Three different regimes in the verification stage according to the spring frequency

K.Somiya, Y.Chen, S.Danilishin,

H.Miao, H.Müller-Ebhardt, and H.Rehbein

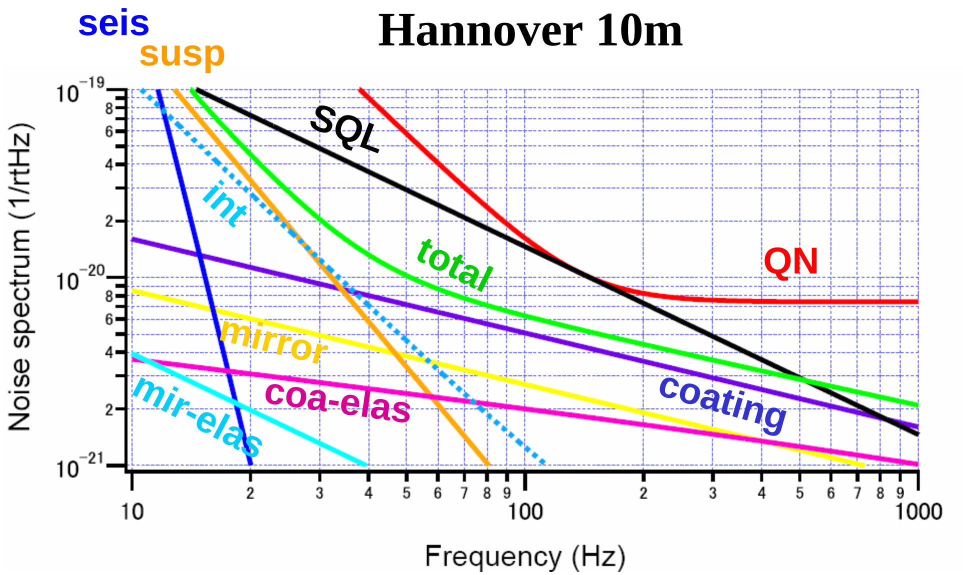
LSC Meeting @ Hannover
2007.10.26

K.Somiya

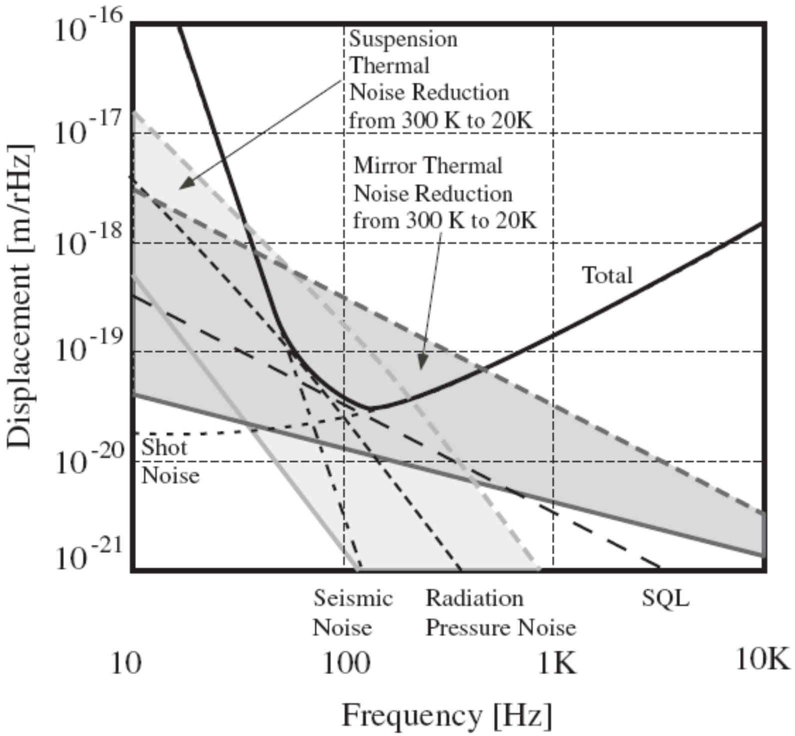
LIGO-G070769-00-Z

MQM

Hannover 10m



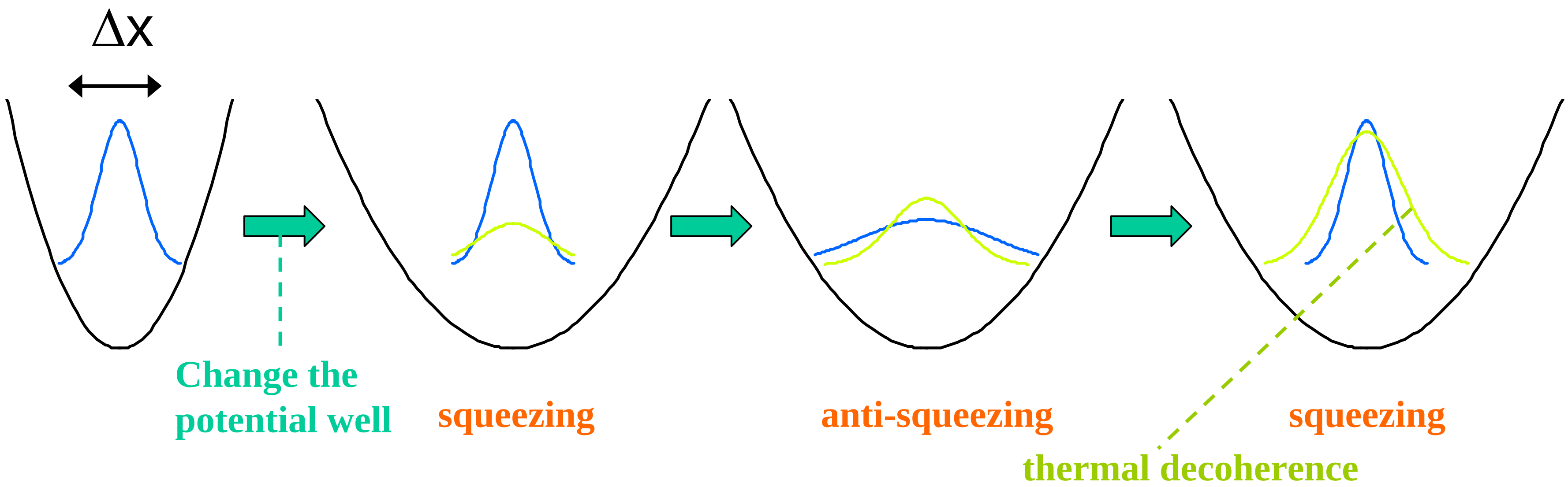
CLIO (CQG 21 S1173)



Sub-SQL interferometer in a near future

➡ **We'll see the quantum behavior of a test mass (MQM=Macroscopic Quantum Measurement)**

