Turbulent Particle Transport in Tore Supra

G.T. Hoang, J.F. Artaud, C. Bourdelle, X. Garbet
and the Tore Supra Team

Association Euratom-CEA
CADARACHE

Particle transport key issue for fusion plasmas

Density profile plays important role in plasma performance

Peaked density profile can

- Reduce heat transport → good confinement
- Increase Fusion Power & Bootstrap current required for continuous operation in ITER

Particle transport study significantly progress

- Peaked density profile due to anomalous pinch in steady-state on TCV & Tore Supra *G.T. Hoang PRL **90** (2003), Zabolotsky, PPCF **45** (2003)*
- Experiments & Turbulent simulations intensively investigated for understanding the parametric dependence

  *e.g., X. Garbet PRL **91** (2003), C. Angioni PoP **10** (2003)*

General model of particle flux

collisional transport

$$\Gamma = -Dn\left[\nabla n/n + C_q\,\nabla q/q - C_T\,\nabla T_e/T_e\right] + V_{neo}n$$

Anomalous diffusion — **Curvature Pinch** — **Thermodiffusion pinch** — **Neoclassical pinch ~ V_{Ware} ($\propto E_\phi$)**

Complex coupling q, T_e and E_ϕ in inductive plasmas

$\rightarrow$ quite impossible to discriminate among these terms

Ideal conditions are now met in Tore Supra plasmas

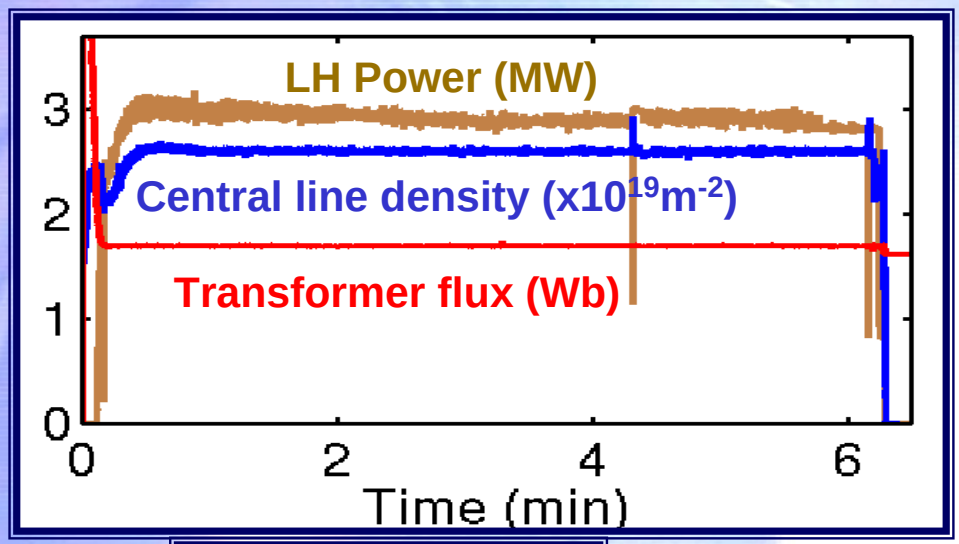
- ✓ No central fuelling (Lower Hybrid Current Drive)
- ✓ Maintaining $V_{Ware} = 0$ for up to 6 min.

