

Linking Edge Flows to the Magnetic Geometry Asymmetry in Tokamaks

S. Rienäcker¹, L. Vermare¹, P. Hennequin¹, C. Honoré¹, S. Coda², B. Labit², L. Frassinetti³, B. Vincent², M. Agostini⁴, M. La Matina⁴, M. Ugoletti⁴, A. Balestri², P. Manas⁵, O. Panico^{1,5}, the TCV⁶, WEST⁷ and EUROfusion Tokamak Exploitation⁸ teams



¹ Laboratoire de Physique des Plasmas (LPP), Ecole Polytechnique, France

² Swiss Plasma Center (SPC), EPFL, Switzerland

³ Division of Fusion Plasma Physics, KTH, Sweden

⁴ Consorzio RFX, Italy

⁵ CEA, IRFM, France

⁶ See author list H. Reimerdes et al 2022 Nucl. Fusion 62 042018

⁷ See author list J. Bucalossi et al 2022 Nucl. Fusion 62 042007,

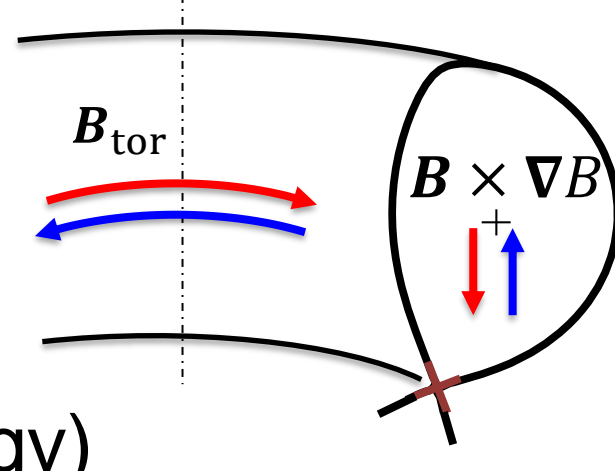
and the WEST team: <https://irfm.cea.fr/en/west/WESTteam/>

⁸ See author list E. Joffrin Nucl. Fusion 2024 10.1088/1741

Background & motivations

Geometric asymmetry in tokamak H-mode access

Power threshold for L-H transition **reduced** / **increased** if ion magnetic ($B \times \nabla B$) drift **toward** / **away from** active X-point.



→ "**Favorable**" vs. "**Unfavorable**" magnetic geometry (or topology)

Also edge flows are sensitive to topology

- Sheared flows: key role in turbulence regulation and confinement transitions
- At plasma boundary, formation of $E_r \times B$ shear layer, associated with E_r "well"
- E_r well **deeper** in **Fav.** than in **Unfav.** [1-3]
- Possible mechanism: Reynolds stress through tilted eddies [4-6]

