Transport and turbulence reduction with negative triangularity : Correlation ECE measurements in TCV

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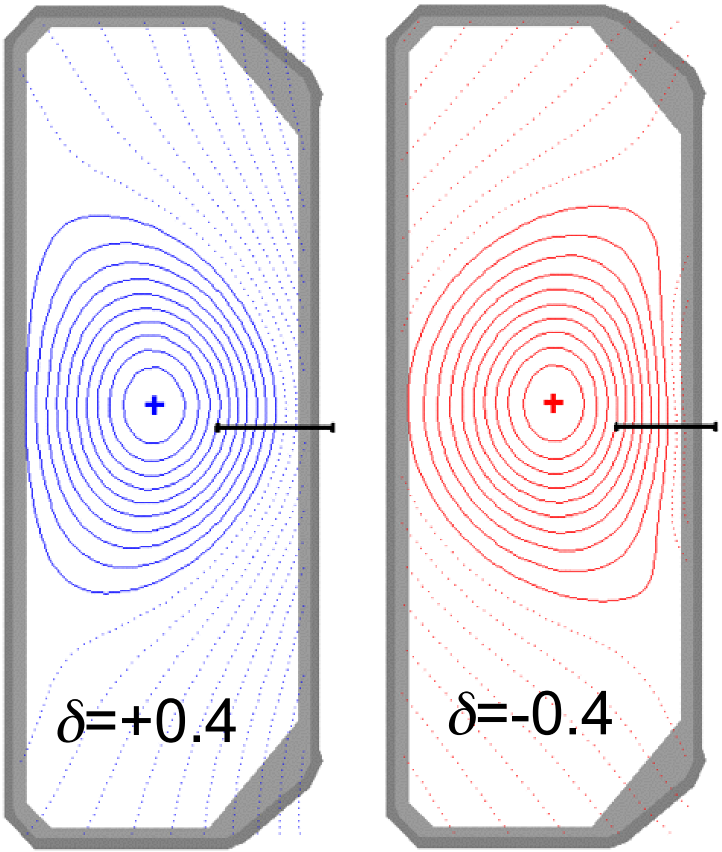
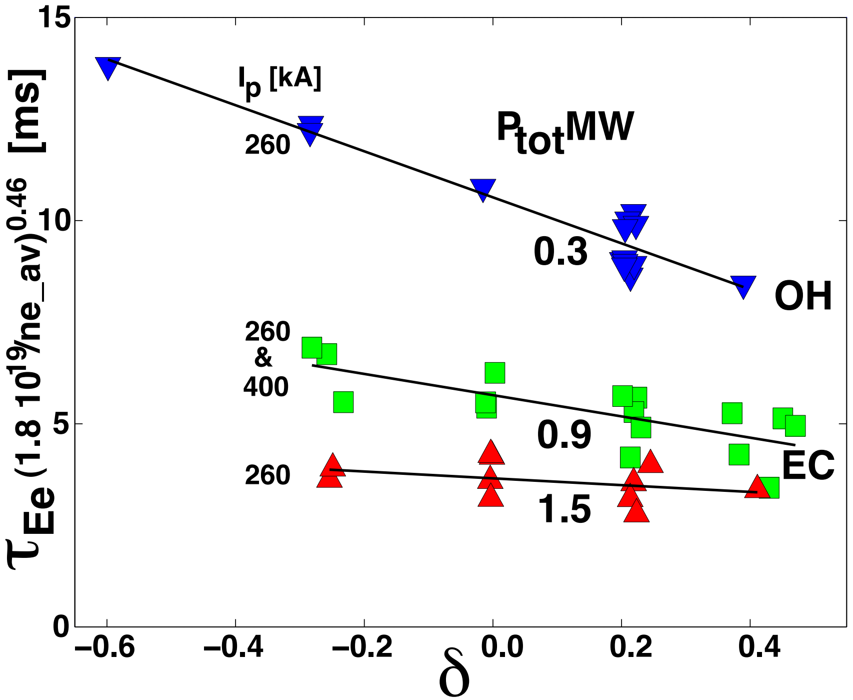
MOTIVATIONS

Why to study also plasma shapes different from ITER?



- A tool for test and validation of transport modeling
- Confinement in the core improves towards negative triangularity (at least in L-mode!)

Energy confinement improves towards $\delta < 0$ (at low $\nu_{eff} \sim 0.2\text{-}1$)

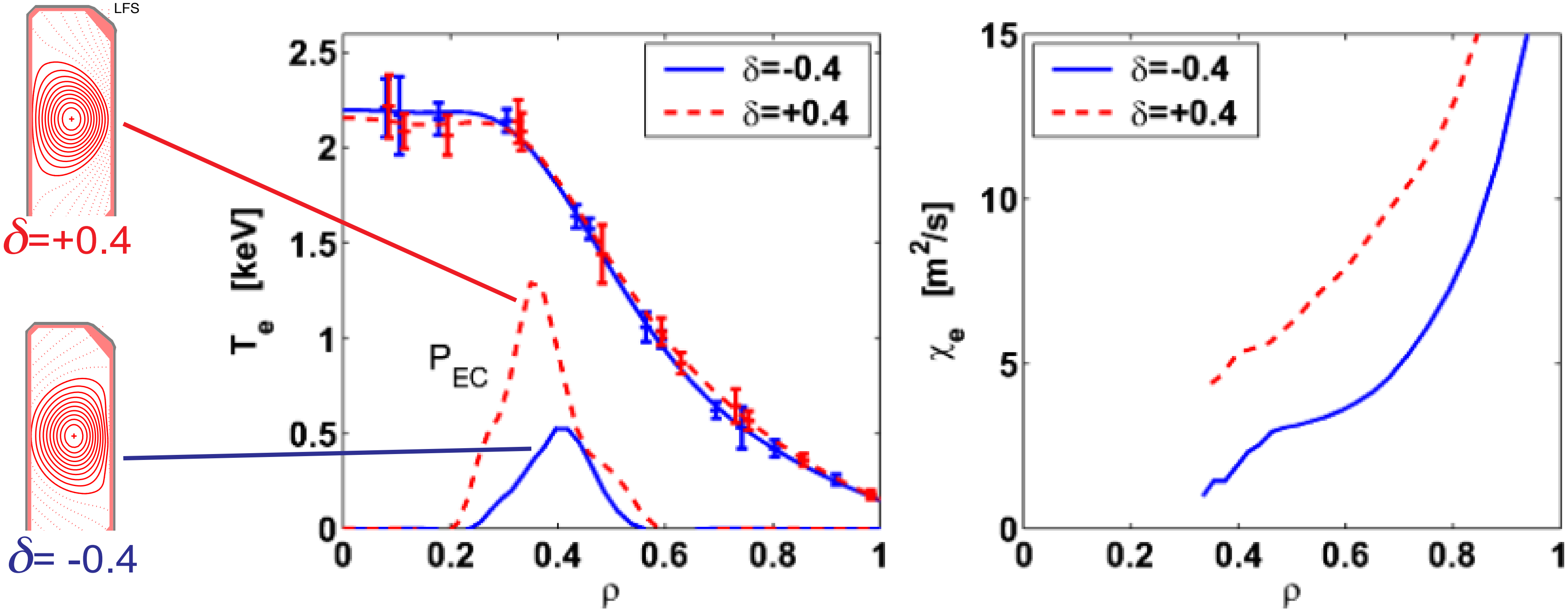


- τ_{Ee} improvement is not explained by gradient geometrical (=shape) factor,
  -> *χ_e is thus varying with triangularity*

