Experimental turbulence studies for gyro-kinetic code validation using advanced microwave diagnostics

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Helmholtz Virtual Institute for Plasma Dynamical Processes and Turbulence Studies using Advanced Microwave Diagnostics

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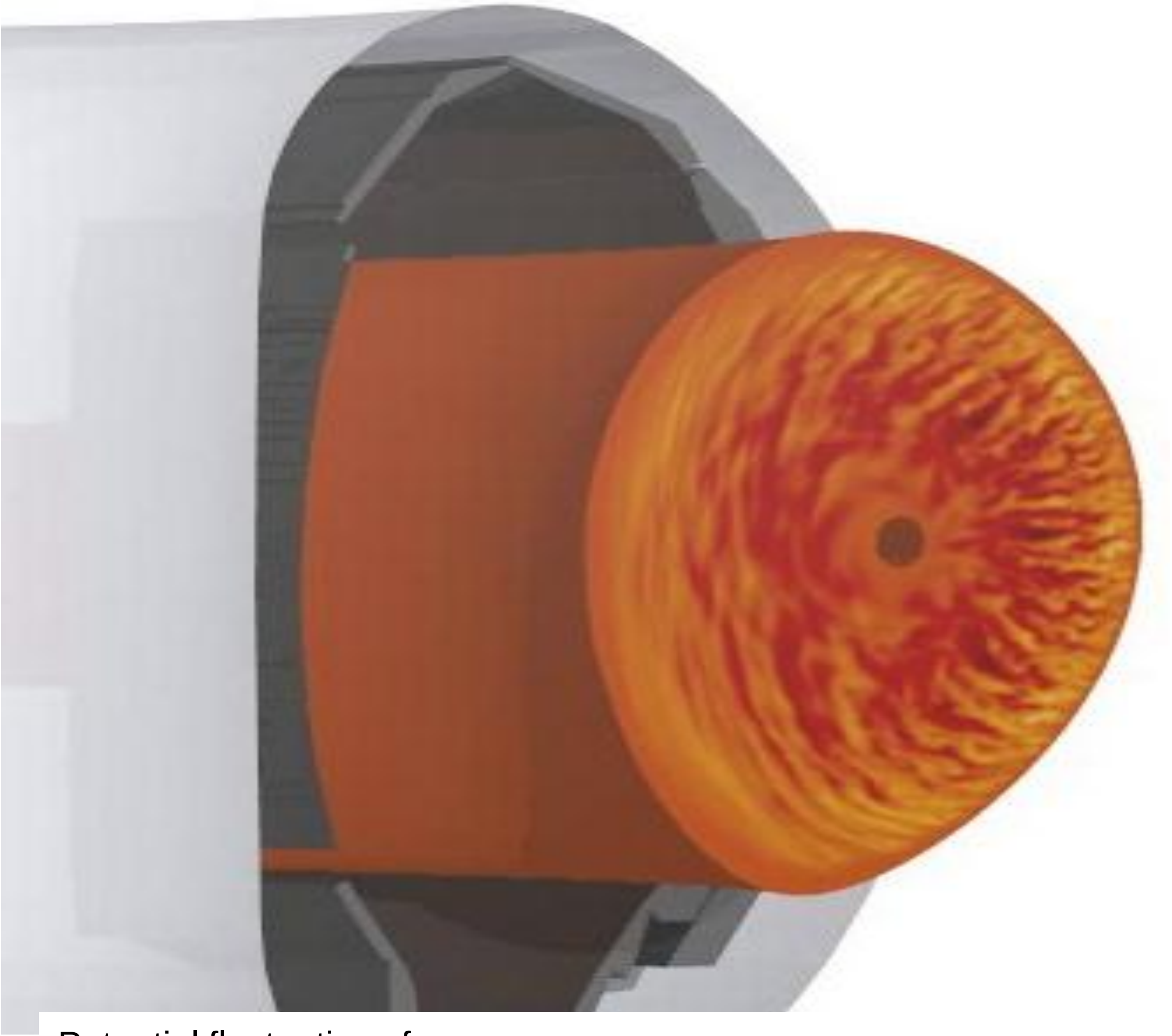
Gyro-kinetic and gyro-fluid codes provide a realistic simulation of turbulence in tokamaks



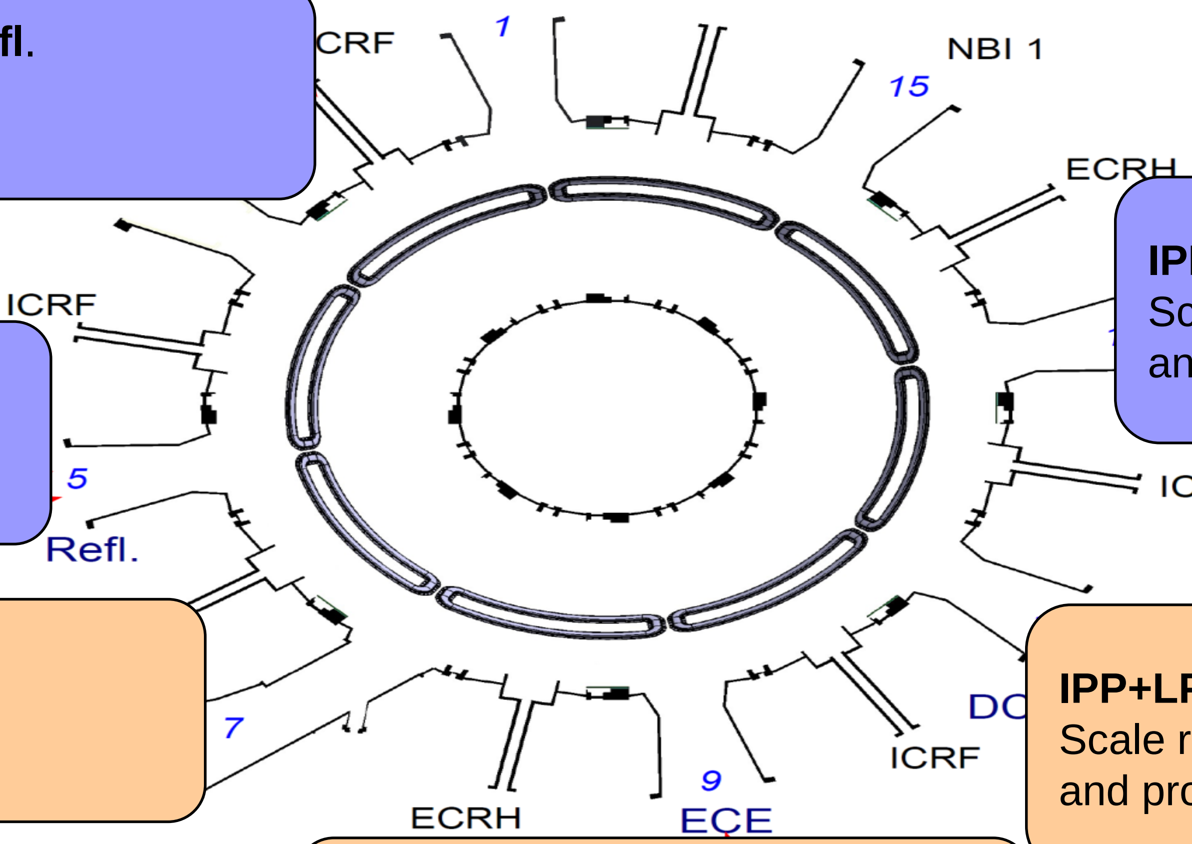
Potential fluctuations from GENE simulations
Jenko, POP 2000

- Codes reproduce experimental power and particle fluxes

- Codes make detailed predictions on the microscopic structure of turbulence
  - fluctuations in all parameters, cross-phase and phase velocities
  - spatial distribution of the fluctuations
  - interactions of zonal flows and GAMs with the turbulence

- **Experimentally test the physical models used in the codes on a microscopic basis**

Microwave diagnostics for turbulence studies on AUG



FZJ 5 antenna correlation refl.
Structure and propagation of fluctuations

IST Multi-band relf.
HFS/LFS asymmetries

CEA Ultra-fast swept refl.
Radial structure of fluctuations
Turbulence spreading

MIT correlation ECE
Temperature fluctuations
n-Te cross-phases

IPP 2 channel Doppler refl.
Scale resolved fluctuations and propagation velocity

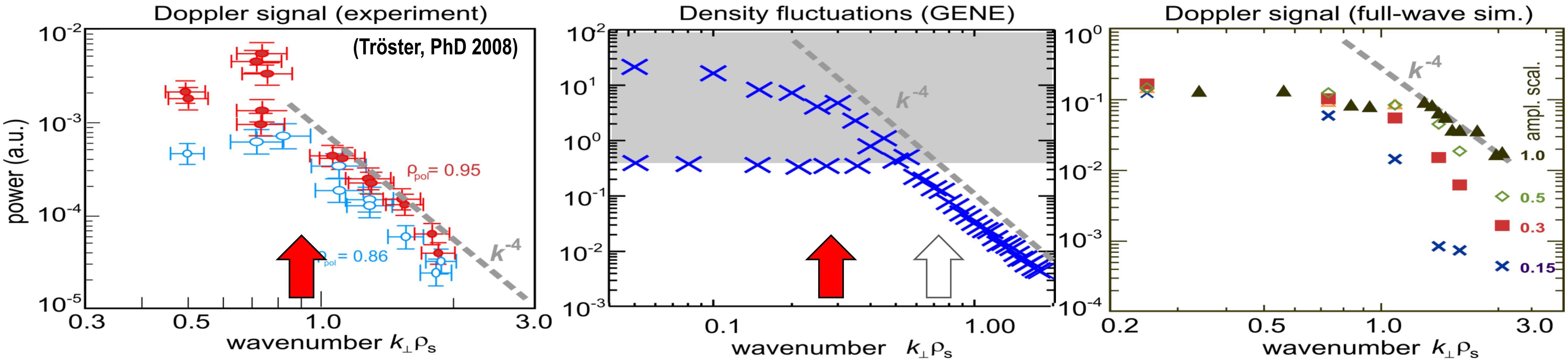
IPP+LPP 2 channel Doppler refl.
Scale resolved fluctuations and propagation velocity

