BOUT simulations of NSTX Boundary Turbulence and Transport

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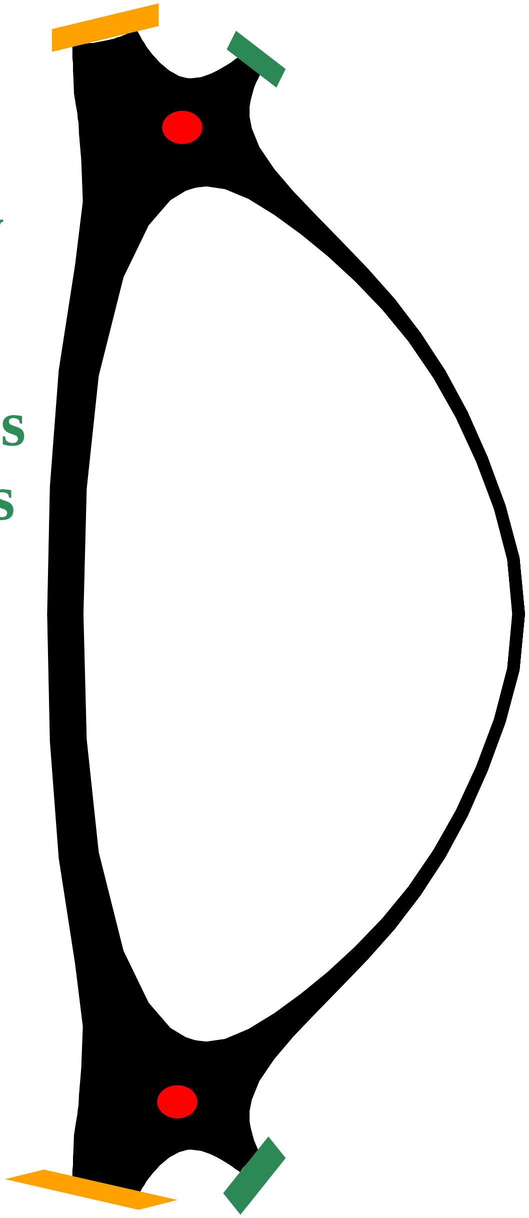
Principal Results

- **Fluctuation level and transport are higher in SN than in DN, maybe due to higher q_{95} in SN.**
- **Frequency spectrum of BOUT simulation resembles that of GPI measurements.**
- **Poloidal fluctuation phase velocity v_p from the resistive X-point turbulence shows experimentally observed structure across separatrix.**
- **Strong poloidal asymmetry of particle flux in the proximity of the separatrix.**

Boundary Plasma Turbulence Modeling is Important

- Turbulence transport in the plasma boundary has a different character than in the core
- Although the present major tokamaks and STs are diverted, few of the turbulence simulations include this geometry
- Edge Pedestal Physics
  - → Observed large velocity shear layer
  - → Proximity of open+closed flux surface
  - → Presence of X-point
- Need to understand dominant modes in X-point geometry



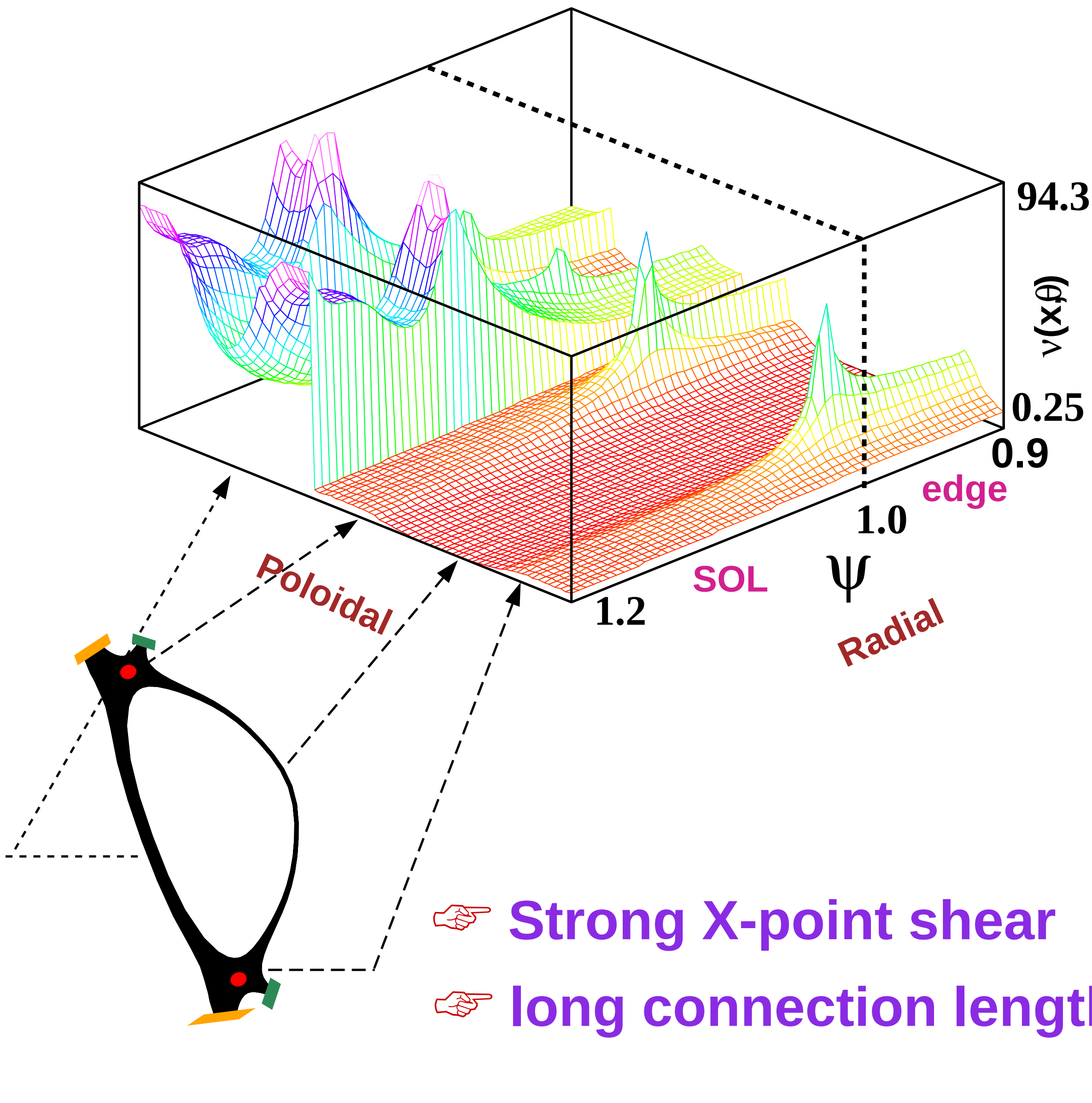
BOUT Solves:

- **the reduced Braginskii equations:**
  - **Vorticity,**
    $\varpi = nq\nabla_\perp^2\phi + nq\nabla_\perp\phi\cdot\nabla_\perp \ln n + \nabla_\perp^2 P_i$
  - **Continuity,** N_i
  - **Parallel Ion Momentum,** $V_{\|i}$
  - **Parallel Electron Momentum,** $V_{\|e}$
  - **Ion Temperature,** T_i
  - **Electron Temperature,** T_e
  - **Magnetic potential,** $A_\|$
- **sheath boundary conditions in SOL**
- **BOUT documentation and publications**

http://www.mfescience.org/users/xu

Local Safety Factor, $\nu(\psi,\theta)$, has strong variations near X-points that affect mode

$$\nu(\psi,\theta)=a_{eff}\,Bt/(RBp)$$

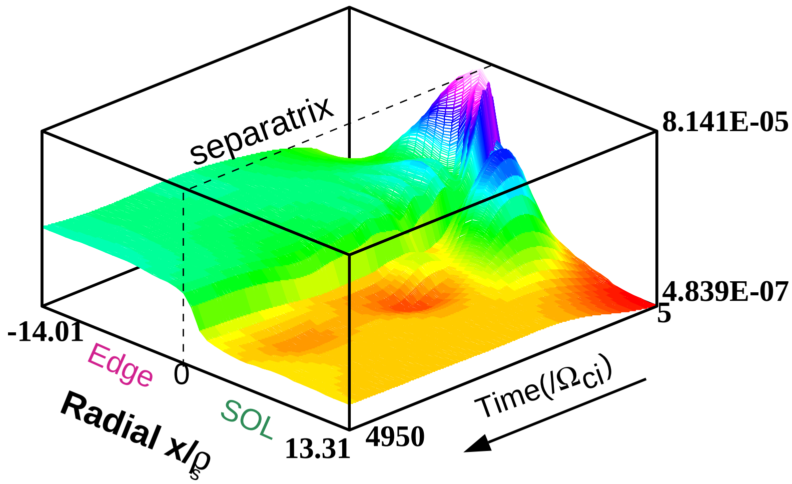


☞ Strong X-point shear

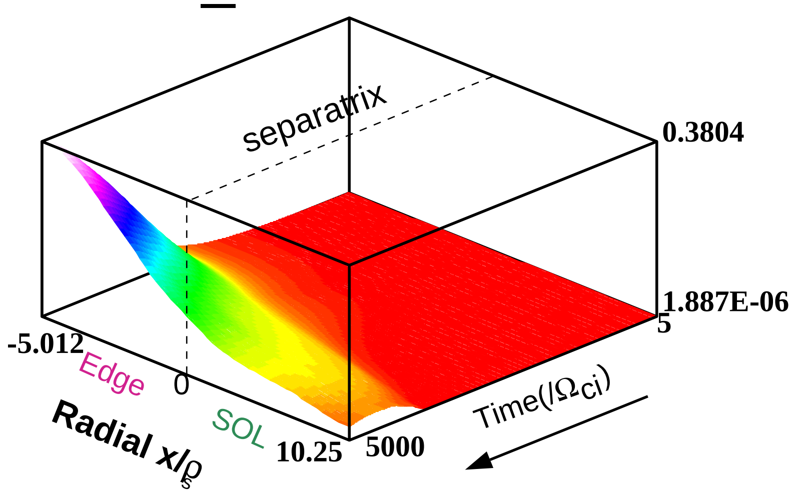
☞ long connection length

BOUT shows Linear Instabilities for NSTX, but not for Circle Tokamak for Curvature Drives being Zero

Ni_rms/N_{i0} for CCT



Ni_rms/N_{i0} for NSTX



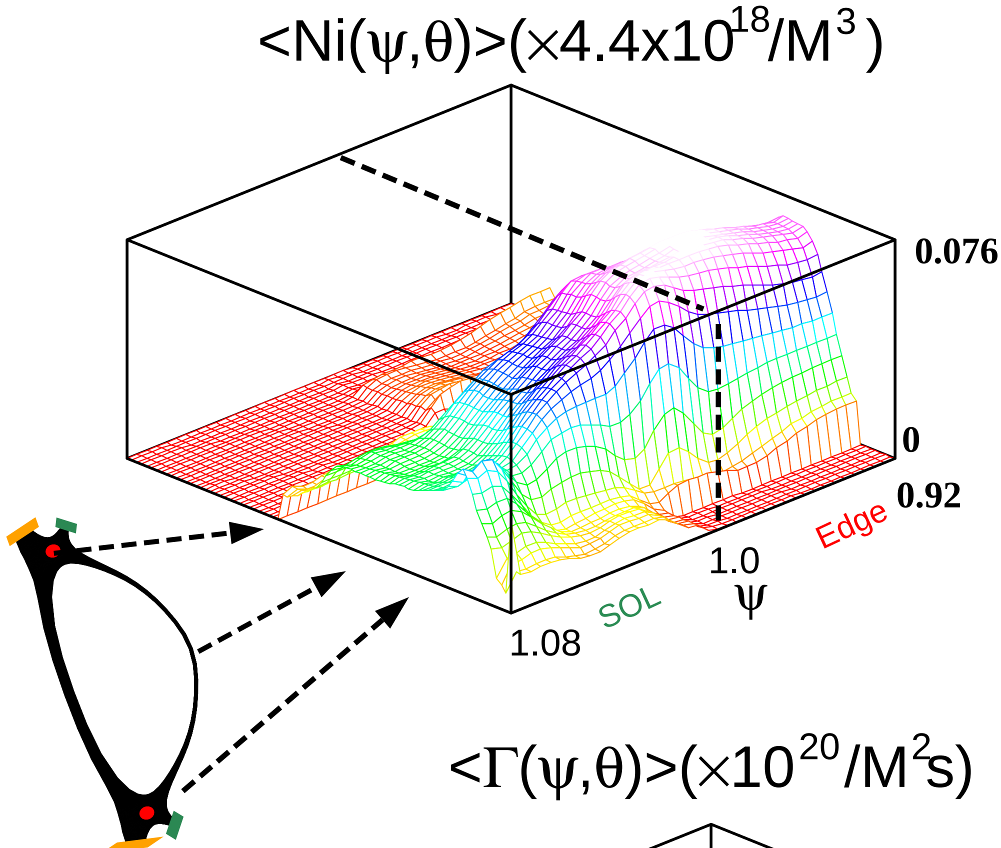
☞ Refection due to strong X-pt shear
⩾ partial standing wave (destabilizing) between X-pts

