Experimental Proposal: A Differential Test of One Way Light Propagation Using a Macroscopic Accelerating Source in Vacuo

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Abstract

This paper proposes two complementary experimental configurations to test the independence of the one-way speed of light from source motion—a cornerstone of Special Relativity's second postulate. While foundational, earlier literature methods were constrained by round-trip averaging, material interactions triggering extinction resets, re-emission biases from mirrors and slits, quantum ambiguities from subatomic sources, range and resolution of interferometer, and the inability to directly isolate one-way source dependence without synchronization assumptions. A key innovation is a differential measurement method using stationary detector arrays that eliminates the need for absolute clock synchronization, addressing a persistent issue in traditional one-way speed tests by avoiding any one-way synchronization circularity. Configuration A uses an accelerating macroscopic transmitter in vacuum with two stationary detectors, measuring how the arrival-time differential (Δt) varies with source velocity. Because both detectors remain at rest relative to each other, any synchronization offset is a static constant that cancels out when measuring changes in Δt—we never need to know the "absolute" time at either detector, only how their relative measurements shift with source motion. Configuration B inverts this approach: a stationary light source with accelerating detector arrays, eliminating ambiguities about light emission in moving frames while maintaining the synchronization-free differential advantage. The designs avoid extinction concerns entirely by using dual direct-emission sources without intervening media, slits, or reflections, ensuring propagation occurs solely in ultra-high vacuum (UHV, 10^{-9} Torr). By presenting both configurations—one with an accelerating source and stationary detectors (Config A), the other with a stationary source and accelerating detectors (Config B)—we provide complementary paths to testing the second postulate, sidestepping potential ambiguities related to light emission or propagation in moving frames. Modern femtosecond timing and ultra-high vacuum technology, along with cost-effective components like off-the-shelf lasers and acceleration systems, make these experiments feasible at a lab scale, with estimated costs under $300k.

1 Introduction

The second postulate of Special Relativity—that the speed of light is independent of the source's velocity—is a foundation of modern physics. However, attempts to measure the one-way speed of light have faced the clock synchronization problem: synchronizing distant clocks without assuming a value for the one-way speed of light creates circularity.

This proposal introduces differential measurement approaches that sidestep the synchronization problem by focusing on changes in arrival-time differentials rather than absolute times.

By using two stationary detectors whose synchronization offset is a constant, we can observe how source motion affects the difference in their measurements. This difference changes predictably if emission theory $(c+v)$ holds, but remains constant if Special Relativity is correct—without needing to resolve the clock synchronization issue.

We present two complementary designs, each addressing limitations in traditional light-speed tests, leveraging existing technologies for practical implementation.

1.1 Historical Limitations and Motivation

Previous experimental efforts to test the second postulate have faced significant architectural and conceptual limitations:

- **Michelson-Morley (1887) [1]:** This is the most famous test of light's constancy.

  - *Limitation:* It utilized a two-way (round-trip) path where light was reflected back to its origin. This averages the speed in both directions, which can mask a one-way anisotropy.

  - *Superiority:* Our method uses one-way propagation with differential timing on stationary detectors, isolating source motion without averaging or reflections.

- **Alväger et al. (1964) [2]:** These researchers used constant-velocity subatomic particles (π mesons).

  - *Limitation:* While their results supported relativity, the experiment is often debated by skeptics (see Fox [5], for example) due to the "window" problem. The gamma rays passed through stationary material (detectors/windows) before being measured, potentially triggering the Extinction Theorem "reset" absorbing any extra speed (if any) [5].

- *Superiority:* We use a macroscopic accelerating source in a window-less UHV environment, eliminating windows/materials and quantum ambiguities from subatomic particles.

- **Beckmann & Mandics (1964) [3]:** This experiment used moving mirrors to test the second postulate.

  - *Limitation:* Like Michelson-Morley, the use of mirrors introduces a "re-emission" bias. According to the Ewald-Oseen theorem, the mirror's atoms act as a new stationary source, effectively "extinguishing" any velocity boost the light might have had from the original source. Nonetheless, while Beckmann & Mandics (1964) [3] used "moving" mirrors, Kantor [18] later made two crucial critiques that, he argued, rendered their experiment unproductive of conclusive results: Their first experiment used a slot to diffract the light reflected from the moving mirror. Kantor [18] correctly pointed out that there is no experimental evidence on the effect that a slit might have, acting as a "new" source, on the speed of light from a moving source. While in their second experiment they avoided using the slit as the "new" source, Kantor [18] pointed out that the underlying Lloyd Mirror Interferometer has an inherent geometrical path difference Δ at high-order fringes which renders the sought for fringe shift a negligibly small and undetectable modification. Thus, the null result doesn't imply constant light speed.

