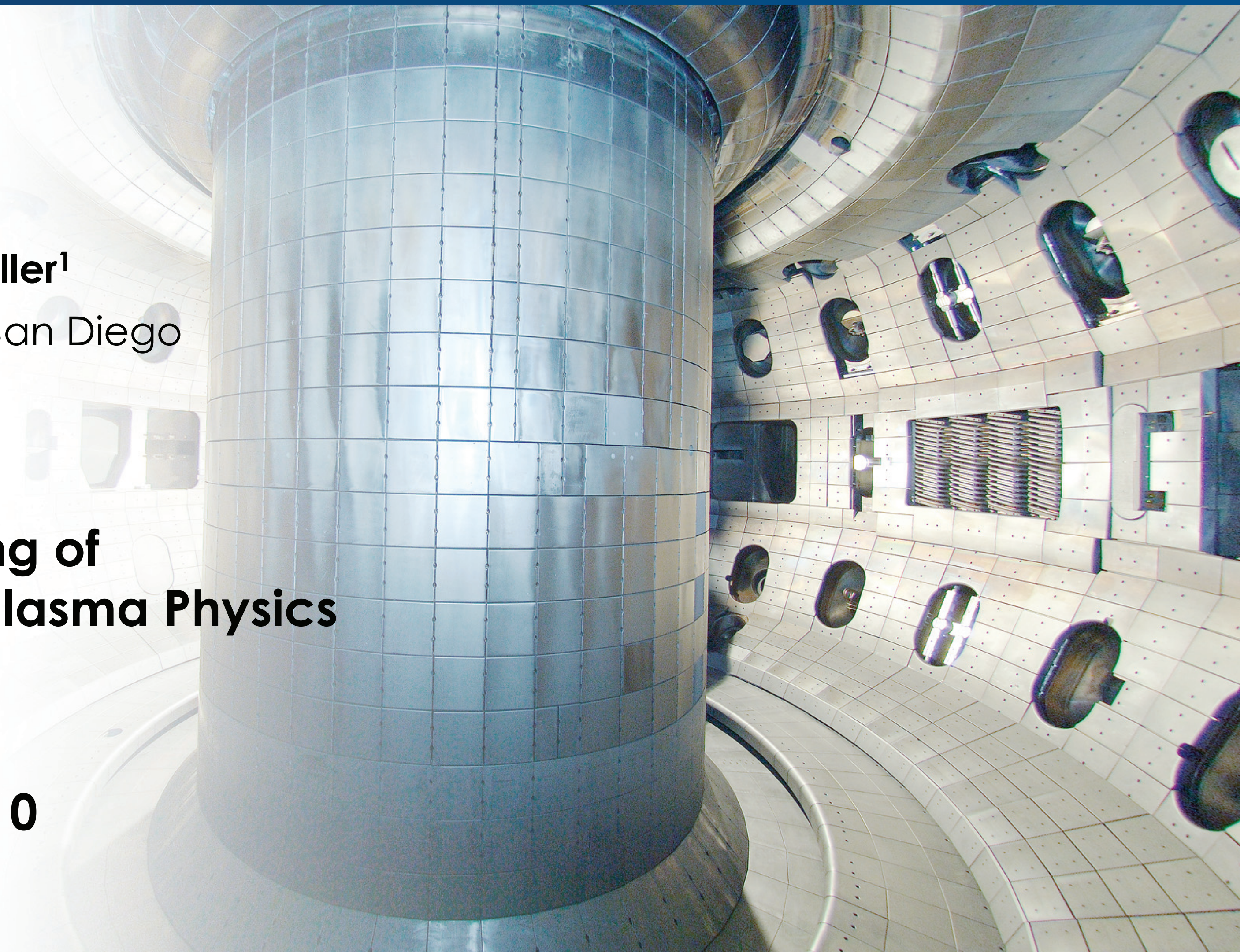
Thermal Ion Orbit Loss and Intrinsic Toroidal Velocity Near the Last Closed Flux Surface



by

J.S. deGrassie

with

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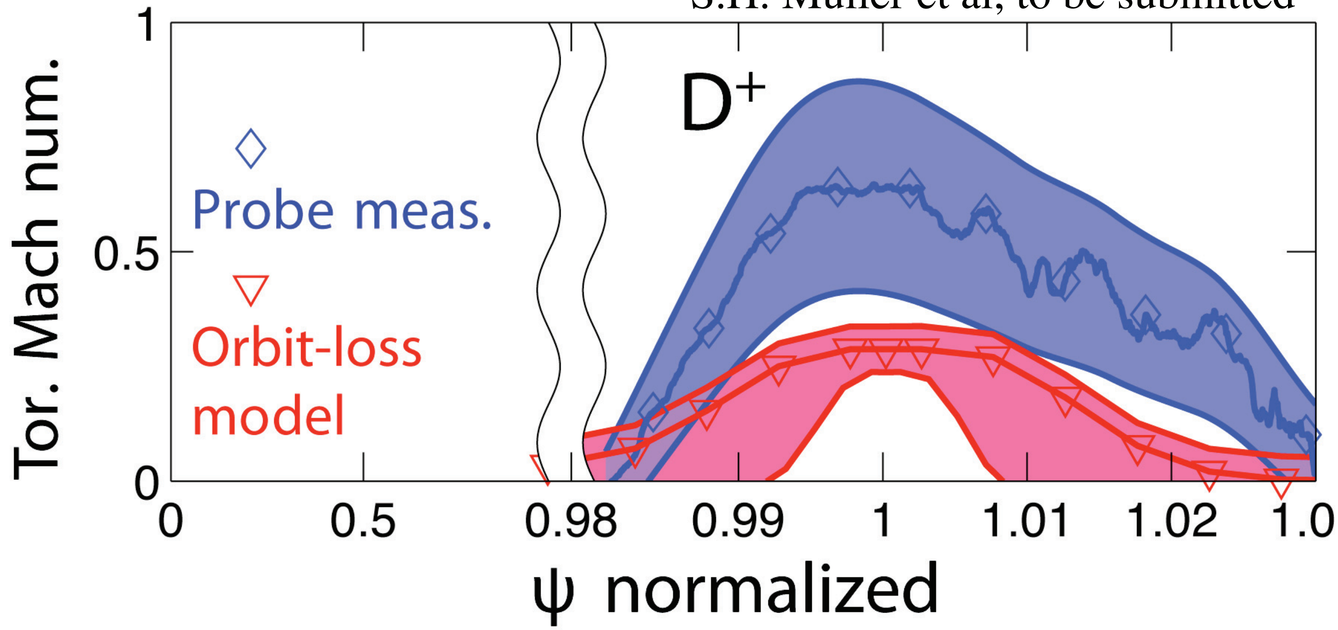
Introduction

- **Recent Mach probe measurements of <u>bulk ion</u> toroidal velocity near the outer LCFS in DIII-D agree in sign, profile width and approximately in magnitude with a simple thermal ion loss model**
  - ECH H-mode => No NBI drive; intrinsic rotation conditions
  - An edge source may be an important ingredient for intrinsic rotation
  - See S.H. Müller, PI2.00003, 3 pm Wednesday
- **Formerly, we considered orbit loss near the top of the pedestal, since momentum needs density. These new measurements indicate that orbit loss plays a role in velocity generation to and through the LCFS**
- **The importance of limiting surfaces in the SOL and the strong radial electric fields measured near the edge in H-mode conditions has motivated us to modify the simple loss model accordingly**
- **The basic result is that the calculated velocity profile is modified, but the general width and height remain**

Simple Orbit Loss Model Compares Reasonably well with Mach Probe Measurements of Bulk Ion Vϕ

- **Compare thermal Mach number values**
  - **Removes some temperature uncertainty in the probe conversion**
  - **Loss model calculation scales as the ion thermal velocity at the LCFS**

