Short time diffusion rates in the delta kicked rotor

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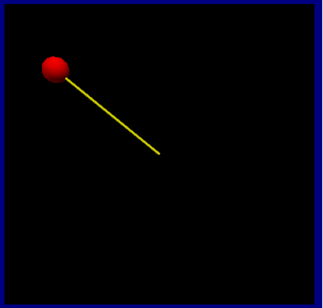
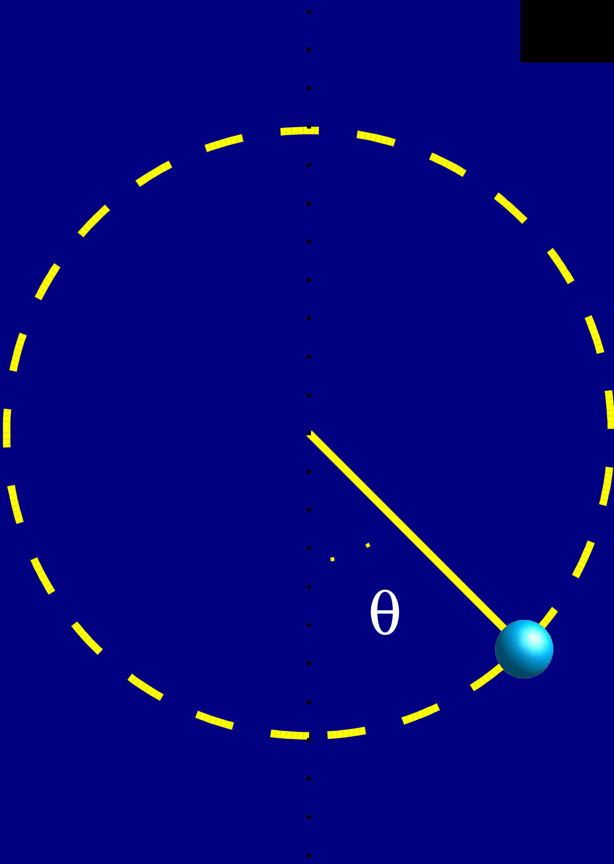
Outline

- Delta kicked rotors
- Atom optics implementation
- First few kicks
- The quantum resonance
- Conclusions
- Future plans

Delta kicked rotor

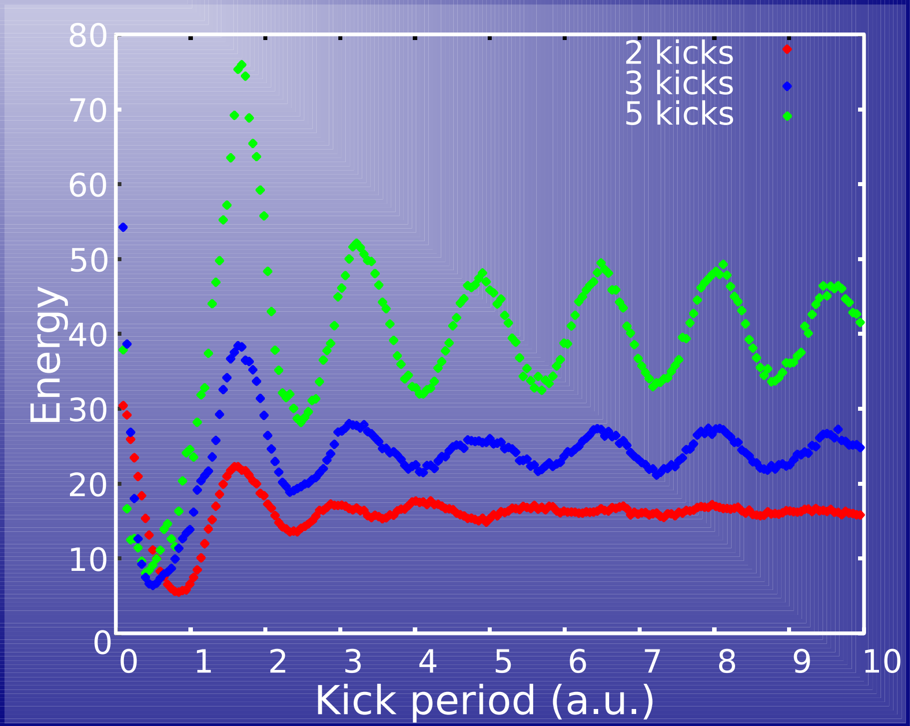


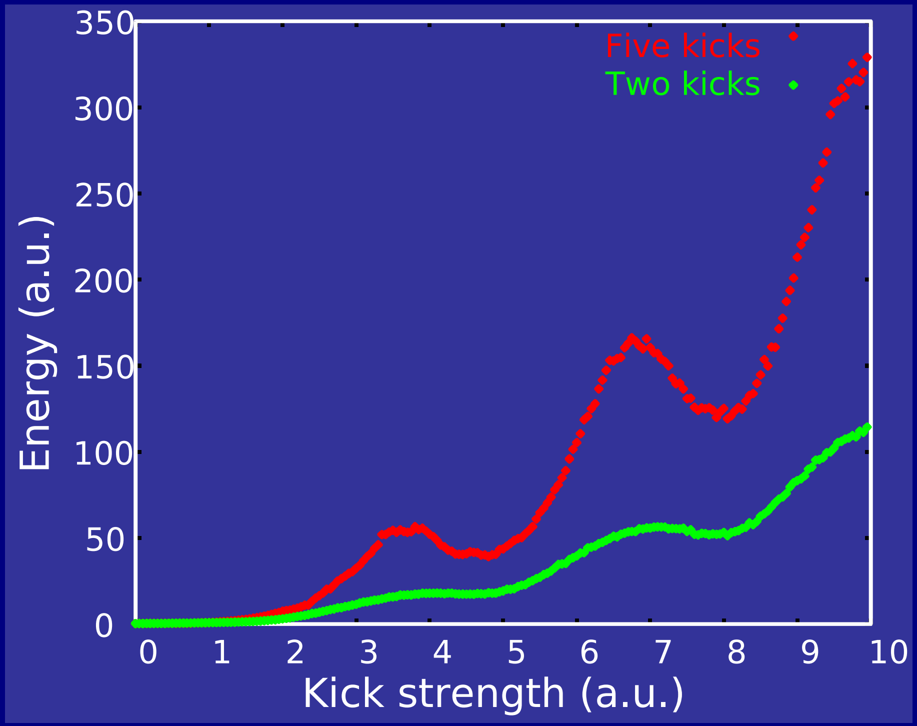
- Ball with mass *m* at the end of a massless stick
- Potential switched
- Non-linear dynamics

