Poloidal asymmetries in SOL turbulence on ASDEX Upgrade in different magnetic configurations

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Outline

“Begin at the beginning," the King said, very gravely, "and go on till you come to the end: then stop.” *Lewis Carroll, Alice in Wonderland*

- Motivation
- Experimental set up
- Methodology

- Study of poloidal asymmetries of SOL/edge turbulence

Results:

HFS/LFS SOL/edge density fluctuations in L-mode

- ✓ Asymmetry $\delta n/n$ in USN, DN, LSN
- ✓ Comparison with GEMR simulations
- ✓ Radial profiles $\delta n/n$

- Summary

Why do we investigate turbulence?

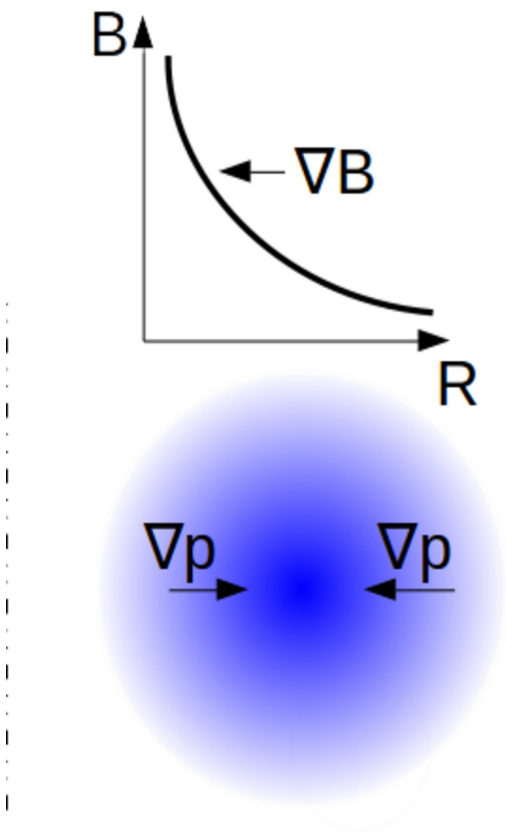
"Due to the high success of fusion …

that takes place in space." *Ellen Zweibel*

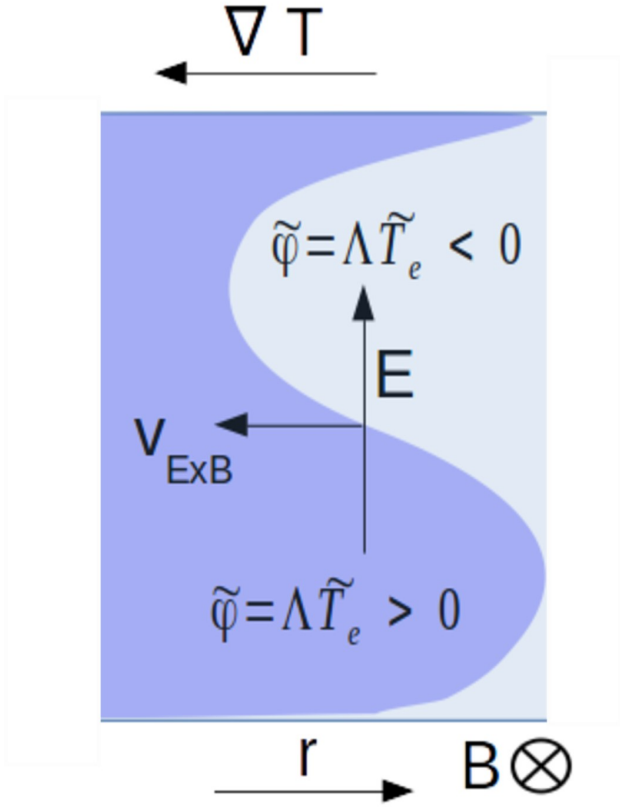
Motivation

- Plasma turbulence greatly enhances energy and particles transport across magnetic field lines - degradation of plasma confinement
- Investigation of turbulence is relevant to improve reliability of a fusion reactor
- SOL/edge turbulence properties are not poloidally symmetric (diamagnetic drift, **E**x**B** drift, Shafranov shift, different connection length, etc)

