# Relativity — Lecture 4

- Summary of Lecture 3
- Galilean Transformations
- Lorentz Transformations
- Observers
- Cosmic muons

22/11/2007

Imperial College London

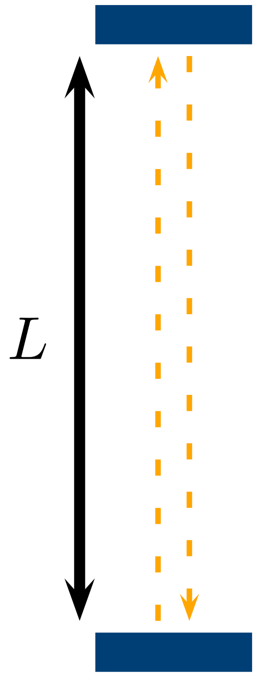
100 years of living science

Patrick Koppenburg

# Lecture 3

# Revision

# Clock

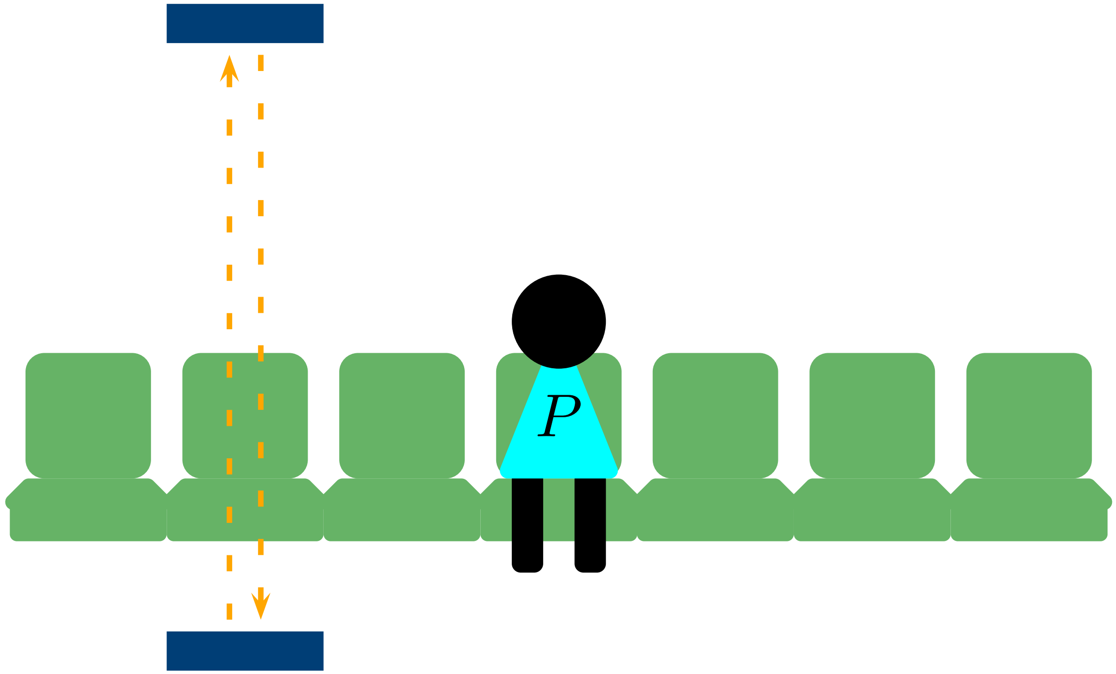



A clock at rest measures the “proper” time interval between two events:

1. The emission of the pulse from the base
2. The detection of pulse at the base

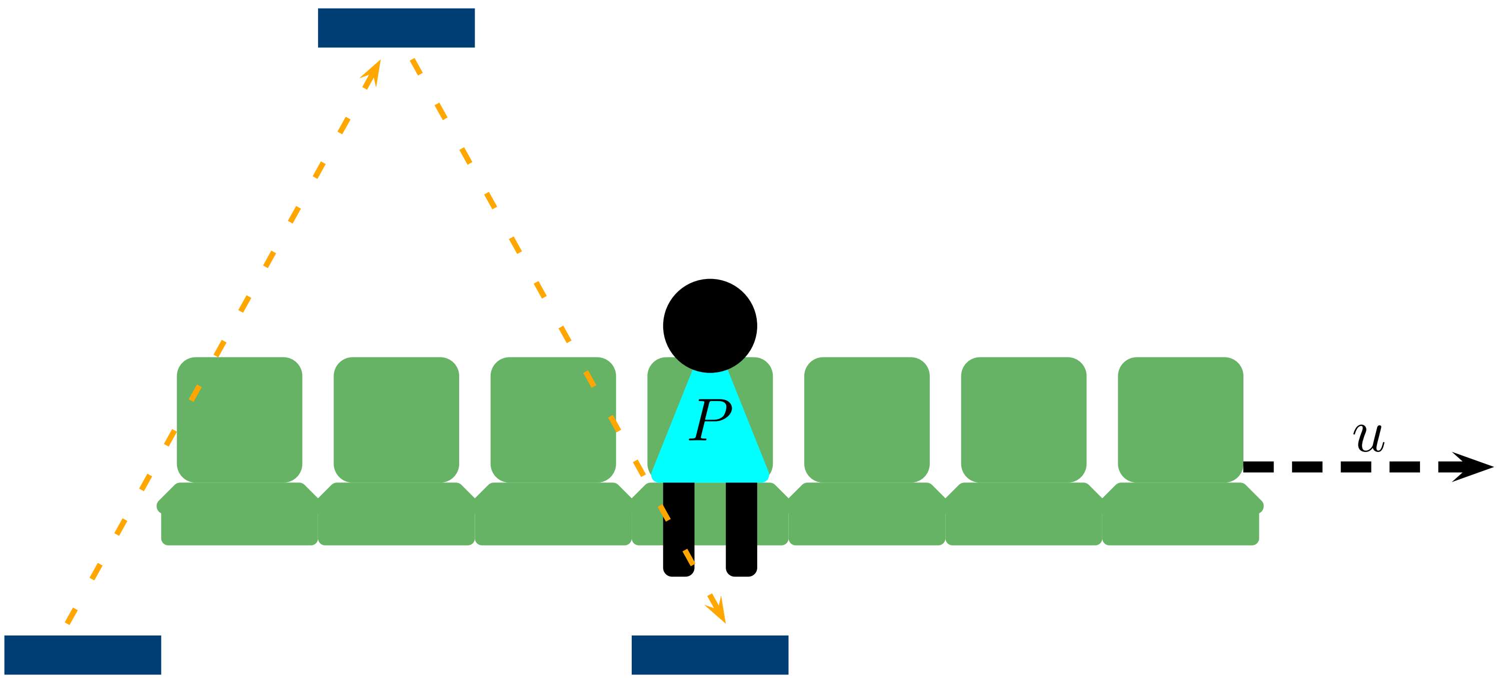
Both events happen at the *same* position in the frame of the clock.

# Clock on a Train




$$t' = \frac{2L}{c}$$

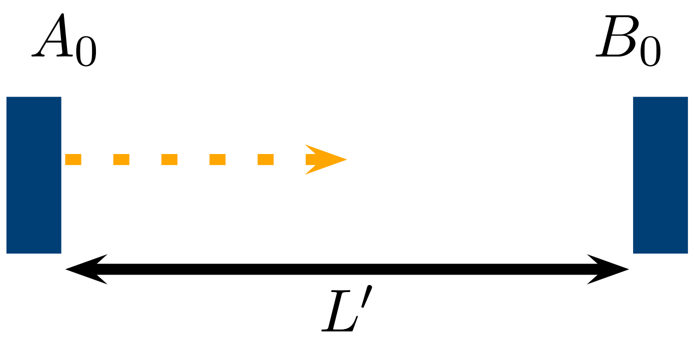
# Clock on a Train




$$t' = \frac{2L}{c}$$

$$\begin{aligned} c^2t^2 &= u^2t^2 + (2L)^2 \\ t^2(c^2 - u^2) &= 4L^2 \\ \Rightarrow \quad t &= \frac{2L}{c}\frac{1}{\sqrt{1-\frac{u^2}{c^2}}} > t' \end{aligned}$$

