Pioneering All-copropagating Scheme for Biphoton Source in Hot atomic System

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Introduction

Biphoton generation has emerged as a pivotal tool in quantum research, offering the capability to produce heralded single photons. Leveraging the strong temporal correlation between two photons, one photon can be used as a trigger, and we can effectively use the second photon to conduct research in quantum information, quantum simulation, and communication. To generate biphotons, the mechanisms of spontaneous parametric down conversion in nonlinear crystals and SFWM in cold or hot atomic vapors are commonly used. In our study, we utilized the all-copropagating scheme, which maintains the phase-match condition, in the spontaneous four-wave mixing (SFWM) process to generate biphotons from a hot atomic vapor.

Double-Lambda transition scheme

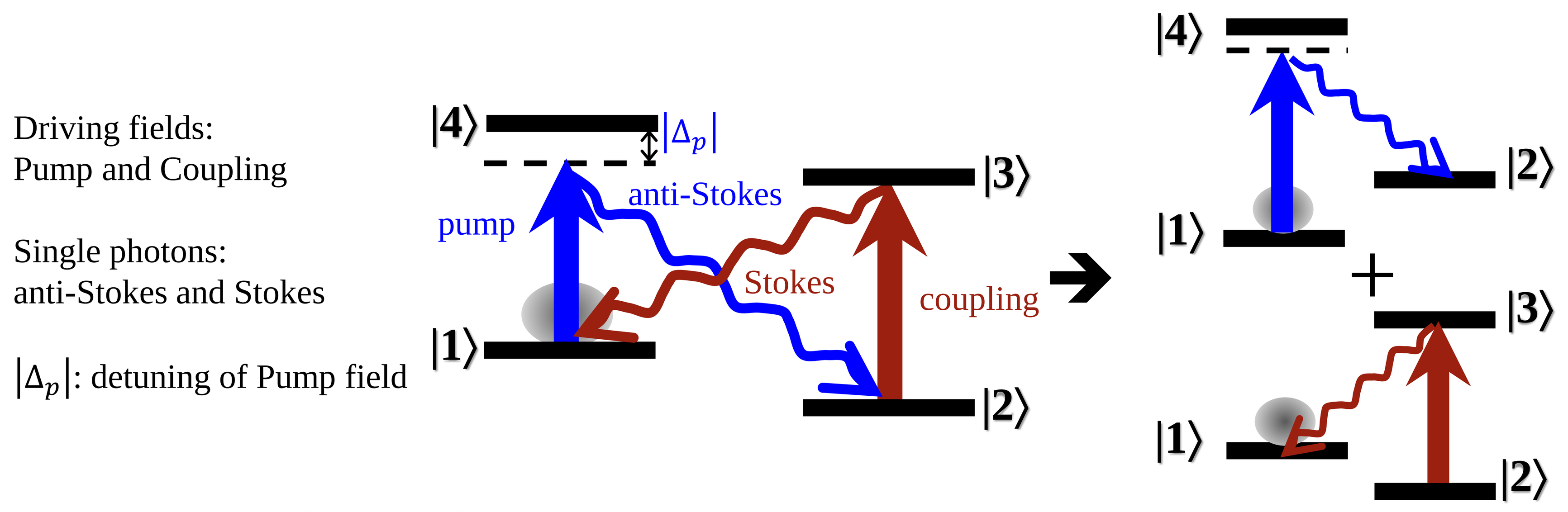

Fig. 1. Transition scheme of the SFWM process. The SFWM in our transition level can be seen as a far detuned Raman transition and an EIT process.

