Modelling the Invisible

Prof. Alexander Lenz
IPPP, Durham University
Orkney Science Festival 11.9.2018

Durham University

- **16 000 students**

Physics:
- **37 professors**
- **12 readers**
- **11 senior lecturers**
- **18 lecturers**
- **about 100 post-doctoral researchers and fellows**
- **150 PhD postgraduate students**
- **each year we admit about 170 students.**

Institute for Particle Physics Phenomenology

@IPPP_Durham modelling invisible.org

- National institute for theoretical particle physics
- Currently 94 members

@IPPP_Durham at the Orkney Science Festival 2018

Westray Junior High School 7.9.

Kirkwall King Street Hall 8.9.

Stromness Academy 5.-7.9.

Kirkwall Town Hall 11.9.

Sanday Junior High School 6.9.

Stronsay Junior High School 5.9.

Kirkwall Grammar School 10.-12.9.

Outline

1. What is Elementary Particle Physics?

2. Elementary Particle Physics for (future) experts*

3. Why to spend billions for a particle accelerator?

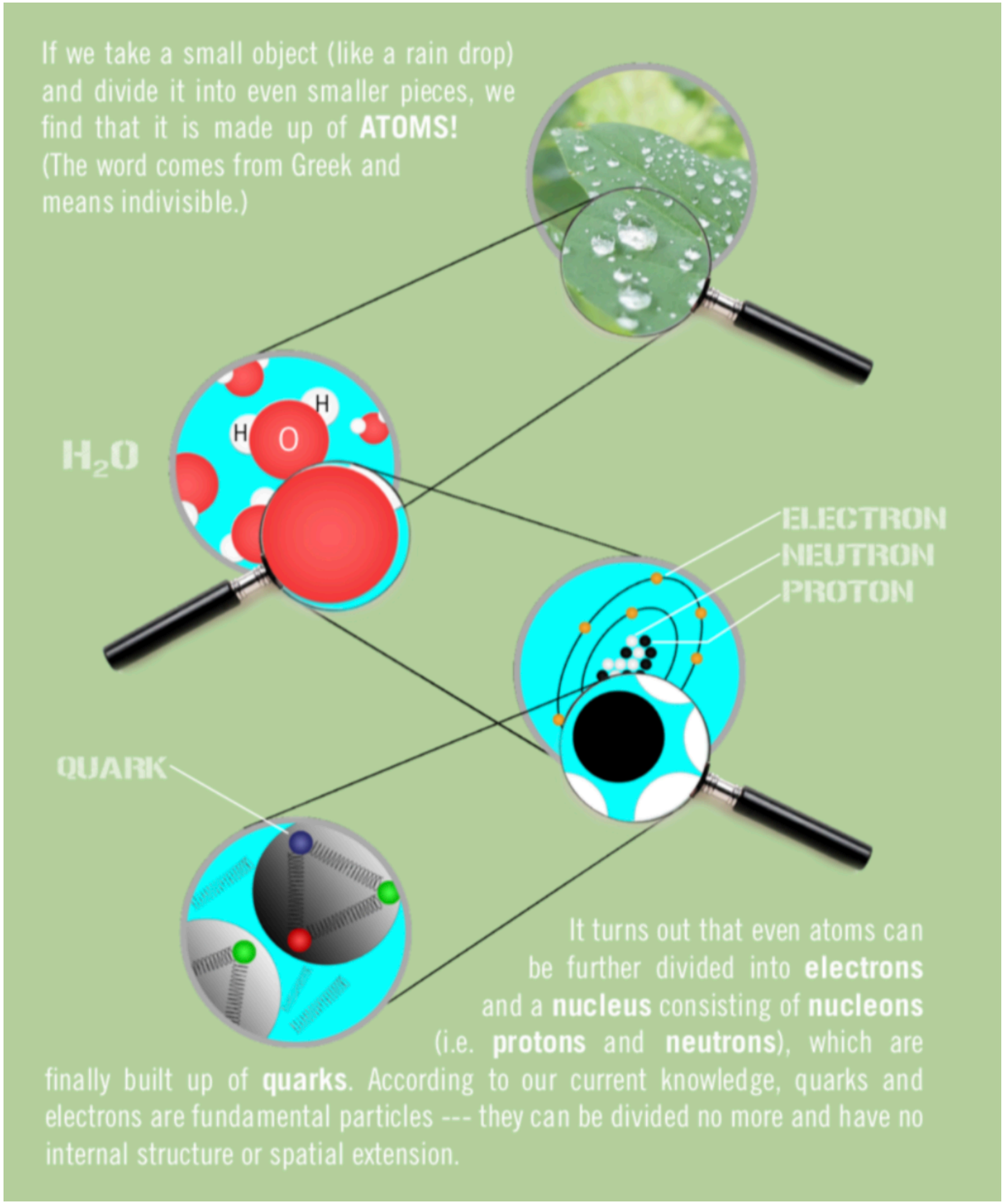
4. Open question in particle physics

5. How to become a scientist?

Intended for the general public, except expert sections denoted by *

What is our world made off?

1. **Molecules**
2. **Atoms**
3. **Electrons** + **Nuclei**
4. **Protons + Neutrons**
5. **Quarks**



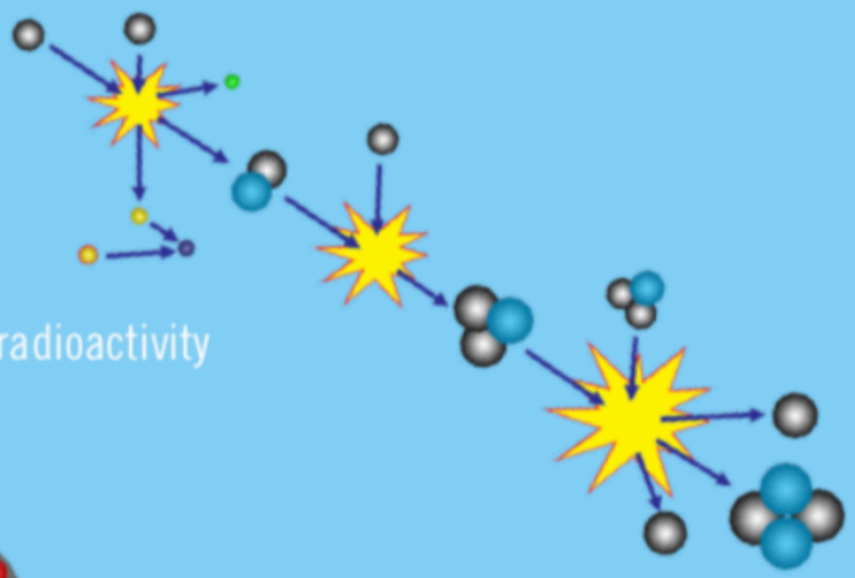
THE FOLLOWING FUNDAMENTAL FORCES (=INTERACTIONS) ARE FOUND IN NATURE....

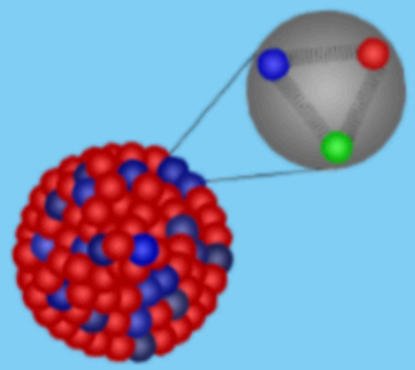
According to our theoretical understanding all forces are transmitted by force carriers.

GRAVITY: lets apples fall from trees
Force carrier: Graviton (not yet observed)

ELECTROMAGNETIC INTERACTION:
makes lightning in a thunderstorm and
is the basis of all electricity and magnetism
Force carrier: Photons

WEAK INTERACTION:
is responsible for the energy
production in the sun and for radioactivity
Force carrier: W, Z Bosons





STRONG INTERACTION:
binds protons and neutrons into nuclei
and quarks into nucleons
Force carrier: Gluons

