Détection non destructive sur horloge à réseau optique au strontium

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SYRTE-Observatoire de Paris

AG FIRST-TF 2018

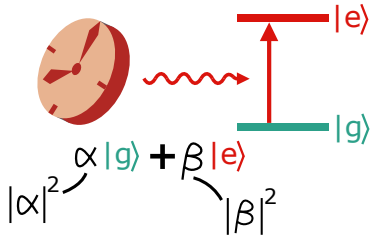
Outlines

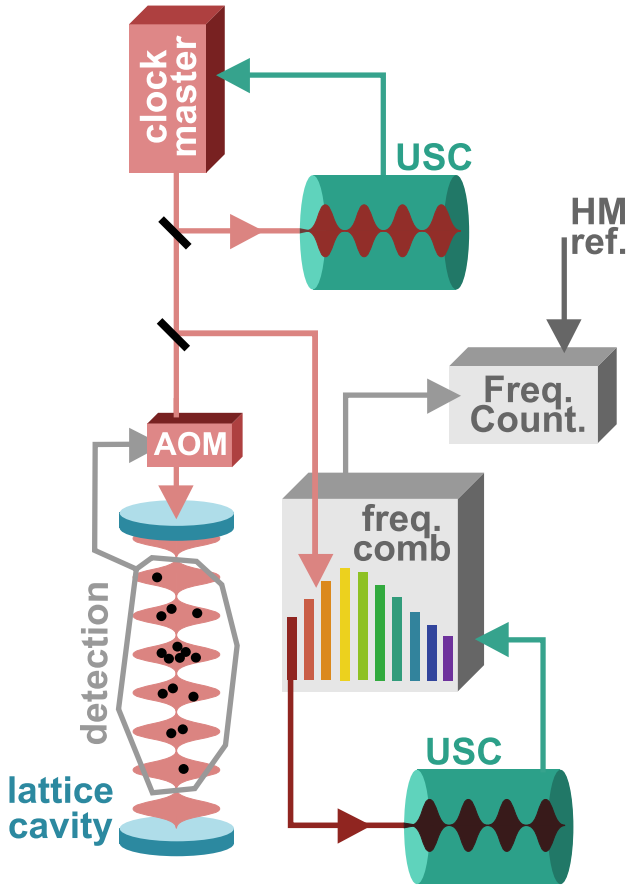
Section I. :

Sr optical clocks

- ultra stable laser probing narrow atomic transition (3 Hz)

$$\longrightarrow Q \sim 10^{14}$$





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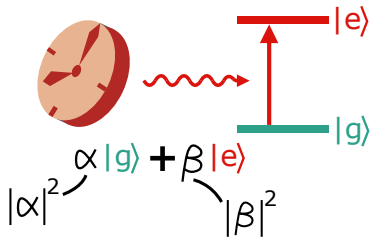
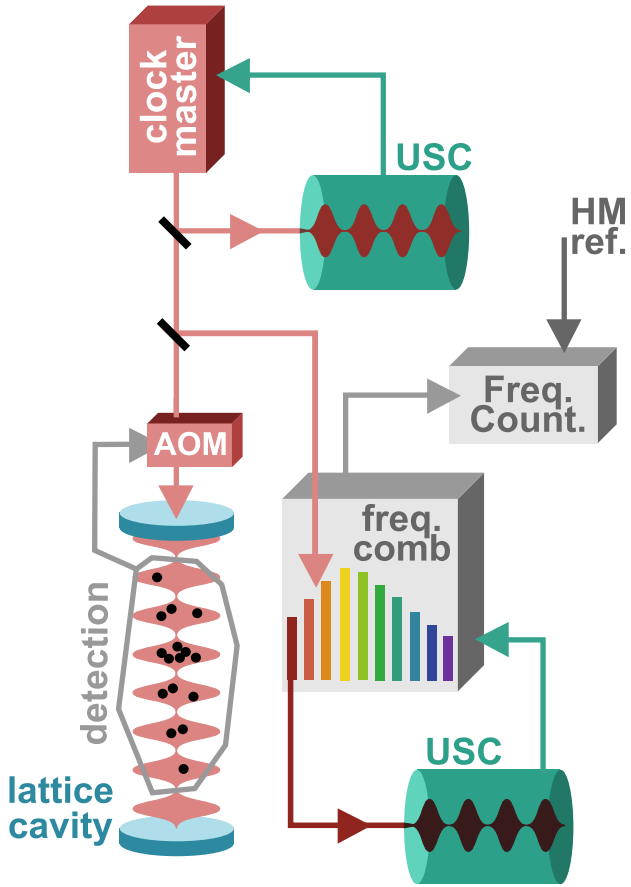


- atoms trapped in a lattice
  $\longrightarrow$ large number of atoms
  $\longrightarrow$ **Lamb-Dicke** regime
  motional effects cancelled



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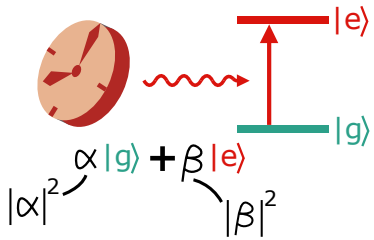

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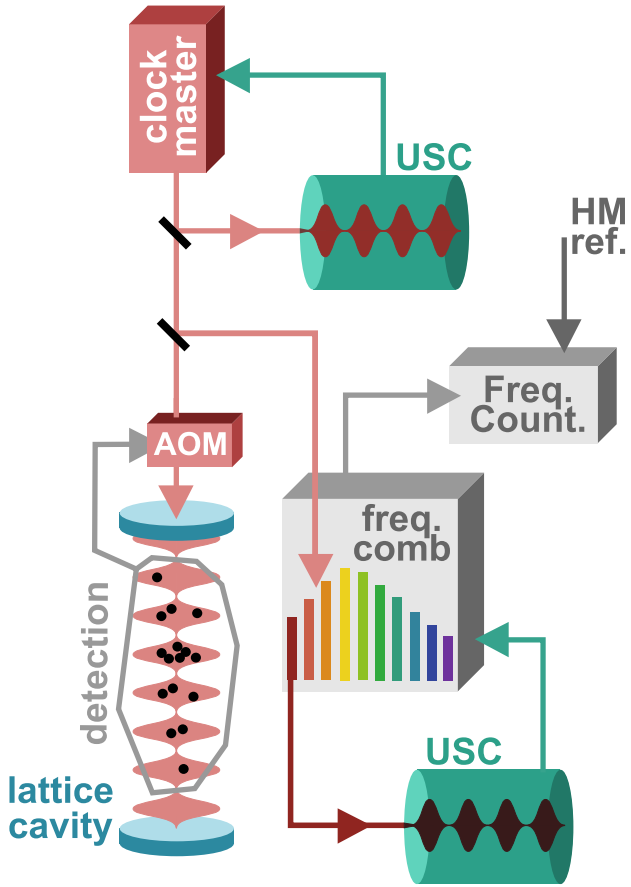

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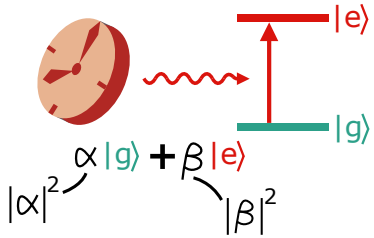

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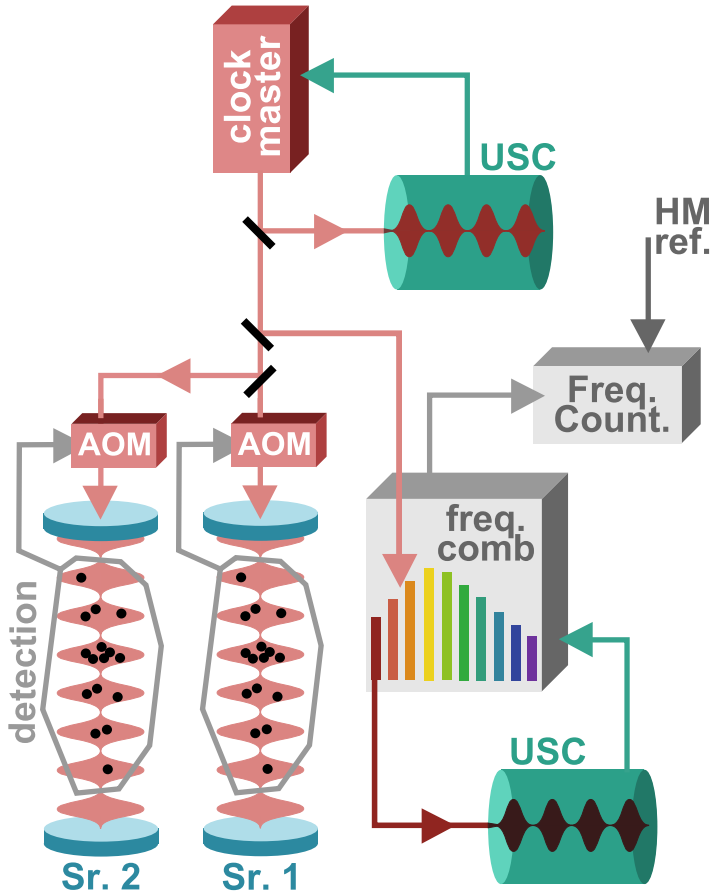


