



# Boundary turbulence simulations of RFX-mod discharges

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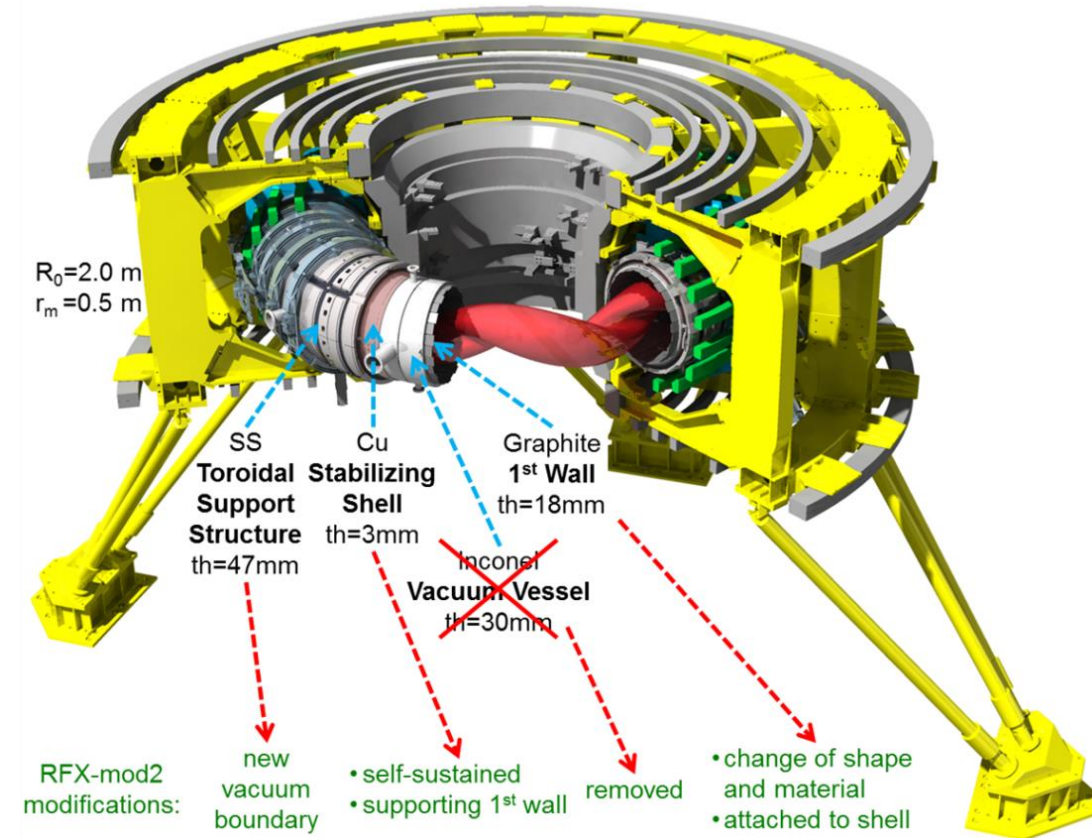
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# The RFX-mod machine



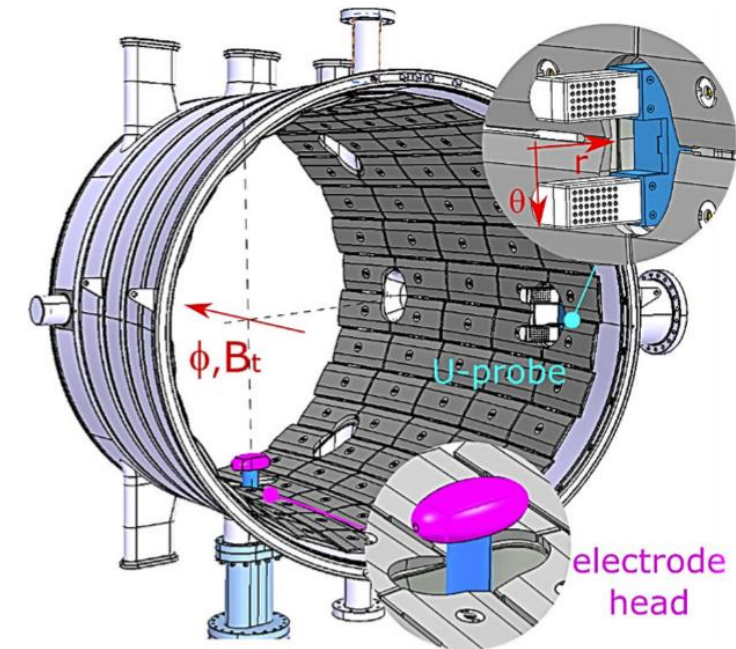
- RFX-mod (soon RFX-mod2) is a magnetic confinement plasma toroidal device.
- Two magnetic configurations possible in RFX-mod: the tokamak and the reversed field pinch (RFP).
- Tokamak: axisymmetric in the toroidal direction, toroidal field imposed externally, poloidal field generated by the plasma current.
- RFP: no magnetic field symmetry and toroidal field reverses direction at the plasma boundary.
- Large plasma in RFX-mod operating as a RFP (2 MA).



