Why spend billions on a particle accelerator?

Alexander Lenz, IPPP, Durham University

Google UK

People also ask

How much did it cost to build the Large Hadron Collider?

The total operating budget of the LHC runs to about $1 billion per year. The Large Hadron Collider was first turned on in August of 2008, then stopped for repairs in September until November 2009. Taking all of those costs into consideration, the total cost of finding the Higgs boson ran about **$13.25 billion**. Jul 5, 2012

How Much Does It Cost To Find A Higgs Boson? - Forbes
www.forbes.com/sites/alexknapp/2012/.../how-much-does-it-cost-to-find-a-higgs-boson/

Search for: How much did it cost to build the Large Hadron Collider?

Home INDEPENDENT

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British workers living in poverty 'at a record high'

theguardian

Child poverty in UK at highest level since 2010, official figures show

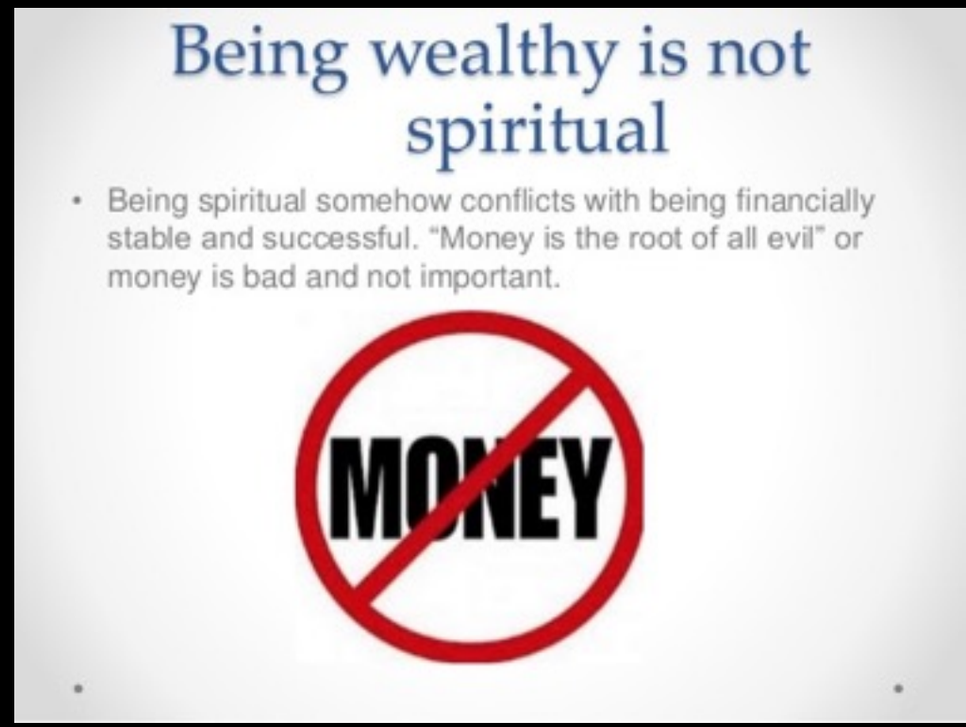
About 30% of Britain's children are now classified as poor, of whom two-thirds are from working families

NHS could face its worst January as it struggles with festive backlog, warns doctor

Health service is facing the equivalent of the 'credit card bill from hell' after Christmas, says president of the Society for Acute Medicine

We should think carefully for what we spend billions!

To start: forget about money!



