PPPL

# PCX Measurements of Alphas and Tritons in TFTR

Presented by

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in collaboraton with

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TFTR

# Overview

***The Pellet Charge Exchange (PCX) diagnostic:***

- *Uses the ablation cloud produced by injected Li and B pellets to neutralize alphas, tritons and RF-driven minority ion species*

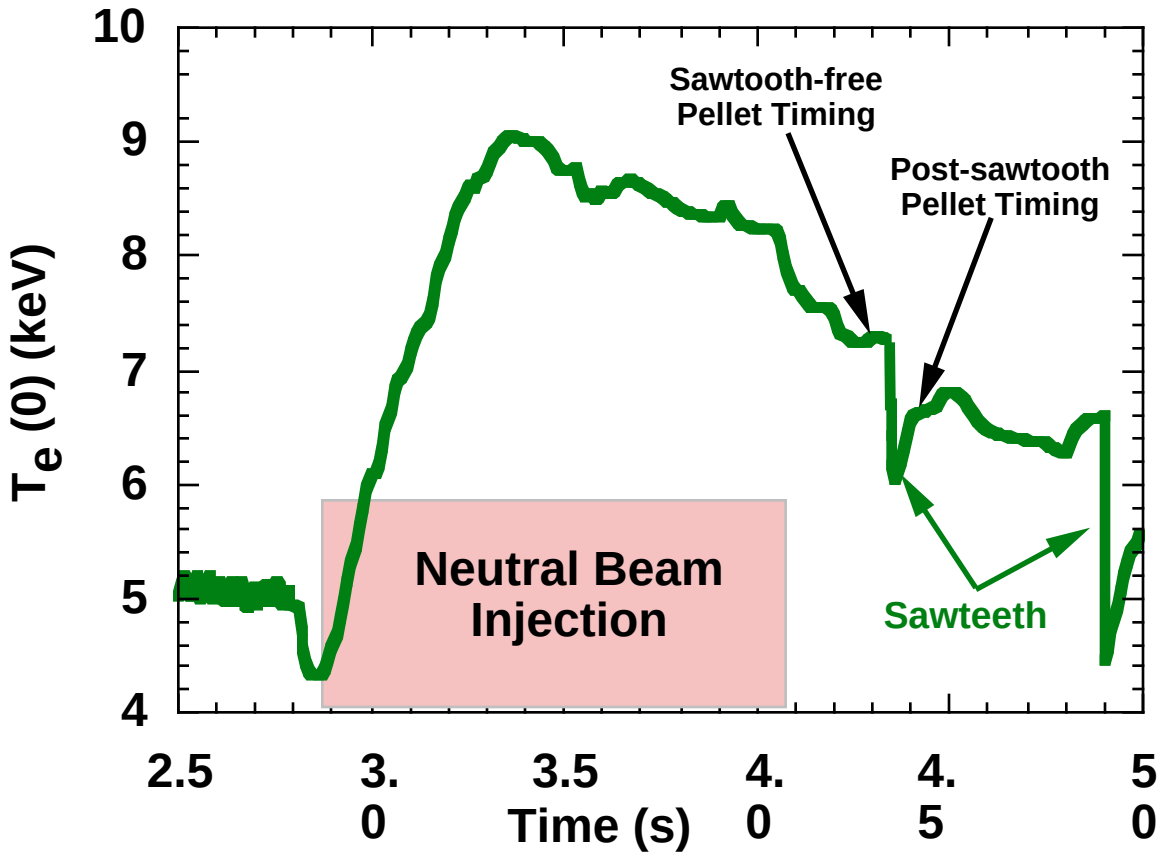
- *Measures radially-resolved energetic ion spectra $^4He^{++}$ ô 0.5 - 3.8 MeV and $T^+$ ô 0.2 - 1.0 MeV*

- *Views deeply trapped ions: $v_{||}/v = - 0.048$*

- *Is not absolutely calibrated due to uncertainty in the ablation cloud ion state mix*

