NSTX transport study via density fluctuation measurement of FIReTIP system

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Abstract

The density fluctuation level measured by the Far Infra Red Tangential Interferometry/Polarimetry (FIReTIP) system on National Spherical Torus Experiment (NSTX) is compared with the energy confinement for the study of turbulence transport. In the 2008 campaign, FIReTIP system was operational with 6 channels including a new channel (CH5) at the tangency radius of 132 cm. Since CH5 measures line integrated density over the turbulence dominated region from the pedestal to Scrape-Off-Layer, the density fluctuation level measured by CH5 provides correlated information with the turbulence induced transport of NSTX boundary. The density fluctuation levels are compared with the stored energy from EFIT equilibria for L-mode and H-mode cases. The possible relation to the turbulent diffusion based on the gyrocenter shift will be discussed.

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3-D CAD View of

Far

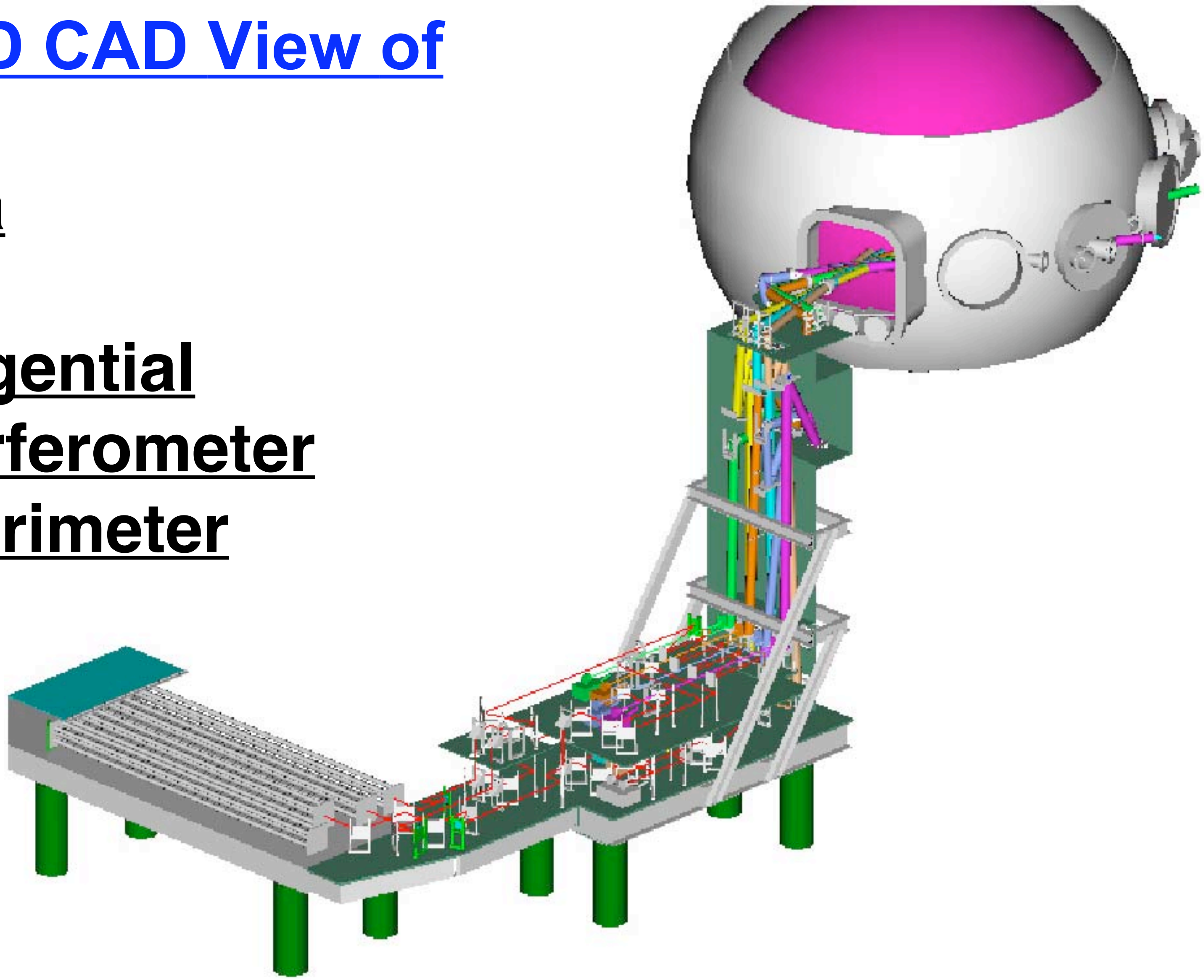
Infra

Red

Tangential

Interferometer

Polarimeter



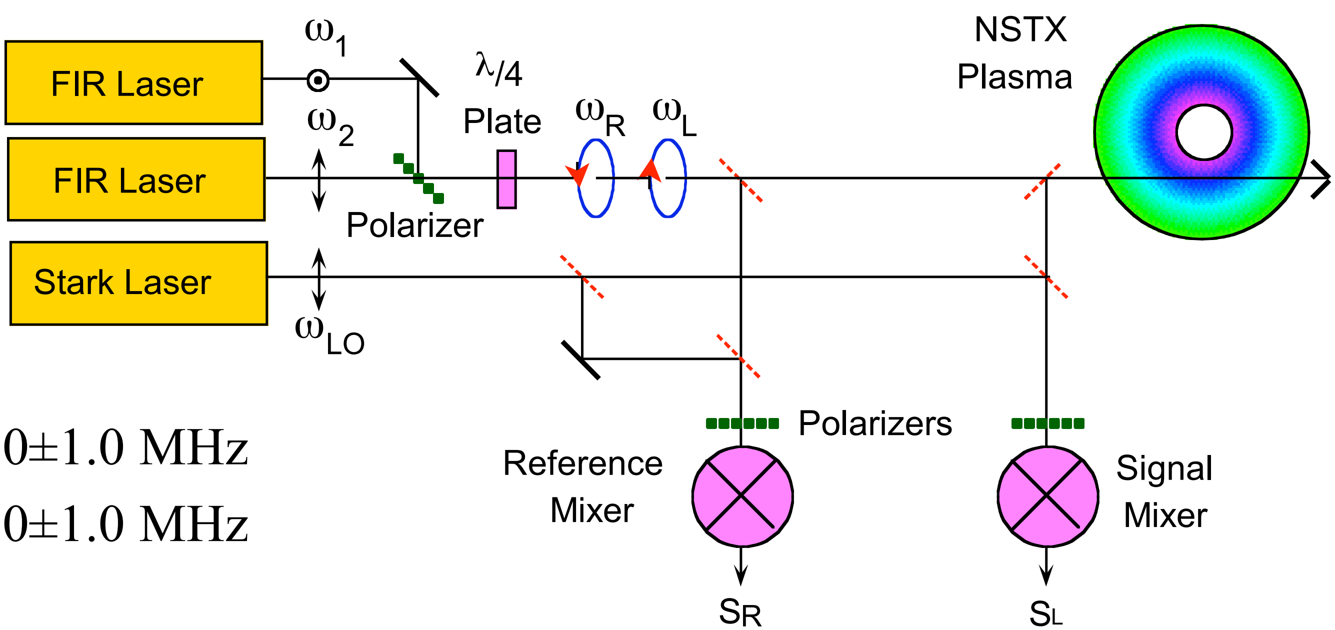
Principle of FIReTIP system on NSTX

$$\phi(x) = 2.8 \times 10^{-15} \lambda \int_0^x n(x')\, dx'$$

$$\Psi(x) = 2.6 \times 10^{-13} \lambda^2 \int_0^x n(x') B_T(x') dx'$$

Rommers & Howard

3-laser system



$$\mathbf{W}_{LO} - \mathbf{W}_1 = 4.0 \pm 1.0 \text{ MHz}$$

$$\mathbf{W}_{LO} - \mathbf{W}_2 = 6.0 \pm 1.0 \text{ MHz}$$

$$\frac{d\phi(t)}{dt} << \omega_{if}$$

[K.C. Lee *et.al.*, IEEE Trans. on Plasma **32**,1721(2004)]

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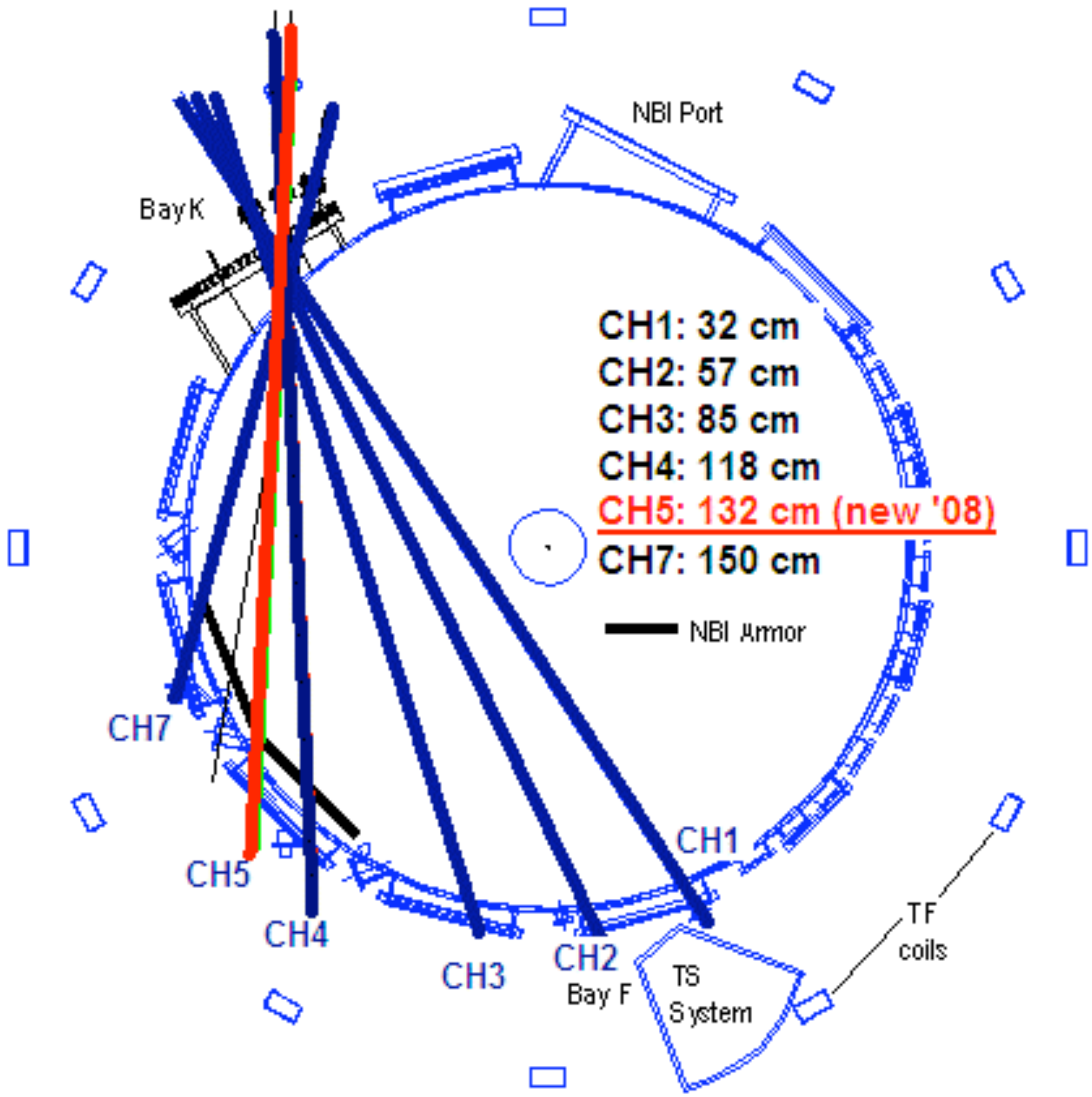
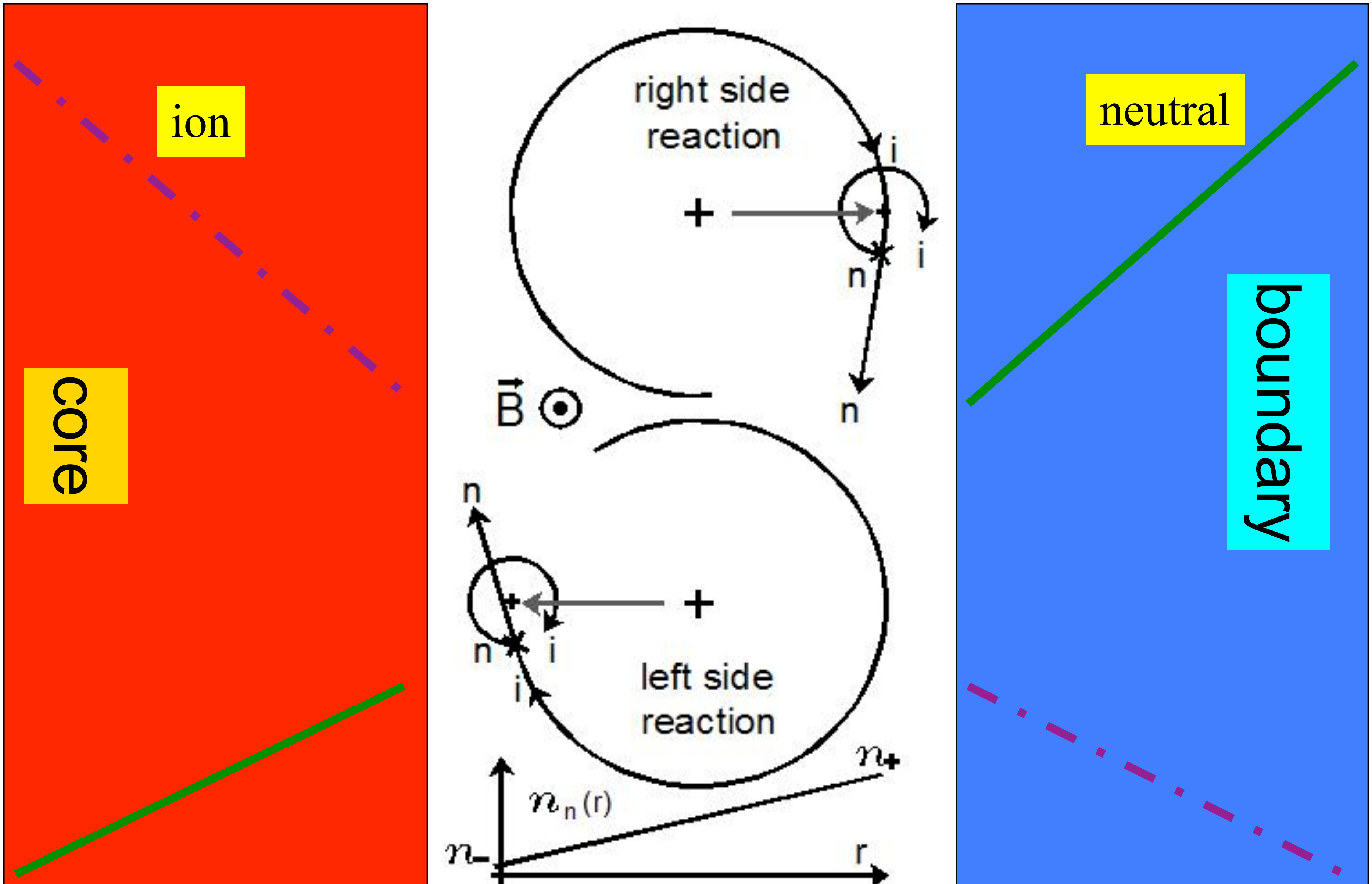
FIReTIP Operated with 6 Channels (2008)