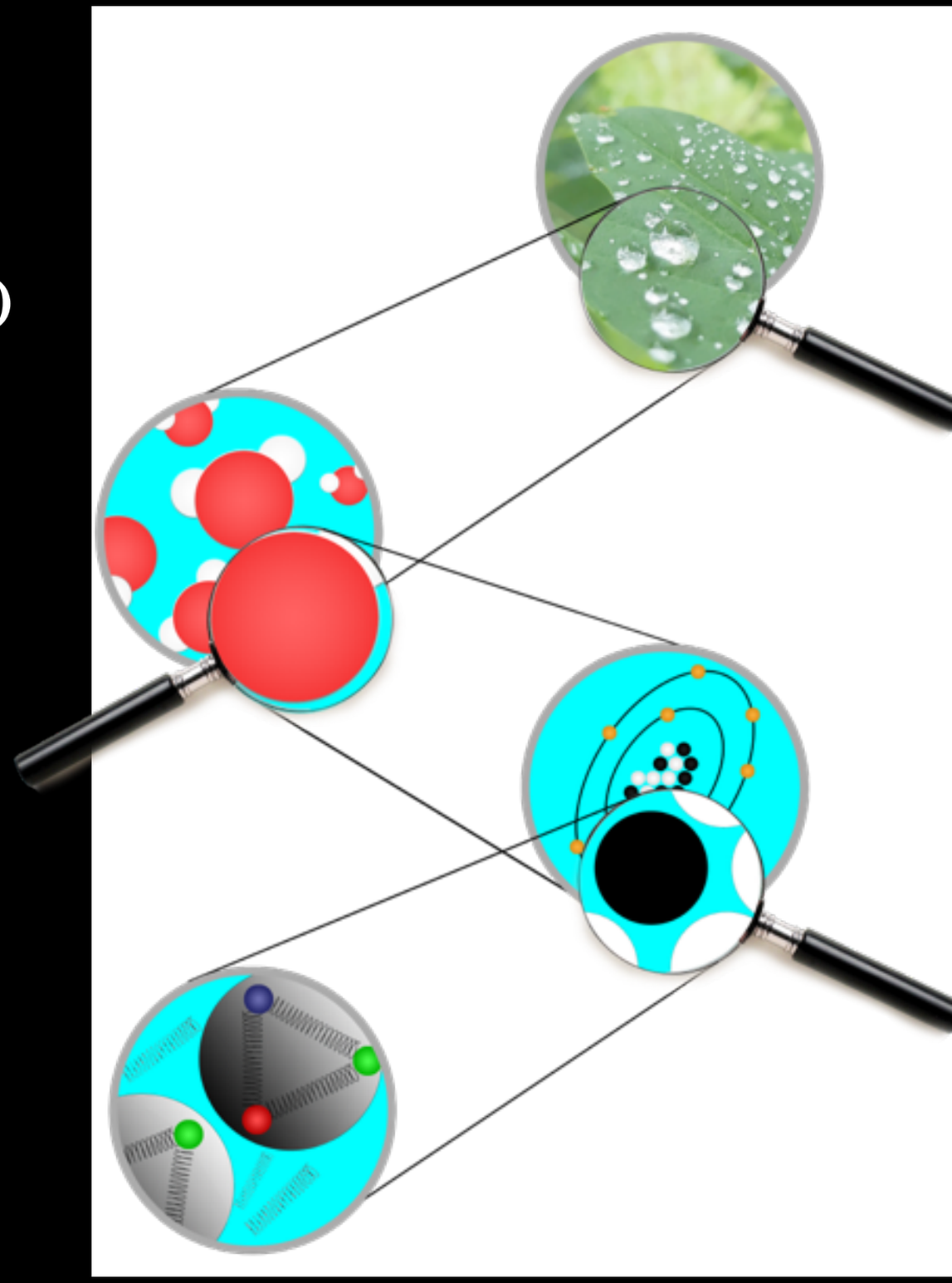
What are we doing in Particle Physics?

Trying to understand the world!

What are the fundamental building blocks of the Universe?
What fundamental forces are acting among them?
Where do we know all of this from?
Is this already the end of knowledge?

What is our world made of?

- All ordinary **matter** consists of **atoms** (atomos [Greek]= indivisible):
  A drop of water consists of H_2O molecules, which are made of 2 hydrogen and one oxygen atom
- **Atoms** consist of **electrons** surrounding a **nucleus**
- A **nucleus** consists of **protons** and **neutrons**
- **Protons and neutrons** are built up of **quarks**



What is our world made of?

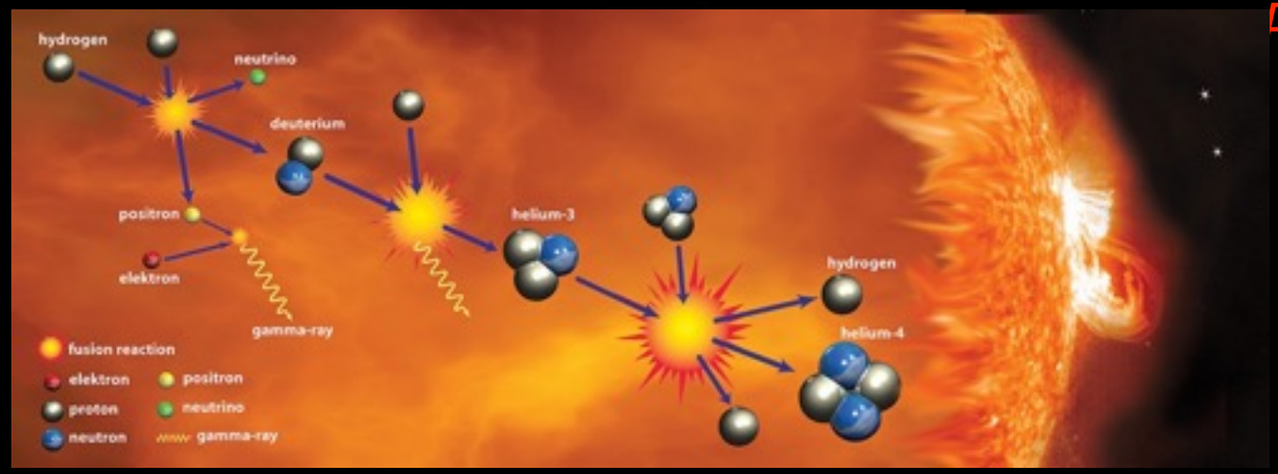
We found the following **fundamental interactions** in nature:

- **Gravity:**

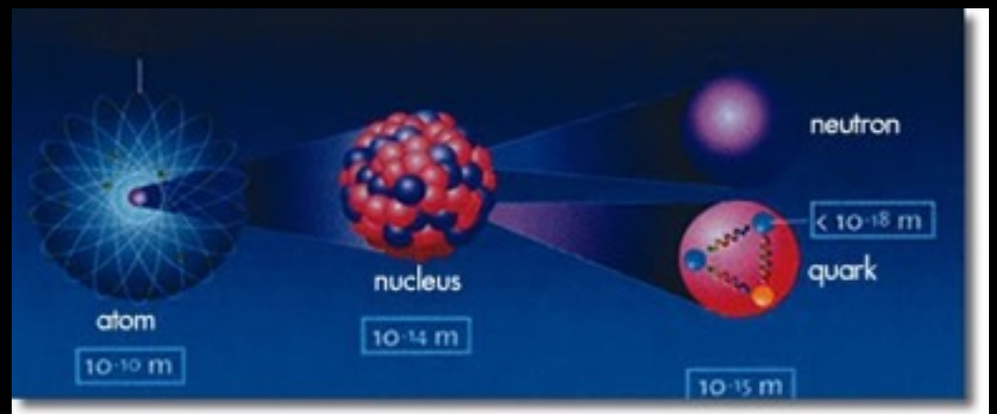
- **Electromagnetic interaction:**

photons

- **Weak interaction:**
  W, Z bosons



- **Strong interaction:**
  gluons



The Standard Model of Particle Physics

All known fundamental particles in the Universe can be structured as

Matter constituents:

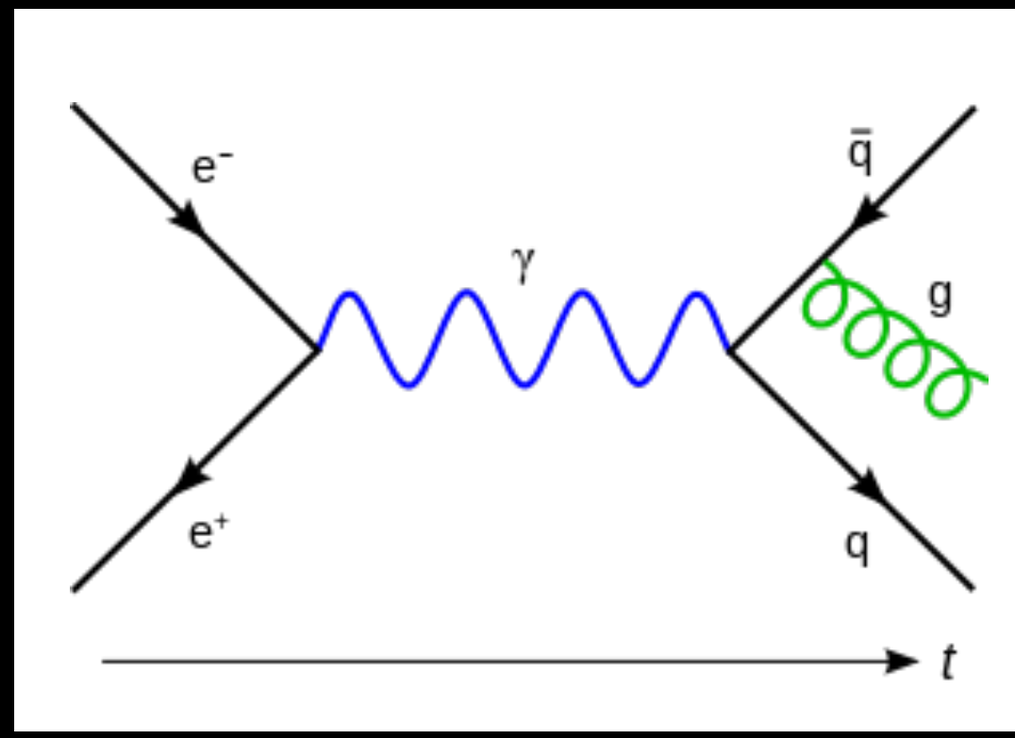
Quarks **Leptons**

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix} \qquad \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

