Introduction

1. The delay upon reflection from a frustrated Gires-Tournois interferometer is predicted to be negative but has never been measured [1].

2. A negative reflection time implies that the peak of a reflected pulse appears before the incident pulse peak has hit the interface.

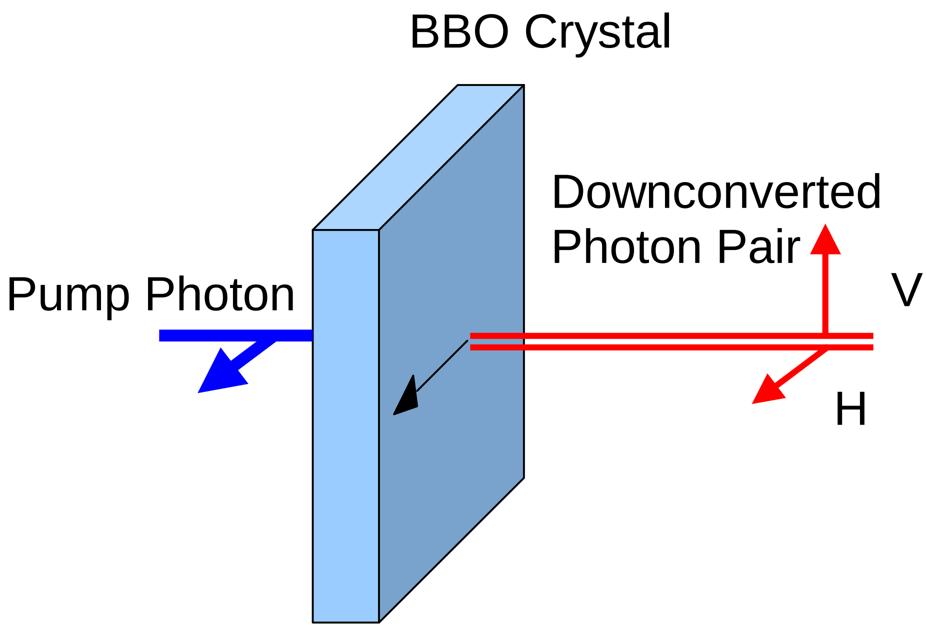
3. In experiments on absorption or tunneling, low transmission probability ensures that energy transport on average never violates causality. However, in this experiment the reflection probability is 100%.

4. The reflection time will be measured with pairs of photons from downconversion in a Hong-Ou-Mandel interferometer.

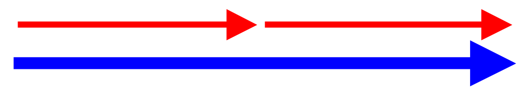
5. The interferometer has been constructed and shown to offer sub-femtosecond resolution.

6. We provide a resolution to the apparent violation of causality.

Type II Downconversion

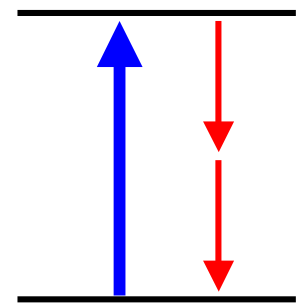


Momentum is conserved..



