CONFINEMENT, FLOW-DAMPING and FLEXIBILITY of QUASI-POLOIDAL STELLARATORS

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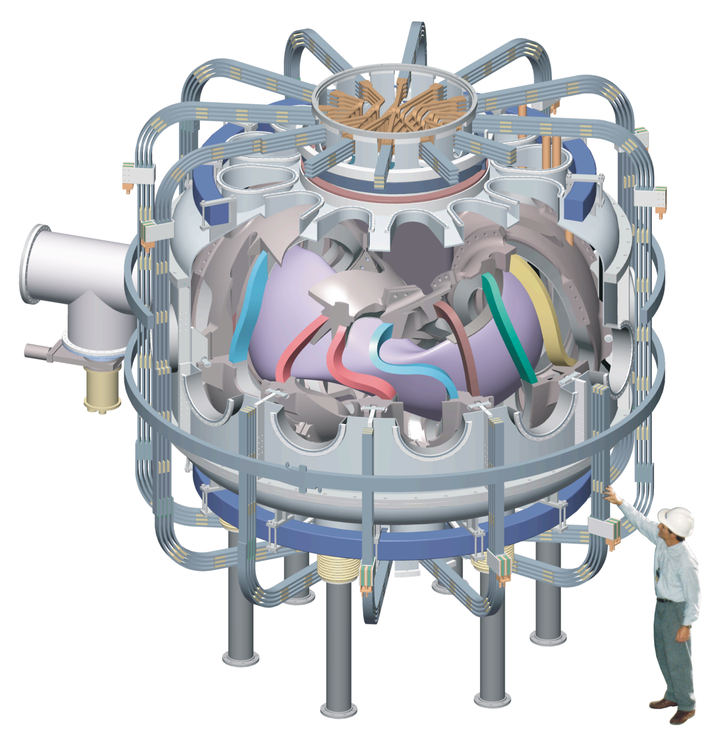


$\langle R_{pl}\rangle$ = 0.95–1 m $\langle a_{pl}\rangle$ = 0.3–0.4 m
I_{plasma} < 50 kA V_{pl} = 2–3 m^3
B_{mod} = 1 T (1.5 s) B_T = ± 0.15 T
P = 2–4 MW rf

1-D Performance Predictions

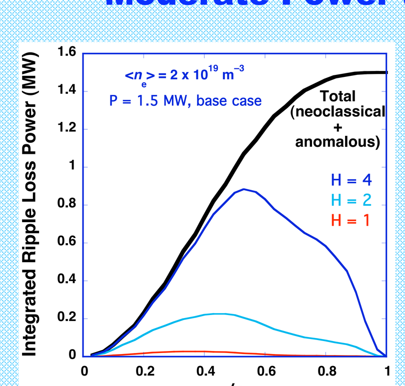
- 1-D transport model
- Fixed density/power deposition profiles
- Neoclassical: Shaing-Houlberg E_r dependence with overall $\epsilon_{eff}^{3/2}$ scaling
- Anomalous: ISS95 transport scaled to give various H factors

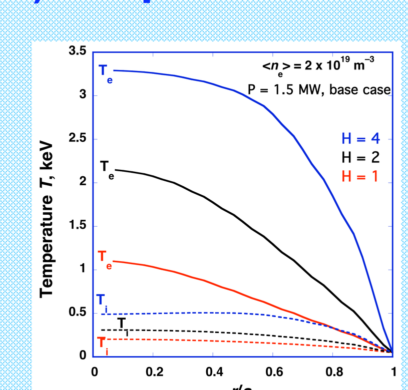
Case	H-ISS95	$\chi_{anom.}$ (m^2/sec)	$\langle\beta\rangle$ (%)	$T_e(0)$	$T_i(0)$
0.15 MW ECH 2×10^{19}m^{-3}	1 2 4	3.9 1.5 0.5	0.2 0.4 0.8	0.27 0.61 1.08	0.2 0.4 0.6
1.5 MW ECH 2×10^{19}m^{-3}	1 2 4	11.3 4.8 1.5	0.5 1.0 2.0	1.1 2.15 3.3	0.2 0.31 0.49

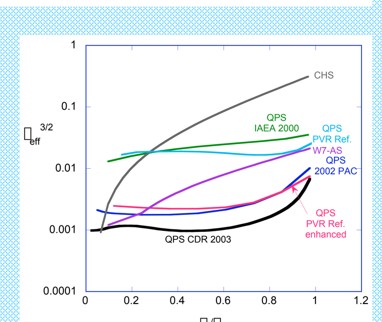
The following cases require development of high density heating techniques.

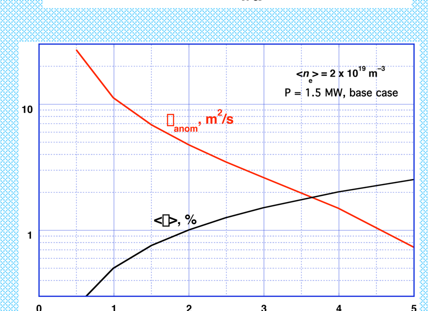
Case	H-ISS95	$\chi_{anom.}$ (m^2/sec)	$\langle\beta\rangle$ (%)	$T_e(0)$	$T_i(0)$
2 MW EBW/ICR 10^{20}m^{-3}	1 2 4	7 2.9 1.2	1.3 2.6 5.2	0.36 0.78 1.5	0.3 0.62 1.0
4 MW EBW/ICR 10^{20}m^{-3}	1 2 4	10 4.2 1.7	1.7 3.4 6.8	0.53 1.14 2.0	0.38 0.74 1.1

