

Supplementary Information

Resonance fluorescence and indistinguishable photons from a coherently driven B centre in hBN

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S1. PHOTOLUMINESCENCE CHARACTERIZATION

Fig. S1 shows a photoluminescence spectrum of the emitter studied in the main text (SPE₁), measured with a fibre-coupled echelle spectrometer. A single peak is observed at about 436 nm. Its linewidth is limited by the spectrometer resolution (50 μeV).

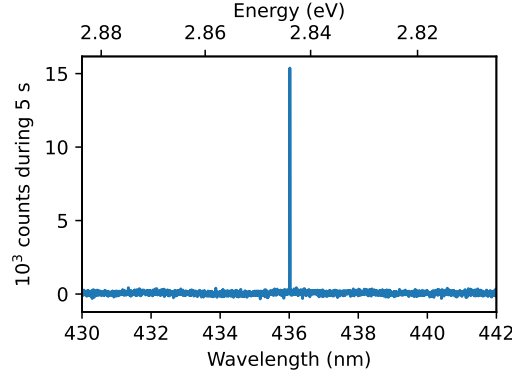


FIG. S1: PL spectrum of SPE₁.

S2. CHARACTERIZATION OF AN ADDITIONAL B CENTRE

We repeat the whole set of measurement described in the main text for another B centre (termed SPE₂) emitting at 436.018 nm. The sample structure is identical to that studied in the main text (SPE₁), except for the crystal thickness (170 nm) and the vertical position of the emitter, which is uncontrolled. This results in a lower enhancement of the collection efficiency and a higher saturation power [S1]. Fig. S2 shows the PLE characterisation in both cw and pulsed regimes. In the cw regime, the resonant laser scan on Fig. S2a provides the time-integrated linewidth of 0.75 GHz. The $g^{(2)}(\tau)$ shown on Fig. S2b allows us to verify that the emitter is maximally coherent at timescales shorter than the spectral diffusion time. In the pulsed regime, the count rate as a function of the laser power exhibits the onset of Rabi oscillations, with a π pulse power of 60 μW , sizeably higher than for SPE₁. Finally, the $g^{(2)}$ in pulsed regime (Fig. S2d) yields $g^{(2)}(0) = 0.03 \pm 0.03$.

The time traces of the zero-phonon line under low-power cw excitation exhibit correlated fluctuations similarly to SPE₁ (Fig. S3a). A similar statistical analysis (Fig. S3b) provides the SNR. The result is shown on Fig. S3c. In the case of SPE₂, the count is comparable to the laser background at low power, and exhibits saturation at power of a few microwatts. Measurements of the $g^{(2)}$ function at various powers reveal Rabi oscillations.

Spectroscopy of the ZPL emission in the high power regime allows us to observe Mollow sidebands with a power-dependent splitting, as can be seen on Fig. S4a. The measurement and fit processes are identical to those performed on SPE₁, and allow us to confirm the square root dependence of the splitting as a function of the laser power (circles on Fig. S4b), which is in good agreement with the Rabi frequency extracted from $g^{(2)}(\tau)$ measurements (stars on Fig. S4b).

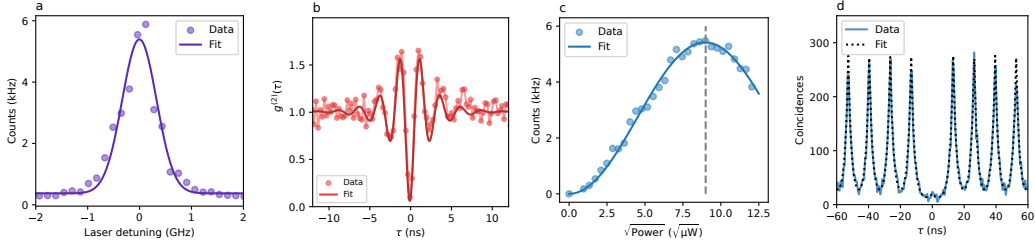


FIG. S2: **PLE characterisation of the emitter.** (a) Dots: low-power ($1.5 \mu\text{W}$) laser scan to infer the emitter inhomogeneous linewidth. Plain line: Gaussian fit to the data. (b) Dots: medium-power ($5 \mu\text{W}$) $g^{(2)}(\tau)$ revealing Rabi oscillations. Plain line: fit to the data. (c) Dots: count rate as a function of the square root of the laser power in pulsed regime. Plain line: sine fit to the data. (d) Blue curve: $g^{(2)}(\tau)$ in pulsed regime. Dotted line: multi-peak fit to the data.