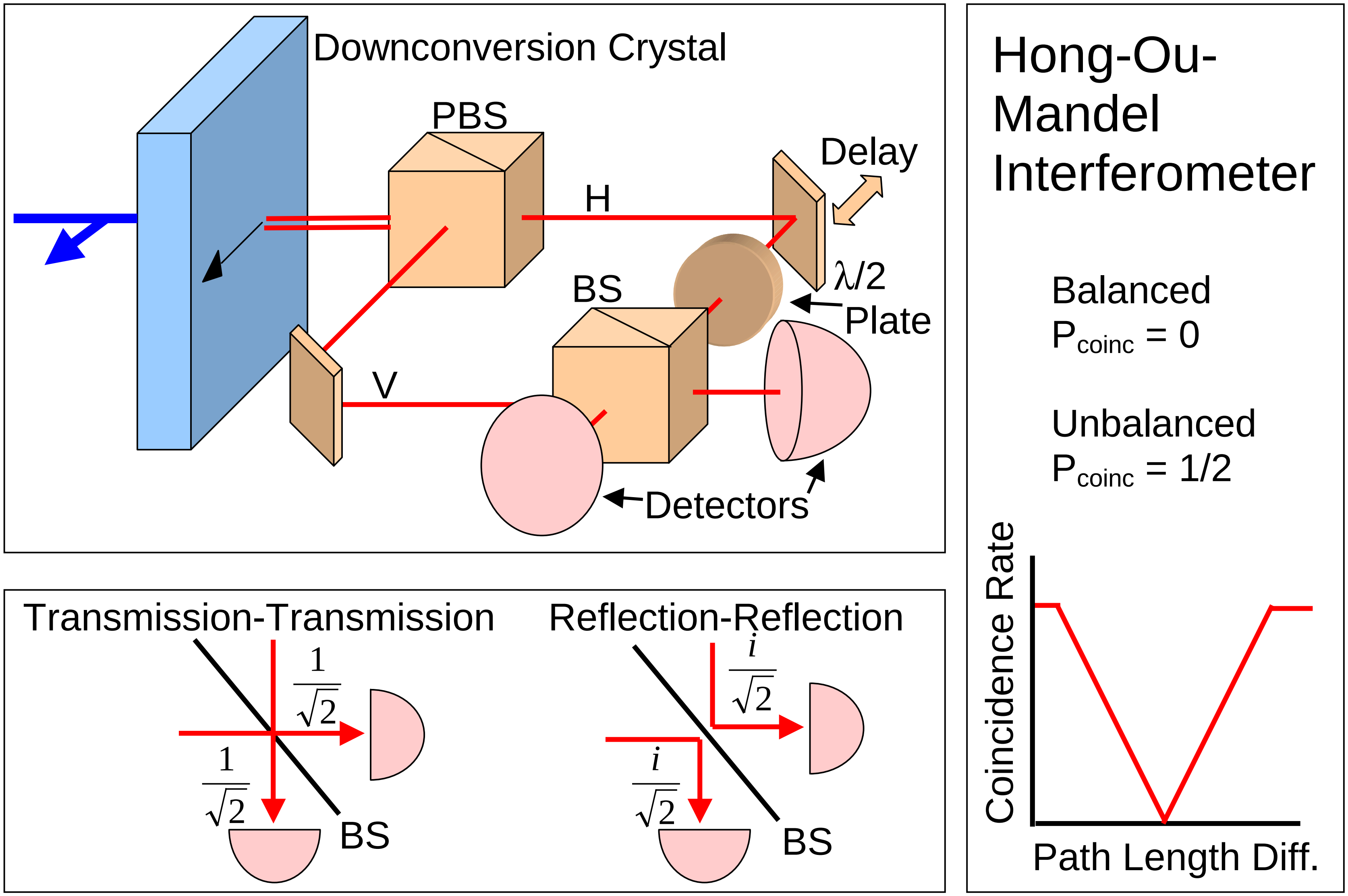
$k_{PUMP} = k_H + k_V$

..as well as energy

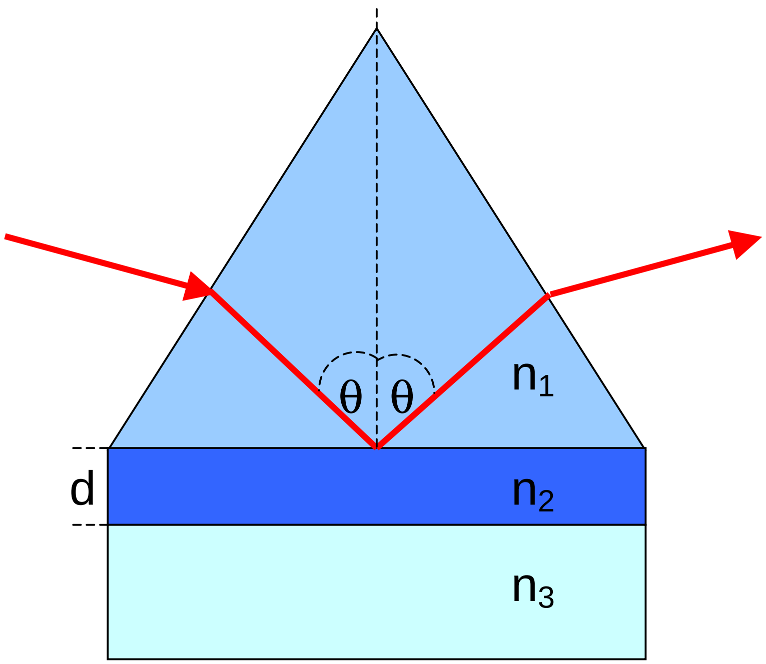


$\omega_{PUMP} = \omega_H + \omega_V$

- The downconverted photons have a coherence length of GVM x L (≈14fs).
- This provides us with our timing mechanism.