- Plasma conditions:
  low density ECH plasmas,
  high R/L_{Te}>7 and T_e/T_i,
  low collisionality ν_{eff}
  -> ***TEM** dominated regime*
  (no ETG due to high Z_{eff} & T_e/T_i,
  in range $0.2<\rho<0.7$)

Coda 98, Pochelon NF99 & EPS99, Weisen NF98

Energy transport reduces by a factor 2 towards $\delta < 0$



Two shapes, $\delta = \pm 0.4$:

Expt. 1: adapting the power at $\delta = -0.4$ to keep the same plasma energy, T_e, n_e and q-profiles than at $\delta = +0.4$:

Only half add. power needed, resulting in χ_e ***halfed*** at mid-radius,

Expt. 2: same powers at $\delta = \pm 0.4$: resulting in ***higher energy & lower χ_e***

OUTLINE

FROM GLOBAL TO LOCAL quantities ...

confinement, transport, turbulence

1. Intro: correlation ECE set-up, effect of collisinality on turbulence
2. Turbulence characteristics with triangularity
3. Global linear gyrokinetic simulations

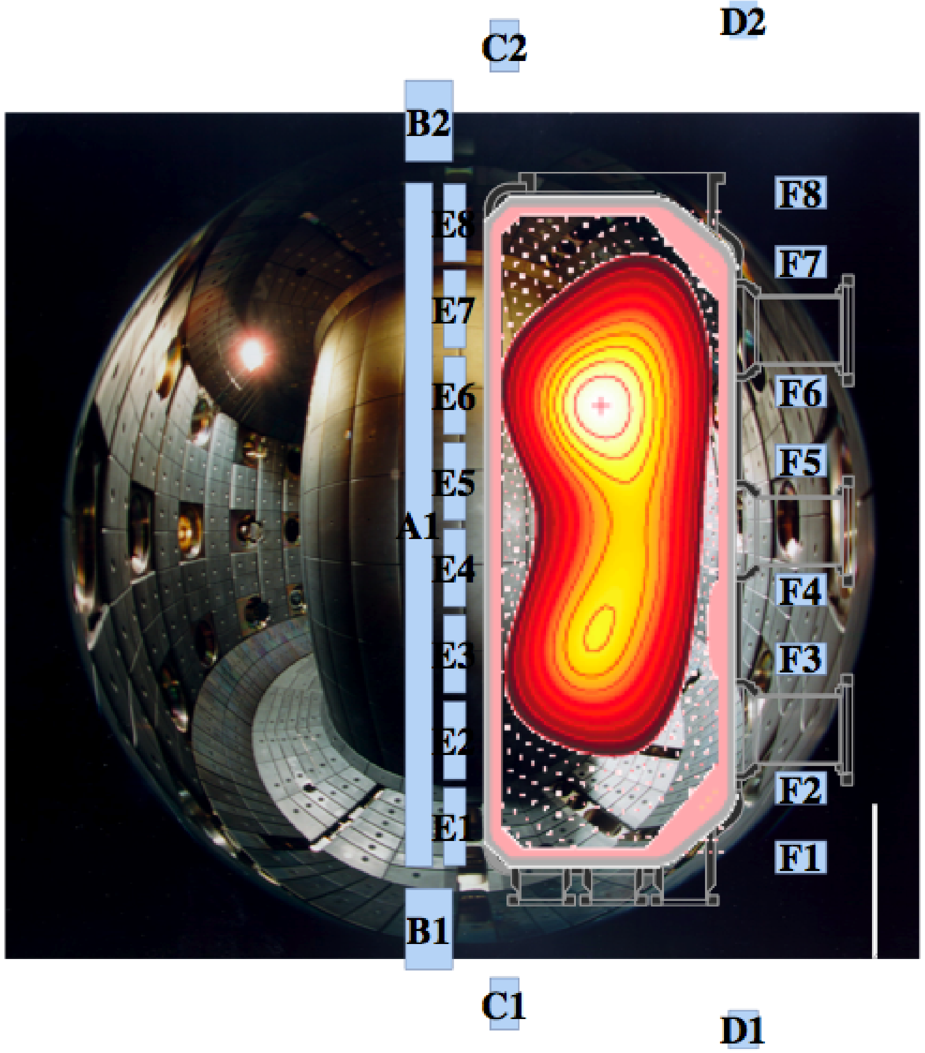
FROM LOCAL TO GLOBAL GK simulations

4. Conclusions and Outlook

TCV facility

TCV:

R = 0.88 m, a = 0.25 m, R/a ~ 3.5
B < 1.5T,
$I_p \leq$ 1MA
elongation 0.9 < κ < 2.8
triangularity - 0.7 < δ < 1
squareness
SN & Snowflake divertor



ECRH:

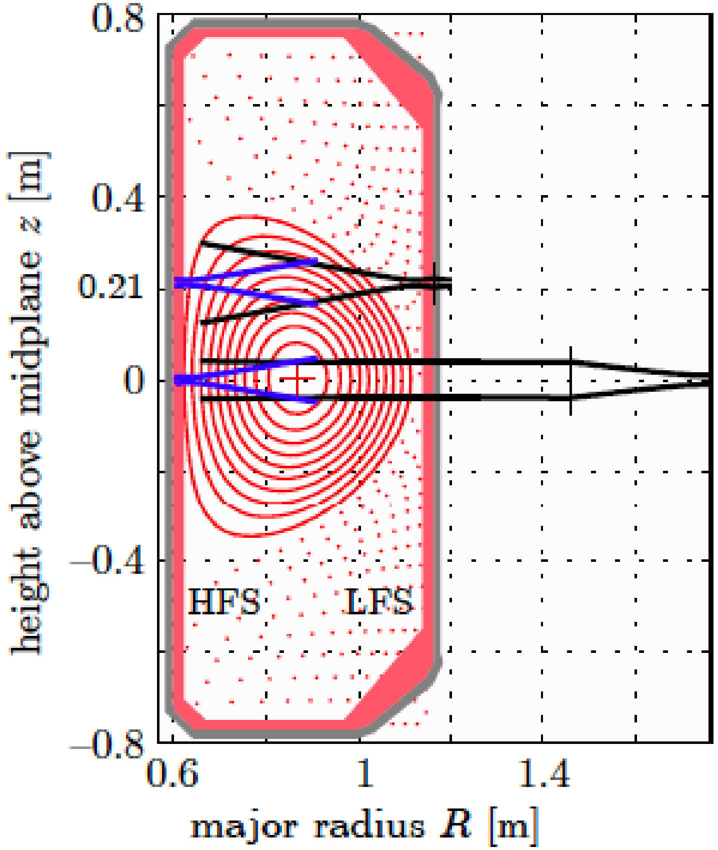
4.5 MW at 2nd and 3rd harmonic

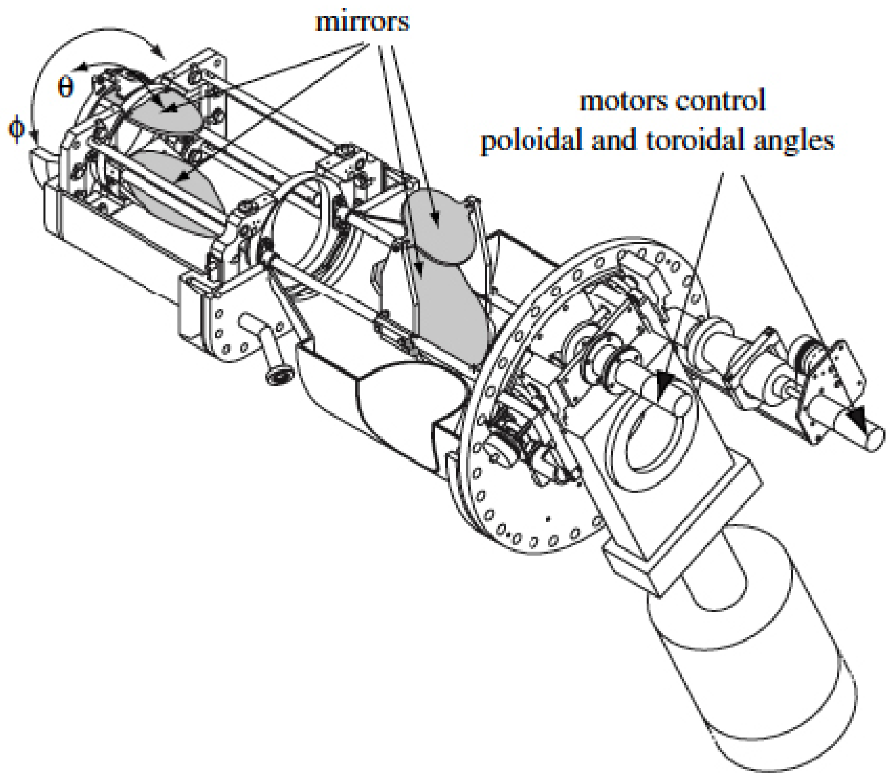
TCV programmatic brainstorming:

15-16 Sept.

Turbulence measurements using ECE

ECE views

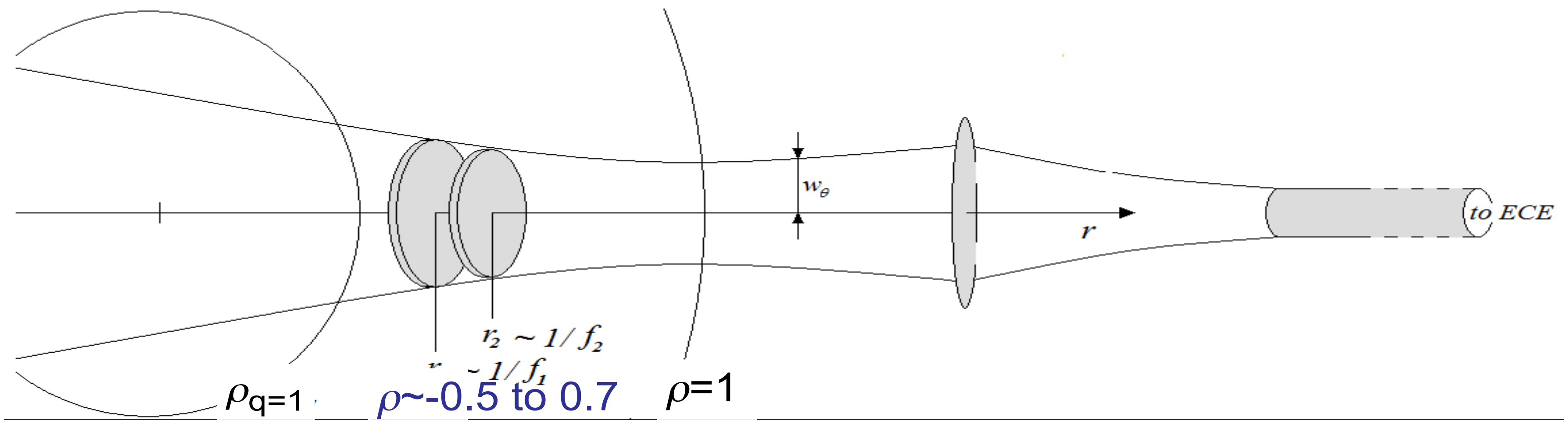




4 normal antennas, equat. LFS with focusing lens

1 sweepable oblique LFS antenna (L7)

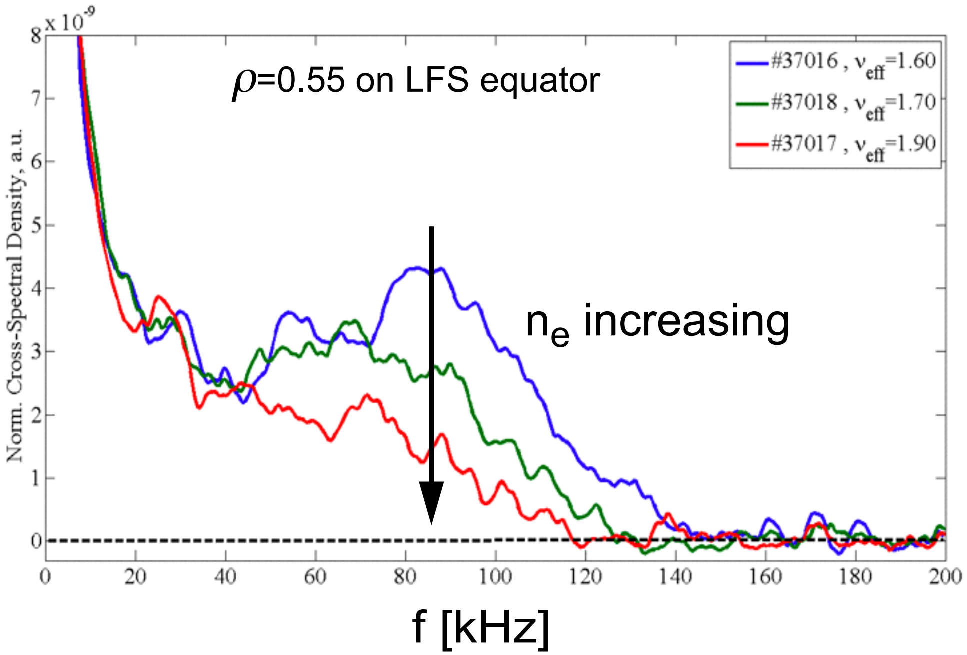
Correlation ECE setup



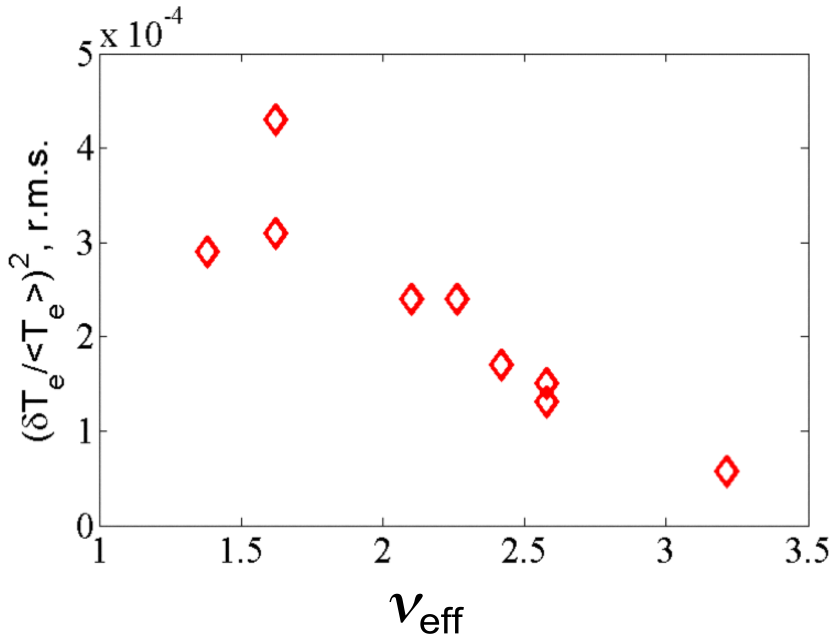
- single Gaussian-beam sight-line measurement from LFS, from 2 narrowband (0.1GHz) *tunable* (61-89GHz) YIG filters, defining two sampling volumes
- focussed beam resolves to $k_\theta \leq 1.4$ cm^{-1}

