Motivation, plans and schedule for momentum transport/hysteresis experiments in HL-2A

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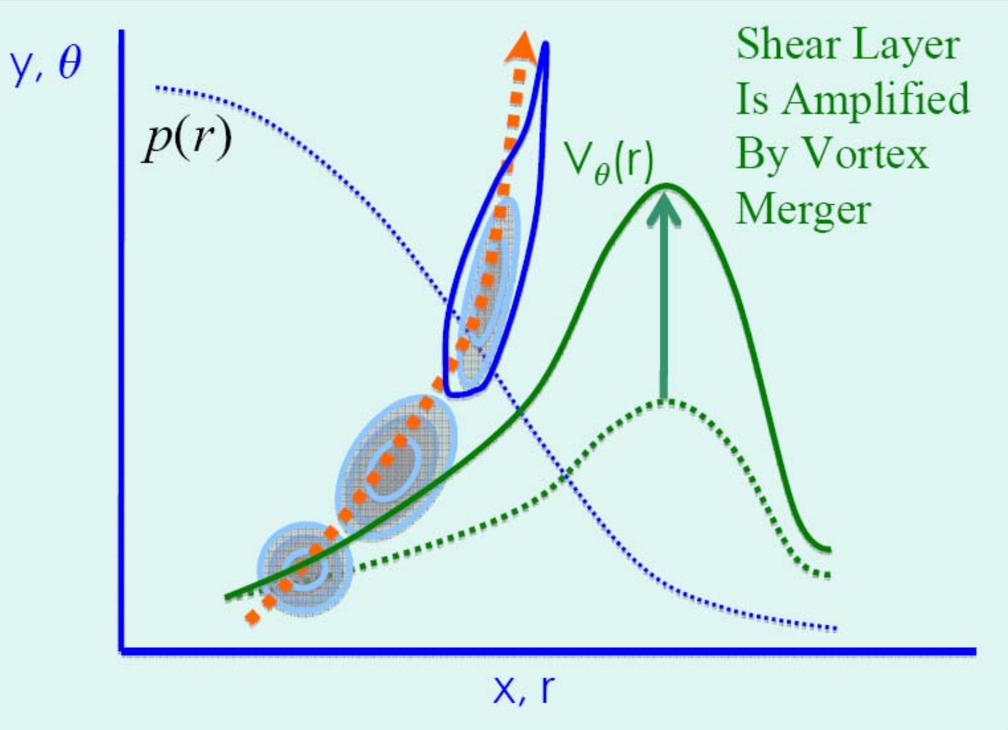
Contents

- **Motivation**
  - **Picture of vortex dynamics suggested by CSDX and DIII-D data**
  - **HL-2A tokamak and relevant experiment results**
- **Experiments plans**
  - **Momentum transport and energy transfer experiment in HL-2A**
  - **Hysteresis experiment**
- **Experiments schedule**
- **Summary**

Picture of vortex dynamics in CSDX

Drift Vortices are tilted, stretched, and absorbed, therefore transfer K.E. and momentum into shear flow.



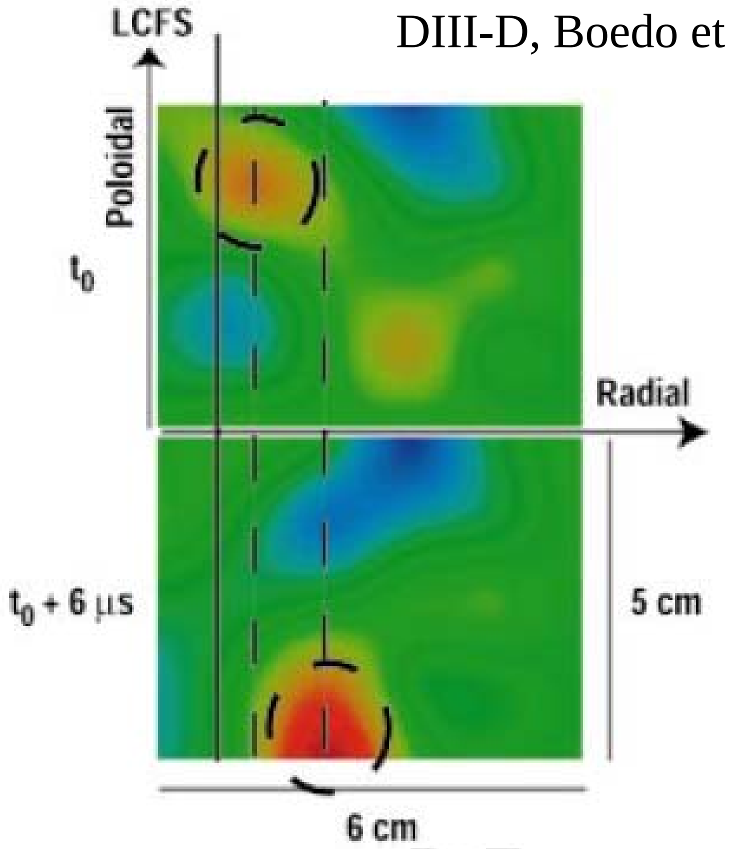
Tynan, Summary of results from CSDX, Tue. afternoon

