



TECHNISCHE  
UNIVERSITÄT  
DARMSTADT

# Biomechanische Modelle für das Laufen und Springen

Seminar M<sup>3</sup>

„Motions in Man and Machines“

18. Juni 2015



Lauflabor

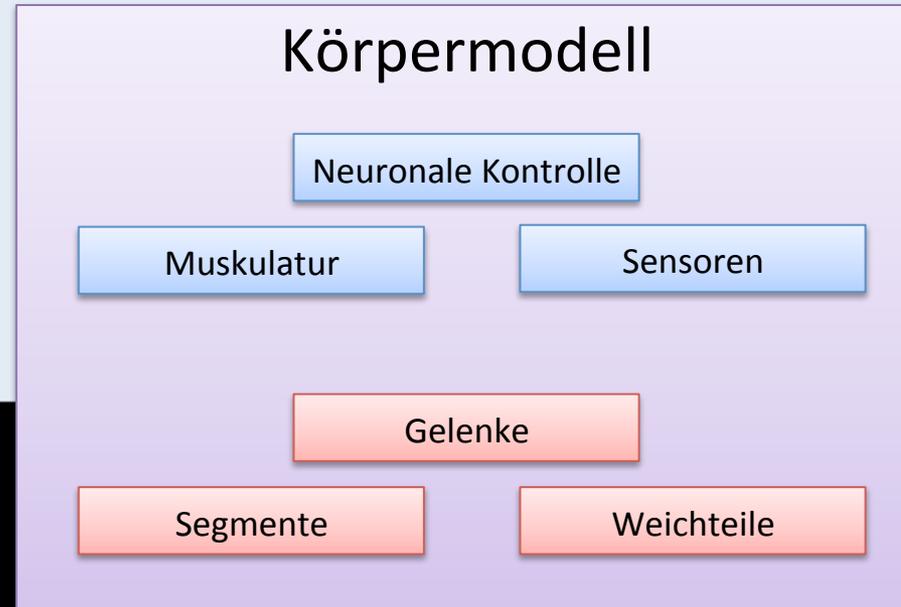
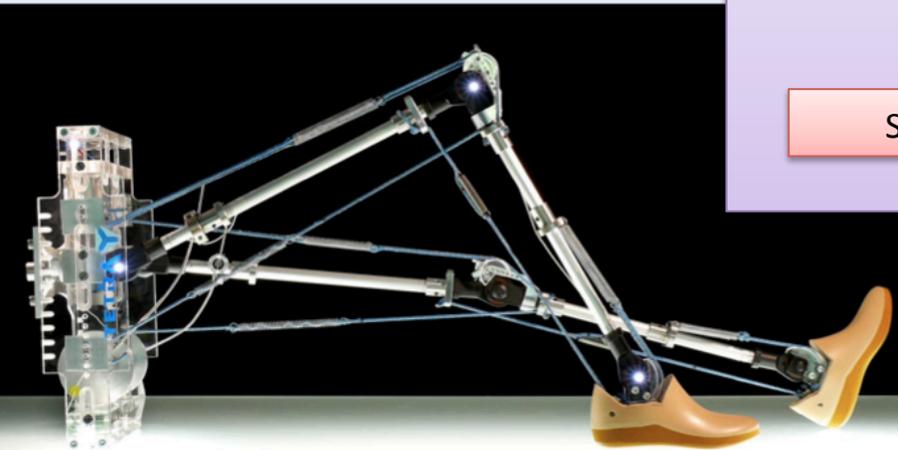
Andre Seyfarth  
Lauflabor TU Darmstadt



# Was ist ein gutes Modell?



# Biomechanische Modelle



Aktiver  
Bewegungs-  
apparat

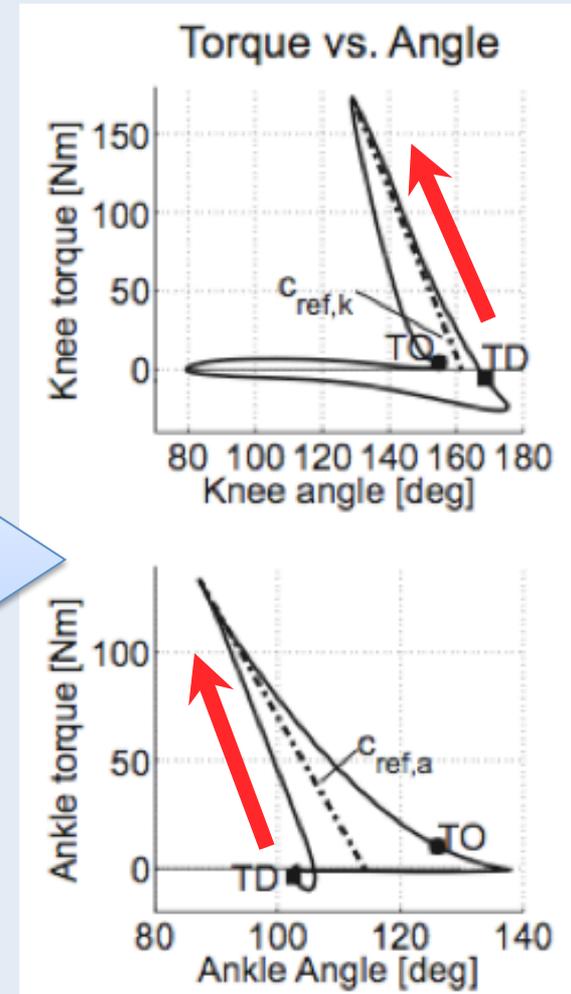
Passiver  
Bewegungs-  
apparat



z.B. Bodenreaktionskraft



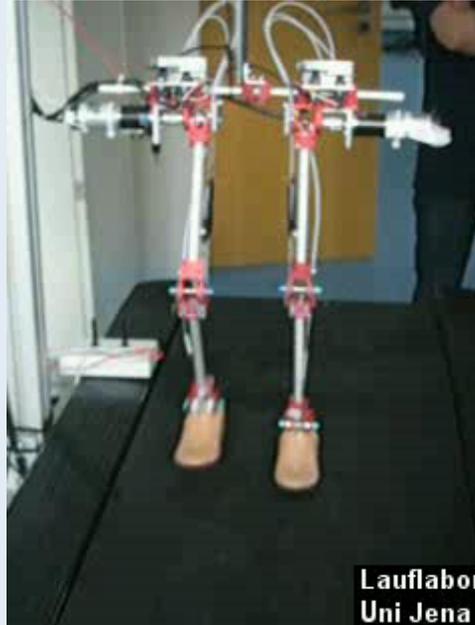
# Inverses Modell (Inverse Dynamik)



# Vorwärtsdynamische Modelle



JenaWalker 2 (2005)



OpenSim: Samuel Hamner (2010)



Fumiya Iida



Reflex-driven biped

Hartmut Geyer  
(WCB, 2006)



# Sprünge



# Sprünge

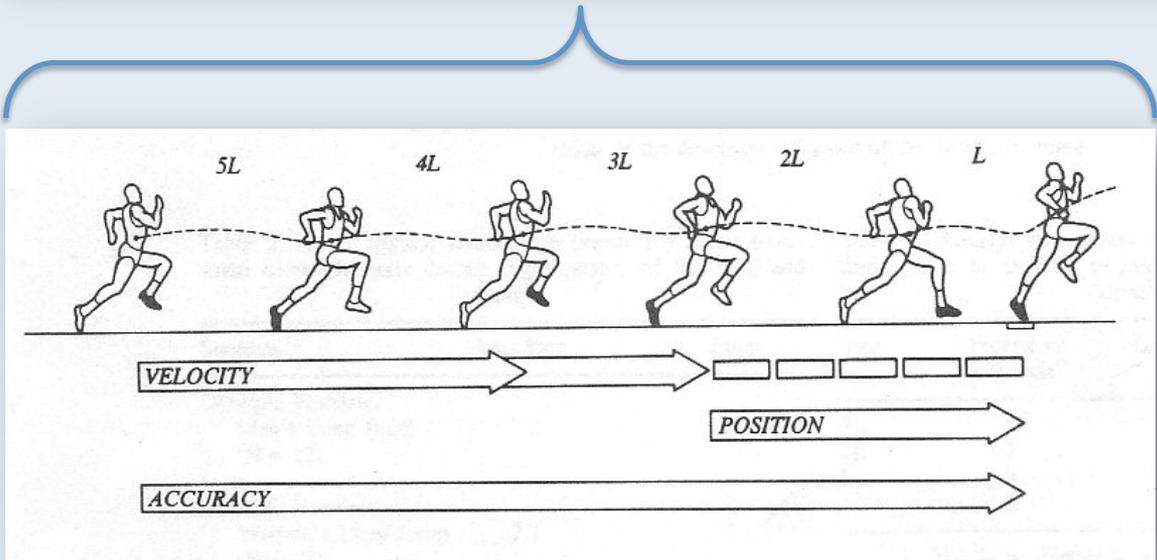
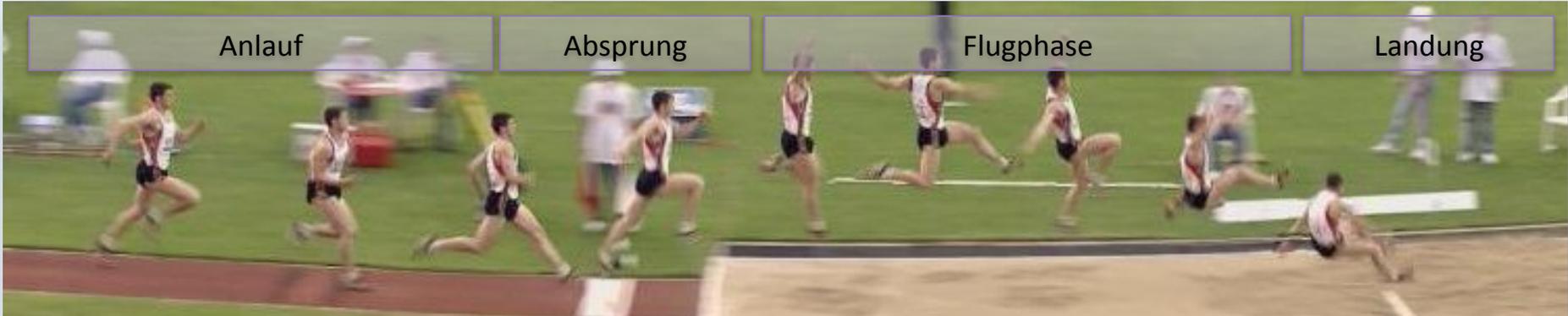
## **Sprünge ohne Anlauf**

- Trampolin
- Hochstrecksprung
- Niedersprung

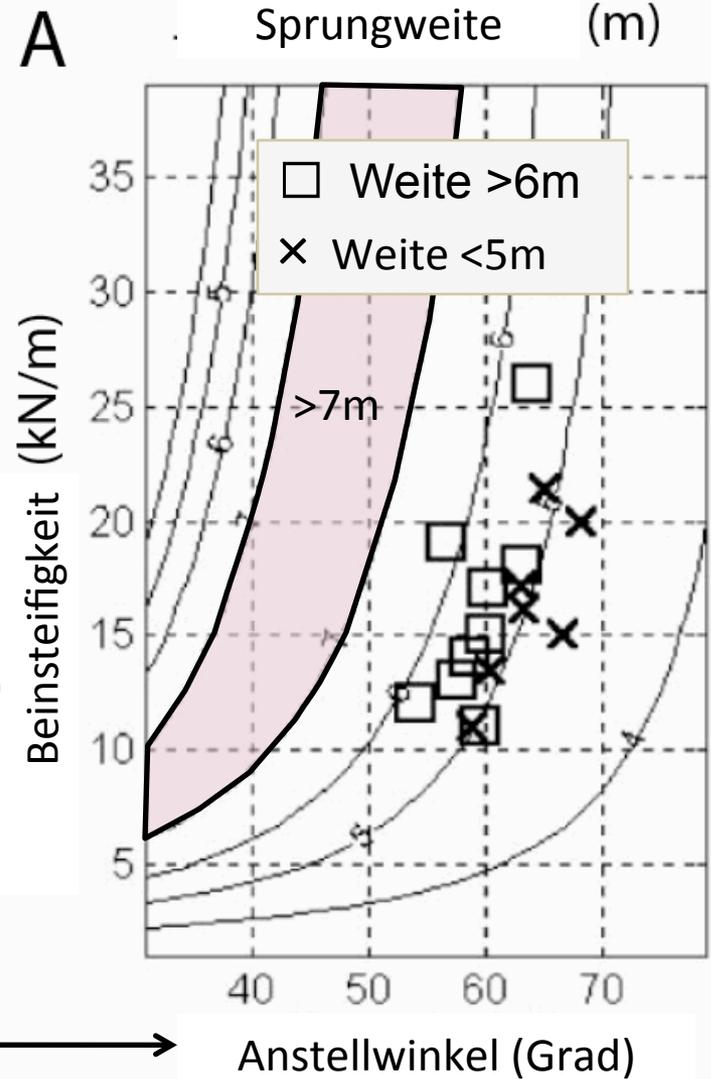
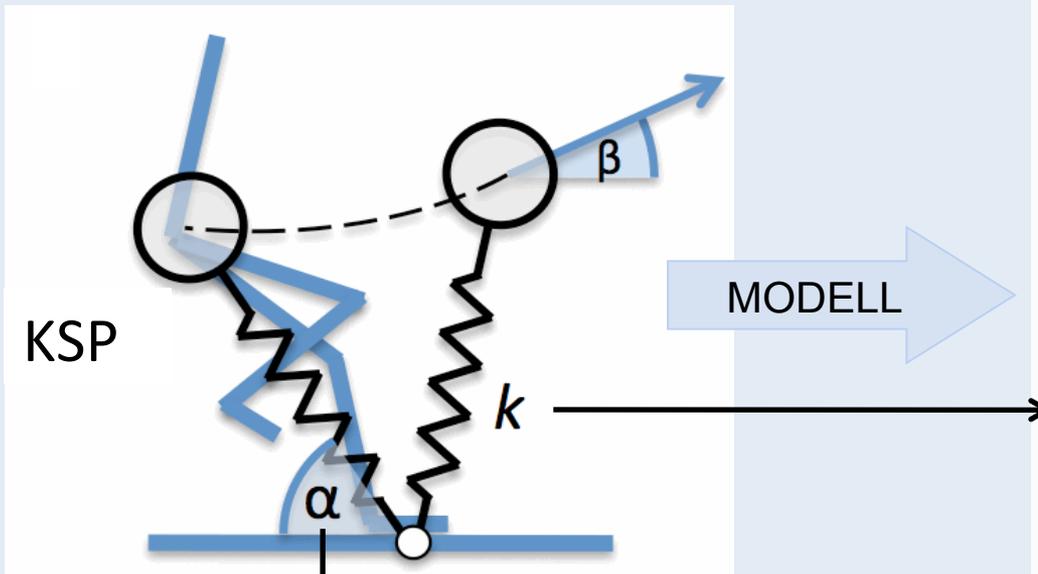
## **Sprünge mit Anlauf**

