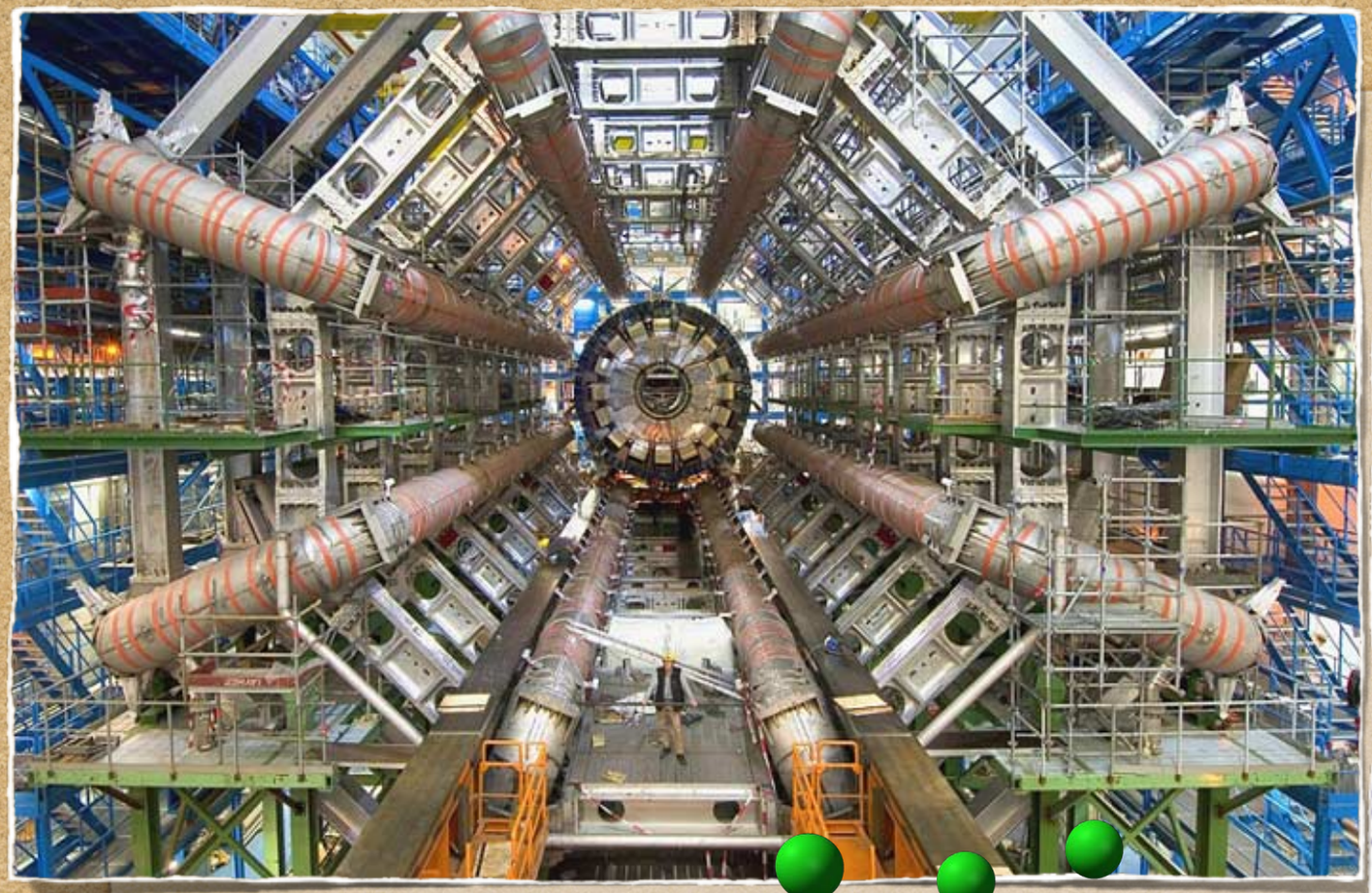
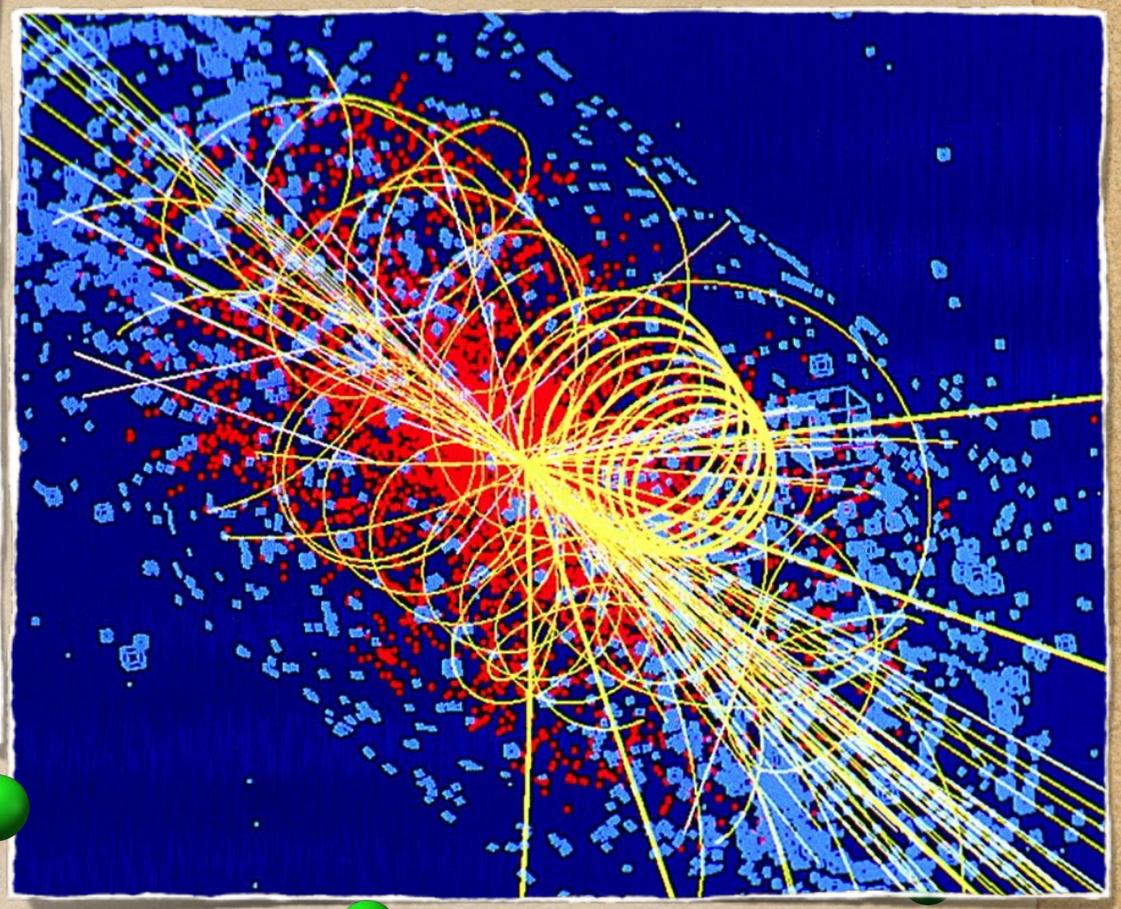
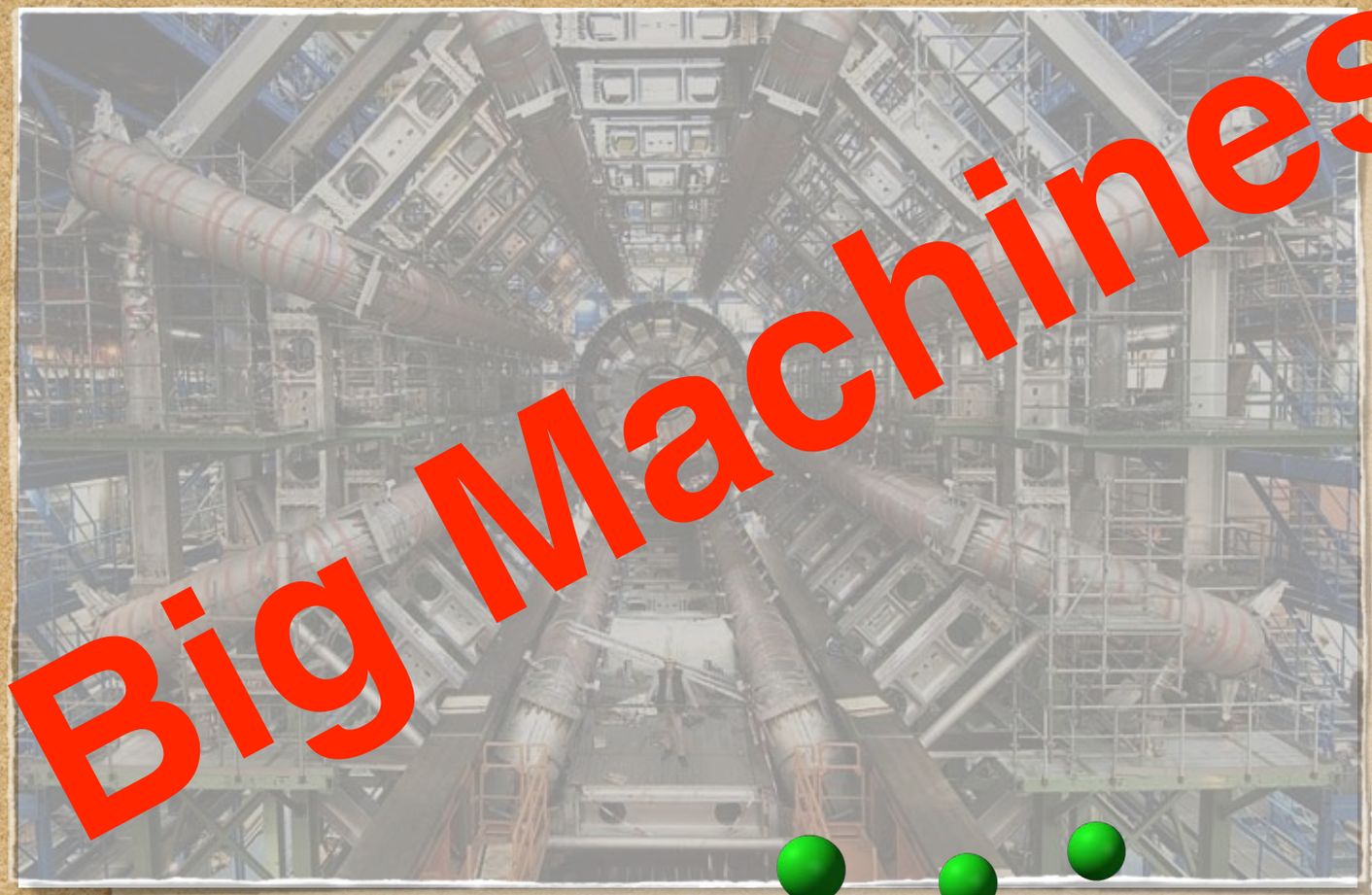


