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

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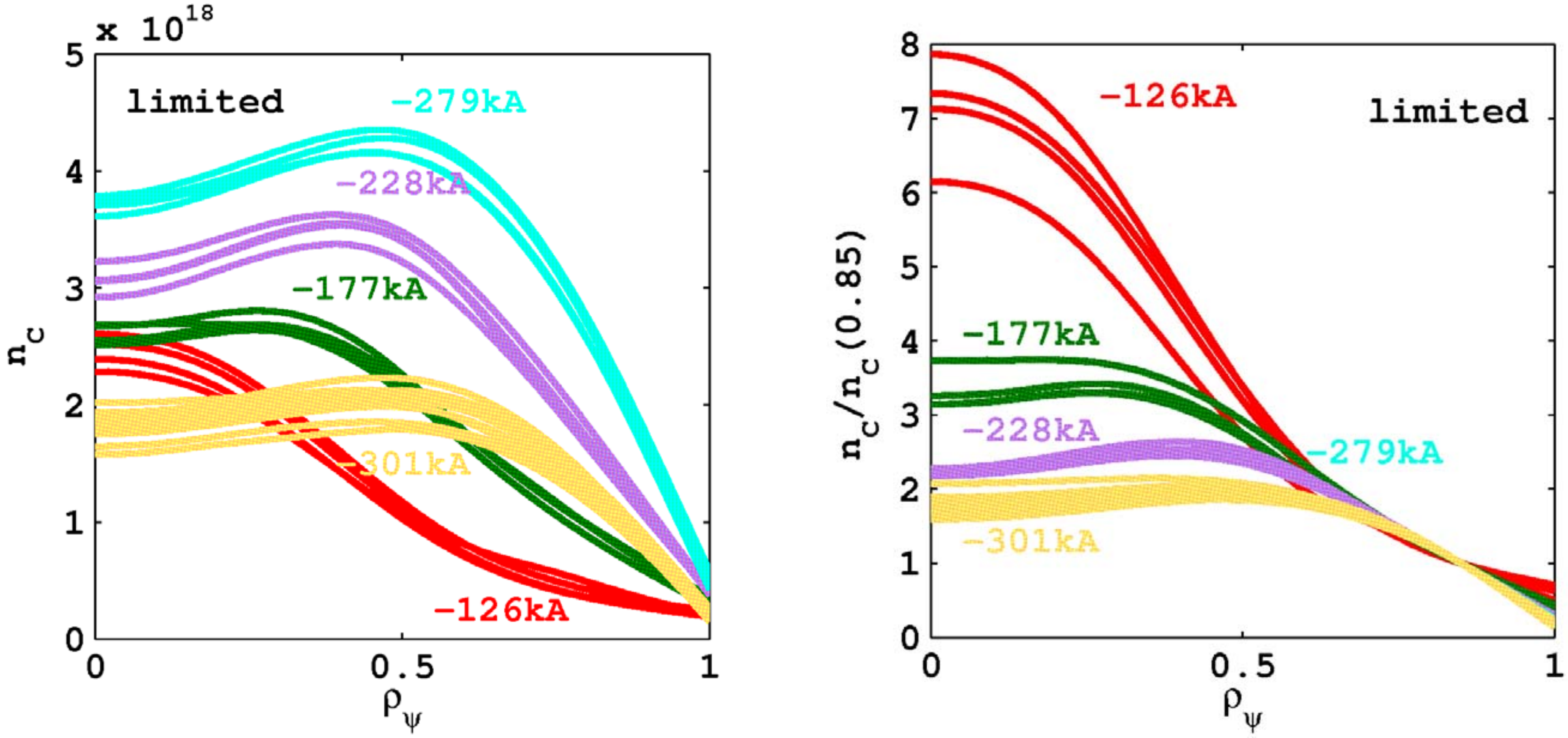
Outline

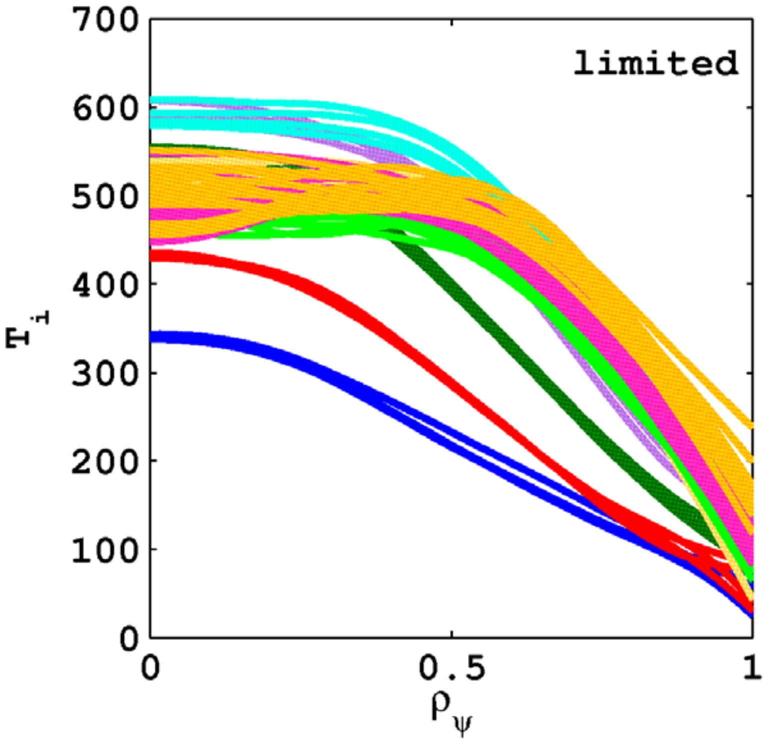
- Motivation
  - Carbon profile shown independent of Ip on TCV
  - Core scalelengths seem independent of Ip, despite $\tau_E \propto I_p$
- Determine R/L_{Te} vs I_p, P_{EC}, δ in core AND edge regions
- Core region is stiff, edge is not
- 1-D transport simulation with new model
- Conclusions

