Fast ion physics on TORPEX

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and

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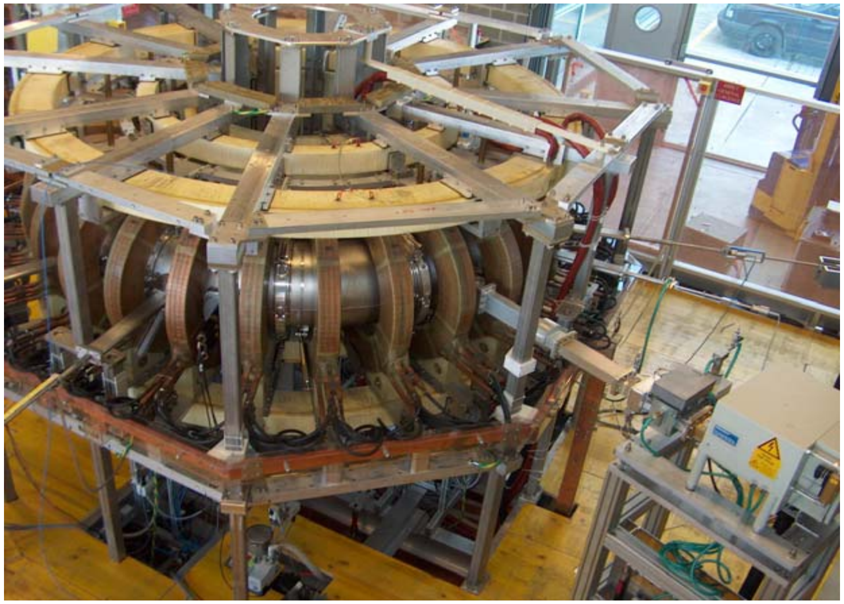
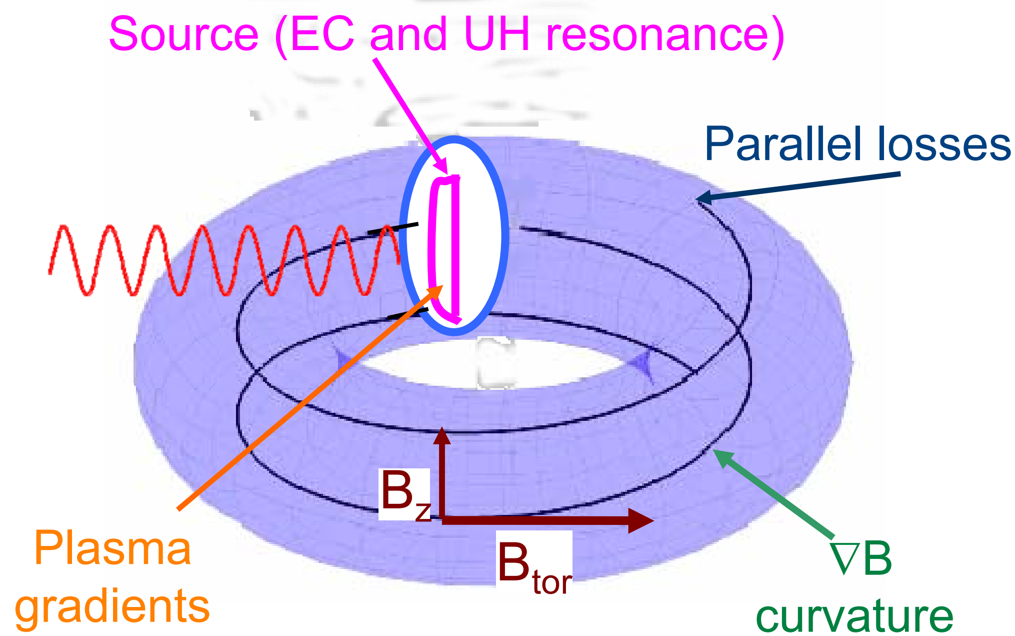
Outline

- TORPEX device
- Fast ion source and fast ion detector development
- First experimental results in interchange-dominated plasmas
- Theory and code development for fast ion physics
- Experiment – simulation comparison
- Summary

The TORPEX device



[A. Fasoli et al., Phys. Plasmas **13**, 055902 (2006)]



- Toroidal device: R=1 m, a=0.2 m
- Plasma production: magnetron (2.45 GHz, < 20 kW, ~1 s);
- Extensive set of diagnostics (electrostatic, magnetic, fast camera)

