Search for Vacuum Magnetic Birefringence with Pulsed Magnets

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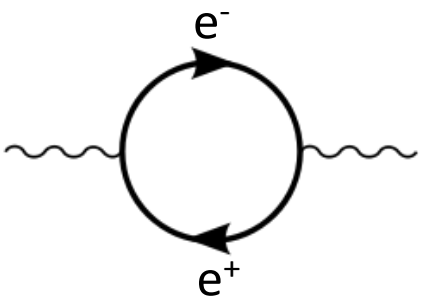
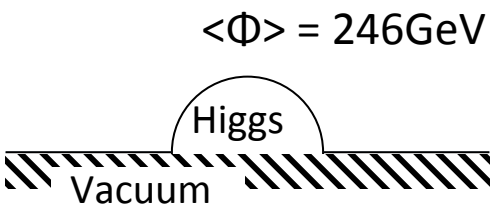
Vacuum as fundamental physics

- Vacuum has rich structures which are related to fundamental physics…

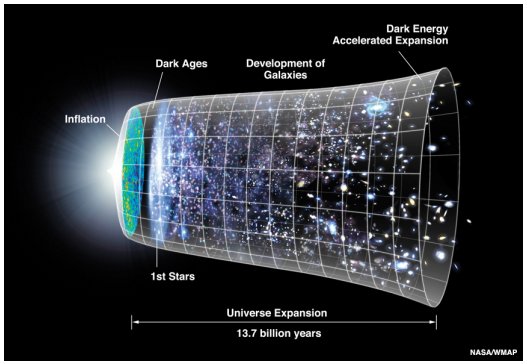
Vacuum Polarization



Higgs Field
(discovered in LHC)



Dark Energy
(Reacceleration of the Universe)



Our target is vacuum polarization

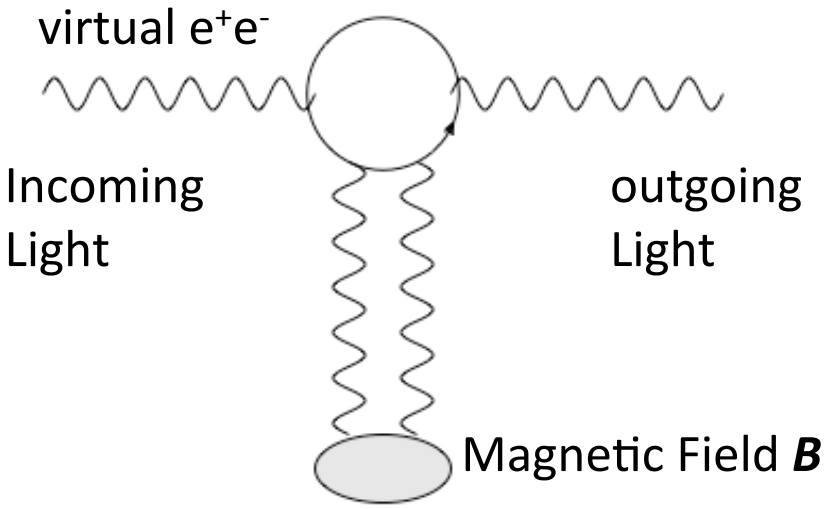
➢***It could induce the anisotropy of vacuum***

Vacuum Magnetic Birefringence

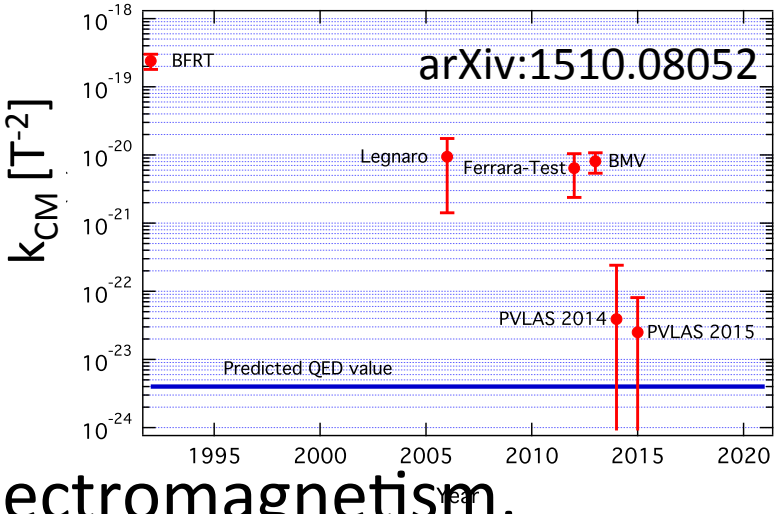
- QED predicts the light and magnetic field can interact each other mediated by the virtual e^-e^+.
- ***As a result, the refractive index of vacuum could become anisotropic***

