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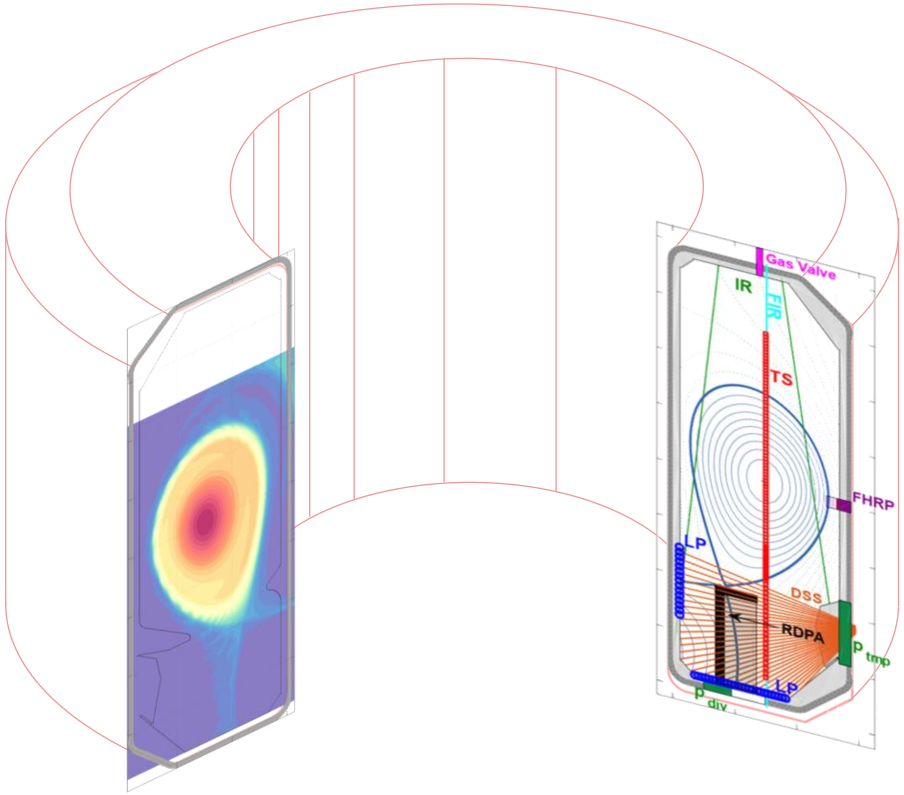

SOLPS analysis and GPI measurements for TCVX21 experiments

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[a] See Reimerdes et al 2022 Nucl. Fusion ***62*** *042018*

Swiss Plasma Center

EUROfusion

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Outline

- Validation of the SOLPS-ITER simulation against the TCV-X21 reference case [1]
- Comparison of filament properties in experiment and GBS simulations in TCV-X21 case [2]
- Summary and outlook

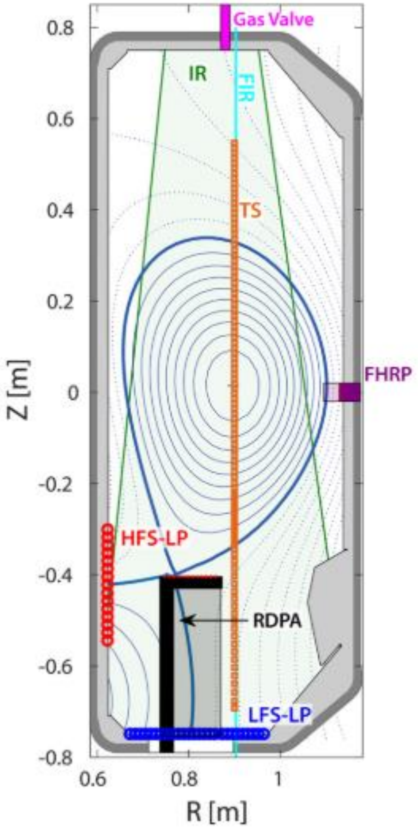
- [1] Y. Wang *et al* 2024 *Nucl. Fusion* **64** 056040
- [2] Y. Wang *et al Nucl. Fusion* **in prep.**

Validation of the SOLPS-ITER simulation against the TCV-X21 reference case

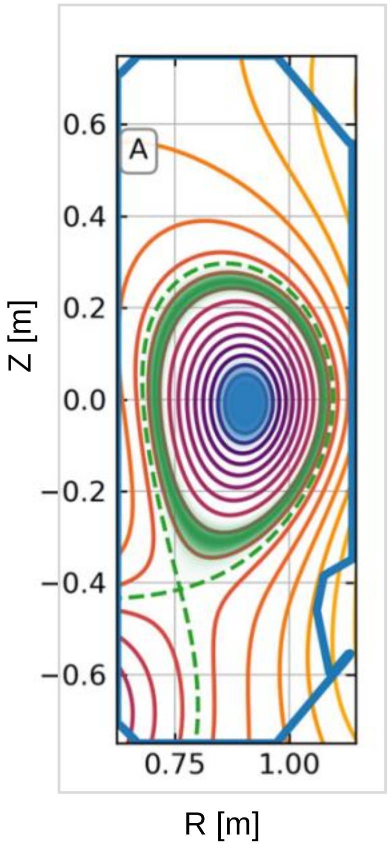
Motivation of SOLPS-ITER TCV-X21 validation

- **In quantitative multi-code validation against the TCV-X21 [1]**
  - Good match outer midplane and upstream
  - Less good match in divertor region
  - **Could be due to assumption of ion source distribution (inside the core), though sheath limited**
- **SOLPS-ITER**
  - 2-D Transport code
  - Monte-Carlo neutral model
  - Suitable tool to investigate neutral effects
  - In this work, no drifts and homogeneous $D_\perp$ and $\chi_\perp$

