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A model of interchange turbulent transport across separatrix with sheared flows

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HAL Authorization

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Context and motivations

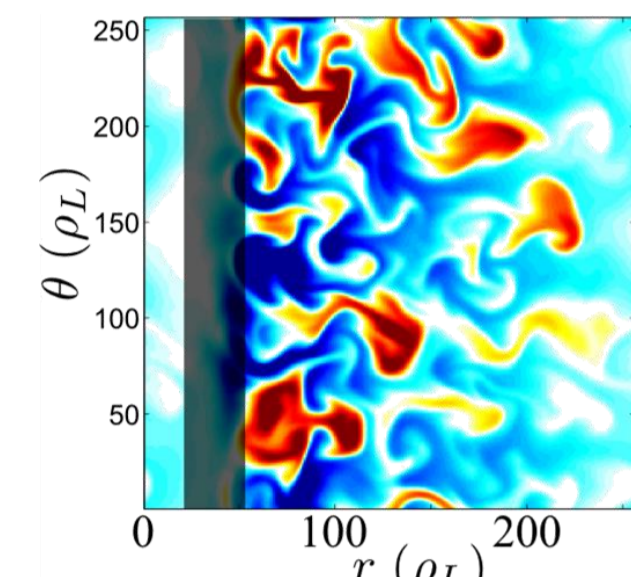
- Filamentary turbulent transport is thought to be responsible of the turbulent transport across flux surfaces in tokamak plasma edges and scrape-off layers (SOL) as proposed by the isolated filament model (IF model)[1-3]
 - Link between turbulent transport and confinement properties as SOL width or energy confinement time not fully understood
 - Interplay between turbulence & shear flow : turbulence mitigation & shear flow generation through Reynolds stress → increase of confinement
 - Geometry strongly impacts both transport & edge shear flow generation : favourable/unfavourable configuration [4]
- Analytical model of edge transport with shear flows is needed

Spectral Filament Model

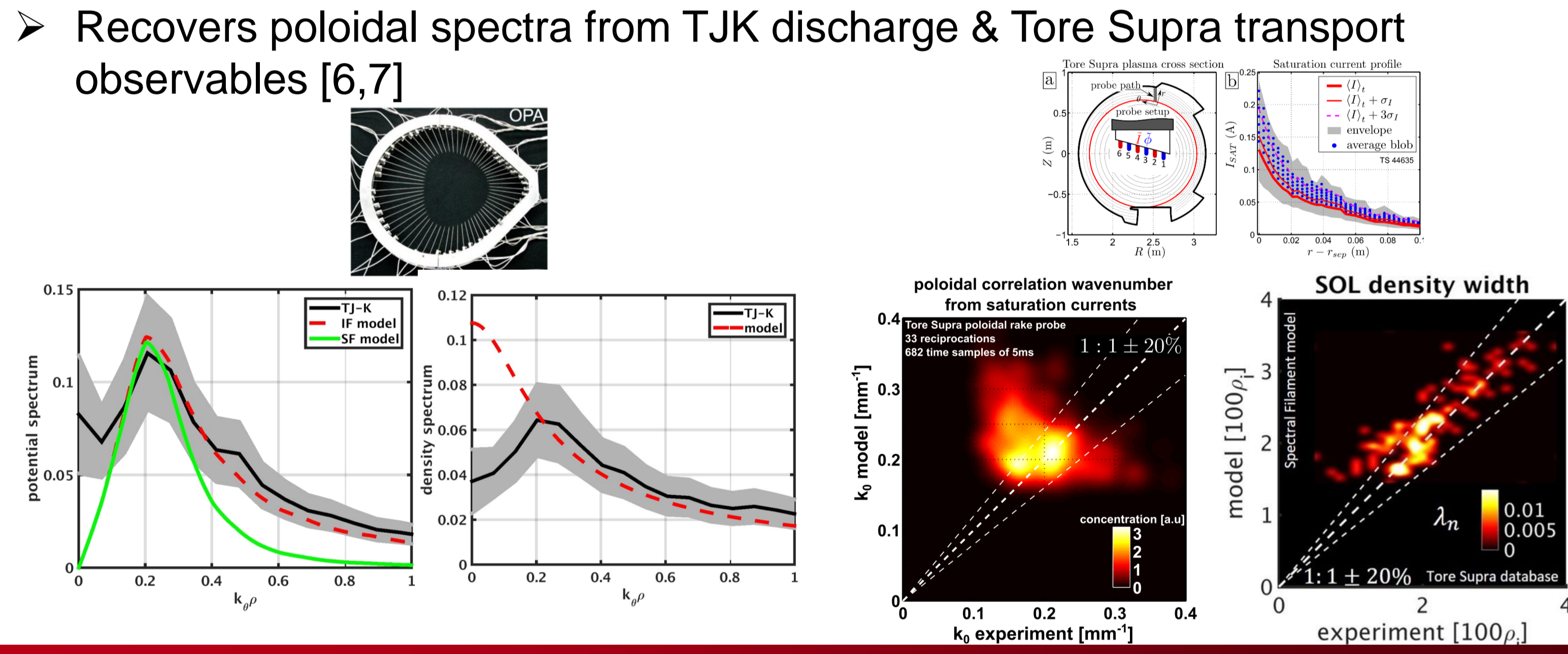
- TOKAM2D isothermal model : Braginskii's equation averaged on field line + flux conservation in scrape-off layer (SOL) [5] :