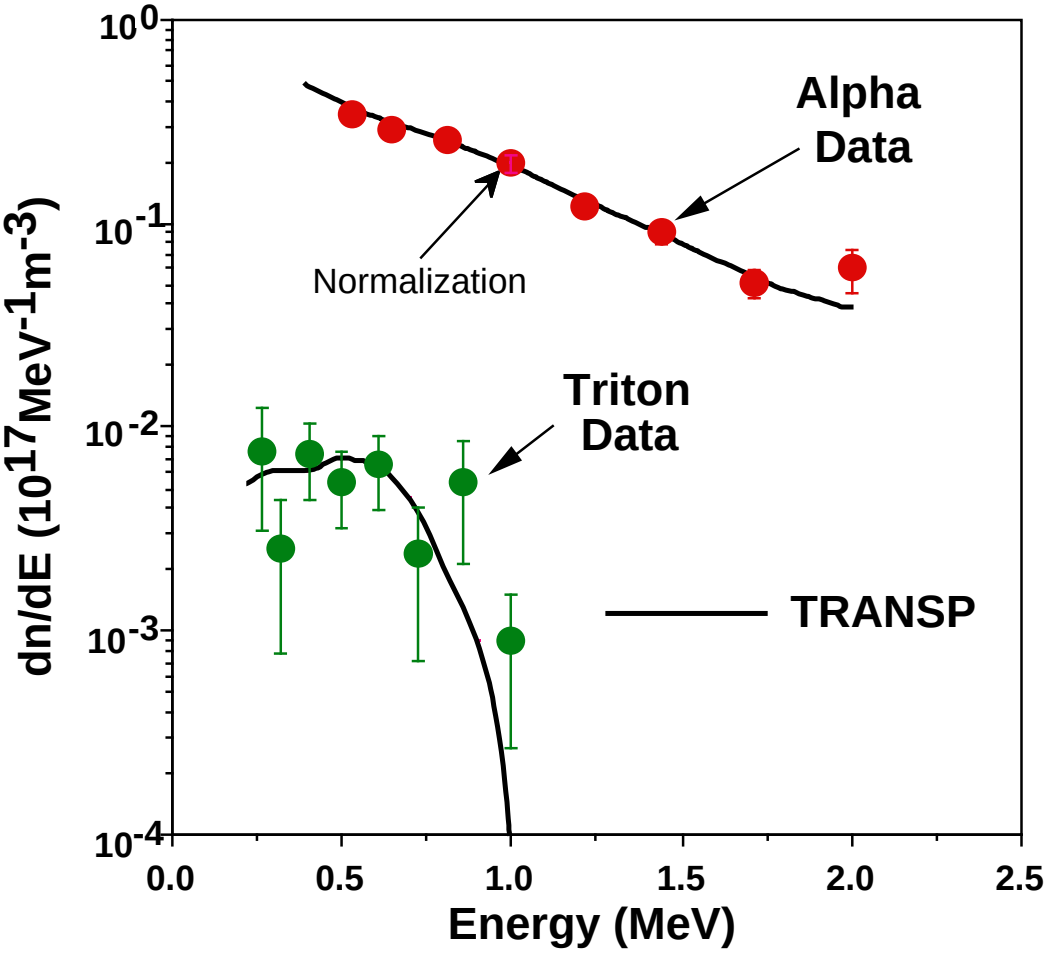
- **Classical Behavior of Alphas and Tritons in MHD-quiescent Plasmas**
- **Sawtooth Redistribution of Trapped Alphas**
- **Stochastic Ripple Loss Effects**
- **Reduced/Reversed Shear Effects**

# PCX Measurements Are Made After Termination of Neutral Beam Injection




- For PCX measurements, post-NBI timing enhances both pellet penetration (due to decay of $T_e$, $n_e$) and signal-to-noise ratio (neutron emission decays faster than the energetic ion density).
- In TFTR supershots, sawtooth activity typically begins 0.25 ± .05 s after termination of beam injection.

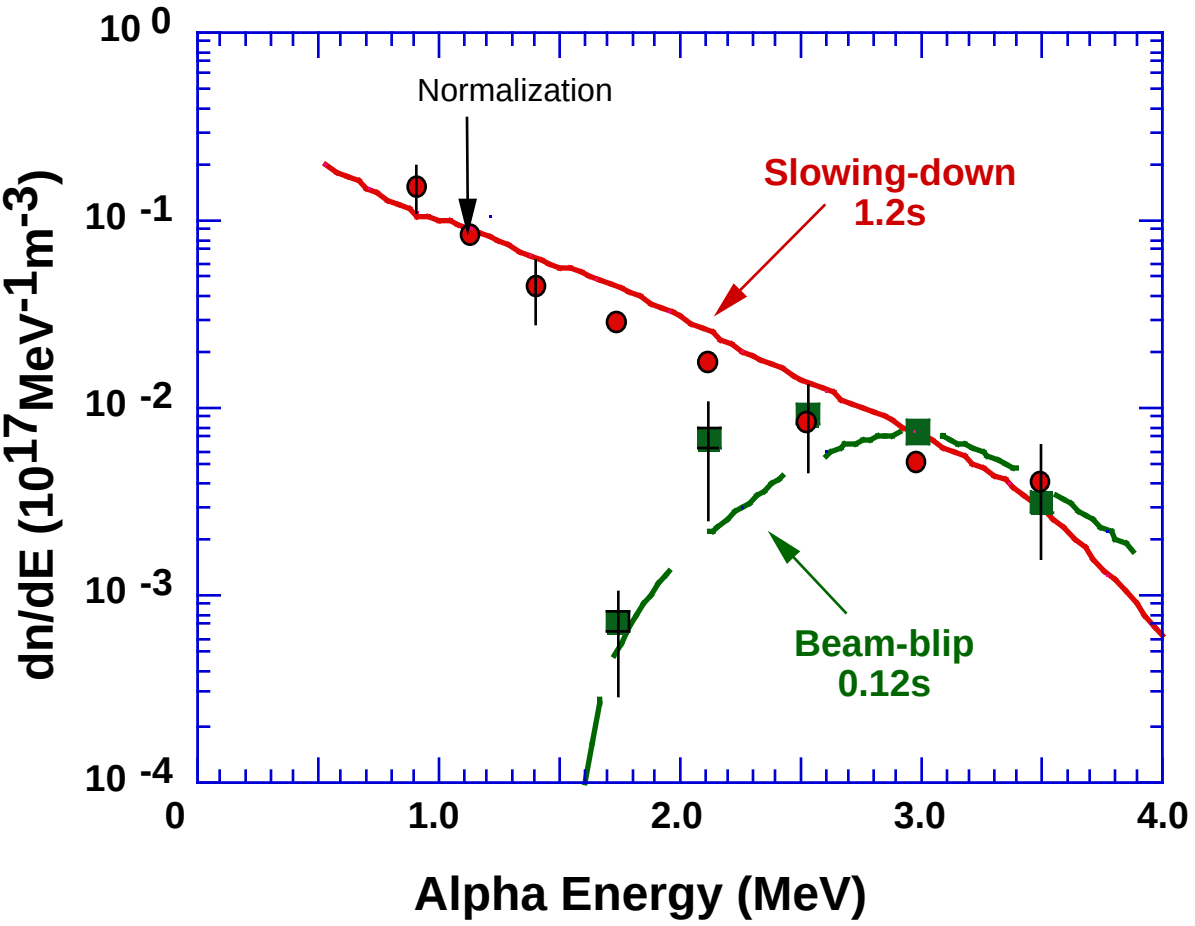
# PCX Alpha and Triton Energy Spectra Agree with TRANSP Simulations




