

High-mass axion searches with novel cavity designs at IBS-CAPP

SungJae Bae
Behalf of CAPP-HF team

Toward High mass axion searches

Conventional approach for high frequency

$f \uparrow, R \downarrow, V \downarrow$
 $\Rightarrow df/dt \propto f^{-20/3}$
 $(2 \times f \rightarrow df/dt \text{ 99\% } \downarrow)$

New approach is required for efficient high mass axion searches

Multiple-cell cavity¹

- Multiple partition with center hole
- f enhancement**
 $\sim 2 \times f_{TM_{010}}$ (4-Cell)
- Efficient volume use
- Single antenna

Higher-order mode searches²

- Use TM_{030} resonant mode
- Dielectric wheel : tuning & C enhancement
- f enhancement** $\sim 3 \times f_{TM_{010}}$
- Use entire cavity volume
- High quality factor
- Single antenna

Photonic crystal³

- Dielectric rods + auxetic tuning structure
- f enhancement** $\sim 10 \times f_{TM_{010}}$
- High quality factor ($10^5 - 10^6$)
- Doable frequency tuning
- Reduced complexity $\sim n_{PC}^{30GHz} : 16$ (cf. $n_{Wire}^{10GHz} : 200$)

Conclusions

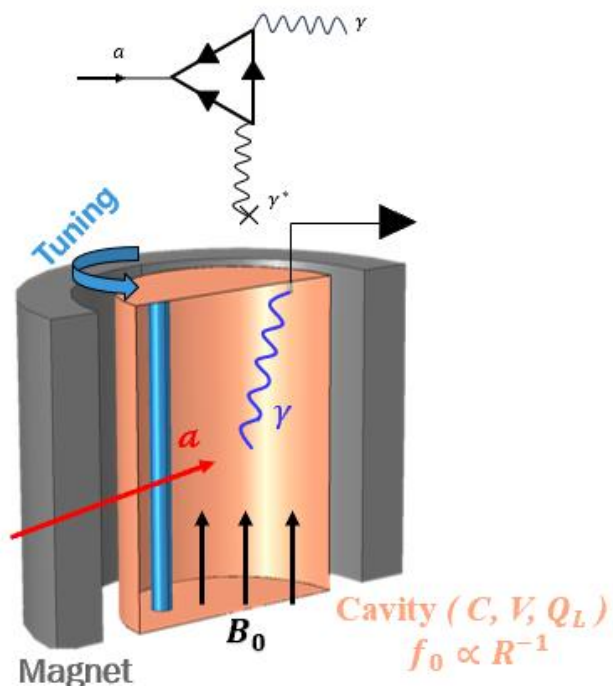
- IBS-CAPP have excluded various high mass axion regions with novel high mass cavities
- Multiple-cell :
 - 2-Cell : $13.0\mu eV - 13.9\mu eV / g_{ax\gamma} \geq 11.1 g_{KSVZ}$
 - 3-Cell (kiwi) : $21.8\mu eV - 22.0\mu eV / g_{ax\gamma} \geq 0.93 g_{KSVZ}$
 - 8-Cell : $24.11\mu eV - 24.56\mu eV / g_{ax\gamma} \geq 1.2 g_{KSVZ}$ (Preliminary)
- Higher order mode searches :
 - 4. Hexagonal : $21.38\mu eV - 21.79\mu eV / g_{ax\gamma} \geq 12.0 g_{KSVZ}$

