Boundary Intrinsic Velocity in DIII-D H-modes

by

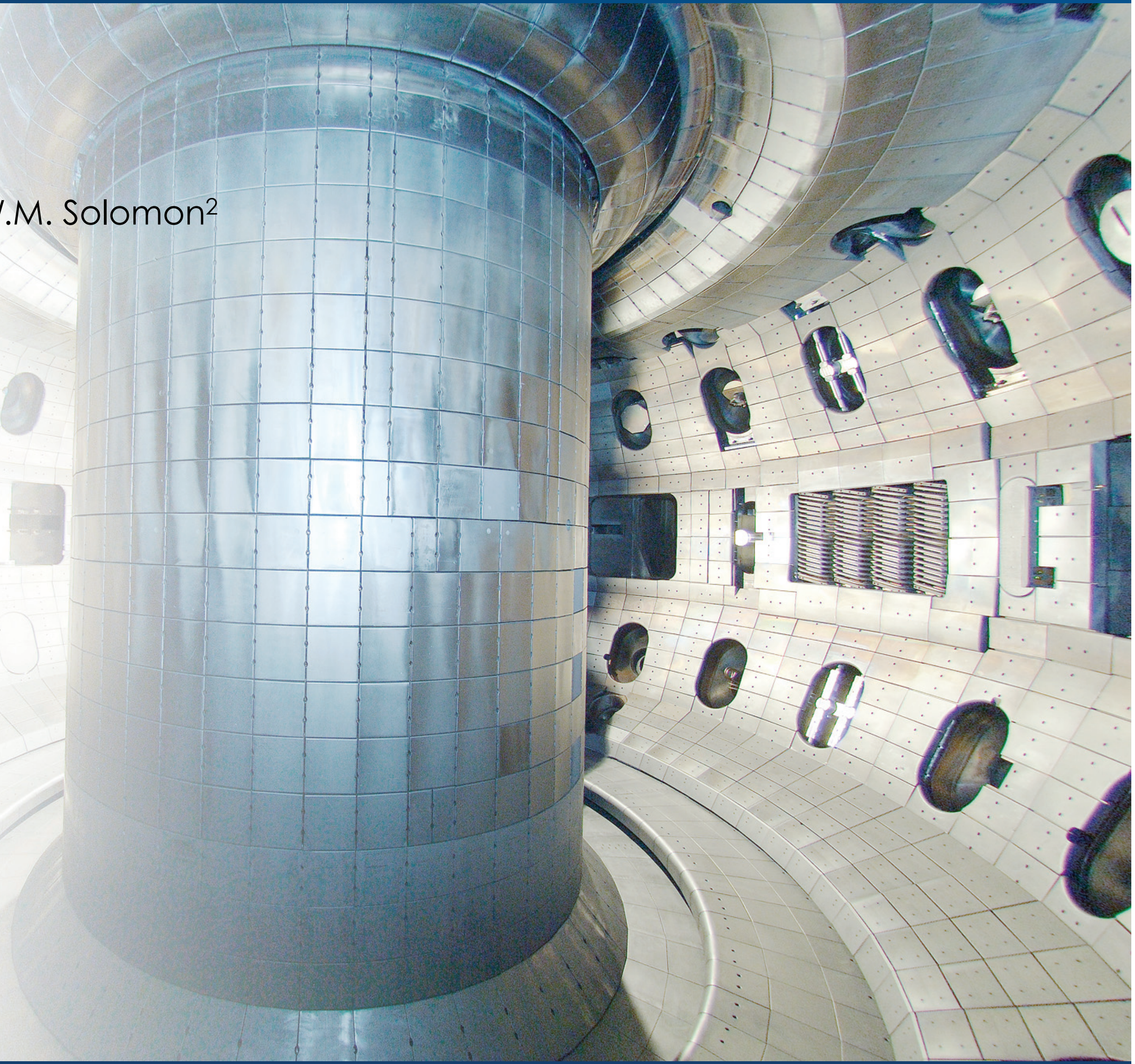
J.S. deGrassie

With

R.J. Groebner[1], K.H. Burrell[1], R.E. Waltz[1], W.M. Solomon[2]

[1]General Atomics

[2]Princeton Plasma Physics Laboratory

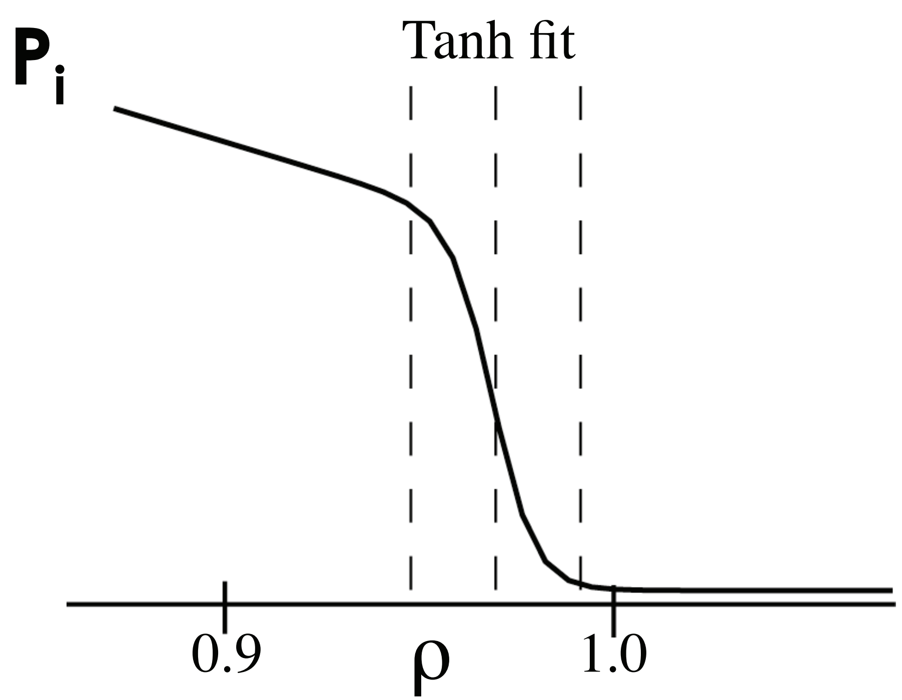


Presented at the
50th APS Annual Meeting of
the Division of Plasma Physics
Dallas, Texas