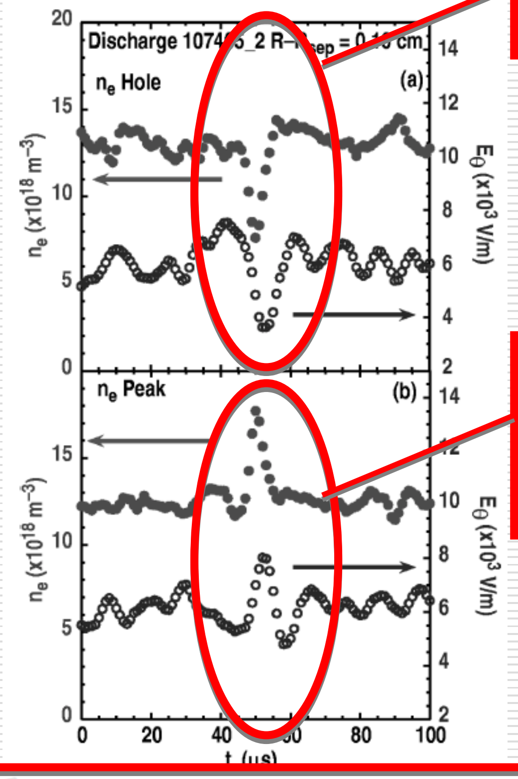
Motivation: Blobs Transport Vorticity (= **MOMENTUM)**

Tynan, ITPA 2010

$$Vorticity\ \tilde{\omega} \equiv \nabla \times \tilde{v} = \nabla^2 \tilde{\phi} \quad for\ v = E \times B / B^2$$

DIII-D, Boedo et al PoP’03





Holes Have ω<0 & Move Inwards

Blobs Have ω>0 & Move Outwards

REYNOLDS FORCE GIVEN AS

$$F_\theta^R = -\partial_r \langle \tilde{u}_r \tilde{u}_\theta \rangle = -\langle u_r \nabla^2 \phi \rangle$$

OUTWARD BLOB MOTION DRIVES BULK PLASMA FLOW

Heuristics of Zonal Flows c.)

1) Ambipolarity breaking → polarization charge ↔ PV Transport → Reynolds stress

- Schematically:
  - Polarization charge $\Rightarrow \boxed{\rho^2}\nabla^2\phi = \boxed{n_{i,GC}(\phi) - n_e(\phi)}$

    polarization length scale

    ion, electron guiding center density

    so $\Gamma_{i,GC} \neq \Gamma_e \overset{\longrightarrow}{\Longrightarrow} \rho^2\left\langle \tilde{v}_{rE}\nabla_\perp^2\tilde{\phi}\right\rangle \neq 0 \Longleftrightarrow$ ‘PV mixing’

    polarization flux
  - If 1 direction of symmetry (or near symmetry):

$$\left\langle \tilde{v}_{rE}\nabla_\perp^2\tilde{\phi}\right\rangle = -\partial_r\left\langle \tilde{v}_{rE}\tilde{v}_{\perp E}\right\rangle$$

(Taylor, 1915)

  - Flow drive: $-\rho^2\partial_r\left\langle \tilde{v}_{rE}\tilde{v}_{\perp E}\right\rangle \Rightarrow$ Reynolds force

Diamond,CMTFO
Annual 2011
From wave momentum
and potential vorticity
mixing…,

Detailed experiments needed

◆ Does ZF/GAM act to nonlinearly scatter turbulent energy into ZF/GAM?
Need to directly measure the nonlinear energy transfer among different structures with different scales.

◆ Does blobs/holes mediate the momentum transport at the edge?
Measure the vorticity flux and relevant correlations

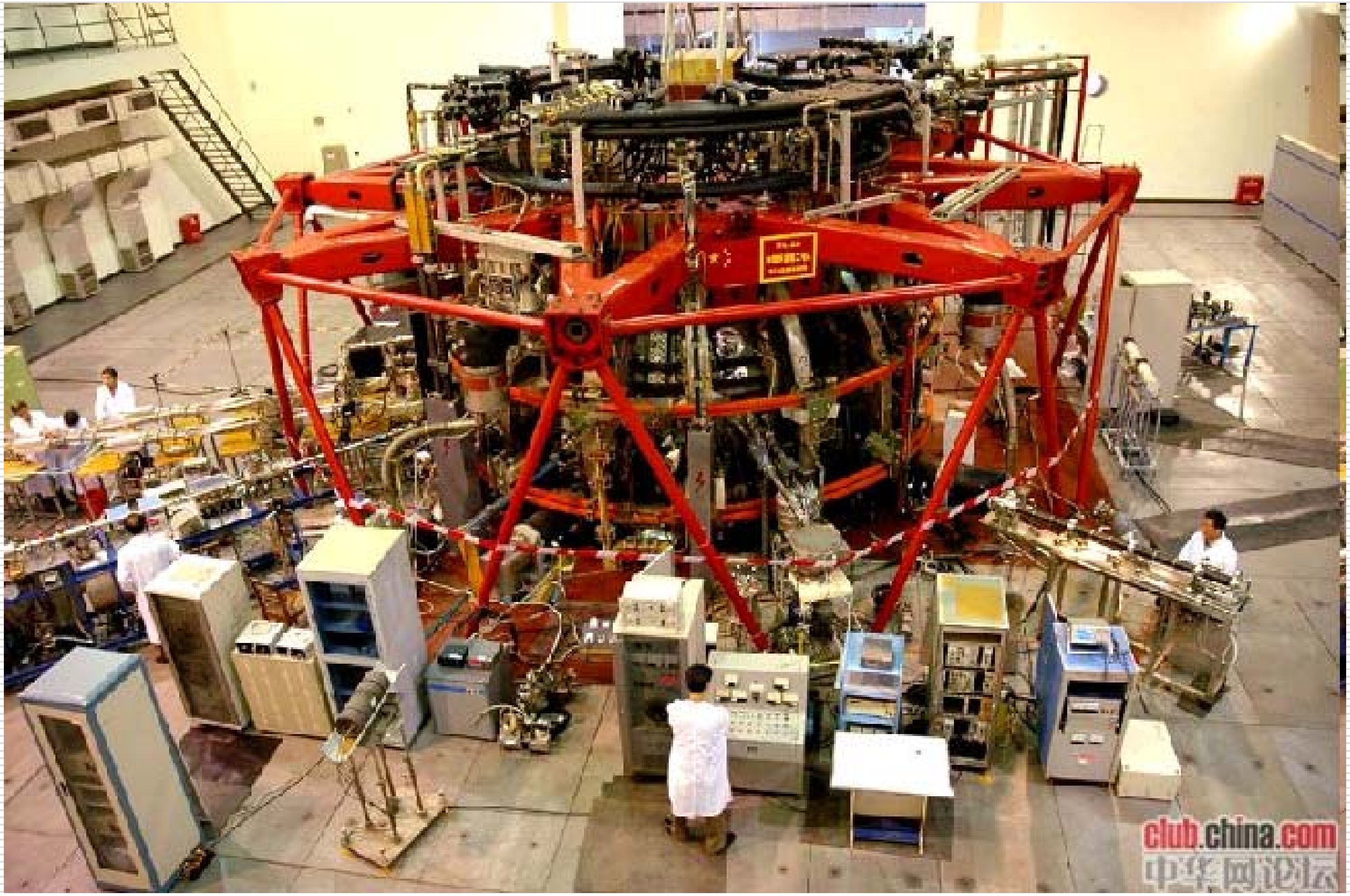
◆ Is the R/S across GAM and ZF region consistent w/ GAM and ZF profiles?
Need the R/S, ZF, and GAM profiles