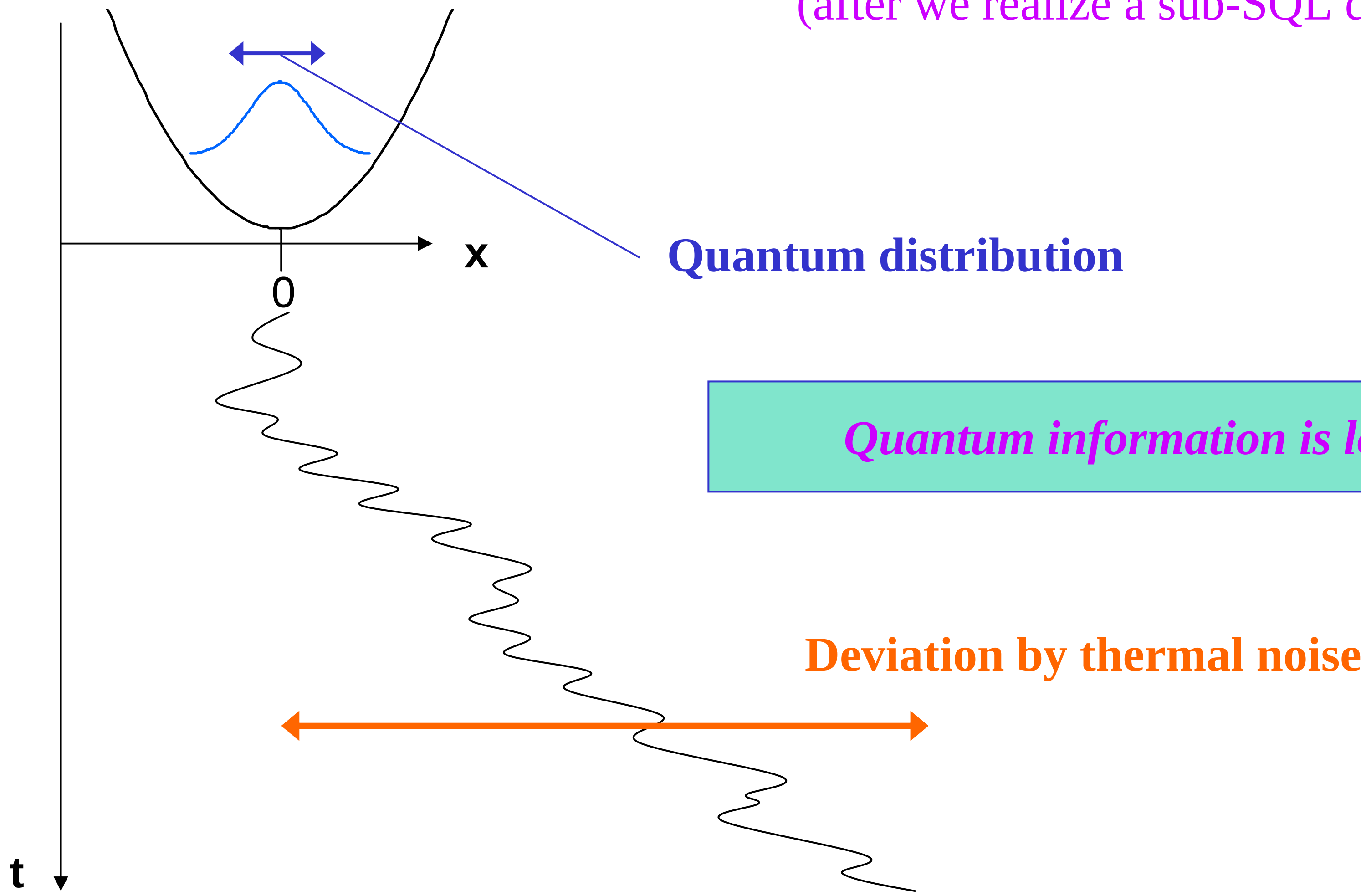
Quantum behavior of a test mass



- Quantum breathing
- Thermal decoherence
- How can we see this?

First we need to prepare a quantum state

(after we realize a sub-SQL detector)



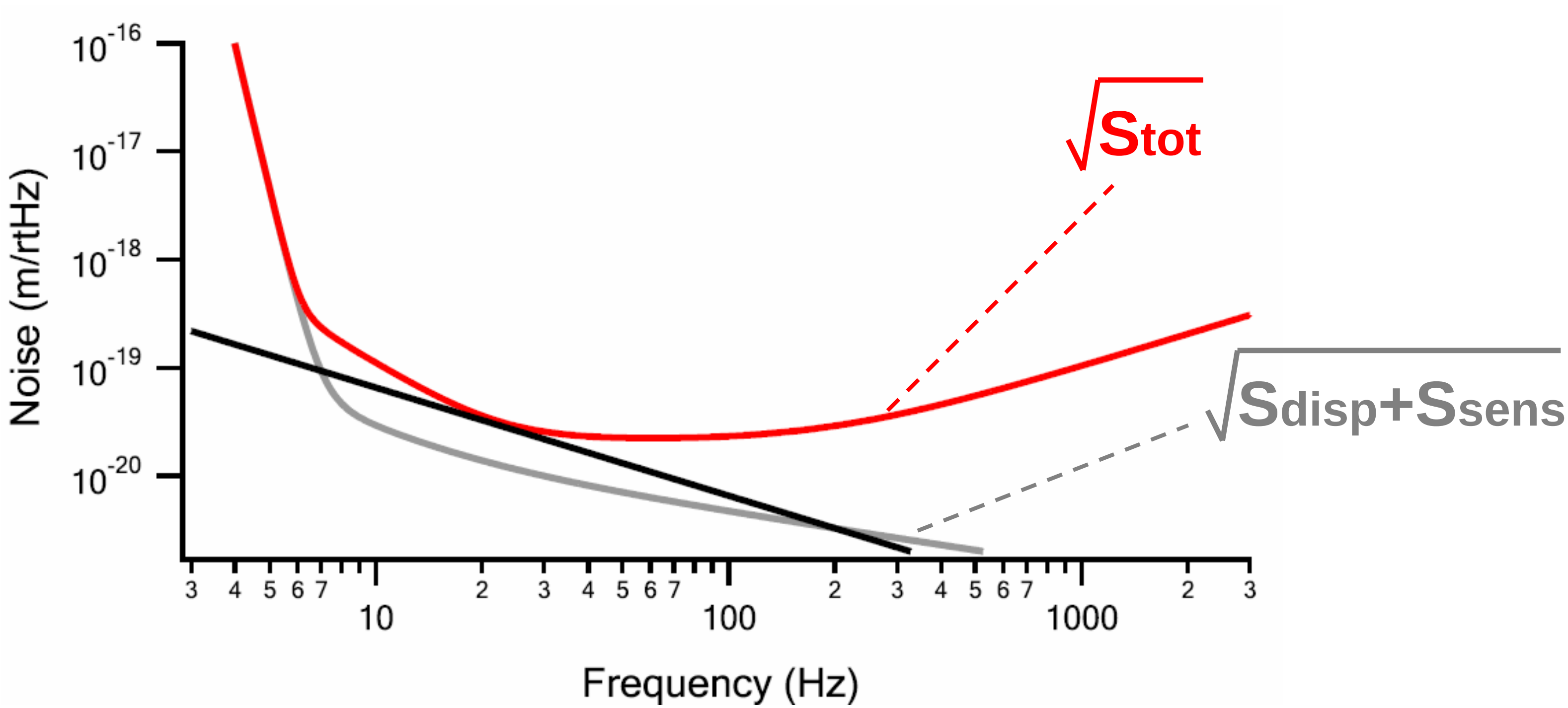
Quantum information is lost

We should identify the center of the wave function.

