EUROfusion

Reduced fast-ion transport in negative triangularity plasmas in the presence of TAEs at TCV.

P. Oyola, M. García-Muñoz, M. Vallar, J. Dominguez-Palacios, E. Viezzer, J. Rueda-Rueda, Y. Todo, S. Sharapov, J. Gonzalez-Marting, A. Fasoli, B. Duval, M. Dreval, A. Karpushov, S. Coda, O. Sauter and the TCV team.

PSFT Plasma Science and Fusion Technology

Universidad de Sevilla

EPFL

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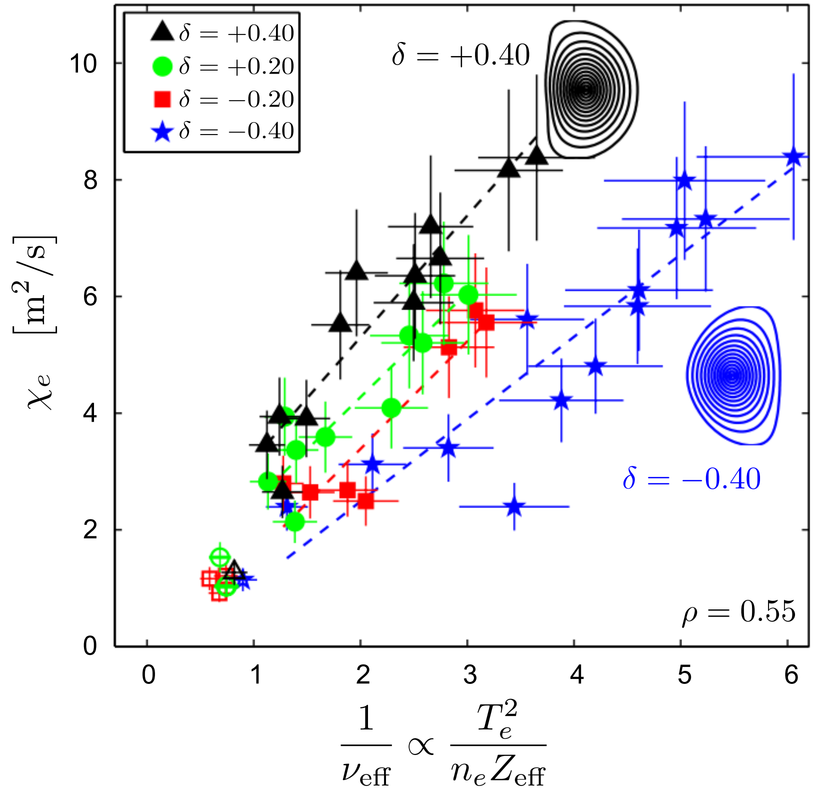
NT as a relevant reactor scenario

- Strong reduction of electron heat flux in NT was first observed in TCV[1,2].



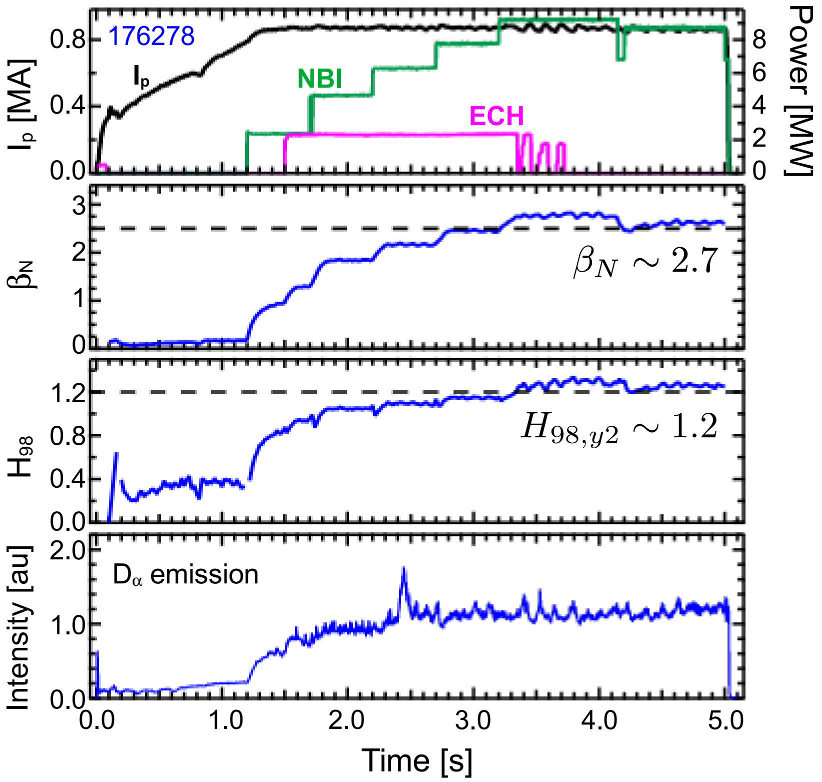
[1] J. -M. Moret *et al.*, Phys. Rev. Lett. **79** 2057 (1997)
[2] Y. Camenen *et al.*, Nucl. Fusion **47** 510-516 (2007)
[3] M. E. Austin *et al.*, Phys. Rev. Lett. **122** 115001 (2019)

NT is an ELM-free regime with H-mode-like confinement

- Strong reduction of electron heat flux in NT was first observed in TCV[1,2].

- DIII-D team first showed that confinement is similar to PT in H-mode[3].
  - ➔ H-mode-like confinement in NT L-mode.
  - ➔ Natural ELM-free scenario.

- Assessment of AEs and fast-ion transport.



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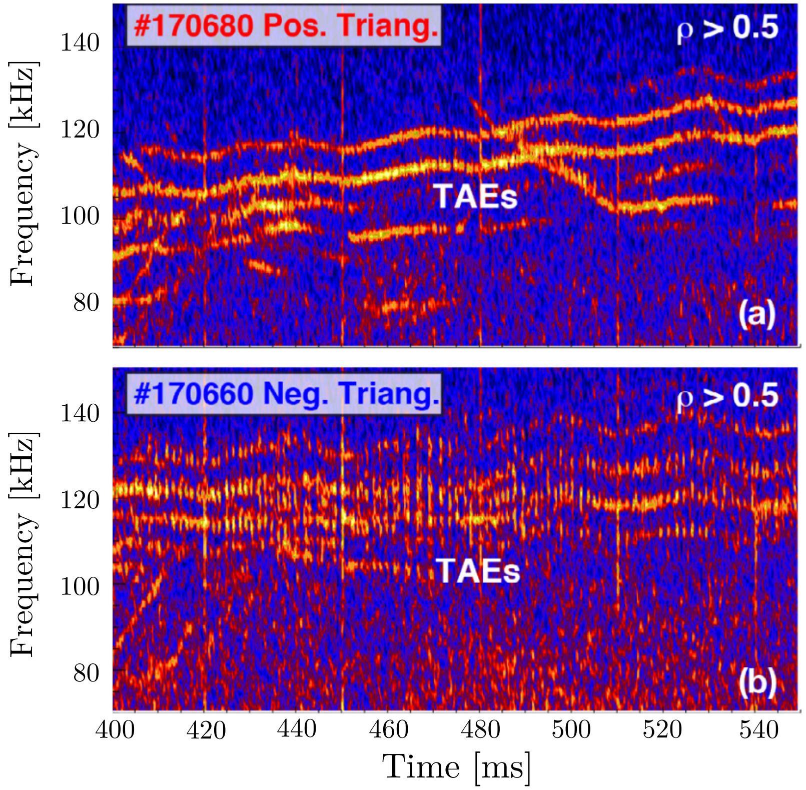
AEs in NT firstly observed in DIII-D

- Experiments in DIII-D[4] to obtain AEs, shows TAEs excited in NT and PT.



