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

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IPP

Outline

- Motivation
- Experimental set up
- Methodology

- Study of poloidal asymmetries of SOL/edge turbulence

Results:

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

- ✓ Asymmetry *δn/n* in USN, DN, LSN
- ✓ Comparison with GEMR simulations
- ✓ Radial profiles *δn/n*

- Summary

Why do we investigate turbulence?

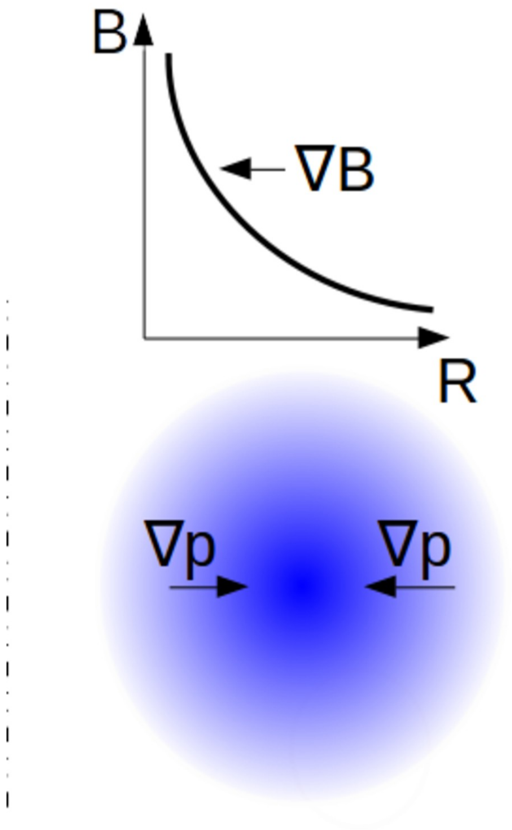
“Due to the high success of fusion …

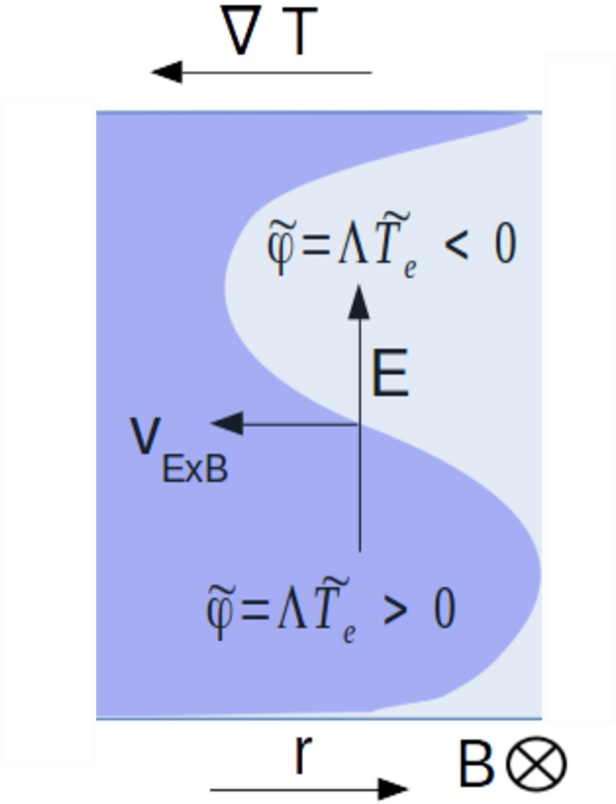
that takes place in space.“ *Ellen Zweibel*

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





Interchange:
driven by ∇p in bad curvature region

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

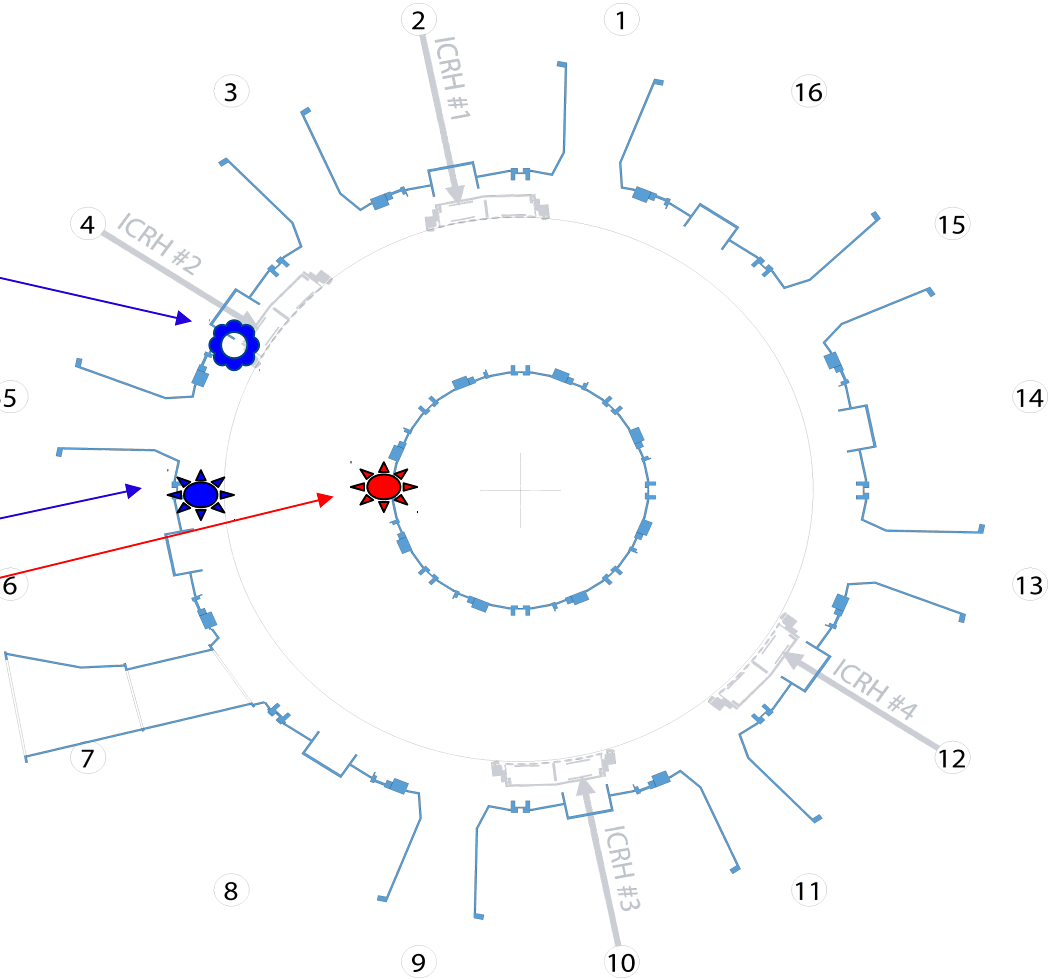
P. Manz et al., Phys. Plasmas 22, 2015
Y. Sarazin et al., J. Nucl. Mater., 2003
H. L. Berk et al., Nucl. Fusion, 1993

Experimental set up, HFS/LFS reflectometers

Multi-channel reflectometer diagnostics

Hopping LFS reflectometer
LFS 2 channels [FLQ, FLV]
FF or hopping
density fluctuation measurements
heterodyne: in-phase & quadrature (IQ) detector:
$I(t) = A(t)\cos(\varphi(t))$ & $Q(t) = A(t)\sin(\varphi(t))$
separation phase $\varphi(t)$ & amplitude $A(t)$ fluctuations

FMCW LFS&HFS reflectometer
LFS: 5 channels [K, Ka, Q, V, W]
HFS: 4 channels [K, Ka, Q, V]
swept frequency → profiles measurements or
FF → density fluctuation measurements
homodyne: single ended detector
$A(t)\cos[2\pi F_0 + \varphi(t)]$
F_0 – microwave source frequency

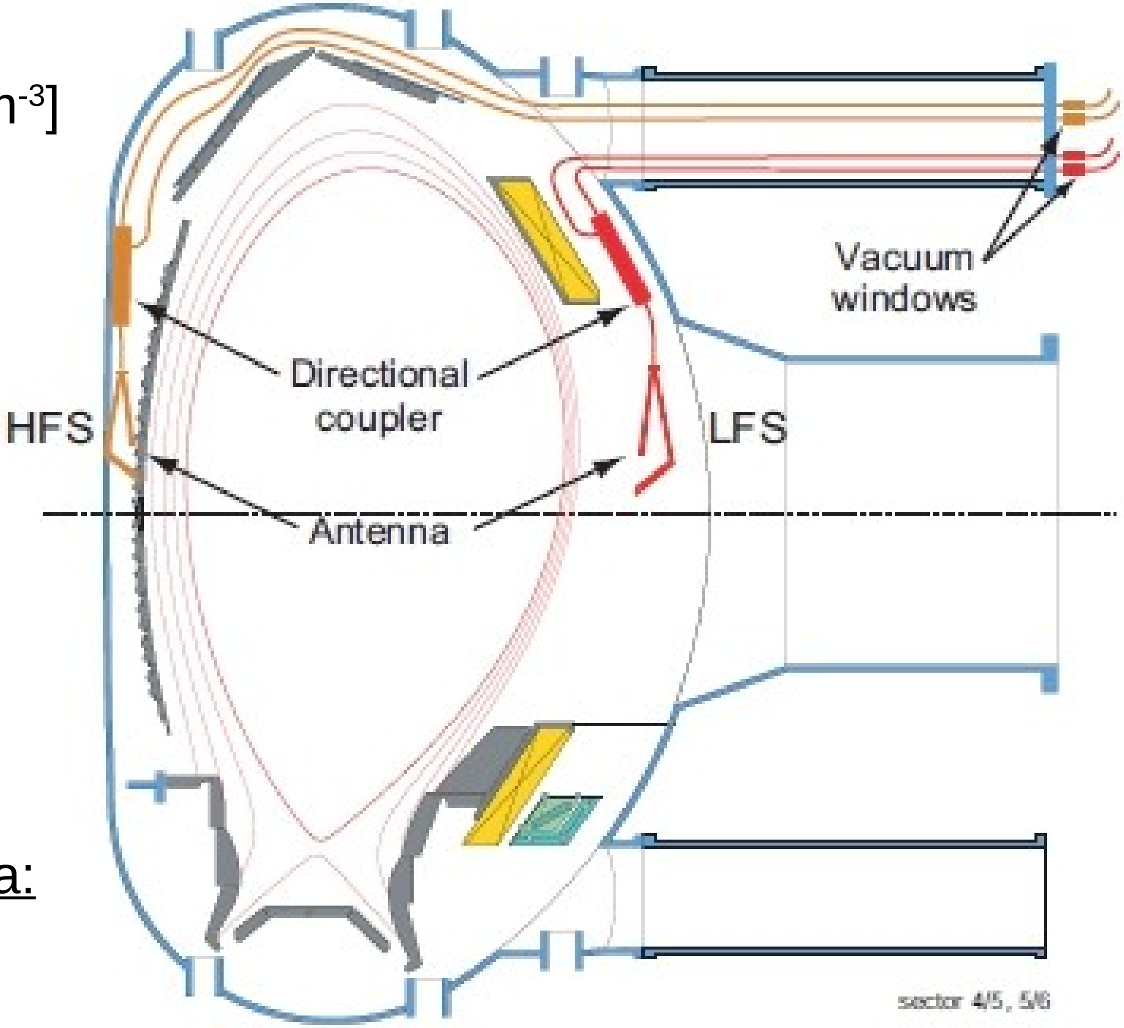


toroidal section of AUG tokamak

HFS&LFS FMCW reflectometer

Density [x10^{19}m^{-3}]

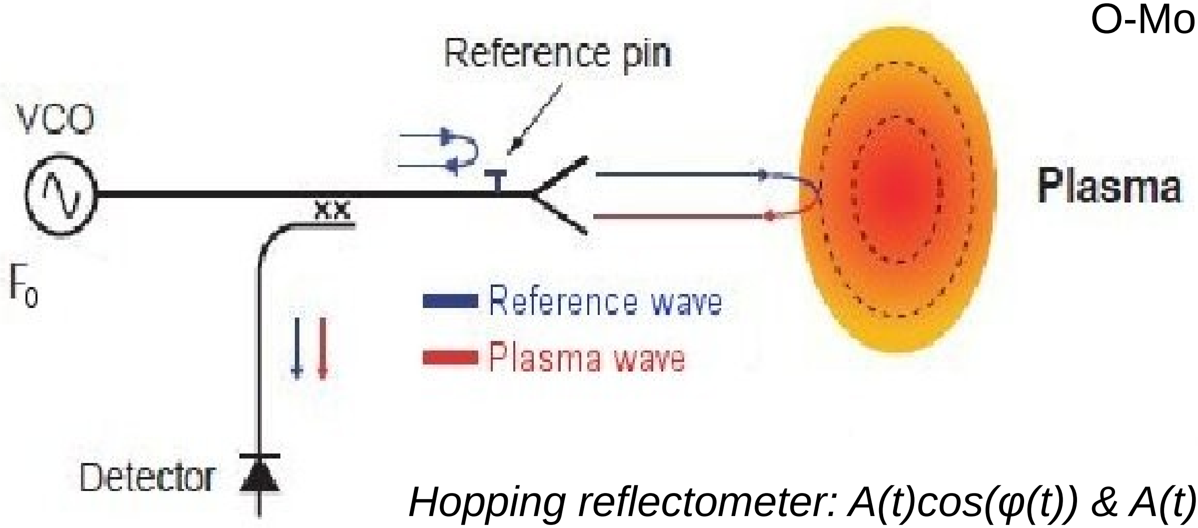
V	3.0 - 7.0
Q	1.5 - 3.0
Ka	0.8 - 1.5
K	0.3 - 0.8



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

Fluctuation Data:
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:

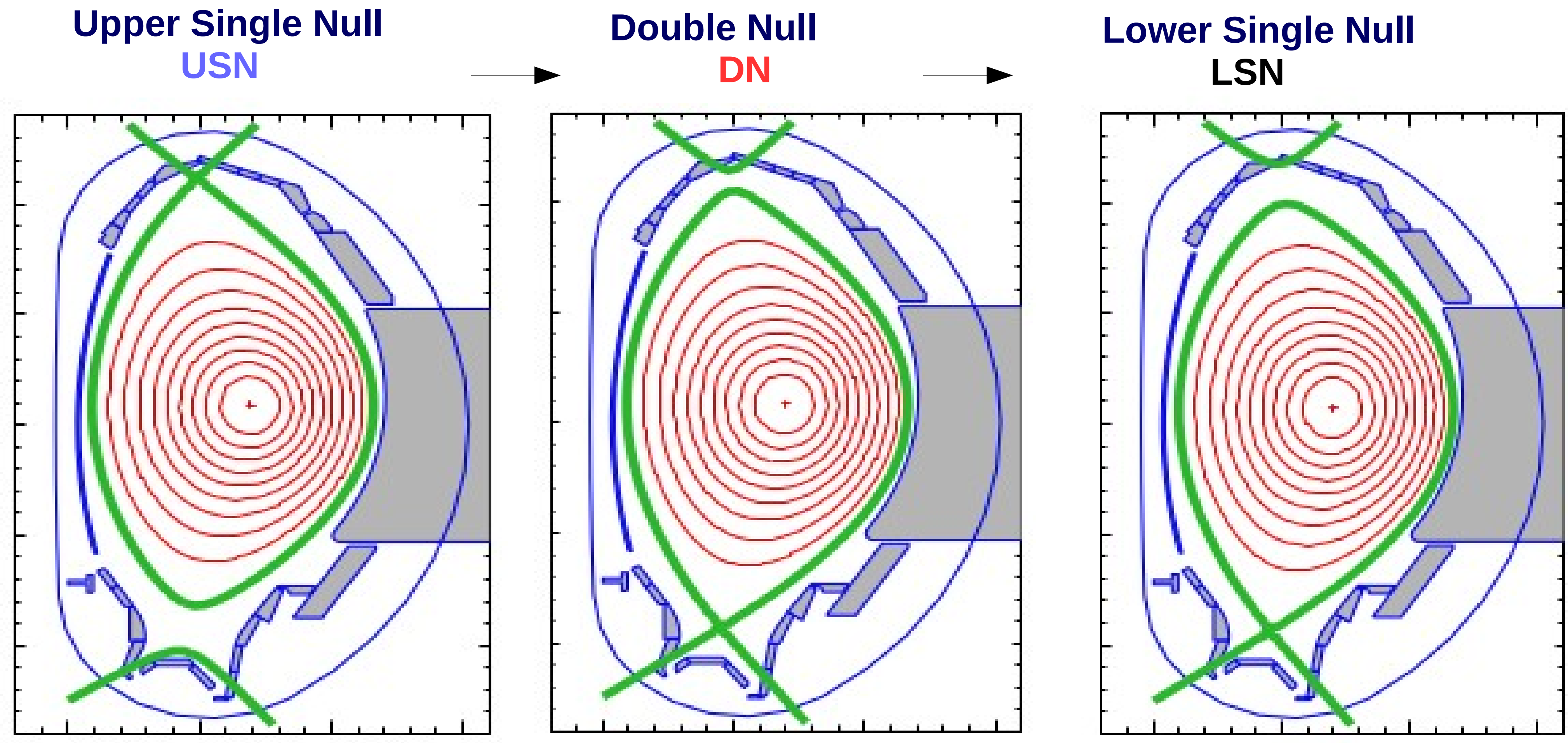
Large wavenumbers $2k_a < k_f < 2k_0$:

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

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

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

Dependence of δ*n*/*n* on the magnetic configuration



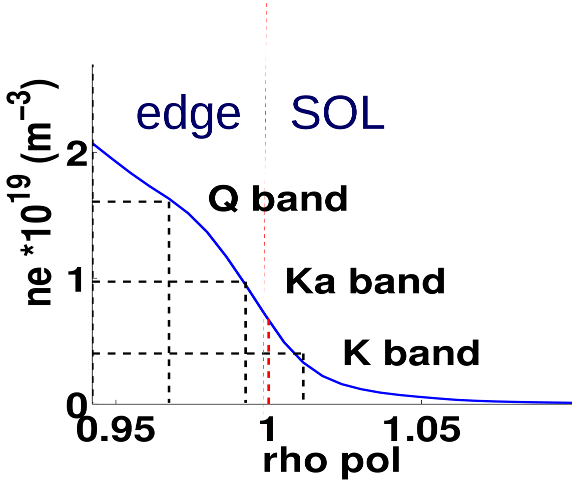
Upper Single Null
USN

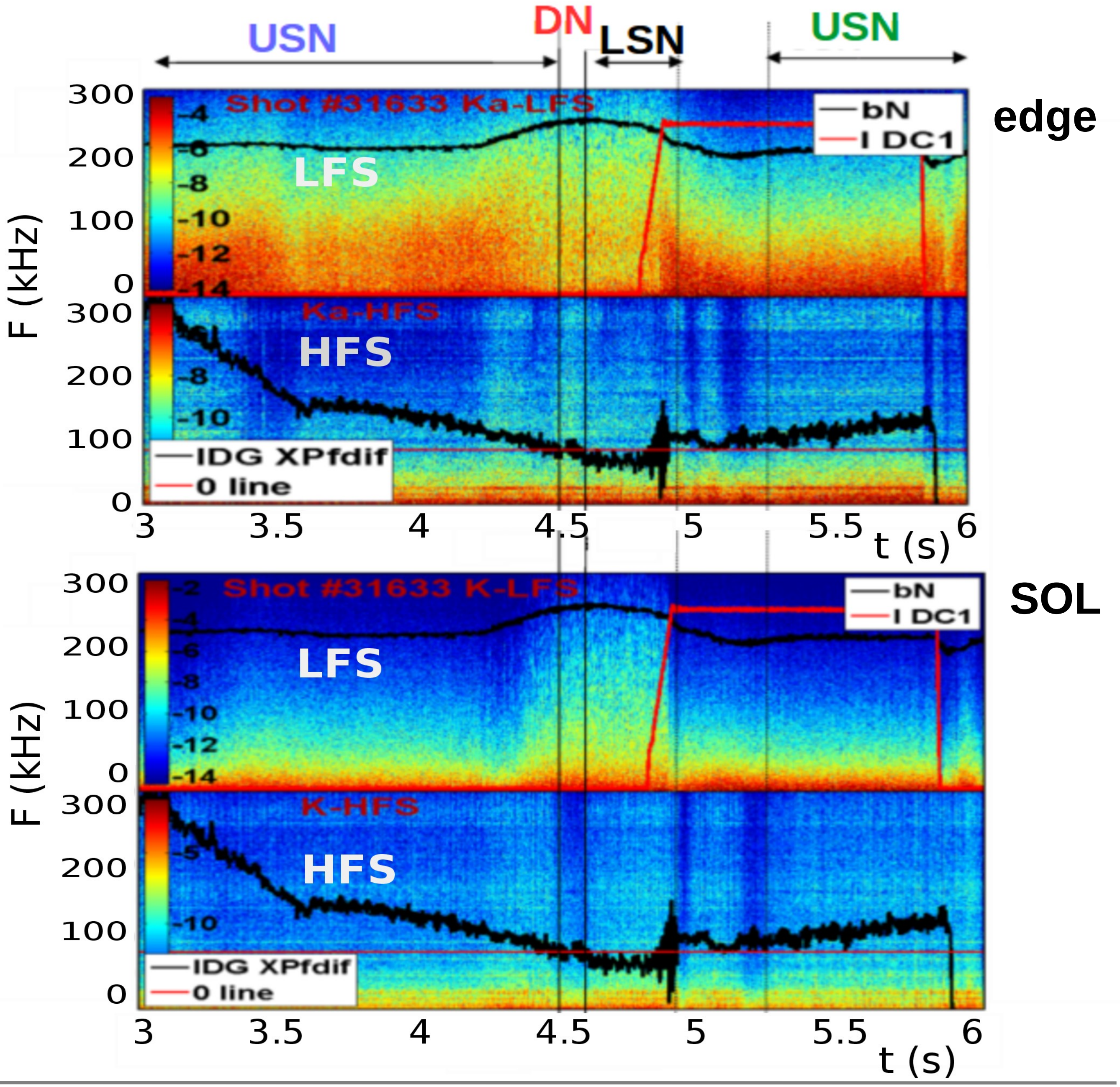
Double Null
DN

Lower Single Null
LSN

Turbulence asymmetries

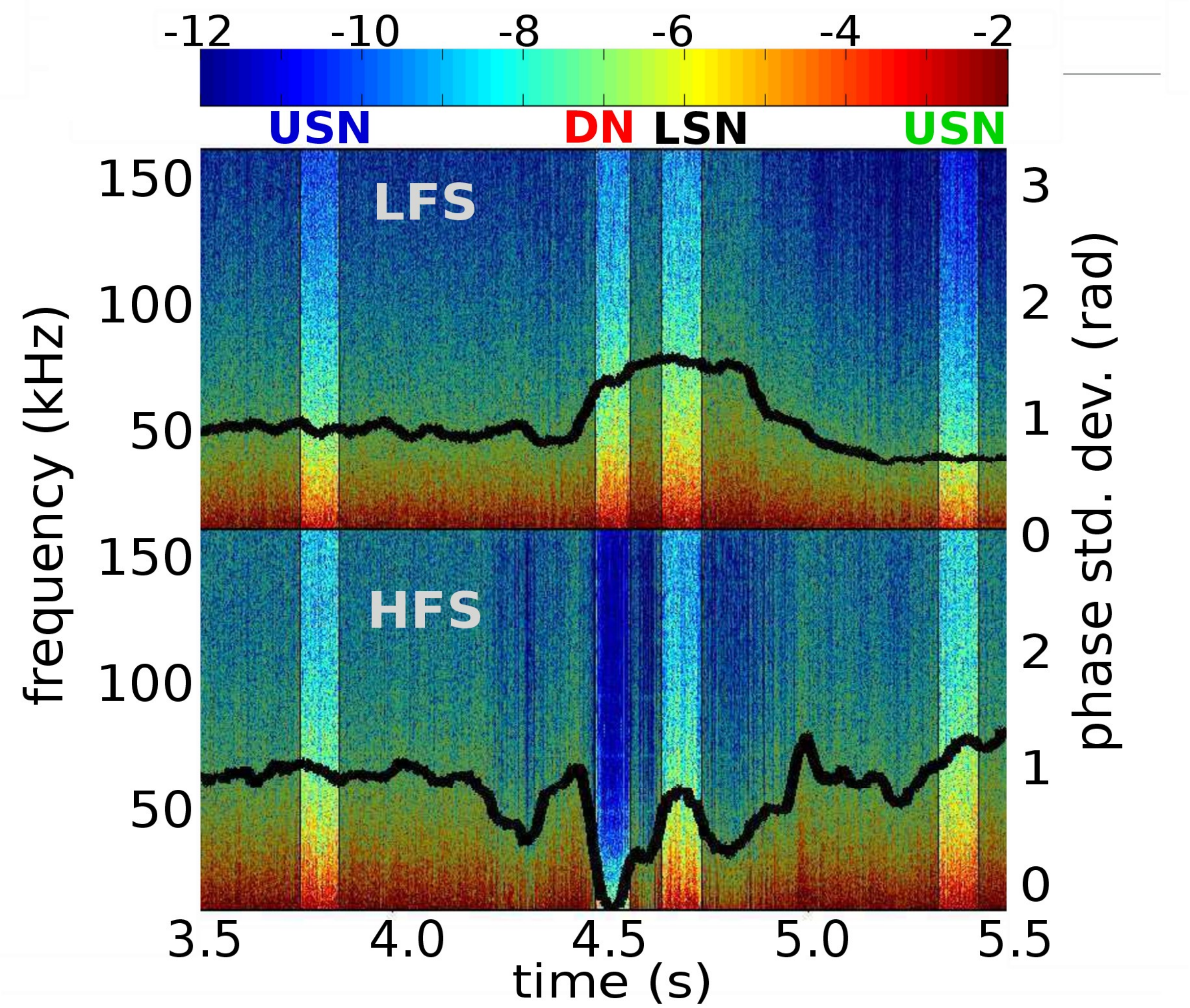
- HFS/LFS
- edge/SOL
- **USN → DN → LSN → USN**