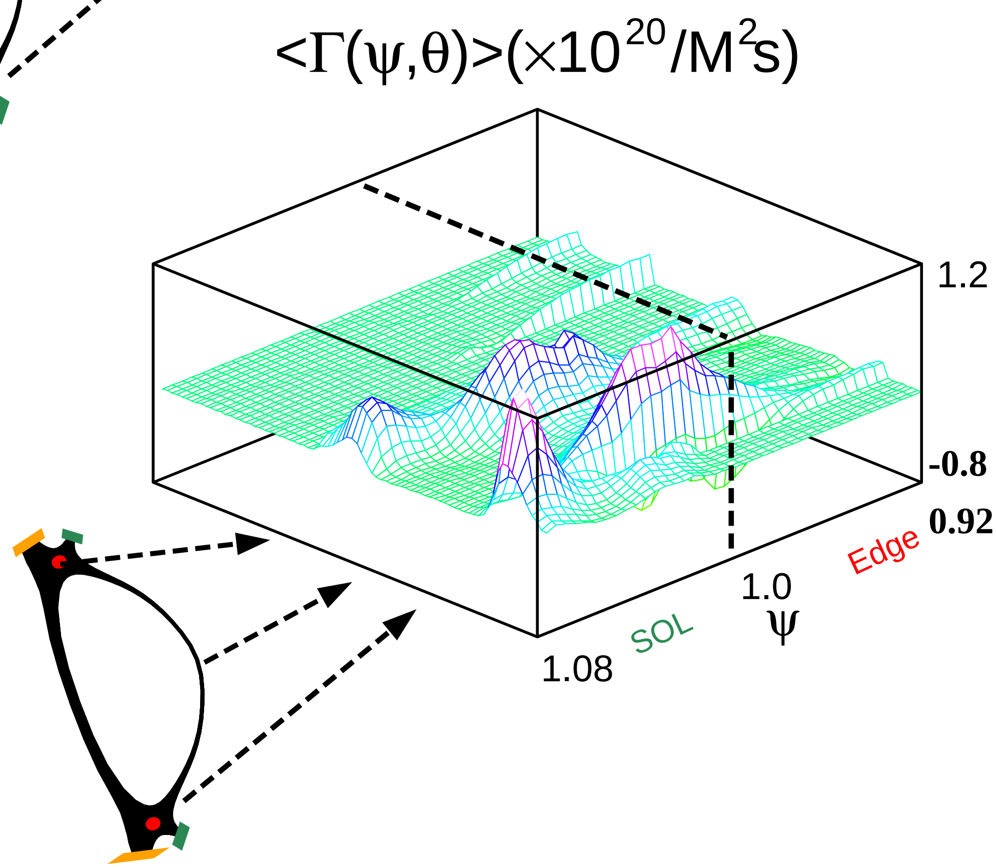
☞ Transimission through X-pt, such as no X-pt,
⩾ outgoing waves (stabilizing) between X-pts

BOUT Simulations of NSTX

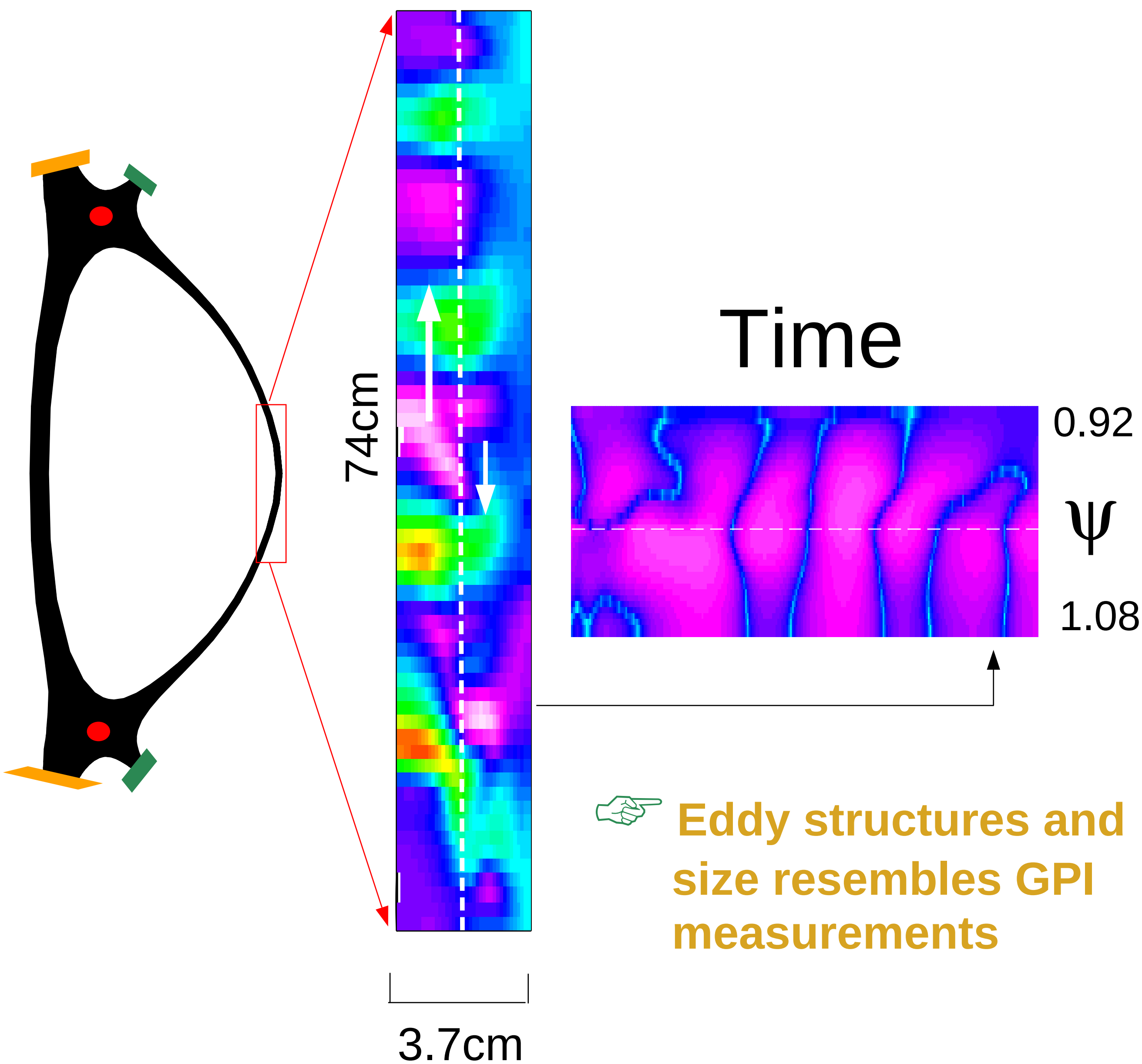
- **Simulations start from plasma profiles in a typical Ohmic plasma for NSTX geometry given by EFIT**
- **Radial midplane plasma profiles take as (tanh) fits given by Uedge**
- **The midplane values on the separatrix are:** $T_e = 30$**eV,** $T_i = 30$**eV, and** $N_i = 2.3 \times 10^{12}/\mathbf{m}^3$**.**
- **BOUT shows Characteristics of Turbulence**
  - **Comparison with GAS-Puff-Image (GPI) expt.**
    - **comparisons with GPI should be interpreted as qualitative beause of the availability of plasma profile measurements.**