# Moving Clock



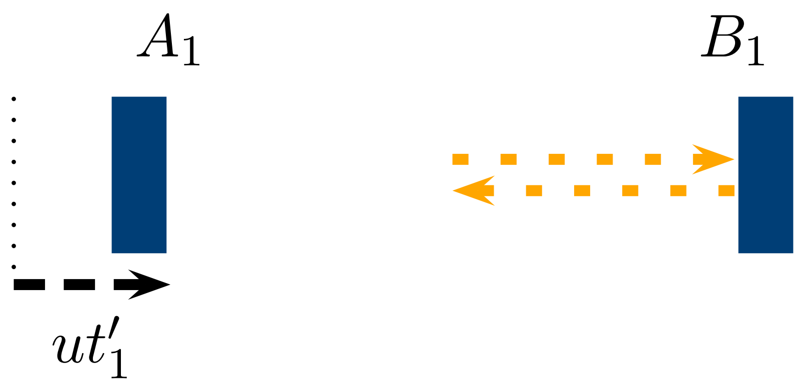

$\boldsymbol{t' = 0}$**:** The ray starts its journey from $A_0$

$$A_0B_1 = L' + ut_1' = ct_1' \rightarrow t_1' = \frac{L'}{c-u}$$

$$B_1A_2 = L' - ut_2' = ct_2' \rightarrow t_2' = \frac{L'}{c+u}$$

$$t' = t_1' + t_2' = \frac{2L'}{c\left(1-\frac{u^2}{c^2}\right)} \rightarrow L' = L\sqrt{1-\frac{u^2}{c^2}} = \frac{L}{\gamma}$$

# Moving Clock




$t' = 0$: The ray starts its journey from $A_0$

$t' = t'_1$: The ray reflects at $B_1$ at $L + ut'$

$$A_0B_1 = L' + ut'_1 = ct'_1 \rightarrow t'_1 = \frac{L'}{c-u}$$

$$B_1A_2 = L' - ut'_2 = ct'_2 \rightarrow t'_2 = \frac{L'}{c+u}$$

$$t' = t'_1 + t'_2 = \frac{2L'}{c\left(1-\frac{u^2}{c^2}\right)} \rightarrow L' = L\sqrt{1-\frac{u^2}{c^2}} = \frac{L}{\gamma}$$

# Moving Clock


- $\boldsymbol{t' = 0}$: The ray starts its journey from $A_0$
- $\boldsymbol{t' = t'_1}$: The ray reflects at $B_1$ at $L + ut'$
- $\boldsymbol{t' = t'_2}$: The ray arrives back at $A_2$ at $ut'_2$

$$A_0 B_1 = L' + ut'_1 = ct'_1 \rightarrow t'_1 = \frac{L'}{c-u}$$

$$B_1 A_2 = L' - ut'_2 = ct'_2 \rightarrow t'_2 = \frac{L'}{c+u}$$

$$t' = t'_1 + t'_2 = \frac{2L'}{c\left(1 - \frac{u^2}{c^2}\right)} \rightarrow L' = L\sqrt{1 - \frac{u^2}{c^2}} = \frac{L}{\gamma}$$

# Summary

**Length contraction:**

**The measured length of a body is *greater* in its rest frame than any other frame.**

**Time dilation:**

**The measured time difference between the events represented by two readings of a given clock is *less* in the rest frame of the clock than in any other frame.**

A body appears to be contracted, and time appears dilated, when seen from *another* frame.

# Definitions

**An *event* is a point in space and time. It has a defined position and time.**

**A physical quantity is *invariant* if it does not depend on the reference frame.**

Examples: $c$, $m$, $q$ . . .

