EXPERIMENTAL STUDY OF RADIAL TURBULENCE WITH THE ULTRA-FAST-SWEPT REFLECTOMETER AT ASDEX UPGRADE

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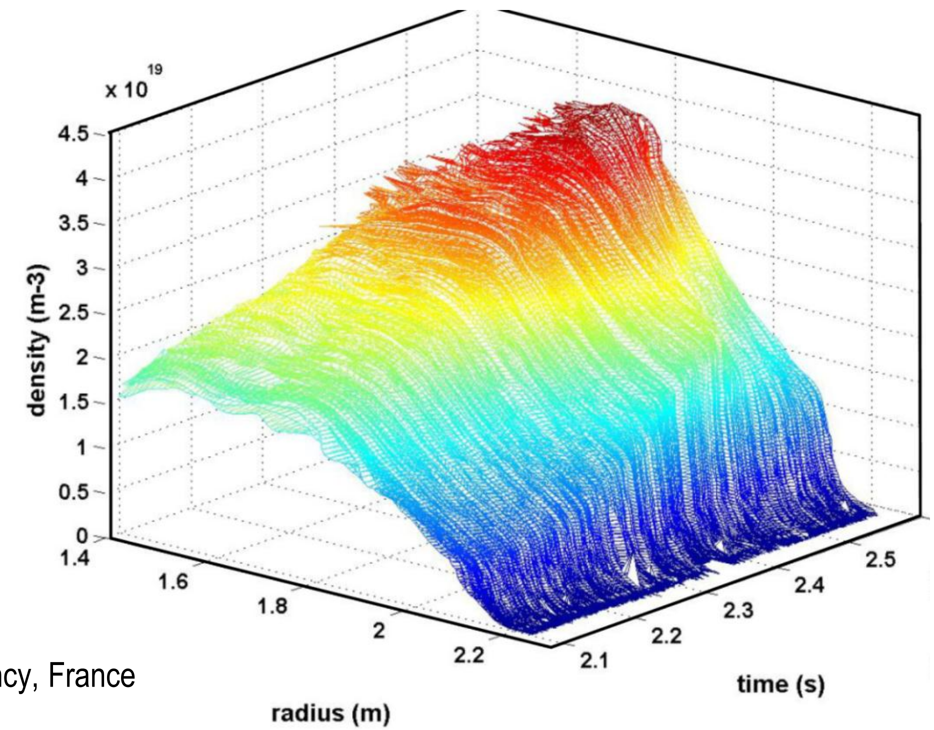


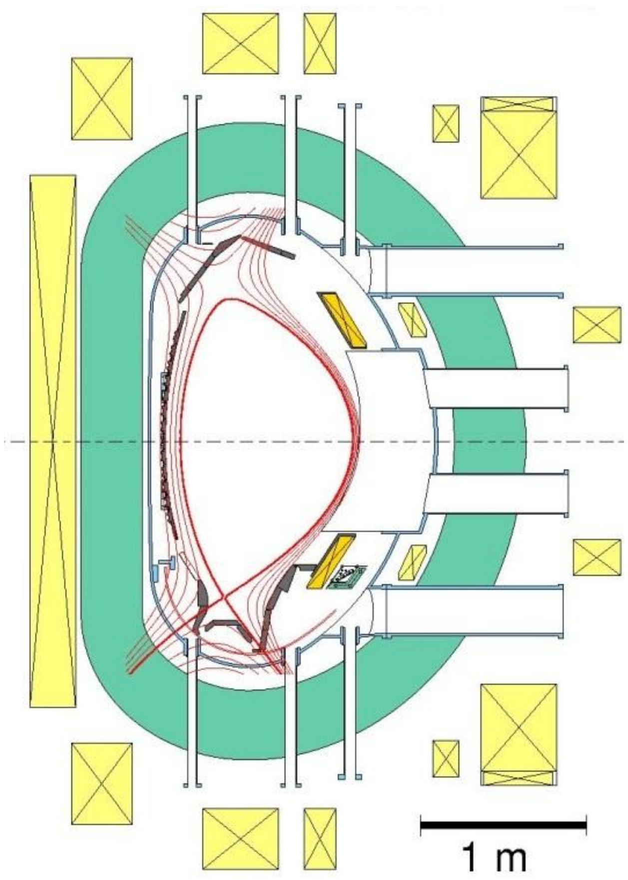
FuseNet PhD Event 2015

OUTLINE

EXPERIMENTAL STUDY OF RADIAL TURBULENCE WITH THE ULTRA-FAST-SWEPT REFLECTOMETER AT ASDEX UPGRADE

- ASDEX Upgrade tokamak
- Reflectometry basics
- Ultra-Fast-Swept Reflectometer installation
- Electron density turbulent fluctuations (methods)
- Experimental results

