Basic Turbulence Studies on TORPEX and Challenges in the Theory-Experiment Comparison

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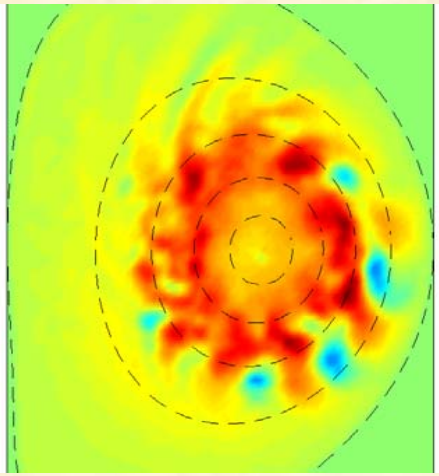
Outline

- Theory-Experiment comparison in the field of plasma turbulence – A challenge
  - Overview
  - Role of basic experiments
- The TORPEX experiment at CRPP
  - The vertical magnetic field B_z, an important parameter
    - Fundamental mechanism – Role for basic confinement
    - B_z as a turbulence control parameter
  - Turbulence Studies – Illustration in terms of B_z
    - Statistical characterization
    - Direct measurement of spatio-temporal structures – The HEXTIP diagnostic

Comparison in the Field of Plasma Turbulence
A Challenge



ORB5 – Courtesy of A. Bottino

Gyrokinetic Models

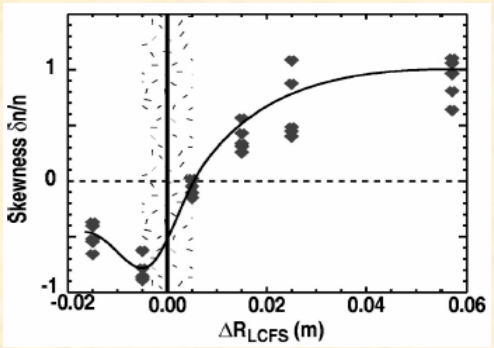
+ Spatio-temporal (S-T) structures

- No statistical description (typical runs: ~100μs)

Tokamak Exp.

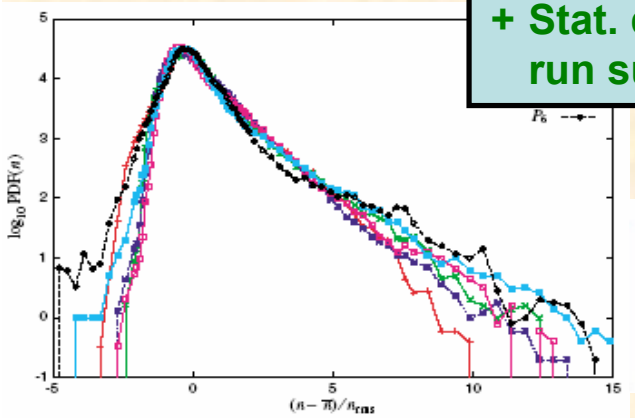
- No S-T structures (limited access for diagnostics)

+ Statistical description



Boedo et al, PoP 2003

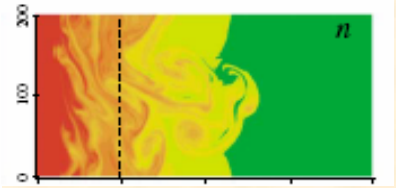
Garcia et al, PRL 2004



Fluid Models

+ S-T structures

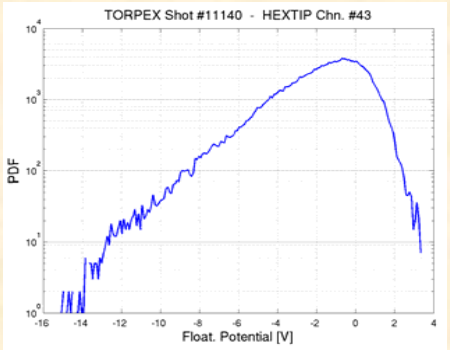
+ Stat. description (can run sufficiently long)