Section II. :

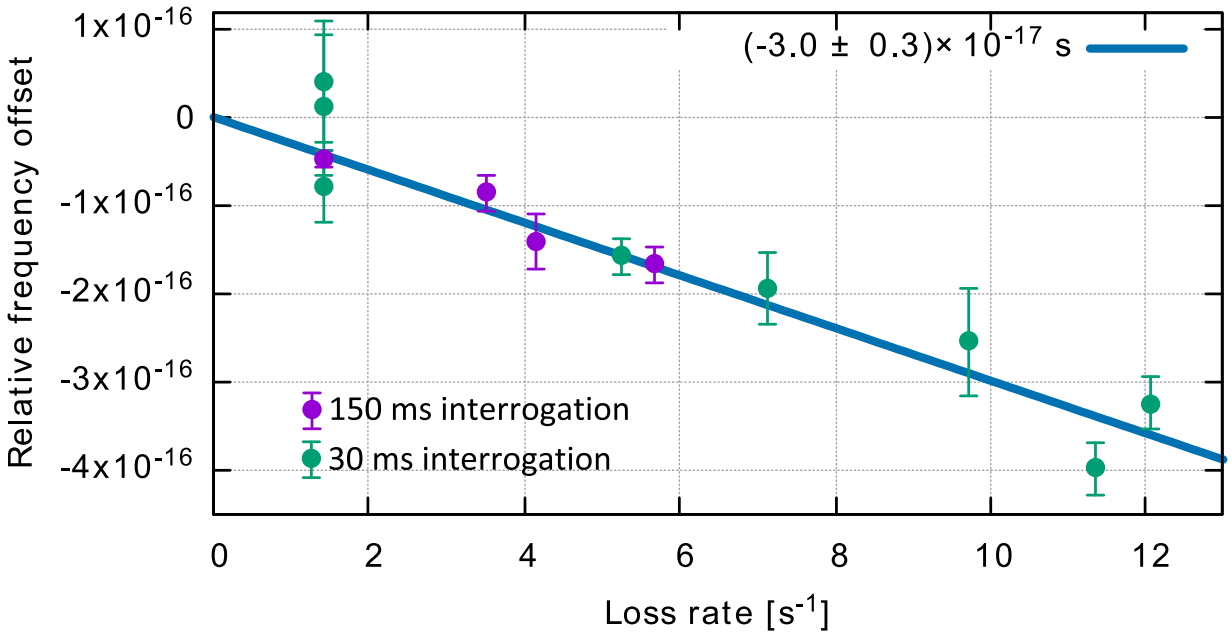
Accuracy

accuracy budget (2018)

EFFECT	Uncertainty (x 10^{-18})
Quad. Zeeman shift	5
Lattice light shift	3
Lattice spectrum	1
Black body	12
Density shift	8
Line pulling	6
Back ground collisions	4
static charges	1.5
Total	17

Effect of hot collisions with residual back ground gas (H_2, pressure P)

- atoms lost at rate $\frac{1}{\tau} \propto P$
- frequency shift $\delta\nu \propto P \propto \frac{1}{\tau}$



effect largely underestimated for Sr until now

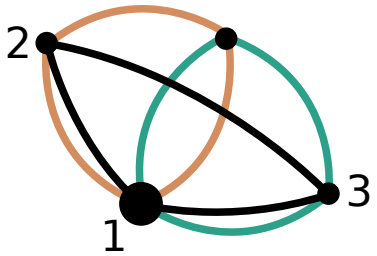
Section III. :

Stability

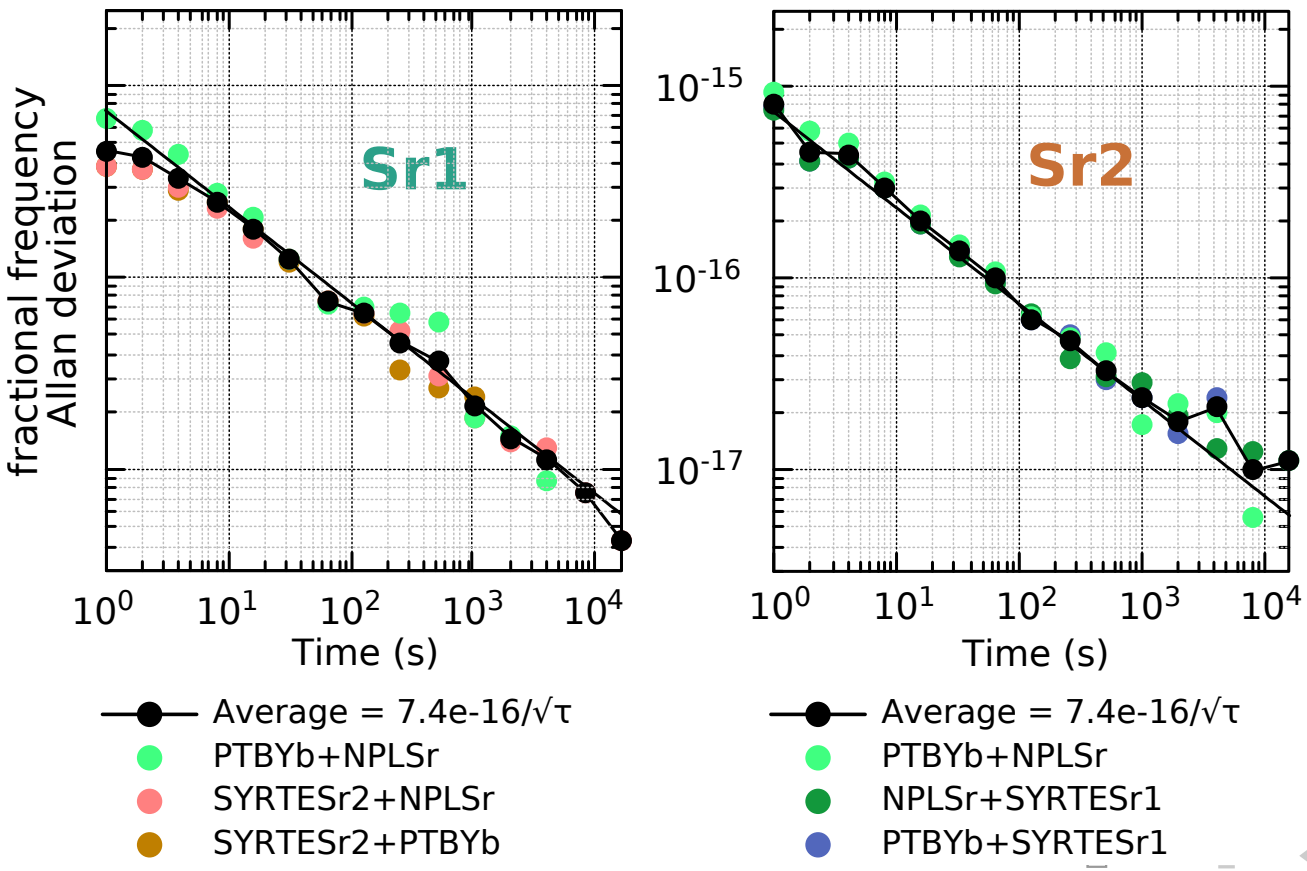
June 2017:thanks to our colleagues from

NPL National Physical Laboratory · PTB · LPL Laboratoire de physique des lasers

3 cornered-hat → single clock stability



$$\sigma_1^2 = \frac{1}{2}\left(\sigma_{12}^2 + \sigma_{13}^2 - \sigma_{23}^2\right)$$



III. STABILITY, III.1. 3 cornered hat stability

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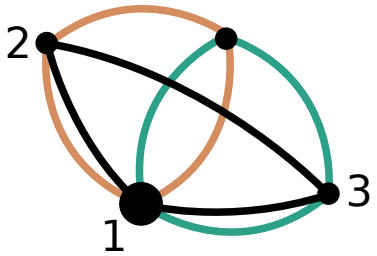