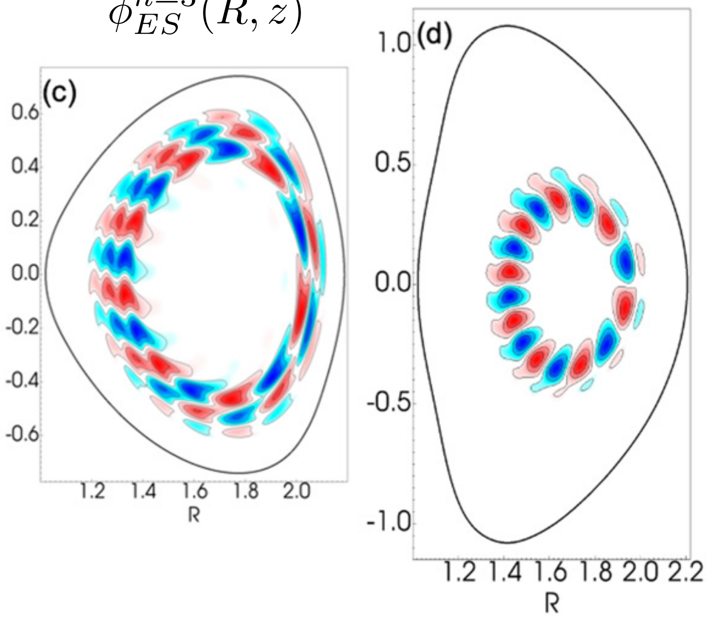
[4] M. A. Van Zeeland *et al.*, NF **59** 086028 (2019)
[5] Y. Ghai *et al.*, NF **61** 126020 (2021)
[6] L. A. Charlton *et al.*, J. Comp. Phys **86** 270 (1990)

Gyrofluid simulations indicate negligible impact on AE activity

- Experiments in DIII-D[4] to obtain AEs, shows TAEs excited in NT and PT.

- Numerical studies[5] with FAR3d[6]:
  - Linear EP-driven AE.
  - 2-moments gyrofluid model for FI
  - Negligible impact of triangularity on AE growth rate

$\phi_{ES}^{n=3}(R,z)$



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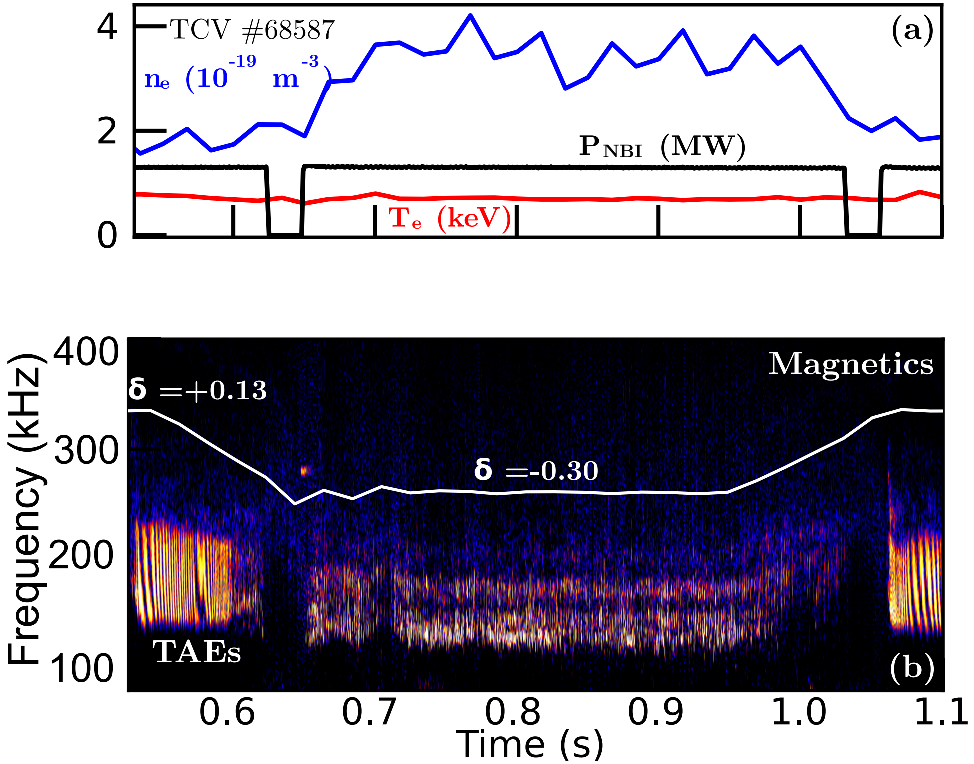
Strong NT impact on AEs at TCV

- Strong impact of triangularity on Alfvénic modes:
  - Amplitude reduction
  - Frequency drops



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- Uncontrolled changes in many variables:
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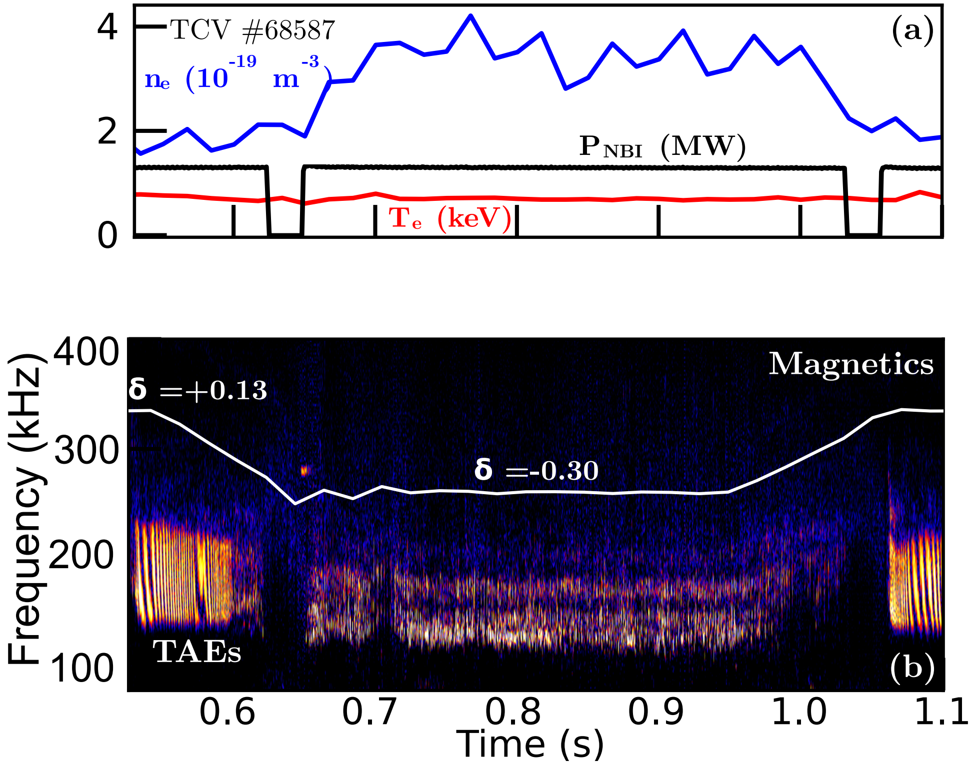
  - Direct comparison between triangularities is difficult.



