NSTX H-mode measurement in conjunction with gyrocenter shift via FIReTIP system

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Abstract

- The Far Infrared Tangential Interferometer/Polarimeter (FIReTIP) which spans the entire plasma is used to measure electron density fluctuations during the low confinement mode (L-mode) to high confinement mode (H-mode) transition on the National Spherical Tokamak Experiment (NSTX). The measured neutral density distribution and the radial electric field evolution are compared to the calculations based on the gyrocenter shift [K. C. Lee, *Phys. Plasmas* **13**, 062505 (2006)].The statistical analysis of electron density fluctuations measured by the FIReTIP system including data from a newly installed additional channel will be reported. Also, the role of the neutral density gradient on the L to H transition associated with the radial electric field formation and

  turbulence suppression will be discussed.

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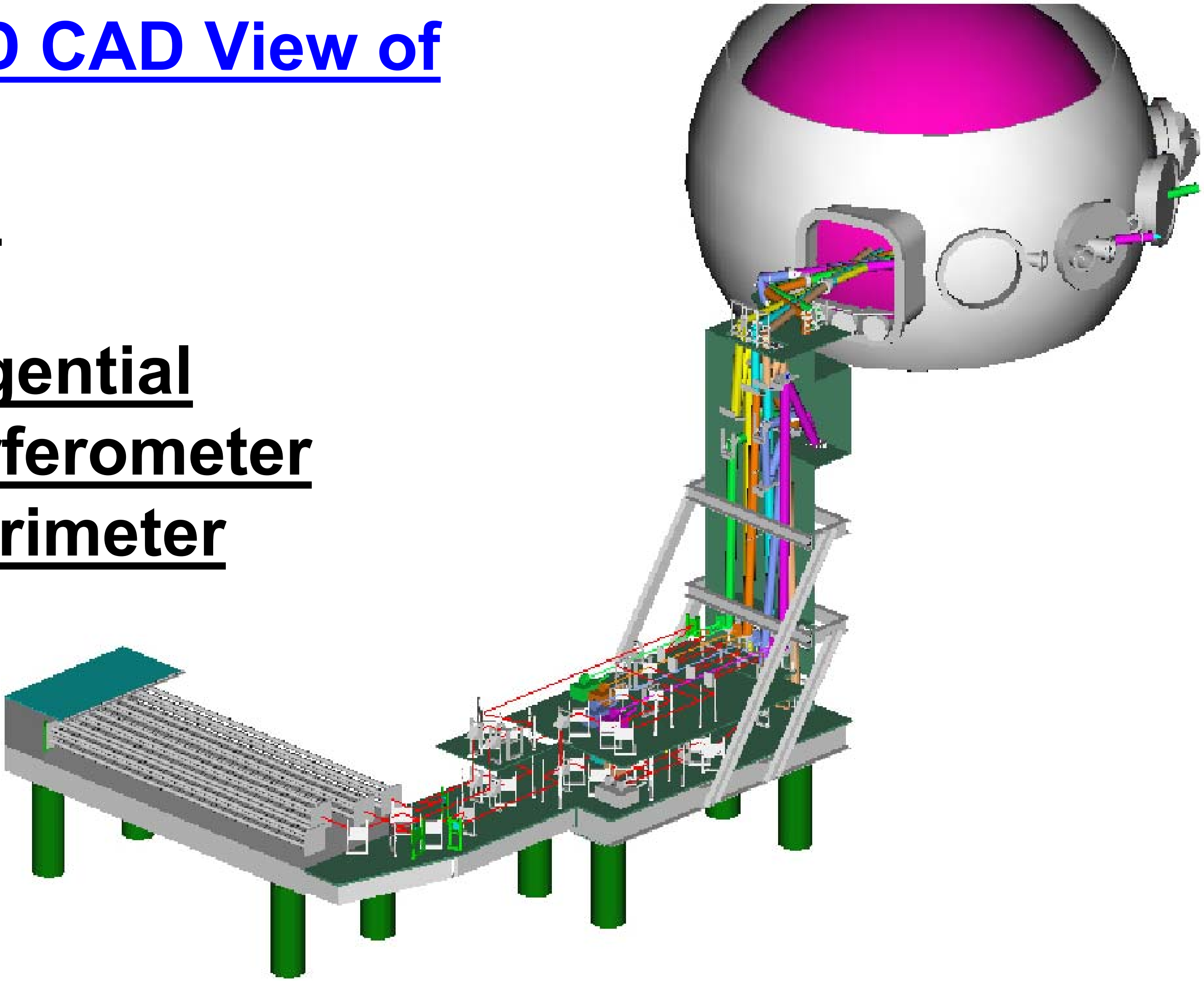
3-D CAD View of