November 17–21, 2008

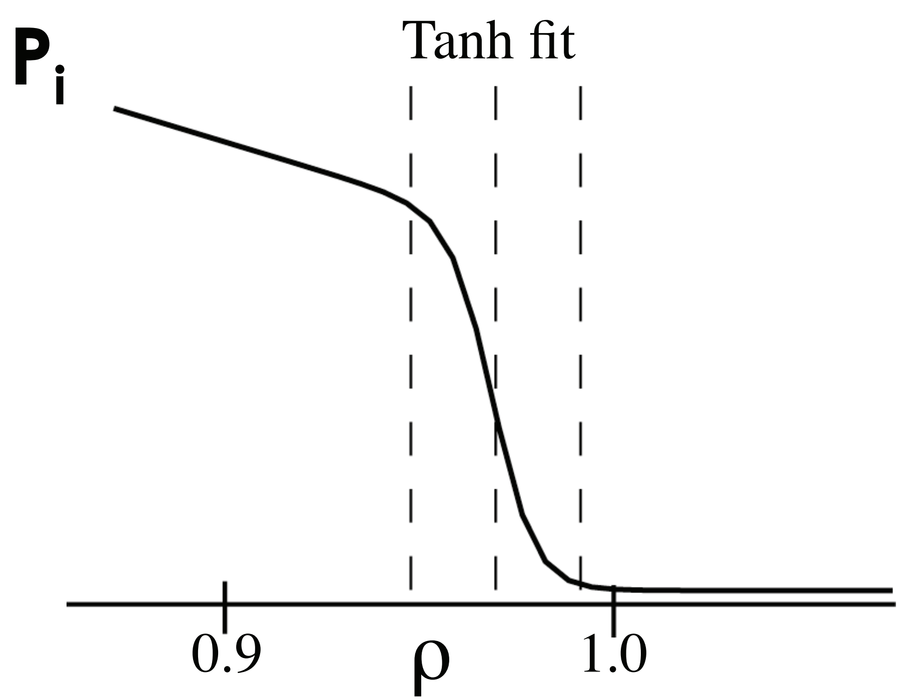
Overview — Focus Upon the Pedestal Region

- Intrinsic toroidal rotation exists without auxiliary torque input (NBI)
- Important to understand for issues related to stability and confinement
- Intrinsic conditions - ECH, OH H-modes, and OH conditions; NBI blips



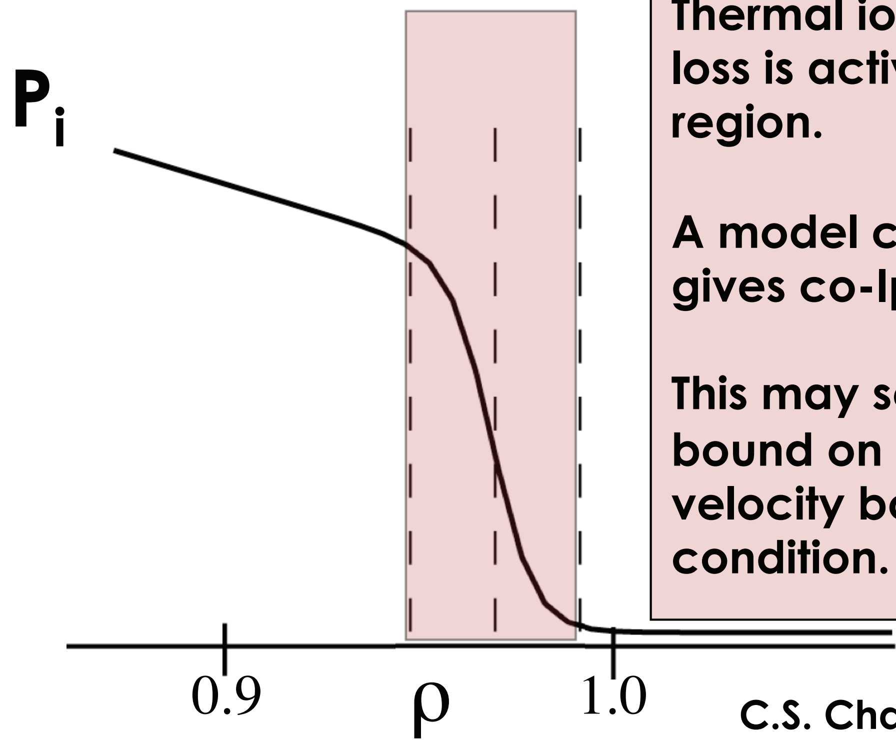
Overview — Focus Upon the Pedestal Region

- Intrinsic toroidal rotation exists without auxiliary torque input (NBI)
- Important to understand for issues related to stability and confinement
- Intrinsic conditions - ECH, OH H-modes, and OH conditions; NBI blips
- Measurements show velocity correlated with temperature, co-Ip $V_\phi \sim T_i$



Overview — Focus Upon the Pedestal Region

- **Intrinsic toroidal rotation exists without auxiliary torque input (NBI)**
- **Important to understand for issues related to stability and confinement**
- **Intrinsic conditions - ECH, OH H-modes, and OH conditions**
- **Measurements show velocity correlated with temperature, co-Ip $V_\phi \sim T_i$**



Thermal ion orbit loss is active in this region.

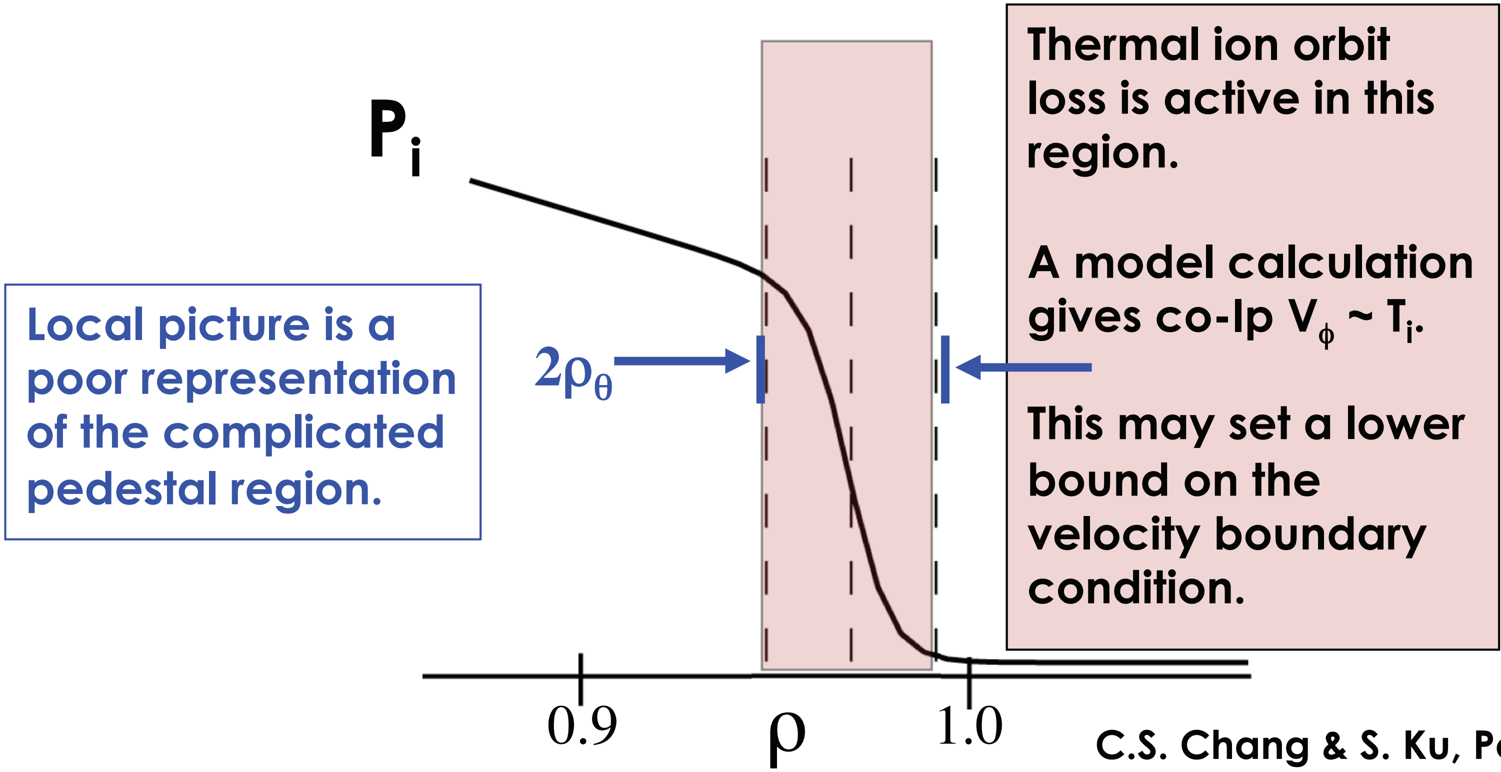
A model calculation gives co-Ip $V_\phi \sim T_i$.

