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Safety factor impact on the radial electric field in gyrokinetic simulations

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Acknowledgments:

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D2.5	Report including statements on the relative impact of some separate ingredients playing a role in the radial electric field formation (orbit losses, ripple, turbulence, neutrals, limiter...)	report or paper submitted, conference contribution	X. Garbet, R. Varenes, L. Vermare, G. Falchetto, P. Donnel	12/2022
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[R. Varenes – PRL 2022]

[R. Varenes – PPCF in resubmission]

+ presented in 8 conferences

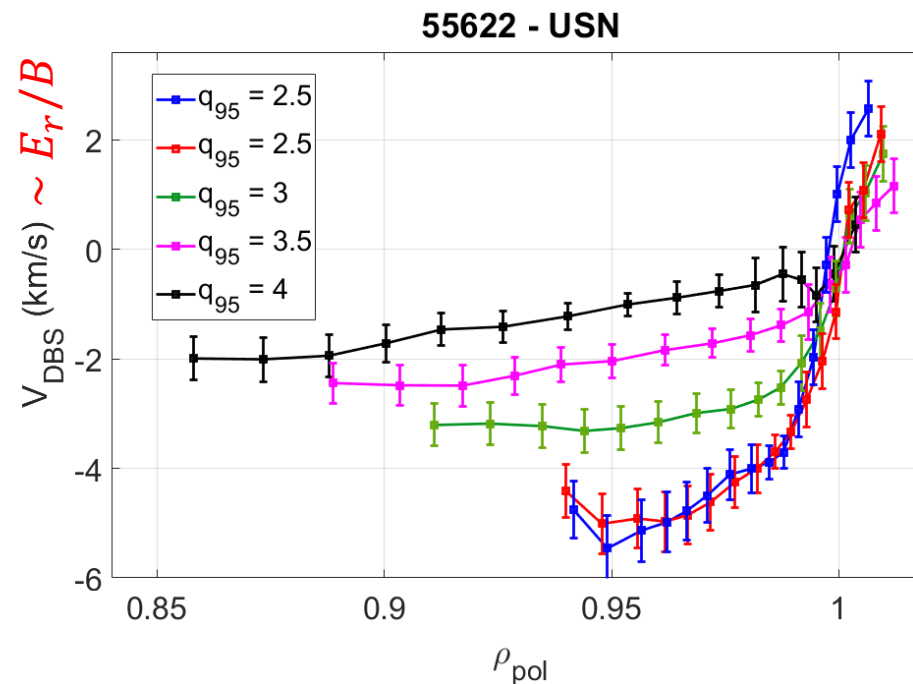
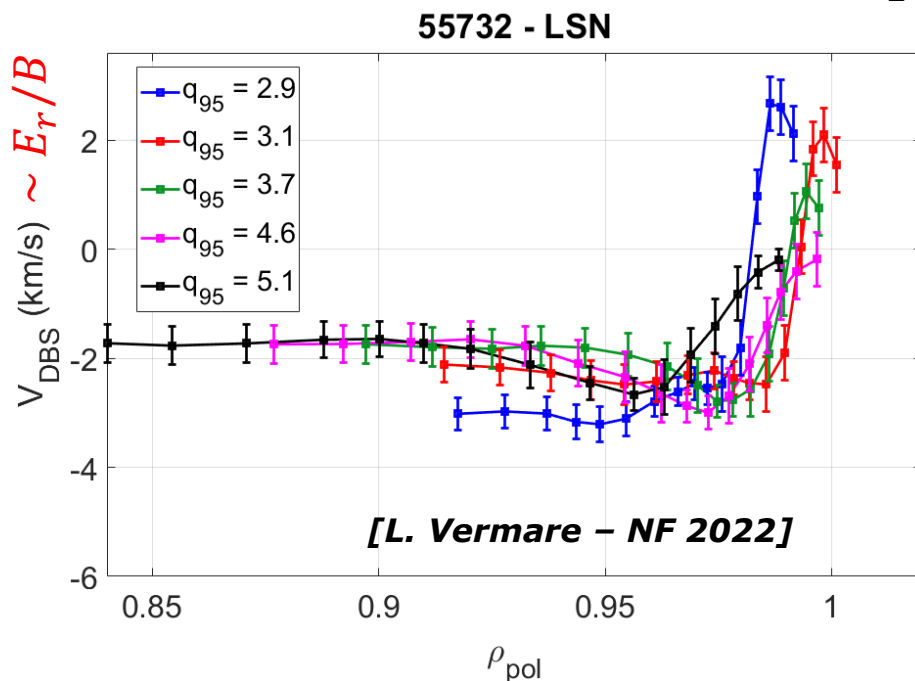
M2.9	Study the development of a radial electric field in response to key parameters such as injected power, collisionality and safety factor, using the GYSELA and ORB5 codes including simplified limiter/SOL - comparison with fluid code results	L. Vermare, X. Garbet, R. Varenes, P. Donnel	06/2022
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Strong impact of plasma current on edge radial electric field in experiment

- ❖ Plasma current I_P scan performed in WEST discharges
- ❖ $I_P \propto 1/q$
- ❖ $|E_r| \nearrow$ at the edge when $I_P \nearrow$ (observed in Tore Supra and MAST)
- ❖ Effect more significant in USN compared with LSN

[P. Hennequin – EPS 2010]

[H. Meyer – JPCS 2008]