# Turbulence plays a key role in fusion devices

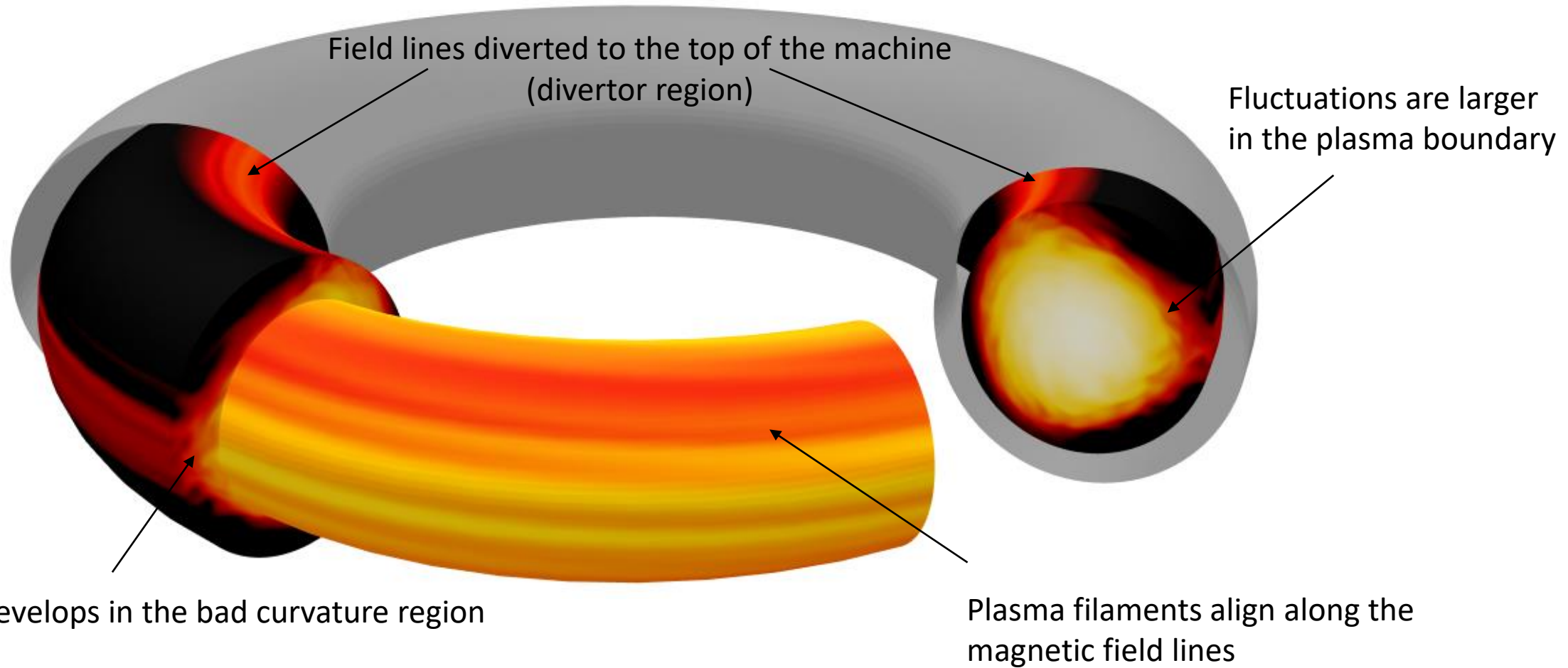


- Steep density and temperature gradients in the plasma boundary enable a set of micro-instabilities and turbulence.
- Turbulent transport controls the performance of a magnetic fusion device and heat flux to the wall.
- Biasing electrode in the edge of RFX-mod reduces turbulent transport and improve plasma confinement.
- **Work presented here: first three-dimensional turbulence simulations of RFX-mod with edge voltage biasing.**
- **We are also working on the first boundary turbulence simulations of a RFP.**



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# GBS simulations of RFX-mod plasma



# Drift-reduced Braginskii model implemented in GBS



$$\frac{\partial n}{\partial t} = \underbrace{-\frac{R_0}{B} [\phi, n]}_{\substack{E \times B \\ \text{CONVECTION}}} + \underbrace{\frac{2}{B} [C(p_e) - nC(\phi)]}_{\substack{\text{COMPRESSIBILITY} \\ \text{DUE TO CURVATURE}}} - \underbrace{\nabla_{\parallel} (nv_{\parallel e})}_{\substack{\text{PARALLEL} \\ \text{FLOW}}} + \underbrace{\nu_{iz}n_n - \nu_{rec}n}_{\text{SOURCE - SINK}}$$

