# Search for Vacuum Magnetic Birefringence with Pulsed Magnets

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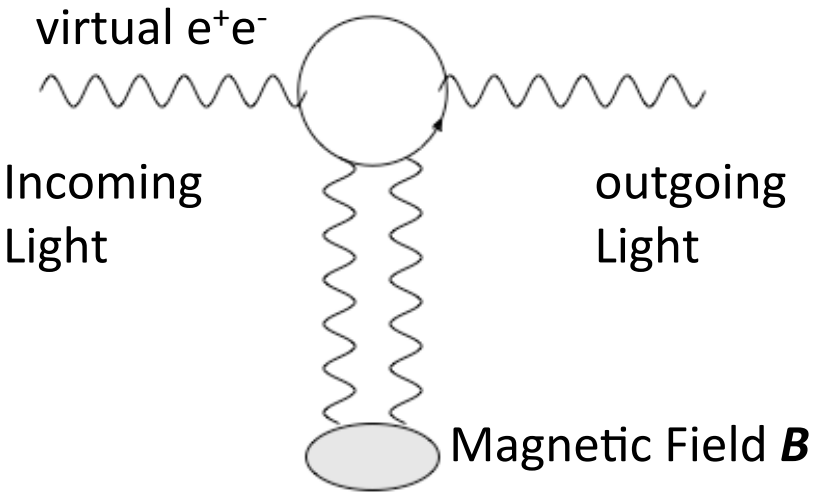
# Vacuum Magnetic Birefringence

- QED predicts the light and magnetic field can interact each other mediated by the virtual $e^-e^+$.
- ***As a result, the refractive index of vacuum could become anisotropic***




$$\Delta n = n_{||} - n_{\perp} = k_{CM} \times B^2$$

**(QED predicts $k_{CM}=4.0\times10^{-24}[T^{-2}]$)**

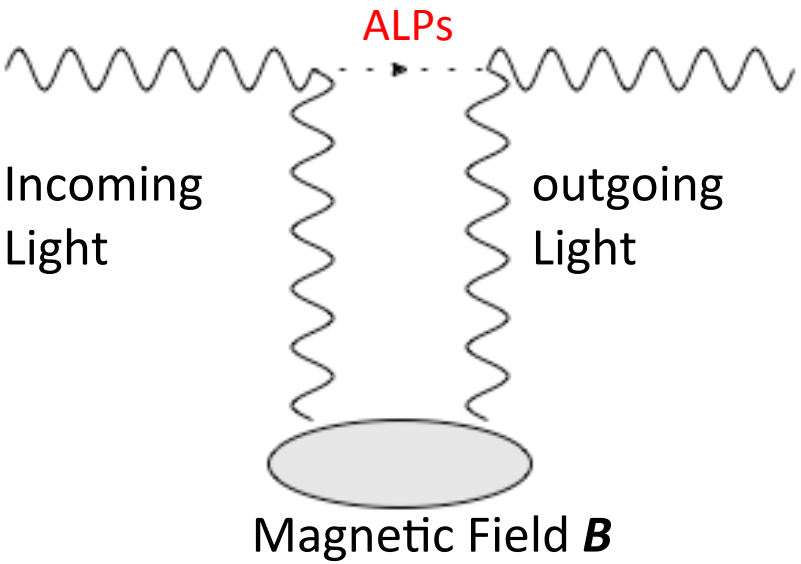
***The best experimental limit to $k_{CM}$ is $< 8\times10^{-23}[T^{-2}]$***

VMB is the non-linear effect of electromagnetism, but not observed yet .

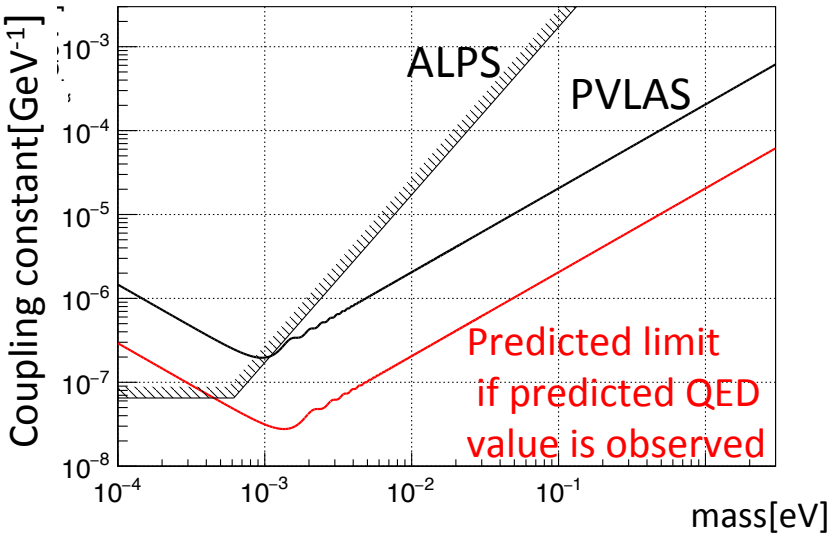
# Contribution from ALPs

- The undiscovered particle which can couple to photons such as **Axion-like particles** (ALPs) could also induce the VMB

