
Exploring the Energy Frontier

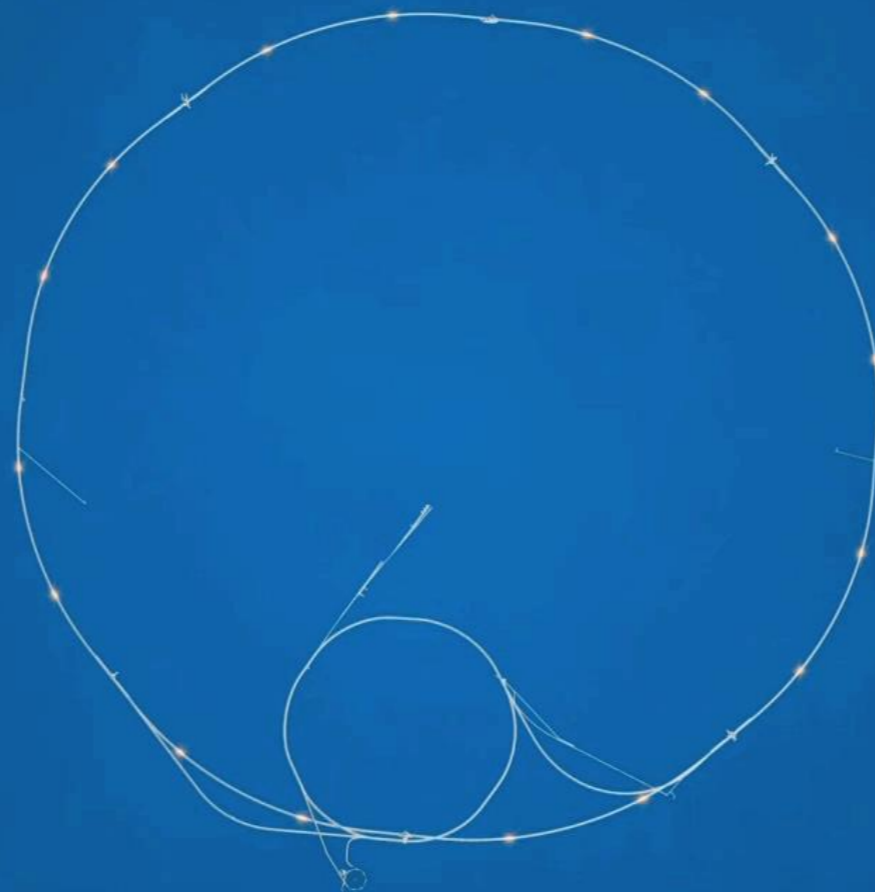
our journey to understanding nature

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Theoretical Physics (ICTP)**

ATLAS EXPERIMENT

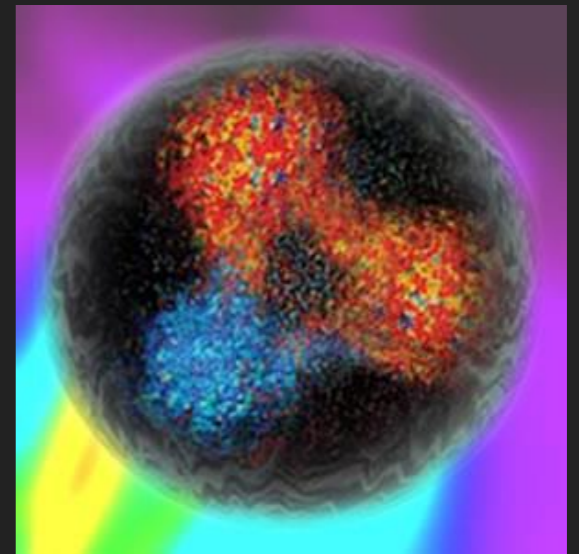
The LHC collides protons **millions of times** a second!
At the **highest** ever energy (13 TeV!)



THE LARGE HADRON COLLIDER

The LHC accelerates some of the **smallest** objects in the universe

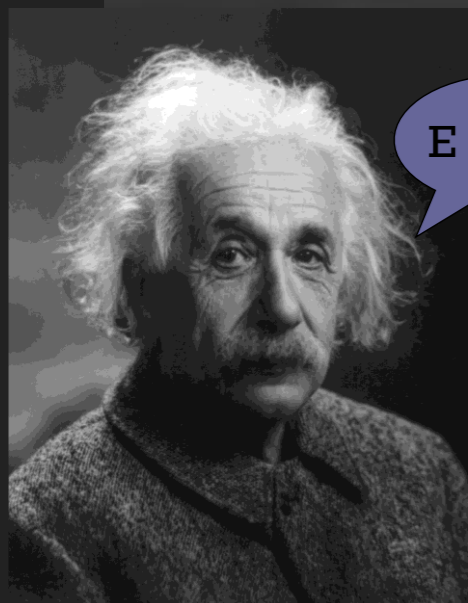
up to almost the **fastest speeds possible** in the universe (*speed of light*)



Using magnets 1.9 K (-271.3°C), **colder** than **outer space!**



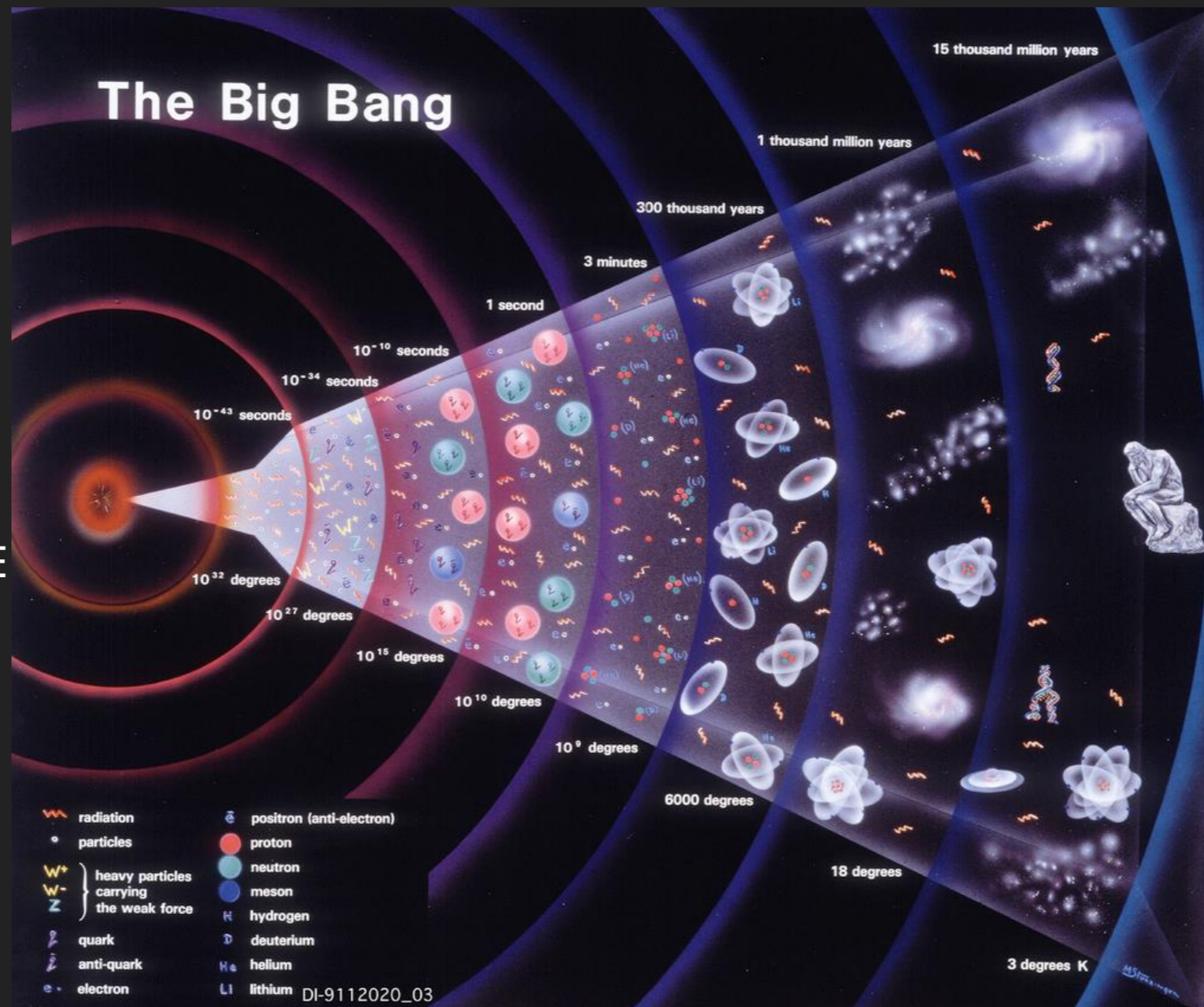
WHY do we smash protons together at high energies millions of times a second?



$E = mc^2$

WHY do we smash protons together at high energies millions of times a second?

