Radial electric field dynamics on ASDEX Upgrade and comparison with neoclassical theory

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and the ASDEX Upgrade Team

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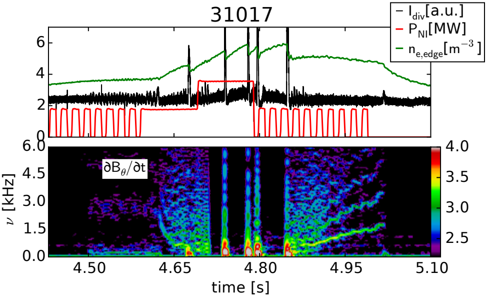
Motivations



- I-phase (dith. H-mode, . . .):
  - present at the L-H and H-L transitions
  - turbulence burts A_D correlated with magnetic signal $\dot{B}_\theta$
- L-I-L transitions:
  - repetitive L-mode to I-phase and back to L-mode transitions

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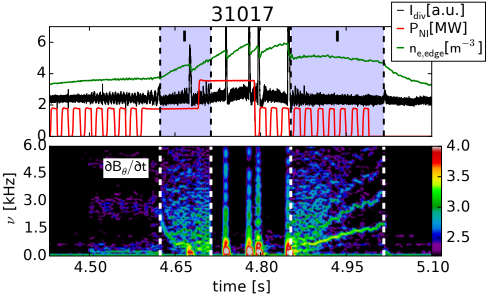

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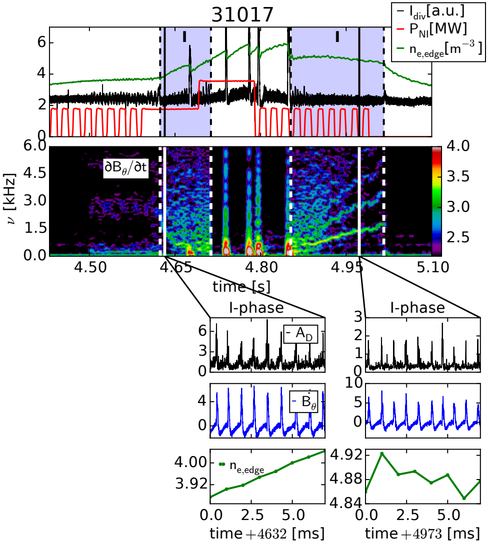

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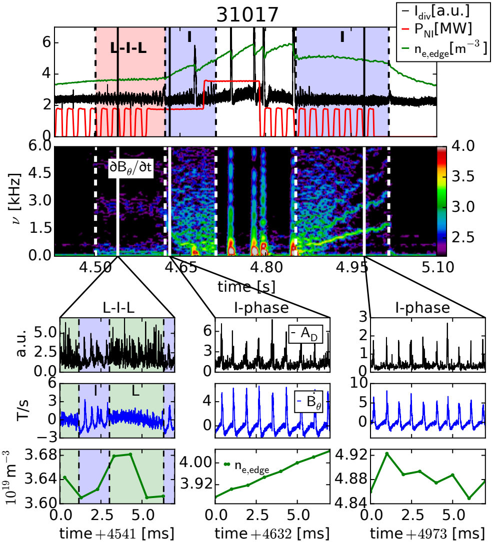

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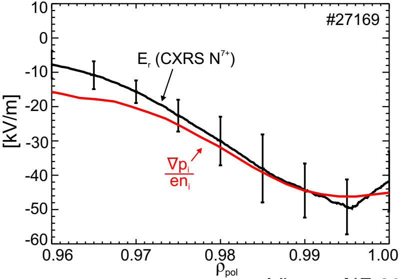
Outline

Nature of the radial electric field

Neoclassical theory predicts [Hinton 1976]:

$$E_{r,\mathrm{NEO}} \simeq \frac{\nabla(T_i n_i)}{e n_i} = v^i_{\mathrm{dia}} B,\ i = \text{main ions}$$