H_2, D, He, Ne, Ar plasmas

B_t=76 mT on axis

B_z= 0 – 6 mT

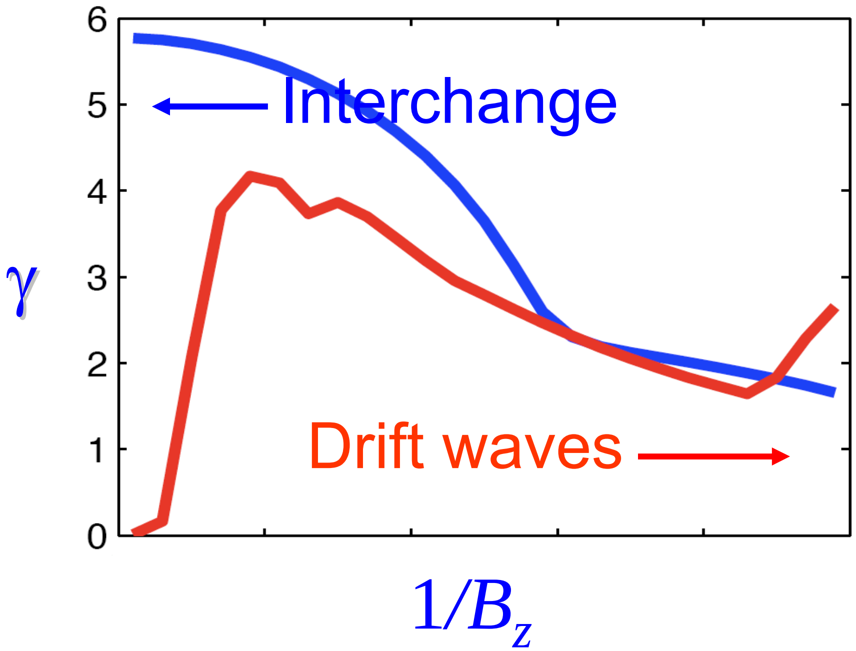
T_e = 2 – 20 eV

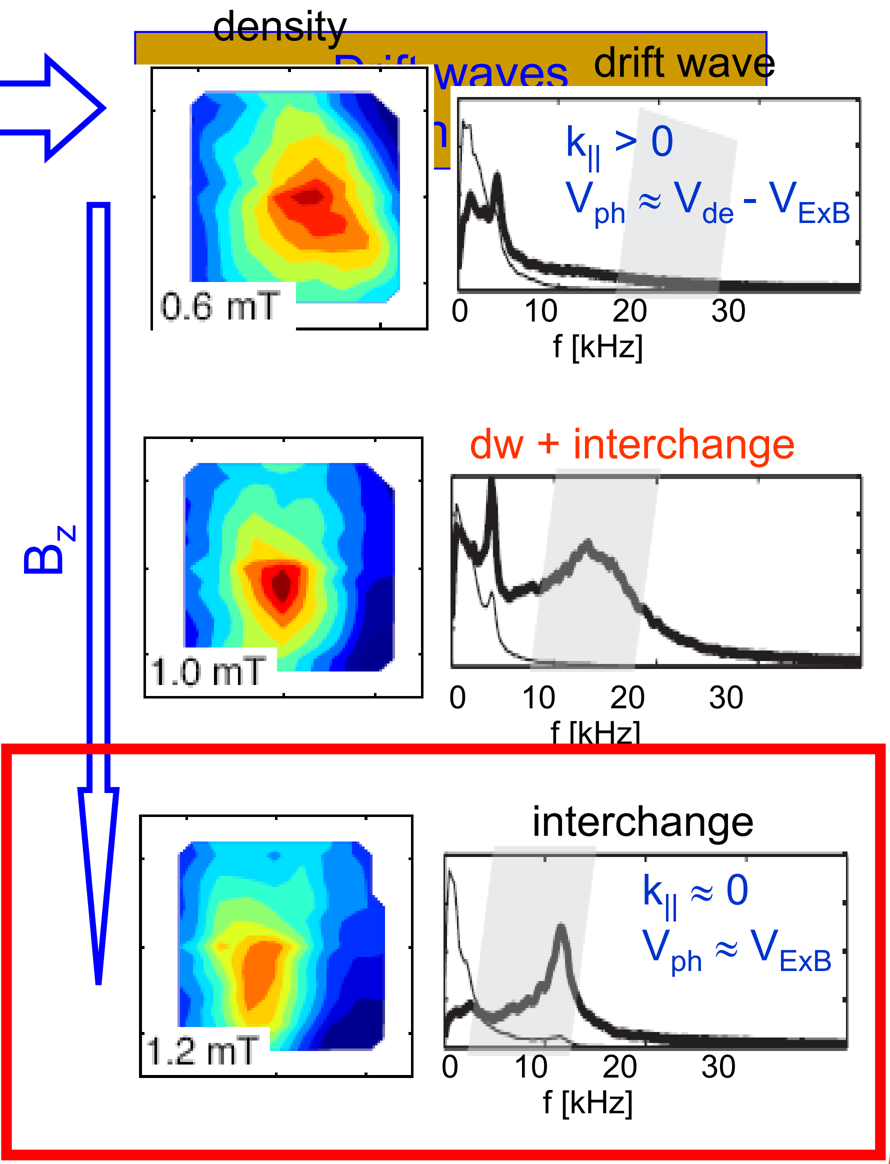
n_e = 0.1 – 5 x 10^{16} m^{-3}

Drift and interchange waves are present

Plasma gradients
+
Magnetic curvature

B_z controls the nature of the instabilities

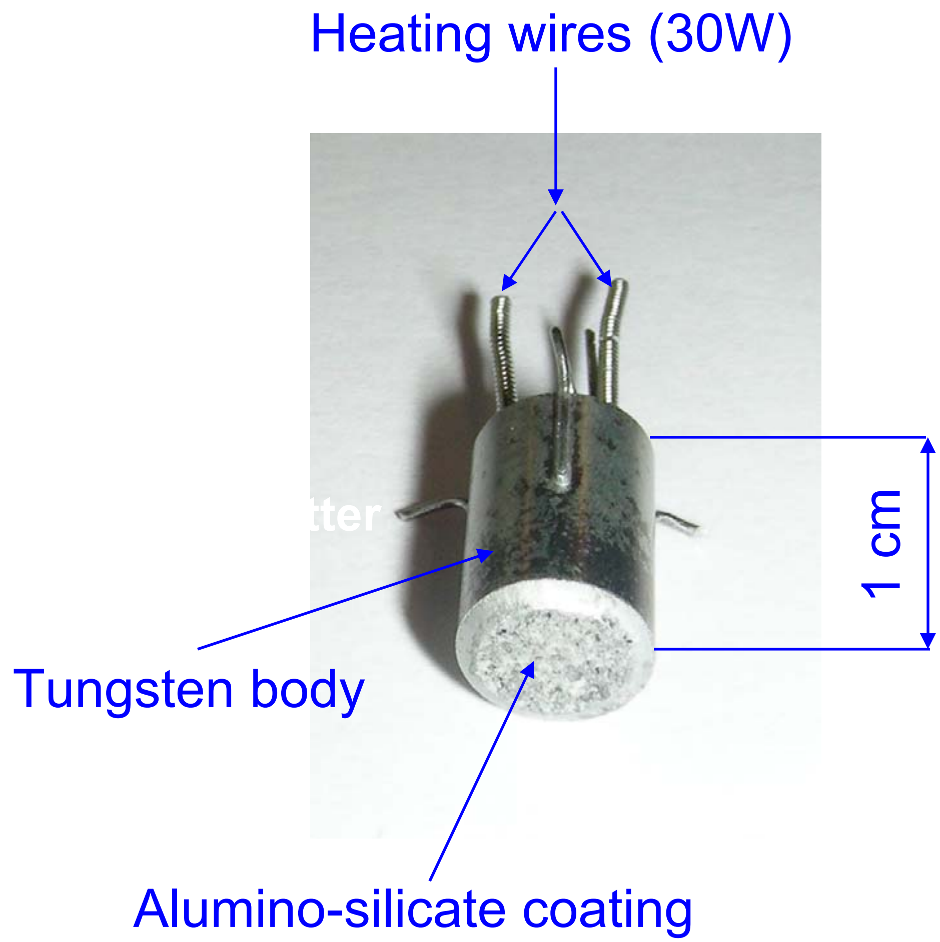




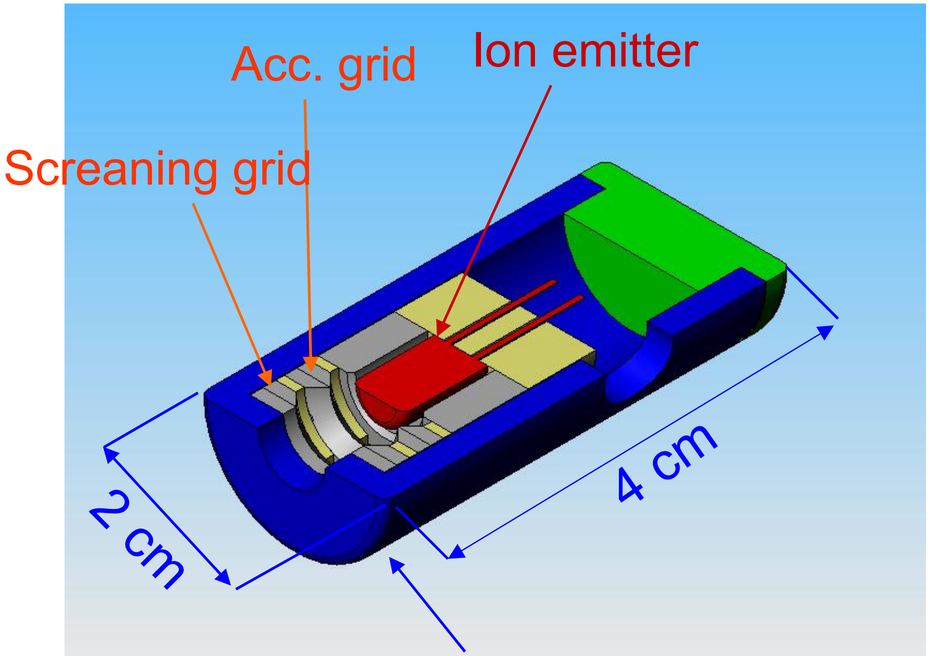