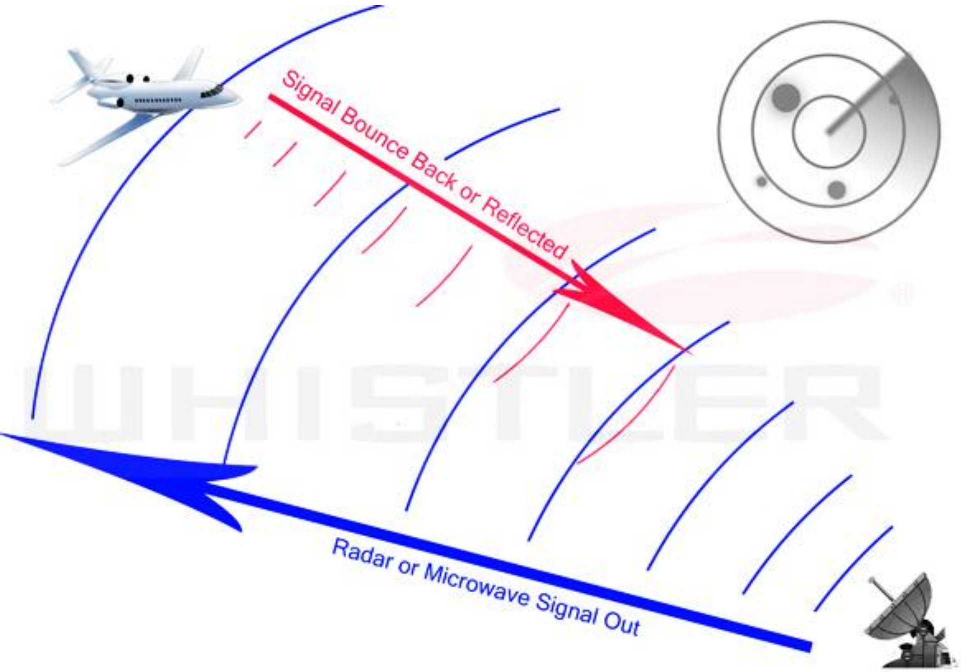
ASDEX UPGRADE TOKAMAK



IPP, Garching, Germany

Material of the first wall	Tungsten
Maximum magnetic field	3.1 T
Plasma current	0.4 MA - 1.6 MA
Pulse duration	< 10 s
Plasma heating:	up to 27 MW
Ohmical heating	1 MW
Neutral beam injection heating	20 MW (with ^2H = D)
Ion-Cyclotron heating	6 MW (30 MHz - 120 MHz)
Electron-Cyclotron heating	2 x 2 MW (105/140 GHz)
Major plasma radius R_0	1.65 m
Minor horizontal plasma radius a	0.5 m
Minor vertical plasma radius b	0.8 m
Plasma types	D, H, He
Plasma density	2 x 10^{20} particles per m^3
Plasma temperature	100 million degrees

RADAR TECHNIQUE: PLASMA REFLECTOMETRY

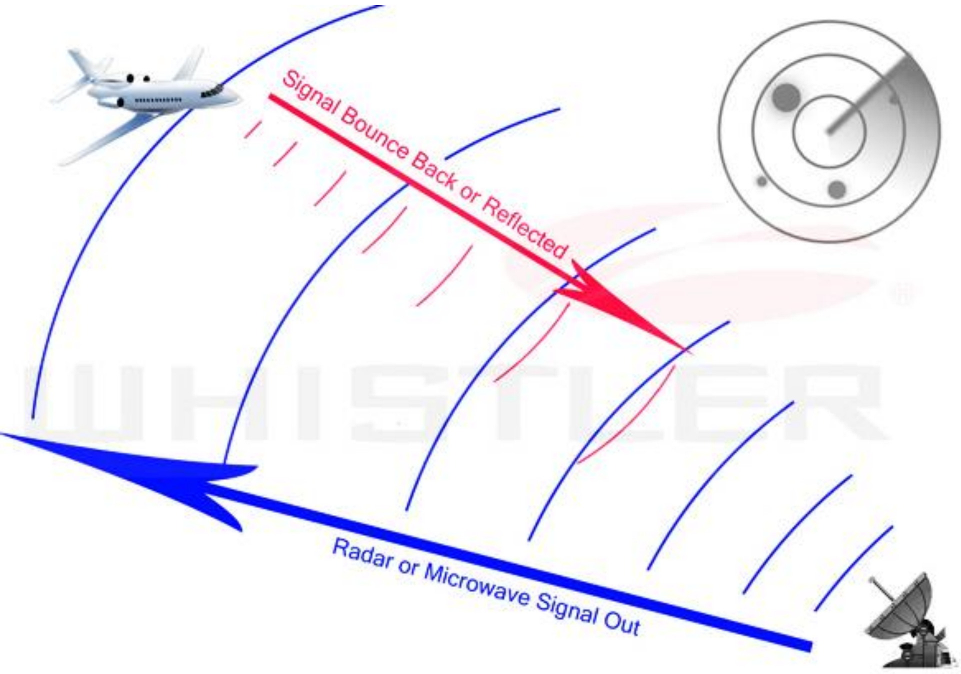


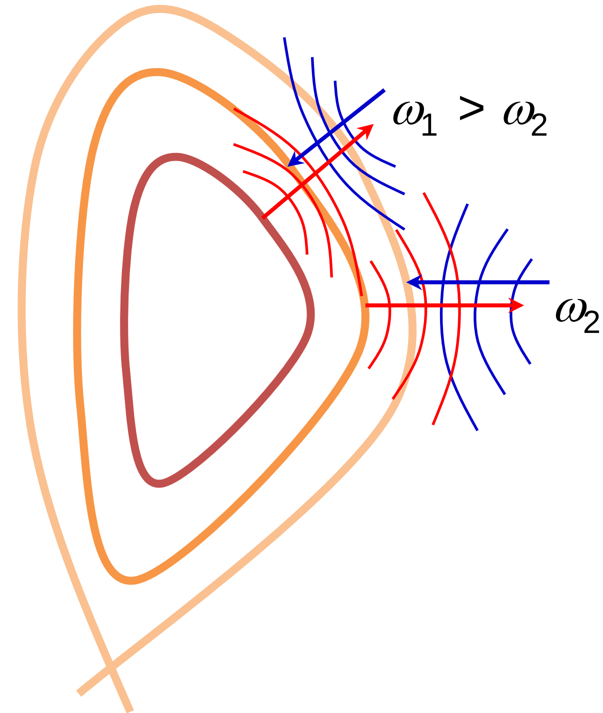
Plane → Amplitude jump A(t)

Signal phase Φ→ distance

ASDEX Upgrade

RADAR TECHNIQUE: PLASMA REFLECTOMETRY





Plane → Amplitude jump A(t)

Signal phase Φ → distance

Plasma → Amplitude jump A(t)

Bigger frequency → Reflection at deeper layer

Signal phase Φ → density and distance

$$\Phi = \frac{4\pi F}{c} \int_{Rref}^{Rcutoff} N[n_e(r), B(r), F]dr - \frac{\pi}{2}$$

$$N_X^2 = 0, F_{cut-off}(n_e, r) = \frac{\pm F_{ce} + \sqrt{F_{ce}^{\ 2} + 4 \cdot F_{pe}^{\ 2}}}{2}$$

SWEPT REFLECTOMETER

- Swept frequency reflectometry:

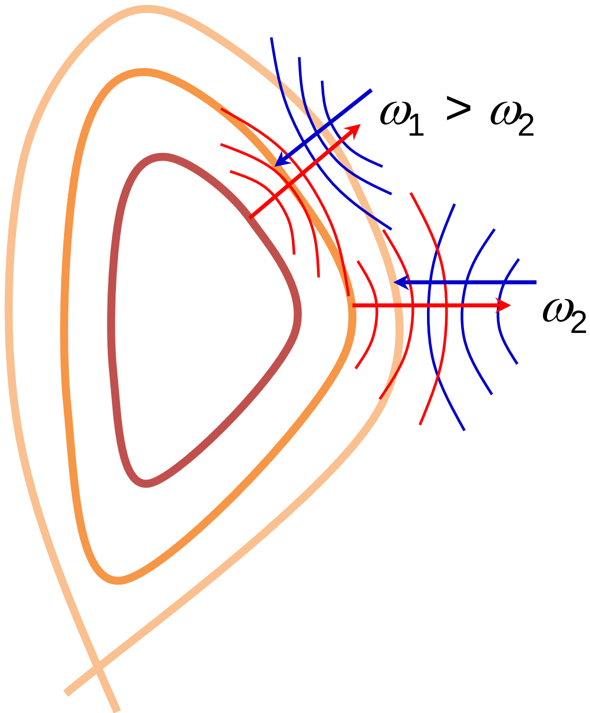
  scan from the edge to the core

- Heterodyne IQ detection : independent amplitude and phase with high S/N ratio

$$S = A \cdot e^{i\Phi(\omega)}$$

$$\boxed{\begin{gathered}\Phi = \langle\Phi\rangle + \delta\Phi, \\ \delta\Phi = f(\delta n)\end{gathered}}$$

- $A(\omega)$ → initialization (plasma edge)
- $\Phi(\omega)$ → electron density profile
- $\delta\Phi(\omega)$ → δn turbulent fluctuations, ω and k-spectra



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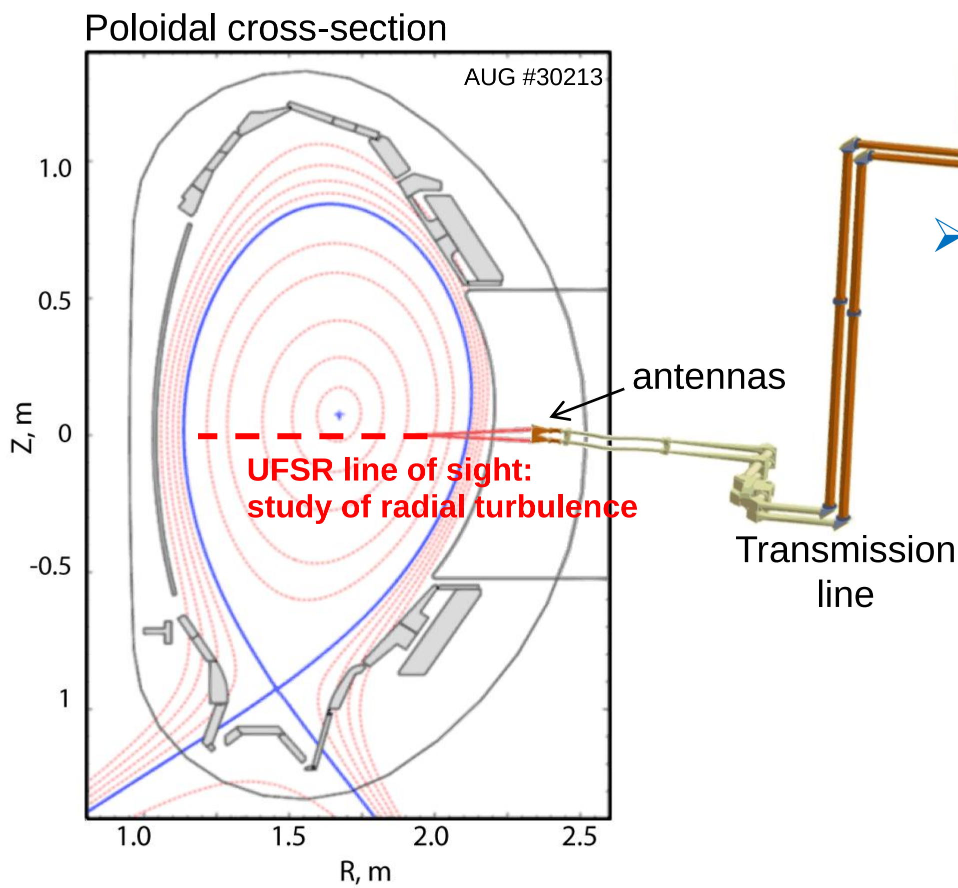
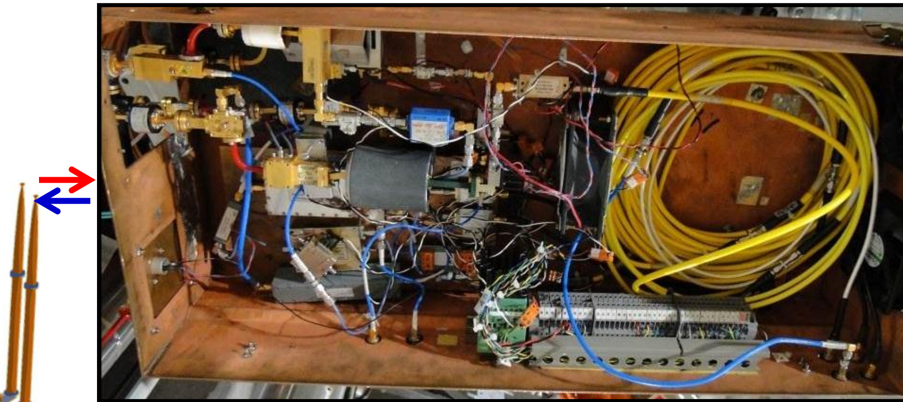
ULTRA-FAST SWEPT REFLECTOMETER INSTALLATION ON ASDEX UPGRADE