Copropagating scheme

We employed the all-copropagating scheme in the double lambda type SFWM scheme for the first time. This configuration maintains a good phase-match condition in the SFWM process.

$$\Delta\phi = L(\vec{k}_p - \vec{k}_{as} + \vec{k}_c - \vec{k}_s)\cdot\hat{z}$$

where L is the length of the atomic vapor, and $\vec{k}_p$, $\vec{k}_c$, $\vec{k}_{as}$, and $\vec{k}_s$ are the wave vectors of the pump and coupling fields and the anti-Stokes and Stokes photons.
The zero angle separation between the strong driving fields and the single photons enables a low decoherence rate in the Doppler-broadened media. The all-copropagating scheme ensures a higher generation rate and also a longer temporal width (narrower biphoton linewidth).

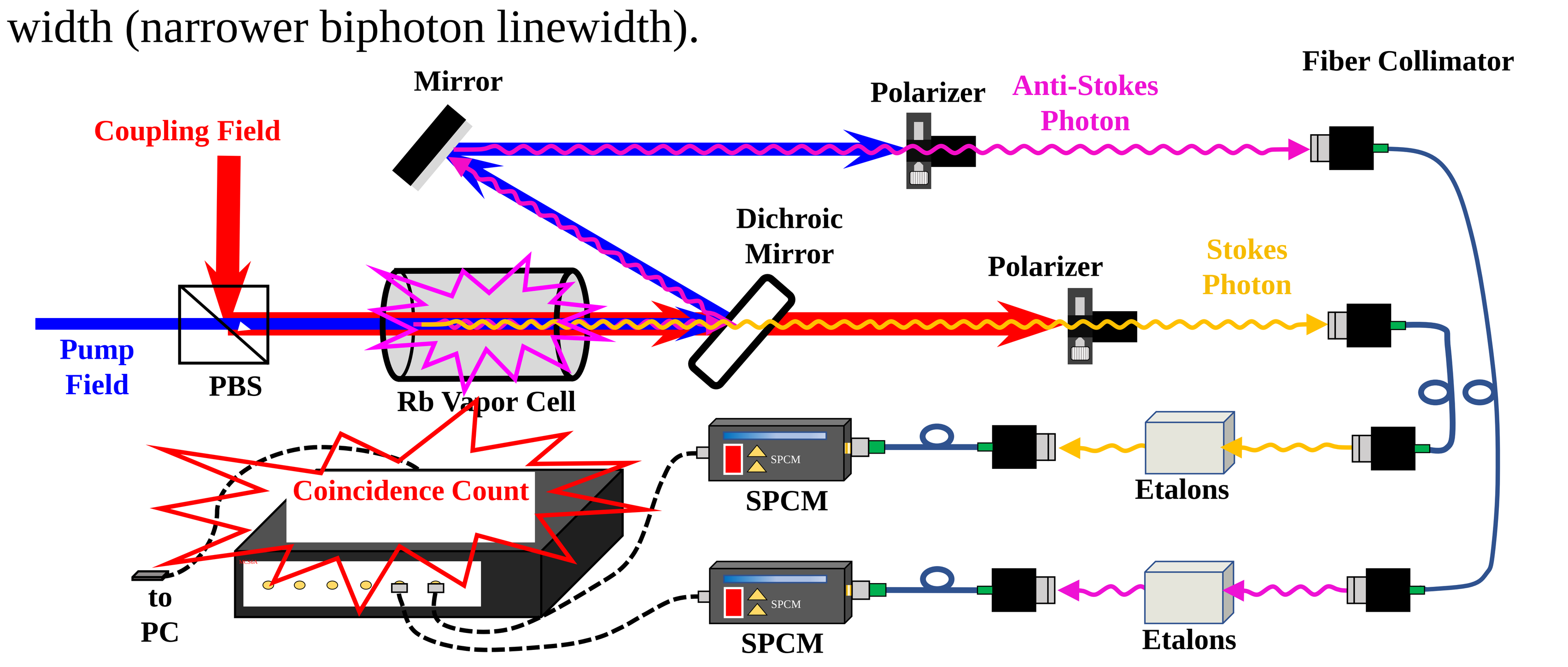

Fig. 2. Experimental setup of **Double-Lambda**-Type biphoton source.

