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The Physics of Electron Internal Transport

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Introduction

Background

- Electron internal transport barriers obtained in TCV in a variety of conditions:
  - Fully noninductive (hollow current profile sustained by off-axis ECCD + bootstrap) (depending on conditions it may evolve to true steady state, several current redistribution times and hundreds of confinement times long)
- Nearly noninductive (small Ohmic perturbation)
- Inductive (comparable Ohmic and ECCD components, can be stationary)
- Transient (pure heating in current ramps)

Main results

- Confinement improvement over L-mode H_{RLW} = 3-6
- Bootstrap current fraction above 70%, up to 90% transiently
- Barriers both in the electron temperature and density profiles, with fixed ratio between logarithmic gradients
- Current profile plays the dominant role: reversed shear is essential
- No dependence observed on rational safety factor values
- Interplay with MHD leads to slow confinement oscillations in some conditions

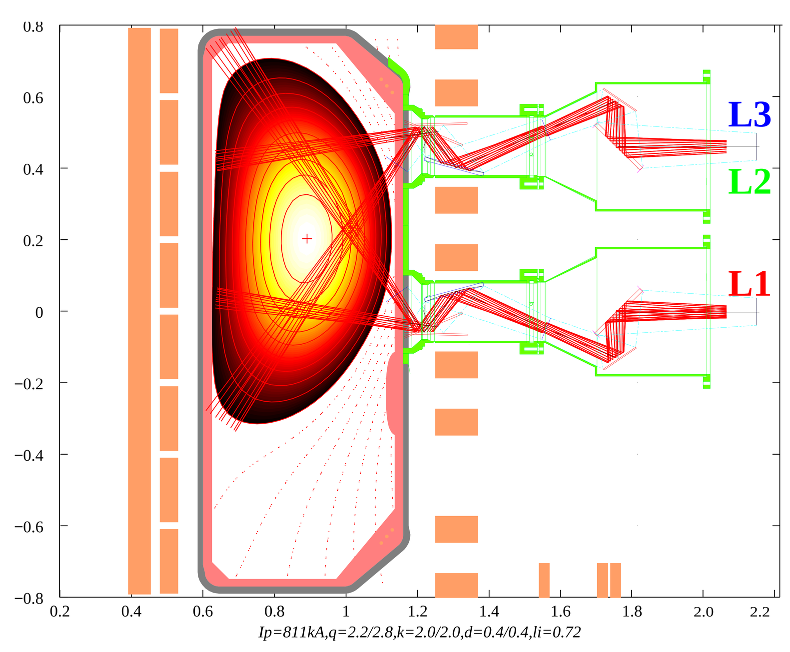
Experimental setup

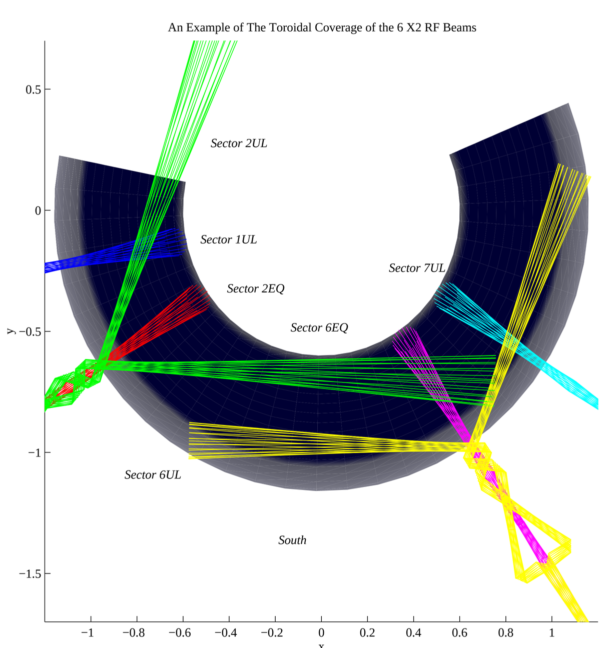
The TCV tokamak

- Elongated vessel (R=0.88 m, a=0.25 m, κ=3, I_p< 1 MA, B_T< 1.54 T)
- Variable plasma shape and position

