Temporal-Spatial Double Slit Interference of Photoelectron

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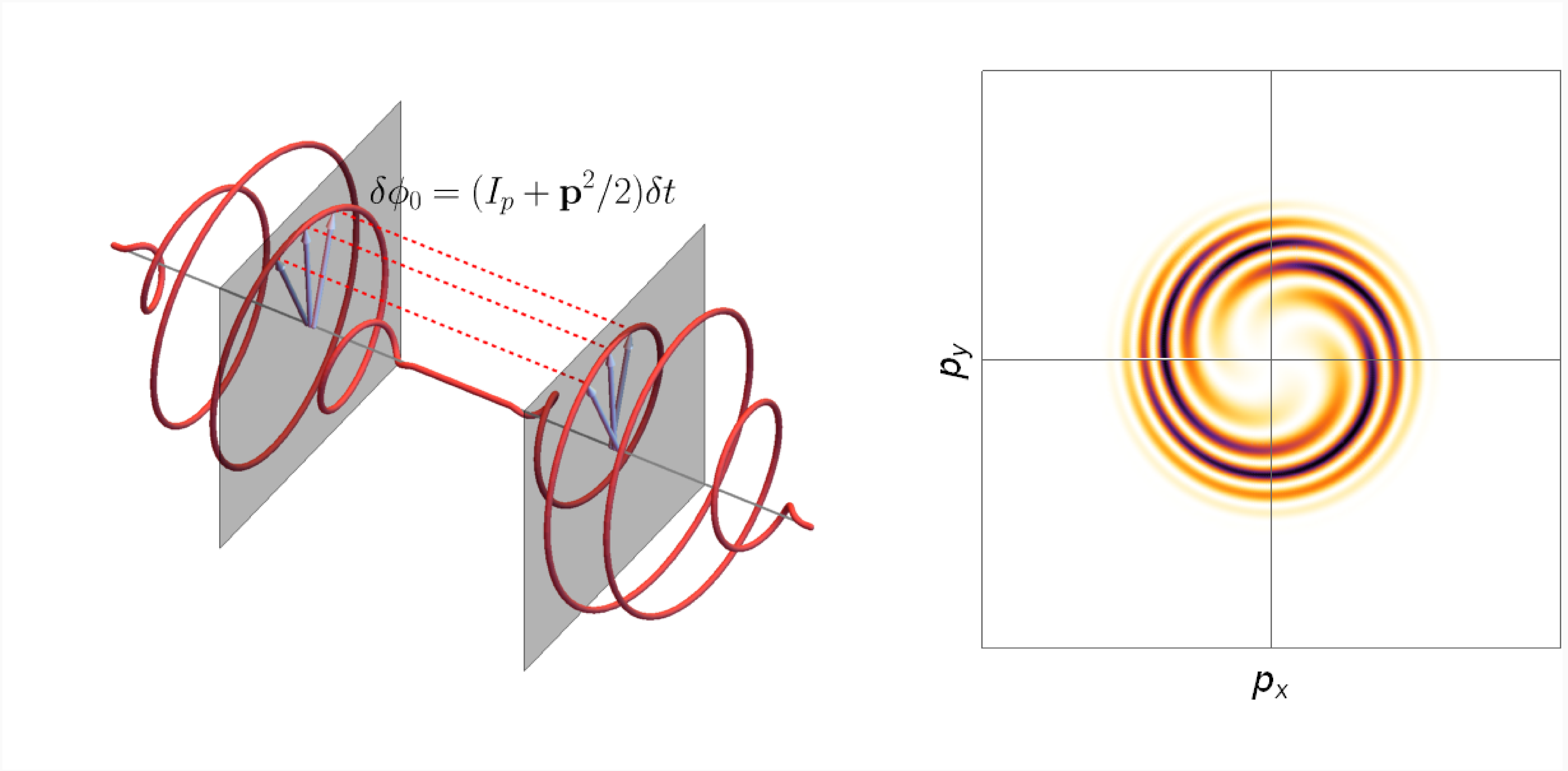
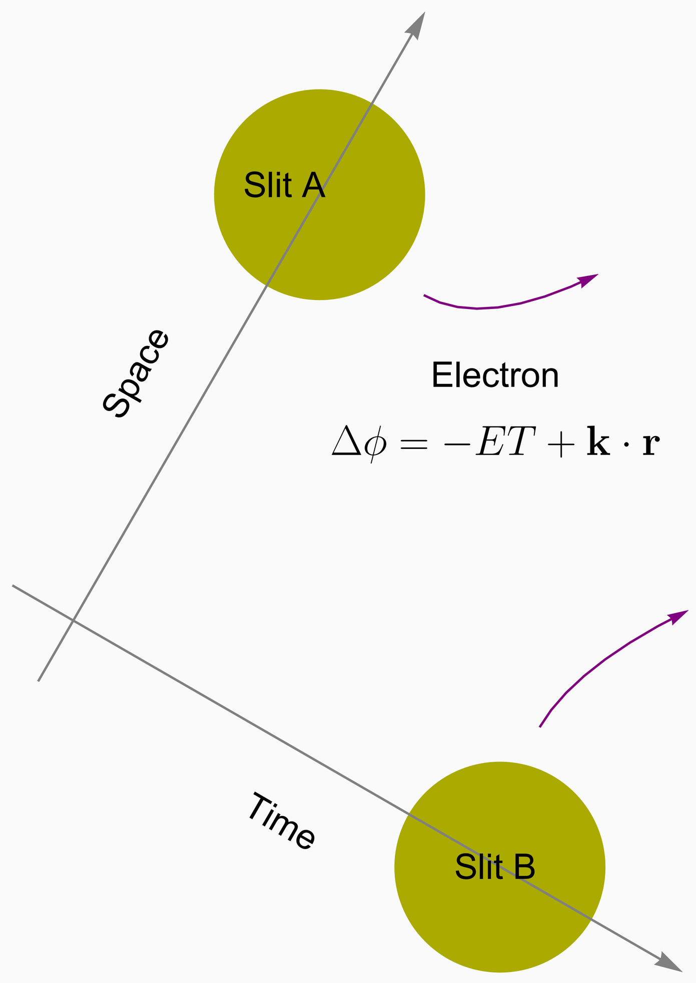
Temporal Double-Slit