  - *Superiority:* Our direct-emission approach in vacuum avoids mirrors, slits, reflections, and re-emission entirely, using accelerating configurations and differential timing to probe emission without such biases.

- **Sadeh (1963) [4]:** One-way measurement using positron annihilation in flight for gamma rays.

  - *Limitation:* Similar to Alväger, potential extinction resets from material interactions in detectors/windows, and reliance on subatomic particles introduces quantum effects that may obscure classical light propagation interpretations.

  - *Superiority:* Our macroscopic lasers in UHV provide a cleaner, classical test without quantum ambiguities or material resets, using stationary detectors for precise differential Δt shifts.

These historical experiments, while foundational, were constrained by round-trip averaging, material interactions triggering extinction, re-emission biases from mirrors, quantum ambiguities from subatomic sources, range and resolution of interferometer, and the inability to directly isolate one-way source dependence without synchronization assumptions.

1.2 The Kantor Critiques and Experimental Ambiguity

Beyond the well-known limitations of the Michelson-Morley or Alväger experiments, a series of critiques by Kantor [7, 8, 12, 13, 14, 15, 17, 18, 19, 20] suggests a broader systemic inconclusiveness in the experimental basis of Special Relativity. Kantor specifically identified flaws in:

- **Doppler Effect Interpretations:** Arguing that Doppler experiments often rely on circular logic regarding velocity addition. [7, 8]

- **Convection and Drag:** Demonstrating that experiments on the convection of light in moving media (e.g., Fizeau-type tests) contain internal contradictions or "pseudo-effects" that mask true light-speed variance. [12, 13, 14, 15]

- **Interferometric Geometry:** Pointing out that high-order fringe shifts in Lloyd mirror setups are often too small to detect, rendering a "null" result physically meaningless rather than a confirmation of constant c. [17, 18, 19, 20]

Collectively, these critiques underscore a critical gap: the lack of a direct, macroscopic, one-way measurement in a vacuum that avoids the "re-emission" biases of mirrors and slits. This proposal addresses this gap by moving away from second-order effects like Doppler shifts and focusing on primary arrival-time differentials Δt. Our proposal is superior because it:

1. Uses purely one-way propagation with differential Δt measurements to eliminate synchronization circularity and round-trip averaging.

2. Employs macroscopic direct-emission lasers in a continuous windowless UHV environment to avoid extinction resets from windows, mirrors, or intervening media.

3. Tests emission from accelerating macroscopic sources (Config A) and detector motion (Config B), sidestepping quantum ambiguities and re-emission biases.

4. Leverages modern femtosecond timing and cost-effective off-the-shelf technology for feasible, high-sensitivity detection of source-velocity dependence.

2 The Clock Synchronization Problem and How This Proposal Addresses It

2.1 The Traditional Problem

The one-way speed of light cannot be measured without defining how to synchronize clocks at different locations. Einstein's synchronization convention involves

sending a light signal from point A to B and back, assuming the one-way speed is the same in both directions. But this assumption is what we aim to test, creating a logical circle. Philosophers and physicists have recognized this as a fundamental issue (see Salmon [40], Ellis [41], and Reichenbach [42]).

2.2 The Differential Measurement Solution

This proposal addresses the synchronization problem by using two detectors stationary relative to each other and measuring only the difference in arrival times (Δt). Since the detectors are stationary and share a common timing reference, any synchronization offset is a constant that subtracts out when computing changes in Δt across source speeds. We look for shifts correlated to source motion: if relativity holds, Δt remains constant; if emission theory holds, Δt decreases as the source approaches the detectors and increases as it recedes.

2.3 How Source Motion Affects Δt

- **Under Special Relativity:** $\Delta t = L/c$ for all source velocities. The differential remains constant.

- **Under Emission Theory** $c \pm v$**:** $\Delta t = L/(c \pm v)$ changes with source velocity and direction. As the source accelerates toward the detectors, Δt decreases; as it recedes, Δt increases.

Rather than an absolute c, we measure the sensitivity $\partial \Delta t / \partial v$. This distinguishes the theories without resolving clock synchronization.

