# Effects of known non-axisymmetric radial magnetic perturbations on the DIII-D boundary plasma

T. E. Evans - General Atomics

R. A. Moyer - U. C. San Diego

P. Monat* - U. C. Berkeley

*2001 undergraduate summer student

# Motivation and Background

# Small resonant magnetic perturbations $\delta b_r/B_\varphi \sim 10^{-4}$ can easily destroy the primary separatrix in diverted tokamaks

- Magnetically confined toroidal plasmas are exposed to many forms of resonant magnetic perturbation from both:
  - internal and external sources which may be of known or unknown origin and magnitude
- The resulting magnetic topology is significantly more complex then the 2D axisymmetic flux surface picture and can produce unexpected changes in the plasma dynamics.
- Diverted plasmas are more susceptible to resonant $\delta b_r$ perturbations due to the high edge magnetic shear and a larger number of low order resonant surfaces near the boundary.
- The resulting edge stochastic layer may be beneficial for dissipating thermal energy, shielding the core from impurities, controlling edge pressure and current profiles, and interacting with edge instabilities (e.g., ELMs), etc.

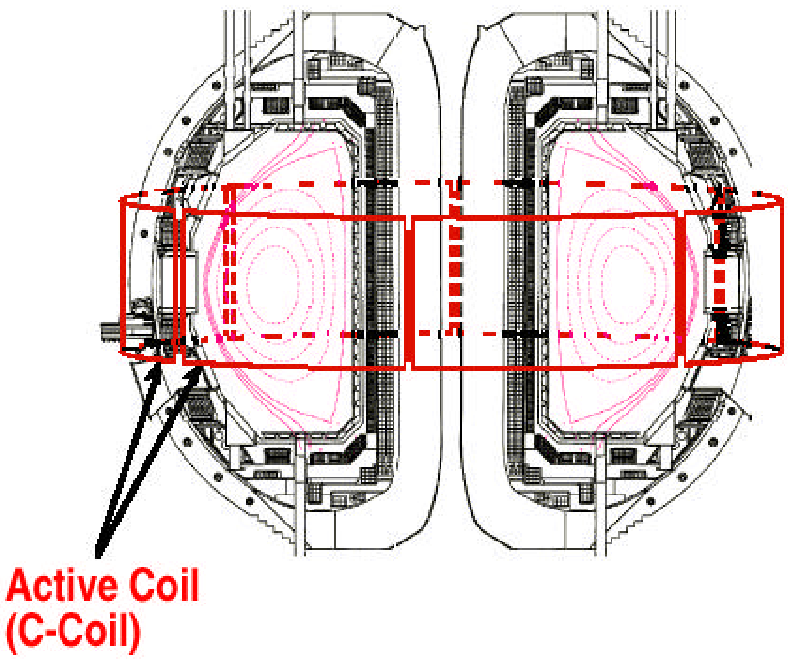
# Many tokamaks have magnetic perturbation coils to control error fields in the core plasma - these coils also have an impact on the edge of the plasma

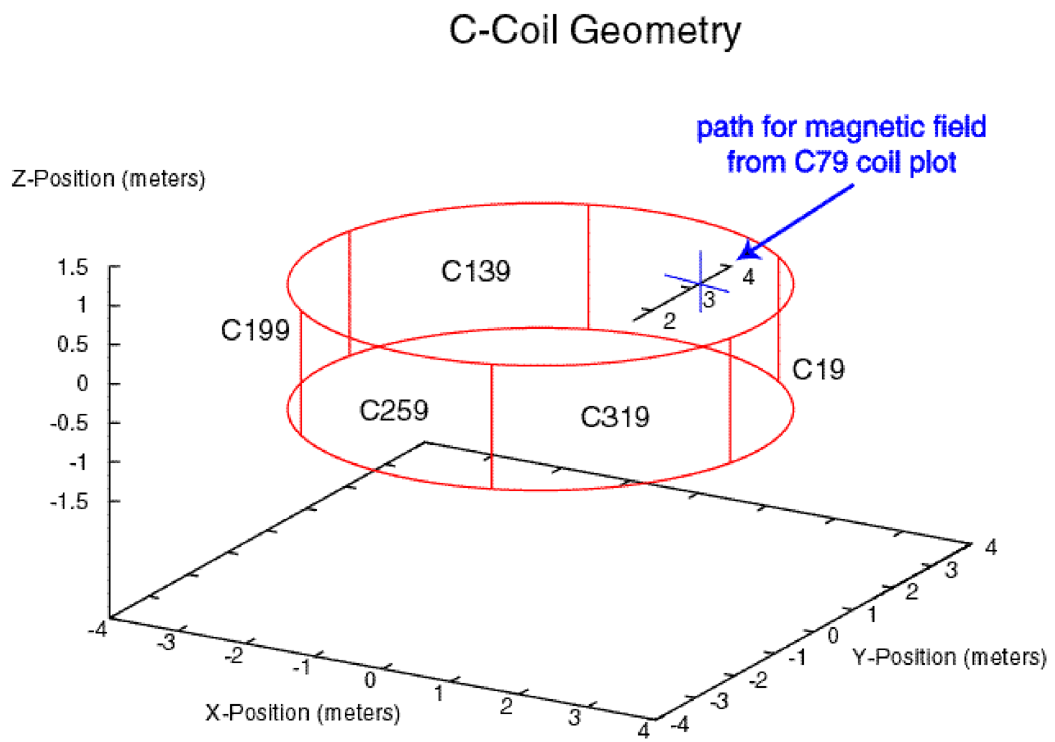
- In DIII-D the C-coil is used to reduce locked modes and improve the core performance - it can also create a stochastic boundary layer extending inside the unperturbed separatrix
- C-coil perturbations are modeled with the TRIP3D field line tracing code using realistic axisymmetric equilibrium fields.
  - DIII-D equilibrium field components obtained from EFIT
  - perturbation field components obtained from a Biot-Savart model of the ‘as designed’ c-coil
  - extensive testing of the axisymmetric and non-axisymmetric field line tracing accuracy indicates uncertainties of $\pm 5 \times 10^{-4}$ m in the Poincaré plots with up to 100 toroidal transits.

See poster GP1.037 by P. Monat, R. A. Moyer, and T. E. Evans for additional details on the TRIP3D code.

# The DIII-D C-coil geometry is modeled with straight line segments and the magnetic field is calculated at any point in space using the Biot-Savart law