We always talk about time domain interference in ultrafast science, and electron vortex[1-3] is a specific type of double-slit in time domain:

- Two delayed pulses: Temporal double-slit
$$\phi_0 = (I_p + p^2/2)(t_2 - t_1) \tag{1}$$
- Circular polarized, count-rotating, with same frequency and intensity: Atto-clock
$$\delta t = \delta\varphi/2\omega \tag{2}$$
- Stripes in momentum angular distribution with spacing
$$\mathrm{ASS} = \pi\omega/(I_p + p^2/2) \tag{3}$$
- Intercycle interference: n-photon absorption $I_p + p^2/2 \approx n\omega, n \in \mathbb{Z}$

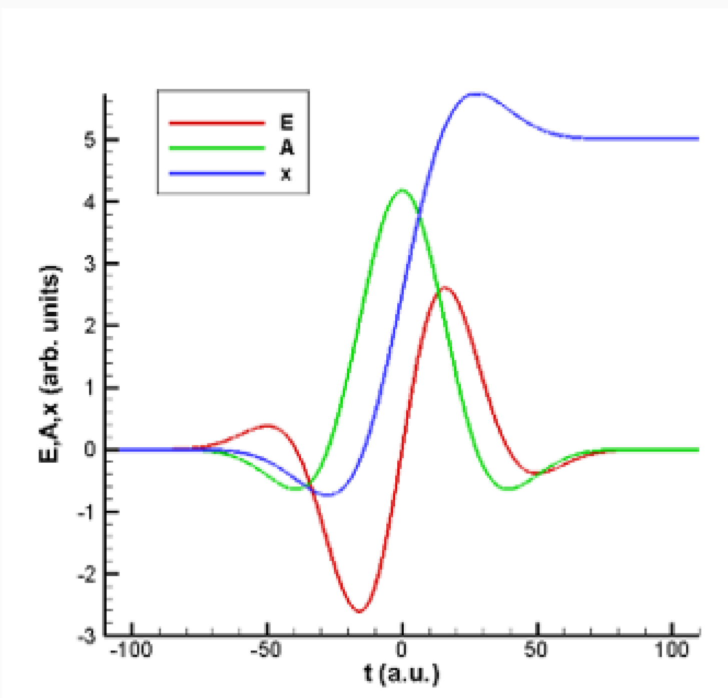
Temporal-Spatial Double Slit?