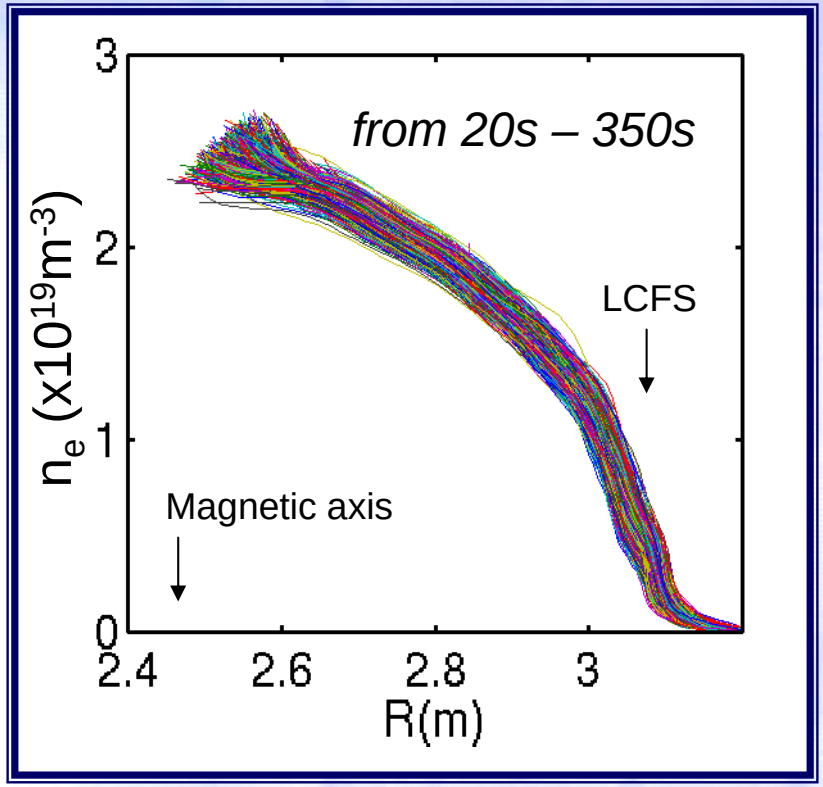
$V_{neo} \sim 0$, hence: $\nabla n/n = - C_q\,\nabla q/q + C_T\,\nabla T_e/T_e$

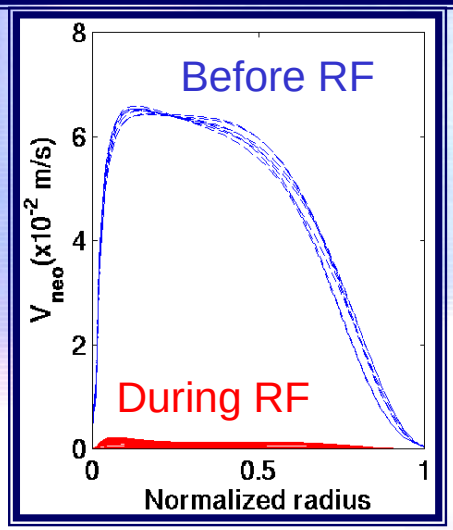
- ✓ Accurate density profiles provided by powerful reflectometry

See R. Sabot EX/P6-25

Peaked density profile in absence of Ware pinch over 6 minutes







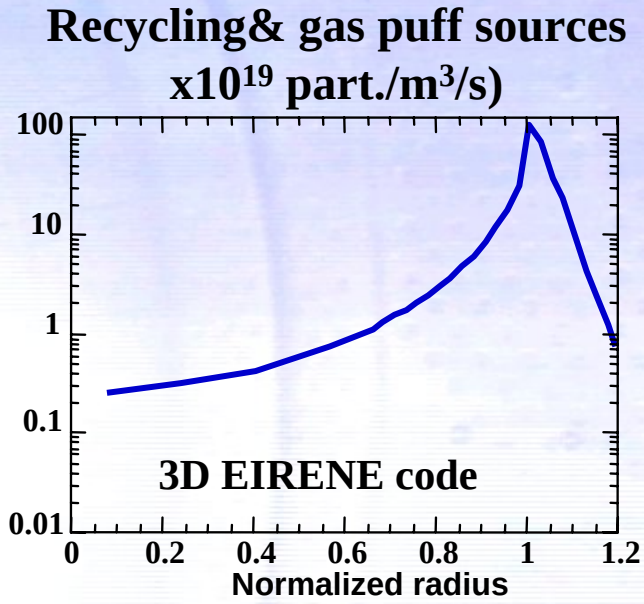
Neoclassical pinch including impurities (NCLASS)

V_{neo} ~10^{-3} m/s cannot explain peaked n_e profile

Peaked profile due to anomalous pinch

Central source?