Credit: CERN

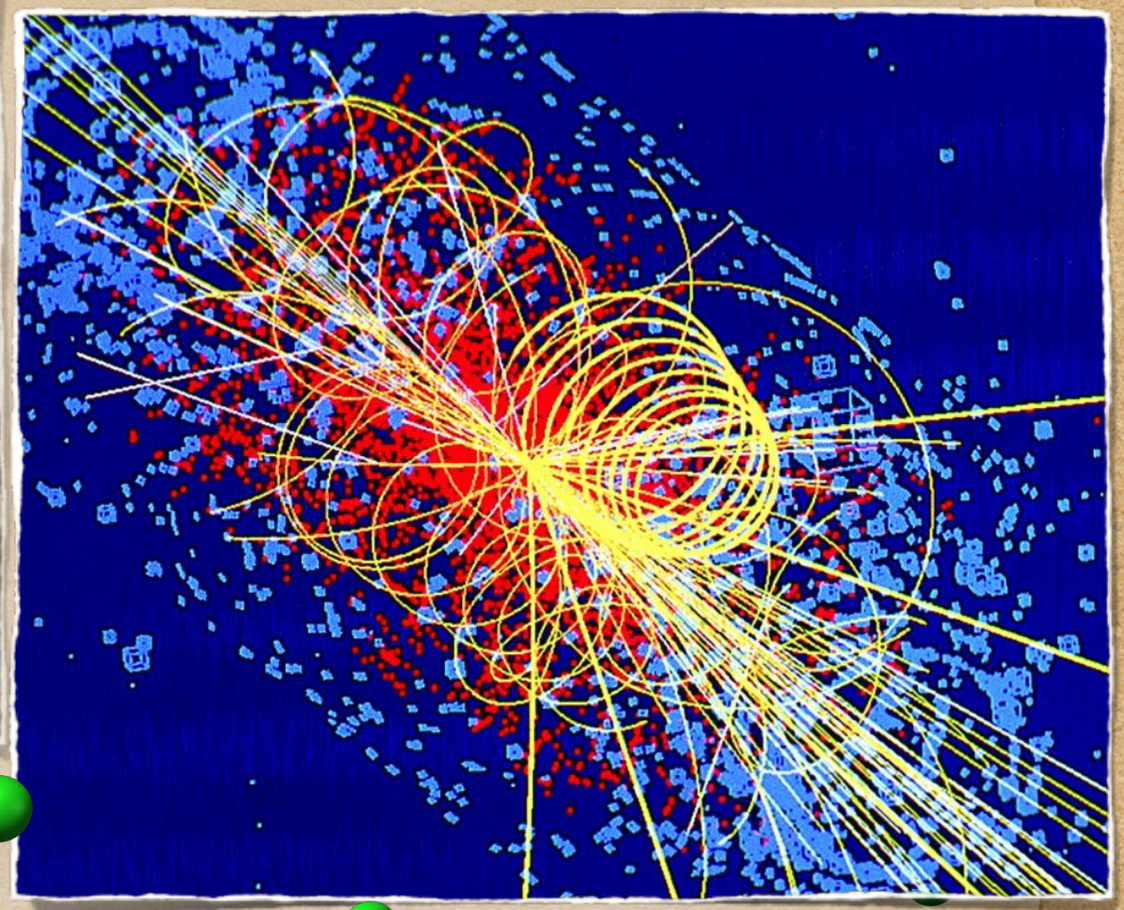


Credit: Lucas Taylor

Big Machines

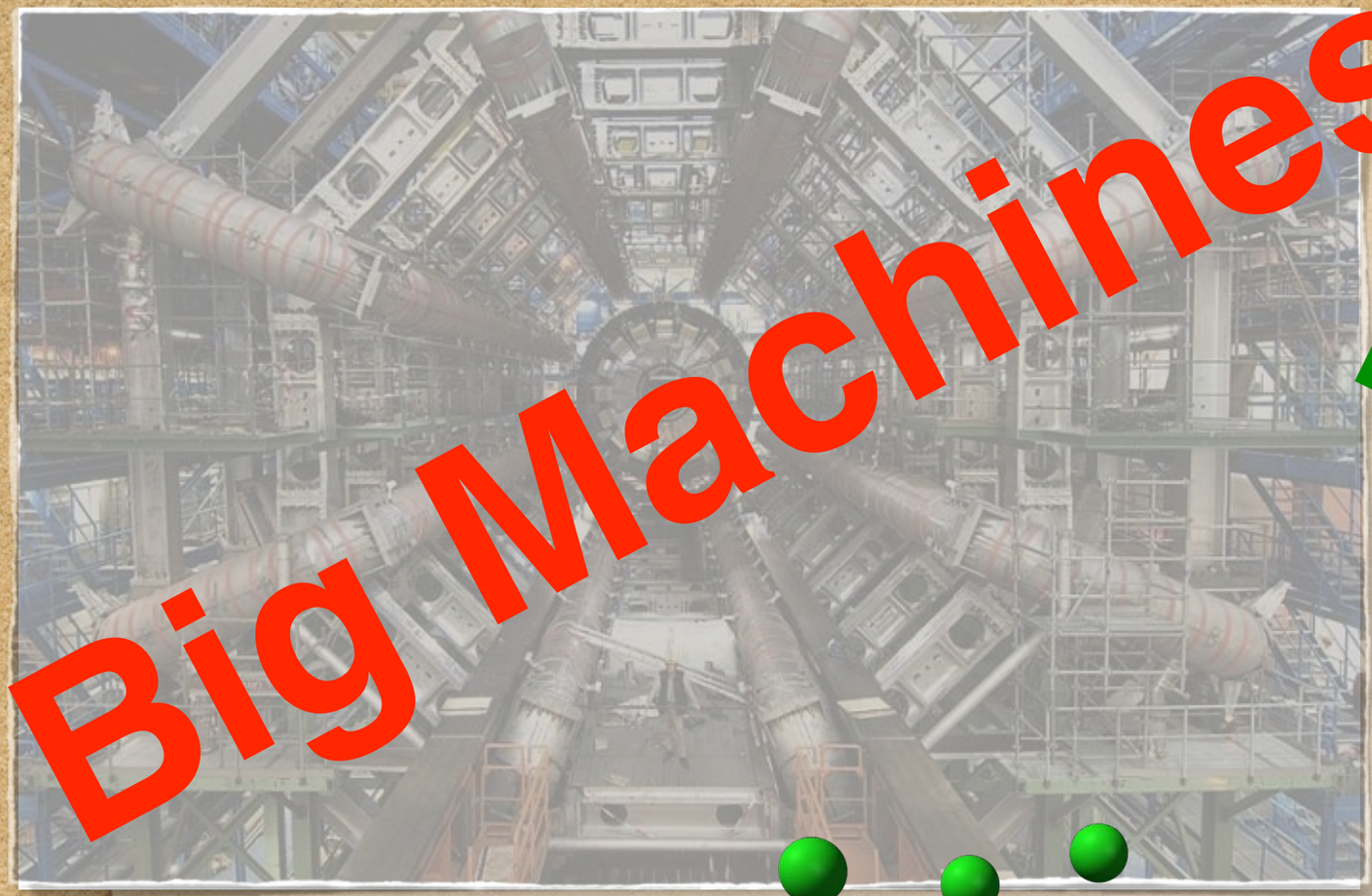


Credit: CERN



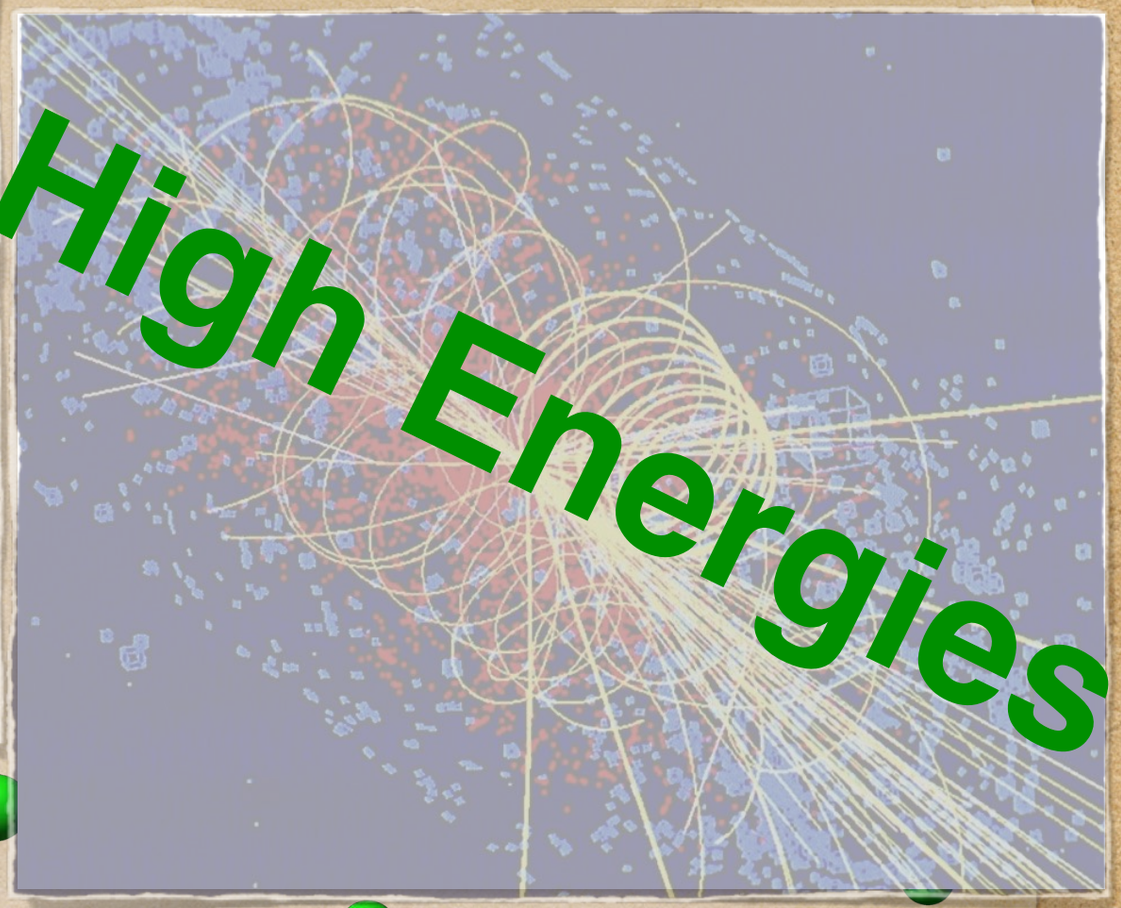
Credit: Lucas Taylor

Big Machines



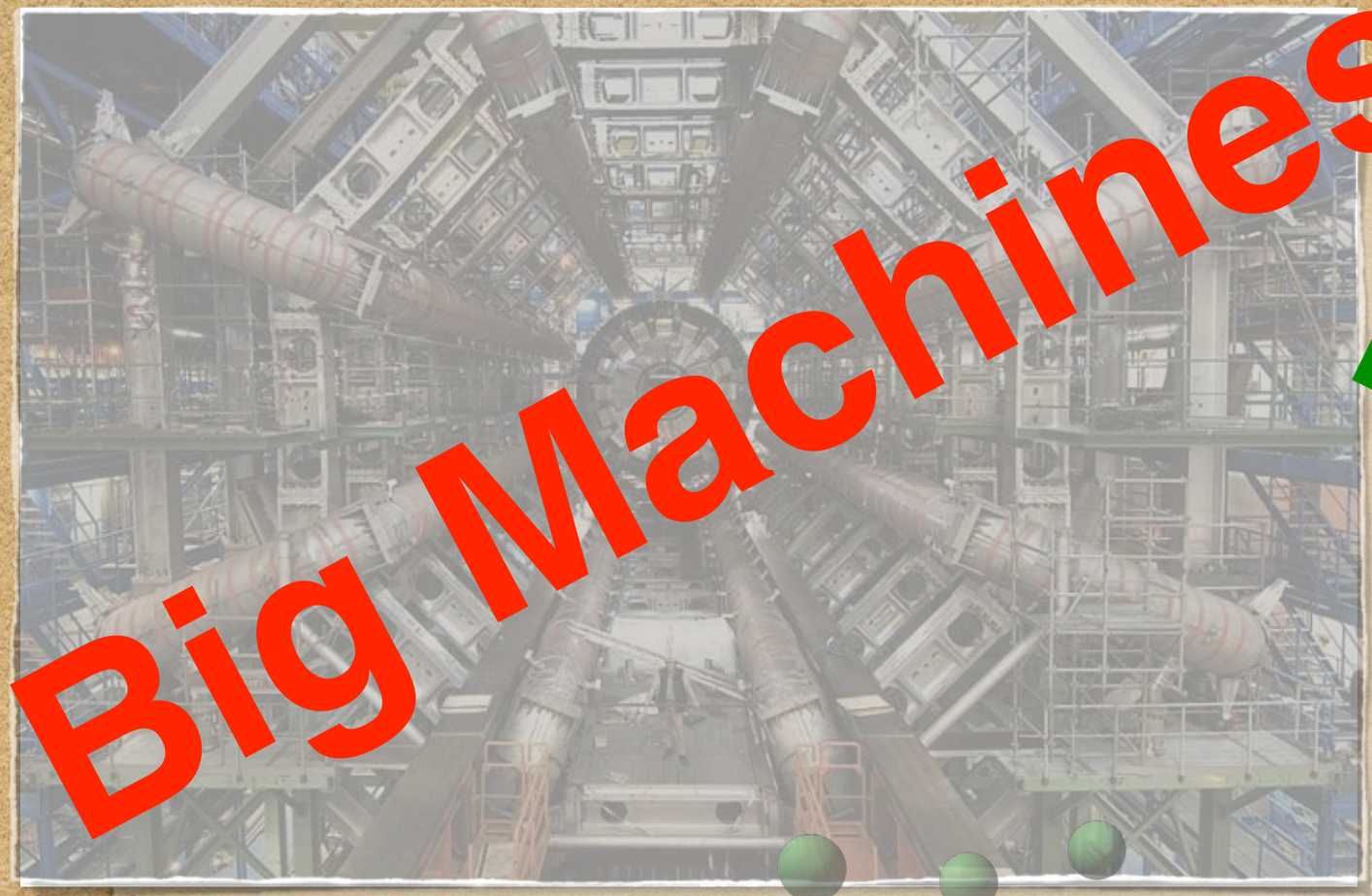
Credit: CERN

High Energies



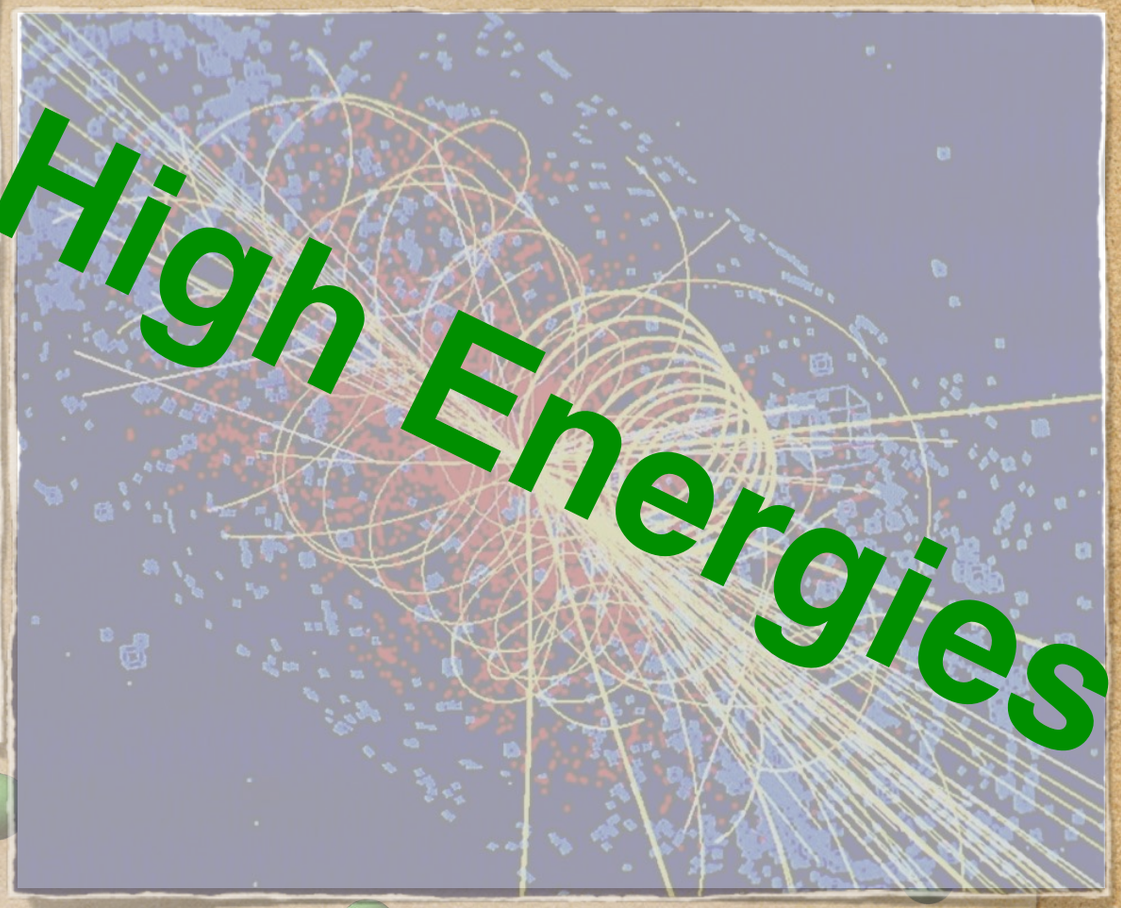
Credit: Lucas Taylor

Big Machines



Credit: CERN

High Energies



Credit: Lucas Taylor

and Tiny Particles

Physics at the Femtoscale

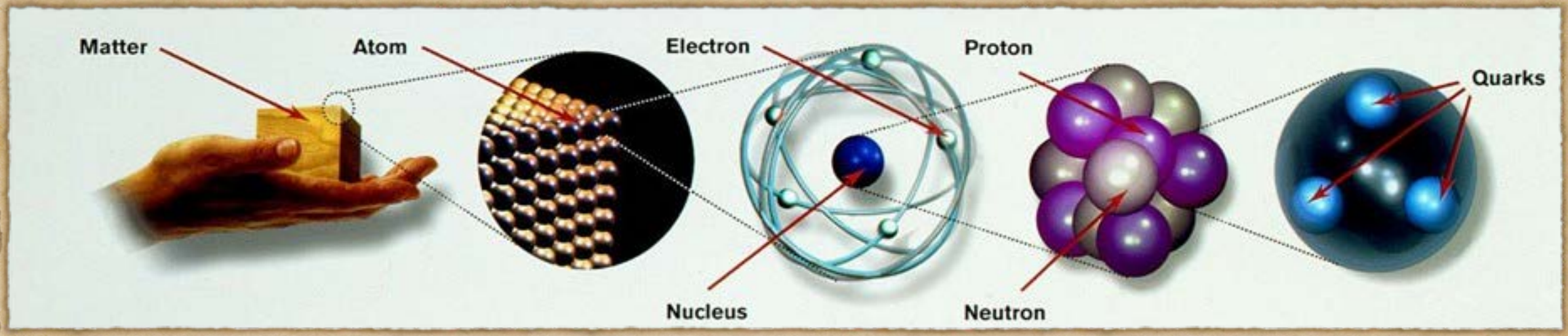
Frederik Van der Veken

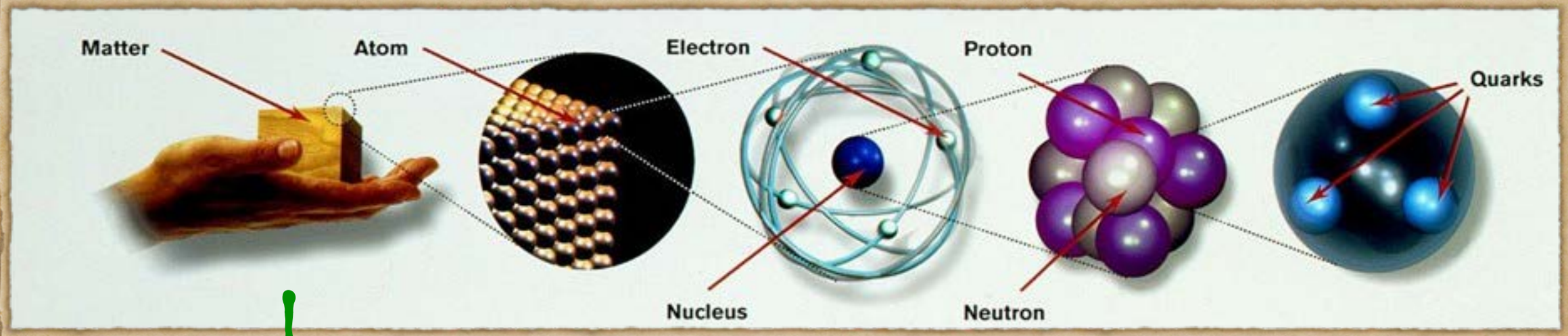
INSPYRE 2020