P. Ricci, *et al.*, Phys. Rev. Lett. **100**, 225002 (2008)

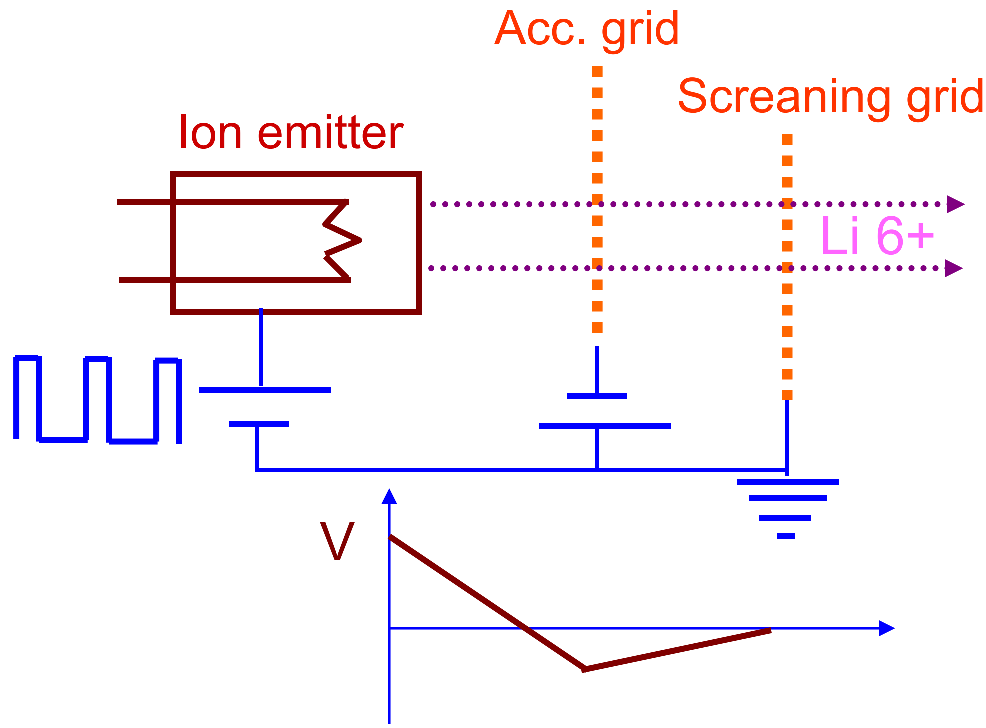
Fast ion source development: the emitter

- Collaboration CRPP-UCI
- Miniaturized Li^{6+} ion emitter produced by Heat Wave Labs
- Thermo-ionic effect (~1200°)
- Dimensions: **0.25''** diameter–1 cm length
- Extraction voltage: 0.1 – 1kV
- Ion current ~ nominal 10µA **(10µA)**
- Lifetime ~ nominal 300 h **(20 h)**



