

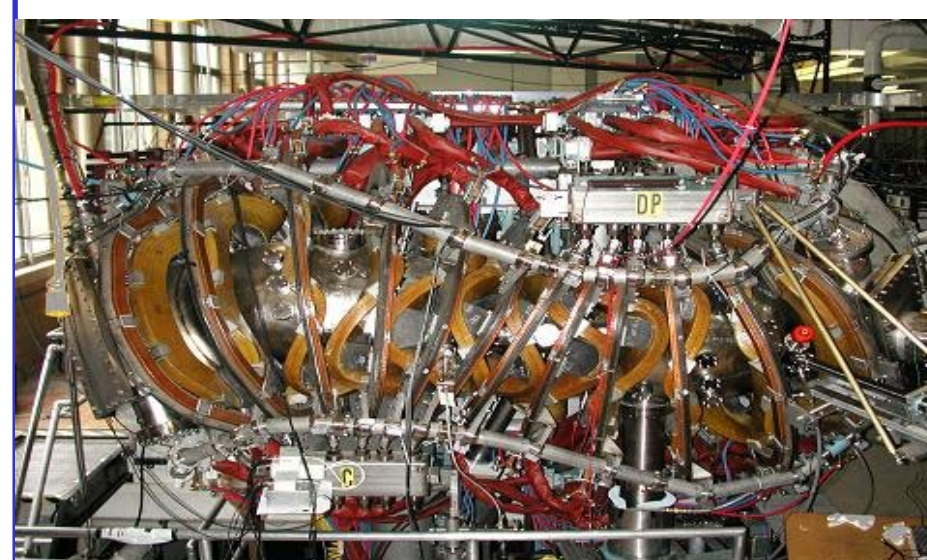


Overview of HSX Results



J.N. Talmadge, D.T. Anderson, F.S.B. Anderson, A. Briesemeister, C. Clark, C. Deng, K. M. Likin,
J. Lore, J. C. Schmitt, G. Weir, R. Wilcox, K. Zhai
HSX Plasma Laboratory, Univ. of Wisconsin, Madison, USA

Summary



HSX Parameters	
$\langle R \rangle$	1.2 m
$\langle a \rangle$	0.12 m
ι	1.05 $\rightarrow$ 1.12
B_0	0.5 -1.0 T
ECRH	28 GHz
	<100 kW

Auxiliary coils degrades quasisymmetry and increases effective ripple, viscous damping and neoclassical transport for comparison to QHS mode. This is called the Mirror mode.

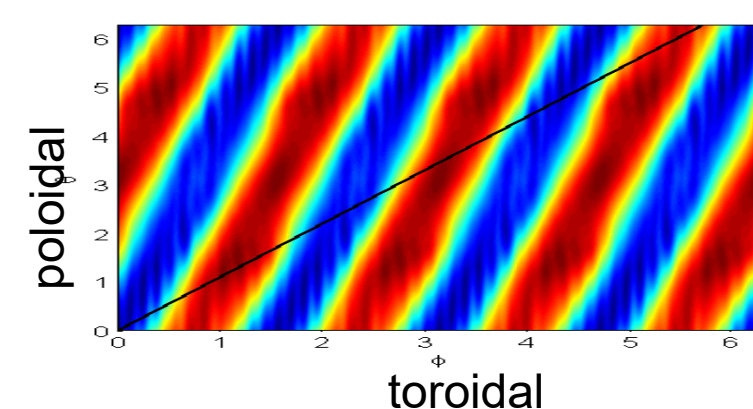
Summary of Results

- Emphasis now is investigating anomalous and neoclassical electron transport by heating electrons to low collisionality regime at $B = 1.0$ T.
- ECRH at 100 kW show $T_e \sim 2.5$ keV highly peaked in core $\Rightarrow$ Evidence of internal transport barrier (CERC) in a quasisymmetric stellarator.
- $E \times B$ suppression of turbulence needed to explain peaked T_e profile.
- CHERS measurements of E_r show agreement with ion root calculation outside plasma core.

- Large (15-20 km/s) parallel flow is due to quasisymmetry; often assumed to be zero for conventional stellarators.
- First observation of helical Pfirsch-Schluter current, as expected for device with no toroidal curvature. Signals from pick-up coils in agreement with V3FIT calculation of field due to evolving bootstrap current.
- Electrode biasing increases flow shear in direction of quasisymmetry.
- At $B=0.5$ T, coherent mode due to energetic electrons observed; consistent with acoustic mode.