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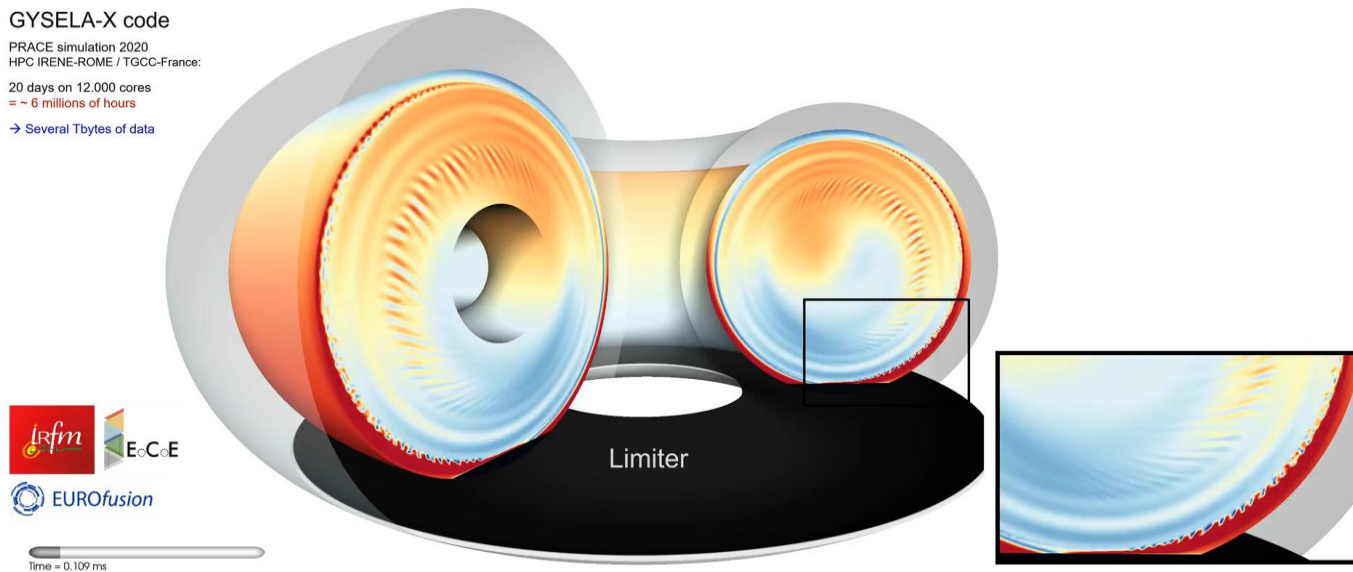
What are the mechanisms at play ?

- GYSELA: kinetic code solving

Fokker-Planck: $\frac{dF}{dt} = C(F)$

Poisson: $\epsilon_R \nabla^2 \phi = -\sum_{\text{species}} e \int F d^3v$

GYSELA-X code
PRACE simulation 2020
HPC IRENE-ROME / TGCC-France:
20 days on 12,000 cores
= ~ 6 millions of hours
→ Several Tbytes of data

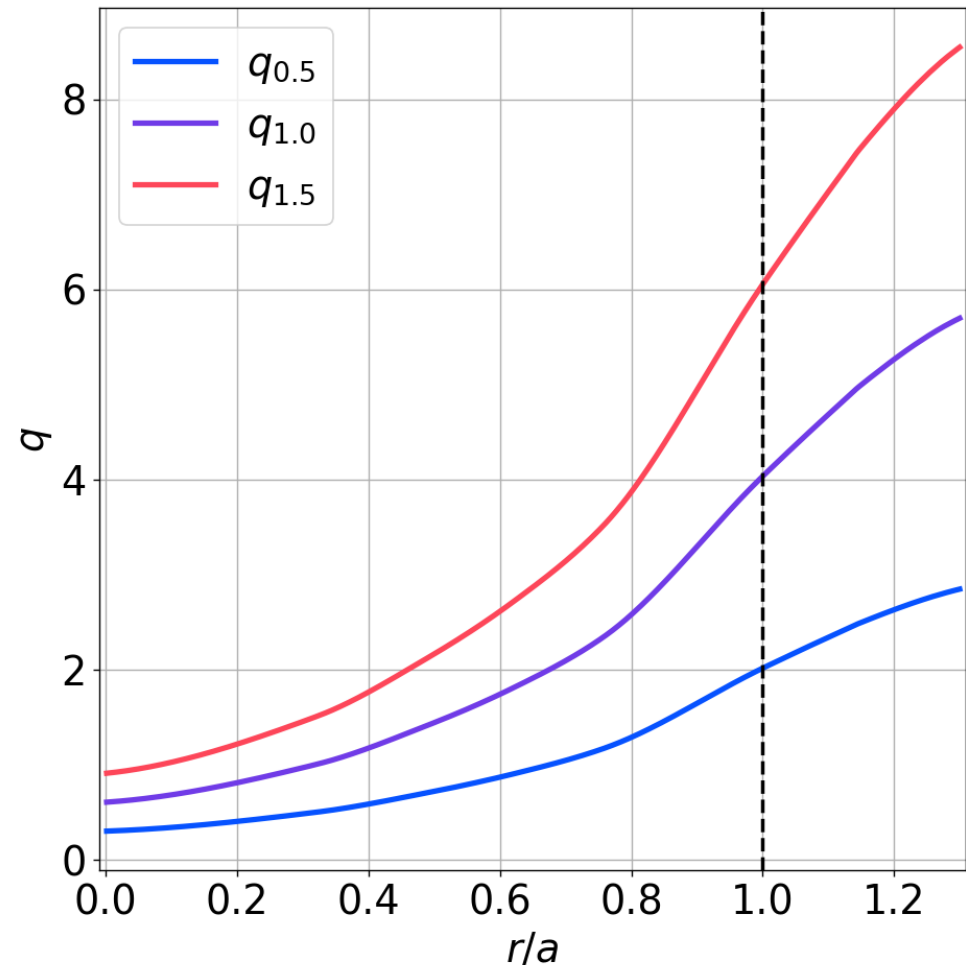


[V. Grandgirard – CPC 2016]

Does GYSELA contains enough physical ingredients to retrieve the deepening of E_r when q decreases ?

