Faster than Light?
Comment on the Experiment of Nimtz and Stahlhofen

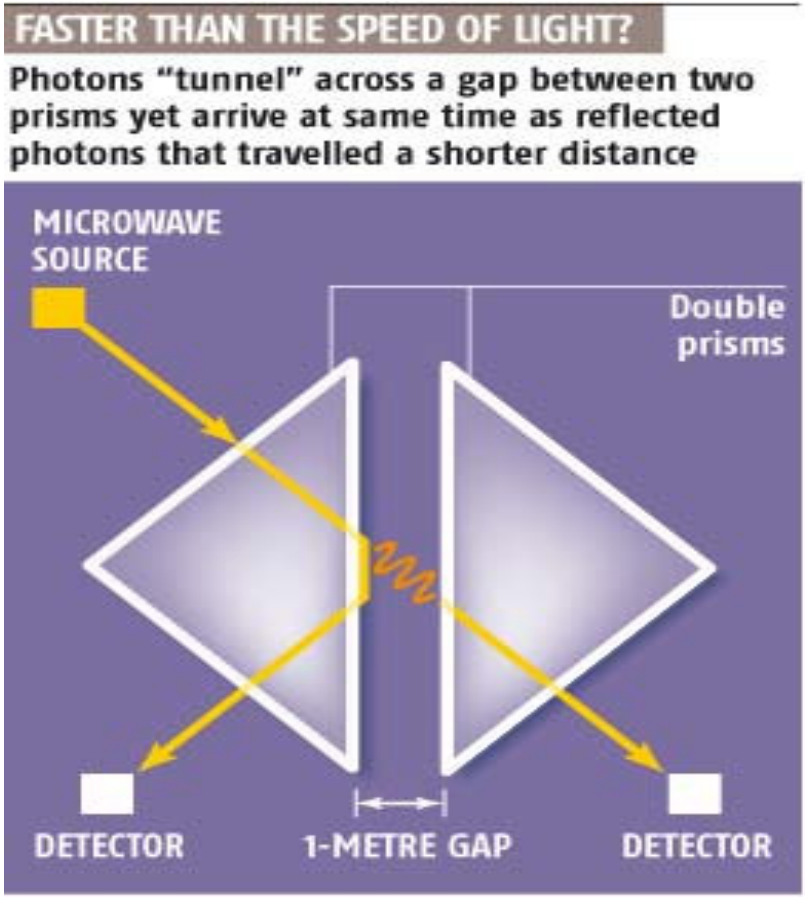
Herbert G. Winful

EECS Dept., University of Michigan

www.sitemaker.umich.edu/herbert.winful

NewScientist

"Photons challenge the light barrier;
A quantum tunnelling experiment has apparently propelled photons faster than the speed of light"
(August, 18, 2007)