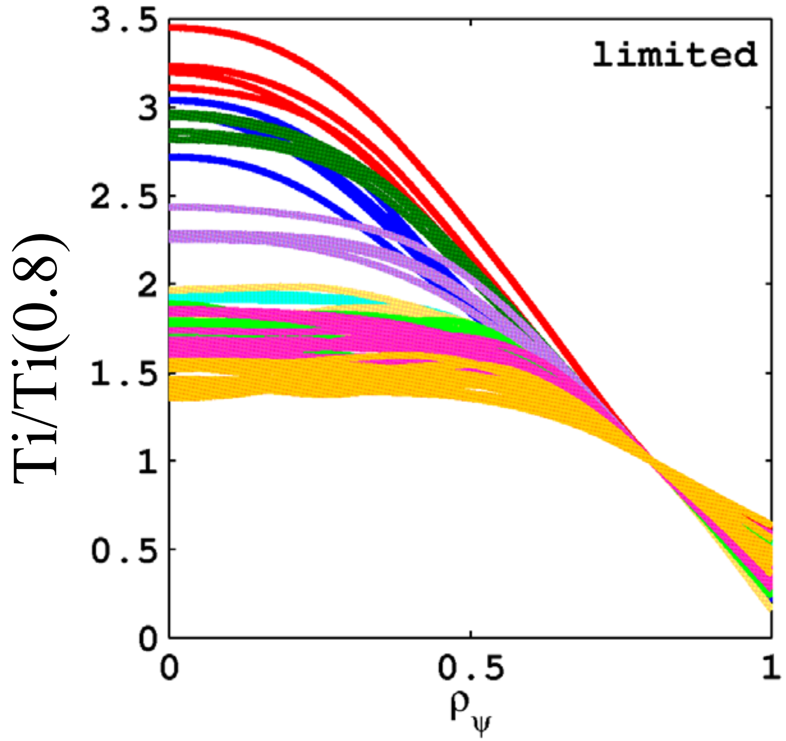
Impurity transport independent of Ip



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

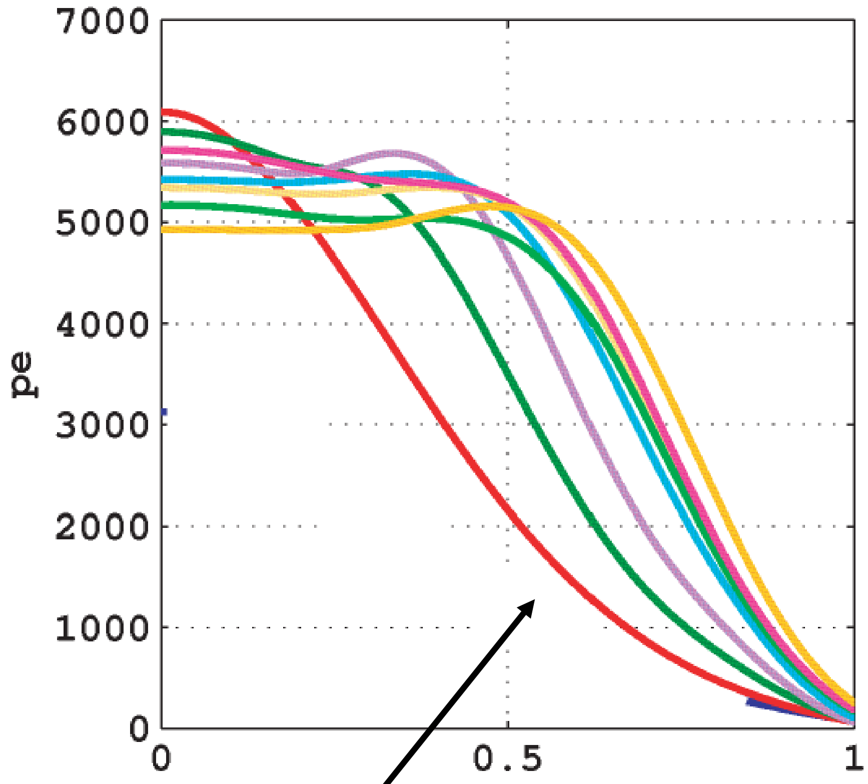
Same for T_i, v_φ independent of Ip

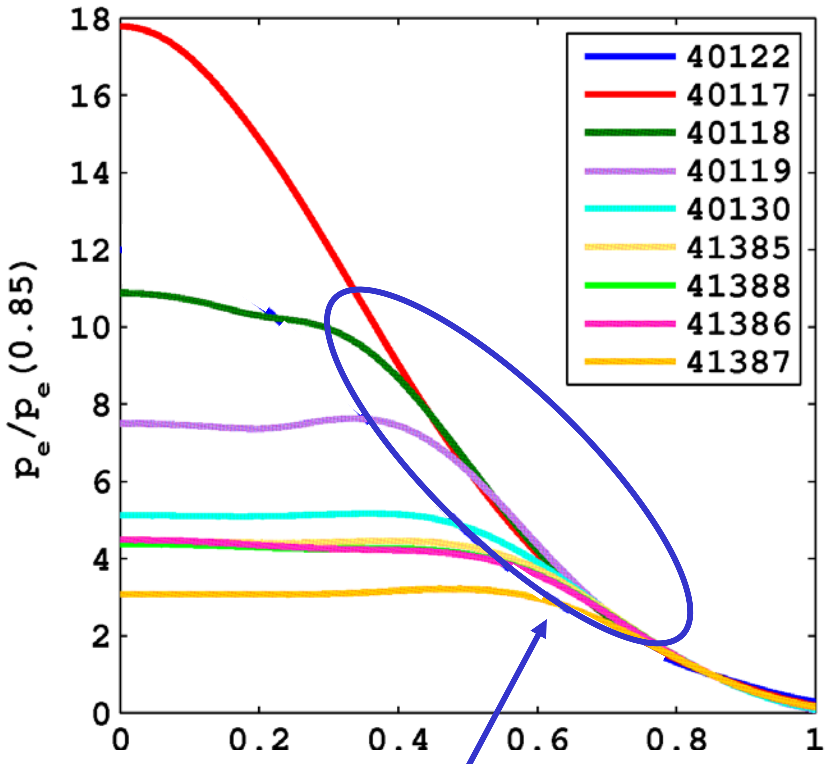




O. Sauter et al, IAEA 2010 EXPC/P8-13 and EXS/P2-1

electron transport independent of Ip as well



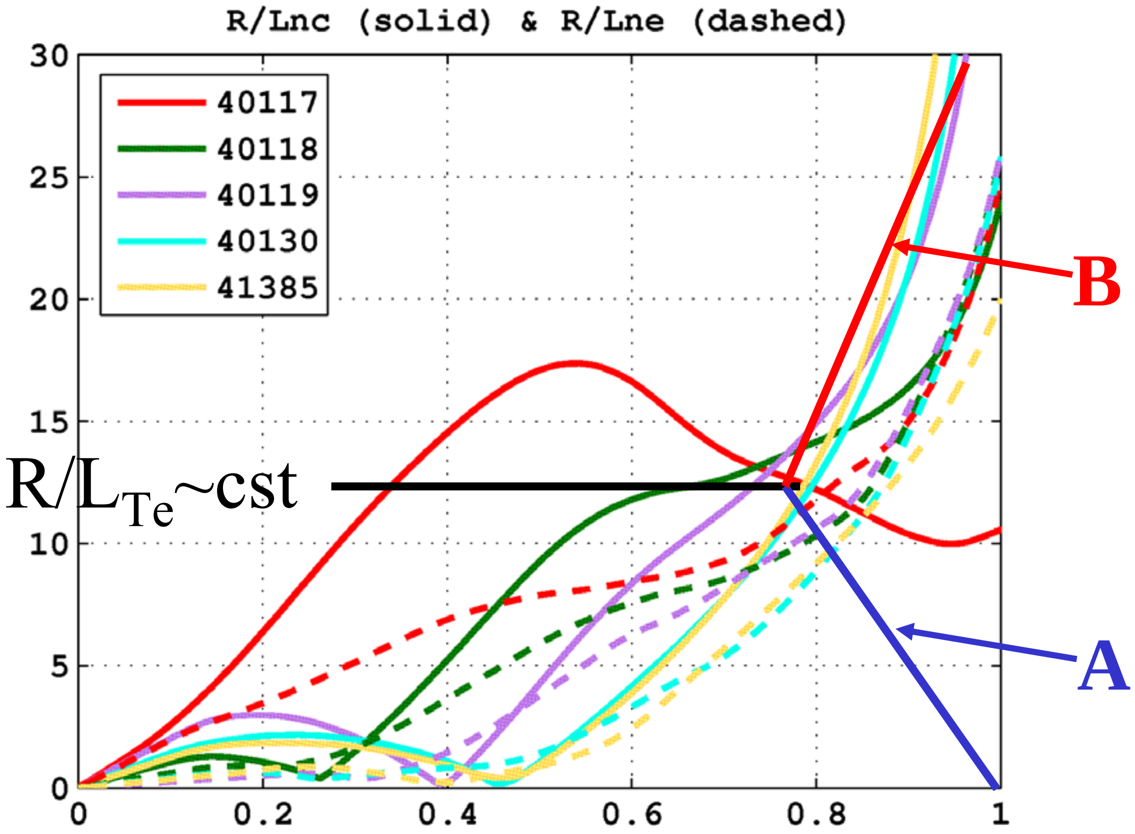


We ∝ Ip

Profiles self-similar outside mixing radius

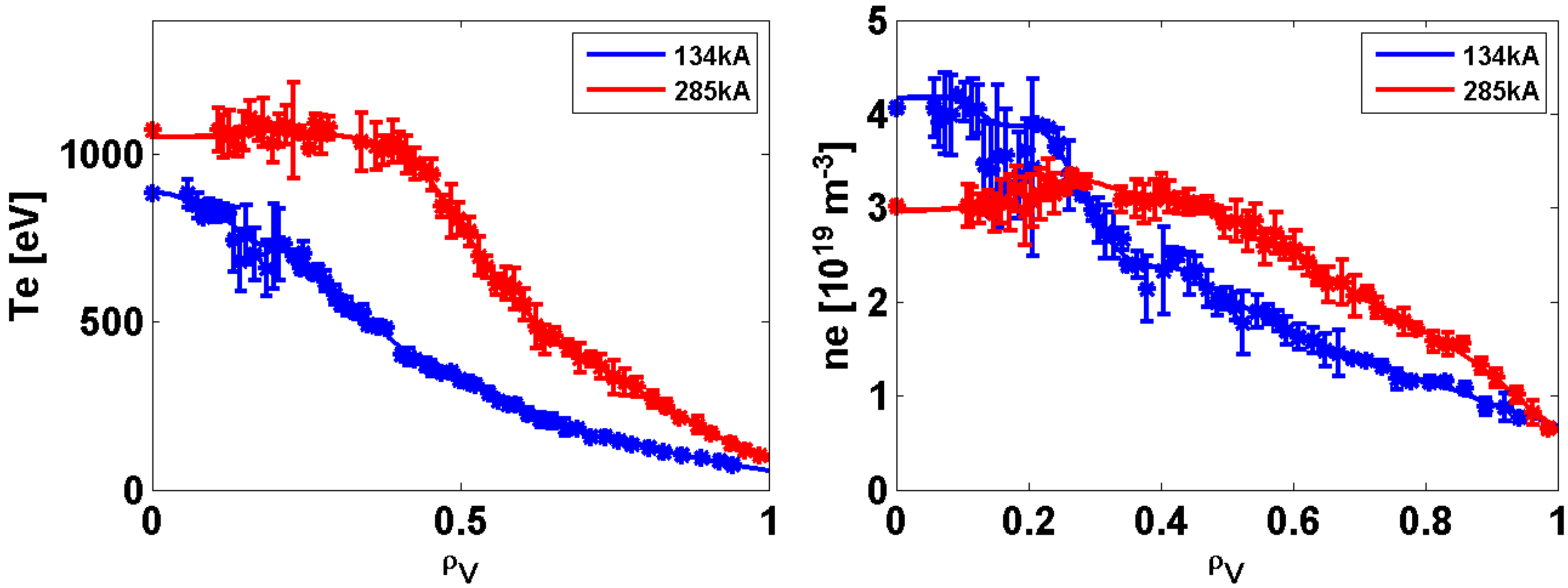
Ip scan: q_{95} from 2.5 to 10

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



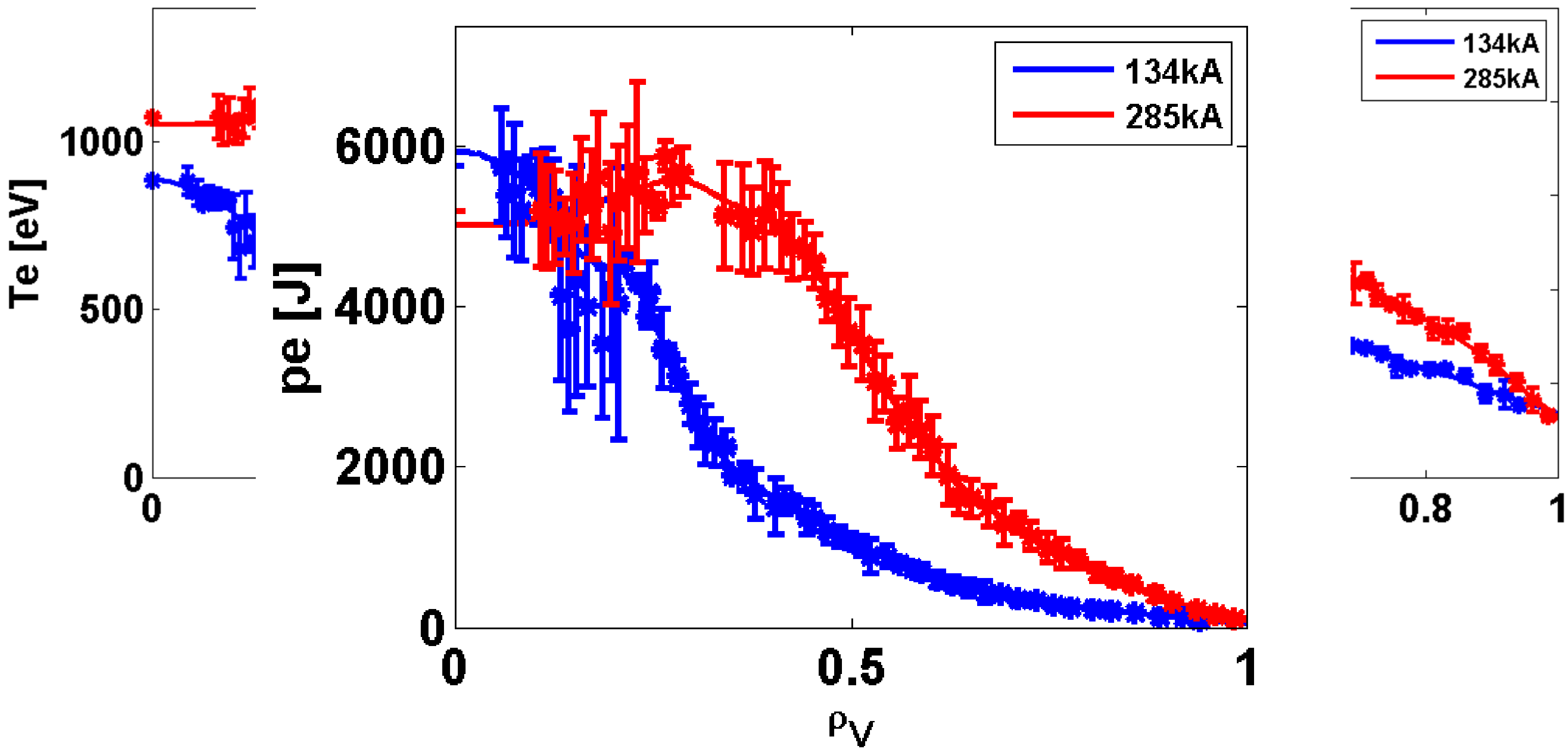
- A: $R/L_{Te} \rightarrow 0$ at $\rho=1$: Used in most simulations
- B: R/LTe →3-10*(core) at $\rho=1$: seems proposed by expt