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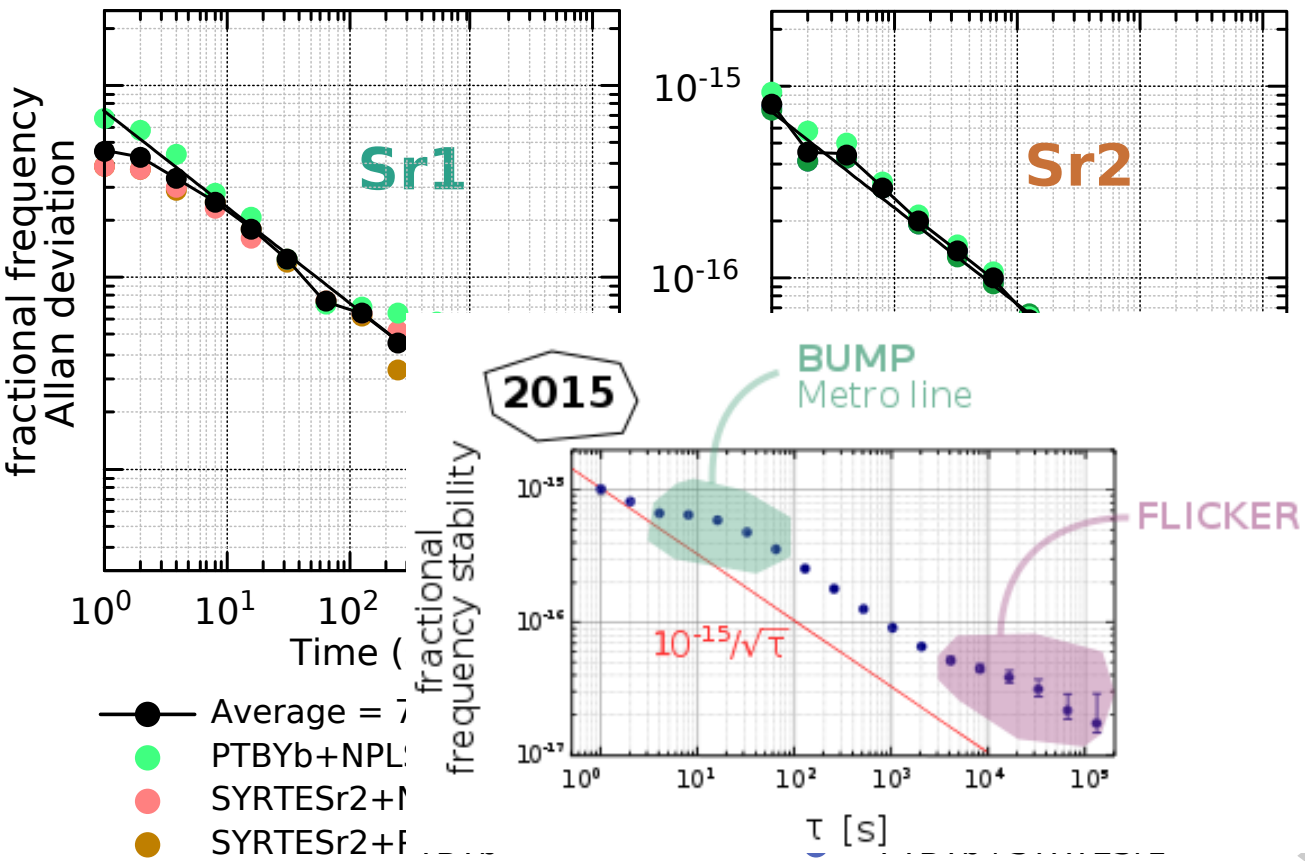
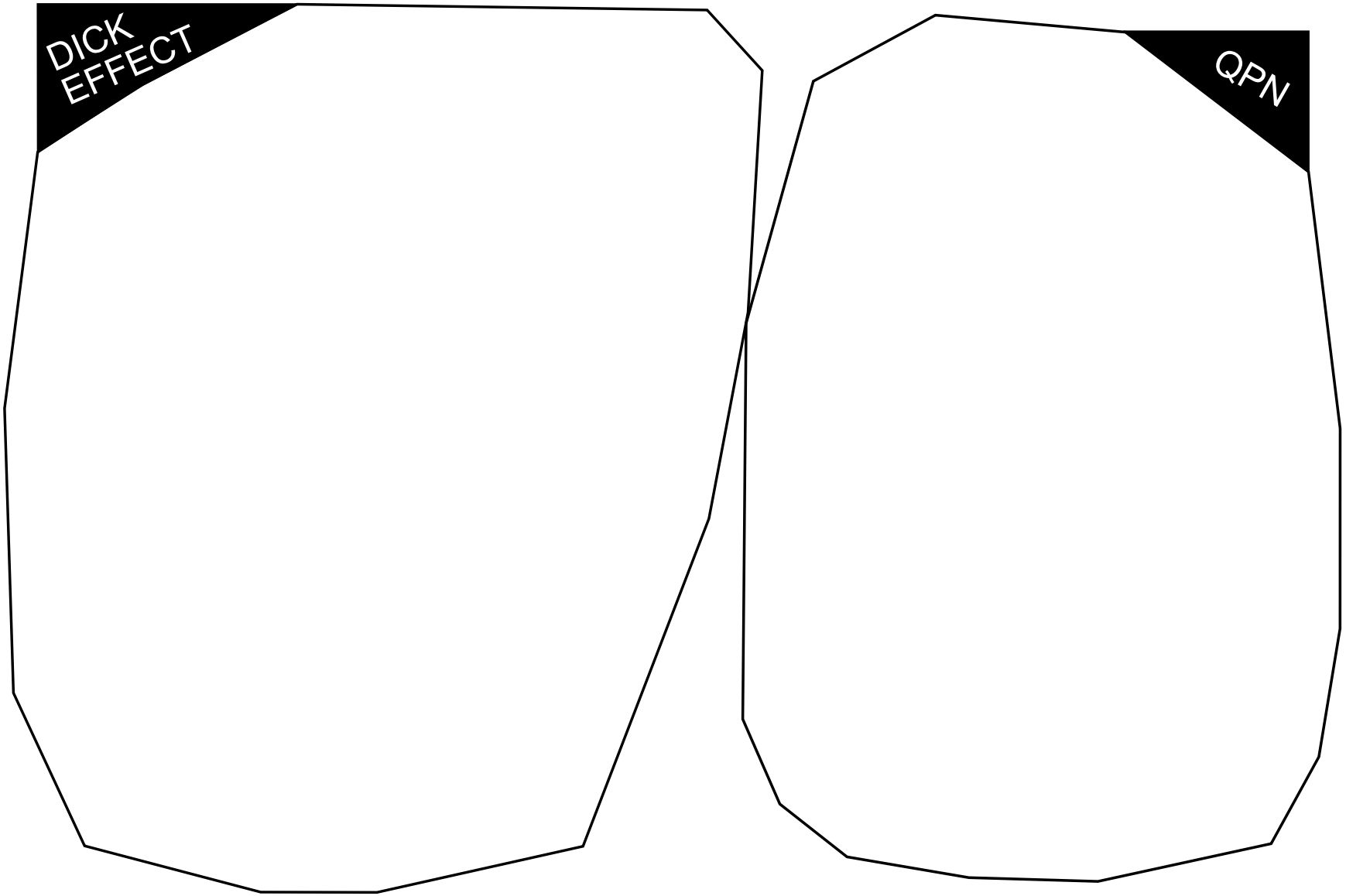
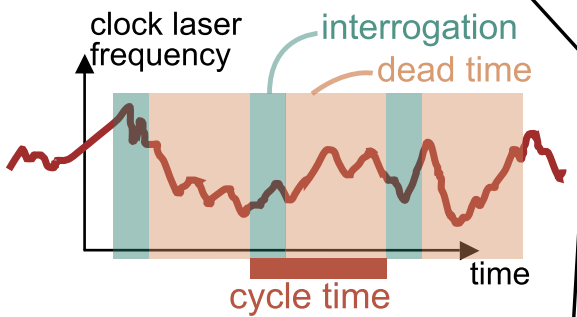