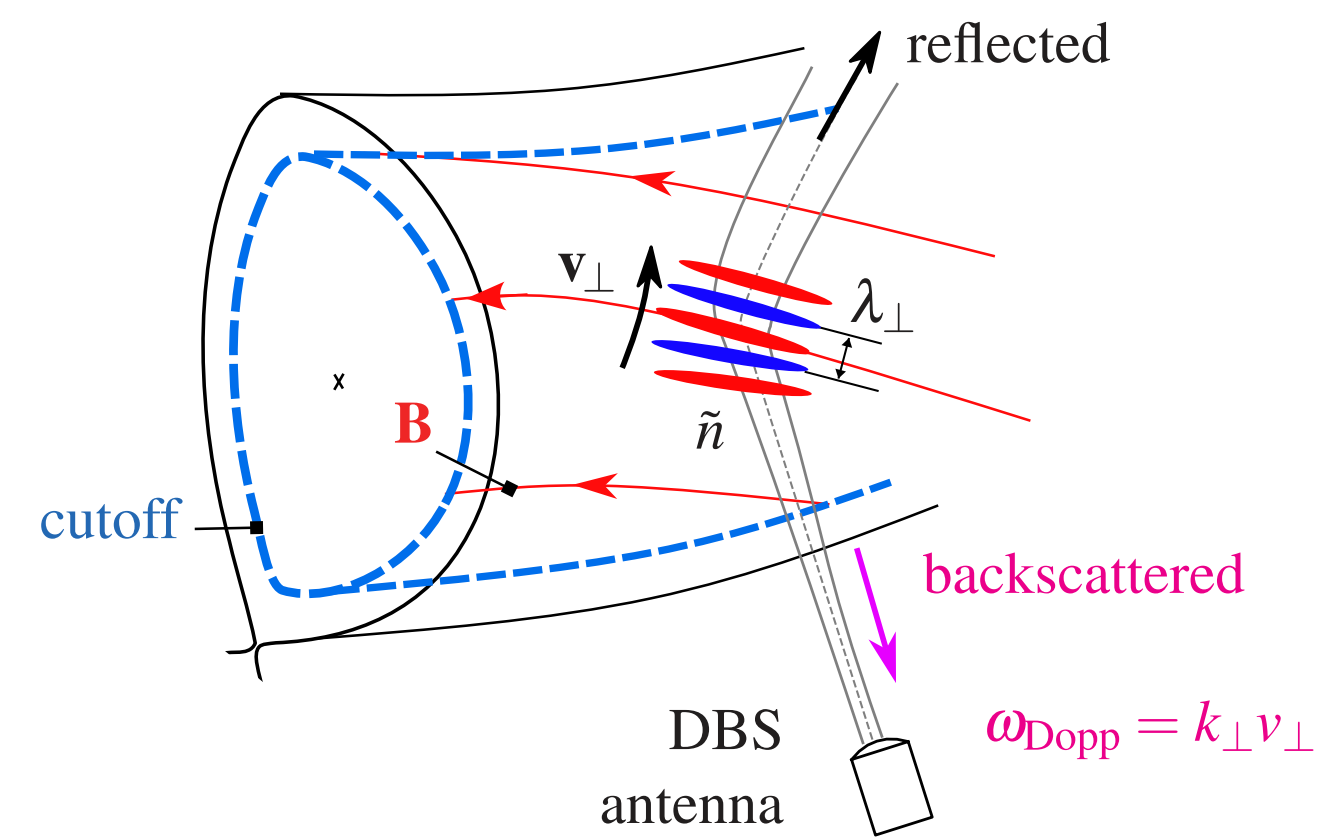
The present multi-device experimental study

- Seeks to clarify the origin^(*) of the modified E_r structure & link with L-H transition
- Now includes also E_r data from TCV, examined here and compared with WEST