- ❖ Reference simulation $q_{1.0}$ close to Tore Supra #45511 discharge
- ❖ → Supplementary simulations $q_{0.5}$ / $q_{1.5}$ to **isolate only the effect of the safety factor**
- ❖ As in WEST experiments, **same magnetic shear** in all simulations

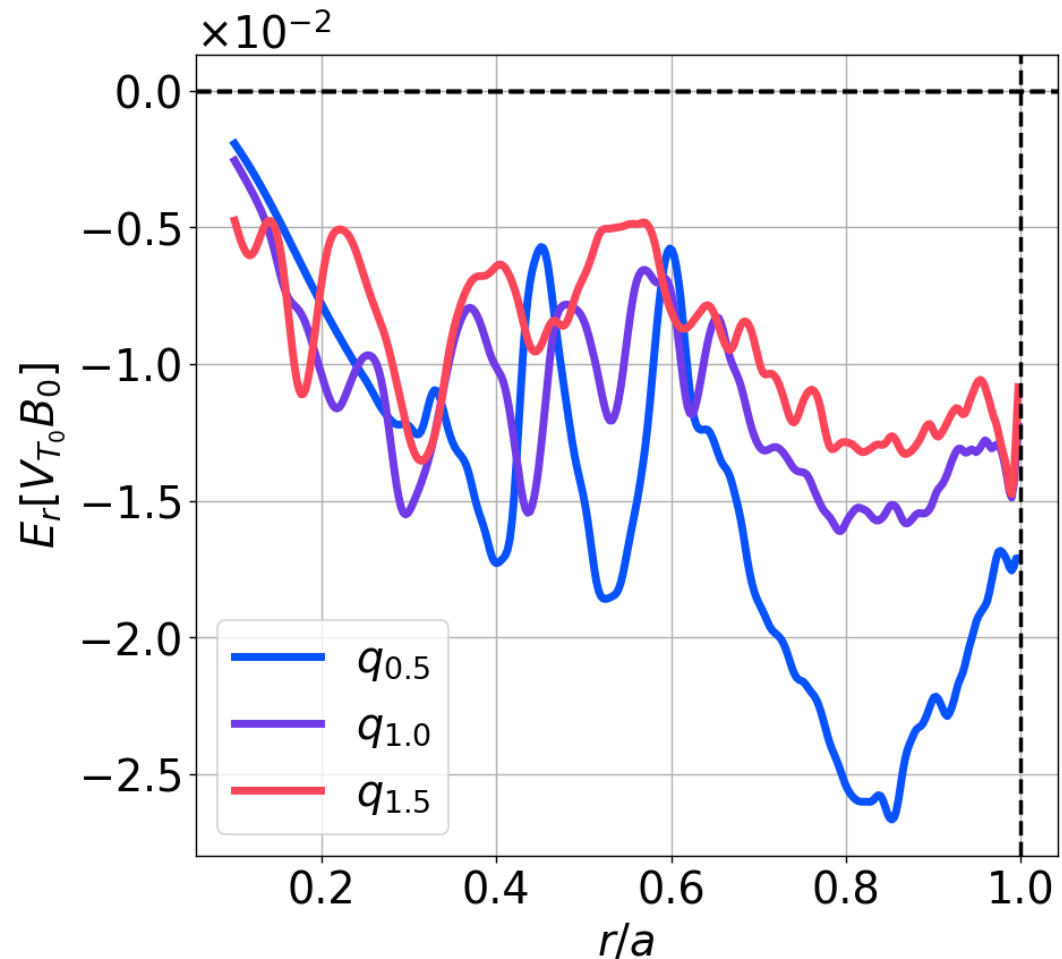
Safety factor profile used in simulations



Same trend as the experiment retrieved on the radial electric field

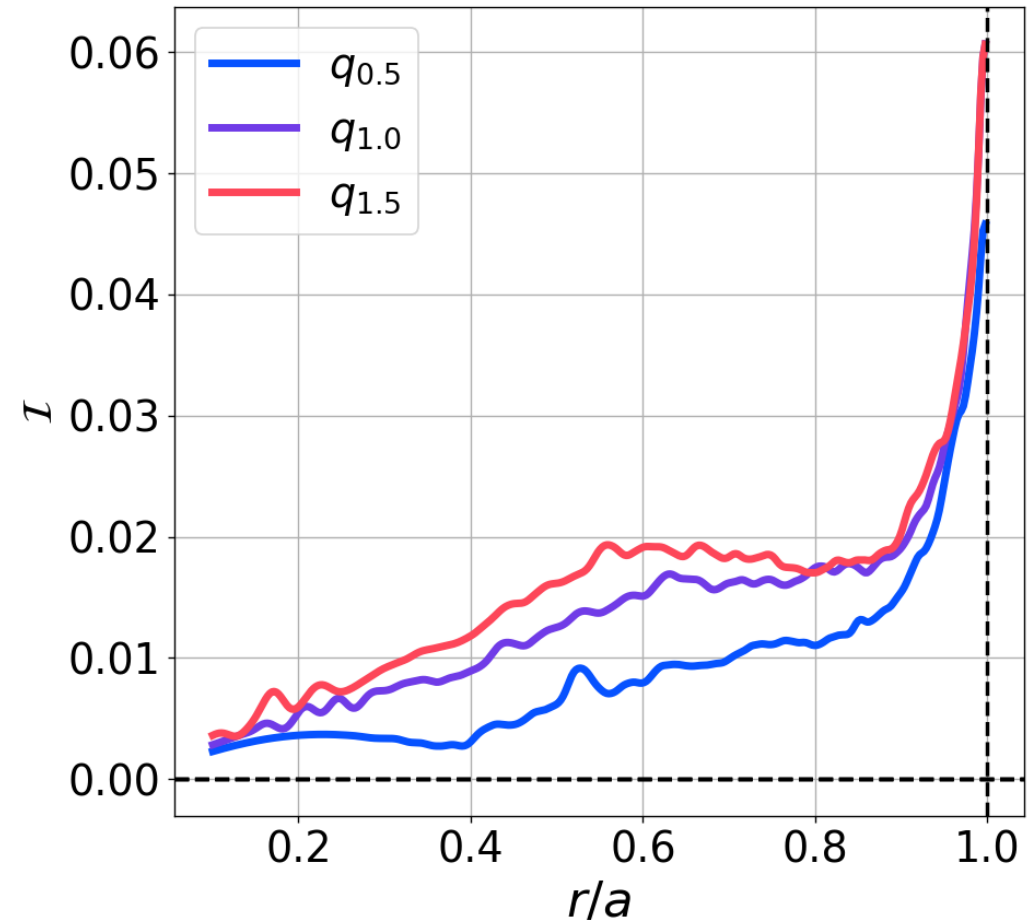
- ❖ Simulations run for $\sim 150\,000 \omega_c^{-1}$
→ in a saturated turbulent state
- ❖ Thermodynamical gradients similar for each case
- ❖ $|E_r|$ observed to increase with I_p near the edge → qualitatively **similar to experiment**