Fluctuating density and particle flux show strong poloidal variation



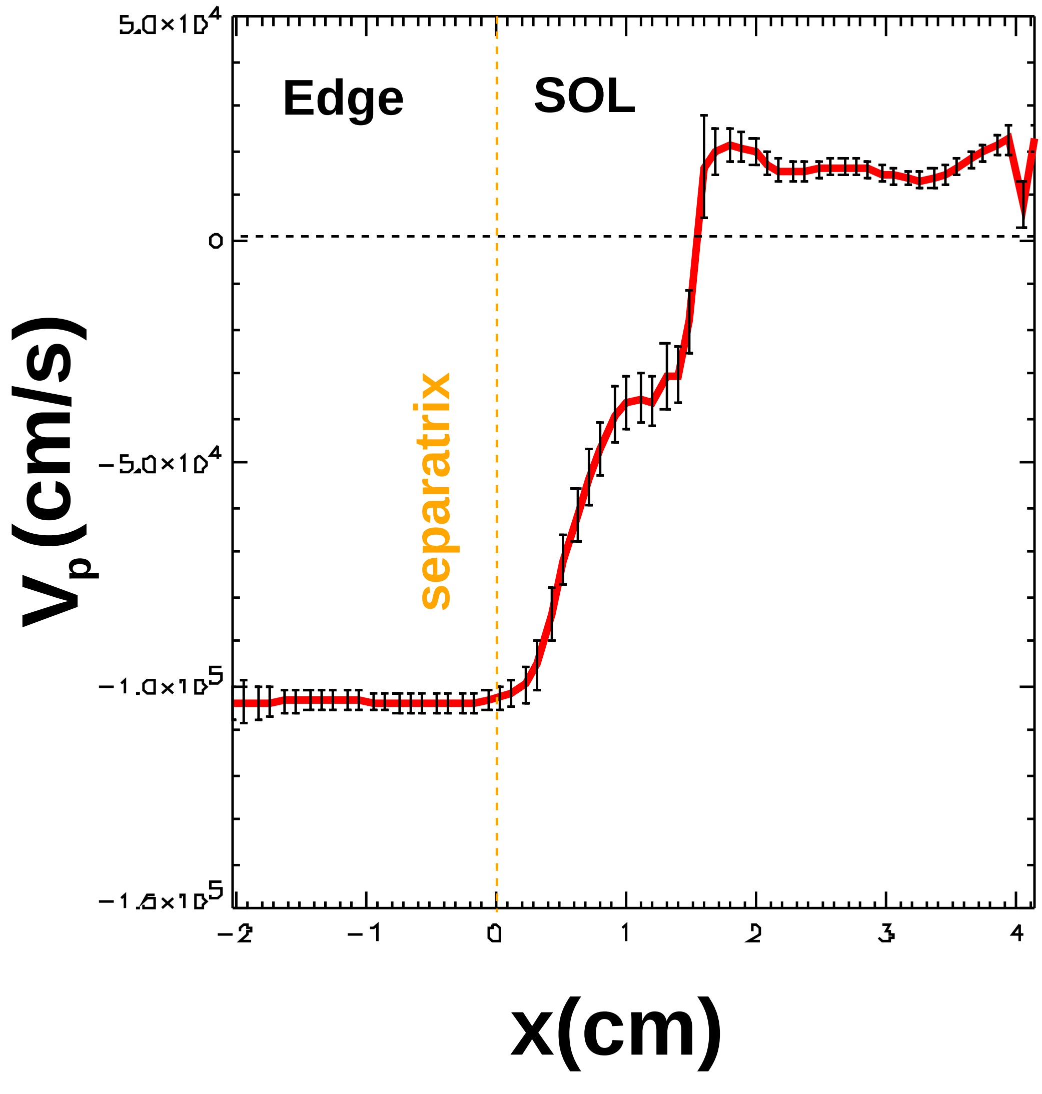


Fluctuating density shows sheared poloidal flow and radial streamer structures across the separatrix



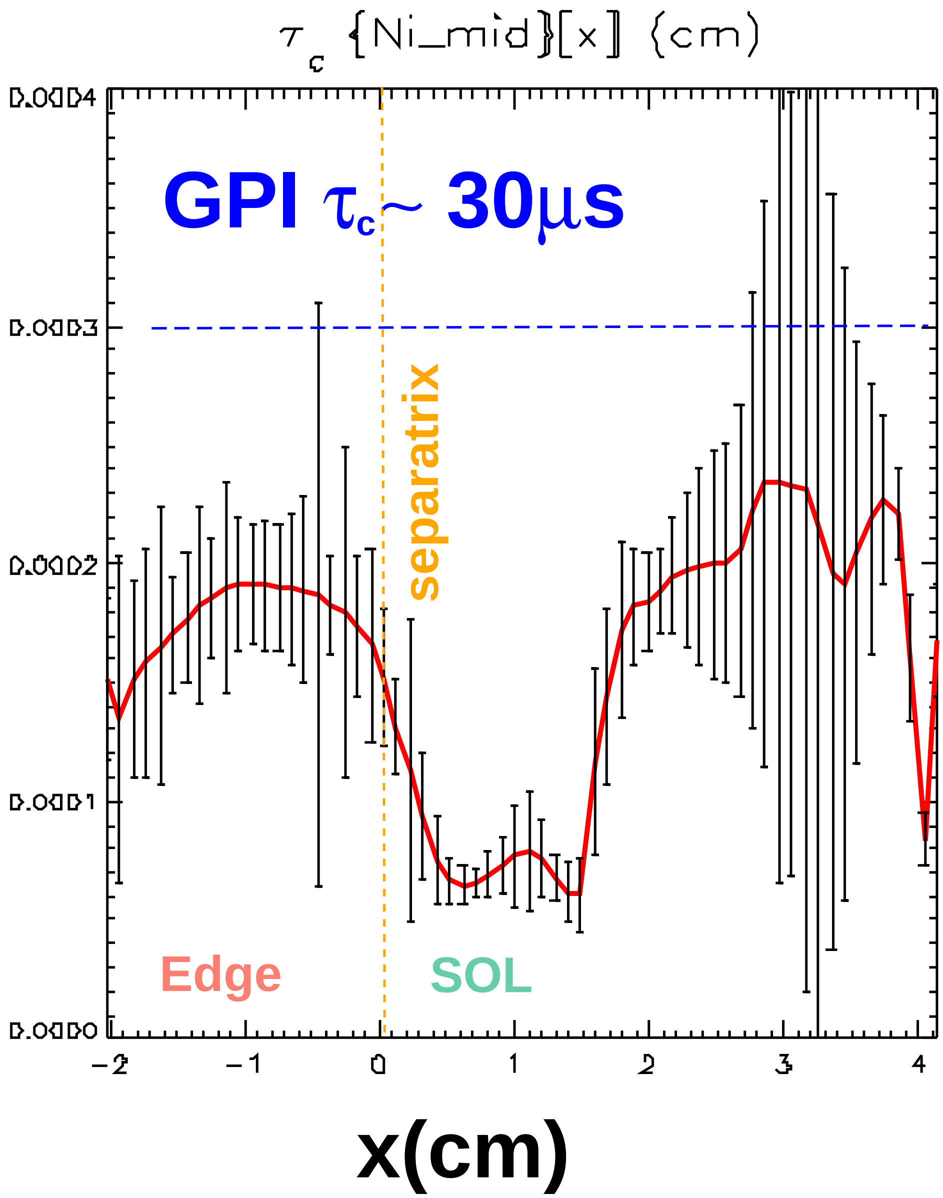
☞ **Eddy structures and size resembles GPI measurements**