How to filter out the classical deviation

→ ***Wiener Filter***

- designed from **S_{disp}** & **S_{tot}**
- different filters for **X** & **P**



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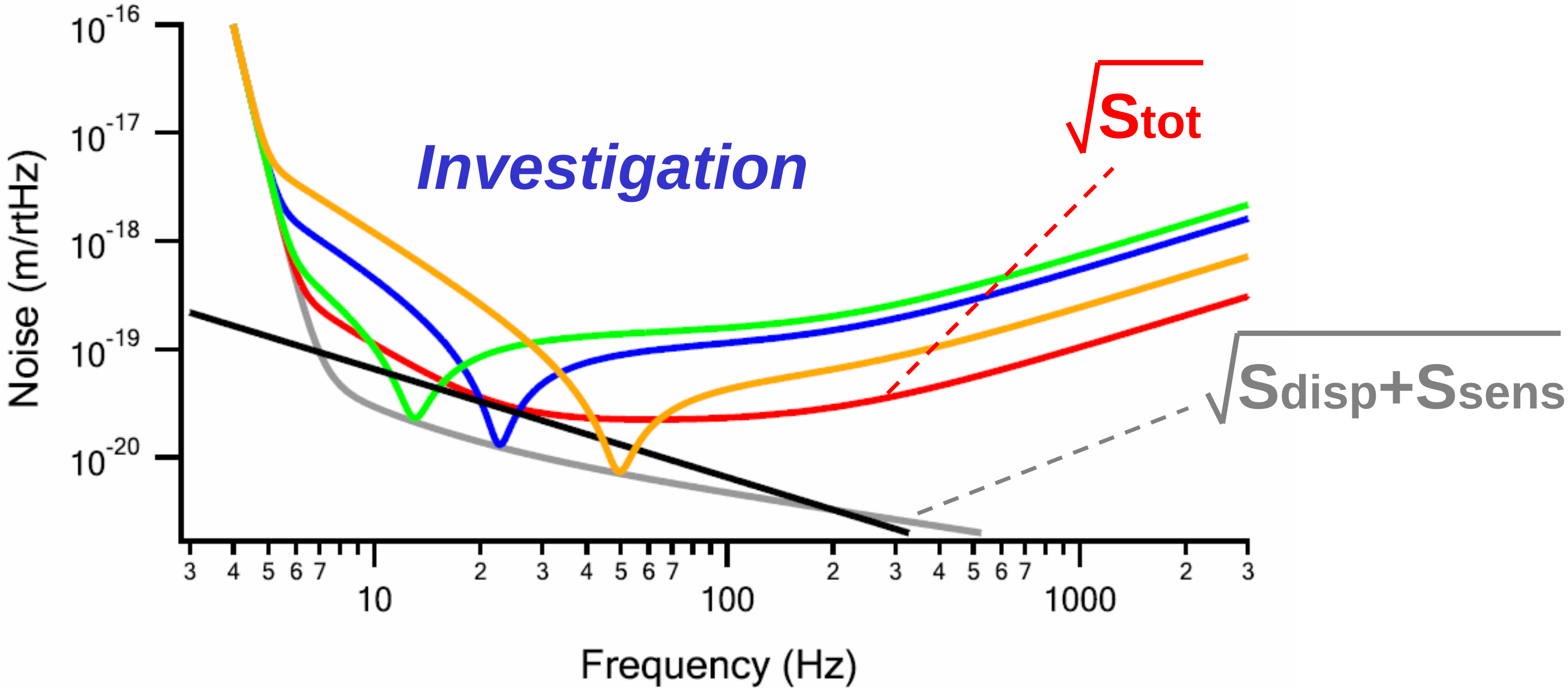
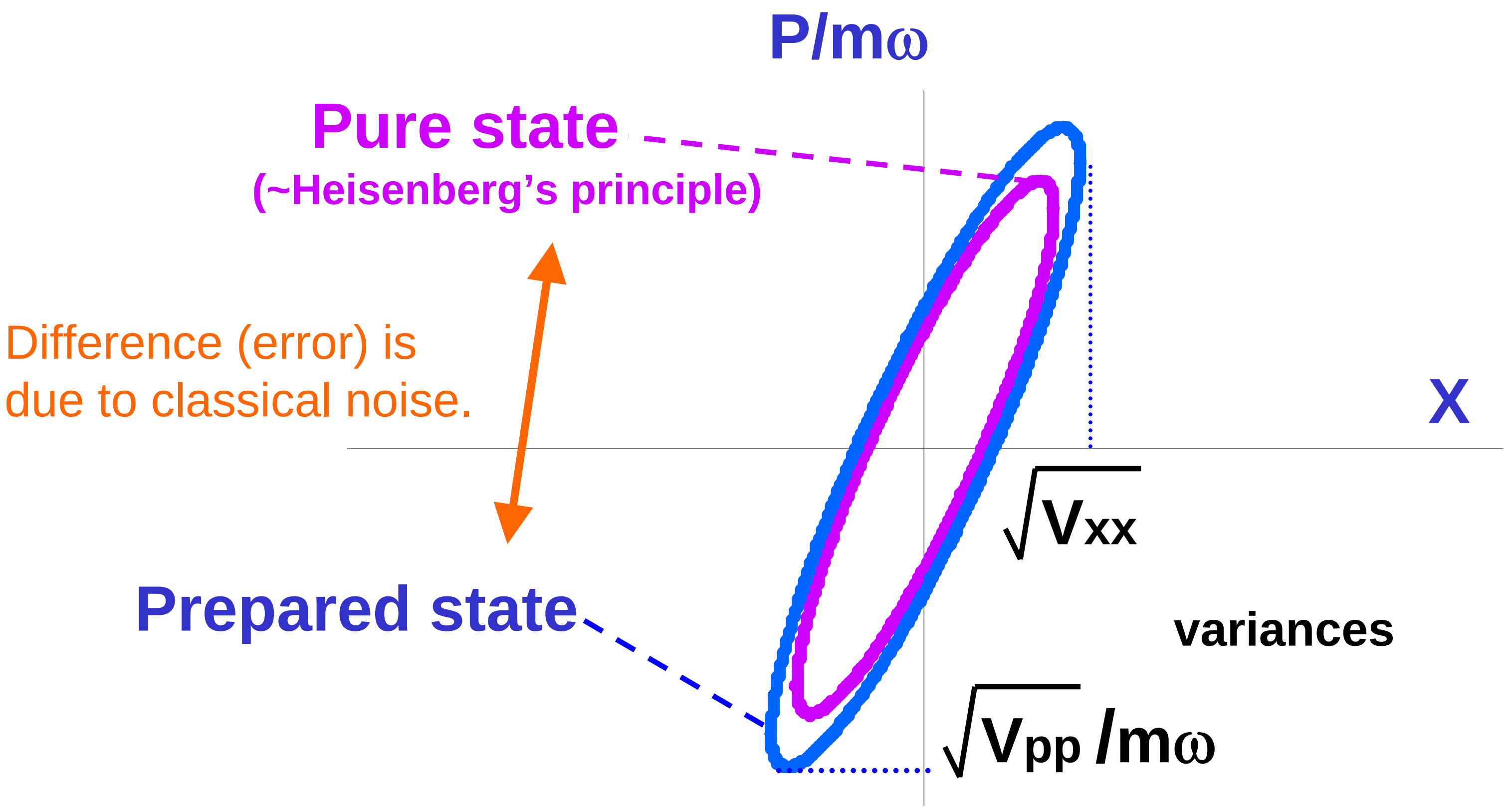


The more the SQL is beyond classical noise, the closer the prepared state is to a pure quantum state.

Prepared quantum state



Squeeze factor depends on the spring frequency ω

Now we should do measurement (verification)

Then, the next step is…

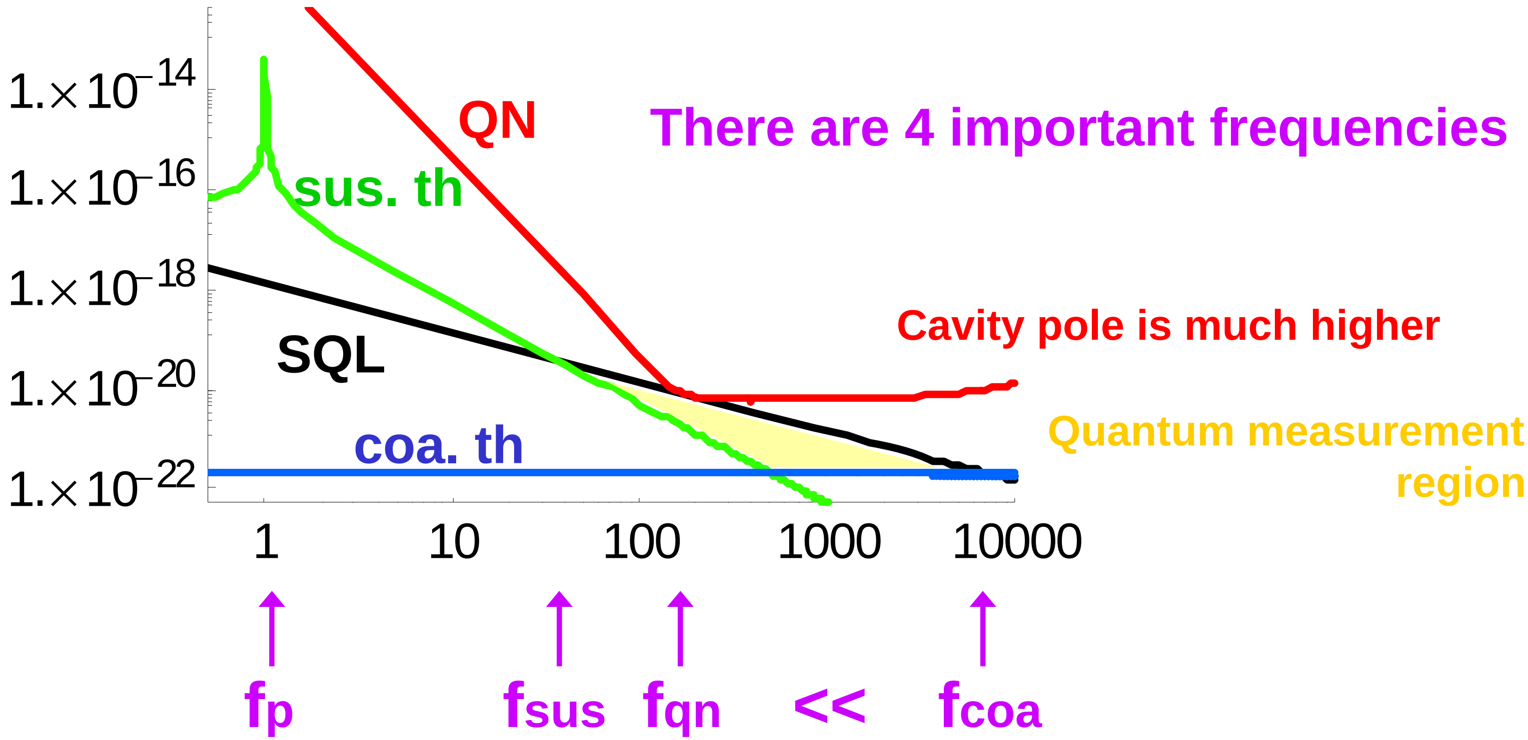
(i) verify if it is almost a quantum state