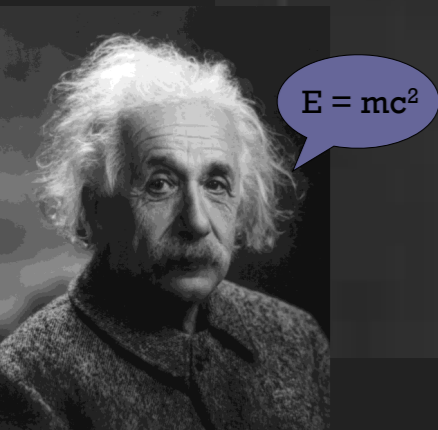
HOT
DENSE



COOL
EXPANDED

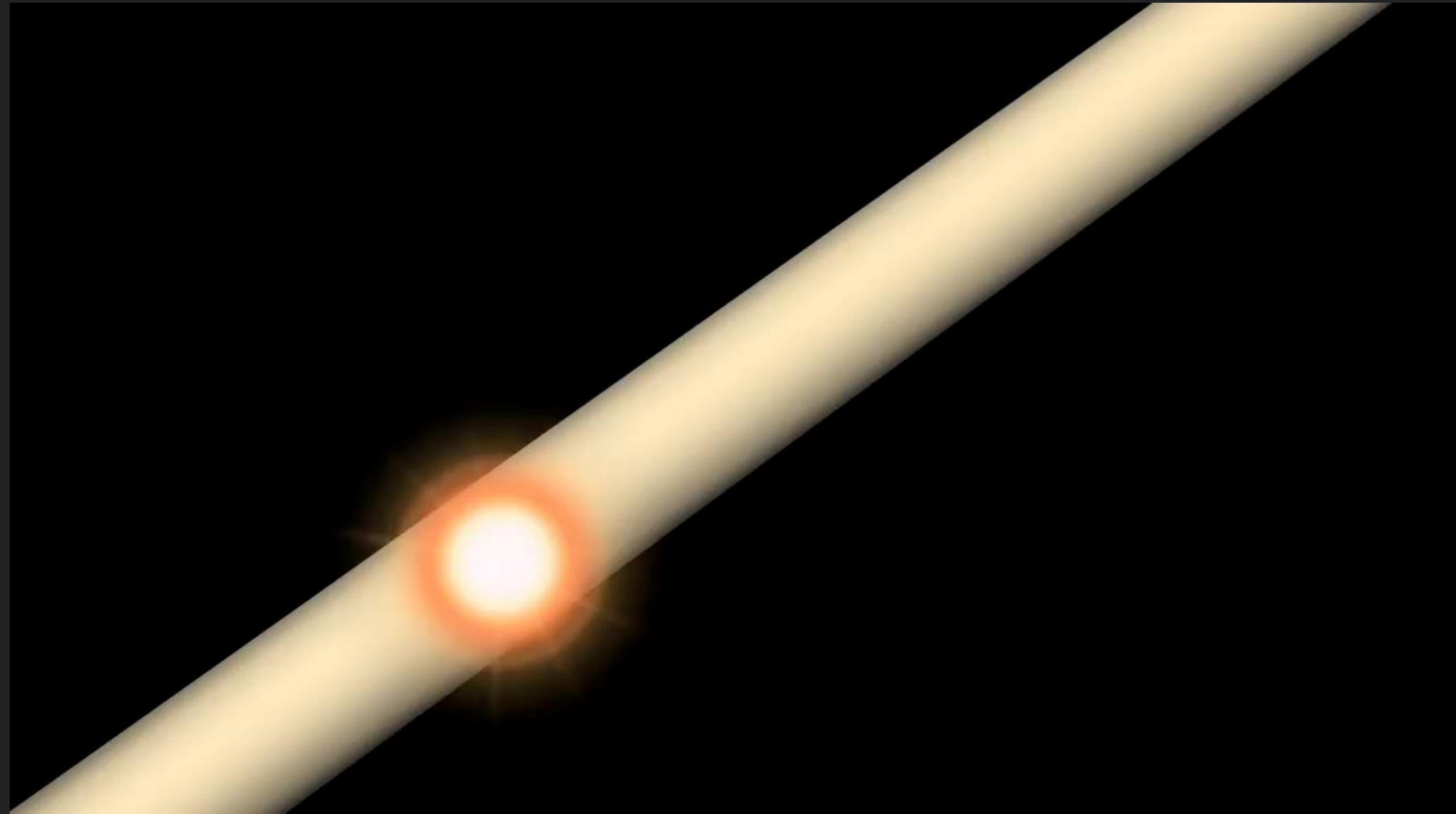
WHY do we smash protons together at high energies **millions of times a second**?

- ✓ **RARE** particles (like Higgs, or particles we haven't found yet) are not made very often – so we need **MANY** collisions to collect a large enough sample



WHY ARE WE SMASHING THINGS TOGETHER

HOW DO WE STUDY PARTICLE PHYSICS?



WHAT DOES A PARTICLE PHYSICIST DO?

Questions we ask:

- ▶ **Where** did everything come from?
- ▶ **What** is everything made out of?
- ▶ **How** does it work (interact)?



Physicists are ambitious!

Turn 20th century Lord Kelvin (maybe) said that Physics was basically finished 😊

Only some decimal places to be sorted out!

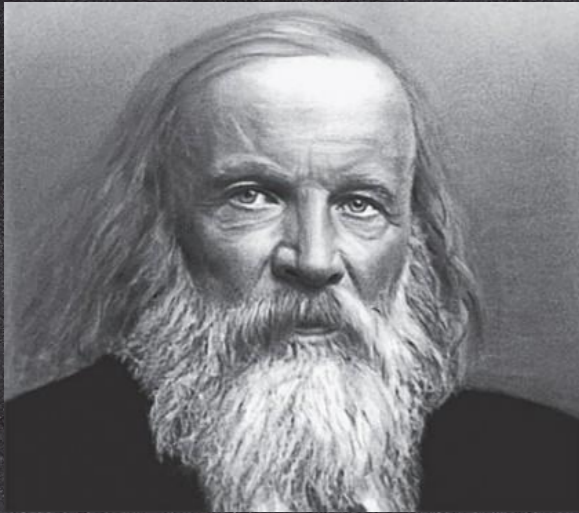
Along came Quantum Mechanics

Special and General Relativity

Quantum Field Theory that led to our

Standard Model of Particle Physics

WHAT IS EVERYTHING MADE OF?



In 1869 Russian chemist **Dimitri Mendeleev** published the **periodic table**, arranging chemical elements by atomic mass.

~ **80 elements** – WHY SO MANY?

Is there a simpler structure?

Высший образую

Табл

Рад

Периодъ 1-й. Периодъ 2-й. Периодъ 3-й. Периодъ 4-й. Периодъ 5-й.

Periodic Table of the Elements

1 IA 11A H Hydrogen 1.008	2 IIA 2A He Helium 4.003																	18 VIIIA 8A
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 III 3B	4 IV 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 9	10 VIII 10	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948	
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80	
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29	
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [209]	86 Rn Radon 222.018	
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [265]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium [288]	114 Fl Flerovium [289]	115 Uup Ununpentium [288]	116 Lv Livermorium [293]	117 Uus Ununseptium [294]	118 Uuo Ununoctium [294]	

Legend: Alkali Metal, Alkaline Earth, Transition Metal, Semimetal, Nonmetal, Basic Metal, Halogen, Noble Gas, Lanthanide, Actinide

Li Be B C N O F

Na Mg Al Si P S Cl

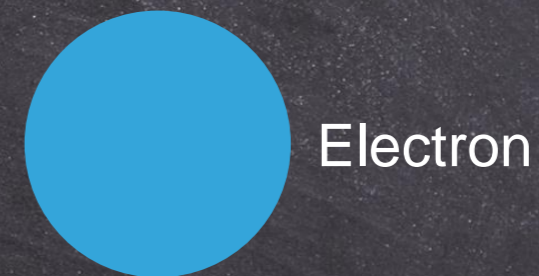
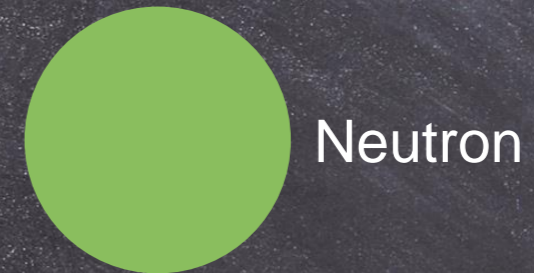
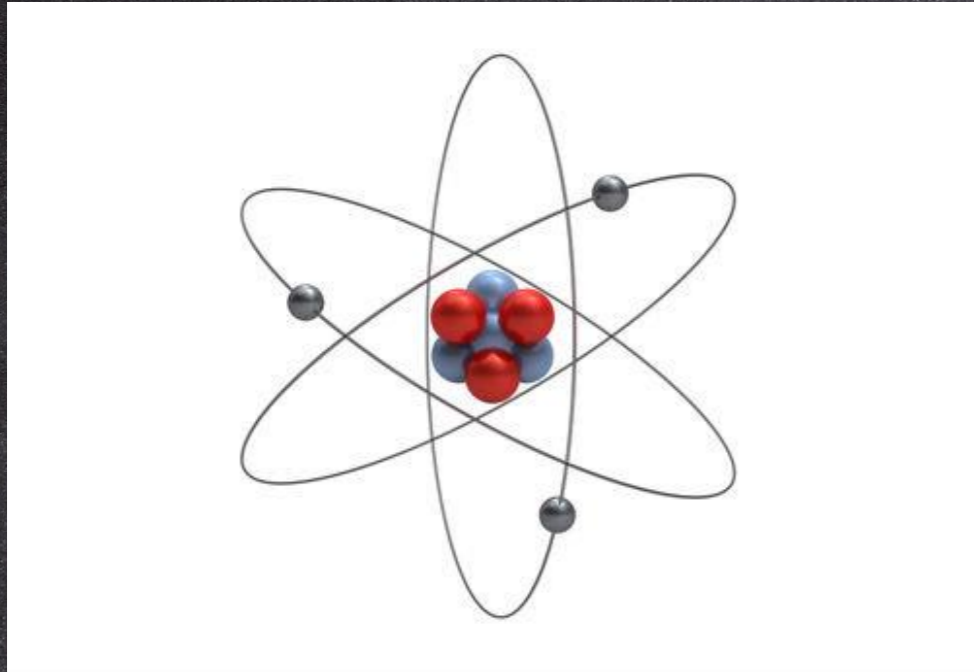
K Ca Ti V Cr Mn Fe Co Ni Cu Zn

Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd

Cs Ba Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn

Fr Ra Rf Db Sg Bh Hs Mt Ds Rg Cn Uut Fl Uup Lv Uus Uuo

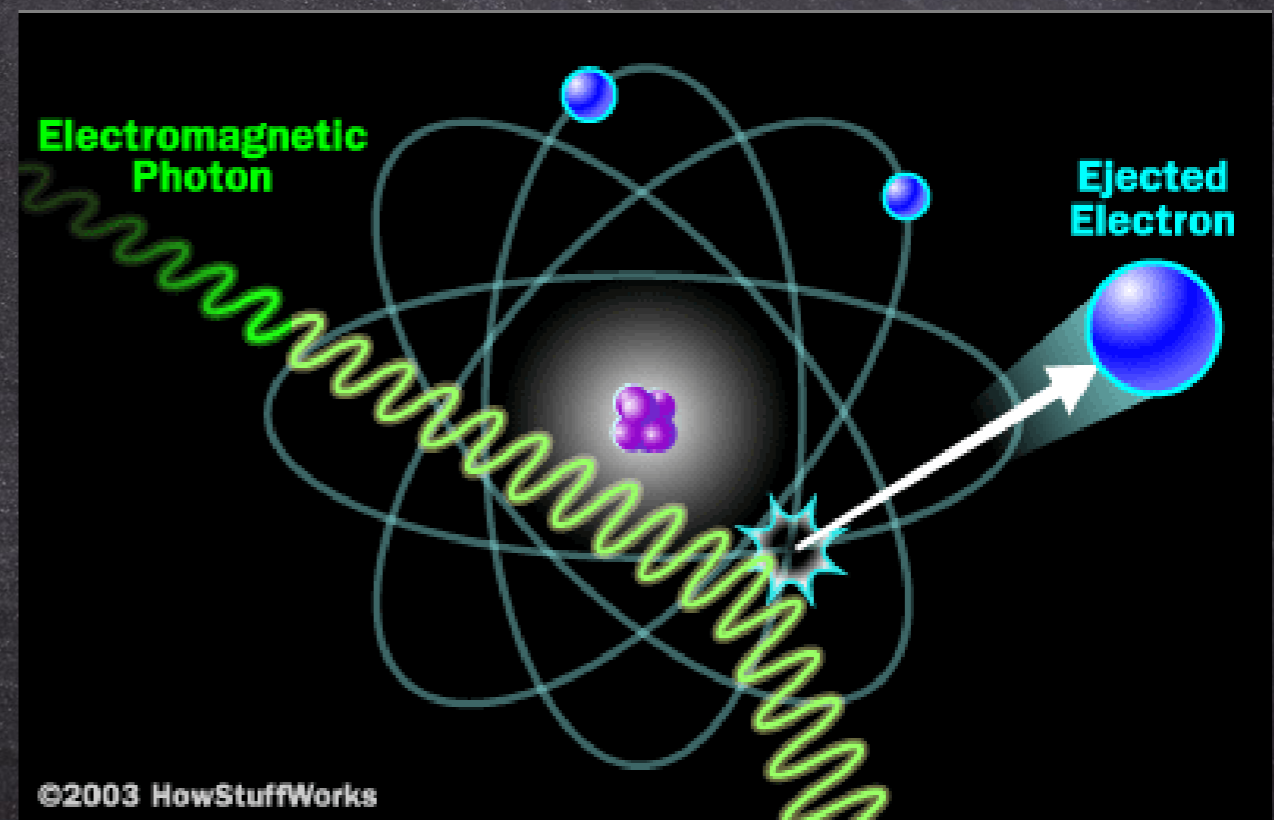
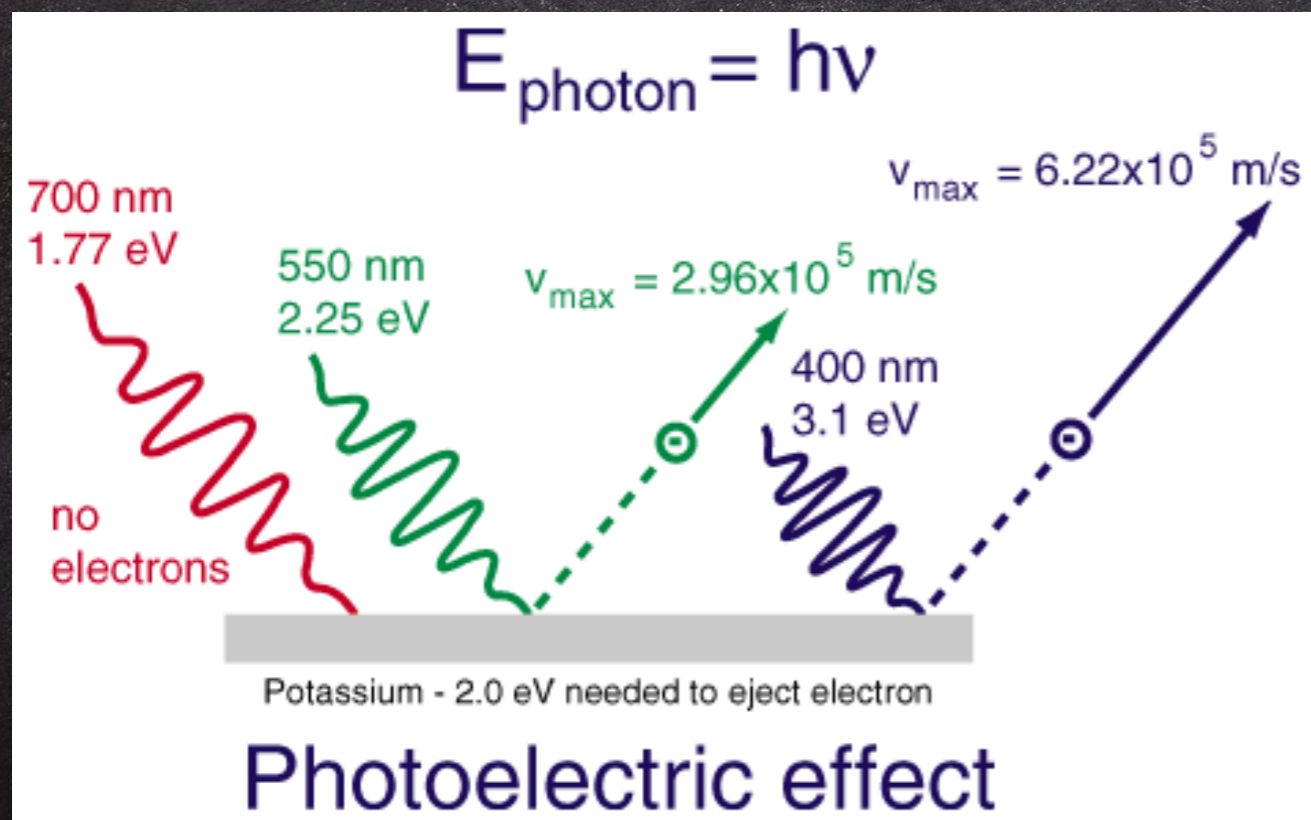
WHAT IS EVERYTHING MADE OF?



- 1897 **electron** discovered by J.J. Thompson
- 1911 **nucleus** of the atom discovered by Ernest Rutherford, and nucleus of hydrogen a **proton**
- 1932 **neutron** discovered by James Chadwick

WHAT IS EVERYTHING MADE OF?

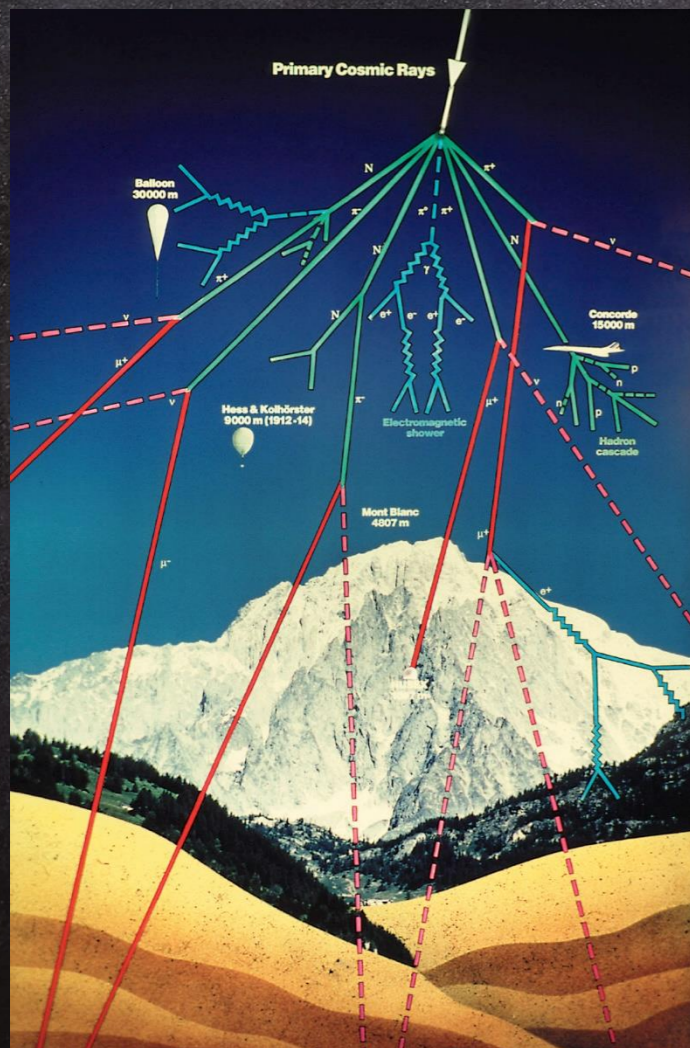
- **Photon** – particle of the **electromagnetic** force suggested by Einstein in 1905
- Electromagnetic waves could only exist as discrete wave packets – light quantum or photon



WHAT IS EVERYTHING MADE OF?

