DE LA RECHERCHE À L'INDUSTRIE

Heat transport study of H-MODE and hybrid plasmas using Qualikiz, TGLF and GLF23

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MOTIVATION AND WORK DONE

The validation of the **transport models** available for the plasma simulation is mandatory to achieve a sufficient prediction capability of the performance of the main operation scenarios for present and future fusion machines

understanding the key aspects and numerically reproduce tokamak **improved confinement scenarios (hybrids)** for different existing machines.

Two new sophisticated **quasi-linear first principle transport models** are available:

- **QuaLiKiz**: gyrokinetic base,
  trapped electrons,
  s-α geometry,
  el
  no ExB shear effect
- **TGLF**: gyrofluid,
  trapped electrons,
  Miller/s-α geometry,
  el/em,
  2 ExB shear effect models

QuaLiKiz and TGLF have been recently coupled to the **CRONOS** suite of codes

-> **comparison of the models in the GA std case**

-> **study of the heat transport in H-modes and hybrids plasmas of JET and JT60-U**

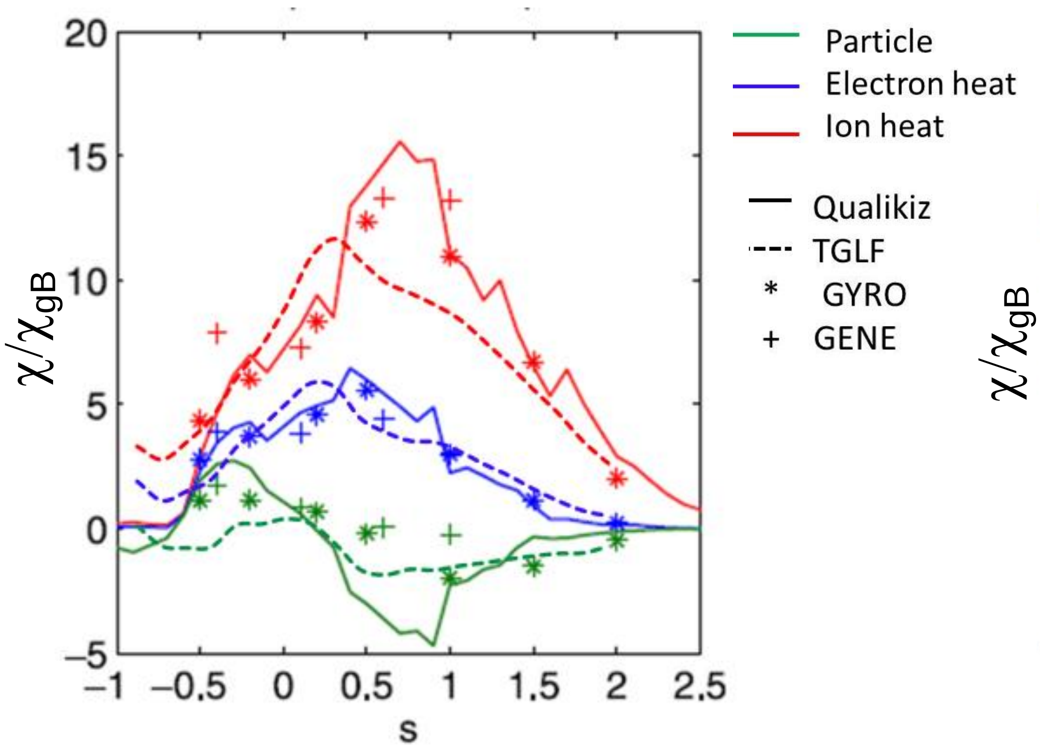
- to **validate** the models through the comparison with the **experimental** data
- to compare the results with **GLF23** (gyrofluid, el, s-α geometry, ExB shear effect);
- to trying to **understand** the possible **physical reasons** of the resulting **discrepancies**.

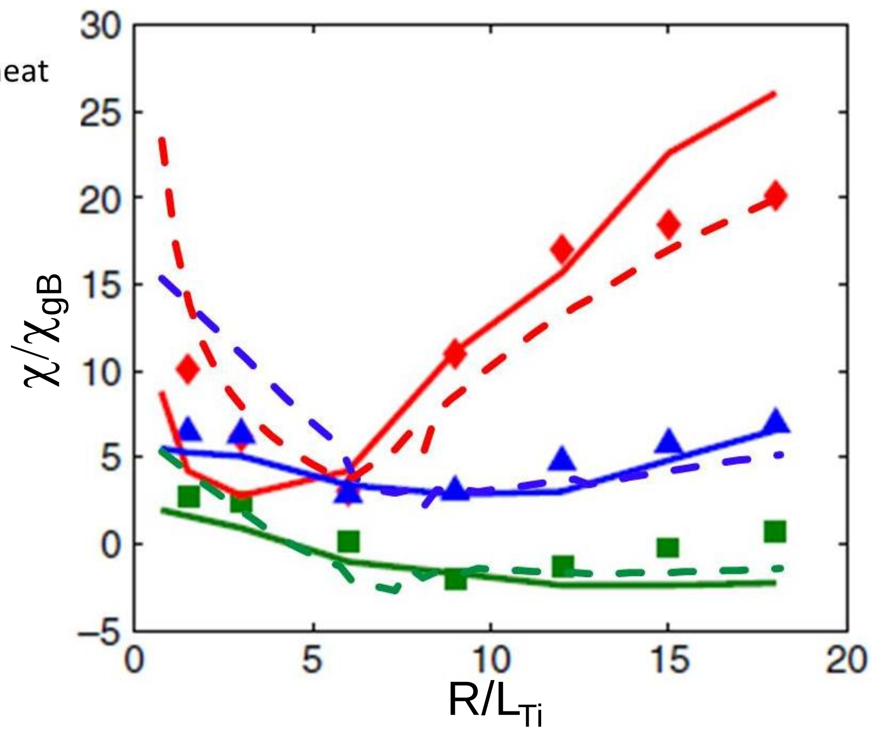
Simulations: - T and j are modelled;
- T pedestal is fixed (according with the experimental measurements)

STAND ALONE COMPARISON: GA STD CASE

QuaLiKiz ,**TGLF**, non linear simulations (scan of s, q, R/L_T, R/L_{Ti}, T_e/T_i, ν_{ei}, Z_{eff})

s-α geometry, electrostatic, no ExB shear effect

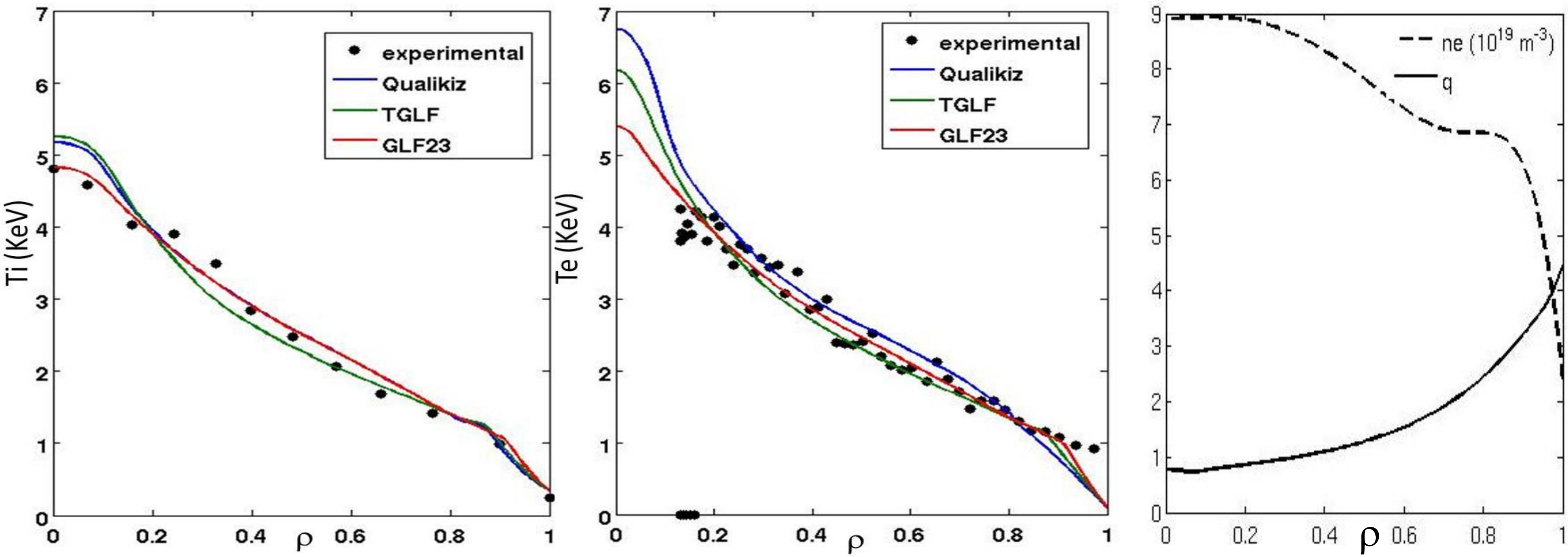




- Substantial agreement among QuaLiKiz, TGLF and non linear simulations
- For high R/LTi (ITG dominance) both TGLF and QuaLiKiz are good; for low R/LTi (TEM dominance) TGLF better for ions, QuaLiKiz for electrons

CARBON WALL JET H-MODES: 77344
SELF CONSISTENT SIMULATIONS

t = 8.8 s



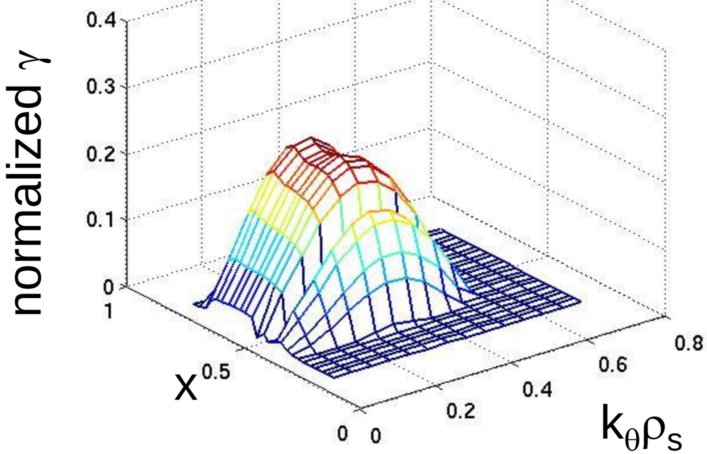
- 0.2 < ρ_{tn} < 0.8: - **Qualikiz** and **GLF23** very similar behaviour, good agreement with data
  - experimental points are well reproduced by **TGLF** too
- no 'artificial' anomalous coefficients imposed in the centre