SOL instabilities



Interchage:
driven by ∇p in bad curvature region

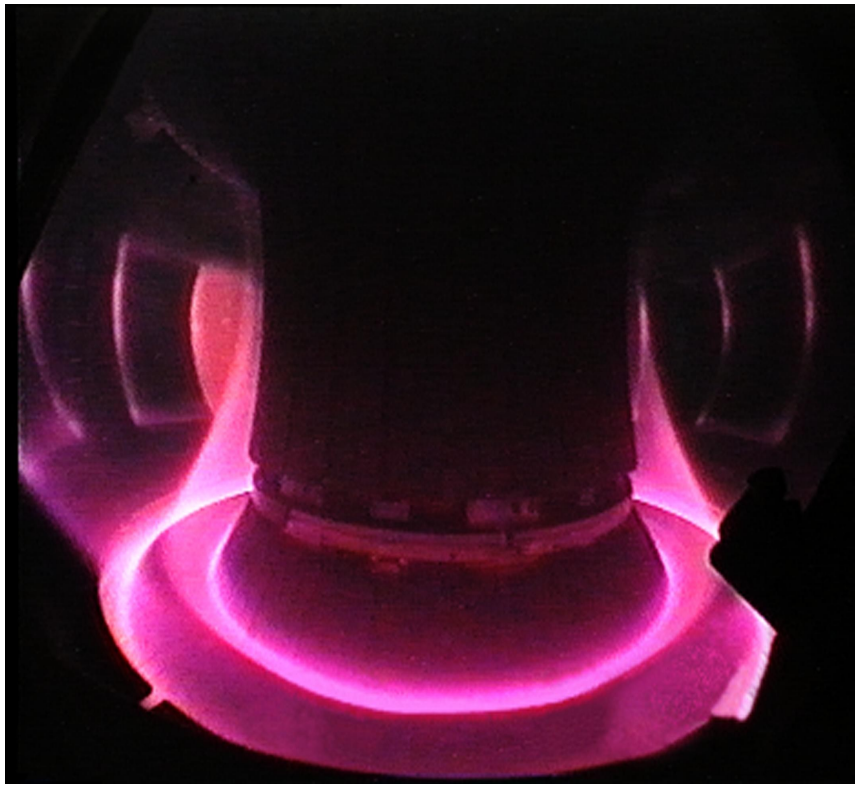


CWI (conducting wall instability):
negative sheath resistivity,
driven by Te

P. Manz et al., Phys. Plasmas 22, 2015
Y. Sarazin et al., J. Nucl. Mater., 2003
H. L. Berk et al., Nucl. Fusion, 1993

ASDEX Upgrade tokamak

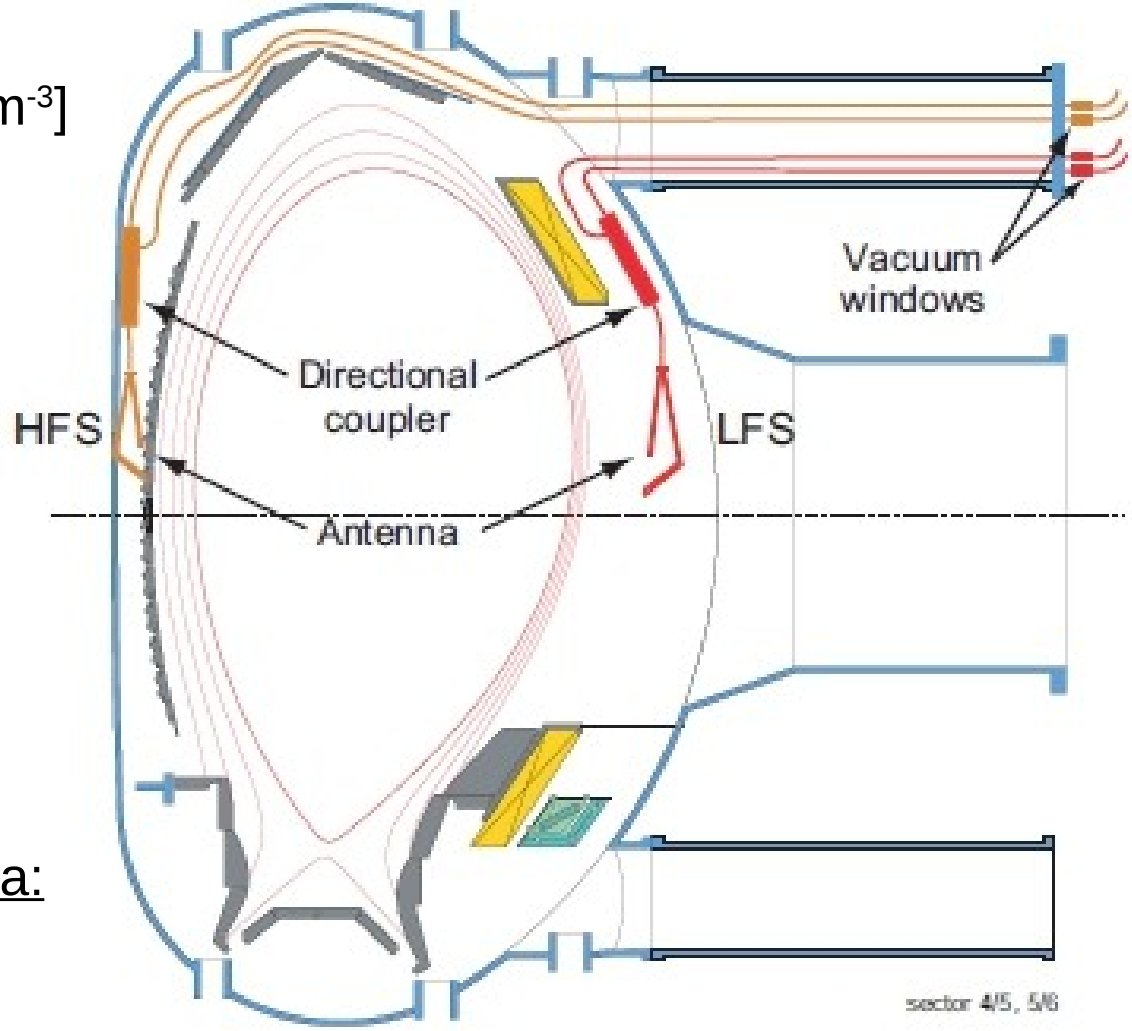
(**A**xially **S**ymmetric **D**ivertor **EX**periment)



- **major radius (*R*)** **1.65 m**
- **minor radius (*a*)** **0.5 m**
- **max plasma current (I_p)** **1.6 mA**
- **max toroidal magnetic field (B_t)** **3.1 T**
- **max pulse duration** **10 s**
- **max electron density (n_e)** **10^{20} m^{-3}**

HFS&LFS FMCW reflectometer

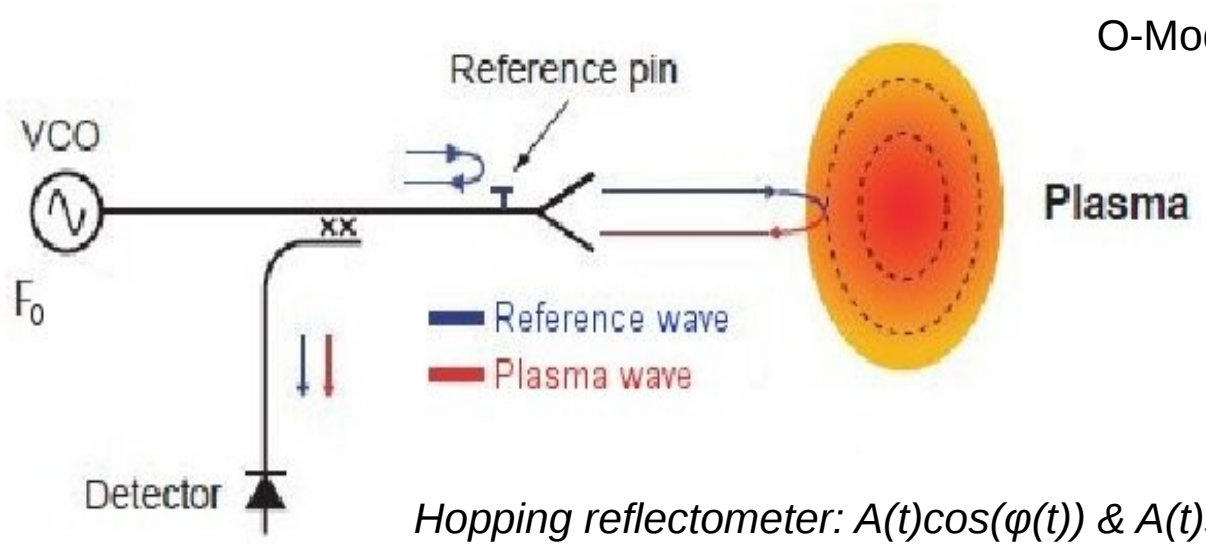
Density [x$10^{19}$$m^{-3}$]
V 3.0 - 7.0
Q 1.5 - 3.0
Ka 0.8 - 1.5
K 0.3 - 0.8



LFS Z=0.14 [m]
HFS Z=0.07 [m]

<u>Fluctuation Data:</u>
8s @2MHz

Methodology of data analysis



O-Mode: $E_{wave} \parallel B_0$: solely depend on n_e

$$F_c = \frac{1}{2\pi}\sqrt{\frac{n_c e^2}{\epsilon_0 m_e}}$$

Hopping reflectometer: A(t)cos(φ(t)) & A(t)sin(φ(t)) → ***φ(t)***

FMCW reflectometer: A(t)cos[2πF$_0$ + φ(t)] *to get* ***φ(t)*** **– *Hilbert transform***

validation of the method is done by comparison with overlapping data obtained by hopping reflectometer

relation between phase *φ(t)* and the density fluctuation level $\delta n_e/n_e$ determined from (O mode):

1D model by C.Fanack:

Large wavenumbers $2k_a < k_f < 2k_0$:

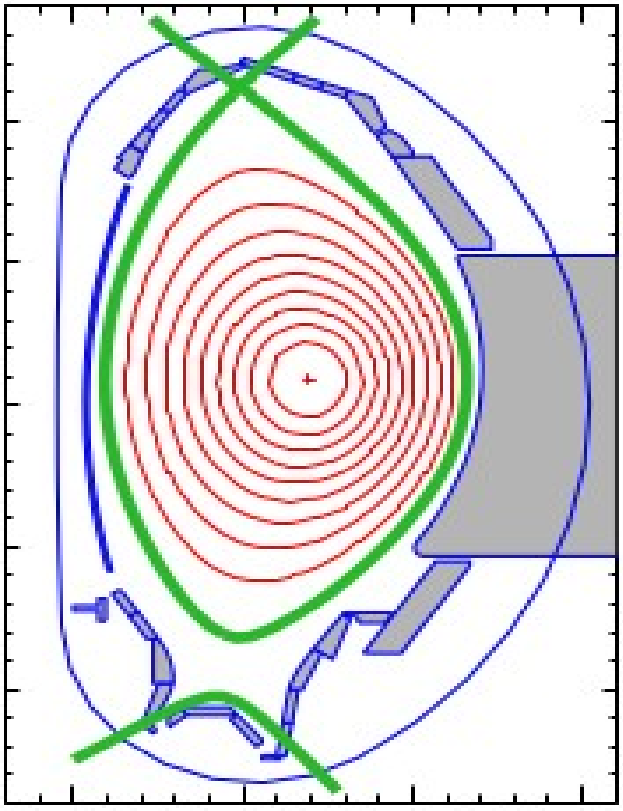
$$k_A = 0.63\, k_0^{2/3} L^{-1/3}$$

$$\frac{\delta n_0}{n_{cr}} = \frac{\Delta\phi_{max}}{\pi\sqrt{2}}\left(\frac{k_f/k_0}{L/\lambda_0}\right)^{1/2}$$