Downconversion Crystal
PBS
Delay
H
λ/2
Plate
BS
V
Detectors
Hong-Ou-Mandel Interferometer
Balanced
$P_{coinc} = 0$
Unbalanced
$P_{coinc} = 1/2$
Coincidence Rate
Path Length Diff.
Transmission-Transmission
$\frac{1}{\sqrt{2}}$
$\frac{1}{\sqrt{2}}$
BS
Reflection-Reflection
$\frac{i}{\sqrt{2}}$
$\frac{i}{\sqrt{2}}$
BS

Frustrated Gires-Tournois Interferometer



- When

  $n_1 > n_3 > n_2$ and

  $\theta > \theta_{13} = \sin^{-1}(n_3/n_1)$,

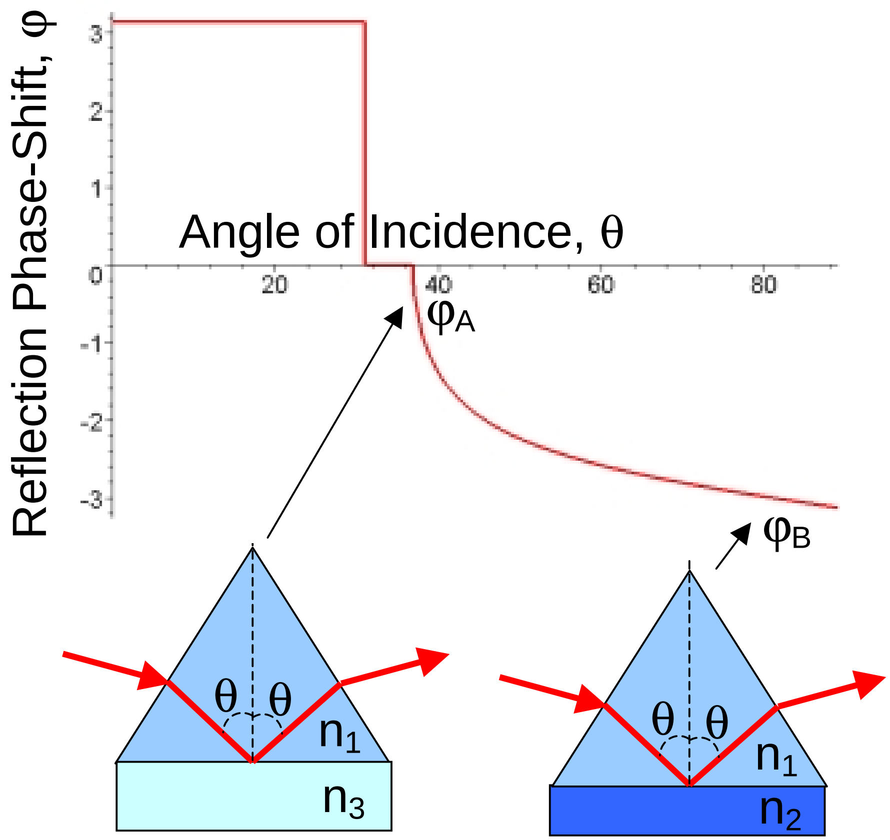
  where θ_{13} is the critical angle, the reflection time is negative.

- The light undergoes total internal reflection since $\theta > \theta_{13} > \theta_{12}$ and the reflection probability is 100%.

- The minimum negative reflection time is one optical period.