- TCV-X21 diagnostics [1]



- Ionization assumed in [1]

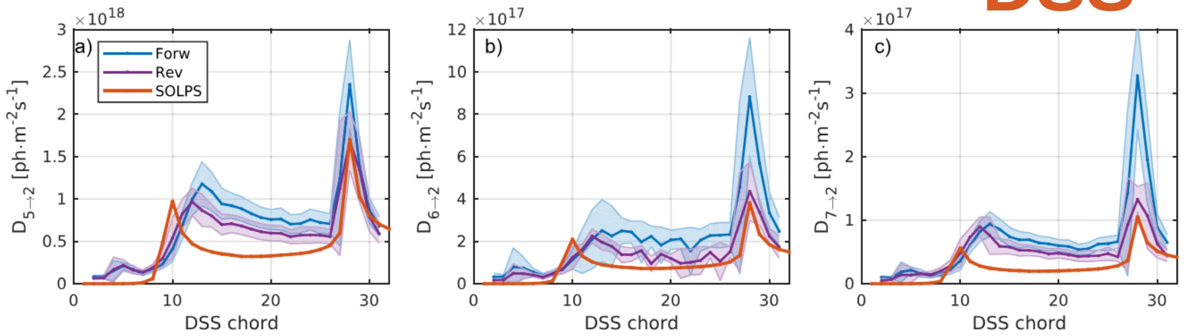


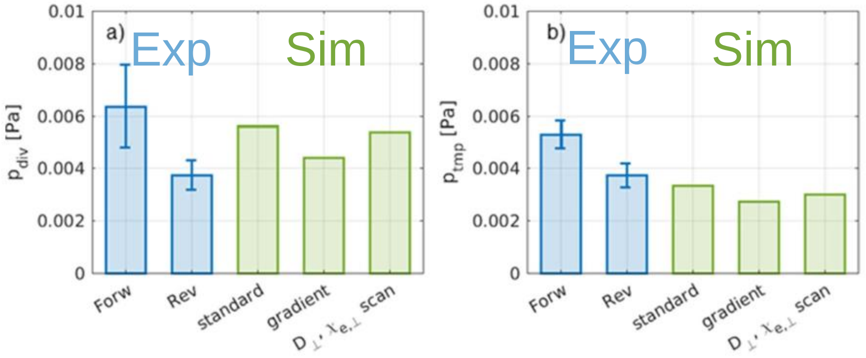
[1] D. S. Oliveira, T. Body, et al, Nucl. Fusion 2022

Extension of the TCV-X21 dataset

- **In this work, we enlarged the TCV-X21 dataset**
  - Include divertor spectroscopy and neutral pressure measurements
  - Link: https://zenodo.org/records/10841179
- **Quantative Validation of 32 observables → overall agreement metric χ**

