Challenges in Particle Physics

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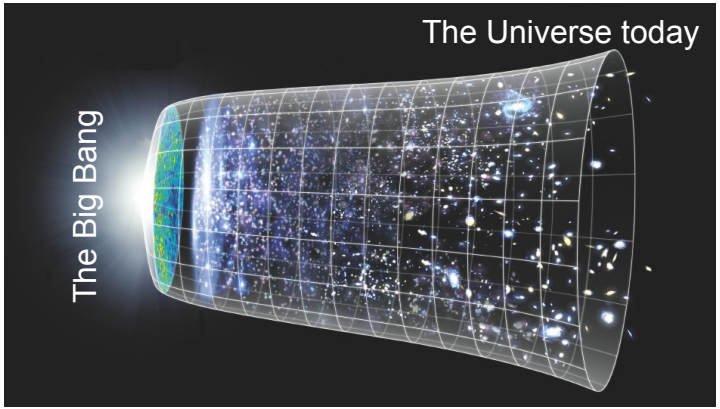
Particle Physics: what is it all about?

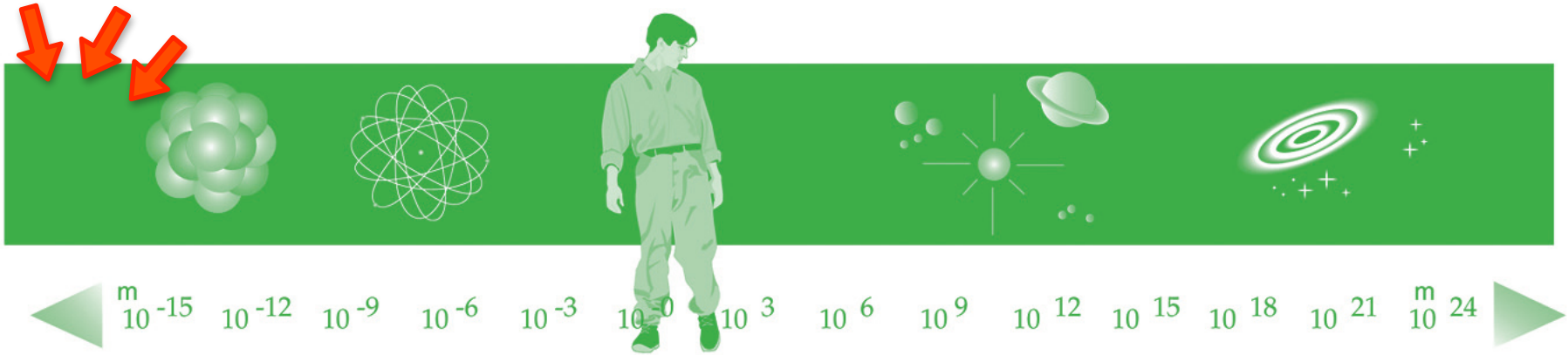
The study of the elementary constituents of matter and their interactions.



What is the Universe made of?

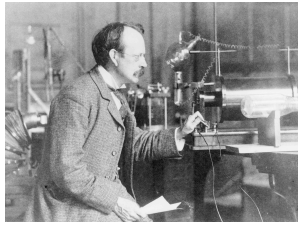
(…how did it develop and how will be its future?)

