Edge radial electric field formation after the L-H transition

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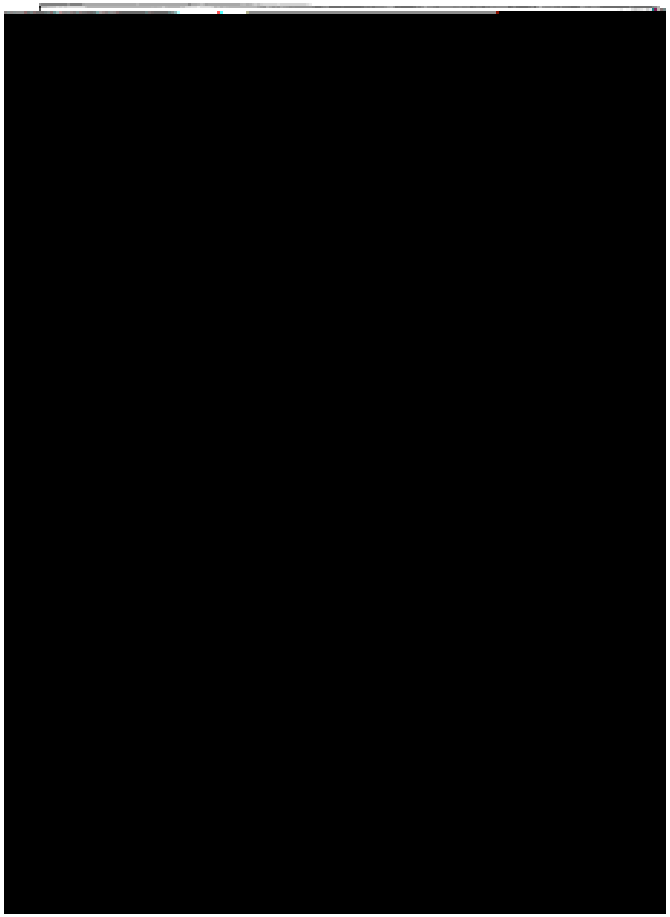
Experimental observations of the radial electric field formation after the L-H transition

Theoretical study of “poloidal shock” formation, and comparison with experimental observations.

Ion orbit loss model near the plasma boundary was proposed *[Itoh and Itoh, PRL1988]*

Transition from the branch of large flux (L) to small flux (H) occurs



before experimental observation

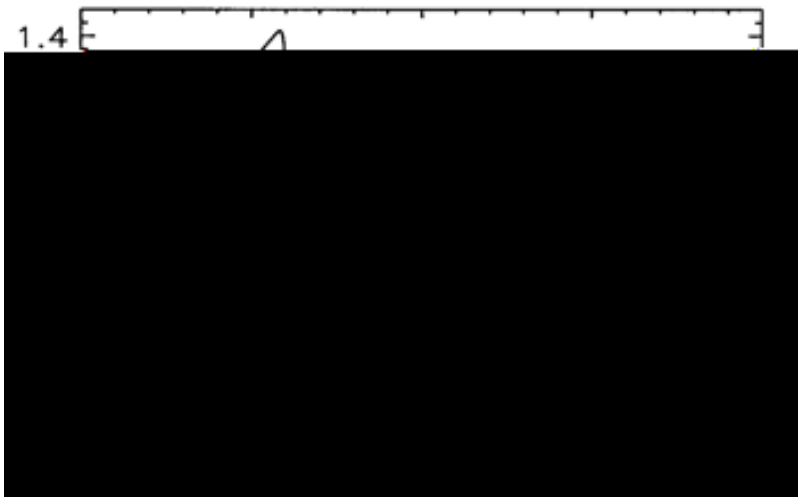
believed

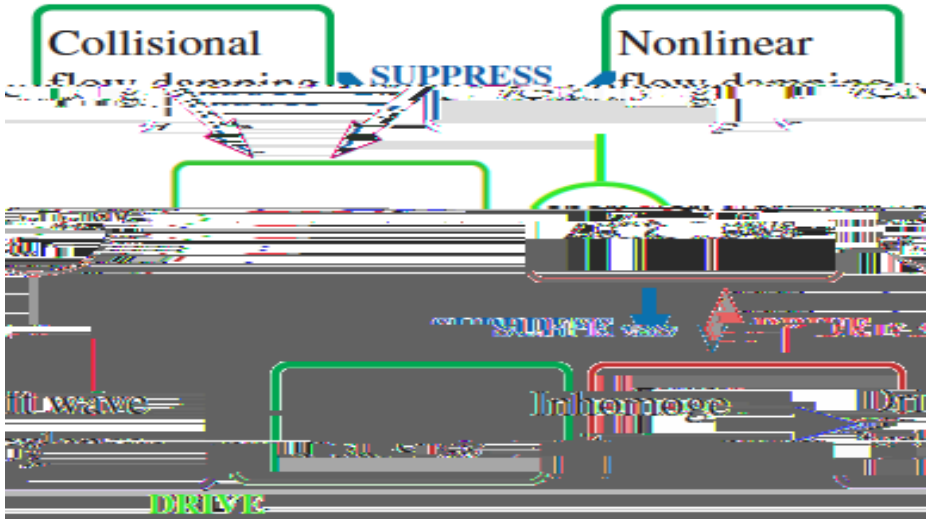
E B shear

a
r/a

Does turbulence Reynolds Stress suffice for an origin of E_r (mean field or ZF) ?