*VMB contribution from ALPs*




Limit to the ALPs




- VMB has a good sensitivity for ALPs

***Measurement of the VMB is also good probe for new physics***

# Concept of the ***OVAL*** experiment

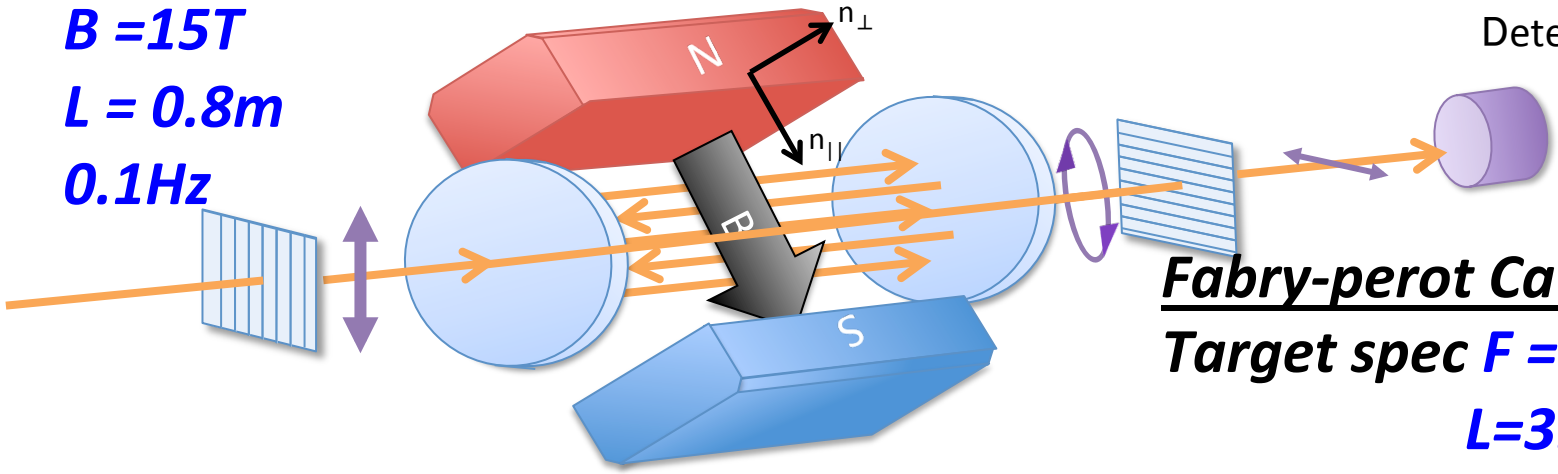
***Pulsed Magnets***

***Target spec***

***B =15T***

***L = 0.8m***

***0.1Hz***




***Fabry-perot Cavity***

***Target spec F = 650,000***

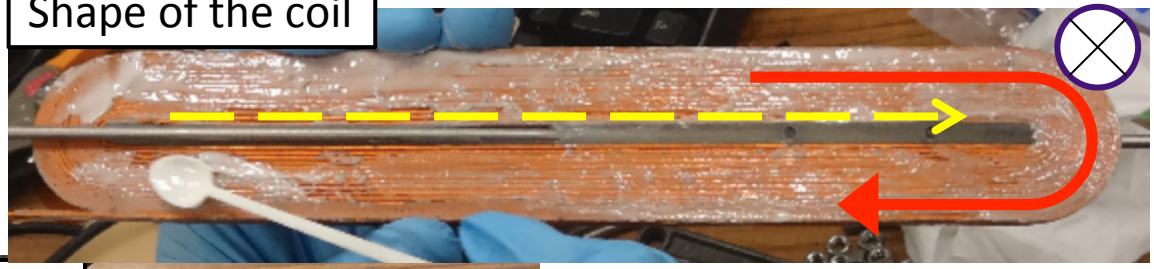
***L=3.2m, 5mW***

- Δn induce the change of polarization, and it is proportional to $B^2L_B$
- **High repetitive pulsed magnets and high finesse Fabry-perot cavity** is used to obtain large polarization change
- QED predicted VMB will be observed with 6 months' DAQ