Far
Infra
Red
Tangential
Interferometer
Polarimeter



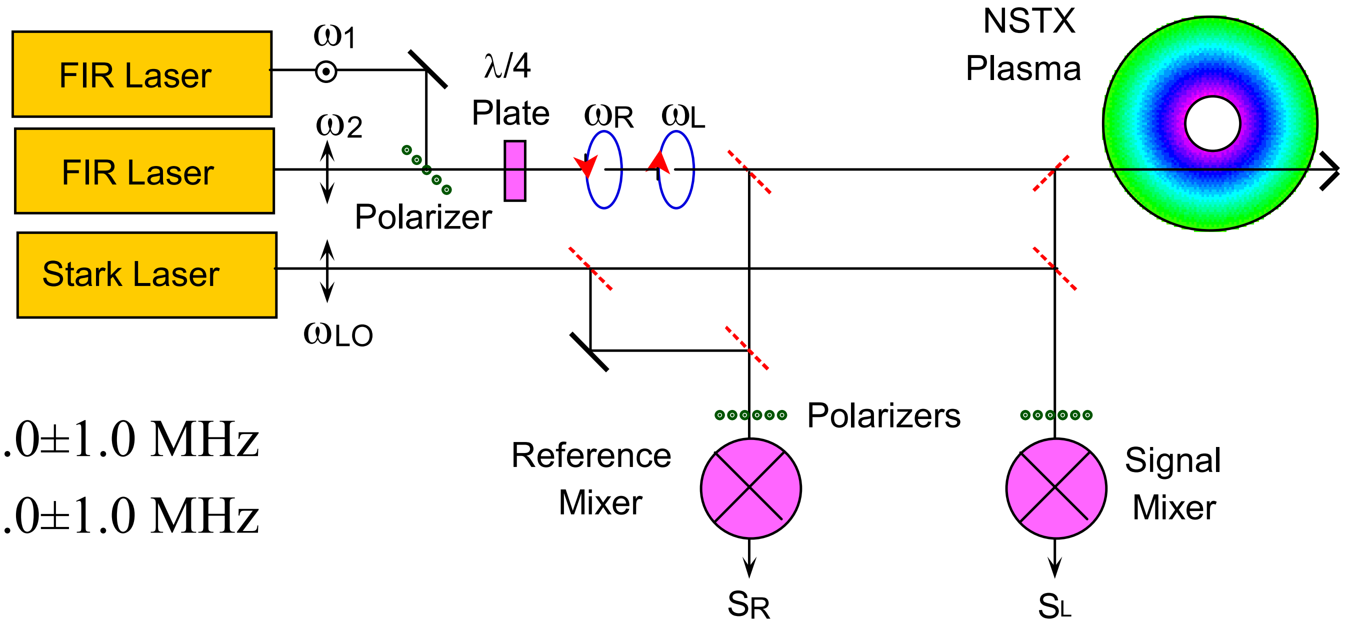
Principle of FIReTIP system on NSTX

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

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

Rommers & Howard

3-laser system



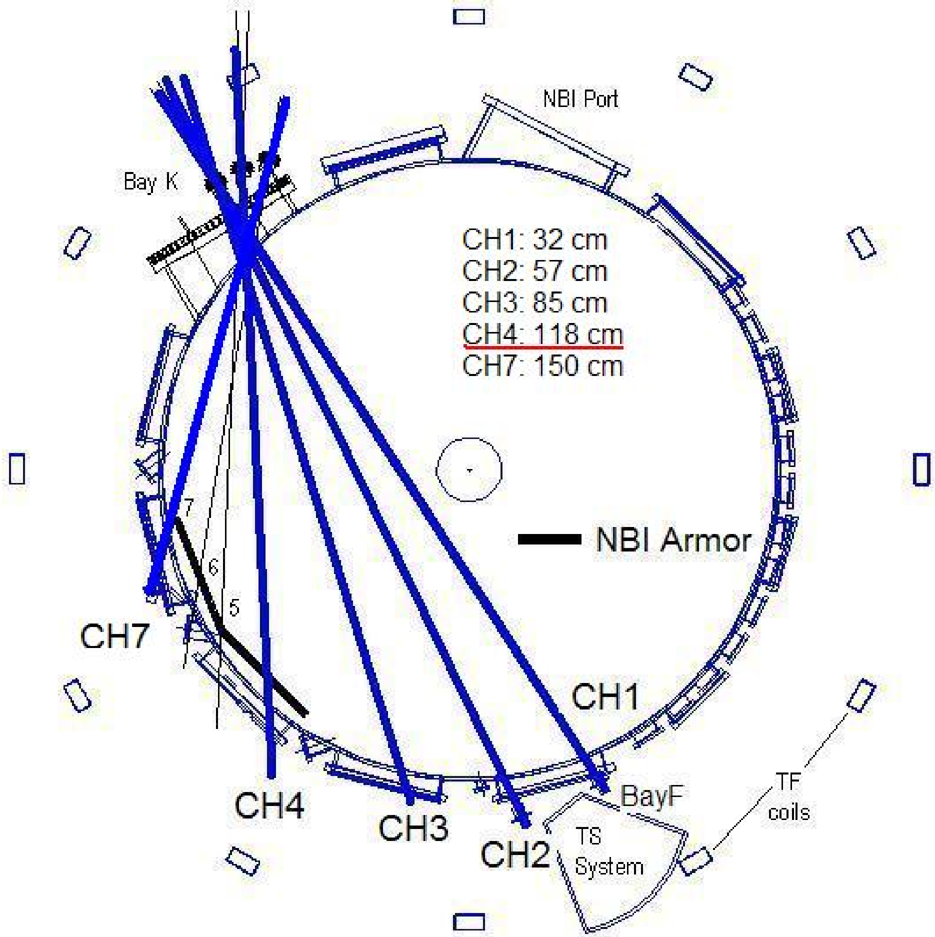
$$\omega_{LO} - \omega_1 = 4.0 \pm 1.0 \text{ MHz}$$

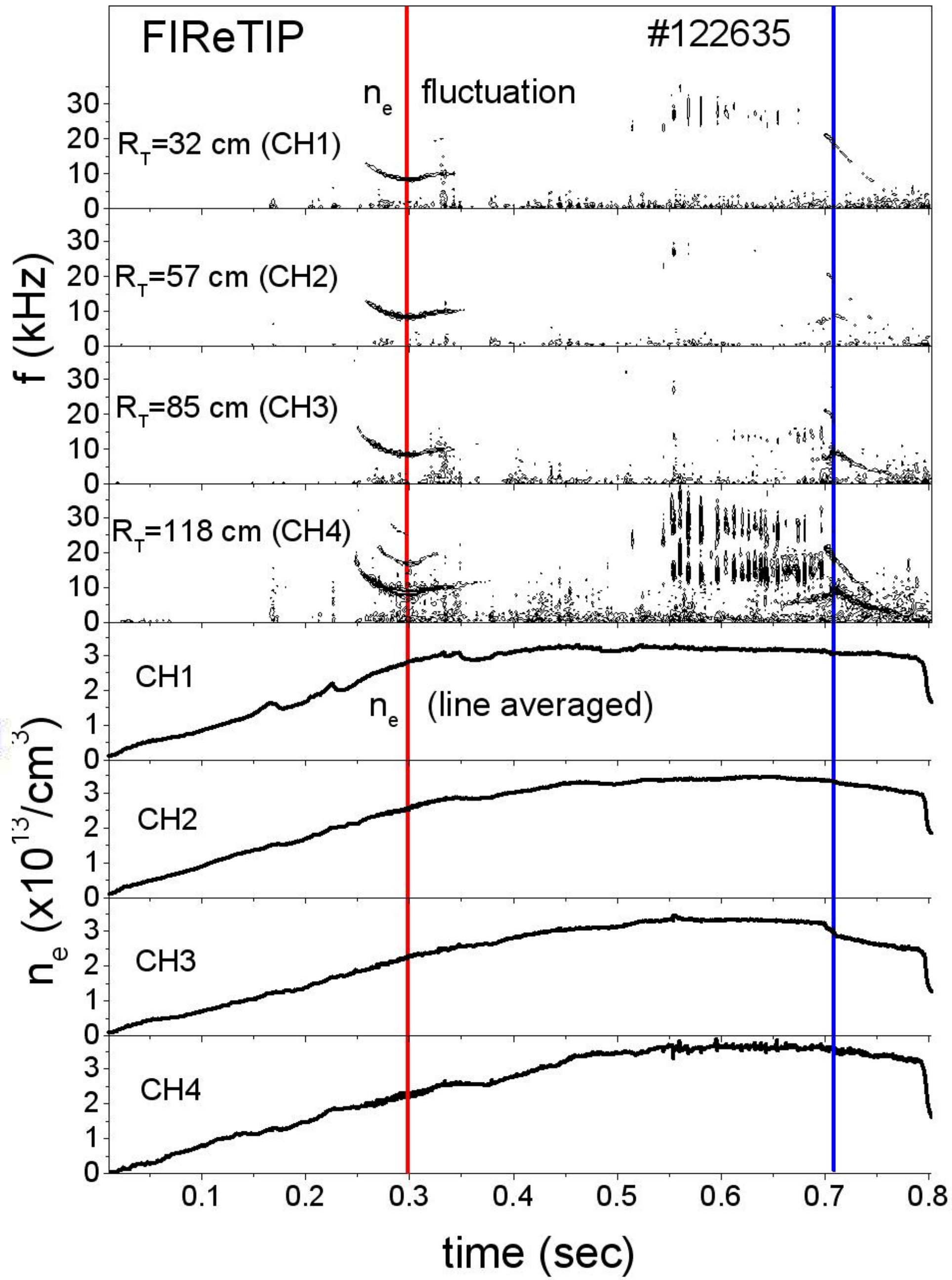
$$\omega_{LO} - \omega_2 = 6.0 \pm 1.0 \text{ MHz}$$

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

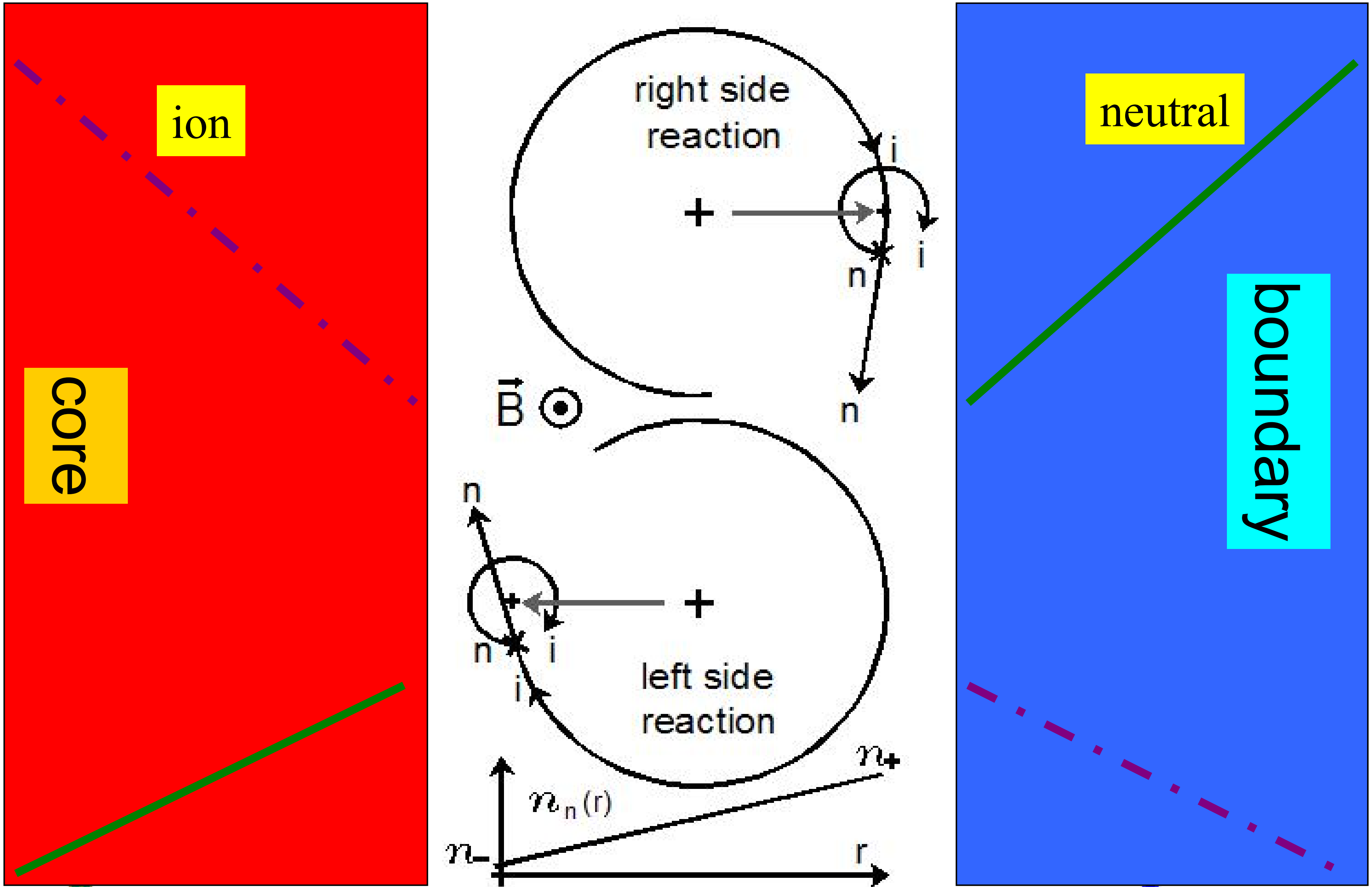
[K.C. Lee *et.al*., IEEE Trans. on Plasma **32**,1721(2004)]