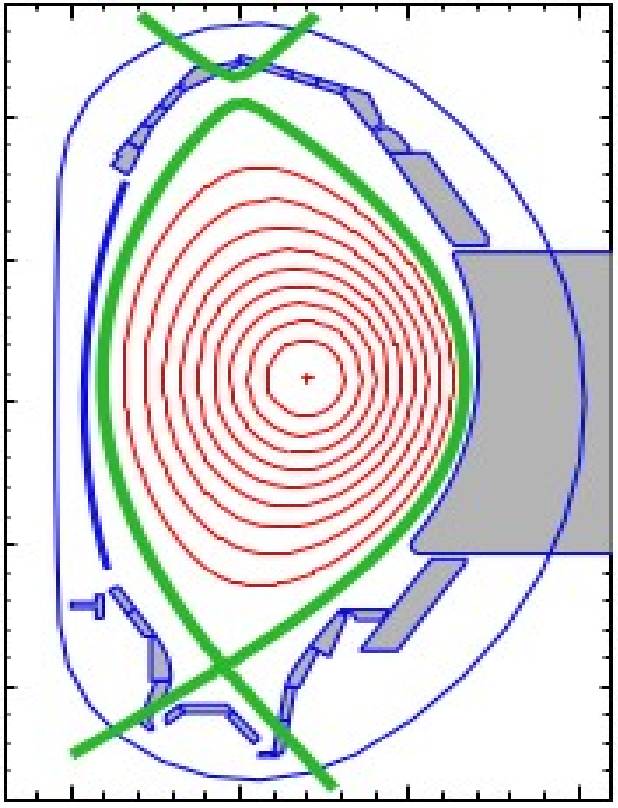
$$L_n = \frac{n_c}{\nabla n_e}$$

Dependence of $\delta n/n$ on the magnetic configuration

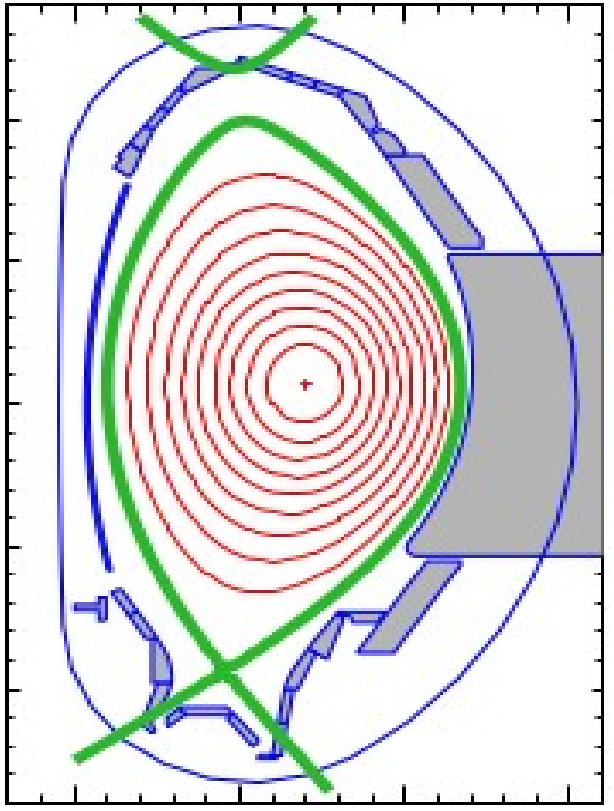
Upper Single Null
USN



Double Null
DN

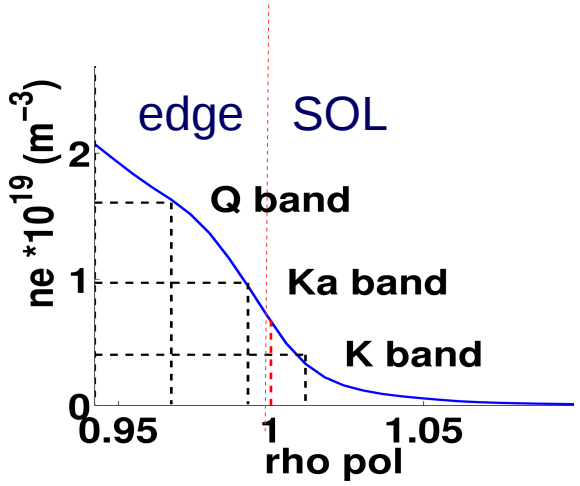


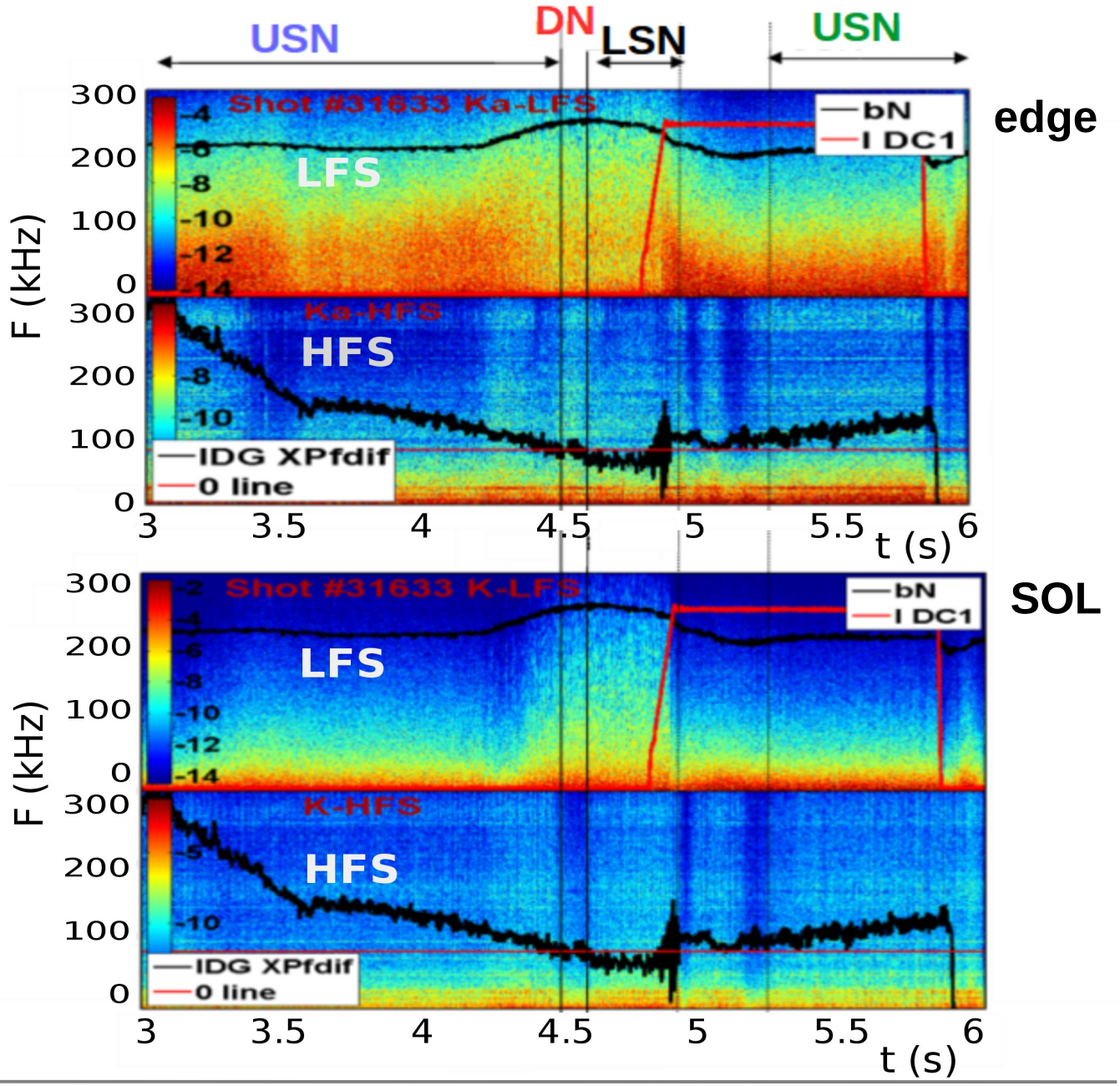