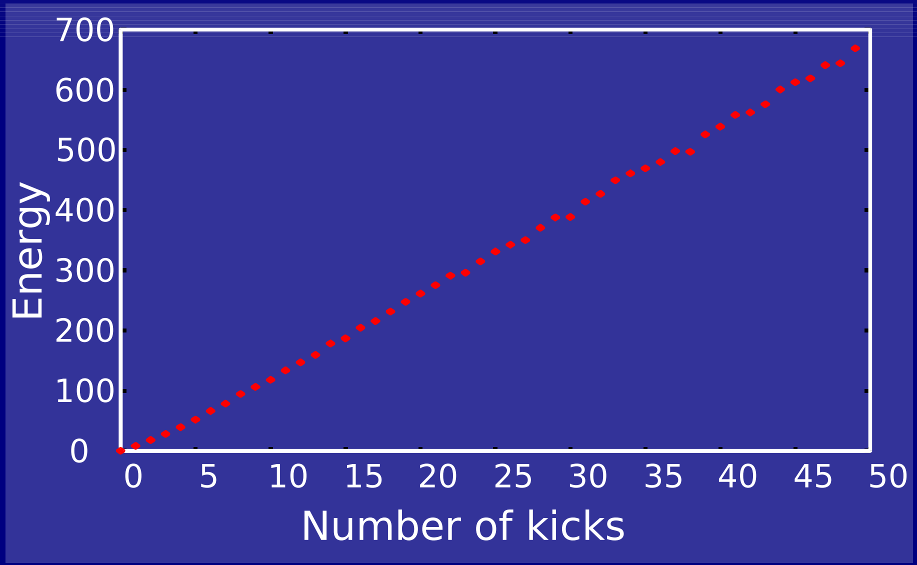


$$V = V_0 \sin\theta \sum_n \delta(t - nT)$$

Classical kicked rotor



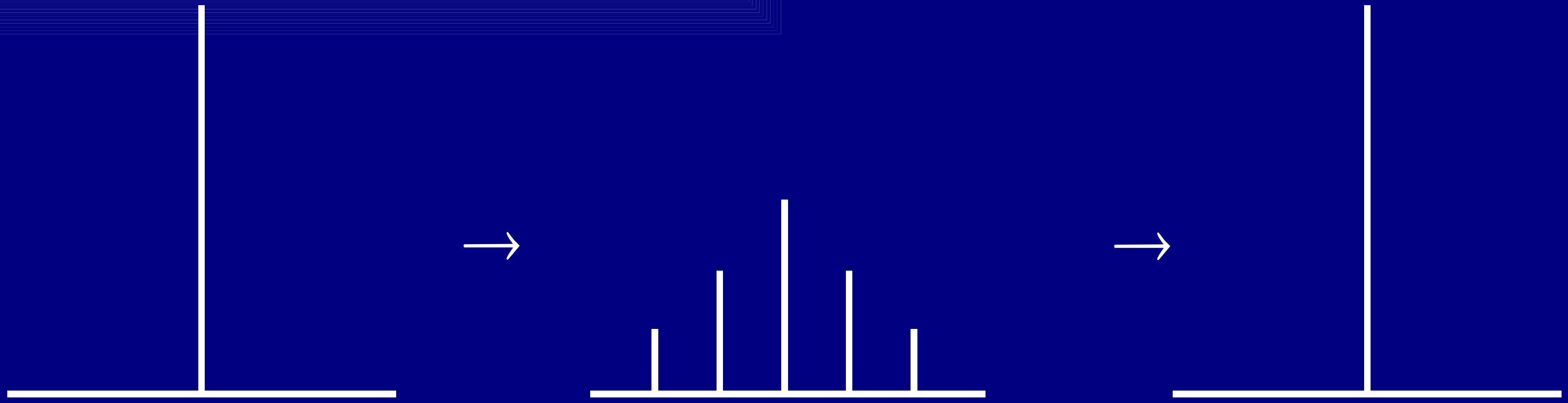




- Oscillations as function of kick period
- Oscillations as fn of kick strength

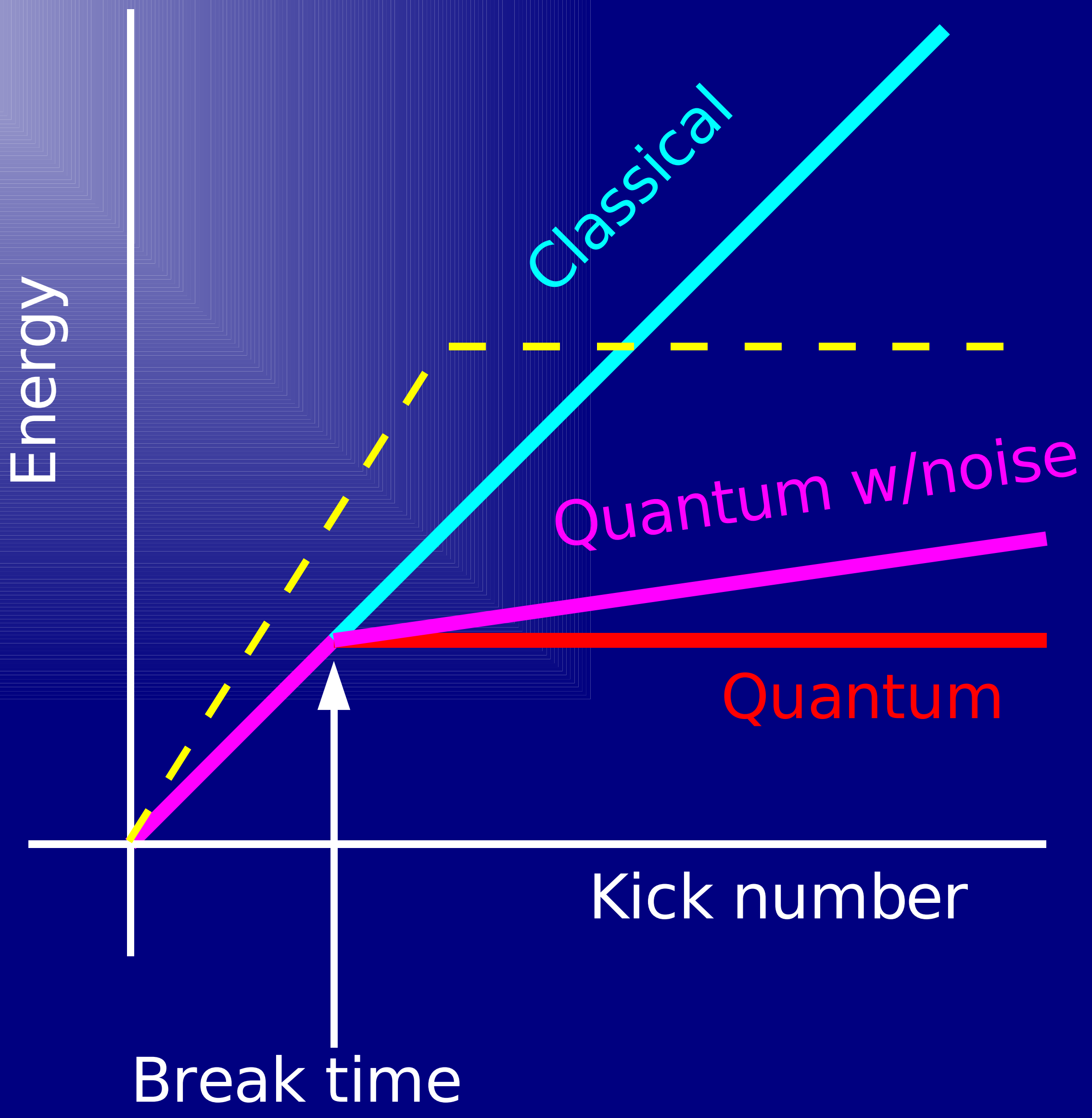
Quantum Kicked Rotor

- In position space:
  - Kick introduces phase shift $\Delta\varphi = \sin kx$
- In momentum space:
  - Delta kick transforms delta function into comb
  - Free evolution accumulates linear phase shift $\varphi = ct$
  - Talbot effect:
    - After $\varphi = 2n\pi$ the same kick would invert the effect



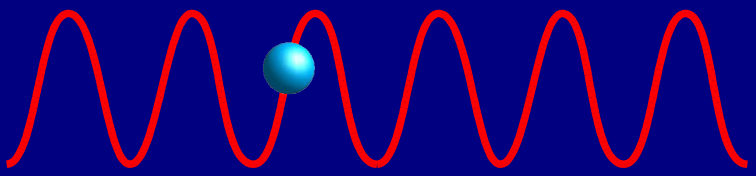
*Duffy et al, Physical Review E **70**, 056206 (2004)*

Dynamical Localisation

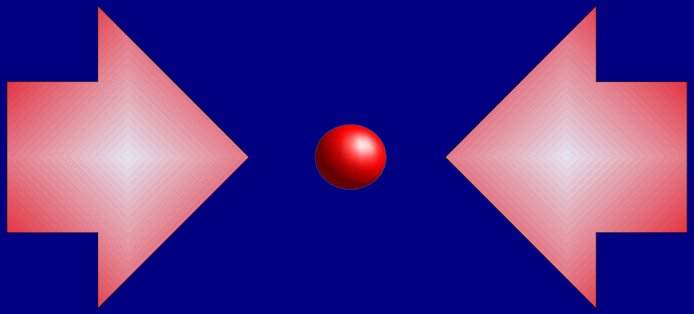


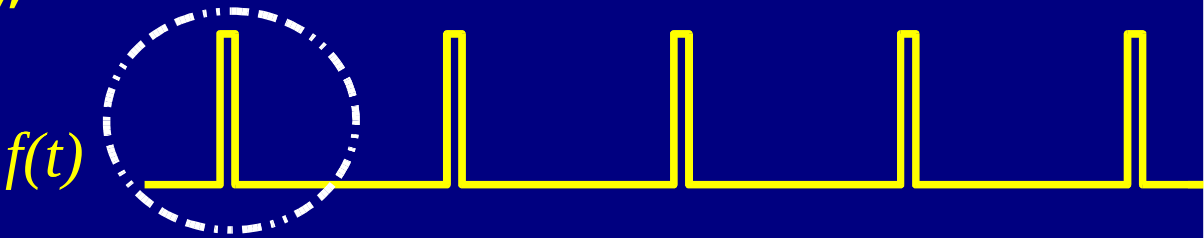
Atom optics kicked rotor

- Atoms in standing wave
  - MOT: hot, integrate over initial momentum states
  - MOT: large, integrate over initial positions
- Motion QM
  - Linear dynamics
  - No chaos
  - Limited energy growth after “break time”



$$H = \frac{\hat{p}^2}{2m} + V_0 \cos(2k\hat{x}) \sum_n f(t - nT)$$





Atom Optics Kicked Rotor

- Scaled Hamiltonian $H = \frac{\rho^2}{2} + \cos(\phi)\kappa \sum_{n=0}^{N} f(t - nT)$
- Scaled position $\phi = 2k_L x$
- Scaled momentum $\rho = ƛ p / (2\hbar k_L)$
- Scaled Planck's constant $ƛ = 4\hbar k_L^2 T / m$
- Commutation relation $[\phi, \rho] = iƛ$

