Annual reports of me for FY2016

M1 Satoru Takano
@中間報告会

Contents

Part 1
Center of Percussion

2016/4/12~2016/9/5

＠Ando Lab

Contents

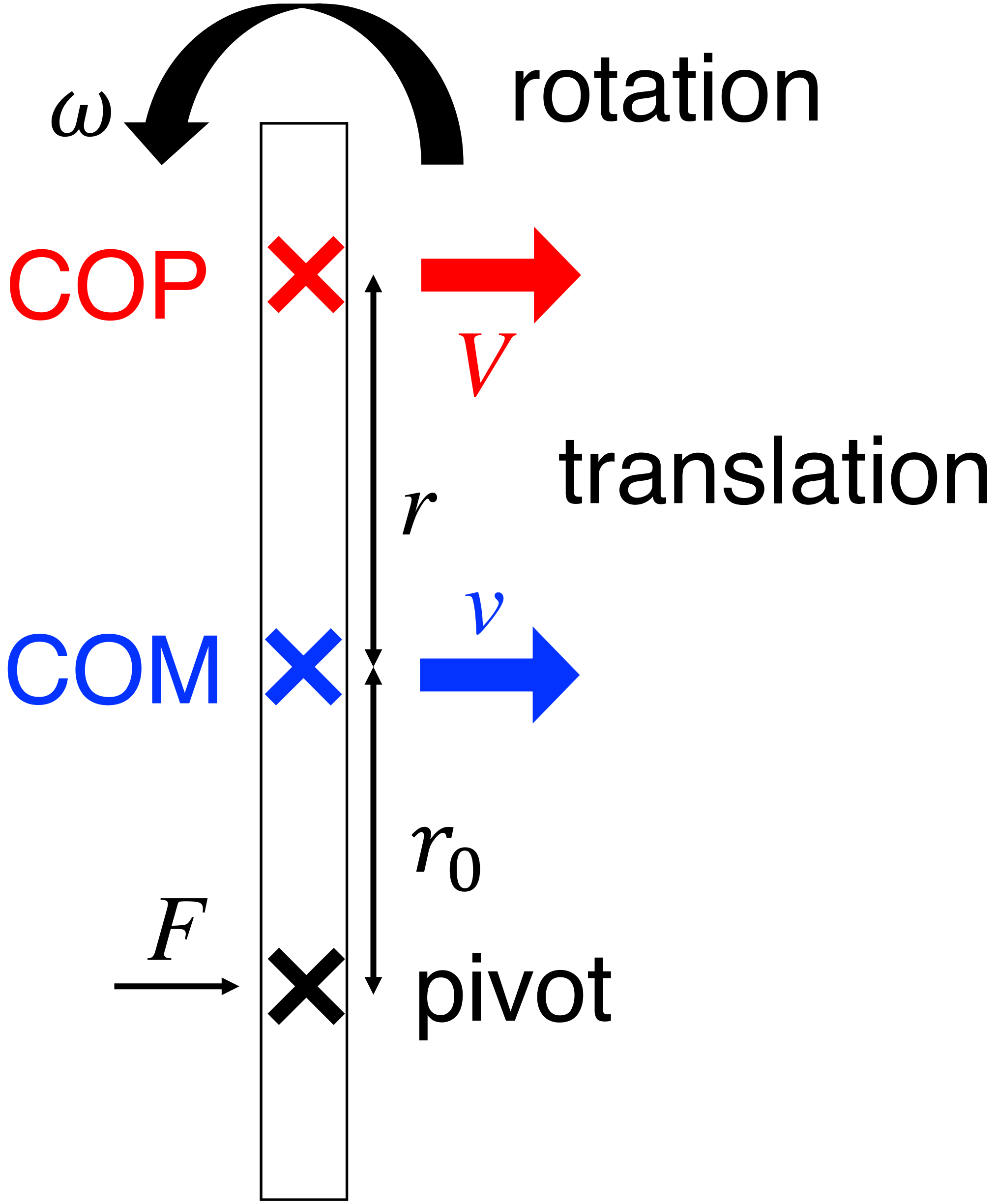
- Center of Percussion
  - Introduction
  - Experiment and Results
- High Harmonics Generation
  - Introduction
  - Experiment and Results
- Future Prospects

Introduction

- What is Center of Percussion (COP)?
  - Center + Percussion ≠ COM (Center of Mass)
- Suppose a rigid body is translating and rotating freely
- There is a point which is not moving at all!
  - rotations and translations are cancelling each other

    → This is the COP

A simple example of COP



$$m\dot{v} = F,\ I\dot{\omega} = Fr_0$$

$$V = v - r\omega$$

$$V = \left(\frac{1}{m} - \frac{r_0 r}{I}\right)\int dt\, F$$

$$\boxed{\text{at } r = I/mr_0\ ,\ V = 0}$$

What COP matter

- An example of coupling of translations and rotations
- Actually, much more complicated
  - c.f. Shimoda-san's Master thesis

- Usually we are trying to decouple these motions
  - Symmetrical configurations
  - Counter masses, actuators, etc.

Magnetically assisted torsion pendulum

- E. Thrane +, arXiv:1512.03137

(I referred to v1, but now v3 is available)

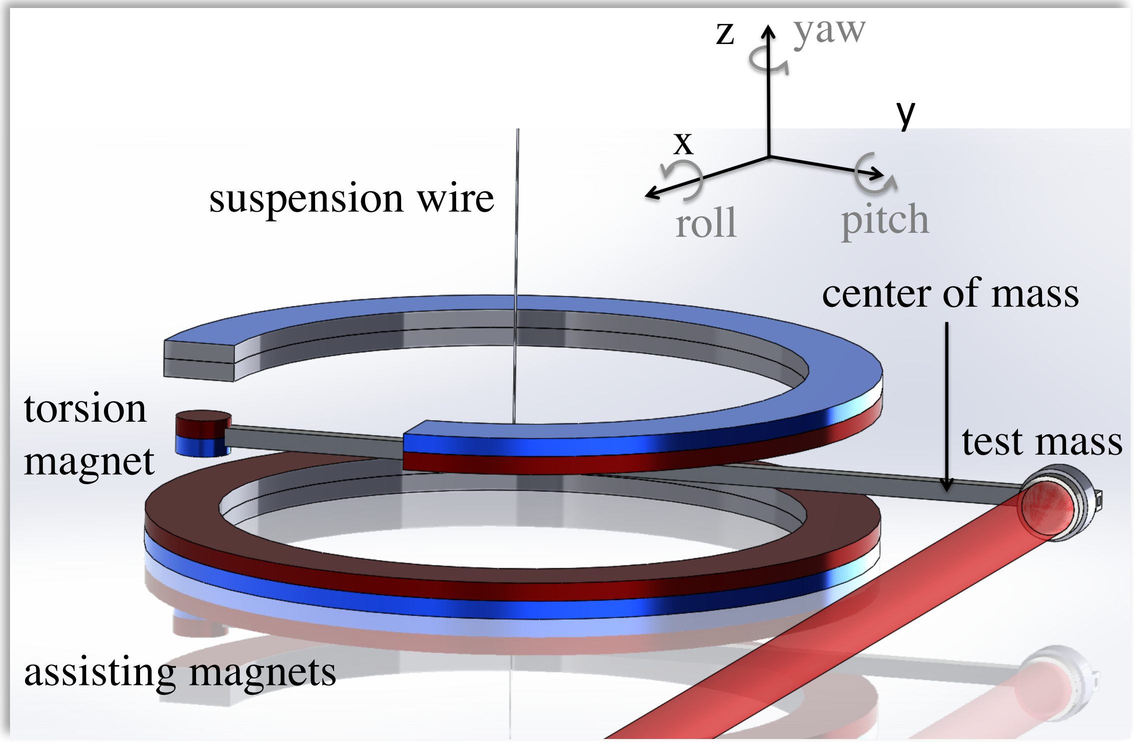
Toward terrestrial detection of millihertz gravitational waves with magnetically assisted torsion pendulums

Eric Thrane,[a] R. P. Anderson, Yuri Levin, and L. D. Turner
School of Physics and Astronomy, Monash University, Clayton, Victoria 3800, Australia
(Dated: December 11, 2015)

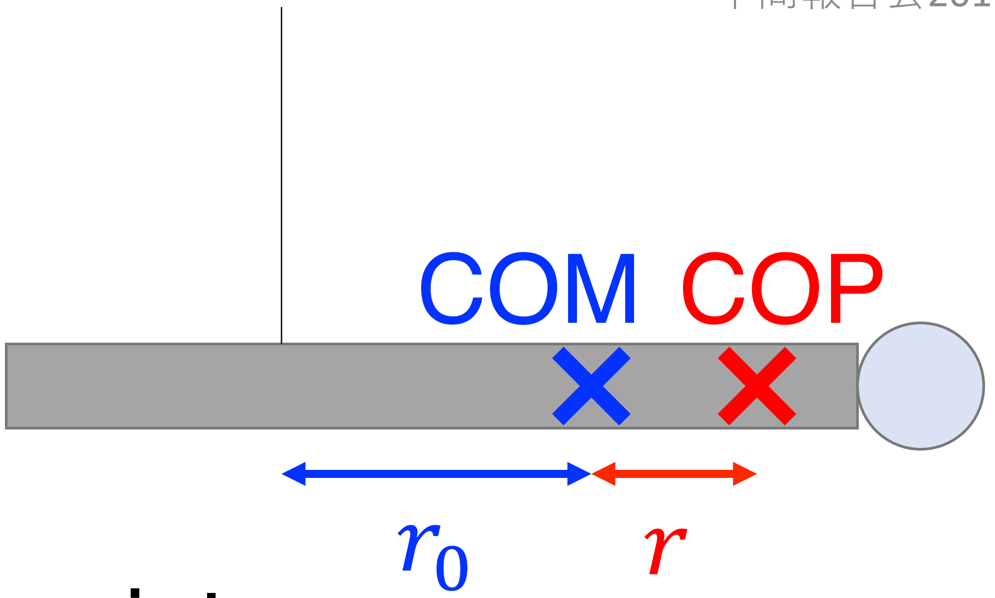
Current terrestrial gravitational-wave detectors operate at frequencies above 10 Hz. There is strong astrophysical motivation to construct low-frequency gravitational-wave detectors capable of observing 10–10^4 mHz signals. However, there are numerous technological challenges. In particular, it is difficult to isolate test masses so that they are both seismically isolated and freely falling under the influence of gravity at mHz frequencies. We propose a Magnetically Assisted Gravitational-wave Pendulum Intorsion (MAGPI) suspension design for use in low-frequency gravitational-wave detectors. We construct a noise budget to determine the required specifications. In doing so, we identify what are likely to be a number of limiting noise sources for terrestrial mHz gravitational-wave suspension systems. We conclude that it may be possible to achieve the required seismic isola-

