Photonics, Particle Accelerators and beyond the Standard Model

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Figure 1 Schéma de la distribution du champ électrique dans une cavité résonnante
This could result in 'tuning' the PrW structure and have found it possible to increase peak field by approximately a factor. Authors show how this behaviour is dependent on varying energy of the uM field is distributed.

Increasing disorder also shown that a small disorder R aN radius and position leads to a maximum results show that a aN disorder in ring a has a greater order to both Rradius and positionS leads to a maximum.

Some degree of disorder for Ps crystals this has been done by several authors examining di
tother...
Photonic \quad a \sim \lambda

Metamaterial \quad a \ll \lambda
ERSF 75KW
Solid State RF

Hughes TWT - RF Tube 100kW
\[
\omega = \sqrt{c^2 \left( \frac{\alpha + \omega^2}{\omega} \right)}
\]

\[
\alpha = \left( \frac{p}{p + h - \Delta h} \right)^2
\]

\[
\gamma_n = \beta_0 \frac{p + h - \Delta h}{p} + \beta_{mm}(\omega) \frac{\Delta h}{p} + (2n + 1) \frac{\pi}{\Delta h}
\]

\[
\beta_{mm}(\omega) = c^{-1} \sqrt{\omega^2 \epsilon_r(\omega) \mu_r(\omega) - \omega^2}
\]
Lorentz's Force Equation

\[ m_0 c^2 \frac{d}{dt} \gamma = -E \]

Time changing in \( m_0 c^2 \gamma \) (DC and AC beam energy) is related by the \( E \cdot v \) dot product in this equation. The DC beam energy \( \gamma dc \) is given by \( (1+Vdc/511) \); \( Vdc \) is the DC beam accelerating potential. While the AC beam energy exchange (stimulated emission) is related by the \( E \cdot v \) dot product in this equation. The 1st order perturbation >> Spontaneous emission

\[ \langle \Delta \gamma_2 \rangle = \frac{1}{2} \frac{d}{d \gamma} \left( \langle \Delta \gamma_1^2 \rangle \right) \]

2nd order perturbation >> Stimulated emission

\[ \frac{\Delta P_{out}}{P_{in}} = \frac{-\frac{1}{2} \frac{d}{d \gamma} \left( \langle \Delta \gamma_1^2 \rangle m_0 c^2 \right) I}{e} \]

Accelerating Potential in KV

![Graph showing Accelerating Potential vs Frequency]
Complementary Split Ring Resonator

Transmission through CSRR interrupting waveguide.
- 1.6 KeV/m Acc gradient
- About 1/5 of the gradient to a comparable pill box resonator

Dispersion relation extracted, black dots, with the light line shown in green.
Figure 1. Band gap diagram of a sapphire-in-air, triangular lattice calculated using the commercial software package RSOFT.  

where $F_{\mu\nu}$ is the usual electromagnetic field tensor and $B_{\mu\nu}$ is the equivalent hidden sector field tensor with associated gauge field $B_{\mu}$.  

2. Photonic structure  

2.1. General properties  

AP B GS tr uctu ri sap e r i o d i ca r ra y vo f va r y i n gp e r m i t t i v i t i e sf or m i n ga lat ti e eo fs c at te r so f EM radiation. PBGs have been extensively studied and have demonstrated a range of novel physical phenomena leading to many applications, particularly in lasing where defects in the lattice are used to produce highly-intense coherent radiation.  

For certain lattice configurations, EM waves with specific frequencies are not able to propagate through the lattice. Figure 1 shows the band structure (wavenumber versus frequency) for a triangular 2D lattice of sapphire rods with the frequency normalized to the speed of light. A 'band gap' in propagating frequencies is clearly present.  