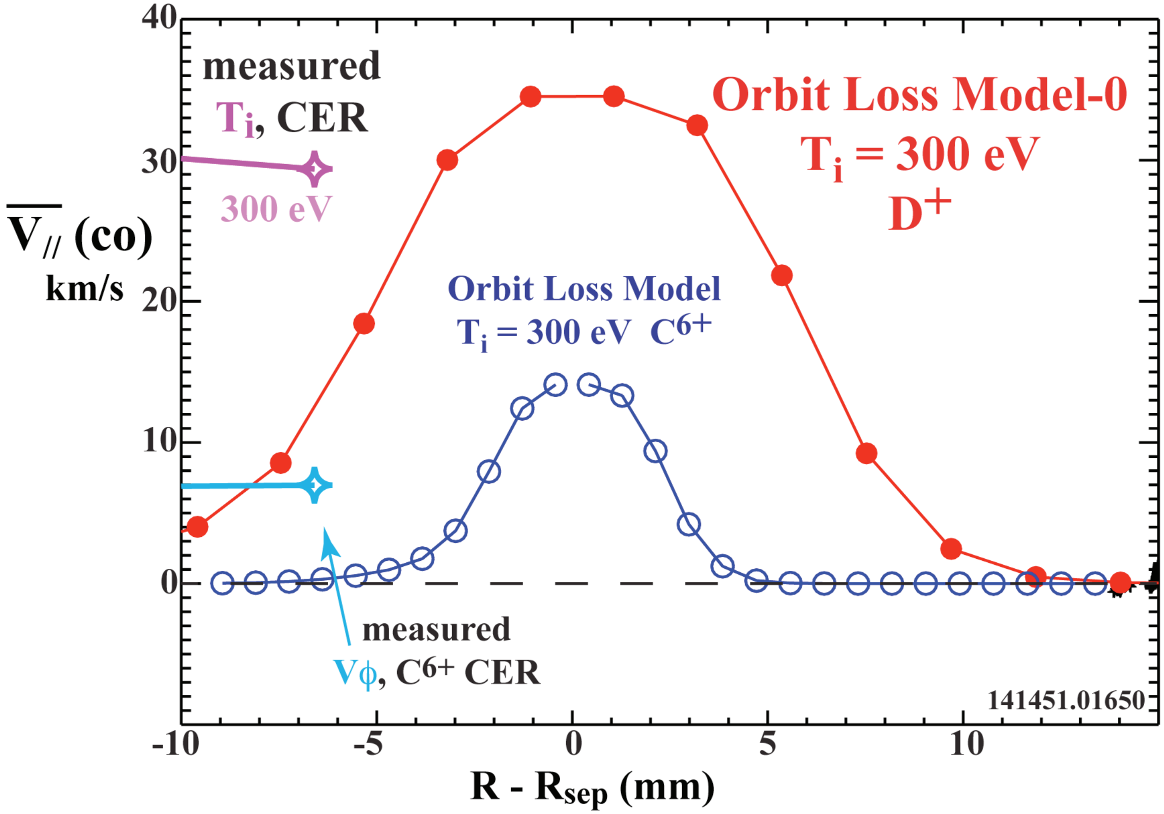
S.H. Müller et al, to be submitted



- **ECH H-mode => Intrinsic conditions**

Profile Width from the Simple Model is Given by the Poloidal Ion Gyroradius; the Height Increases with Thermal Velocity

- **Absolute model-computed velocity profile from the previous slide, showing the width of the narrow velocity layer in mm**



- **This simple model velocity calculation assumes loss cones are empty, that loss is only through the X-point, and neglects any radial electric field effects**

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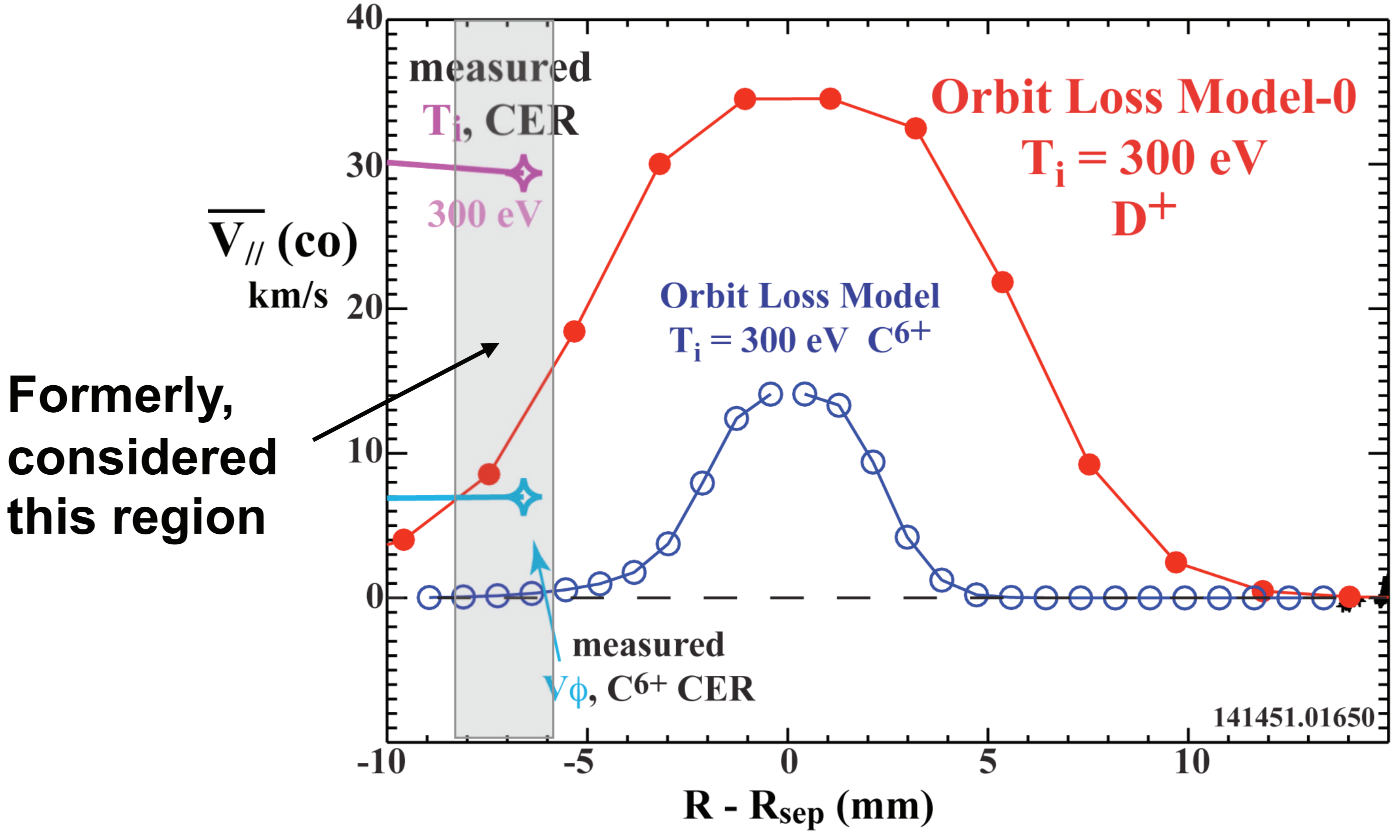

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Thermal Ion Orbit Loss from the Edge of A Tokamak Has Been Considered by Many, for Some Time

- **Typically, related to looking for a bifurcation mechanism in the radial electric field, or concerning energy transport. Recently, velocity generation has been addressed.**