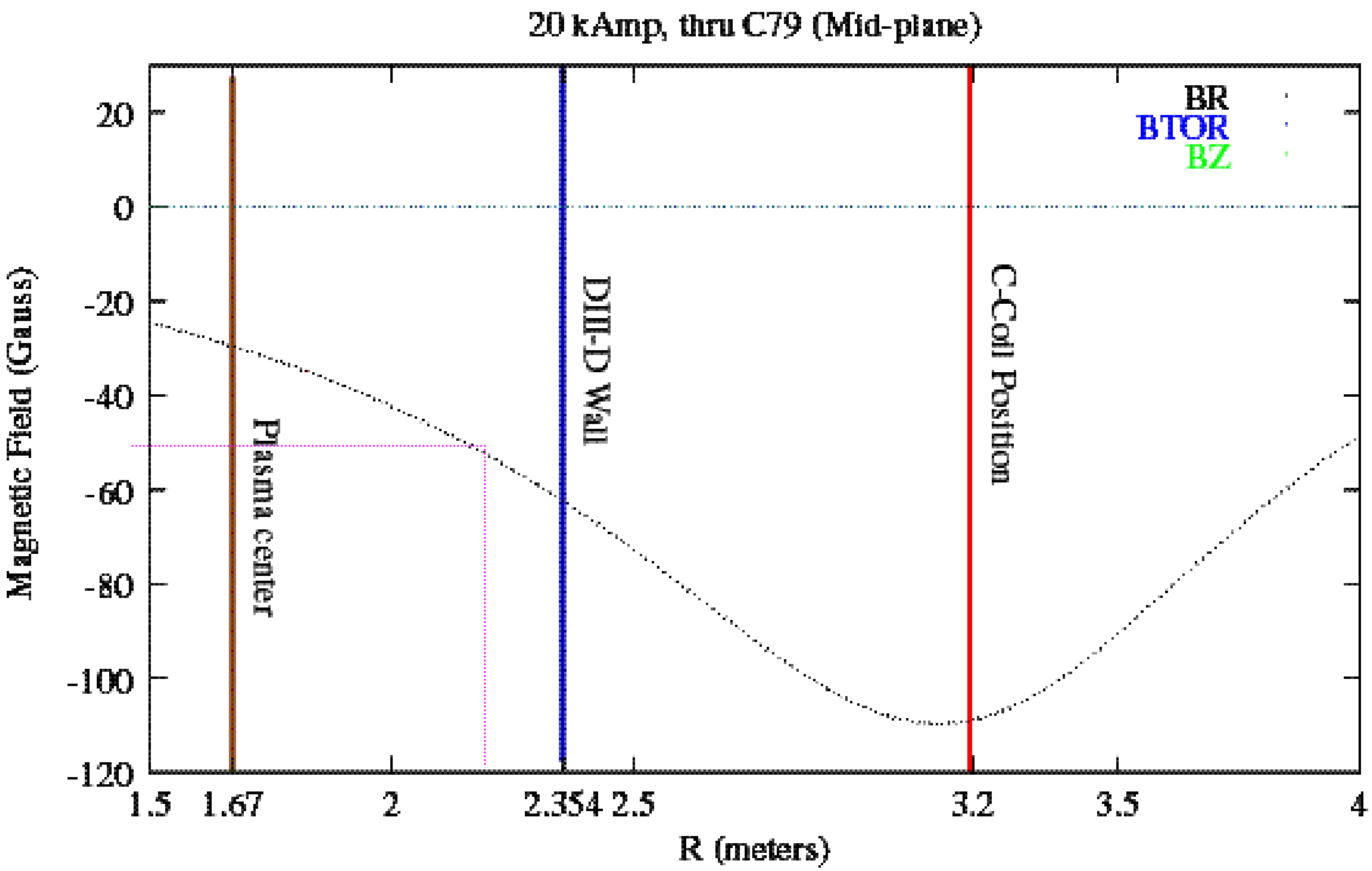
- The C-coil currents can either be set to match experimental data or scaled and phased independently to study the effects of the perturbations over a range of conditions (scaling studies).

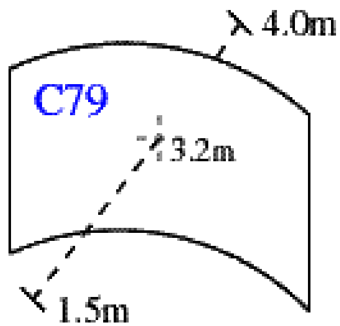


# Calculated magnetic field distributions from the C-coil model are in good agreement with analytic estimates of the field along the axis of each coil

- The total $b_r$ from each C-coil segment with $I_c$ = 20 kA is ~52 gauss at the edge of the plasma.

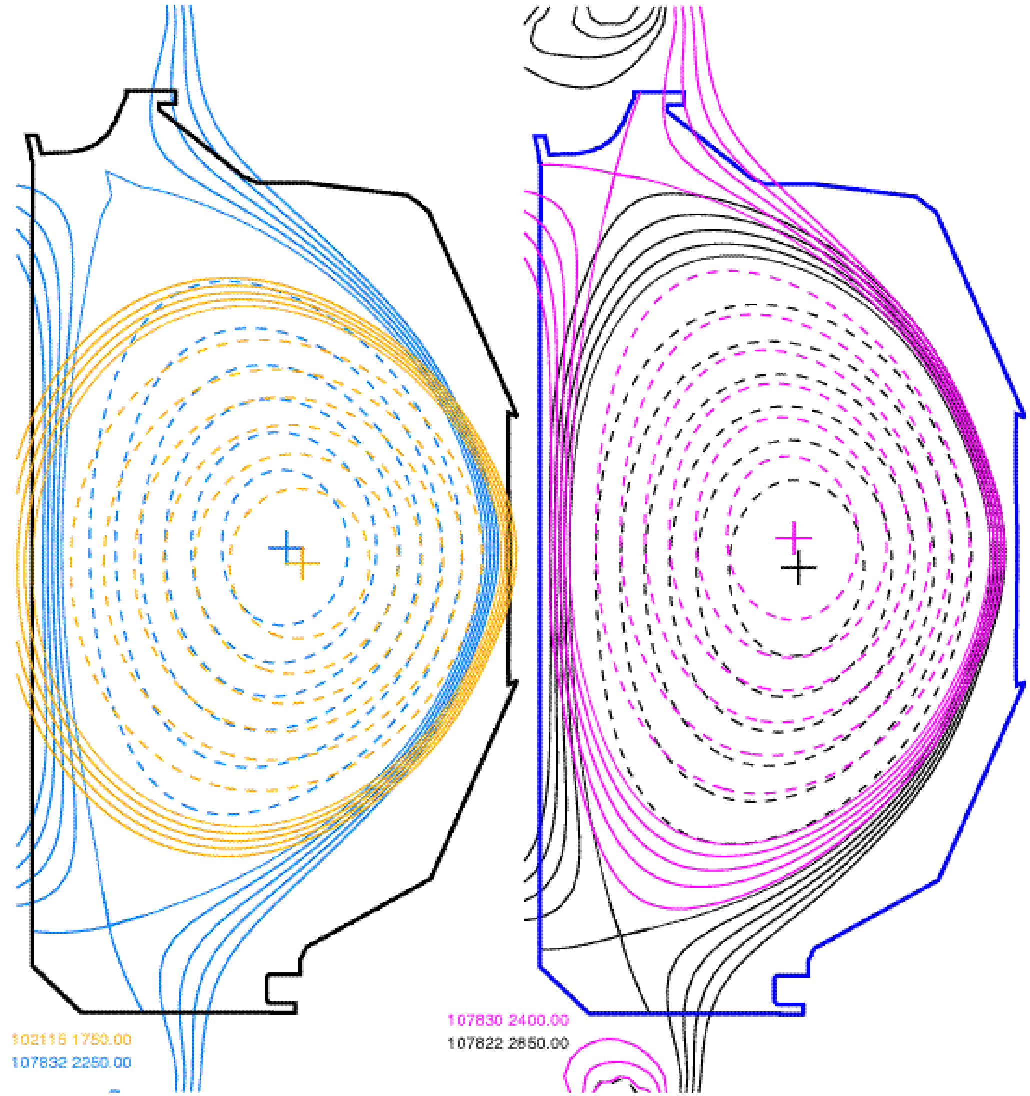


# Changes in the shape of the plasma have a significant impact on the properties of the edge stochastic layer produced by the DIII-D C-coil