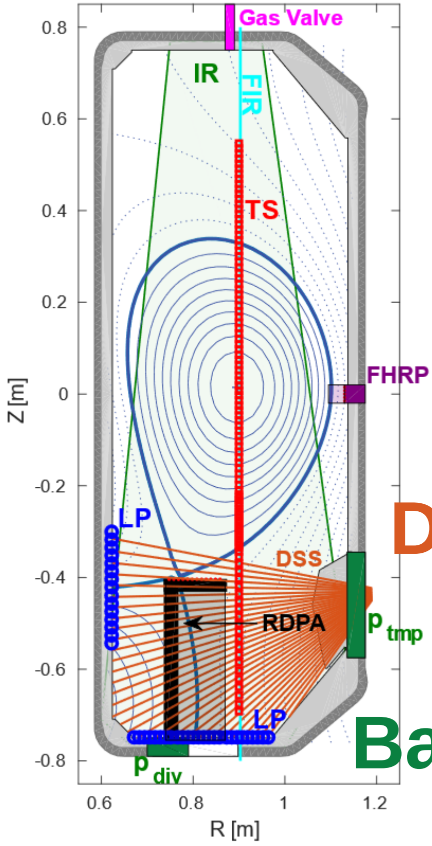
DSS





Neutral pressure

- TCV-X21 extended diagnostics

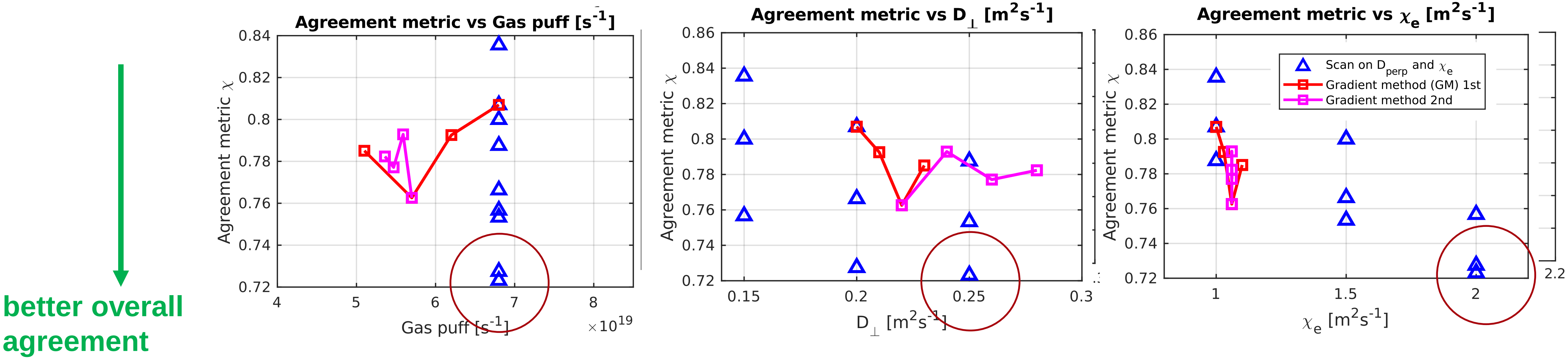


DSS

Baratron gauges

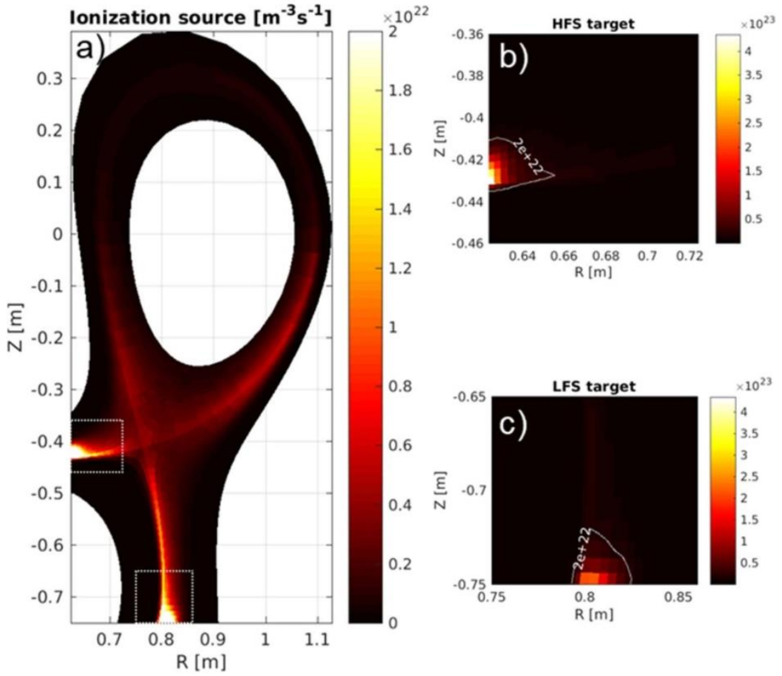
Scan parameters for better agreement

- **Manually scan the input parameters (gas puff, particle and heat transport coefficients) to minimize the χ metric**
  - Indicates higher perpendicular transport coefficients than usually used for TCV lead to better overall agreement
- **Also explore the gradient method for minimization**
  - Less effective here than simple scan

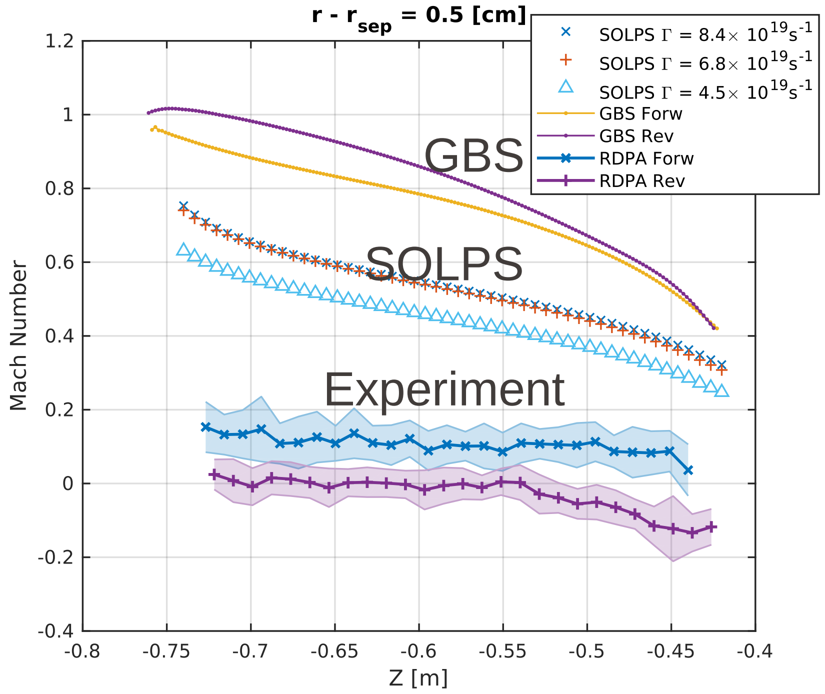


Some effects of the neutrals

- **Obtain the neutral ionization distribution from SOLPS → Deviation from the assumption made in previous simulations**
  - Total ionization source distribution simulated from SOLPS-ITER



