

An aerial, high-angle photograph looking down into the massive, circular ATLAS detector at CERN. The detector is a complex of concentric rings of equipment, with a central beam pipe. The structure is surrounded by a dense network of green metal walkways and scaffolding. Numerous blue and red cables are visible, snaking across the detector's surface. The overall scene is dimly lit, with some bright spots from overhead lights. The text "Theoretical physics" is overlaid in white, centered on the image.

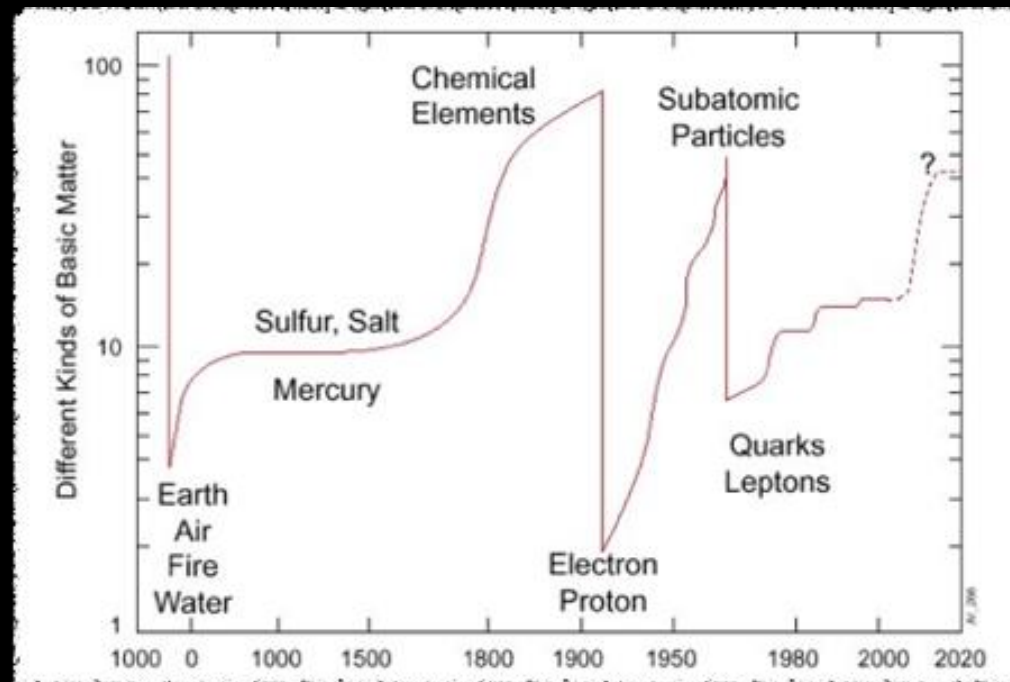
Theoretical physics

Aleksi Kurkela

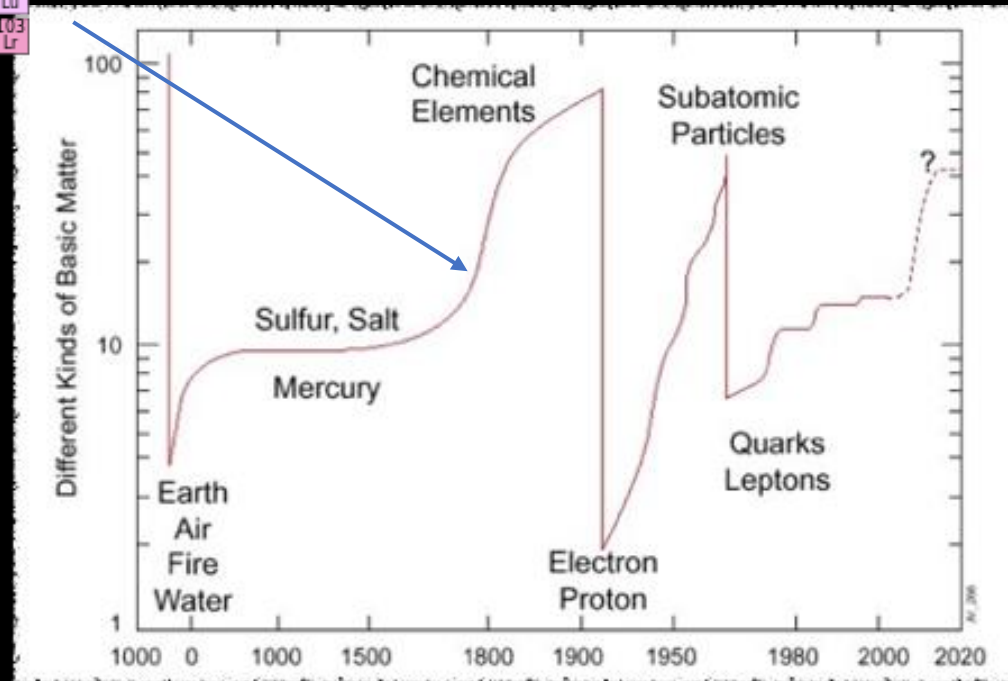


Who am I

- Theoretical particle physicist:
 - PhD in Helsinki Finland, 2008
 - ETH Zurich, 2008-2010
 - McGill Montreal, 2010-2013
 - CERN, 2013-2020
 - Stavanger, 2015 –
- Research: particle physics, nuclear physics, astrophysics,...

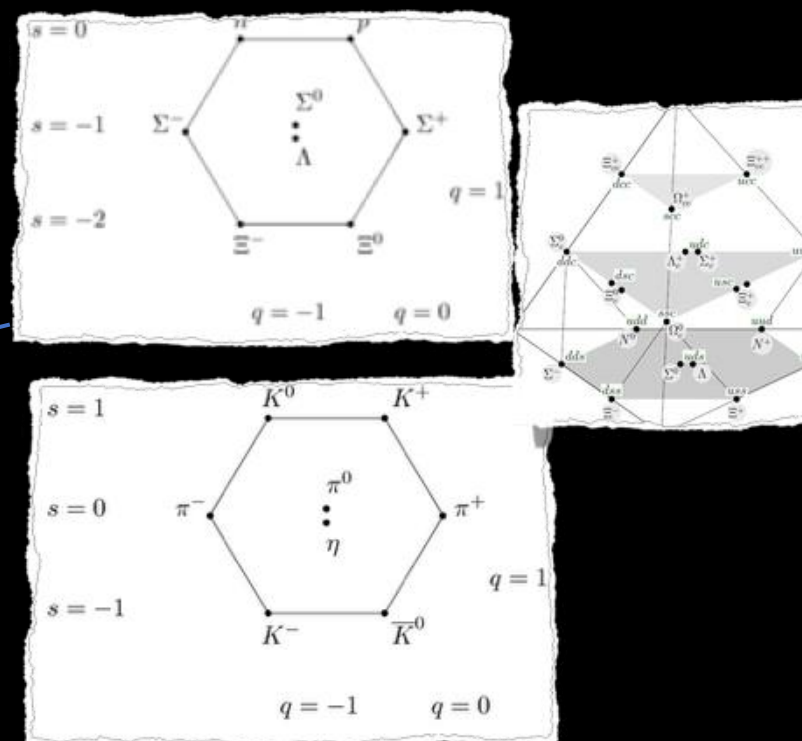
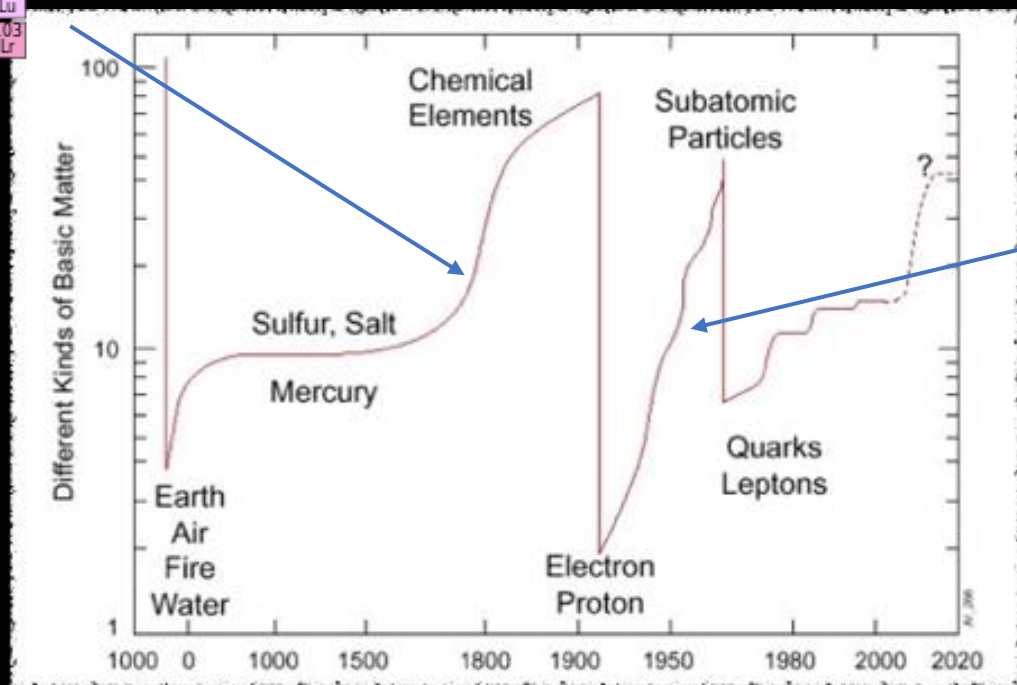


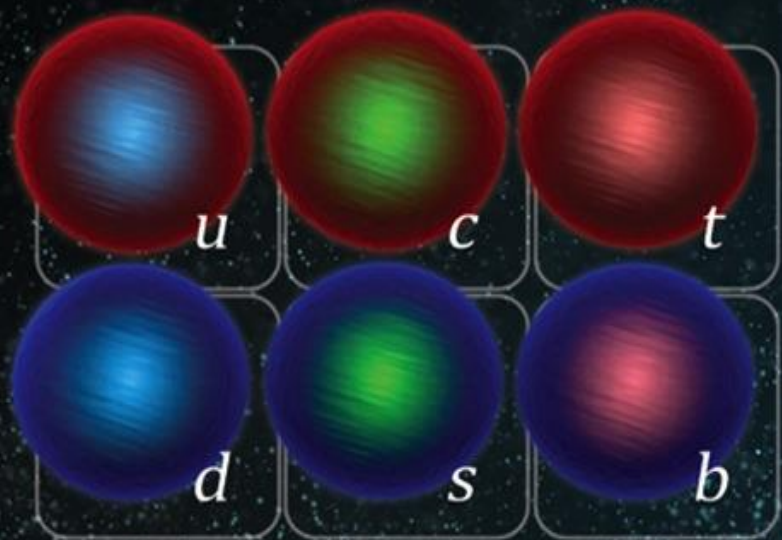
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3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uu	111 Rg	112 Cn	113 Nh	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo



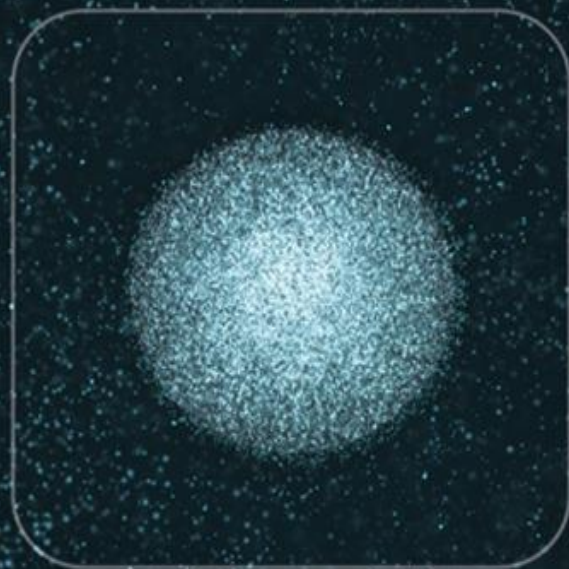
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37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo	

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

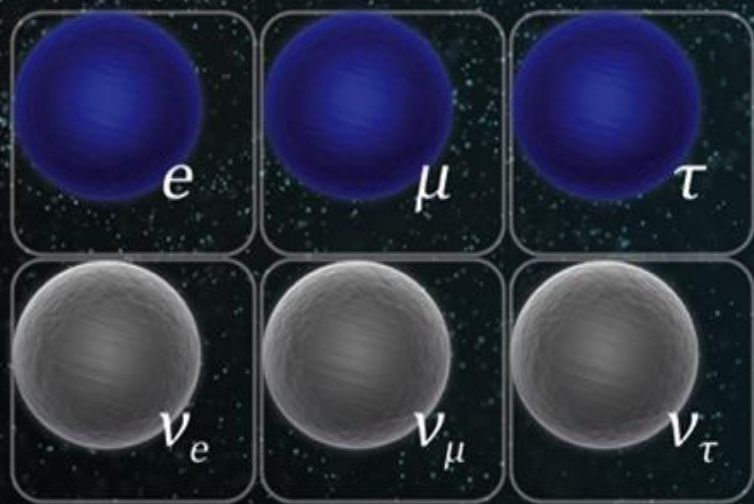




Quarks



Higgs boson



Leptons



Forces

Periodic table of particle physics:

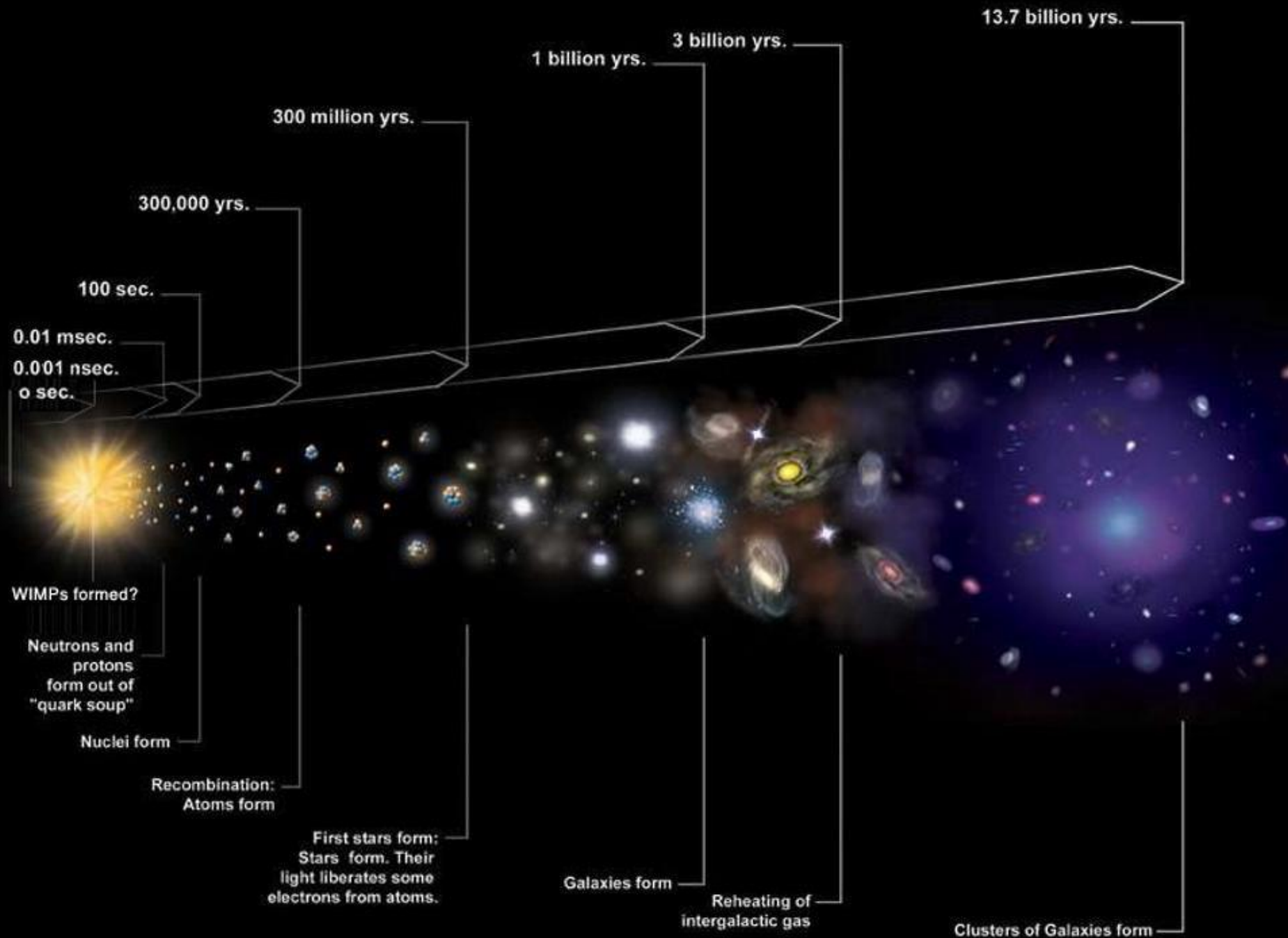


Higgs 125 GeV

THREE GENERATIONS OF MATTER						
MATTER CONSTITUENTS: FERMIONS	QUARKS			LEPTONS		
	I	II	III			
	2.75 UP	1300 CHARM	178000 TOP			
	6 DOWN	1110 STRANGE	4500 BOTTOM			
	0.511 ELECTRON	105.7 MUON	1777 TAU			
	$< 3 \cdot 10^{-6}$ NEUTRINO ν_e	< 0.19 NEUTRINO μ	< 18.2 NEUTRINO τ			
				CHARGE:	FORCE CARRIERS: BOSONS	
				$2/3$	91188 Z^0	
				0		
				$-1/3$	80430 W^+/W^-	
				± 1		
				-1	$< 10^{-25}$ PHOTON	
				0		
				0	theory: 0 GLUON	
				0		

ALL MASSES IN MEV;
ANIMAL MASSES
SCALE WITH
PARTICLE MASSES

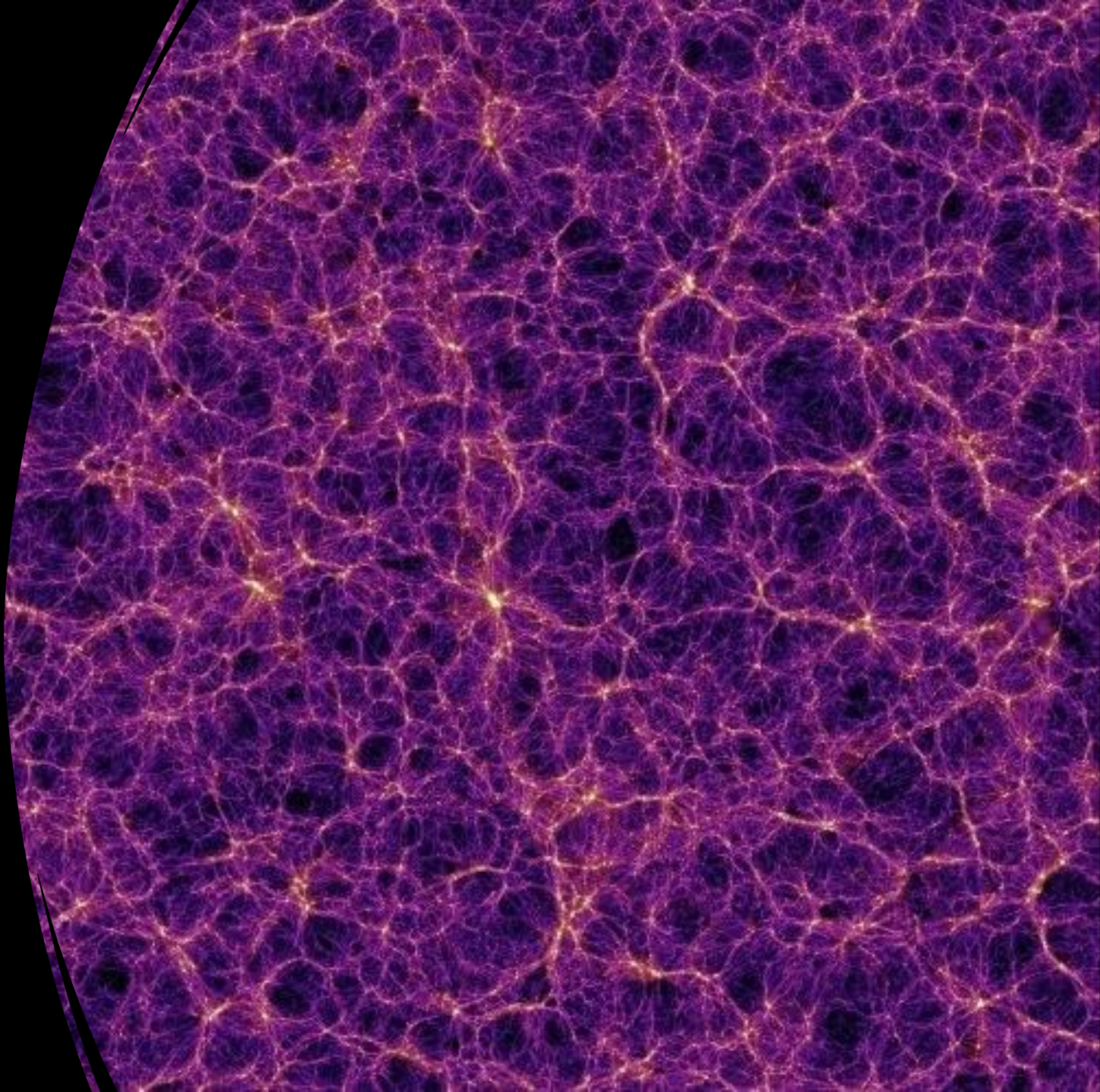
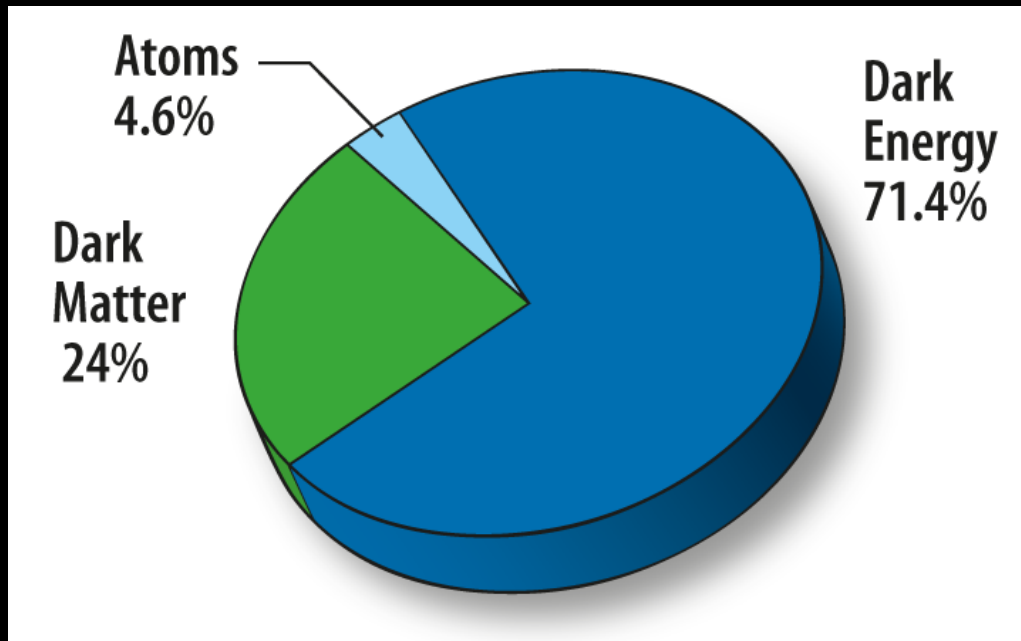
The Standard Model
fundamental particle zoo