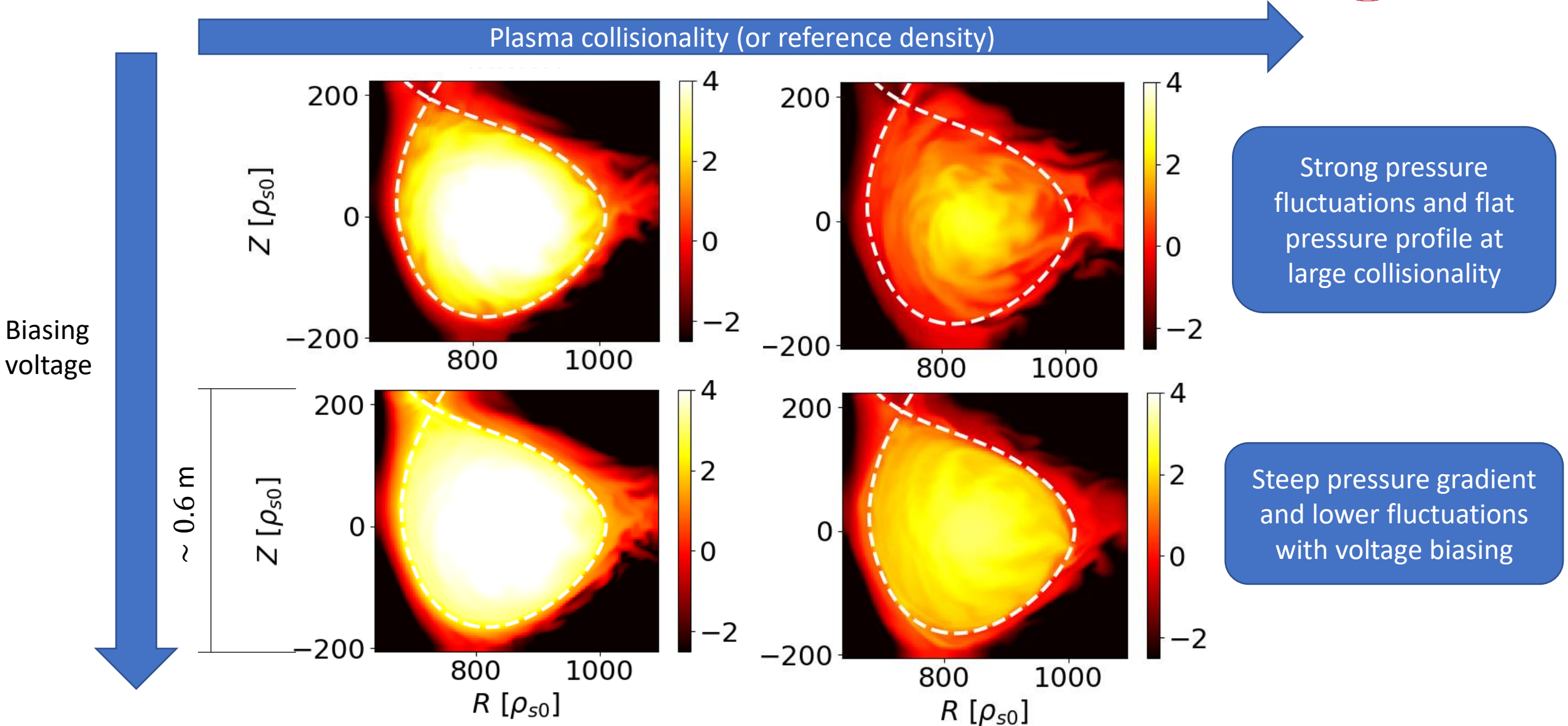
$T_e, T_i$   $\longrightarrow$  similar equations

$$\frac{\partial \nabla \cdot \vec{\omega}}{\partial t} = \underbrace{-\frac{R_0}{B} \nabla \cdot [\phi, \vec{\omega}]}_{\substack{\text{POLARIZATION} \\ \text{CURRENT}}} + \underbrace{\frac{B^2}{n} \nabla_{\parallel} j_{\parallel}}_{\substack{\text{PARALLEL} \\ \text{CURRENT}}} + \underbrace{\frac{2B}{n} C(p)}_{\substack{\text{DIAMAGNETIC} \\ \text{CURRENT}}} + \dots$$

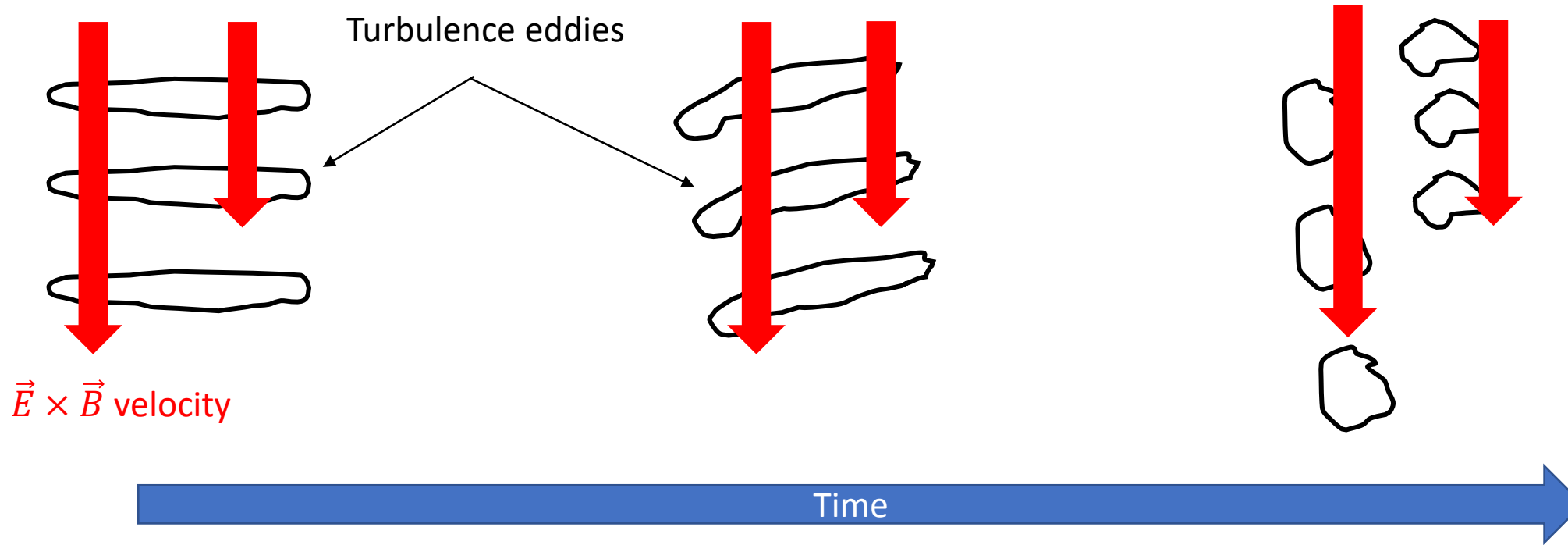
$v_{\parallel e}, v_{\parallel i}$   $\longrightarrow$  Parallel momentum balance

$$\nabla \cdot (n \nabla_{\perp} \phi) = \nabla \cdot \vec{\omega} - \nabla_{\perp}^2 p_i \quad \text{Poisson's law}$$