Asymmetry is wonderful

- Magnetically assisted
  - Asymmetric configuration
  - Freely moving about yaw rotation
- GW signal can be detected as x translation of TM
- Decrease translational seismic noise @~1mHz by measuring x translation at COP

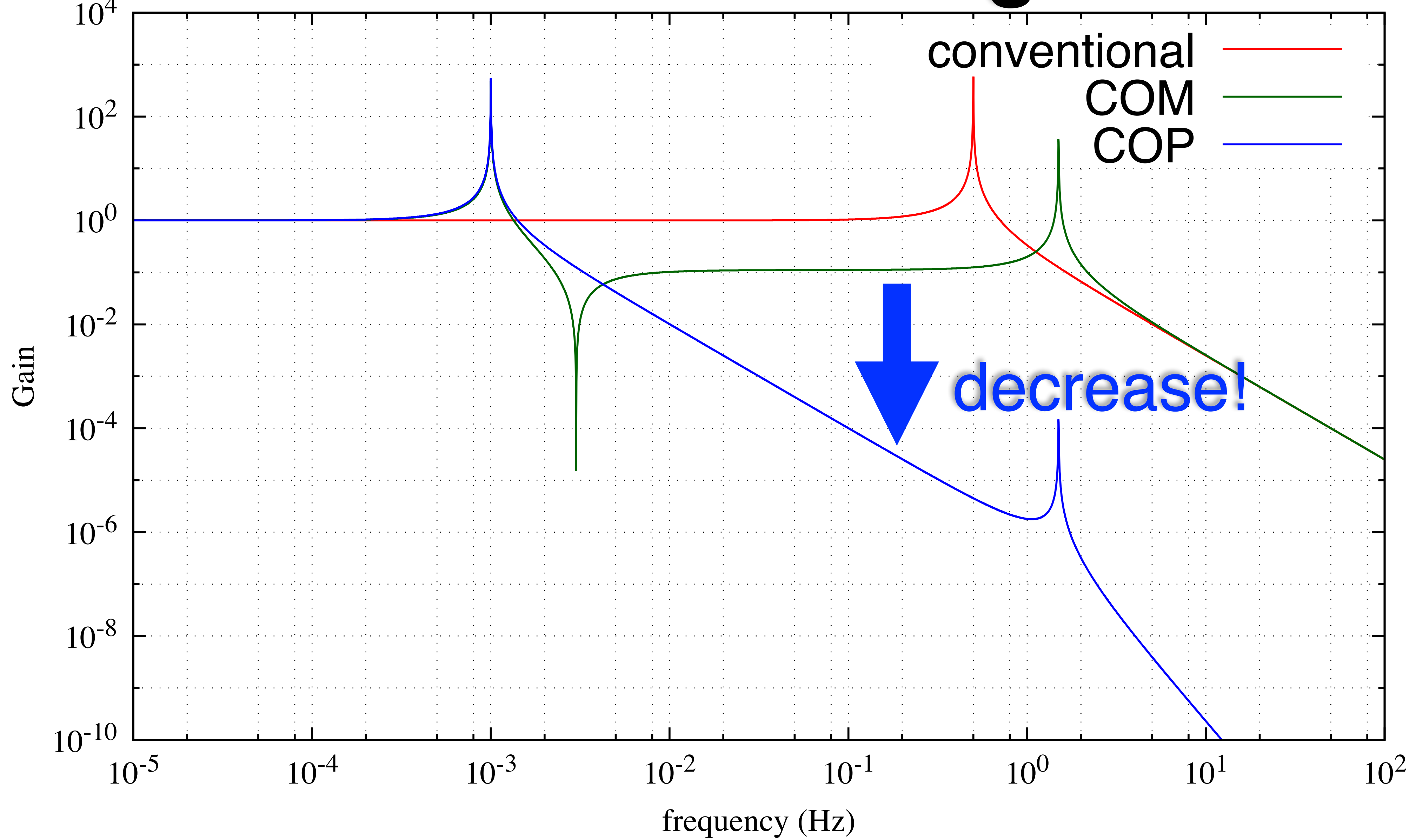


Setups



- Resonant frequencies:
  - Translational $f_0 = 0.5\text{Hz}$
  - Rotational $f_r = 1\text{mHz}$
- COM : r_0 from the suspension point
- A parameter $\kappa = \frac{mr_0^2}{I} + 1$
  - ➢An index of asymmetry of the bar
- COP: $r = \frac{I}{mr_0} = \frac{r}{\kappa - 1}$

Transfer functions from ground to TM



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Goal to the experiment

- To measure the transfer function is difficult technically
- Then, the goal :

➢ measure the translational resonance at many point

➢ check how the peak values is changing

- First of all, I had to design a magnetic levitation system
- After all, this is the biggest problem in this experiment...

Magnetic levitation

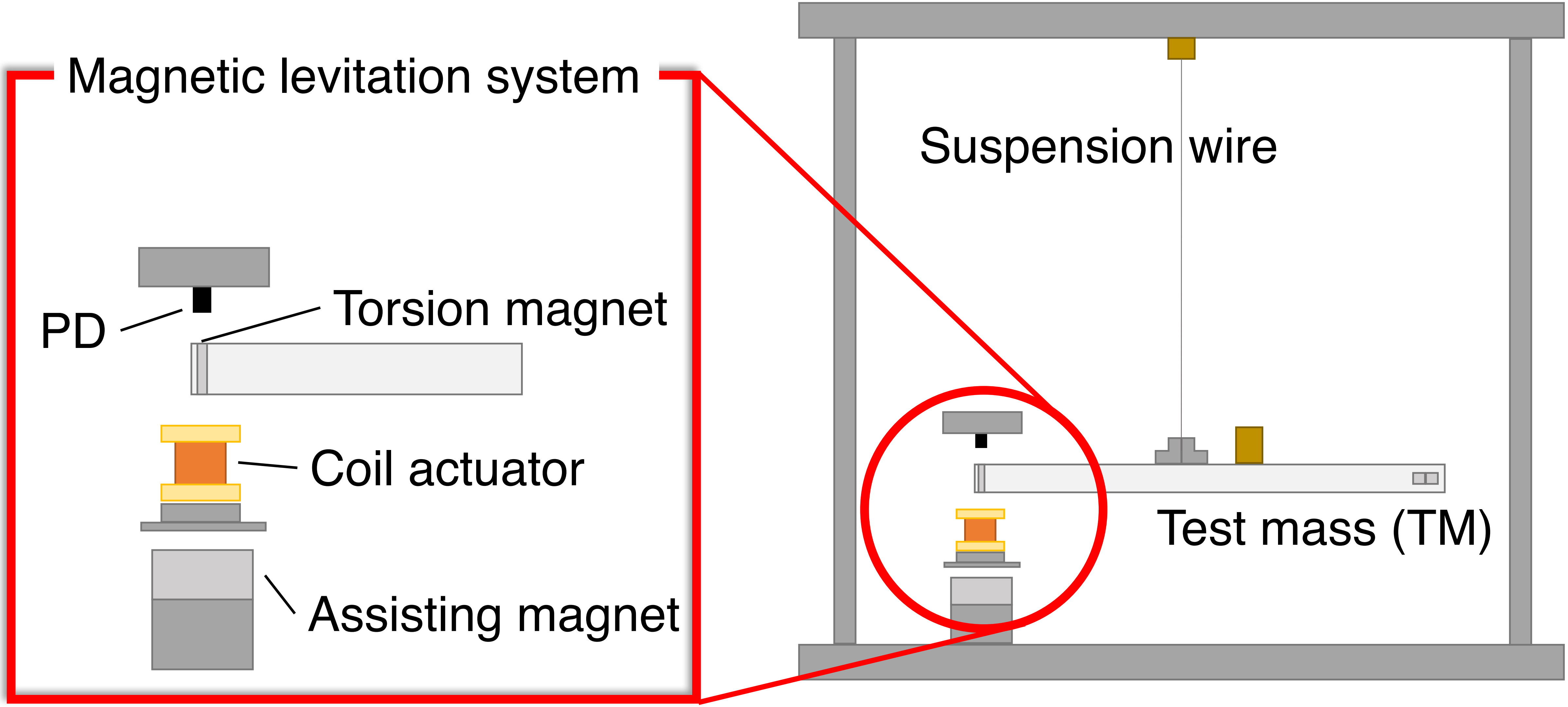
- Earnshaw's theorem:

  A collection of point charges cannot be maintained in a stable stationary equilibrium configuration solely by the electrostatic fields