$$(\partial_t - D_{\perp} \Delta_{\perp})n = [n, \Phi] - n\sigma_{\parallel} e^{(\Lambda - \Phi)} + S$$

$$(\partial_t - \nu \Delta_{\perp})\Delta_{\perp} \Phi = [\Delta_{\perp} \Phi, \Phi] + \sigma_{\parallel} (1 - e^{(\Lambda - \Phi)}) - \frac{g \partial_y n}{n}$$

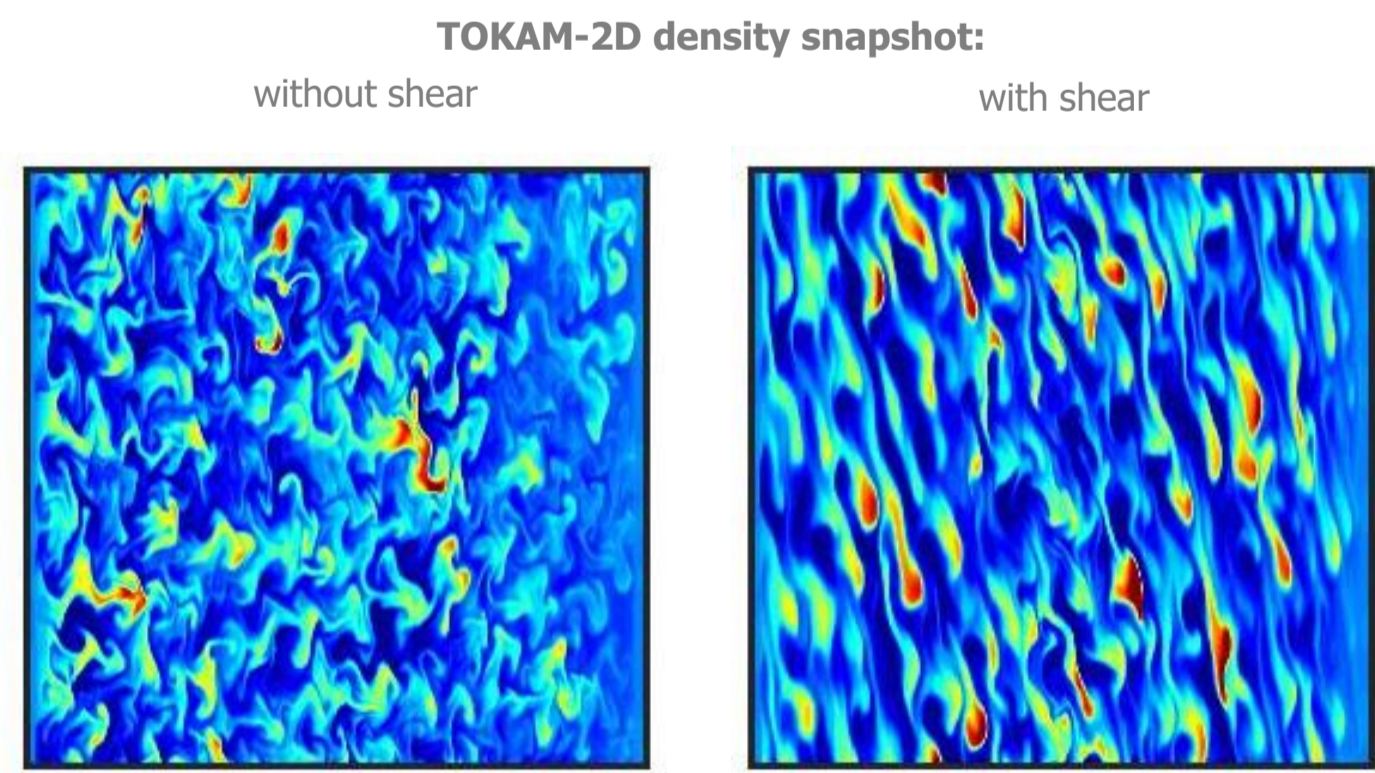


- Quantitative description of limiter SOL properties [1,2] for :
 - Intermittent transport (blob)
 - Exponentially decaying equilibrium profiles