- Developed at CEA, Cadarache, transferred to AUG in 2013





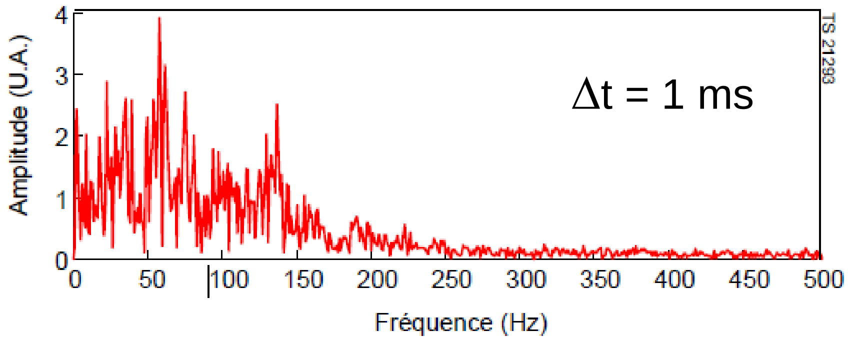
- Specifications
  - V & W frequency bands, 50.5-105 GHz

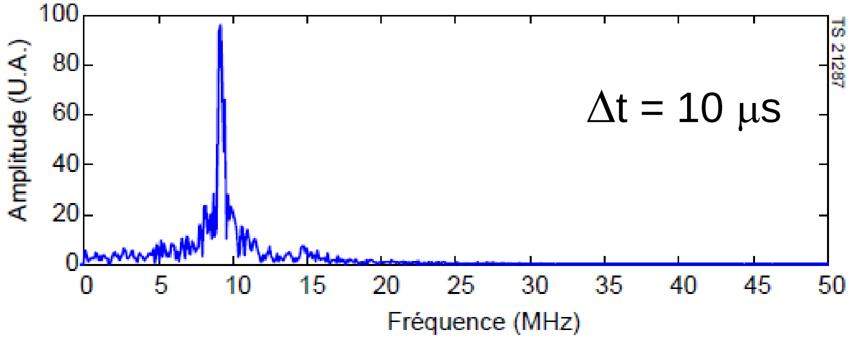
  2013:
  - sweep time 2 μs, spectra up to 200 kHz
  - up to 12.000 profiles per discharge

  2015:
  - sweep time 1 μs, spectra up to 400 kHz
  - up to 200.000 profiles per discharge

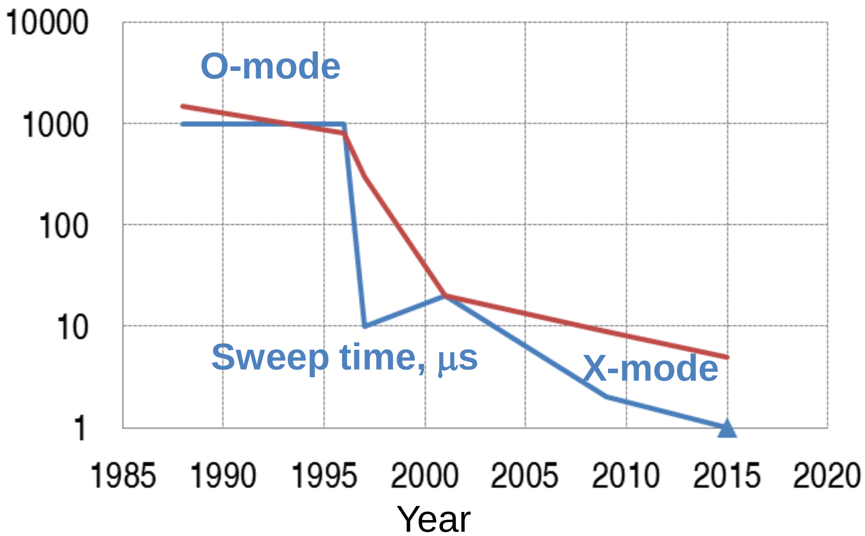
ULTRA-FAST SWEPT REFLECTOMETER : IMPROVING SWEEP TIME