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

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



Limit to the k_{CM}

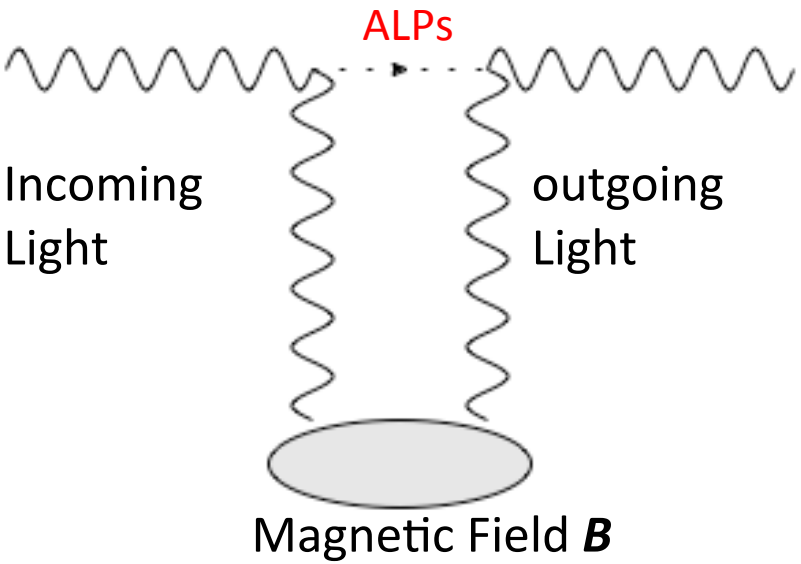


VMB is the non-linear effect of electromagnetism, but not observed yet .