This may set a lower bound on the velocity boundary condition.

C.S. Chang & S. Ku, PoP 15, 2008.

Overview — Focus Upon the Pedestal Region

- Intrinsic toroidal rotation exists without auxiliary torque input (NBI)
- Important to understand for issues related to stability and confinement
- Intrinsic conditions - ECH, OH H-modes, and OH conditions
- Measurements show velocity correlated with temperature, co-Ip $V_\phi \sim T_i$



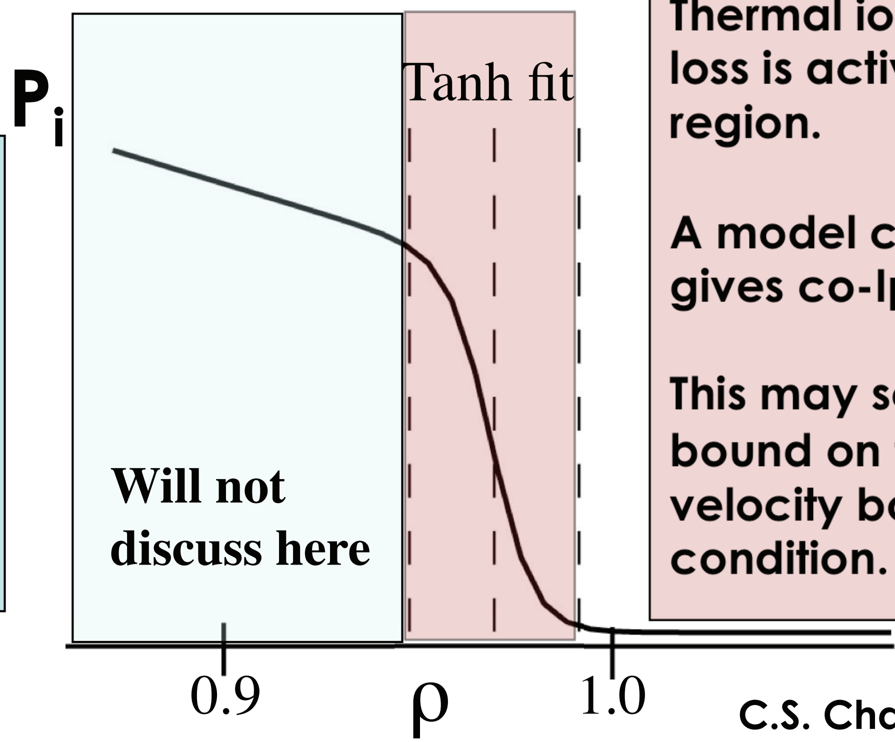
C.S. Chang & S. Ku, PoP 15, 2008.

Overview — Focus Upon the Pedestal Region

- **Intrinsic toroidal rotation exists without auxiliary torque input (NBI)**
- **Important to understand for issues related to stability and confinement**
- **Intrinsic conditions - ECH, OH H-modes, and OH conditions**
- **Measurements show velocity correlated with temperature, co-Ip $V_\phi \sim T_i$**

Inside the pedestal we also measure co-Ip $V_\phi \sim T_i$.

We postulate a pinch, V^P, with $V^P/\chi_\phi \sim \nabla T_i / T_i$



Thermal ion orbit loss is active in this region.

A model calculation gives co-Ip $V_\phi \sim T_i$.

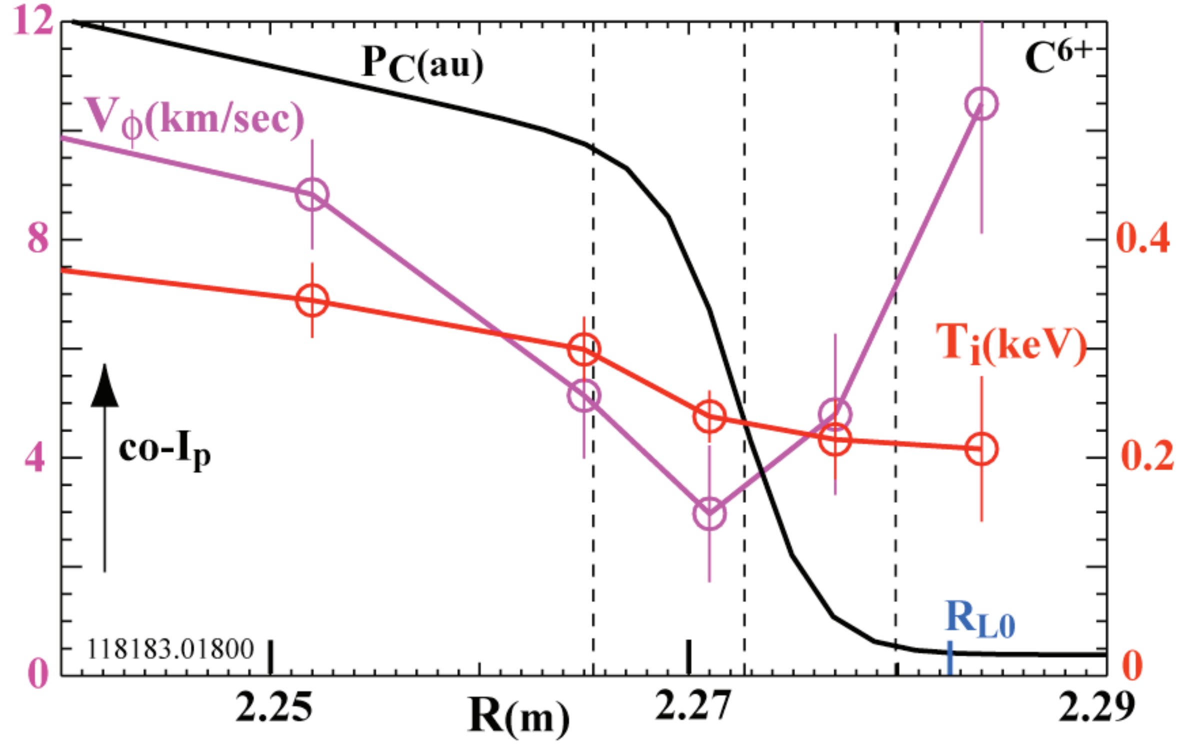
This may set a lower bound on the velocity boundary condition.