H-mode: $E_r \sim E_{r,\mathrm{NEO}}$ at the edge



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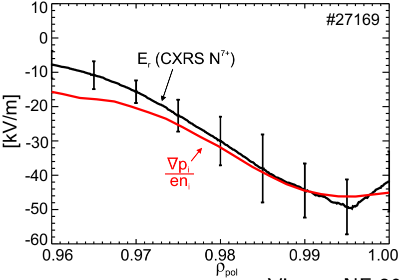

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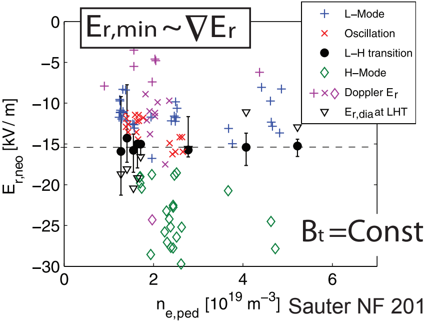
Correlation between H-mode onset and ion heat flux



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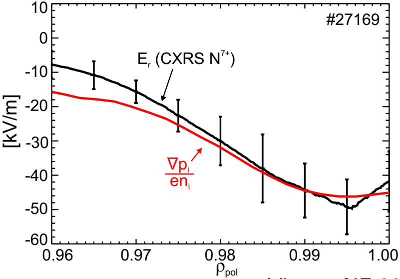

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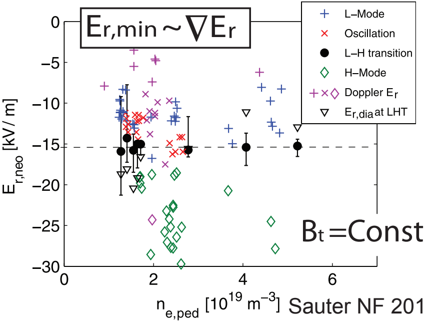

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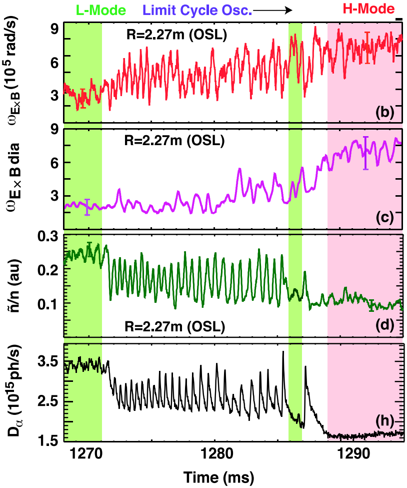
Importance of neoclassical E_r in L-H transition physics

Evidence of zonal flows in the DIII-D tokamak



Schmitz PRL 2012

$\omega_{\mathrm{E\times B}} \sim E_r$ (red) fluctuates with the same frequency as $\tilde{n}/n$ (green) but $\omega_{\mathrm{E\times B,dia}} \sim E_{r,\mathrm{NEO}}$ (purple) does not

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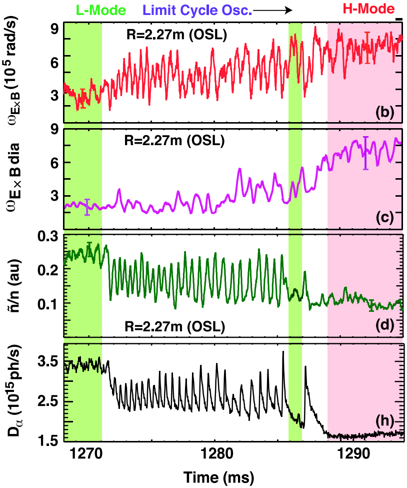

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Zonal Flows
(Self-induced turbulence shear)

Charge eXchange Recombination Spectroscopy

CX spectra contributions:

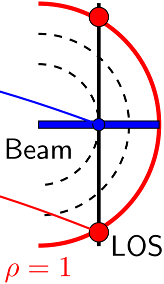
- Active:

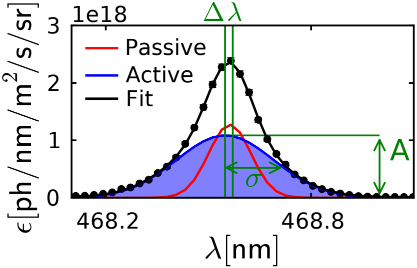
  $\mathcal{A}^{Z+} + D^0_{beam} \rightarrow \mathcal{A}^{(Z-1)+} + h\nu + D^+$

- Passive:

  $\mathcal{A}^{(Z-1)+} + e, i \rightarrow \mathcal{A}^{(Z-1)+} + h\nu + e, i$

  $\mathcal{A}^{Z+} + D^0_{thr} \rightarrow \mathcal{A}^{(Z-1)+} + D^+_{thr} + h\nu$



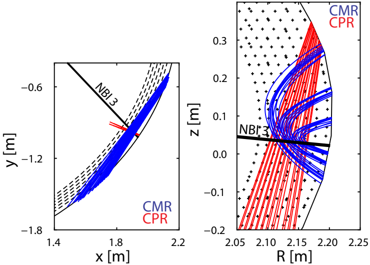


Localized measurements of:

- $\sigma \Rightarrow T_\alpha \sim T_i$
- $A \Rightarrow n_\alpha$
- $\Delta\lambda \Rightarrow v_\alpha$

$$\Rightarrow E_r = \frac{\nabla p_\alpha}{e Z_\alpha n_\alpha} - v_{p,\alpha} B_t + v_{t,\alpha} B_p$$

Upgrade of the edge charge exchange system



- 52 LOS (beam 3):
  CPR: 21 poloidal (1 head)
  CMR: 31 toroidal (3 heads)

- radial coverage and resolution:
  $R_{maj} \in [2.10, 2.16]$ m, $\Delta r \leq 5$mm

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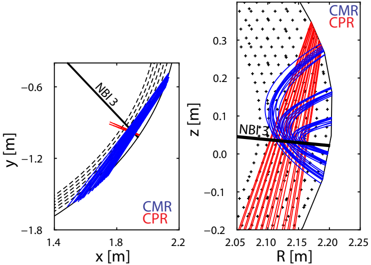

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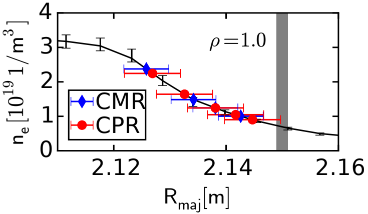
LOS setup of L-H transition studies



- temporal resolution:
  35 LOSs@2.3 ms, 9 LOSs@100 μs
  ⇒ impurity seeding
- timescales:
  - Radial force balance established on Alfven time ∼ 1 μs
  - Thermal equilibration time He-D*:∼ 30 μs
  - Thermal equilibration time D-D*:∼ 100 μs

$^{*}T_i = 100$ eV $n_i = 2.0 \times 10^{19}$ m^{-3}

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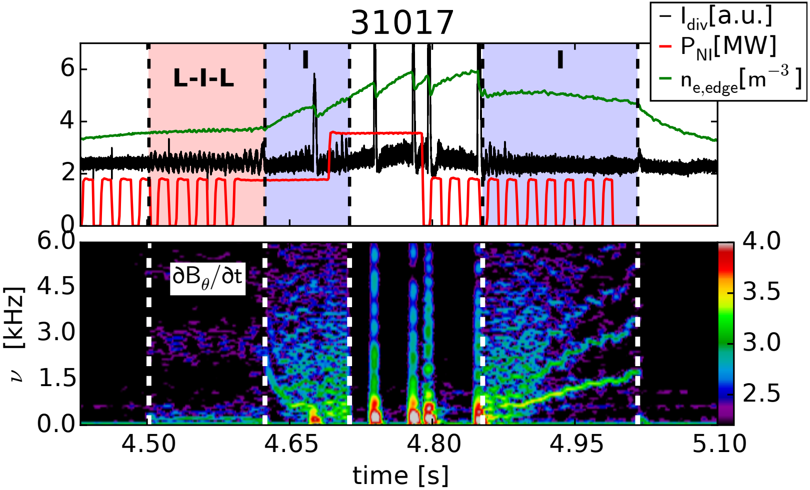
Strongest confinement change: the I-phase onset