References

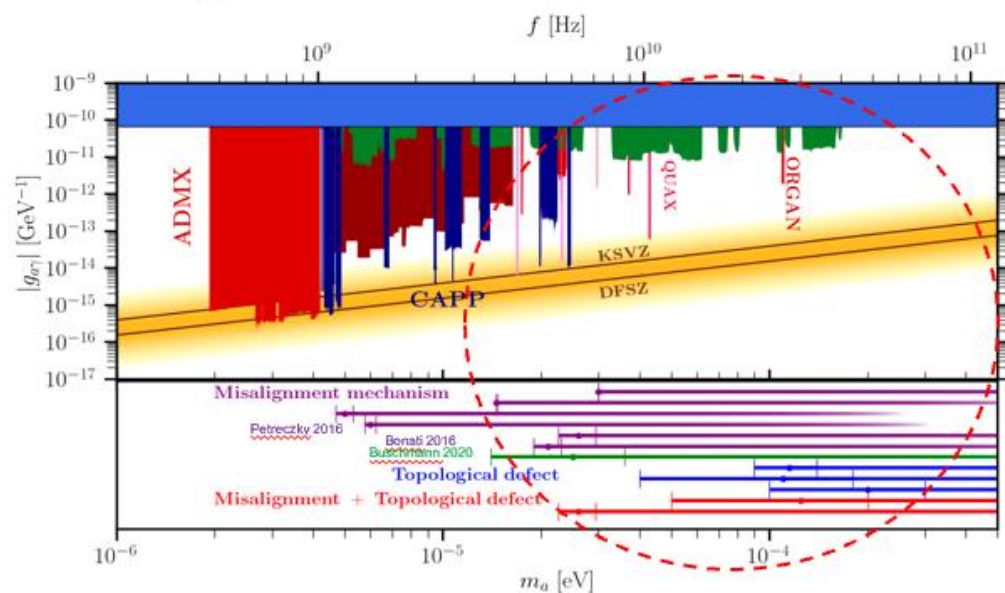
- Phys. Lett. B 777 (2018)
- J. Phys. G: Nucl. Part. Phys. 47 035203
- Phys. Rev. D 107 01512
- Phys. Rev. Lett. 125, 221302
- Phys. Rev. Lett. 133, 051802
- PoS(CHEP2022)092
- arXiv:2403.13390

Motivation

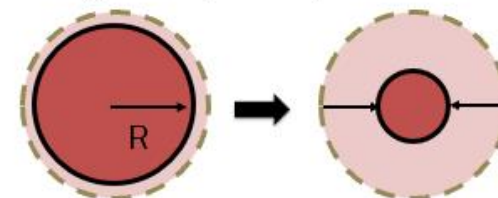
Axion(a) – photon(γ) interaction



Toward High mass axion searches



Conventional approach for high frequency searches



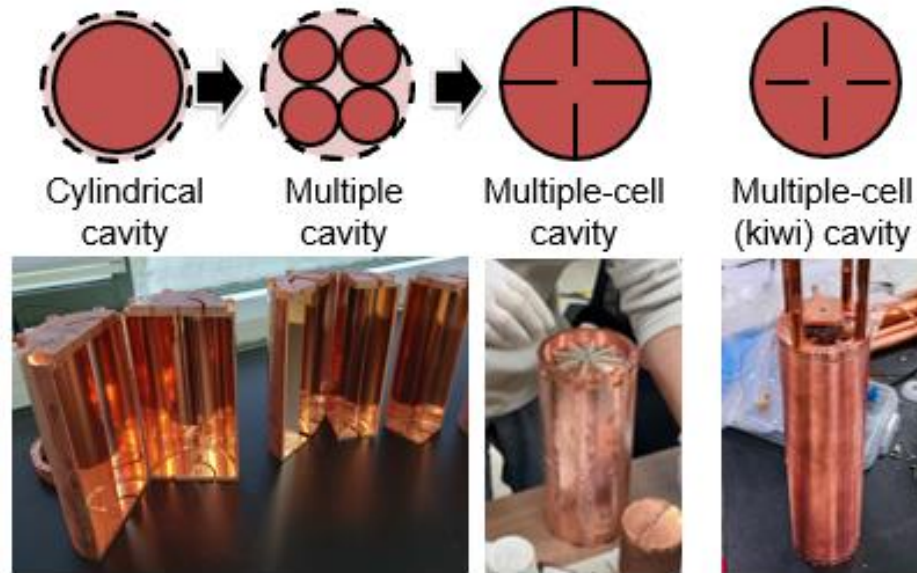
$$f \uparrow, R \downarrow, V \downarrow$$