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



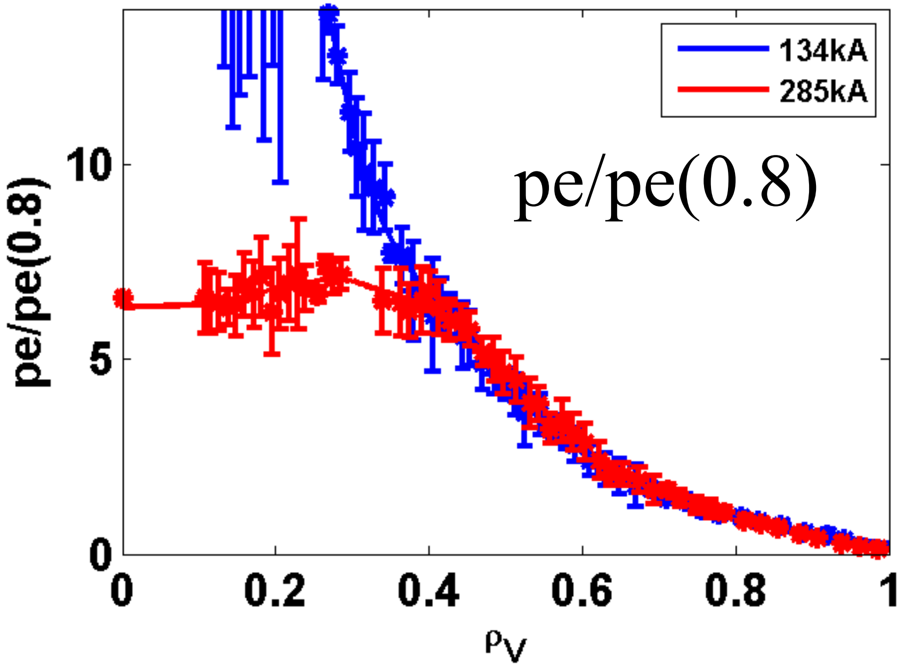
Thomson data, with slow z-axis sweep

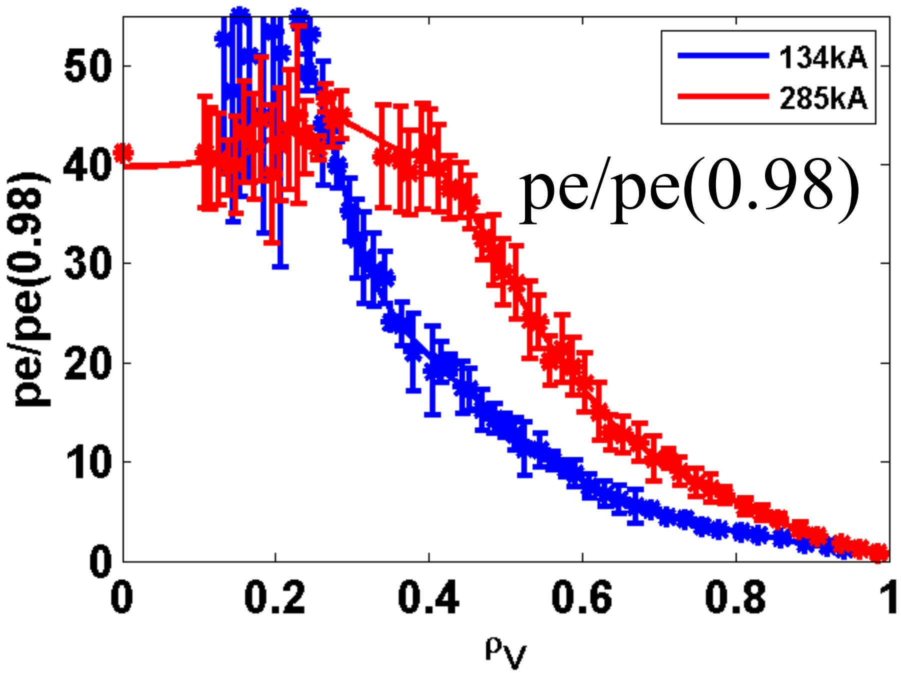
n_e, T_e versus I_p in TCV, with z-axis sweep



Clear increase of total energy with Ip

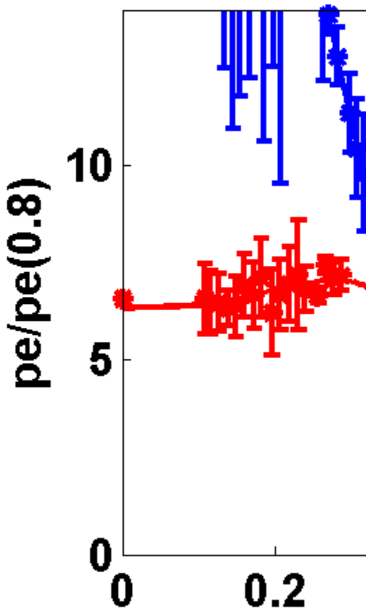
Change of scalelengths only for ρ_V>0.85

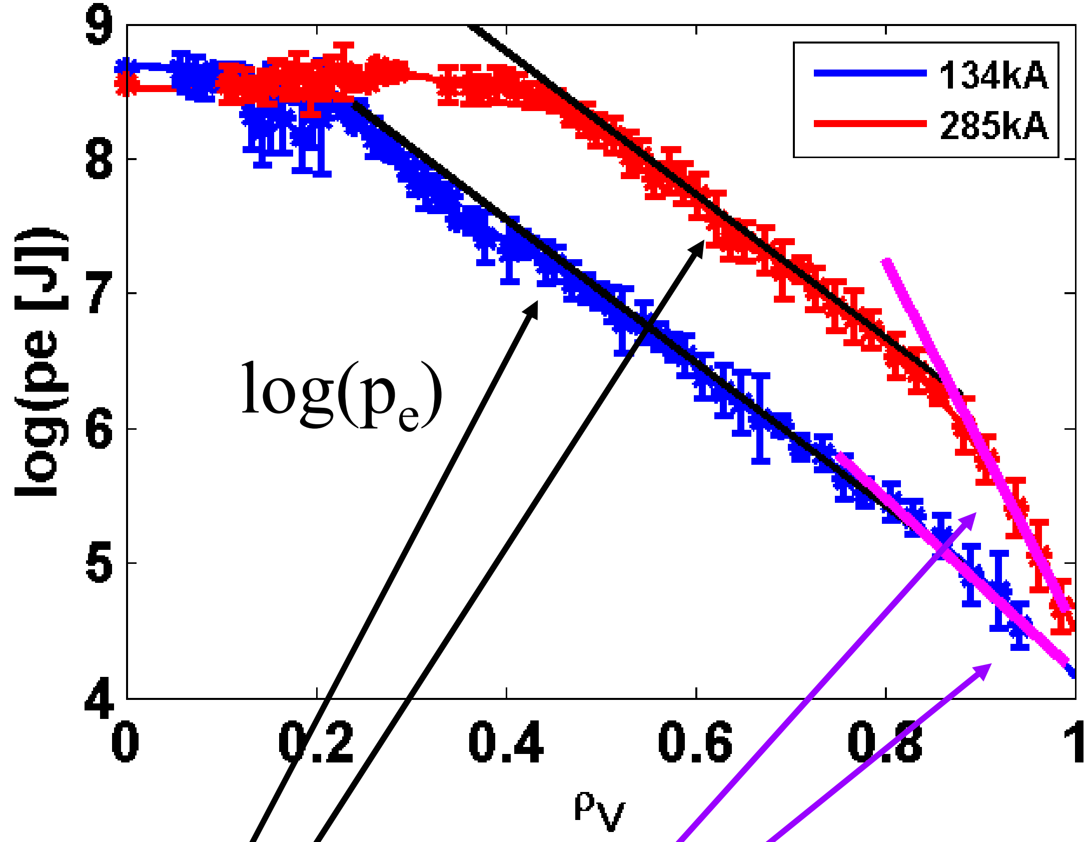


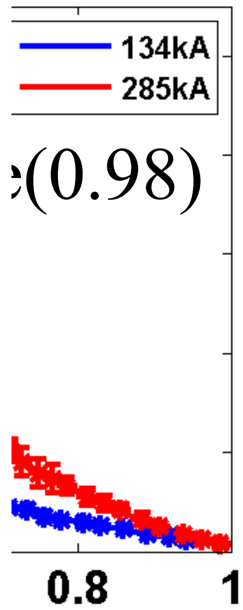


- Normalization vs value at ρ=0.8 is not a good idea
- Normalizing at ρ=0.98 depends on the quality of fit

Change of scalelengths only for ρ_V>0.85







:(0.98)