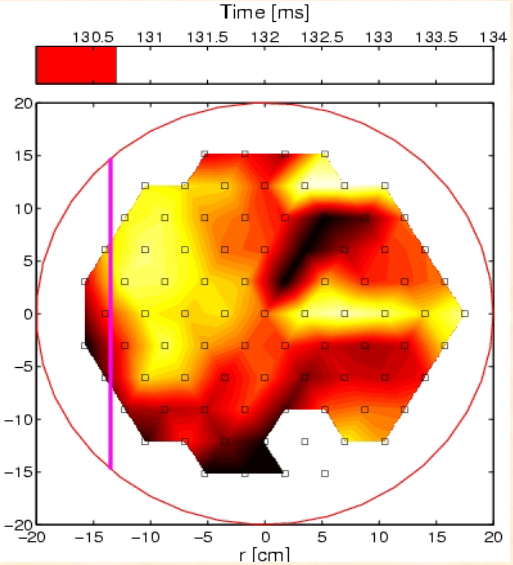


Basic Experiments

+ S-T structures

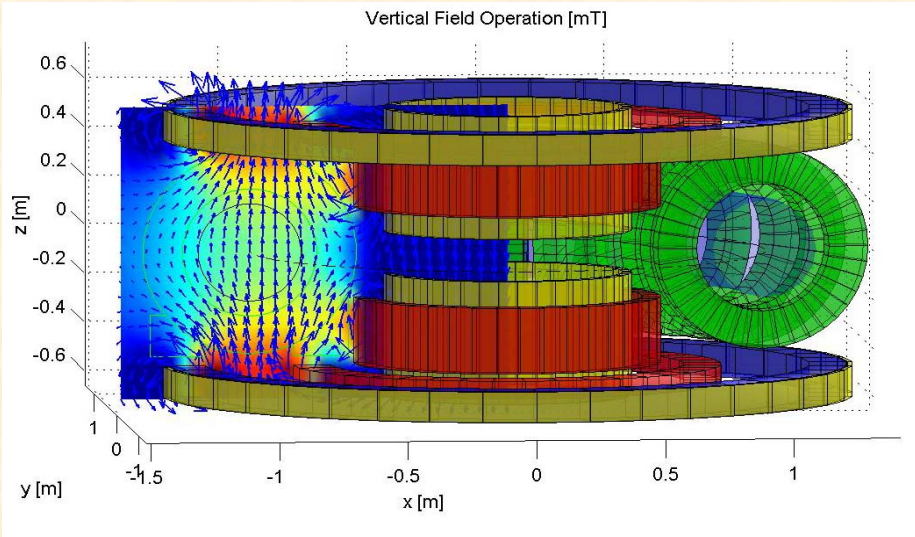
+ Stat. description





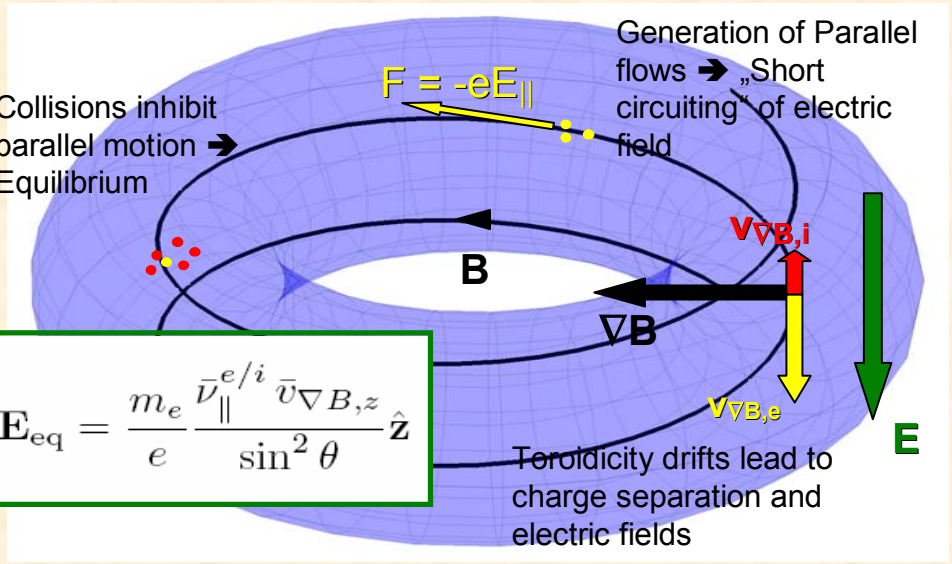
TORPEX
A Basic Plasma Physics Experiment

- Operational since March 2003
- Turbulence & Transport
- Versatile electromagnetic fields
  - Toroidal field up to 0.3 T (now: 0.1 T)
  - Poloidal fields: vertical, cusp; max 0.1 T (now: $B_z < 5$ mT)
  - Tokamak-like operation (induction coils)
- Current free discharges (ECRF waves)
  - 100 ms at max. 30 kW, continuous wave at max. 5 kW
  - Precisely controllable source
  - Advanced power modulation capabilities
- Diagnostics
  - More than 180 es. probes, em. and optical probes
  - Simultaneously operating
  - Distributed in the entire plasma
- Very high reproducibility of discharges
- Efficient shot-cycle (~ 200 shots per day)



