# Sensitivity of Final Field Position to the Punt Initial Conditions in American Football

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# Outline

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# Introduction

Figure: Photograph of a football punter, Zoltán Meskó[1]

[1] "Fourth play" by cgilmour on Flickr is licensed under CC BY 2.0.

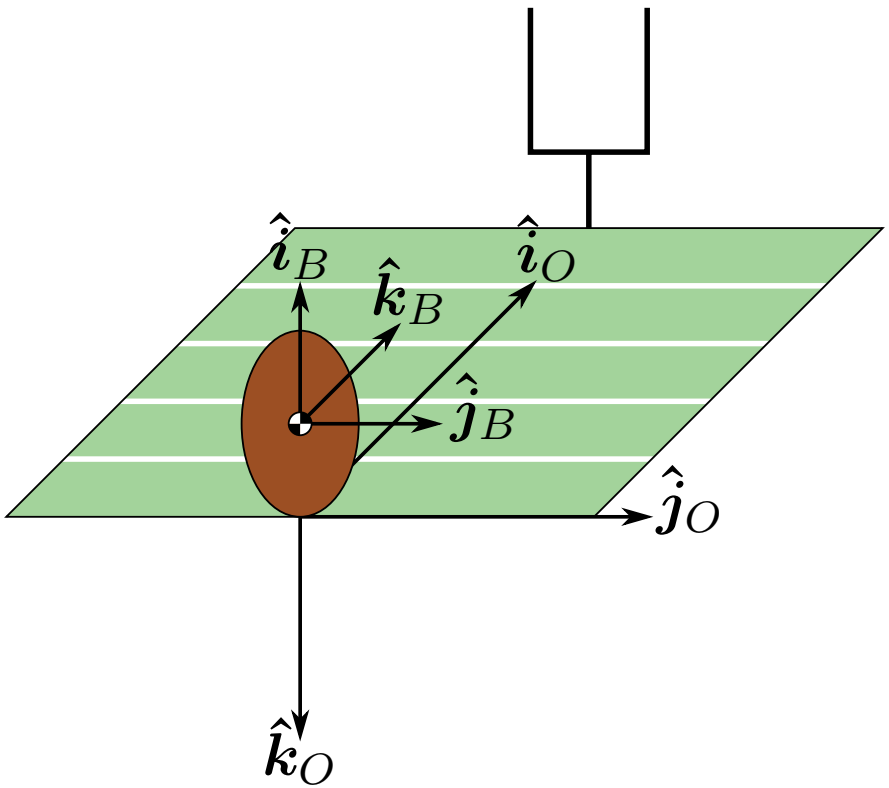
# Introduction

- Important characteristics of football kicks
  - distance traveled before impact
  - hang time in the air
  - distance traveled after bouncing
- Imprecise control over initial conditions
- Flight and bouncing of a football are highly nonlinear
- Are there large regions of initial conditions that have final distances relatively insensitive to initial conditions?

# Outline

# Coordinate Systems

- Body-fixed coordinate system $B = \left\{\hat{\boldsymbol{i}}_B, \hat{\boldsymbol{j}}_B, \hat{\boldsymbol{k}}_B\right\}$
- Global coordinate system $O = \left\{\hat{\boldsymbol{i}}_O, \hat{\boldsymbol{j}}_O, \hat{\boldsymbol{k}}_O\right\}$
- Orientation of $B$ relative to $O$ represented as a quaternion



# Flight Model

- State of the football represented by

$$\boldsymbol{x} = \begin{bmatrix} x_O & y_O & z_O & v_{xB} & v_{yB} & v_{zB} & \omega_x & \omega_y & \omega_z & e_0 & e_1 & e_2 & e_3 \end{bmatrix}^\top$$