(ii) wait for one cycle ($2\pi/\omega$) and see how different from (i)

↓

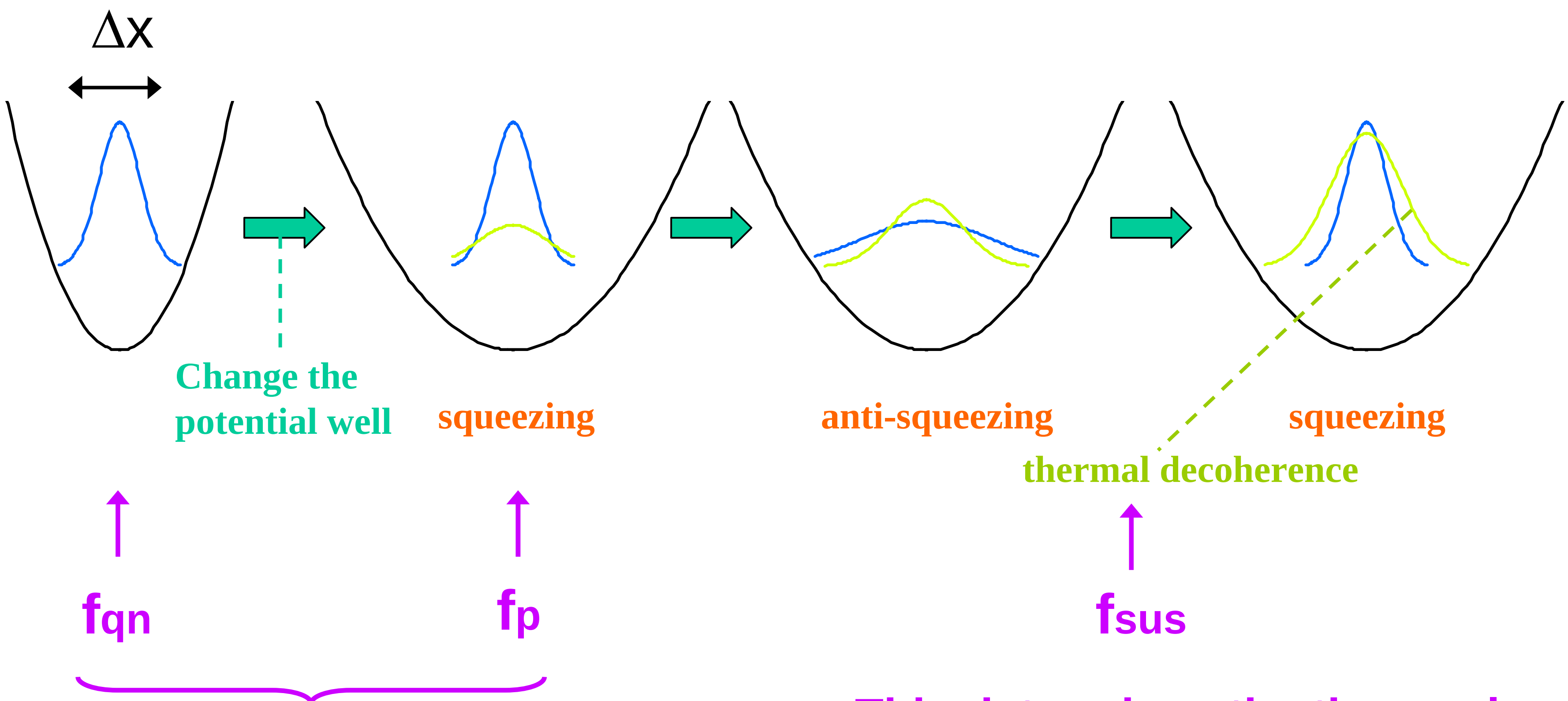
I'll show 3 different regimes depending on the spring frequency

Three situations in a simple model



(1) $f_p < f_{sus} < f_{qn}$
(2) $f_{sus} < f_p < f_{qn}$
(3) $f_{sus} < f_{qn} < f_p$

What do these frequencies mean?



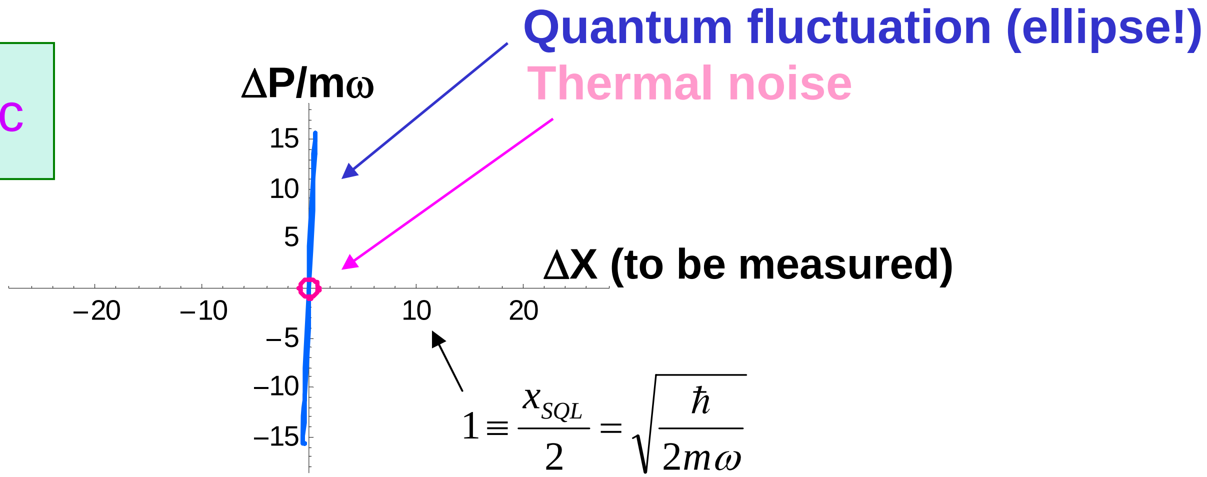
These determine the width of the potential wells.

This determines the timescale of thermal decoherence.

(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

(1Hz, 35Hz, 160Hz)

Snap shot at t=0.005sec



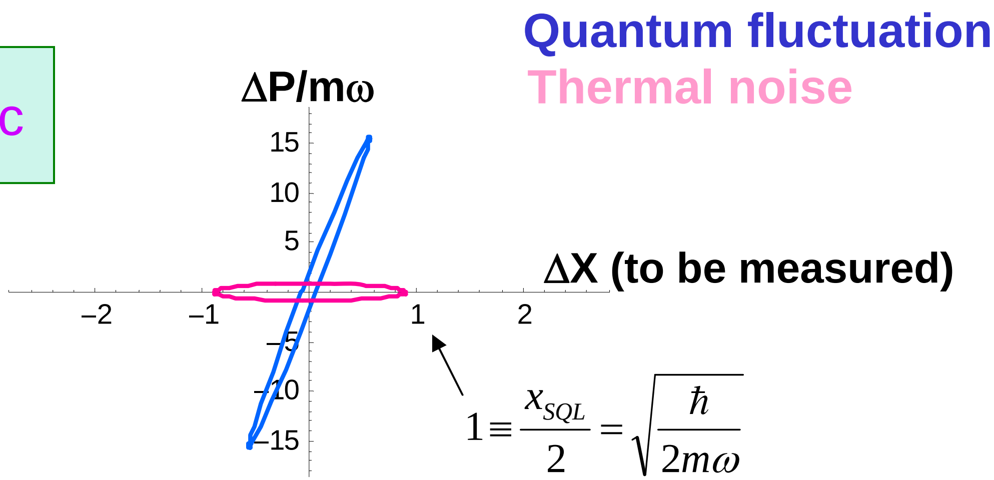
$$1 \equiv \frac{x_{SQL}}{2} = \sqrt{\frac{\hbar}{2m\omega}}$$