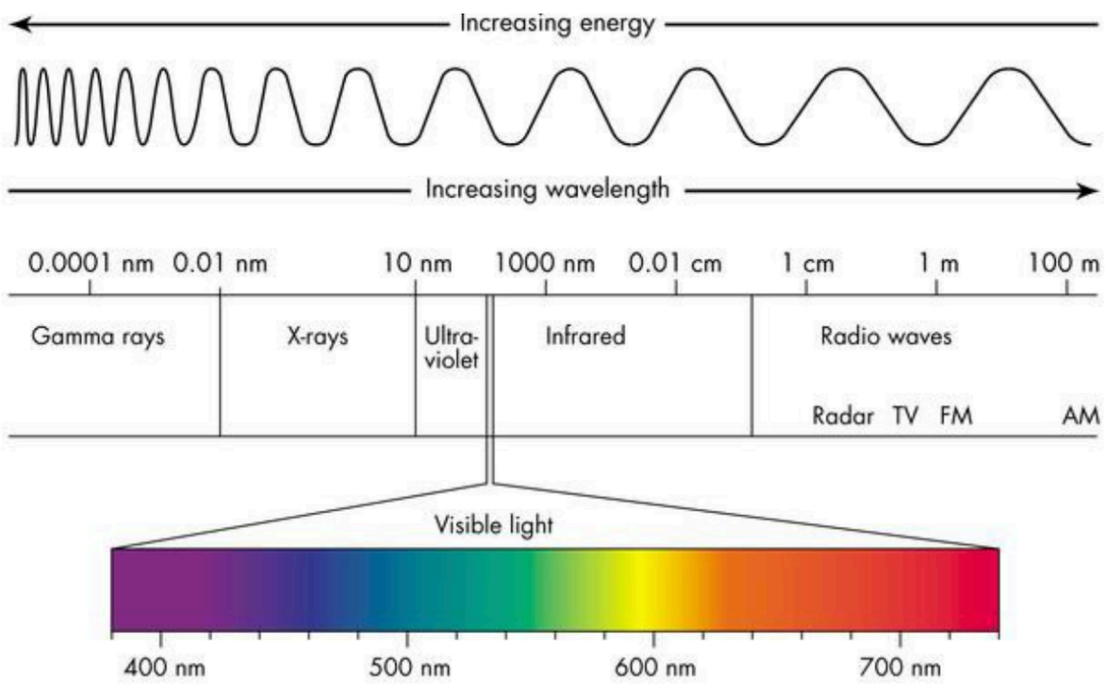
Particles without forces =
Chess pieces without rules

Imagine a world without:

- **weak force:**
  no sun is shining
- **strong force:**
  no nuclei
- **electro-magnetic force:**
  no atoms

How do we know about that?

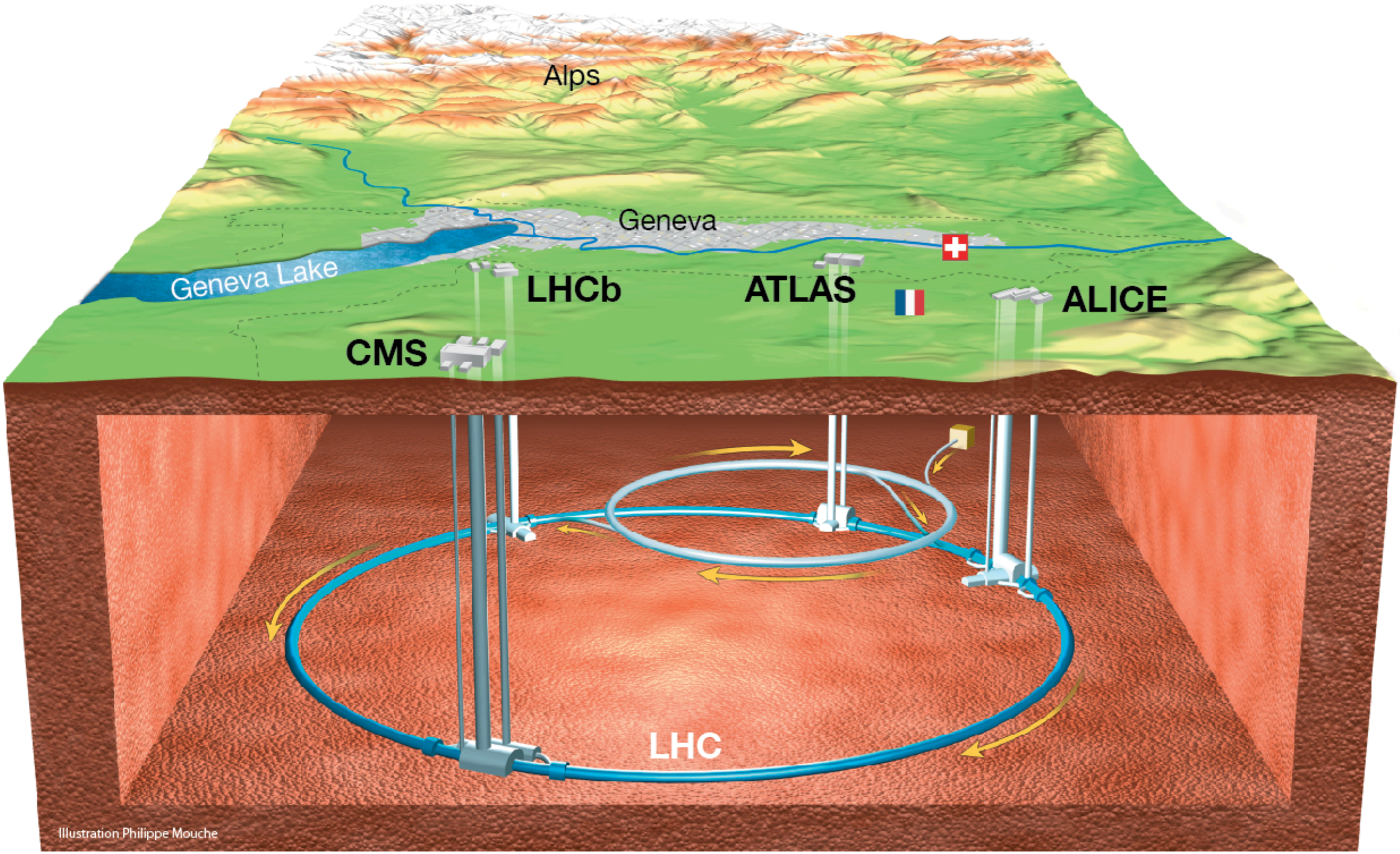
Microscopes can only resolve objects that are smaller than the wavelength of light



What to do in order to see objects that are much smaller than the wavelength of light?

The true use of stone circles!

The Large Hadron Collider



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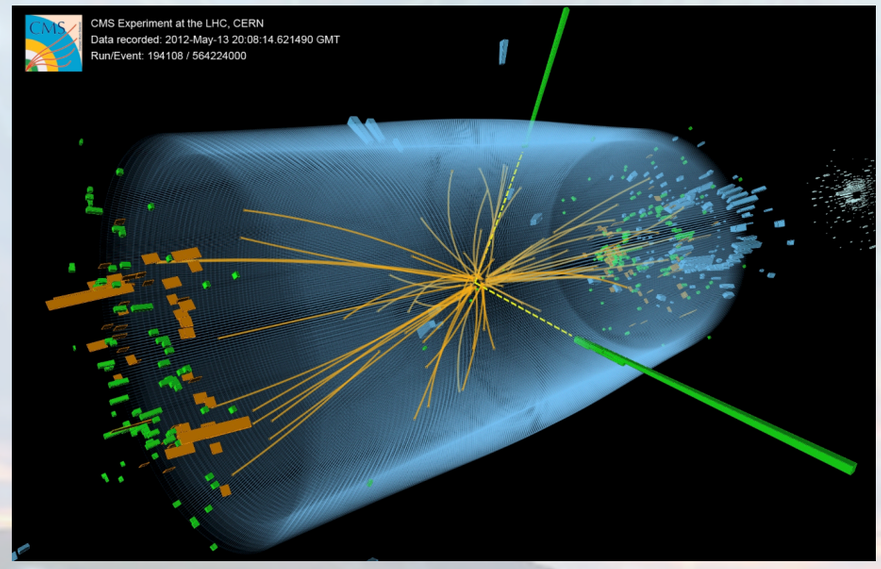
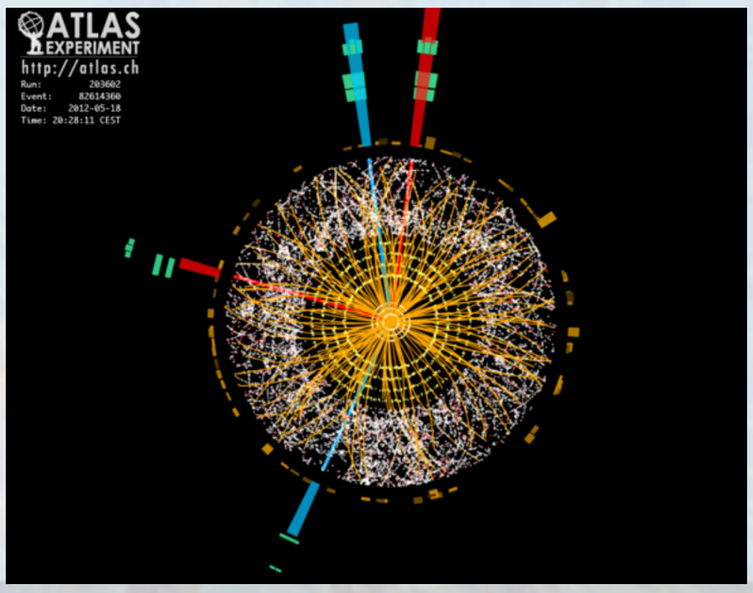
The Standard Model of Particle Physics