Lower Single Null
LSN



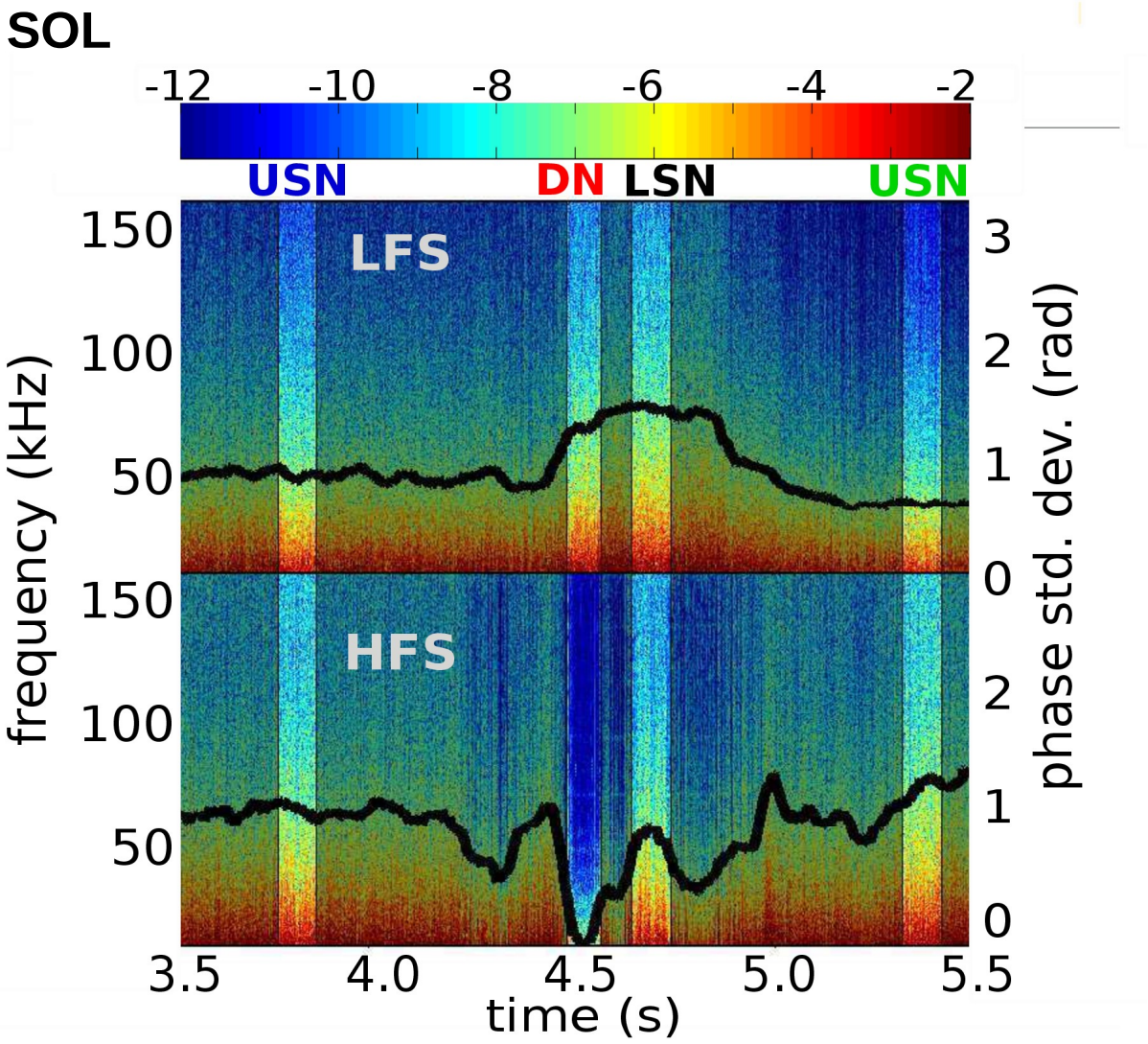
Turbulence asymmetries

- HFS/LFS
- edge/SOL
- USN → DN → LSN → USN

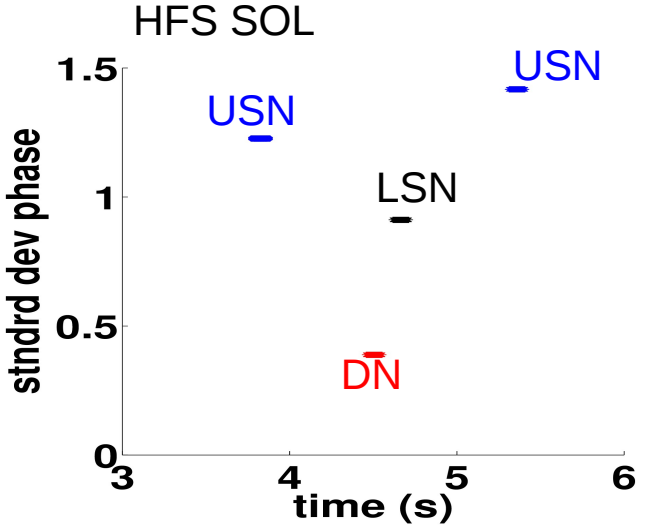




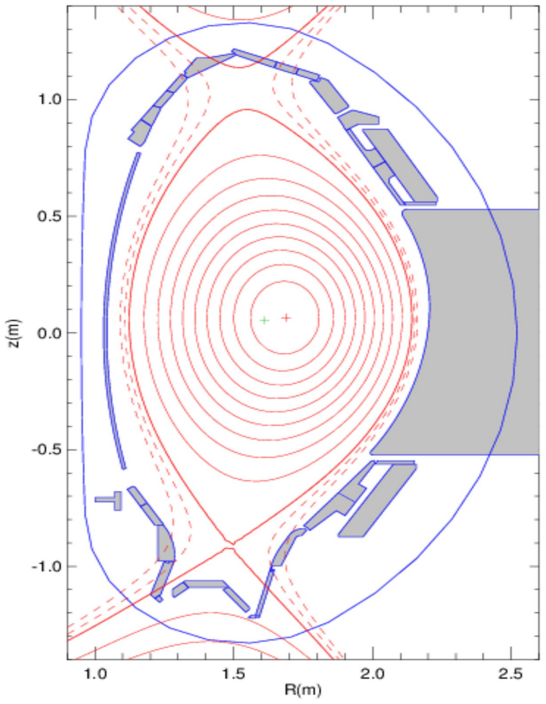
Turbulence asymmetries