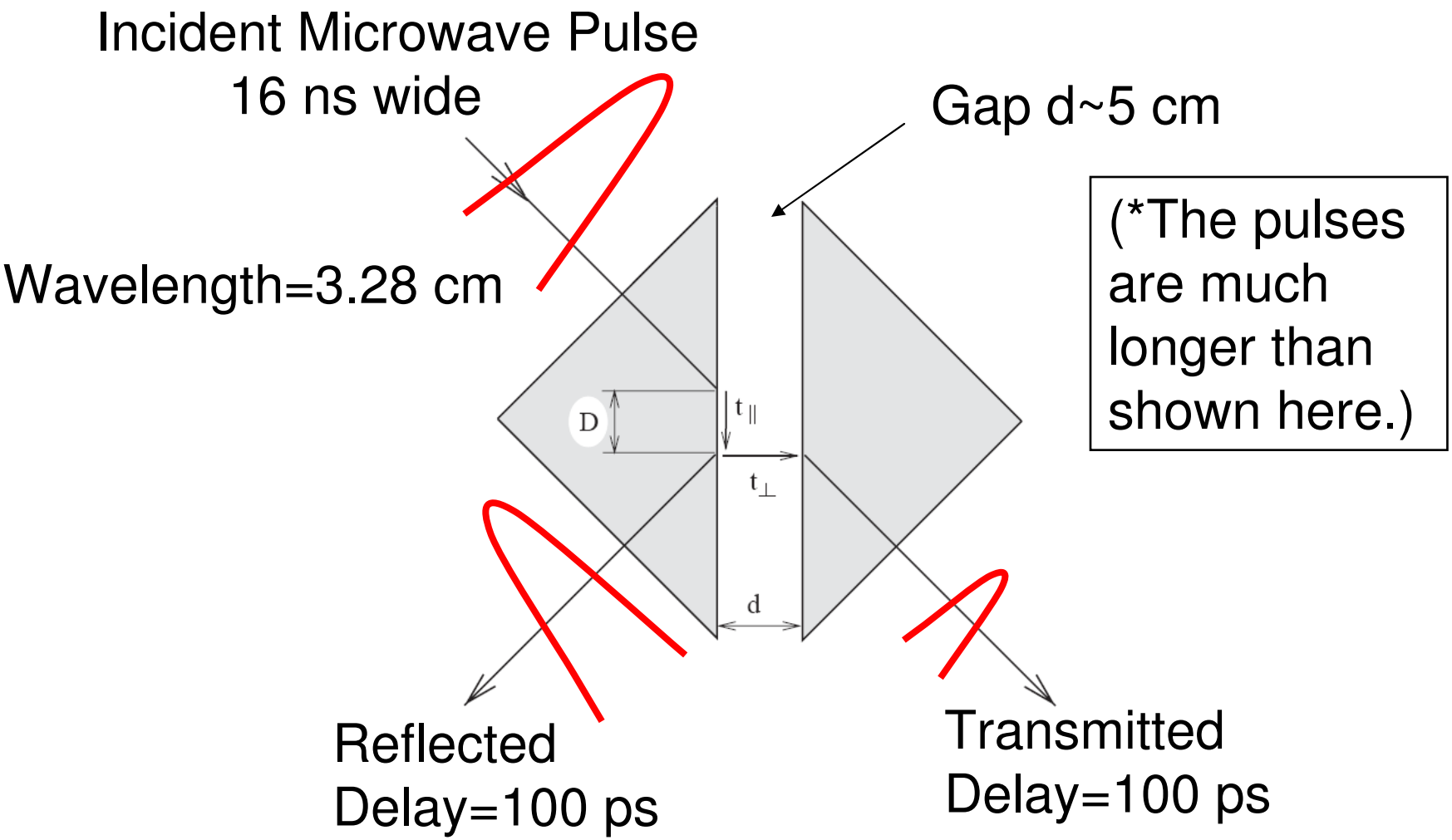


"Nimtz and Stahlhofen said the reflected photons and the tunneled photons both arrived at their respective photodetectors at the same time, leading them to conclude that some of the microwaves traveled faster than the speed of light. They also found that the tunneling time didn't change on a distance of up to three feet."

So What's Really Going on?

- Here I show that Nimtz and Stahlhofen have simply measured the decay time of stored energy in the cavity formed by the prisms.
- Nothing traveled faster than the speed of light in vacuum.
- No violation of relativity since the experiment is described by the fully relativistic Maxwell equations.

