**Introduction**

- 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)

**Background**

- Confinement improvement over L-mode $H_{\text{LW}} = 3.6$
- Bootstrap current fraction above 70%, up to 90% transiently
- Barriers both in the electron temperature and density profiles, with fixed ratio logarithmic
- 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

**Main results**

- Determination of the current profile
  - No current density measurement on TCV: we must rely on modeling
  - $q_{95}$-3D (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 diagonal mode, with constrained total current and constrained pressure profiles, to obtain the current profile and the equilibrium consistently
  - How to set the electron diffusivity?

- Assumption 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

**Experimental setup**

- **The TCV tokamak**
  - Elongated vessel ($R=0.88 \text{ m}, a=0.25 \text{ m}, x=3, I_p = 1 \text{ MA}, B_r = 1.54 \text{ T}$)
  - Variable plasma shape and position
  - Six 0.5 MW gyrotrons at 82.7 GHz in X-mode (X2)
  - Independently steerable poloidal and toroidal mirrors

**X2 ECH/ECCD system**

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

**Performance**

- Stationary discharges only

**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

**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 (NH 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.