Signal spectra for different sweep times



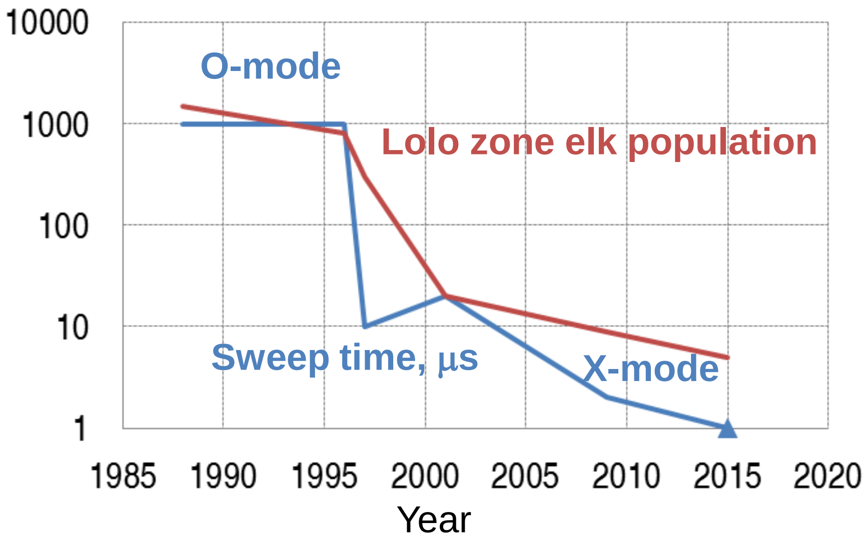


F.Clairet, thèse HDR



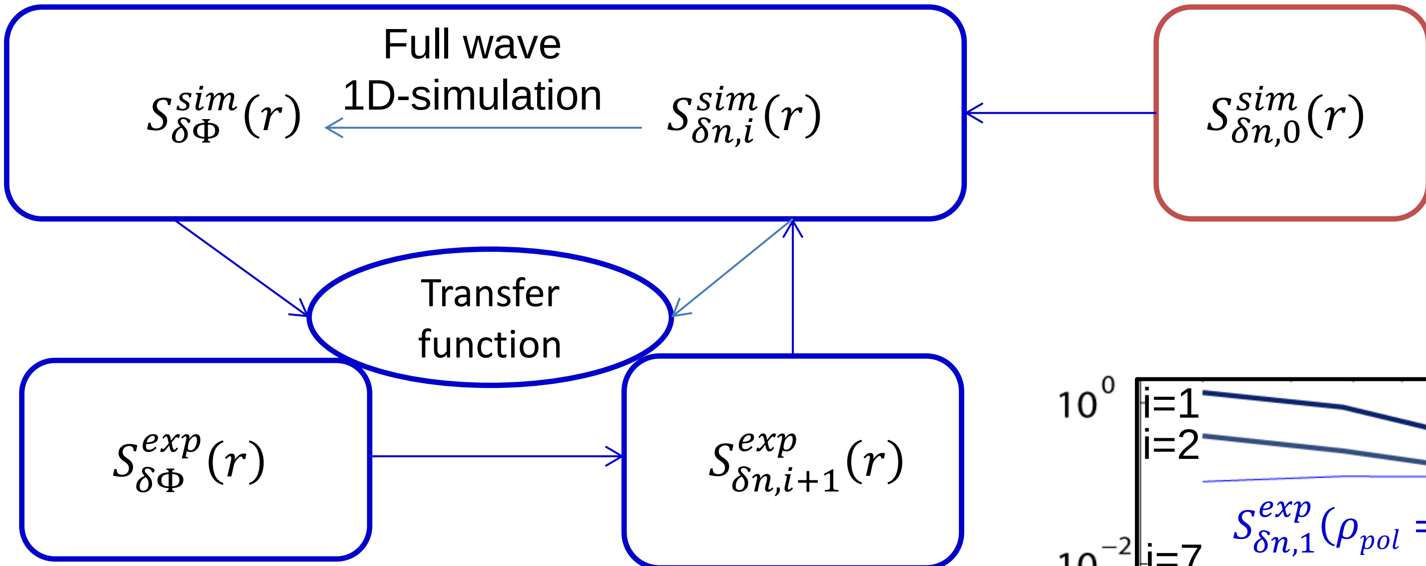
sweep time 1 μs < turbulence time scale

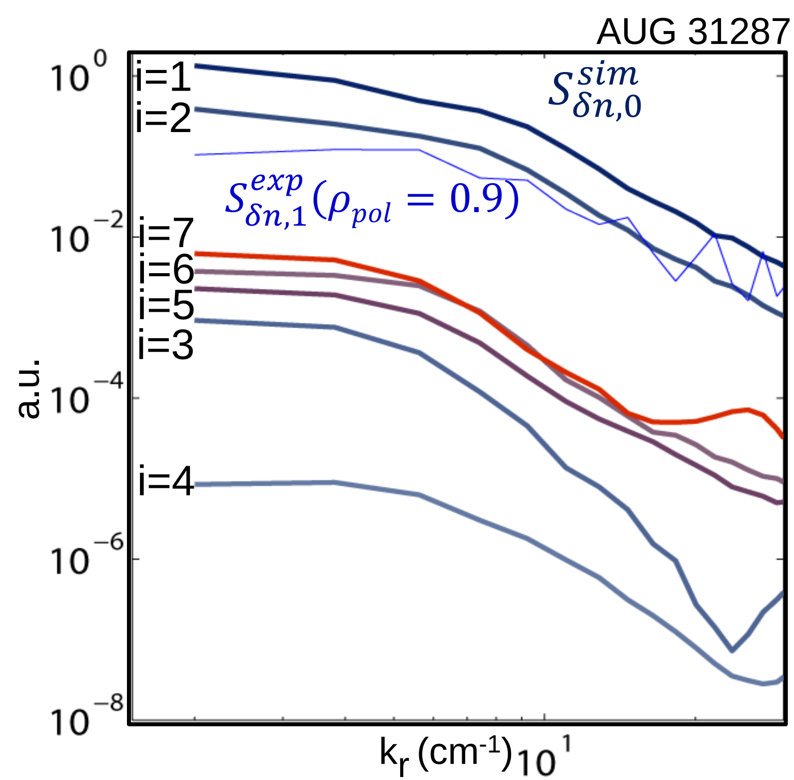
ULTRA-FAST SWEPT REFLECTOMETER : IMPROVING SWEEP TIME



sweep time 1 μs < turbulence time scale

DENSITY FLUCTUATIONS AND K-SPECTRA RECONSTRUCTION: CLOSED-LOOP METHOD





Signal phase fluctuations are induced by density fluctuations: $S_{\delta n}(k) = T(k) \cdot S_{\delta\Phi}(k)$

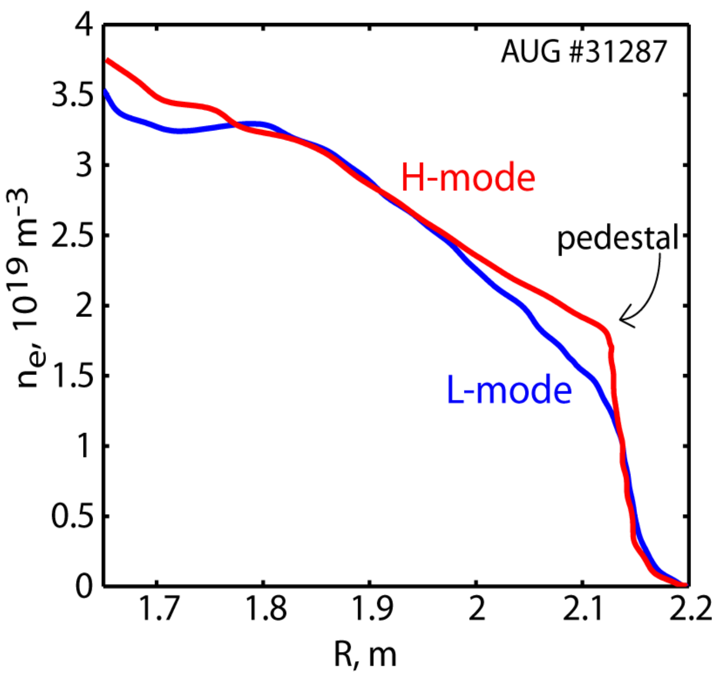
Density fluctuations level:

$$\left(\frac{\delta n}{n}\right)^2 = \frac{1}{k_{max} - k_{min}} \int_{k_{min}}^{k_{max}} S_{\delta n}(k)\, dk$$