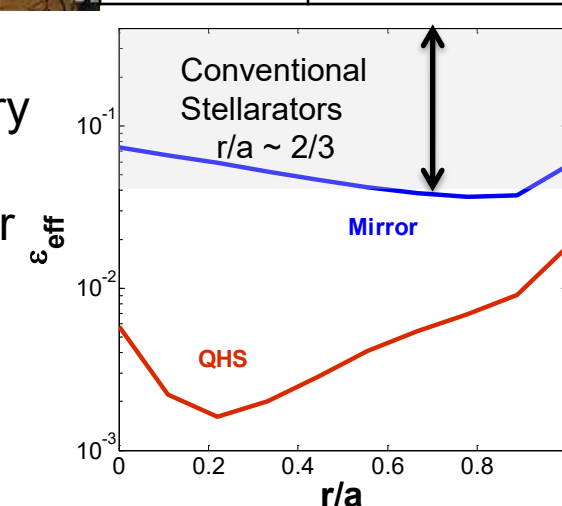
New Directions & Collaborations

Second gyrotron comes on-line in December; Impurity transport (TJ-II); Magnetic geometry effects on turbulence and zonal flows(TJ-II, IPP, PPPL, Warwick); Ion heating (ORNL);

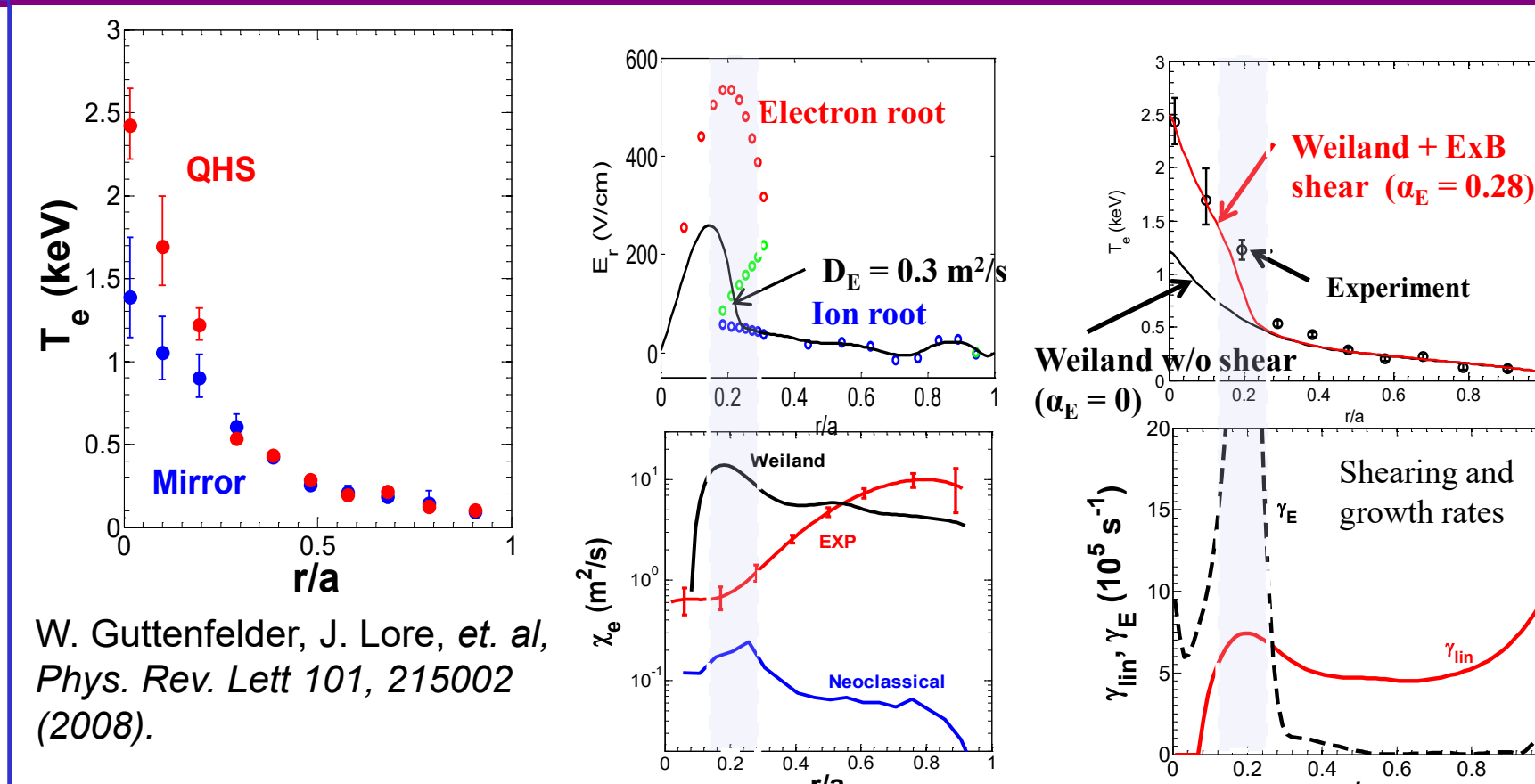


Field line travels once around toroidally $\rightarrow$ 3 periods in $|B| \rightarrow \iota \sim 3$

HSX is a quasi-helically symmetric stellarator (QHS) with almost no toroidal curvature and a high effective transform: $\iota_{\text{eff}} \sim 3$. This yields small banana widths, low plasma currents, low neoclassical transport.