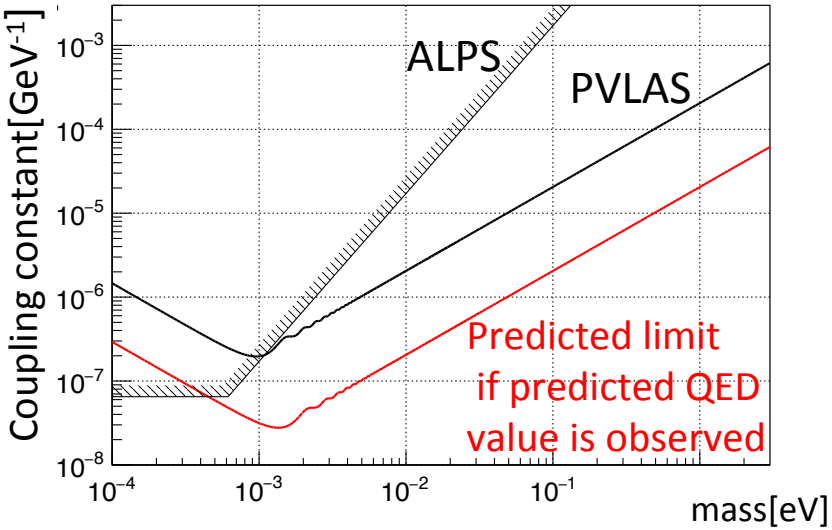
Contribution from ALPs

- 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 our experiment

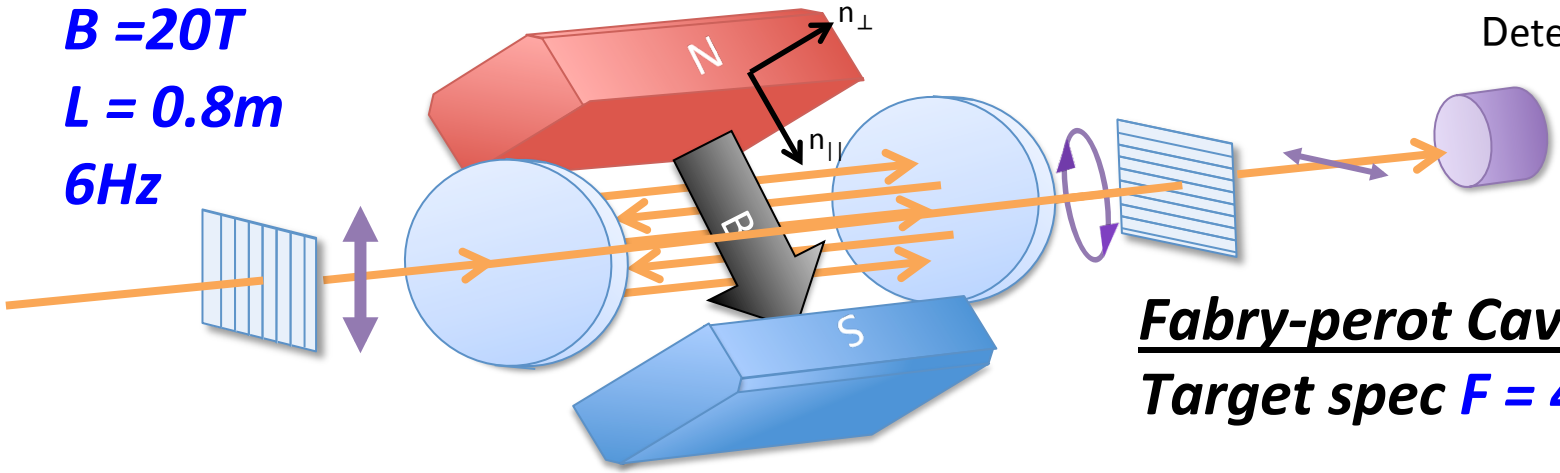
Pulsed Magnets

Target spec

B =20T

L = 0.8m

6Hz

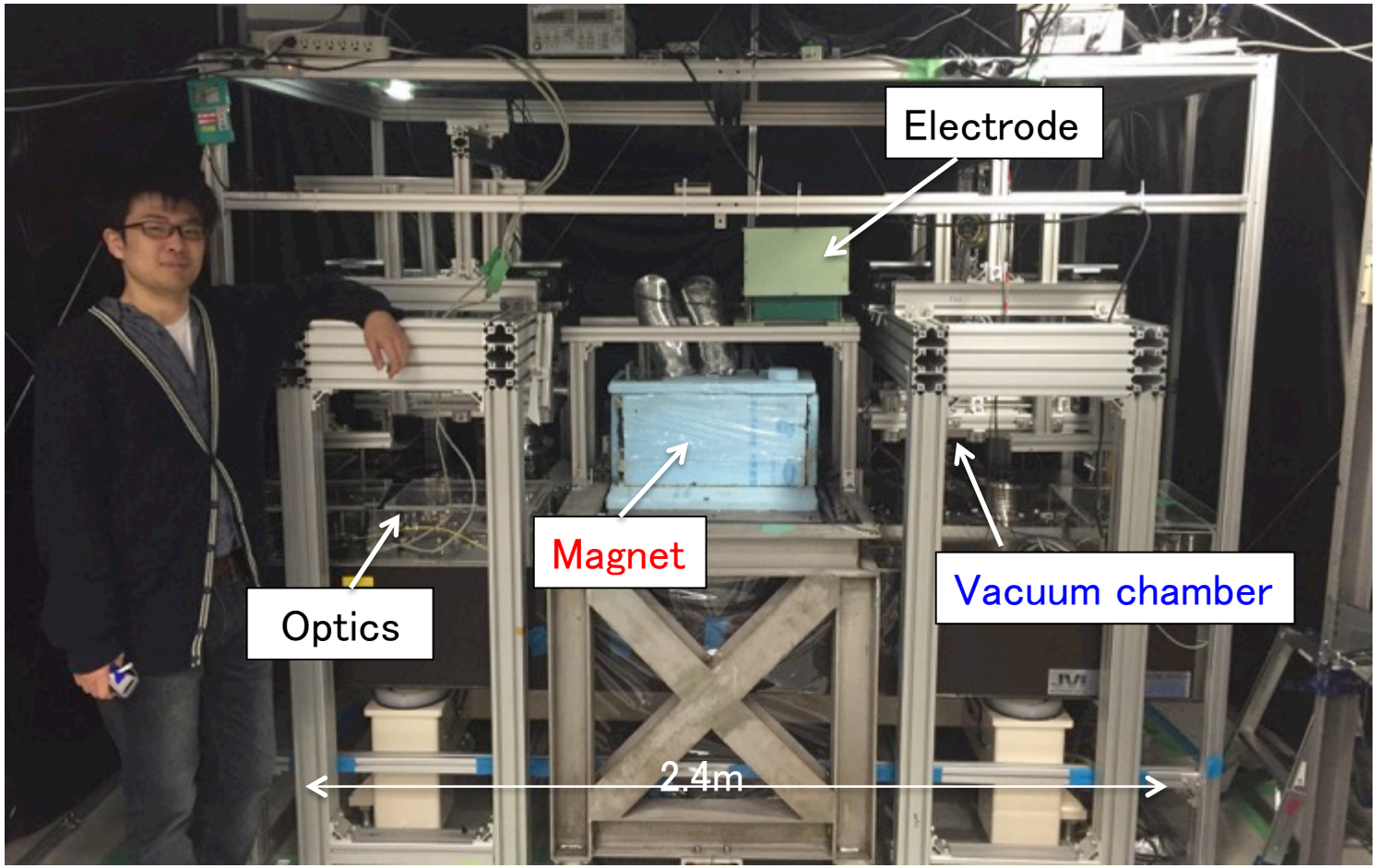


Fabry-perot Cavity

Target spec F = 450,000

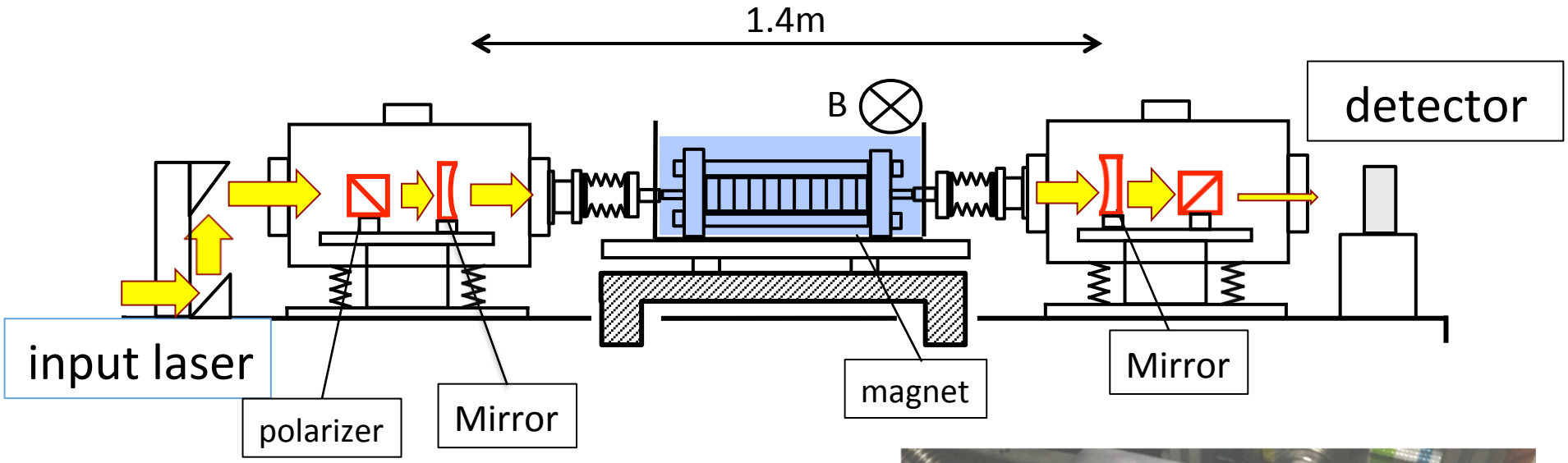
- Δn induce the change of polarization, and it is proportional to B^2L_B
- To obtain strong magnetic field and enough statistic, we use **high repetitive pulsed magnet**
- **Fabry-perot cavity** is used to enhance the effective path length by 2*Finesse/π.