An Important Parameter: The Vertical Magnetic Field B_z

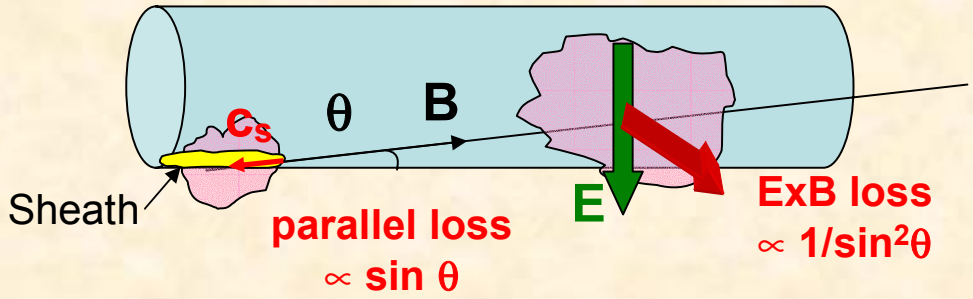
Important mechanism



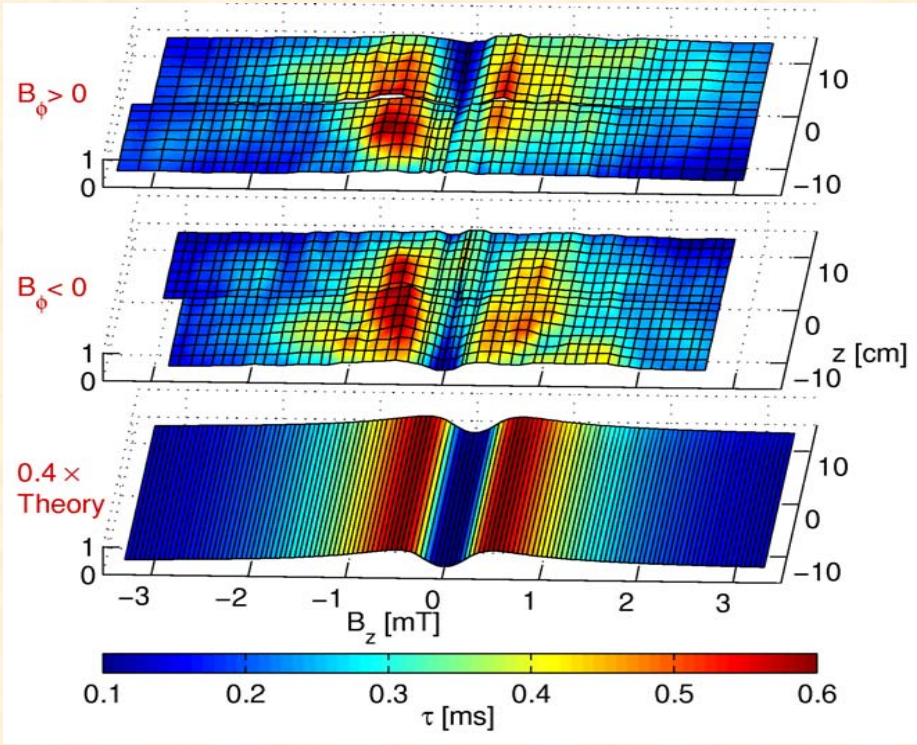
$$\mathbf{E}_{eq} = \frac{m_e}{e}\frac{\bar{\nu}_{\parallel}^{e/i}\,\bar{v}_{\nabla B,z}}{\sin^2\theta}\hat{\mathbf{z}}$$

Implications for confinement

Competition between two basic loss channels:



Theory and measurement of confinement time:



S. H. Müller et al, PRL 2004

➔ *Important role of B_z for basic confinement*

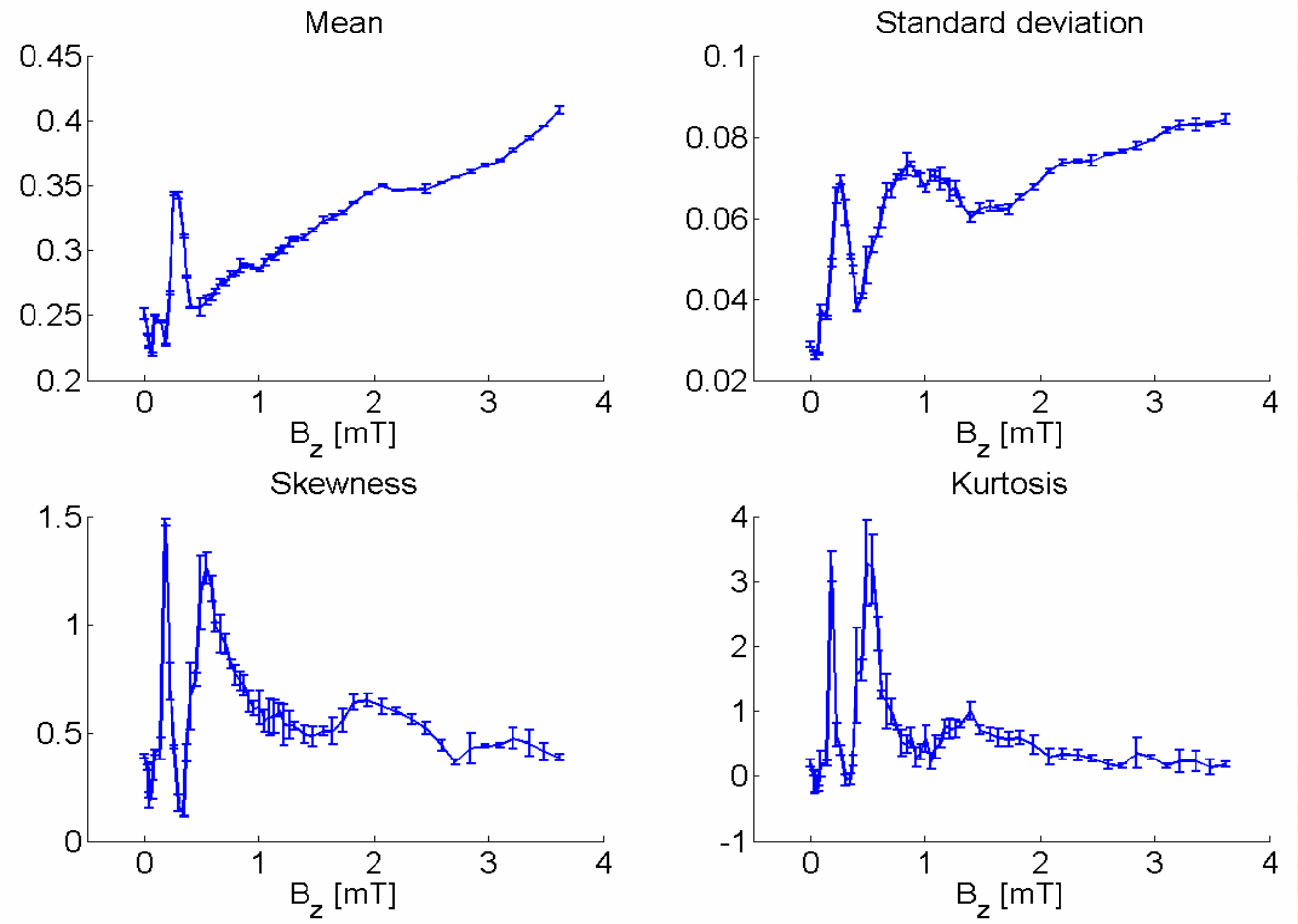
➔ *In the following: B_z as a control parameter for turbulence*

Statistical Characterization of Turbulence Illustration in terms of B_z

- Optical measurements
  - Hydrogen plasma
  - Radially viewing telescope on equatorial plane
  - Photomultiplier
- First four moments of PDF
- Errorbars from shot-to-shot reproducibility

