KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2013 to **François Englert** and **Peter W. Higgs** "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".

The Nobel Prize 2013 **in Physics**

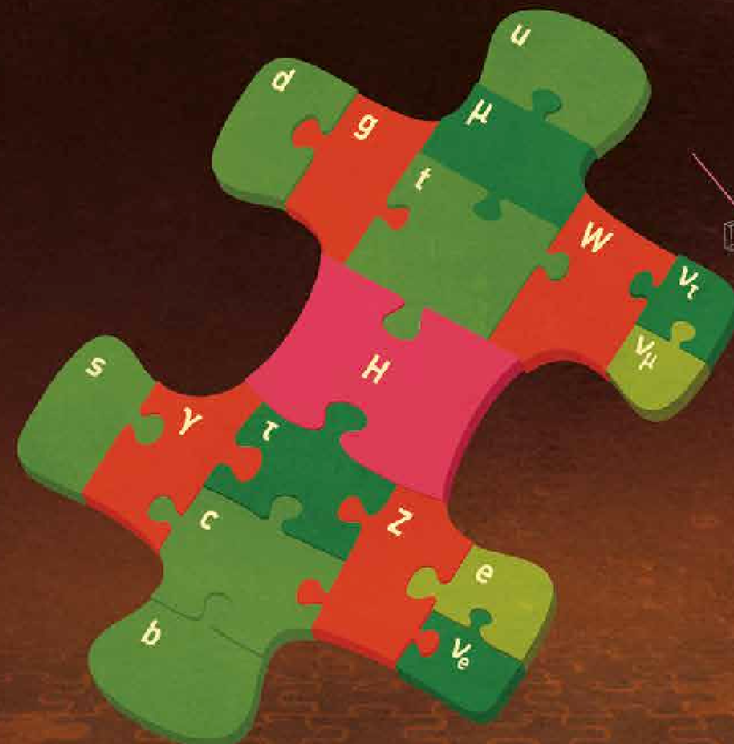
Here, at last!

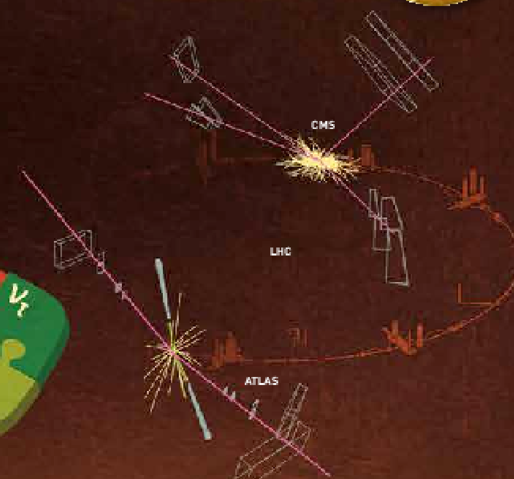
François Englert and Peter W. Higgs are jointly awarded the Nobel Prize in Physics 2013 for the theory of how particles acquire mass. In 1964, they proposed the theory independently of each other (Englert did so together with his now-deceased colleague Robert Brout). In 2012, their ideas were confirmed by the discovery of a so-called Higgs particle, at the CERN laboratory outside Geneva in Switzerland.

The awarded mechanism is a central part of the Standard Model of particle physics that describes how the world is constructed. According to the Standard Model, everything – from flowers and people to stars and planets – consists of just a few building blocks: *matter particles* which are governed by forces mediated by *force particles*. And the entire Standard Model also rests on the existence of a special kind of particle: *the Higgs particle*.

The Higgs particle is a vibration of an invisible field that fills up all space. Even when our universe seems empty, this field is there. Had it not been there, nothing of what we know would exist because particles acquire mass only in contact with the Higgs field. Englert and Higgs proposed the existence of the field on purely mathematical grounds, and the only way to discover it was to find the Higgs particle.