Results of Double-Lambda SFWM

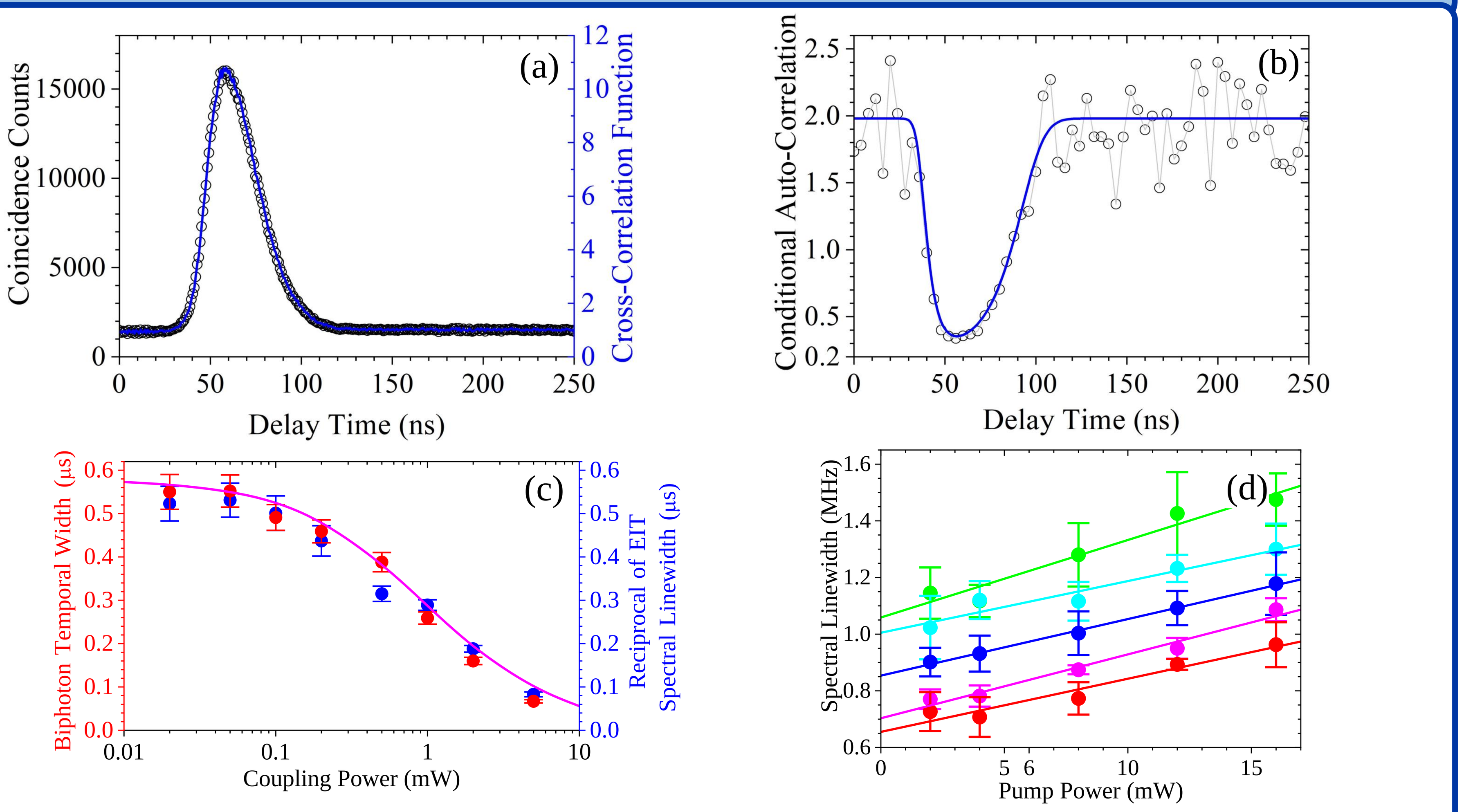

Fig. 3. (a) Biphoton wave packet. (b) Conditional Auto-correlation. (c) Tunable biphoton temporal width (Spectral linewidth) by varying Coupling power. (d) Tunable Spectral linewidth by changing vapor cell temperature and Pump power. Green, cyan, blue, magenta, and red circles are the experimental biphoton data measured at the vapor cell temperatures of 38, 44, 53, 60, and 65 °C with different Pump power. Lines are the best linear fits.