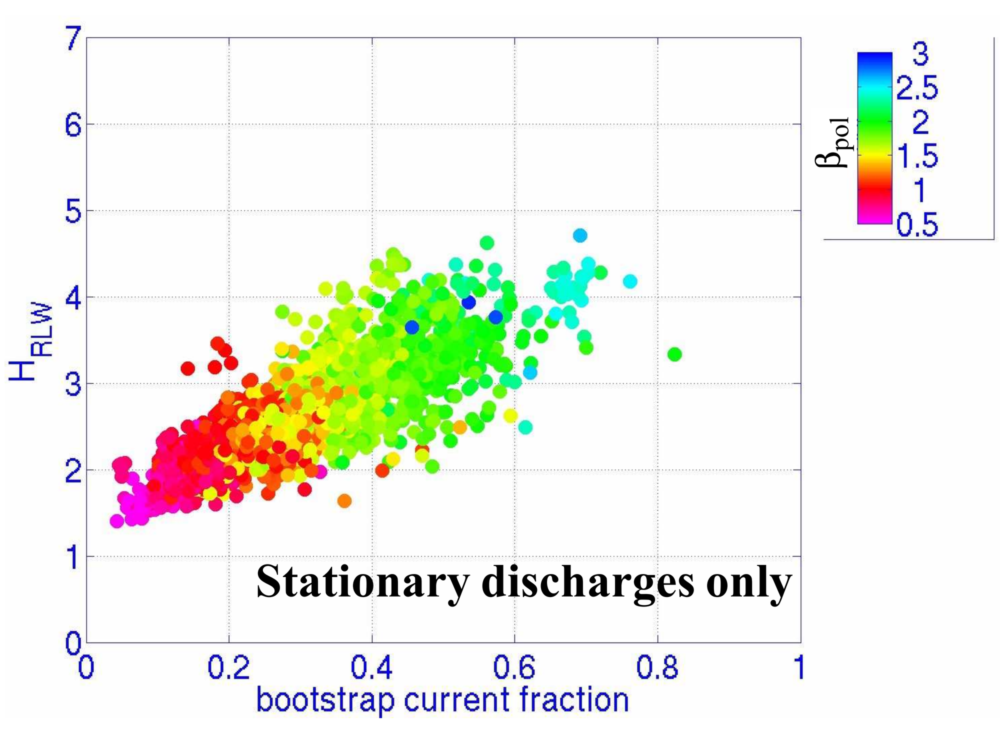
X2 ECH/ECCD system

- Six 0.5 MW gyrotrons at 82.7 GHz in X-mode (X2)
- Independently steerable poloidal and toroidal mirrors