Force carriers: all fundamental forces are transmitted by them

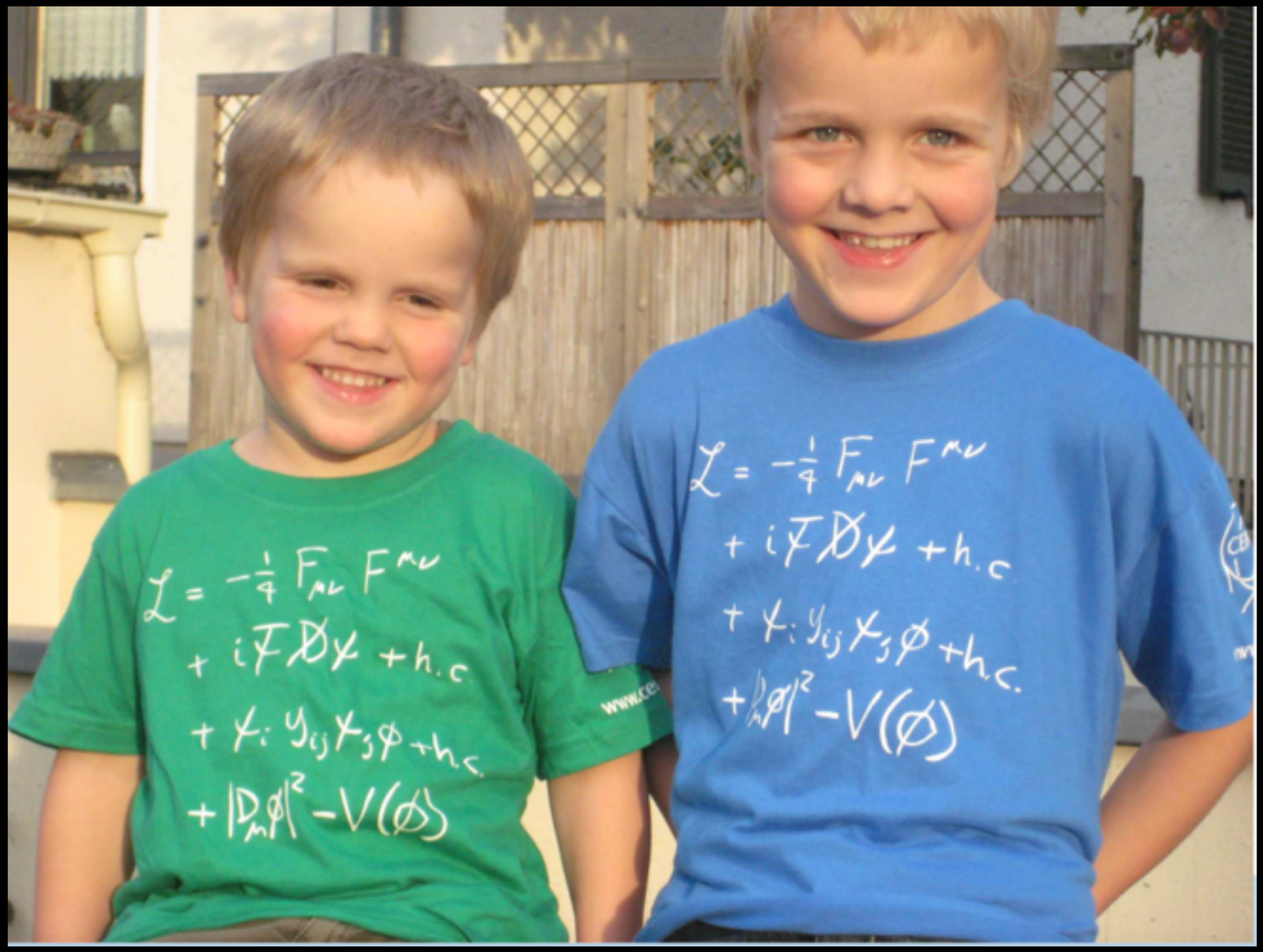
photon: electro magnetic interaction
gluons: strong interaction
W, Z bosons weak interaction

Mass creation: Higgs boson h



The Standard Model of Particle Physics

= all our knowledge of particle physics



Gravity is not included because we do not have a quantum version of it and its effects are also negligible in the microworld.

How do we know all of this?

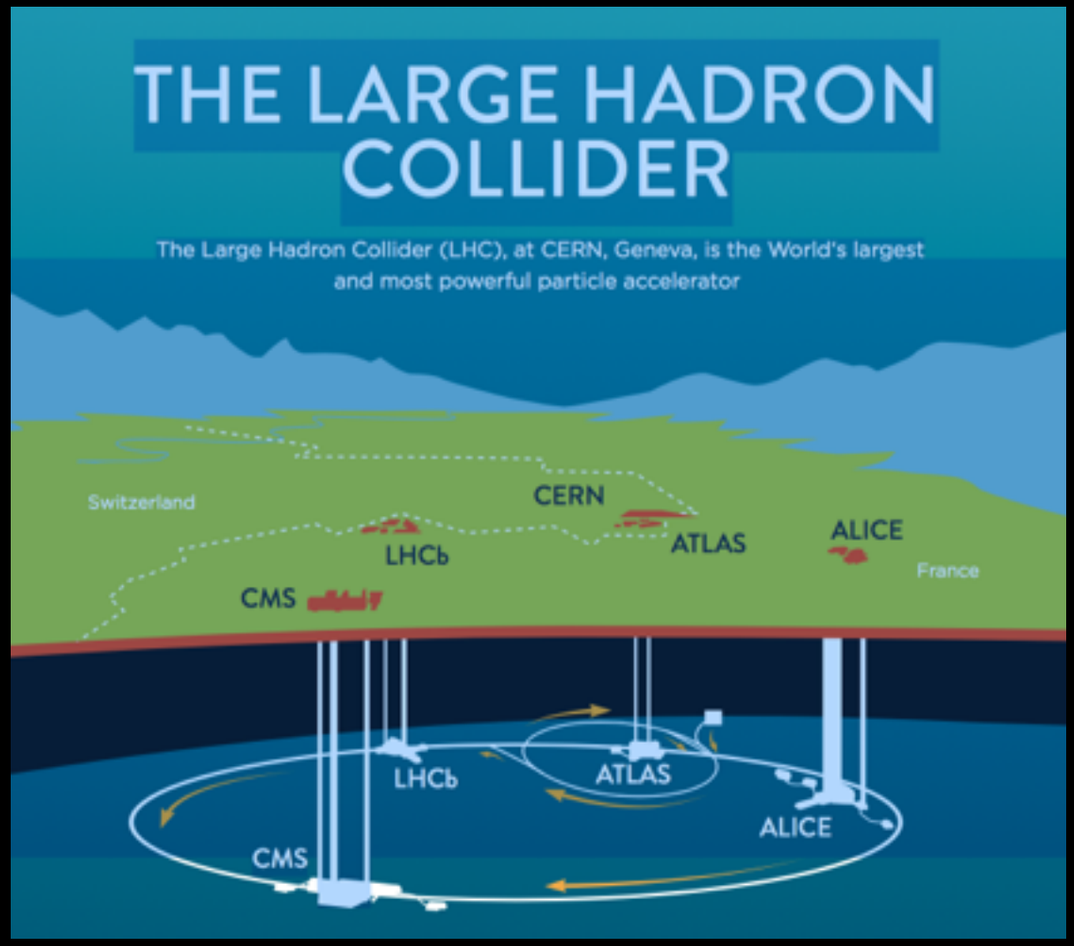
Optical microscope: objects as small as the wavelength of light - size of **small bacteria**