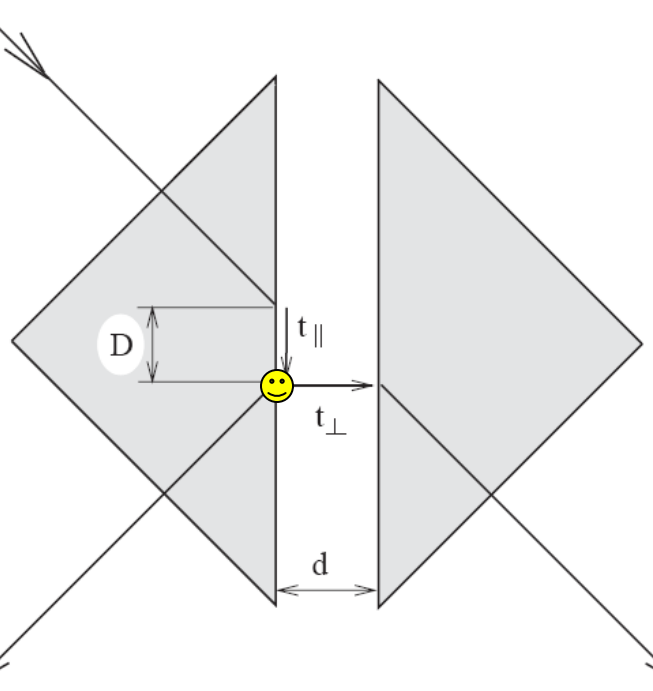
The Experiment



The Assumptions

Incident Microwave Pulse

Common assumption: photons are localized objects following definite paths.



"The paths of the reflected and transmitted beams are equal except that the transmitted one has in addition crossed the evanescent region of length d." (Nimtz)

Reflected

Transmitted

- The notion of localized particles following definite paths is deeply flawed.
- Upon reflection at the interface, the transmitted evanescent wave spreads to fill the gap: its energy is distributed throughout the gap, decreasing exponentially with distance.

What Nimtz and Stahlhofen actually measured

(1) Transmission group delay = 100 ps

The transmission group delay is the time at which the transmitted field reaches a maximum, given that the incident field reached a maximum at t=0.

(2) Reflection group delay = 100 ps

The reflection group delay is the time at which the reflected field reaches a maximum, given that the incident field reached a maximum at t=0.

(3) Group delay versus gap width (reported in New Scientist)

It was found that the group delay becomes independent of gap width d.

What Nimtz and Stahlhofen inferred

Because the reflection and transmission group delays are equal, the authors infer that the transmitted (tunneled) pulse traveled faster than the speed of light *c.*
According to Nimtz: “The barrier is crossed in zero time.”

A closer look at the experiment

Wavelength = 3.28 cm Group delay = 100 ps

Spatial length of delay = *c* x 100 ps = 3 cm

Note: The delay is less than a wavelength!

Pulse width $\tau_p = 16$ ns Group delay = 100 ps

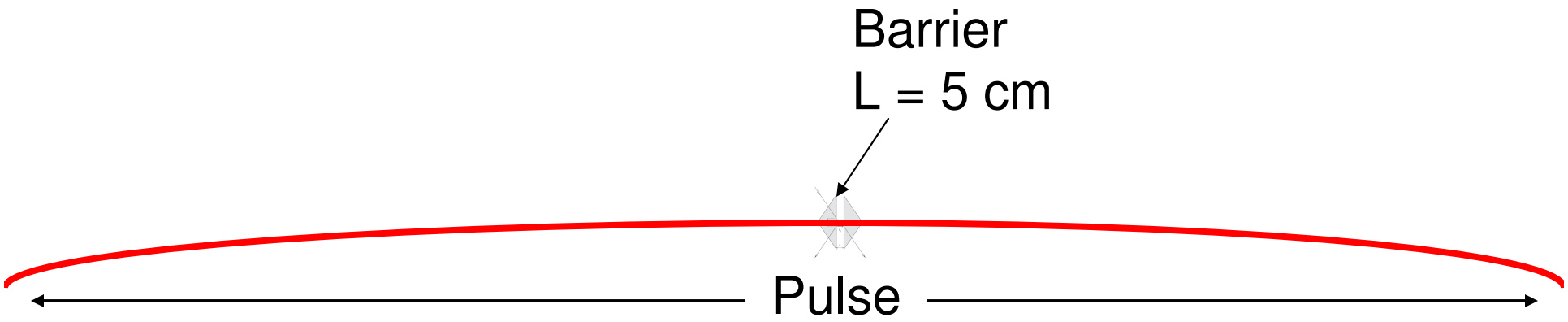
Note: The delay is two orders of magnitude less than pulse width!