Overview of Current setup

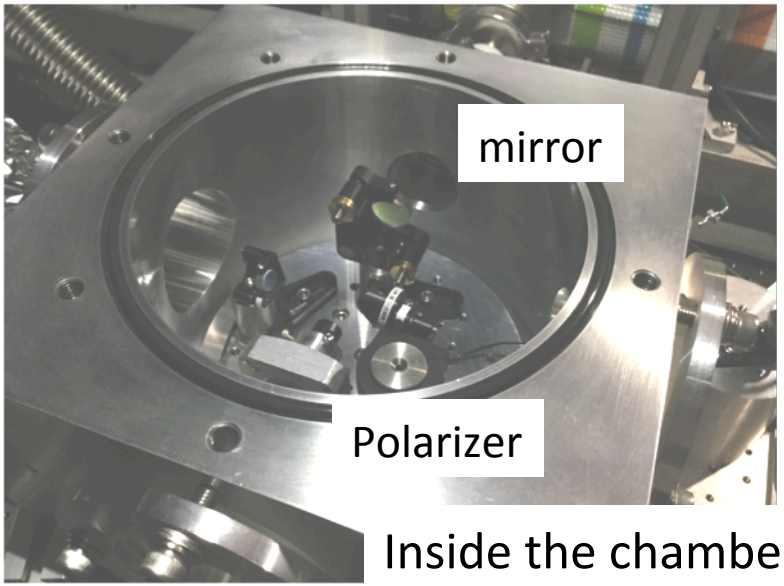


- Arranging optics and a magnet on a 1.2m*2.4m optical bench

Schematic view of setup



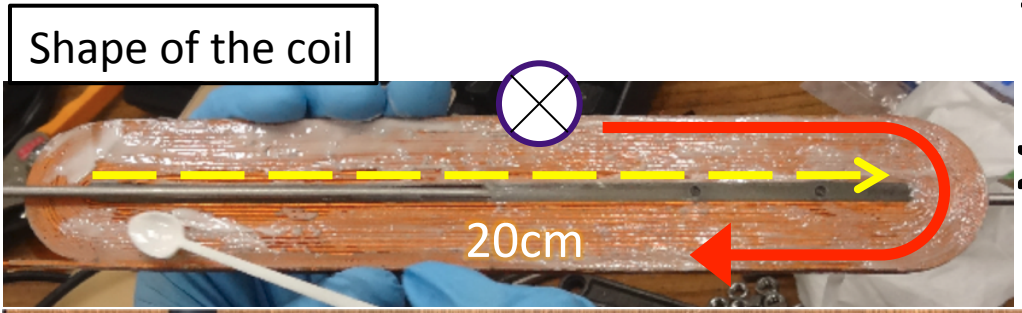
- One magnet between the two mirrors.
- Mirrors and polarizers are in the vacuum chamber connected to the magnet.

