Two sets of MHD simulations are presented in which resonant magnetic perturbation (RMP) vacuum fields are imposed on DIII-D equilibria

Three simulations with DIII-D shot 113317 (NIMROD code is used for all simulations) **Four simulations with DIII-D shot 119690**

- Not an RMP experimental discharge
- Measured density and temperature profiles
- Three artificially imposed rotation profile
- 3 kA even parity I-coil currents
- Measured error fields + 1 kA C-coil currents
- S (= $\tau_{L/R}/\tau_A$) = 3×10^5

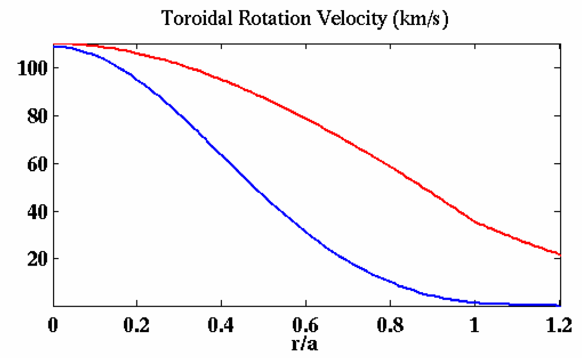
- Low collisionality odd parity I-coil experiment
- Measured n_e and T_e profiles
- Measured rotation profile
- 4.4 kA I-coil current (odd parity and even parity cases)
- Measured error fields, no I-coil current
- S=5 $\times10^5$ and 5 $\times10^6$

- Three simulations with:

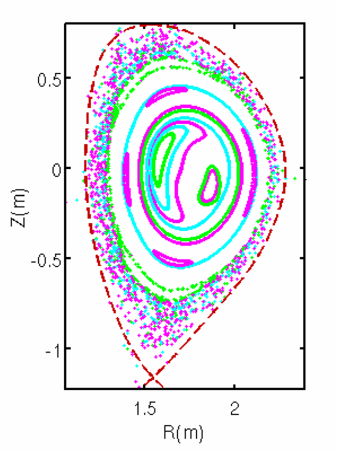
1)No rotation

2)Low edge rotation

3)High edge rotation

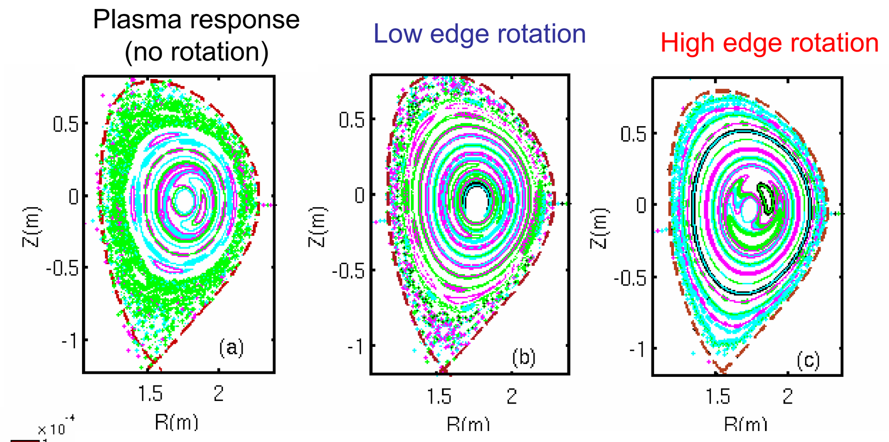


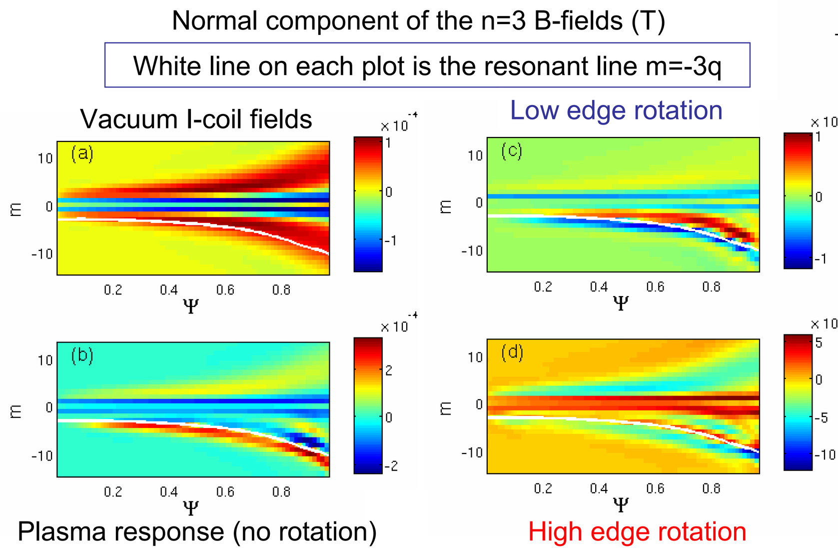
- Effects of rotational screening on applied RMP fields are investigated in real geometry



