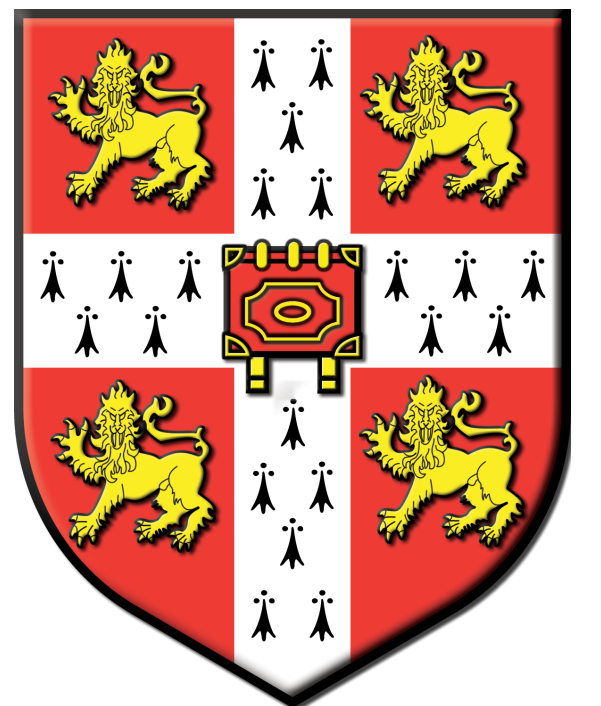


Uncovering the building blocks of the Universe

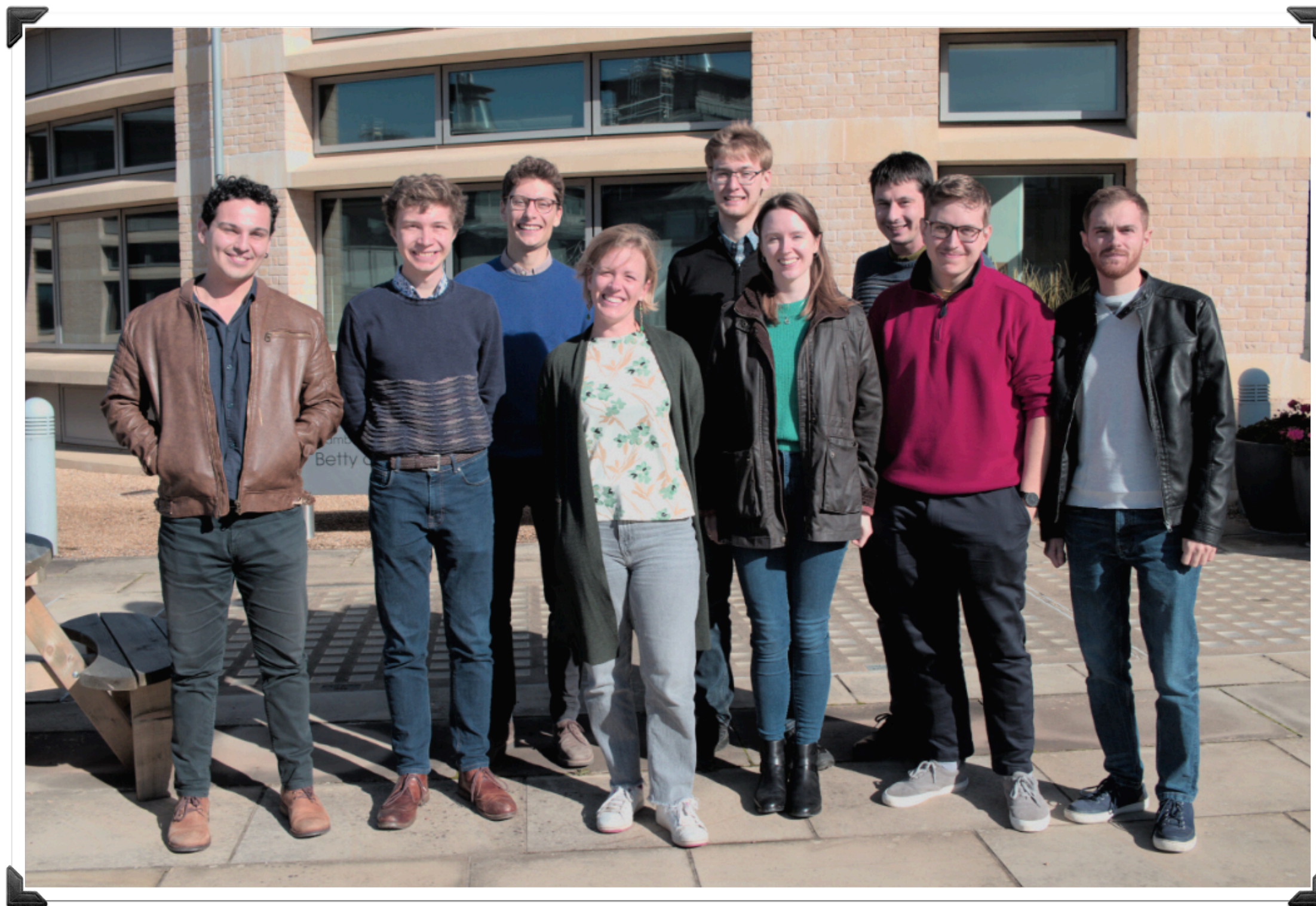
The magic interplay between protons and new physics

The PBSP crew: Elie Hammou, Luca Mantani, Manuel Morales, Maria Ubiali
Department of Applied Mathematics and Theoretical Physics



The PBSP adventure

From October 2020: Physics beyond the Standard Proton

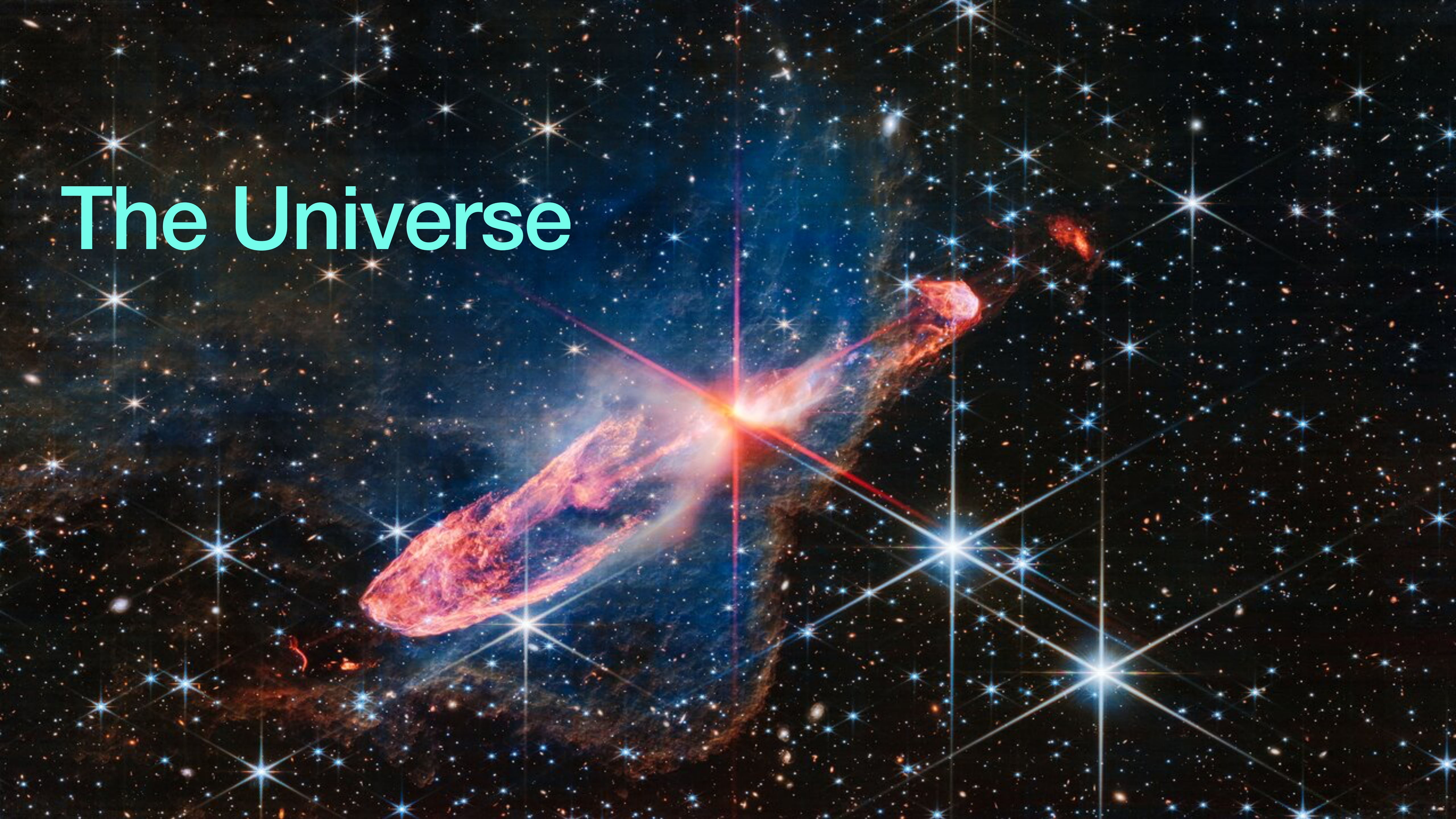


PBS  



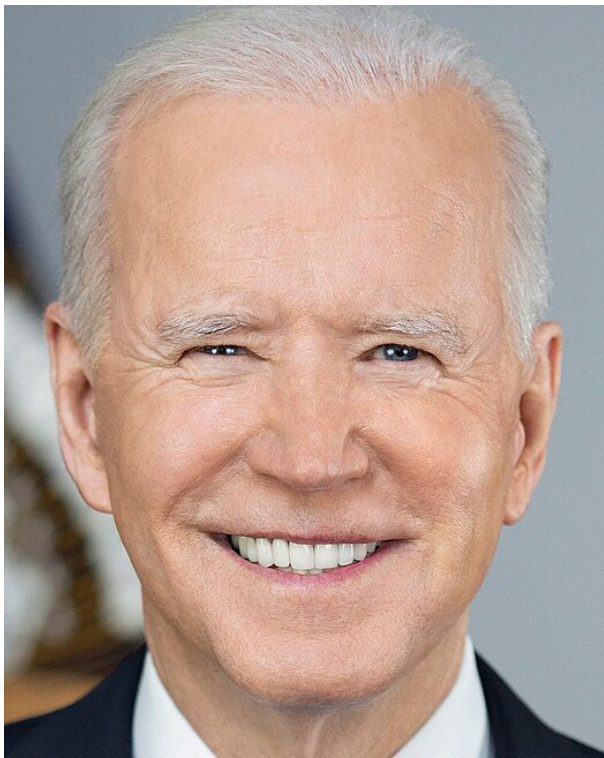
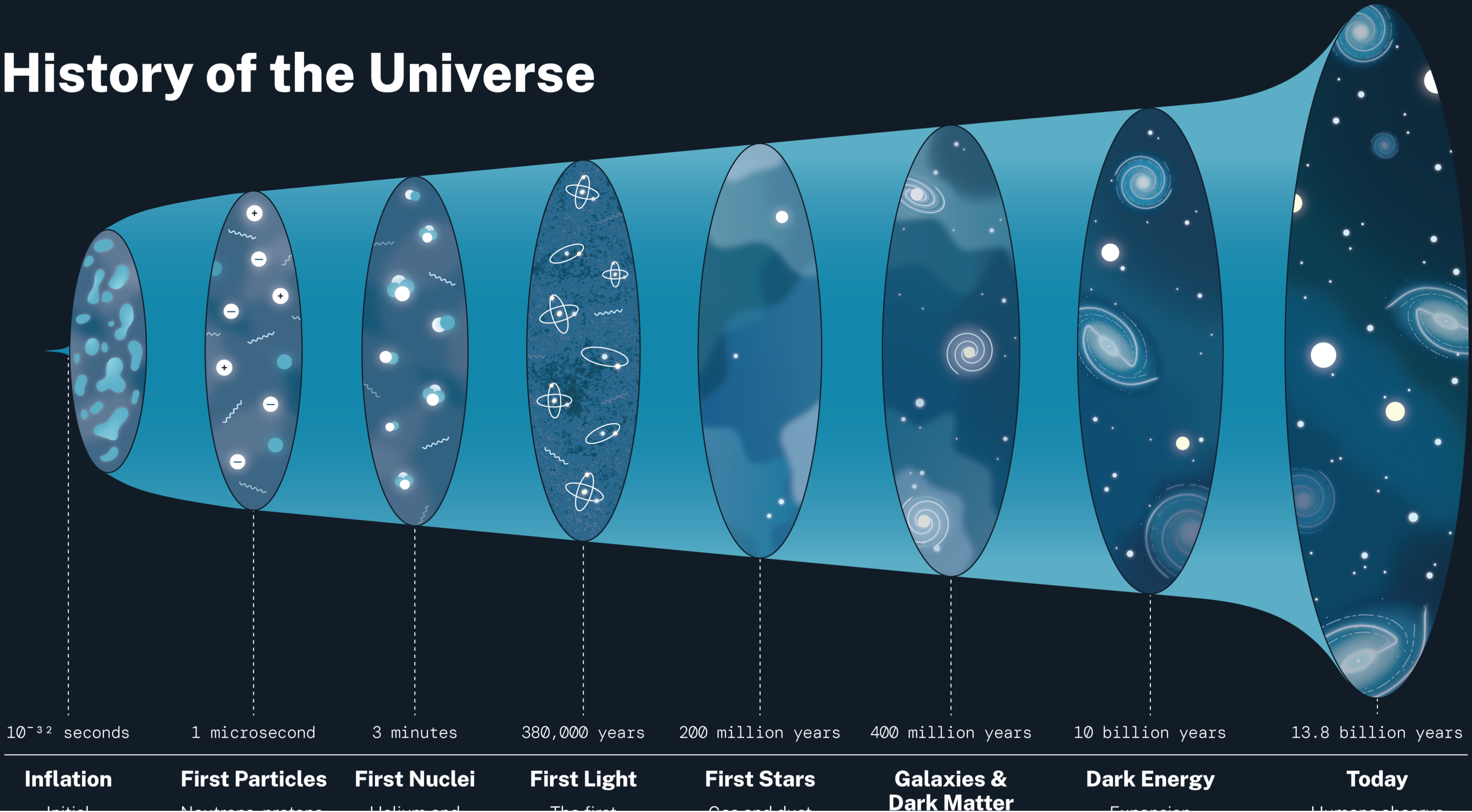
**THANK
YOU!**

Mark Costantini, Fabian Esser, Elie Hammou, Shayan Iranipour, Zahari Kassabov, Maeve Madigan,
Luca Mantani, Francesco Merlotti, James Moore, Manuel Morales, MU, Cameron Voisey



The Universe

History of the Universe



Different scales: different rules

Example of speed

Low speed
(microscopic)



Average speed
(mesoscopic, i.e. us)



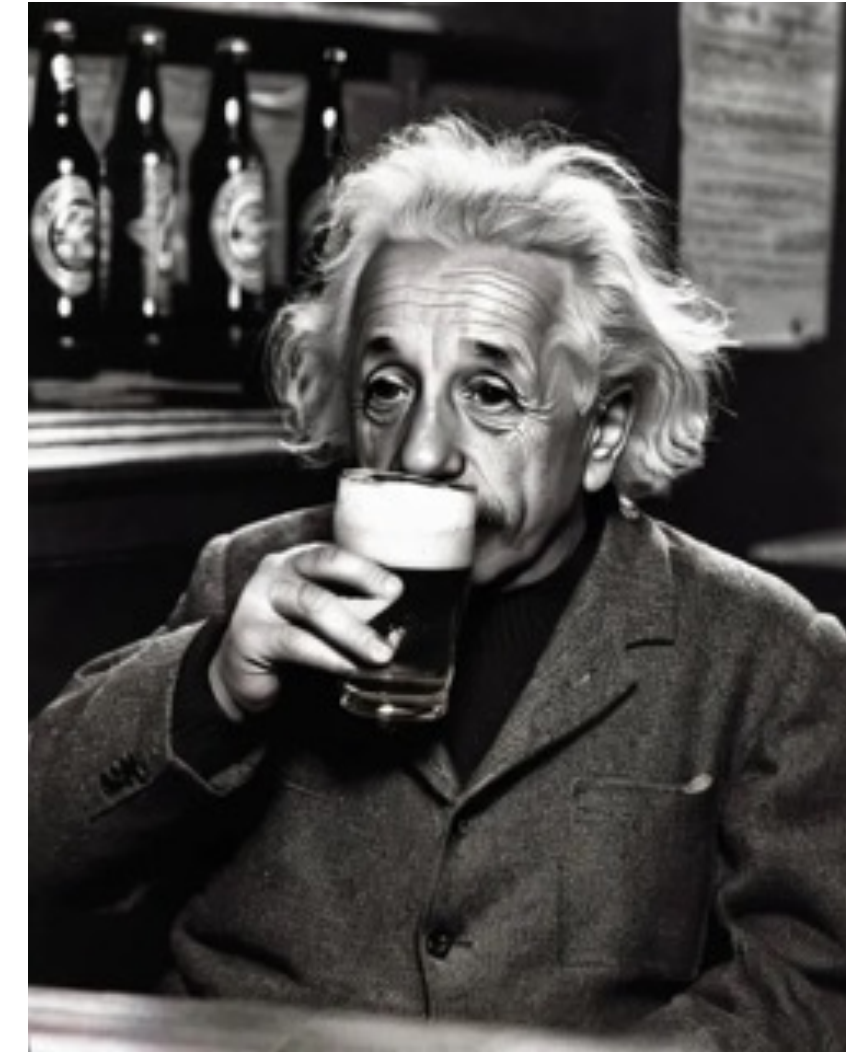
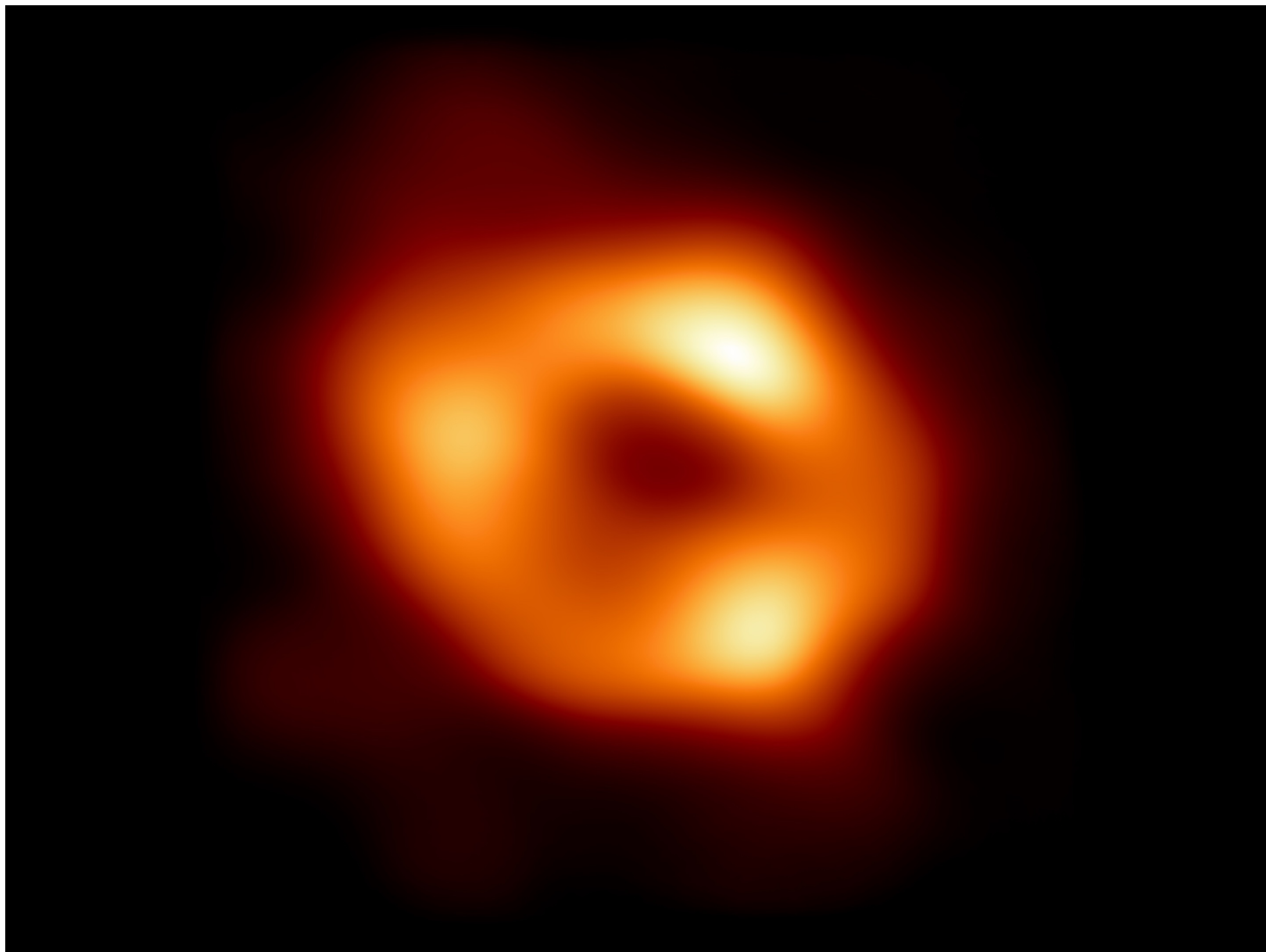
High speed
(macroscopic)



The large scales

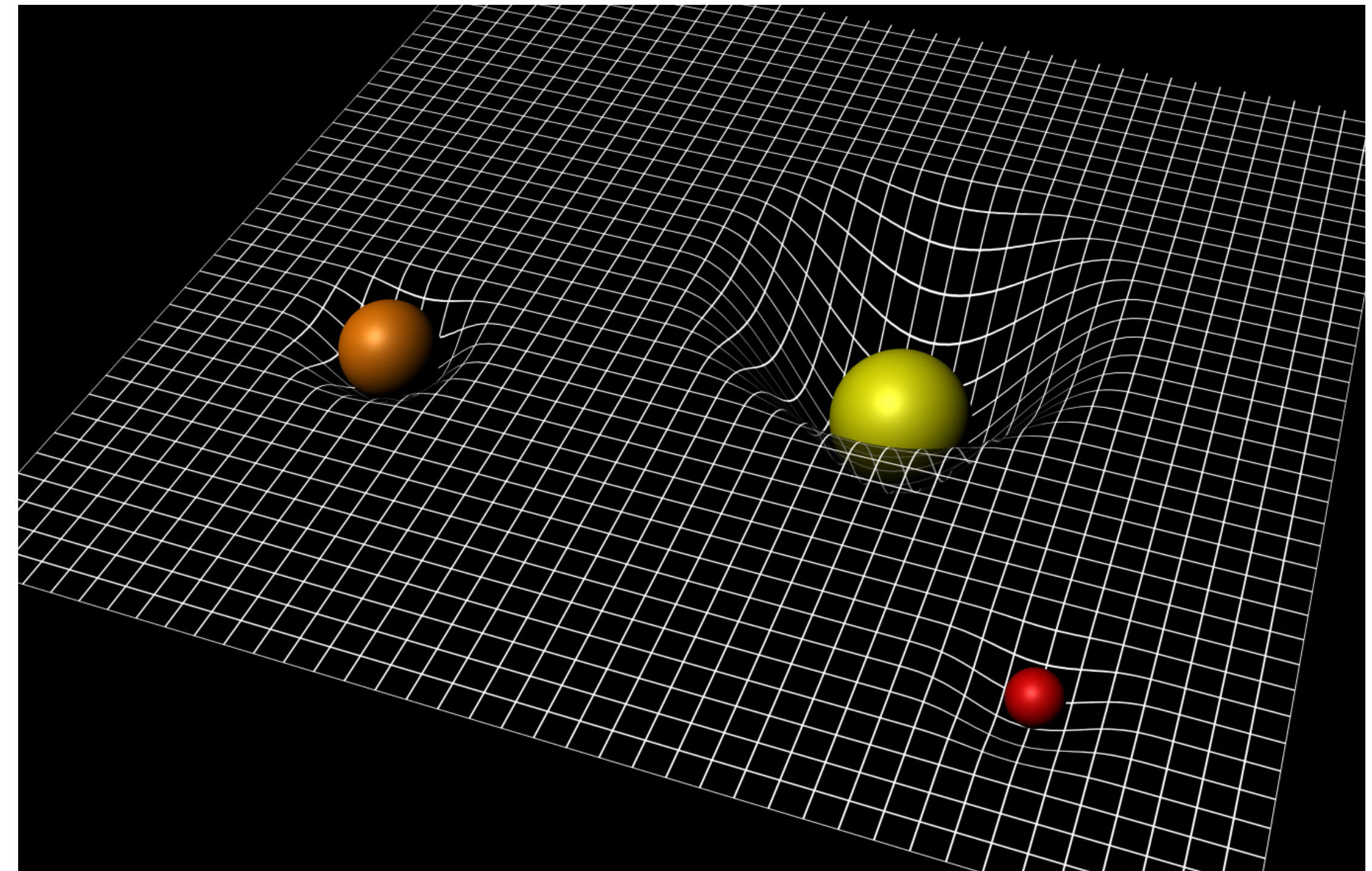
Black holes and General relativity

Center of our Galaxy: Black Hole



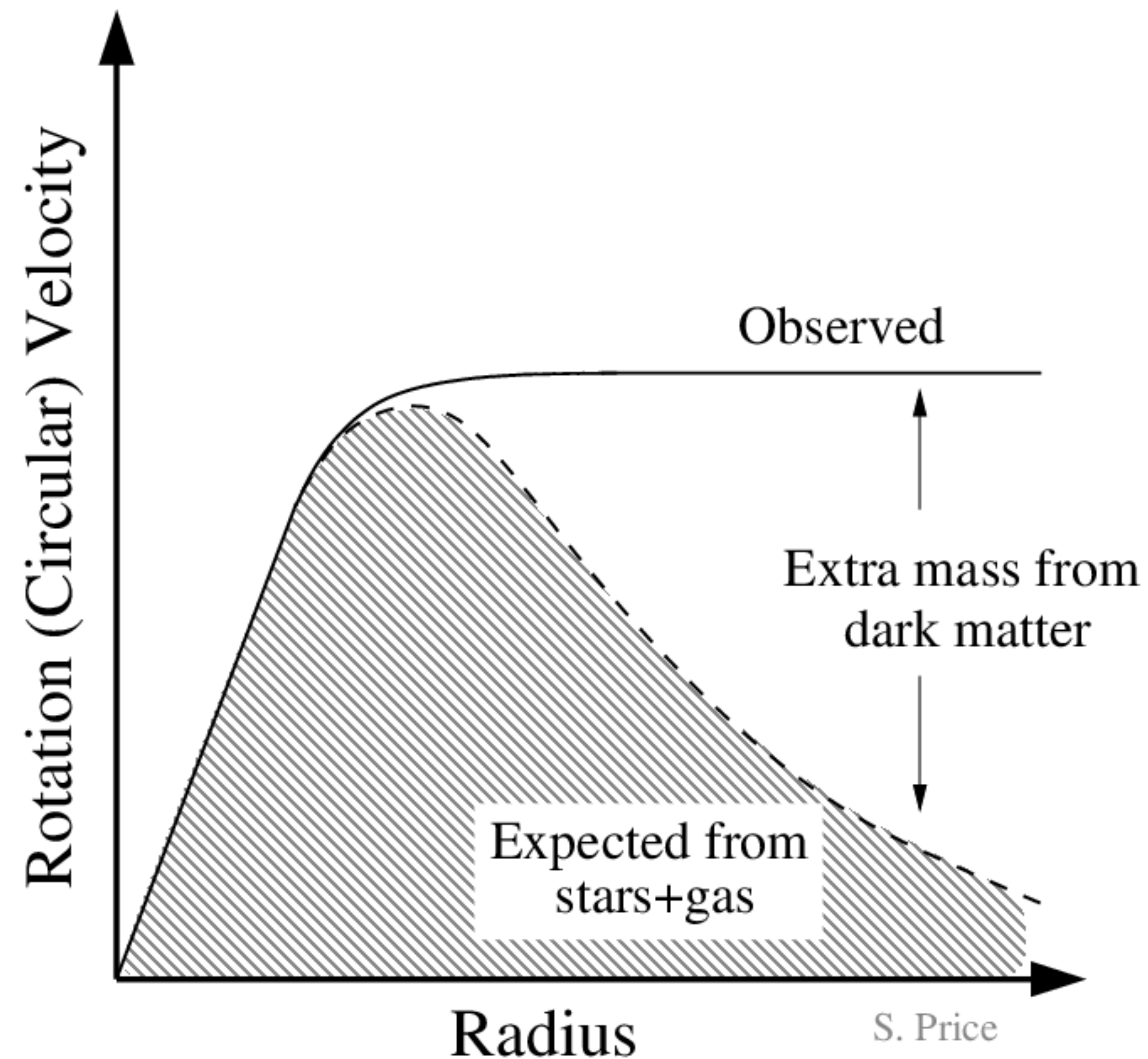
(Please don't ask me any hard question about this...)

Spacetime is curved by mass!