Experimental method: E_r measurements on WEST & TCV

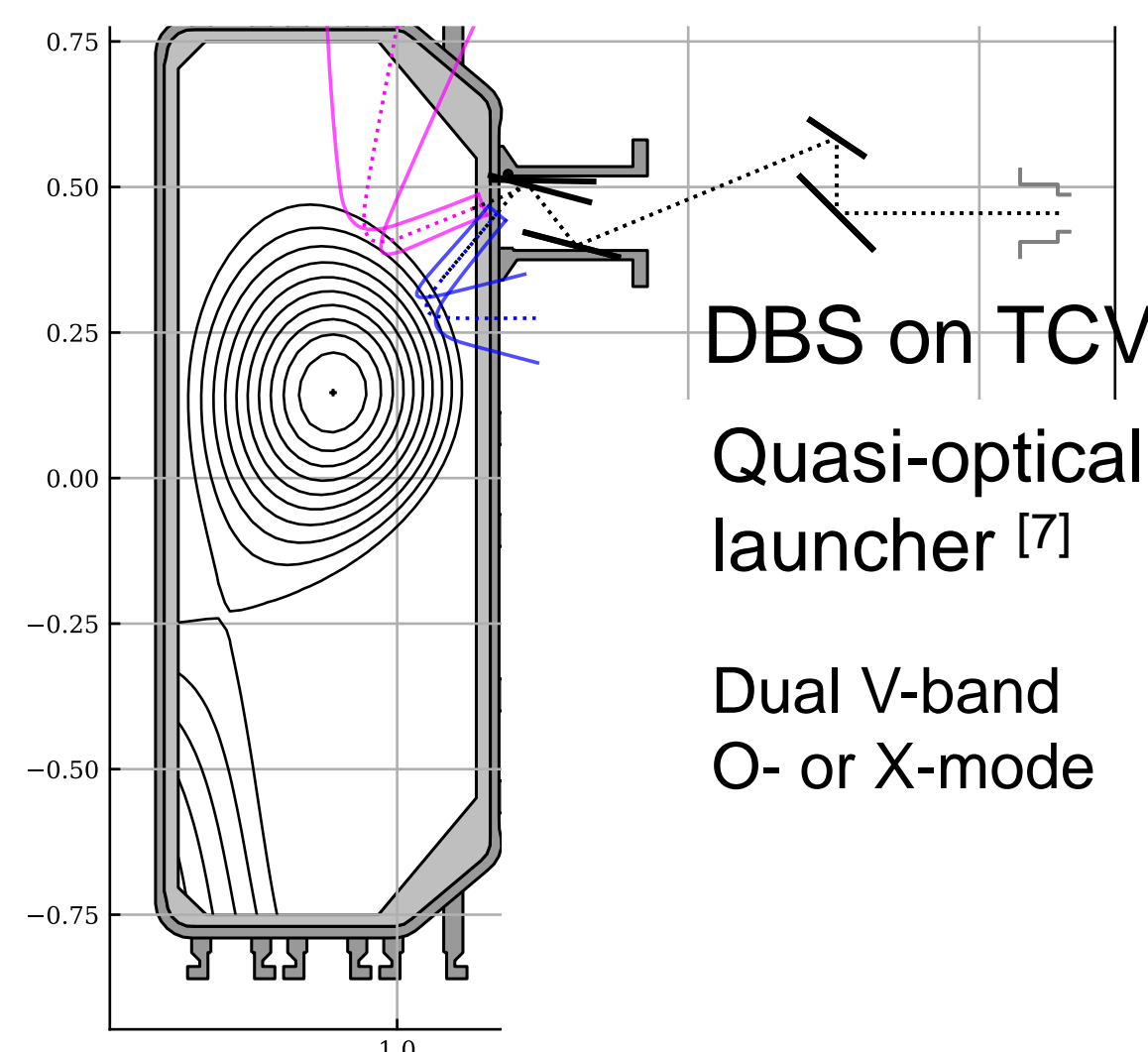
Access to E_r profiles from Doppler backscattering (DBS):

- Detects microwave scattered off density fluctuations (\tilde{n}) around radial cutoff
- \tilde{n} are advected by $E_r \times B$ velocity
- Doppler shift → $v_{\perp} \approx E_r/B$