- Data points are active measurements of the alpha spectrum the MHD-quiescent core of a DT discharge and the triton spectra from a similar DD discharge.

- Both the shape of the energy spectra and the alpha-to-triton ratio agree well with TRANSP simulations, which assume classical alpha thermalization.

# PCX Alpha Energy Spectra during Birth and Slowing Down Phases

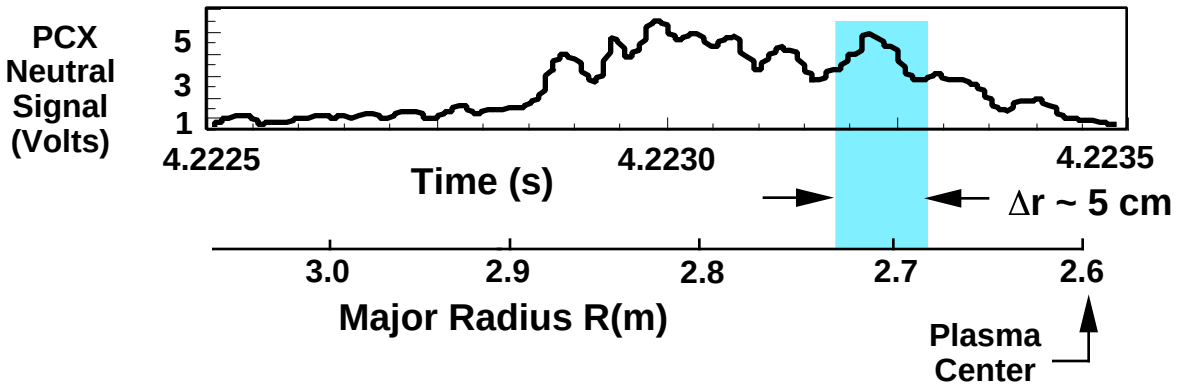



1.0 s NBI pulse (#86291, Pb = 15 MW)
Boron pellet @ 200 ms after NBI

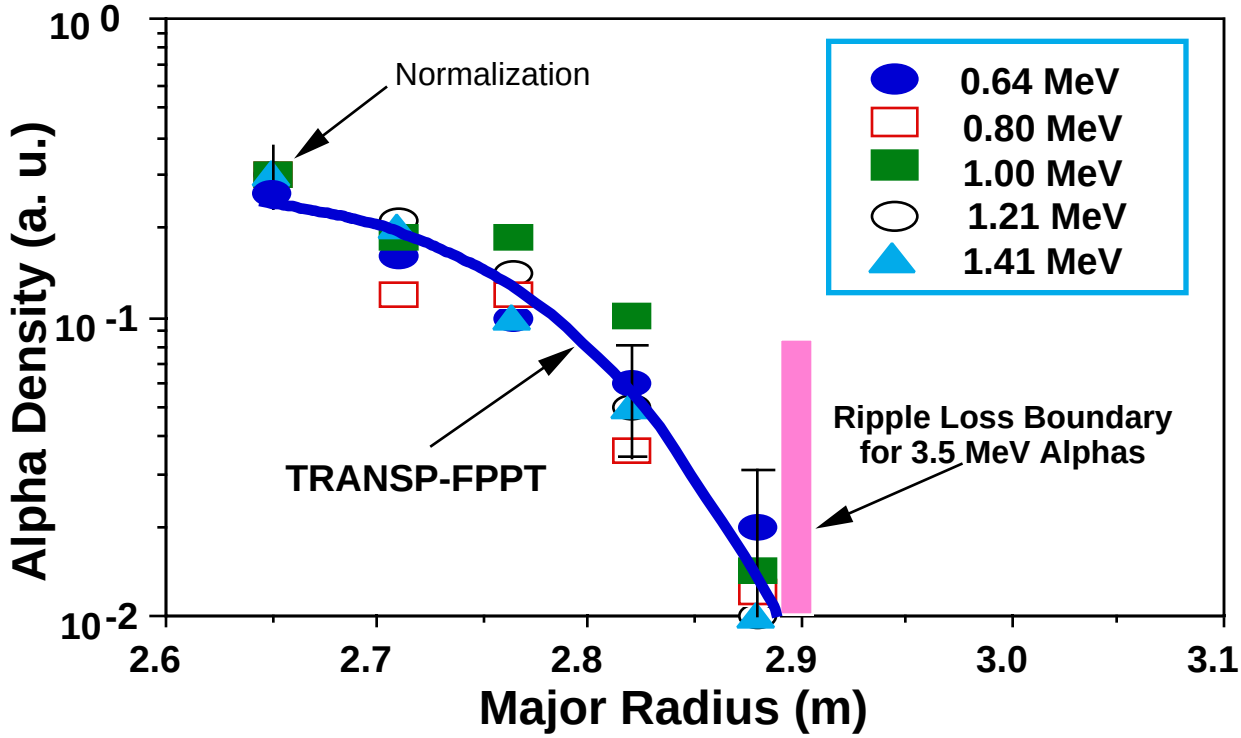
0.1 s NBI "blip" (#86299, Pb = 20 MW)
Boron pellet @ 20 ms after NBI

- Curves are TRANSP-FPPT simulations which include Doppler spreading of the alpha birth spectrum.
- Alpha particles are well confined and thermalize classically in the MHD quiescent core of DT plasmas.