For smaller objects we need shorter wavelengths - which is equivalent to **higher energies**

The highest possible energies can currently be created with the **LHC**, which is thus our biggest microscope

In every second at the LHC, we can have 600 million collisions of a proton with another proton.

The energy of the proton beam corresponds to the energy of 2 ton vehicle with a velocity of more than 1000 mph!



Is there anything beyond the Standard Model?

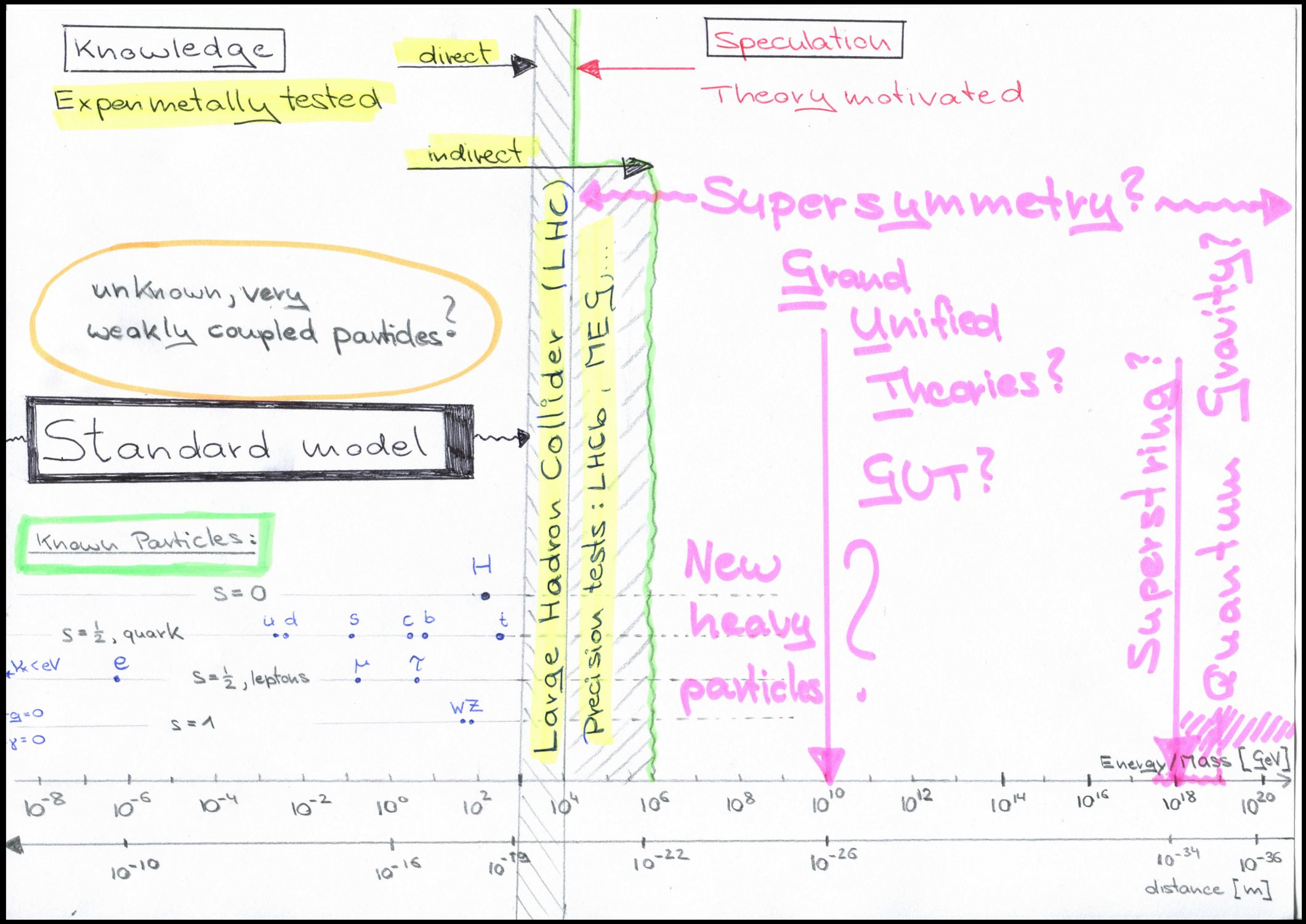
Is there anything beyond the Standard Model?