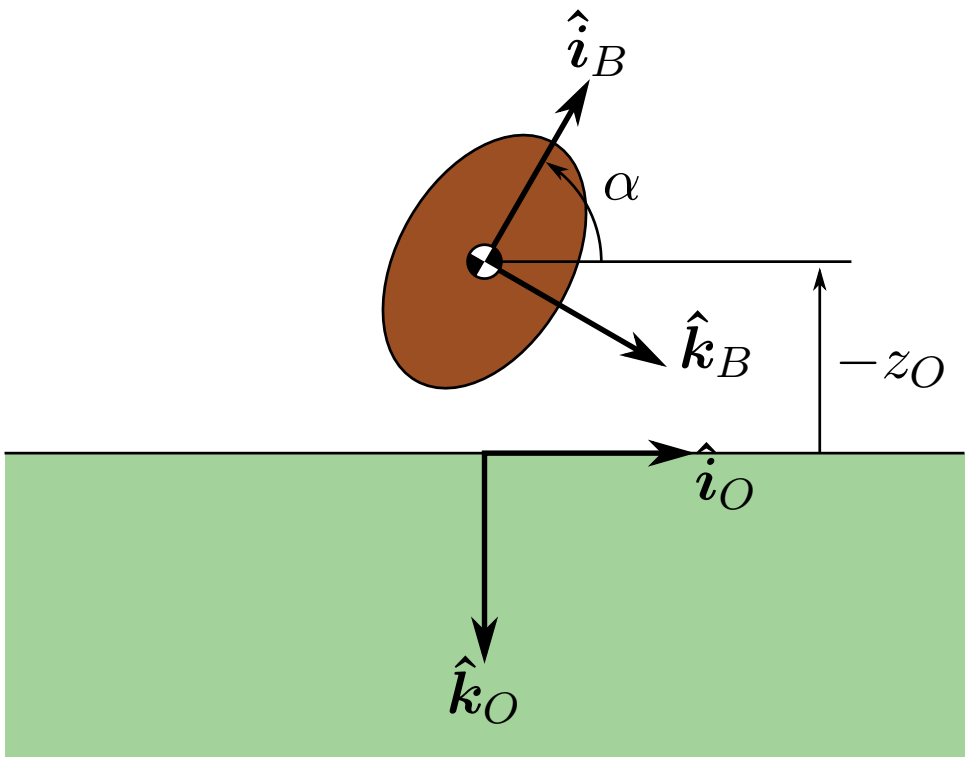
- Motion of the ball was described by a first order ODE

$$\dot{\boldsymbol{x}} = \boldsymbol{f}(\boldsymbol{x})$$

  using an empirical model from Lee, et al. (2013).
- Model accounted for:
  - gravity
  - aerodynamic forces (drag, lift, and yaw)
  - aerodynamic pitching moment (roll and yaw moments assumed to be negligible)

Collision when

$$z_O \geq 0 \quad \text{or} \quad (r_{\text{major}} \sin\alpha)^2 + (r_{\text{minor}} \cos\alpha)^2 - z_O^2 \geq 0$$



# Bouncing

- Highly nonlinear because of ellipsoidal ball
- Rough empirical model based on interpolation/extrapolation of data from Cross (2010)
- Limited to the $x_O$–$z_O$ plane
- Model accounted for
  - orientation
  - velocity
  - angular velocity