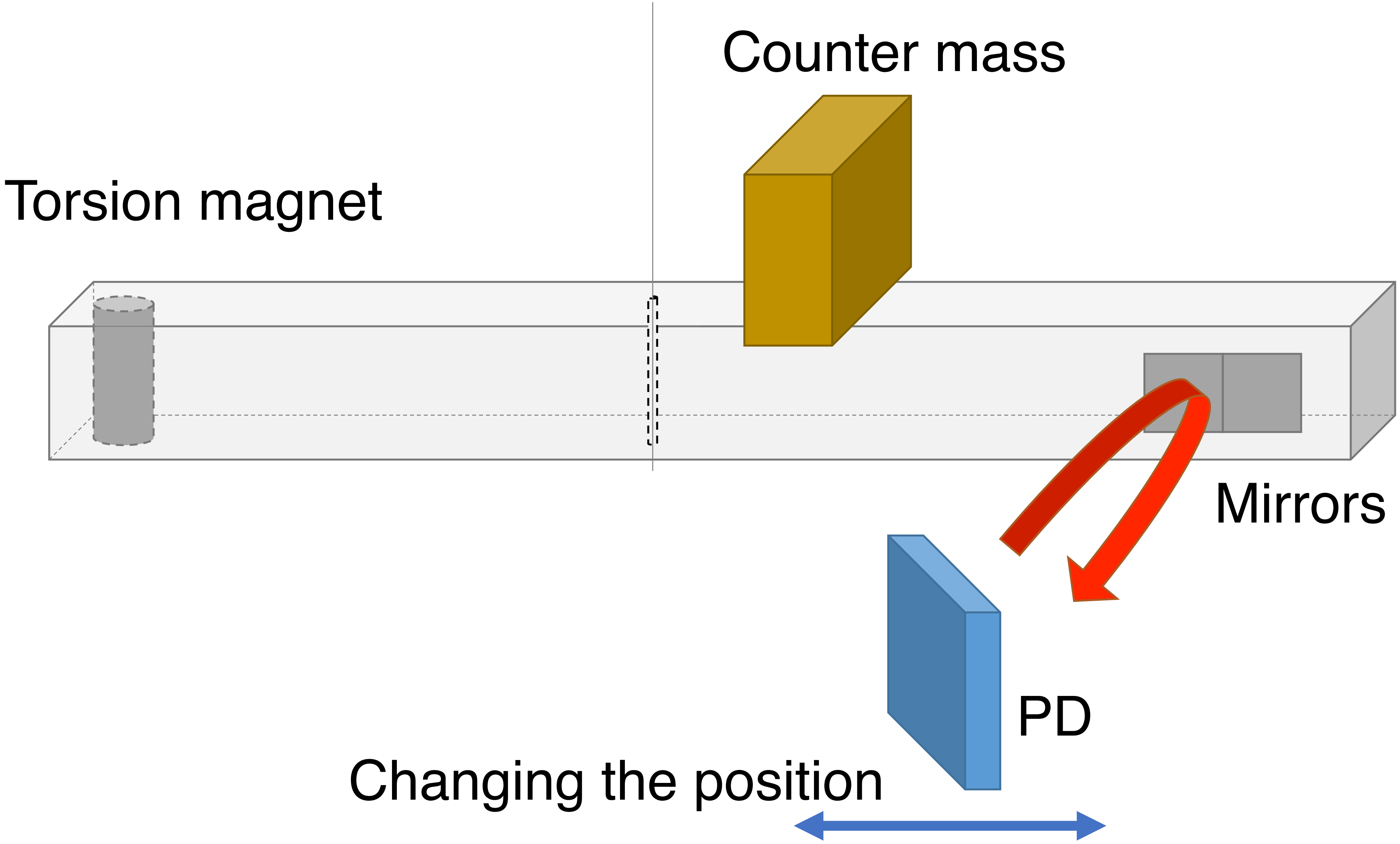
  (from Wikipedia)

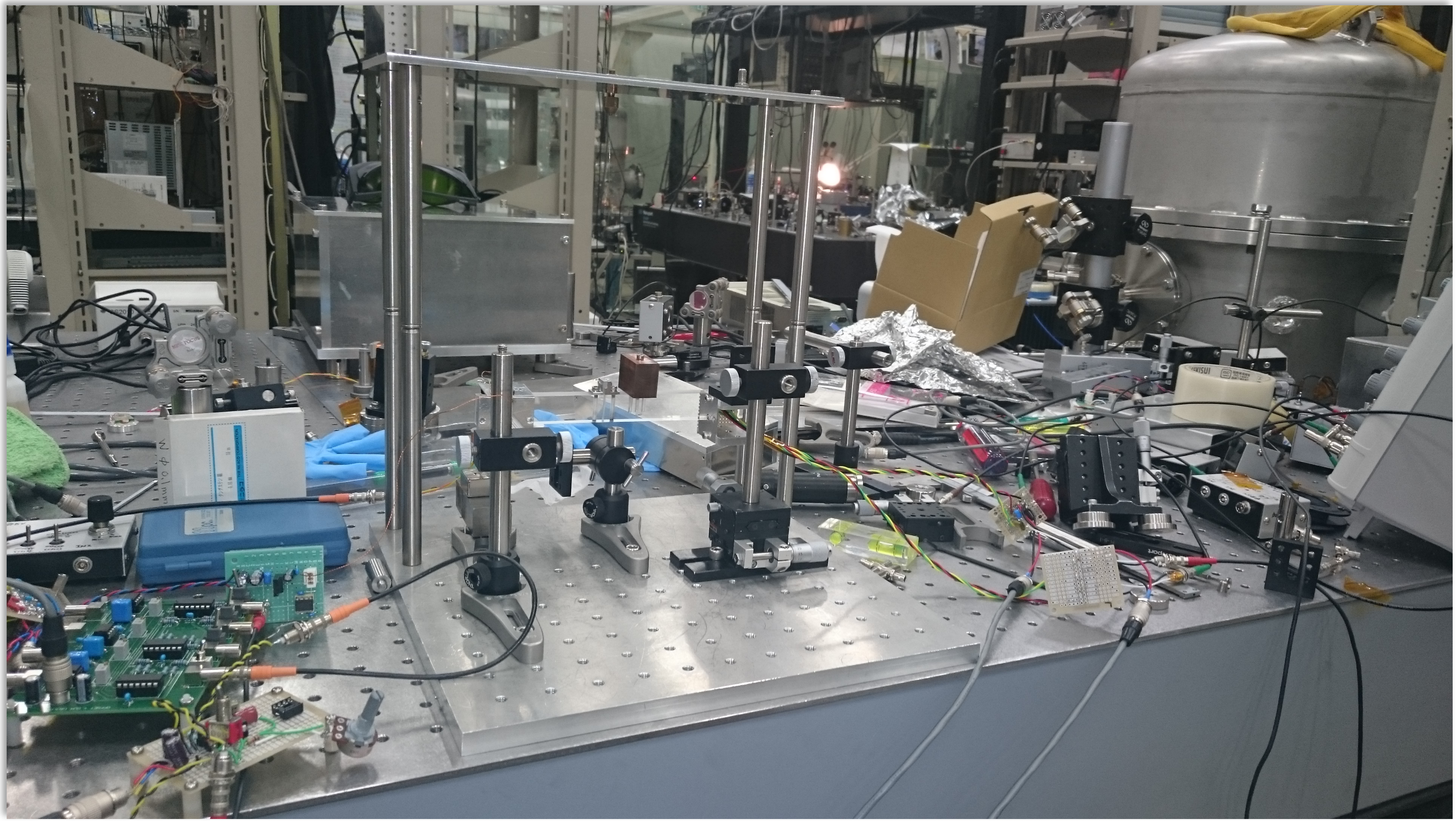
  in magnetostatics as well
- Need to use some feedback system
- Measure the displacement by PD and feedback to a coil

Experimental Setup



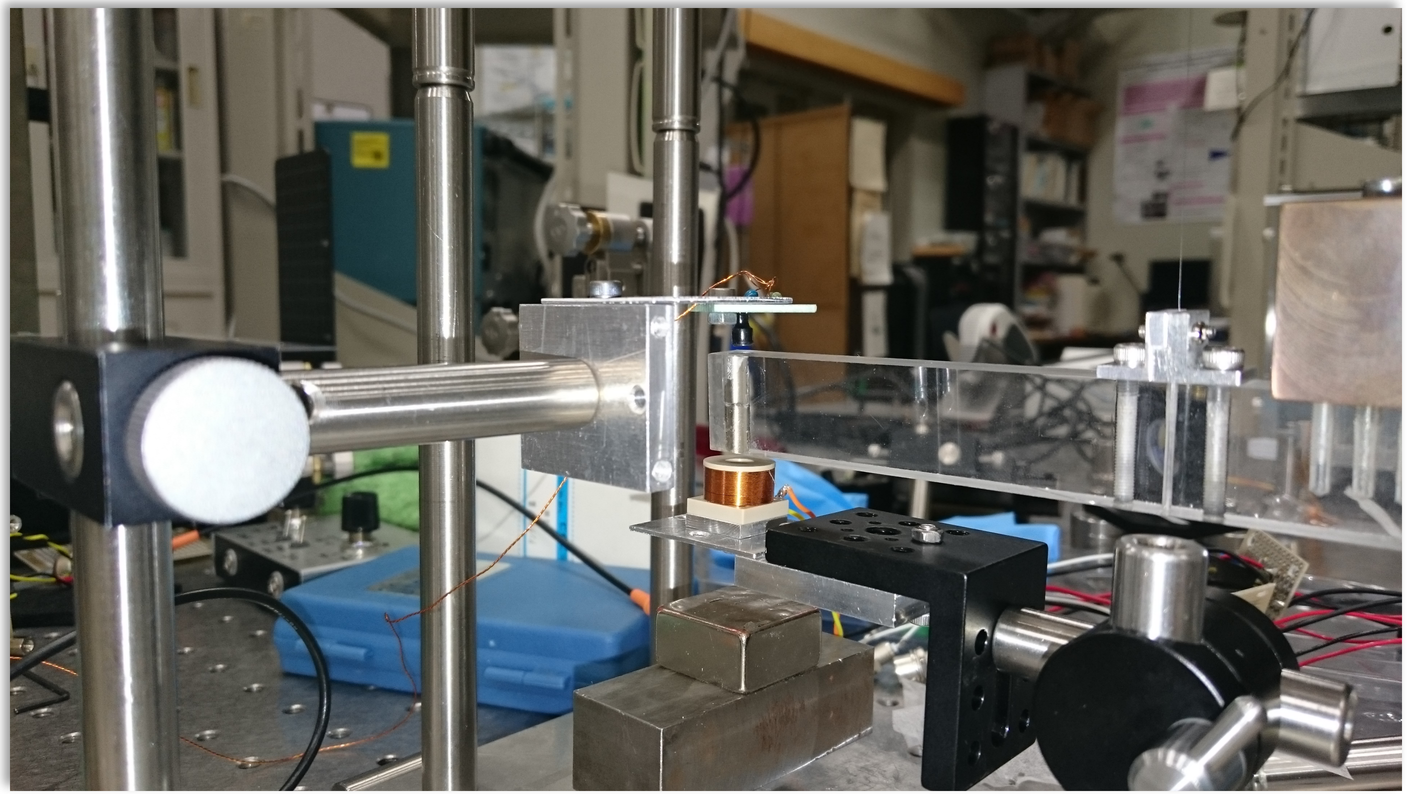
Test mass


Counter mass
Torsion magnet
Mirrors
PD
Changing the position



Results

- Succeeded in levitating the TM magnetically…



- But not so stable that could test the procedure
  - Apparently oscillating in yaw rotation