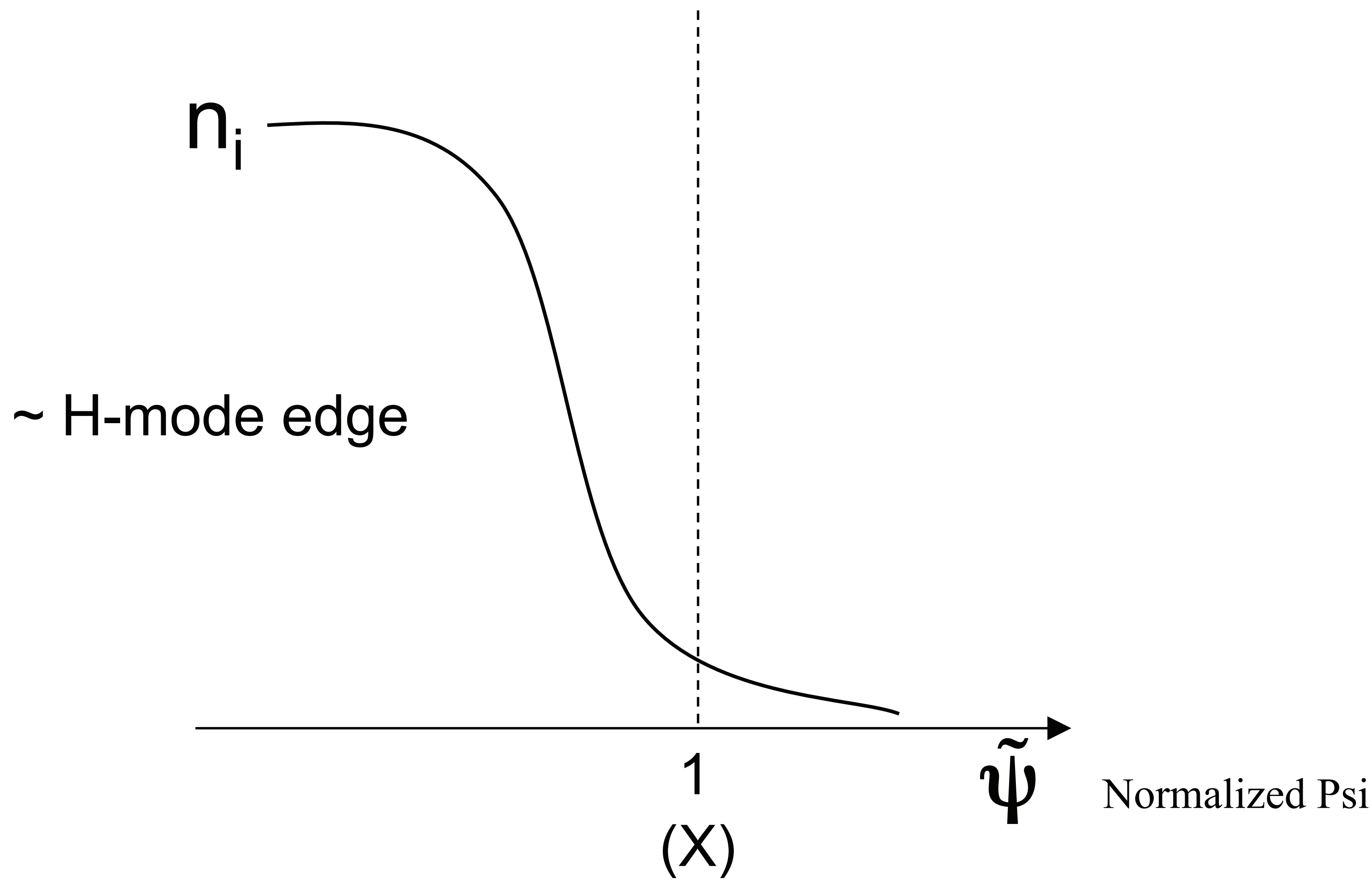
Berk and Galeev, PF **10**, 441 ('67).
Pre-divertor torus. <u>Investigating loss cone generated instabilities.</u>

Hinton and Chu, NF **25**, 345 ('85).
Shaing and Crume, PRL **63**, 2369 ('89).
Shaing, PF-B **4**, 3310 ('92).
Chankin and McCracken, NF **33**, 1459 ('93).
Miyamoto, NF **36**, 927 ('96).
Heikkinen, Kiviniemi, and Peeters, PRL **84**, 487 ('00).
Kiviniemi, Heikkinen, and Peeters, NF **40**, 1587 ('00).

Ku, Baek, and Chang, PoP **11**, 5626 ('04) <u>"velocity space hole"</u> numerical orbits.
Chang and Ku, PoP **15**, 062510 ('08). Simulation; <u>co-Ip rotation due to edge orbit loss</u>

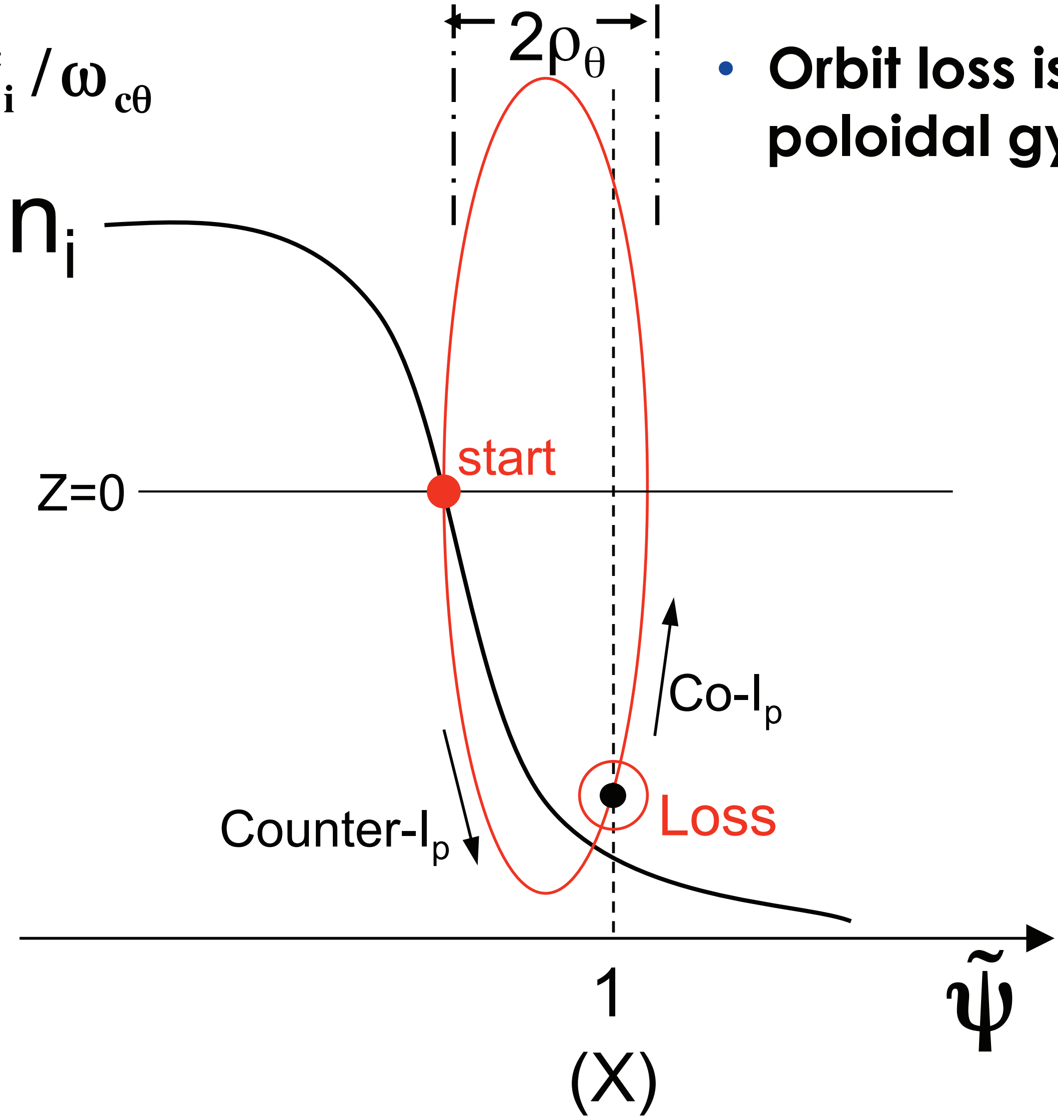
deGrassie, Groebner, Burrell, and Solomon, NF **49**, 085020 ('09). "former"