- Weitsprung
- Hochsprung
- Dreisprung

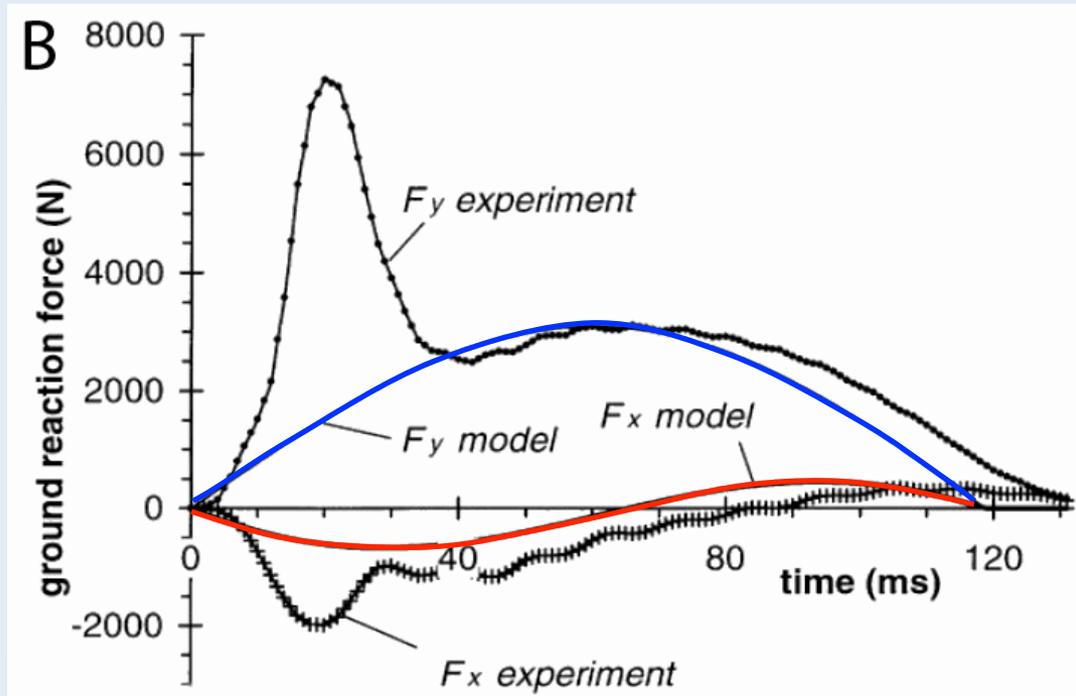
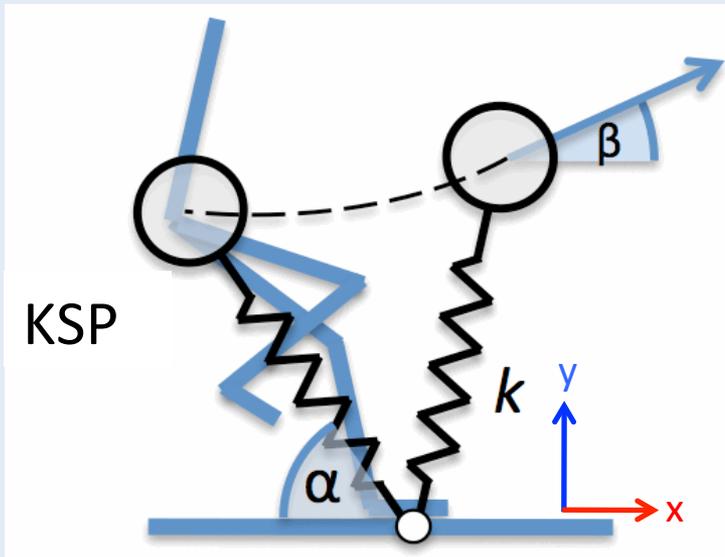
# Weitsprung



# Dynamik des Weitsprungs

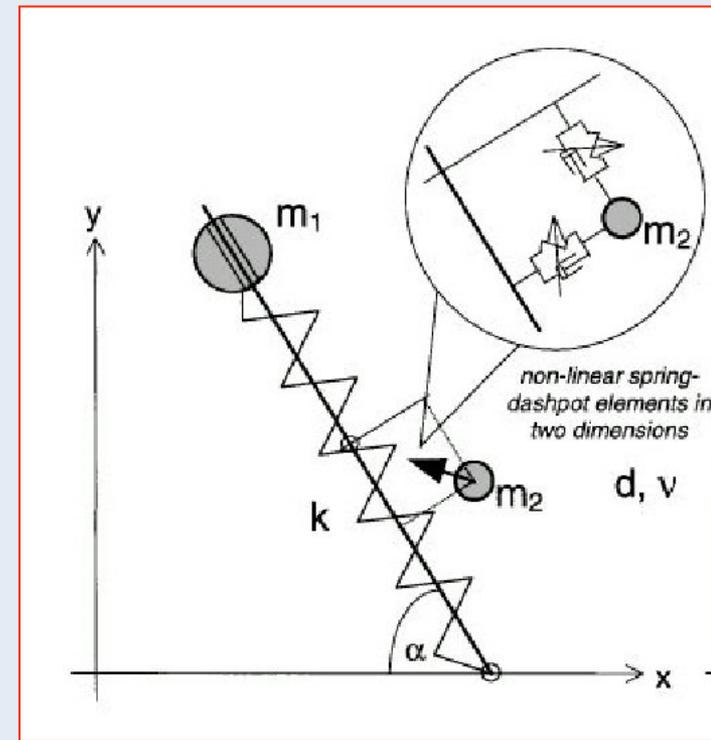
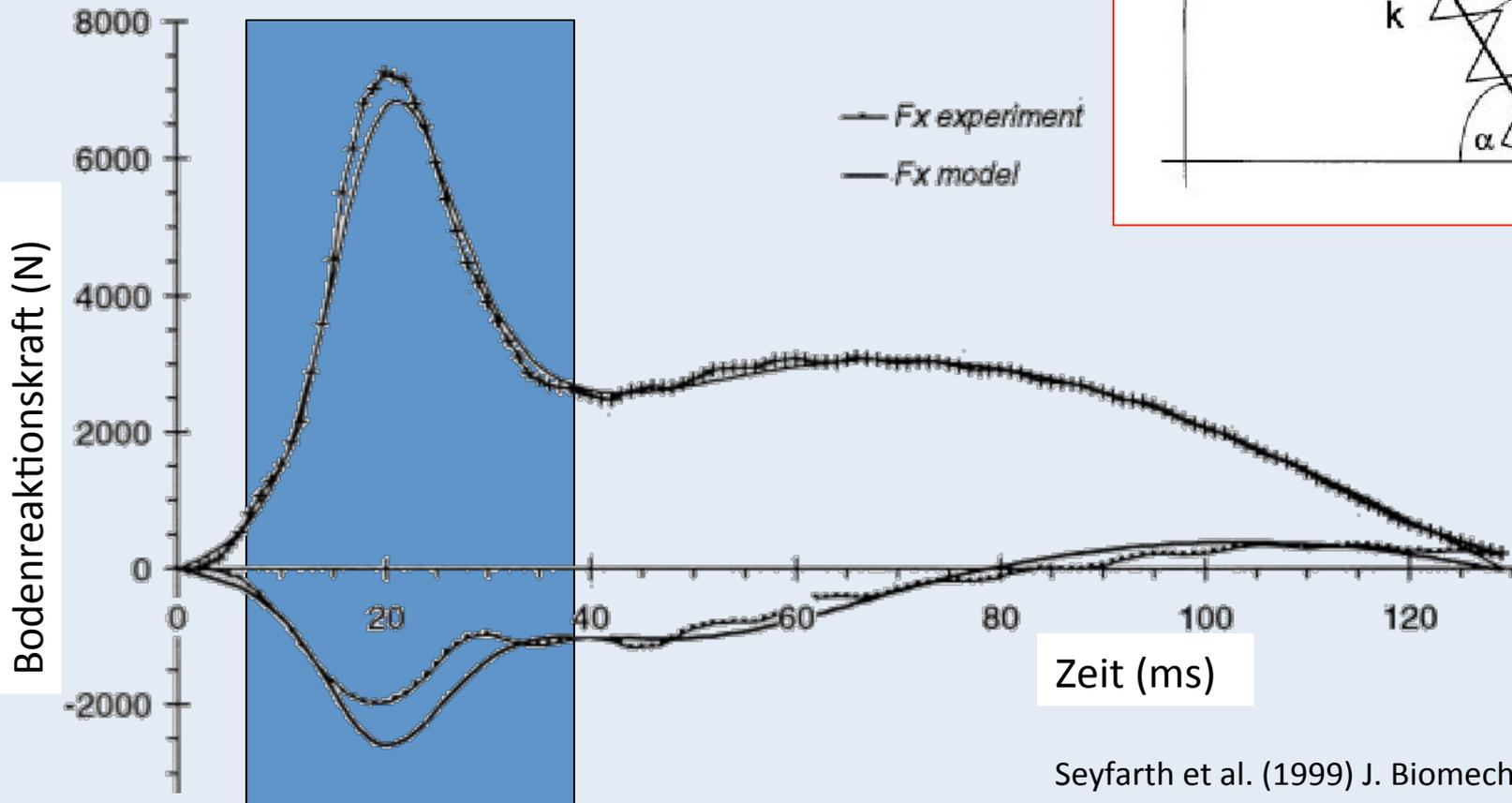


# Dynamik des Weitsprungs

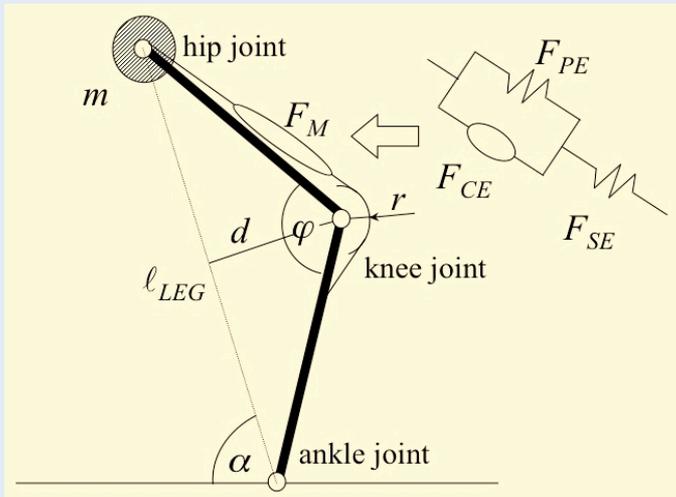


# Dynamik des Weitsprungs (Landestoß)

Was verursacht  
den Landestoß?



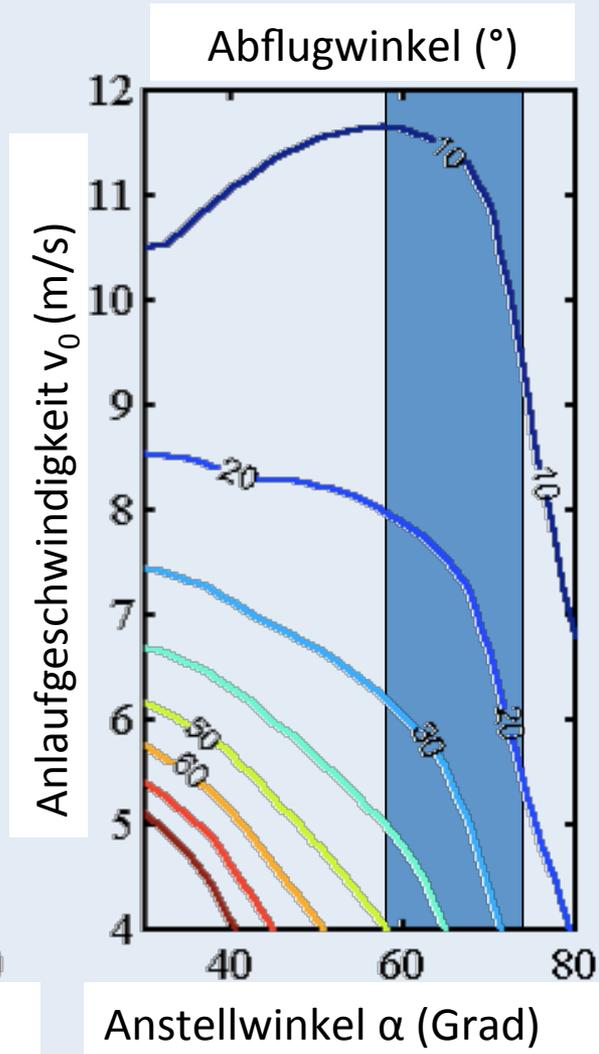
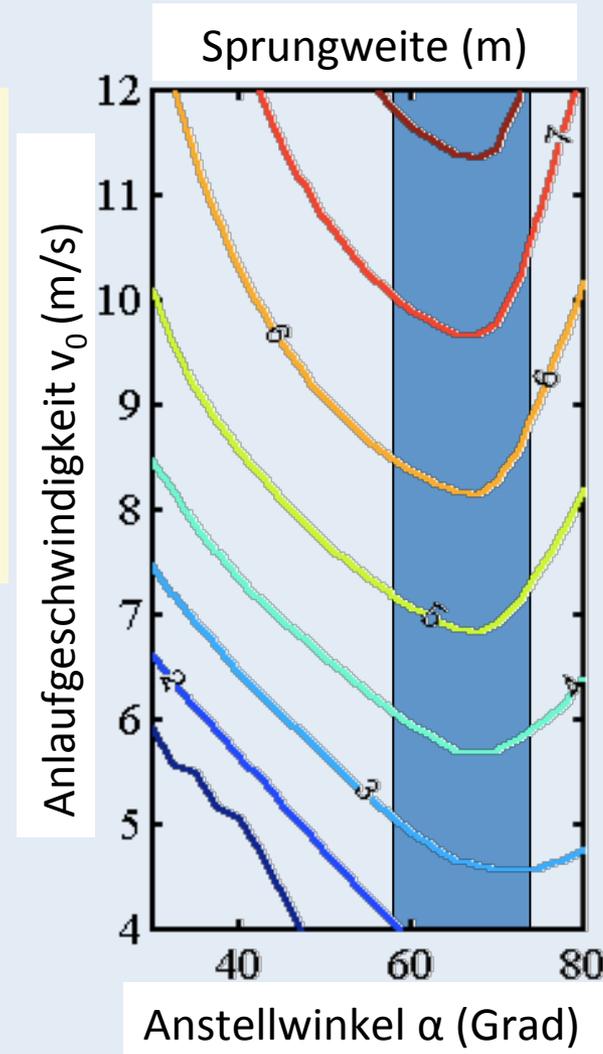
# Dynamik des Weitsprungs (Muskel)



Erweitertes Beinmodell  
für den Absprung

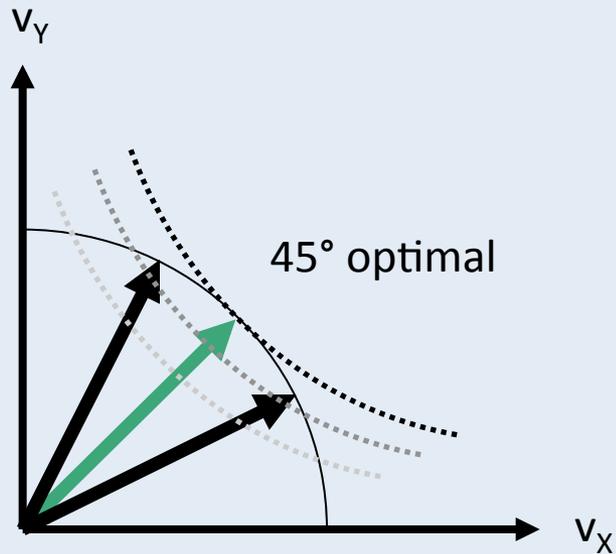
- > Segmentierung
- > Streckermuskel

Seyfarth et al. (2000) J Exp. Biol.