Substantial Wave Propagation in electron diamagnetic direction

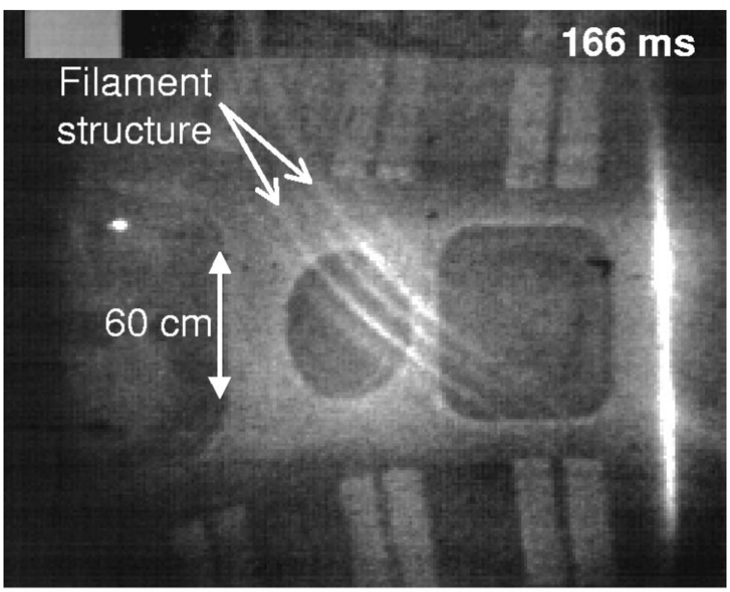


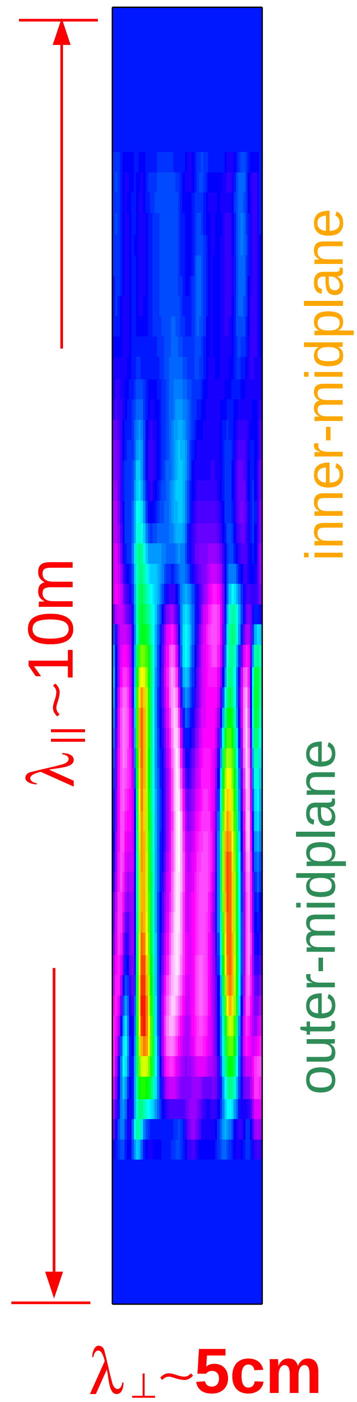
☞ **Poloidal fluctuation phase velocity reversal has been observed in tokamaks, and stellarators**