**An equation is *covariant* if it holds in any reference frame.**

Examples: momentum, energy conservation

# Definitions

$$\beta = \frac{u}{c}, \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

# Lecture 4

# A Bad Observer

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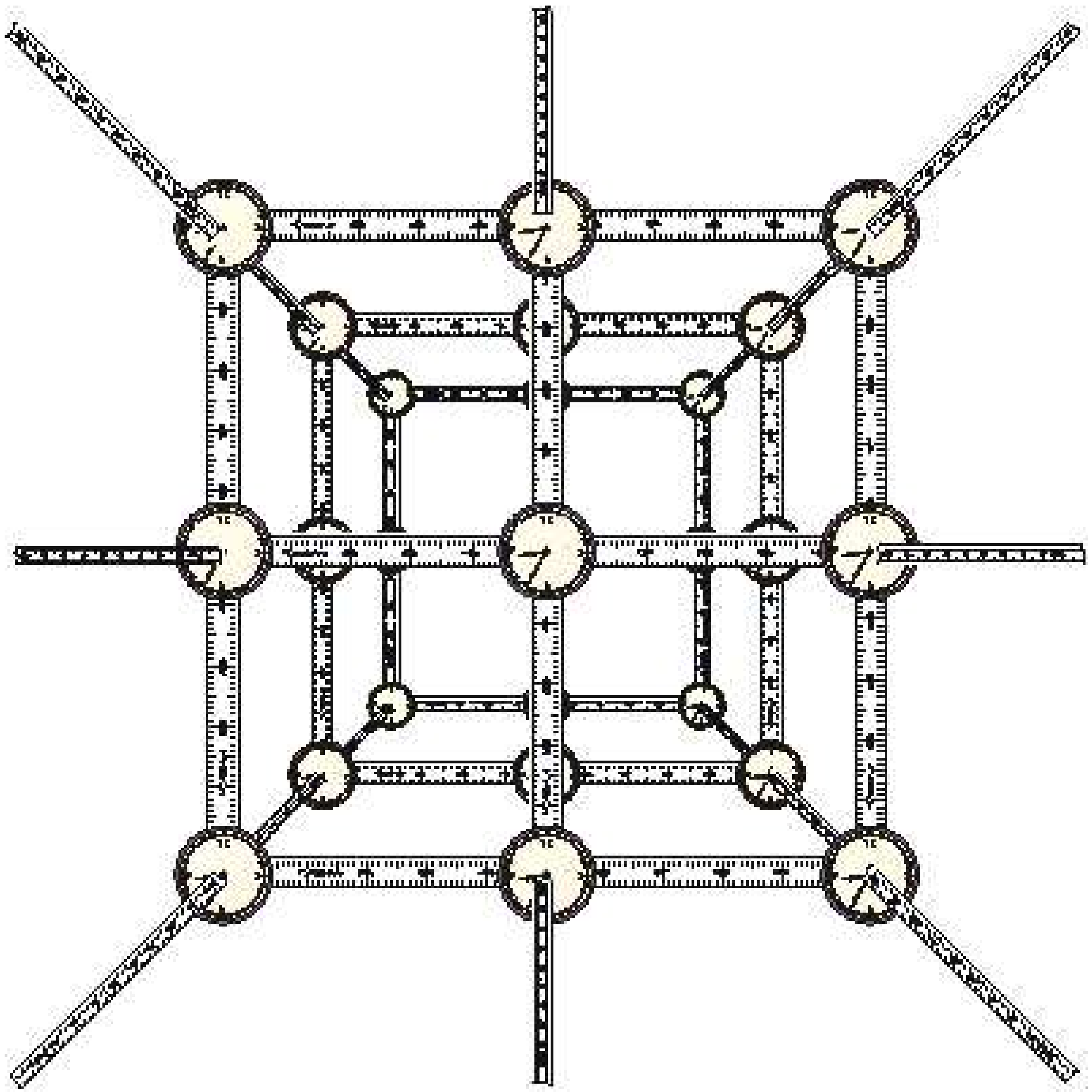
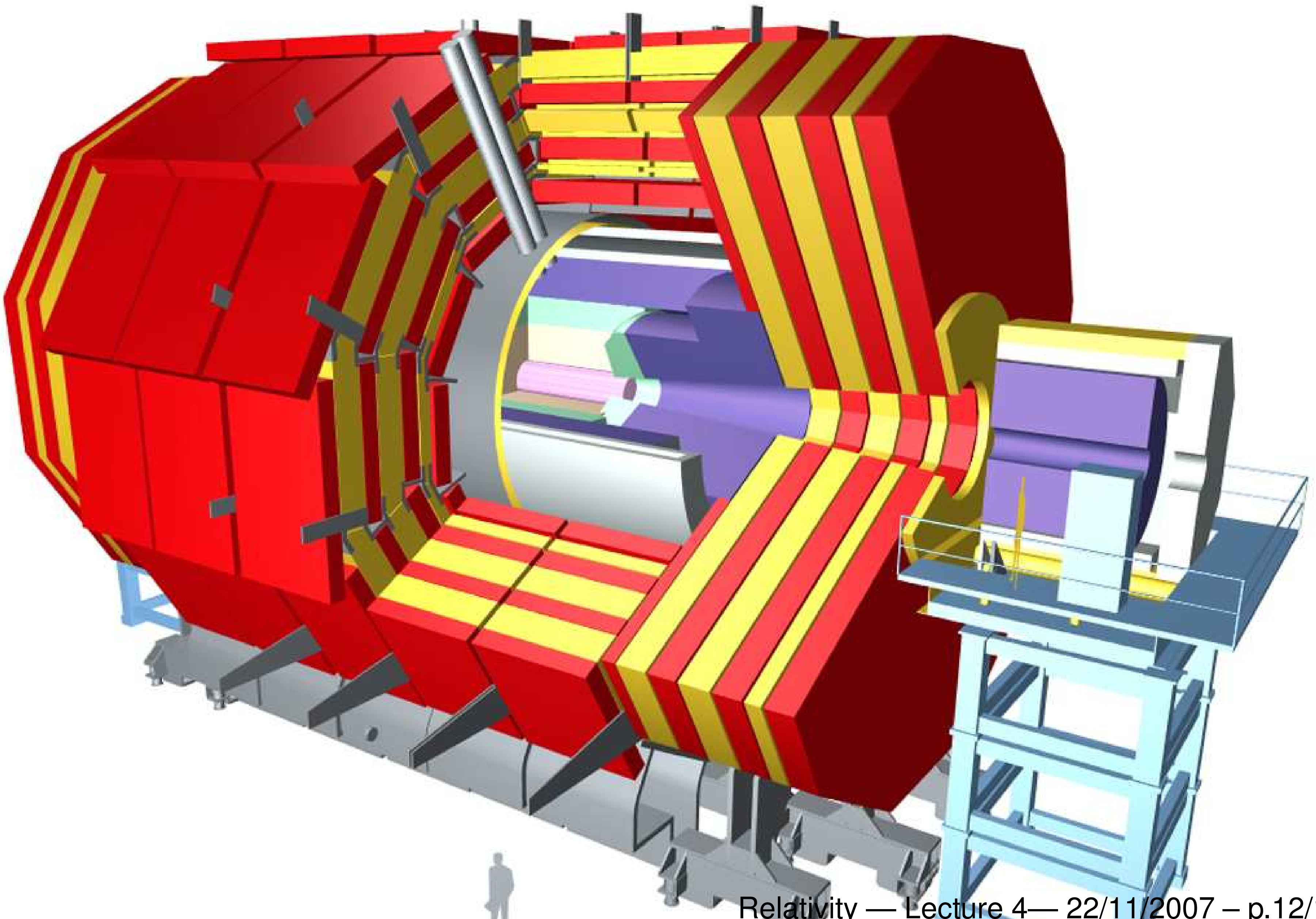
London

# A Good Observer



# The CMS Detector at CERN



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