However other particles not part of the atom seemed to appear!

- 1932 **positron** detected (predicted by Dirac in 1928)
- 1934 **neutrinos** established in theory — detected in 1956



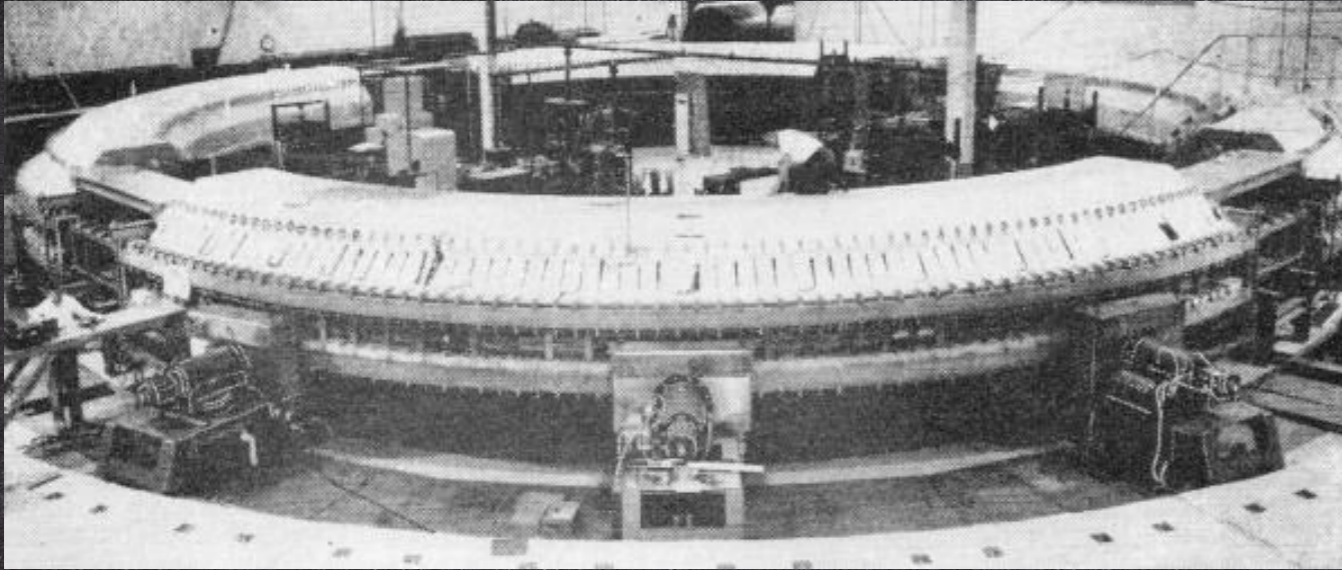
- 1937 **muons** were discovered in cosmic rays

Who ordered that?

- 1947 **pions** (a type of meson) were also discovered!!

*Things were getting out of hand!
What were all these particles?*

Atom smashers (1950s)



The Brookhaven Cosmotron, at 1.3 – 3.3 GeV accelerator



Plethora of **NEW** particles started coming out of these **atom smashes!**

Sigma particles, **rho particles**, **Delta particles**, **kaons**, **Lambda...**

Some of the Particles in the "Particle Zoo"

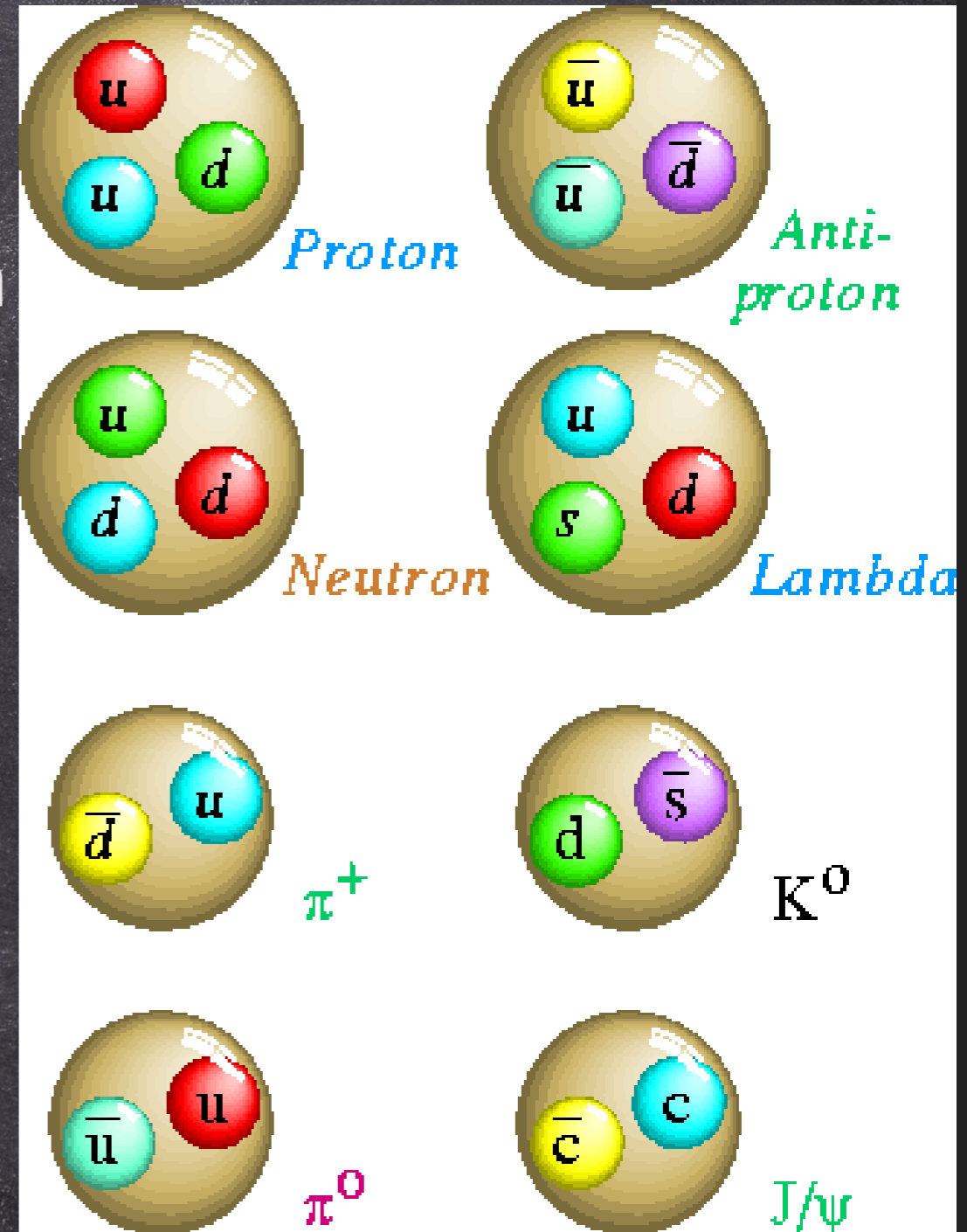
p^+ n^0 $\Sigma^- \Sigma^0 \Sigma^+ \Sigma^{++}$ $\Delta^- \Delta^0 \Delta^+ \Delta^{++}$
 Λ^0 $\Omega^- \Omega^0 \Omega^+$ $e^+ e^-$ $\pi^+ \pi^0 \pi^-$
 $\Xi^- \Xi^0 \Xi^+ \Xi^{++}$ $\tau^+ \tau^-$
 $\eta \eta'$ $\mu^+ \mu^-$ ω $\rho^+ \rho^0 \rho^-$
 $\nu_e \nu_\mu \nu_\tau$ ϕ γ $K^+ K^0 K^-$

BREAK THROUGH!!!

1960s Murray Gell-Mann of Caltech said **hadrons** are composed of **more fundamental** particles which he called **quarks**.



The word comes from a line in *Finnegans Wake*, a book written by James Joyce.



DISCOVERY: Bottom, Top, WZ, HIGGS!

