

# Quanten**Elektro**Dynamik in einer Nussenschale

Christian B. Lang  
Inst f. Physik, Universität Graz



# Elektrodynamik

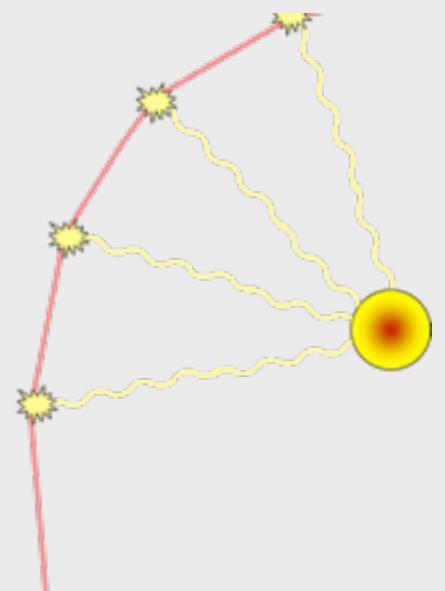
- ist die Theorie der elektrisch geladenen Objekte
- einfachster Fall: Elektronen und Photonen
- Quantentheorie: Photonen sind Welle und Teilchen (“Dualität”)

# Quantenelektrodynamik (QED)

ist die Quantentheorie der Elektrodynamik:  
eine **Quantenfeldtheorie**

Das fundamentale Feld der QED ist das  
**Photonenfeld**

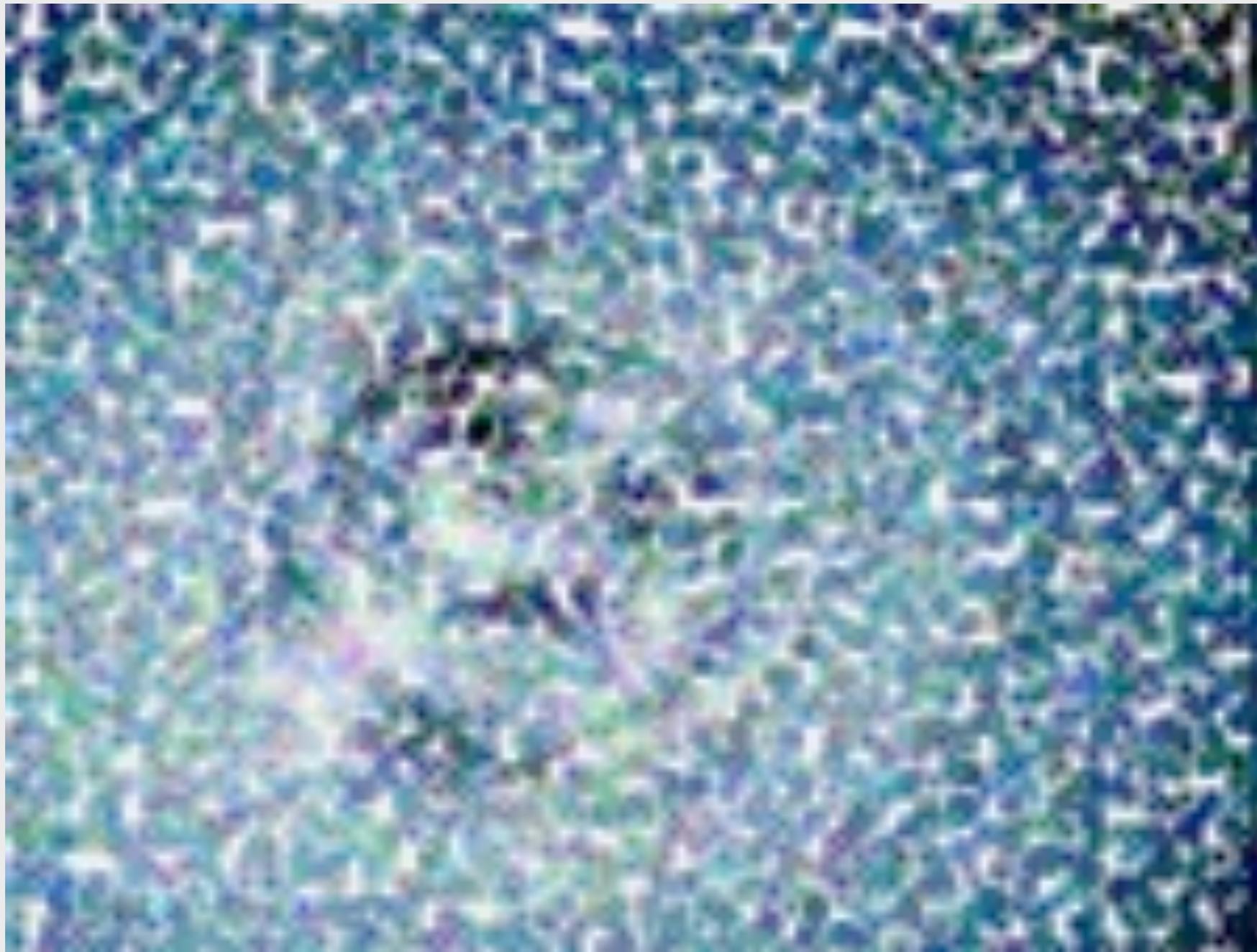
Alle auftretenden Kräfte der QED werden  
durch **Photonen** vermittelt