FIReTIP operated with 5 CHs (2007)





Gyrocenter shift due to charge exchange



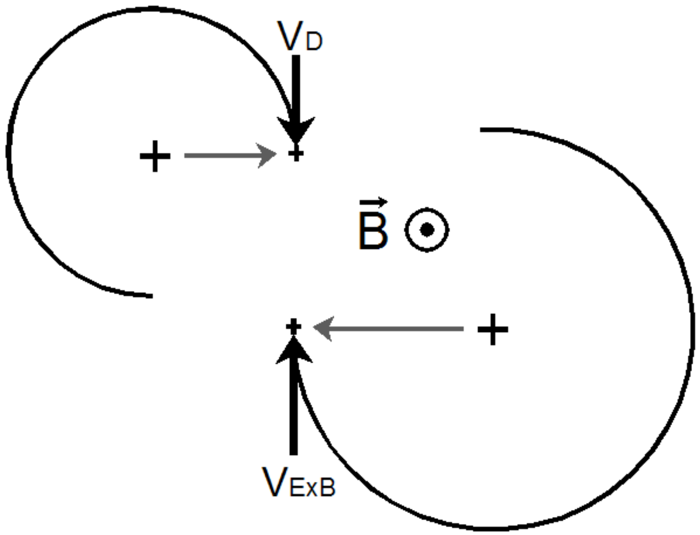
Gyrocenter shift and drift velocity

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

momentum sink due to charge exchange

$$\boxed{J_x^{GCS} = \frac{m_i n_i n_n}{B} < \sigma_{cx} v_i > (\underbrace{\frac{E}{B} - \frac{\nabla p}{qBn_i}}_{\text{drift velocity}} + \frac{T_i \nabla n_n}{qBn_n})}$$

[K.C. Lee, Physics of Plasmas, **13,** 062505 (2006)]



for low temperature / high density

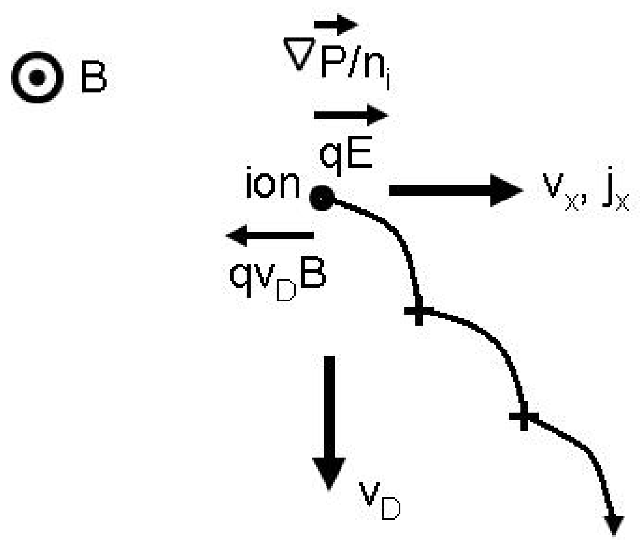
=> high collision rate with neutrals
/ short mean free path

$\Rightarrow$ drift velocity needs modification (generalization) for including high collisional cases

Progress of gyrocenter shift theory

Generalization of formula for the high collisional plasmas

$$J_x^{GCS} = \frac{m_i n_i n_n}{B} < \sigma_{cx} v_i > [\frac{1}{1 + r_L^2 / \lambda_{cx}^2}(\frac{E}{B} - \frac{\nabla p}{qBn_i}) + \frac{T_i \nabla n_n}{qBn_n} e^{-r_L / \lambda_{cx}}]$$



$\mathrm{F_x} = \; qE - qv_D B - \nabla p / n_i$

($\mathrm{v_D}$: drift velocity)

$\mathrm{v_x} = \; \mu(E - v_D B - \nabla p / qn_i)$

(μ : mobility)

$\mathrm{F_y} = \; qv_x B$

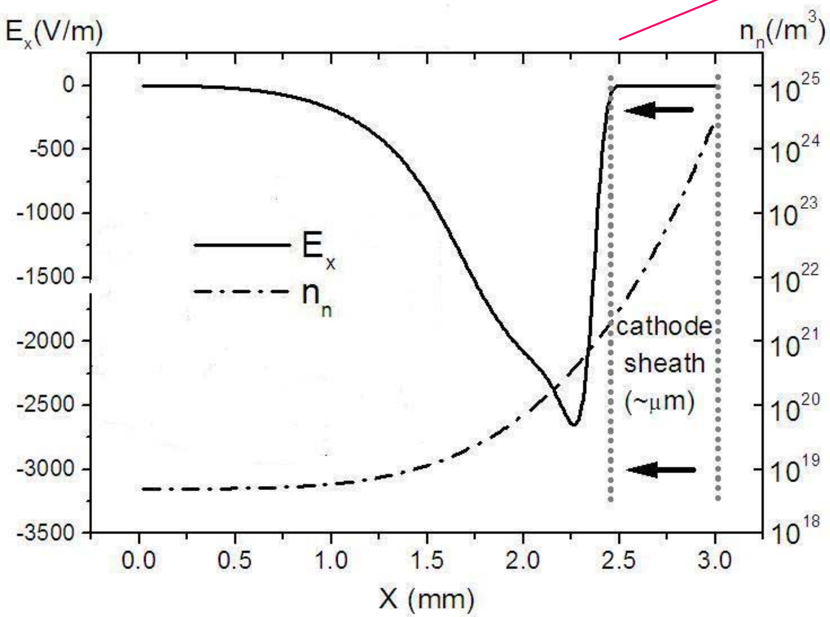
$\mathrm{v_D} = \mu^2 B(E - v_D B - \nabla p / qn_i)$