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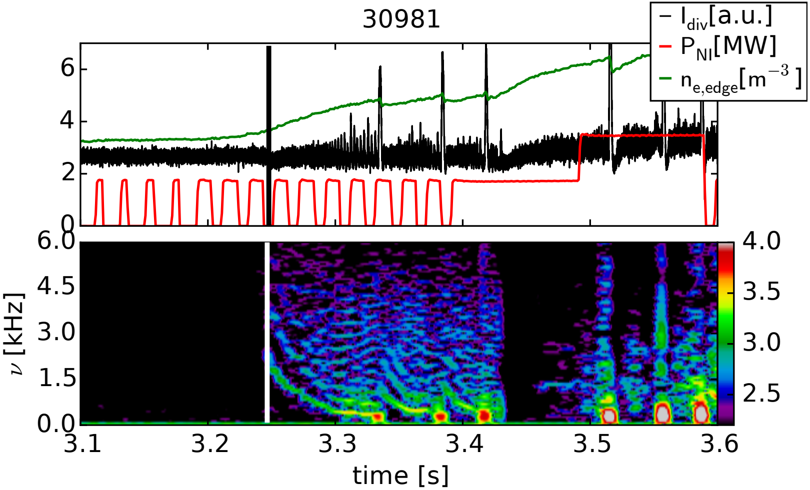

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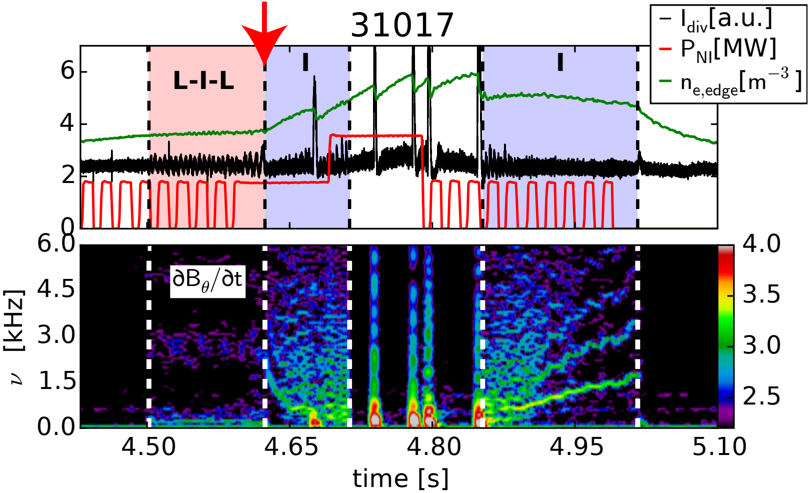
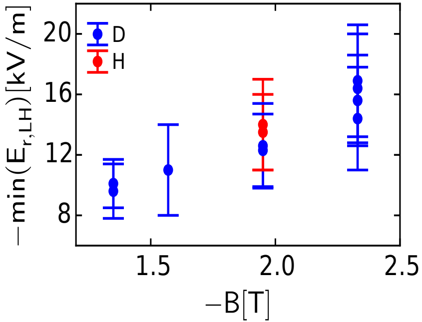


P_{thr} scan: B_t scan in D and H



- minimum of E_r ($\sim \nabla E_r$) scales at the L-H transition roughly linearly with B, coherent with P_{thr}
- H evaluations align with D
- Is this a threshold of $v_{E\times B}$ for the H-mode onset? It depends how edge turbulence changes with B

$$\min(v_{E\times B}) \sim \frac{dv_{E\times B}}{dr} \geq ?$$

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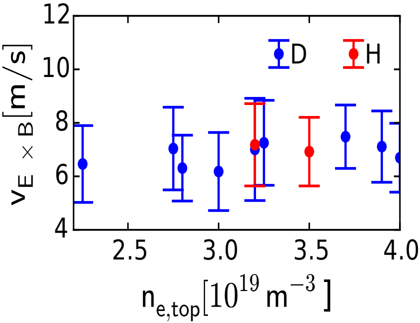