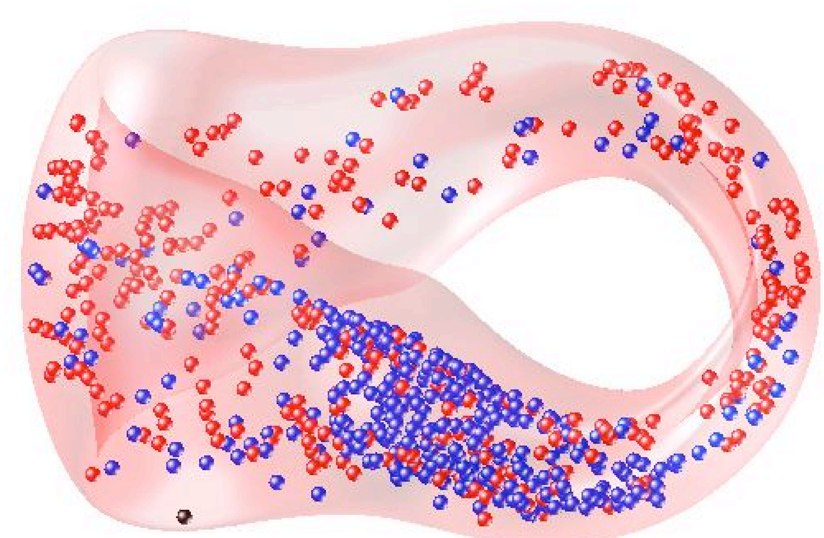
Moderate Power (1.5 MW) ECH predictions









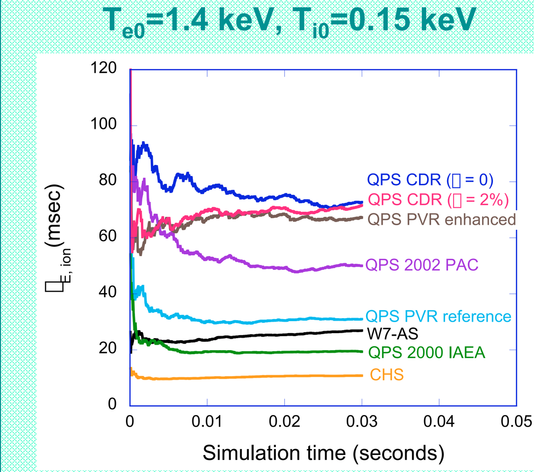


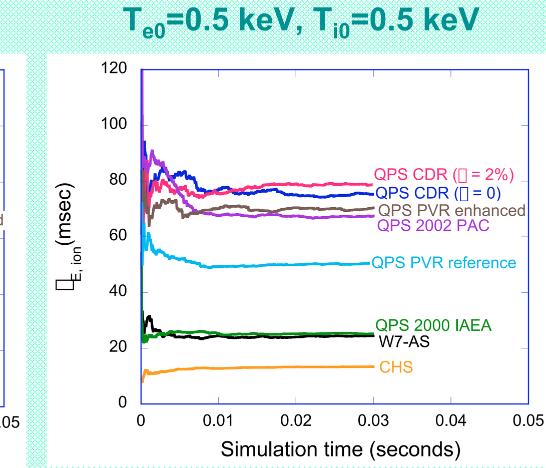
Monte Carlo assessments

- Global Monte Carlo includes diffusive and nonlocal losses
- Current QPS design shows improved $\tau_{E,ion}$ over earlier designs and existing devices
- Flexibility studies show $\tau_{E,ion}$ can be varied by a factor of 2

Monte Carlo configuration comparisons

ECH regime: n = 1.8×10^{19}m^{-3}, T_{e0}=1.4 keV, T_{i0}=0.15 keV
ICH regime: n = 8.3×10^{19}m^{-3}, T_{e0}=0.5 keV, T_{i0}=0.5 keV

