Turbulence and transport reduction with innovative plasma shapes in TCV - correlation ECE measurements and gyrokinetic simulations

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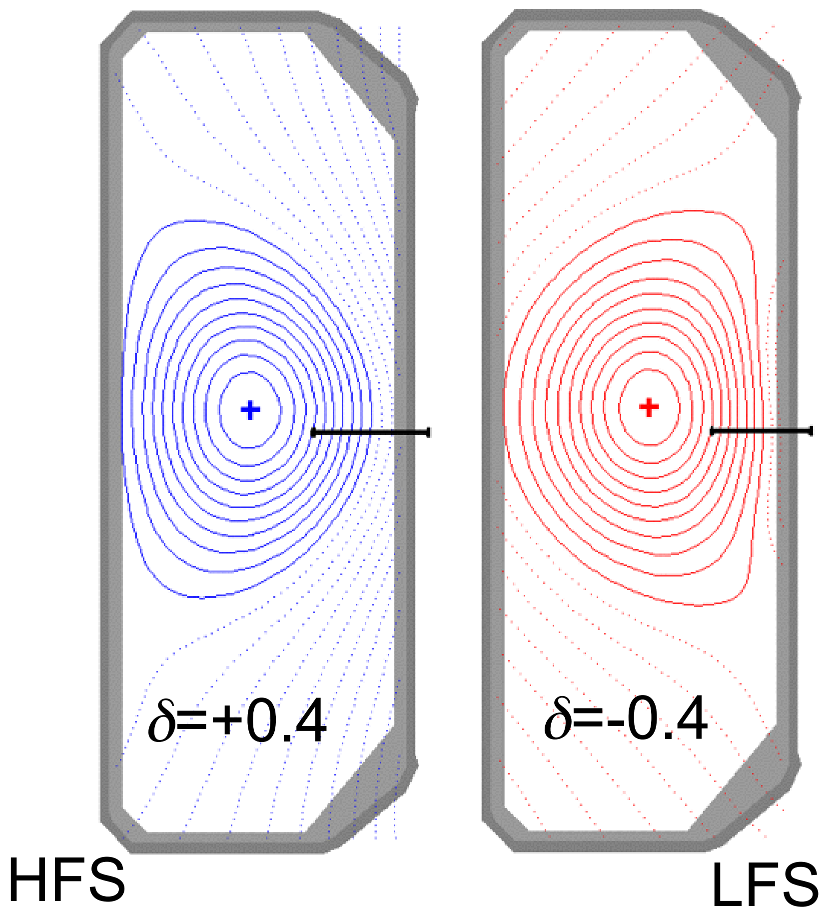
[1]see IAEA FEC 2010 list

MOTIVATION

Why study plasma shapes different from ITER?

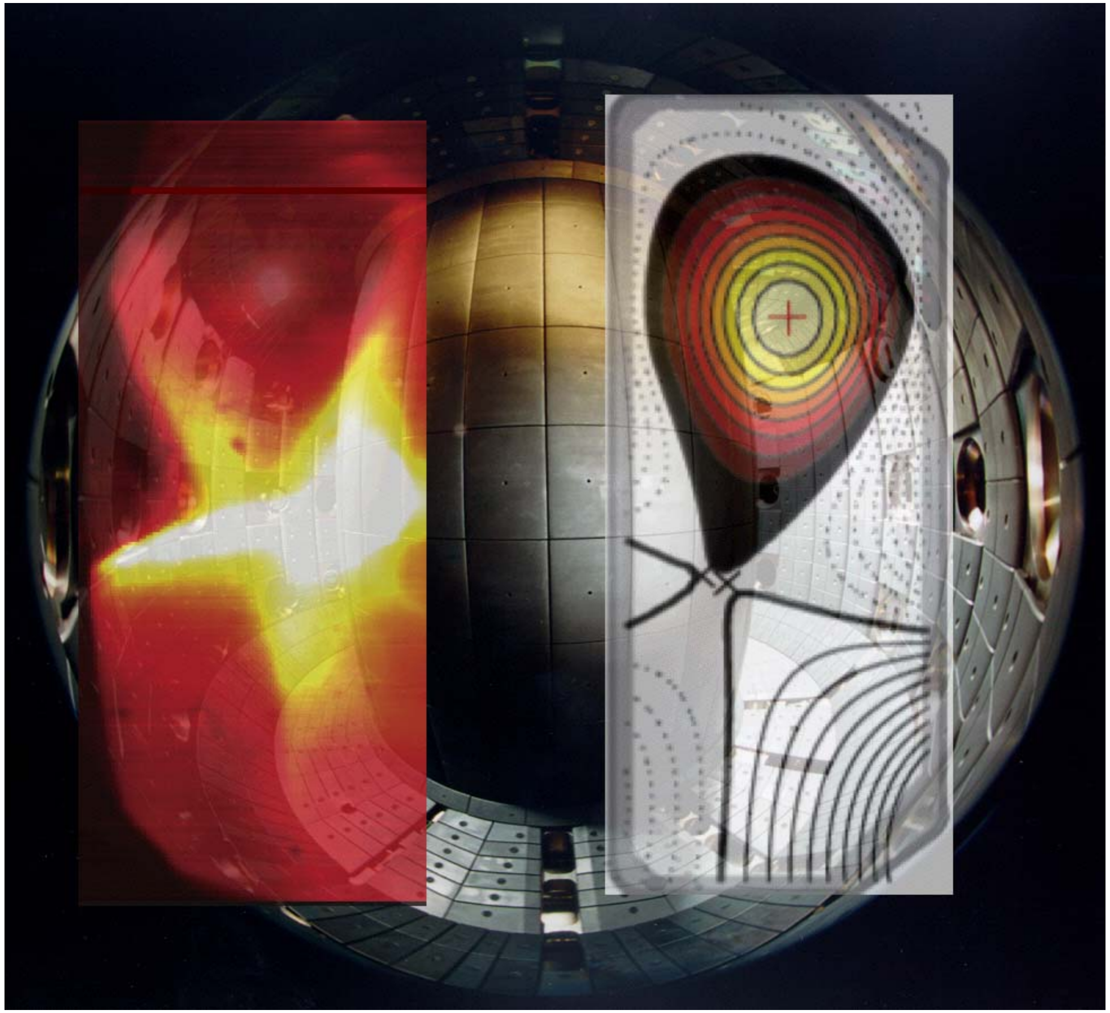


- Shaping: a tool for the test and validation of plasma modeling, in particular transport modeling
- Usual τ_E-scaling laws exhibit no triangularity dependence
- Confinement in TCV core plasma is found to improve towards negative triangularity $\delta < 0$ (in L-mode)

TCV facility

TCV: shaping flexibility

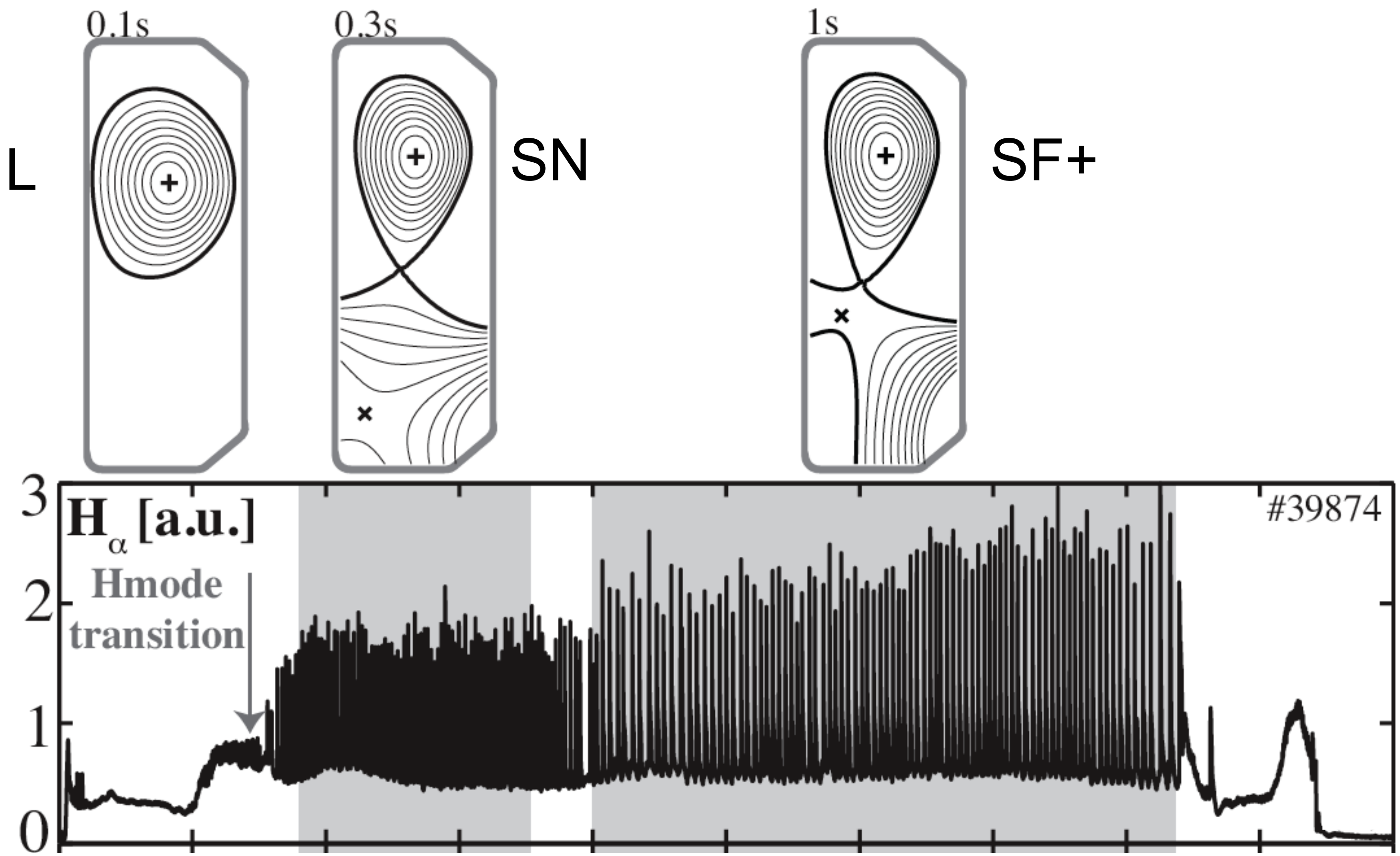
R = 0.88 m, a = 0.25 m, $R/a \sim 3.5$
$B \leq 1.5$T, $I_p \leq 1$MA
16 independent pol. field coils
elongation 0.9 < κ < 2.8
triangularity - 0.7 < δ < 1