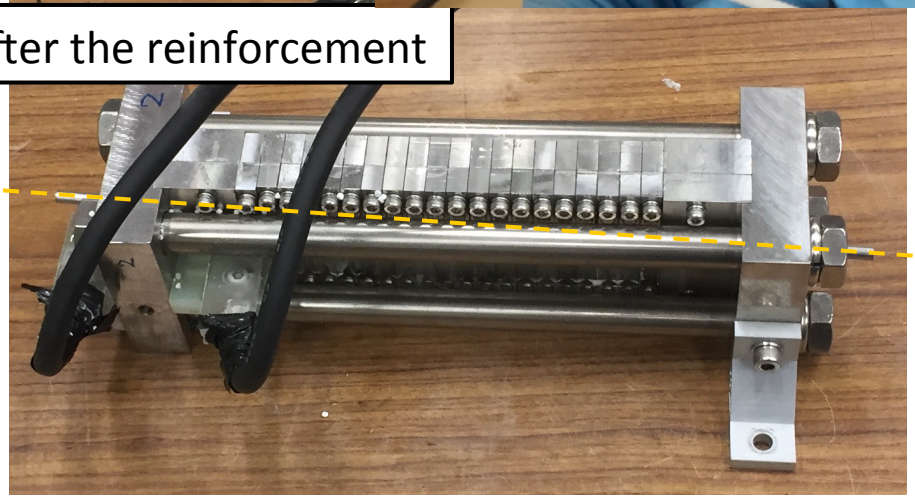
# Current status ① Magnet

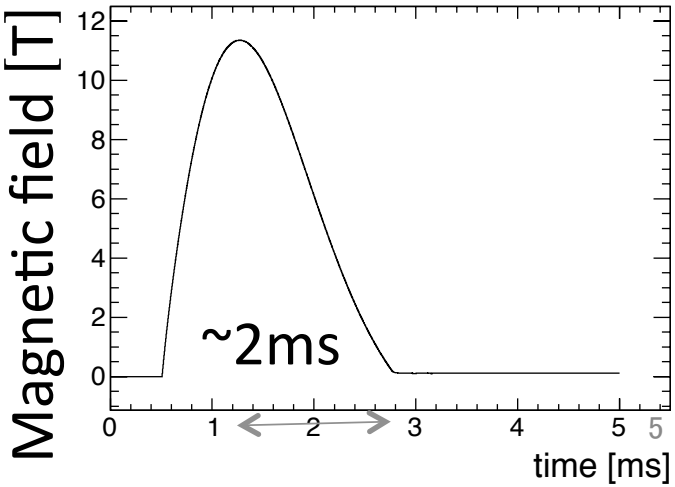
- We are developing strong pulsed magnet with high repetition
- The length of the magnetic field is 20cm along the light.
- $B_{max}$ = 11.4T and continuous operation with 9T and -4.5T, 0.15Hz was achieved ⇆ Target spec is 15T, 0.15Hz
- The maximum magnetic field is limited by the strength of wound wire

Shape of the coil



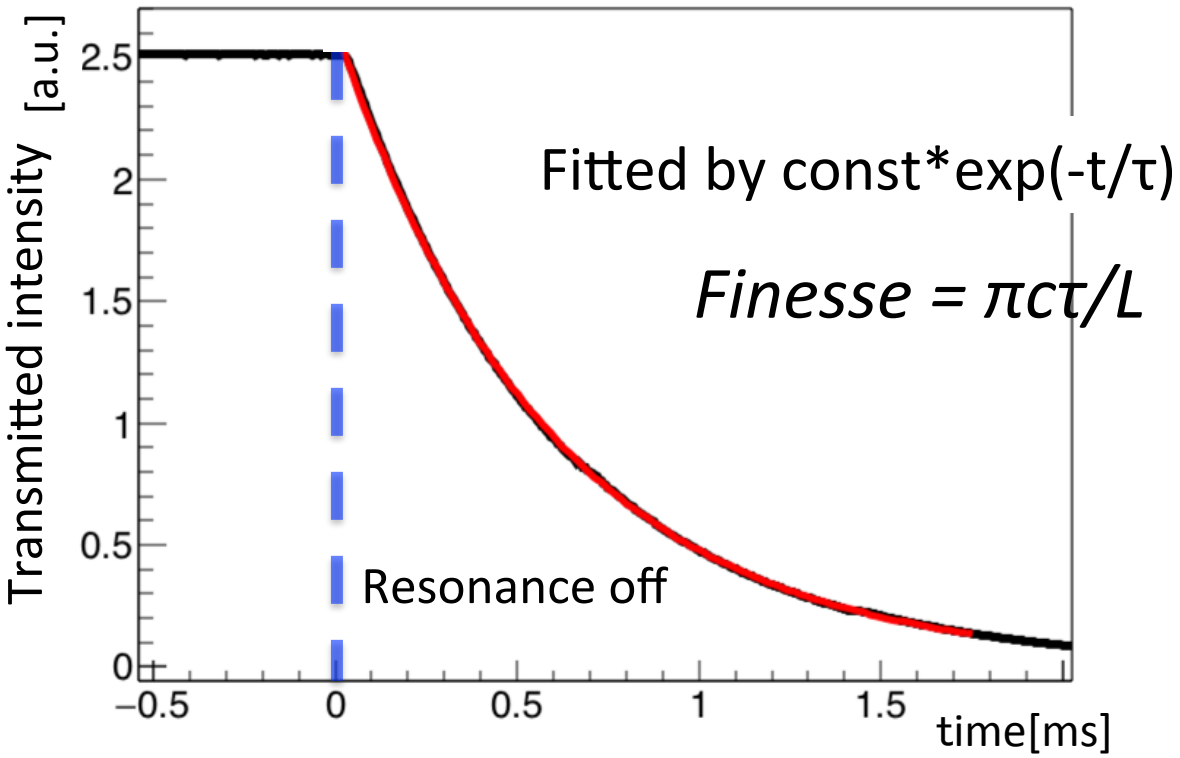
After the reinforcement





# Current status ② Fabry−Perot Cavity

- We made a L = 1.4m Fabry-perot cavity using R>99.999% mirrors




- Measured finesse from decay time of the transmitted intensity is ***~350,000***