Need to be done in one shot or highly identical shots under various different conditions to check the consistency.

Why HL-2A?

- Machine time available
- Realized H-mode
- Good manpower support
- Interest physics exist (ZFs, GAMs)
- Allow us to stick in Langmiur probes

HL-2A tokamak at SWIP



HL-2A tokamak at SWIP

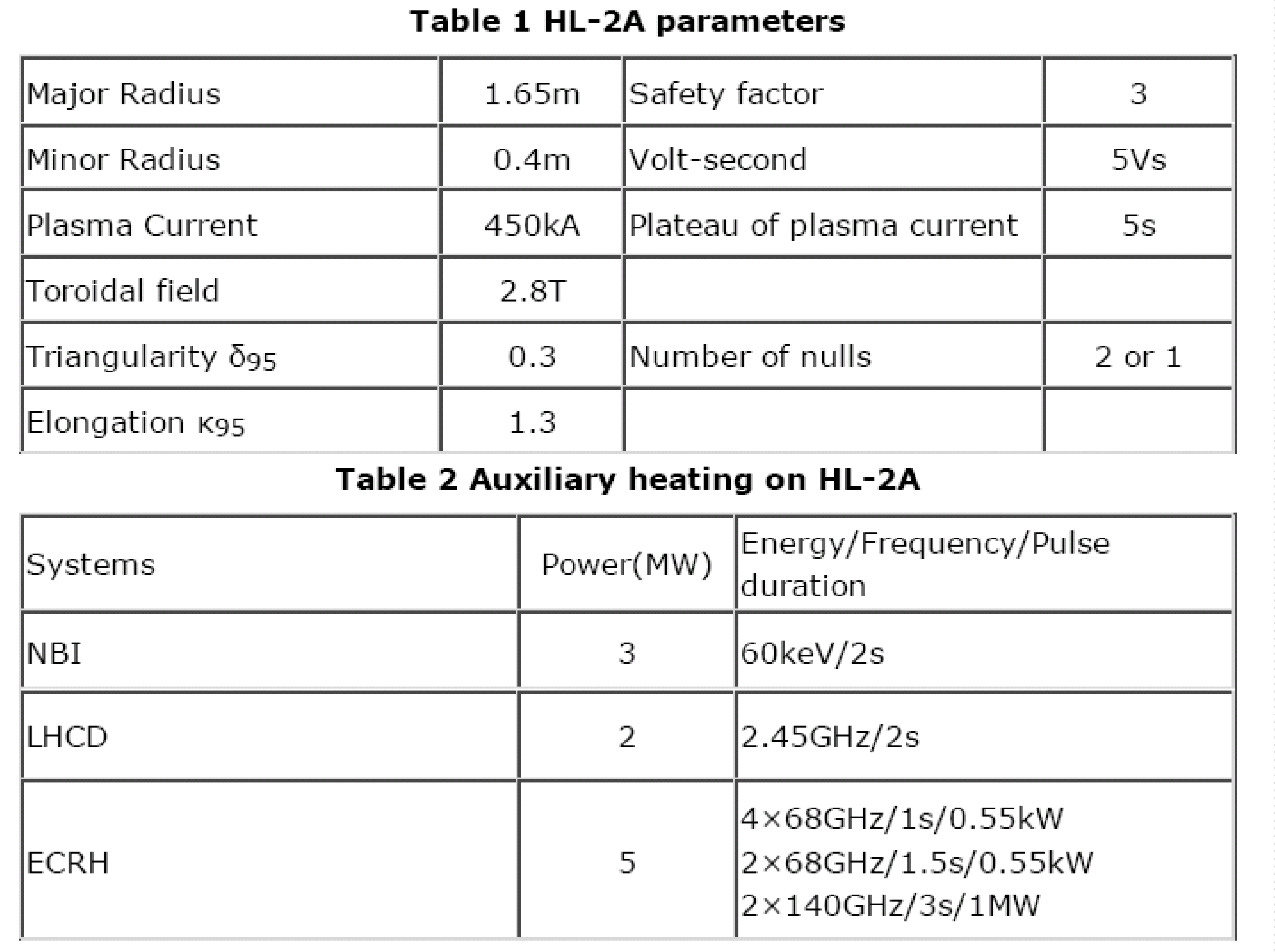


Table 1 HL-2A parameters

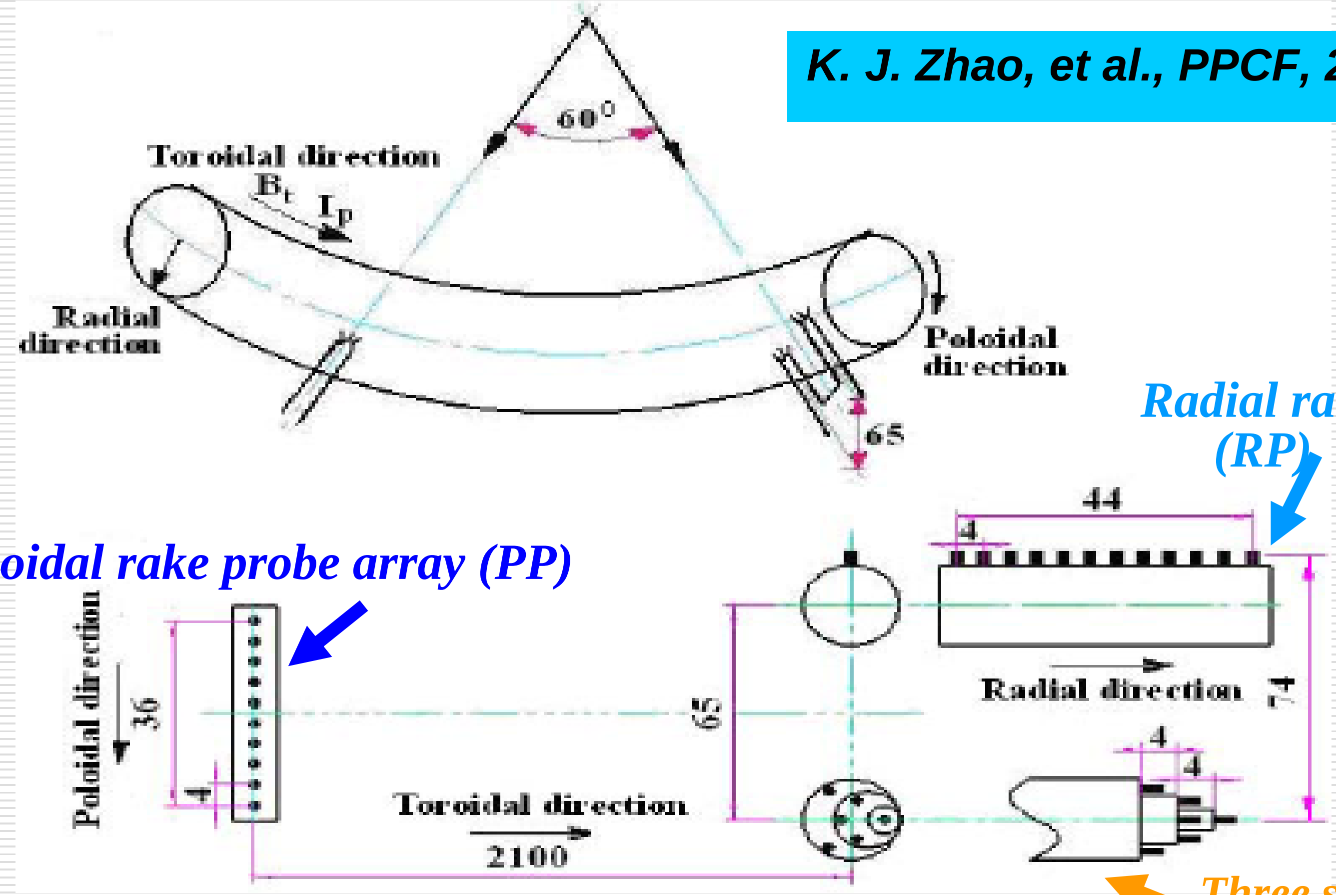
Major Radius	1.65m	Safety factor	3
Minor Radius	0.4m	Volt-second	5Vs
Plasma Current	450kA	Plateau of plasma current	5s
Toroidal field	2.8T		
Triangularity δ_{95}	0.3	Number of nulls	2 or 1
Elongation κ_{95}	1.3		

Table 2 Auxiliary heating on HL-2A

Systems	Power(MW)	Energy/Frequency/Pulse duration
NBI	3	60keV/2s
LHCD	2	2.45GHz/2s
ECRH	5	4×68GHz/1s/0.55kW 2×68GHz/1.5s/0.55kW 2×140GHz/3s/1MW

