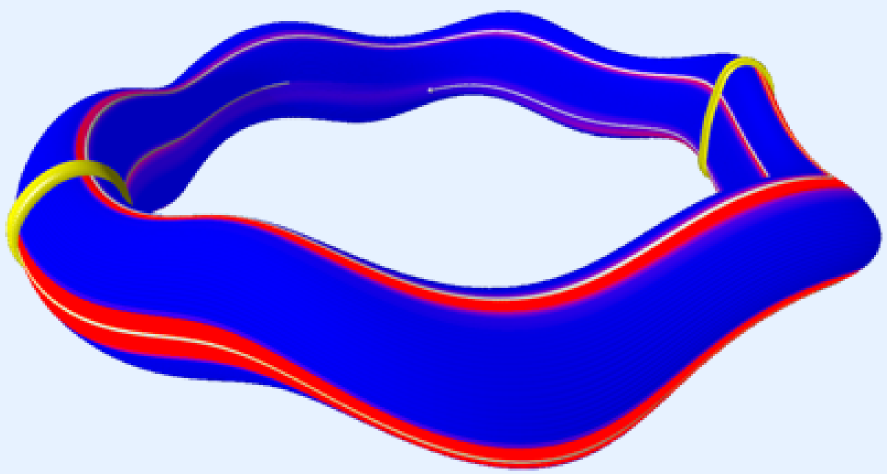
Institut für Plasmaforschung
Universität Stuttgart

3D Effects in Drift-Wave Turbulence



G. Birkenmeier, Z. Ivady, B. Nold,
M. Ramisch, U. Stroth

TTF-Workshop, San Diego, April 9th, 2011

Outline

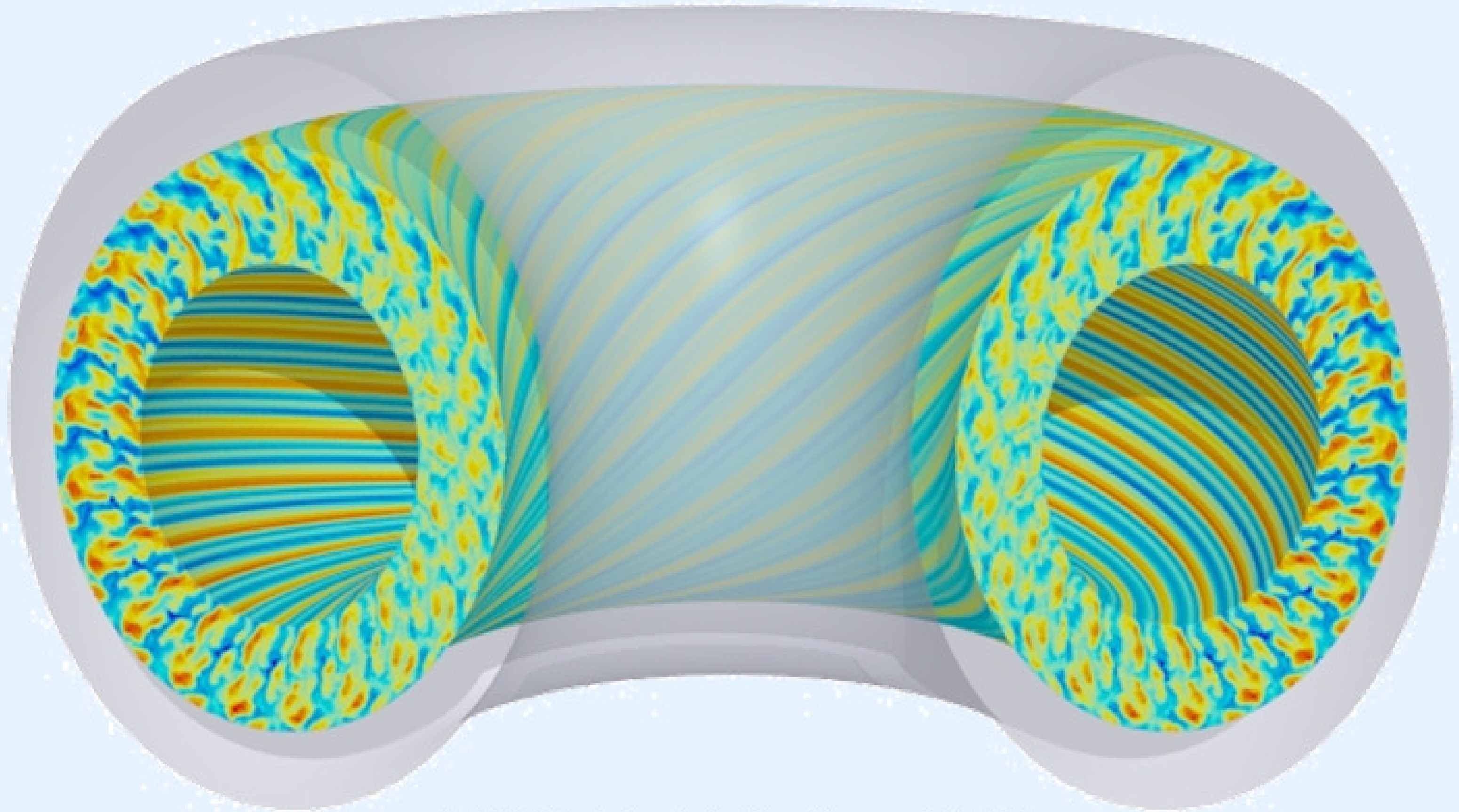
Why Turbulence Investigation in 3D?

Turbulence Experiment TJ-K

Experimental Results I: Turbulent Transport Measurements

Experimental Results II: 3D-Shape and Dynamics of Turbulent Structures

Drift-wave turbulence: a 3D phenomenon



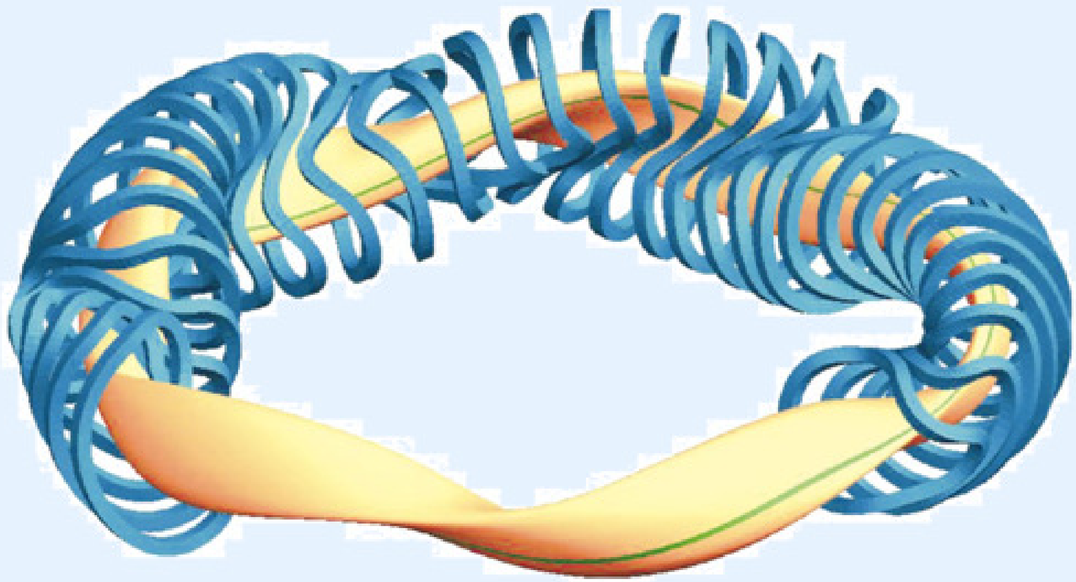
[GENE, F. Jenko *et al.*, Phys. Plasmas **7** (2000)]

- Elongation, triangulation vs. confinement
- Poloidal transport asymmetries: influx into SOL and divertor

Drift-wave turbulence: a 3D phenomenon

E.g.: Optimization criteria for W7-X:

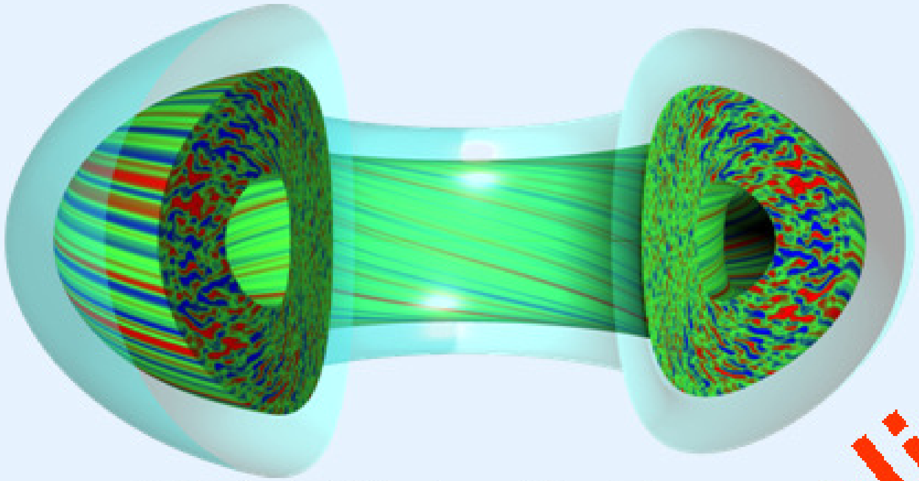
- "good" vacuum flux surfaces (small islands)
- high β
- high MHD-stability
- small neoclassical transport
- small bootstrap-current
- good alpha particle confinement
- modular coil design



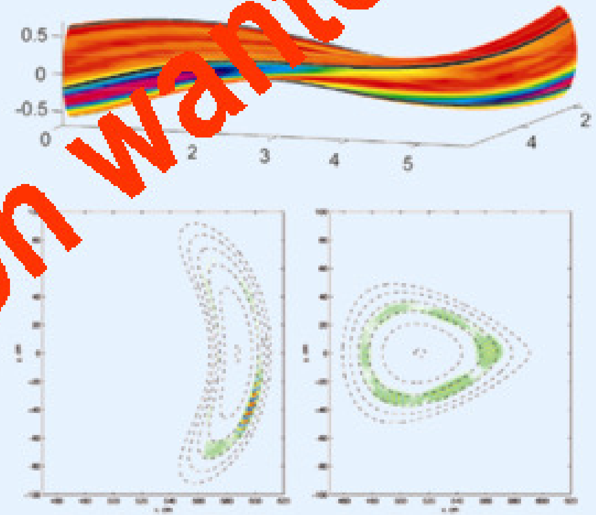
[IPP, Greifswald, www.ipp.mpg.de]

Missing: minimization of turbulent transport!

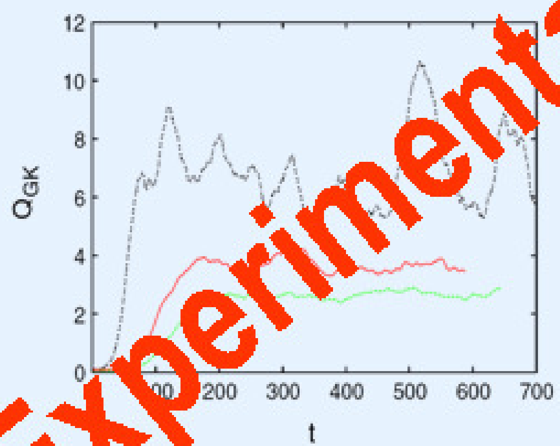
Drift-wave turbulence: a 3D phenomenon



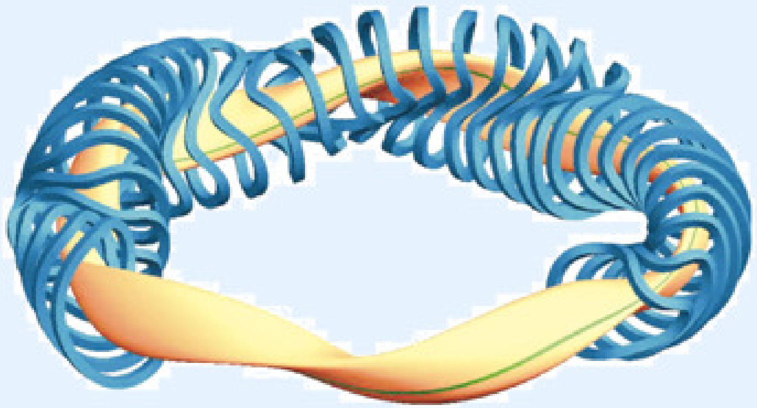
[GYRO, Candy, Waltz, General Atomics]



[V. Kornilov *et al.*, PoP **11**, (2004)]



[Mynick, Pomphrey, and Xanthopoulos, PRL **105** (2010)]

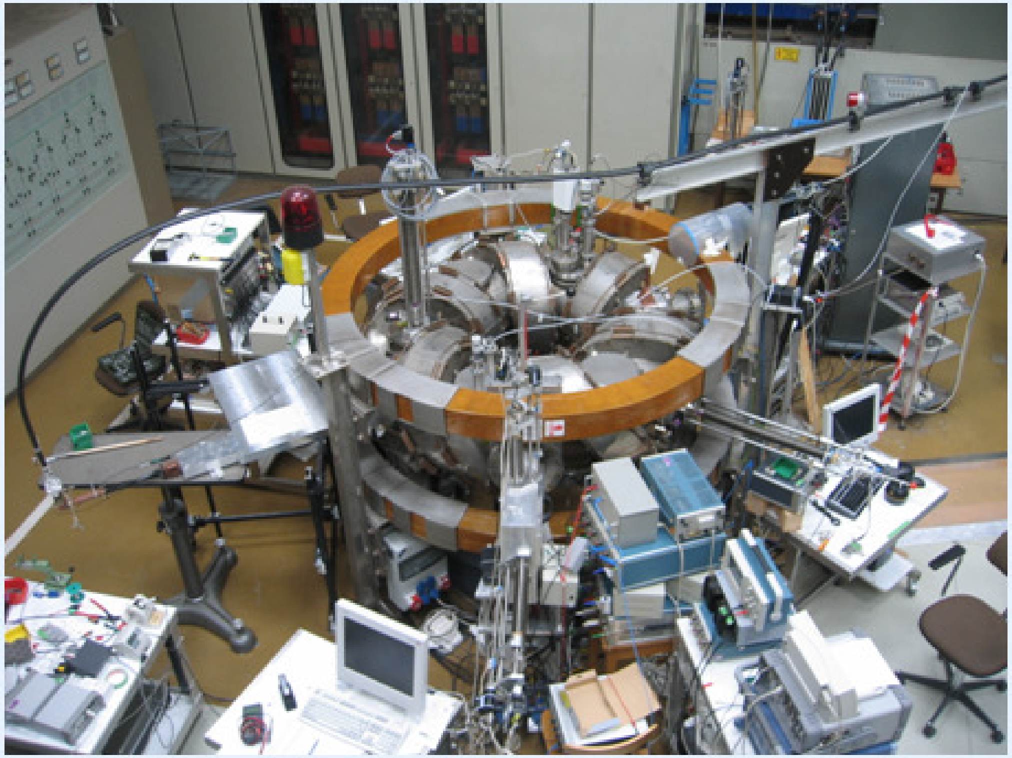


Experimental validation wanted!