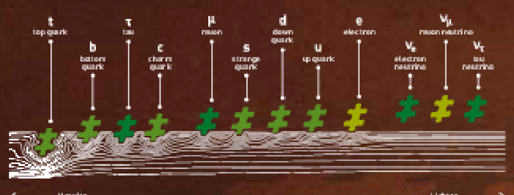
The Nobel Laureates probably did not imagine that they would get to see the theory confirmed in their lifetimes. To do so required an enormous effort by physicists from all over the world. Almost half a century after the proposal was made, on July 4, 2012, the theoretical prediction could celebrate its biggest triumph, when the discovery of the Higgs particle was announced.





ATLAS
In the collision, a short-lived Higgs particle is created, which decays into two muons (tracks in red) and two electrons (tracks in green).

CMS
A short-lived Higgs particle is created in the collision and decays into four muons (tracks in red).

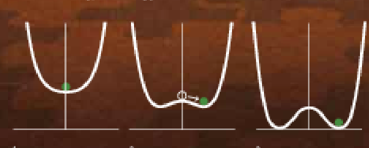


The Particle Collider LHC
Protons – hydrogen nuclei – travel at almost the speed of light in opposite directions inside the circular tunnel, 27 kilometres long. The LHC (Large Hadron Collider) is the largest and most complex machine ever constructed by humans. In order to find a trace of the Higgs particle, two huge detectors, ATLAS and CMS, are capable of seeing the protons collide over and over again, 40 million times a second.

↑
The Field
Matter particles acquire mass in contact with the invisible field that fills the whole universe. Particles that are not affected by the Higgs field do not acquire mass, those that interact weakly become light, and those that interact strongly become heavy. For example, electrons acquire mass from the field, and if it suddenly disappeared, all matter would collapse as the suddenly massless electrons dispersed at the speed of light. The weak force carriers, W and Z particles, get their masses directly through the Higgs mechanism, while the origin of the neutrino masses still remains unclear.

→
Broken Symmetry
The Higgs mechanism relies on the concept of spontaneous symmetry breaking. Our universe was probably born symmetrical (1), with a zero value for the Higgs field in the lowest energy state – the vacuum. But less than one billionth of a second after the Big Bang, the symmetry was broken spontaneously as the lowest energy state moved away (2) from the symmetrical zero-point. Since then, the value of the Higgs field in the vacuum state has been non-zero (3).

Potential energy of the Higgs field



The Puzzle
The Higgs particle (H) was the last missing piece in the Standard Model puzzle. But the Standard Model is not the final piece in the cosmic puzzle. One of the reasons for this is that the Standard Model only describes visible matter, accounting for one sixth of all matter in the universe. To find the rest – the mysterious so-called dark matter – is one of the reasons why scientists continue to chase unknown particles at CERN.

← ←
François Englert
Belgian citizen. Born 1932 in Etterbeek, Belgium. Professor emeritus at Université Libre de Bruxelles, Brussels, Belgium.

←
Peter W. Higgs
British citizen. Born 1929 in Newcastle upon Tyne, United Kingdom. Professor emeritus at University of Edinburgh, United Kingdom.

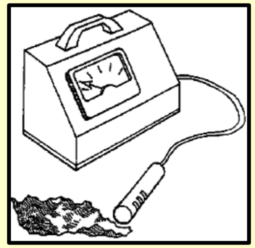
FURTHER READING!

What's the matter?!