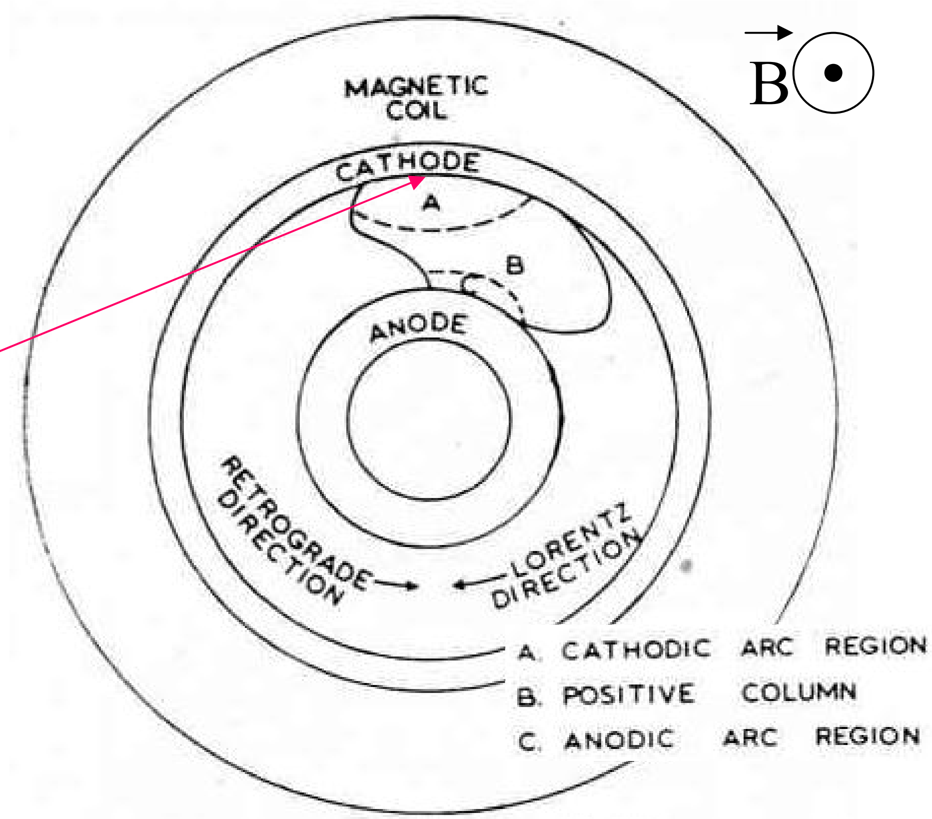
$$\boxed{v_D = \frac{1}{1 + r_L^2 / \lambda_{cx}^2}(\frac{E}{B} - \frac{\nabla p}{qBn_i})}$$

$$\frac{\text{number of ions that contribute}}{\text{total number of ions}} = e^{-r_L / \lambda_{cx}}$$

Retrograde motion of arc cathode

- retrograde motion was noticed by Stark (1903)
- no satisfactory explanation despite numerous attempts.

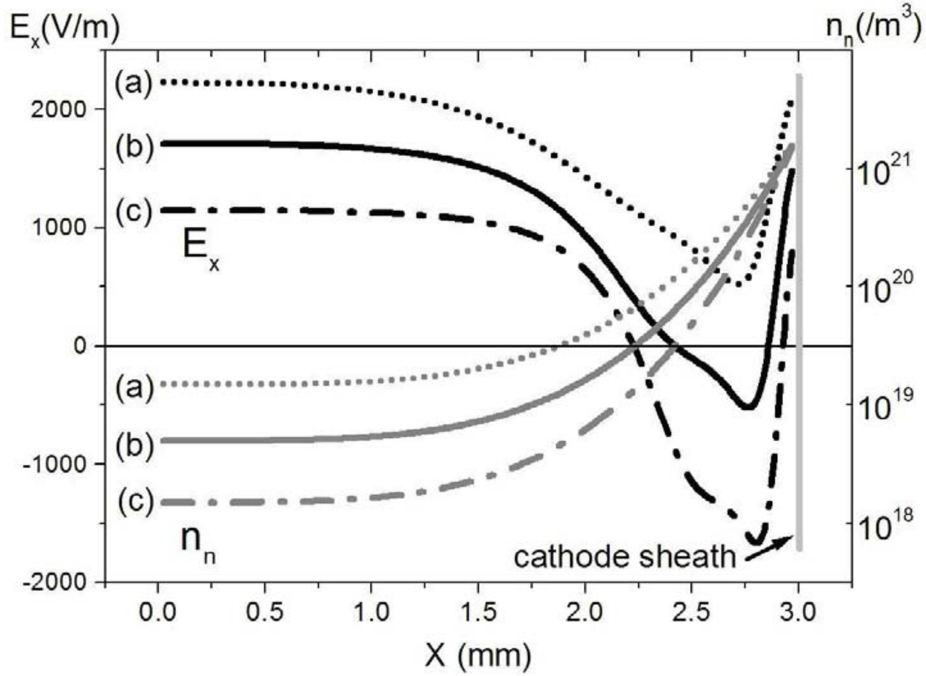


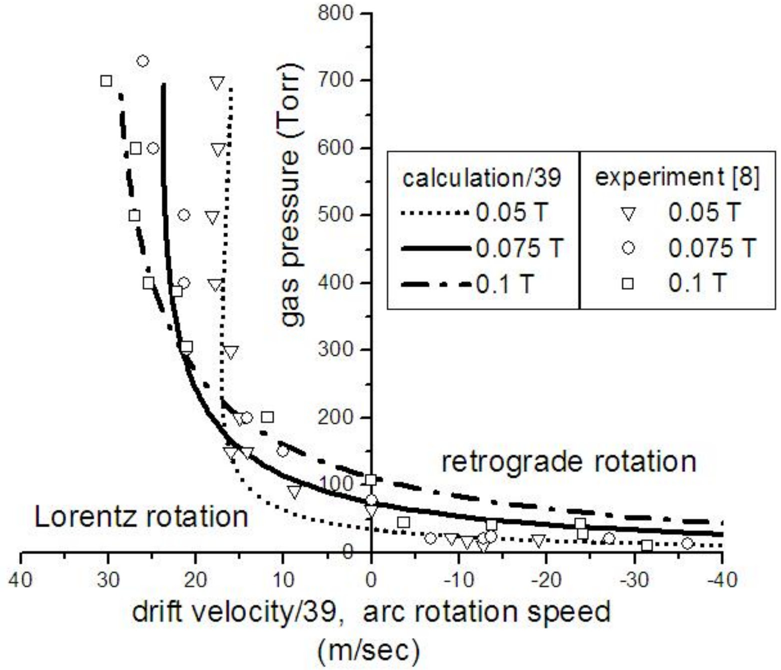


reversed electric field is formed

E_x vanishes when $n_n > \sim 10^{21}/m^3$

E_r and v_D calculation from gyrocenter shift





$$v_D = \frac{1}{1 + r_L^2 / \lambda_{cx}^2} \left(\frac{E}{B} - \frac{\nabla p}{qBn_i} \right)$$

v_D is proportional to arc rotation speed

oral presentation BO5.00012

[K.C. Lee, PRL, Vol 99, 065003, 2007]

- **higher neutral density → higher column electric field (constant current)**
- **high gas pressure → positive electric field in front of cathode**
- **low gas pressure → negative electric field in front of cathode**