BOUT shows that the correlation time is shortest inside the velocity shear layer

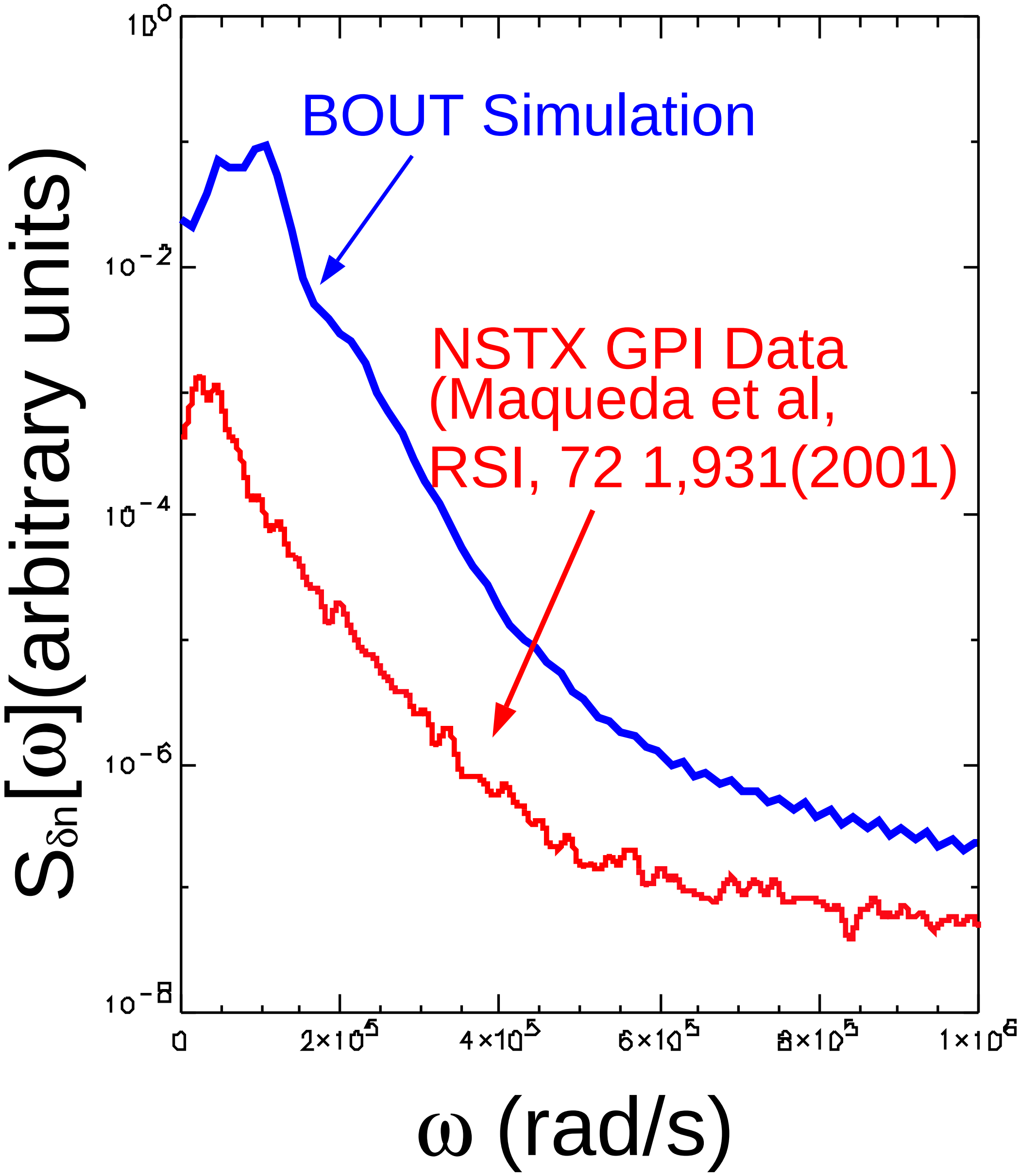


Filament-like structures observed in BOUT and GPI

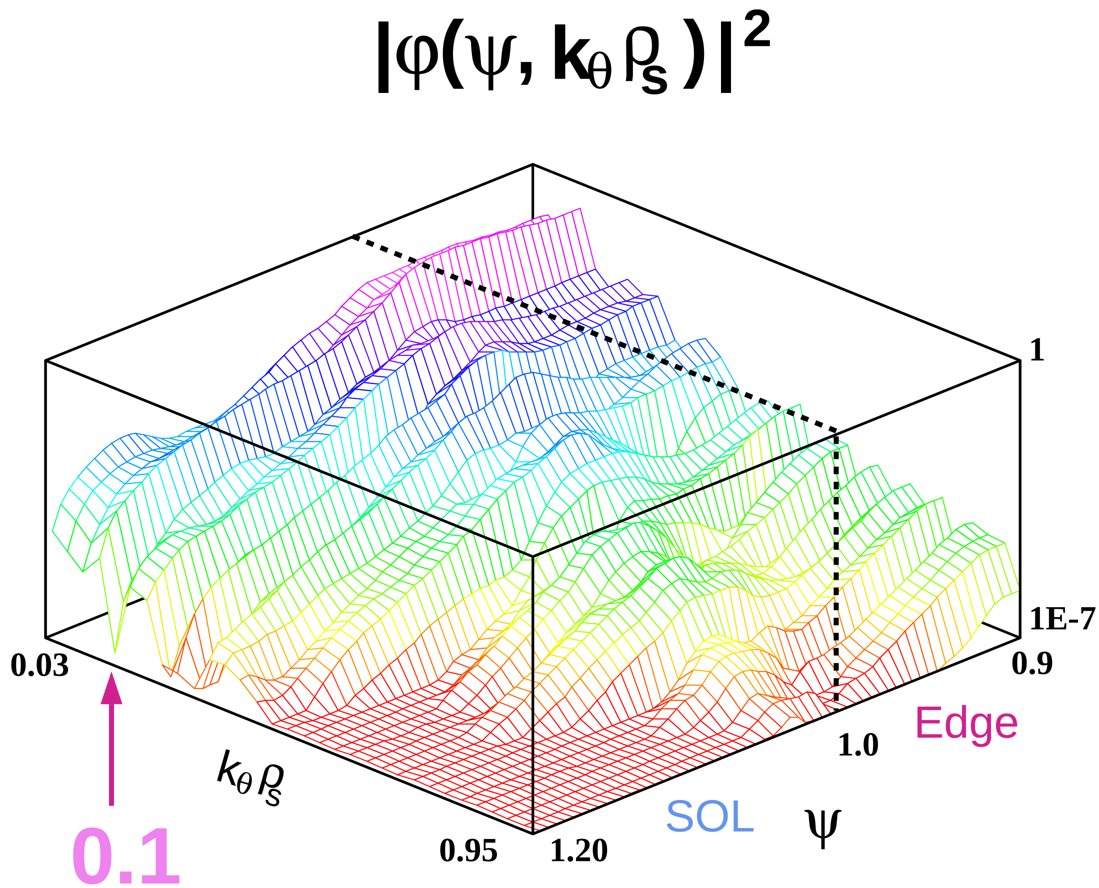




BOUT shows simular frequency spectrum as Gas Puff Image

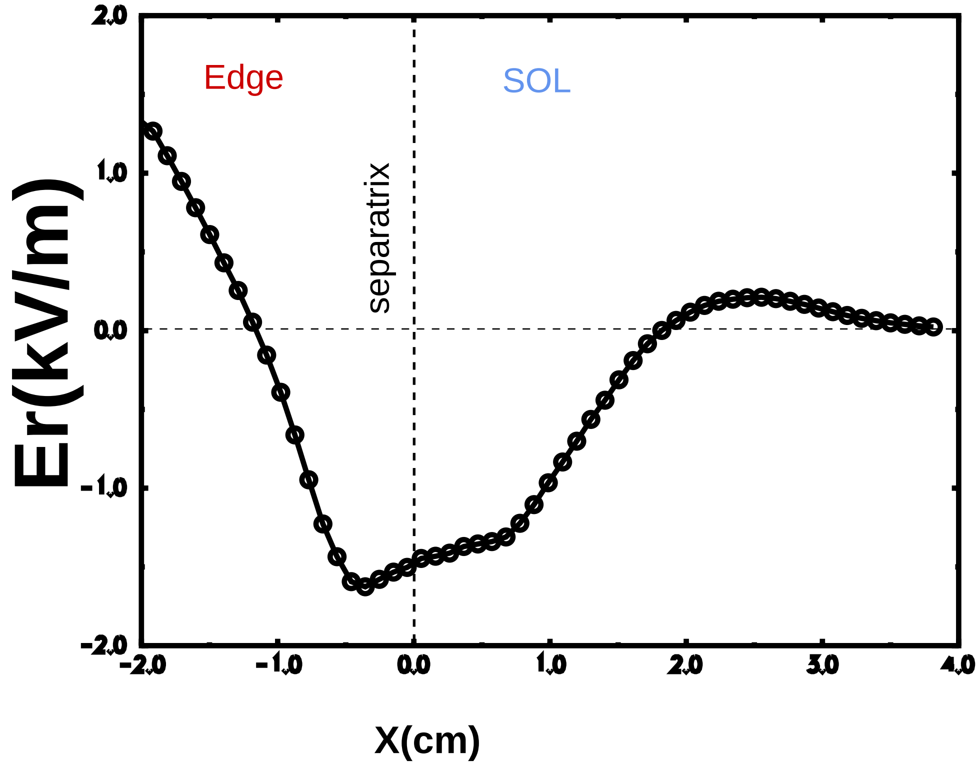