Gravitation

reach	:	∞
strength	:	10^{-41}
charge	:	mass

Weak force

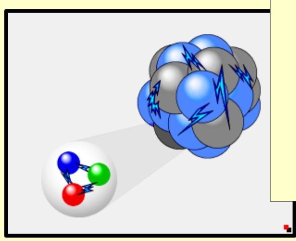


reach	:	10^{-17}m
strength	:	10^{-14}
charge	:	weak isospin

Electromagnetism

reach	:	∞
strength	:	$1/137$
charge	:	electric charge

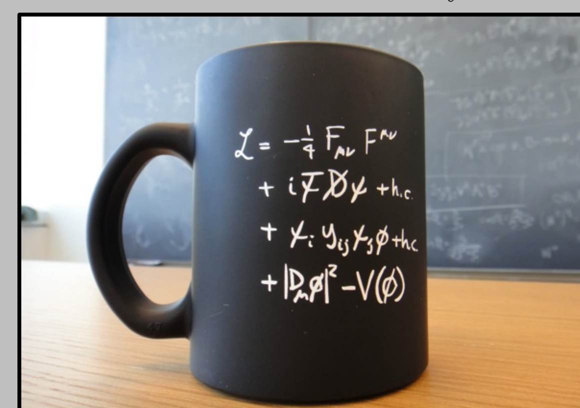
Strong force



reach	:	10^{-15}m
strength	:	$\mathcal{O}(1)$
charge	:	color

Simple principle of *Gauge Symmetries*!

Standard Model of Particle Physics



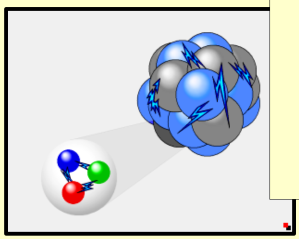
Lagrangian Density of (baryonic) Matter

What's the matter?!

Gravitation

reach	:	∞
strength	:	10^{-41}
charge	:	mass

Strong force

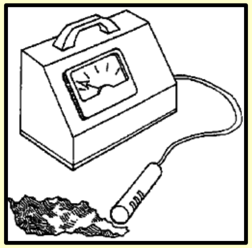


reach	:	10^{-15}m
strength	:	$\mathcal{O}(1)$
charge	:	color

Electromagnetism

reach	:	∞
strength	:	$1/137$
charge	:	electric charge

Weak force



reach	:	10^{-17}m
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Simple principle of *Gauge Symmetries*!

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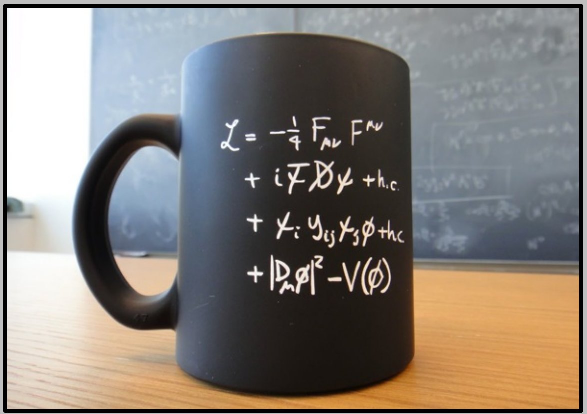

Lagrangian Density of (baryonic) Matter

What's the matter?!

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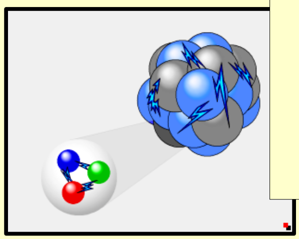
reach : ∞
strength : 10^{-41}
charge : mass

Strong force



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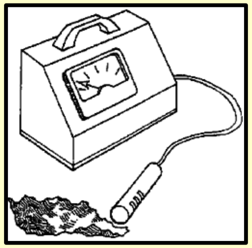

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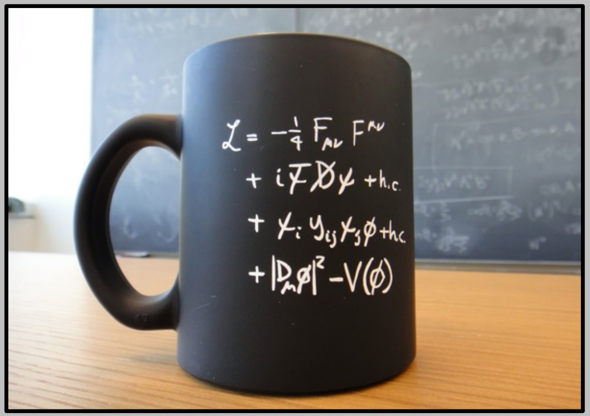
Higgs Mechanism