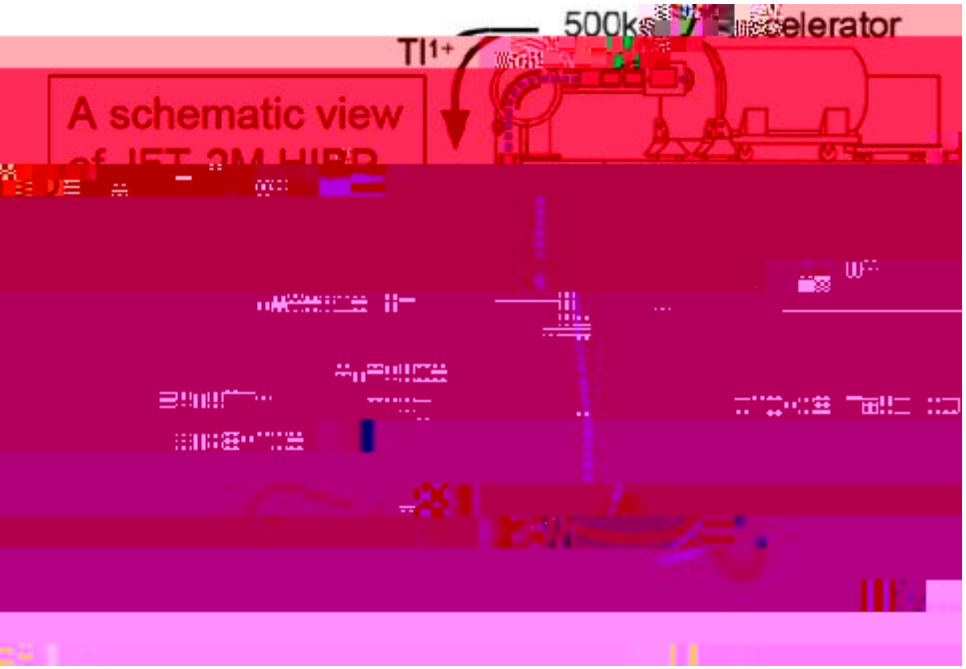
Model

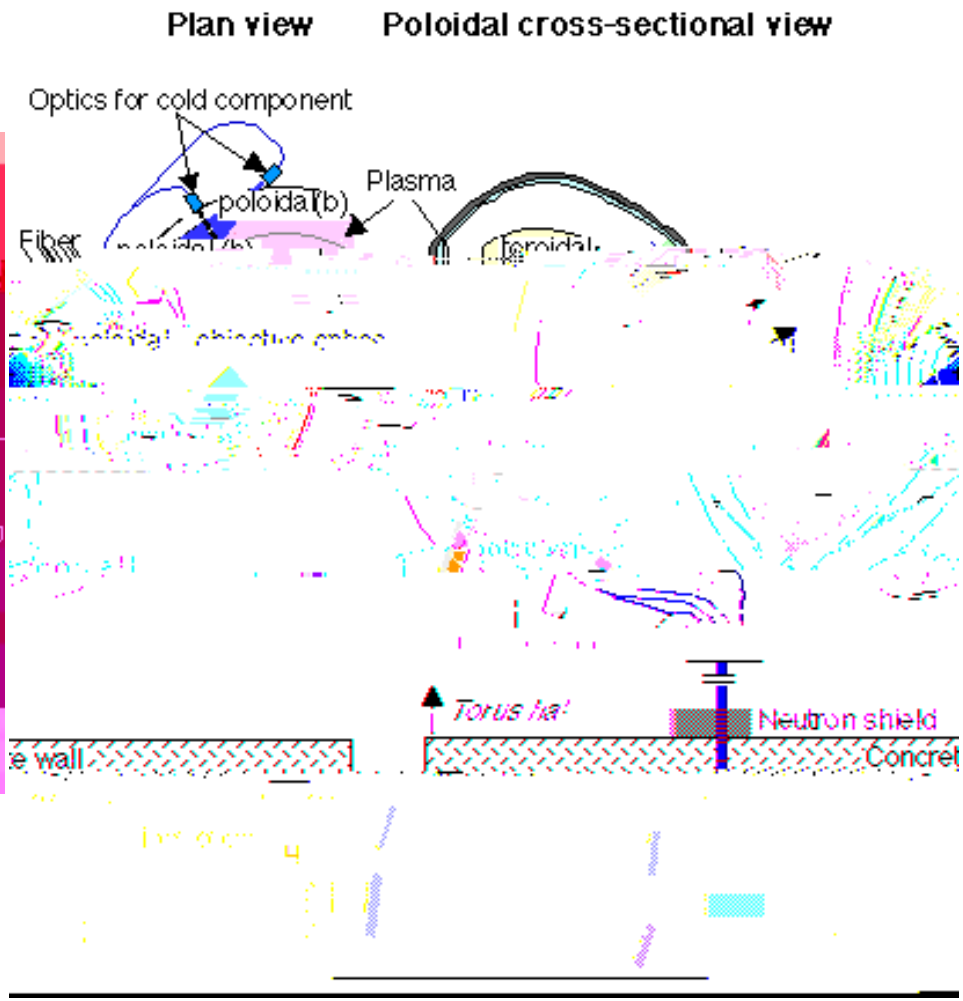




Key diagnostics

(*HIBP and CXRS*)





HIBP and CXRS are the most powerful tool for the physics study of edge Er formation