Problems and for further experiments

- Apparently oscillating in yaw direction
  - Increase the gain in the feedback circuit
  - Failed to levitate
- COP is near the edge of the mirrors
  - Fitting is probably wrong
  - Need to design the configuration again
- In this configuration, yaw rotational frequency gets much higher
  - A new idea for realizing freely moving in yaw and assisting the TM

Part 2
High Harmonics Generation

2016/9/27~2017/01/18

＠Sakai Lab

Contents

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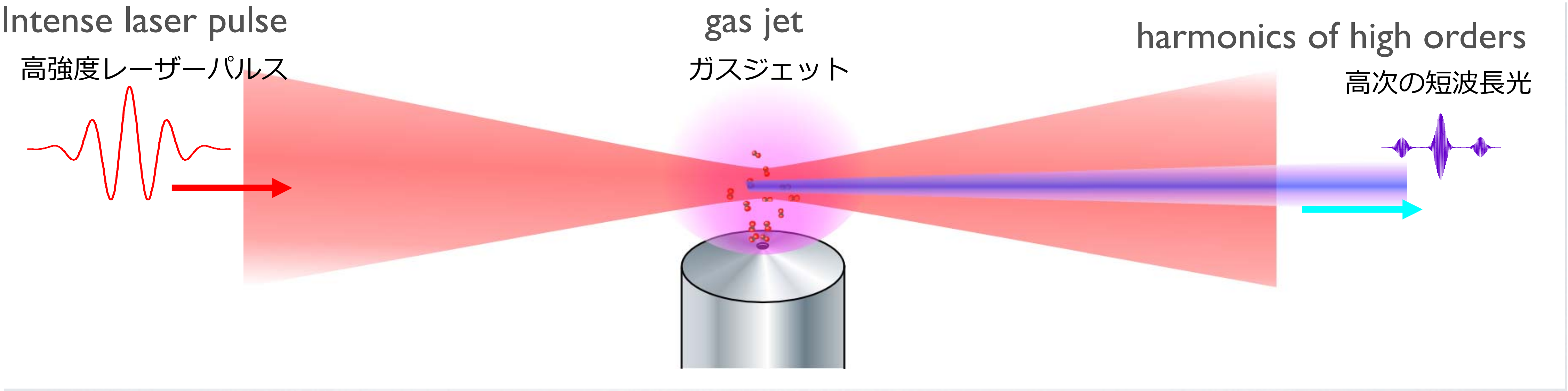
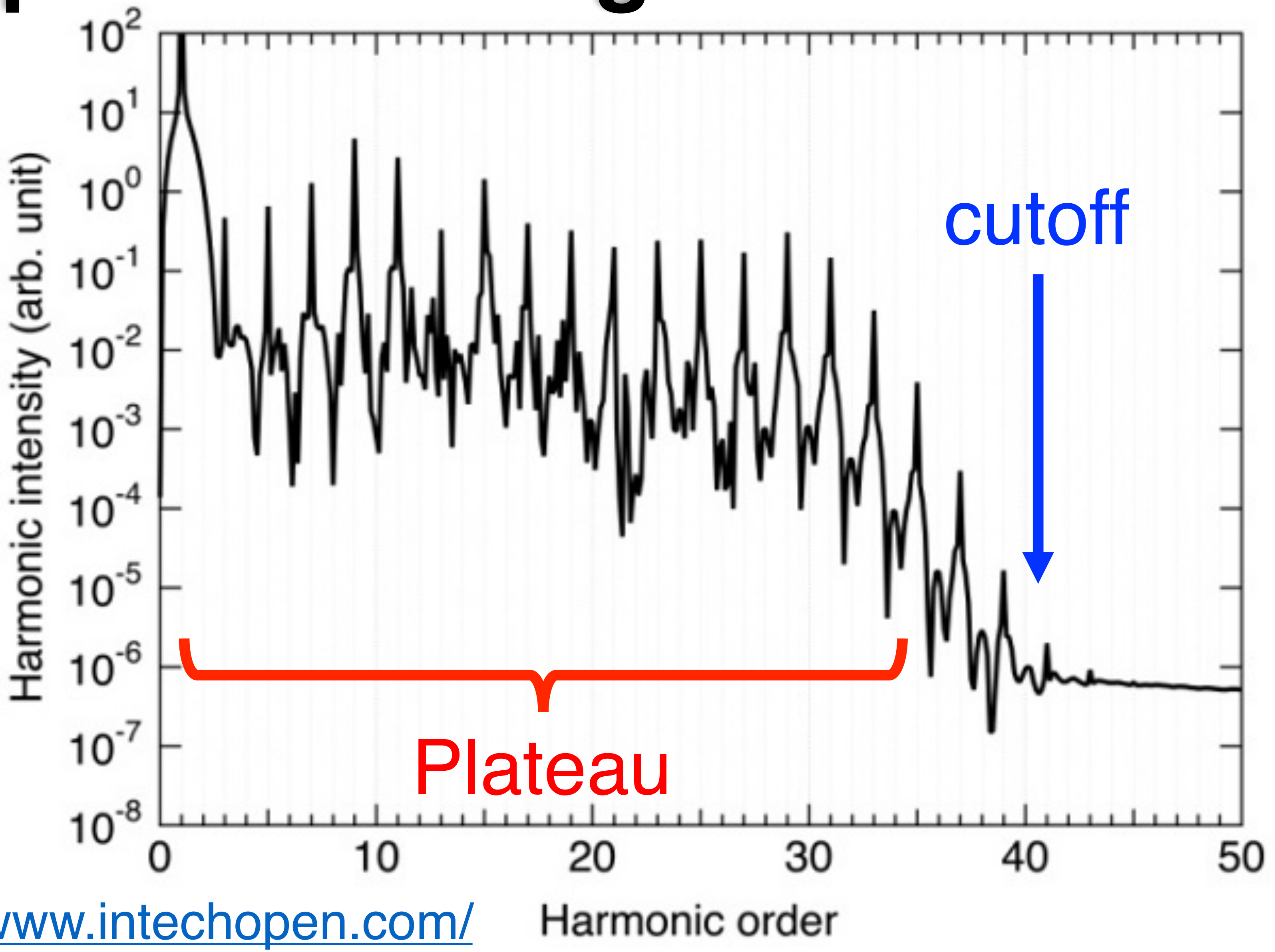
High Harmonics Generation (HHG)

- Nonlinear (nth order) optical effect
- Non-perturbative



From: http://ishiken.free.fr/english/lectures/APLS04.pdf

The spectrum of high harmonics



From: https://www.intechopen.com/

Characteristics

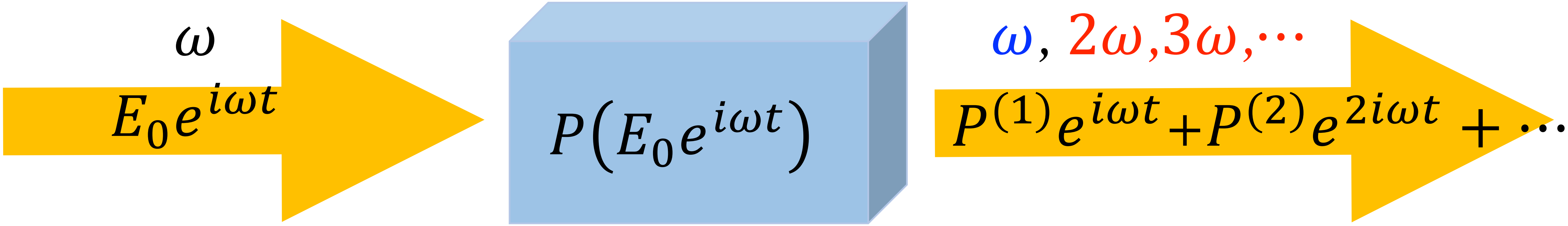
- Two structures:
  - Plateau: where the intensity doesn't decrease with increasing the order
  - Cutoff : the intensity radically falls off
- The relation between the cutoff order and that energy:

$$E_p \approx I_p + 3.17\, U_p$$

  - I_p: the ionization potential
  - $U_p = \frac{e^2 {E_0}^2}{4m\omega^2}$: the ponderomotive energy
- Only odd number order

Why even number orders don't exist

$$D(E) = \varepsilon_0 E + P,$$
$$P(E) = \varepsilon_0\Big[\underset{\substack{\uparrow \\ \text{linear}}}{\chi^{(1)}E} + \underbrace{\chi^{(2)}E^2 + \chi^{(3)}E^3 + \cdots}_{\text{Nonlinear}}\Big]$$