3 Experimental Configuration A: Accelerating Source with Stationary Detectors

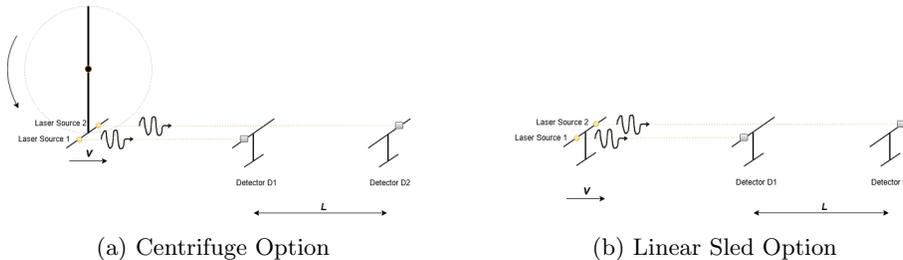Figure 1 shows two alternative setups for experimental configuration A.

(a) Centrifuge Option　　　　(b) Linear Sled Option

Figure 1: Experimental configuration A: moving source and stationary detectors.

3.1 The Source Assembly ("The Throne")

The transmitter consists of two identical high-speed pulsed lasers (femtosecond Ti:sapphire models like Coherent Chameleon Ultra or Vitara [32], ˜$50k each) mounted horizontally stacked (10–50 cm separation) on a rigid aluminum frame. This assembly achieves varying instantaneous velocities (v) via high-magnitude linear acceleration or a centrifuge. The lasers emit parallel beams tangent to the motion direction, triggered simultaneously by a shared FPGA-based circuit (Xilinx Kintex-7 KC705 development board [33], ˜$2k) for ¡10 fs jitter. A beam splitter was considered for splitting a single pulse but avoided to prevent reflection or propagation through any medium, which could trigger extinction concerns and reset light speed.

3.2 Acceleration Mechanisms

To sample different source velocities, emissions occur during multiple runs at varying speeds and directions (e.g., different RPM or burst velocities), allowing measurement of Δt shifts as a function of v. This avoids the need for continuous in-run acceleration.

Centrifuge Option: (Figure 1.a) Mount the assembly on a high-speed direct-drive rotary arm (radius 2–5 m, custom or from Aerotech ARMS [46]/ADRT [47] series, ˜$30k–$60k) for tangential v up to 20–100 m/s (e.g., 100–300 RPM at 5 m radius). These stages are designed for high-rate motion simulation (e.g., inertial testing) with brushless motors for smooth, vibration-minimized operation. Trigger via rotary encoders (Heidenhain ERA 4000 series [35], ˜$1k) when the tangent aligns beams with detectors. Balance the system for minimal vibrations using dynamic counterweights. This option provides reliable, repeatable velocities in a compact footprint suitable for UHV enclosure.

Linear Sled Alternative: (Figure 1.b) Use high-speed electromagnetic linear motors (e.g., LinMot PS01 series [43] or Parker Ironless linear motors [44], PI V-817 series [49], ˜$20k–$40k) for straight-line bursts ($v = 5$–20 m/s over 10–100 m tracks, with custom extensions for higher v). These vacuum-compatible systems offer simpler alignment and shorter runs but lower maximum speeds than rotary (limited by lab-scale power and safety to ˜5 m/s off-shelf; custom rail systems for 20 m/s). Track length must accommodate acceleration (e.g., at a=10 m/s², ˜20 m to reach 20 m/s), coast (˜10-20 m for emissions), and deceleration (˜20 m), totaling ˜50-100 m for bidirectional runs (+v/-v via reversal). For higher velocities, custom coil-based accelerators could be explored, though they increase complexity and cost.

In general, centrifuge option allows us to reach higher v but adds complexity on triggering accuracy and alignment. Enclose in UHV chamber. With off-the-shelf components and existing lab facilities, total costs remain under $300k.

3.3 The Detector Array

Two high-precision avalanche photodiodes (APDs, e.g., Excelitas SPCM-AQRH series [37], ˜$5k each) fixed at distance L (˜50 m) in the lab frame, horizontally offset to match sources. Connected to common time-correlated single-photon counting (TCSPC) system (PicoQuant TimeHarp 260 [38], ˜$20k) with ˜25 ps single-shot resolution. Effective femtosecond precision is achieved via statistical averaging over many pulses (e.g., 10^6 emissions, reducing noise to ¡10 fs). For single-shot fs resolution, a streak camera (e.g., Hamamatsu C13410 [45], ˜$50k) could supplement. Constant synchronization offset cancels in Δt.

The detector separation L and the differential $\Delta(\Delta t) = \Delta t_+ - \Delta t_-$ (where + and - denote approach/recede directions) are critical for sensitivity. At $v = 100$ m/s and $L = 50$ m $\Delta(\Delta t) \approx 111$ fs under emission theory, providing a strong signal. This differential must exceed error sources (e.g., ¡10 fs jitter from triggering and alignment), which is achievable with averaging. Higher resolution can be obtained by increasing RPM (for higher v) or extending vacuum tubes for larger L (e.g., 100 m), though this raises costs.