All what we know about particle physics can be

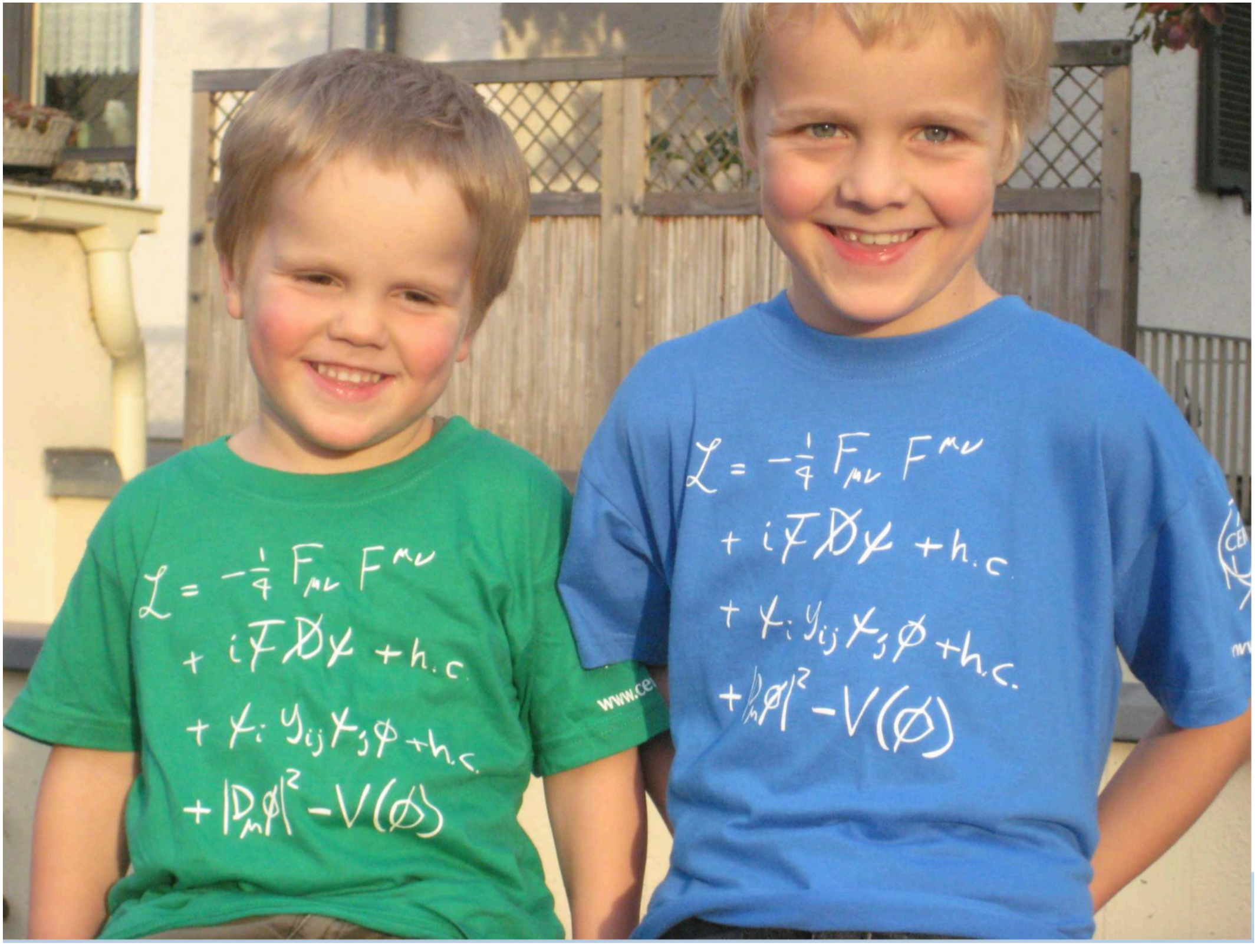
written very compactly in a single formula with 4 lines



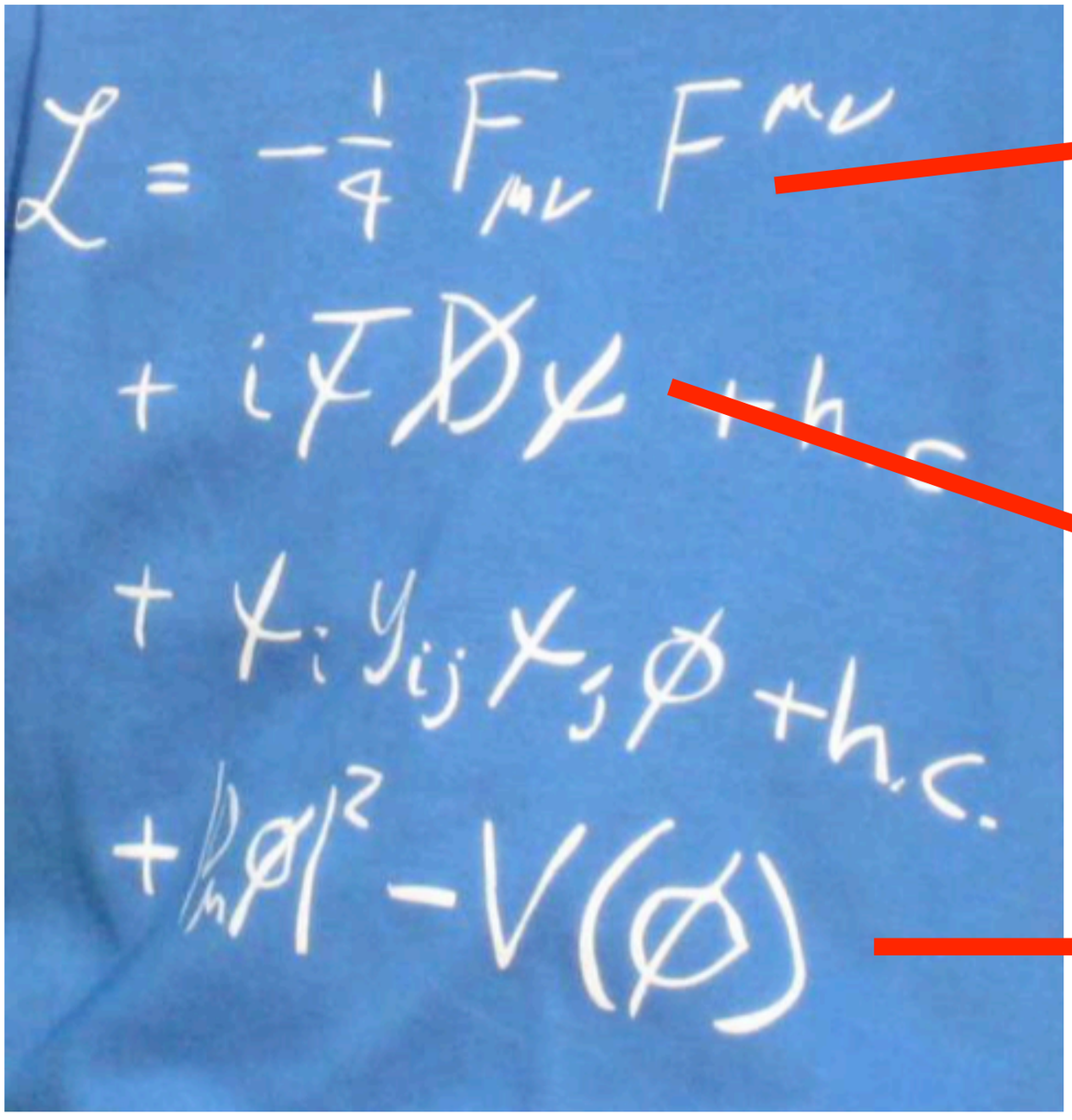


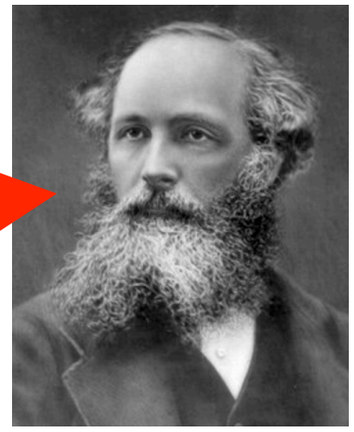
Explains thousands of measurements,
partly with a precision higher than a per mille

The Standard Model of Particle Physics

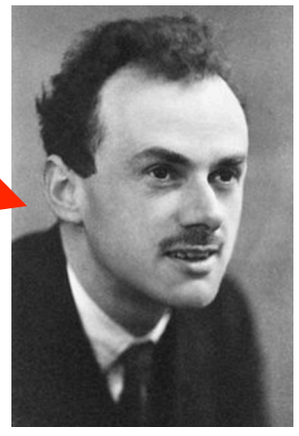


The Standard Model of Particle Physics





James Clarke Maxwell
(1831- 1879)