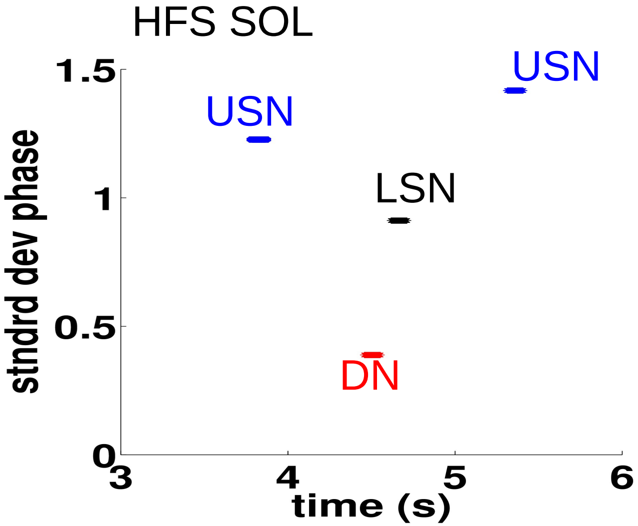


Turbulence asymmetries

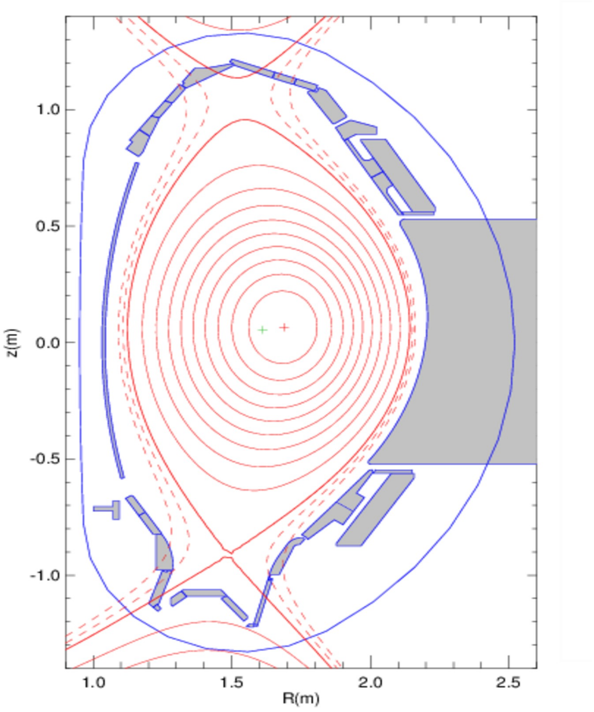
SOL

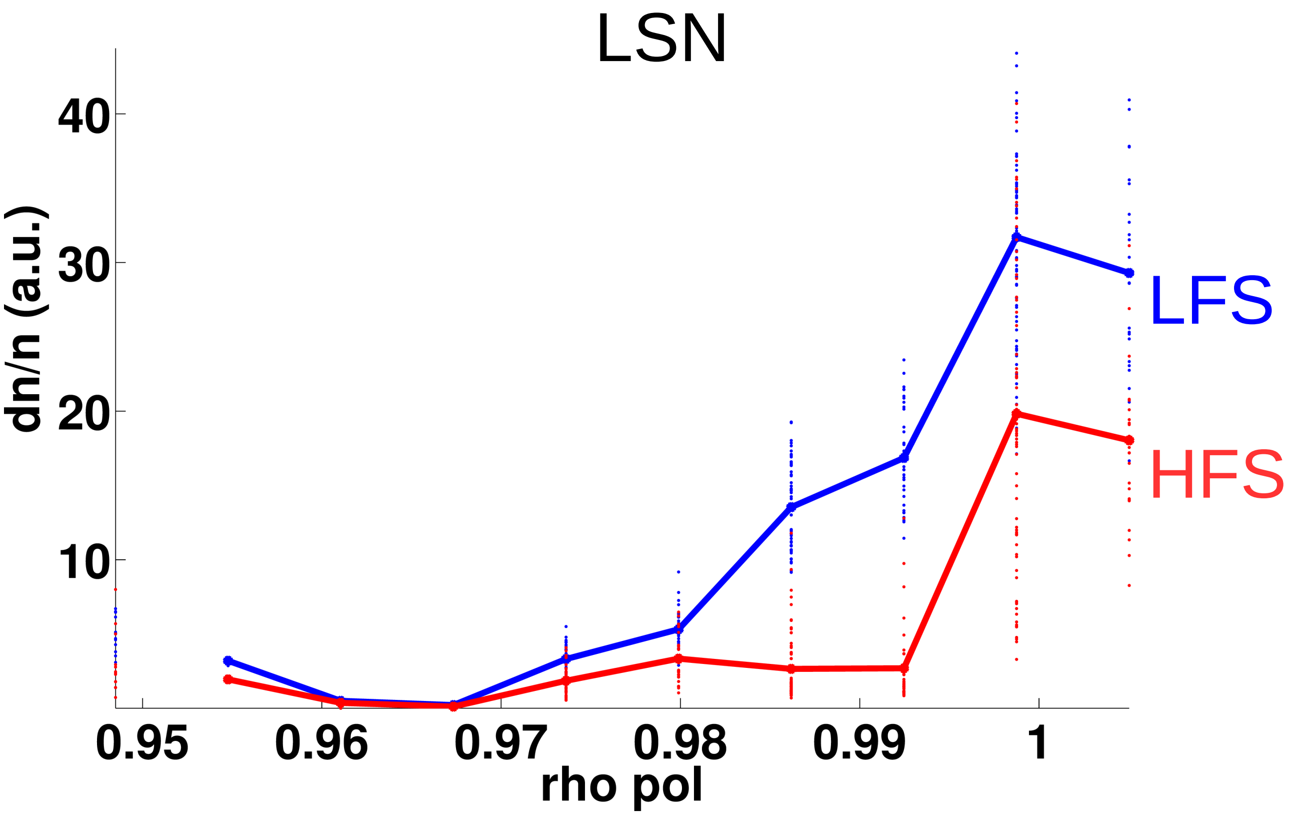


spectrograms of signal phase

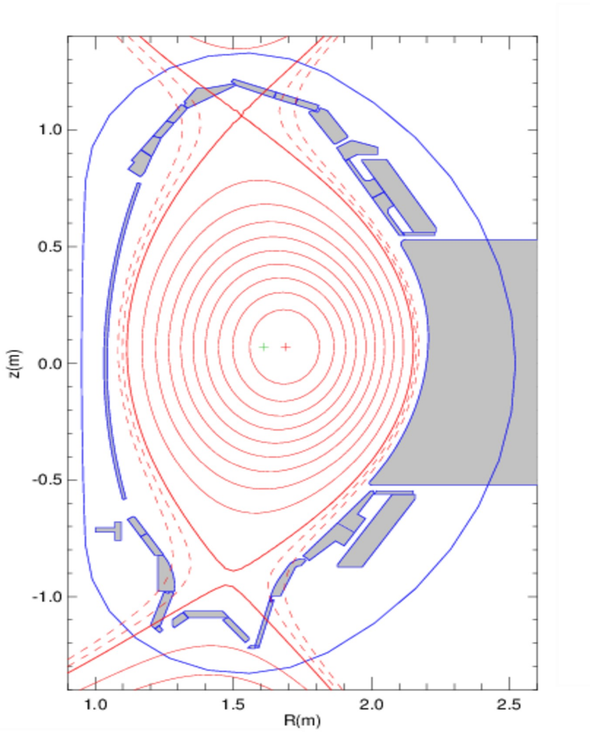


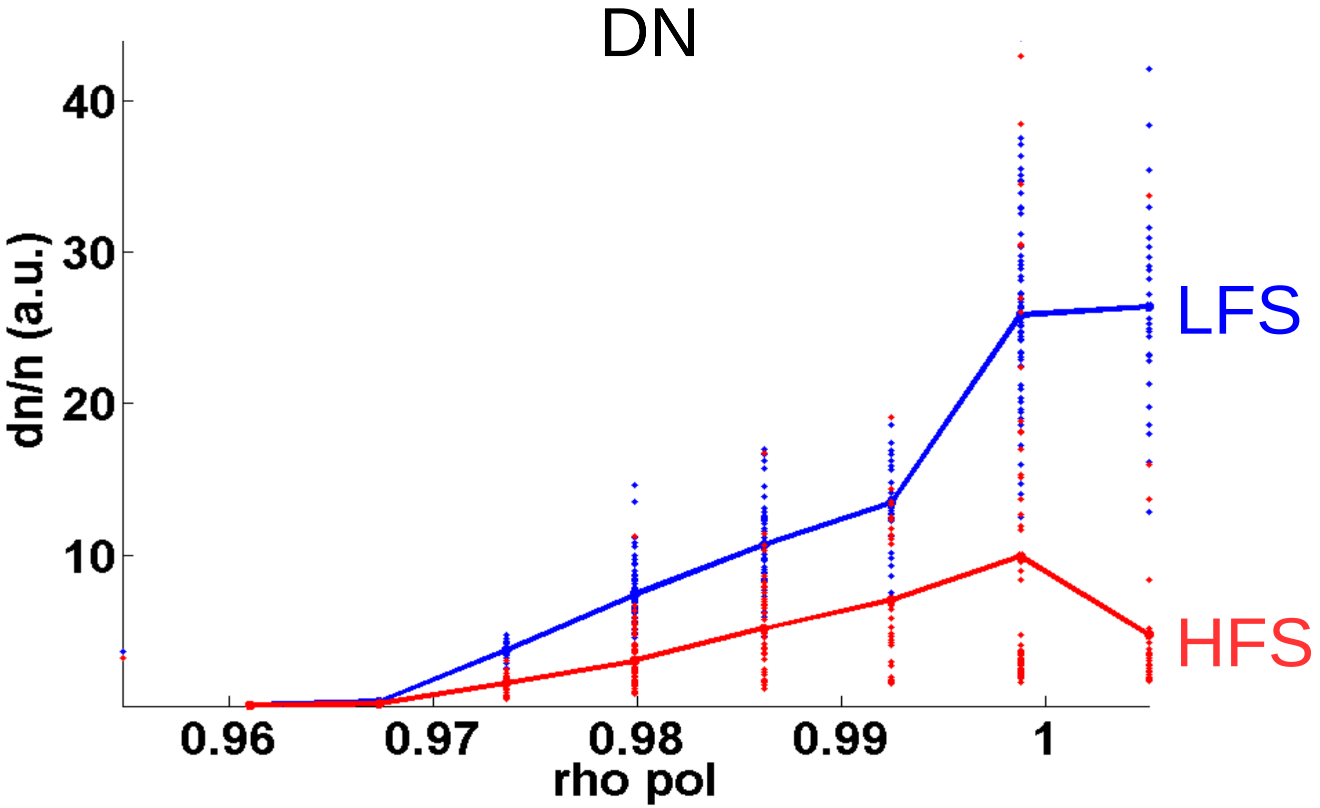
LSN HFS/LFS δn/n fluctuations





DN HFS/LFS δn/n fluctuations

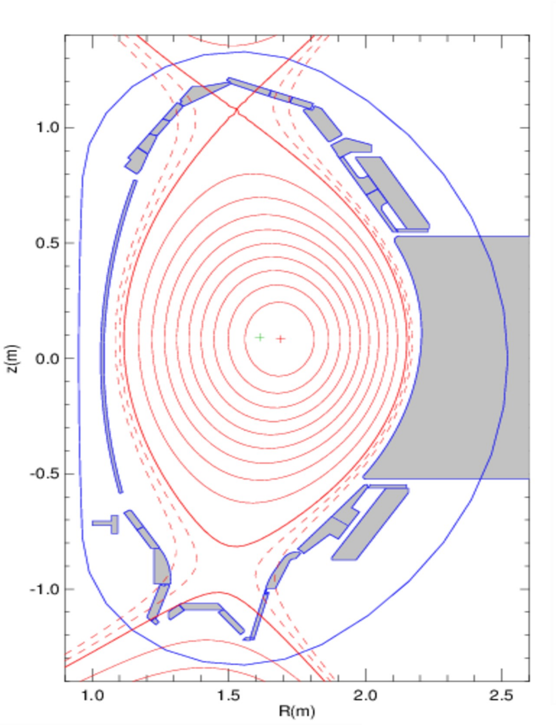


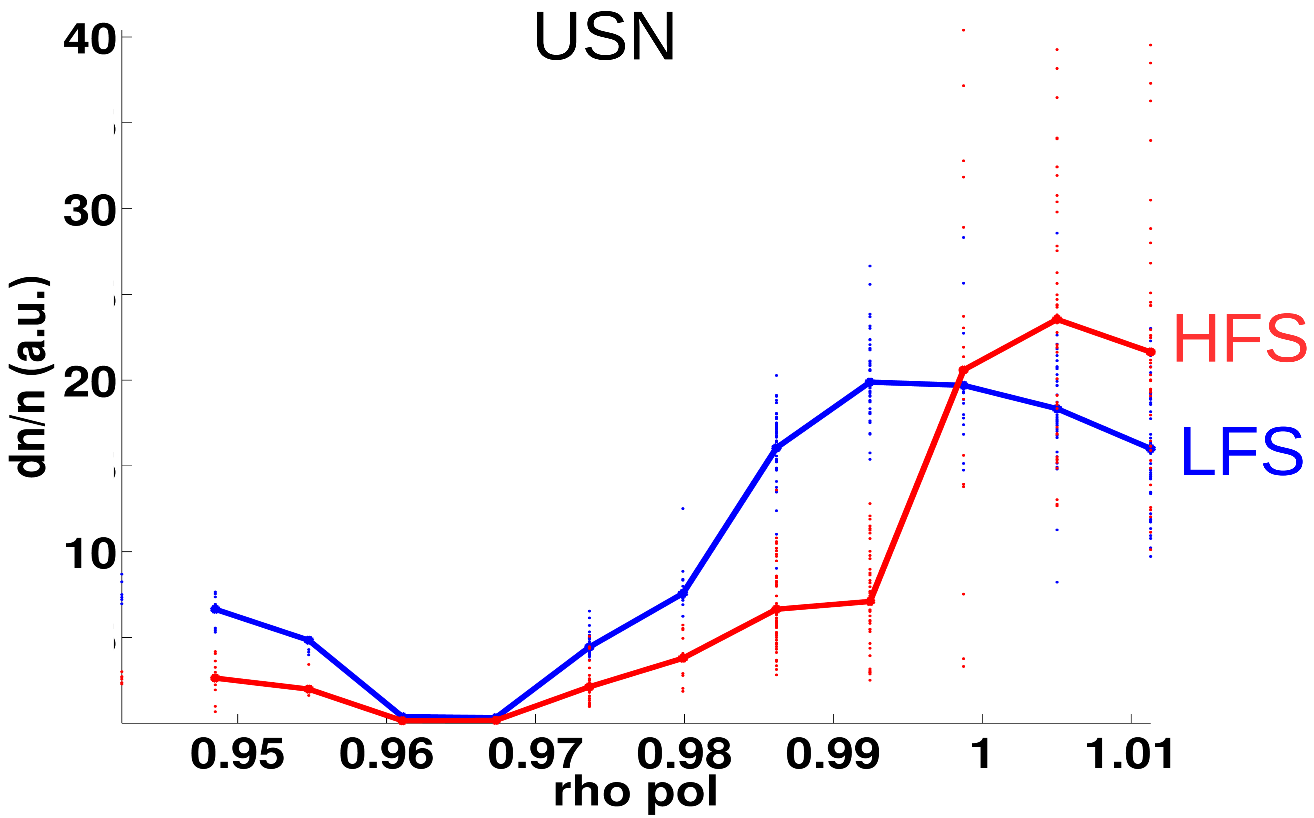


DN SOL – HFS becoming isolated from LFS

USN HFS/LFS δn/n fluctuations

beginning of the discharge



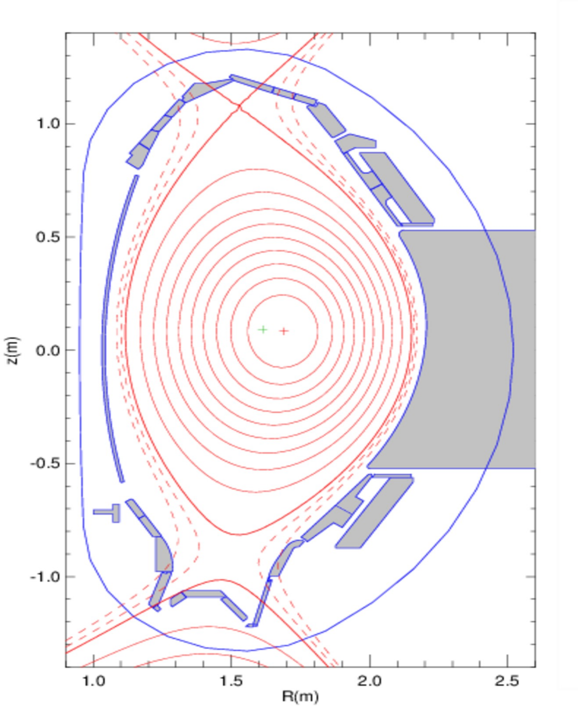


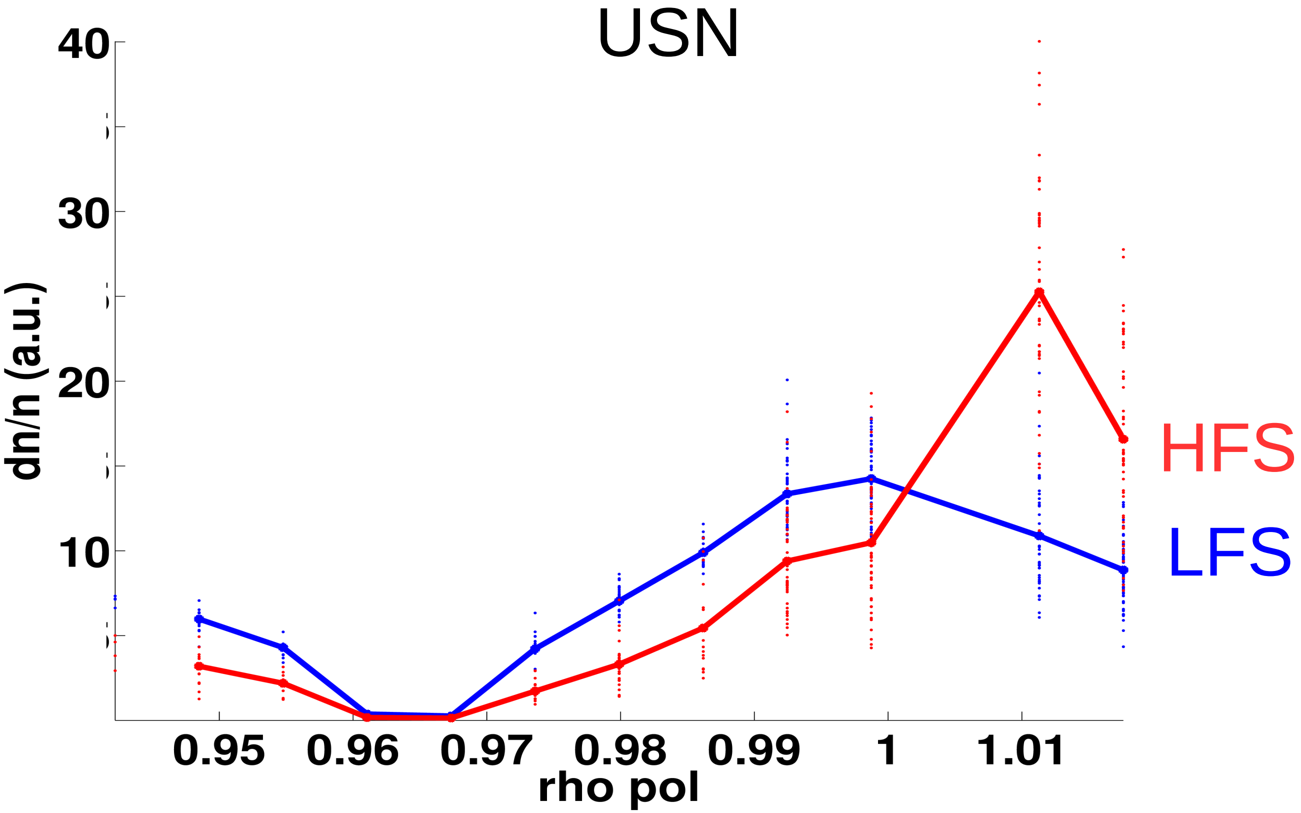
USN SOL – HFS δn/n > LFS δn/n unexpected!