- Effective Planck's constant changes with kick period

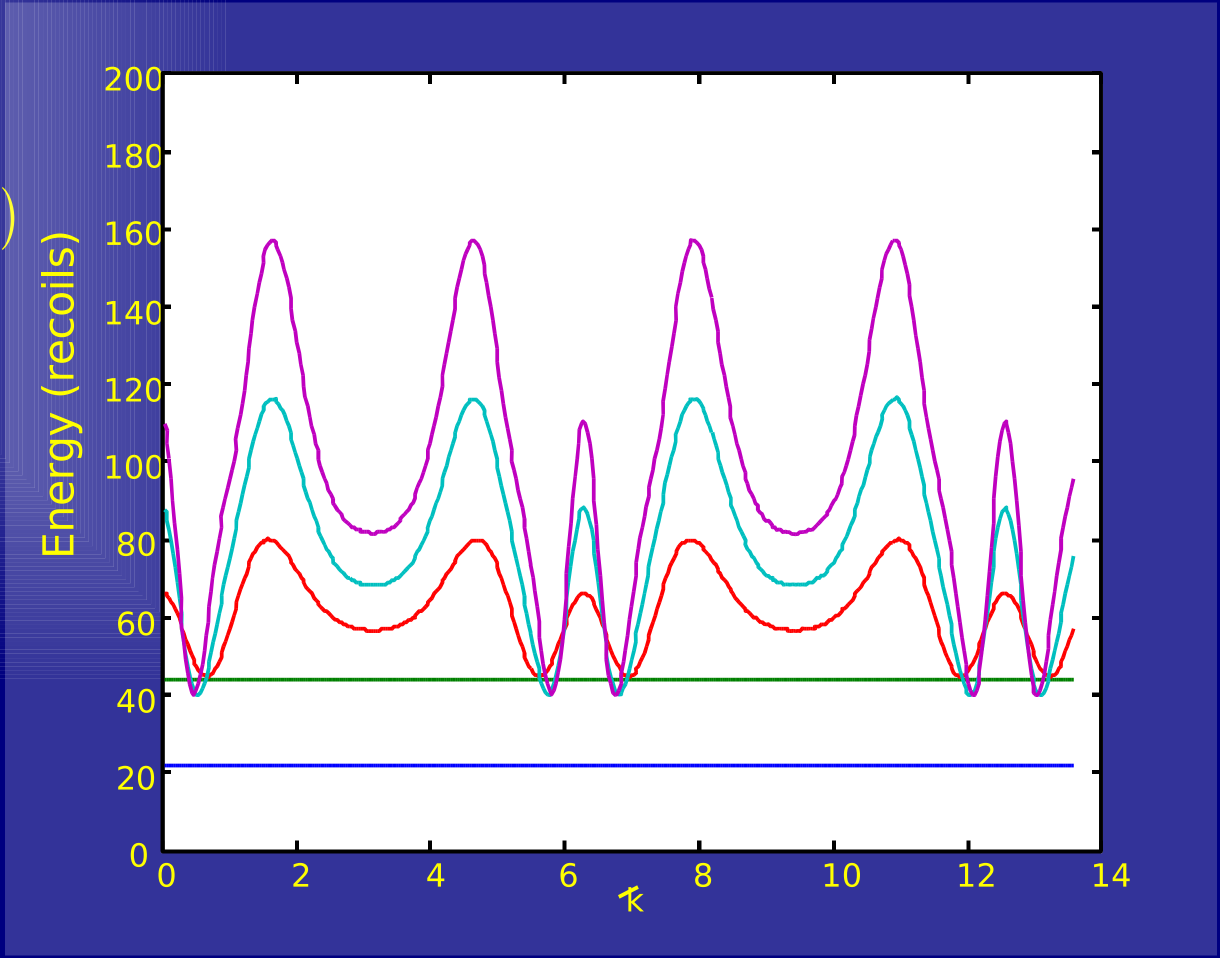
Analytical expressions

$$D_1 = \phi_d^2$$
$$D_2 = D_1$$
$$D_3 = D_2 - 2\phi_d^2 J_2(\kappa_q)$$
$$D_4 = D_3 + 2\phi_d^2 (J_3^2(\kappa_q) - J_1^2(\kappa_q))$$
$$D_5 = D_4 + 2\phi_d^2 J_2^2(\kappa_q)$$

where

$$D_i = E_i - E_{i-1}$$
$$\phi_d = \frac{\kappa}{k} = \frac{\Omega_{eff}\tau_p}{2}$$
$$\Omega_{eff} = \frac{\Omega^2}{\Delta}$$
$$\Omega^2 = \frac{\Gamma^2 I}{2 I_s}$$
$$\kappa_q = 2\phi_d \sin(k/2)$$

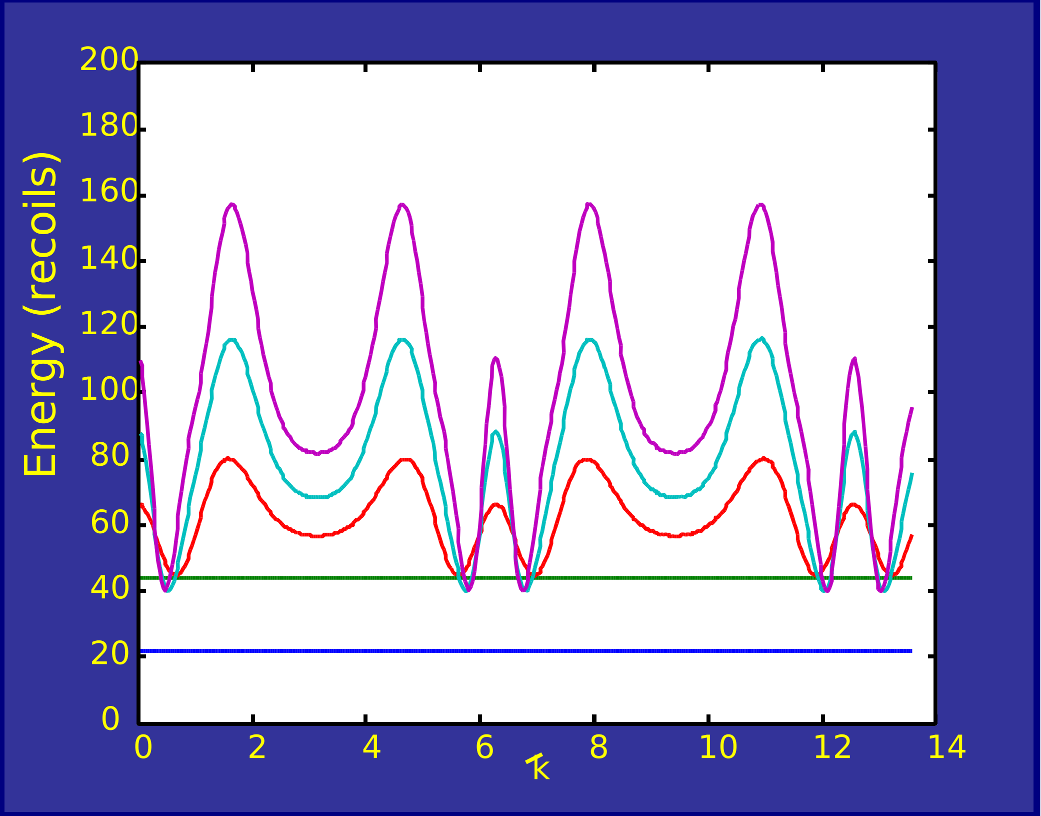
$J_n(x)$ is nth Bessel function



Kick period

Programme

- Measure development of diffusion resonances
- Quantitatively compare with theory
- Measure diffusion resonances for large kick power
- Demonstrate periodicity