The **Standard Model** is **extremely successful**
it accurately predicts
hundreds of observables at the quantum level

BUT

Leaves some important questions open, like
How was matter created in the Universe?
What is the origin of dark matter?

How far does our knowledge stretch?



IPPP @ Durham University

- **National Institute for Particle Physics Phenomenology**

- International team about **80 scientists, PhD students and support staff**

- 2016: > **200 scientific papers** and involved in the organisation of > 30 scientific meetings

Located in the North-east of England close to Hadrians Wall

Similar to:

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

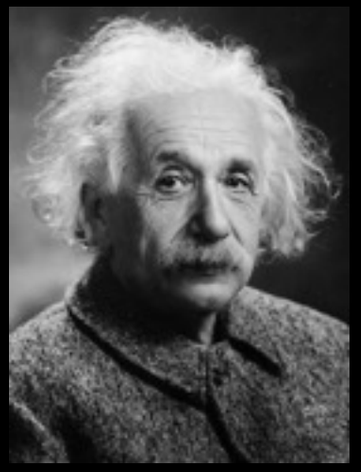
Fundamental research: Spin-offs

- 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,…



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!

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

There is more in life than money…

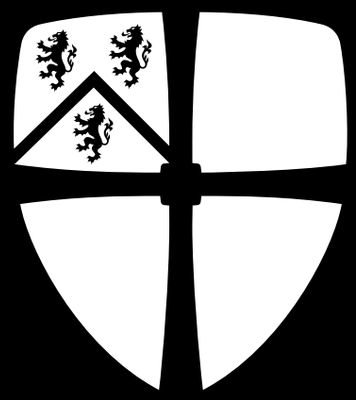
SENATOR PASTORE: Is there anything connected in the hopes of this accelerator that in any way involves the security of the country?
DR. WILSON: No, it has nothing to do directly with defending our country **except to help make it worth defending.**

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

(Richard Feynman)

www.modellinginvisible.org

Twitter: @IPPP_Durham #modellinginvisible



Durham
University

The End

Exhibit #1

The Galton board exhibit shows a similar problem: As the steel balls roll down, they scatter off the needles and a hidden shape, but just from looking at the collection bins, it is hard to work out the shape directly.

What can be done, however, is to simulate the board with different hidden shapes and compare the outcome…

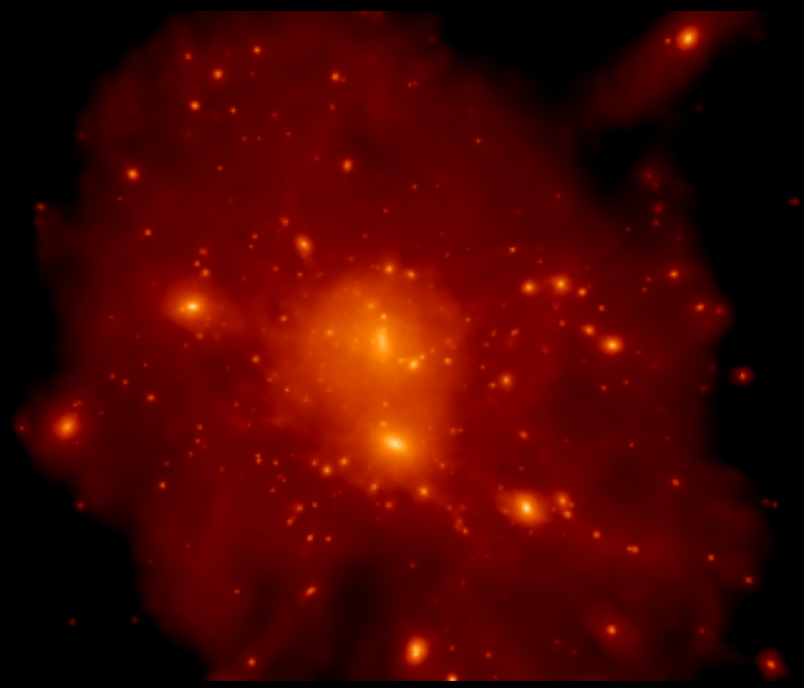
Exhibit #1

Image 1: Simulation of galton board

Image 2: LHC data compared to simulation

The procedure at the LHC is very similar; simulated data of various possible models is compared with the measured data points. The more data we collect, the better the comparison becomes at distinguishing between options.