Gyrocenter shift due to charge exchange



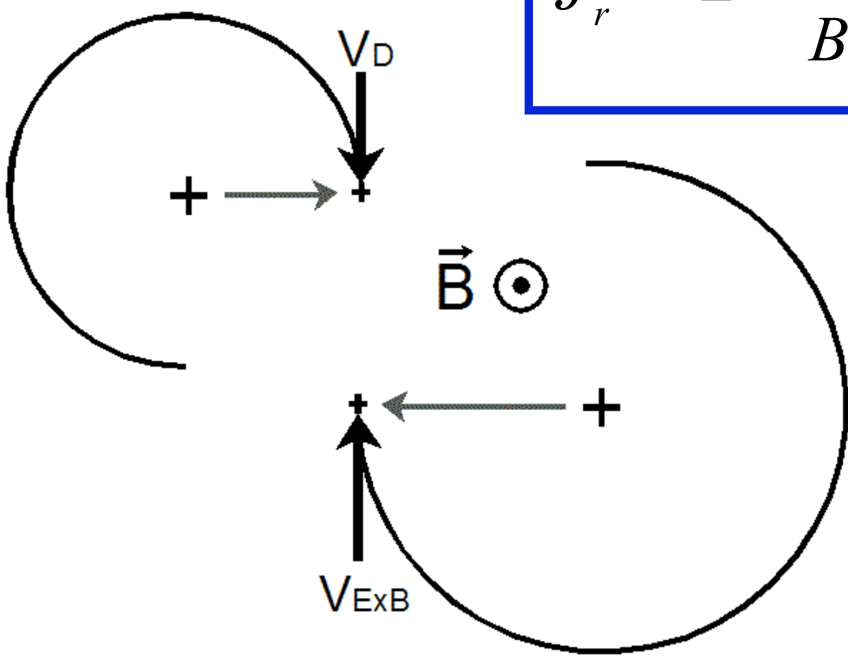
Gyrocenter shift calculation by fluid picture

From a fluid equation of motion ; $J \times B = n_i R_{av} S_i^m$

$$v_{av} = \frac{\sigma v_i \oint v n_n(x) d\theta}{\sigma v_i \oint n_n(x) d\theta} = \frac{1}{2} r_L v_\perp \frac{1}{n_n} \frac{\partial n_n}{\partial r}$$

momentum sink by charge exchange $S_i^m = m_i v_{av}$

$$J_r^{GCS} = \frac{m_i n_i n_n}{B^2} < \sigma v_i > \left(E - \frac{1}{q_i n_i} \frac{\partial p_i}{\partial r} + \frac{T_i}{q_i n_n} \frac{\partial n_n}{\partial r}\right)$$



$$v_{E \times B} = \frac{E}{B} \qquad v_D = -\frac{1}{q_i B n_i} \frac{\partial p_i}{\partial r}$$

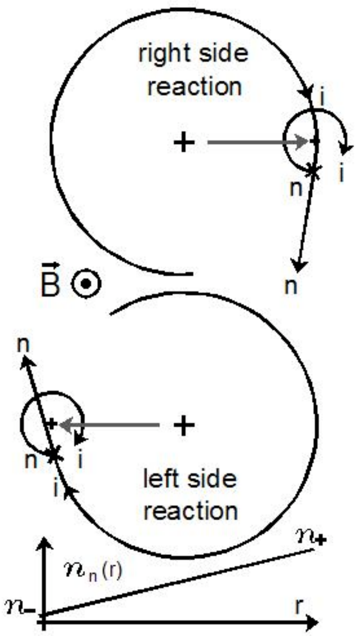
other contributions of v_{av}

(ExB and diamagnetic drifts)

ExB drift is in opposite direction

=> return current (E_r saturation)

Turbulence Diffusion and H-mode Transition in Conjunction with Gyro-Center Shift



$$J_r^{GCS} = e n_i \frac{r_{Li}}{\lambda_{i-n}} \left(\frac{E}{B} - \frac{1}{eB} \frac{\nabla P_i}{n_i} + \frac{kT_i}{eB} \frac{\nabla n_n}{n_n} \right)$$