•Norm … idea

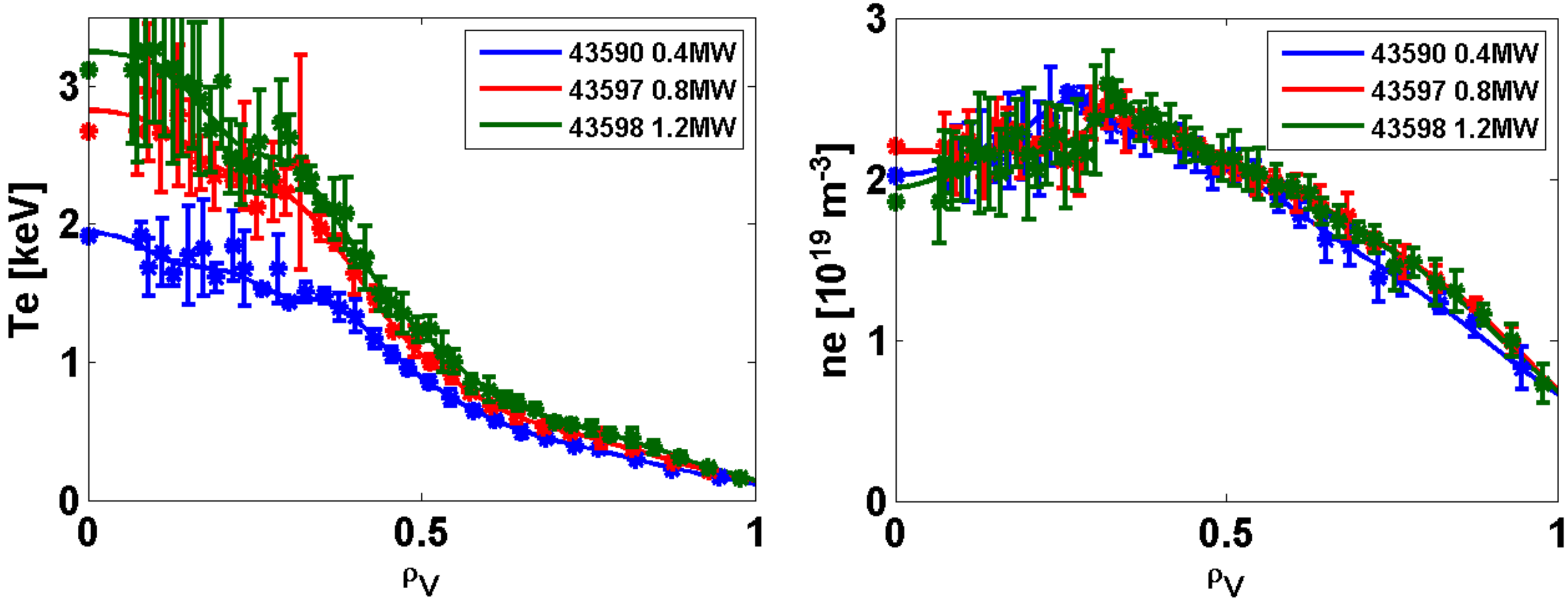
•Norm … of fit

R/Lpe identical in core

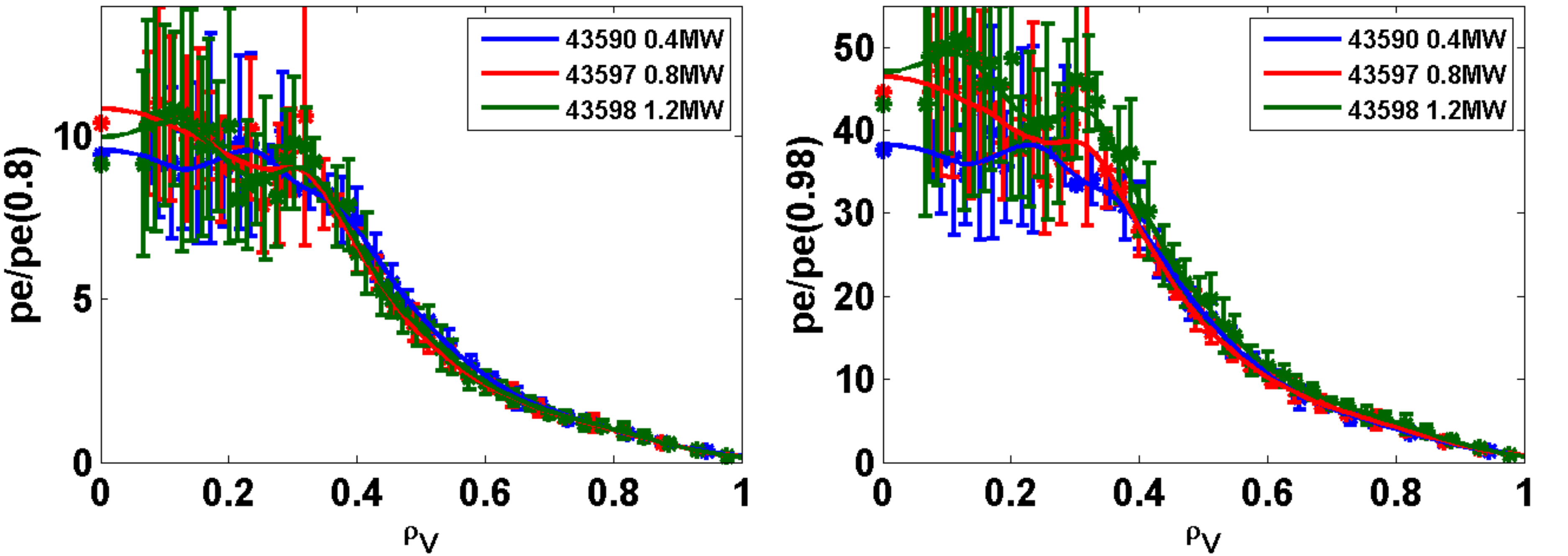
R/Lpe ∝ Ip for ρ_V>0.8 ***(x2.6>core at Ip=285kA)***