Consider Orbit Loss Dynamics on the Backdrop of An H-mode Density Pedestal Profile

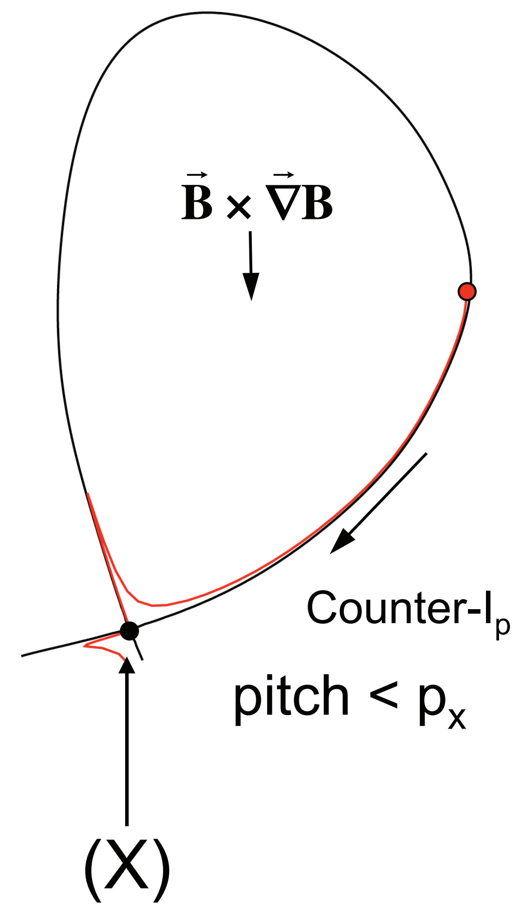


Inside, counter-I_p Starting Guiding Center Orbit Can Be Lost with Sufficient Orbit Width

$$\bar{\rho}_\theta = \bar{v}_i / \omega_{c\theta}$$

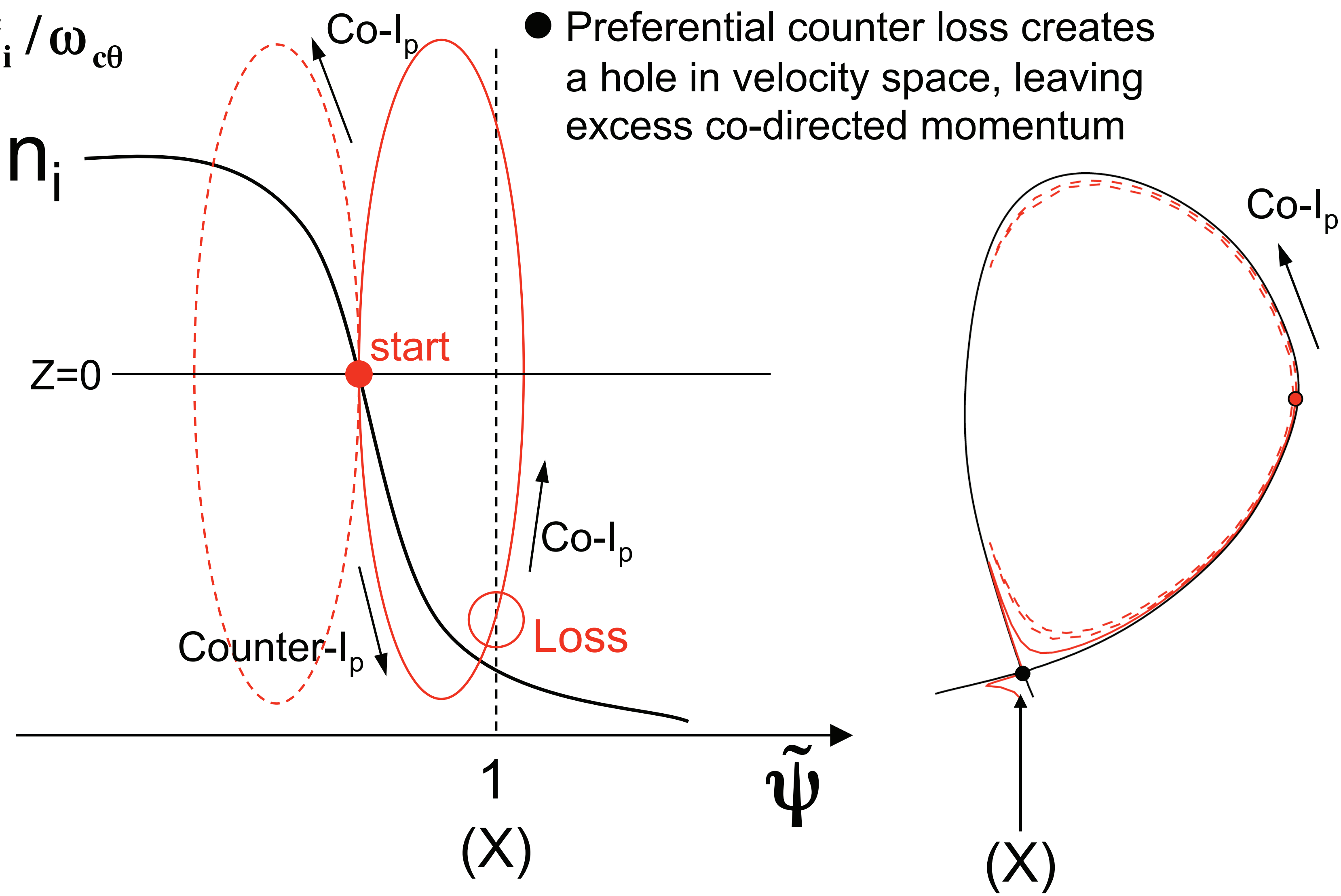


- **Orbit loss is limited to a few poloidal gyro-radii from the LCFS**



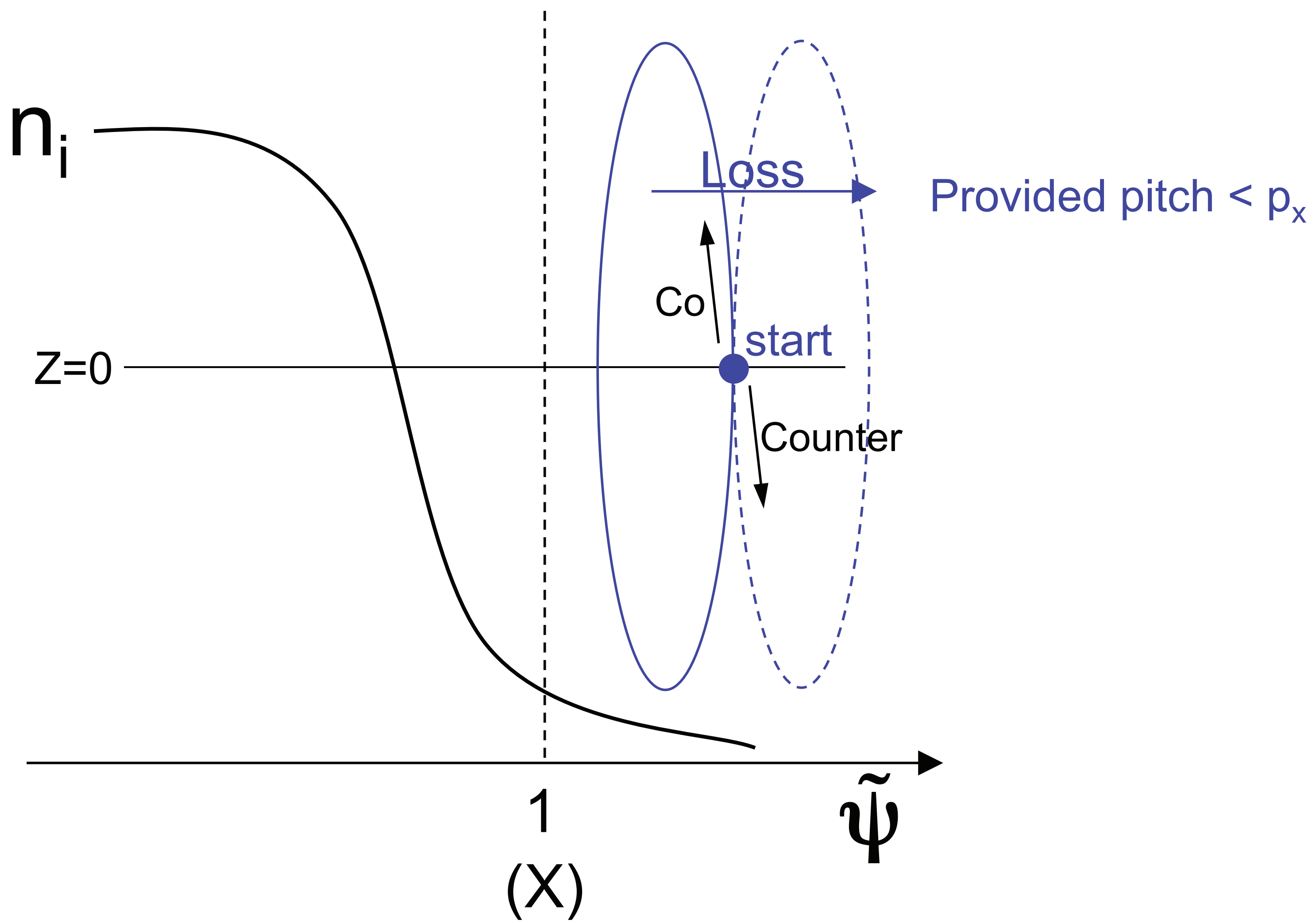
Inside, co-I_p Starting Guiding Center Orbit is Confined, As it Drifts Further from the LCFS

