On the non-stiffness of edge transport in L-modes

O. Sauter, D. Kim, R. Behn, S. Coda,

B. P. Duval, T. P. Goodman and the TCV team

Ecole Polytechnique Fédérale de Lausanne (EPFL)

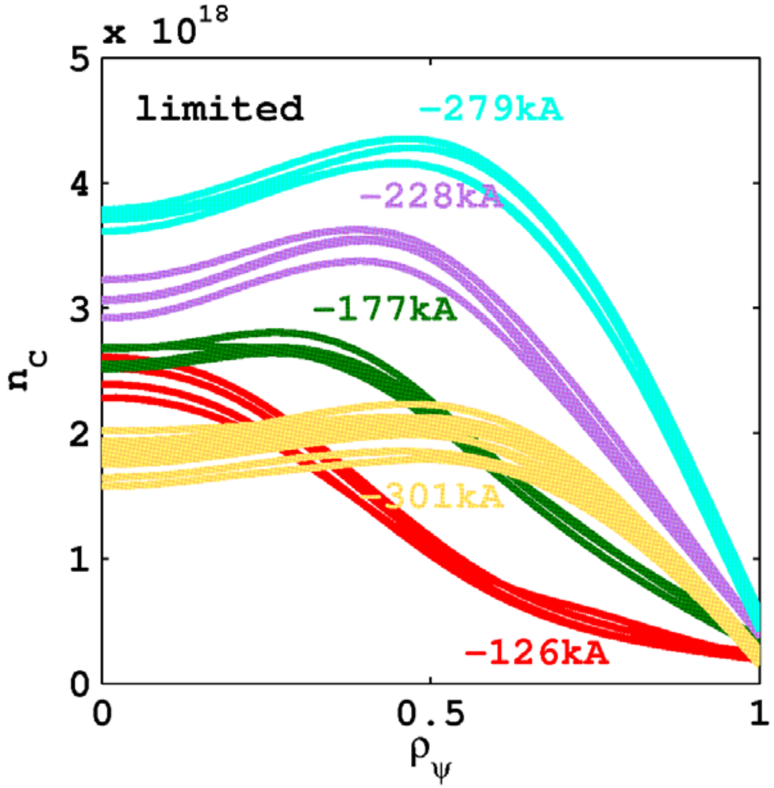
Centre de Recherches en Physiques des Plasmas (CRPP)

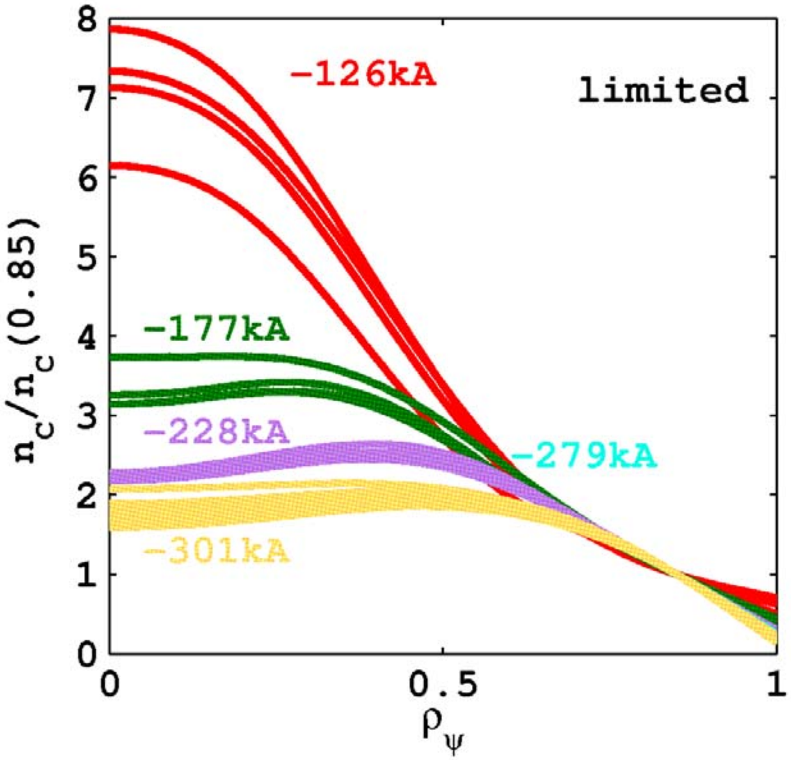
Lausanne, Switzerland

Outline

- Motivation
  - Carbon profile shown independent of Ip on TCV
  - Core scalelengths seem independent of Ip, despite $\tau_E \propto I_p$
- Determine R/L_{Te} vs I_p, P_{EC}, δ in core AND edge regions
- Core region is stiff, edge is not
- 1-D transport simulation with new model
- Conclusions

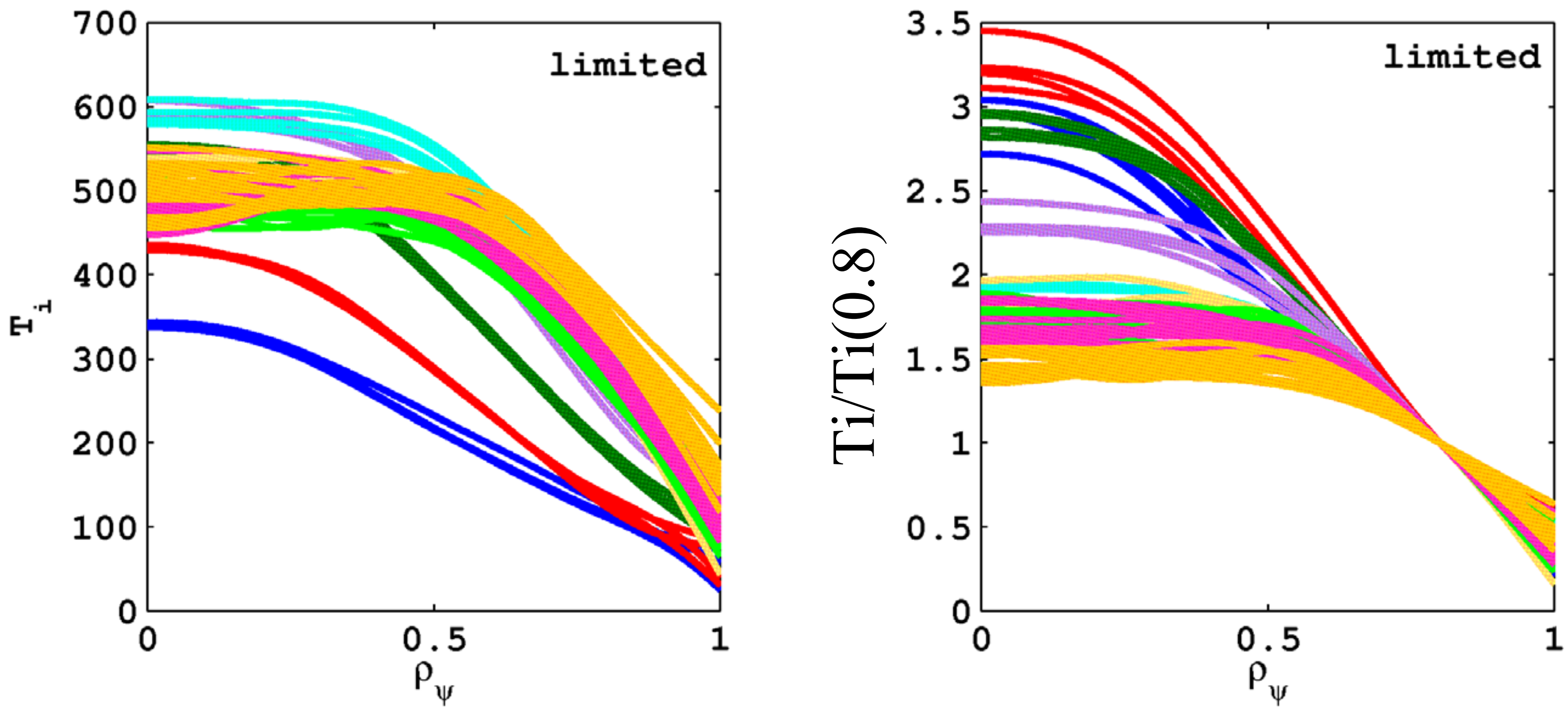
Impurity transport independent of Ip





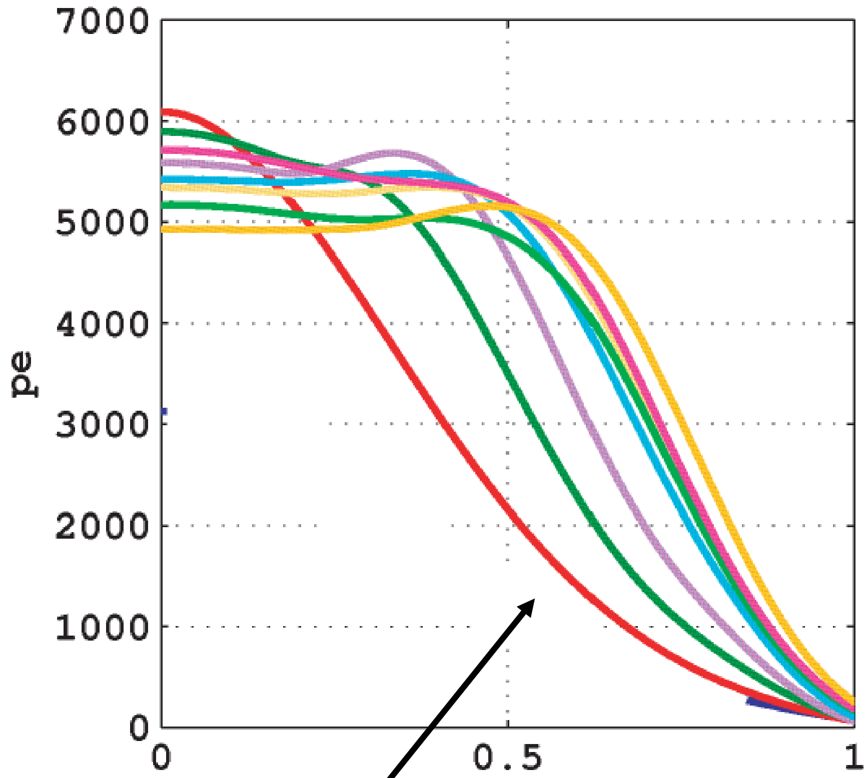
O. Sauter et al, IAEA 2010 EXPC/P8-13 and EXS/P2-1