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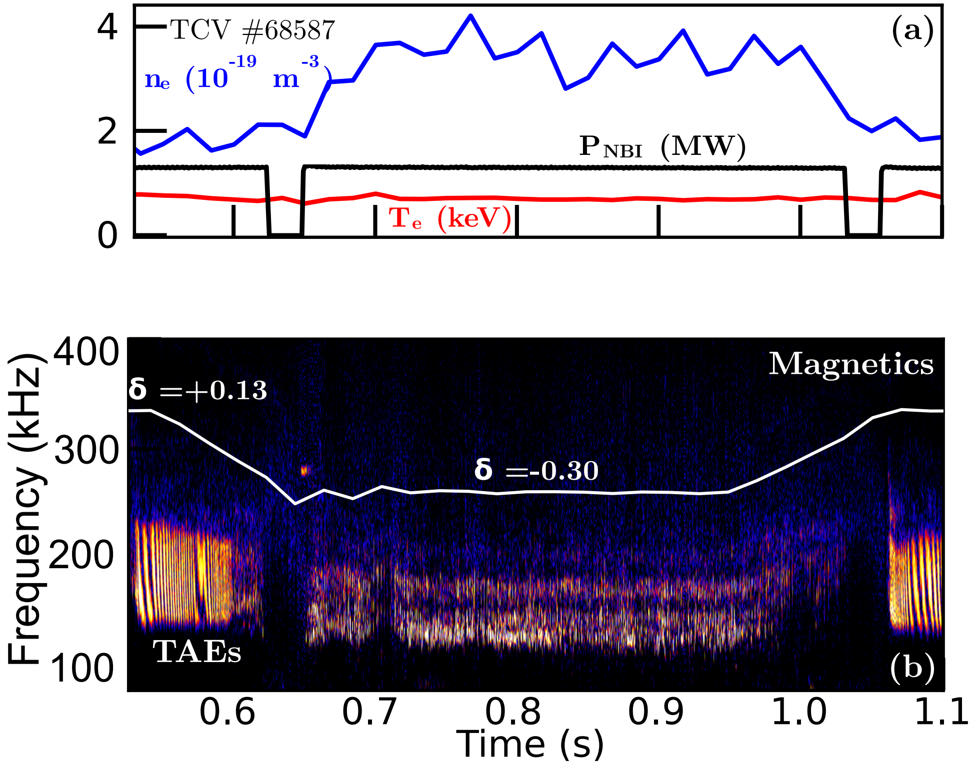
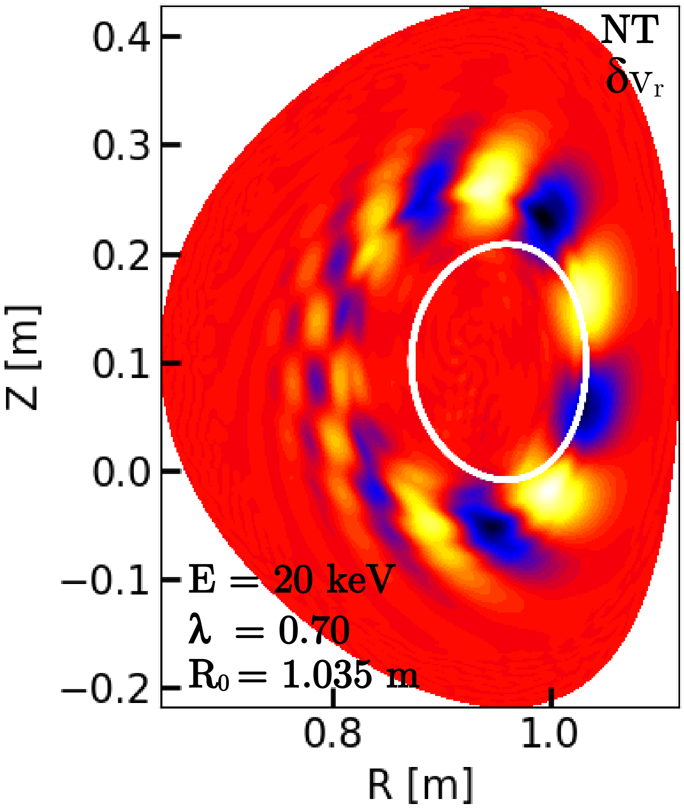
- Nonlinear hybrid simulations help unreveal the impact of δ in the Alfvén Eigenmodes and induced fa



Outline

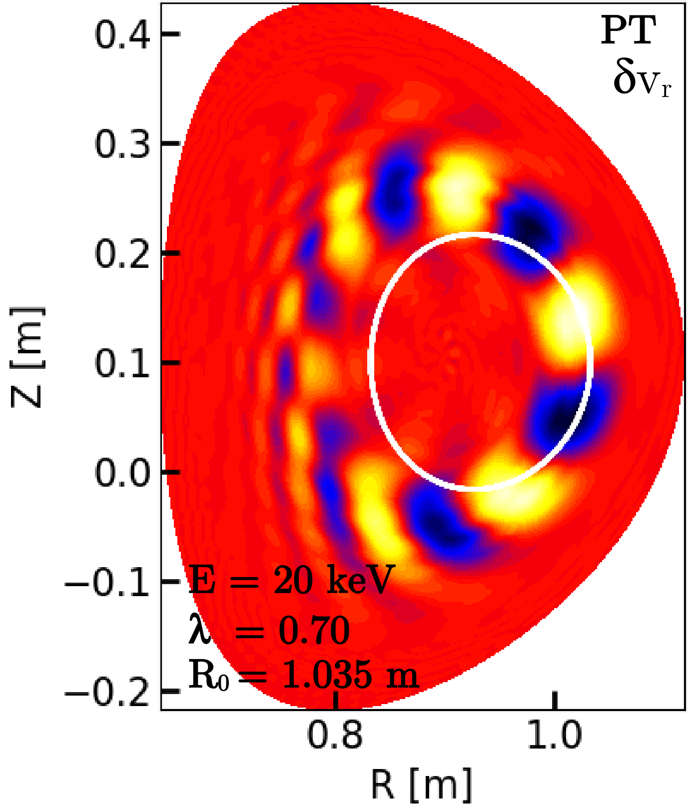
- MEGA: 3D nonlinear hybrid kinetic-MHD
- Simulation setup for TCV
- TAEs in NT and PT
- Wave-particle resonances in the FI phase-space
- Fast-ion losses induced by TAE in NT and PT



MEGA[7]: Nonlinear 3D hybrid kinetic-MHD code

Bulk plasma

- Full resistive-MHD model.



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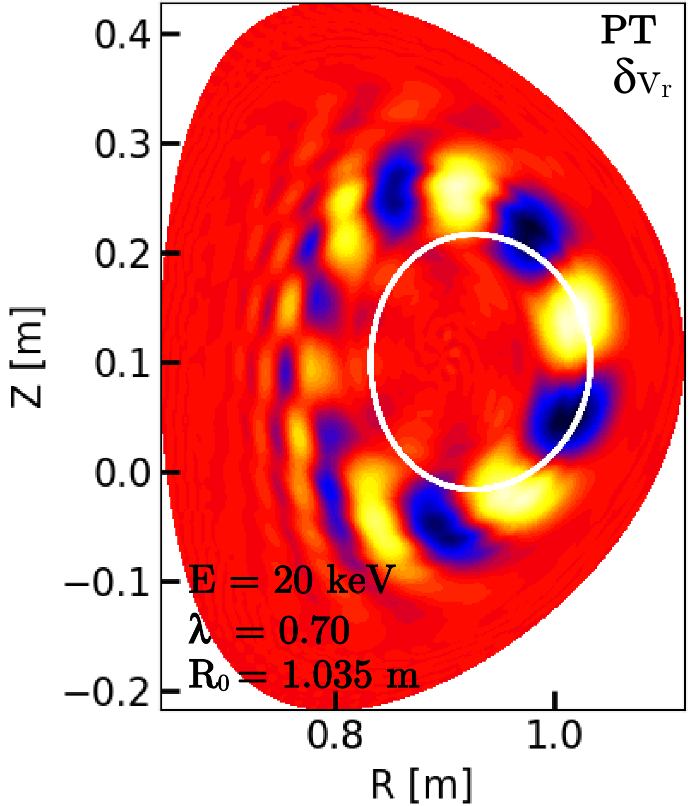
Fast-ions

- *Particle-in-cell*: markers sampling distribution function.
- Gyrokinetic equation (δf or *full*-f).