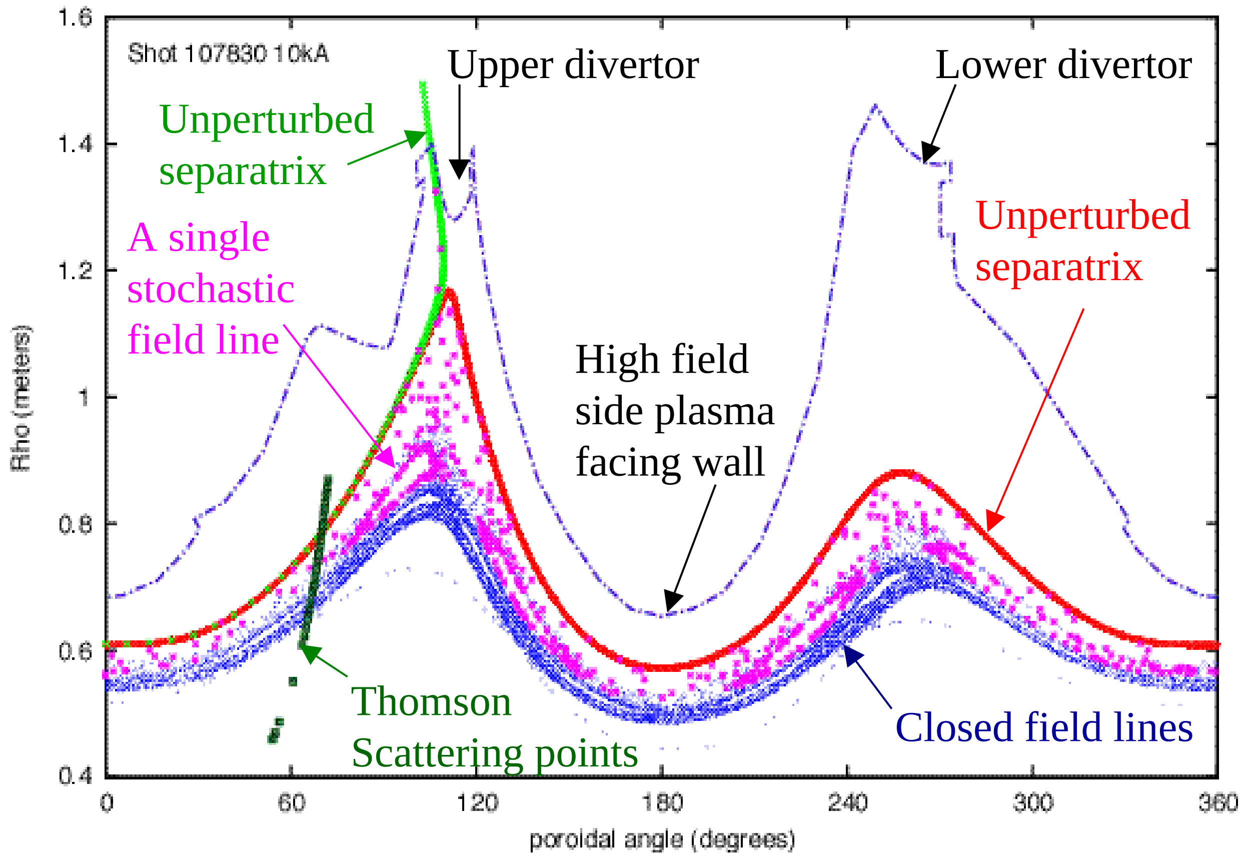
# The shape of the plasma has a strong impact on the edge magnetic topology produced by the C-coil

- Three diverted shapes, lower single null (LSN), upper single null (USN) and double null (DN) , are compared to an inner wall limited (IWL) shape.
- The widths and detailed properties of the stochastic layer produced with a given C-coil current can be significantly different depending on the plasma shape.



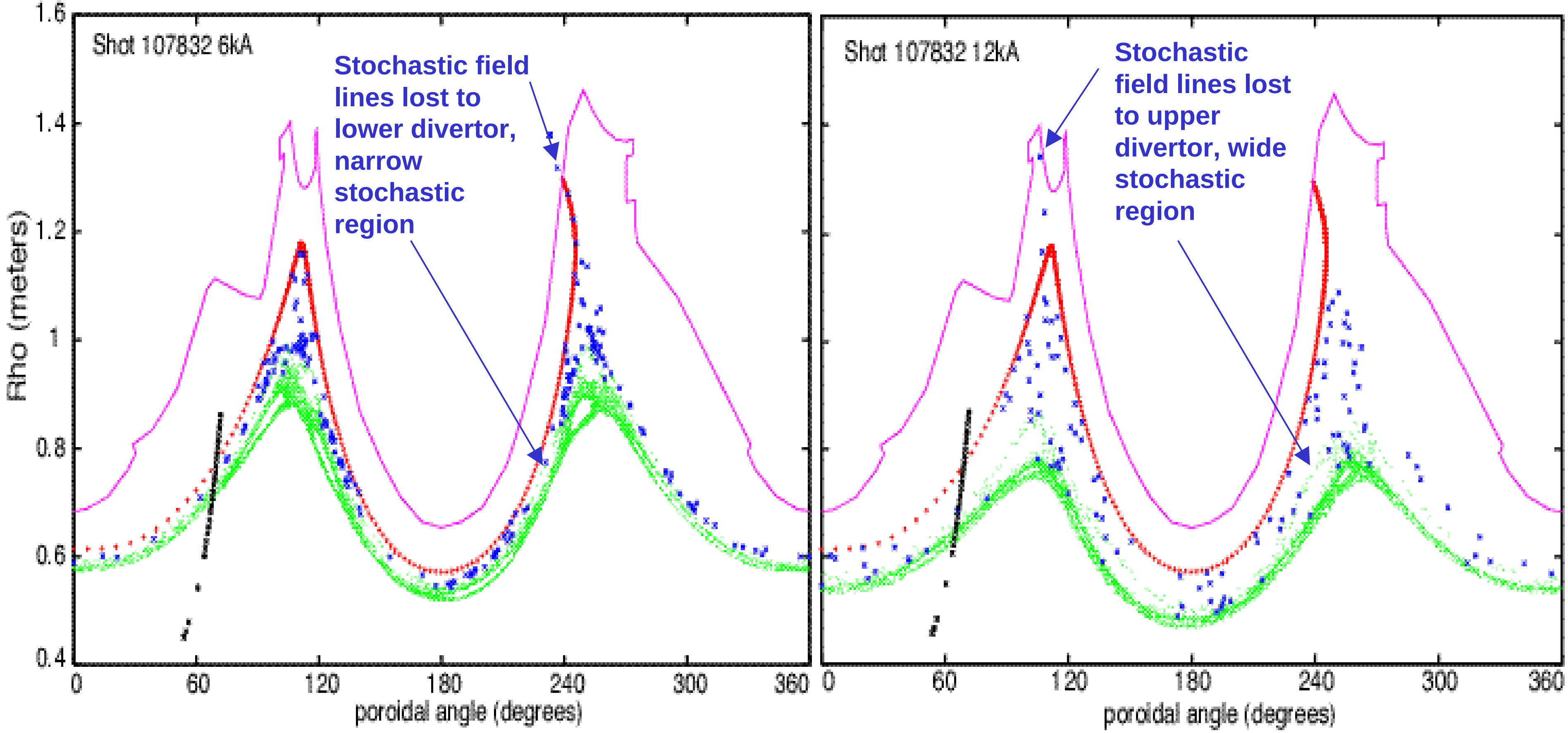
# Some field lines in the stochastic region are lost to the divertor and some are confined to remnant islands