The large scales

Missing mass: is there Dark Matter?



Extra mass not
radiating any light:

"Dark matter"

About 5 times more dark matter
than regular matter...

Universe expansion: missing energy

Dark energy???

Our scale



Our world:

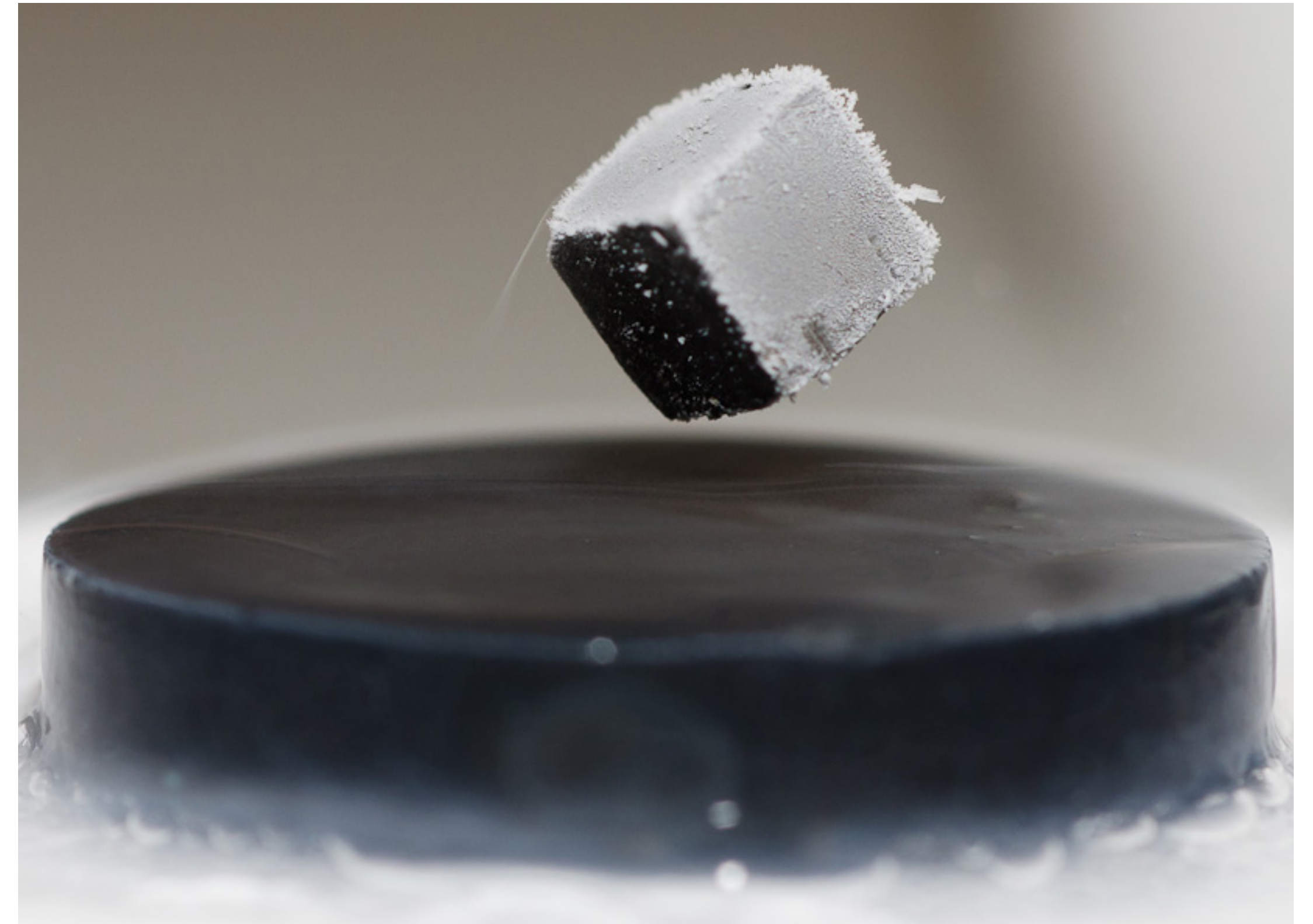
- Flat spacetime
- Matter continuous (TBC)
- Visible interactions:
 - Gravitation
 - Electromagnetism

Our scale

Electro-



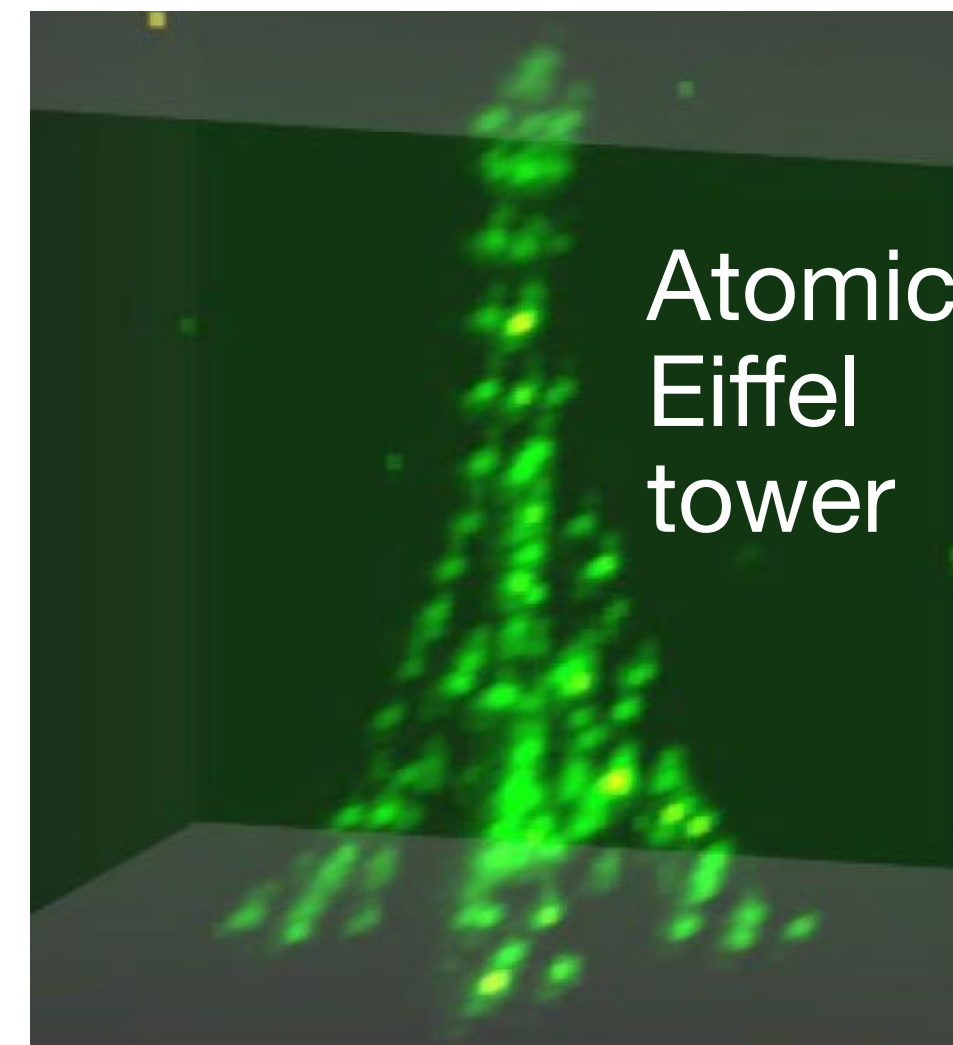
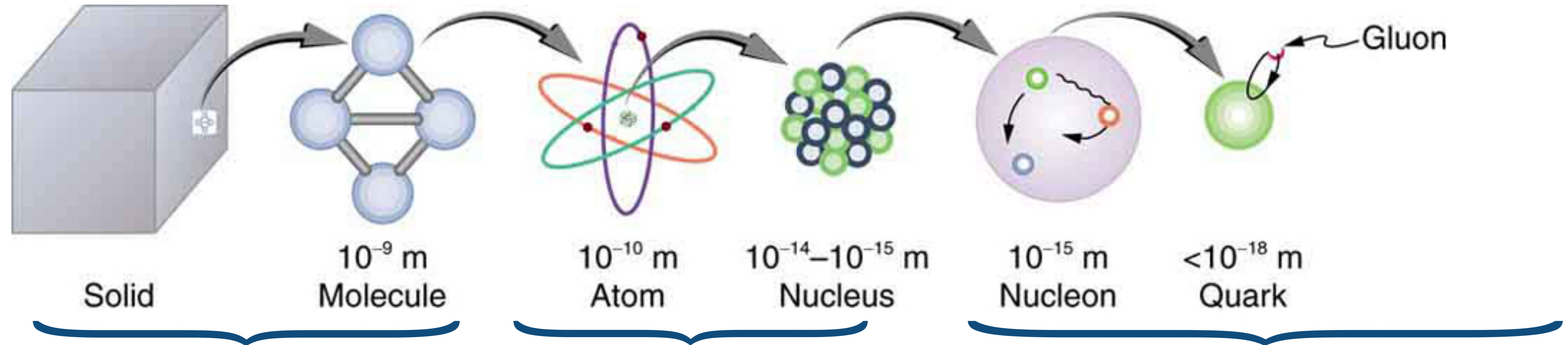
magnetism



(Meissner effect)

The small scales

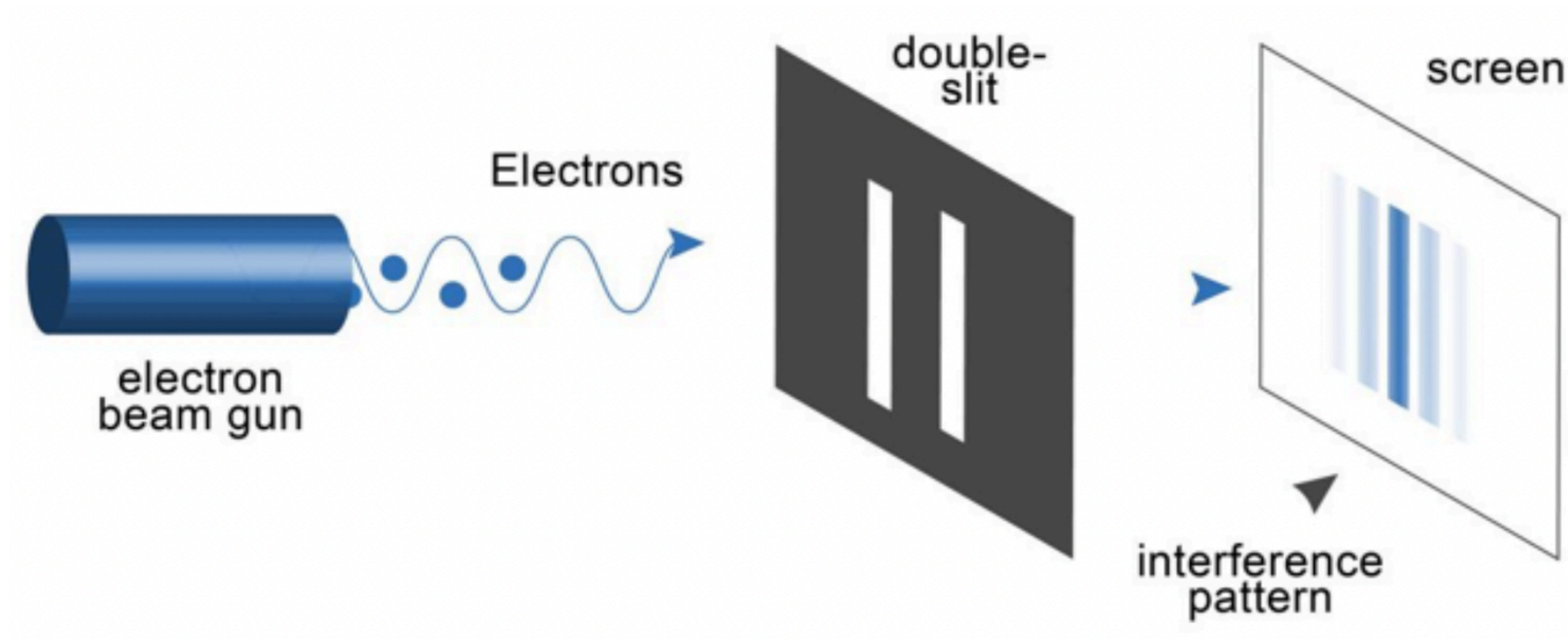
The substructure of the matter



Quantum physics

Is God playing with dice?

Double slit experiment (Young)

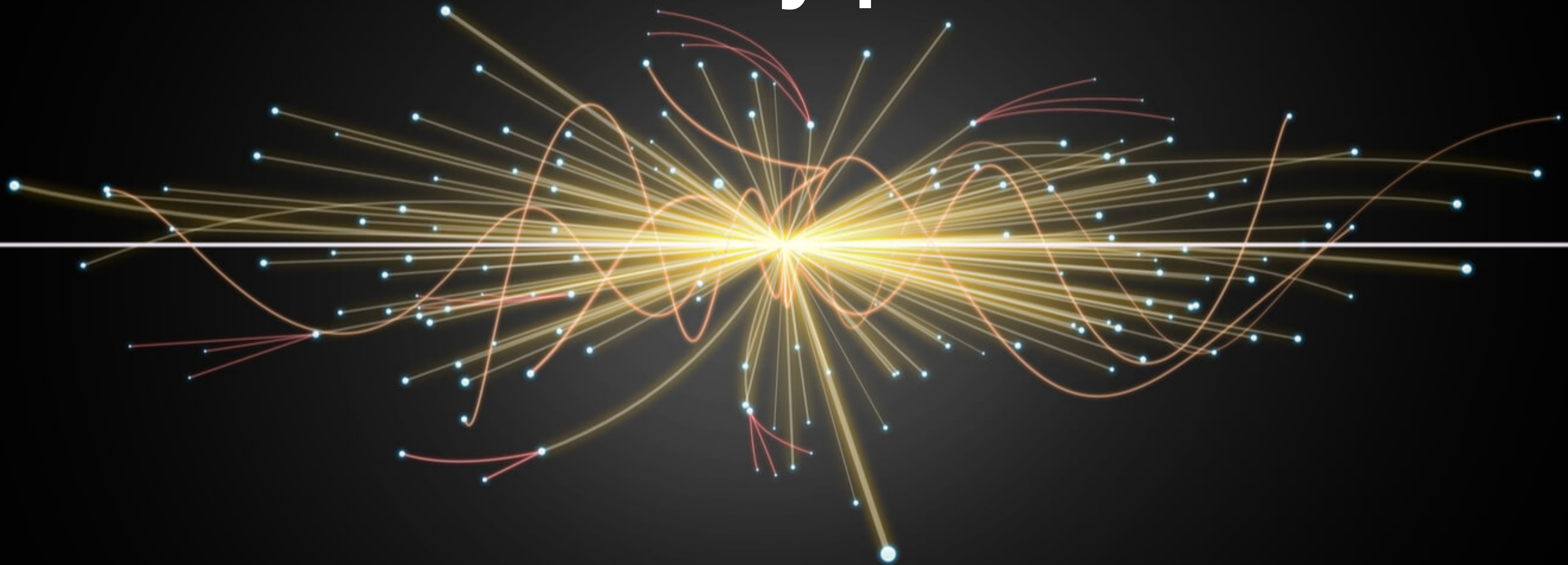


Quantum Mechanics:

- Confusing laws
- Duality wave-particle
- Probabilistic (not deterministic)

Can we describe the small scales with a physical model?

A model of elementary particles



The theoretical physics perspective

Theoretical physicists are... nerds

They like math, order and simplicity



$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

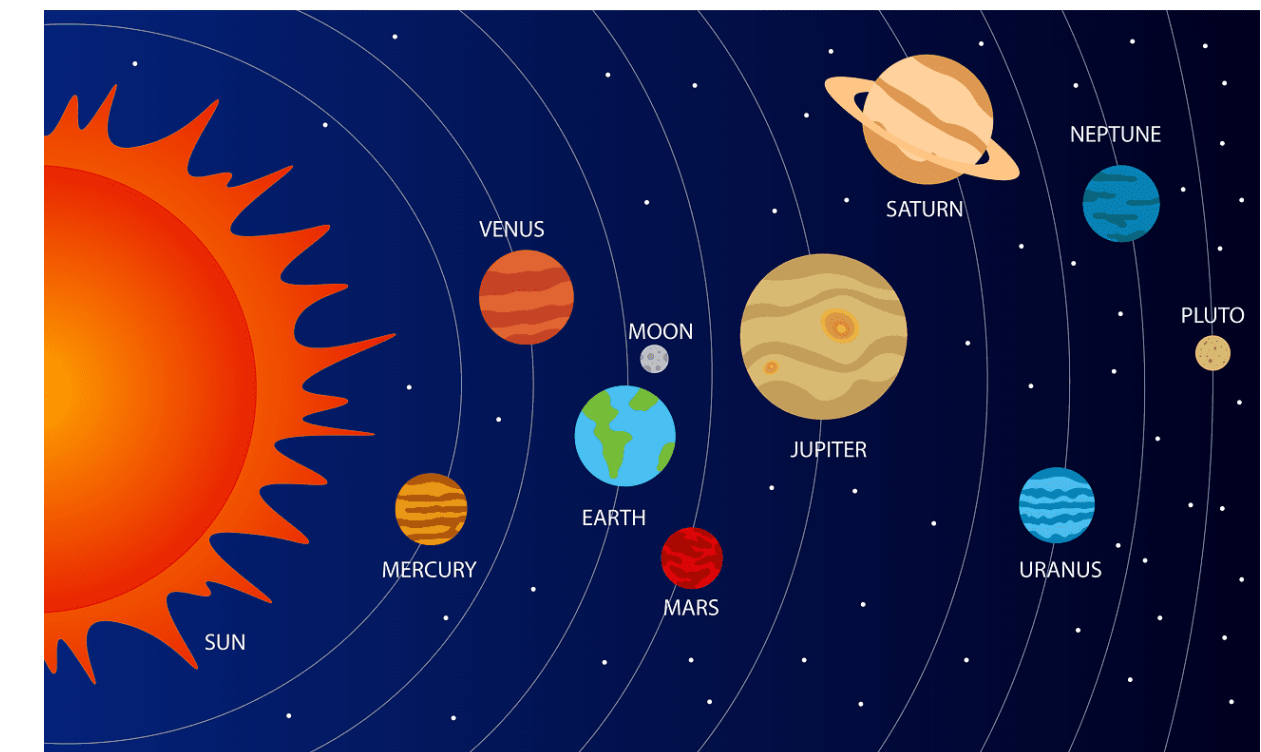
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t}$$



$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi GT_{\mu\nu}$$



A model of elementary pizza constituents



Elementary constituents:

- Pepperoni
- Mozzarella

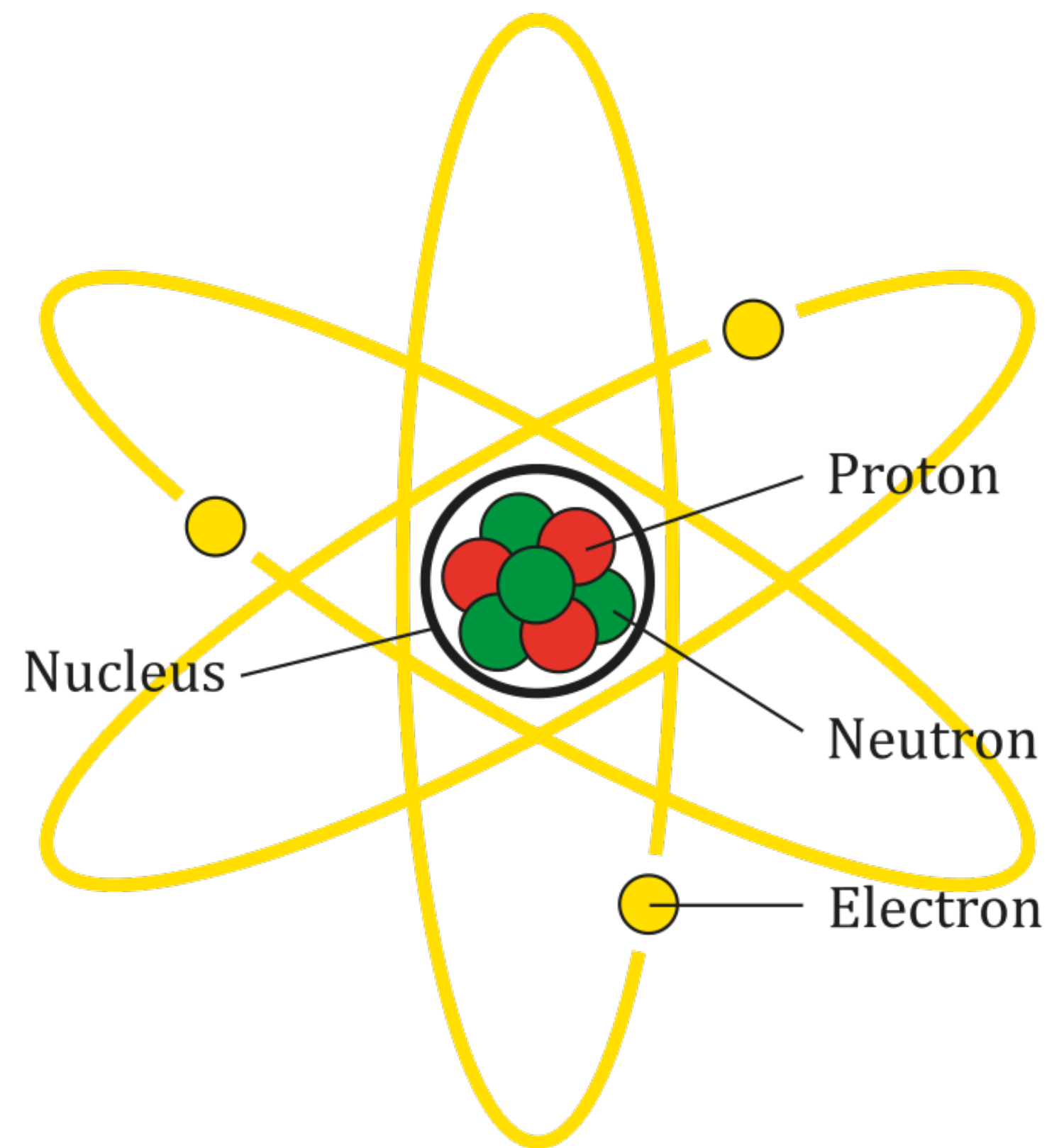
Dough: **composite object**,
difficult without further inspection

Tomato sauce keeps it together: **interactions**

Are all ingredients visible?
Maybe we are **missing elements**! (Dark basil?)

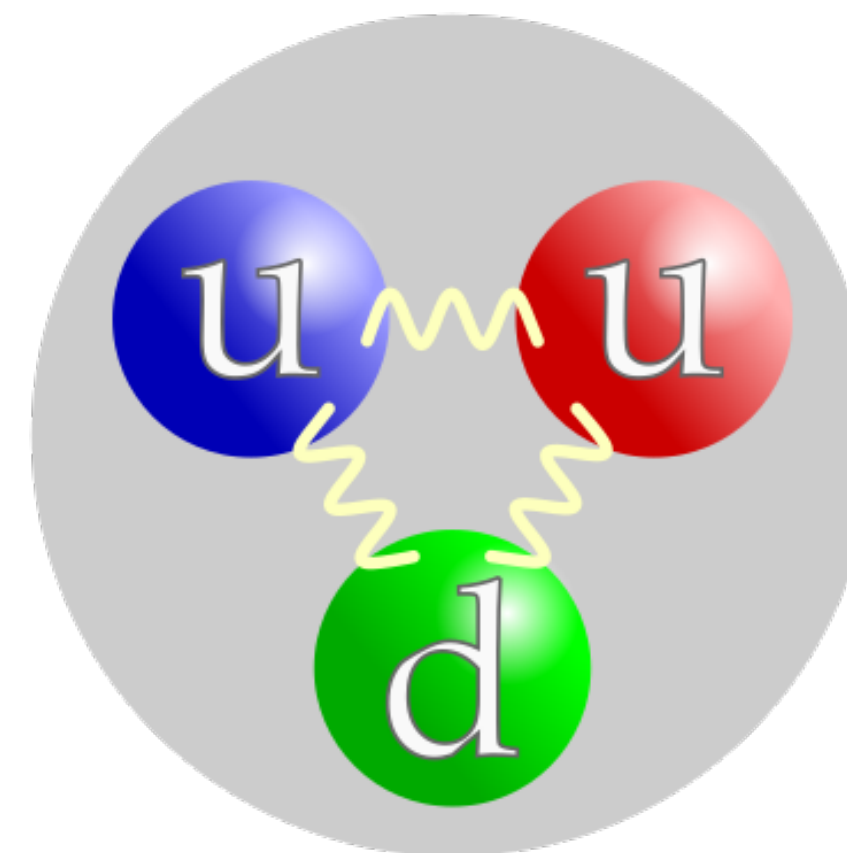
The ingredients of the Universe

Assumptions: Nature is ultimately described by microscopic particles

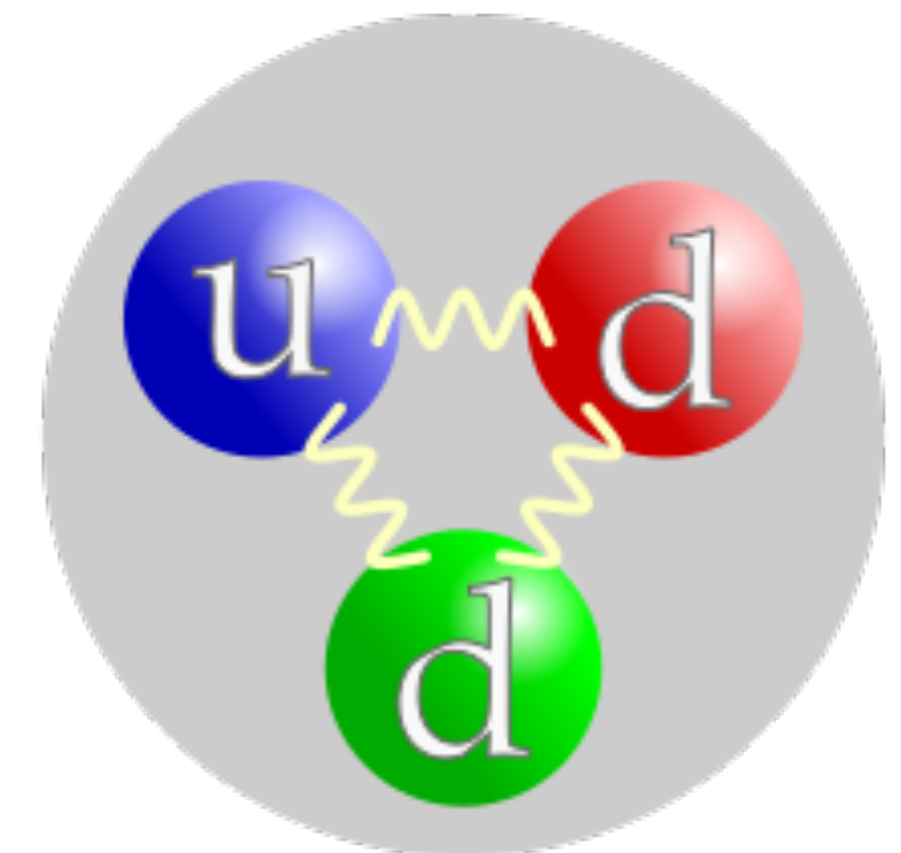


Composite: like the dough!