Turbulence Experiment TJ-K

Stellarator TJ-K

- Major plasma radius: $R = 0,6$ m
- Minor plasma radius: $a = 0,1$ m
- Magnetic field: 48 mT $\leq B \leq$ 300 mT
- **Electron temperature: $T_e \approx 10$ eV**
- **Ion temperature: $T_i \approx 1$ eV**
- Electron density: $n_e \approx 5 \cdot 10^{17}$ m^{-3}
- Gases: H, D, He, Ne, Ar
- Iota: 0.13 – 0.4

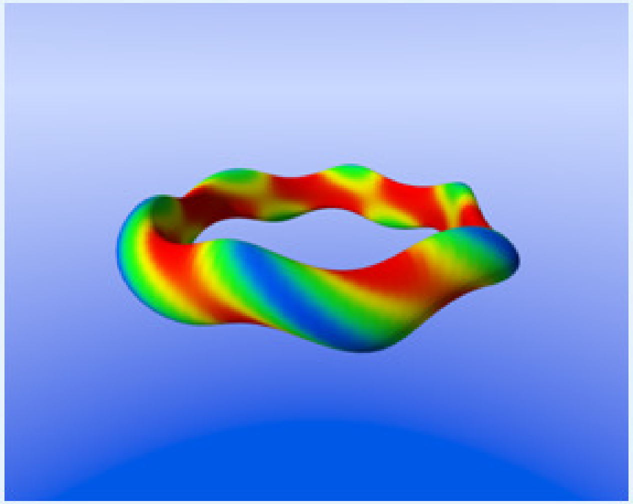


➡ **Langmuir-probes accessible to the whole confinement region**

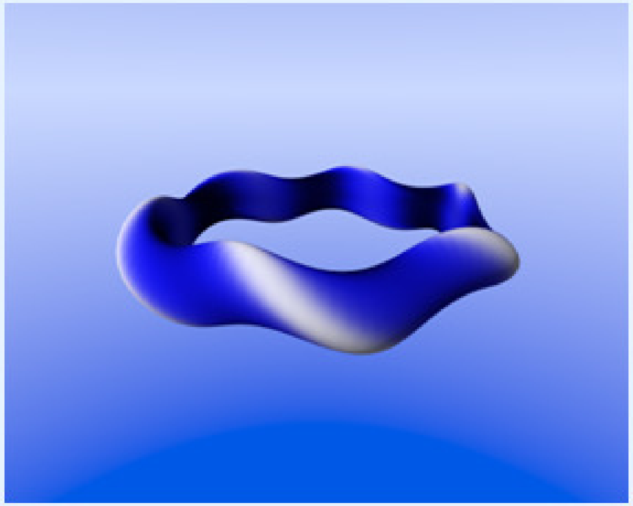
➡ **Discharges dimensionally similar to fusion edge plasmas**

Turbulence Experiment TJ-K

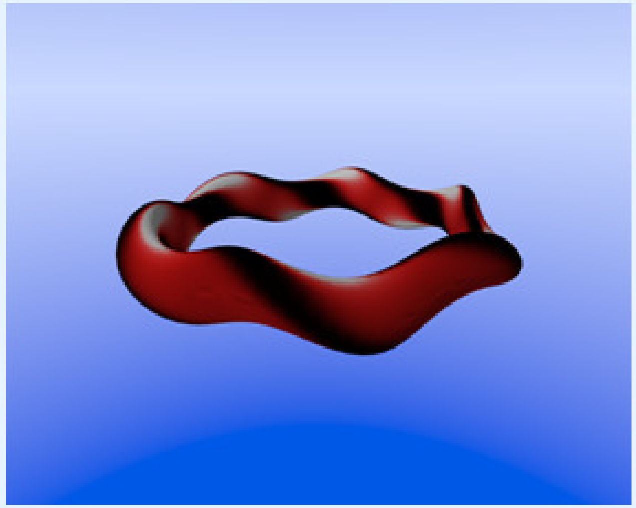
B-field and curvatures for TJ-K:



|B|



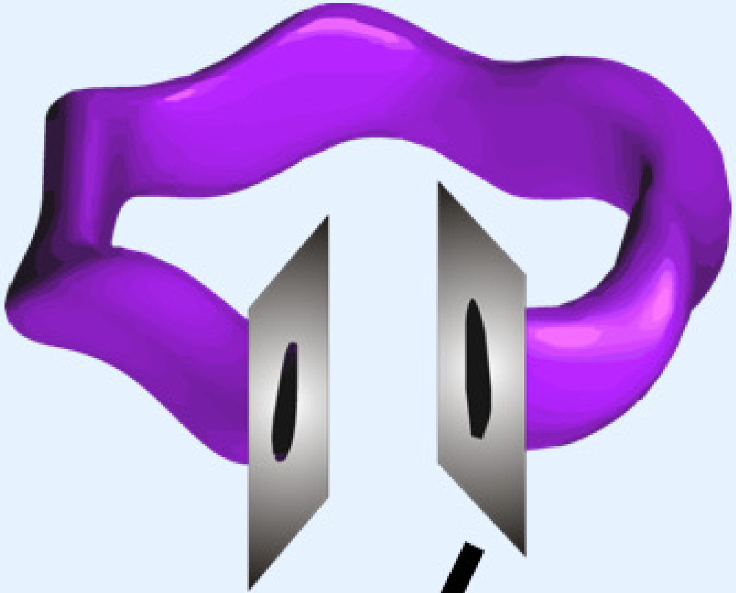
normal curvature

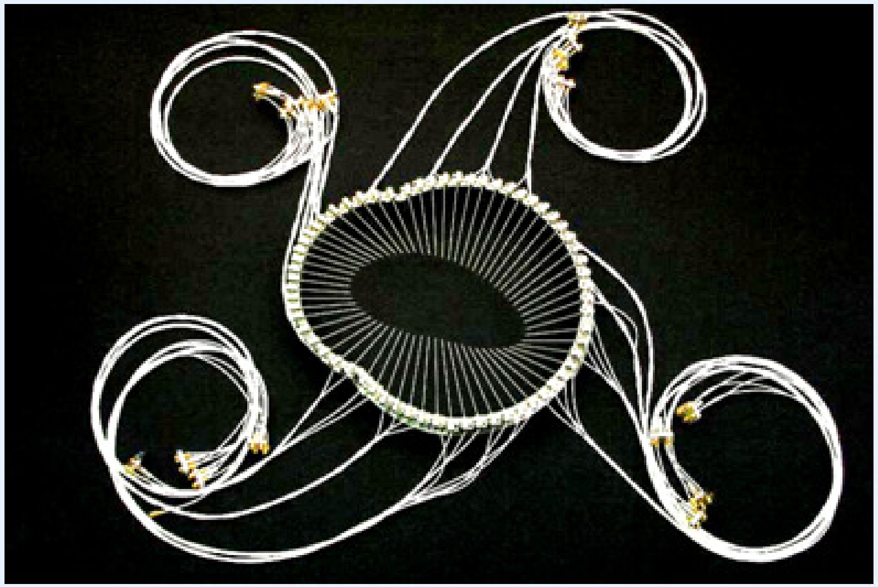


local magnetic shear

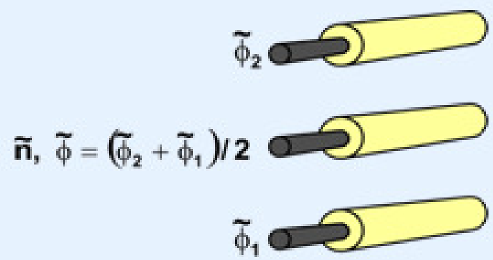
→ How does drift-wave turbulence behave in 3D?

Measurements at a Poloidal Cross Section





- Fluctuations:
  - Ion-saturation current: $\tilde{I}_{i,sat} \sim \tilde{n}$
  - Floating potential: $\tilde{\phi}_{fl} \sim \tilde{\phi}_p$
- Transport: $\Gamma = \langle \tilde{n}\tilde{v}_r \rangle$



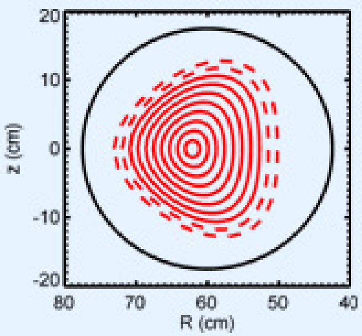
$$\tilde{v}_r = \frac{(\tilde{\phi}_2 - \tilde{\phi}_1)}{Bdx}$$

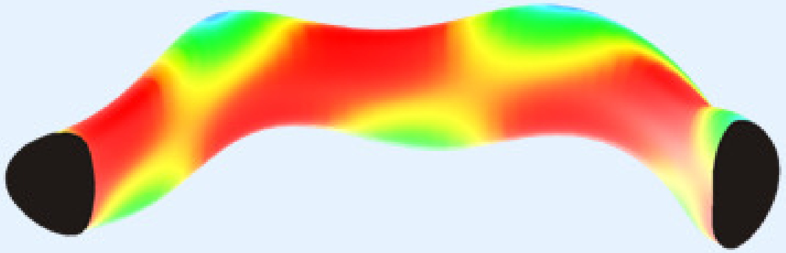
64 Langmuir-probes at one toroidal position

Turbulence Experiment TJ-K

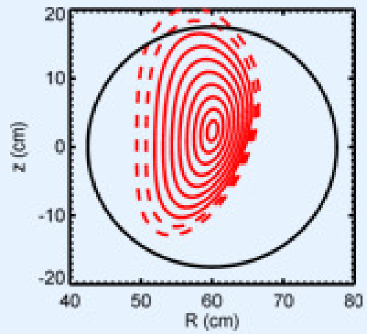
Simultaneous measurements at 128 positions on a flux surface

φ = 270°

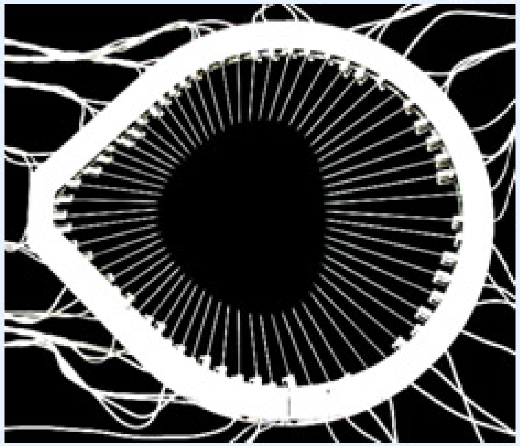




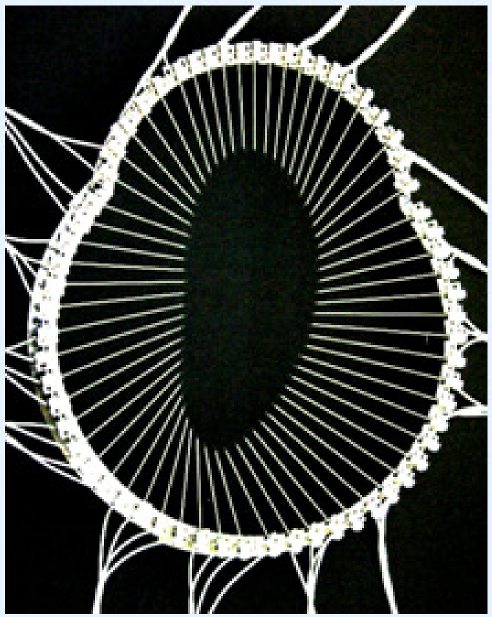
φ = 70°



Outer Port Array (OPA)

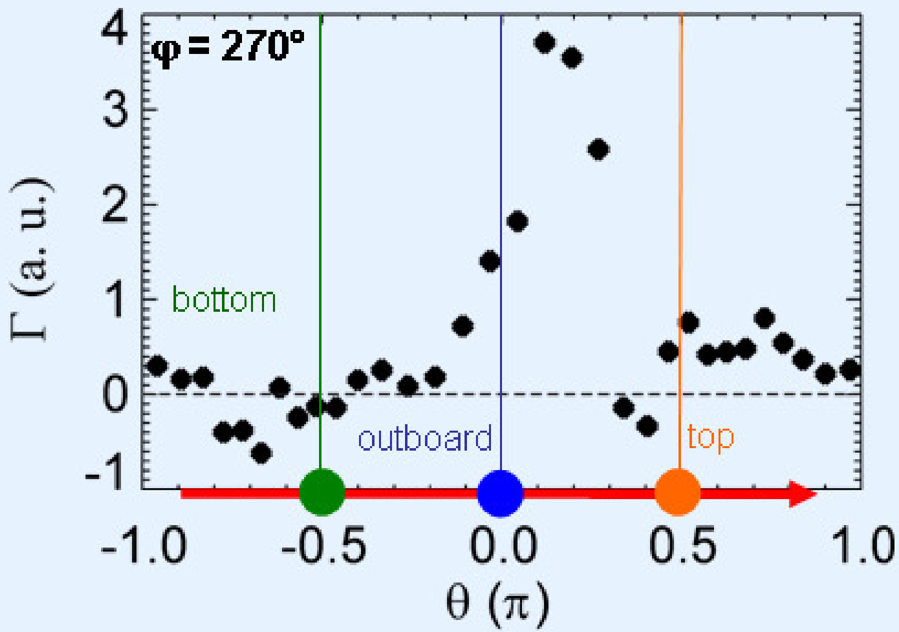


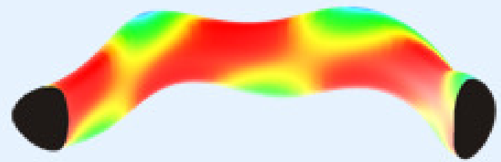
Top Port Array (TPA)



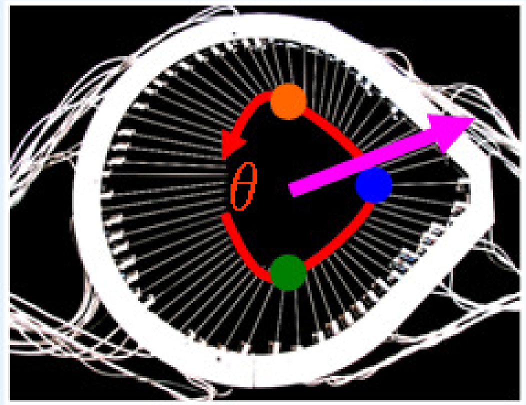
Turbulent Transport Measurements

Turbulent transport:





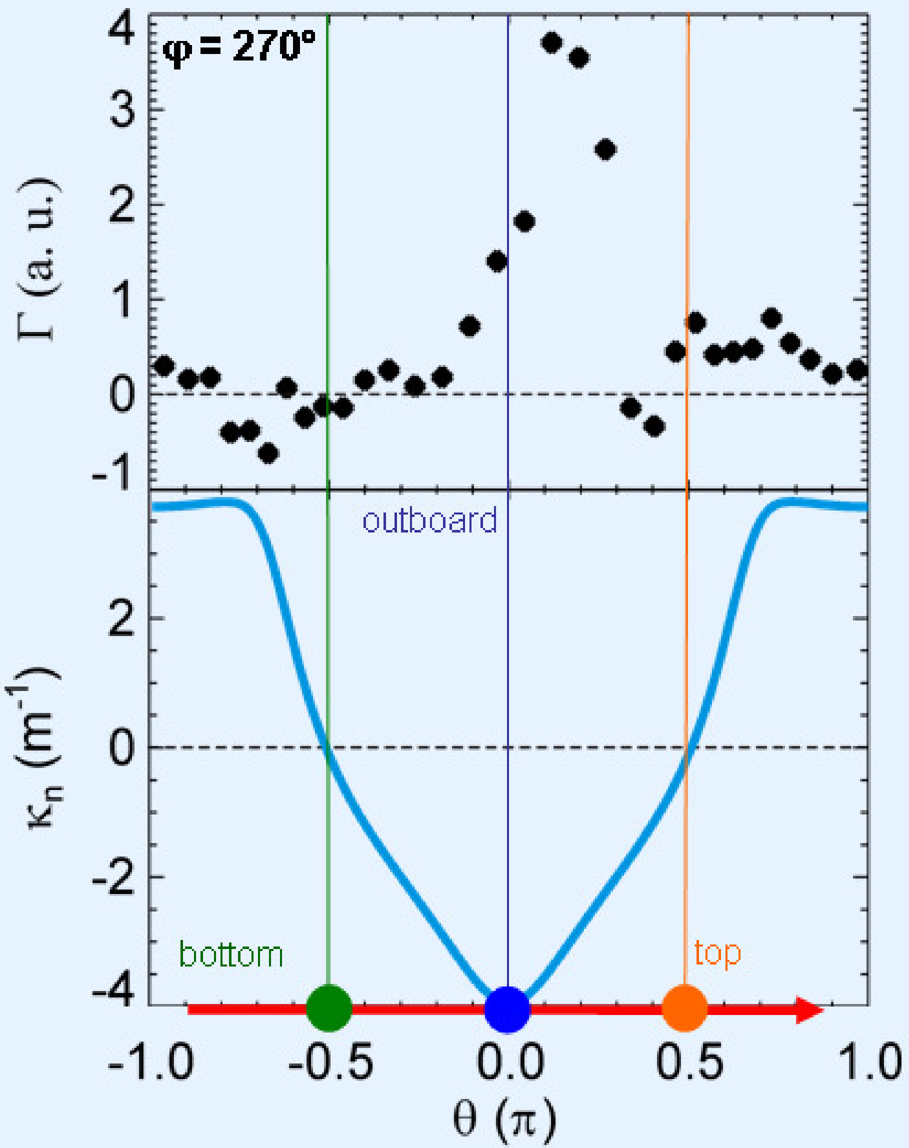
Outer Port Array (OPA)