- Interference in Temporal domain $\Rightarrow$ Patterns in Energy Spectra
- Interference in Spatial domain $\Rightarrow$ Patterns in Momentum Spectra
- $E = p^2/2$
- Can we see something special from the photoeletron momentum distribution?
- Molecule is not an idea candidate since atoms are always there.

Pulse induced displacement

For a electron moving on the laser field
$$p_{\mathrm{mech}} = p_0 + A(t), \tag{4}$$
after integration
$$x(t) = p_0 t + \int A(\tau)\,\mathrm{d}\tau. \tag{5}$$
So, a short laser pulse would provide a net spatial shift for free electron
$$r = \int A(\tau)\,\mathrm{d}\tau. \tag{6}$$



We can use such short pulse to move one temporal slit in the coordinate space!
Now the phase difference between two slits respect to angle is
$$\delta\phi = 2n\delta\varphi + \delta p \cdot r, \tag{7}$$
and we have the unevenly distributed patterns with spacing
$$\mathrm{ASS} \approx \frac{2\pi}{2n + pr\sin(\phi - \phi_r)}. \tag{8}$$

Additional Remark

The displacement can also be derived from Volkov phase
$$\begin{aligned}\phi &= -\frac{1}{2}\int (p + A(t))^2\,\mathrm{d}t \\ &= \underbrace{-\frac{1}{2}p^2 t}_{\text{kinetic energy}}\ \underbrace{-\frac{1}{2}\int A(t)^2\,\mathrm{d}t}_{\text{ponderomotive energy}} - p\cdot\underbrace{\int A(t)\,\mathrm{d}t}_{\text{displacement!}}\end{aligned} \tag{9}$$

Results and Discussion[4]

We present our 3D time-dependent Schrödinger equation (TDSE) calculation of hydrogen atom below. We employ a pair of eight-cycle $\cos^2$-shaped pulses with a wavelength of 400 nm and a peak intensity of $3 \times 10^{13}\,\mathrm{W/cm^2}$. The time delay τ between them is taken to be 12 optical cycles. A single-cycle Gaussian-shape linearly polarized pulse along the x axis is inserted between two pulses with a wavelength of 800 nm and an intensity of $5 \times 10^{12}\,\mathrm{W/cm^2}$.