  $t_{GTmin} = -1/\omega$

Heuristic Motivation



Case A: d<<λ

Case B: d>>λ

$\theta > \theta_{13} > \theta_{12}$

$\therefore \ \varphi_A > \varphi_B$

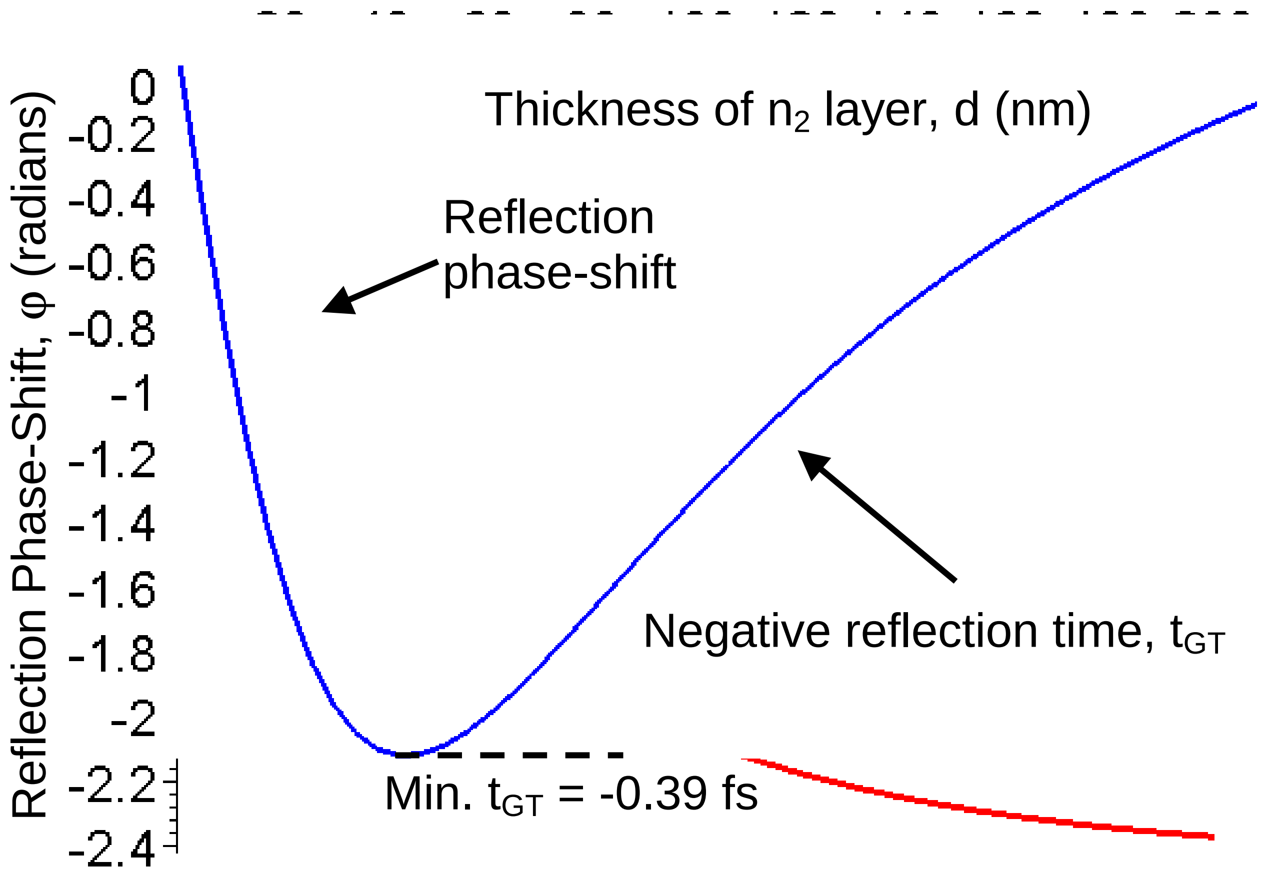
As d increases, φ decreases.

$$\frac{\partial \varphi}{\partial \omega} = t_{GT}$$ is the delay.

Since d is the only inherent scale in the system to compare λ with, a derivative with respect to ω is equivalent to one with respect to d.

∴ The reflection time is negative.