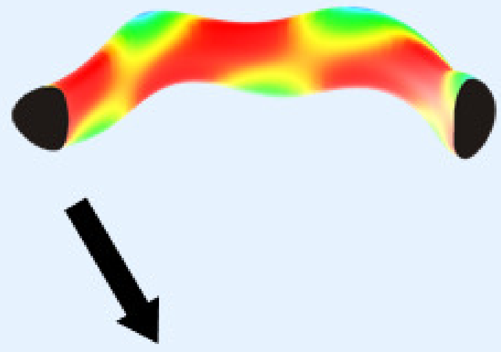


Turbulent Transport Measurements

Turbulent transport:

Normal curvature:





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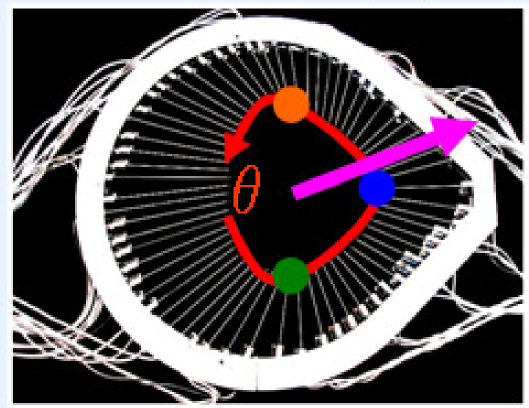

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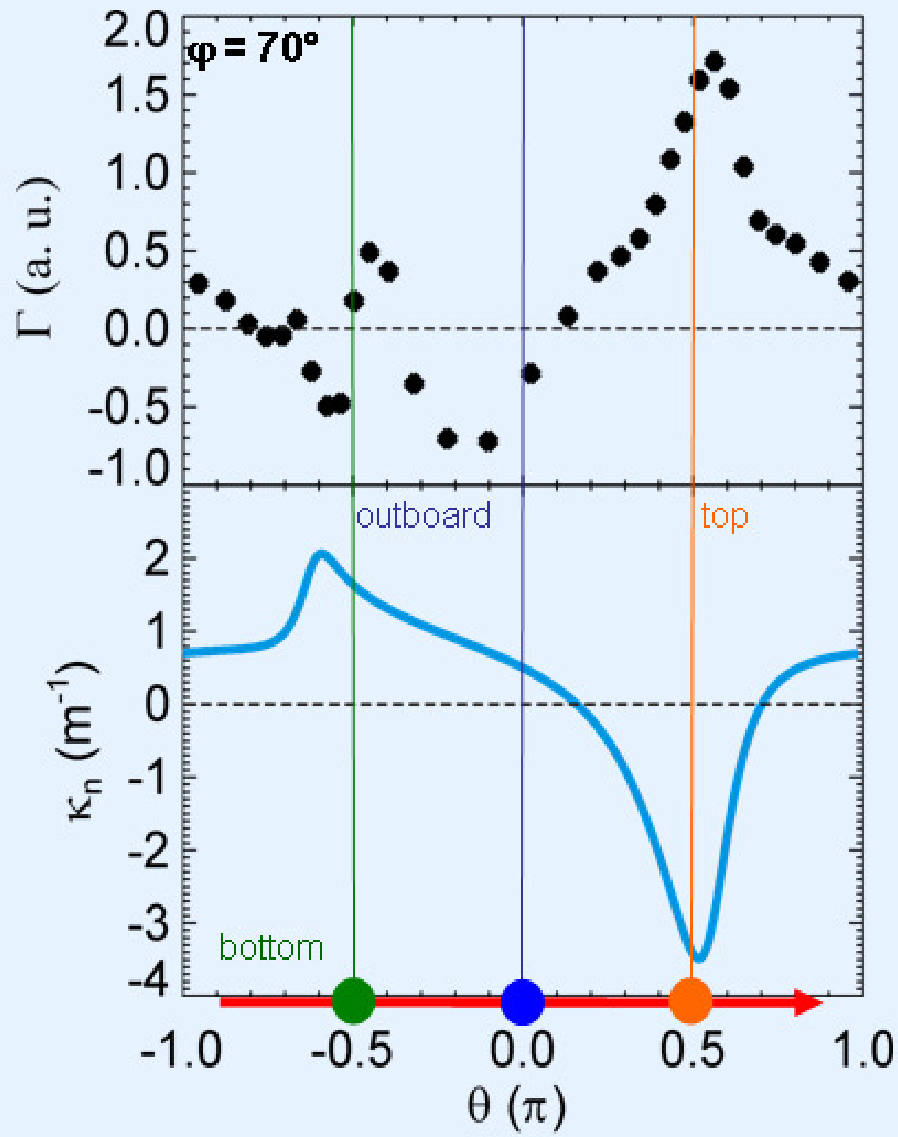
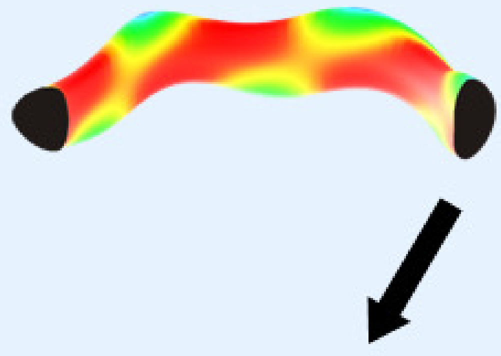
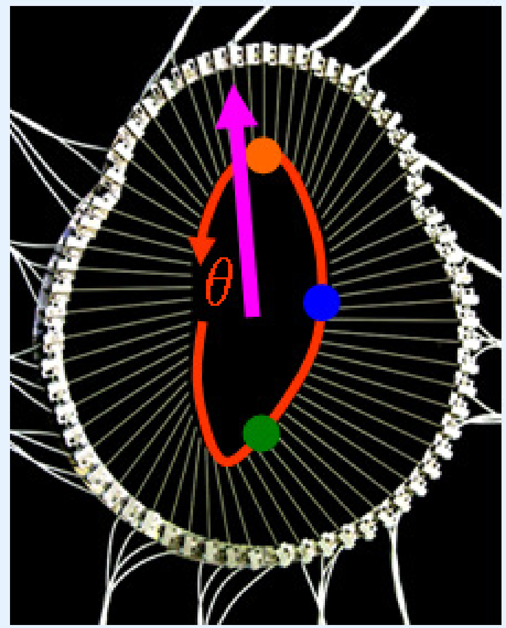




Top Port Array (TPA)



Turbulent Transport Measurements

Comparison with growth rates from a drift-fluid model:

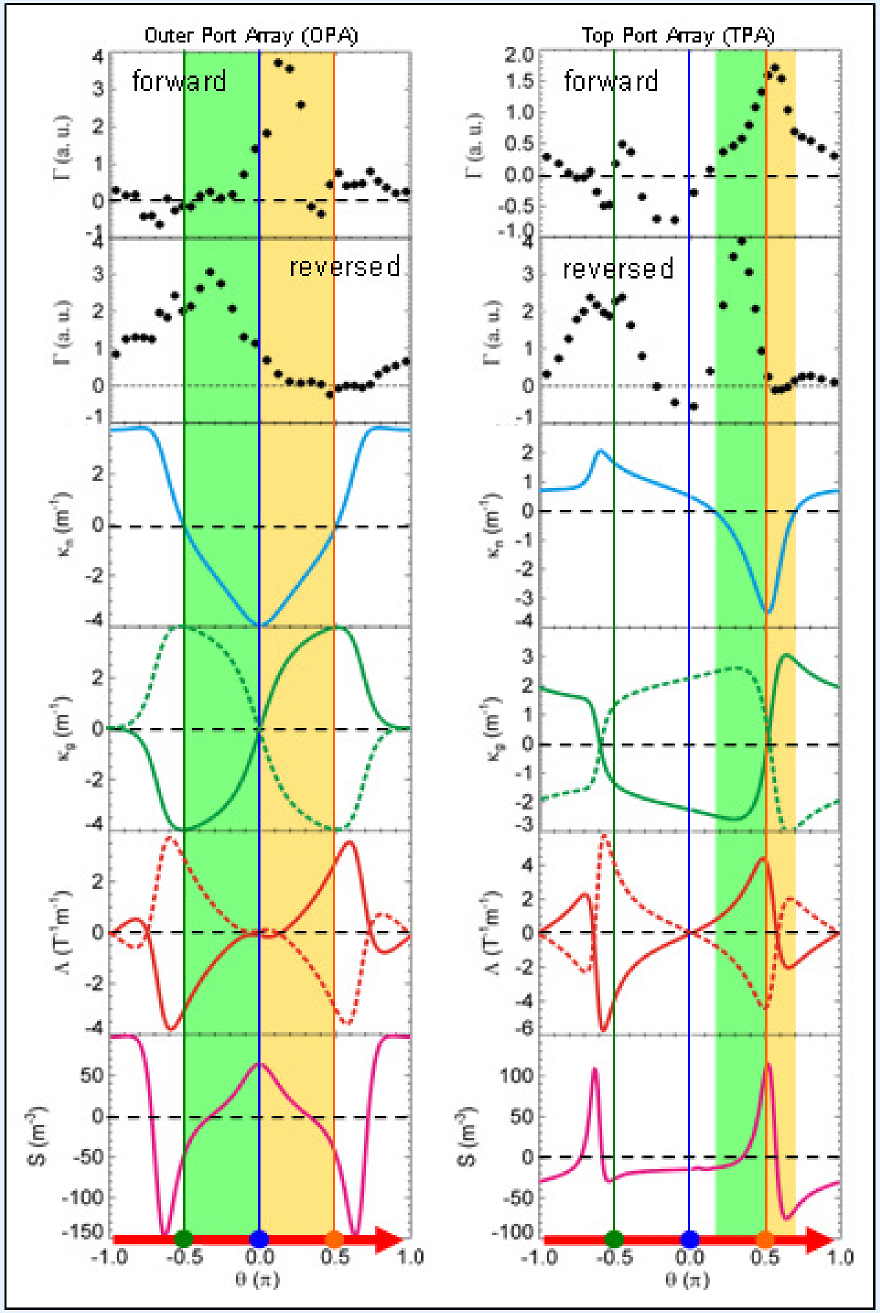
$$\gamma \sim -\Omega_d = -\frac{T_e}{e\chi'} k_\alpha \left[(\ln n_0)' - \frac{2}{\sqrt{G^{ss}}} \left\{ \kappa_n + \kappa_g \frac{\chi'}{B} G^{ss} (\Theta_k - \Lambda) \right\} \right]$$

Normal curvature $\kappa_n = \vec{\kappa} \cdot \vec{n}$

Geodesic curvature $\kappa_g = \vec{\kappa} \cdot (\vec{n} \times \vec{t})$

Integrated local magnetic shear $\Lambda = \frac{g^{\rho\xi}}{g^{\rho\rho}}$

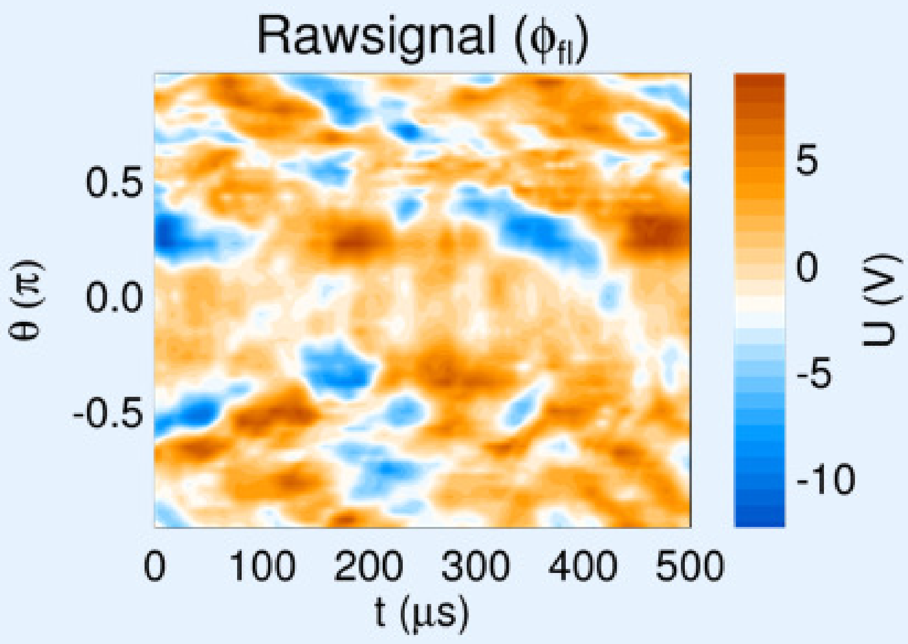
Local magnetic shear $S = -B \cdot \nabla \Lambda$

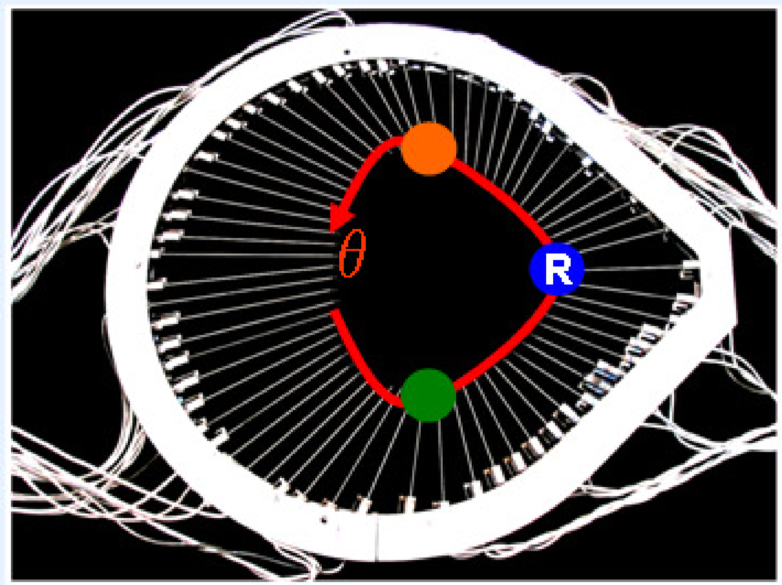


3D-Shape of Turbulent Structures

Cross correlation detects coherent structures:

$$C_{x,y}(\Delta t) = \frac{\langle x(t)\, y(t+\Delta t)\rangle}{\sigma_x\, \sigma_y}$$