- Stochastic field lines fill the outer region of the plasma sometimes circling remnant islands
- Stochastic field lines are typically lost along the unperturbed separatrix
- Field line lengths vary from 10's of meters to 10's of kilometers in the stochastic region

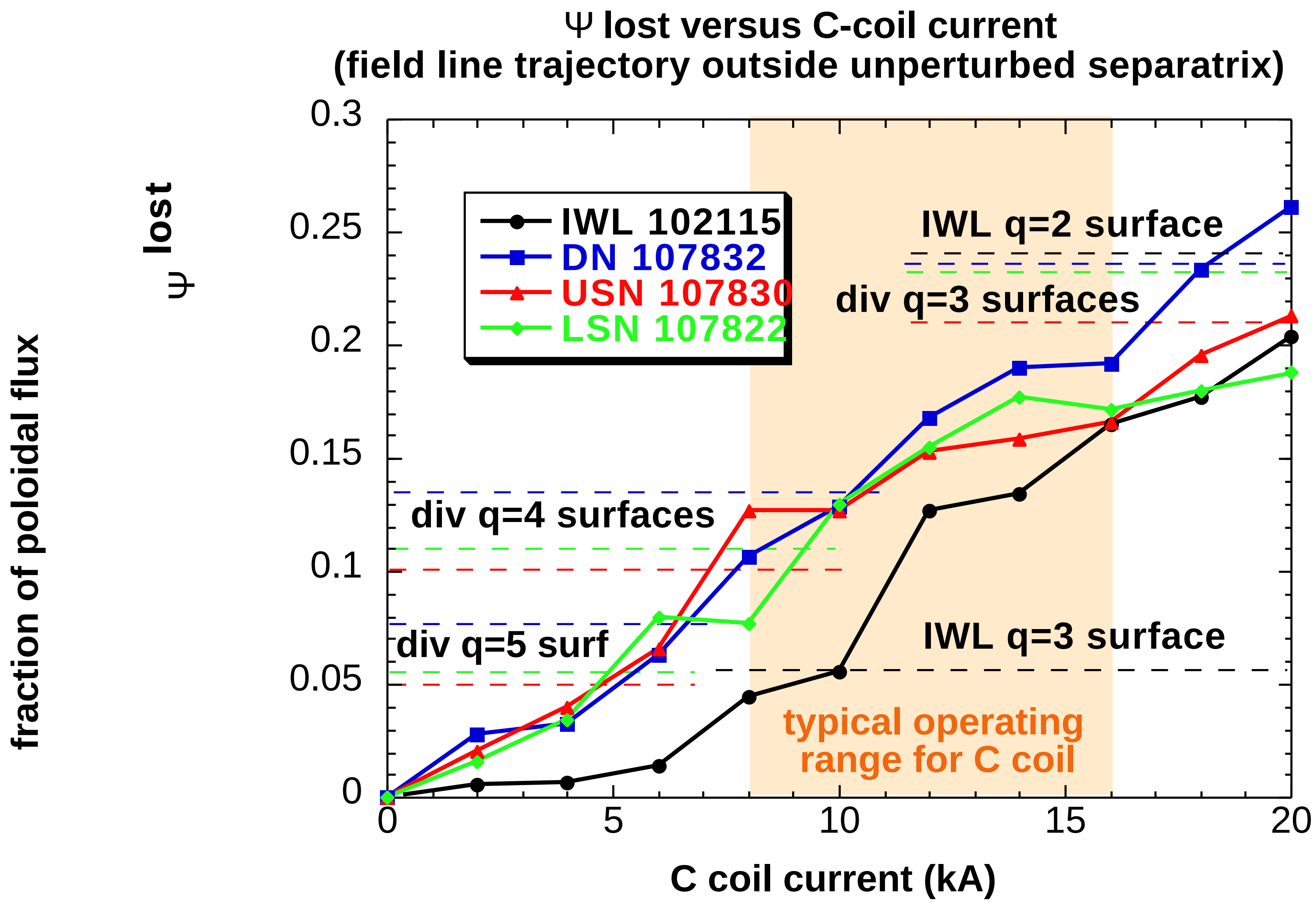



- Rectangular Poincaré map of the edge vacuum magnetic field topology in a DIII-D USN plasma with a C-coil current $I_c$ = 10kA.

# Stochastic field lines are lost either to the upper or lower divertor in DN plasmas depending on the amplitude of the C-coil current