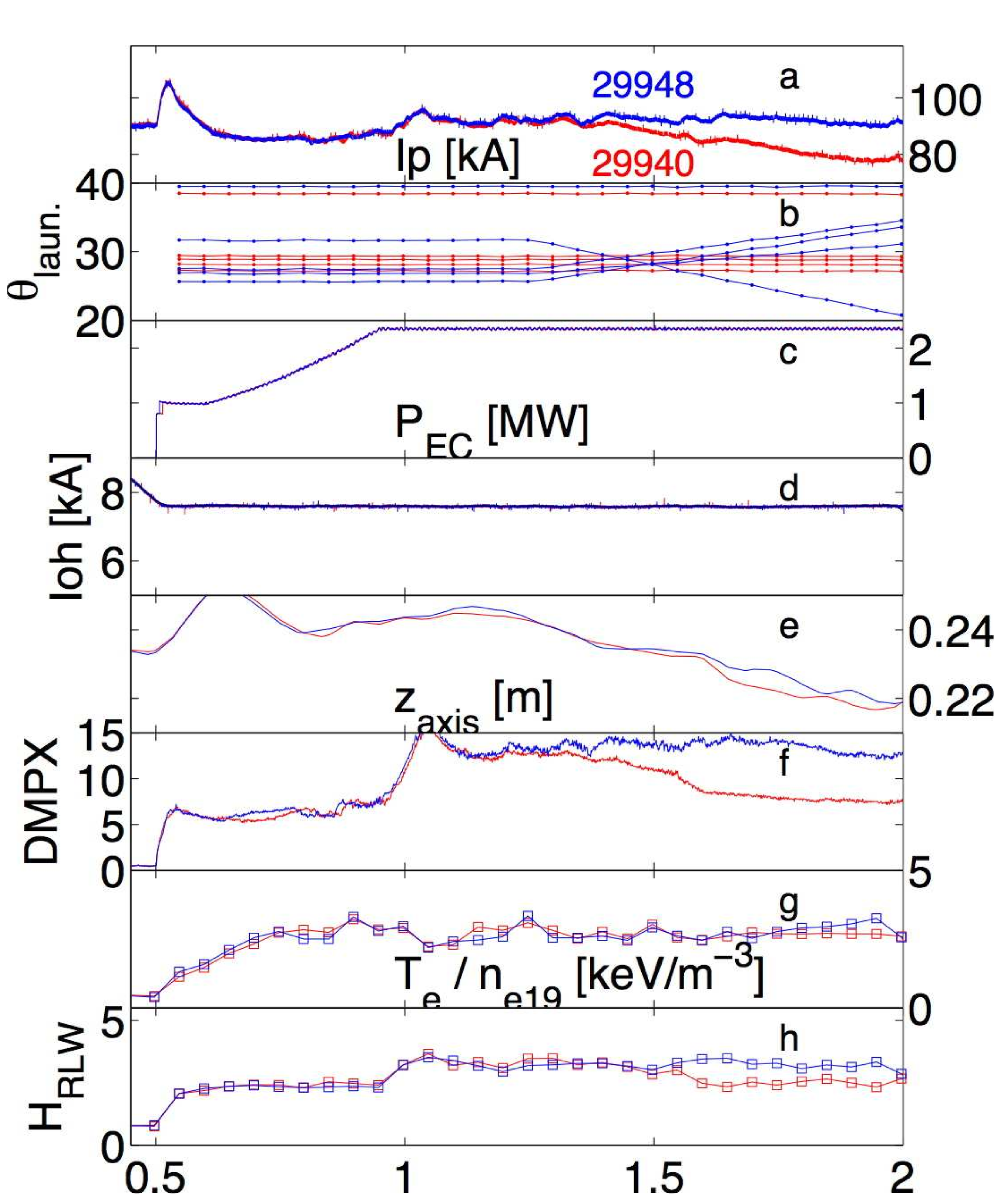


Performance



Bootstrap fraction up to 90% and H factor up to 6 transiently

Control



Open-loop eITB control

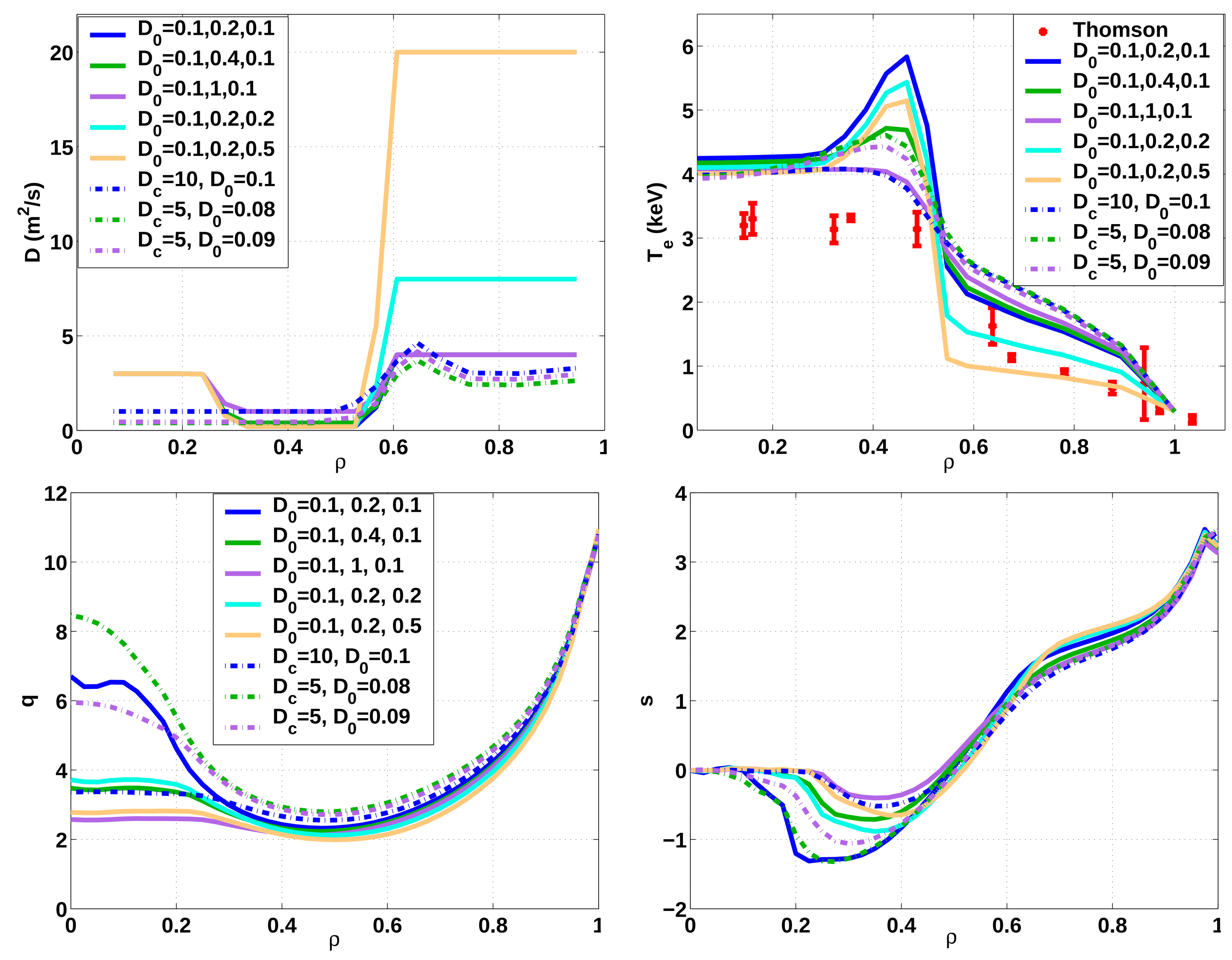
- Plasma shifted vertically (to improve effective resolution of Thomson scattering), tracked by ECRH beams: eITB maintained
- Control case: no tracking, eITB lost