Outline

- Importance of synthetic diagnostics
- **Transition from ITG to TEM turbulence in the plasma core**
- **Geodesic Acoustic Modes**
- Poloidal asymmetry of turbulent fluctuations
- Non-local effects in turbulence

Experiment-theory comparison needs synthetic diagnostics

- Example: Analysis of density fluctuation spectra at the plasma edge (AUG)



- Slope is similar (-4) but "knee" appears at different wavenumbers
- Full-wave simulations indicate non-linear saturation at large amplitudes shifting knee to larger wavenumbers
- **Comparison of wavenumber spectra from experiment and simulation has to be done through a synthetic diagnostic**

Lechte, Görler et al, PPCF t.b. subm.

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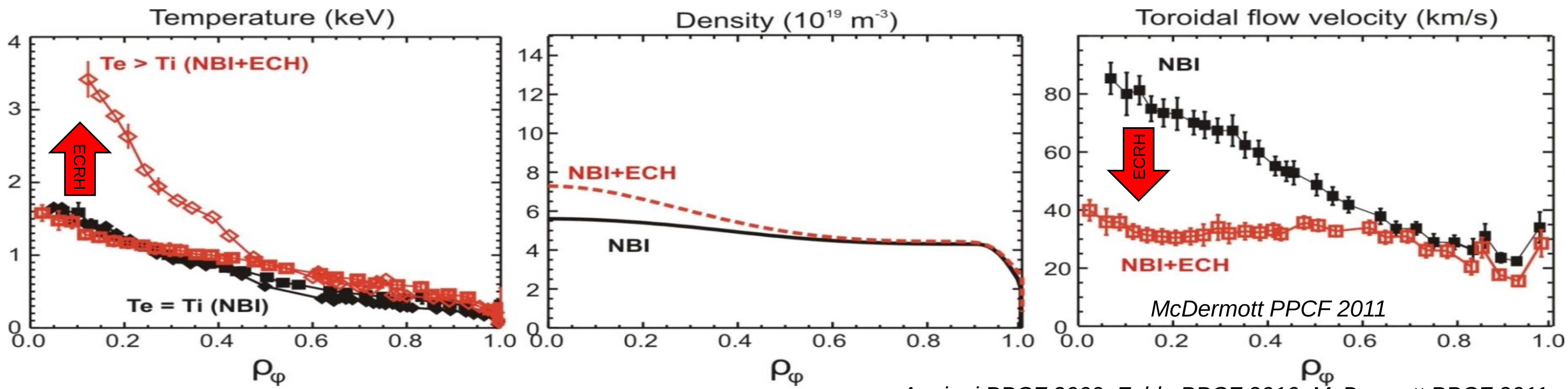
Core turbulence in the ITG-TEM regime

- ECRH drives plasma from ITG towards the TEM regime



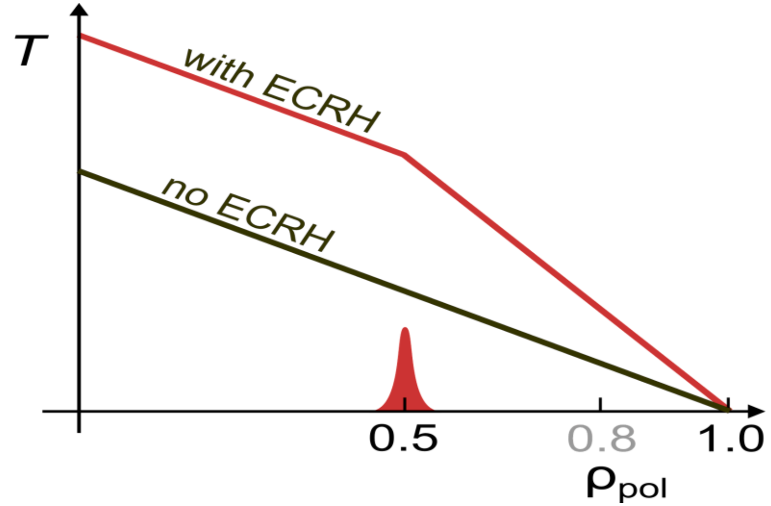
Angioni PPCF 2009, Fable PPCF 2010, McDermott PPCF 2011, Angioni PRL 2012, McDermott NF 2014

- Core density peaking (and change in rotation) is successfully described by gyro-kinetic calculations (GS2)
- Collisionality → turbulence regime → density peaking → plasma rotation

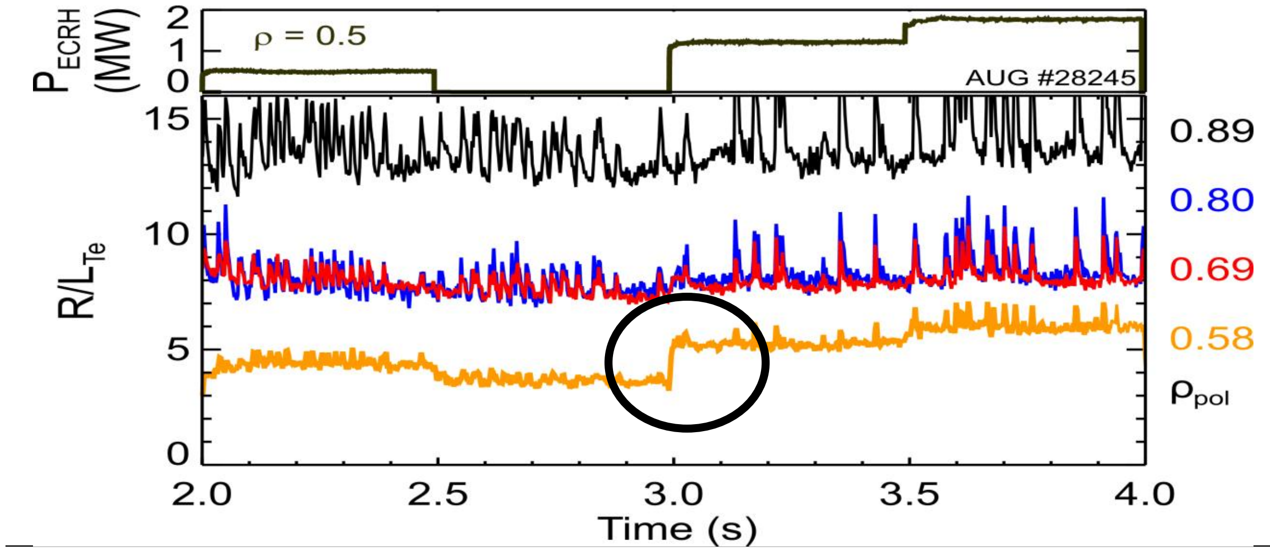
- **Test the models used in the codes on the basis of fluctuations**