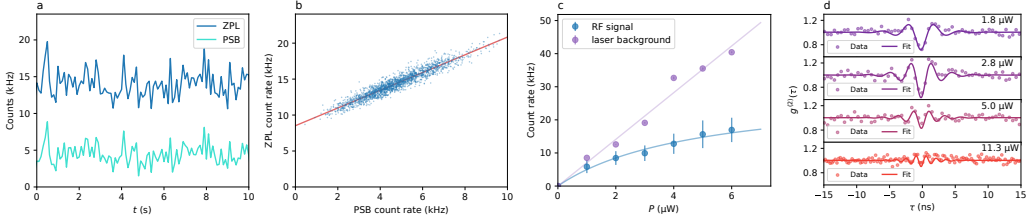


FIG. S3: **Photon statistics of the ZPL signal.** (a) Intensity time traces in the ZPL (blue) and PSB (turquoise) detection arms. (b) Blue dots: ZPL count rate as a function of the PSB count rate in the same time bin. Red line: linear fit to the data. (c) Extracted emitter count rate (blue dots) and laser background (orange dots) as a function of the laser power. Error bars: 1 standard deviation. (d) Dots: $g^{(2)}(\tau)$ measured in the ZPL arm at four different powers, demonstrating Rabi oscillations. Plain lines: fit to the data.

Fig. S5 shows the HOM interference measurement in pulsed regime. The laser power is set at 70 % of a π pulse (corresponding to an excited state population of 0.92), as a trade-off between optimising the count rate and minimising the laser background. The RF decay is shown on Fig. S5a can be used to identify the laser background (orange shading) and the SPE emission (blue shading), which we post-select in the HOM measurement. The green (resp. orange) dots Fig. S5b shows the coincidence histogram in parallel (resp. orthogonal) polarisation configuration, each measured during 180 h. A multi-peak fit provides the values of $g_{\parallel}^{(2)}(0) = 0.04^{+0.12}_{-0.04}$ and $g_{\perp}^{(2)}(0) = 0.45 \pm 0.11$ for the parallel, resp. orthogonal polarisation case. We deduce an estimation of $V_{\text{HOM}} = 0.92^{+0.07}_{-0.26}$, in good agreement with the values obtained for SPE_1 .

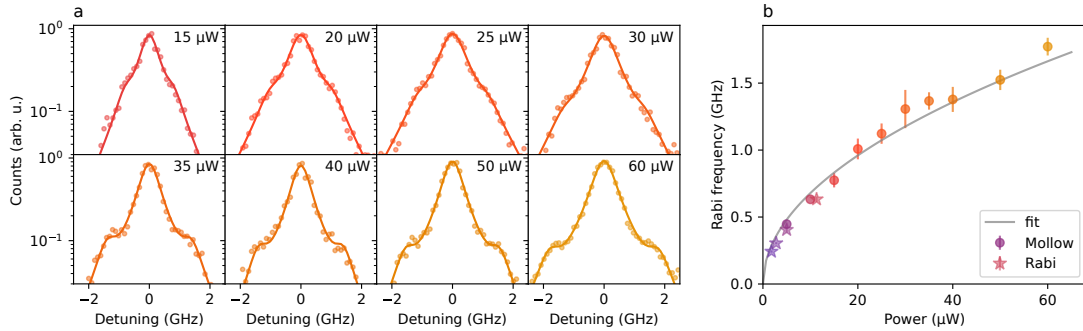


FIG. S4: **Observation of the Mollow triplet.** (a) Dots: count rate as a function of the detuning of the scanning FP filter at height different powers. Plain line: fit to the data. (b) Circles: Rabi frequency extracted from the Mollow triplet splitting. Plain line: fit to the data. Stars: Rabi frequency extracted from the ZPL $g^{(2)}$ oscillations. Error bars: 1 standard deviation.