# Quantenfelder

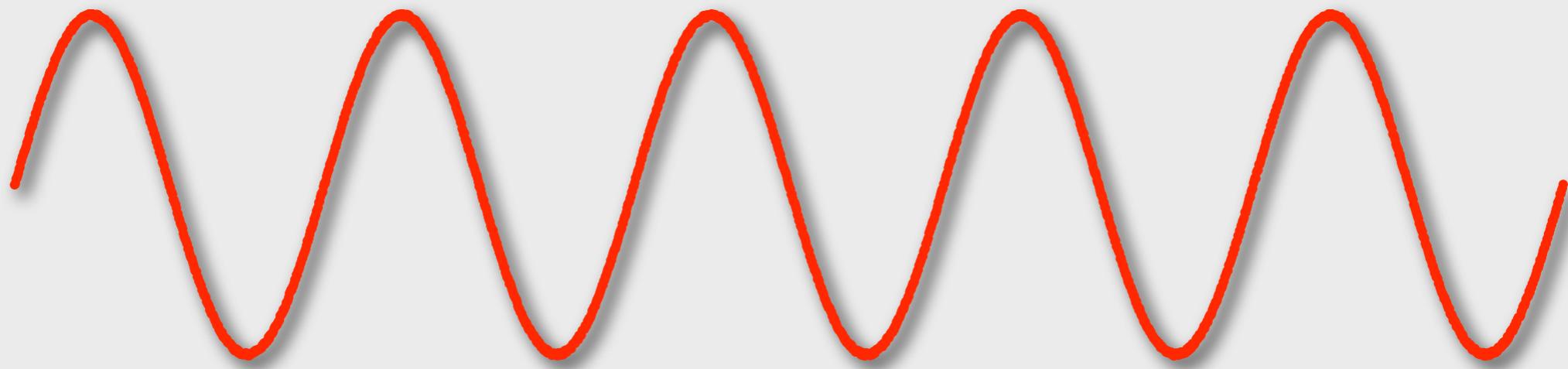


# Quantenfelder

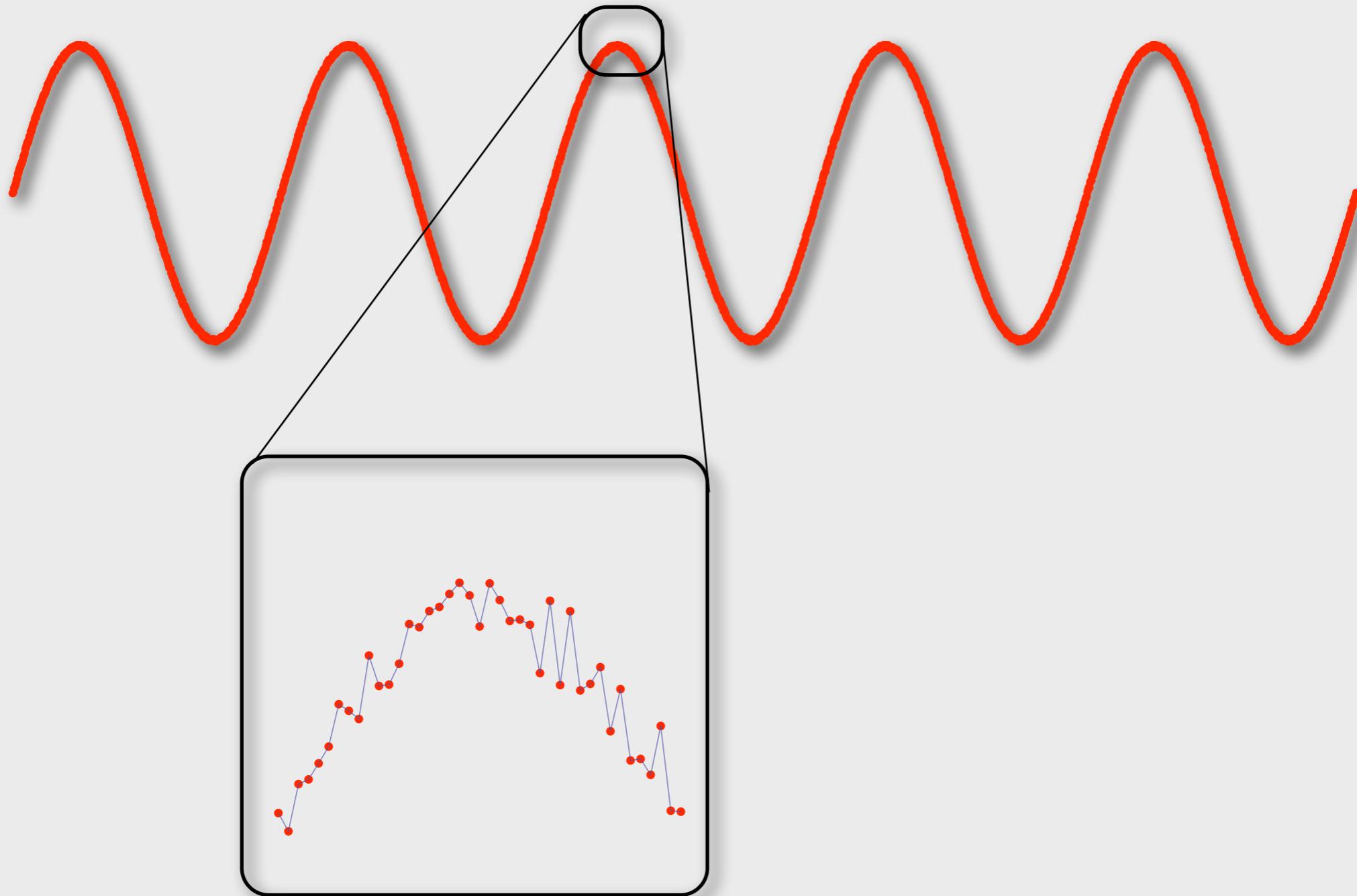


sind nicht glatt sondern “fuzzy”