C.S. Chang & S. Ku, PoP 15, 2008.

Pedestal Intrinsic Velocity is co-Ip

LSN
I_p = 1.1 MA
B_T= 1.79 T
β_N= 0.85
q_{95}= 4.25
$\overline{n}_e$= 4.0x10^{19}
P_{OH}= 0.4 MW
P_{ECH}= 1.0 MW

First msec of NBI blip in ECH H-mode

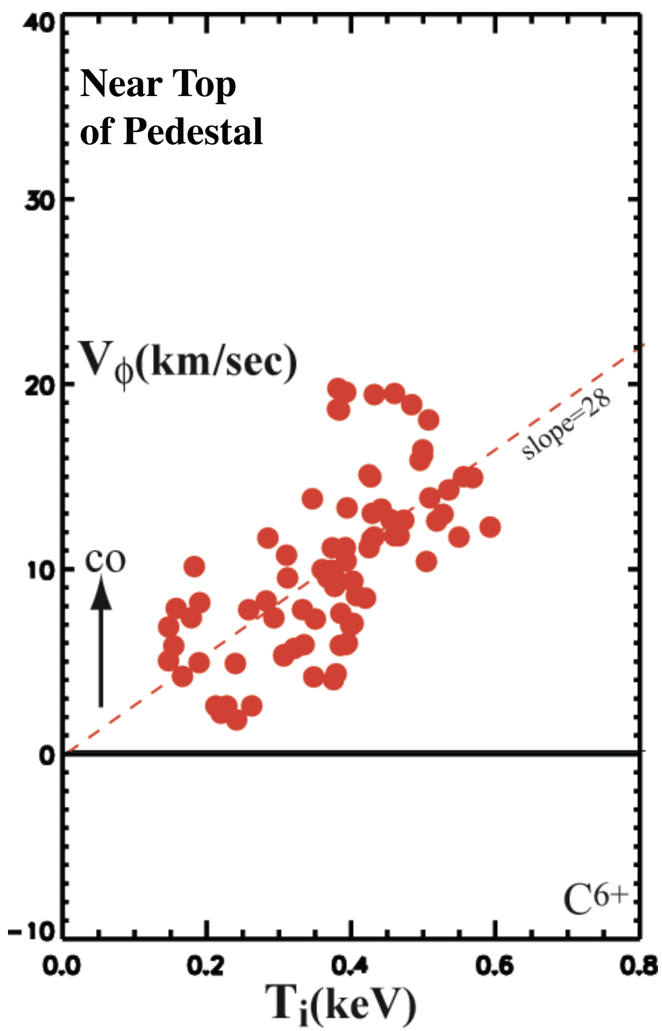


$R_{L0} = R(LCFS)_{EFIT}$

signs ← $\vec{B}, \vec{V}_{//}$ → $\hat{\phi}, \vec{I}_p$

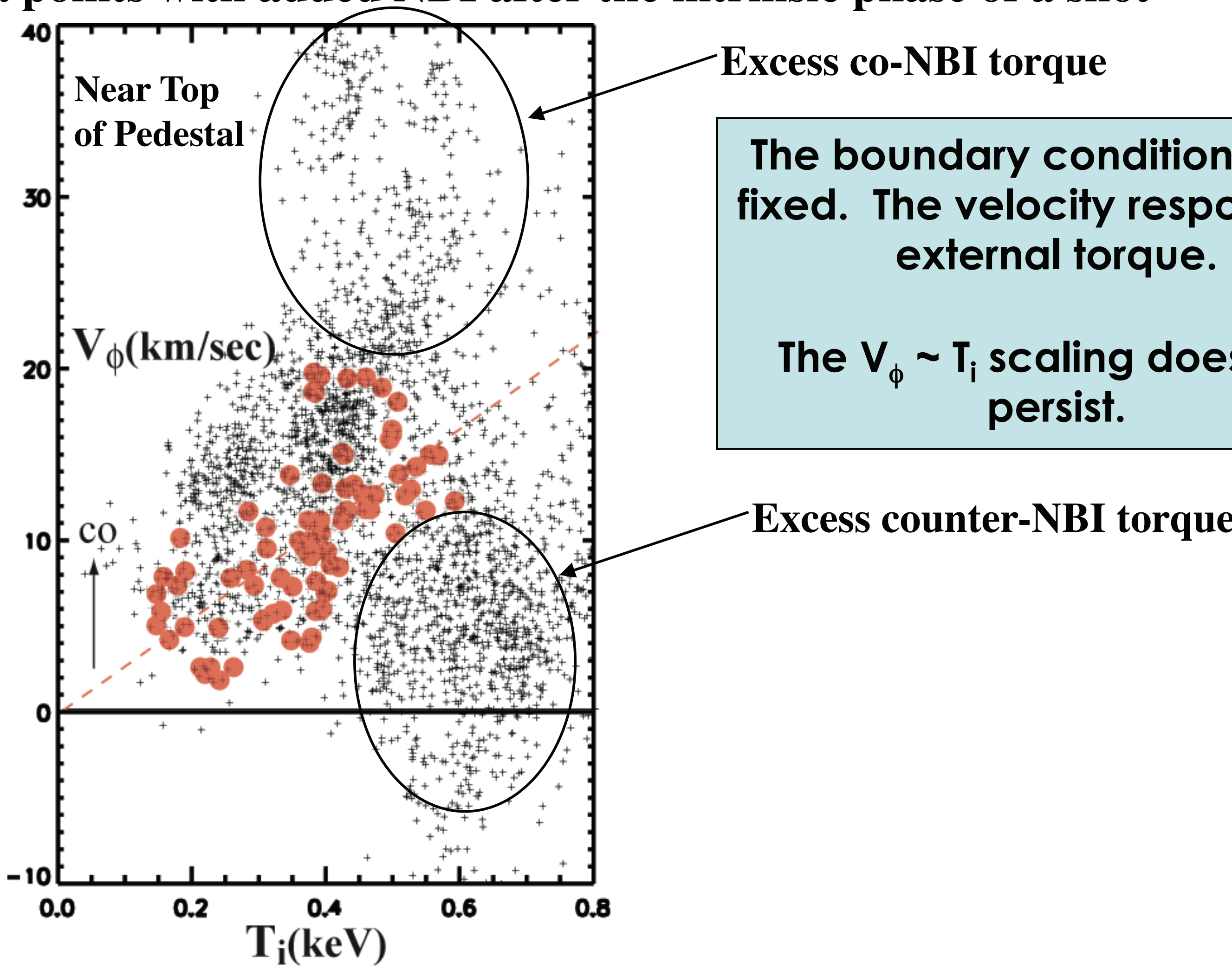
$V_\phi \approx -V_{//}$

$V_\phi \sim T_i$ Across Database at Fixed Location