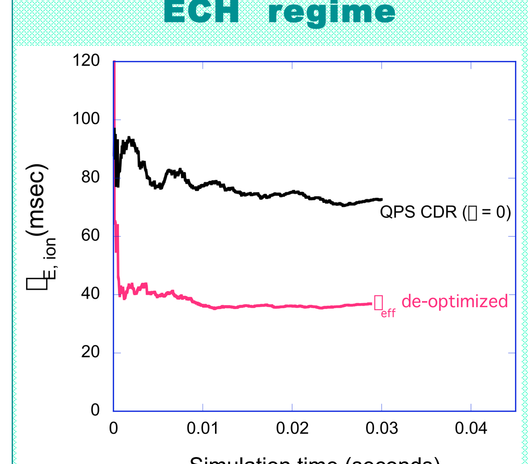


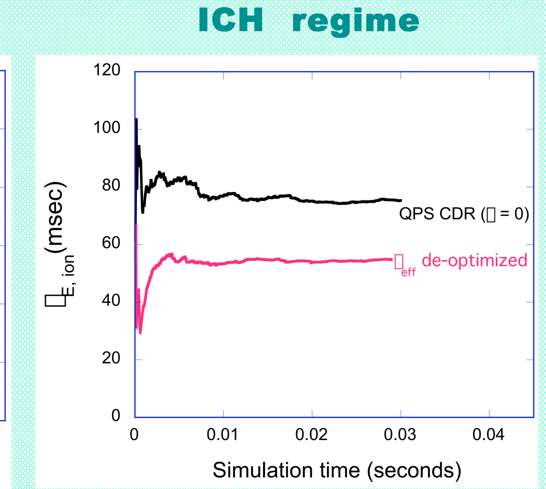


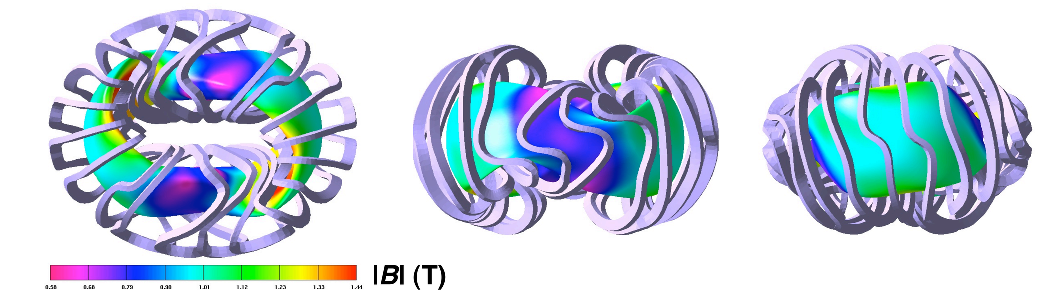
Monte Carlo flexibility studies

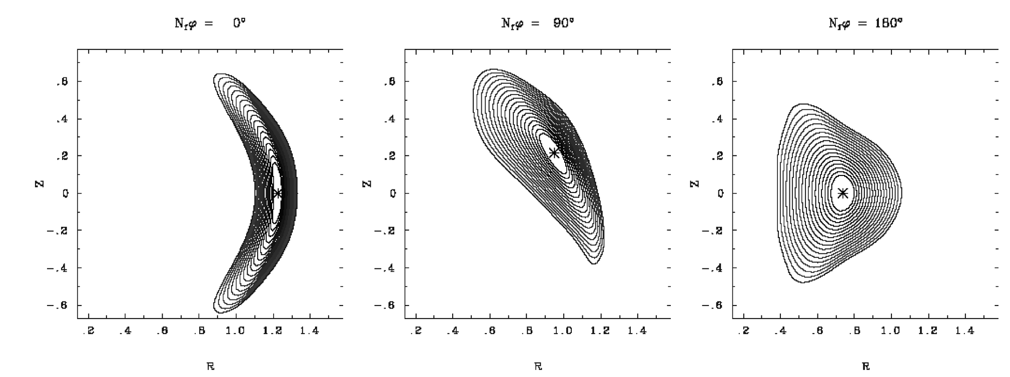
(using coil current variation)