This means exploring smaller and smaller scales…

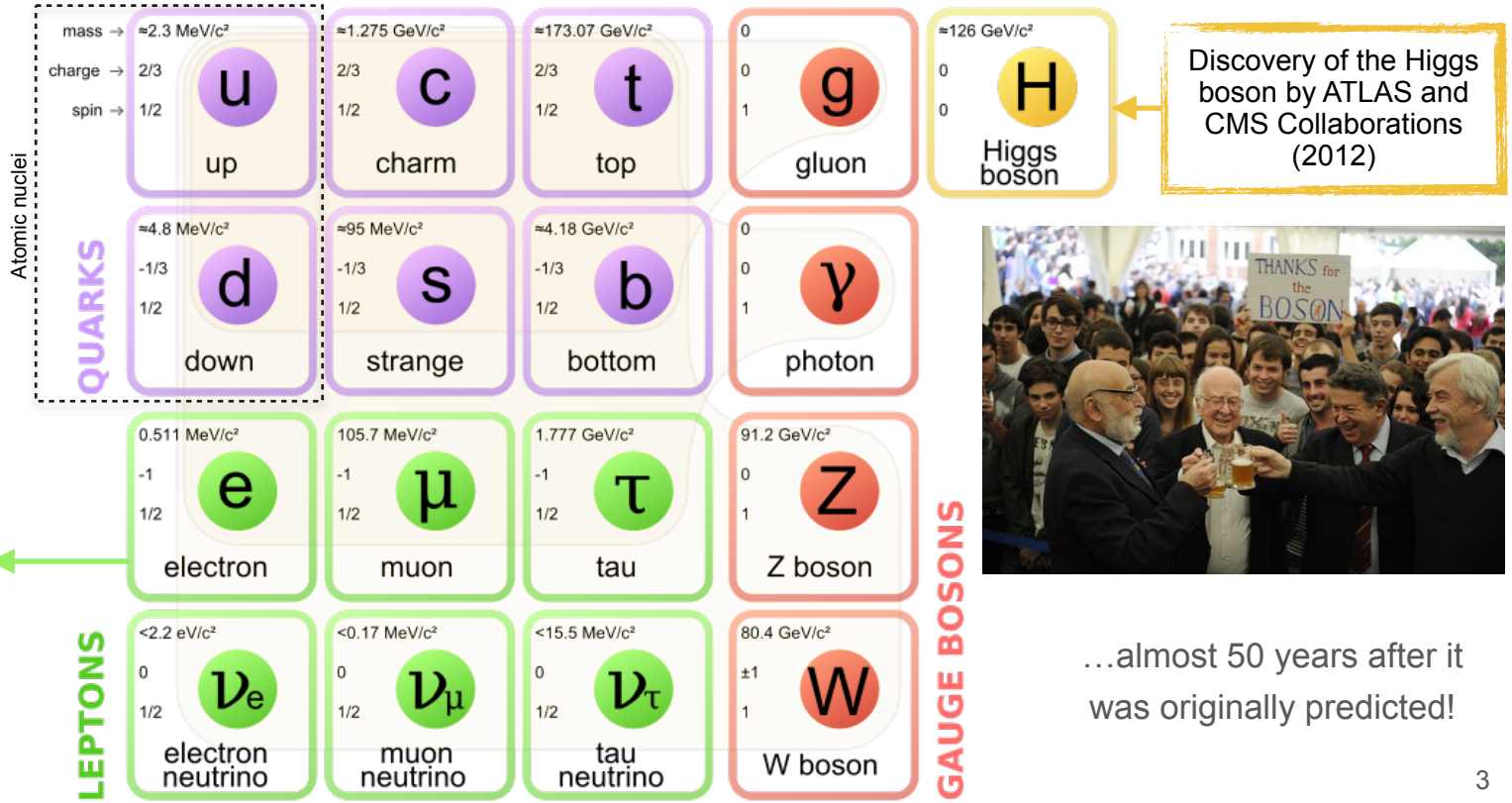


The Standard Model of Particle Physics

A century in the making



Discovery of the electron by J. J. Thompson (1897)



Discovery of the Higgs boson by ATLAS and CMS Collaborations (2012)

…almost 50 years after it was originally predicted!

The Higgs boson is special

- It’s a manifestation of the Higgs field.
  - …and the **Higgs field** is everywhere!

