# <span id="page-0-0"></span>Turbulence statistical properties in FELTOR TCV761XX simulation Are the filaments truly field aligned?

#### S. Brynjulfsen

Faculty of Physics and Technology UiT Arctic University of Norway

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# Probe setup

- $\triangleright$  32 toroidal planes, axisymmetric
- $\blacktriangleright$  Field aligned grid of probes  $32 \times 29 \times 21 = 19488$
- ▶  $\approx$  8 ms currently, converged for  $\approx$  3ms (x 32)
- Sampling rate  $f = 10$ MHz
- ▶ Simulation of TCV shots  $76186(B_\varphi>0)$  and 76142 $(B_\varphi < 0)$
- $\blacktriangleright$  Normalization  $n'_e = n_e/n_0 \sim 10^{-1}$  after convergence



# Probe grid



## <span id="page-5-0"></span>Stochastic model FPP:

$$
\Phi_K(t) = \sum_{k=1}^{K(T)} A_k \phi\Big(\frac{t-t_k}{\tau_k}\Big), \tag{1}
$$

 $\gamma = \frac{\tau_d}{\tau_u}$  $\frac{\tau_d}{\tau_w}$ ,  $\tau_d = \langle \tau_k \rangle$ ,  $\tau_w = \mathcal{T} / \langle K \rangle$ .



6/41 Normalization  $\tilde{n_e} = (n_e - \langle n_e \rangle)/n_{\text{erms}}.$ 

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## <span id="page-7-0"></span>OMP time series

Signal at various radial positions at the outboard midplane. Favourable and unfavourable curvature drift direction.



Figure:  $B_{\varphi} > 0$ .



## <span id="page-8-0"></span>OMP density statistics



Figure: Density statistics at the outboard midplane for different field directions.

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# <span id="page-9-0"></span>OMP Probability density function



Figure: PDF for  $B_{\varphi} > 0$ .

−5 0 5 10 *n*˜*e* 10−<sup>6</sup> 10−<sup>5</sup> 10−<sup>4</sup> 10−<sup>3</sup> *P*( ˜*ne*) 10−<sup>2</sup> 10−<sup>1</sup>  $x - x_{\text{sep}} = -20$  $-x<sub>sen</sub> =$ *x*−*x*sep = 8  $x - x_{\text{sep}} = 14$  $x - x_{\text{sep}} = 20$ 

Figure: PDF for  $B_{\varphi} < 0$ .

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# <span id="page-10-0"></span>OMP Power spectral density and conditionally averaged pulse shapes



11/41 Fig[ure](#page-9-0): [P](#page-11-0)[SD](#page-10-0) [an](#page-7-0)[d](#page-8-0) [C](#page-12-0)[A](#page-5-0) [f](#page-11-0)[or](#page-12-0)  $B_{\varphi} < 0$  $B_{\varphi} < 0$ . 11 / 41

## <span id="page-11-0"></span>OMP ExB and parallel electron velocity



Figure: Velocity mean and rms for  $B_{\varphi} > 0$ .

Figure: Velocity mean and rms for  $B_{\omega} < 0$ . **◆ロト→伊**  $\leftarrow \equiv$  $\bar{\Xi}$  $2990$ 12/41 12 / 41

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## <span id="page-13-0"></span>**Timeseries**

At position  $x - x_{\text{sep}} = 8$ mm.



Figure: Timeseries for different poloidal positions for plane  $\varphi = 0$ .

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800  $90$  $R/\rho_s$ 

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## <span id="page-14-0"></span>Separatrix density statistics

At position  $x - x_{\text{sep}} = 0$ mm.



Figure: Poloidal density statistics at the separatrix for different field directions.

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## <span id="page-15-0"></span>Probability density function

At position  $x - x_{\text{sep}} = 8$ mm.



# <span id="page-16-0"></span>Power spectral density and conditionally averaged pulse shapes

At position  $x - x_{\text{sep}} = 8$ mm.