Highly squeezed ($f_p << f_{qn}$)

(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

(1Hz, 35Hz, 160Hz)

Snap shot at t=0.005sec



Highly squeezed ($f_p << f_{qn}$)

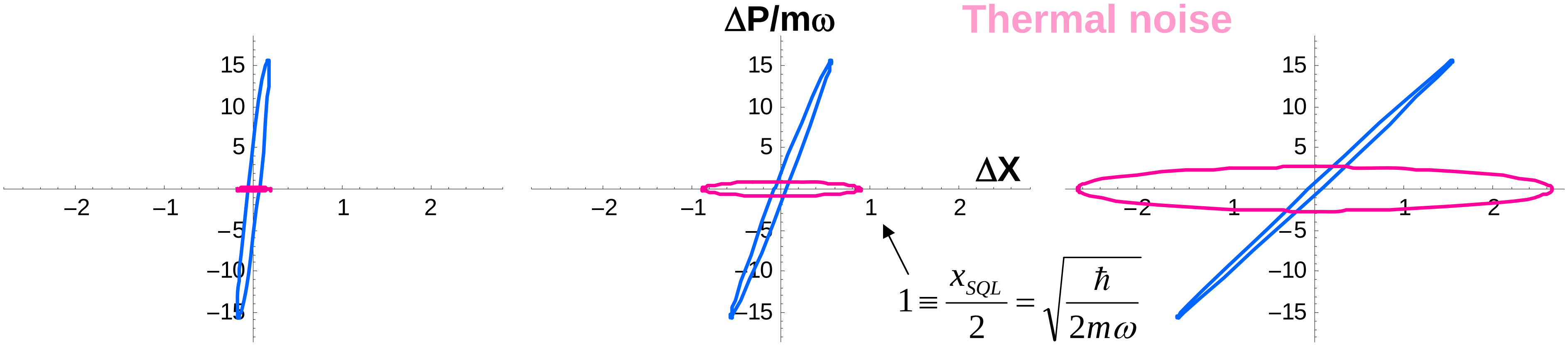
(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

(1Hz, 35Hz, 160Hz)

Evolution in time

Quantum fluctuation

Thermal noise



$$1 \equiv \frac{x_{SQL}}{2} = \sqrt{\frac{\hbar}{2m\omega}}$$

t=0.001 sec

t=0.005 sec

t=0.015 sec

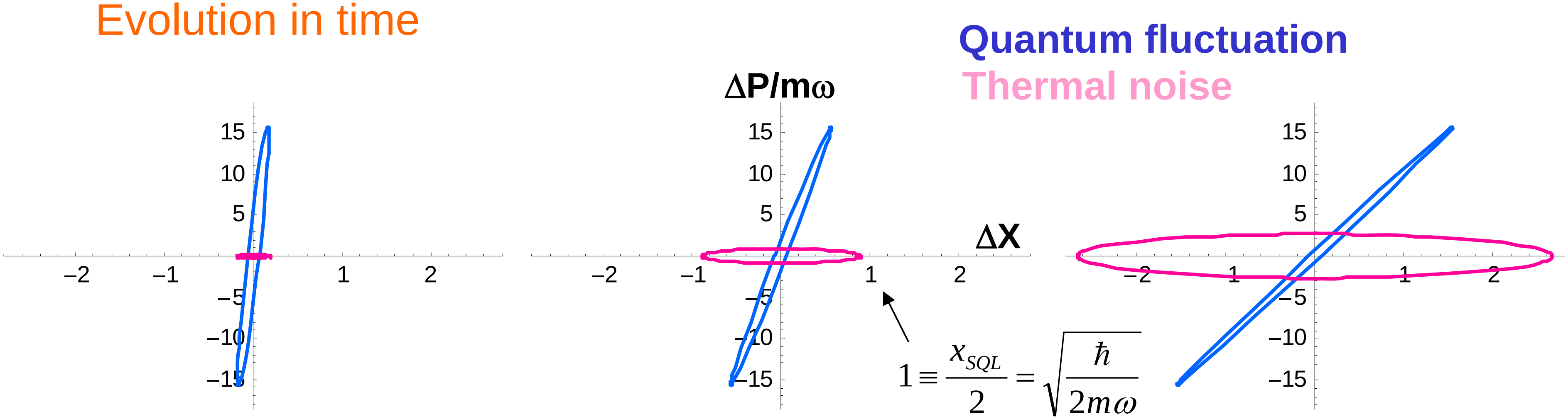
Thermal noise becomes bigger very soon.

But the information of P and X can be obtained quickly due to the strong squeezing (hope).

(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

(1Hz, 35Hz, 160Hz)

Evolution in time



$$1 \equiv \frac{x_{SQL}}{2} = \sqrt{\frac{\hbar}{2m\omega}}$$

t=0.001 sec   t=0.005 sec   t=0.015 sec

Note that these are snap shots.

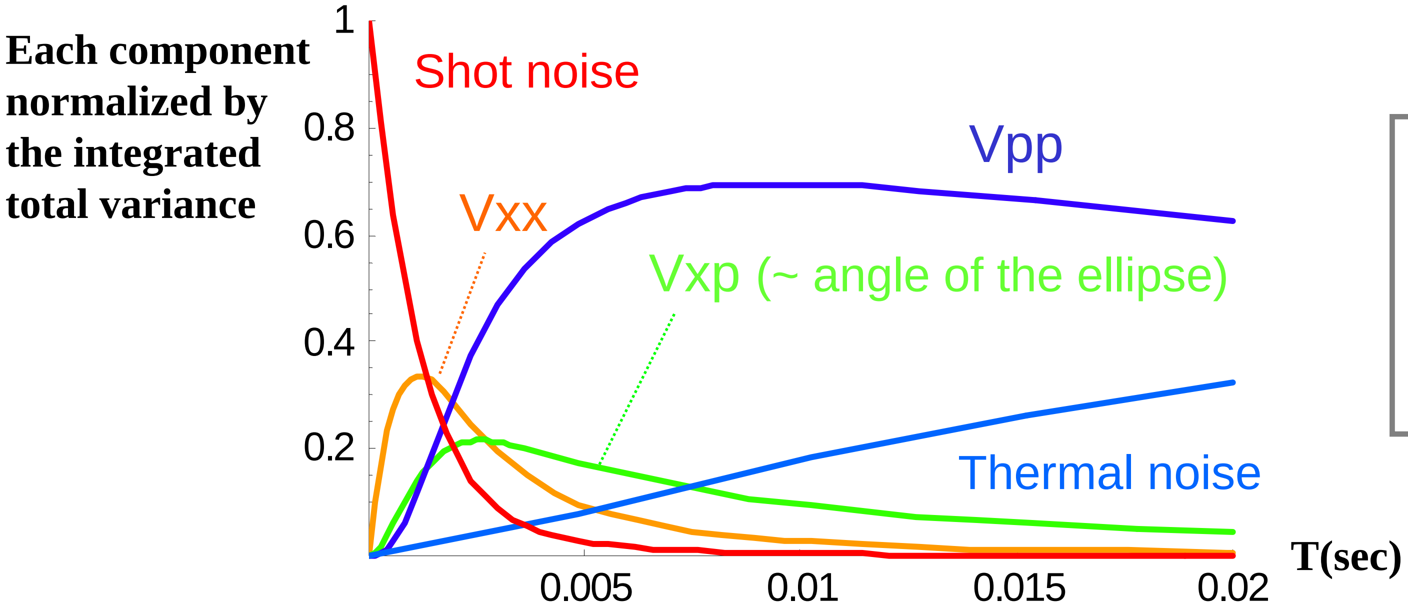
We shall measure it (Δx) for some amount of time.