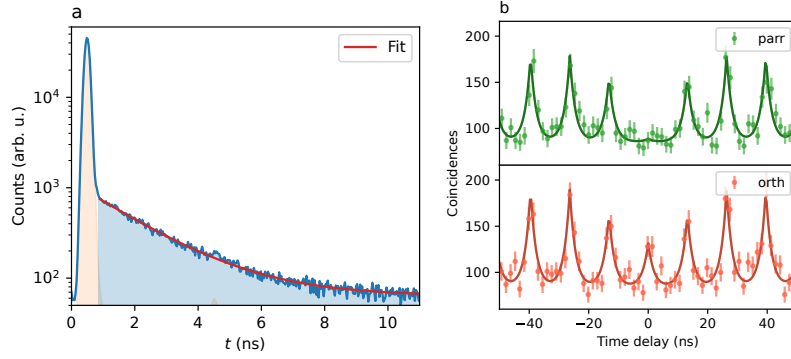


FIG. S5: **Two-photon interference in the resonant pulsed regime.** (a) Blue line: histogram of the photon detections in the pulsed regime. Light from the laser is visible as the initial short peak, followed by a slower decay. The red line is a fit to the data, providing the relaxation time $T_1 = 1.91$ ns. Blue shading: events falling into the post-selection time window. Orange shading: unsuppressed laser, normalized to the same peak value. (b) Green dots: two-photon coincidences measured in the parallel configuration. Orange dots: coincidences measured in the orthogonal configuration. Plain lines: multi-peak fits to the data. Error bars: 1 standard deviation.

S3. COUNT RATE AND SETUP COLLECTION AND DETECTION EFFICIENCY

In the Hong-Ou-Mandel experiment, we measure about 250 coincidences per 13.1 ns period over 62 h integration time, corresponding to a count rate of 600 Hz on the two APDs under π excitation at $f_{\text{rep}} = 76$ MHz – *i.e.* a photon detection probability of about 8×10^{-6} per pulse. This low count rate is explained by the cumulated losses in the different stages of the setup. In the following, we provide an estimation of the collection, transmission and detection efficiencies of the various parts of our setup.

Transmission of the cross-polarisation setup T_{CP} . The output count rate after the filtering setup for separating the photon emission from the laser light is about 8 % of the original count rate. This is due to the following reasons:

- The dichroic mirror removes about 20 % of the total counts, corresponding to the LO phonon replica, which is collected in the other arm.
- The cross-polarisation suppression removes 50 % of the light emission
- The transmission of the double Glan-Taylor is about 50 % in the relevant wavelength range.
- The coupling efficiency to the output fibre (also including fibre losses) is about 50 %.

Transmission of the HOM interferometer T_{interf} . The interferometer has a total transmission of about 4 %. This includes:

- Grating peak transmission: 65 %
- Fabry-Perot filter peak transmission: 80 %
- Fraction of the coherent ZPL photons within the near-resonant light emission: 40 %.
- Cumulated transmission of the other optical elements (waveplates, polarizer): 50 %.
- Fibre coupling, insertion losses and fibre connectors: 40 %

APD efficiency η_{APD} . The detection efficiency of the APDs is about 40 %.

Collection efficiency η_{coll} . The collection efficiency is defined as the proportion of emitted photons that we collect with our microscope objective and convey to our free-space setup. It includes the fraction of the light which is emitted towards the top of the sample, the efficiency of the collection by the microscope objective, and the transmission of the objective and of the cryostat windows. We can estimate it from two of the experiments presented in the main text.

- The saturation rate R_{sat} of the ZPL photons of 60 kHz (Fig. 2c) is measured through the cross-polarisation setup and detected by an APD, thus $R_{\text{sat}} = 0.5\Gamma_1\eta_{\text{coll}}T_{\text{CP}}\eta_{\text{APD}}$, where the initial factor 0.5 stands for the excited state population above saturation. From this, we estimate $\eta_{\text{coll}} \approx 0.75$ %.