Air gap length = 50 mm

Pulse length = *c* x 16 ns = 4.8 m

Note: The pulse is two orders of magnitude longer than the gap!

Pulse length>>Barrier length>Delay

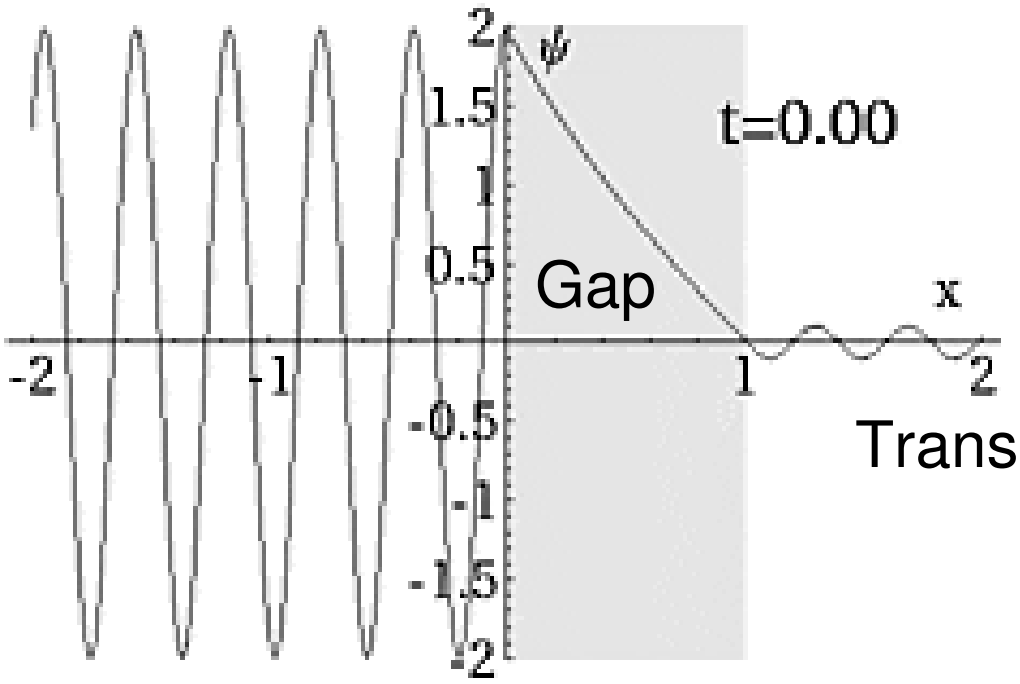


$c\tau_p = 4.8$ m

Delay = 3 cm = 0.6% of pulse length!