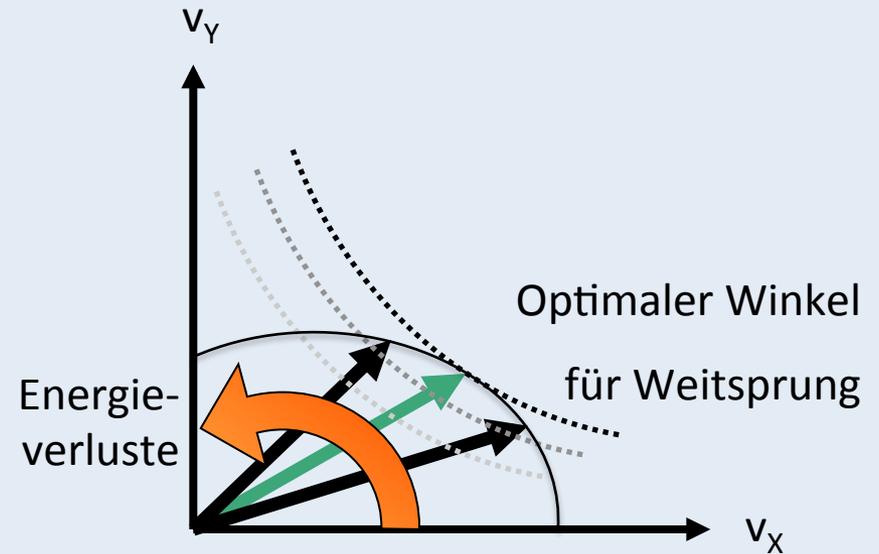


# Optimaler Abflugwinkel

$v$  konstant



$v$  nicht konstant

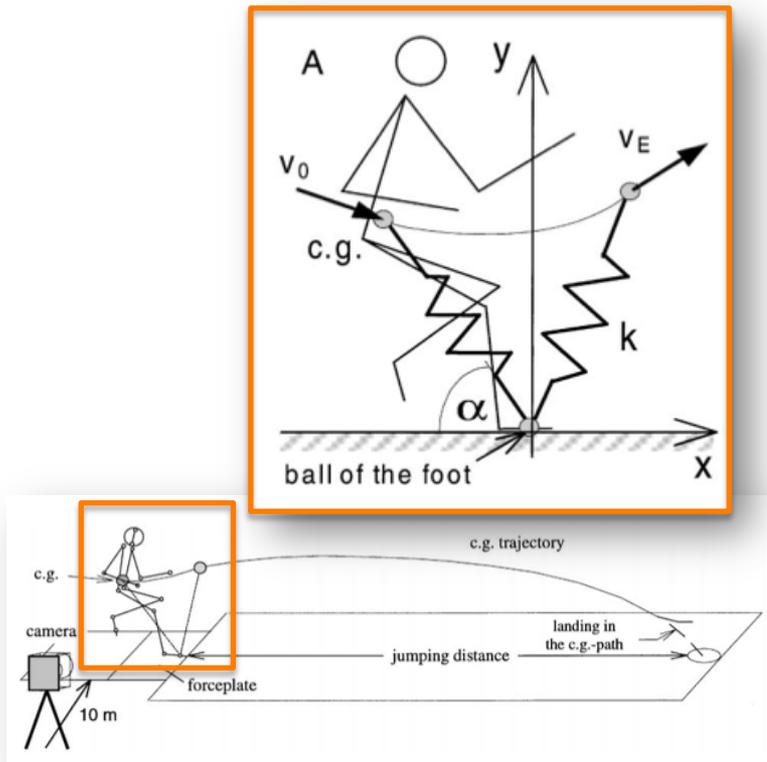


# Laufbewegungen



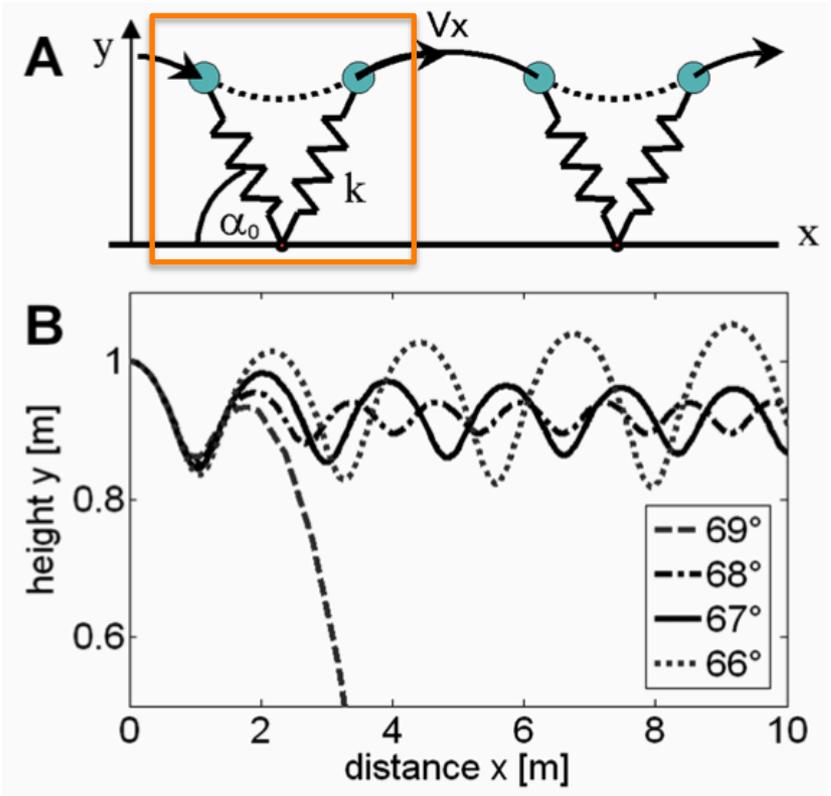
# Beinfunktion als Feder

## Weitsprung



Seyfarth et al., 1999 J Biomechanics

## Laufbewegungen



Blickhan, 1989 J Biomechanics  
Seyfarth et al., 2002 J Biomechanics

# Beinfunktion als Feder

## Bewegungsgleichungen

$$\ddot{x} = a_x$$

$$\ddot{y} = a_y$$

$$m\ddot{x} = P \cdot x$$

$$m\ddot{y} = P \cdot y - m \cdot g$$

in der Standphase:

$$P = k(\ell_0 / \sqrt{x^2 + y^2} - 1)$$

Integration

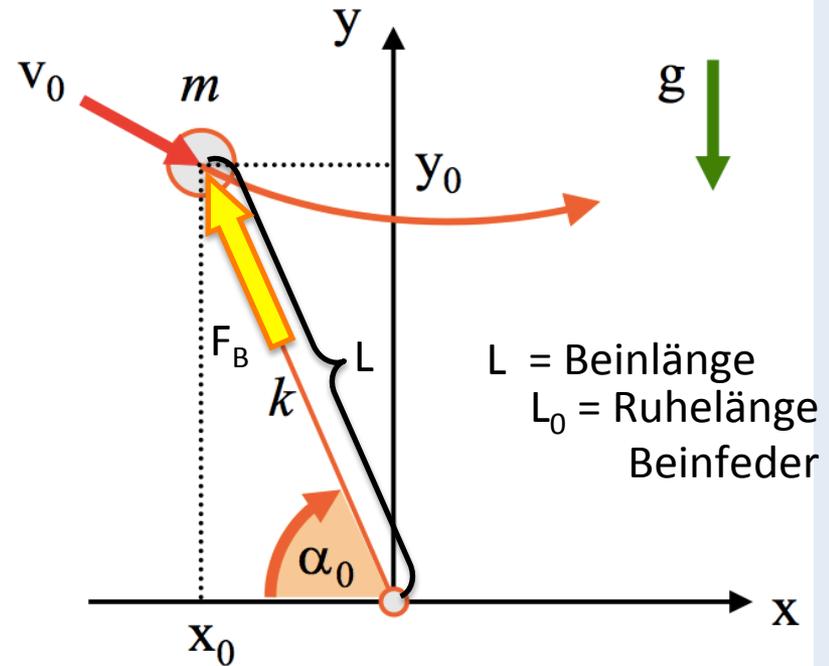
$$\ddot{x} \rightarrow \dot{x} \rightarrow x$$

$$\ddot{y} \rightarrow \dot{y} \rightarrow y$$

$$F_B = k(L_0 - L)$$

$$P = F_B / L$$

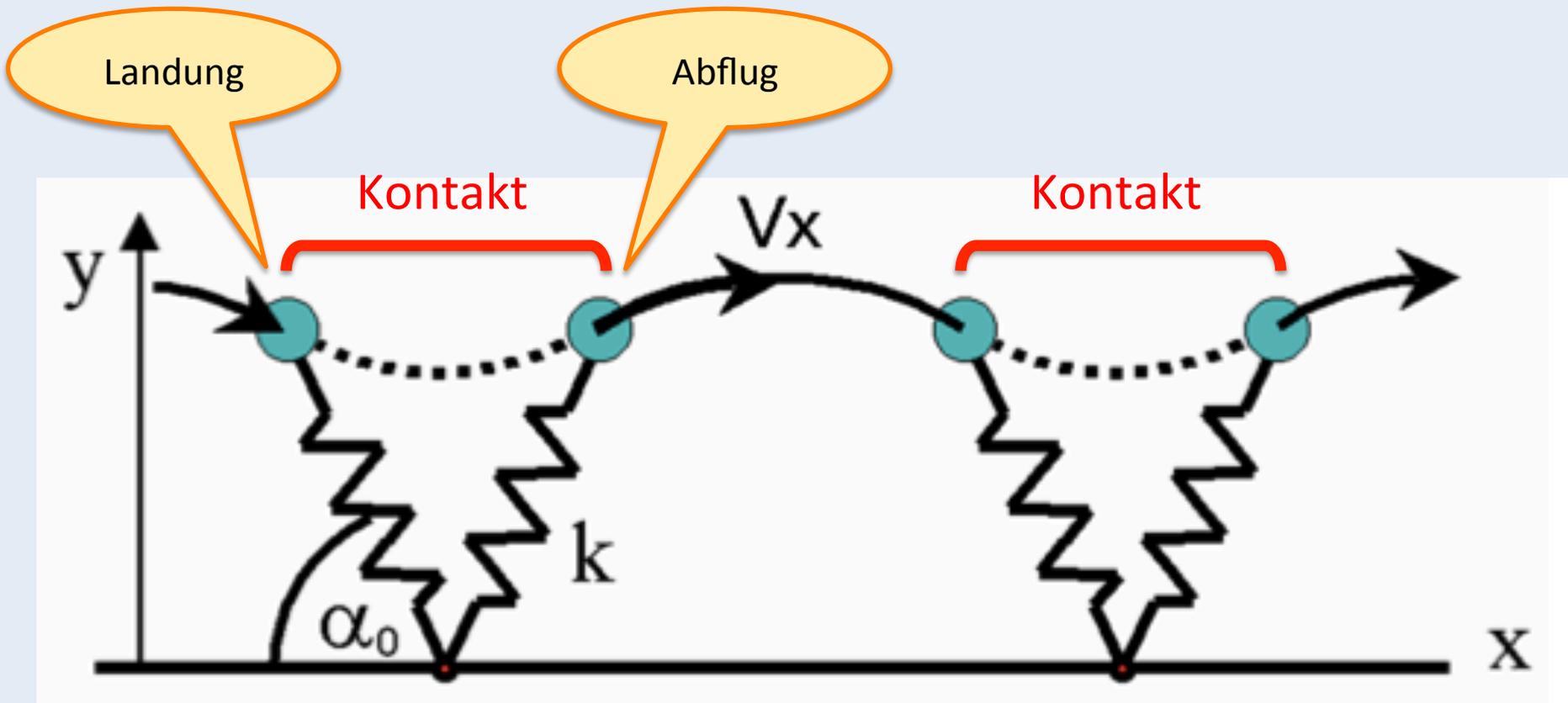
$k$  Steifigkeit  
 $l_0$  Ruhelänge



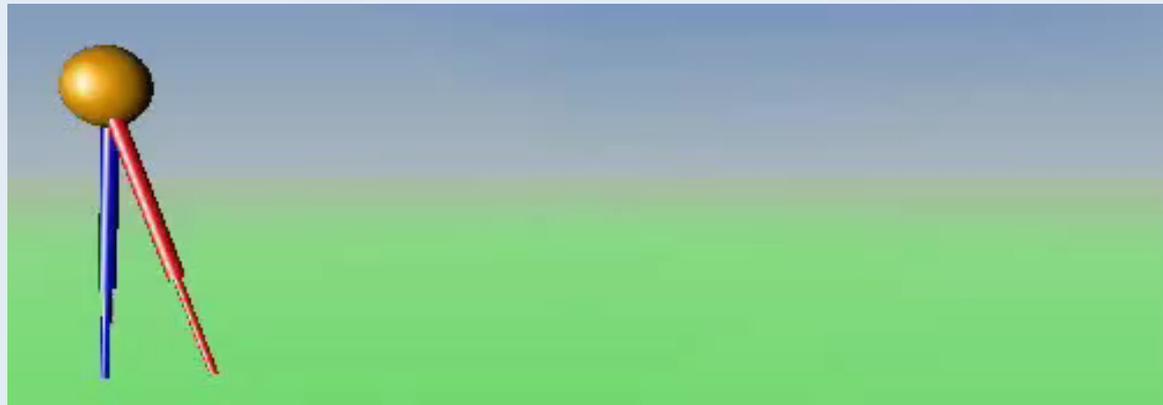
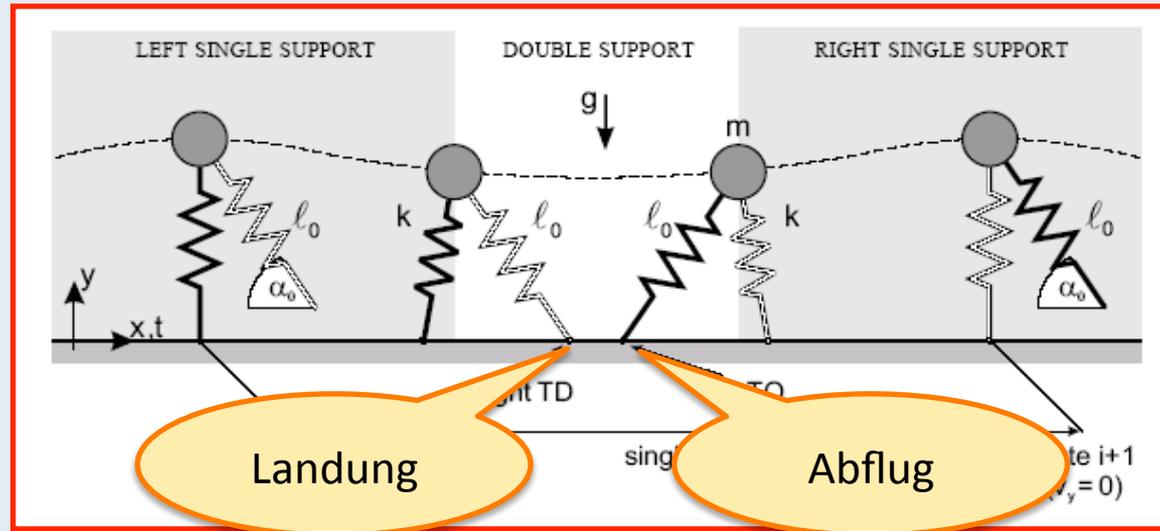
# Ereignisse beim Laufen