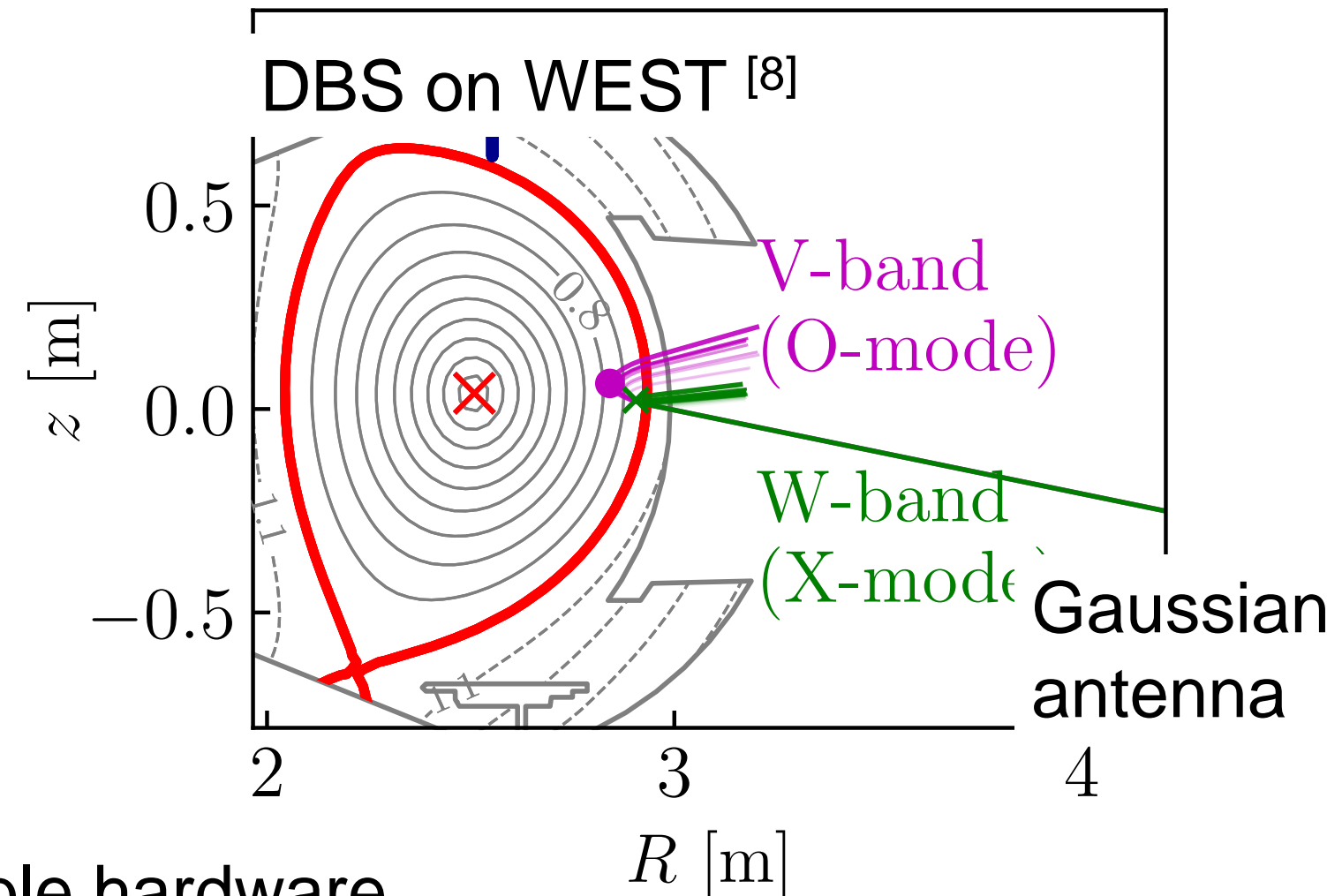
TCV tokamak

- Smaller, flexible geometry
- Carbon wall
- High power density heating



WEST tokamak

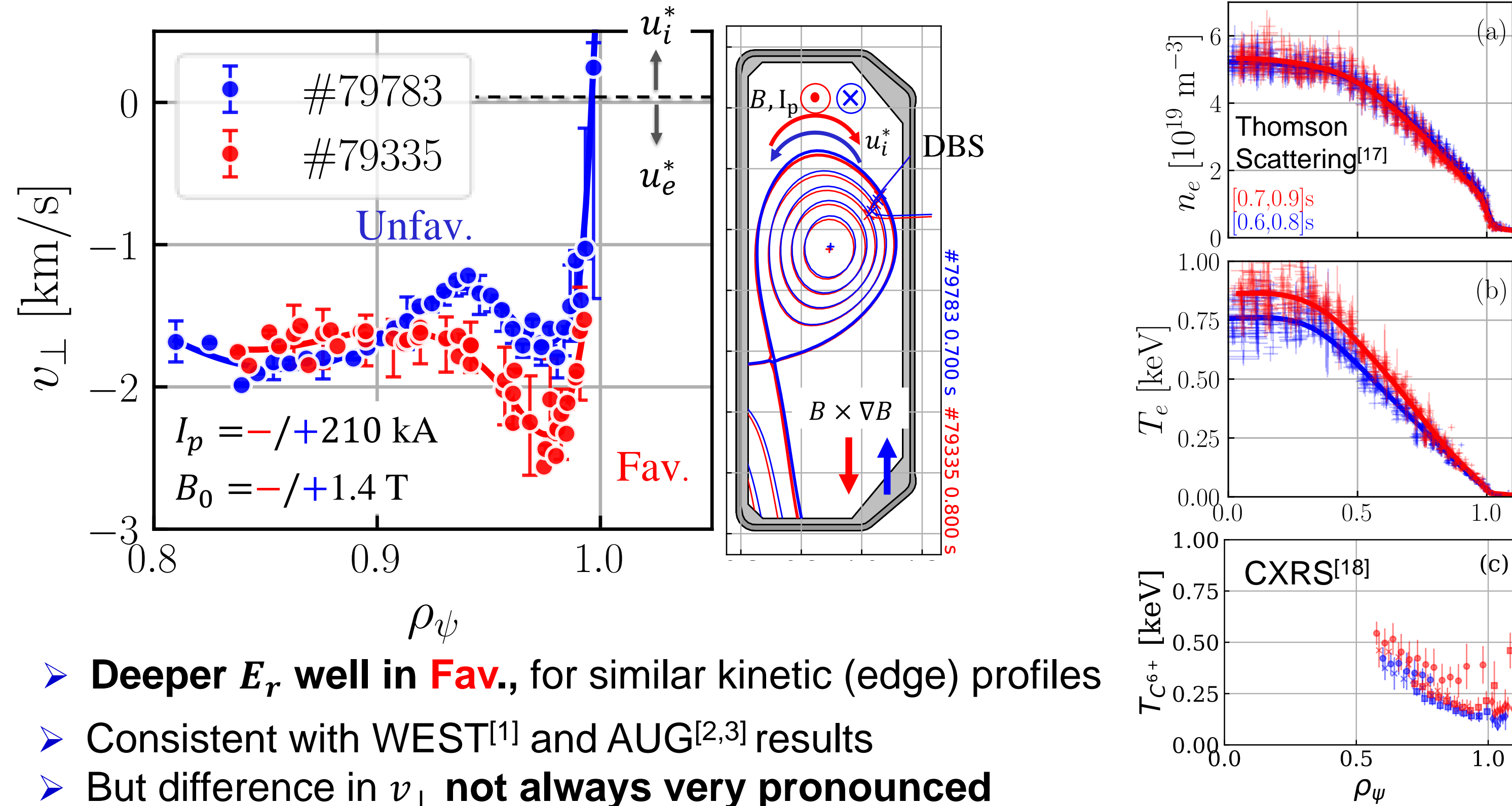
- Strong ripple ($\delta \leq 2\%$)
- High aspect ratio ($A=5$)
- Tungsten wall



- Both DBS systems from LPP, comparable hardware
- X-mode: $k_{\perp} \in [4,10] \text{ cm}^{-1}$ (~2x higher for WEST) → ~similar $k_{\perp} \rho_s \sim [0.5,1.2]$ @ $T_e = 100 \text{ eV}$
- Different beam properties, plasma region differs slightly

Confirmation of flow shear sensitivity to topology on TCV

Example of matched LSN Ohmic discharges in **Fav.** vs. **Unfav.** $B \times \nabla B$



- **Deeper E_r well in Fav.**, for similar kinetic (edge) profiles
- Consistent with WEST^[1] and AUG^[2,3] results
- But difference in v_{\perp} **not always very pronounced**
- Edge/SOL fluctuation levels from THB^[9] insensitive to $B \times \nabla B$