It follows that PBG structures containing a defect in the periodic lattice can behave analogously to a conventional microwave resonant cavity. Wave propagation in this periodic structure is governed by Bloch–Floquet theory. If an EM wave has a half-wavelength comparable to the size of the defect region and a frequency that lies inside the band gap, the 'mode' becomes spatially localized at the defect site. The frequency dependence of the localization effect makes it possible to create a structure where a specific mode is confined, but all other modes propagate away from the defect site through the PBG lattice. The ability of the lattice to confine an EM field by virtue of the periodicity of the lattice alone, means the structure can confine EM modes to the defect regions without the need for any external waveguide or cavity to support the mode.  

To define the EM field tensor in equation (1) and hence either of $\chi$ which is measurable, we consider a specific PBG geometry consisting of a two-dimensional triangular lattice of sapphire scatterers with relative permittivity of $\varepsilon_0$ and filling factor $f$. These parameters define the propagation of EM waves in the photonic structure, the frequency and size of the band gap, and the frequency/Q of the confined EM state. The choice of...
Considering a finite lattice, where the top and bottom of the lattice shown in figure 4.1 are covered by metal plates, the defect region becomes a semi-enclosed space where EM waves can be excited. EM waves confine in the defect region see the surrounding global lattice, which presents band gap(s) only for TM polarised waves according to figure 2.6. Therefore, only the TM waves at frequencies inside the band gap can be confined in the defect, other TM waves and all the TE waves are not able to be confined, but propagate through the lattice, as they are in the propagation bands of the lattice.

According to this frequency-selective property, PCs bring the opportunity to make mode-control resonators that only hold specific resonant states. This is an advantage over the conventional pillbox cavities, as a pillbox cavity with fully enclosed boundary confines all the resonances formed by both TE and TM polarised waves. In the application to RF generation, only the TM01-like (or monopole-like) resonance state is needed, which is similar to E. I. Smirnova's application to particle accelerators [4, 42]. E. I. Smirnova examined a metallic PC with a triangular lattice and a single site defect (figure 4.2 (a)), and found that by having the rod radius-spacing ratio $r/a$ between 0.1 and 0.2, only a TM01-like state was confined.
pillbox and PC resonators after 16 and 34 resonant periods.

Figure 5.4: Spectrums of the fundamental and first higher-order resonances in the pillbox cavity and the output PC, obtained from Ansoft HFSS.

According to the findings in [36], to efficiently excite the higher-order harmonics, the electron bunch was slightly offset from the beam tube. Being a plasma medium containing a very wide range of frequencies, the beam tube was emitted at a voltage of 30 kV into each resonator through a gaussian distribution in a cylindrical region of 1.8 mm length and 1.6 mm width, set transversely by 1 mm away from the beam centre, to ensure that each bunch substantially couple their geometry. An electron bunch with a very low charge, 5.6 × 10^6 nC, with a gaussian distribution in a cylindrical region of 1.8 mm length and 1.6 mm width, was excited all the possible resonances in each resonator, whose frequencies and spectrum strengths can be diagnosed by performing Fourier Transform (FFT) upon the transient fields. Figure 5.3 shows that the fundamental resonances have been excited in both the electron bunch, whose frequency components, f_0 = 9.532 GHz, Q_{ohmic} = 3850, and the first higher order harmonic, f_1 = 14.82 GHz, Q_{ohmic} = 4600.

Figure 5.2: The wave patterns, frequencies and Q-factors of the fundamental and first higher-order resonances in the pillbox cavity and the output PC, obtained from Ansoft HFSS.

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Figure 3.1: Schematic diagram of a two-cavity klystron.

The angular frequency of the input signal, which is usually the resonant frequency of the input cavity. Electrons that see a forward electric field are accelerated and those see a backward electric field are decelerated. This process is known as velocity modulation [6, 7, 8, 9]. The electrons leave the input cavity at time $t_1$ and transit the drift tube for a distance $L$, during which velocity modulation results in a bunching effect, where accelerated electrons catch up with decelerated electrons. The electrons arrive at the output cavity at time $t_2$ when optimum bunching has been formed, resulting in an electron beam of RF current $I$.