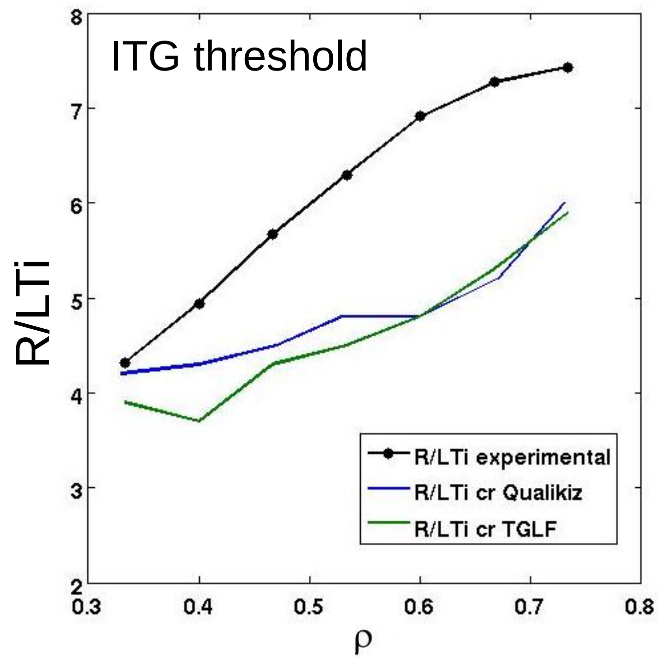
Qualikiz , TGLF and GLF23 agree with experimental T profiles in the core (0.2 < ρ_{tn} < 0.8)

CARBON WALL JET H-MODES: 77344 TURBULENCE STUDY

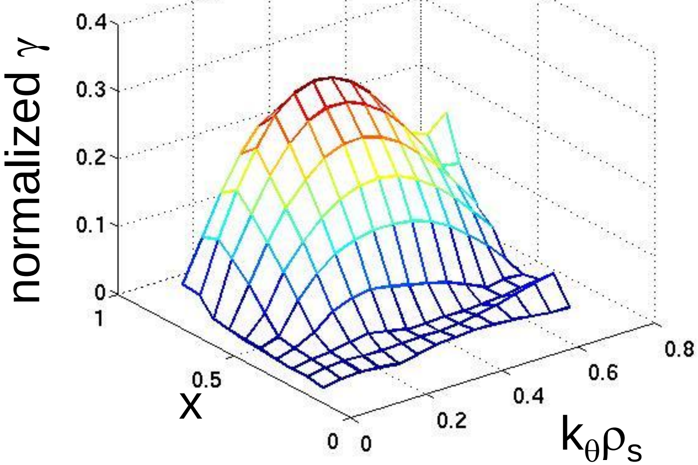
t = 8.8 s

QuaLiKiz (eletrostatic, s-α geometry)





TGLF (electromagnetic, Miller geometry)

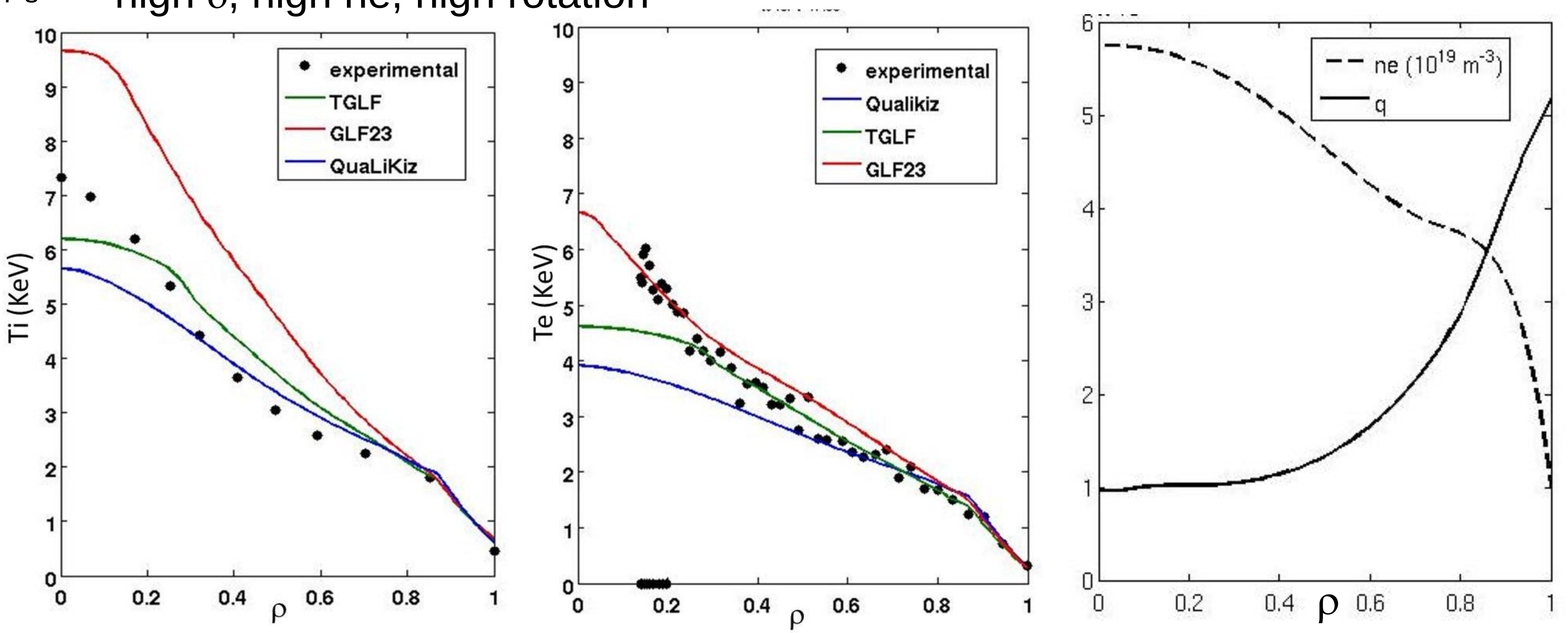


- **Turbulence study**

- both QuaLiKiz and TGLF predict the **dominance of the ITG** instabilities.
- ITG threshold clearly under the experimental R/LTi values of these discharges, as expected for typical JET H-modes (**ITG regime**).

HYBRID: JET SHOT 77922
SELF CONSISTENT SIMULATIONS

t = 7 s   high δ, high ne, high rotation



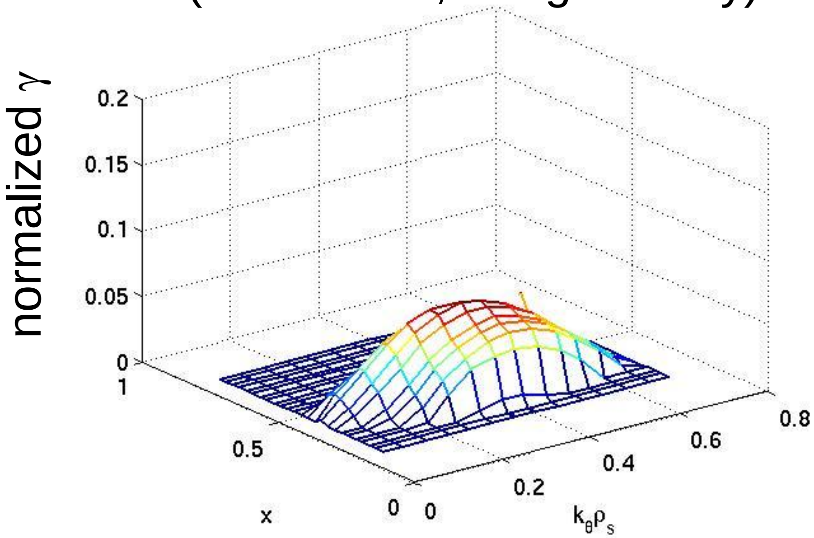
- $0.2 < \rho_{tn} < 0.8$: - **Qualikiz** underestimates electron T, better for ion T;
  - **TGLF** well reproduces electron T, ion T is slightly overestimated;
  - **GLF23** overestimates ions T, better for electron T.
- $\rho_{tn} < 0.2$: for TGLF ‘artificial’ anomalous coefficients imposed

Differences among the simulated temperatures and the experimental data

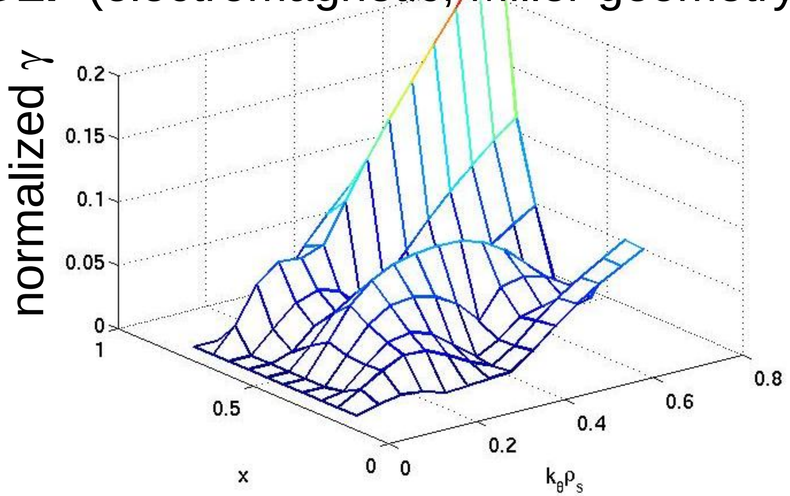
HYBRID: JET SHOT 77922 TURBULENCE STUDY

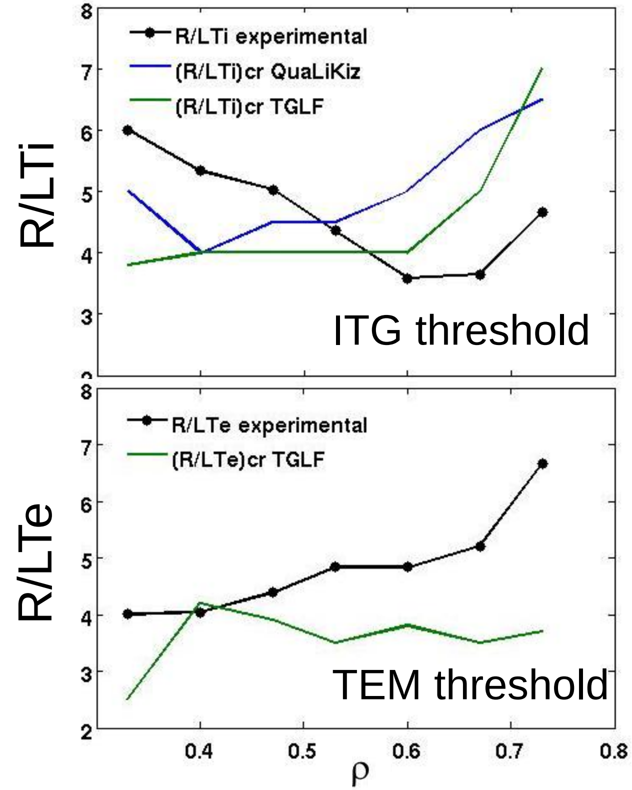
t = 7 s

QuaLiKiz (eletrostatic, s-α geometry)