Reflection Phase-Shift From GT Interferometer



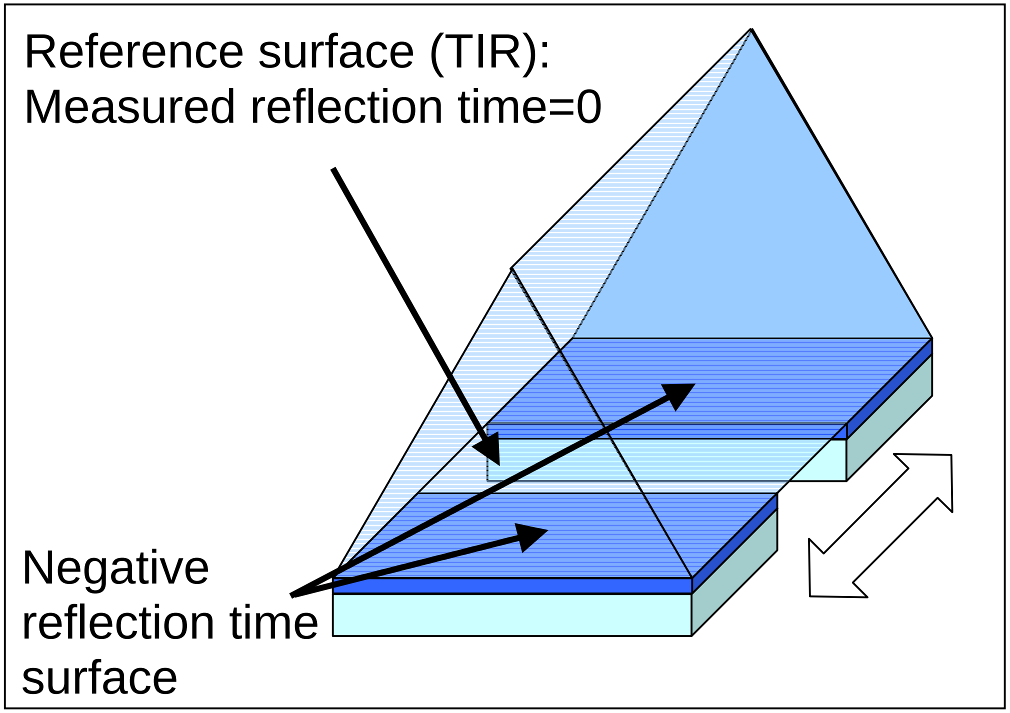
System Specifications

n_1 = 1.7112 (SF10)
n_2 = 1.38 (MgFl)
n_3 = 1.64

$\theta_{13} = \sin^{-1}(n_3/n_1) = 73.4°$
$\theta_{12} = 53.8°$

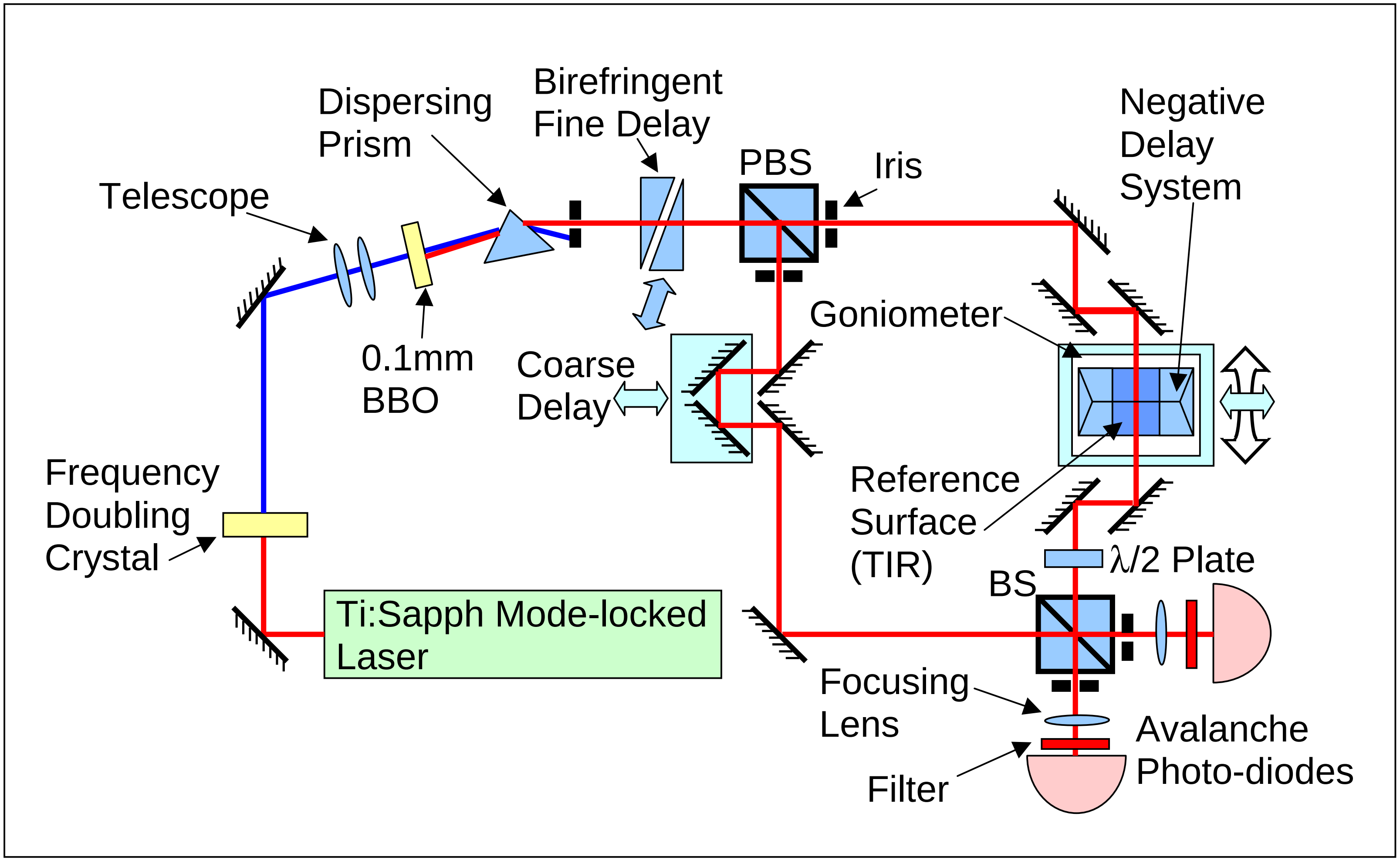
d= 46 nm
The n_3 layer is 5000 nm thick to act as a bulk medium.

Min t_{GT} = -.39 fs



For each point in the coincidence dip, a measurement will be made of the reflection time for each section of the prism base.