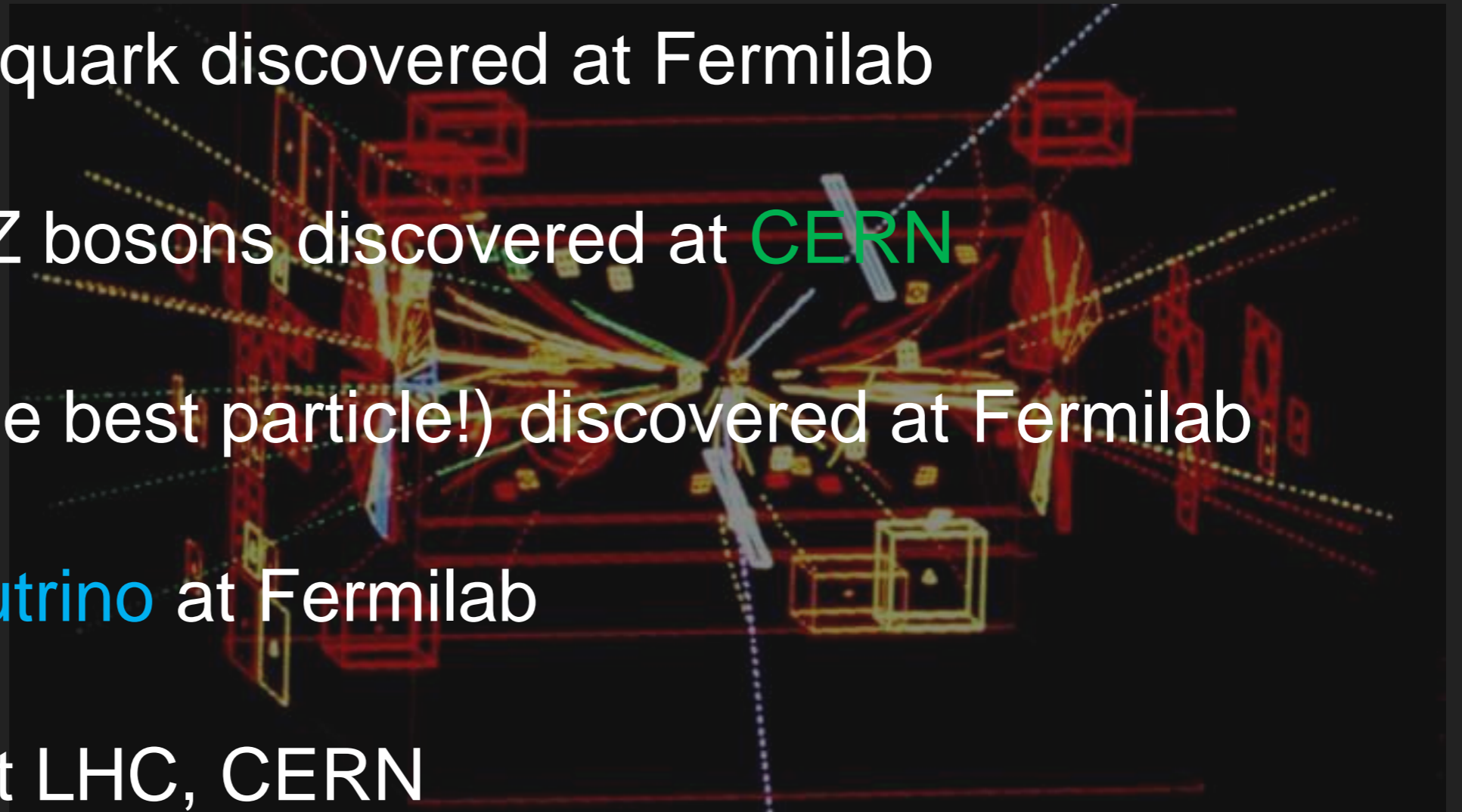
1977 **Bottom** quark discovered at Fermilab

1983 W and Z bosons discovered at **CERN**

1995 **TOP** (the best particle!) discovered at Fermilab

2000 **Tau neutrino** at Fermilab

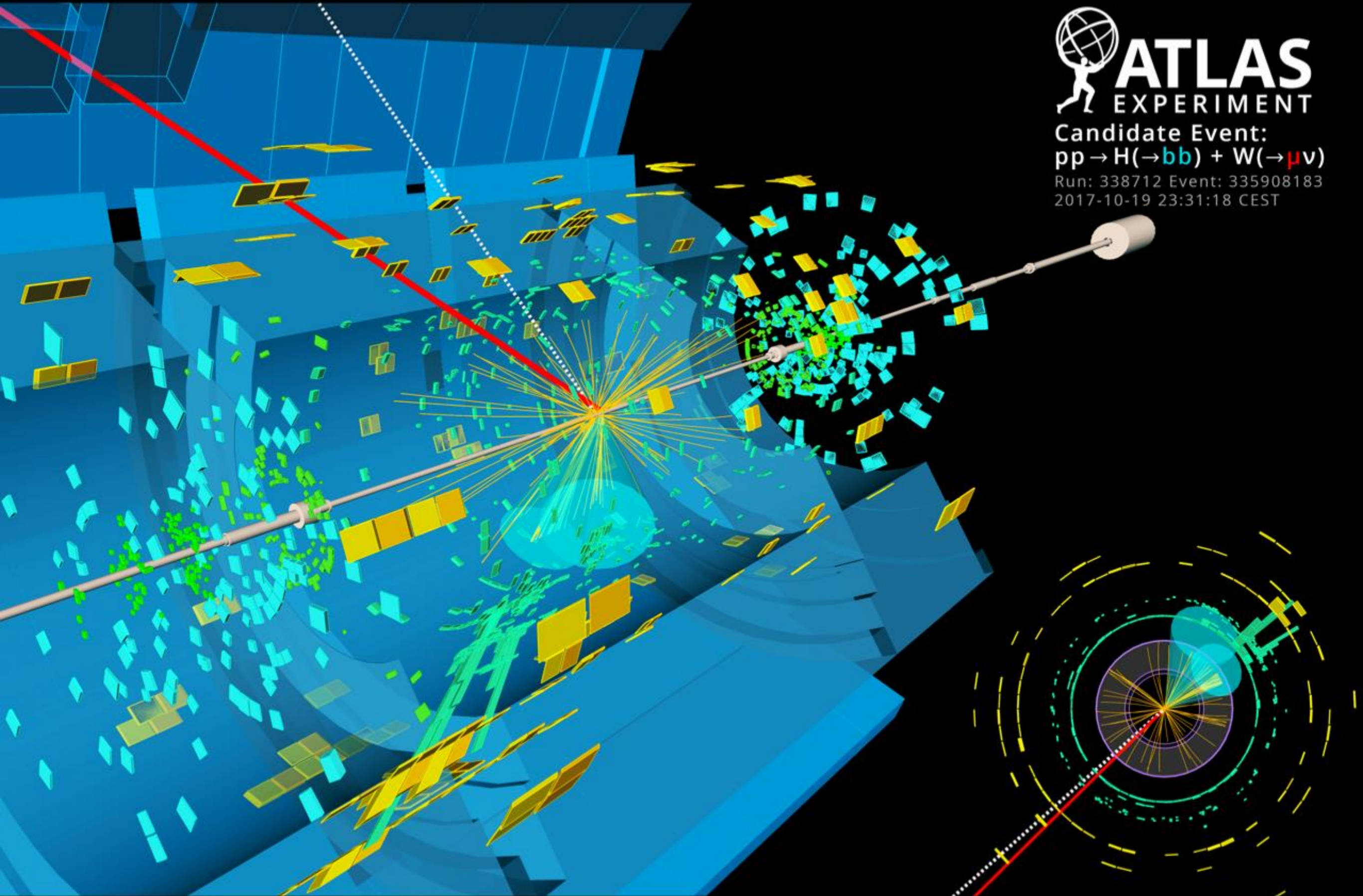
2012 **Higgs** at LHC, CERN



WHAT IS EVERYTHING MADE OF?



ATLAS
EXPERIMENT
Candidate Event:
 $pp \rightarrow H(\rightarrow bb) + W(\rightarrow \mu\nu)$
Run: 338712 Event: 335908183
2017-10-19 23:31:18 CEST

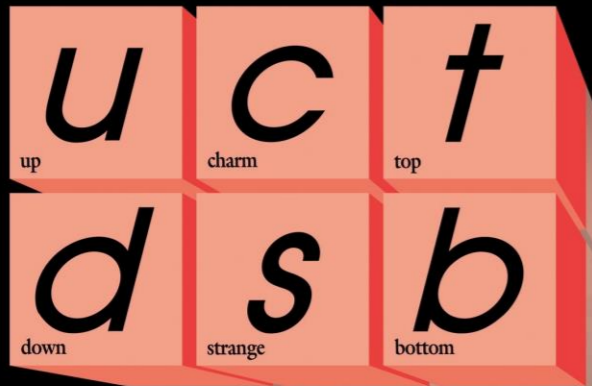


WHAT IS EVERYTHING MADE OF?