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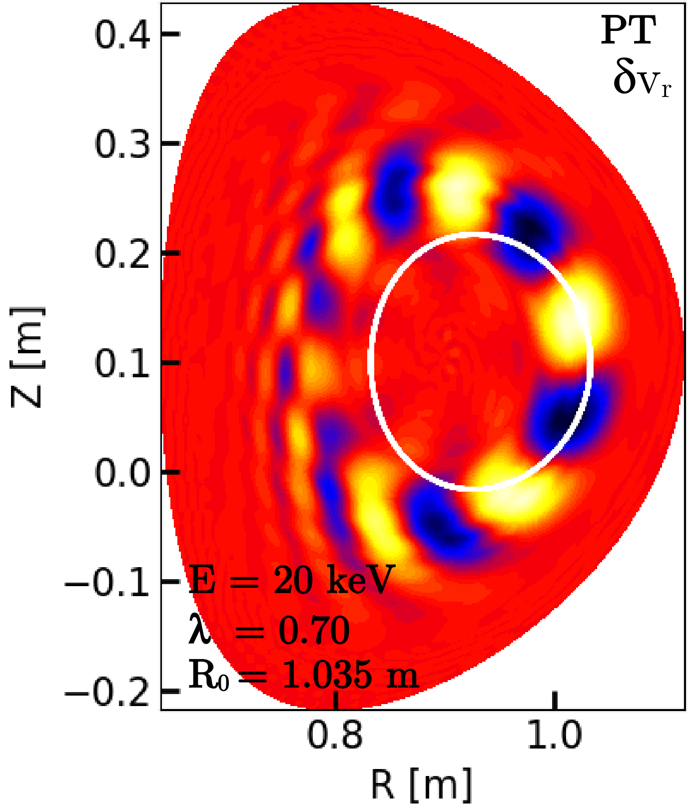

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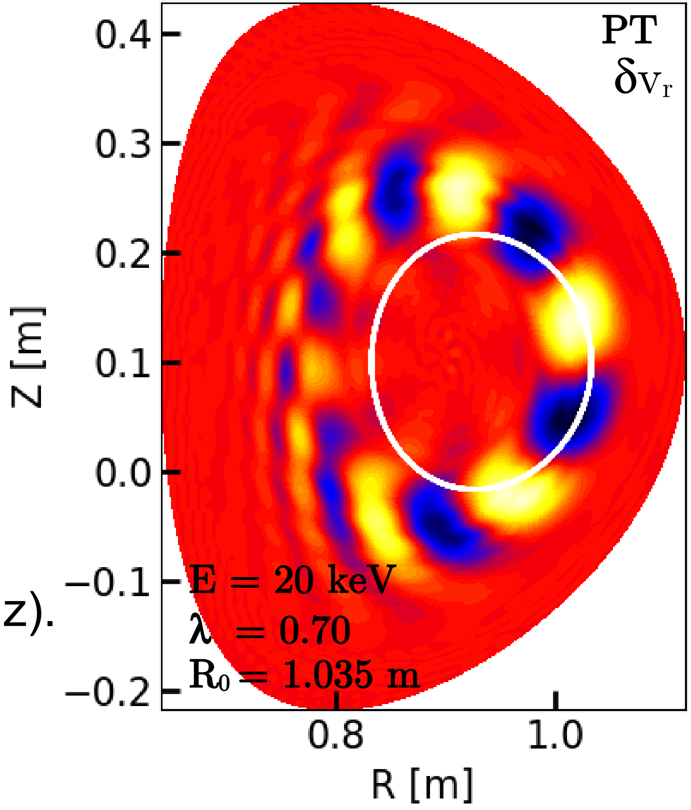

- 4th order finite differences in **cylindrical** coordinates (R, ϕ, z).

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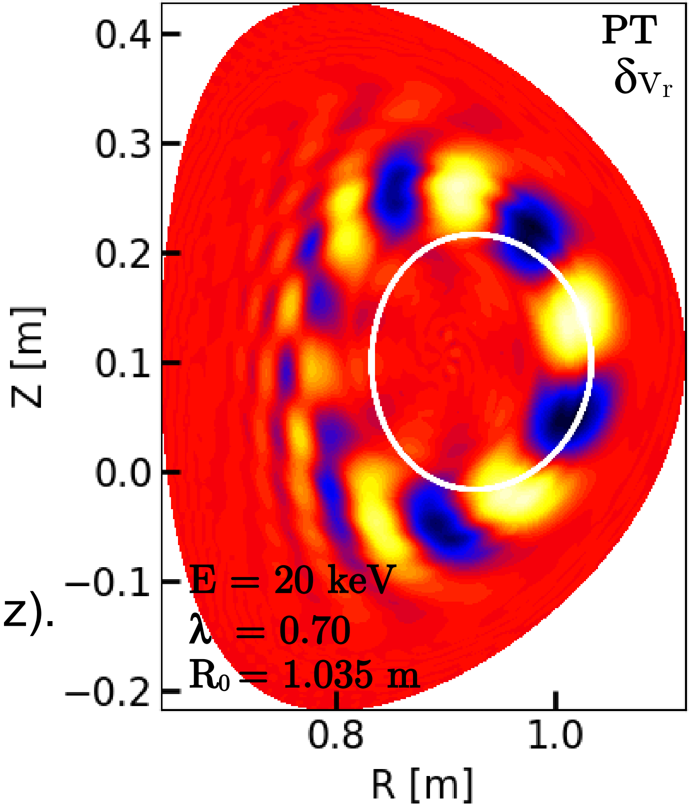
- Explicit 4th Runge-Kutta for time-integration.



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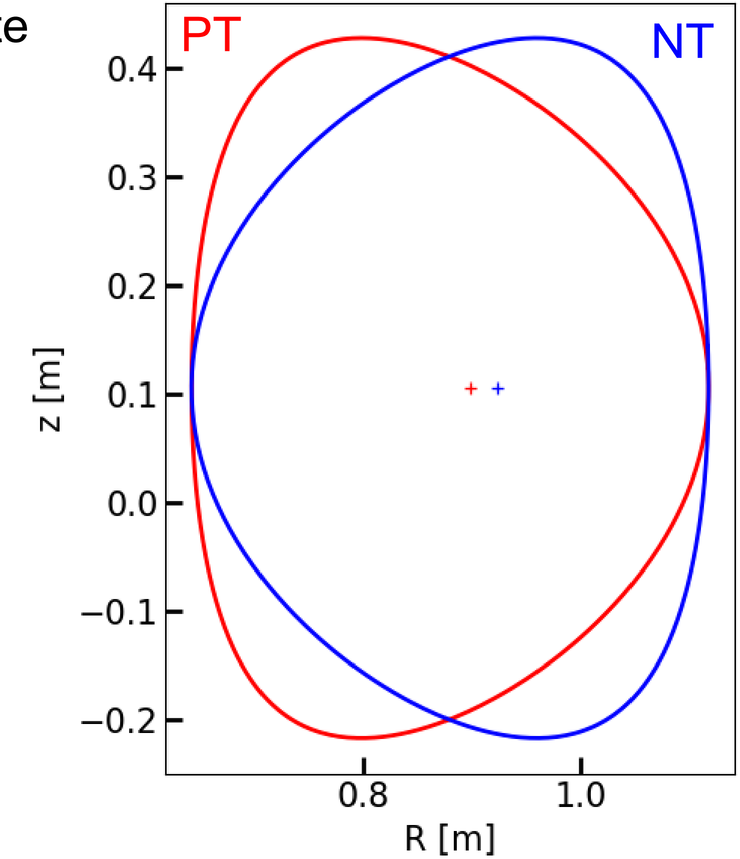
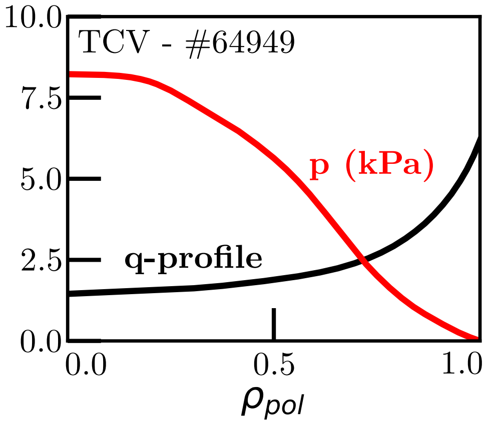
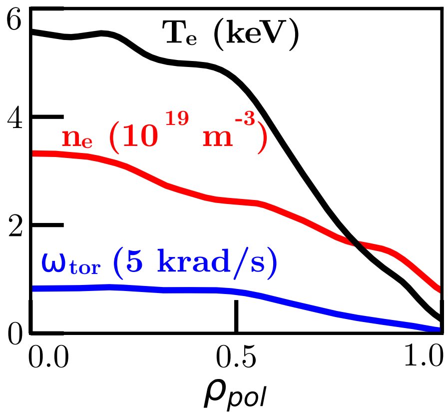
Simulation setup for the δ comparison