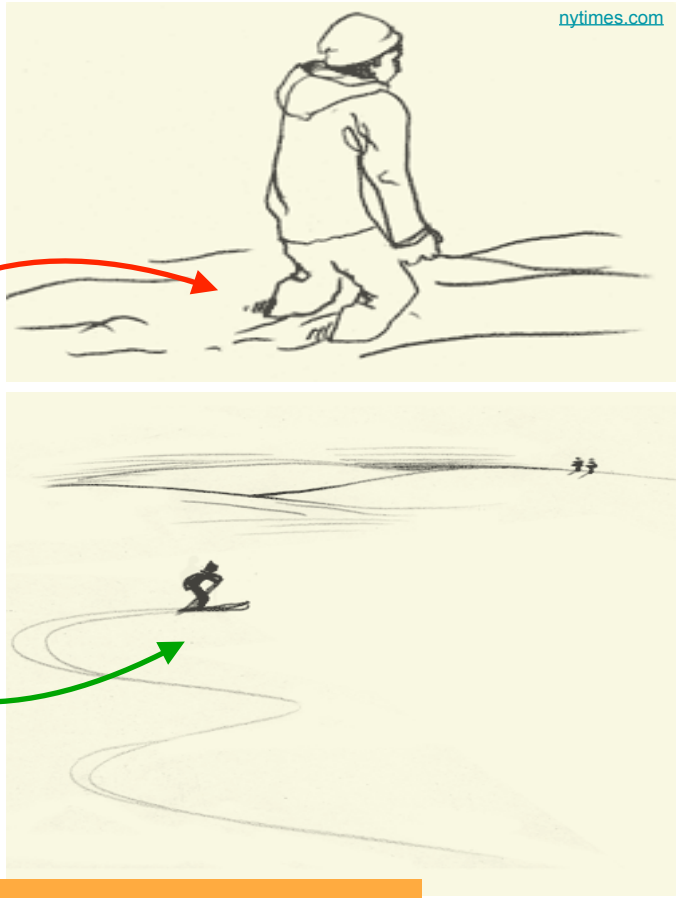
- The field gives particles their mass:

➡ Heavy particles are “slowed down" by the field.

➡ Light particles meet little resistance from the field.

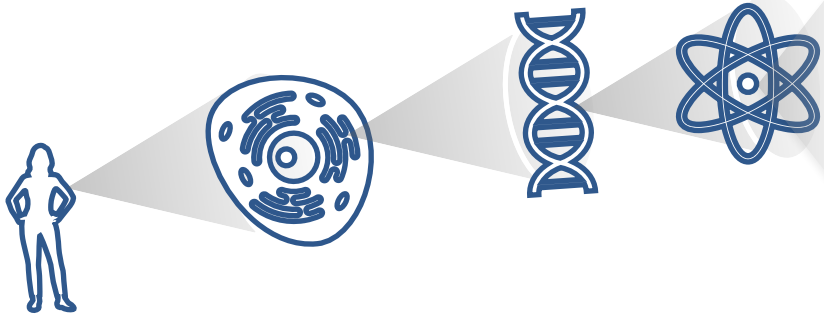
➡ Massless particles just travel through.

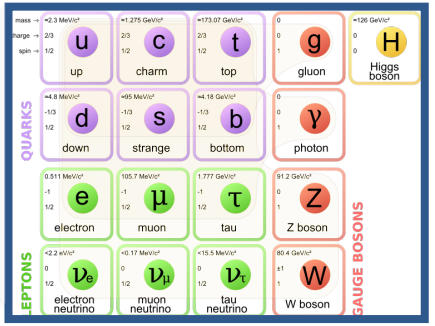
- **It’s an intriguing particle, unlike any other we know, and we’re only getting started! There’s much more to understand…**



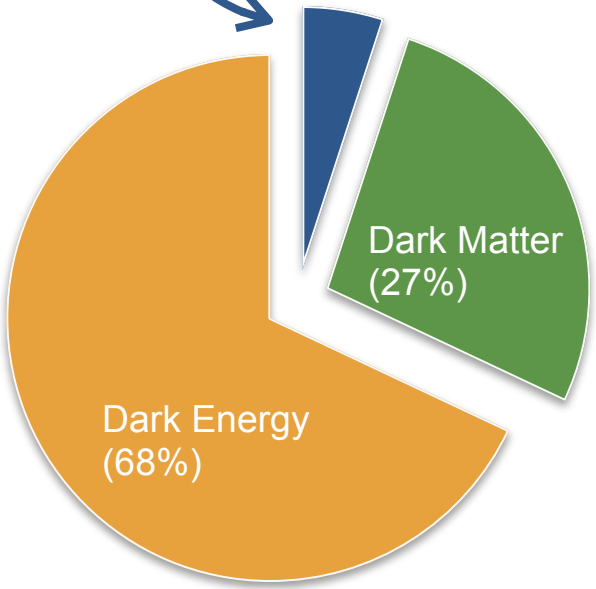
The discovery of the Higgs boson marked the beginning of the journey to understand it**. But why is it so important?**