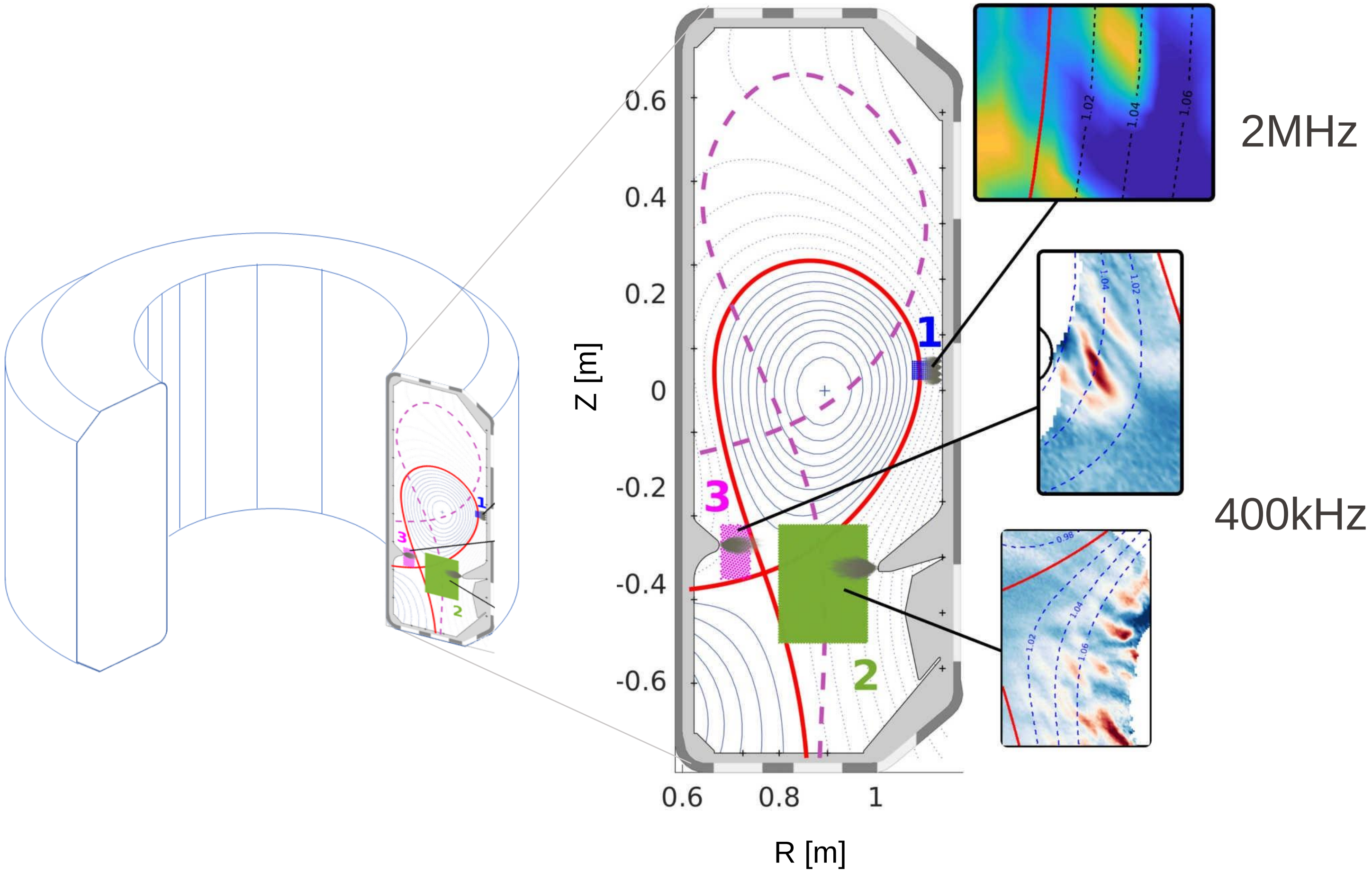
- Divertor flows: GBS **systematically larger** than the SOLPS-ITER. This suggests some flow reduction in the divertor by the neutrals.
- The parallel Mach numbers from SOLPS-ITER still **substantially larger** than those measured with RDPA (reciprocating divertor probe array)



Comparison of filament properties in experiment and GBS simulations in TCV-X21 case

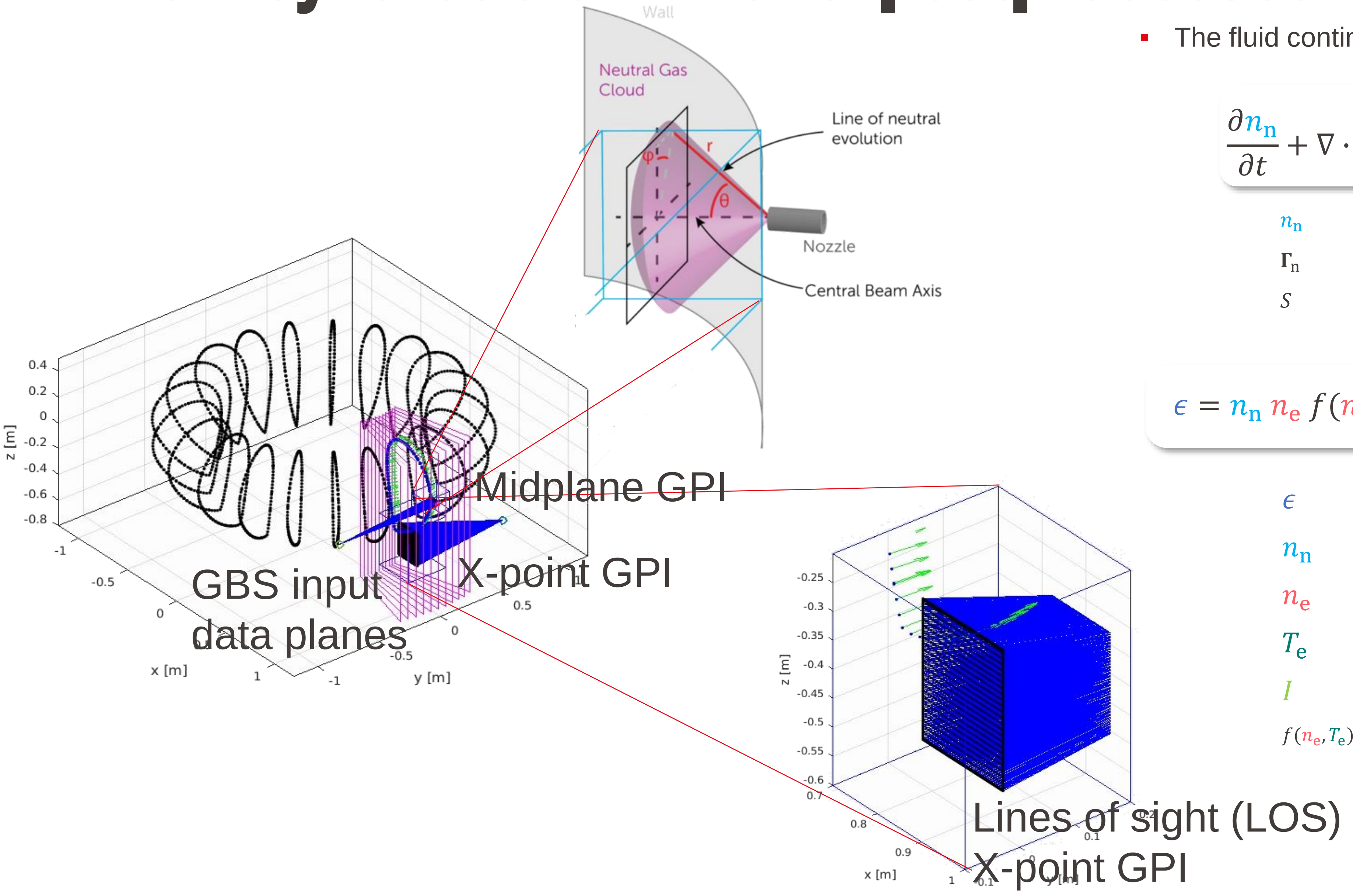
GPI (Gas Puff Imaging) diagnostics at TCV