$$\bar{\rho}_\theta = \bar{v}_i / \omega_{c\theta}$$

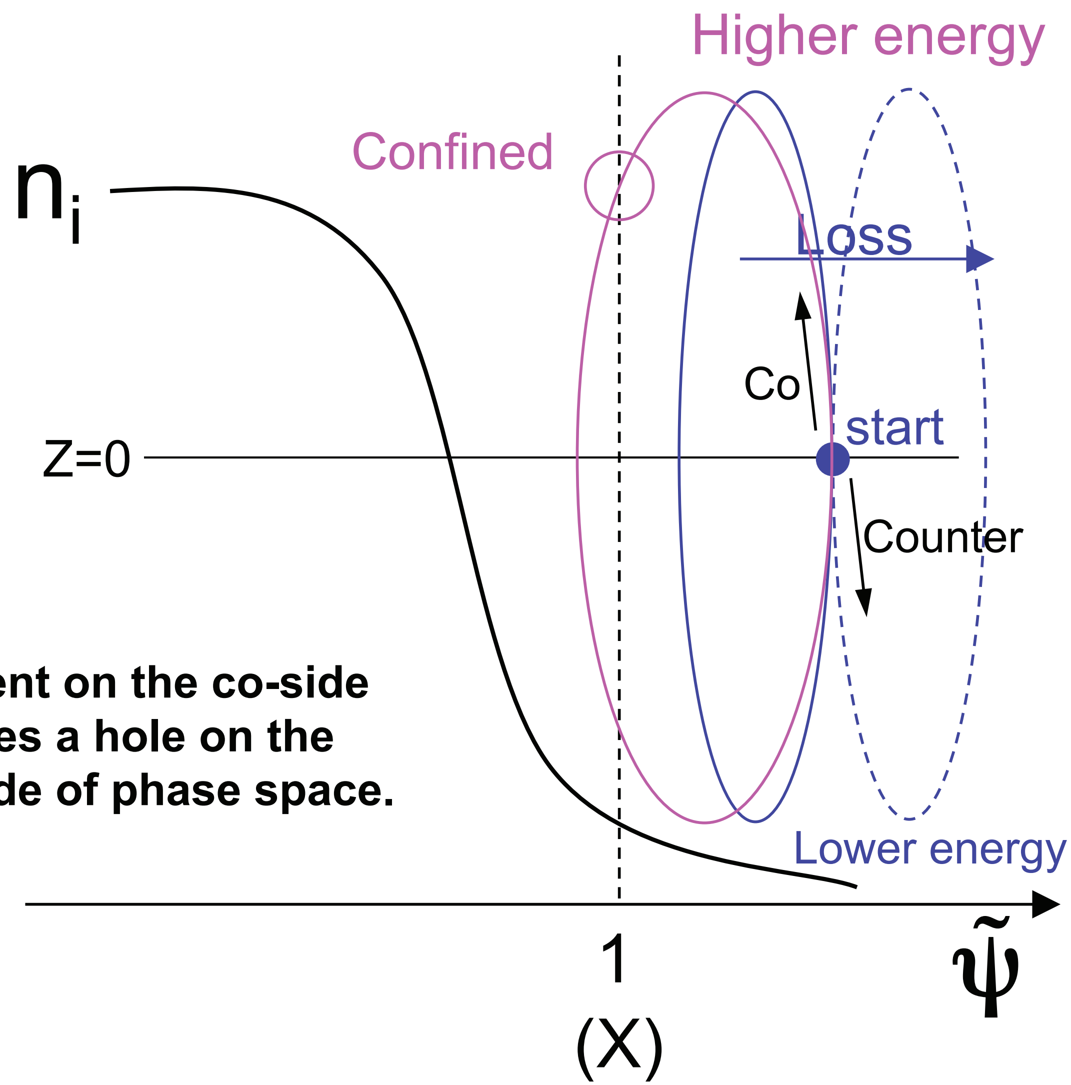


- Preferential counter loss creates a hole in velocity space, leaving excess co-directed momentum

