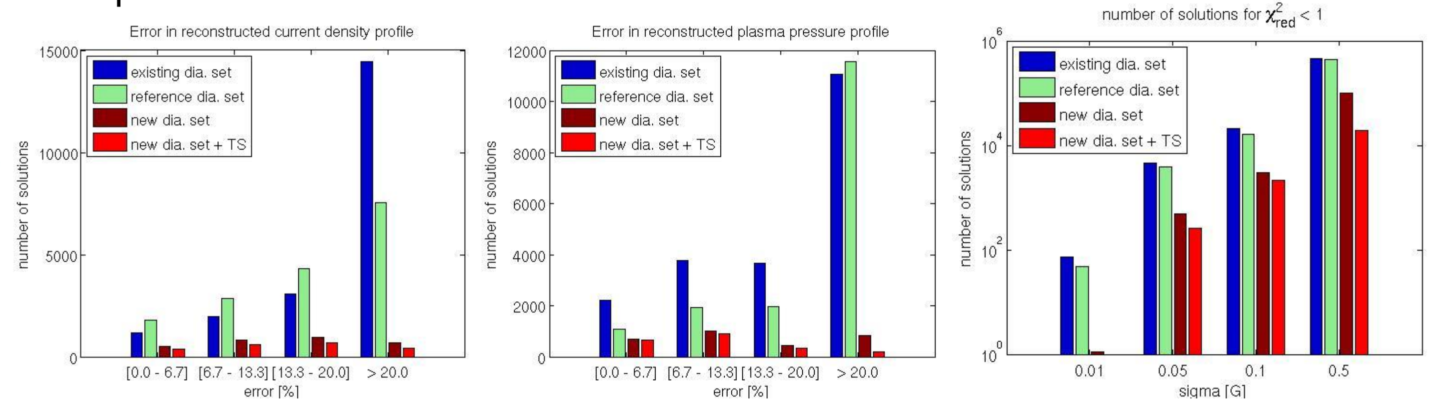
Core density fluctuation spectrum is affected by:

- ECRH heating location.
  - Density peaks while temperature drops
- Applied bias @r/a=.7
  - Density flattens and broadens



Plasma equilibrium reconstruction (poster by E. Chlechowitz)

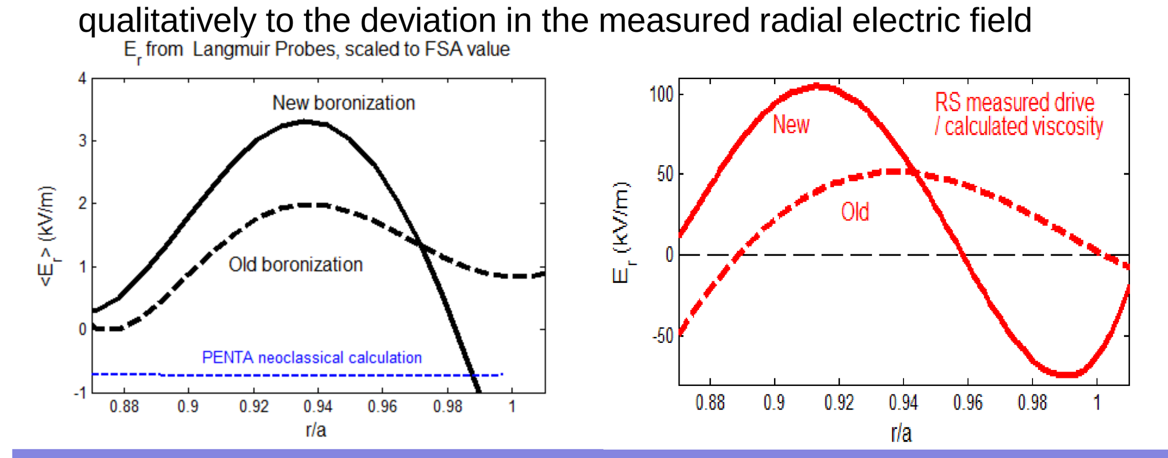
- Investigate MHD equilibrium properties via plasma reconstruction using the V3FIT code, experimental data and modeled signal responses
- Magnetic diagnostic upgrade for improved reconstruction by solution reduction and improved signal-to-noise ratio
- Calculations used to find most sensitive diagnostics relative to measured equilibrium currents