$$\Rightarrow df/dt \propto f^{-20/3}$$

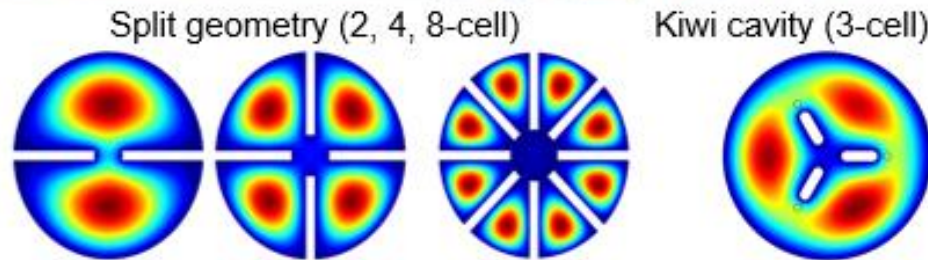
New approach is required for efficient high mass axion searches

Novel high frequency cavity designs at IBS-CAPP

Multiple-cell cavity ¹



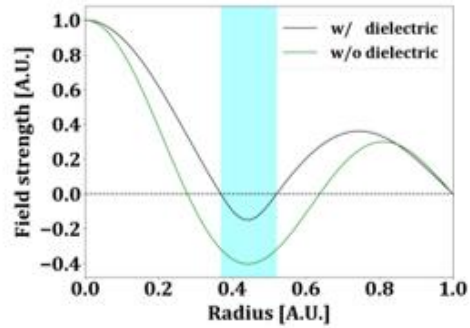
- Multiple partition with a center hole
- **f increases**
 $\sim 2 \times f_{TM_{010}}$ (4-Cell)
- Efficient volume uses
- Single antenna



E field distribution of multiple-cell cavities & 3-cell kiwi cavity

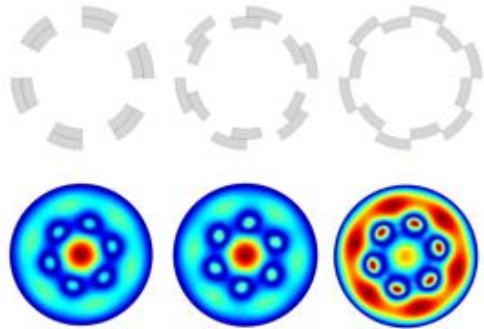
Novel high frequency cavity designs at IBS-CAPP

Higher-order mode searches ²



- Use TM_{030} resonant mode
- Dielectric : tuning & C enhancement
- f increases $\sim 3 \times f_{TM_{010}}$
- Use entire cavity volume
- High quality factor
- Single antenna

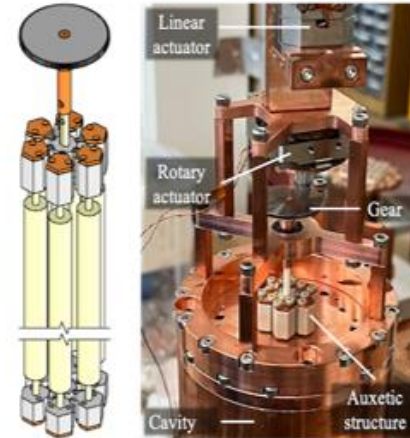
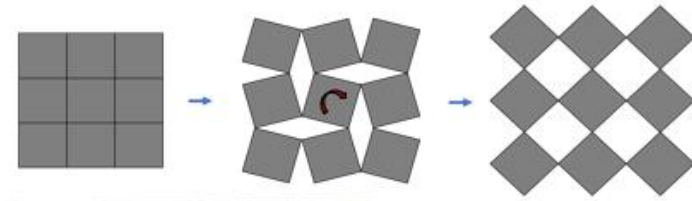
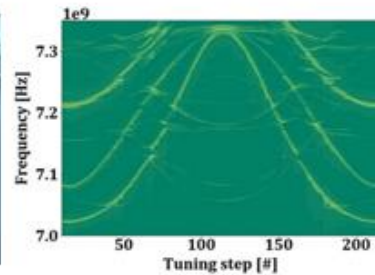
C enhancement using dielectric