frederikvanderveken@gmail.com

1

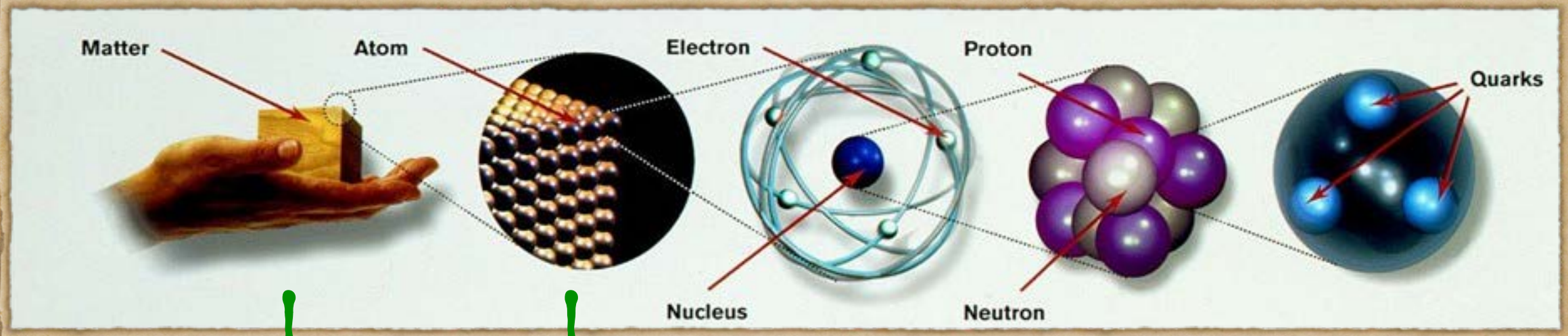
Whát scale… ?


Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron



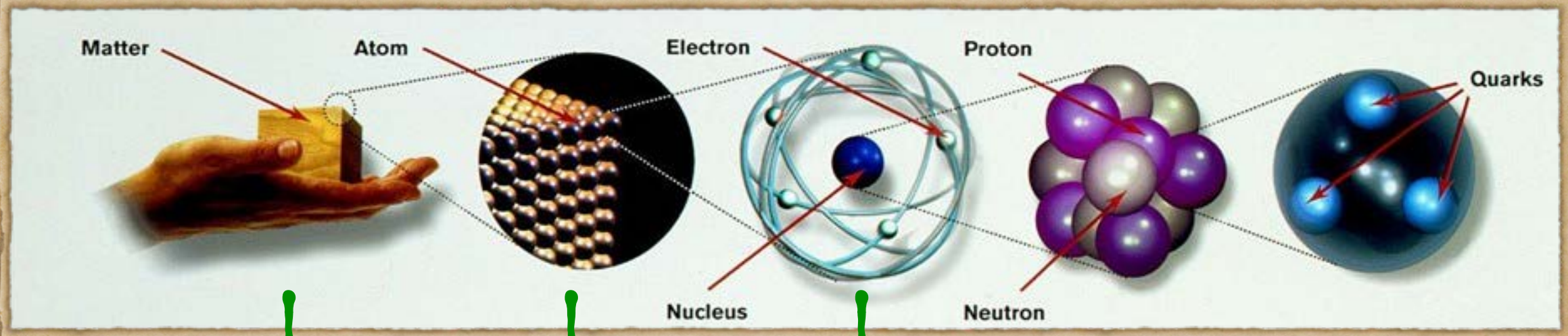
5cm

(10^{-2}m)



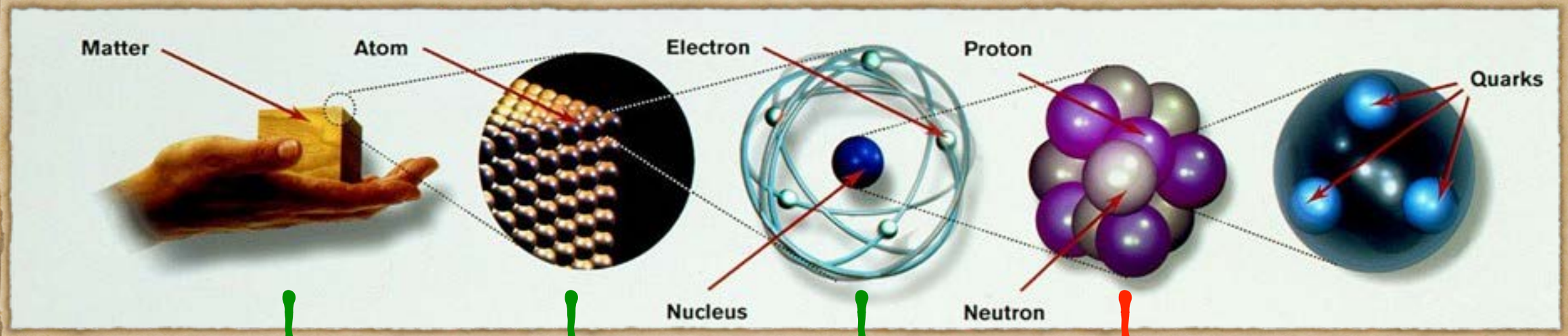
5cm 1Å

(10^{-2}m) (10^{-10}m)



5cm 1Å 0.01pm

(10^{-2}m) (10^{-10}m) (10^{-14}m)



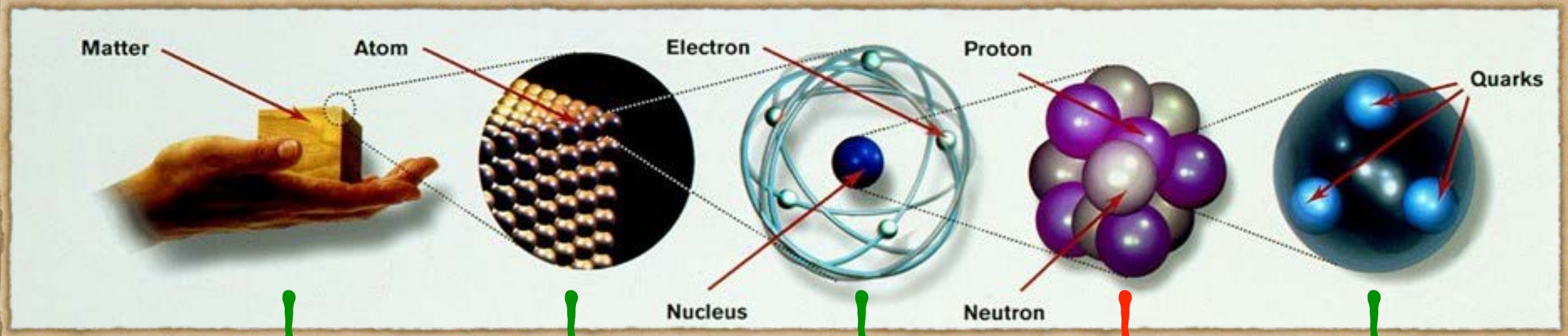
5cm (10^{-2}m)

1Å (10^{-10}m)

0.01pm (10^{-14}m)

Femto!

(10^{-15}m)



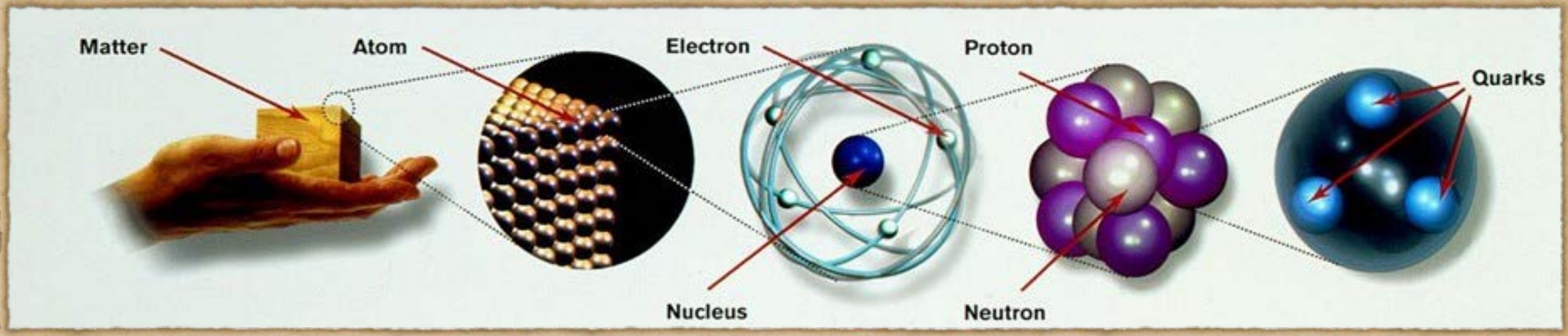
5cm (10^{-2}m)

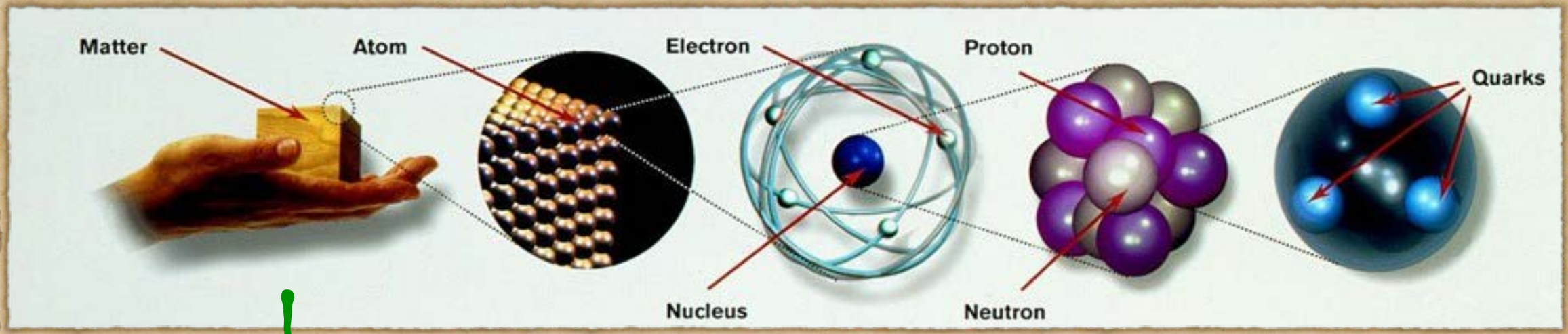
1Å (10^{-10}m)

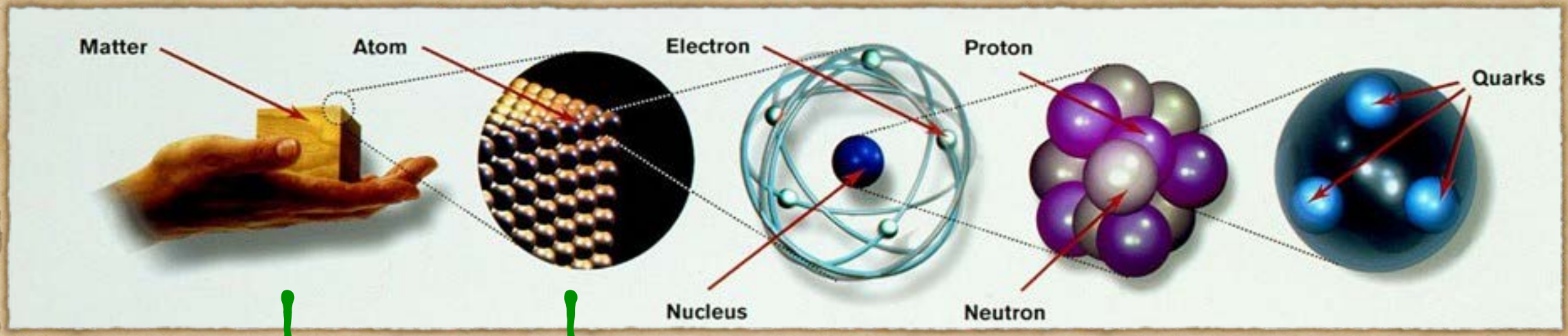
0.01pm (10^{-14}m)