- Model reduction via poloidal spectra inspired from isolated filament model [3]
 - Sheath loss & mode coupling saturation phenomena
 - Allows prediction for transport observables
- Verified with a 2D non-linear flux-driven simulation database



Sheared Spectral Filament Model

- Introduction of uniform shear σ_s + interchange recall → Constant tilt



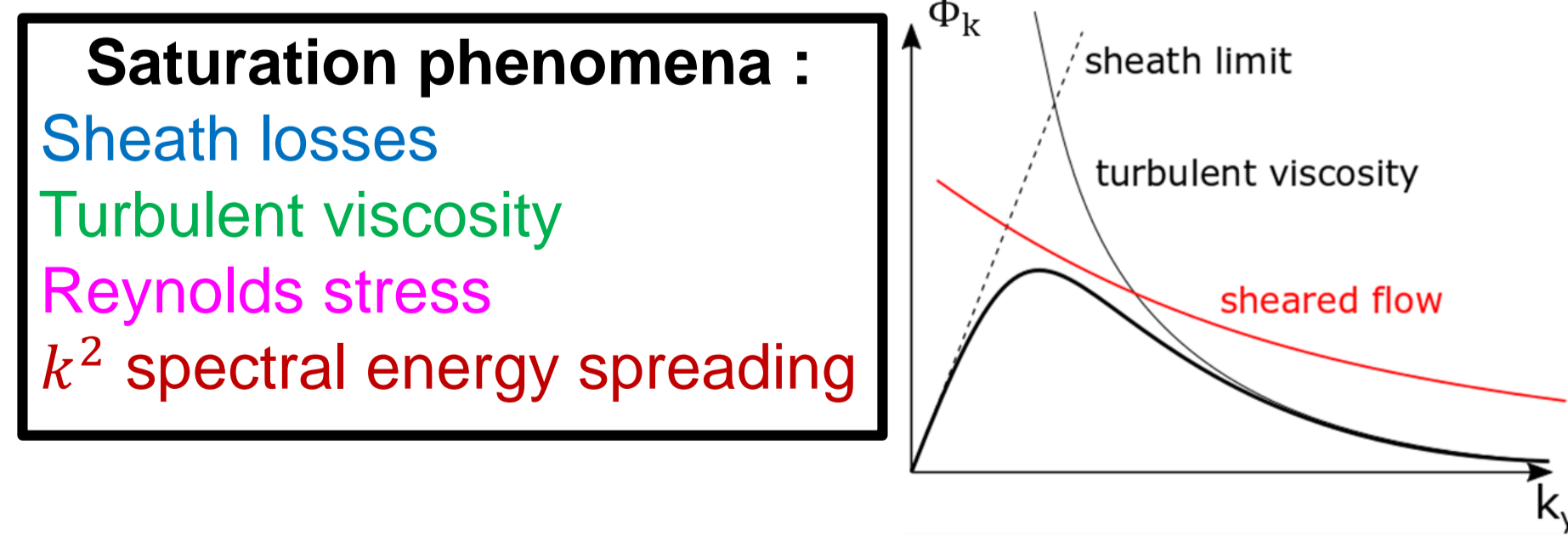
$$\partial_t k_x = -\sigma_s k_y - \frac{k_x - k_x^0}{\tau}$$