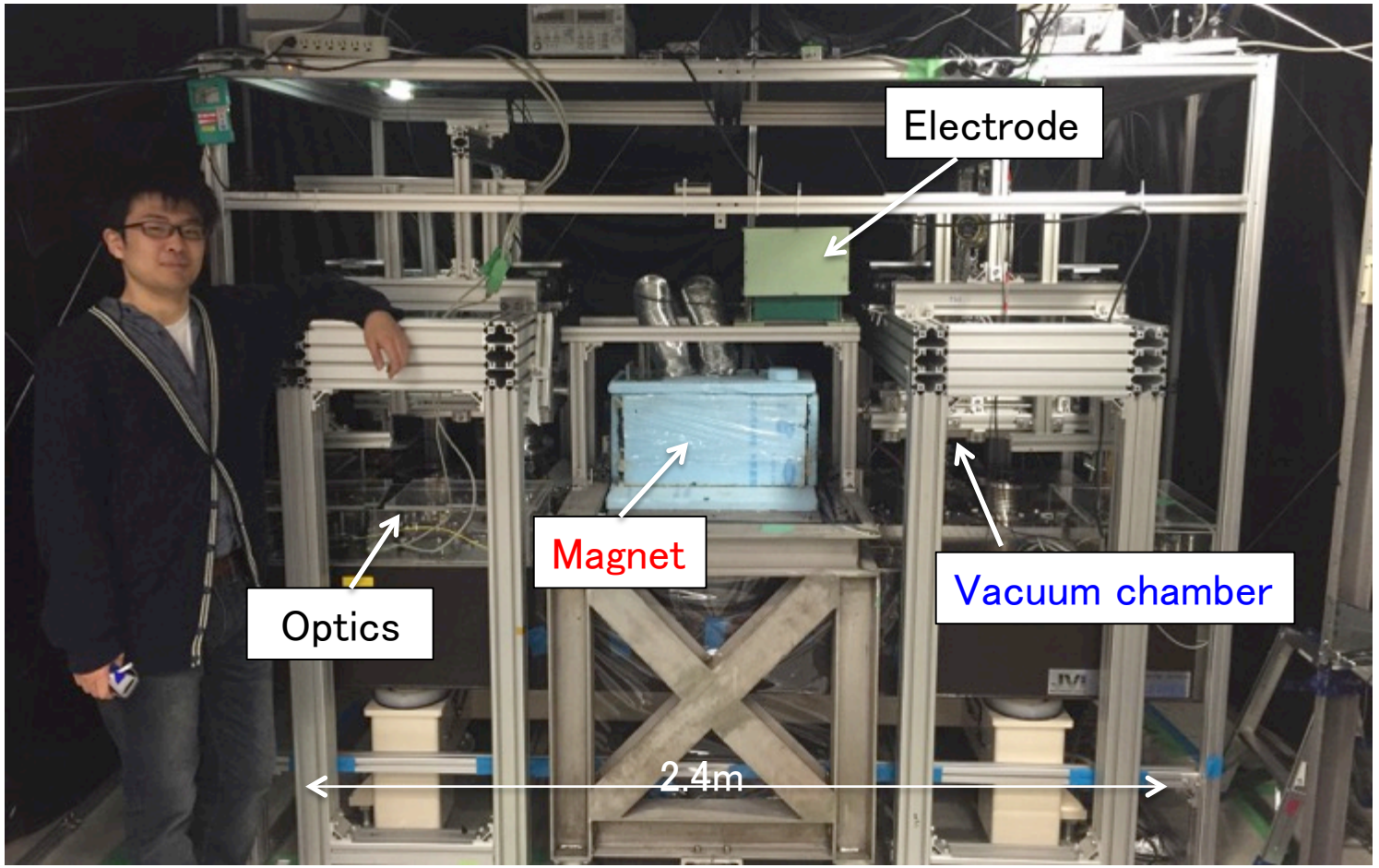
# $1_{st}$ Operation of current system

***Summary of the Current status of OVAL experiment***

- Magnet B = 9T, $L_B$ = 0.2m, 0.15Hz
- Fabry-perot cavity F = 350,000 , Intensity 30μW