ECRH: matched by flexible heating

4.5 MW at **2nd** and 3rd harmonic
with 7 independent launchers
allowing local power deposition

Example: H-mode Snowflake divertor plasmas on TCV



Piras PPCF09
Piras PRL10
Piras PPCF10

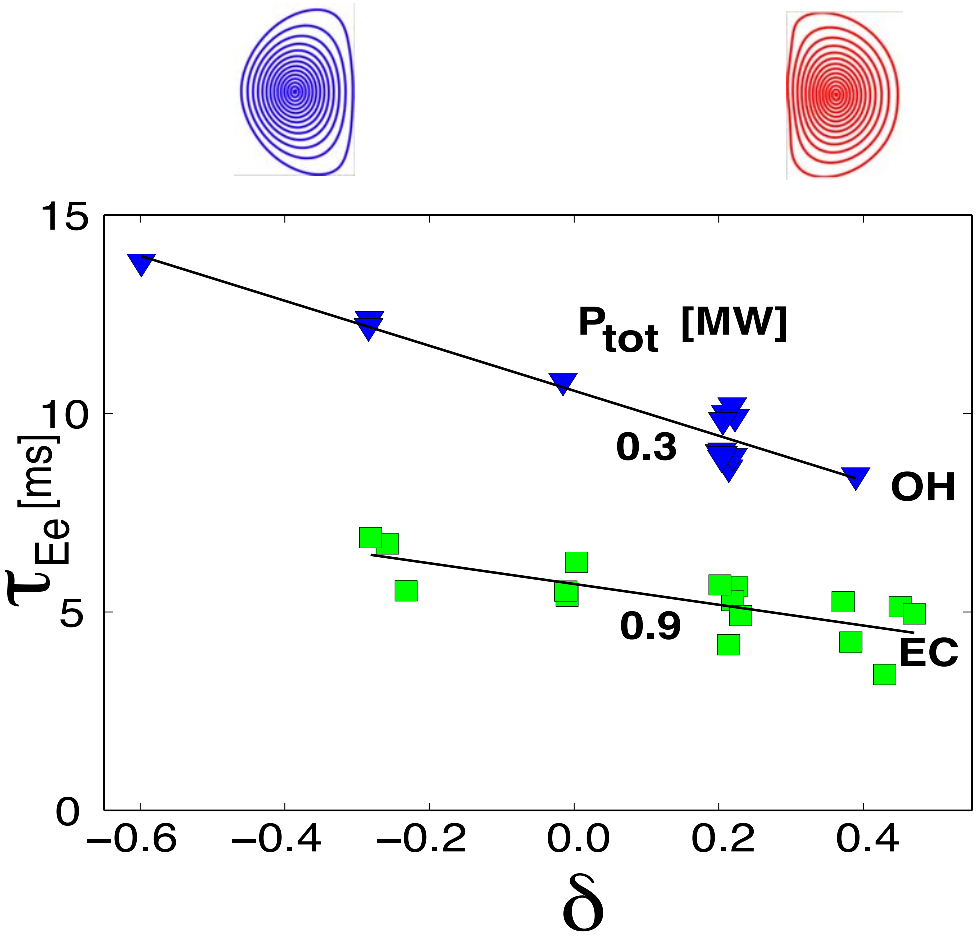
F.Piras : PP9.136
Wednesday p.m.
Snowflake Divertor H-mode

OUTLINE

1. **Confinement and transport versus triangularity**
2. **Gyrokinetic simulations, local and global**
3. **Initial turbulence measurements versus triangularity**
4. **Conclusions and Outlook**

1. Confinement and transport versus triangularity

Energy confinement improves towards $\delta < 0$ (at low collisionality)



Plasma conditions:
low density ECH plasmas,
low collisionality ν_{eff} ~0.2-1
high R/L_{Te}>7 and T_e/T_i~3-5

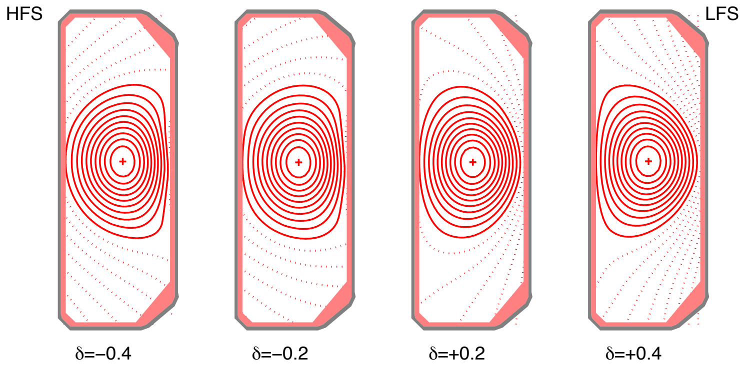
TEM dominated regime

Coda 98, Pochelon NF99 & EPS99

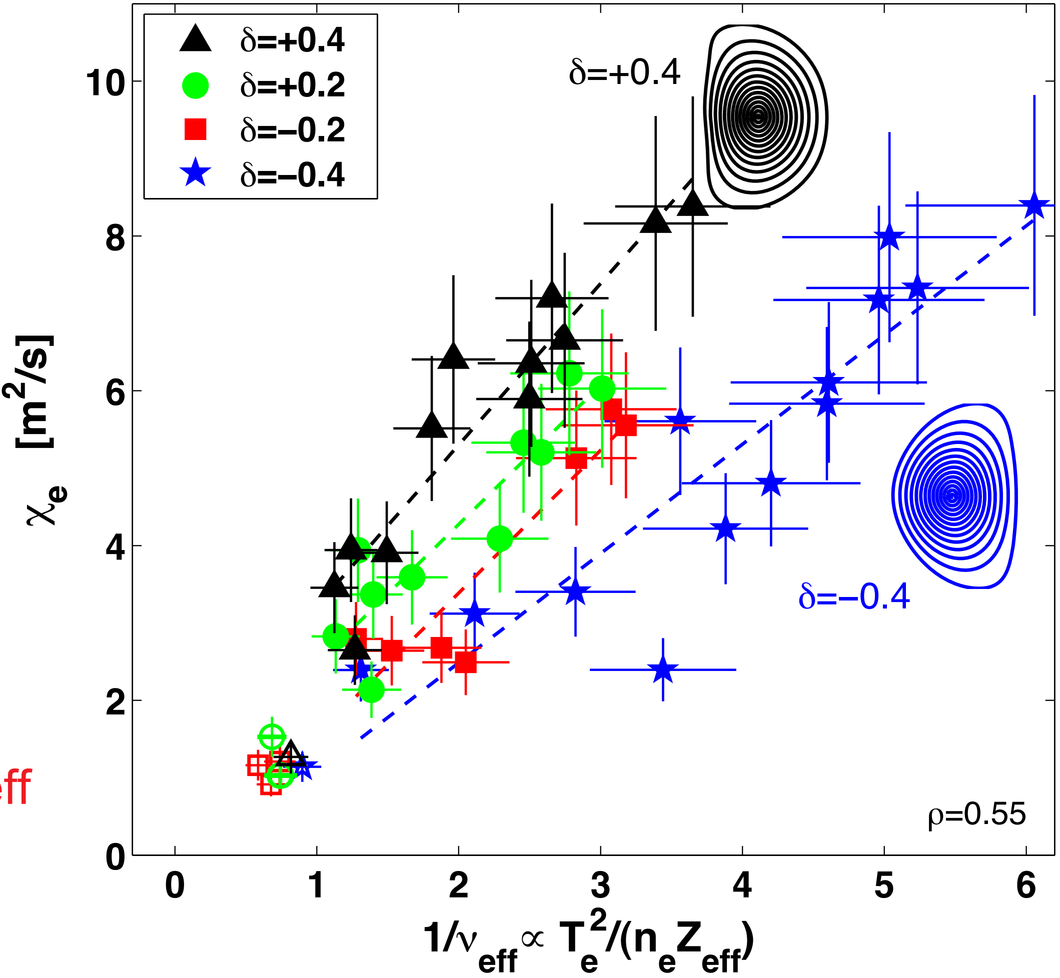
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CRPP