Gyro-Center Shift

Turbulence Induced Diffusion

$$D = \frac{2}{\pi} \eta^2 \frac{kT_e}{eB} \qquad \left(\eta \equiv \frac{\tilde{n}}{n} \right)$$

Submitted PPCF 2008

Reynolds Number of Ion-Neutral Collision

$$\mathrm{Re} = \frac{eB}{kT_i} \lambda_{i-n} \left(\frac{E}{B} - \frac{1}{eB} \frac{\nabla P_i}{n_i} + \frac{kT_i}{eB} \frac{\nabla n_n}{n_n} \right)$$

E_r Formation
PoP 2006

Arc Discharge
PRL 2007

L\H Transition on NSTX
Invited Talk APS 2006

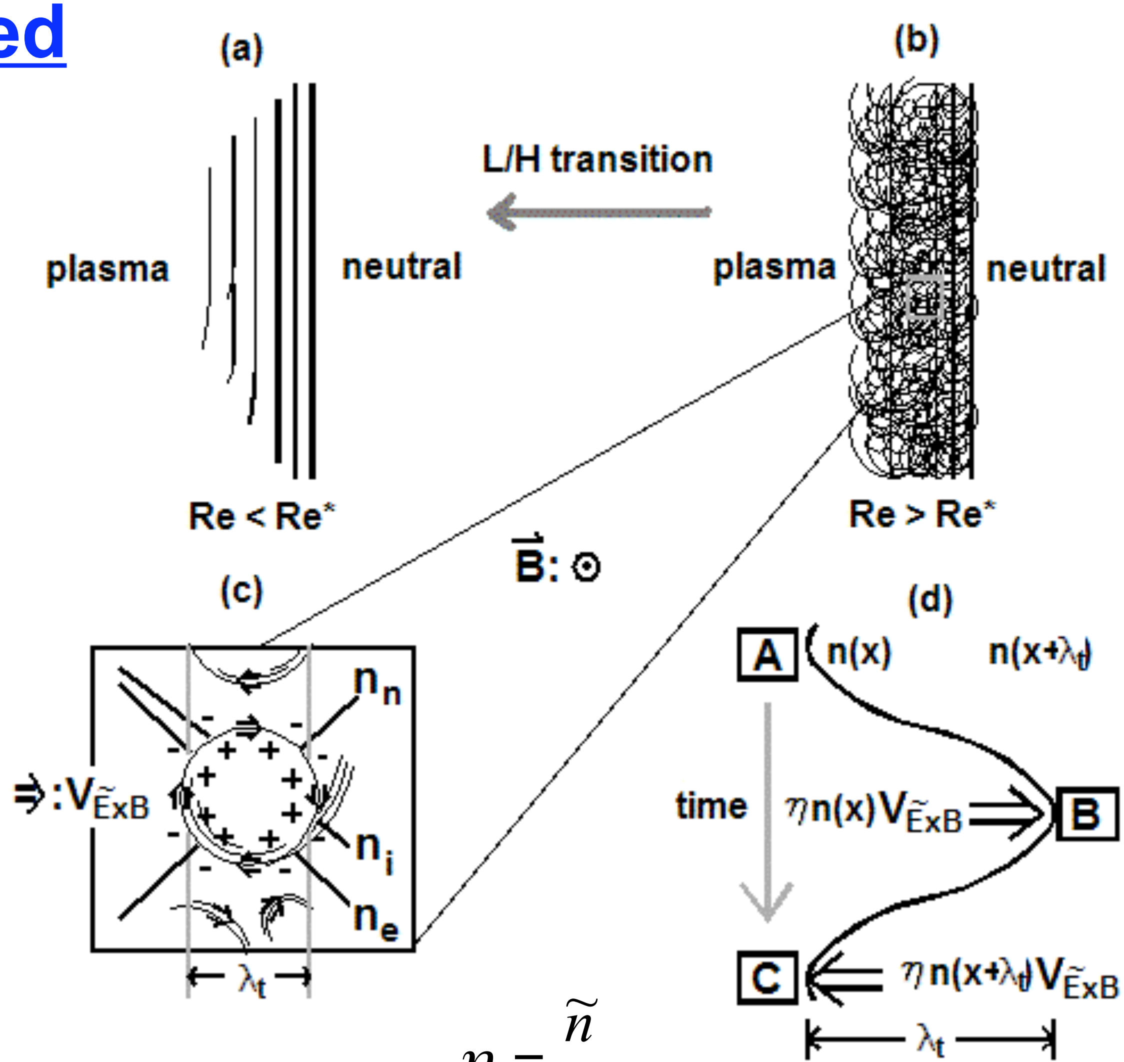
Turbulence Induced Diffusion

$$\Gamma \approx \partial n \cdot \tilde{v}$$

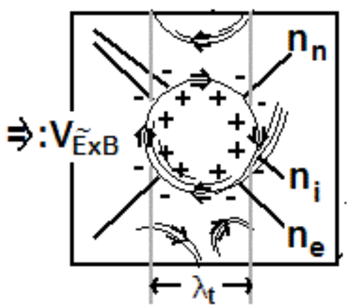
$$\eta \lambda_t \nabla n \qquad V_{\tilde{E}xB} = \frac{\tilde{E}}{B}$$

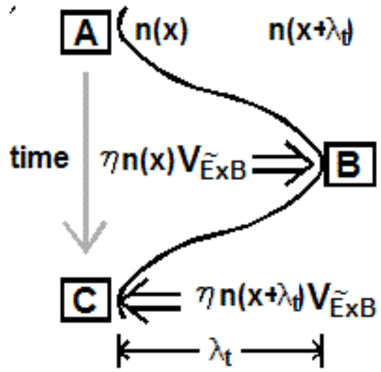
$$\frac{e\tilde{E}\lambda_t}{2} \approx \eta k T_e$$