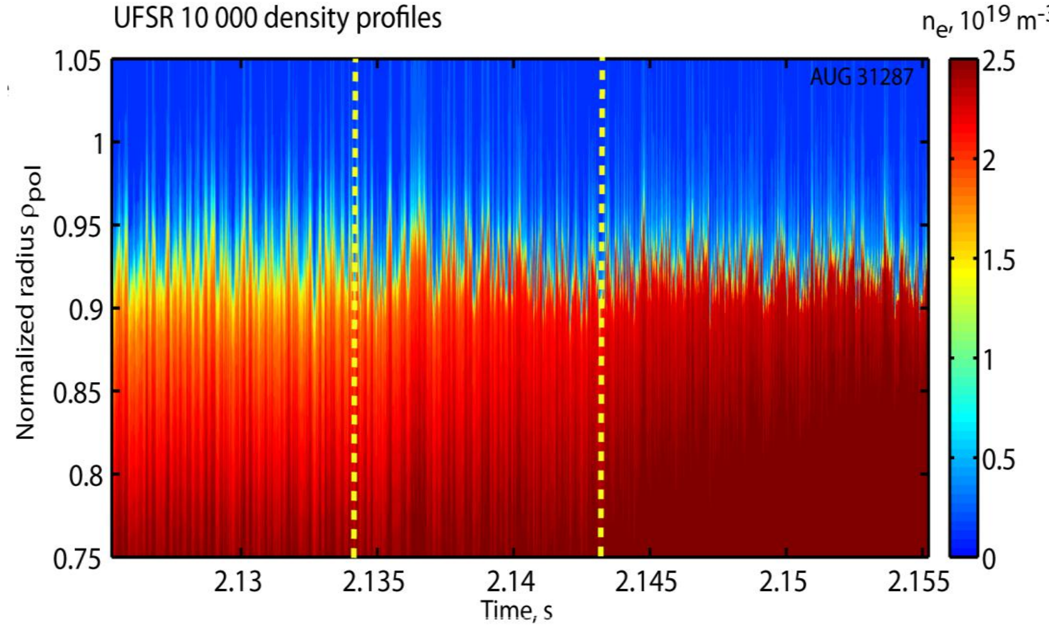
DENSITY DYNAMICS DURING L-H TRANSITION

- 2 MW Electron Cyclotron Resonance Heating → H-mode
- Edge pedestal forms (transport barrier)
- Edge plasma density and temperature gradients steepens