Create discharges in the domain of the ITG-TEM transition

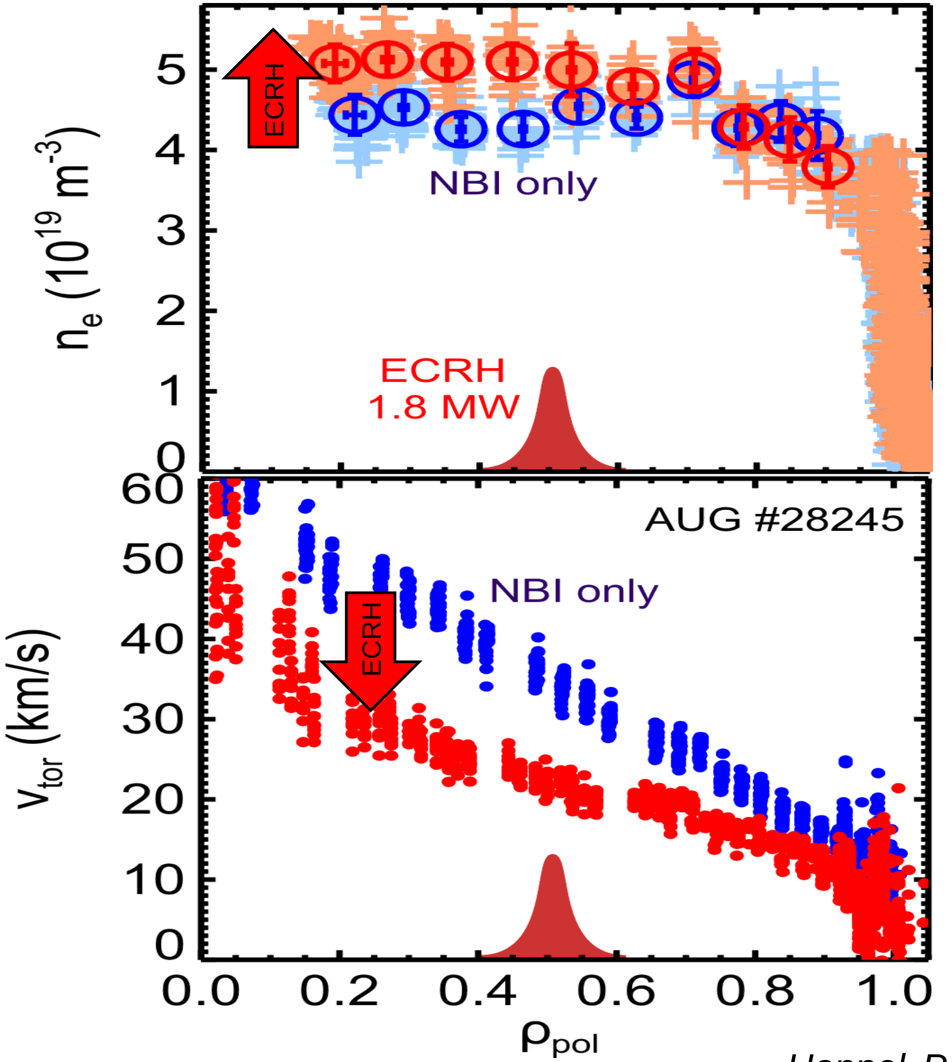
- H-mode (2.5 MW, NBI) add up to 1.8 MW off-axis ECRH