References

- [1] L. Vermare et al. Nuclear Fusion (2021)
 [2] J. Schirmer et al. Nuclear Fusion (2006)
 [3] U. Plank et al. Physics of Plasmas (2023)
 [4] N. Fedorczak et al. Plasma Physics and Controlled Fusion (2013)
 [5] M. Peret et al. Physics of Plasmas (2022)
 [6] O. Grover et al. Nucl. Fusion (2024)
 [7] P. Molina Cabrera et al. Rev. Sci. Instrum. (2018)
 [8] P. Hennequin et al. Nuclear Fusion (2006)
 [9] M. Ugoletti et al. Review of Scientific Instruments. Submitted (2024)
 [10] S. Rienäcker et al TTF23 Nancy, poster (2023)
 [11] P. Hennequin et al. 37th EPS Conference on Plasma Phys. (2010)
 [12] A.G. Peeters et al Computer Physics Communications (2009)
 [13] R. Varennes et al Plasma Phys. Control. Fusion (2024)
 [14] F. Jenko et al Physics of Plasmas (2000)
 [15] M. Cavedon et al. Plasma Phys. Control. Fusion (2024)
 [16] S. Coda et al. 49th EPS Conference Plasma Phys., poster (2023)
 [17] P. Blanchard et al Journal of Instrumentation (2019)
 [18] C. Marini. PhD Thesis EPFL (2017)

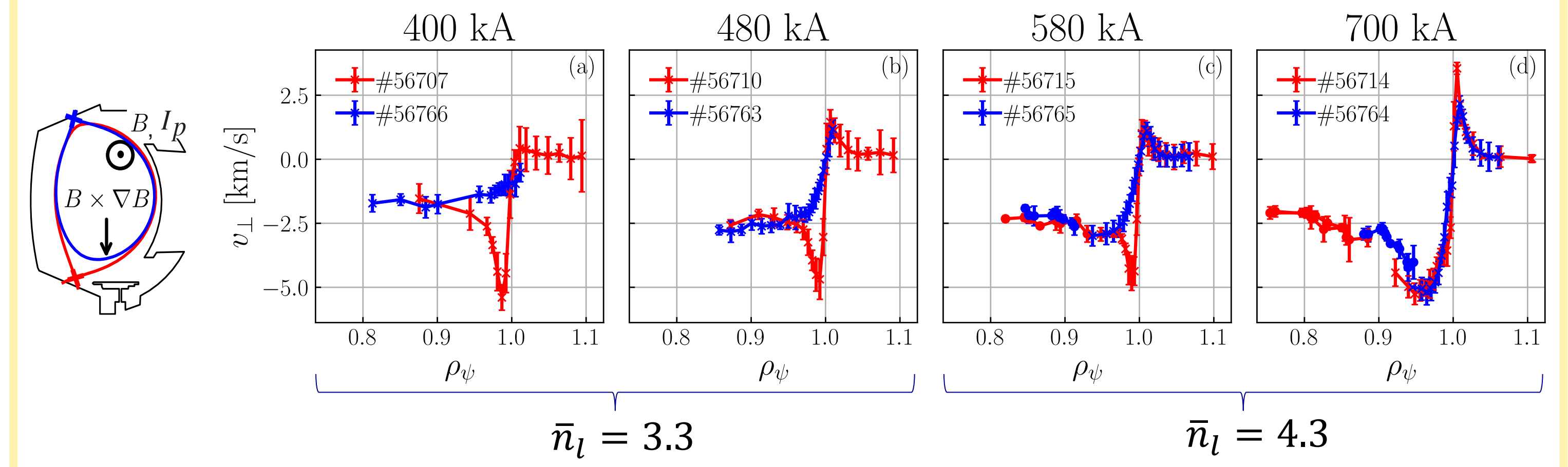
$E_r \times B$ flow asymmetry along I_p scan

Motivated by WEST [1,10], TS^[11] results we confront them to a similar Ohmic I_p scan on TCV

device	topology	I_p [kA]	q_{95}	\bar{n}_i/n_G	\bar{n}_i^{19} [m^{-3}]	B_0 [T]	$v_e(\rho_{\psi} = 0.9)$
WEST	LSN Fav.	400 → 700	5.8 → 3.3	0.55 → 0.37	3.2-4.4	-3.7	~ similar to TCV (no edge T_e data)
	USN Unfav.		4.7 → 2.8				
TCV	LSN Fav.	150 → 250	5.0 → 3.0	0.44 → 0.26	3.6-4.2	±1.4	10 → 1 (plateau)
	LSN Unfav.						