↑ Shear tilt
→ Interchange recall

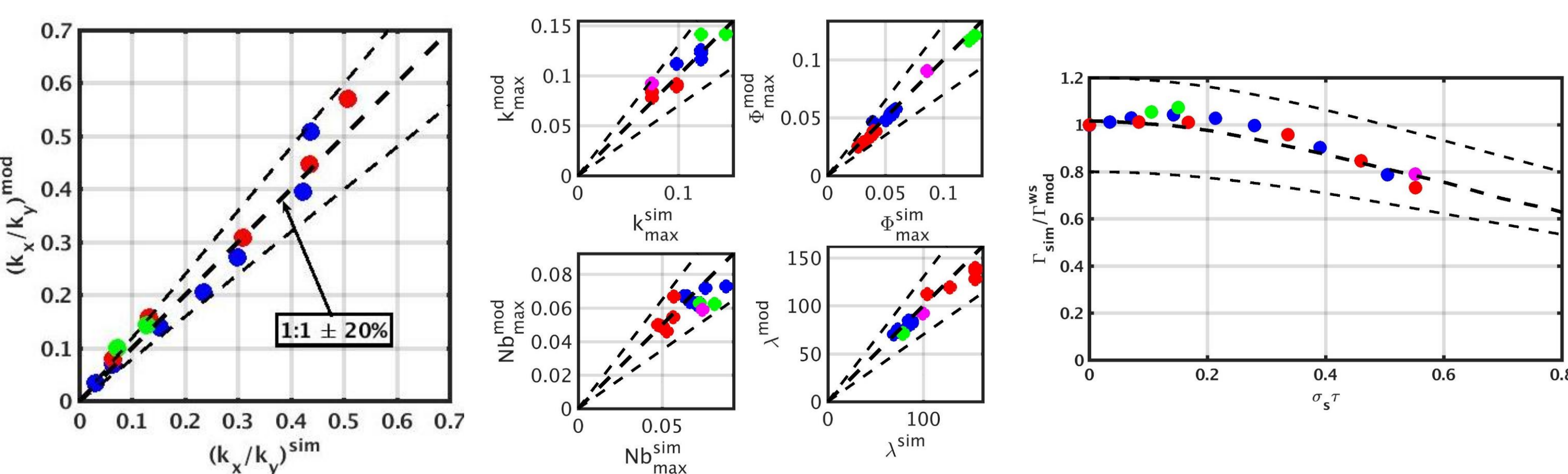
$$\Phi_k = \frac{g k_y}{k_0} \frac{1}{\sigma_{\parallel} \lambda_n \sqrt{1 + \frac{k_y^2}{k_0^2} (1 + \sigma_s^2 \tau^2)} \left(1 + \frac{2\sigma_s^2 \tau^2}{\sigma_{\parallel}^2} k_y^2 + \frac{1}{2} \frac{k_y^4}{k_0^4} \right)}$$

$$n_k = \frac{1}{\lambda_n k_0 \sqrt{1 + \frac{k_y^2}{k_0^2} (1 + \sigma_s^2 \tau^2)}}$$

$$\tau = 0.43 \frac{\lambda_n}{g} \quad k_0 = \frac{1.06 \sqrt{\sigma_{\parallel} \tau}}{(1 + \sigma_s^2 \tau^2)^{0.25}}$$



- Verified against simulations (colors = pairs of $[g, \sigma_{\parallel}]$)