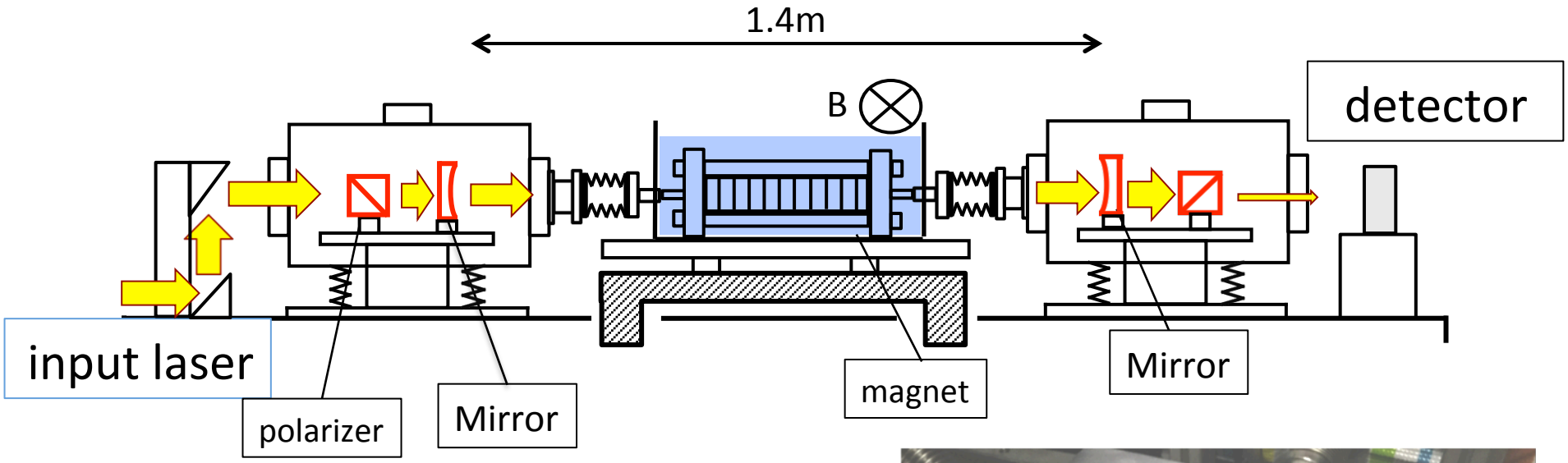
- $1_{st}$ run of current system was performed in December.
- **The expected sensitivity is worse than the QED predicted value,** but this measurement can clarify the present issues.
- 2 types of measurement were performed
  - ① **Measurement of the birefringence of $N_2$ gas for the validation**
  - ② **Measurement in the vacuum**

# Overview of Current setup

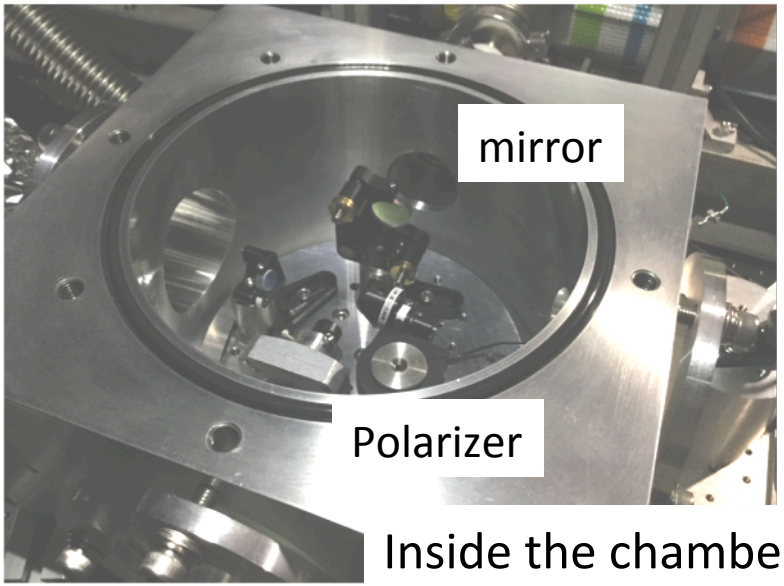



- Arranging optics and a magnet on a 1.2m*2.4m optical bench

# Schematic view of Our Current setup




- One magnet between the two mirrors.
- Mirrors and polarizers are in the vacuum chamber connected to the magnet.