# Turbulent transport is reduced with voltage biasing



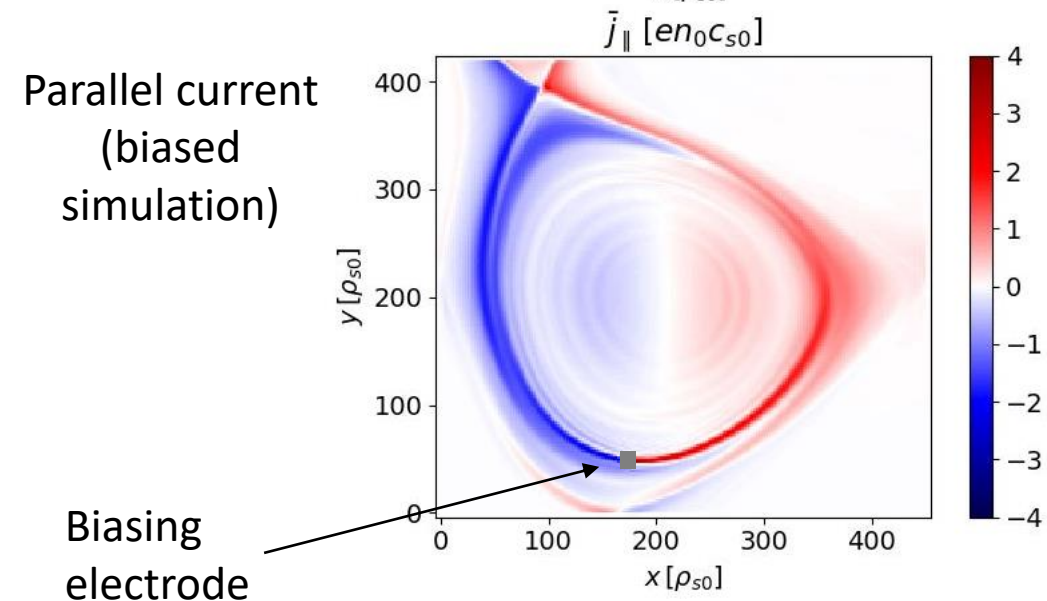
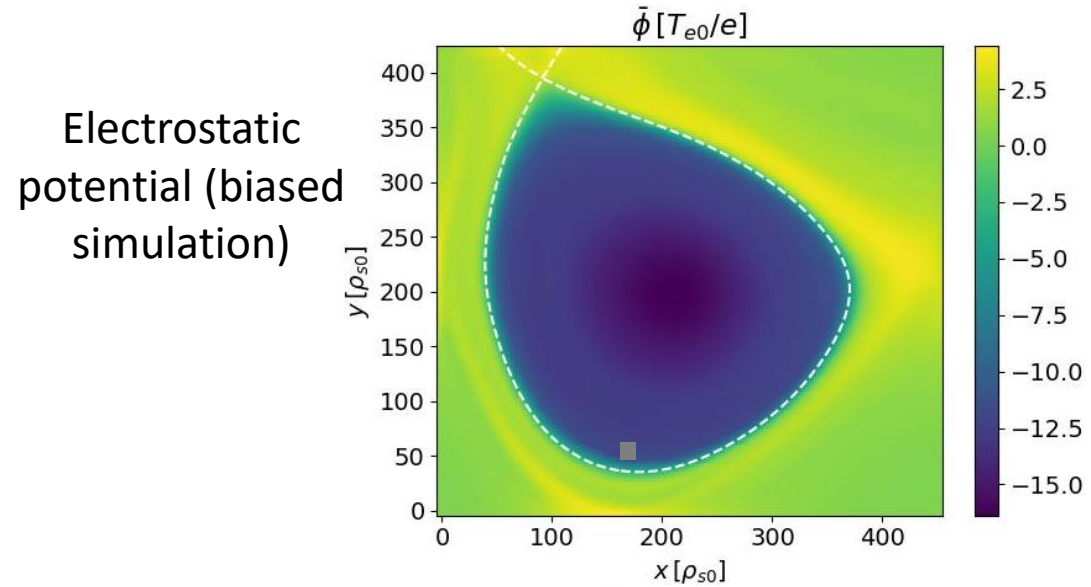
# Turbulence suppression caused by $\vec{E} \times \vec{B}$ velocity shear



The radial size of turbulence eddies is reduced by velocity shear

What about the RFX-mod simulations with voltage biasing?