- $L_{Te} = T_e/\nabla T_e$ successfully modified

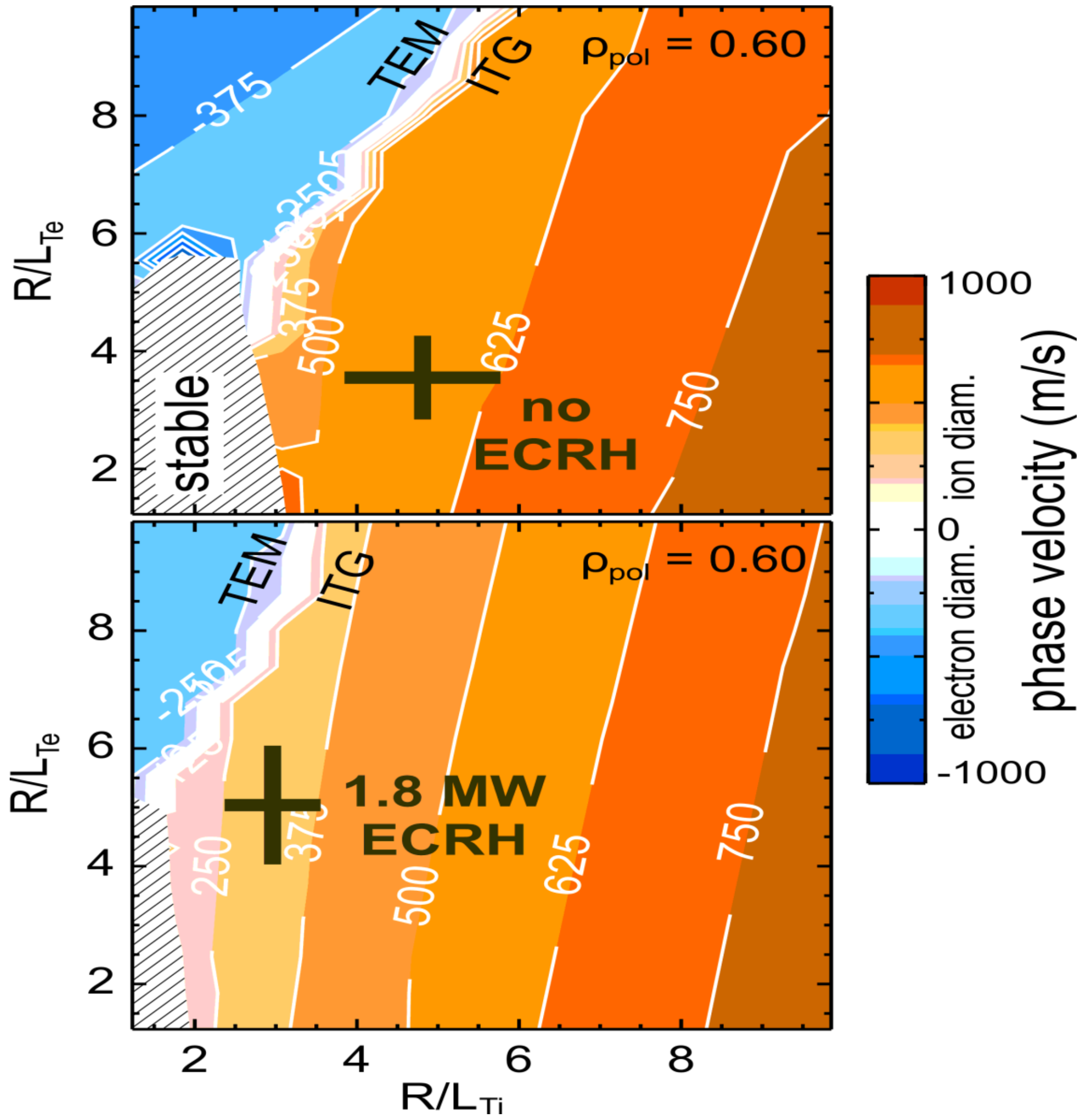


- Profiles respond as expected
  - Density more peaked, rotation flattens



Happel, PoP submitted

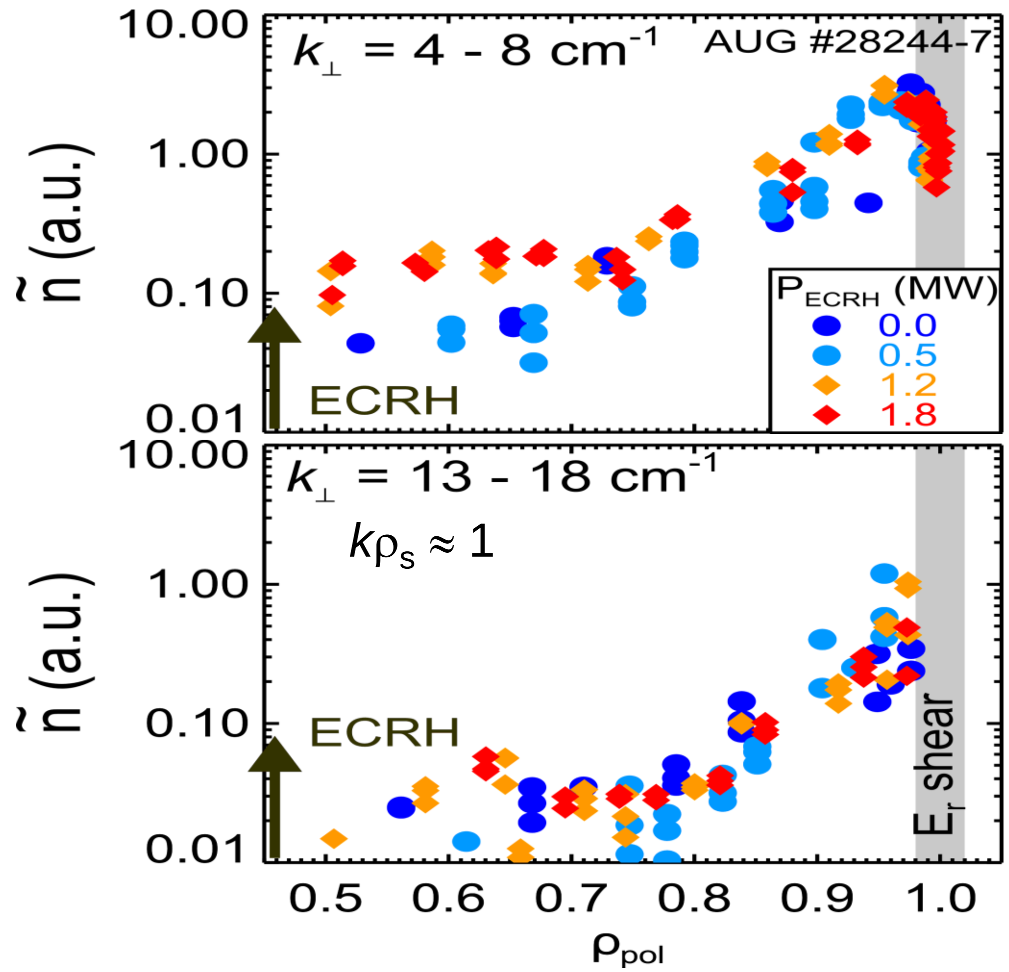
- TEM and ITG growth rates

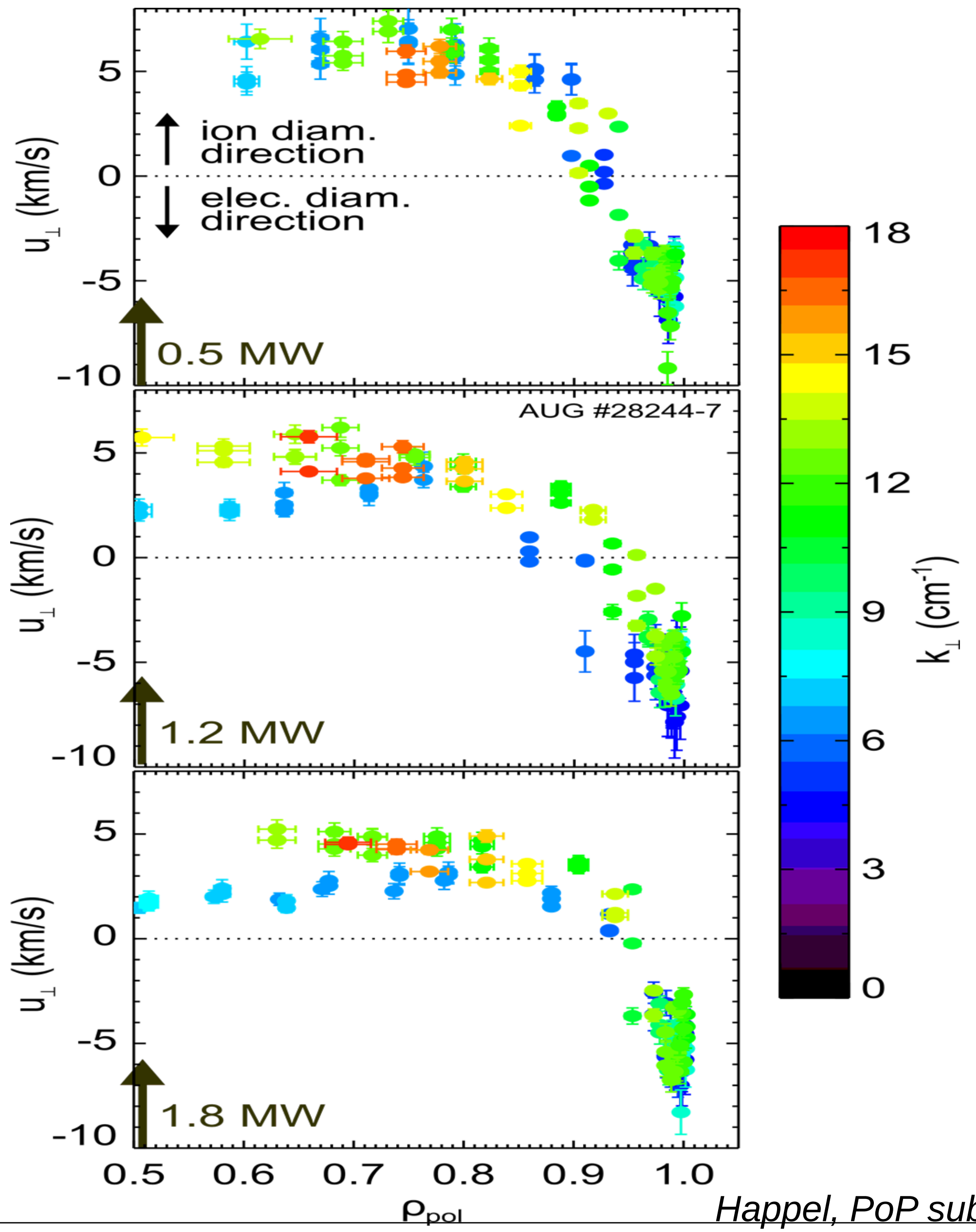


- Both phases are in the ITG regime
- ECRH pushes plasma towards the TEM regime
- What can we expect from the ITG-TEM transition?
  - About the same turbulent scales
  - Shift of phase velocity from the ion- to the electron-diamagnetic drift direction

Happel, PoP submitted

Scale resolved observations from Doppler reflectometry

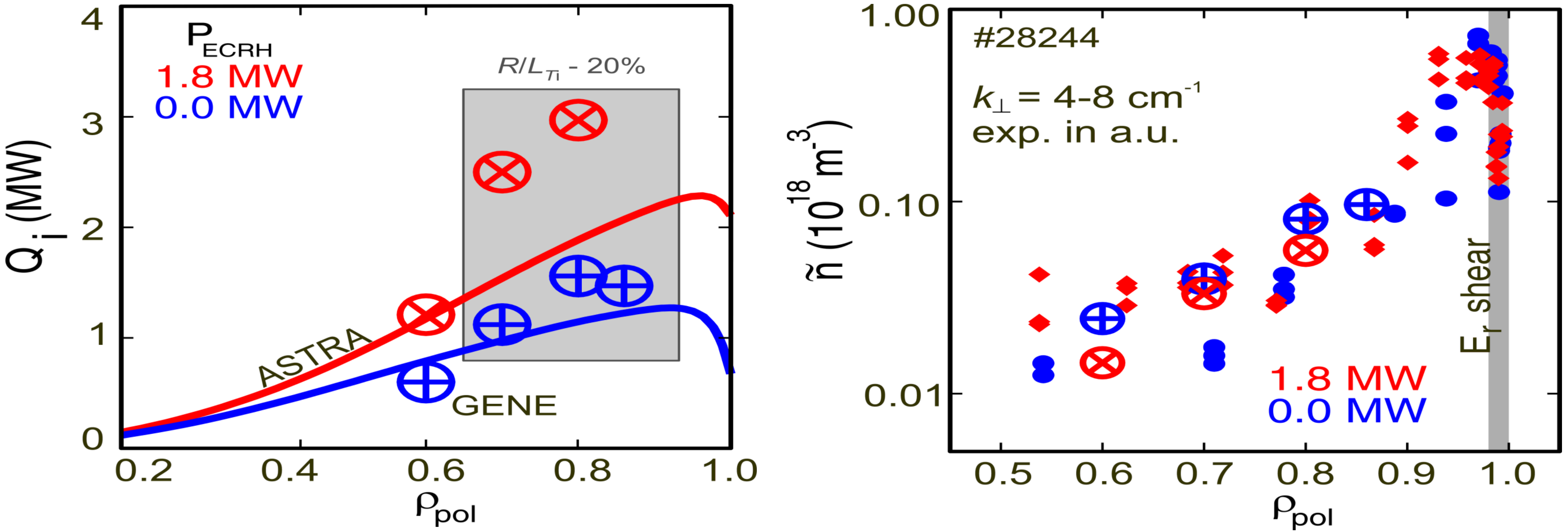




- Large scale amplitudes increase
- Phase velocity of about 3 km/s into electron-diamagnetic direction (larger than expected)

Happel, PoP submitted

Comparison with GENE simulations

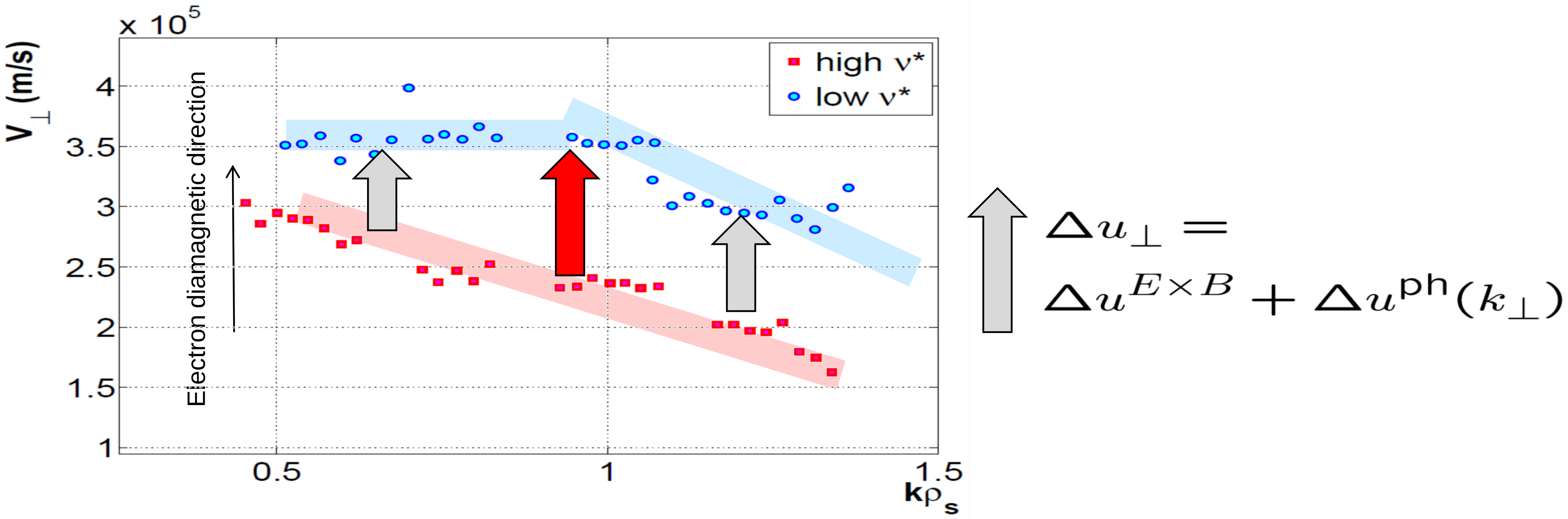


- Electron and ion power fluxes matched within experimental error bars
- Radial increase in fluctuation amplitude reproduced quantitatively
- Dependence on heating power not yet recovered