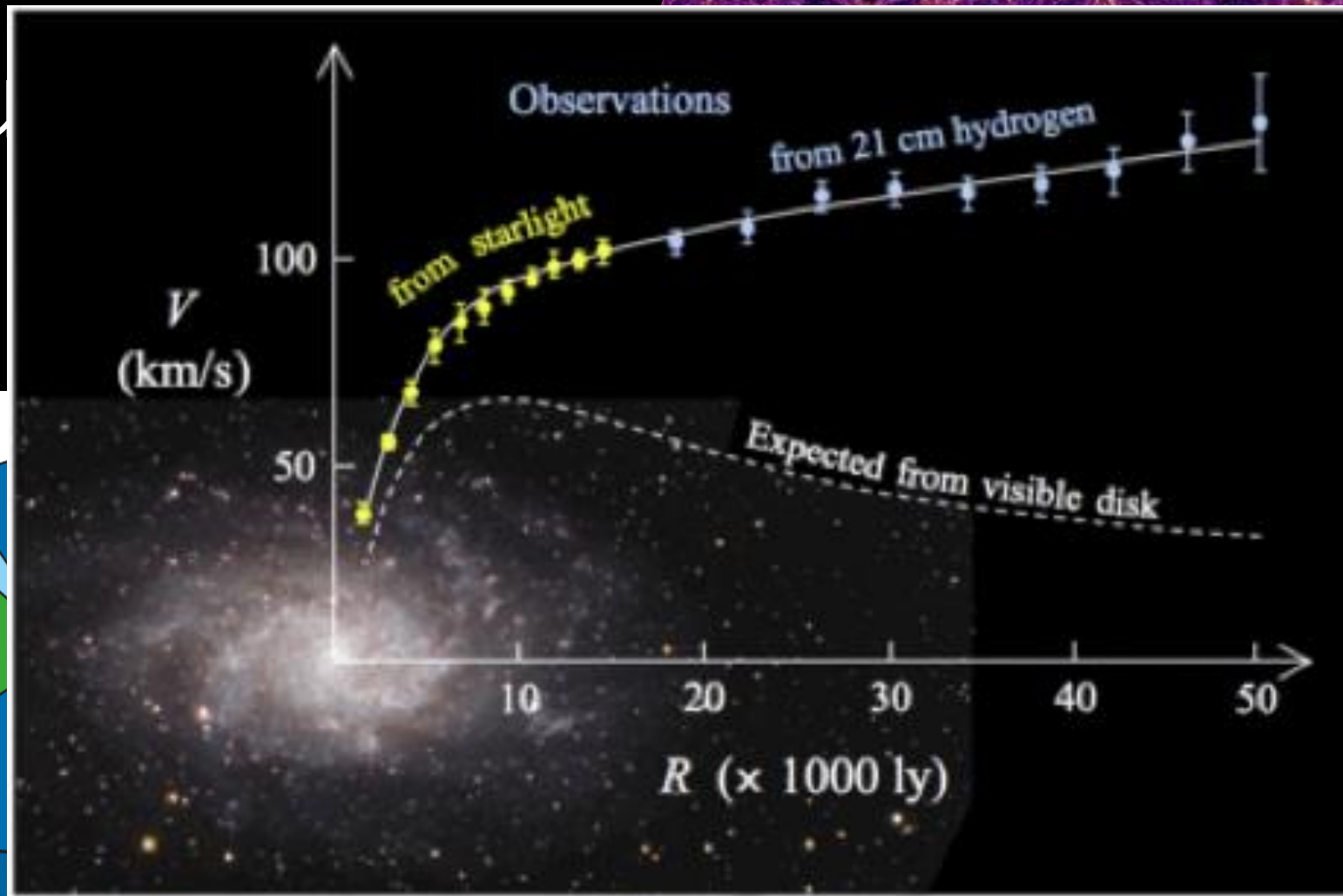
The standard model is incomplete!

- Why the “periodic table”?
- How do the elementary particle behave?
- Why universe has a lot of matter and no anti-matter?
- How does gravity fit in all this?
- Something is missing!

Dark universe:



Dark u

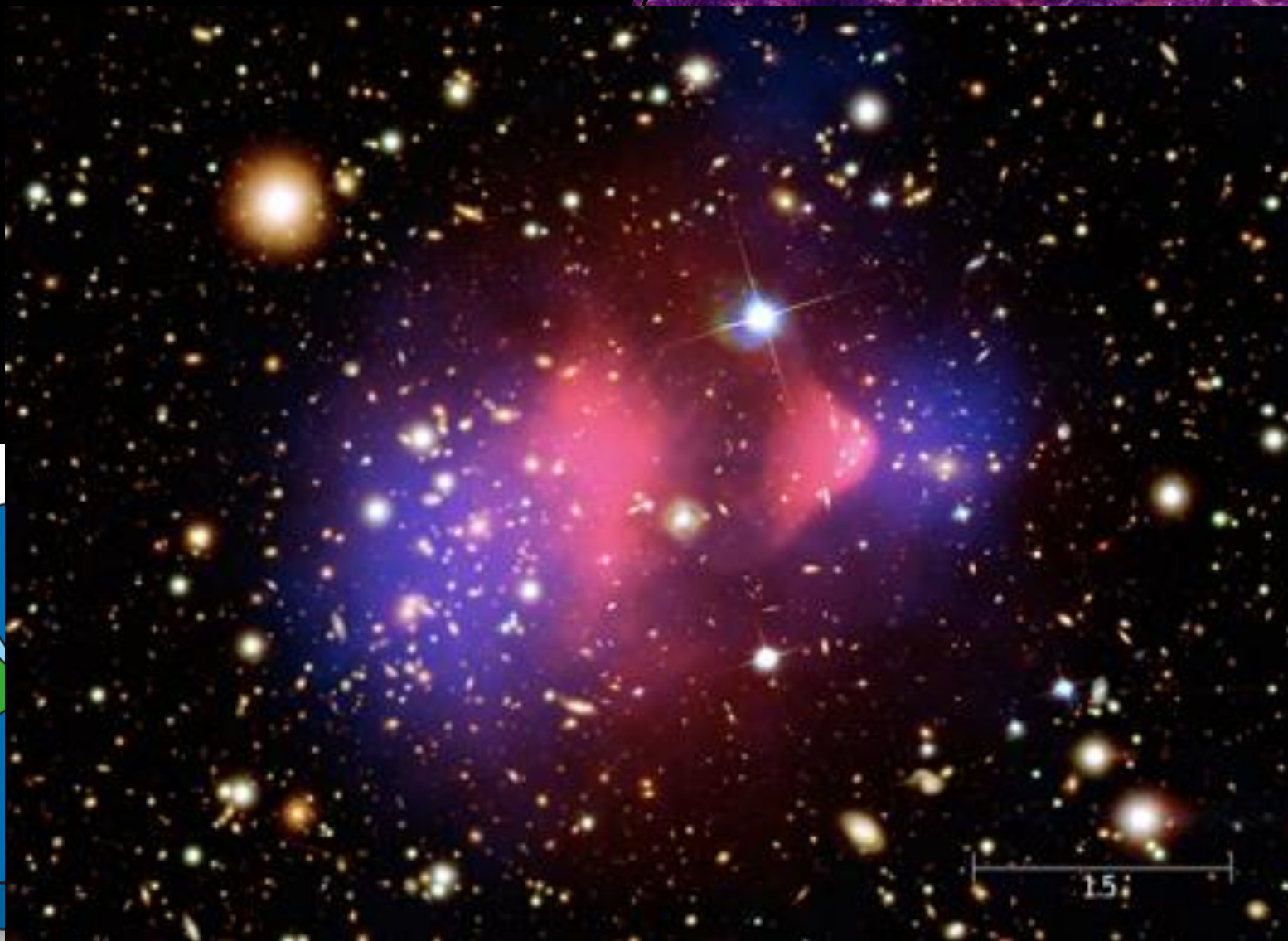


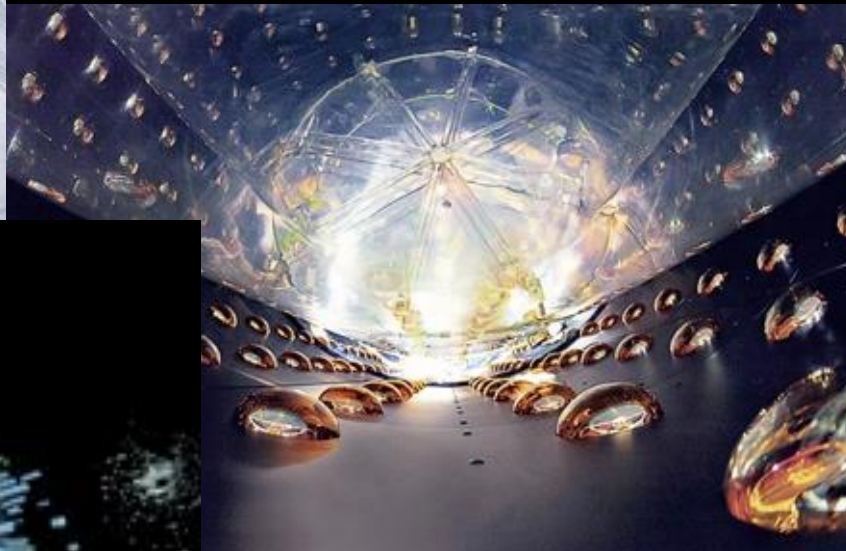
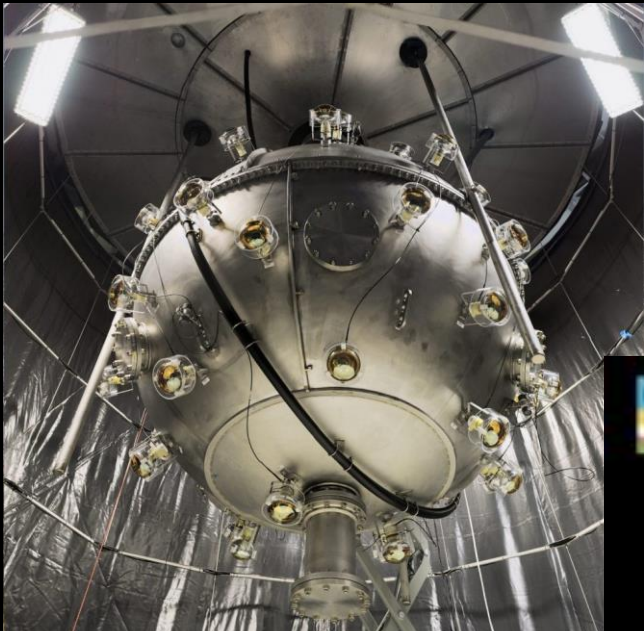
Atoms
4.6%

Dark
Matter
24%

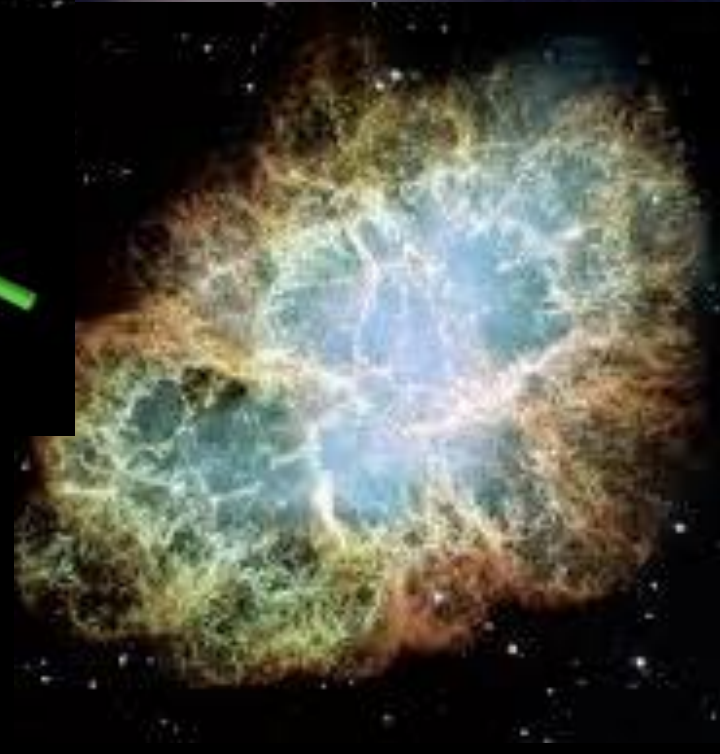
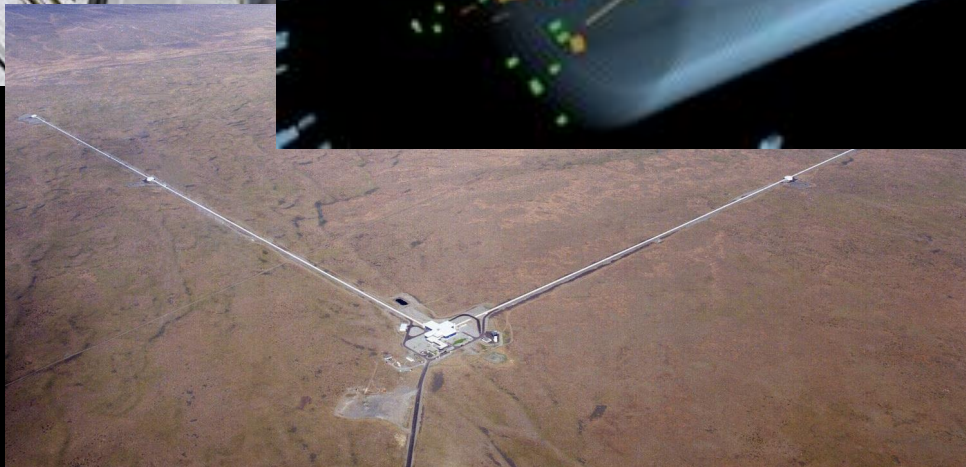
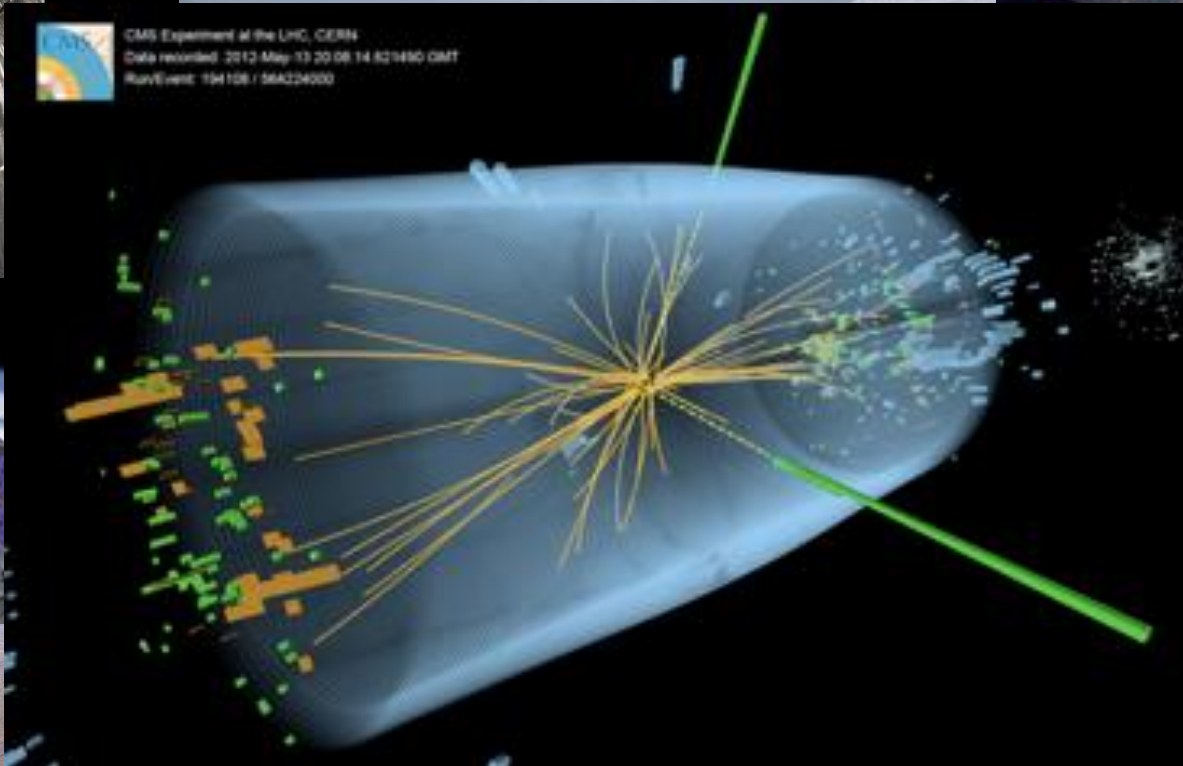


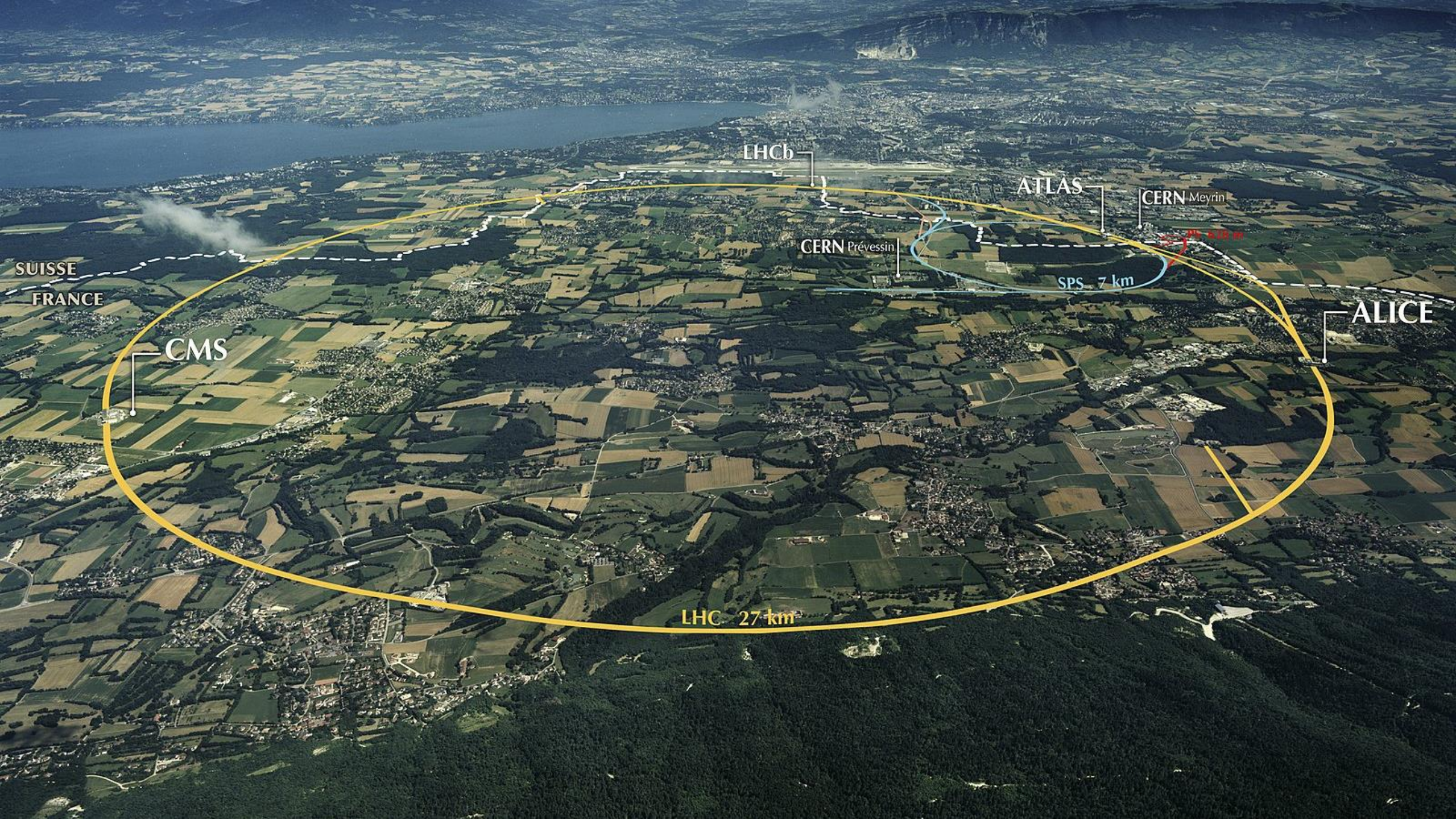
Dark u





CMS Experiment at the LHC, CERN
Data recorded: 2012 May 13 20:08:14.827450 GMT
Run/Event: 194108 / 56A224000





