



THE SMALLEST PIECES OF OUR UNIVERSE

SOURABH DUBE



25th September, 2016

SCIENCE =

REGULAR PERSON ASKS “WHY?”

ANSWER: “BLAH BLAH BLAH”

RP: “OH GREAT!”

SCIENCE =

REGULAR PERSON ASKS "WHY?"

ANSWER: "BLAH BLAH BLAH"

RP: "OH GREAT!"

SCIENCE LOVER : "WHY?"

ANSWER: "BLAH BLAH BLAH"

SL: "OH GREAT! AND HOW?"

WHAT ARE THE SMALLEST PIECES?

Take a piece of chalk.

Break it in pieces.

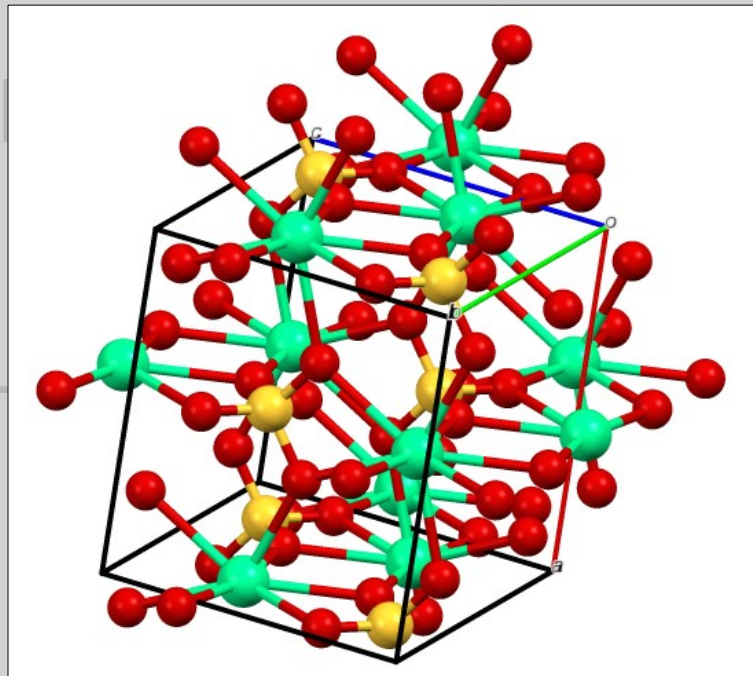
Take smallest piece.



WHAT ARE THE SMALLEST PIECES?

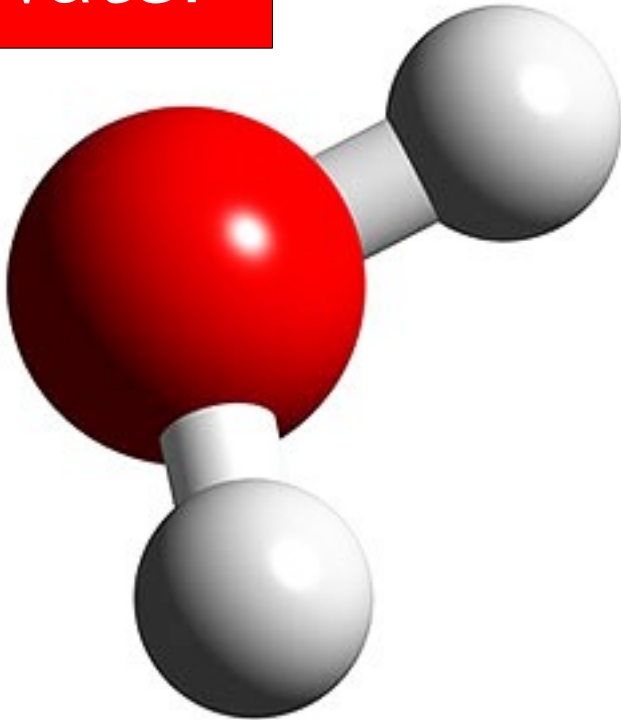
Take a piece of chalk.

Gypsum.

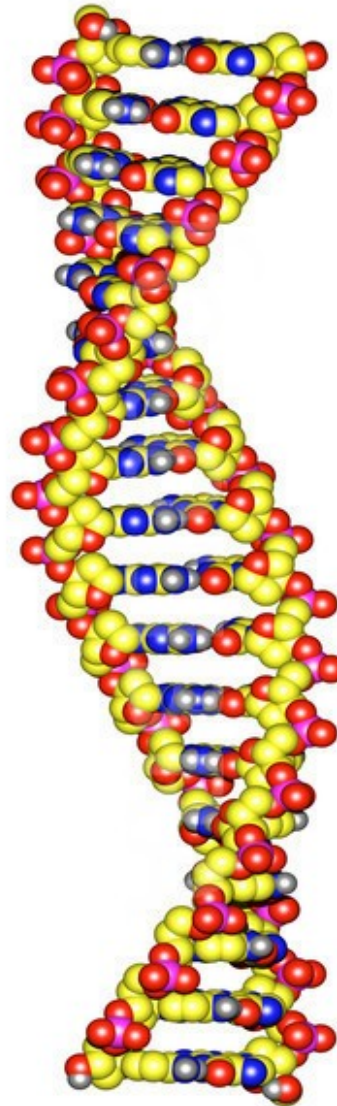


MOLECULES MAKE UP EVERYTHING (?)

Water



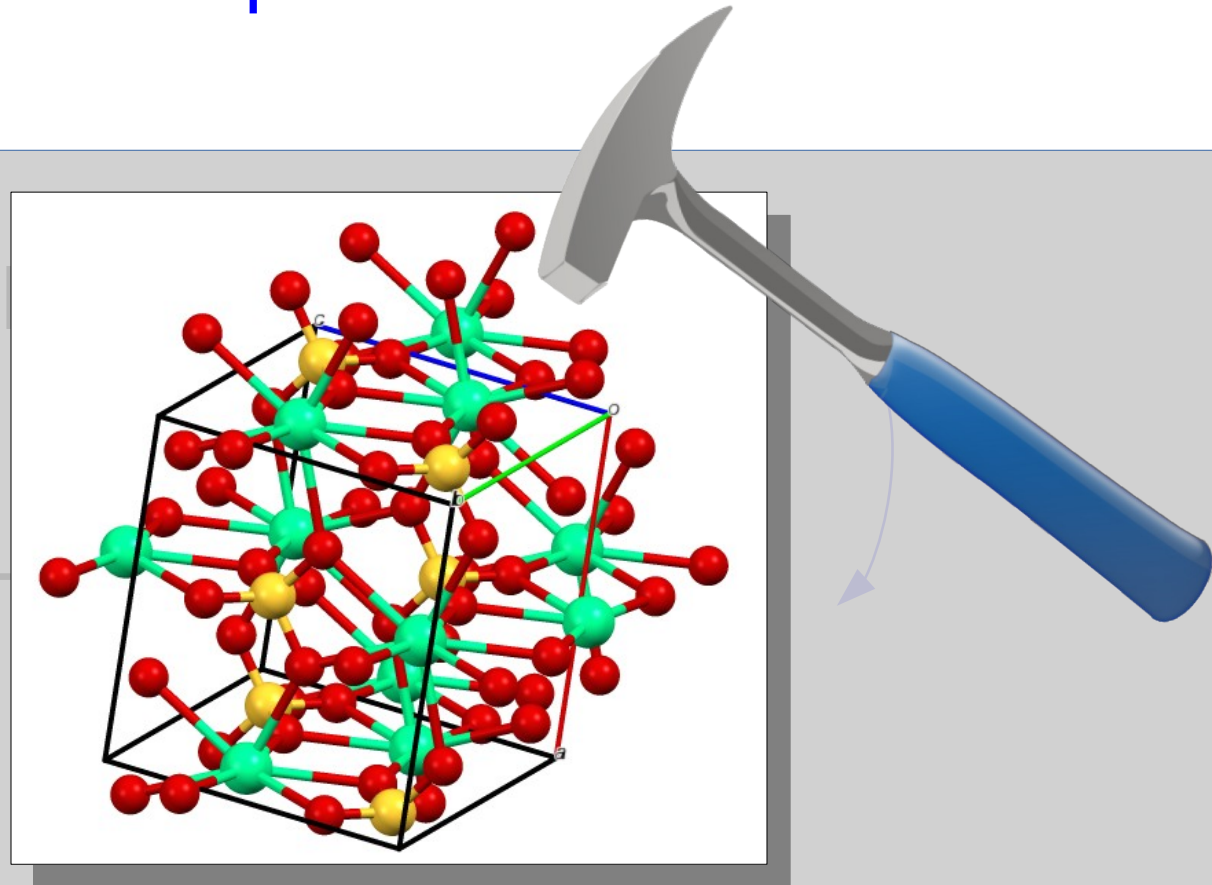
DNA



WHAT ARE THE SMALLEST PIECES?

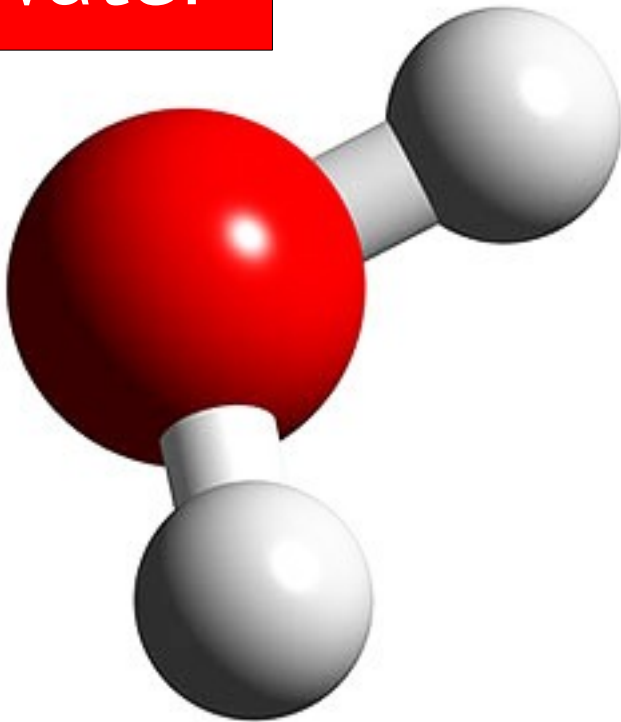
Take a piece of chalk.

Gypsum.
Calcium
Sulphur
Oxygen
Hydrogen

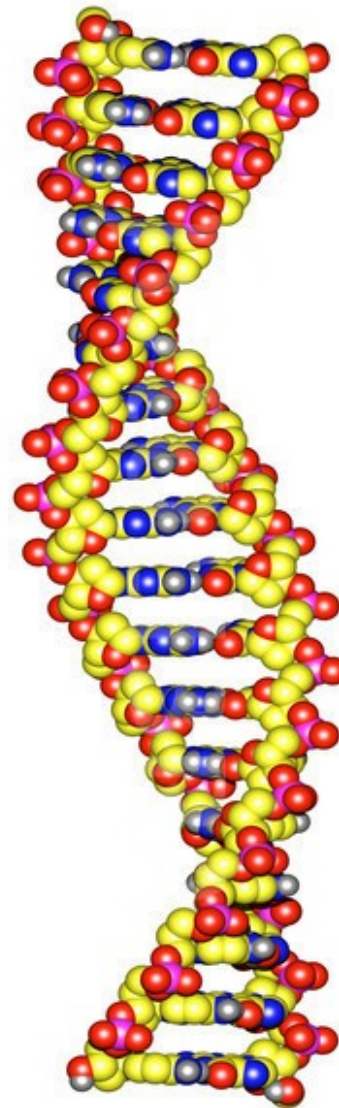


MOLECULES BROKEN INTO ATOMS

Water



Oxygen



DNA

C
H
O
N
P

INDISTINGUISHABILITY OF ATOMS

Each atom of oxygen is *exactly identical* to every other atom of oxygen.