Landung:  $y \downarrow$  und  $y = l_0 \sin \alpha_0$   
Abflug:  $F \downarrow$  und  $F=0$

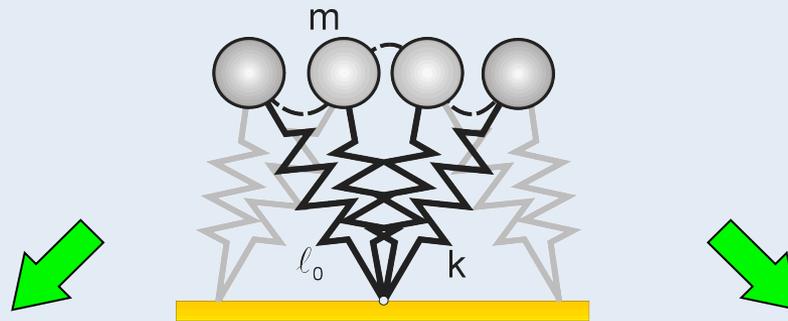
Tutorial im IFS-WIKI  
Modellierung Laufbewegungen



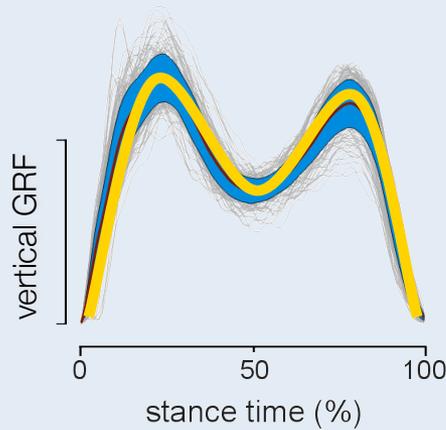
# Vom Rennen zum Gehen



# Masse-Feder-Modell



Gehen

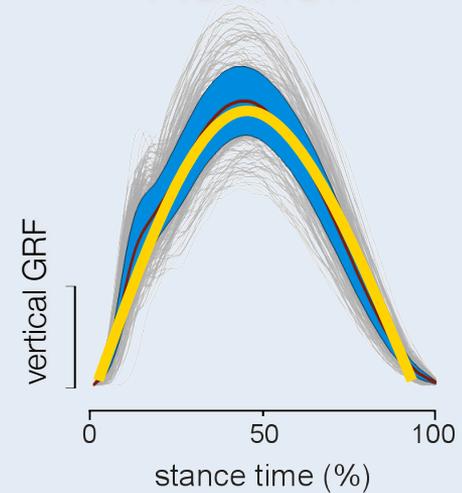


GRF = Bodenreaktionskraft  
(ground reaction force)

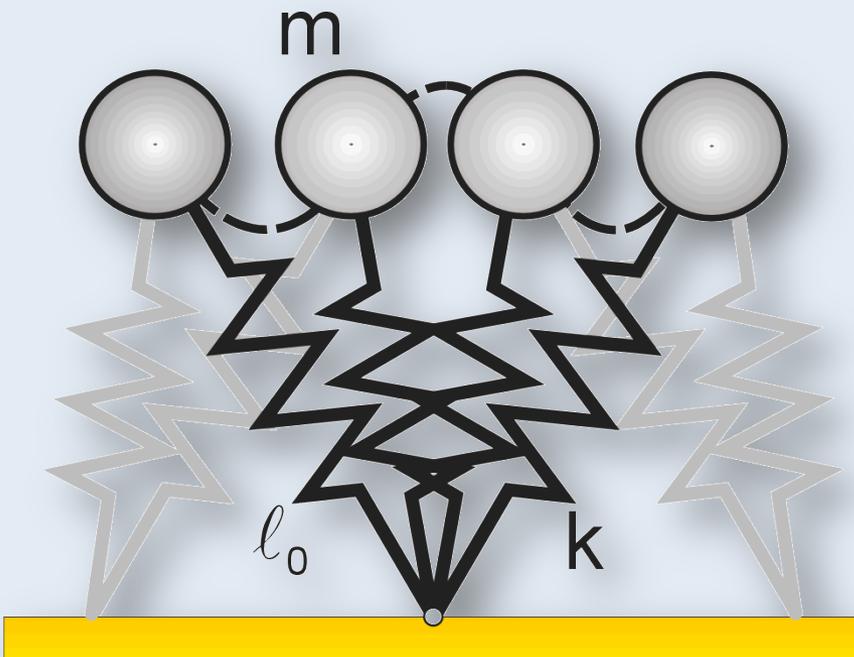
**Blau = Experiment**

**Gelb = Modell**

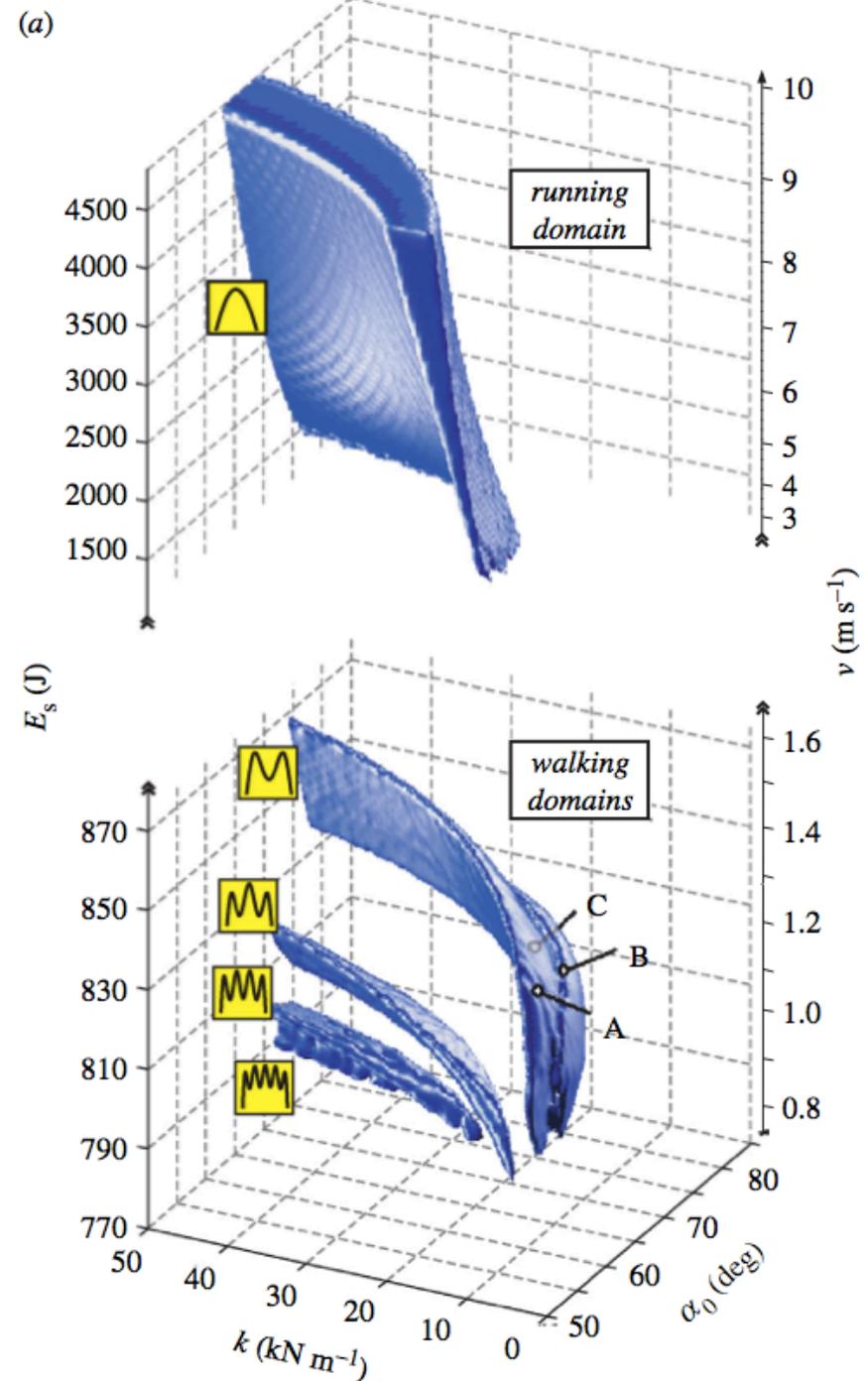
Rennen



# Masse-Feder-Modell



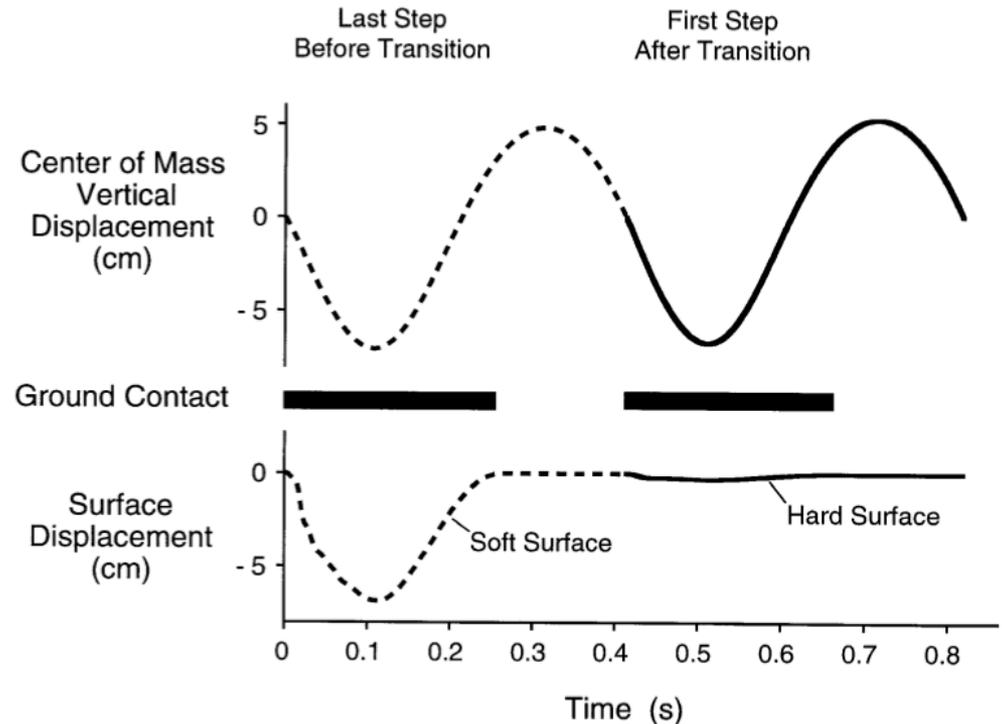
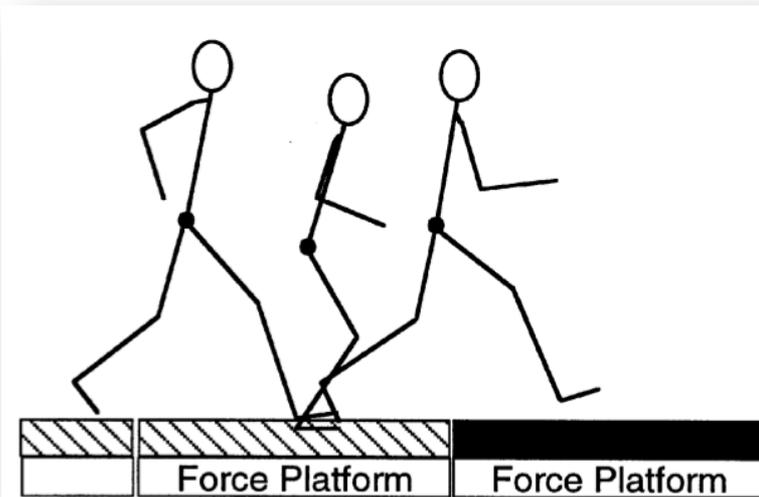
Geyer et al. (2006) Proc Roy Soc Lond B



# Anpassung bei Beineigenschaften

## Rennen

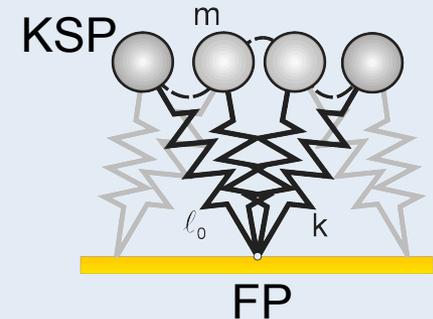
auf weichem / hartem Untergrund



# Masse-Feder-Modell

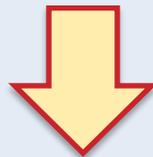
## Was bedeutet das Modell?

- Kräfte zeigen zum Körperschwerpunkt (KSP)
- Kräfte sind proportional zur Beinverkürzung
- fester Fußpunkt (FP) auf dem Boden

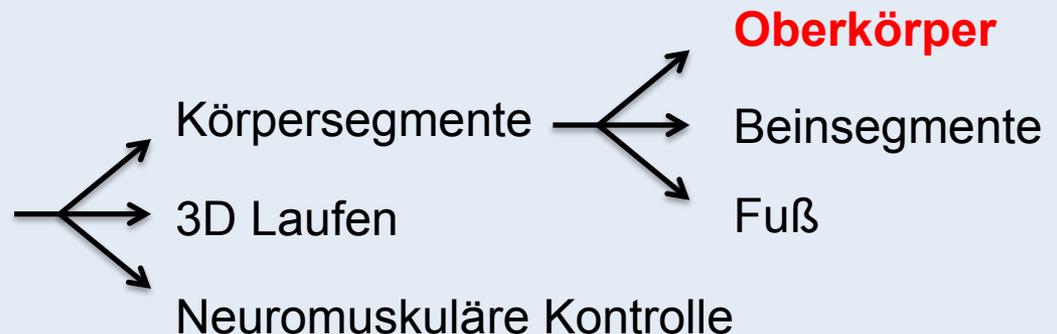


## Wie können wir das Modell prüfen?

- Vergleich mit **experimentellen Daten**

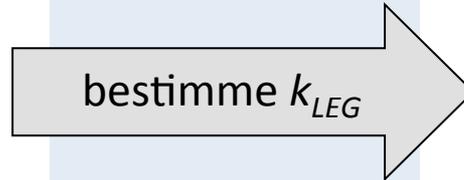
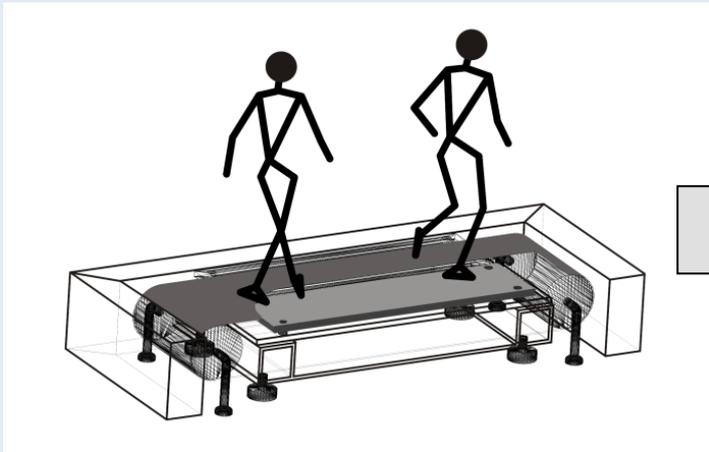