TGLF (electromagnetic, Miller geometry)





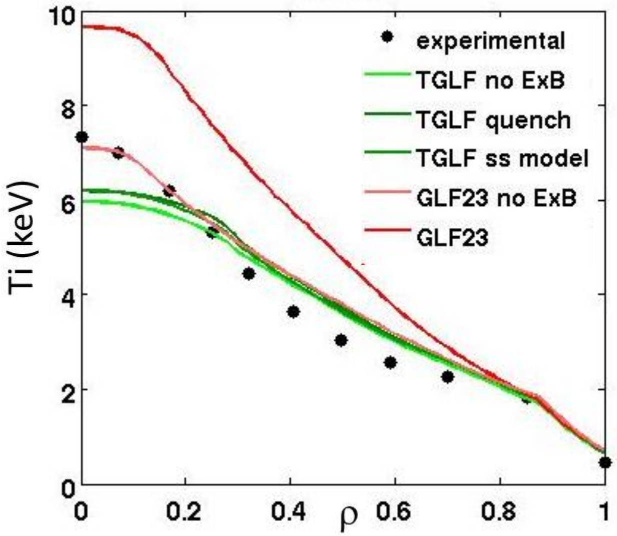
- TGLF: ITG, even TEM (centre, 0.6<ρ<1)
- QuaLiKiz: dominance of ITG, even in the centre (low T)

Different conditions: em/el, geometry, w/wo ExB shear: how much do they count?

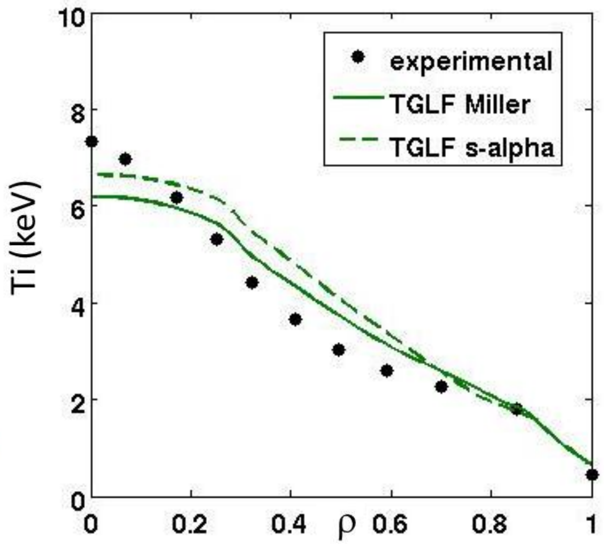
HYBRID: JET SHOT 77922
TGLF AND GLF23: EXB SHEAR, GEOMETRY AND EM EFFECTS

- **Shot 77922**: high triangularity ($\delta/\kappa=0.34/1.7$), high density (n_{e0}=6 10^{19} m^{-3}), high rotation (v_{tor} = 1 10^5 rad/s), high β (β_N=2.7)

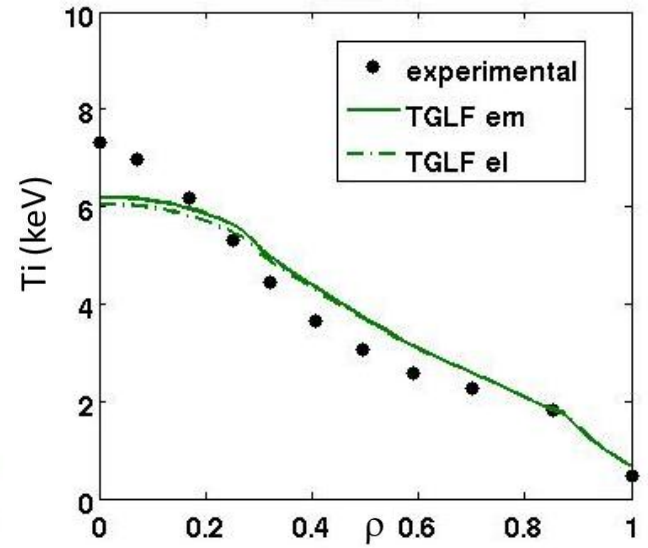
ExB shear effect



Geometry effect



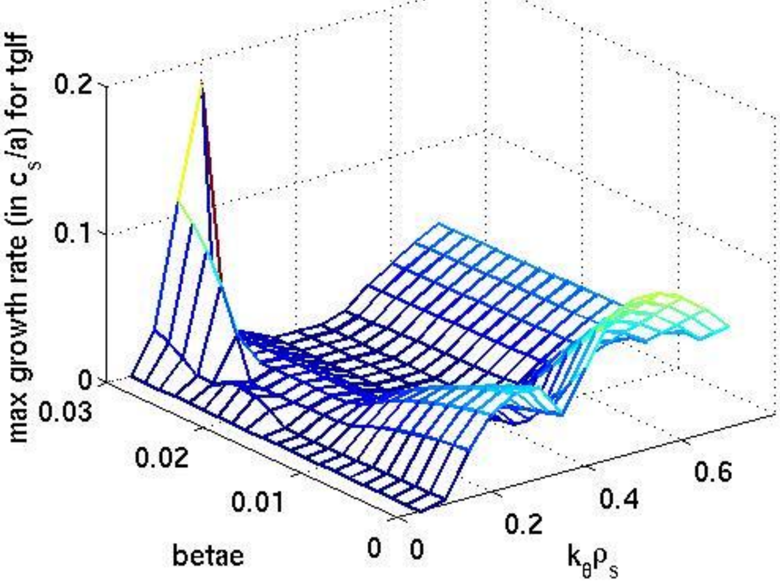
Em effect



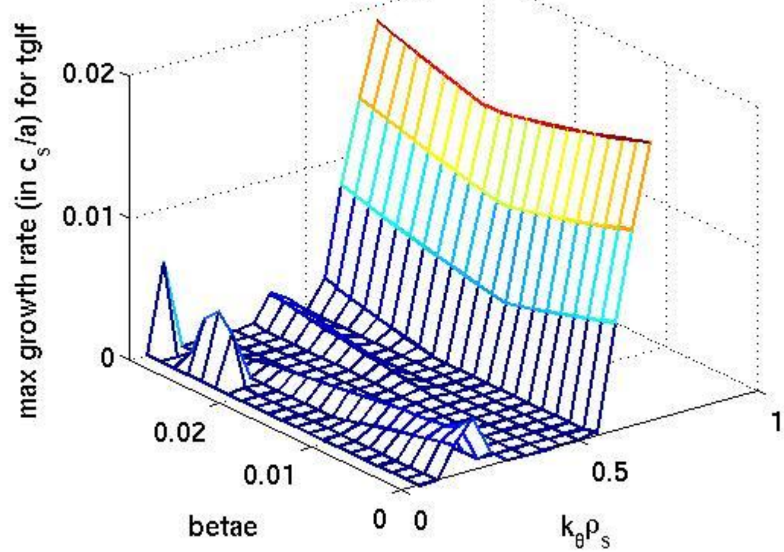
- ExB shear effect negligible for TGLF, as expected for a JET high density shot and from linear GYRO simulations (Voitsekhovitch 2012);
  GLF23 overestimates the ExB shear turbulent transport reduction (Litaudon 2013);
- The different description of the geometry has a relevant impact in reproducing better the T profile, as expected for an high shape shot;
- It's the different description, not the geometry that changes the T profiles (s-α description overestimates the R/Lti threshold with respect to Miller with κ = 1 and δ = 0 (Lapillonne 2009));
- The em effect is negligible.

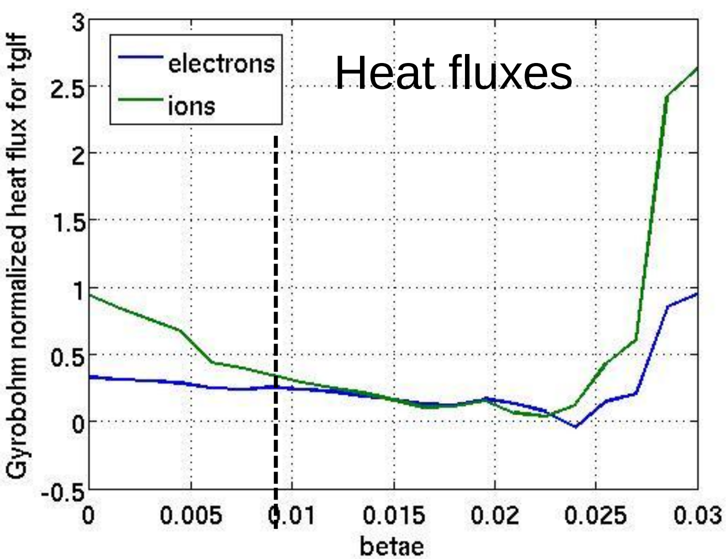
HYBRID: JET SHOT 77922
TGLF: EM EFFECTS: 'TURBULENCE' ANALYSIS IN X=0.33

βe scan: experimental T profiles



βe scan: simulated T profiles





No KBM found by TGLF. From linear GYRO simulations γ is very close to the limit of the KBM dominant domain (Voitsekhovitch 2012).