$$D = \frac{2}{\pi}\eta^2 \frac{kT_e}{eB}$$



$$\eta \equiv \frac{\tilde{n}}{n}$$





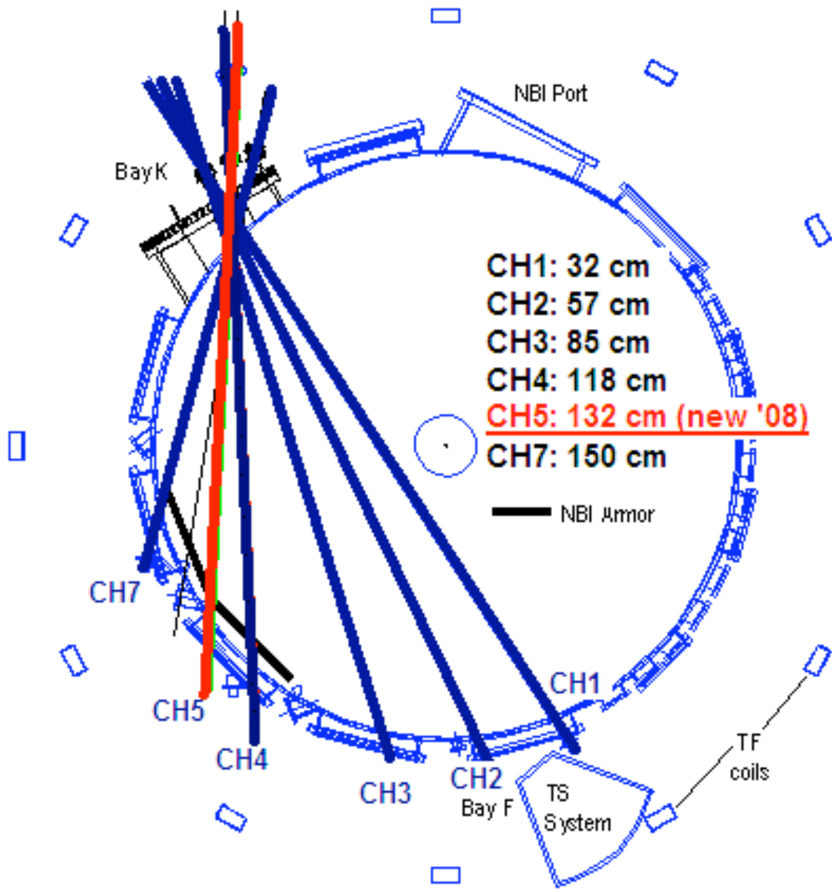
Turbulence induced diffusion of particles and charge

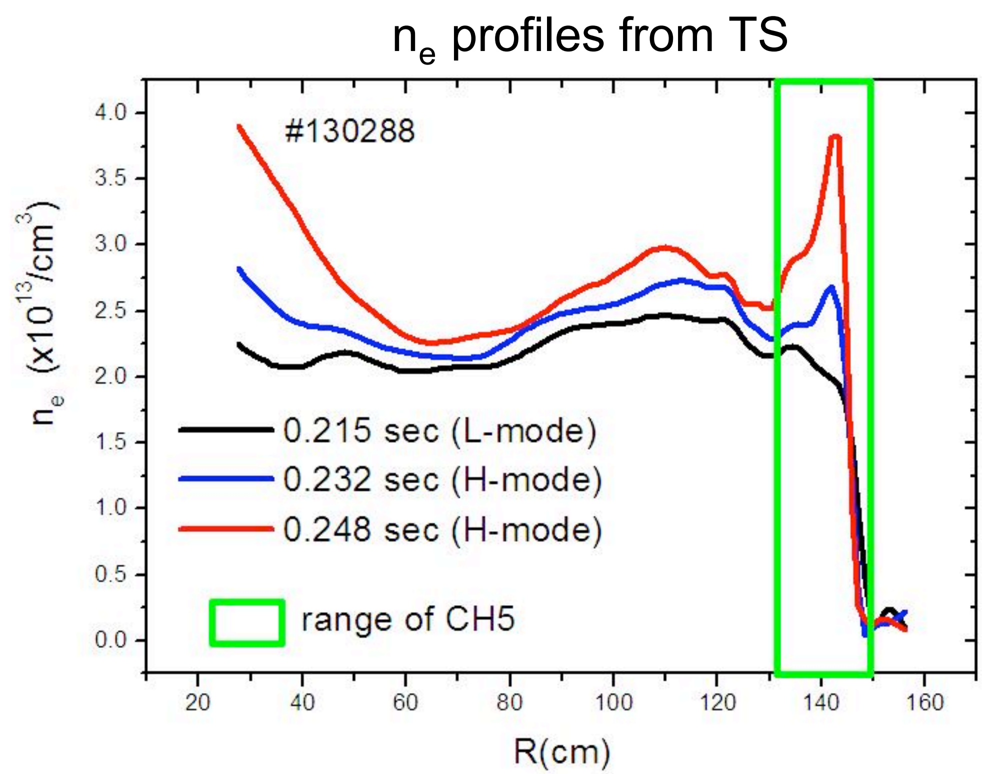
$$\eta \equiv \frac{\tilde{n}}{n}, \quad n' \equiv \frac{\partial n}{\partial x} < 0$$

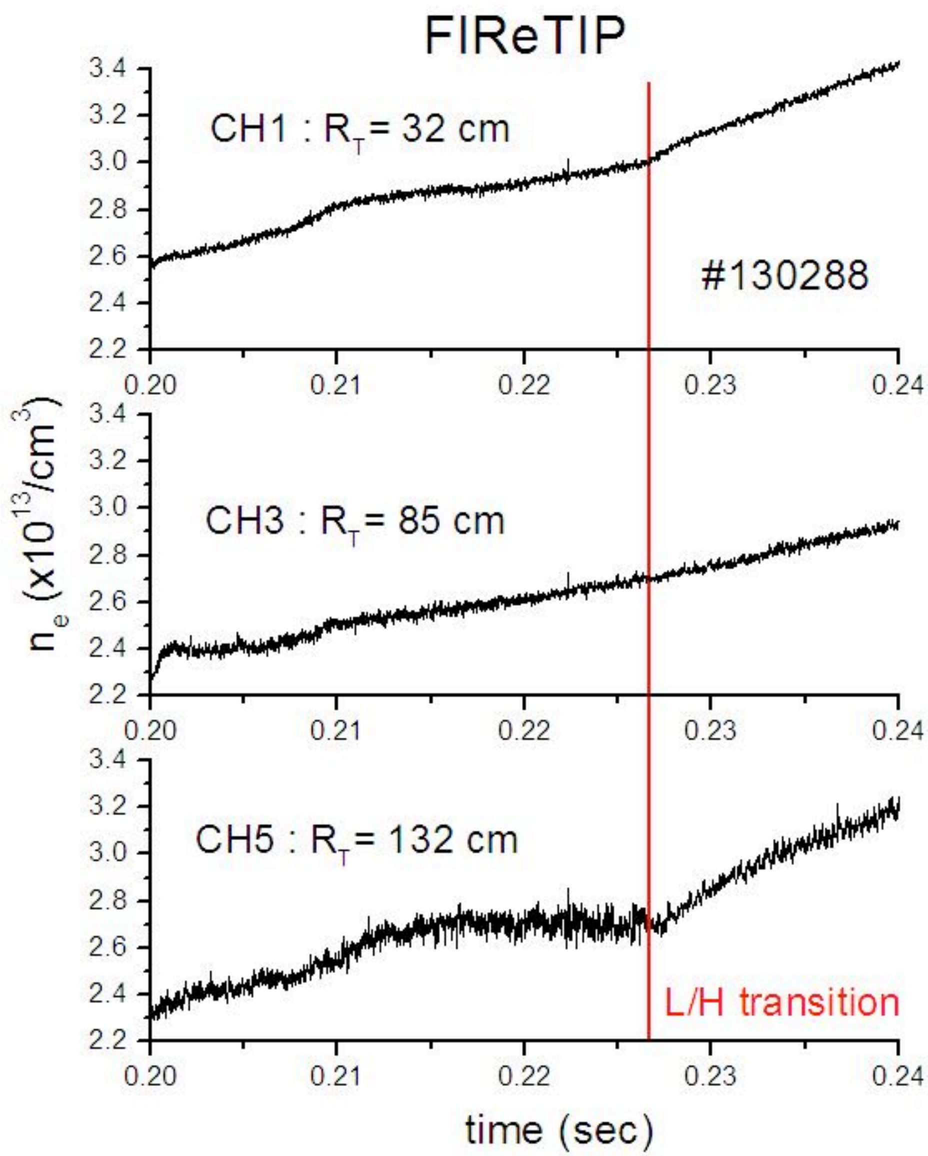
	x	$x+\lambda_t$
[A]	$n_{i,e}(x) \equiv n_{i,e}$	$n_{i,e}(x+\lambda_t) = n_{i,e} + \lambda_t n'_{i,e}$
[B]	$n_{i,e} - \eta n_{i,e}$	$n_{i,e} + \lambda_t n'_{i,e} + \eta n_{i,e}$
[C]	$n_{i,e} - \eta n_{i,e} + \eta n_{i,e} + \eta\lambda_t n'_{i,e} + \eta^2 n_{i,e}$ $\approx n_{i,e} + \eta\lambda_t n'_{i,e} = n_{i,e}(x) + \eta\lambda_t n'_{i,e}$	$n_{i,e} + \lambda_t n'_{i,e} + \eta n_{i,e} - \eta n_{i,e} - \eta\lambda_t n'_{i,e} - \eta^2 n_{i,e}$ $\approx n_{i,e} + \lambda_t n'_{i,e} - \eta\lambda_t n'_{i,e} = n_{i,e}(x+\lambda_t) - \eta\lambda_t n'_{i,e}$