(integrate)

(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

(1Hz, 35Hz, 160Hz)

Let's see the integral of <X(t)X(t')> over time T.



notes

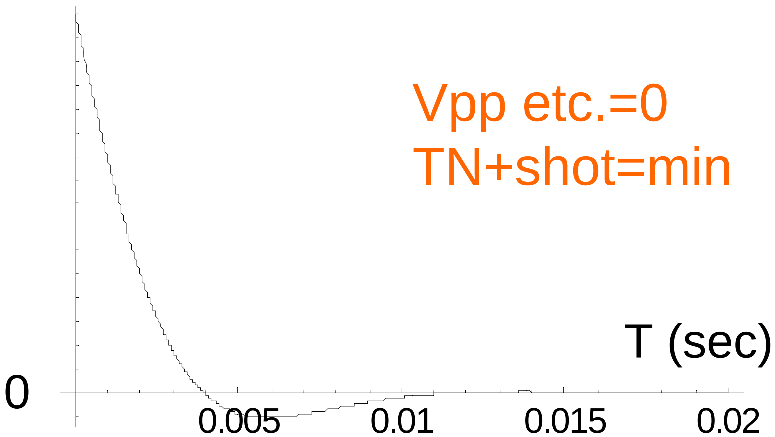
ϕ_{sus}=2e-6
P_0=1W
BAE (no RPN)

- At a peak of each, Vxx/Vtot=34% and Vpp/Vtot=70%
- Optimal filter will make these number better

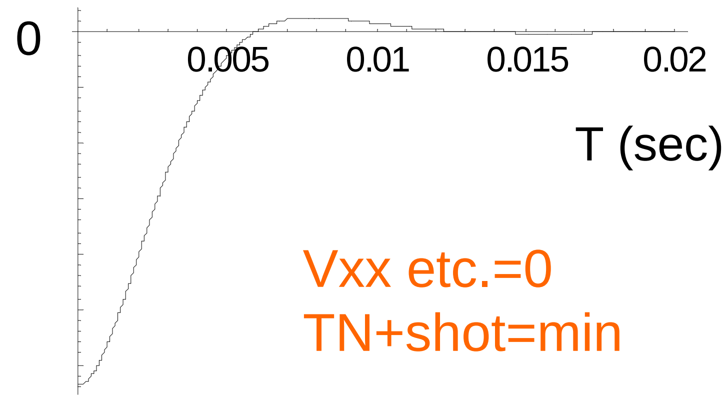
(1) $f_p < f_{sus} < f_{qn}$ [pendulum]

Optimal filters

for Vxx



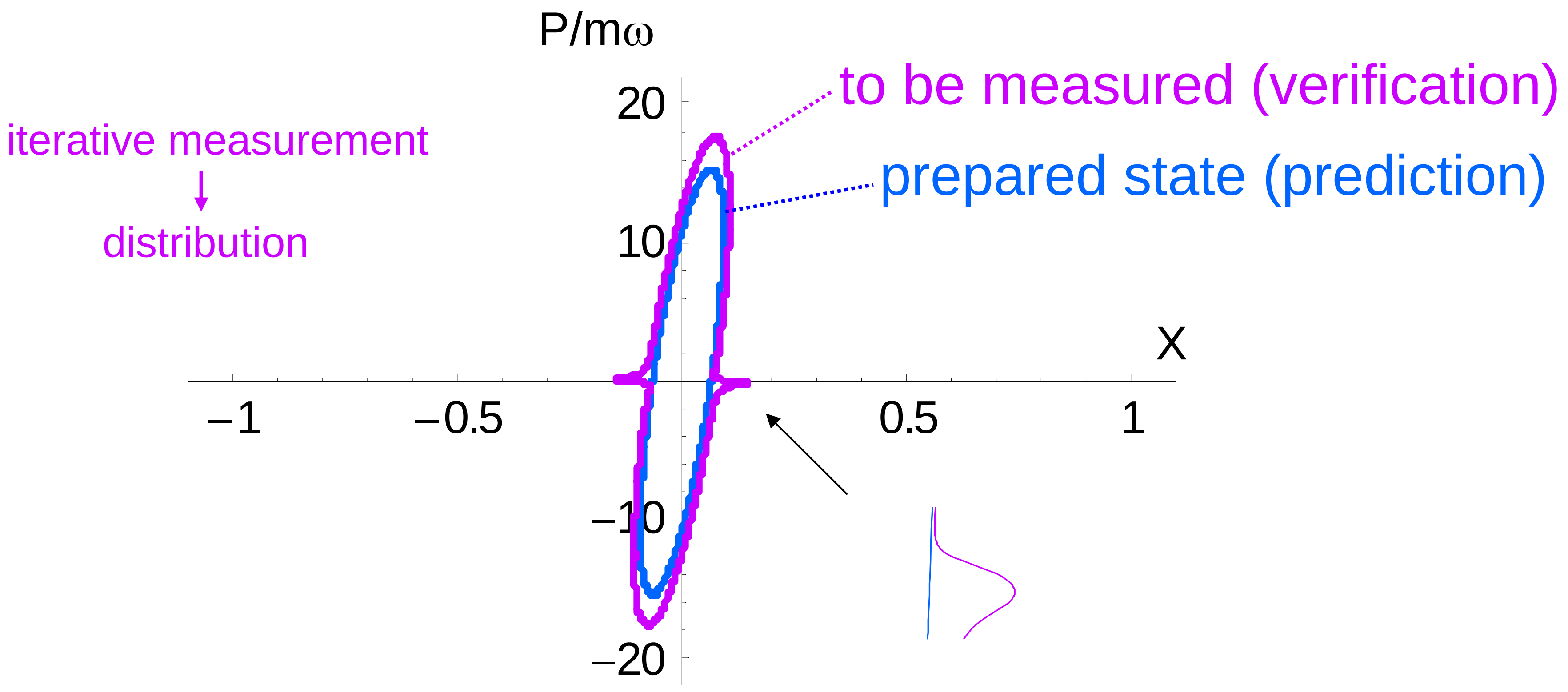
for Vpp



optimal function	**48%**	**76%**
(simple window)	34%	70%

We can use the filter for each quadrature between X and P.

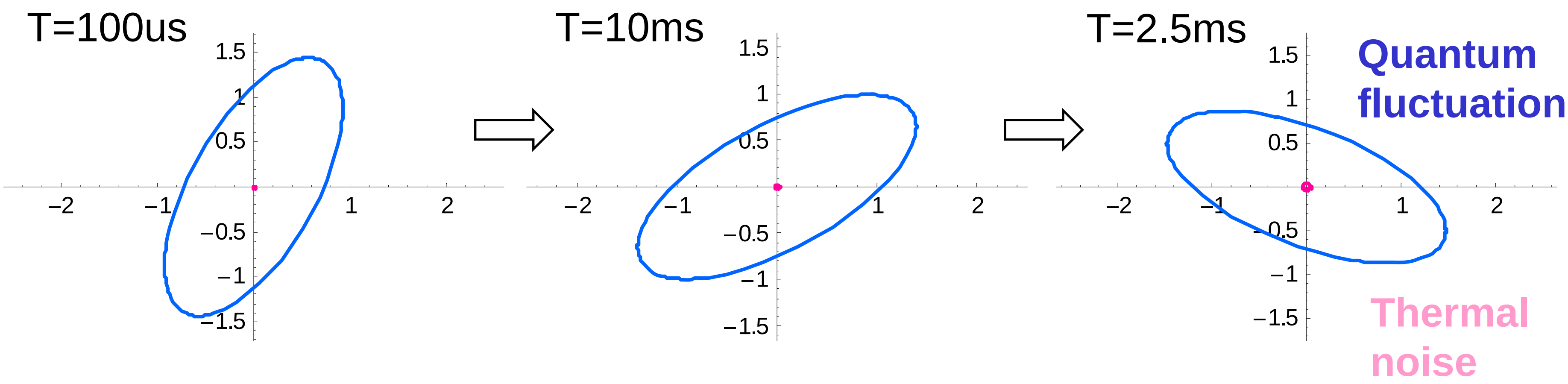
(1) $f_p < f_{sus} < f_{qn}$ [pendulum]



If a quantum state is prepared correct, we'll be able to verify it in this way.