Diamond-Type Transition Scheme

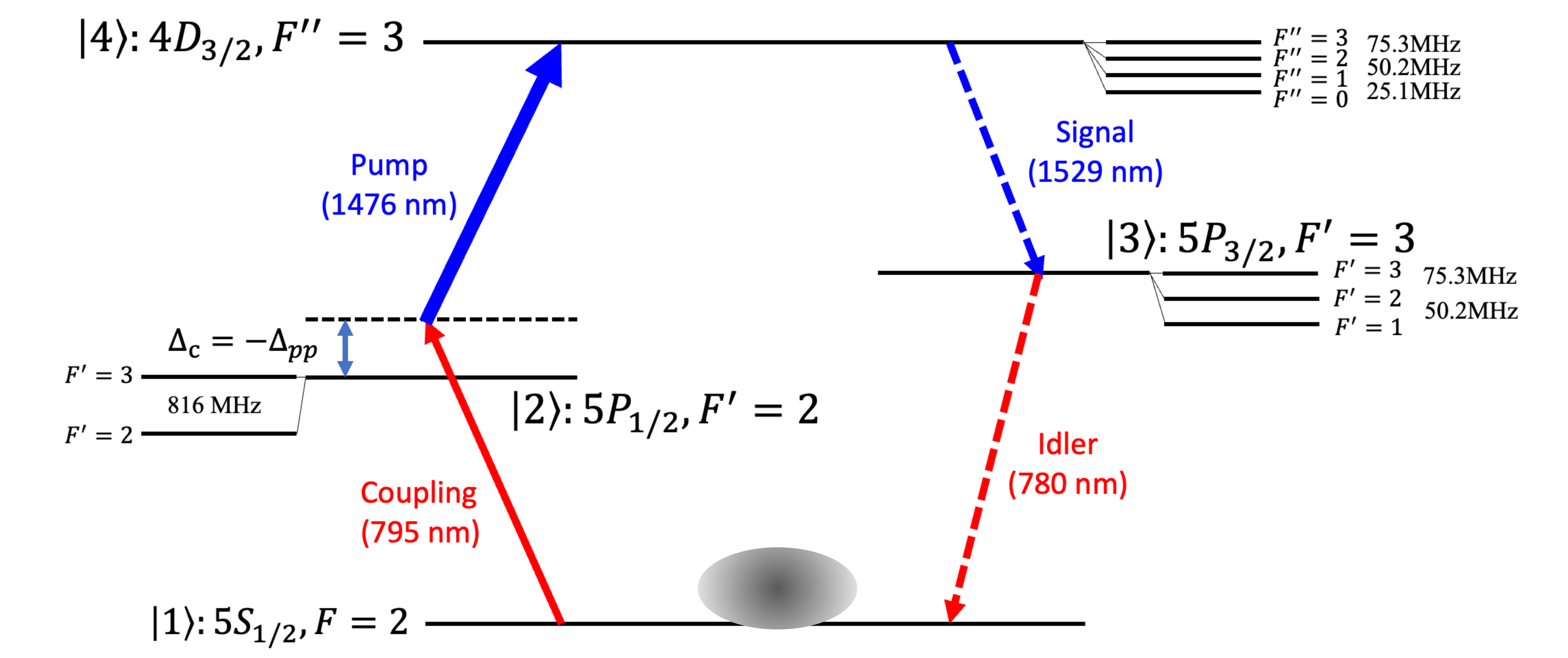

Fig 4. Transition scheme of the SFWM process.