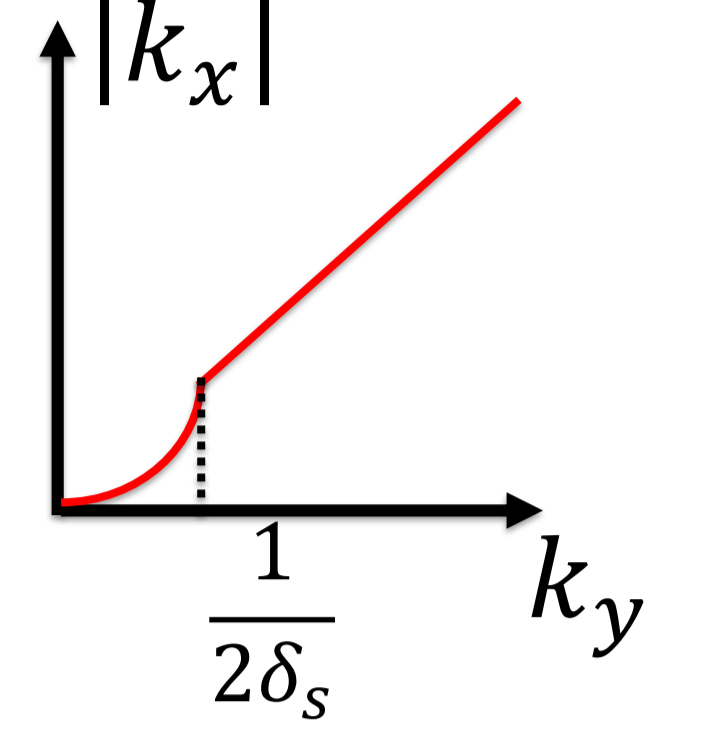
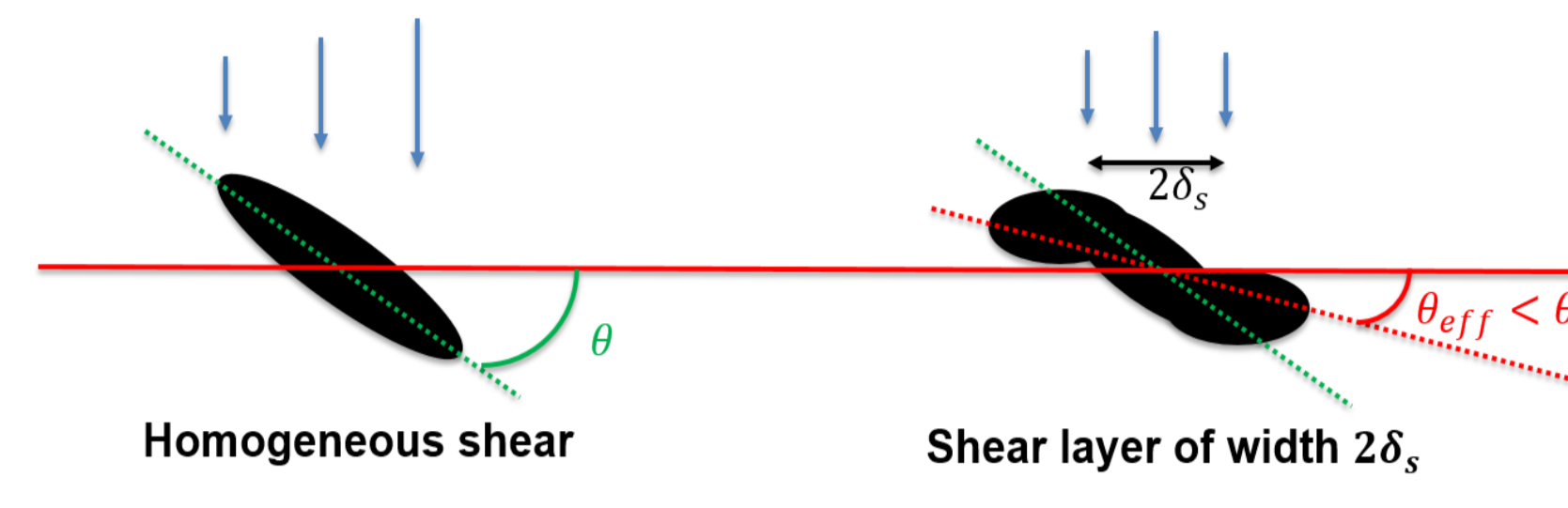


Impacts of the geometry on turbulence

- Pedestal structure size $\sim 10\rho_L \sim 1\text{cm}$ ~ shear layer width δ_s