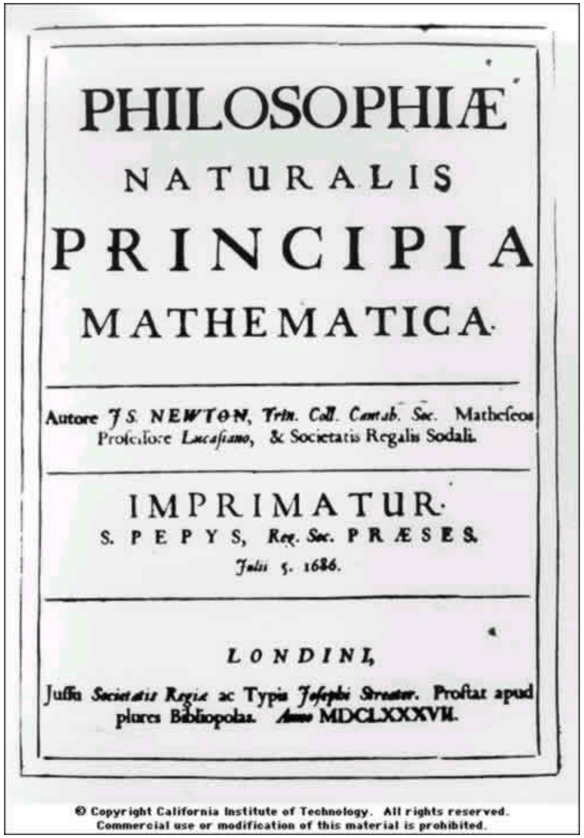
Simple principle of *Gauge Symmetries*!

Standard Model of Particle Physics



Lagrangian Density of (baryonic) Matter

Mass $\neq$ Mass



PHILOSOPHIÆ

NATURALIS

PRINCIPIA

MATHEMATICA.

Autore J S. NEWTON, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.

S. PEPYS, *Reg. Soc.* PRÆSES.

Julii 5. 1686.

LONDINI,

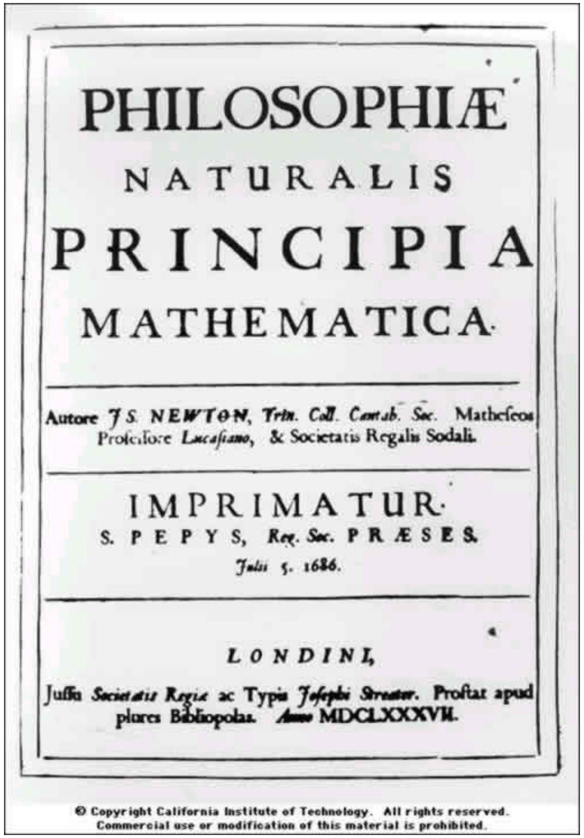
Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Newton's law of gravitation:

$$m \cdot \vec{a} = G\frac{m \cdot M}{\vec{r}^2} \cdot \frac{\vec{r}}{|\vec{r}|}$$