# PCX Radial Alpha Density Profiles

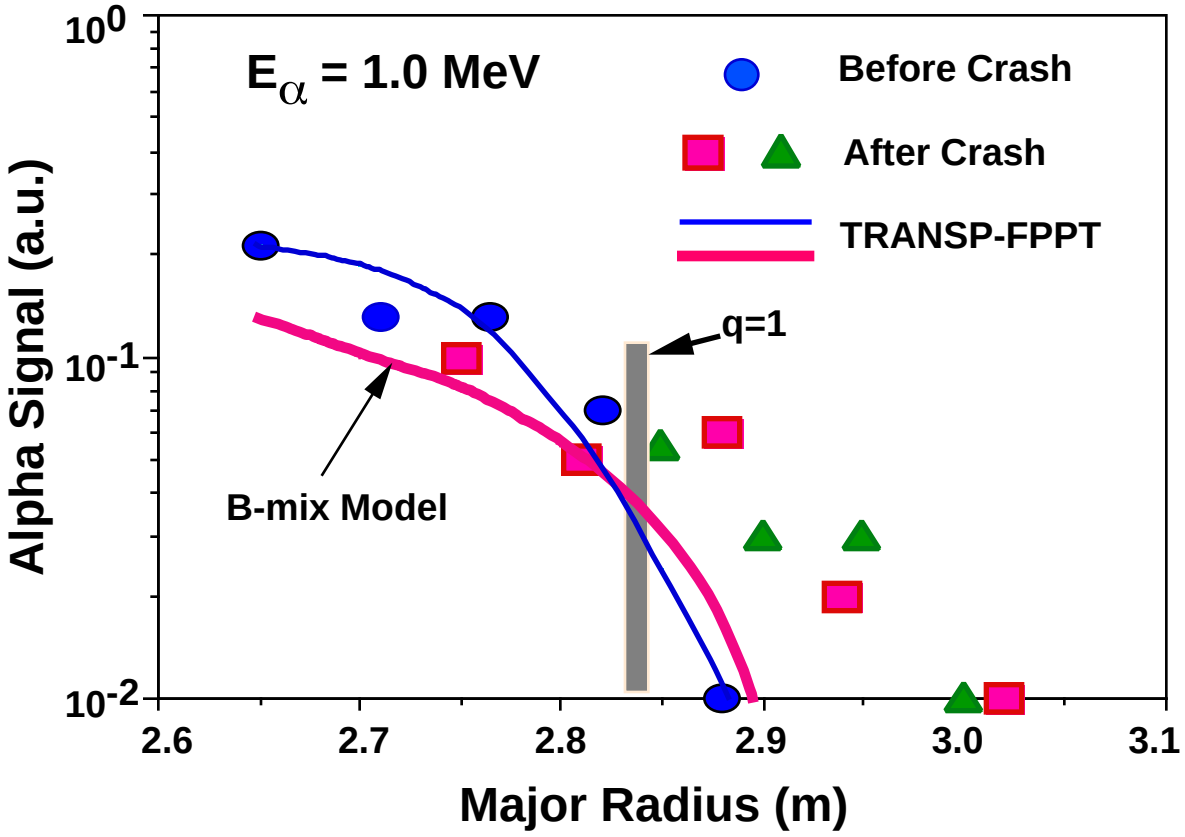



- Conversion of PCX signals into radial density profiles is made using pellet position and velocity measurements from a linear diode array .




- In a sawtooth free discharge, the PCX radial alpha density profiles are consistent with the stochastic ripple loss boundary for $E_\alpha$ = 3.5 MeV.