Happel, PoP submitted

Change of turbulence through collisionality in Tore Supra

- At lower collisionality a transition from ITG to TEM can be expected



- Strongest velocity shift into electron-diam. direction is also at $k\rho_s \approx 0.75$
- Velocity change consistent with GENE predictions but experimental velocities are again larger (km/s) than in simulations (100 m/s)

Vermarre PoP 2011

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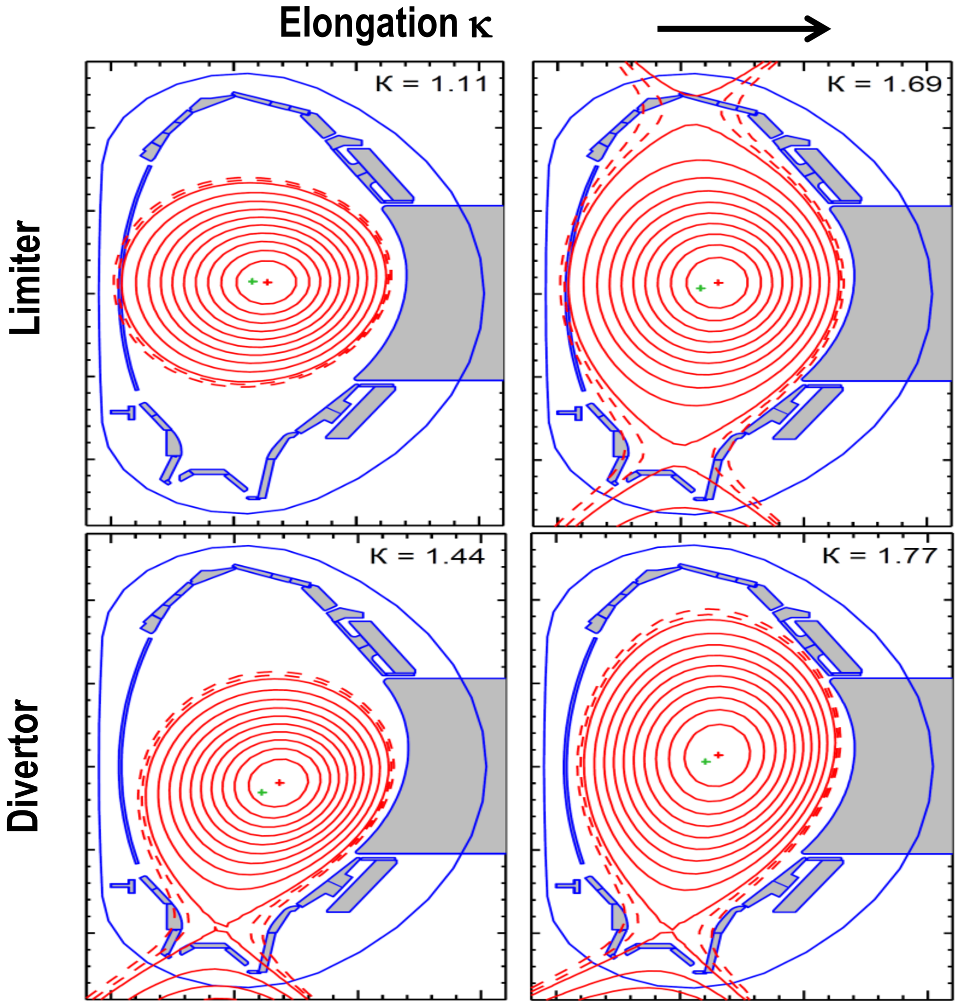
Frequency scaling of Geodesic Acoustic Modes

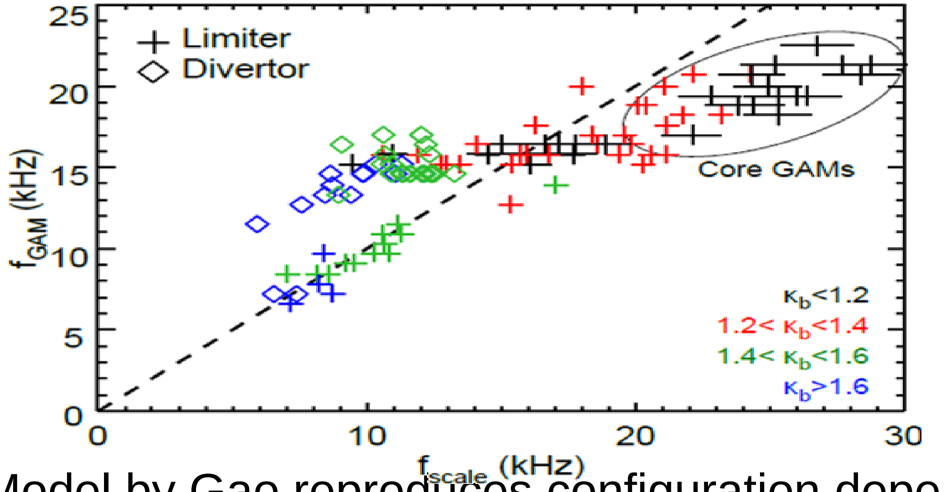
Simon, PhD.

- Systematic configuration scan on AUG



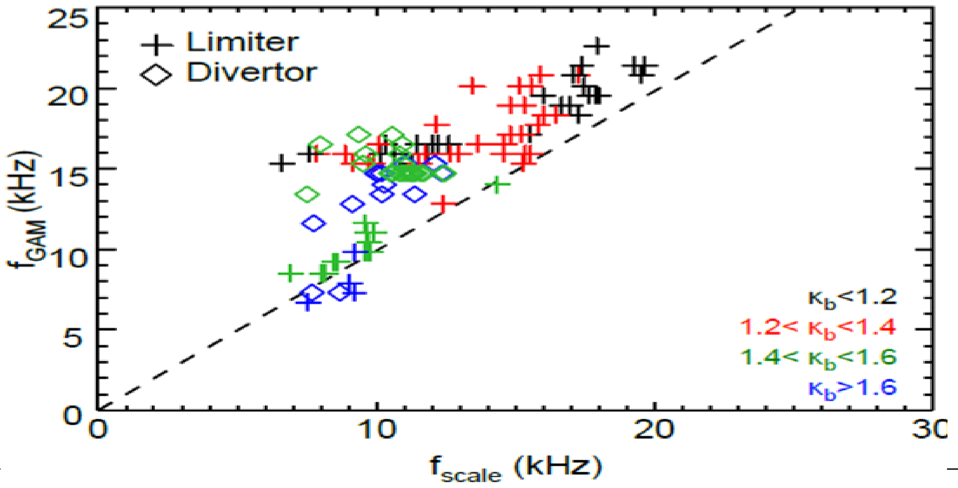
- Empirical model by Conway reproduces average trend

Conway PPCF 2008



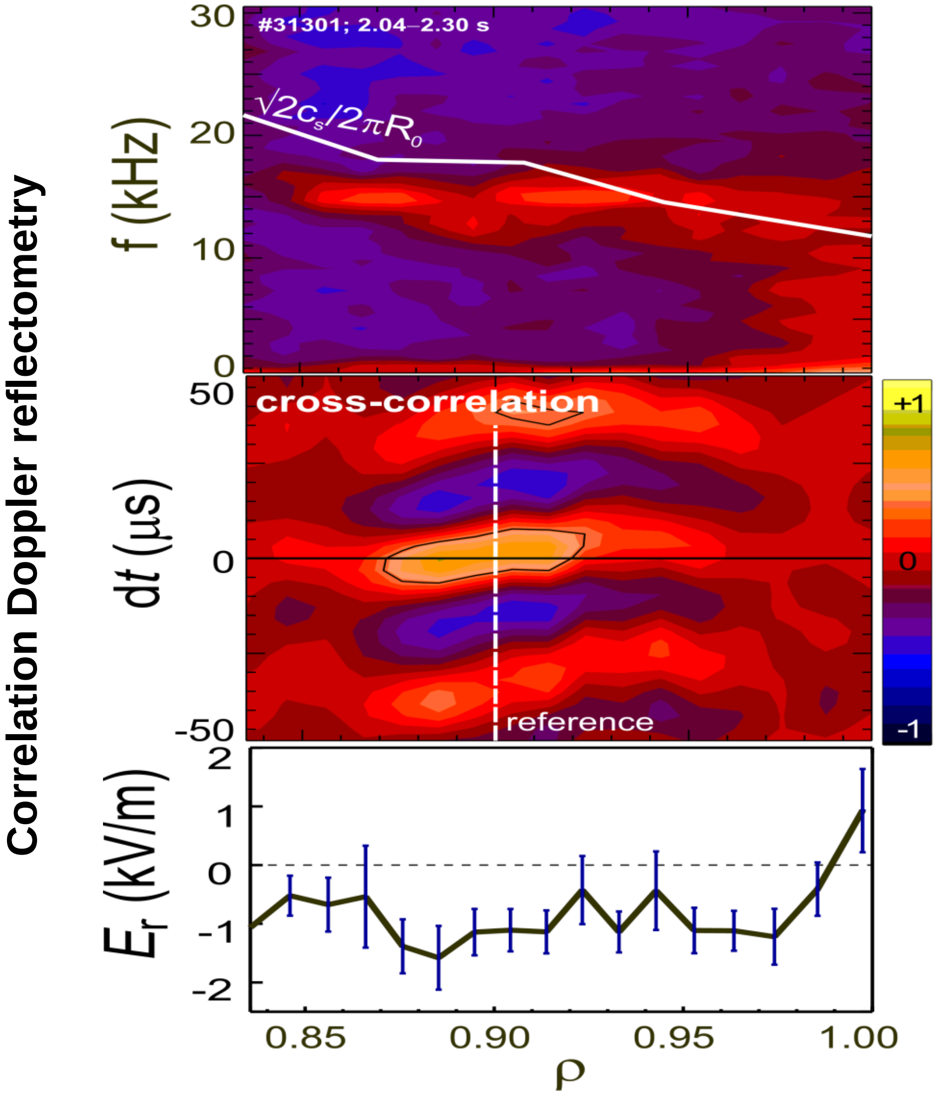
- Model by Gao reproduces configuration dependence, frequency is too low