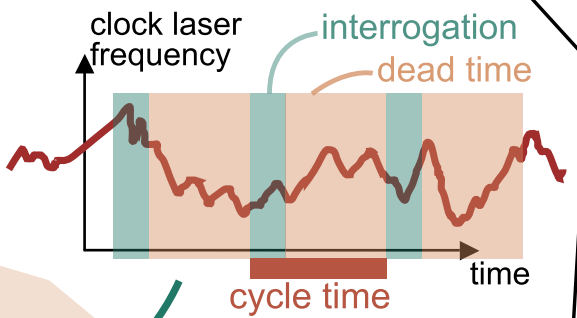

DICK
EFFECT
QPN

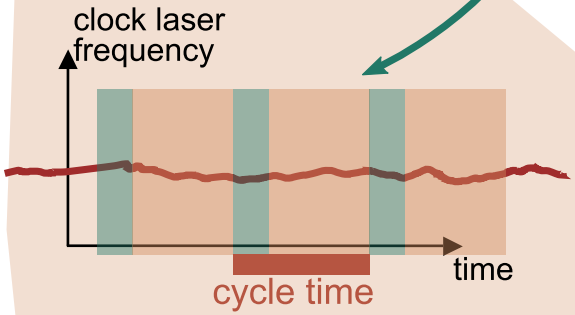
DICK EFFECT



QPN

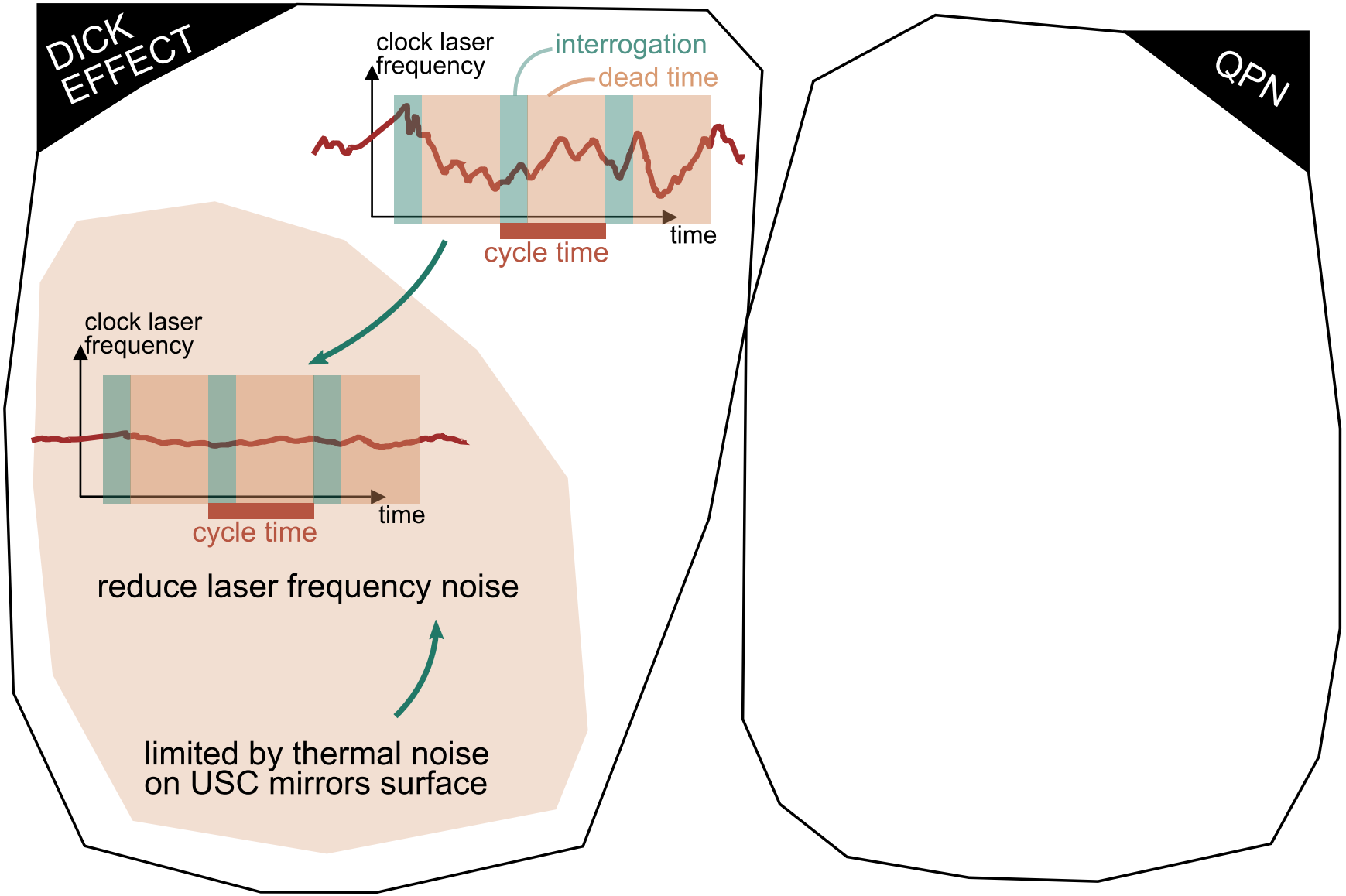
DICK EFFECT



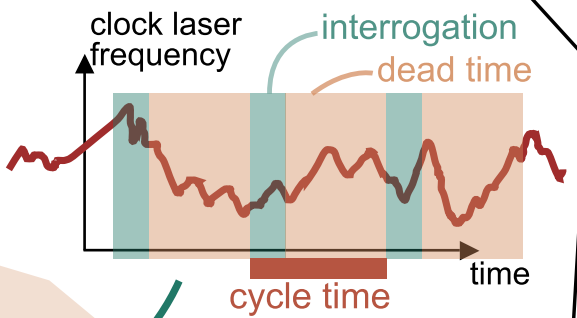


reduce laser frequency noise

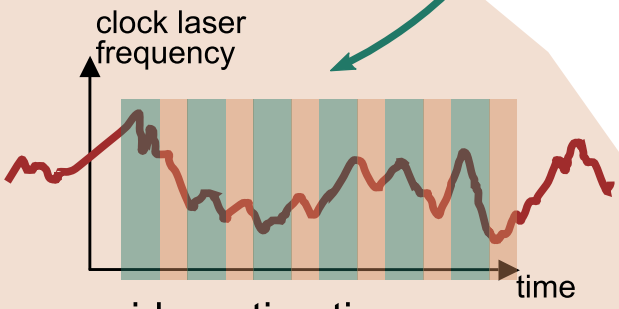
QPN


DICK EFFECT
clock laser frequency
interrogation
dead time
time
cycle time
clock laser frequency
time
cycle time
reduce laser frequency noise
limited by thermal noise on USC mirrors surface
QPN

DICK EFFECT



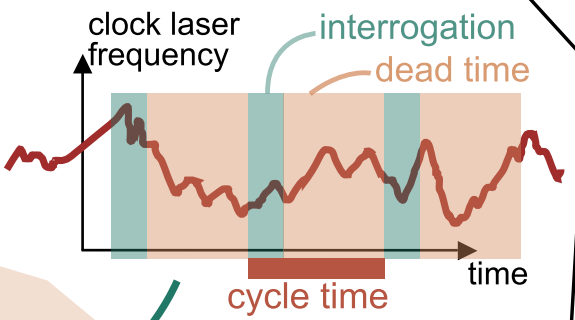
reduce the dead time



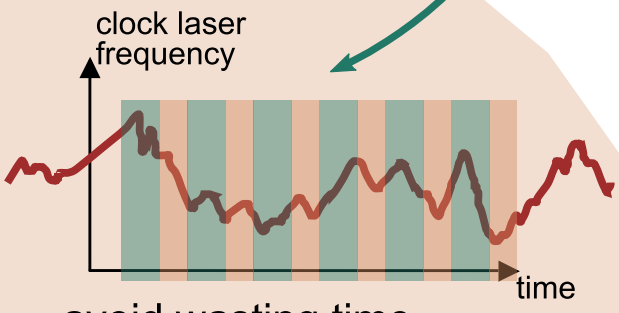
avoid wasting time reloading the lattice trap