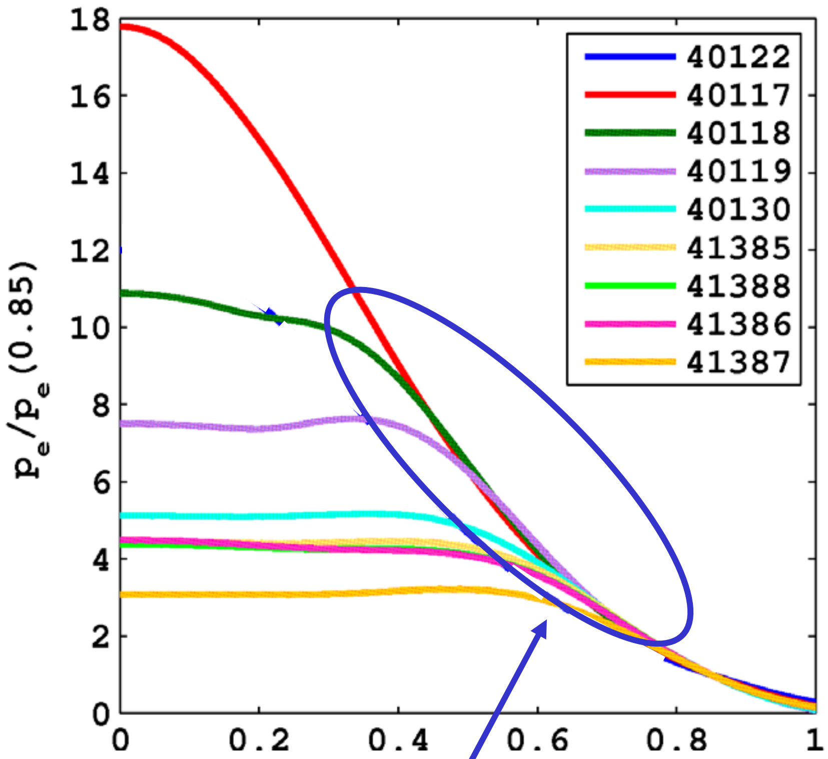
Same for T_i, v_φ independent of Ip



O. Sauter et al, IAEA 2010 EXPC/P8-13 and EXS/P2-1

electron transport independent of Ip as well



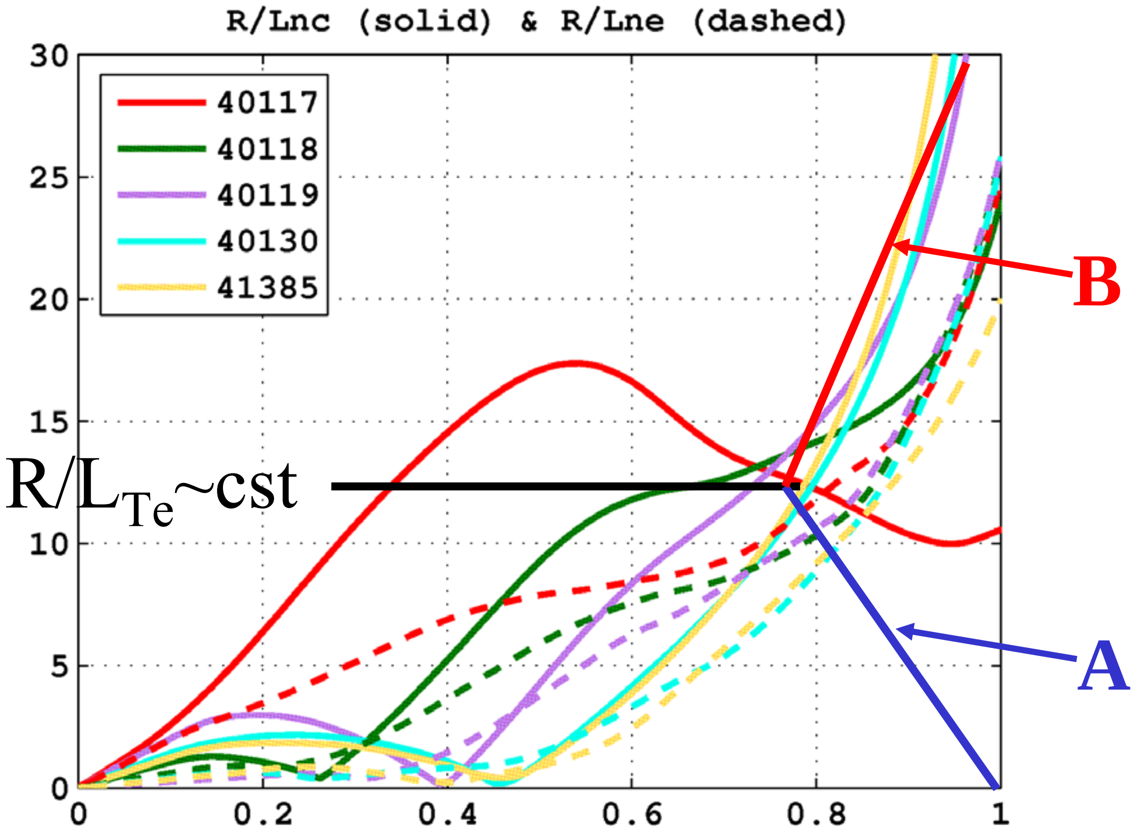


We ∝ Ip

Profiles self-similar outside mixing radius

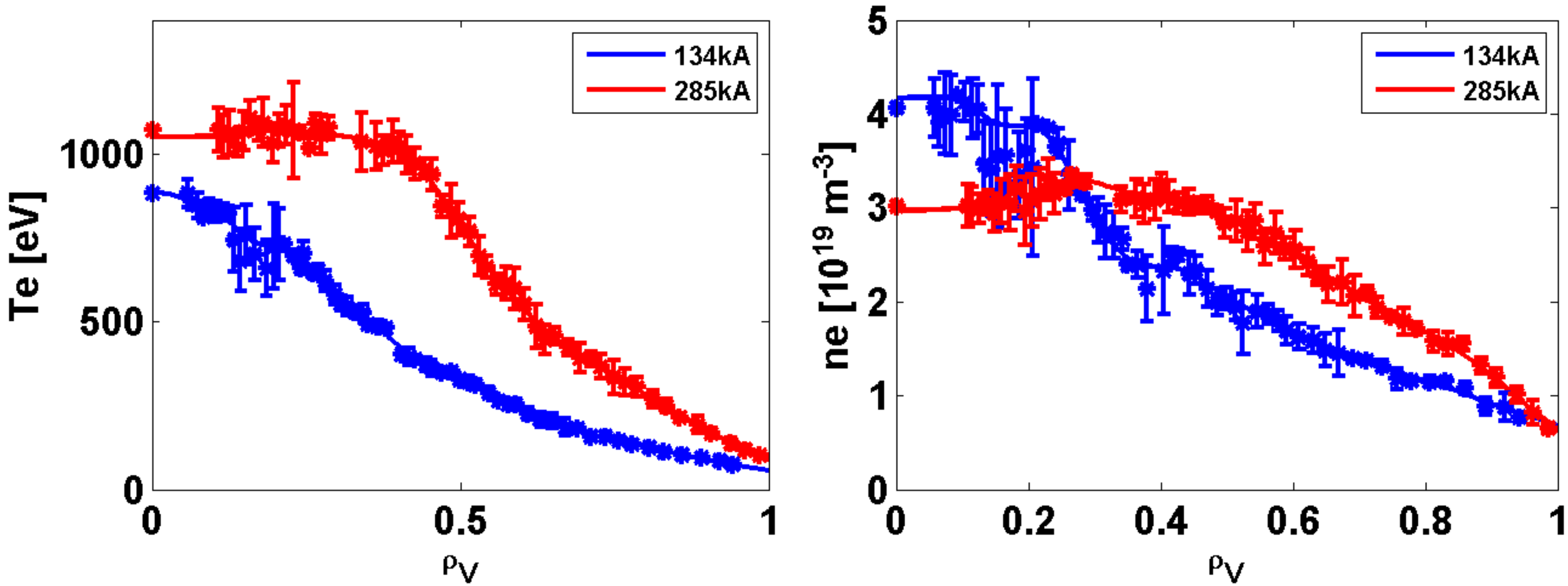
Ip scan: q_{95} from 2.5 to 10

What is R/L_{Te} global profile for gyrokinetic?



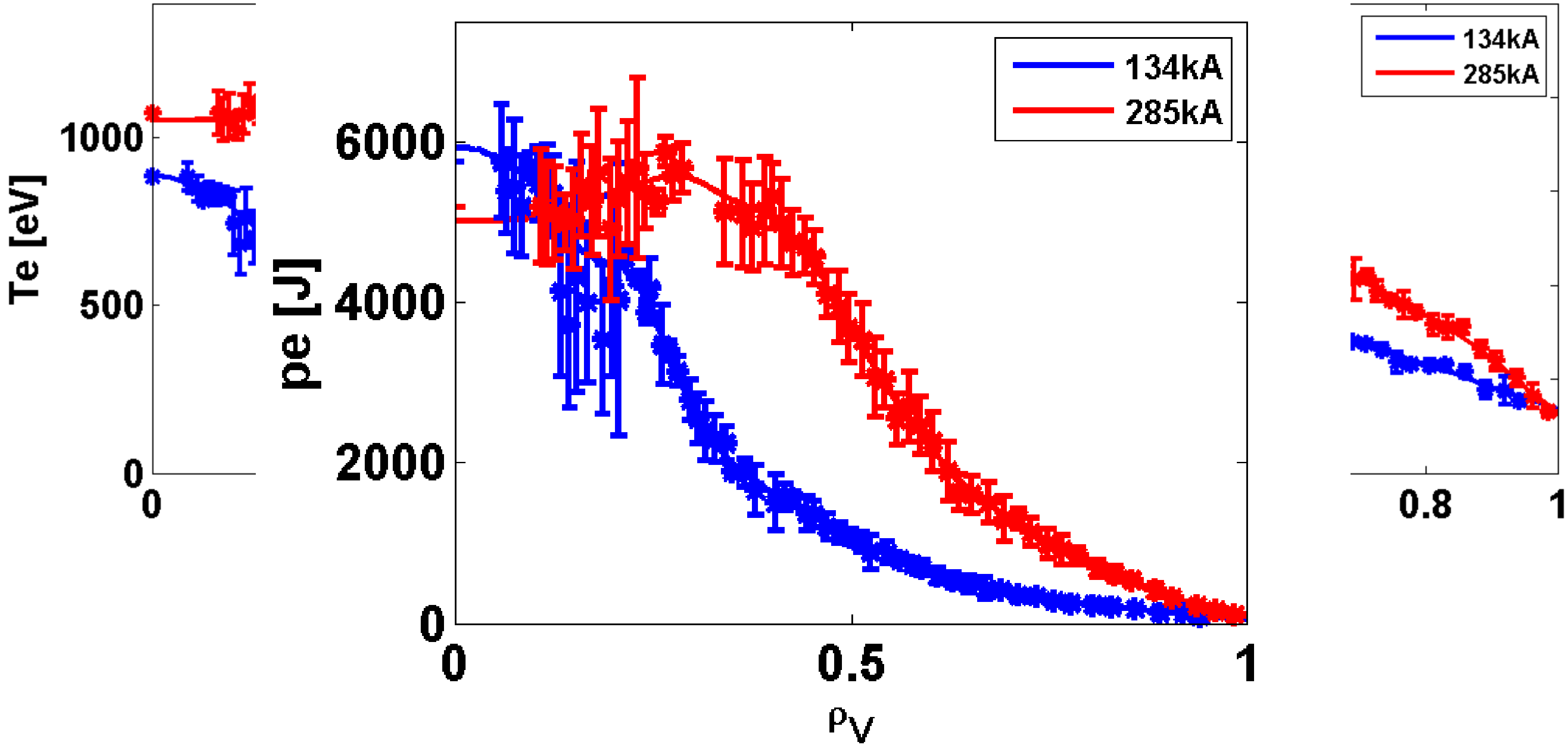
- A: R/L_{Te} →0 at ρ=1 : Used in most simulations
- B: R/LTe →3-10*(core) at ρ=1 : seems proposed by expt