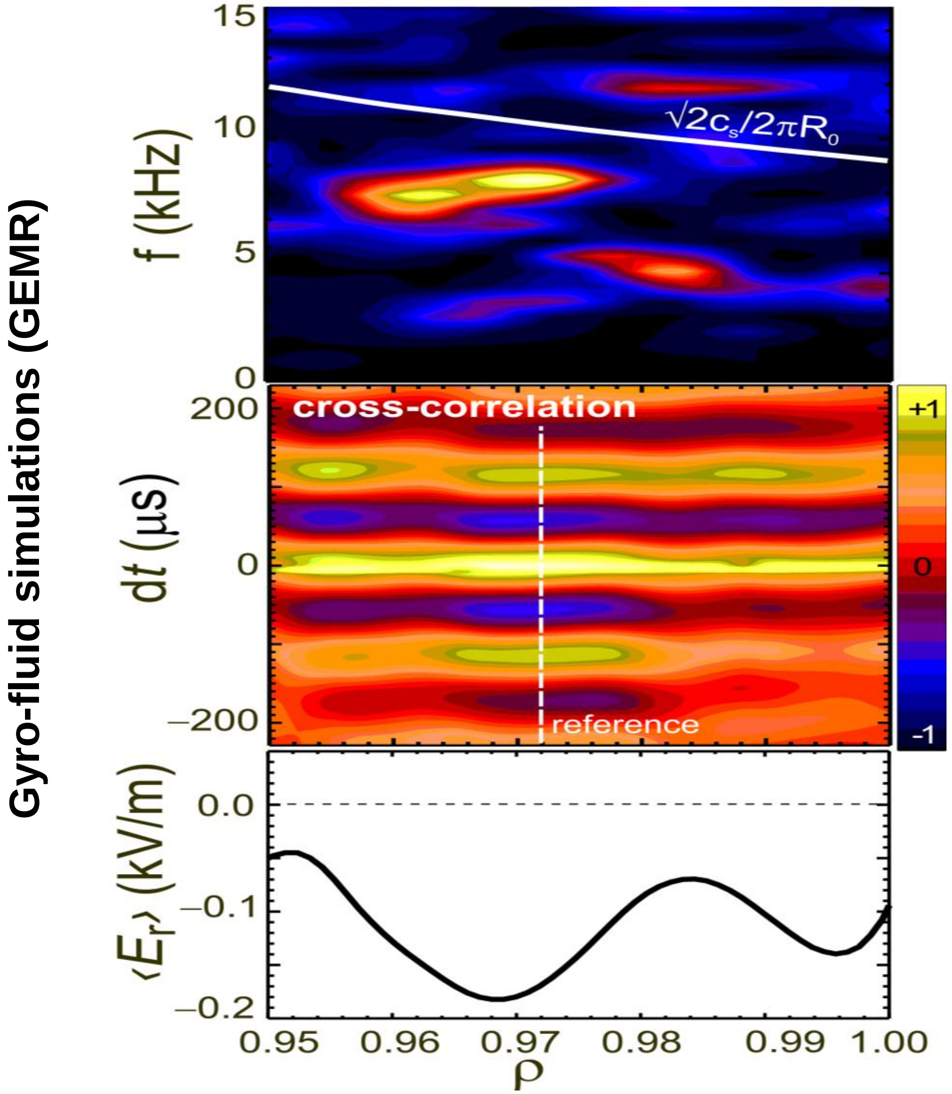
Gao PST 2011



Spatiotemporal structure of GAMs in AUG

P. Simon, PhD

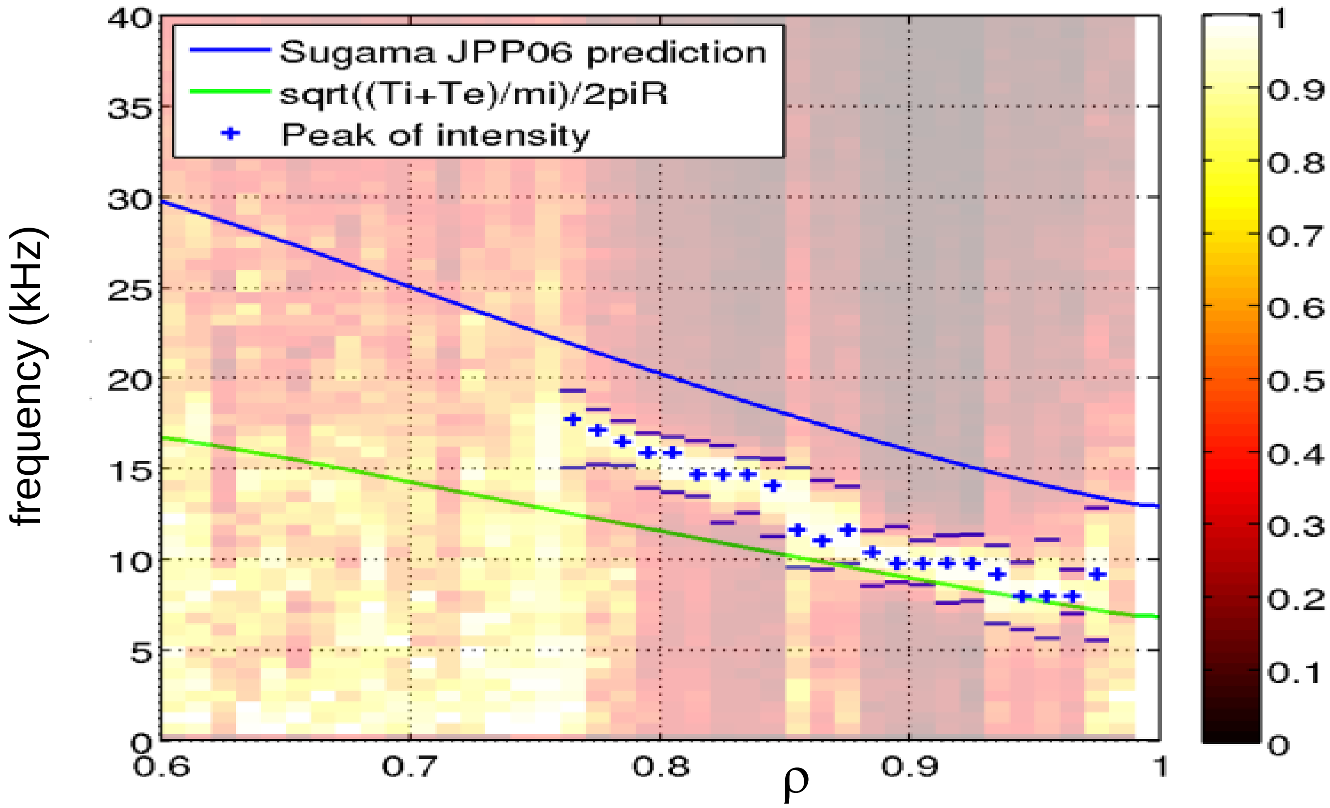




- Frequency “locking” over wider radial region in exp. and simulation
- No clear sign of radial propagation