An RF signal is induced and accumulated to a higher power in the output cavity, which is coupled to an external load. Finally, the electrons leave the output cavity and are absorbed in the collector.

3.2 Velocity Modulation

Velocity modulation is the fundamental principle for klystrons. The analysis of velocity modulation in this section is carried out with the following assumptions [6]:

1. The cross-section area of the electron beam is small.
2. The DC electron beam has uniform charge density.
3. The DC beam current $I_0$ is small, so that space charge effects are ignored.
4. The input signal $V_1 \sin \omega t$ is perfectly longitudinal and $V_1 \ll V_0$.
Figure 4. Velocity modulated beam dynamics: Raw beam profiles velocity modulation and charge density distribution; NBO beam transverse phase space plots at points A, B, C, and D.

Figure 5. Proof of principle experimental setup and results. NBO The two IPO module and experimental system setup. NCO Spectrum of output signal excited by a beam of $V_{dc} = y \text{kV}$ and $I_{dc} = x \text{mm} \mu$A modulated by an EM field in ML of $P_{in} = y \text{W}$ at 9.5 GHz. NCO $P_{out}$ versus $P_{in}$ at 9.5 GHz at $V_{dc} = y \text{kV}$ and $I_{dc} = x \text{mm} \mu$A. NCO $P_{out}$ versus $I_{dc}$ at $V_{dc} = y \text{kV}$ and $P_{in} = 5 \text{W}$ at 9.5 GHz. NCO $P_{out}$ versus $V_{dc}$ at $I_{dc} = x \text{mm} \mu$A and $P_{in} = 5 \text{W}$ at 9.5 GHz. The strength of the EM field excited by the modulated beam in the EL defect was significantly limited by the low beam current. Hence the energy exchanged from the electron bunches to the NCO New Journal of Physics 14 (2012) 013014 (http://www.njp.org/)

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Figure 5.4: Spectrums of the fundamental and first higher-order resonances in the pillbox cavity and the optical resonator from VORPAL code [87], whose post-processing function was achieved using the Particle-In-Cell (PIC) code VORPAL [87], with Ansoft HFSS.

Figure 5.3: Graphical view of the electron bunch driven harmonic pattern of the first higher-order harmonic in each resonator tube centre, to ensure that each bunch substantially coupled was emitted at a voltage of 30 kV into each resonator through a gaussian distribution in a cylindrical region of 1.8 mm length and 1.6 mm width, according to the findings in [36].

This was to exempt their ohmic losses and hence only examine electron bunches with a very low charge, 5 nC, with a distribution set transversely by 1 mm. The beam tube was slightly offset from the beam axis in figure 5.4, where the spectrums of the fundamental resonances have been excited in both the electron bunch, whose frequencies and Q-factors are shown in figure 5.3.

The wave patterns, frequencies and Q-factors of the electron bunch passing through each resonator from the VORPAL simulations are shown in figure 5.2. Being a plasma medium containing a very wide range of frequency components, the fundamental and first higher-order harmonics, 

\[
\begin{align*}
  f_0 &= 9.532 \text{ GHz} \\
  Q_{\text{ohmic}} &= 3850 \\
  f_1 &= 14.82 \text{ GHz} \\
  Q_{\text{ohmic}} &= 4600 \\
  f_0 &= 9.532 \text{ GHz} \\
  Q_{\text{total}} &= 3200 \\
  f_1 &= 13.03 \text{ GHz} \\
  Q_{\text{total}} &= 205
\end{align*}
\]

The spectrum strength for the beam on and beam off conditions is shown in figure 5.5.

Yoon Kang, Ali Nassiri, IPAC 1998
with the central rod coupler dedicated to the monopole-like state and the side rod couplers for the sextupole-like state. Notice that unlike the central rod coupler with additional tuning rods around it, the side rod coupler solely lies in the unique lattice, hence is not tunable unless changing the lattice r/a.