(2) $f_{sus} < f_p < f_{qn}$ [spring]

(35Hz, 100Hz, 160Hz)



Modest squeezing ($f_p \sim f_{qn}$)

Thermal noise grows slowly ($f_{sus} < f_p$)

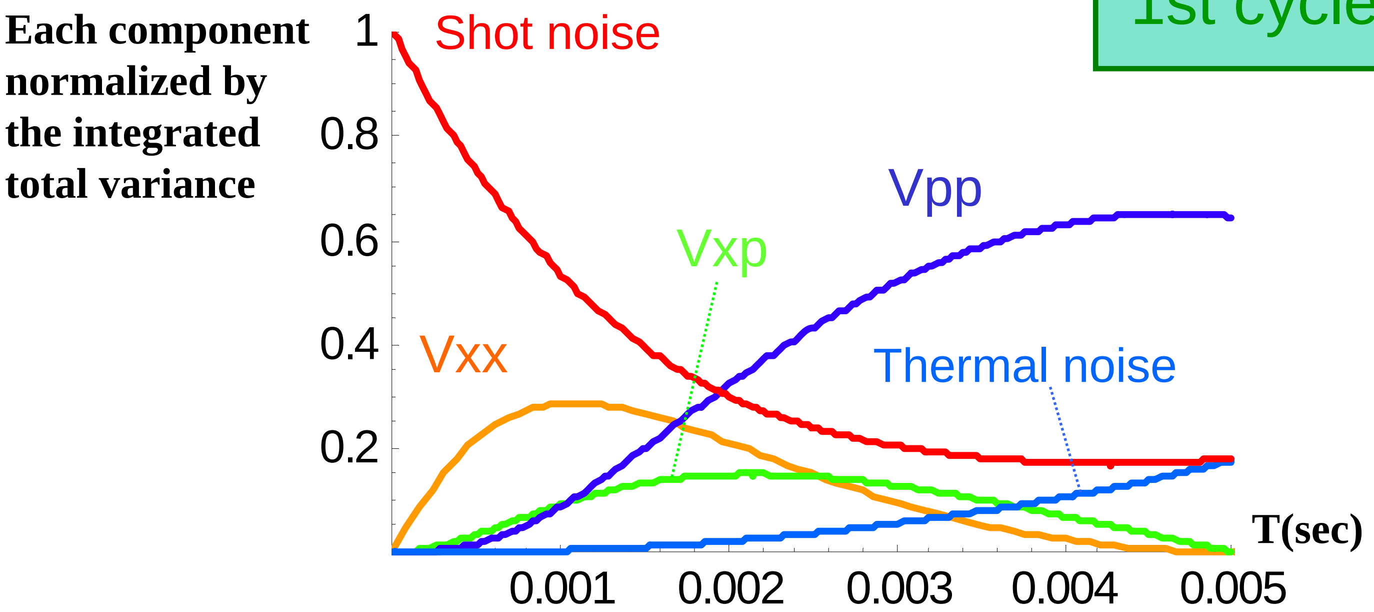
Let's see the integrated variances.

(2) $f_{sus} < f_p < f_{qn}$ [spring]

(35Hz, 100Hz, 160Hz)

measurement starts at

1st cycle



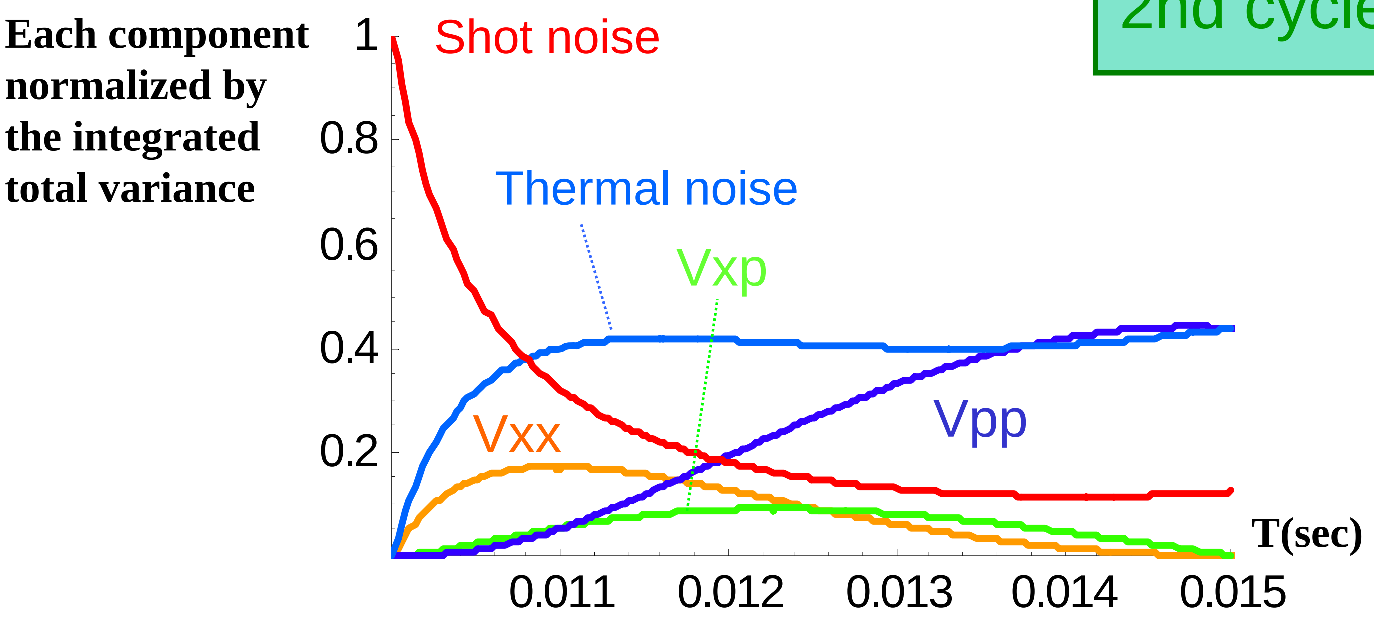
Reasonably fine.

(2) $f_{sus} < f_p < f_{qn}$ [spring]

(35Hz, 100Hz, 160Hz)

measurement starts at

2nd cycle



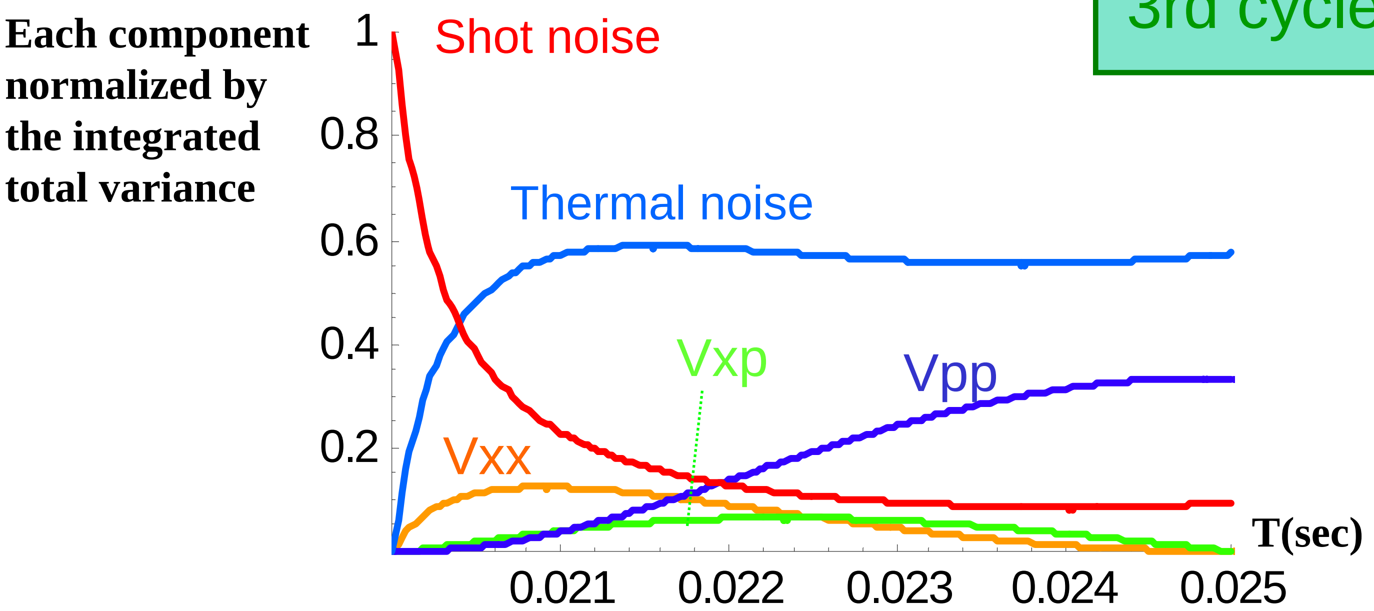
Thermal decoherence is bigger than the 1st cycle.