- Vacuum fields superposed on the equilibrium is a non-equilibrium initial condition

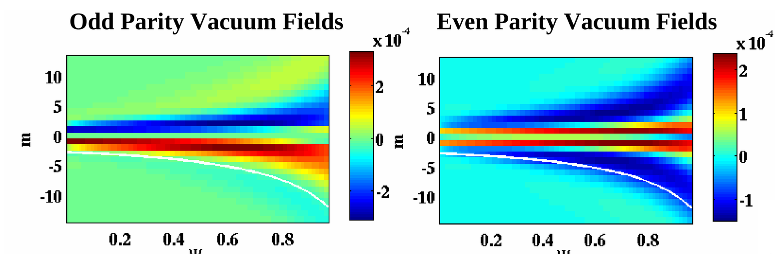
Each simulation is evolved for several reconnection times until a steady state magnetic field configuration is reached





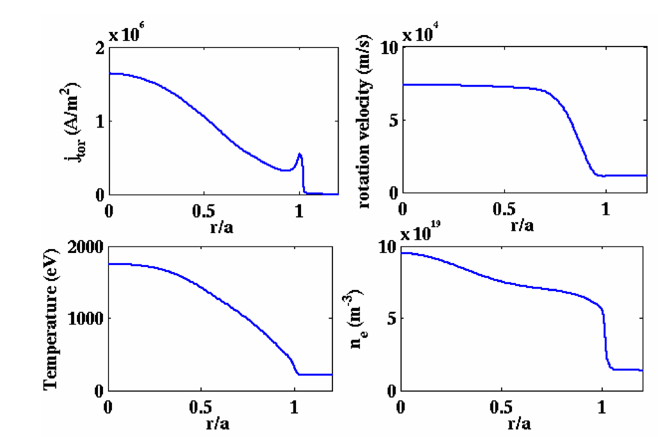
- Without rotation, final saturated state has larger stochastic region than initial condition
- Increasing rotation at the edge produces better quality flux surfaces as RMP fields are screened

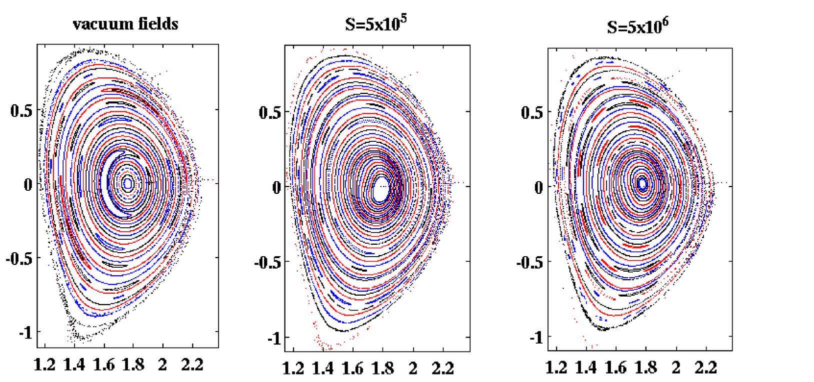
- Four simulations: even and odd parity I-coils; S=5x10^5 and S=5x10^6