6.2.4 Analyses of a 6-Beam 2-PC Dual-State Klystron

A 6-beam 2-PC dual-state klystron can be formed by having two identical 6-defect PCs shown in figure 6.19, one as input and one as output, separated by 6 beam tubes of a certain distance, as shown in figure 6.21.

Figure 6.21: A 6-beam 2-PC dual-state klystron.

Considering all the 6 electron beams used in this klystron are identical, with each beam accelerated by a DC voltage of \( V_0 = 100 \text{ kV} \) with a DC current of \( I_0 = 2 \text{ A} \) at beam radius \( r_b = 5 \text{ mm} \), this gives low beam perveance \( 63.246 \text{ nPerv} \) at beam current density \( \times 10^4 \text{ A/m}^2 \) and beam filling factor \( r_b/r_a = 0.77 \) for each beam.

Figure 6.5: Coupled-defect schemes of 6-defect PCs with defect centre-to-centre spacing \( l_{bb} = (a) \sqrt{3} a \), \( (b) 2a \), \( (c) \sqrt{7} a \), \( (d) 3a \), \( (e) 2\sqrt{3} a \) and \( (f) 4a \).
Figure 6.2 shows that the 6-defect PC presents 4 resonant states: monopole-like, dipole-like, quadrupole-like, and sextupole-like states. The states are numbered from 1 to 6, each with a different frequency and polarization pattern. The monopole-like state (figure 6.2 (a)) has the lowest frequency and is the most localized, while the sextupole-like state (figure 6.2 (f)) has the highest frequency and is the least localized. The dipole-like and quadrupole-like states (figures 6.2 (b) and (e)) are degenerate with the monopole-like and sextupole-like states, respectively, with higher frequencies and stronger spatial patterns. The quadrupole-like state splits into two with the same frequency and pattern but arranged differently among the defects. All other states are in the propagation band and are not localised in the vicinity of any defect.
\[ \hat{H}_{ij} = < \tilde{E}_0(\vec{r} - \vec{R}_i)|\hat{\omega}|\tilde{E}_0(\vec{r} - \vec{R}_j) > \]

\[ = \begin{cases} 
(\omega_0/c)^2 = \alpha & (i = j), \text{the same defect} \\
(\omega_0/c)^2 \beta_1 & (i \neq j), \text{the first-neighbour defect} \\
(\omega_0/c)^2 \beta_2 & (i \neq j), \text{the second-neighbour defect} \\
(\omega_0/c)^2 \beta_3 & (i \neq j), \text{the third-neighbour defect} 
\end{cases} \]

\[ \begin{bmatrix} \alpha - \gamma & \beta_1 & \beta_2 & \beta_3 & \beta_2 & \beta_1 \\
\beta_1 & \alpha - \gamma & \beta_1 & \beta_2 & \beta_3 & \beta_2 \\
\beta_2 & \beta_1 & \alpha - \gamma & \beta_1 & \beta_2 & \beta_3 \\
\beta_3 & \beta_2 & \beta_1 & \alpha - \gamma & \beta_1 & \beta_2 \\
\beta_2 & \beta_3 & \beta_2 & \beta_1 & \alpha - \gamma & \beta_1 \\
\beta_1 & \beta_2 & \beta_3 & \beta_2 & \beta_1 & \alpha - \gamma \end{bmatrix} = 0 \]
When the electron bunches were tuned to have 180° phase difference, the FFT spectrum presented only the monopole-like state, as shown in Figure 6.11. This means even though all the resonant states can be excited in the 6-defect PC, the FFT spectrum presented only the monopole-like state, as shown in Figure 6.11. This indicates that disorder up to 1% has negligible effects on the FFT spectrum.