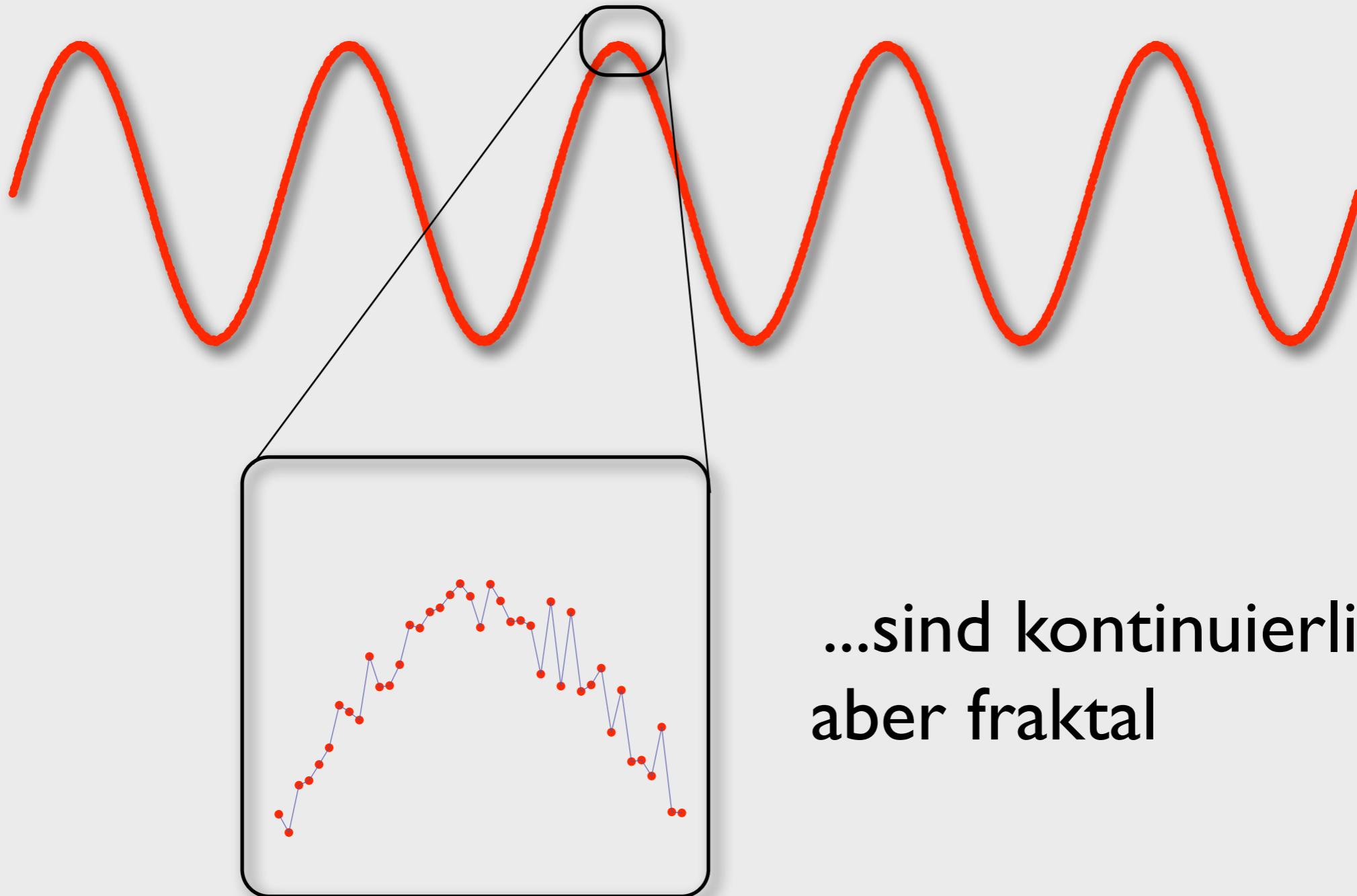
# Wellen



# Wellen



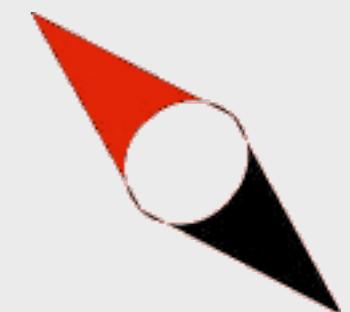
# Wellen



**...sind kontinuierlich  
aber fraktal**

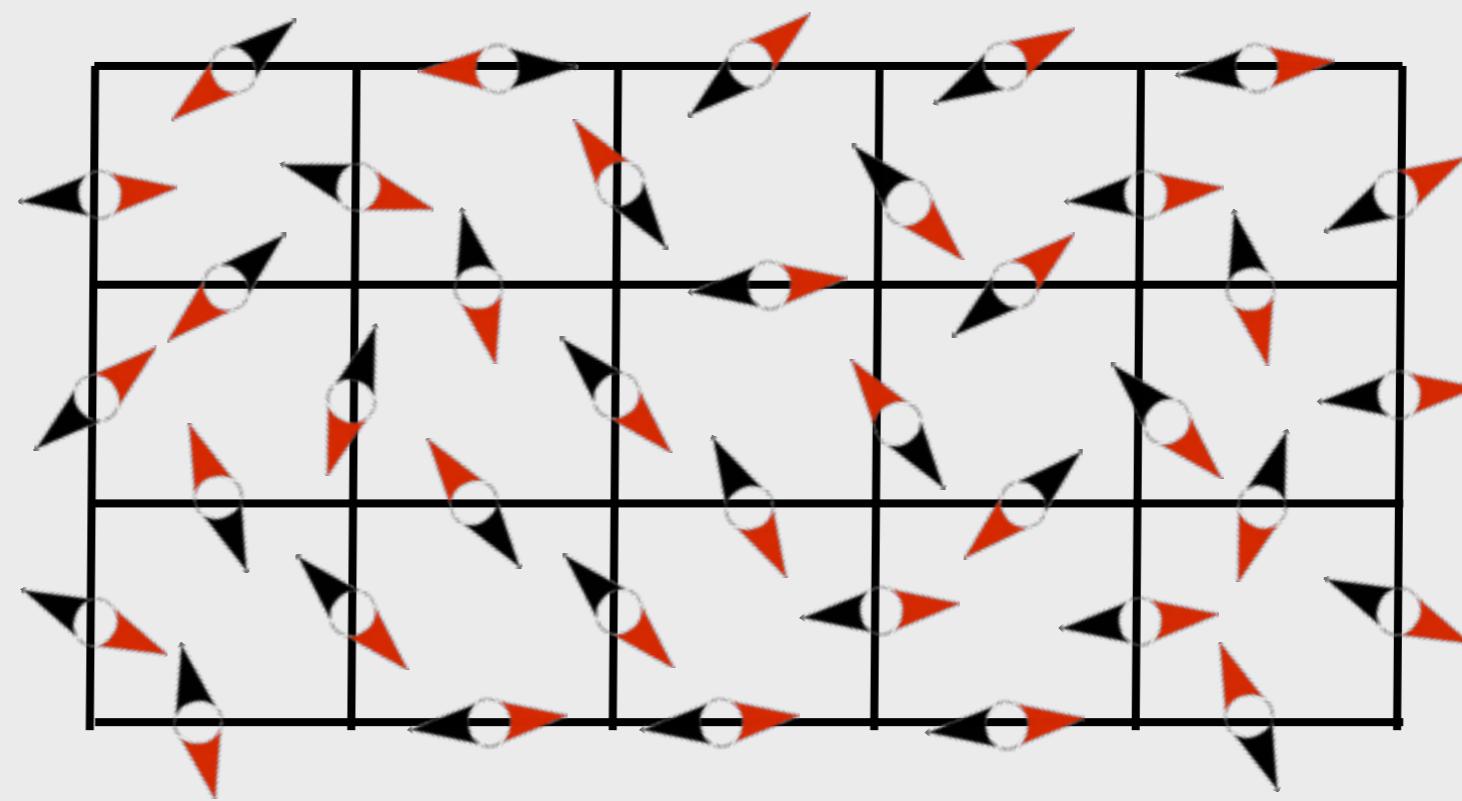
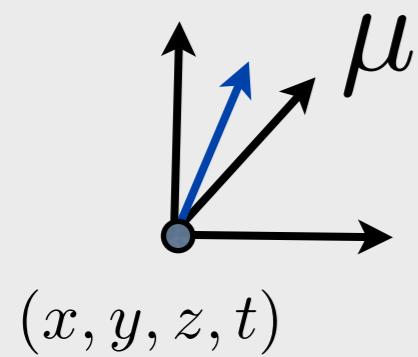
# Quantisierung

- kann als Summe über alle denkbaren Feldkonfigurationen  $U(x,y,z,t; \mu)$  gedacht werden: “Feynmansches Wegintegral”
- $U(x,y,z,t; \mu)$  = Wert des Photonfeldes am Punkt  $(x,y,z,t)$  in Richtung  $\mu$
- $U = \exp(i\varphi)$  = komplexe Zahl
- Beachte:  $|U| = 1$  ,  $-\pi < \varphi \leq \pi$