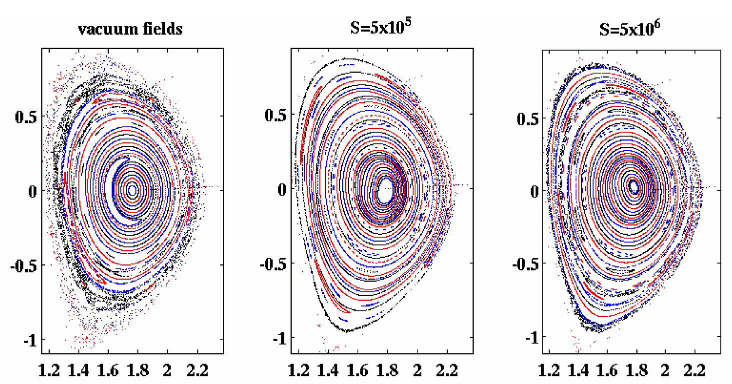
- Even up-down I-coil parity has stronger resonant components than odd parity

Experimental Profiles





↑Odd parity I-coil fields



↑Even parity I-coil fields

- Mostly non-resonant fields produce small islands, little stochasticity
- Higher S case most closely resembles the 119690 experiment (still one order of magnitude too resistive).
- Considerable vacuum field edge stochasticity is well screened by the plasma even at low S
- In all cases, m=1/n=1 island is well screened by the plasma rotation

Comparison of simulations with cylindrical error field theory

- Theory does not include any toroidal effects such as mode coupling, hence the comparison can give some insight into the importance of realistic geometry

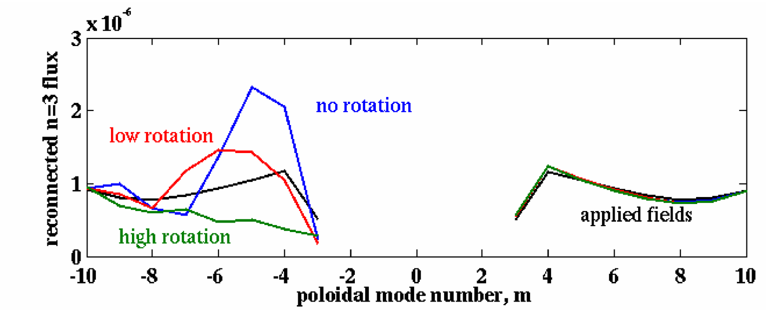
$$\Psi_s = \frac{2m}{-\Delta' + \Delta(\omega)}\Psi_v$$

Reconnected flux — Vacuum flux — Tearing stability index — n times plasma rotation frequency — Boundary layer response to the applied error fields at the mode rational surface

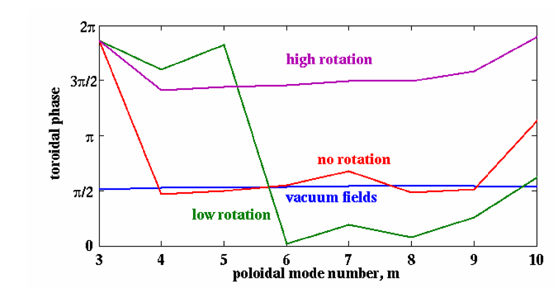
→ Without rotation, error fields are amplified in tearing stable plasmas with $-\Delta'<2m$

- Mode amplification is an ideal response dependent only on the tearing stability parameter, Δ'
- Rotational screening is a resistive effect dependent on rotation velocity, resistivity, viscosity and other factors

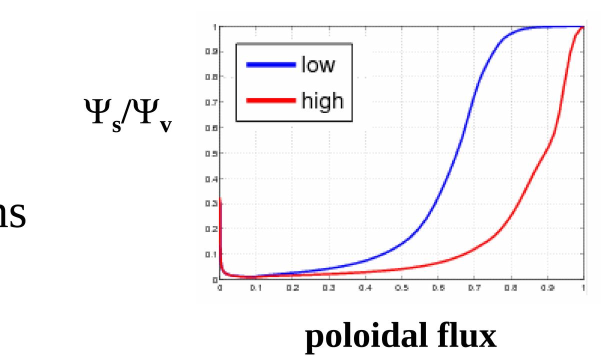
Ψ_s and Ψ_v for 113317

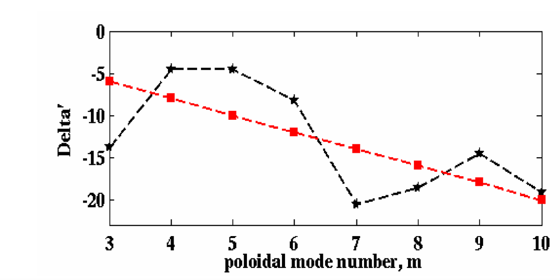


- Positive m are non-resonant modes (unaffected by plasma response), resonant negative m components are amplified, screened