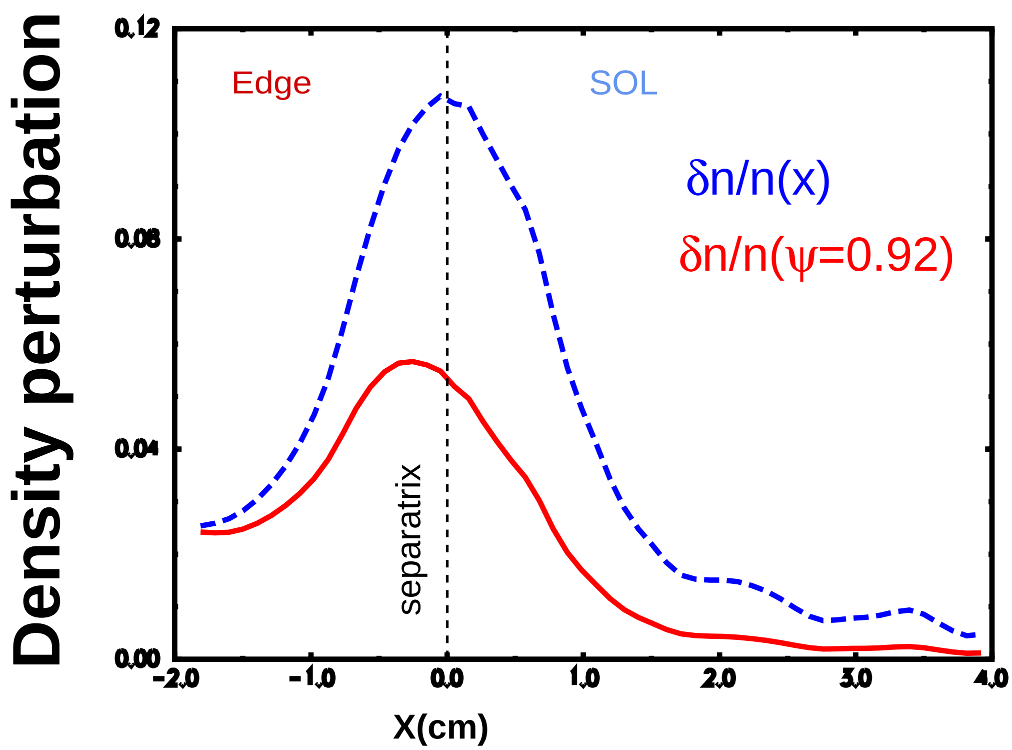
The spectrum of midplane plasma electrostatic potential shows a peak near $k_\theta \rho_s \approx 0.1$



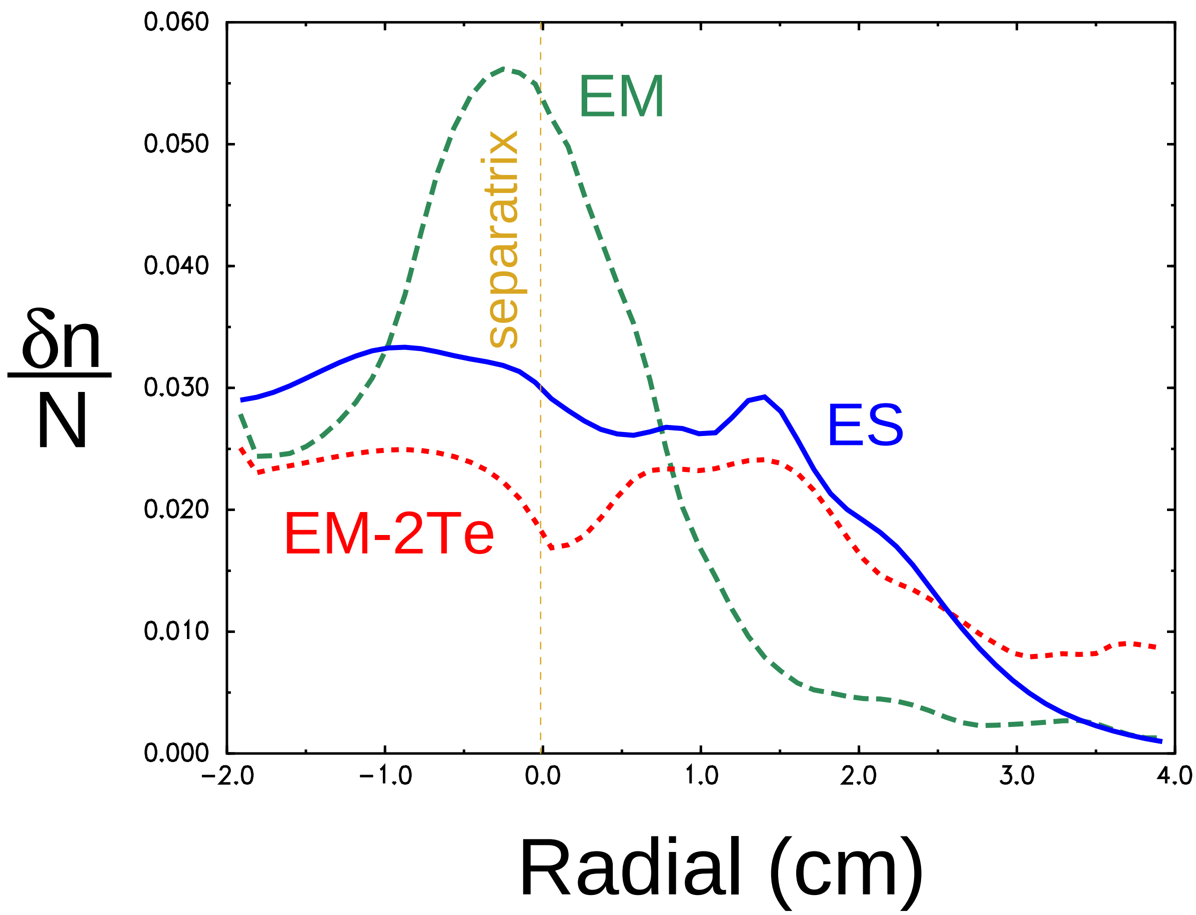
GPI yields $k_\theta \rho_s$ ~0.2

Electric Field and density fluctuation across separatrix show similar radial structure as Tokamaks