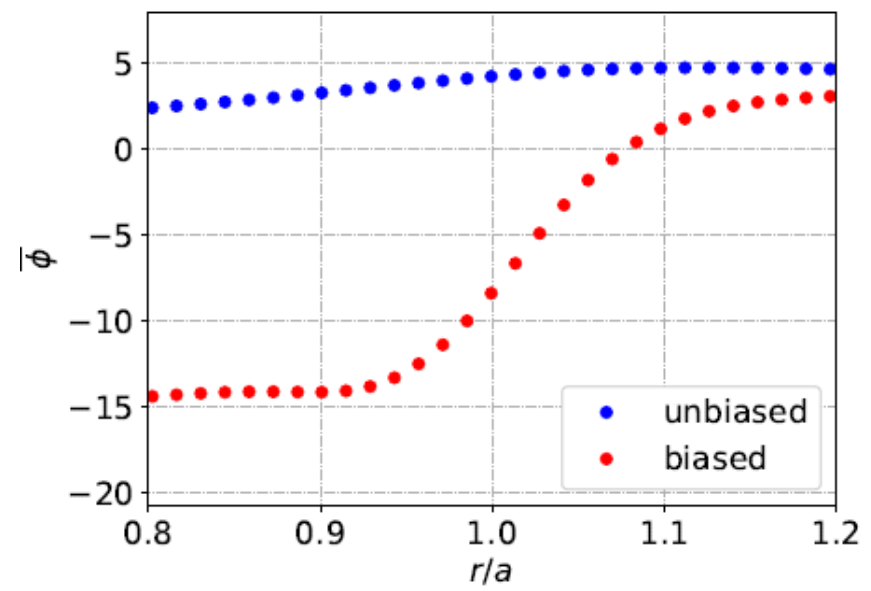
# Strong $\vec{E} \times \vec{B}$ velocity shear caused by the voltage biasing



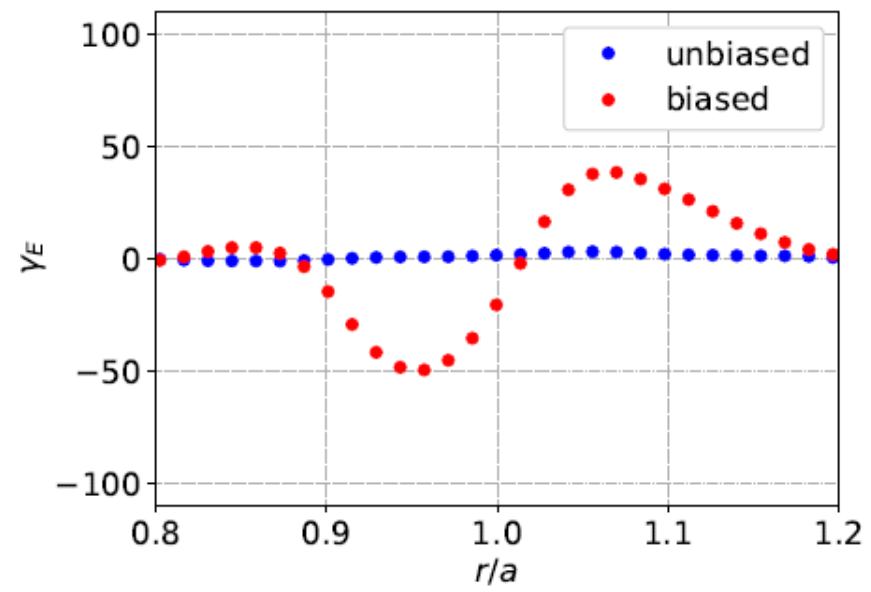
# Strong $\vec{E} \times \vec{B}$ velocity shear caused by the voltage biasing



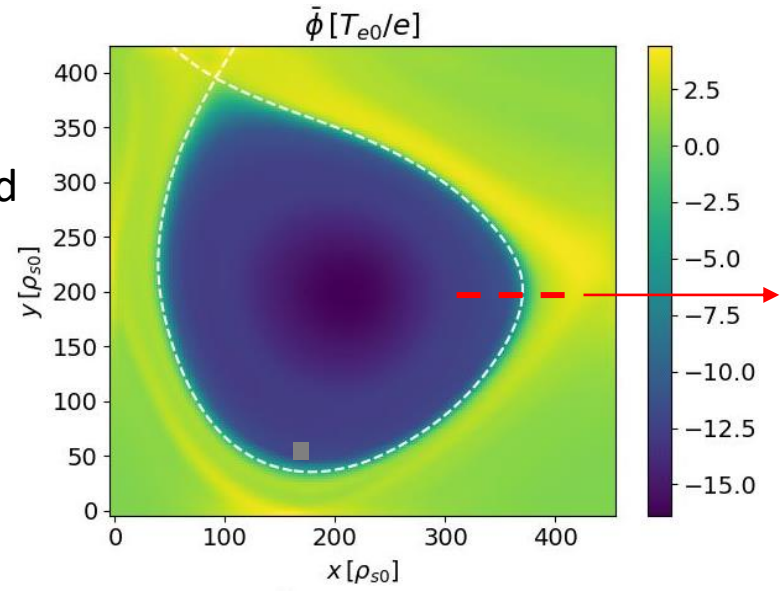
Radial profile of the electrostatic potential



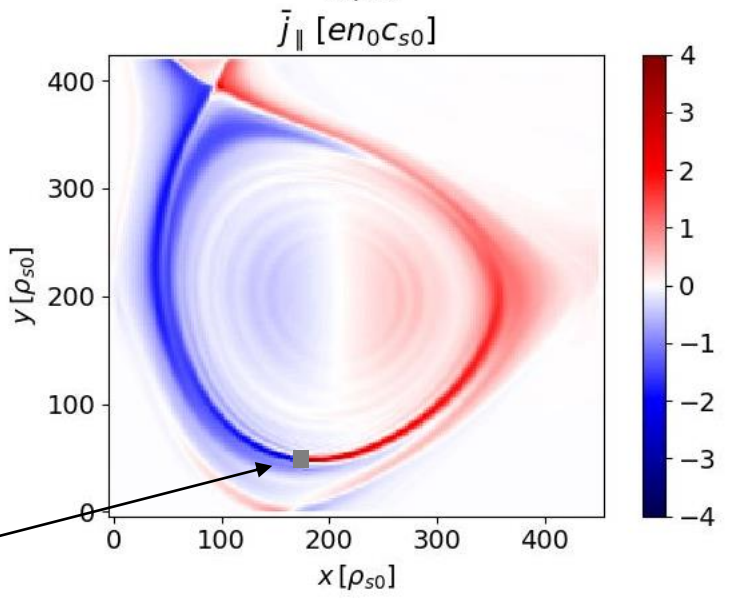
$\vec{E} \times \vec{B}$  velocity shear is much stronger in the biased case