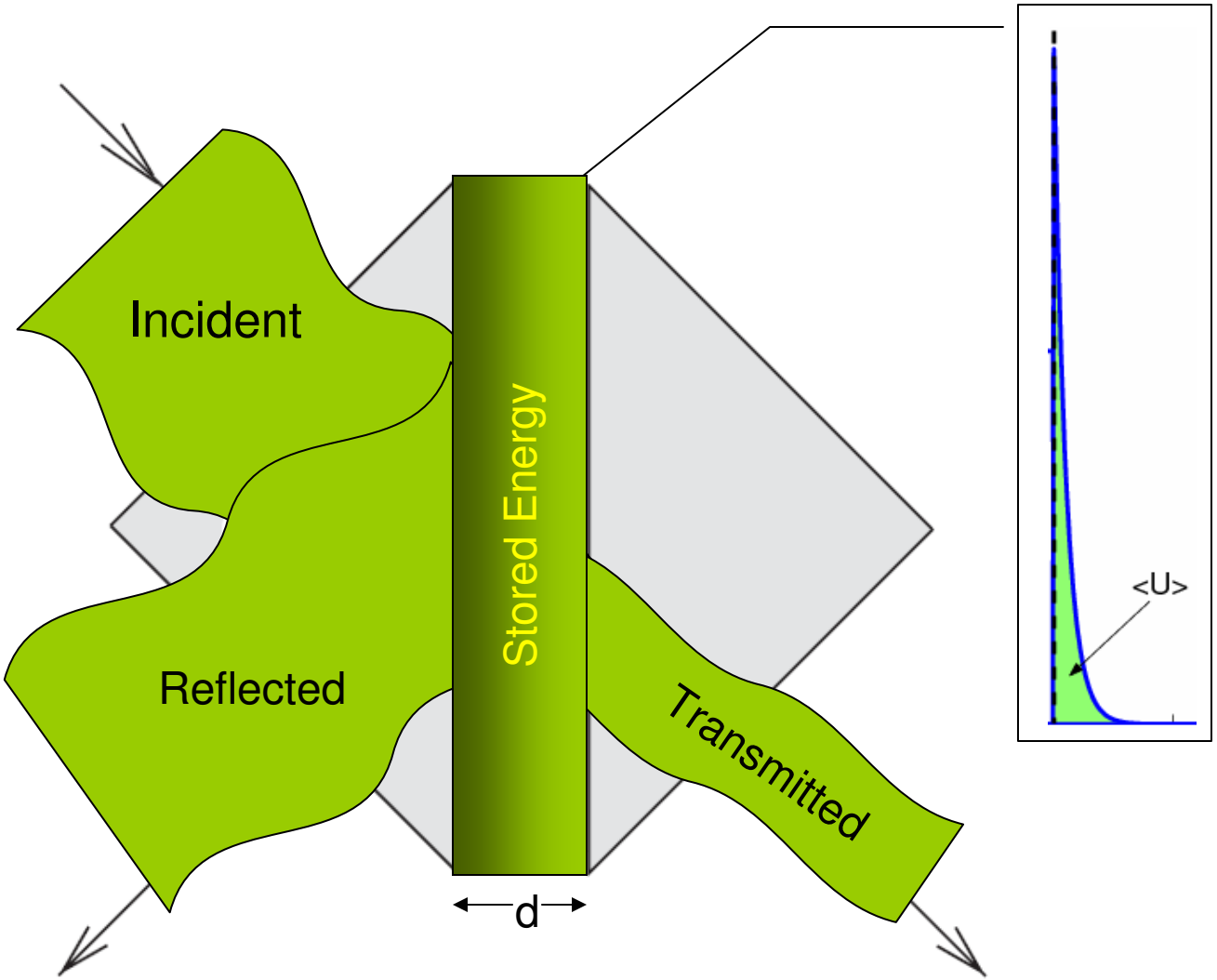
Tunneling: the movie

Incident
+
Reflected



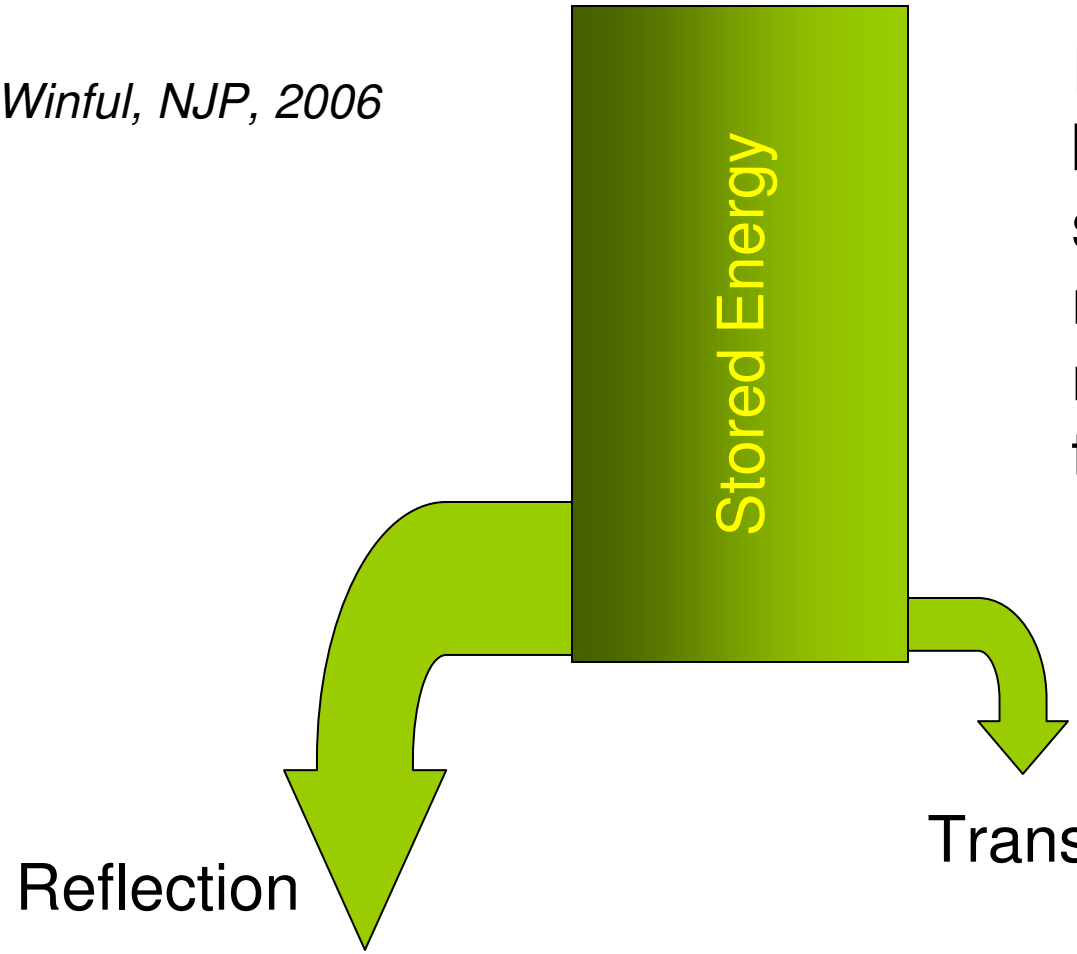
Transmitted

Stored energy in cavity (tank)



Group delay = time to empty tank from both sides simultaneously

H.G. Winful, NJP, 2006



For symmetric barrier delay is the same whether monitored on reflection or transmission side

My interpretation of the Nimtz-Stahlhofen experiment

1. The prisms and the gap between them form an electromagnetic cavity that stores energy.

2. The stored energy in the cavity has a finite lifetime since it can leak through the transmission and reflection channels.