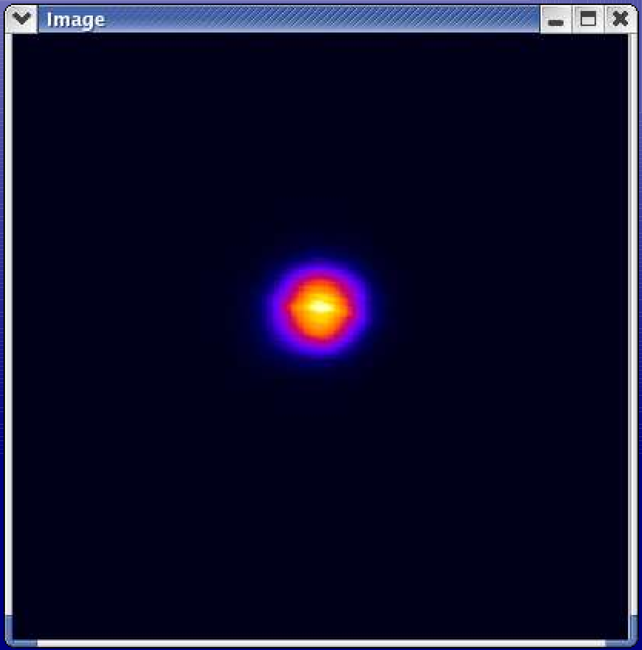


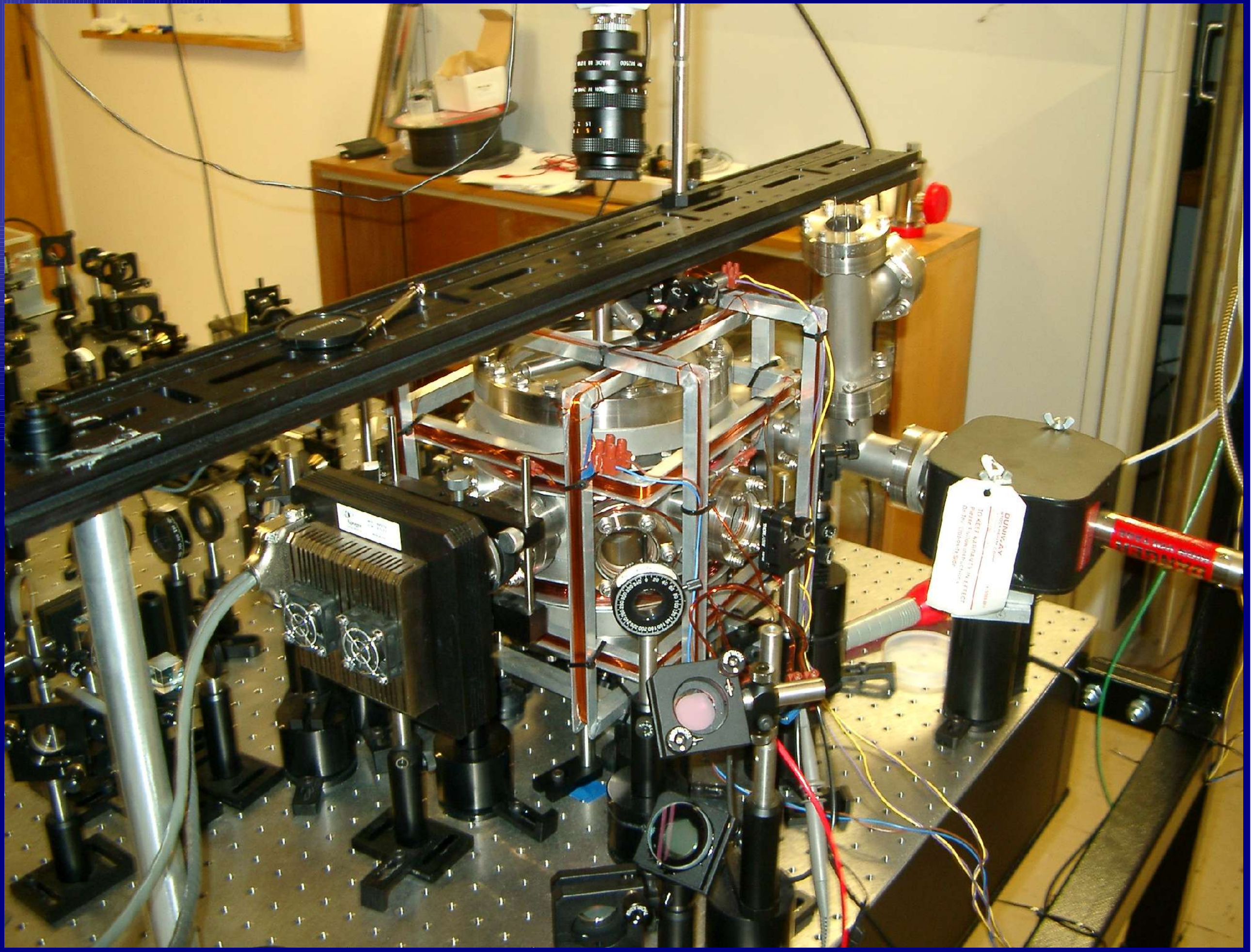
~~Simulations~~

~~Theorists~~

Equipment

- Rubidium 85
- Kick laser locked to ^{87}Rb, Δ= 1.3 GHz

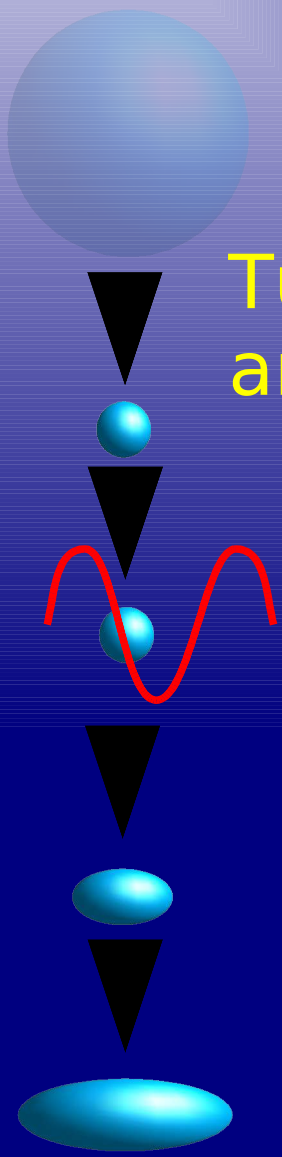




Experimental

- All lasers switched by AOMs
- Kick laser switched by home-build function/pulse generator
- Computer control using RTAI Linux
- VNC desktop for remote control

Experimental sequence

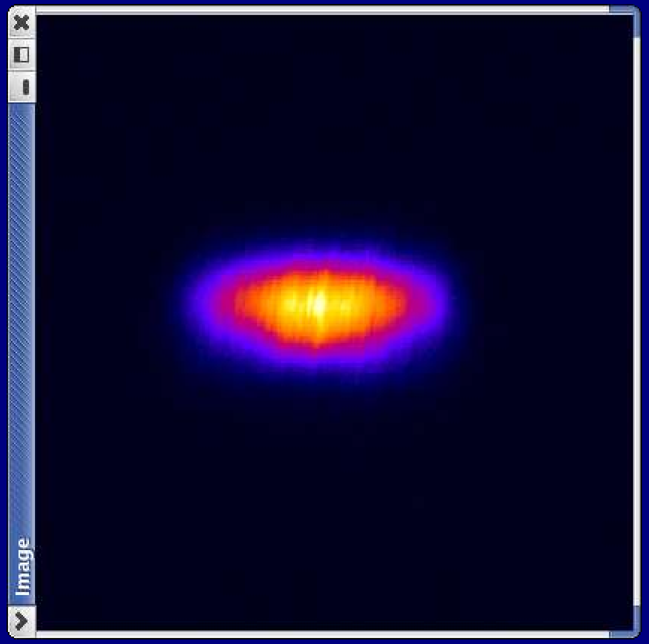


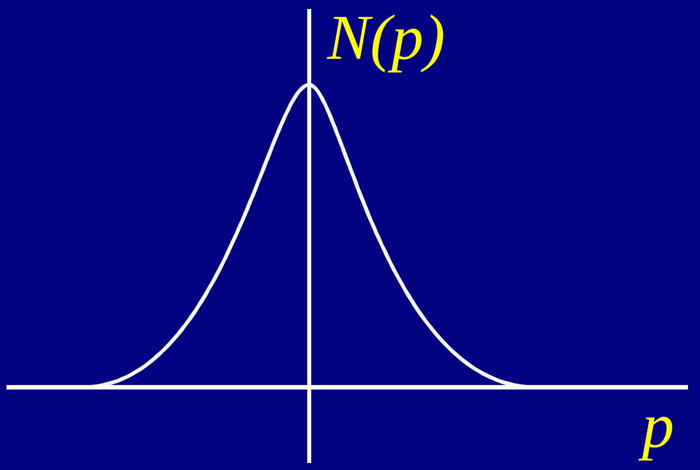
Turn on trapping beams and magnetic field