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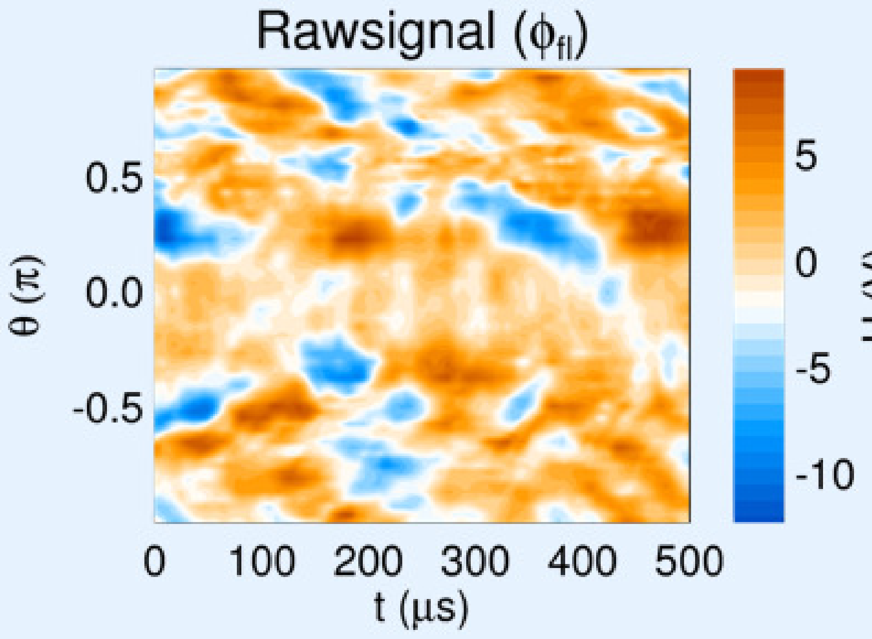
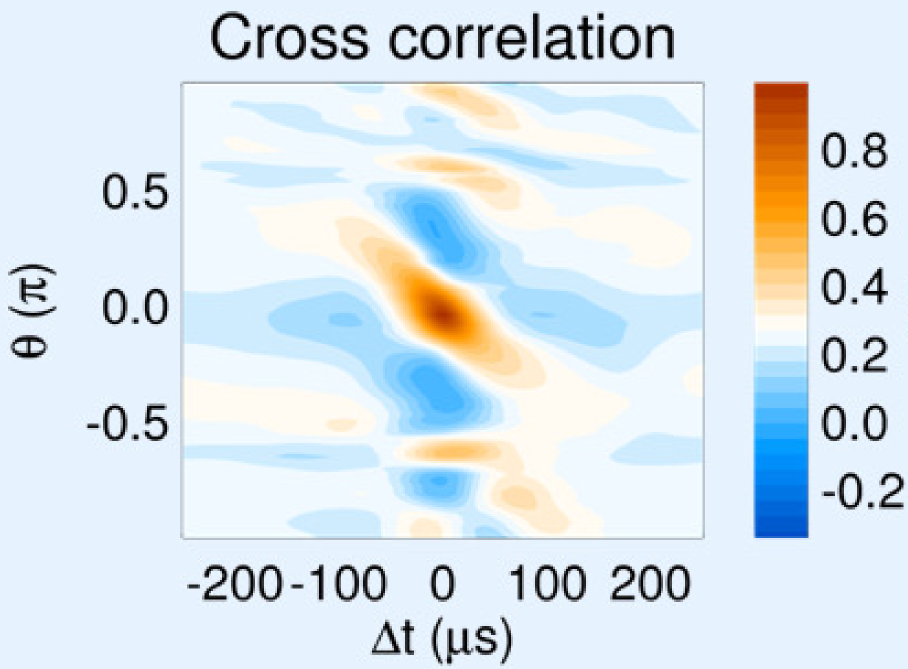
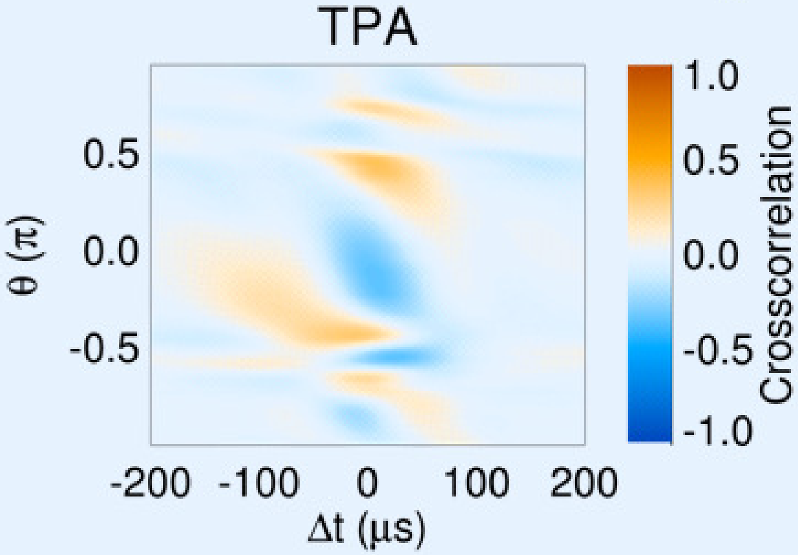
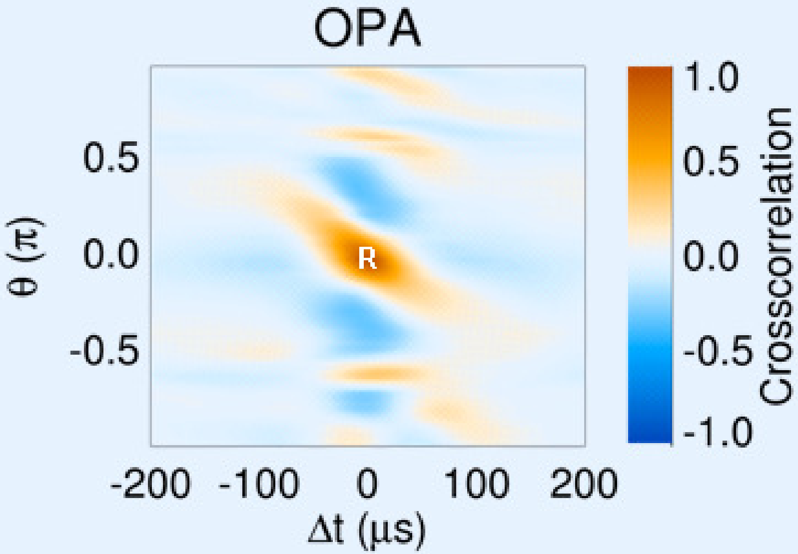


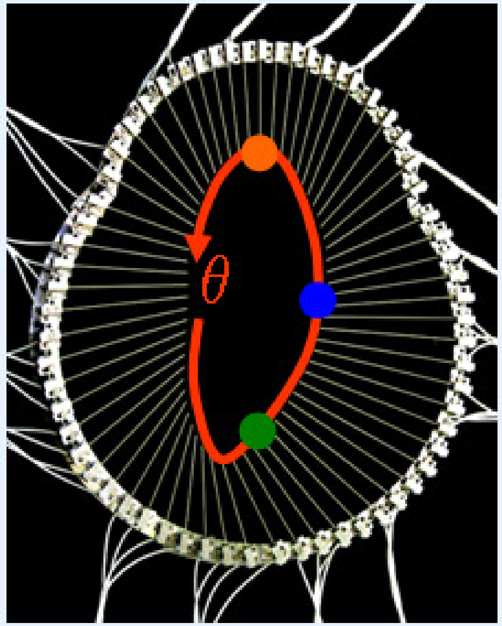


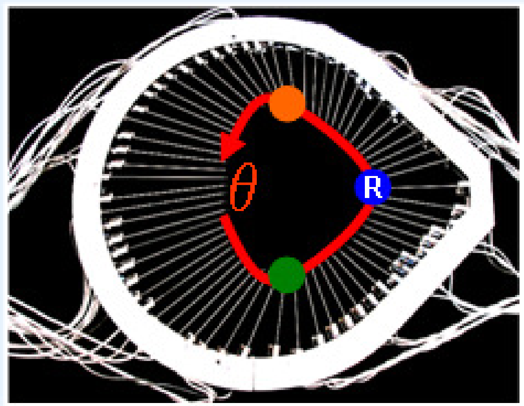
3D-Shape of Turbulent Structures

Cross correlation between both arrays:



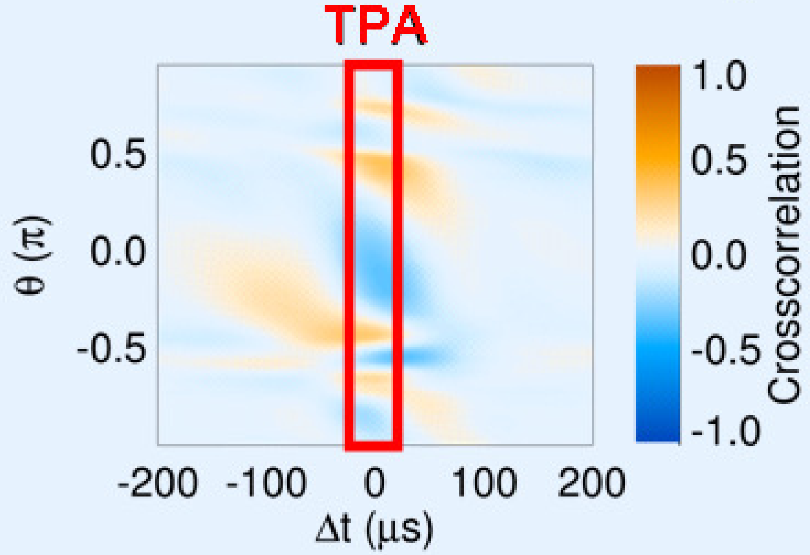


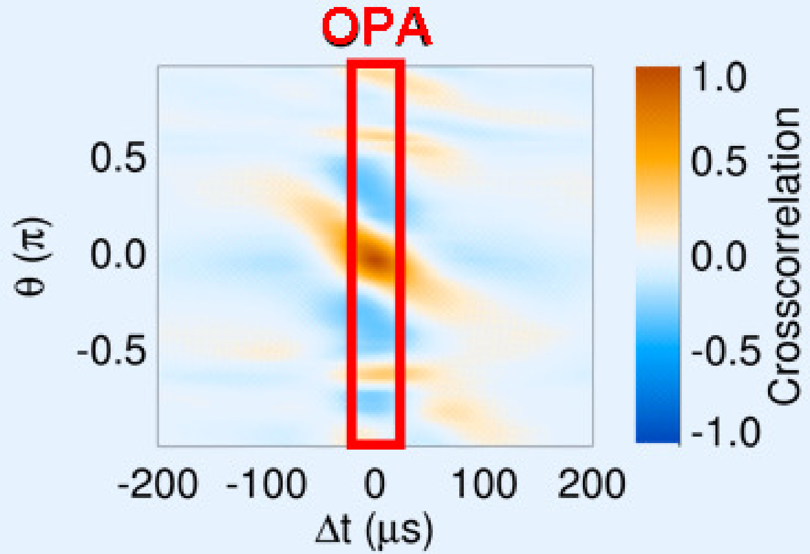


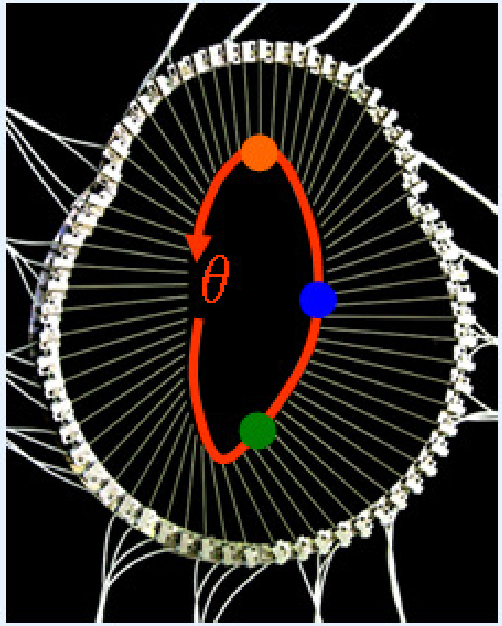


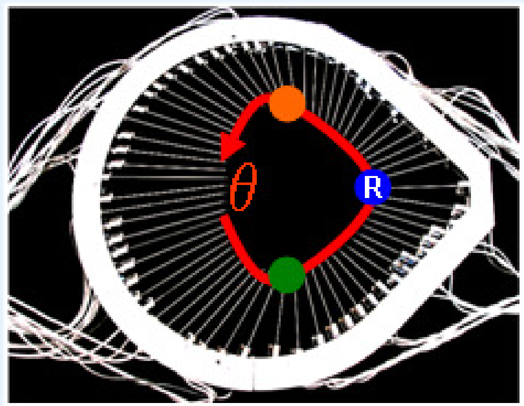
3D-Shape of Turbulent Structures

Cross correlation between both arrays:





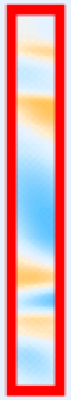




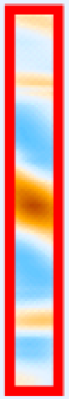
3D-Shape of Turbulent Structures

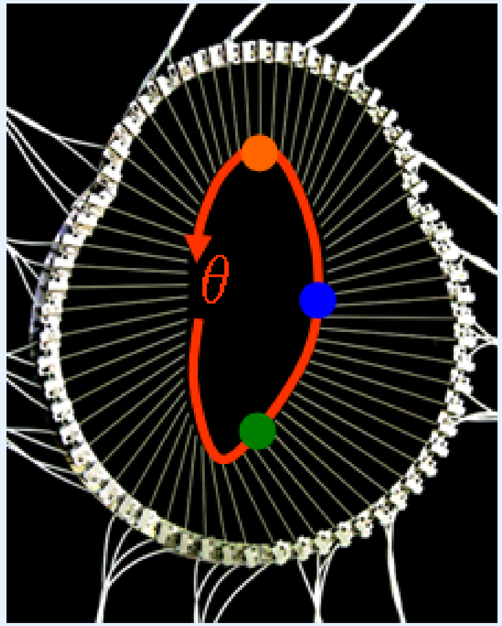
Cross correlation between both arrays:

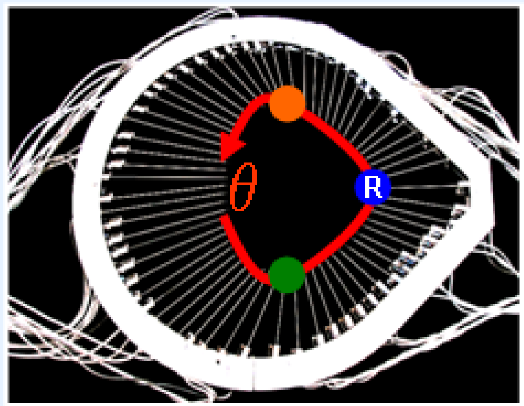
TPA



OPA

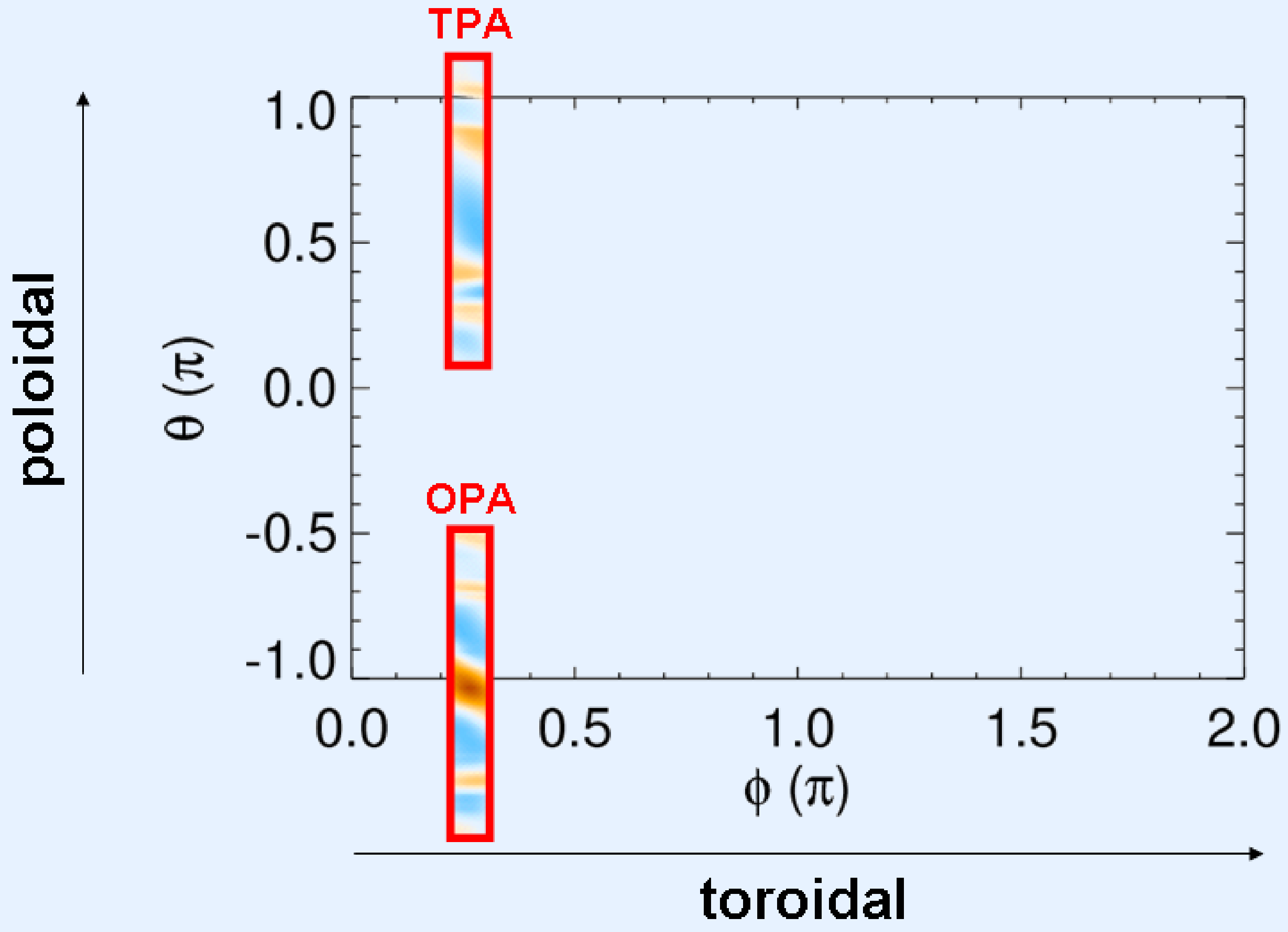






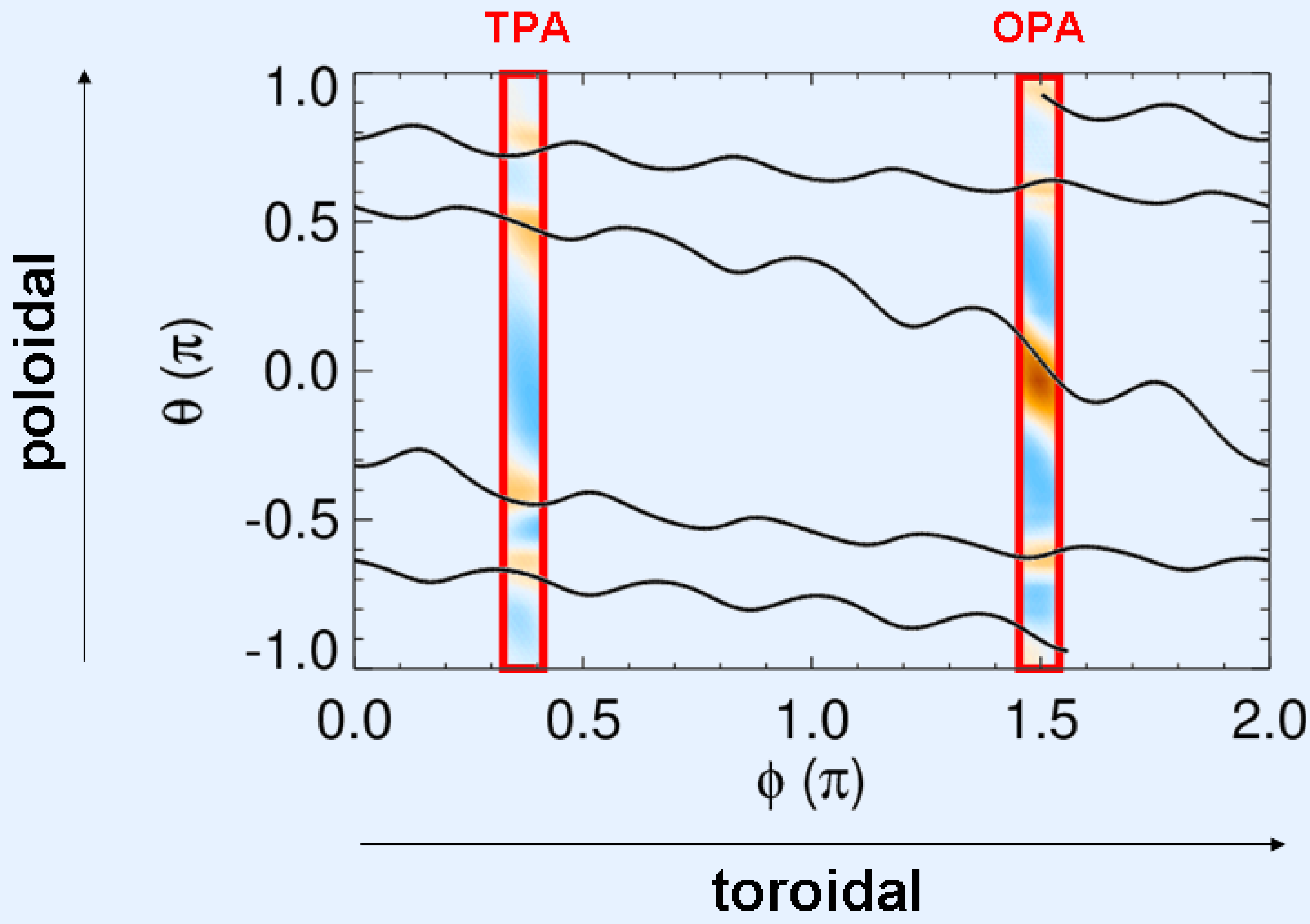
3D-Shape of Turbulent Structures

Position in the ϕ–θ–plane of a fluxsurface:

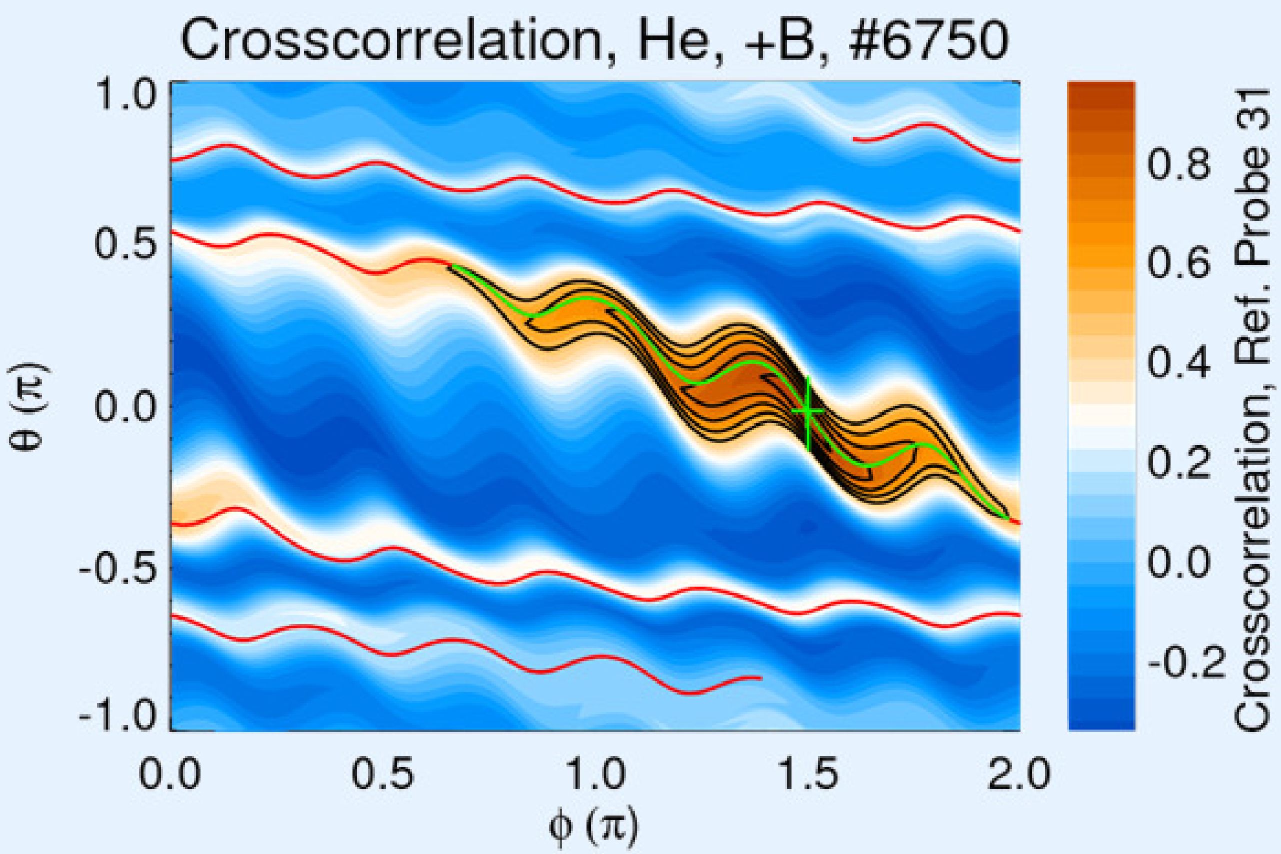


3D-Shape of Turbulent Structures

Position in the ϕ–θ–plane of a fluxsurface: fieldline



3D-Shape of Turbulent Structures

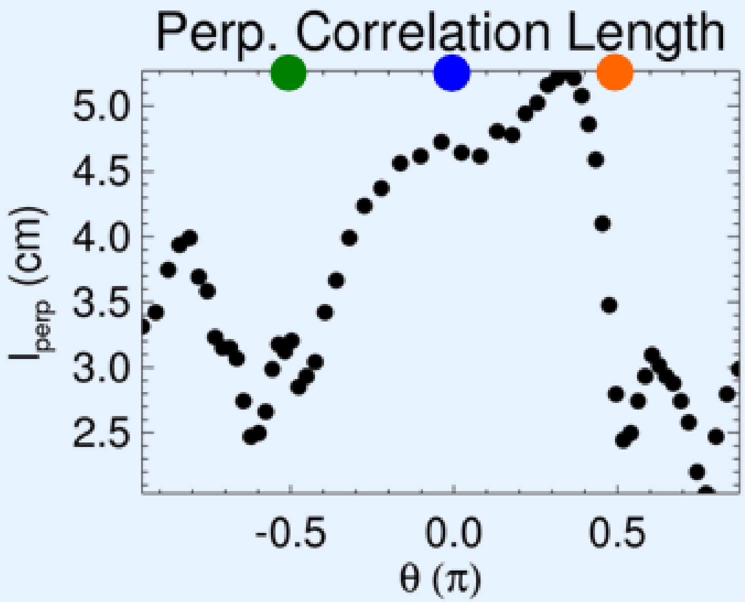


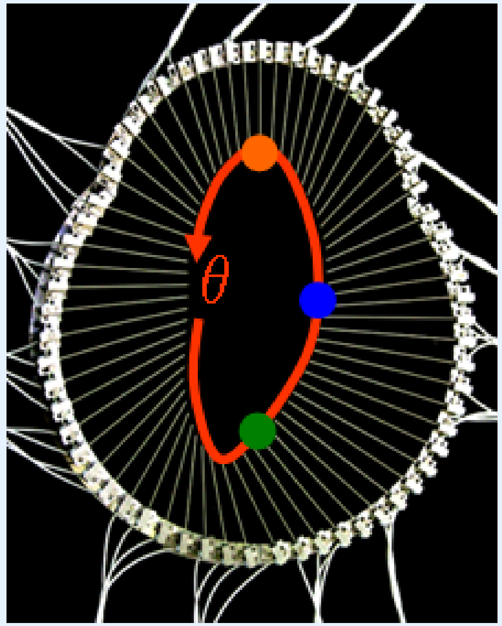
50% CC-level →

$l_{parallel}$	=	2.80 m
l_{perp}	=	4 cm
$l_{perp} / l_{parallel}$	=	0.014

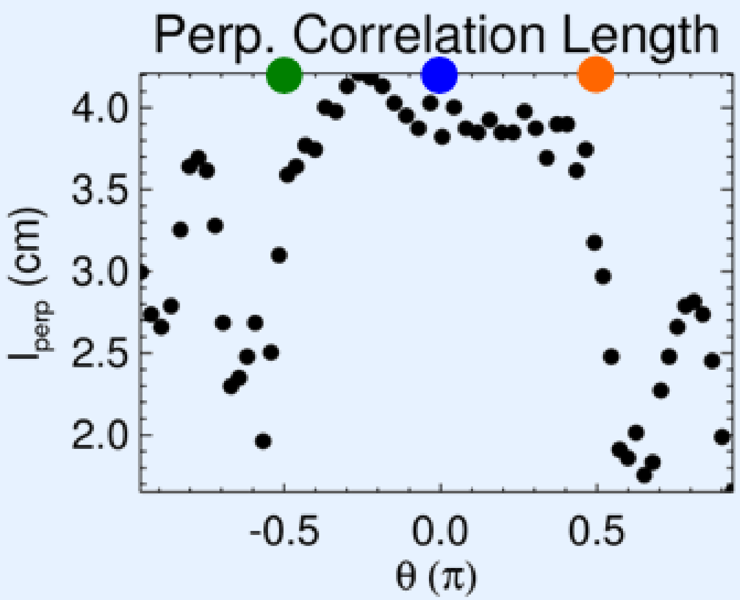
3D-Shape of Turbulent Structures

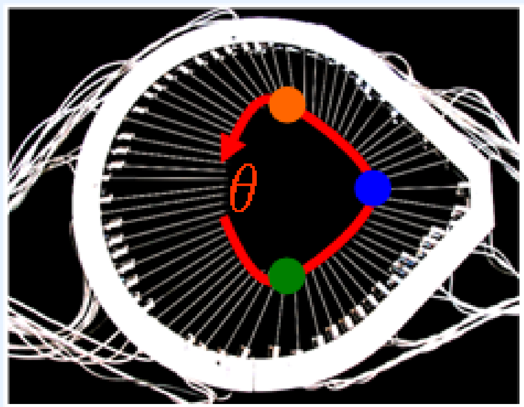
TPA:





OPA:

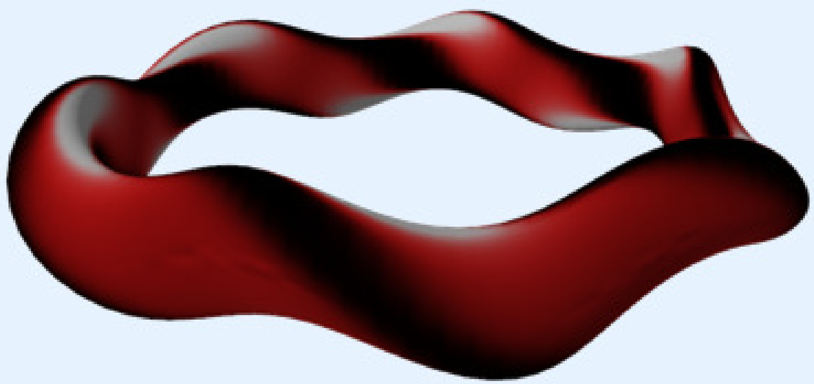


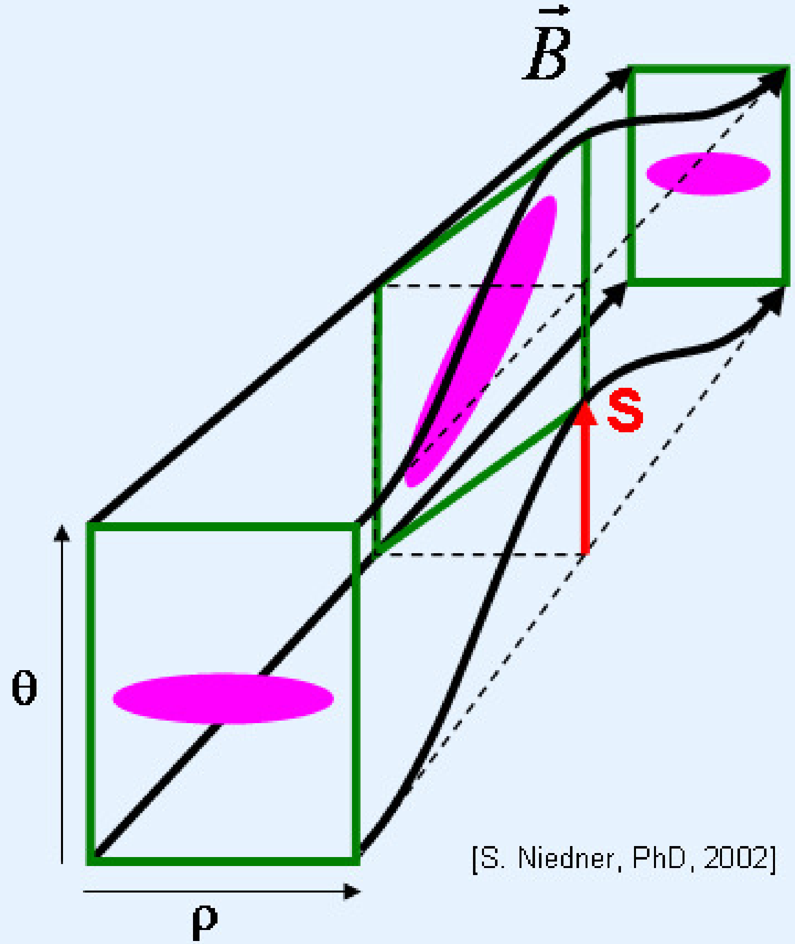


3D-Shape of Turbulent Structures

Local magnetic shear:

$$S(\rho,\theta,\phi) = -\frac{\left(\nabla\rho\times\vec{B}\right)\cdot\nabla\times\left(\nabla\rho\times\vec{B}\right)}{|\nabla\rho|^4}$$