Figure: PSD and CA for  $B_{\varphi} > 0.$ 

Figure: PSD and CA for  $\cdot$   $B_{\varphi}$  $B_{\varphi}$   $\ll$  [0.](#page-13-0) Extra 重→ 重 のぬぐ 17/41 17 / 41

## <span id="page-17-0"></span>Velocity field

Straightened out field lines.



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## <span id="page-19-0"></span>Field line alignment



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## Time delay estimation from OMP

Condition on OMP:  $\tilde{n}_{e}(d\varphi = 0) > 2.5$ 



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## Time delay estimation from OMP

Time delay estimation using cross conditionally averaging (CCA) with condition  $\tilde{n}_e > 2.5$  at  $d\phi = 0$ . Compared to Cross correlation (CCR) method.



Figure: CCA.

Figure: CCR.

# Conditionally averaged amplitudes



Figure: Amplitude along the field line for various radial positions (OMP values).  $\tilde{A_{\parallel}} = (A - \langle n_{\rm e} \rangle_{t,\parallel})/n_{\rm ems(t,\parallel)}.$ 

$$
x - x_{\text{sep}} = -20
$$
  
\n
$$
x - x_{\text{sep}} = 0
$$
  
\n
$$
x - x_{\text{sep}} = 8
$$
  
\n
$$
x - x_{\text{sep}} = 14
$$
  
\n
$$
x - x_{\text{sep}} = 20
$$

 $\bar{n_{e}} = \langle n_{e} | \tilde{n_{e}} (d\varphi = 0) \rangle$  $2.5\rangle$ Choices:

$$
\blacktriangleright A = \max(\bar{n_e}(t))
$$

$$
\blacktriangleright A = \bar{n_e}(t = 0)
$$
\n(dashed)

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## <span id="page-23-0"></span>Separatrix transition



Figure: Filament amplitude change around the separatrix.

#### Filament amplitude scale length along field line Gaussian fit to exp  $\left(-\frac{(\mathsf{x} - \mu)}{2\sigma^2_{\mathsf{A}}} \right)$  $\frac{\left(\chi-\mu\right)}{2\sigma_A^2}$ A



Figure: Scale length of the amplitude along  $\varphi$  from a Gaussian fit for various radial positions.

#### Filament amplitude scale length along field line Gaussian fit to exp  $\left(-\frac{(\mathsf{x} - \mu)}{2\sigma^2_{\mathsf{A}}} \right)$  $2\sigma_A^2$  $\setminus$



Figure: Scale length of the amplitude along  $\varphi$  for different field directions.

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# <span id="page-27-0"></span>Conclusion

Validating the simulation

- ▶ In agreement with FPP model
- ▶ Some behaviours are different than expected, possible simulation limits

Investigating the differences and new opportunities given by 3D simulations compared to 2D

- ▶ Large scale background circulations
- ▶ Filament alignment to field line varies
- $\blacktriangleright$  Filament scale length halves when exiting the separatrix

4 0 X 4 8 X 4 3 X 4 3 X 4 8 Y 4 0 4 0 4 1

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## Radial density profile



Figure: Density scale lengths from a piece-wise, near and far SOL, exponential fit.

## <span id="page-30-0"></span>Poloidal change of density profile



Figure: Radial profiles for different poloidal positions, from X-point to top of torus. Near/far separation relatively constant.

## <span id="page-31-0"></span>Poloidal change of density scale length



32/41 Figure: Density scale lengths from a piece-[wis](#page-30-0)e[, n](#page-32-0)[e](#page-30-0)[ar](#page-31-0) [a](#page-32-0)[n](#page-27-0)[d](#page-28-0) [fa](#page-40-0)[r](#page-27-0)[SOL](#page-40-0), exponential fit for varying poloidal posit[ion](#page-0-0)s for each field direction[.](#page-40-0)  $\frac{32}{32/41}$ 

#### <span id="page-32-0"></span>8mm density statistics

At position  $x - x_{\text{sep}} = 8$ mm.