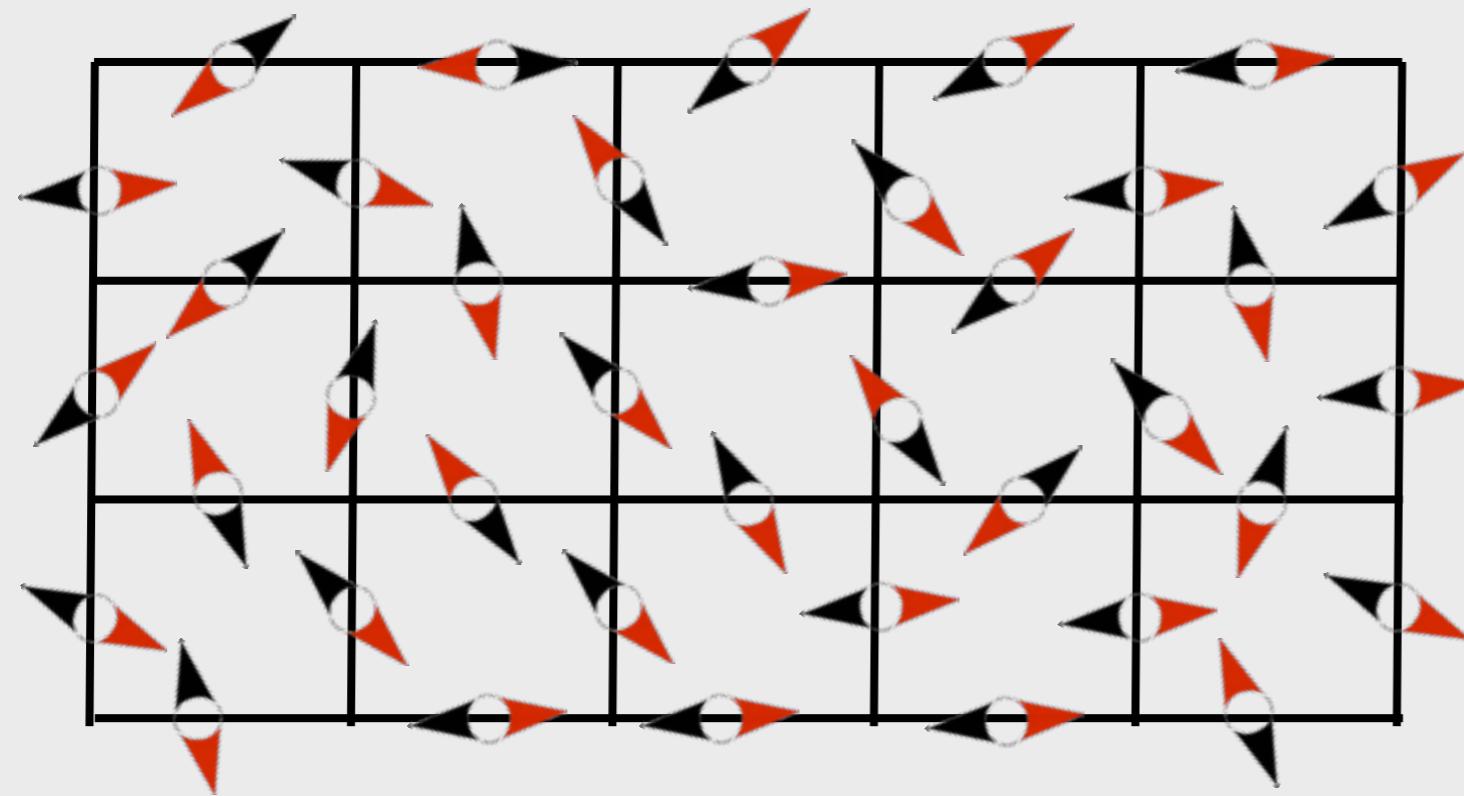
# Gitter

Regularisierung: Raum-Zeit Gitter

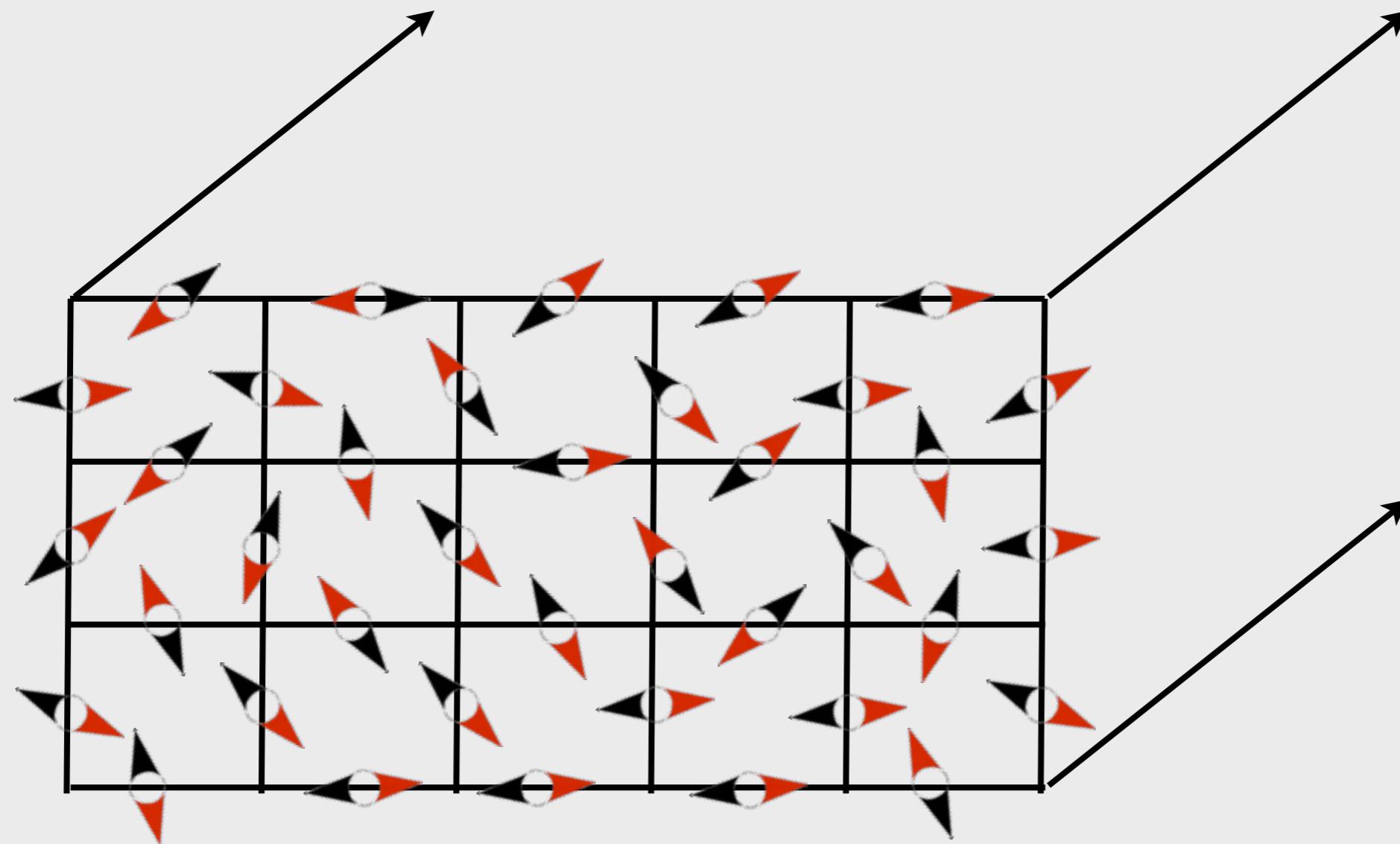


$$U(x, y, z, t; \mu)$$

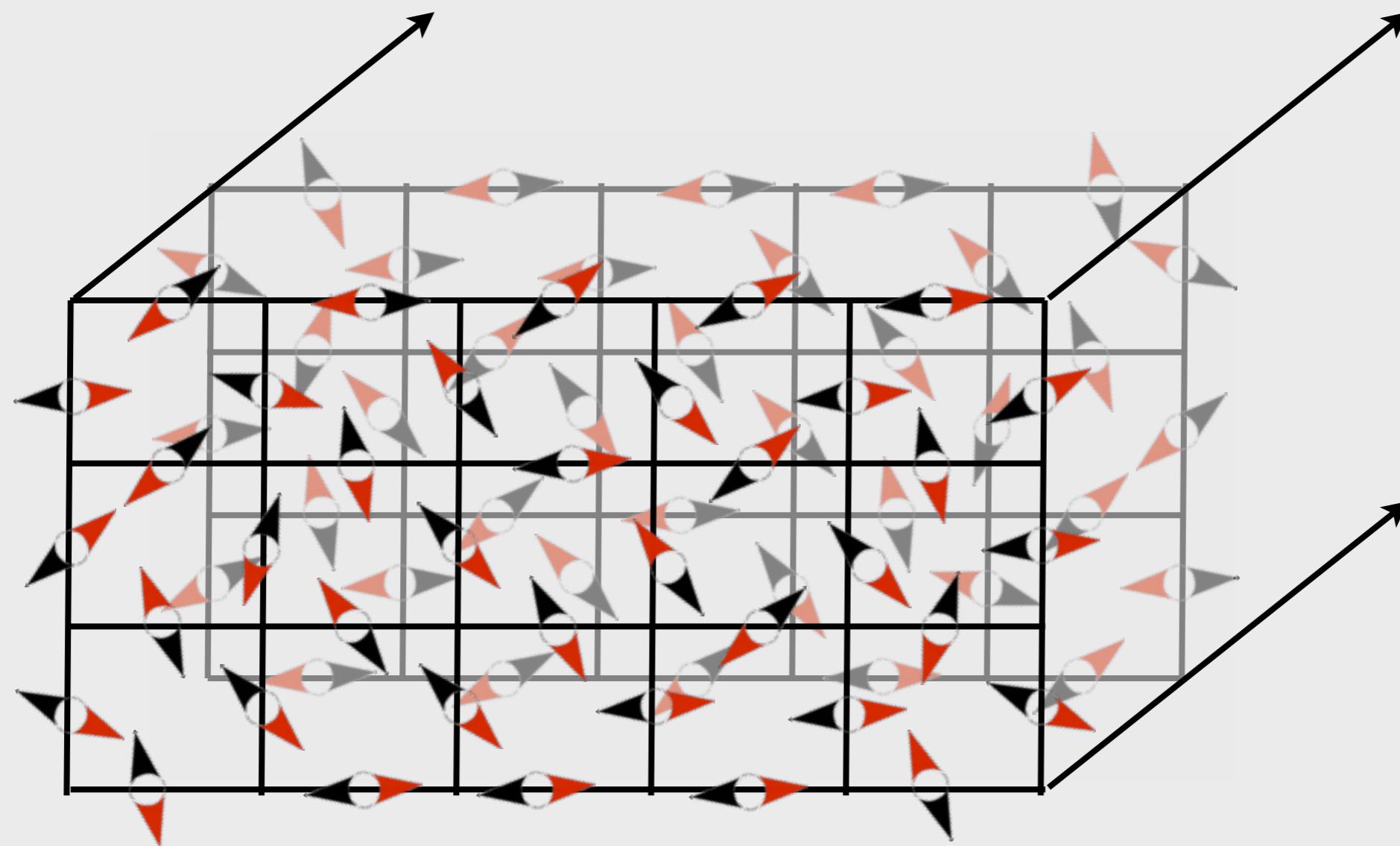