n_e, T_e versus I_p in TCV, with z-axis sweep



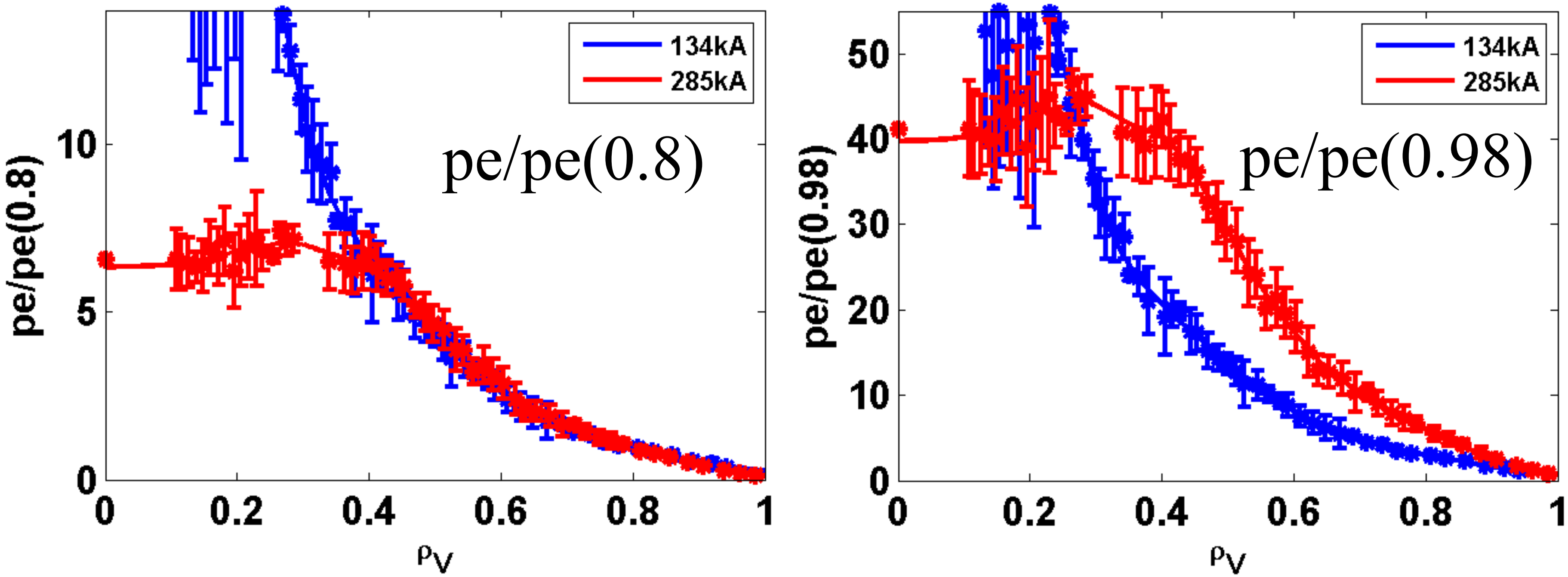
Thomson data, with slow z-axis sweep

n_e, T_e versus I_p in TCV, with z-axis sweep



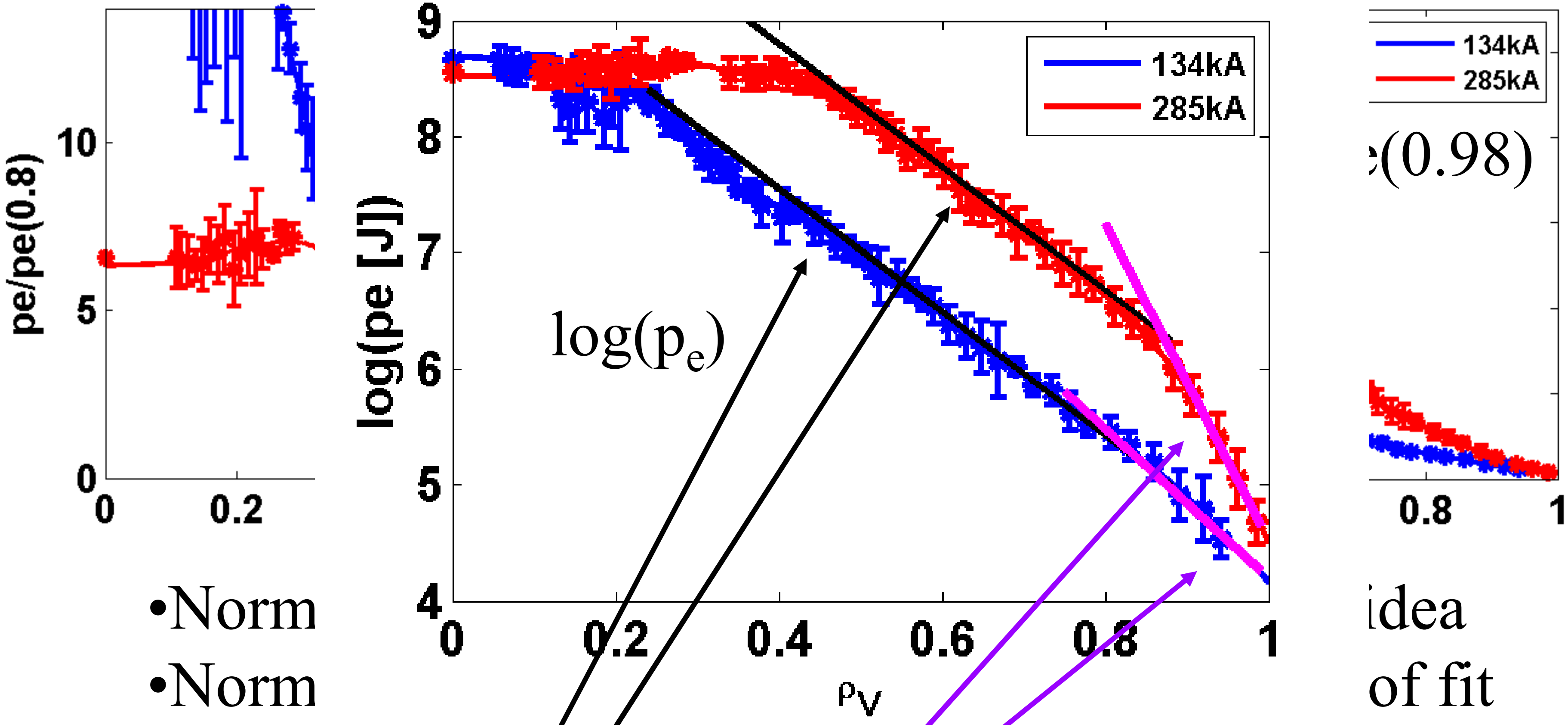
Clear increase of total energy with Ip

Change of scalelengths only for ρ_V>0.85



- Normalization vs value at ρ=0.8 is not a good idea
- Normalizing at ρ=0.98 depends on the quality of fit