$$(i\gamma^\mu \partial_\mu - m)\,\psi = 0$$

Mass $\neq$ Mass



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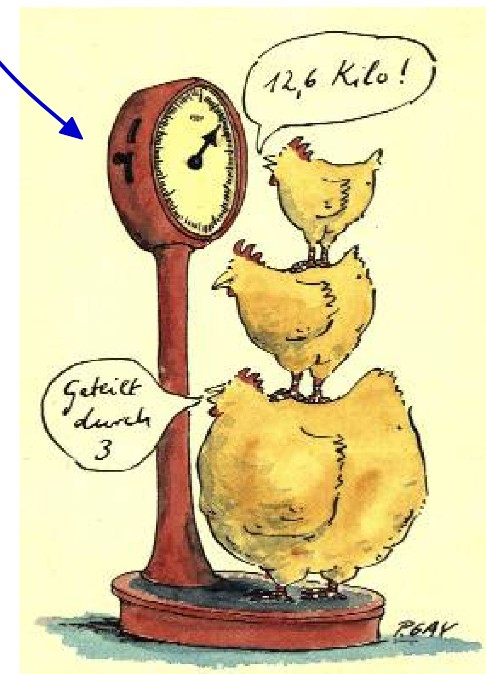

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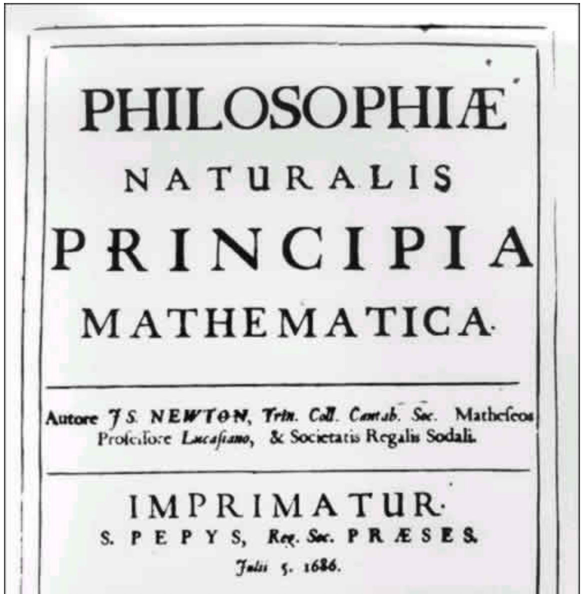

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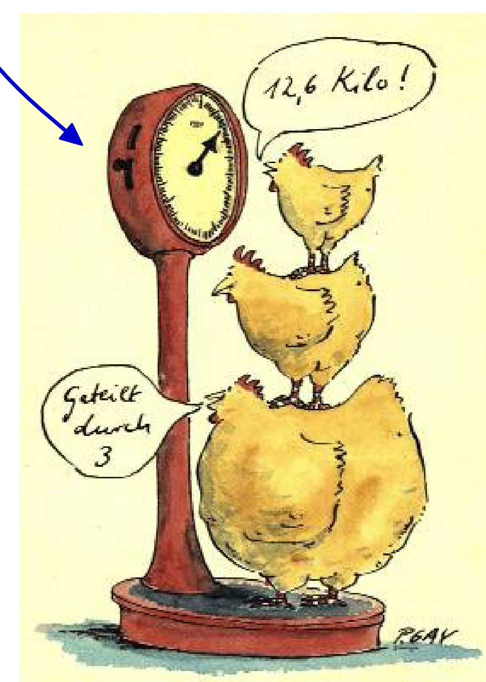
mass of inertia