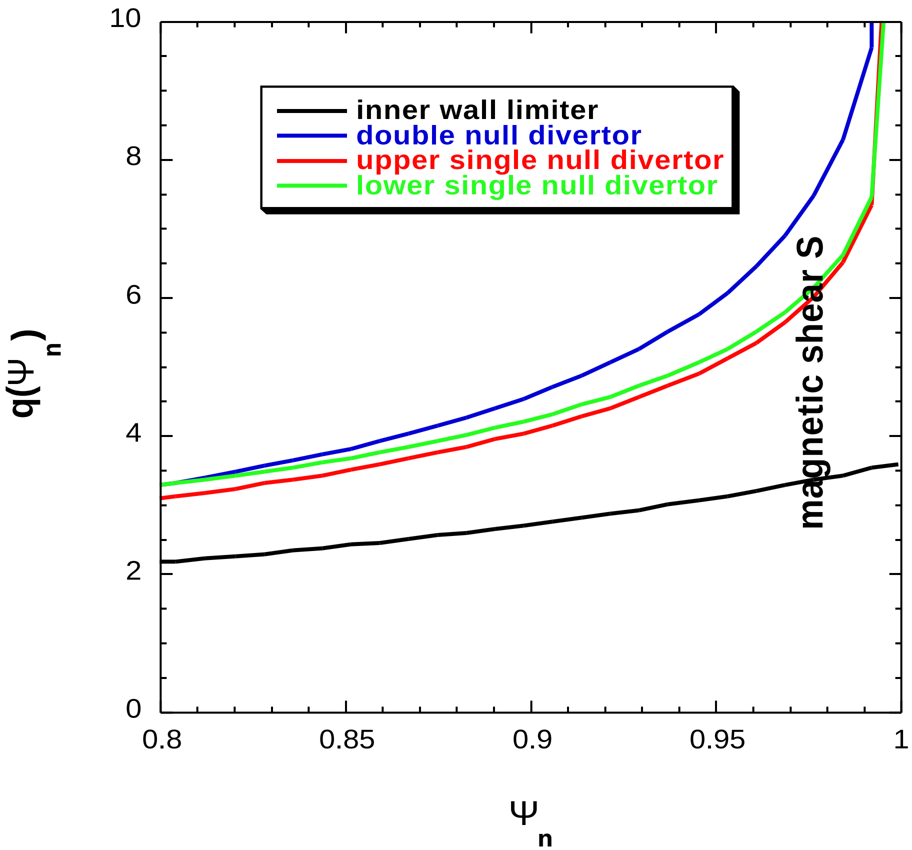


# The edge magnetic flux loss is a complex function of the C-coil current, mode spectrum and plasma shape

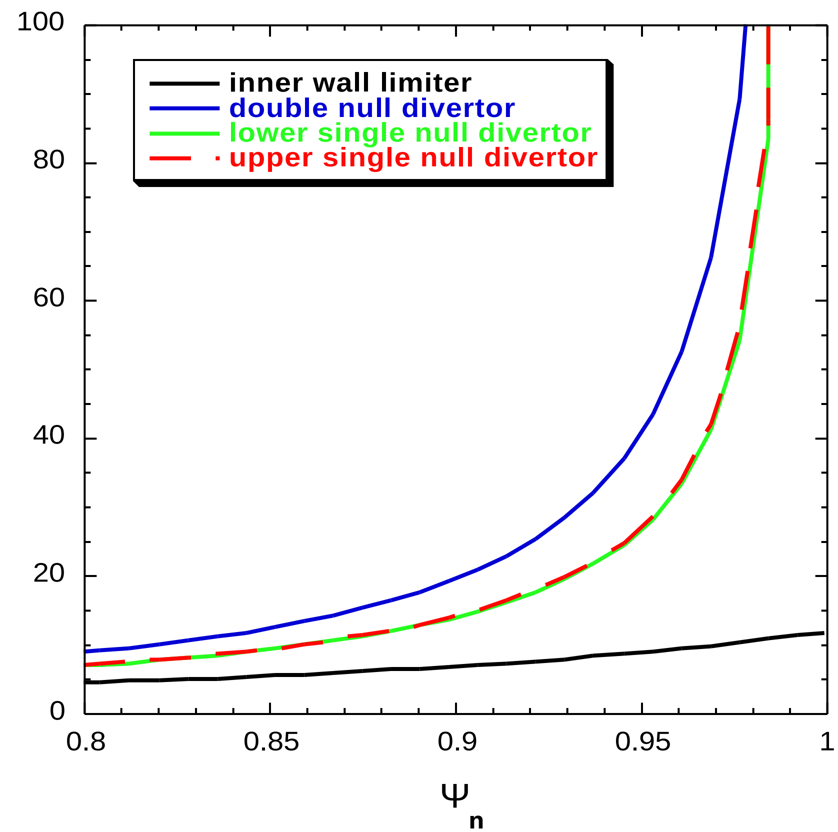


# The four shapes used provide a wide range of q(ψ) and magnetic shear s(ψ) profiles for scaling studies

**variation of edge q profile with divertor geometry**

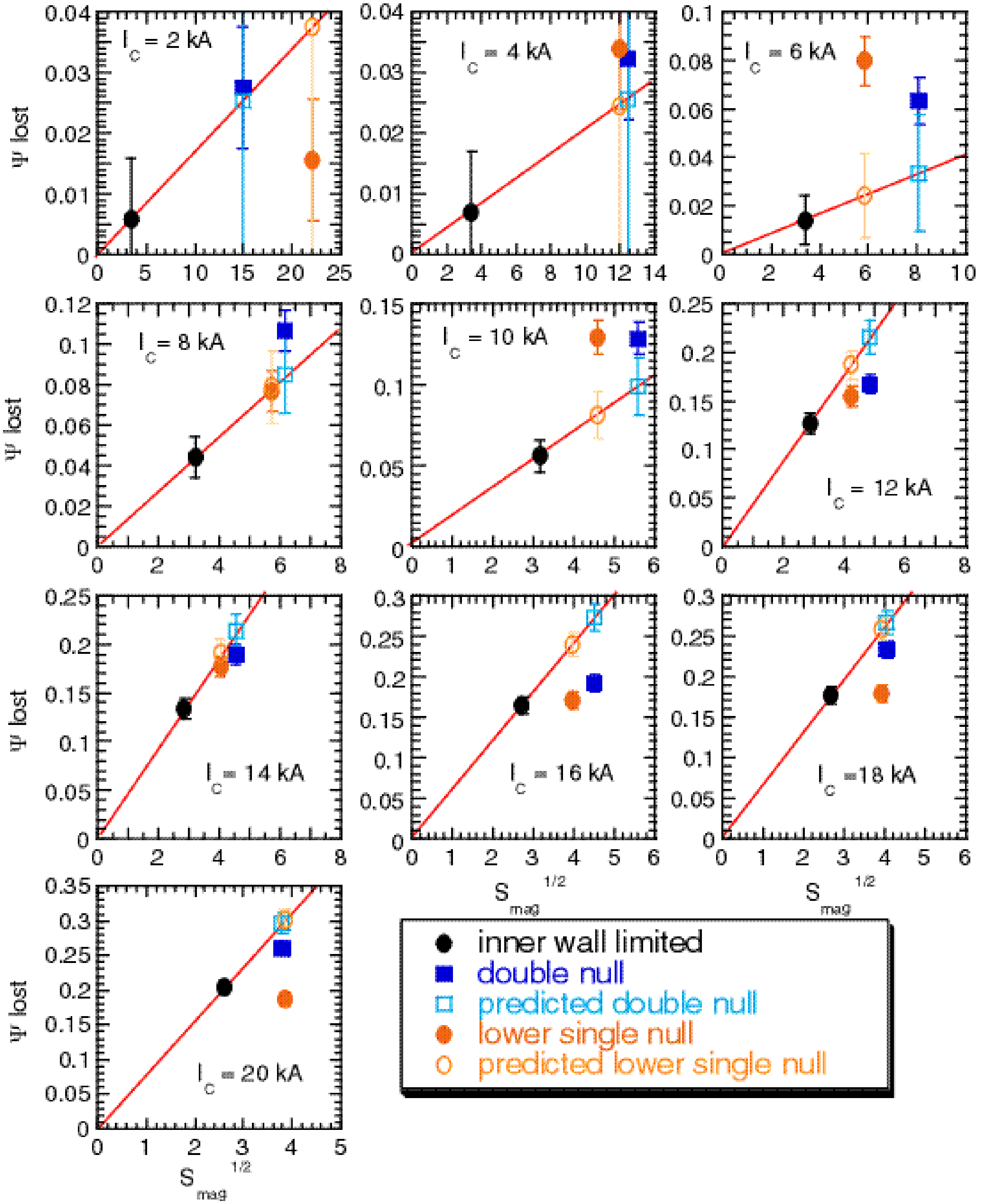



**variation of edge magnetic shear with divertor geometry**

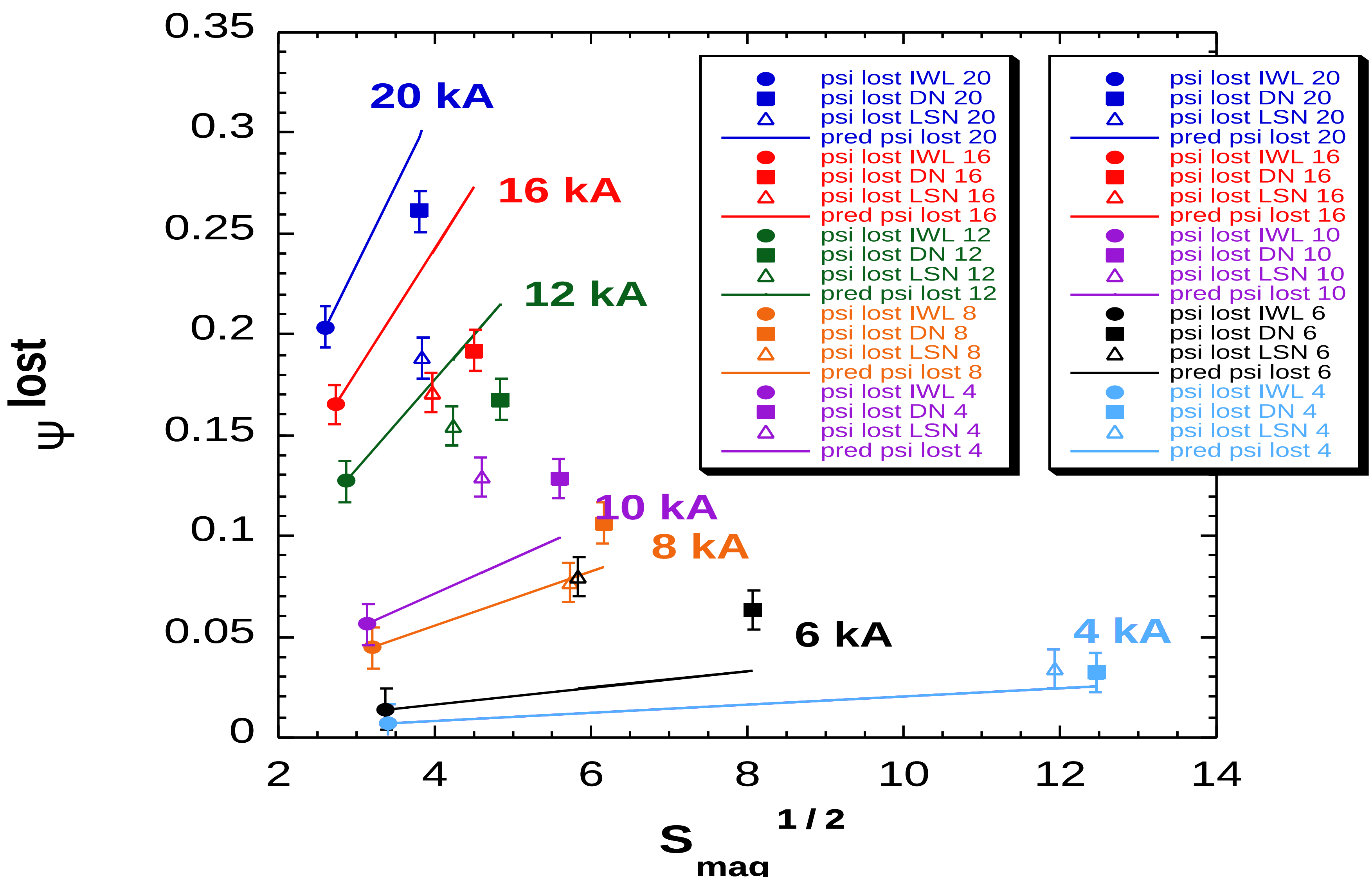



- The Chirikov overlap model predicts $\delta\psi \quad s^{1/2}$ where $s = \partial q(\psi)/\partial\psi$ is the magnetic shear: $\sigma_{Chirikov}(w_{mn}) = (w_{mn} + w_{m'n'}) / 2|\psi_{mn} - \psi_{m'n'}| \quad s^{1/2}$.