Outside, "Low" Energy co-I_p and Counter-I_p Starting g.c. Orbits are Lost

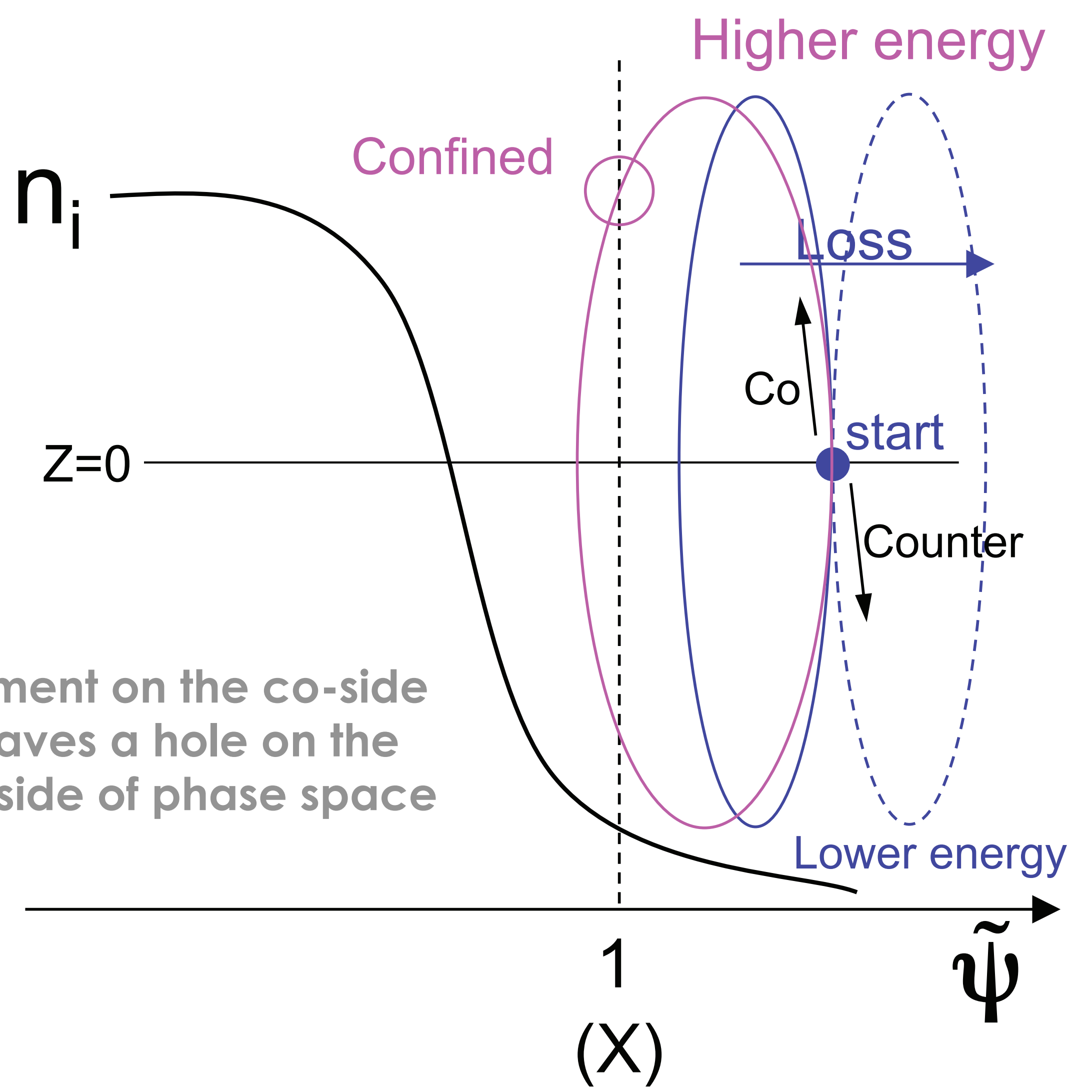


Outside, "Higher" Energy co-I_p Orbits Have Sufficient Width to Get Inside at The X-point Major Radius, and Be Confined



- **Confinement on the co-side again leaves a hole on the counter side of phase space.**

Outside, "Higher" Energy Co-I_p Orbits Have Sufficient Width to Get Inside and Be Confined

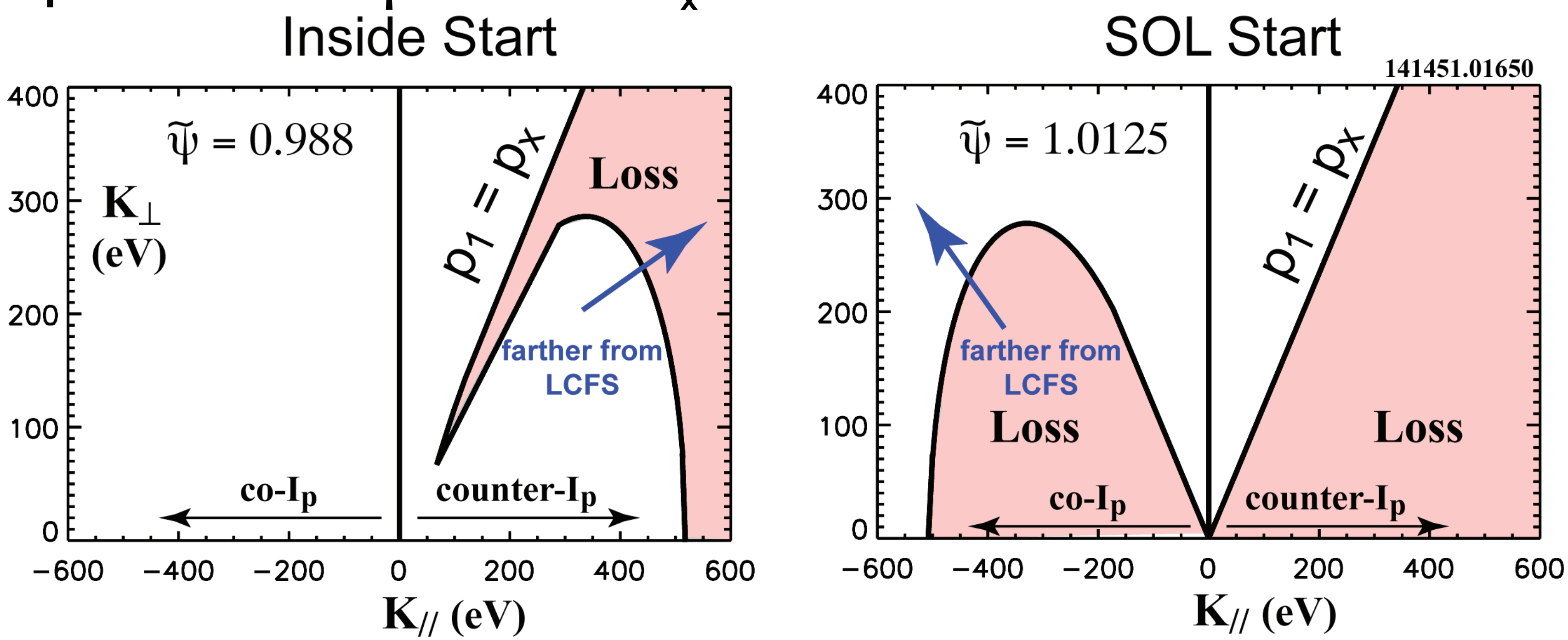


- Confinement on the co-side again leaves a hole on the counter side of phase space

- **Assume steady state, empty loss cone**
- **The radial E field is a measured quantity. The process that ensures charge balance is not specified. e^- loss?**
- **Orbit loss is by no means a self contained model for intrinsic rotation, but may have some role as a seed**

The Loss Cones Computed By the Model Show the Asymmetry in Parallel Velocity

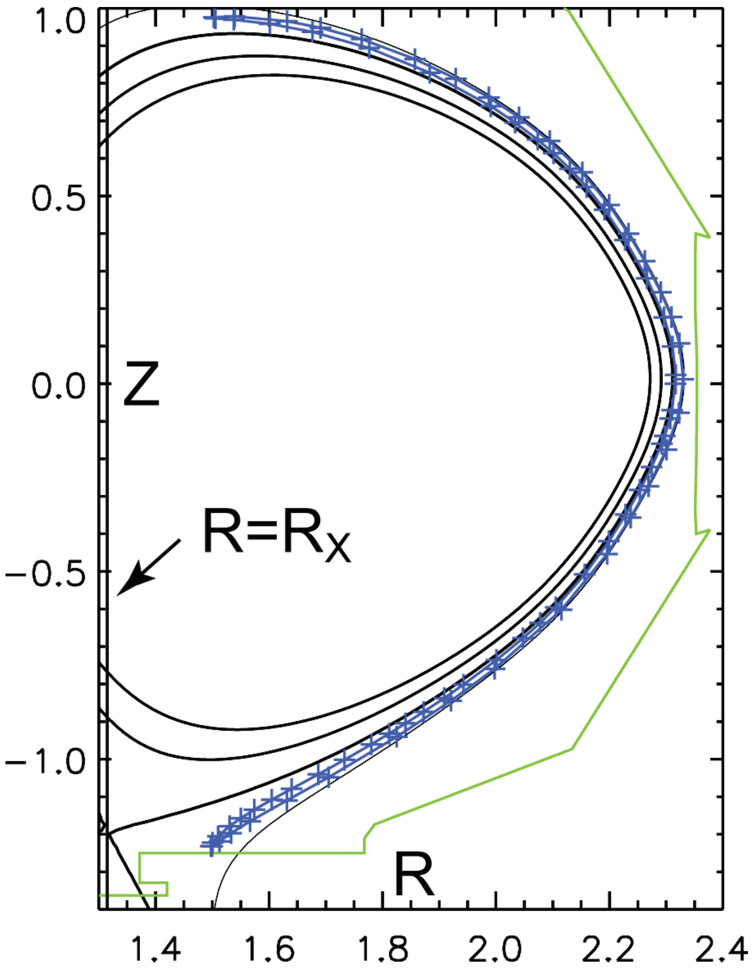
- **The loss boundaries are calculated using the constants of motion and the requirement that $\tilde{\psi} > 1$ at R = R$_x$**



- **Numerical guiding center orbits in the actual EFIT equilibrium are used to check these model-computed boundaries**