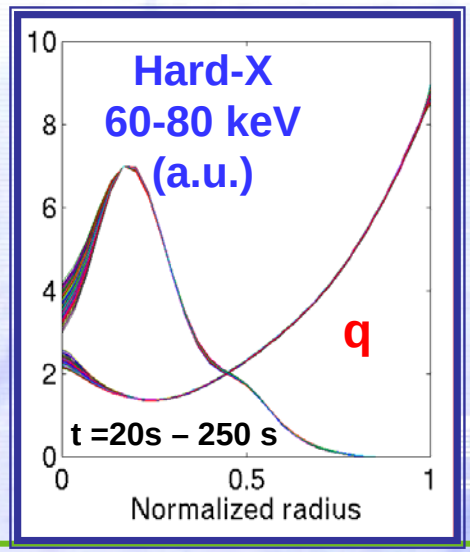
- Same observation in D and H plasmas, i.e. different neutral sources
- Total ionized D from recycling & fuelling < 1% within r/a ~ 0.6
- Negligible impurity ($Z_{eff} \leq 2$)



Detrapping of suprathermal electrons generated by LH waves?

Not by collisions (50keV – 175keV)

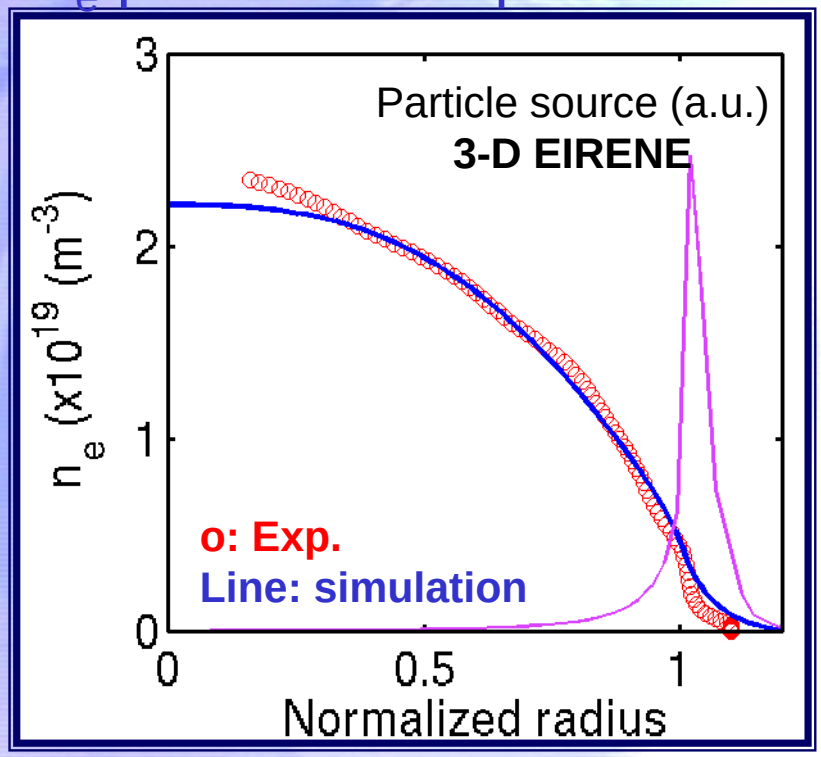
Need V ~ 100 km/s when taking into account ripple loss