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





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

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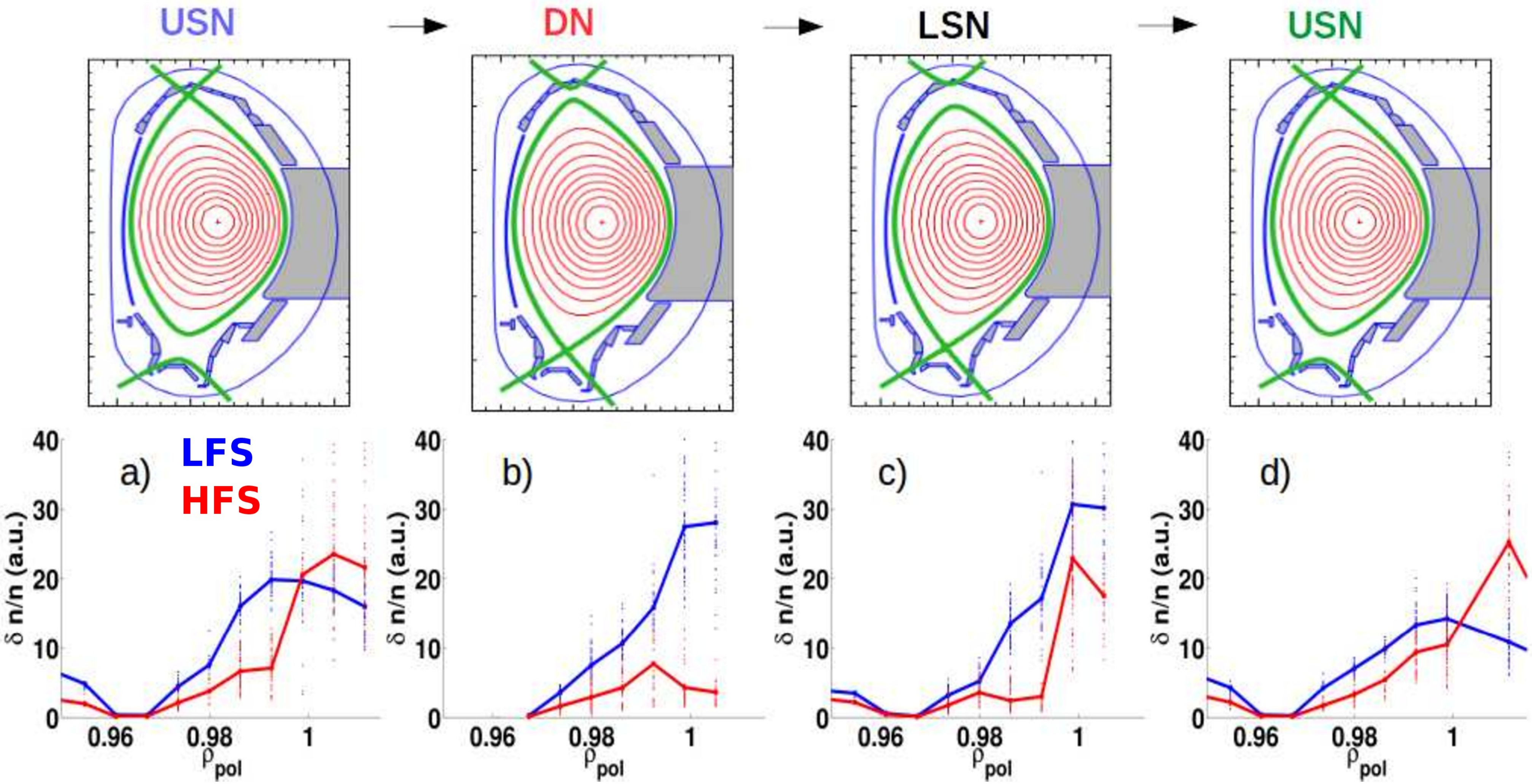
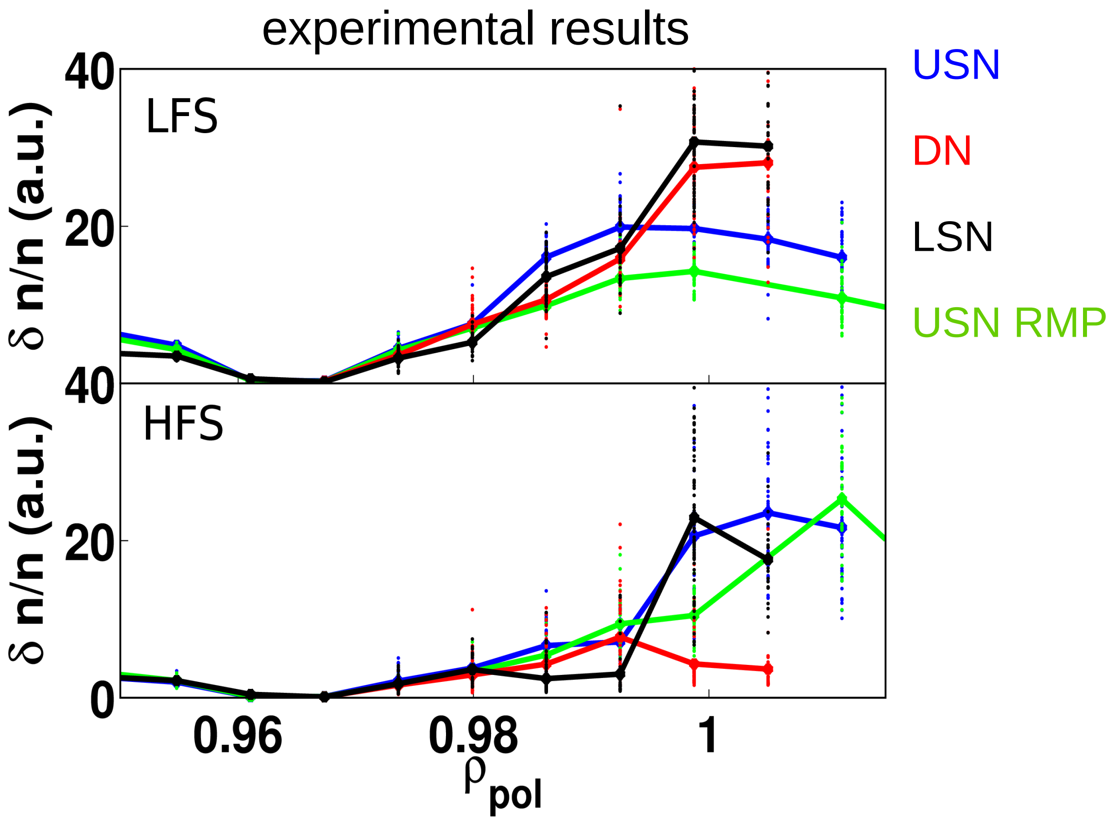
S.C. Liu et al. Phys. Plasmas 19, 042505 (2010)

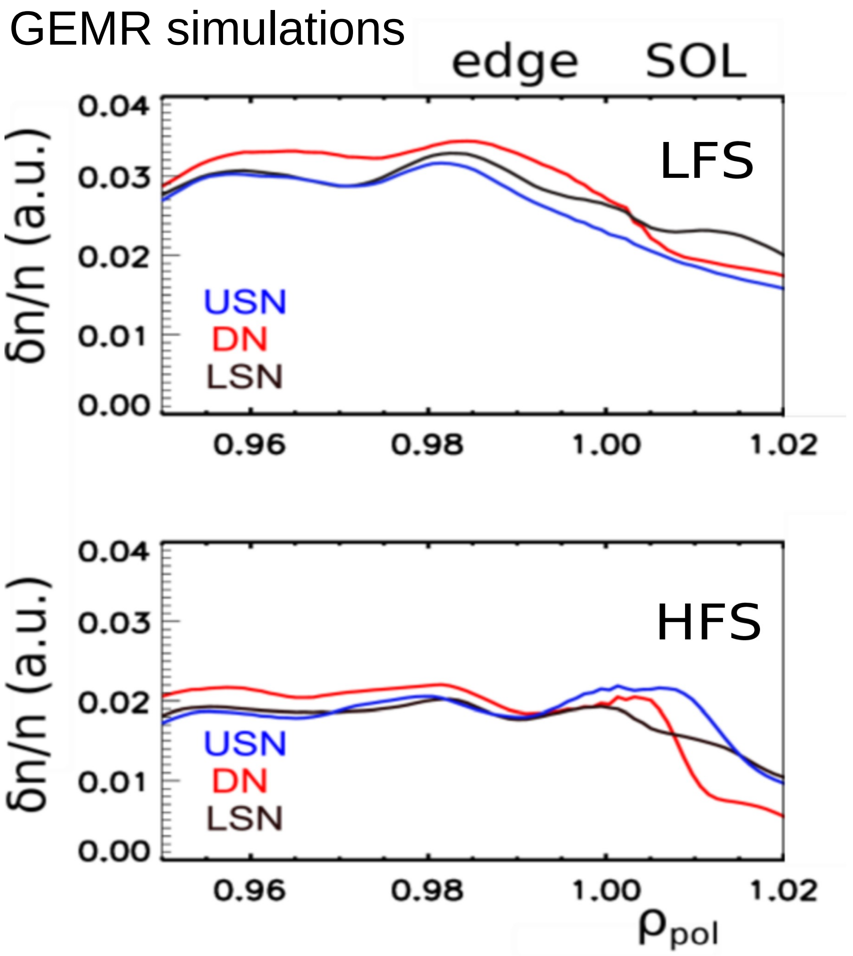
Dependence of δ*n/n* on the magnetic configuration



b) DN SOL – HFS becoming isolated from LFS
a), c) **USN SOL – HFS δn/n > LFS δn/n unexpected!**
a) - d) δn/n drop at around ρ = 0.96

Comparison with GEMR code





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

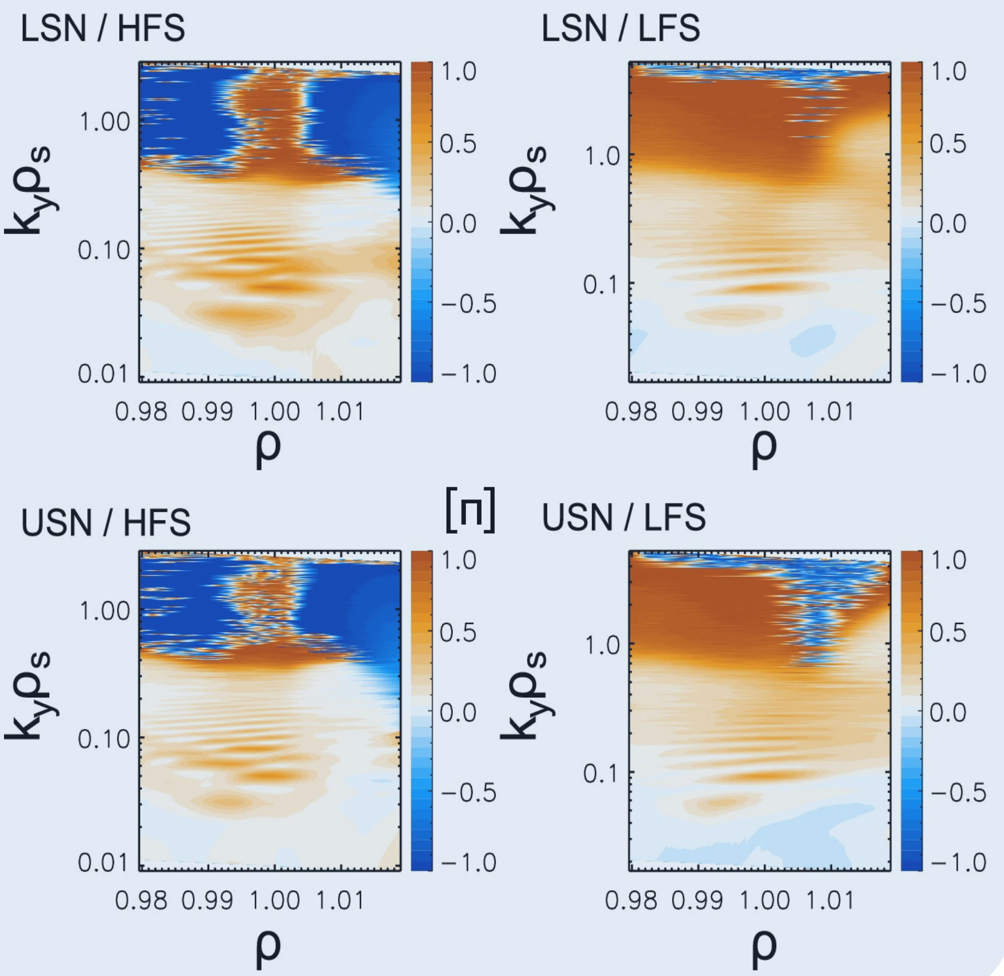
(T. T. Ribeiro et al., Plasma Phys. Control. Fusion 50, 008)

- **DN** is similar to **LSN** on LFS and to **USN** on HFS
- In **USN** HFS SOL δn/n exceeds those of the LFS

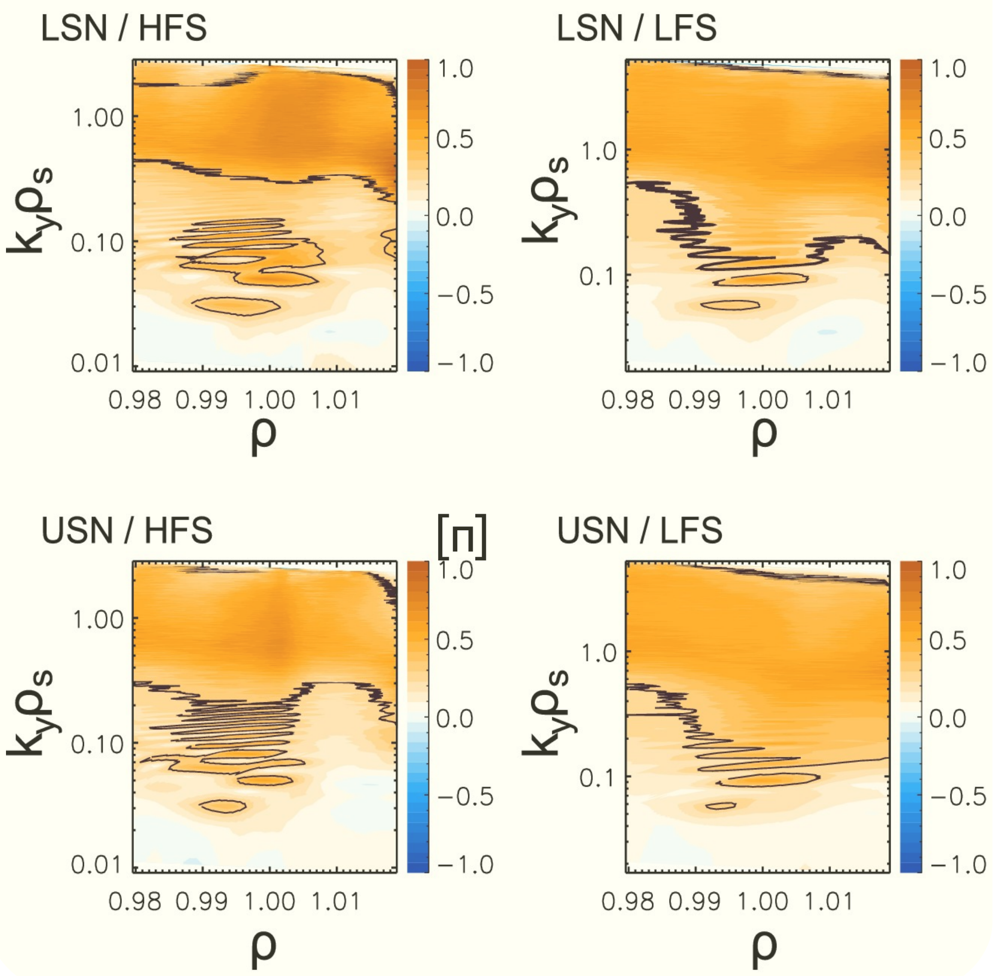
GEMR simulations, cross phases ne – φ, Te - φ