Change of scalelengths only for $\rho_V>0.85$

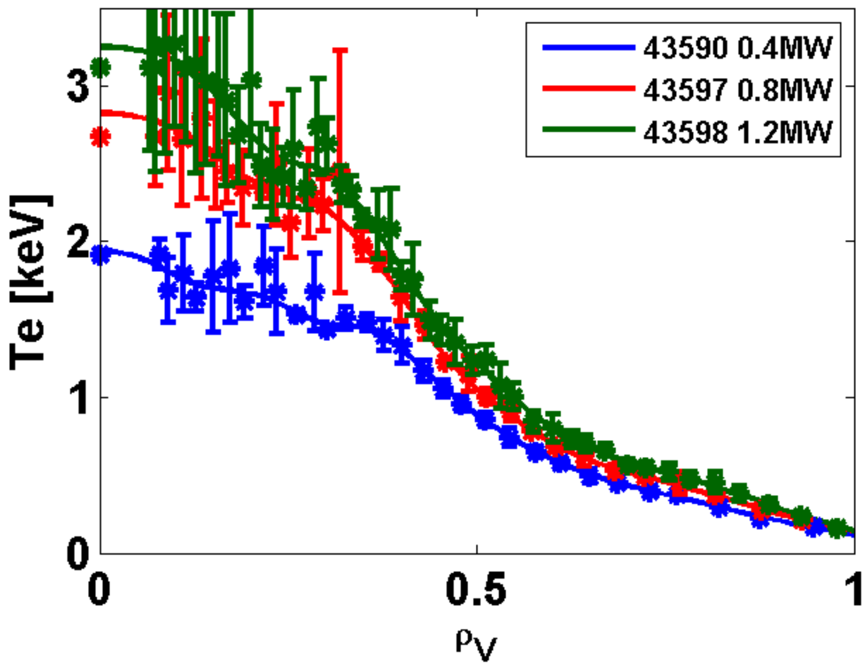


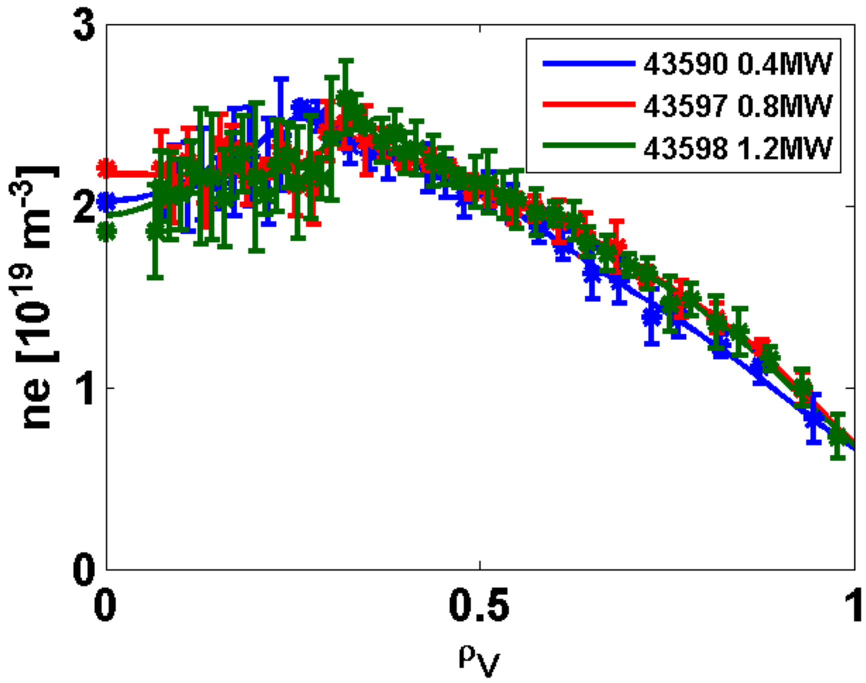
R/Lpe identical in core

R/Lpe ∝ Ip for $\rho_V>0.8$ ***(x2.6>core at Ip=285kA)***

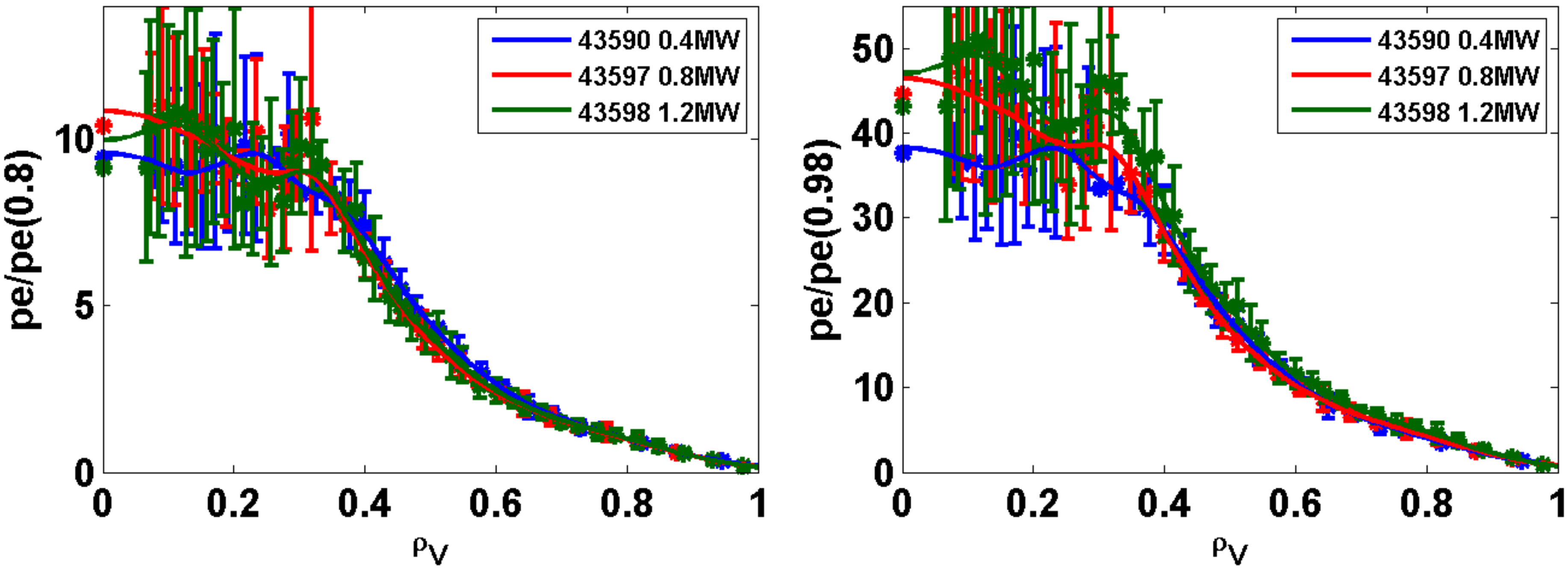
Note: ρ_ψ too narrow edge region

PEC scan at constant Ip



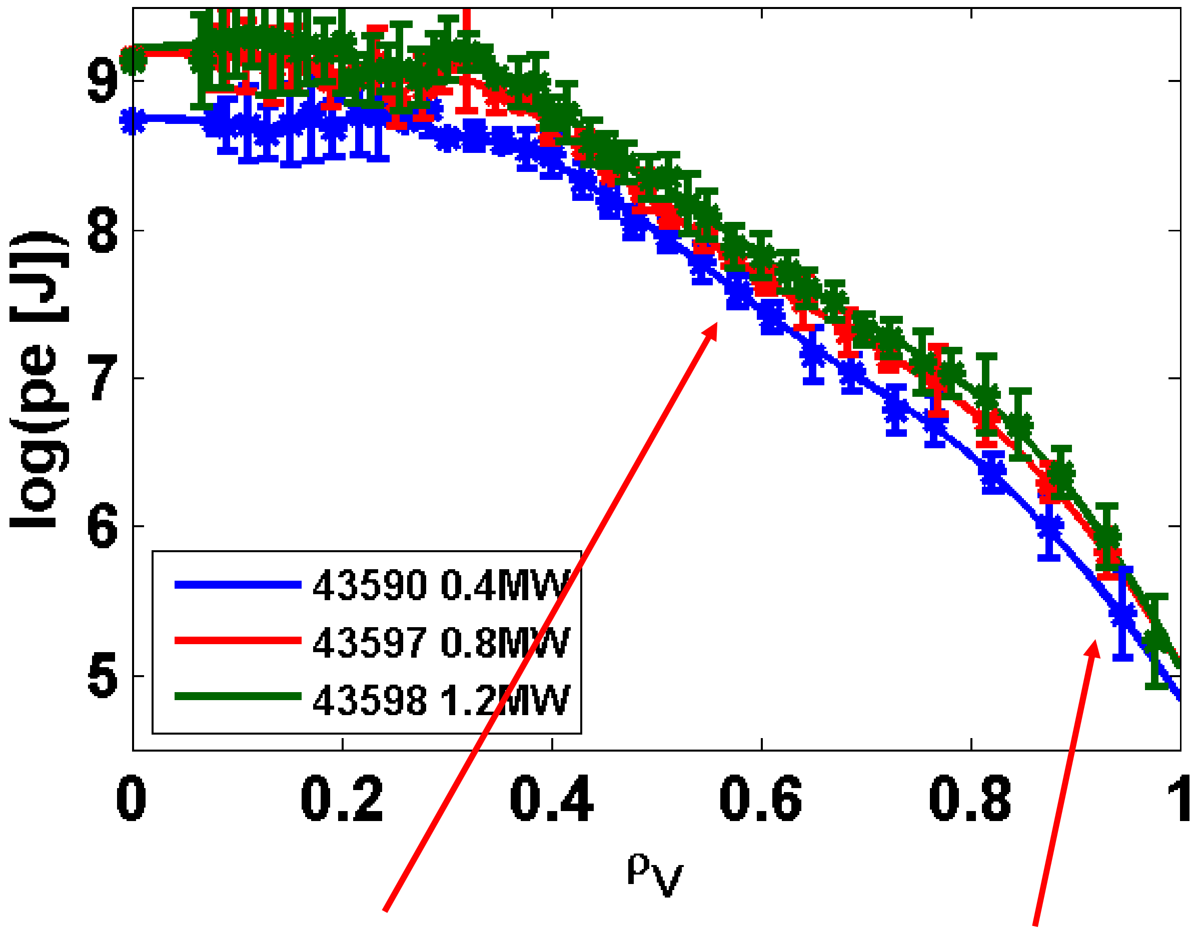


PEC scan at constant Ip



- Normalization on $p_e(0.8)$ shows self-similar profiles

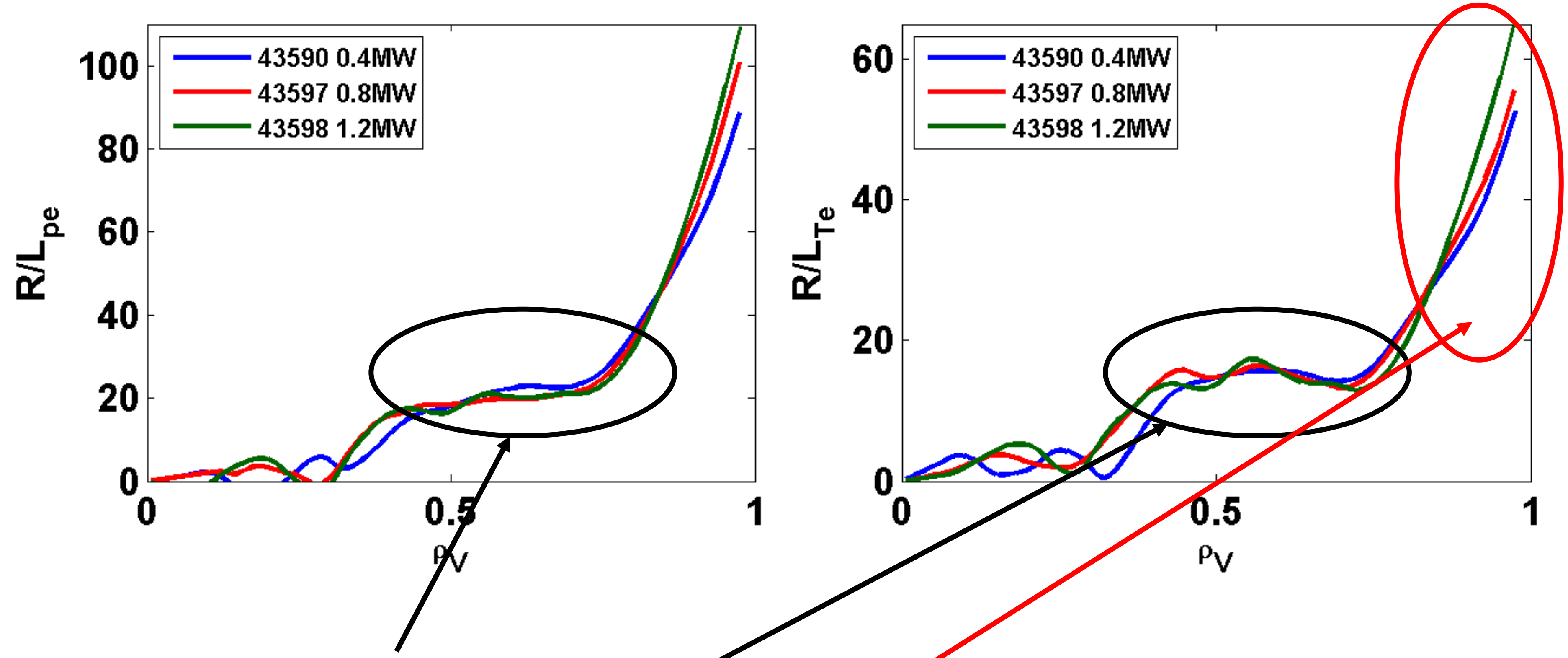
PEC scan at constant Ip



Stiff in core

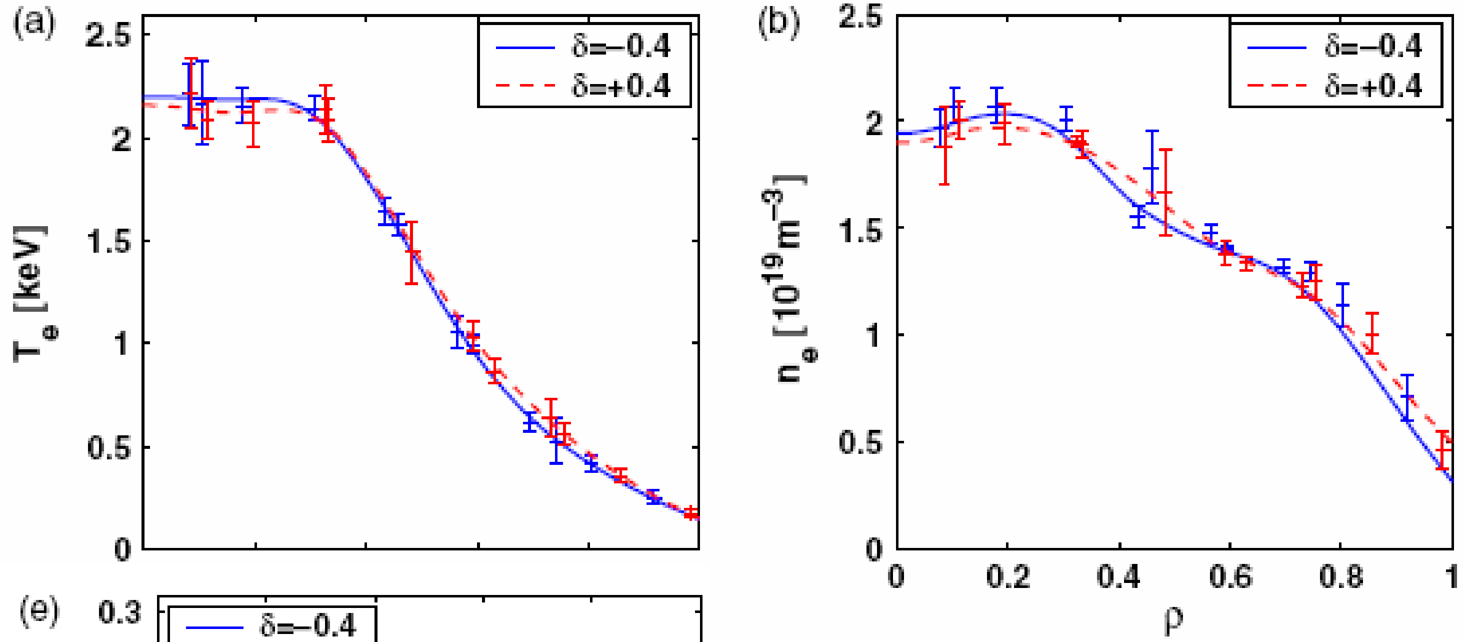
non-stiff in edge

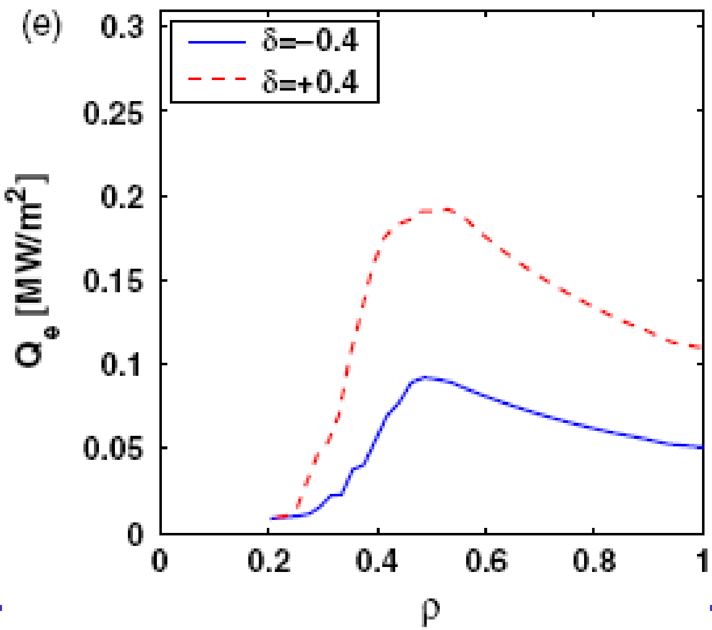
P_{EC} scan at constant Ip



- Stiff in "core" region $R/L_{Te} \approx 15$
- R/L_{Te} >30-40 in edge region

Strong effect of δ on global profiles

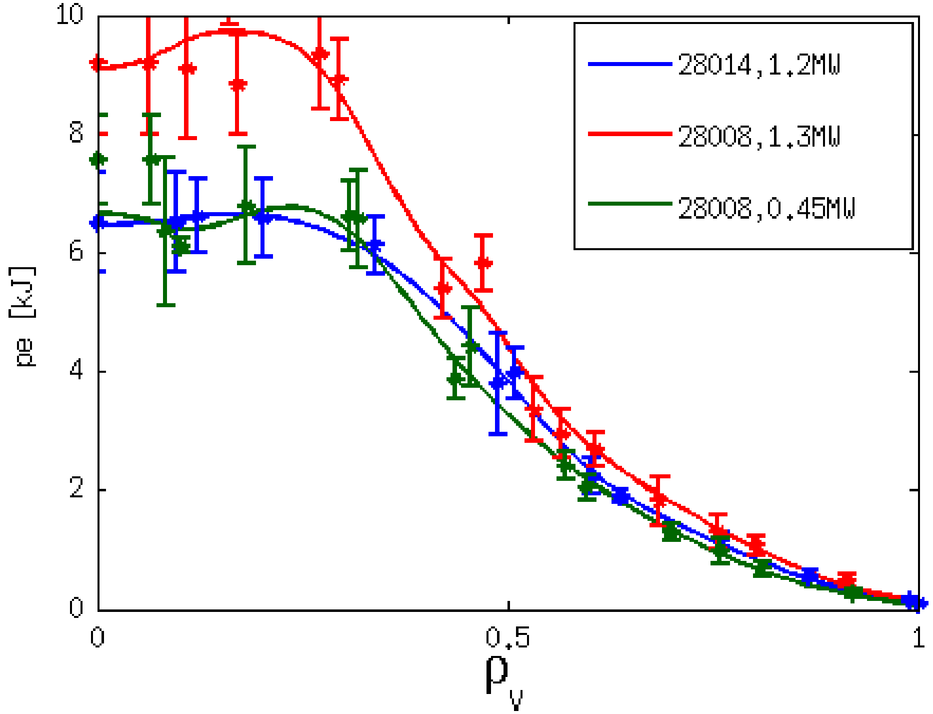