## Erweiterung des Modells

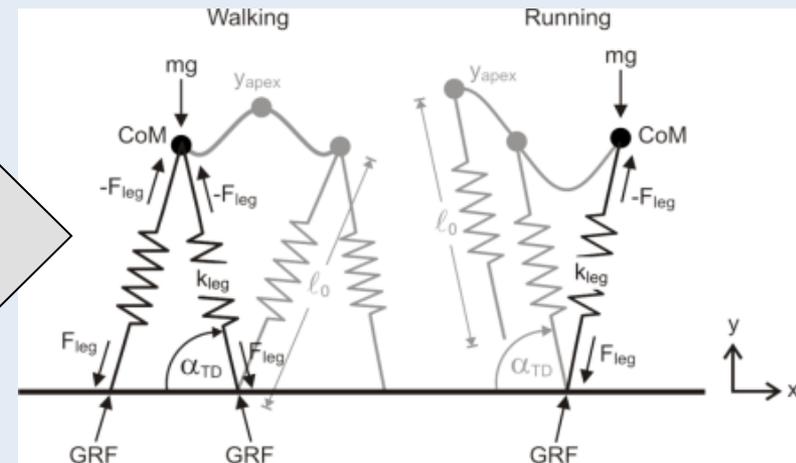


# Gibt es eine elastische Beinfunktion beim Gehen und Rennen?

Laufband-Experiment



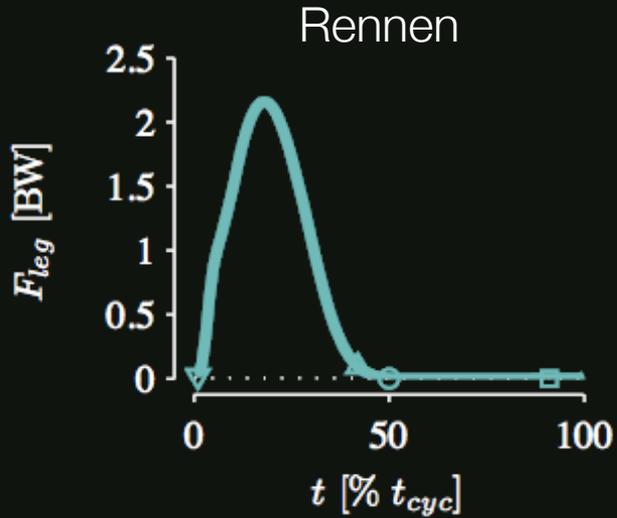
Gang-Modell



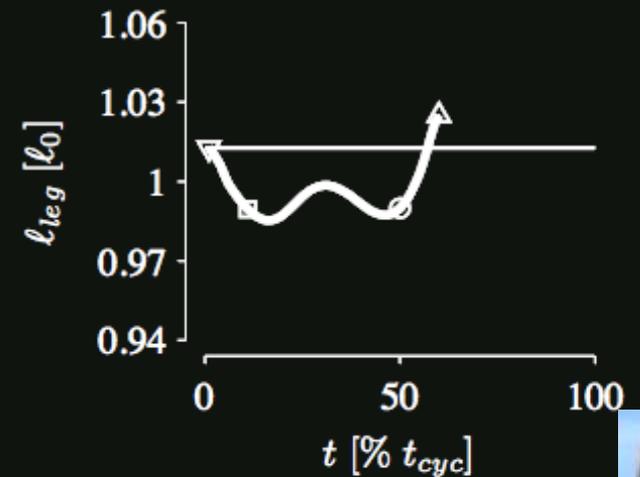
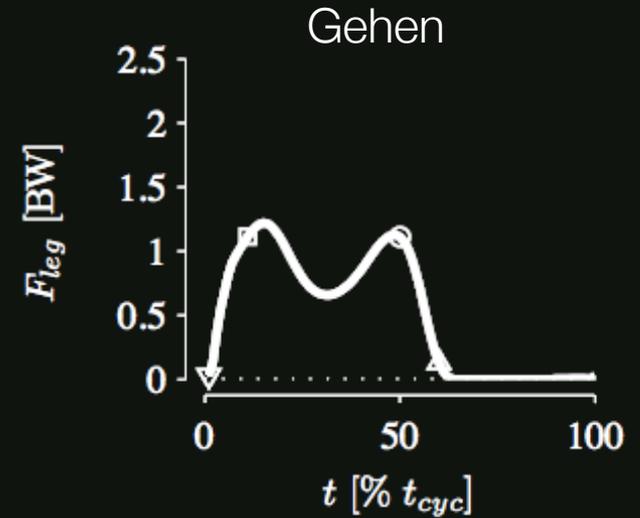
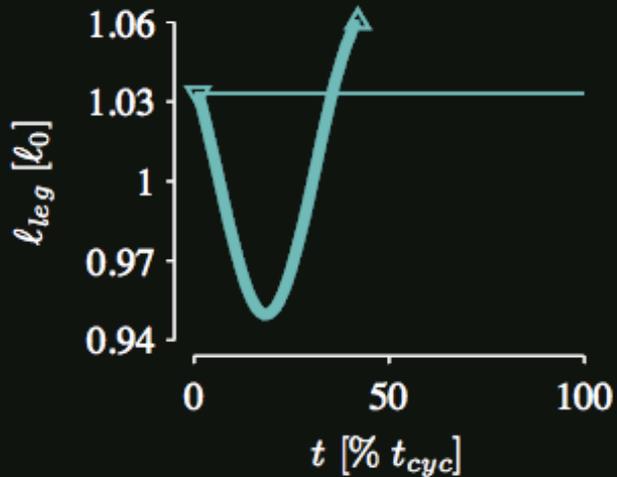
CoM = center of mass (Körperschwerpunkt)  
GRF = ground reaction force (Bodenreaktionskraft)

# Gibt es eine elastische Beinfunktion?

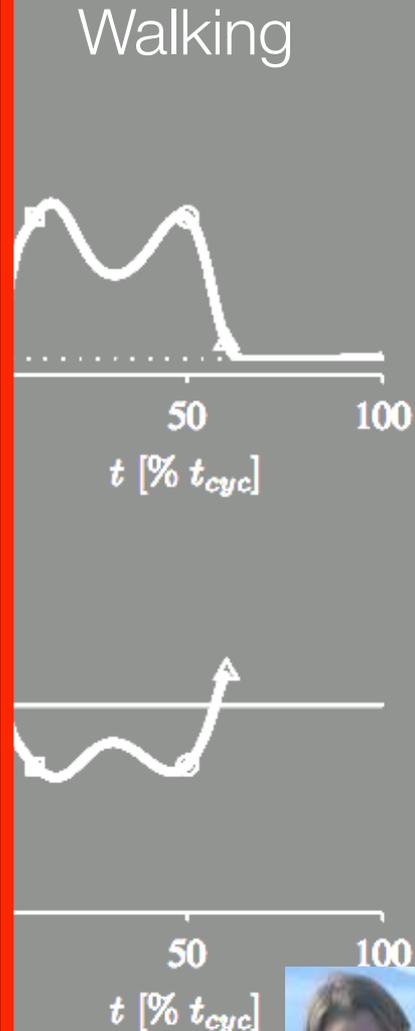
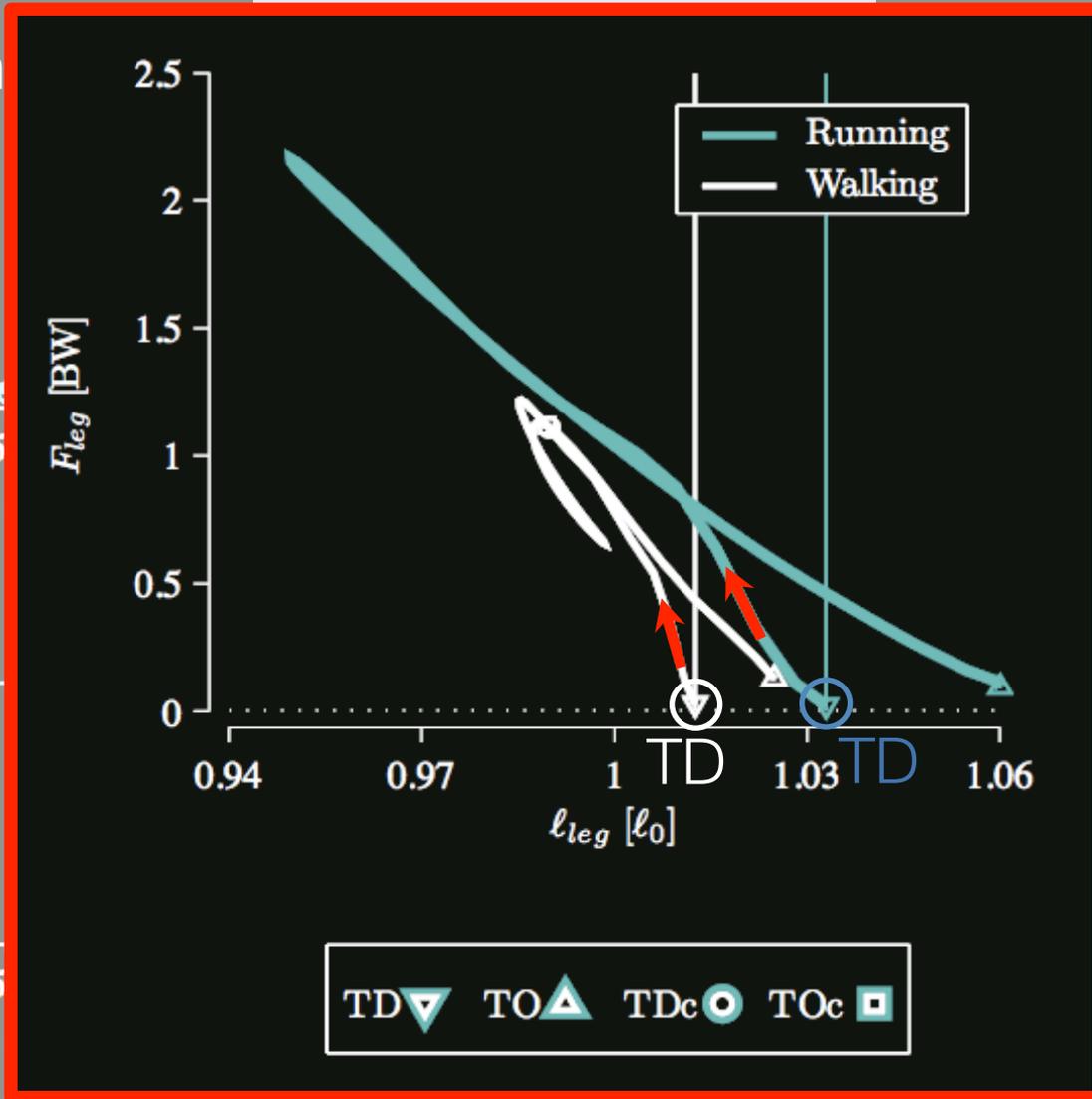
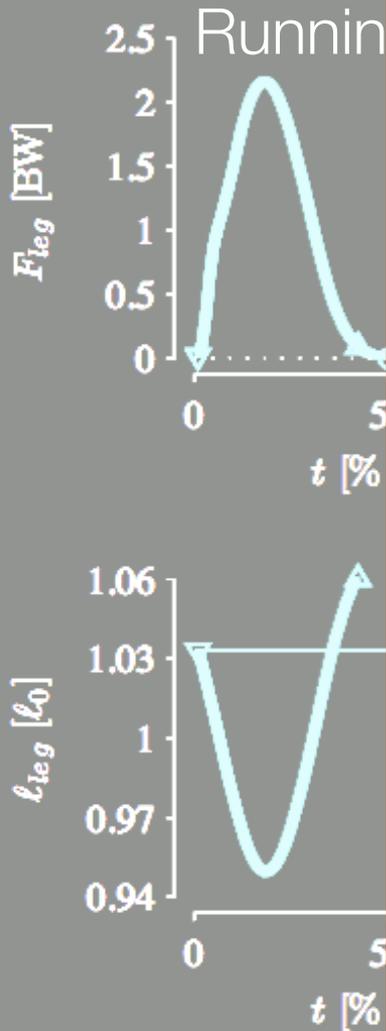
Bein-  
kraft