Paul Dirac
(1902- 1984)

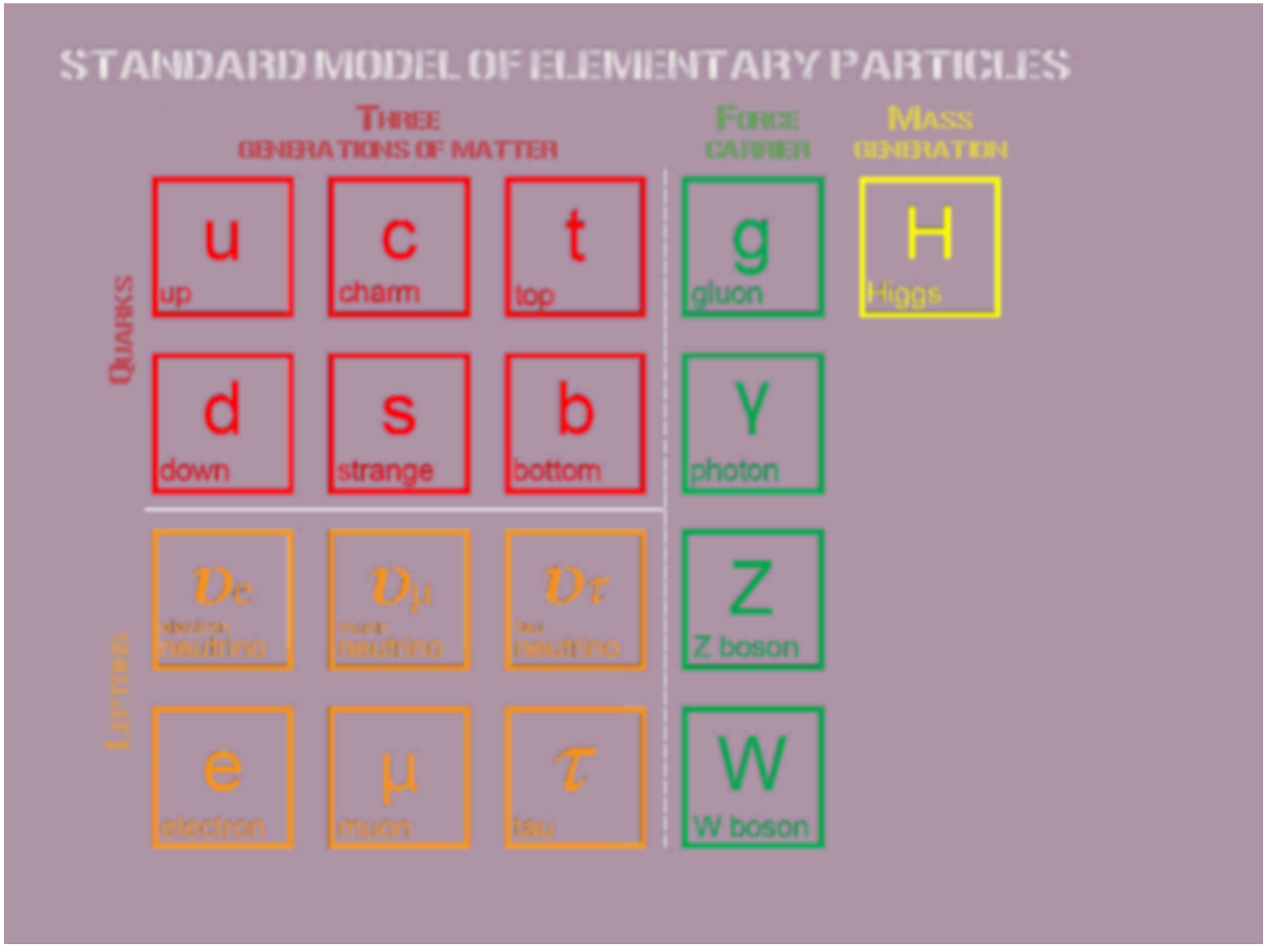
THE STRANGEST MAN
September 11 → 9:00 pm — 10:00 pm
Orkney Theatre, KGS, Kirkwall

Peter Higgs

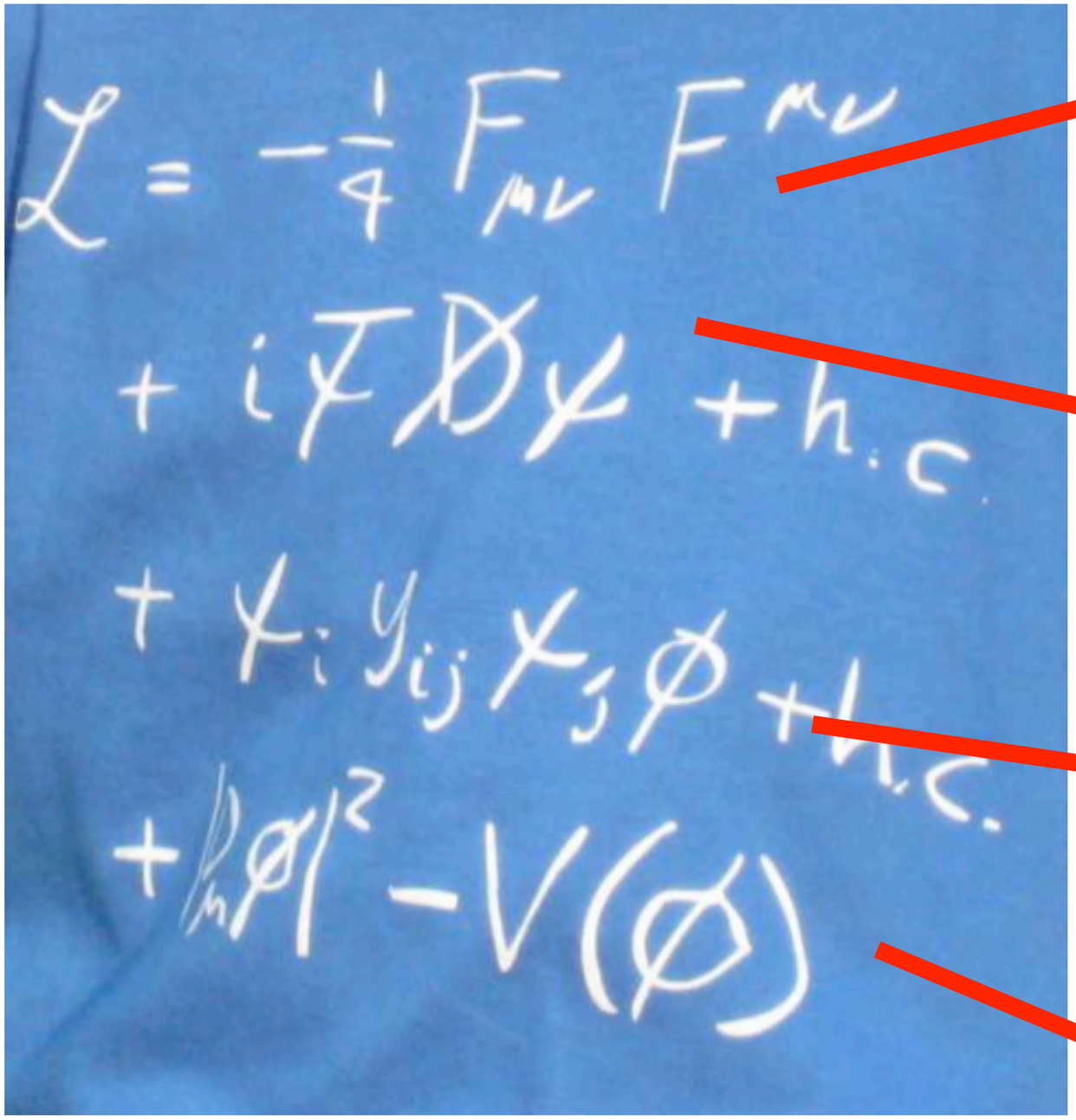
PETER HIGGS IN CONVERSATION
September 11 → 7:30 pm — 8:30 pm
Orkney Theatre, KGS, Kirkwall