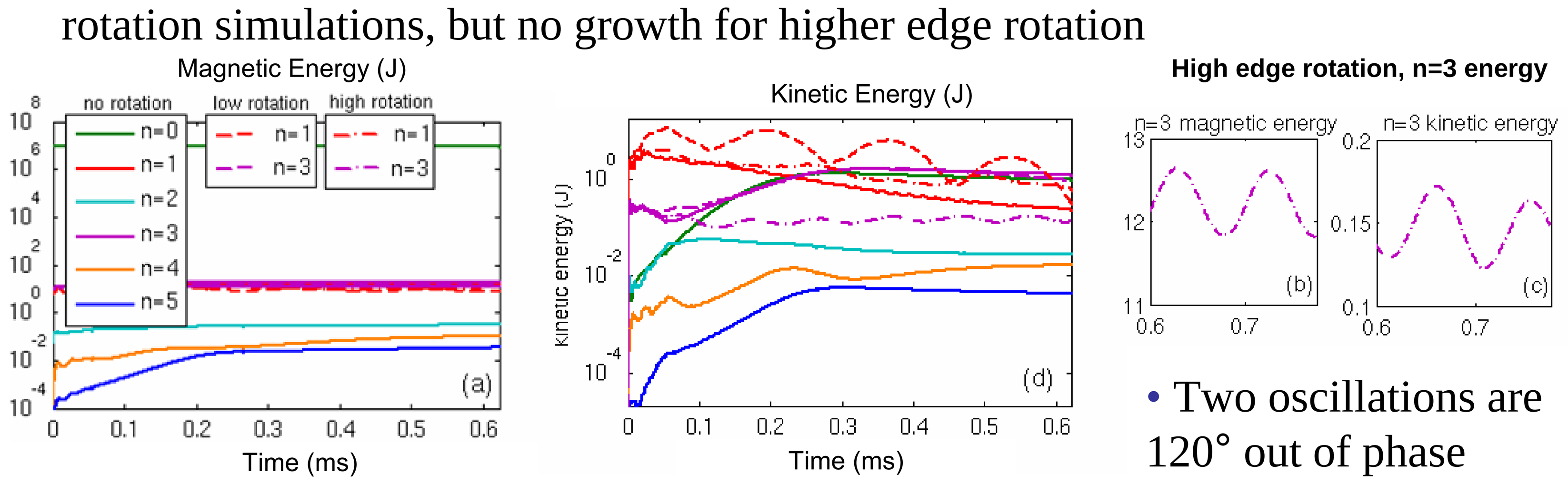
- Phases of the resonant components evaluated at the resonant surfaces. A strongly screened mode in the visco-resistive regime has a phase shift of $\pi/2$
- Theoretically calculated screening factors calculated for the low and high rotation simulations assuming $-\Delta'$=2m (no amplification)



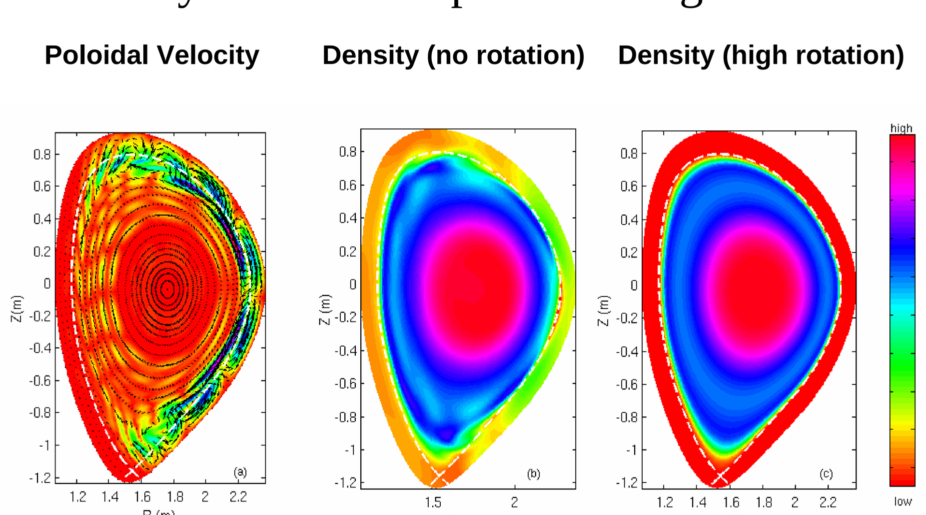


- The non-rotating simulation is used to determine the amplification alone, which depends only on Δ'