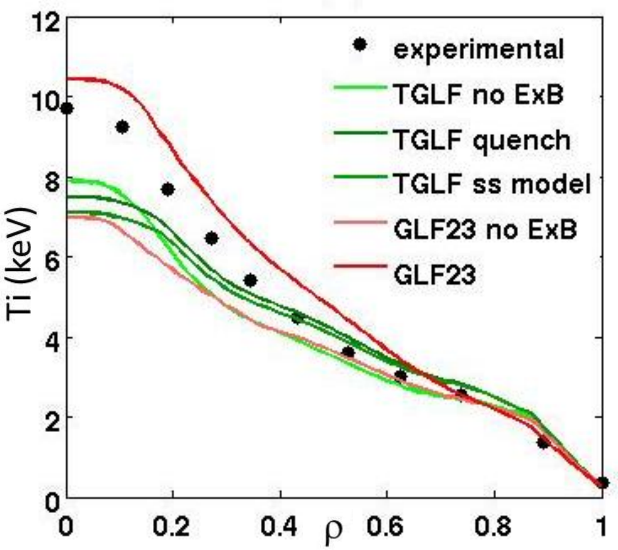
- weak dependence on βe, γ and fluxes very low in the simulation, even in the electrostatic case;
- taking the experimental T profiles as imput, the fluxes are reduced by increasing βe, even KBM threshold is farer than for GYRO (filter on in TGLF);

Other em instabilities not included in TGLF could have an important role (MTM) or some non linear effects could trigger ITG (NZT) -> **this could explain T overestimation**

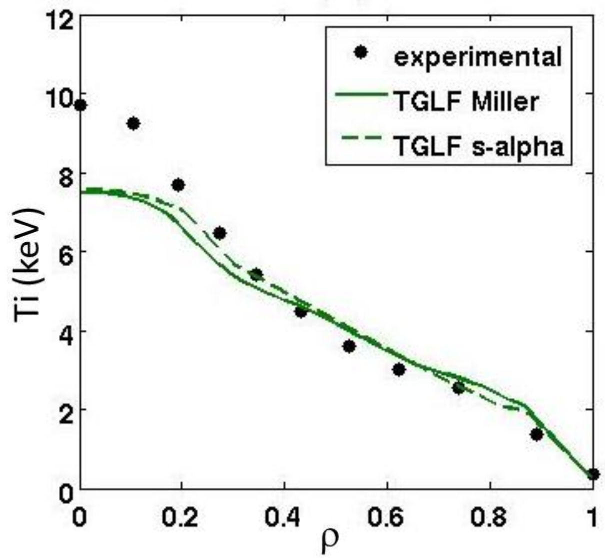
HYBRID: JET SHOT 75225
TGLF AND GLF23: EXB SHEAR, GEOMETRY AND EM EFFECTS

- **Shot 75225**: low triangularity ($\delta/\kappa = 0.23/1.64$), low density ($n_{e0}=1\ 10^{19}\ m^{-3}$),
  high rotation (v_{tor} = 1 10^5 rad/s), high β (β_N=3), high fast ions population

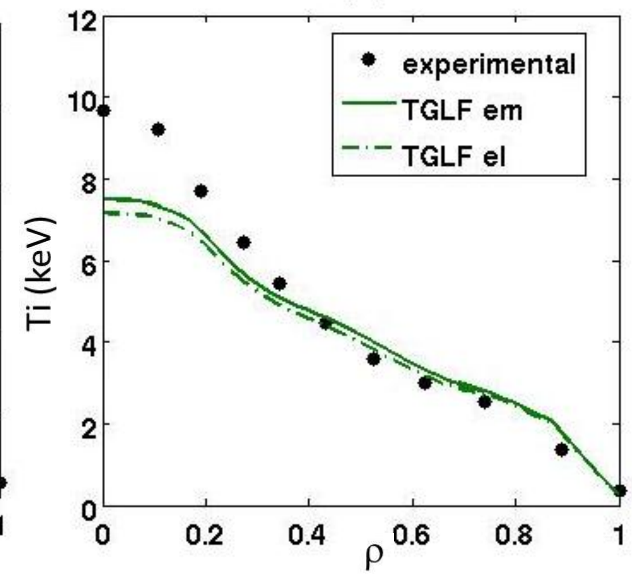
ExB shear effect



Geometry effect



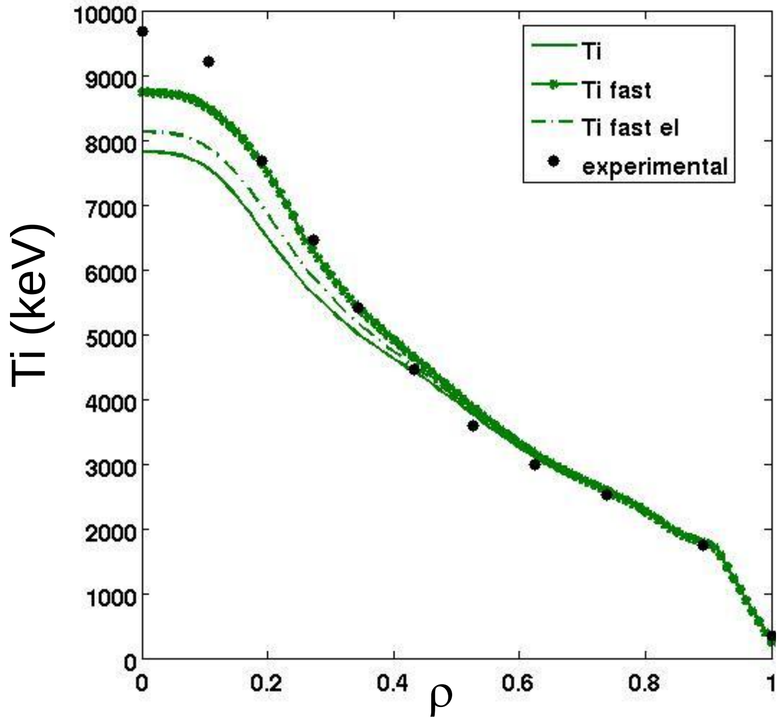
Em effect

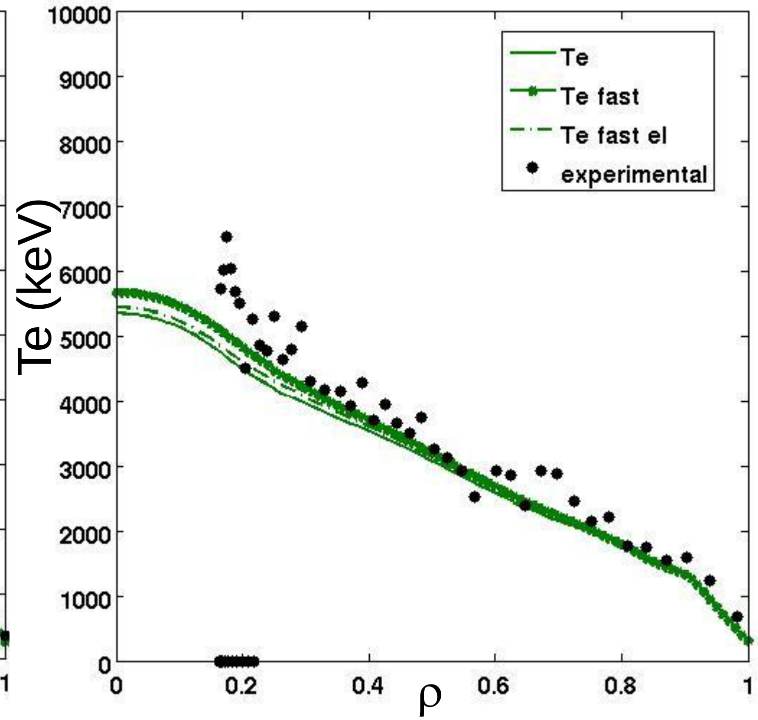


- ExB shear effect important for TGLF, in accord the the presence of an high rotation and a low density; GLF23 always overestimates the ExB shear effect;
- The effect of the both rules are in accord even for this shot;
- The impact of the different geometry description is not relevant, as expected for an low shape shot;
- The em effect is very weak, slightly stabilizing. No KBM found by TGLF. Gyrokinetic GENE simulations of this shot confirm the absence of KBM (Garcia, Citrin 2013)

HYBRID: JET SHOT 75225
TGLF: INCLUSION OF FAST IONS

- **Shot 75225**: low δ, low n_e, high v_{tor}, high β, high fast ions population



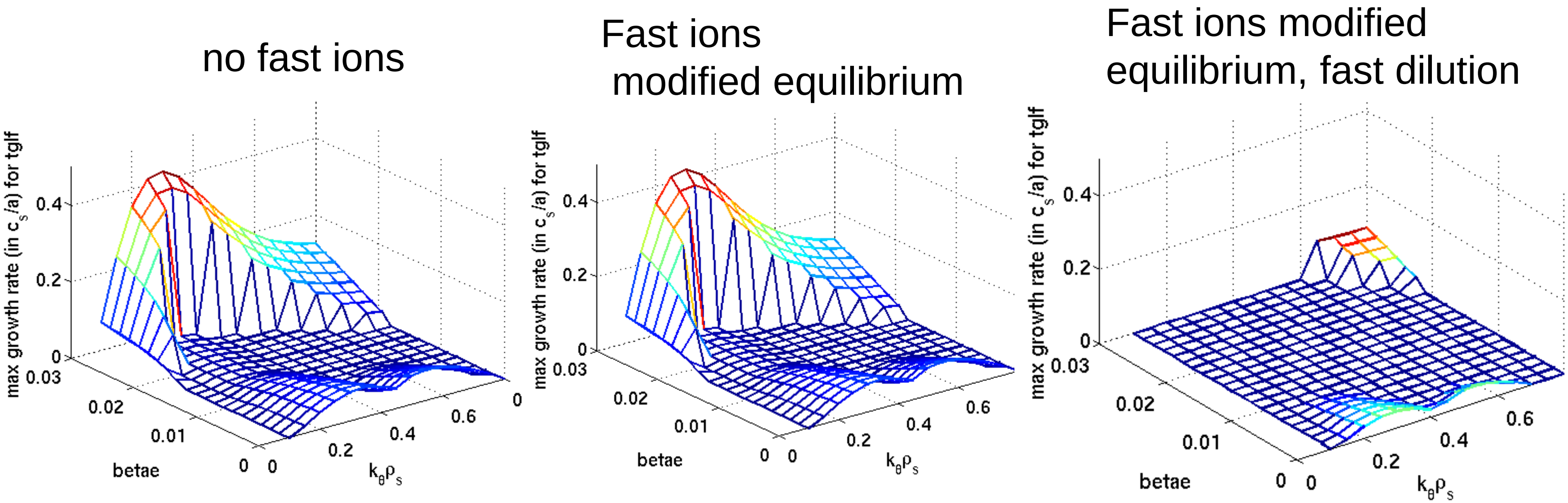


TGLF with
- ExB shear effect;
- em instabilities;
- Miller geometry

- Dilution of fast ions: density and energy of fast ions calculated with interpretative analysis performed with code SPOT (Garcia 2013);
- Linear stabilization of ITG in the core by fast ions, known mechanism (Tardini 2007, Bourdelle 2005)