Experimental Setup

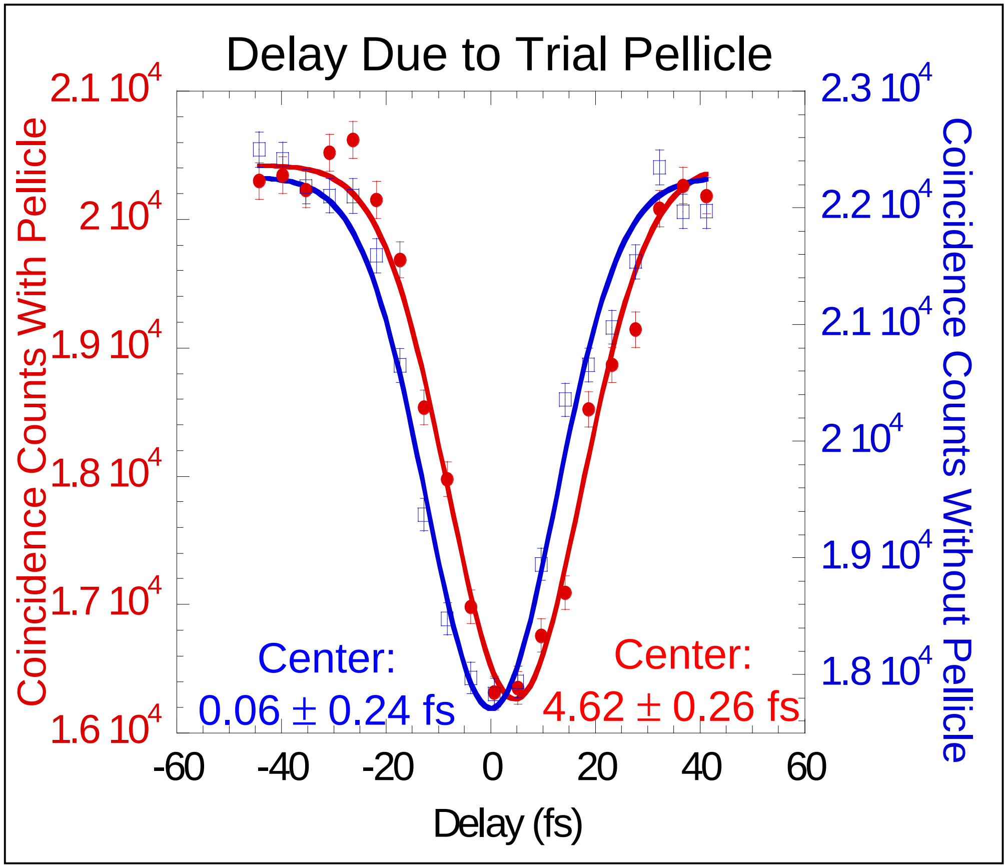


Method of Reflection Time Measurement

The shift in the center of the coincidence dip gives the group-delay of the reflected light.