Note: ρ_ψ too narrow edge region

PEC scan at constant Ip

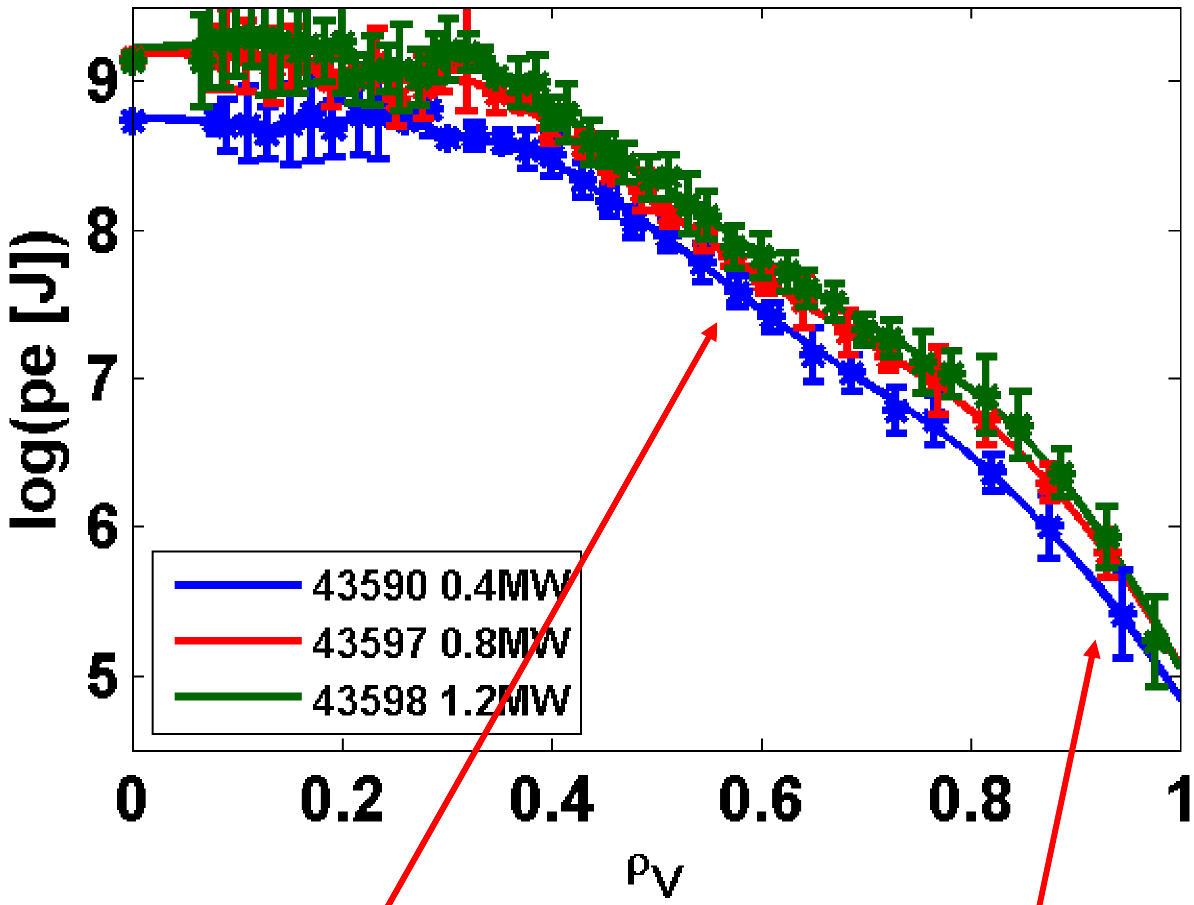


PEC scan at constant Ip



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

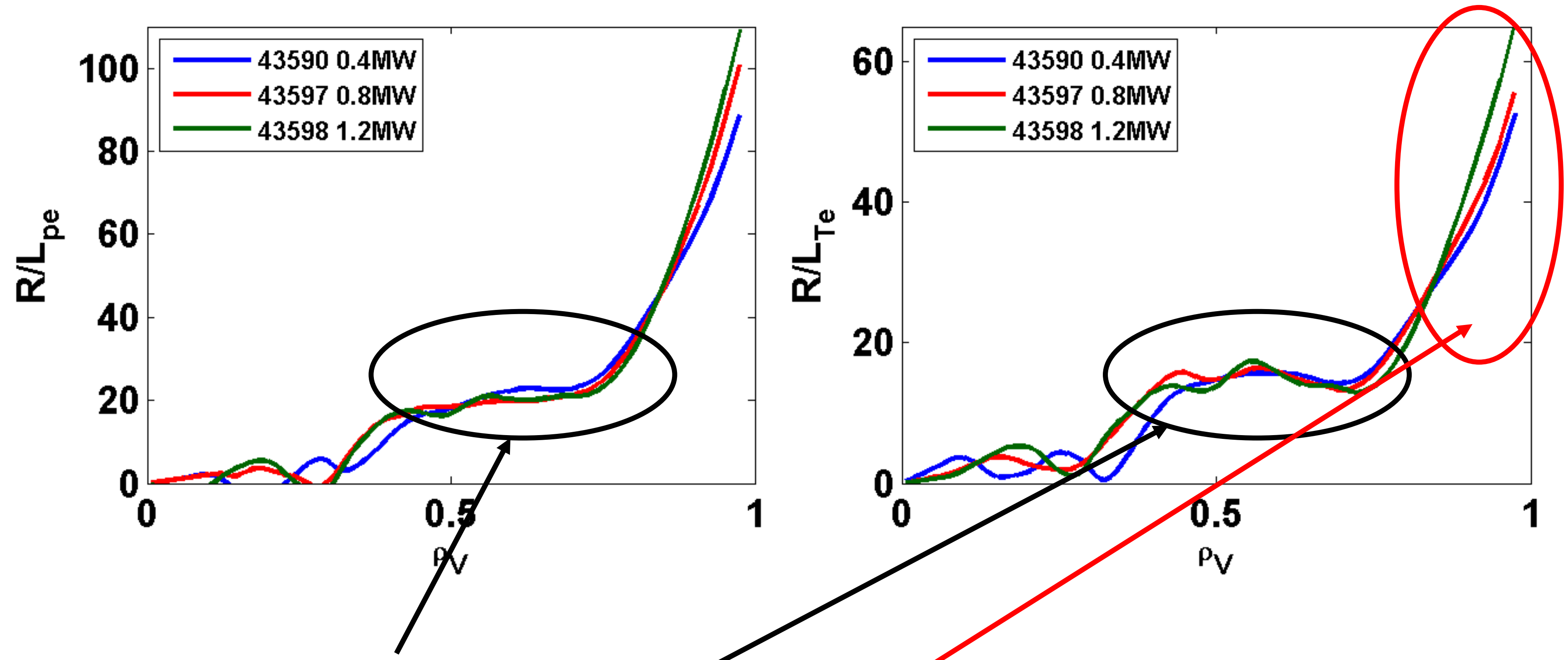
PEC scan at constant Ip



Stiff in core

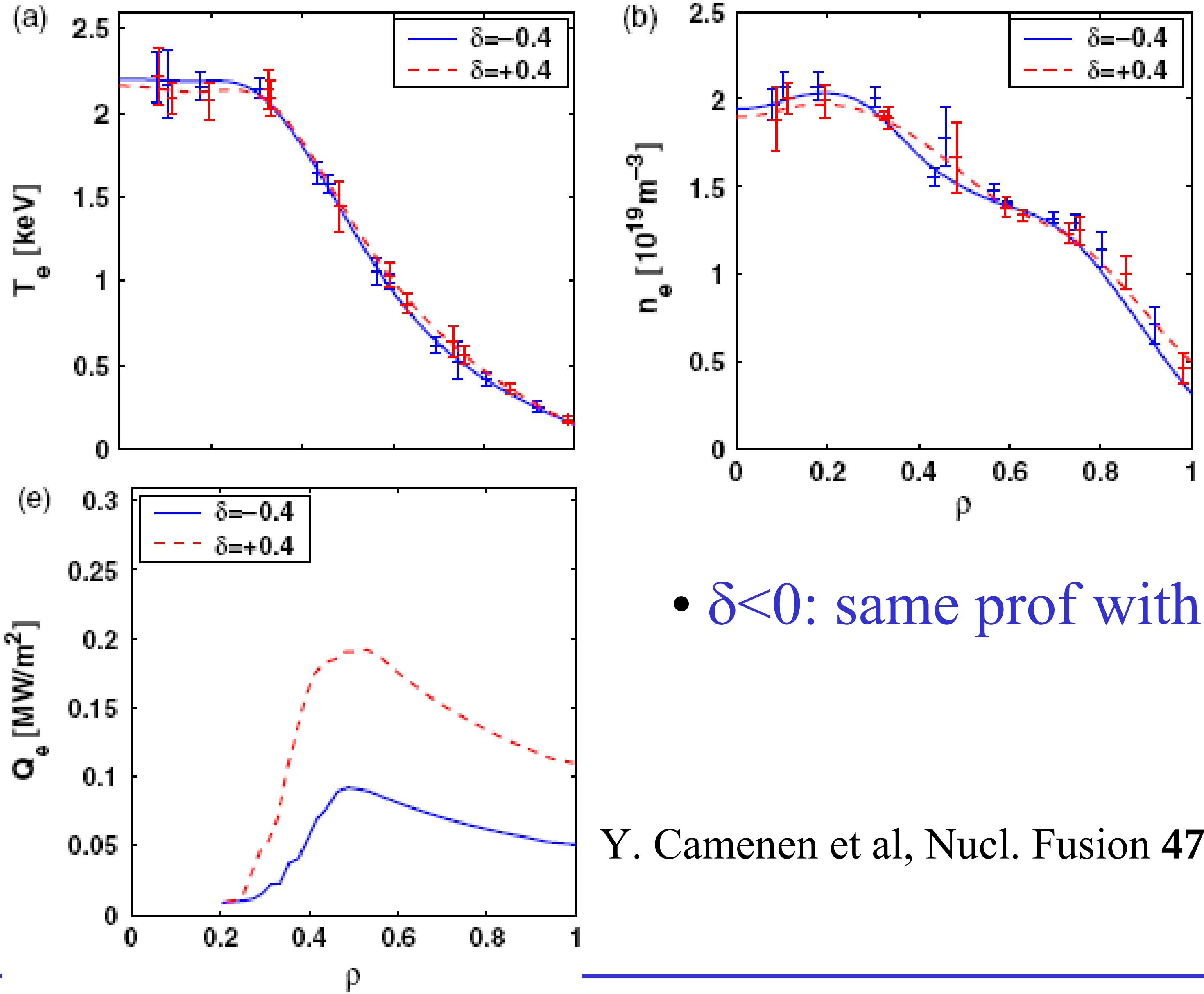
non-stiff in edge

P_{EC} scan at constant Ip



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

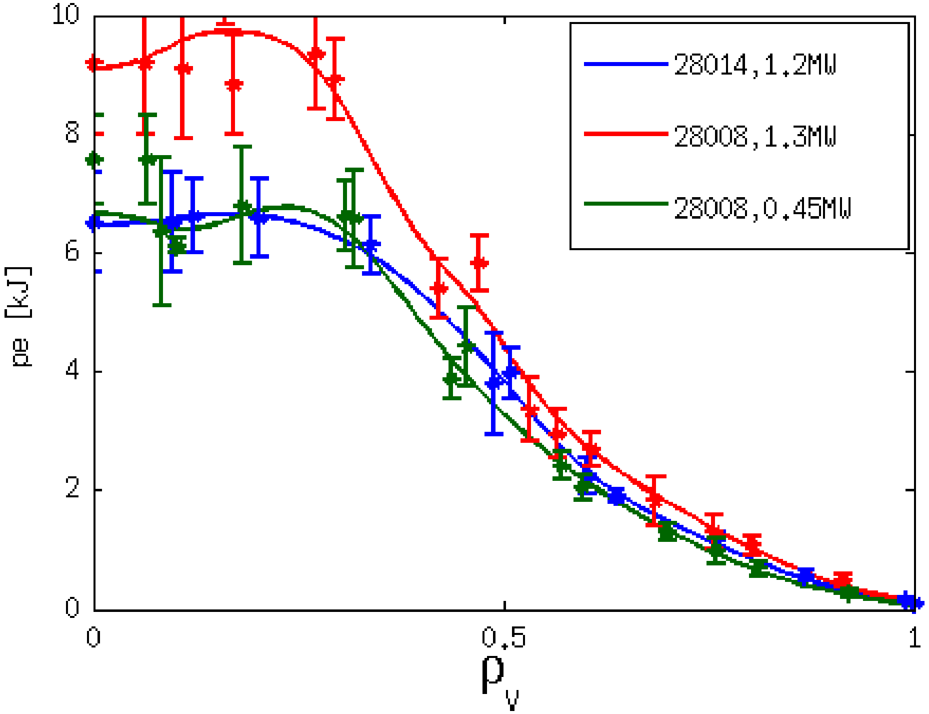
Strong effect of δ on global profiles

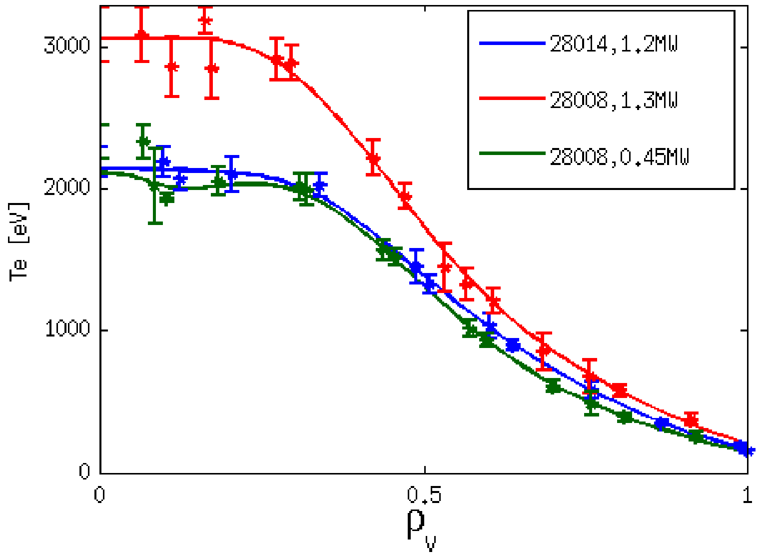


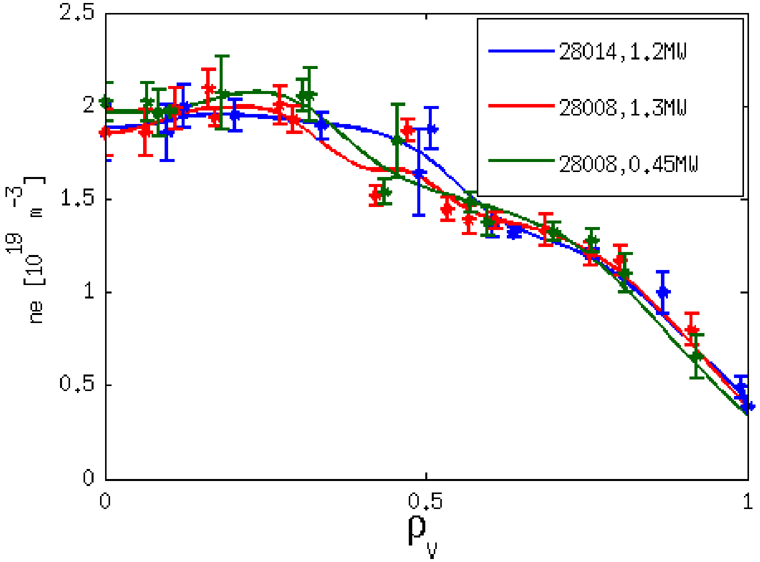
- δ<0: same prof with ½ P_{EC}

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:

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

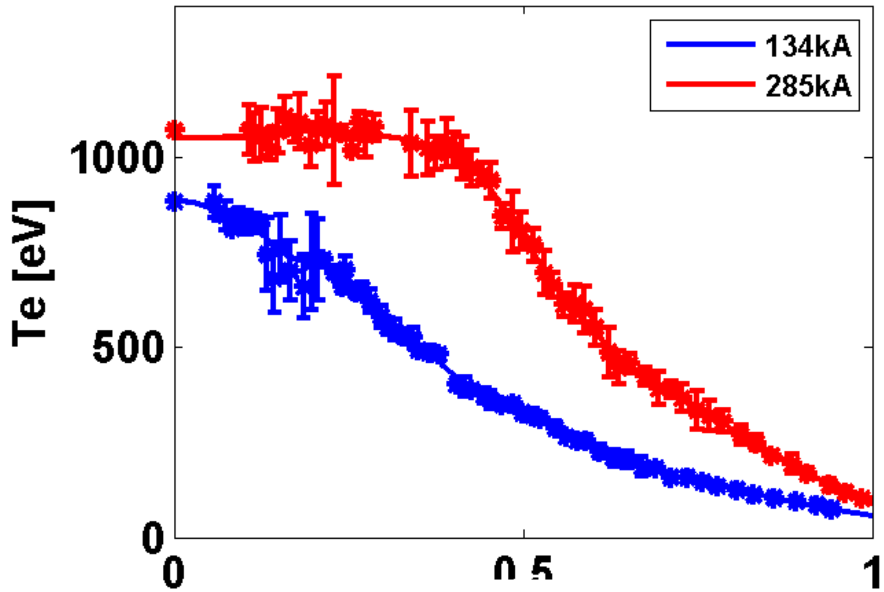
$$V' = \frac{\partial V}{\partial \rho} \qquad\qquad \frac{R_0}{L_{Te}} = -\frac{R_0}{T_e}\frac{\partial T_e}{\partial \rho}\left\langle |\nabla\rho| \right\rangle$$