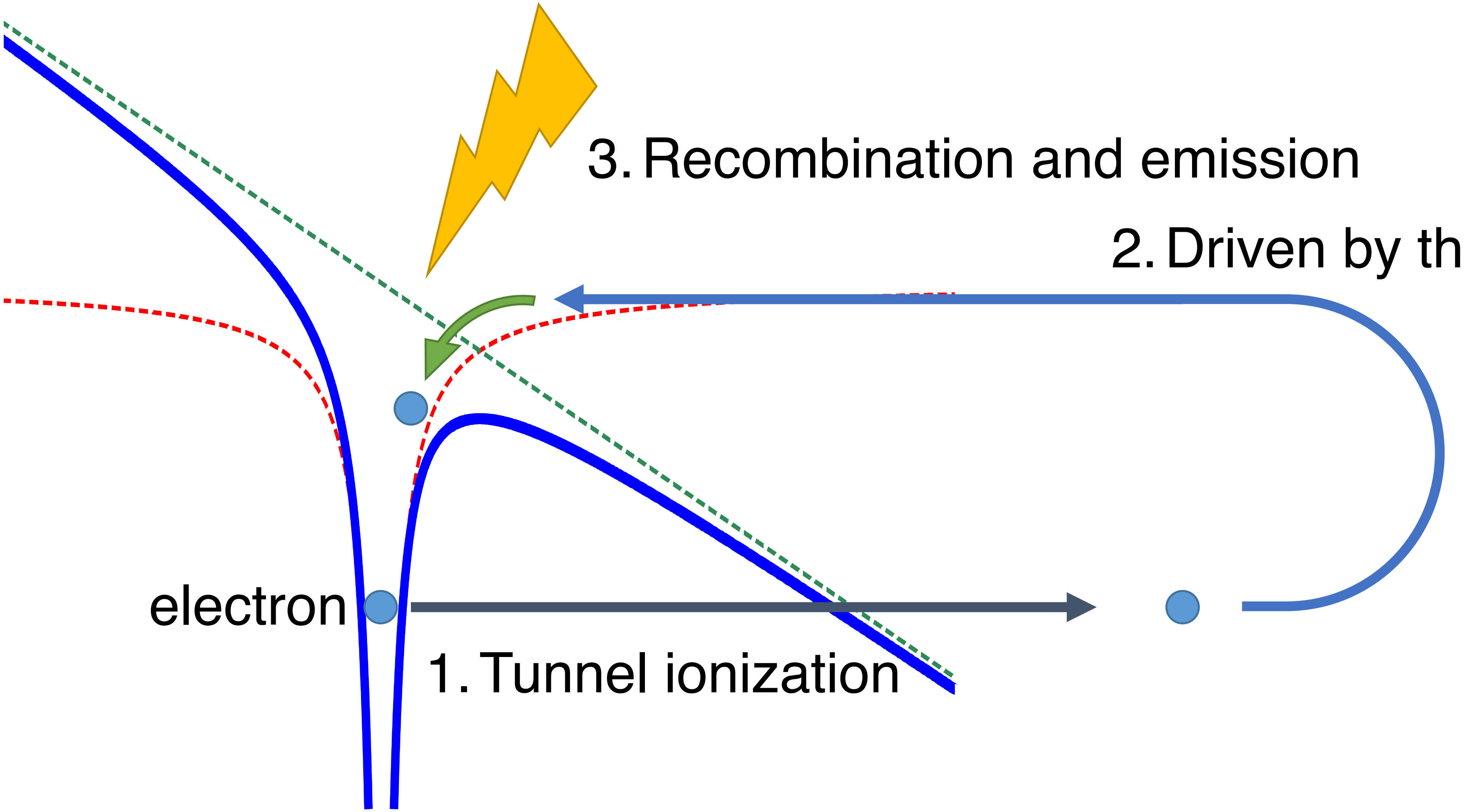
- In isotropic materials, $P(E) = P(-E)$
  - ➢ $\chi^{(2)}, \chi^{(4)} \cdots = 0$

Mathematical description

- 3 step model (semiclassical model)
  - HHG consists of 3 step:
    - Tunnel ionization
    - Driving by the laser field
    - Recombination
  - 1st, 3rd is quantum mechanical, but 2nd is not
- Lewenstein model
  - Treating 2nd process quantum mechanically
    - Strong field approximation

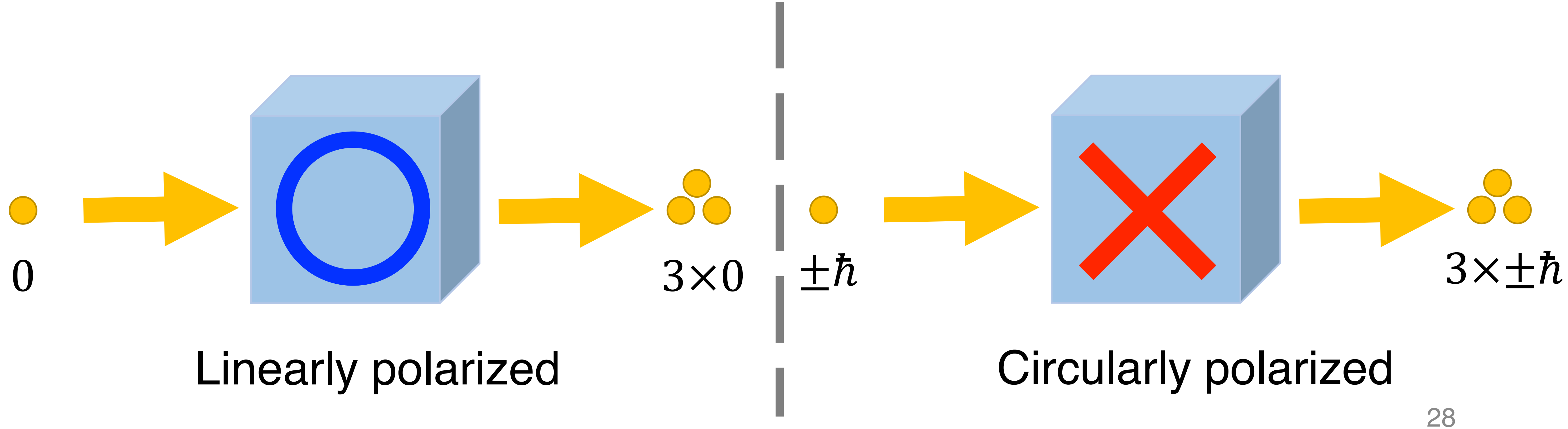
3 step model

Paul B. Corkum, Phys. Rev. Lett. 71, 1994 (1993)



The polarization

- HHG from circular polarized light is prohibit experimentally and theoretically
- contradict to the conservation of angular momentum



Linearly polarized

Circularly polarized

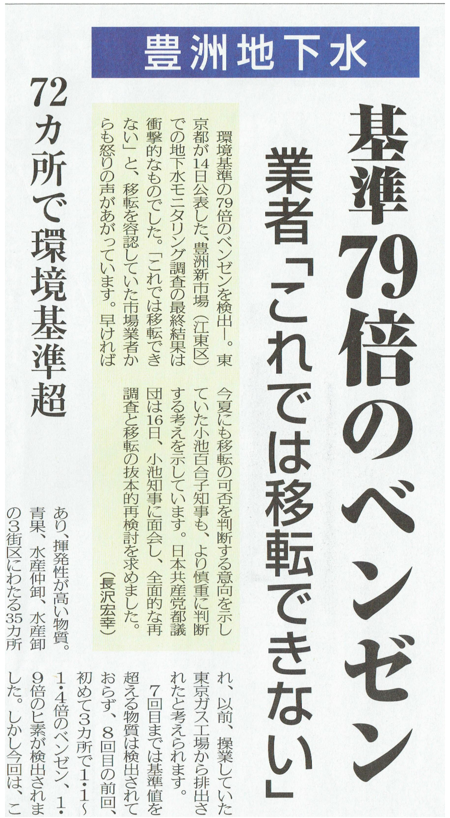
Symmetrical molecules

- For special cases, circular polarized could be generated
- Molecules which have n-fold rotational symmetry
  - CO_2(2-fold), benzene(6-fold),etc.
- To observe circular polarized harmonics efficiently, we should align molecules in the same direction

Contents

setups

- Gas medium: benzene
- Using 2 laser
  - Ti:Sapphire (880 nm): generate harmonics
    Intensity: 1.6W
  - YAG (1064): align benzene molecules


豊洲地下水

基準79倍のベンゼン

業者「これでは移転できない」

環境基準の79倍のベンゼンを検出―。東京都が14日公表した、豊洲新市場（江東区）での地下水モニタリング調査の最終結果は衝撃的なものでした。「これでは移転できない」と、移転を容認していた市場業者からも怒りの声があがっています。早ければ今夏にも移転の可否を判断する意向を示していた小池百合子知事も、より慎重に判断する考えを示しています。日本共産党都議団は16日、小池知事に面会し、全面的な再調査と移転の抜本的再検討を求めました。（長沢宏幸）