STANDARD MODEL

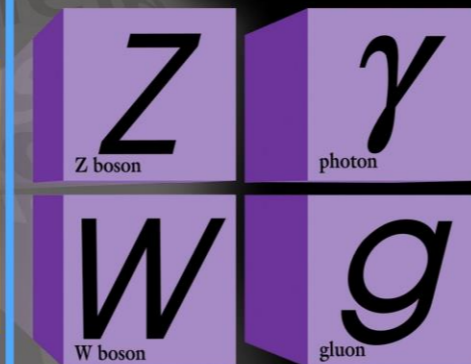
Fermions: spin = 1/2 particles

Quarks



Vector Bosons: spin = 1 particles

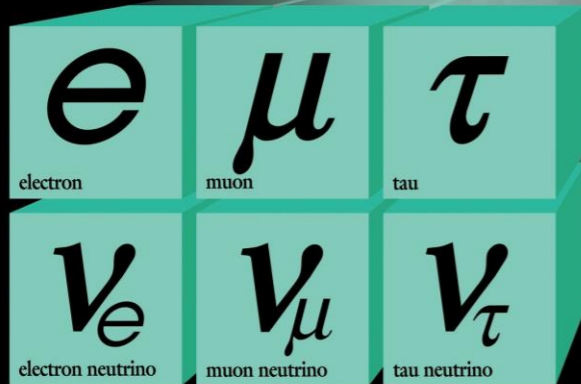
Forces



H

Higgs boson

Higgs Boson:
spin = 0
fundamental
scalar particle



Leptons

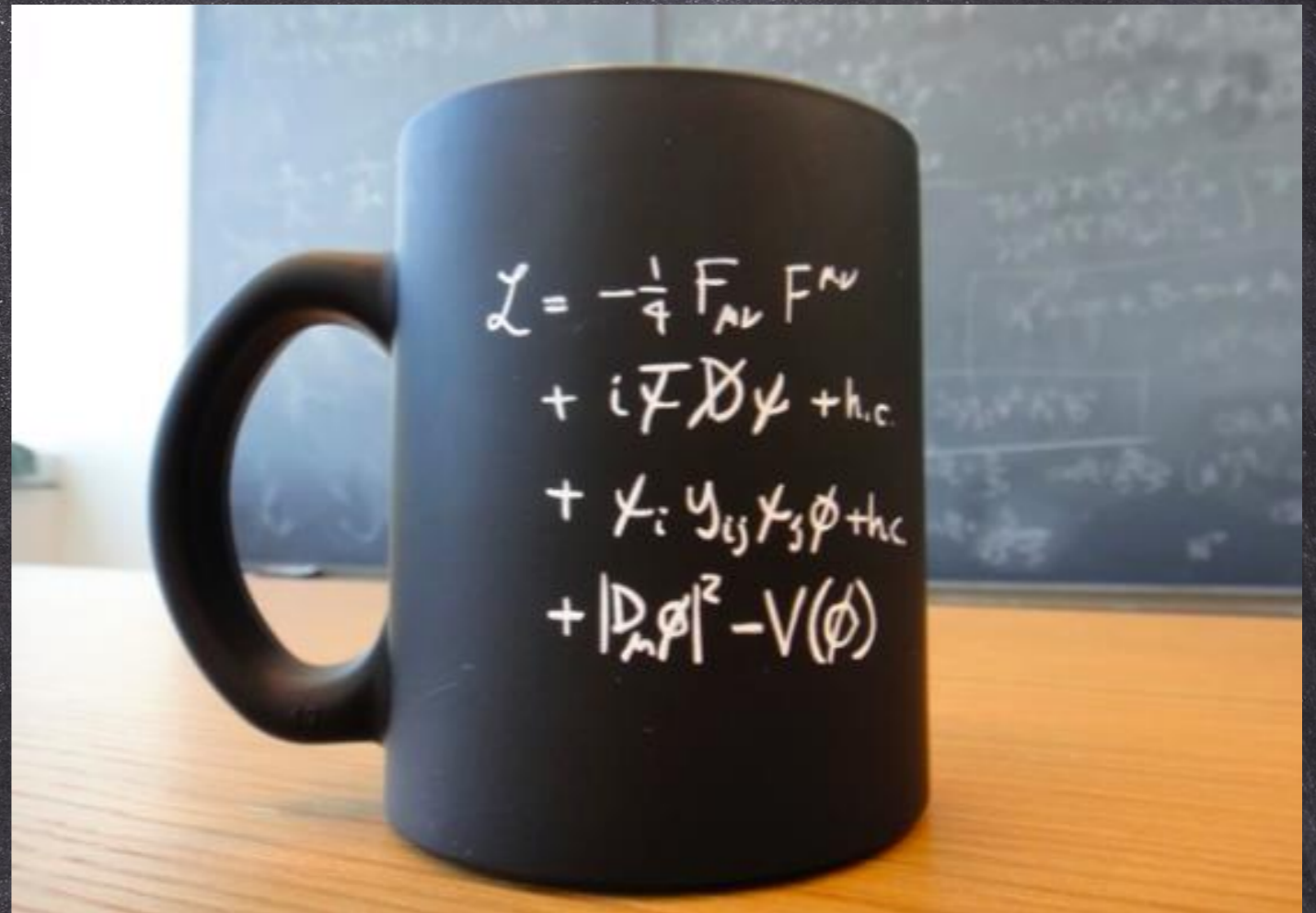
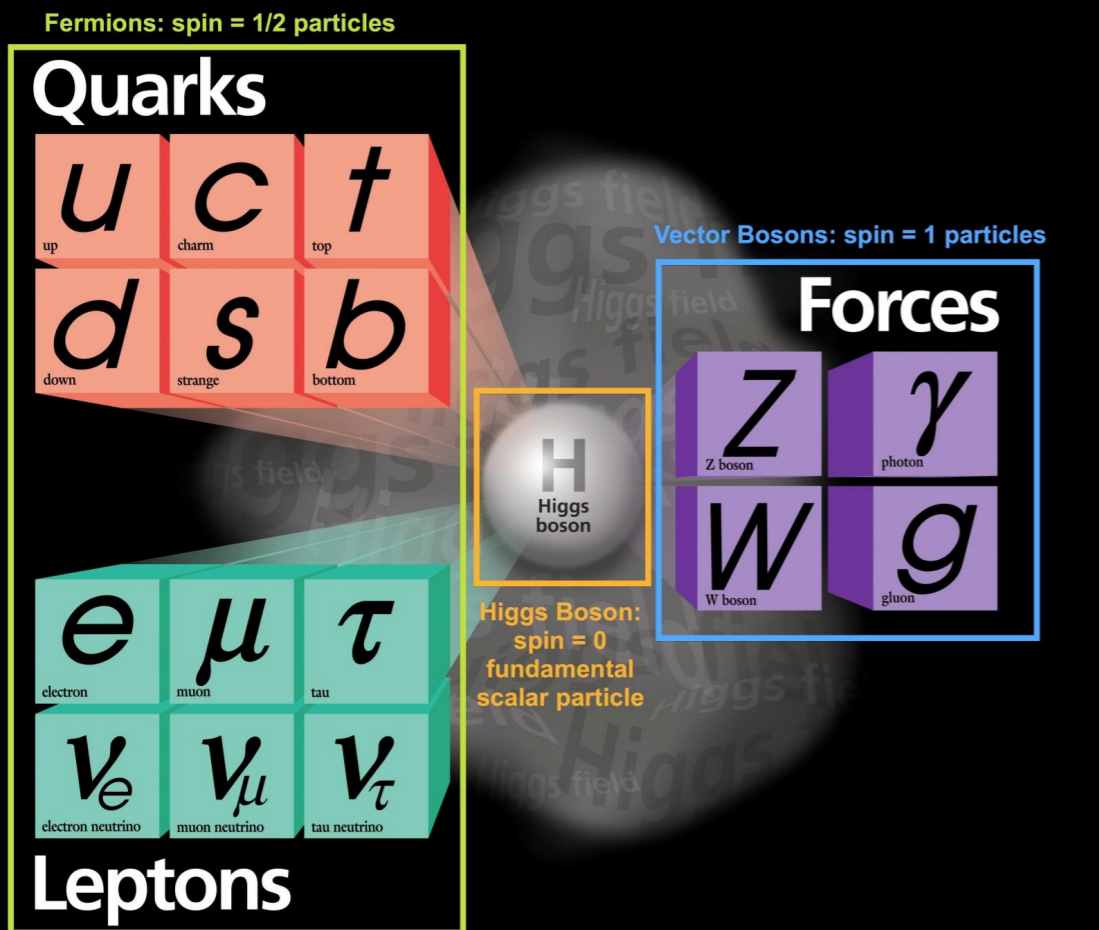
WE STILL
HAVE **NO**
IDEA WHY
THE
STANDARD
MODEL
WORKS **SO**
WELL!!!

WHAT IS EVERYTHING MADE OUT OF AND HOW TO THINGS INTERACT

STANDARD MODEL OF PARTICLE PHYSICS

FUNDAMENTAL PARTICLES

RULES OF HOW THEY INTERACT



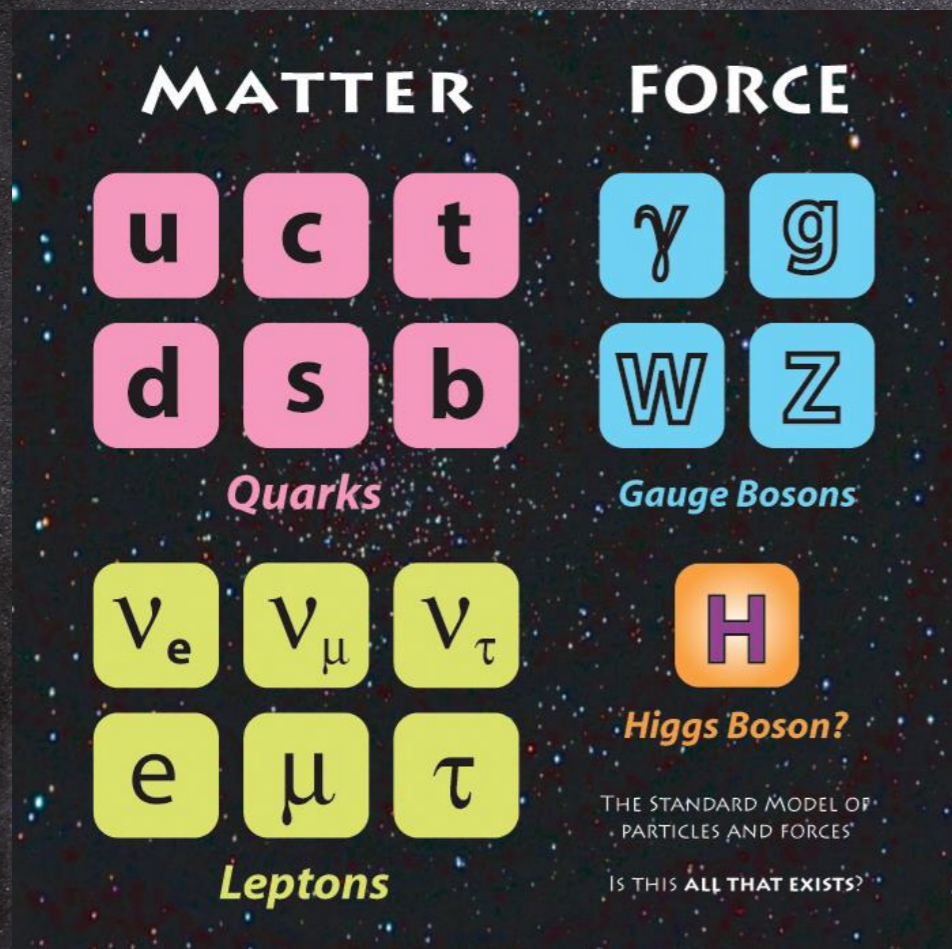
STANDARD MODEL HD!