QPN

DICK EFFECT



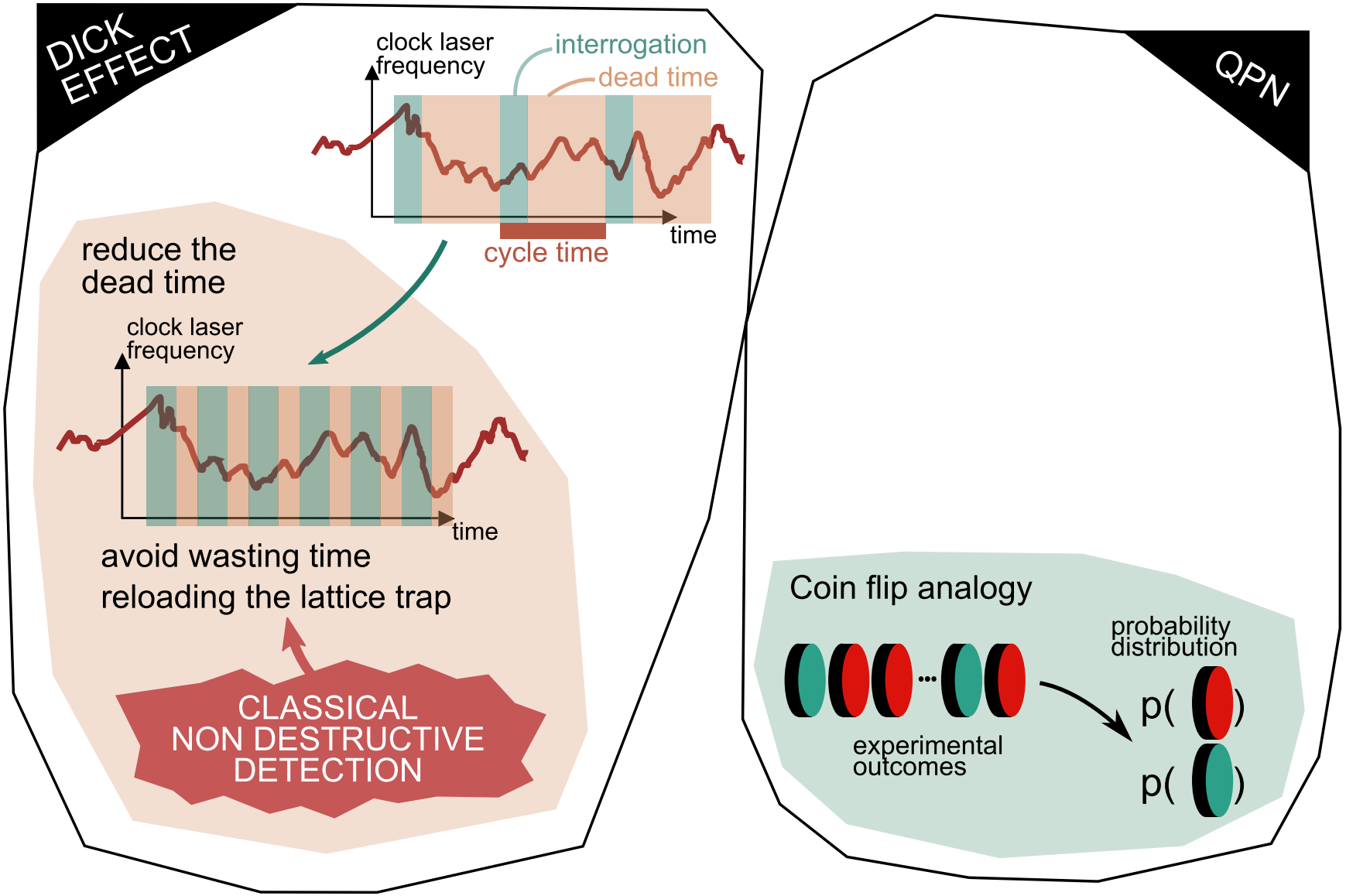
reduce the dead time

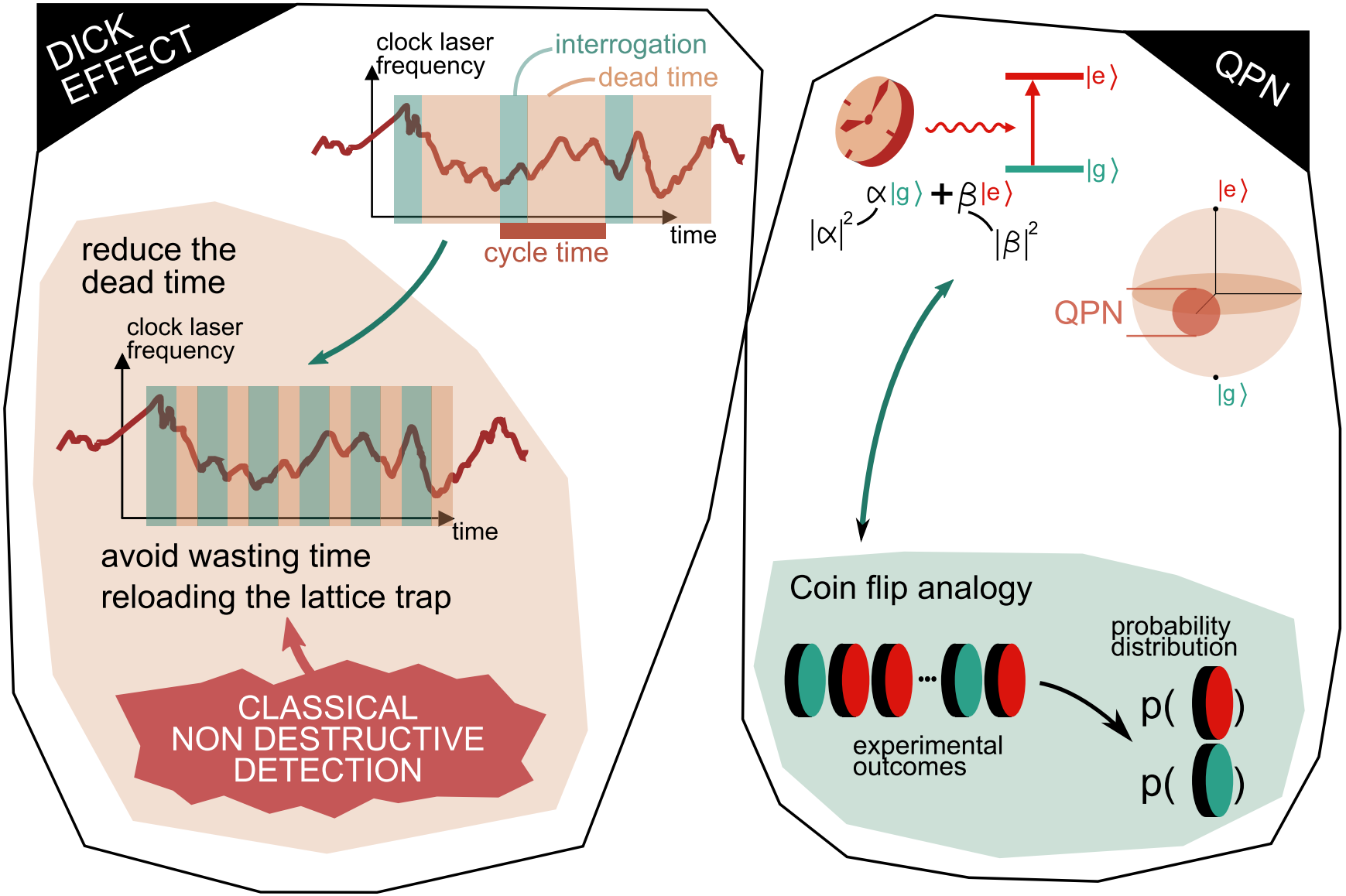


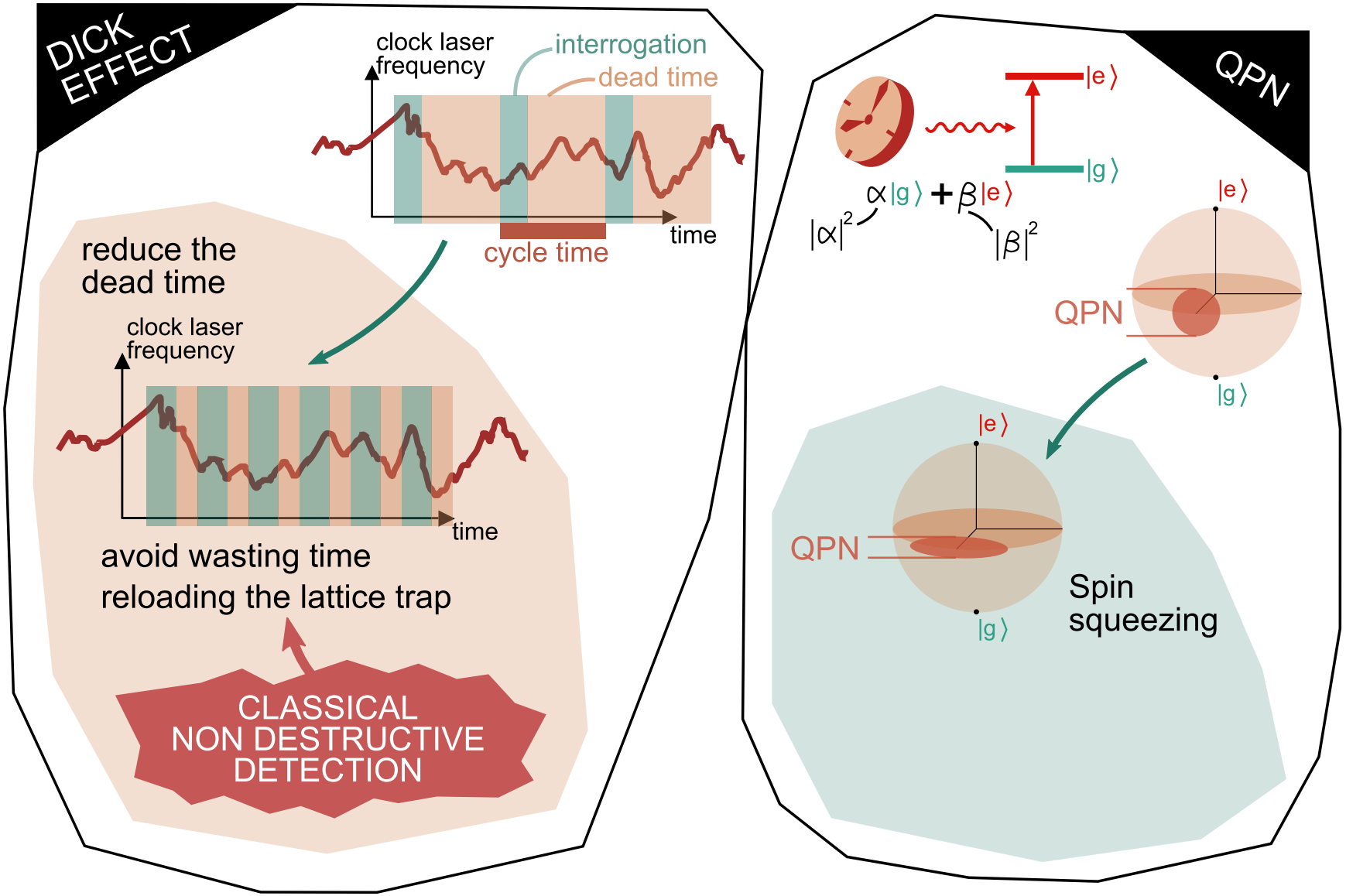
avoid wasting time reloading the lattice trap