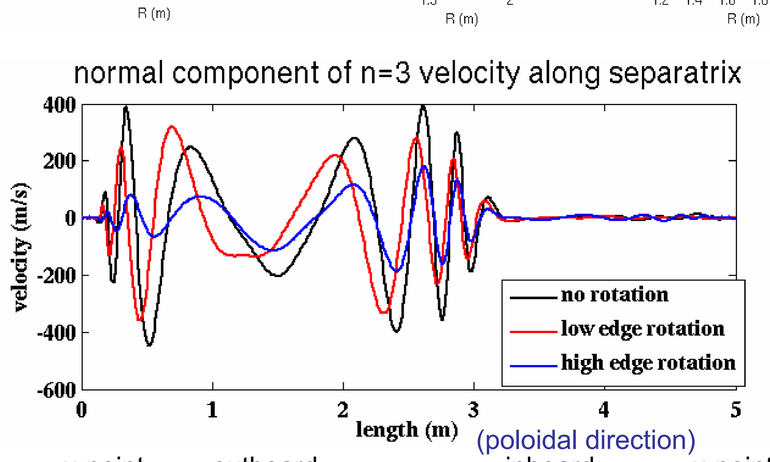
- Growth of n=3 kinetic energy observed in no rotation and low edge rotation simulations, but no growth for higher edge rotation



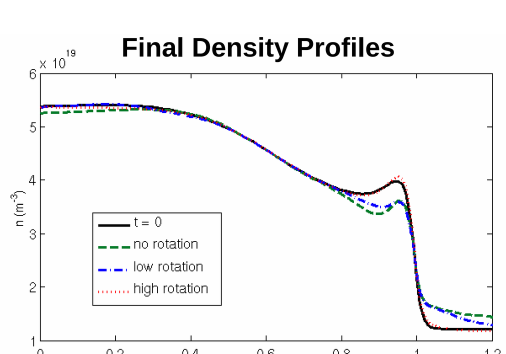
- Two oscillations are 120° out of phase
- 10 kHz n=3 oscillation for high edge rotation, and 5.8 kHz n=1 oscillation for low rotation are observed in the mode energy time history
- Density evolution depends on edge rotation velocity:



- ExB n=3 convection cells crossing the separatrix push particles into the vacuum region
- High rotation at the separatrix eliminates the density pump-out effect