The Big Picture



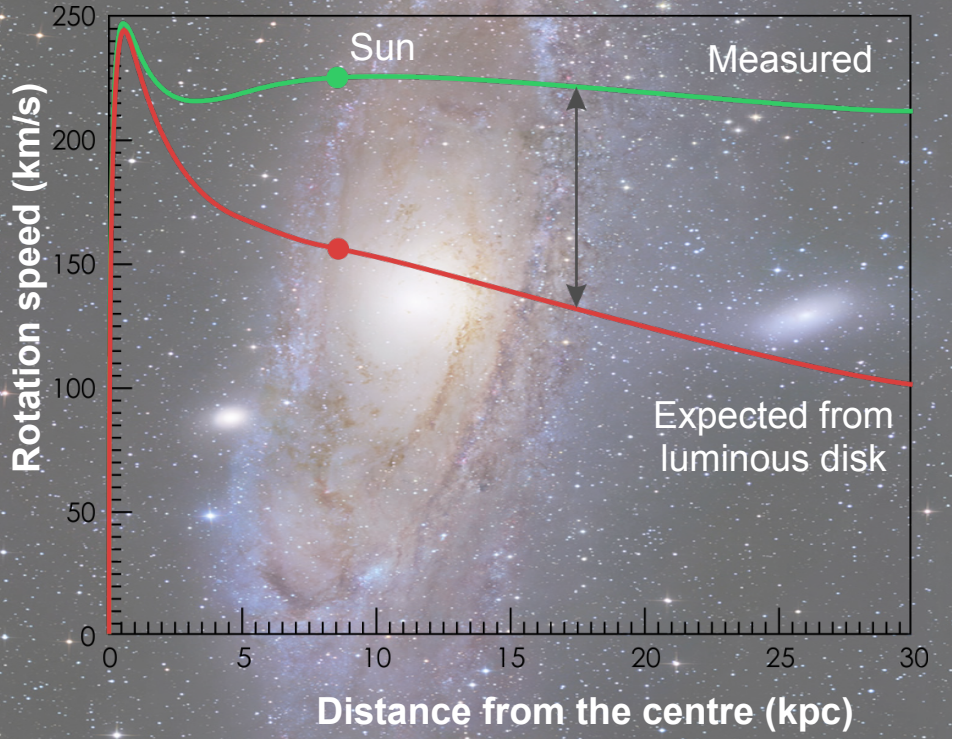


This is us!

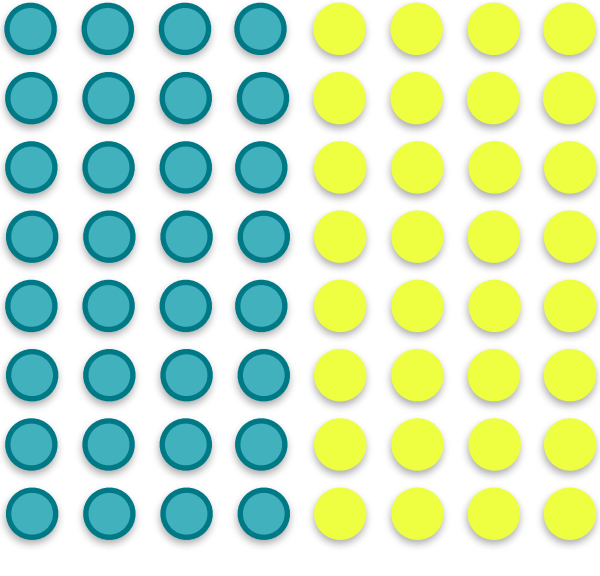


- The Standard Model describes a wide range of phenomena with an impressive degree of accuracy.
- But there is more to the Universe than the Standard Model.
- The Higgs boson is a new path towards discovery!
- **And there are many discoveries to be made…**

Dark matter problem



Matter/antimatter problem



Known sources of asymmetry in the Standard Model are too small to explain the observed matter dominance.