# At some C-coil currents $s^{1/2}$ scaling is reasonable, at other currents it is not



# The DN shape generally fits an $s^{1/2}$ scaling while the LSN shape deviates from the $s^{1/2}$ scaling at high $I_c$



# Fractional flux loss has a complex dependence on $I_c$ and the coil's mode spectrum.

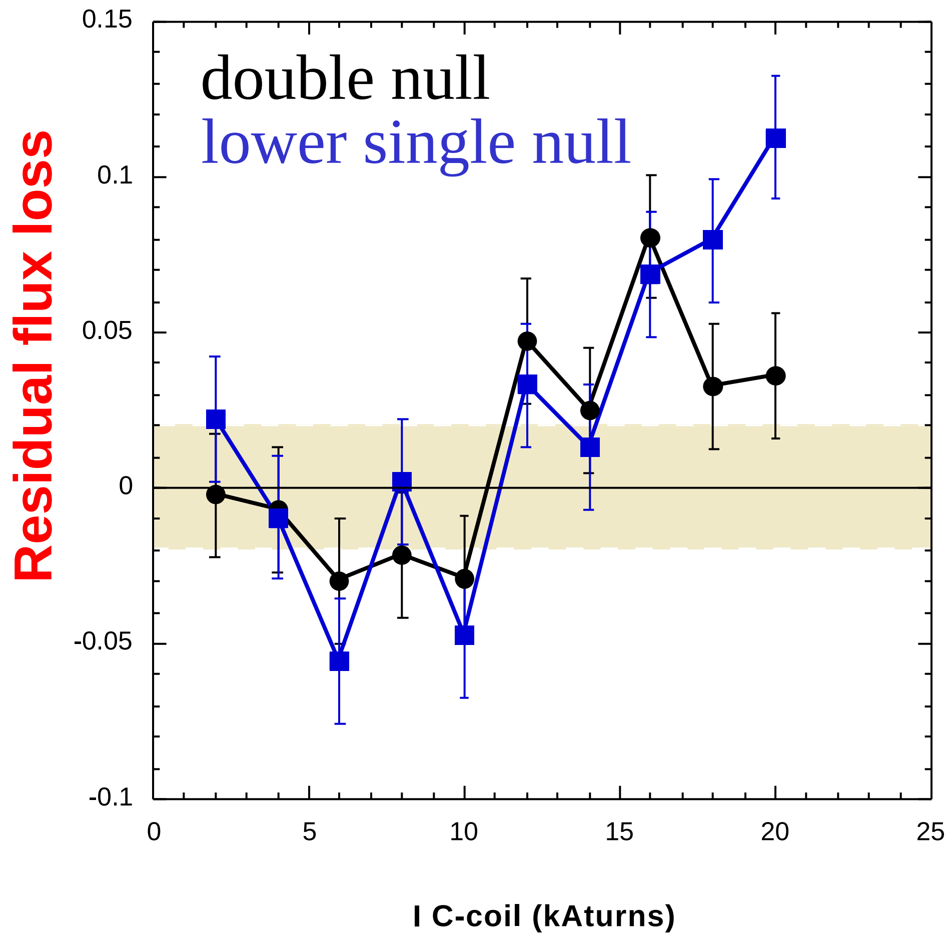
**R = "residual flux loss"**

$\delta\Psi_{scaled} = \delta\Psi_{IWL} \times (s_{divert}/s_{IWL})^{1/2}$

$\delta\Psi_{predicted} = \delta\Psi_{diverted}$ **from TRIP3D simulation of diverted discharge**