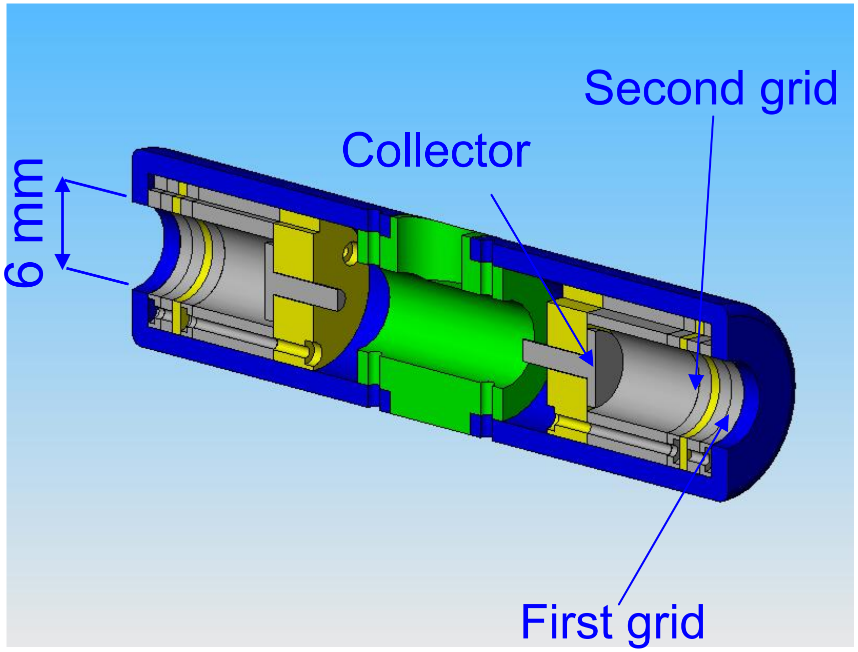
The fast ion source for TORPEX

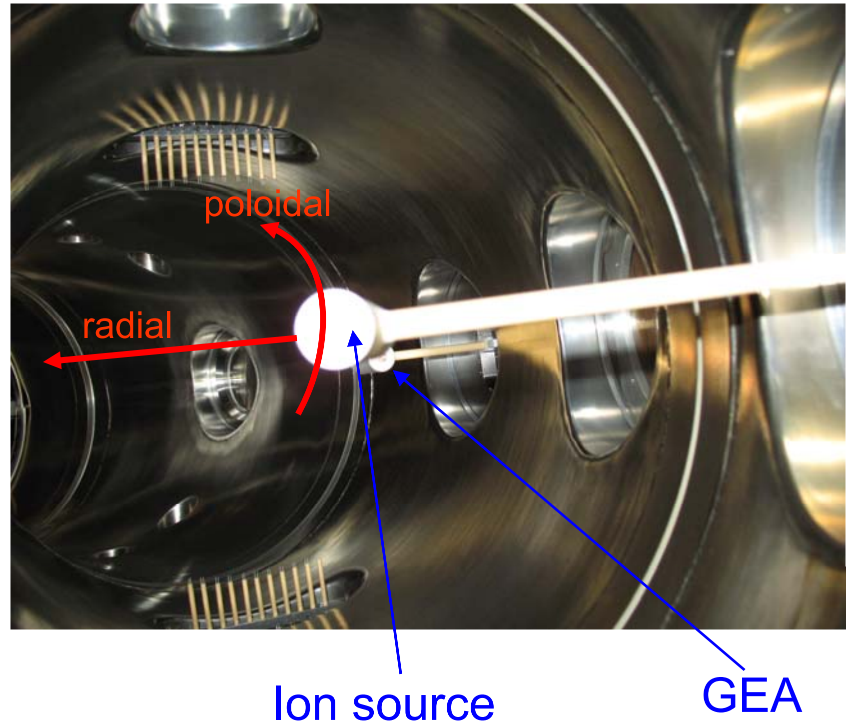




- ❑ Compact, vacuum and plasma safe BN casing
- ❑ Double grid accelerating scheme
- ❑ Grid geometry optimized for small beam divergence
- ❑ Screen grid at plasma/ground potential ⇒ reduce disturbance
- ❑ 0.1 -1 kV modulated (~1kHz) PS ⇒ synchronous detection to increase SNR

Double gridded-energy analyzer (GEA)