# Gitter QED



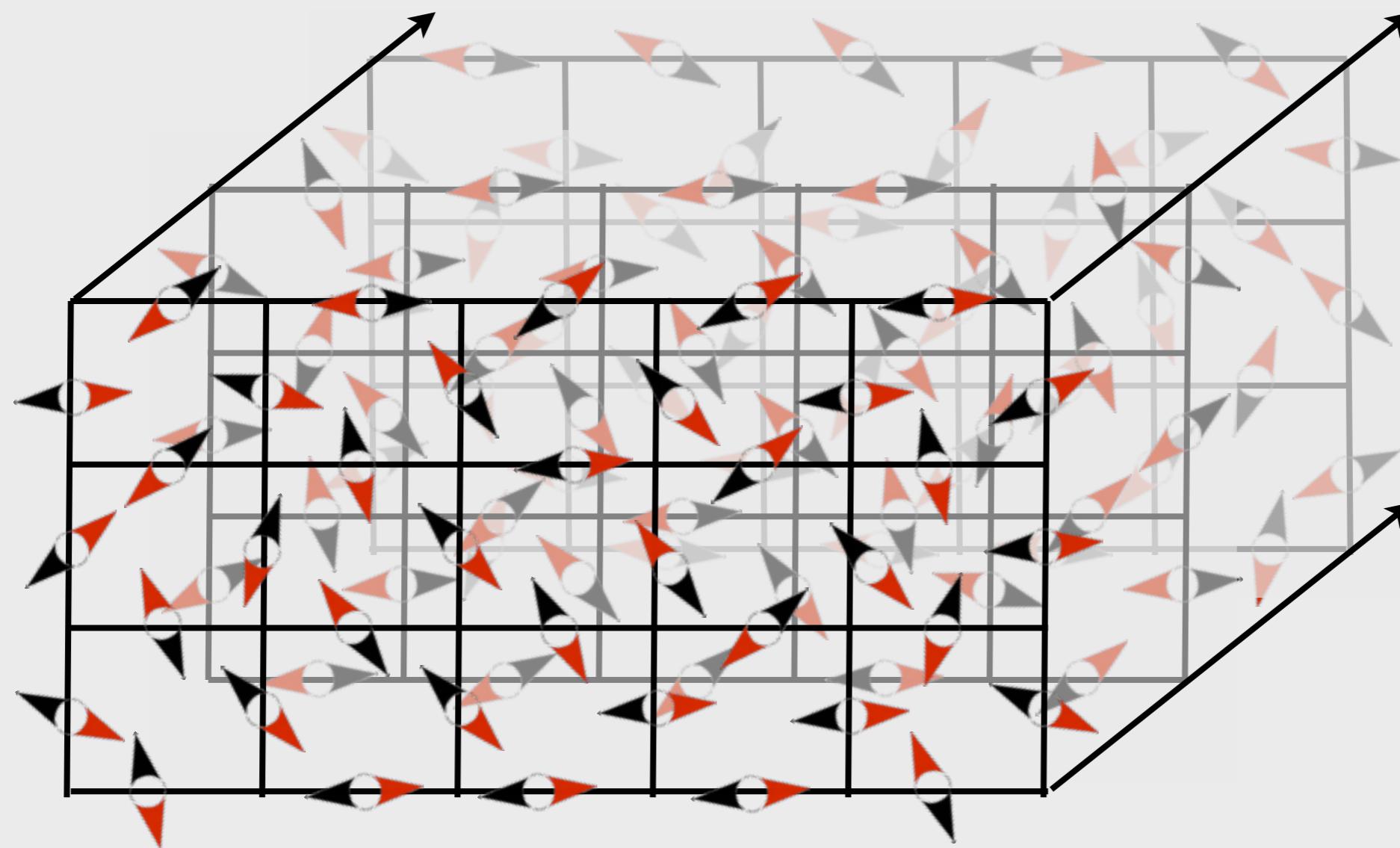
# Gitter QED



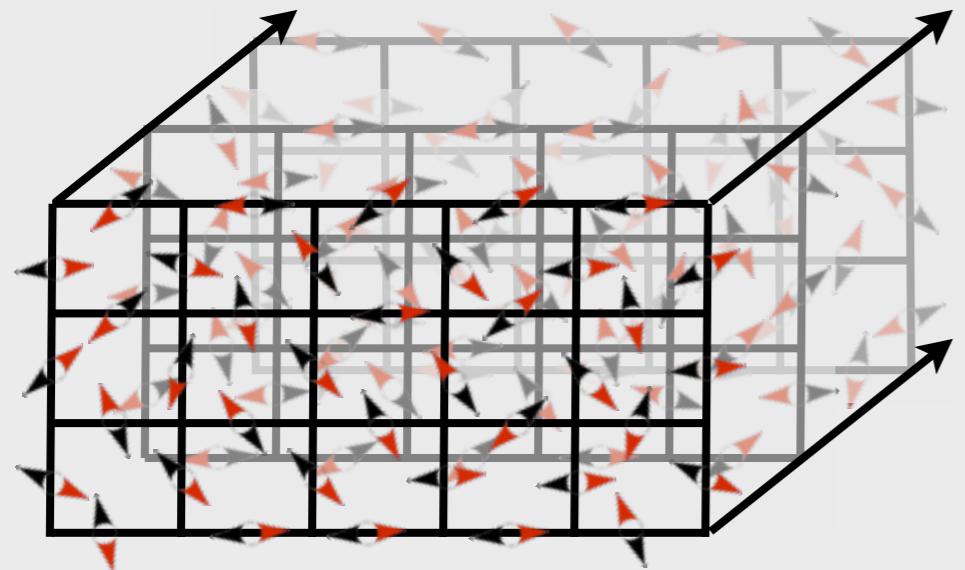
# Gitter QED



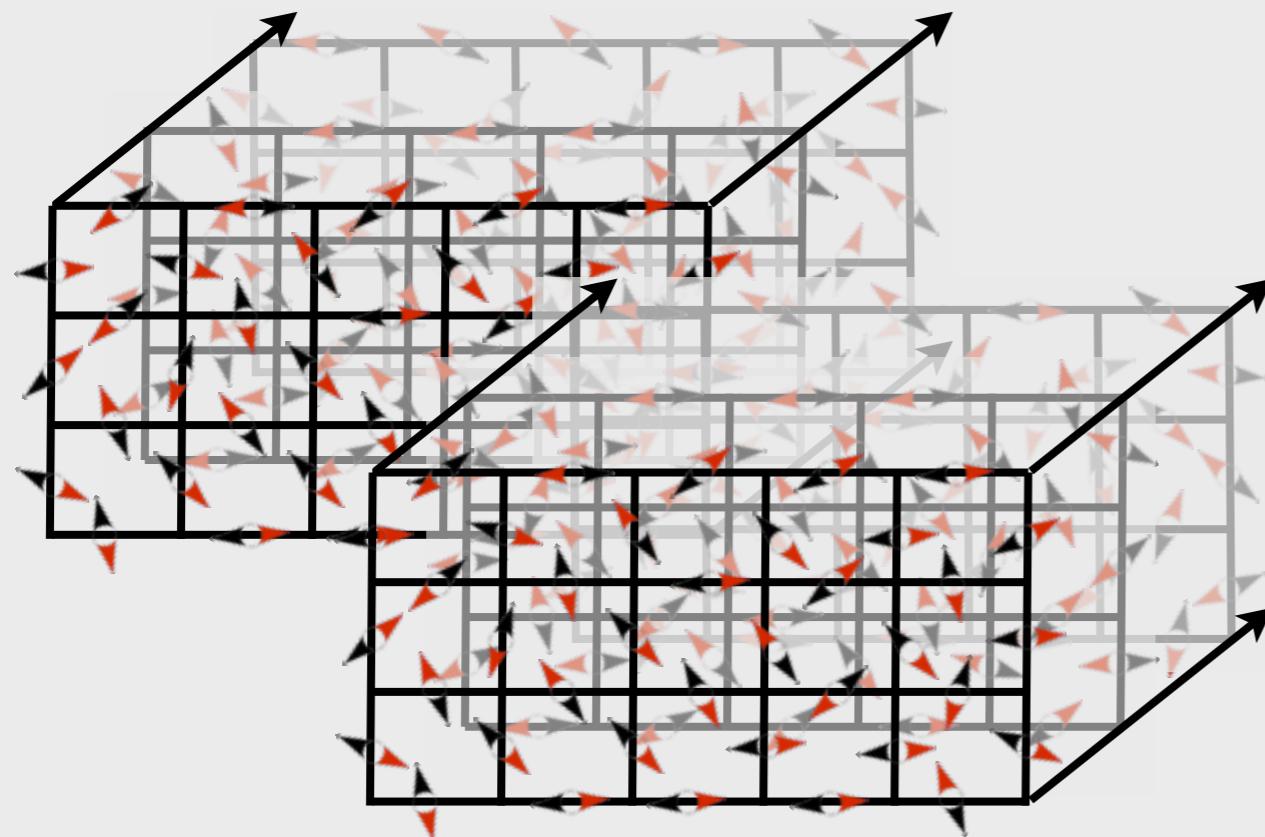
# Gitter QED



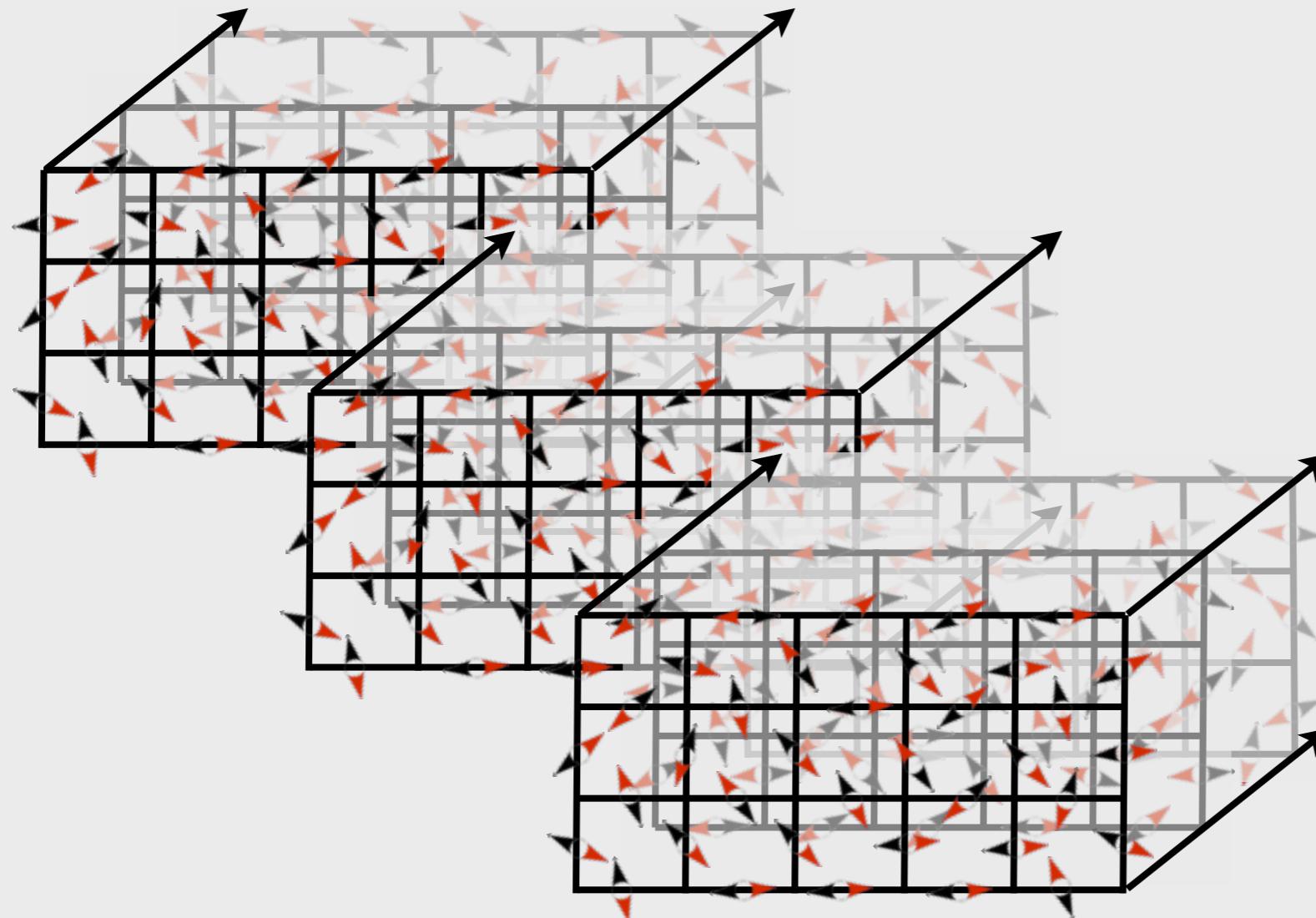