Thus one water molecule is exactly the same as any other water molecule.

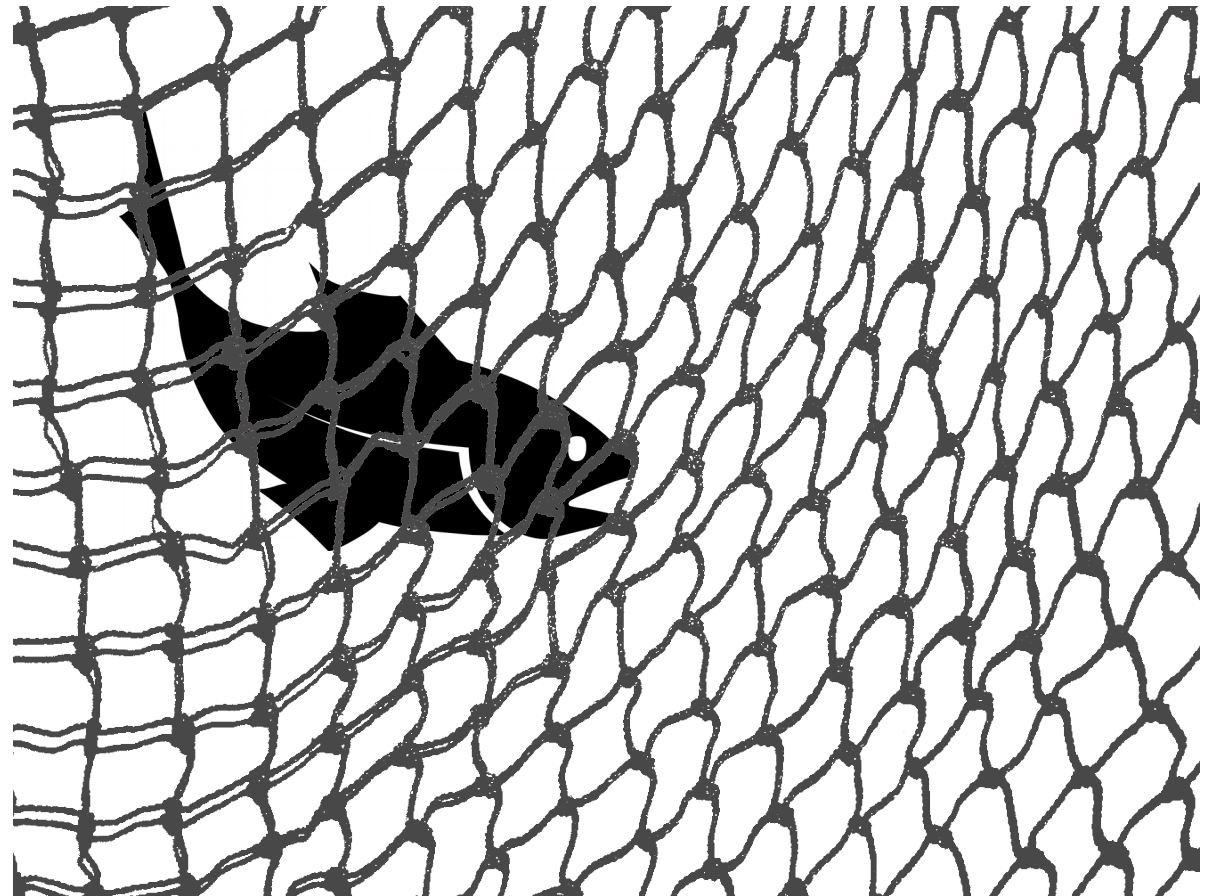
TOO SMALL TO SEE...

But what if object is smaller than wavelength of light?



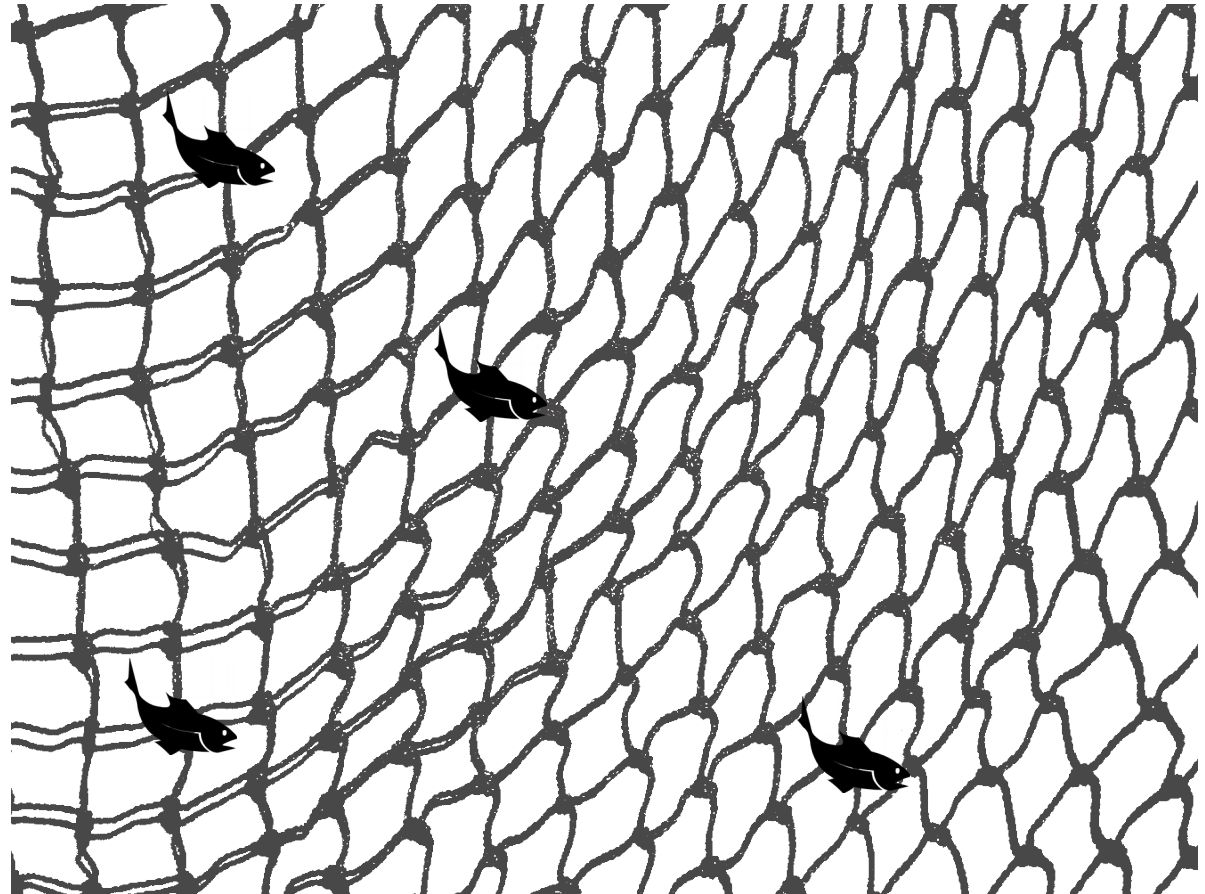
TOO SMALL TO SEE...

Objects larger than wavelength
can be seen

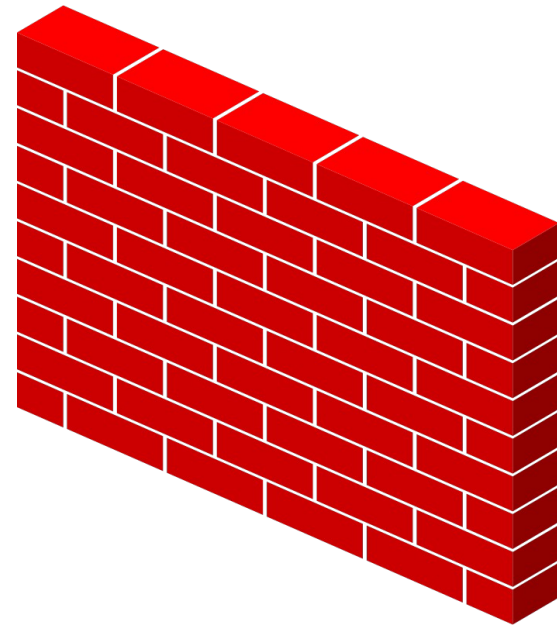


TOO SMALL TO SEE...

Objects smaller than wavelength need to be “seen”



TOO SMALL TO SEE...

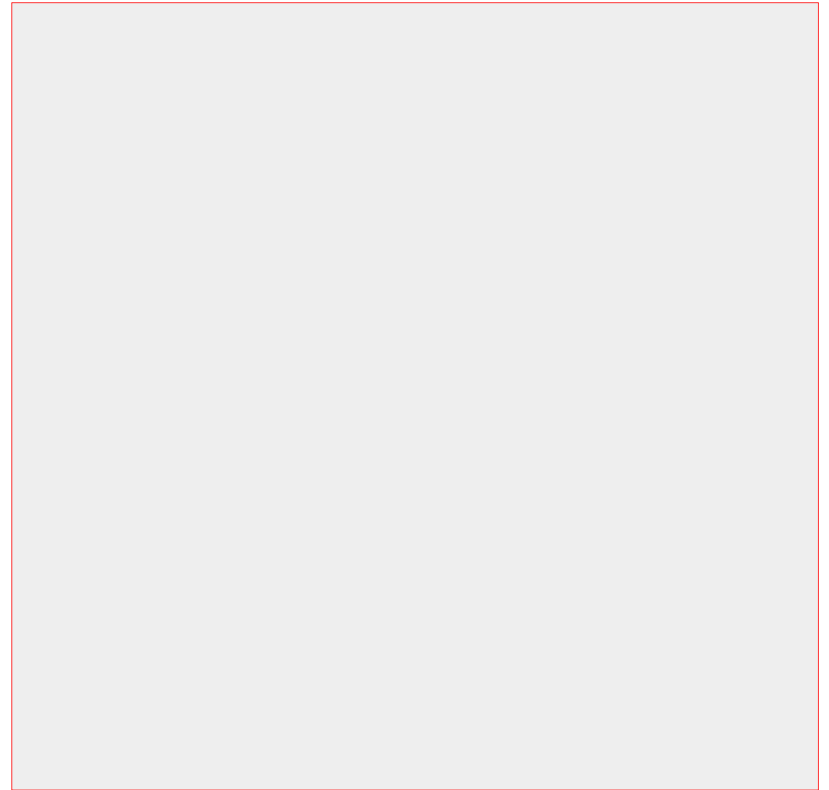


TOO SMALL TO SEE...

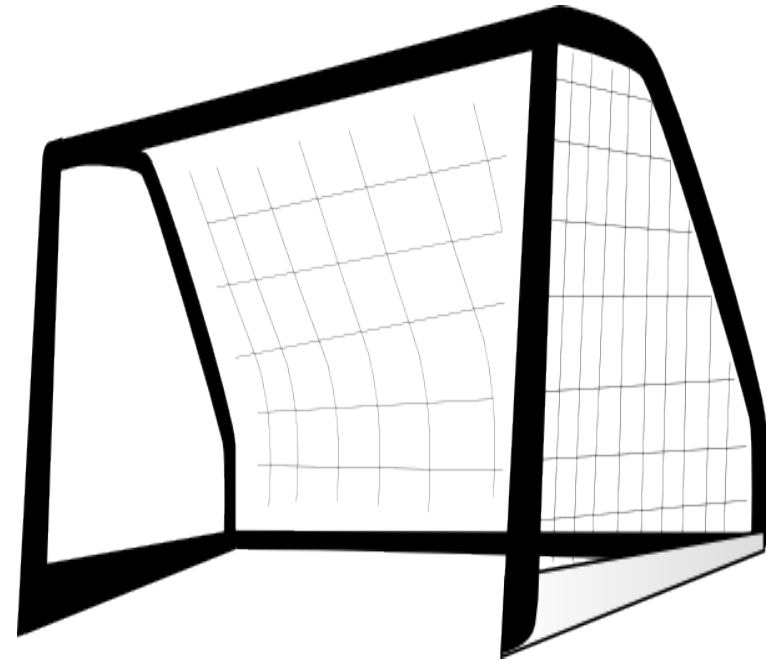


What if the wall
is invisible?