Radial electric field E_r profiles



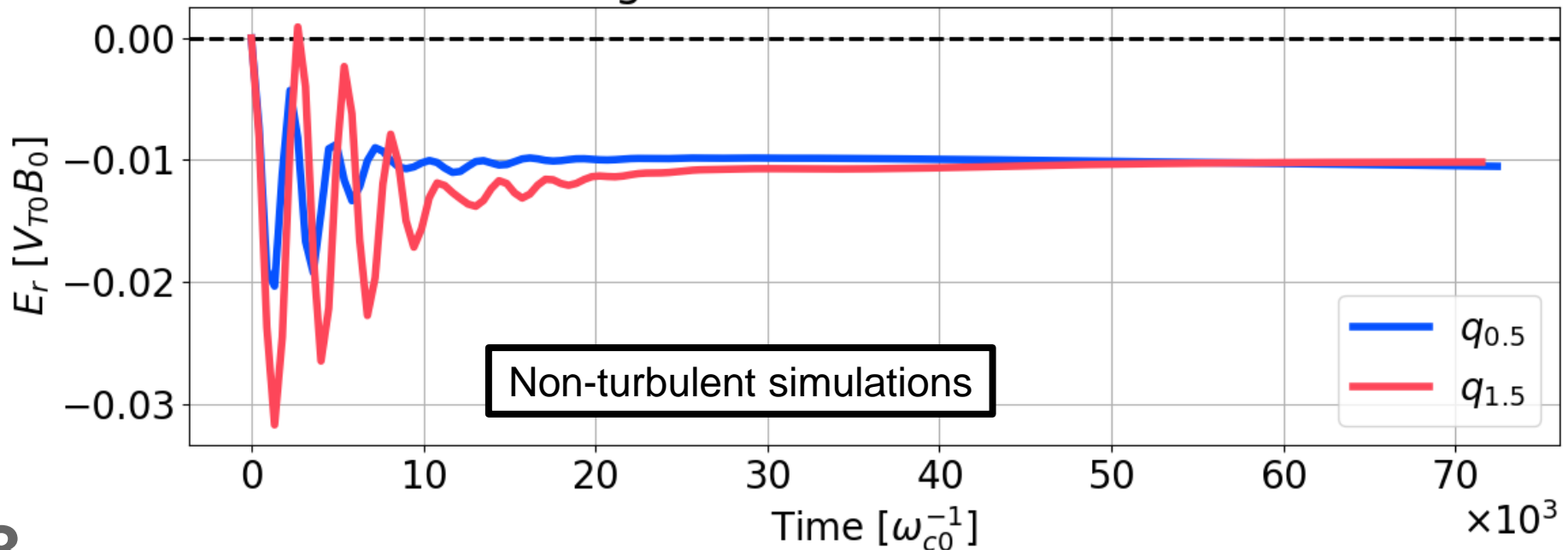
- ❖ Turbulent intensity \nearrow with q
 - Expected from theory/experiment
 - [T. Dannert – PoP 2005] [C.C Petty – PoP 2004]
- ❖ Non linear evolution → saturation
 - [R.E. Waltz – PoP 1997]
- ❖ Effect of turbulence less important in low q case ?
 - Neoclassical effect prevails ?

Turbulent intensity profiles



- ❖ Same simulations performed with artificially killing all turbulent modes
- ❖ No significant effect of q on these neoclassical simulations

Temporal evolution of the flux-averaged electric potential ϕ_{00}
Average between $0.75 < r/a < 0.85$