# Summe über viele Feldkonfigurationen



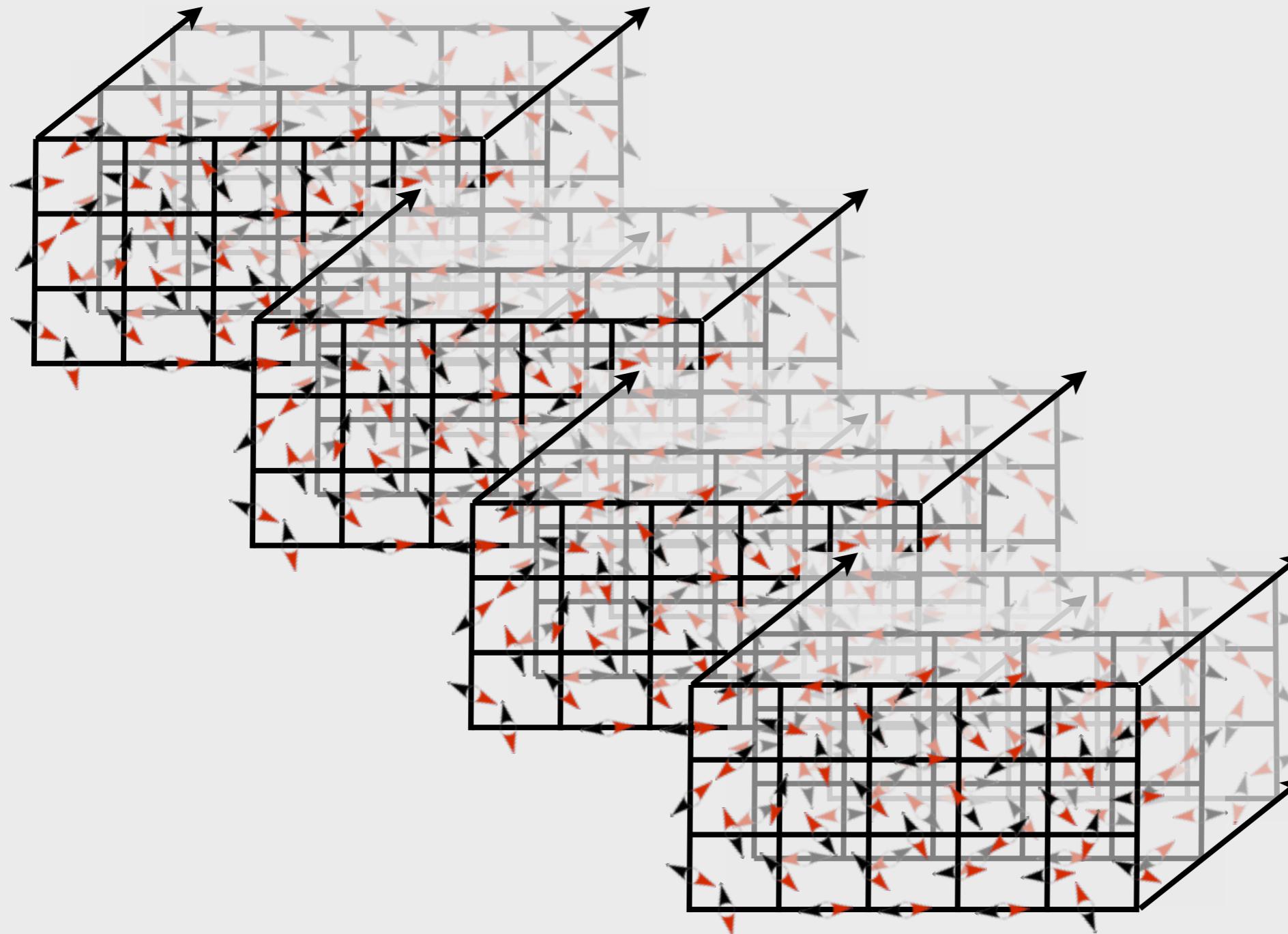
# Summe über viele Feldkonfigurationen



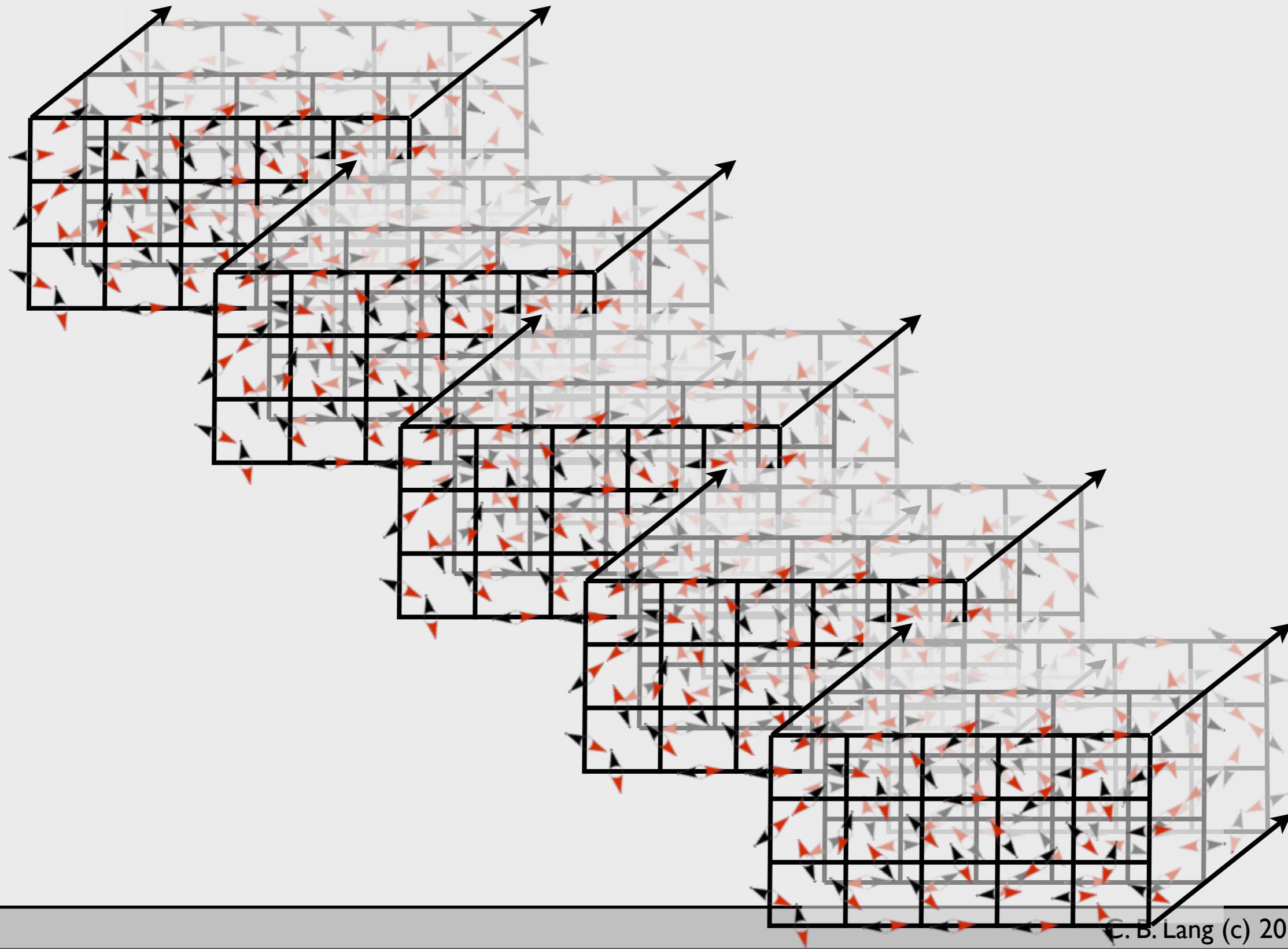