Transport depends on both triangularity and collisionality



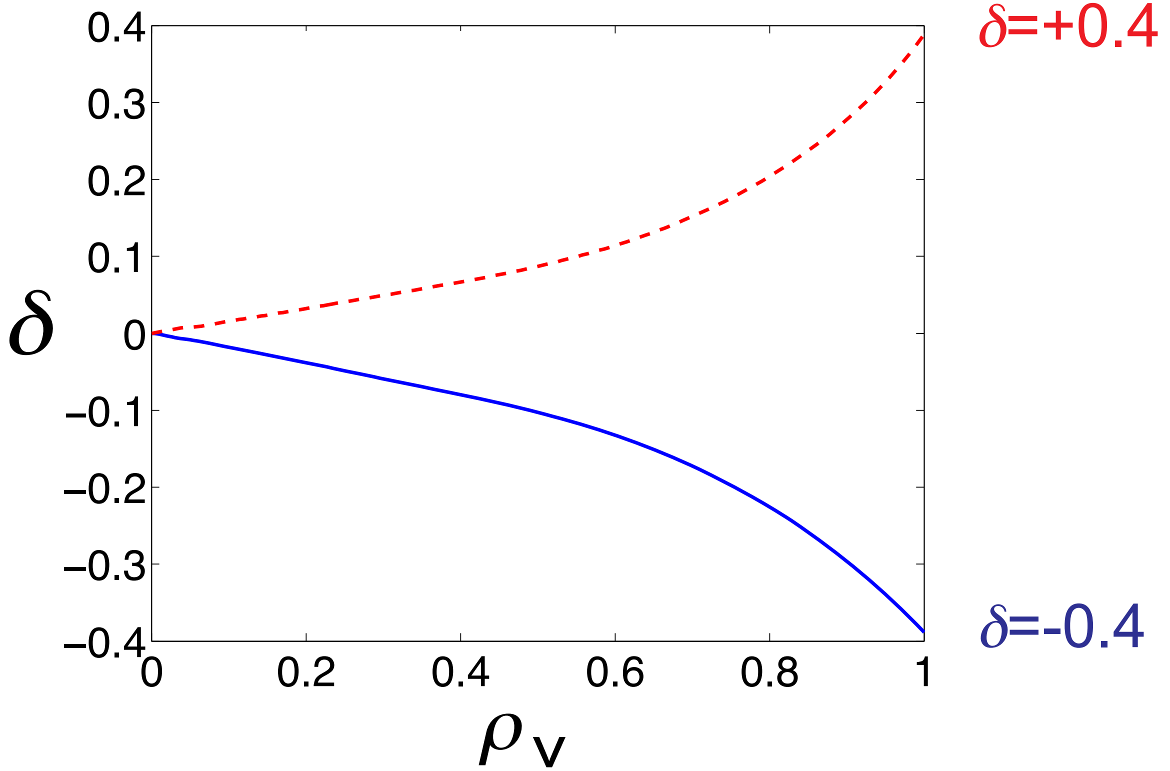
δ = -0.4 -0.2 +0.2 +0.4



Negative triangularity δ
shows reduced heat diffusivity χ_e
over a wide range of collisionality ν_{eff}

Camenen NF07

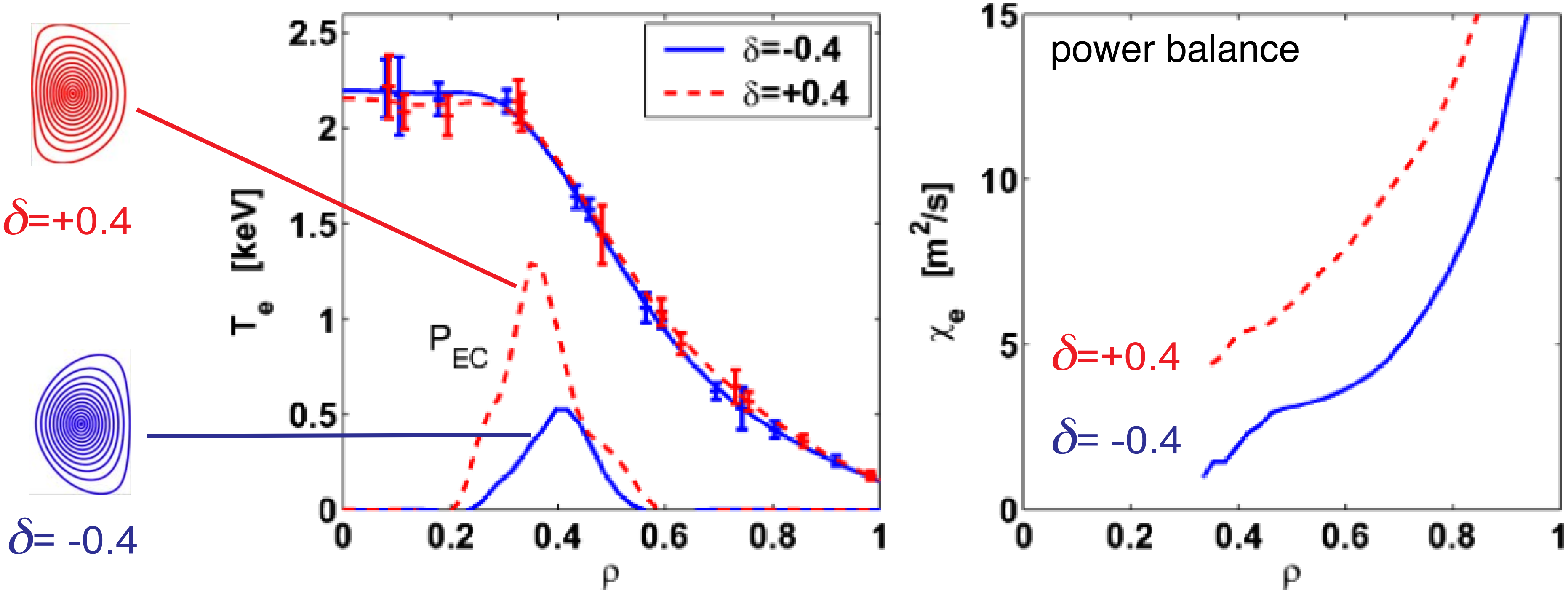
Puzzle: limited triangularity penetration, but strong effect



