# PHY492: Nuclear & Particle Physics

## Lecture 1

Forces

Relativistic kinematics

# Extended class time

- My research in High Energy Physics makes it necessary for me to travel often
- I would like to eliminate the Friday class to allow this travel
- I don't want to short change you
- I would like class time to be MW 9:00 - 10:10
- If this means you must arrive late or leave early, just sit near a door to cause the least amount of disturbance.
- The first 10 minutes of class is usually a review. Elimination of one class day per week saves 10 minutes/week

# Syllabus

**Syllabus for PHY492, Spring 2007**

Lecturer: Prof. Carl Bromberg; E-mail: bromberg@pa.msu.edu; Office: Rm. 3225 BPS;
Phone:5-9200 Ext. 2122; Office hrs: Mon. & Wed.,10:30-12:30, or by appointment.

TA: Yixing Wang E-mail: wangyix@pa.msu.edu; Phone: 59200, ext.2080.
See Yixing for grading issues. Disagreements will be forwarded to me ONLY by Yixing

Lectures:

- Mon. and Wed., 9:00 - 10:10 pm, in room 1415 BPS (see Course Schedule).
- Optional Seminar: bi-weekly, based on 5 lectures in streaming video by L. Lyons.

Required Textbooks:

- 1)"Introduction to Nuclear and Particle Physics" (2nd Edition), A. Das and T. Ferbel, World Scientific Pub., 2003, ISBN 981-238-744-7 (pbk)
  2)"Facts and Mysteries in Elementary Particle Physics", M. Veltman, World Scientific Pub., 2003, ISBN 981-238-149-X (pbk)

Optional Text:

- "Statistics for Nuclear and Particle Physicists", Louis Lyons, Cambridge University Press, 1989, ISBN 0 521 37934 2 (pbk)

Course Topics:

- Course covers the topics shown in the **Course Schedule** (on the next page).
- Lectures may not cover all topics presented in the **Reading Assignments**. All topics, in the assigned reading or presented in lecture may appear on an exam.
- Lectures on Mon. and Wed. will be posted on the Course Web site by Fri of that week.

Tier II Writing Assignment

- You are required to write an 8-10 page technical paper (referenced) on a subject to be assigned in class on Monday, April 2.
- A 1 page detailed outline or draft of this paper will be due on Monday, April 16. Deadline for submission is May 4, 9:45 am. No exceptions.

Homework (HW) and Exams:

- There will be 7 homework assignments with due dates as indicated in the **Course Schedule**. Homework handed in late will not be graded, but will be logged. All missing homework assignments must be submitted by the last class on April 27.
- Two, **60 minute exams** will be given in class on the dates indicated in the Course Schedule. **Note Below**: Tier II paper is the Final Exam
- Documented medical (or other) excuses for **one** 60 minute exam will be considered on a case by case basis. Resolution may involve an oral exam.