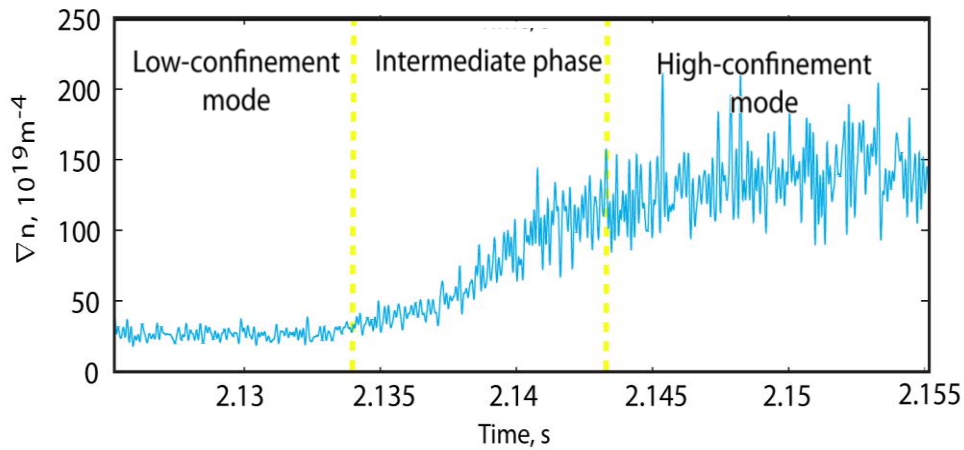
Density profiles @2.13 and 2.145s



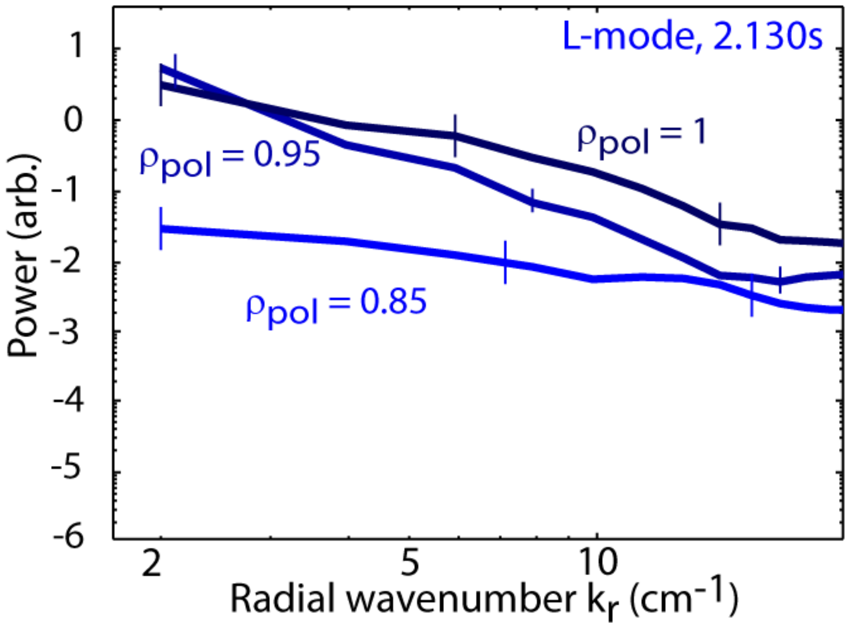
UFSR 10 000 density profiles

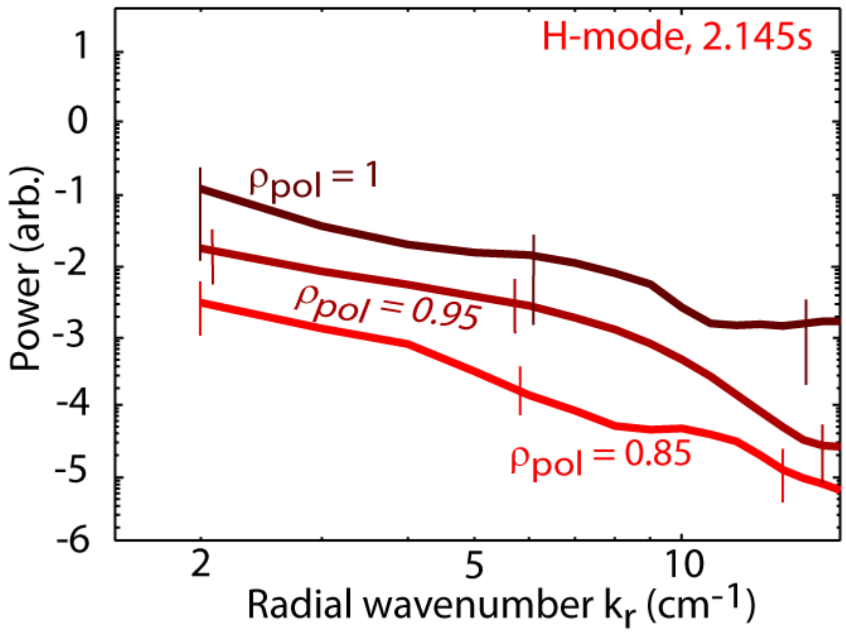


Pedestal density gradient



TURBULENT FLUCTUATIONS K_r –SPECTRA

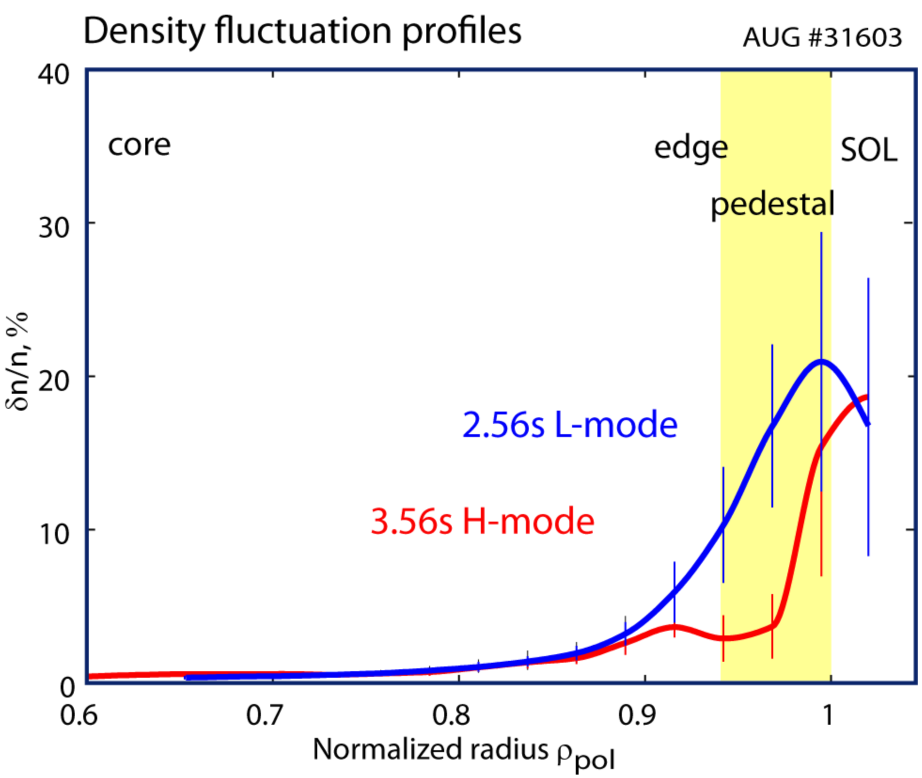


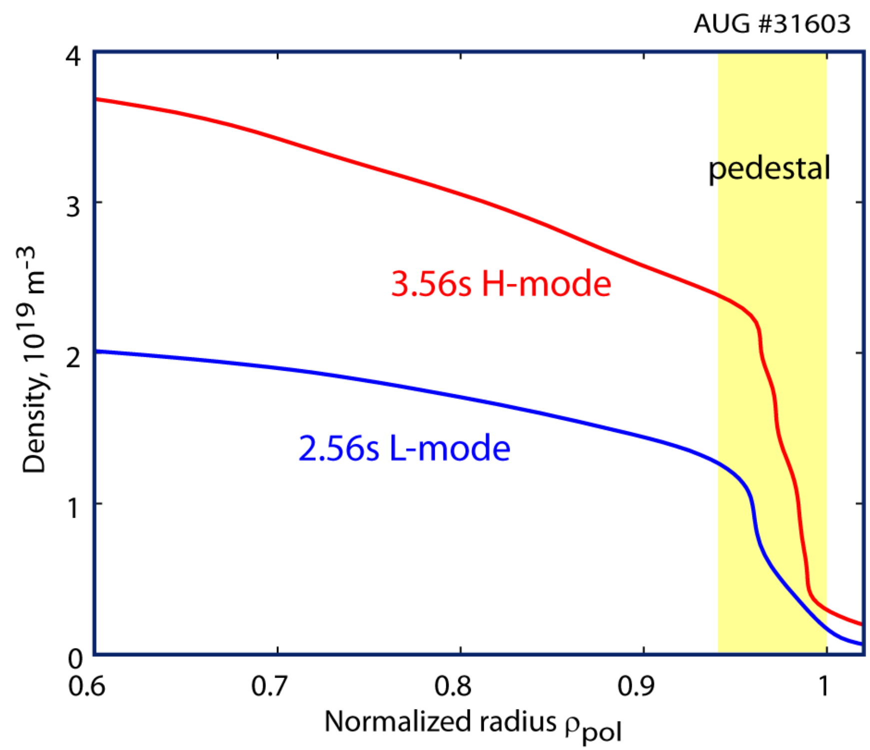


- After L-H transition large scale density fluctuations are suppressed in the pedestal region
- Turbulence level falls towards core

DENSITY FLUCTUATIONS AND K-SPECTRA DURING L-H TRANSITION

- UFSR allows to reconstruct density fluctuation profile from edge to plasma core
- Integrate k_r spectra (2 cm^{-1}< k_r < 20 cm-1) → δn/n
- 50 profiles for one density fluctuation profile (total 150 μs average)





- δn/n falls in pedestal region → transport barrier

CONCLUSION

- Diagnostic transferred from Tore Supra, CEA to ASDEX Upgrade and successfully commissioned

- First studies of the electron density profile dynamics, $\delta n/n$, k_r and ω spectra performed in 2014-2015

- Large scale density fluctuations decrease in pedestal region in H-mode

- Major diagnostic upgrade: improved resolution and better statistics
  - Sweep time: 2μs → 1μs
  - Profiles 12 000 → 200 000