Proton



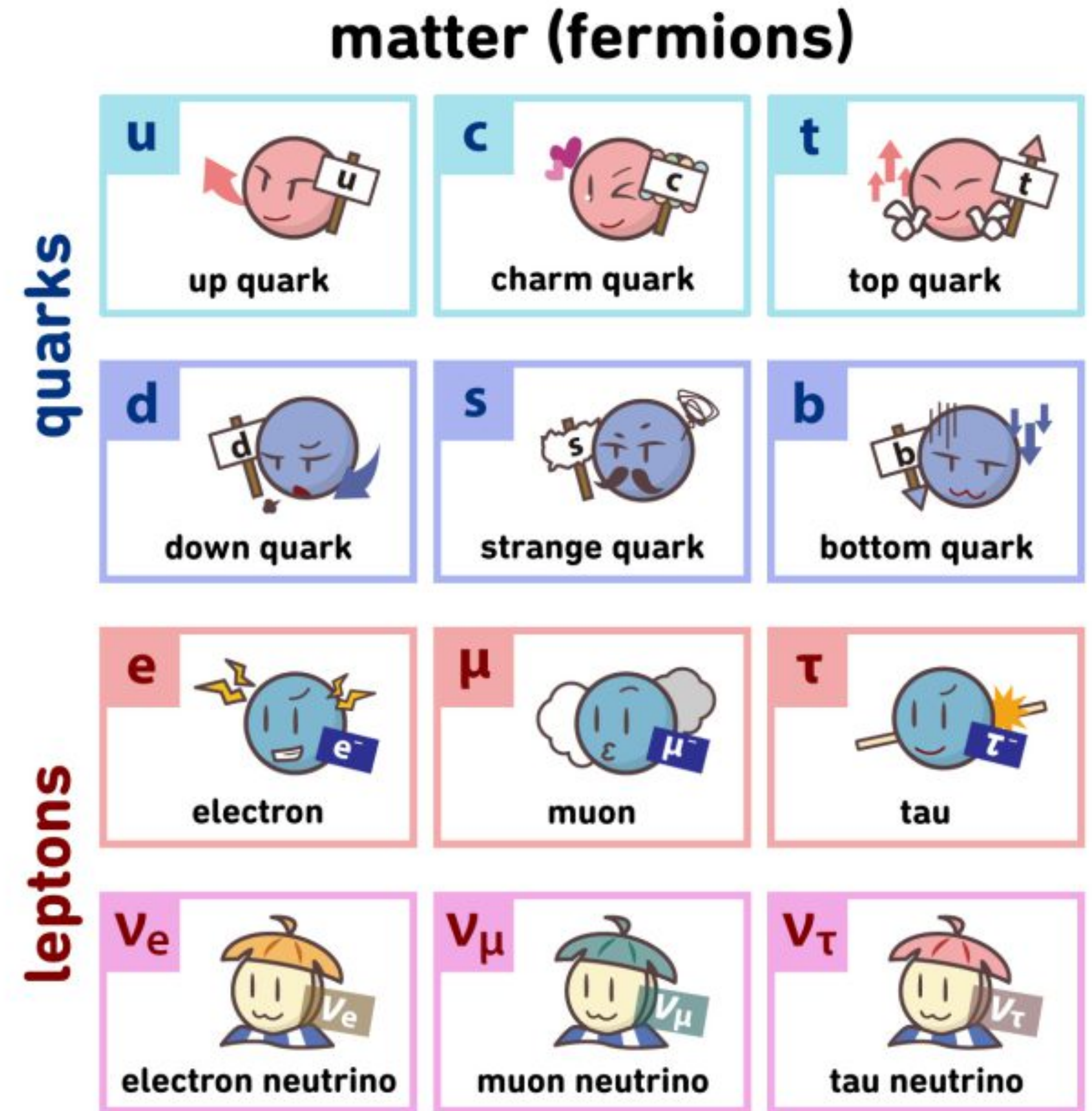
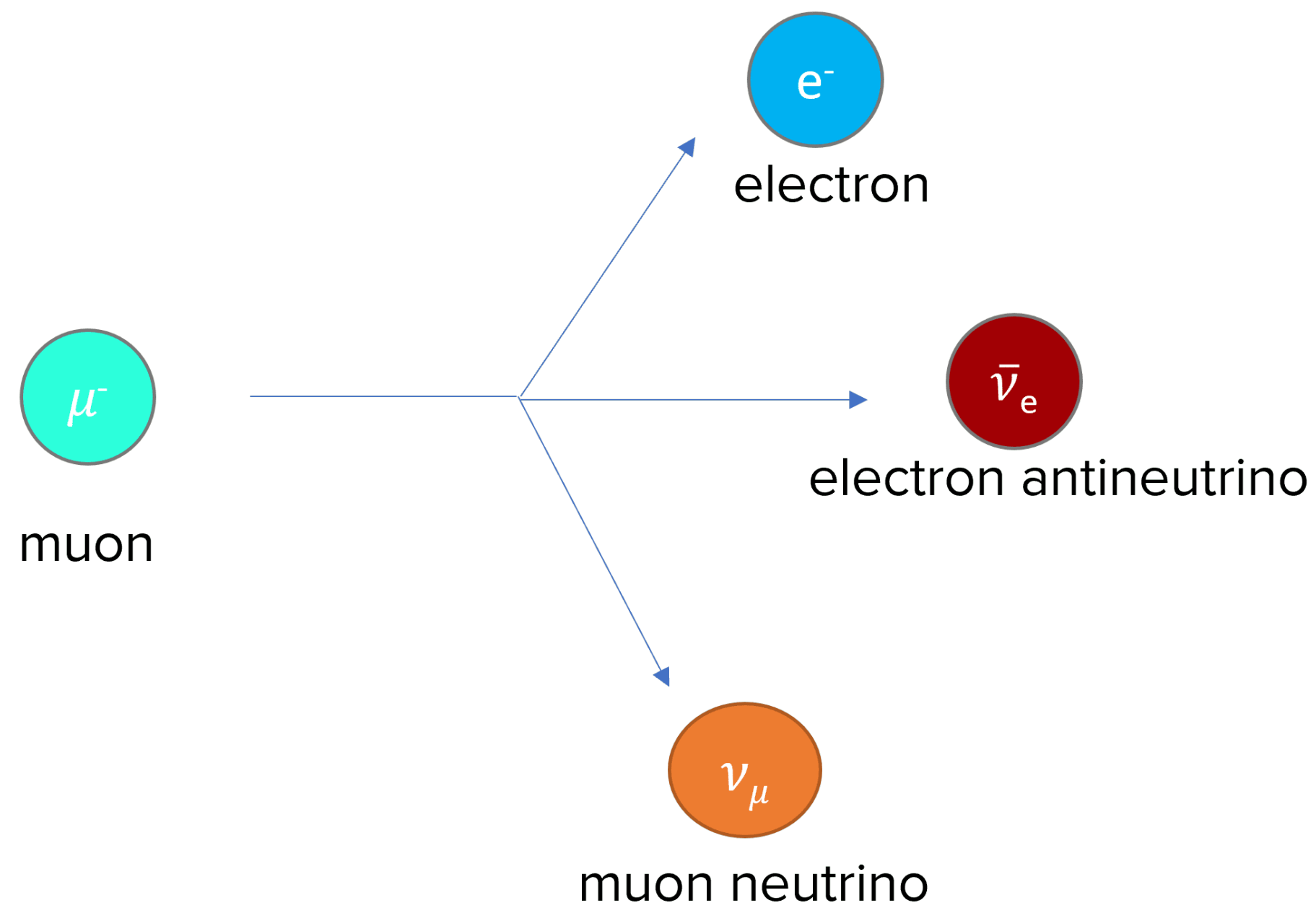
Neutron



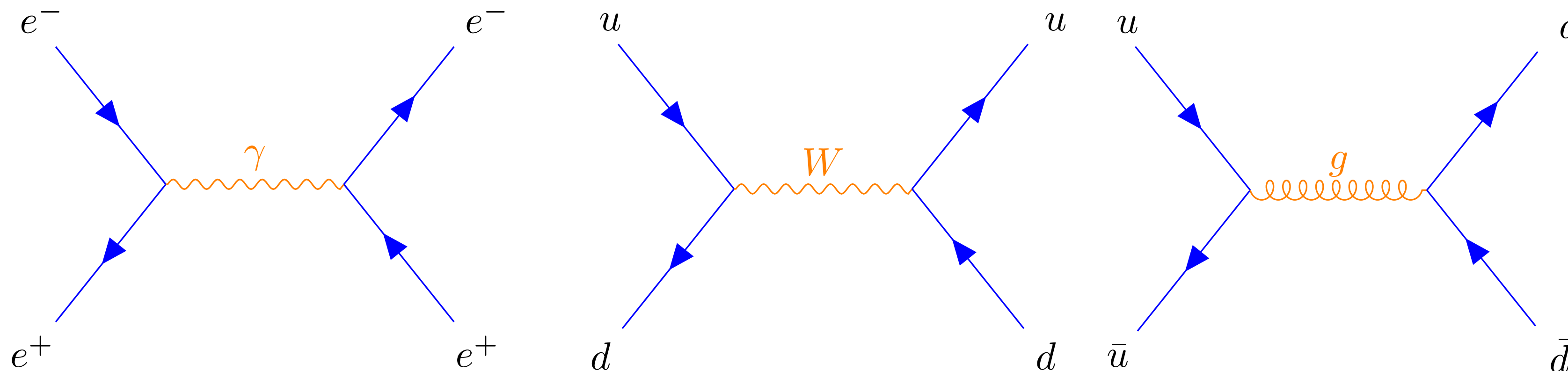
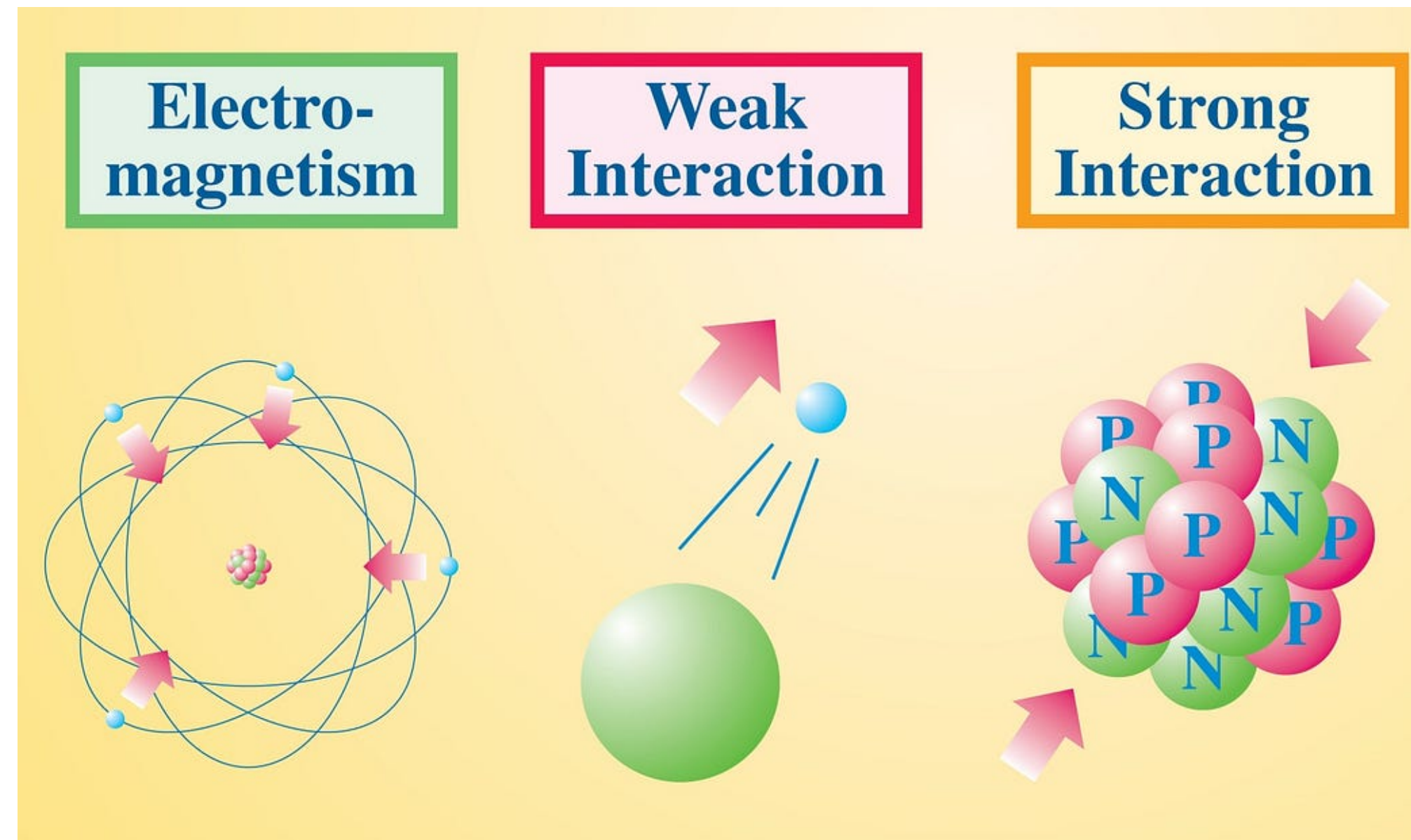
Who ordered these?

We kept looking and found new matter constituents

They are **heavy and unstable**



The fundamental interactions



gauge bosons	
γ	photon
g	gluon
Z, W^\pm	weak bosons
	electro-magnetic
	strong
	weak

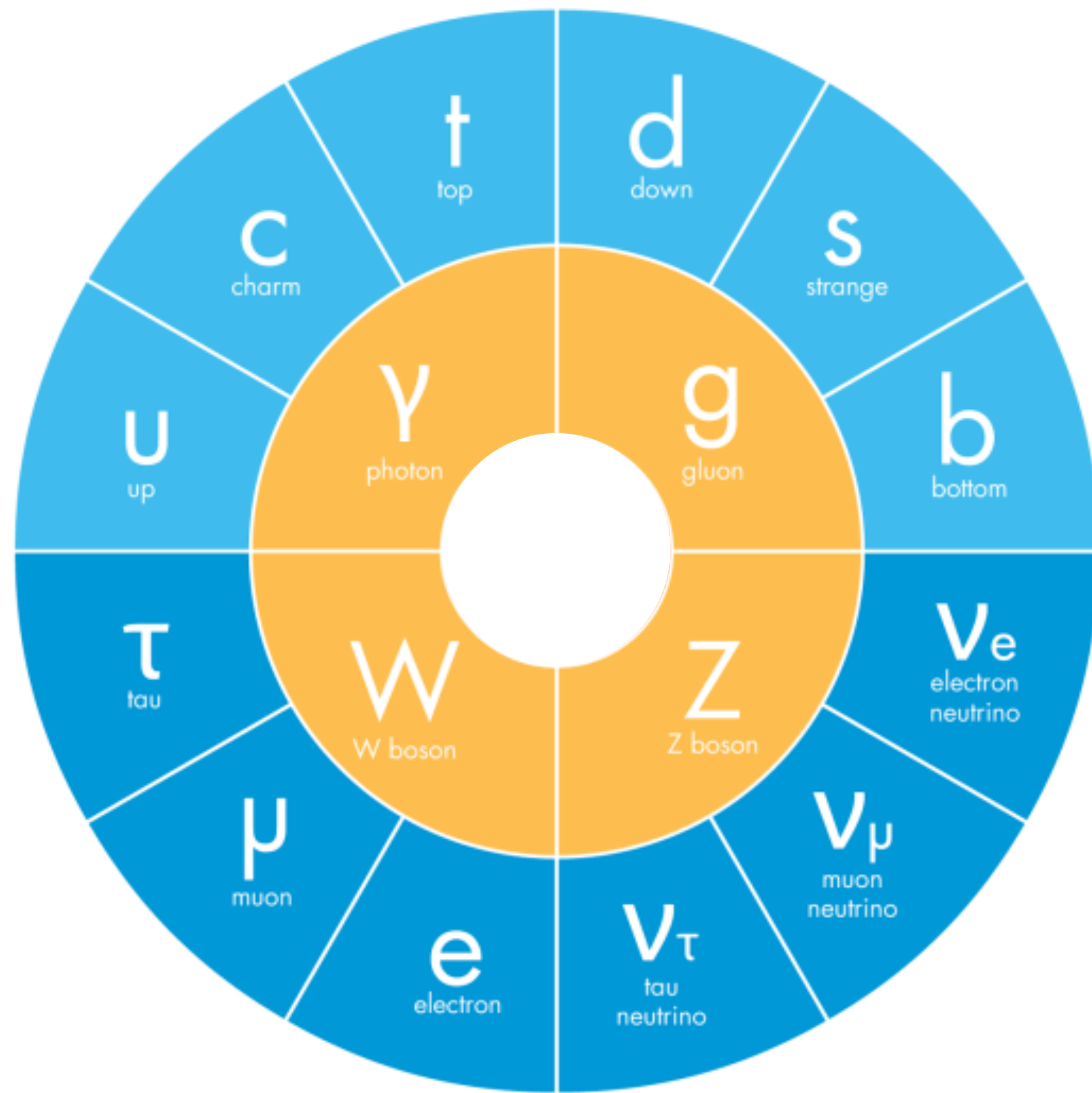
©Yuki Akimoto

The Standard Model of particle physics

The most successful theory in History!!

Unifies the description of 3 fundamental forces

But... **I think we forgot something:**
the model explodes at high energy!



The Higgs Boson

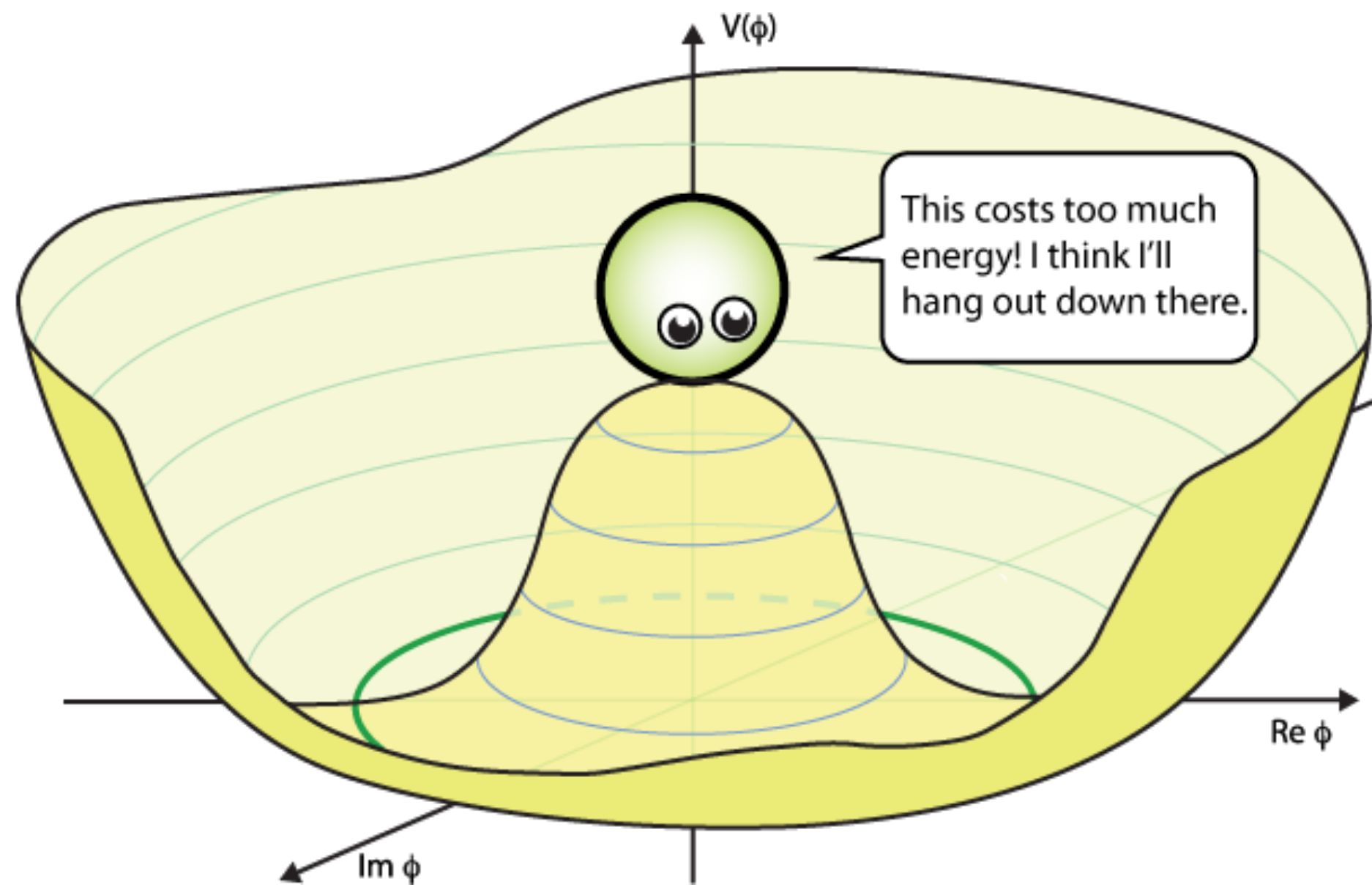


It is a bit complicated, but... the EW interactions do not allow masses

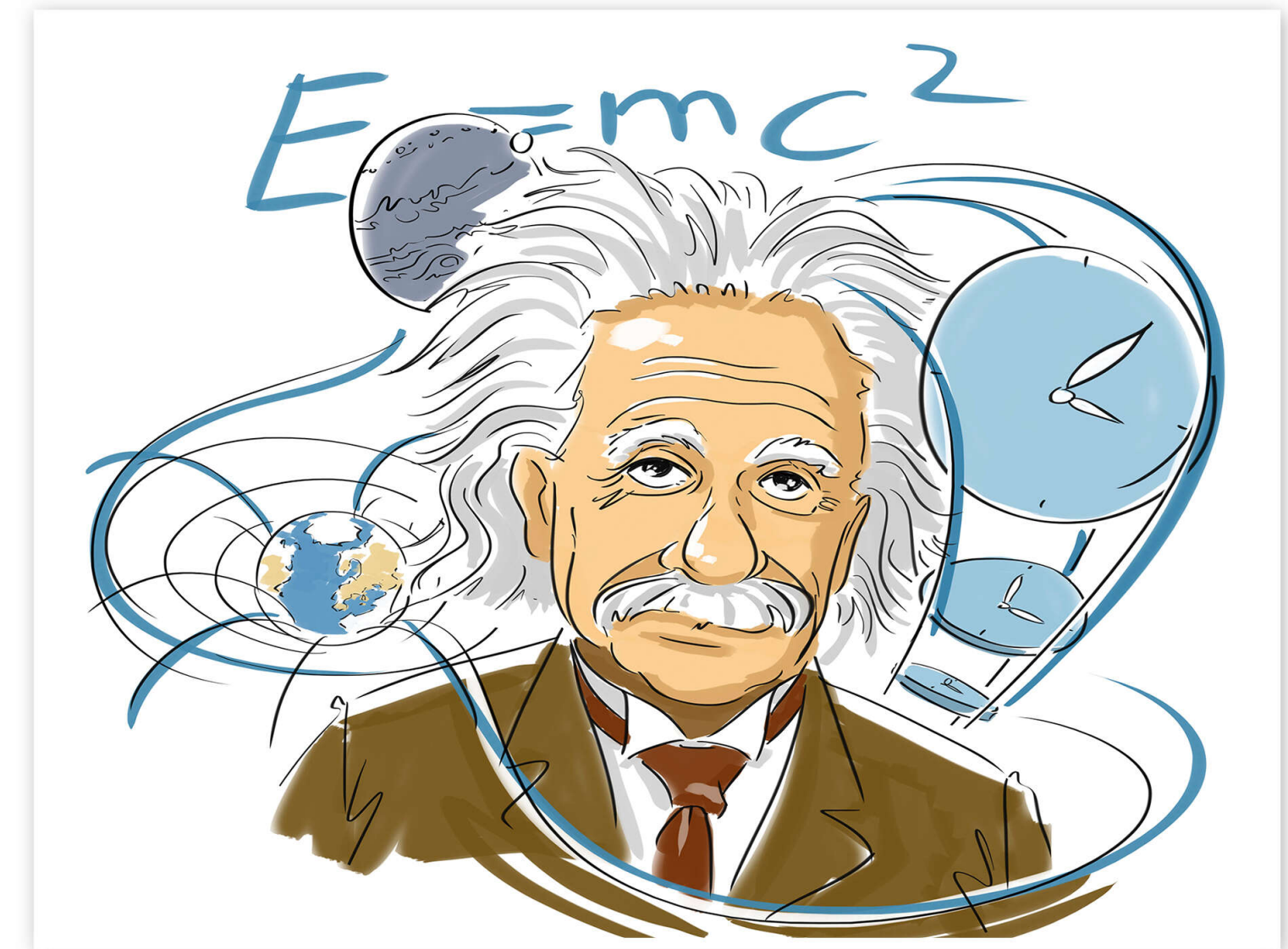
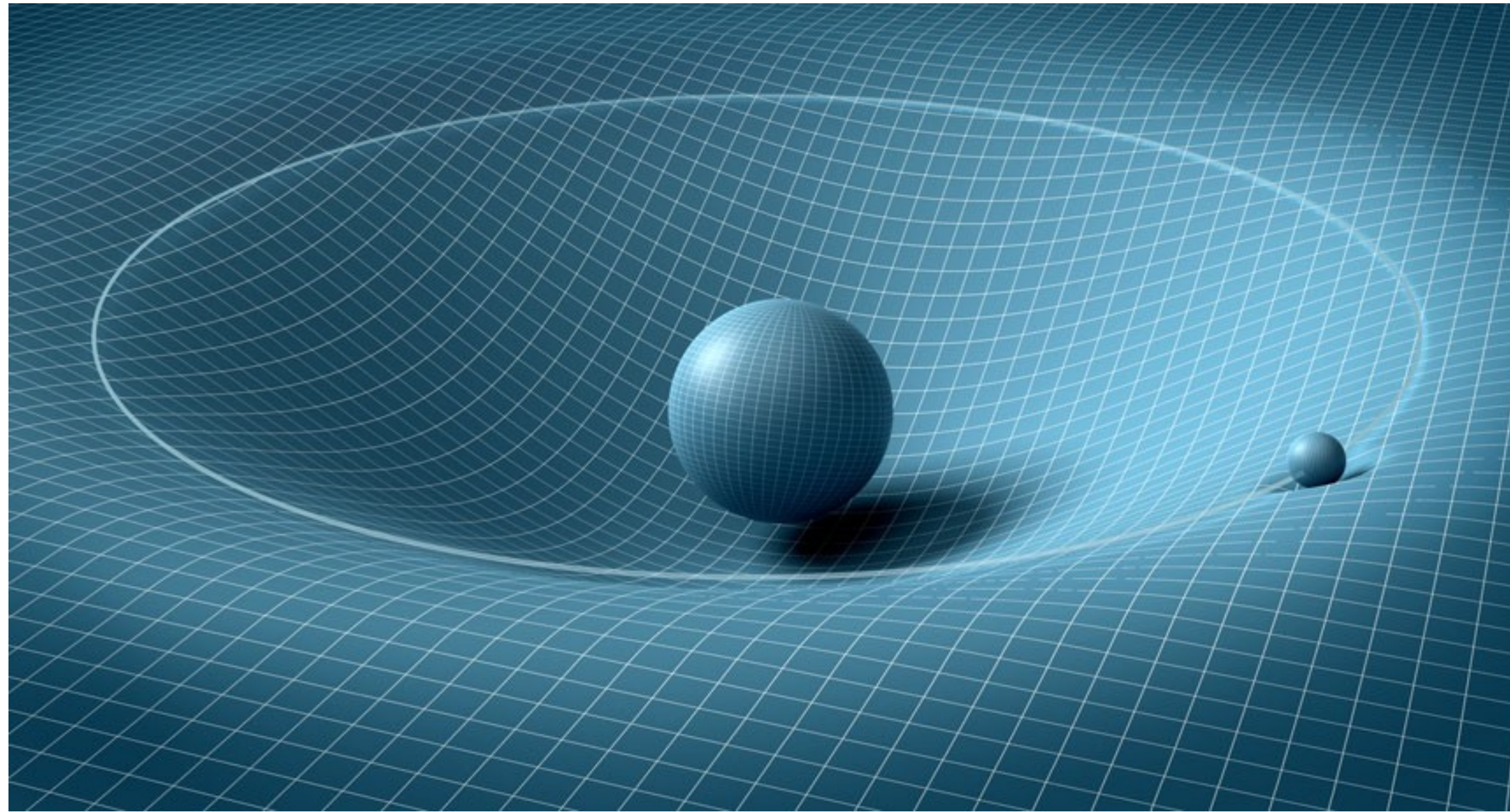
But we know that **masses are there!**

We introduce the **Higgs field**:

Particles interacting with it acquire mass



What about gravity?



Really difficult to put together with the SM:
missing a quantum theory!