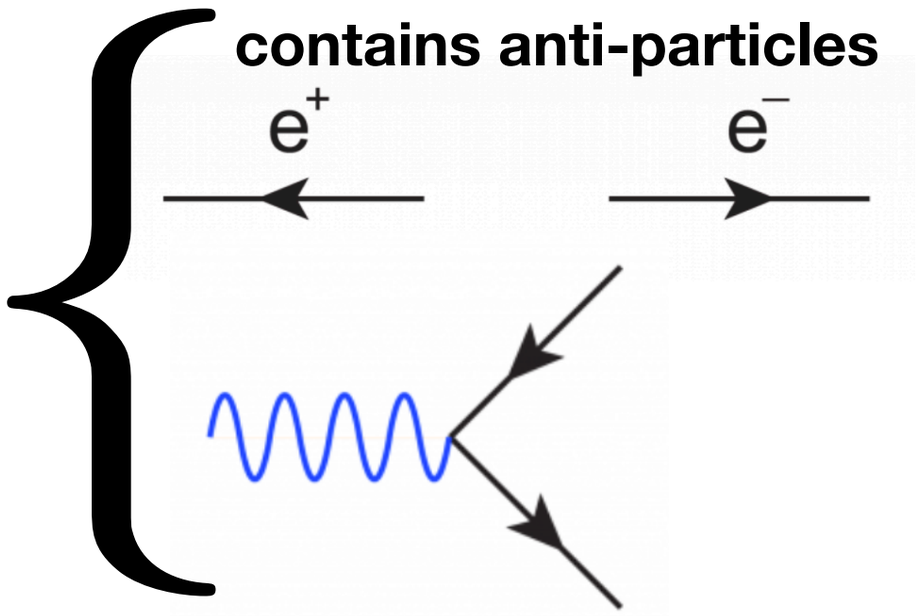
+ many others

The Standard Model of Particle Physics

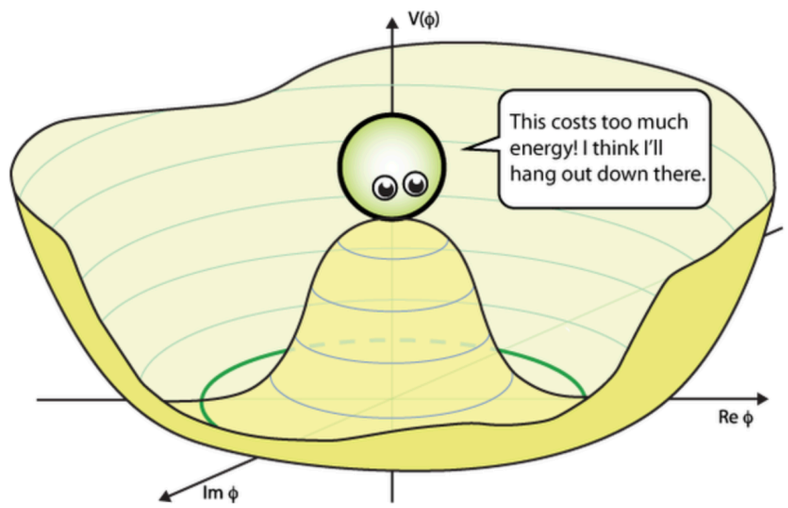


The Standard Model of Particle Physics



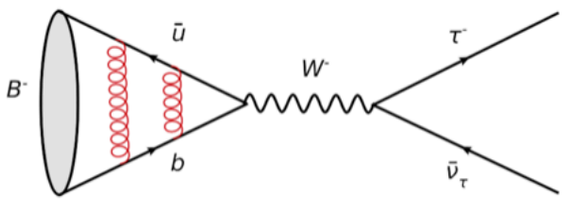


CKM matrix: Explanation for existence of matter in the Universe?

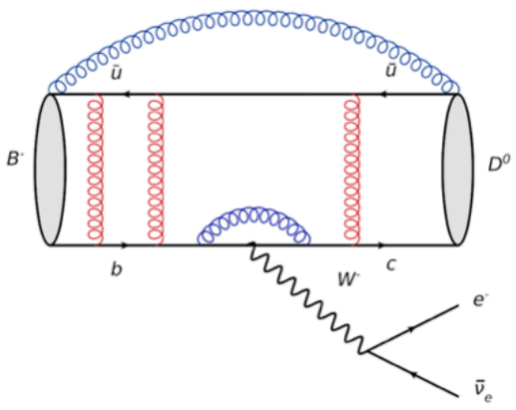


Heavy Flavour Physics

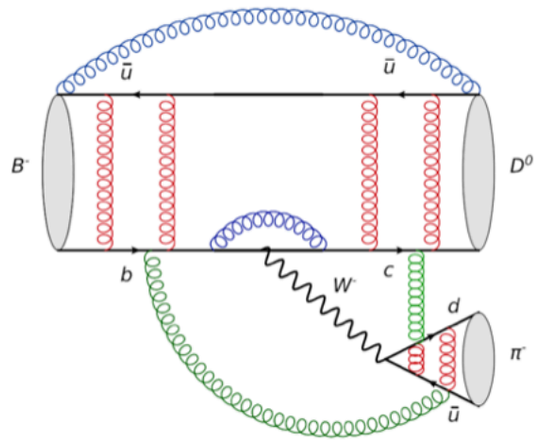
- **Leptonic decays**



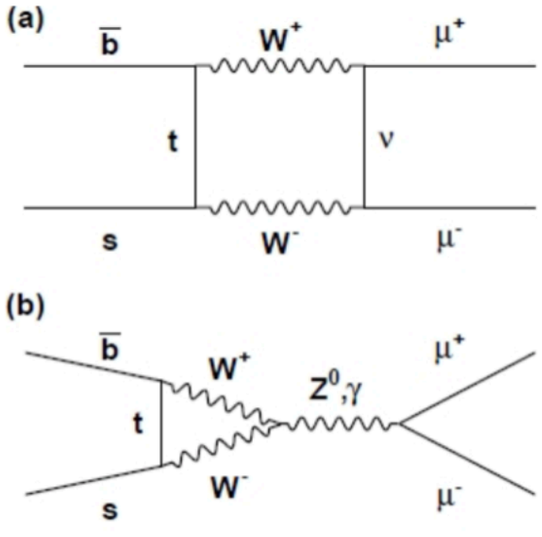
- **Semi-Leptonic decays**



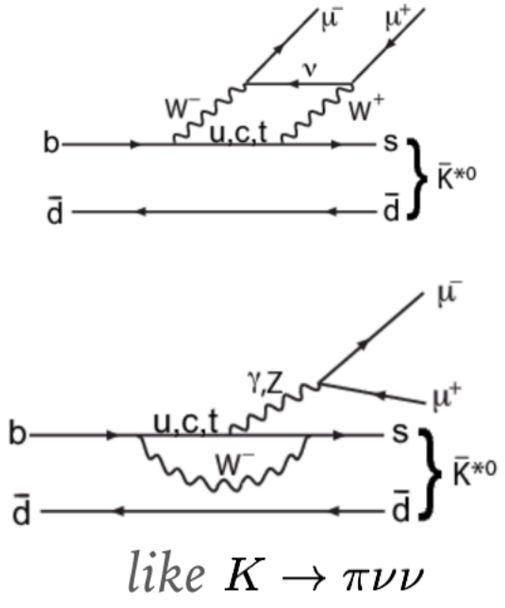
- **Non-Leptonic decays**



- **Leptonic decays**

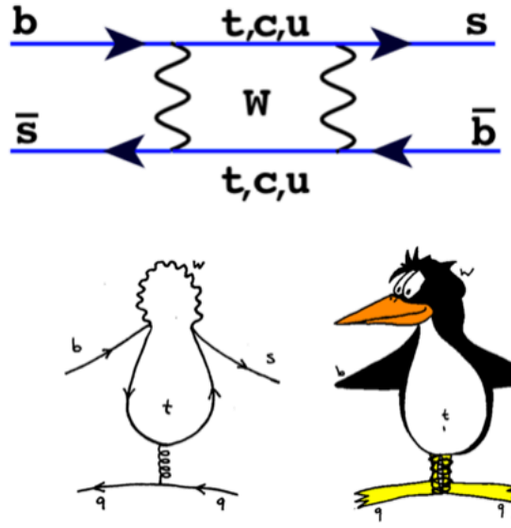


- **Semi-Leptonic decays**



like $K \to \pi\nu\nu$

- **Mixing**



These and similar processes have been measured very precisely (in particular LHCb) and they agree well with complicated quantum theoretical calculations

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3. Why to spend billions for an accelerator?

Fundamental vs. applied research

Fundamental research:

- increase human knowledge - unexpected findings
- economic application is **not** the main aim

Applied research:

- improve technology - expected/hoped for findings
- economic application is an important aim

As usual:

too little and too much are not good

Fair balance: if our ancestors did only do applied research we would have the most sophisticated torches, but we never had invented the LED

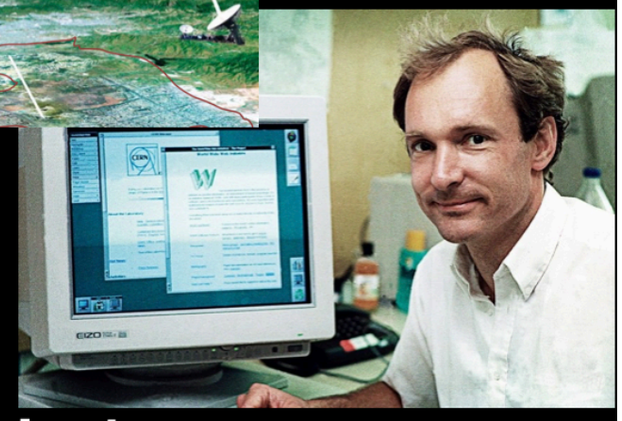
3. Why to spend billions for an accelerator?