- Outlook: experiments and data analysis for radial propagation, turbulence during ELMs and L-H transition study

ASDEX Upgrade

AMD

TECHNISCHE UNIVERSITÄT MÜNCHEN

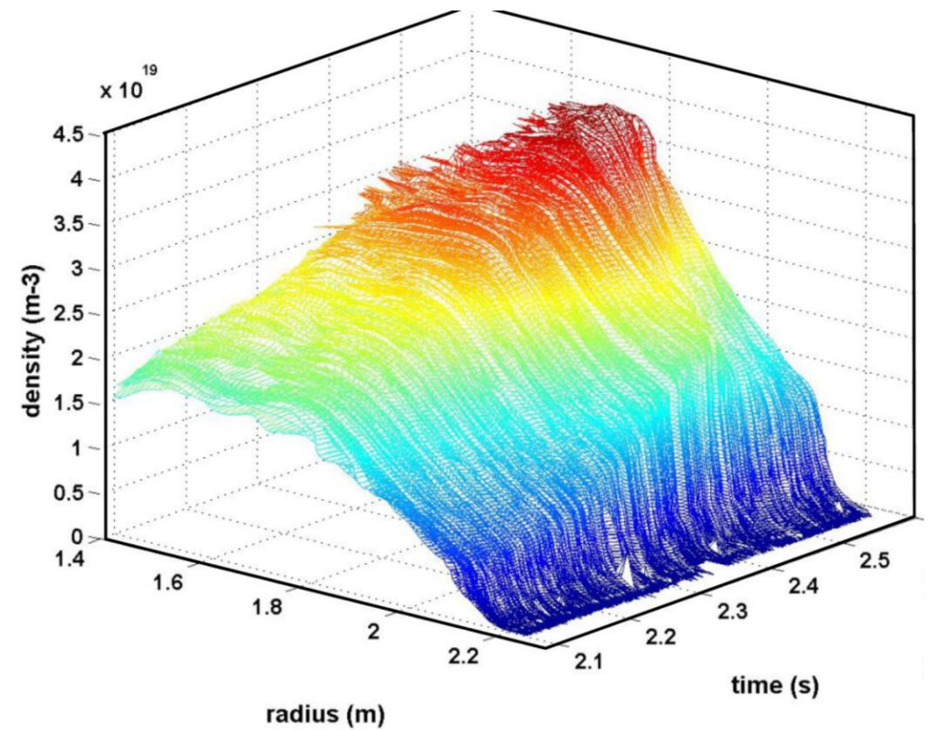
ERASMUS MUNDUS FUSION DC

UNIVERSITÉ DE LORRAINE

DE LA RECHERCHE À L'INDUSTRIE cea

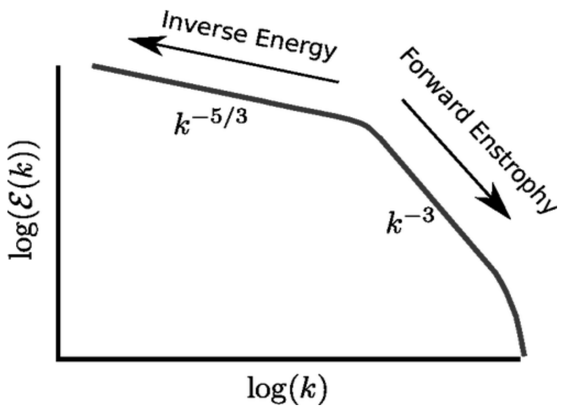
IPP

Thank you for your attention!



WAVENUMBER SPECTRA

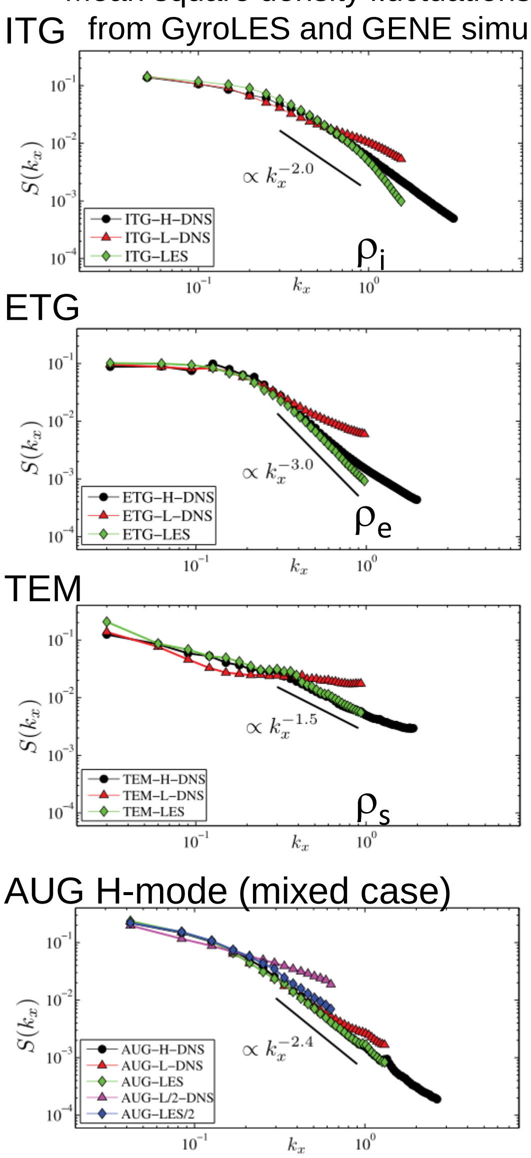
For 2D turbulence energy cascades both up and down the wavenumber k range: Kolmogorov/Kraichnan-type power spectrum



Forward transfer of enstrophy, and inverse transfer of energy in a 2D turbulence simulation

In reality different spectral slopes may be seen due to the anisotropy, modes coupling, Landau damping etc.

Mean square density fluctuations spectra from GyroLES and GENE simulations



[Bañón Navarro et al. Phys. Plasmas 21, 032304(2014)]

ρ_{pol}= 0.56

ASDEX Upgrade

ELECTRON DENSITY PROFILE RECONSTRUCTION

The cut-off position depends on n_e and B.
By sweeping the frequency (50-105 GHz), the probing position changes from the SOL to the core.