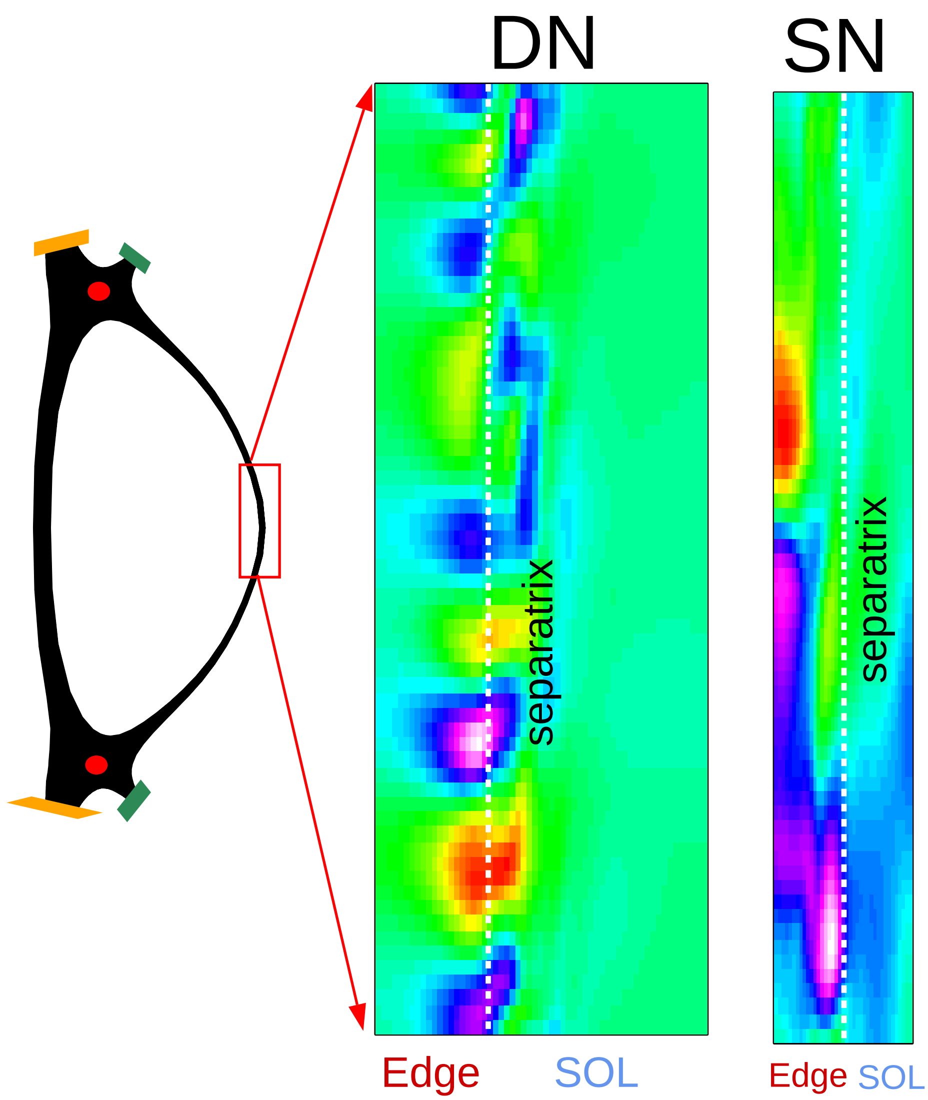




BOUT shows higher density fluctuation for high collisional plasma at outside midplane



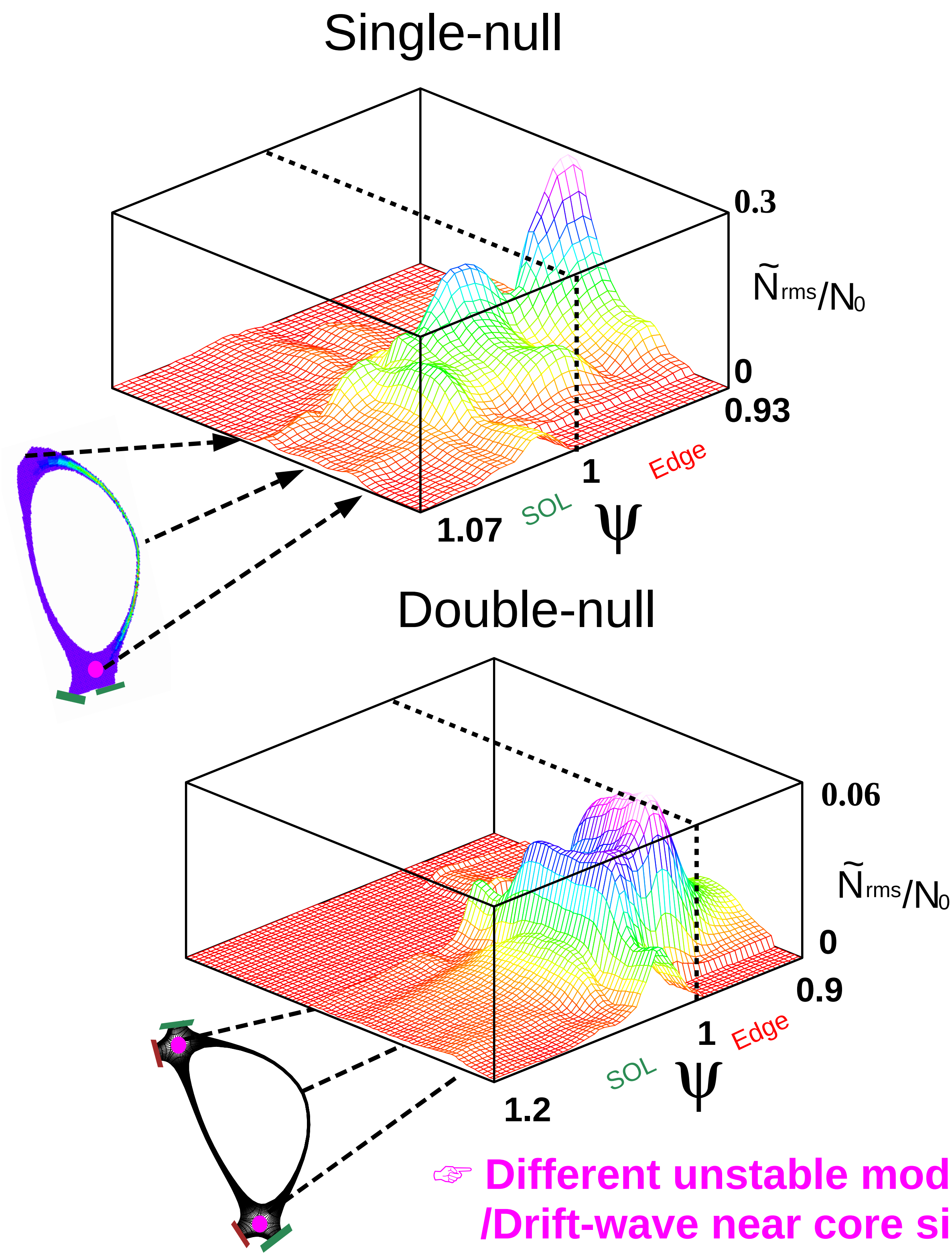
Higher fluctuation level and longer eddy size in SN is consistent with higher q95



- q_{95}~ 6 for SN, and q_{95}~ 4 for DN
- higher q allows more lower n mode unstable and longer scale length ($k_\theta \sim nq \propto$ conts.)

Single-null Generates Higher Fluctuating Density and Different Radial Mode Structure

$\langle N(\psi,\theta,\varphi,t)\rangle_{rms}$



☞ **Different unstable modes /Drift-wave near core side in SN**

Summary

- **BOUT contains much of the relevant physics for the pedestal barrier problem**
- **Encouraging results have been obtained when using NSTX configurations**
  - **Fluctuation level and transport are higher in SN than in DN, maybe due to higher q_{95} in SN.**
  - **Frequency spectrum of BOUT simulation resembles that of GPI measurements .**
  - **Poloidal fluctuation phase velocity v_p from the resistive X-point turbulence shows experimentally observed structure across separatrix.**
  - **radial electric field shows measured flow shear structure across separatrix**
  - **show strong poloidal asymmetry of particle flux**