3. The measured group delay (100 ps) is the lifetime of the stored energy. Nothing is traveling faster than light.

4. The equality of transmission and reflection group delays is what one expects for energy leaking out of both ends of a symmetric cavity.

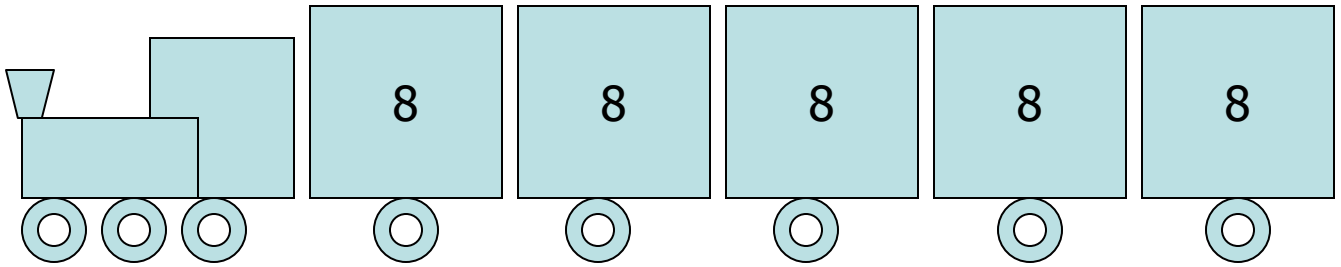
5. The saturation of the group delay with gap length (Hartman effect) is due to the saturation of stored energy with gap length. Since the group delay is proportional to the stored energy, it saturates with gap length in the same manner.
   (*H.G. Winful, Optics Express, 2002; PRL 2003*)