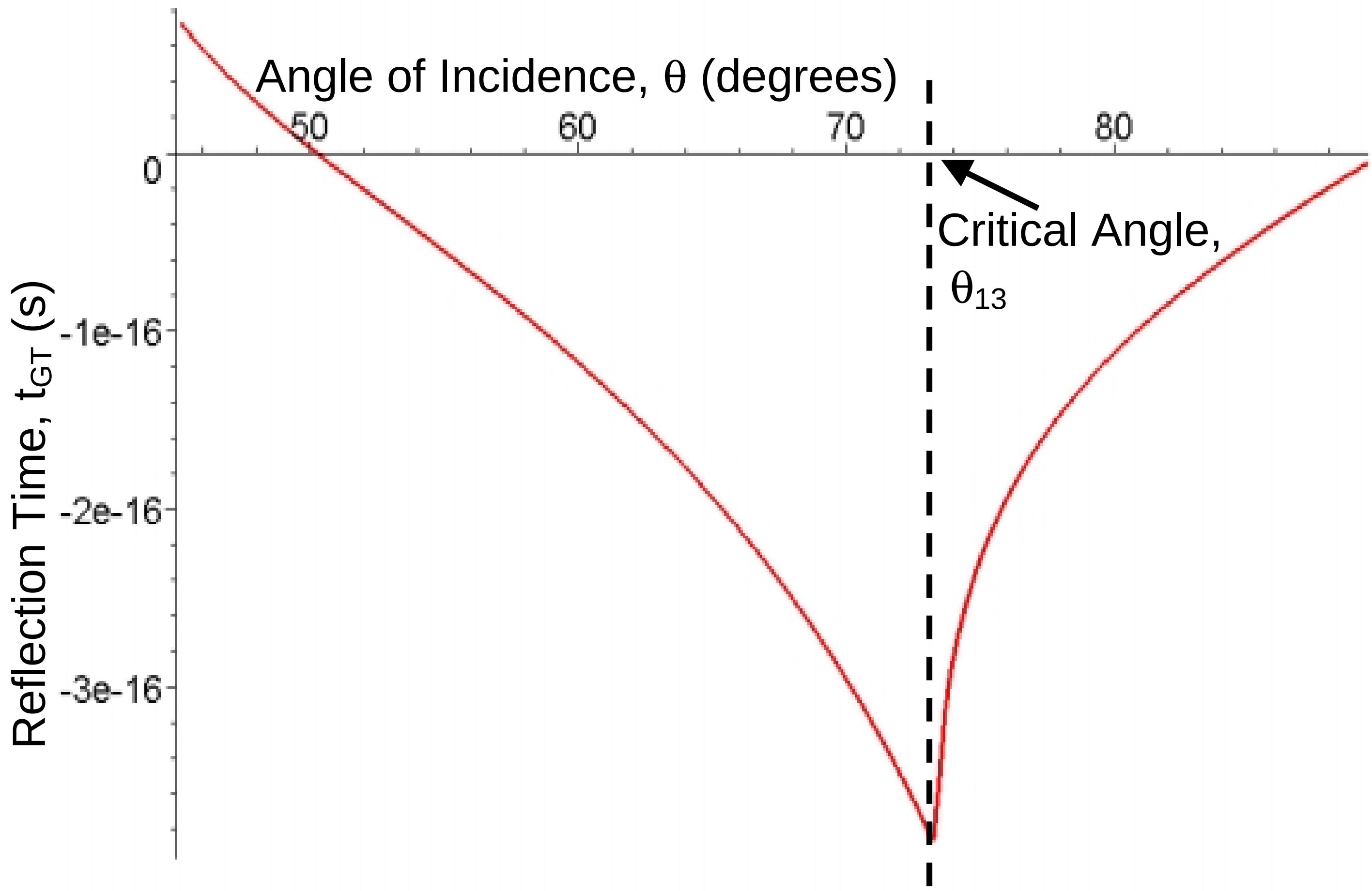
The HOM Interferometer is advantageous because:

- It measures the group-delay not the phase-delay of light.
- It has sub-femtosecond time resolution.
- The effect of first-order dispersion is absent.

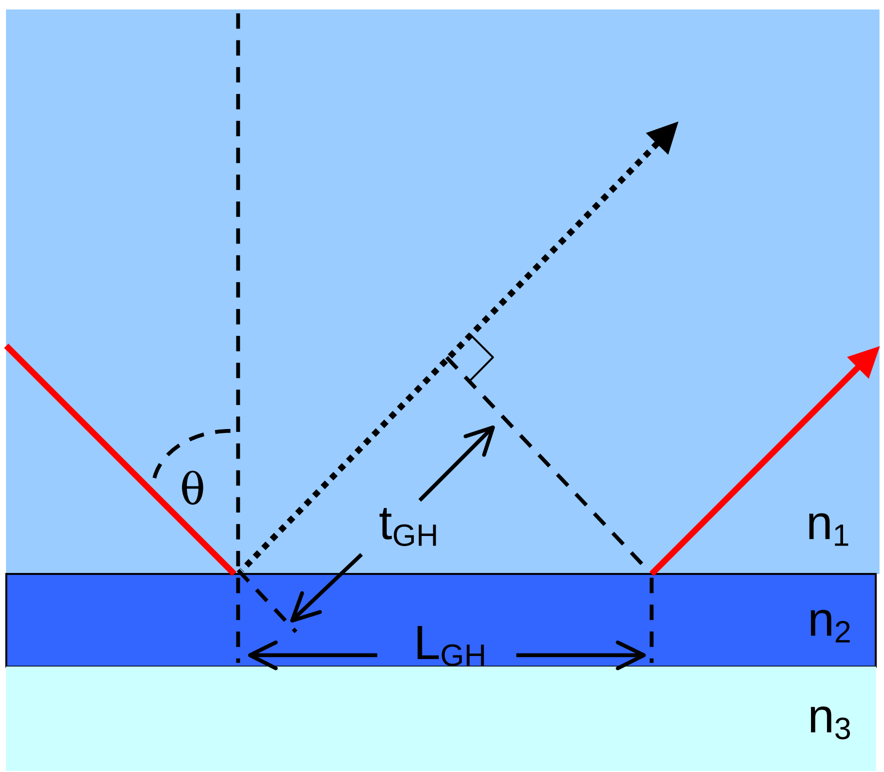


Expected Reflection Time vs. Angle of Incidence

For Stated System Specifications



Theoretical Implications of the Goos-Hänchen Shift



In total internal reflection, the reflected pulse is laterally shifted along the surface by L_{GH}.

