CAPP’s Axion Data with mass range around 10 μeV

Woohyun Chung

Center for Axion and Precision Physics Research (CAPP)
Institute for Basic Science (IBS)
• Introduction
  – IBS/CAPP
  – CAPP’s effort (CULTASK)
• CAPP-PACE (Pilot Axion Cavity Exp.)
  – R&D machine
  – First complete LT axion experiment
  – 50 MHz data and more…
• Critical R&D
  – High Field Magnets
  – Quantum-limited Amplifiers
  – SC and dielectric cavity
• Future Plans
  – Improve $B^2$ and $T_{sys}$
• Summary
Center for Axion and Precision Physics Research (CAPP) Funded by the Institute for Basic Science (IBS)

- Led by Director Yannis Semertzidis
- Physics at CAPP:
  - Dark Matter Axion Search (Cosmic Frontier)
  - Storage Ring Proton EDM (Strong CP)
  - Muon $g-2$, J-PARC, COMET, CAST, ARIADNE
- Located at and working with KAIST (Korea Advanced Institute of Science and Technology)
- 50+ members and growing
CAPP’s Axion Research

Axion Research at CAPP

CULTASK

CAPP-PACE (9)
CAPP8TB (6)
CAPP18T (3)
CAPP12T (0.5)
CAPP25T (0.5)

CAPP/CAST

ARIADNE & GNOME
Axion Detection Scheme (CULTASK)

P. Sikivie’s Haloscope:

Axion Conversion Power ($\sim 10^{-24}$W):

$$P_{a\rightarrow\gamma\gamma} = g_{a\gamma}^2 \frac{\rho_a}{m_a} B^2 V C_{mn} \text{min}(Q_L, Q_a)$$

Signal to Noise Ratio:

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} = \frac{P_{a\rightarrow\gamma\gamma}}{k_B T_{\text{syst}}} \frac{1}{\Delta f_a} \left( \frac{t_{\text{int}}}{T_{\text{syst}}} \right)$$

Scan rate:

$$\frac{df}{dt} \sim B^4 V^2 C^2 Q_L T_{\text{syst}}^{-2}$$

Cryogenics

<50mK

High Field SC Magnet

25T and then 35T

BNL (HTS Technology) Design

SQUID Amplifier

SQUID or JPA (commercial?)

High Q Tunable Cavity

Superconducting Coating

Prof. Jhinhwan Lee of KAIST

To RF Receiver

(Reverse) Primakoff Effect

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Axion Lab with 7 Low Vibration Pads in KAIST Munji campus
CAPP Experimental Hall (LVP)
### Magnets

<table>
<thead>
<tr>
<th>B field</th>
<th>Bore (cm)</th>
<th>Material</th>
<th>Vendor</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>26T</td>
<td>3.5</td>
<td>HTS</td>
<td>SUNAM</td>
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</tr>
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### Refrigerators

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<tr>
<th>Vendor</th>
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<tr>
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<tr>
<td>Leiden</td>
<td>DRS1000</td>
<td>100</td>
<td>1mW @100mK</td>
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</tr>
<tr>
<td>Oxford</td>
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## CULTASK Refrigerators and Magnets

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- R&D Machine preparing for CAPP25T
- First complete axion experiment in Korea
- Optimization study for
  - Cryogenics and cryo-RF
    (Heat vs Noise)
- First engineering run in Jan. 2018
  - 2.45 – 2.50 GHz scan for 22 days
  - Flawless operation of
    - Freq. tuning system w/ Piezo actuators and a sapphire rod
    - DAQ and Controls
  - Target sensitivity: 10*KSVZ
- Second run is about to start
  - 2.50 – 2.75 GHz
- $T_{\text{cavity}}$ : $< 40 \text{mK (WR)}$
- Magnetic field: 8T
- Bore size: 11.8cm
- Cavity volume: 0.59L
- Frequency: 2.45~2.75GHz
  (2.45~2.50 at 1st run)
- Q unloaded: $> 80,000$
- Low noise amplifier: HEMT (1K noise)
- C (geometrical factor) $> 0.55$
- DAQ Efficiency: 0.45
- Target sensitivity: $10 \times \text{KSVZ}$
Cavity: OFHC Cu split type
    Unloaded Q-factor of $\sim 120,000$ w/ Sapphire rod
    Pure (6N) Cu and Al (annealed) will be fabricated