ECH regime **ICH regime**



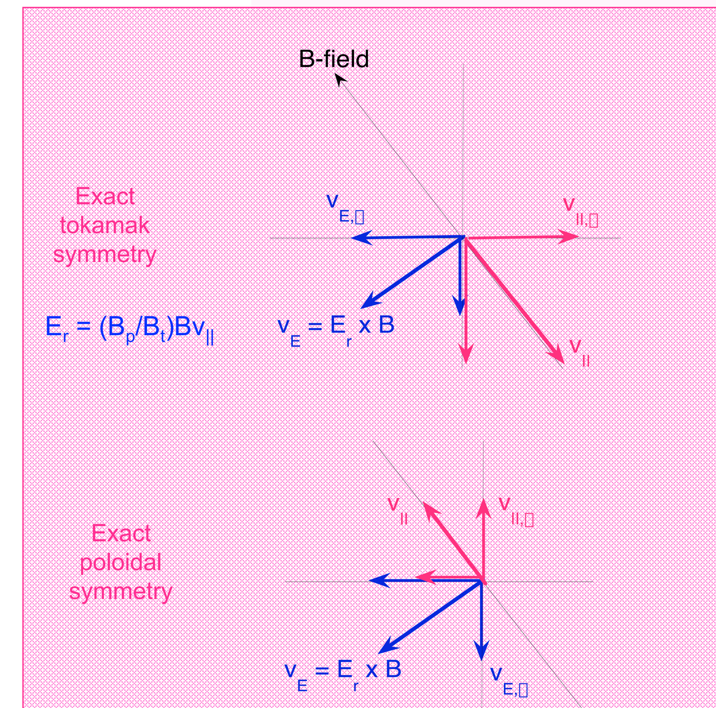




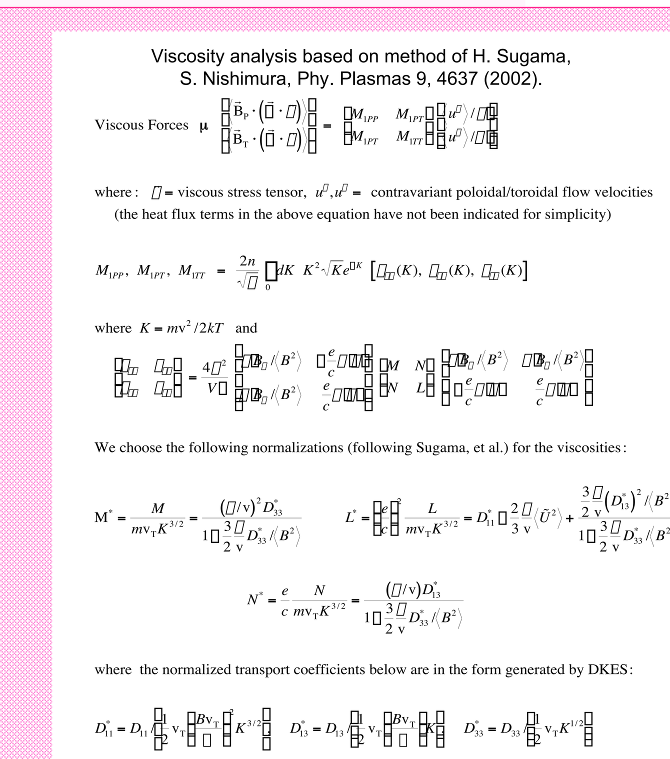


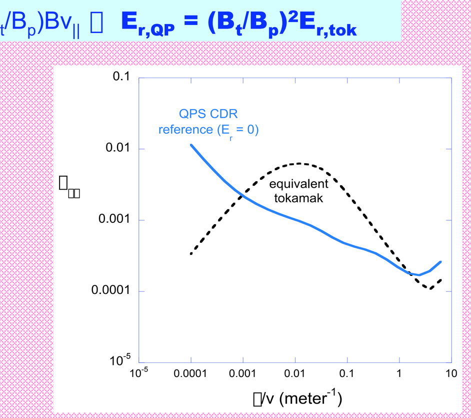
Viscosities/flow damping

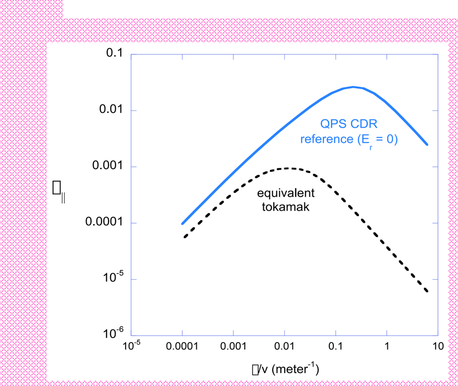
- Exact QP E_r $(B_{tor}/B_{pol})^2$ larger than that in a tokamak
- QPS (multi-helicity) poloidal viscosity factor of 10 < tokamak
- Potential for greater control over E_r shear/confinement enhancement



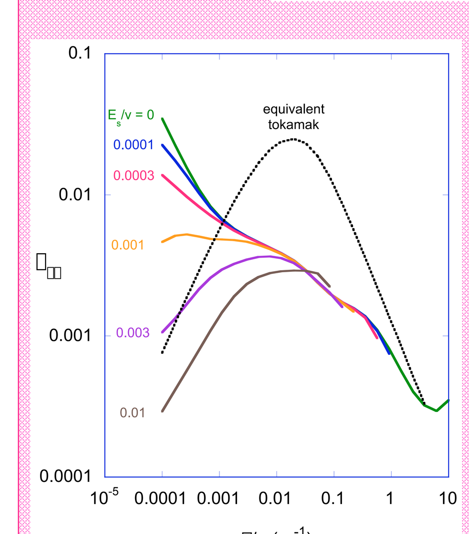
$E_r = (B_t/B_p)Bv_{||}$ $E_{r,QP} = (B_t/B_p)^2E_{r,tok}$