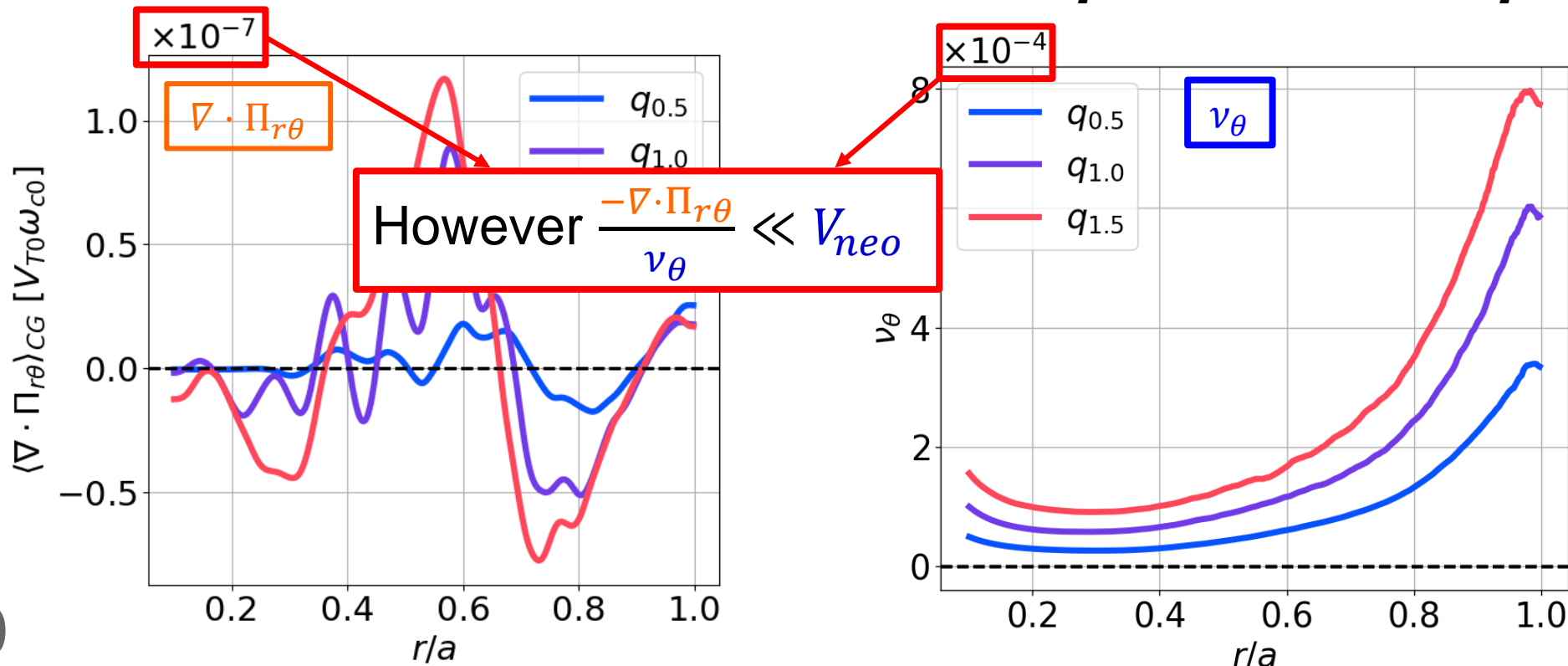


However, synergy between neoclassic and turbulent effect may still matter

❖ Neoclassical effects can modify the turbulent drive

$$\partial_t V_P = \underbrace{-\nabla \cdot \Pi_{r\theta}}_{\text{Turbulent}} - \underbrace{v_\theta}_{\text{Neoclassical}} (V_P - V_{neo}) \quad \rightarrow \quad V_{P,eq} = \frac{-\nabla \cdot \Pi_{r\theta}}{v_\theta} + V_{neo} \sim E_r/B$$

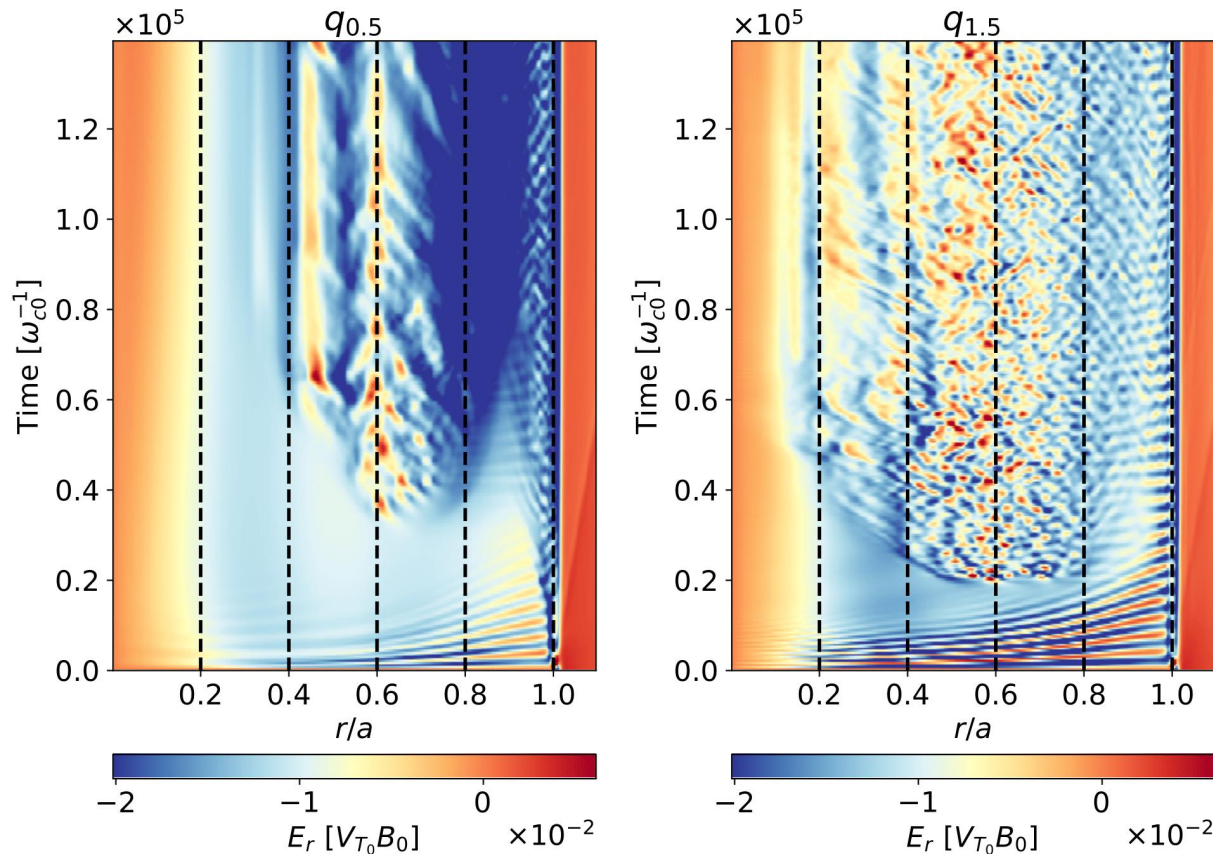
[T.A. Giannakon - PoP 2002]