1am (10^{-18}m)

Femto! (10^{-15}m)


Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron


Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron


Matter
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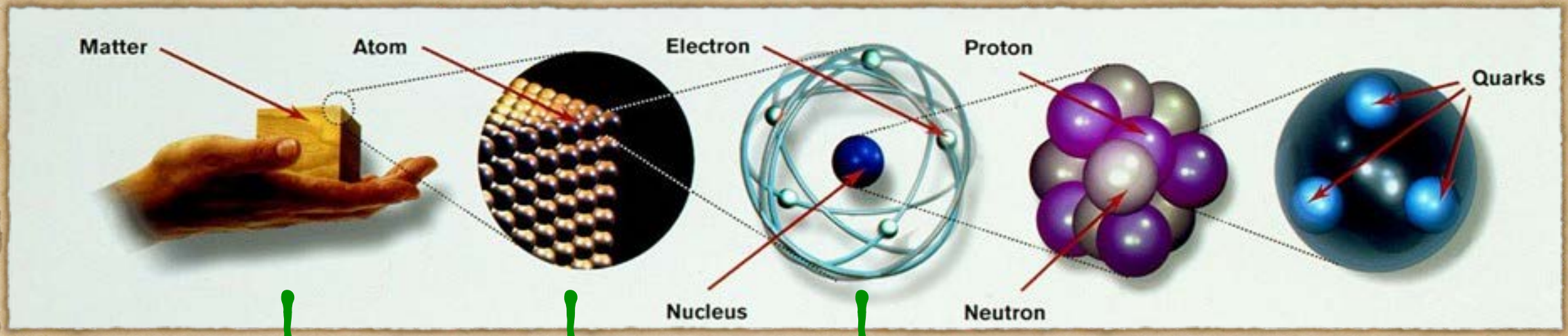
Matter
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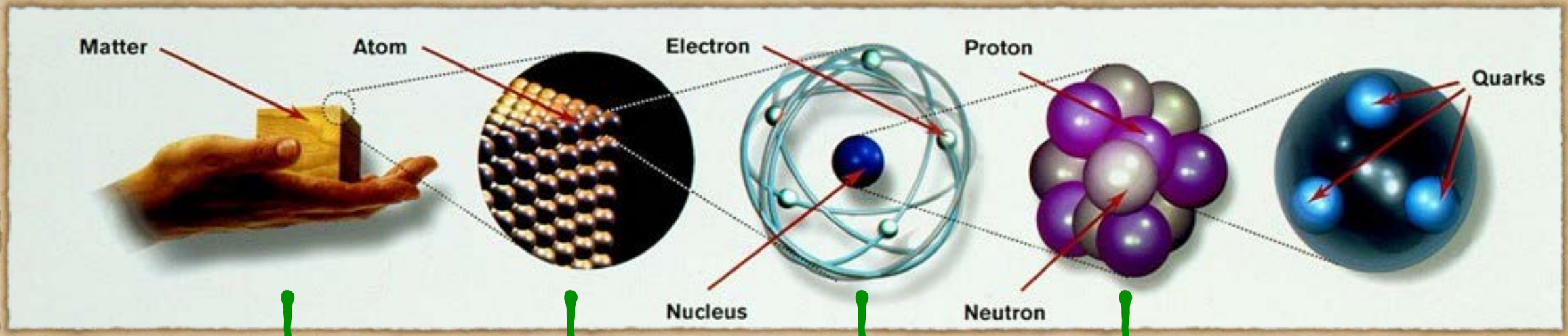
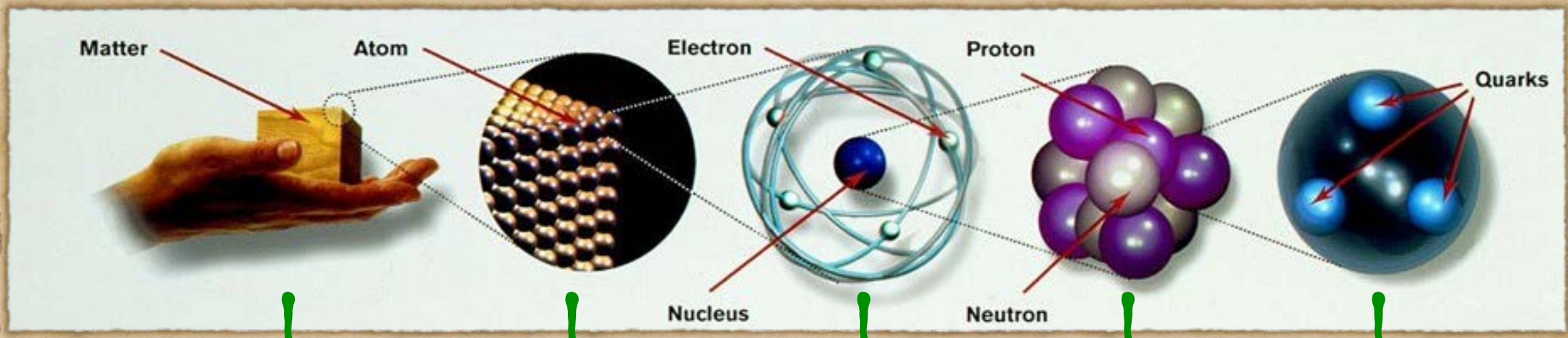
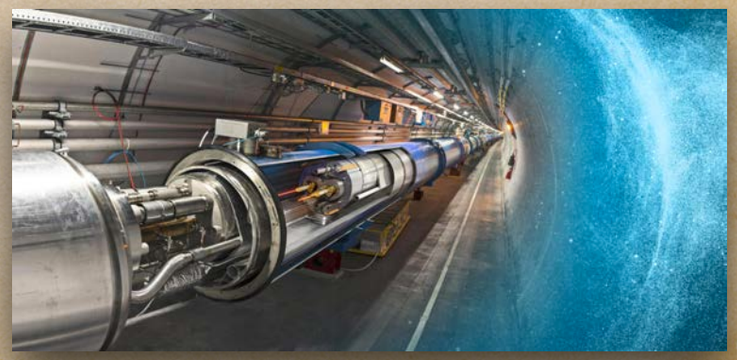


Credit: CERN



Credit: CERN



Credit: CERN

Big machines

reach high energy

By accelerating protons

(of femtometer size)

and use them to search

for tiny particles

2

Big Machines

Particle Colliders

Particle Colliders

Accelerate: increase the energy of their particles

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Collide: smash two particles on each other to release extreme energy

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Particle Colliders

Accelerate: increase the energy of their particles

Collide: smash two particles on each other to release extreme energy

Detect: observe the creation of (new) particles

~~**Understand:** analyse the results, to deeply probe the mysteries of Life~~

Humans, not machines (though this is changing…)

Particle Colliders

Prime example: the Large Hadron Collider

Particle Colliders

Prime example: the Large Hadron Collider

26.659 km 9593 magnets

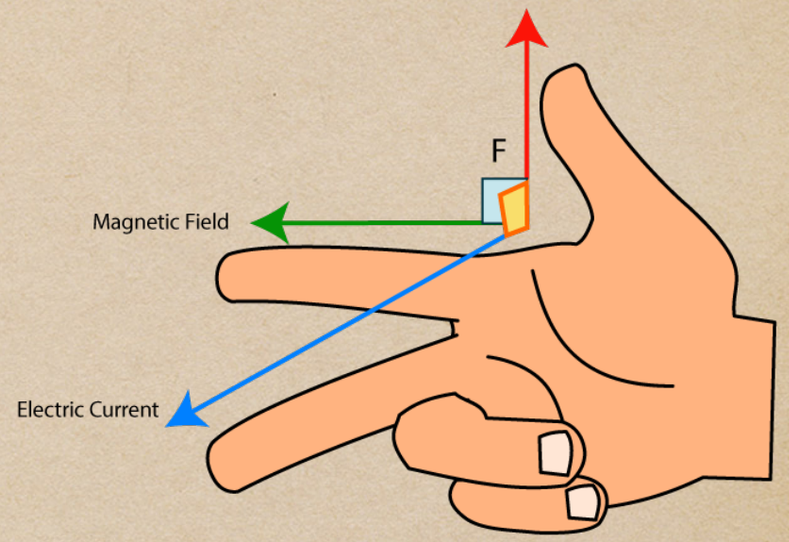
1~2 billion collisions / s

Accelerators

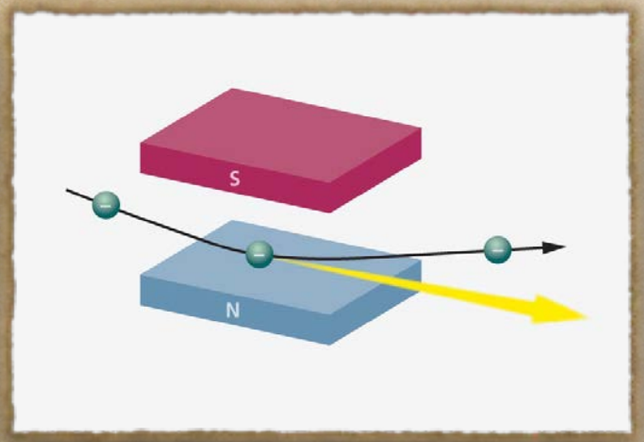
Magnets?

Accelerators

Magnets?

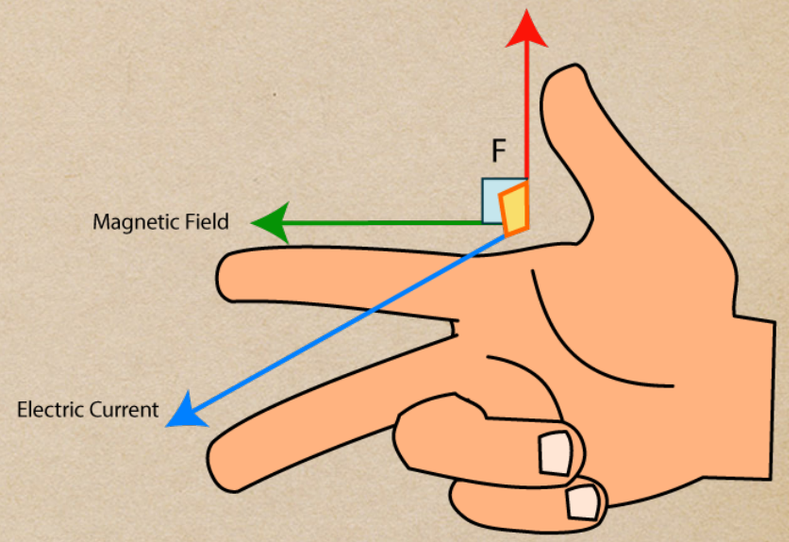


Lorentz force is *perpendicular*



Accelerators

Magnets?



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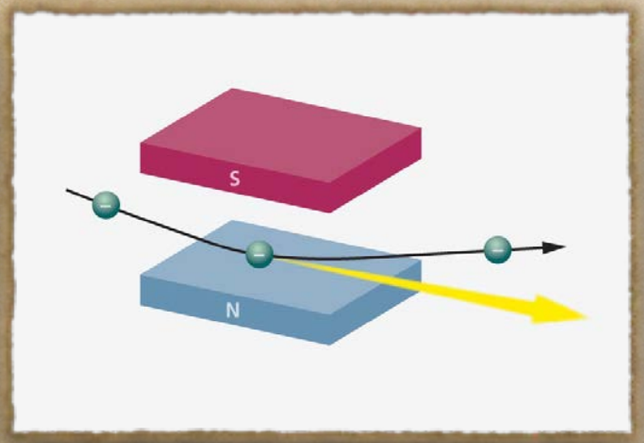
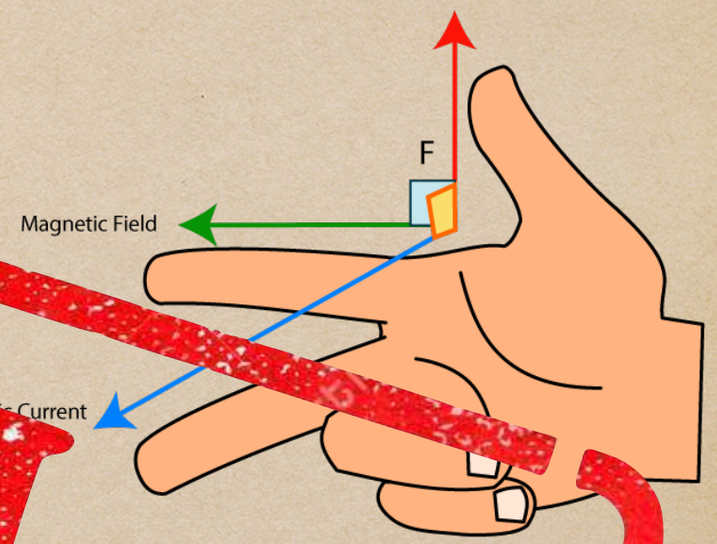


Effect of magnet is in ‘wrong’ direction

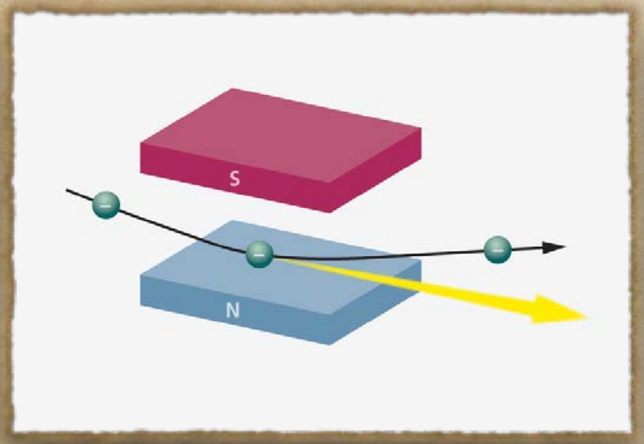
Like pushing a swing from the side

Accelerators



Magnets?