Ion and electron temperatures are well reproduced by TGLF

HYBRID: JET SHOT 75225
TGLF: INCLUSION OF FAST IONS AND EM EFFECTS
'TURBULENCE' ANALYSIS IN X=0.33



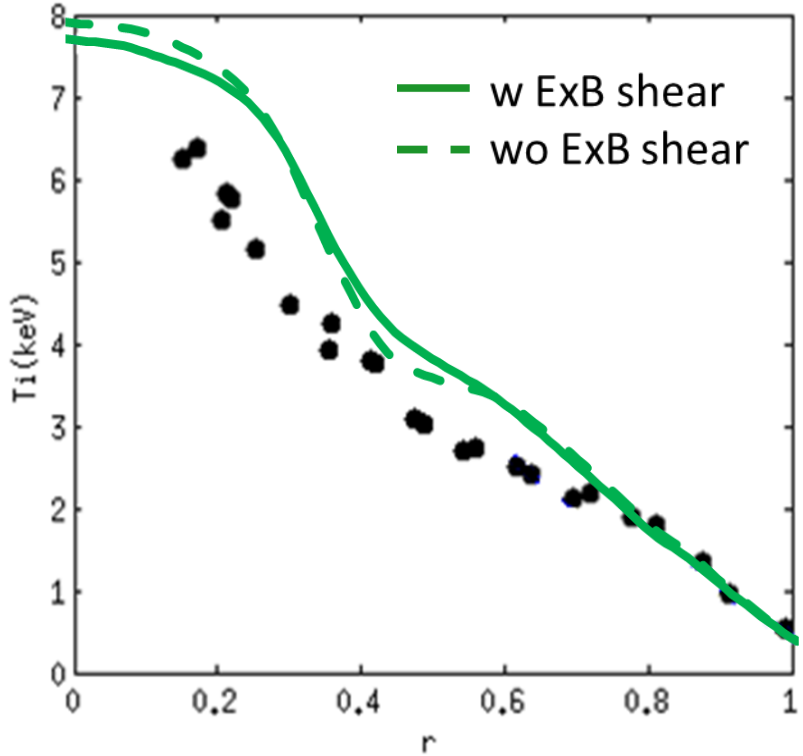
βe exp = 0.008

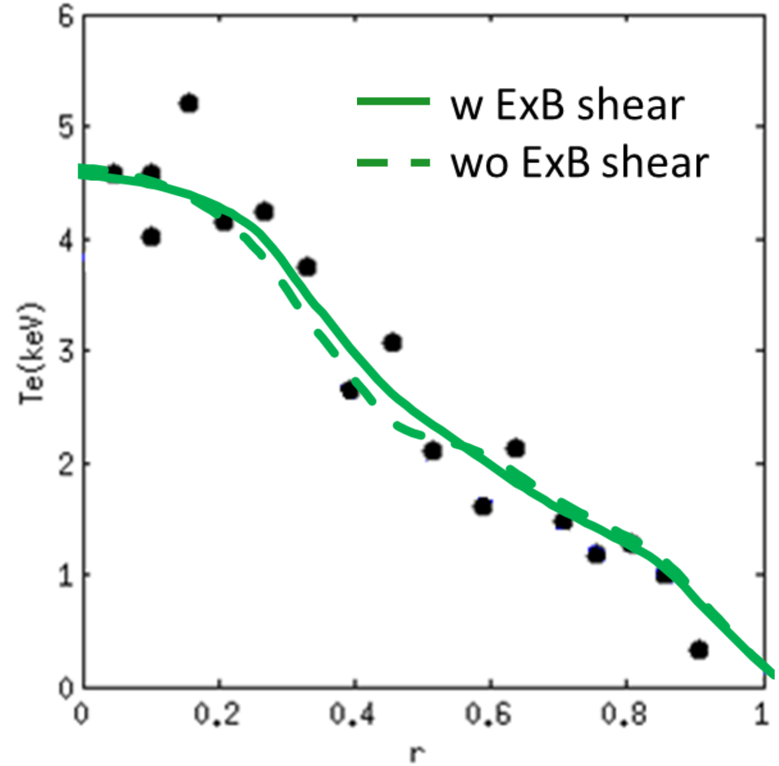
- NO KBM foreseen by TGLF (filter on);
- Stabilization due to βe finite effects and to the inclusion of fast ions:
  - the contribution of the em effects is more important
  - for the the contribution of the inclusion of fast ions, the dilution plays the big role in the stabilization

… however em gyrokinetic simulations (GENE) predict the presence of KBM if fast ions are included -> work in progress about fast ions and em effects for high β

HYBRID: JT60-U SHOT 48158
TGLF: ROLE OF EXB SHEAR

- **Shot 48158**: $\delta/\kappa=0.33/1.4$, low rotation, $\beta_N=2.6$, high fast ions population





- Electron temperatures are well predicted;
- Ion temperatures are overestimated, however they are closer to the experimental data with respect the simulations done using GLF23, BgB, .. (Garcia 2013);
- Role of ExB shear negligible, as expected for 48158 (low rotation)
- Role of em instabilities and fast ions? Work in progress

SUMMARY

- **Heat transport simulations** of 2 carbon wall **JET H-modes** and 2 **JET hybrids using** the two new quasilinear first principle transport models **QuaLiKiz** and **TGLF in CRONOS**;
- **Turbulence analysis** with the study of the threshold for ITG and TEM through the stand alone version of **QuaLiKiz** and **TGLF**;
- Study of the impact of the **ExB shear effect,** the **geometry,** the **em effects** and the inclusion of the **fast ions** for **JET hybrids** using **TGLF**;
- **Heat transport simulation** of 1 **JT60-U hybrid** discharge using **TGLF.**

-> **GA STD CASE**

- substantial agreement among QuaLiKiz and TGLF and non linear simulations;

-> **JET H-MODES**

- good agreement among QuaLiKiz, TGLF with GLF23 simulations and experimental data (ITG regime);

-> **JET HYBRIDS**

- discrepancies among QuaLiKiz, TGLF, GLF23 simulations and experimental data;
- TGLF gives T profiles closer to the experimental data than QuaLiKiz;
- ITG dominated for QuaLiKiz, also presence of TEM for TGLF;
- the inclusion of the Miller geometry description in TGLF contribute to give better results;
- TGLF redemensions properly the weight of the ExB shear effect, in accord with the characteristic of the simulated JET and JT60-U hybrids, despite on GLF23 that always overestimates it;
- for JET hybrids with a large presence of fast ions (75225) the inclusion in TGLF of the fast ions dilutions gives the best results, confirming their importance in the interaction mechanism with electromagnetic effects in high β hybrids.

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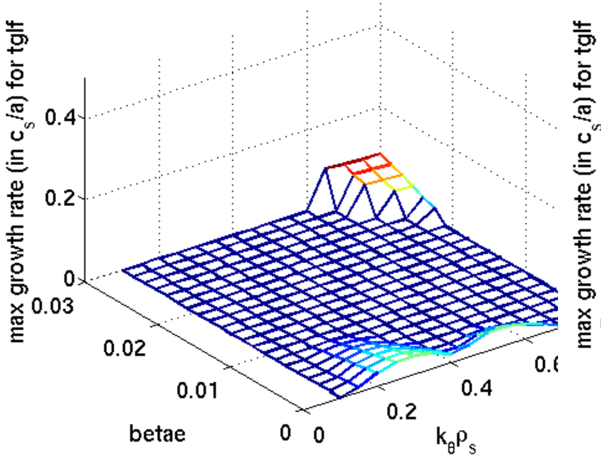
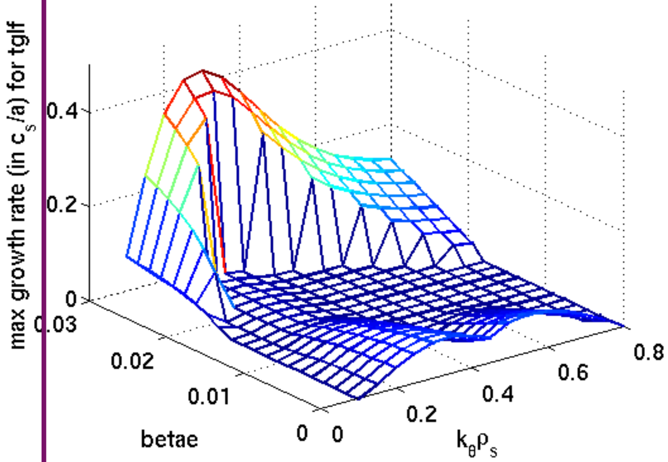
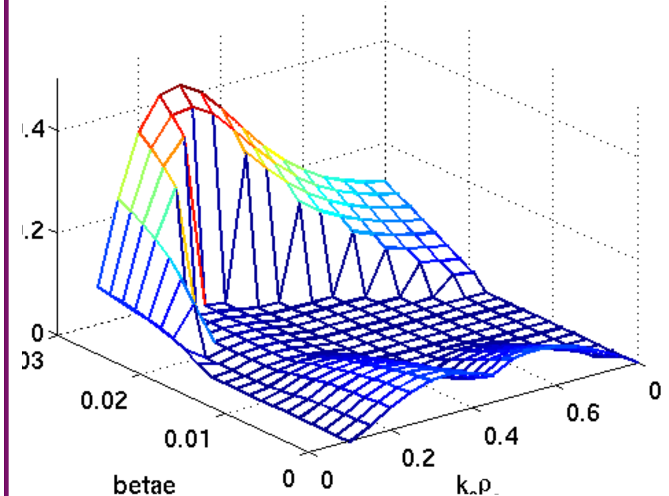
HYBRID: JET SHOT 75225
TGLF: INCLUSION OF FAST IONS AND EM EFFECTS
‘TURBULENCE’ ANALYSIS IN X=0.33: FILTER ON

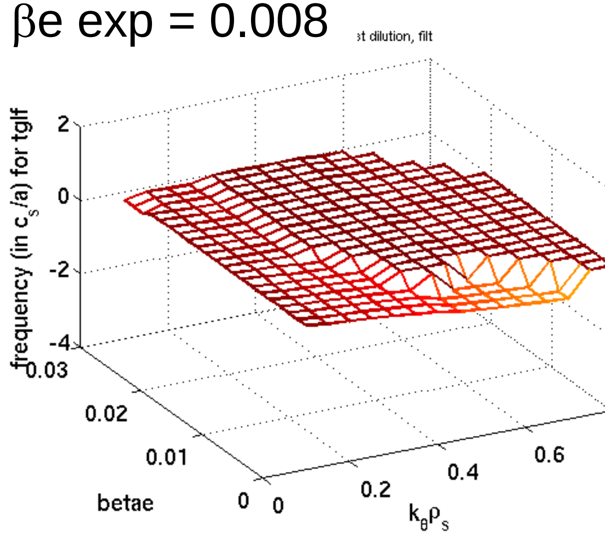
input with fast, fast dilution | input with fast, no fast dilution | input without fast