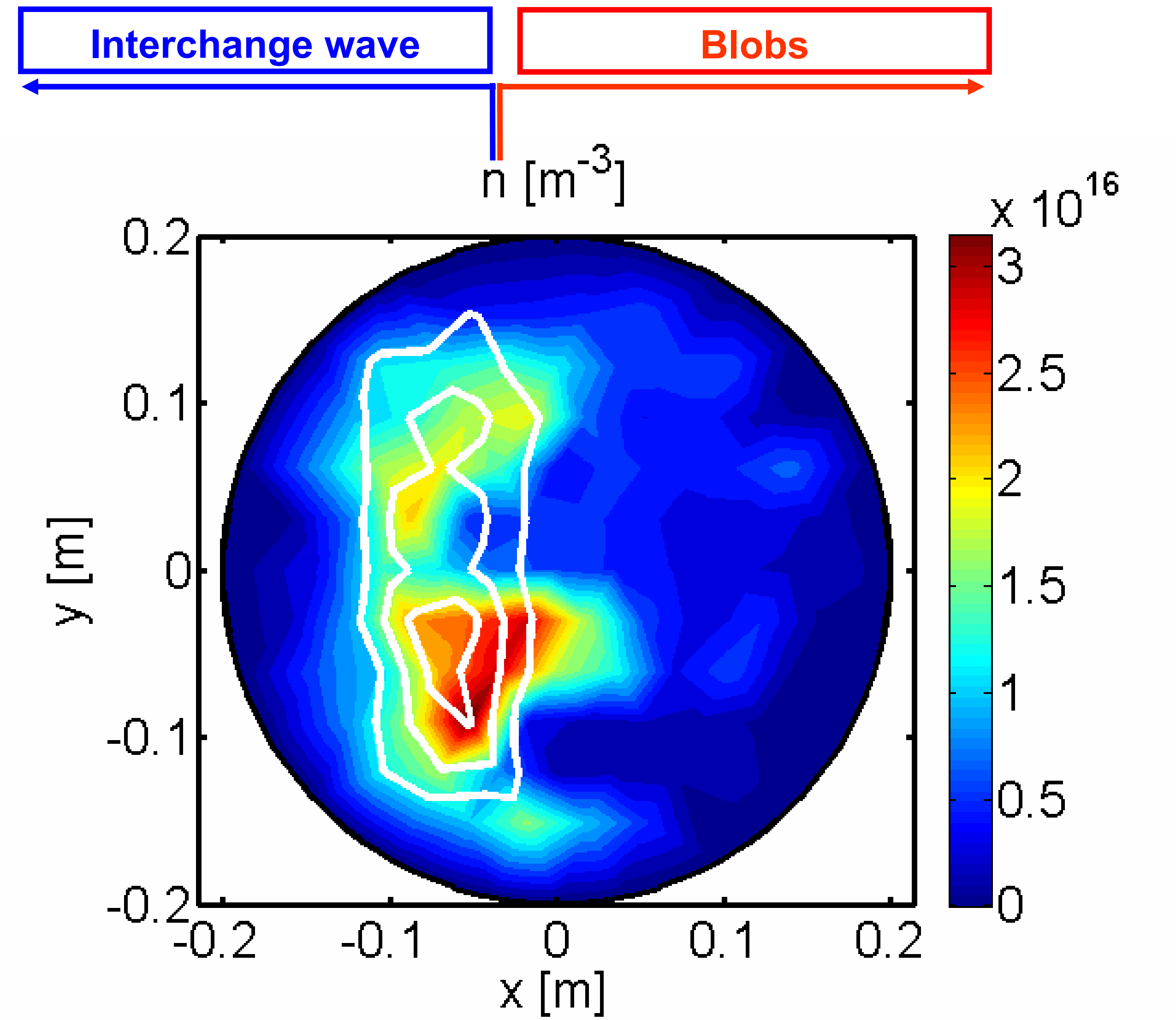




- ❑ Two identical GEA for background noise reduction
- ❑ Sweeping frequency 1kHz ⇒ 1ms time resolution
- ❑ 6mm space resolution

- ❑ Both ion source and GEA on 2D movable system ⇒ complete coverage of poloidal section
- ❑ Toroidal spacing ~ 10 cm - 5 m

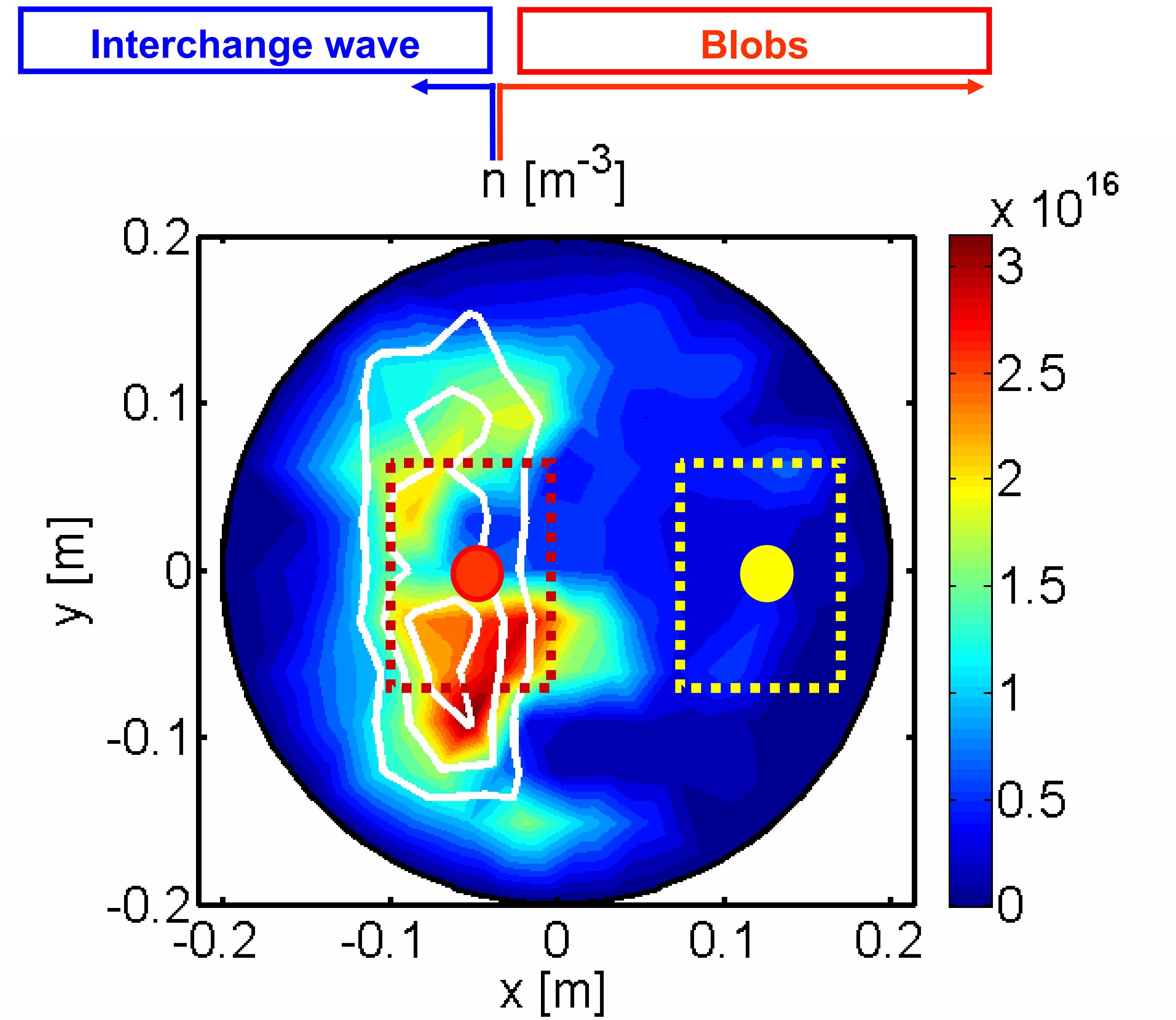
Target: interchange-dominated plasma



- **H_2 plasma**
- P_f = 400 W
- B_t=76 mT on axis
- B_z=2.1mT
- p_{gas}=6.0 x 10^{-5} mbar