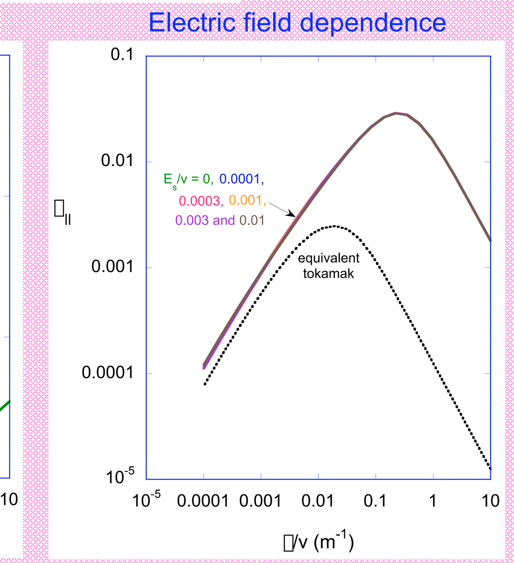


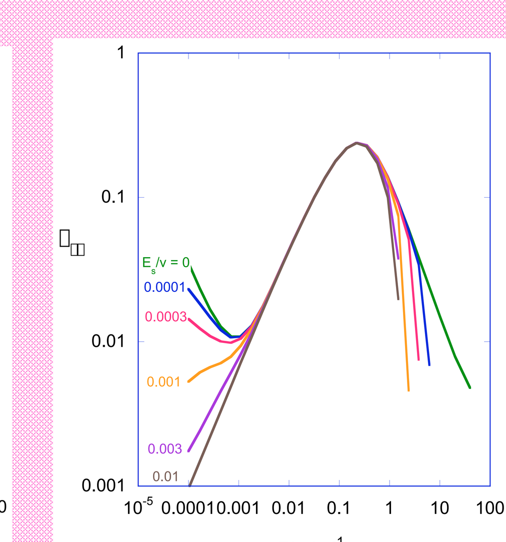


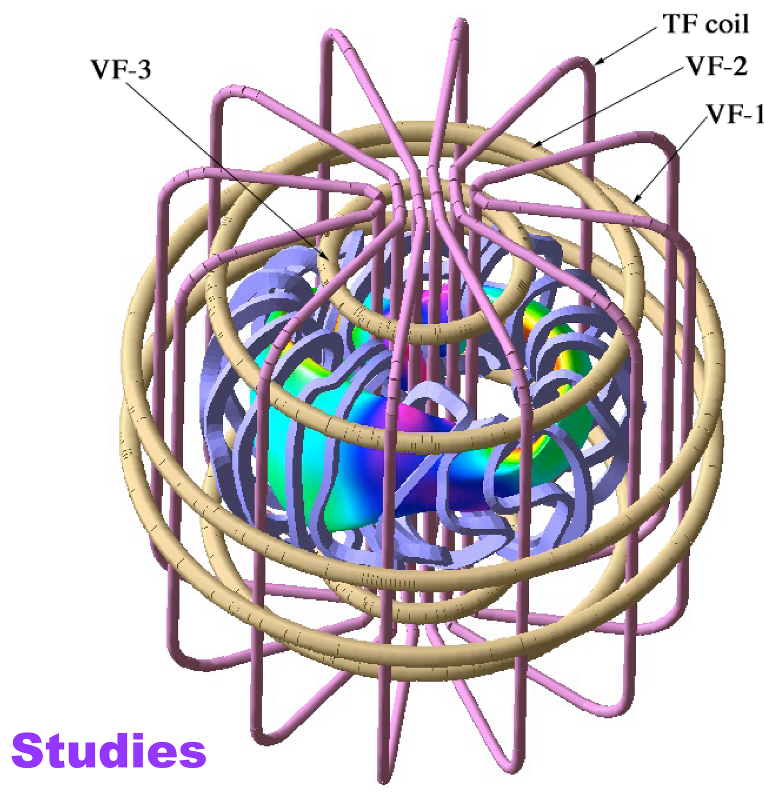


Electric field dependence









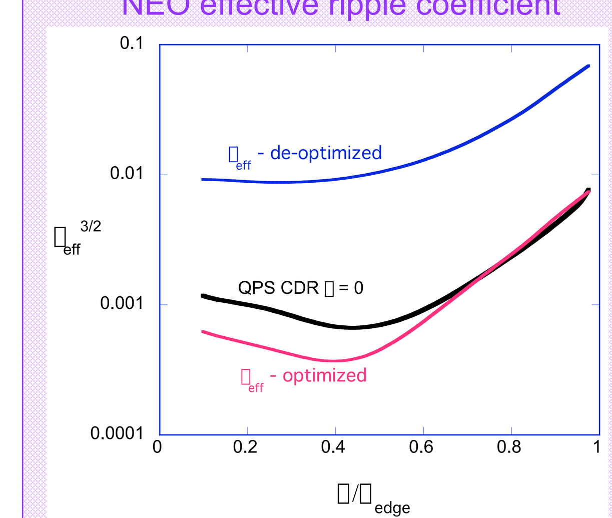
Flexibility Studies

QPS Flexibility Studies

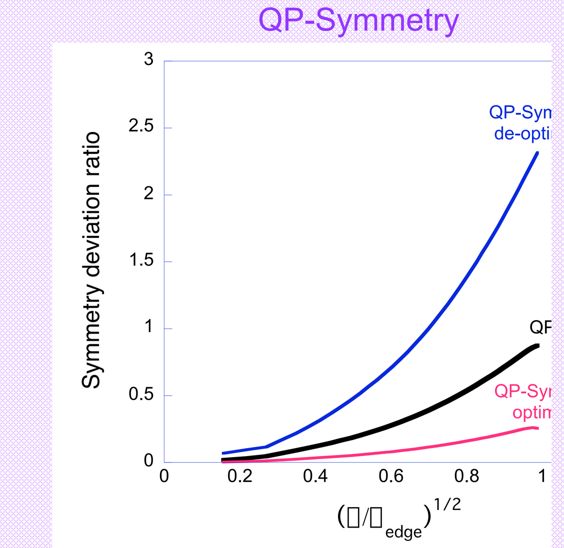
- Flexibility is a significant advantage offered by stellarator experiments
- Flexibility will aid scientific understanding in:
  - –Flux surface fragility/island avoidance
  - –Neoclassical vs. anomalous transport
  - –Transport barrier formation
  - –Plasma flow dynamics
  - –MHD stability
- QPS offers flexibility through:
  - –5 individually powered modular coil groups, 3 vertical field coil, toroidal field coil set, Ohmic solenoid. Variable ratios of Ohmic/bootstrap current