- **GPI diagnostics**
  - Neutral gas (D2, He) puff
  - Interaction with boundary plasma → emission
- **They can provide**
  - 2-D, toroidally localized cross-section of plasma structure
  - At midplane and X-point
  - High time (0.4~2Mhz) and spatial resolution (~mm, <1cm)
  - Appearance frequency, size (poloidal and radial), velocity, …



Schematic TCV tokamak, GPI diagnostics snapshots at TCV.
Inner image taken from [1] *N. Offeddu, C. Wüthrich, W. Han, et al., RSI 2022*

0-T Synthetic GPI model postprocesses GBS input



- The fluid continuity equation

$$\frac{\partial n_n}{\partial t} + \nabla \cdot \boldsymbol{\Gamma}_n(\boldsymbol{x}, t) = S(\boldsymbol{x}, t)$$

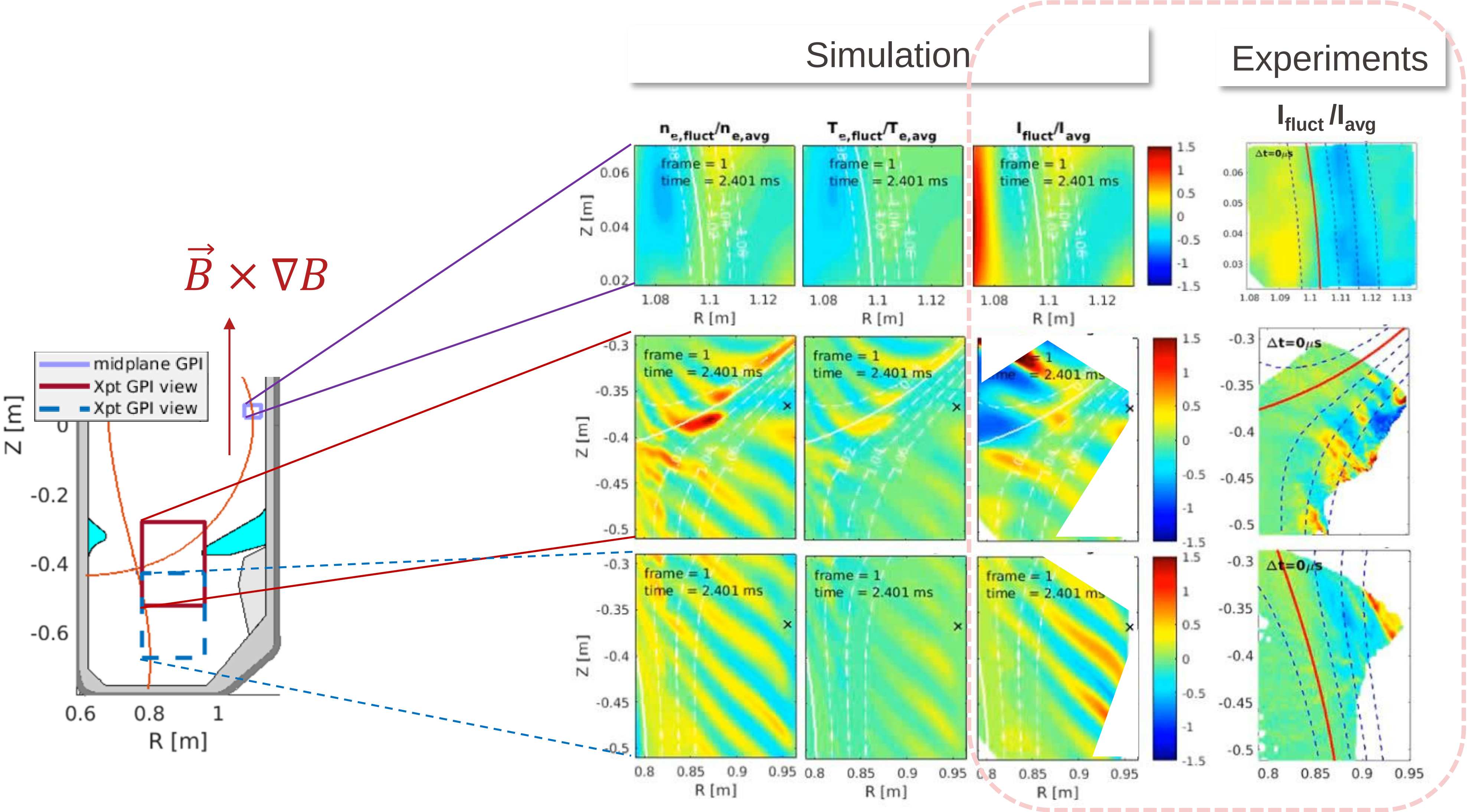
n_n	The neutral density
$\boldsymbol{\Gamma}_n$	The neutral flux
S	The sink of neutrals (GBS n_e T_e)

$$\epsilon = n_n \, n_e \, f(n_e, T_e)$$

$$I = \int_{LOS} \epsilon \, dl$$

ϵ	Emissivity
n_n	Neutral density
n_e	Electron density
T_e	Electron temperature
I	Line-integrated light intensity
$f(n_e, T_e)$	Photon emission coefficient (PEC), deexcitation of neutrals