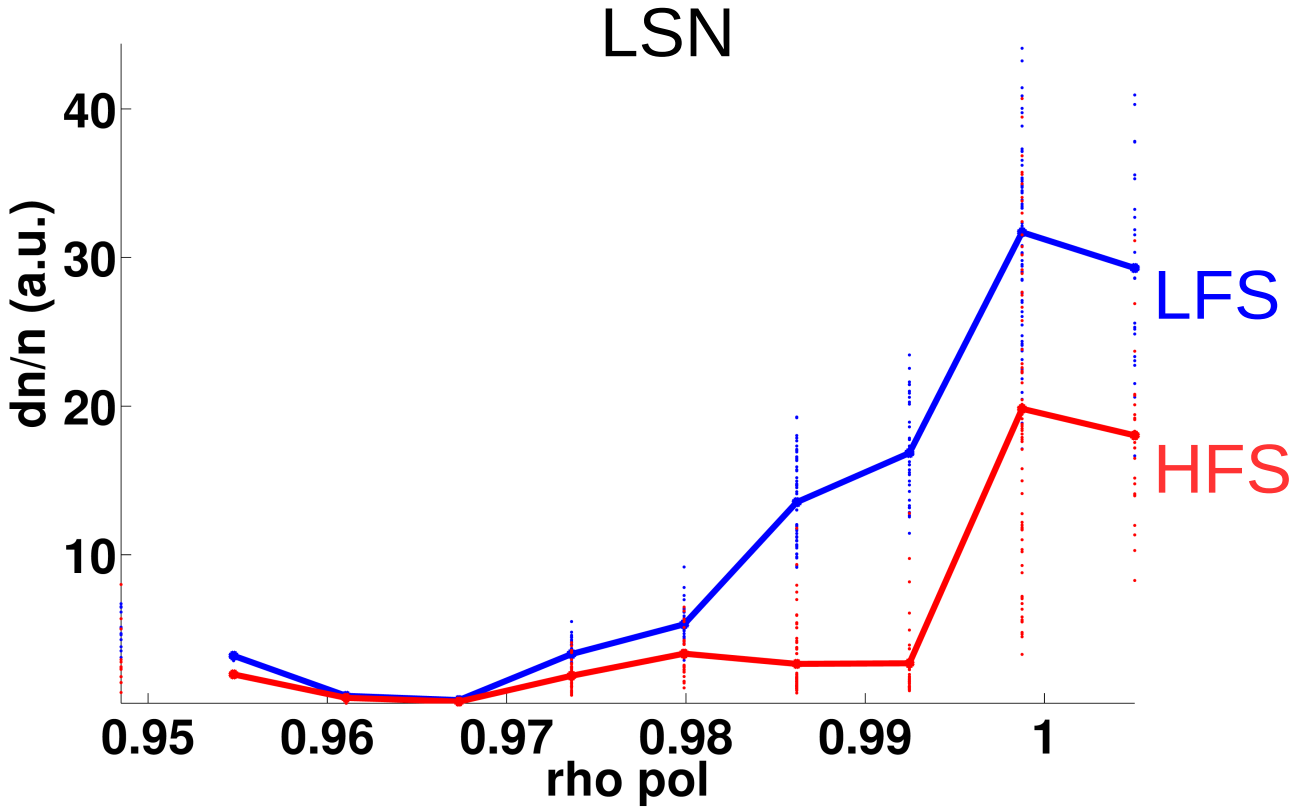


spectrograms of signal phase

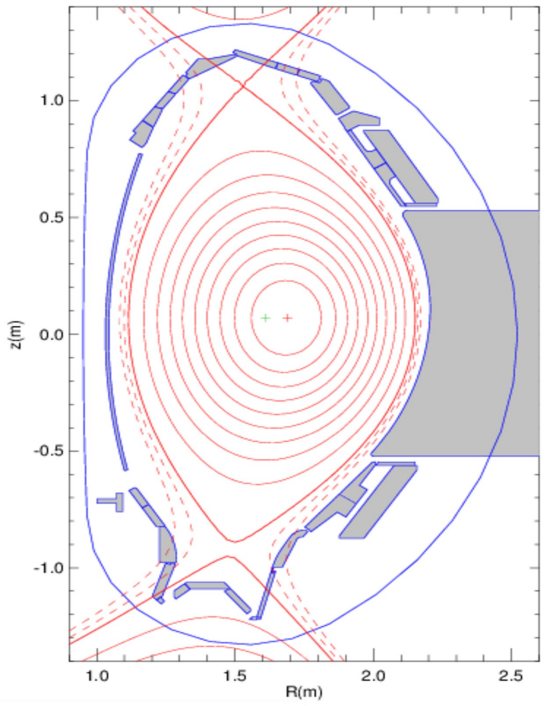


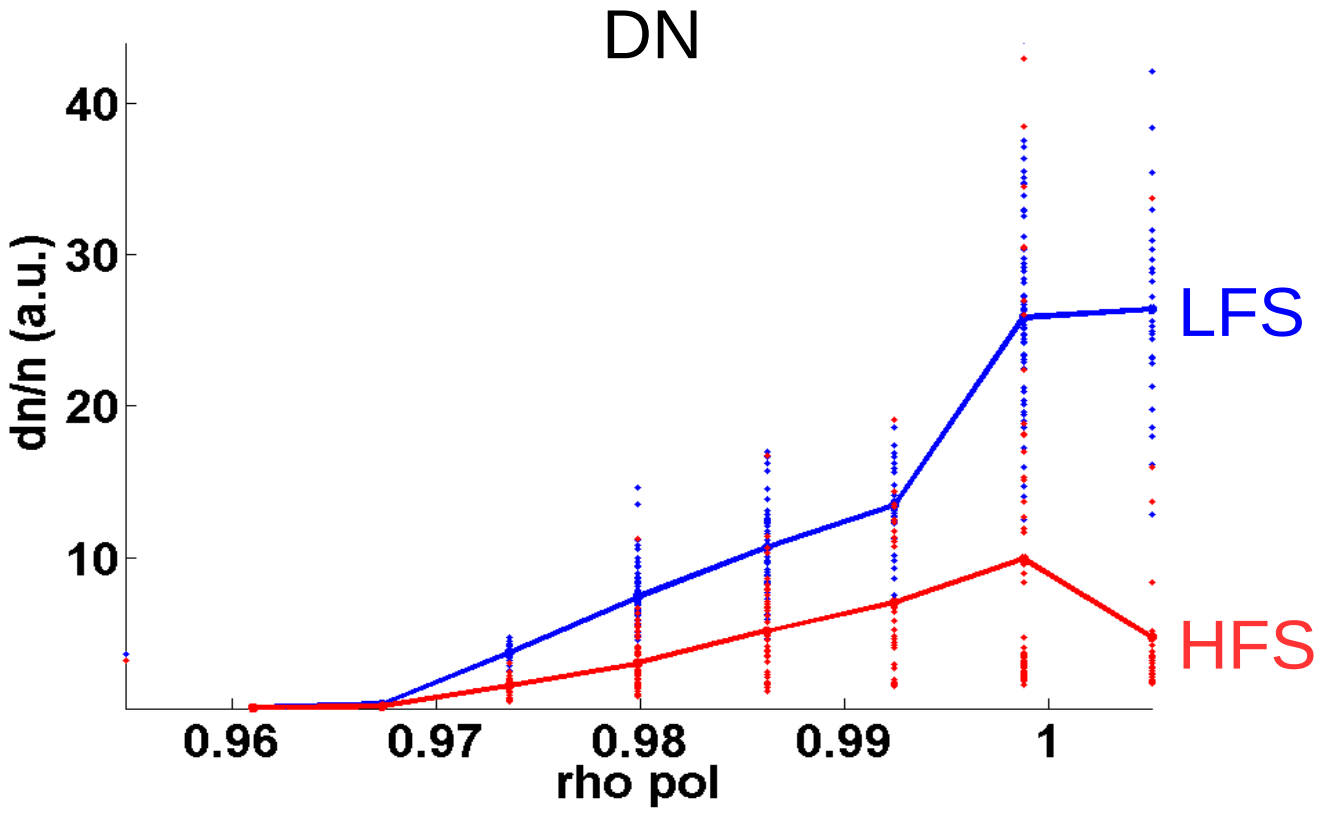
LSN HFS/LFS δn/n fluctuations





DN HFS/LFS δn/n fluctuations



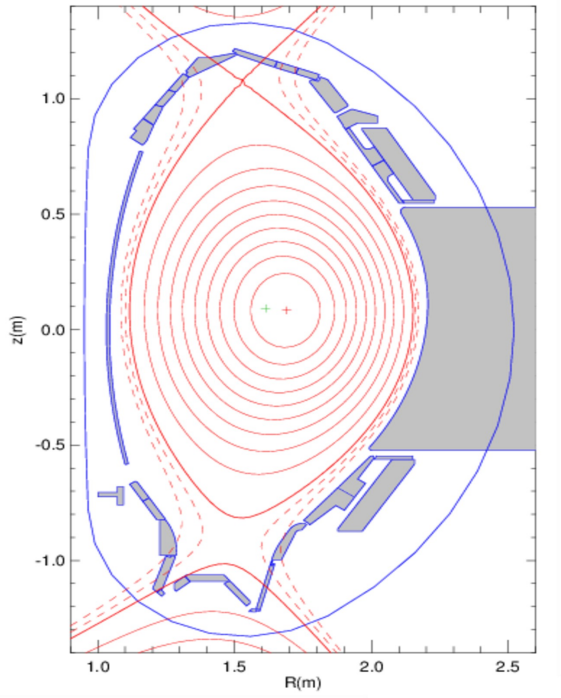


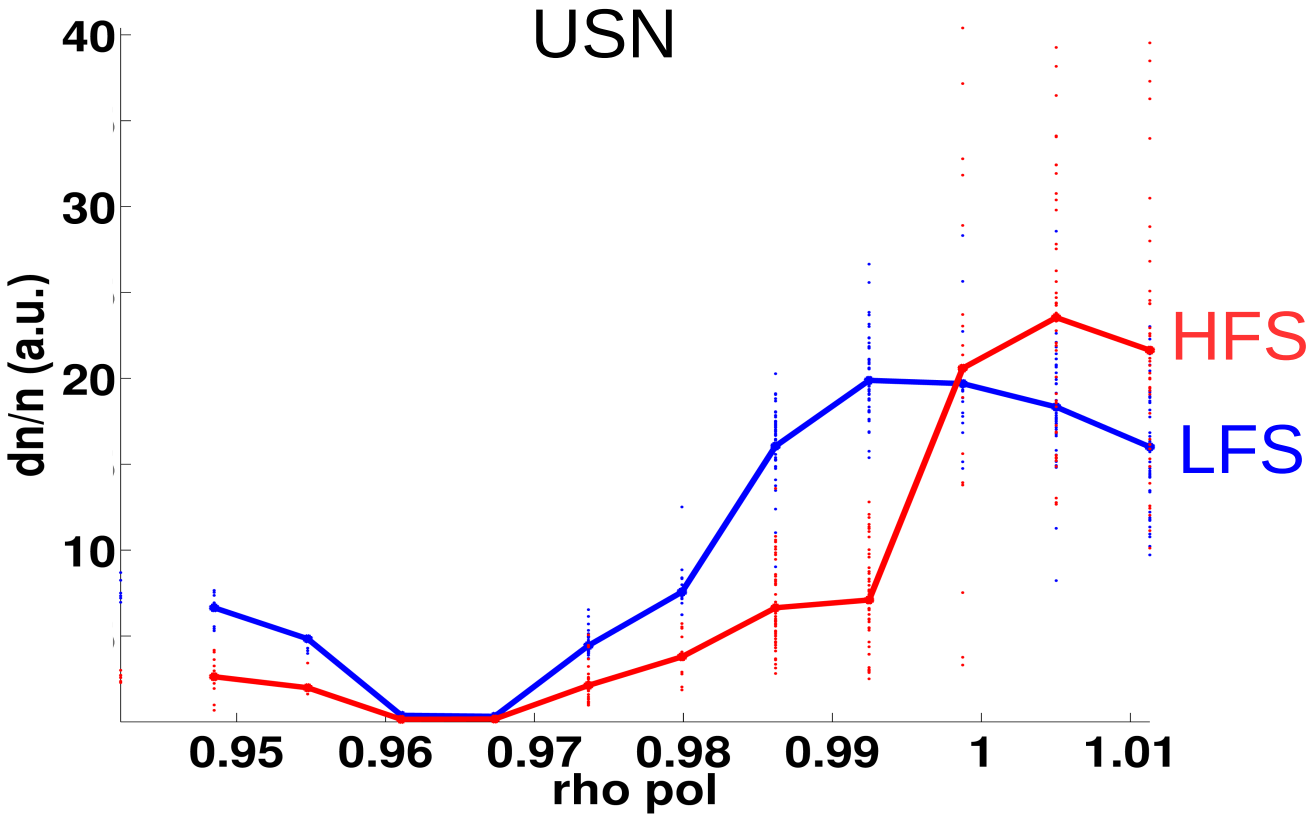
DN SOL – HFS becoming isolated from LFS

USN HFS/LFS δn/n fluctuations

beginning of the discharge

"Curiouser and curiouser!" Cried Alice (she was so much surprised, that for the moment she quite forgot how to speak good English)."
Lewis Carroll, Alice in Wonderland