Large transport variations with δ measured at mid-radius,

but triangularity at mid-radius only represents ~25% of δ_{edge}

Same profiles, different powers at $\delta = \pm 0.4$

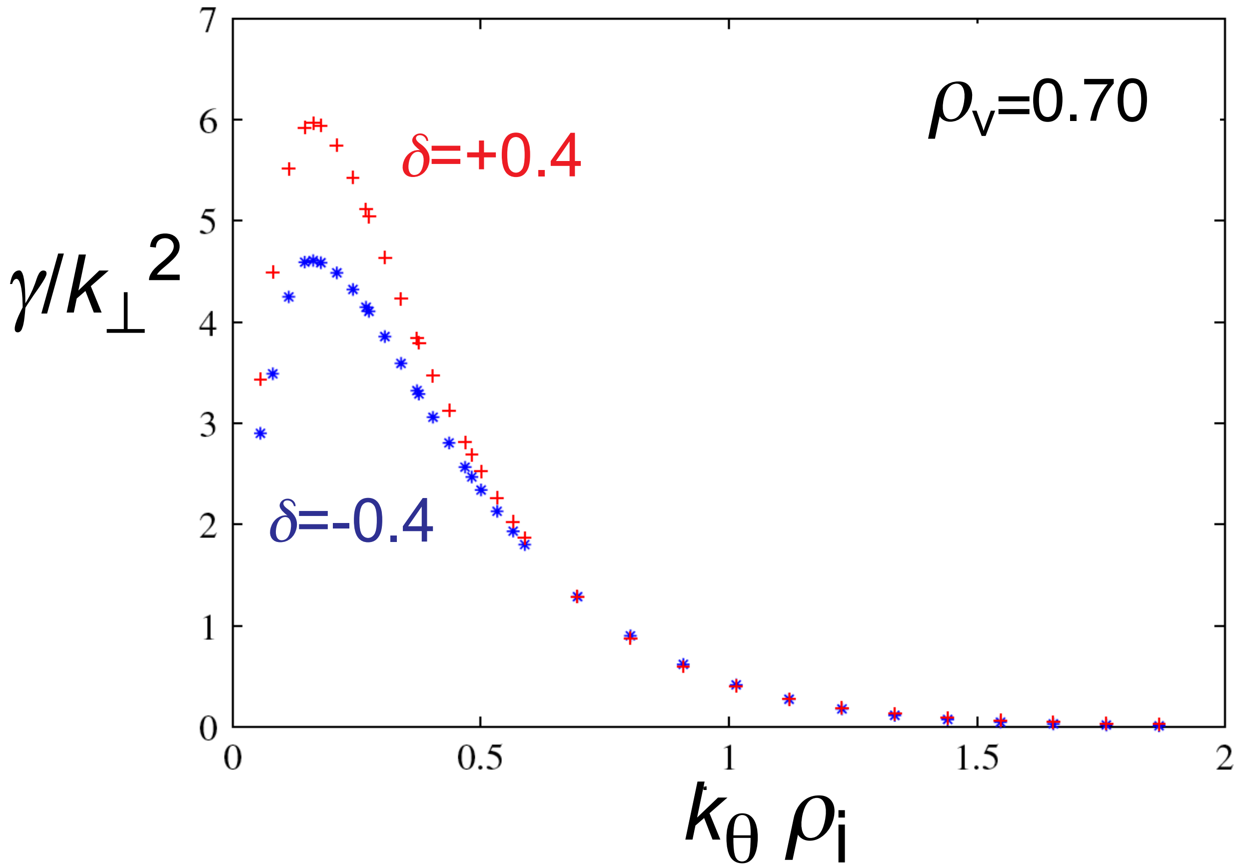


Adjusting power at each triangularity $\delta = \pm 0.4$
to reach the same T_e, n_e, (i.e. same plasma energy), and q-profiles :
- only half power needed at $\delta = - 0.4$,
- resulting in χ_e *halved* over all radia outside heat deposition (from pow bal)

Camenen NF07

2. Gyrokinetic simulations, local and global

local GK simulations: GS2, local (flux-tube), linear



Mixing length estimate of heat diffusivity decreases towards δ<0:
in qualitative ageement with experiment

Most TEM transport occurs in the range $k_\theta\ \rho_i \sim 0.3$

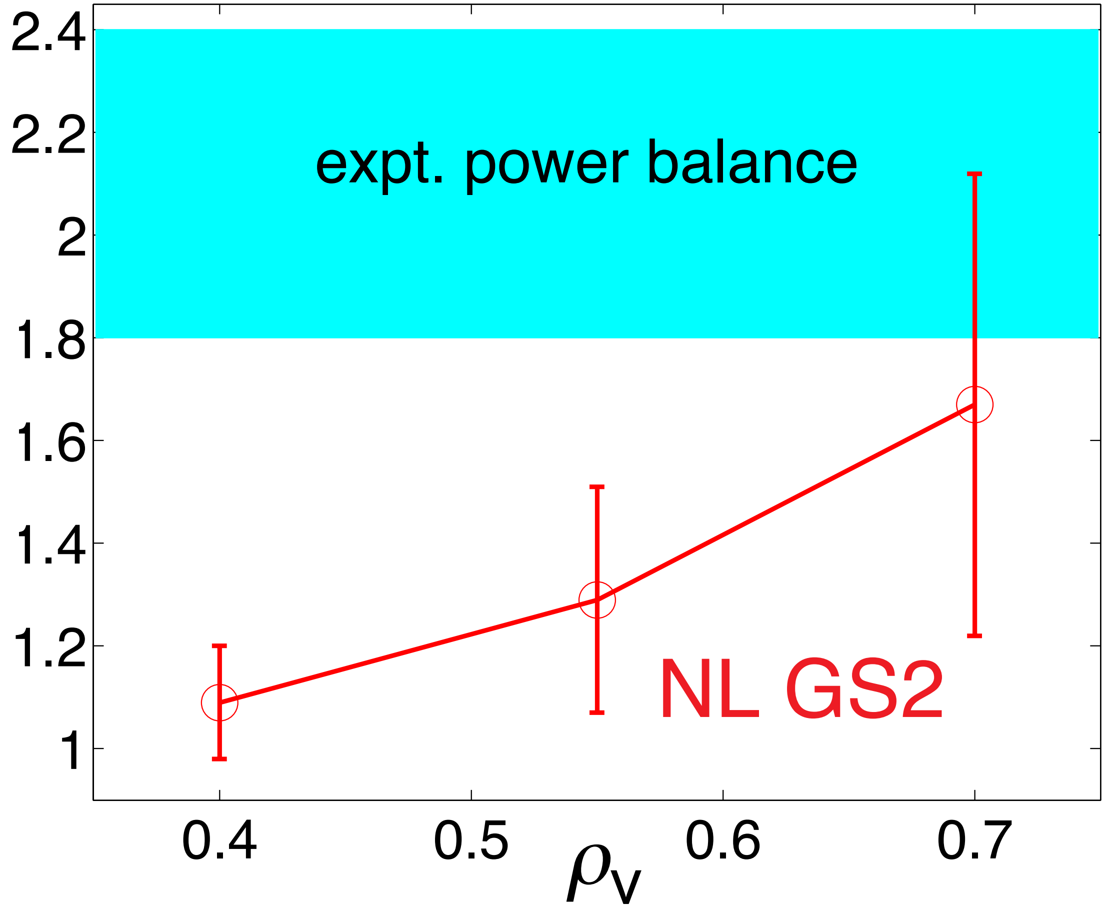
this same range is the one mostly affected by changing triangularity

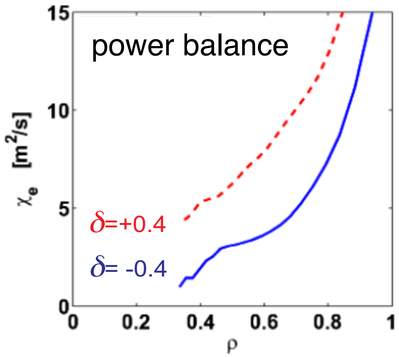
All simulations based on TCV equilibria

Marinoni PPCF09

Penetration of δ-effect on χ_e (for 'non-linear flux-tube' & 'power balance')

$$\frac{\chi_{e,\delta=+0.4}}{\chi_{e,\delta=-0.4}}$$





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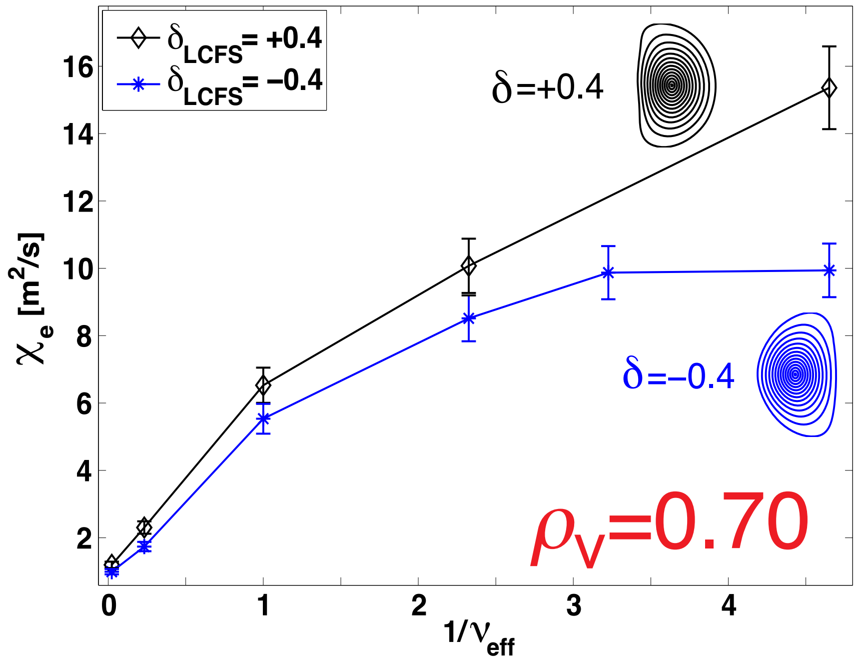
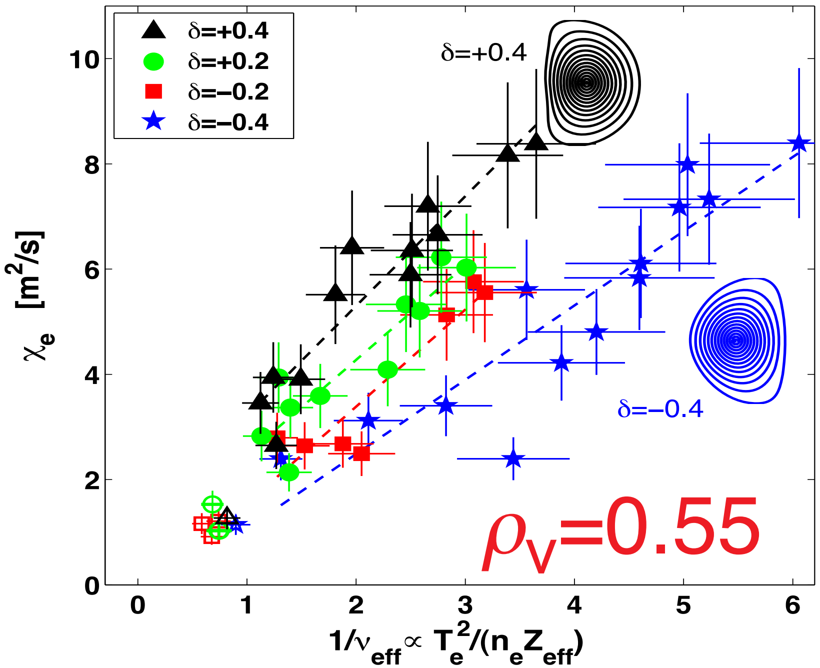
Triangularity effect on χ_e from local GK simul. vanishes towards the centre, unlike in experiment, where the triangularity effect does penetrate