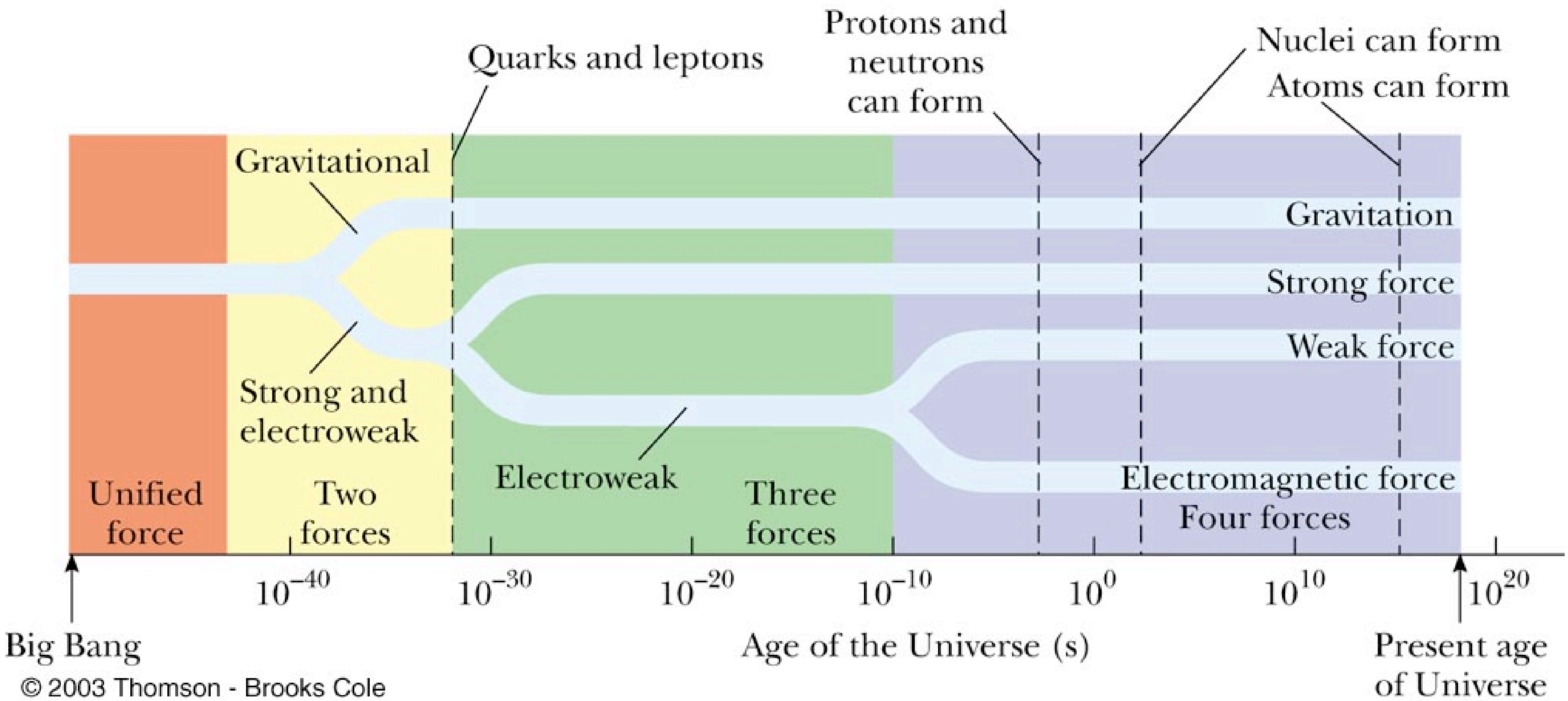
Grades

- HW (~2 points/problem, 100 points), 2 exams (200 points each), Tier II paper (100 points), Straight scale. >400 points will get a 4.0, and cuts are 40 points lower for each 0.5 in grade. If a Tier II paper is not submitted, you will receive a 0 course grade.
- Frequently check the **WEB** site, **http://www.pa.msu.edu/courses/PHY492**, for announcements, HW (hints, corrections) and exam solutions, scores and grades.

Miscellaneous

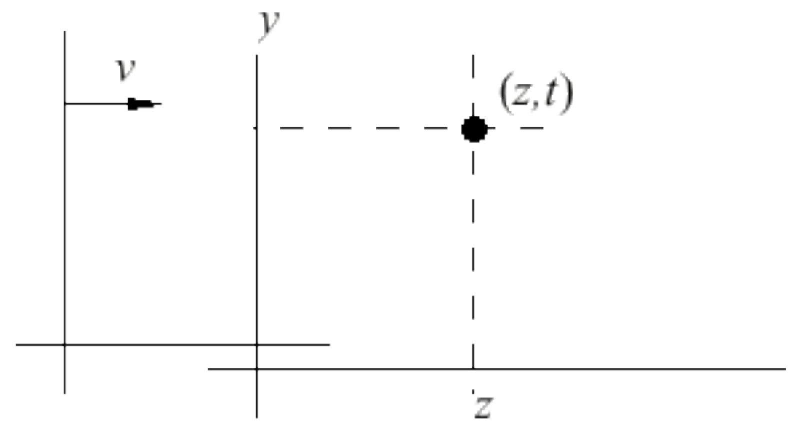
- No HEAD-phones, IPODs, CD-players, CELL-phones, or HATs in class.

# Forces through time



# Special Relativity

Event at position $z$, and time $t$, observed from a frame moving with a velocity $v$ with respect to the original.




## Lorentz Transformations

$$x' = x$$
$$y' = y$$
$$z' = \gamma(z - \beta ct)$$
$$ct' = \gamma(ct - \beta z)$$

$$\beta = \frac{v}{c}$$
$$\gamma = (1-\beta^2)^{-\frac{1}{2}}$$

Choose direction of frame motion as $z$.
Could be motion direction of a particle.