The role of the current profile

Determination of the current profile

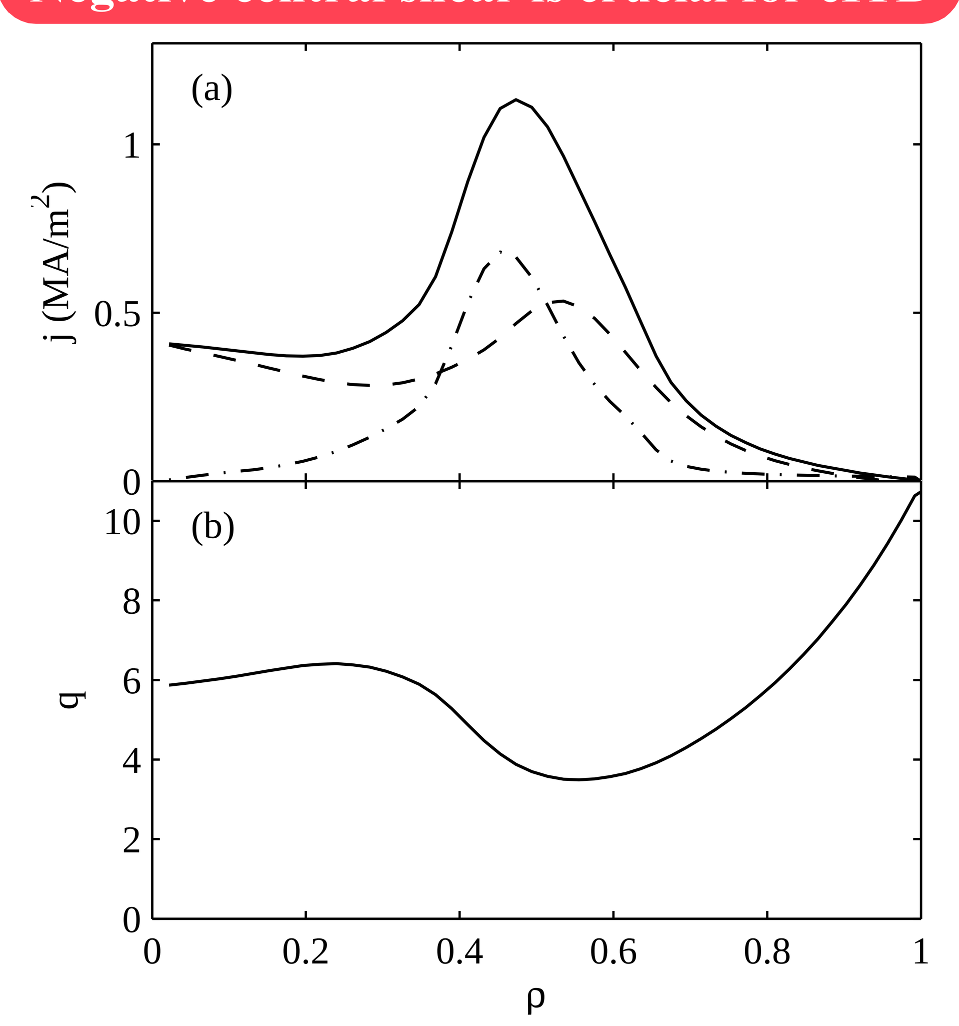
- No current density measurement on TCV: we must rely on modeling
  - CQL3D (Fokker-Planck) for ECCD current profile
    - The radial diffusivity is crucial in determining the current profile broadening and the overall current
    - The diffusivity is constrained by the total ECCD current (plasma current minus bootstrap and Ohmic currents)
  - ASTRA in diagnostic mode, with constrained total current and constrained pressure profiles, to obtain the current profile and the equilibrium consistently
- How to set the electron diffusivity?
  - Assume that the particle diffusivity is proportional to the energy diffusivity (power balance). This still leaves an extra free parameter, i.e. the core diffusivity which is not measurable owing to small power deposition there
  - Alternatively, use a piecewise constant diffusivity in 3 regions: barrier, inside, outside. The density is fixed, we must then match the electron temperature profile