72カ所で環境基準超

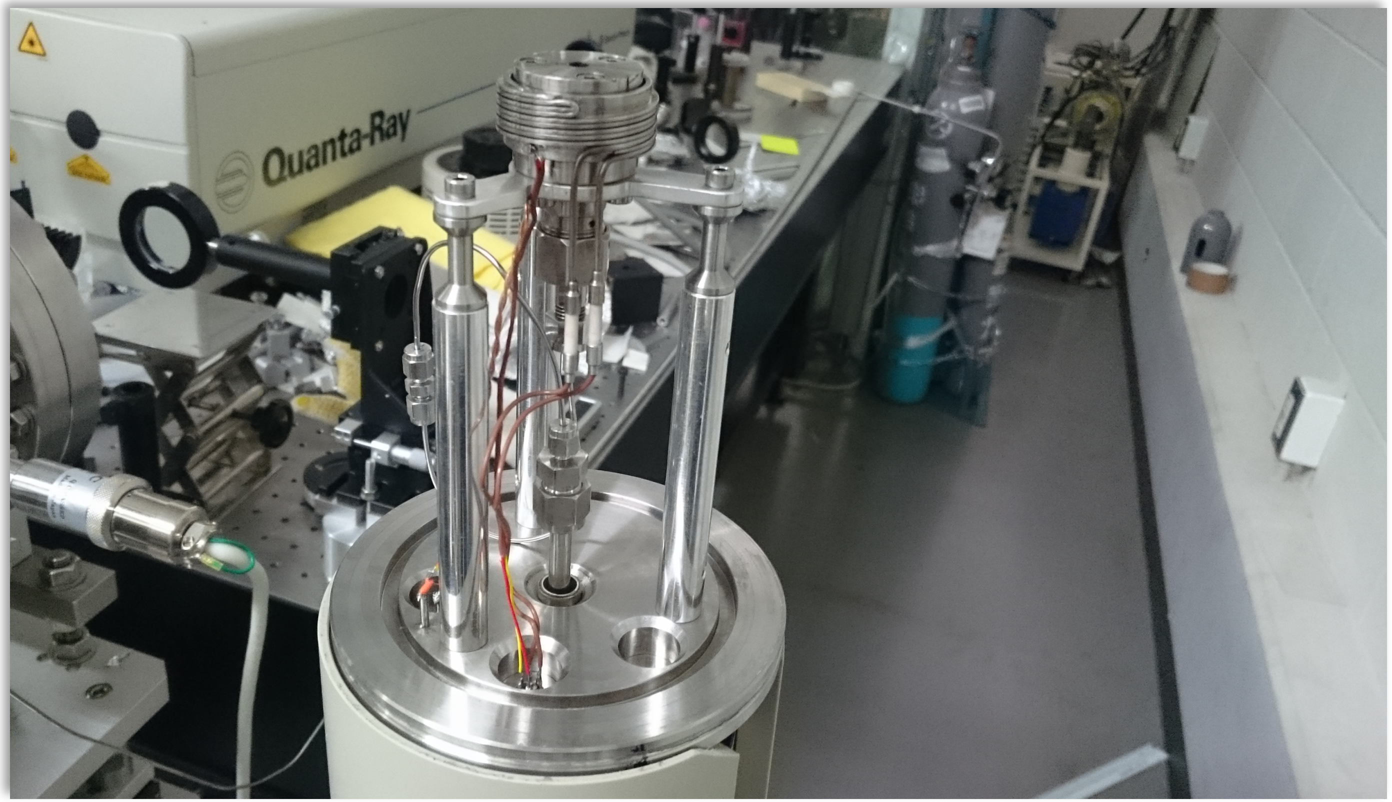
あり、揮発性が高い物質。青果、水産仲卸、水産卸の3街区にわたる35カ所

れ、以前、操業していた東京ガス工場から排出されたと考えられます。

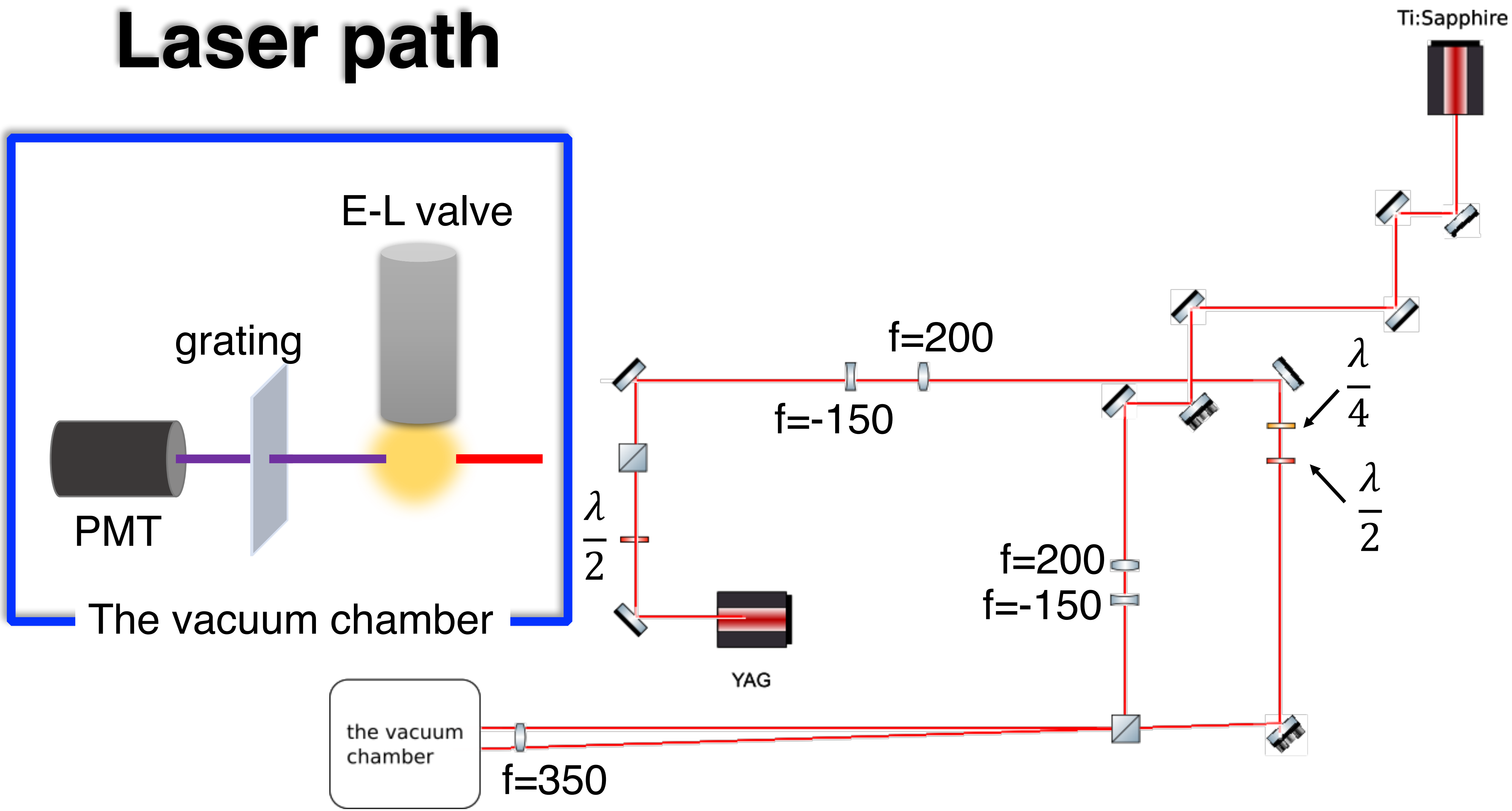
7回目までは基準値を超える物質は検出されておらず、8回目の前回、初めて3カ所で1・1～1・4倍のベンゼン、1・9倍のヒ素が検出されました。しかし今回は、こ

How to observe HHG

- Generated harmonics is diffracted and converted into digital signal by PMT
- To synchronize pulse timing and gas jet, use Even-Lavie valve