Variation of transport criteria with coil current optimization/de

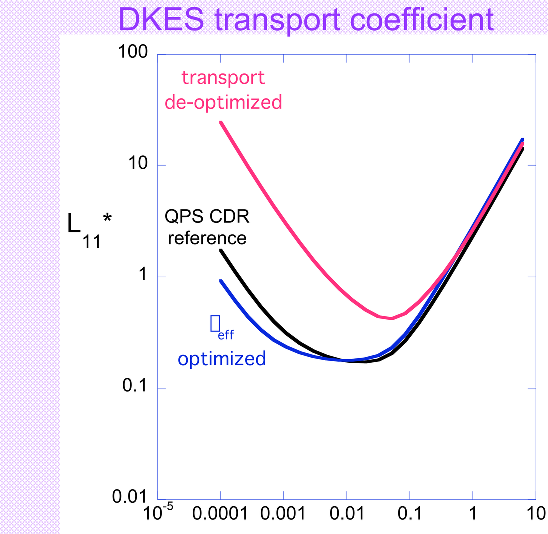
NEO effective ripple coefficient



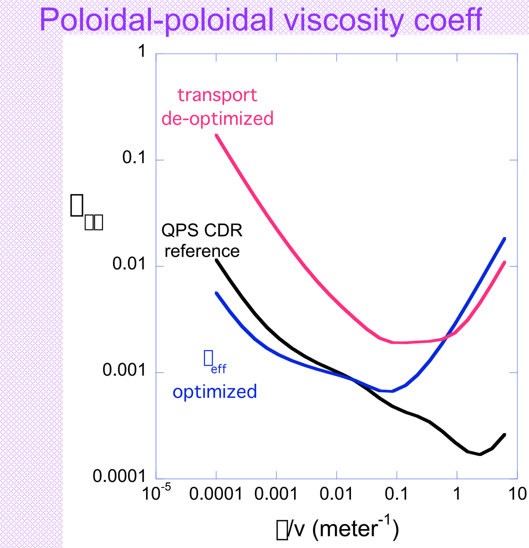
QP-Symmetry



DKES transport coefficient

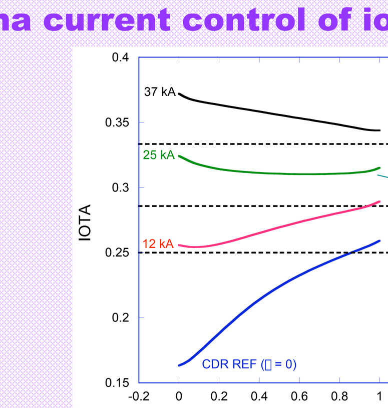


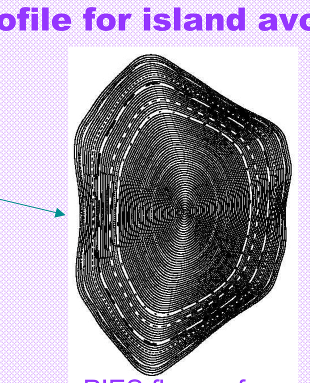
Poloidal-poloidal viscosity coeff



Coil/plasma current control of iota profile for island avoidanc

β = 0%

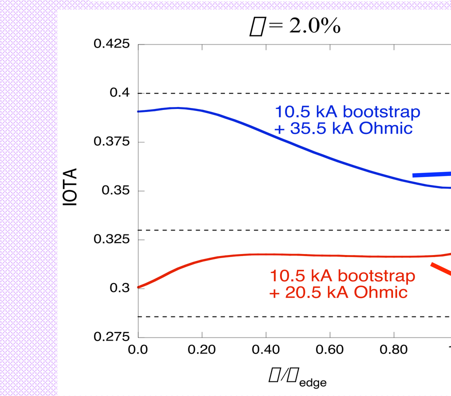


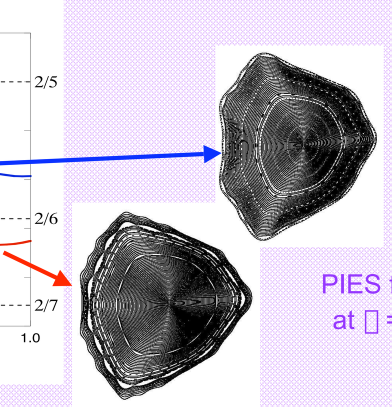


PIES flux surface at ϕ = 0° plane

β = 2.0%

β = 2%



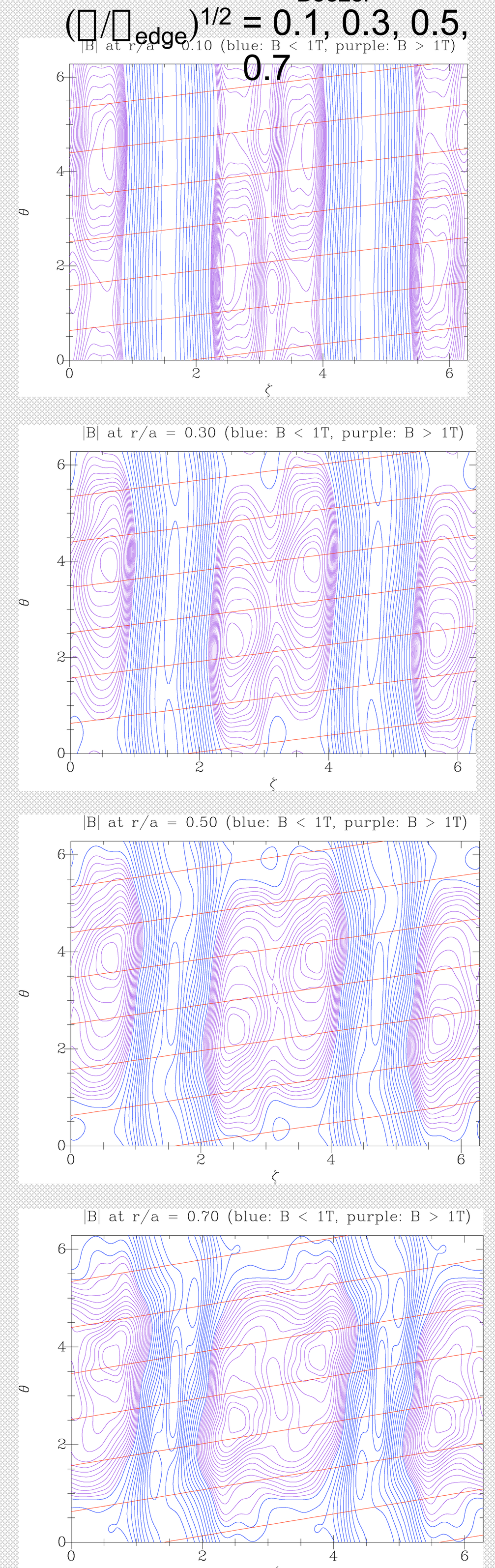


PIES flux surf at ϕ = 90° pl

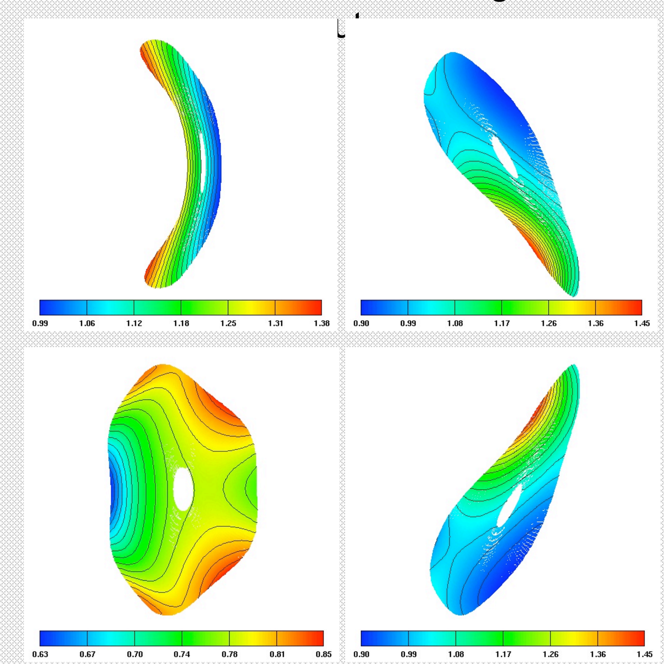
QPS Magnetic Structure

- Exact poloidal symmetry would make P_θ a constant of the motion