LHCb

ATLAS

CERN Meyrin

CERN Prévessin

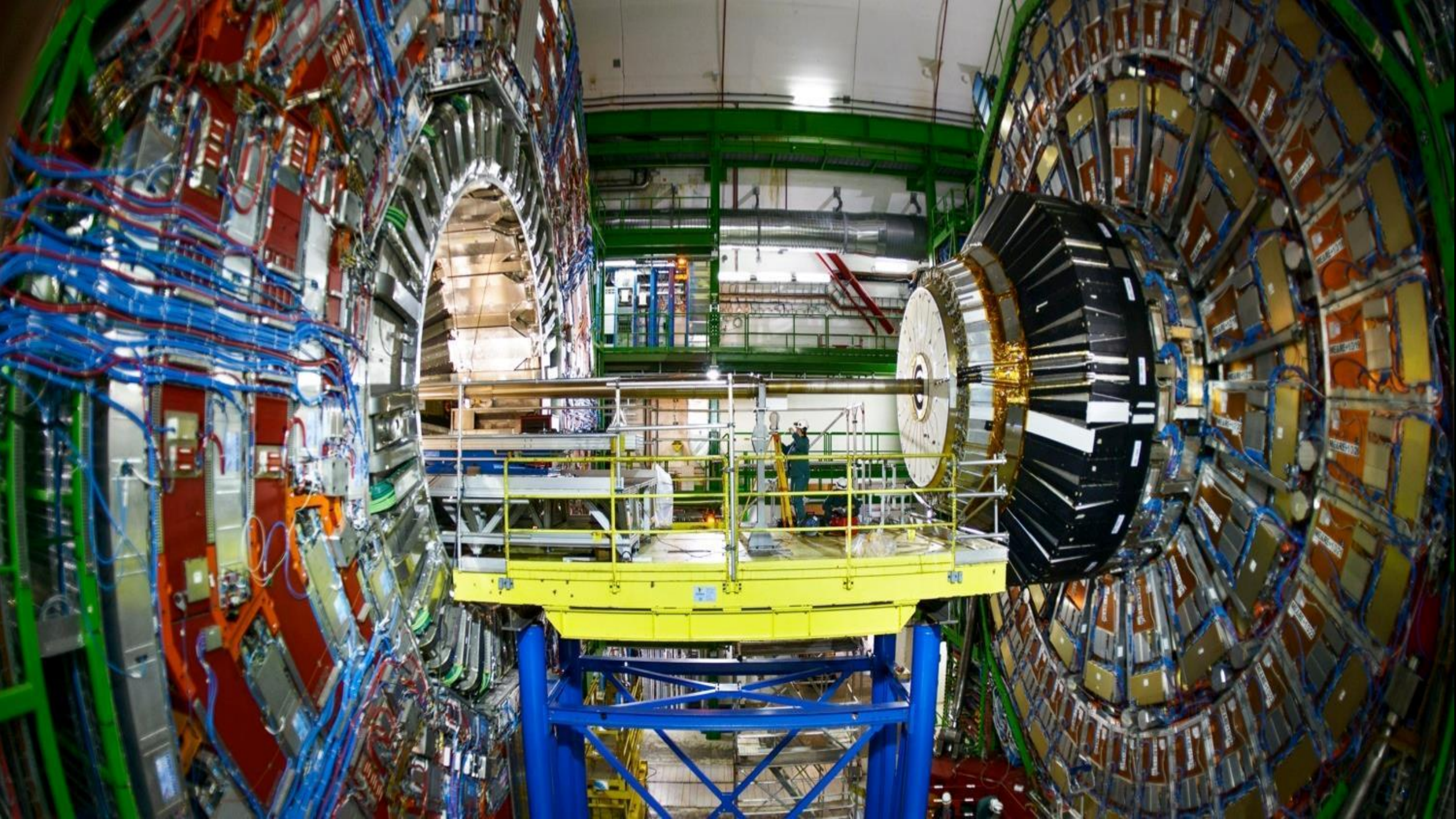
SPS 7 km

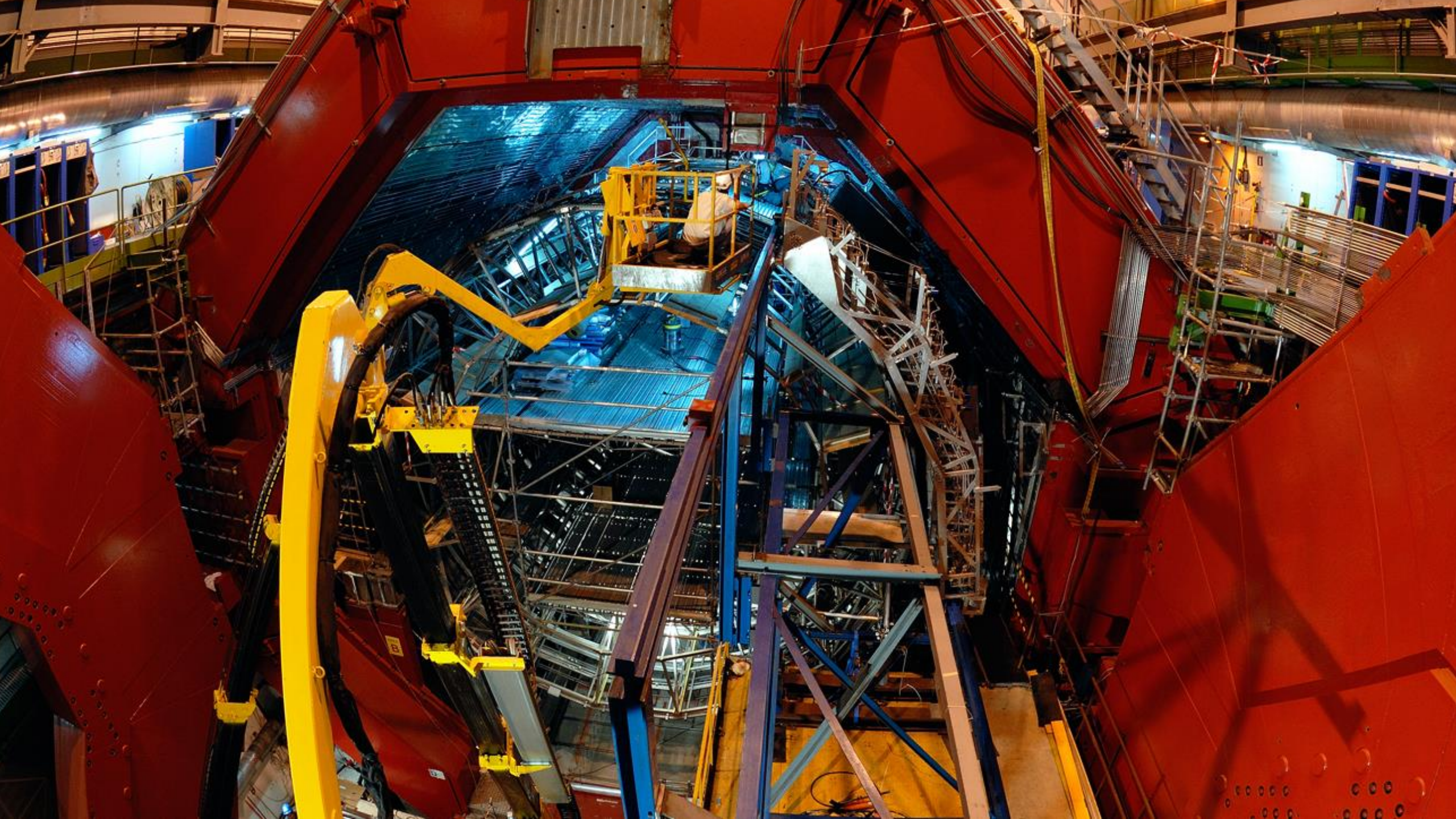
ALICE

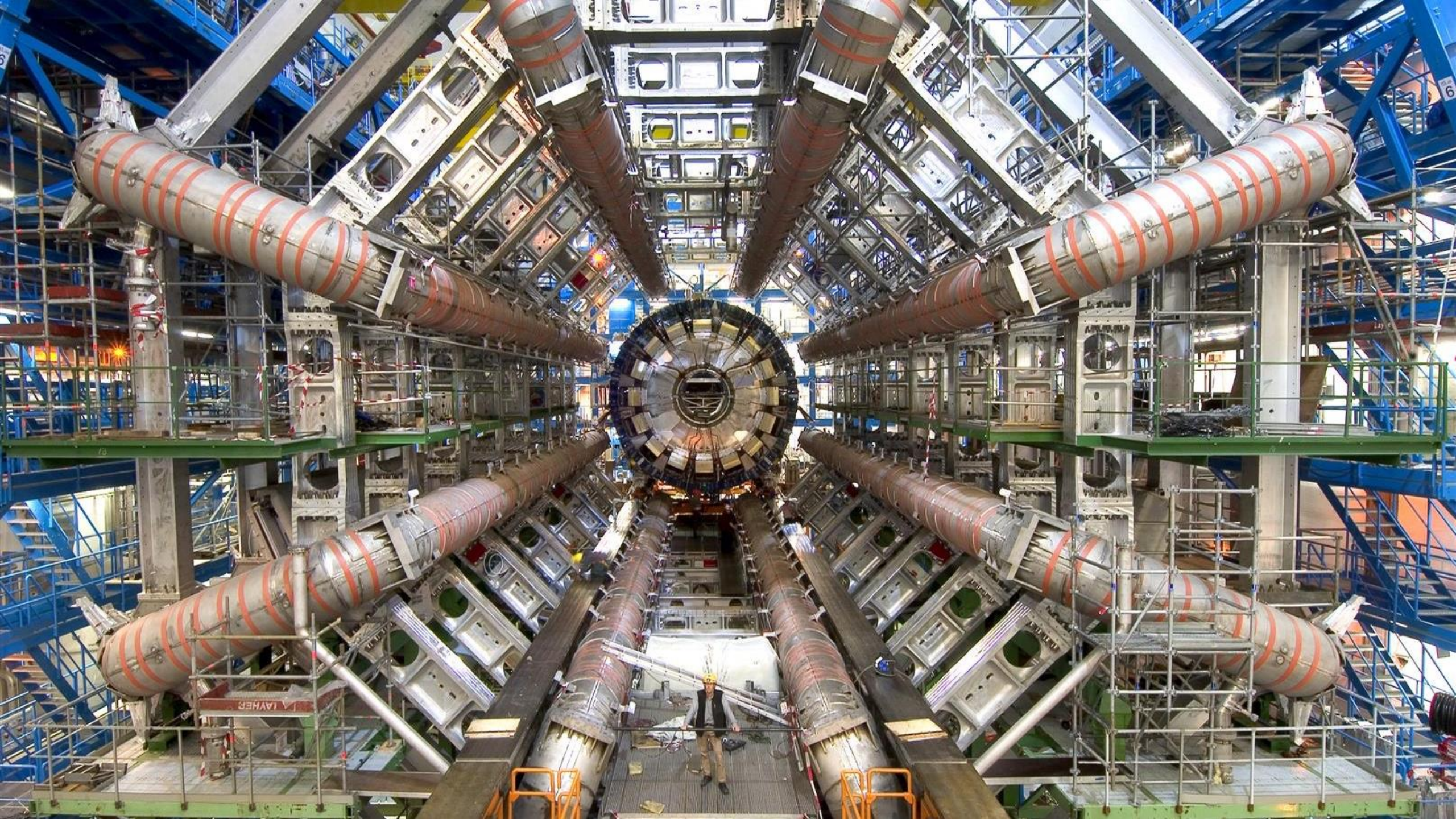
CMS

LHC 27 km

SUISSE
FRANCE

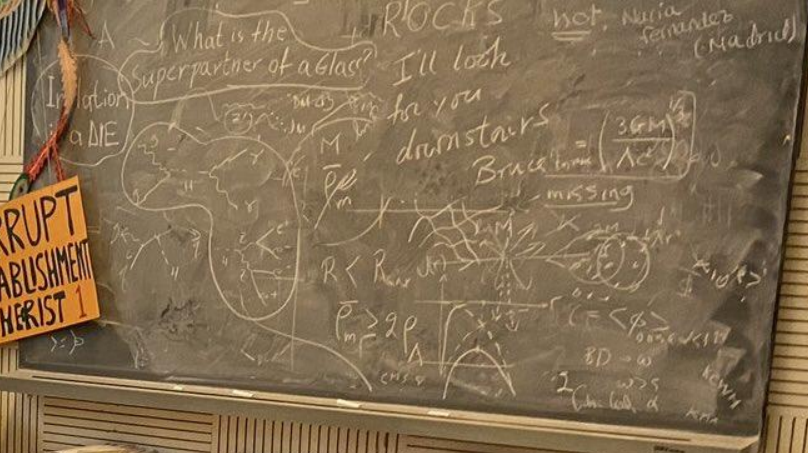








CORRUPT
ESTABLISHMENT
THERIST 1



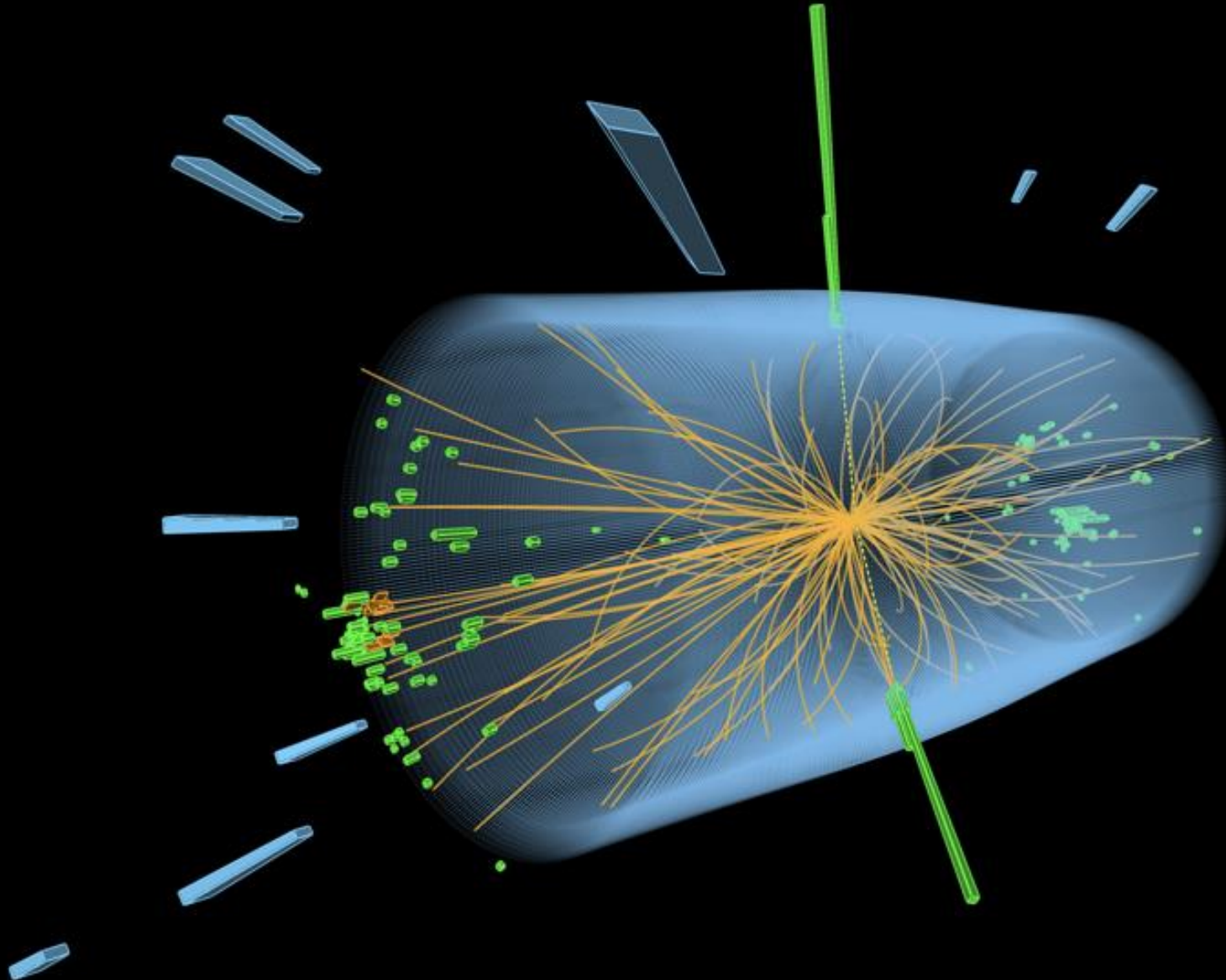
A hand with red-painted fingernails points upwards towards a particle that is emerging from a colorful, iridescent bubble. The particle is depicted as a trail of fine white dots, suggesting a path of discovery or a subatomic particle. The background is solid black, which makes the bubble and the particle stand out.

What does it mean to discover a
particle?

A billion collisions per second

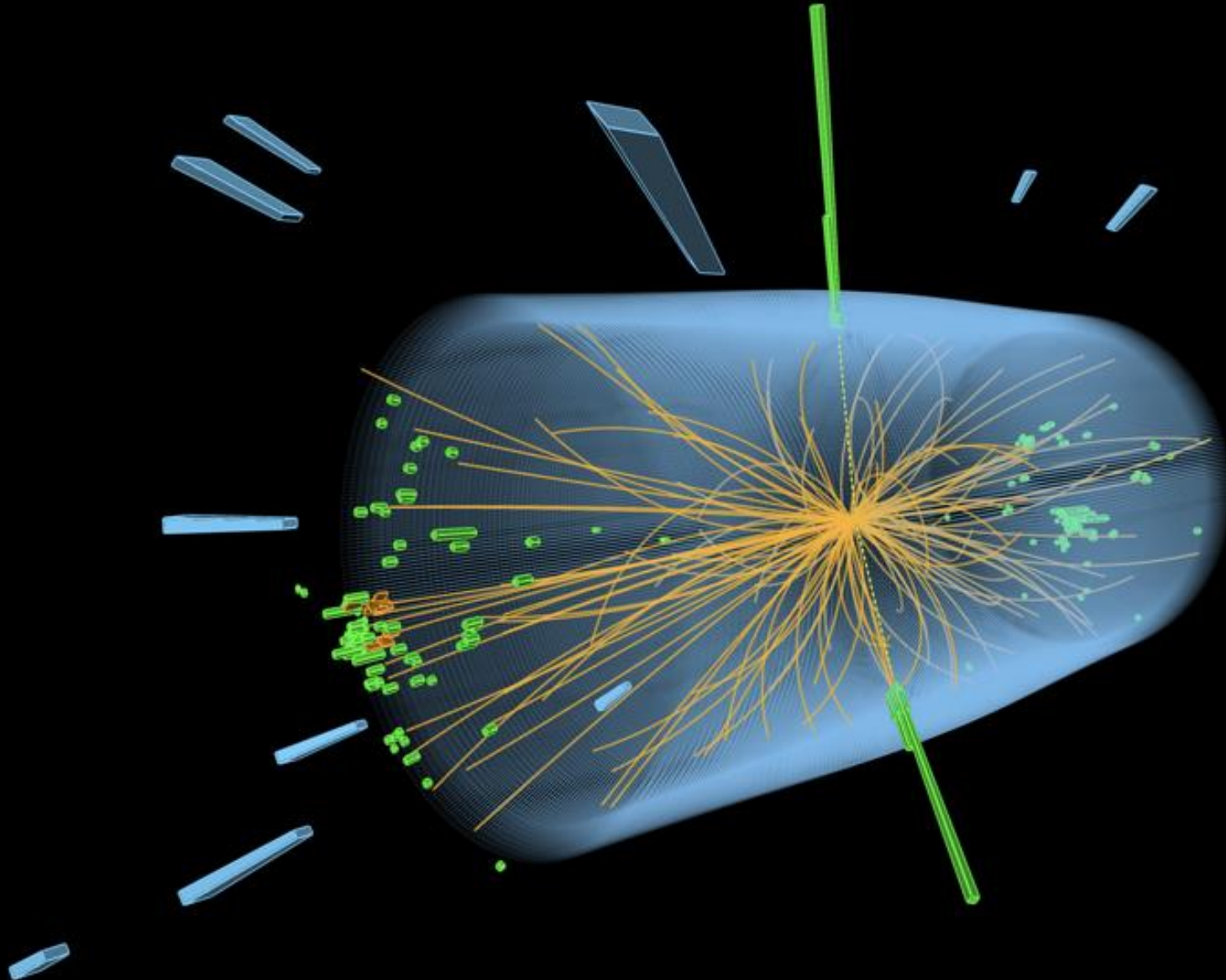
The energy of the particles in collision is converted into new particles.

$$E = m c^2$$



A billion collisions per second

The energy of the particles in collision is converted into new particles.