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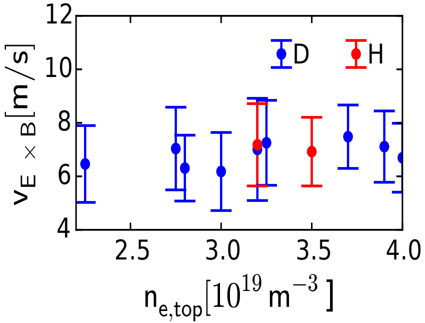

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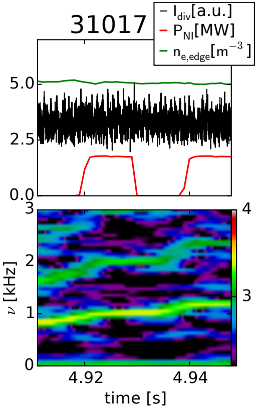

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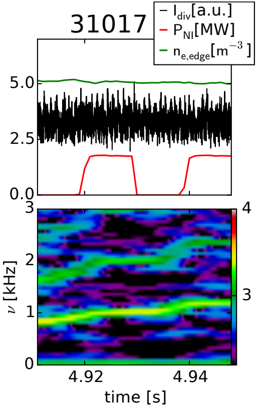

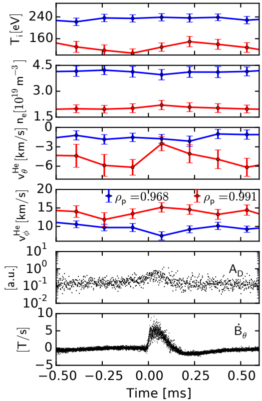

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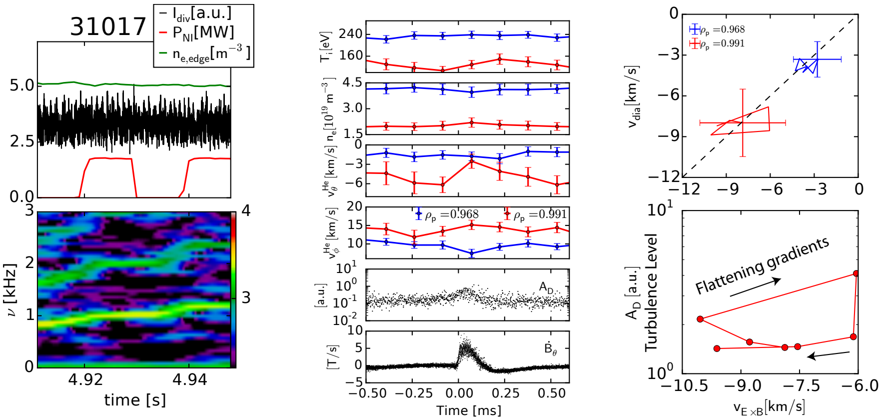

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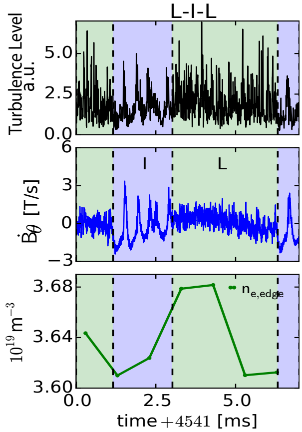

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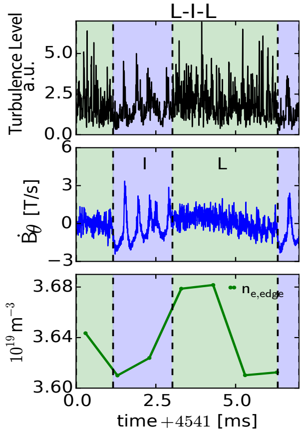