# Large Sawteeth Broaden the Alpha Density Profile to Well Beyond the q = 1 Radius



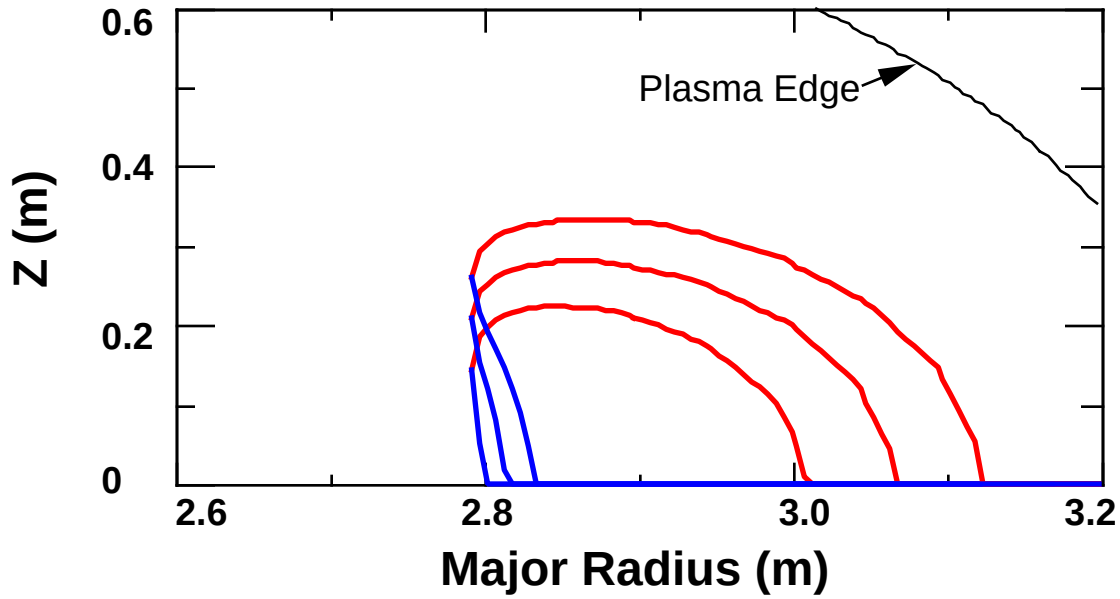

- The magnetic reconnection model yields insufficient broadening for the radial redistribution of trapped alphas due to sawtooth activity.

- A new model was developed wherein a helical electric field (m = 1) produced by the sawtooth crash generates alpha mixing due to E x B drift.

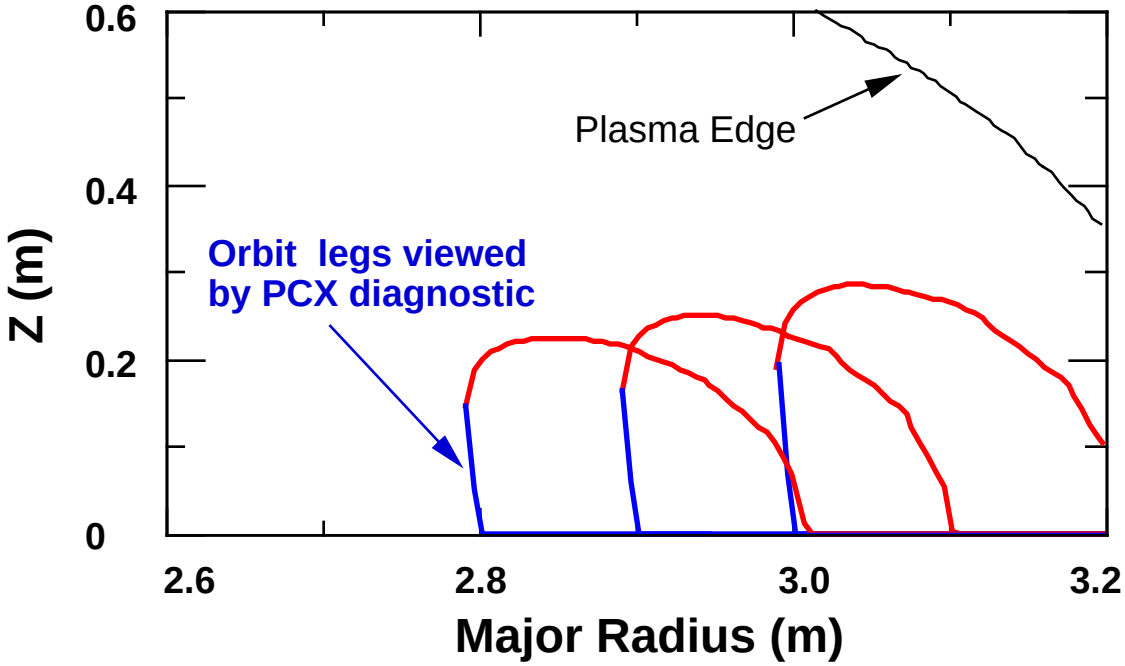
  This electric field preferentially changes the energy of the trapped (rather than passing) alphas.

# Trapped Alpha Particle Orbits in Magnetic Reconnection and E x B Drift Models

Magnetic Reconnection Model (E=0)