→ Mitigation of structure tilt

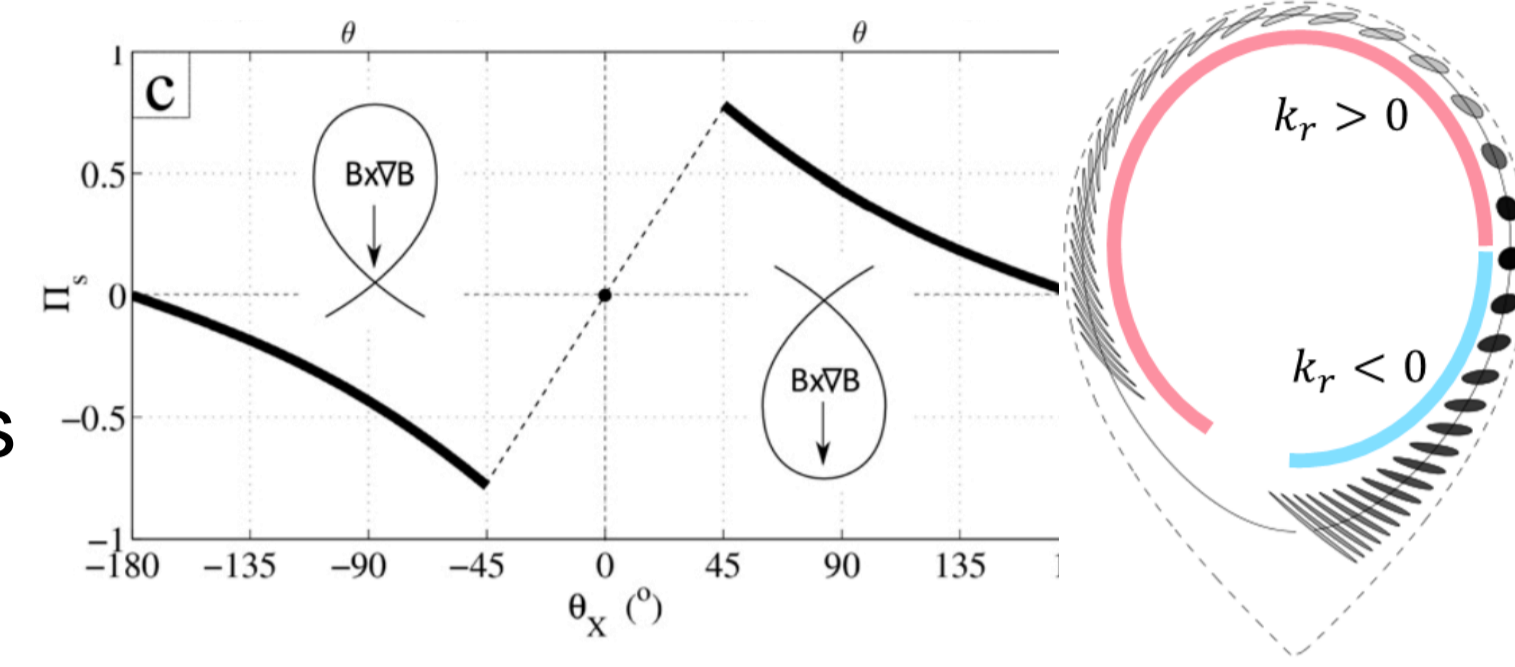
$$\rightarrow k_x = f(\gamma_{E \times B}, \delta_s, k_y, \tau)$$