TOO SMALL TO SEE...

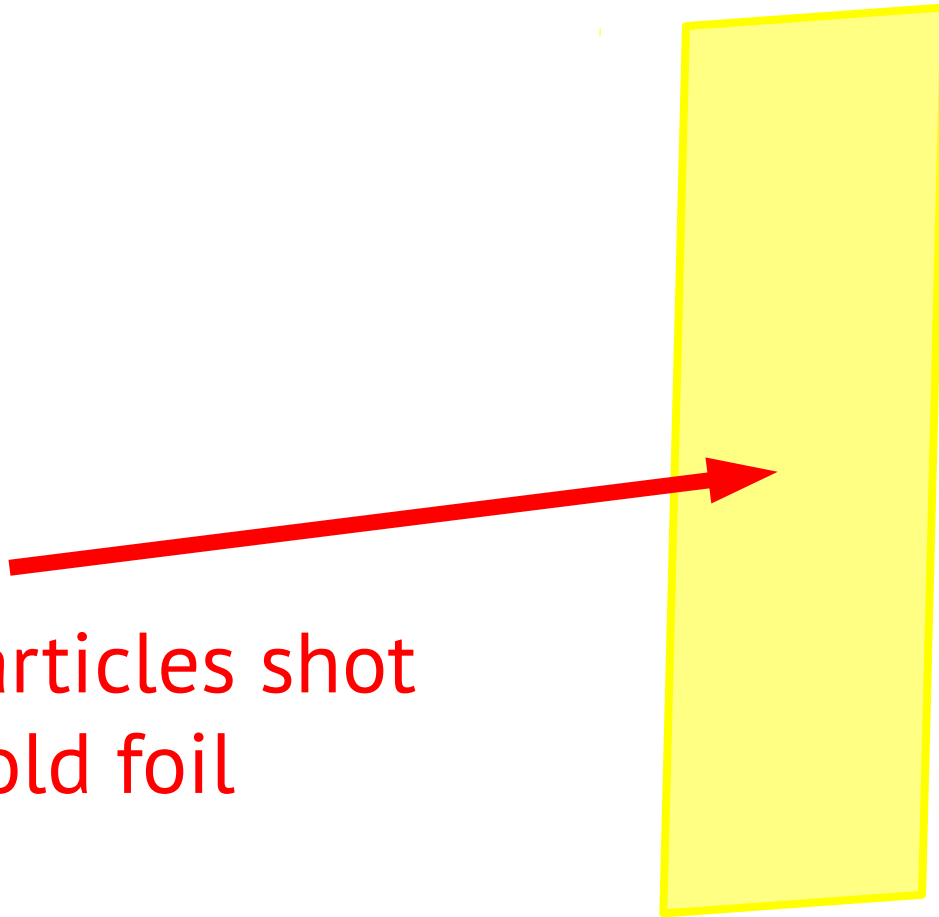


TOO SMALL TO SEE...