Structure GAM in Tore Supra

- Doppler reflectometry

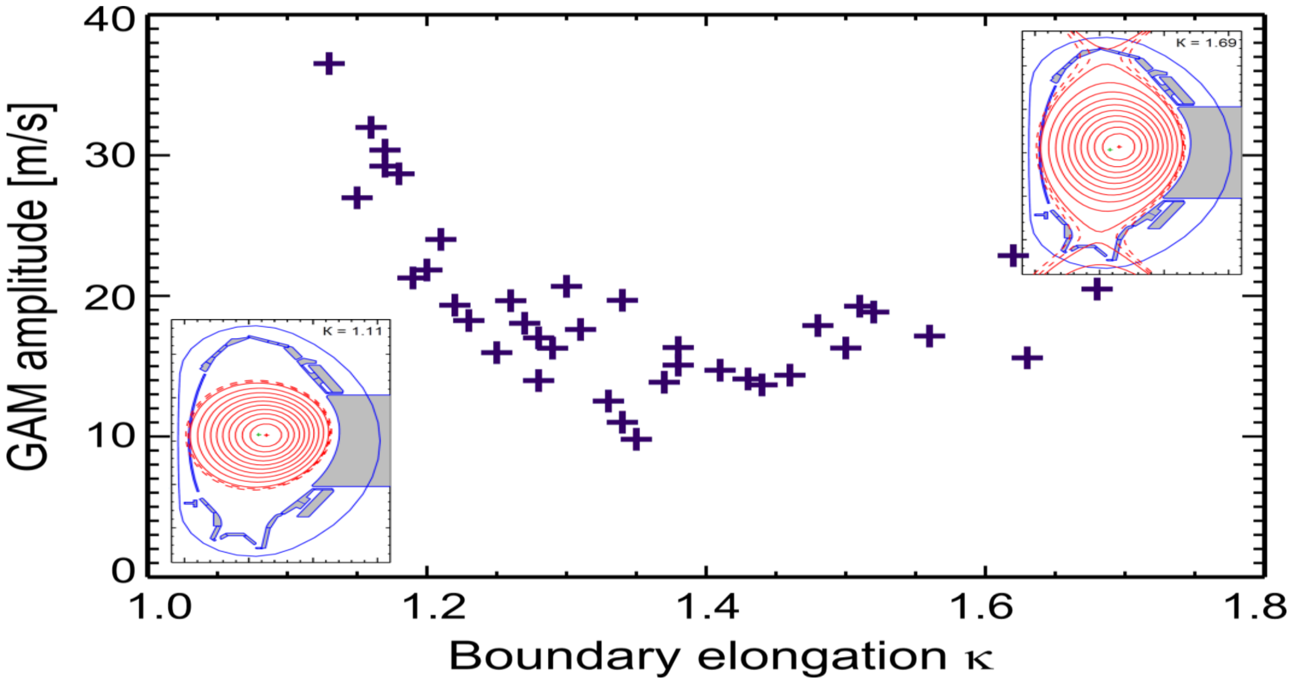


- Frequency plateaus are also seen but general trend of c_s/R is recovered

A. Storelli, PhD, TTG 2014

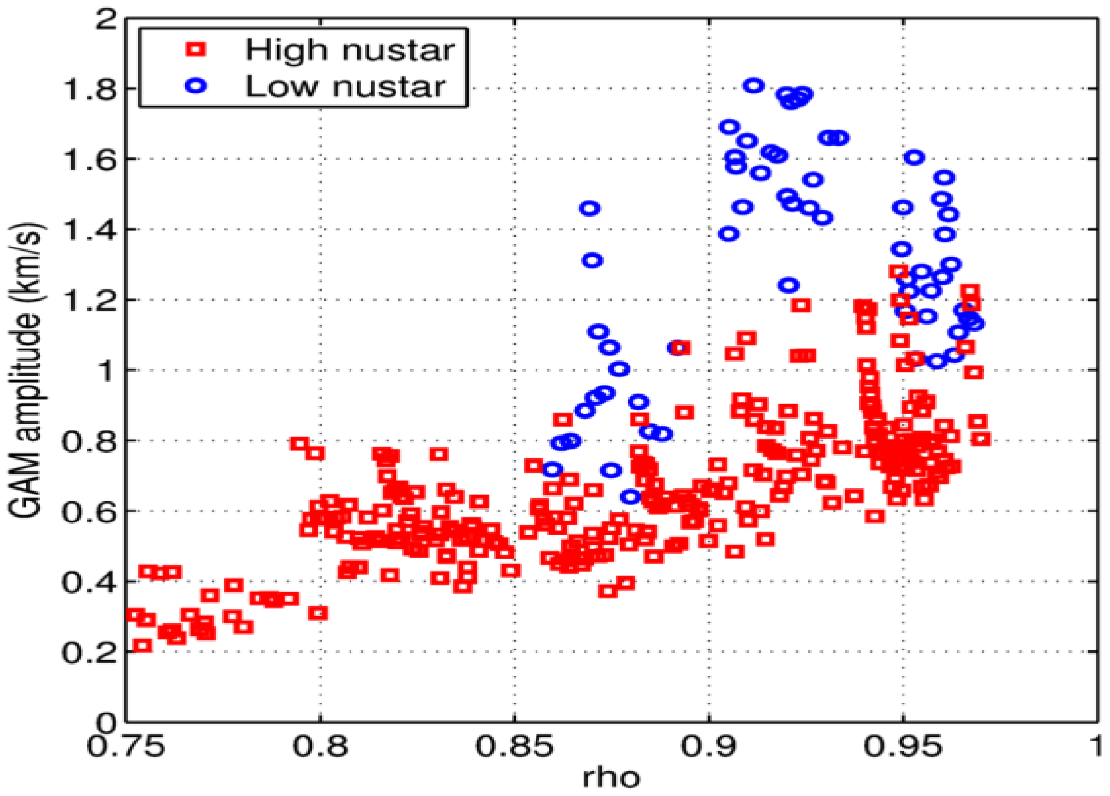
GAM damping in AUG and Tore Supra

- Larger GAM amplitudes in circular plasmas (AUG)



P. Simon, PhD

- Larger GAM amplitudes at lower collisionality (Tore Supra)



A. Storelli, PhD, TTG 2014

- GAM amplitude follows qualitatively the inverse damping rate

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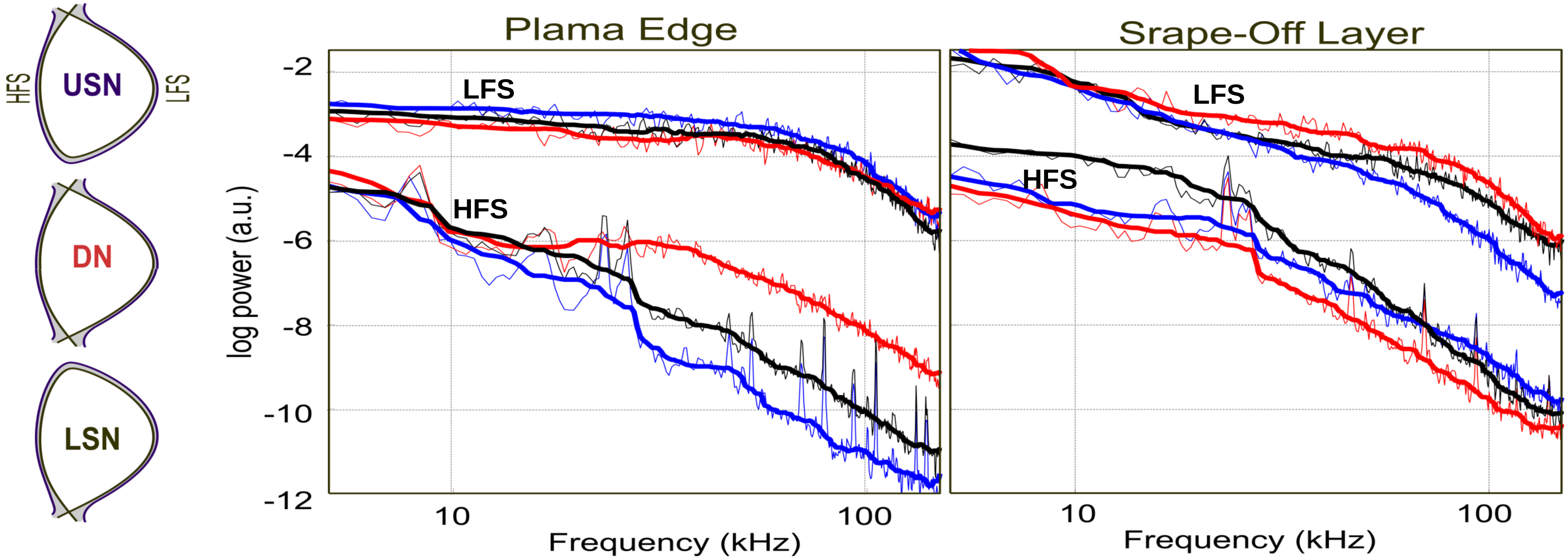
Poloidal structure of turbulence HFS/LFS reflect. on AUG



V. Nikolaeva, PhD

- Strong HFS/LFS asymmetry (ballooning); increasing with frequency
- Stronger asymmetry in the SOL at low frequencies; DN and SN are similar
- Comparison with gyro-fluid simulations (GEMR) under way