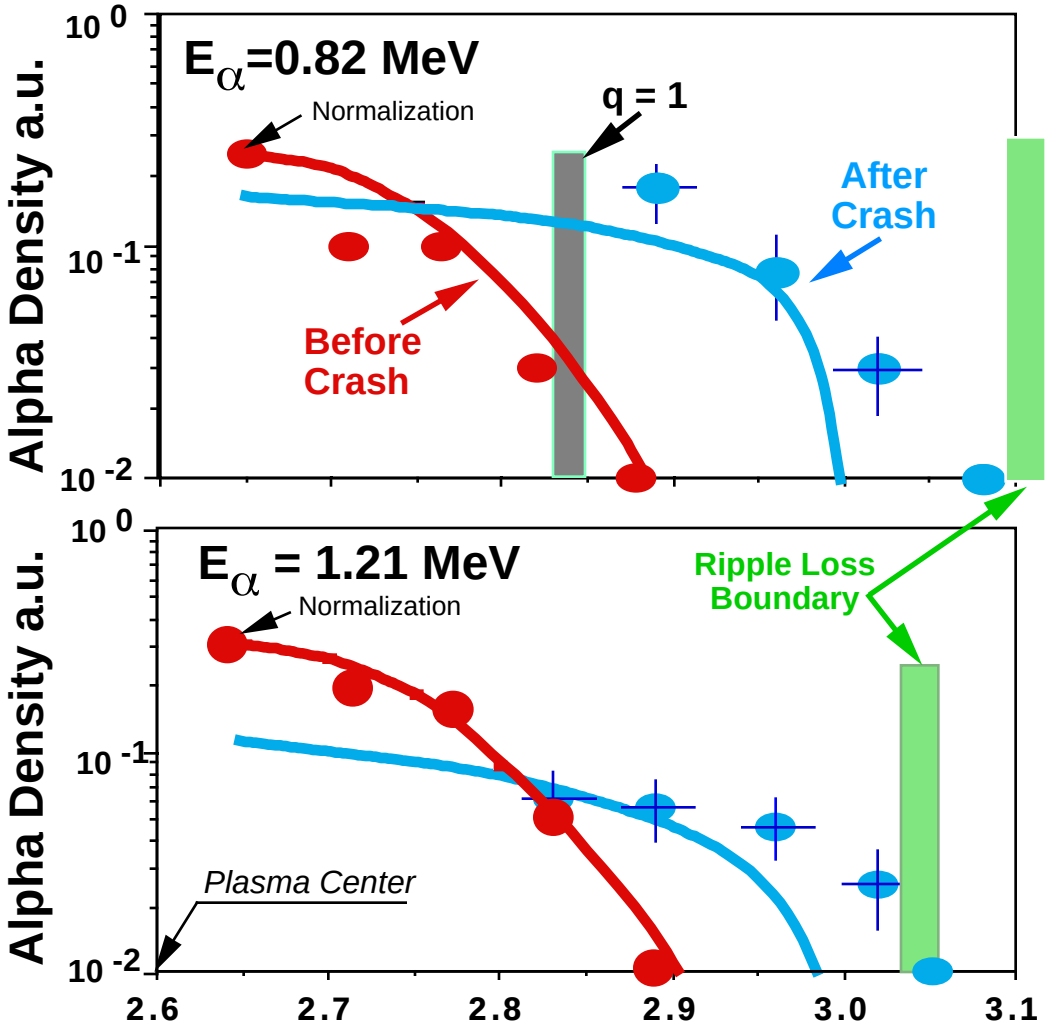



Model with E x B Drift



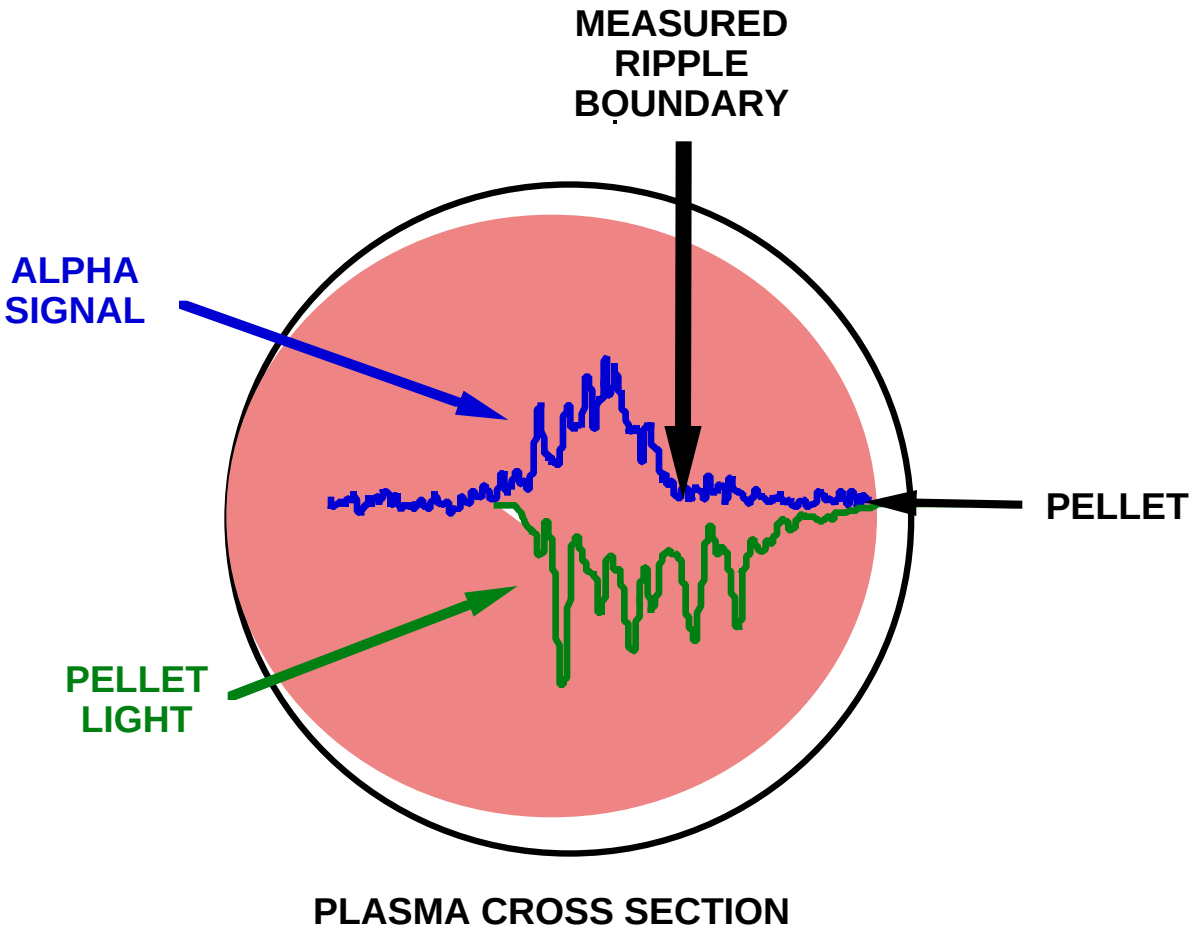

- The E x B model provides much stronger alpha displacement along the major radius than the magnetic reconnection model.