Recent experimental results *(JFT-2M)*

JFT-2M (JAERI Fusion Torus-2M)

tokamak

R = 1.3 m, a = 0.35 m

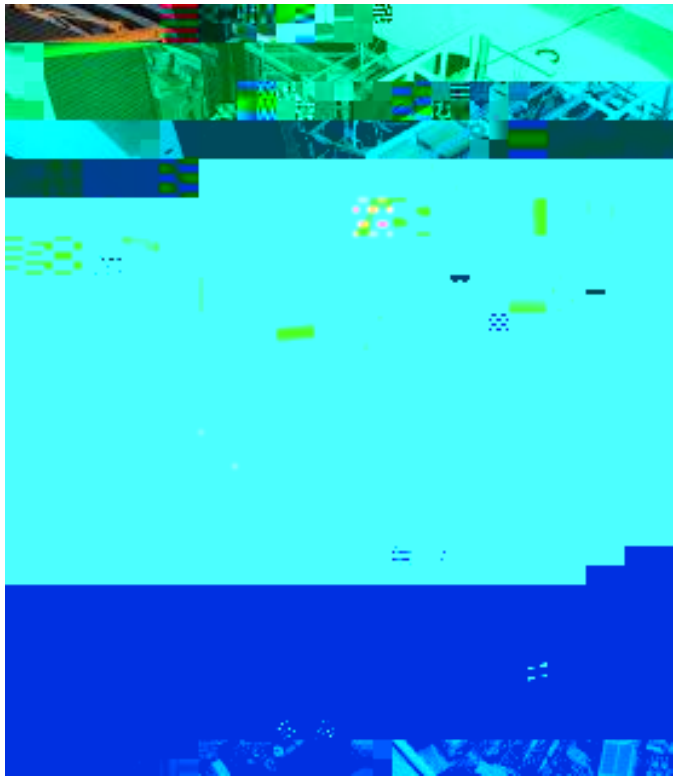
$B_t \leq 2.2$ T

$I_p \leq 0.5$ MA

(Medium sized tokamak)

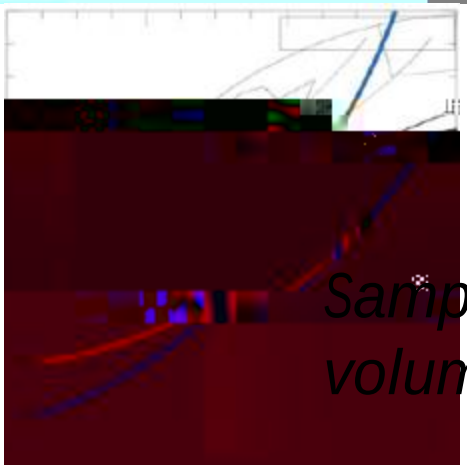
NBI power

http://www-jt60.naka.jaea.go.jp/jft2m/



A 500 keV Heavy Ion Beam Probe (HIBP) diagnostic on JFT-2M

JFT-2M



Sample volumes

JFT-2M

H-mode;

Steep gradient in I_{HIBP} (

)

Strong E_r (=-d /dr)

E_r B velocity (~ 30 km/s)

(~0.5 km/s)

Micro-scale turbulence in LCO phase was also similar to that in L-mode

Power spectrum of φ

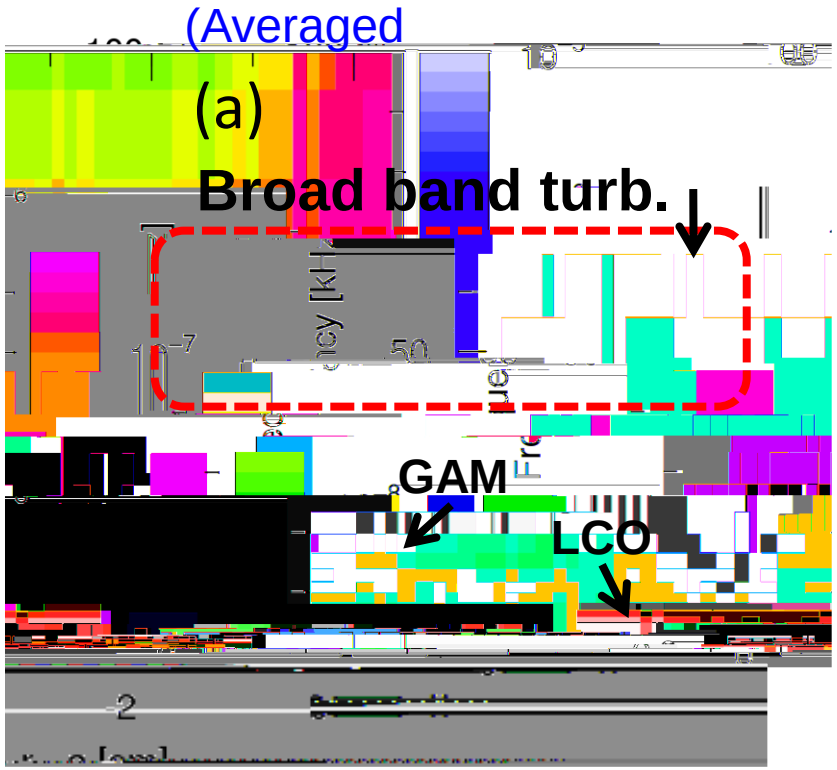
r - a = -1 cm

LCO

L

Broad band turbulence

H



In H-mode, high frequency component is suppressed.

Reynolds stress drives only ~15 m/s of poloidal velocity modulation during LCO

JFT-2M

$$\Pi_{r\theta} = \langle E_r E_\theta \rangle / B^2$$

$$= -S^2 k_r k_\theta / (2 B^2)$$

$$\Pi_{r\theta} = -S_0^2 k_r k_\theta \{2S/S + k_r/k_r + k_\theta/k_\theta\} / (2 B^2)$$

[redacted]

$$\epsilon_\perp = [redacted]$$

[redacted] $\sim$ 15 m/s

(conditional average of 21 oscillation periods)

Discussion:

E_r

S

L_n^{-1}

JFT-2M

at the location of maximal E_r amplitude during LCO.