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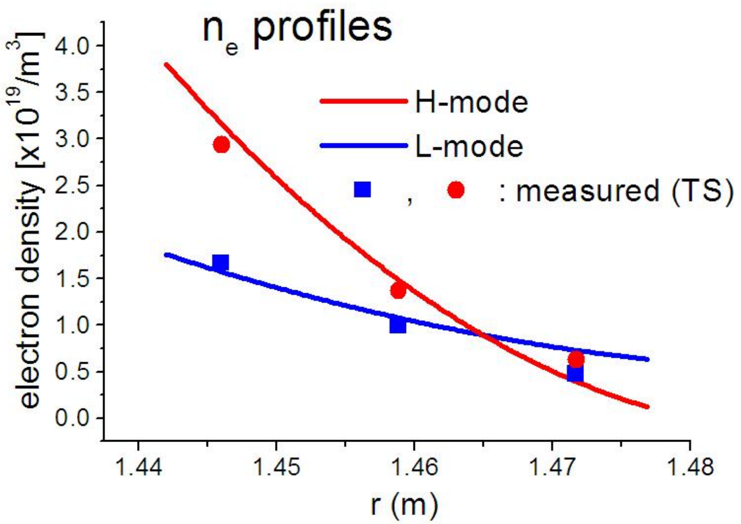
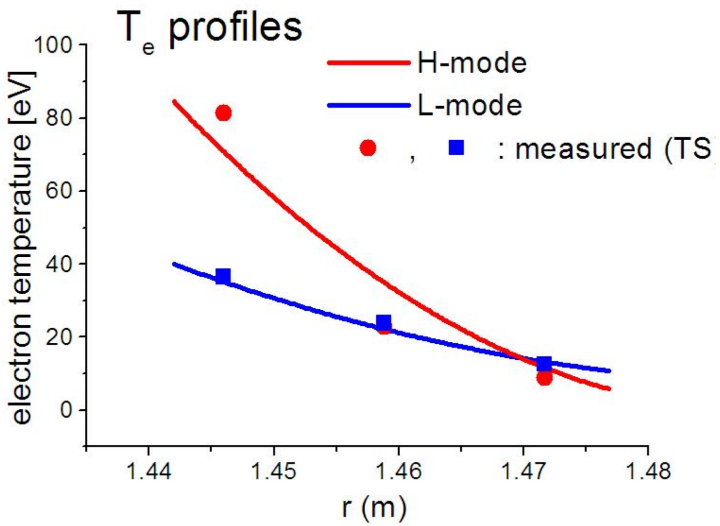
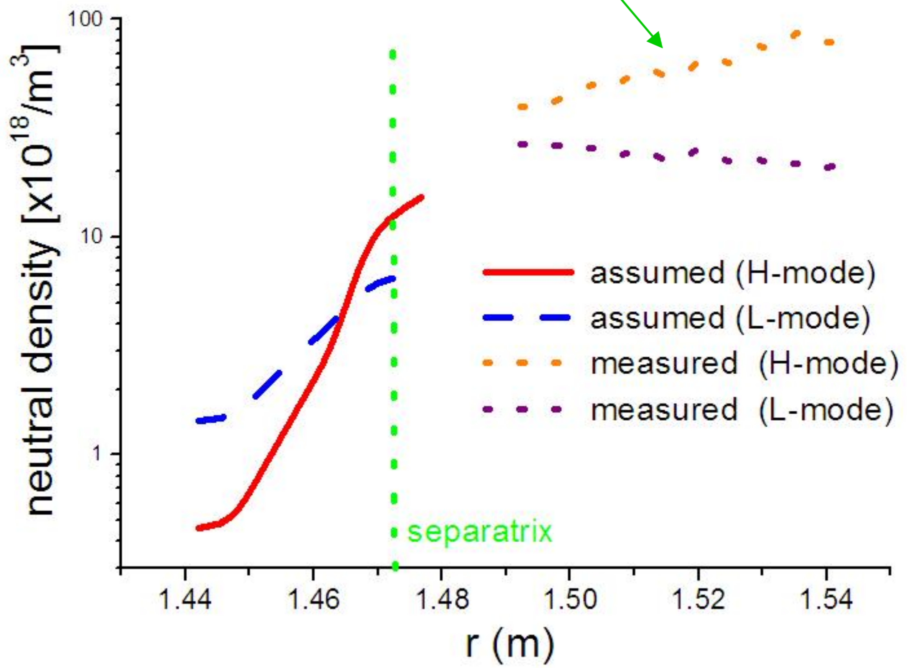
NSTX H-mode measurements

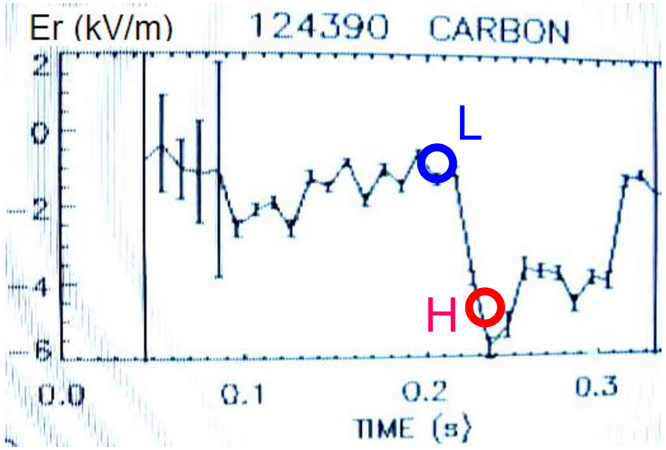


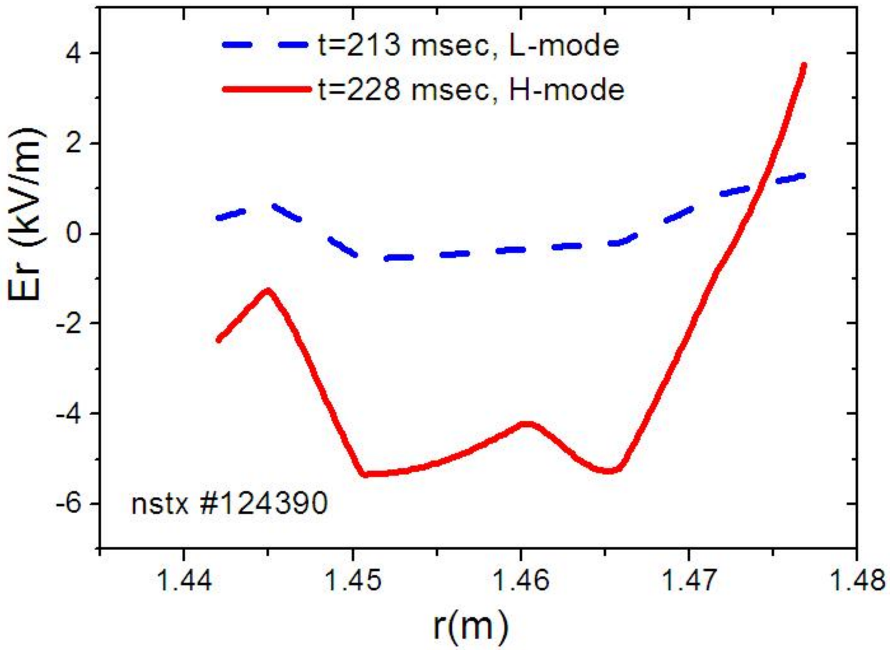


- n_e and T_e from Thomson Scattering
- neutral density measurement from mid-plane D-beta emission compared with calculation



E_r measurement and calculation from gyrocenter shift



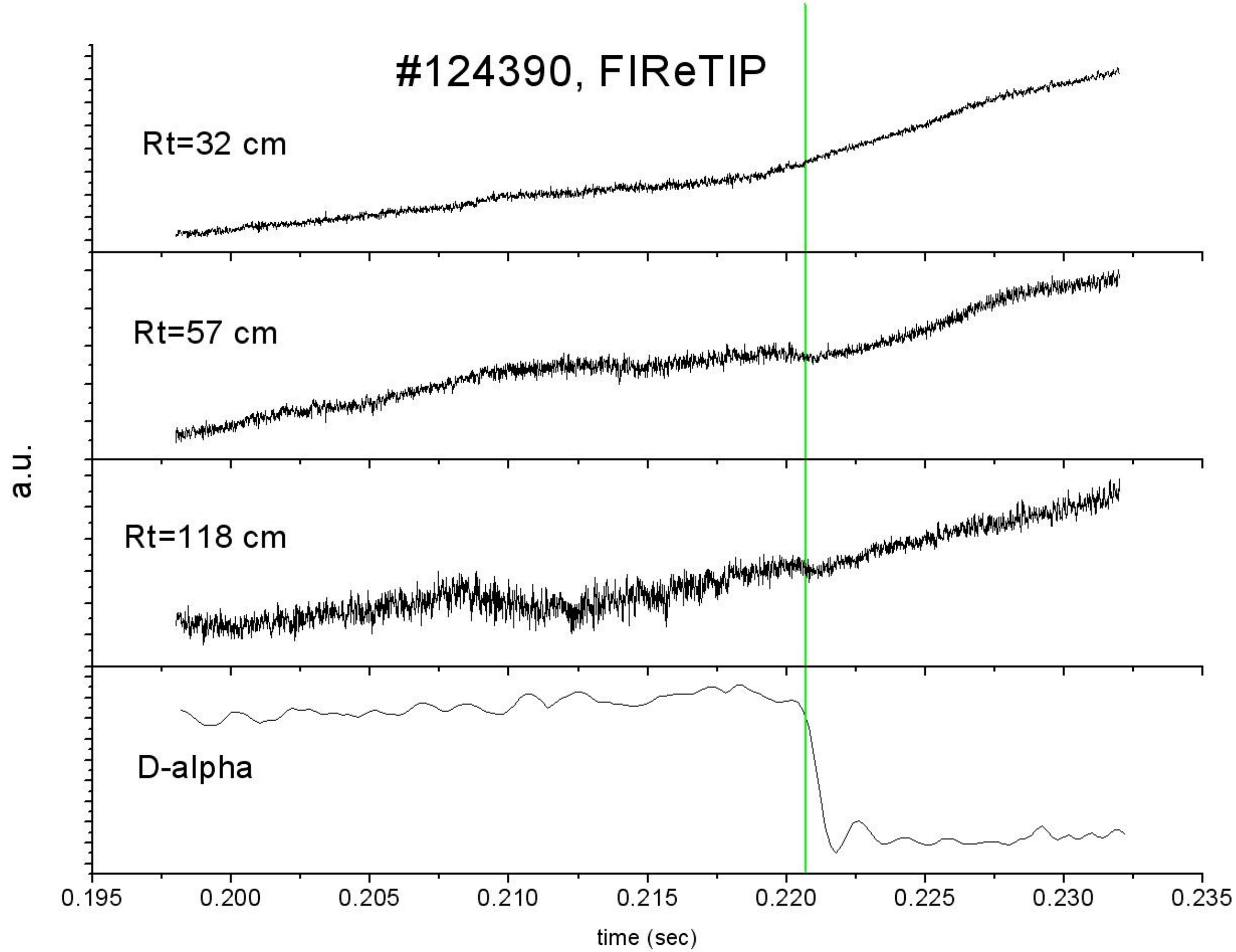


- E_r measurement from edge rotation diagnostics
- Er calculation from gyrocenter shift with n_e, T_e, n_n profiles