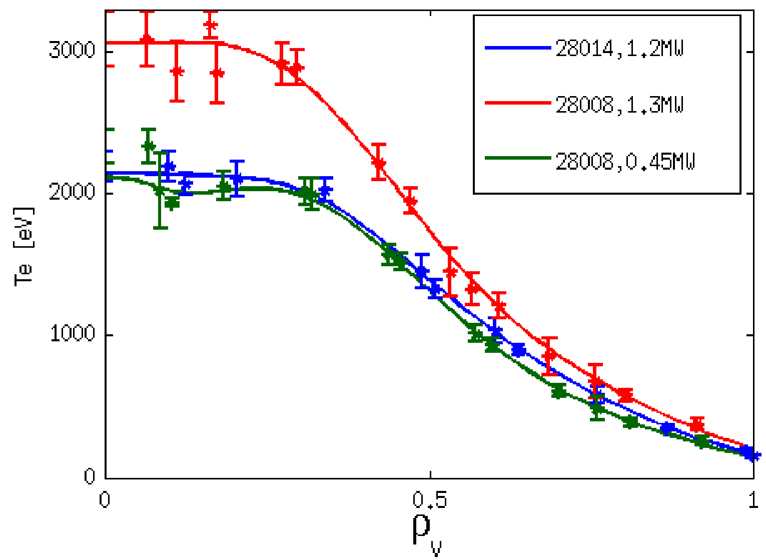


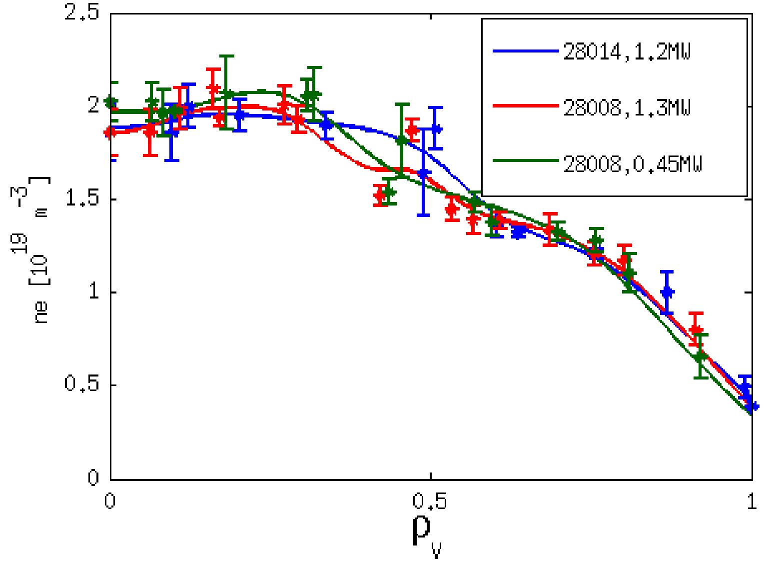
- δ<0: same prof with ½ P_{EC}

Y. Camenen et al, Nucl. Fusion **47** (2007) 510

Strong effect of δ on global profiles







- δ<0: same prof with ½ P_{EC}
- δ<0: higher p_e with same P_{EC}

1½-D transport simulations with ASTRA

"Local" transport characteristics in stationary state:

$$V'Q_e = \int_0^\rho S_e dV = -n_e \chi_e V' \langle |\nabla\rho|^2 \rangle \frac{\partial T_e}{\partial \rho}$$

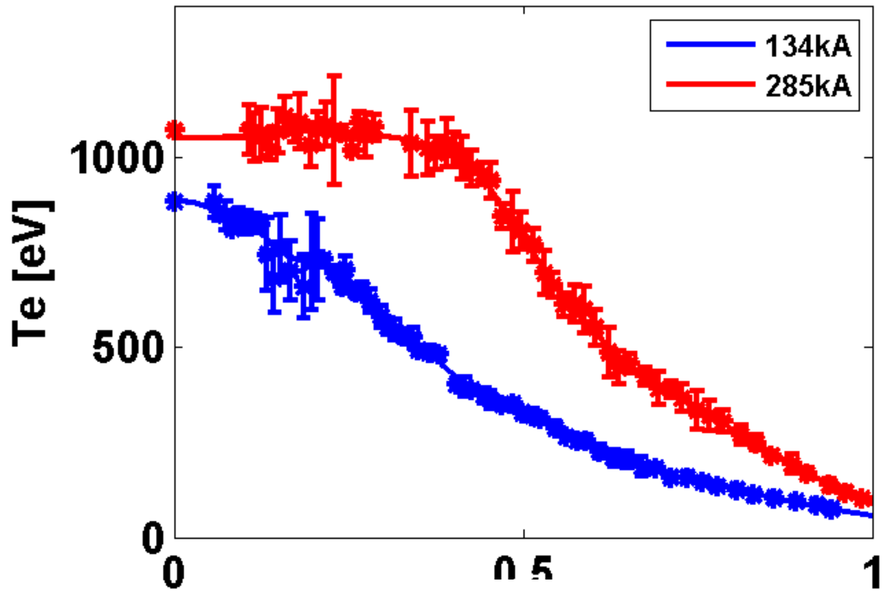
$$V' = \frac{\partial V}{\partial \rho} \qquad \frac{R_0}{L_{Te}} = -\frac{R_0}{T_e}\frac{\partial T_e}{\partial \rho}\langle |\nabla\rho| \rangle$$

$$\frac{\langle |\nabla\rho| \rangle}{\langle |\nabla\rho|^2 \rangle}\frac{V'Q_e}{T_e} = n_e \chi_e V' \frac{R_0}{L_{Te}}$$