3.4 The Vacuum Environment

The entire path is in a continuous, windowless Ultra-High Vacuum (UHV) chamber (10^{-9} Torr, custom from Pfeiffer Vacuum HiCube NEO series [39], ˜$50k) to avoid extinction resets.

4 Experimental Configuration B: Stationary Source with Accelerating Detectors

Figure 2 shows two alternative setups for experimental configuration B.

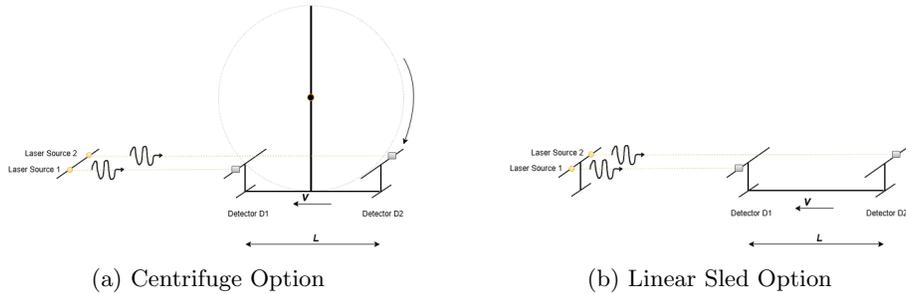(a) Centrifuge Option   (b) Linear Sled Option

Figure 2: Experimental configuration B: stationary source and moving detectors.

This configuration inverts Config A to address potential ambiguities in light emission from moving sources. Here, the dual lasers remain stationary, emitting parallel beams, while the detector array (two APDs separated by L ˜50 m)

is mounted on an accelerating assembly (e.g., LinMot linear motors [43] or Aerotech ARMS [46]/ADRT [47] rotary arm). Triggers are synchronized via the shared FPGA [33], with emissions timed to align with detector motion.

Acceleration mechanisms prioritize linear motion to simplify beam-detector alignment: linear bursts up to 5–20 m/s using electromagnetic motors (e.g., LinMot PS01 series [43], PI V-817 [49], ~$20k–$40k) for straight-line paths over ~50-100 m tracks (accommodating ~20 m accel/decel at a=10 m/s^2 for v=20 m/s, plus coast for emissions; bidirectional for +v/-v to optimize length), ensuring beams remain aligned during light travel time (~167 ns over 50 m). Off-shelf products are available at max v ~5 m/s; custom for 20 m/s. For higher velocities (up to 100 m/s) and stronger signals (e.g., 222 fs differential at L=50 m), rotary arms can be used as an alternative, with emission pre-triggered by the travel time using encoder feedback (Heidenhain ERA 4000 [35]) and FPGA delays to compensate for detector displacement during flight (negligible ~0.017 mm at 100 m/s). The UHV chamber encloses the path, with detectors moving in vacuum to maintain 10^{-9} Torr [39]. Timing uses the same TCSPC system [38] or streak camera [45] for fs precision (e.g., resolving 22 fs differentials at lower v with averaging), focusing on Δt shifts with detector velocity. To enhance resolution at lower linear v (11-44 fs at v=5-20 m/s, L=50 m), extend L to 100 m (22-88 fs).

Config B is advantageous because it avoids the longstanding debate on the Ewald-Oseen extinction theorem's applicability to emission from moving sources [5, 6]. This debate centers on whether the theorem—well-established for light propagating through matter, where it extinguishes the incident wave and re-radiates at c independent of source speed—extends to the emission process itself, where photons are created by atomic transitions in a moving frame. Critics argue that extinction resets may not fully apply at emission, potentially allowing source-dependent speeds [5], [48]. By using a stationary source, Config B ensures emission occurs in the lab rest frame, eliminating this ambiguity while still testing velocity dependence via moving detectors. Costs remain under $300k, with similar feasibility.

5 Expected Results and Sensitivity Analysis

Under Special Relativity, no Δt shift is expected with v. Under emission theory, detectable shifts (e.g., 111 fs at 100 m/s, L=50 m) exceed noise floors. Sensitivity improves with larger L or v, but g-forces limit max v to ~100 m/s for component safety. Statistical analysis over 10^6 pulses yields ¡1 fs resolution, sufficient to distinguish theories at 5σ confidence.

6 Conclusions

These configurations provide a synchronization-free, extinction-robust test of the second postulate using lab-scale tech. Config A probes moving emission

directly; Config B sidesteps emission debates. Future work could extend to higher v via advanced accelerators. Estimated timeline: 6-12 months with $300k budget.

7 Acknowledgements

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