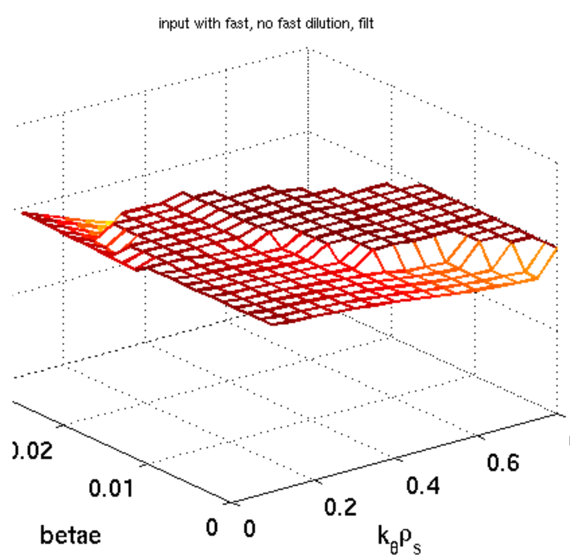


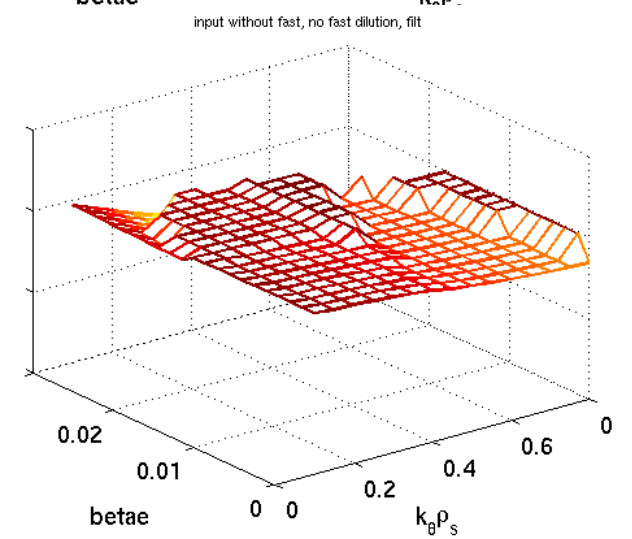




βe exp = 0.008



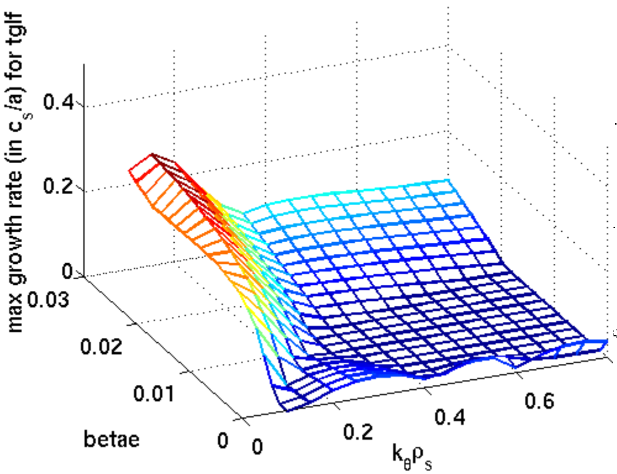


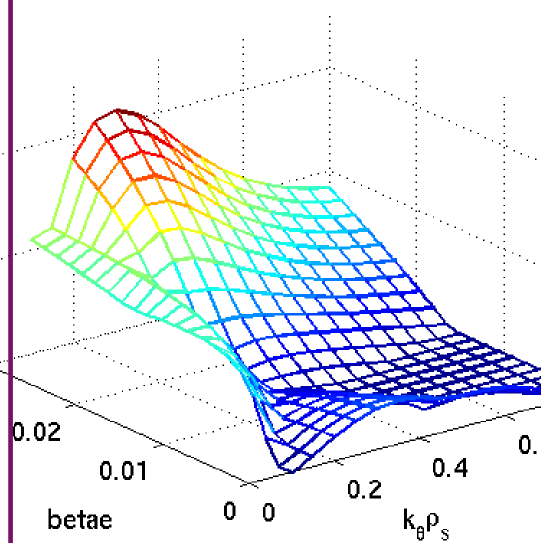


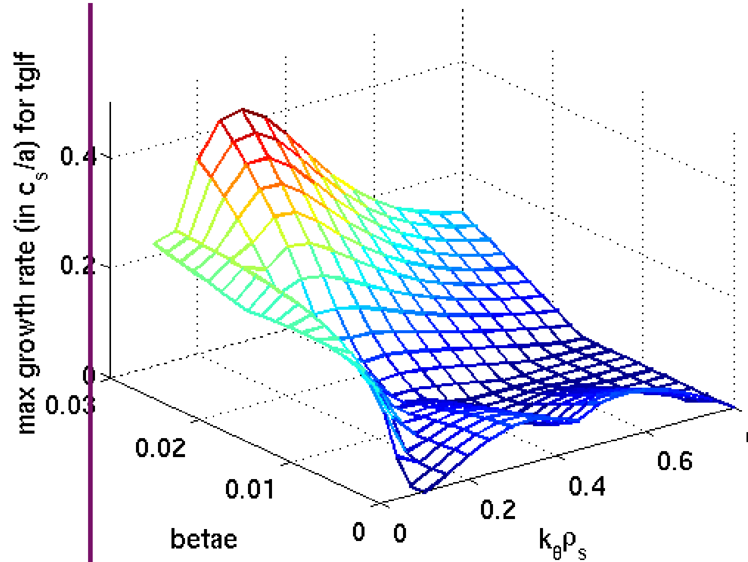
Filter on: ‘ignore unstable modes with a frequency divided by the largest drift frequency bigger than the value of the filter’.

HYBRID: JET SHOT 75225
TGLF: INCLUSION OF FAST IONS AND EM EFFECTS
‘TURBULENCE’ ANALYSIS IN X=0.33: FILTER OFF

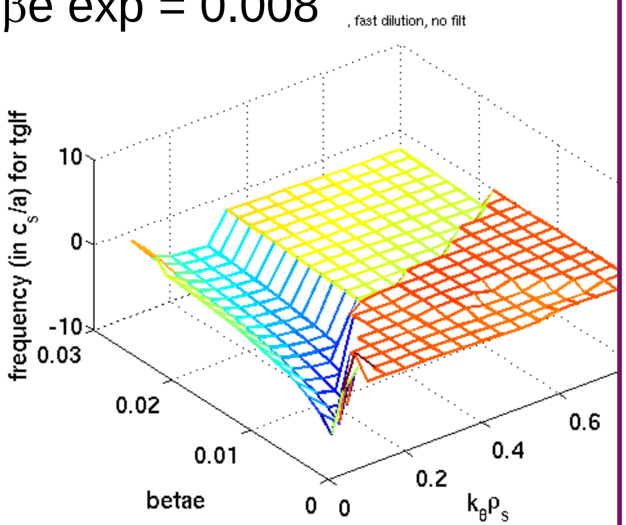
input with fast, fast dilution | input with fast, no fast dilution | input without fast