- ► net movement of one cycle is $\eta\lambda_t \nabla n$: same result from L-R-L and R-L-R cycles
- ► turbulence induced charge diffusion can be calculated same way as density: $\eta\lambda_t \nabla\rho$
- ► diffusion takes place from high density region to low density region
  - ► ion and electron move toward boundary => ***diffusion***
  - ► charge (ρ) moves toward core => ***return current =>*** **saturation condition**

NSTX FIReTIP CH5 provides dn_e data of density fluctuation dominant region







$$D = \frac{2}{\pi}\eta^2 \frac{kT_e}{eB} \qquad \eta \equiv \frac{\tilde{n}}{n}$$

- FIReTIP CH5 shows high η
- energy confinement time $\mathbf{t}_E$

$\mathbf{t}_E \sim 1/D$

- t_E calculated by EFIT
- T_e and n_e from Thomson Scattering

Comparing confinement time with dn_e

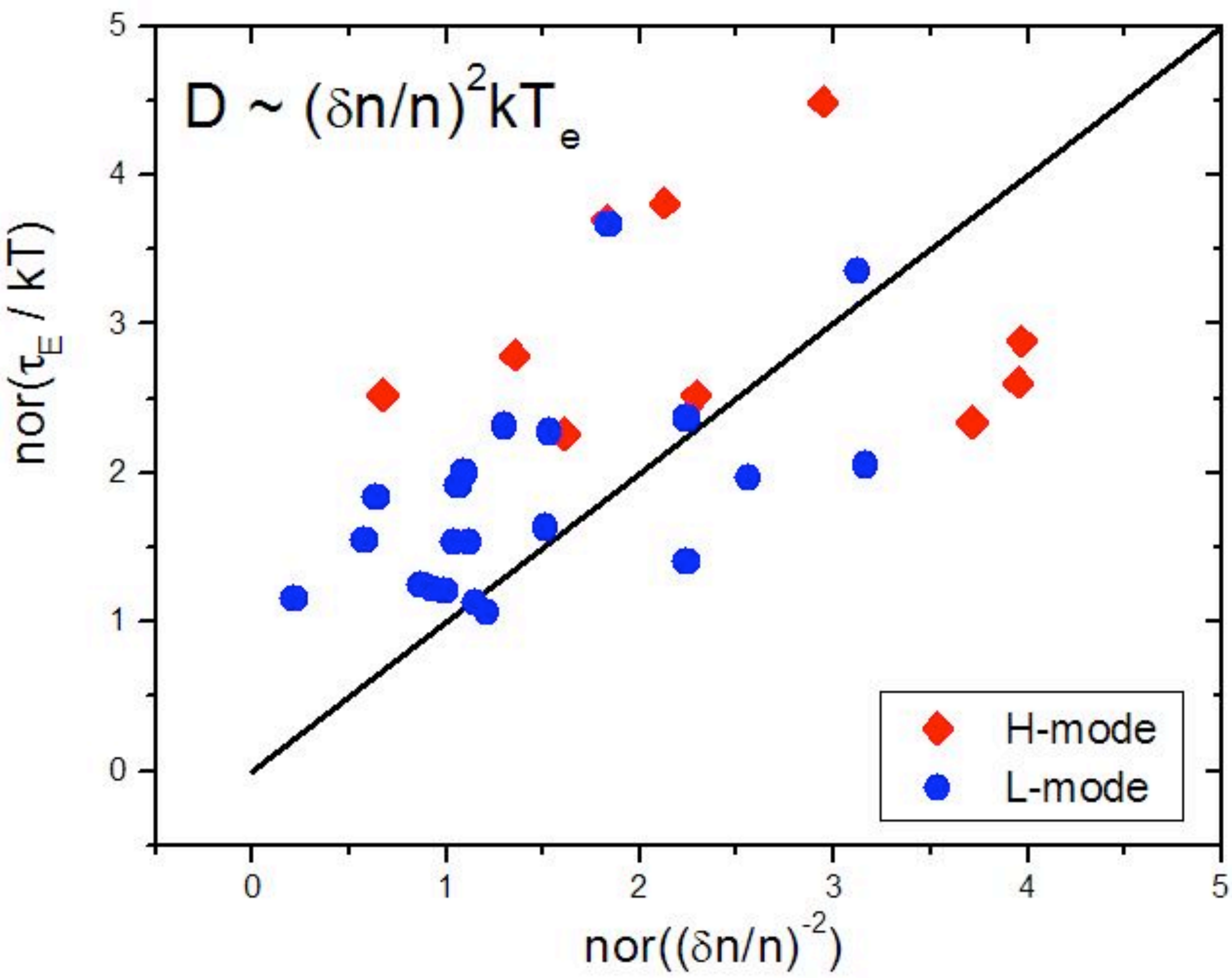
► 16 shots are analyzed.