(2) $f_{sus} < f_p < f_{qn}$ [spring]

(35Hz, 100Hz, 160Hz)

measurement starts at

3rd cycle



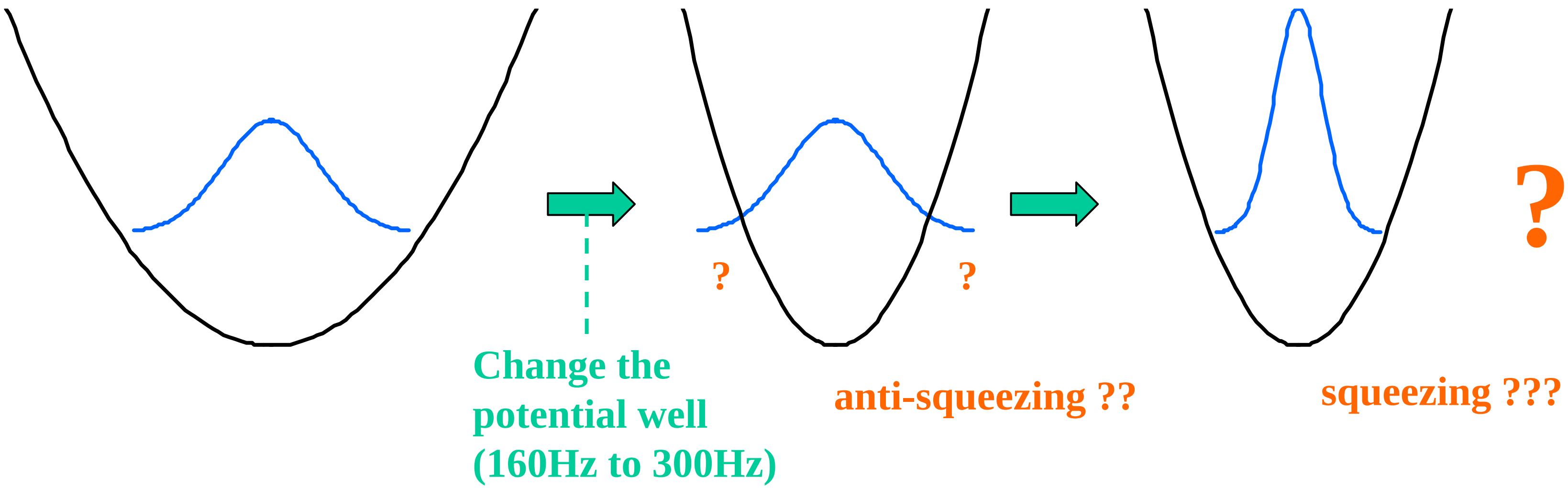
We'd like to see the results with the optimal filter.

→ However it is not available yet… I'll do soon.

(3) $f_{sus} < f_{qn} < f_{p}$ [spring]

(35Hz, 160Hz, 300Hz)

This is a subtle situation…

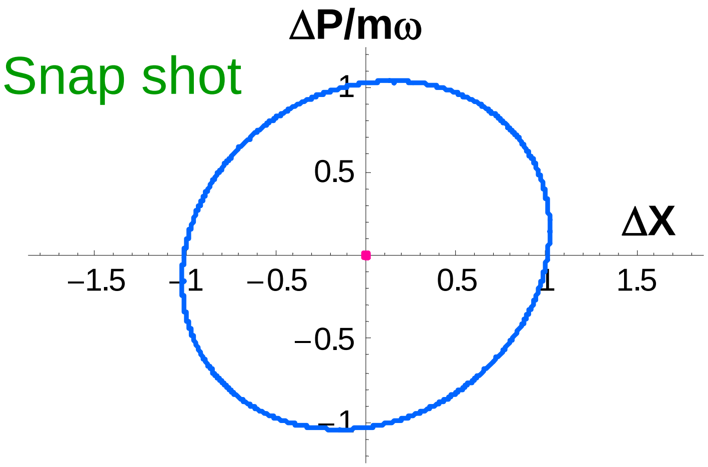


Let’s see the calculated result.

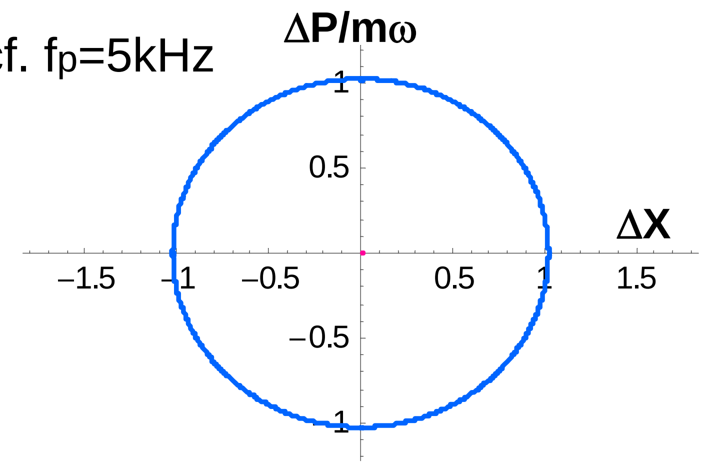
(3) $f_{sus} < f_{qn} < f_p$ [spring]

(35Hz, 160Hz, 300Hz)

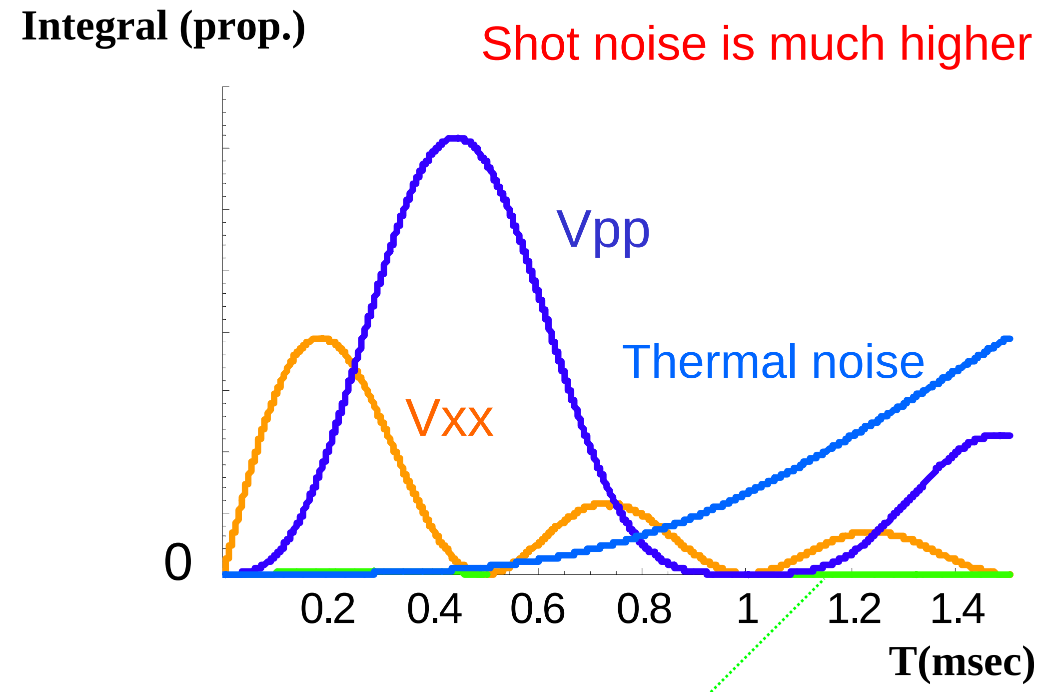
Snap shot



cf. f_p=5kHz



Shot noise is much higher



Vxp is quite small
(as it's not squeezed)

So, this situation is not interesting…

Conclusion

- The pendulum case seems *hopeful*:
  $f_p << f_q$ → high squeezing
  $f_p < f_{sus}$ → thermal decoherence grows fast

- The middle-freq spring case seems *interesting*:
  $f_p \sim f_q$ → not so high squeezing
  $f_{sus} < f_p$ → measurement can be done several times

- The high-freq spring case was *different* from what I thought:
  $f_q << f_p$ → almost no squeezing (no anti-squeezing)

Some more calculation should be done.
Note that this is with a very simple model.