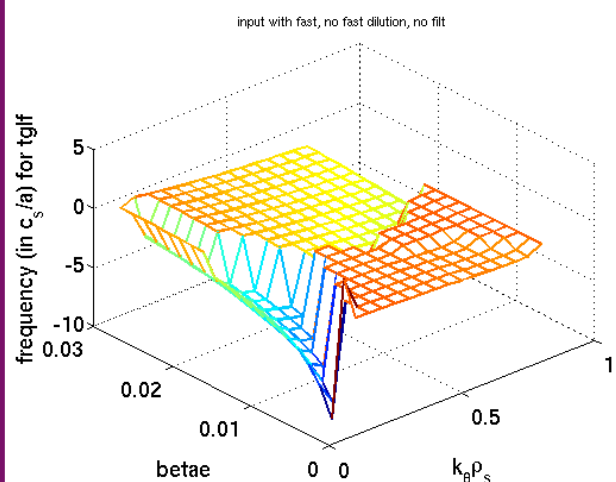


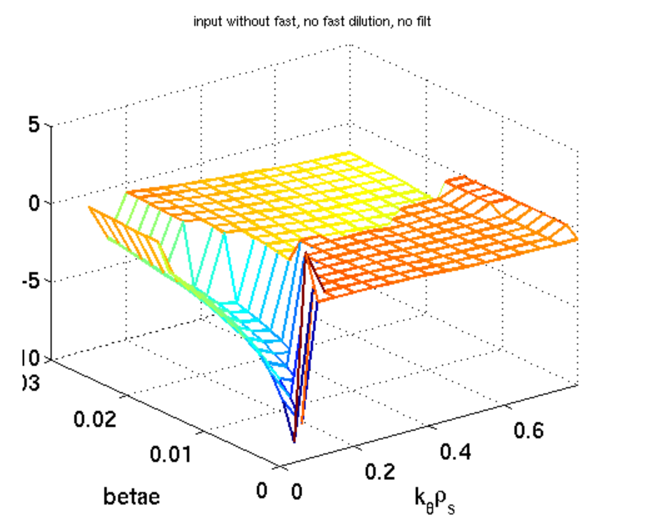




βe exp = 0.008

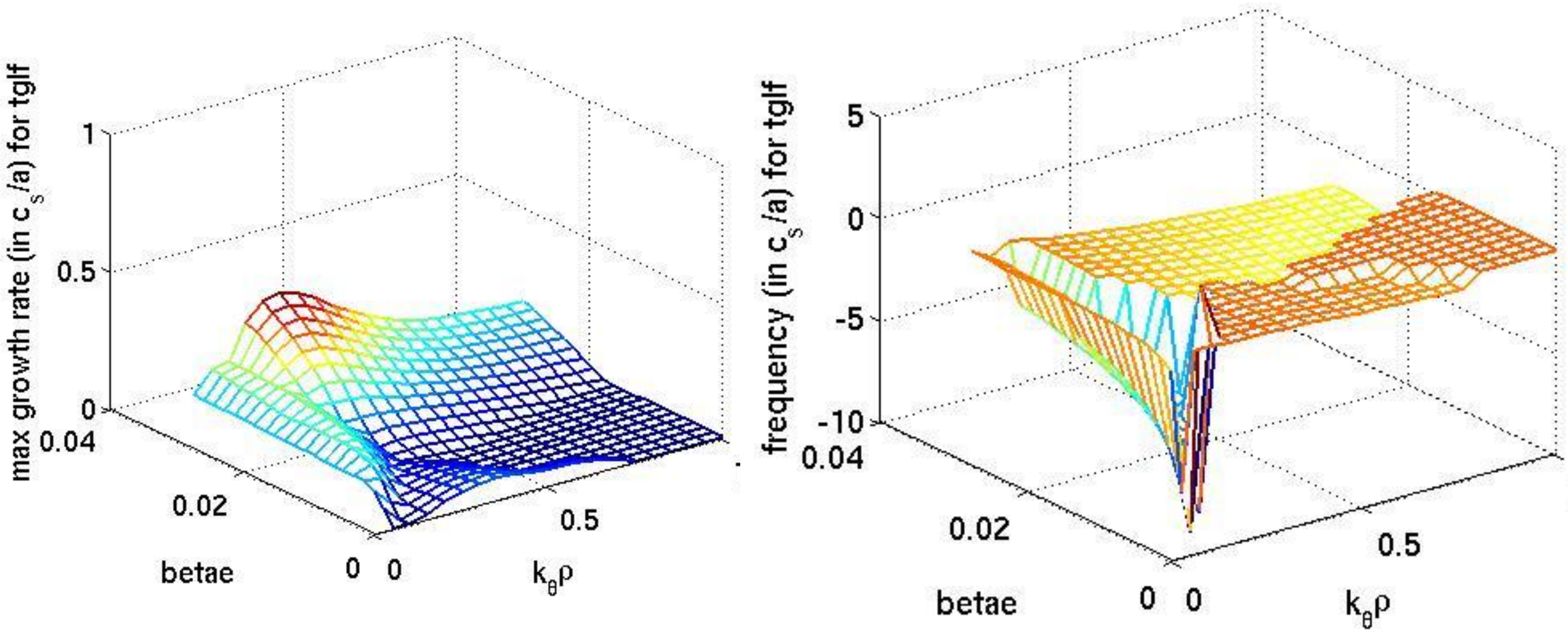


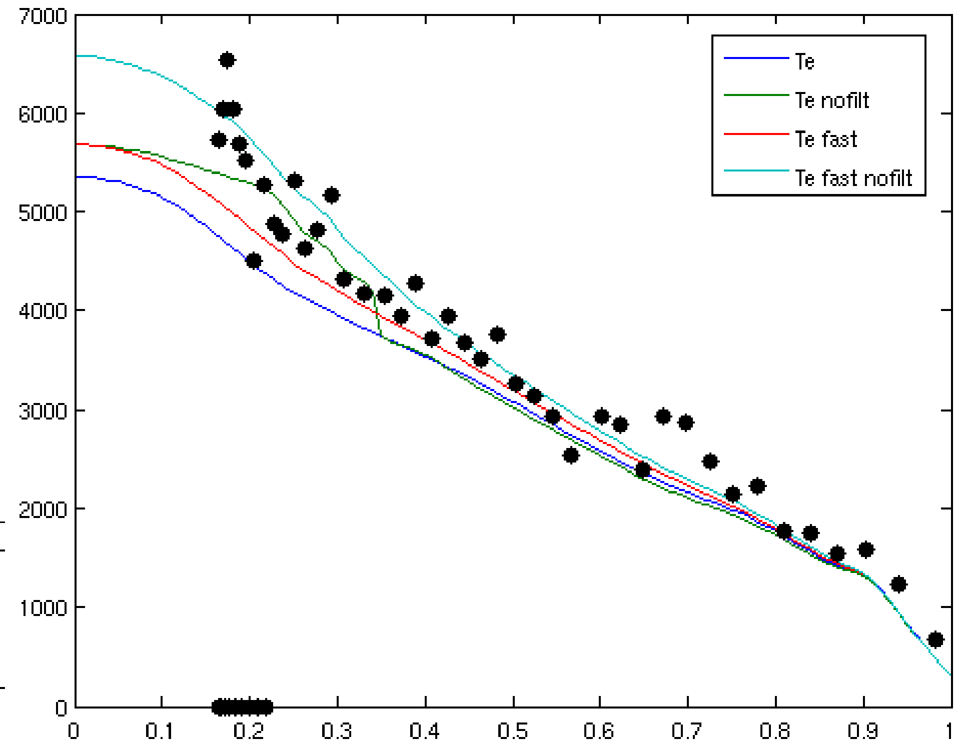




HYBRID: JET SHOT 77922
TGLF: EM EFFECTS
'TURBULENCE' ANALYSIS IN X=0.33: FILTER OFF

βe exp = 0.009

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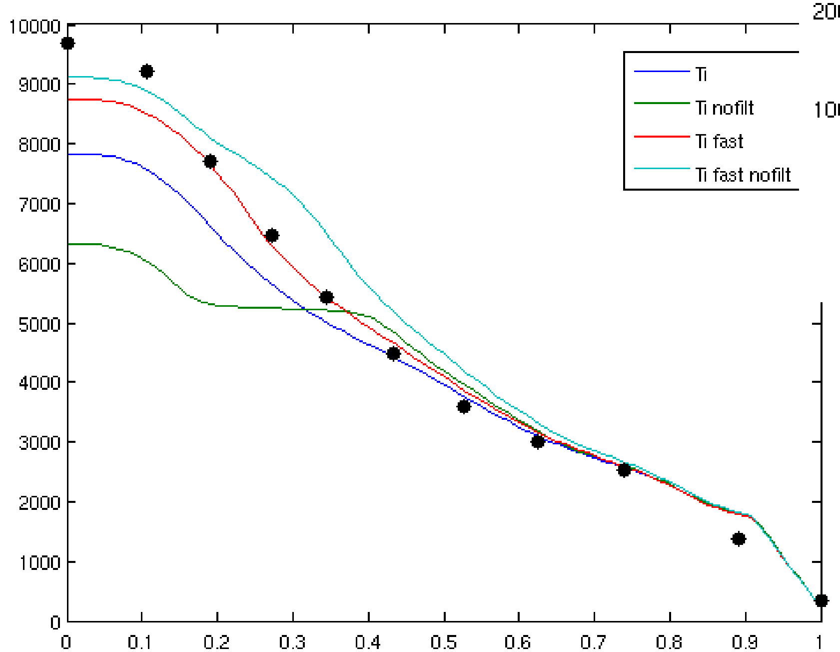
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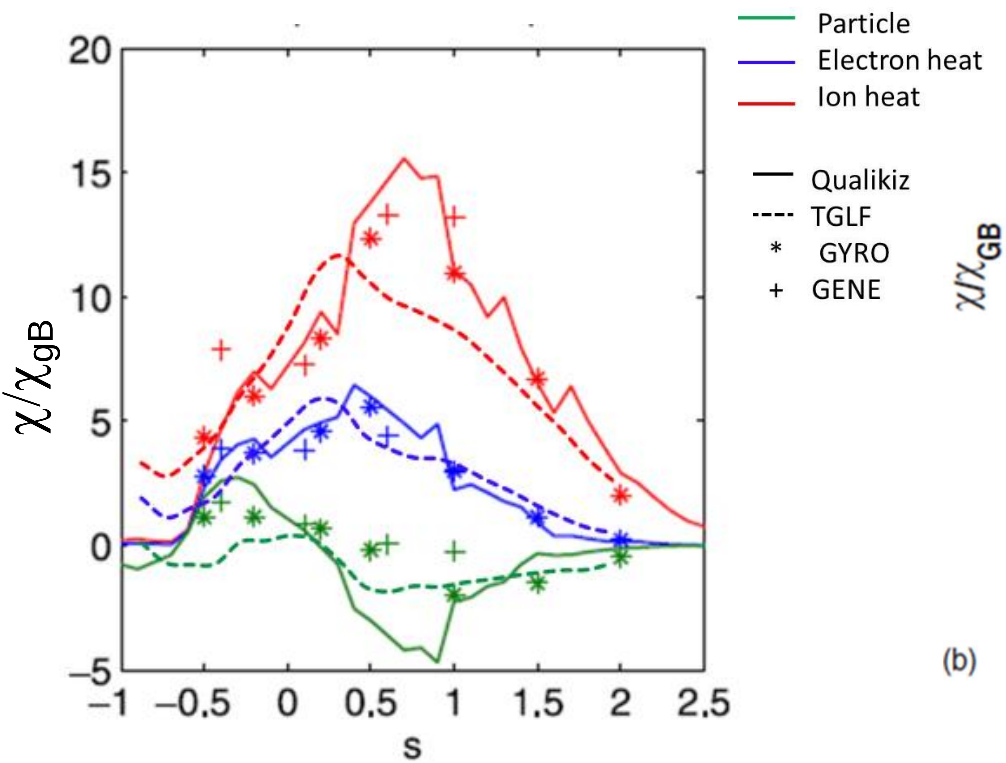
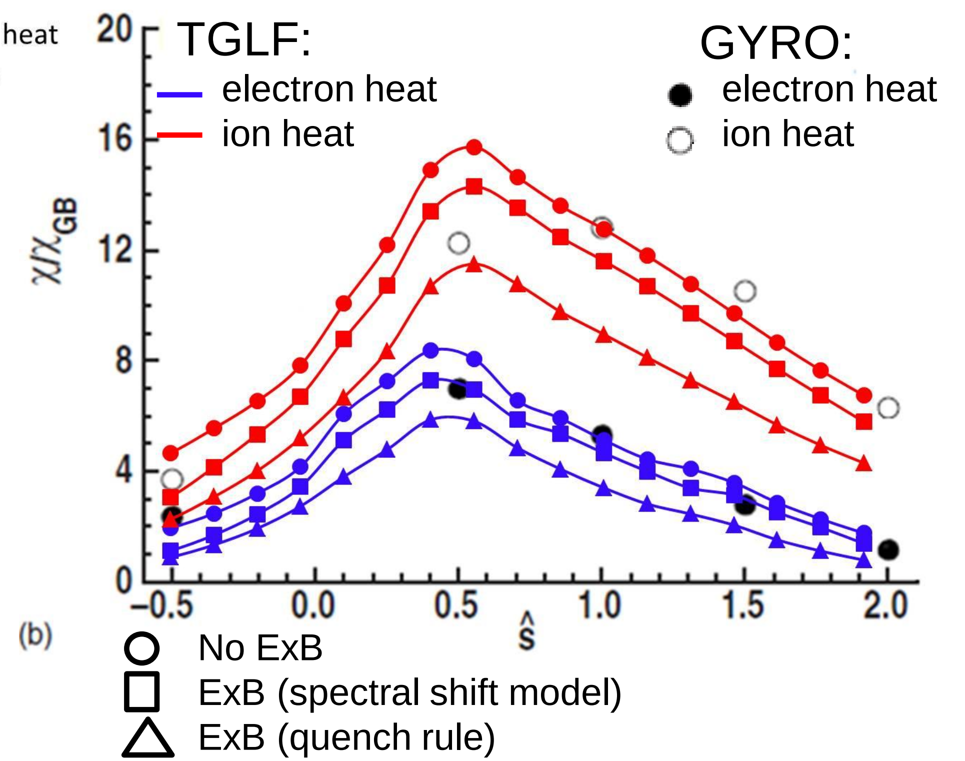
STAND ALONE COMPARISON: GA STD CASE