# E x B Modeling of Trapped Alpha Sawtooth Mixing



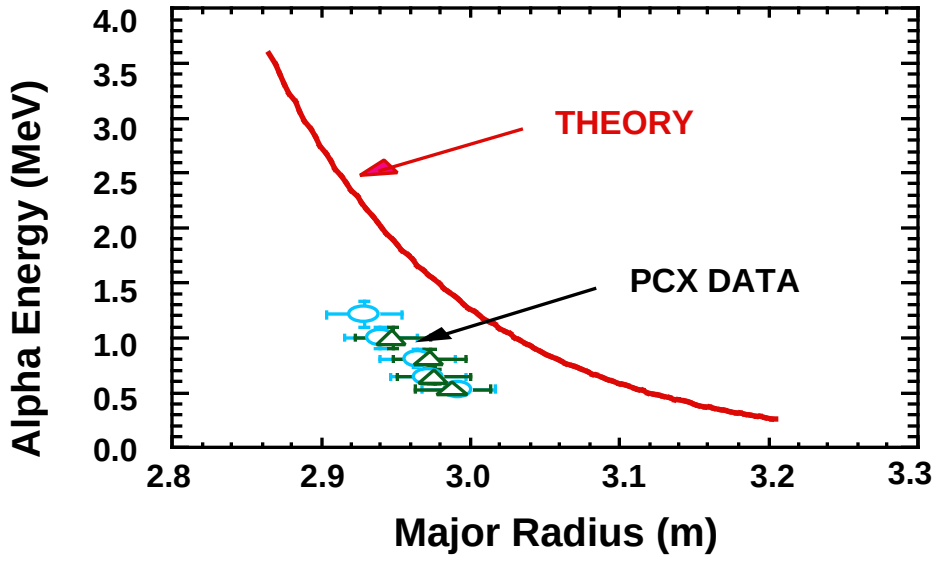

- The ExB model uses a critical energy parameter with an adjusted value of $E_{cr}$ = 3.5 MeV which corresponds to $\tau_{crash} \sim 10$ μs.
- Broadening decreases with increasing energy.
- For trapped alphas, the sawtooth redistribution is caused predominantly by ExB drift.

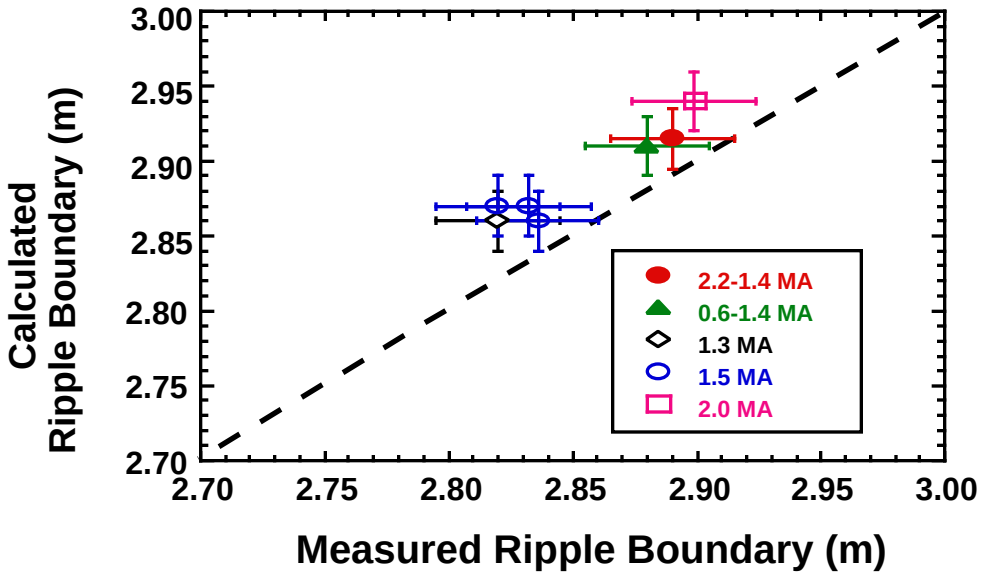
# PCX Alpha Signals Reflect Trapped Ion Ripple Loss Effects




- During pellet penetration, the rise of the PCX alpha signal is delayed relative to the pellet light emission.
- The delayed rise of the alpha signal correlates with the pellet crossing inside the ripple loss boundary for the trapped ions ($v_{||}/v$ = - 0.048) viewed by the PCX.