GS2: local non-linear, with collisions

GS2 simulations



experiment



- From flux-tube calculations, triangularity effect on χ_e remains confined to the edge

Marinoni PPCF09

From flux-tube to global GK: ORB5, linear runs

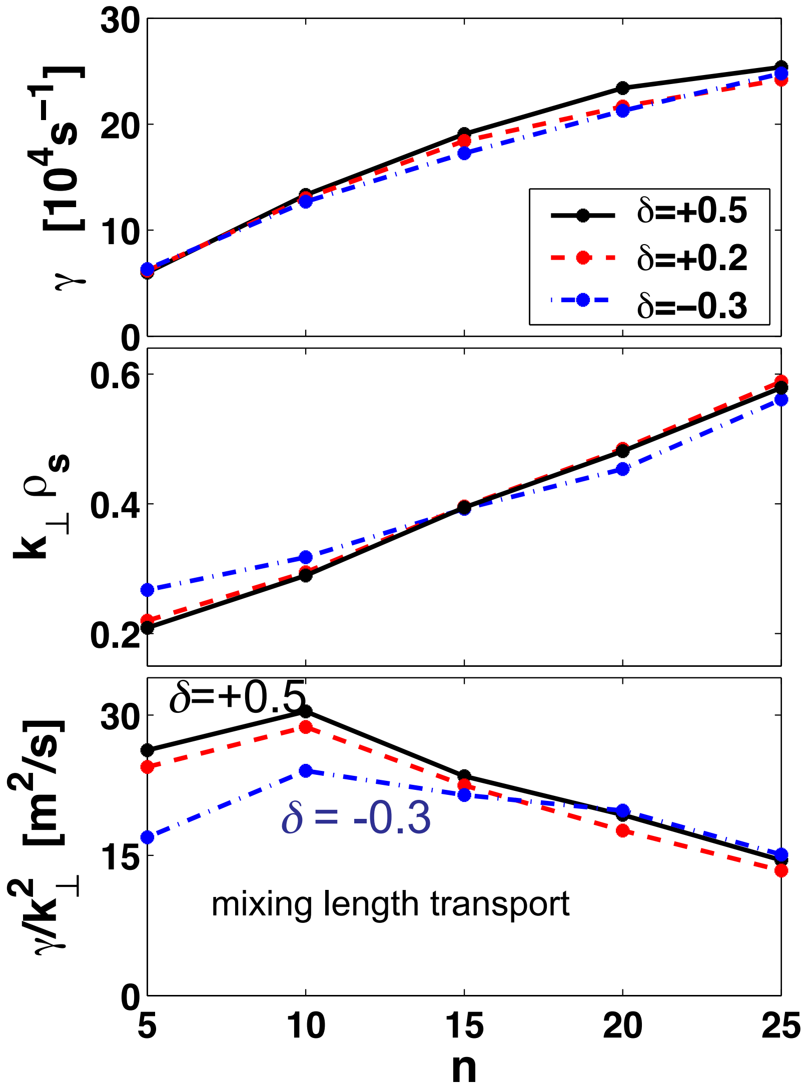
- $\rho^* = \rho_L / a \sim 1 / 70$
  thus finite ρ^* effects expected, i.e. differences between local and global simulations

- global simulations required to account for the full radial profiles

- the global gyrokinetic code ORB5 enables to carry out linear and non-linear, collisional simulations

- currently, for the present triangularity study, linear global ORB5 runs have been carried out so far

$k_\perp$ larger at negative triangularity -> lower mixing length $\gamma/k_\perp^2$

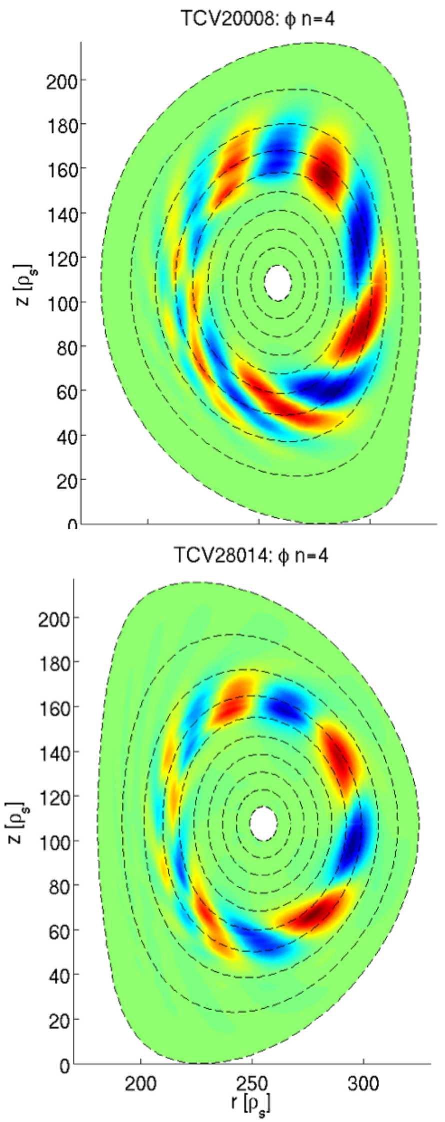


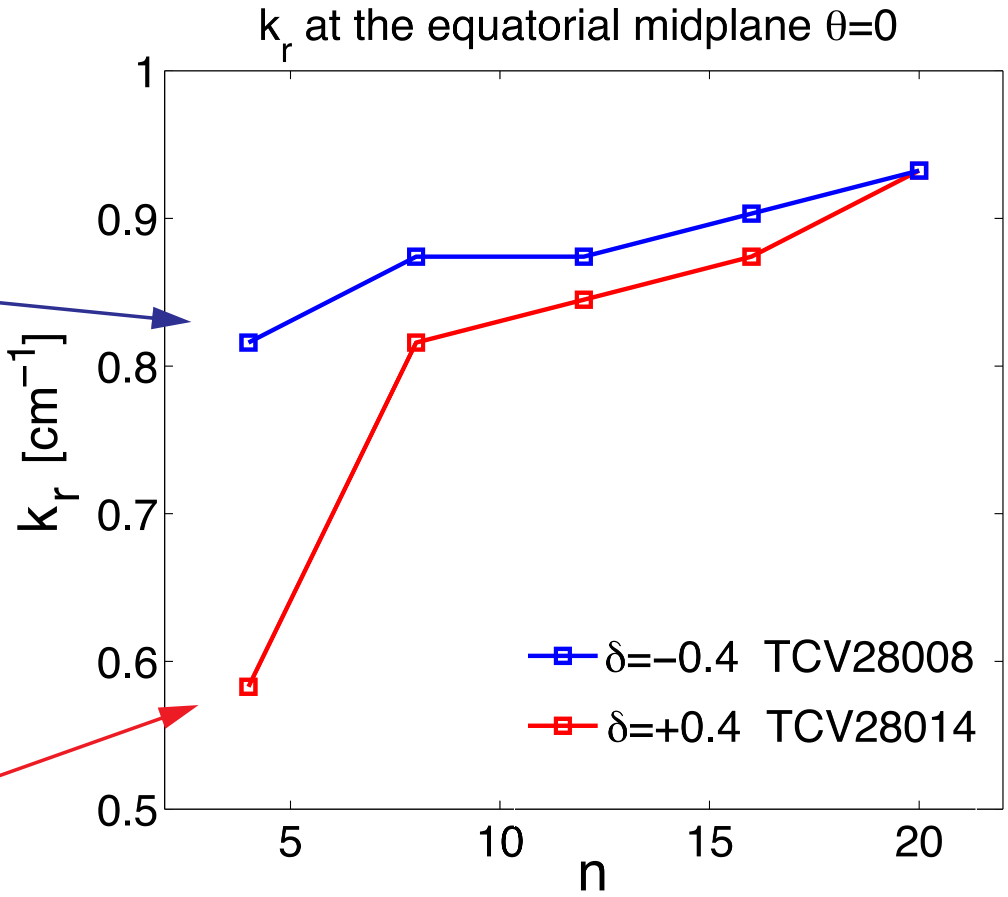
Mixing length transport estimate reduced for $\delta < 0$,
through reduction of $k_\perp$ at low n