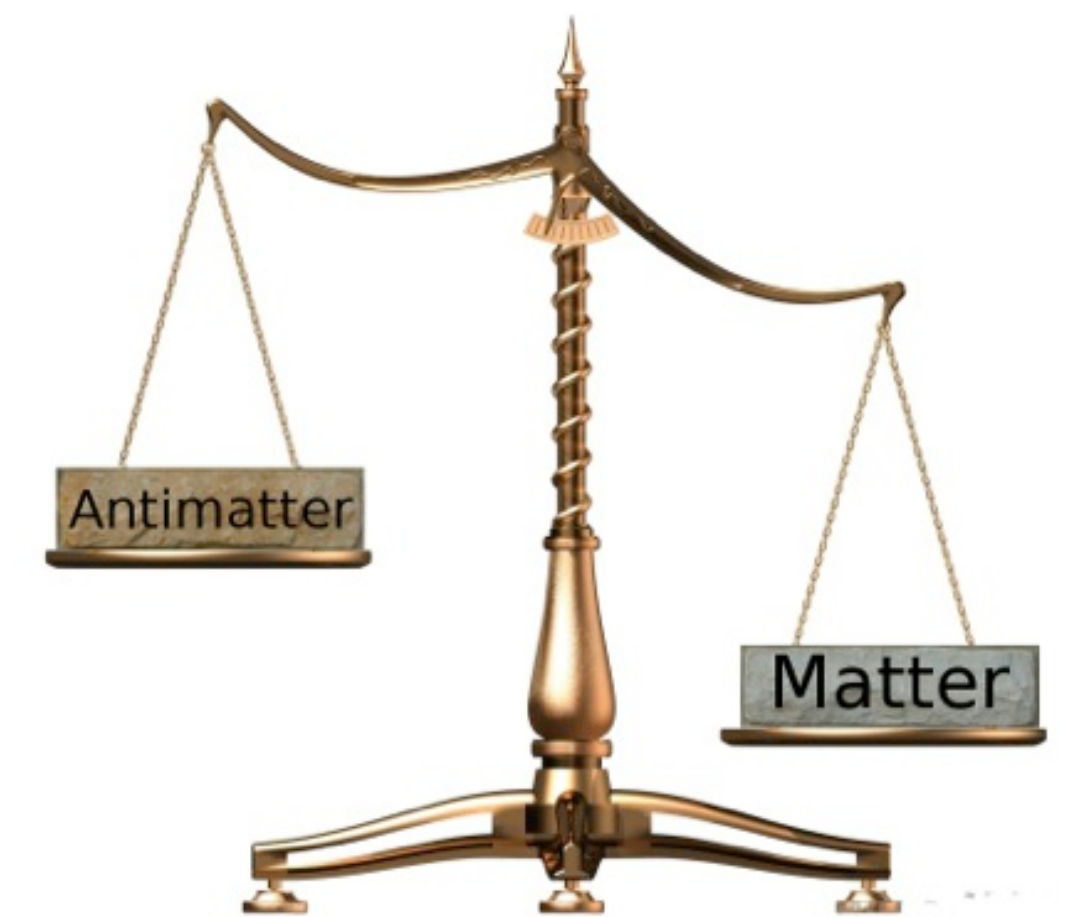
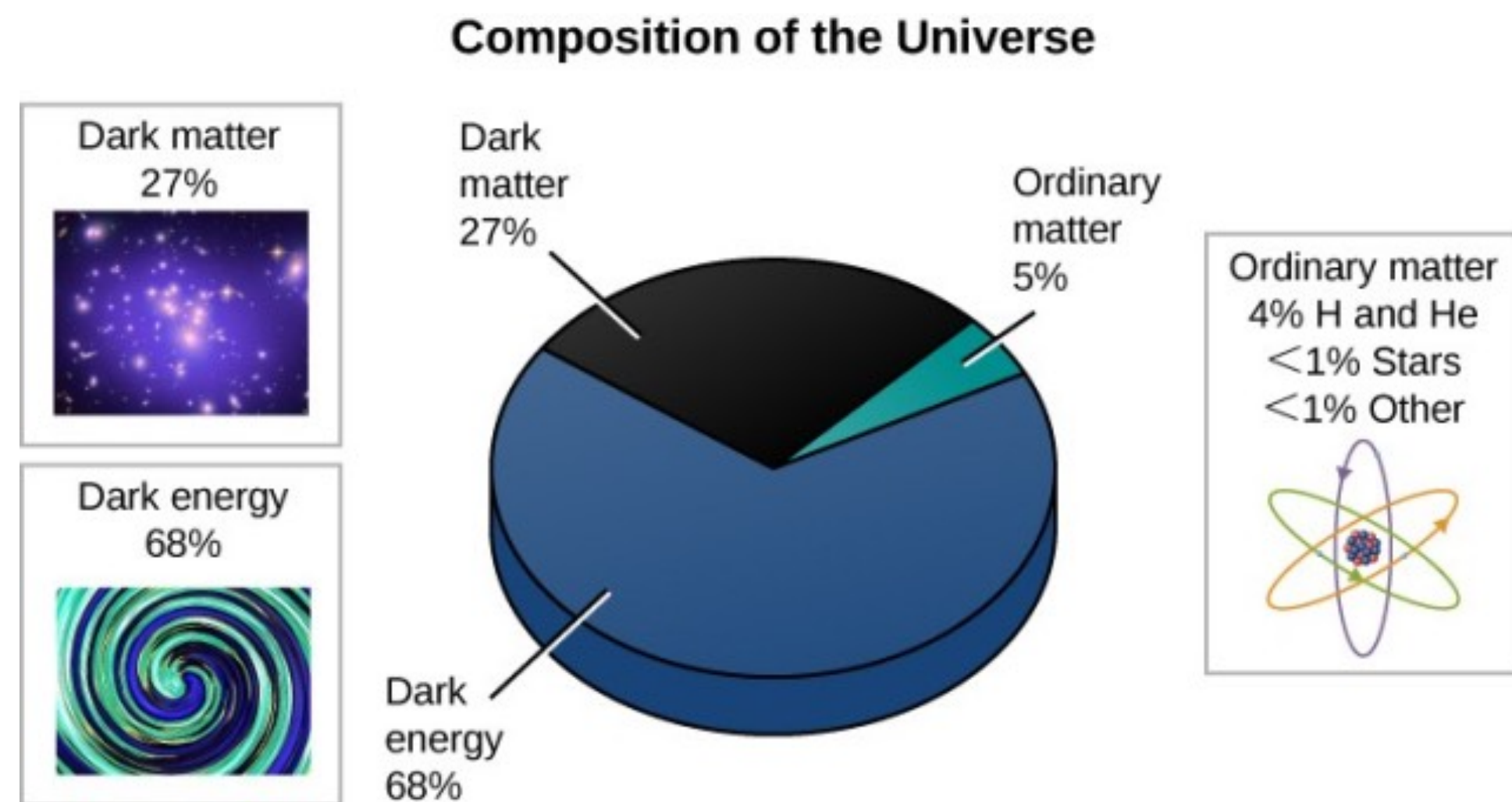
Open problem!



Is the SM the final theory?

The SM is incredibly good...

but physicists believe there must be something else...



How can we investigate these problems?

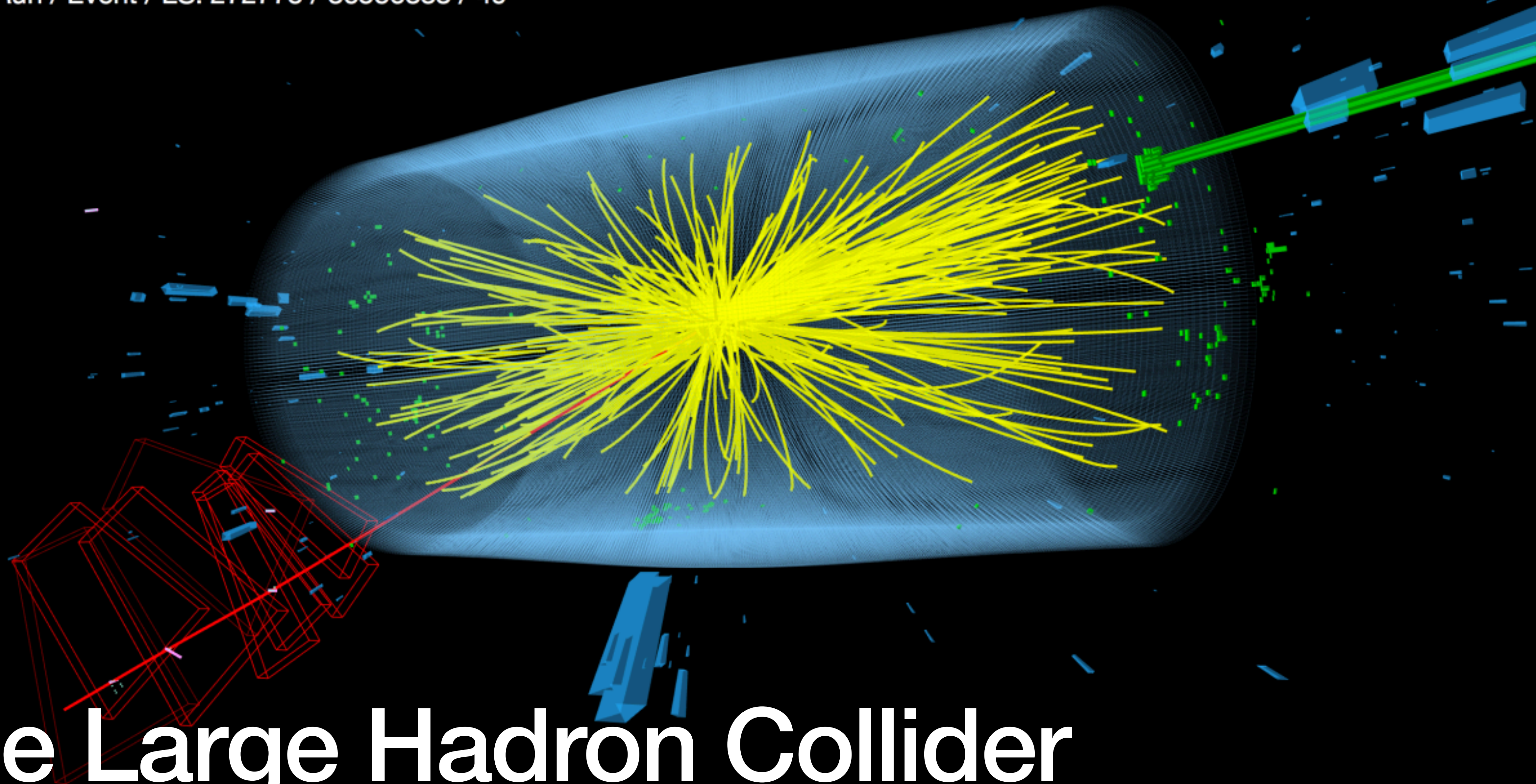
Hint: Einstein taught us that $E = mc^2$...



CMS Experiment at the LHC, CERN

Data recorded: 2016-May-07 02:15:29.192000 GMT

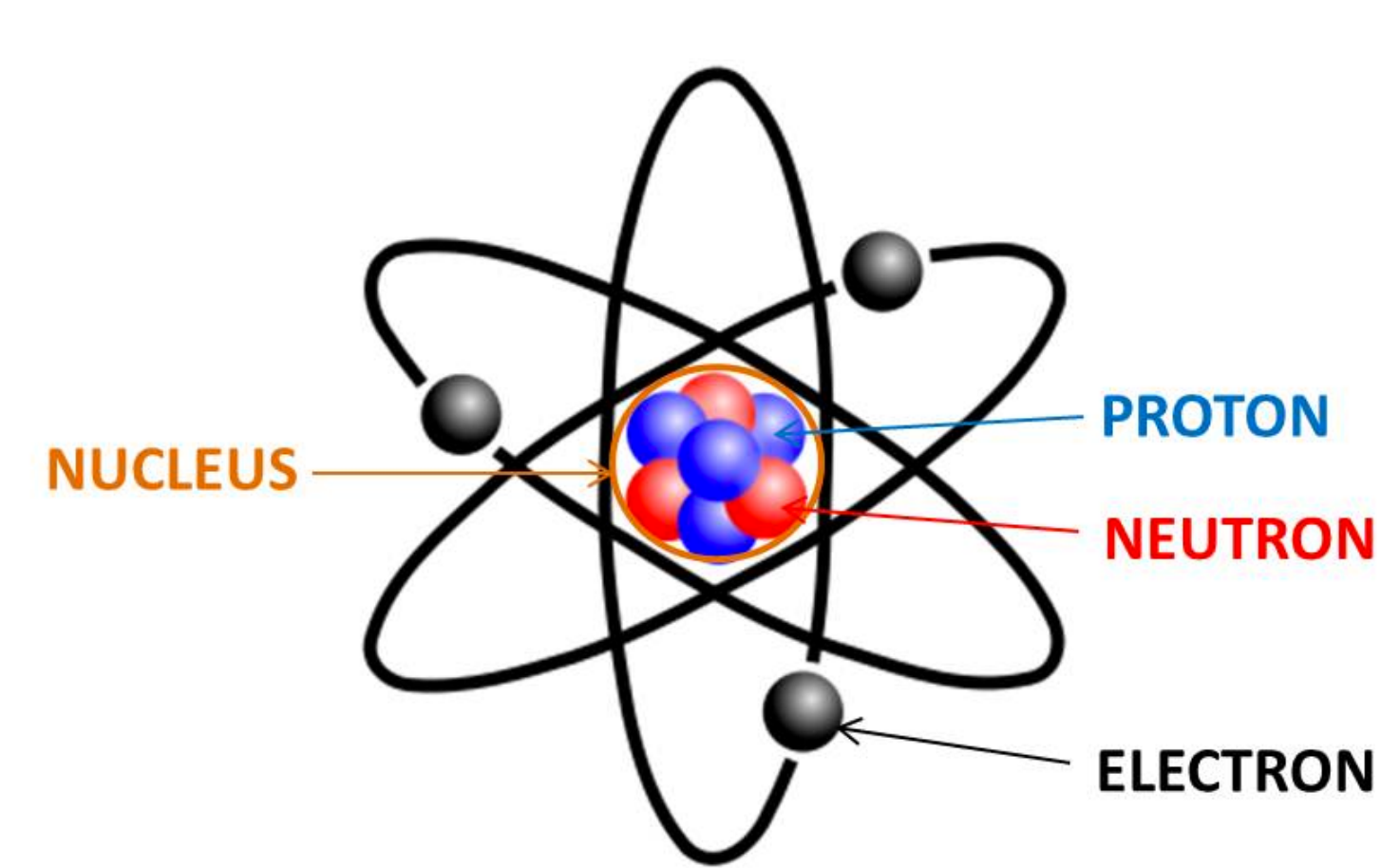
Run / Event / LS: 272775 / 36556333 / 49



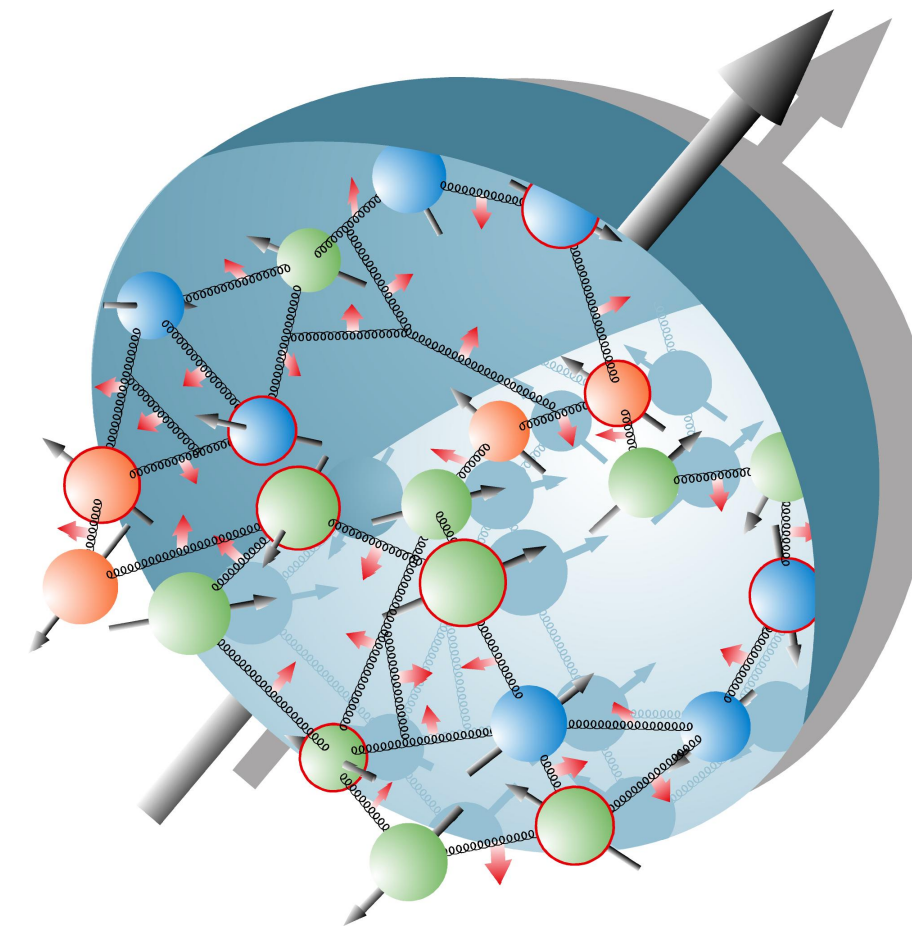
The Large Hadron Collider

The instruments of particle physics

Looking into the smallest constituents of the Universe



Atoms' nucleus is 10000 smaller than atom itself



The quarks that make up protons are 10000 smaller than the proton!

The history of the living world can be summarized as the elaboration of ever more perfect eyes within a cosmos in which there is always something more to be seen.

Pierre Theilhard de Chardin
(The Phenomenon of Man 1955)

What kind of microscope do we need to observe nuclear and subnuclear particles?

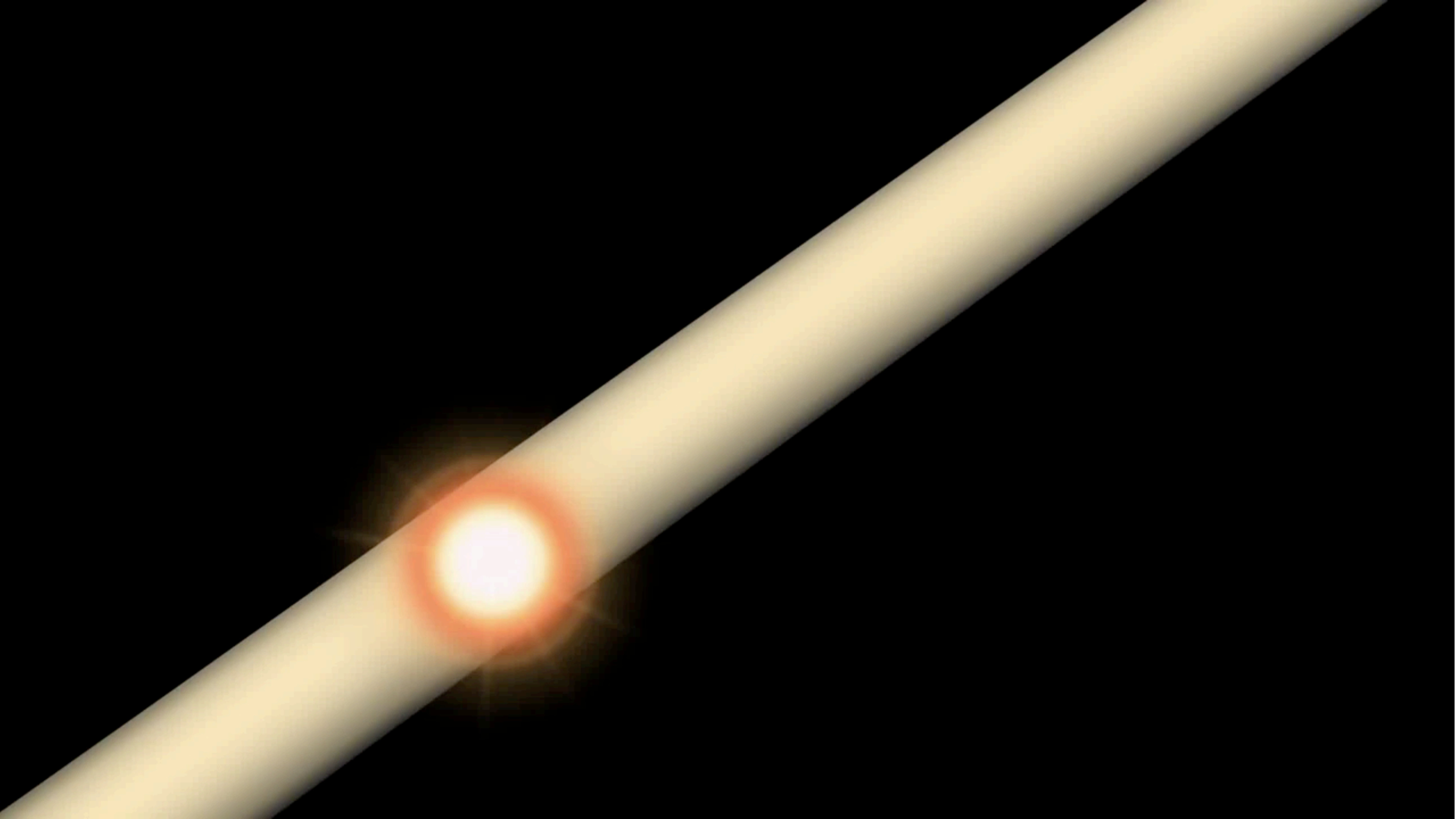


The Large Hadron Collider

@CERN

- **15** miles ring under the French-Swiss border.
- **2** proton beams accelerated at almost the speed of light.
- **4** huge detectors to capture the outcome of proton collisions!





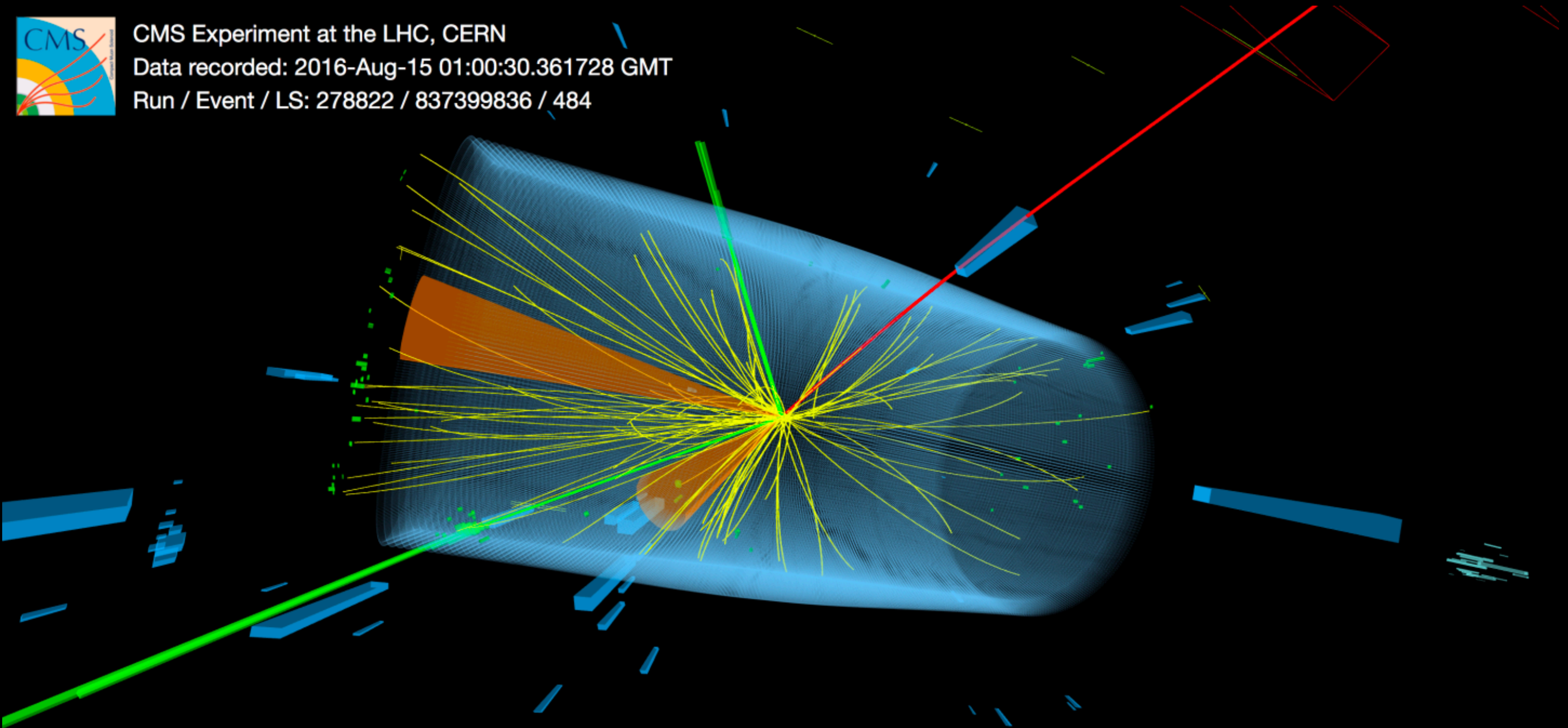
Experimental events at the LHC



CMS Experiment at the LHC, CERN

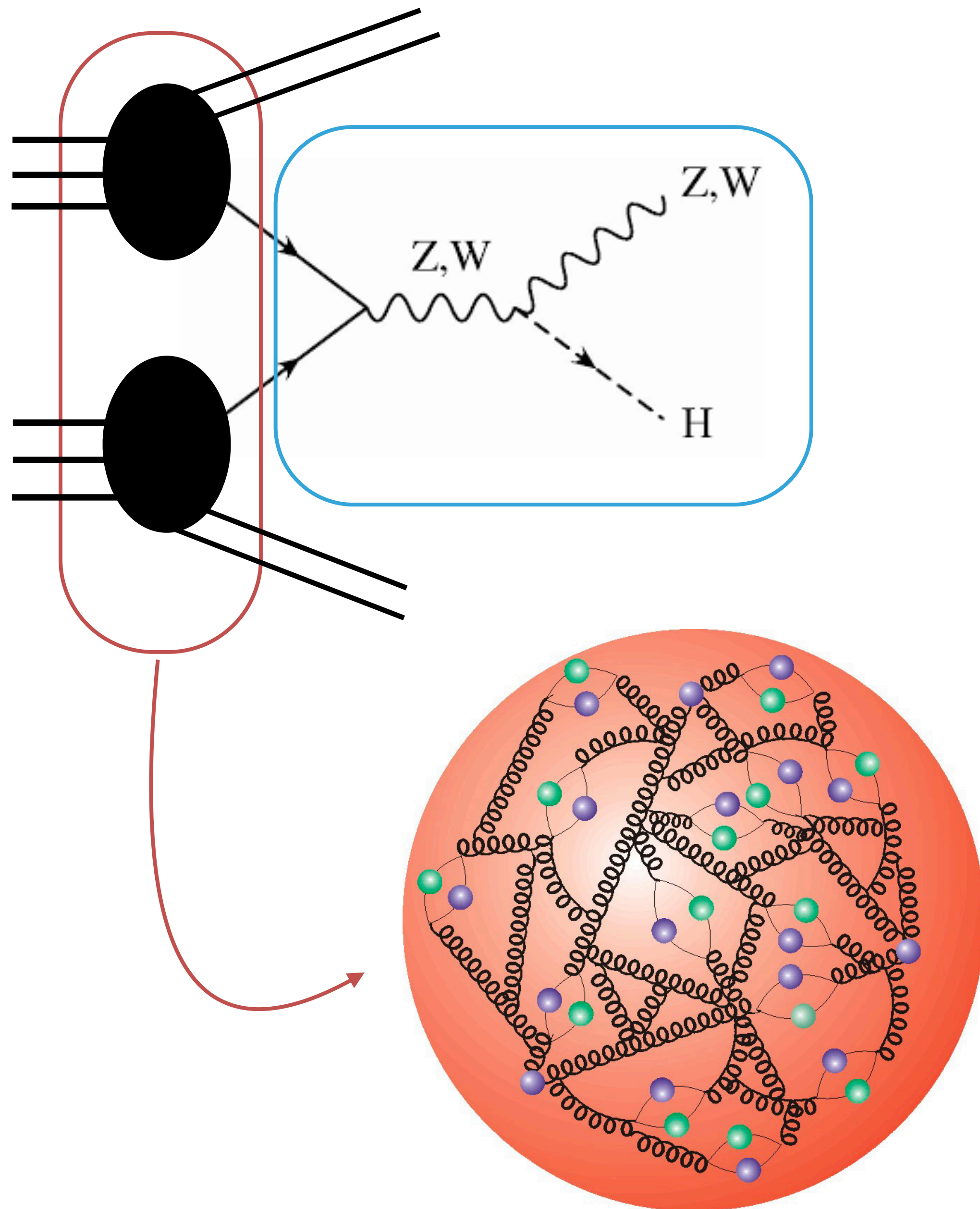
Data recorded: 2016-Aug-15 01:00:30.361728 GMT