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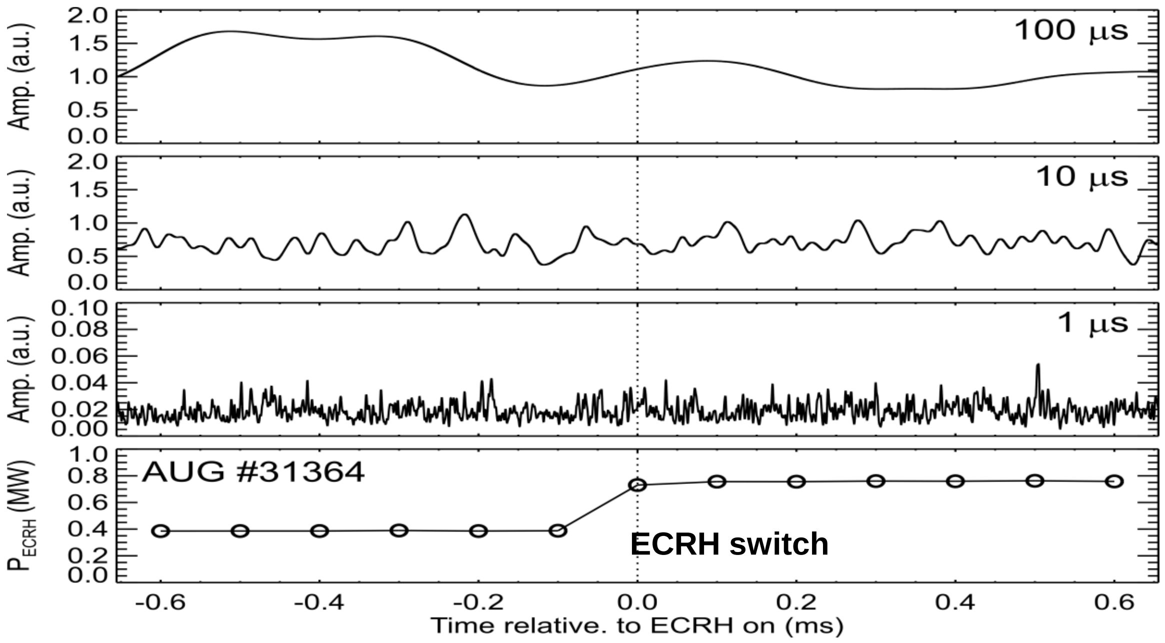
Search for non-local effects and fast turbulence spreading

- In ECRH modulation experiments on LHD, fluctuations reacted faster than local plasma parameters

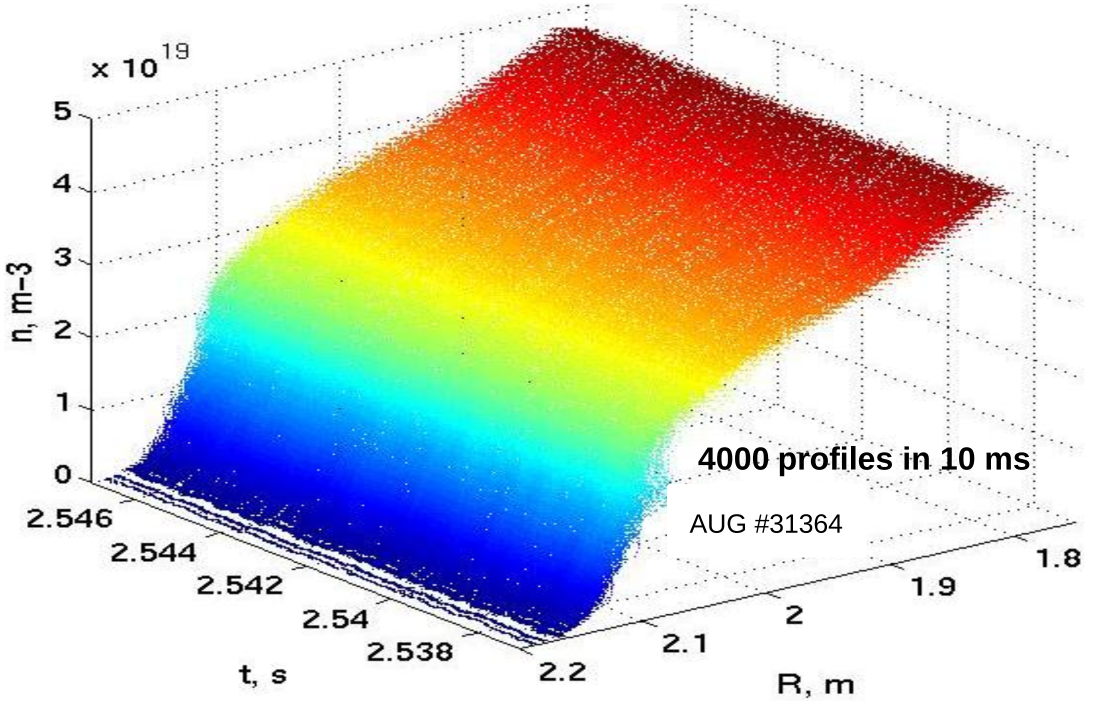
Inagaki NF 53 (2013)

- Reaction of edge Doppler data to core ECRH modulation on AUG

Conditional averaging on wavelet filtered fluctuation signals

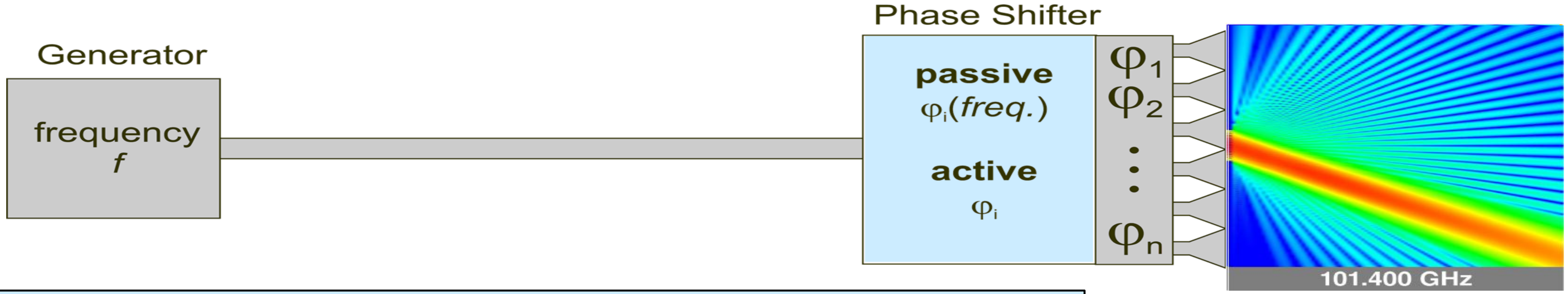


- Density profiles from ultra-fast swept reflectometer during ECRH switch-on



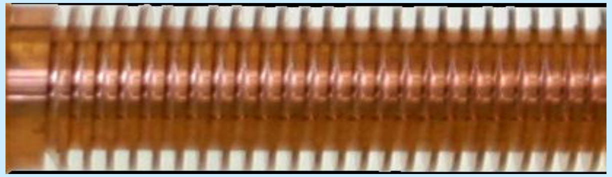
A. Medvedeva, PhD

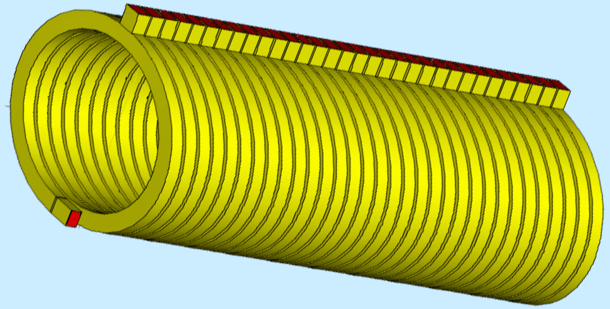
- So far no evidence for non-local transport in the density
- Extent search to lower collisionality



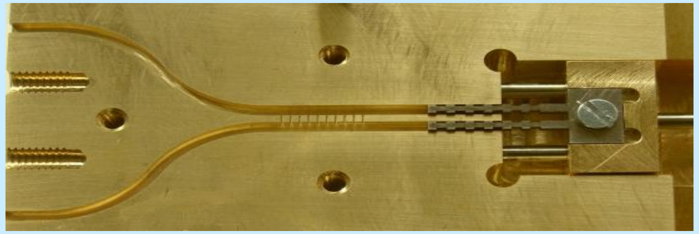
S. Wolf, PhD

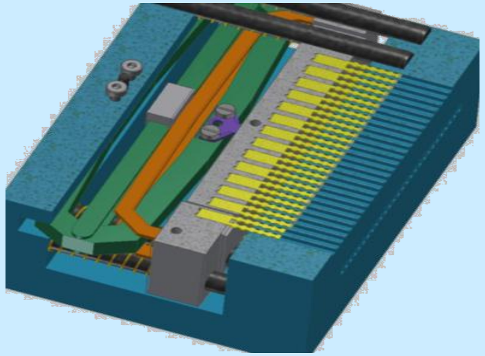
Passive phase shifter





Active phase shifter





32 horn array antenna

C. Koenen, PhD

- To be installed and tested on AUG and TCV

Summary

- Validation of physical models in turbulence codes needs to be done on a microscopic level in a comprehensive fashion
- This is not an easy task: it requires excellent hardware and often synthetic diagnostics and many CPU hours
- First results encouraging: agreement is found e.g. for
  - Wavenumber spectra, radial variation of fluctuation amplitudes; change in drift direction at ITG-TEM transition
  - GAM frequency scaling, damping and frequency plateaus
- …but there is still much to do, e.g.
  - Wavenumber spectra
  - The correct turbulent phase velocity
  - ZF and GAM interaction with turbulence
  - …