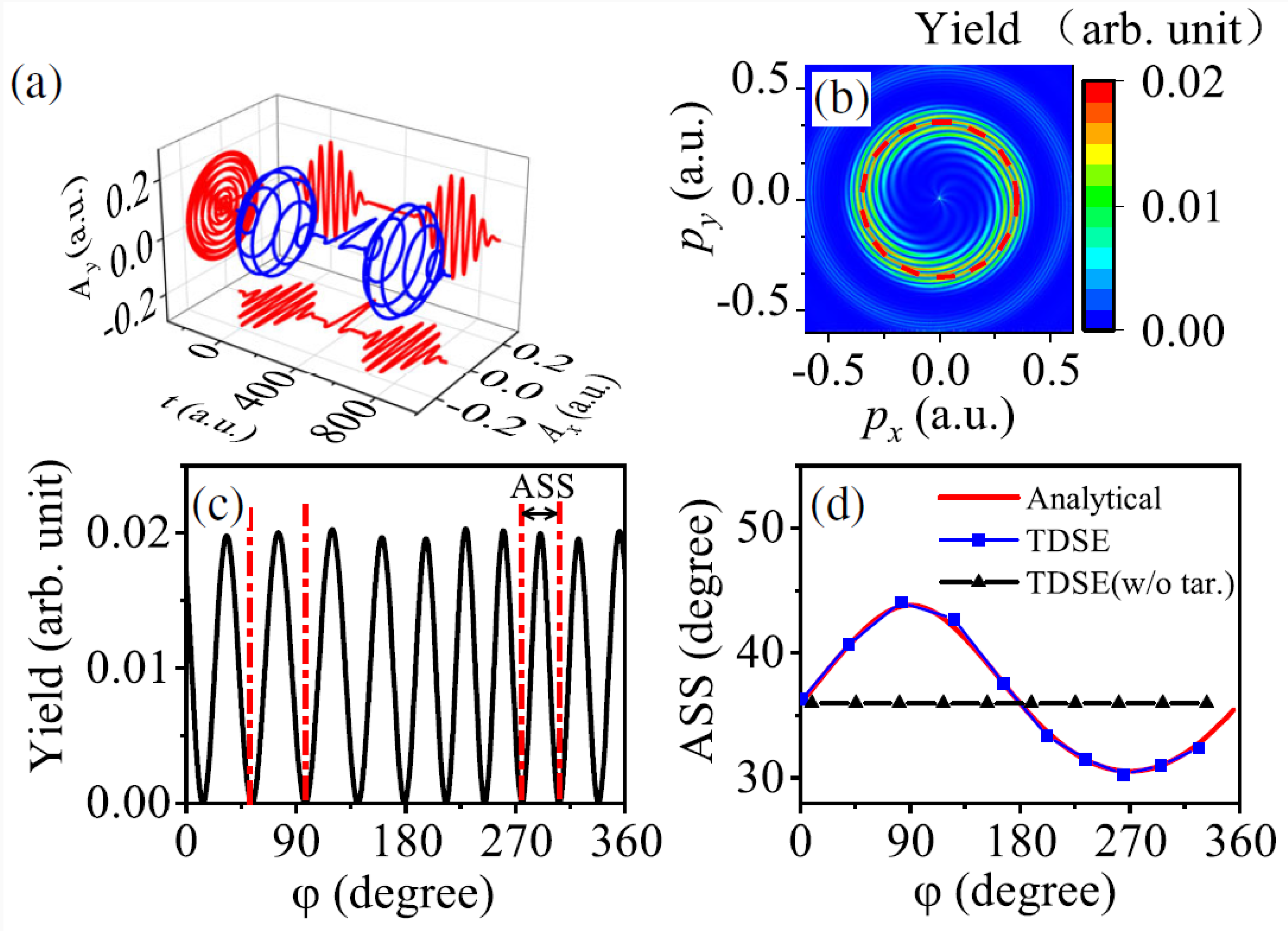


Figure 1: (a) The proposed configuration of laser pulses in a practical experimental measurement. From a numerical solution to the 3D TDSE, we get (b) the photoelectron distribution (PED) in the laser polarization plane, (c) the photoelectron angular distribution (PAD) at $p = \sqrt{2(5\omega - I_p)}$, and (d) the angular stripe spacing (ASS) extracted from (c). The red solid curve in (d) is the analytical result from Eq. (8).

It can be found that our analytical formula coincide well with the TDSE calculation, and the ASS is insensitive to both the CEP and intensity. Thus, it also provide a way to accurate measure the laser induced displacement. We regard (r, ϕ_r) as two parameters and fit them from TDSE results
$$(r, \varphi_r) = (5.26 \pm 0.21\,\mathrm{a.u.}, 0.00 \pm 0.02\,\mathrm{rad}). \tag{10}$$
These results are close to direct integration from vector potential $(5.03\,\mathrm{a.u.}, 0)$.