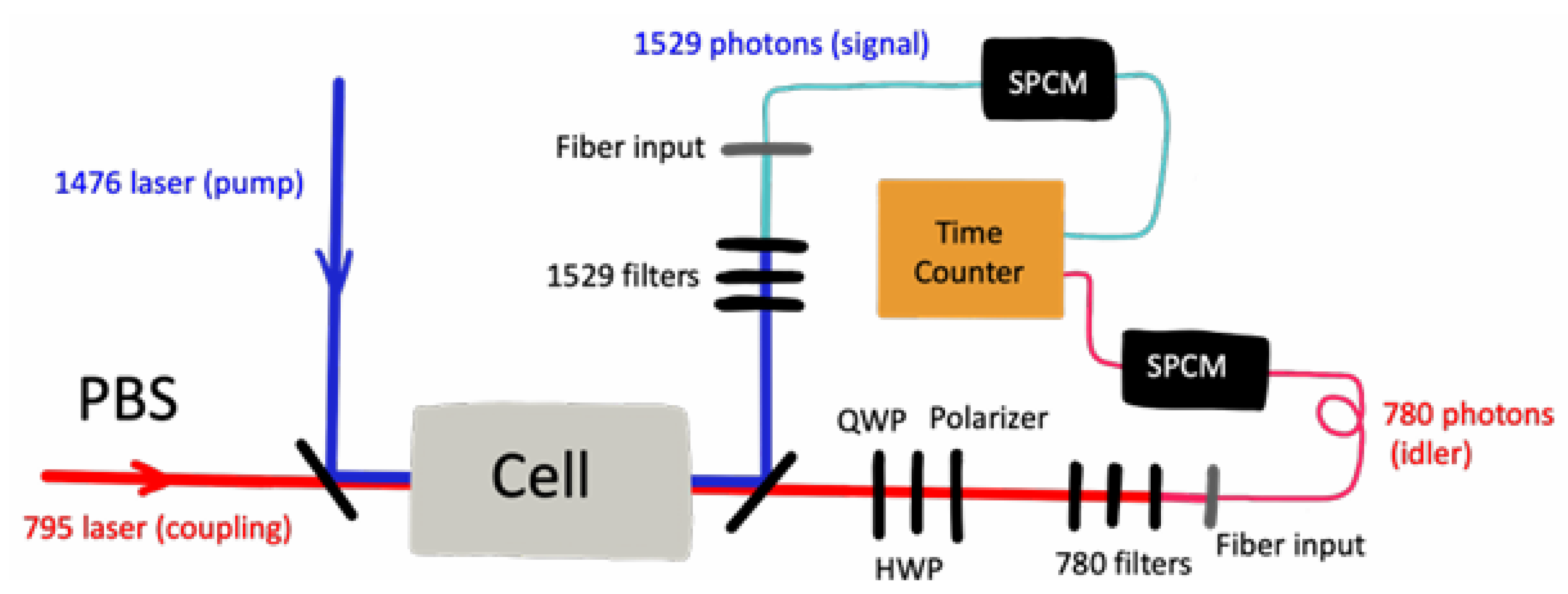

Fig 5. Experimental setup of Diamond-Type biphoton source.