Run / Event / LS: 278822 / 837399836 / 484



$pp \rightarrow t (b W (\mu \nu)) Z(ee) q$

Theoretical predictions at the LHC

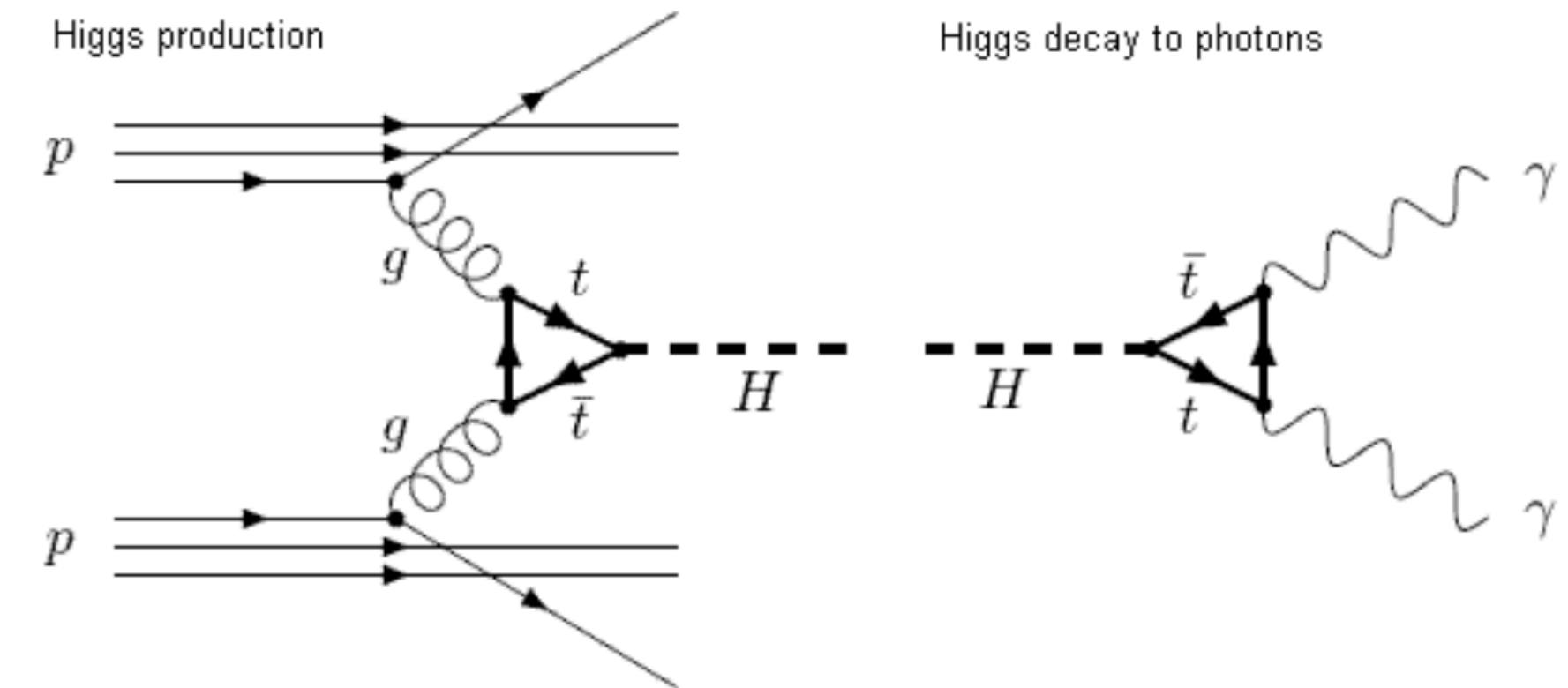
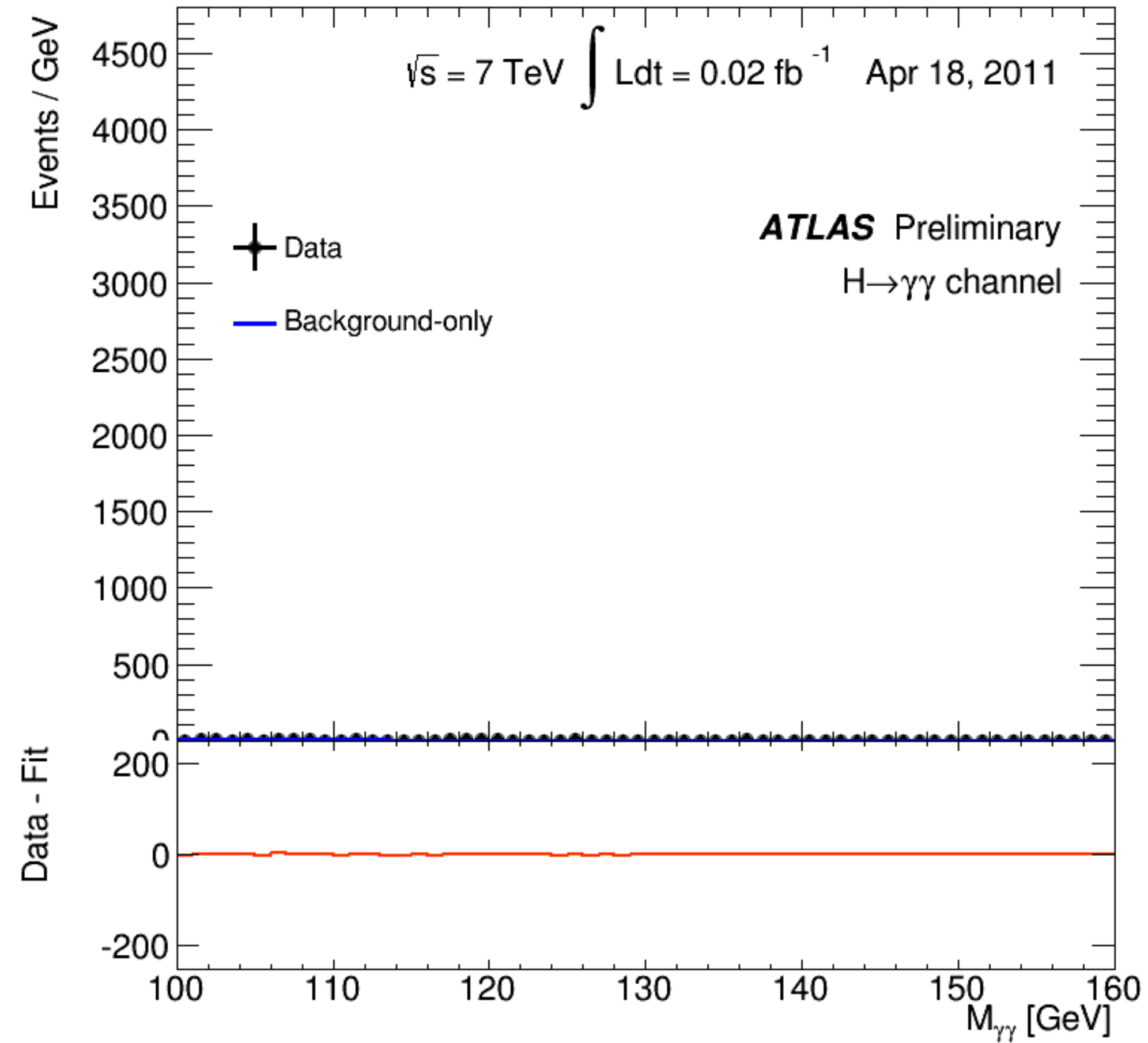


The structure of the proton in terms of its elementary constituents is the other crucial input to any theoretical prediction for the LHC

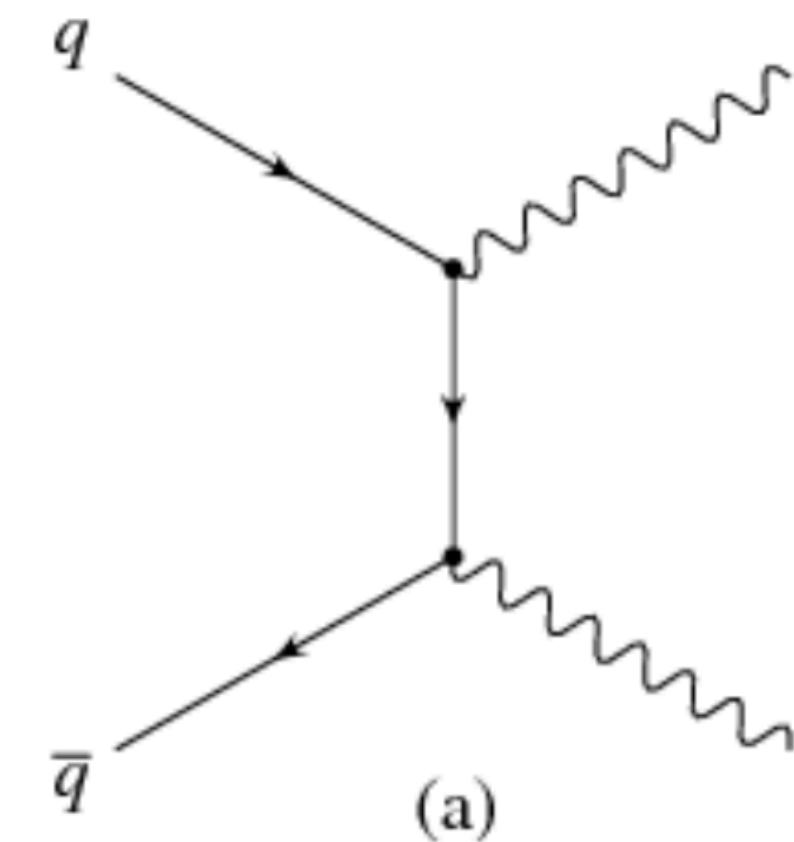
What's the probability that a given constituent carrying a fraction x_1 of the proton's velocity smashes against another constituent carrying a fraction x_2 of the other proton's velocity at the time of the collision?

An example: the Higgs discovery

An example of signal



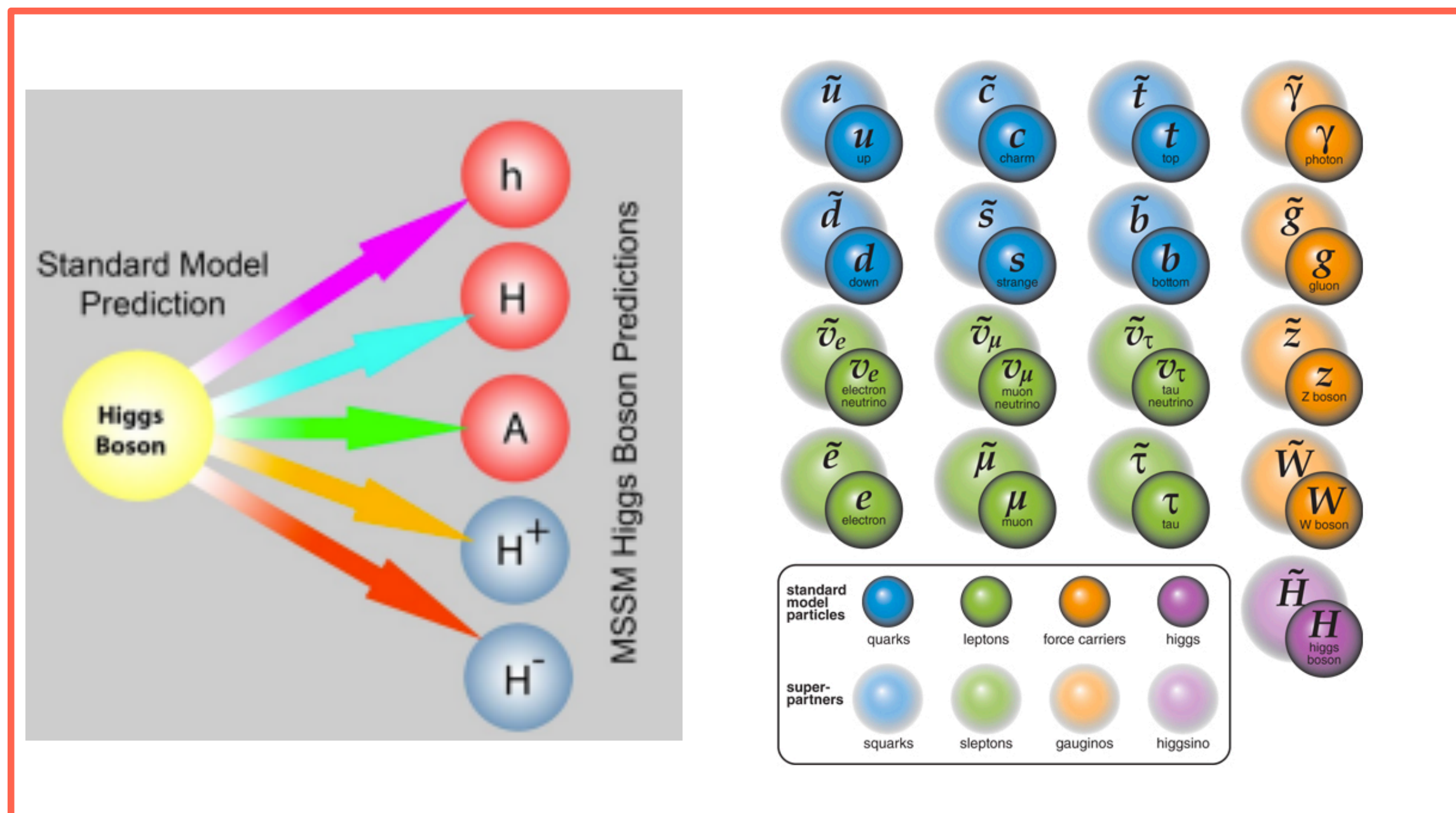
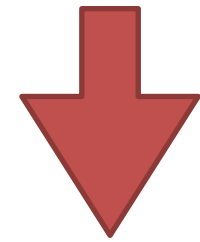
An example of background



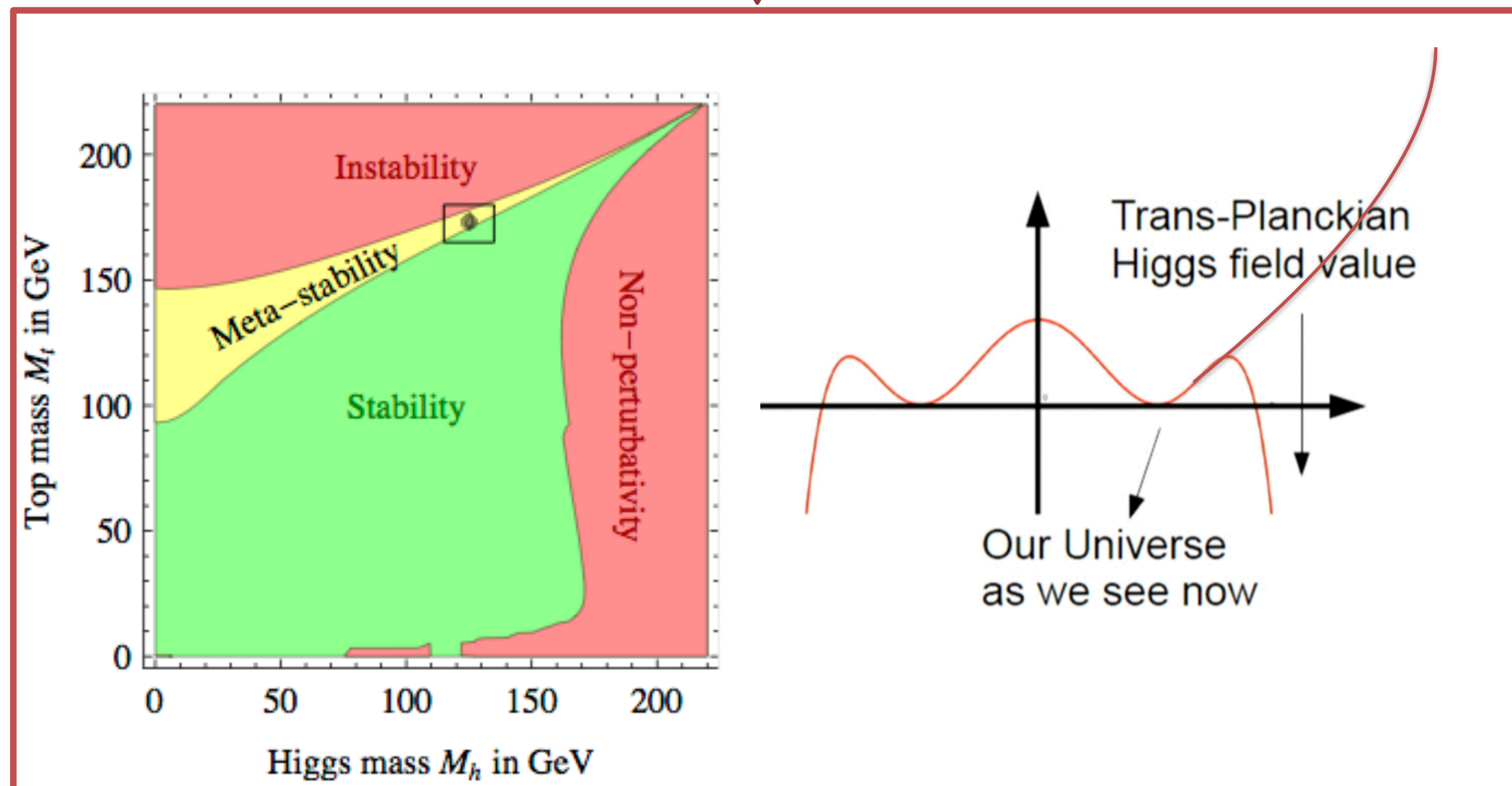
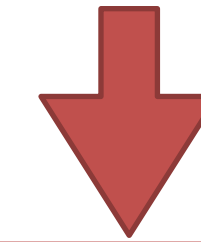


Higgs boson: a portal to new physics

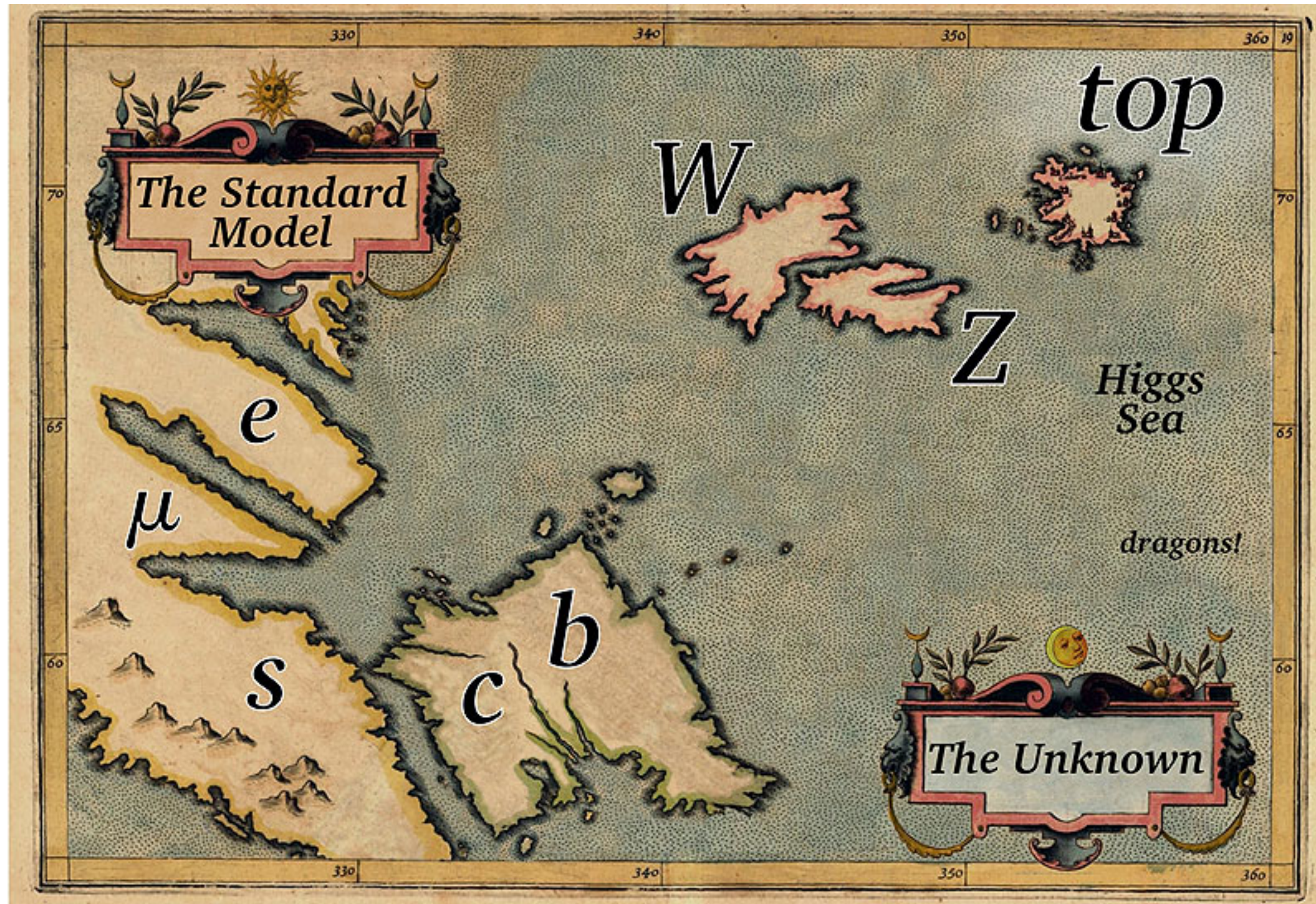
From a theoretical point of view, it would be natural to have an extended Higgs sector and unveil new fundamental symmetries



The fate of our universe is linked with the properties of the Higgs: are we going to quantum-tunnel into a completely different universe?



New Physics where are thou?



@Fermilab outreach

GeV

10^{19} : PLANK SCALE

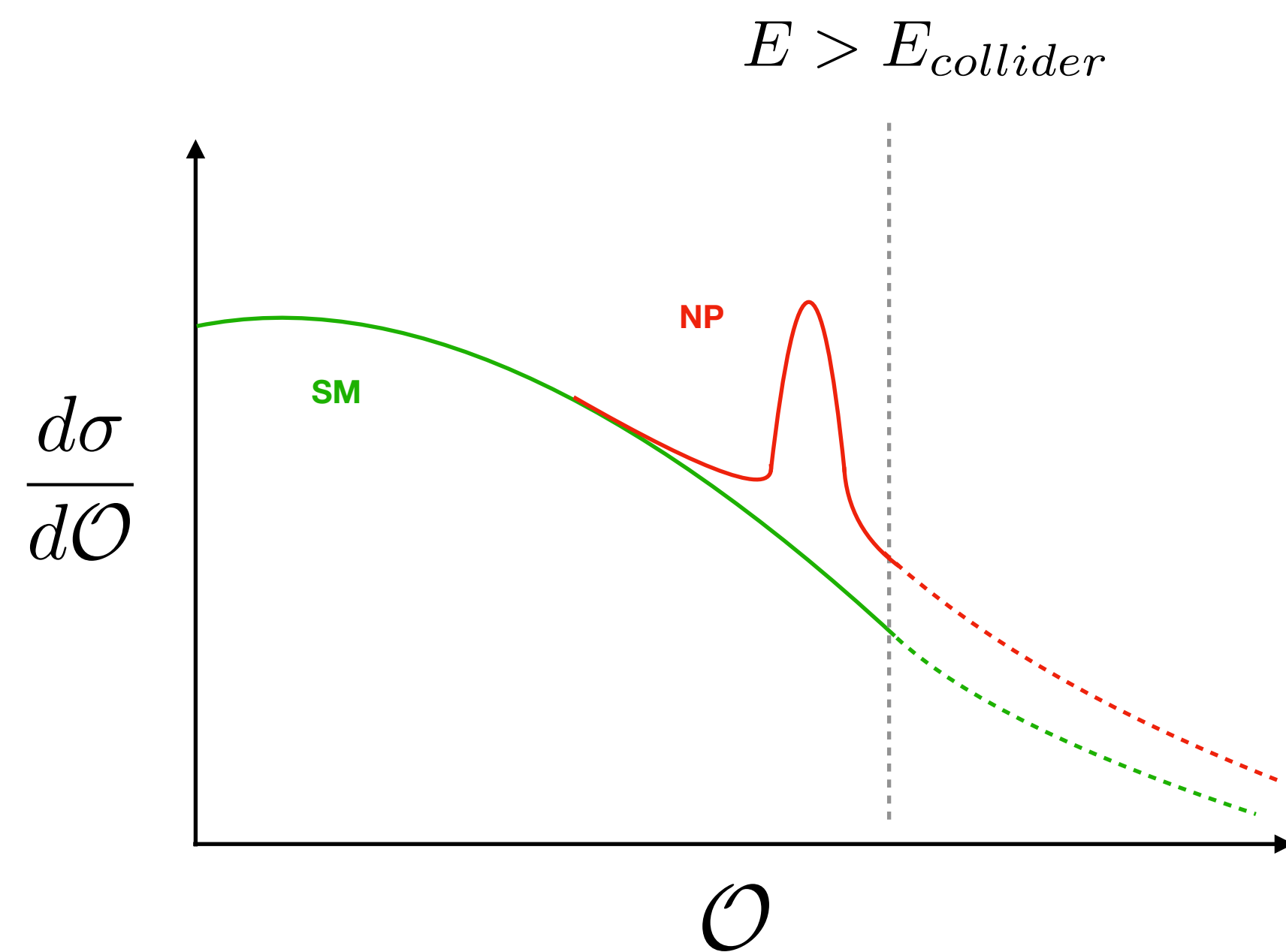
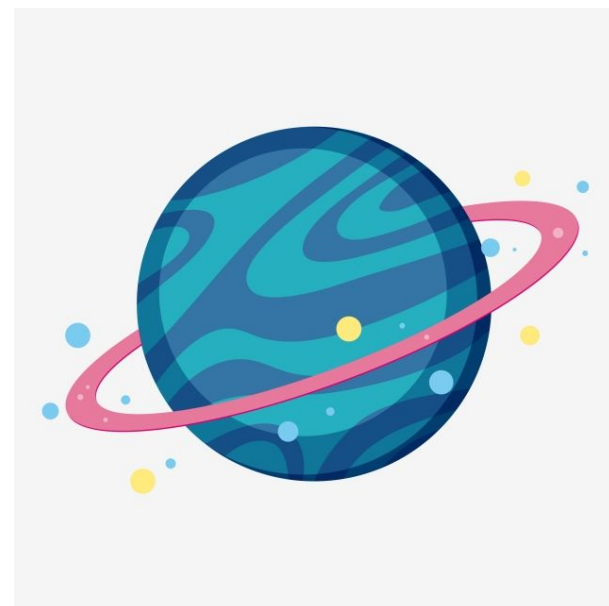
The unknown = New physics

$\Lambda = ?$

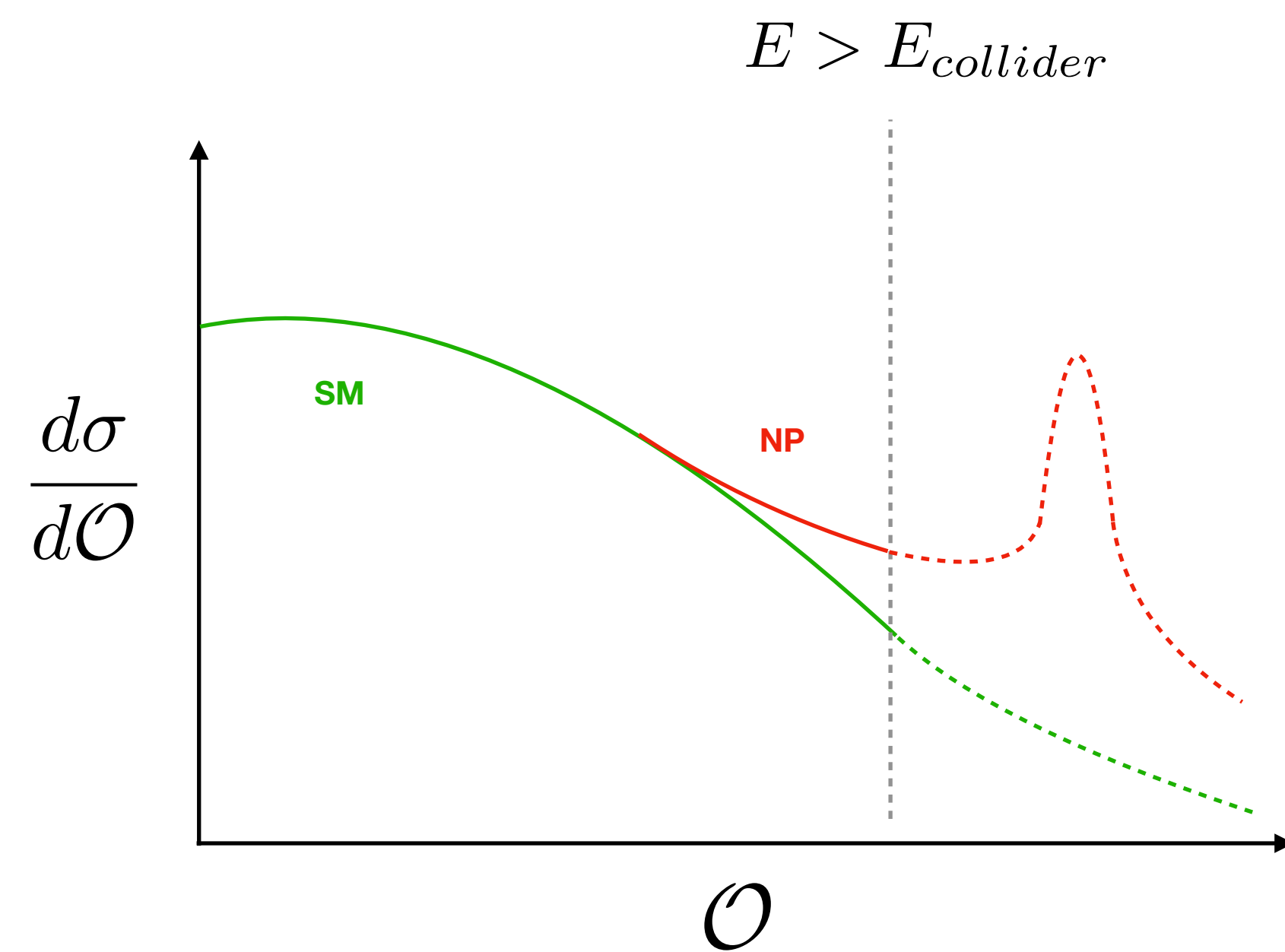
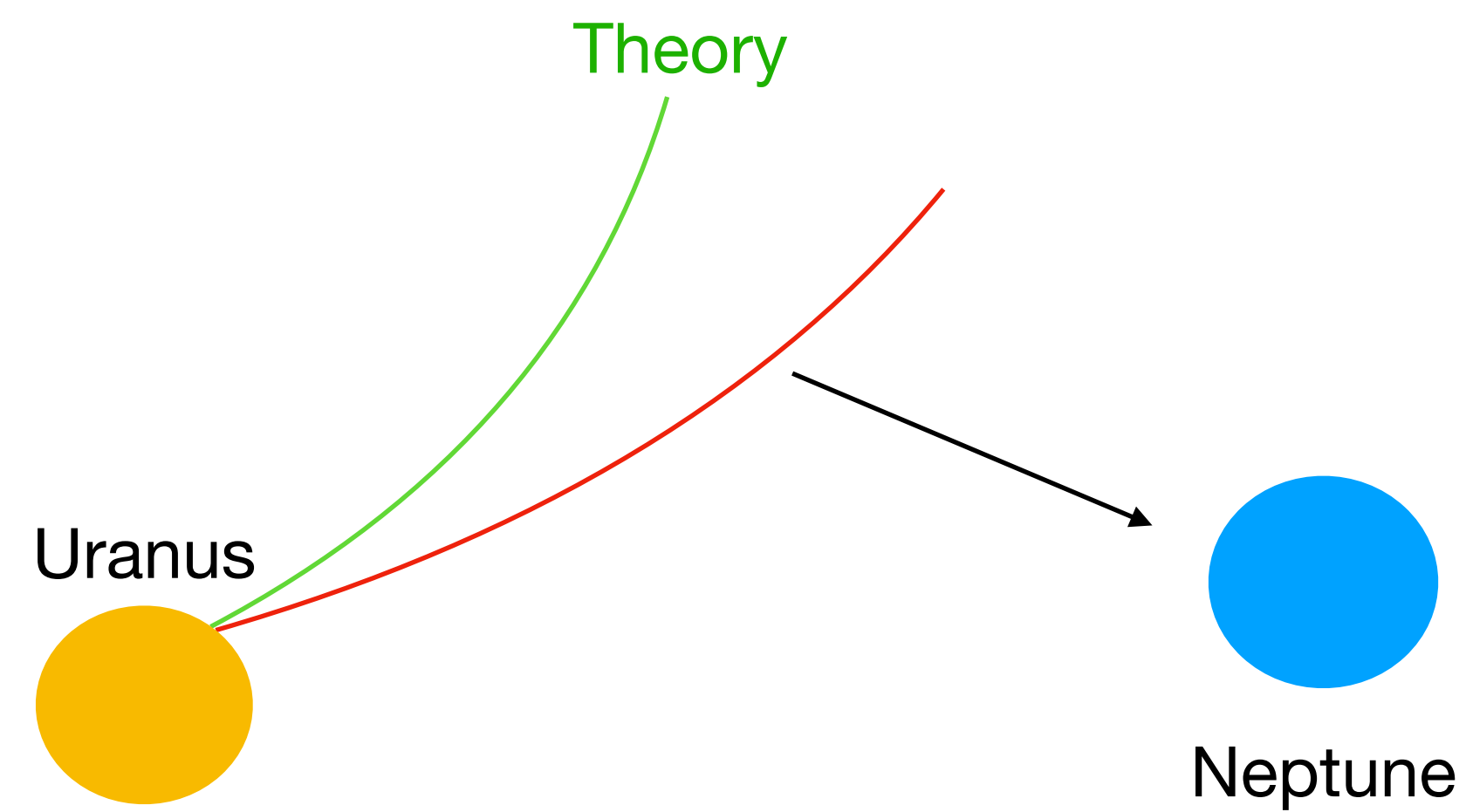
L
H
C