- Flipped equilibrium to isolate the +δ / -δ effects on AE activity.







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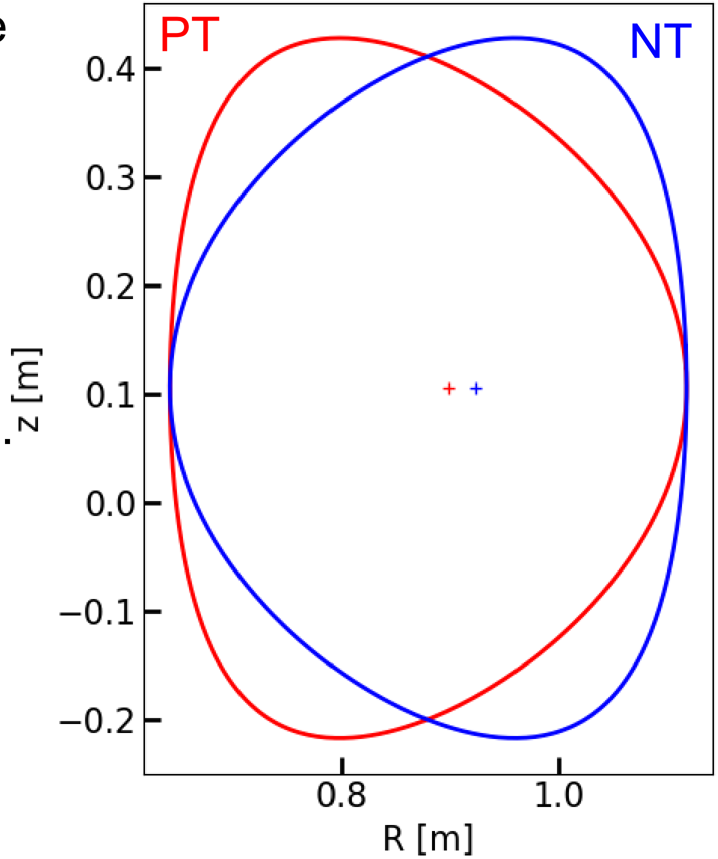
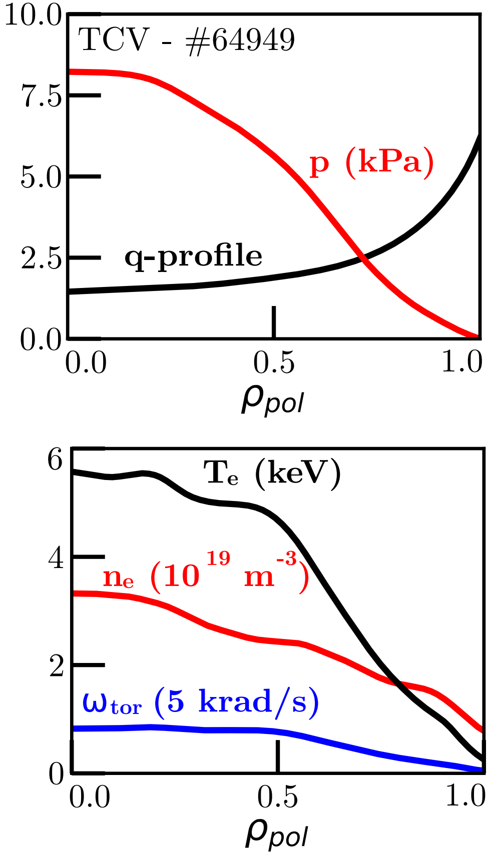
Simulation parameters

- δf-method for kinetic species.
- #markers = 23M particles
- Multi-*n* simulation (n < 5)





Ad-hoc initial FI distribution

Analytical anisotropic slowing-down distribution

$$f_0 \propto e^{\frac{(\rho-\rho_0)^2}{2(\Delta\rho_0)^2}} \frac{1}{v^3 + v_{crit}^3} erfc\left(\frac{v - v_{birth}}{\Delta v}\right) e^{\frac{(\Lambda-\Lambda_0)^2}{2(\Delta\Lambda)^2}}$$

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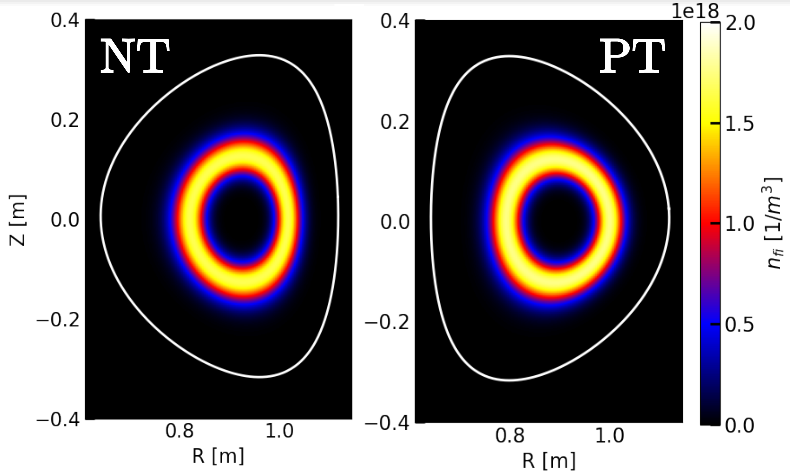

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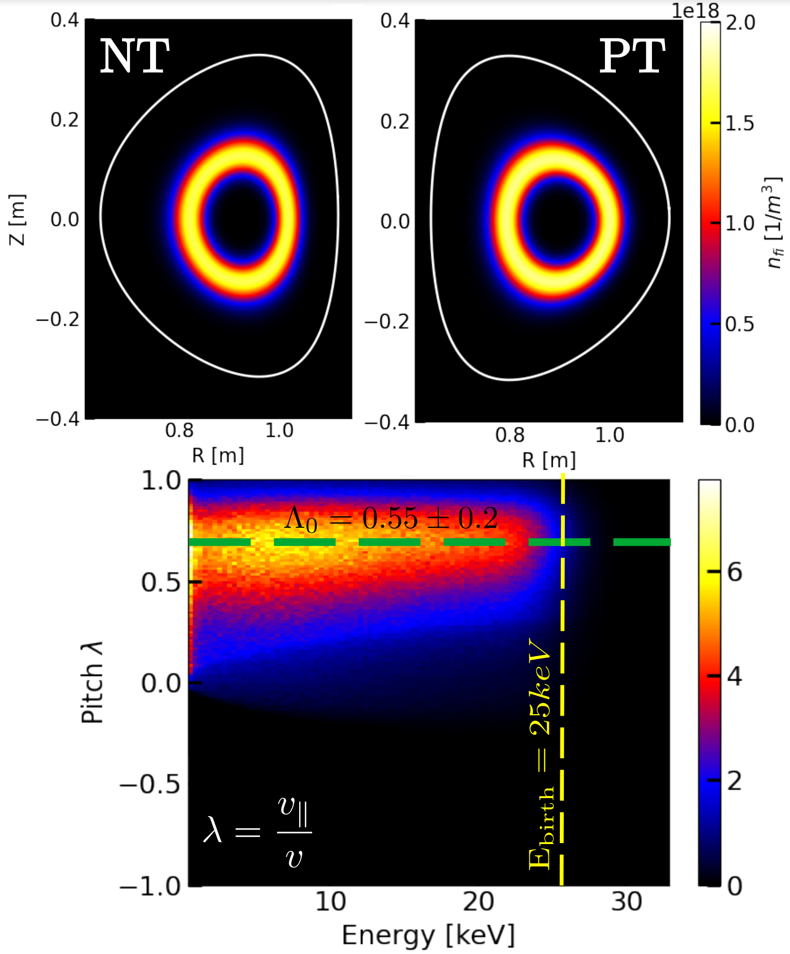
$$\Lambda_0 \equiv \frac{\mu B_{\text{axis}}}{E}$$