RUTHERFORD'S GOLD FOIL EXPERIMENT

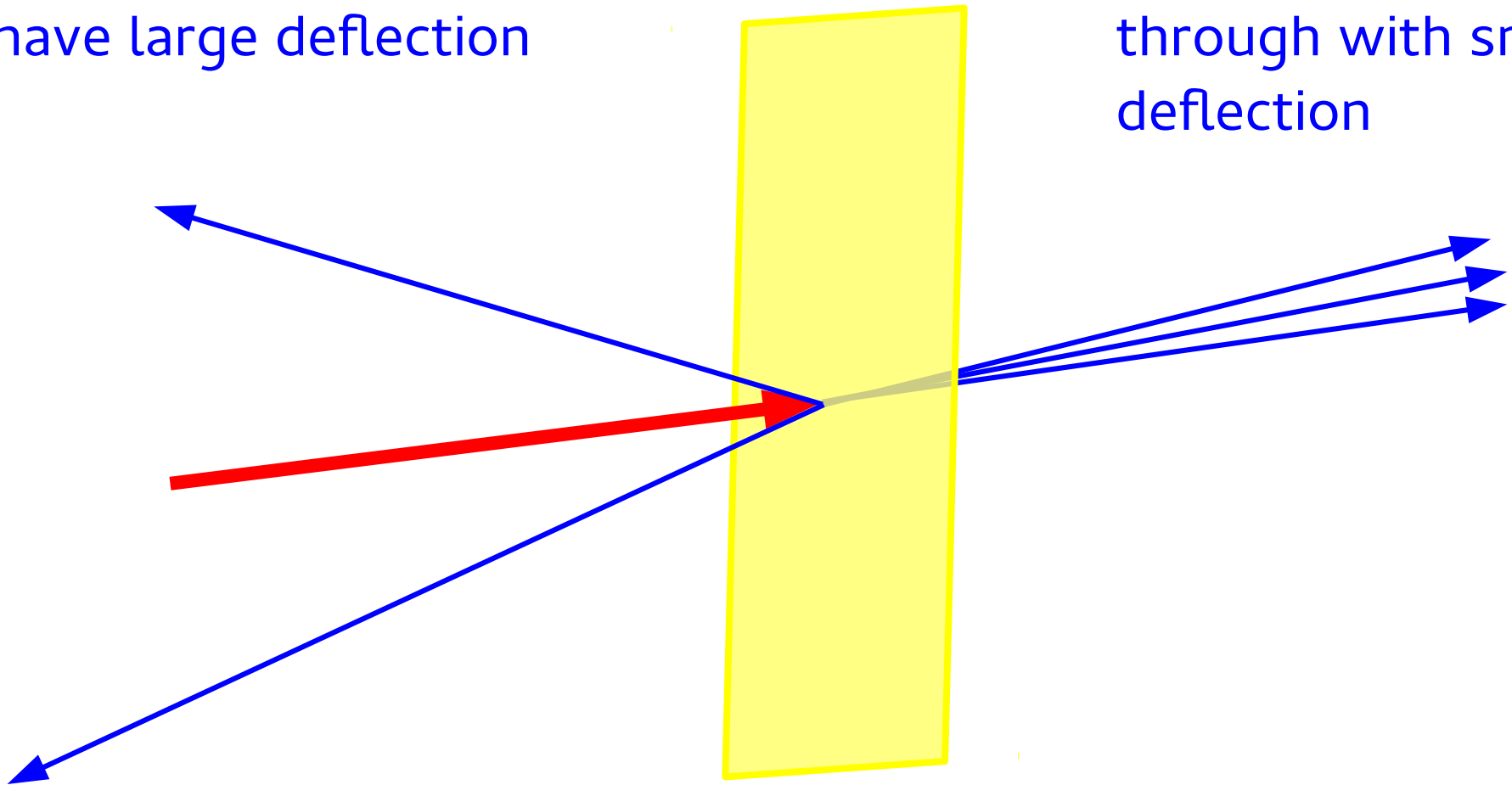
α -Particles shot
at gold foil



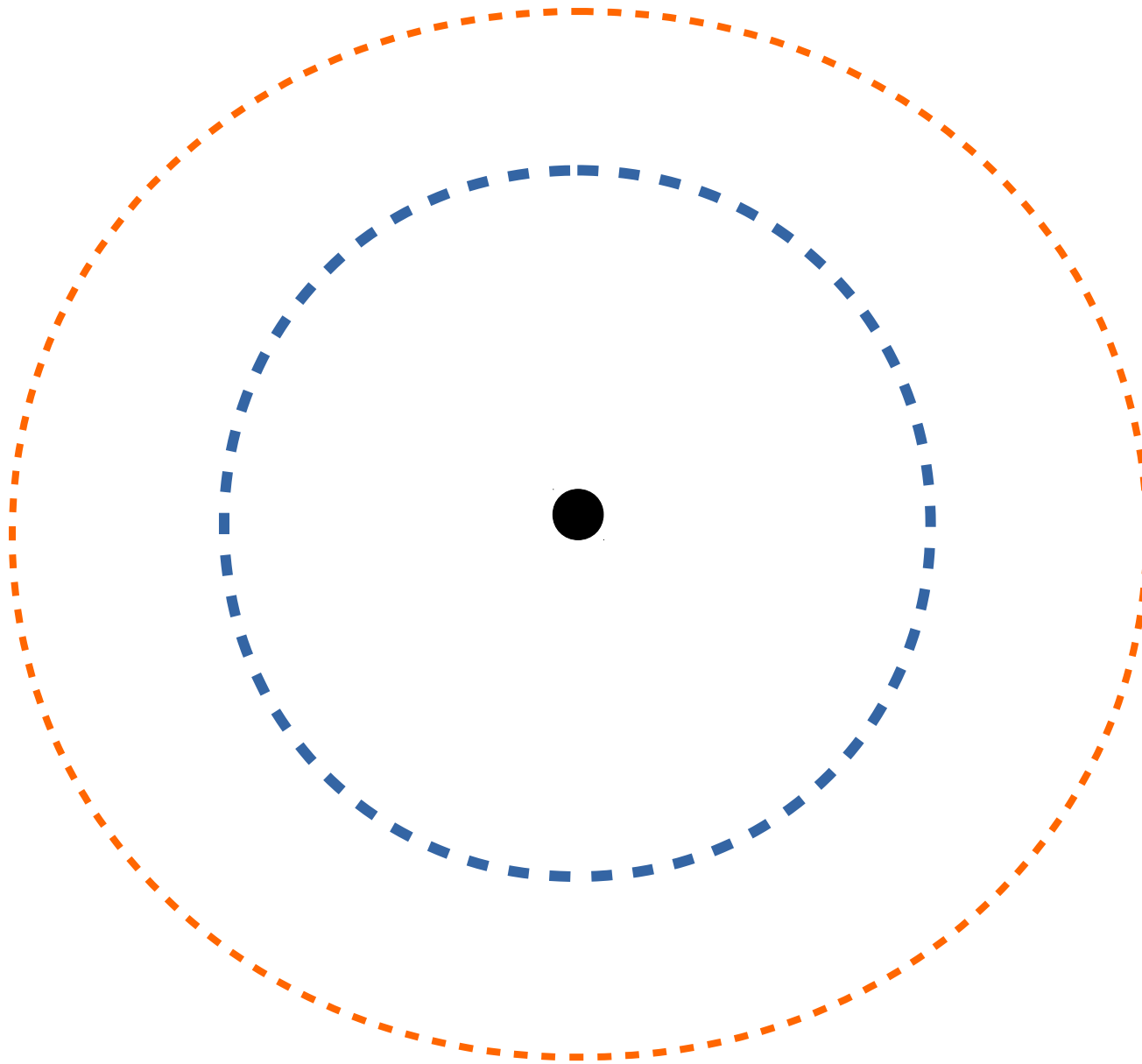
RUTHERFORD'S GOLD FOIL EXPERIMENT

Some α -Particles
have large deflection

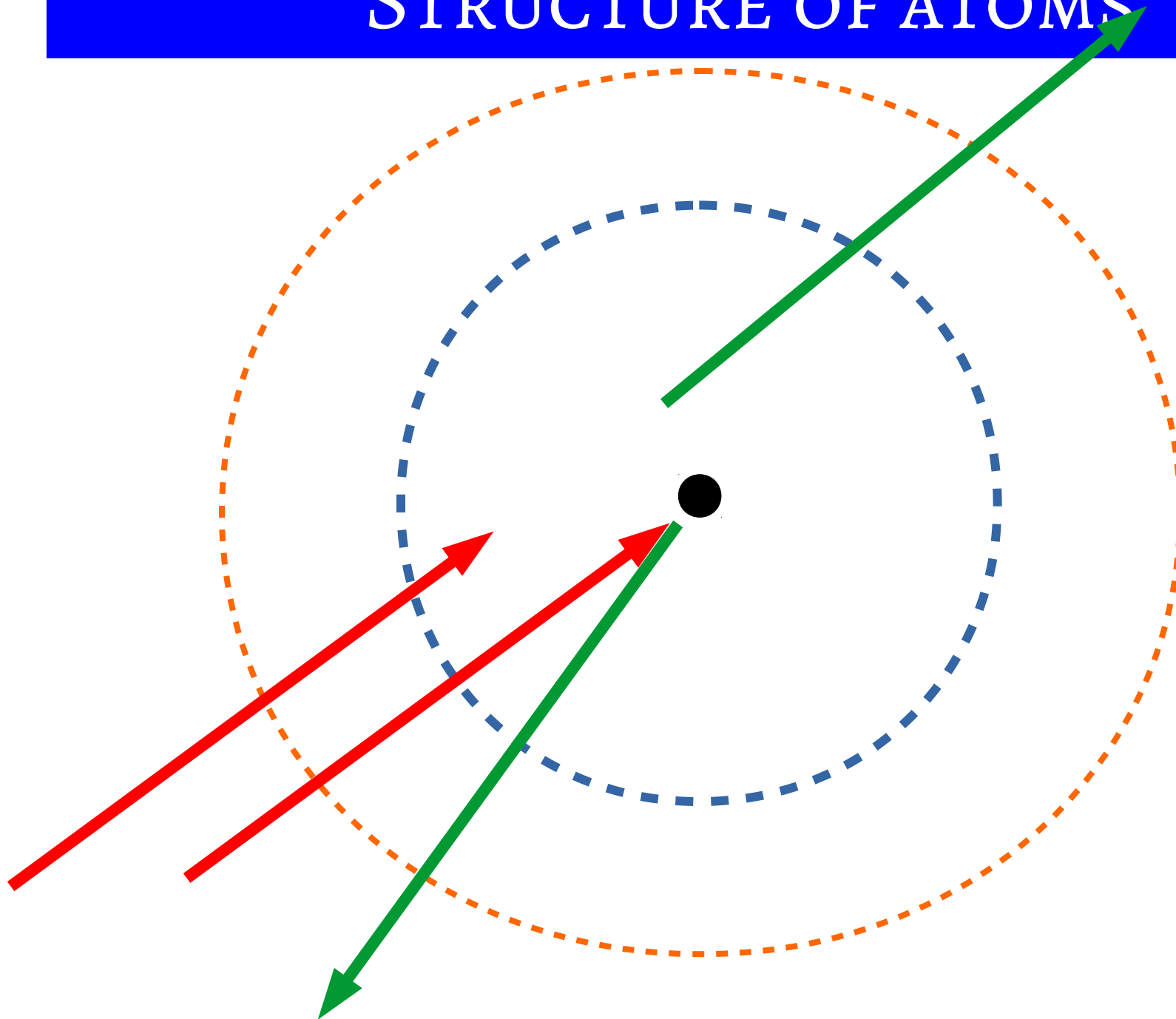
Most α -Particles go
through with small
deflection



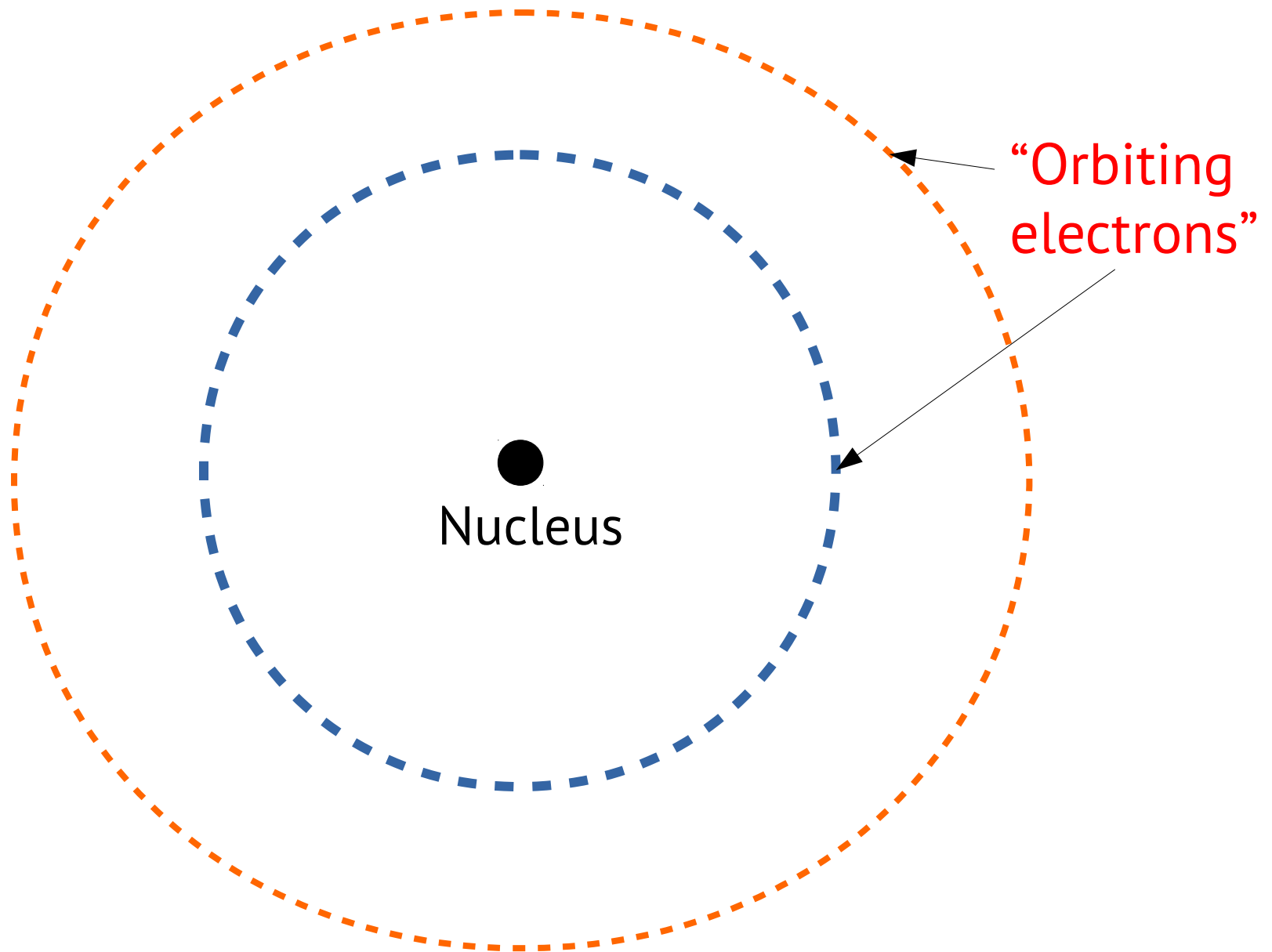
STRUCTURE OF ATOMS



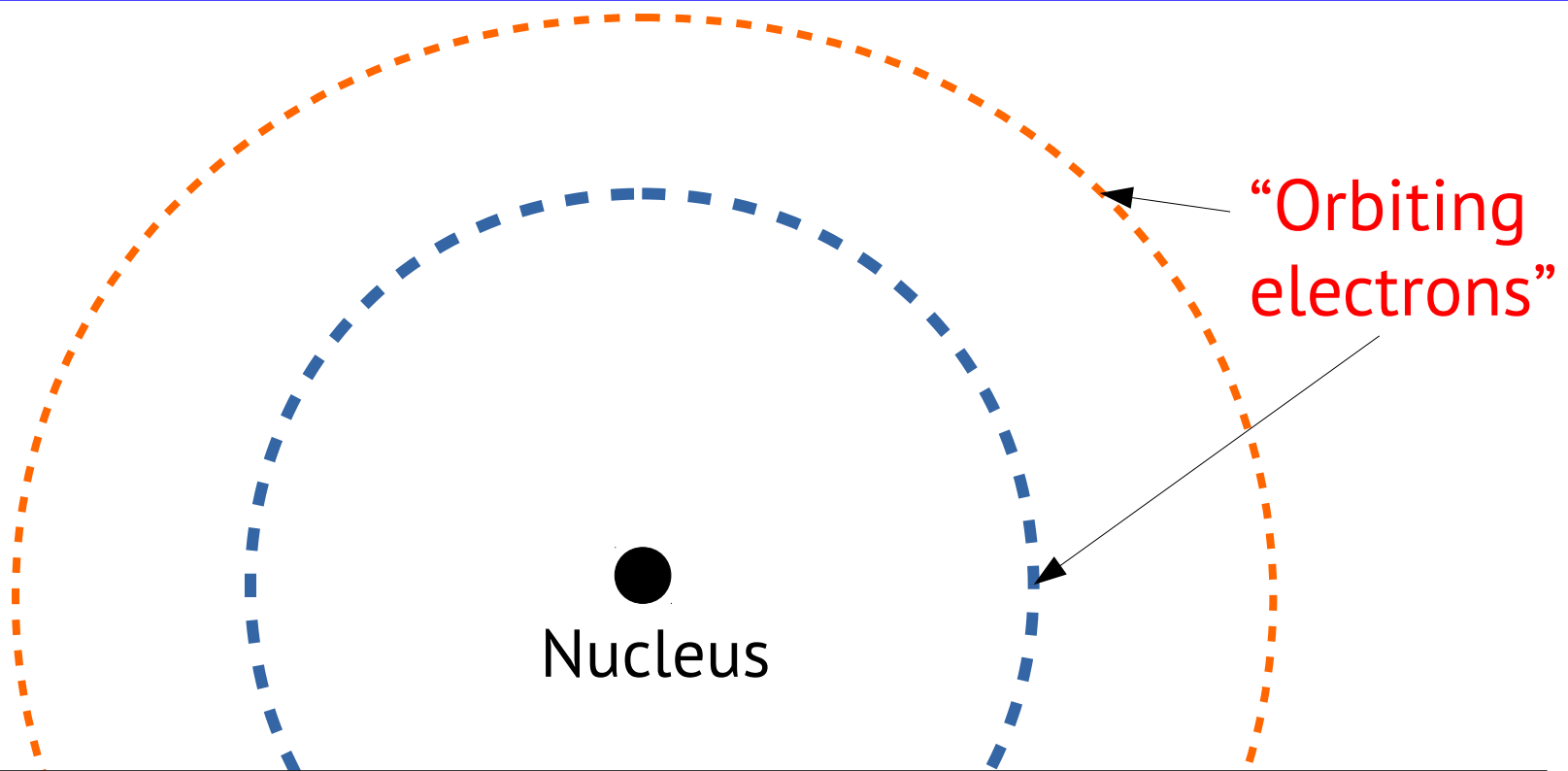
STRUCTURE OF ATOMS



STRUCTURE OF ATOMS

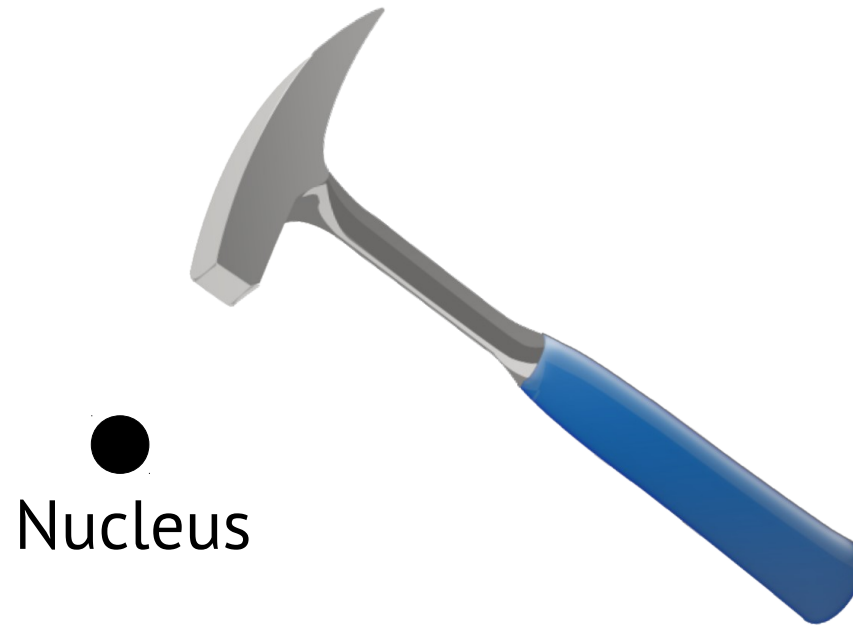


STRUCTURE OF ATOMS



ATOMS ARE MOSTLY EMPTY. IF A NUCLEUS WERE AS BIG AS A PERSON, THEN CLOSEST ELECTRON IS ROUGHLY 100 KMS AWAY.