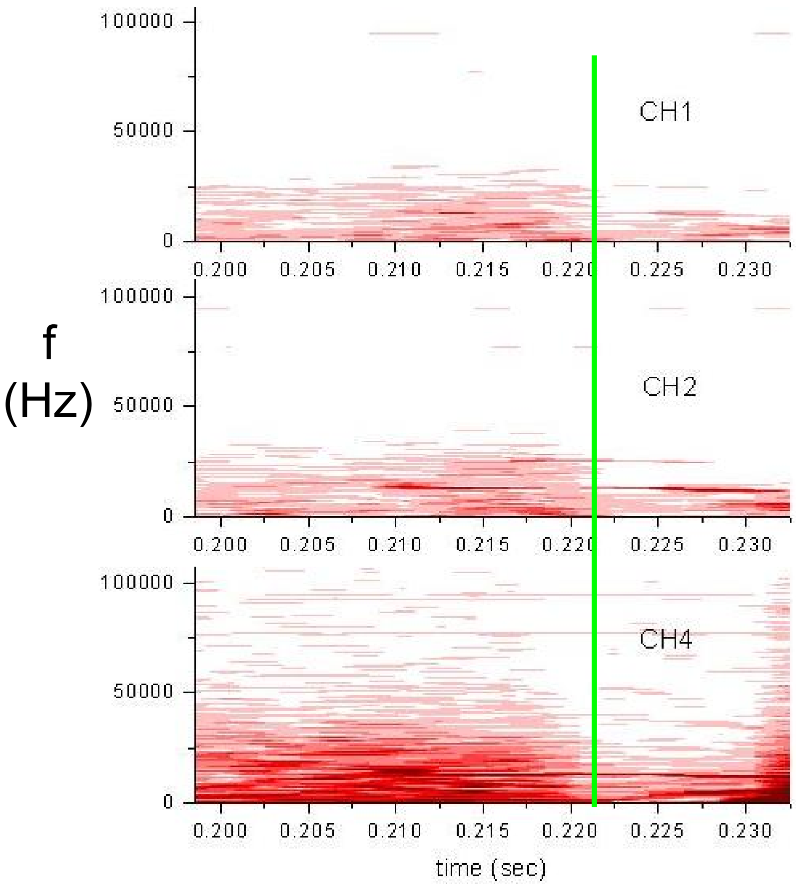
$$J_x^{GCS} = \frac{m_i n_i n_n}{B} < \sigma_{cx} v_i > \left(\frac{E}{B} - \frac{\nabla p}{qBn_i} + \frac{T_i \nabla n_n}{qBn_n}\right)$$

H-mode measurement via FIReTIP

- density fluctuation reduction at H-mode transition



H-mode n_e fluctuation study via FIReTIP



- spectrum n_e fluctuation measured by FIReTIP

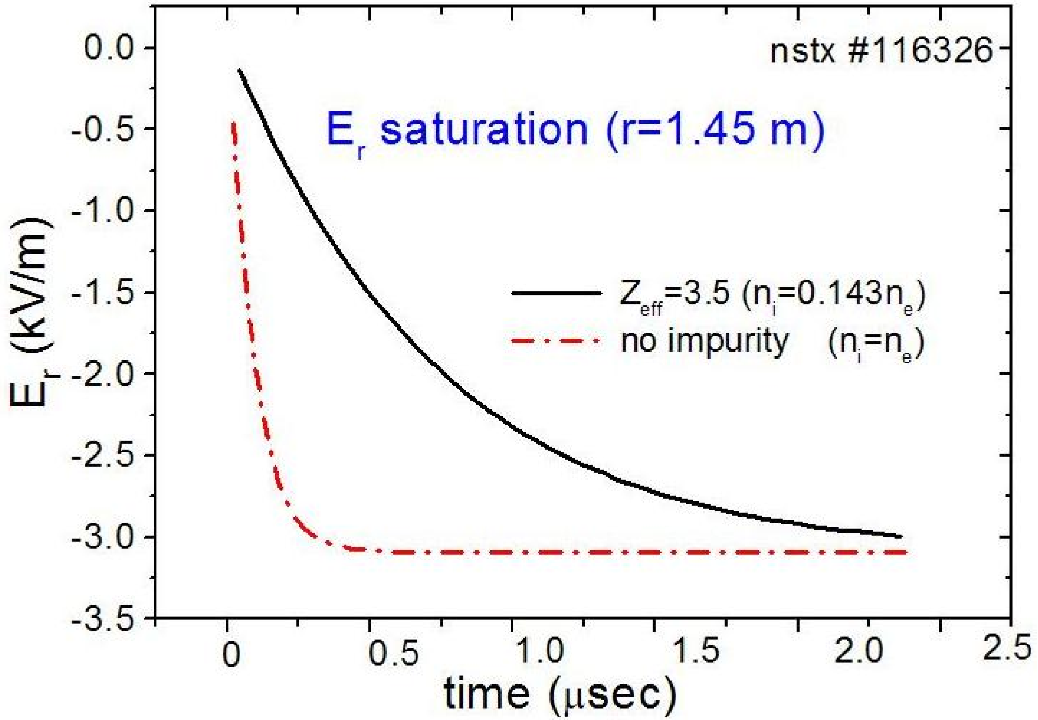
- fluctuations above 10~20 kHz are suppressed by ExB flow increase

- coherent oscillation remained after transition (10 kHz MHD)

n_e fluctuation and edge transport by gyrocenter shift

- **no density fluctuation => E_r saturates at ambipolar electric field**

$$J_x^{GCS} = \frac{m_i n_i n_n}{B} < \sigma_{cx} v_i > \left(\frac{E}{B} - \frac{\nabla p}{qBn_i} + \frac{T_i \nabla n_n}{qBn_n}\right) \approx 0$$