Camenen NF07

Larger k_r at negative triangularity

ϕ , n=4



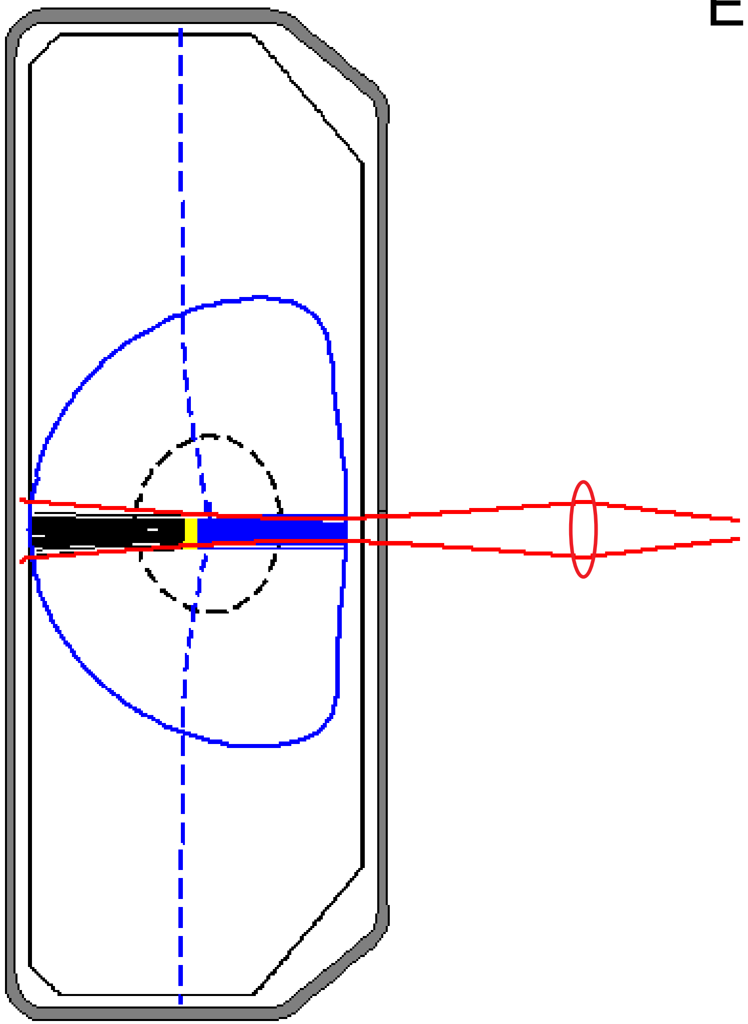


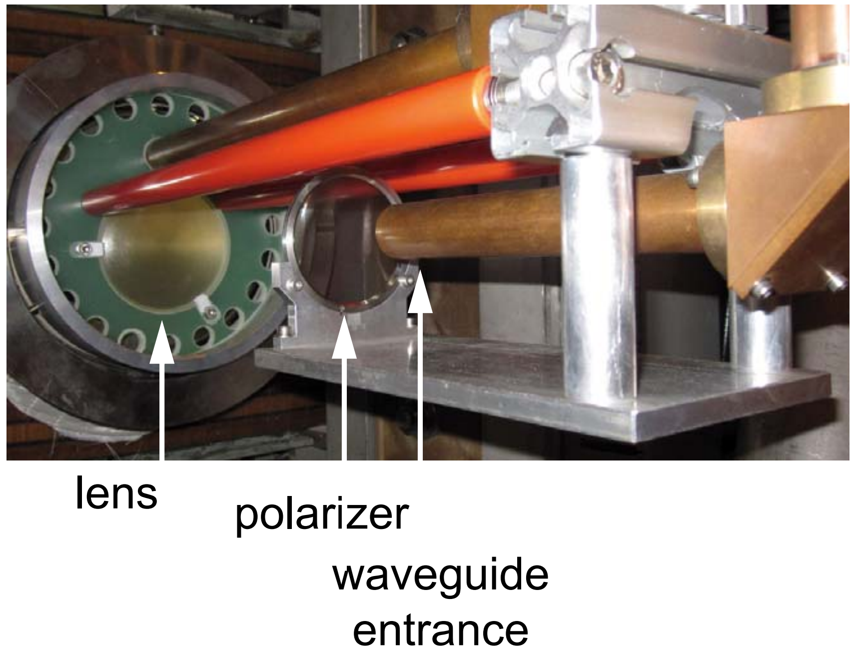
- Triangularity predominantly affects k_r at the low *n*'s, which are the important modes for TEM transport
- k_r useful for comparison with radial correlation length measurements in experiment