10^2 : HIGGS BOSON

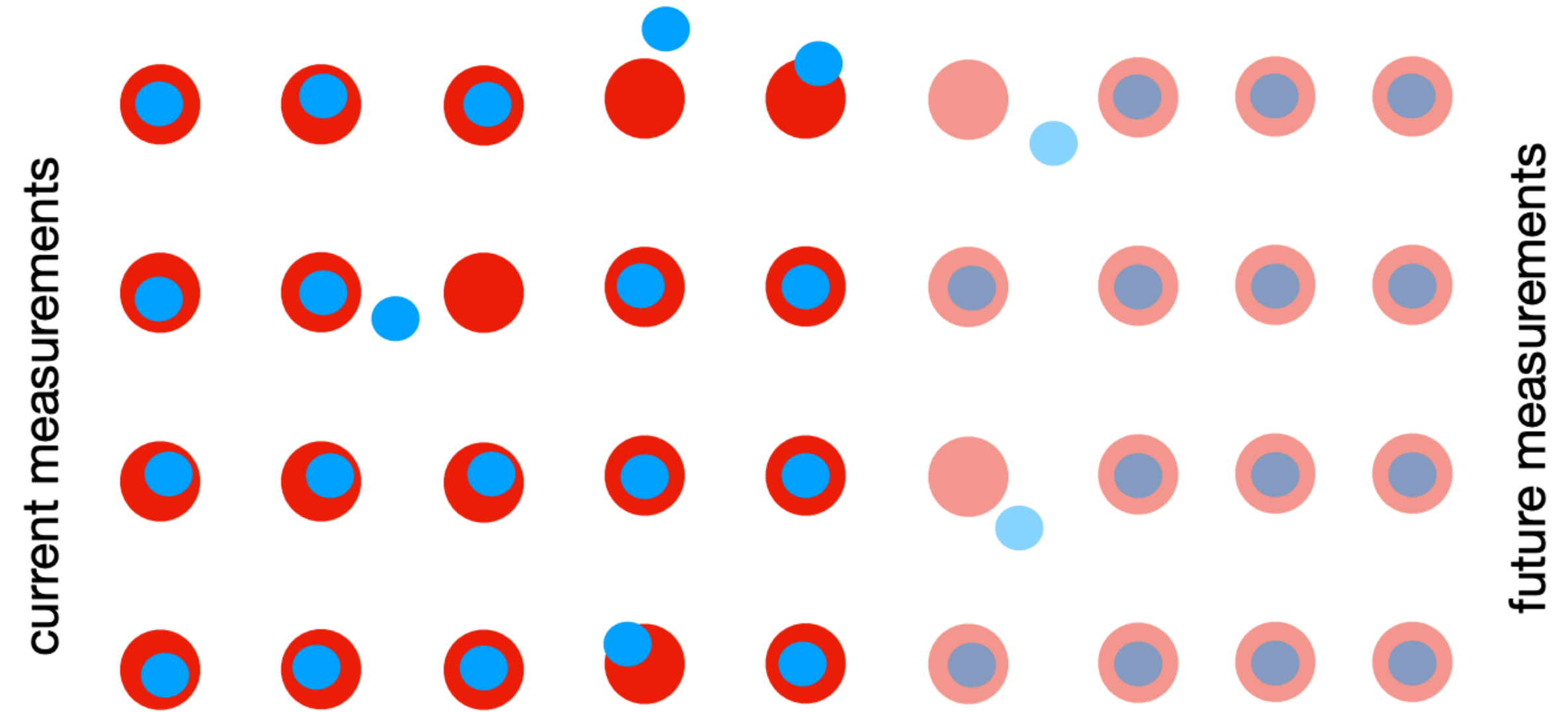
Direct searches



Indirect searches

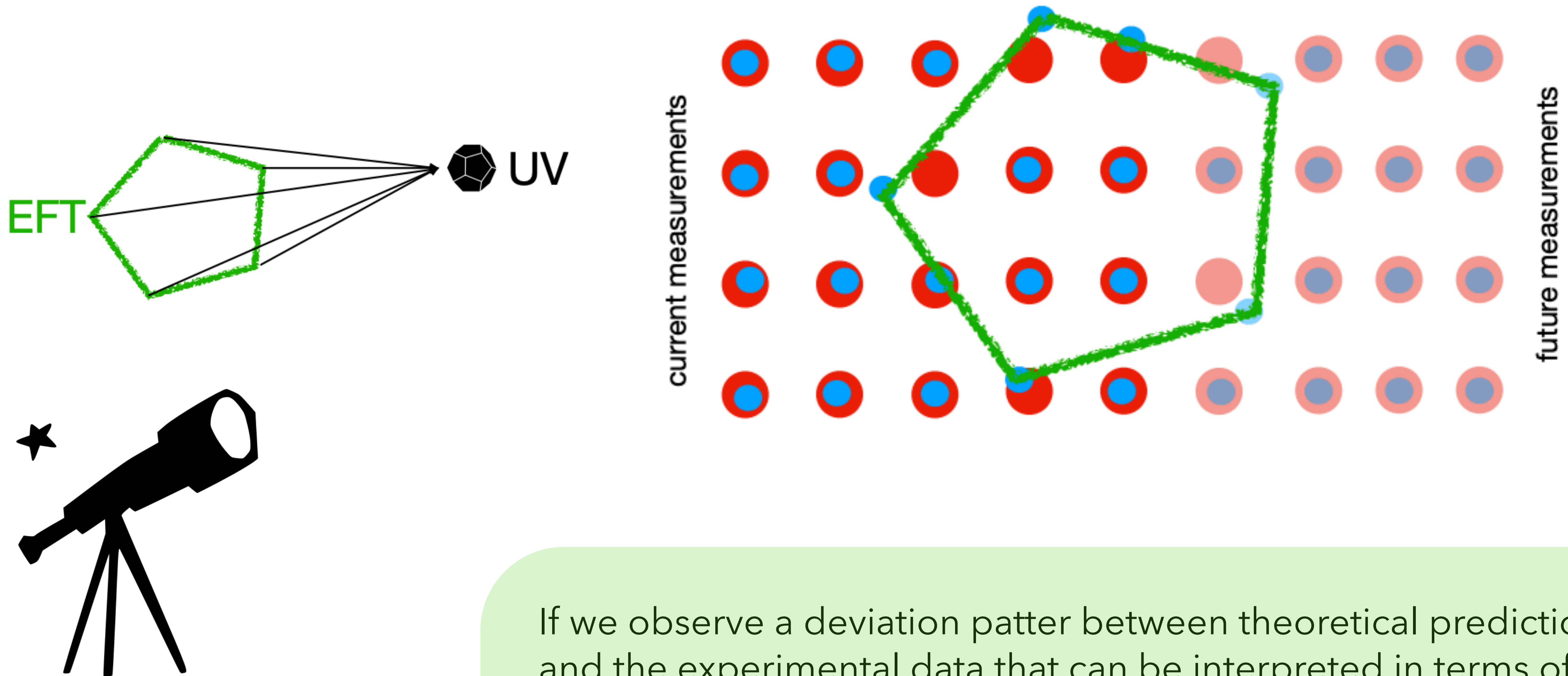


A mathematical bridge to new physics

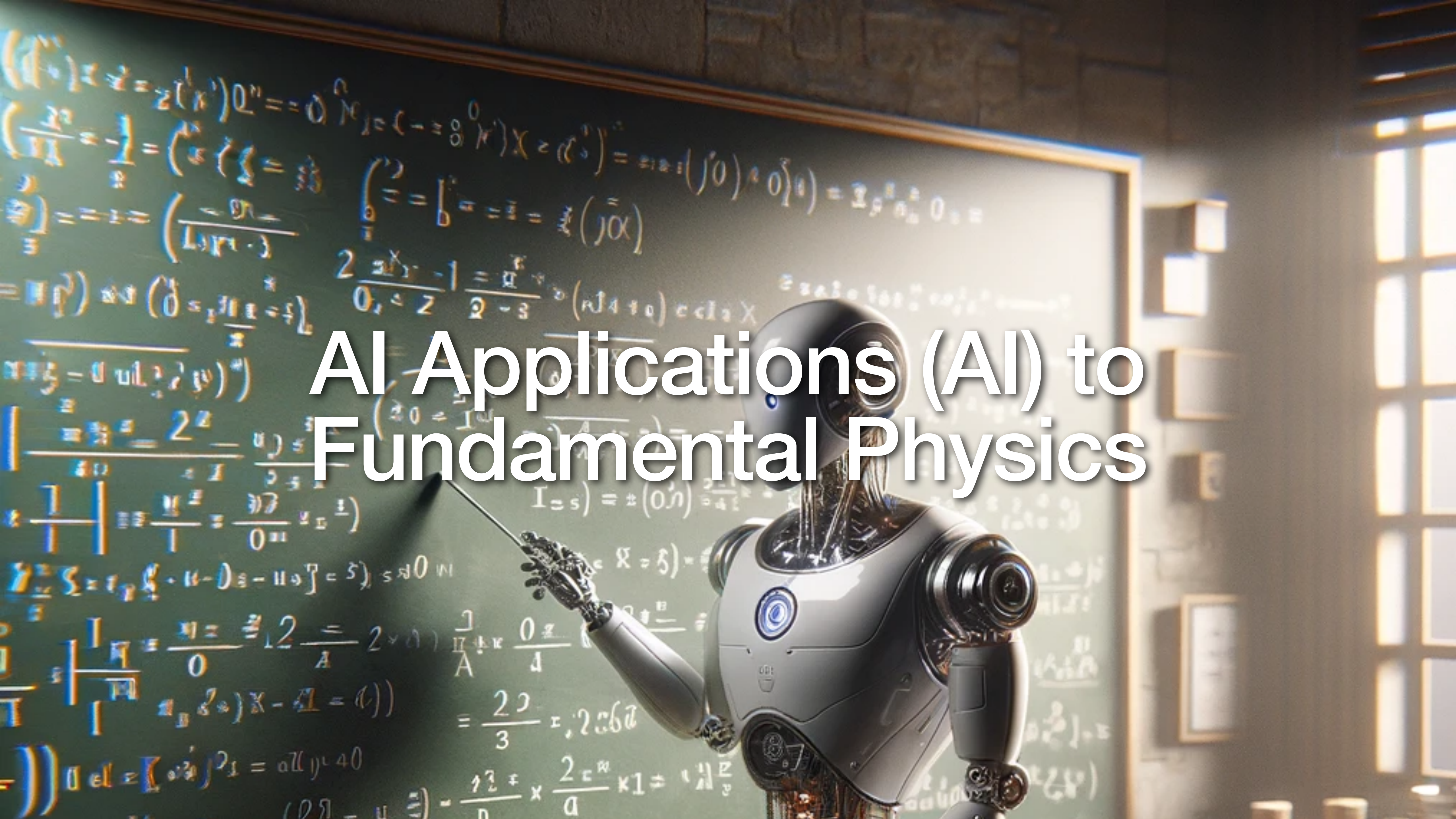


Even if new physics, new particles were living at an energy scale that we cannot reach at experiments in the next 100 years, there is a mathematical method to see the effects that these heavy particle have at the energy that is currently explored at CERN.

A mathematical bridge to new physics



If we observe a deviation pattern between theoretical predictions and the experimental data that can be interpreted in terms of something that lives at high energy that we still cannot reach, then it means that we have indirectly discovered new physics.



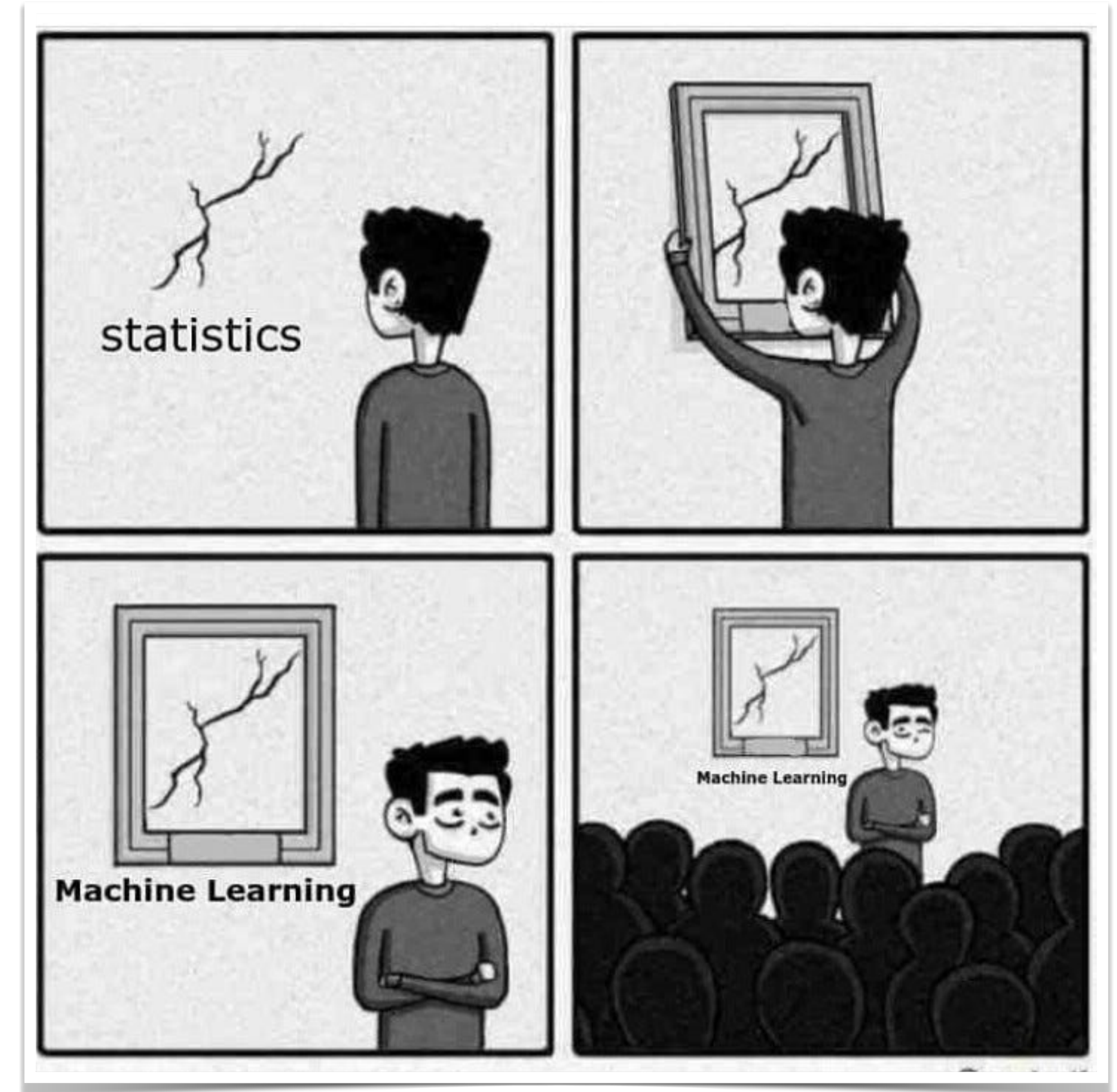
AI Applications (AI) to Fundamental Physics

AI to the rescue!

We see AI having more and more impact in science and society

Physics is *not* the exception!

But ... what is AI?



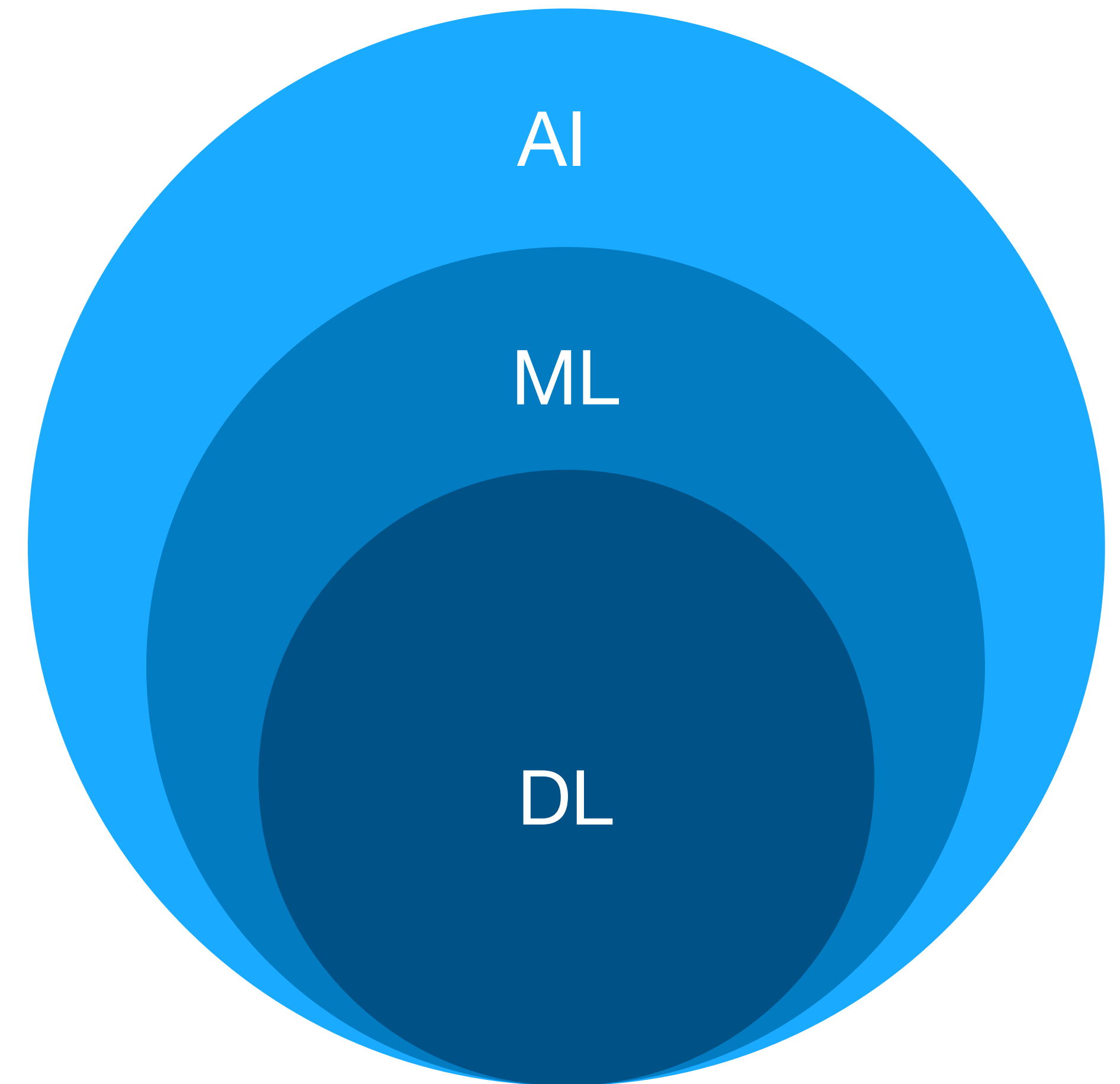
AI, and ML, and so forth ...

Terms are often used interchangeably

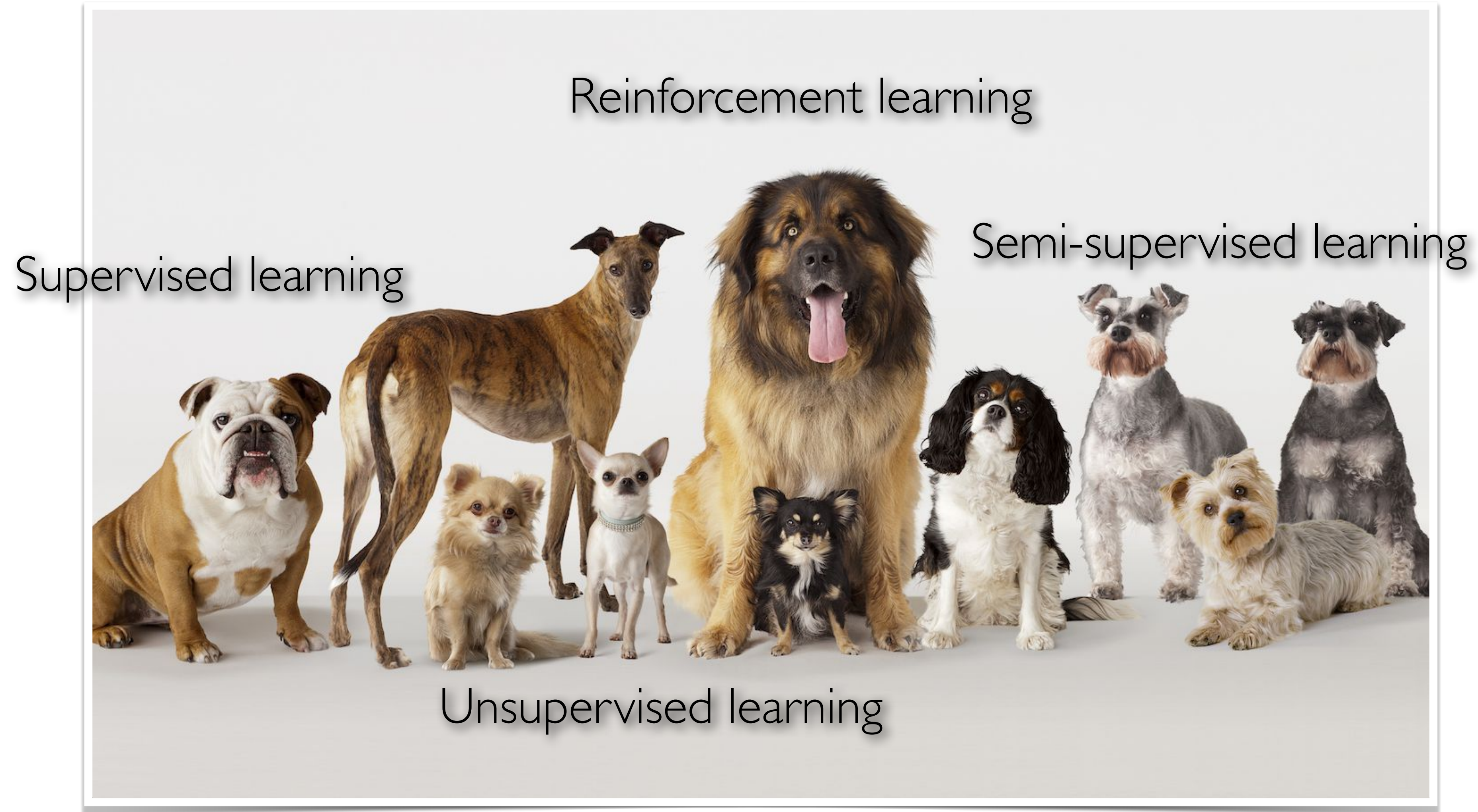
Artificial intelligence (AI): enable problem solving in machines