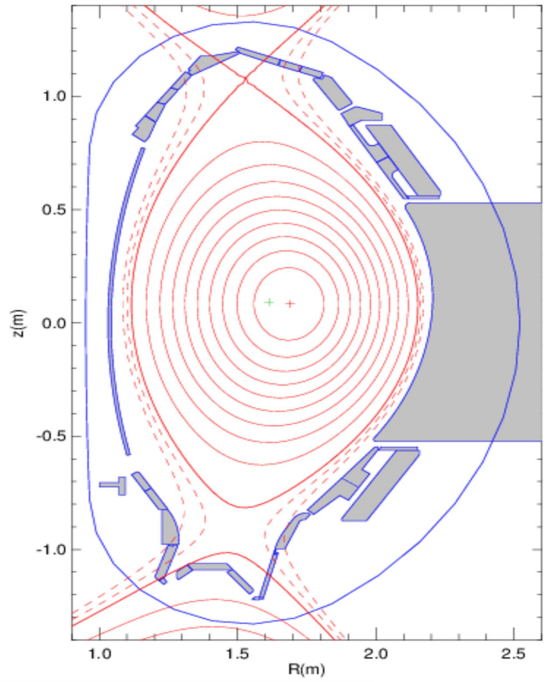


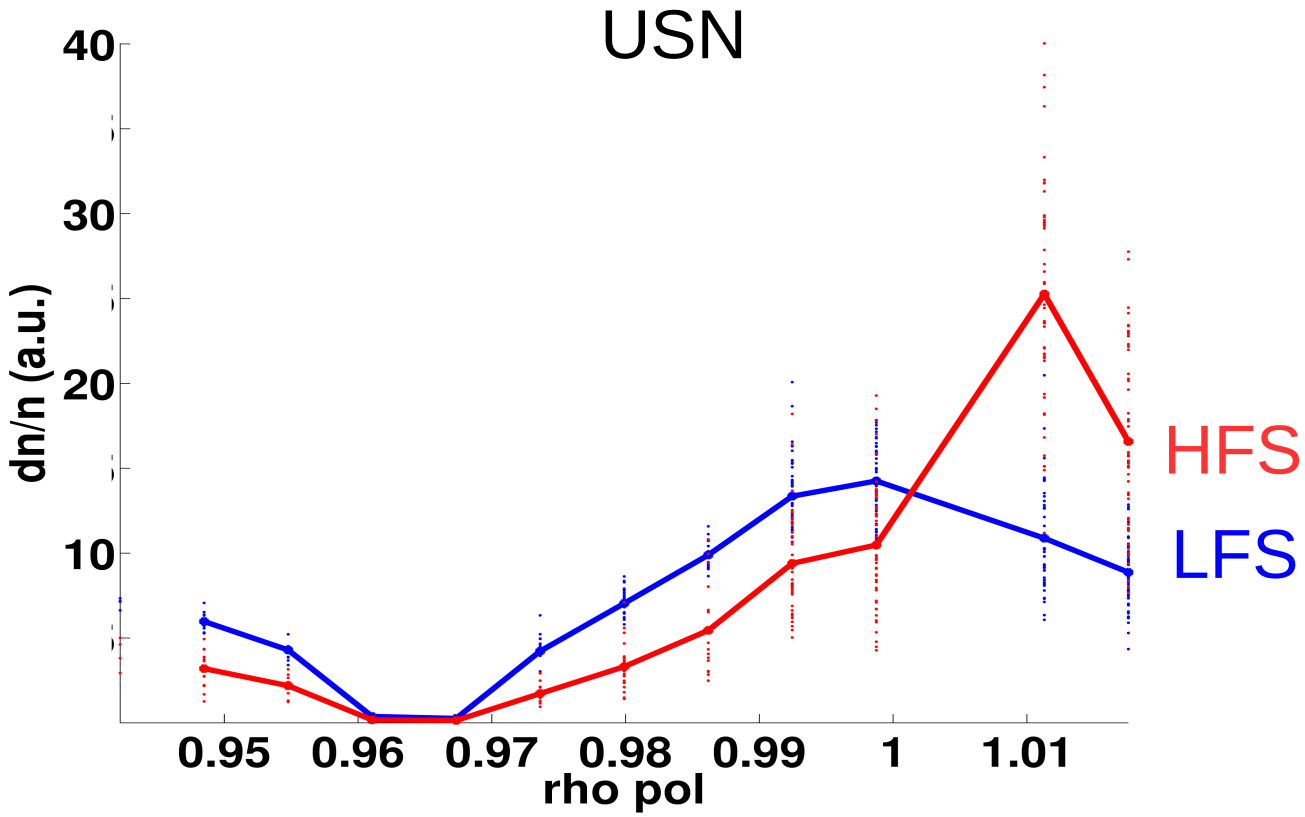
USN SOL – HFS δn/n > LFS δn/n unexpected!

EAST USN upper divertor HFS jsat > LFS jsat ,
S.C. Liu et al. Phys. Plasmas 19, 042505 (2010)

USN HFS/LFS δn/n fluctuations

end of the discharge, RMP





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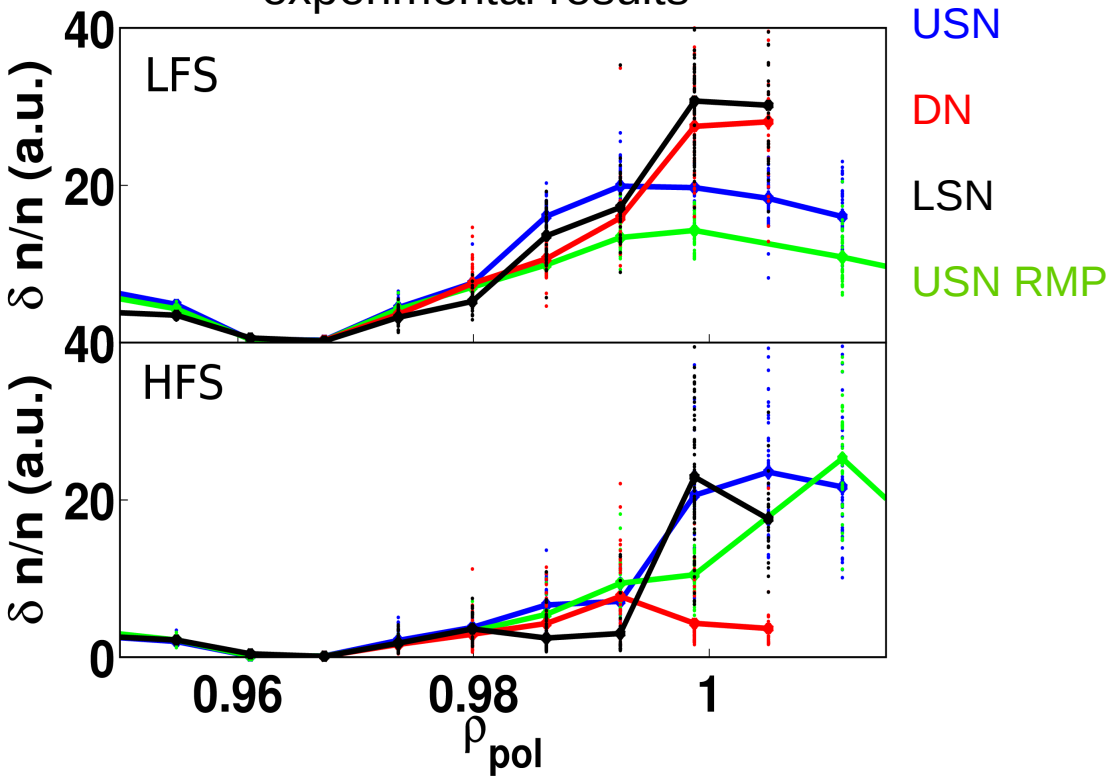
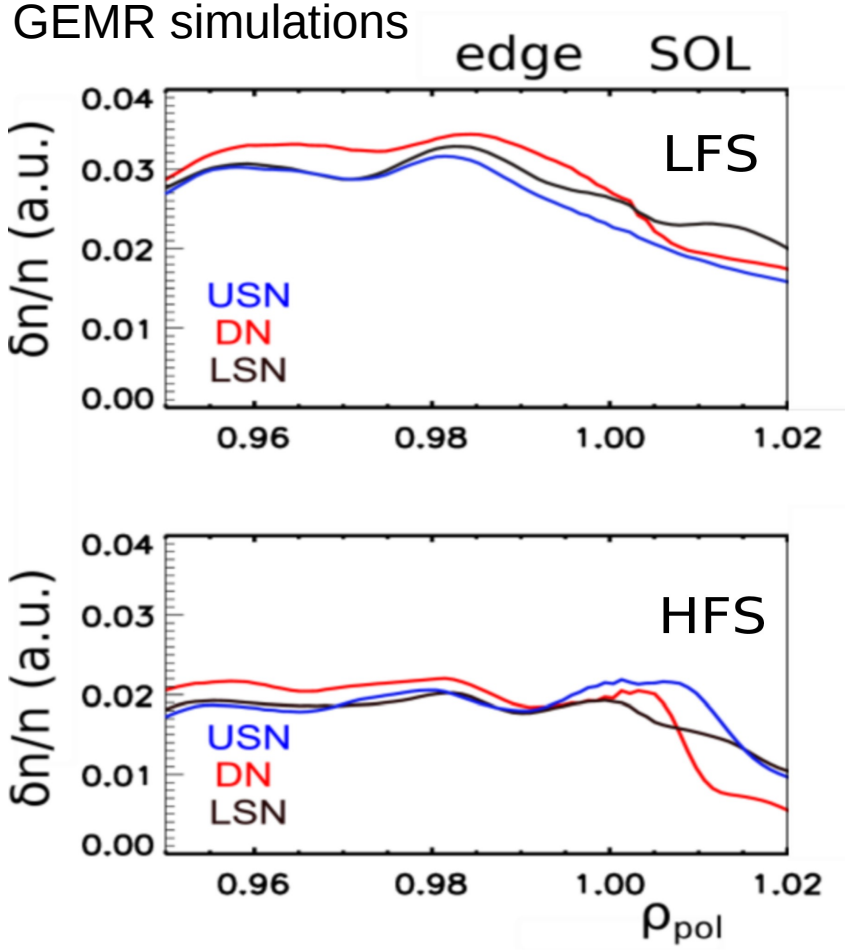
Comparison with GEMR code