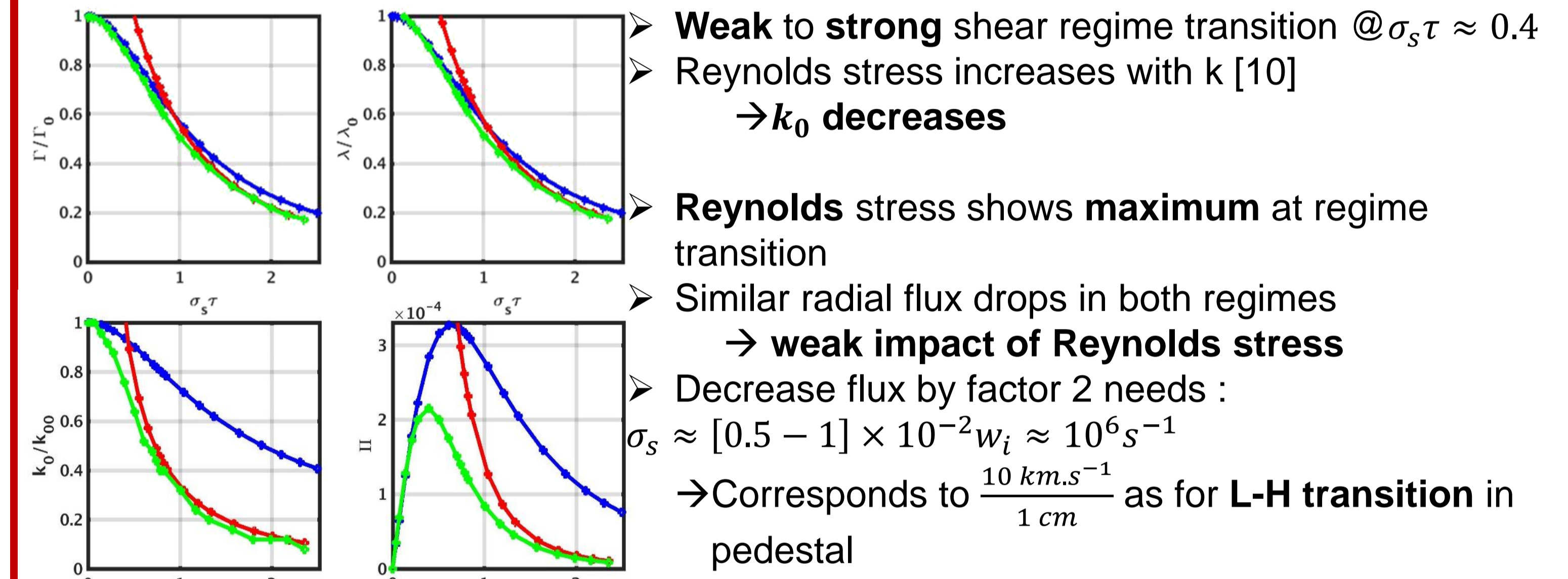
- X-point or limiter :

→ Non-zero flux surface average of magnetic shear induced tilt [8,9]

→ Magnetic shear induced Reynolds stress



1D flow generation model : comparison with experiment



Weak to strong shear regime transition @ $\sigma_s \tau \approx 0.4$
Reynolds stress increases with k [10]
→ k_0 decreases

Reynolds stress shows maximum at regime transition

Similar radial flux drops in both regimes
→ weak impact of Reynolds stress

Decrease flux by factor 2 needs :