Machine learning (ML): make machines learn without explicit programming

Deep learning (DL): neural networks



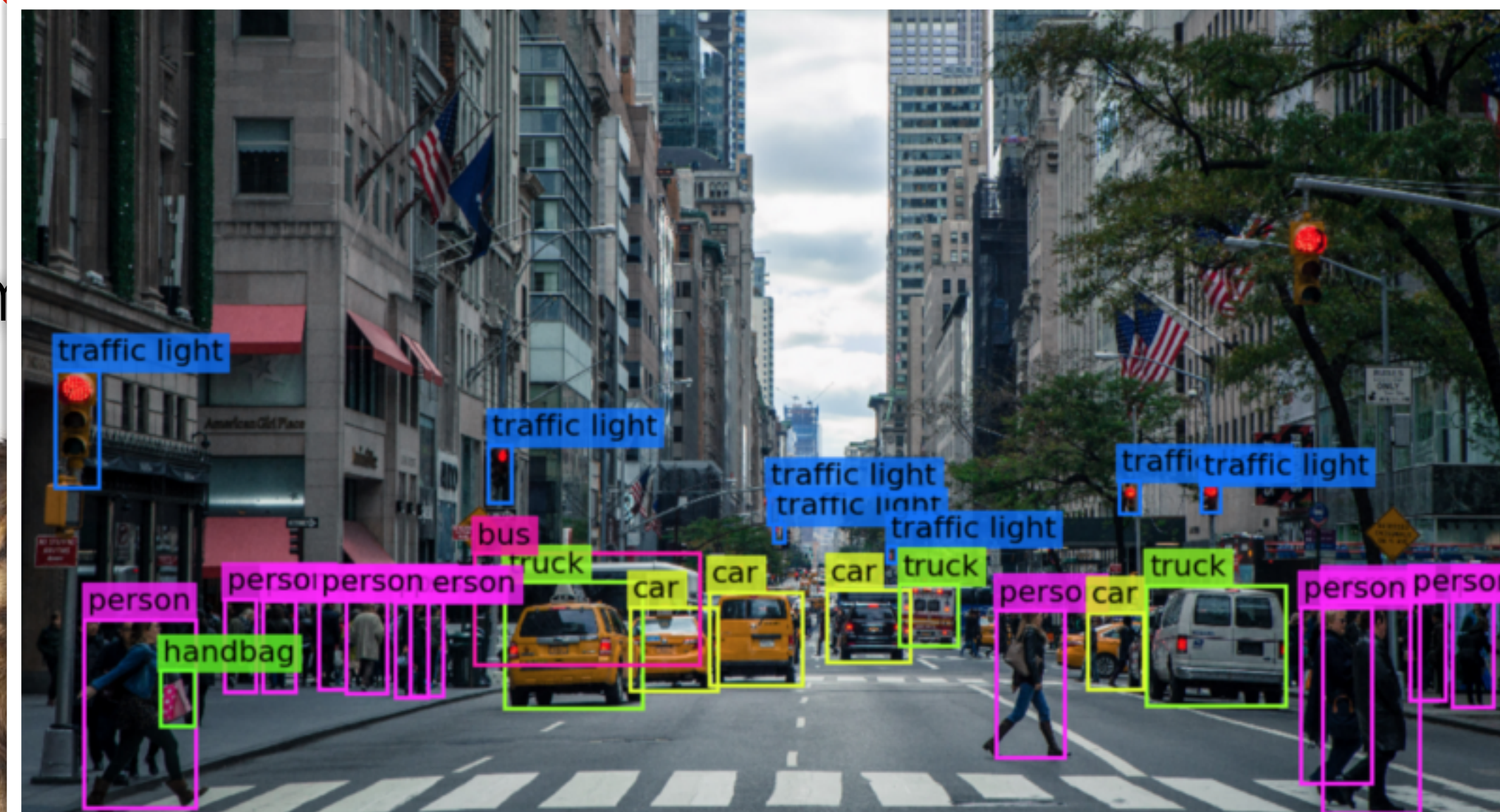
ML in all shapes and forms



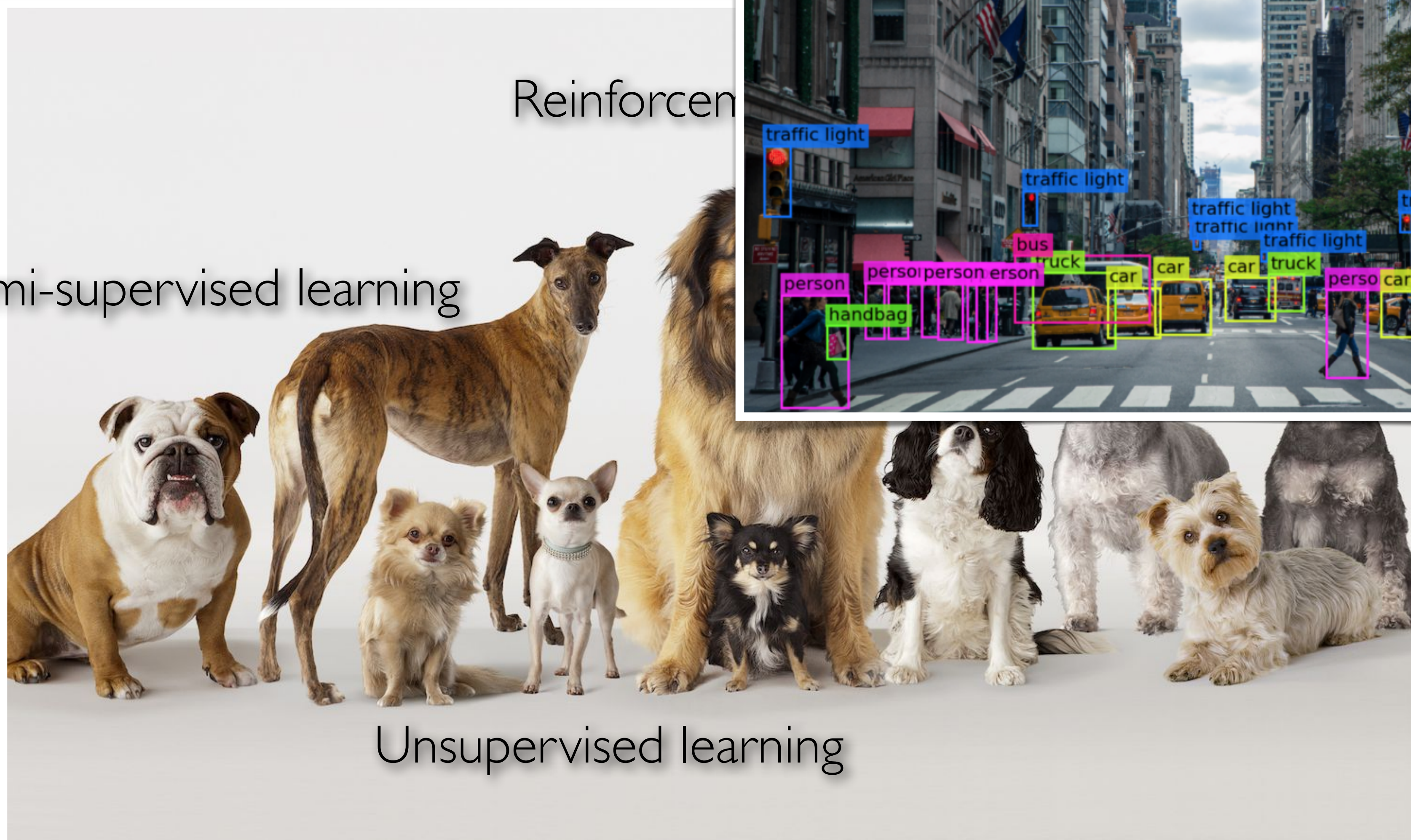
ML in all shapes and forms

Semi-supervised learning

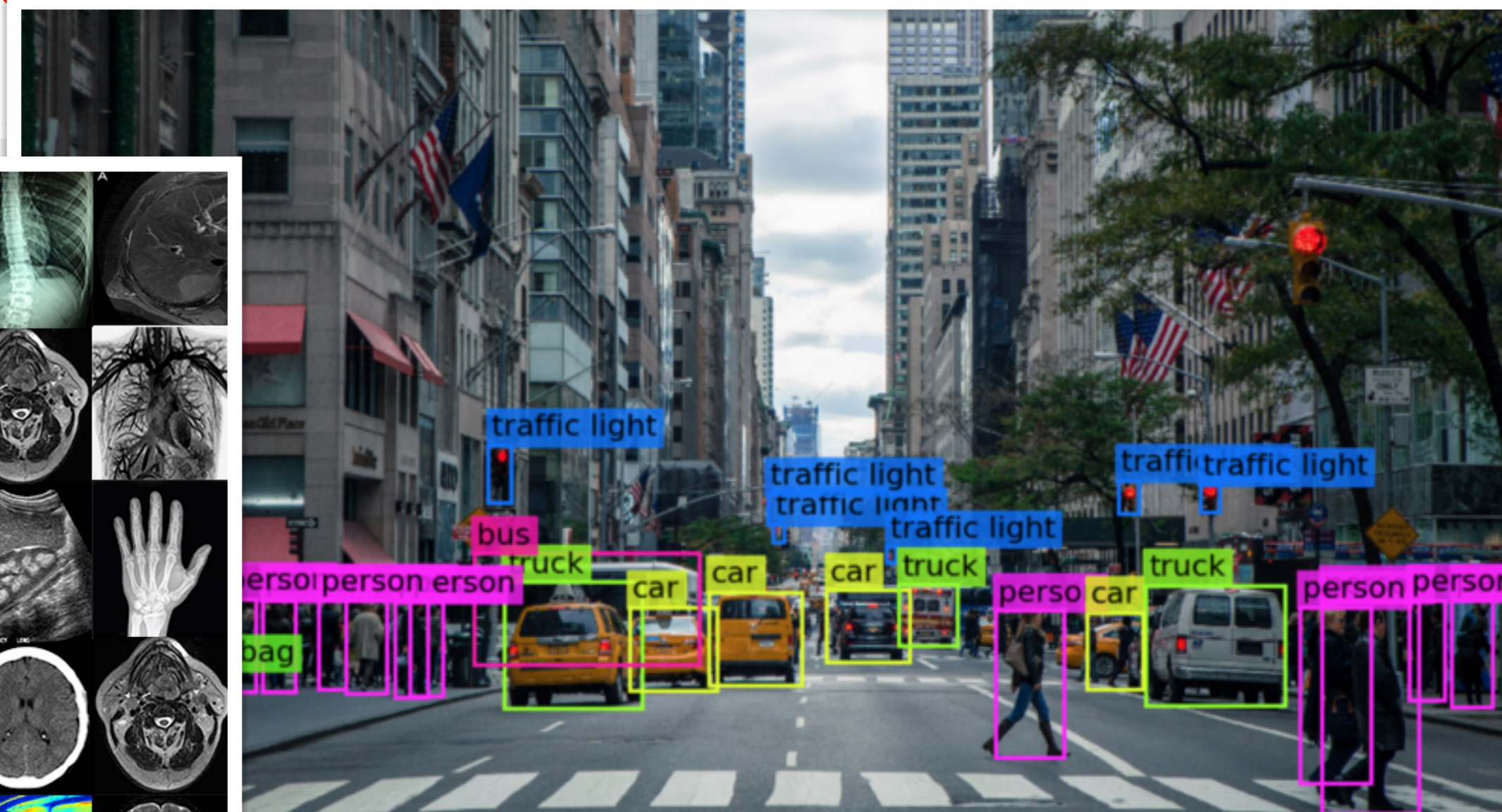
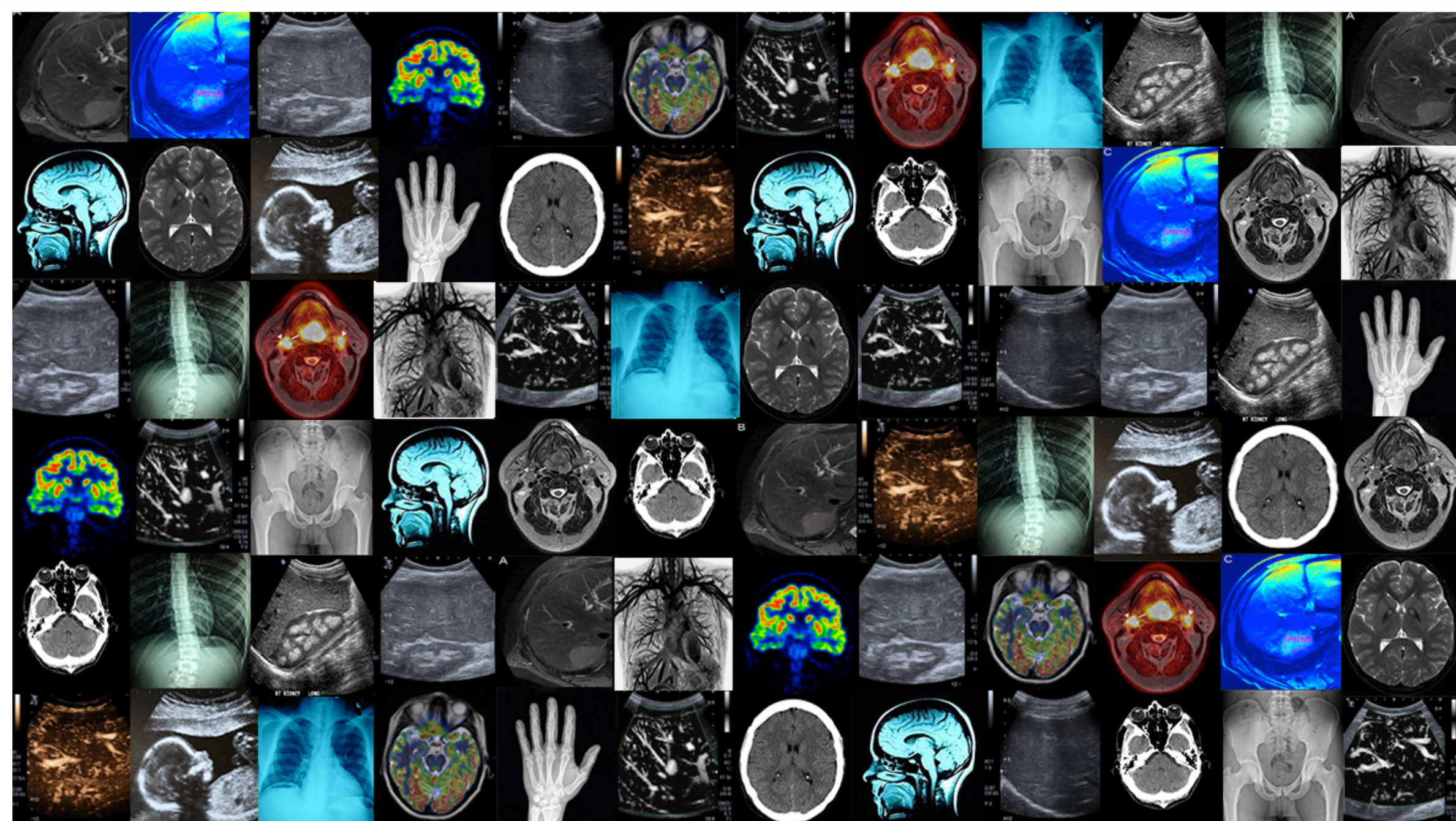
Reinforcement



Unsupervised learning

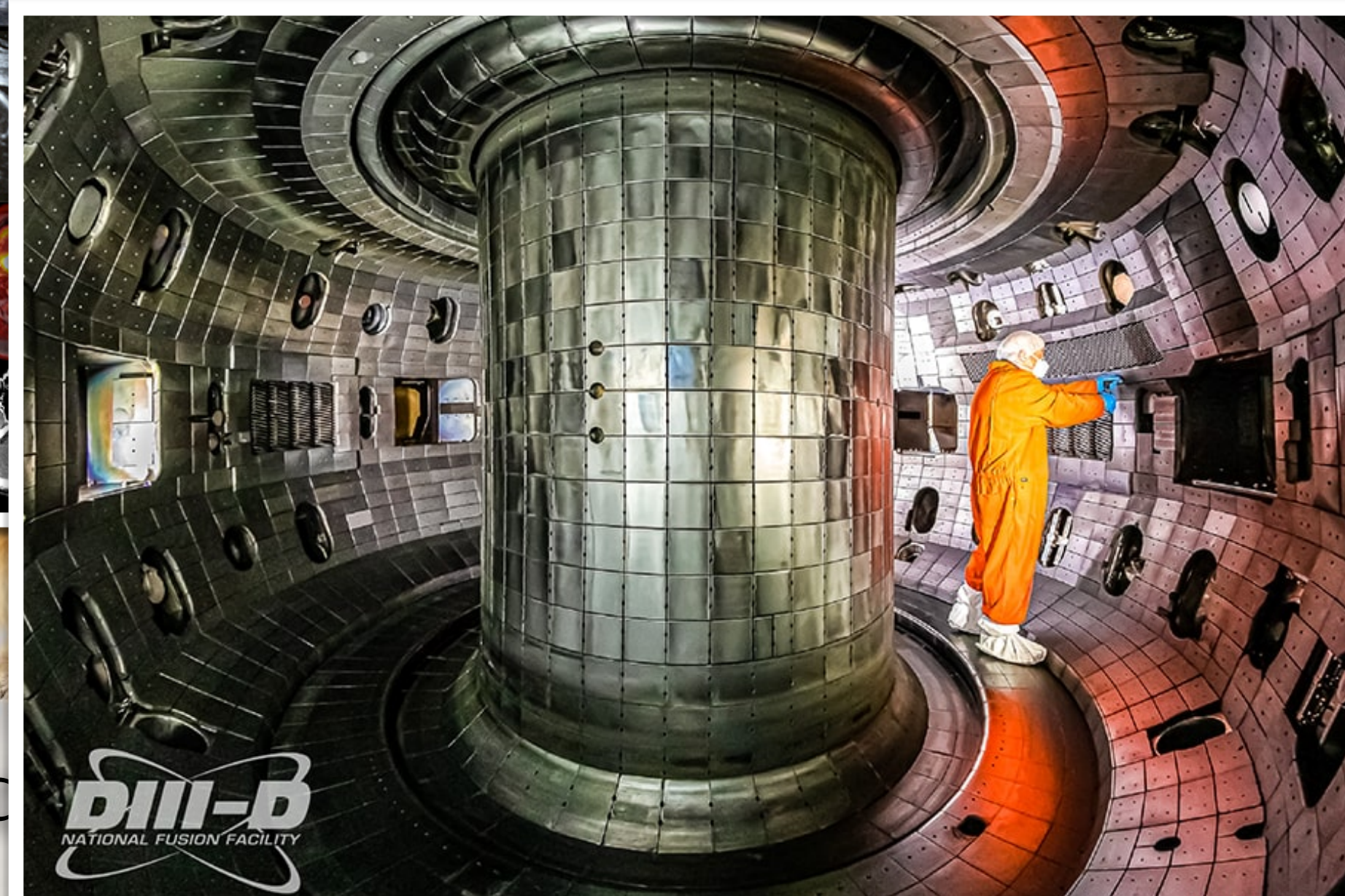
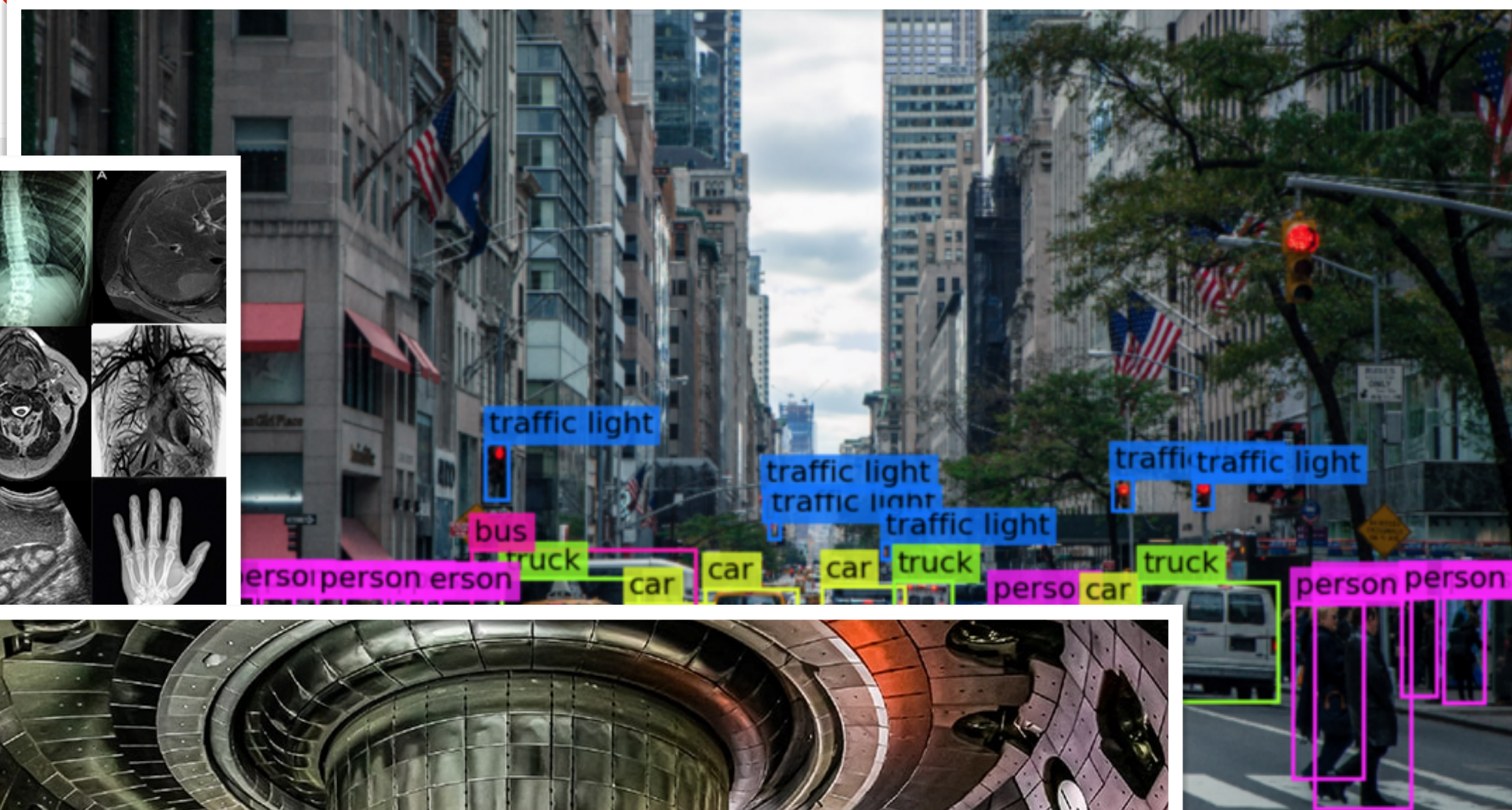
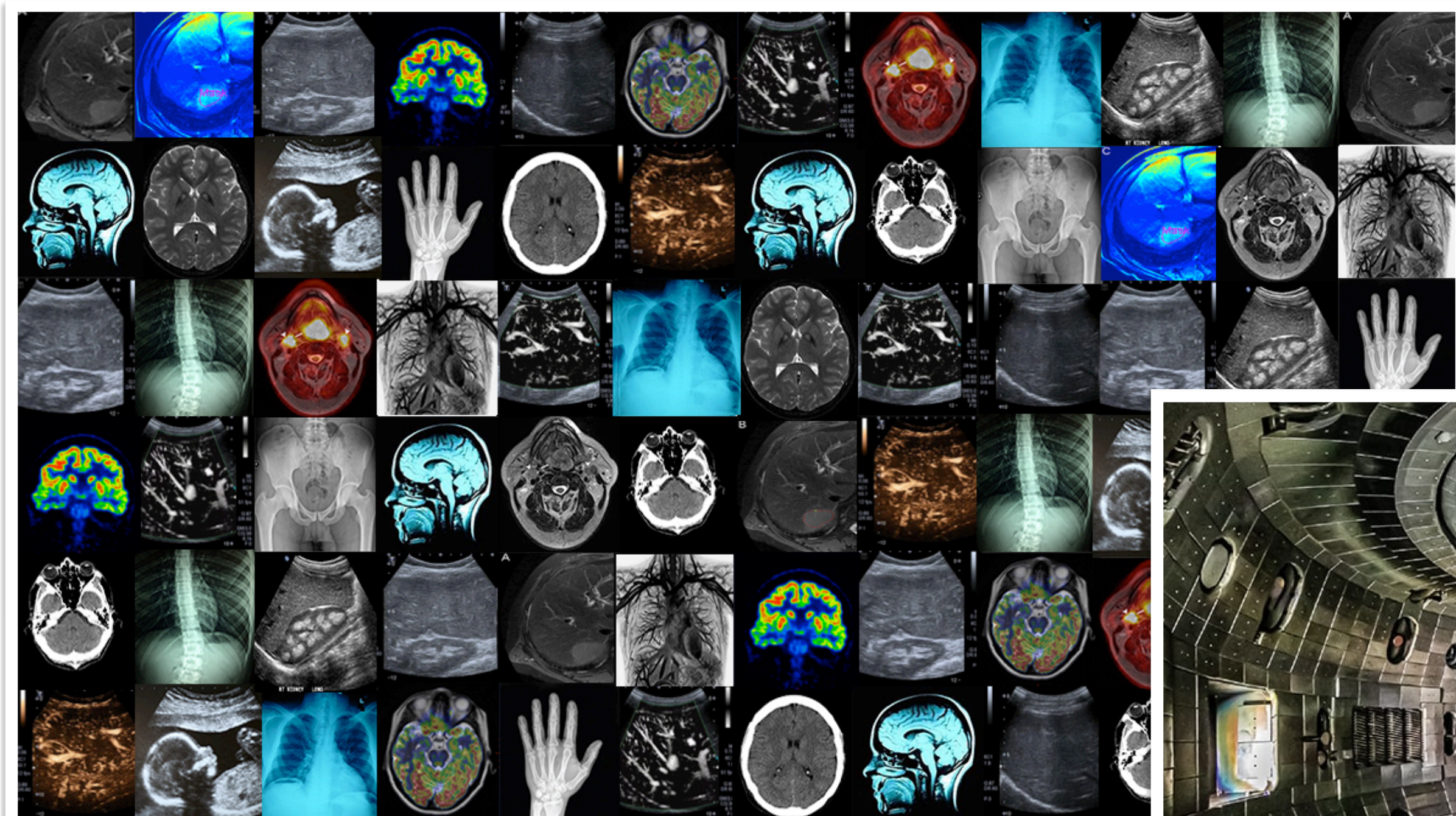


ML in all shapes and forms

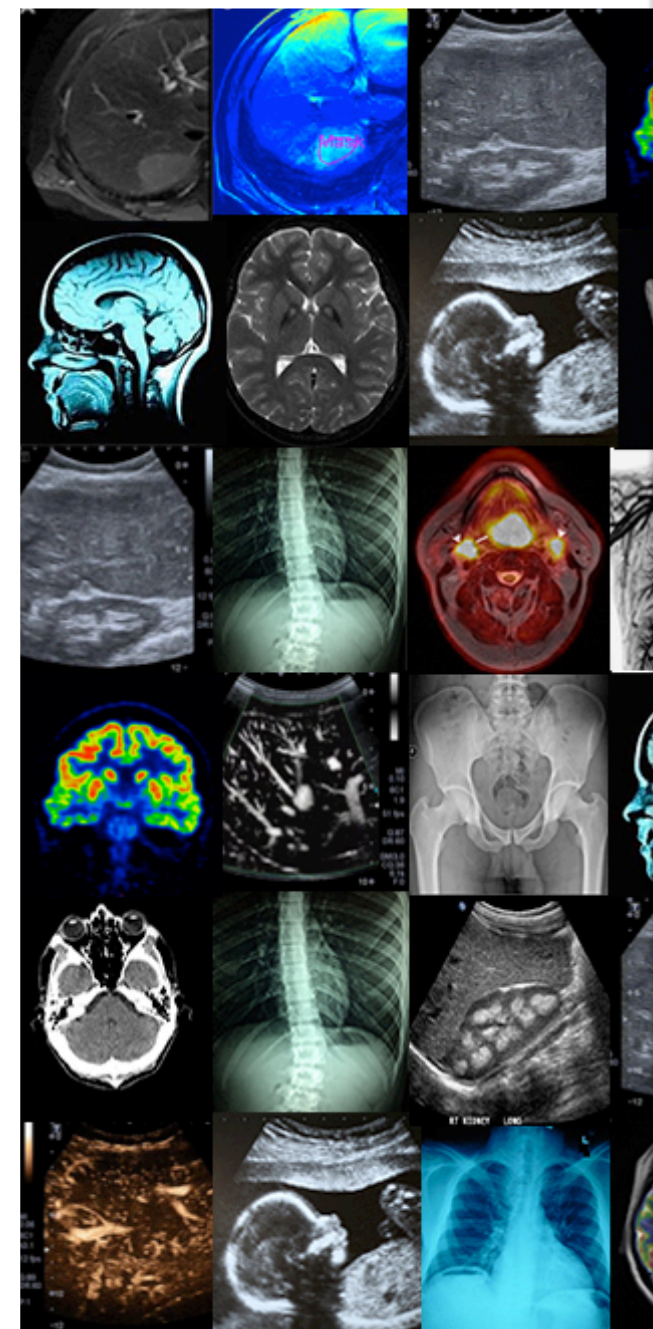


Unsupervised learning

ML in all shapes and forms



ML in all



MA

You

prepare a ML introduction for a pint of science session



ChatGPT

Absolutely, here's a draft for an introduction to machine learning that you can use for a "Pint of Science" session—a casual setting where the audience is eager to learn something new while enjoying their beverages:

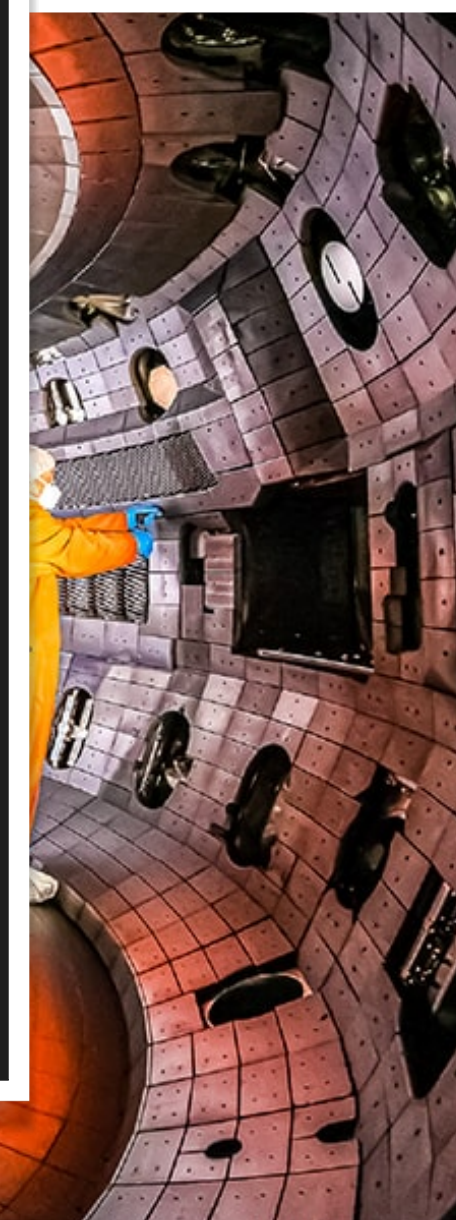
Introduction to Machine Learning: Unraveling the Magic Behind AI

Good evening, everyone!

As we settle in with our pints tonight, let's dive into a topic that's as buzzing as the atmosphere in this room—**Machine Learning**. It's a term that pops up everywhere these days, from your smartphone's camera and your favorite streaming service's recommendations to more critical uses like healthcare diagnostics and self-driving cars. But what exactly is machine learning, and why is it so revolutionary?

What is Machine Learning?

Imagine teaching your computer to spot the difference between an ale and a lager just by showing it thousands of examples. That's somewhat similar to how machine learning works. It's a branch of artificial intelligence that teaches computers to think in a way that is similar to how humans learn, gradually improving their accuracy and decision-making without being explicitly programmed to do so.