Dark matter

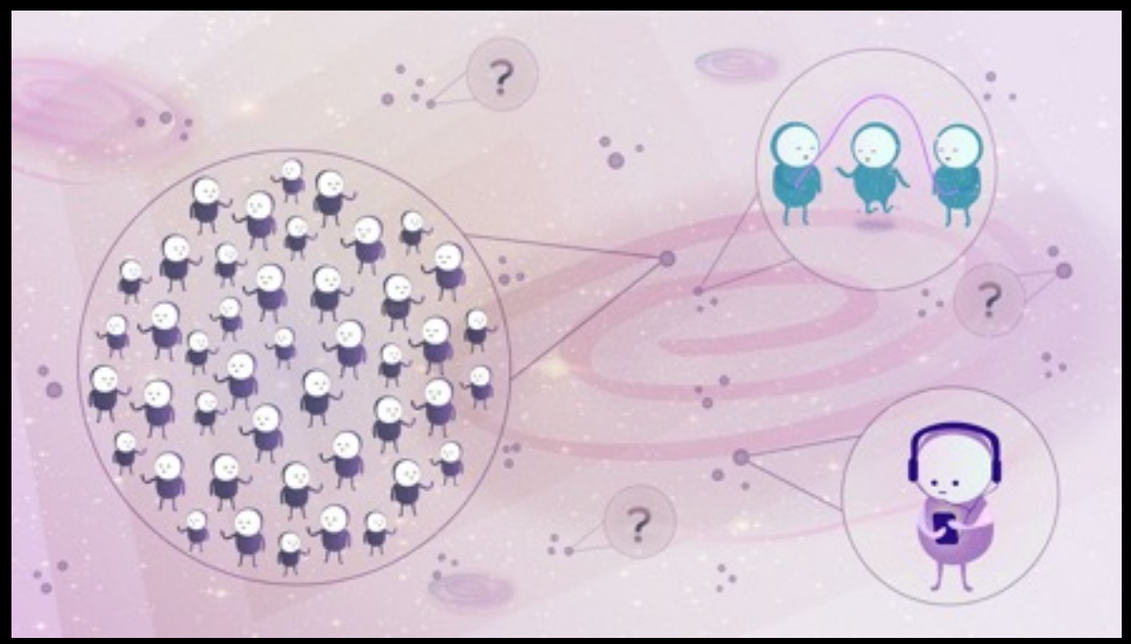


In the early 1970s Vera Rubin and Kent Ford confirmed that the stars in nearby galaxies **rotated faster** than what was expected from their visible mass.

If Einstein's theory of gravity is correct, the only reasonable explanation for this is that there should be **more mass** around the each galaxy that we **cannot see** (the so-called halo). This is what physicists call **Dark Matter.**

In order to agree with the observed rotational velocities one can infer that, in addition to all the visible matter, there must be **5 times** more Dark Matter that is **invisible to us**.

Dark matter



How does Dark Matter fit in the Standard Model?

Physicists have many different theories about what Dark Matter could be.

Since all the particles predicted by the Standard Model have been discovered, but don’t have the right properties, Dark Matter has to be something experiments have never seen before.

Furthermore, it must interact **very weakly** with the Standard Model particles, since otherwise we would have seen such interactions by now.

Exhibit #2

One could try to build a **detector** specifically designed to give a signal if a Dark Matter particle passes through it.

However, since Dark Matter interacts very weakly, the **chances** to detect a Dark Matter particle are very small. Furthermore, the radiation emitted by materials around us and the muons created by cosmic rays in the atmosphere produce a **very similar** signal in the detector.

For example, a muon passes through your hand **every two seconds** and therefore, the high frequency of these fake signals makes detecting a Dark Matter particle even more challenging.