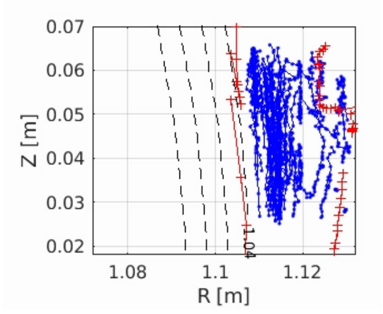
Comparison with GBS simulations

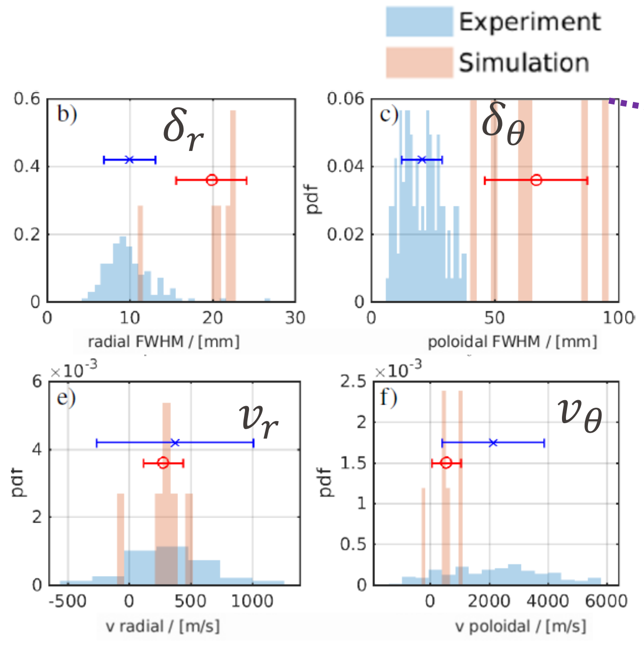


[1] Offeddu & Wüthrich *et al* 2022 *RSI* **93** 123504
[2] D. Oliveira & T. Body et al 2022 NF 62 096001

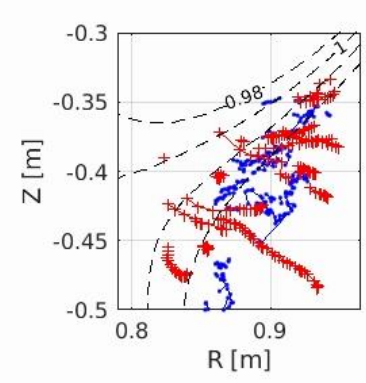
Sim-Exp comparison of filament size and velocity