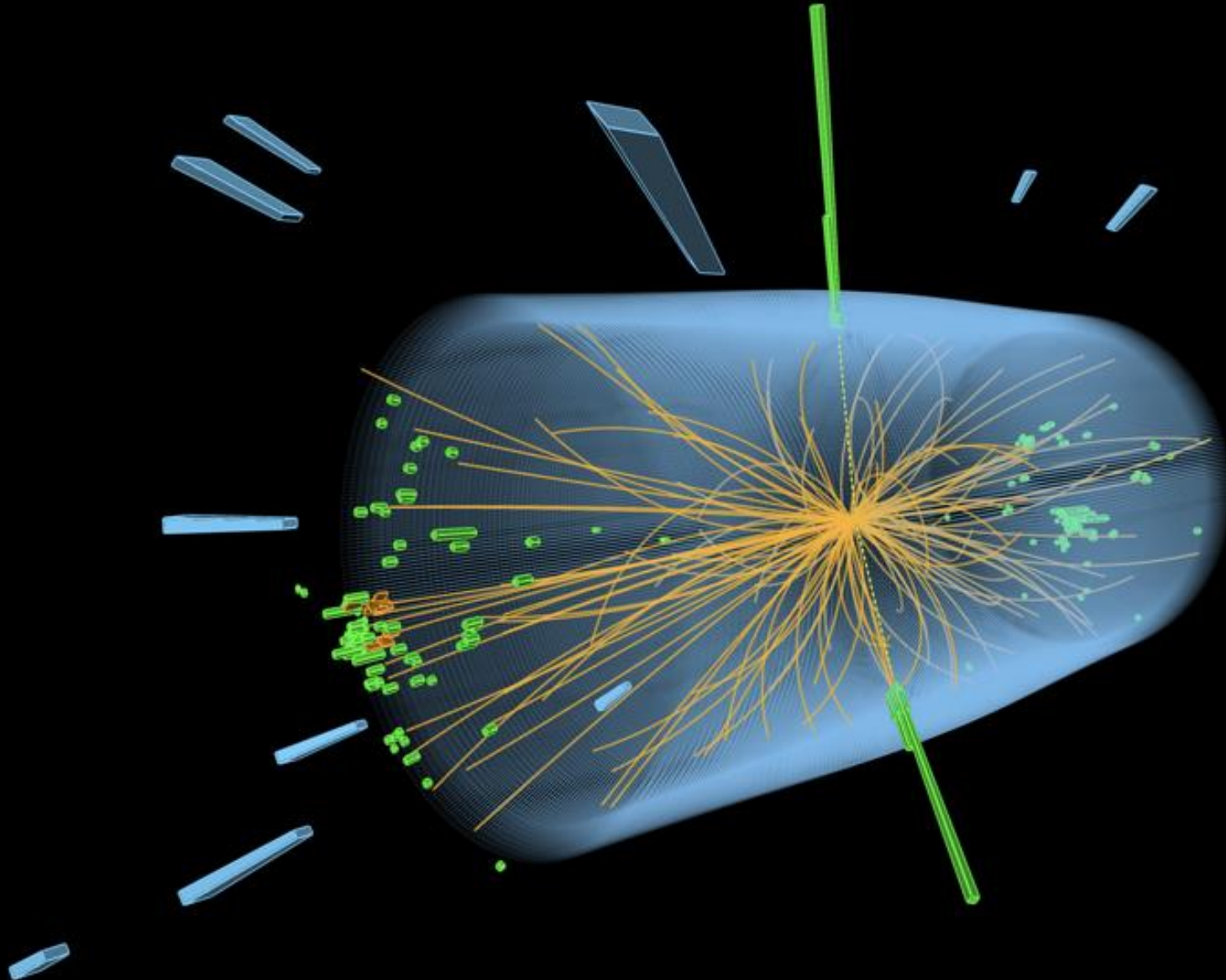


$$E = m c^2$$

13TeV

A billion collisions per second

The energy of the particles in collision is converted into new particles.

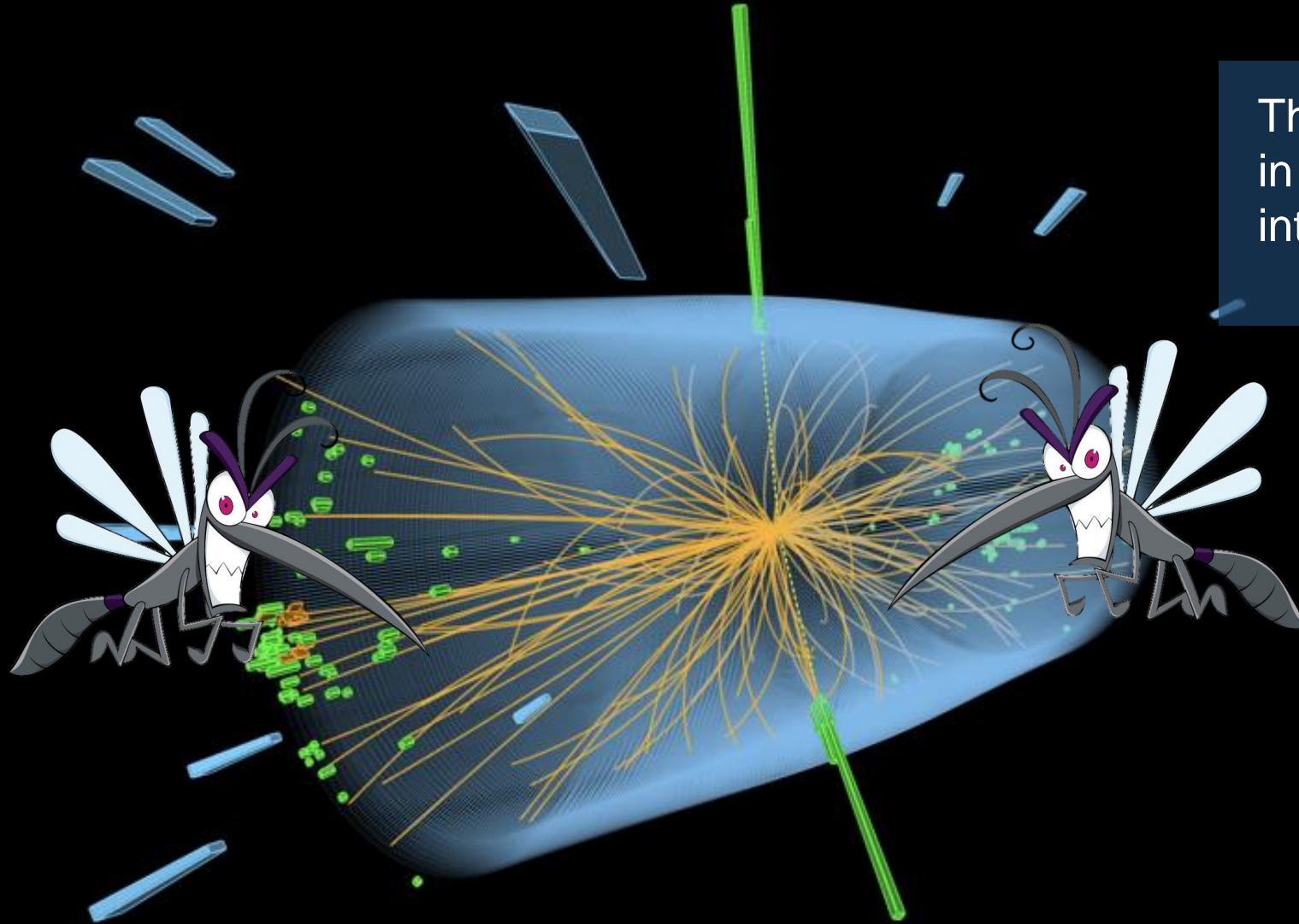


$$E = m c^2$$

$$13\text{TeV} = 2 \mu\text{J}$$

A billion collisions per second

The energy of the particles in collision is converted into new particles.

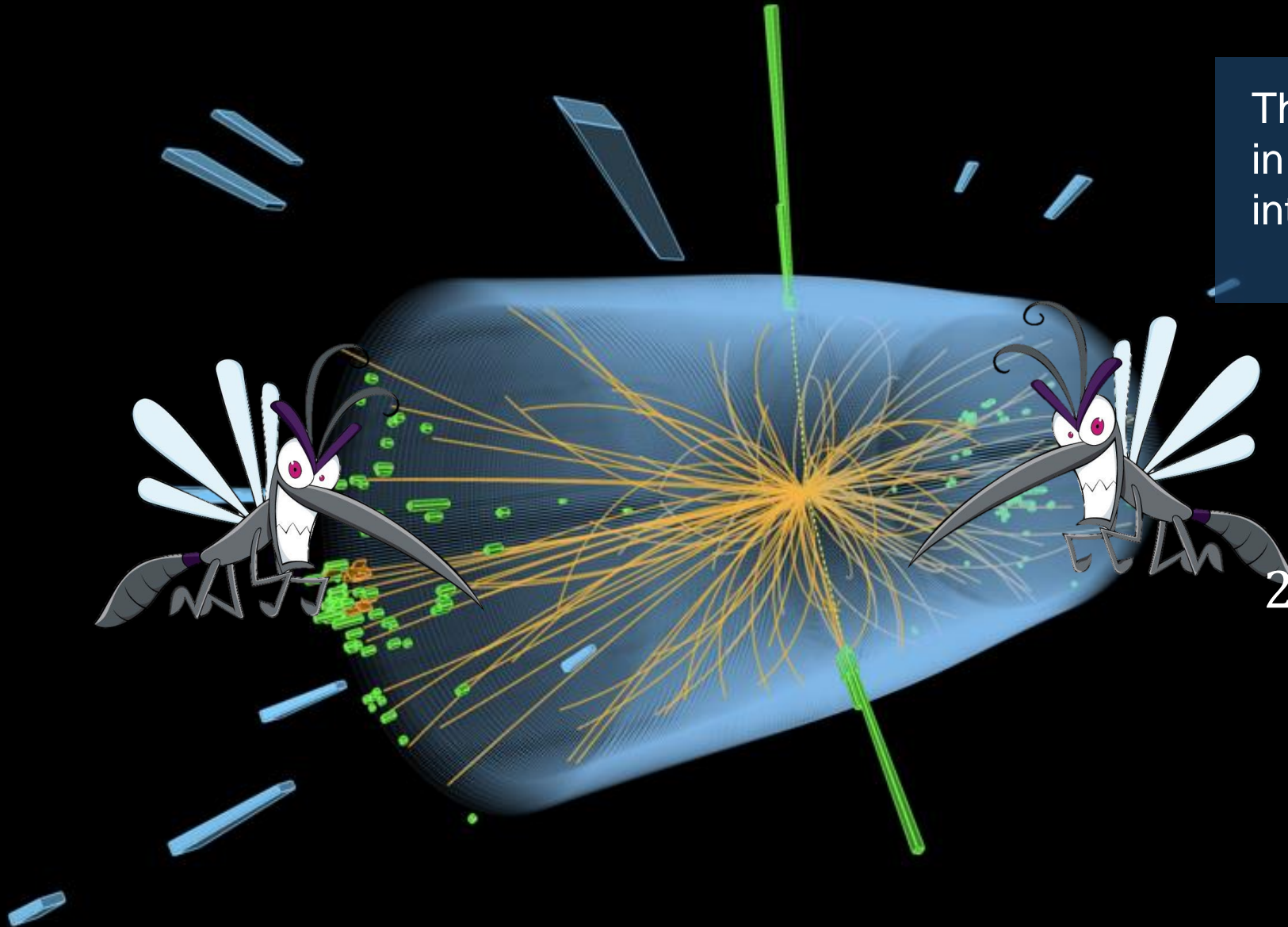


$$E = m c^2$$
$$13\text{TeV} = 2 \mu\text{J}$$

$$E_k = \frac{1}{2} m \cdot v^2 \Rightarrow E_k = \frac{1}{2} (0.1\text{g}) \cdot (0.2\text{m/s})^2 \sim 13 \text{ TeV}$$

A billion collisions per second

The energy of the particles in collision is converted into new particles.



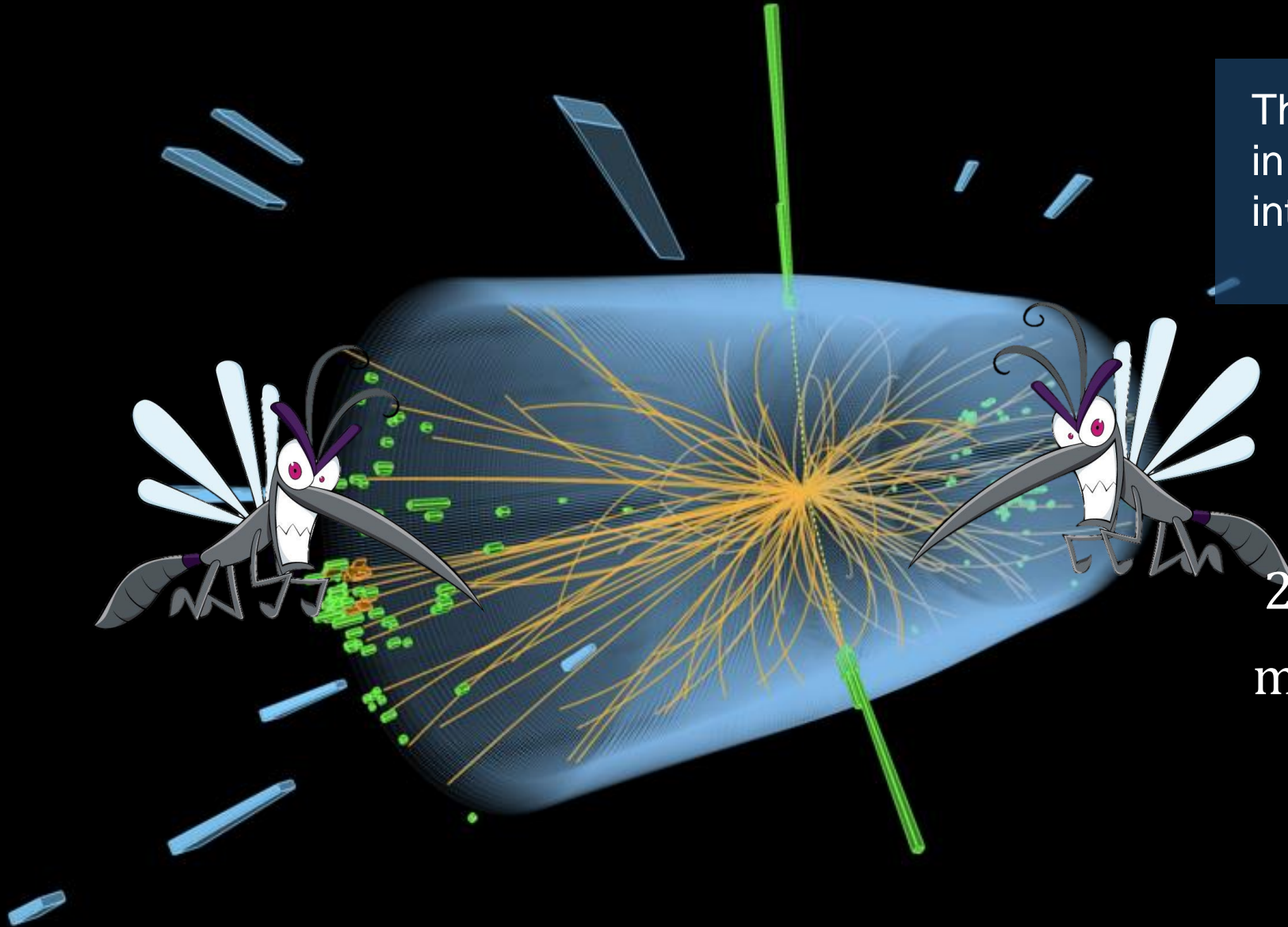
$$E = m c^2$$

$$13\text{TeV} = 2 \mu\text{J}$$

$$2 \mu\text{J} / c^2 = 2.3 \cdot 10^{-23} \text{kg}$$

A billion collisions per second

The energy of the particles in collision is converted into new particles.



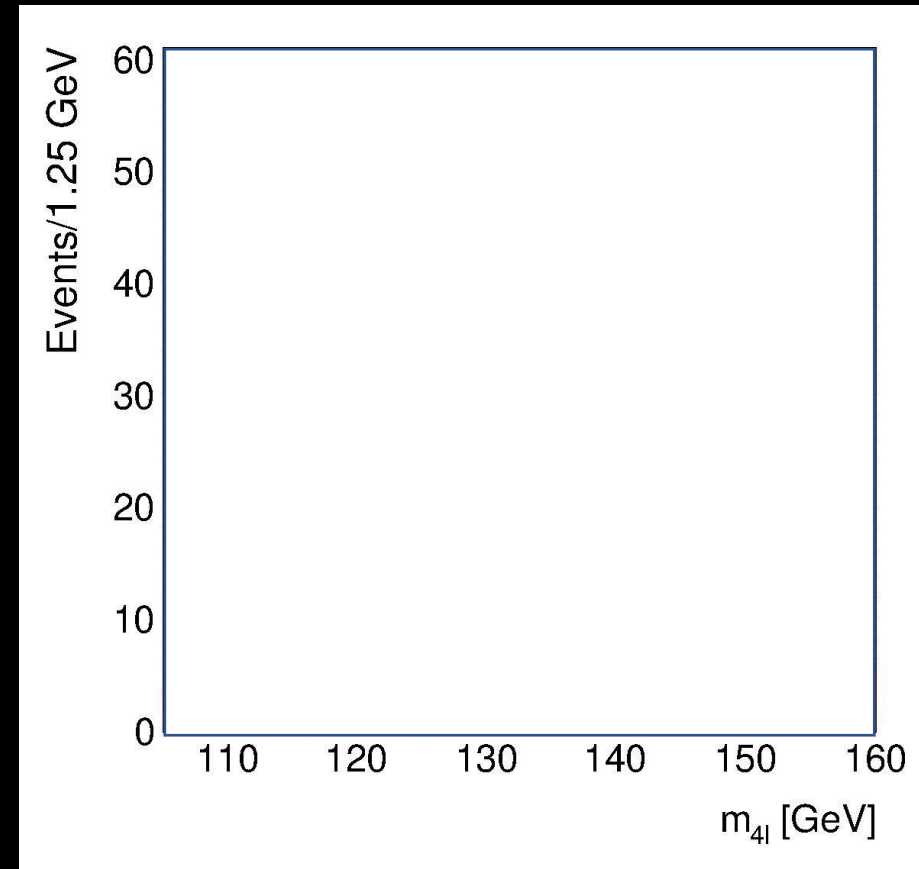
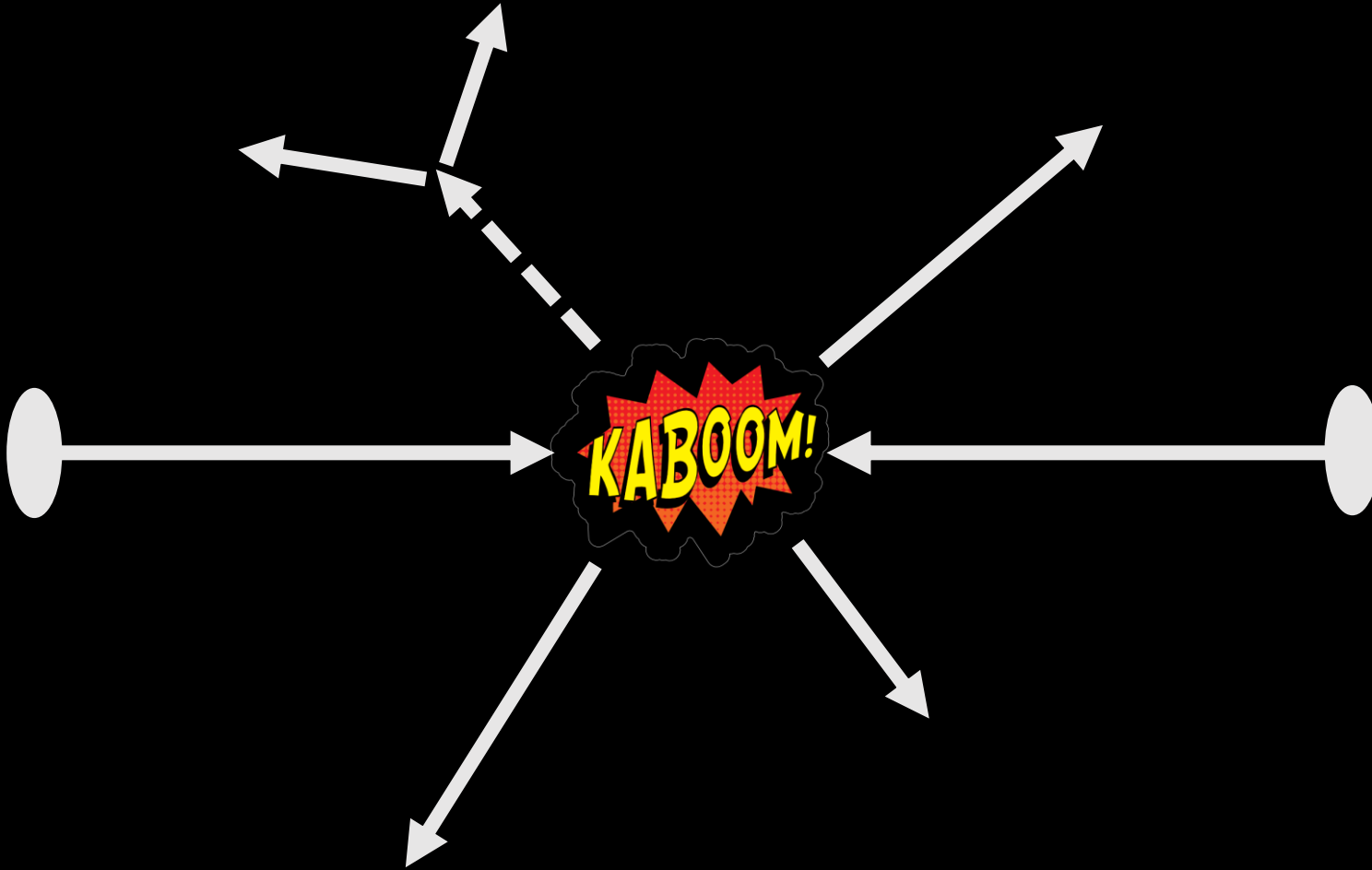
$$E = m c^2$$