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

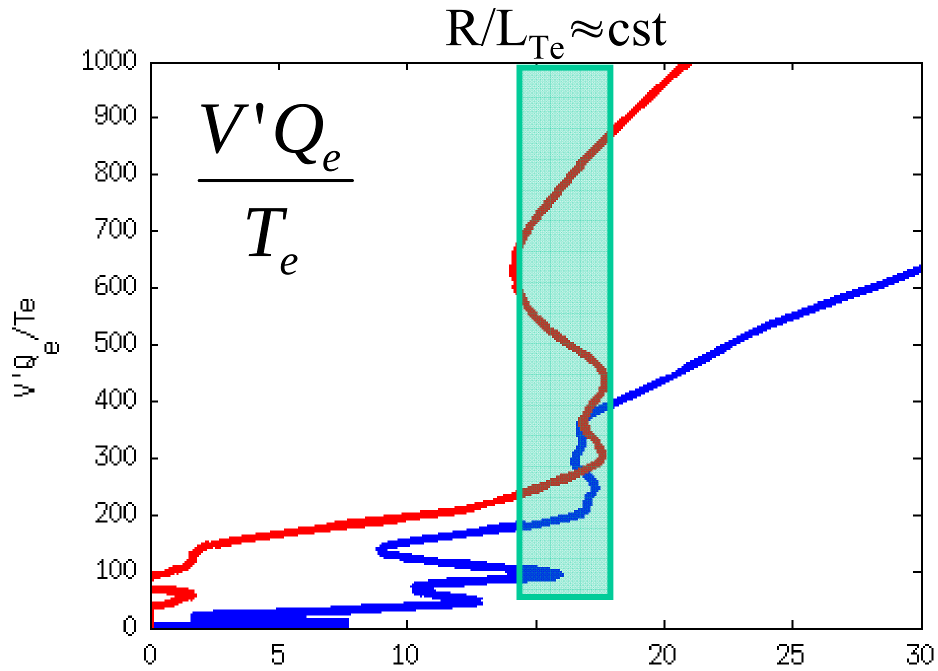
Stiff: χ_e increases when Q_e increases => $R/L_{Te} \approx$cst

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}

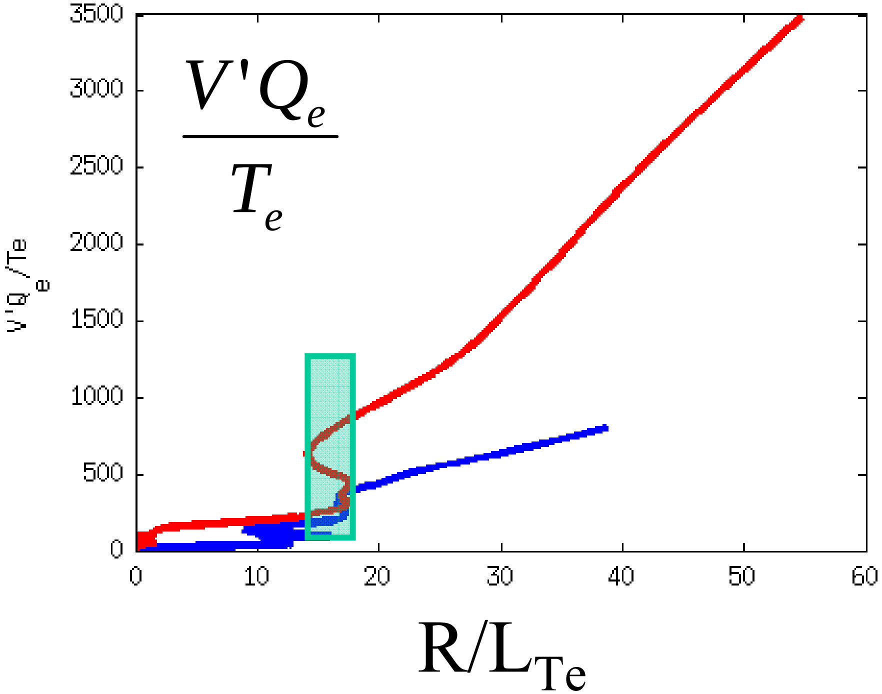


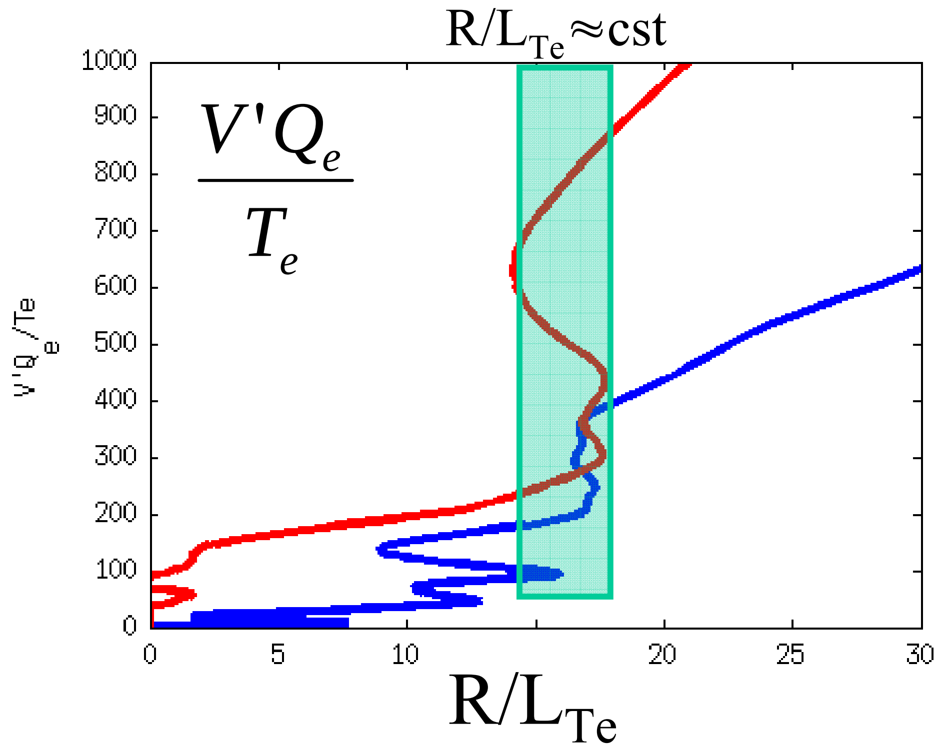
R/L_{Te}

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

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

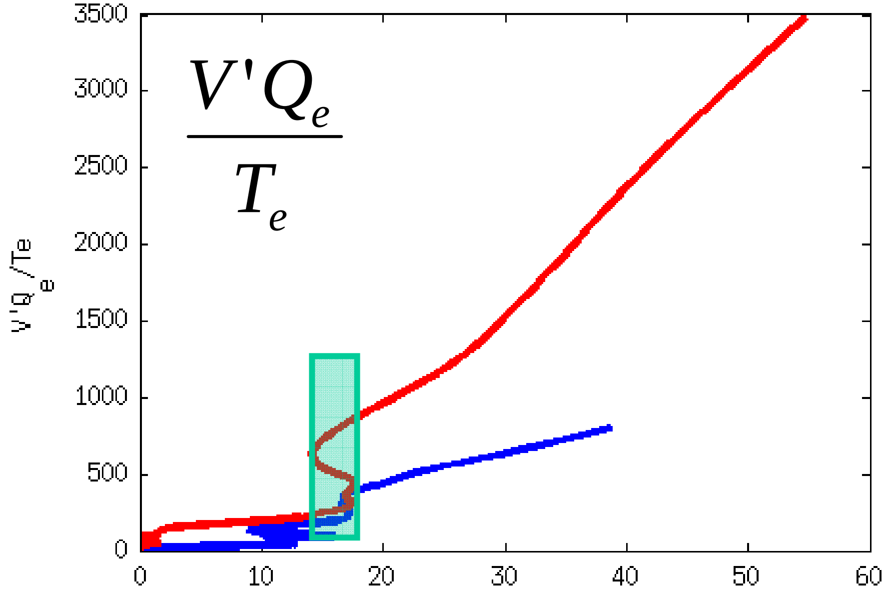




X_e(edge) is large but it is relation between Q_{e_norm} and R/L_{Te} which matters