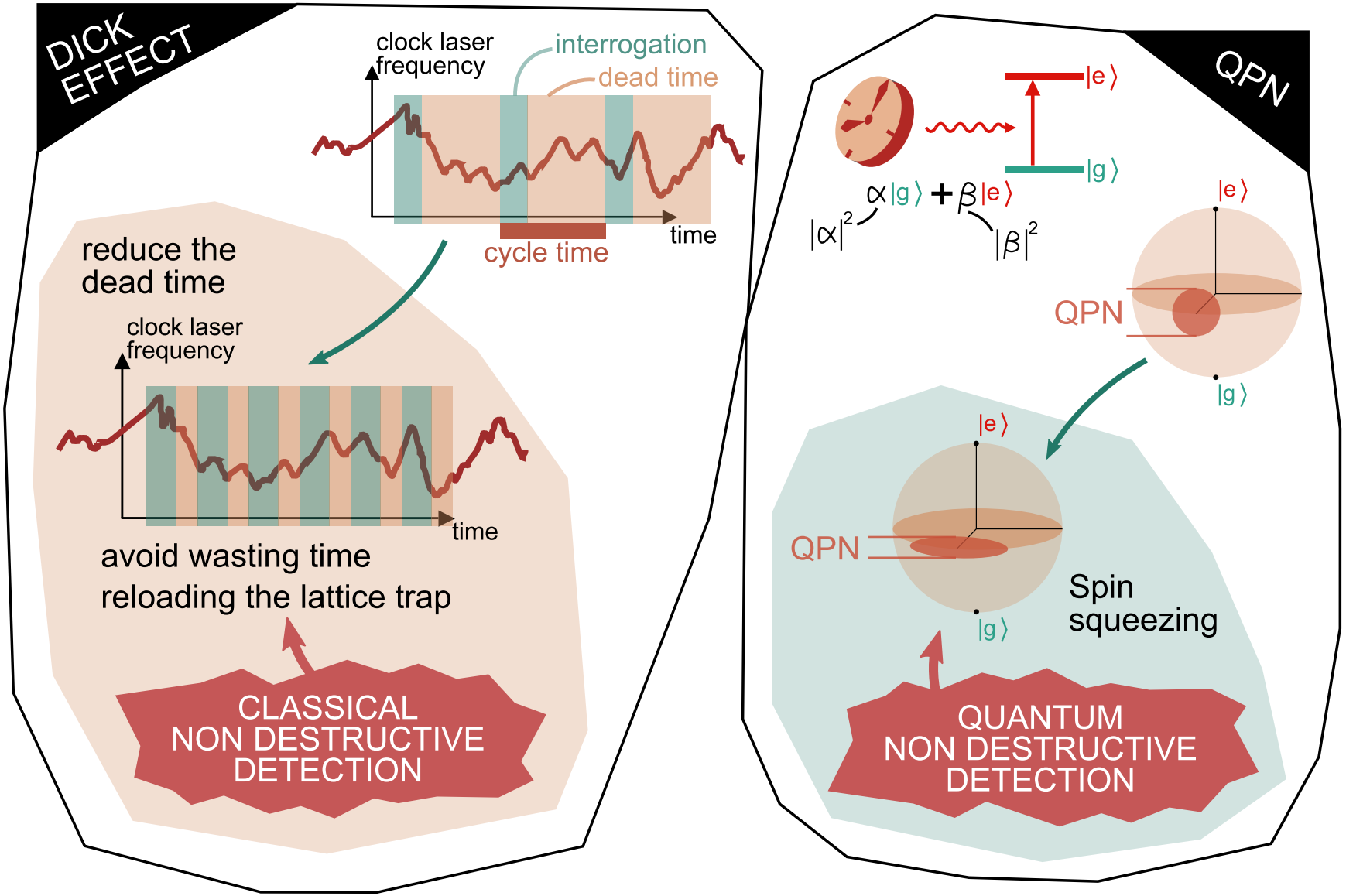
CLASSICAL NON DESTRUCTIVE DETECTION

QPN


DICK EFFECT
clock laser frequency
interrogation
dead time
time
cycle time
reduce the dead time
clock laser frequency
time
avoid wasting time
reloading the lattice trap
CLASSICAL NON DESTRUCTIVE DETECTION
QPN
Coin flip analogy
probability distribution
p(
p(
experimental outcomes


DICK EFFECT
clock laser frequency
interrogation
dead time
time
cycle time
reduce the dead time
clock laser frequency
time
avoid wasting time
reloading the lattice trap
CLASSICAL NON DESTRUCTIVE DETECTION
QPN
|e⟩
|g⟩
α|g⟩ + β|e⟩
|α|²
|β|²
|e⟩
QPN
|g⟩
Coin flip analogy
probability distribution
experimental outcomes
p( )
p( )


DICK EFFECT
clock laser frequency
interrogation
dead time
time
cycle time
reduce the dead time
clock laser frequency
time
avoid wasting time
reloading the lattice trap
CLASSICAL NON DESTRUCTIVE DETECTION
QPN
|e⟩
|g⟩
α|g⟩ + β|e⟩
|α|²
|β|²
|e⟩
QPN
|g⟩
|e⟩
QPN
|g⟩
Spin squeezing


DICK EFFECT
clock laser frequency
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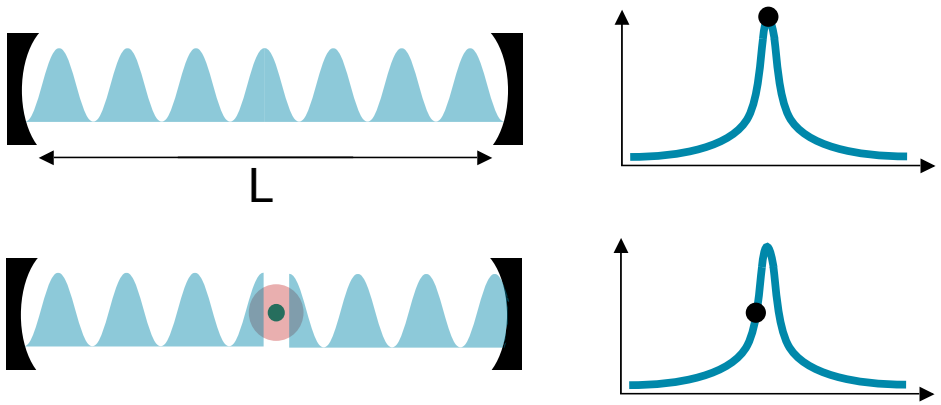
CLASSICAL NON DESTRUCTIVE DETECTION
QPN
|e⟩
|g⟩
α|g⟩ + β|e⟩
|α|²
|β|²
|e⟩
QPN
|g⟩
|e⟩
QPN
|g⟩
Spin squeezing
QUANTUM NON DESTRUCTIVE DETECTION

Section IV. :

Non-destructive detection (NDD)