$-E_r$ S L_n^{-1}

L_n^{-1} S

$-E_r$ L_n^{-1}

Observed temporal evolution seems to be corresponds to the E_r bifurcation model

E_r

Recent experimental results (*JT-60U*)

R = 3.4 m, a = 1 m

$B_T \leq 4$ T

$I_P \leq 3$ MA

(Large sized tokamak)

http://www-jt60.naka.jaea.go.jp

$$I/I_0 = 1 + (E_r')^2 + E_r E_r$$

Diagnostic

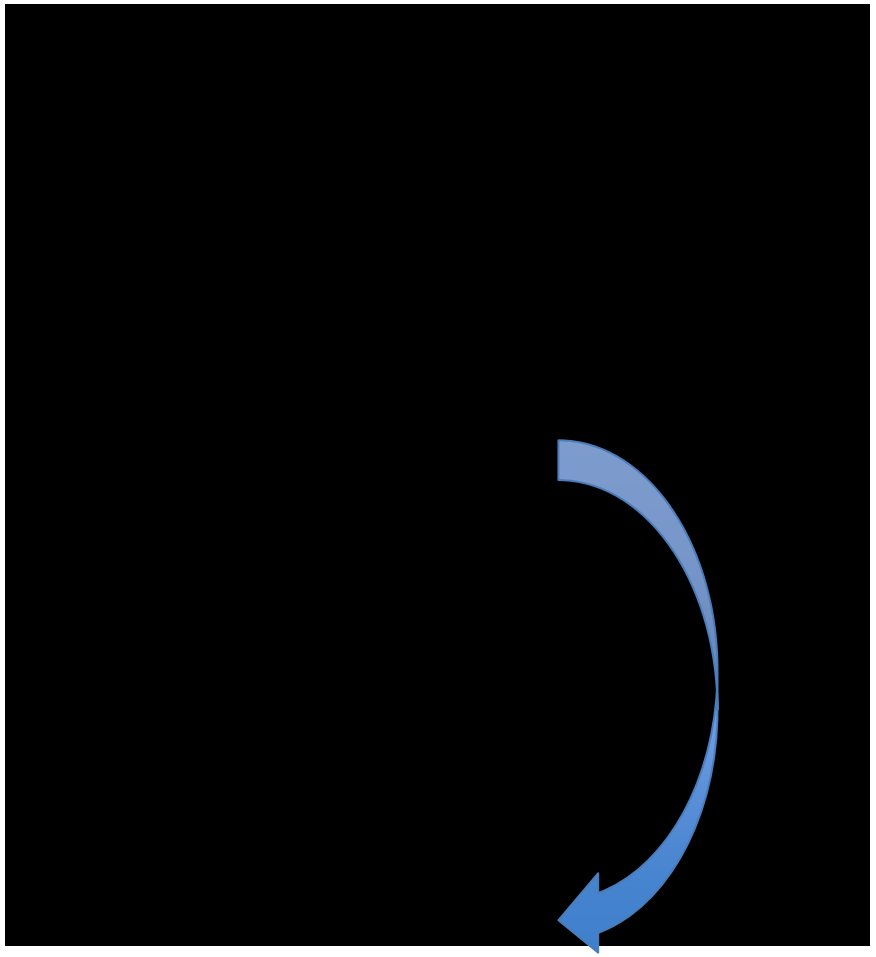
Diamagnetic

Poloidal

Toroidal Velocity Term

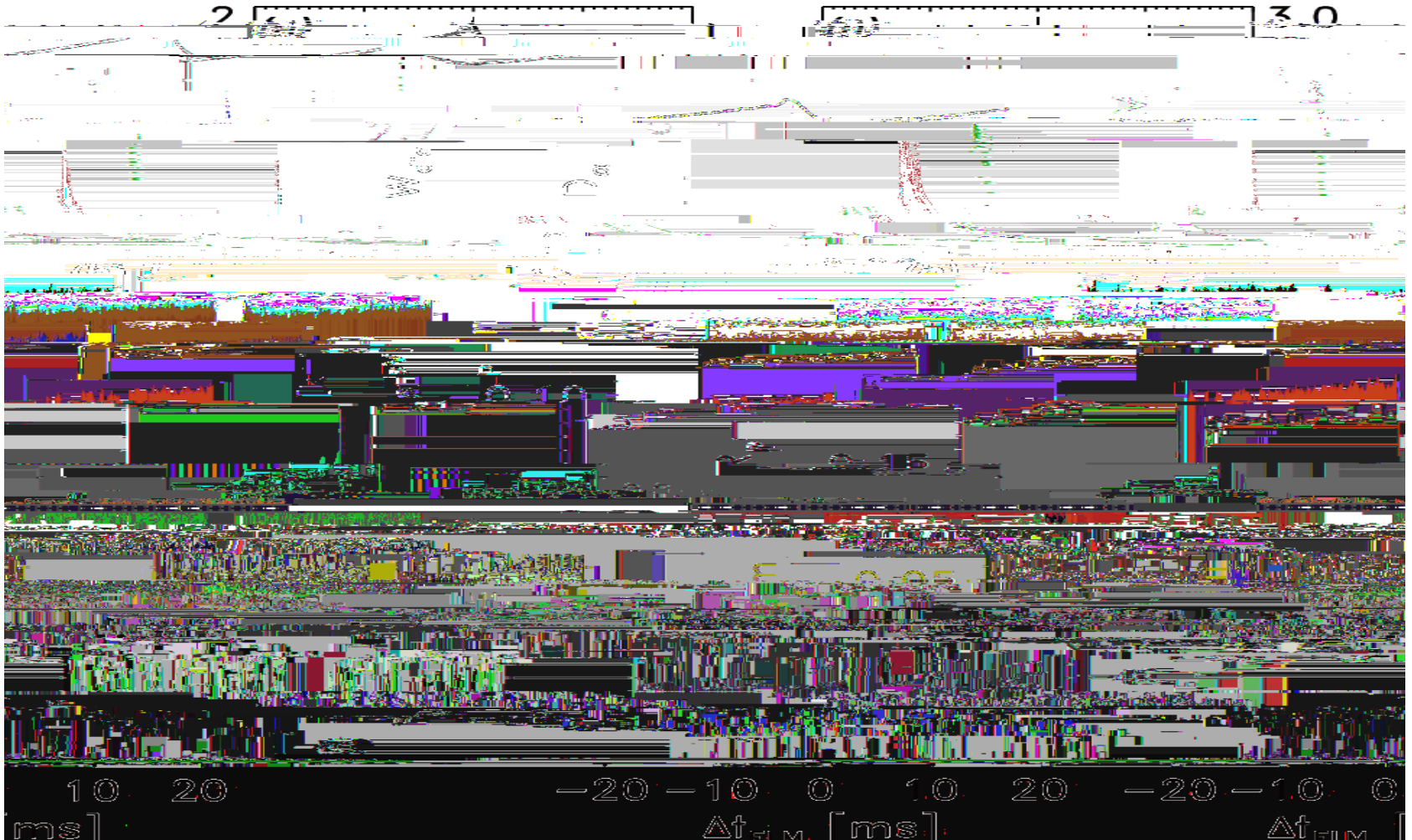
Improved statistics in assessing the temporal behavior of the measurements can be obtained