Turn off trapping apparatus and apply kicks

Free Expansion

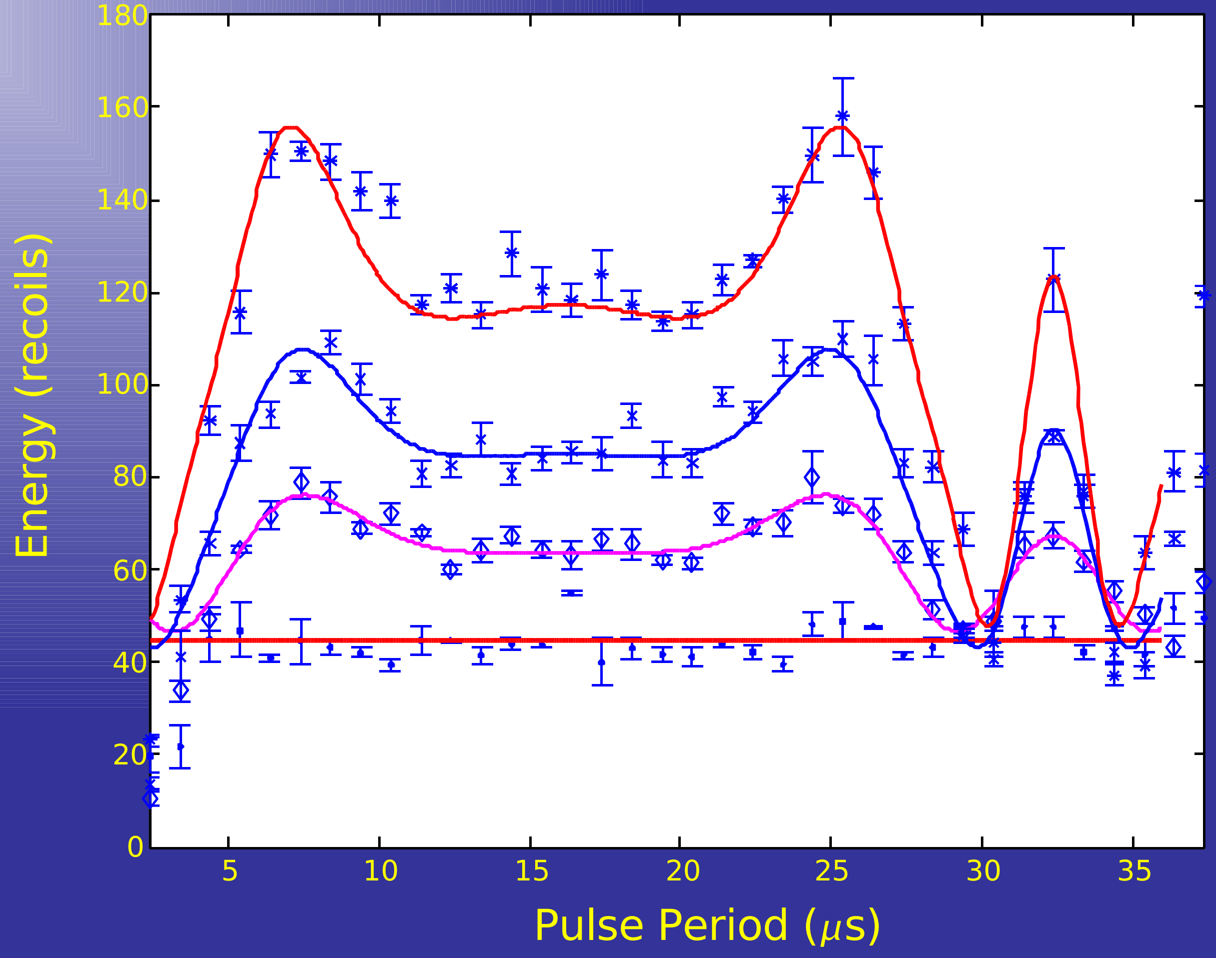
Molasses beams on and image cloud





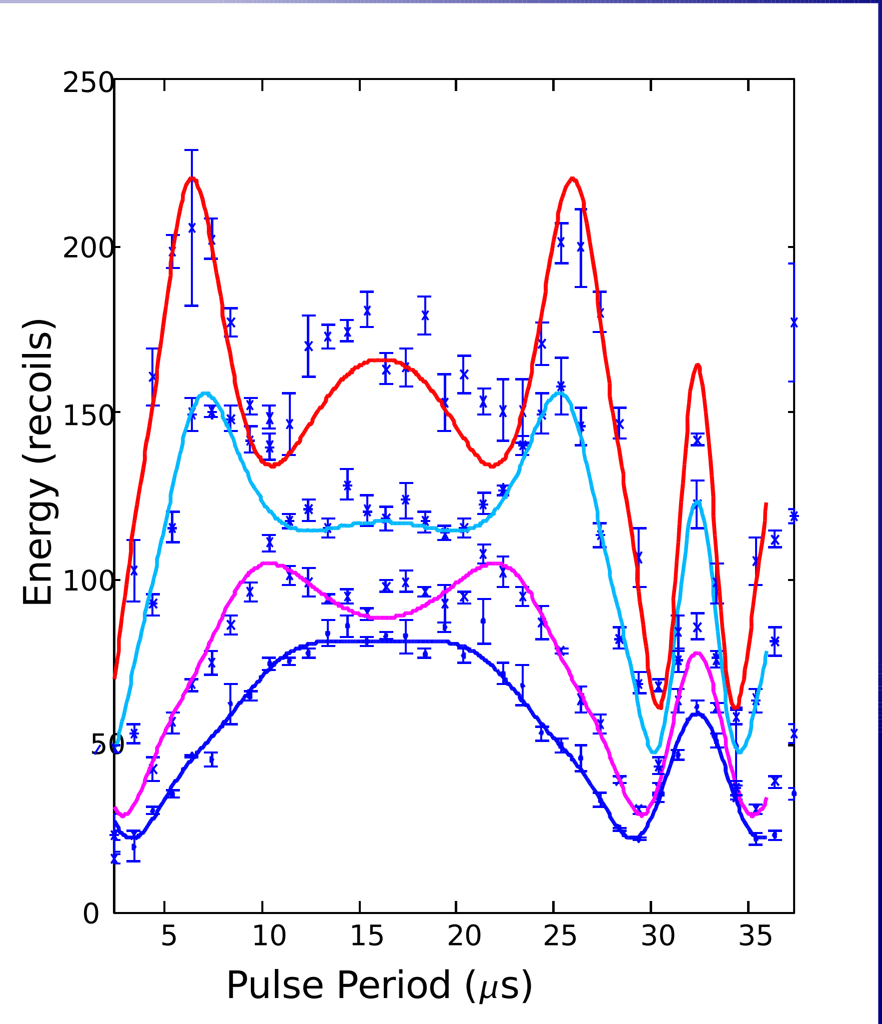
$\Rightarrow \sigma$

Small # kicks

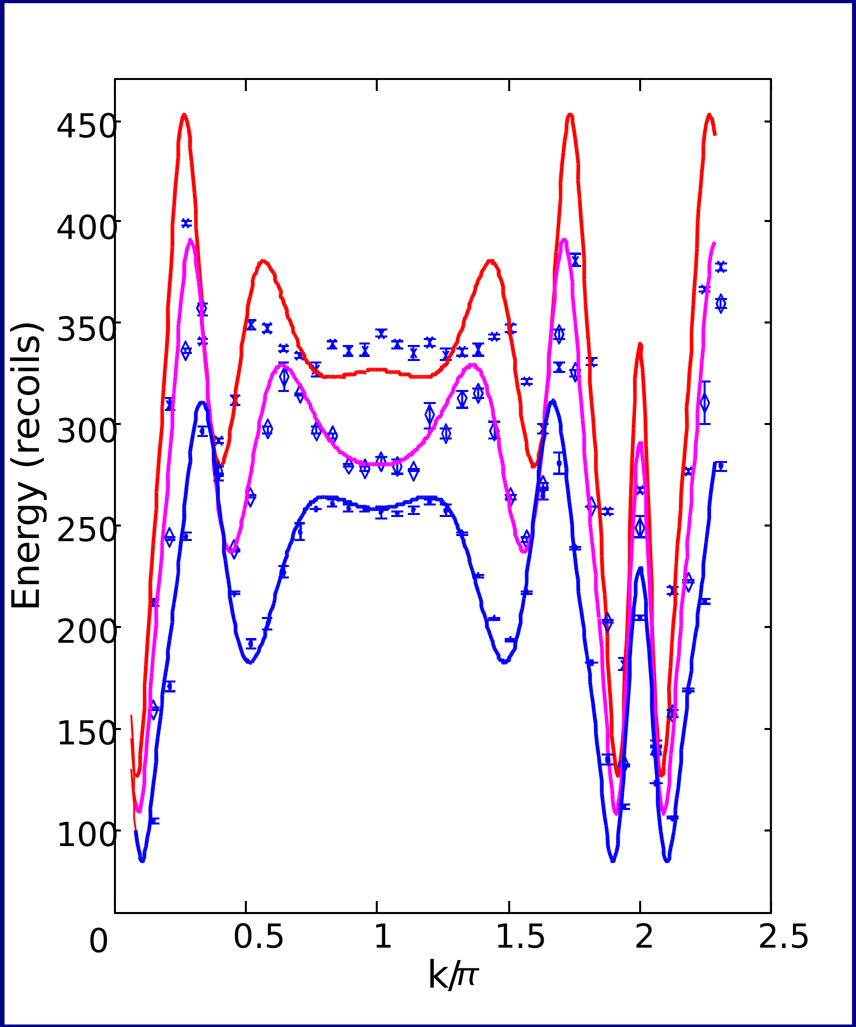


- ϕ_d=4.7

5 kicks



Energy (recoils)
Pulse Period (μs)
0
50
100
150
200
250
5
10
15
20
25
30
35

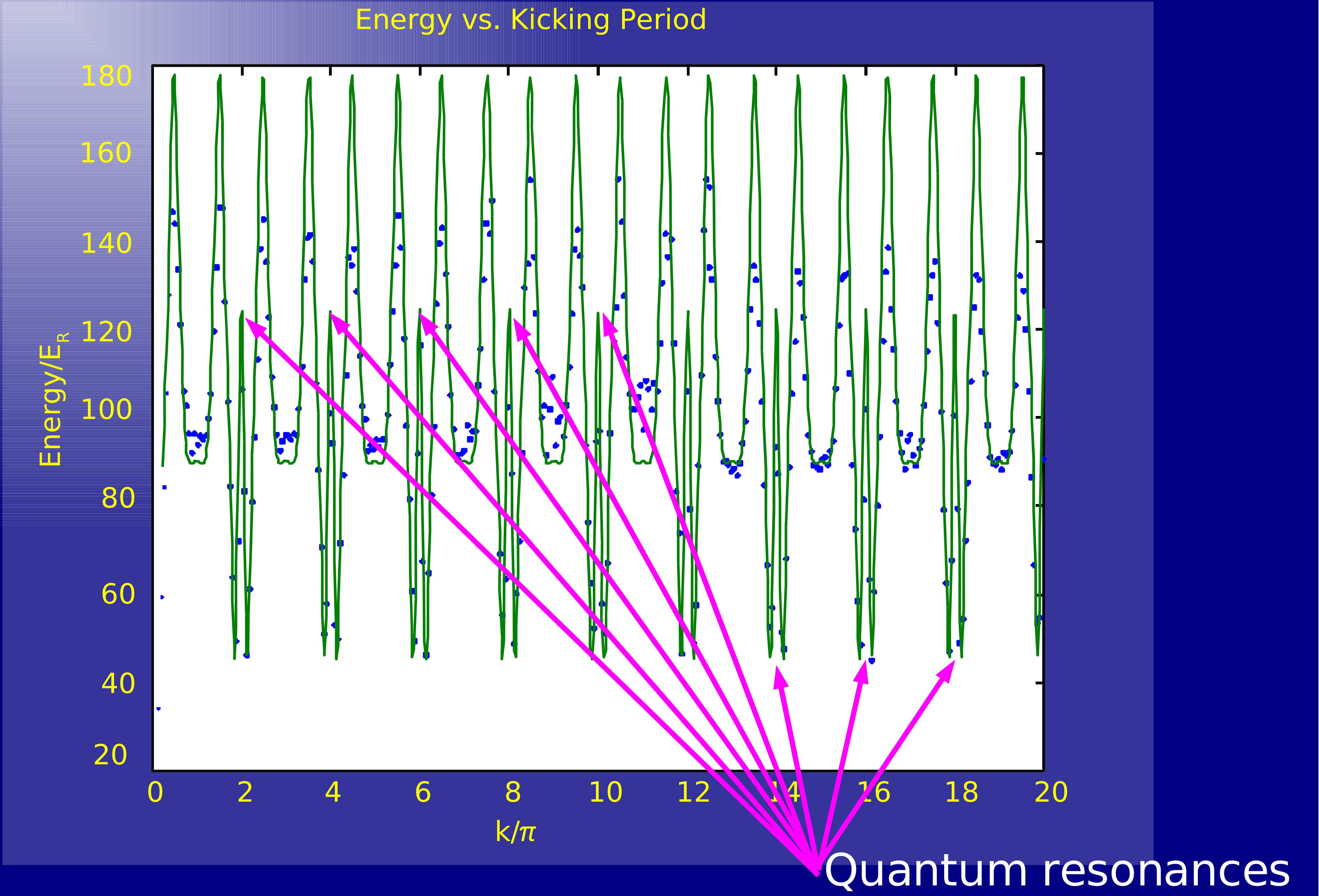


Energy (recoils)
k/π
100
150
200
250
300
350
400
450
0
0.5
1
1.5
2
2.5

Observations