A ML algorithm

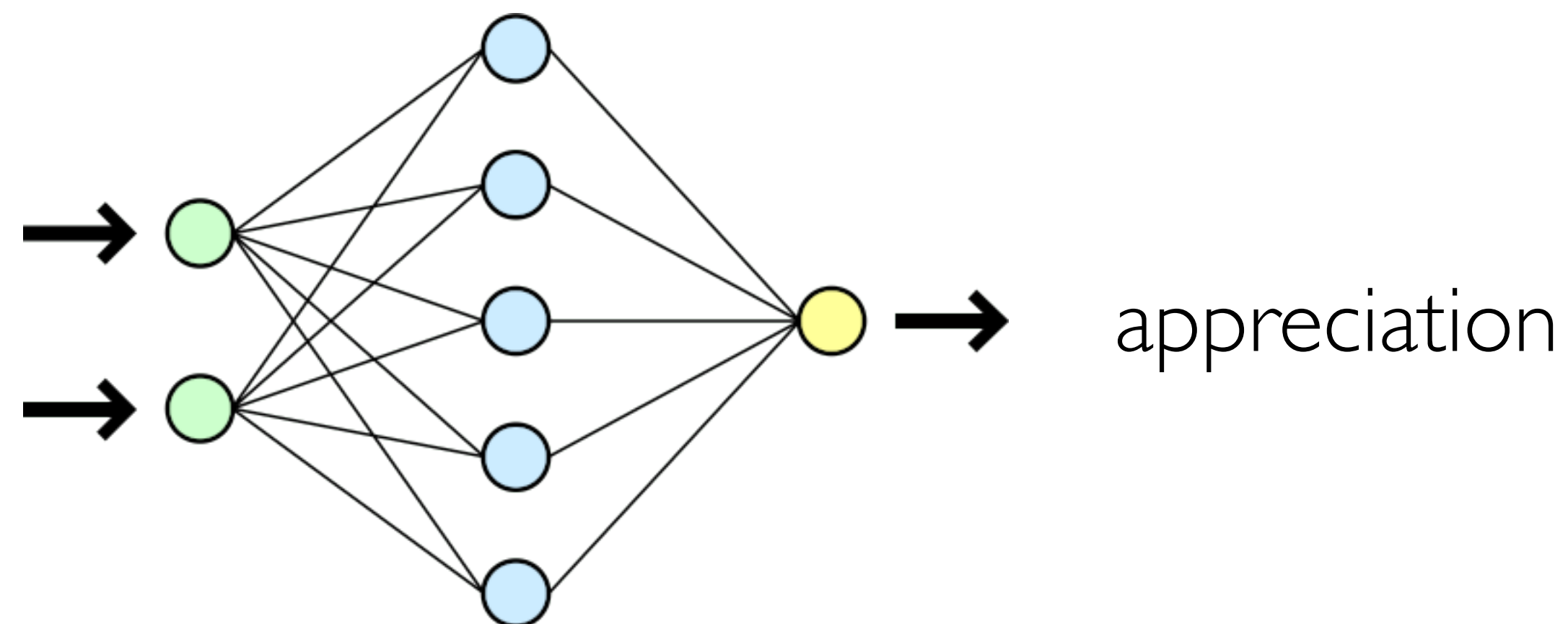
You want to find your favourite beer
(maximise *appreciation*)

1. Evaluate how good the beer you took was
2. Determine what would make the beer better
3. Update your beer preference

Iterate

features:

type of beer,
alc/vol, price,
...



A ML algorithm

You want to find y
(maximise *appreciation*)

1. Evaluate how good

2. Determine what

3. Update your beer

Iterate

features


type of
alc/vol

...

[nature](#) > [nature communications](#) > [articles](#) > article

Article | [Open access](#) | Published: 26 March 2024

Predicting and improving complex beer flavor through machine learning

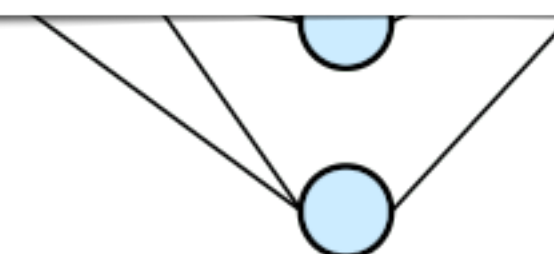
[Michiel Schreurs](#), [Supinya Piampongsant](#), [Miguel Roncoroni](#), [Lloyd Cool](#), [Beatriz Herrera-Malaver](#), [Christophe Vanderaa](#), [Florian A. Theßeling](#), [Łukasz Kreft](#), [Alexander Botzki](#), [Philippe Malcorps](#), [Luk Daenen](#), [Tom Wenseleers](#) & [Kevin J. Verstrepen](#) 

[Nature Communications](#) **15**, Article number: 2368 (2024) | [Cite this article](#)

62k Accesses | **859** Altmetric | [Metrics](#)

Abstract

The perception and appreciation of food flavor depends on many interacting chemical compounds and external factors, and therefore proves challenging to understand and predict. Here, we combine extensive chemical and sensory analyses of 250 different beers to



ML can solve difficult problems

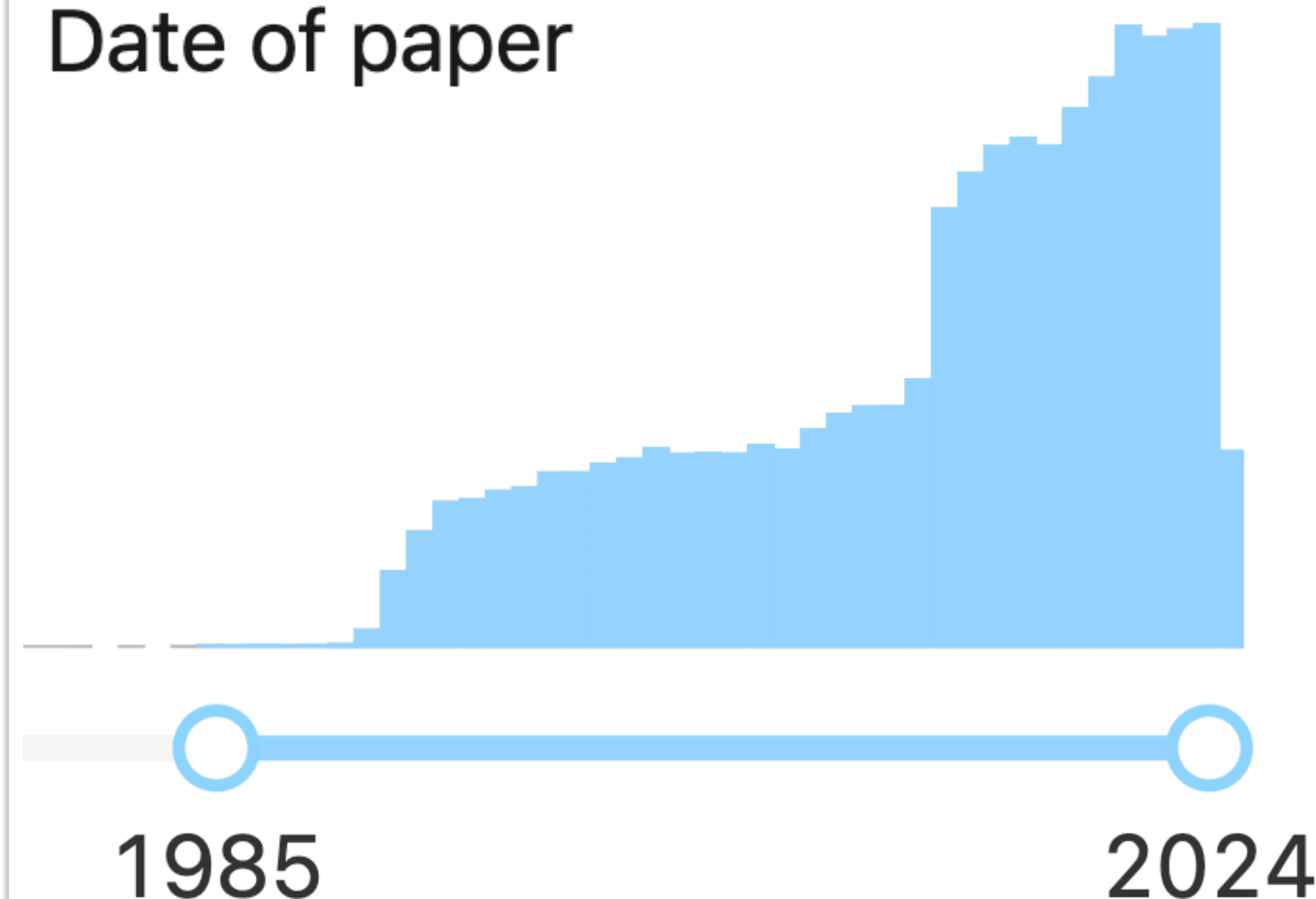
Muffin or Chihuahua? (*Classification* task)

ML gains traction in fundamental physics!



literature ▾ ('machine learning' or 'AI') in hep-th 🔍

Date of paper



ML for jet tagging

Jet: collimated shower of particles in the detector

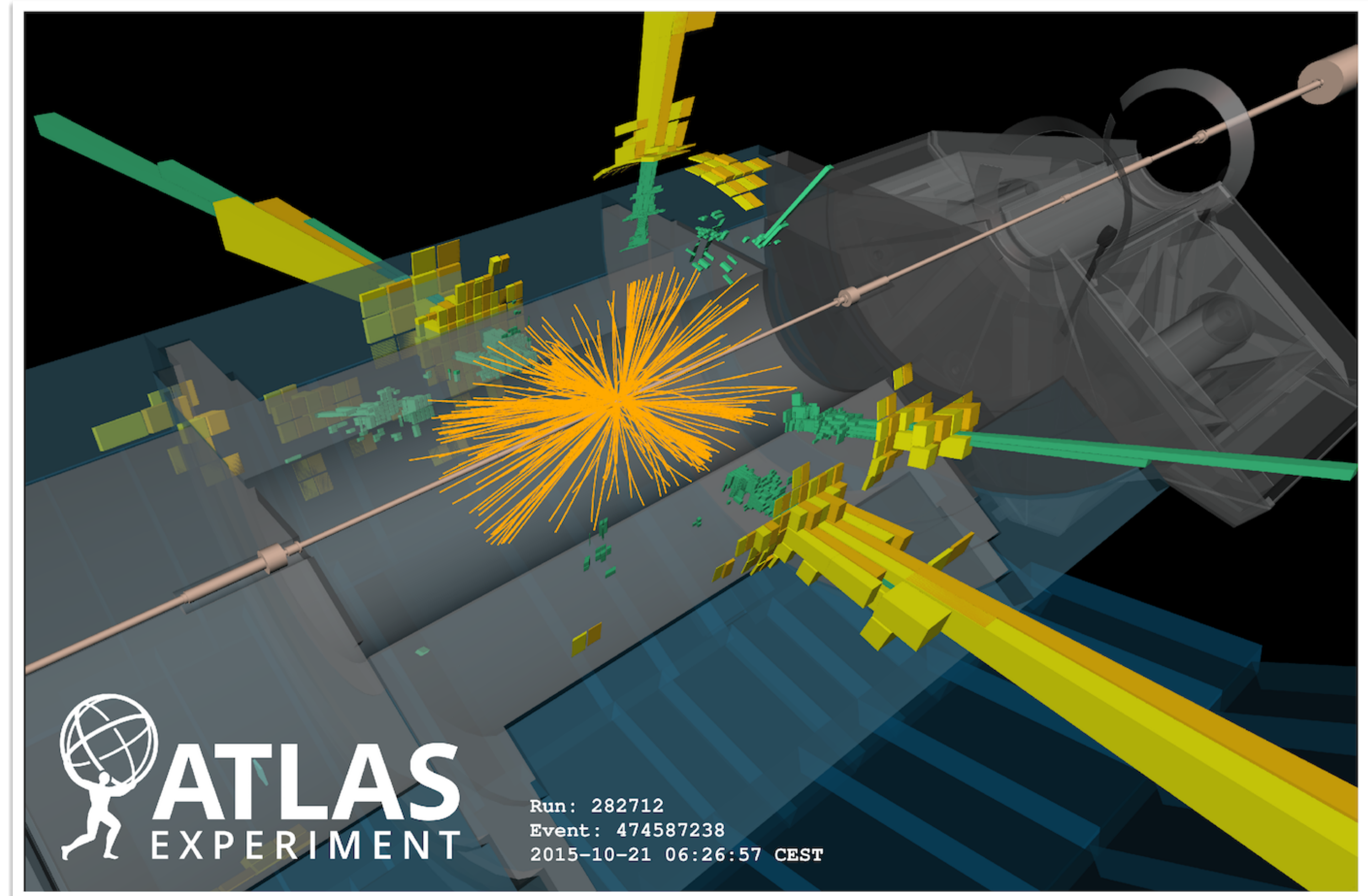
Tagging: gluon, light quark, bottom, top?

2 million simulated jet events

200 particles per jet

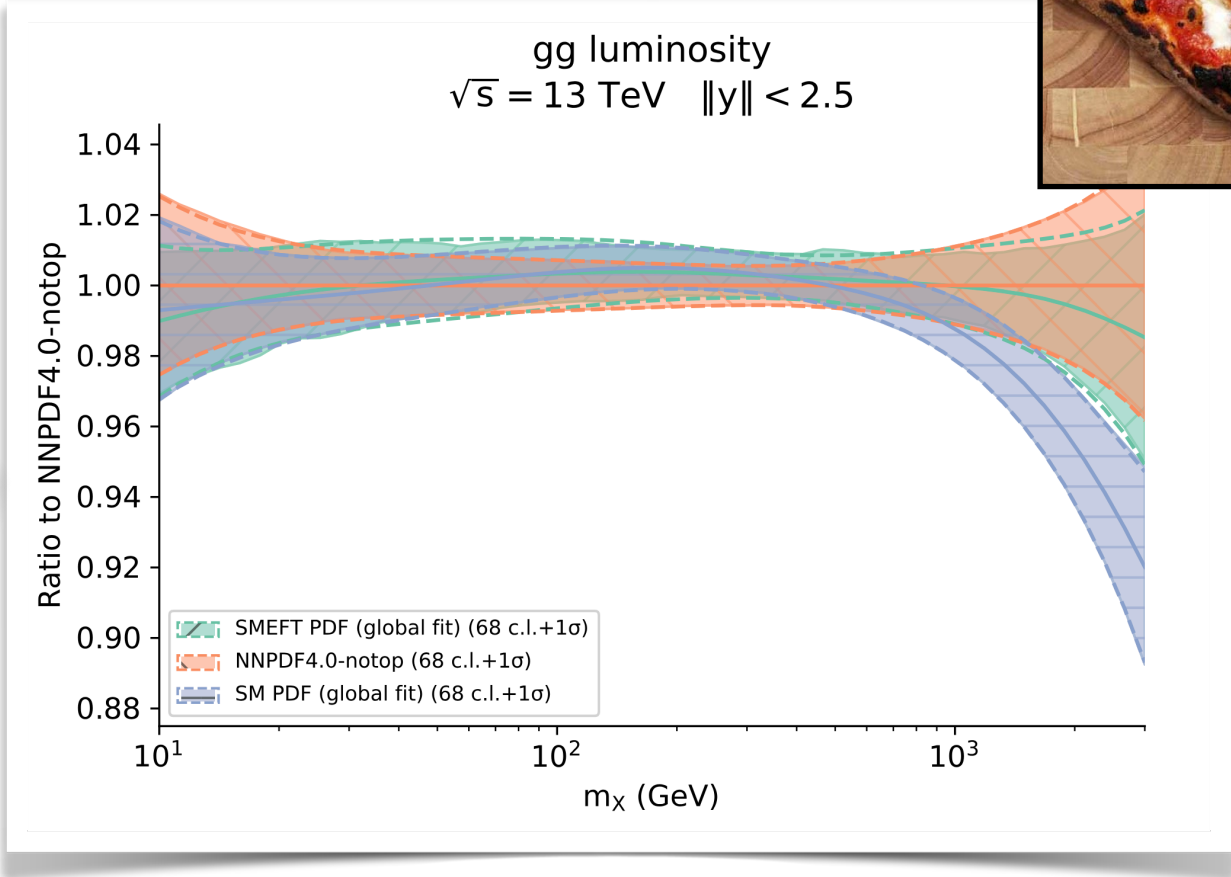
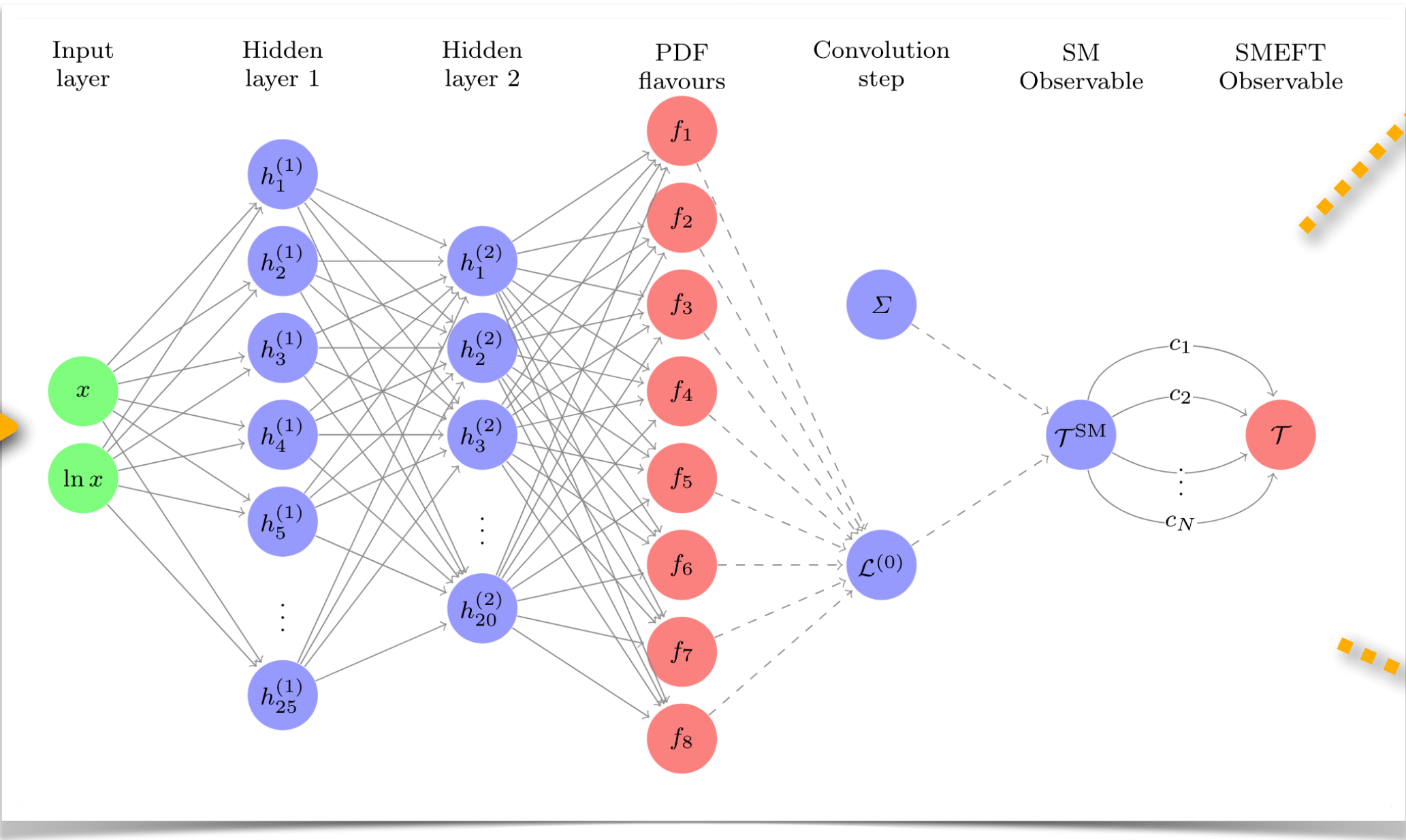
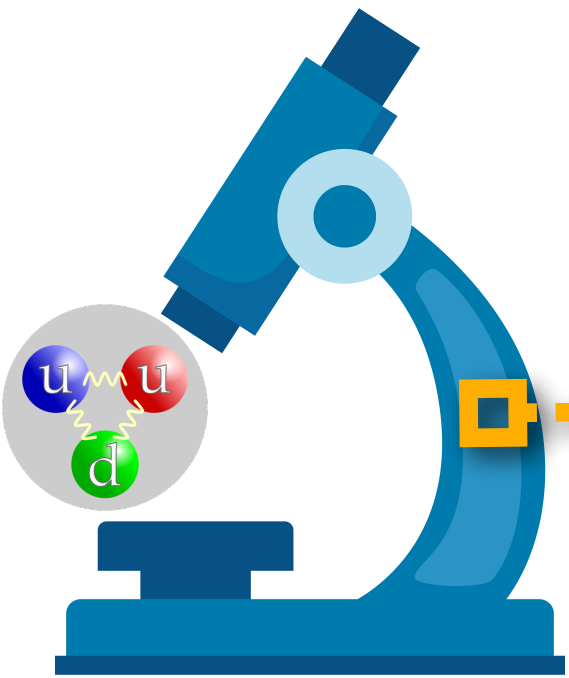
3 features per particle

ML to the rescue ...

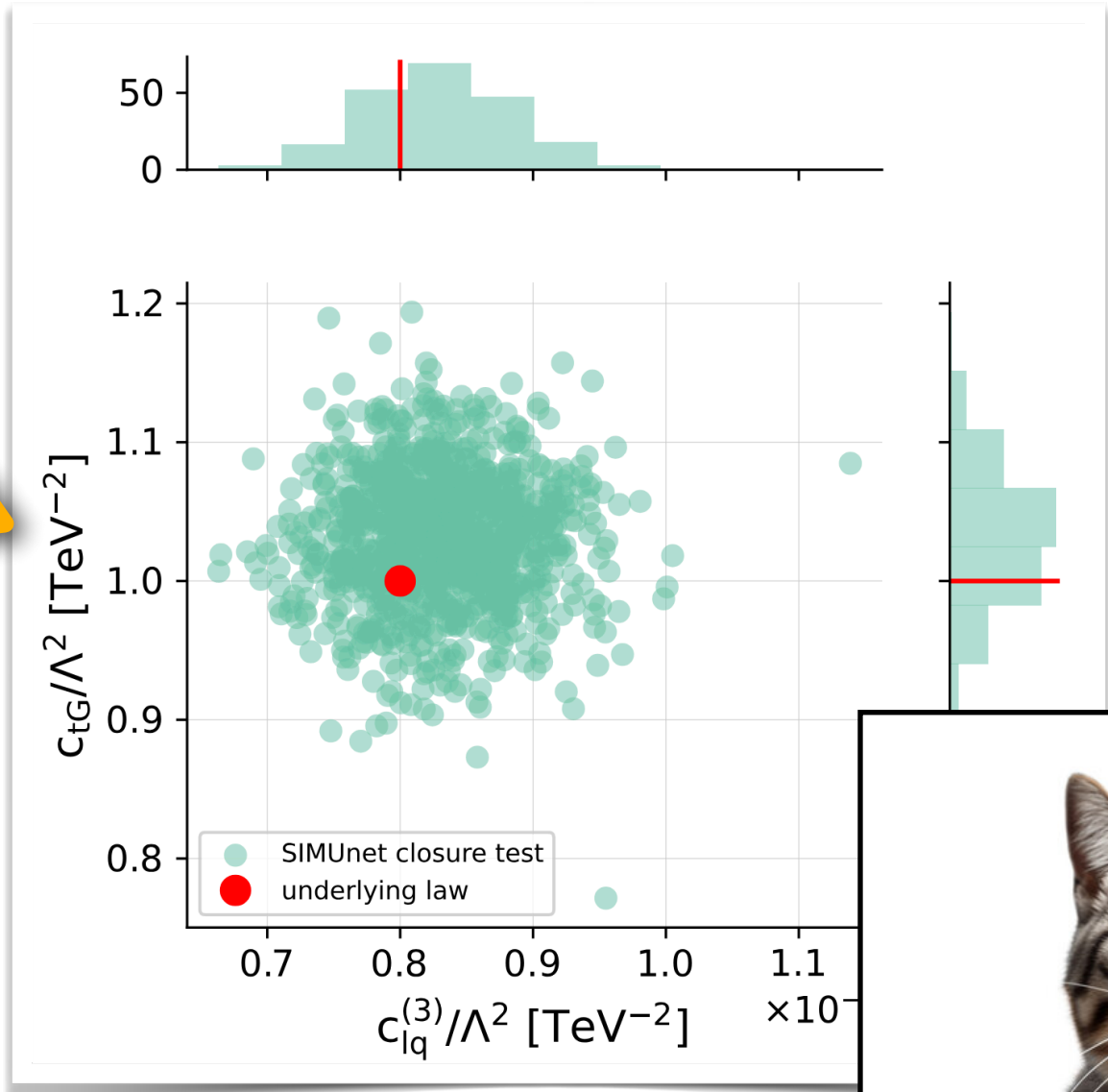


ML to model the proton structure

We can explore the proton with deep learning



proton
structure

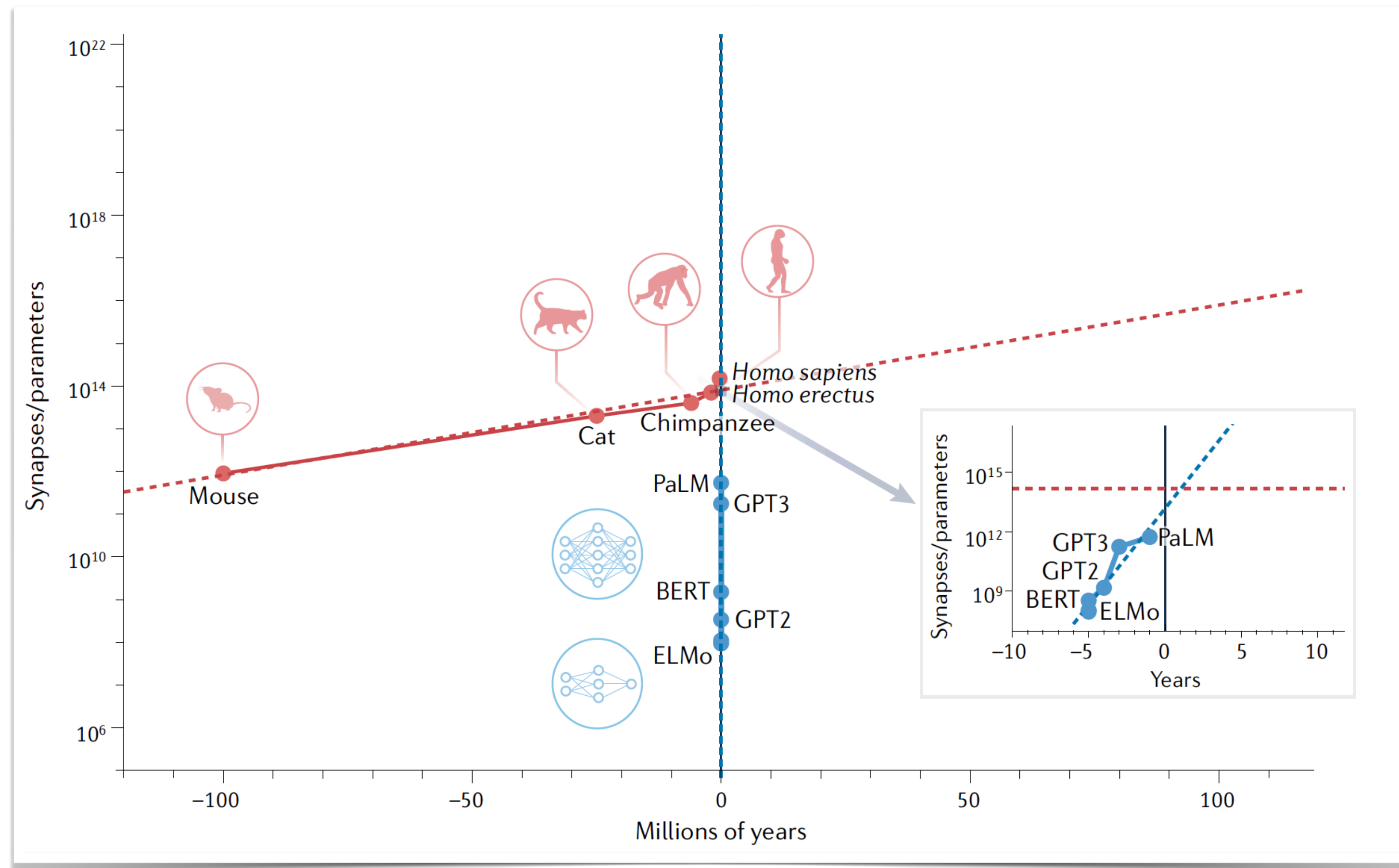


new
physics



The future of ML and physics

ML intelligence has caught up with biological intelligence



M. D. Schwartz, 741-642, NRP (2022)

Are the problems too hard to solve?

Can machines help us be better physicists?

Can machines be creative?

Exciting times ahead!

Conclusions

Physics describes phenomena across **different scales**

The SM is good, but **it is not the whole story** ...

Physics in the SM and beyond is tested to unprecedented accuracy at the **LHC**

ML is helping to **push the boundaries** of our understanding of fundamental physics!

"Great discoveries, which seem to mark the end of a story, mark in fact the beginning of a new, more extraordinary one"

G. Ilioupoulos

Back-up

The Higgs Boson