  but not variation in mechanical properties of football or turf

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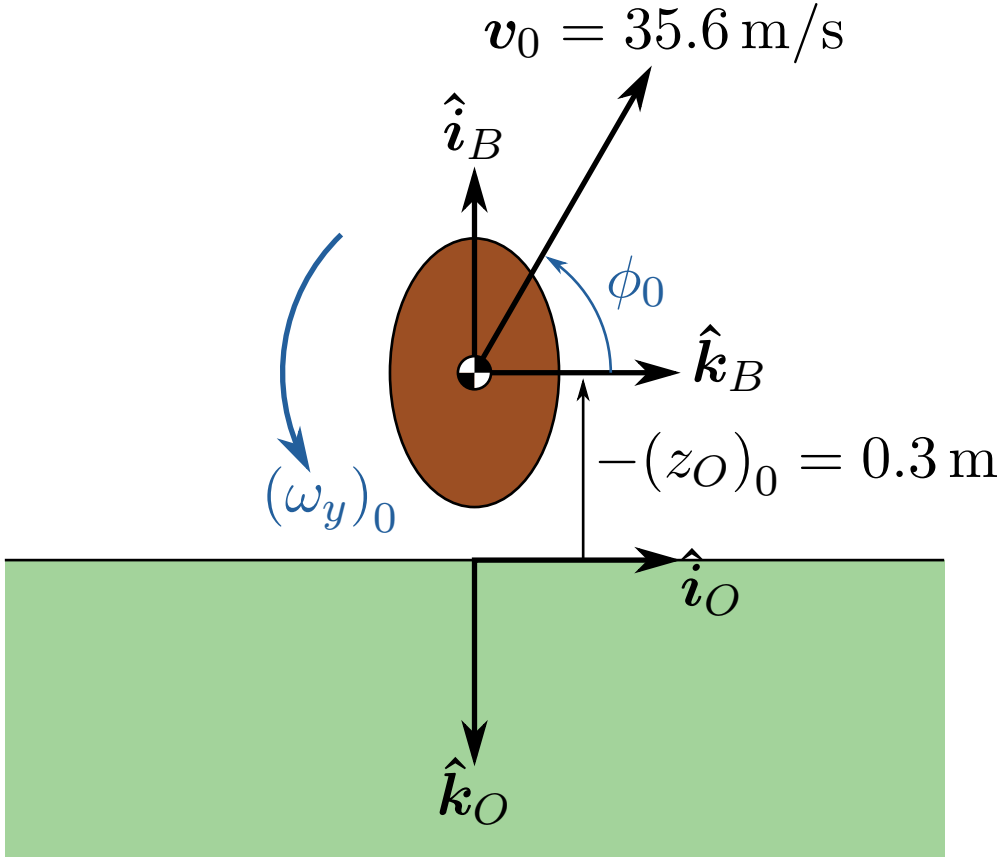
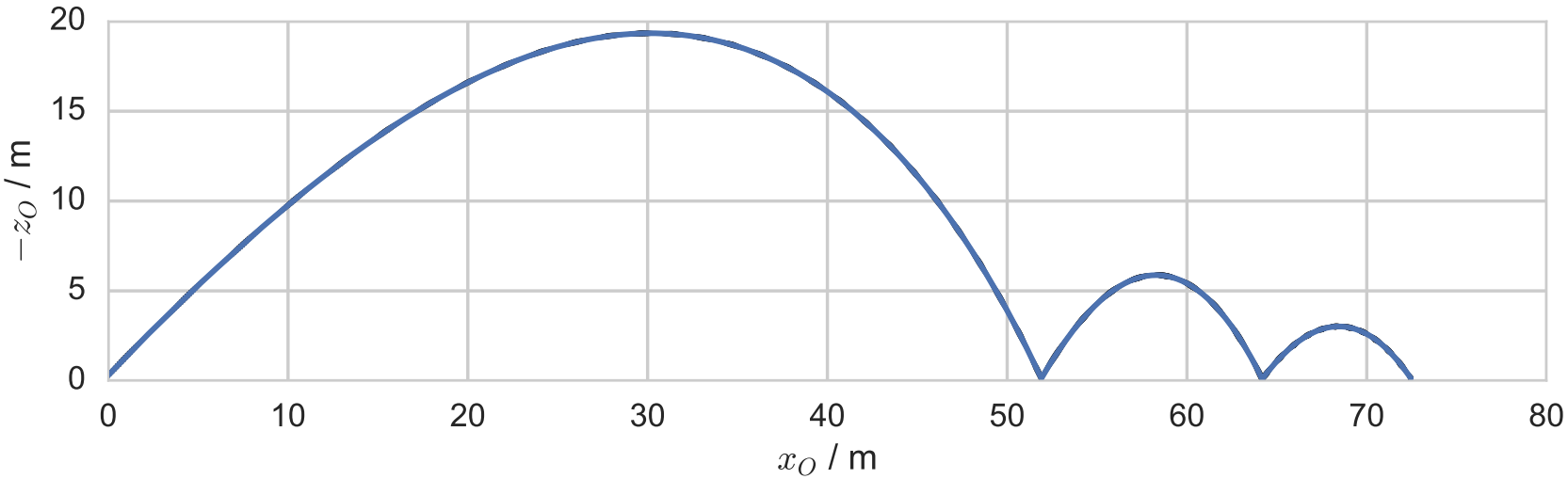
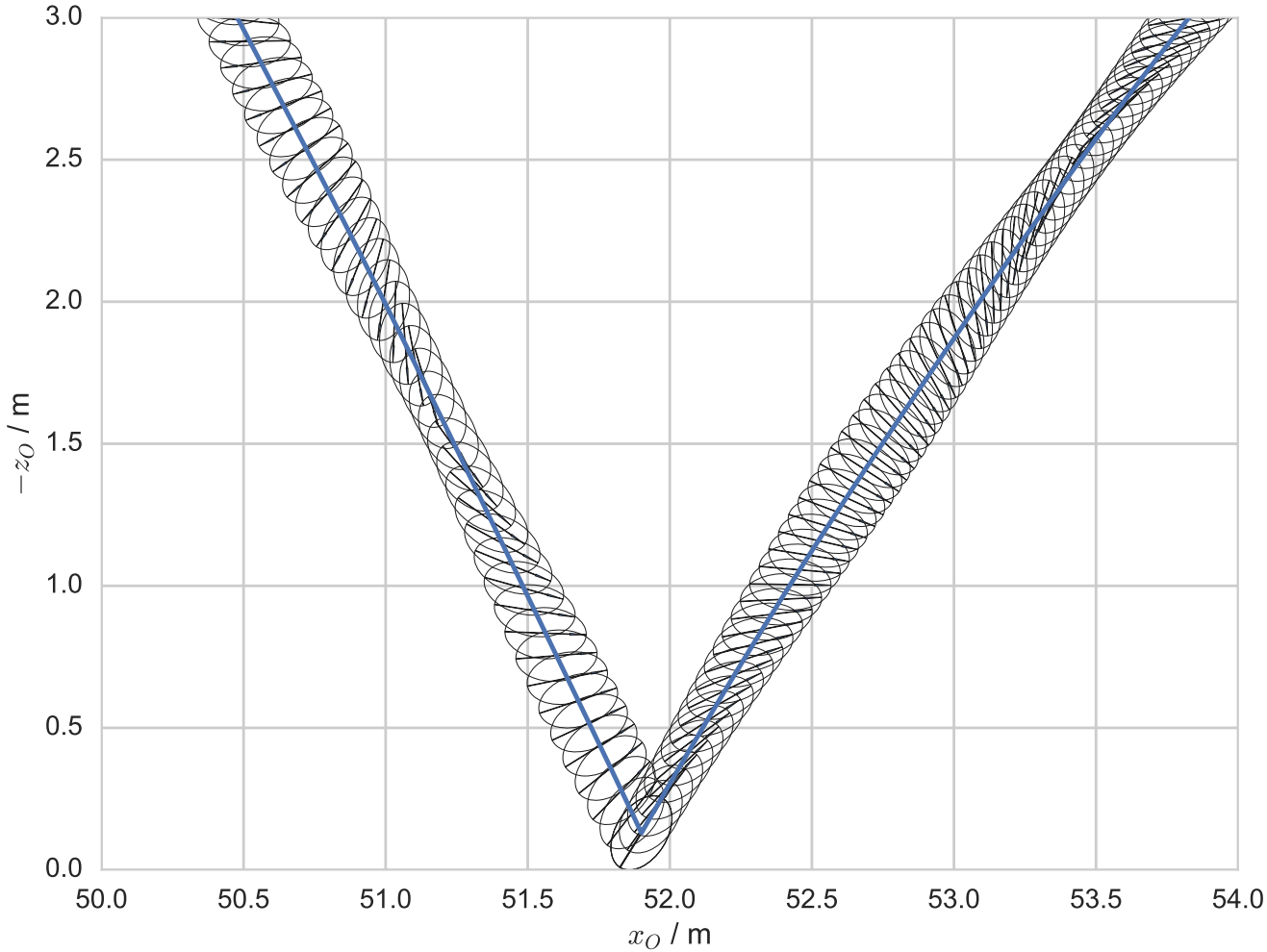
# Initial Conditions