$$13\text{TeV} = 2 \mu\text{J}$$

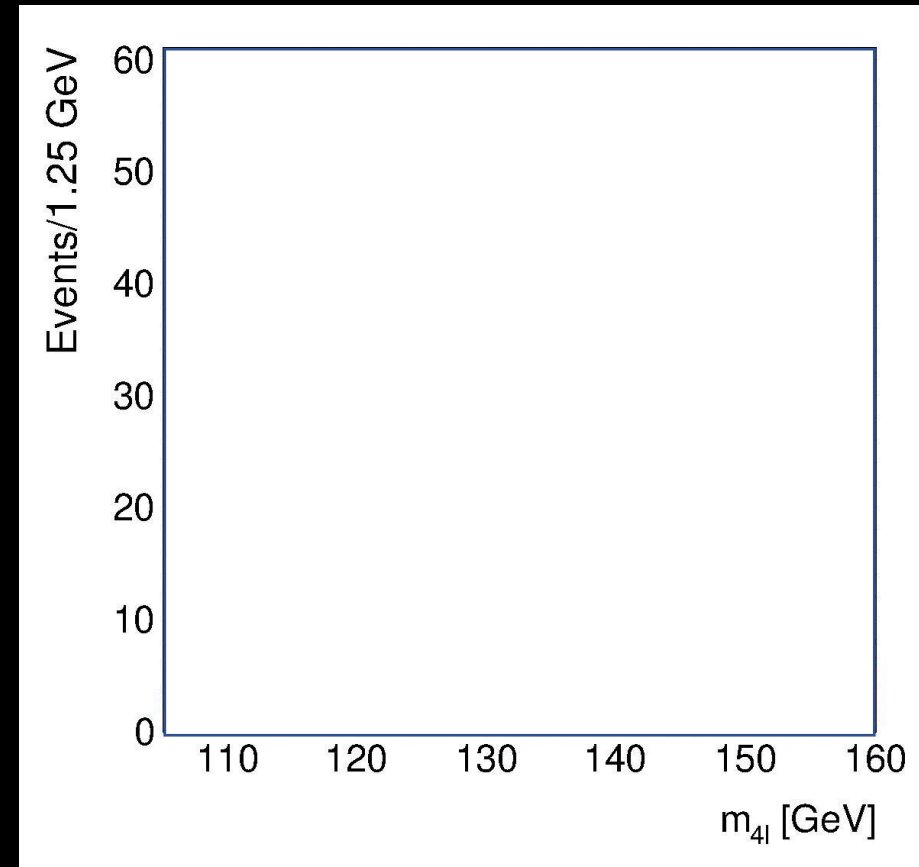
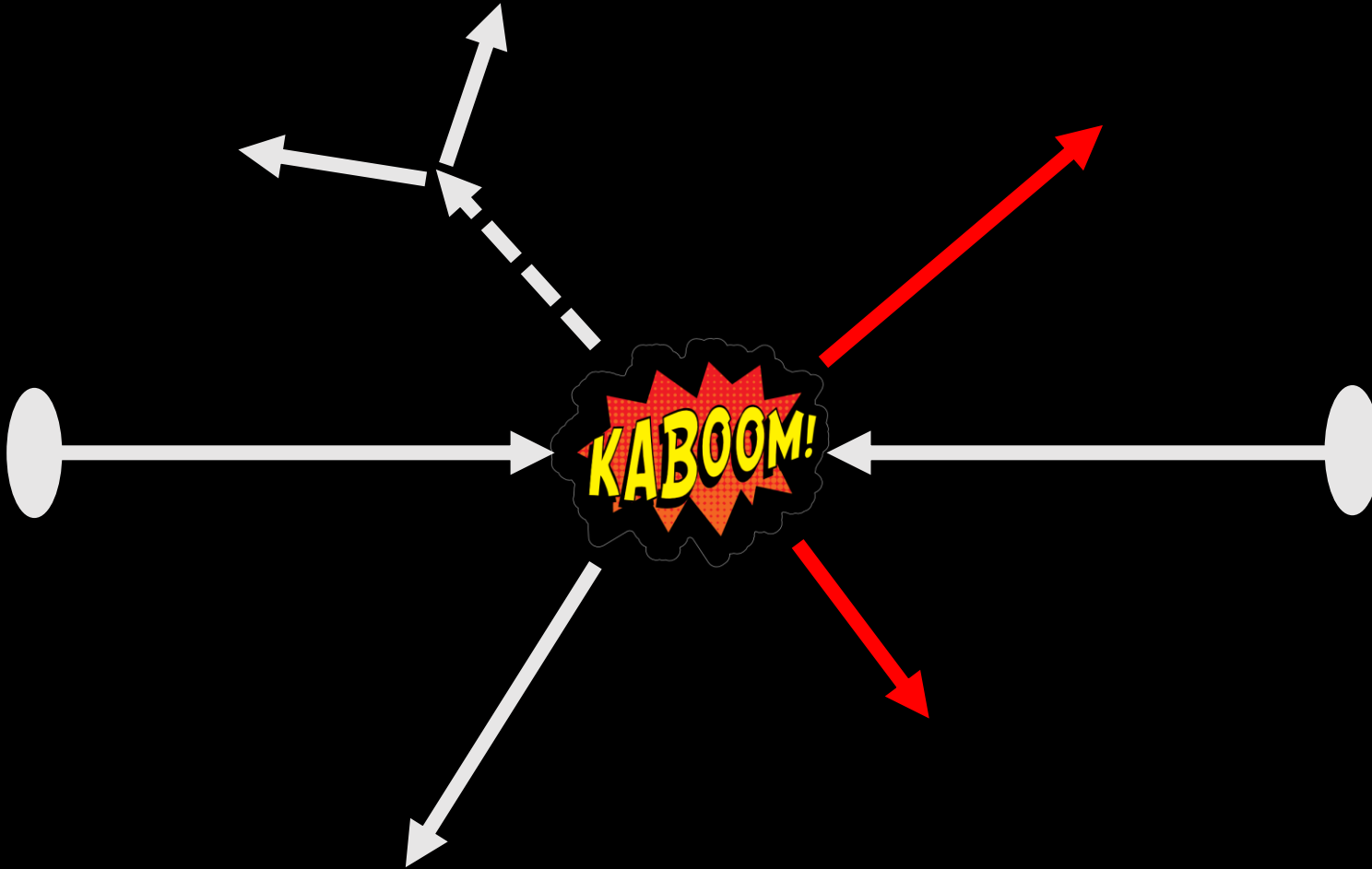
$$2 \mu\text{J} / c^2 = 2.3 \cdot 10^{-23} \text{kg}$$

$$m_{\text{higgs}} = 2 \cdot 10^{-25} \text{kg}$$

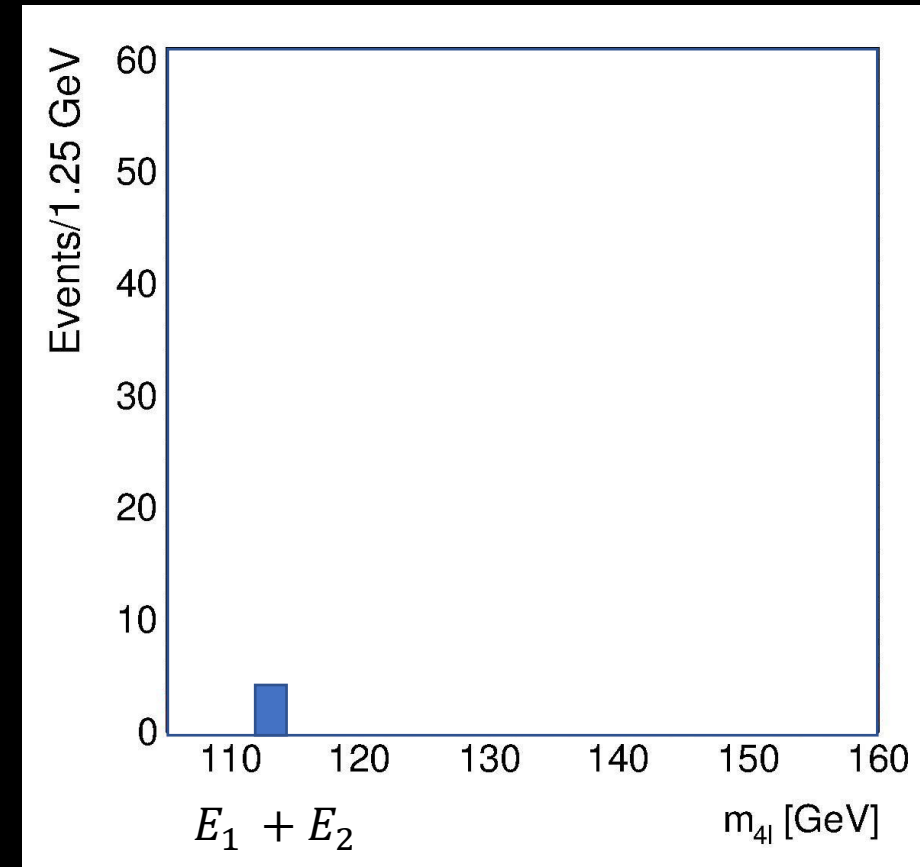
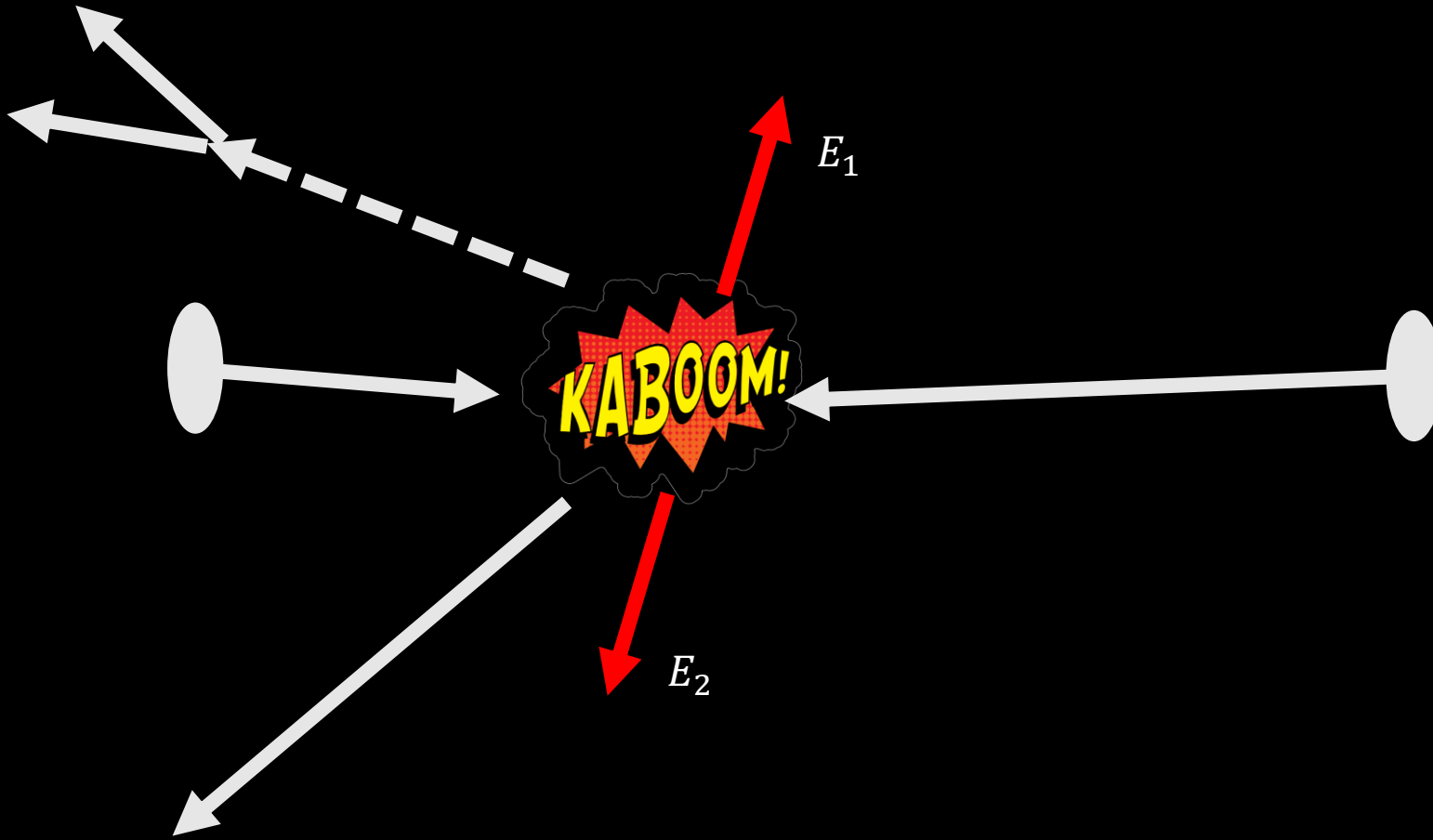
How to find a particle?



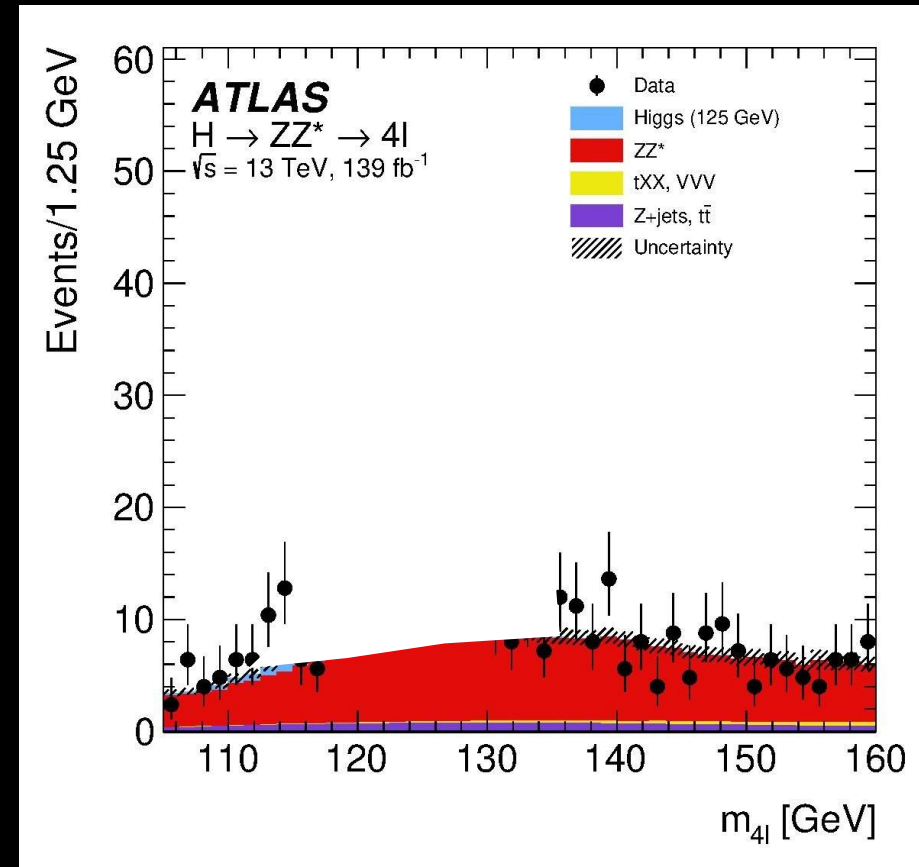
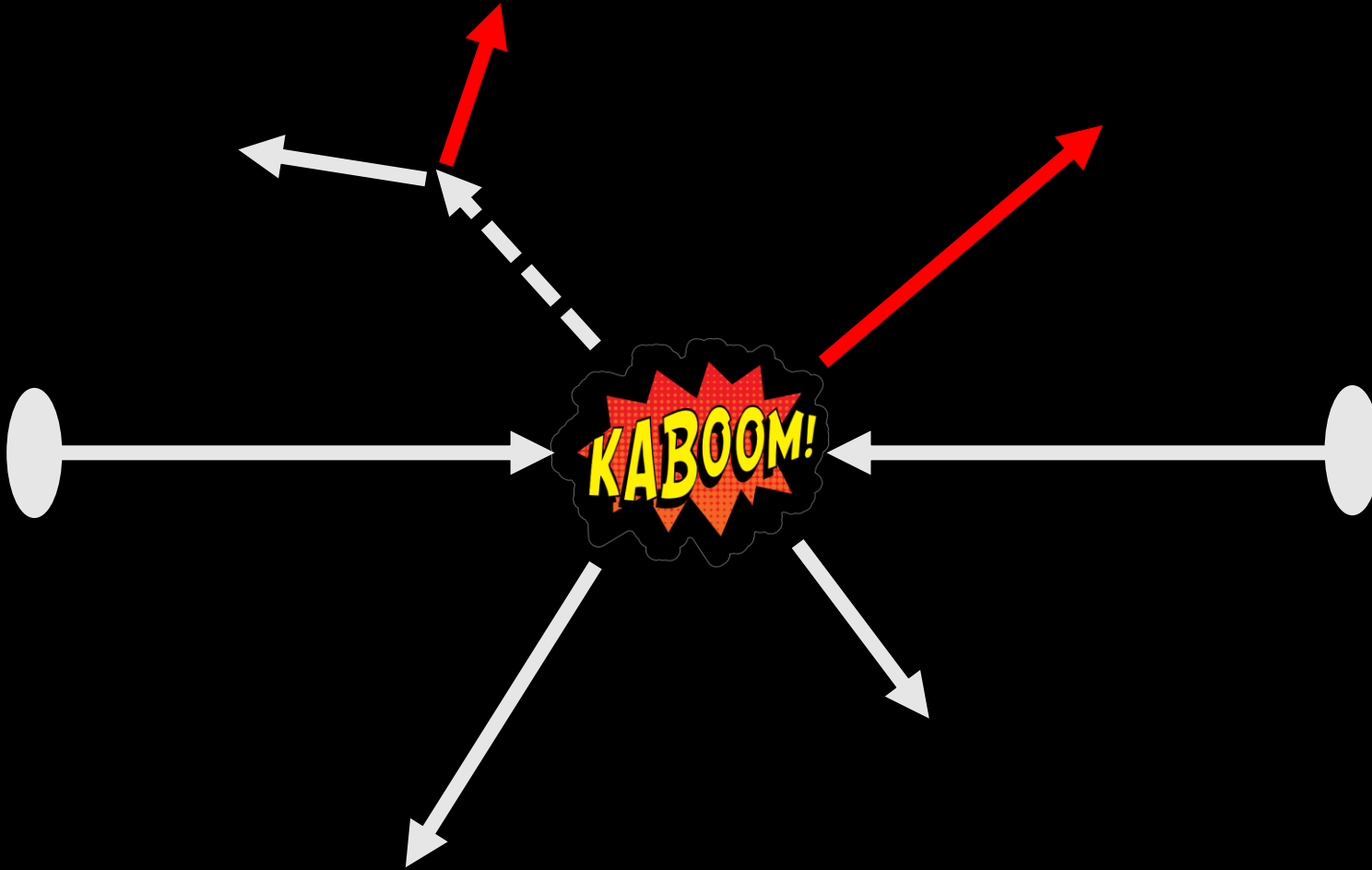
How to find a particle?



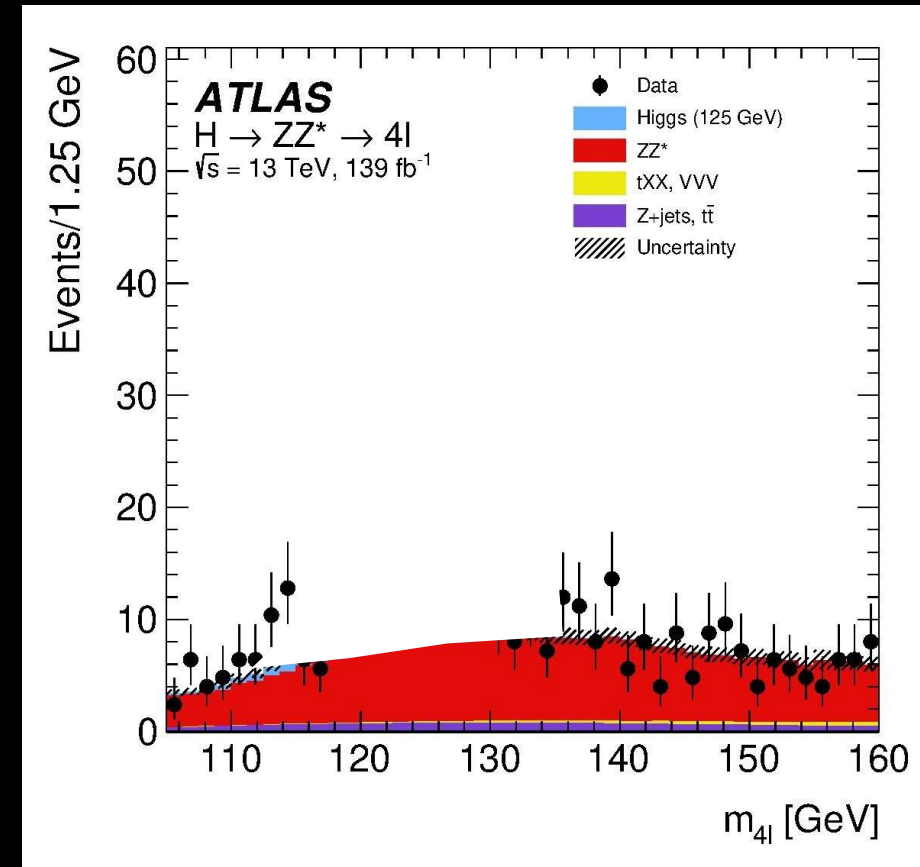
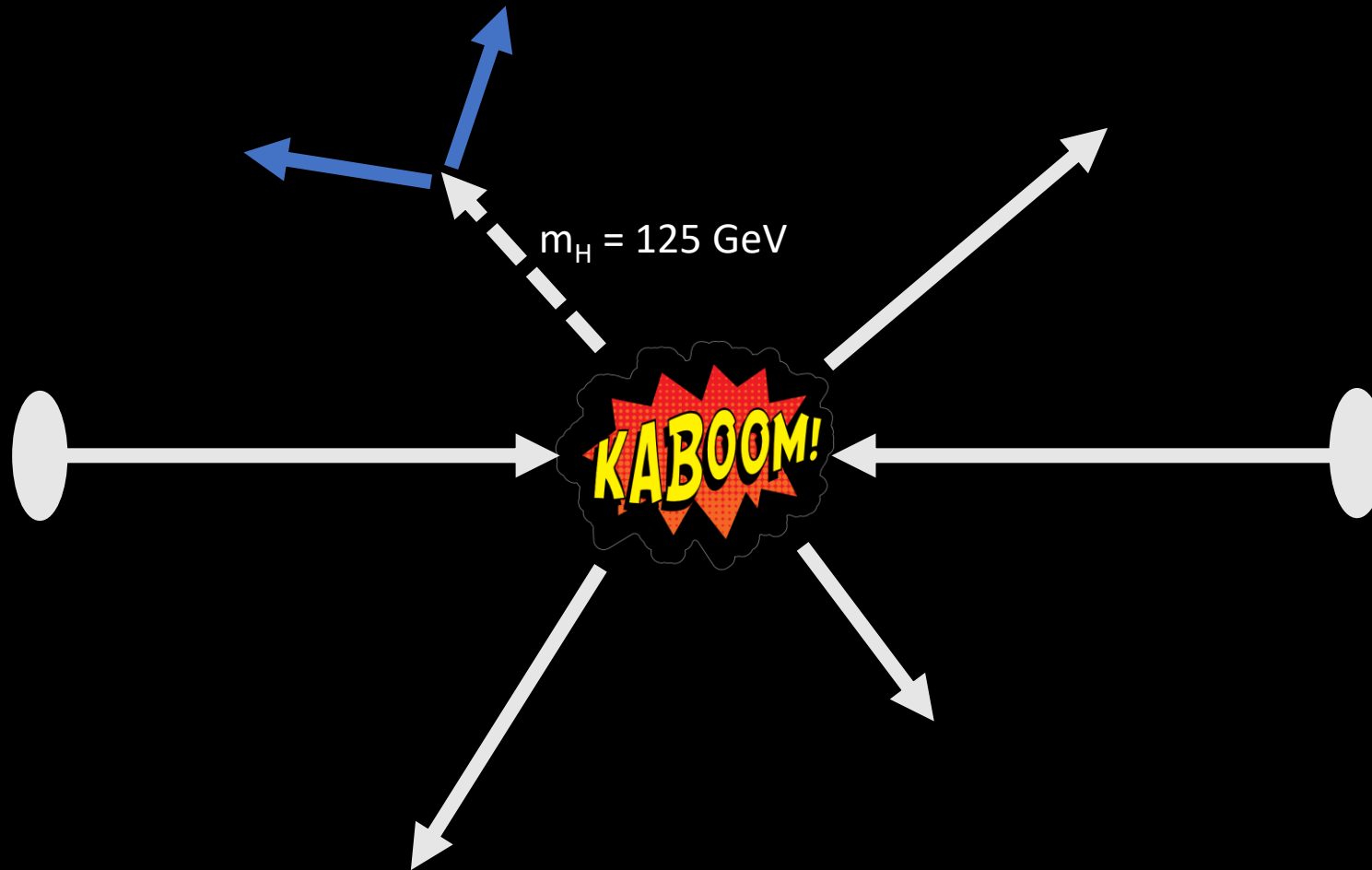
How to find a particle?