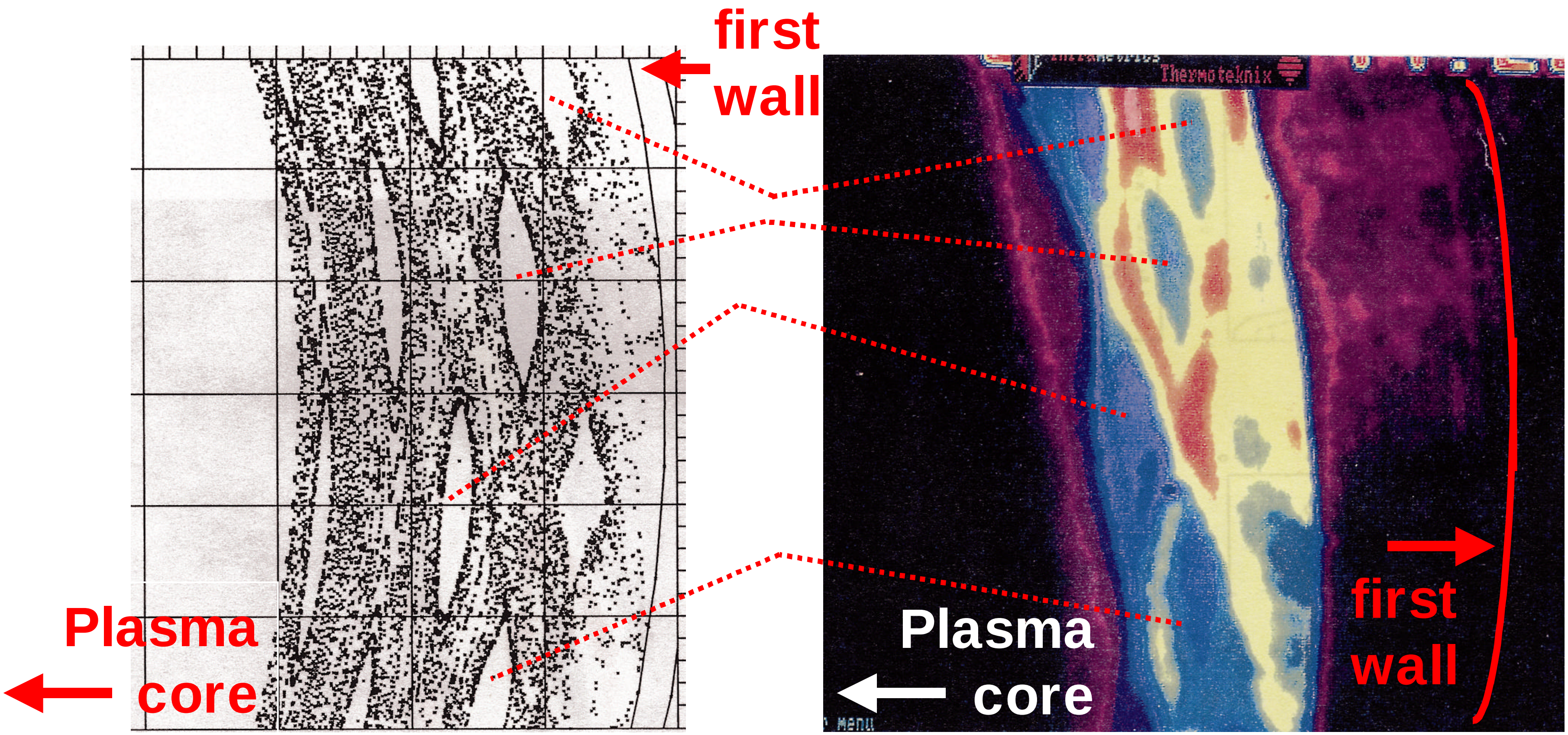
- Fractional flux losses due to known C-coil perturbations qualitatively agree with $s^{1/2}$ scaling but also have a complex dependence on $I_c$ and the coil's mode spectrum.

$$R = \delta\Psi_{scaled} - \delta\Psi_{predicted}$$



# Edge Stochastic layers can produce unexpected effects in the behavior of the plasma

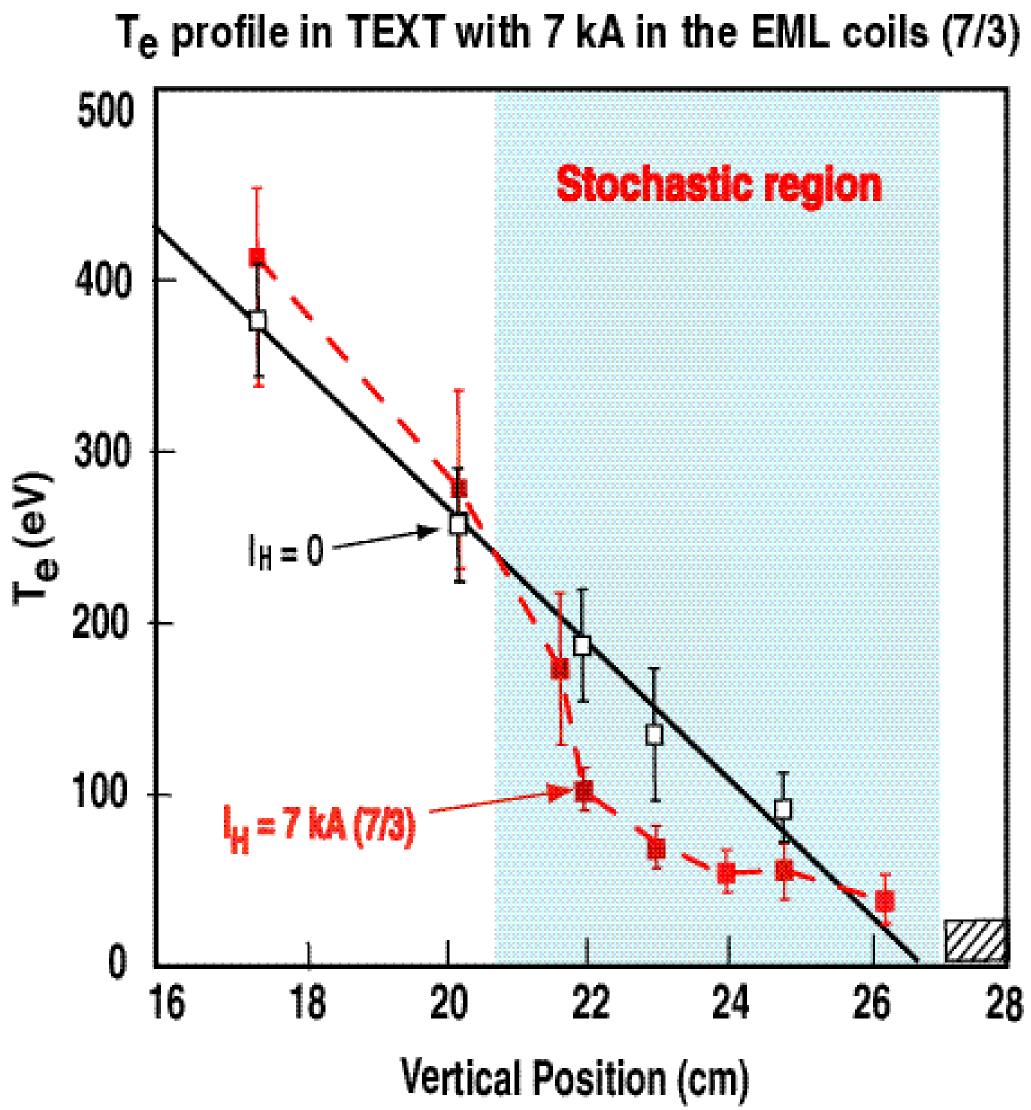
# Based on very limited experimental data calculated field lines are a good representation of the plasma topology




- TRIPND vacuum magnetic field line tracing of the Tore Supra boundary ($I_{ed}$ =15 kA)
- Total recycling light from the Tore Supra boundary with an ergodic coil current of 15 kA