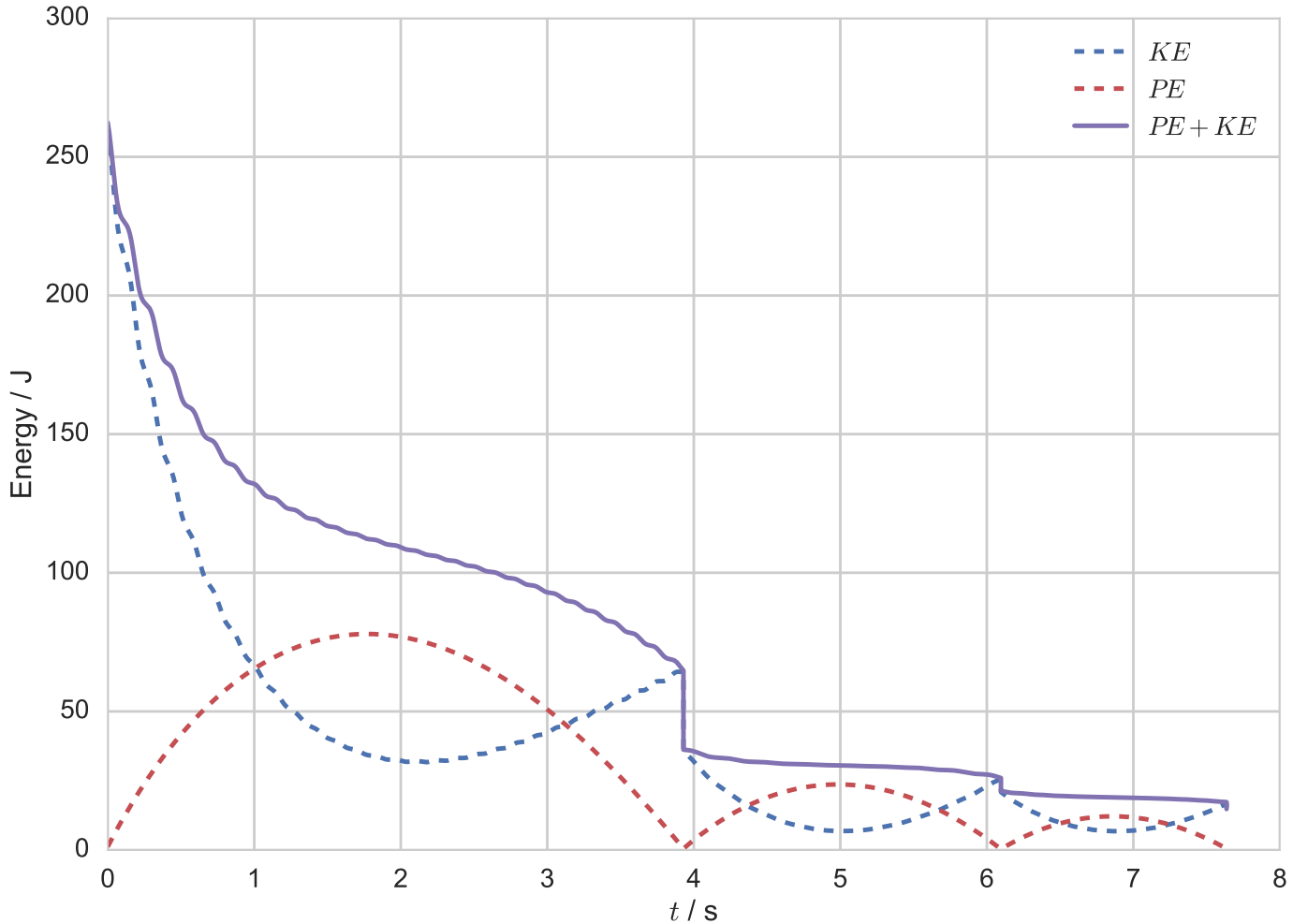
# Sample Trajectory



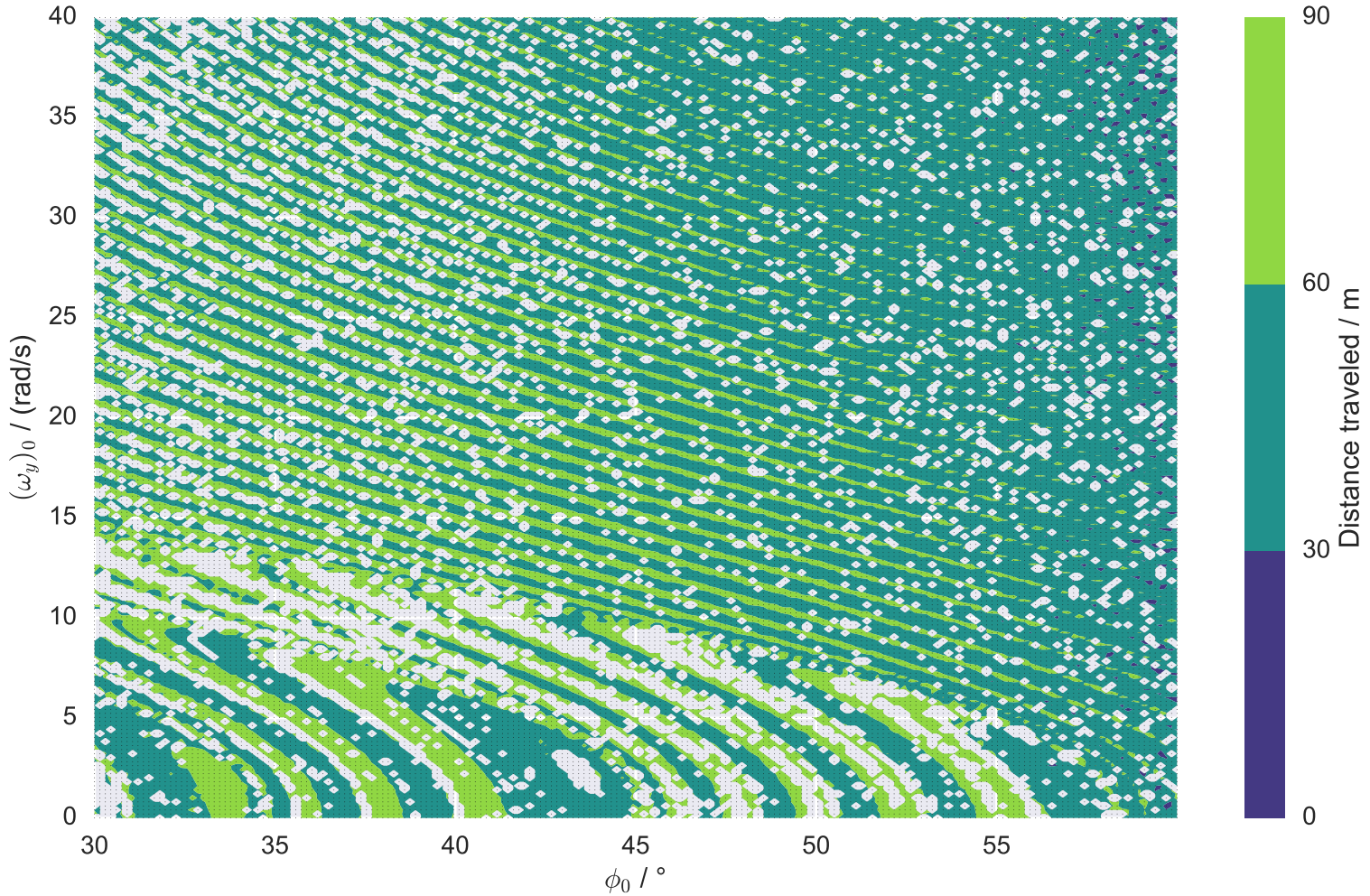
# Sample Bounce



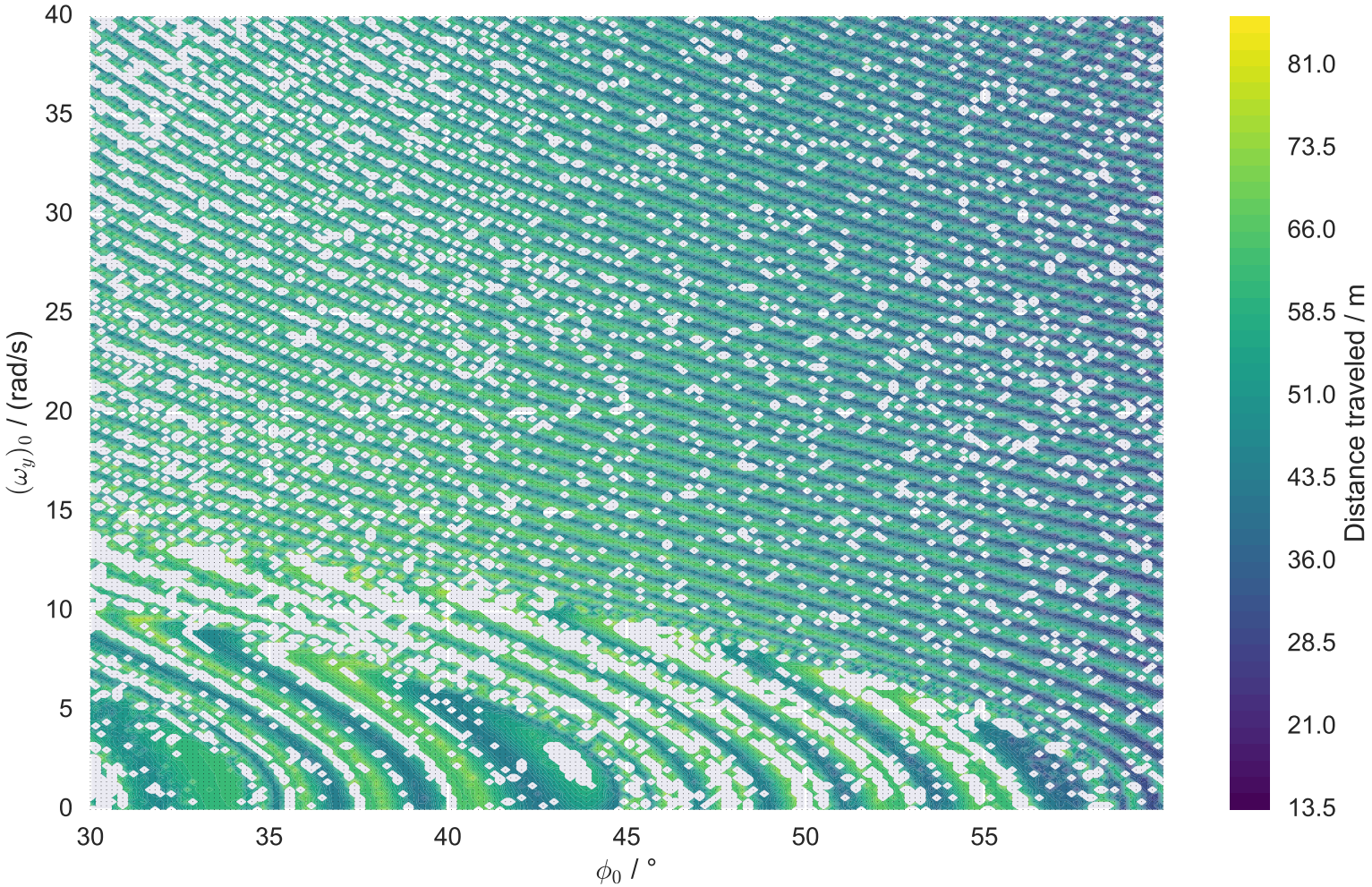
# Sample Energies



# Distance Traveled



# Distance Traveled



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# Conclusions

- Model for flight and bouncing
- Variation in sensitivity to initial conditions
- Kicker could target large desirable region
- Future: 3-D bounce model with wider range of velocities