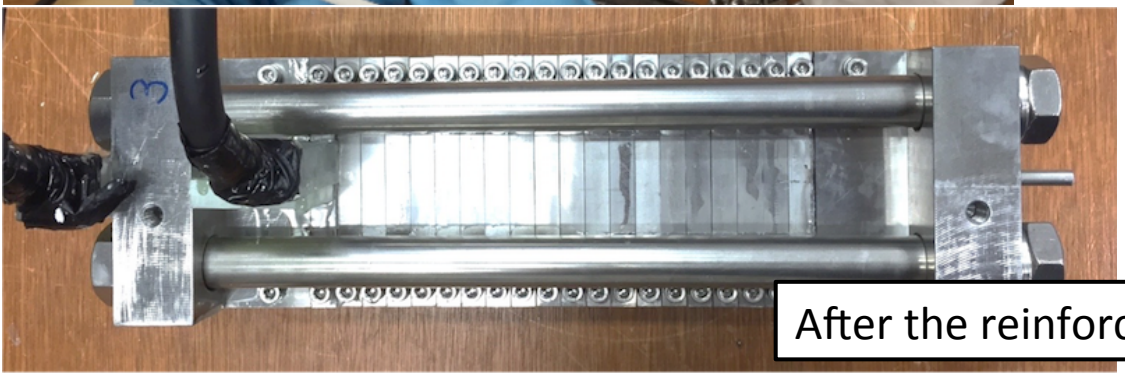


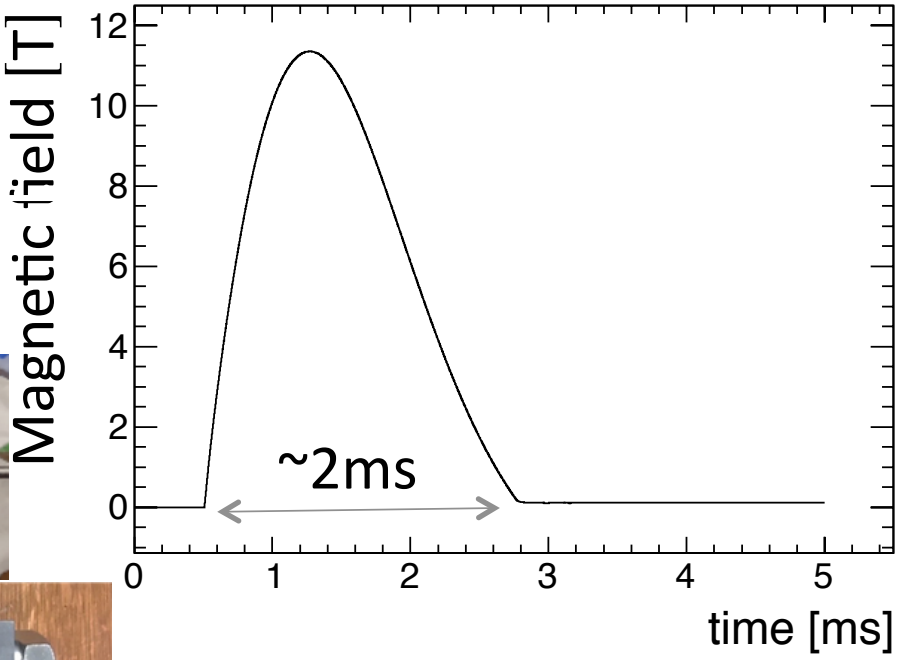
Inside the chamber

Current status ① Magnet

- We are developing strong pulsed magnet with high repetition
- The length of the magnetic field is 20cm along the light.
- 11.4T for single shot and 8T 0.15Hz continuous operation was achieved

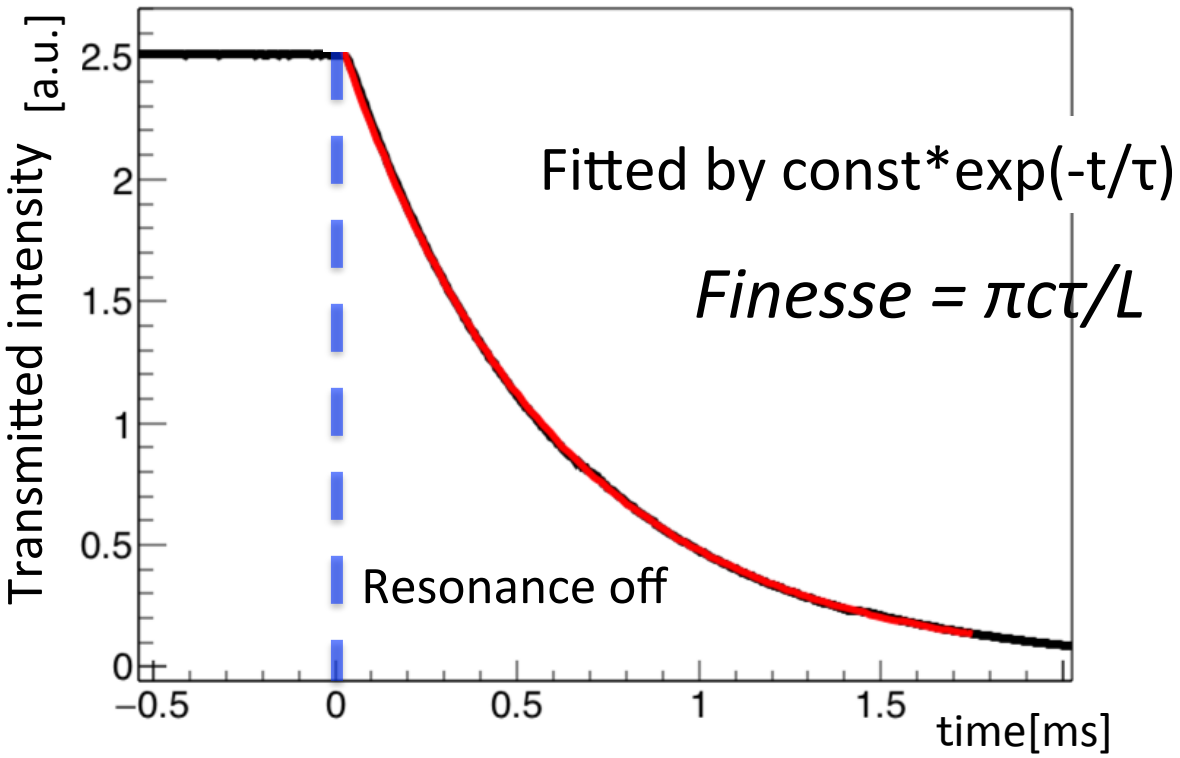






Current status ② Fabry−Perot Cavity

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



- Measured finesse from decay time of the transmitted intensity is ***~300,000***