$V_\phi \sim T_i$ Across Database at Fixed Location

Many data points with added NBI after the intrinsic phase of a shot

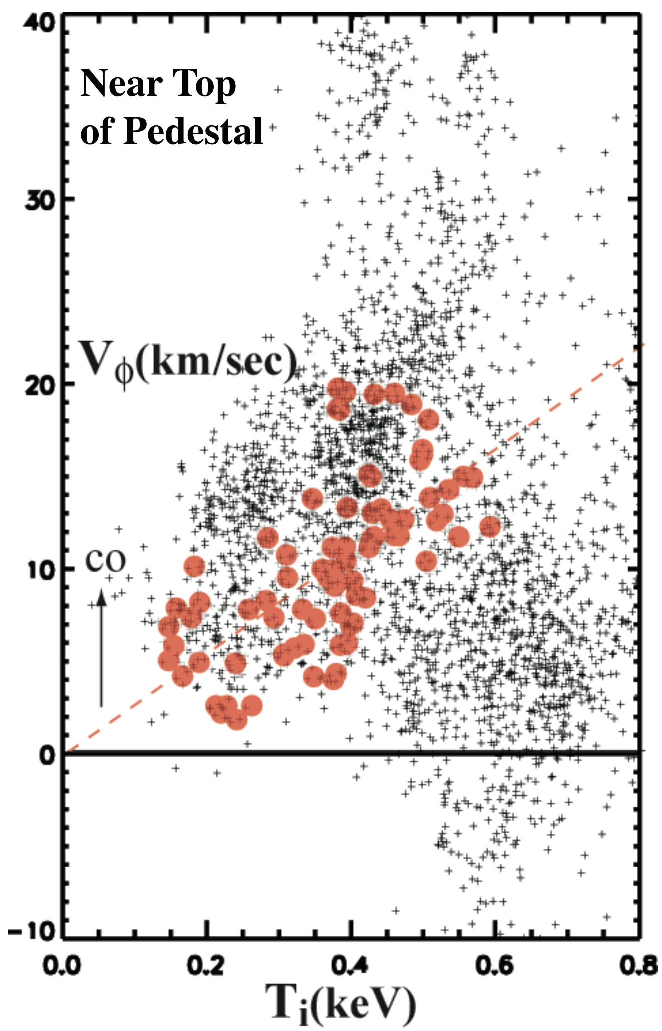


The boundary condition is not fixed. The velocity responds to external torque.

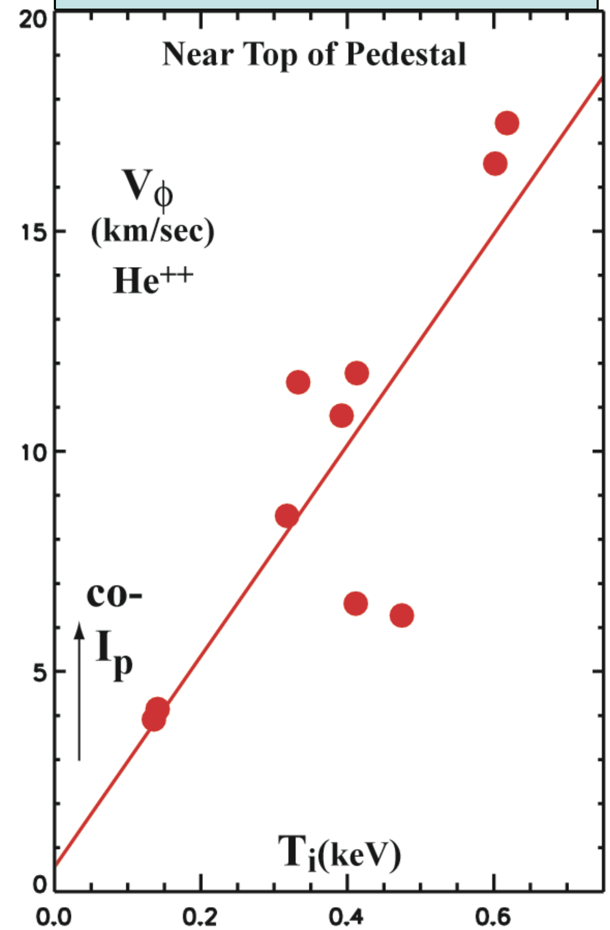
The $V_\phi \sim T_i$ scaling does not persist.

DIII-D
NATIONAL FUSION FACILITY

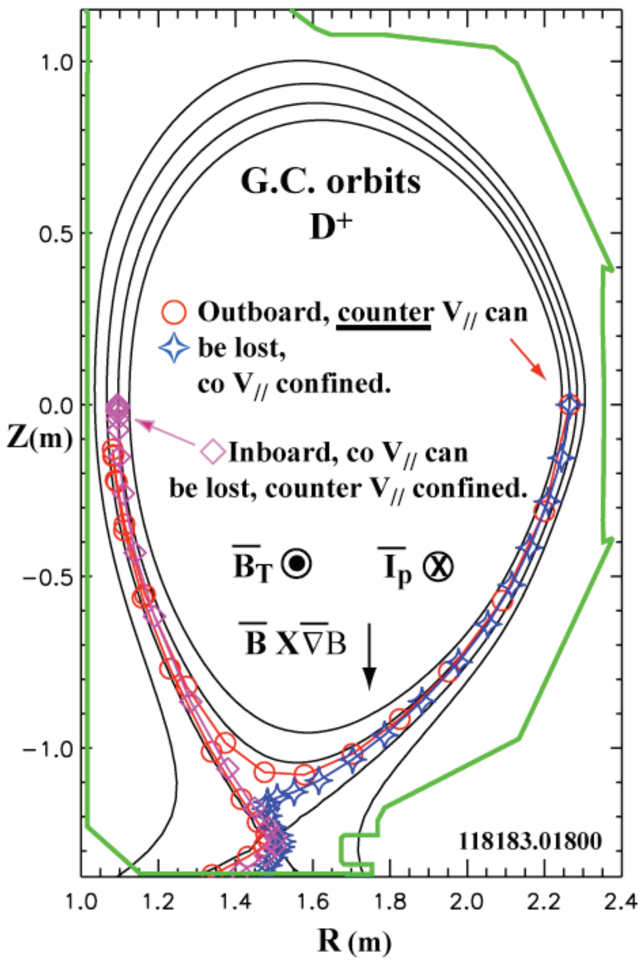
$V_\phi \sim T_i$ Across Database at Fixed Location