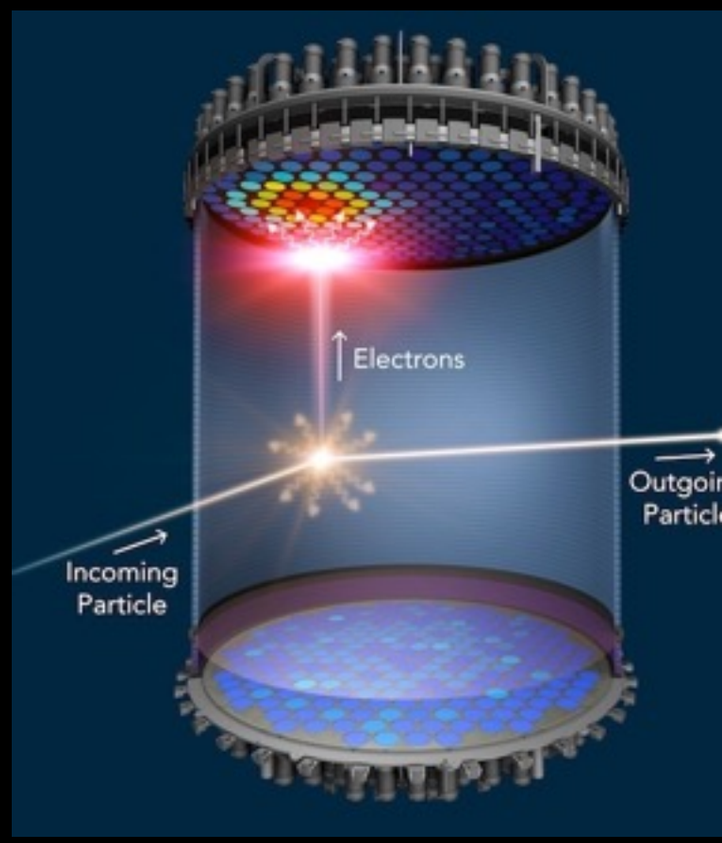
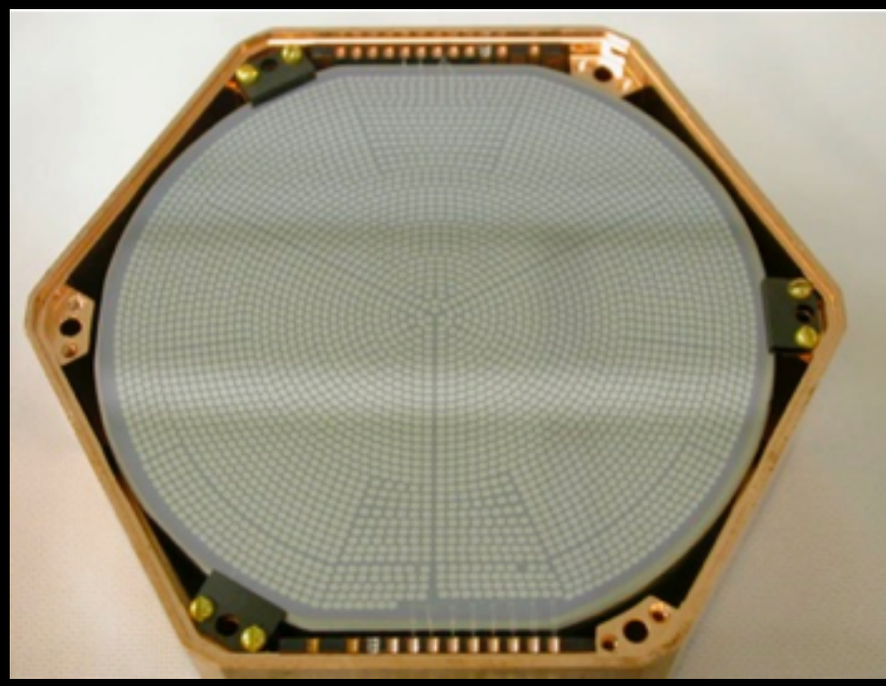


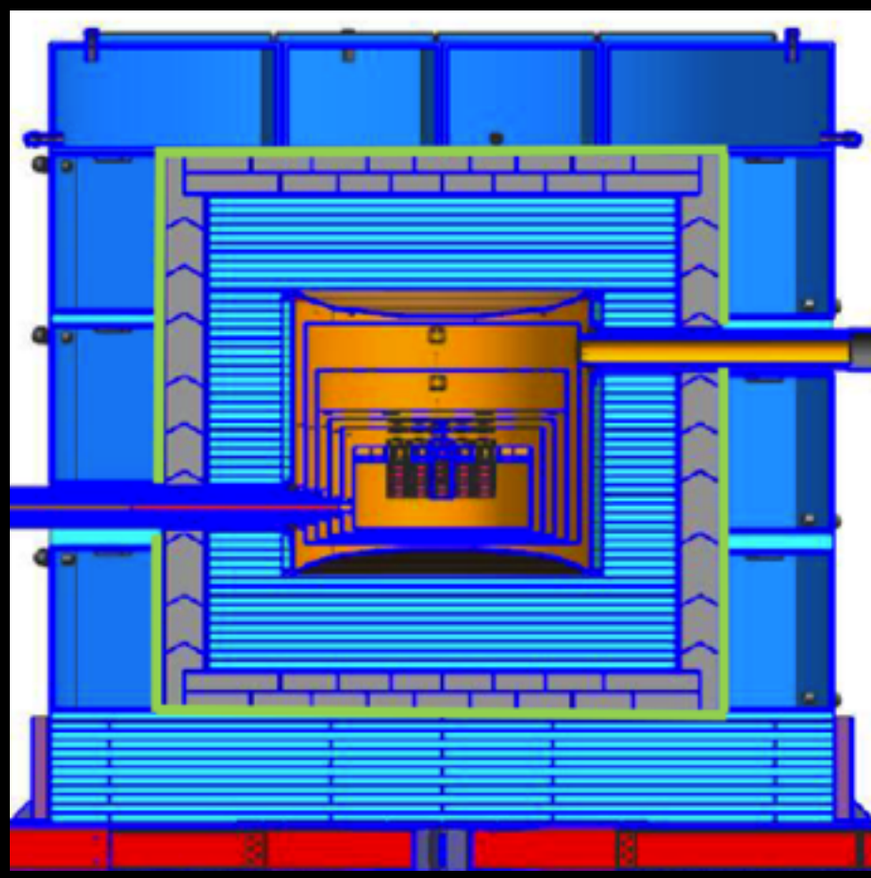
Exhibit #2



In order to increase the odds of discovering a Dark Matter particle, one could, for example:

1) **Bury** the detector deep underground so that the cosmic muons get stopped by the rocks within the Earth.

2) **Shield** the detector to stop the photons and electrons emitted by the rocks around the detector.



3) Improve the **purity** of the shield's material so that it does not emit any radioactivity that could be confused with a signal.

This sounds simple, but one needs to make sure that the cost of the experiment stays within **budget**. Maximizing the chances of discovery keeping the expenses in mind then becomes a difficult task!