Test run

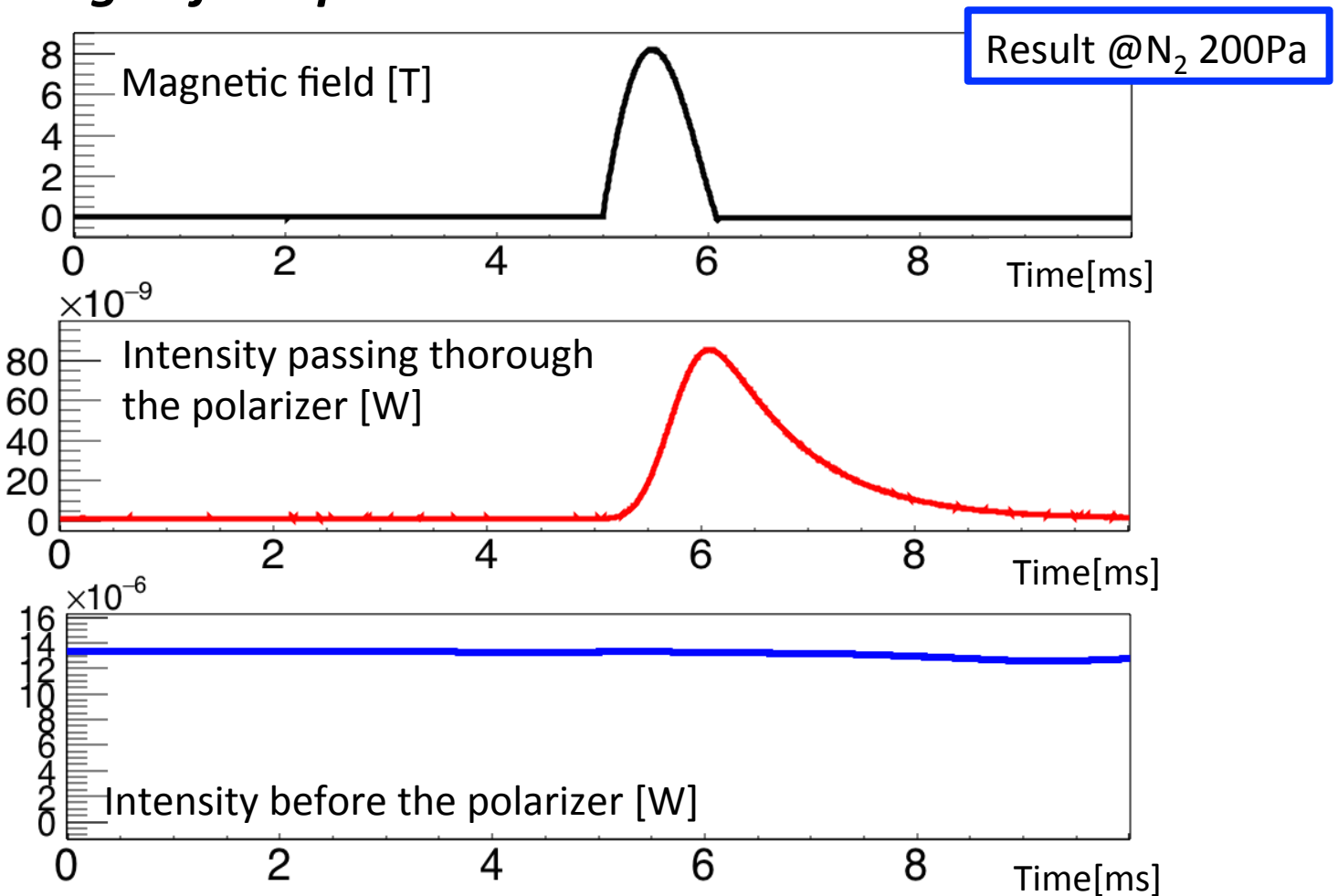
Summary of the Current status

- Magnet B = 8T, L_B = 0.2m, 0.15Hz
- Fabry-perot cavity F = 300,000, Intensity 40μW

- Test run was done in December.
- 2 types of measurement were performed
  - ①Measurement using N_2 for calibration
  - ②Measurement in the vacuum

Measurement of N_2

- 8T and -4T magnetic field is applied inside the cavity by turns
- ***The change of the polarization is observed***