Fluctuation amplitudes versus collisionality

cross-spectral density (CSD)
decrease with density
Ohmic, q~10, κ~1.4, δ~0.3



fluctuation amplitude
CSD integrated over<30-130kHz>
to avoid MHD-modes



T_e-fluctuation amplitudes decrease with collisionality ν_{eff}

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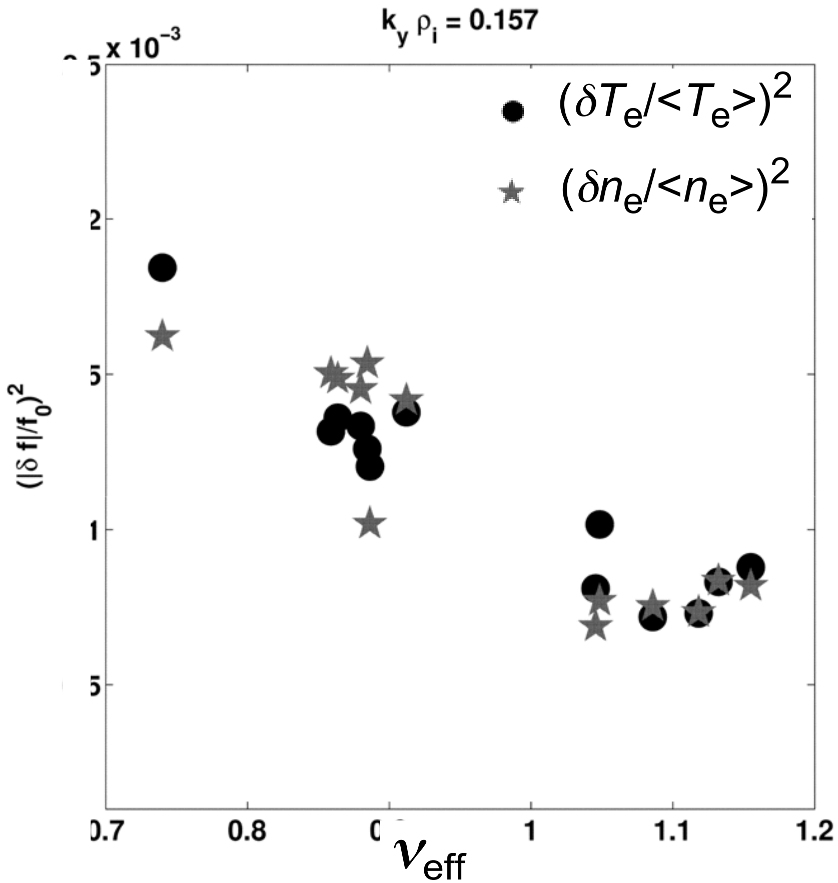
T_e and n_e fluctuations behaviour with ν_{eff} (from GS2 simulations)



Motivation: outer plasma not totally blackbody in for ECE:

- since optical depth at ρ_V=0.55 is < 3, thus measured fluct. attributable to both T_e and n_e

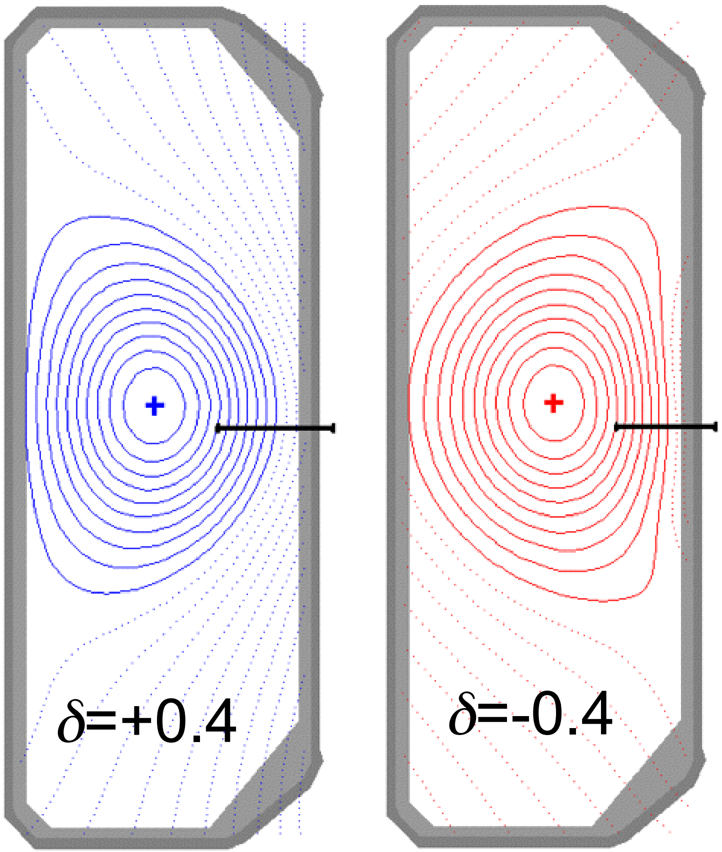
- from GS2:
  - both (T_e,n_e)-fluctuations show *same* trend with ν_{eff}
  - direction of propagation characteristic of TEM

The amplitude reduction with ν_{eff} is also consistent with TEM drive reduction due to TE collisional detrapping