WEST

Clear deepening of E_r with I_p in **Unfav.** (not only Ohmic) discharges



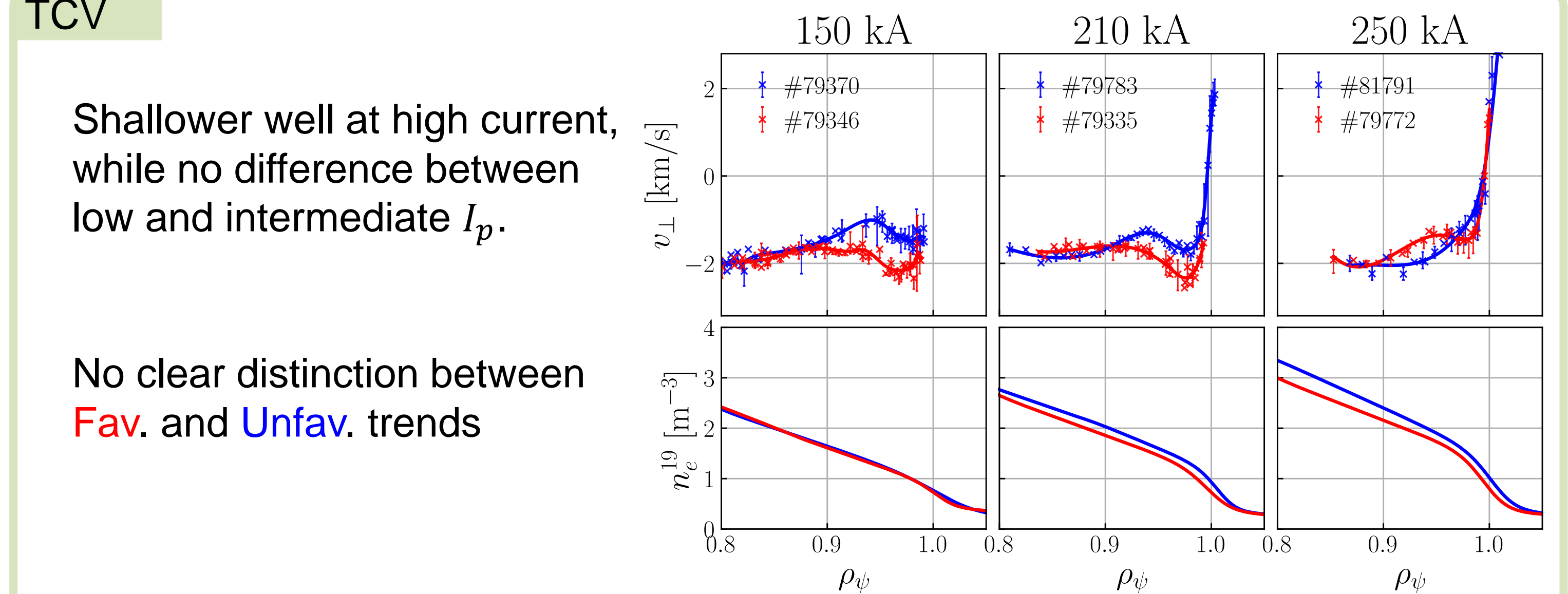
- Linear gyrokinetic analysis with GKW^[12] at $\rho_{\psi} = 0.9$ → TEM dominated (a)
- Nonlinear gyrokinetic simulations of ITG turbulence in circular geometry^[13]:
 - E_r decreases with $I_p \propto q^{-1}$ (but less pronounced than in experiment)
 - E_r mainly driven by turbulent R.S. ($\propto q^{-0.5}$), while competition with neoclassical flow damping ($\propto q^{1-2}$) invoked to explain trend with q
- Why this sensitivity stronger in **Unfav.** not clear

(a) Courtesy of P. Manas. For a representative USN WEST discharge (#55622). Missing T_i profiles, and n_e profiles should be refined.