Co.: f_{ELM} = 33.2 [Hz], $W_{ELM}/W_{ped.}$ = 9.3 [%]
Ctr: f_{ELM} = 40.1 [Hz], ($W_{ELM}/W_{ped.}$ = 6.1 [%])

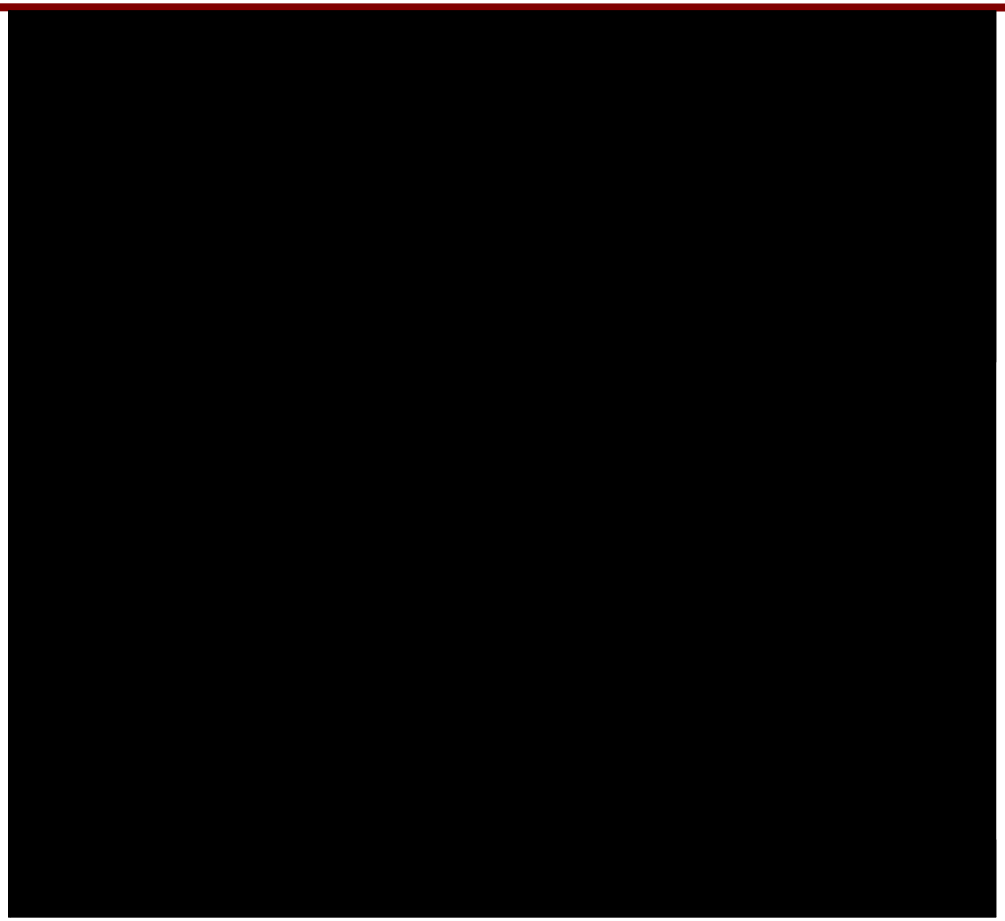


By mapping of multiple, reproducible ELM cycles onto a single time basis (defined by relative time to the ELMs, t_{ELM}).