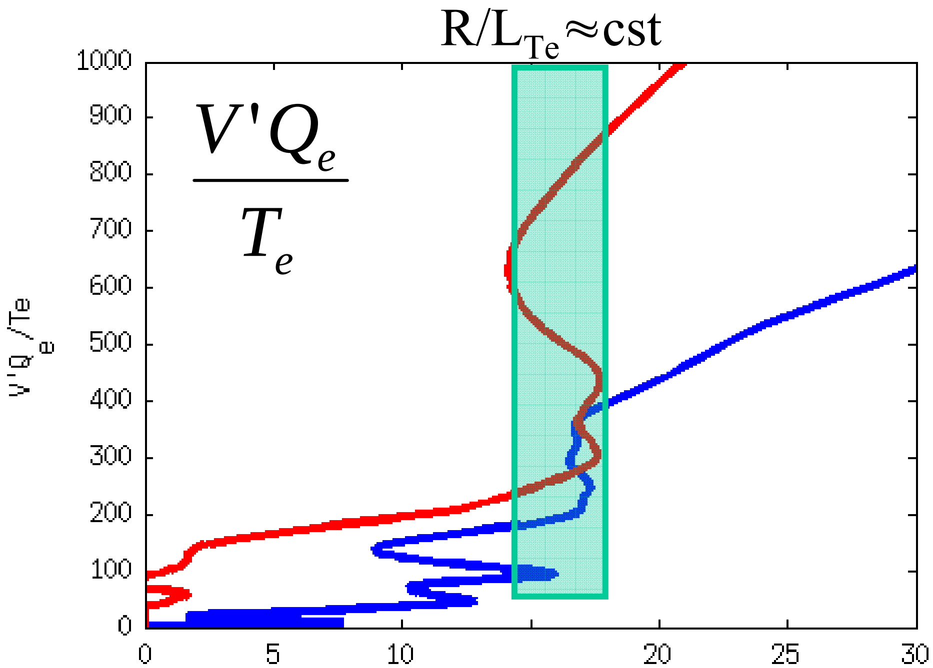
Stiff: χ_e increases when Q_e increases => $R/L_{Te} \approx$ cst

Qe/Te versus R/LTe from TCV data

$$\frac{\langle|\nabla\rho|\rangle}{\langle|\nabla\rho|^2\rangle}\frac{V'Q_e}{T_e}=n_e\chi_e V'\frac{R_0}{L_{Te}}$$



R/L$_{Te}$

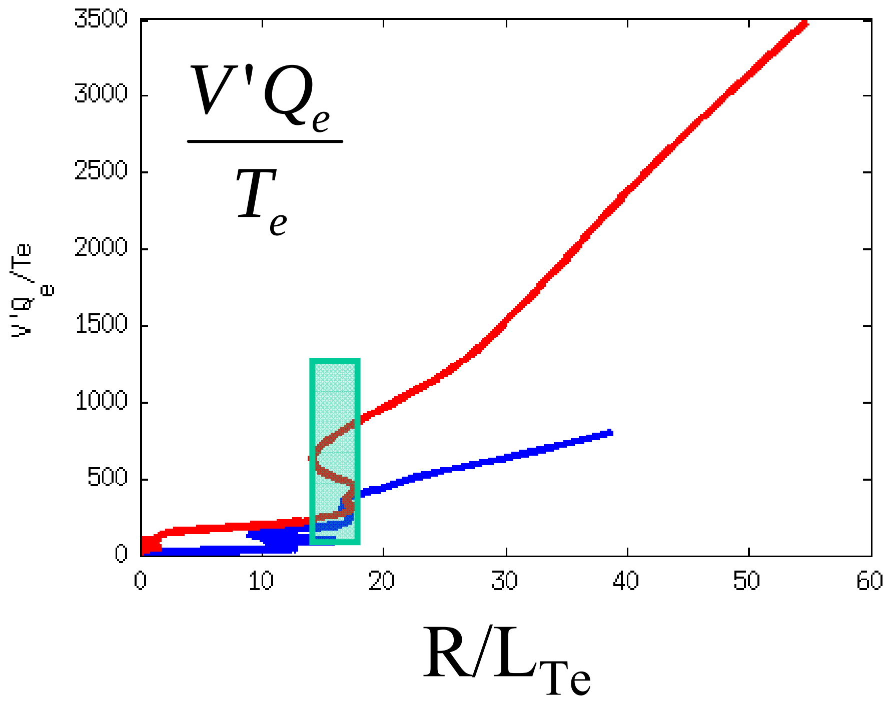


R/L$_{Te}$

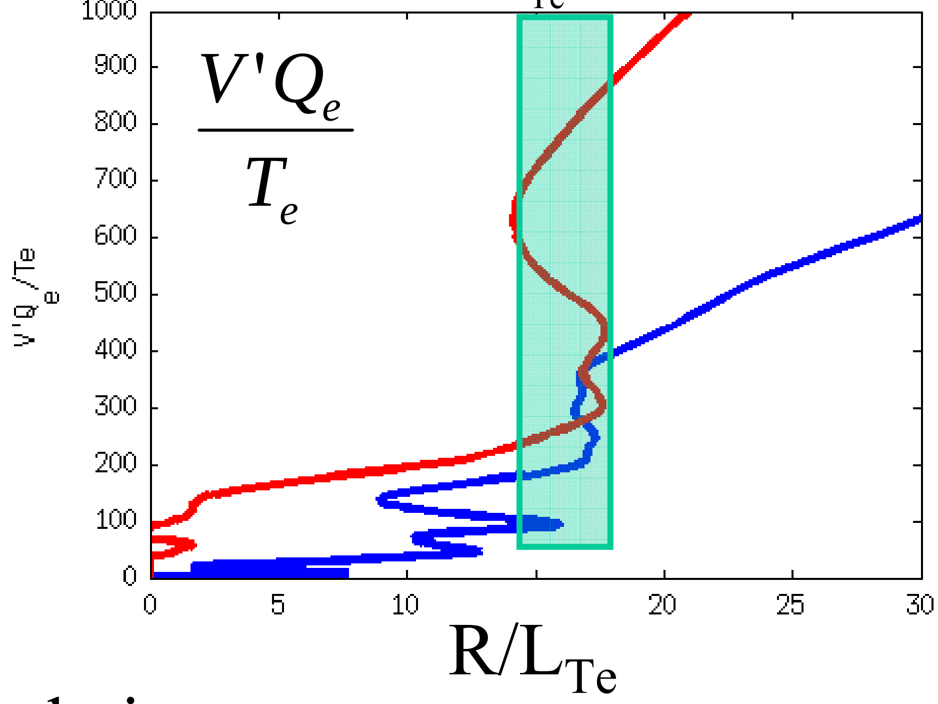
X_e(edge) is large but it is relation between Q_{e_norm} and R/L$_{Te}$ which matters

Qe/Te versus R/LTe from TCV data

$$\frac{\langle|\nabla\rho|\rangle}{\langle|\nabla\rho|^2\rangle}\frac{V'Q_e}{T_e}=n_e\chi_e V'\frac{R_0}{L_{Te}}$$



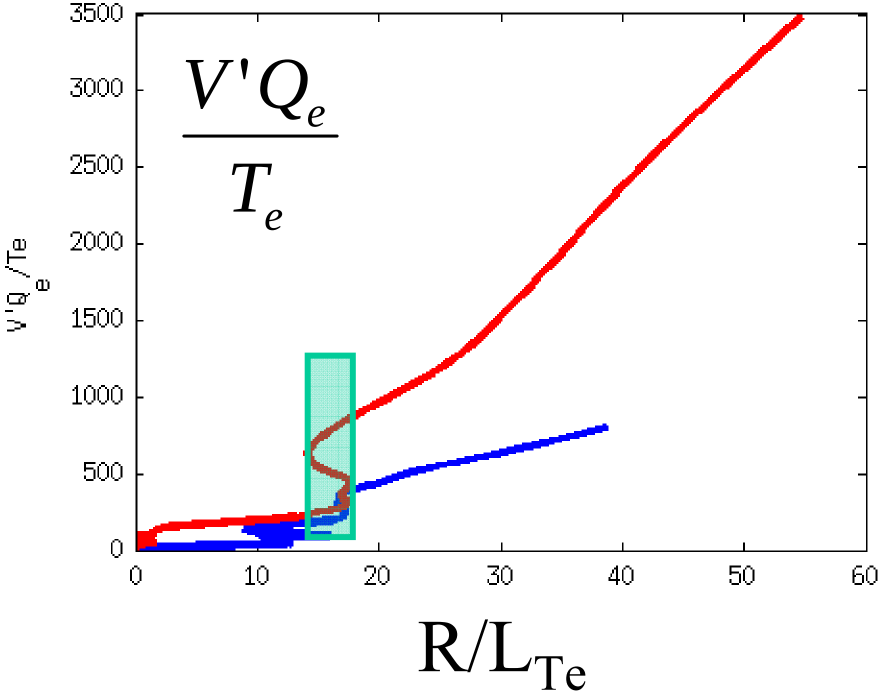
R/L$_{Te}\approx$cst

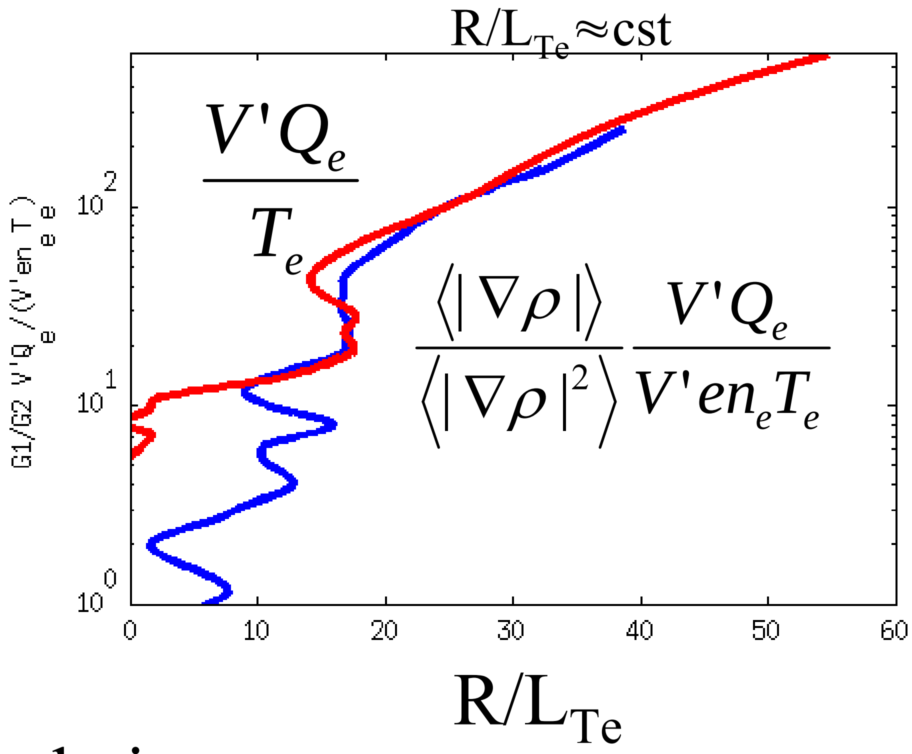


X_e(edge) is large but it is relation between Q_{e_norm} and R/L$_{Te}$ which matters