- **A Maxwellian at rest in the lab frame is placed over empty loss cones to compute <V$_{//}$>**

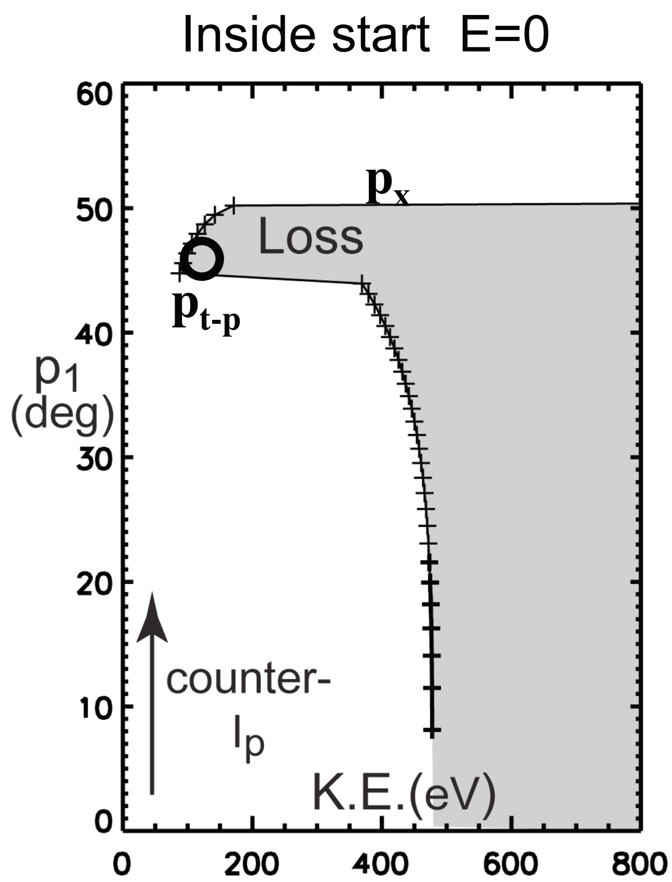
The Agreement with Probe Measurements Motivated Including Other Effects in the Loss Model: SOL Limiters



- Outside starting ions can be lost without sufficient pitch angle to reach $R = R_x$
- Expansion of the flux surfaces leads orbits to the baffle, away from the X-point surface. This effect becomes larger as the starting distance from the LCFS increases

The Agreement with Probe Measurements Motivated Including Other Effects in the Loss Model: E Field

- **Nonzero E shifts the loss boundaries in phase space, modifying p_x, and the trapped/passing boundaries**



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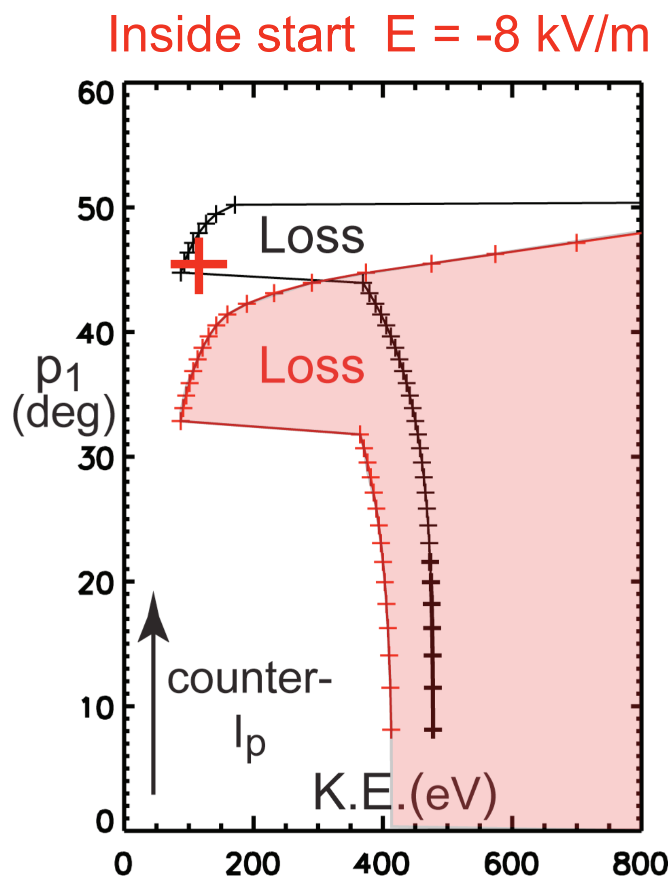

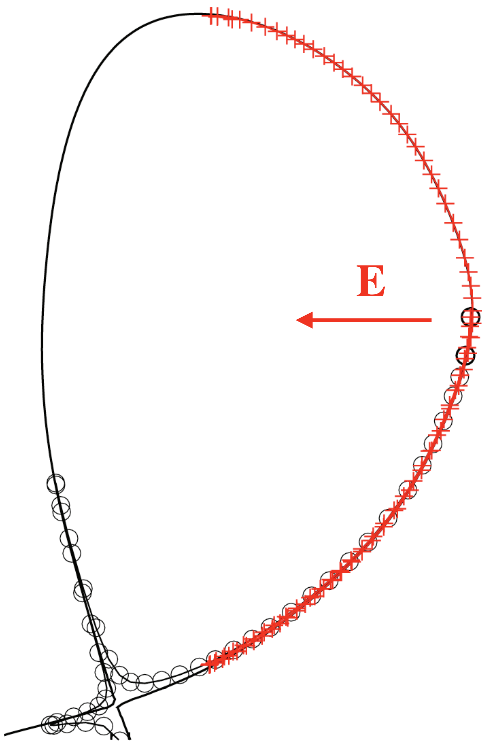

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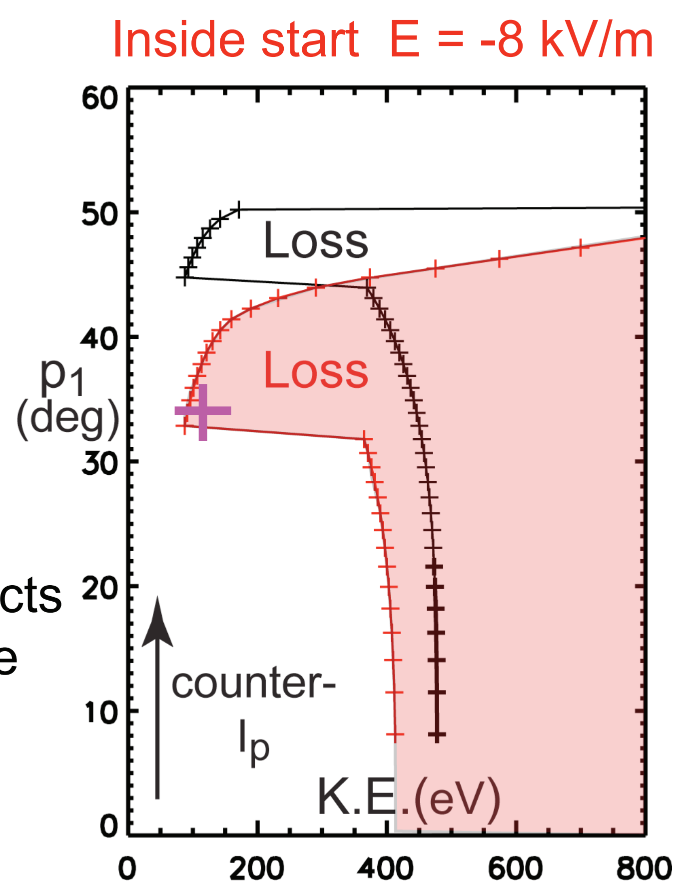
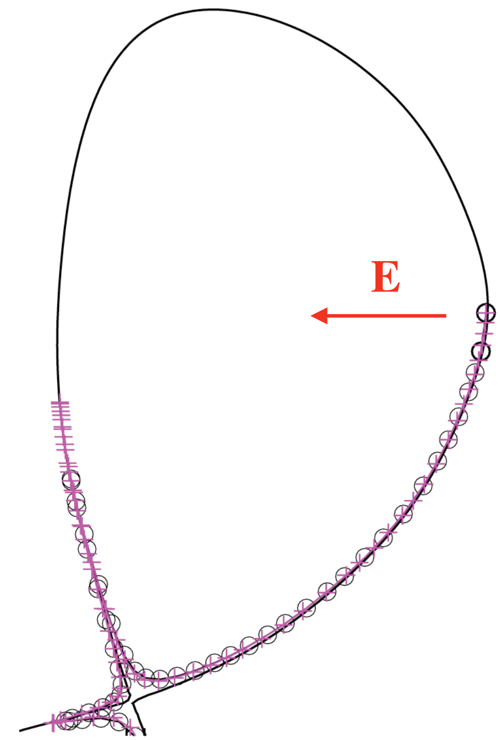