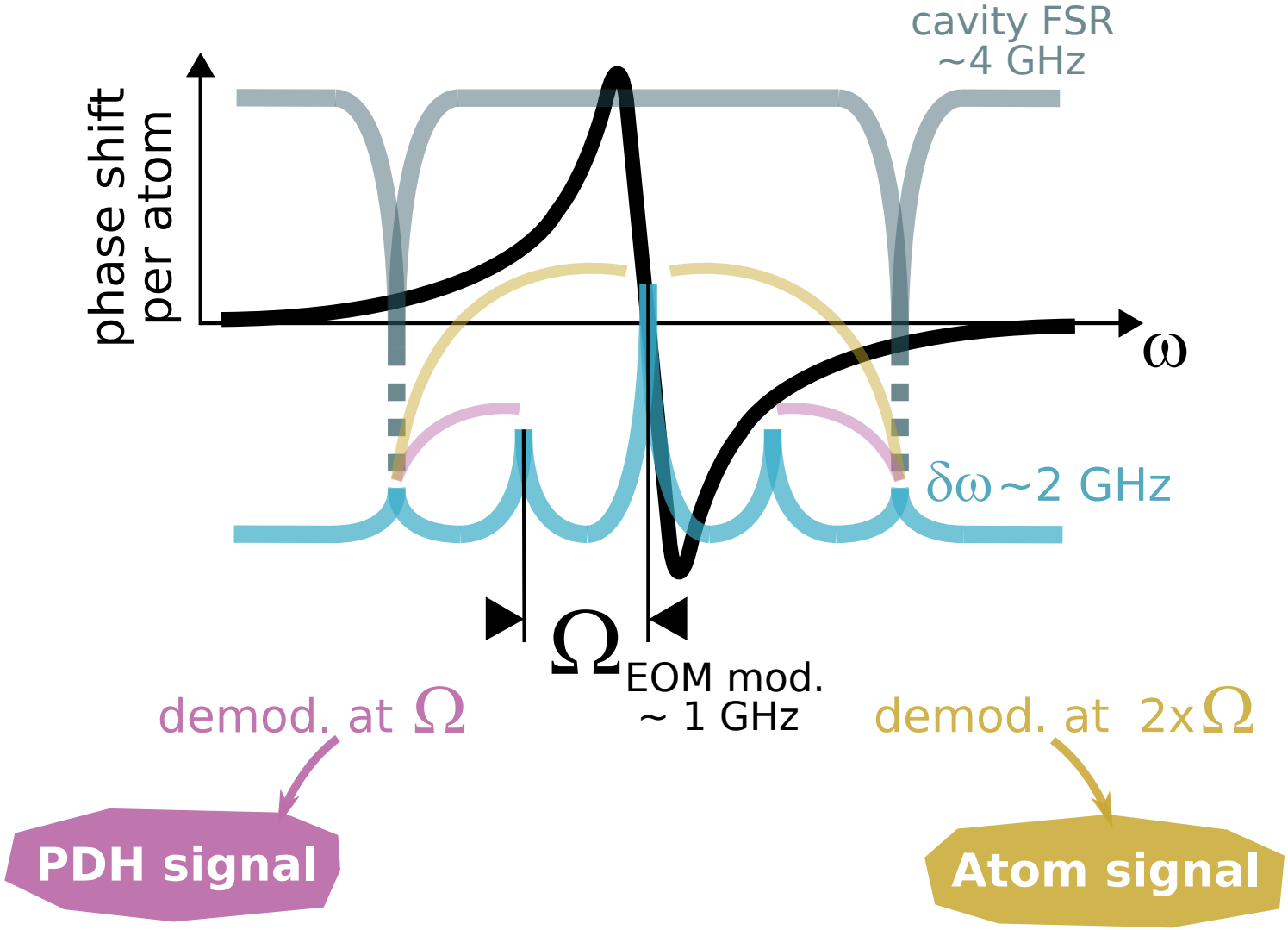
keep L half an integer multiple of λ

measure how far the cavity is from resonance

deduce the total phase shift imprinted by the atoms

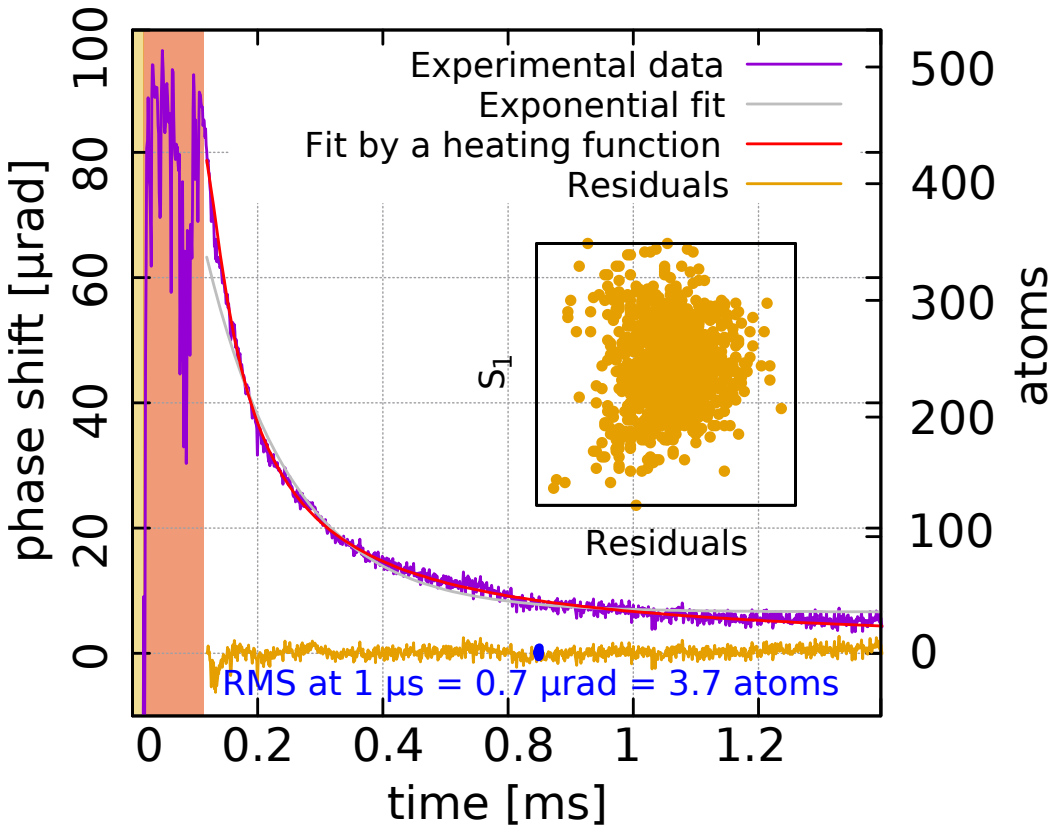
knowing the phase shift per atom

number of atoms in the cavity



$$\phi_{atom} \sim 0.19\ \mu rad$$

IV. NDD, IV.2. Classical NDD **results**



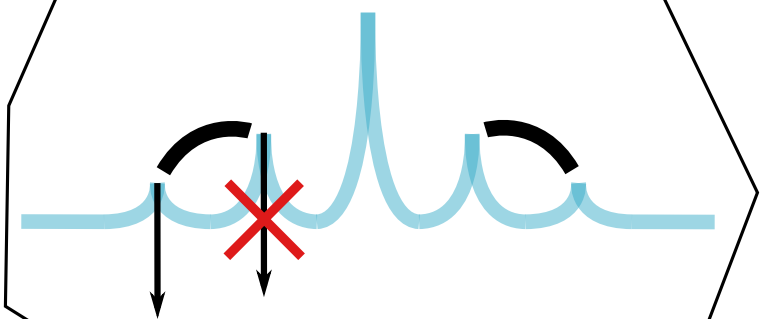
- 38 photons/µs per atom,
  SNR ~ 135 (for 500 atoms)
  > **classical non destructivity**