Lorentz force is *perpendicular*



Effect of magnet is in ‘wrong’ direction

Like pushing a swing from the side

Accelerators

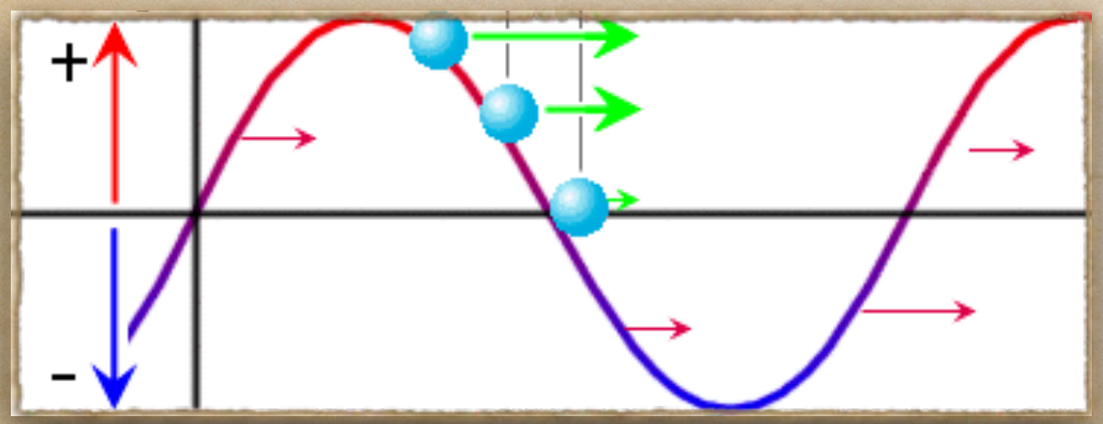
Accelerators

Electric field

Accelerators

Electric field

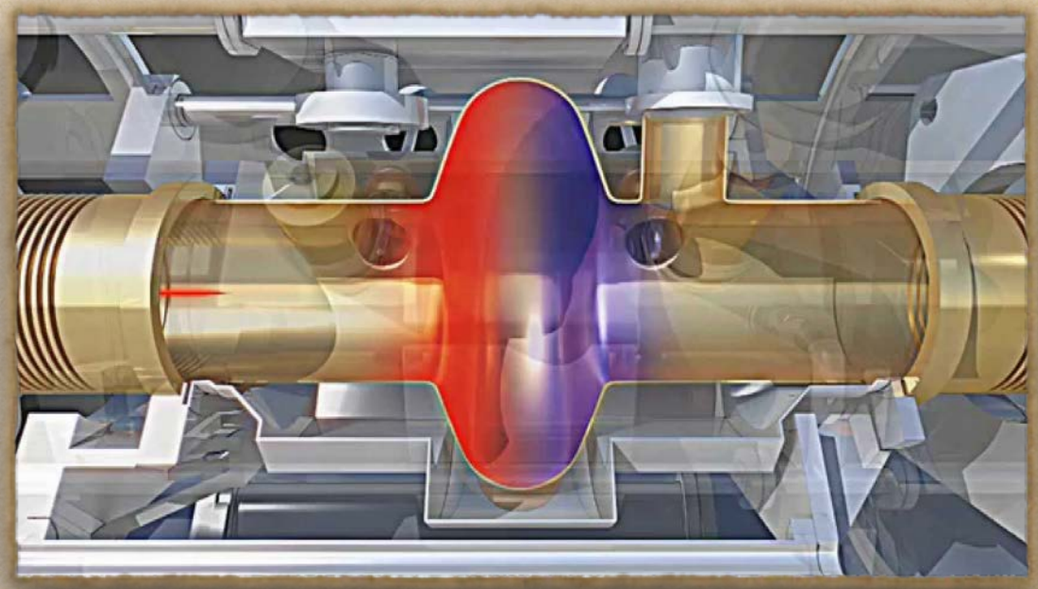
Force is *longitudinal*



Credit: JLAB

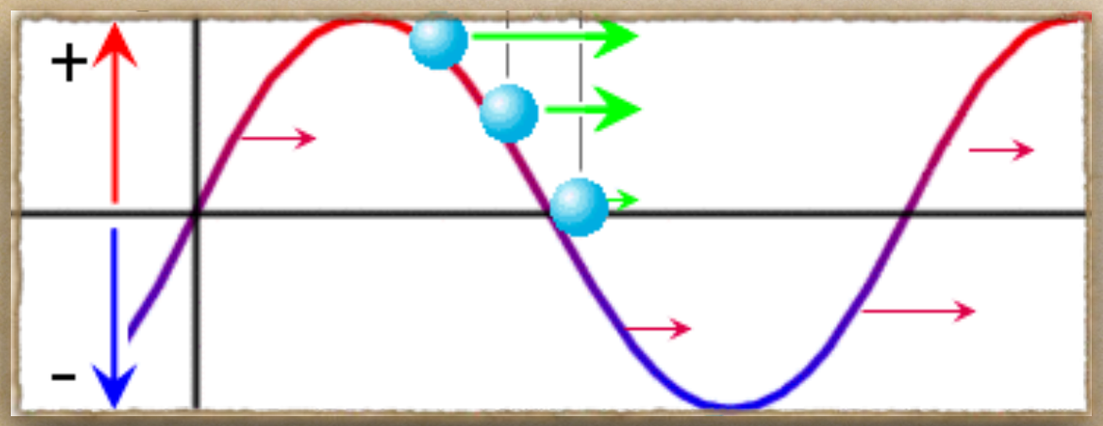
Accelerators

Electric field : cavities



Credit: CERN

Force is *longitudinal*



Credit: JLAB

Field should be positive at right moment

Correct timing is crucial

But..

But..

But..

But..

LHC has 9600 magnets!

But..

But..

LHC has 9600 magnets!

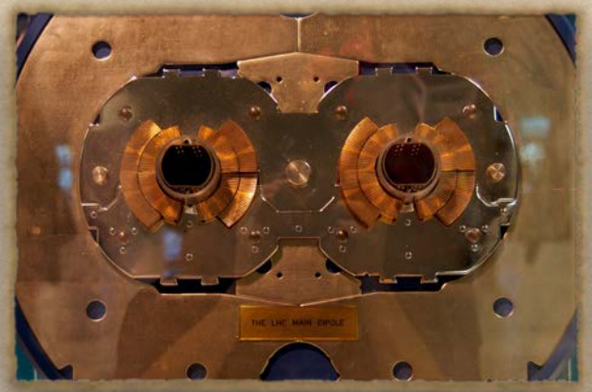
Then.. why?

Magnets

Magnets

dipole:

bending

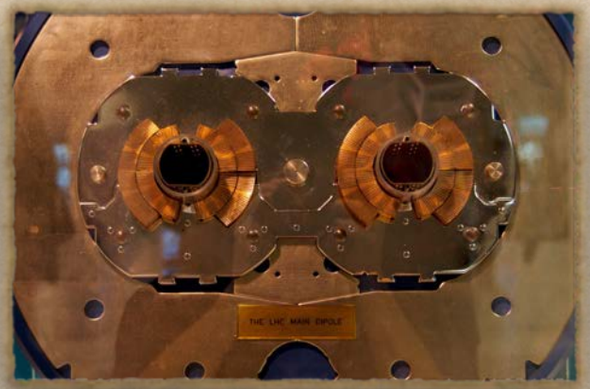


Credit: CERN

Magnets

dipole:

bending



Credit: CERN

quadrupole:

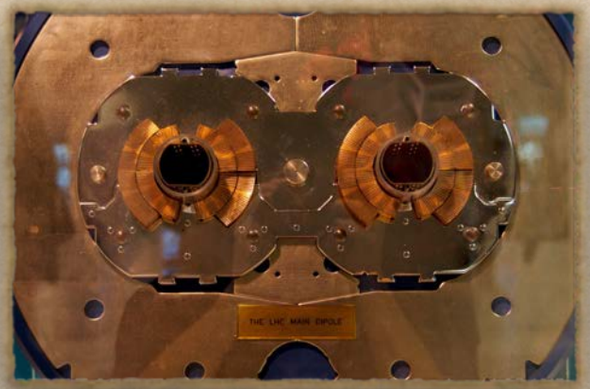
focussing

Credit: CERN

Magnets

dipole:

bending



Credit: CERN

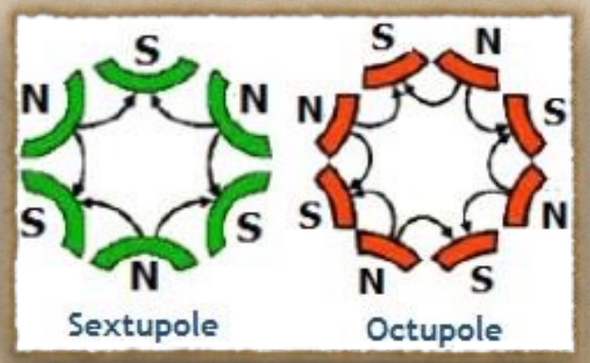
quadrupole:

focussing

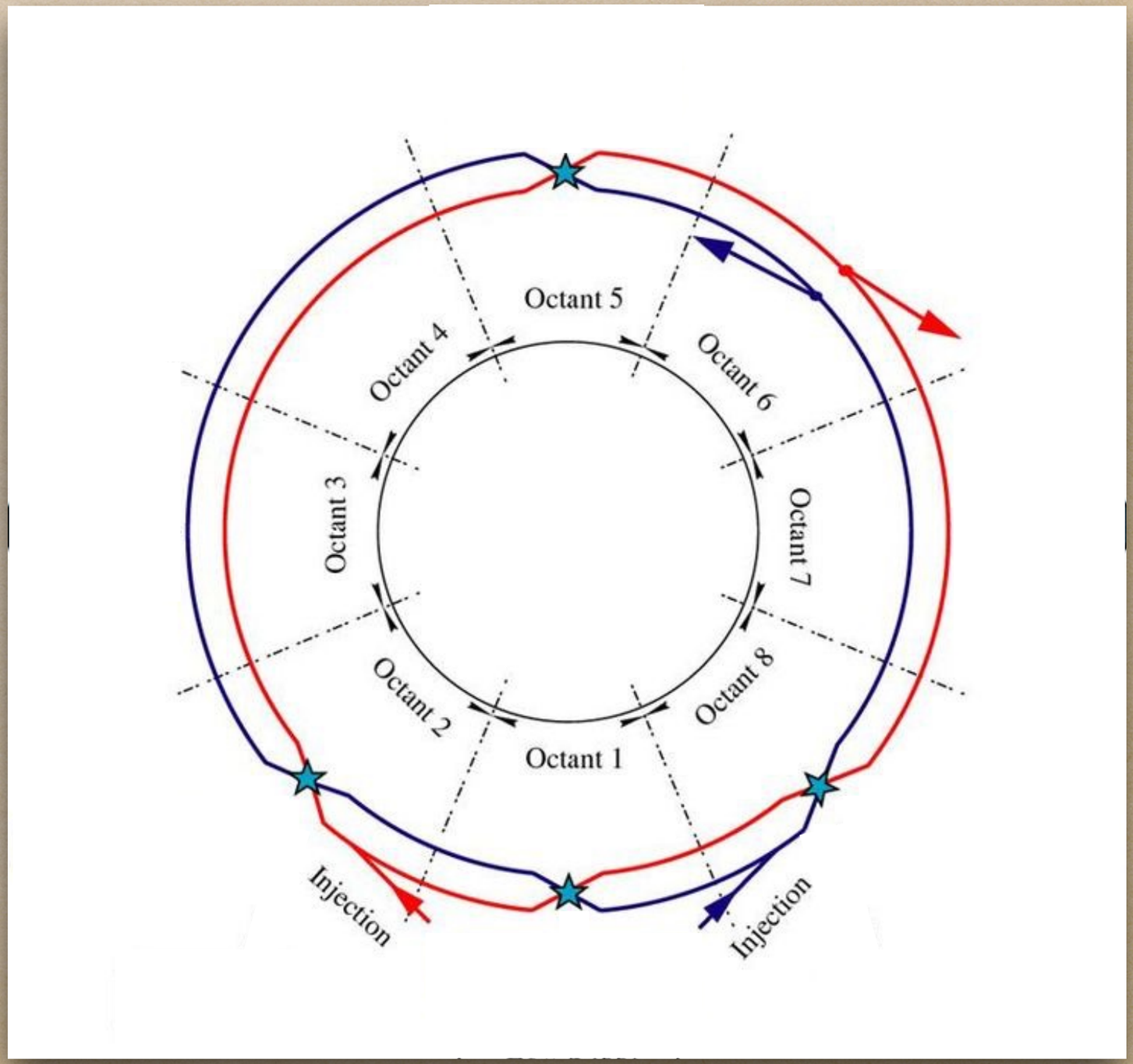
Credit: CERN

higher orders:

other stuff

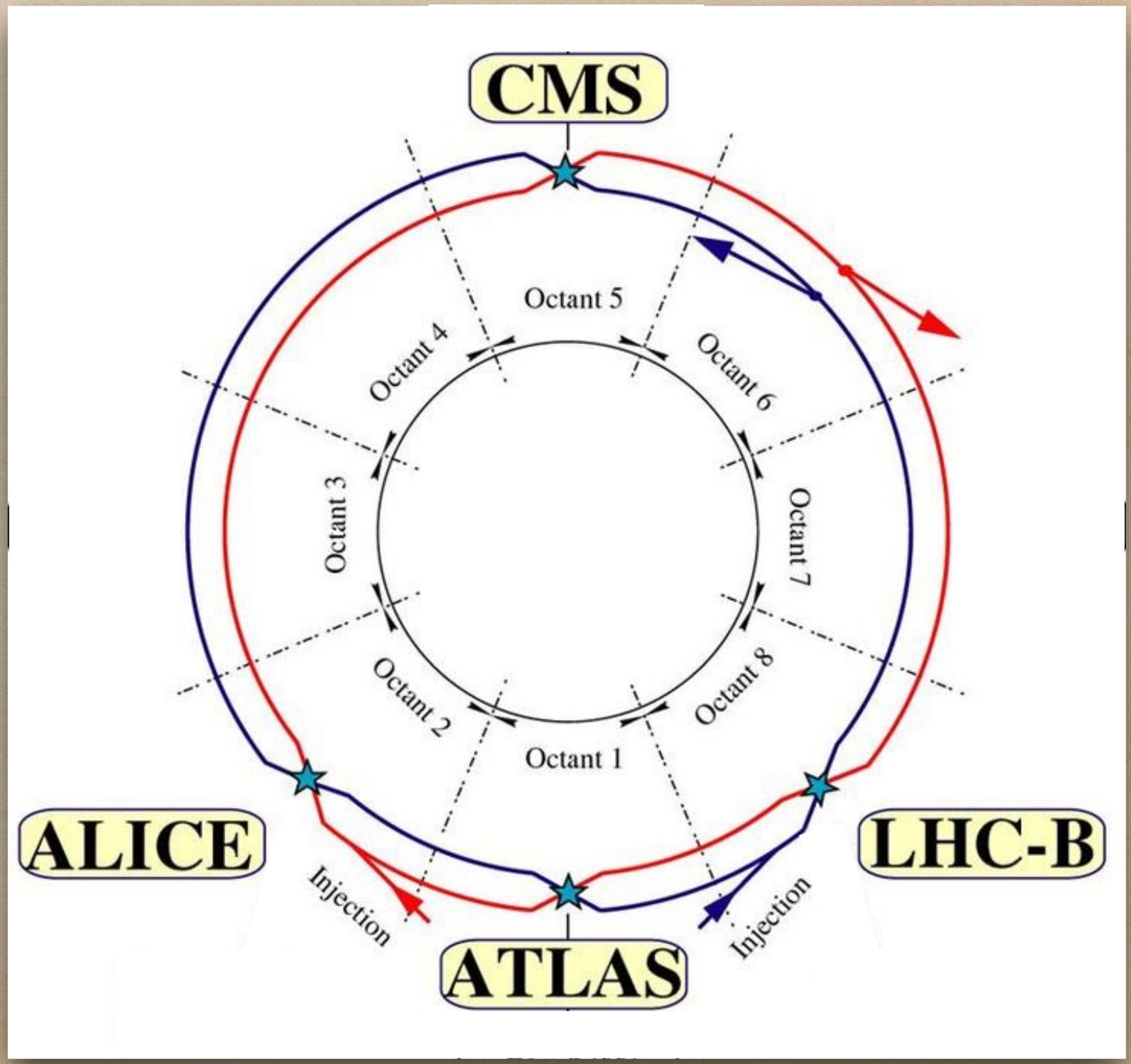


The Large Hadron Collider



The Large Hadron Collider

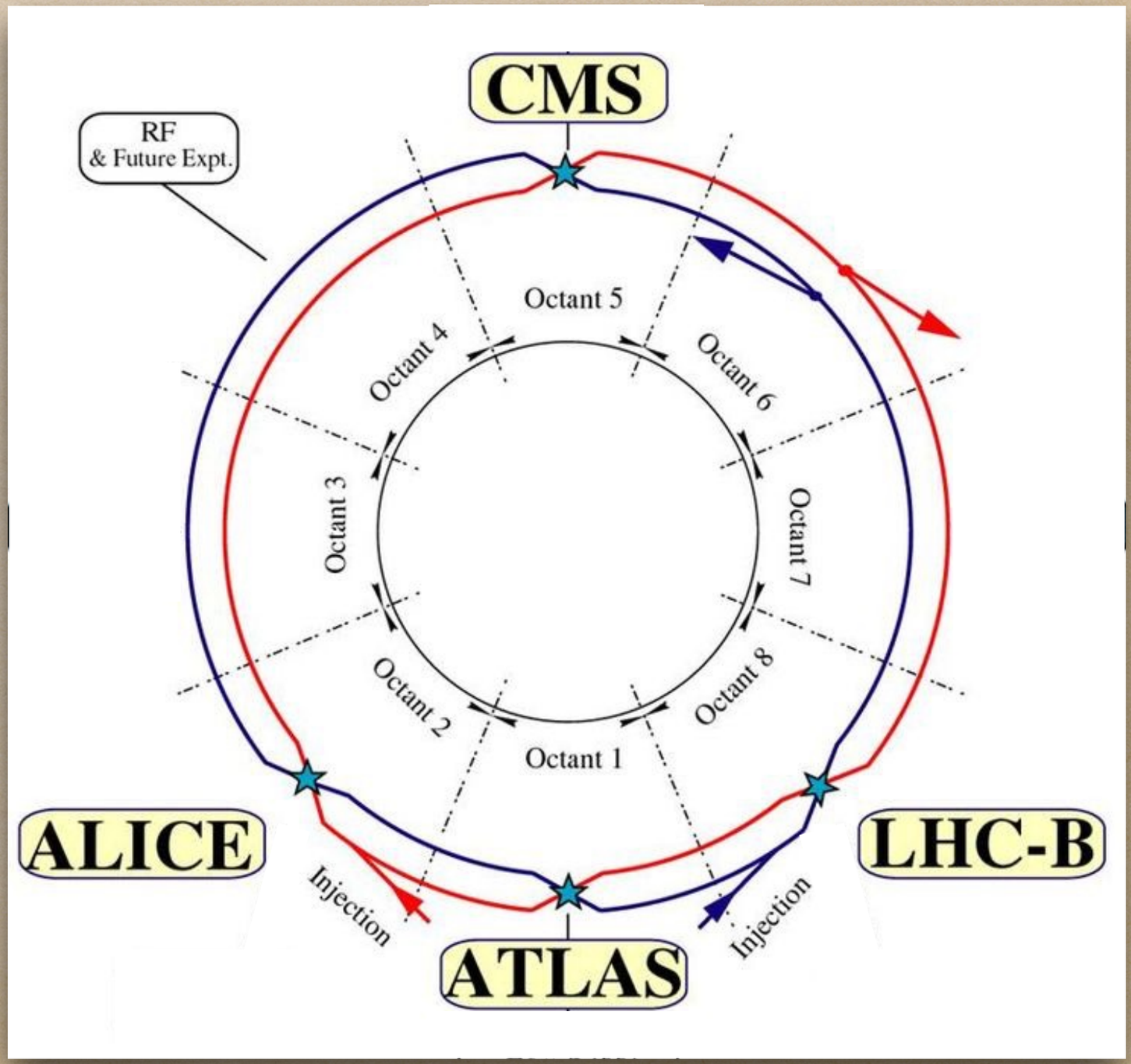
Detectors



The Large Hadron Collider

Detectors

Acceleration

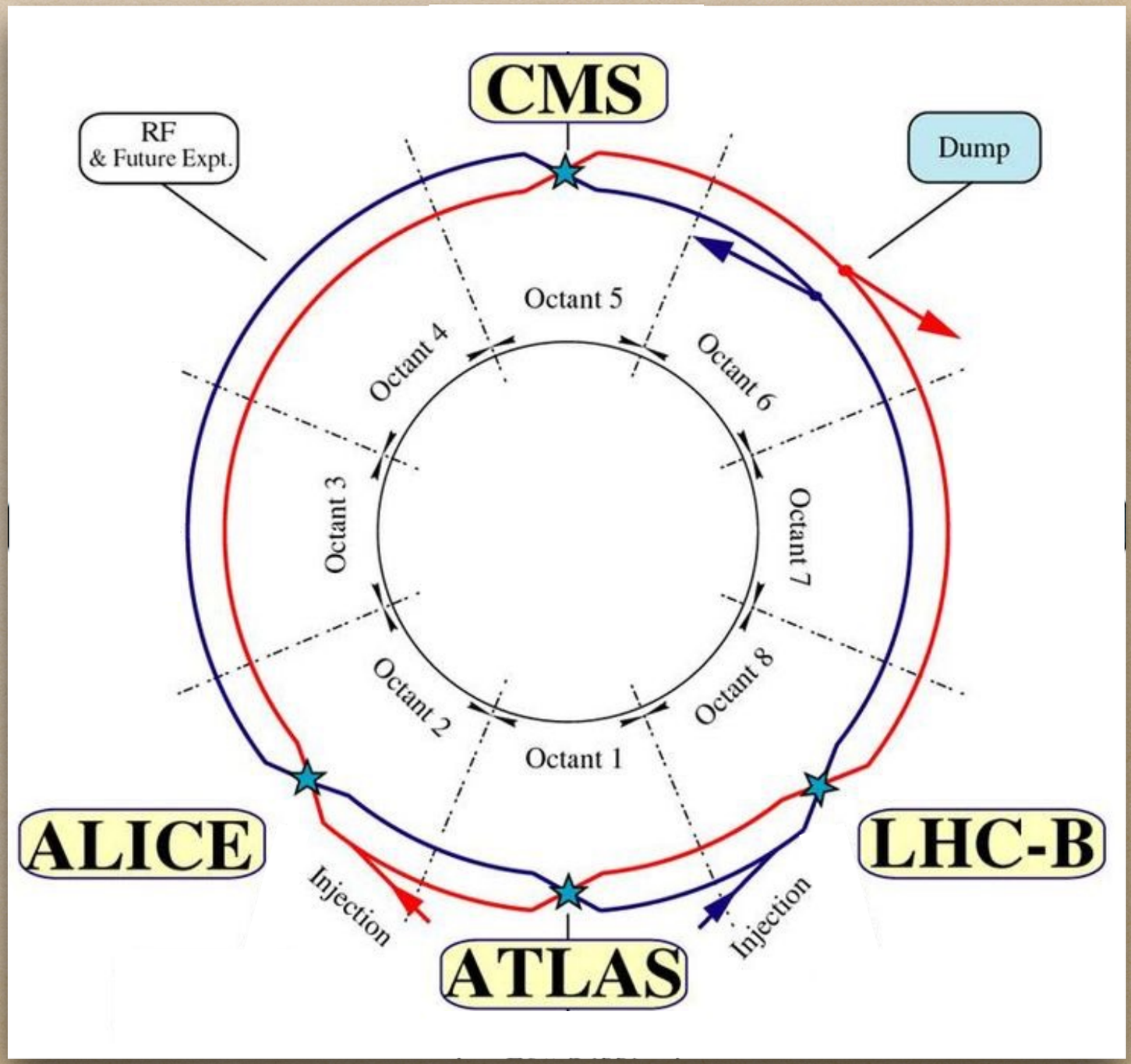


The Large Hadron Collider

Detectors

Acceleration

Beam dump



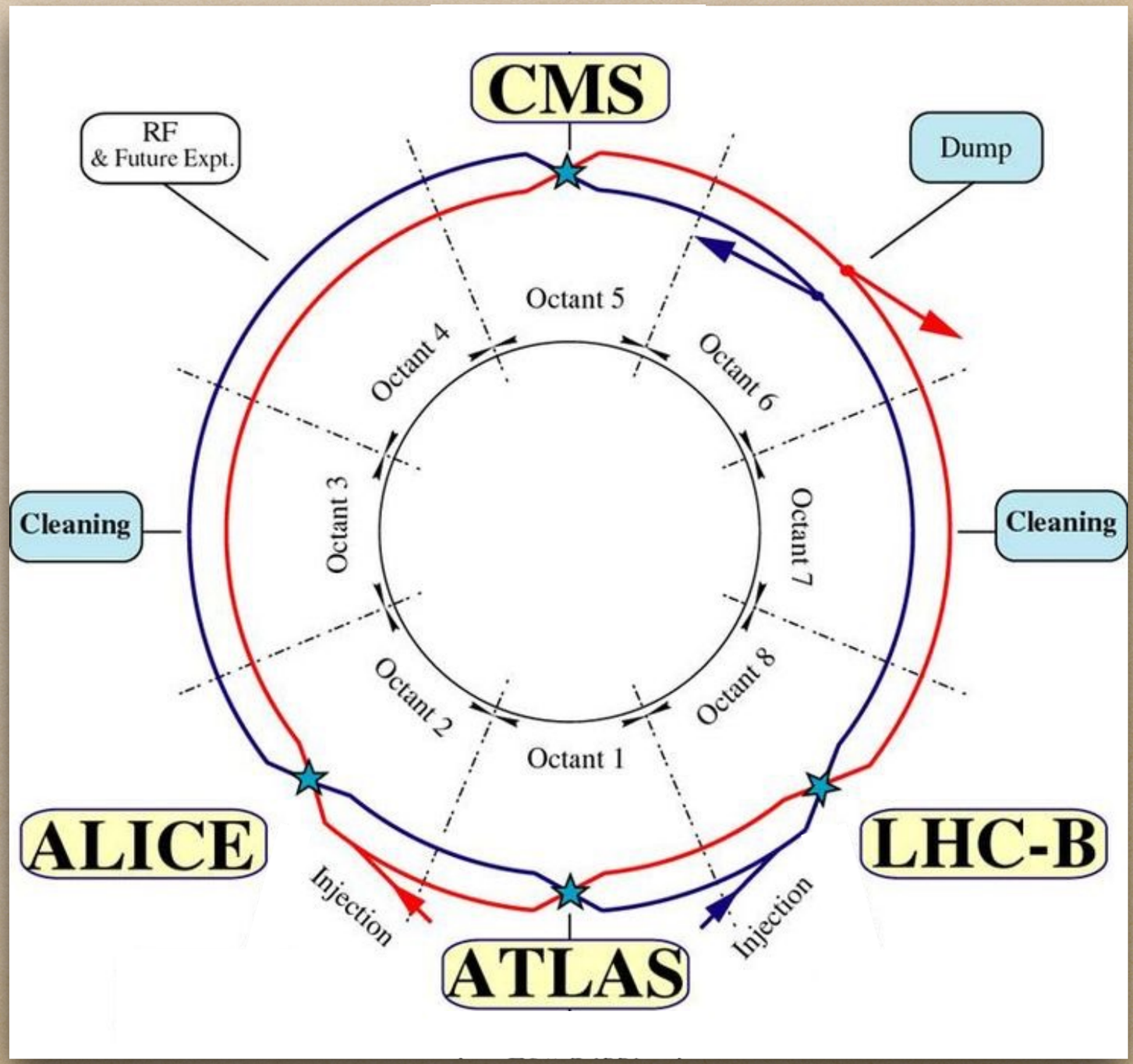
The Large Hadron Collider

Detectors

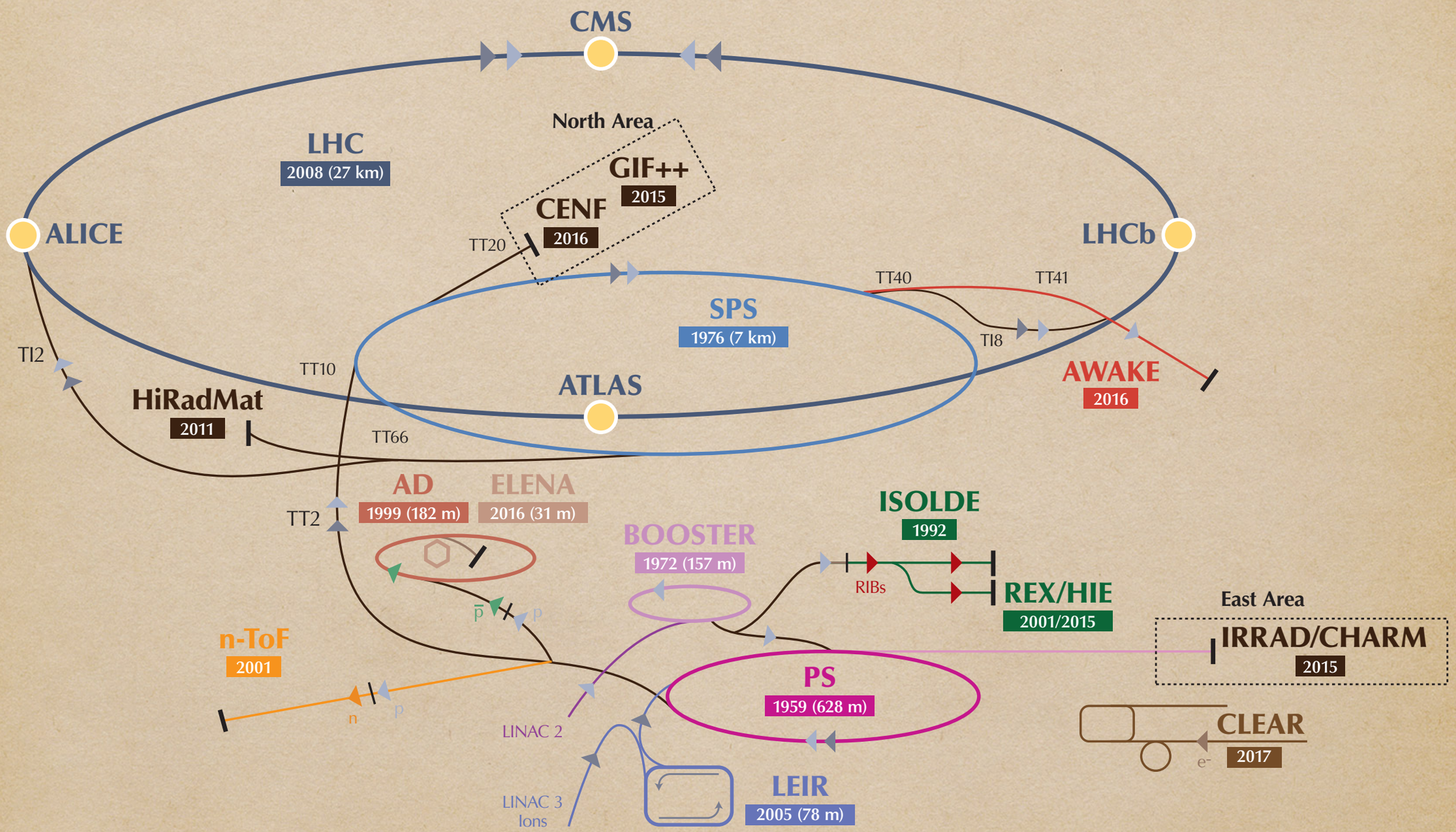
Acceleration

Beam dump

Beam cleaning



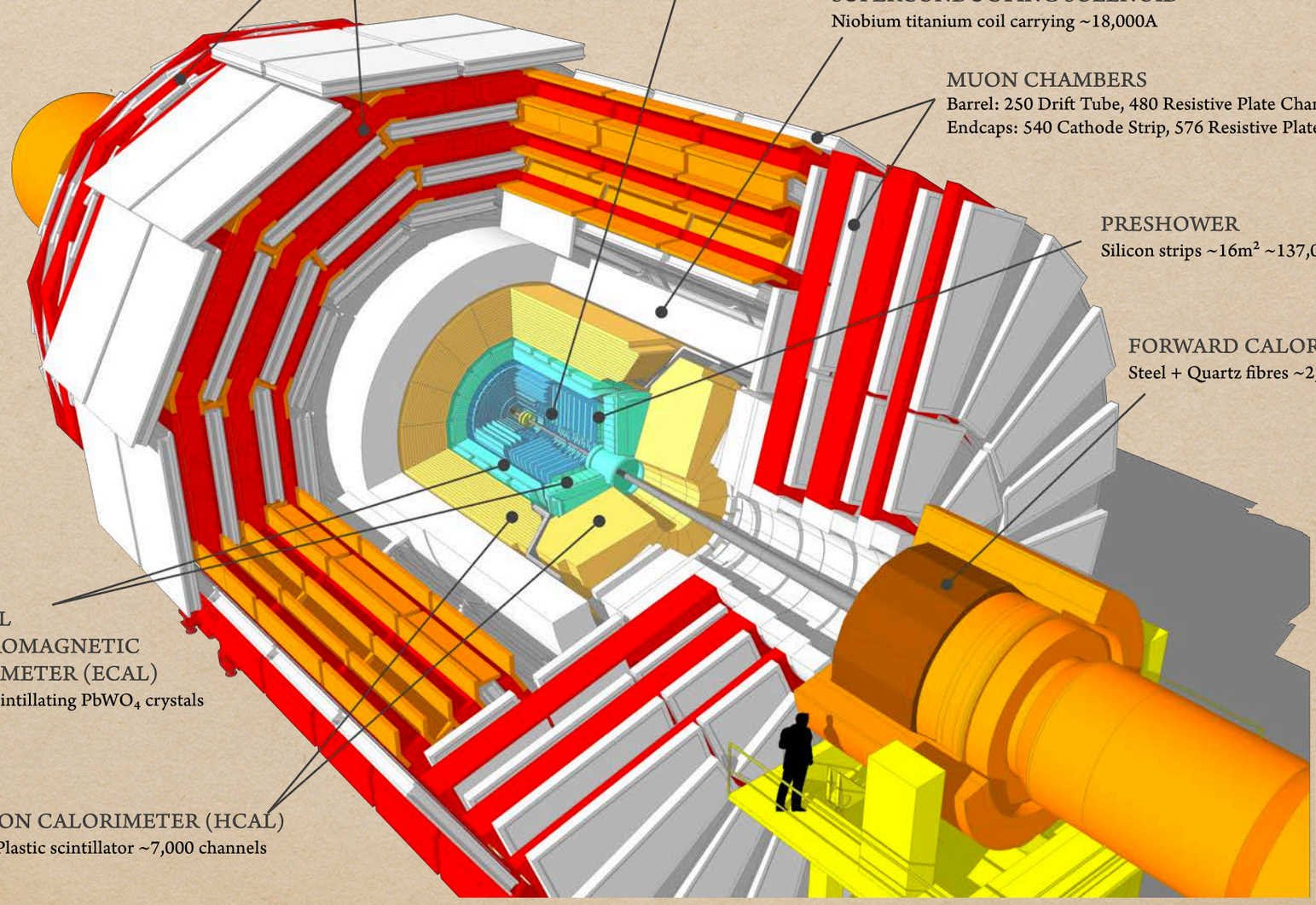
The Accelerator Complex



Detectors

CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T



STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~1m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

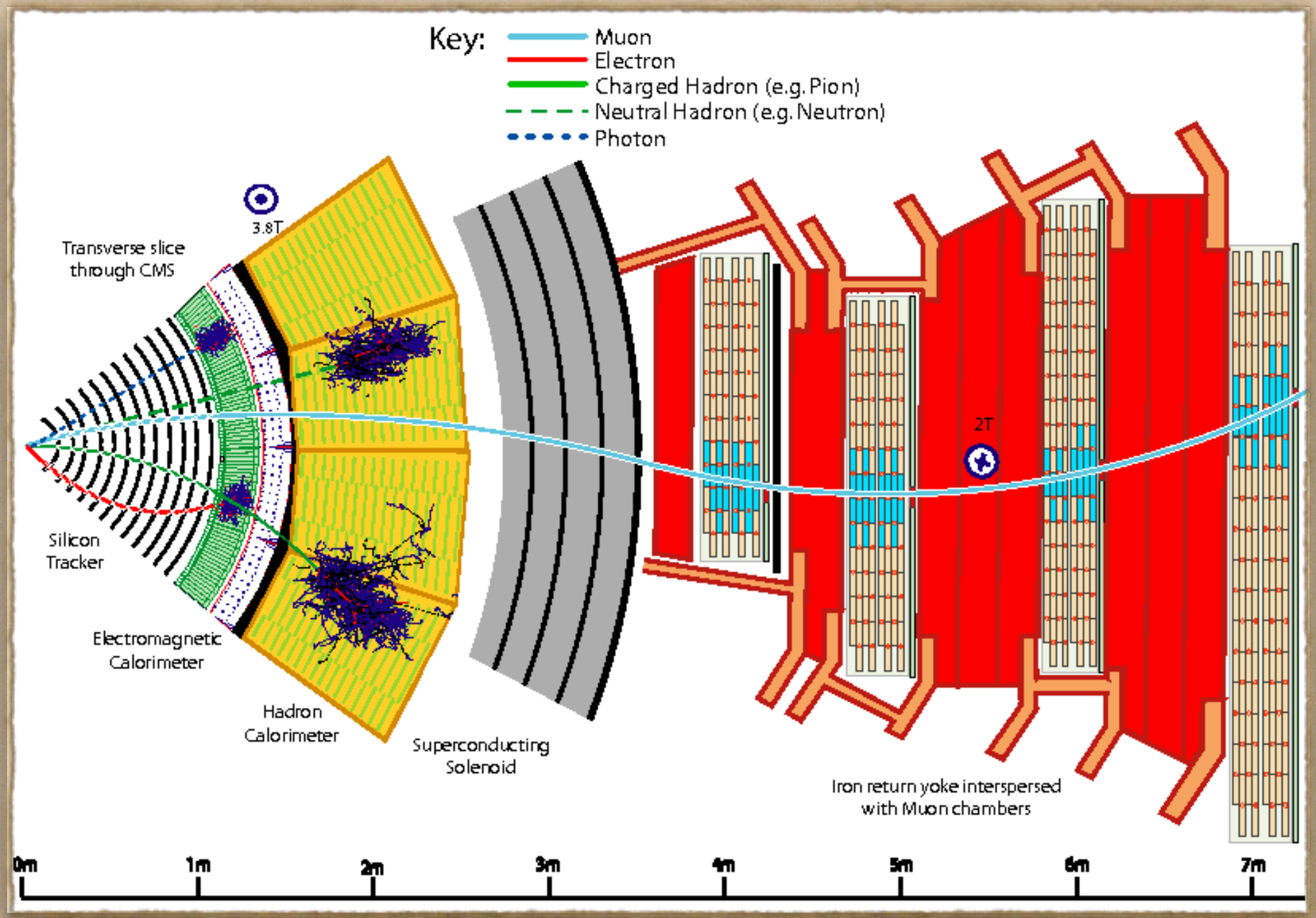
PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Detectors


Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
Transverse slice through CMS
3.8T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0m
1m
2m
3m
4m
5m
6m
7m

3

Tiny particles

What are we made of?

What are we made of?

What is the universe made of?

What are we made of?

What is the universe made of?

Why does everything just “work”?

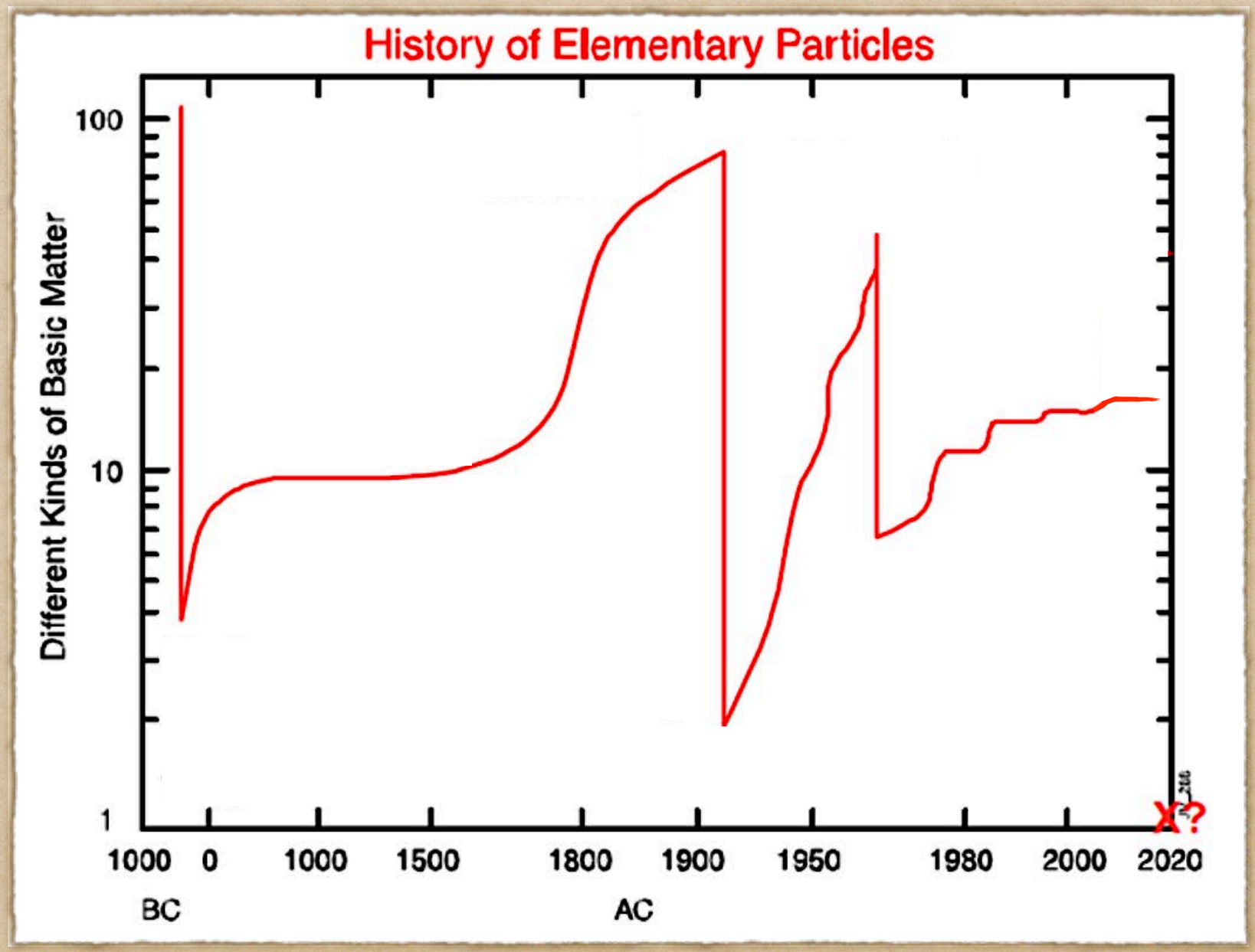
What are we made of?

What is the universe made of?

Why does everything just “work”?