Important Points

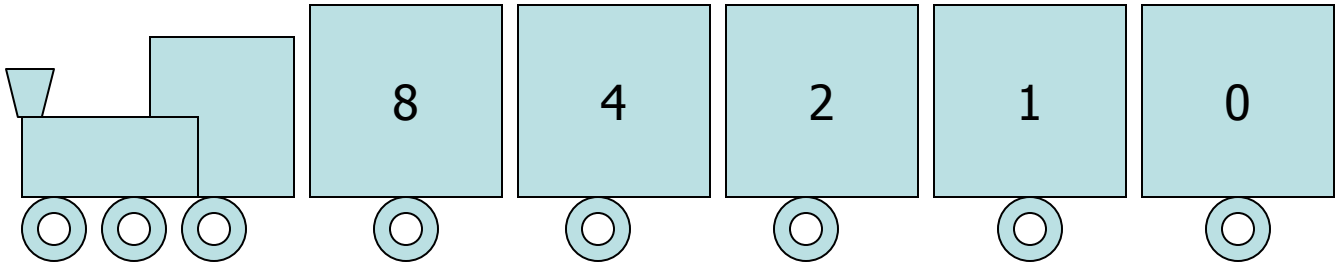
1. Because the pulse length is orders of magnitude greater than the gap length d, the interaction with the structure is quasi-static.
2. The measured group delay is the lifetime of the stored energy leaking out at both ends. It is not a transit time and hence cannot be related to “group velocity”. Indeed group velocity is a meaningless concept here since the pulse is orders of magnitude longer than the barrier and cannot be localized within it.

Train analogy: group delay= time it takes to empty the train

Consider two trains of the same length.



Air Train has
40 passengers

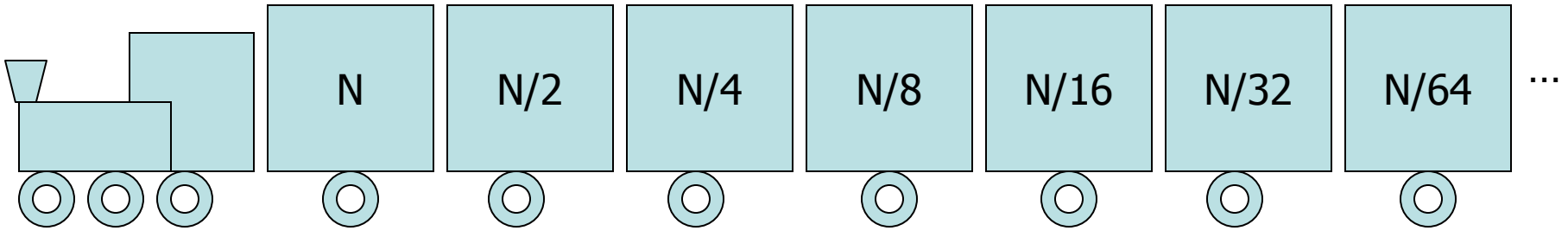


Barrier Train has
15 passengers

If the time needed to empty a train is proportional to the number of passengers, which train will empty out first? Clearly, the Barrier Train with fewer passengers.

The Train Analogy to the Hartman Effect

Suppose that each car carries half the number in the previous car.



No matter how long we make the train the maximum number of people it can carry is 2N.

The delay time is the time it takes for the people in the train to exit. It is proportional to the total number of passengers on the train.

If the number of passengers becomes independent of the train length the the delay time also becomes independent of the length of the train!