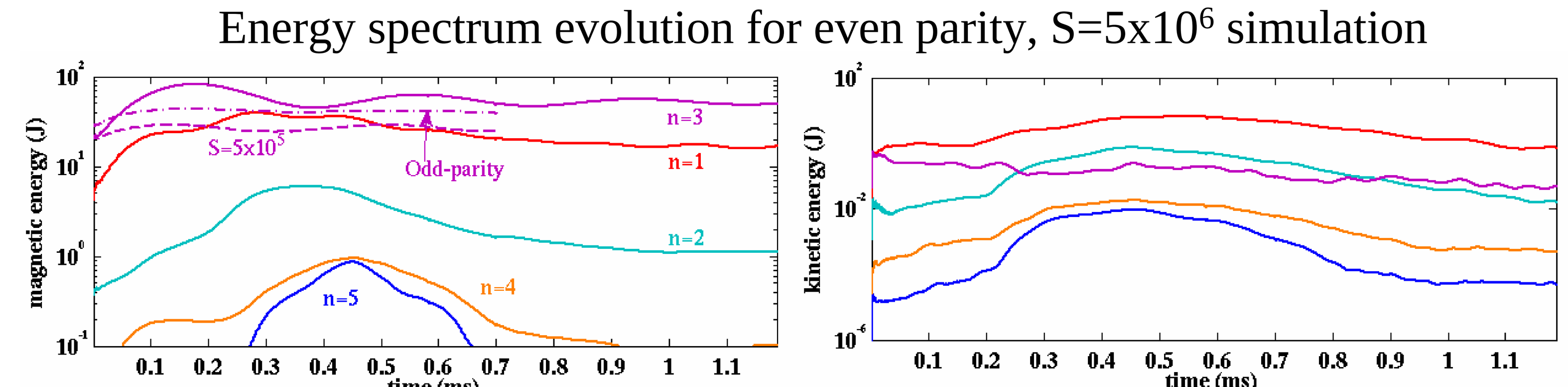


- Pedestal density is reduced for no, low rotation, unchanged at high rotation

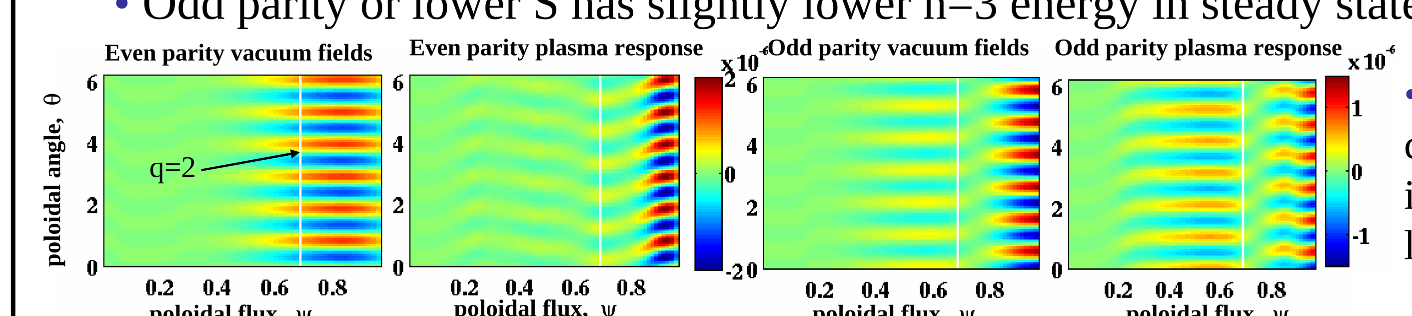


- Radial velocity at the separatrix is reduced as rotation is increased
- Reduction by half for high edge rotation

Energy spectrum evolution for even parity, S=5x10^6 simulation

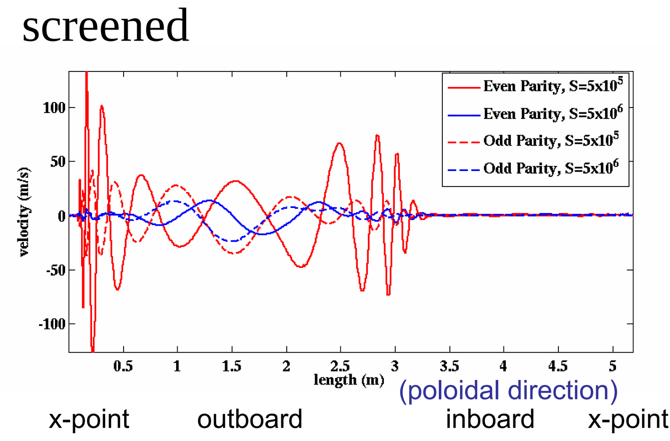


- No case shows the marked growth of n=3 kinetic energy seen for 113317
- Odd parity or lower S has slightly lower n=3 energy in steady state



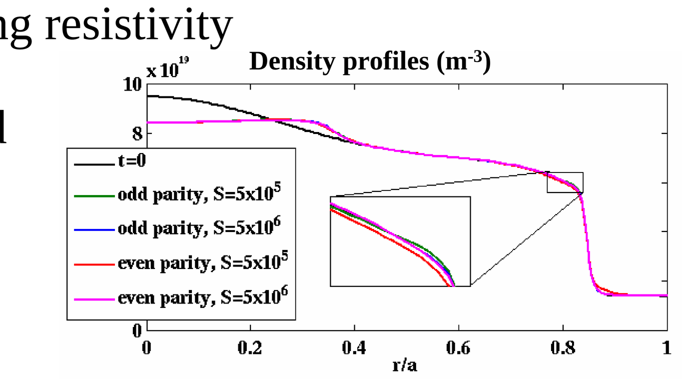
- m=6, n=3 component of B_n in straight field line coordinates

- Not only amplitude but structure of resonant fields differs greatly between odd and even parity I-coil fields
- In odd parity case, opposite sign vacuum fields inside the resonant surface are amplified by the plasma response, while the fields outside the resonant surface are screened