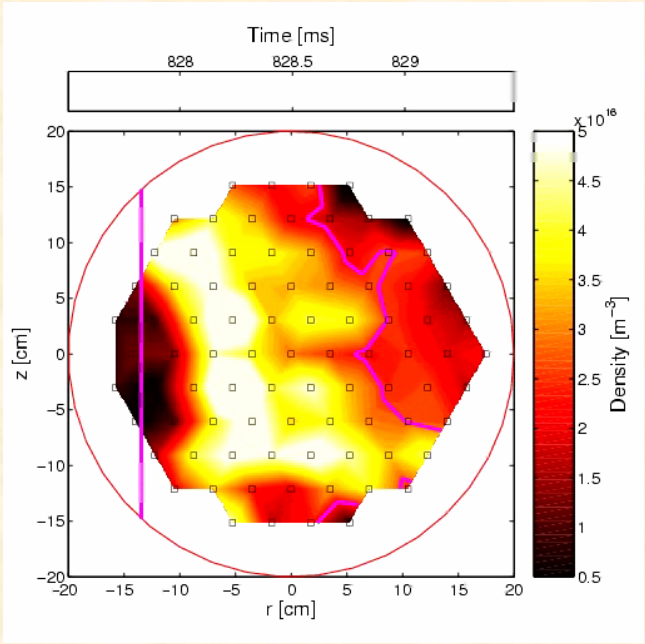
➔ *Reproducible, non trivial variation*

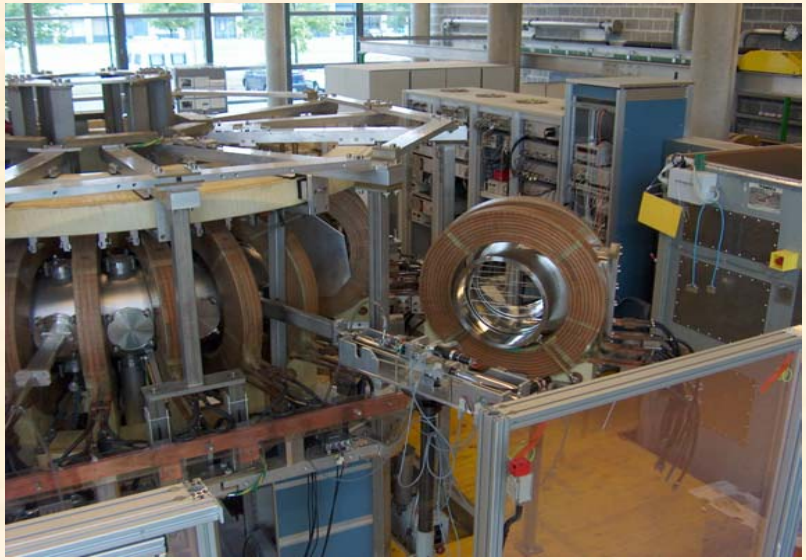
➔ *Importance of B_z as a "turbulence control parameter"*