Electrostatic potential (biased simulation)



Parallel current (biased simulation)

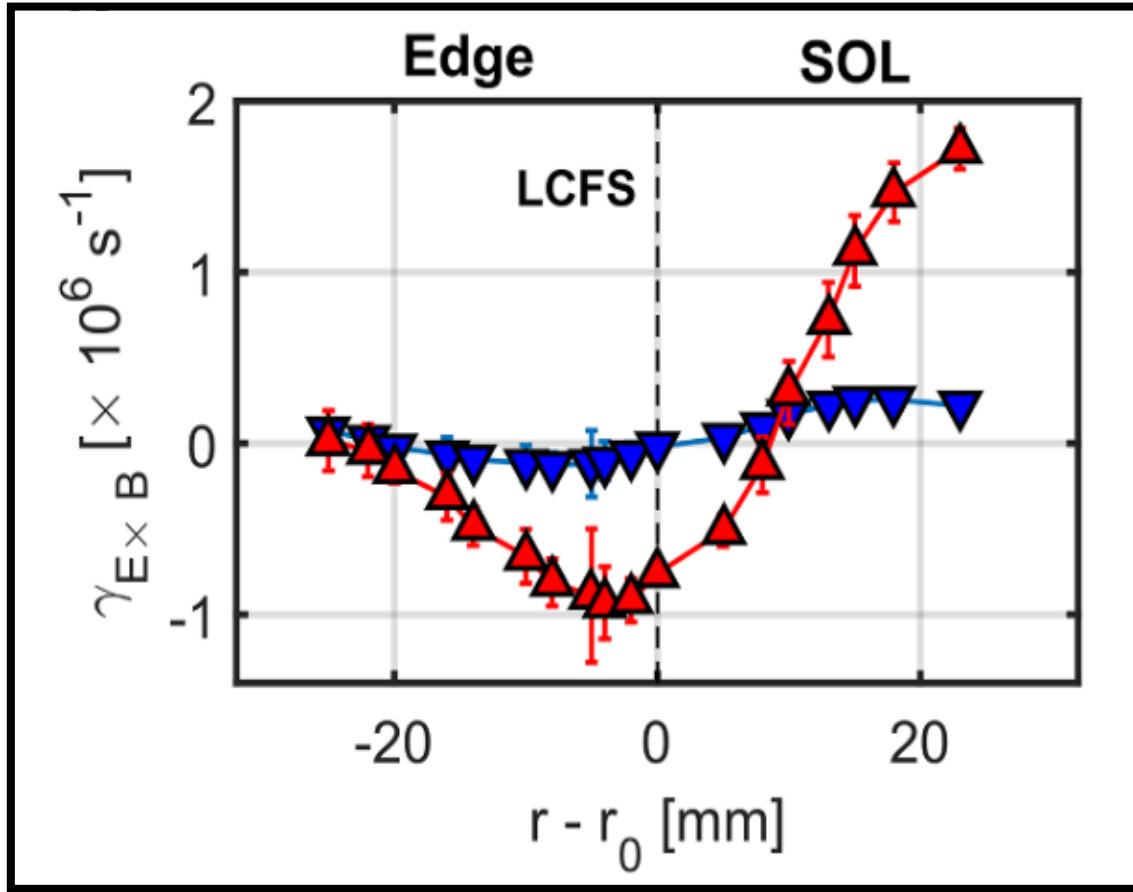


Biasing electrode

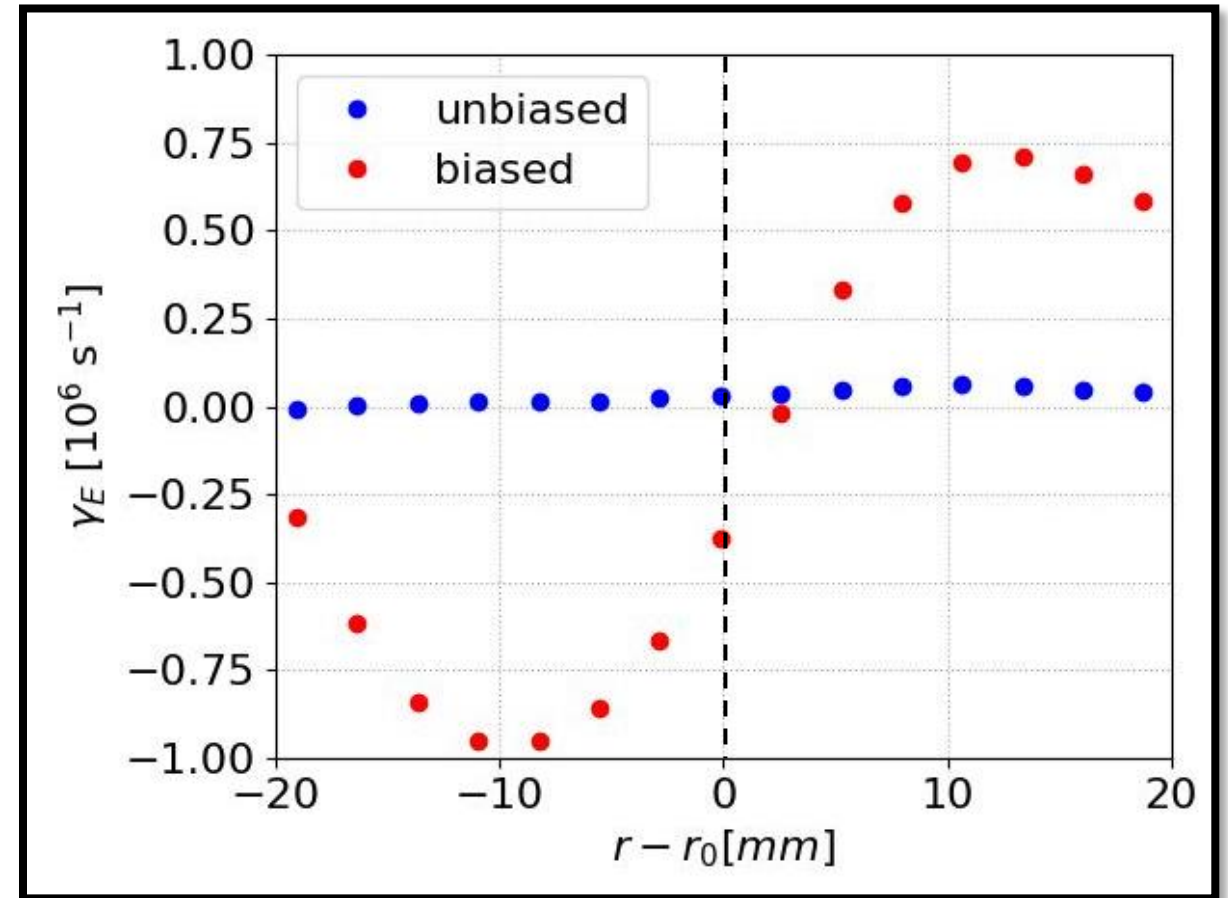
# $\vec{E} \times \vec{B}$ velocity shear profile agrees with experiments



Experimental measurements in RFX-mod  
[Grenfell et al 2020 Nucl. Fusion 60 126006]



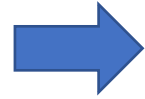
Flow shear radial profiles from GBS simulations