NEXT STEP?



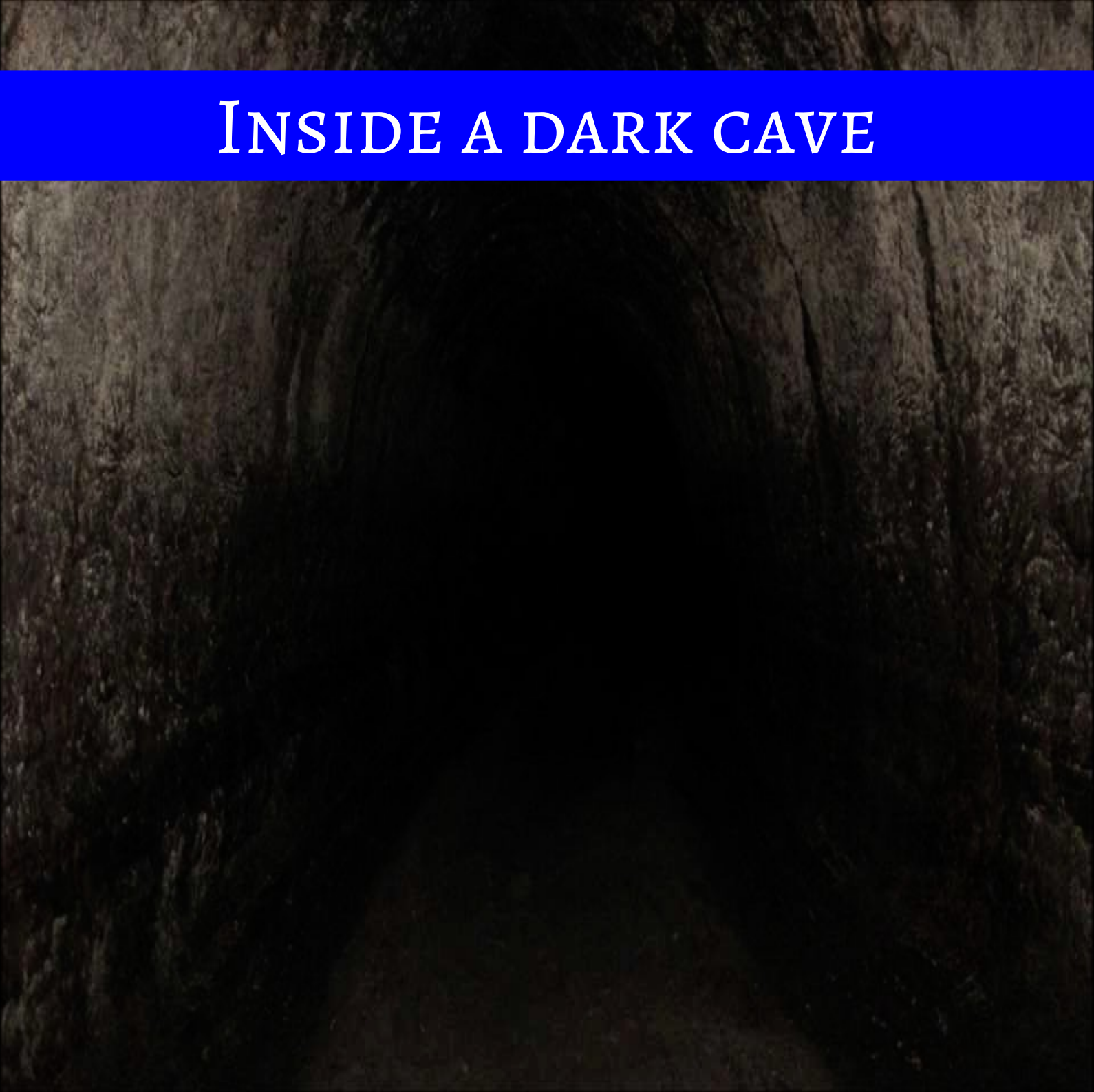
NEED FOR 'HIGH' ENERGY

A nucleus is very small.

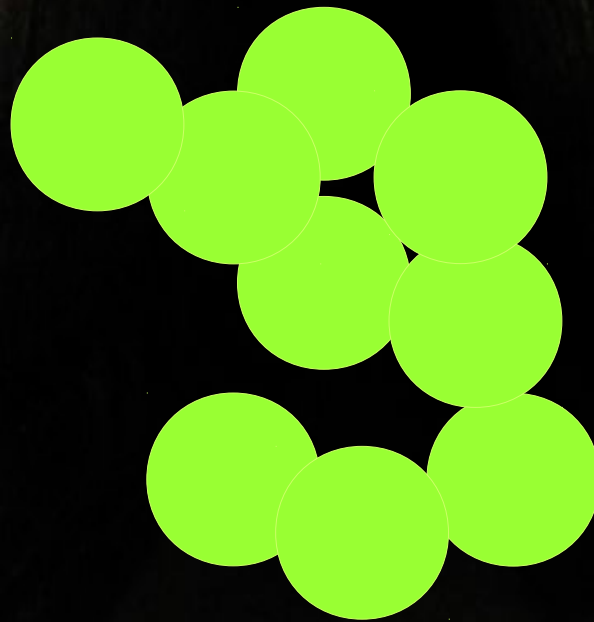
To be able to 'look' inside it, we need a small object of high energy.

Let me explain with an example.

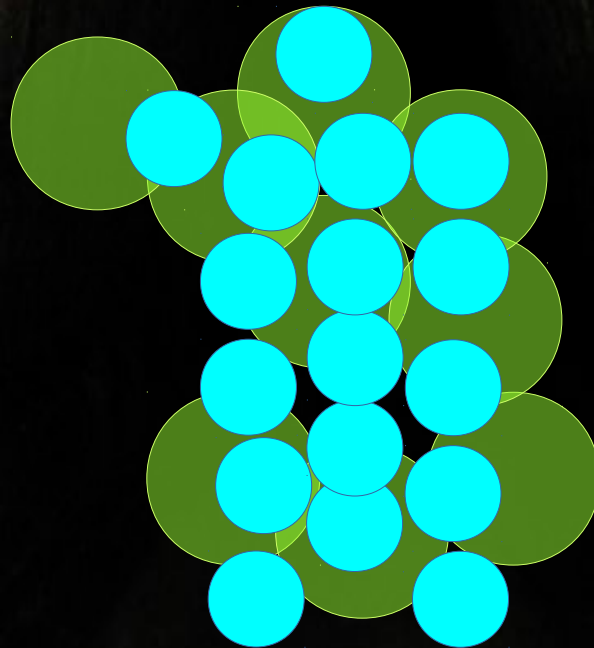
INSIDE A DARK CAVE



INSIDE A DARK CAVE



INSIDE A DARK CAVE



INSIDE A DARK CAVE



SIZE AND ENERGY

Size we can look at, is inversely proportional to momentum

If

Length

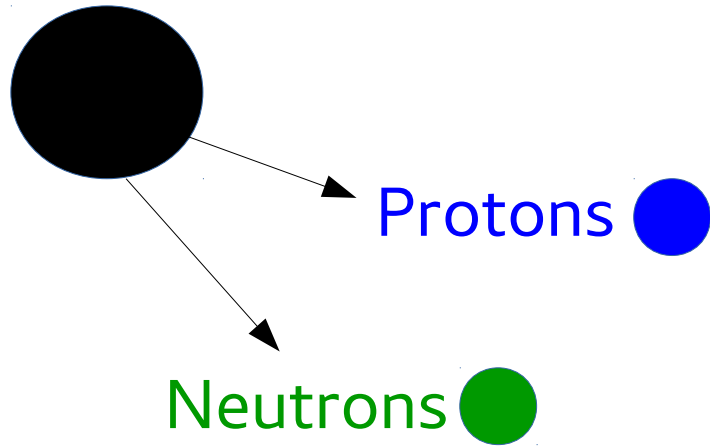


Then

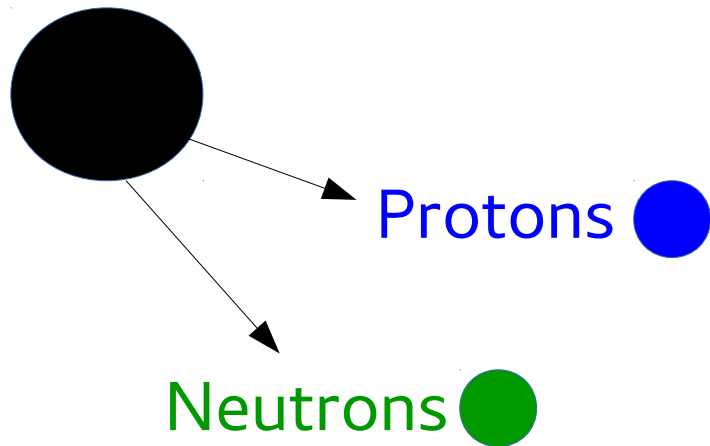
Energy



SO WHAT'S IN A NUCLEUS?

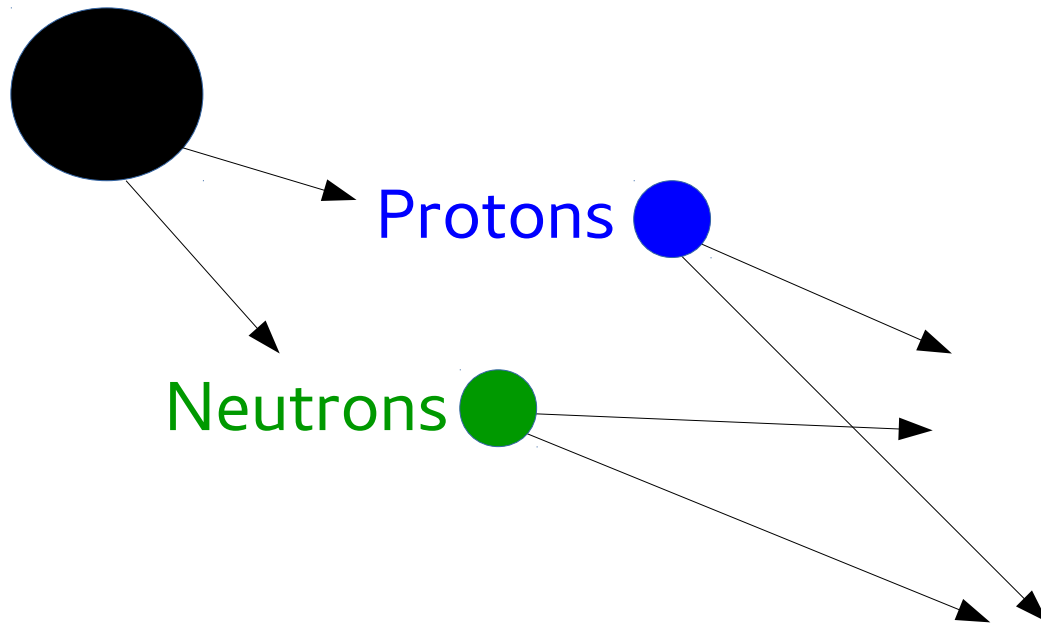


SO WHAT'S IN A NUCLEUS?