## Lorentz "Invariant" $z^2 - c^2t^2$

$$\begin{aligned} z'^2 - c^2t'^2 &= \gamma^2(z-\beta ct)^2 - \gamma^2(ct - \beta z)^2 \\ &= \gamma^2\left[z^2 - 2\beta ctz + \beta^2c^2t^2 - c^2t^2 + 2\beta ctz - \beta^2 z^2\right] \\ &= \gamma^2(1-\beta^2)(z^2 - c^2t^2) \\ &= (z^2 - c^2t^2) \end{aligned}$$

# Relativistic Kinematics

Particle with mass $m$, and velocity $v$.

particle's beta and gamma
$$\beta = \frac{v}{c}\ ,\ \gamma = \left(1-\beta^2\right)^{-\frac{1}{2}}$$

| | Non-relativistic | Relativistic |
| --- | --- | --- |
| Momentum, $p$ | $mv$ | $\gamma mv$ |
| Energy, $E$ | $\frac{1}{2}mv^2$ or $\frac{p^2}{2m}$ | $\sqrt{p^2c^2+m^2c^4}$ |
| Kinetic Energy, $T$ | " | $E-mc^2$ |

The energy equivalent of the mass ↗ ($E - mc^2$)

In Nuclear Physics, the Kinetic Energy $T$, is nearly always "the energy".
In High Energy Physics, the Total Energy $E$, is nearly always "the energy".

If a particle's Kinetic Energy, $T$, is much less than the energy equivalent of the mass $mc^2$, it is logical to specify $T$, and not $E$ .

# Useful Concepts and Relationships

At low $v$, Relativistic Kinetic Energy --> N.R. Energy

$$T = E - mc^2 = \sqrt{p^2c^2 + m^2c^4} - mc^2$$
$$= mc^2\sqrt{1 + \frac{p^2}{m^2c^2}} - mc^2 \approx mc^2\left(1 + \frac{p^2}{2m\left(mc^2\right)}\right) - mc^2 \ ; \quad pc << mc^2$$
$$= \frac{p^2}{2m}$$

Lorentz Transformations

Frame of reference moving with speed, $v$ .

$$p'c = \gamma\left(pc - \beta E\right)$$
$$E' = \gamma\left(E - \beta pc\right)$$

$$\beta = \frac{v}{c}, \quad \gamma = \left(1 - \beta^2\right)^{-\frac{1}{2}}$$

"The mass" $m$ , is an "invariant".

$$m^2c^4 = E^2 - p^2c^2$$

$$E'^2 - p'^2c^2 = \gamma^2\left(E - \beta pc\right)^2 - \gamma^2\left(pc - \beta E\right)^2$$
$$= \gamma^2\left(E^2 - p^2c^2\right)\left(1 - \beta^2\right)$$
$$= E^2 - p^2c^2 = m^2c^4$$

# When to include the $c^2$ ?

## Rest Energy of the Proton

$$mc^2 = \left(1.67\times10^{-27}\ \text{kg}\right)\left(3\times10^{8}\ \text{m/s}\right)^2$$
$$= 1.50\times10^{-10}\ \text{J}\left(\frac{1}{1.6\times10^{-19}\ \text{J/eV}}\right)$$
$$= 0.94\times10^{9}\ \text{eV} = 0.94\ \text{GeV} = 940\ \text{MeV}$$
$$m = 940\ \text{MeV/c}^2$$

## Converting Joules <--> electron-Volts

$$qV = T$$
$$(1e)(1V) = \left(1.6\times10^{-19}\ \text{C}\right)(1V) = 1.6\times10^{-19}\ \text{J}$$
$$1 = \frac{1.6\times10^{-19}\ \text{J}}{1\ \text{eV}} = 1.6\times10^{-19}\ \text{J/eV}$$

$$E^2 = p^2c^2 + m^2c^4$$

## Units

$$E,\ pc,\ mc^2\ \text{(all in eV)}$$
$$p\ \text{(eV/c)},\ m\ (\text{eV/c}^2)$$

## Short Hand for the brave or foolhardy

$$E^2 = p^2 + m^2$$
$$\text{but remember: } p \text{ in eV/c \& } m \text{ in eV/c}^2$$