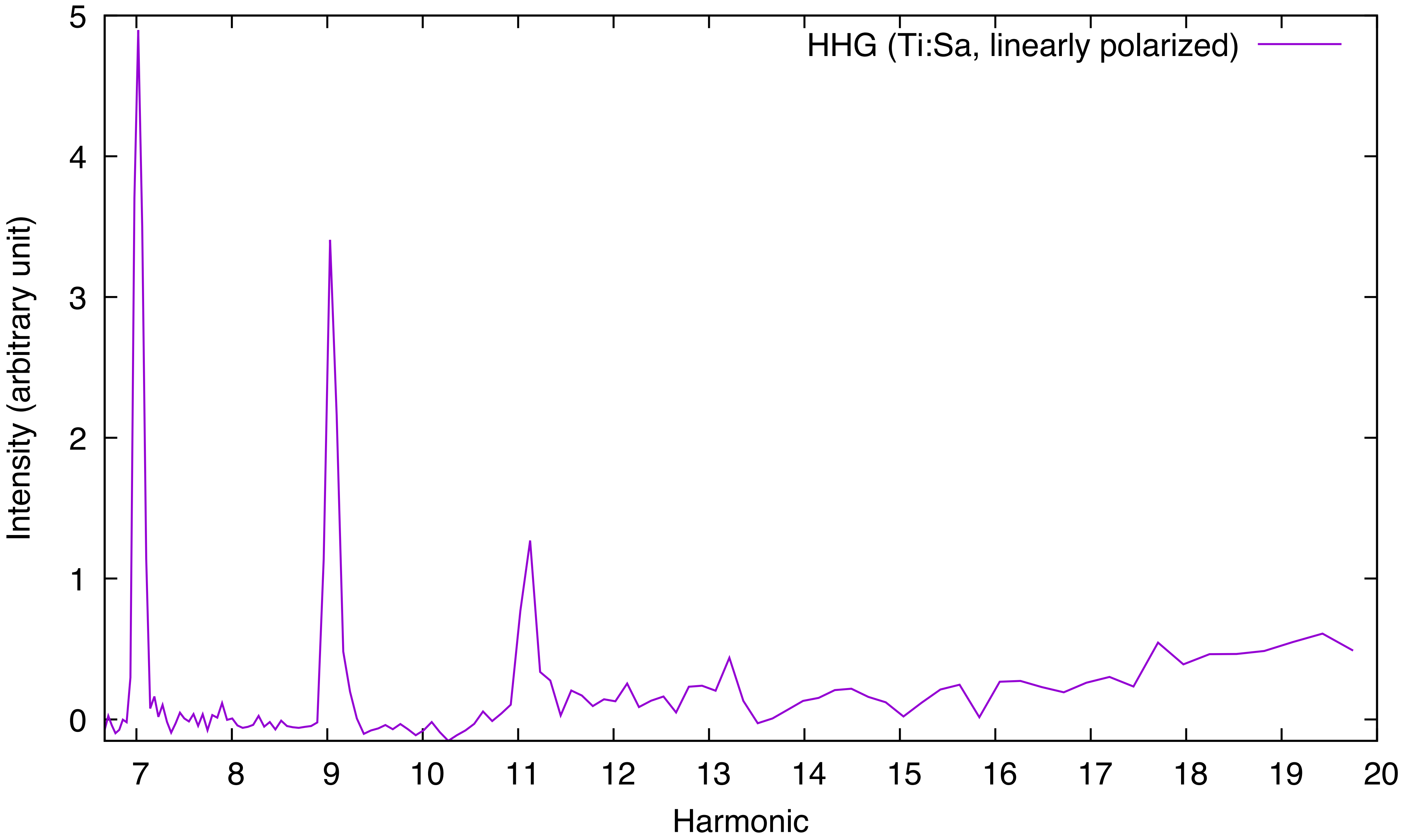


Laser path

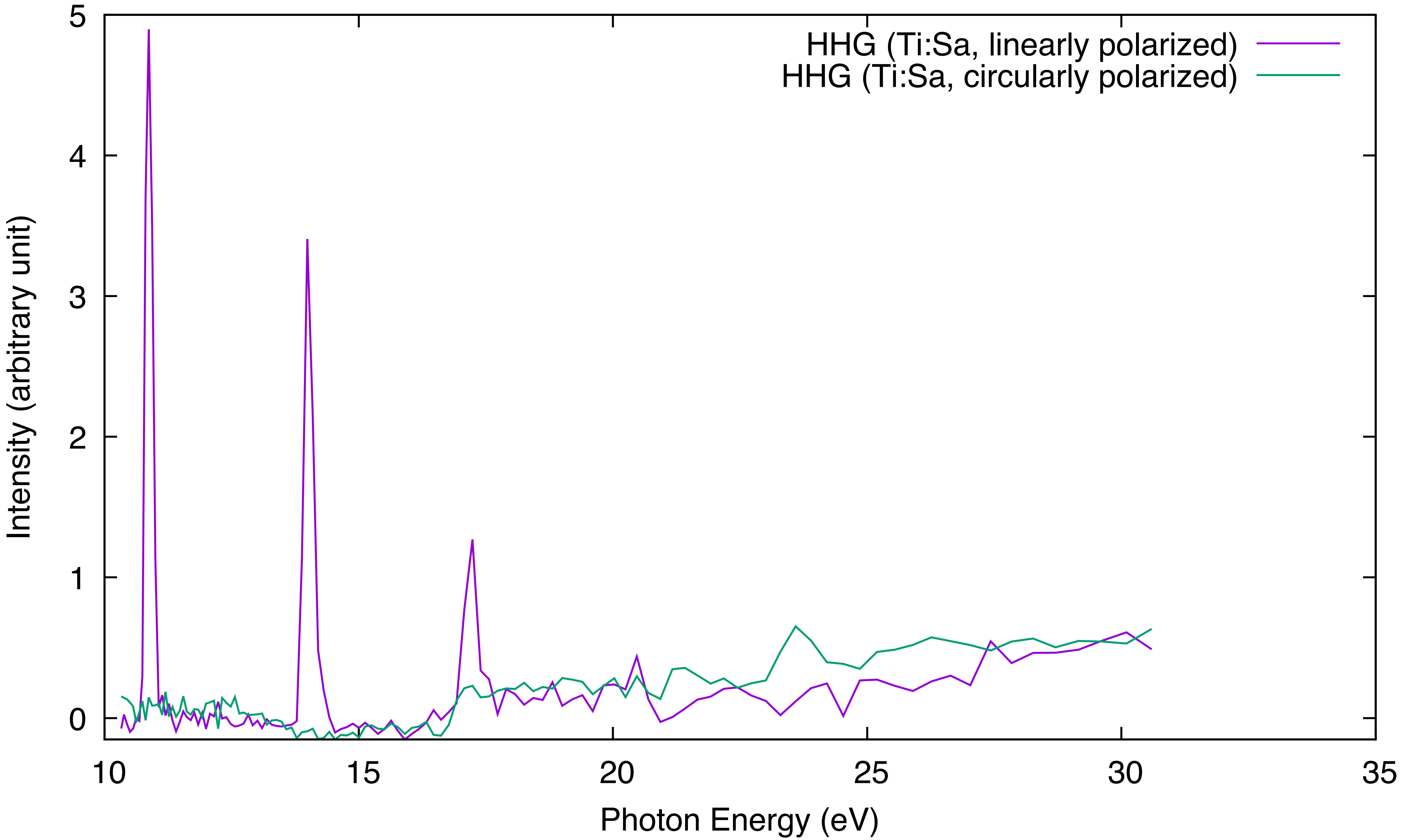


Ti:Sapphire
E-L valve
grating
PMT
The vacuum chamber
f=200
f=-150
$\frac{\lambda}{4}$
$\frac{\lambda}{2}$
$\frac{\lambda}{2}$
YAG
f=200
f=-150
the vacuum chamber
f=350

Results

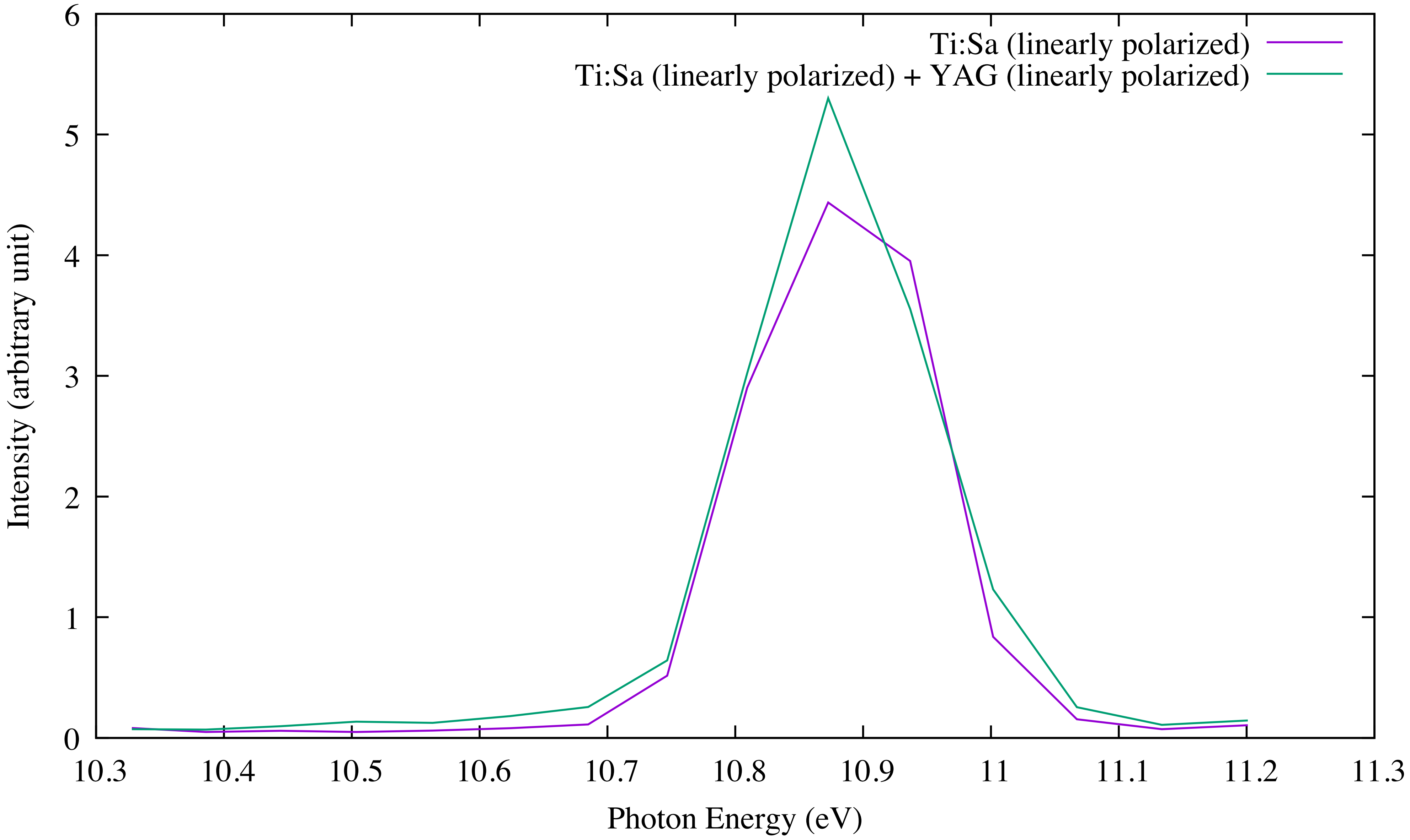

HHG (Ti:Sa, linearly polarized)
Intensity (arbitrary unit)
Harmonic
0
1
2
3
4
5
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Results



HHG (Ti:Sa, linearly polarized)
HHG (Ti:Sa, circularly polarized)
Intensity (arbitrary unit)
Photon Energy (eV)
0
1
2
3
4
5
10
15
20
25
30
35

Results


Ti:Sa (linearly polarized)
Ti:Sa (linearly polarized) + YAG (linearly polarized)
Intensity (arbitrary unit)
Photon Energy (eV)
0
1
2
3
4
5
6
10.3
10.4
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2
11.3

Results

- Without YAG, HHG was observed
  - ➢Ti:Sa laser and E-L valve were in work
  - ➢Circularly polarized laser indeed didn't generate high harmonics
- With YAG, the spectrum got worse than before
  - ➢Only 7th harmonics was enough strong to compare the intensity
  - ➢There was no sufficient difference
  - ➢Need to improve YAG alignment

Part 3
Future Prospects

Contents

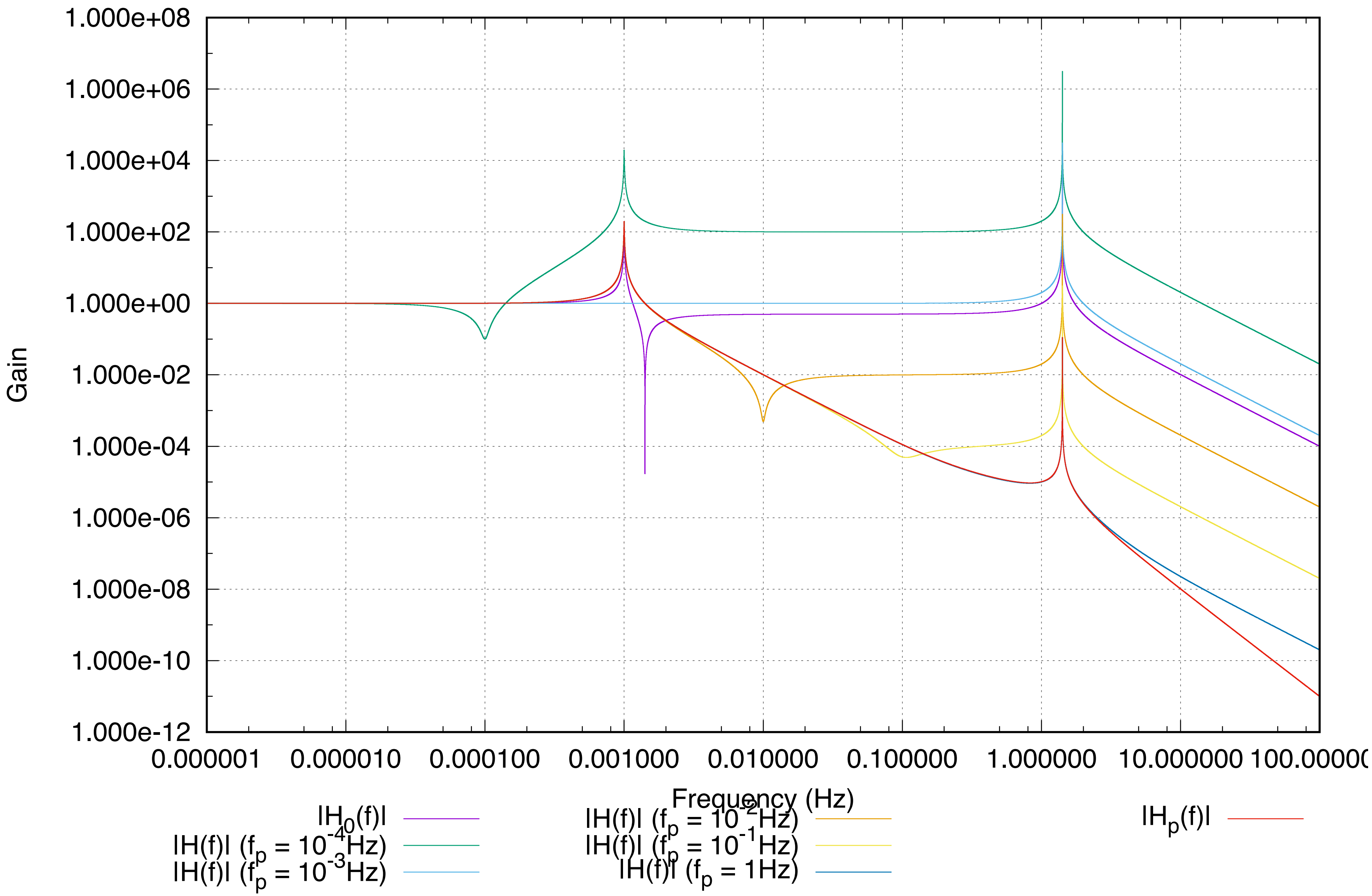
Future prospects

- TOBA
  - Unknown noise < 0.1 Hz
  - From scattering? Remanence of the test mass?
  - To final TOBA
  - Measurement not only GW but something else
- COP
  - The experiment has stopped halfway
  - Finally to measure the translational signal
- HHG
  - no consideration