Deep Inelastic Scattering experiments with electrons

SO WHAT'S IN A PROTON/NEUTRON?



QUARKS

Up quark

Down quark

Proton = uud

Neutron = udd

THE SMALLEST PIECES OF OUR UNIVERSE

Electron

Up quark

Down quark

THE SMALLEST PIECES OF OUR UNIVERSE

Electron

Up quark

Down quark

AHEM!



THE SMALLEST PIECES OF OUR UNIVERSE

Electron

Up quark

Neutrino

Down quark

PERIODIC TABLE OF ELEMENTS

Periodic Table of the Elements

1 IA 1A												18 VIII 8A					
1 H Hydrogen 1.008	2 He Helium 4.003											13 B Boron 10.811	14 C Carbon 12.011	15 N Nitrogen 14.007	16 O Oxygen 15.999	17 F Fluorine 18.998	18 Ne Neon 20.180
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 Al Aluminum 26.982	6 Si Silicon 28.086	7 P Phosphorus 30.974	8 S Sulfur 32.066	9 Cl Chlorine 35.453	10 Ar Argon 39.948
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 III B 3B	4 IV B 4B	5 V B 5B	6 VI B 6B	7 VII B 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Ga Gallium 69.732	14 Ge Germanium 72.61	15 As Arsenic 74.922	16 Se Selenium 78.972	17 Br Bromine 79.904	18 Kr Krypton 84.80
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 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	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 [208.982]	85 At Astatine 209.987	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 [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

Normal melting points are in °C.
TP = Triple Point
Pressure is listed if not 1 atm.
Allotrope is listed if more than one allotrope.

Atomic Number	Melting Point
Symbol	
Name	
Atomic Mass	

Lanthanide Series

57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
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Actinide Series

89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]
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- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Semimetal
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

STANDARD MODEL OF PARTICLE PHYSICS

Three generations
of matter (fermions)

	I	II	III	
mass →	2.4 MeV/c ²	1.27 GeV/c ²	171.2 GeV/c ²	0
charge →	2/3	2/3	2/3	0
spin →	1/2	1/2	1/2	1
name →	u up	c charm	t top	γ photon
	4.8 MeV/c ²	104 MeV/c ²	4.2 GeV/c ²	0
	-1/3	-1/3	-1/3	0
	1/2	1/2	1/2	1
Quarks	d down	s strange	b bottom	g gluon
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	91.2 GeV/c ²
	0	0	0	0
	1/2	1/2	1/2	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ Z boson
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	±1
	1/2	1/2	1/2	1
Leptons	e electron	μ muon	τ tau	W[±] W boson

125 GeV/c²

0

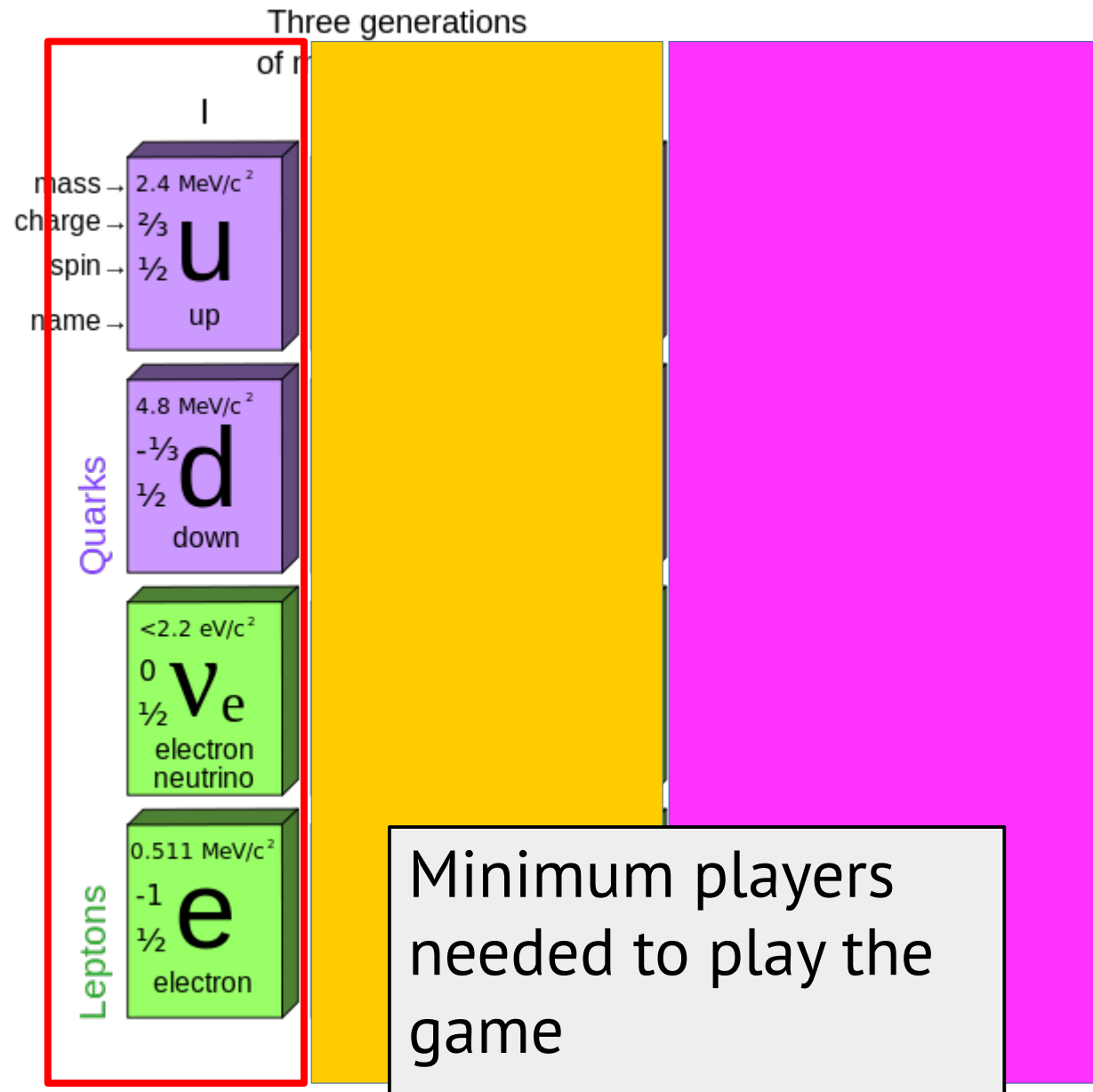
0

H

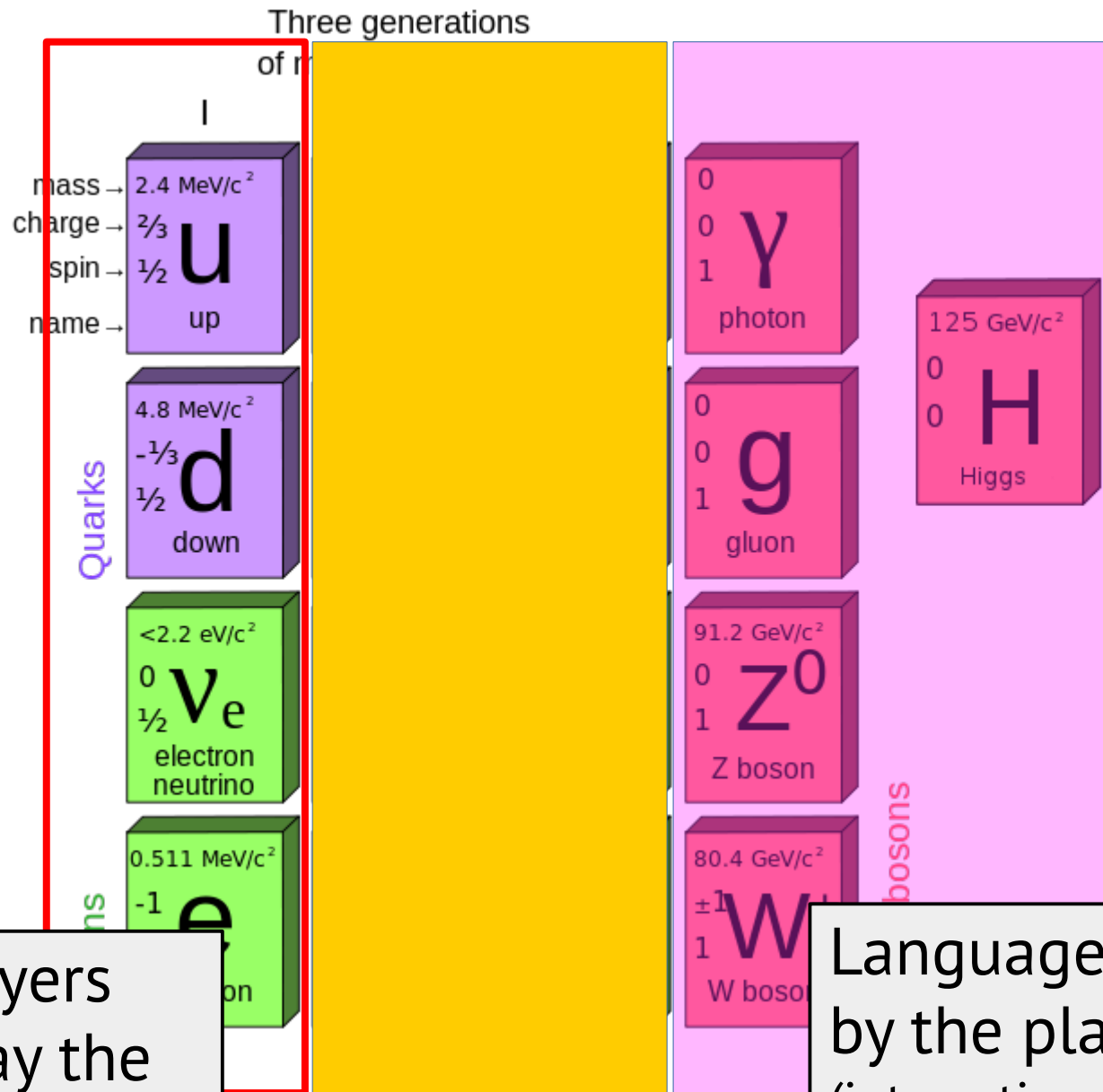
Higgs

PERIODIC TABLE OF PARTICLES

SM EXPLAINED...