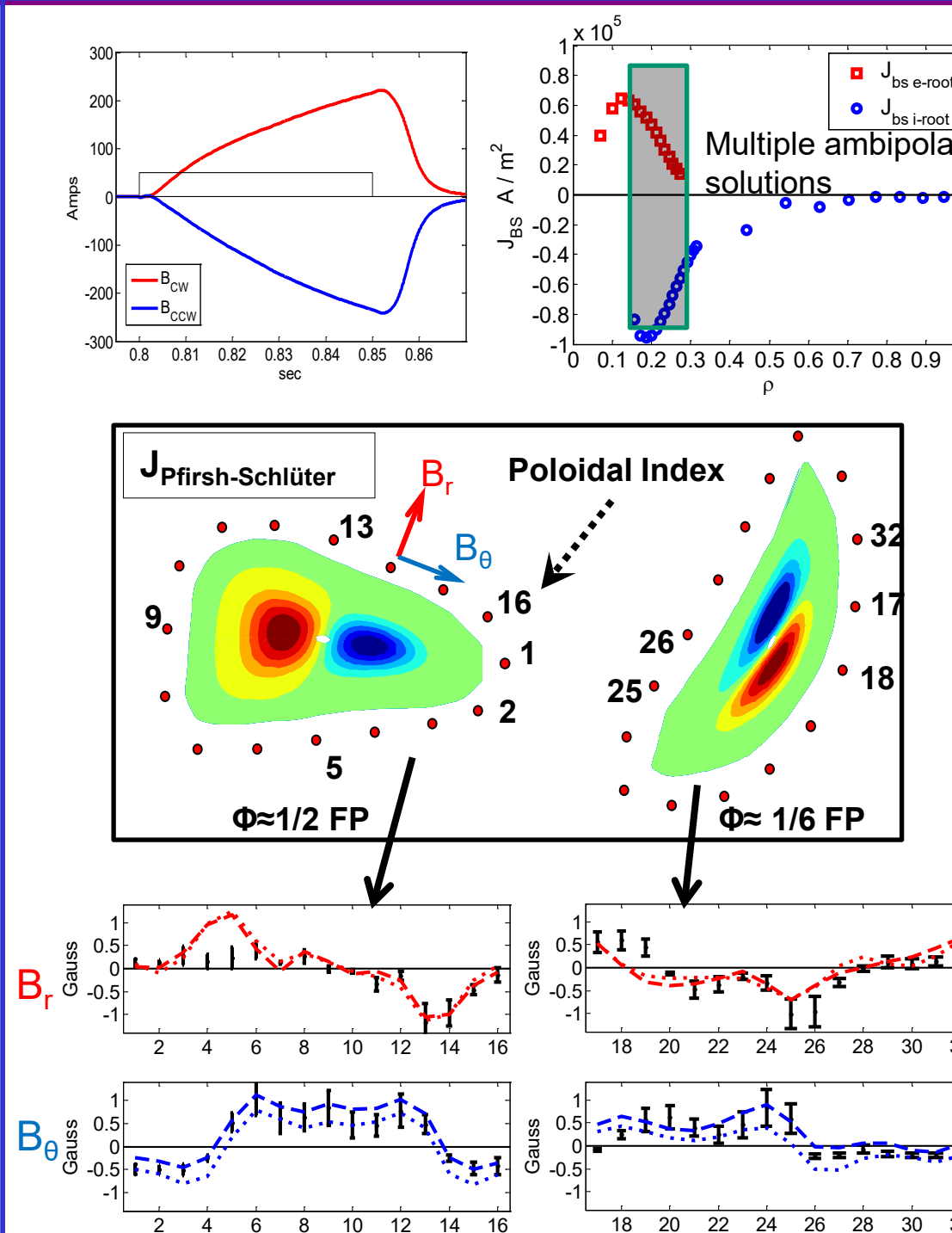
Internal Transport Barrier



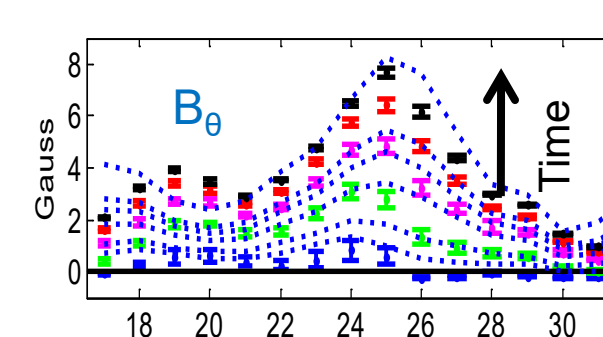
- $T_e(0) \sim 2.5$ keV $\rightarrow$ steep T_e gradient at plasma core is evidence of CERC for QHS configuration.
- Quasi-linear Weiland model simulates transport due to Trapped Electron Mode.
 - 2-D model assumes single class of trapped electrons.
 - Validated by 3D GS2 code.
- Electric field profile modeled with diffusion equation $\rightarrow$ large T_e gradient in location of ExB shear layer
- Inside plasma core, anomalous $\chi_e \sim 10$ times experimental value.
- Shearing rate greater than maximum linear growth rate inside $r/a \sim 0.3$
- ExB shear suppresses turbulence: diffusivity scaled by quench rule:
 $D \rightarrow D * \max(1 - \alpha_E \gamma_E / \gamma_{\text{max}}, 0)$; γ_E = shearing rate; γ_{max} = maximum growth rate
- Without shear suppression ($\alpha_E = 0$), T_e at core is underestimated.
- $\alpha_E = 0.3$ gives good agreement with temperature at core.
- Density threshold ($\sim 5 \times 10^{12} \text{ cm}^{-3}$) for transport barrier consistent with having ion root throughout entire plasma.

See invited talk by Lore

Plasma Currents



- Toroidal current in HSX is due to bootstrap current.
- Current evolves during discharge $\rightarrow$ Use Strand-Houlberg model.
- Steady-state bootstrap current is calculated by PENTA code. Total integrated current depends on electron (~ 250 A) or ion root (~ 400 A).
- Ultimate goal is to use V3FIT+ code for equilibrium reconstruction $\rightarrow$ At present, we use code in forward direction to calculate field due to plasma currents
- 16 3-axis coils measure field at two toroidal locations



- The helical Pfirsch-Schluter current in HSX has been experimentally demonstrated $\rightarrow$ there is little toroidal curvature in HSX.
- Both the PS and bootstrap current are reduced in magnitude compared to a tokamak because of the high effective transform.
- Bootstrap current verified to flow in opposite direction to current in tokamak $\rightarrow$ decreases rotational transform. See talk by Schmitt

*S.P. Hirshman, et. al., Phys Plasma, 11, 595 (2004). Thanks to J. Hanson & S. Knowlton for assistance.