Therefore, to further analyze the effects of disorder, the input PC is excited in the 6-defect PC by the synchronous and disordered bunches. The FFTs of the fields excited by 5 bunches of the input PC are compared to distinguish the excitations from the synchronous and disordered bunch trains. The results show that disorder up to 1% has negligible effects on the FFT spectrum.
Figure 6.11: The FFT of the axial electric fields excited by one bunch in each defect of the 6-defect PC, with 180° phase difference between any adjacent two bunches.

Furthermore, the sensitivities of the resonant states excitation were examined by comparing the excitations from a bunch train in each defect containing 5 in-phase bunches and 5 bunches with 1% random disorder. The FFTs of the fields excited in the 6-defect PC by the synchronous and disordered bunches from VOR-PAL PIC simulations were plotted together for comparison. Comparisons for the monopole-like and sextupole-like states are presented in figures 6.12 (a) and (b), respectively.

Figure 6.12: Comparisons of the FFTs of the fields excited by 5 synchronous and 1% disordered bunches in each defect for (a) the monopole-like and (b) the sextupole-like states.

Figure 6.12 shows that none of the monopole-like and sextupole-like states distinguishes the excitations from the synchronous and 1% disordered bunch trains. This indicates that disorder in bunches up to 1% has negligible effects on the EM COMSOL 2D eigenmode simulation. The results are shown in figure 6.2.

Figure 6.2: Resonant states in a 6-defect PC: (a) monopole-like state, (b) and (c) dipole-like degenerate states, (d) and (e) quadrupole-like degenerate states, (f) sextupole-like state.

Figure 6.2 shows that the 6-defect PC presents 4 resonant states: monopole-like (figure 6.2 (a)), dipole-like (figure 6.2 (b) and (c)), quadrupole-like (figure 6.2 (d) and (e)) and sextupole-like (figure 6.2 (f)), ranged from the lowest frequency to higher. The dipole-like and quadrupole-like states are degenerate, which split each into two with the same frequency and pattern but arranged differently among the defects. All other states are in the propagation band and are not localised in the defects. Notice that figure 6.2 (a)-(f) present only the regions around the defects.

In fact the full lattice was set to have 6 rows of rods around the defects. According to E. I. Smirnova's research in [42], 3 rows of rods can produce reactive Q-factor of the order of $10^5$, which is much higher than the Ohmic Q-factor of the order of $10^3$. Therefore 6 rows of rods were considered to be well sufficient for EM...
Hidden Sector Photon Searches
2. Theoretical Framework

\[
\nabla^2 \mathbf{E} - \mu_\varepsilon \varepsilon_0 \omega^2 \frac{\partial^2 \mathbf{E}}{\partial t^2} = 0
\]
$\nabla^2 E - \mu \delta n_0 \omega^2 \frac{\partial^2 E}{\partial t^2} = 0$
In this paper we propose a novel experimental technique to detect WISPs with masses in the range $10^{-6}$, unconstrained by experiment. The key parameters to be determined by any HSP search are the mass of the HSP and the probability that a HSP will convert to a photon, which is proportional to the square of the hidden sector mixing parameter.

The probability of conversion can be calculated using the Lagrangian density $\mathcal{L}$:

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{\chi}{2} F_{\mu\nu} B^{\mu\nu} + \frac{m_{\gamma}^2}{2} B^\mu B_\mu$$
In the following sections we propose to extend the regime of WISP searches using photonic band gap (PBG) structures at microwave frequencies as an analogue to the LSW experiments. This allows the theoretically interesting potential of this approach for HSPs as this allows for a simpler experimental design. However, a disadvantage of these approaches is that there is no direct control of the axion field could be applied to enable the same technique to be sensitive to axions.

The key parameters to be determined by any HSP search are the mass of the HSP \( m \), the mixing parameter \( \chi \), and of order 10 meV. In the few meV range model-independent constraints are being set by optical laser and intense accelerator-based free electron laser LSW experiments. But the non-observation of distortions in the cosmic microwave background that would arise from the non-observation of photon regeneration in CAST has recently been surpassed by solar lifetime calculations.