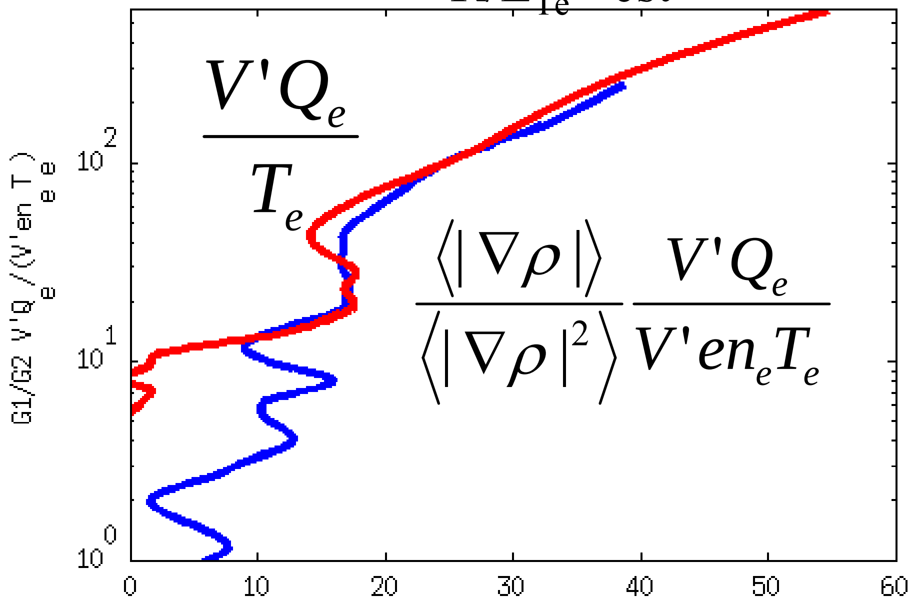
Qe/Te versus R/LTe from TCV data

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



R/L_{Te}

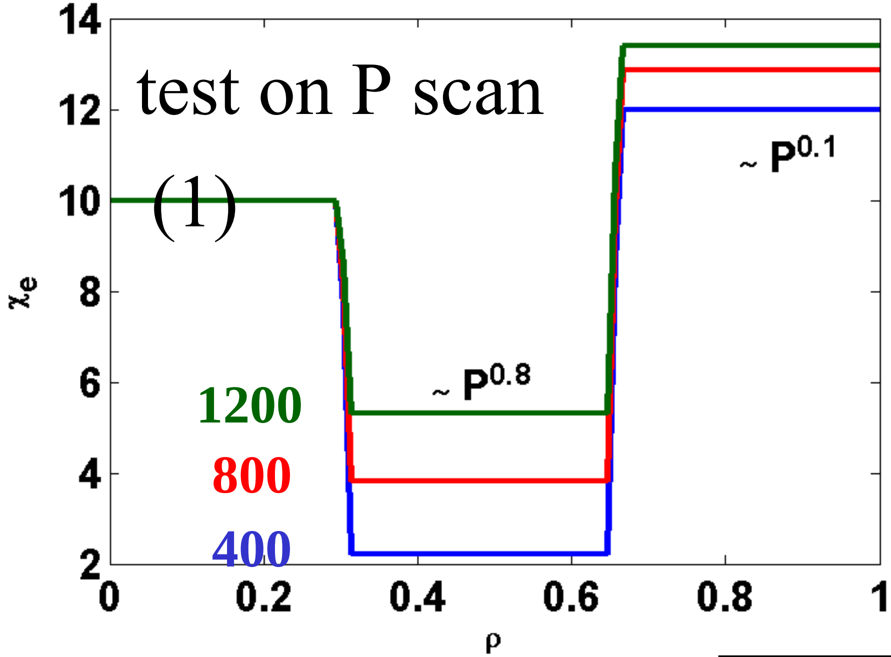
R/L_{Te}≈cst



R/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:

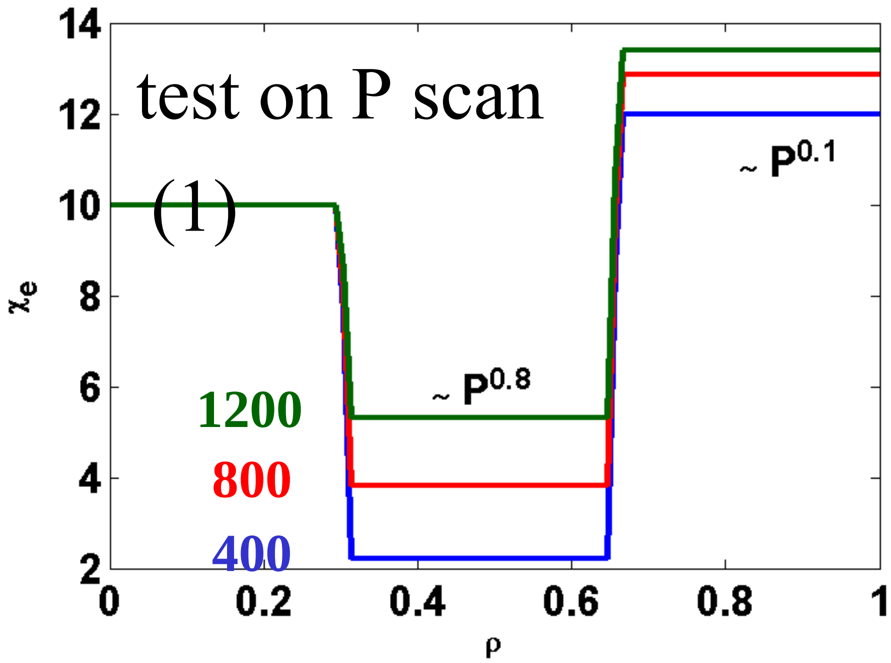
$$(3)\quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0-0.2}$$

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

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

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



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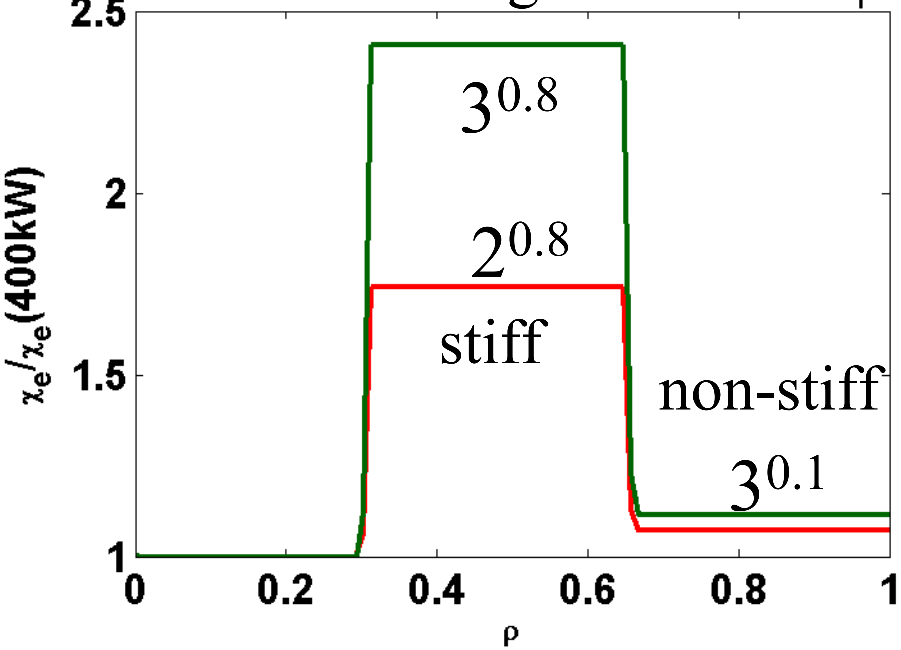
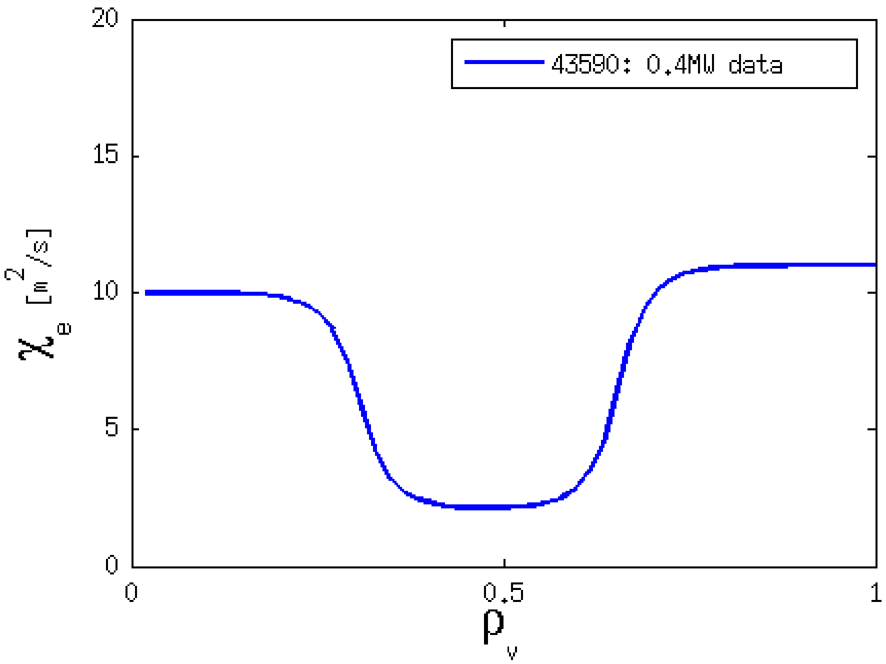
Assuming edge non-stiff:

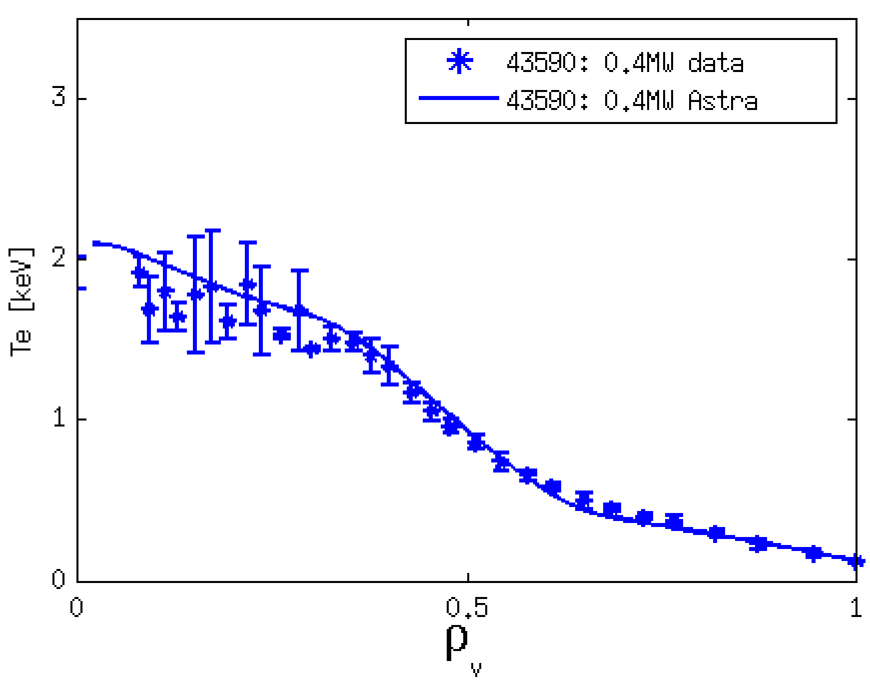
$$(3)\quad \chi \propto \frac{a^2}{\tau_E} \propto P^{0-0.2}$$