$$\begin{aligned}
 \mathcal{L}_{SM} = & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w (\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - Z_\nu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\nu^0 (W_\nu^+ \partial_\mu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+)) - \\
 & igs_w (\partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - A_\nu (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + A_\mu (W_\nu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+)) - \frac{1}{2}g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^+ W_\nu^- + g^2 c_w^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - \\
 & Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 s_w^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_w c_w (A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-) - \frac{1}{2}\partial_\mu H \partial_\mu H - 2M^2 \alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
 & \beta_h \left(\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right) + \frac{2M^4}{g^2} \alpha_h - \\
 & g\alpha_h M (H^3 + H\phi^0 \phi^0 + 2H\phi^+ \phi^-) - \\
 & \frac{1}{8}g^2 \alpha_h (H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2) - \\
 & gMW_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\mu^0 H - \\
 & \frac{1}{2}ig (W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)) + \\
 & \frac{1}{2}g (W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) + W_\mu^- (H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)) + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) + \\
 & M (\frac{1}{c_w} Z_\mu^0 \partial_\mu \phi^0 + W_\mu^+ \partial_\mu \phi^- + W_\mu^- \partial_\mu \phi^+) - ig \frac{s_w^2}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + igs_w M A_\mu (W_\mu^+ \phi^- - \\
 & W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \\
 & \frac{1}{4}g^2 W_\mu^+ W_\mu^- (H^2 + (\phi^0)^2 + 2\phi^+ \phi^-) - \frac{1}{8}g^2 \frac{1}{c_w^2} Z_\mu^0 Z_\mu^0 (H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-) - \\
 & \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - \\
 & g^2 s_w^2 A_\mu A_\mu \phi^+ \phi^- + \frac{1}{2}igs \lambda_{ij}^a (\bar{q}_i^a \gamma^\mu q_j^a) g_\mu^a - \bar{e}^\lambda (\gamma^\mu \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda (\gamma^\mu \partial + m_\nu^\lambda) \nu^\lambda - \bar{u}_j^\lambda (\gamma^\mu \partial + \\
 & m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma^\mu \partial + m_d^\lambda) d_j^\lambda + igs_w A_\mu (-\bar{e}^\lambda \gamma^\mu e^\lambda + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)) + \\
 & \frac{ig}{4c_w} Z_\mu^0 \{ (\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \gamma^5) d_j^\lambda) + \\
 & (\bar{u}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 + \gamma^5) u_j^\lambda) \} + \frac{ig}{2\sqrt{2}} W_\mu^+ ((\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) U^{lep}{}_{\lambda\kappa} e^\kappa) + (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)) + \\
 & \frac{ig}{2\sqrt{2}} W_\mu^- ((\bar{e}^\kappa U^{lep}{}_{\kappa\lambda}^\dagger \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\kappa C_{\kappa\lambda}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\lambda)) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^+ (-m_e^\kappa (\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa} (1 - \gamma^5) e^\kappa) + m_\nu^\lambda (\bar{\nu}^\lambda U^{lep}{}_{\lambda\kappa} (1 + \gamma^5) e^\kappa) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^- (m_e^\lambda (\bar{e}^\lambda U^{lep}{}_{\lambda\kappa}^\dagger (1 + \gamma^5) \nu^\kappa) - m_\nu^\kappa (\bar{e}^\lambda U^{lep}{}_{\lambda\kappa}^\dagger (1 - \gamma^5) \nu^\kappa) - \frac{g}{2} \frac{m_\lambda^\lambda}{M} H (\bar{\nu}^\lambda \nu^\lambda) - \\
 & \frac{g}{2} \frac{m_\lambda^\lambda}{M} H (\bar{e}^\lambda e^\lambda) + \frac{ig}{2} \frac{m_\lambda^\lambda}{M} \phi^0 (\bar{\nu}^\lambda \gamma^5 \nu^\lambda) - \frac{ig}{2} \frac{m_\lambda^\lambda}{M} \phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda) - \frac{1}{4} \bar{\nu}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \hat{\nu}_\kappa - \\
 & \frac{1}{4} \bar{\nu}_\lambda M_{\lambda\kappa}^R (1 - \gamma_5) \hat{\nu}_\kappa + \frac{ig}{2M\sqrt{2}} \phi^+ (-m_d^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1 - \gamma^5) d_j^\kappa) + m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa) + \\
 & \frac{ig}{2M\sqrt{2}} \phi^- (m_d^\lambda (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - m_u^\kappa (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 - \gamma^5) u_j^\kappa) - \frac{g}{2} \frac{m_\lambda^\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \\
 & \frac{g}{2} \frac{m_\lambda^\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda^\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_\lambda^\lambda}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c + \\
 & \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + igc_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \\
 & \partial_\mu \bar{X}^+ X^0) + igs_w W_\mu^+ (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) + igc_w W_\mu^- (\partial_\mu \bar{X}^- X^0 - \\
 & \partial_\mu \bar{X}^0 X^+) + igs_w W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + igc_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \\
 & \partial_\mu \bar{X}^- X^-) + igs_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \\
 & \partial_\mu \bar{X}^- X^-) - \frac{1}{2}gM (\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2} \bar{X}^0 X^0 H) + \frac{1-2c_w^2}{2c_w} igM (\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-) + \\
 & \frac{1}{2c_w} igM (\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-) + igMs_w (\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-) + \\
 & \frac{1}{2}igM (\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0) .
 \end{aligned}$$

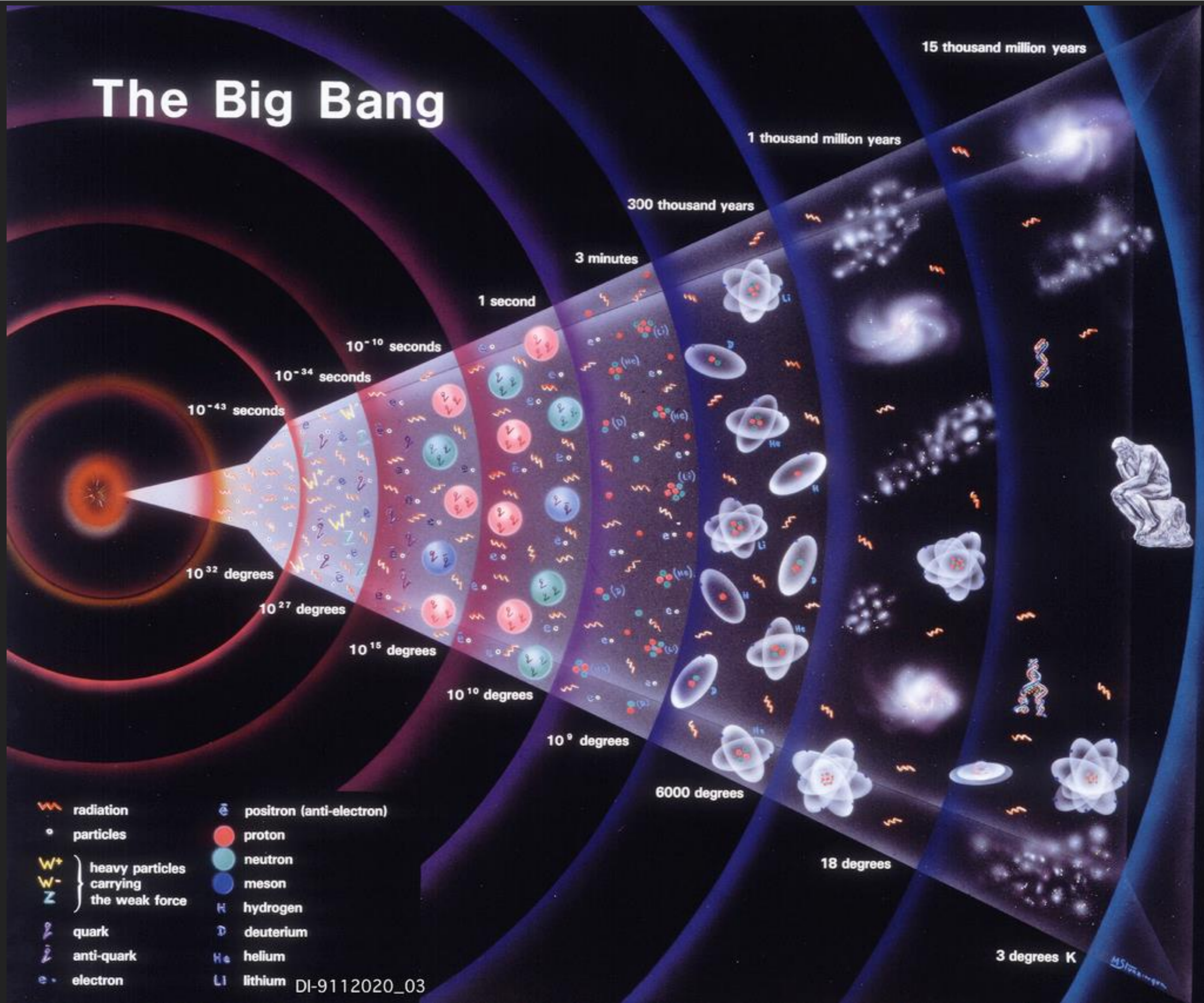
WHAT IS EVERYTHING MADE OUT OF?



If the Universe were a game of chess, the theories of the forces (such as the EM force) would dictate the way the pieces (or particles) would move..



- Each particle / chess piece has its own **properties** so we know what it 'looks' like
- With particle physics, how they **move/interact** is dependent of the **rules** of the Standard Model



WHAT ARE WE LOOKING FOR?

WHAT ARE WE LOOKING FOR?

THERE MUST BE **NEW PHYSICS** AT **HIGHER ENERGIES**

– solve hierarchy problem 😊

THERE ARE UNSOLVED MYSTERIES!!!