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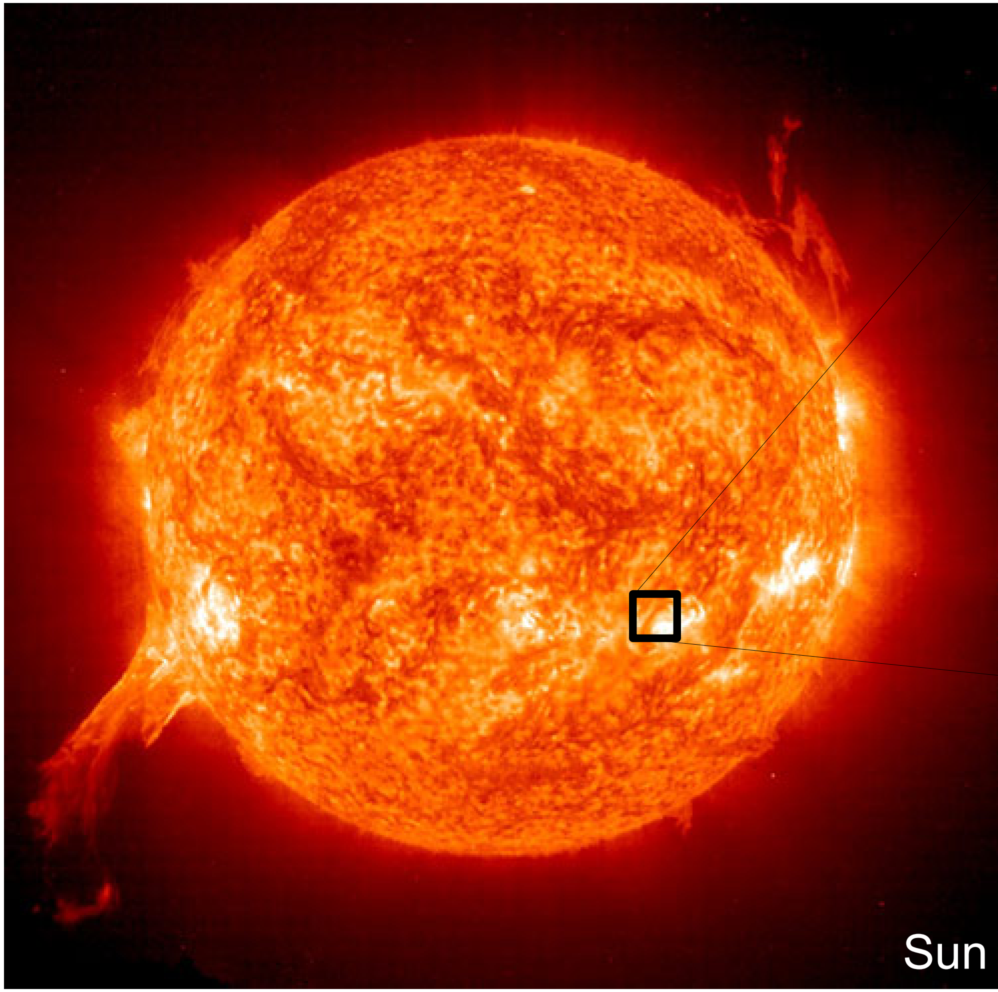
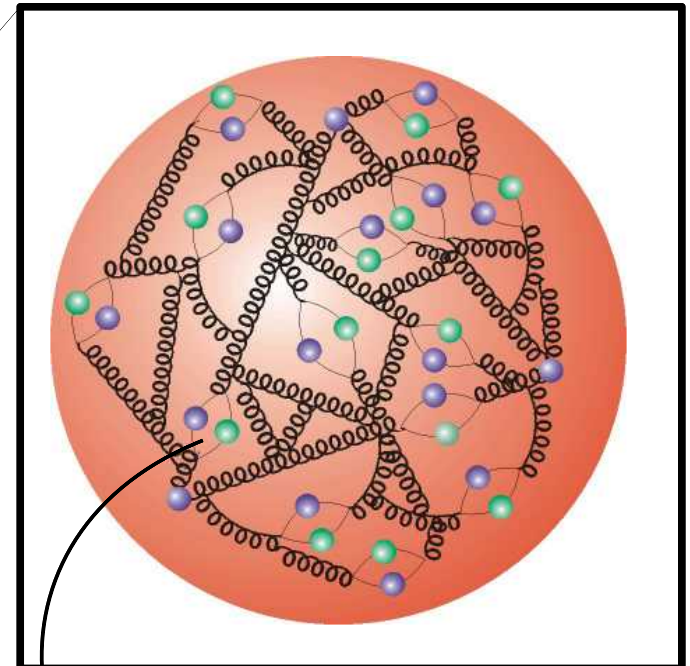