Effect of Reynolds stress on momentum balance

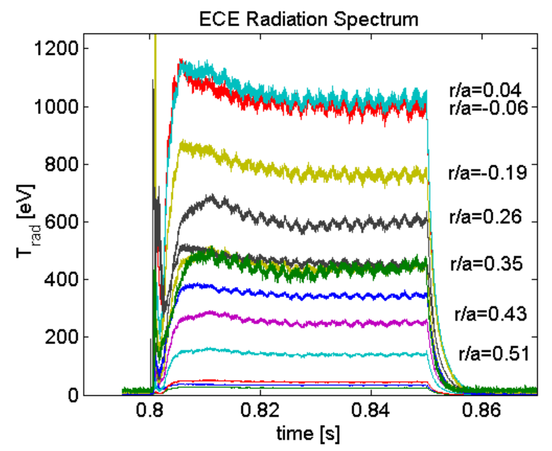
(poster by R. Wilcox)

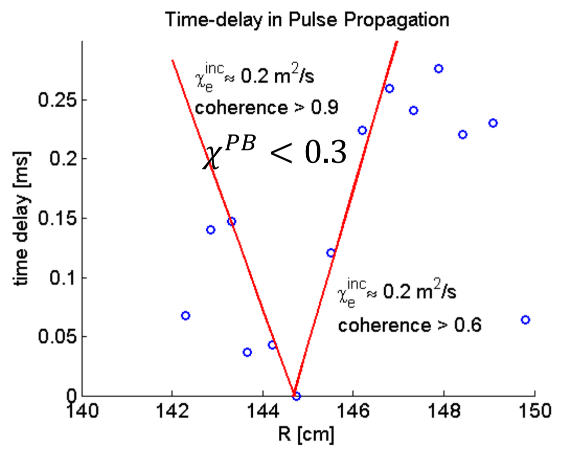
- Measurements with both Langmuir probes and CHERS indicate that E_r deviates from neoclassical calculations which calculate particle flux and enforce the ambipolarity condition
- A 5-pin Langmuir probe measures floating potential to infer $\tilde{E}_r \sim \tilde{v}_\theta$ and $\tilde{E}_\theta \sim \tilde{v}_r$ and differential ion saturation current configured as a mach probe for $V_\parallel$
- Reynolds stress drive calculated from fitted $\langle \tilde{v}_r \tilde{v}_\theta \rangle$ measurement curve and calculated poloidal viscosity, including approximate neoclassical and neutral damping terms
- Local measurements of Reynolds stress indicate a flow drive corresponding qualitatively to the deviation in the measured radial electric field



Modulated ECH experiments (poster by G. Weir)

- A second 100 kW / 28 GHz ECH system has been installed and tested, doubling the heating capacity of HSX and allowing modulated heating experiments.
- Modulated heating experiments are used to determine the electron thermal diffusivity from the dynamic response of the electron temperature using the Electron Cyclotron Emission (ECE) diagnostic.
- Initial measurements yield an incremental thermal diffusivity consistent with the power-balance value in the core of HSX and consistent with other stellarator results.





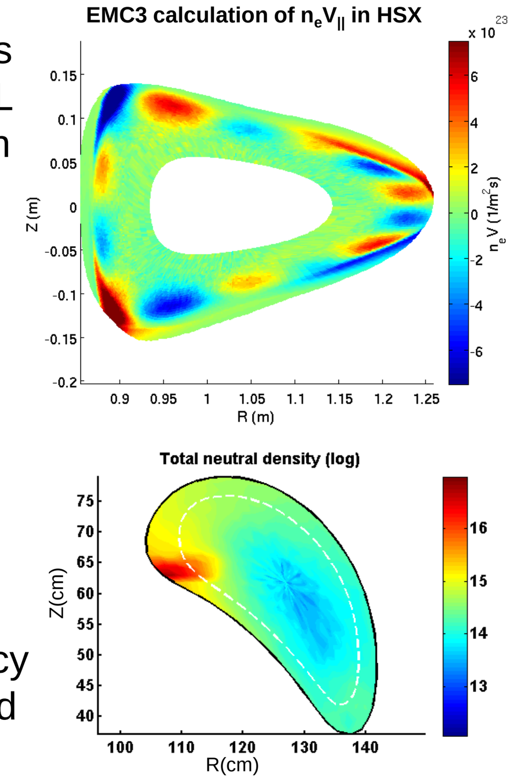
Divertors and fueling (posters by A. Bader & L. Stephey)