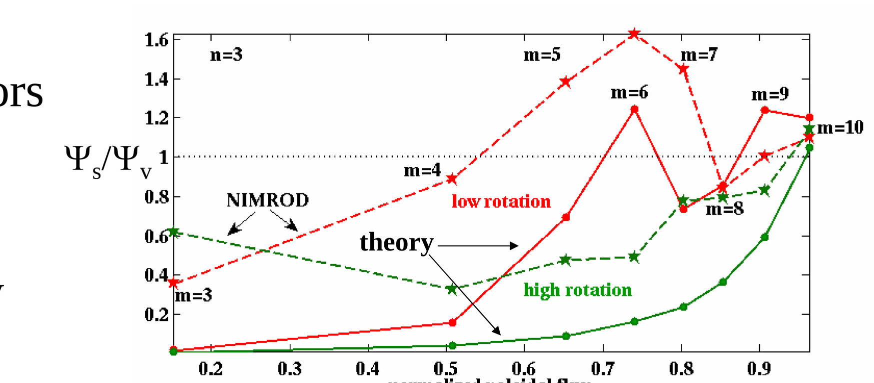


- Lower resistivity significantly reduces velocity at high and low-z locations, slightly reduces it at the outboard side
- Less resonant odd parity fields have lower convection velocity, but identical trend with decreasing resistivity

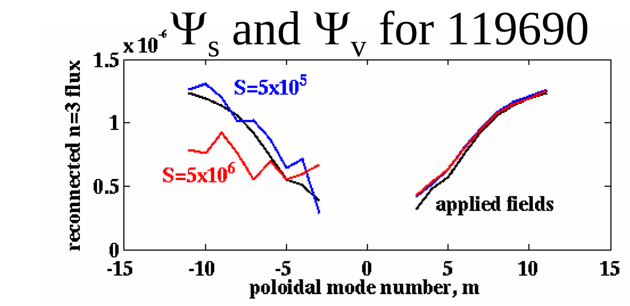
- Slight change in pedestal density is observed only in lowest S, even I-coil simulation
- Transport time scales are longer than simulation times– profiles are evolving



- The estimated values of Δ' and the theoretically calculated screening factors are combined to predict the mode amplitudes in the rotating simulations
- Predicted amplitudes are consistently lower than NIMROD results

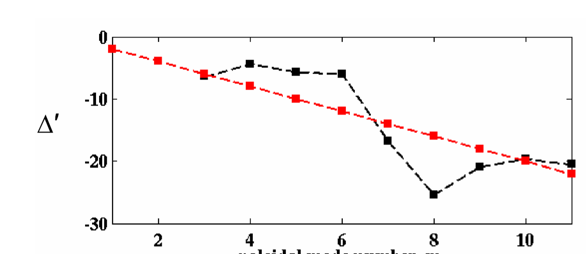


Ψ_s and Ψ_v for 119690

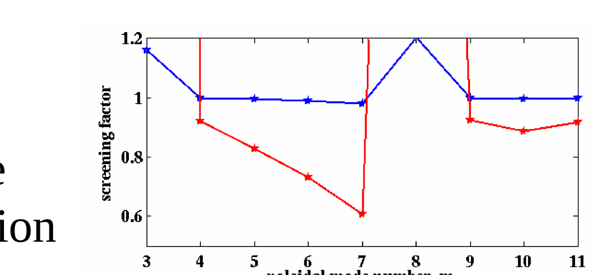


- Two odd-parity simulations
- Amplification is independent of S
- Screening factor $\Delta(\omega)$ is $\propto \eta^{-5/6}$ in the visco-resistive regime

- Estimates for Δ' and $\Delta(\omega)$ can be backed out from results of two simulations



- Screening results are inconsistent with theoretical dependence on resistivity and rotation



Conclusions- NIMROD simulations of DIII-D plasmas with RMP fields show:

- Increased screening of vacuum fields with increased edge rotation
- ExB convection near the separatrix can pump particles into the vacuum region
- A reduction of ExB convection cell velocity with: increased edge rotation, decreased resistivity, decreased resonant mode amplitude (odd parity I-coils)
- Compared with cylindrical error field theory, more realistic model tends to predict larger resonant mode amplitudes and shows qualitative anomalies likely linked to toroidal mode coupling effects