- Low power:
  - no diffusion resonances
- Increasing power:
  - Diffusion resonances developing
  - Quantum resonance stays
  - Diffusion resonances moving
- High power:
  - Multiple diffusion resonances
  - Around QR still very low diffusion

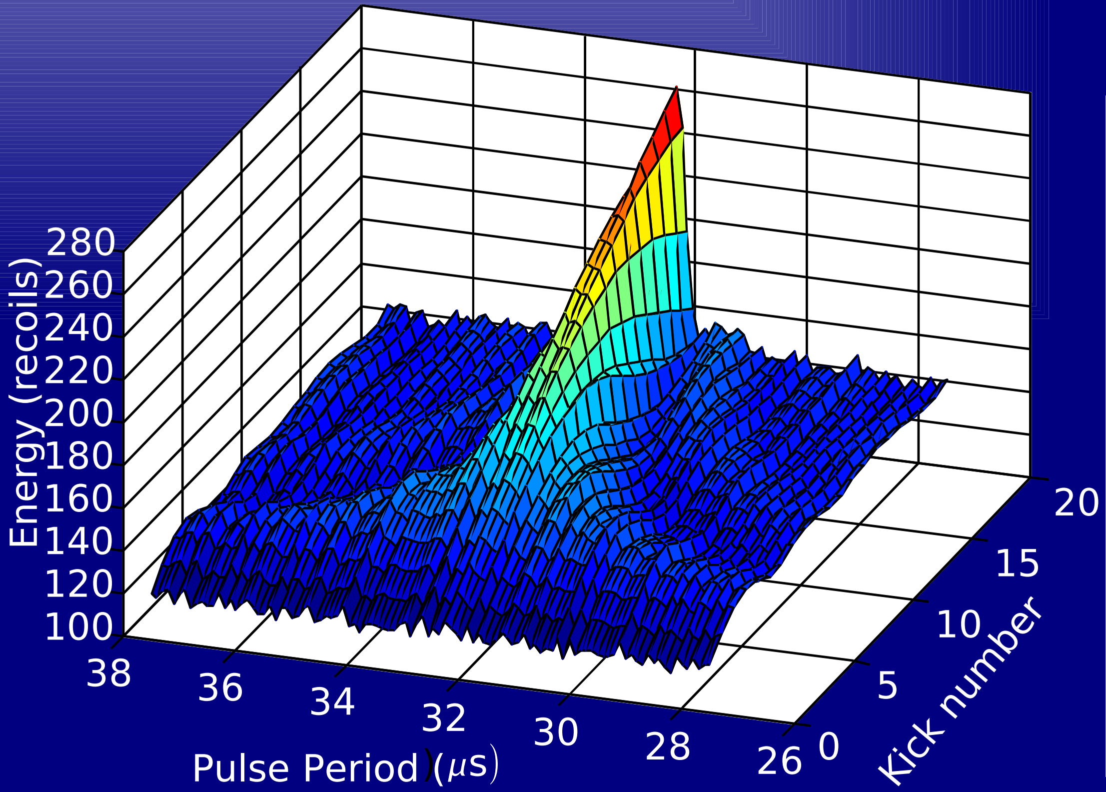
Periodic kicked rotor energy



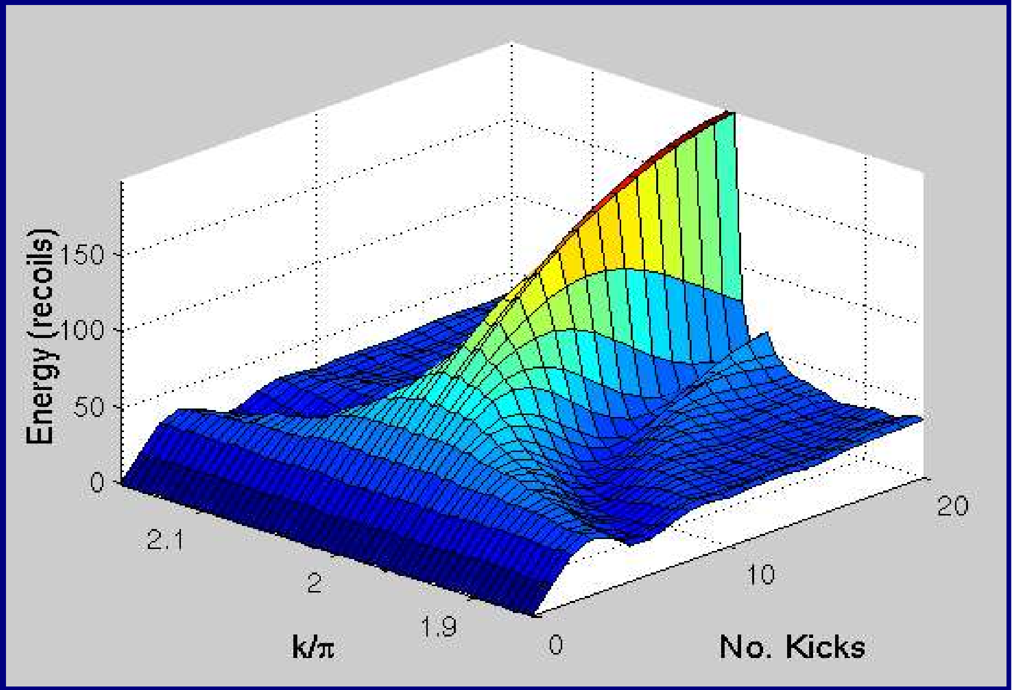
The quantum resonance

- $2n\pi$ accumulated phase
- System behaves classically as if free evolution had not happened