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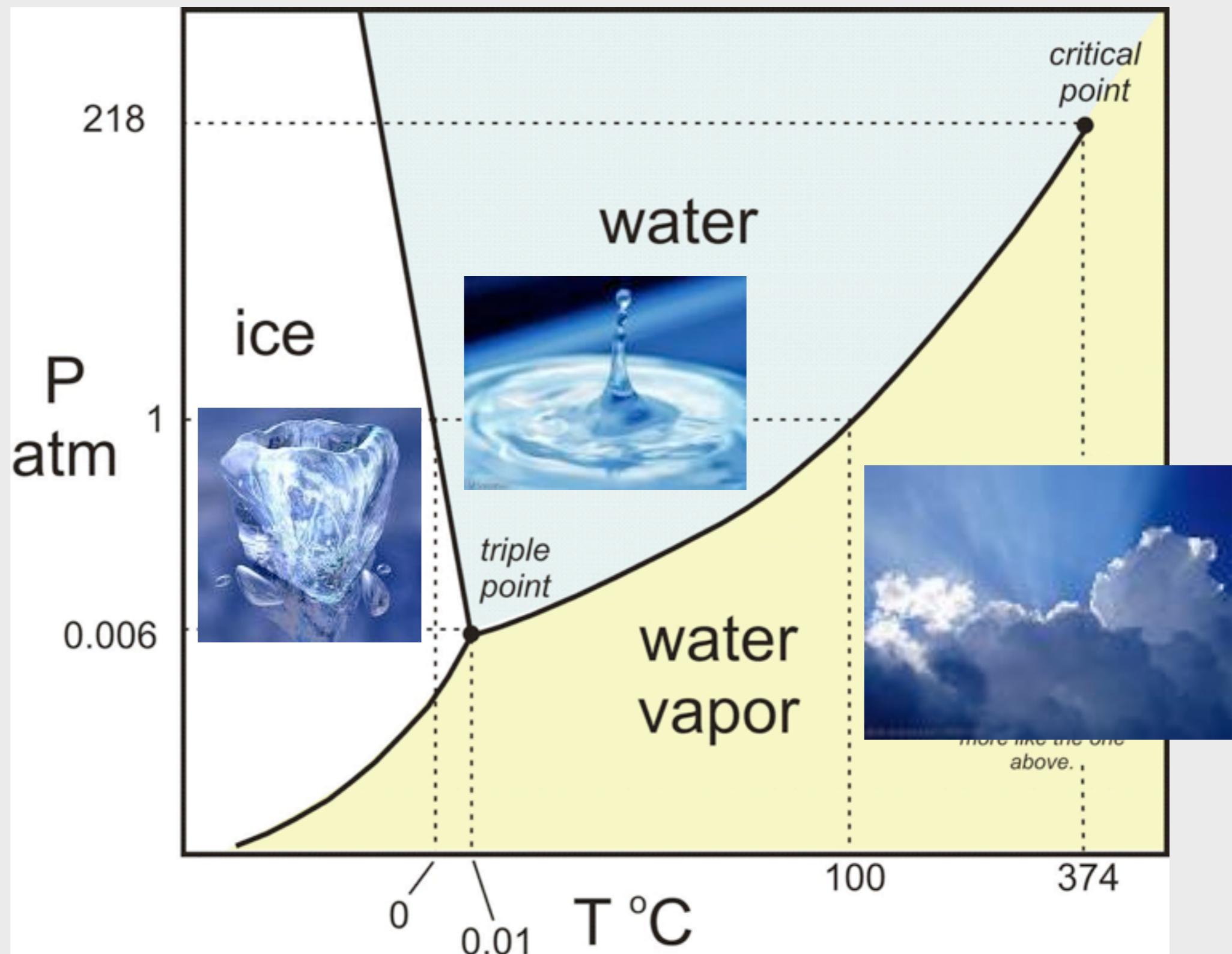
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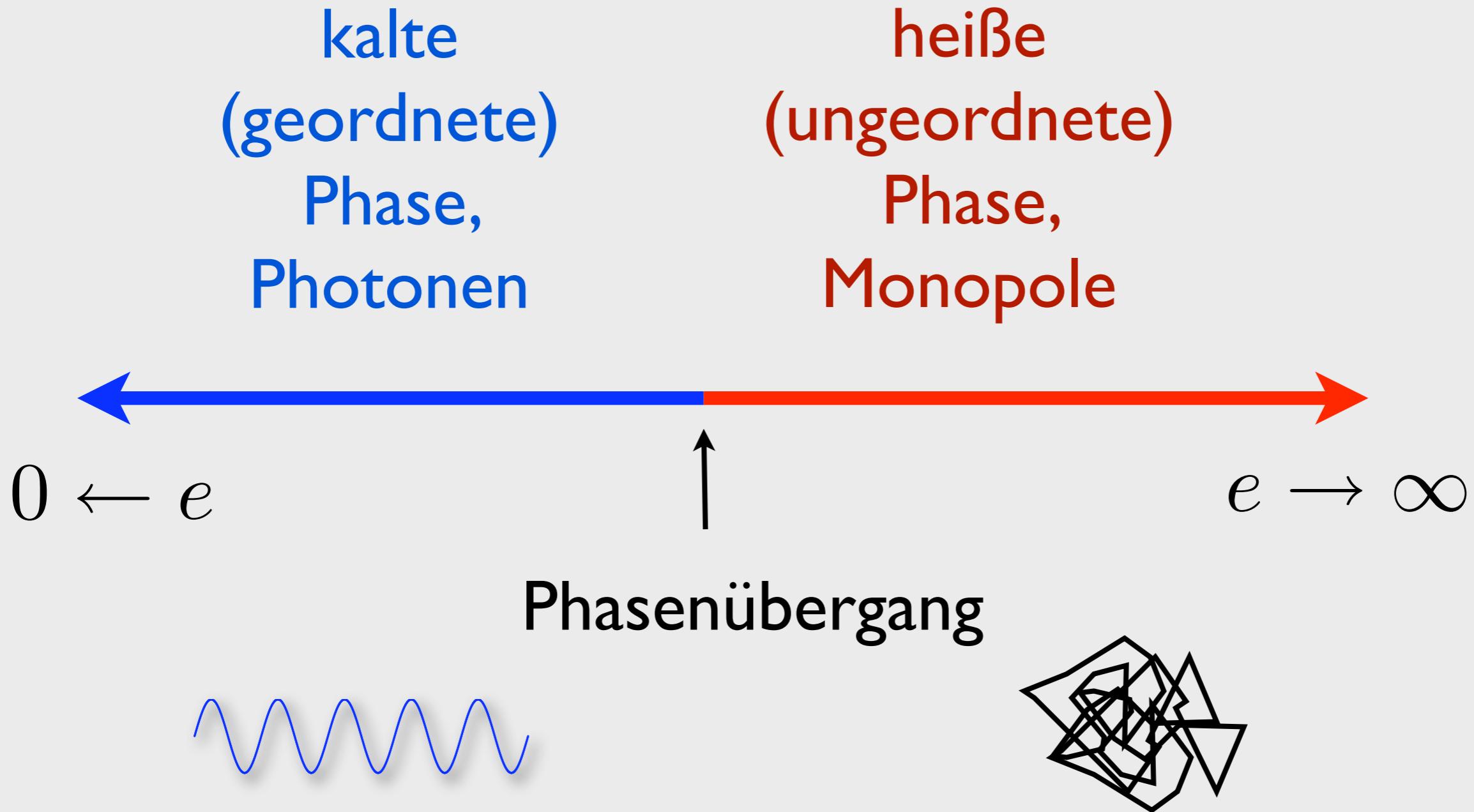
# Summe über viele Feldkonfigurationen