HL-2A Fast-scan probes

K. J. Zhao, et al., PPCF, 2010 .



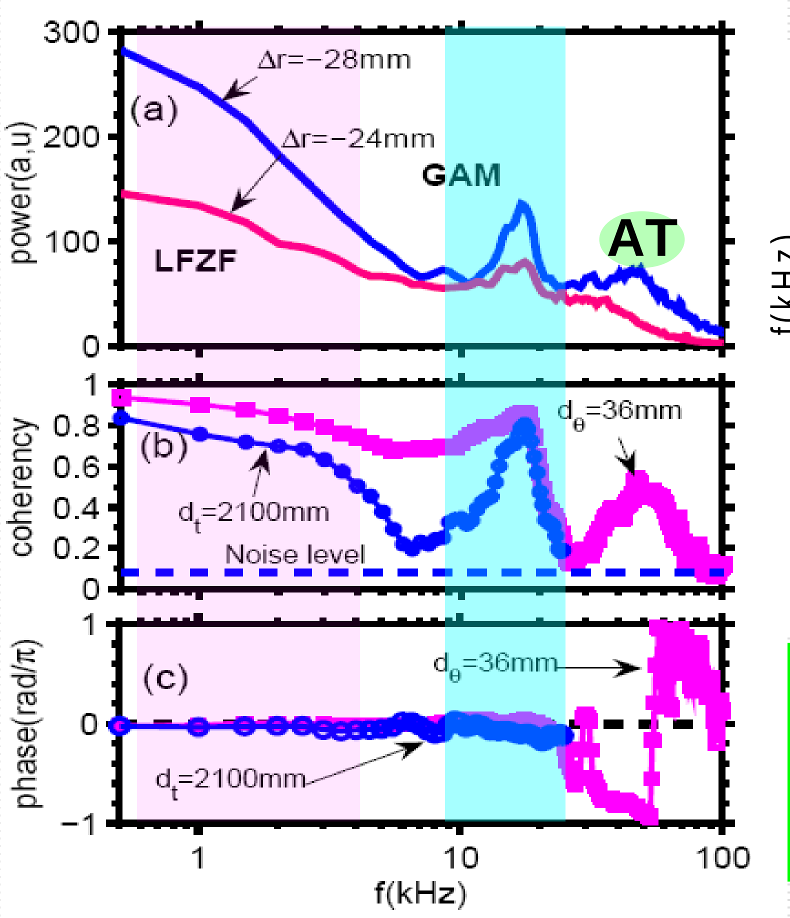
Radial rake probe array (RP)

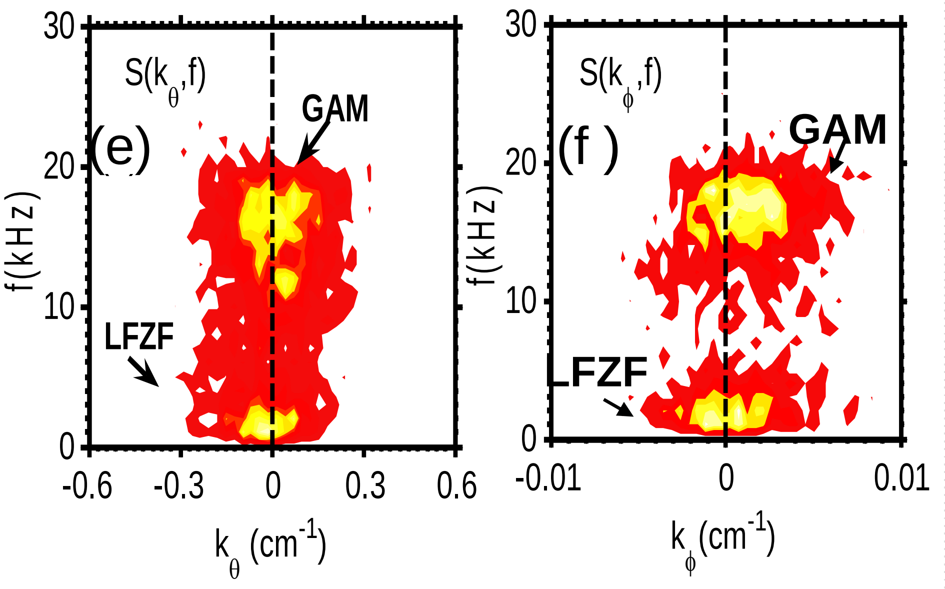
Poloidal rake probe array (PP)

Three step Langmuir probe array (TSLP)