Udintsev, Fable US-TTF09

Triangularity scan

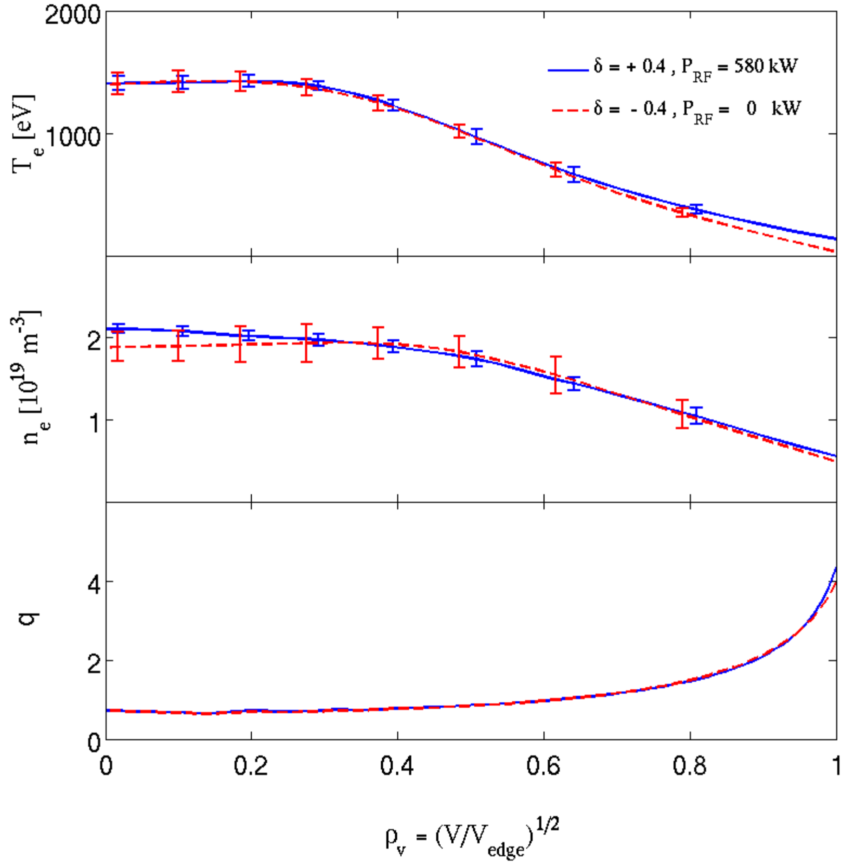
measuring location



ρ_V=0.6 on LFS equator

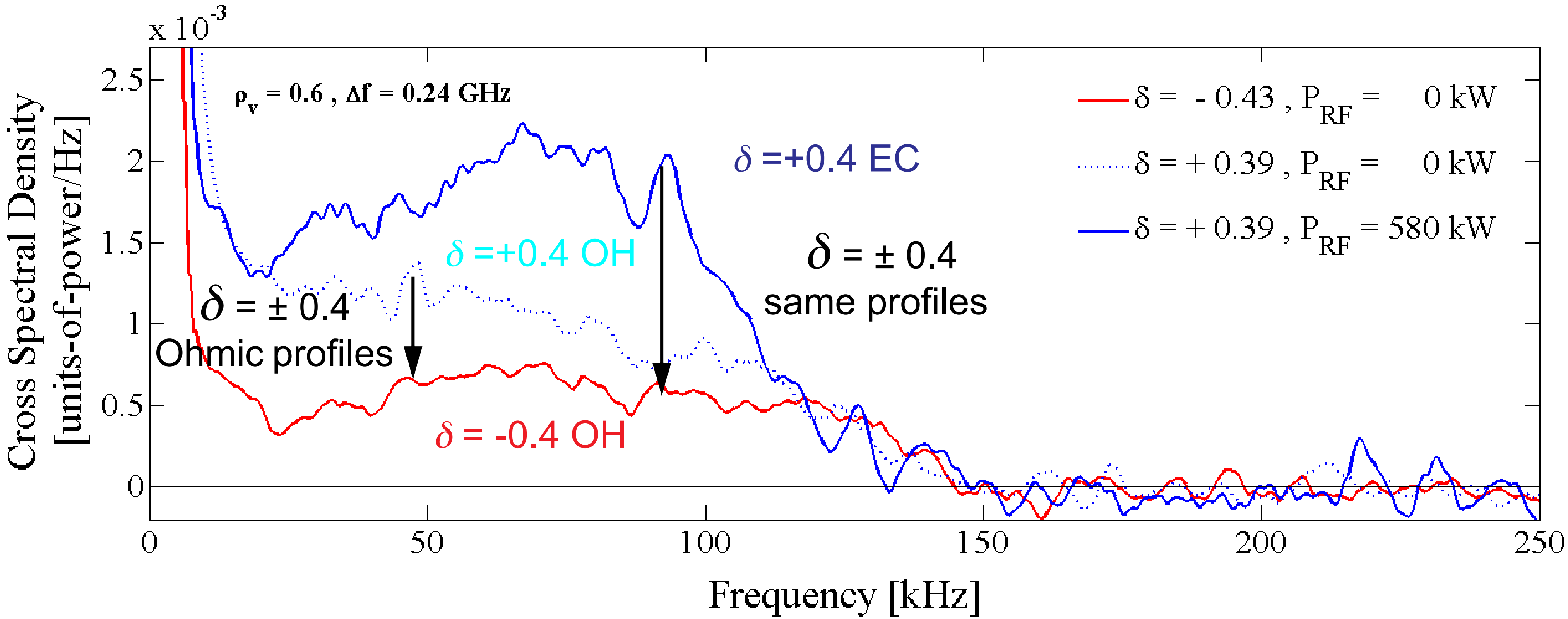
(taking into account varied Shafranov shift in δ=±0.4; significative since CSD doubles each $\Delta R/a$~10%)

profiles



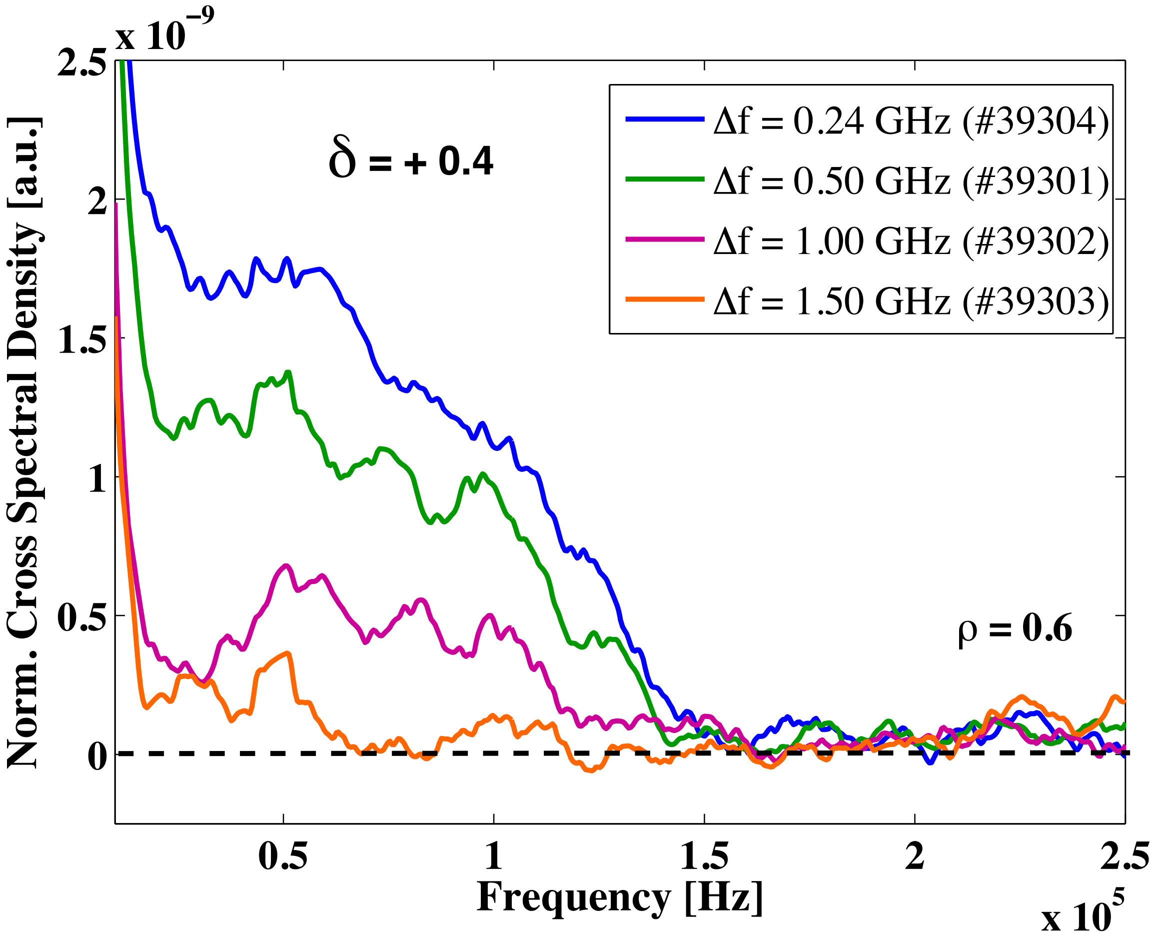
matching δ=-0.4, 250 kW Ohmic profiles by adding 580 kW ECH in δ=+0.4