QLK and **TGLF** - non linear simulations (scan of s, q, R/L_T, R/L_{Ti}, T_e/T_i, ν_{ei}, Z_{eff})

s-α geometry



Miller geometry

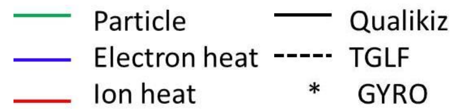


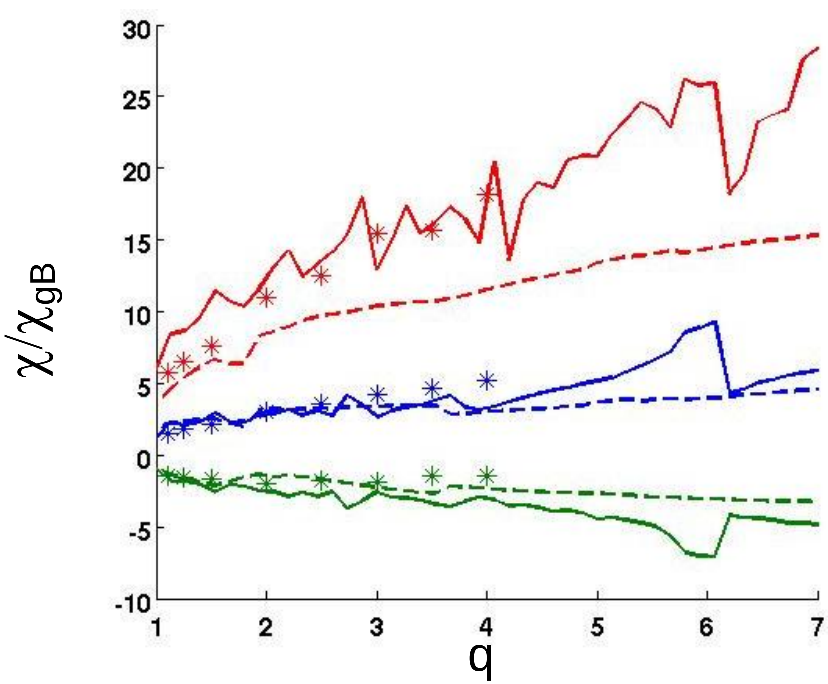
- Substantial agreement among QuaLiKiz, TGLF and non linear simulations

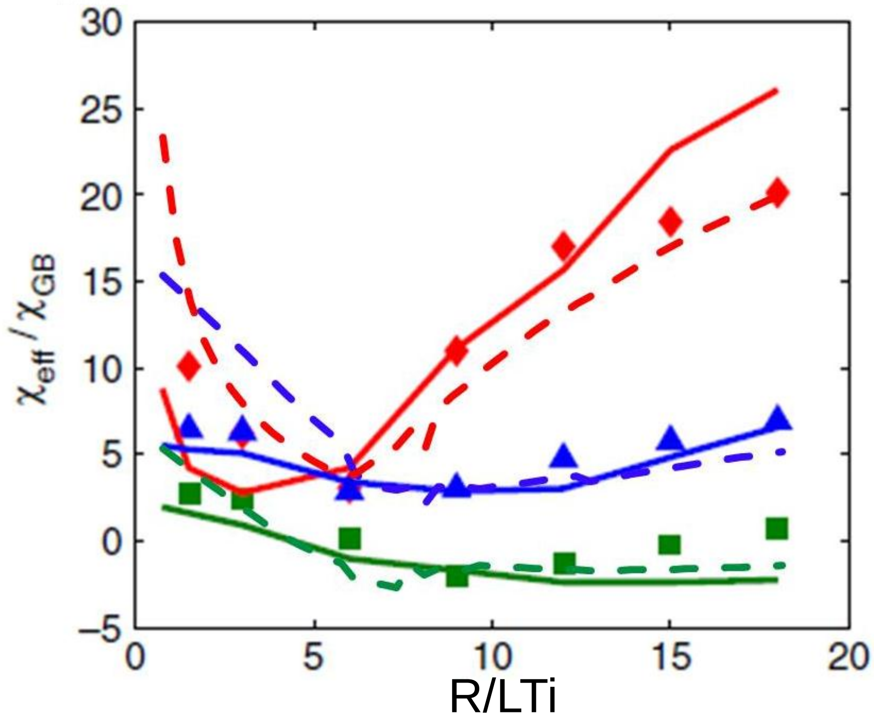
- Better agreement of TGLF with Miller geometry
- Presence of ExB shear factor has significant impact

STAND ALONE COMPARISON: GA STD CASE

s-α geometry





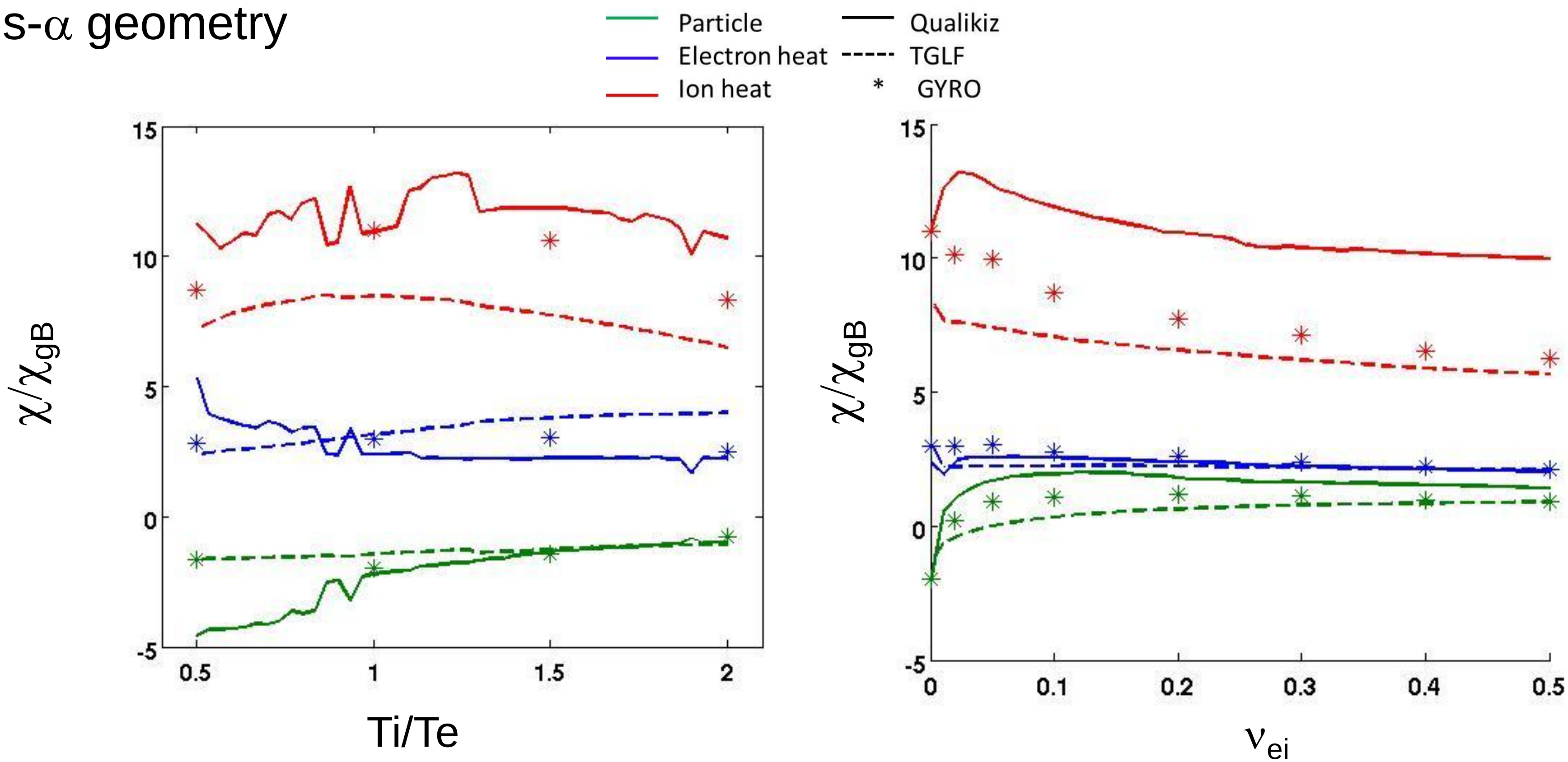


- QuaLiKiz well reproduces the non linear results, TGLF gives lower χ_i for high q (low k_θ resolution problem?)

- For high R/LTi (ITG dominance) both TGLF and QuaLiKiz are good; for low R/LTi (TEM dominance) TGLF better for ions, QuaLiKiz for electrons

STAND ALONE COMPARISON: GA STD CASE

s-α geometry



- Good agreement for QuaLiKiz, except for Te>>Ti; TGLF gives lower χ_i, good for electrons and particles
- QuaLiKiz overestimates χ_i; both TGLF and QuaLiKiz are good for χ_e; for particles both the models change the sign of the effective diffusivity, QuaLiKiz before than TGLF

s-α GEOMETRY, MILLER GEOMETRY

s-α geometry

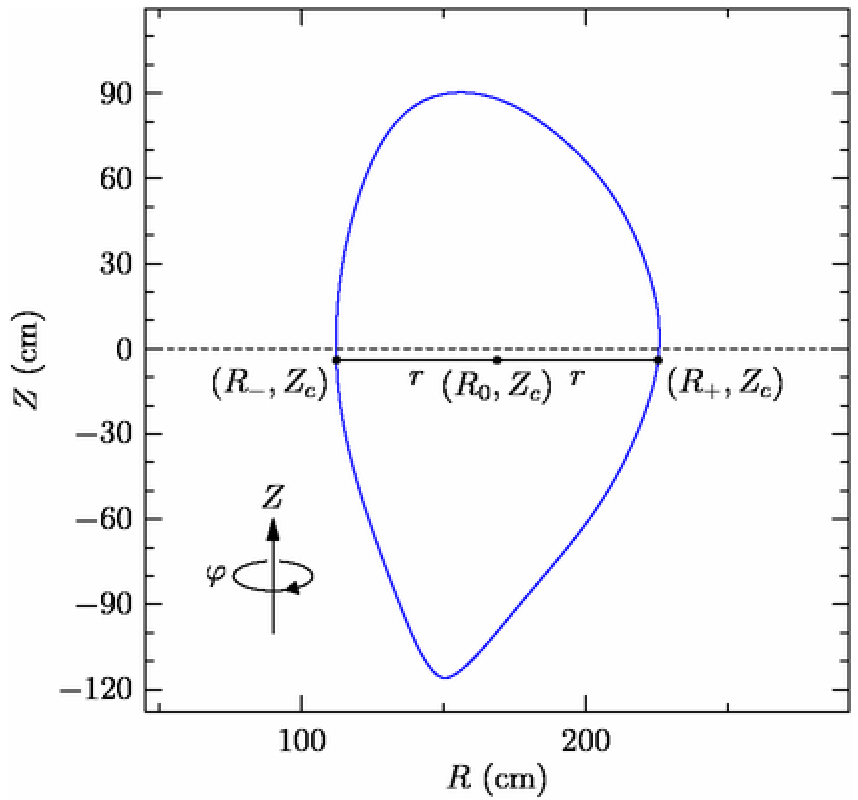
$$R = [R_0 + \Delta(r)] + r\cos\theta,$$

$$Z = r\sin\theta.$$

Miller geometry

$$R_s = R_0 + r\cos[\theta + (\sin^{-1}\delta)\sin\theta],$$

$$Z_s = \kappa r\sin\theta,$$



recipe to convert a circular s_a transport model to a Miller geometry:

- to use the circular model
- to replace the toroidal magnetic field by an effective field:
  $B_{unit} = B_0 S_h(r)$, where B_0 is the magnetic field on the magnetic axis
  $S_h(r) = \rho d\rho / r dr$ is the shape factor

GA STD CASE: parameters