The flow structure generated by turbulence observed to depend on I_P

- ❖ Observed in simulations:
 - At low q : static zonal structures
 - At high q : high frequency events

Spatio-temporal evolution of E_r



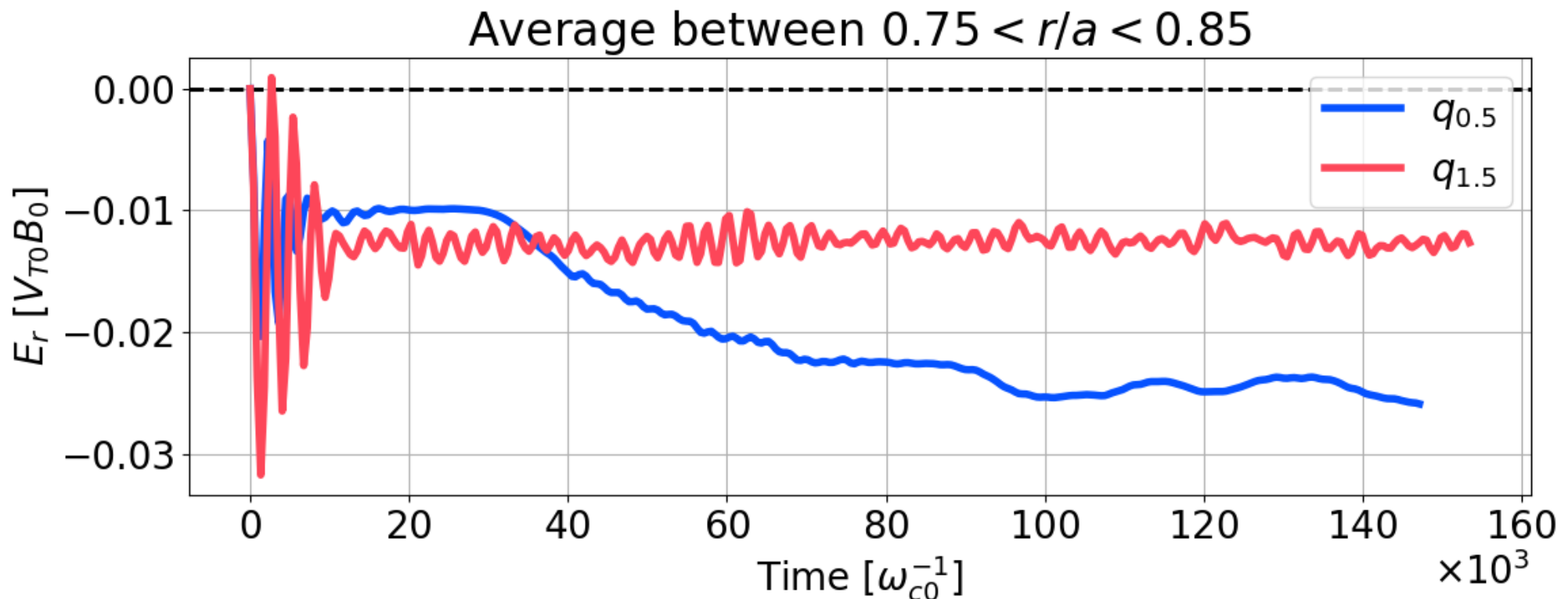
Turbulence feeds Zonal Flows and GAMs differently depending on q

- ❖ Zonal Flows are quasi-static poloidal flows generated by turbulence
- ❖ GAMs \rightarrow oscillations of ϕ due to toroidal curvature ... that can be driven by turbulence

[P. Angelino - PPCF 2006]

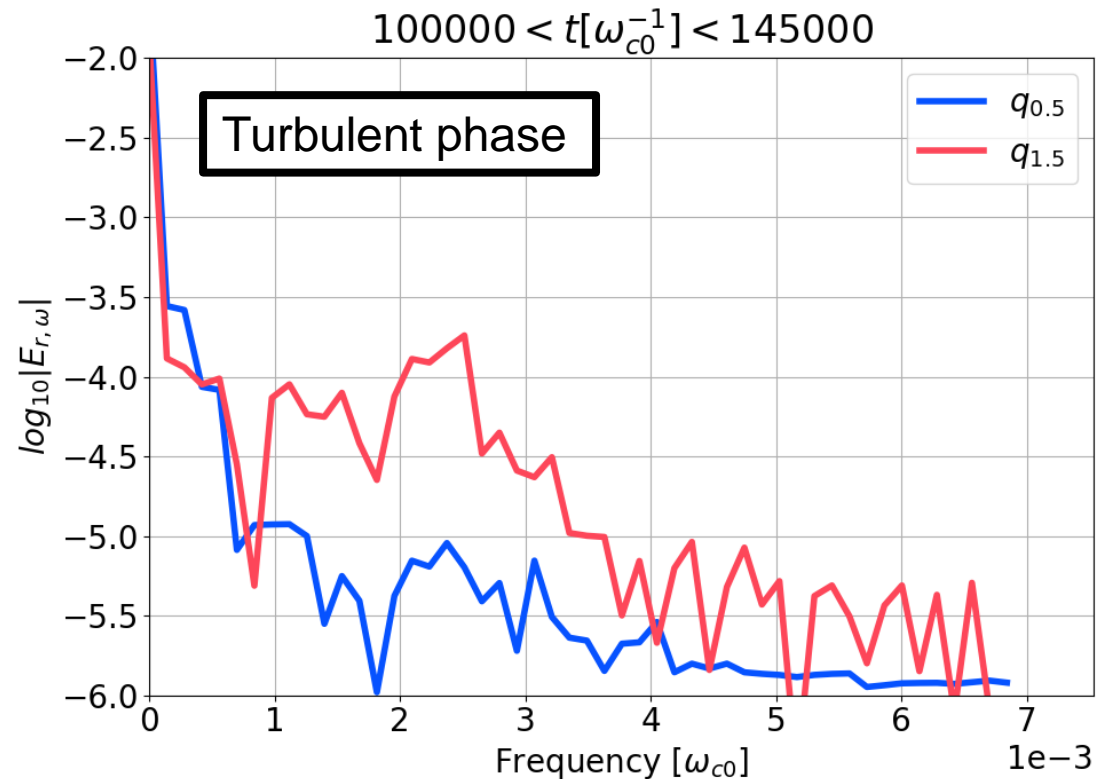
[N. Miyato - PoP 2004]