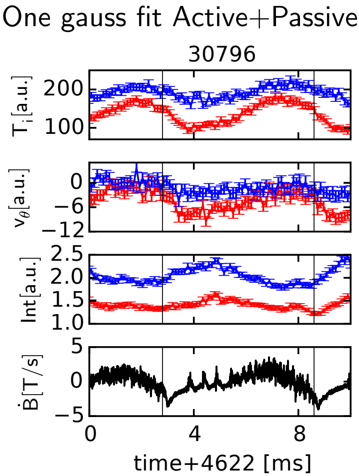

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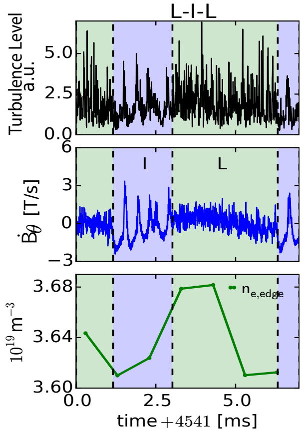

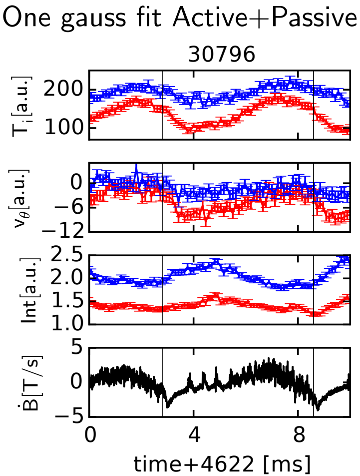

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Conclusions and Outlook

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  21 + 31 LOS in 6 cm with temporal resolution of 100 μs

- $\mathbf{\min(E_{r,LI}) \propto B}$ **in hydrogen and deuterium:**
  Critical $v_{E\times B}$ for the H-mode onset? $\nabla E_r \sim \min E_r$?

- **any change in** $\mathbf{v_{E\times B}}$ **is connected with** $\mathbf{v^i_{dia}}$ $\mathbf{(\nabla n_e, \nabla T_i)}$ **even at really short timescales (**$\sim$ **100** μ**s)**

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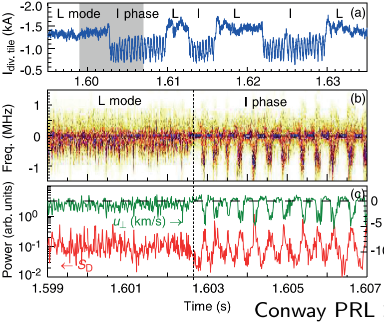
I-phase

Fluctuating phase of edge E_r and turbulence is observed in between L and H mode in different machines (in AUG is almost always there)

- dithering H-mode, I-phase, limit cycle oscillation, IM-mode, M-mode, ...
- periodic suppression of turbulence (1 k Hz-20 kHz) by fluctuating E_r $\Rightarrow$ playground for zonal flows



Conway PRL 2011

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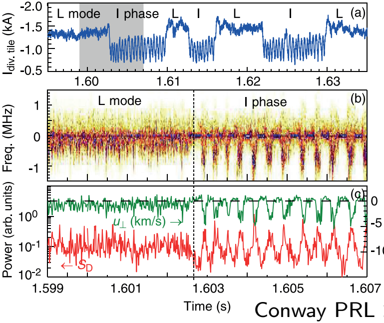
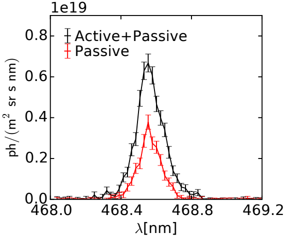


Conway PRL 2011

Compare neoclassical predictions of E_r with measurements to assess when and how much do turbulence unduced flows do contribute to the total $v_{E\times B}$

Passive spectra of He^{1+}

$E_i(\mathrm{He}^{1+} \rightarrow \mathrm{He}^{2+}) \sim 54.4\,\mathrm{eV} \Rightarrow$ passive emissivity extends inside confined plasma



- strong contribution from passive to spectra at plasma edge
- passive changes on fast timescales

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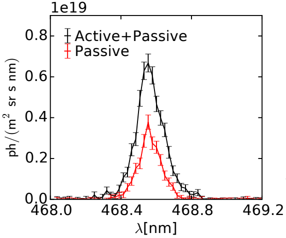