The Lagrangian density \( \mathcal{L} \) respectively.

\[
\mathcal{L} = -\frac{1}{4} F^{\mu \nu} F_{\mu \nu} - \frac{1}{4} B^{\mu \nu} B_{\mu \nu} - \frac{\chi}{2} F^{\mu \nu} F_{\mu \nu} + \frac{m^2}{2} B^\mu B_\mu
\]
In the following sections we propose to extend the regime of WISP searches using photonic cavity techniques. To date none of these approaches has revealed evidence for the existence of WISPs, although they have been used to significantly constrain the allowed parameter spaces for both axion and HSP models. One direction for future experimental searches comes from Jaeckel and Ringwald. We concentrate on demonstrating the potential of this approach for HSPs as this allows for a simpler experimental design. However, a disadvantage of these approaches is that there is no direct control of the axion or other WISP source.

The key parameters to be determined by any HSP search are the mass of the HSP field and the probability that a HSP will convert to a photon, which is proportional to the square of the hidden sector mixing parameter. The presence of a static magnetic field via the Primakoff effect. Examples include astrophysical sources are required to be produced by resonant production of HSPs, which do not require to be superconducting to achieve high Qs, a strong magnetic field could be applied to enable the same technique to be sensitive to axions.

There is a vast improvement in sensitivity of current experiments over previous limits. However, unlike axions, massive HSPs would couple to standard model (SM) photons via kinetic mixing, resulting in vacuum oscillation between them, similar to flavour-changing neutrino oscillations. Current constraints on the associated coupling constant come from Cavendish-type tests of Coulomb's Law in the microwave frequencies standard copper cavities and superconducting cavities have Qs of the order 10^6, respectively.

Reason for this vast improvement is the high quality factor of RF cavities and of order 10^6 potential of this approach for HSPs as this allows for a simpler experimental design. However, microwave cavity searches for axions with galactic origins, such as the axion dark matter experiment (ADMX) cavity searches for axions with galactic origins, such as the CERN axion solar telescope (CAST) which uses observations in helioscopes, such as the CERN axion solar telescope (CAST) which uses.

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Alternatively, 'light shining through wall' (LSW) laser experiments be produced by resonant production of HSPs, which do not require to be superconducting to achieve high Qs, a strong magnetic field could be applied to enable the same technique to be sensitive to axions.

To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector.

The probability that a HSP will convert to a photon, which is proportional to the square of the hidden sector mixing parameter, is given by the following Lagrangian:

\[ \mathcal{L} = -\frac{1}{4} F_{\mu \nu} F^{\mu \nu} - \frac{1}{4} B_{\mu \nu} B^{\mu \nu} - \frac{\chi}{2} F_{\mu \nu} B^{\mu \nu} + \frac{m_{\gamma}^2}{2} B^{\mu} B_{\mu} \]
The key parameters to be determined by any HSP search are the mass of the HSP and of order $10^{-15}$ eV. Unlike axions, massive HSPs would couple to standard model (SM) photons via kinetic mixing, resulting in vacuum oscillation between them, similar to flavour-changing neutrino mixing, with the probability that a HSP will convert to a photon, which is proportional to the square of the mixing parameter.

To date none of these approaches has revealed evidence for the existence of WISPs, although they have been used to significantly constrain the allowed parameter spaces for both axion and HSP models. One direction for future experimental searches comes from Jaeckel and Ringwald. We concentrate on demonstrating the potential of this approach for HSPs as this allows for a simpler experimental design. However, an LHC dipole magnet mounted with its primary axis directed toward the sun arose from the non-observation of distortions in the cosmic microwave background that would be produced by resonant production of HSPs.