# Edge pressure gradient steeper with voltage biasing



Voltage biasing generates large  $\vec{E} \times \vec{B}$  flow shear

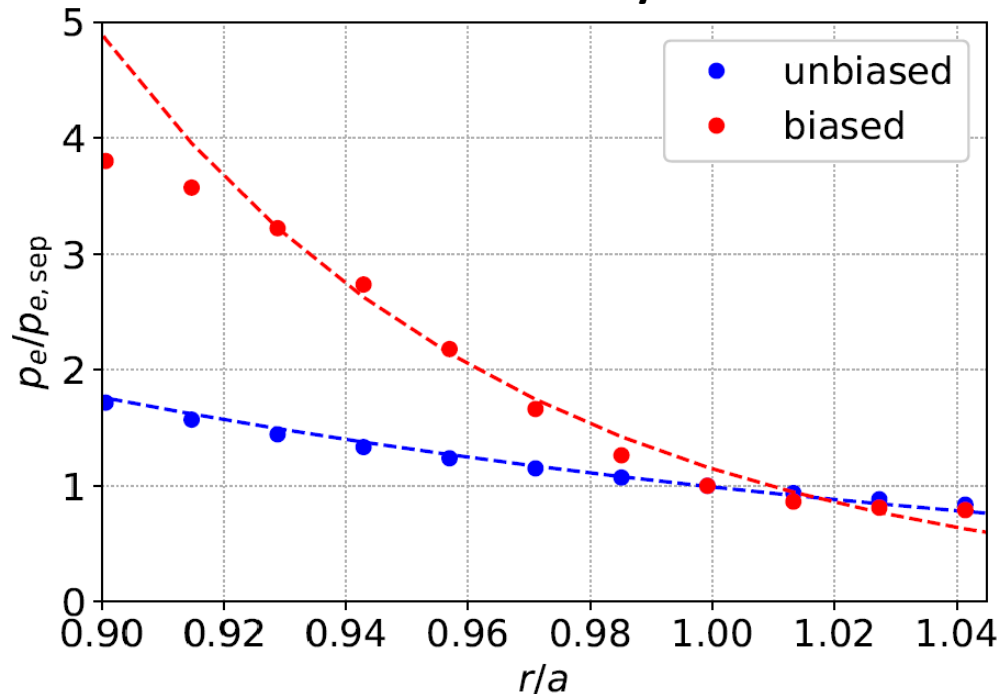


Flow shear reduces turbulent transport in the plasma boundary

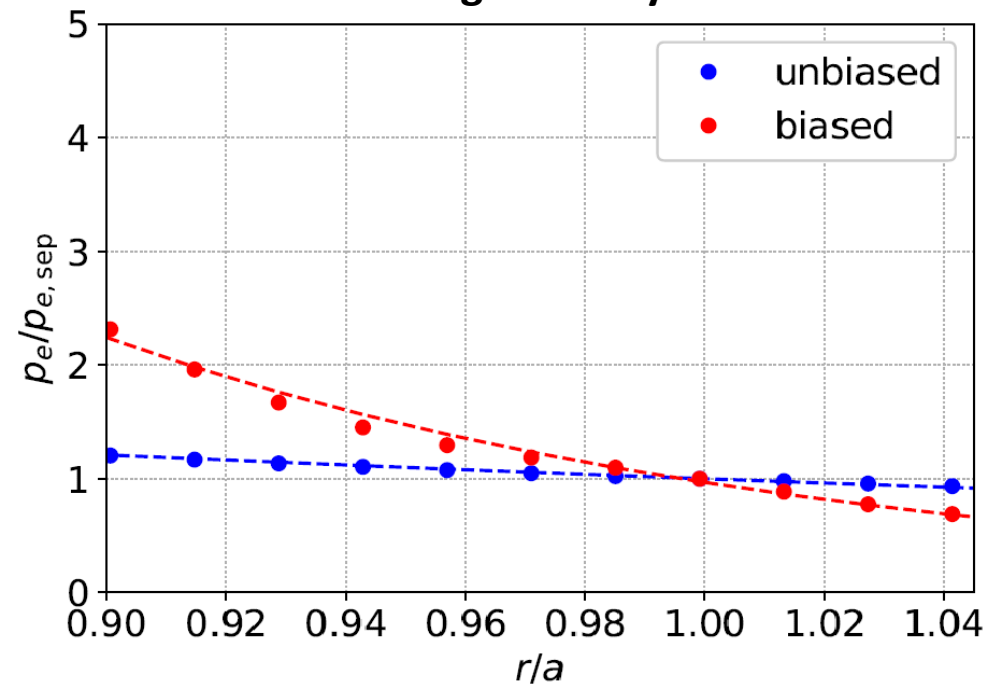


Smaller turbulent transport leads to steeper pressure profile

Low density



High density



- RFX-mod is a flexible magnetic confinement plasma device, where various magnetic configurations are investigated.
- More turbulence diagnostics will be available next year in RFX-mod2.
- Turbulence simulations with the biasing electrode reproduce the turbulence suppression observed in RFX-mod experiments.