Results of Diamond-Type SFWM

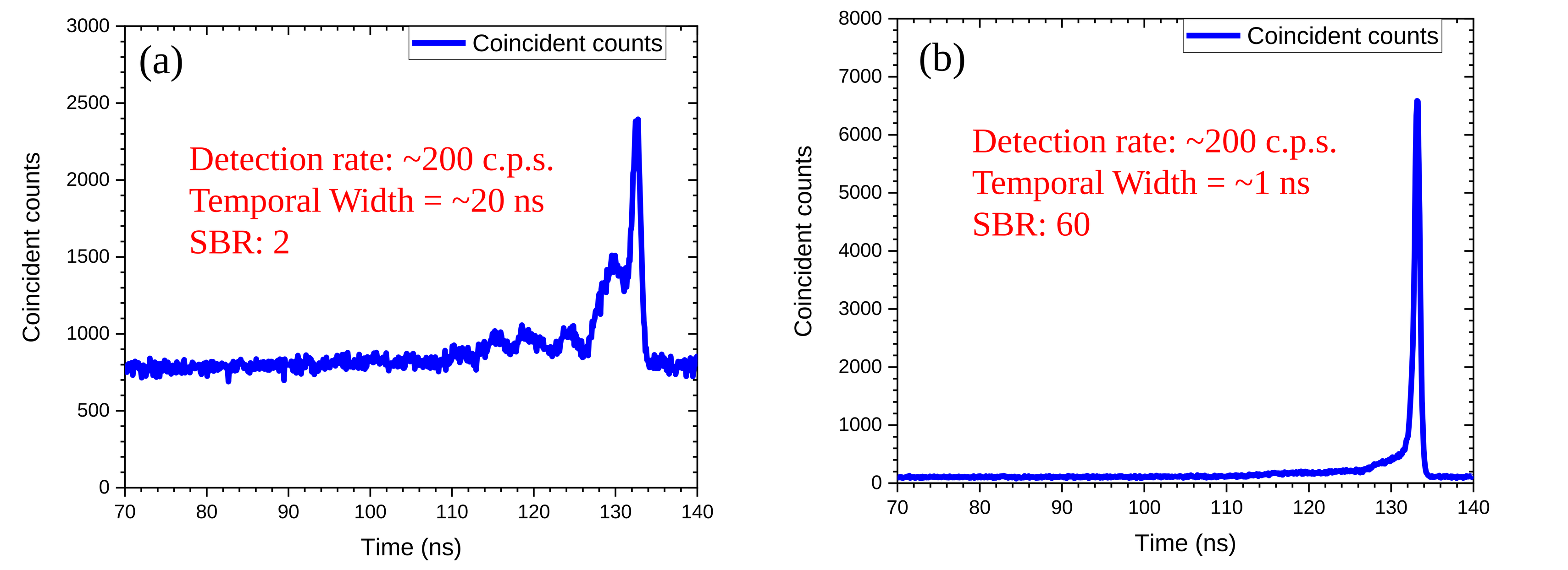

Fig. 6. (a) Biphoton wave packet when two-photon resonance for the atom with $k_{795}\cdot v = 0$.
(b) Biphoton wave packet when two-photon resonance for the atom with $k_{795}\cdot v = 460$ MHz.

Conclusions

- The phase match makes the generation process efficient, and the low decoherence rate results in a narrow biphoton linewidth. Thus, a high-rate source of narrow linewidth biphotons was achieved in this work.
- The high generation rate, together with the narrow linewidth, results in a spectral brightness of 1.1×10^6 pairs/s/MHz, which is better than all known results with all kinds of media.
- This method has been successfully applied to generate biphoton sources in cold atom systems and even directly within optical fibers, showcasing its versatility and potential impact across various platforms.

		Best Linewidth	Best Generation Rate per Linewidth
Single-Mode Solid-State SPDC		3 MHz[1]	3.0×10^5 pairs/s/MHz[2]
Microresonator SFWM		92 MHz[3]	1.4×10^5 pairs/s/MHz[3]
Cold-Atom SFWM	Earlier Works	250 kHz[4]	470 pairs/s/MHz[5]
	Our Work	**49 kHz**	**720 pairs/s/MHz**
Hot-Atom SFWM	Earlier Works	2 MHz[6]	1.4×10^4 pairs/s/MHz[7]
	Our Work	**290 kHz[8]**	**1.1×10^6 pairs/s/MHz**

References

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