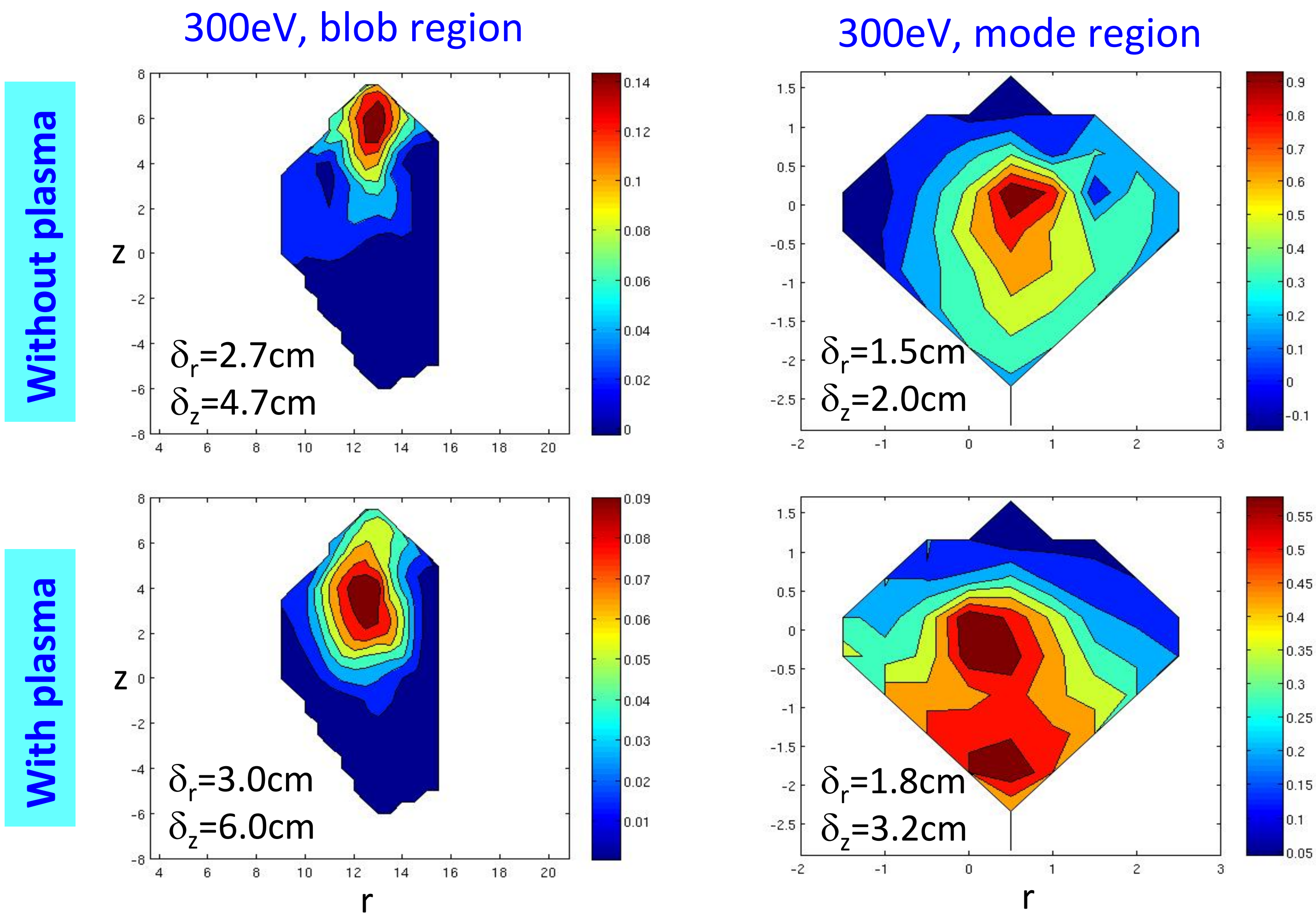
S. H. Müller, et al., Phys. Plasmas **14**, 110704 (2007); I. Furno, et al., Phys. Rev. Lett. 100, 055004 (2008);

Target: interchange-dominated plasma



- Ion source and detector are 25 cm toroidally apart
- E_{ion} = 300 eV at source
- Ions with E > 50eV are detected

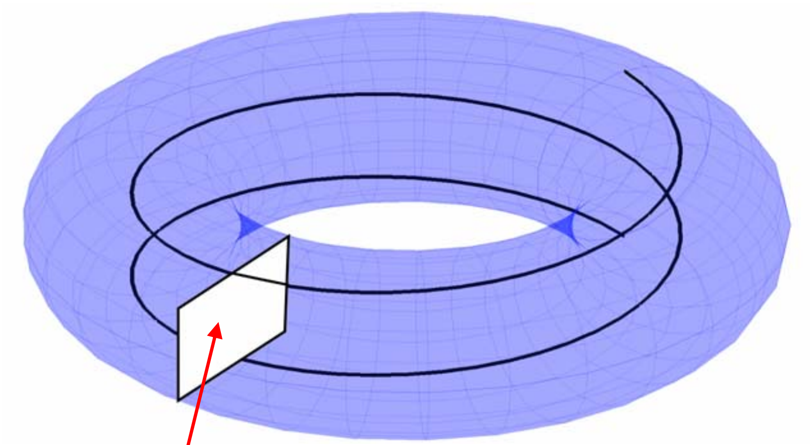
Experimental Fast Ion Current Density Profiles



Fast ion current density profiles are broadened (both in r and y) by the plasma.