► ~46 points are selected within constant NB heating period.
=> density increasing period : η decreasing within relatively short time. (T_e is evolving)

► first point of a shot => fiducial point : other points of same shot are normalized by the fiducial point.
=> to remove shot to shot difference such as wall-conditioning. (no B_T effect)

► including L/H transitions, excluding MHD activities

Comparing t_E with η^2 : including T_e effect



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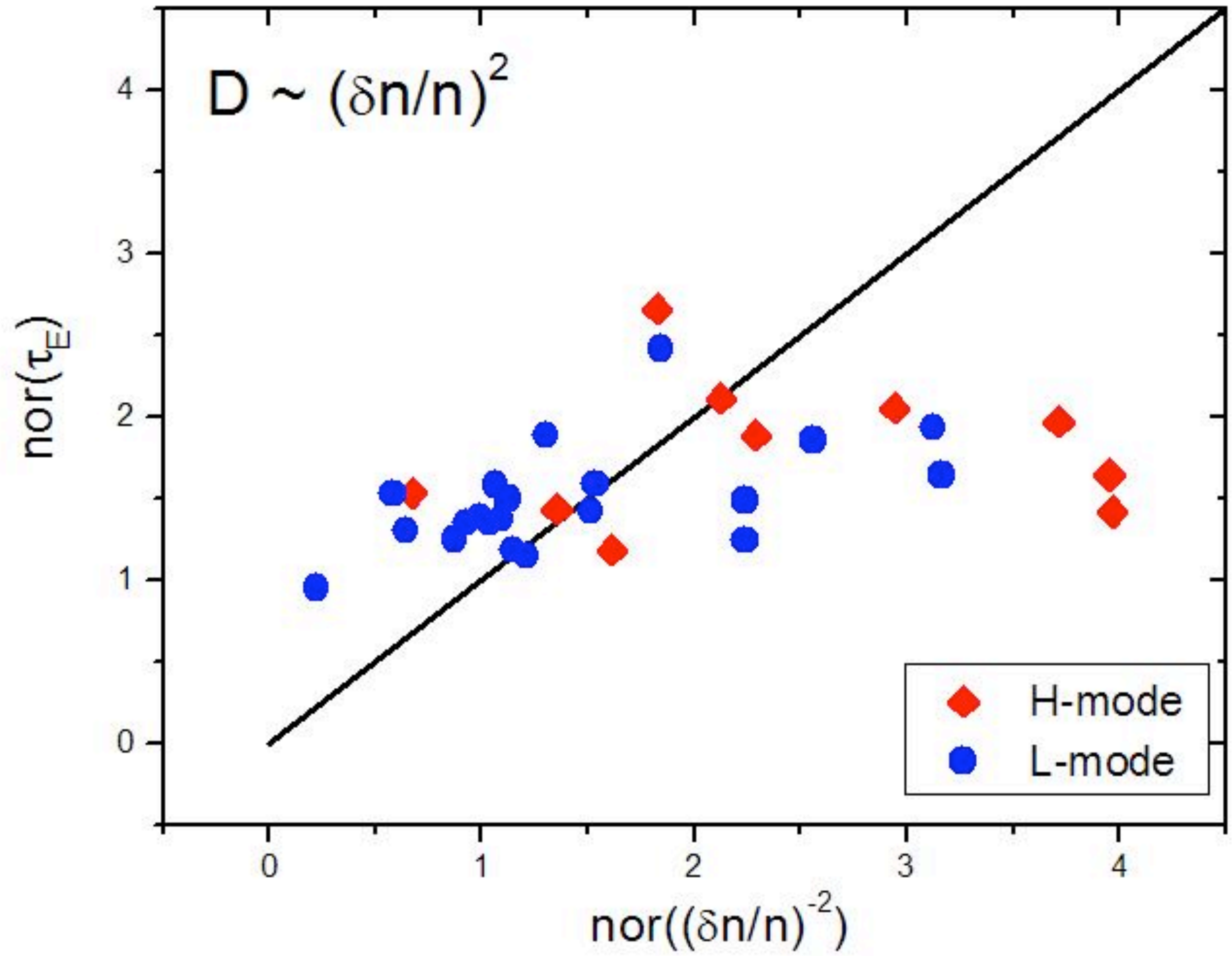
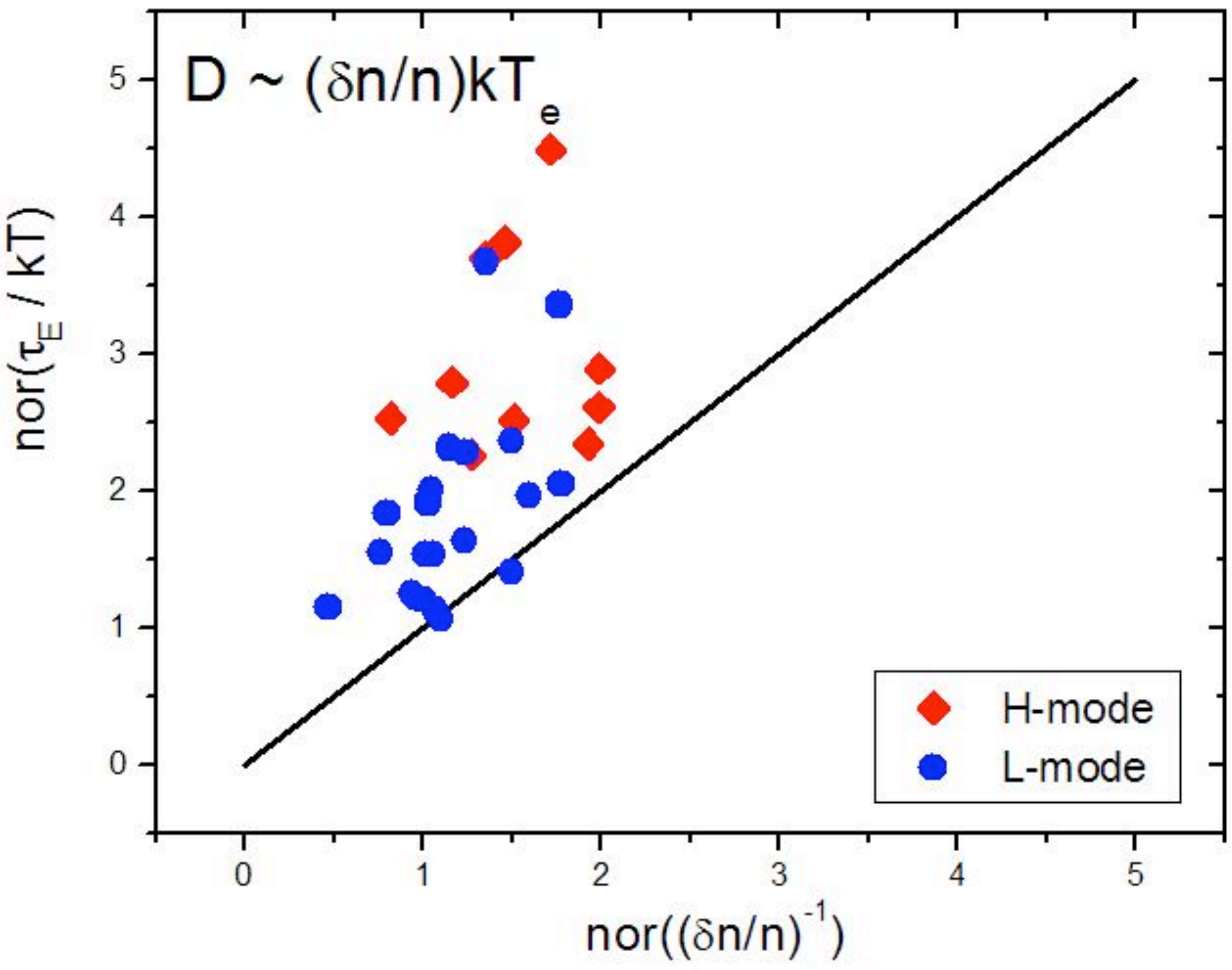
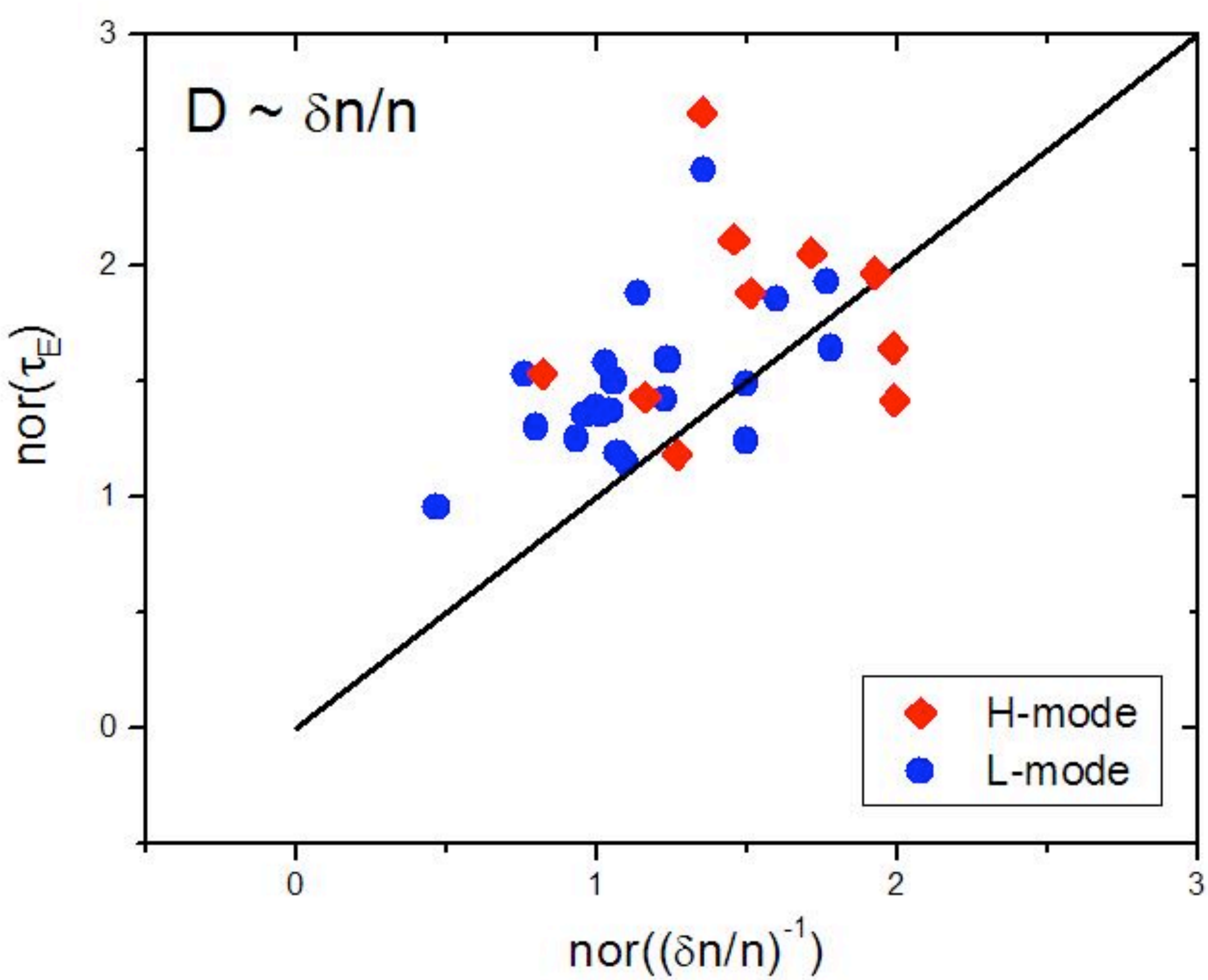
Comparing t_E with η^2 : no T_e effect



Comparing t_E with η : including T_e effect



Comparing t_E with η : no T_e effect



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Summary

- **FIReTIP measured density fluctuations with CH5 (R_T=132 cm) which is new in 2008 covering highest density fluctuation region**

- **gyrocenter shift theory is expanded to the diffusion coefficient;**

$$D = \frac{2}{\pi}\eta^2 \frac{kT_e}{eB}$$

- **comparison of confinement time (EFIT) with density fluctuation (FIReTIP CH5) of NSTX showed better linearity for $t_E \infty 1/(\eta^2 kT_e)$ than $t_E \infty 1/(\eta^2)$** and **$t_E \infty 1/(\eta kT_e)$** => $D \infty \eta^2 (kT_e/eB)$

- **$t_E \infty 1/(\eta^2 kT_e)$ case indicates clearer separation of H-mode points from L-mode points than $t_E \infty 1/\eta$**

- **explanation of weak correlation $t_E \infty 1/(\eta^2)$ in former study [Nuclear Fusion, 46** 848 **(2006)]**

- **2009 campaign will provide more data from CH5**