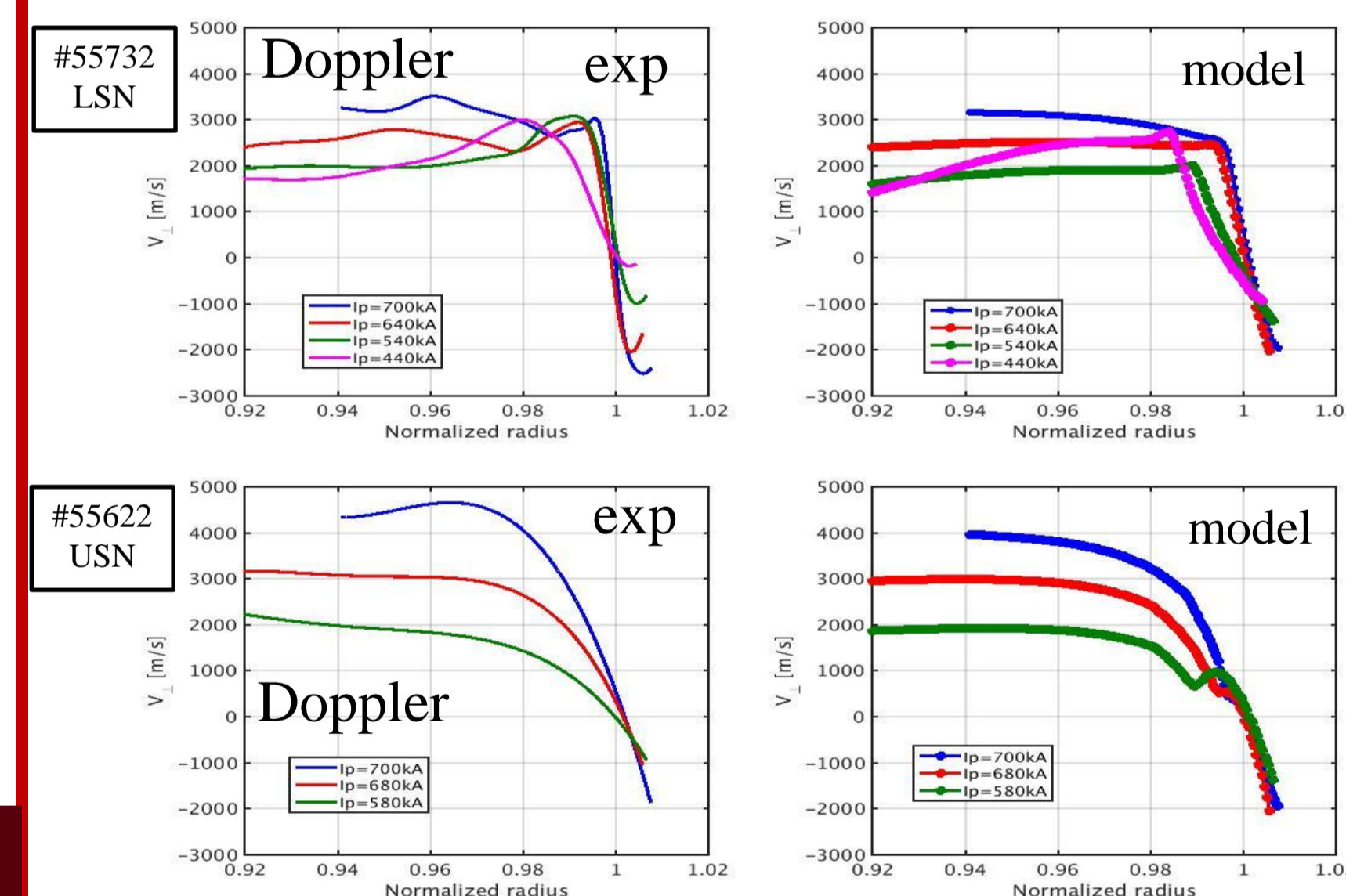
$$\sigma_s \approx [0.5 - 1] \times 10^{-2} w_i \approx 10^6 \text{ s}^{-1}$$

→ Corresponds to $\frac{10 \text{ km.s}^{-1}}{1 \text{ cm}}$ as for L-H transition in pedestal

$$\partial_t V_{E \times B} = -\partial_r \Pi_{turb} - (\nu - \chi \partial_r^2) (V_{E \times B} + v_i^{dia}) - \chi_{SOL} (V_{E \times B} - V_{E \times B}^{SOL})$$

SSF model

Neoclassical



- WEST experiments :

→ Impact of geometry on edge rotation
→ Unfav. config. (USN) deeper than fav. config. (LSN)

→ Non standard feature

→ Difference vanishes @ high Ip

→ No clear well in unfav. config.

→ Model recovers both Ip & config. dependencies for edge rotation

Conclusion and perspectives

- Derivation of a model of edge turbulent transport verified against simulations & validated against experiment

- Derivation of a model of impact of background shear on interchange :

→ Spectral model + structure tilt model

- Validation against 2D flux-driven simulations for turbulence properties (Φ_k, n_k, k_0) & transport (Γ_r, λ)

- Impact of shear on density and potential perturbations phase shift not treated
→ does not seem to be important in our simulations

- Spatial variation of shear taken into account

→ 1D model on shear flow generation by Reynolds stress with magnetic shear :

→ Validation of the 1D model against WEST experiment

→ Recovery of geometry and Ip dependencies of edge rotation

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