  - –banana width ~ gyroradius in toroidal rather than poloidal field
- Finite value of m = 0 modes at magnetic axis allows
  - – high degree of poloidal symmetry near axis (m≠0 modes go to 0 at axis)
  - – Finite levels of bootstrap current at the magnetic axis

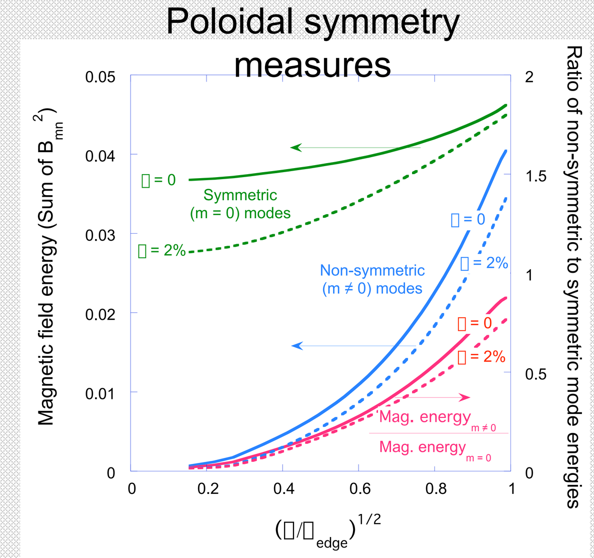
|B| vs. $(\theta, \phi)_{Boozer}$ for $(\psi/\psi_{edge})^{1/2}$ = 0.1, 0.3, 0.5, 0.7



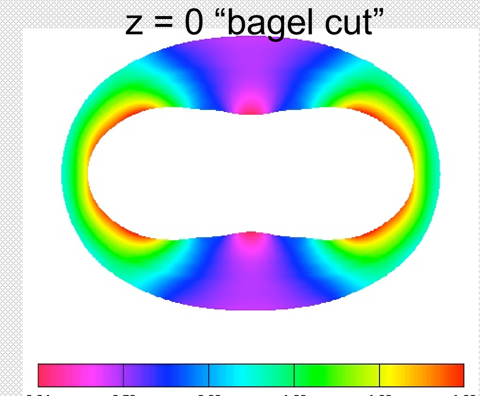
Constant toroidal angle



Poloidal symmetry measures

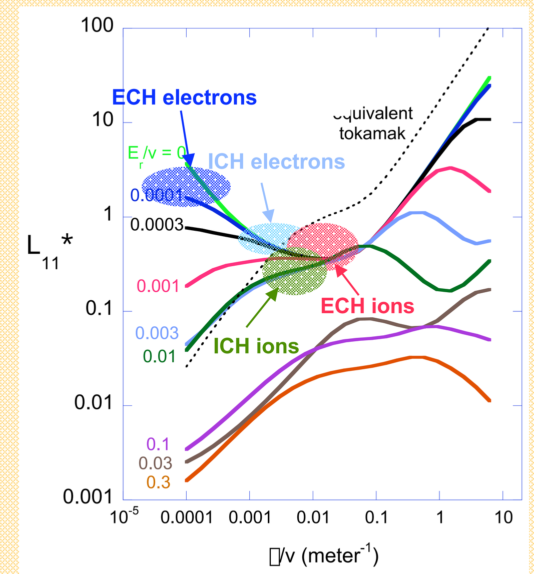


z = 0 "bagel cut"

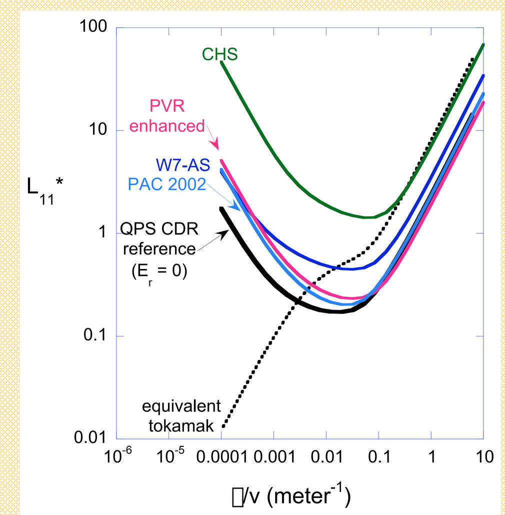


Transport coefficients

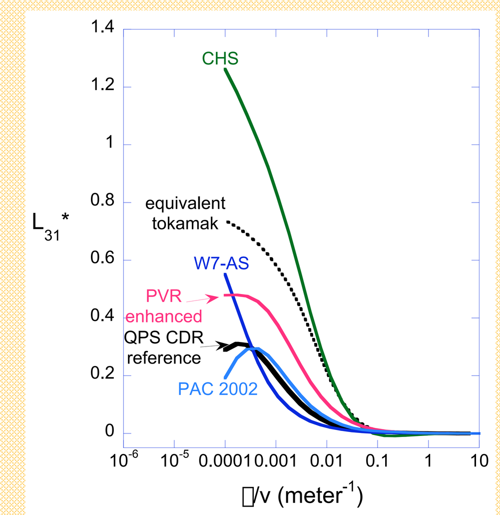
- Low collisionality: ϵ_{eff} from NEO code*
- Finite collisionality: L_{11}, L_{13}, L_{33} from DKES
- Ambipolar electric field roots
- Will be integrated into 1-D model