- **ambipolar electric field induces ambipolar diffusion**

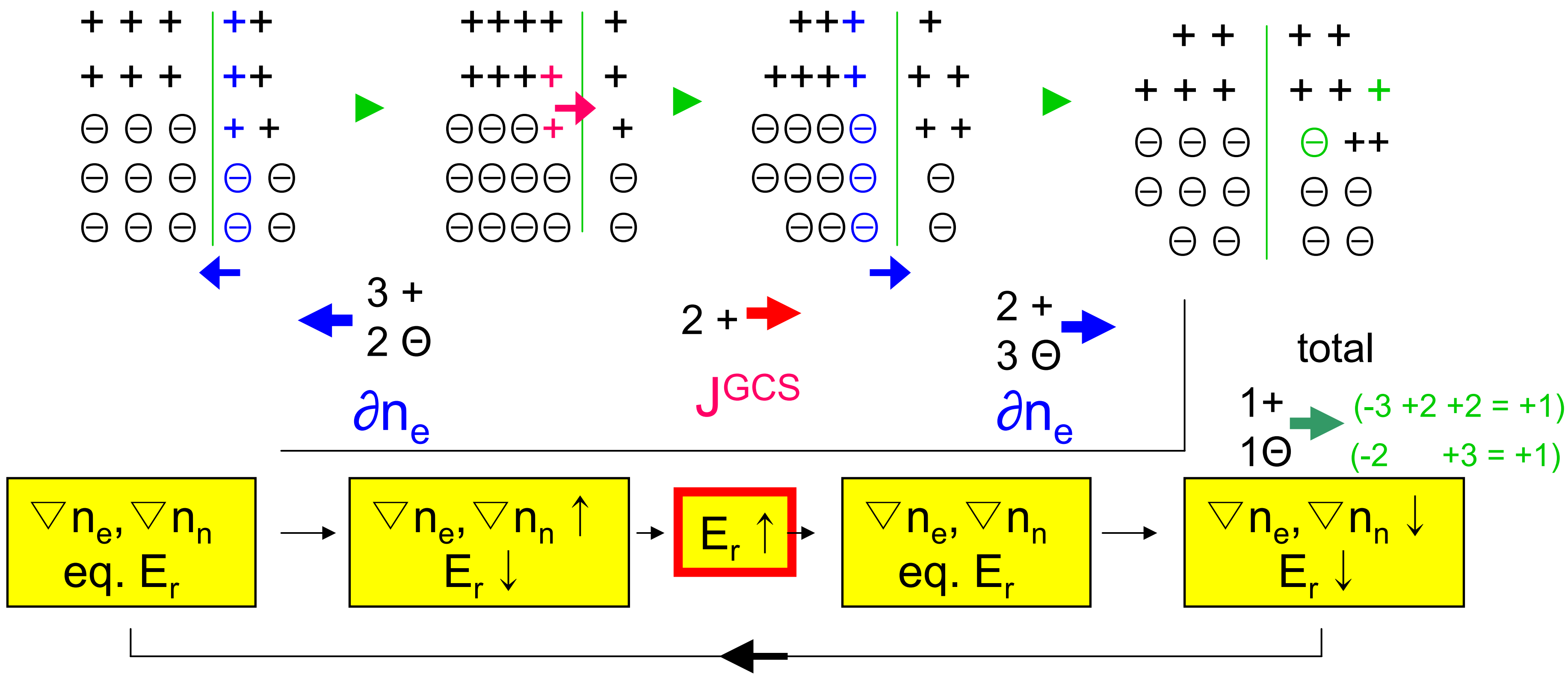
$$\approx \nu_{ion} r_{Le}^2 << 1$$

ν_{ion} :electron impact ionization frequency

- **calculation starts with zero initial E_r**

- **gyrocenter shift of impurity is neglected (small cross-section)**

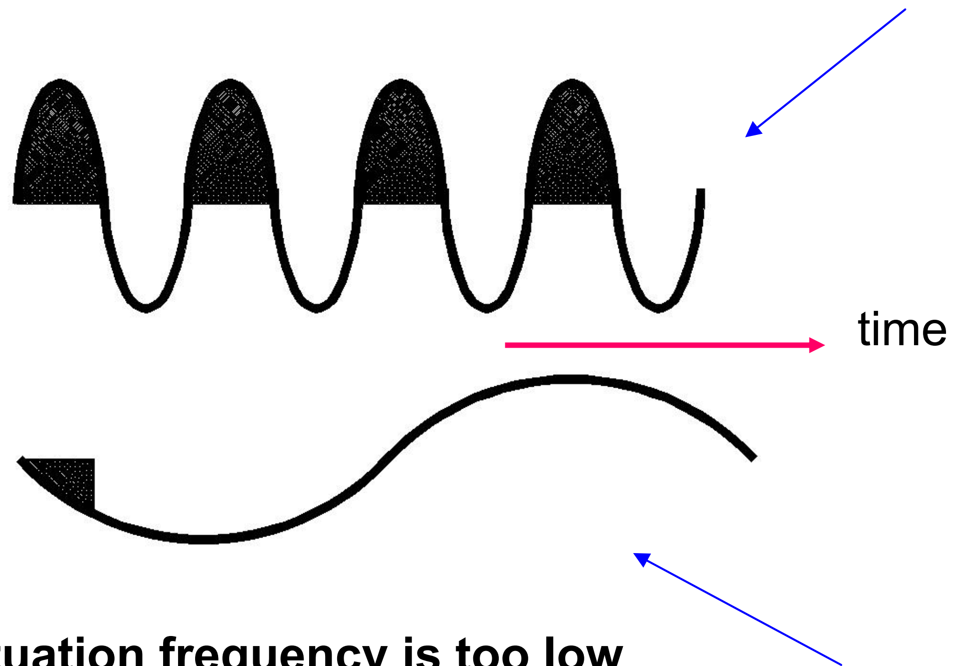
n_e fluctuation generates edge transport



- **both forward and backward density flow dilute charge separation : $E_r \downarrow$**
- **only backward density flow increase density gradients => J^{GCS}**
- **repeat of density fluctuation flow generates transport ; maximum $\approx$ 1/2J^{GCS}**

Threshold of n_e fluctuation frequency

- when density fluctuation frequency is sufficiently fast
  => transport occurs 1/2 of the cycle



- when density fluctuation frequency is too low
  => transport occurs only during a small part of the entire cycle

- typical saturation time from NSTX calculation : ~μsec,
- FIReTIP measurement showed threshold of ~20 kHz

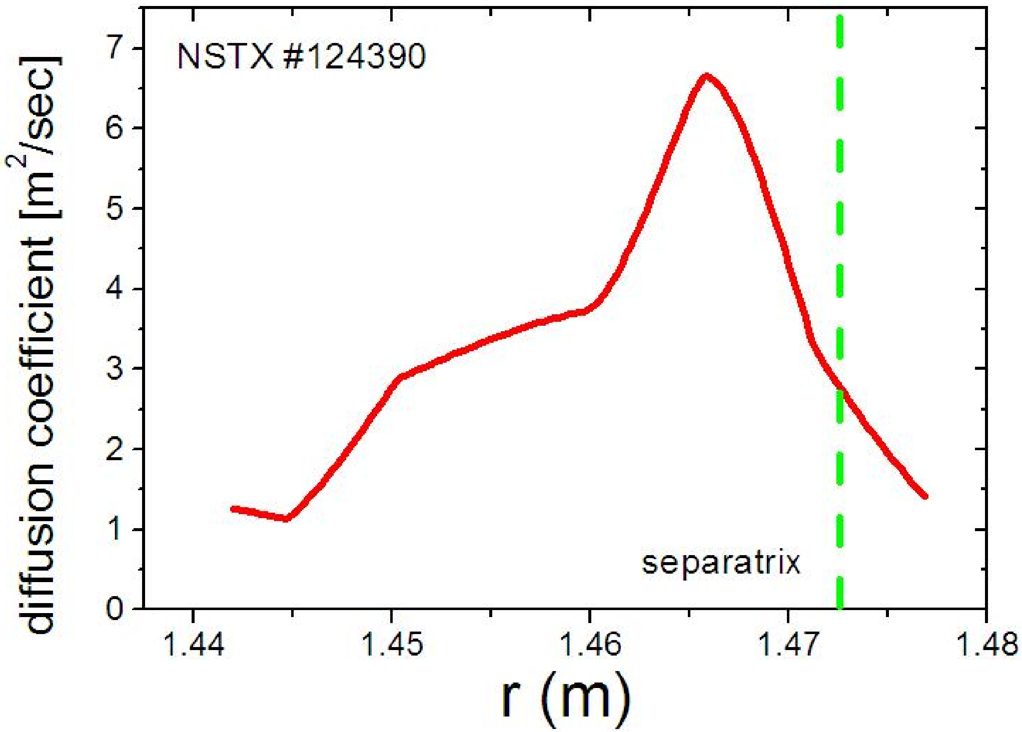
Preliminary quantitative study of n_e fluctuation generated edge transport

$$\Gamma_{\max}^{fluctuation} \approx \frac{J_r^{GCS}(E=0)}{2e} = \frac{m_i n_i n_n}{eB} < \sigma_{cx} v_i > (-\frac{\nabla p}{eBn_i} + \frac{T_i \nabla n_n}{eBn_n})$$

diffusion coefficient,

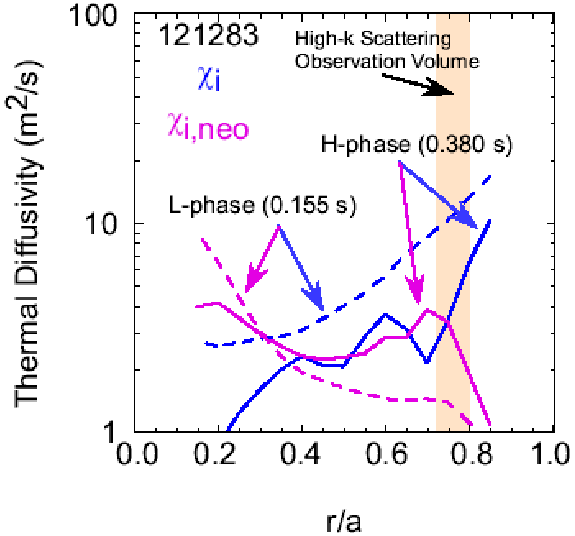
$$D_{\max}^{fluc} \approx \Gamma_{\max}^{fluc} / (\frac{\nabla n_i}{n_i})$$