New Directions

Double ECRH Power

Second ECRH gyrotron operational by end of year; additional 400 kW available with steerable mirror for off-axis heating. Also, power modulation for transient

Impurity Transport

• Comparison of impurity transport on TJ-II and HSX. Laser blow-off experiments of light (B) and heavy (Al) impurities for ECRH discharges in TJ-II (Zurro) beginning November, 2009. Determination of convective and diffusive transport, as well as density and power scans. Also, initial calculations of impurity transport with PENTA code. Goal is to determine 'temperature screening' as function of symmetry-breaking and the role of E_r on impurity transport. See poster by Clark

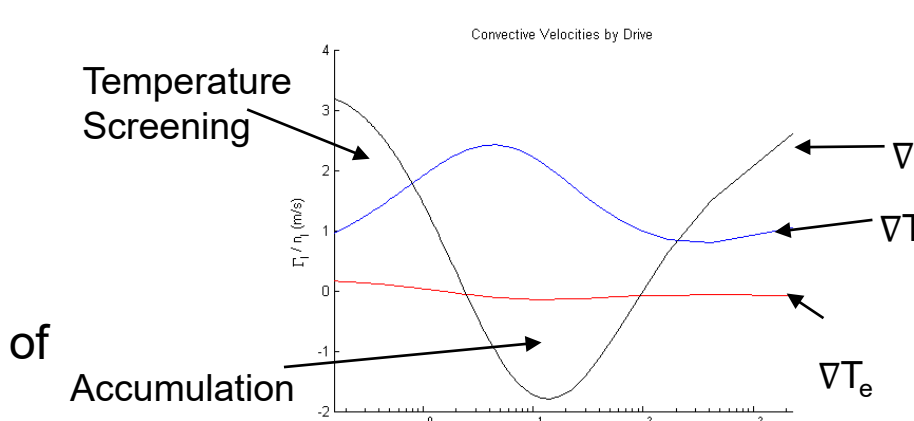
Zonal Flows and Electrode Biasing

• Collaboration with TJ-II (Hidalgo) on magnetic geometry effects on turbulence and zonal flows. Theory predicts reduced zonal flow damping with quasisymmetry. We have begun looking at effect of electrode biasing on long-range correlations. First results show improved particle confinement. Large increase in flow shear at edge, consistent with flow in symmetry direction. See poster by Wilcox

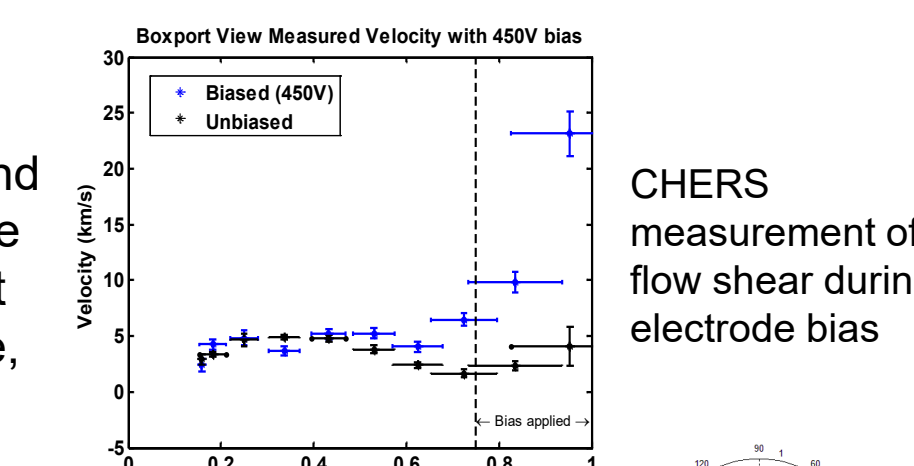
ICRF

• Collaboration with ORNL (Diem and Rasmussen) on ICRF experiments in HSX. First experiments will concentrate on antenna design and coupling with 5 kW source. Higher power transmitter (100 kW / 5-30 MHz) is also available.

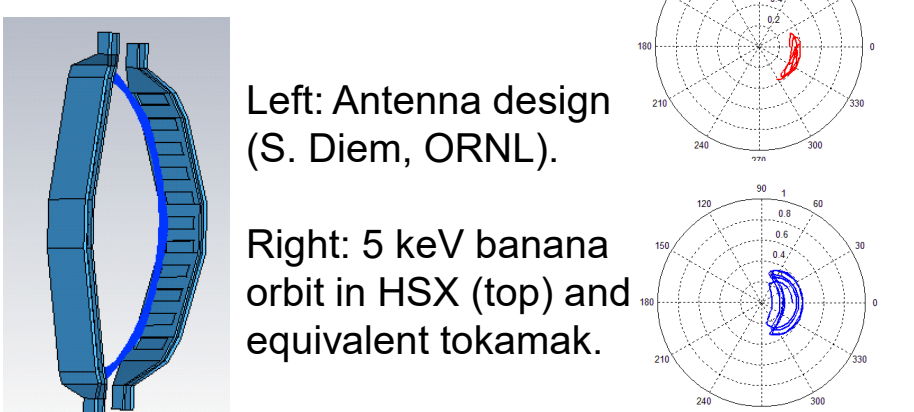
• Experiments will investigate effect of magnetic geometry on ion distribution. Collaboration with Kyoto University (Murakami) on 5-D GNET calculation. Acquisition of CX analyzer to compare distribution function to model predictions. See poster by Likin