Device comparison: L_{11}

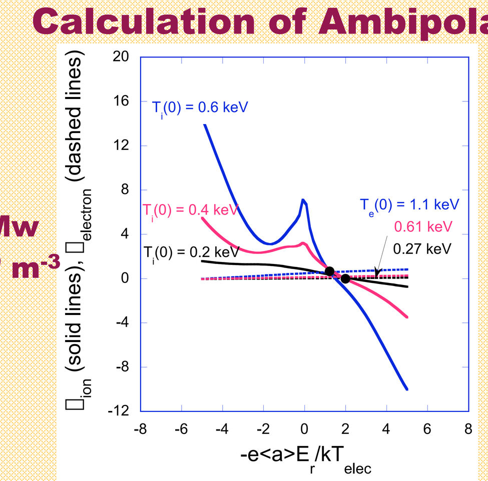


Device comparison: L_{31}

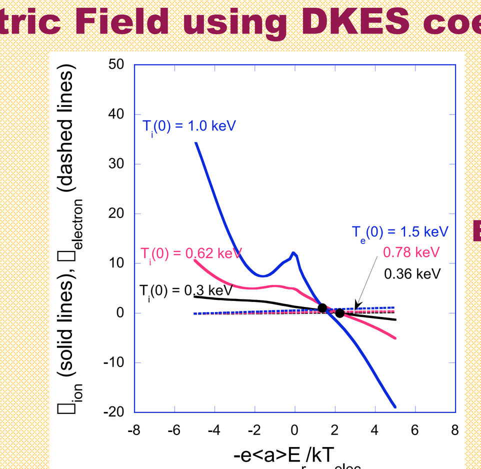


Calculation of Ambipolar Electric Field using DKES coefficients:

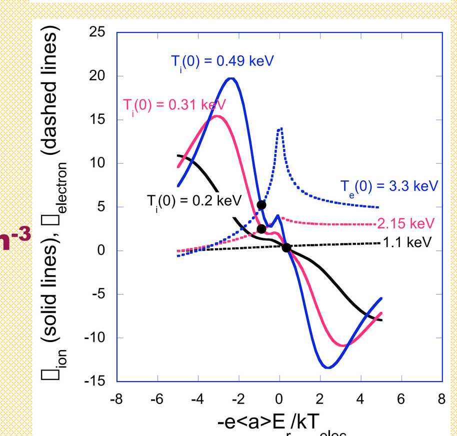
ECH, 0.15 Mw
n(0) = 2x10^{19} m^{-3}



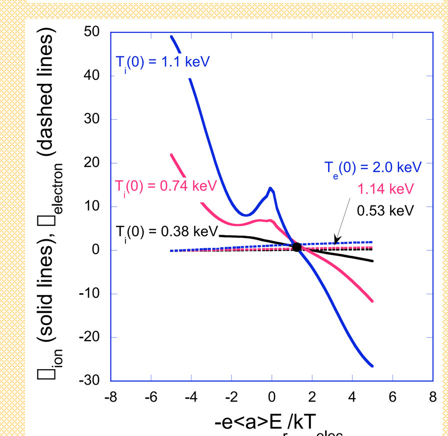
EBW/ICH, 2 Mw
n(0) = 10^{20} m^{-3}



ECH, 1.5 Mw
n(0) = 2x10^{19} m^{-3}



EBW/ICH, 4 Mw
n(0) = 10^{20} m^{-3}



Multi-species transport with momentum conserving corrections

- Based on Appendix C of H. Sugama, S. Nishimura, Phys. Plasmas 9, 4637 (2002).
- Classical parallel friction included
- m_e/m_{ion} << 1, electrons + single ion species assumed

$$\begin{pmatrix} \Gamma_e \\ Q_e/T_e \\ \Gamma_i^{bn} \\ Q_i/T_i \\ J_E^{BS} \end{pmatrix} = \begin{pmatrix} L_{11}^{ee} & L_{12}^{ee} & L_{11}^{ei} & L_{12}^{ei} & L_{1E}^{e} \\ L_{21}^{ee} & L_{22}^{ee} & L_{21}^{ei} & L_{22}^{ei} & L_{2E}^{e} \\ L_{11}^{ie} & L_{12}^{ie} & L_{11}^{ii} & L_{12}^{ii} & L_{1E}^{i} \\ L_{21}^{ie} & L_{22}^{ie} & L_{21}^{ii} & L_{22}^{ii} & L_{2E}^{i} \\ L_{E1}^{e} & L_{E2}^{e} & L_{E1}^{i} & L_{E2}^{i} & L_{EE} \end{pmatrix} \begin{pmatrix} X_{e1} \\ X_{e2} \\ X_{i1} \\ X_{i2} \\ X_E \end{pmatrix}$$

where $\Gamma_{e,i}$ = electron and ion particle fluxes

$Q_{i,e}$ = electron and ion energy fluxes

J_E^{BS} = bootstrap current

$$X_{a1} = -\frac{1}{n_a}\frac{\partial p_a}{\partial s} - e_a\frac{\partial \Phi}{\partial s}, \qquad X_{a2} = -\frac{\partial T_a}{\partial s}$$

$$X_E = \langle B E_\parallel \rangle / \langle B^2 \rangle^{1/2}$$

QPS ambipolar electric field roots based on above fluxes