To be continued…

Extra slides

Transfer function in this setup



The solution

- At $t = \ t_0$, the electron is ionized with velocity 0 at the origin
- Under the laser field $E = E_0 \cos \omega t$, the eq. of motion:

$$m\ddot{x} = -eE_0 \cos \omega t, \quad v(0) = 0, \quad x(0) = 0$$

- The solution:

$$x(t) = \frac{eE_0}{m\omega^2} [\cos \omega t - \cos \omega t_0 + \omega(t - t_0) \sin \omega t_0]$$

The kinetic energy of electron

- At $t = \tau$, the electron comes back to origin

$$\cos\omega\tau - \cos\omega t_0 + \omega(\tau - t_0)\sin\omega t_0 = 0$$

- The kinetic energy:

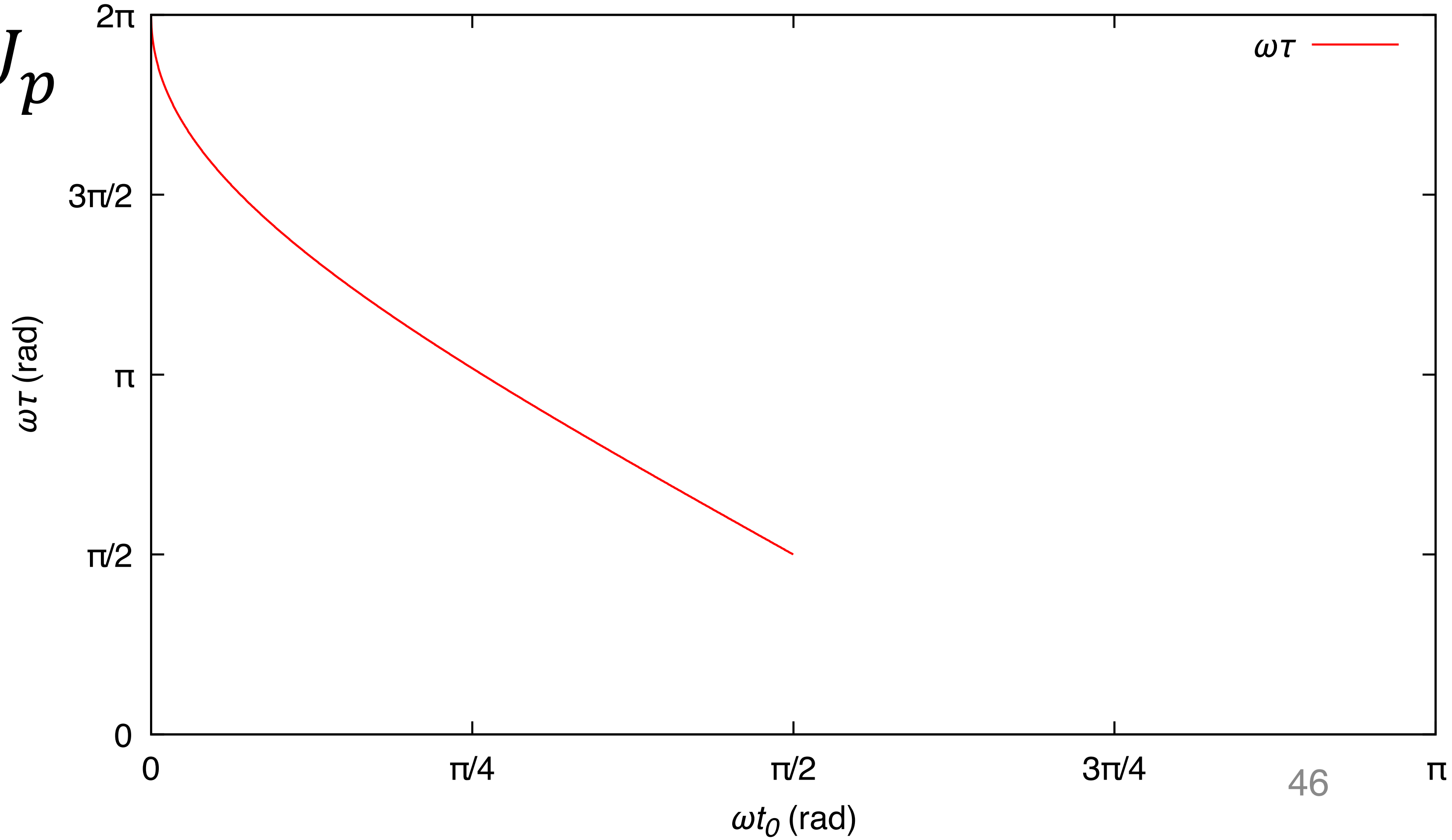
$$K(t) = \frac{e^2 {E_0}^2}{2m\omega^2}(\sin\omega t - \sin\omega t_0)^2$$
$$\equiv 2U_p(\sin\omega t - \sin\omega t_0)^2$$

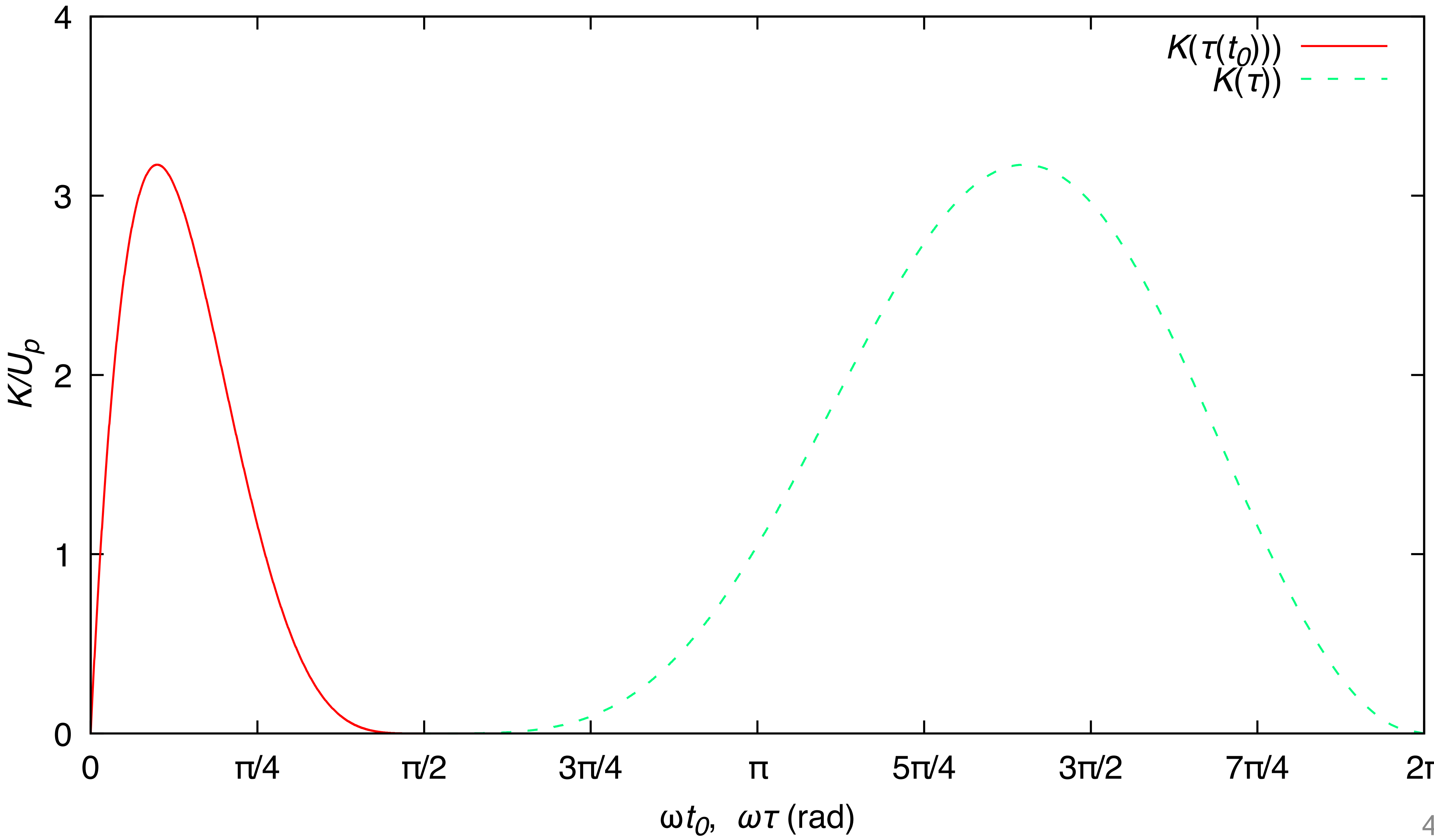
- $U_p = \frac{e^2 {E_0}^2}{4m\omega^2}$: the ponderomotive energy

The cutoff law

- By calculating τ numerically, we can evaluate the maximum of $K(t)$

➢ $K_{max} \approx 3.17\ U_p$





4
3
2
1
0
K/U_p
0
π/4
π/2
3π/4
π
5π/4
3π/2
7π/4
2π
ωt_0, $\omega\tau$ (rad)
$K(\tau(t_0)))$
$K(\tau))$

The cutoff law

- The maximum of the total energy is

$$E_p \approx I_p + 3.17\, U_p$$

  - ➢Derive the cutoff law!