GEMR simulations

Cross phase ne - φ



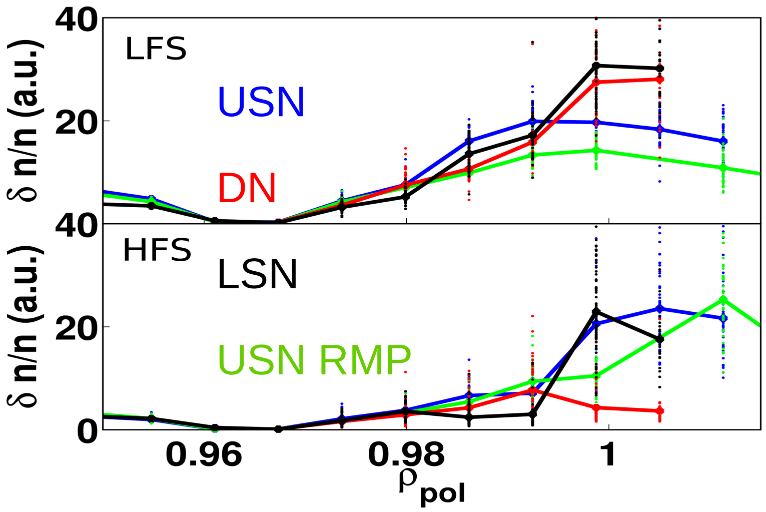
Cross phase Te - φ

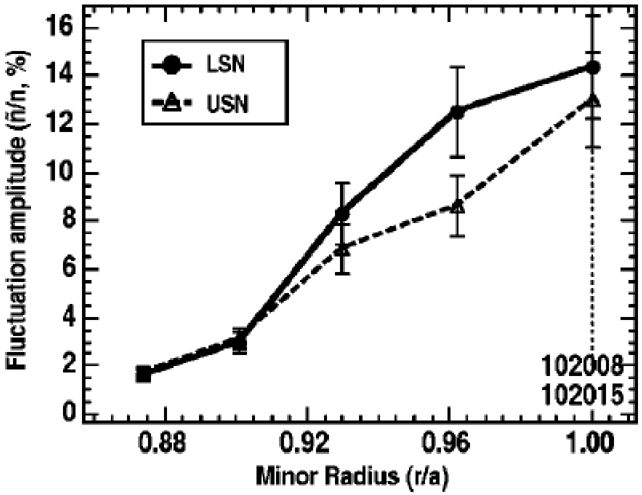


$\alpha(\tilde{\varphi},\tilde{n}_e)$ closer to 0 than to $\pi/2$ → drift-wave

$\alpha(\tilde{\varphi},\tilde{T}_e)$ closer to 0 than to $\pi/2$ → CWI

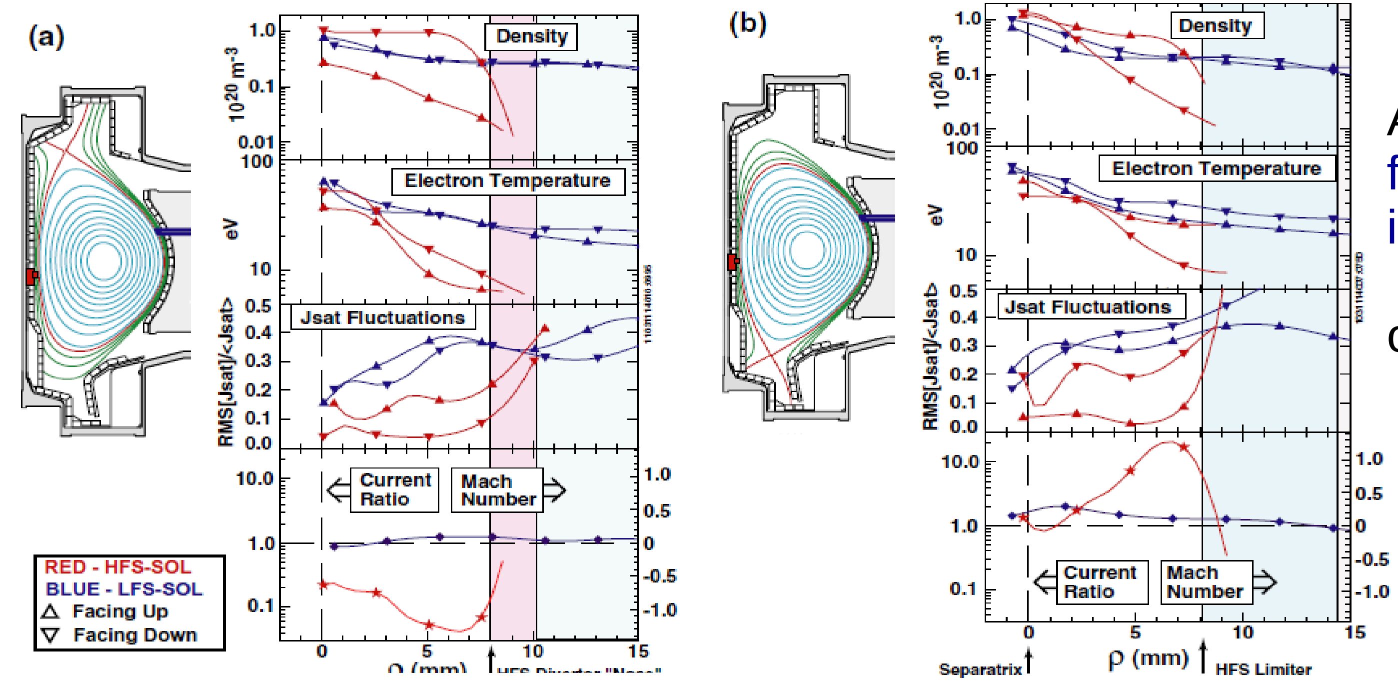
Comparison with other machines





DIII-D LFS:
fluctuation level higher
in LSN compared to USN

Fenzi et al.,
Phys. Plasmas 12, 2005

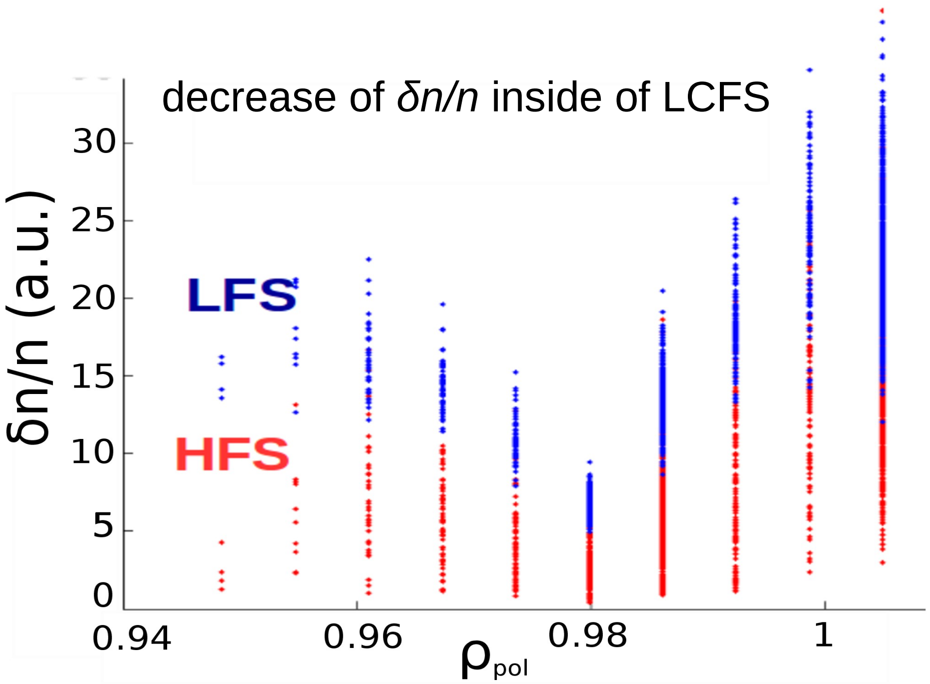


N. Smick et al. / Journal of Nuclear Materials 337–339 (2005) 281–285

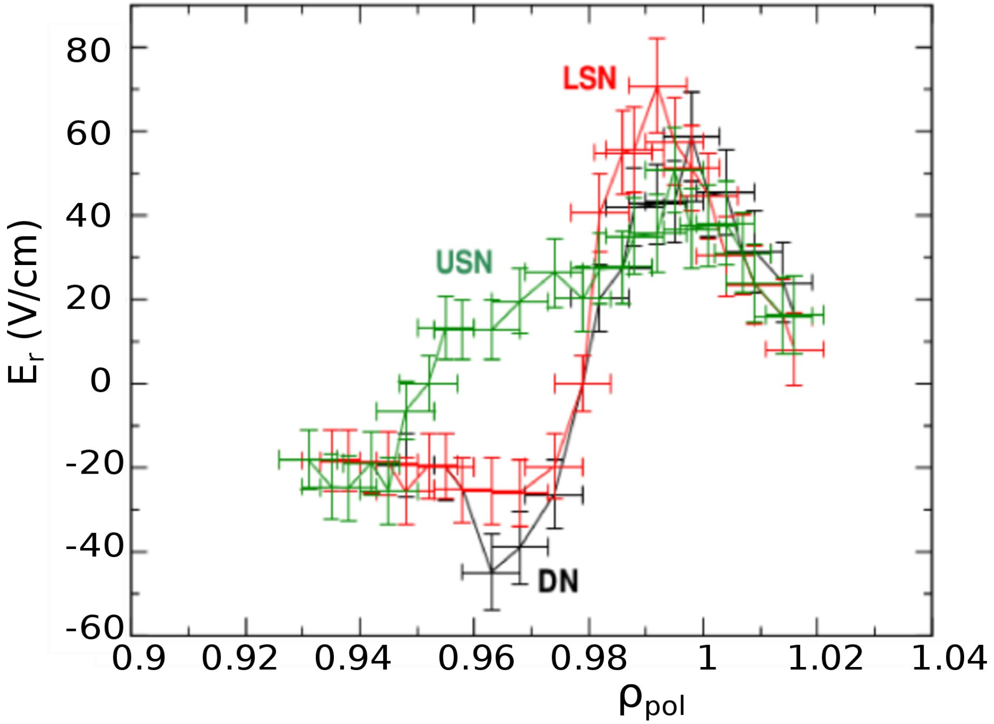
Alcator C-Mod:
fluctuation level higher:
in LSN compared to USN

on LFS compared to HFS

HFS/LFS radial profile of density fluctuations



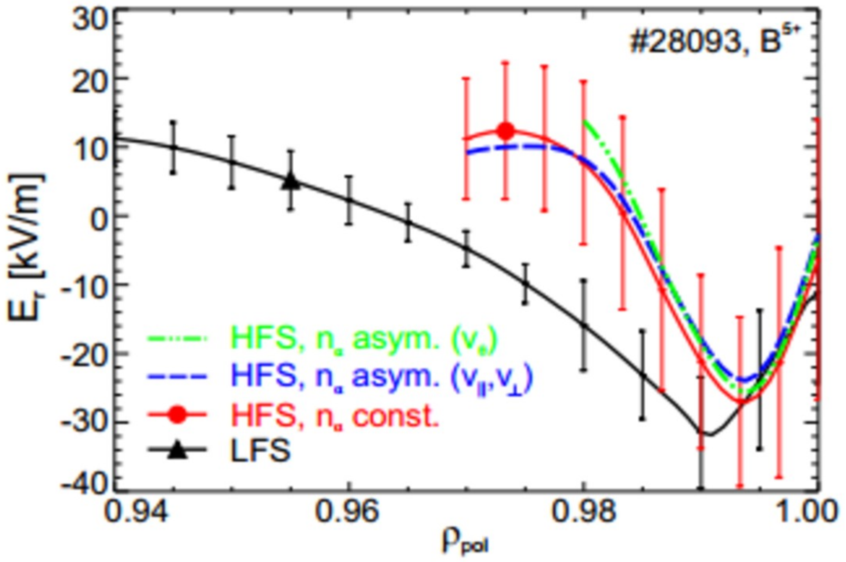
decrease of *δn/n* inside of LCFS



Thesis of J. Schiermer, 2005

region of strong Er shear inside of LCFS

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



Thesis of E. Viezzer, 2012

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, that is in agreement with the previous experimental results at AUG and turbulence stabilization theories

Support slides

Hilbert transform method

FMCW: homodyne - single ended detector

$A(t)\cos[2\pi F_0 + \varphi(t)]$

Any analytic signal can be written in the form:

$$z(x)=f(x)+iH[f(x)]=f(x)+i\hat{f}(x)$$

imaginary part is the Hilbert transform of the real part.

Hilbert transform is given by:

$$H[f(x)]=\frac{1}{\pi}p.v.\int_{-\infty}^{+\infty}\frac{f(x')}{x-x'}dx'$$

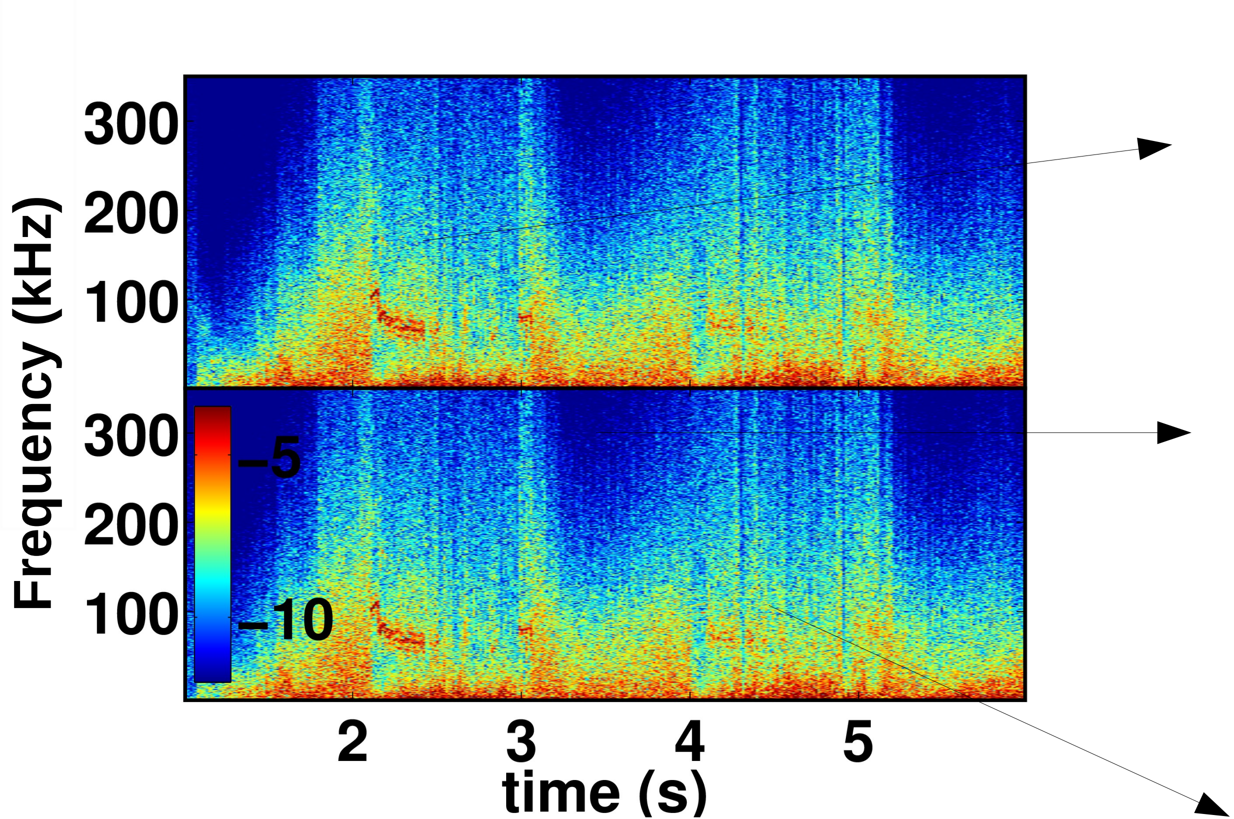
for f(x) $L^P(R)$, $1<p<\infty$

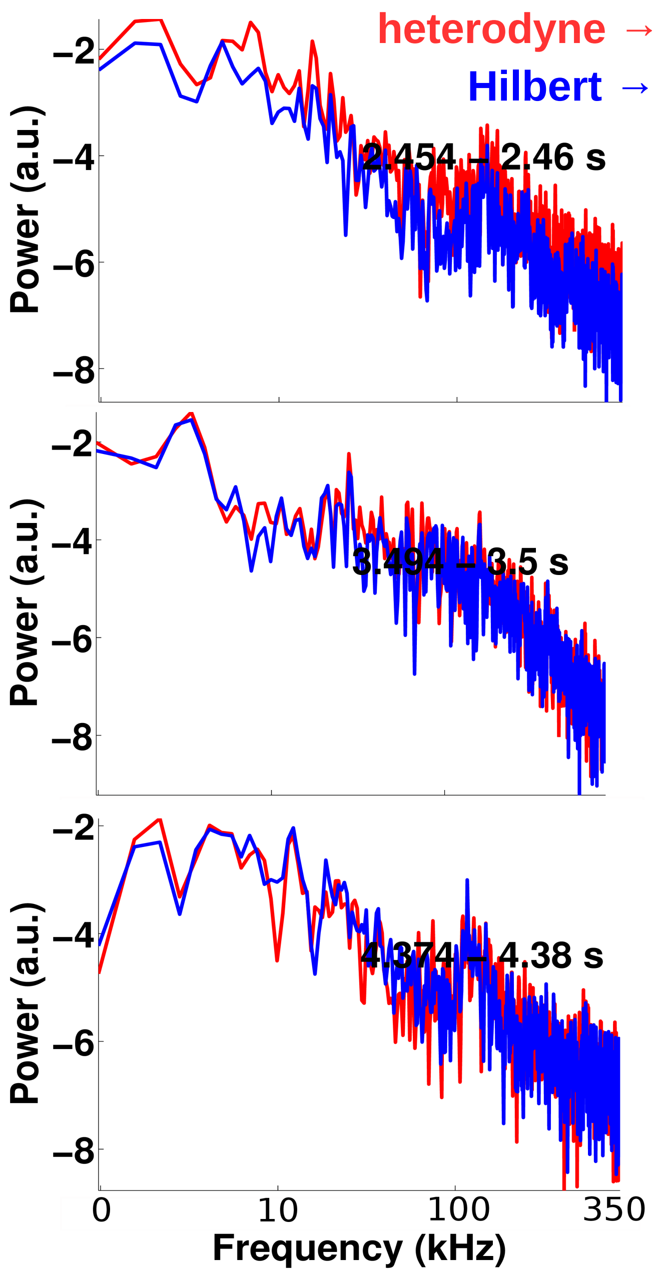
Phase of our signal then can be defined as

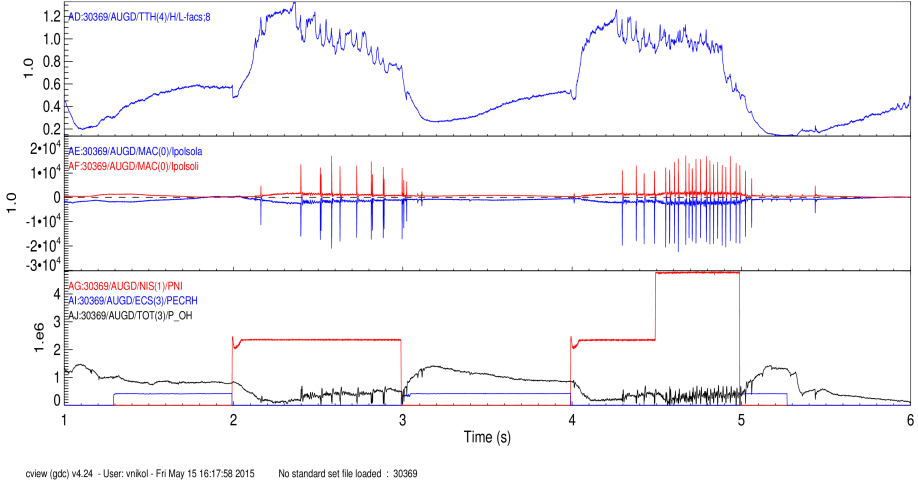
$$\boxed{\varphi(x)=\arctan\left(\frac{\mathrm{Im}[z(x)]}{\mathrm{Re}[z(x)]}\right)=\arctan\left(\frac{\hat{f}(x)}{f(x)}\right)}$$

if $\langle f(x)\rangle = 0$

Validation of Hilbert transform method, hopping refl



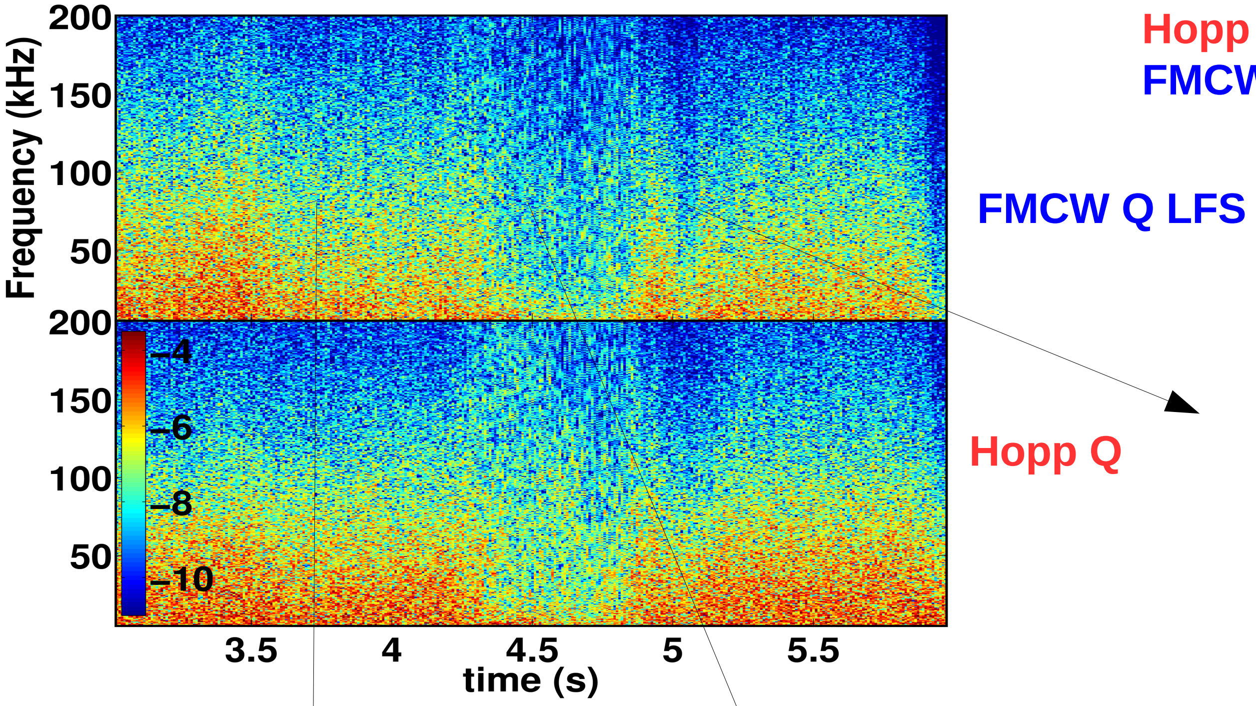


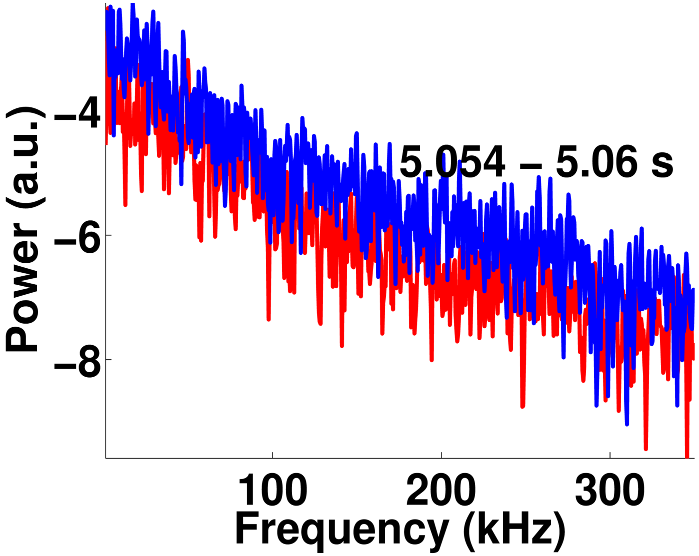


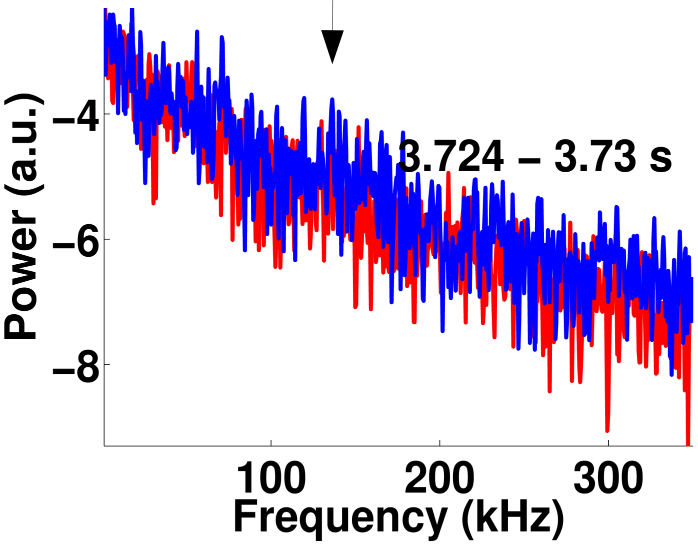
Hopping Q and FMCW Q LFS, phase PS

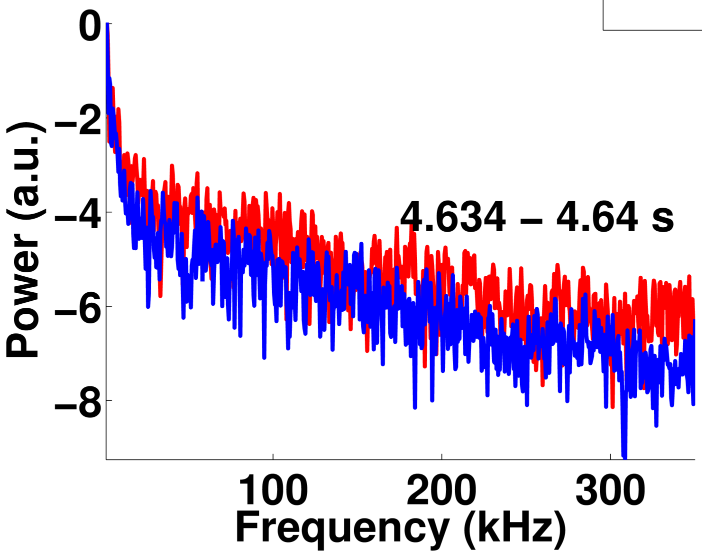
Hopp Q (heterodyne → φ)

FMCW Q LFS (homodyne → Hilbert → φ)





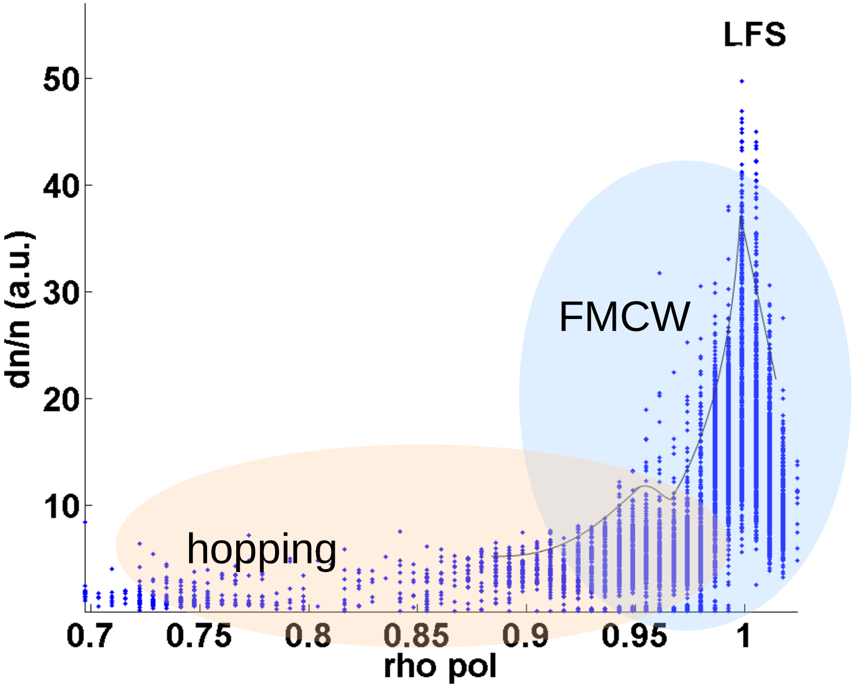


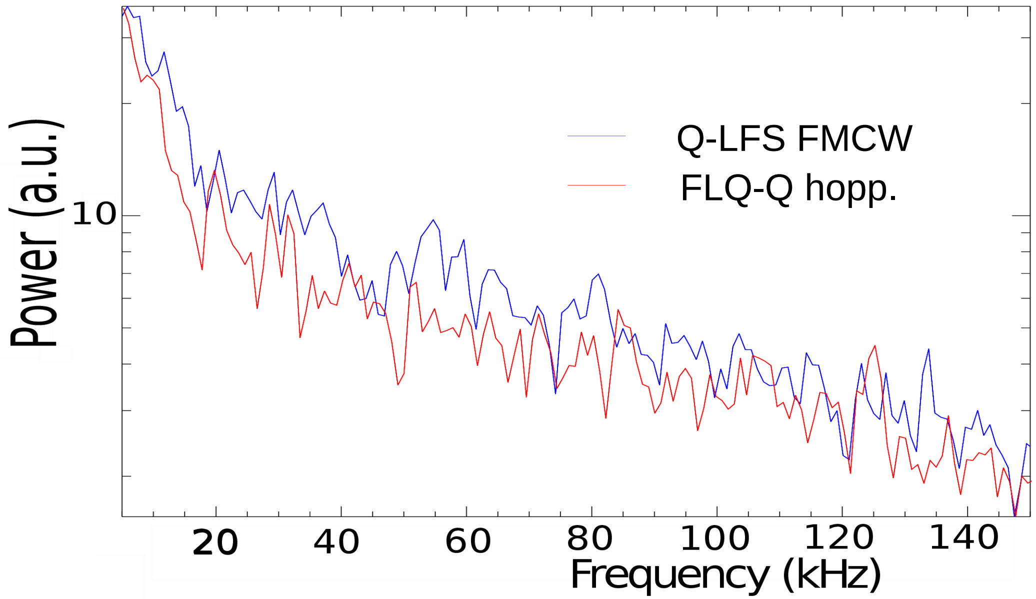


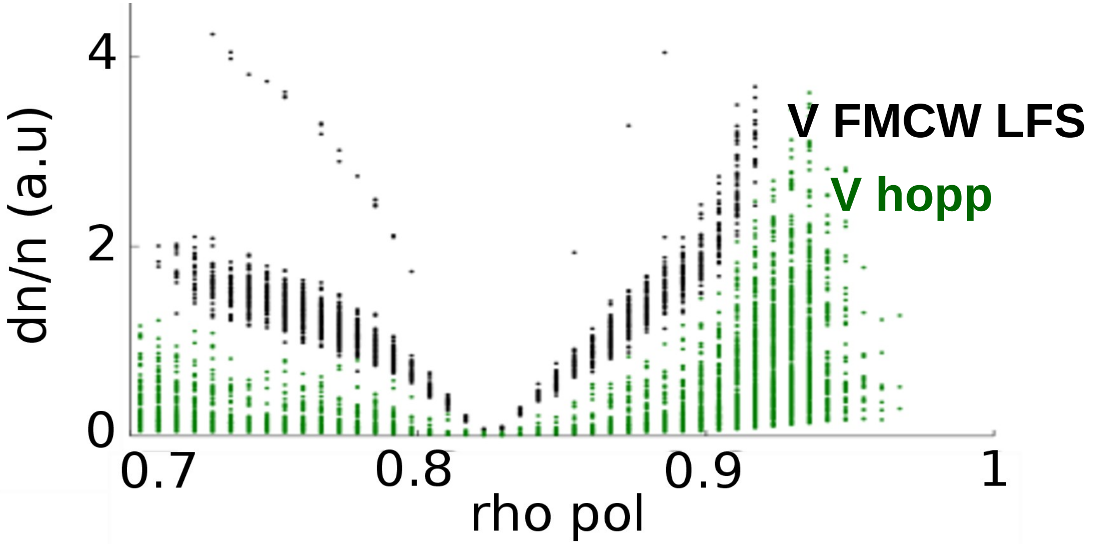
PS Hopp Q and FMCW Q phases:

- ✓ agreement in shape and scale

Data validation, FMCW and hopping reflectometers

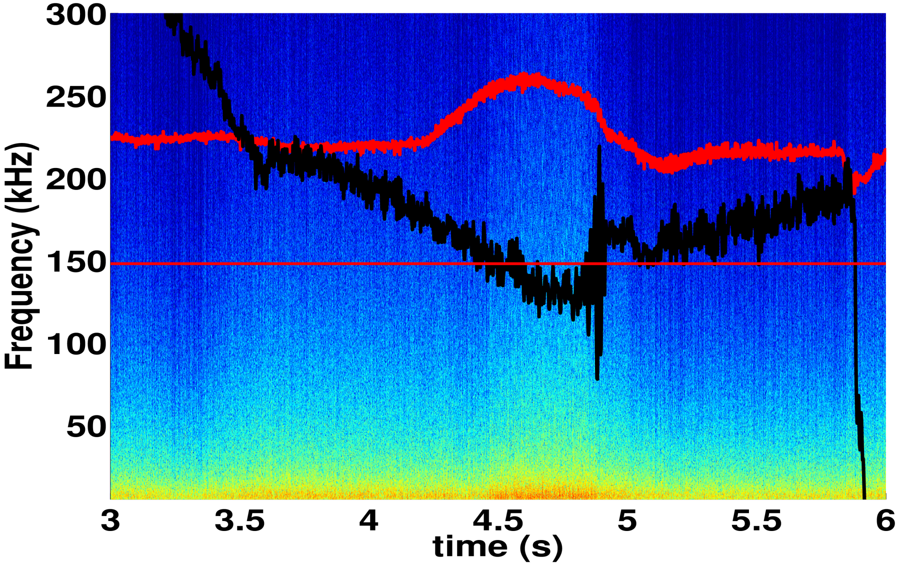




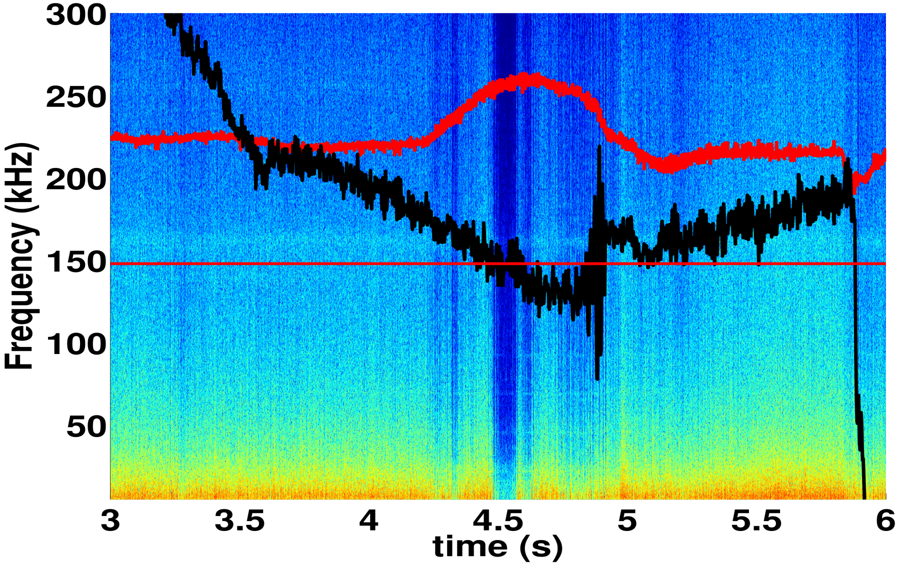


FMCW reflectometer can be used for turbulence studies

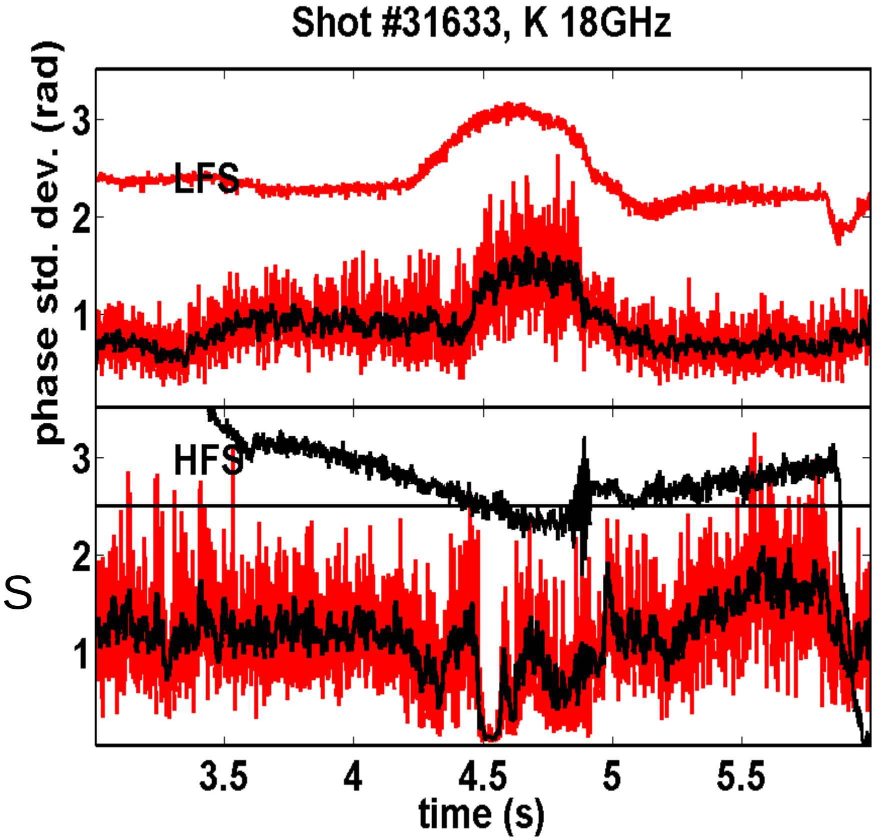
K phase, SOL



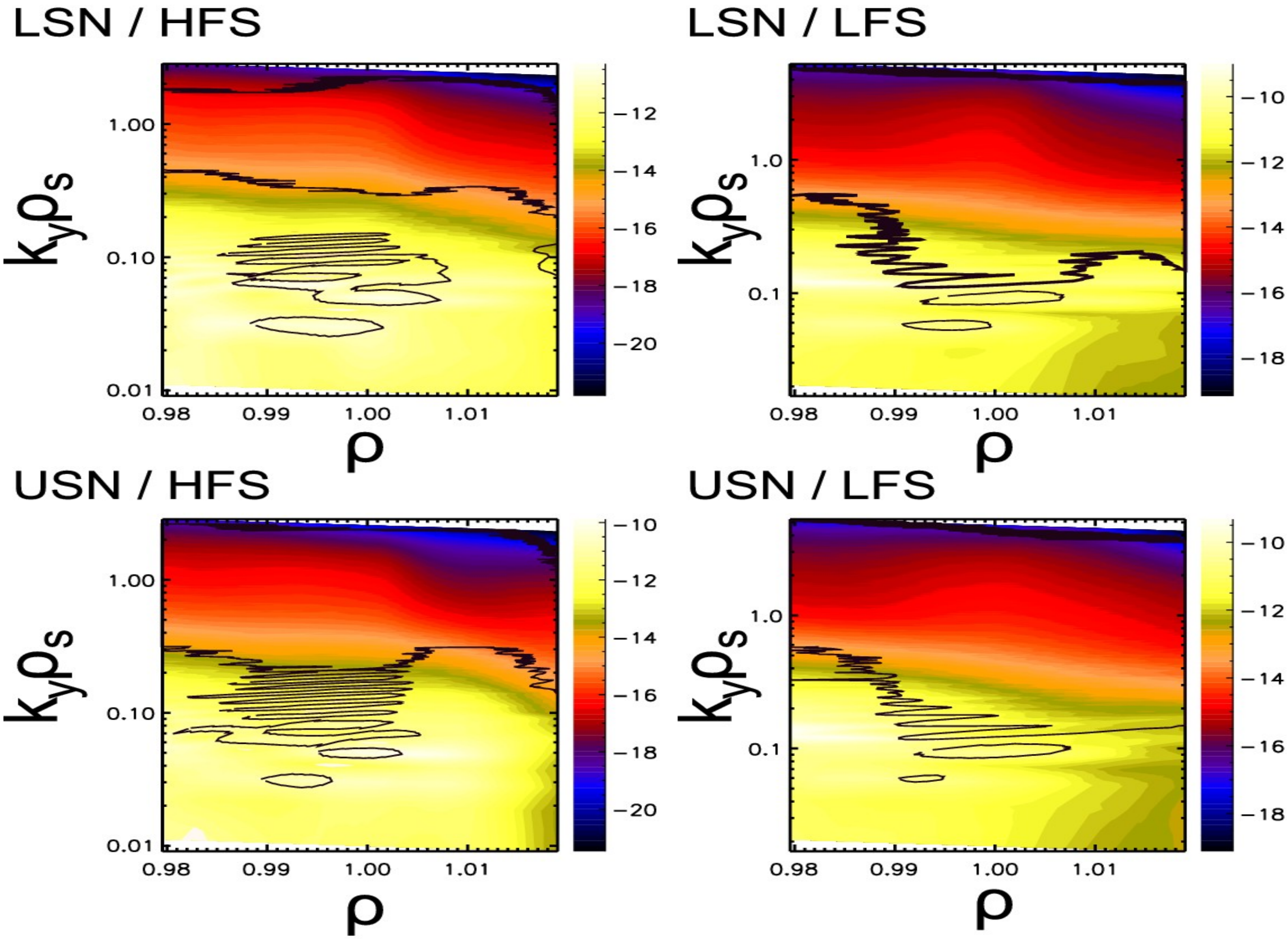
LFS



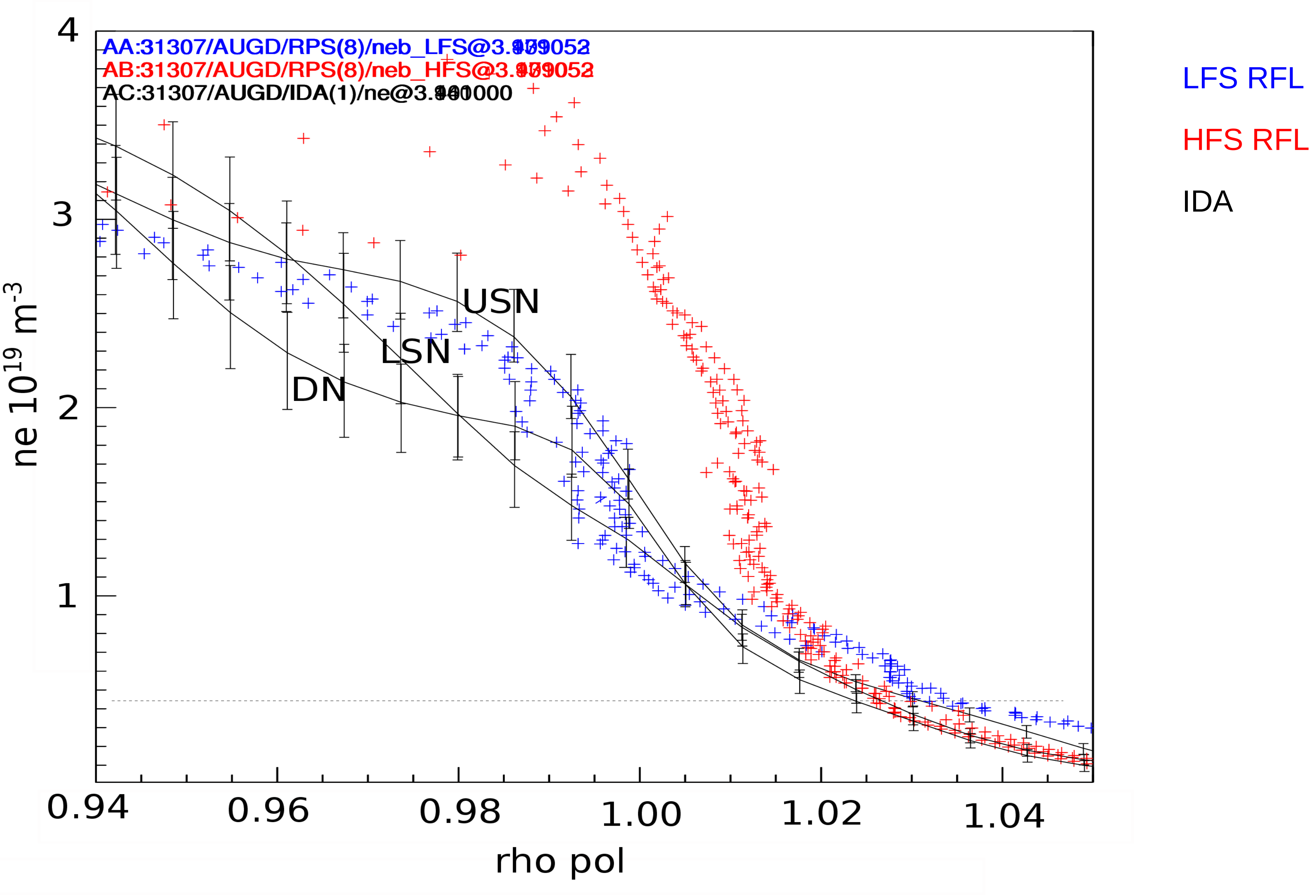
HFS



GEMR simulations, n spectra



HFS/LFS ne profiles in different configurations



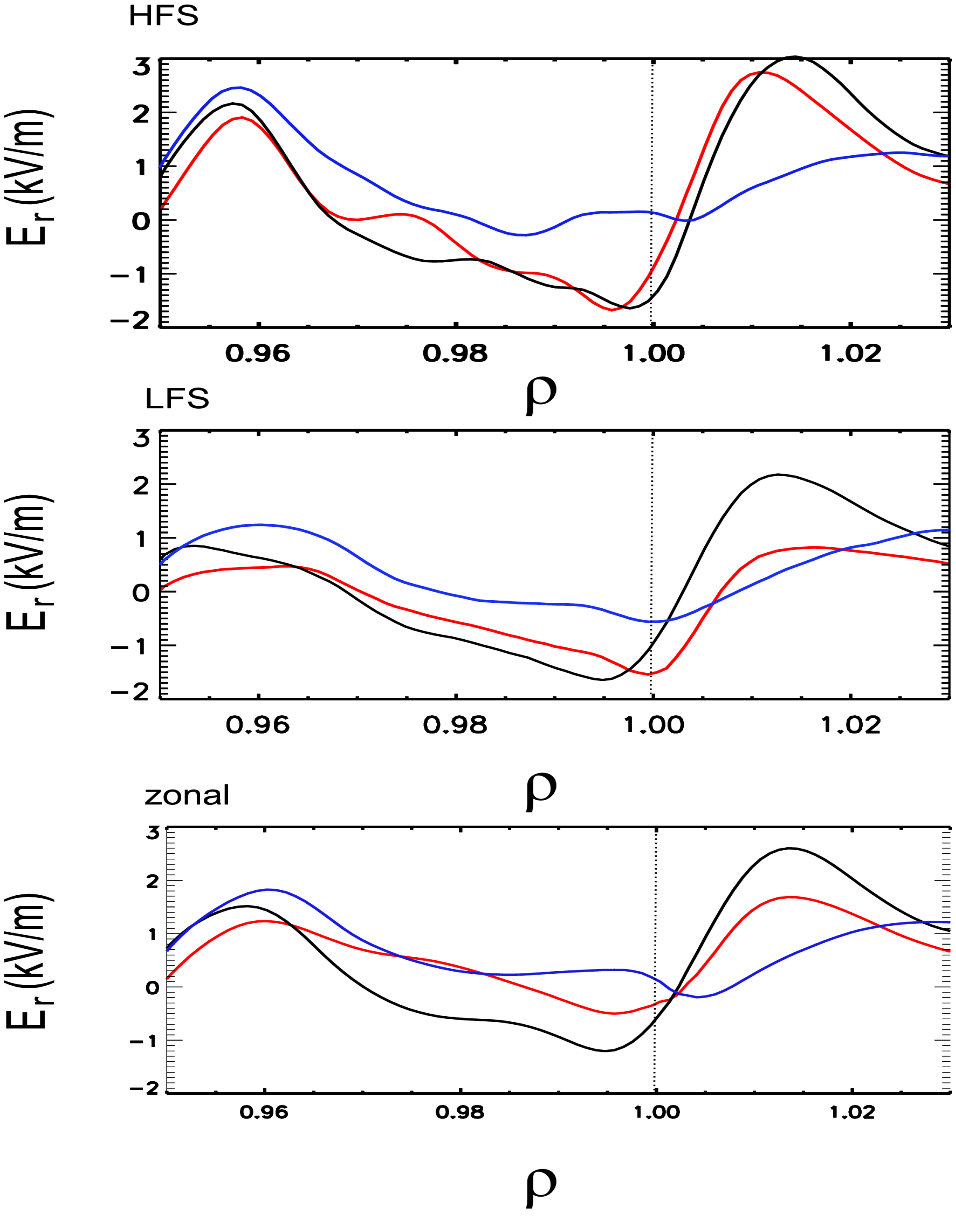
Er profiles, DR data and GEMR simulations