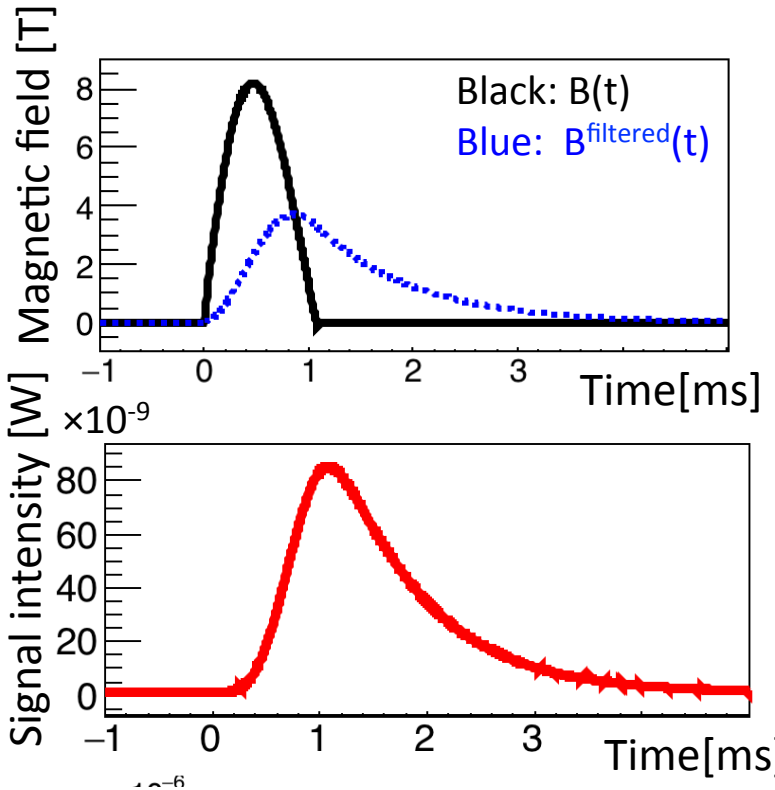


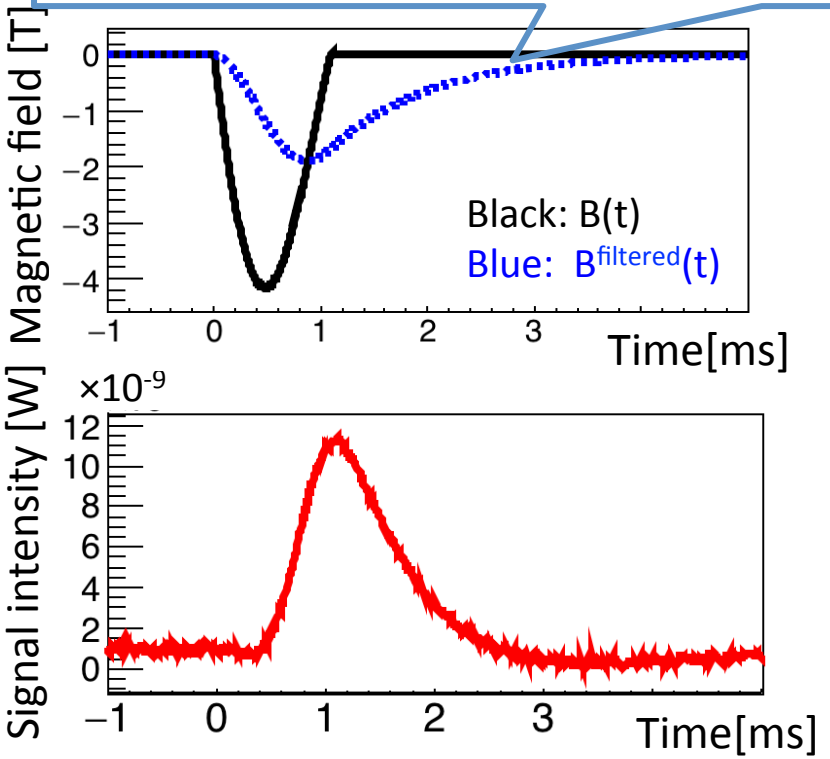

Inside the chamber

# $N_2$ measurement

- Vacuum chamber is filled with $N_2$ and 9T and -4 T magnetic field is applied to the interaction region.
- The intensity measured by the detector changes during applying the magnetic field .

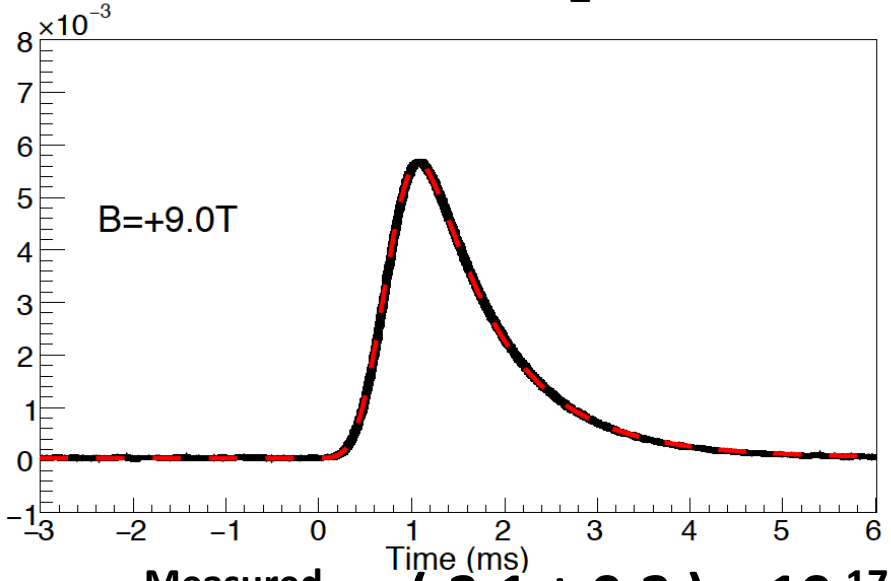
A high finesse cavity acts as a low-pass filter, so the effective magnetic filed should be filtered