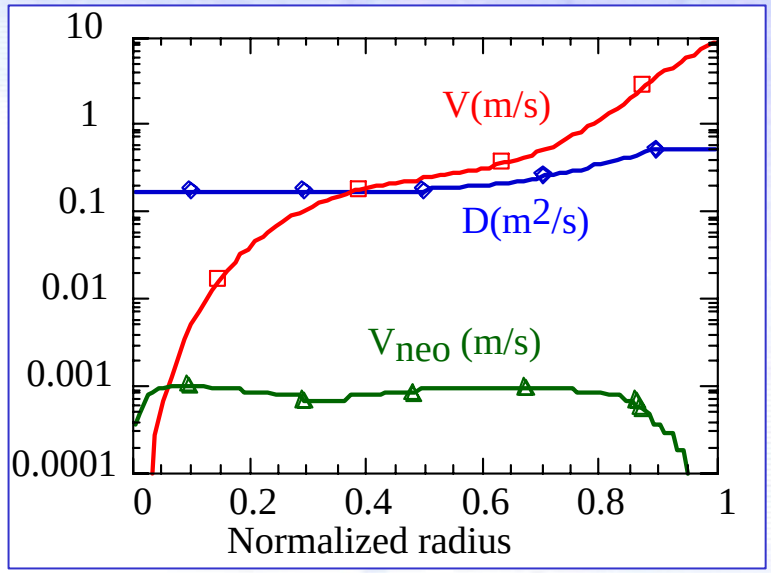


Suprathermal < 0.1 % thermalpopulation

1-D simulation

n_e profile well reproduced



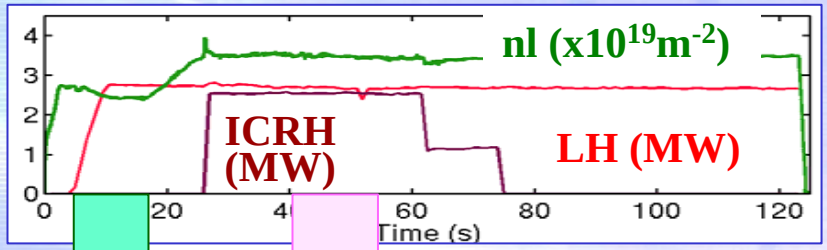


D value during OH phase (under estimated)

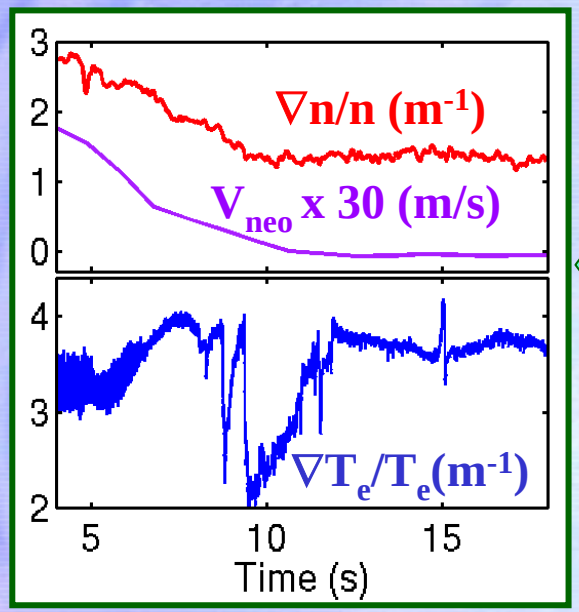
V_{neo} mainly the impurity contribution (NCLASS)

Need a pinch velocity two orders of magnitude higher than neoclassical value (0.1 –10 m/s for r/a > 0.2)