TCV

Shallower well at high current, while no difference between low and intermediate I_p .

No clear distinction between **Fav.** and **Unfav.** trends



- NB: additional helicity scan shows no impact on E_r
- Edge density increases with I_p (at fixed \bar{n}_i) → difficult to isolate effect of I_p
- Linear gyrokinetic analysis with GENE^[14] at $\rho_{\psi} = 0.9$: TEM dominated (b)

(b) Courtesy of A. Balestri.

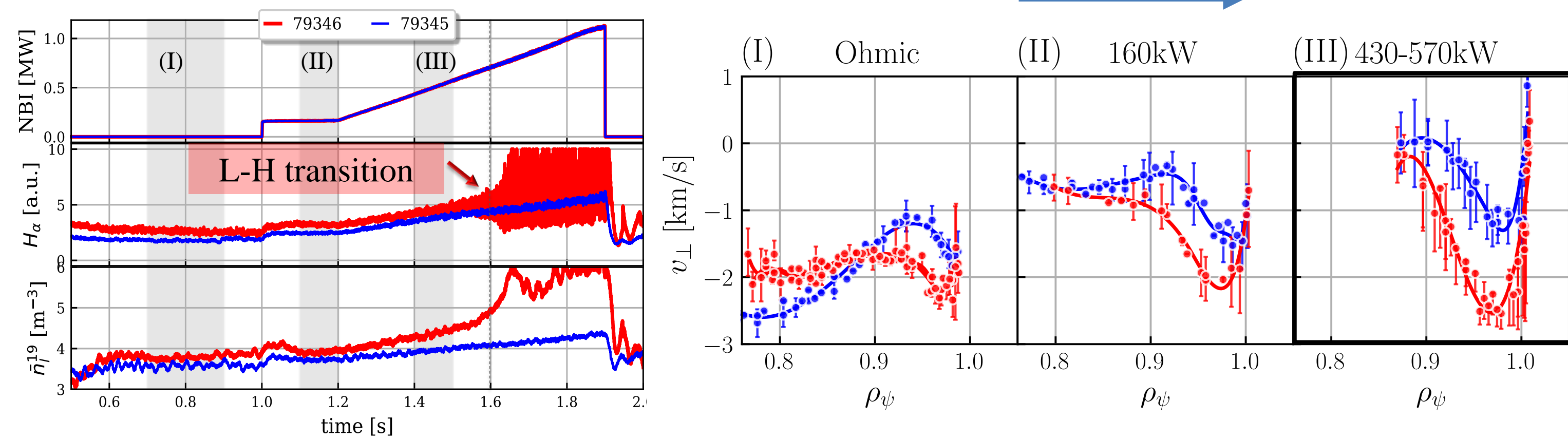
Experimental trends are not consistent:

Well becomes shallower with I_p at TCV, not deeper as on WEST (for Unfav.).

Evolution approaching the L-H transition

Matched **fav./unfav.** LSN, $I_p = 150 \text{ kA}$

Co-current injected NBI ramp



- E_r deepens & **inner shear increases** in **favorable** configuration
- Similar trend at 210 kA
- Compatible with H-mode turbulence suppression localized in inner $E \times B$ shear layer [15]

Summary

- TCV L-mode plasmas display flow shear sensitivity to **fav./unfav.** geometry as for WEST, AUG → **robust feature**
- Ohmic I_p scan replicated on TCV, showing discrepancies w.r.t. WEST
- Heating ramps on TCV support the idea of facilitated H-mode access in **fav.** due to increased $E_r \times B$ shear

Outlook

- TCV & WEST: Clarify E_r sensitivity to density/ collisionality in **Fav.** vs. **Unfav.**
- Extend I_p scan to AUG
- Fluid edge simulations desirable
- Apply O. Grover^[6] model to WEST & TCV
- Investigate link between topology and shaping effects [16]