[G.D. Conway - NF 2022]



- ❖ E_r frequency spectra in the range $0.75 < r/a < 0.85$
- ❖ Same “available” energy in each simulation
- ❖ GAMs → strongly **driven by turbulence** in the high q case
- ❖ **Low q** : weak turbulent intensity & weak GAM drive → energy has to aliment ZF ?

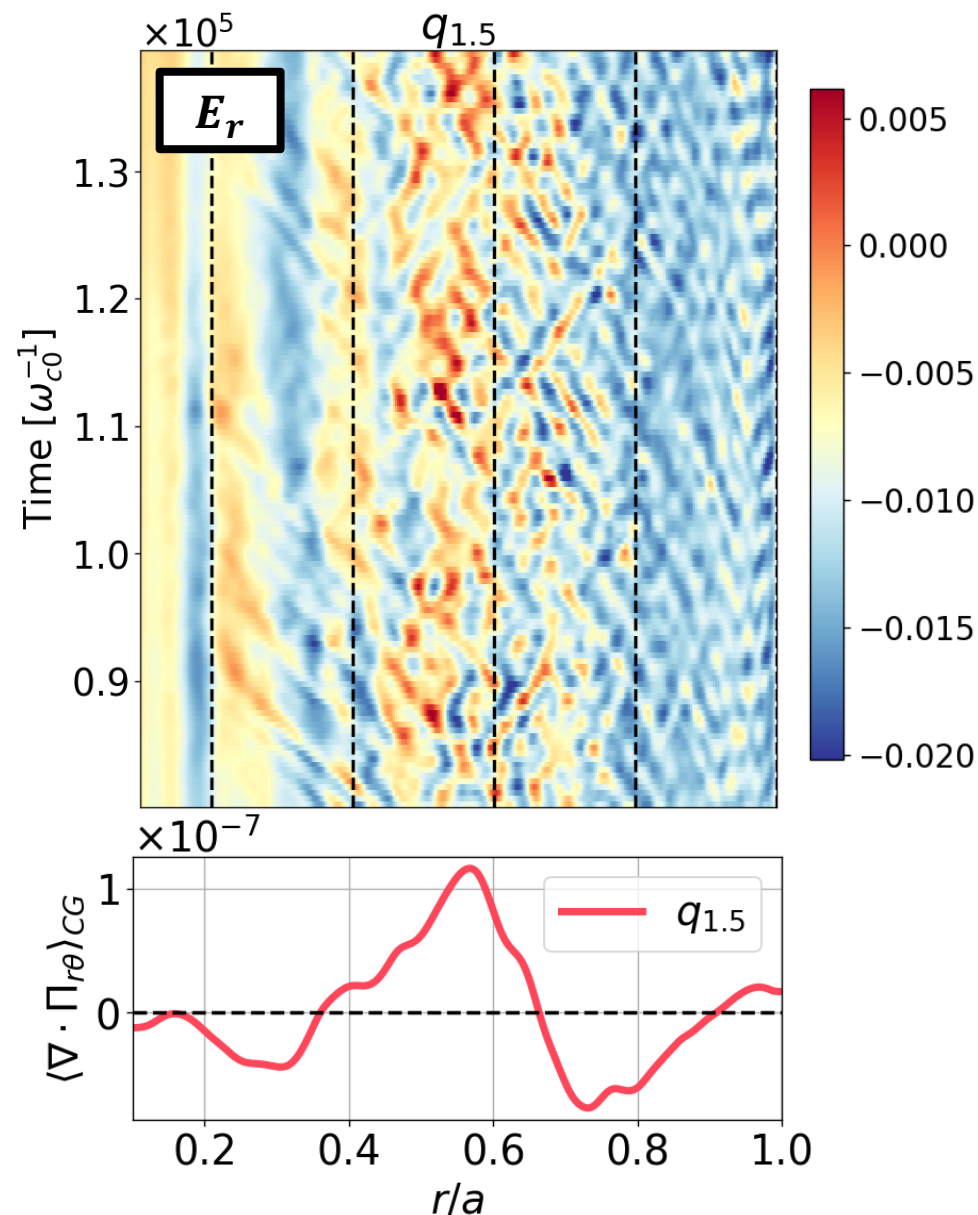
Profiles of frequency spectra



The location of zonal flow source coincide with the E_r well

- ❖ $\nabla \cdot \Pi_{r\theta} \rightarrow$ Turbulent source
- ❖ Zonal Flows and GAMs \nearrow with $\nabla \cdot \Pi_{r\theta}$
- ❖ **Low q** \rightarrow Turbulence feeds ZF
- ZF responsible for internal **transport barriers** that reduce turbulence
- ❖ **High q** \rightarrow Turbulence feeds GAMs
- GAMs less efficient to quench turbulence

[K. Miki - NF 2011]



- ❖ Experiments on WEST show that **edge** E_r when $I_p \nearrow$ so when $q \searrow$
- ❖ This effect is **retrieved** qualitatively **with gyrokinetic simulations**
- ❖ **Neoclassical processes are negligible** regarding the E_r well formation
- ❖ Main effect seems to be the **turbulent energy transfer** that favor either the **zonal flows** or the **GAMs** depending on the safety factor value
- ❖ Further study \rightarrow 'advanced' signal processing tools (bicoherence...)