- extrapolating to 1 photon/T :
  SNR ~ 20 (for 500 atoms)
  > **quantum non destructivity**

entering the quantum regime

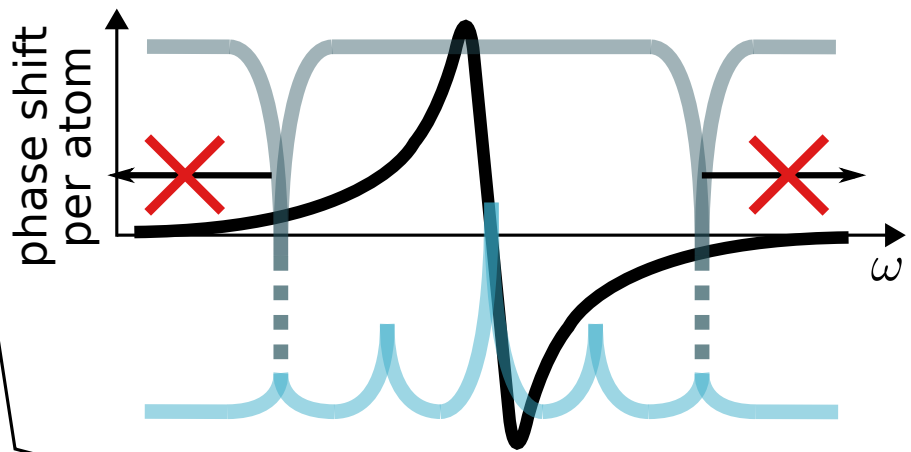
requires interacting **100** times less with atoms

lower the power sent to atoms

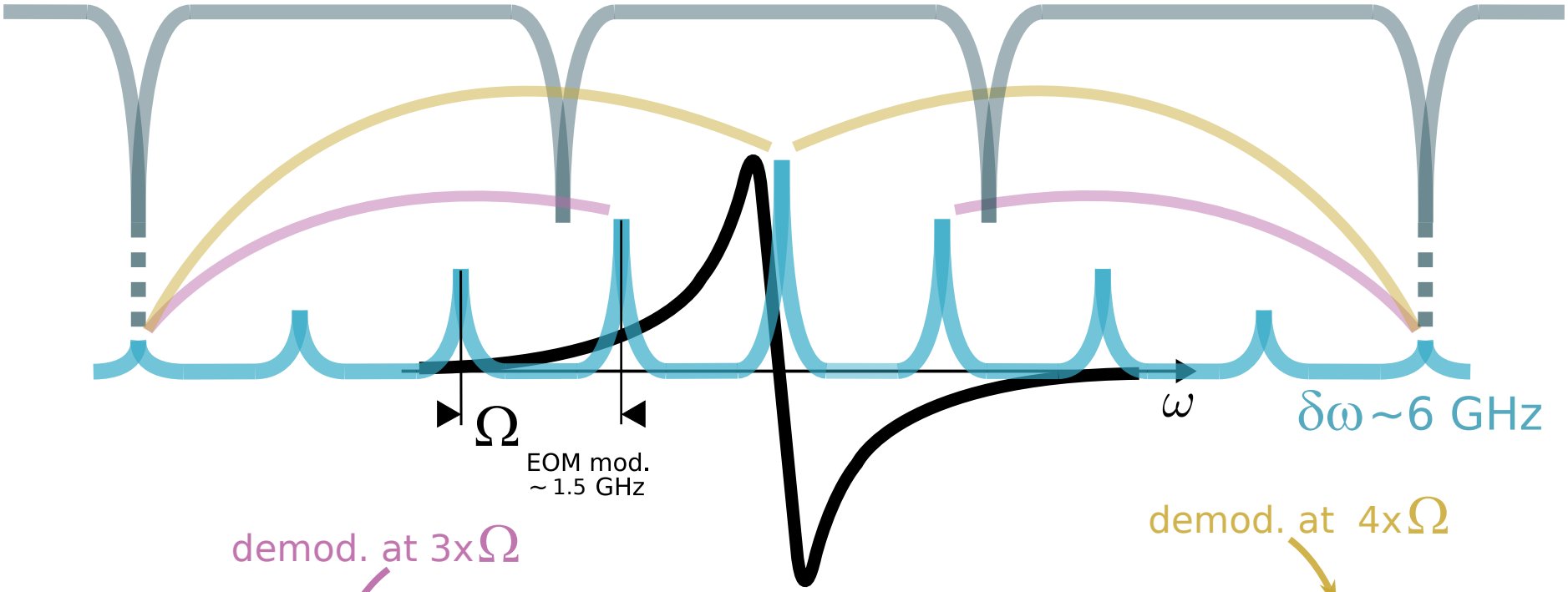


J_1 J_2 too low to lock

go further from atomic resonance $\sigma \propto \frac{1}{\delta\omega^2}$



FSR determined by cavity geometry



demod. at 3xΩ

PDH signal

demod. at 4xΩ

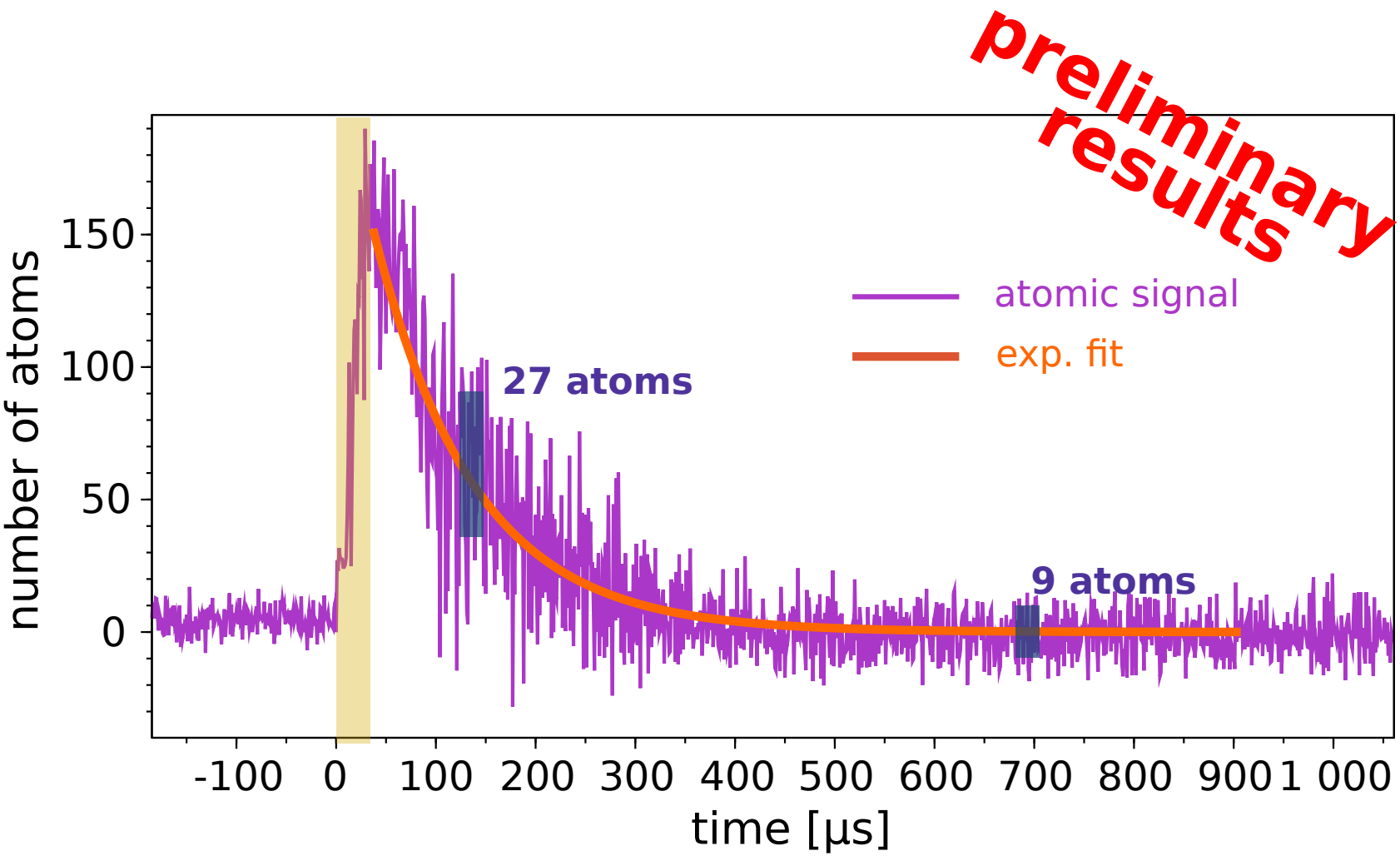
Atom signal

$\delta\omega' = 3\delta\omega \longrightarrow \sigma' \sim 0.1\,\sigma$

$P' = 0.1P \longrightarrow$ x 0.1

x 0.01

entering the quantum regime


preliminary results
atomic signal
exp. fit
27 atoms
9 atoms
number of atoms
150
100
50
0
-100
0
100
200
300
400
500
600
700
800
900
1 000
time [µs]

V. Conclusion and out looks

- **First measurement of back ground collision shifts**: currently deriving a workable model,
- **Quantum NDD detection SNR to be improved**: new photodetector arrived recently,
- **check squeezing**: artificially increase the QPN above DICK effect decreasing the number of atoms

$$QPN \propto \frac{1}{\sqrt{N_{at}}}$$

- **Postdoc position available**

THANK YOU FOR YOUR ATTENTION