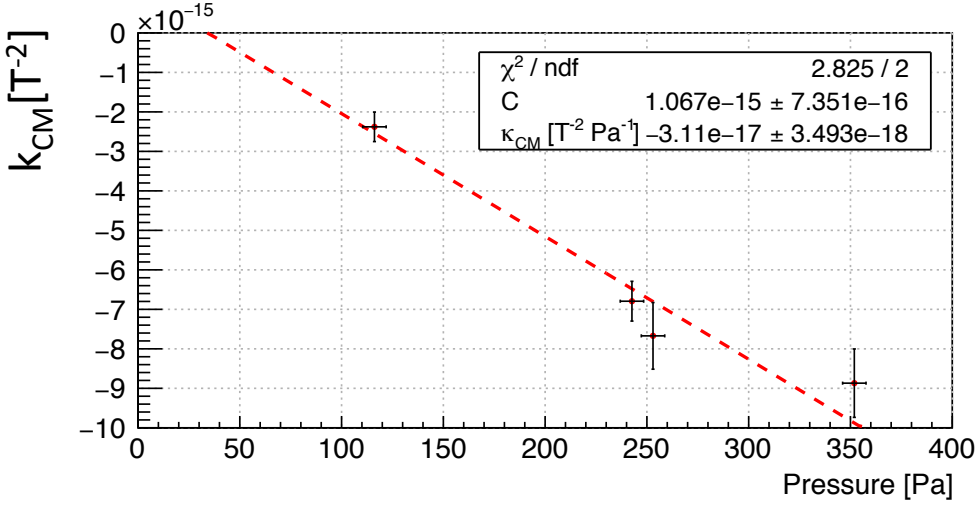


# $N_2$ measurement: Analysis

- The polarization change is fitted by using $B^{filtered}(t)$.
- From the pressure dependence of polarization change, the anisotropy of the refractive index induced by $N_2$ can be decided



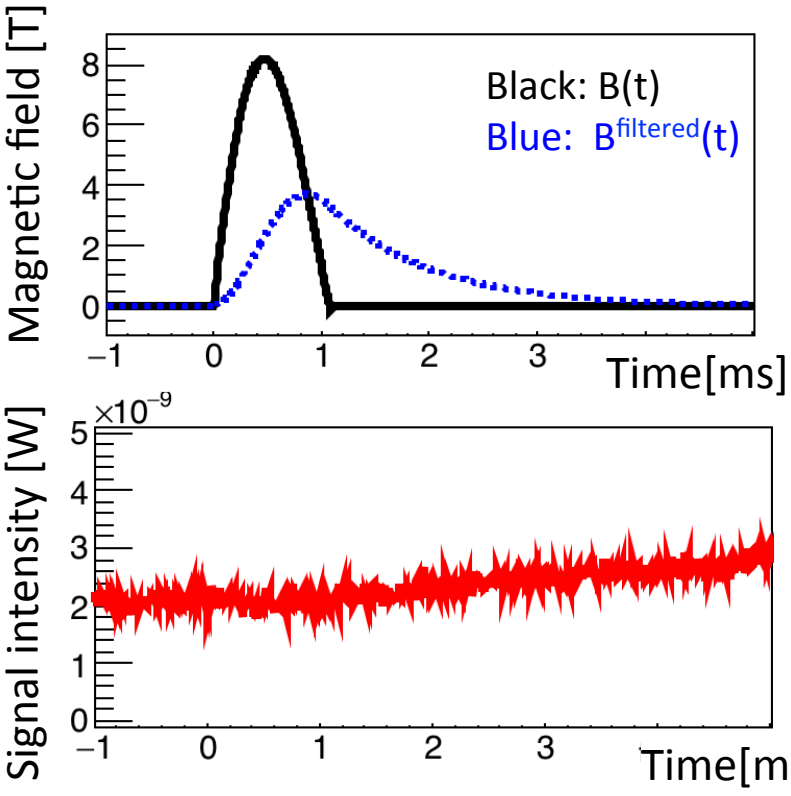

$\kappa_{CM}^{Measured} = (-3.1 \pm 0.3) \times 10^{-17}\ [T^{-2}\,Pa^{-1}] \rightleftarrows$

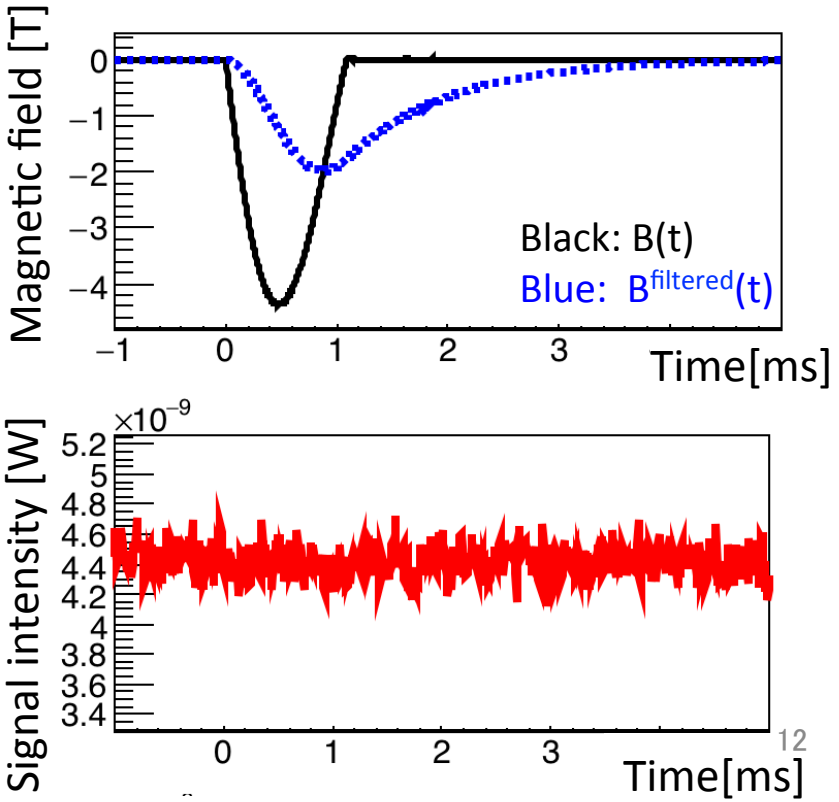
$\kappa_{CM}^{Theory} = -2.7 \times 10^{-17}\ [T^{-2}\,Pa^{-1}]$