Parametric dependence study requires long discharges

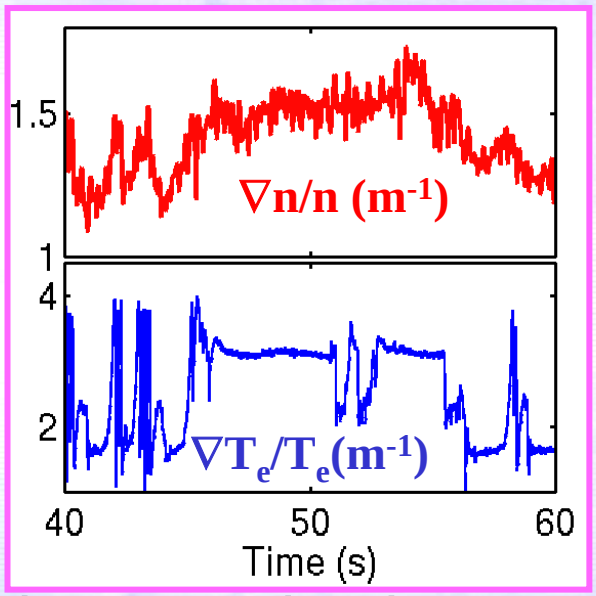


@ r/a =0.3, $\nabla q/q \sim 3.8\ (m^{-1})$



Flattening of n when vanishing Ware pinch decreases

@ r/a =0.3
$\nabla q/q \sim 3.8\ (m^{-1})$
$V_{neo} \sim 10^{-3}$ m/s

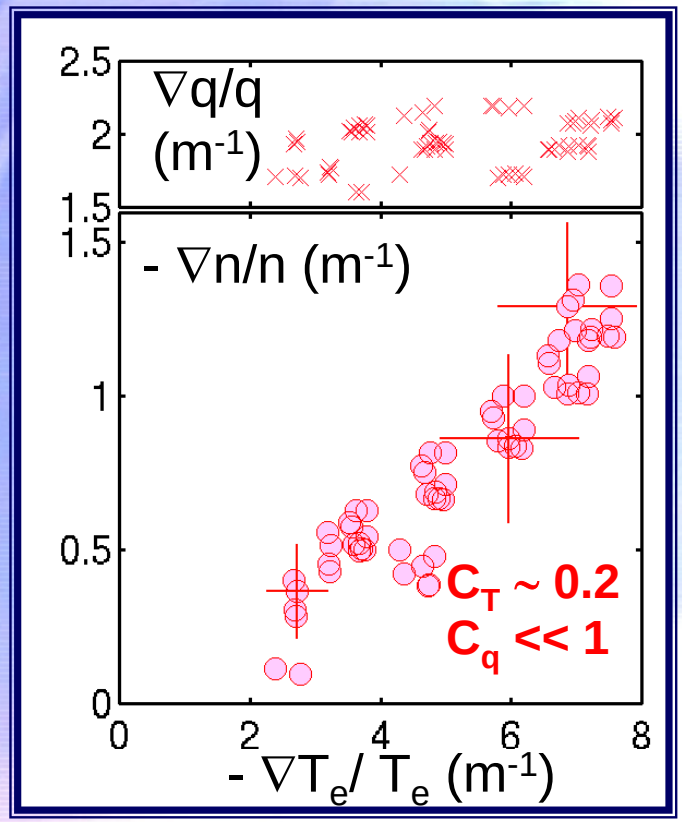


Weak correlation between $\nabla n/n$ and $\nabla T_e/T_e$

Small thermodiffusion pinch can only be identified when $V_{Ware} = 0$

Turbulent pinches in the plasma center r/a < 0.3

$$\nabla n/n = - C_q \nabla q/q + C_T \nabla T_e/T_e$$

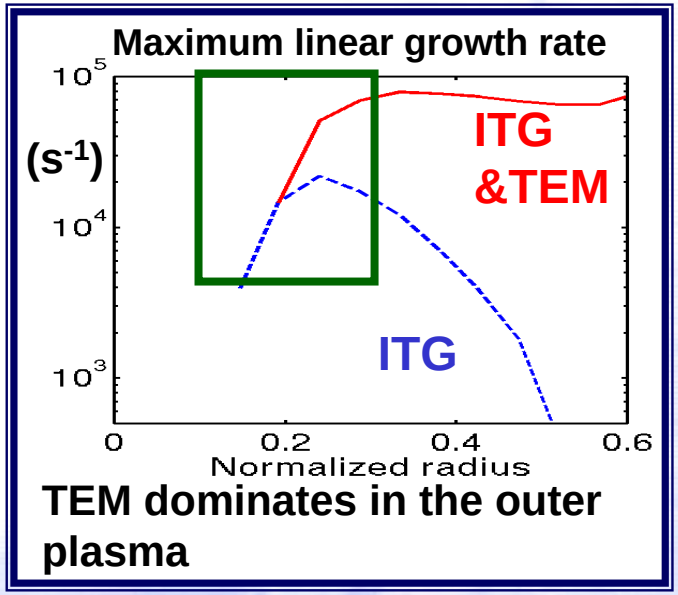


From a set of 7 discharges
$T_e(0)$ = 4- 8keV; q_{edge} = 8.9-14

Inward thermodiffusion

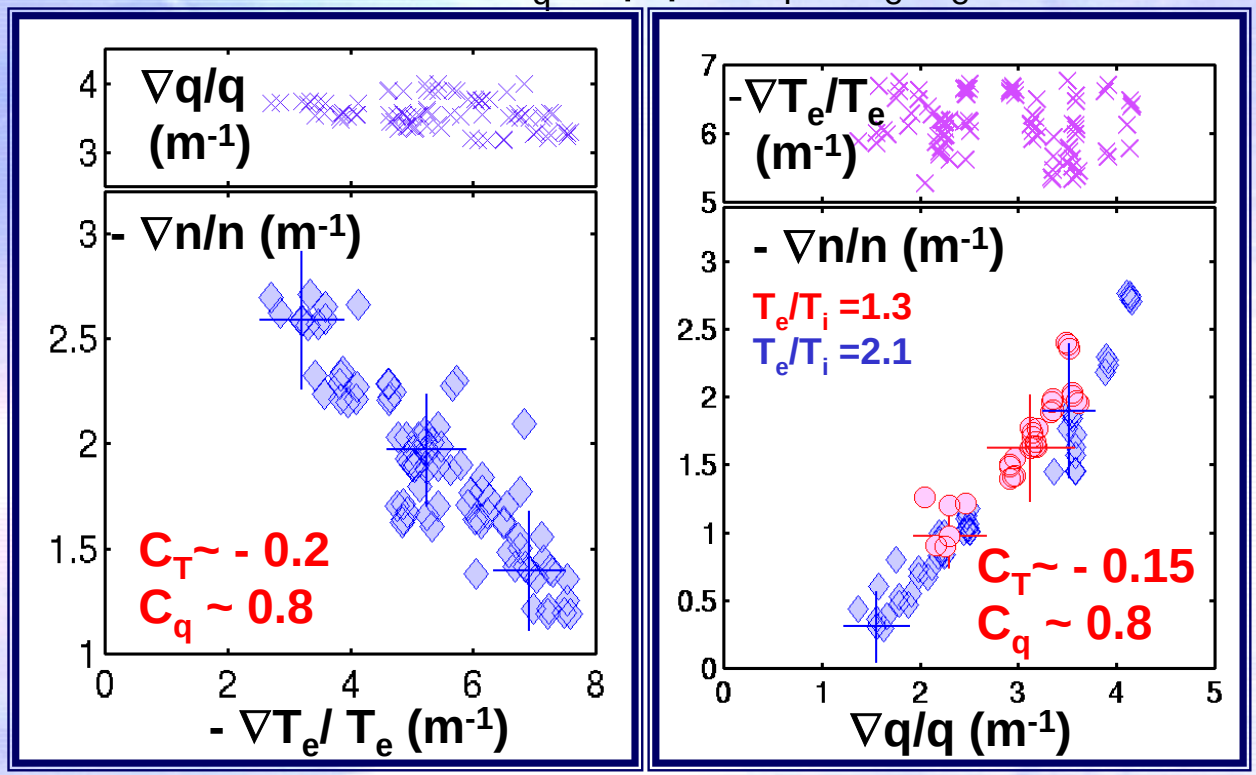
Curvature pinch quite negligible

correlated with dominant ITG