Bein-  
länge



# Gibt es eine elastische Beinfunktion?



TD = touch down, TO = take off, c = contralateral leg

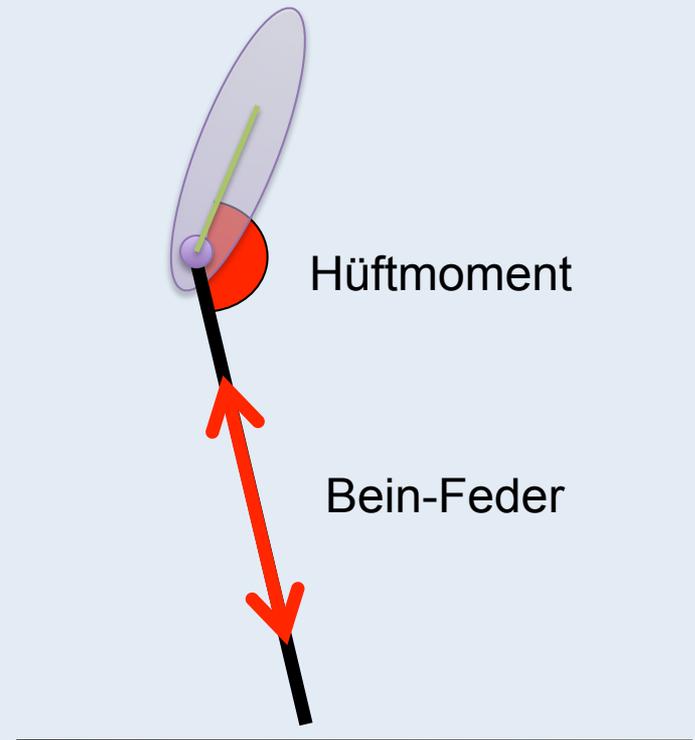
Susanne Lipfert (2009) Dissertation



# Der Oberkörper

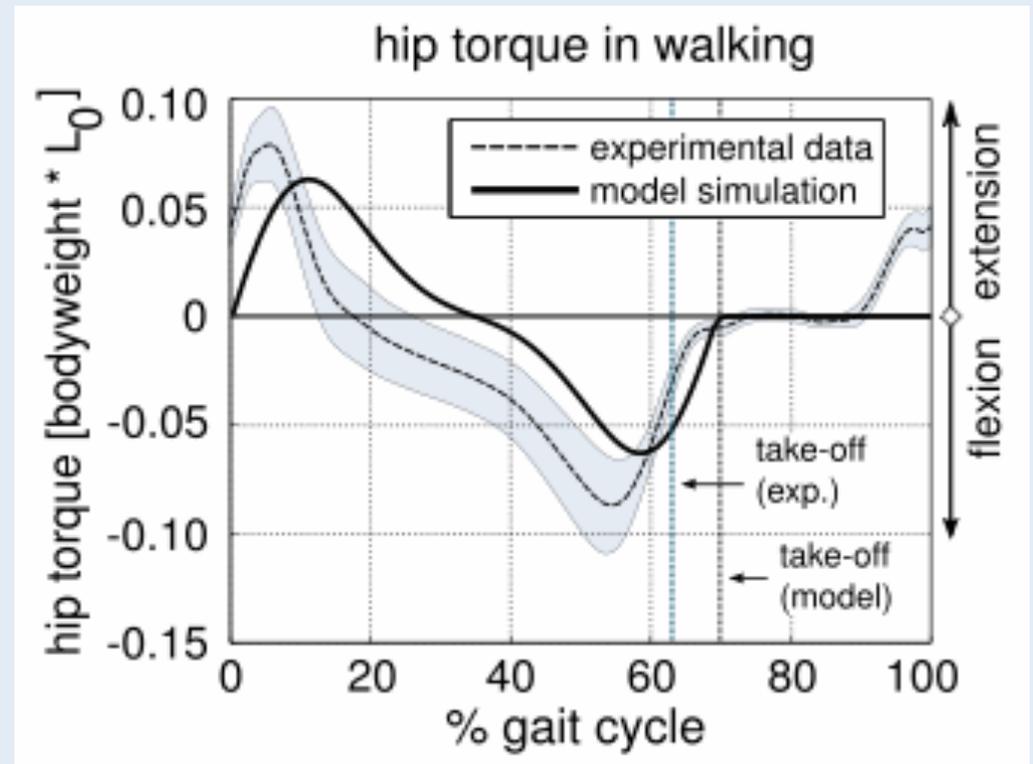
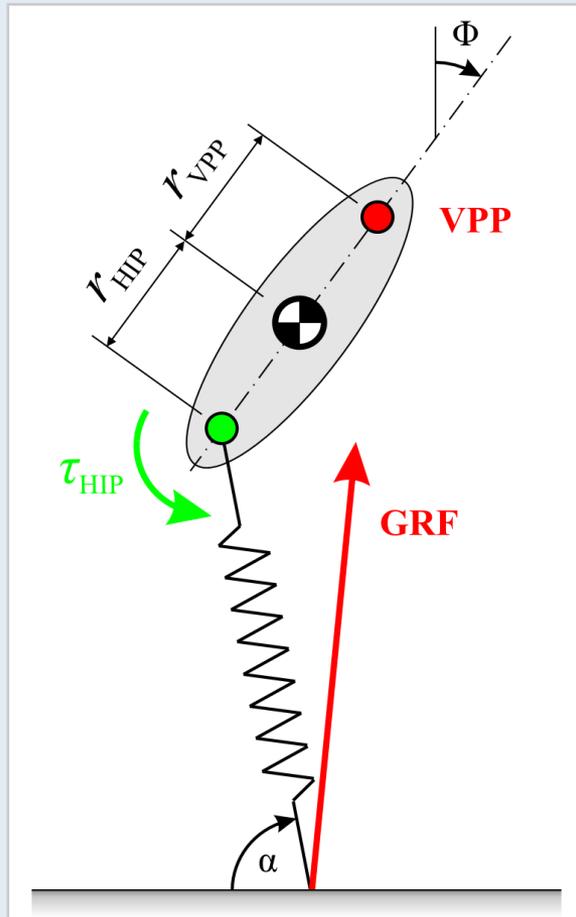


Maus et al. (2010) Nature Communications



# Virtual Pivot Point (VPP model)

Idee: Hüftmoment lenkt  
Beinkraft auf VPP aus



VPP Modell: Maus et al. (2008) CLAWAR

### running VPP model

simulation time: 0.0 sec.

$k=20\text{kN/m}$   $\alpha_0=67.0^\circ$  step height: -10.0 cm

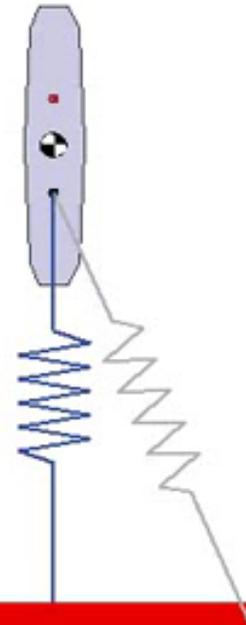
force leg 1: -----

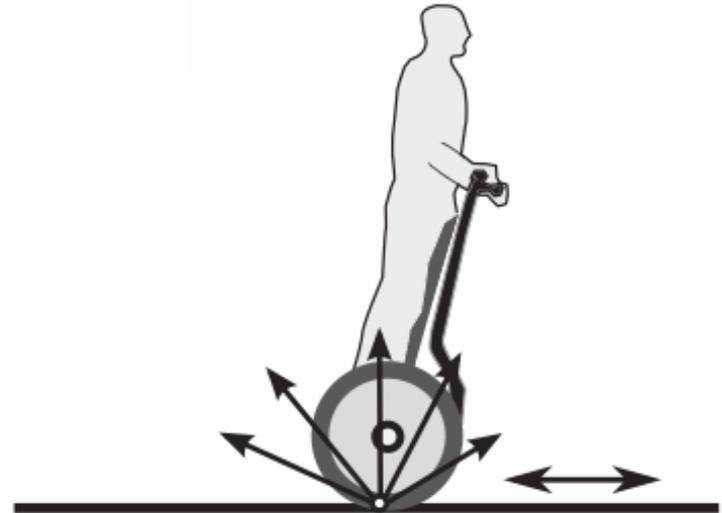
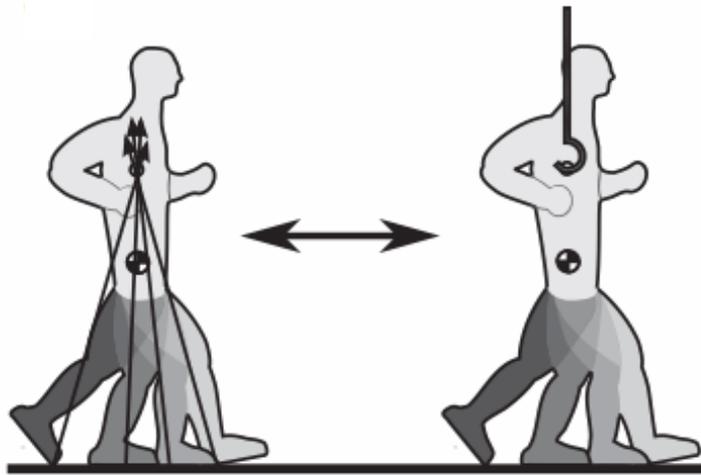
force leg 2: -----

hip torque 1: -----

hip torque 2: -----

*speed*  $\text{ms}^{-1}$

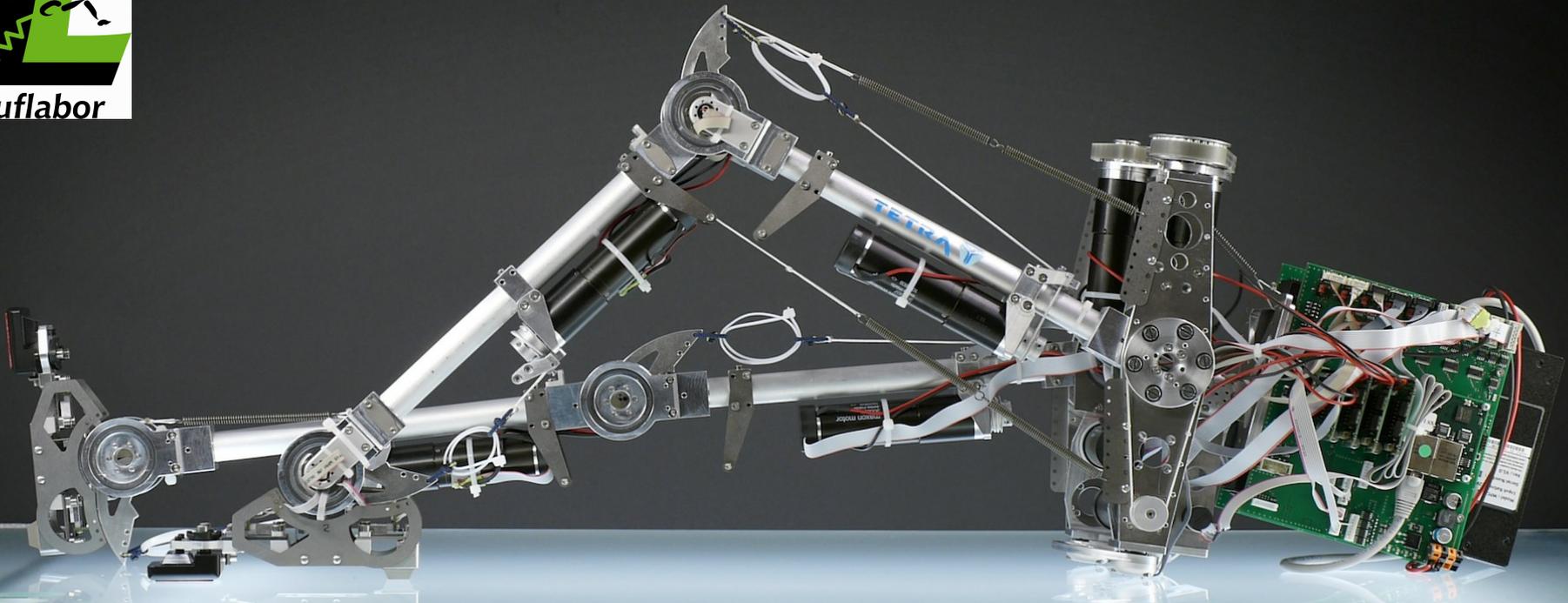




Maus et al. (2010) Nature Communications



# Vielen Dank!

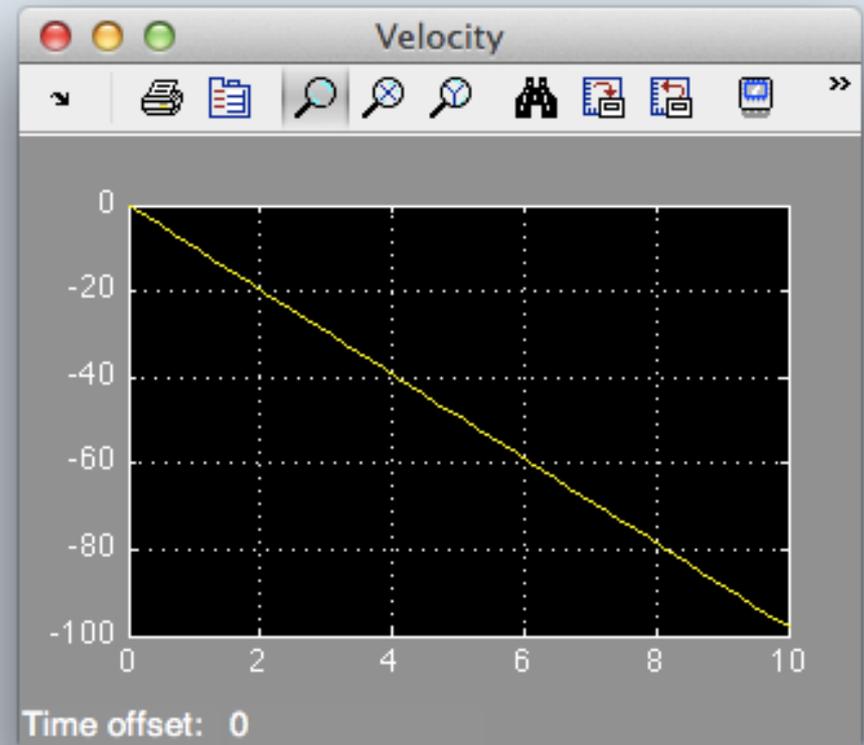
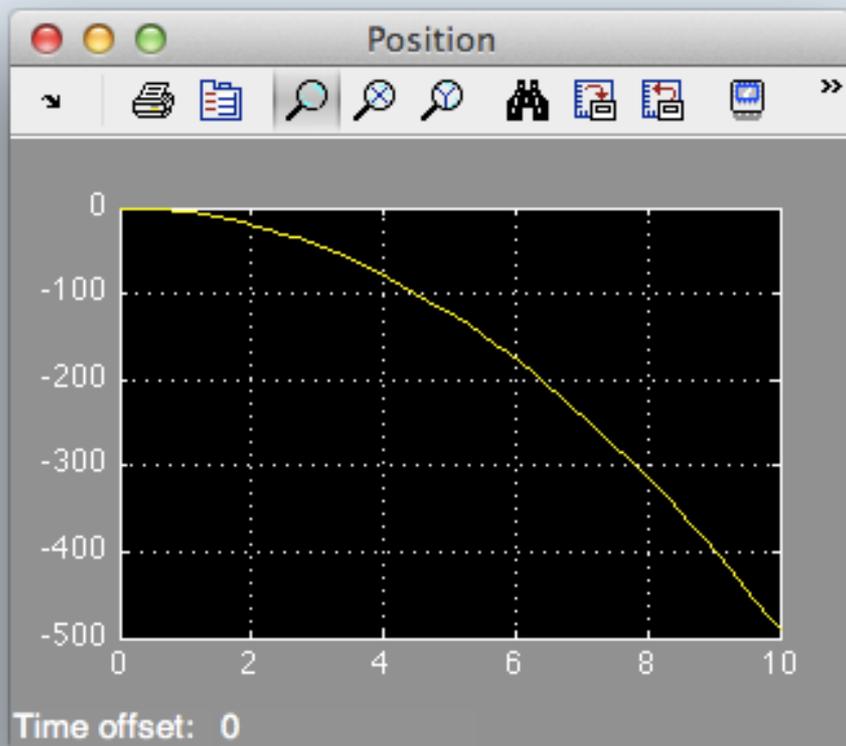
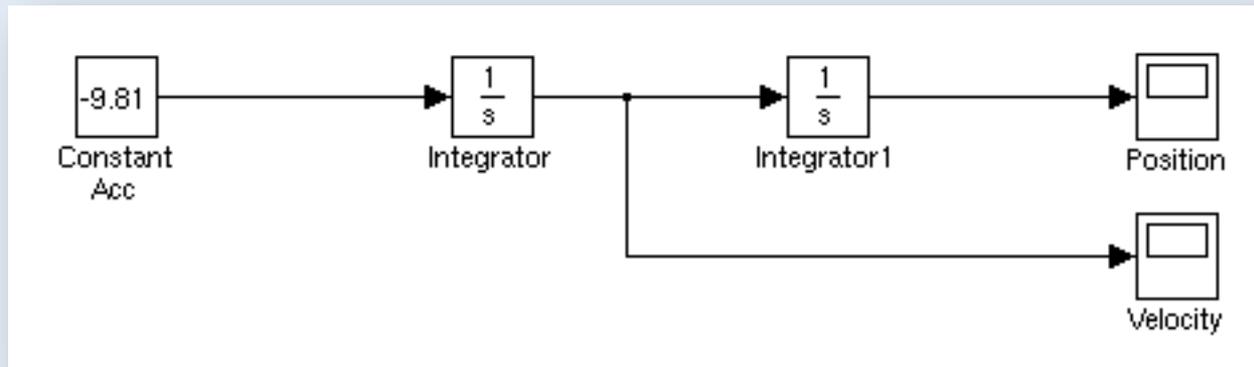