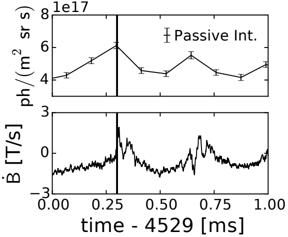

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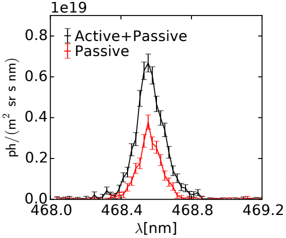

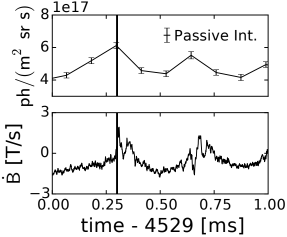

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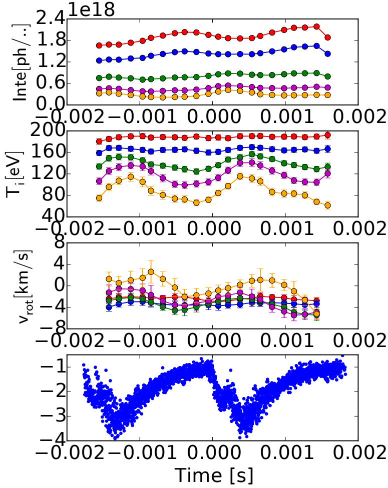
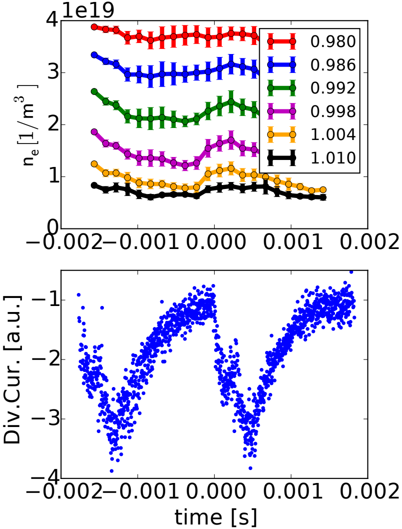
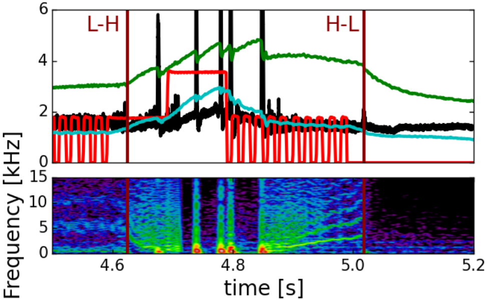
Conditional synchronization and subtraction of passive spectra necessary to extract active informations

Time traces during fast fluctuations 31018



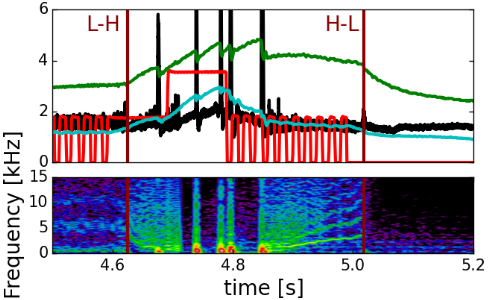


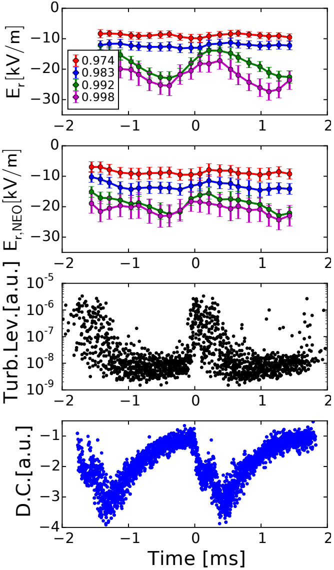
Experiments



- fluctuations live in between ELMs and end before the H-L transition ⇒ H-mode!
- $E_r \sim E_{r,\text{NEO}}$: turbulence induced flow shear seems not to play a role in this phase