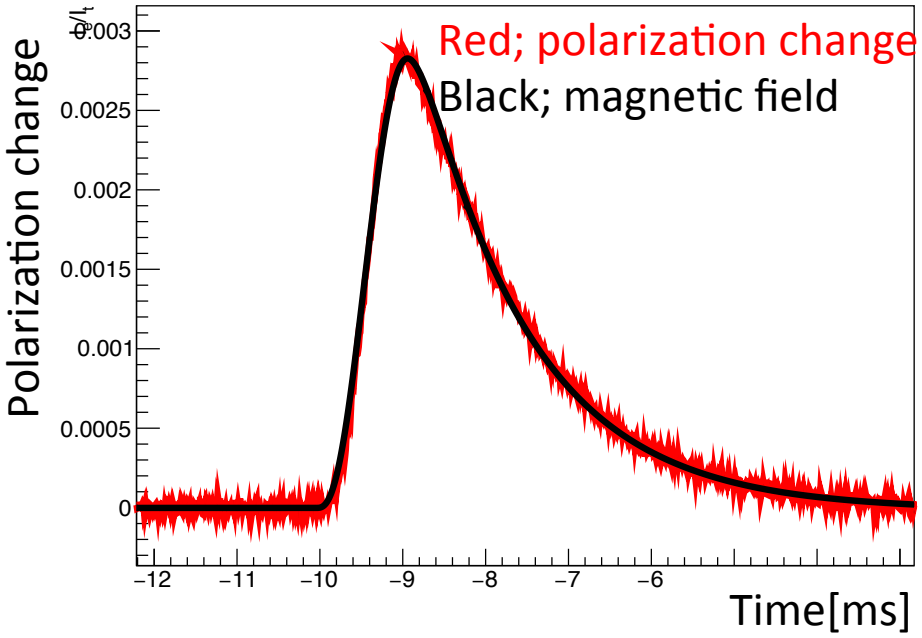


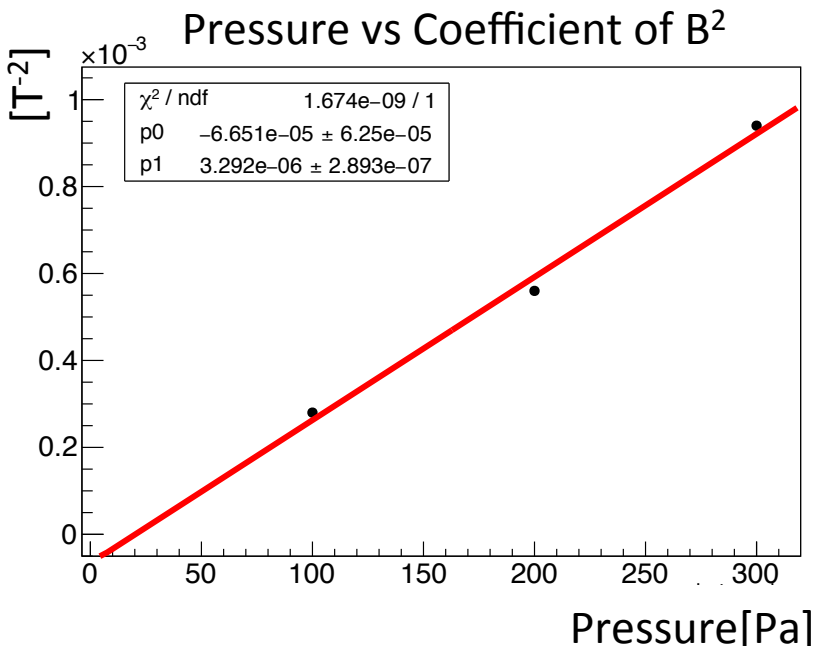
Analysis of the N_2 measurement

- The change of the polarization is fitted by the magnetic field.
- From the pressure dependence, the anisotropy of the refractive index induced by the N_2 can be decided.
- $|k_{CM}{}^{N2}{}_{measured}| = 2.5*10^{-17}\ [T^{-2}Pa^{-1}]$

$\rightleftarrows\ |\ k_{CM}{}^{N2}{}_{calculated}\ | = 2.3*10^{-17}\ [T^{-2}Pa^{-1}]$ @90k

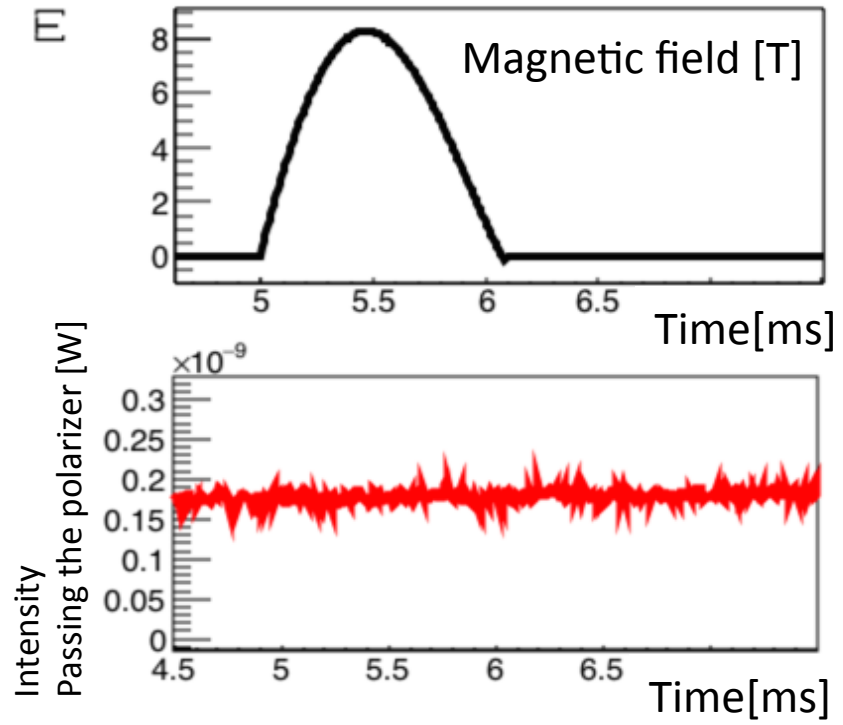
Fitting result

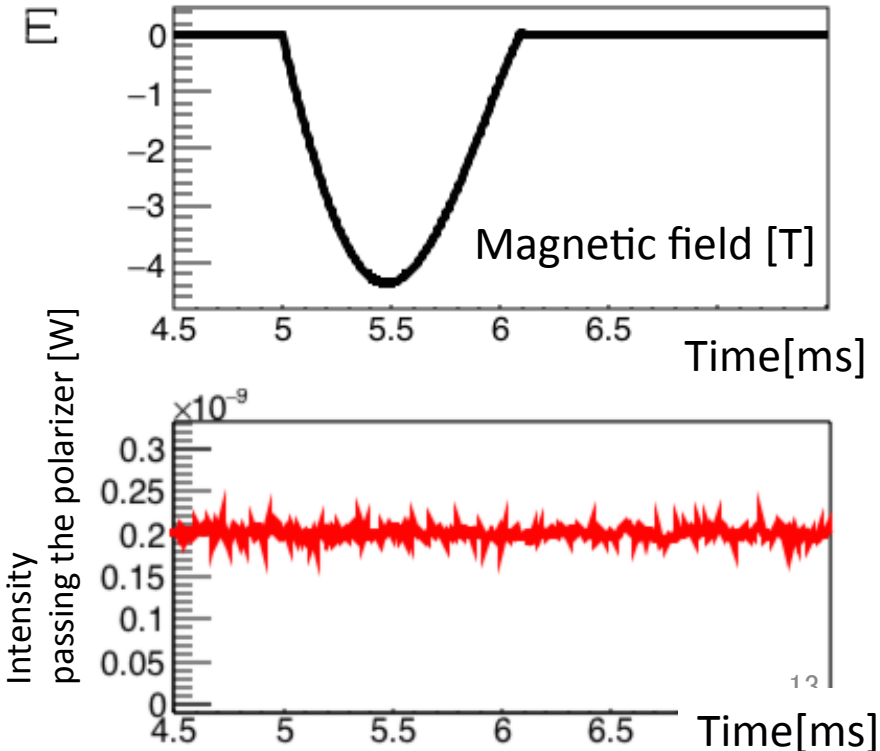




Test run in the vacuum

- The test run in the vacuum was also done.
- ~100 pulse was applied inside the cavity for each polarity of the magnetic filed.
- For current sensitivity, no signal should be observed.