Turbulent pinches when TEMs dominate ($0.3 \leq r/a \leq 0.6$)

$$\nabla n/n = - C_q \nabla q/q + C_T \nabla T_e/T_e$$



Outward thermodiffusion dominated by curvature pinch ($C_q \sim 0.8$, $C_T \sim - 0.2$) $\rightarrow$ n_e governed by q-profile

Larger outward thermodiffusion predicted by turbulent simulations! Garbet et al, PRL **91**, 035001 (2003)

Density profile varies likely as $1./q^{0.5}$

Empirical model $\nabla n/n = -0.5\, \nabla q/q$ reproduces well experiments as found by Boucher&Rebut&Watkins for JET and ITER database

CR Acad. Sci. T315, Ser. II, 273 (92)

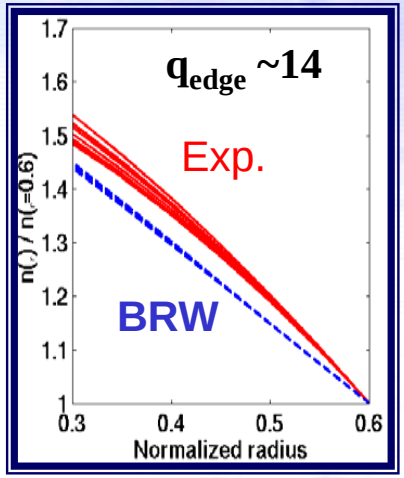
Over estimated by model 1/q proposed by Nycander Yankov (fits TFTR supershots) *PoP **2** 1995*

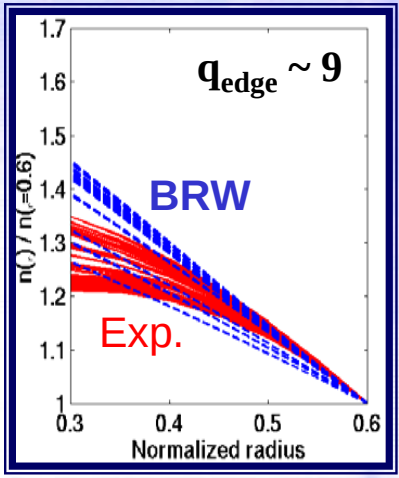
Slightly under estimated using Isichenko's formula based on ITGs