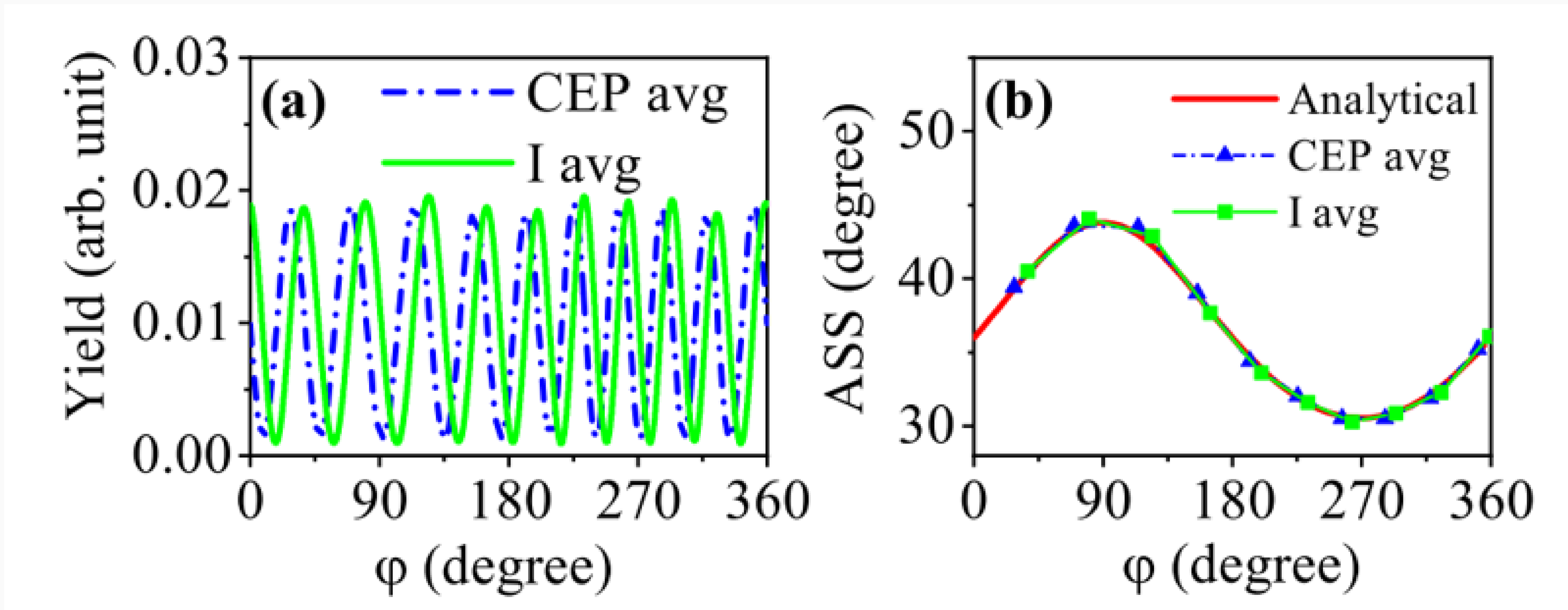


Figure 2: In (a), the same PADs as in Fig. 1(c) are, respectively, shown after averaging over the focusing volume effects (solid curve) and the jitter of CEP (dashed curve). From the averaged PAD from (a), the extracted ASS is shown in (b) (symbols) together with the analytical result (red solid line).

Conclusion

- We proposed a way to demonstrate temporal-spatial double-slit interference of photoelectron.
- The displacement induced by a short pulse can be measured precisely in this way.

Acknowledgement

This work is partially supported by the National Key R&D Program of China (Grant No.2018YFA0306302) and by the National Natural Science Foundation of China (NSFC) under Grants No. 11725416 and No. 11574010.

Reference

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