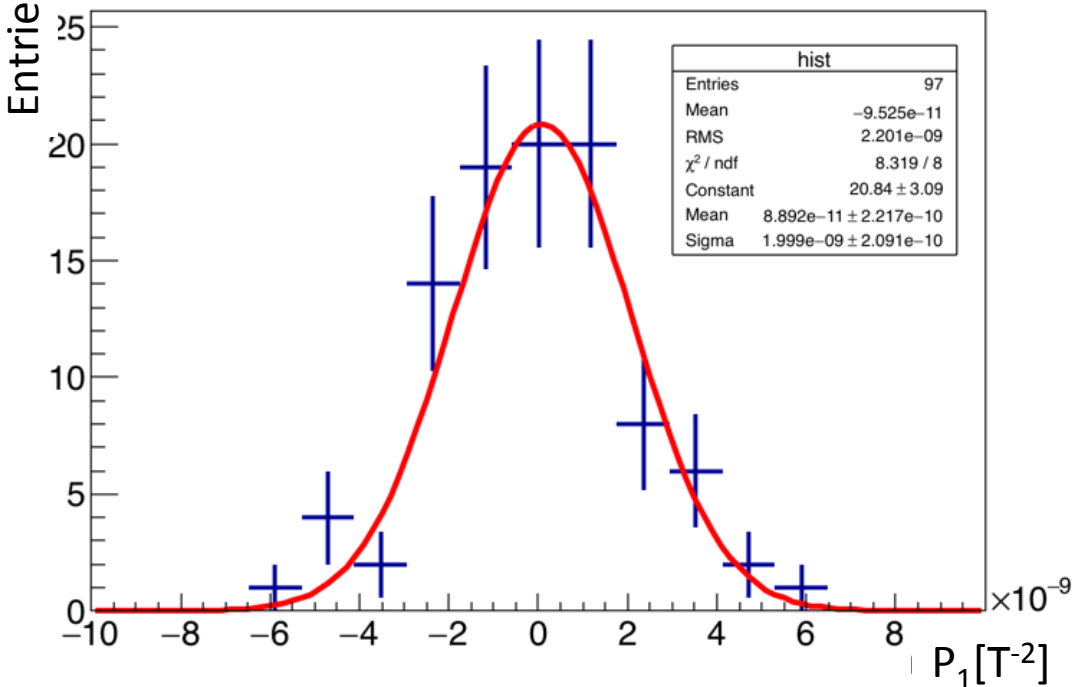


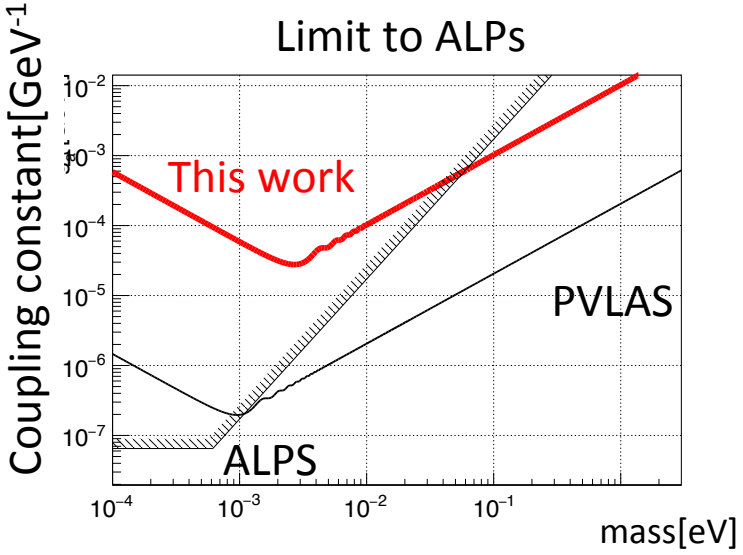
Analysis of vacuum measurement

- The change of the polarization is fitted by $P_0 + P_1 * B(t)^2$ for each polarity of magnetic filed at the same time.
- The mean value of the distribution of P_1 is ***consistent with 0 as expected.***

$k_{cm\ measured} < 3\times10^{-18}[T^{-2}]$ *@95% C.L*

Distribution of P_1





Future prospect

- Next upgrade toward the observation of VMB
  - ✓ Improvement of the pulsed magnet
    - ➢ Change the wound wire from Cu to Ag-Cu to achieve 20 T
  - ✓ Building longer cavity with more magnets
    - ➢ L =3.2m with 4 magnets (L_B = 0.8m)
  - ✓ Improvement of the fabry-perot
    - ➢ more intensity is needed to reduce the noise

First observation of VMB will be accomplished in a year

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
- Test run of the current system is performed with 8T and 0.2m pulsed magnet and F = 300,000 fabry–perot cavity.
- The obtained limit is 3×10^{-18} [T^{-2}] (95C.L.)
- Upgrades of the magnets and cavity is under planning.