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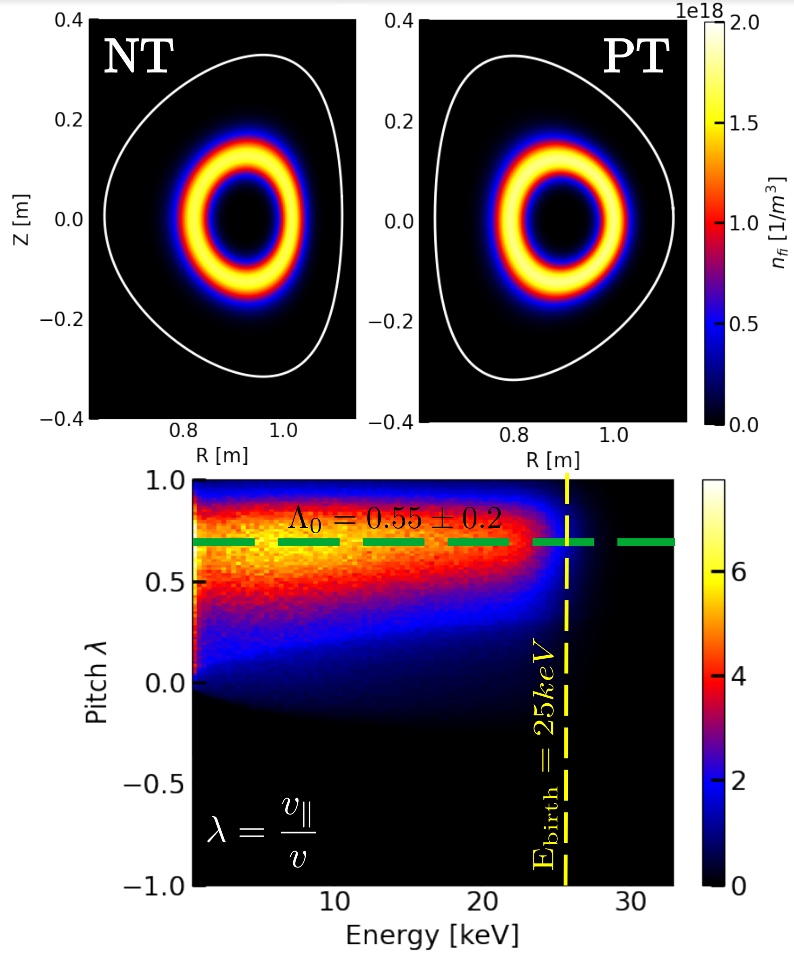
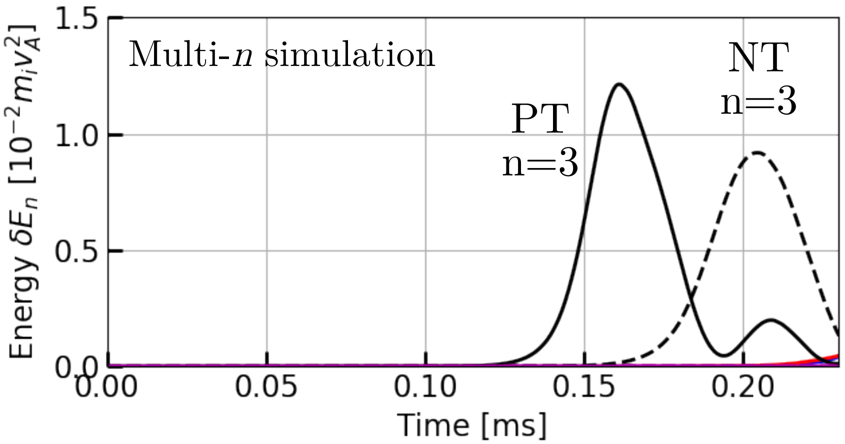
- Scan in different pitch-angle injections $\Lambda_0 \equiv \frac{\mu B_{\mathrm{axis}}}{E}$
- Scan in different fast-ion gradient location ρ_0



TAEs is mitigated in NT vs PT

TAEs appear both in PT and NT:

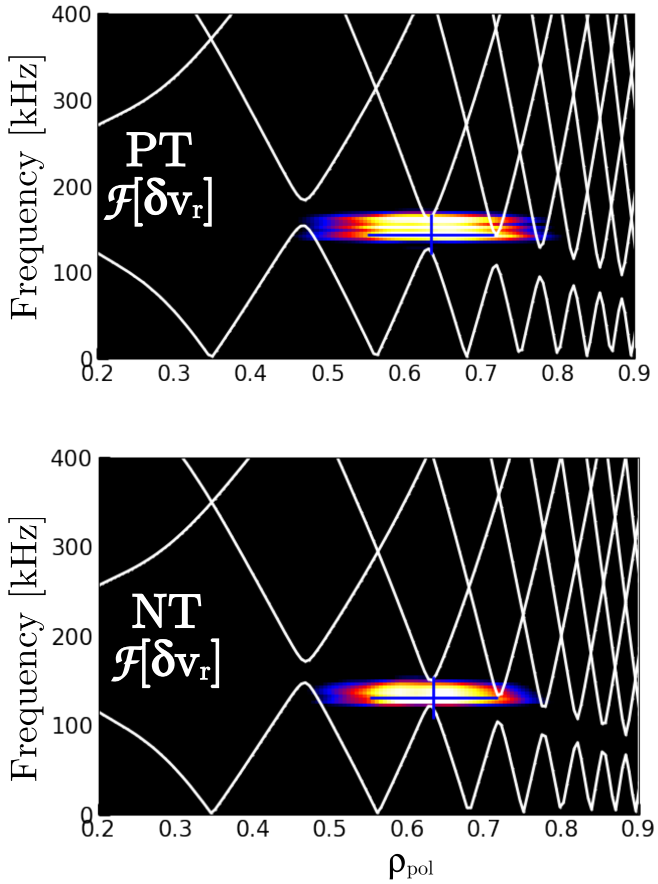
- PT reaches an energy ~40% higher.



TAEs appearing in the same location

TAEs appear both in PT and NT:

- PT reaches an energy ~40% higher.
- TAE observed in the same location. SAW not hardly affected by δ.