L. W. Yan, et al., RSI, 2006.

Coexistence of intensive LFZFs and GAMs

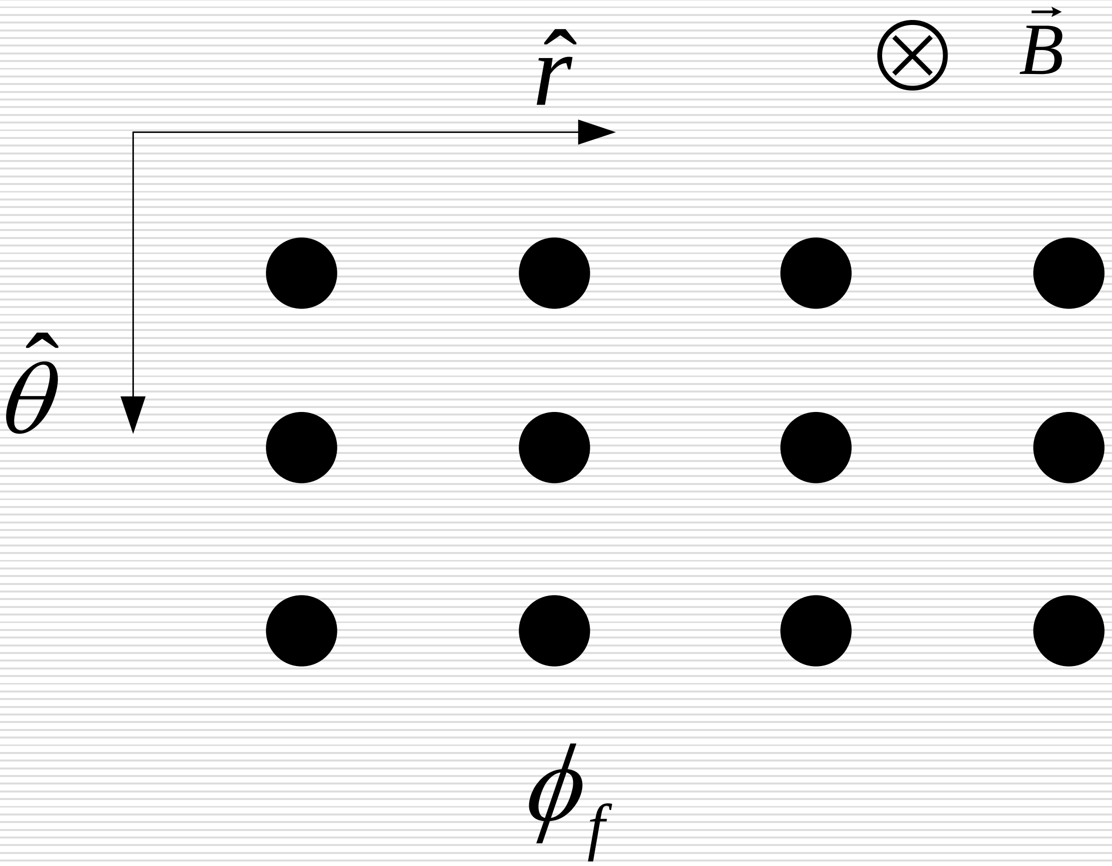




The poloidal and toroidal symmetries, i.e, *m=0,n=0* were measured, simultaneously, for LFZF and GAM.

Langmiur probe array layout

CMTFO



- ◆ ***NL energy transfer***
- ◆ ***Vorticity flux***
- ◆ ***Gradient of R/S***

Mom. transport and energy transfer Expt.

Meauring the NL energy transfer directly from ion momentum equation:

$$\left\langle \frac{1}{2}\frac{\partial\left|\nabla_\perp\phi_f\right|^2}{\partial t}\right\rangle = \left\langle -\mathrm{Re}\sum_{f_1}(\hat{z}\times\nabla_\perp\phi_f^*)\cdot[(\hat{z}\times\nabla_\perp\phi_{f-f_1}\cdot\nabla_\perp)(\hat{z}\times\nabla_\perp\phi_{f_1})]\right\rangle$$

$$+\left\langle \frac{\mu_\perp}{\Omega_{ci}\rho_s^2}\mathrm{Re}[(\hat{z}\times\nabla_\perp\hat{\phi}_f^*)\cdot\nabla_\perp^2(\hat{z}\times\nabla_\perp\hat{\phi}_f)]\right\rangle + \left\langle -\frac{\nu_{i-n}}{\Omega_{ci}}\left|\nabla_\perp\phi_\omega\right|^2\right\rangle$$

assumptions:

$$\vec{u}^{\,e,i}_{fluid} \approx \frac{\vec{E}\times\vec{B}}{B^2} \simeq \frac{-\nabla\phi\times\vec{B}}{B^2}$$

$$u_{thi} \ll \frac{\omega}{k}$$

Discharge conditions

1) Ohmic plasma

$I_p \sim 150kA\,,\;\; B_t \sim 1.2T$ 5 good shots with plateau duration > 200 ms

2) L-mode plasma

$I_p \sim 150kA\,,\;\; B_t \sim 1.2T\,,$

$ECRH \sim 100kW\,,\; 200kW\,,\; 300kW\,,\; 400kW\,,\; 500kW\,,\; 600kW$

For each condition, 5 good shots with plateau during >200 ms (total 30 good shots)