**This result assured us that our system working as expected**

# Operation in the Vacuum

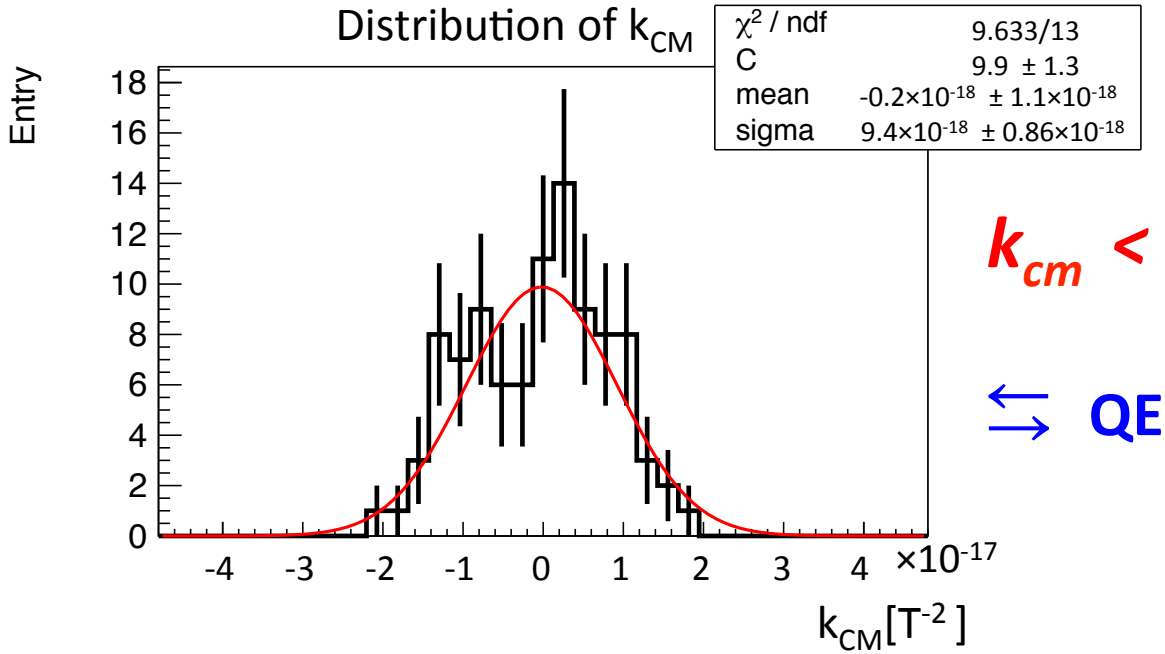
- The chambers and magnets are evacuated
- Total 100 pulse was applied to the interaction region for each polarity of the magnetics field.



# Vacuum measurement: Analysis

- The measured polarization change is fitted by $p_0 + p_1 \times B^2$ for each shot
- $k_{CM}$ is calculated from $p_1$ and its limit can be obtained from the distribution of $k_{CM}$ for every shot.




↑The mean value of this distribution is consistent with 0

***$k_{cm} < 2.2\times10^{-18}[T^{-2}]$ @95% C.L***

⇆ **QED predicted value is $k_{CM} = 4.0\times10^{-24}[T^{-2}]$**

# Future Steps of ***OVAL*** experiment

- Let's discuss the feasibility of observing VMB after upgrade and improvement of the issues found in this measurement

| | This measurement | Target value | Gain | Upgrade plan/Status |
|---|---|---|---|---|
| **Magnetic filed** | **9[T]** | **15[T]** | **3** | **Changing wound wire from Cu to Ag-Cu** |
| **Field length** | **0.2[m]** | **0.8[m]** | **4** | **Preparing for loading 4m optical bench now** |
| **Pulse width** | **1.2[ms]** | **4.8[ms]** | **2** | **The Modification of the power supply unit.** |
| **DAQ time** | **20[min]** | **180[days]** | **140** | **Building a stable DAQ system is on going** |
| **Finesse** | **350,000** | **650,000** | **2** | **Upgrade is succeeded** |
| **Intensity** | **0.03[mW]** | **5[mW]** | **40** | **Upgrade is succeeded** |
| **Intensity noise** | **$1\times10^{-4}$ [1/√Hz]** | **$1\times10^{-5}$ [1/√Hz]** | **3** | **Upgrade is succeeded** |

→ total gain is **$5\times10^{5}$**

QED predicted VMB is observed as expected

# Summary

- VMB is non-linear electro-magnetic effect predicted by QED, but not observed yet.
- We are developing a high-finesse fabry-perot cavity and strong pulsed magnets to observe VMB.
- $1_{st}$ run of the ***OVAL experiment*** was done with 9T and 0.2m pulsed magnet and F = 350,000 fabry–perot cavity.
- The obtained limit is $2.2\times10^{-18}$ [$T^{-2}$] (95C.L.)
- Upgrades of the magnets and cavity is on going.