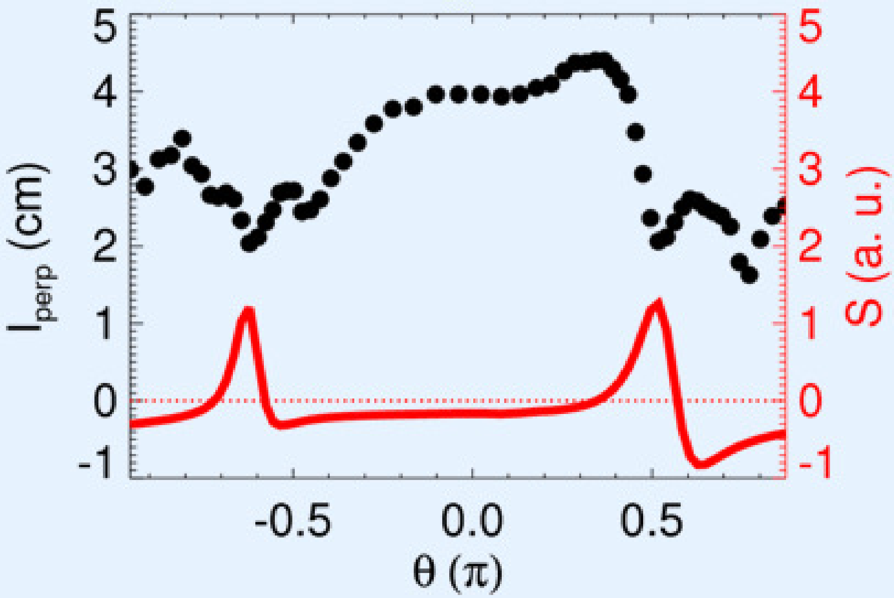
[S. Niedner, PhD, 2002]

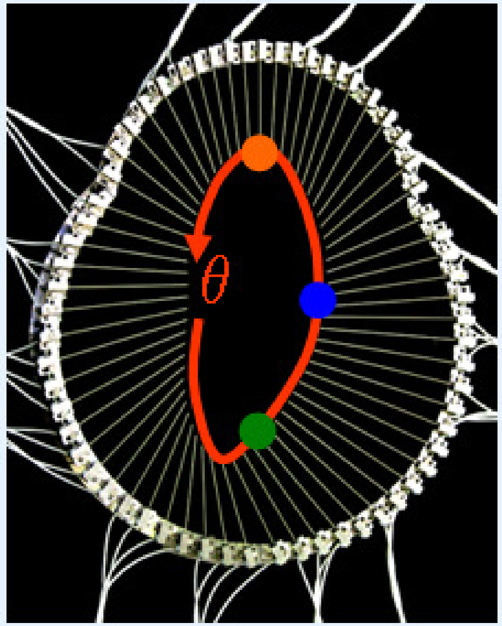
→ **Magnetic shear tilts/deforms turbulent structures**

3D-Shape of Turbulent Structures

l_{perp} dominated by local magnetic shear?

TPA:





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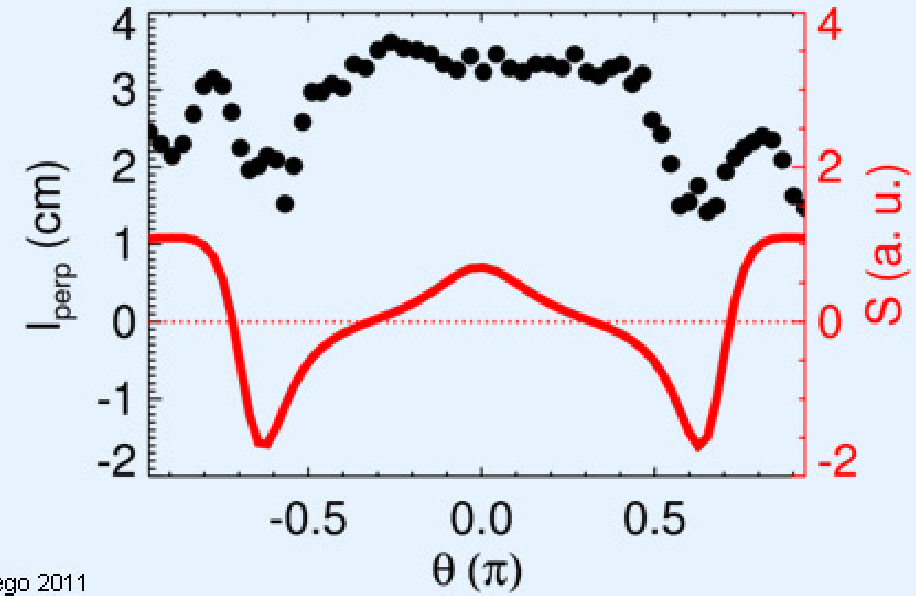
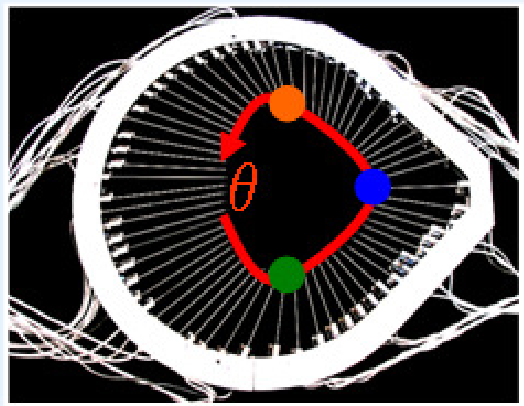
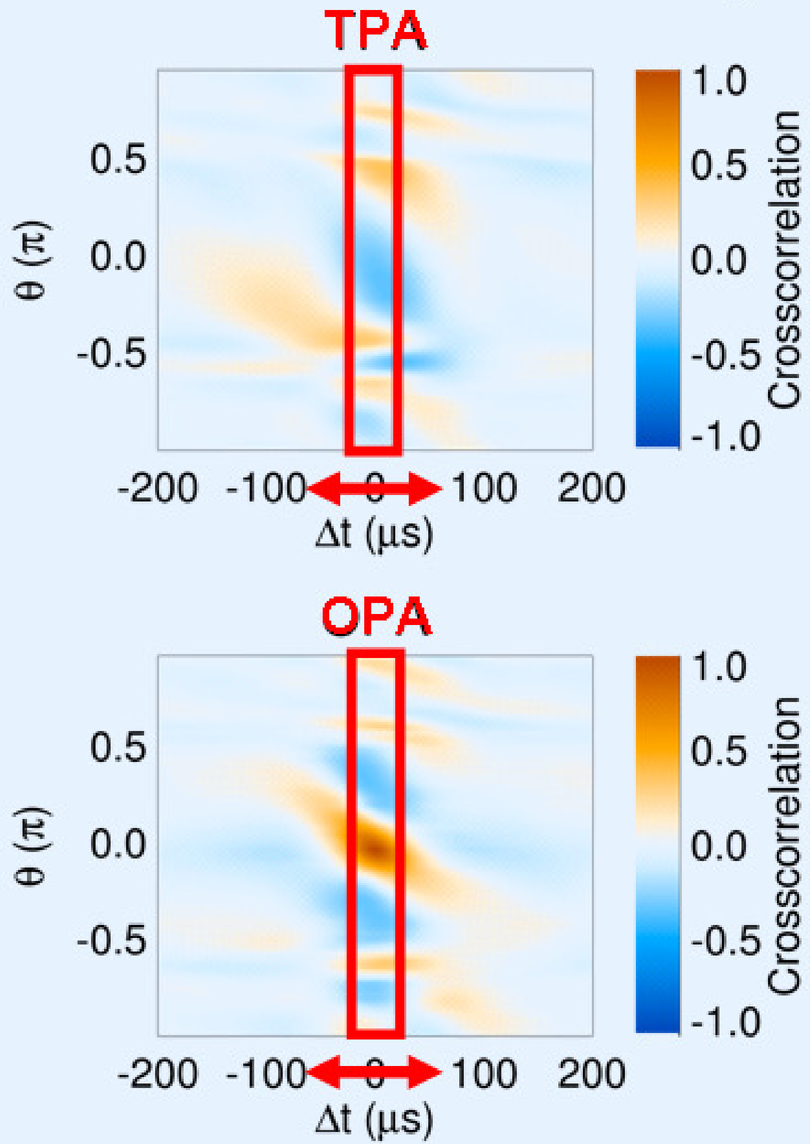
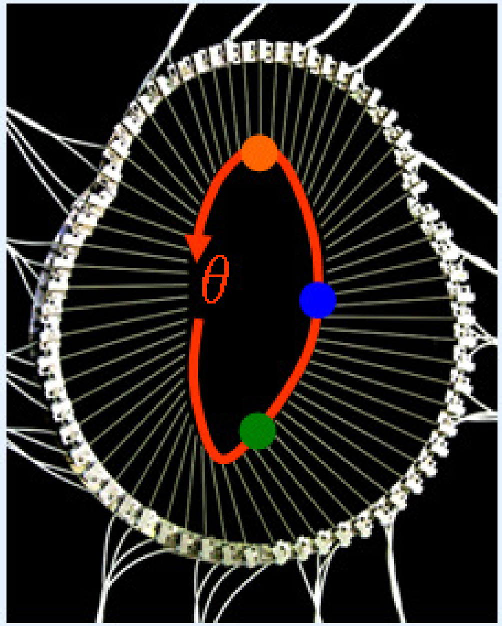


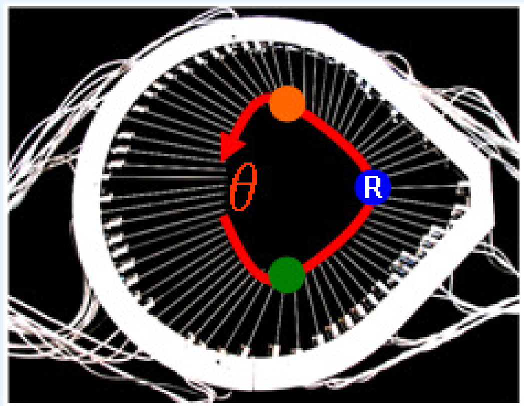


Dynamics of Turbulent Structures

Cross correlation between both arrays:







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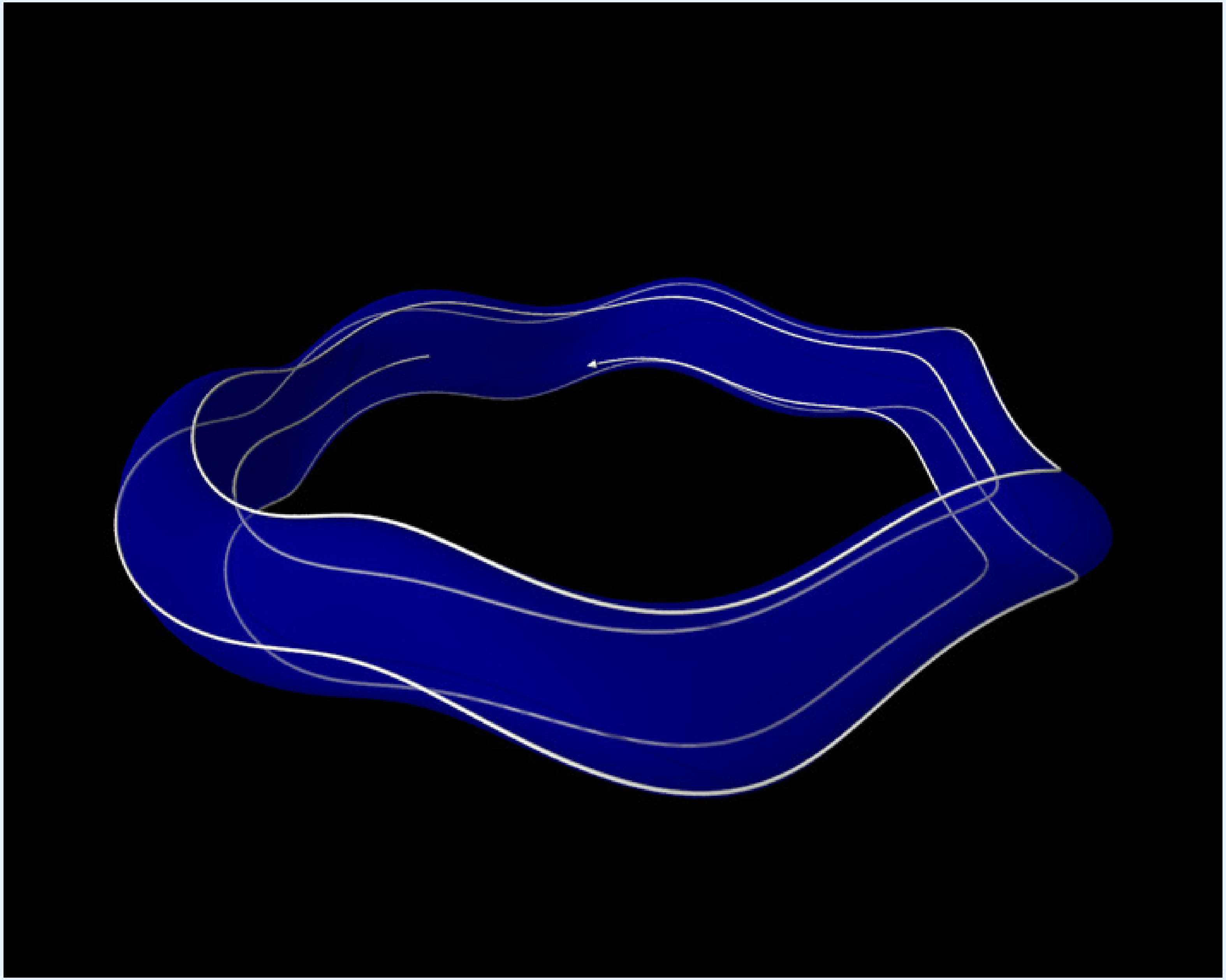
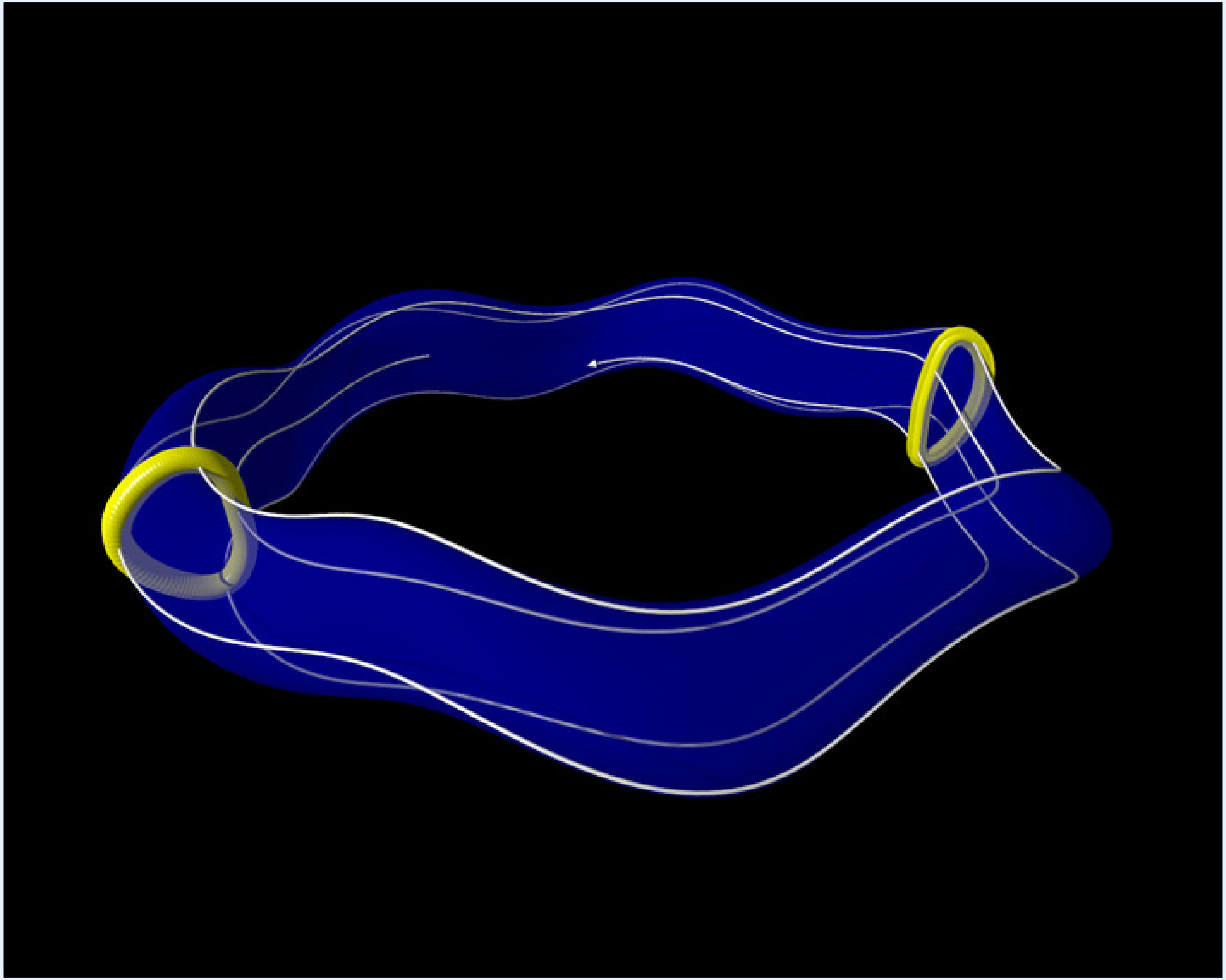
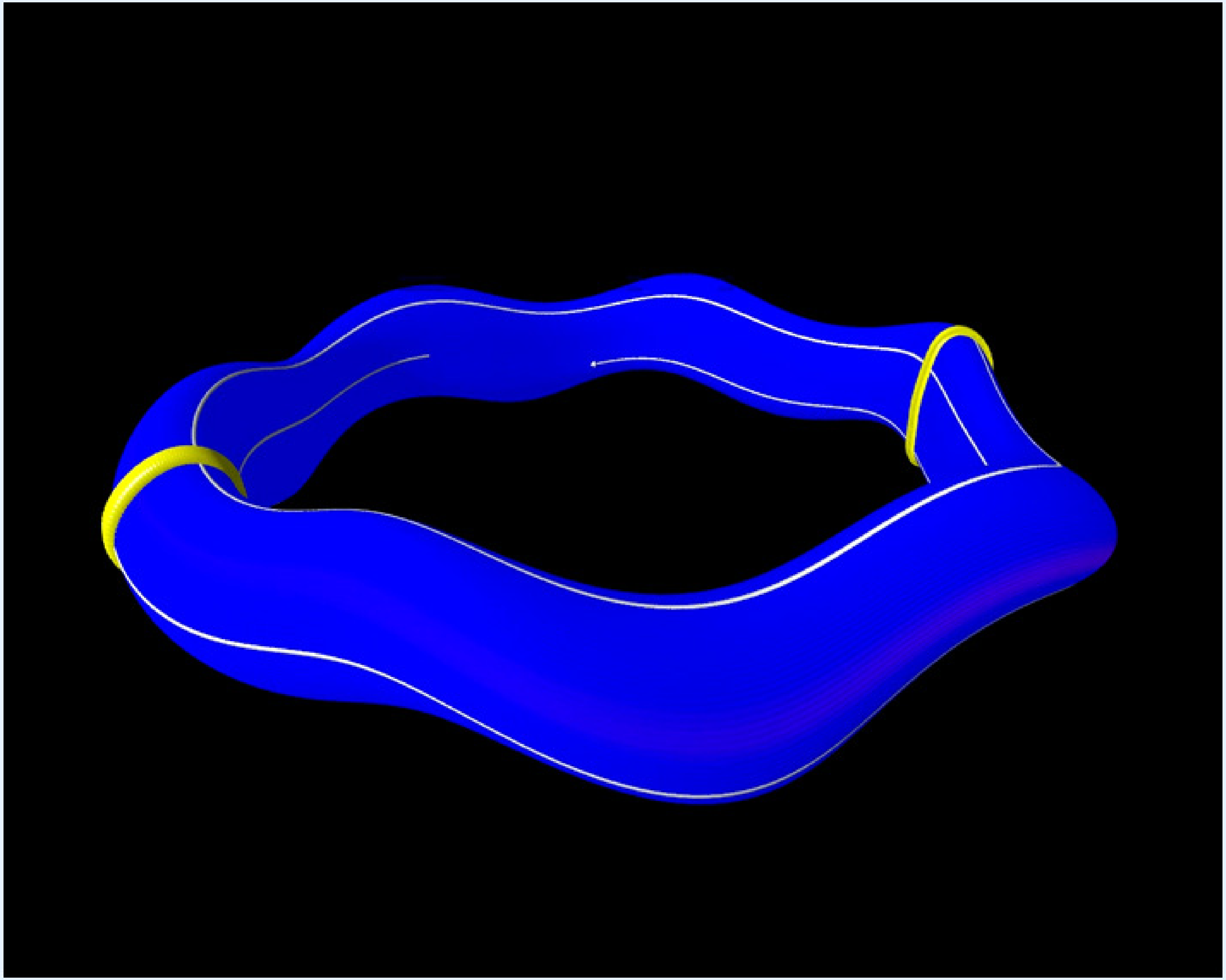


Dynamics of Turbulent Structures



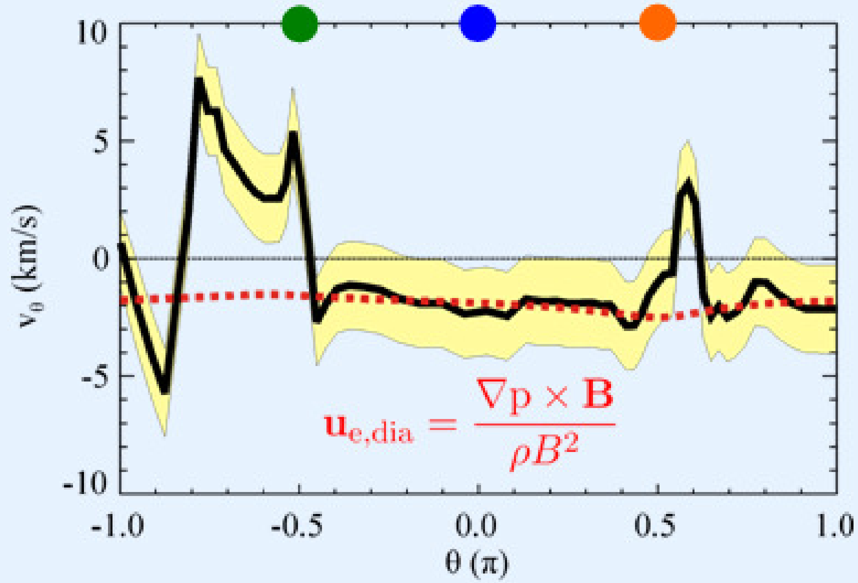
Dynamics of Turbulent Structures

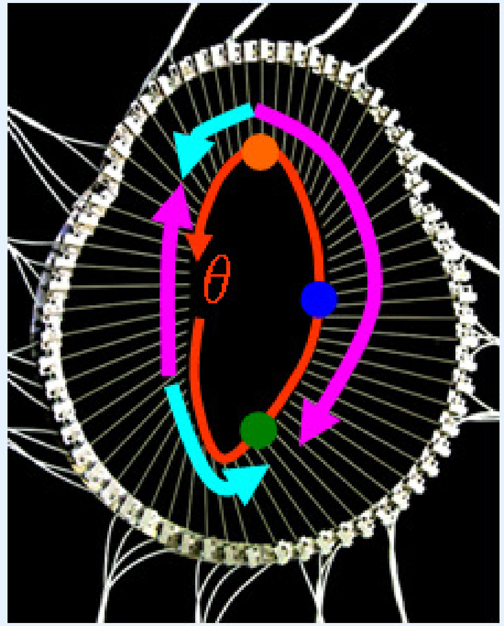


Dynamics of Turbulent Structures

Perpendicular velocities:

TPA:





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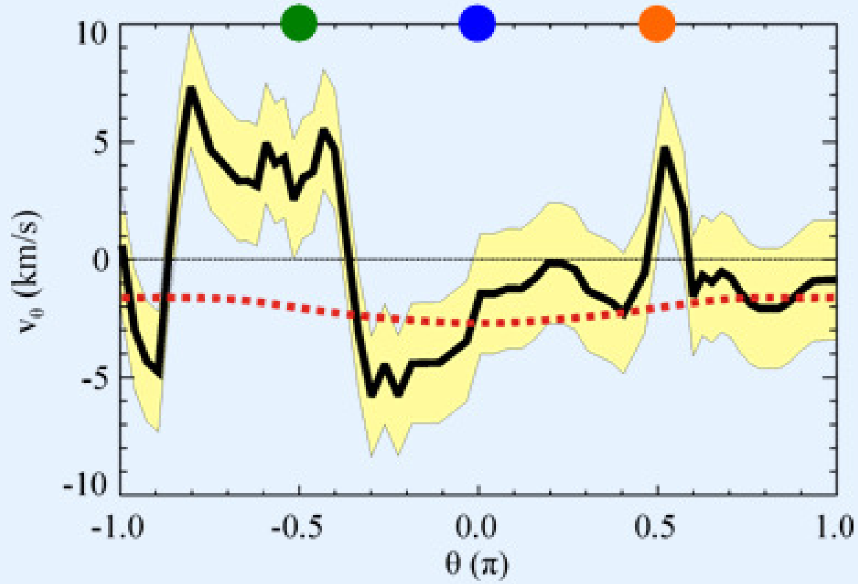
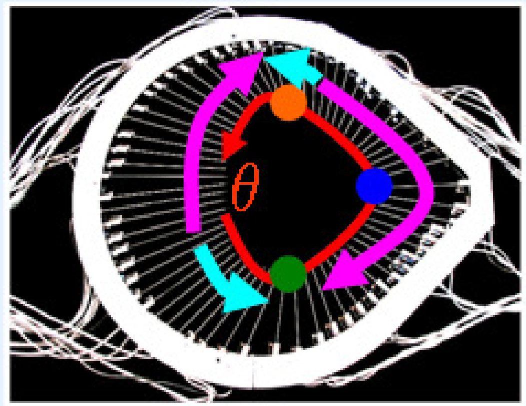
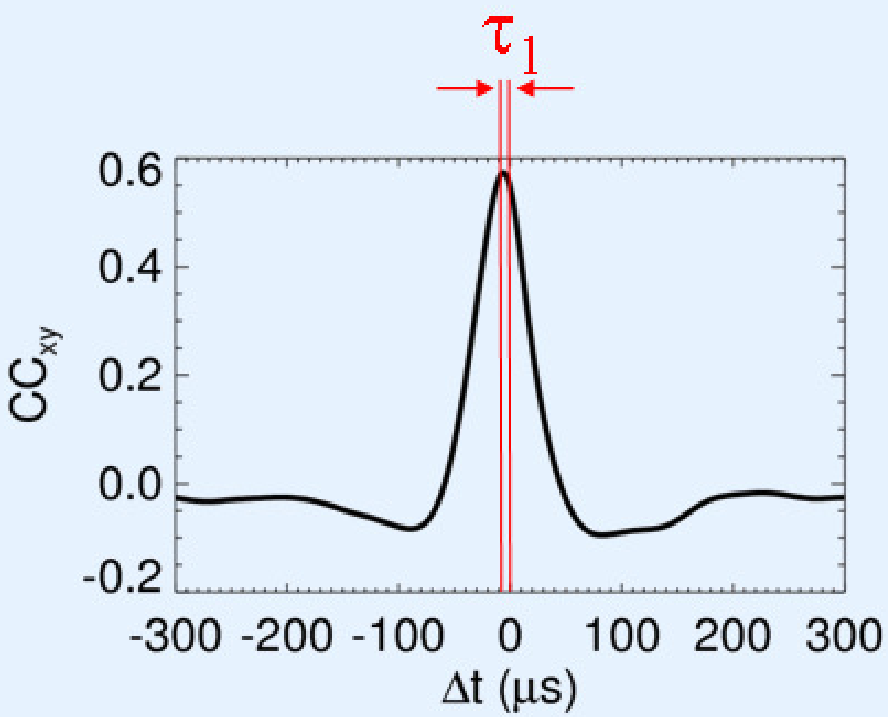