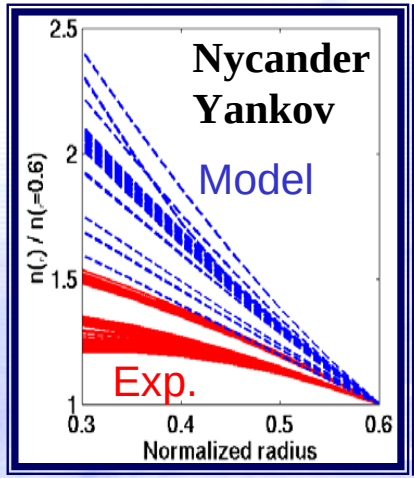
$$\frac{n(r)}{n(0)} = 1 - \frac{1}{R}\int_0^r \left(\frac{1}{2} + \frac{4}{3} r \frac{\nabla q}{q}\right) dr$$

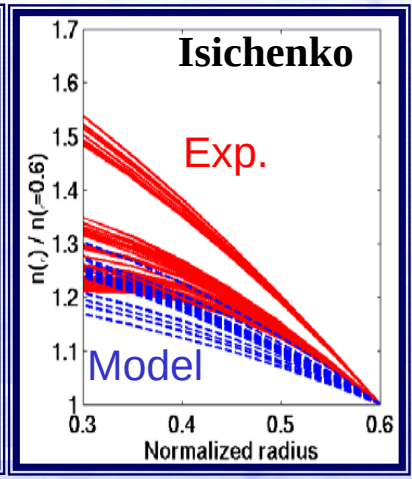
(fits TFTR L-mode) *PRL**74**,1995*

n_e normalized to the value @ r/a =0.6
50 profiles from 10 shots.







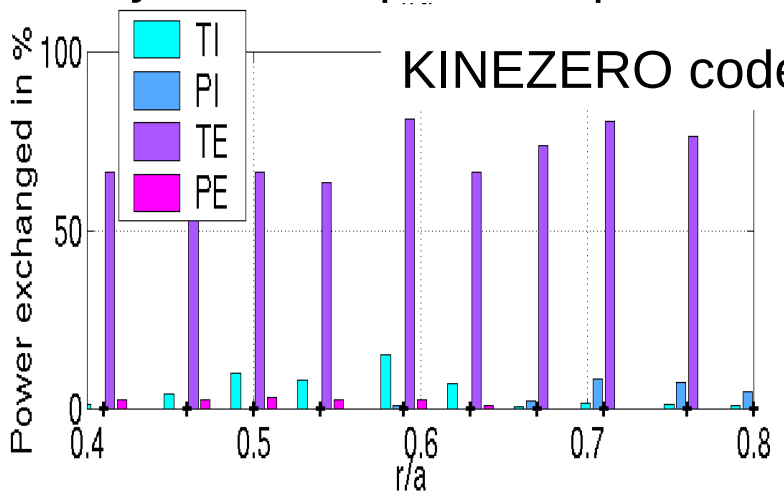


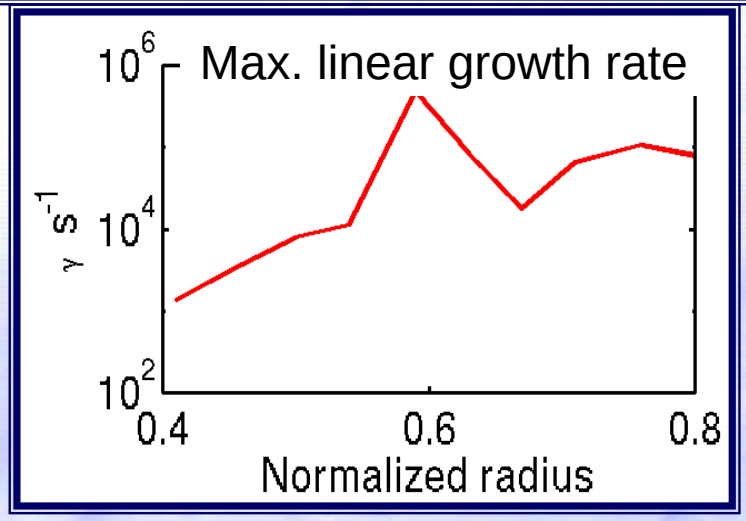
Trapped Electron Modes Expected in ITER reference scenario