Leads to strong diff. with P↑



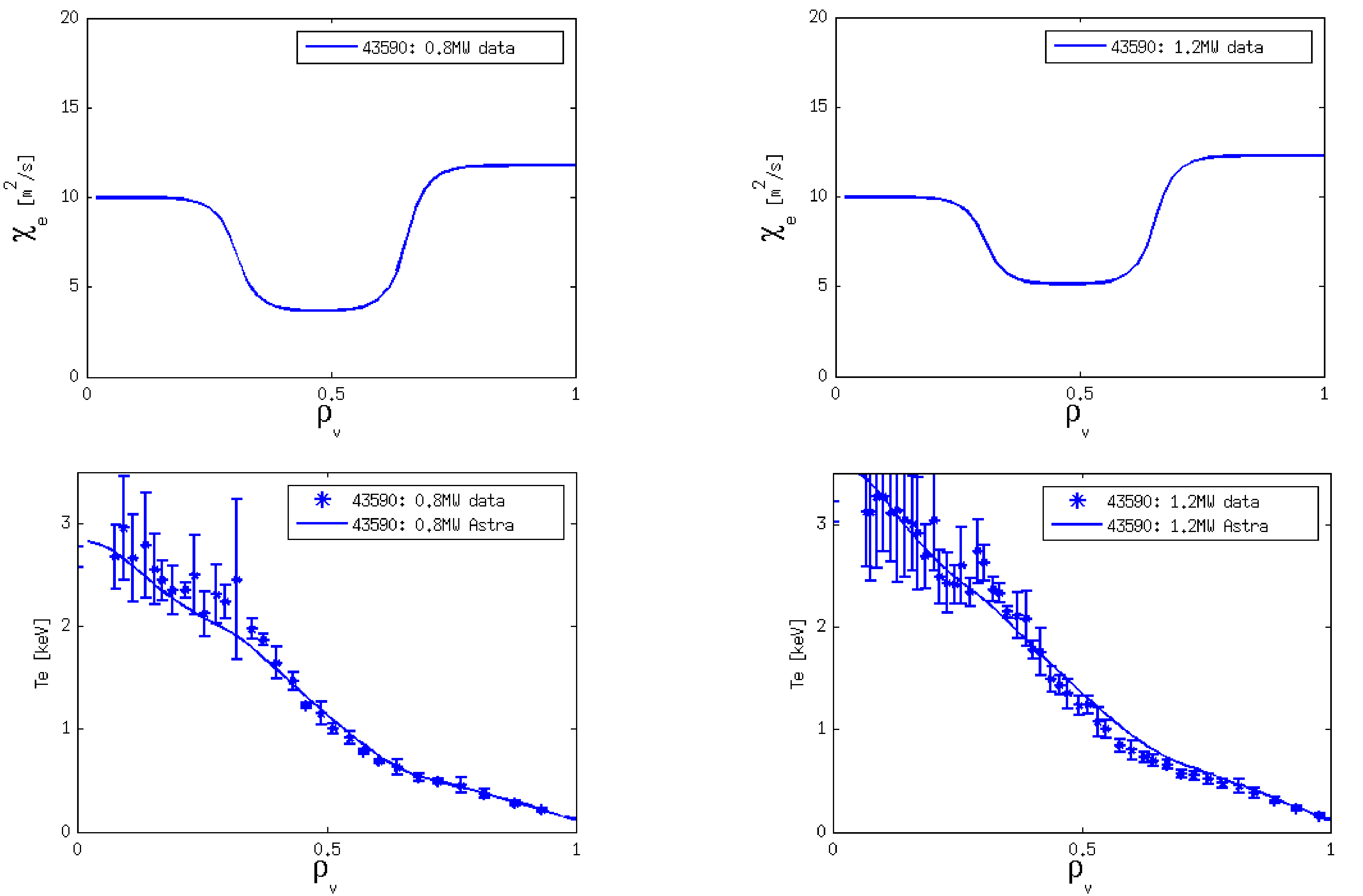
Results using 1-D ASTRA model



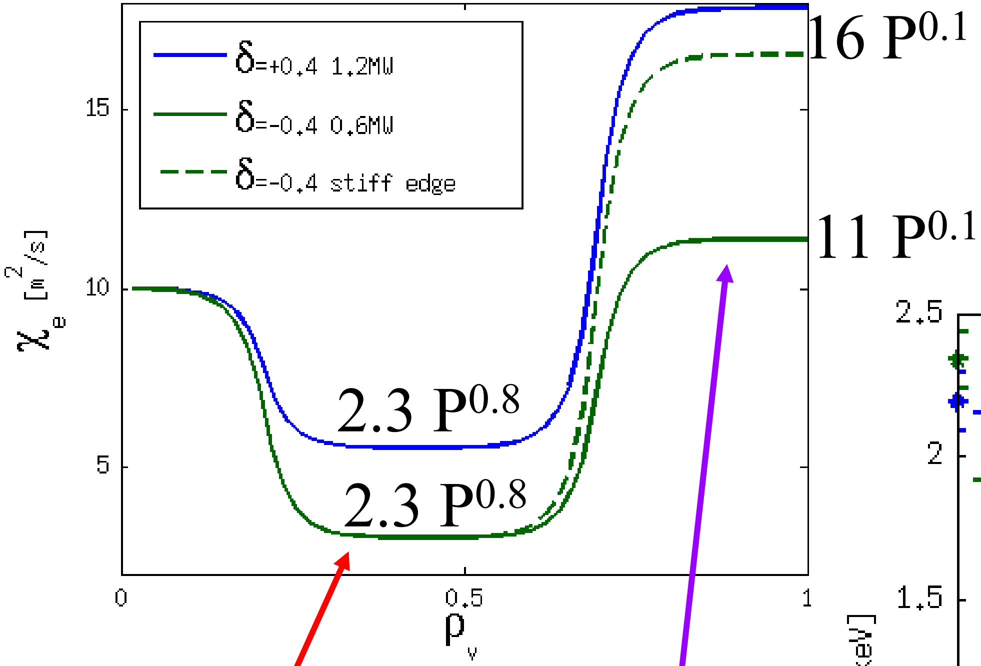


- We start from this χ_e profile and other plasma parameters
- Scale core $\chi_e \sim P^{0.7}$ and edge with $P^{0.1}$

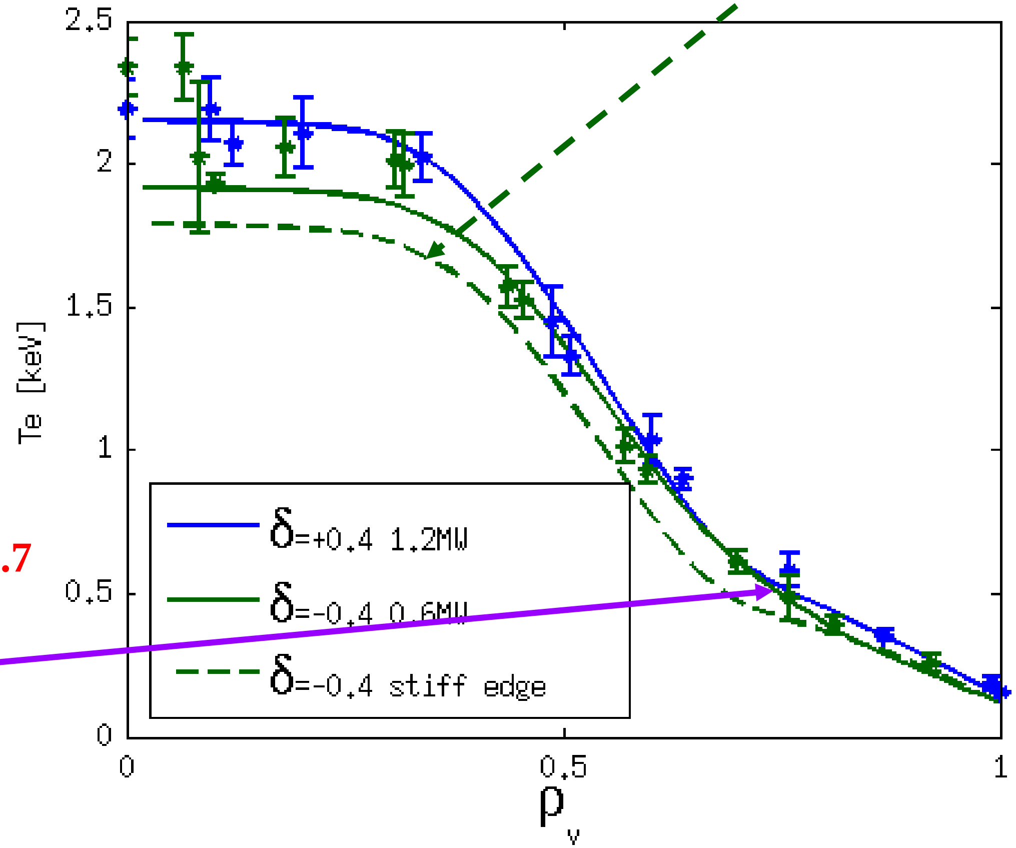
Results using 1-D ASTRA model



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



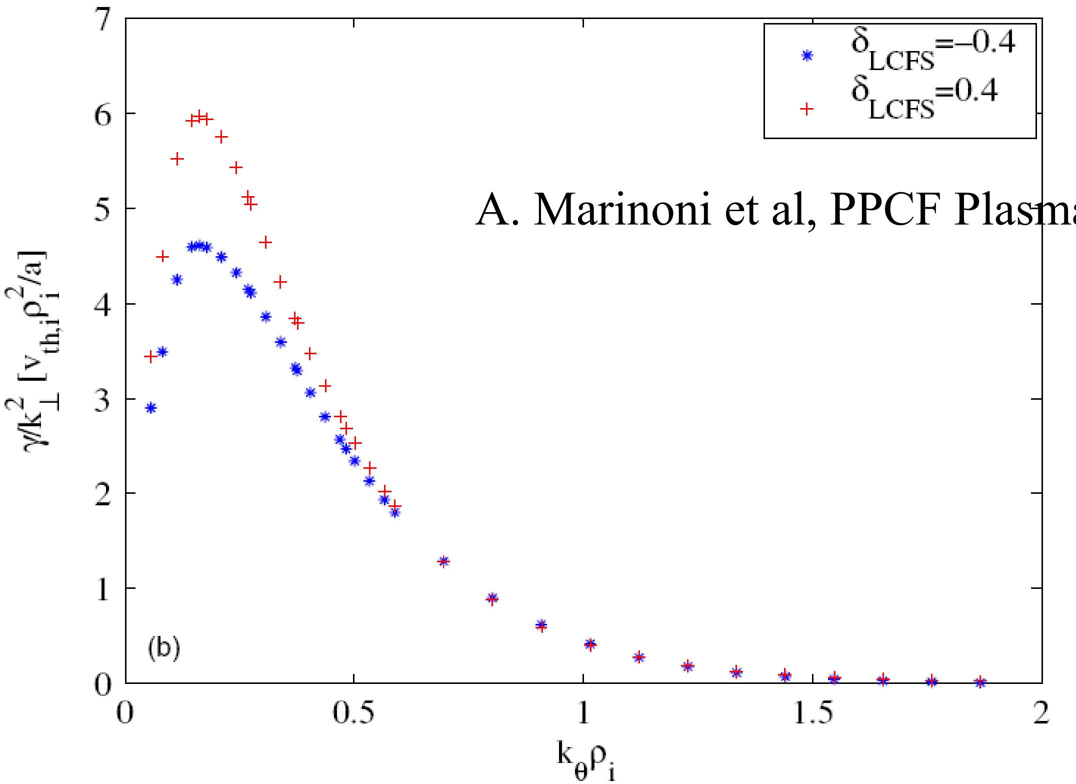
Stiff edge not sufficient



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