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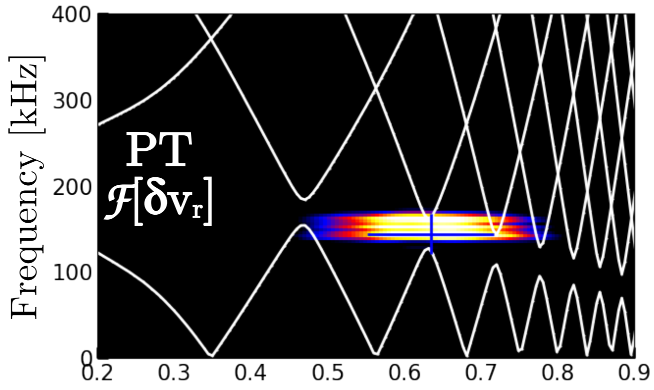
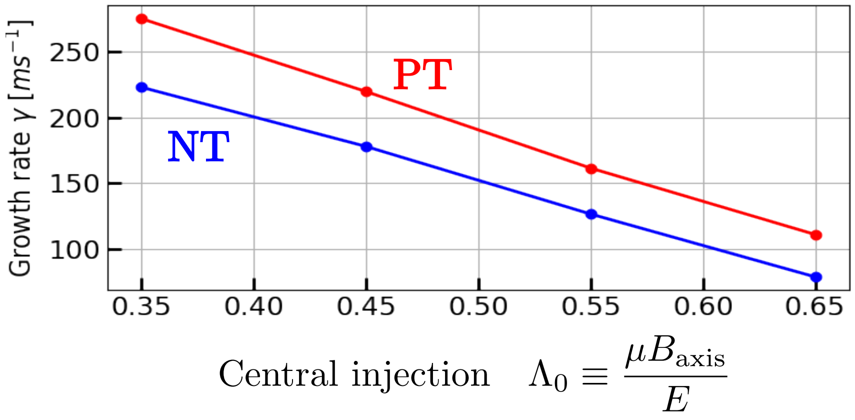
- Trend is independent on the initial fast-ion distribution function.





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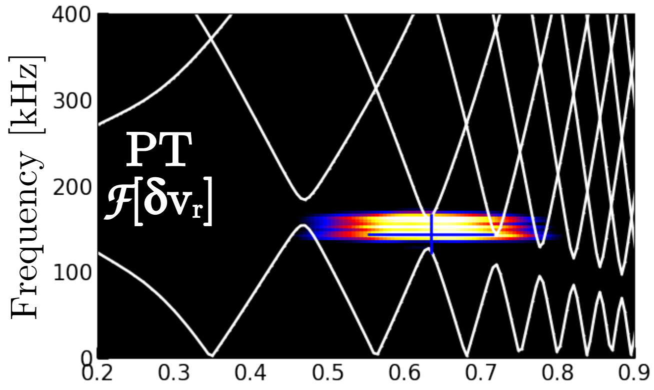
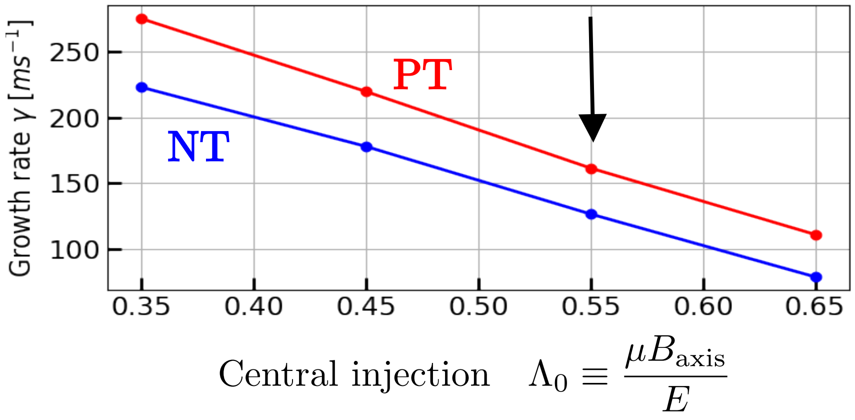
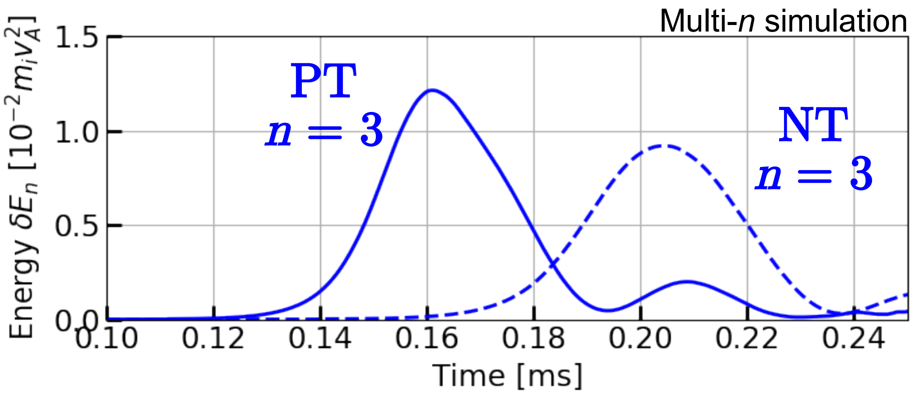
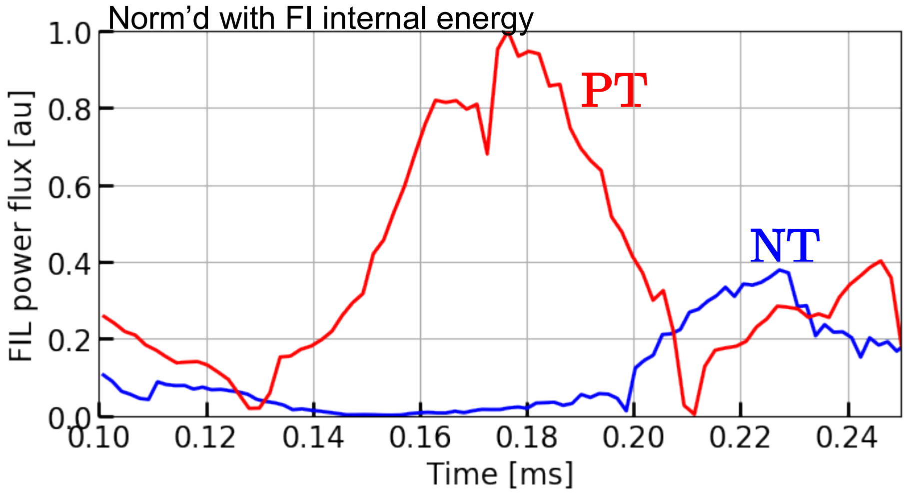




TAE-induced FIL are 3x lower in NT

- 2D wall used to get fast-ion losses (FIL)[8].
- Fast-ion losses in NT is **smaller** than its counterpart in PT.
  - 3x times lower at the peak.
  - 3x times lower integrated FIL.
- Correlated FIL bursts with TAE saturation.
- Single-*n* simulations shows similar results for a *n*=3 TAE.





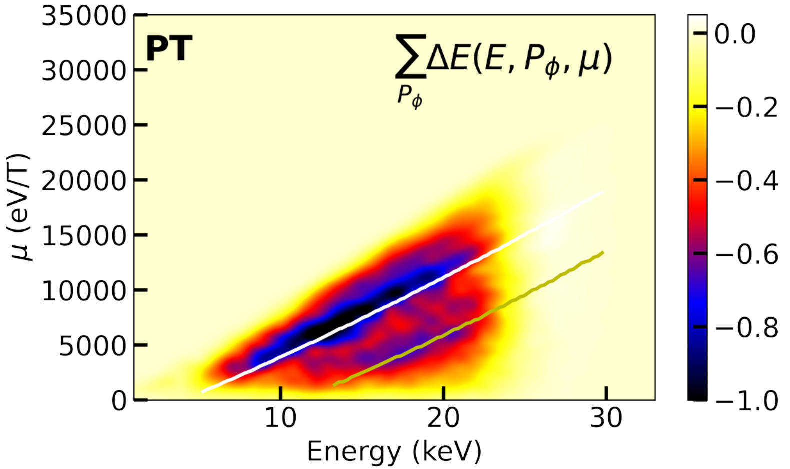
[8] P. Oyola *et al.*, RSI **92** (2021)