Cross spectral density : $\delta = \pm 0.4$, OH/EC



CSD reduced towards $\delta < 0$

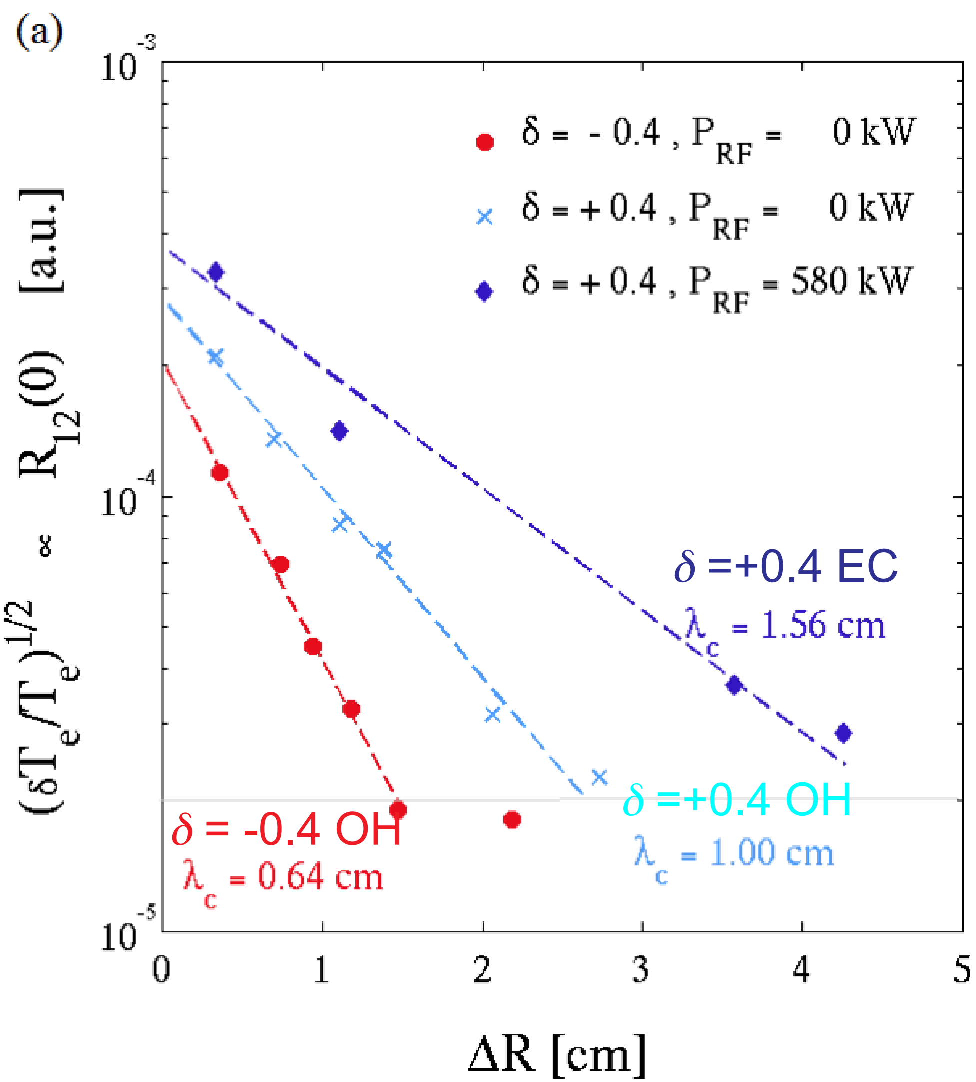
Varying separation of detection volumes



Δf [GHz] - scan, ρ_v~0.6

CSD amplitude decreasing with radial separation

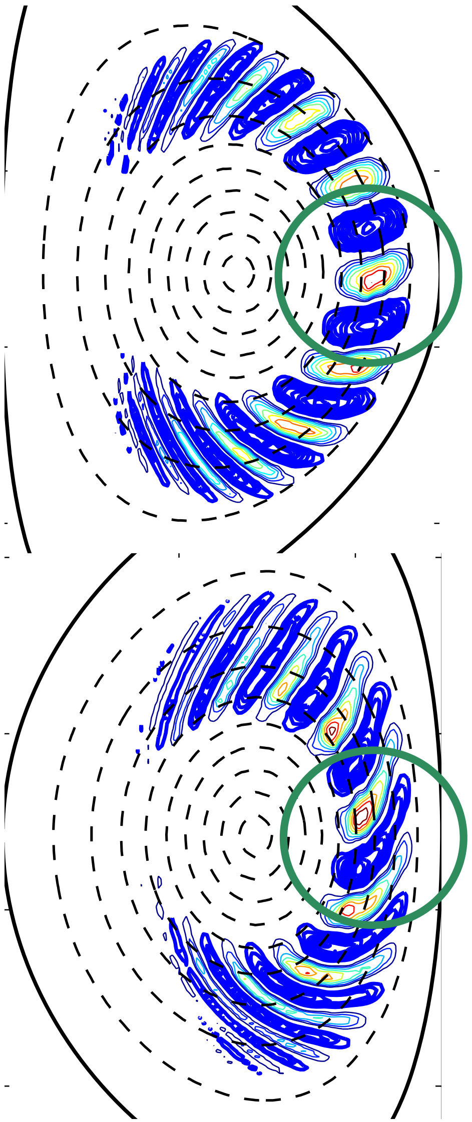
Correlation lengths: $\delta = \pm 0.4$, OH/EC



Radial correlation length λ_c:

- shorter at δ <0 (factor ~ 2)
- larger with EC to reach same T_e and n_e profiles, but thus with doubled heat flux