3) H-mode with minimum heating power

$I_p \sim 150kA\,,\;\; B_t \sim 1.3T\,,\;\; ECRH + NBI \sim 1.1MW\,,$ with SMBI

5 good shots with plateau duration > 200 ms

Hysteresis experiments

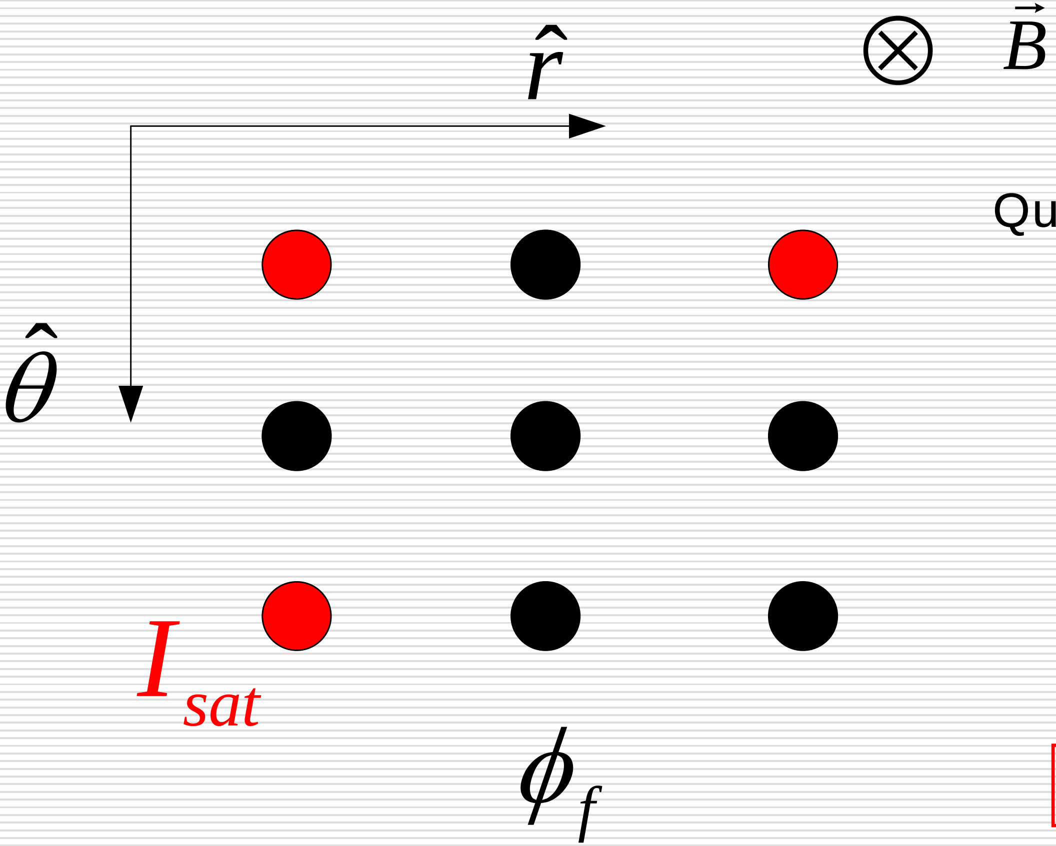
Goal of the experiment:

Measure the particle flux, Reynolds stress, vorticity flux, etc. vs. density and velocity gradients during the L-H and H-L transition phases. In other words, we will be able to map out the s-curve.

Understand the bifurcation problem from the microscopic view, and

technically will benefit the machine performance by identifying the buffer zone for H-mode.

Langmiur probe array layout



Quantities can be measured:

$$\langle \tilde{v}_r \tilde{v}_\theta \rangle \quad \langle \tilde{n} \tilde{v}_r \rangle \quad \nabla \langle n \rangle \quad \nabla \langle V_\theta \rangle$$

But phase shifts exist…

Discharge conditions

1) Mapping out within one shot

Lowest possible heating power for H-mode

$I_p \sim 150kA$, $n_e \sim 1.5\times10^{19}cm^{-3}$, $B_t \sim 1.3T$, $ECRH + NBI \sim 1.1MW$, with SMBI

Require 5 good shots with very short (<20 ms) H-mode plasma.

2) Mapping out by two shots

Lowest possible heating power for H-mode

$I_p \sim 150kA$, $n_e \sim 1.5\times10^{19}cm^{-3}$, $B_t \sim 1.3T$, $ECRH + NBI \sim 1.1MW$, with SMBI

Require 5 good shots for L-H transition, and another 5 good shots for the H-L transition

Difficulties

- The probe array must be deep enough and stay in the shear region for at least a few ms in the H-mode plasma.

- Probes may have to survive a few ELMs since the timing of L-H transition is with big uncertainty and the timing of appearance of ELMs is not predicatable.

- Need to roughly predicate the L-H transition time and the H-L transition time for shooting in the probe.

- Could SMBI be used to modify the H-mode plasma such that the stabilized H-mode lasts less than 20 ms to avoid ELMs? If so, then it will be possible for the probe stay inside the shear region for all the L-H transition, H-mode, and the H-L transition phases.

ELMs in the data

For either experiment, the Langmiur probes will encounter the ELMs.

◆ Try to avoid ELMs using SMBI due to probe overheat

◆ Can measure the ELM fluctuations at the edge if the probe can survive a few ELMs

Q1: How do density, particle flux, and R/S, etc. evolve with ELMs?
Q2: How does the SMBI affect ELMs?

Initial experiments schedule

Early March to May 2011

Approx. machine time: ~ 2 weeks

- Ohmic plasma 3x4 probe array: 2 day
- L-mode plasma with 3x4 probe array: 4 days
- H-mode plasma with 3x4 probe array: 2 days
- Hysteresis experiment: 3~4 days

Summary

◆ Directly measure nonlinear energy transfer among ZFs, GAMs, and turbulence.