– The measurement of Rabi oscillations in the pulsed regime (Fig. 1d) leads to a count rate of about 8 kHz in the PSB arm under π excitation at 76 MHz repetition rate. The upper bound of the PSB arm throughput T_{PSB} is about 0.5. In addition, the optical PSB emission is only about 15 % of the total spectrum, and the polarised beamsplitter transmission is 0.5 for 45° polarized light. Accounting for the APD detection efficiency, we obtain $\eta_{\text{coll}} \approx 0.7$ %, consistently with the estimation from the saturation count rate.

We note that this collection efficiency is a lower bound, since any source of loss we would have underestimated or overlooked is attributed to η_{coll} .

The count rate R at the output of the HOM interferometer can be estimated as $R = f_{\text{rep}}\eta_{\text{coll}}T_{\text{CP}}T_{\text{interf}}\eta_{\text{APD}} \approx 680$ Hz, which is consistent with the measured count rate. This also confirms our estimation of the collection efficiency, which could be improved using photonic structures such as 0D cavities. The planar structure used in this work, while improving the count rate by a factor ~ 2 in average compared with a bare exfoliated crystal [S1], is insufficient to yield a high collection efficiency, as would a structure with lateral light confinement, such as DBR-based micropillars, bullseye cavities, etc. due to the predominance of emission to in-plane propagating modes, which we do not collect. We also note that the internal quantum efficiency of the B centres was estimated to be close to unity using the same samples [S1], and measurements of long-time $g^{(2)}$ under pulsed excitation have excluded the presence of efficient shelving states [S2], which would have further degraded the count rate.

S4. INTEGRATED $g^{(2)}$

To ensure the absence of bunching due to blinking, spectral diffusion or metastable states at timescales up to ~ 2.6 μs , we plot the integrated $g^{(2)}$ in pulsed regime (where coincidences are binned according to the period difference) over 200 periods for both SPE_1 and SPE_2 . The results, shown Fig. S6, show that the coincidence rate is constant over the considered timescale. As an additional confirmation, the standard deviation of the coincidences in non-zero periods matches that expected for a Poissonian distribution in both cases.

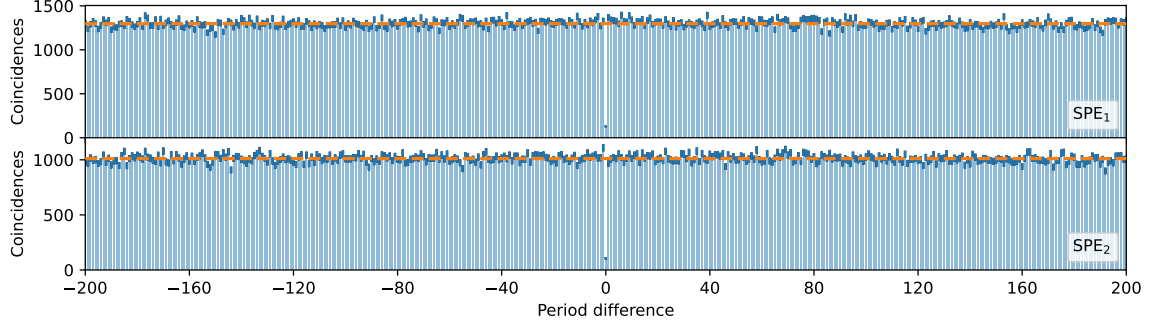


FIG. S6: **Coincidence rate in pulsed regime.** Period-wise $g^{(2)}$ of SPE_1 (a) and SPE_2 (b). The dashed orange line represents the mean number of coincidences of non-zero periods. Error bars: 1 standard deviation.

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- [S1] D. Gérard, A. Pierret, H. Fartas, B. Berini, S. Buil, J.-P. Hermier, A. Delteil, Quantum efficiency and vertical position of quantum emitters in hBN determined by Purcell effect in hybrid metal-dielectric planar photonic structures, *ACS Photonics* **11**, 5188 (2024).
[S2] D. Gérard, S. Buil, J.-P. Hermier, A. Delteil, Crossover from inhomogeneous to homogeneous response of a resonantly driven hBN quantum emitter, *Phys. Rev. B* **111**, 085304 (2025).