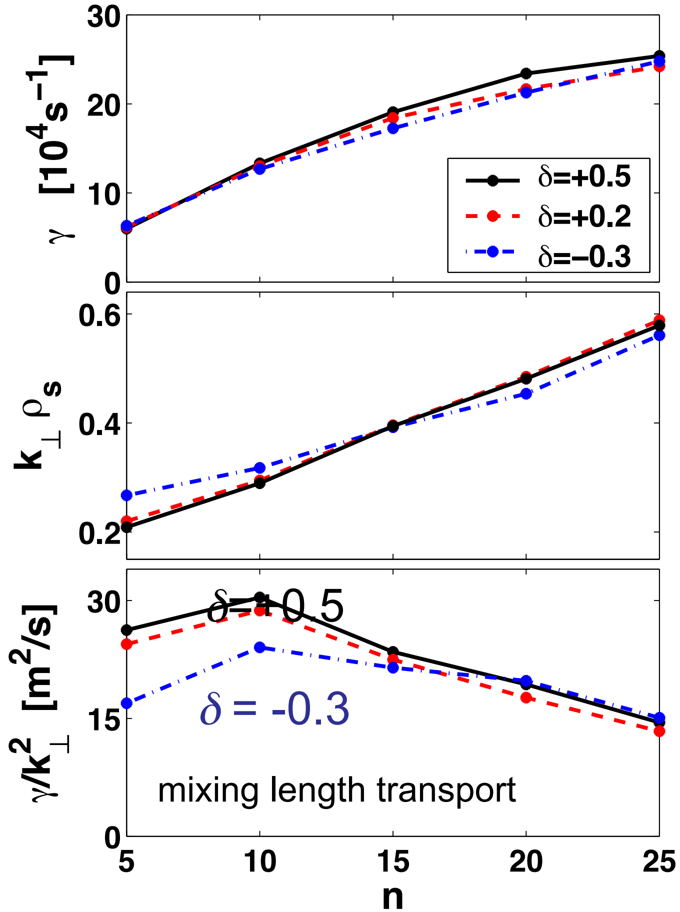
Global linear GK simulation with ORB



δ = +0.5

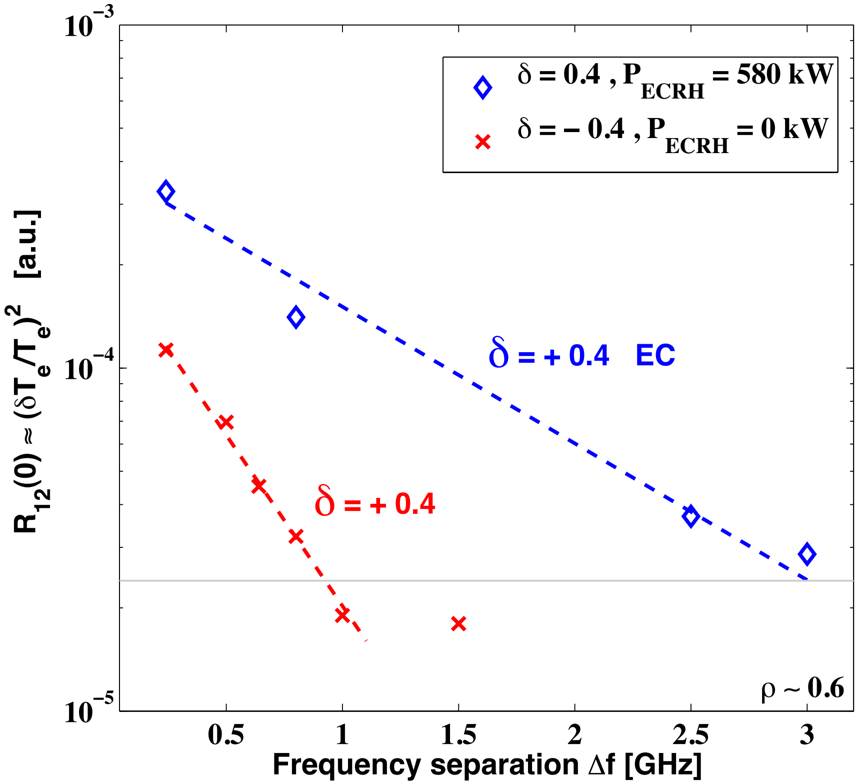
δ = -0.3

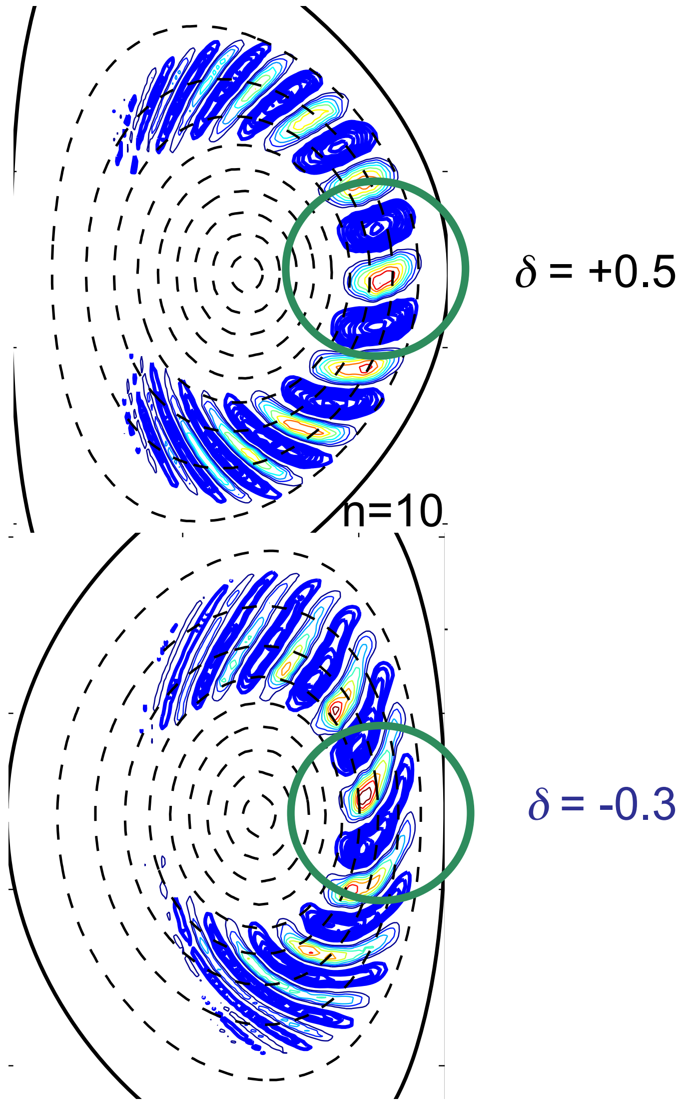
n=10



LORB GK simul.
linear, global [Camenen, Bottino05]

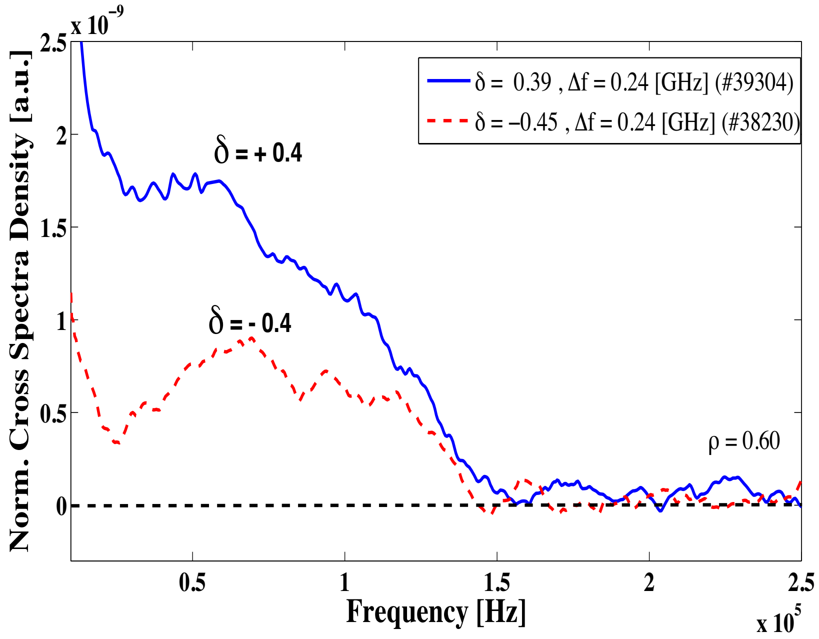
Comparing correlation length: expt. λ_c / $k_\perp$ lin. global GK simul.