3. Initial turbulence measurements versus triangularity

Turbulence measurements using ECE

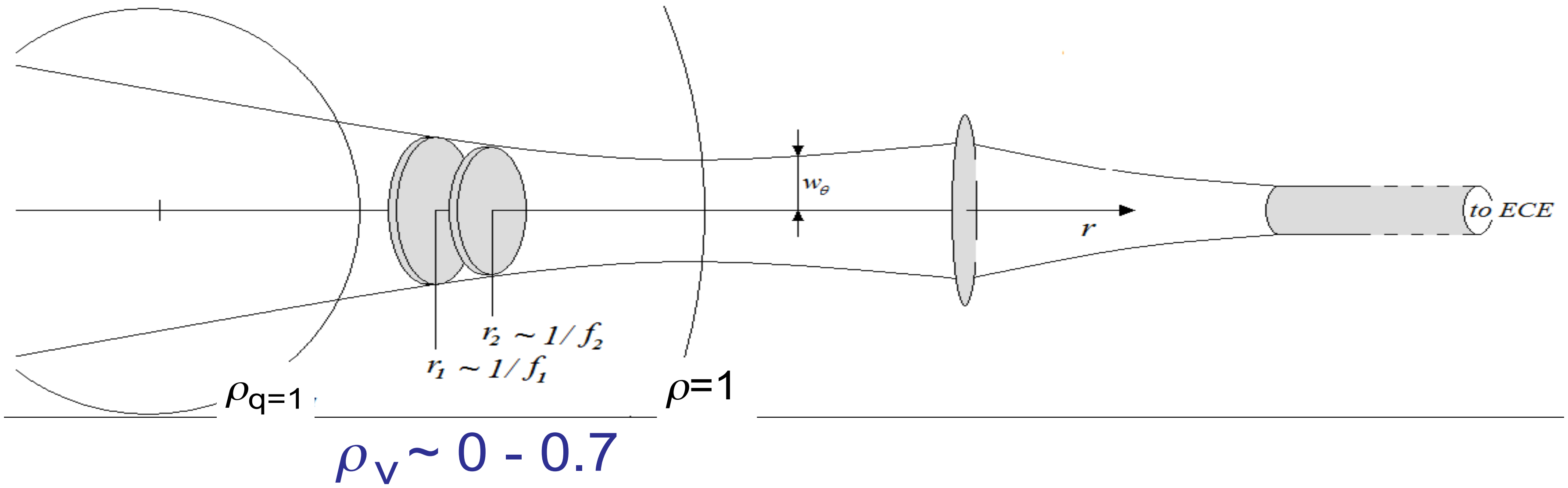
ECE view





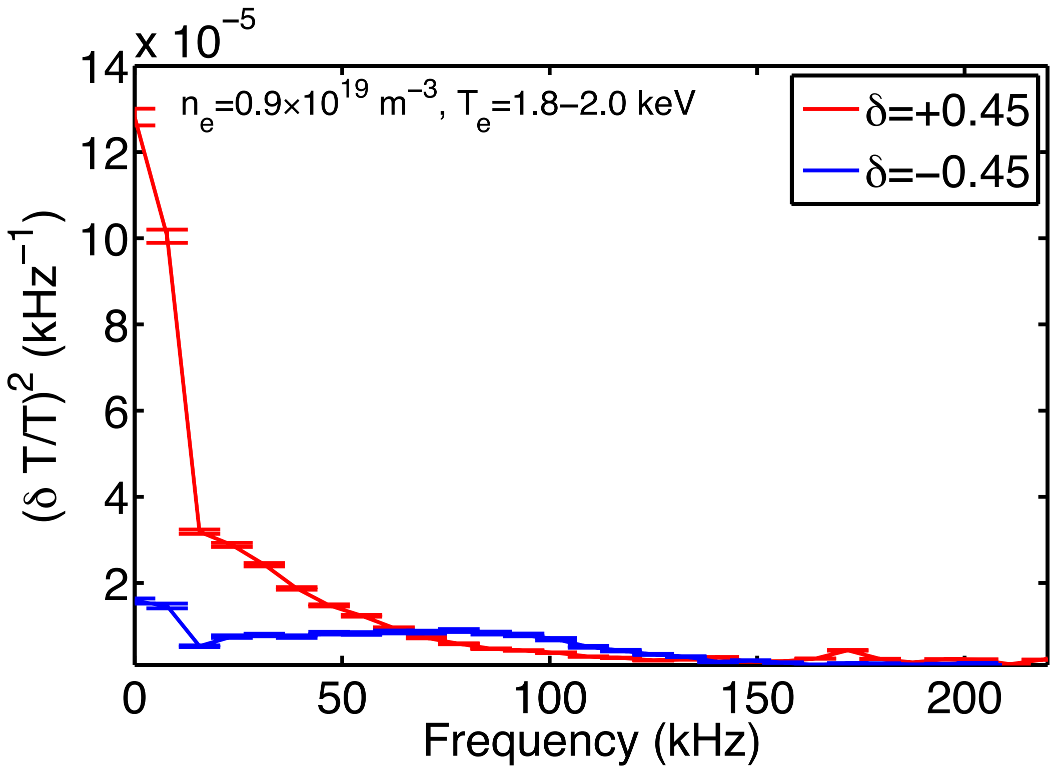
equatorial LFS with focusing lens

New correlation ECE diagnostic setup, geometry



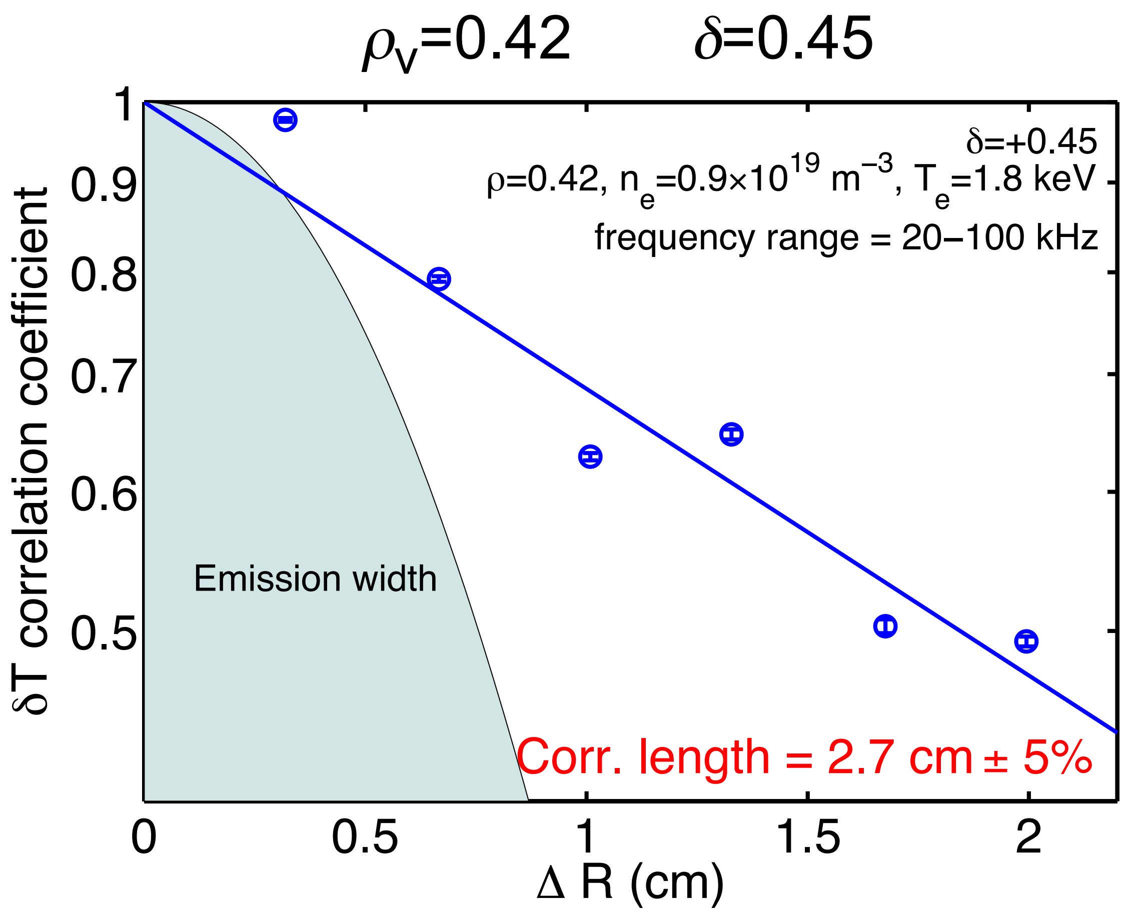
- single Gaussian-beam line-of-sight measurement from LFS
- 2 tunable, narrowband (100-160MHz) YIG filters
- range 69-81GHz, $0.0<\rho_V<0.7$
- accessible range $k_\theta \leq 0.5\text{-}0.8\ \mathrm{cm}^{-1}$ ($k_\theta\, \rho_s \leq 0.3\text{-}0.5$)
- optical thickness τ~3-4, i.e. blackbody radiation, thus only T_e fluct.

T_e-fluctuation cross-spectra



- Low frequency peak < 20kHz
- TEM turb range up to ~130kHz
- *T_e* fluctuations from integral on spectral range 20-100kHz

Corr ECE allows a clear correlation length measurement at δ =+0.4



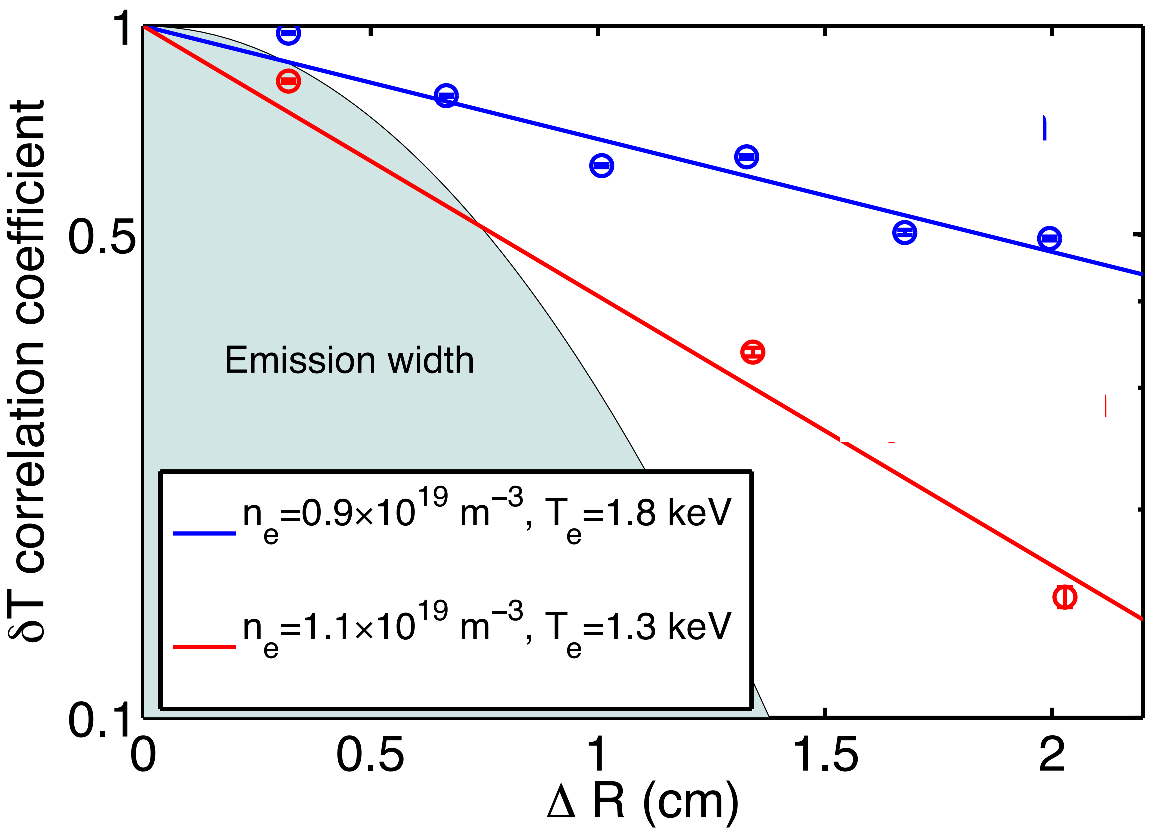
shot-intensive experiments to overcome two limitations:

- two channels

- long integration times for statistics

L_c = 2.7 cm ~ 4 ρ_s

Correlation length decreases with density (collisionality)