Qe/Te versus R/LTe from TCV data

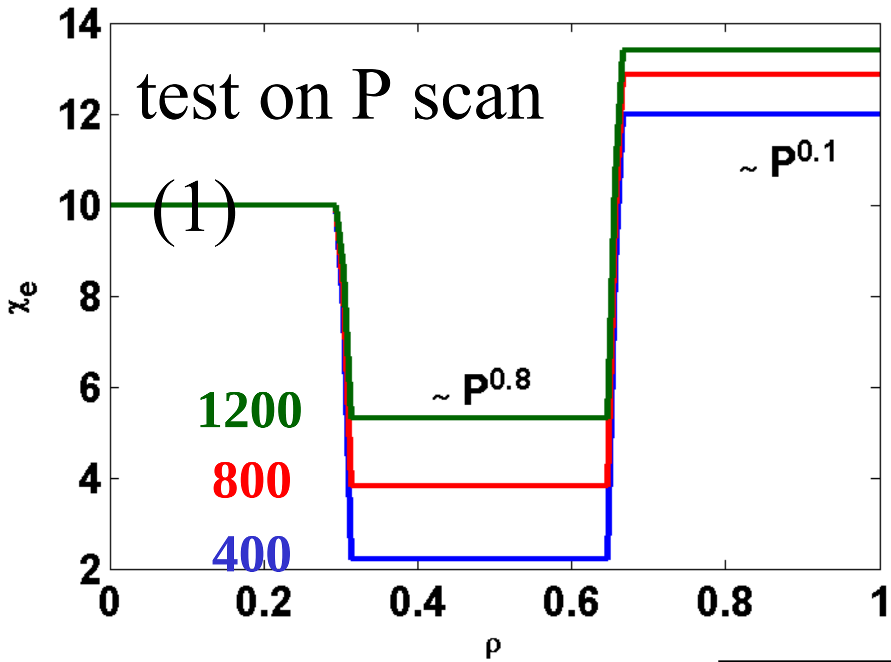
$$\frac{\langle|\nabla\rho|\rangle}{\langle|\nabla\rho|^2\rangle}\frac{V'Q_e}{T_e}=n_e\chi_e V'\frac{R_0}{L_{Te}}$$





X_e(edge) is large but it is relation between Q_{e_norm} and R/L_{Te} which matters

A combined core-stiff / edge-non-stiff model



Assuming edge non-stiff:

$$(3)\quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0-0.2}$$

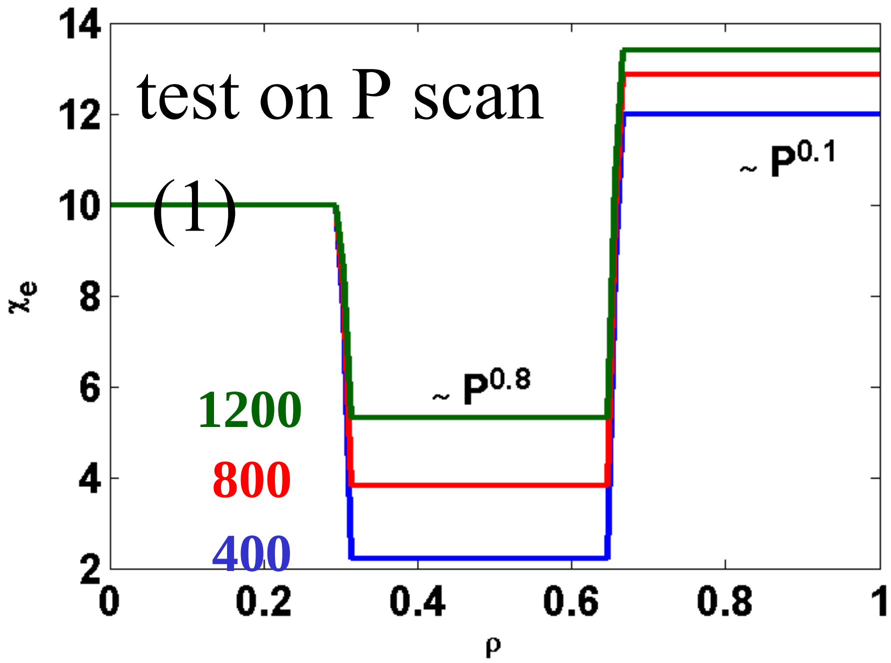
Stiffness: $\tau_E \propto P^{-0.7}$

$$(2)\quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0.7}$$

Three main regions w.r.t transport:

1) center: ST/current hole effects: large χ
2) Core: stiff, R/L_{Te}~cst
3) Edge: non-stiff

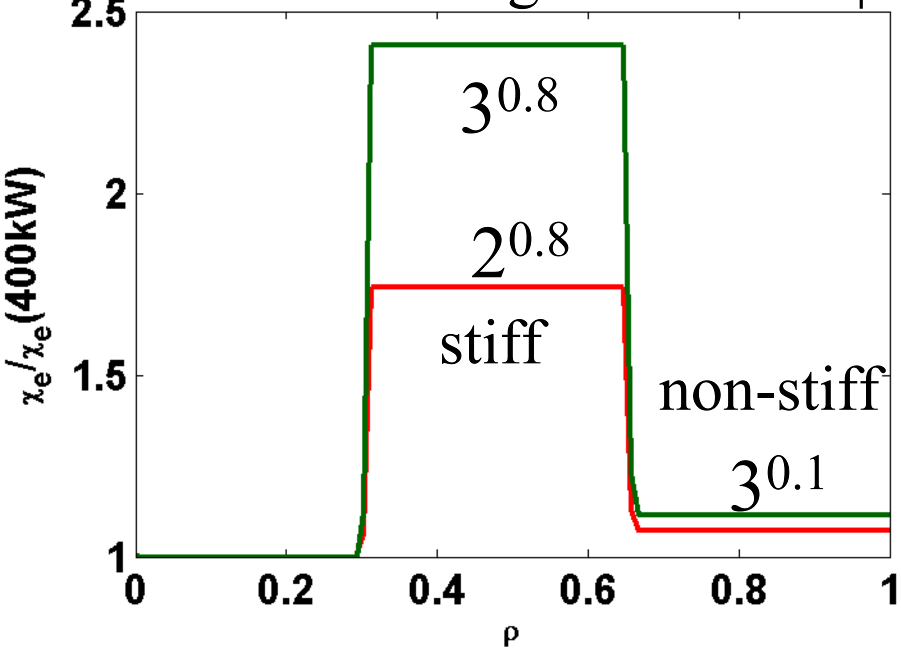
A combined core-stiff / edge-non-stiff model



Assuming edge non-stiff:

$$(3) \quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0-0.2}$$

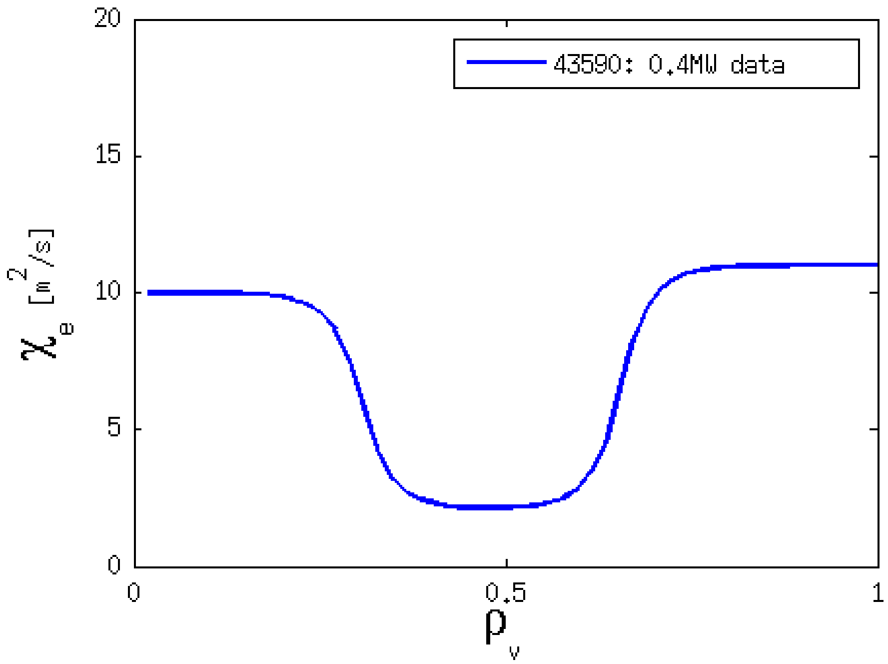
Leads to strong diff. with P↑

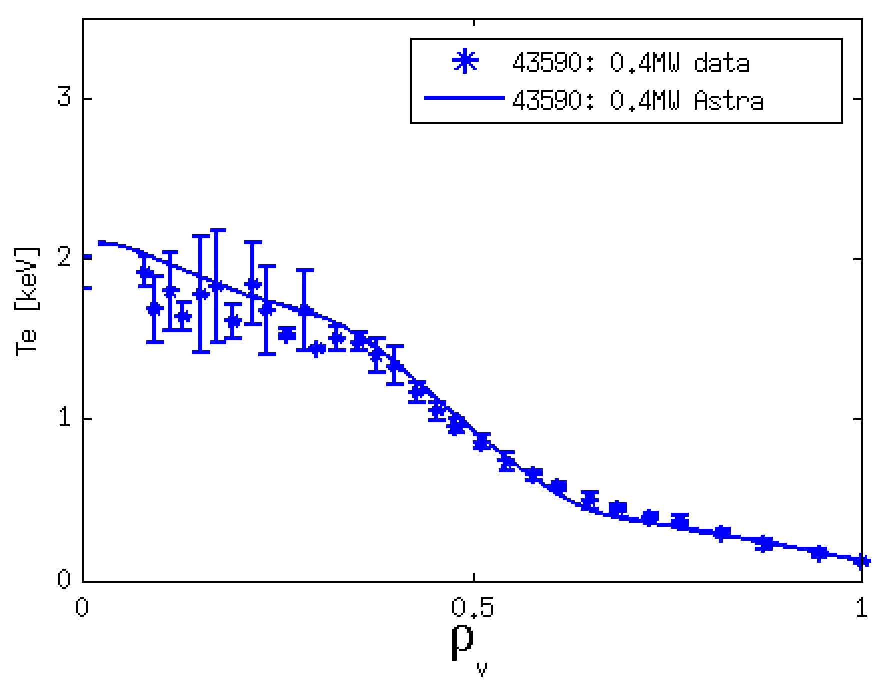


Stiffness: $\tau_E \propto P^{-0.7}$

$$(2) \quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0.7}$$

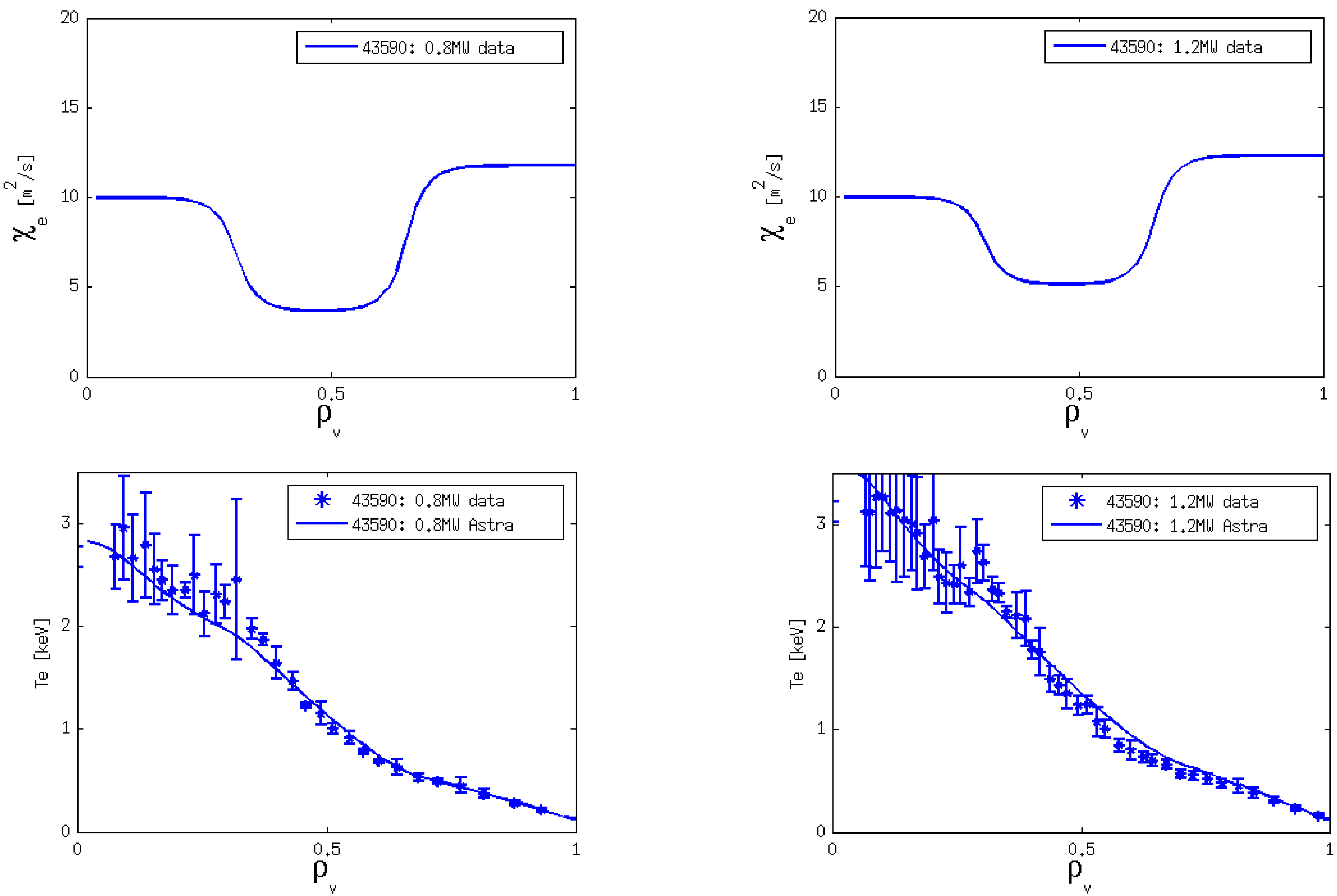
Results using 1-D ASTRA model



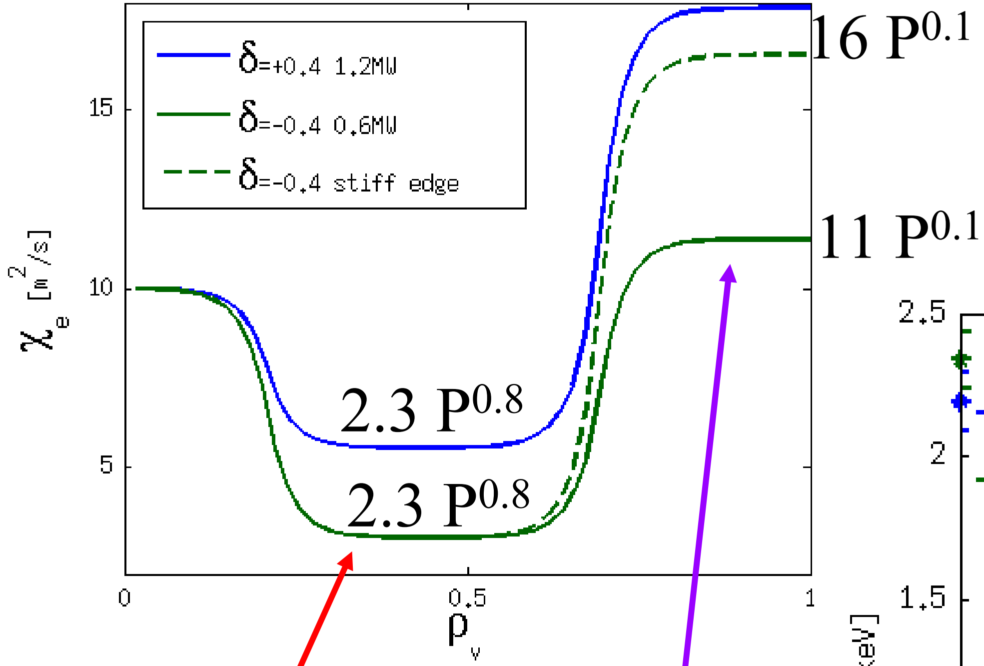


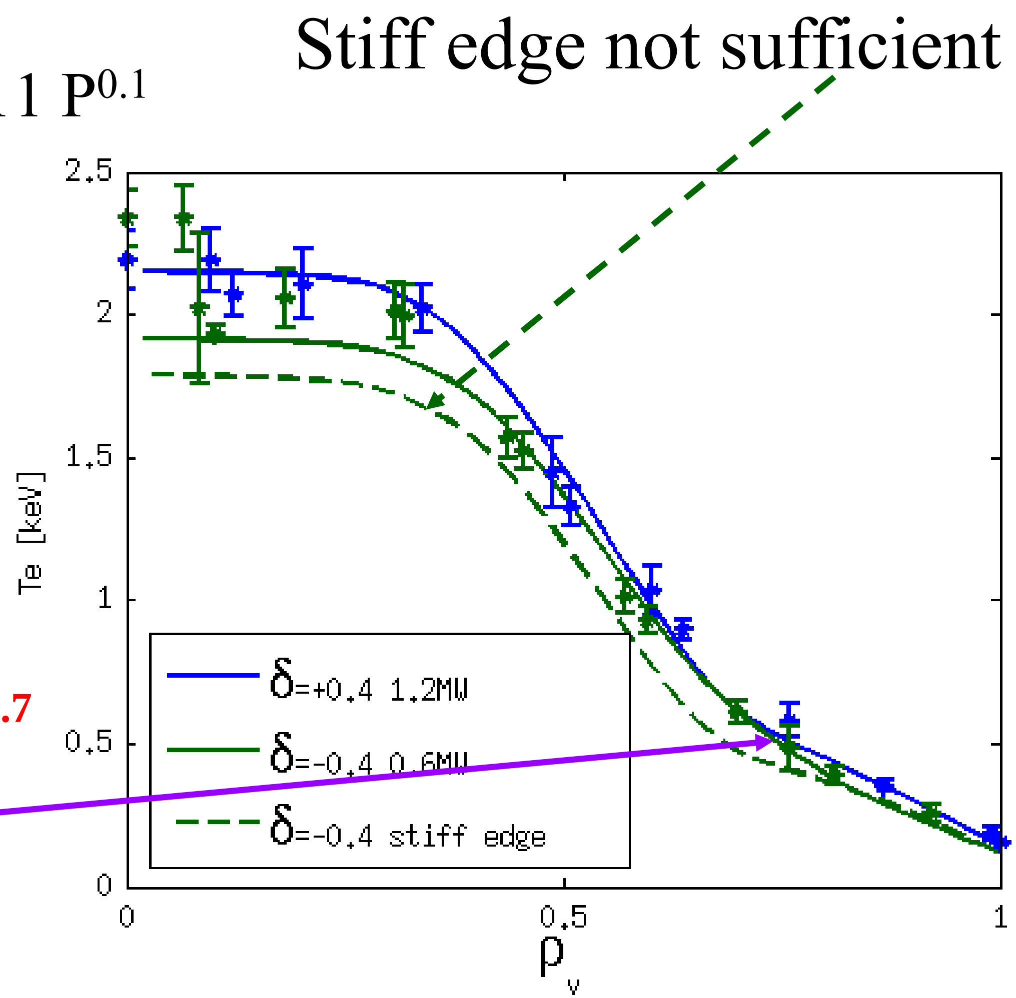
- We start from this χ_e profile and other plasma parameters
- Scale core $\chi_e \sim P^{0.7}$ and edge with $P^{0.1}$

Results using 1-D ASTRA model



Same technique for δ=+0.4, δ=-0.4 cases

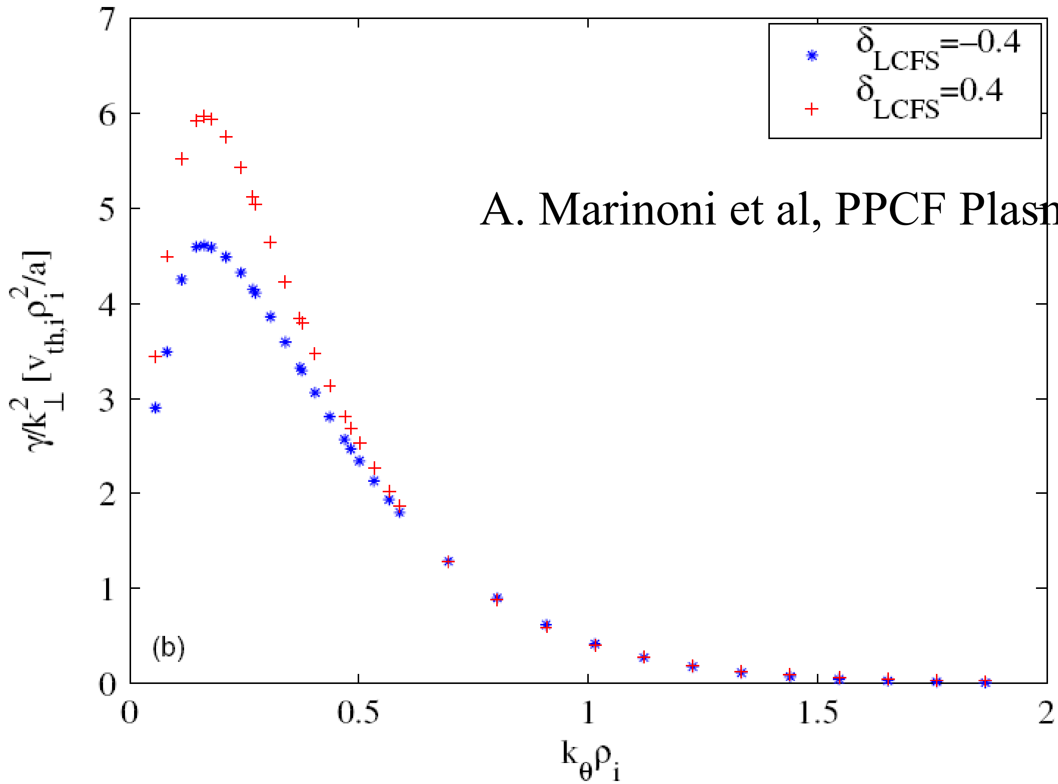




Recover profiles with:

1. **Same transport in core: $P^{-0.7}$**
2. **Reduced transport near edge with δ<0**

Reconciles with gyrokinetic simulations



A. Marinoni et al, PPCF Plasma **51** (2009) 055016

- Difference in linear and nonlinear simulations found only for ρ>0.7
- Present model resolves this issue

GAMs, see TCV comprehensive analysis S. Coda TTF2013

Conclusions

- Core transport limits R/L_{Te} (and R/Lne to some extent)
- Even with favourable Ip scaling profiles remain self-similar
- Therefore values at ρ=0.8 are changing with Ip
- This is possible with non-stiff transport in [0.8,1]:
  - χ hardly increase with increased power
- Simple model recovers Ip, P scsaling and δ effects with:
  - $\chi \sim P^{0.7\text{-}0.8}$ in core
  - $\chi \sim P^{0\text{-}0.2}$ in edge
- Explains effects of negative δ (which does not penetrate)
- Explains good P scaling of edge I-mode
- Explains profile consistency
- Explains "I-family", + can have wide variety of parameters
- Shows how L-mode builds up $R/L_{Te} \rightarrow 100$ with increasing power towards H-mode transition