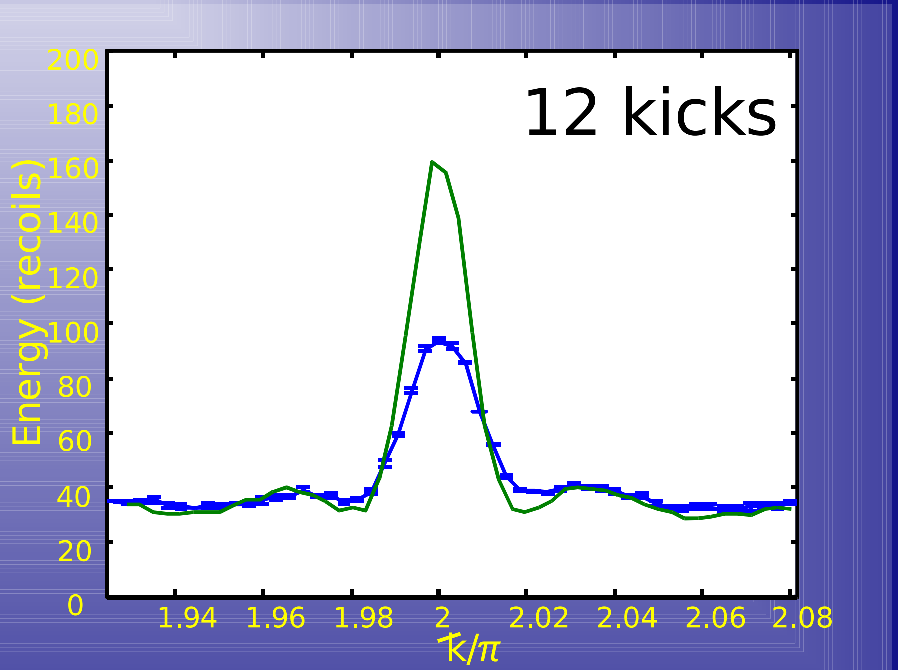
QM

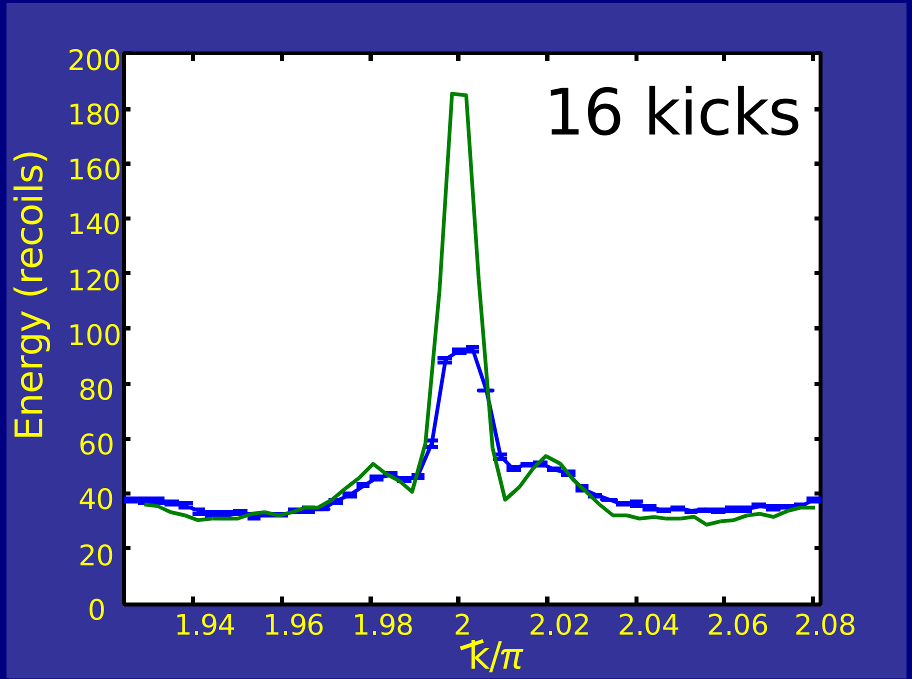


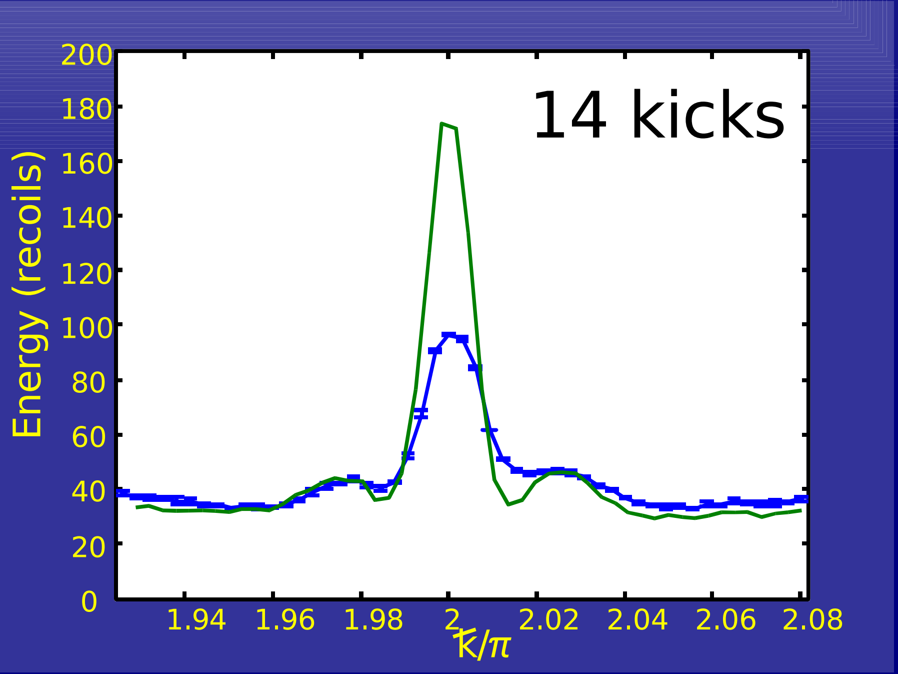
Classical

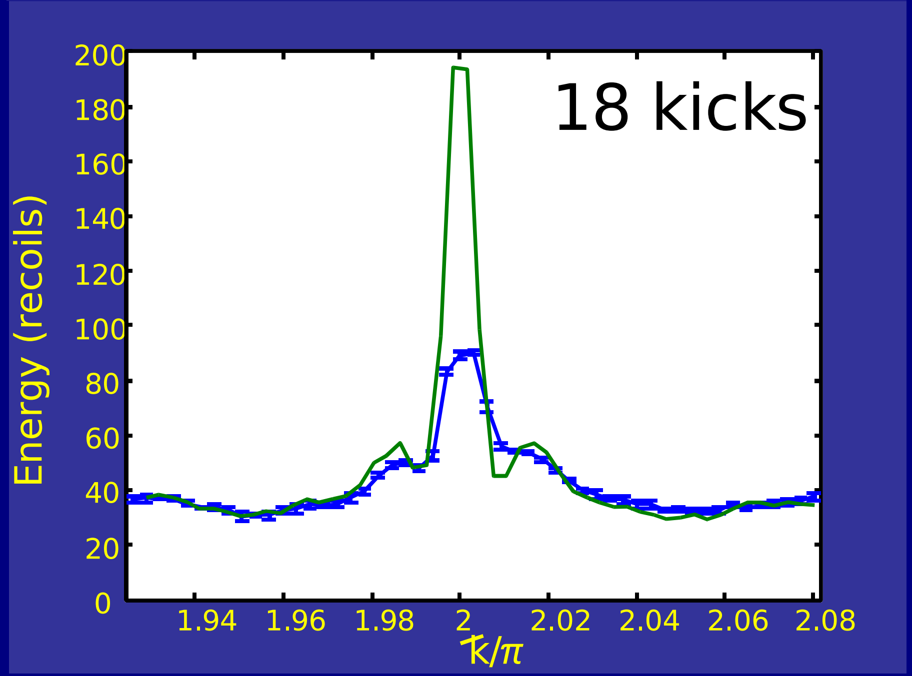


ϵ-quasi-classical

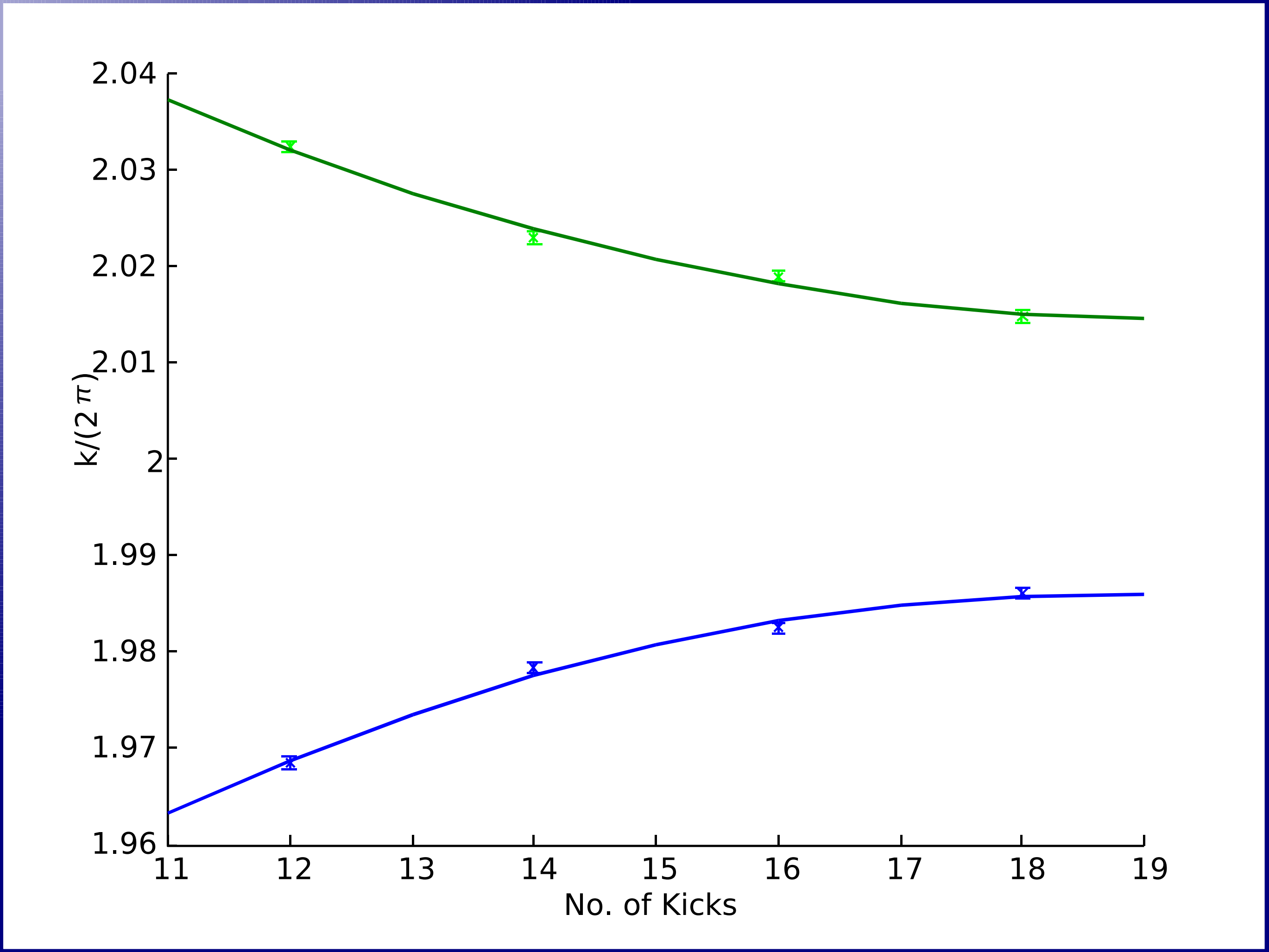








ϵ-classical



$$|\epsilon| = C\frac{\kappa}{n}$$

ϵ-classical effects

- System behaves quasi-classically in quantum regime
- Classical sidebands reproduced
- Sideband height, asymmetry and position agree with ϵ-classical and QMC simulations

Conclusions

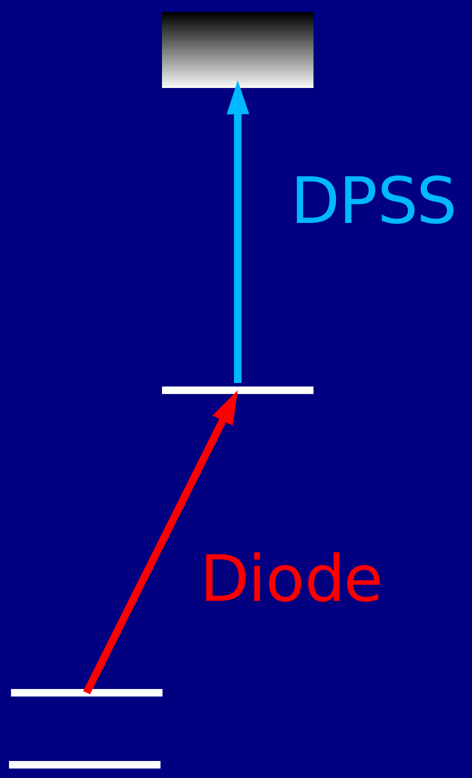
- Quantum system can behave quasi-classically