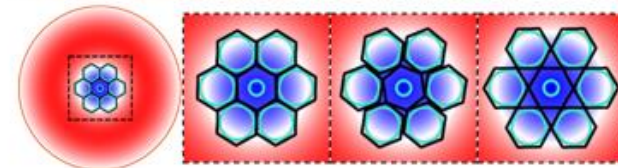
Wheel tuning mechanism



Demo cavity & mode map at 4K



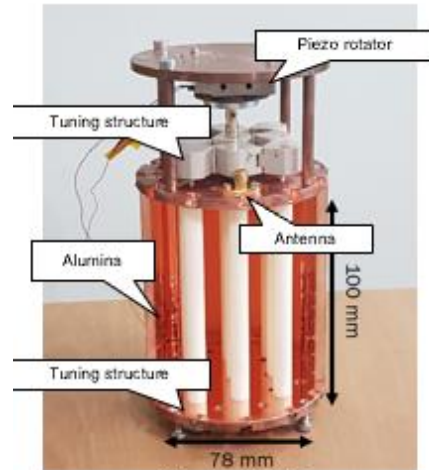
- Use TM_{020} resonant mode
- f increases $\sim 2 \times f_{TM_{010}}$
- Tuning with auxetic structure (hexagon)
- Uniform space changing
- Frequency tuning by rotating only center cell



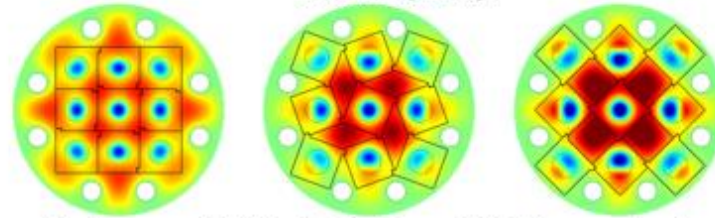
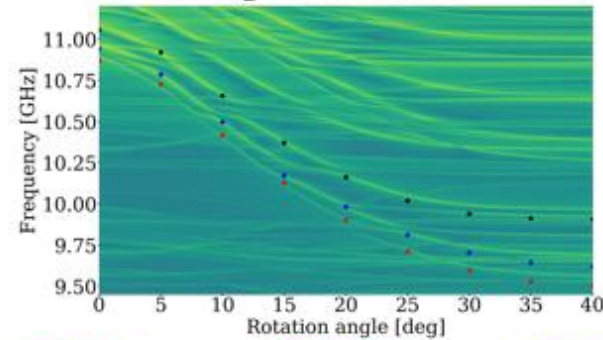
E field distribution of TM_{020} with auxetic tuning structure

Novel high frequency cavity designs at IBS-CAPP

Photonic crystal³



1-layer PhC
Demonstration



Mode map & field distribution of PhC demonstration



5 × 5 square array on planing

- Dielectric rods + auxetic tuning structure

- **f increases $\sim 10 \times f_{TM_{010}}$**

- **High quality factor ($10^5 - 10^6$)**

- **Doable frequency tuning**

- **Reduced complexity $\sim n_{PhC}^{10GHz} : 16$**

(cf. $n_{Wire}^{10GHz} : 200$)

Conclusions

- IBS-CAPP have developed various novel high mass cavities and implemented in axion searches
- Multiple-cell :
 - 2-Cell : $13.0\mu\text{eV} - 13.9\mu\text{eV} / g_{a\gamma\gamma} \geq 11.1 g_{KSVZ}$ ⁴
 - 3-Cell (kiwi) : $21.86\mu\text{eV} - 22.0\mu\text{eV} / g_{a\gamma\gamma} \geq 0.93 g_{KSVZ}$ ⁵
 - 8-Cell : $24.11\mu\text{eV} - 24.56\mu\text{eV} / g_{a\gamma\gamma} \geq 1.2 g_{KSVZ}$ (Preliminary)⁶
- Higher order mode searches :
 - 4. Hexagonal : $21.38\mu\text{eV} - 21.79\mu\text{eV}$ ⁷
 $g_{a\gamma\gamma} \geq 12.0 g_{KSVZ}$

References

1. *Phys. Lett. B* 777 (2018)
2. *J. Phys. G: Nucl. Part. Phys.* 47 035203
3. *Phys. Rev. D* 107 01512
4. *Phys. Rev. Lett.* 125, 221302
5. *Phys. Rev. Lett.* 133, 051802
6. *PoS(ICHEP2022)092*
7. *arXiv:2403.13390*