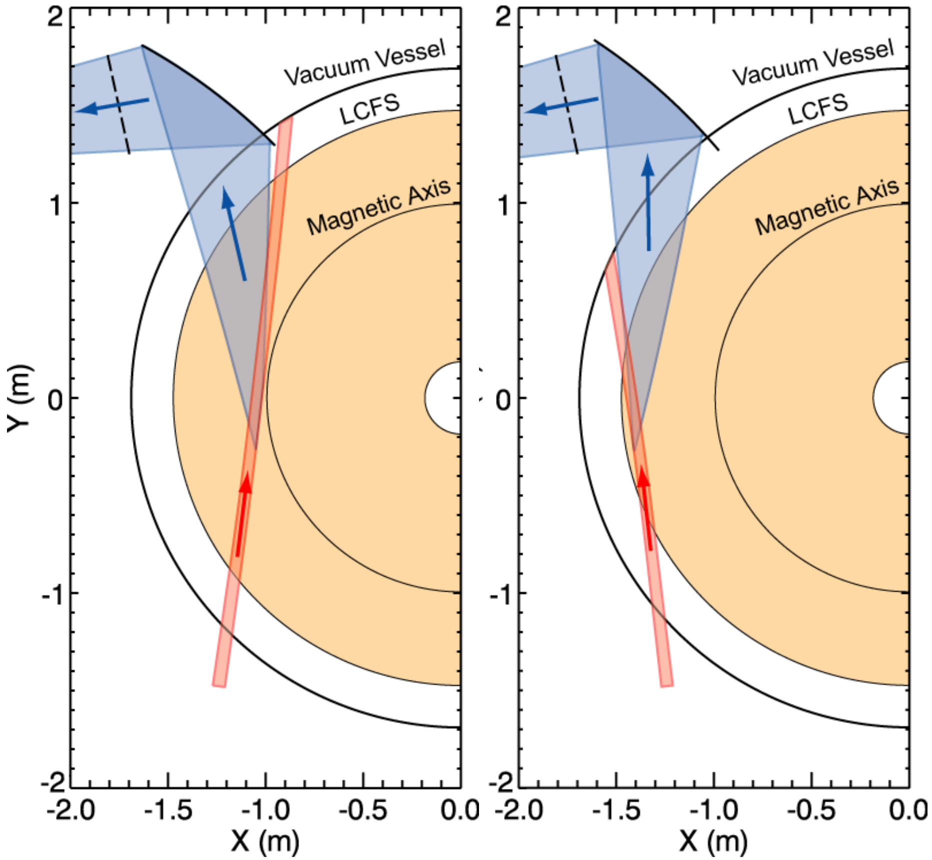
- **large uncertainty from unknown factors; neutral density, impurity, neutral fluctuations, etc.**



Future gyrocenter shift study via high-k system

- Tangential multi-channel (5) scattering system:
  - P_o ~100 mW
  - λ_o ~1 mm (280 GHz)
  - System NF ~ 5000°K
- System resolution
  - $\Delta k = a/2 \sim 1.0\ cm^{-1}$

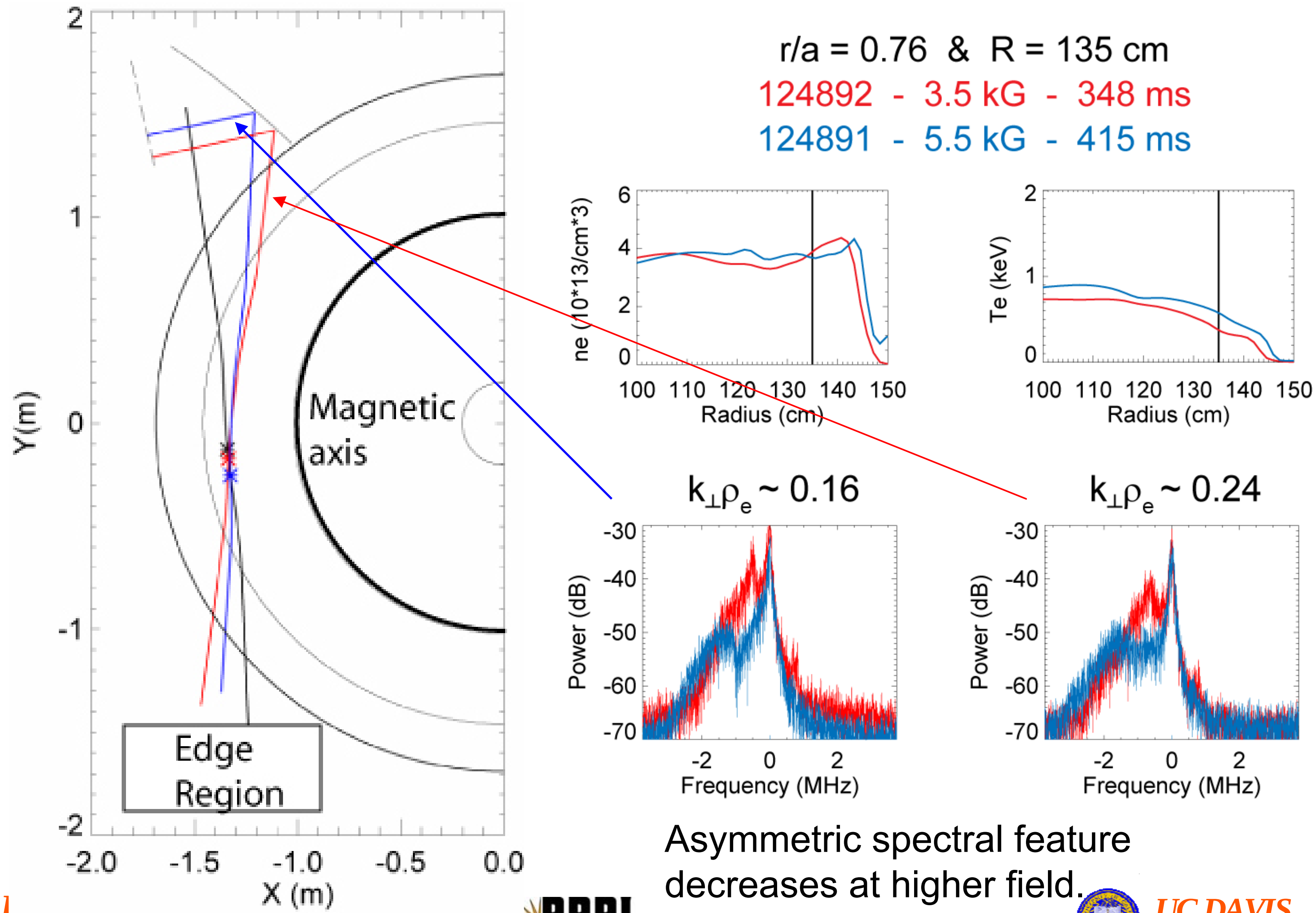




Inboard $\rho = 0.05$
$k_\perp \rho_e$ up to 0.7

Outboard $\rho = 0.75$
$k_\perp \rho_e$ up to 0.4

Edge experimental results from high-k



Asymmetric spectral feature decreases at higher field.

Conclusions

● FIReTIP measured H-mode density fluctuations with 5 channels in 2007 including one additional channel

● gyrocenter shift theory is expanded to low temperature cases and explained retro grade motion of cathode arc spots

● NSTX measurement and gyrocenter shift calculations are compared on the radial electric field formation at the H-mode transition

● density fluctuation possibly can generate edge transport in conjunction with gyrocenter shift

● density fluctuation measured by FIReTIP showed threshold of ~20 kHz ; transport related with gyrocenter shift has frequency threshold ~100kHz

● further accurate diagnostics are required for the study of gyrocenter shift