◆ Measure the vorticity flux

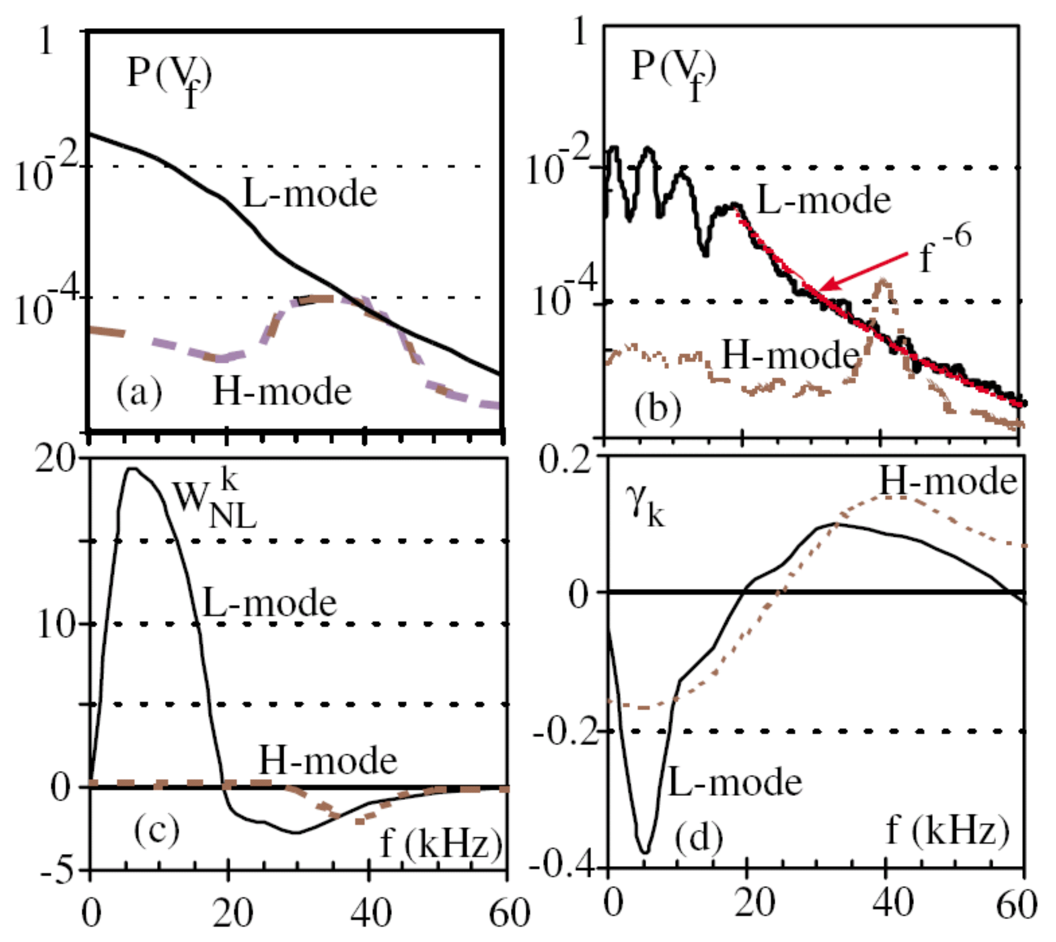
◆ R/S, ZF, and GAM profiles

as the heating power approaches L-H threshold.

◆ Hysteresis mapping and ELMs fluctuation measurement

BACKUP

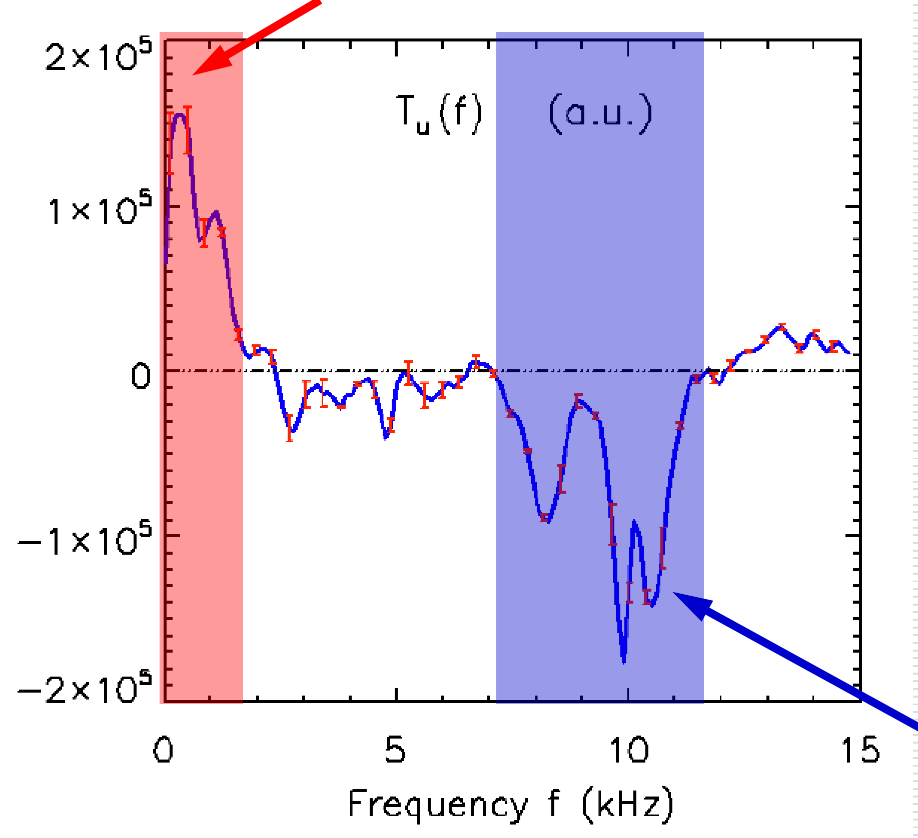
HL-2A tokamak at SWIP



H. Xia et al, PRL 2003

One field model
Might be problematic
due to the multi-field
nature of plasma.

gaining energy



losing energy

$$T_u(f) \equiv \sum_{f_1} T_u(f, f_1)$$

Kinetic energy is transferred from intermediate frequency regions to both low and high frequency regions.