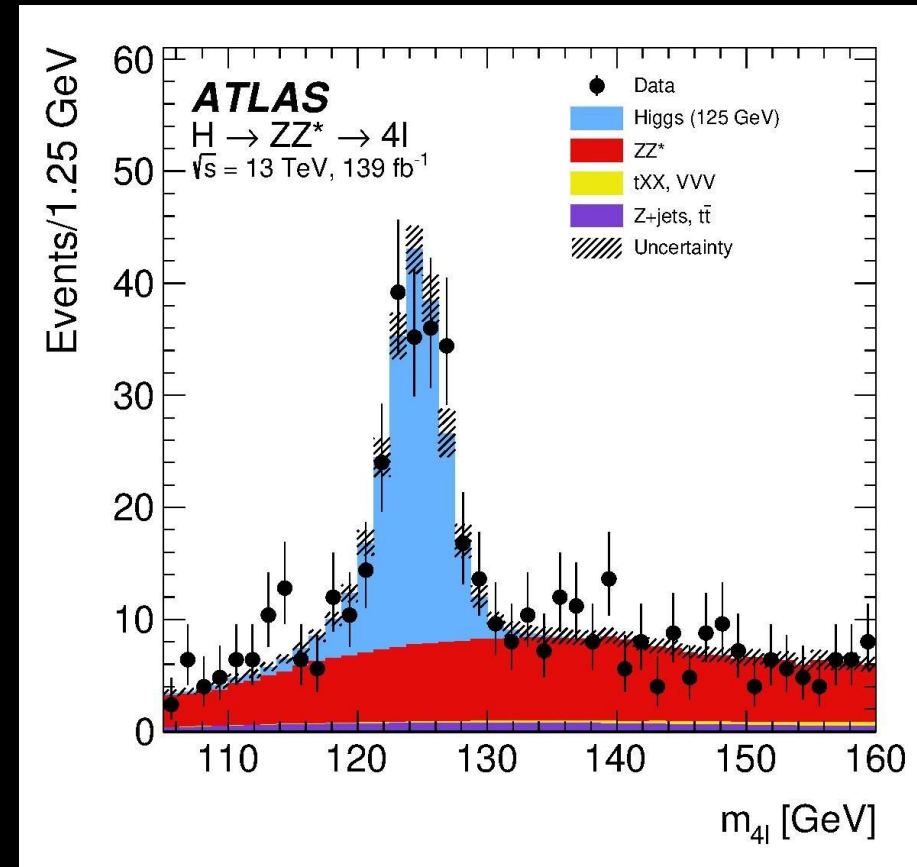
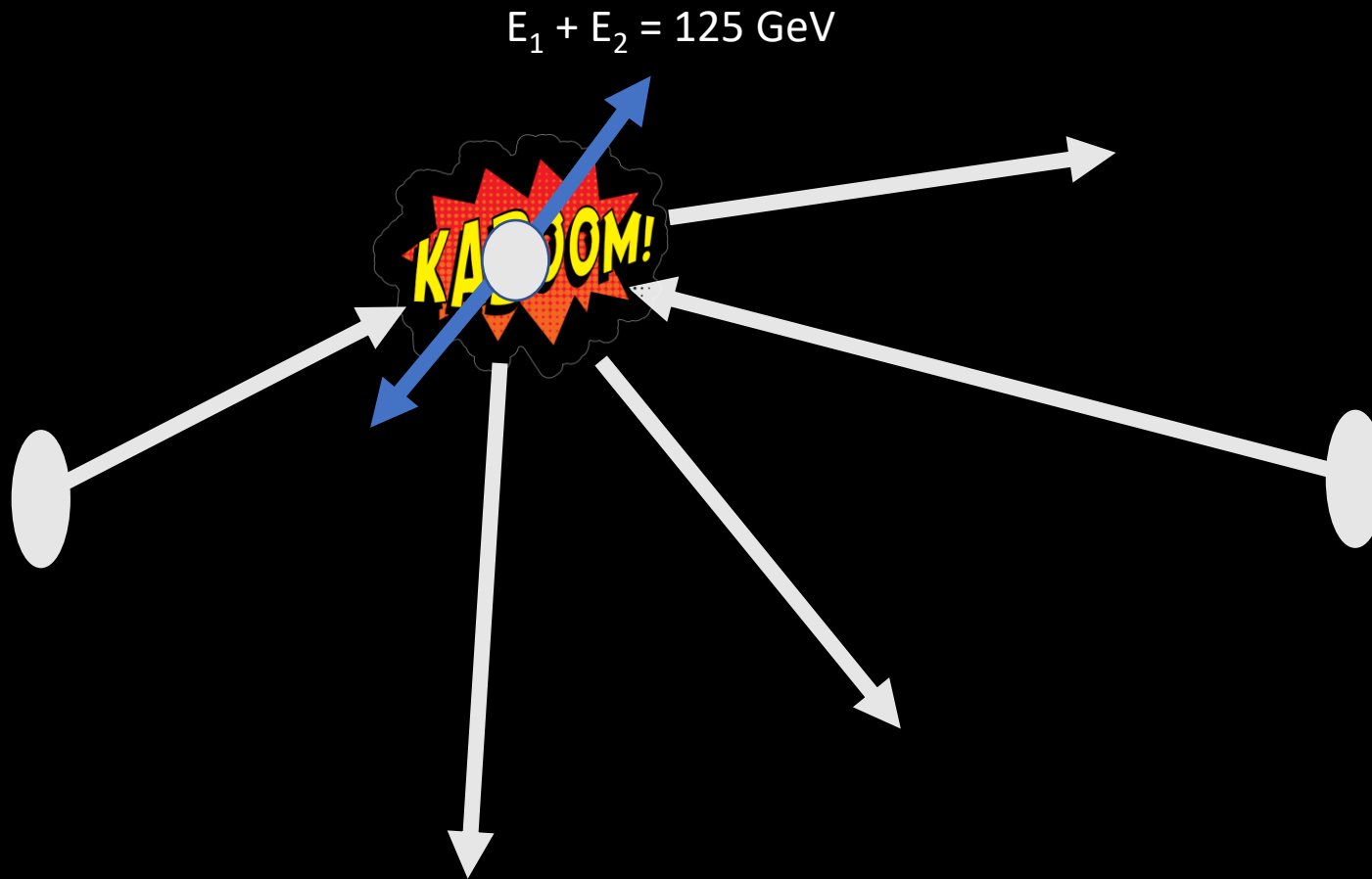
How to find a particle?



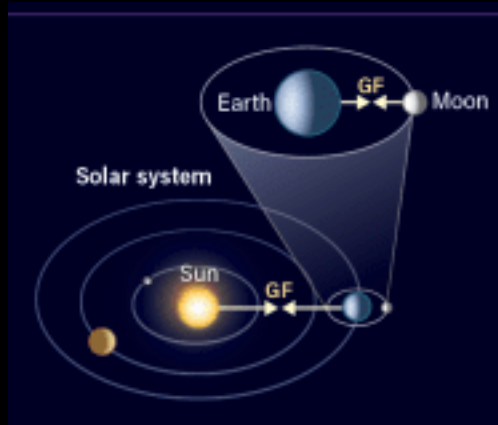
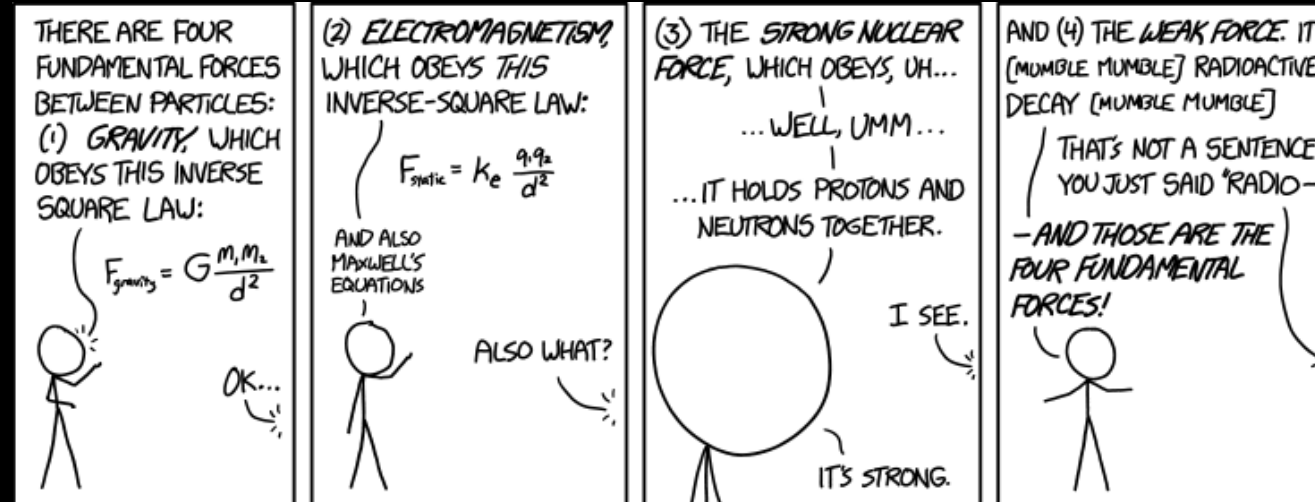
How to find a particle?



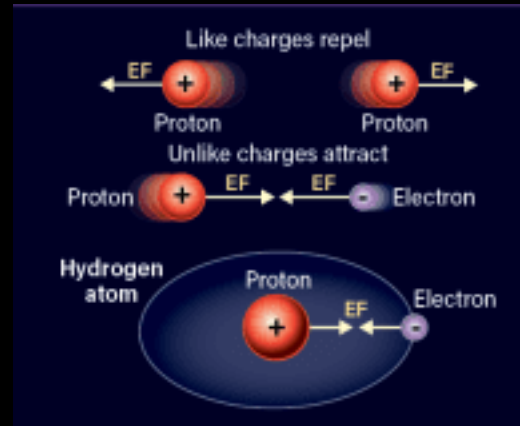
How to find a particle?



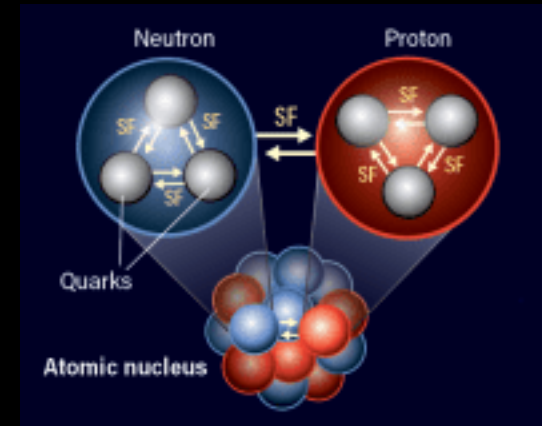
Forces of Nature



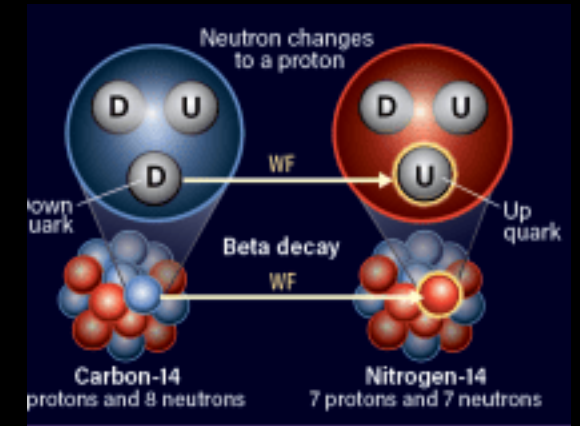
Gravity



Electromagnetism



Strong nuclear force



Weak nuclear force

Quantum mechanics

Uncertainty principle

$$\Delta x \Delta p > \hbar$$

Special relativity

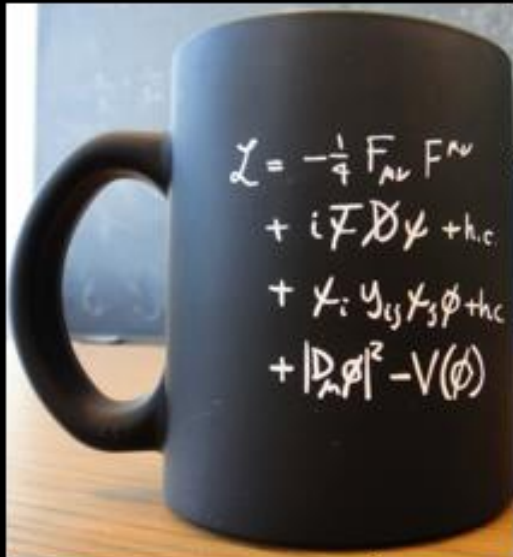
Constant speed of light,
frame independence

Gravity

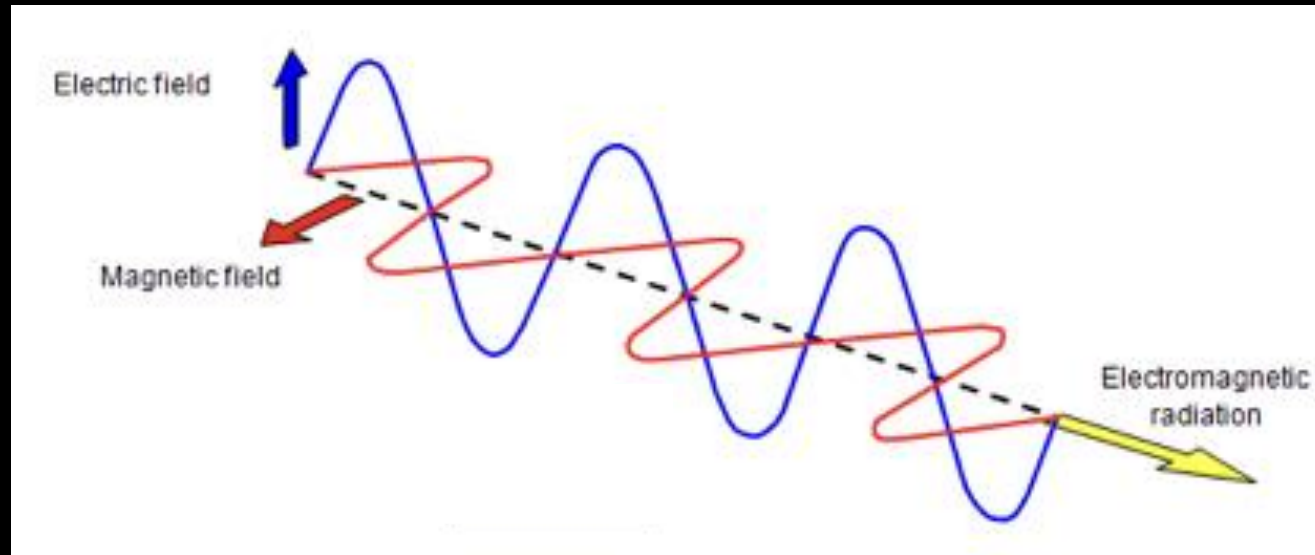
General relativity

Quantum field theory

Particle-field duality



Fields are particles too:



Light is oscillations in electric and magnetic fields

The smallest possible vibration: Photon

Fields are particles too:

Electric and
Magnetic fields

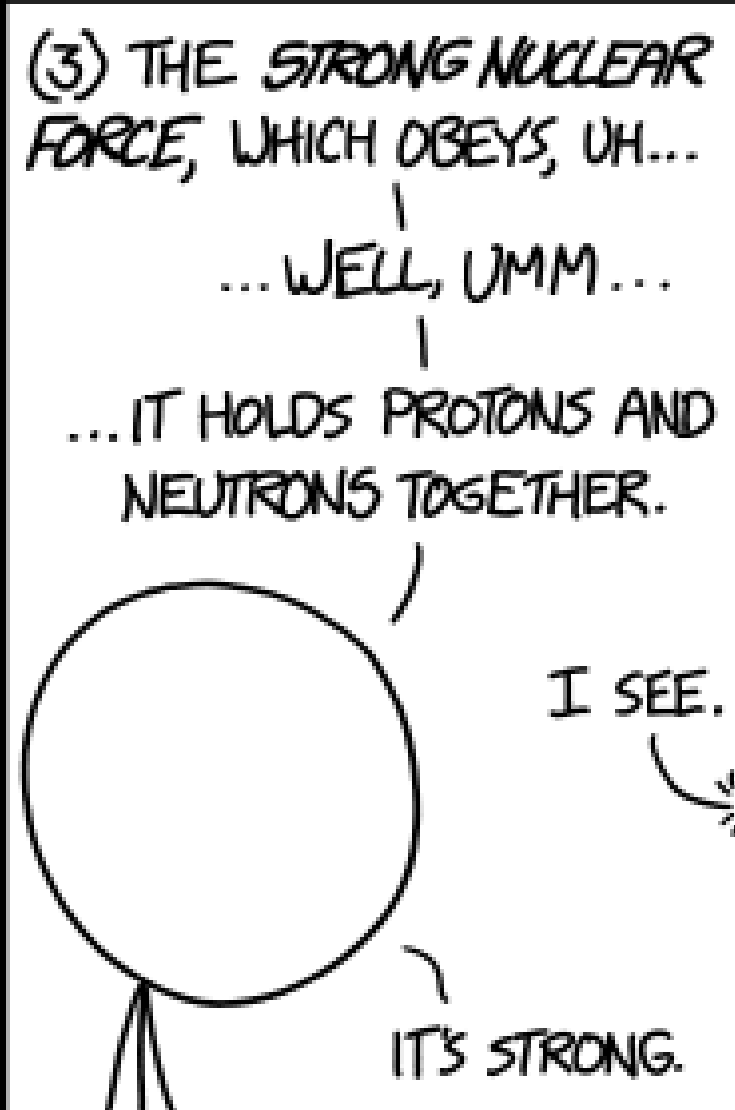


Chromoelectric and
Chromomagnetic field

SU(2) fields

+ gravitational field
and graviton?