Bulk ion, He^{++}, also shows this correlation - limited database

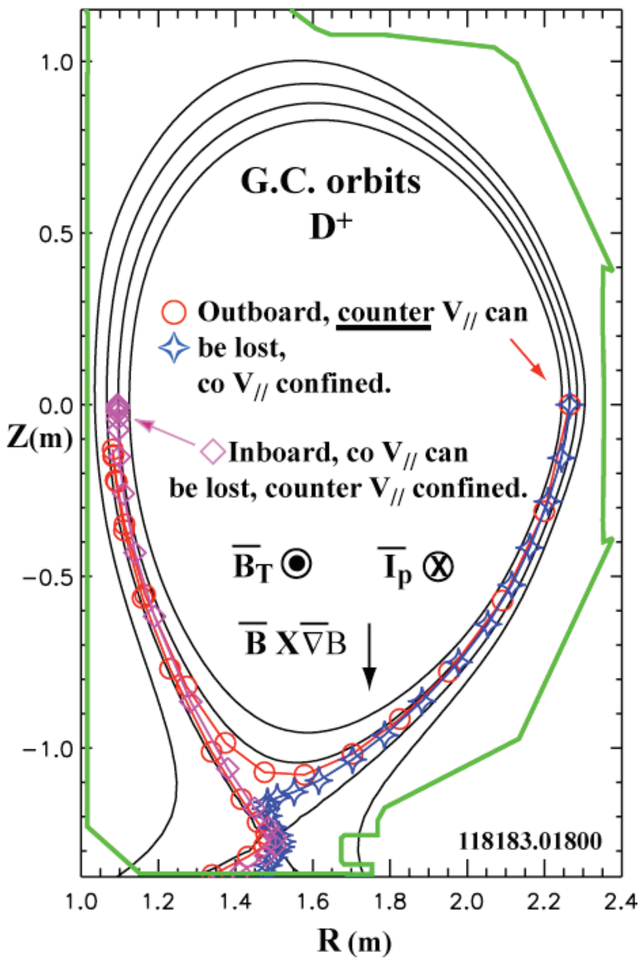


Pedestal Thermal Ion Orbit Loss Weighted to Counter-I_p $V_{//}$ loss

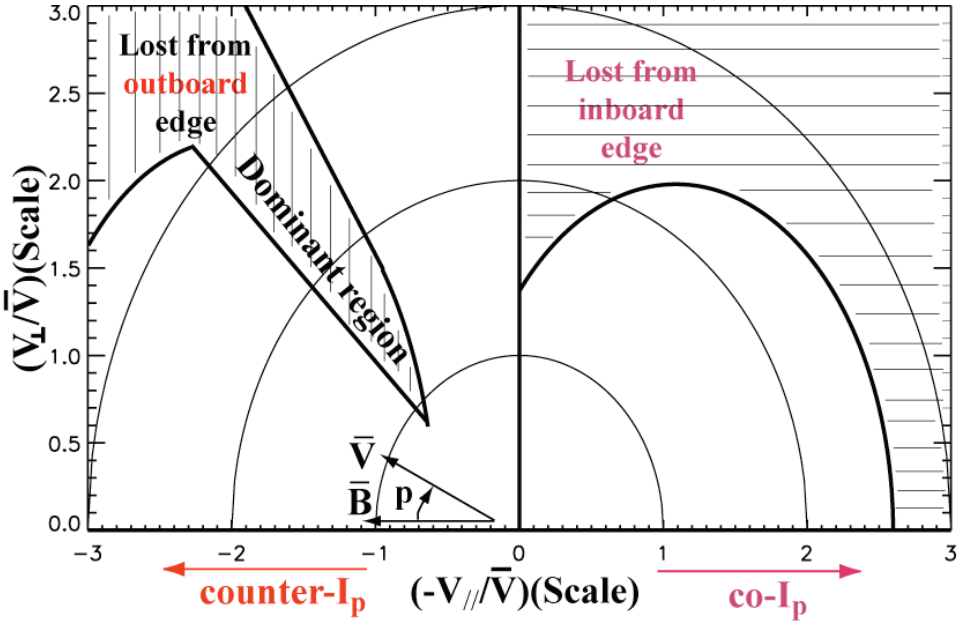


DIII-D NATIONAL FUSION FACILITY

Pedestal Thermal Ion Orbit Loss Weighted to Counter-I_p $V_{//}$ loss

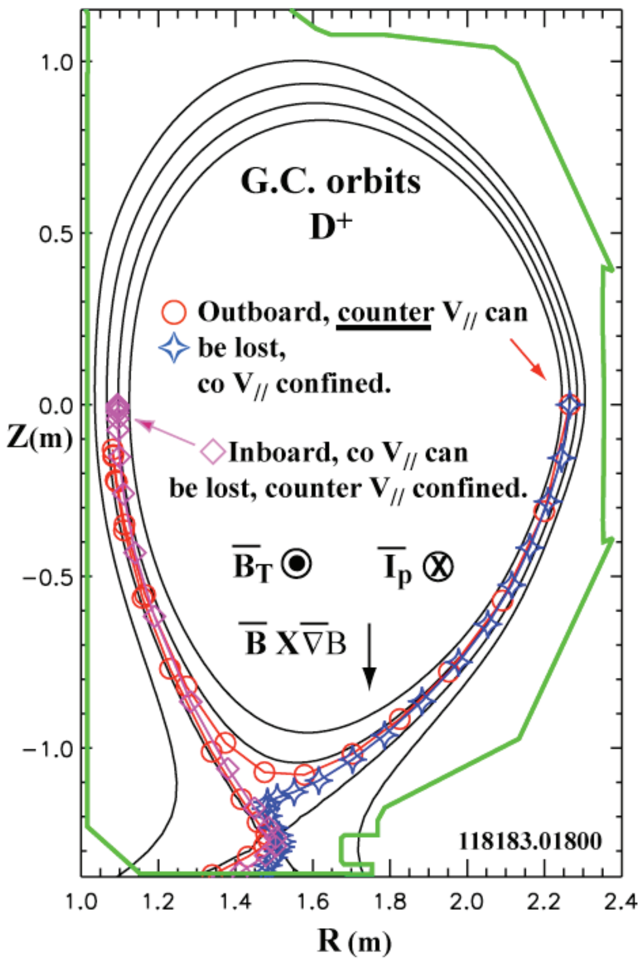


Dominant region pedestal orbit loss tends to leave a counter-Ip hole in velocity space.