The work in ongoing ...

! Work in progress !

- ❖ 0D model from Miki & Diamond → energy transfer between turbulence/GAMs/ZF
[K. Miki – NF 2011]
- ❖ Exploratory model → simplified version ... but with main q dependences
- ❖ Lot of unknown parameters set ah-hoc → not for precise quantification

Turbulent energy: $\partial_t I = II_L - I^2 - C_0 I \mathcal{E}_0 - C_G I \mathcal{E}_G$

ZF energy: $a_0 \partial_t \mathcal{E}_0 = \mathcal{E}_0 I - \mathcal{E}_0 I_0 - \mathcal{E}_0^2$

GAM energy: $a_G \partial_t \mathcal{E}_G = \mathcal{E}_G I - \mathcal{E}_G I_G - \mathcal{E}_G^2$

❖ 4 types of stationary solutions

!! Work in progress !!

- ❖ No flows $I \neq 0$, $\varepsilon_0 = \varepsilon_G = 0$
- ❖ ZF only $I \neq 0$, $\varepsilon_0 \neq 0$, $\varepsilon_G = 0$
- ❖ GAMs only $I \neq 0$, $\varepsilon_0 \neq 0$, $\varepsilon_G = 0$
- ❖ Mixed ZF/GAM $I \neq 0$, $\varepsilon_0 \neq 0$, $\varepsilon_G \neq 0$

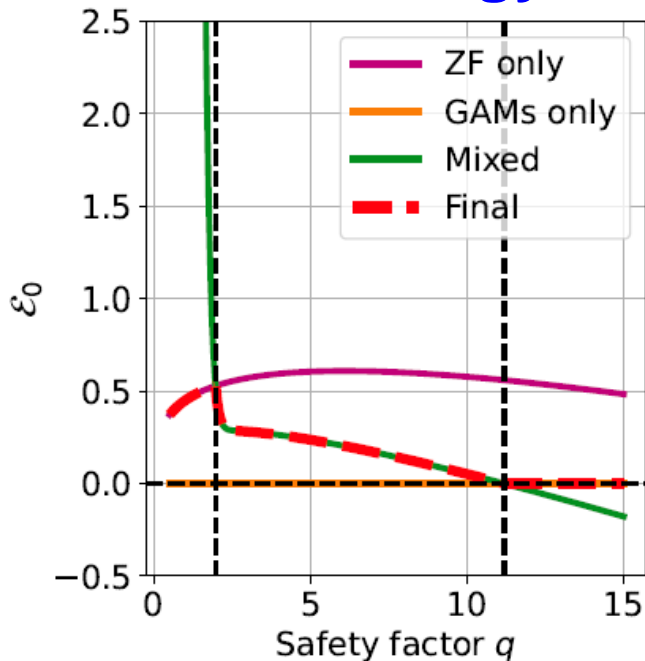
❖ Only accounted dependence with safety factor

- ❖ Normalized growth rate $I_L = \bar{I}_L \sqrt{q}$ (Observed in simulations)
- ❖ ZF damping rate $I_0 = \bar{I}_0 q$ (Neoclassical friction)
- ❖ GAMs damping rate $I_G = \bar{I}_G q^5 \exp\left(-\frac{11}{4} q^2\right)$ (Collisionless prediction)

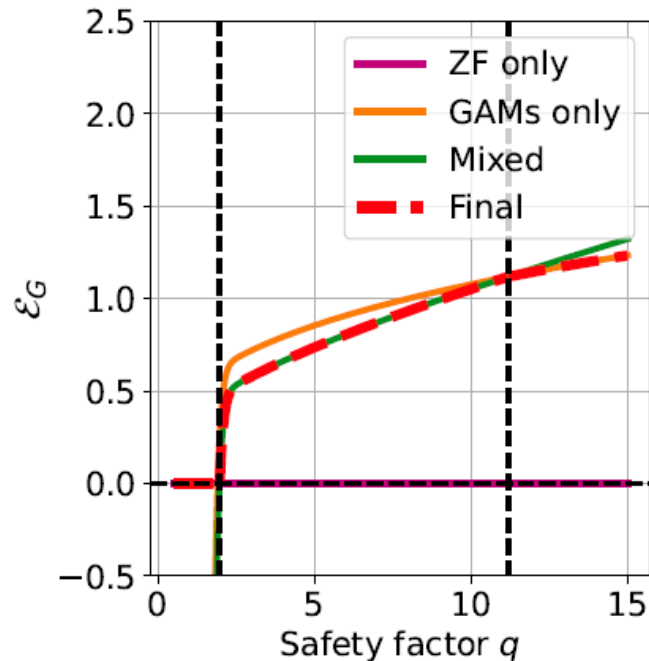
- ❖ With the scaling $\bar{I}_0 \ll \bar{I}_L \ll \bar{I}_G$, the simulations behavior is retrieved
- ❖ Lot of assumptions in the model ... but still encouraging

!/\ Work in progress !/

ZF energy



GAM energy



Turbulent energy