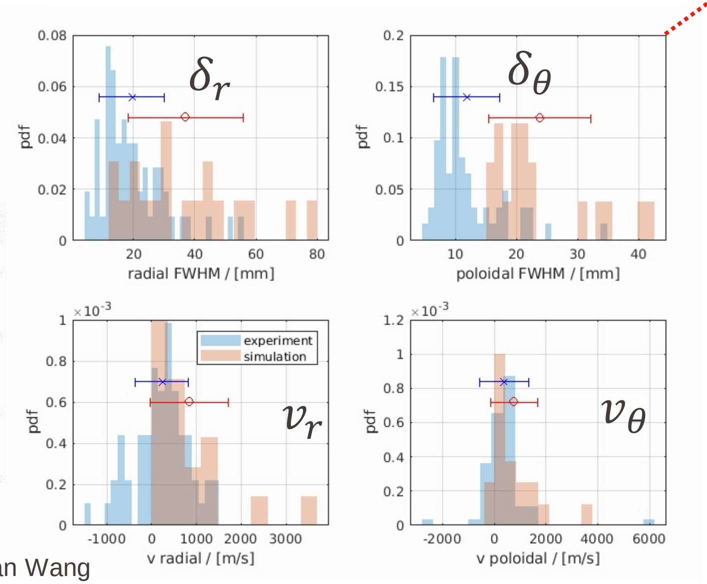
- **Outboard midplane**



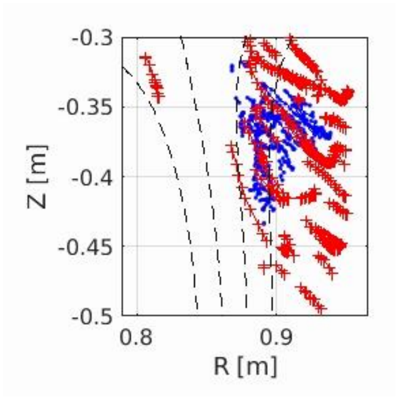


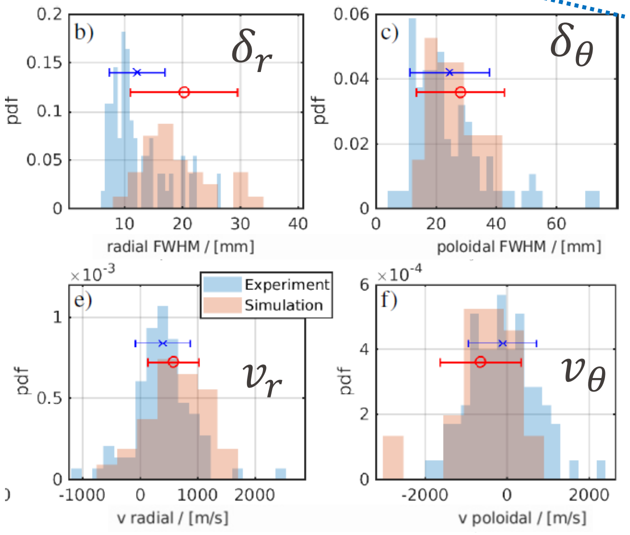
- **X-point region**





- **Divertor leg region**



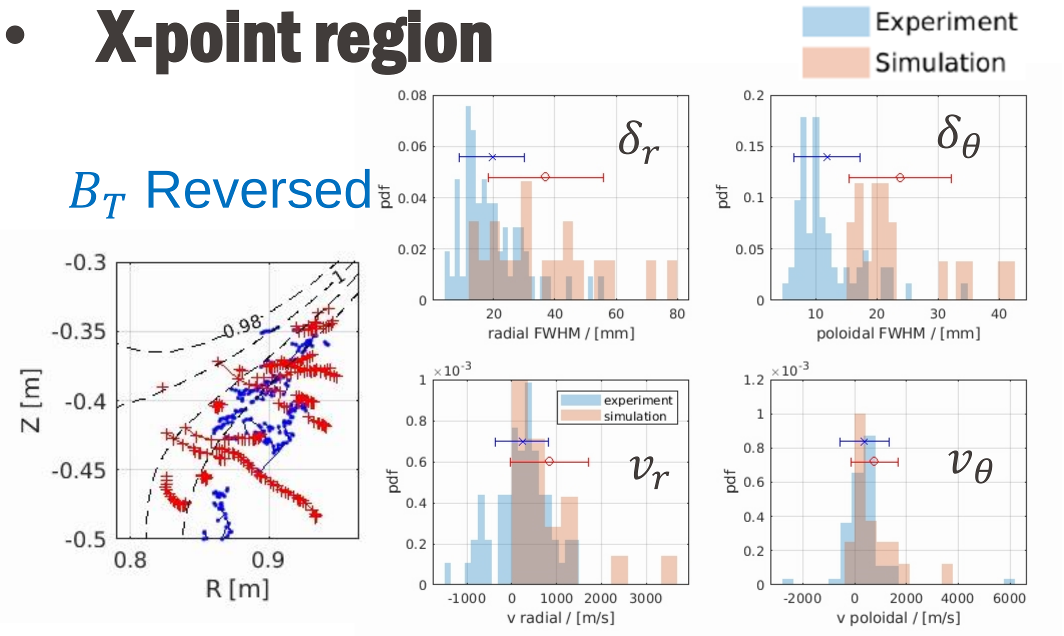


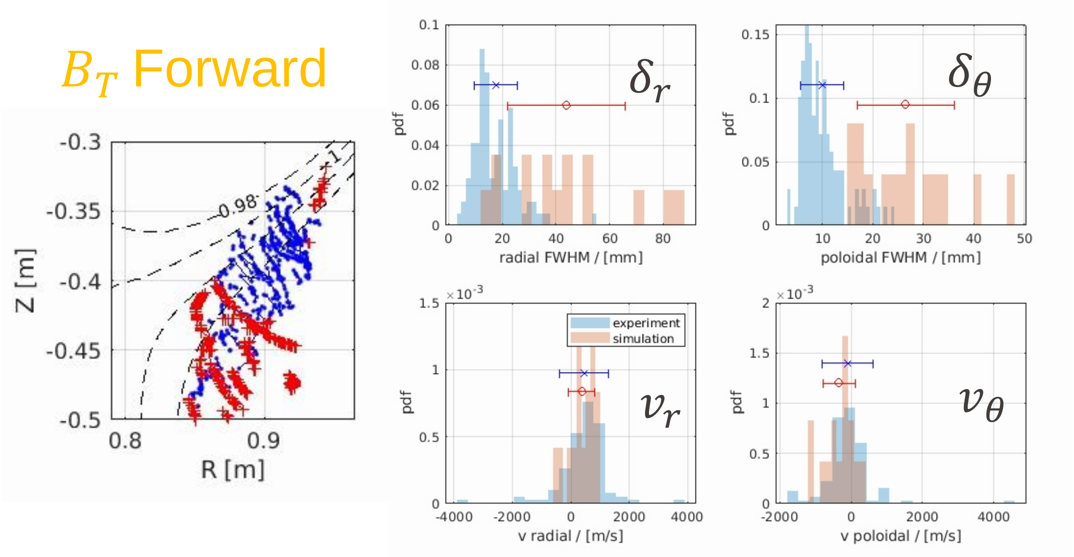
- **Key observations**
  - **The distribution of filament velocity: well reproduced** by the simulation, especially in the Xpt and divertor leg region.
  - The simulations generally **overestimate the poloidal and radial size**, by a factor 2−3.
  - Including different toroidal planes to increase simulation statistics is ongoing.