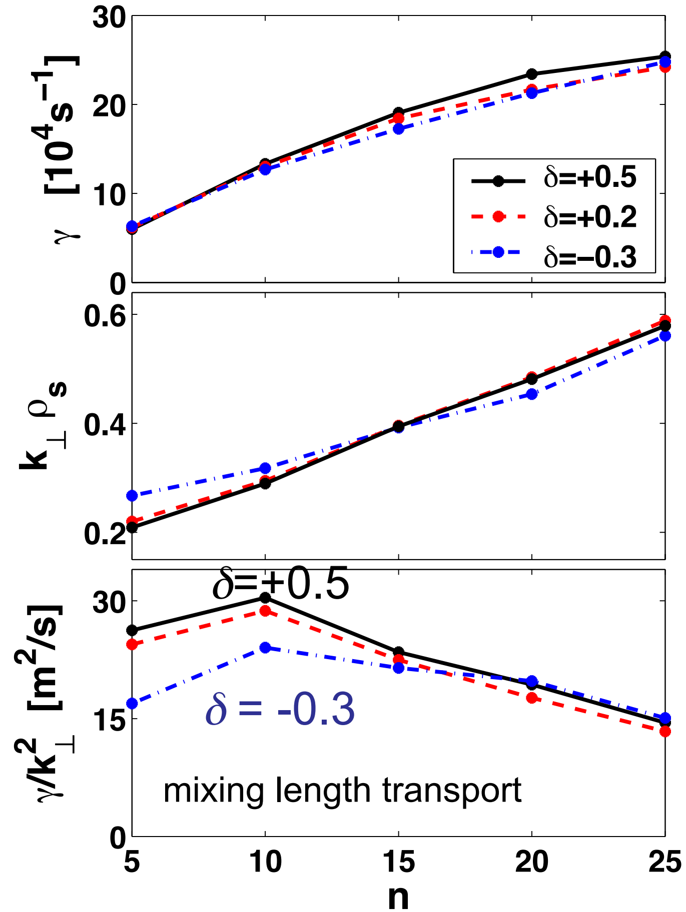




Radial turb. correlation length λ_c
and $\lambda_\perp$ ~1/$k_\perp$,
both reduced by factor ~ 2
linear global GK simulations appear
to suggest correct trend!

Comparing spectra (expt. turbulence / GK TEM transport)





CSD reduced at $\delta<0$, predominantly at the low frequencies

$\chi_{e\_mixing\ length}$ reduced at $\delta<0$, predominantly at the low *n* (role of the large, global structures)

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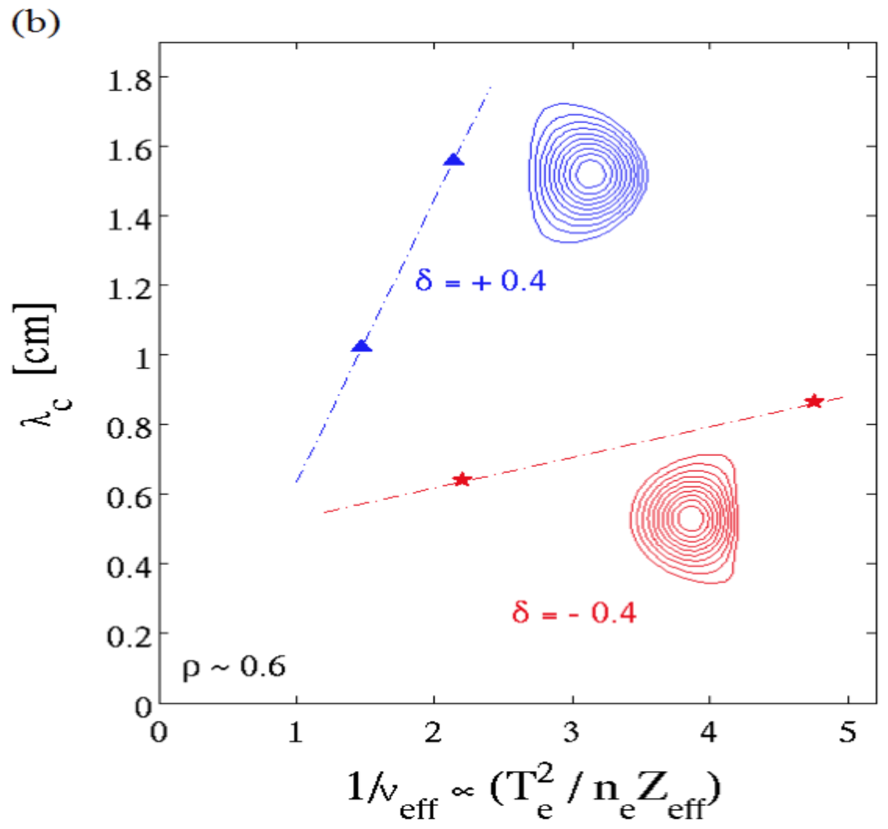
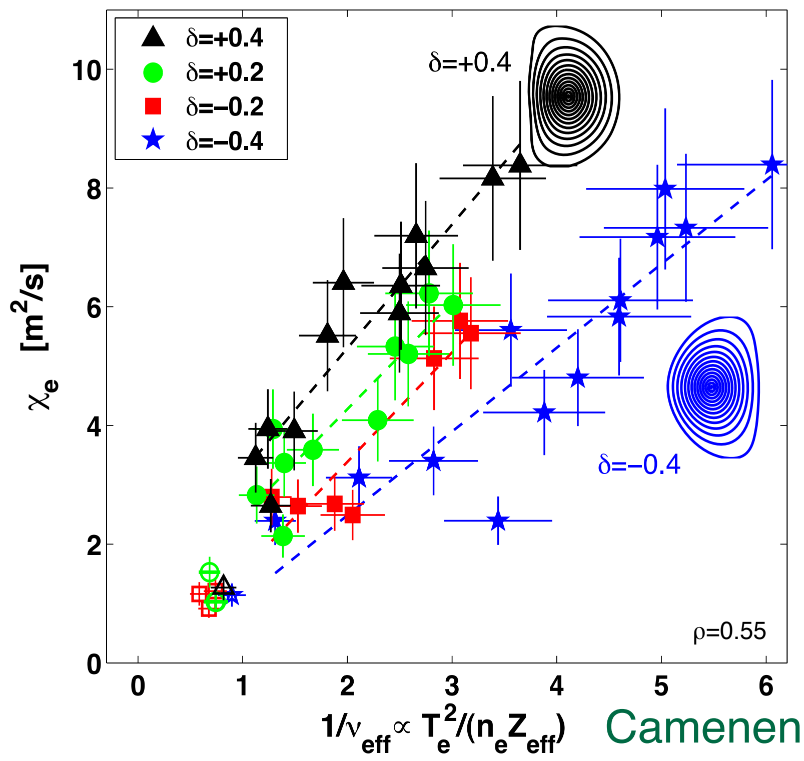
Correlation length λ_c and χ_e versus collisionality

from corr - ECE



from power balance



Camenen 07

Correlation length λ_c and χ_e
show both similar reduction
with collisionality and negative triangularity

Conclusions

- At negative triangularity, compared to positive,
  - τ_{Ee} is improved and χ_e reduced (both factor ~2)
  - both radial correlation length λ_c,
    and turbulence amplitudes reduce (by factor ~2)

- The (so far linear) comparison with global GK code ORB shows similar trends:
  – $\lambda_\perp \sim 1/k_\perp$ is reduced with negative triangularity
    (similar trend with δ as the measured correlation length λ_c,
    apparently a relevant (linear!) hint for TEM developped turb. ...)
  - role of low *n,* low frequency - large radial structures - in the variation of transport with δ.

- plasma shape: a tool to investigatate transport properties for model validation - in particular their dependence on equilibrium geometry!

Outlook

- next step aims at a more detailed comparision beween expt and GK-modeling, using e.g. non-lin global ORB5 code with an artificial diagnostics, mimicking corrECE measurements

- wishful next experimental step: evolve to multi-channel corrECE (from present 2-point-correlation diag.) :
  - opens to *new physics domain*: non-local transport, avalanches, meso-scale structures (as in present NL global GK codes)
  - allows for a more efficient tokamak use, 2-point-only-correlations limiting investigations

- further explorations with oblique line-of-sight angles to resolve turbulence structures (e.g.: link between λ_c and potential cell orientation)