Strong force: Quantum Chromodynamics



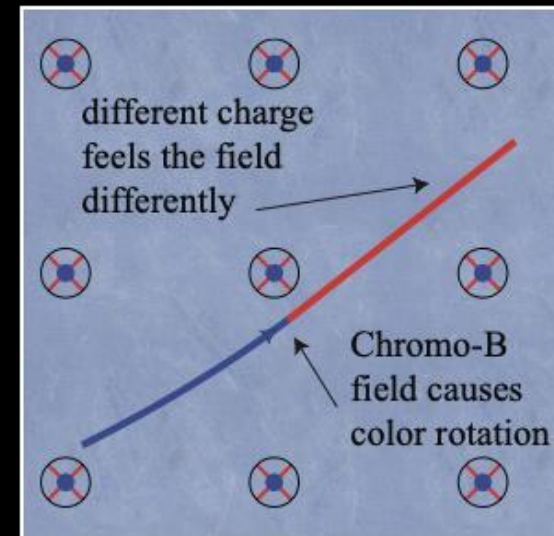
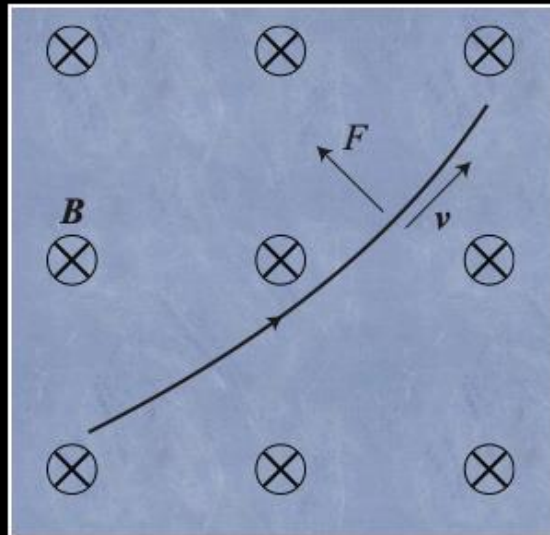
Strong force: Quantum Chromodynamics



Three **colors** of quarks

Chromoelectric and –magnetic fields like electric and magnetic fields but see **color** instead of electric charge

Chromo fields change not only momentum but also **color**



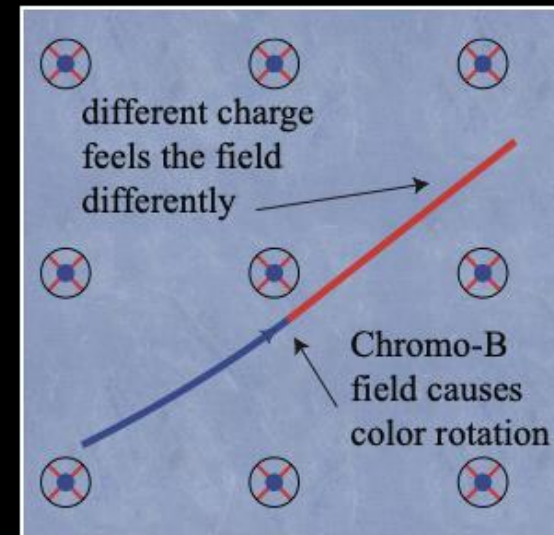
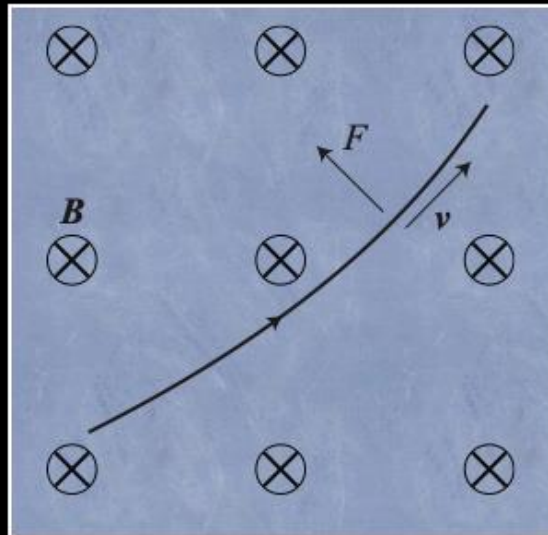
Strong force: Quantum Chromodynamics



Three **colors** of quarks

Chromoelectric and –magnetic fields like electric and magnetic fields but see **color** instead of electric charge

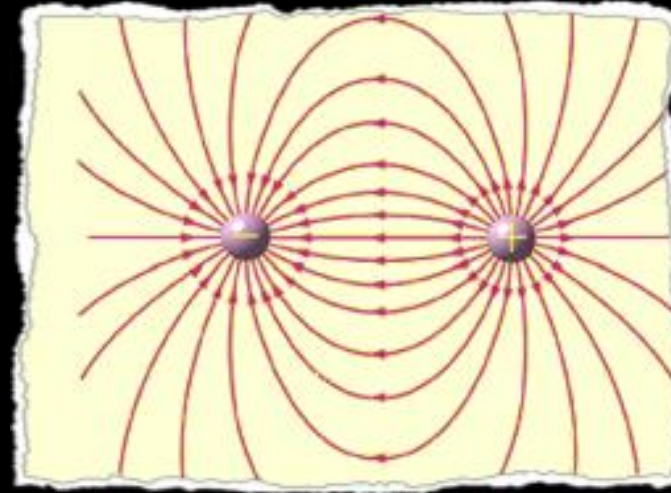
Chromo fields change not only momentum but also **color**



Chromo fields have **colors** too -> Self interaction!

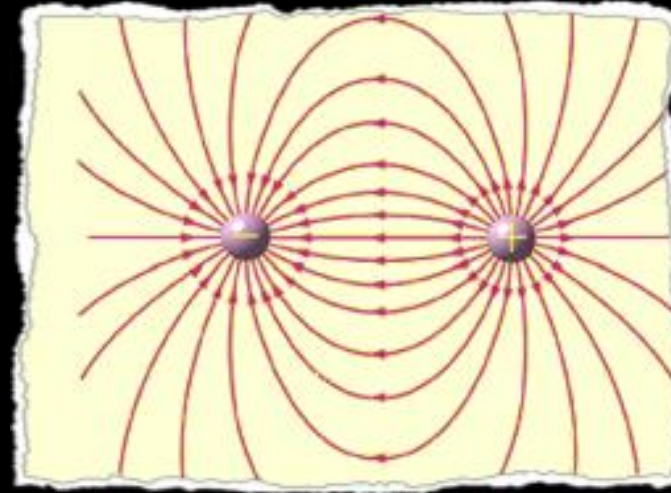
Strong force: Quantum Chromodynamics

Inverse square law for
electric charges



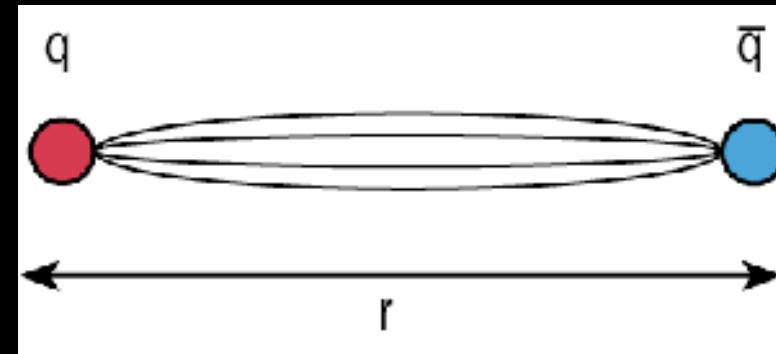
Strong force: Quantum Chromodynamics

Inverse square law for
electric charges

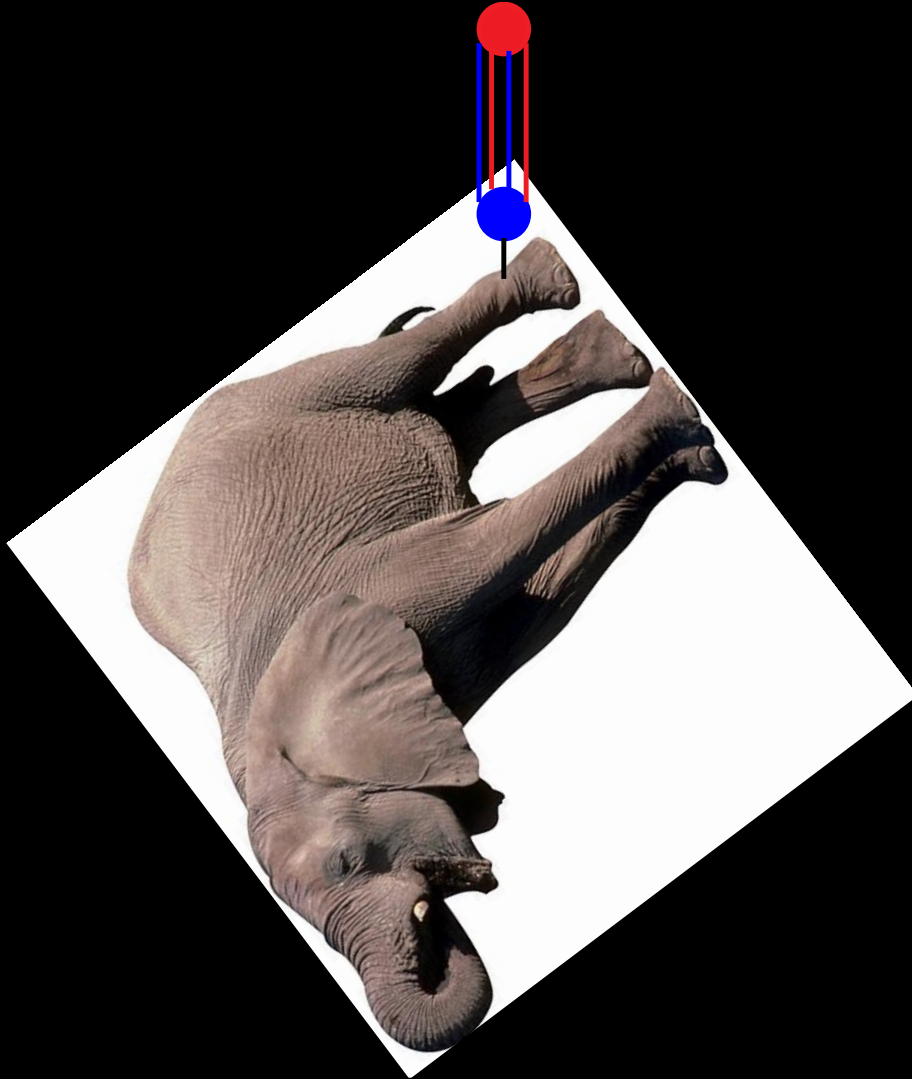


Constant string force between quarks

$$F = (400 \text{ MeV})^2$$



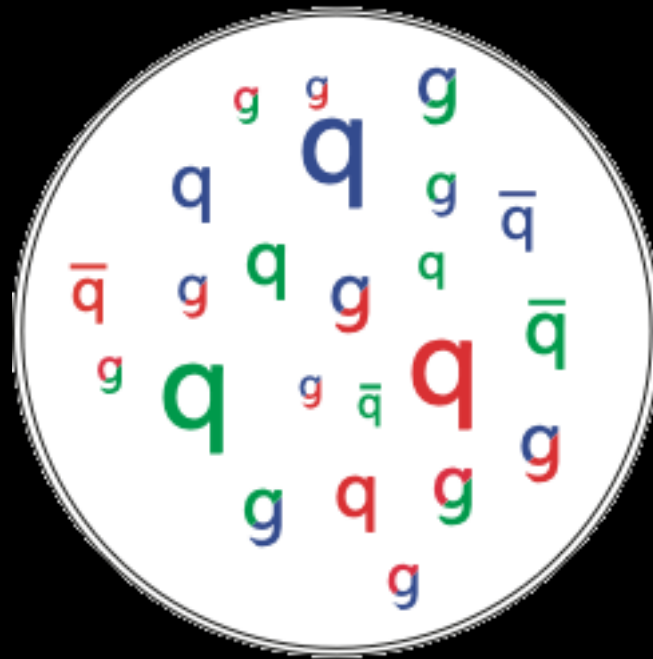
Strong force: Quantum Chromodynamics



$$F = (400 \text{ MeV})^2 = 130 \text{ kN}$$

Color confinement
Millennium Prize 1M\$

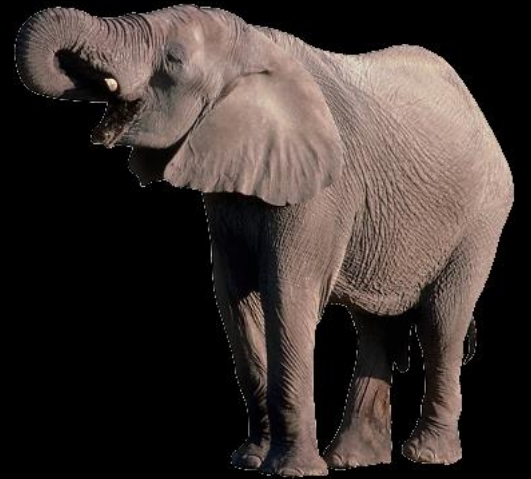
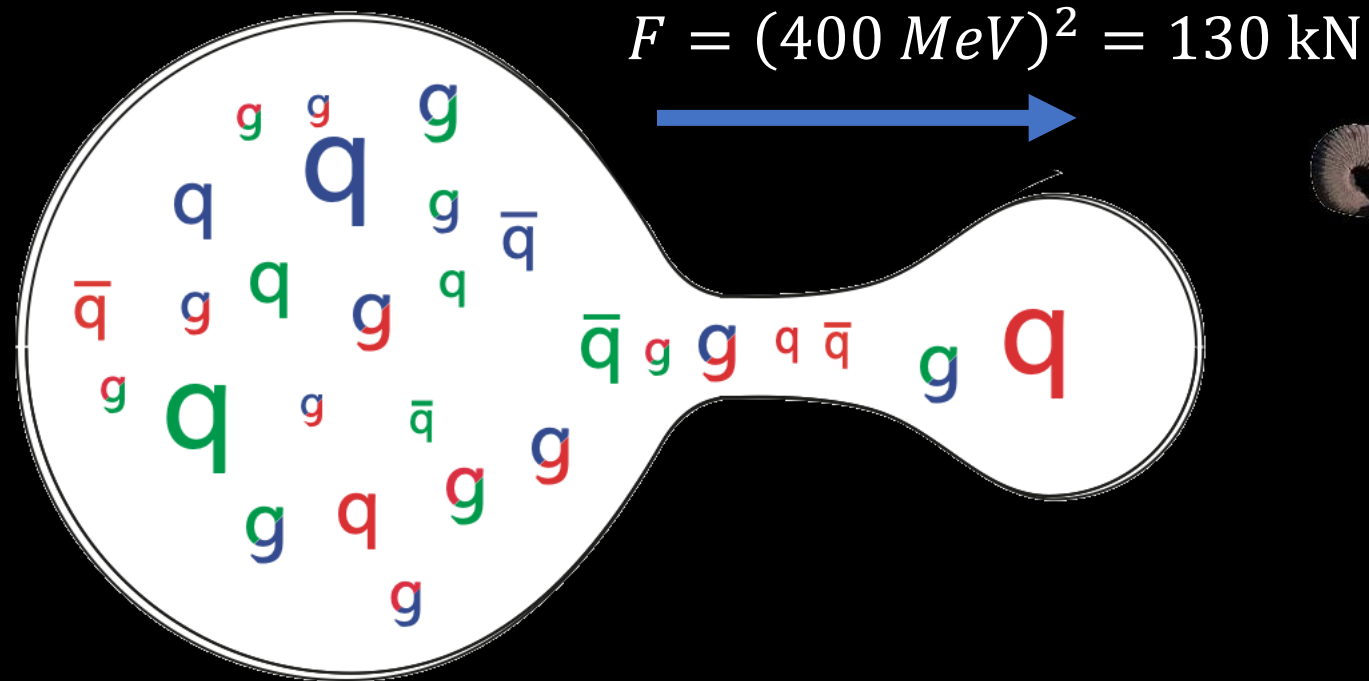
Quarks are confined into hadrons:



Quarks are confined into hadrons:

$$\begin{aligned} W &= F \cdot dx \\ &= 130 \text{ kN} \times 10^{-15} \text{ m} \\ &= 1.3 \cdot 10^{-10} \text{ J} \end{aligned}$$

$$\begin{aligned} m &= E/c^2 \\ &= 1.5 \cdot 10^{-27} \text{ kg} \\ &= \text{mass of a } \textit{pion} \end{aligned}$$

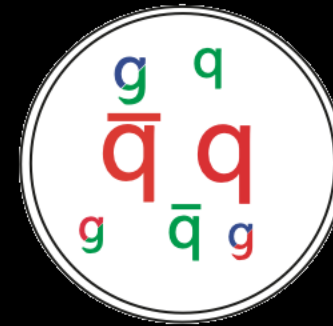
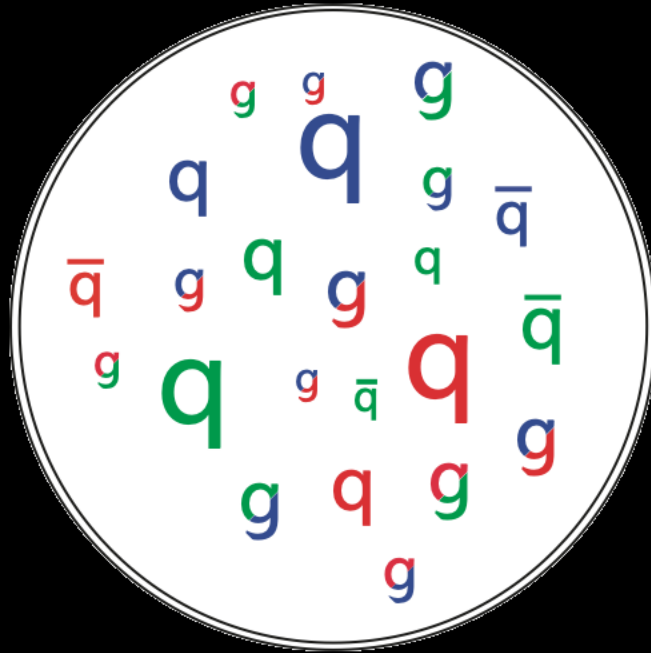


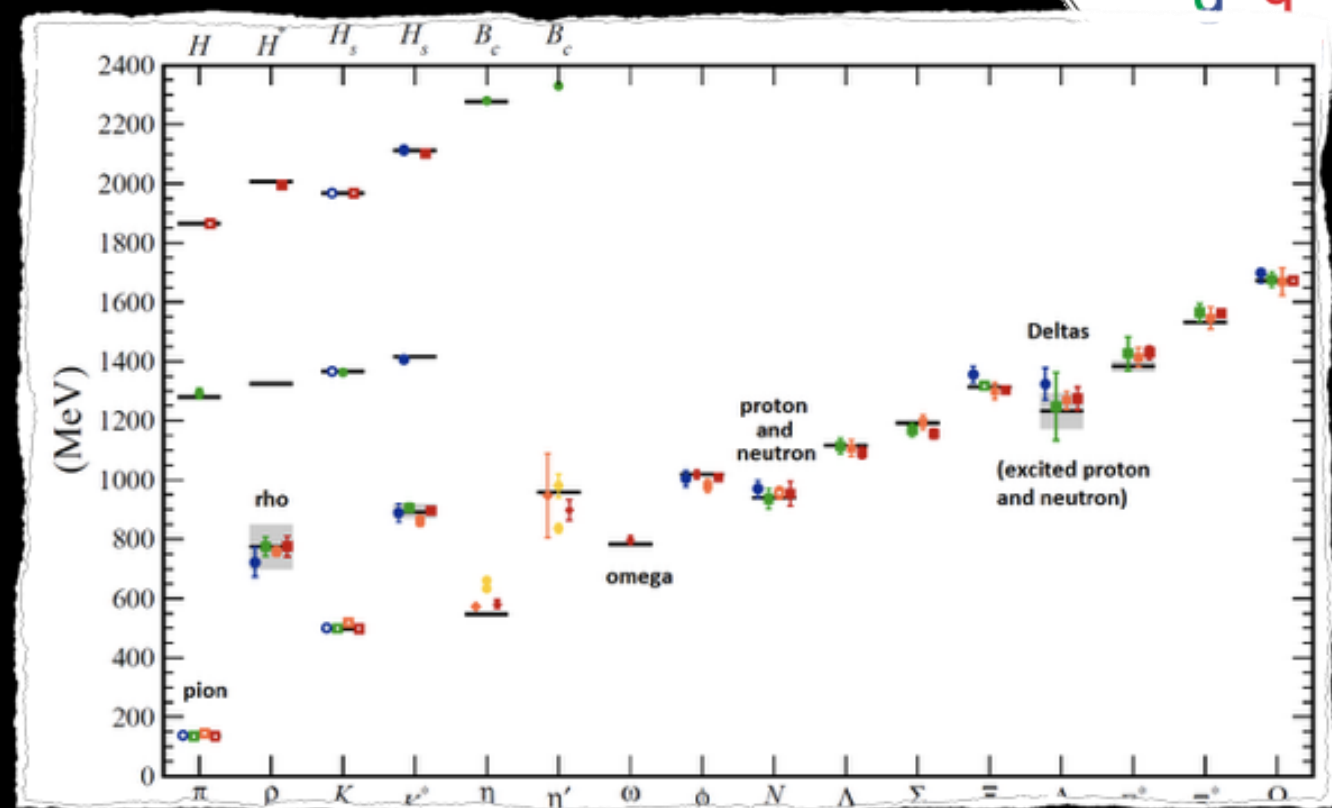
Quarks and gluons are confined into hadrons

Quarks are confined into hadrons:

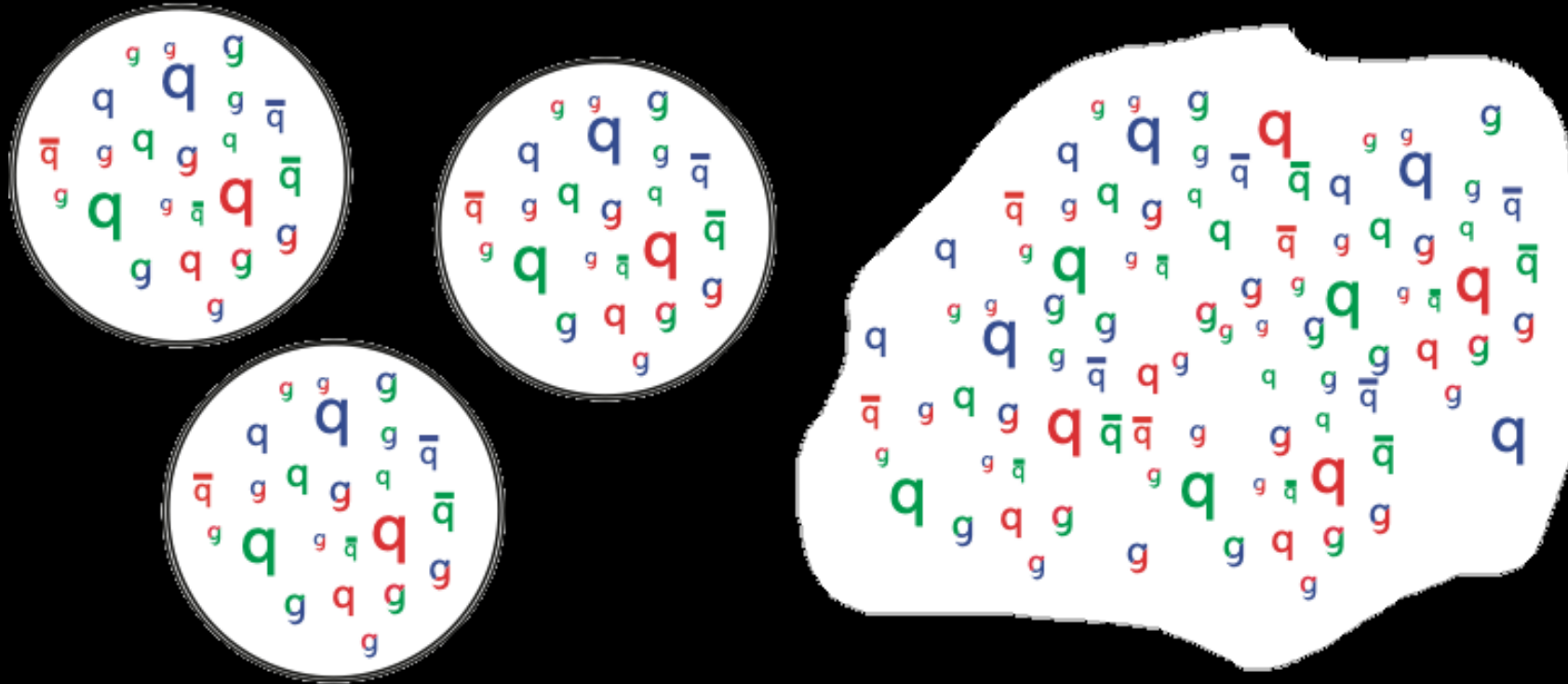
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Quark matter:



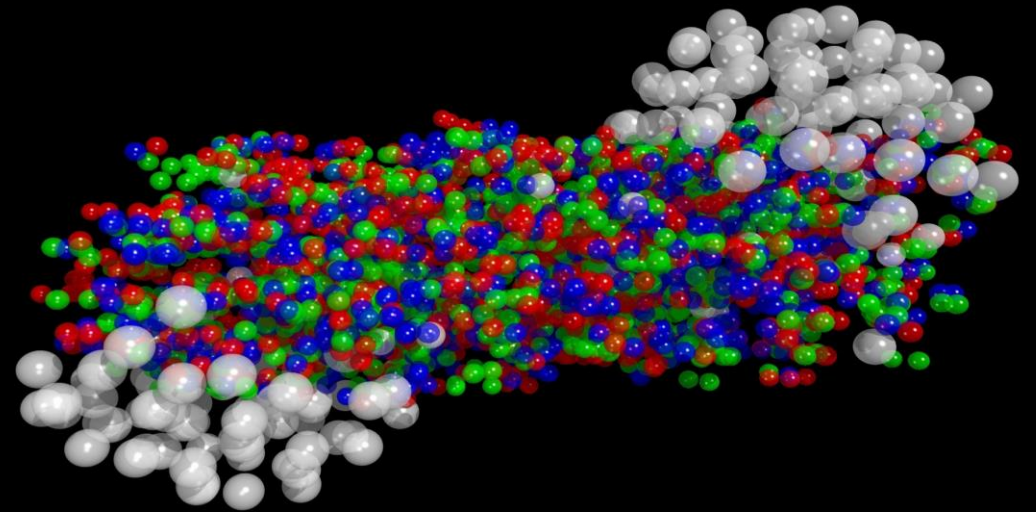
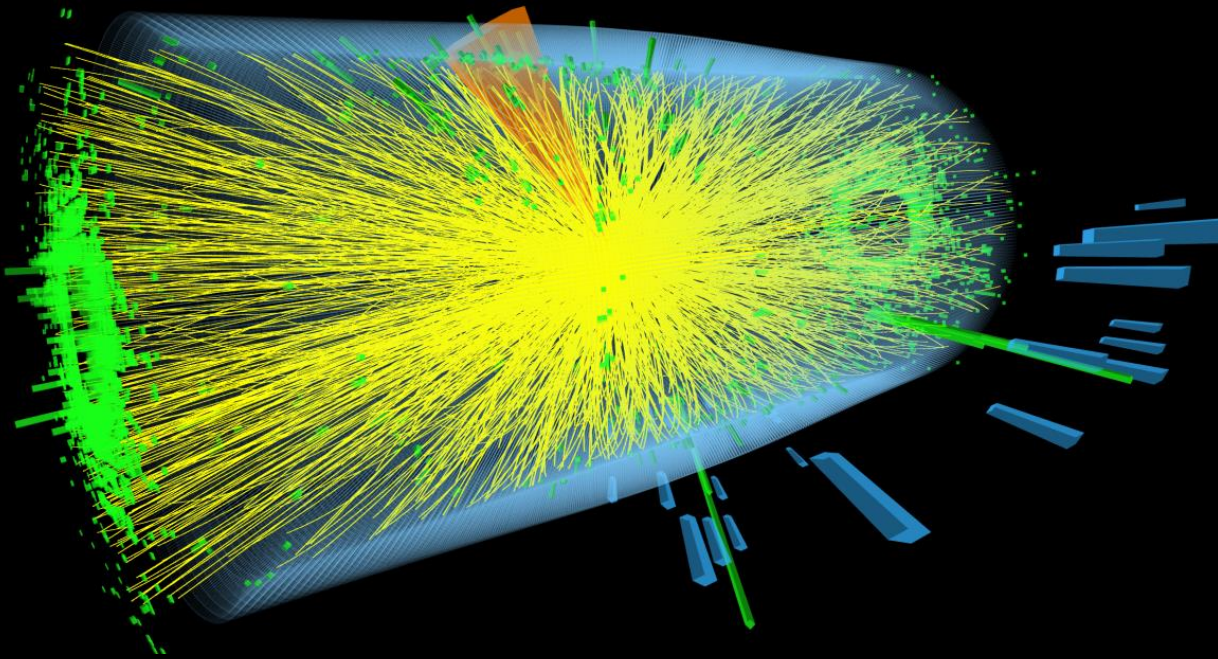
Heavy-ion collisions

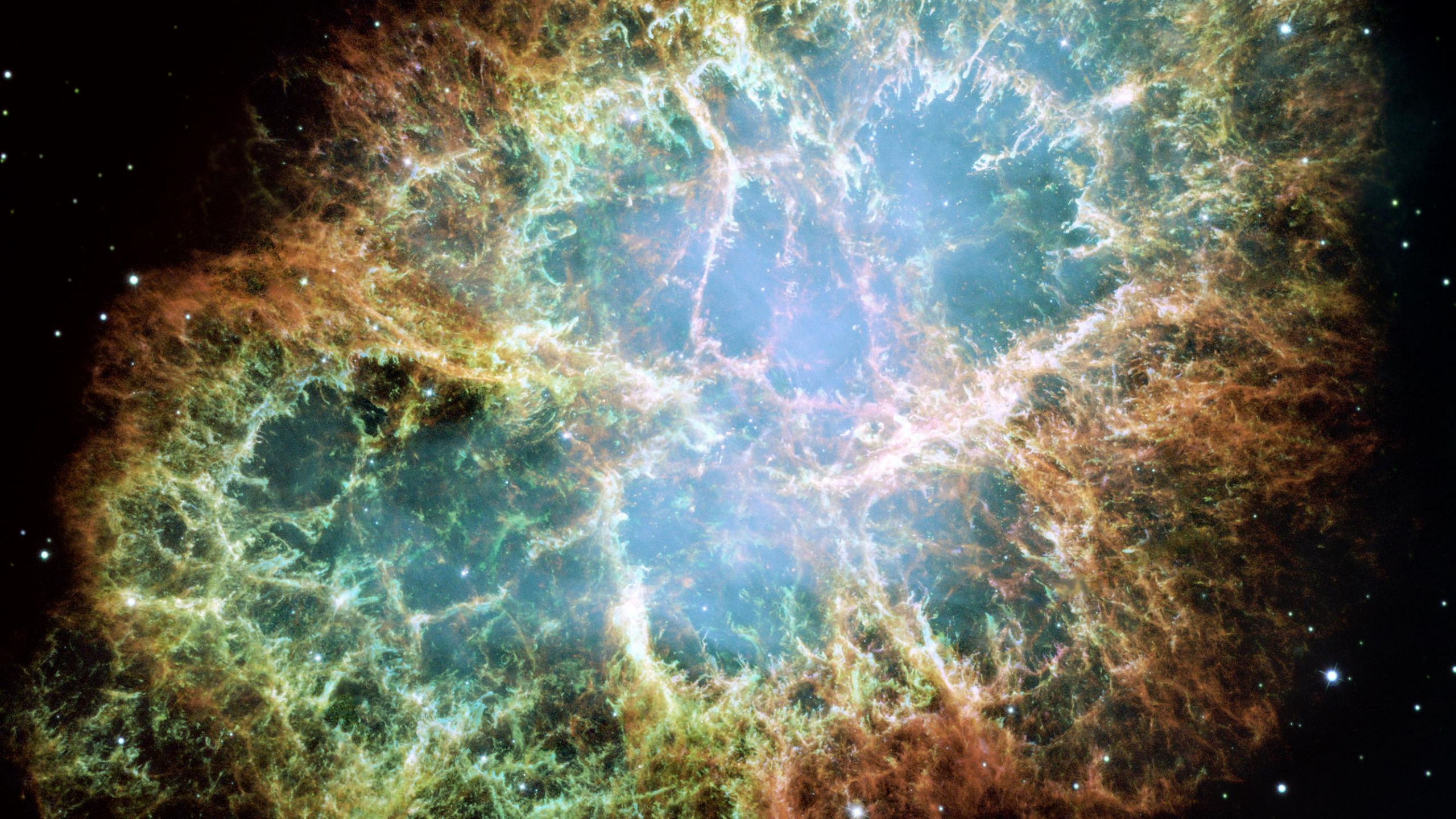


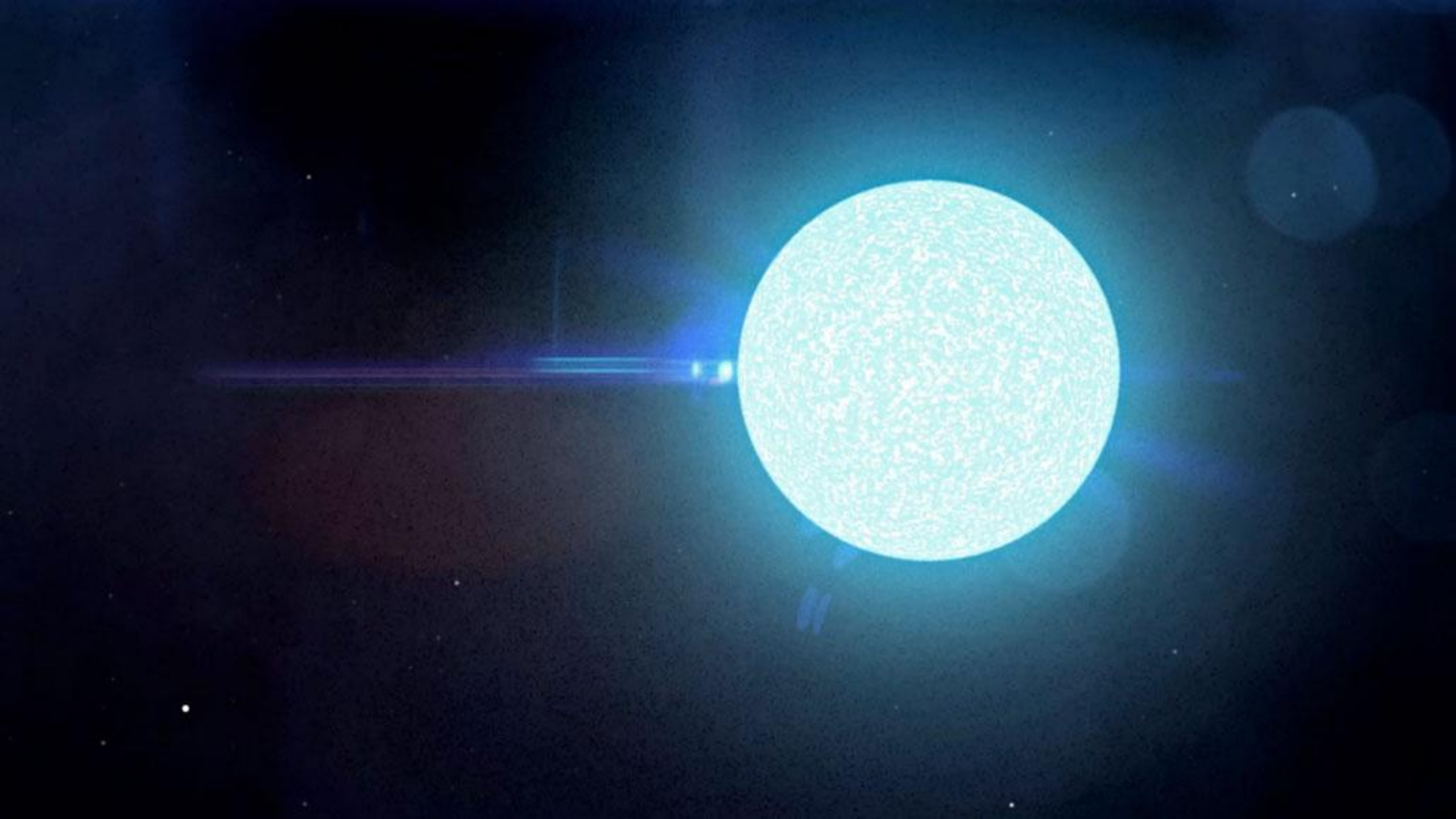
CMS Experiment at the LHC, CERN

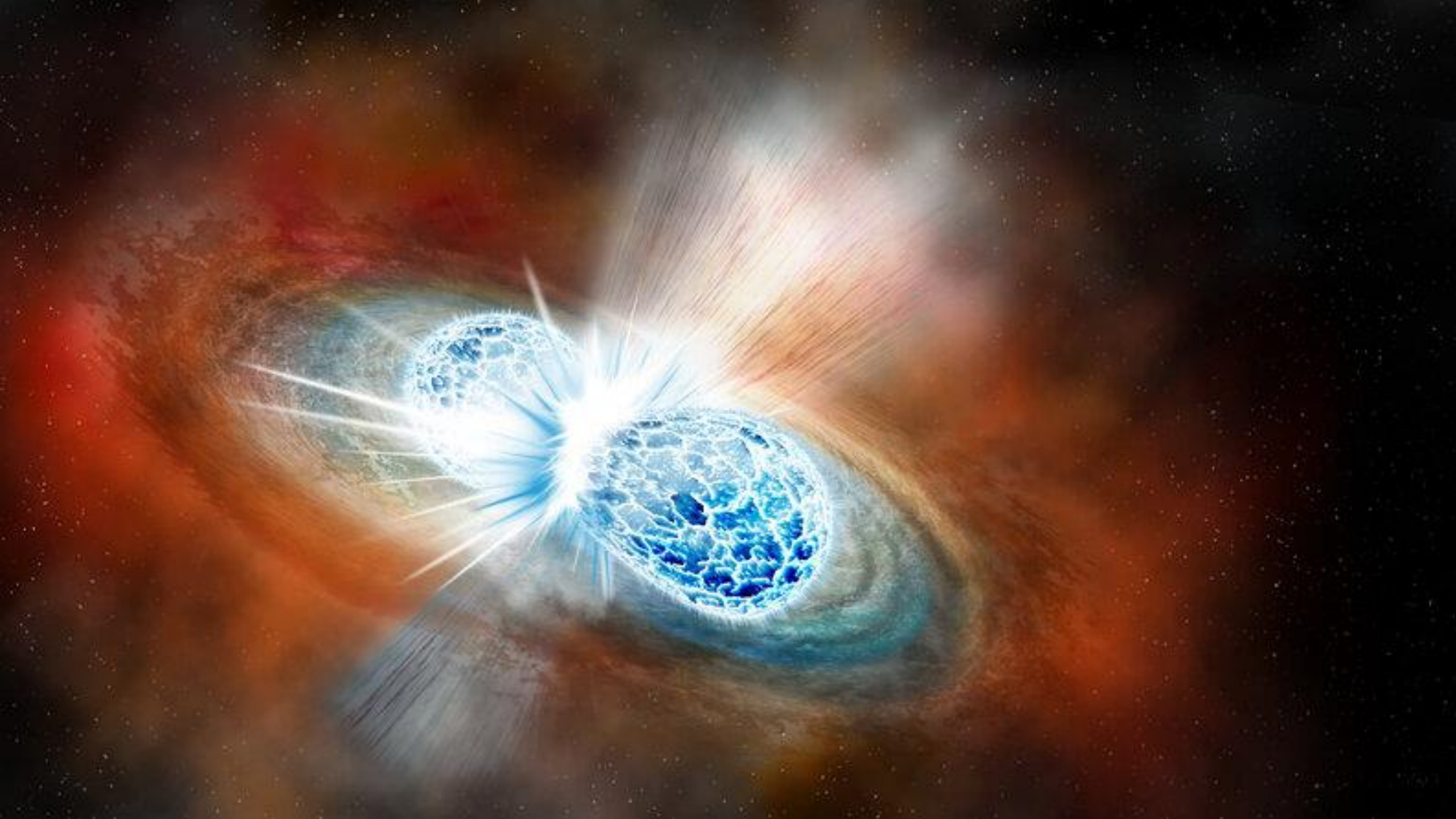
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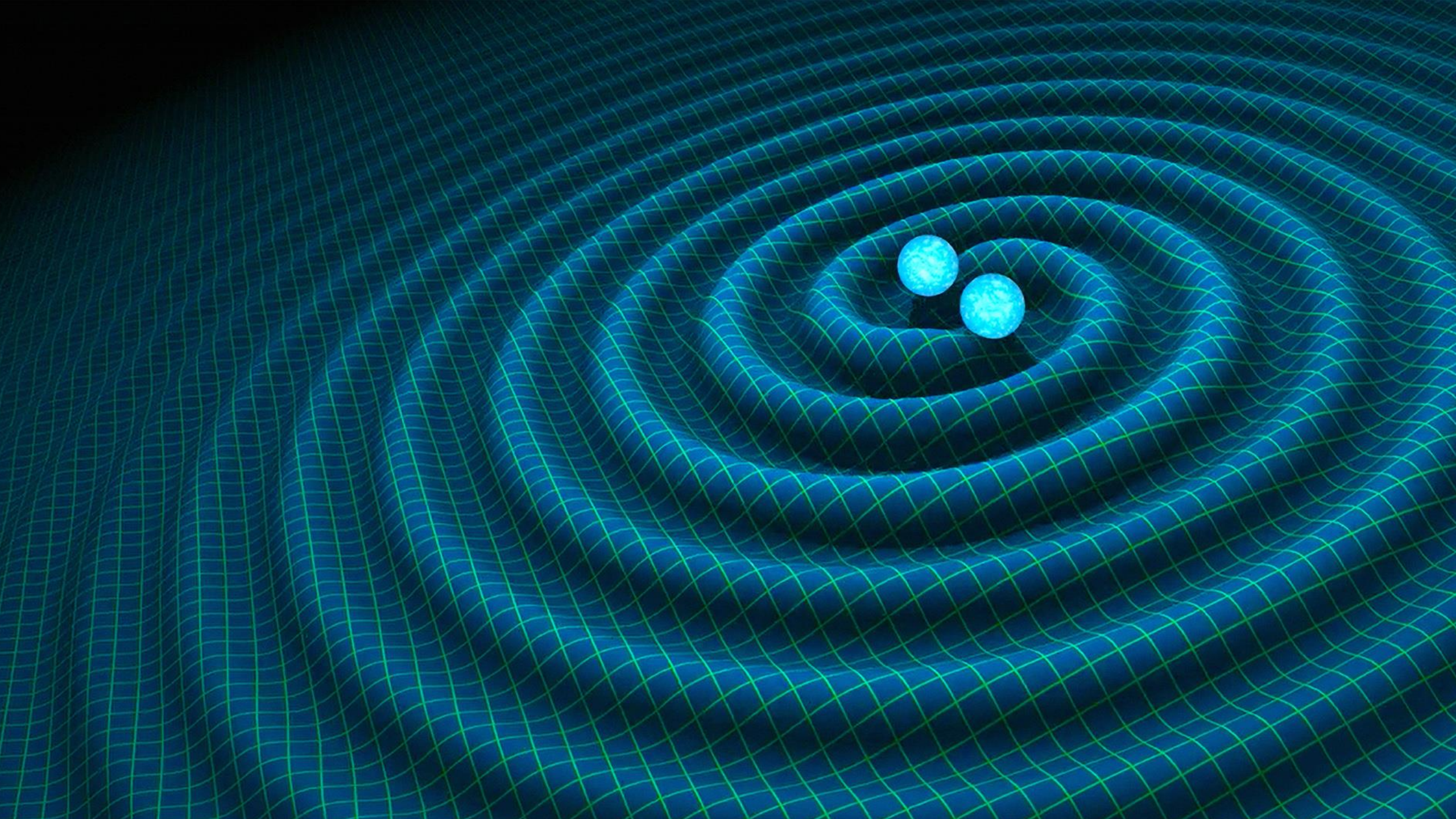
Run / Event / LS: 326586 / 2491137 / 6















Quark
Matter !

Evidence for quark-matter cores in massive neutron stars

Nature Physics **16**, 907–910 (2020)

**SKY
& TELESCOPE**

THE ESSENTIAL GUIDE TO ASTRONOMY

Interactive Sky Chart

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stars

κ -matter cores in massive neutron

Nature Physics 16, 907–910 (2020)

N-PACT 2023

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