- Shepelyansky expressions for quantum behaviour confirmed
- Purely periodic behaviour with kick period

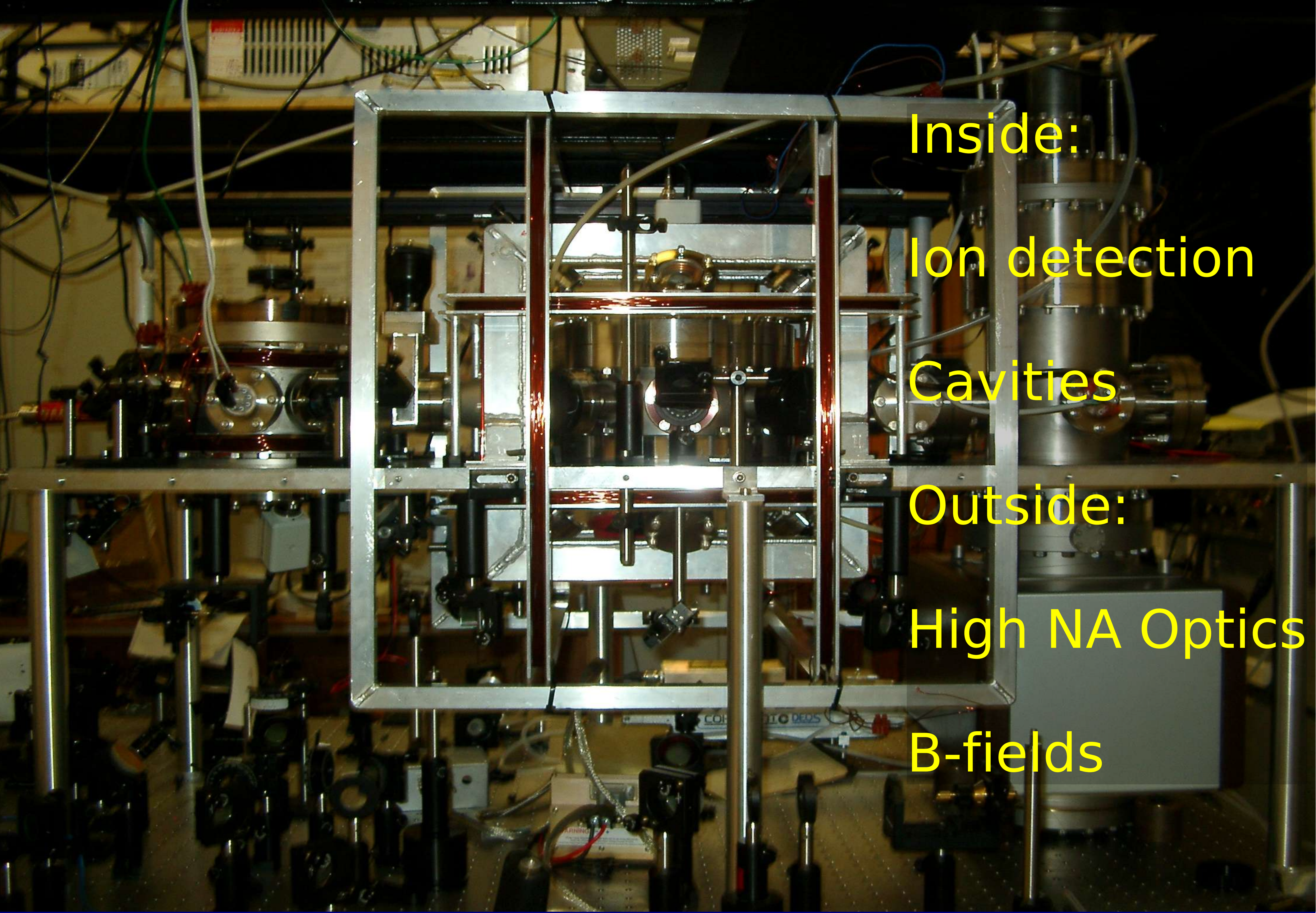
The future?

- BEC in focused CO_2 laser

- BEC experiments:
  - Atom counting statistics
  - Atom by atom phase
  - Collective emission effects
  - Optical cavities

- Quantum Information experiments
  - Detect qubits
  - Qubit entanglement with Cavity fields
  - Quantum logic
  - Quantum computers





Inside:

Ion detection

Cavities

Outside:

High NA Optics

B-fields

Graduate student projects available