Spatio-



Relationship between the Max. normalized temperature gradient and E_r (and/or E_r”) locations

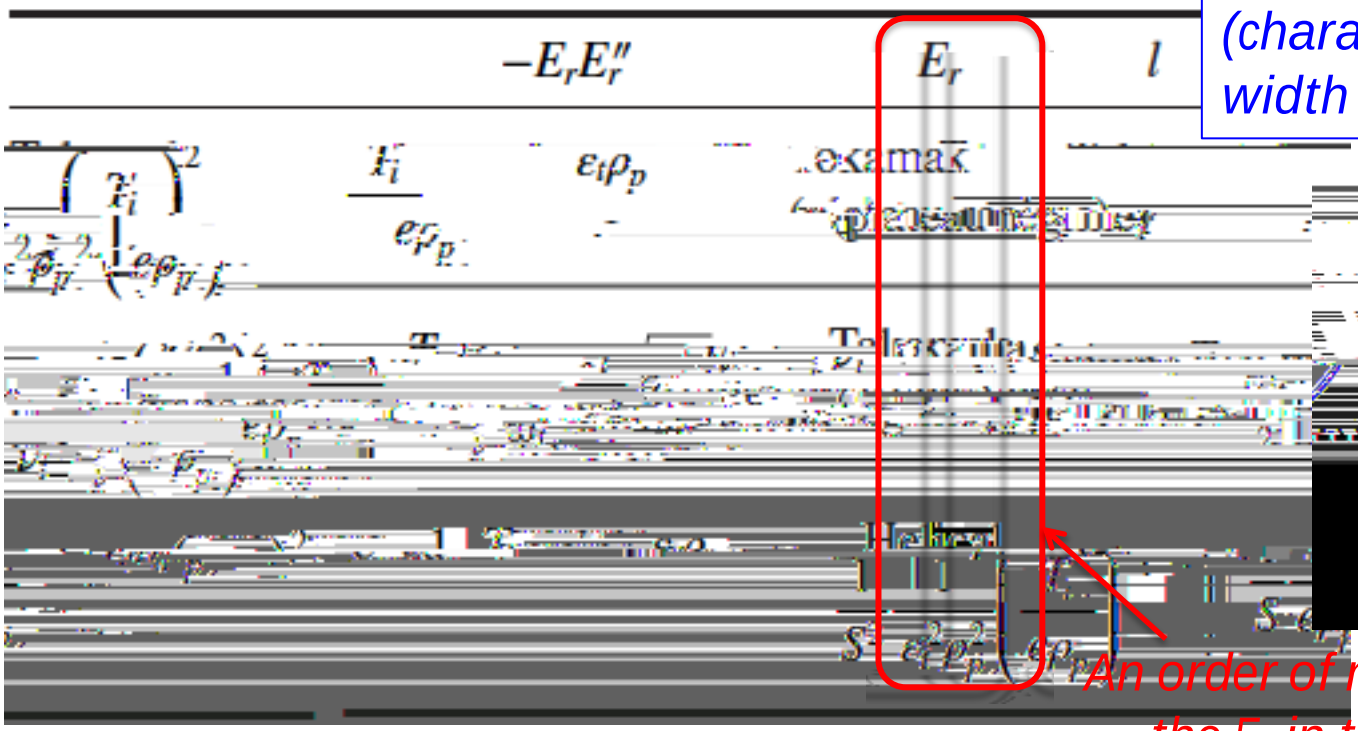


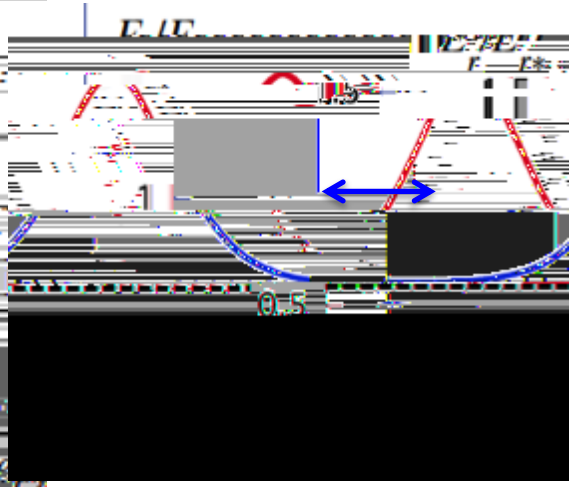
Separation of E_r-shear locations for both positive and negative values is about $_i$ (or more) =>

Scaling relations of the solitary structure in the edge electric field have been developed

[K. Itoh, et al., Plasma Phys. Control. Fusion 57 (2015) 075008]

(characteristic value for the width of the peaked profile)





An order of magnitude estimate of the E_r in the experimental units:

Basic equation: $\frac{\partial}{\partial t} E_r = \nabla \cdot \mu_i \nabla E_r - \frac{1}{\varepsilon_0}(J_r - J_{ext})$.

Boundary condition: $E_r \to E_{r\infty}$ and $|\nabla E_r| \to 0$ at $x \to \infty$

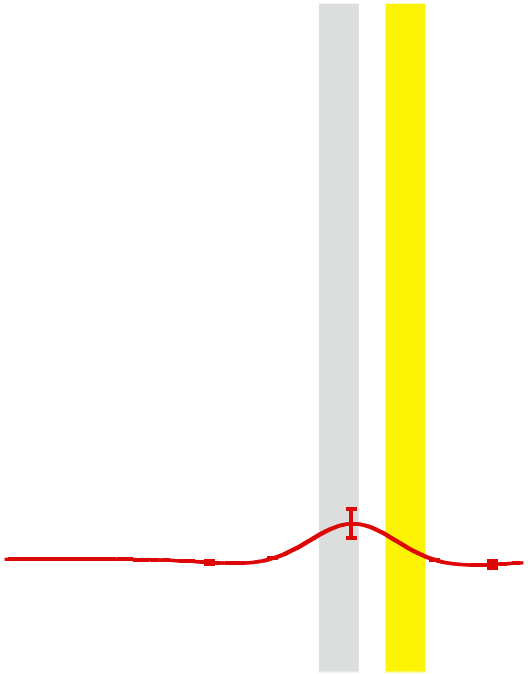
Non-linear conductivity: (bulk viscosity)

$$J(E_r) = \frac{en_i\rho_p r}{\sqrt{\pi}} \frac{1}{\omega} \mathrm{Im} Z(X + i\omega\tau_i^{-1})(E_r - E_{r\infty})$$