Figure:P[o](#page-28-0)lo[i](#page-27-0)dal density statistics at  $x - x_{\rm sep} = 8/\bar{m}$  $x - x_{\rm sep} = 8/\bar{m}$ m [f](#page-27-0)o[r d](#page-40-0)i[ff](#page-28-0)[ere](#page-40-0)[nt](#page-0-0)≡field۹۹۰  $\frac{33}{41}$ directions.  $33/41$ 

<span id="page-33-0"></span>**Timeseries** 

At position  $x - x_{\text{sep}} = 0$ mm.



Figure: Timeseries for different poloidal positions for plane  $\varphi = 0$ .

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## <span id="page-34-0"></span>Flux density field



Figure:  $B_{\varphi} > 0$ .



Figure:  $B_{\varphi} < 0$ .

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## <span id="page-35-0"></span>Spatial delay estimation from OMP



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## <span id="page-36-0"></span>Time delay estimation from OMP (reverse) Condition on OMP:  $\tilde{n}_e(d\varphi = 0) > 2.5$



## <span id="page-37-0"></span>Time delay estimation from OMP (reverse)

Time delay estimation using cross conditionally averaging (CCA) with condition  $\tilde{n}_e > 2.5$  at  $d\phi = 0$ . Compared to Cross correlation (CCR) method.



Figure: CCA.

Figure: CCR.

# Conditional averaging

Choose an amplitude threshold, and when the signal  $\Phi$  crosses the threshold (usually 2.5Φ<sub>rms</sub>) record

- ▶ Position of peaks
- ▶ Amplitude of peaks
- $\blacktriangleright$  Shape of the signal around peaks

and compute an average shape, ect.

Cross conditional average: take values form one signal using another as reference.



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## Stochastic model

FPP:

$$
\Phi_K(t) = \sum_{k=1}^{K(T)} A_k \phi\left(\frac{t - t_k}{\tau_k}\right),\tag{2}
$$

 $K(T)$ : no. of pulses in T,  $A_k$ : pulse amplitude,  $t_k$ : pulse arrival time,  $\tau_k$ : pulse duration

- $\blacktriangleright$  Shot noise behaviour
- ▶ Describes events, excluding origin
- $\triangleright$  Convolution of a pulse function with a forcing

Intermittency parameter:

$$
\gamma = \frac{\tau_d}{\tau_w},\tag{3}
$$

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 $\tau_d = \langle \tau_k \rangle$  is a constant duration time, and average waiting time between pulses  $\tau_w = T/\langle K \rangle$ .

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## <span id="page-40-0"></span>Stochastic model

Assuming:

- $\blacktriangleright$  uncorrelated arrivals
- ▶ neglecting end effects
- ▶ Amplitude  $P_A(A) \sim$  exp

► Exp. pulse shape  $\phi(\theta)$ ,  $\theta = (t - t_k)/\tau_d$ , with asymmetry  $\lambda$ The PDF and PSD are:

$$
P_{\tilde{\Phi}}(\tilde{\Phi}; \gamma) = \frac{\gamma^{1/2}}{\Gamma(\gamma)} \Big(\gamma^{1/2} \tilde{\Phi} + \gamma\Big)^{\gamma - 1} \exp\Big(-\gamma^{1/2} \tilde{\Phi} - \gamma\Big), \qquad (4)
$$

$$
\Omega_{\tilde{\Phi}}(\omega; \lambda, \tau_d) = \frac{2\tau_d}{[1 + (1 - \lambda)^2 \tau_d^2 \omega^2][1 + \lambda^2 \tau_d^2 \omega^2]]}
$$
(5)

Normalization  $\tilde{n}_{e} = (n_{e} - \langle n_{e} \rangle)/n_{\text{erms}}$