Fundamental research: Spin-offs

- Quantum mechanics
  - ⋆ **Laser**
  - ⋆ **computer**
  - ⋆ **semi-conductor**
  - ⋆ **Quantum Computer**

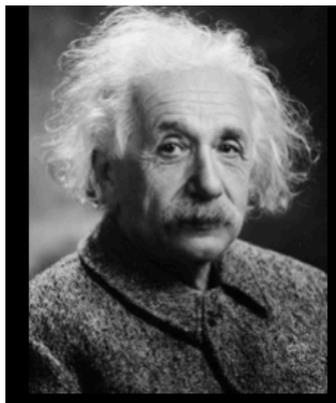
- General Theory of Relativity
  - ⋆ **GPS**

- Particle Physics
  - ⋆ **WWW**
  - ⋆ **radiation therapy**



- General education
  - ⋆ **mechanics @ formula 1 team**
  - ⋆ **most of our post-docs not in academia**
- Contribution to culture, internationalisation,…

3. Why to spend billions for an accelerator?



Numbers are also relative

Other big numbers

- 2.849 trillion US$ UK GDP
- 31 billion £ Trident replacement
- 27 billion £ Buyout Northern Bank
- 500 million £ Blue passport

Actual LHC contribution

2016: UK 14.64% of 1127.2 million CHF
this is equivalent to **2£ per UK inhabitant**

1 pint per year!

This is THE pint of science!

3. Why to spend billions for an accelerator?

Hard facts

Forecasting the Socio-Economic Impact of the Large Hadron Collider: a Cost-Benefit Analysis to 2025 and Beyond

Massimo Florio[1], Stefano Forte[2], and Emanuela Sirtori[3]

a) Scientist —- knowledge
b) Post-doc/PhD —- human capital
c) Companies —- technological spillover
d) General public —- direct cultural effects

2025, assuming a range of values for some critical stochastic variables. We conservatively estimate that there is around a 90% probability that benefits exceed costs, with an expected net present value of about 2.9 billion euro, not considering the unpredictable applications of scientific discovery.

no unexpected inventions taken into account!

Google: 1603.00886

3. Why to spend billions for an accelerator?

There is more in life than money…

SENATOR PASTORE: Is there anything connected in the hopes of this accelerator that in any way involves the security of the country?
DR. WILSON: No, it has nothing to do directly with defending our country **except to help make it worth defending.**

Physics is like sex: sure, it may give some practical results, but that's not why we do it.

(Richard Feynman)

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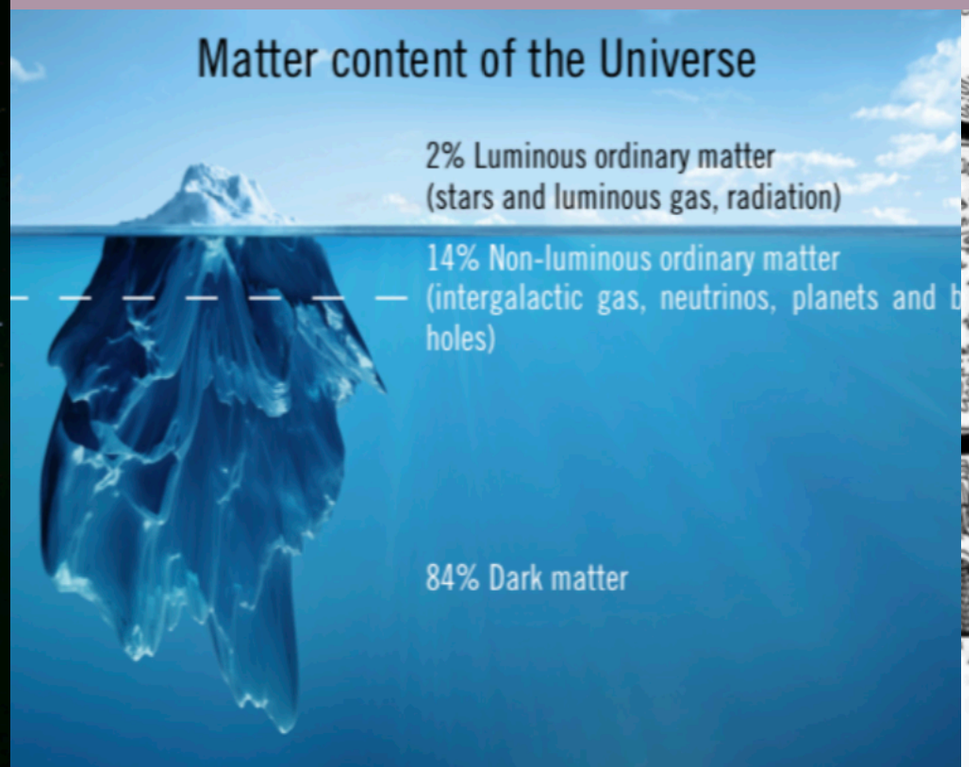
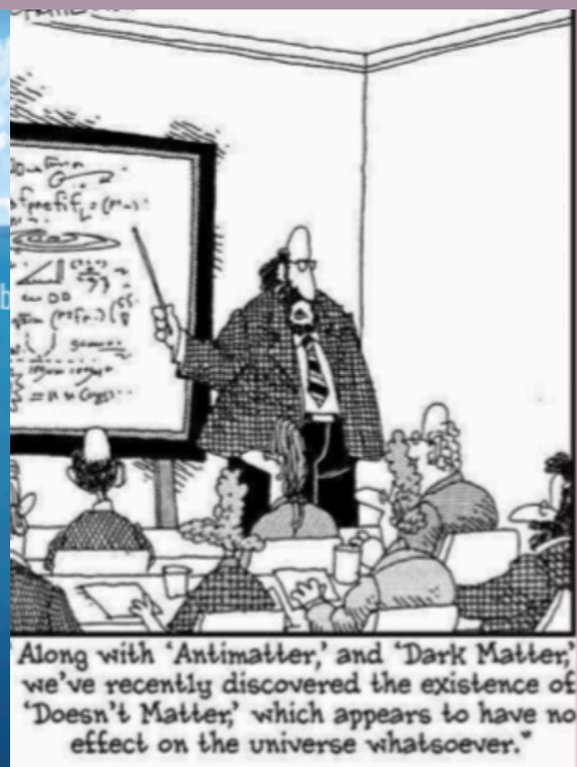
Open questions in particle physics

What is the origin of **DARK MATTER?**
How was **MATTER CREATED** in the Universe?
Why are **NEUTRINOS** almost **MASSLESS?**
Why do we have three copies of **Quarks** and **LEPTONS?**
Is there a **QUANTUM THEORY OF GRAVITY?**
y is the top **QUARKS SO MUCH HEAVIER** than the **ELECTRON?**





Indirect Search for New Physics

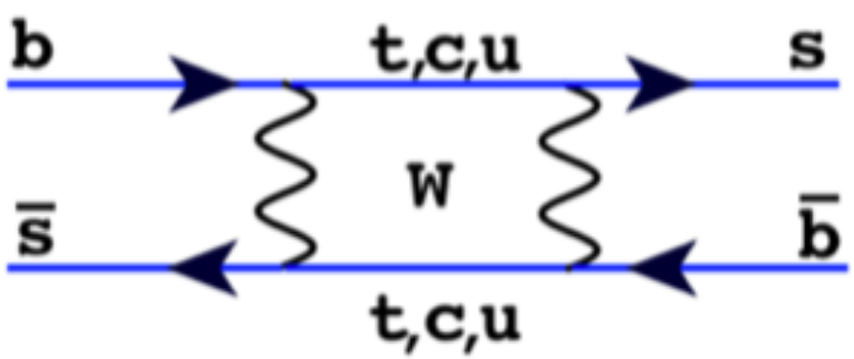
Indirect Search for New Physics:

To find hints for New Physics beyond the Standard Model we can either use brute force (= higher energies) or more subtle strategies like high precision measurements.