An order of E_rE_r" predicted by model is not far from experimental observations

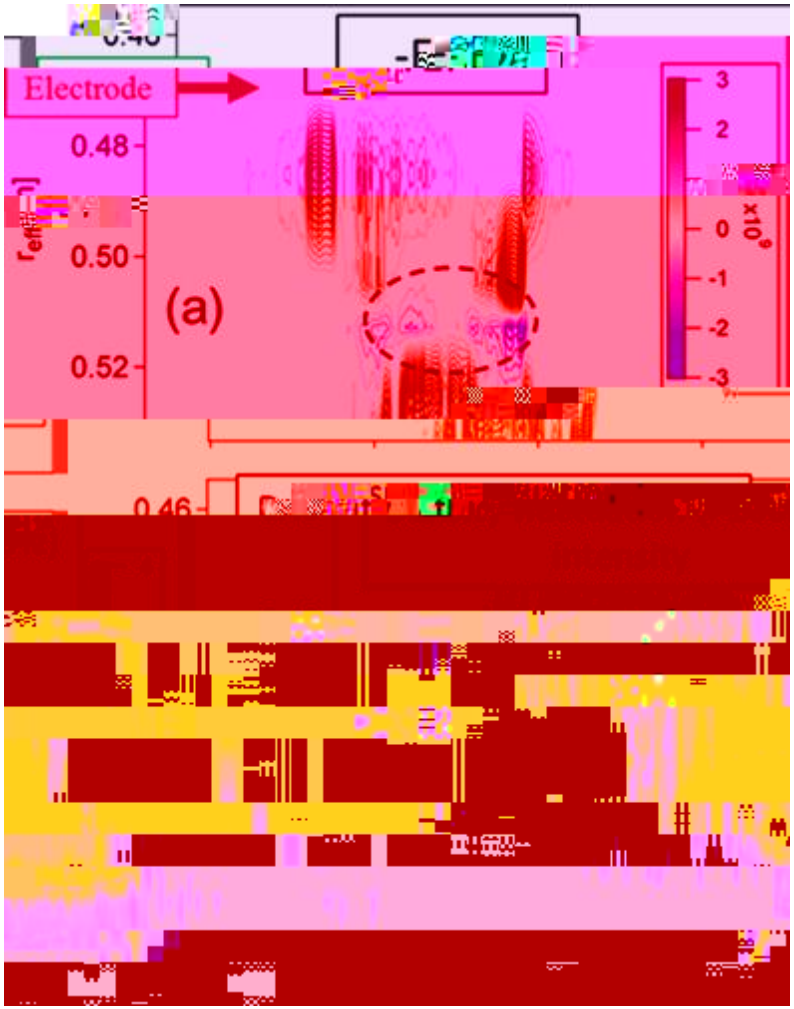
JT-60U (ELMy H-modes): E_rE_r"≈$10^{13\sim14}$ [V^2/m^4].

Kamiya, PoP2014



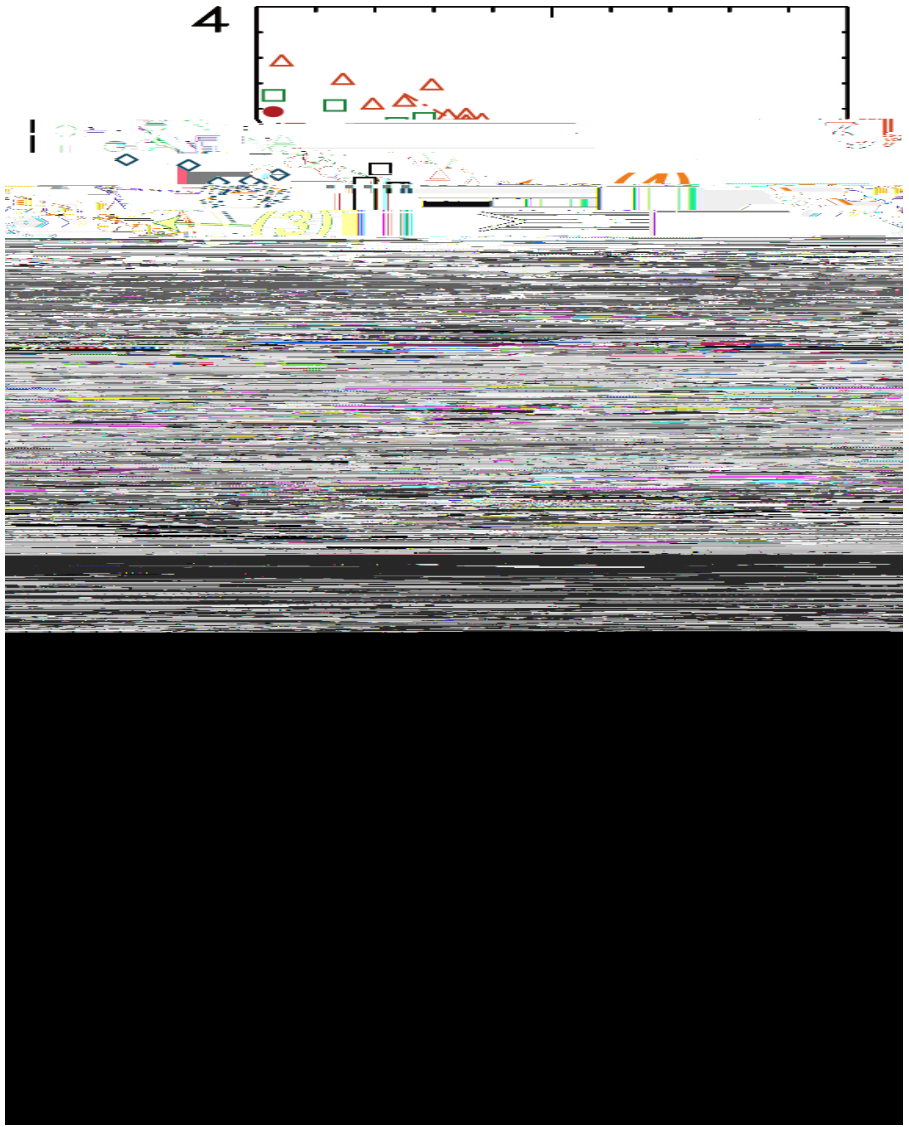
LHD (electrode biasing): ErEr"≈10^9 [V^2/m^4].