Dominant trapped electron (TE) contribution

→ Dominant turbulent ∇q/q term expected, thus peaked density profile

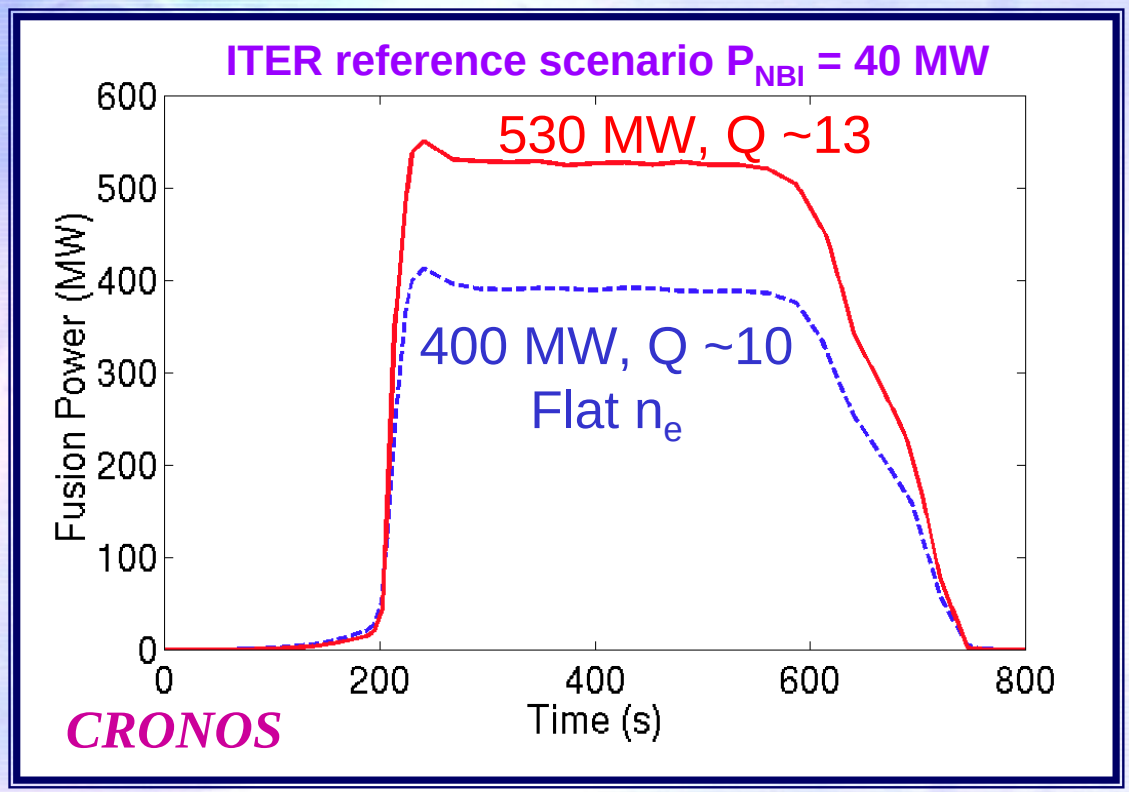
Power transferred to unstable modes by different particle species





Extrapolation to ITER

Possible gain of 30% in fusion power when using $\nabla n/n = -0.5\, \nabla q/q$



CRONOS simulation in a consistent manner using 0D scaling laws:

ITERH-98P(y,2), bootstrap, Z_{eff}, edge conditions....

No Impurity transport. But, scalings include an increase of Z_{eff} (1.5 to 1.7)

OPEN QUESTIONS

Inward or Outward Thermodiffusion in ITER plasmas?

What about Impurity accumulation?

Impurity transport, low Z?

CONCLUSIONS

- ✓ Evident turbulent pinche observed in Tore Supra
- ✓ Both the Thermodiffusion & Curvature pinches co-exist.
- ✓ Weak Thermodiffusion. Inward when ITGs dominant

  Outward when TEMs dominant
- ✓ n_e profile governed by q-profile: $\nabla n/n \sim -0.5\ \nabla q/q$

  correlated with dominant TEM

  possible control by non-inductive current drive (ECCD, LHCD)
- ✓ Results agrees with turbulence theories & simulations

  Except for the observation of small thermodiffusion pinch