Resonant energy exchange in FI phase-space

- Power exchange in FI phase-space shows particle-wave resonances.

$$\Delta E > 0 \longrightarrow \text{Energy to the FI}$$

$$\Delta E < 0 \longrightarrow \text{Energy to the wave}$$



- Two main regions of the phase-space providing energy to TAE:

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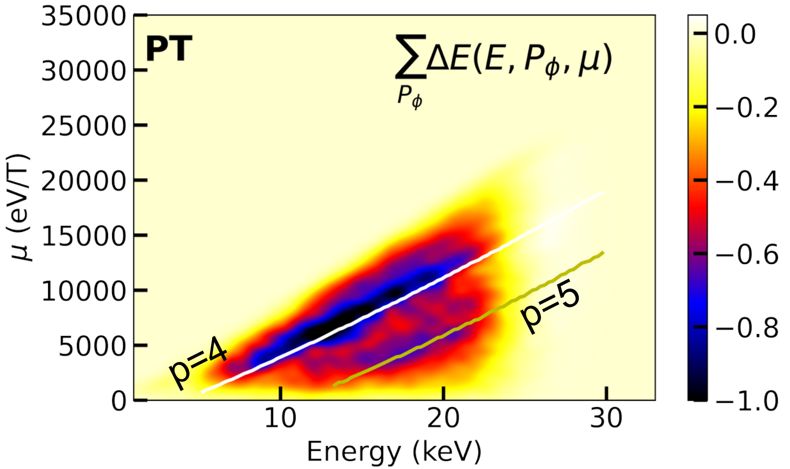


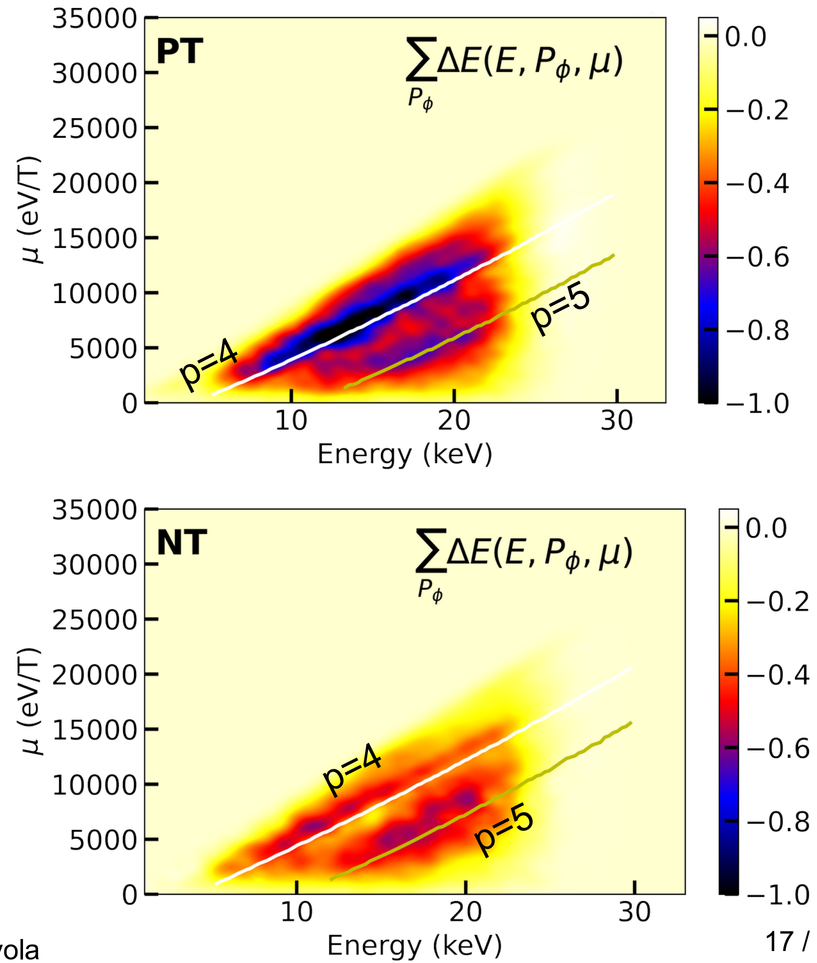
- Two main regions of the phase-space providing energy to TAE:
  - Wave-particle resonances[9].

$$\omega_{\mathrm{TAE}} = n\omega_\phi - p\omega_{\mathrm{pol}}$$

[9] Y. Todo, Rev. Mod. Plasma Phys **3**, 1 (2019)

NT damps the lower bounce harmonic

- Alignment of analytical resonances with structures in FI phase-space.
- In PT, lower bounce harmonic is most excited.
- In NT, damps lower bounce harmonics.



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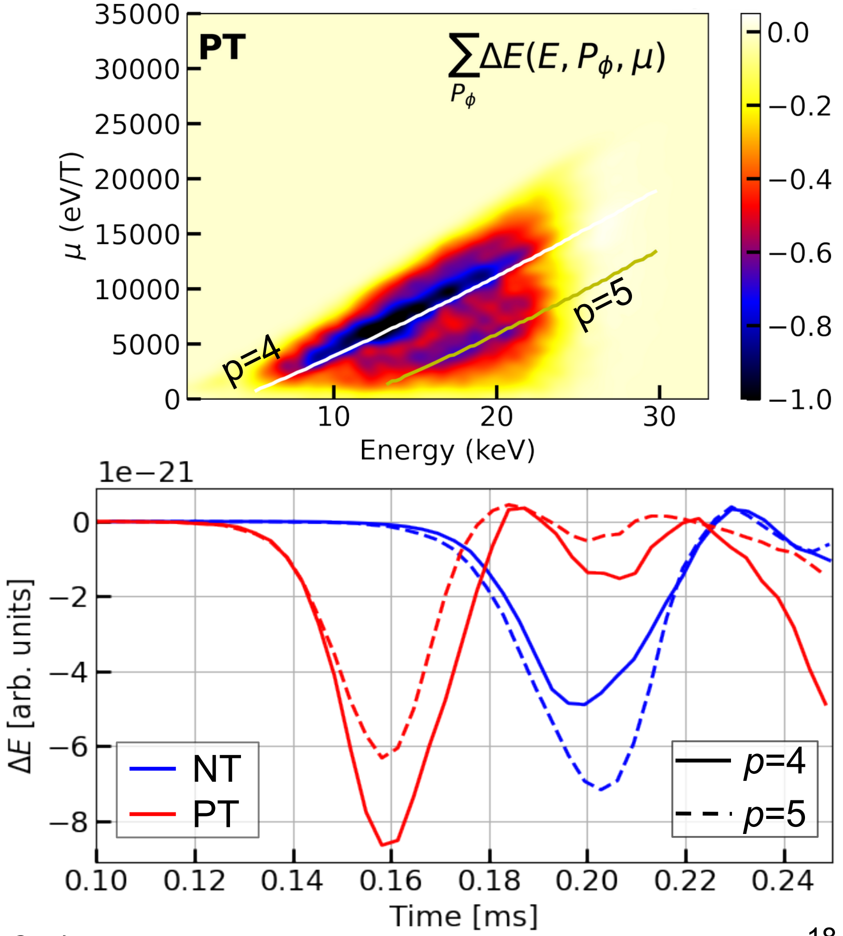
- Alignment of analytical resonances with structures in FI phase-space.
- In PT, lower bounce harmonic is most excited.
- In NT, damps lower bounce harmonics.
- Overall energy transfer is larger in PT.



Conclusions

- In experiments, TAEs appear weaker in NT than in its counterpart PT.
- MEGA sims used to isolate the δ effects.
- 50% lower energy in NT with respect to PT.
- Lower bounce harmonics are damped in NT.
- Fast-ion losses are 3x lower in NT.