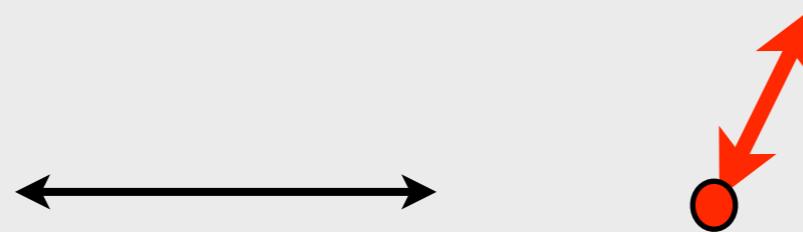
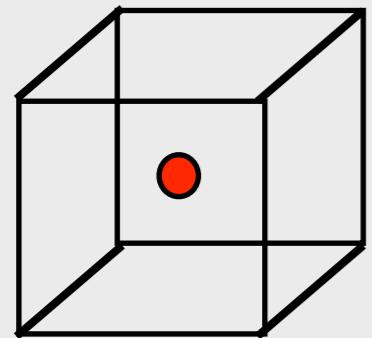
# Phasendiagramm



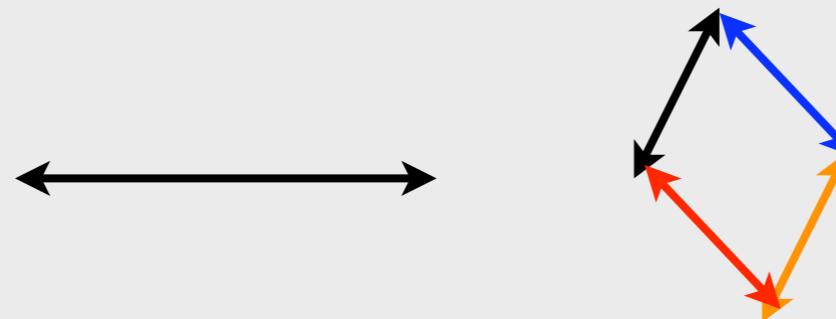
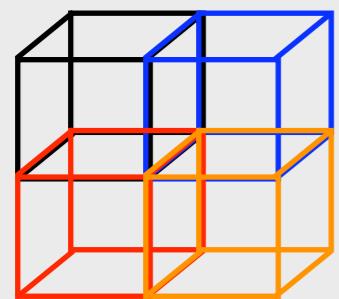
# Phasenstruktur Gitter QED



# Welche Eigenschaften?



Monopole link



Monopole loop

$e > e_{krit}$  : “heiße Phase”,  
*sehr* viele Monopole Loops