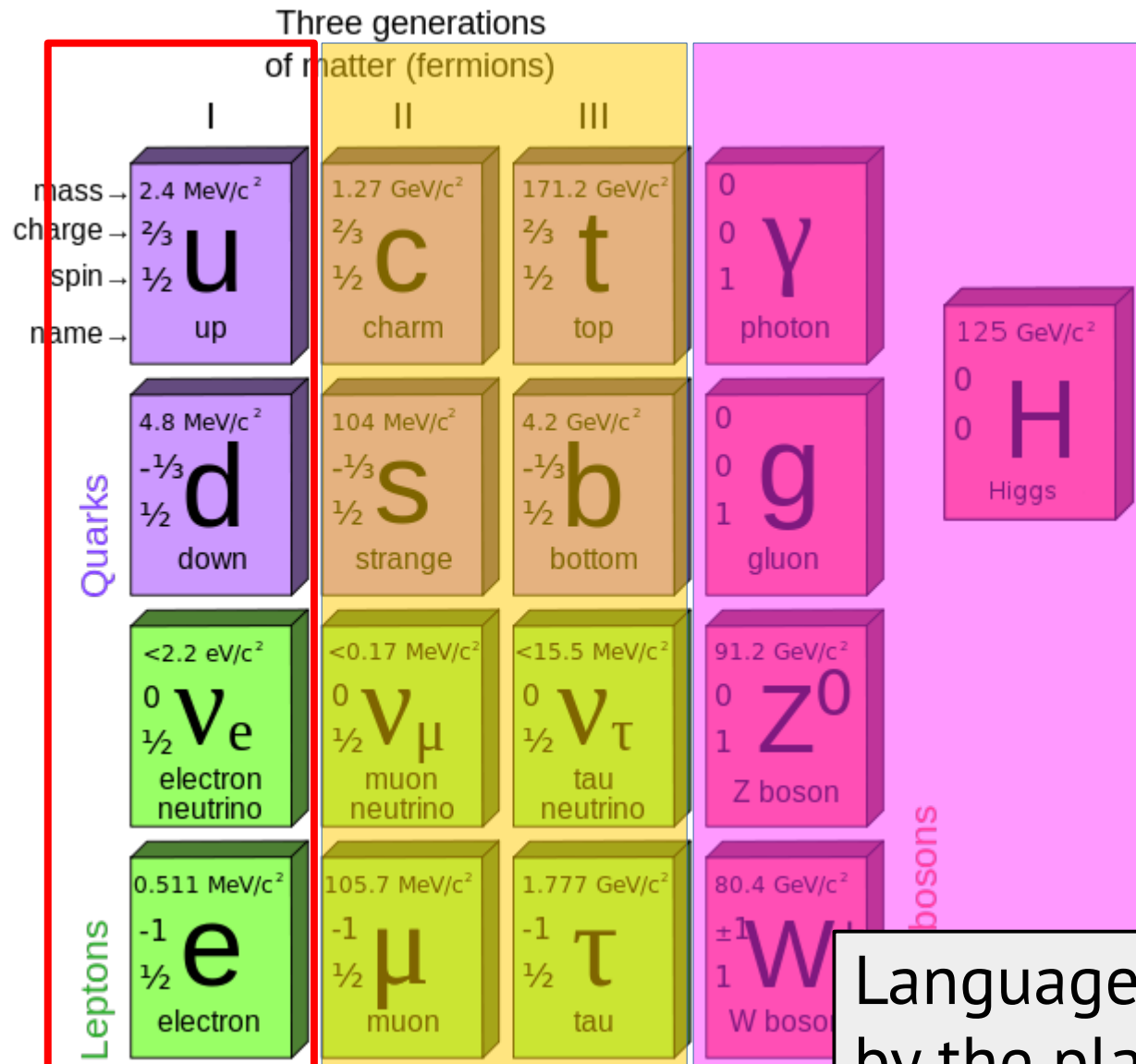
SM EXPLAINED...



Minimum players needed to play the game (Matter)

Languages spoken by the players (interactions between matter)

SM EXPLAINED...



More players (Matter)

Languages spoken by the players (interactions between matter)

STANDARD MODEL OF PARTICLE PHYSICS

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of matter (fermions)

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mass →	2.4 MeV/c ²	1.27 GeV/c ²	171.2 GeV/c ²	0
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spin →	1/2	1/2	1/2	1
name →	u up	c charm	t top	γ photon
	4.8 MeV/c ²	104 MeV/c ²	4.2 GeV/c ²	0
	-1/3	-1/3	-1/3	0
	1/2	1/2	1/2	1
Quarks	d down	s strange	b bottom	g gluon
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	91.2 GeV/c ²
	0	0	0	0
	1/2	1/2	1/2	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ Z boson
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	±1
	1/2	1/2	1/2	1
Leptons	e electron	μ muon	τ tau	W[±] W boson
				125 GeV/c ²
				0
				0
				H Higgs
				Gauge bosons

Particles speak these
'languages'

- Electromagnetic interaction
- Strong interaction
- Weak interaction
- 'Higgs' interaction

STANDARD MODEL OF PARTICLE PHYSICS

Three generations
of matter (fermions)

	I	II	III	
mass →	2.4 MeV/c ²	1.27 GeV/c ²	171.2 GeV/c ²	0
charge →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin →	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name →	u up	c charm	t top	g gluon
	4.8 MeV/c ²	1.7 GeV/c ²	4.2 GeV/c ²	125 GeV/c ²
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
Quarks	d down	s strange	b bottom	H Higgs
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	91.2 GeV/c ²
	0	0	0	1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z ⁰ Z boson
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	± 1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
Leptons	e electron	μ muon	τ tau	W [±] W boson
				Gauge bosons

Keep atoms together,
basis of chemistry,
biology

Particles speak these
'languages'

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- Strong interaction
- Weak interaction
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STANDARD MODEL OF PARTICLE PHYSICS

Three generations of matter (fermions)

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charge →	2/3	2/3	2/3	0
spin →	1/2	1/2	1/2	1
name →	u	c	t	γ
	4.8 MeV/c ²			
	-1/3			
	1/2			
Quarks	down	strange	bottom	gluon
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	91.2 GeV/c ²
	0	0	0	0
	1/2	1/2	1/2	1
	ν_e	ν_μ	ν_τ	Z⁰
	electron neutrino	muon neutrino	tau neutrino	Z boson
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	±1
	1/2	1/2	1/2	1
Leptons	e	μ	τ	W[±]
	electron	muon	tau	W boson
				125 GeV/c ²
				0
				0
				H
				Higgs
				Gauge bosons

Keep nucleus together (protons, neutrons)

- Particles speak these 'languages'
- Electromagnetic interaction
 - Strong interaction
 - Weak interaction
 - 'Higgs' interaction

STANDARD MODEL OF PARTICLE PHYSICS

Three generations
of matter (fermions)

	I	II	III	
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charge →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin →	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name →	u up	c charm	t top	γ photon
Quarks	4.8 MeV/c ² $-\frac{1}{3}$ $\frac{1}{2}$ d down	104 MeV/c ² $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4.2 GeV/c ² $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 0 g gluon
Leptons	<2.2 MeV/c ² 0 $\frac{1}{2}$ ν_e electron neutrino	105.7 MeV/c ² 0 $\frac{1}{2}$ ν_μ muon neutrino	1.777 GeV/c ² 0 $\frac{1}{2}$ ν_τ tau neutrino	125 GeV/c ² 0 0 H Higgs
	0.511 MeV/c ² -1 $\frac{1}{2}$ e electron	105.7 MeV/c ² -1 $\frac{1}{2}$ μ muon	1.777 GeV/c ² -1 $\frac{1}{2}$ τ tau	80.4 GeV/c ² ± 1 1 W^\pm W boson
				Gauge bosons

Make radioactivity,
make the Sun glow!

Particles speak these 'languages'

- Electromagnetic interaction
- Strong interaction
- Weak interaction
- 'Higgs' interaction

STANDARD MODEL OF PARTICLE PHYSICS

Three generations of matter (fermions)

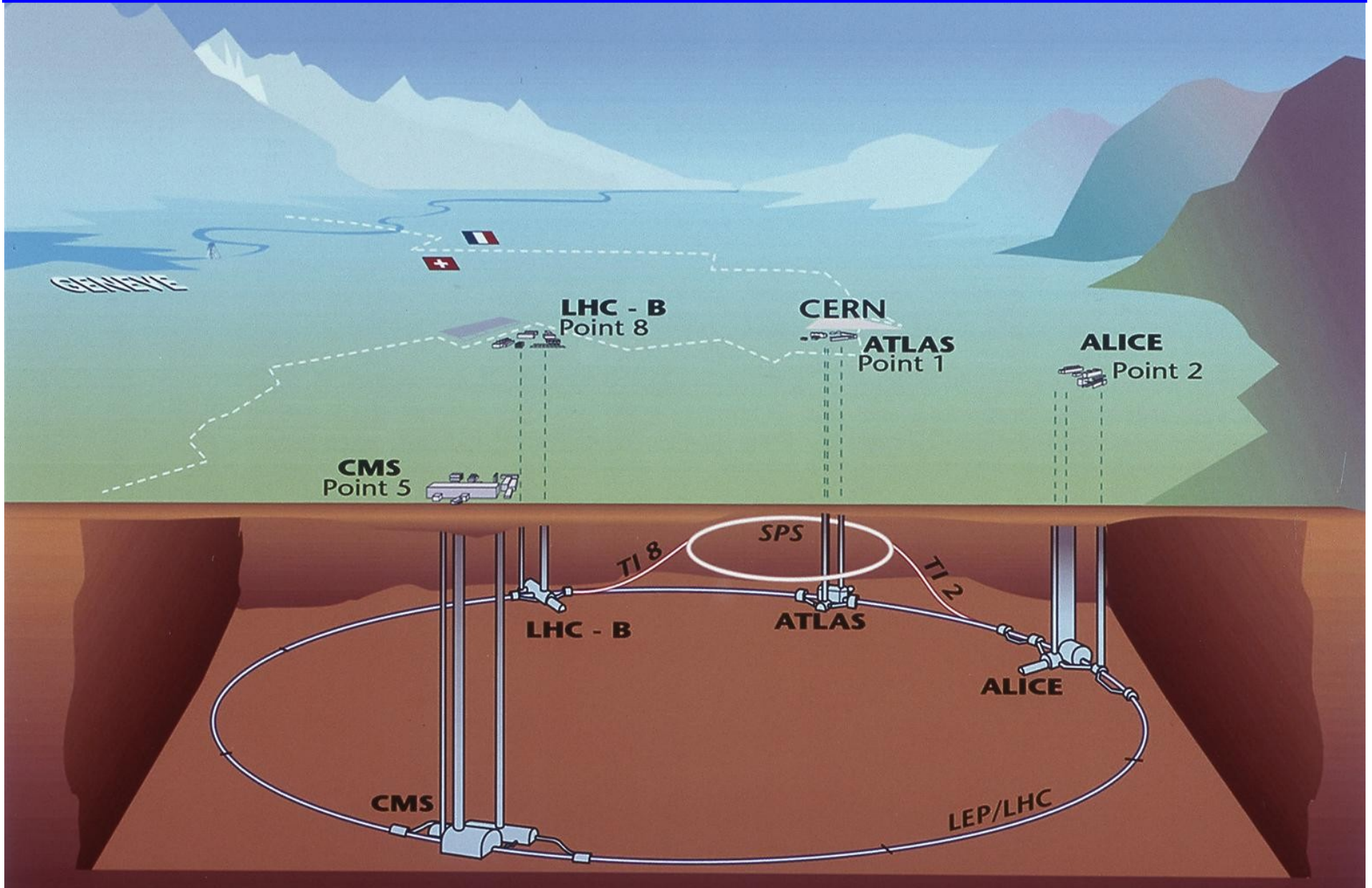
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charge →	2/3	2/3	2/3	0
spin →	1/2	1/2	1/2	1
name →	u up	c charm	t top	γ photon
	4.8 MeV/c ²	104 MeV/c ²	4.2 GeV/c ²	0
	-1/3	-1/3	-1/3	0
	1/2	1/2	1/2	1
Quarks	d	s	b	g
	<2			125 GeV/c ²
	0			0
	1/2			0
	electron neutrino	muon neutrino	tau neutrino	Z boson
Leptons	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	±1
	1/2	1/2	1/2	1
	e electron	μ muon	τ tau	W[±] W boson
				Gauge bosons

Give mass to fundamental particles!