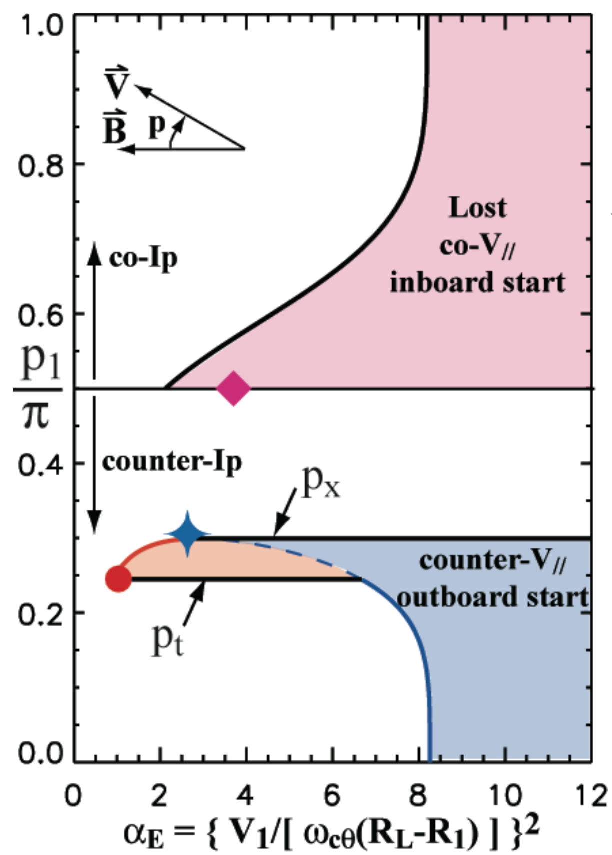


$\bar{V} = \sqrt{T_i/M}$

Pedestal Thermal Ion Orbit Loss Weighted to Counter-I_p $V_{//}$ loss



Loss boundaries from constants of the motion: midplane start



"1" are initial values

p = pitch angle

p_t = trap/pass boundary

p_x = X-point turn

$R_L = R_{LCFS}$

α_E = energy parameter $\sim(\rho_\theta/\Delta)^2$

$\Delta^2 = (R_L - R_1)^2$

A.V. Chankin & G.M. McCracken, NF **10**, 1459 (1993).
K. Miyamoto, NF **36**, 927 (1996).

Loss Model Predicts a "Diamagnetic-Like" Boundary Value, $V_\phi \sim T_i/B_\theta$

G.C. loss region defined by:

$$\frac{1}{\sqrt{\alpha_E}} \leq -\sigma_\phi \cos(p_1) \pm \sigma_\phi \left(R_x/R_1\right)\sqrt{1-\left(R_1/R_x\right)\sin^2(p_1)}$$

$$\sigma_\phi \equiv \mathrm{sign}\,(B_T)$$

- Assume this loss cone is empty. No collision limit
- Consider only dominant counter-I_p finger region

DIII-D
NATIONAL FUSION FACILITY

Loss Model Predicts a "Diamagnetic-Like" Boundary Value, $V_\phi \sim T_i/B_\theta$

G.C. loss region defined by:

$$\frac{1}{\sqrt{\alpha_E}} \le -\sigma_\phi \cos(p_1) \pm \sigma_\phi (R_x/R_1)\sqrt{1-(R_1/R_x)\sin^2(p_1)}$$

$$\sigma_\phi \equiv \text{sign}(B_T)$$

- Assume this loss cone is empty. No collision limit
- Consider only dominant counter-I_p finger region
- Compute $\langle V_{//} \rangle$ for remaining distribution (D^+):

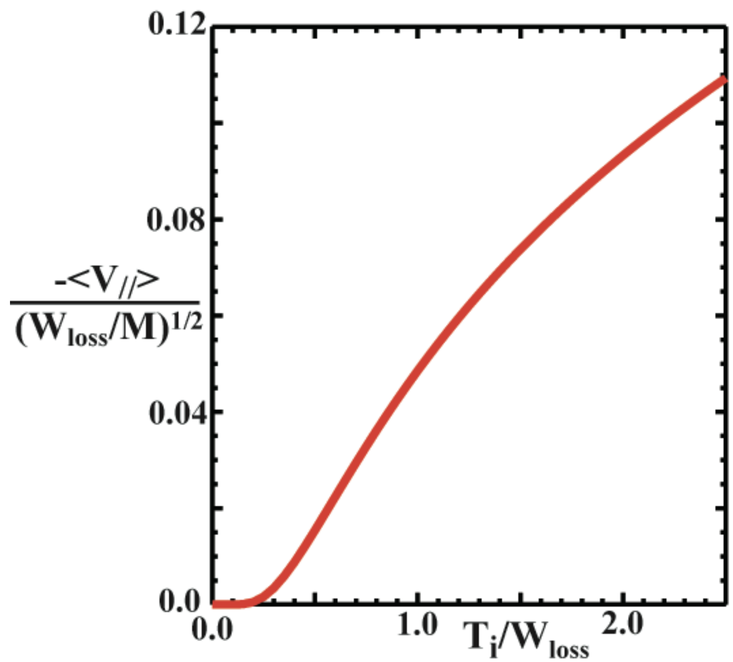
$$\langle V_{\parallel} \rangle \approx -(2/\pi)^{1/2}\overline{V}(b+1)e^{-b}(x-r_1)/2D(b,x,r_1)$$