PENTA calculation of C+6 transport in a tokamak, showing temperature screening in banana and PS regime, accumulation in plateau.

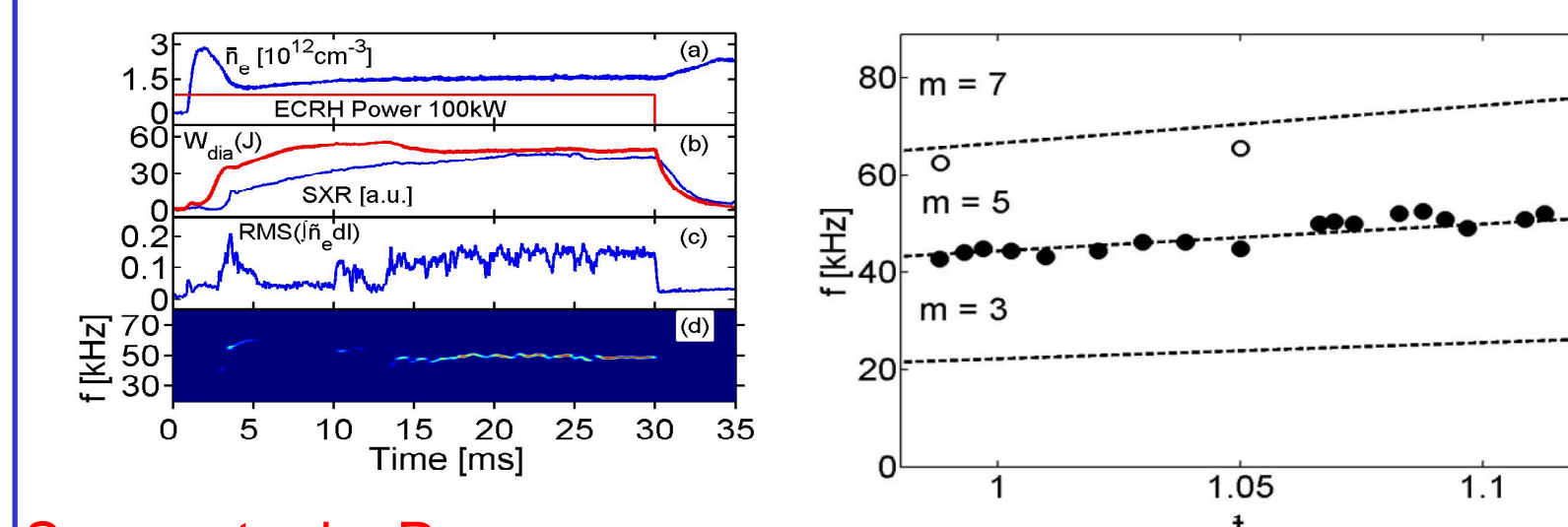


CHERS measurement of flow shear during electrode bias



Energetic Particle Instability

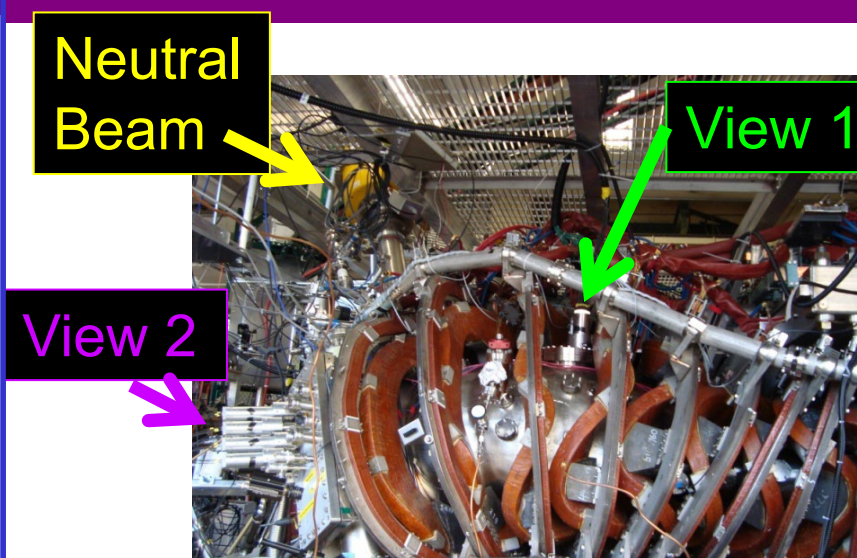
- Collaborative effort with Brower (UCLA), Spong (ORNL) & Breizman (Texas)
- Energetic electrons produced by 2nd harmonic ECRH at 0.5T produce coherent, global fluctuations in range 20 – 120 kHz.
- Mode frequency has weak dependence on transform making it unlikely that it is Alfvénic mode. Stellgap (Spong) calculation including coupling of Alfvénic to sound waves; this coupling best explains experimental results.



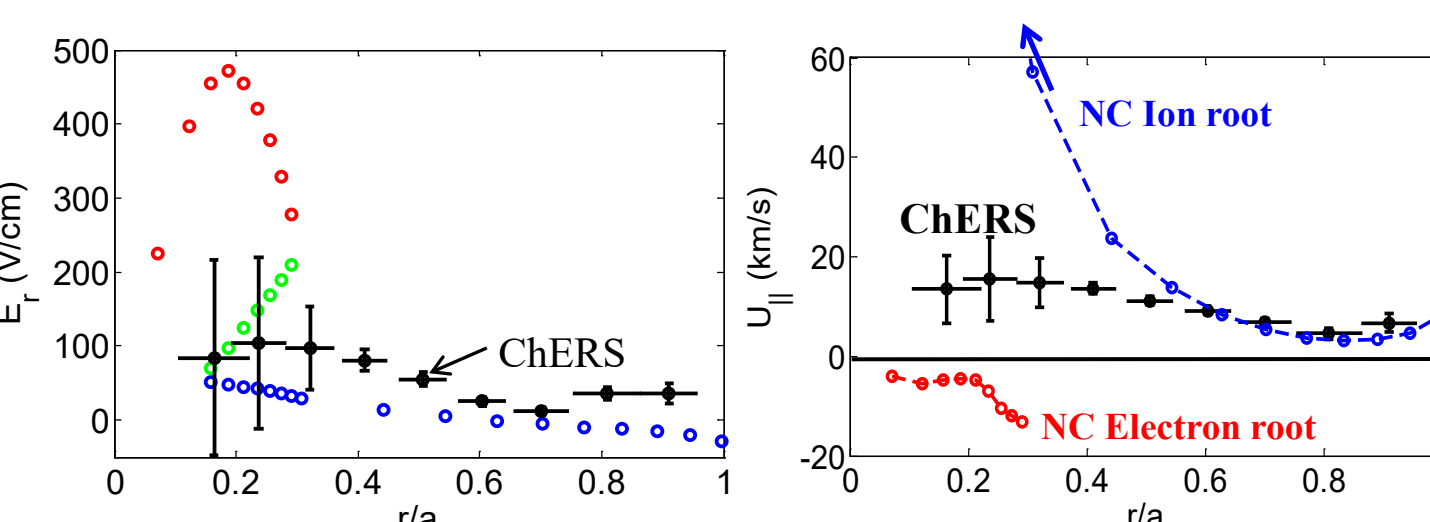
See poster by Deng

See paper by C Deng, D.L. Brower et al., PRL 103, 025003 (2009).

CHERS Measurements



- 30 keV neutral H beam for charge exchange; two 0.75m spectrometers measure 539 nm C+5 line
- 10 mostly 'toroidal' (view 1 above) and 10 mostly 'poloidal' (view 2)



Radial electric field in reasonable agreement with ion root at edge, large uncertainty at location of electron root.

Large parallel flow (15-20 km/s) observed for QHS configuration, often neglected in standard neoclassical calculation.

See poster by Briesemeister

- First results of Z_{eff} profile based on plasma bremsstrahlung measured by poloidal array of ChERS system. Intensity calibrated with integrating sphere. Reconstruction yields preliminary profile.

See poster by Zhai