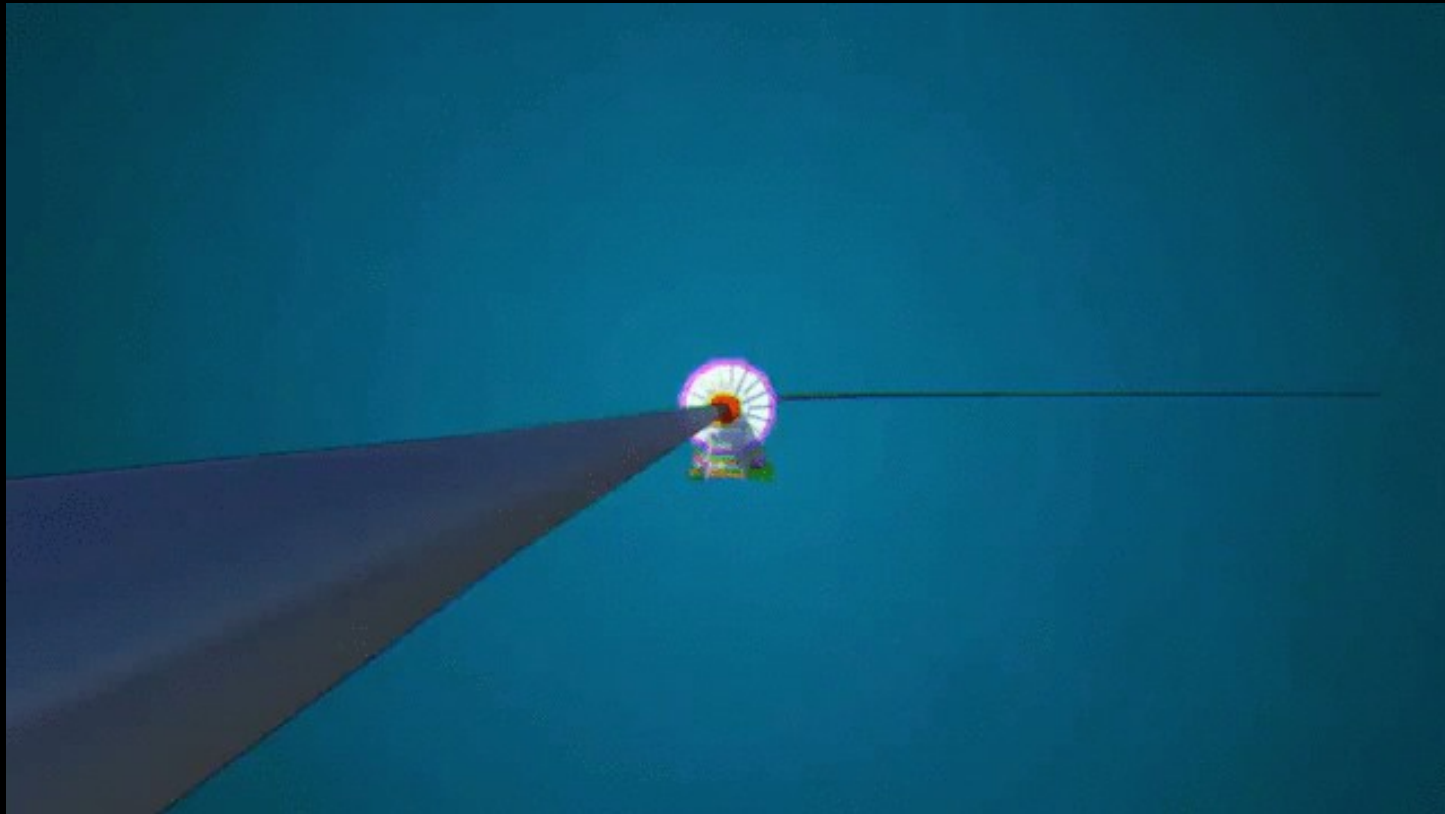
Particles speak these 'languages'

- Electromagnetic interaction
- Strong interaction
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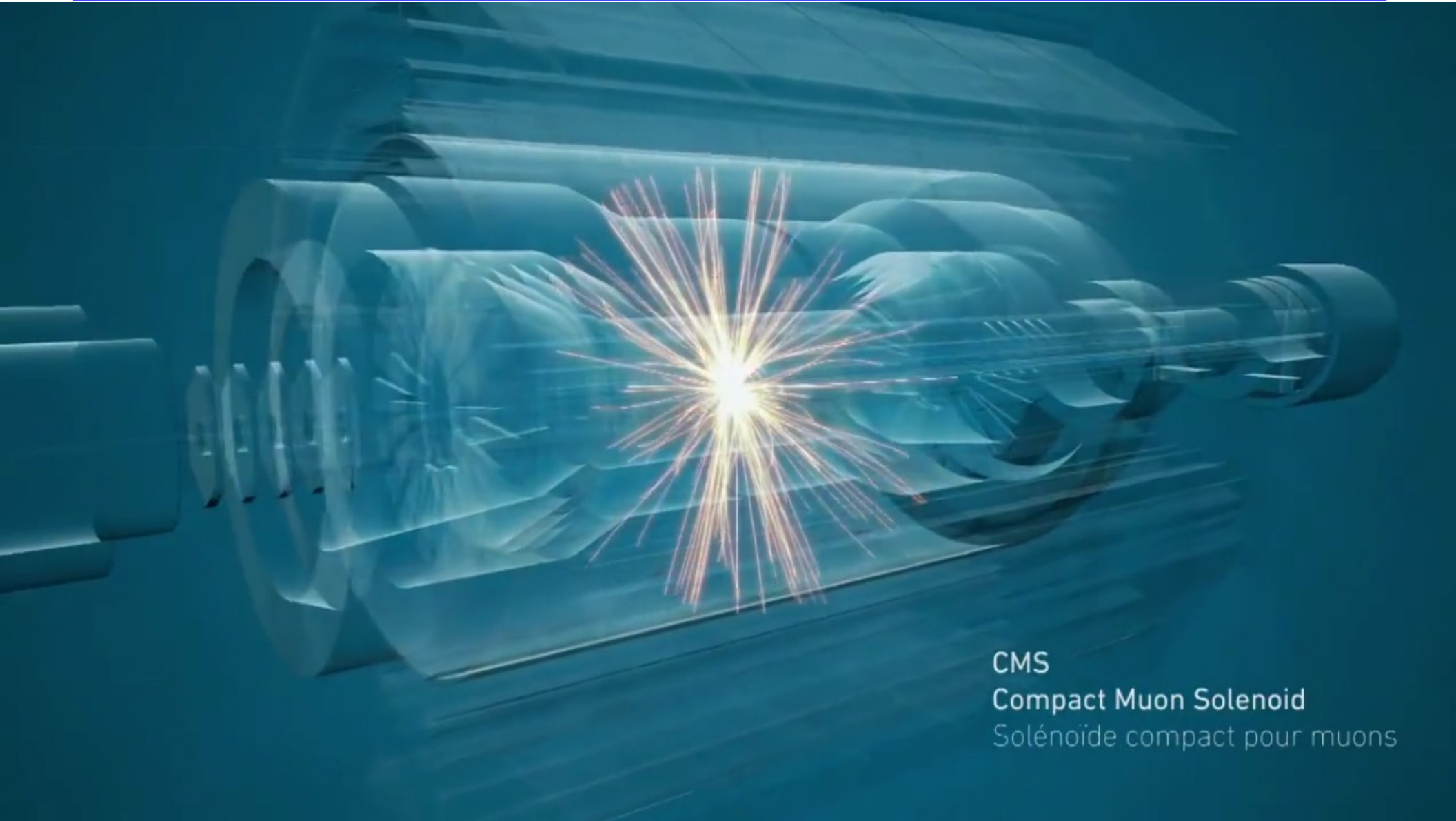
LHC: LARGE HADRON COLLIDER



CMS DETECTOR

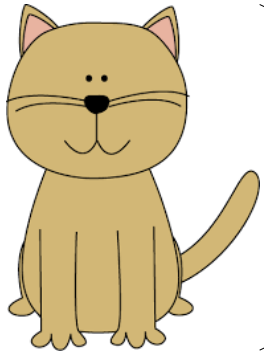


CMS IS A GIANT CAMERA



CMS
Compact Muon Solenoid
Solénoïde compact pour muons

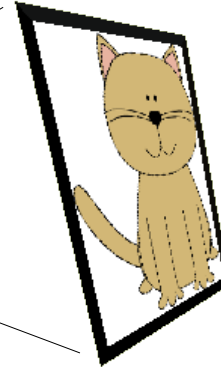
RECONSTRUCTION



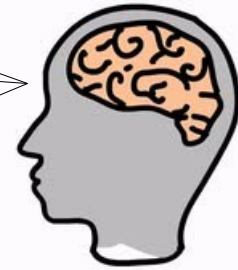
Object



Detector

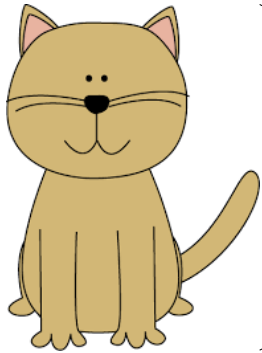


Data collected



Data analyzed

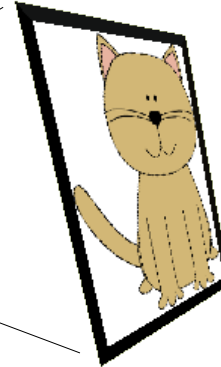
RECONSTRUCTION



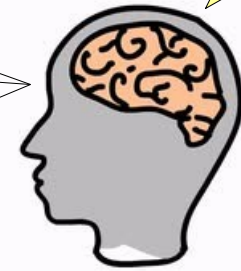
Object



Detector



Data collected



Data analyzed

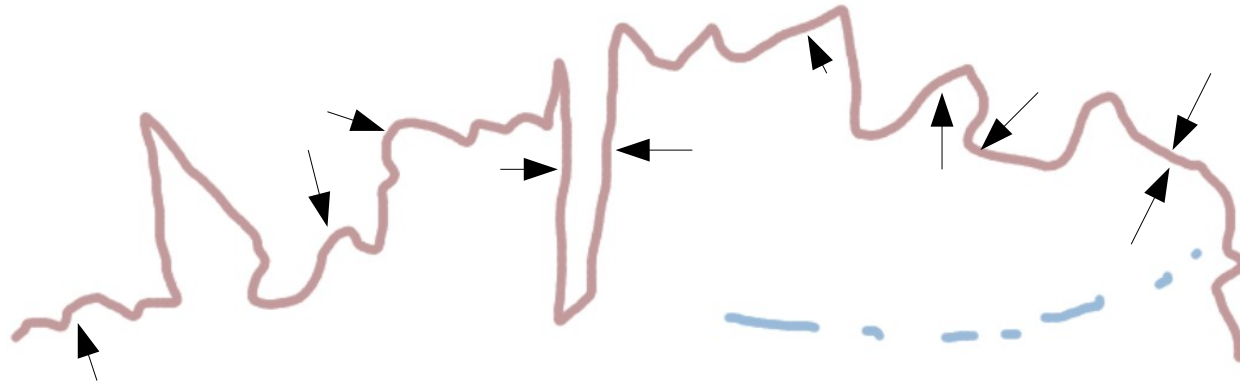
CAT!

NATURE OF RESEARCH



A non-researcher's view...

NATURE OF RESEARCH



THE EDGES OF
HUMAN KNOWLEDGE

A researcher's view...

WHY I LIKE SCIENCE?

- ▶ OBJECTIVE PROOF
(does not depend on specific person)
- ▶ CAUSE AND EFFECT (reproducible)
- ▶ WHY? AND HOW?

IISER PUNE CMS GROUP



...along with summer students