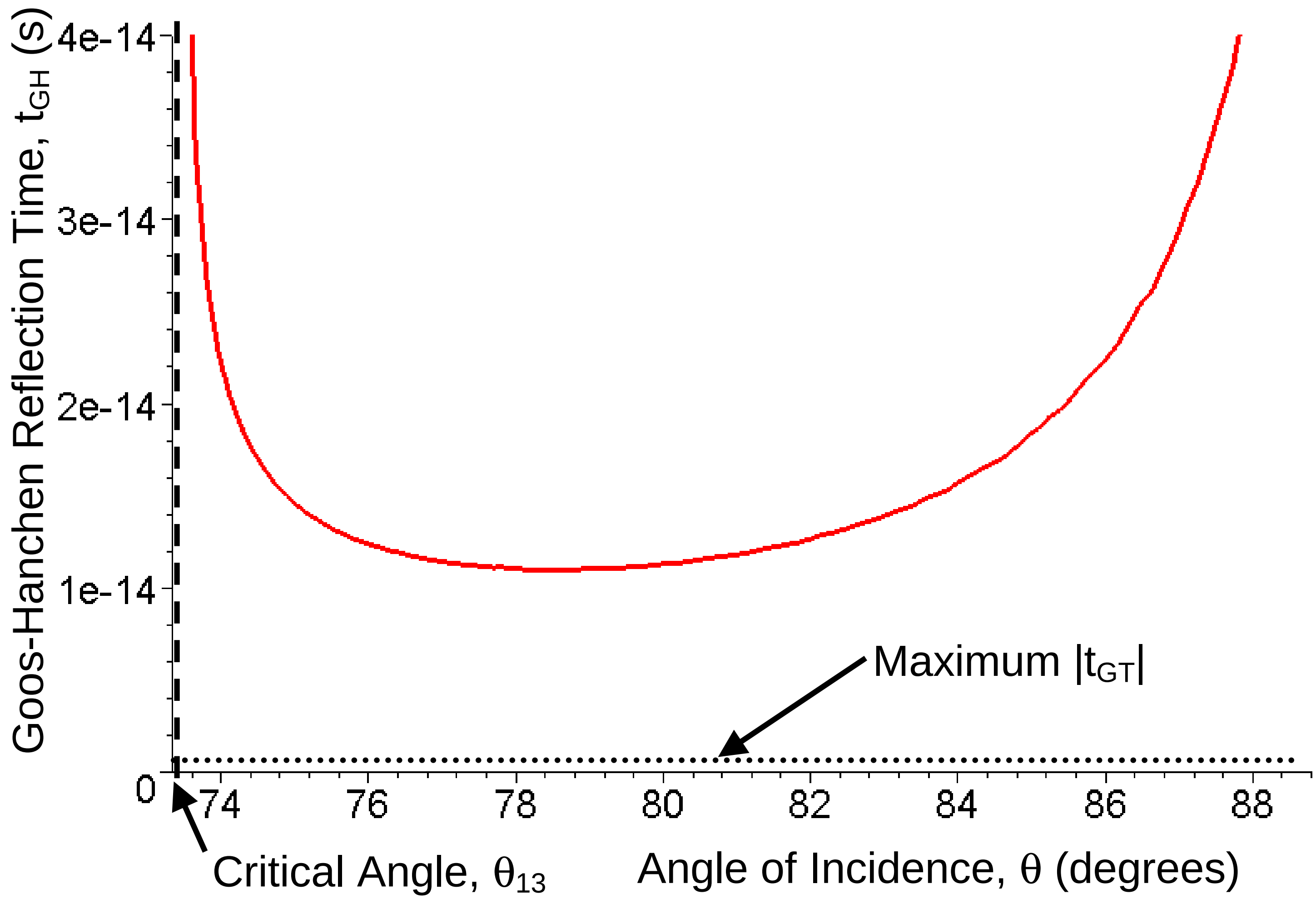
Associated with this shift is a time delay:

$$t_{GH} = n_1 L_{GH} \sin\theta / c$$

The delay is such that an unshifted pulse would be aligned with the shifted pulse.

∴ Due to geometrical considerations, the Hong-Ou Mandel Interferometer does not measure t_{GH}.

Goos-Hanchen Reflection Delay vs. Angle



Summary

- We have constructed a polarization based Hong-Ou-Mandel Interferometer.
- The shift in the coincidence dip will allow us to measure the group-delay upon reflection.
- The interferometer has a preliminary resolution of 0.3 fs.
- Causality is saved by the Goos-Hanchen delay time, which causes the total reflection time to be positive.
- However, we will measure a minimum delay of –0.39 fs because the interferometer is insensitive to the Goos-Hanchen delay time.

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