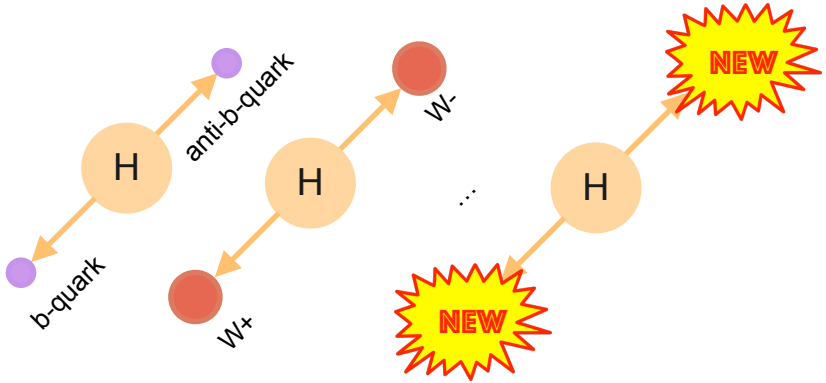
Where do we go from here?

Measuring the Higgs boson

The precision program: Higgs boson as a discovery tool

The Higgs boson interacts with particles that have mass.

Could be a link to new ones!

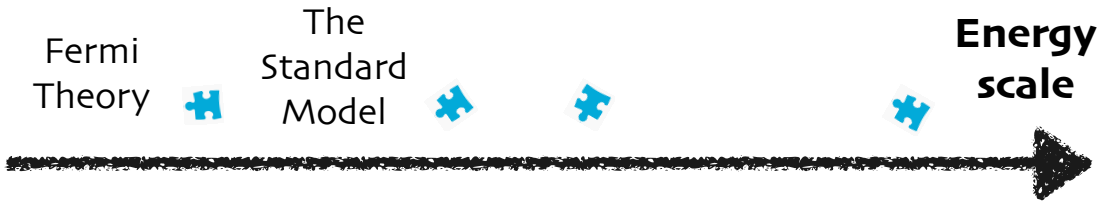


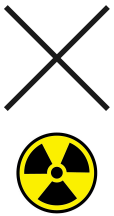
Best performed with copious Higgs bosons and the "clean environment" of a lepton-collider: **a Higgs Factory.**

E.g. if there are decays unaccounted for, it could be the first hint of new phenomena!

The energy frontier

An exploratory mission

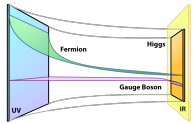




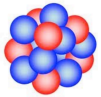
Radioactive decays…

…are exchanges of W bosons when we look more closely.

We are here



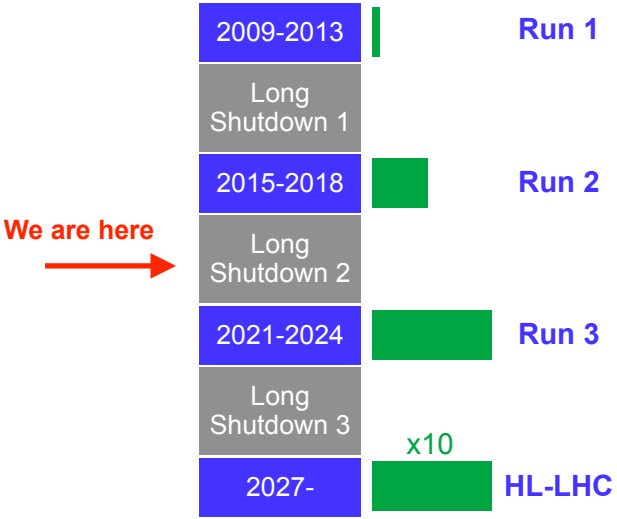
Extra dimensions?



Composite Higgs?

Something completely unexpected?