- Edge transport barrier (and better performance) thanks to turbulent transport reduction.
- A theoretical scaling describing the pressure gradient in the presence of voltage biasing is being derived.
- Future works:
  - In-depth validation of the GBS simulations against RFX-mod(2) turbulence measurements.
  - Effect of voltage biasing on the density limit physics.

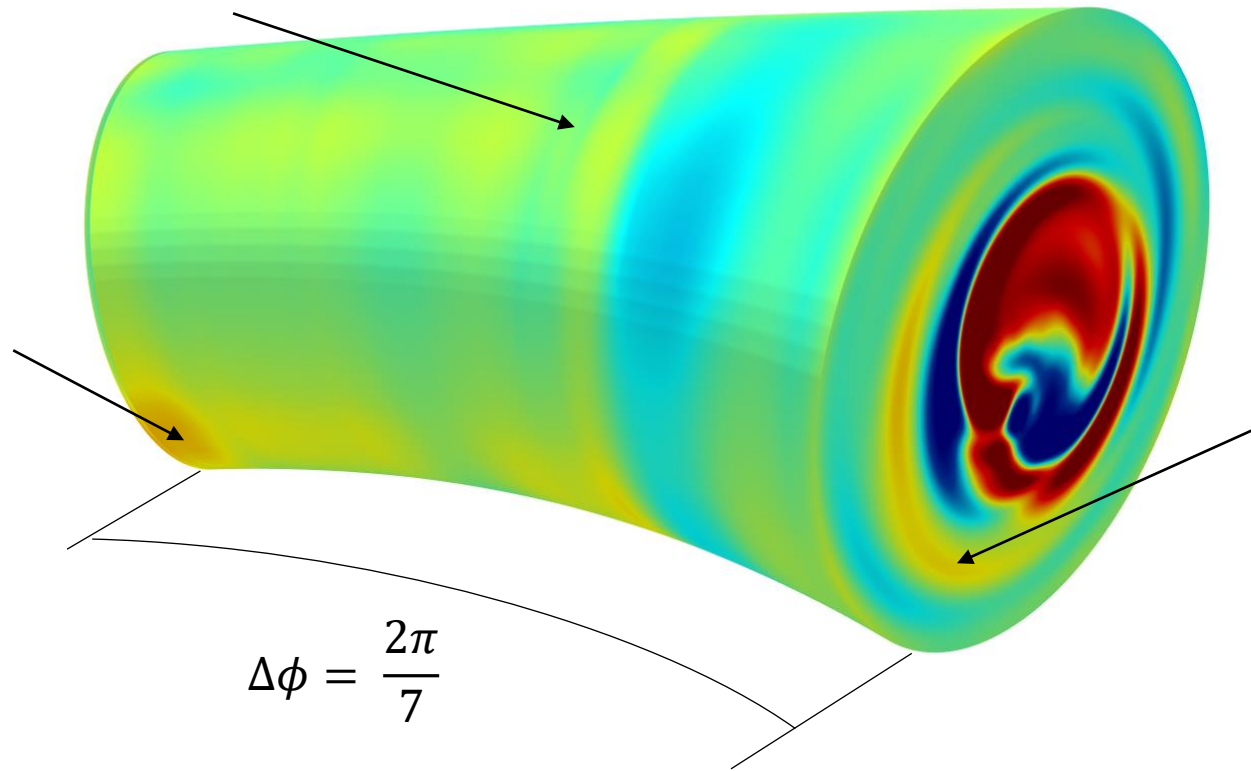
# Outlook: RFP simulations



Very preliminary three-dimensional global turbulence simulation of a RFP configuration

Electron parallel velocity mostly poloidal in the edge (vanishing toroidal magnetic field)

Strong variation in the toroidal direction



Appearance of some current layers

This is work-in progress