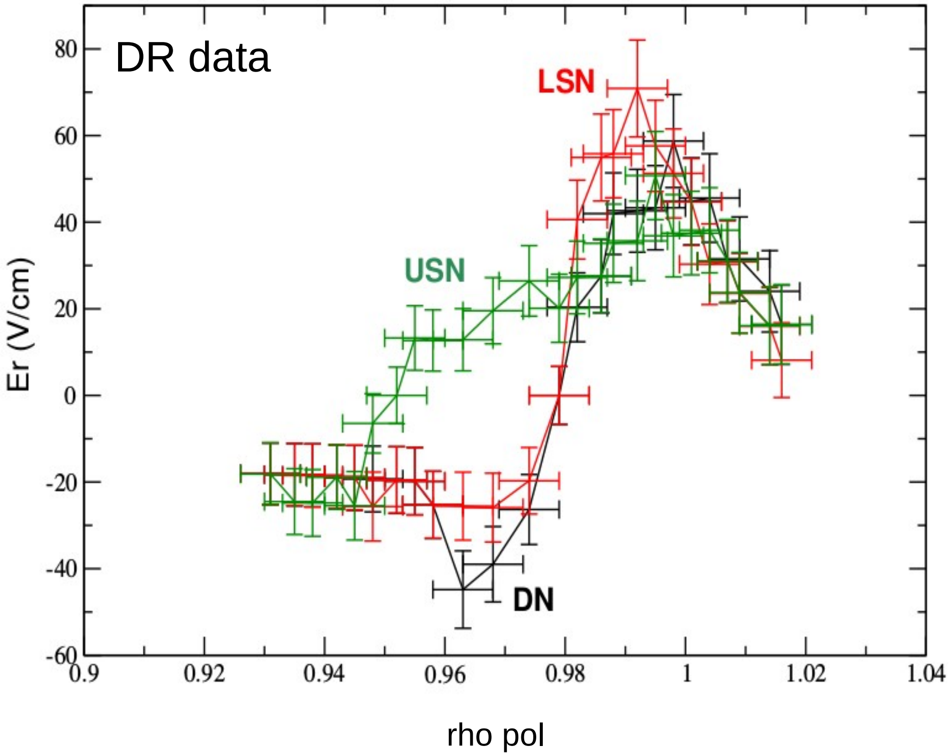
USN

DN

LSN

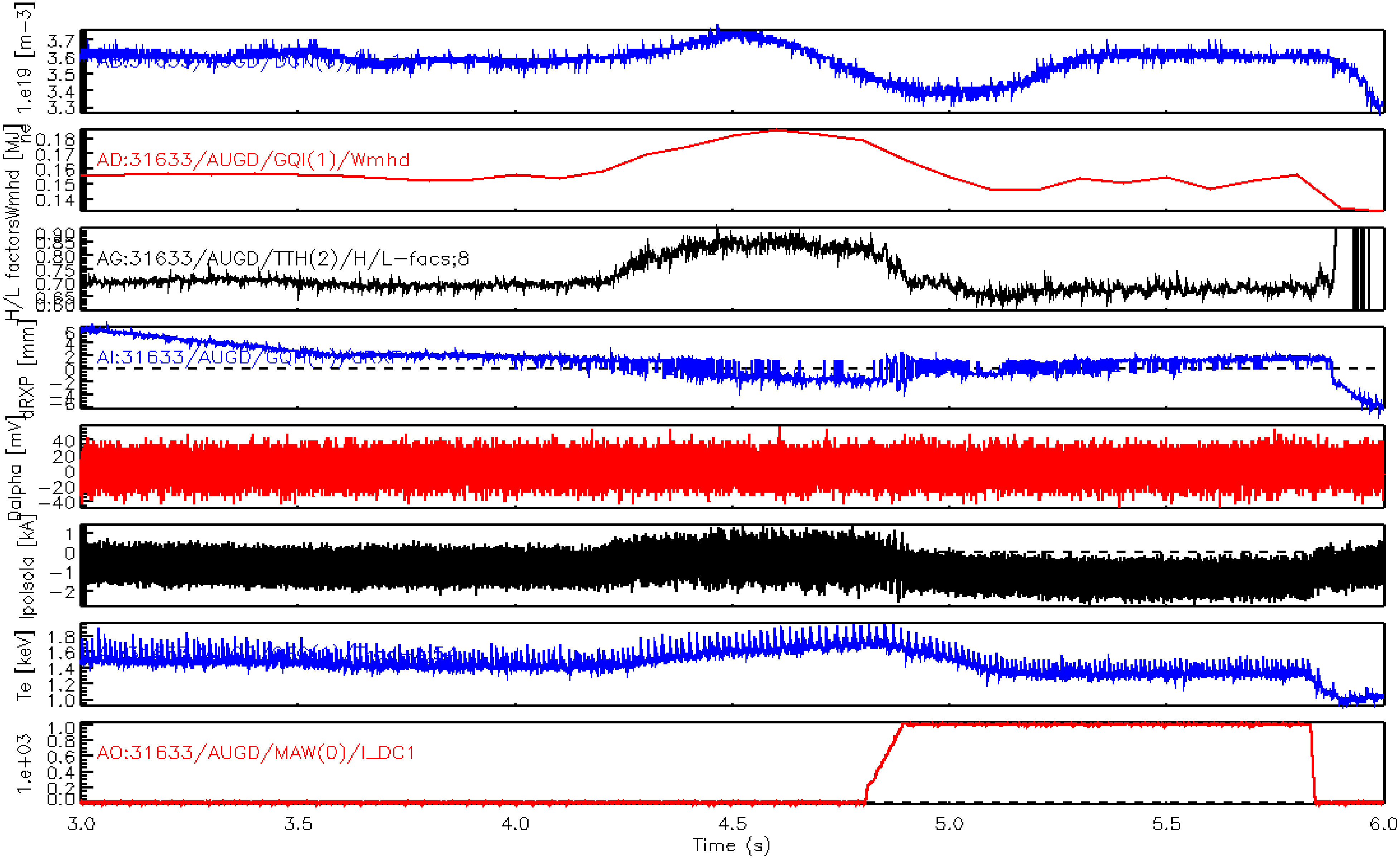
GEMR simulations by P. Manz





Thesis of J. Schirmer, 2005

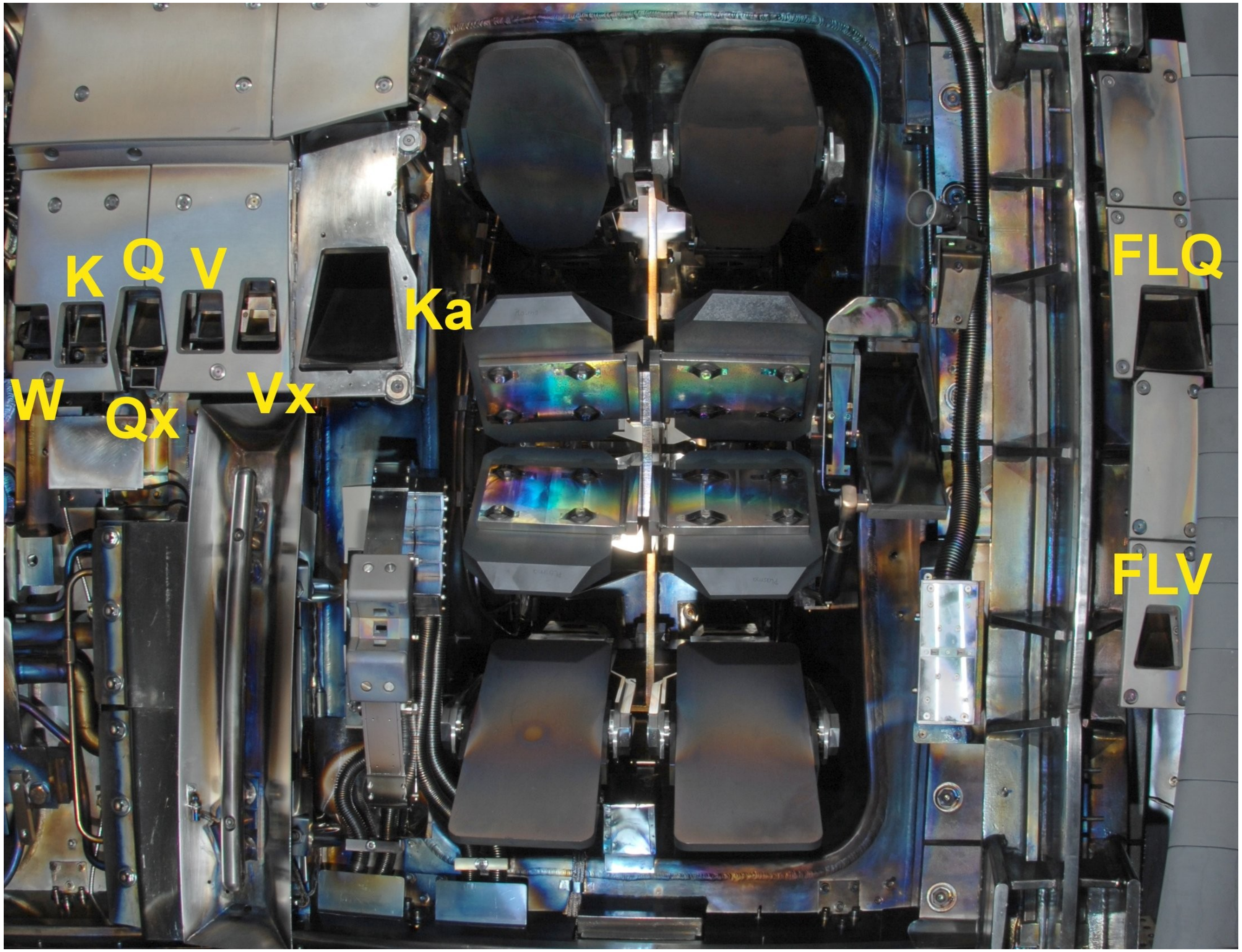
Shot parameters

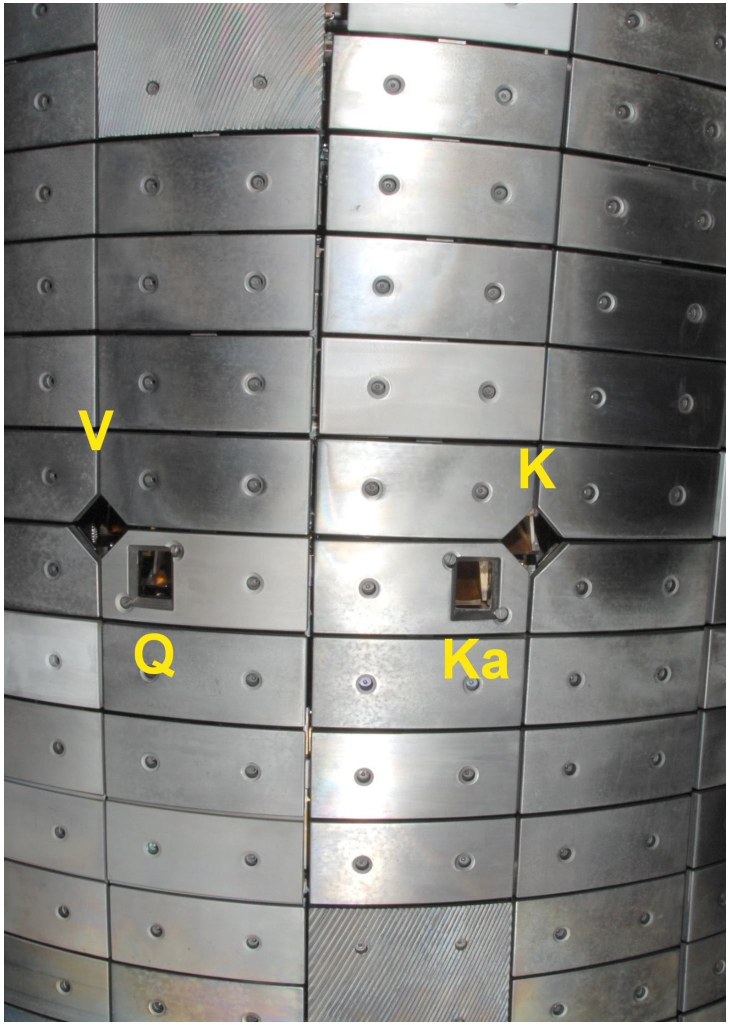


In-vessel components (2013-2014)

R=2.326m
LFS Sectors 5/6

Wall R=1.045m
HFS Sectors 4/5





ECRH stray radiation compatibility: *A. Silva, P. Varela et. al., RSI 83*
By L. Guimarais

1D model of cutoff oscillation

The I-Q detection of the hopping frequency reflectometer RFL allows to separate of φ(t) and A(t) fluctuations
φ(t) - sensitive to radial displacement of density cutoff layer and scattering effects
A(t) - sensitive to scattering effects

$\phi(t)=\phi_0+\delta\phi(t)$ φ_0 - position of cutoff layer, $\delta\varphi(t)$ - phase fluctuation near the cutoff layer

relation between φ and the density fluctuation level $\delta n_e/n_e$ can be determined in O mode:

1D model by C.Fanack:

Small wavenumbers $k_f << k_0$

$$\Delta\phi_{max}\approx F2\pi\frac{\delta n_0}{n_{cr}}\left(\frac{L/\lambda_0}{k_f/k_0}\right)^{1/2} \qquad F\approx 0.91$$

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

- density gradient length at the cutoff layer

Large wavenumbers $2k_a < k_f < 2k_0$: 'spatial' regime of Bragg scattering for Gaussian perturbations

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

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

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