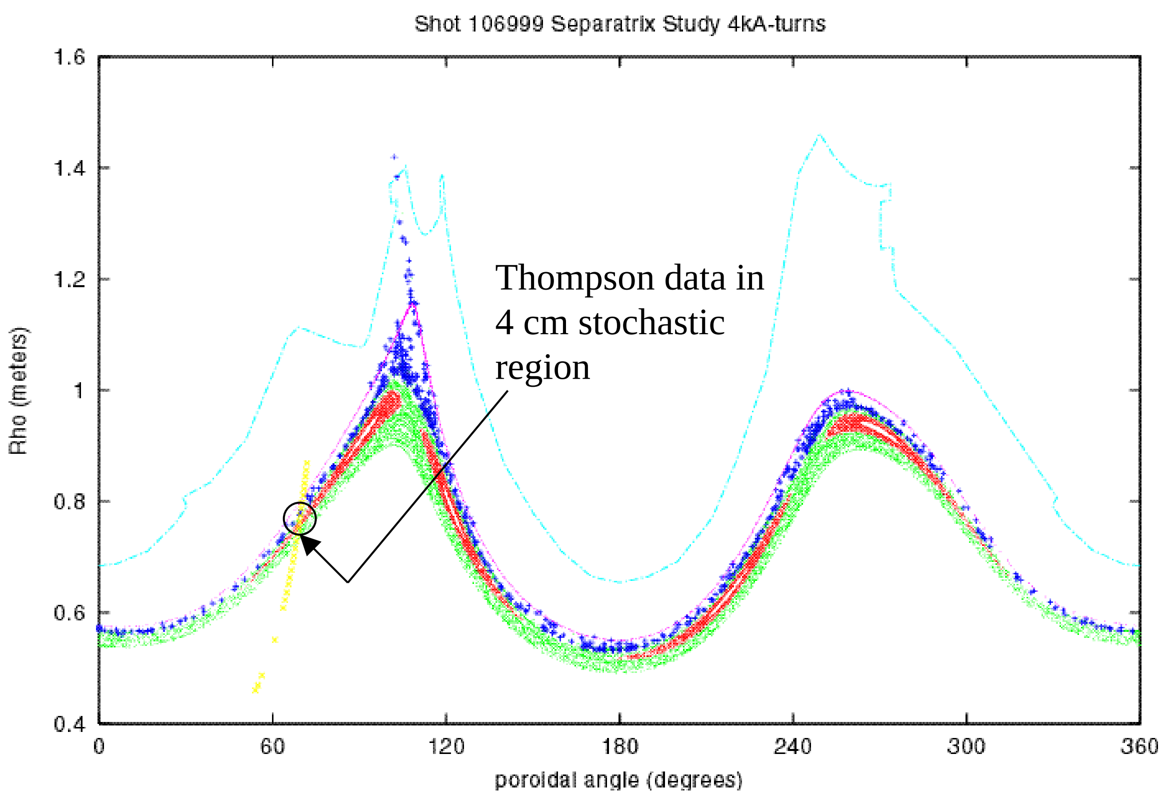
# Stochastic boundary layers typically create flat $T_e$ profiles in low power limited plasmas

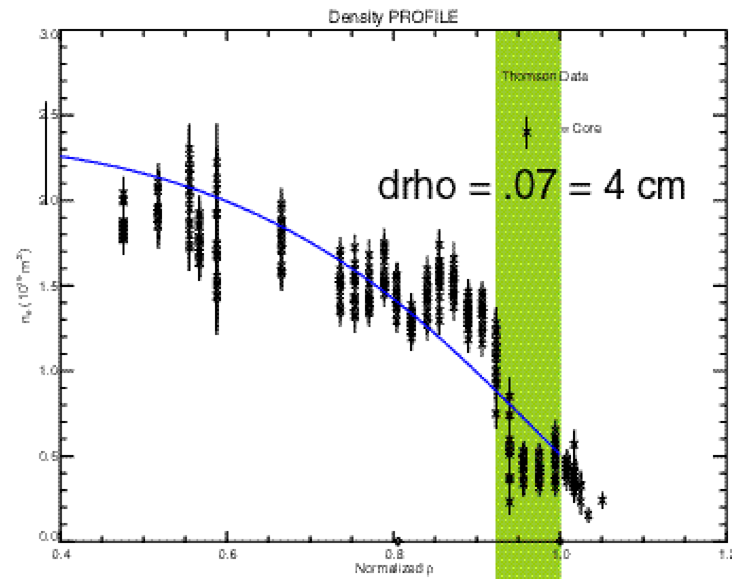
- Flat boundary layer $T_e$ and $n_e$ profiles are seen with the C-coil in DIII-D plasmas under some conditions but not under others.
- Near the inner boundary of the stochastic region the average field line connection length exceed the parallel collisional mean free path length (quasi-closed region) and the effectiveness of the stochastic layer is reduced ( $T_e$ increases)

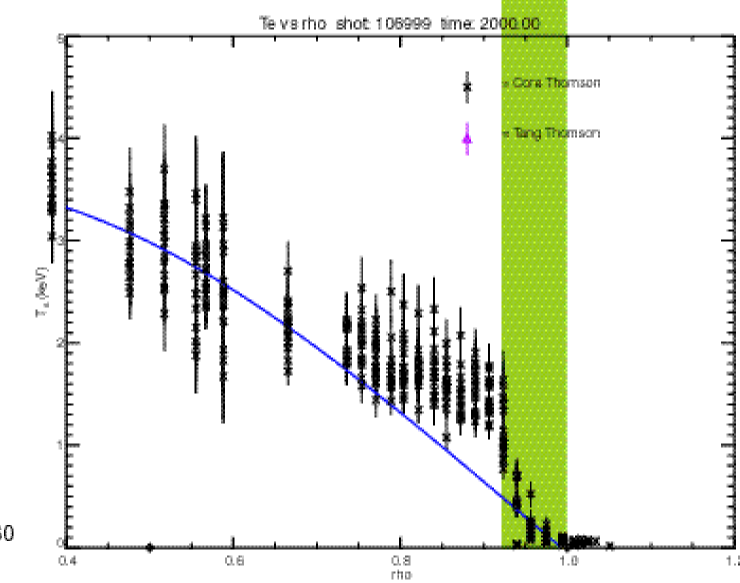


# The width of the stochastic layer along Thomson chord is consistent with flattening of the edge $n_e$ and $T_e$ profiles

- High performance QDB shot with a flat edge $n_e$ and $T_e$ profiles.
- Blue points indicate 4 cm wide stochastic region along the Thomson chord.



# The impact of the stochastic layer on the boundary plasma may depend on several physics issues

- Field line connection length versus collisionality
- Auxiliary heating power
- Momentum input/plasma rotation

- The TRIP3D code, the C-coil, profile diagnostics, and a new tangentially viewing midplane camera (P. West) provide an unique opportunity to investigate the plasma response to formation of a stochastic boundary layer.

# Summary and conclusion

- Fractional flux losses from the DIII-D boundary due to known C-coil perturbations qualitatively agree with an $s^{1/2}$ scaling but also have a complex dependence on $I_c$ and the coil's mode spectrum.
- Flattening in $T_e$ on some shots is roughly in agreement with the width of the calculated stochastic layer due to the C-coil at the Thomson location.
- Previous stochastic boundary layer experiments suggest that complex edge physics interactions can produce unexpected results as the input power and edge collisionality are changed.
- Additional modeling and experiments are needed to assess the potential benefits of the stochastic boundary (e.g., heat dissipation, impurity screening, edge/pedestal pressure profile control, plasma surface interactions, etc.) .