New contributions to an observable f are identified via:

$$f^{\mathrm{SM}} + f^{\mathrm{NP}} = f^{\mathrm{Exp}}$$

My favourite process: B-mixing



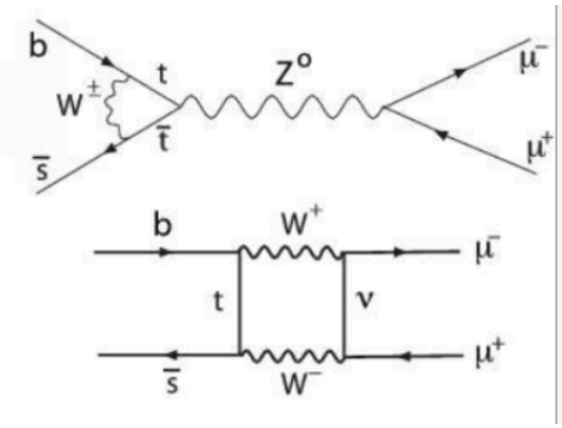
$$\boxed{\Delta M_s^{\mathrm{SM,\,2017}} = (20.01 \pm 1.25)\ \mathrm{ps}^{-1}\ .}$$

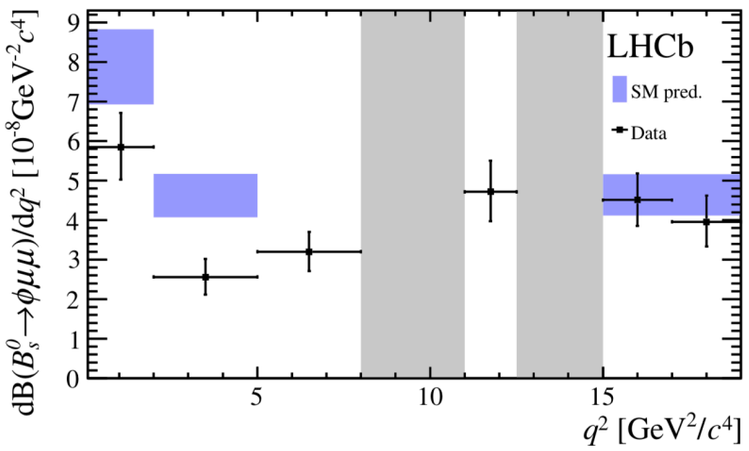
$$\Delta M_s^{\mathrm{Exp}} = (17.757 \pm 0.021)\ \mathrm{ps}^{-1}$$

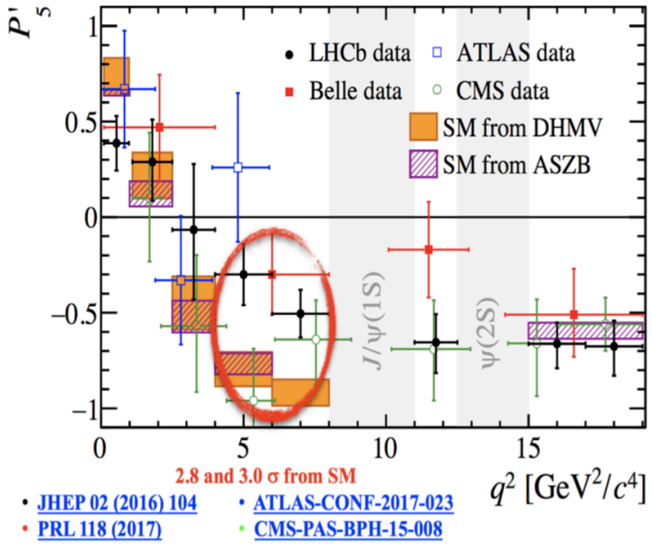
Hot Topic: Anomalies

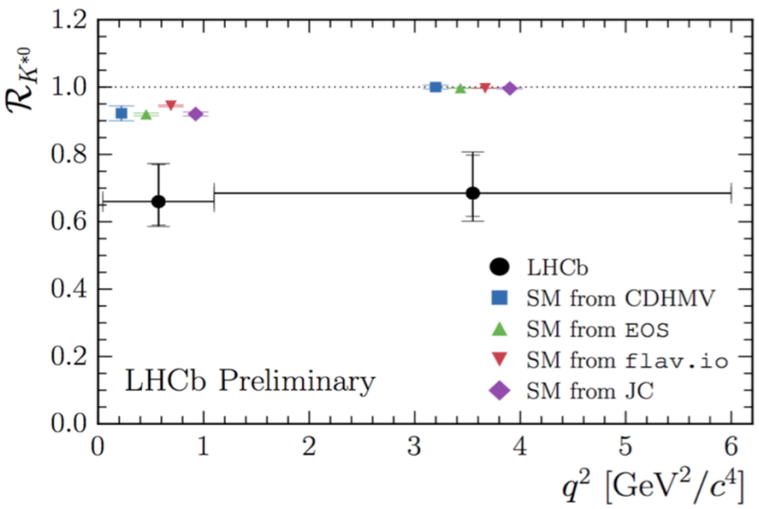
Observables:

- Branching ratios $Br(B_s \to \phi\mu\mu),\ Br(B \to K^*\mu\mu),$
- Angular observables, e.g. P_5' — hadronic uncertainties cancel partially
- Ratios $R_K = \dfrac{Br(B^+ \to K^+\mu^-\mu^+)}{Br(B^+ \to K^+e^-e^+)}$ — hadronic uncertainties cancel completely