Sensitivity study: effect of particle diffusivity on q profile



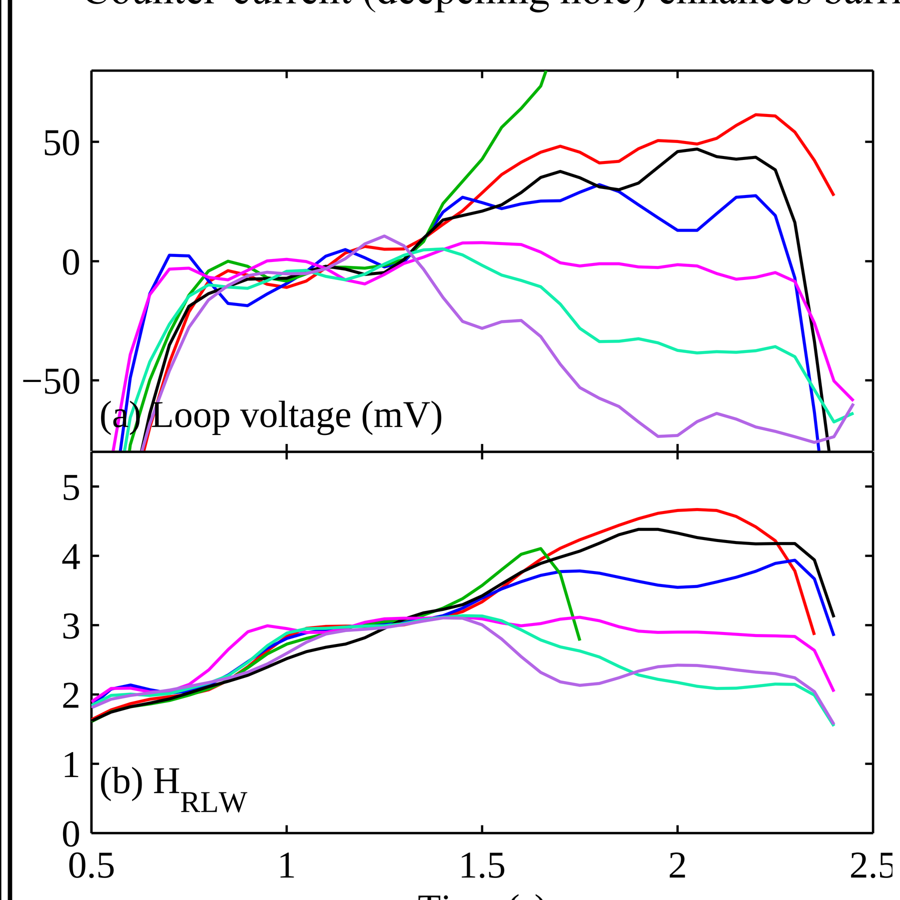
- Very robust for ρ > 0.4
- Small variance of the shear inside the barrier (could be significant for theoretical models)

Negative central shear is crucial for eITB



Demonstration by Ohmic perturbation

- Very high efficiency compared to ECCD
- ⇨ pure current injection with negligible energy transfer (3 kW)
- Small loop voltage (-90 to +60 mV)
  - ⇨ dramatic effect on confinement
  - Co-current (NB negative voltage!) degrades barrier
  - Counter-current (deepening hole) enhances barrier



More controlled version of previous experiment with varying central ECCD: effects of counter-Ohmic and counter-ECCD are comparable.