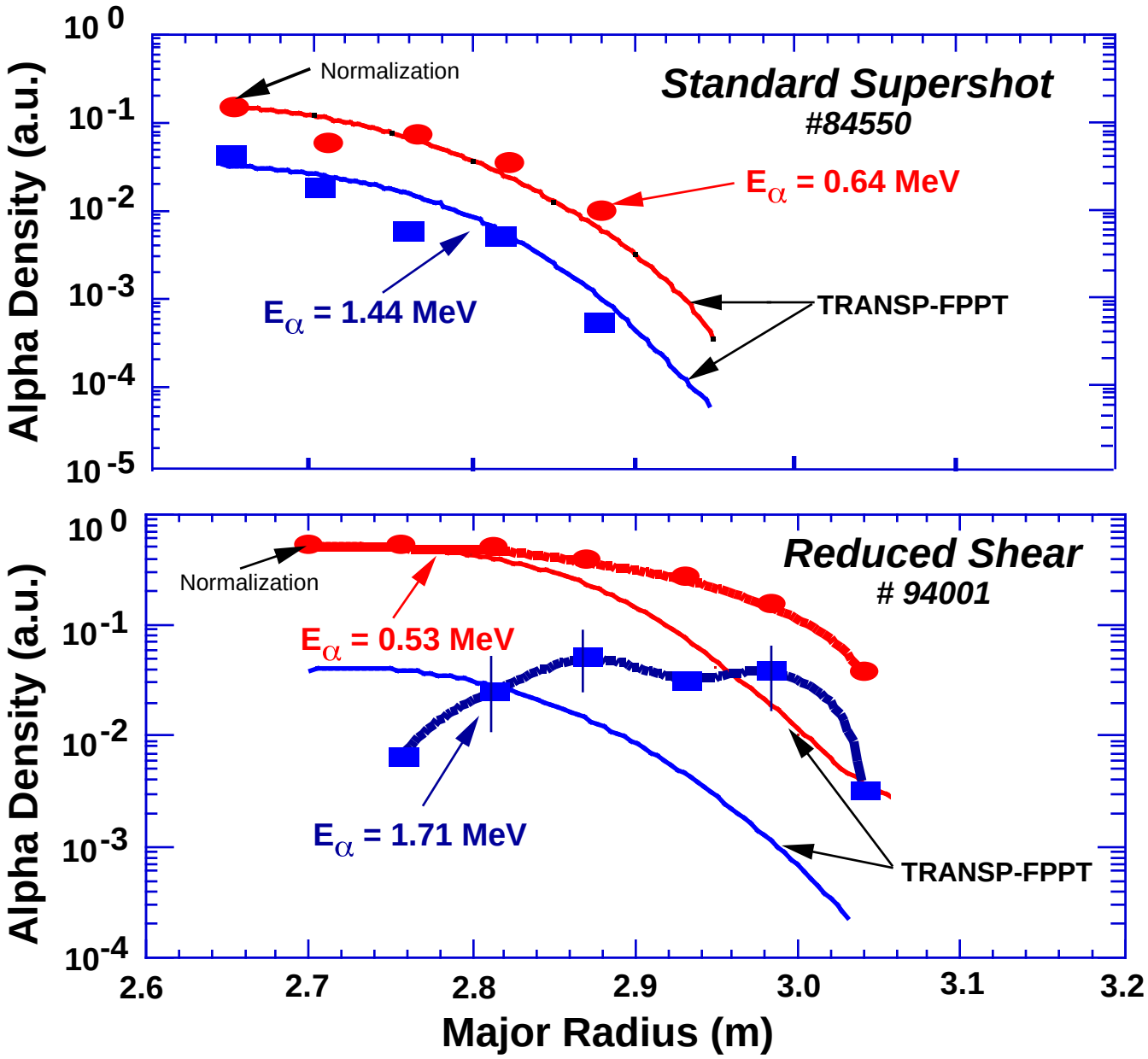
# Sawtooth Broadened Alpha Profiles Used to Study Ripple Effects




- Radial origin of PCX signals is consistent with the energy (upper panel) and q (lower panel) scaling of the Goldston-White-Boozer ripple theory.

# Broadened Trapped Alpha Density Profiles Are Observed in Reduced Shear Discharges




- Unlike sawteeth, the broadening during reduced shear appears to increase with increasing alpha energy.
- Alpha profile broadening due to reduced/reverse shear operation could impact alpha physics on other machines (JET, ITER) using such scenarios.

# Summary

- **Classical Behavior**

  In the MHD-quiescent plasma core, alpha and triton energy spectra are consistent with classical thermalization of well confined ions.

- **Sawtooth Mixing**

  Large sawteeth broaden the alpha density profile to well outside the q = 1 radius, but not beyond the stochastic ripple loss boundary.

  A trapped alpha sawtooth model was developed (TRANSP-FPPT code) which is based on alpha redistribution due to ExB drift.

- **Stochastic Ripple Loss**

  Onset of the PCX signal correlates with the pellet crossing inside the stochastic ripple loss boundary and agrees with the energy and q scaling of the Goldston-White-Boozer ripple theory.

- **Reduced/Reversed Shear Effects**

  Broadening of the trapped alpha density profile was observed during reduced and reversed shear operation. The broadening mechanism remains to be identified.

# PCX Poster Sessions

# Additional Topics

## Alpha Confinement/Transport

"Measurements of the Confinement and Transport of Alpha Particles in TFTR Using the Pellet Charge Exchange (PCX) Diagnostic"

- includes more data on reduced/reversed shear effect on PCX alpha density profiles

R. K. Fisher, *et al.* [6Q.15]

## RF-driven Ion Tails

Measurements of RF-driven Energetic Ion Tails in TFTR D-T Plasmas Using the Pellet Charge Exchange (PCX) Diagnostic.

H. H. Duong, *et al.* [6Q.16]