experimental results



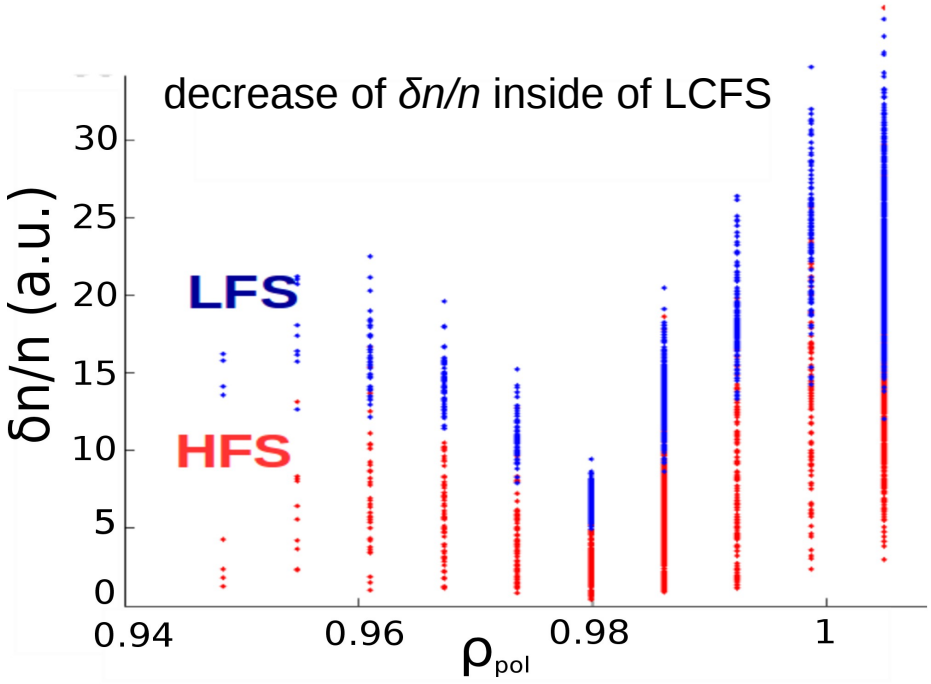
GEMR simulations

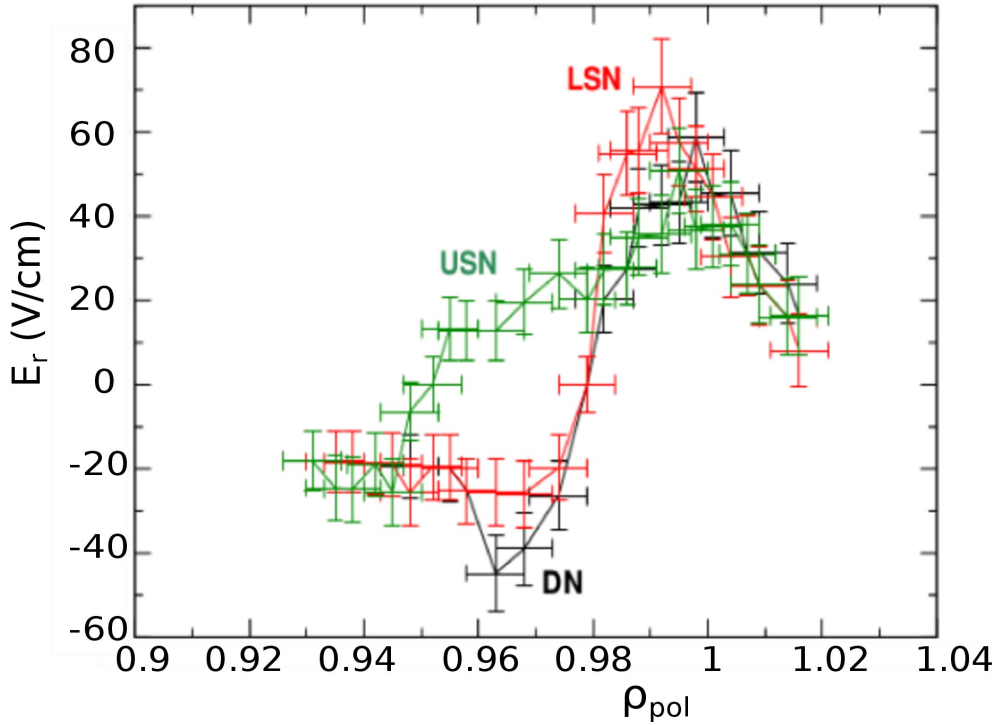


Experimental results and GEMR simulations show:

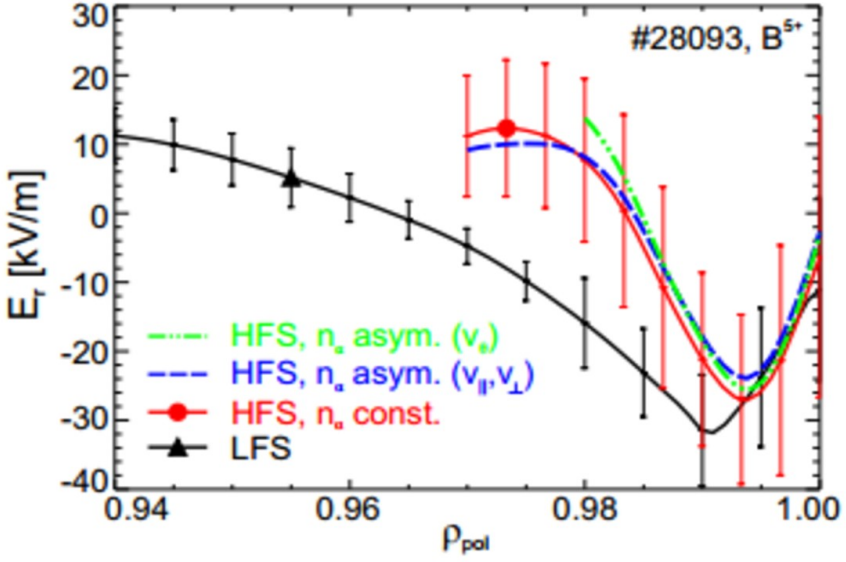
- Effect of magnetic configuration on poloidal asymmetries of **δn/n** is mainly pronounced in SOL
- δn/n SOL on LFS is higher for **LSN** than **USN** and on the HFS the other way around
- the strongest HFS/LFS asymmetry of δn/n in **DN** SOL, also seen with GEMR earlier
  (T. T. Ribeiro et al., Plasma Phys. Control. Fusion 50, 008)
- **DN** is similar to **LSN** on LFS and to **USN** on HFS
- In **USN** HFS SOL δn/n exceeds those of the LFS

HFS/LFS radial profile of density fluctuations





Thesis of J. Schiermer, 2005



Thesis of E. Viezzer, 2012

region of strong Er shear inside of LCFS

H. Biglari et al., Phys. Fluids B2, 1 (1990)

Conclusions

- **Turbulence poloidal asymmetries in USN, DN, LSN**
  - The strongest HFS/LFS asymmetry of fluctuations in DN SOL, was also seen with the GEMR code, HFS being isolated from LFS
  - Effect of magnetic configuration (USN, DN, LSN) on the poloidal asymmetries of density fluctuations is more pronounced outside the separatrix
  - Surprisingly, in USN configurations, HFS SOL turbulence increases above the LFS level. This behavior is currently under investigation and might be induced by conducting wall instability CWI driven by different temperature gradients at these locations that are configuration dependent
- **HFS/LFS radial profiles of density fluctuations**
  - Drop of density fluctuations inside the separatrix both at LFS and HFS is observed in the region of strong radial electric field Er shear for all configurations – USN, DN, LSN

Thank you for your attention!

Night. Sitting in the office. The tokamak is nearby.
My reflectometer is broken, but I believe in better life.
The data looks a bit like nonsense, and difficult to interpret.
I like it, waiting for the fusion to be achieved in 20 years.