We are here



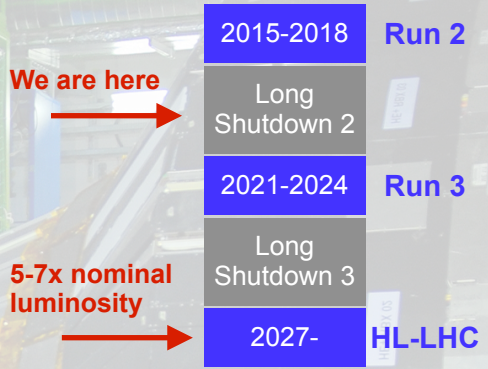
Even if new phenomena are outside the energy reach of a collider, their signs could be visible.

The technological frontier

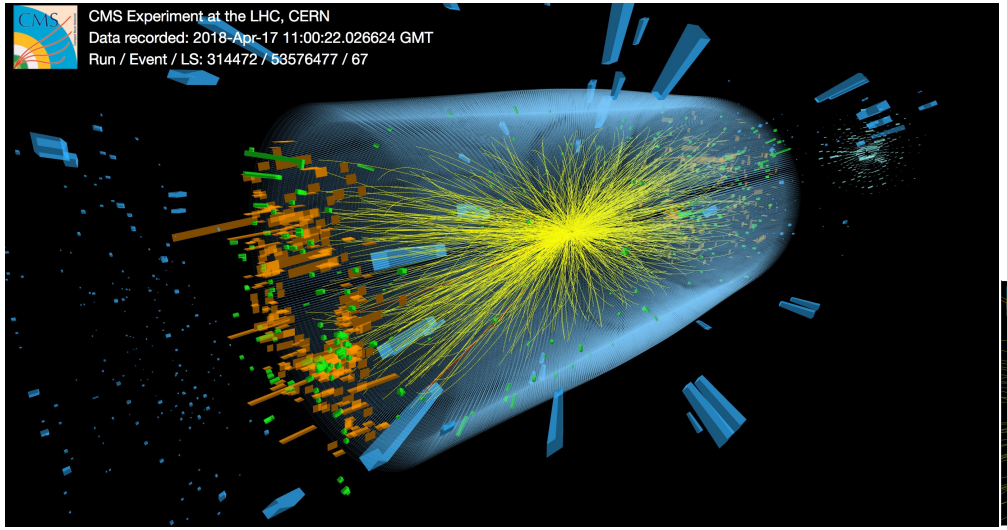
The technological frontiers

Detector electronics

40 million collisions per second, but we can only store 10 000 every second. Need to decide which ones on-the-fly!

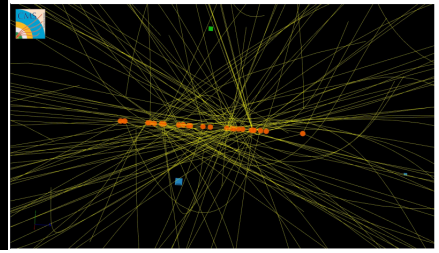


CMS tracker alone has 75 million electronic read-out channels

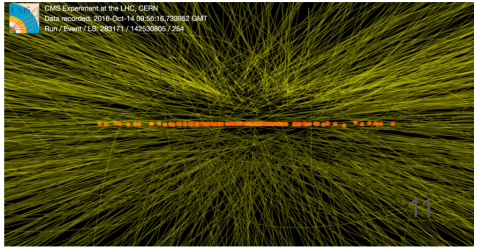


We need fast, high-rate and radiation tolerant electronics to meet the challenges of higher collision rates.