DIVERTORS and EDGE STRUCTURES

- EMC3 predicts the existence of measurable flows around remnant island structures in the HSX SOL
- Islands give rise to counter-streaming ion flows in the edge which are thought to degrade edge performance in stellarators such as W7-AS.
- Flow strength and location can be altered significantly with external coils, providing a testable basis for code validation.
- Measurements of flows around the islands in the edge of HSX are underway

FUELING

- DEGAS has been upgraded to simulate a supersonic gas injector (SGI) in HSX
- Simulations indicate an improved fueling efficiency
- HSX is upgrading to use a SGI fueling ystem, and increasing the toroidal number of H-alpha arrays



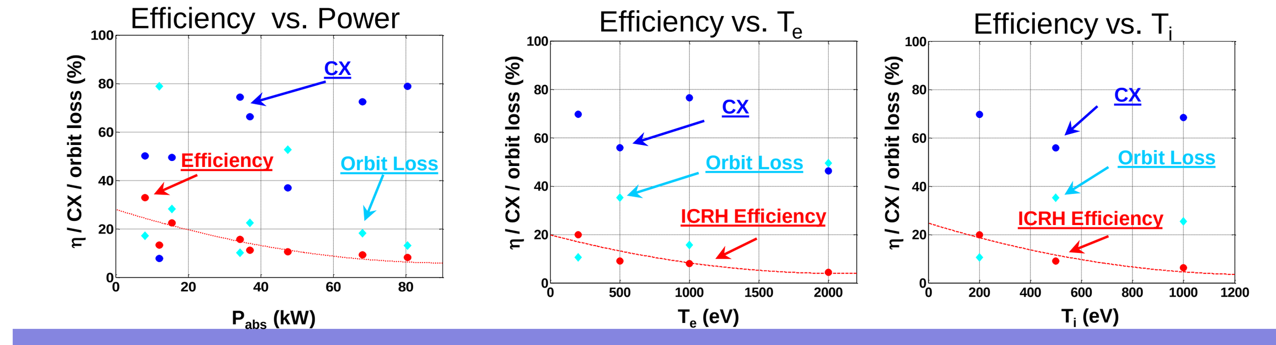
ICH and ion confinement (poster by K.M. Likin)

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

- Low ion collisionality regime becomes accessible

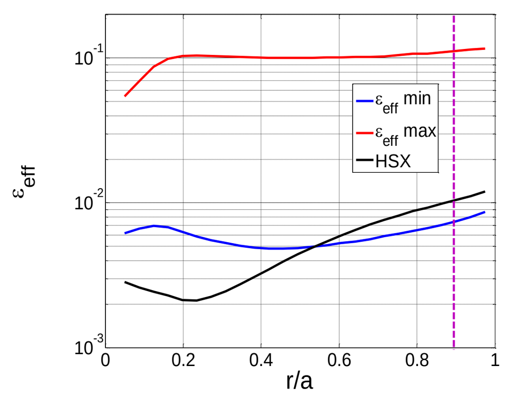
The GNET code can predict (1) efficiency of ion cyclotron resonance heating (ICRH); (2) fast ion confinement; (3) charge-exchange losses; (4) ion confinement in different magnetic configurations

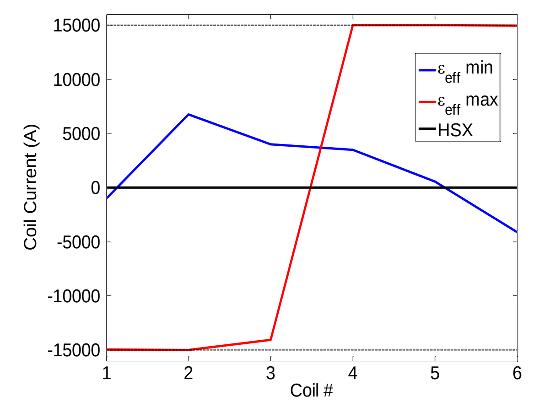


HSX Magnetic configuration studies (poster by J.N. Talmadge)

- Goal is to vary magnetic configuration using auxiliary coils and minimize or maximize target physics parameters: effective ripple, energetic particle confinement or bootstrap current. Then, test this capability experimentally.
- Initial optimization runs show that the effective ripple can be decreased with the auxiliary coils, but difficult to decrease energetic trapped particle losses at the core.
- The [n,m] = [48,0] component of the magnetic field spectrum, due to the 48 modular coils, leads to large trapped alpha particle losses in an HSX reactor. Doubling the number of coils reduces this loss.
- Minimization of effective ripple does not lead to optimized alpha particle confinement.

Optimization of ε_{eff} at r/a = 0.9





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