Proton

$$m_p = 938.3 \text{ MeV}$$

$$m_u = 2 - 3 \text{ MeV}$$

$$m_u \approx {}^{1}/_{500} \cdot m_p$$

So, what's the importance then of m?!?

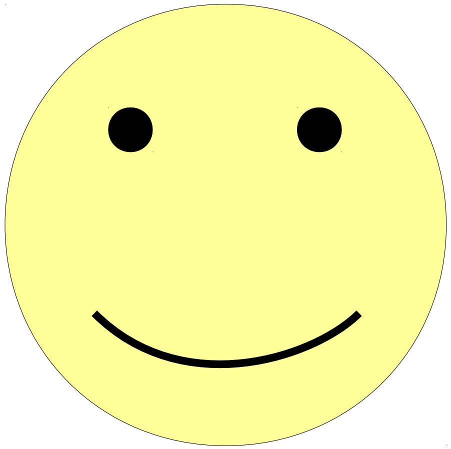
Without m ...

Karlsruhe Institute of Technology

- … no Newtonian Laws.

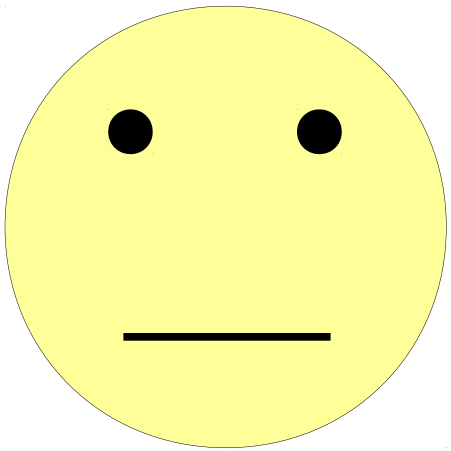
Without m ...

- … no Newtonian Laws.
- … everybody would move at the speed of light.



Without m ...

- … no Newtonian Laws.
- … everybody would move at the speed of light.
- … no weak force as we know it.



Without m ...

- … no Newtonian Laws.
- … everybody would move at the speed of light.
- … no weak force as we know it.
- … no Standard Model.

Without m ...

- … no Newtonian Laws.
- … everybody would move at the speed of light.
- … no weak force as we know it.
- … no Standard Model.
- … no Lecture on Higgs Physics.

Modul Teilchenphysik II – Higgs-Physik (4022181)

- **Einordnung in Studiengang:** Master Physik, Experimentelle Teilchenphysik.
- **Vorlesung:** 2 SWS Vorlesung + 2 SWS Vorlesung/Übungen abwechelnd.
- Wahlfach im Masterstudiengang Physik, als Teilmodul eines Vertiefungs- bzw Ergänzungsfachs (6 oder 8 LP) mit mündlicher Modulprüfung.
- Für mehr Information siehe Modulhandbuch Master Studiengang Physik (Seite 32).

Modul Teilchenphysik II – Higgs-Physik (4022181)

- You will find the lecture material hosted on the web page of Prof. Günter Quast.