Sim-Exp comparison of filament size and velocity

- Key observations
  - **The distribution of filament velocity: well reproduced** by the simulation, especially in the Xpt and divertor leg region.
  - The simulations generally **overestimate the poloidal and radial size**, by a factor 2−3.
  - Including different toroidal planes to increase simulation statistics is ongoing.
  - Similar result in both field direction in the Xpt region

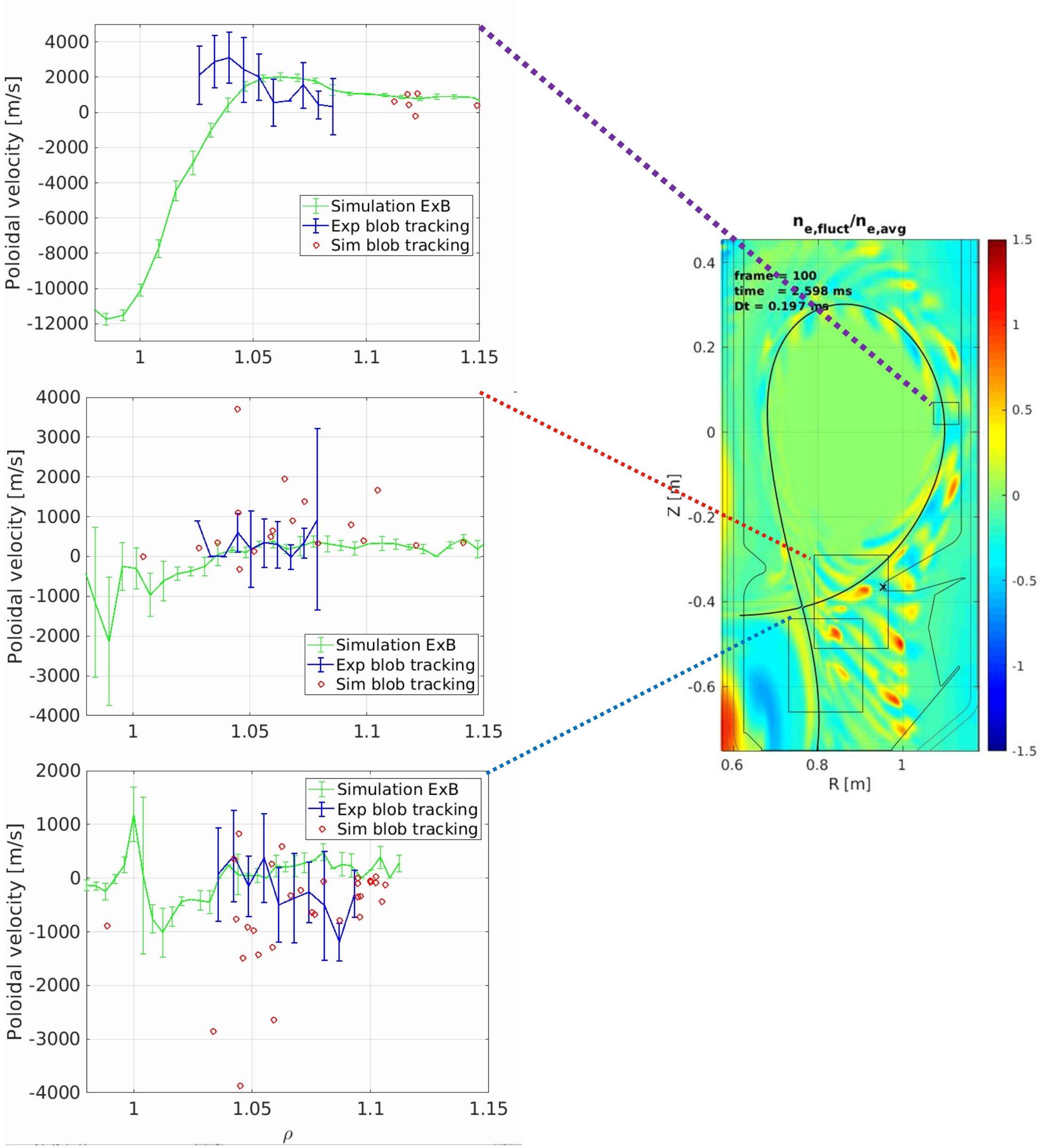
- X-point region





Filament poloidal velocity compared with mean $E \times B$ drift

- **Outboard midplane**
  - Follow the mean $\boldsymbol{E}\times\boldsymbol{B}$ velocity trend at ρ>1.05
  - Large spread
- **X-point region**
  - Also consistent with the mean $\boldsymbol{E}\times\boldsymbol{B}$ velocity trend
- **Divertor leg**
  - Not following the mean $\boldsymbol{E}\times\boldsymbol{B}$ velocity
  - Possibly follow the direction of the flux tube motion



EPFL

Summary and Outlook   Thank you!

SOLPS-ITER Validation of the TCV-X21 case

- Based on the global agreement metric, we optimized free input parameters, showing better agreement for an increased transport coefficient compared to what is usually used for TCV L-mode plasmas.
- These simulations show a significant portion of neutral ionization to occur in the SOL.
  This is a major difference compared with the assumption used in the first turbulence code validation in the TCV-X21 validation case, motivating the self-consistent inclusion of neutrals in future TCV-X21 turbulence studies.
- GBS divertor flows systematically larger than the SOLPS-ITER flows. This suggests some flow reduction in the divertor by the neutrals. The parallel Mach numbers from SOLPS-ITER still substantially larger than those measured with RDPA.

Comparison of filament properties in experiment and GBS simulations in TCV-X21 case

- Poloidal and radial filament velocities are in good agreement between simulations and experiments.
- Compared to the experiments, the simulations overestimated filament sizes (by a factor $2-3$) in radial and poloidal dimension.
- In the simulation, filaments are dominantly represented by a density fluctuation and show low temperature fluctuations, which is consistent with previous assumptions in experimental analysis of cross-field turbulent transport from GPI data.
- Filament velocities are found not follow the mean ExB in the divertor region, though follow it in the ourboard midplane.
- On the path towards fully predictive simulations, a better sim-exp agreement of filament sizes will be needed. Several paths are currently being pursued: self-consistent inclusion of neutrals, removal of Boussinesq approximation, more realistic resistivity (numerically challenging).