G. Plyushchev's PhD Thesis

Theory development: fluid model



- 2-Fluid model, evolving N, ϕ, T_e.
- ∇B and curvature taken into account.
- 2D geometry with dissipation in the parallel direction.
- Diffusion coefficients from Braginskii equations.
- Source terms from the experiment.

Density:

$$\frac{dN}{dt} = D_n \nabla^2 N + \frac{2}{R}\left(N\frac{\partial T_e}{\partial z} + T_e\frac{\partial n}{\partial z} - n\frac{\partial \phi}{\partial z}\right) - \sigma N\sqrt{T_e}\, e^{\Lambda-\phi/T_e} + S_n$$

Temperature:

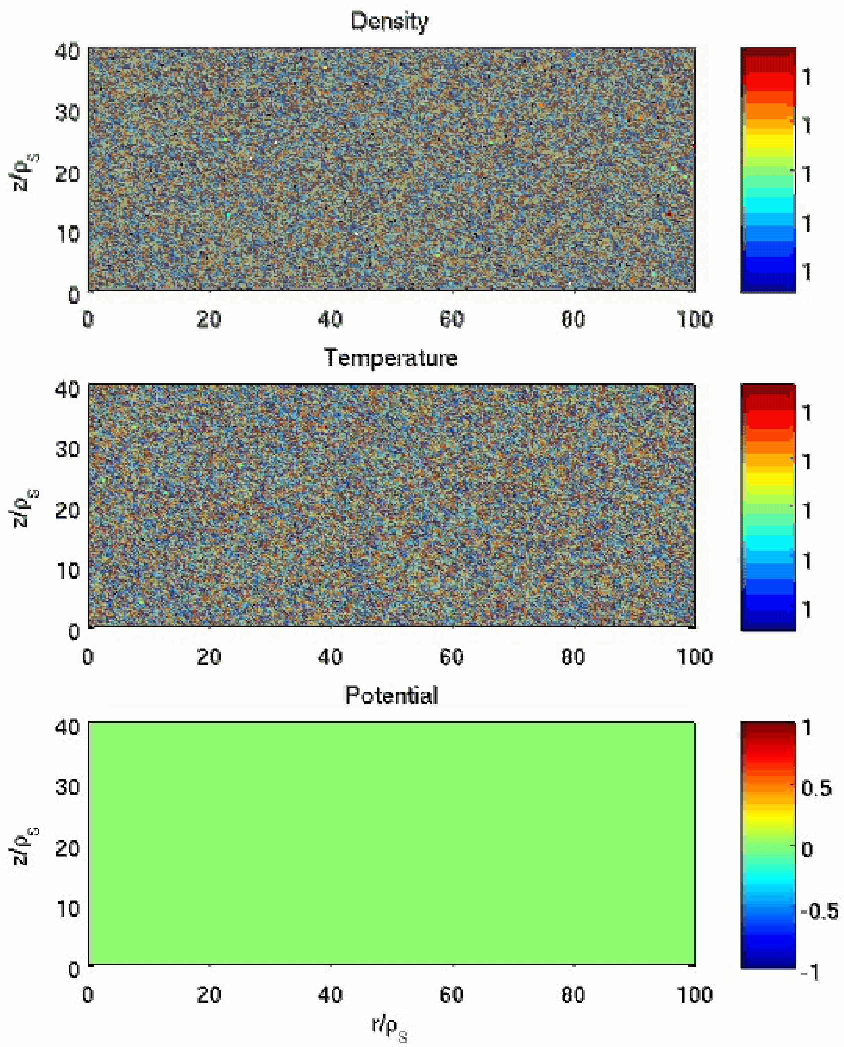
$$\frac{dT_e}{dt} = D_T \nabla^2 T_e + \frac{4}{3R}\left(\frac{7}{2} T_e\frac{\partial T_e}{\partial z} + \frac{T_e^2}{n}\frac{\partial n}{\partial z} - T_e\frac{\partial \phi}{\partial z}\right) - \sigma\sqrt{T_e^3}\, e^{\Lambda-\phi/T_e} + S_T$$

Potential:

$$\frac{d\nabla^2 \phi}{dt} = D_\phi \nabla^4 \phi + \frac{2}{R}\left(\frac{T_e}{n}\frac{\partial n}{\partial z} + \frac{\partial T_e}{\partial z}\right) + \sigma\sqrt{T_e}\left(1 - e^{\Lambda-\phi/T_e}\right)$$