FTS: Attocube piezoelectric actuators
    Thermal link to 1K plate
    $\rightarrow$ Sapphire rod to cavity by cryo bearing
    Rotator resolution of 1/1000 deg $\rightarrow$ 16 kHz per step
CAPP-PACE

RF read-out chain & Controls

July 5th 2018
ICHEP - 2018 Seoul
CAPP-PACE 1st data (2.24-2.50 GHz)
CAPP-PACE Sensitivity (planned)
How to improve?

- **Maximize $B^2V$**
  - 25T 10cm bore HTS magnet by BNL (2020)
  - 12T 32cm bore LTS magnet by Oxford (2020)
  - Way to increase frequency with volume fixed
    - Dielectric rings ($TM_{030}$ and $TM_{050}$)
    - Photonic cells

- **Scan faster (minimize $T_{amp}$ $\Leftarrow$ dominating factor)**
  - Quantum Amplifier - SQUID or JPA
  - Optimize cryo-RF receiver chain

- **Others**
  - Improve Q-factor of cavity – pure metal or SC cavity
  - Dead-time-less DAQ
25T 10cm bore HTS magnet by BNL

- The first (of 24) pancake wound! - test will follow
- 5 km of SC tape will be delivered next 5 months
• “Cold Terminator method” with cryo-switch
• “On-Off Resonance method” ADMX style
• Custom-made Y-factor method
• LHe dewar tests
CAPP-PACE NT Measurements

Before Corrections

Cold Terminator Method

After Corrections

1.4 K

1.0 K
Andrei Matlashov is leading an effort to optimize SQUID for axion experiment
New type of microwave SQUID amplifier from IPHT (Jena, Germany)

Sergey Uchaikin (from D-Wave) will join the group in July to lead JPA effort
# Timeline (CAPP-PACE)

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>now</td>
<td>2/4</td>
<td>%</td>
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<tr>
<td><strong>CAPP-PACE 1\textsuperscript{st} run</strong></td>
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<tr>
<td><strong>Cavity size up</strong></td>
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<tr>
<td><strong>CAPP-PACE 2\textsuperscript{nd} run</strong></td>
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<tr>
<td><strong>SQUID optimization</strong></td>
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<tr>
<td><strong>CAPP-PACE 3\textsuperscript{rd} run</strong></td>
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<td>✓</td>
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<tr>
<td><strong>High frequency cavity</strong></td>
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<tr>
<td><strong>25T magnet delivery</strong></td>
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<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>CAPP-25T commission / CAPP-PACE 4\textsuperscript{th} run</strong></td>
<td></td>
<td>✓</td>
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- **2018**:
  - 10KSVZ-50MHz-22days
  - Twice bigger, 3times faster
  - 10KSVZ-250MHz-40days
  - <0.5K
  - KSVZ-7.5MHz-a year
  - ~7.5GHz, ~12GHz
  - 25T, 10cm bore size
  - DFSZ-50MHz-a year
## Timeline (CAPP25T)

<table>
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<tr>
<th>CAPP25T</th>
<th>2018</th>
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<tbody>
<tr>
<td>Magnet delivery from BNL</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Magnet Installation &amp; commissioning (test)</td>
<td></td>
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<tr>
<td>Design &amp; fabricating cavity, FTS and RF electronics</td>
<td></td>
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<tr>
<td>Detector Commissioning</td>
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<td>Engineering Run</td>
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<td>Physics Run</td>
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• Axion Research at CAPP/IBS in Korea is getting mature

• CAPP-PACE is becoming a complete axion experiment and leading R&D efforts of CAPP

• Major R&D Efforts
  – Higher B Field: HTS (18T, 25T…)
  – Larger Volume: (12T 32cm LTS magnet)
  – Adding SQUID or JPA
  – R&D for Higher Frequencies (>10 GHz)

• Stay tuned for optimized Quantum Amplifiers!
Thank You For Your Attention!