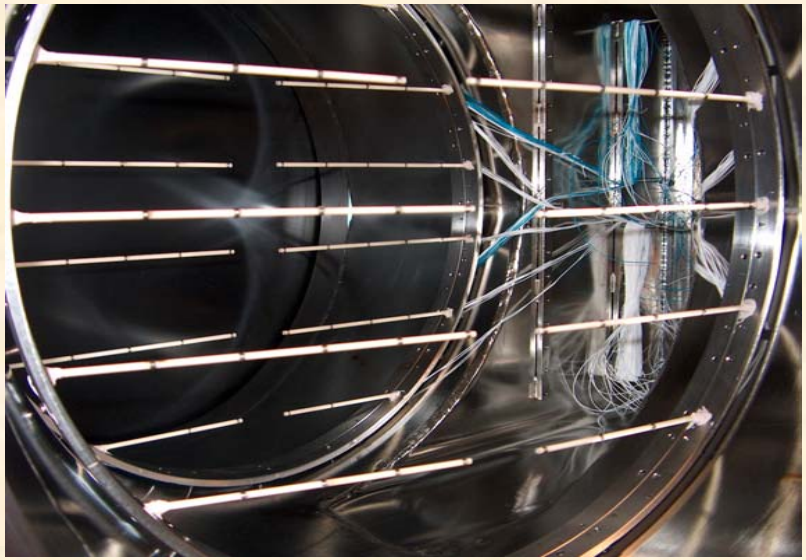


Turbulence Imaging on TORPEX
The HEXTIP Diagnostic

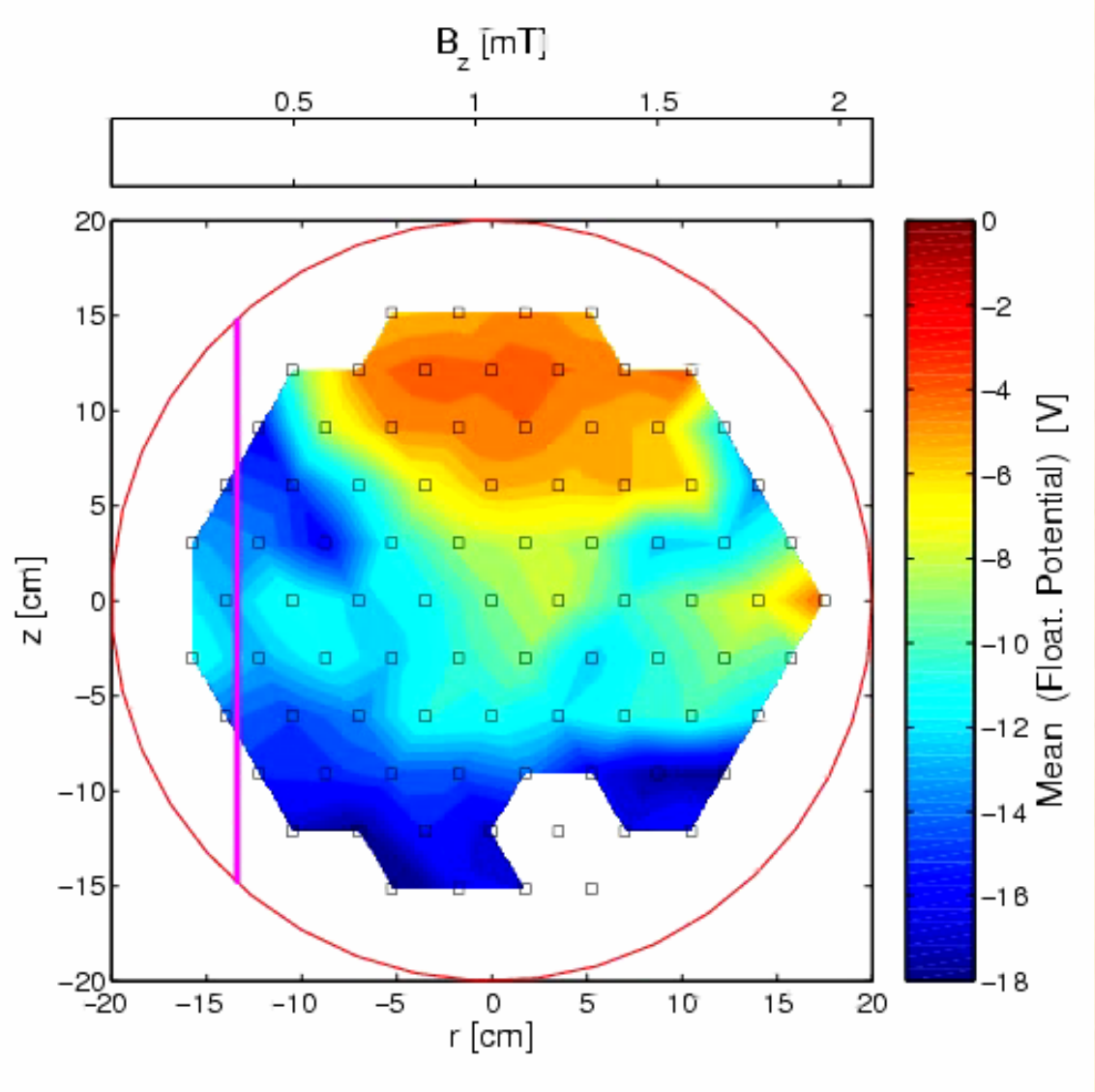
- Goal
  - Space and time
  - Background and fluctuations
  - Ion saturation current and floating potential
- Design
  - 4 independent rings mountable at different toroidal positions
  - 86 ring-shaped tips separated by 3.5 cm