> - **Teilchenphysik II - Higgs-Physik** (mit Dr. Wolf, Dr. Wayand)
>   Do., 14:00 -15:30, Kl. HS B
>
> Modulhandbuch Material Virtuelle Maschine (für VirtualBox)
>
> **Seminar/Übung zur Vorlesung** Termin noch festzulegen ;
>
> **Literatur:**
>
> Grundlagen:
>
> U. Husemann, *Vorlesung Teilchenphysik I*, EKP (2015)
>
> z.B.: C. Berger, *Elementarteilchenphysik*, Springer
>
> oder D. Griffiths, *Introduction to Elementary Particles* , Wiley
>
> zum Kurs:
>
> K. Kumericki, *Feynmandiagrams for Beginners*
>
> R. Wolf, *The Higgs Boson Discovery at the Large Hadron Collider* Springer e-book
>
> K. Jakobs, G. Quast, G. Weiglein, Chap. 6 in *The Large Hadron Collider - Harvest of Run 1* Springer e-book

- Prof. Günter Quast (Geb. 30.23 9-4 guenter.quast@cern.ch)
- Dr. Roger Wolf (Geb. 30.23 9-20 roger.wolf@cern.ch)
- Dr. Stefan Wayand (Geb. 30.23 8-20 stefan.wayand@cern.ch)

Lecture program

Karlsruhe Institute of Technology

VL-01	CW-16	Relativistic QM
VL-02	CW-17	Lagrange Formalism and Gauge Theories
VL-03	CW-17	The EWK Sector of the SM
EX-01	CW-18	Exercises Discussion (3 p&p homework exercises)
VL-04	CW-19	Sponteneous Symmetry Breaking (Part-I: Introduction)
VL-05	CW-19	Sponteneous Symmetry Breaking (Part-II: Incorporation into the SM)
VL-06	CW-20	From Theory to Observable
VL-07	CW-20	Perturbation Theory at Higher Order Precision
EX-02	CW-21	Exercises Discussion (3 p&p homework exercises)
VL-08	CW-22	From Observable to Measurement
VL-09	CW-22	Experimental Particle Physics in Practise (Part-I: Knowing Your Hardware)
VL-10	CW-23	Experimental Particle Physics in Practise (Part-II: The School of Data Analysis)
EX-03	CW-23	Exercises Discussion (3 p&p homework exercises)
VL-11	CW-24	Statistical Methods in Particle Physics
VL-12	CW-24	Higgs Boson Searches before the Advent of the LHC
EX-04	CW-25	Exercises Discussion (2 computing exercises)
EX-05	CW-25	Exercises Discussion (2 computing exercises)
VL-13	CW-26	The Higgs Boson Discovery at the LHC
VL-14	CW-26	Properties of the Discovered Higgs Boson
VL-15	CW-27	Higgs Bosons Beyond the SM
EX-06	CW-26	Exercises Discussion (free discussion and all you can ask)

- Slides English, presentation German/English.
- Exercise sheets uploaded to web (well) in advance, slides after lectures.

What's so special about this lecture?

- Higgs boson physics is a hot topic of particle physics.
- The whole sector of Higgs physics is covered here at KIT:
  - Theory (→ e.g. Prof. D. Zeppenfeld, Prof. M. Mühlleitner, …)
  - Experiment (→ e.g. Prof. G. Quast, Dr. R. Wolf, Dr. A. Gilbert, Dr. S. Wayand)
- These people and their groups are not just some guys among many others – these guys directly participated in the discovery of the Higgs boson in 2012 and are world leading experts in the field.

Integrated course

- Presence exercises (during lectures) + homework exercises.
- Homework exercises: 9 pen & paper, and 2 computing.
- Lecture blocks embraced by sessions for discussions of exercises.
- Special lectures given by leading experts from CERN (→ A. Gilbert).
- Paper seminar equivalent to *Hauptseminar* at the end of the semester.

- **Certification of success:**
  - Certificate: attend + do (esp. computing) exercises + give seminar talk (→ 8 LP).
  - Certificate: attend + do (esp. computing) exercises (→ 6 LP).

Literature

- Course will be based on *The Higgs Boson Discovery at the Large Hadron Collider* (Springer 2015).
- Freely accessible as e-book (from KIT intranet).
- Makes sense to prepare and/or post-process lectures by reading corresponding passages in book.
- Paper seminar will be based on first hand literature (=*Primärliteratur*). Organization seminar will be made during first Exercises session (CW-18).
- If you want to be up to date: drop us your favorite e-mail address.