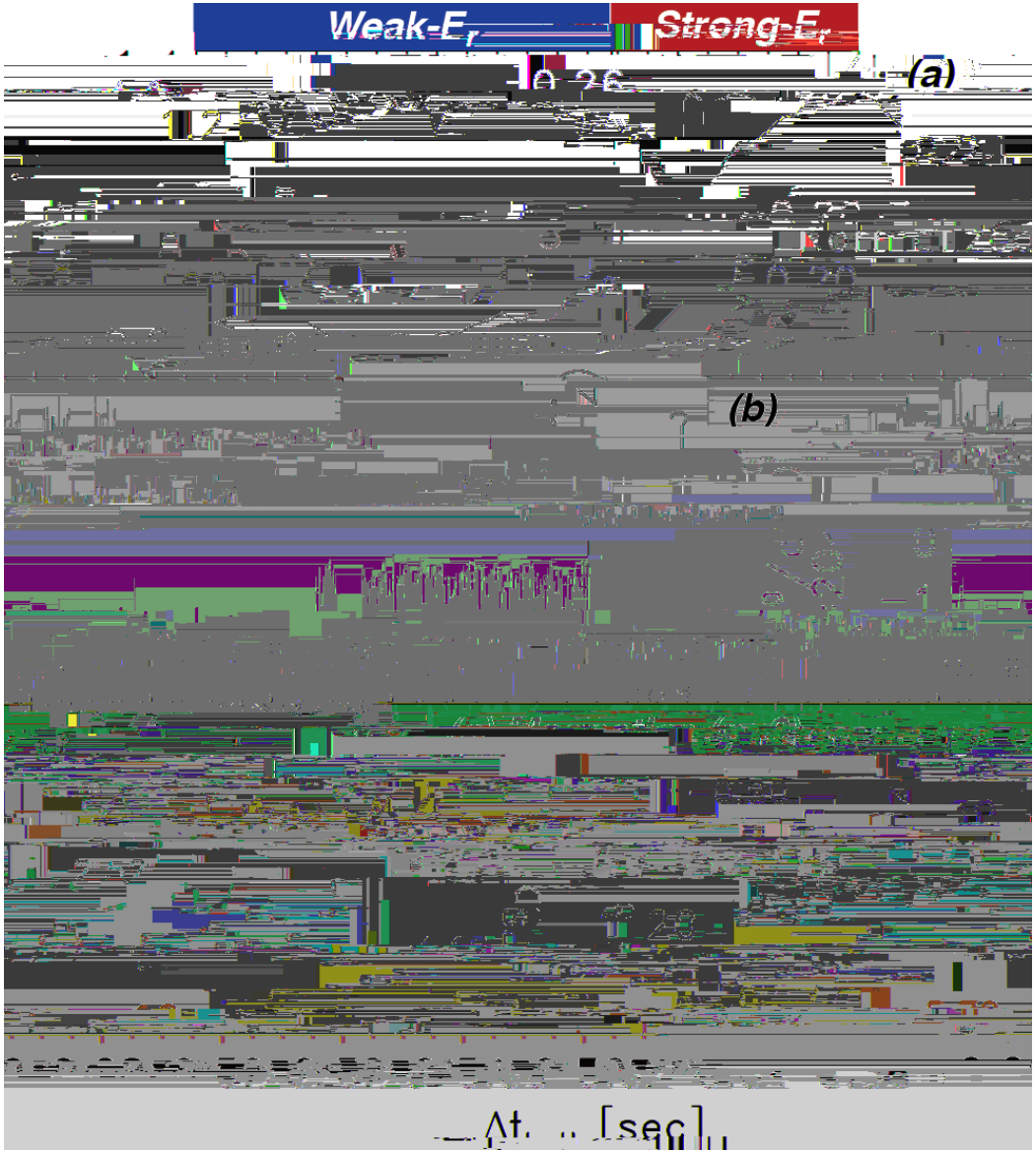
Tokuzawa, PoP2014



$$-E_rE_r'' \simeq \frac{1}{\varepsilon^2}\frac{1}{a^2\omega^2}\left(\frac{T_i}{eB}\right)^2$$

T_i pedestal may not necessarily be followed by the change in the E_r structure, especially for a later H-phase




Weak-E_r
Strong-E_r
(a)
(b)

Acknowledgement