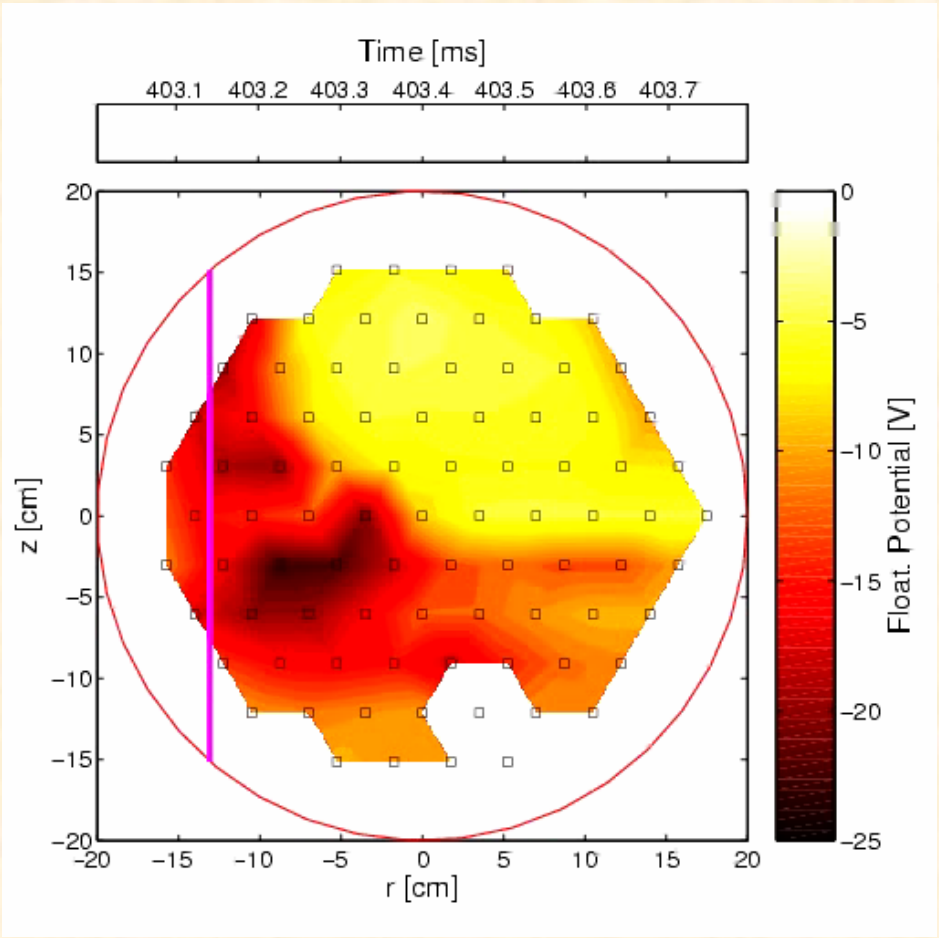


Profiles as a Function of B_z
1 Shot = 1 Profile = 1 Movie Frame

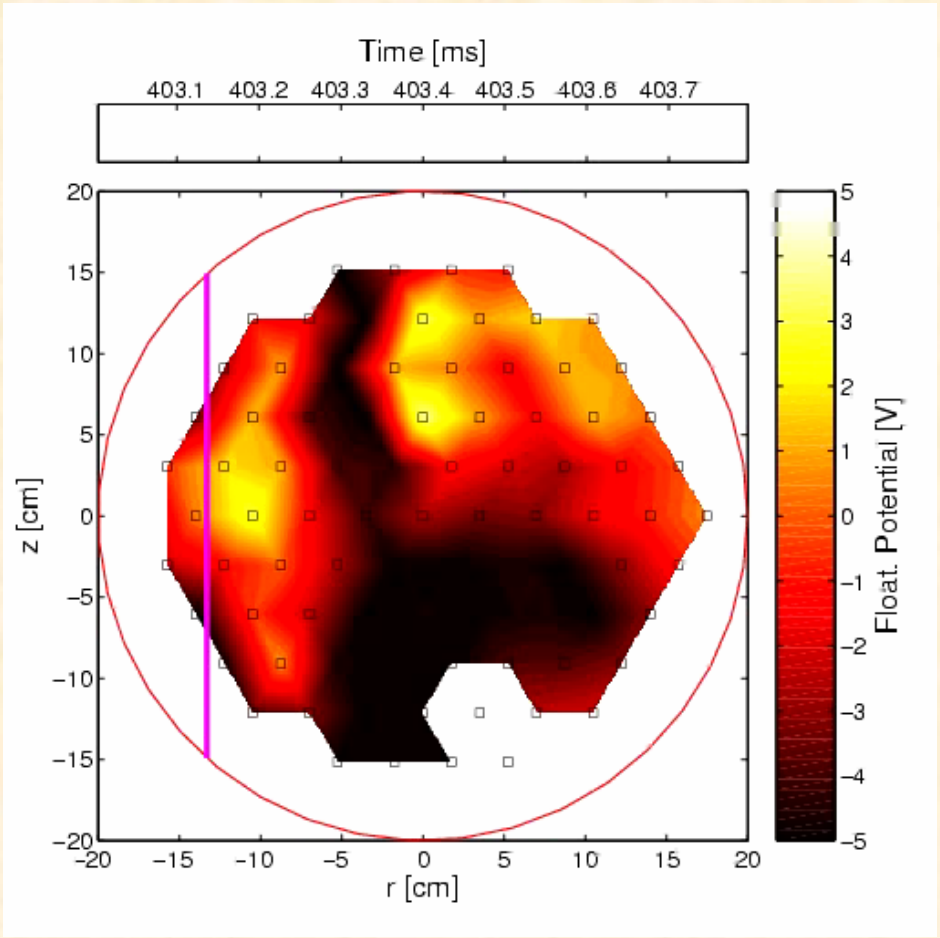


Turbulence Imaging
Illustration in terms of B_z

Low B_z

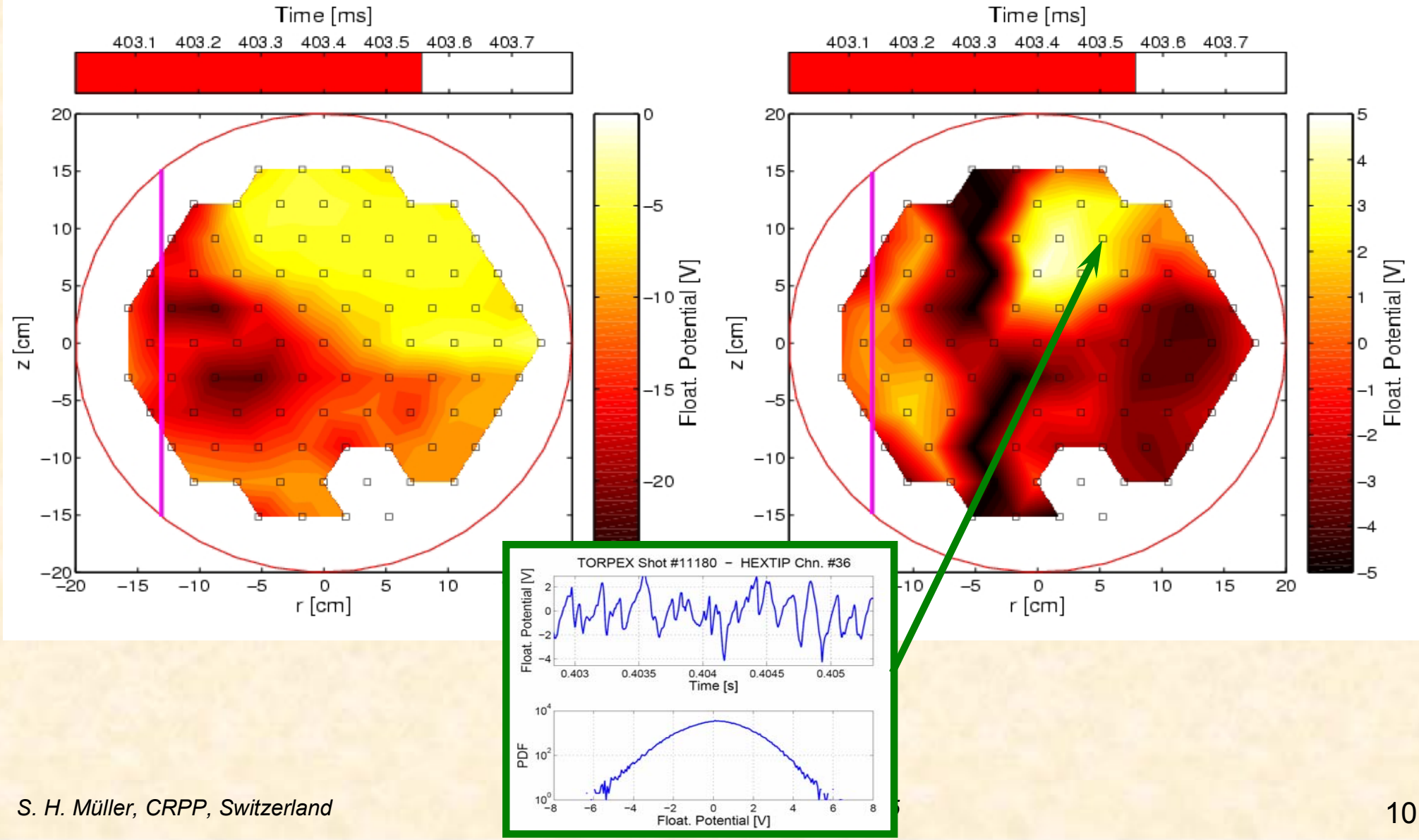


High B_z



Bringing the Two Approaches Together…

Low B_z High B_z



Conclusions

- Basic experiments like TORPEX can provide information on both:
  - Turbulence statistics
  - Turbulent structures
- Complete spatio-temporal turbulence records available on TORPEX through the HEXTIP diagnostic
  - “Hands free” to scan other parameters than probe positions
  - 200 shots per day = 200 records of a control parameter per day
  - Opens the way to study transients (plasma production, plasma decay, power modulation) and rarely reproducible events (bifurcations, …)
  - Benchmark for commonly used lock-in methods (e.g. conditional averaging)
- Important parameter: the vertical magnetic field B_z
  - Basic mechanism for parallel flow generation
  - Clear experimental evidence of its importance for particle confinement, profiles and turbulence
  - Basic mechanism at work at tokamak SOLs?

Work in Progress…

- Statistical characterization vs. turbulence imaging
  - Benchmark the two ways of comparison against each other
  - Bijective mapping between “PDFs” and “poloidal blobs”?
- Theory
  - Adapt a 2D two-fluid turbulence code to account for the essential effects of B_z *(Collaboration with V. Naulin and Risoe people)*
  - Direct comparison with the experiment
    - Equilibrium profiles, confinement times, transients, …?
    - Statistical properties?
    - Spatio-temporal behavior/structures?
- Miming a tokamak…
  - Induce a plasma current using the TORPEX transformer coil system
  - Progressively close the fraction of closed flux surfaces → study transition from “core-like” to “SOL-like” turbulence