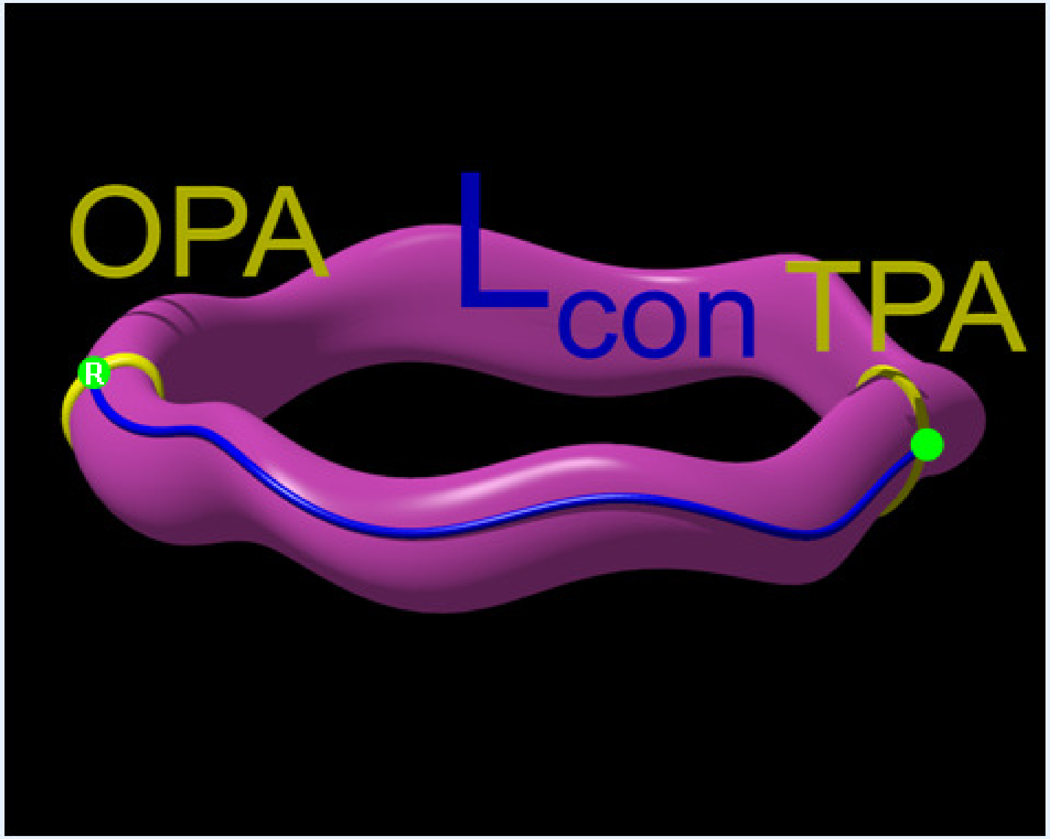


Dynamics of Turbulent Structures

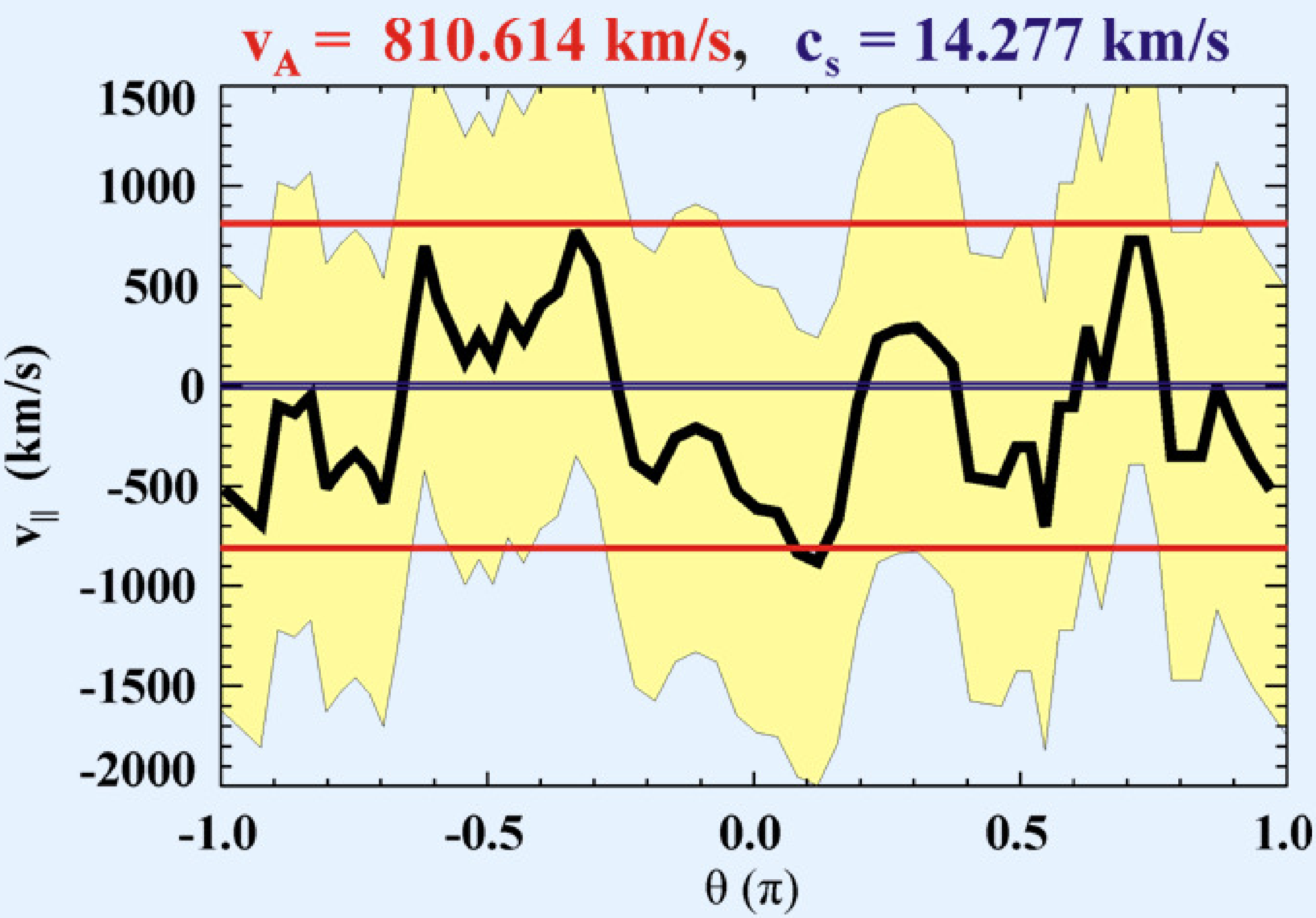
Parallel velocity:

$$v_{||} = \frac{L_{con}}{\tau_1}$$





Dynamics of Turbulent Structures

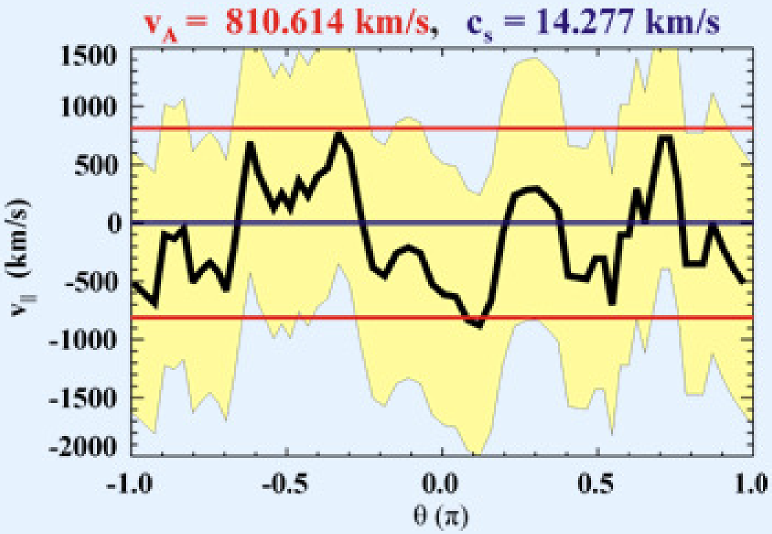


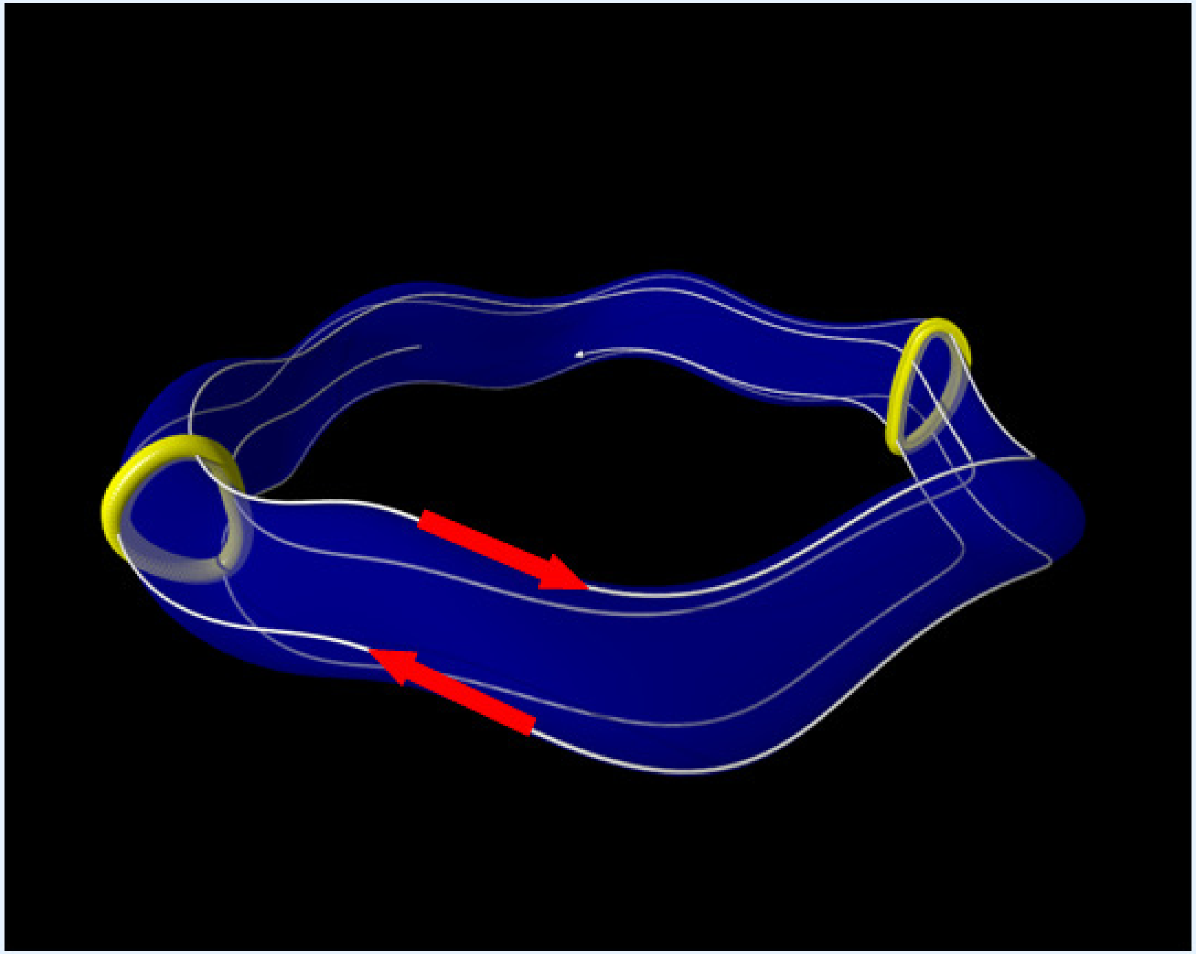
$$\mathbf{v}_A = \frac{B}{\sqrt{\mu_0 m_i n}}$$

$$c_s = \sqrt{\frac{T_e}{m_i}}$$

Parallel propagation velocity for helium: $\bar{v}_\parallel = (4.01 \pm 2.8) \times 10^5$ m/s

Dynamics of Turbulent Structures

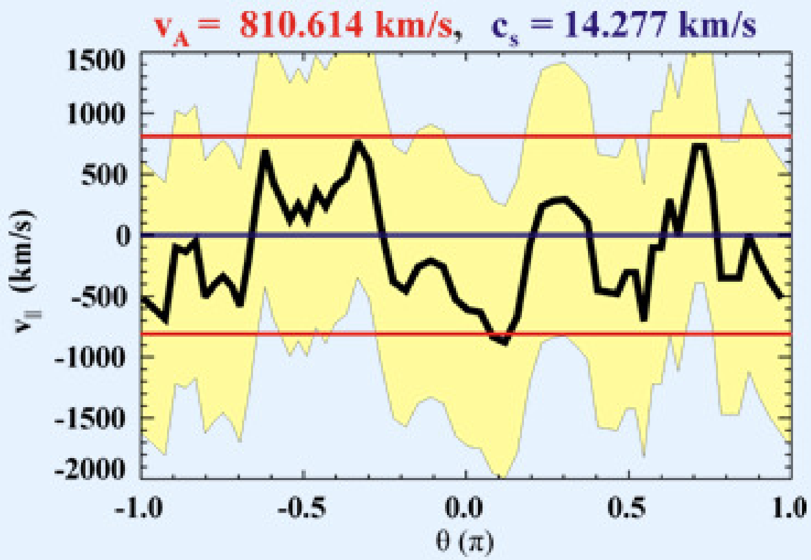


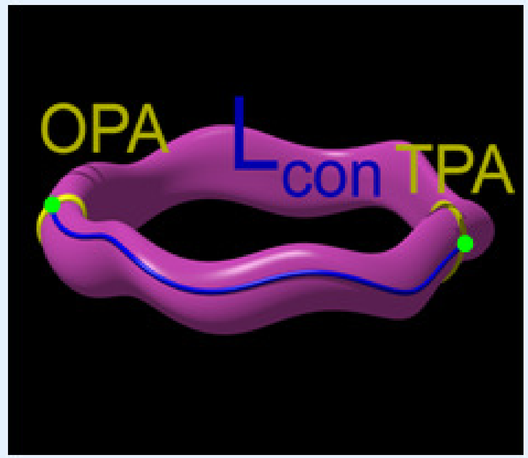


Parallel propagation velocity for helium: $\bar{v}_{\parallel} = (4.01 \pm 2.8) \times 10^5$ m/s

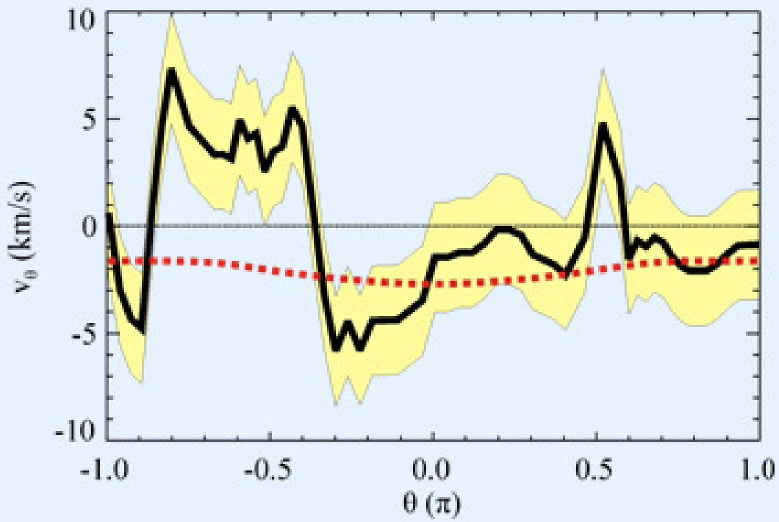
Dynamics of Turbulent Structures

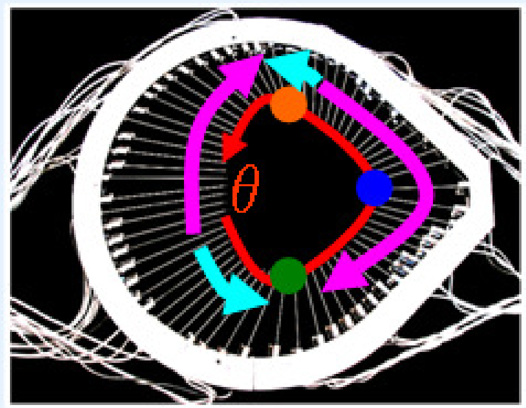
Parallel velocity:





Perpendicular velocity:

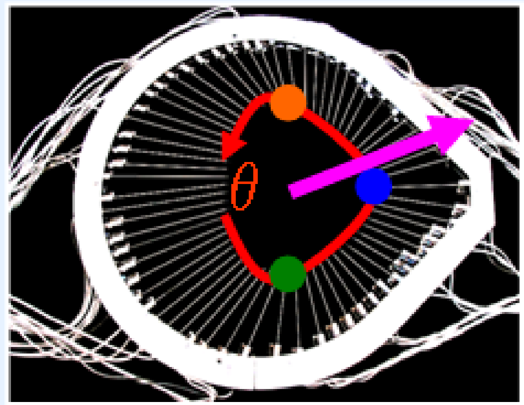




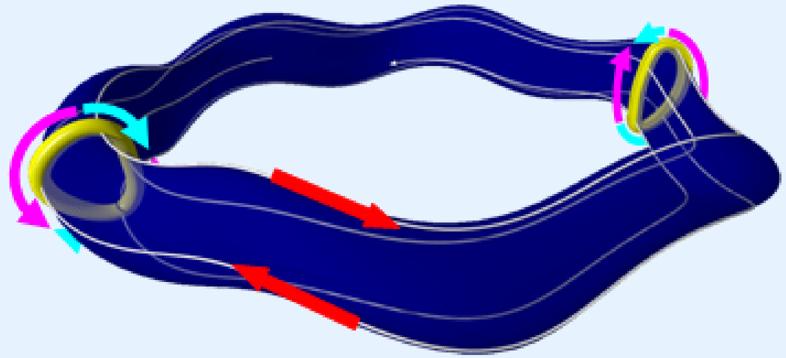
Summary

3D-Effects on turbulence:

- Pronounced turbulent transport maxima found in bad curvature region



- Perpendicular correlation lengths reduced in regions with high local magnetic shear
- Structure and dynamics of quasi-coherent modes in agreement with drift wave theory



- Surprising: change of direction of parallel and perpendicular propagation

⇒ Only 3D investigations reveal complete dynamics of turbulence


Thank you
for your
attention!