The parameters of HSPs are also relatively generally well-understood, and the limits obtained are only weakened in the case of specific (or other WISP) source. In the case of helioscope searches, the production conditions are temperature-dependent or density-dependent WISP models. More significantly, limits from $(ADMX)$ and $(CAST)$ are being set by optical laser and intense accelerator-based free electron laser LSW type tests of Coulomb's Law in the red/visible radiation impinges on a wall, on the other side of which is a sensitive photon detector. To maximize the conversion probability, strong magnetic fields and intense radiation are required.

$\sum A_{\mu}$

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$\sum A_{\mu}$
shown by the dashed curve in figure 6. Temperatures, each defect is separated by 30 lattice spacings and 1 kW of power is supplied to enable us to specify the parameters of the lattice. Although detailed analysis needs to be undertaken for a specific geometry we can estimate to an accuracy of 1% the dimensions required for our proposed structure. At 10 GHz our sapphire scatterers would have a radius of 2 mm and a...
equation (6.8) for a 6-defect PC can be estimated as having a very small overlap between defects. Hence the values of the coupling strength between defects.

Materials is determined by the thermal and mechanical properties, the frequency stability of the spatially-localized TM010 state in one of the defects. The natural symmetry presented by the magnetic field through the lattice is straightforward, thereby enabling axion searches as well.

Figure 6.7: Change of coupling strengths ($\beta_{ij}$) as a function of defect separation, $l_{bb}$. The coupling coefficient $\beta = (\langle n_i | \tilde{P} | n_j \rangle)^2 / c$ with the condition that $l_{bb}$ is an integral multiple of $2a$. The suppression factor for the PBG structure used in figure 6.6 as a function of defect separation.

Figure 4. Normalised $E_z$ Field as a function of distance (a) for a 6-defect PC. The data-taking period of the envisaged experiment. A representative example of the results obtained from both the semi-analytical and full numeric simulations. The results from both the semi-analytical and full numeric simulations suggest that the sensitivity of such structures to the presence of HSPs can be achieved using this type of lattice (comparable to those of microstructures with a PBG structure of 30 lattice spacings, which is then used in the remaining part of this paper to study the sensitivity of these structures to the presence of HSPs.

Figure 3. Normalised Frequency $\omega_{ij} / 2\pi c = \alpha / \lambda$ as a function of defect separation, $l_{bb}$. The determinant in equation (6.14) is a sixth-order circular determinant. As discussed previously, the coefficients $\alpha$ can be determined from the single-defect resonant frequencies.

Figure 2.2. Accelerator Applications.
The Lagrangian density

\[ \mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{\chi}{2} F_{\mu\nu} B^{\mu\nu} + \frac{m_\gamma^2}{2} B^\mu B_\mu \]

where \( F_{\mu\nu} \) and \( B_{\mu\nu} \) are field strengths, \( \chi \) and \( m_\gamma \) are parameters, and the various terms represent different interactions in the theory.

This Lagrangian is used to study the behavior of WISP models in photonic band gap (PBG) structures, which can be used for high-precision searches of dark matter candidates.

The graph shows the exclusion sensitivity for a given model with approximately 1 year of running, or equivalently to the expected 5

### Figure 5.

The bounds on the range of operation of the PBG structure for HSPs from figure 8 of the paper. The dashed line indicates the experimentally observed exclusion which is potentially four orders of magnitude greater sensitivity than other approaches. The primary advantage is the simplicity of the experimental design, although they have been used to significantly constrain the allowed parameter spaces for both astrophysical and laboratory-based methods, free from external models. In these experiments intense infra-galactic searches rely on assumptions regarding the local density of dark matter. More significantly, limits from helioscope observations in helioscopes, such as the CERN axion solar telescope (CAST) which uses the presence of a static magnetic field via the Primakoff effect. Examples include astrophysical PBG structures do not require to be superconducting to achieve high Qs, a strong magnetic potential of this approach for HSPs as this allows for a simpler experimental design. However, sources are required to specify the parameters of the lattice. Although detailed analysis needs to be undertaken for a given value of the Primakoff matrix, it is possible to derive an upper bound on the allowed parameter space for PBG structures in a given model.