Advection | Diffusion | Interchange drive | Parallel losses | Source

Simulation of interchange-dominated plasmas

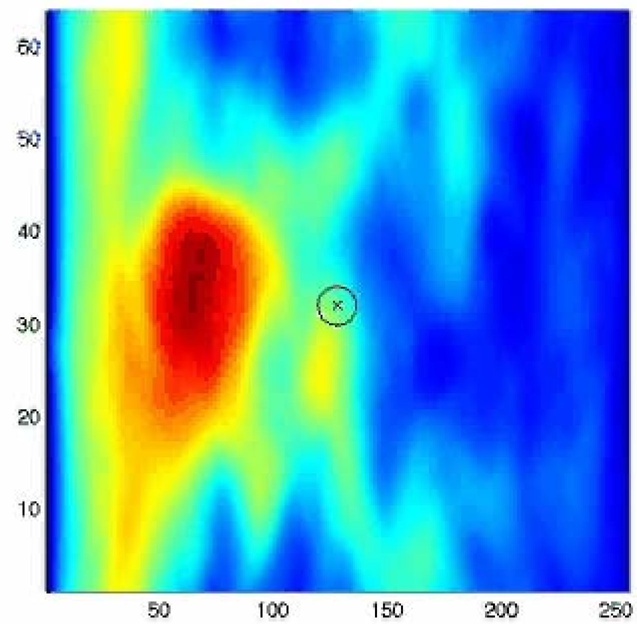


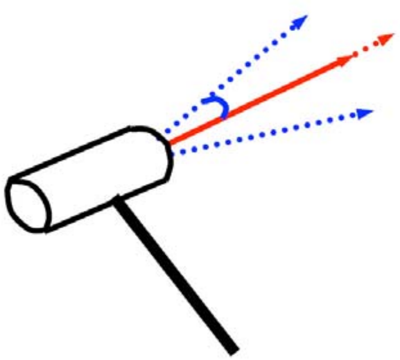
- Numerical code based on 2D-ADS code by O.E. Garcia, numerical schemes in V. Naulin, J. Sci. Comput. **25**, 104, 2003.
- The simulation is started from constant values and $_e$nergy and particles increase during first phase.
- An interchange mode is destabilized. During the non linear stage, the generation of blobs is observed.
- A framework for experiment-simulation comparison has been developed ⇒ definition of observables [P. Ricci, et al., Phys Plasmas (2008)]

Fast ions in turbulent fields

$$\begin{cases} \dfrac{d\vec{r}}{dt} = \vec{v} \\ m\dfrac{d\vec{r}}{dt} = q\left[\vec{E}(\vec{r},t) + \vec{v}\times\vec{B}(\vec{r},t)\right] \end{cases}$$

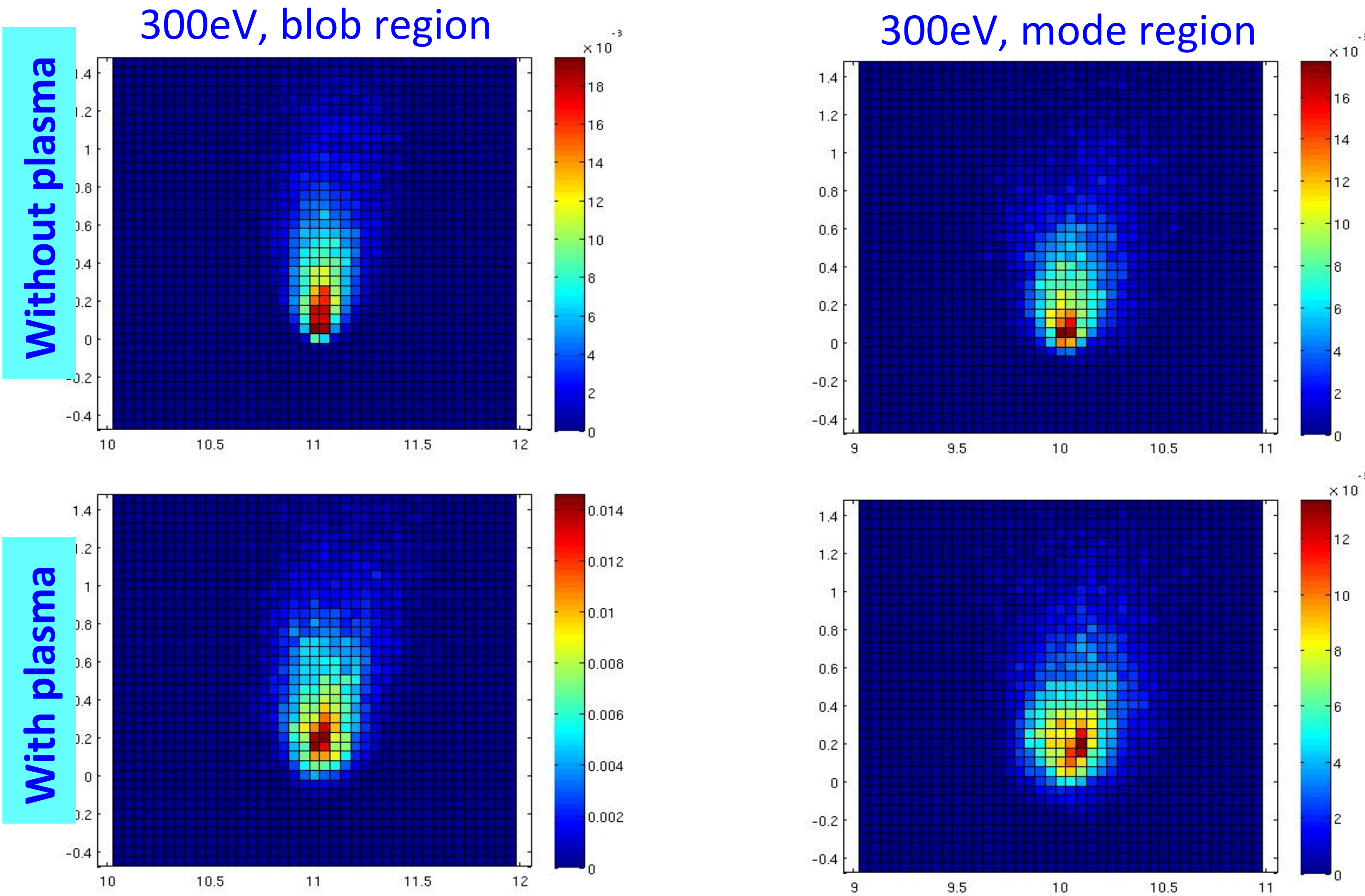
- Turbulent electric field: provided by the simulations
- values interpolated using bicubic method. Integrate the eq. of motion using the Boris algorithm:
- - implicit scheme
- - first order error.





The source:
sigma in of 10% of
sigma in the angles of 0.2 rad

Simulated Fast Ion Current Density Profiles



The elongated profiles can be explained by the spread in velocity distribution.
The simulation qualitatively explains the shape of the experimental profiles.
The broadening in r direction, predicted by simulation is observed in the experiments.

Summary

- A fast ion source and a fast ion detector have been developed for TORPEX. Both source and detector are portable to other devices.
- A larger source (0. 5’’) is currently under testing.
- First experiments reveal effects of plasma turbulence on fast ion profiles
- A framework for experiment-simulation comparison has been developed.