# Tutorial

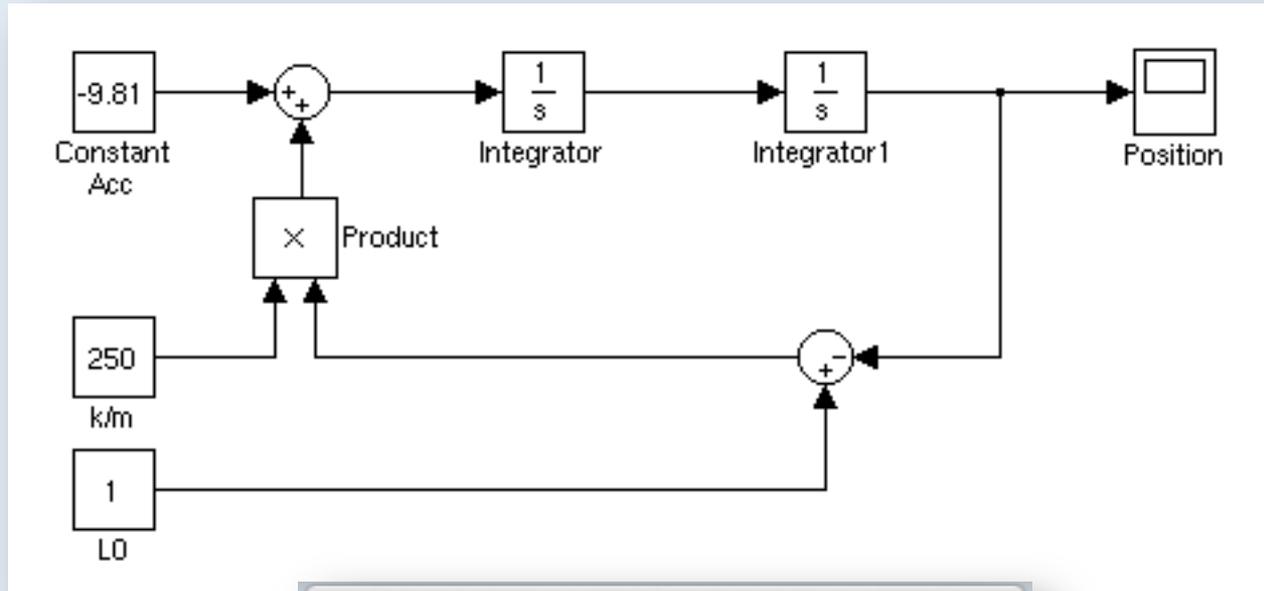
## Matlab/Simulink

- 1) Freier Fall
- 2) Feder-Masse-Schwinger 1D
- 3) Feder-Masse-Schwinger 2D
- 4) Feder-Masse-Modell (SLIP) für das Springen
- 5) Feder-Masse-Modell (SLIP) für das Rennen

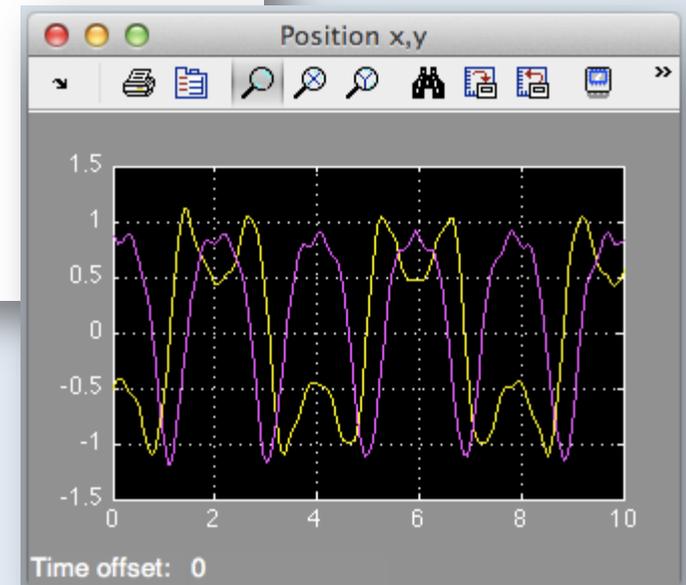
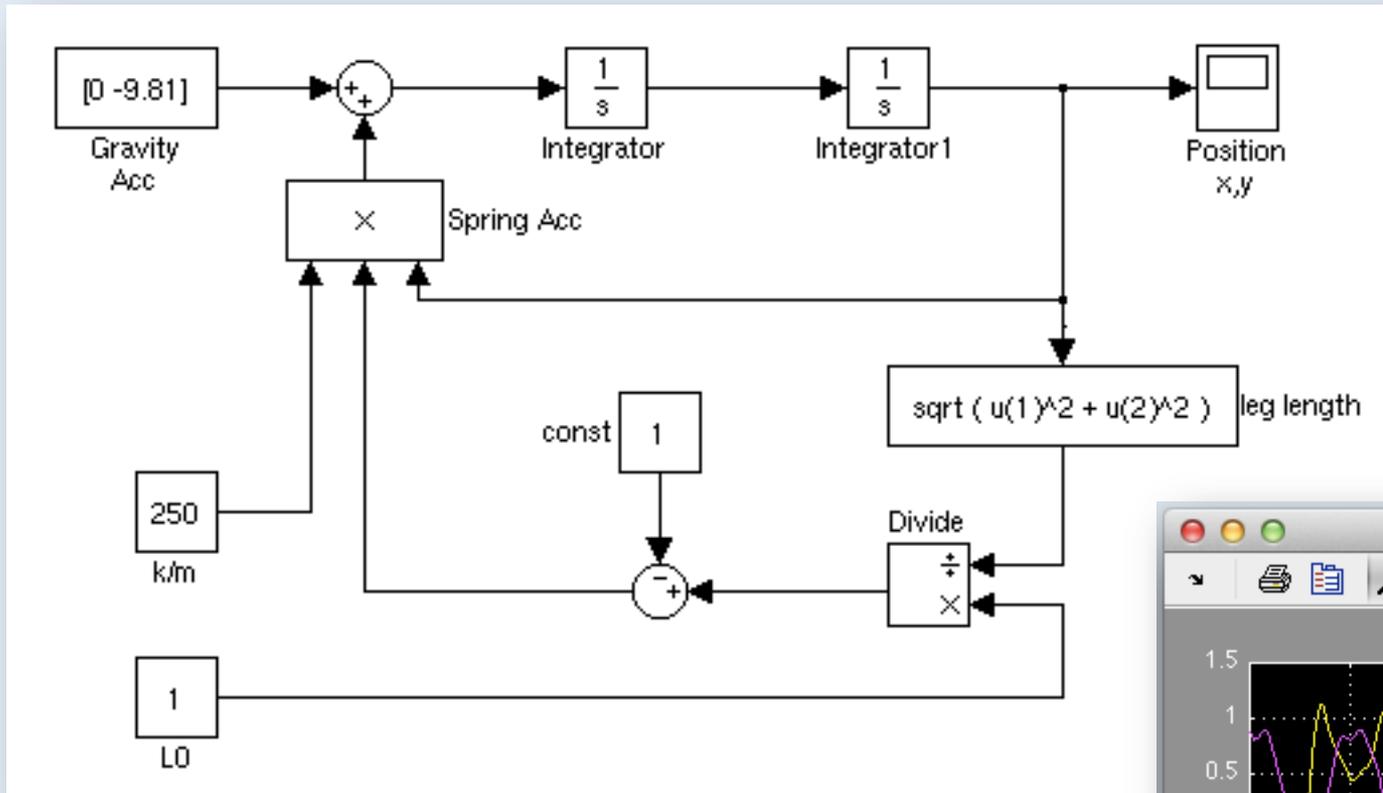
# Free\_Fall



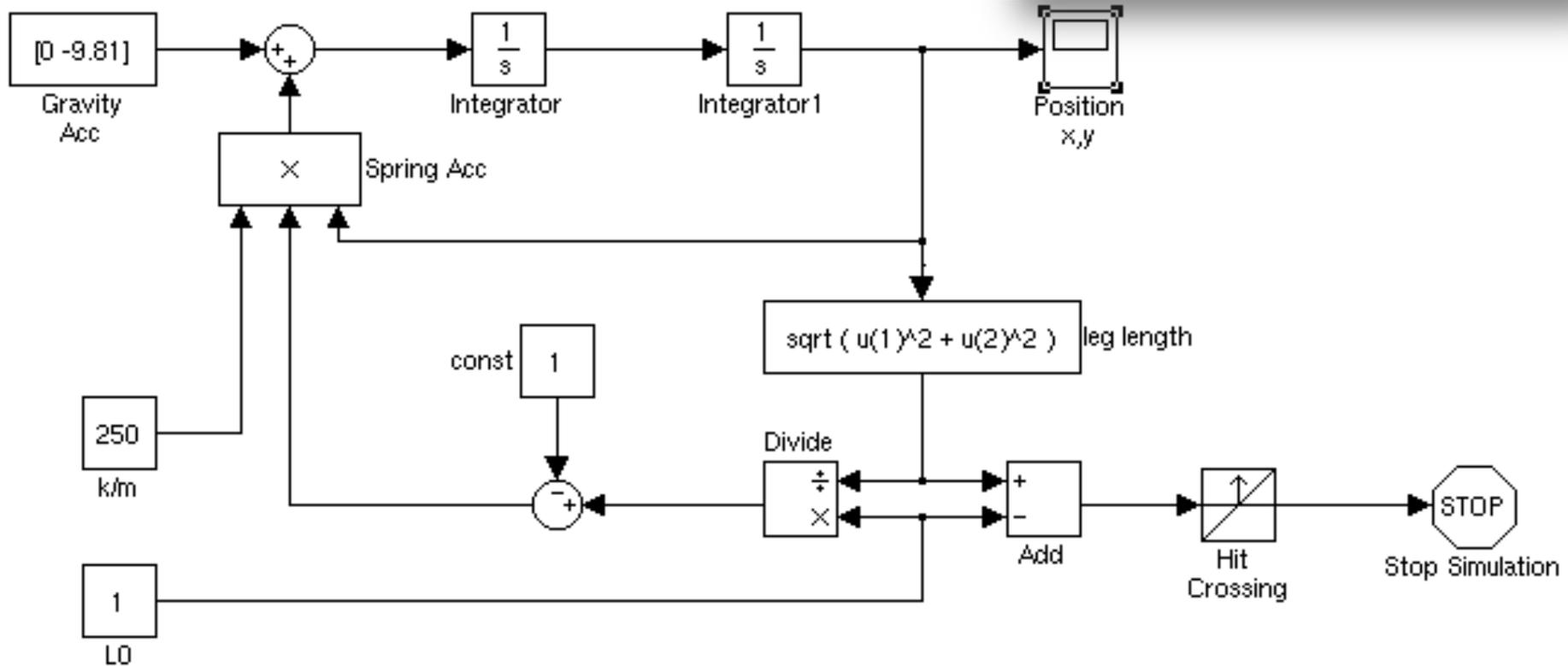
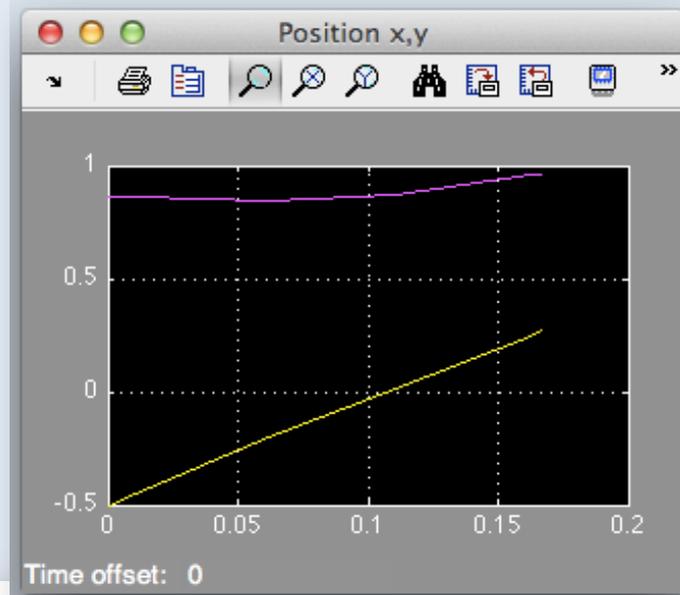
# Spring\_Mass\_1D



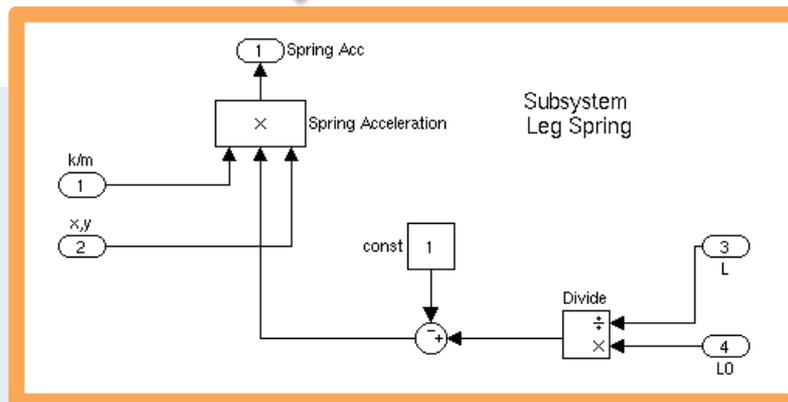
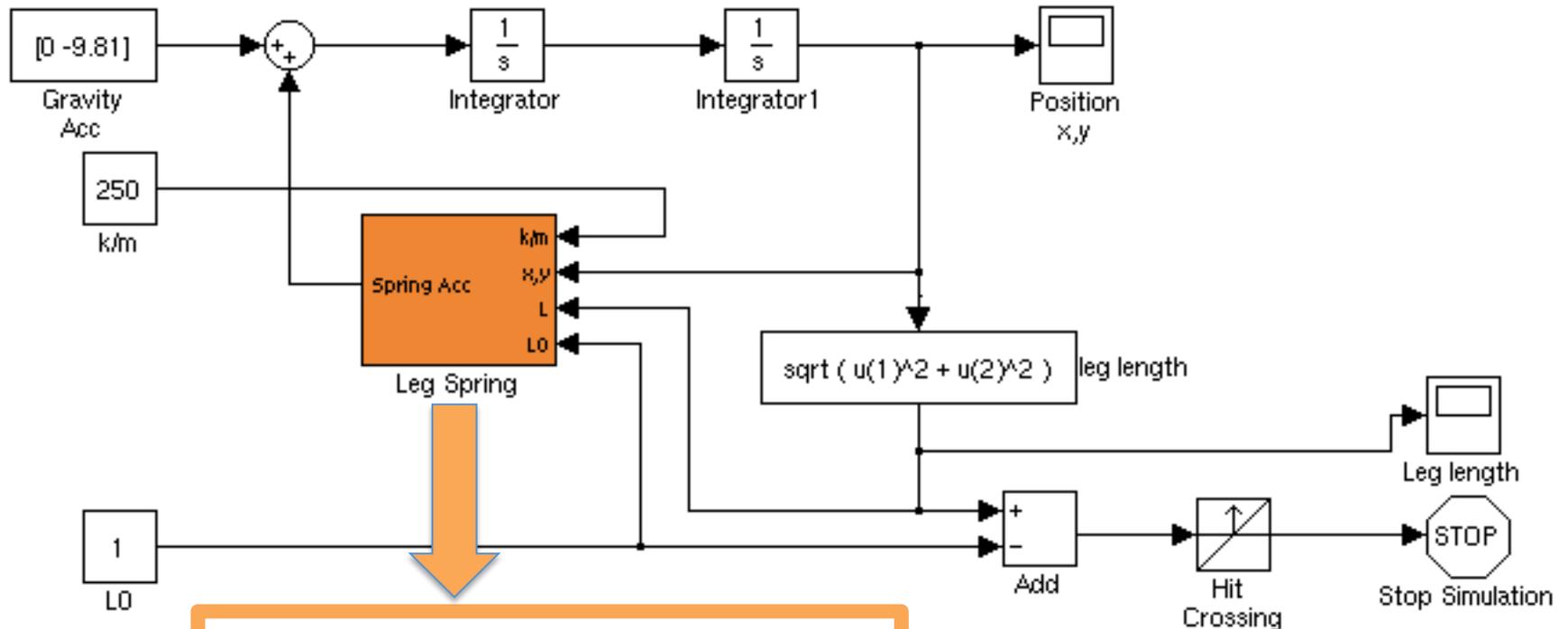
# Spring\_Mass\_2D



