Search for Vacuum Magnetic Birefringence with Pulsed Magnet

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8th International Workshop on Fundamental Physics Using Atoms 2015 The Structure of Vacuum -Viewpoint from Particle Physics-



• "Vacuum" is thought to exhibit rich structures, such as...



and QCD vacuum, Inflaton, Axion, ... What else?

Search of "vacuum" structure is a good probe for **Fundamental Physics**



Vacuum Magnetic Birefringence

- Due to virtual e⁺e⁻ creation, QED predicts that light can interact with other magnetic field, so the refractive index can be anisotropic depending on the polarization parallel or perpendicular to *B*.

 $\Delta n = n_{||} - n_{\perp} = k_{CM} \times B^2 \quad (QED \text{ predicts } k_{CM} = 4.0 \times 10^{-24} [T^{-2}])$ virtual e⁺e⁻
Incoming
Light
Understand Structure outgoing
Light
Magnetic Field **B**

• This is a nonlinear electro-magnetic interaction in vacuum and has not been observed yet

Contribution from Axion Like Particles

• Undiscovered particle which can mediate electro-magnetic interaction, such as Axion-like particles (ALPs), can affect the size of birefringence $(=k_{CM})$



• Search for VMB also has a good sensitivity for ALPs search.



- Δn changes the polarization of incoming light, so can be detected by using two polarizers
- The size of polarization change is proportional to $B^2 \times L$ **Strong Magnetic Field & Long Interaction Length** are crucial to detect small Δn 6



- (1) Strong magnetic field with high repetition rate pulsed magnet is used to generate large Δn .
- (2) Fabry-Perot Cavity are used to enhance interaction length by factor $2F/\pi$.

(*F*: Finesse of the FP cavity \rightleftharpoons number of reflections inside the cavity)

Current States Overview



We are developing each apparatus



③ Polarizer & Analyzer

(4)Photo Detector

1) Pulsed Magnet



- Strong magnetic field is available due to extremely narrow magnetic region
- 14T×0.2m has already been achieved
- Our development is supported by Prof. Nojiri (Tohoku Univ.), and Prof. Kindo (UTokyo)





①' Power Supply



- Power supply for pulsed magnets has also been prepared
- C=3.0mF, V=4.5kV, 15kVA for magnet operation





② Fabry-Perot Cavity





 High Finesse >10⁵ Fabry-Perot cavity are now being developed

• Two mirrors are enclosed in vacuum chamber to avoid outer disturbance

Fabry-Pérot Cavity

PD for It L=0.94m Mirrors inside vacuum chambers

(2) Fabry-Perot Cavity



- ✓ The finesse was measured from photon-lifetime $\tau=FL/\pi c$ as F=180,000
 - Now changing to new high quality mirrors: F>300,000 assured!
- Resonance locking system is also prepared and resonance was kept longer than 10 minutes by the system.



③ Polarization Prisms



- Polarization extinction ratio σ², which is the light transmittance of two vertically aligned polarizers, is a crucial parameter of our experiment.
- Two good σ² Glan-Laser Prisms (*OptoSigma: GLPB series*) were prepared as Polarizer and Analyzer.
- The σ^2 was measured to be $\sigma^2 = 7.0(1) \times 10^{-7}$





(4) Low Noise Photo-Detector



- Standard Quantum Noise limited detector is required to achieve best sensitivity
 - →SQN limited Photo Detector was developed with Si PD



 \checkmark Measured noise is low enough for our experiment

Roadmap to VMB Measurement

- First, we are going to conduct calibration and noise study of our apparatus by measuring Helium gas birefringence.
- Helium gas also exhibits birefringence in magnetic field and the value at 1 Pa is k_{CM}^{He} = 2.2×10⁻²¹[T⁻²], 500 times higher than VMB (k_{CM} = 4.0×10⁻²⁴[T⁻²])
- Now integrating each apparatus for the birefringence measurement.



Roadmap to VMB Measurement

Now Integrating each Apparatus!



Reinforced Pulsed Magnet

FP vacuum chamber

Summary and Roadmap



- VMB is a nonlinear electro-magnetic effect in vacuum and has good sensitivity to ALPs, but not observed yet.
- We are developing, 1 20T, 0.2m×4, 6Hz Pulsed Magnets and 2F=450,000 ultra-stable Fabry-Pérot cavity to perform highest sensitivity experiment.
- Development of individual parts is completed, now integrating each apparatus
- Calibration of apparatus with Helium gas birefringence measurement will be conducted in this year.

Vacuum Magnetic Birefringence experiment will start in 2015