Experiments





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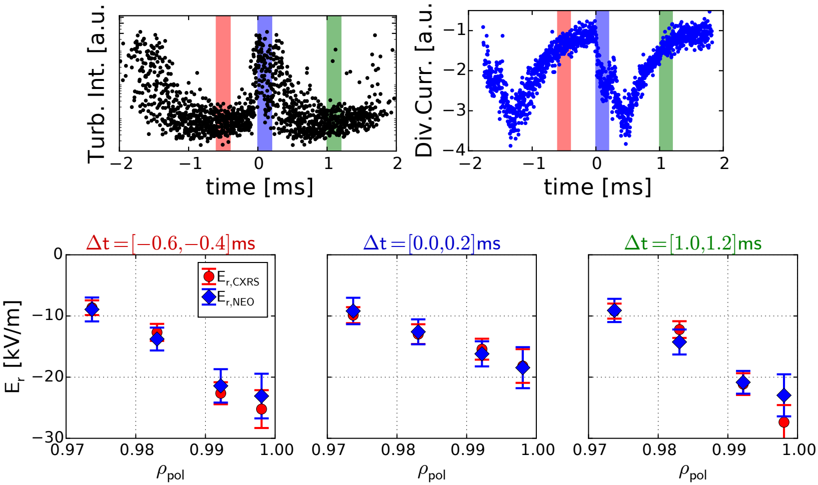
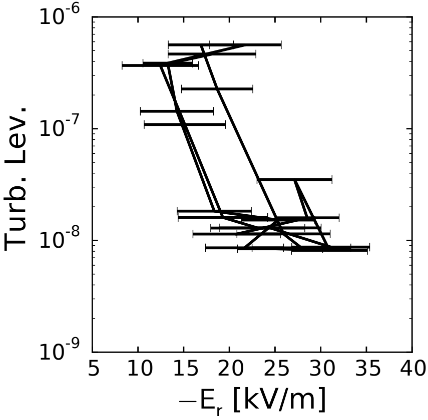
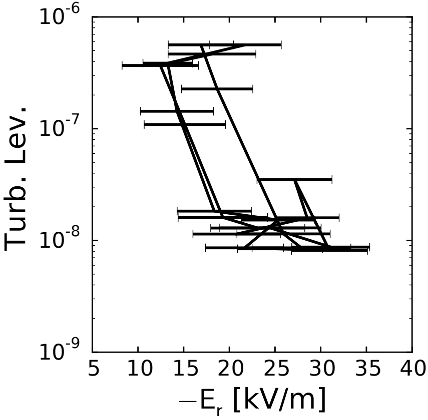
I-phase: H-L transition

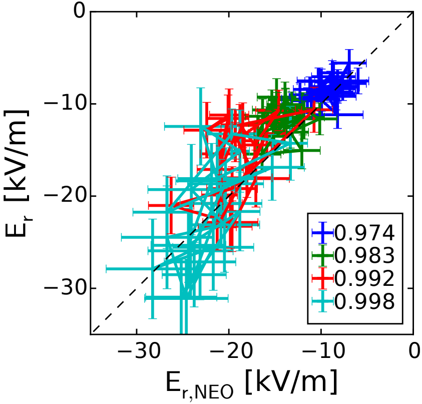


Limit cycle oscillation?



Limit cycle oscillation?





0-D model of P_{thr}

$$P_{thr} = n_e^{0.7} B_T^{0.8} S^{0.9}$$

- if $E_r = E_{r,\mathrm{NEO}} \Rightarrow P_{thr}$ has to be thought in function of the ions (Ryter) $\Rightarrow$ explanation for the minimum
- linear dependence on $n_e \Rightarrow$ number of particles to heat
- $\dfrac{dv_{E\times B}}{dr} > \omega_* \eta \sim k_y \rho_i \dfrac{v_{th}}{R} \dfrac{R}{L_T}$
  where $k_y \rho_i$ is a constant at the edge
- $E_{r,\mathrm{NEO}} \sim \nabla T_i + T_i \dfrac{n_e}{n_e}$