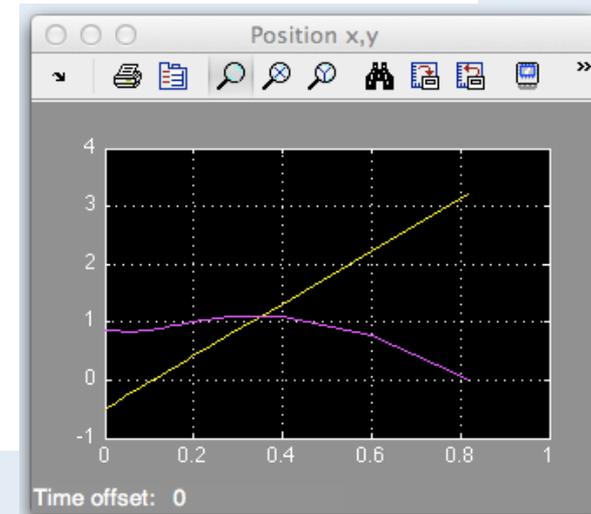
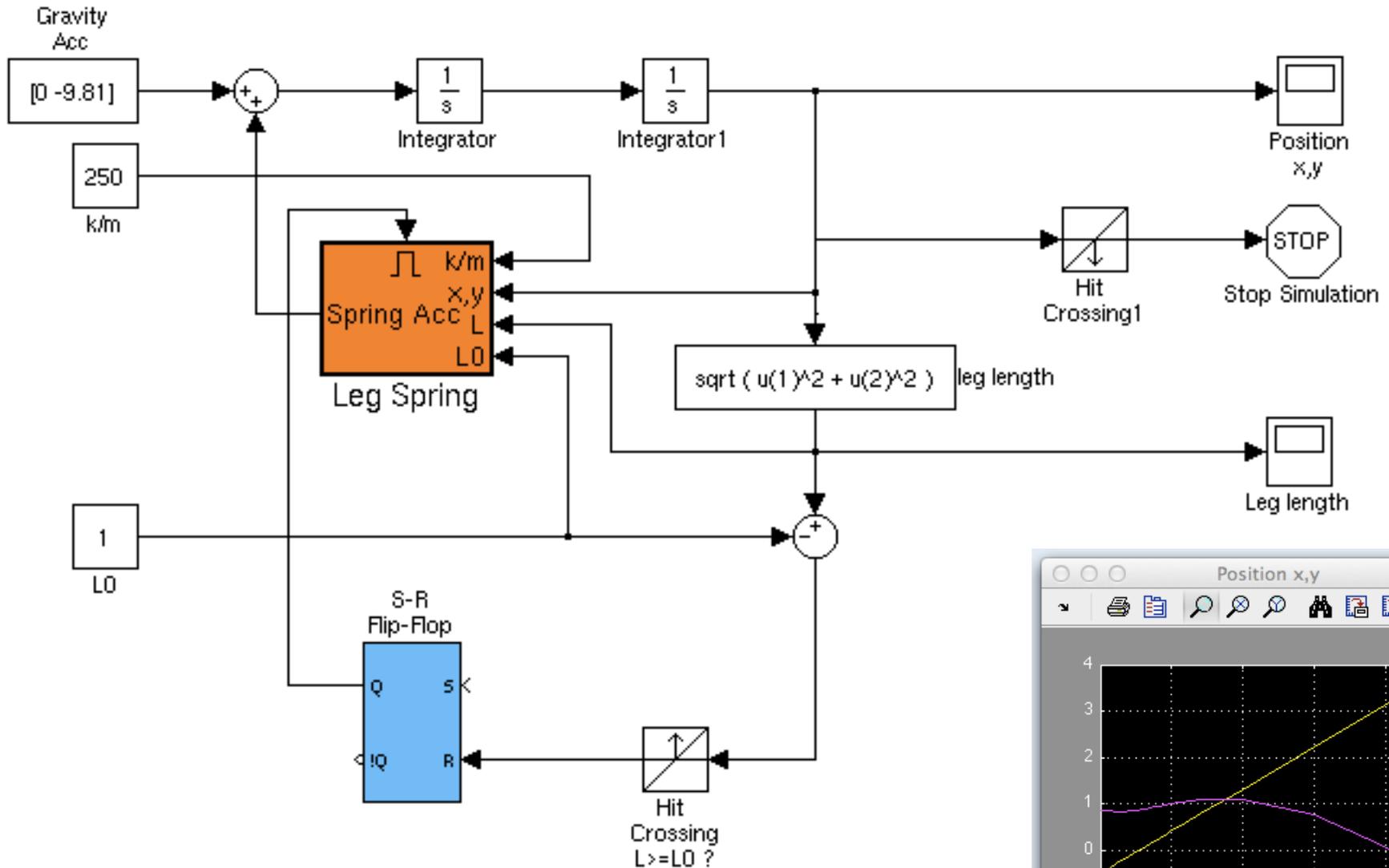
# Spring\_Mass\_Jump



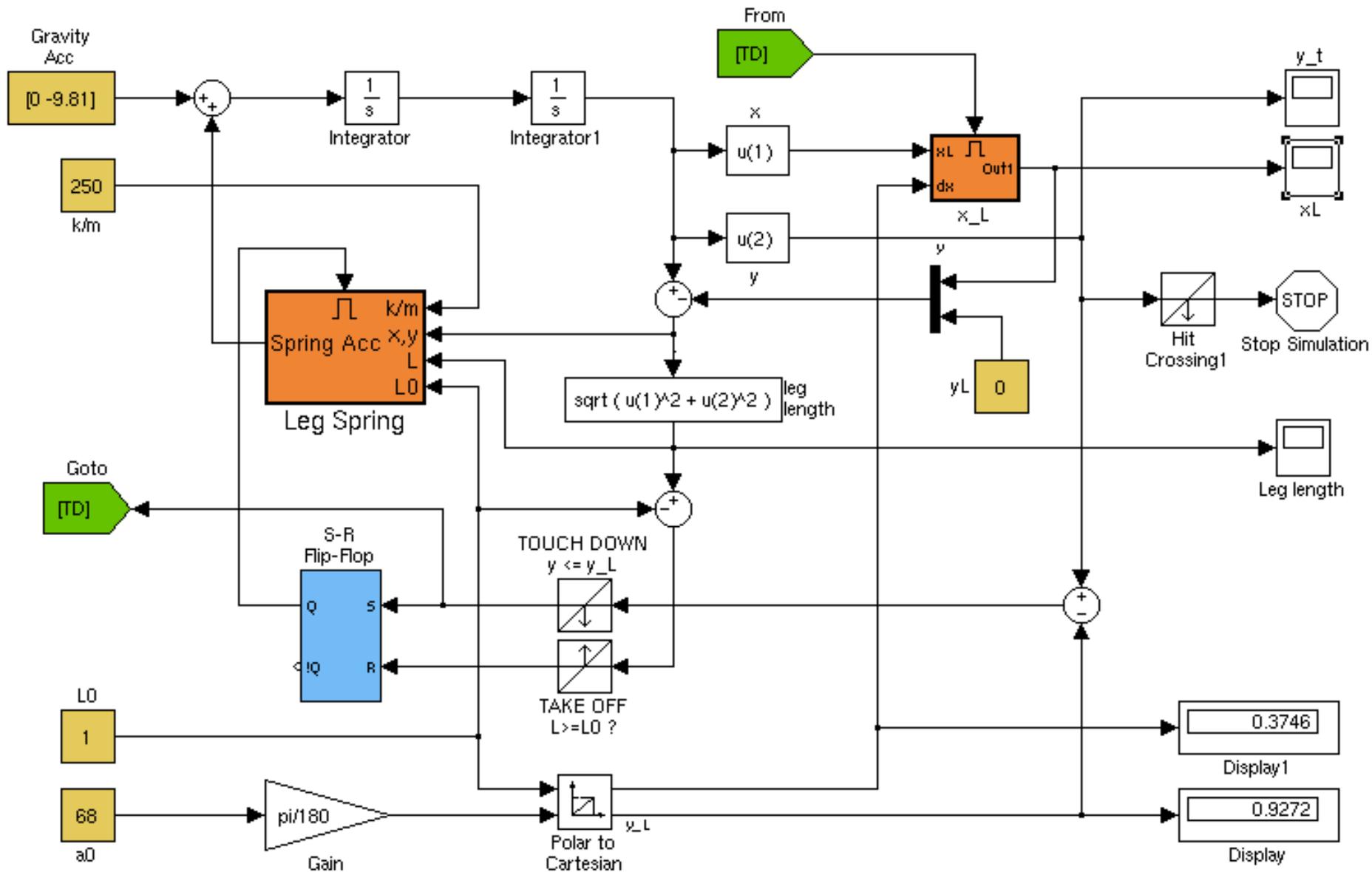
# Create Subsystem



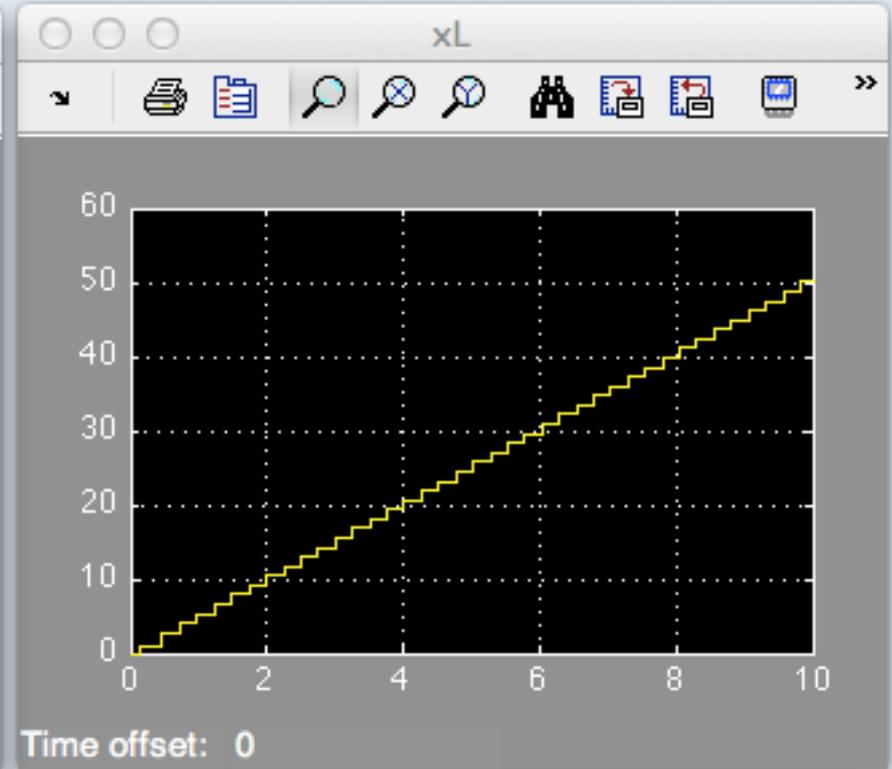
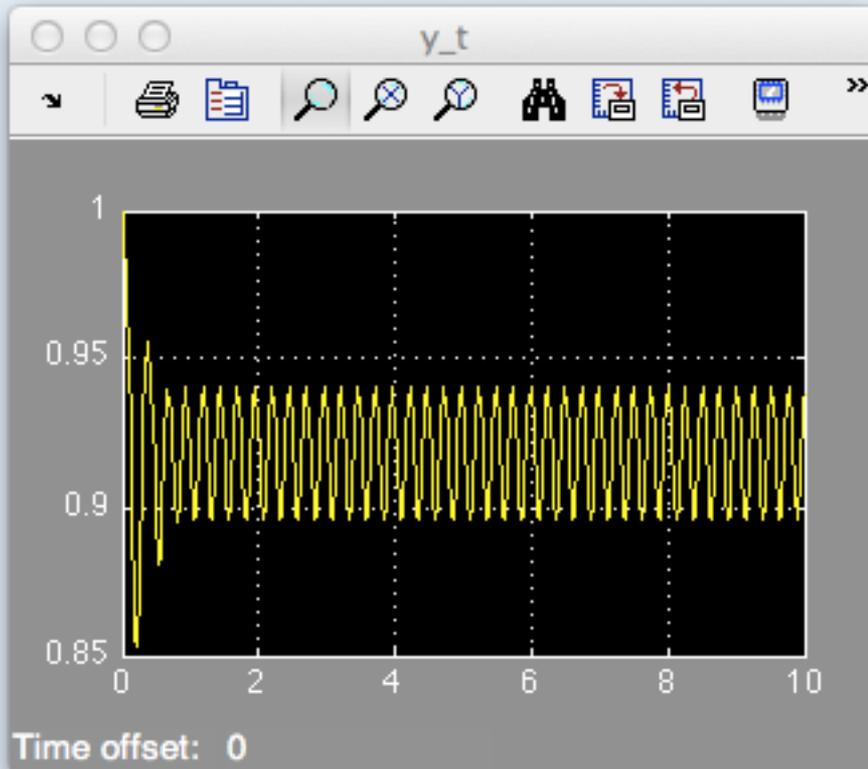
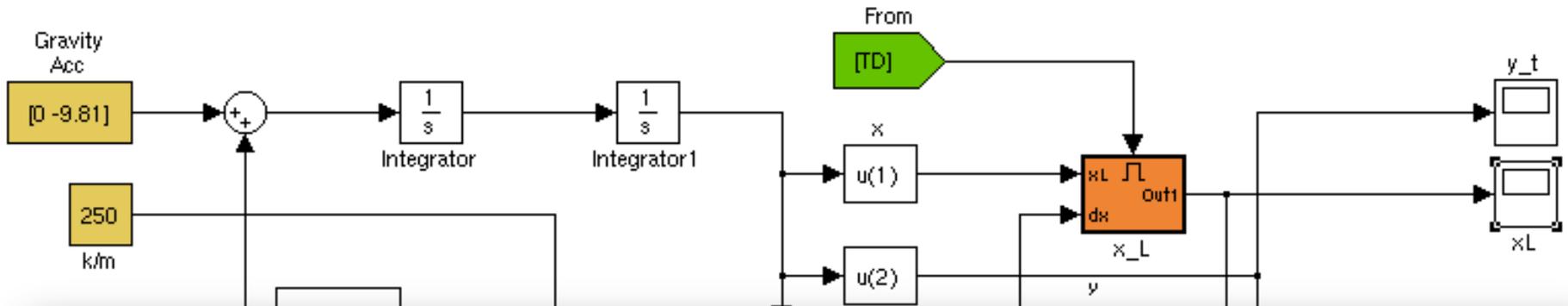
# Spring\_Mass\_Jump\_Landing



# Spring\_Mass\_Running



# Spring\_Mass\_Running



**End of Tutorial**

# Projektvorschläge

- 1) Übergänge (Gehen/Rennen, Rennen/Sprung)
- 2) 3D Rennen mit Richtungswechsel
- 3) Muskeleigenschaften im Bein beim Rennen und Springen
- 4) Einfluss von Bodeneigenschaften beim Rennen und Springen

# Gruppen TU Darmstadt (+Partner)

Gruppe				
1 Neuronales	Isabell W	Cynthia M	Carola E	
2 Neuronales +Muskel	Sabrina C	Birgit S	Toni S	Christian S