Now

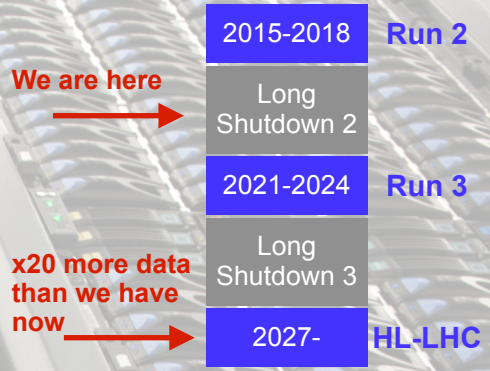


HL-LHC

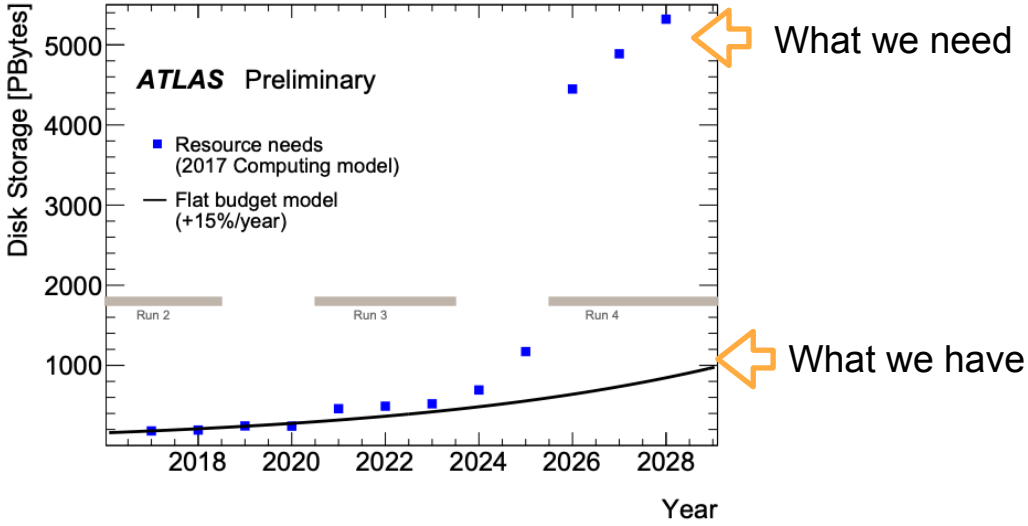


The technological frontiers
Computing

Examining every corner of the Standard Model requires unprecedented data rates and volumes.



Disk storage projection for one experiment



Current solutions don't scale to the CPU and storage demands of the HL-LHC.

Urgent need to tackle the massive data challenges of the LHC experiments.

Need sustainable and effective software solutions for the next decades of computing advances.

LHC resources in 2017:
1 exabyte storage, 500k CPU cores

The technological frontiers

Accelerators

For decades, larger and more powerful accelerators have driven us to the frontiers of particle physics.

Smaller scales

↓

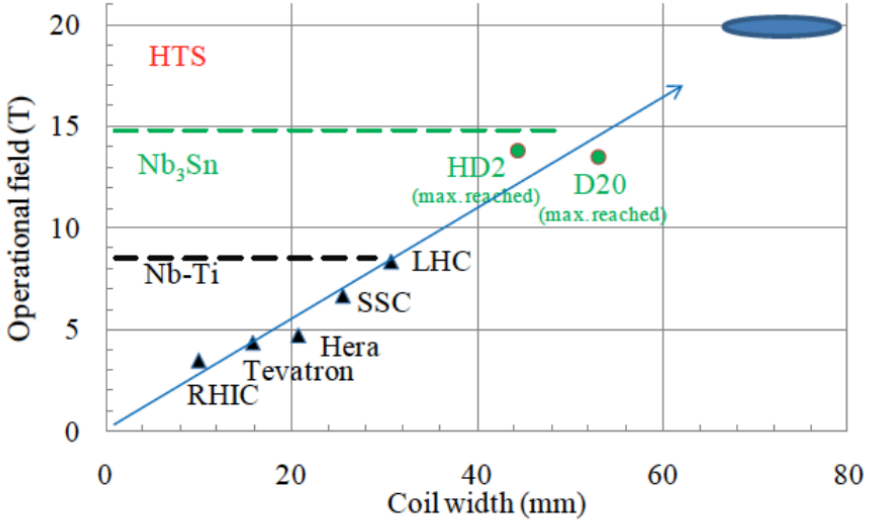
Higher energies

↓

More powerful accelerators

↓

Stronger magnets



Evolution of superconducting Nb-Ti magnets for particle accelerator use.

The LHC magnets are the current state-of-the-art.

Higher collision rates and energies require pushing the limits of superconducting materials and high-field magnet technologies.

Summary

- The Standard Model is one of the greatest scientific achievements of the 20th century…but it is glaringly incomplete.
- The scientific argument is clear: there is more to be discovered and the Higgs boson will be essential.

We are in the lucky position of having the tools, expertise and infrastructure for discovery.