$$b = \alpha_E^{av} W_{loss}/T_i \qquad x = R_x/R_1$$

$$\overline{V} = \sqrt{T_i/M} \qquad r_1 = R_{1in}/R_1$$

$$D \approx 1$$

Loss cone: co-Ip $-\langle V_{//}\rangle \sim V_\phi \sim T_i$

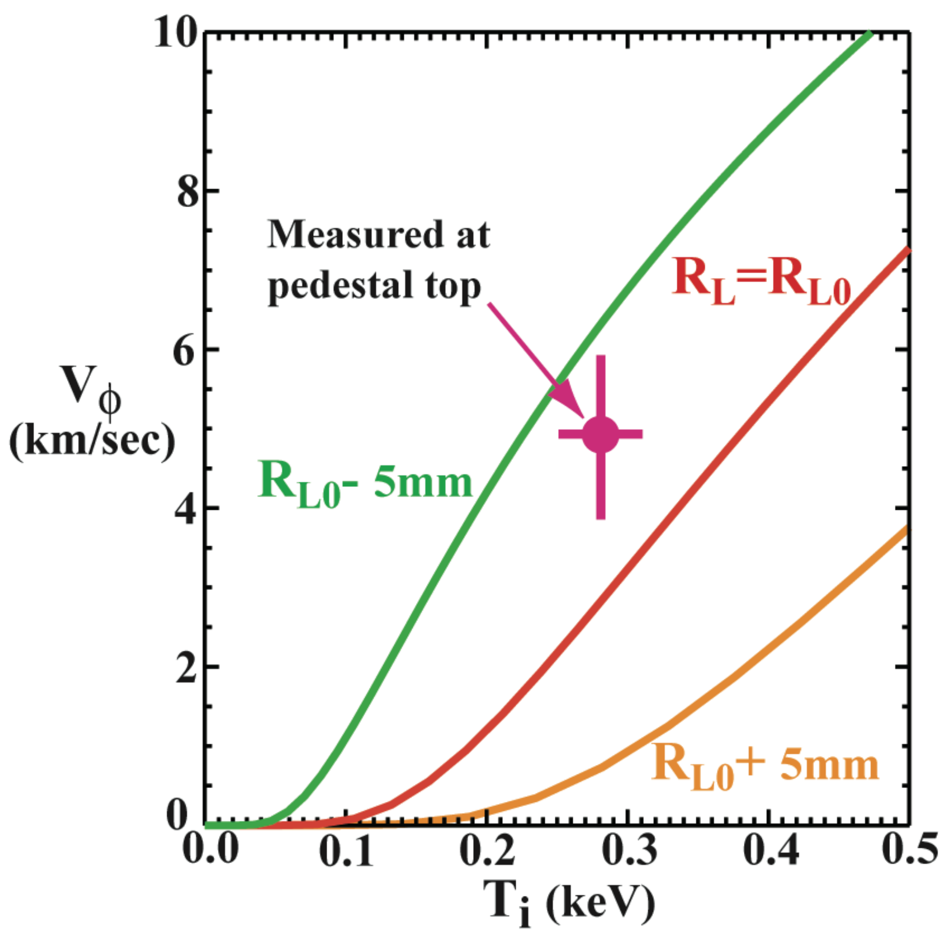


$$W_{loss} = M\Delta^2\omega_\theta^2/2$$

$$V_\phi(\text{ped}) \sim \delta_p T_i/\Delta B_\theta$$

Absolute Comparison Limited by Uncertainty in EFIT Determination of R_{L0} the Midplane LCFS Location

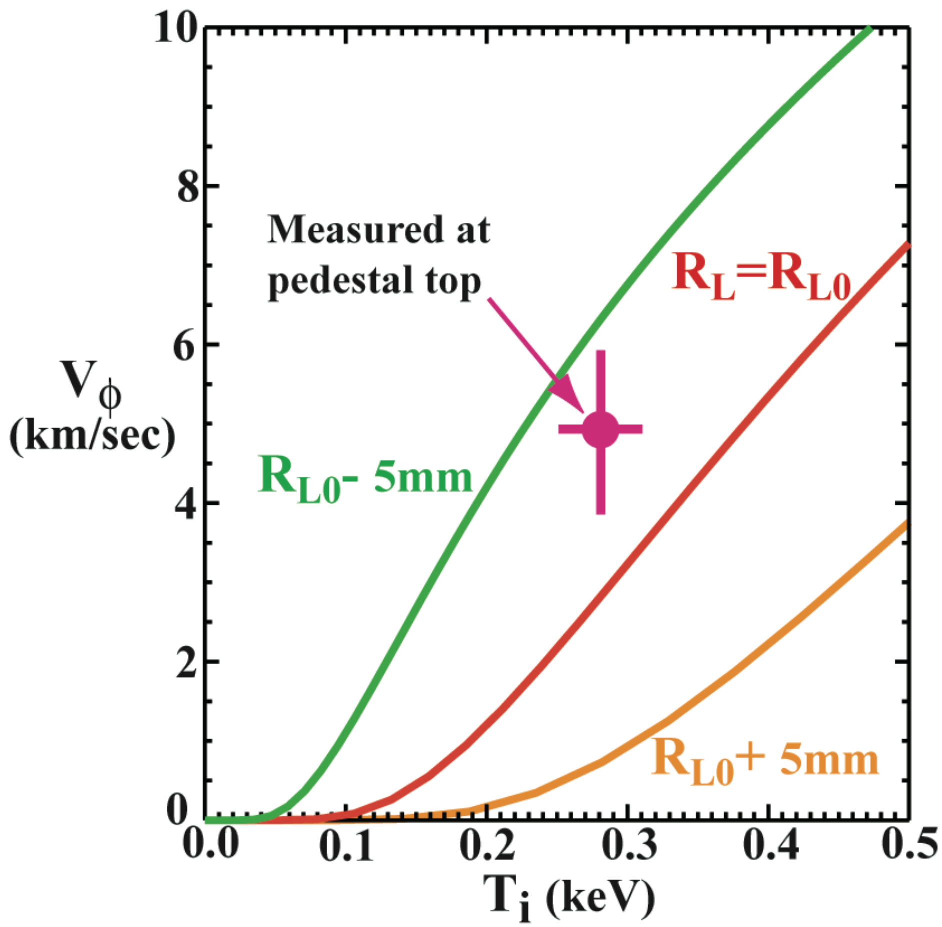
δR_{L0} = +/- 5 mm*



* Porter et al, Phys Plasmas 1998

Absolute Comparison Limited by Uncertainty in EFIT Determination of R_{L0} the Midplane LCFS Location

δR_{L0} = +/- 5 mm*



* Porter et al, Phys Plasmas 1998

Caveat

- Orbit escape $W_{loss} \sim Z^2/M$, thus C^{6+} is negligible compared with D^+, at the same T_i.
- To provide the measured boundary condition we must assume that D^+ sets the velocity and C^{6+} is dragged along in the pedestal region.

DIII-D NATIONAL FUSION FACILITY

Summary

- In the H-mode pedestal, we find V_ϕ is co-I_p and correlated with the local T
- We observe this correlation for the carbon impurity, and for the bulk ion in helium ECH H-mode discharges
- This scaling is consistent with a simple approximate model of thermal ion orbit loss from the pedestal region, which gives $V_\phi \sim T_i/B_\theta$, co-I_p directed
- Our approximation is for an empty loss cone; collisionless. The recent simulation of Chang and Ku including collisions finds that thermal orbit loss produces a co-I_p velocity in the pedestal region. In DIII-D intrinsic H-mode conditions, at the pedestal top $\nu_i^* \sim 1$
- This classical effect may provide a robust minimum pedestal velocity in intrinsic conditions, and act as the boundary condition

Phenomenological Model to Carry $V_\phi \sim T_i$ Inside of the Pedestal Boundary Region

- **Local momentum flux:** $-\chi_\phi(\partial\ell/\partial r) + V^p\ell = H(r)$

  0 internal source

  $\ell = Mn_i\langle R^2\rangle\omega_\phi$ momentum density

  $\chi_\phi =$ momentum diffusivity

  $V^p =$ momentum pinch velocity

- for $\frac{n'}{n} << \frac{V_\phi'}{V_\phi} \sim \frac{T_i'}{T_i}$ weak density gradient inside pedestal, and $\left|\frac{R_0 V_\phi'}{V_\phi}\right| >> 1$

- the local momentum equation becomes $-\chi_\phi(\partial V_\phi/\partial r) + V^p V_\phi = 0$

- If we use $\frac{V^p}{\chi_\phi} = k\frac{\partial T_i/\partial r}{T_i}$ turbulence

  Coppi, NF **42**, 1 (2002) qualitatively
  Shaing, Phys. Plasmas **8**, 193 (2001).
  Diamond, et al, Phys. Plasmas **15**, 012303 (2008).

- Then $V_\phi = V_\phi(a)[T_i/T_i(a)]^k$