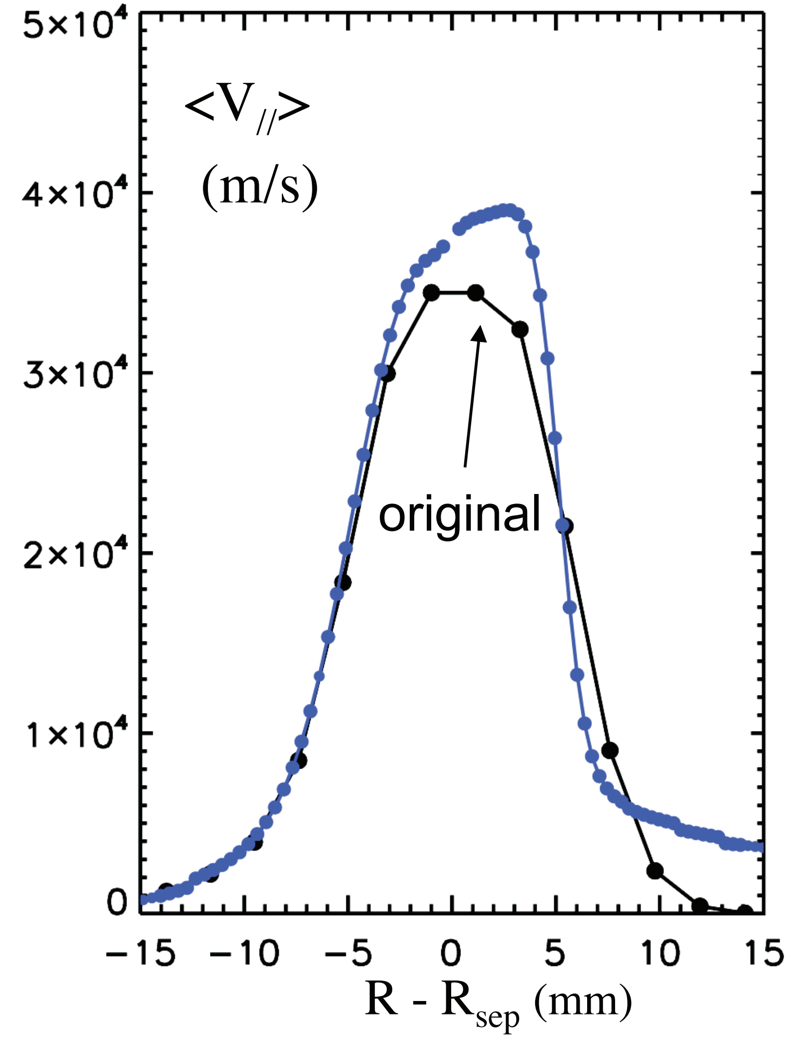


Have only considered effects of rigid rotor E fields on the loss cone velocity,

$$\Phi = \text{const} \times \Psi$$

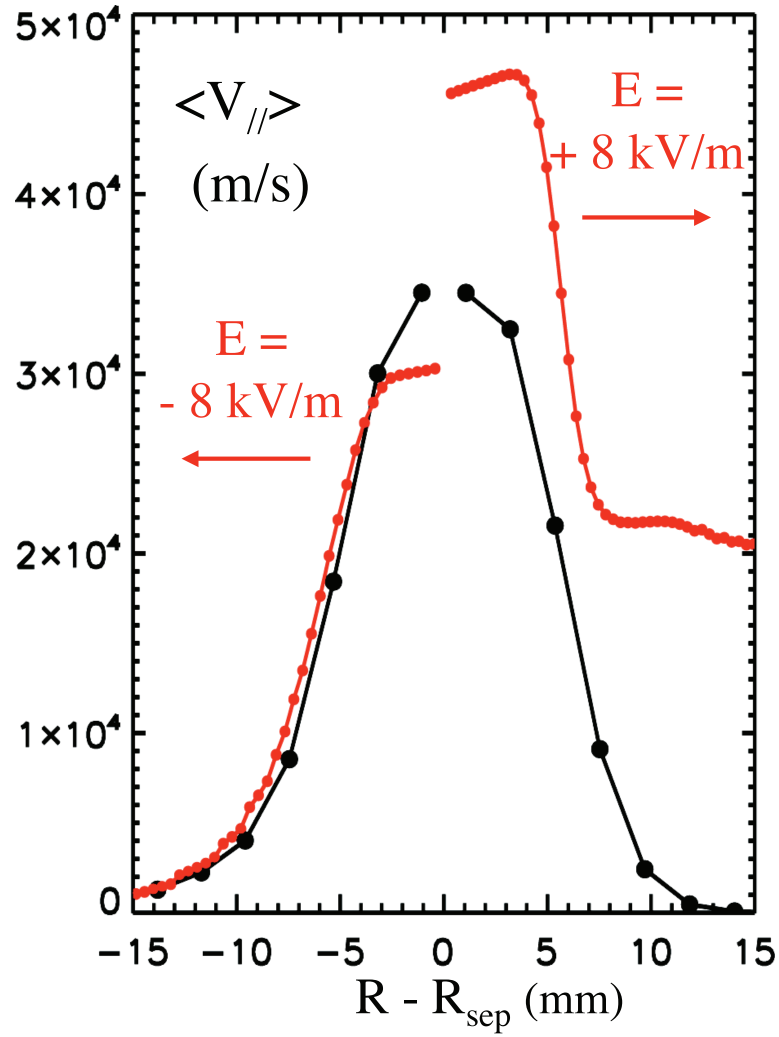
These Additional Effects Modify But Do Not Wipe Out The Computed Loss Cone Model Velocity Profile

- **Baffle loss increases the co-I_p computed velocity, primarily in the SOL**



These Additional Effects Modify But Do Not Wipe Out The Computed Loss Cone Model Velocity Profile

- Add E field effect for values comparable to those measured in ECH H-modes, negative inside, positive outside
- Negative E reduces and positive E increases the computed co-I_p loss cone model velocity
- Considering a measured electric potential profile is best left to Monte-Carlo simulations, which can also include collisions



If Measurements Indicate A Loss Cone Distribution Exists in the Tokamak Edge, What About Instabilities?

- **Our interest here is whether an instability can tap into the asymmetry in $V_{//}$ and have consequences for momentum transport. Former well-studied instabilities should be reconsidered in toroidal geometry with pedestal-like gradients**

- **Some candidates**
  - Drift Cyclotron Loss Cone (DCLC)
  - Drift Cyclotron
  - Inverse Gradient
  - Current Driven Ion Cyclotron

- **The loss cone drive for the diverted tokamak is weak compared to a mirror**

- **These will be considered more in the future**

Summary

- A simple thermal ion orbit loss model is in approximate agreement with Mach probe measurements for the bulk ion, near the LCFS in H-modes without NBI drive
- The velocity profile features are not washed out with the addition of other experimental effects; limiters in the SOL and a radial E field
- The steady state distribution function in the presence of a measured H-mode radial E field and collisions should be addressed with simulations
- Many more experiments are needed, to test the simple model qualitatively, and to see if there is a relation to intrinsic rotation
- Instabilities?