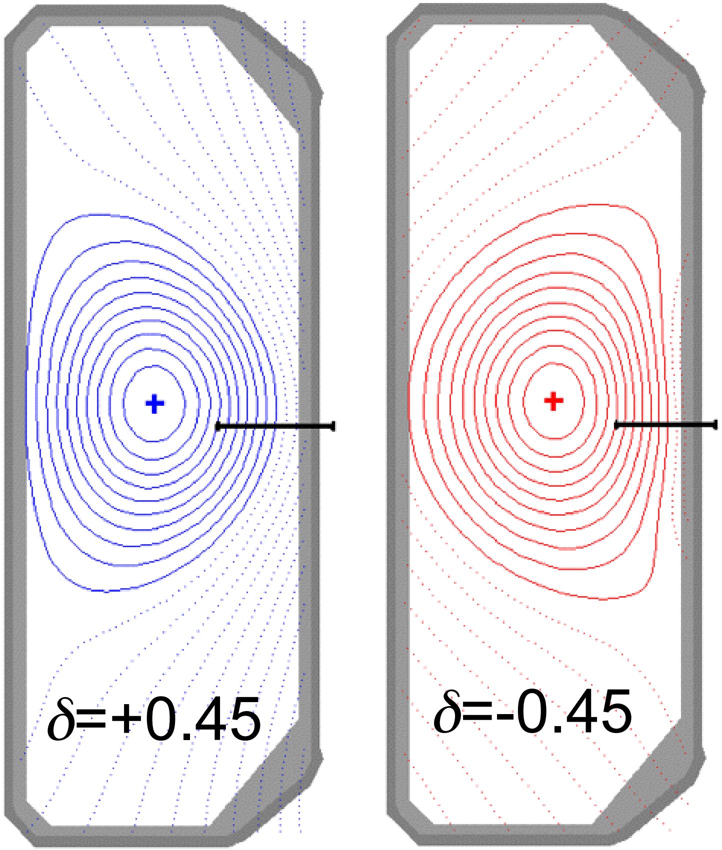
L_c = 2.7cm ~ 4ρ_s

L_c = 1.1cm ~ 2ρ_s

at given power, L_c very sensitive to density, which needs to be well controlled

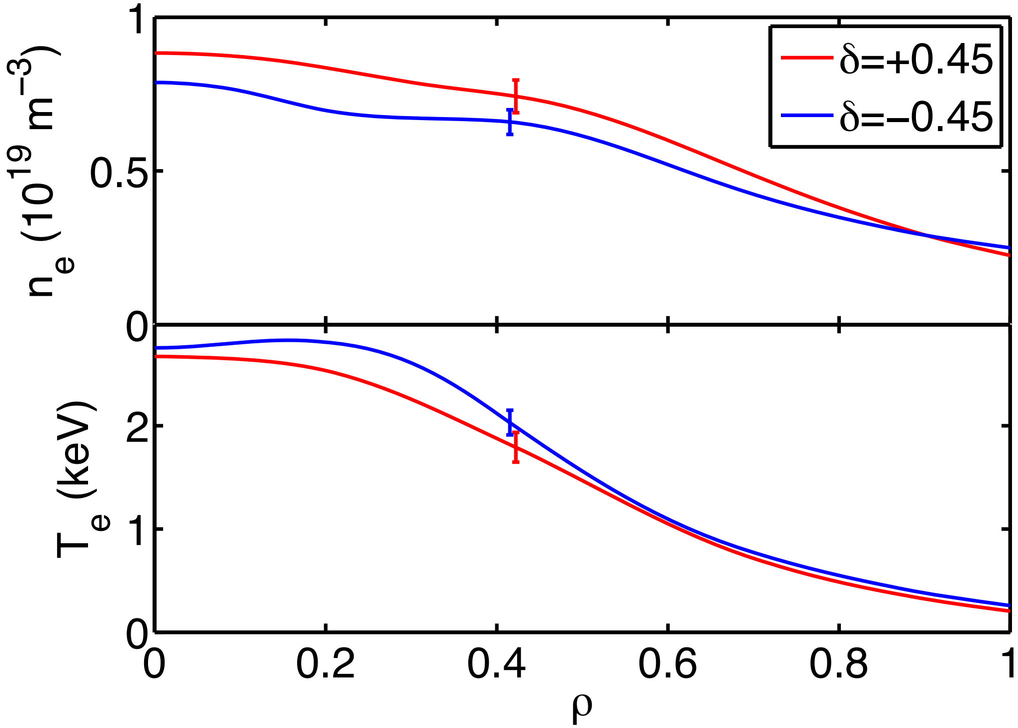
Comparison between positive and negative triangularity

measuring location



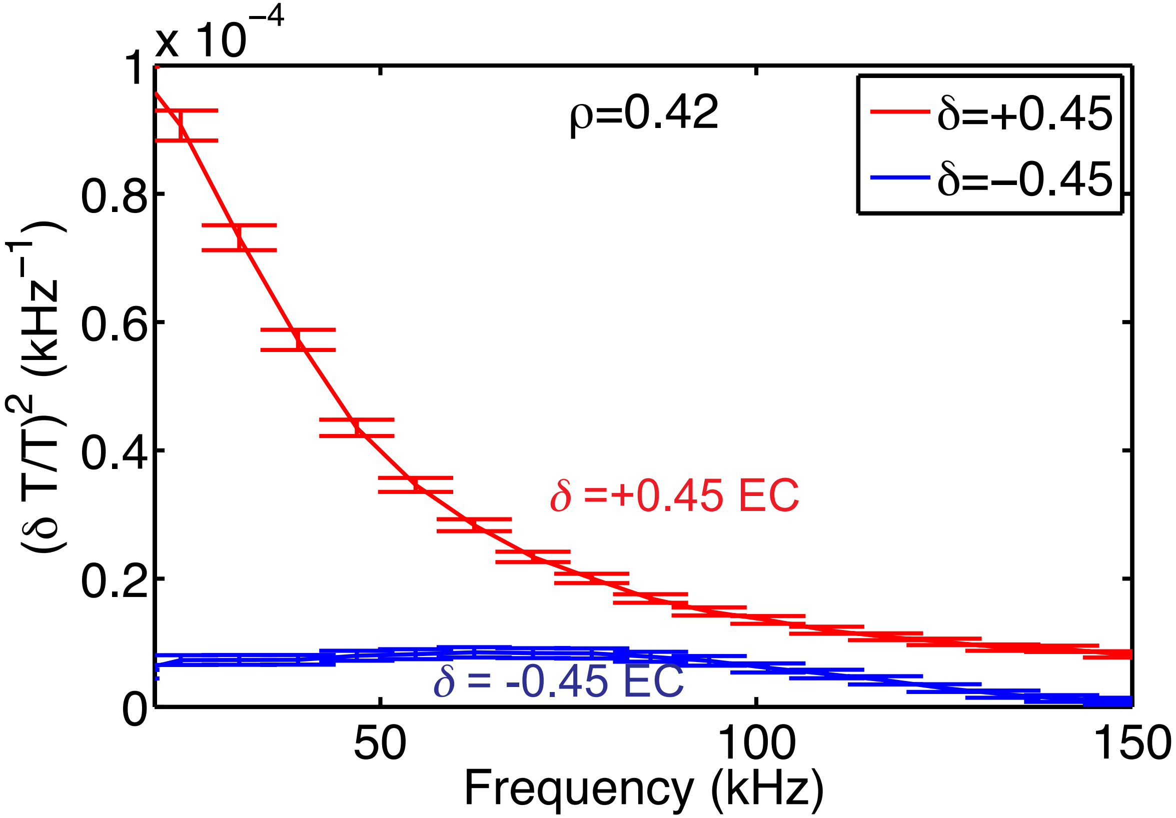
$0.33 < \rho_V < 0.53$
on LFS equator

profiles



matching n_e and T_e profiles at δ=±0.45,
by adding more ECH at $\delta > 0$

Strong reduction of turbulence level for $\delta < 0$



going from δ=+0.45 to δ=-0.45,
results in a strong reduction of fluctuations;
especially below 80kHz

4. Conclusions and Outlook

Conclusions from experiment

Confinement and transport

- confinement time τ_{Ee} is increased towards $\delta<0$ up to factor 2
- heat diffusivity at mid-radius $\chi_{e\ PB}$ is reduced up to factor 2

Turbulence

- correlation lengths have been measured at $\delta>0$: $L_c/\rho_s \sim 2\text{-}4$
- turbulence amplitude at mid-radius, is strongly reduced at $\delta<0$, over the entire spectral range
- L_c is very sensitive to density/collisionality (TEM regime)

Challenges for experiment

- measure correlation length at $\delta<0$, in spite of reduced turb. signal
- a shorter correlation length is expected, as inferred from simulated k_r

Conclusions from gyrokinetic simulations

Local simulations

- linear: triangularity affects the low *k* modes
- non-linear: the effect of triangularity does not penetrate radially as found in experiment

Global simulations (linear runs)

- low *n*, large structures, responsible for the transport change with δ
- radial wave vector k_r is larger at δ<0, particularly in the low *n*'s

Challenges for GK simulations

- develop a synthetic diagnostic for non-linear global code, mimicking T_e-fluctuations from correlation ECE
- reproduce the *lower turbulence amplitude* and *different spectral shape* found at δ<0