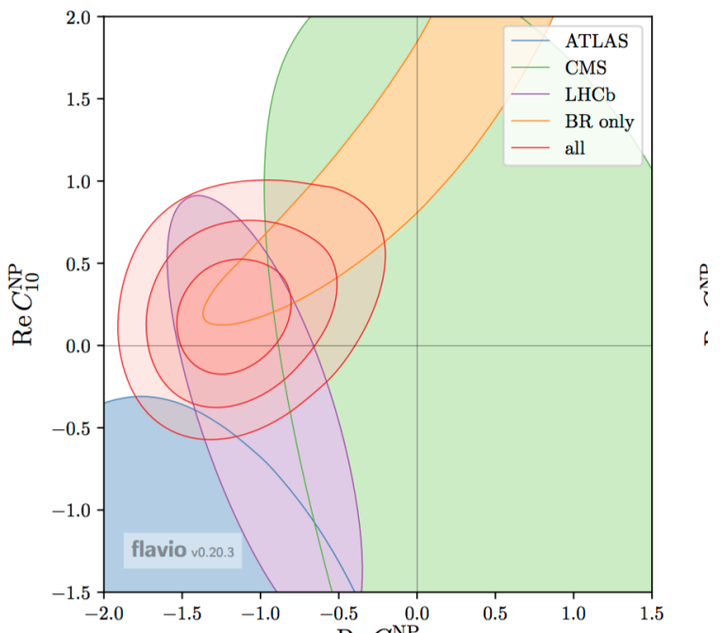


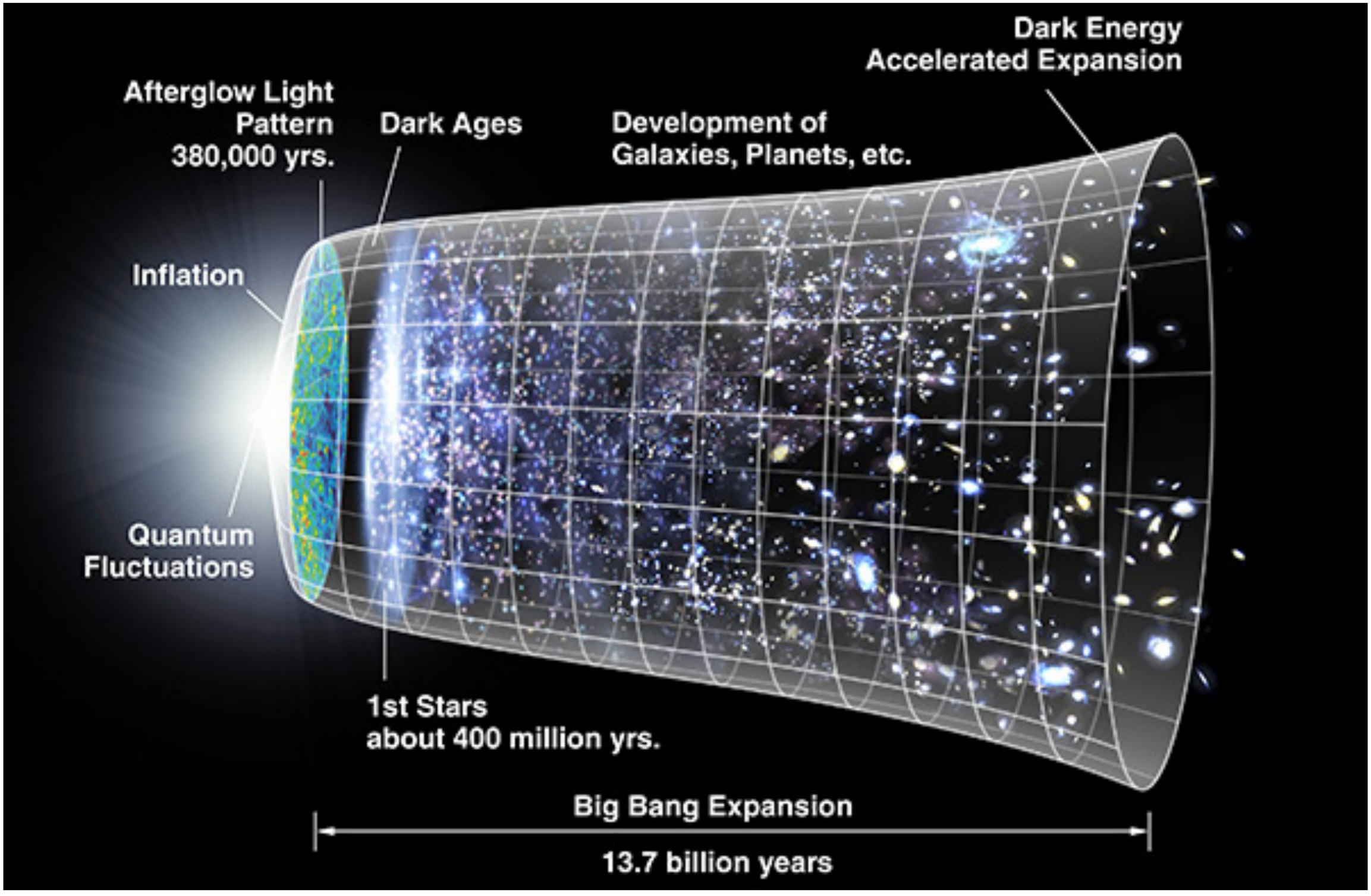


The first glimpse of physics beyond the standard model?

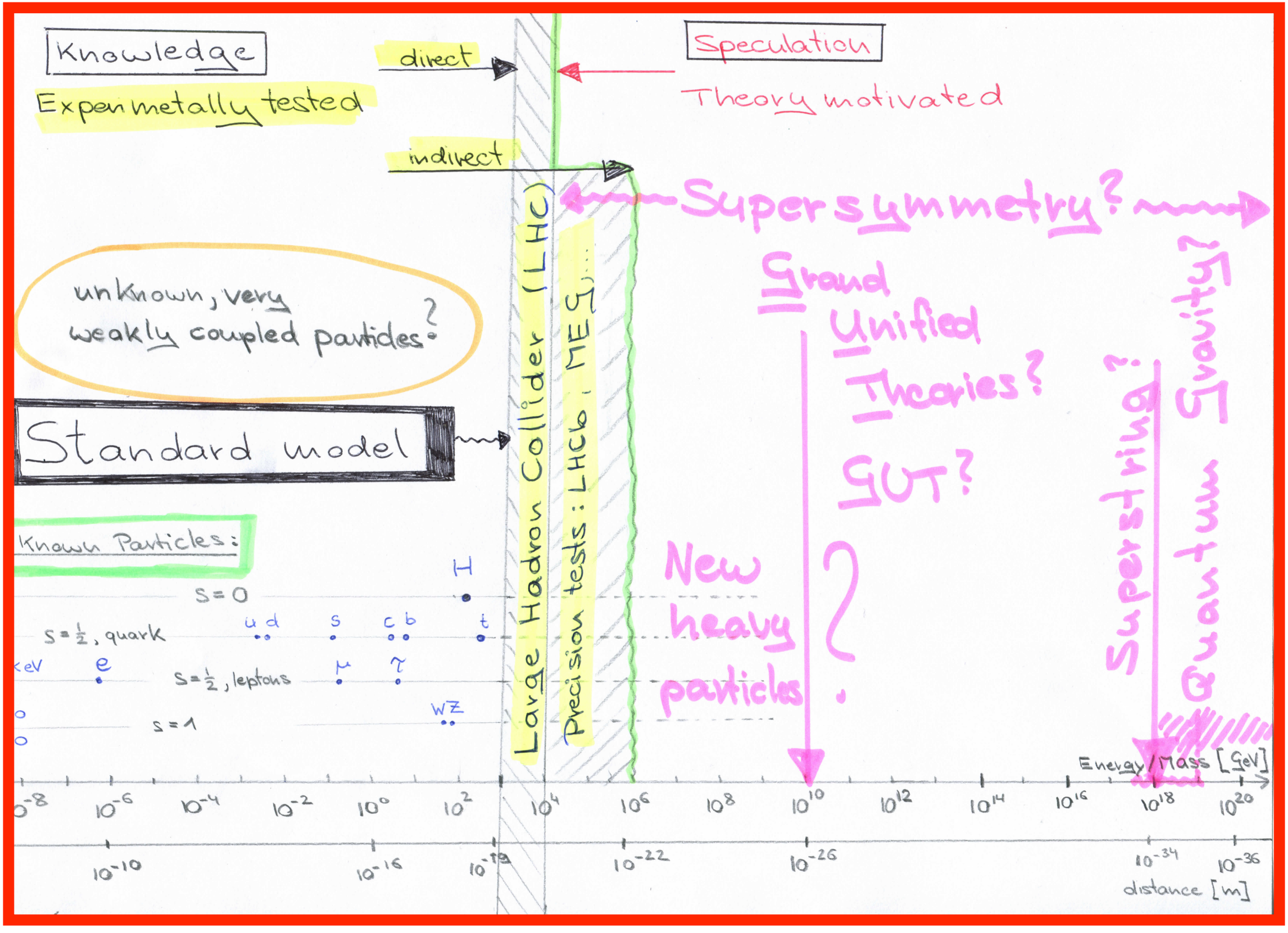
$$Q_{9V} = \frac{\alpha_e}{4\pi}\left(\bar{s}_L\gamma_\mu b_L\right)\left(\bar{l}\gamma^\mu l\right)$$

$$Q_{10A} = \frac{\alpha_e}{4\pi}\left(\bar{s}_L\gamma_\mu b_L\right)\left(\bar{l}\gamma^\mu\gamma^5 l\right)$$




Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

4. Open questions in particle physics



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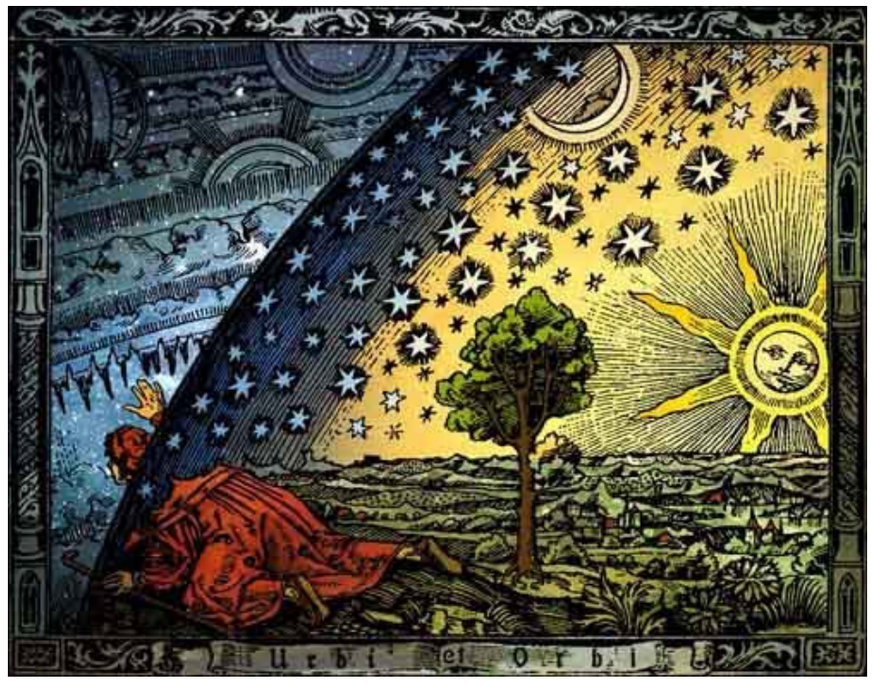
Be curious and do not stop asking questions



Formal education:

1. University degree: 3 - 4 years

2. PhD: 4 years

3. Post-docs: several 2-3 year positions

4. After a lot of hard work and some luck:
get your first permanent position and
start to do a lot of administration….

87 papers found, 83 of them citeable (published or arXiv)

Citation summary results	Citeable papers	Published only
Total number of papers analyzed:	83	55
Total number of citations:	6,691	4,904
Average citations per paper:	80.6	89.2
Breakdown of papers by citations:		
Renowned papers (500+)	2	1
Famous papers (250-499)	7	5
Very well-known papers (100-249)	11	10
Well-known papers (50-99)	10	9
Known papers (10-49)	31	22
Less known papers (1-9)	19	7
Unknown papers (0)	3	1
h_{HEP} index [?]	37	34

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