- ✓ DARK MATTER – DARK ENERGY
- ✓ MATTER – ANTIMATTER ASYMMETRY
- ✓ GRAVITY – HOW DOES IT FIT IN?

THE DARK UNIVERSE



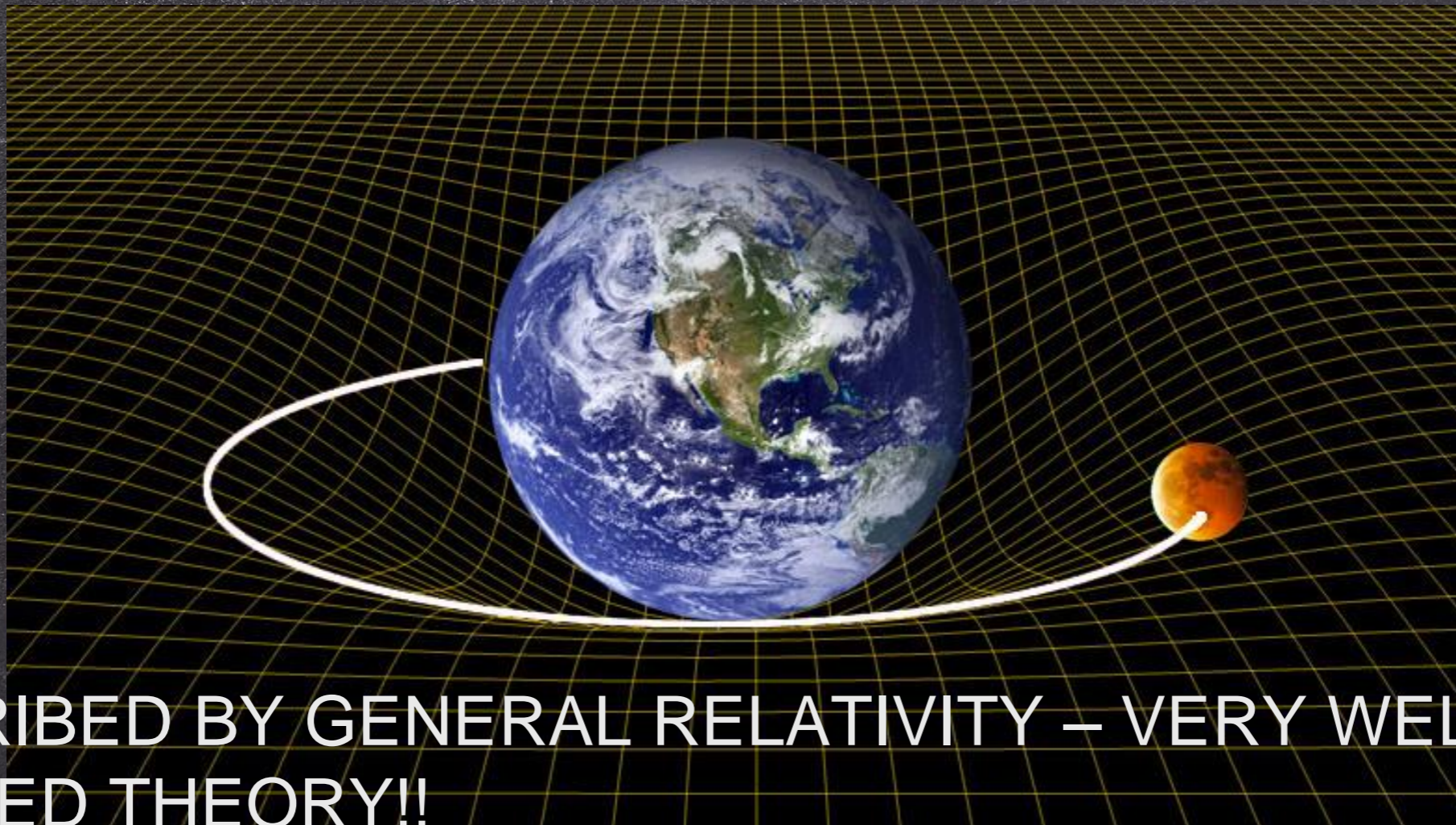
WHAT ARE WE LOOKING FOR?

WHERE IS ALL THE ANTIMATTER?

WHAT ARE WE LOOKING FOR?

THE PROBLEM WITH GRAVITY

THE PROBLEM WITH GRAVITY



DESCRIBED BY GENERAL RELATIVITY – VERY WELL VERIFIED THEORY!!

WE CURRENTLY **CANNOT DESCRIBE GRAVITY** IN THE STANDARD MODEL – IT'S TOO **WEAK**, WE CAN'T **QUANTIZE** IT :(

A LOT TO DO..

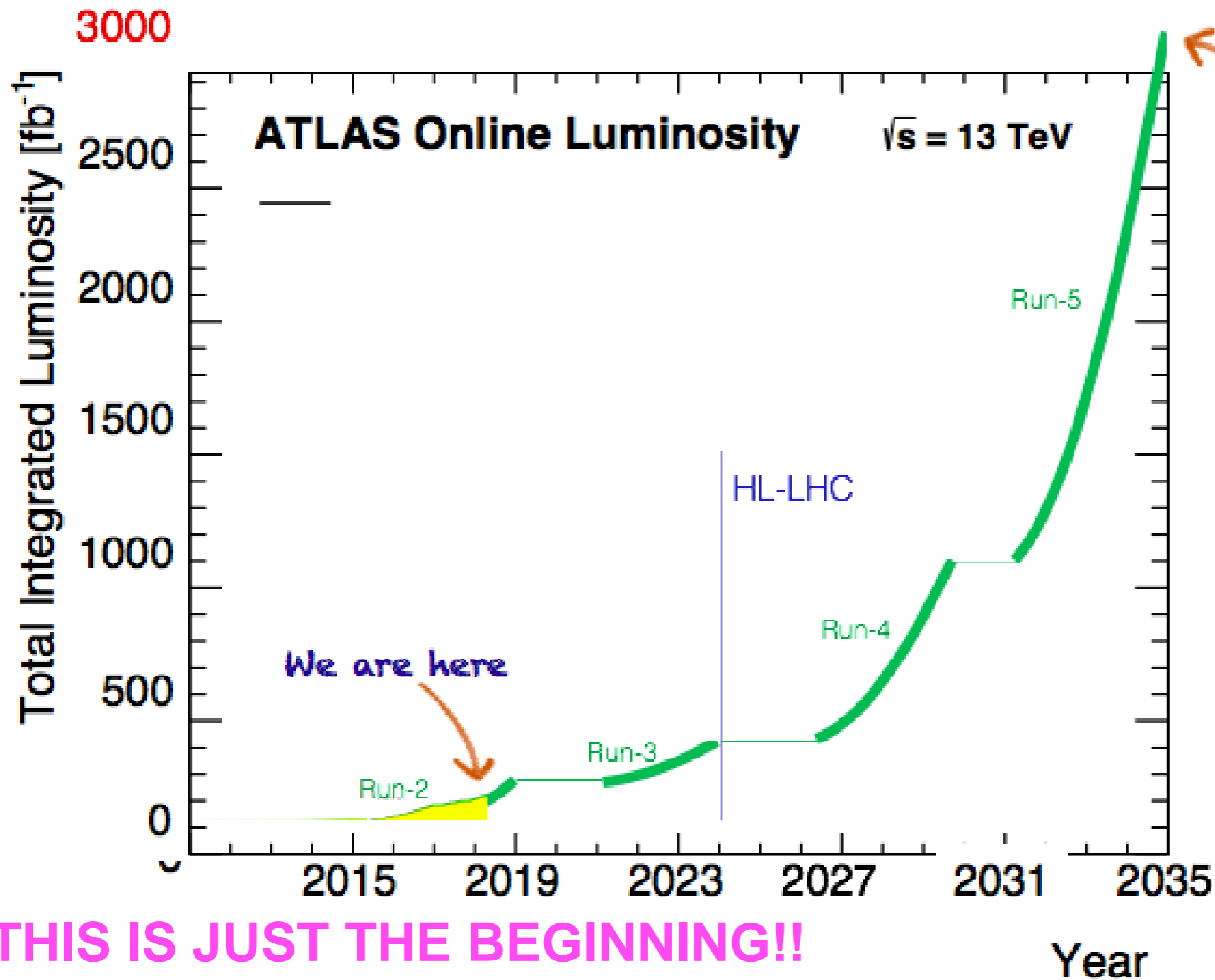
WE HAVE BUILT AN AMAZING **MACHINE** THAT IS RUNNING AT **UNPRECEDENTED** RATES AND ENERGIES !

WE HAVE **THOUSANDS** OF SCIENTISTS, ENGINEERS, AND TECHNICIAN ALL OVER THE WORLD, **WORKING TOGETHER** WITH A **COMMON GOAL!**

WE HAVE TOOLS WE NEVER HAD BEFORE!

- MACHINE LEARNING / DEEP LEARNING
- GRID AND CLOUD COMPUTING
- CUTTING EDGE TECHNOLOGY, ELECTRONICS, HARDWARE





We will be going here
Possibly up to 4 ab⁻¹

We are here

THIS IS JUST THE BEGINNING!!

EXCITING TIME TO BE STUDYING PHYSICS!

- 100 years ago scientists thought physics was almost complete, look how far we have come
- Who knows what the next 100 years of investigation will bring, along with advances in technology and tools

The unanswered questions we have about our Universe tell us...

we have just scratched the surface, there is a deeper and more connected theory that describes matter, space and time

There is so much more to learn

Watch this space .

We are at the beginning of a **tremendous journey**, with thousands of scientists utilizing and **developing cutting edge technology!**

We are on the brink of a **new way** of understanding matter space and time.