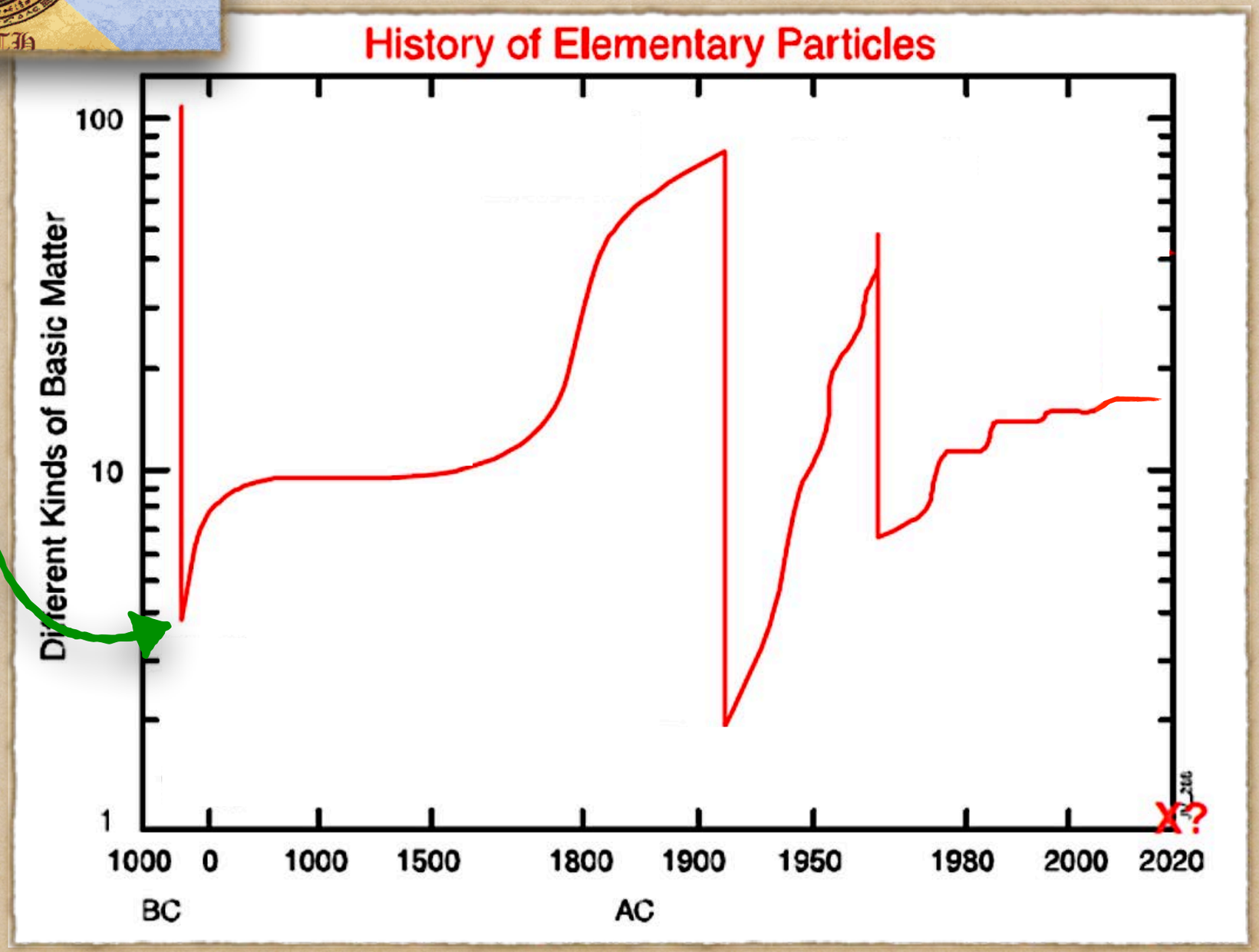
… ?

Basic Bricks of the Universe



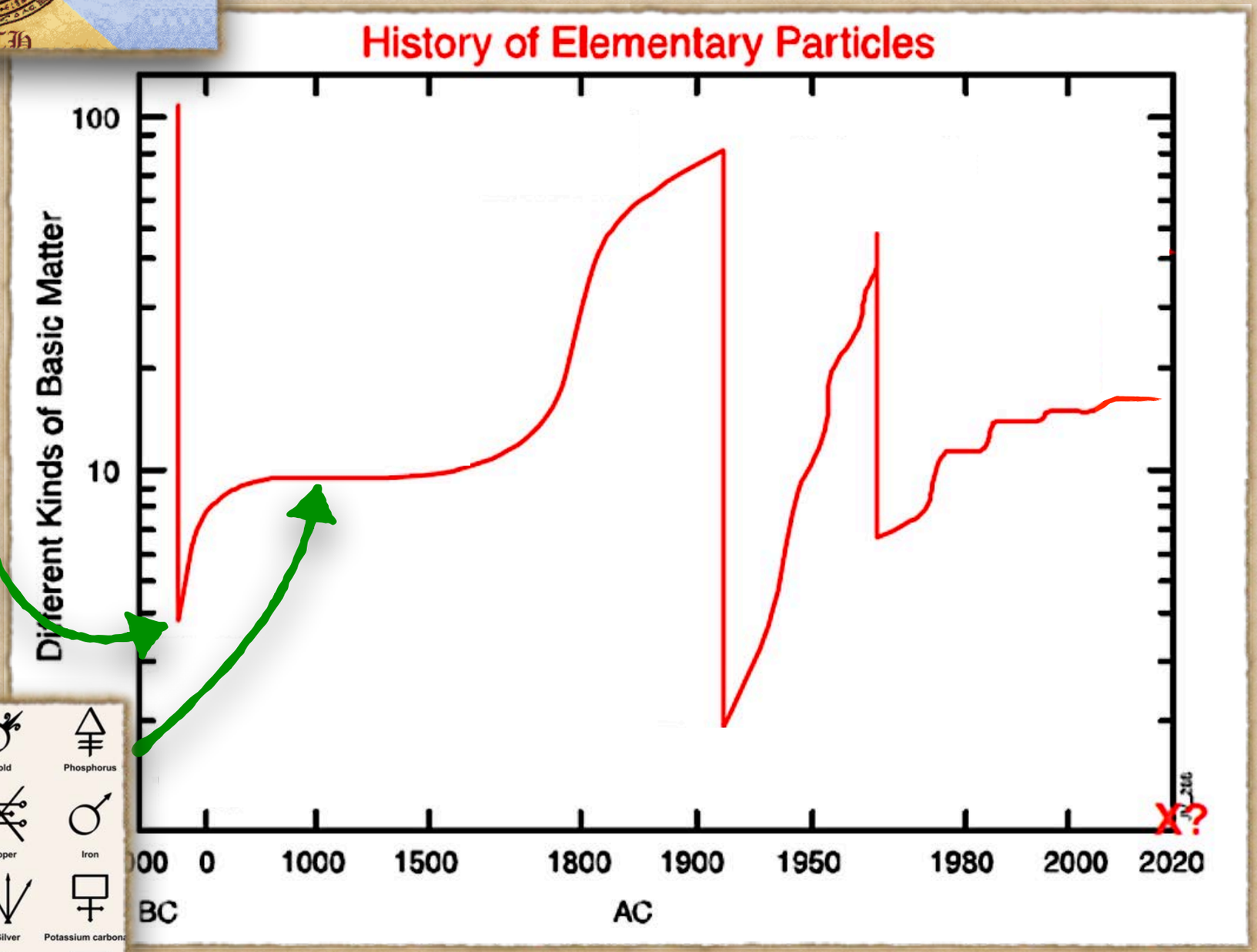
Credit: http://arxiv.org/abs/1311.1769

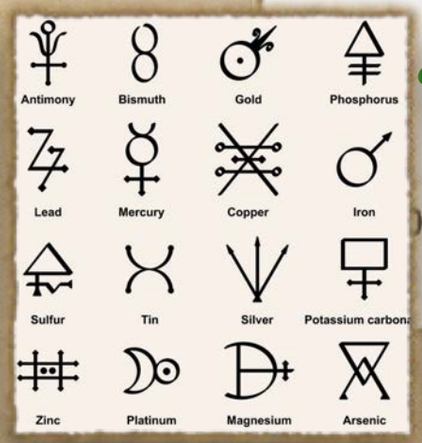
ricks of the Universe



Credit: http://arxiv.org/abs/1311.1769

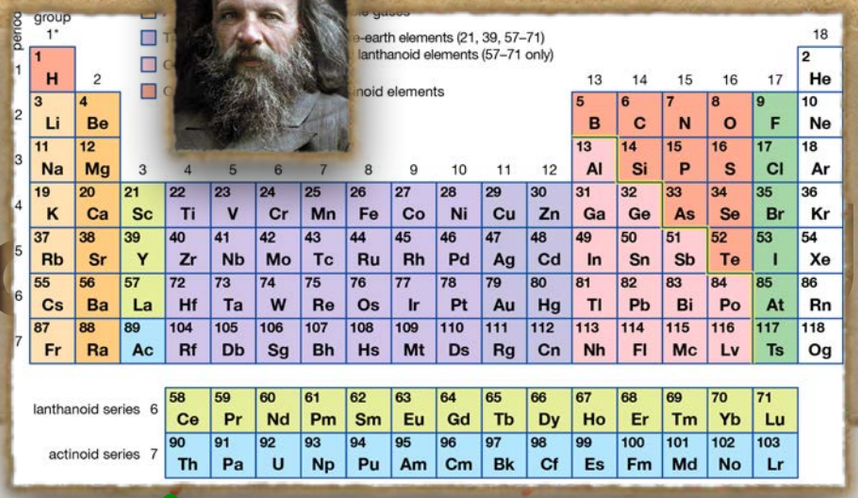
ricks of the Universe

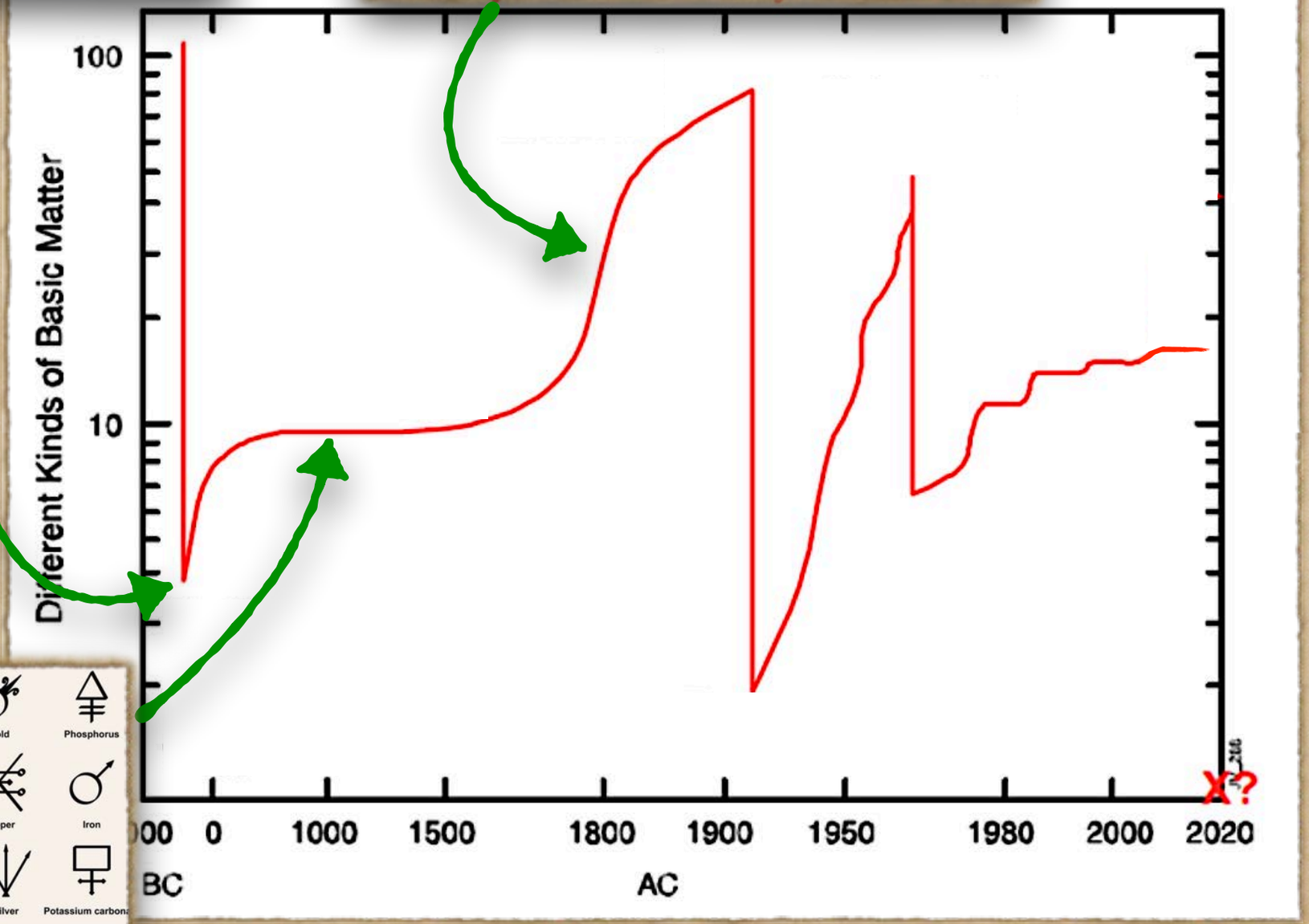


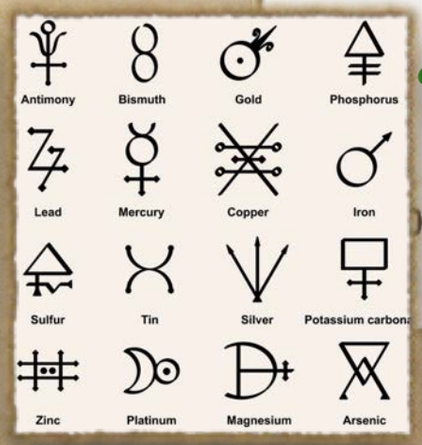


Credit: http://arxiv.org/abs/1311.1769

...ori... ...niverse

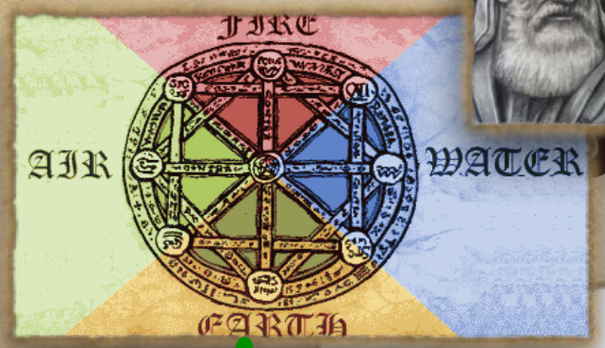


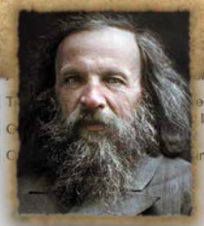


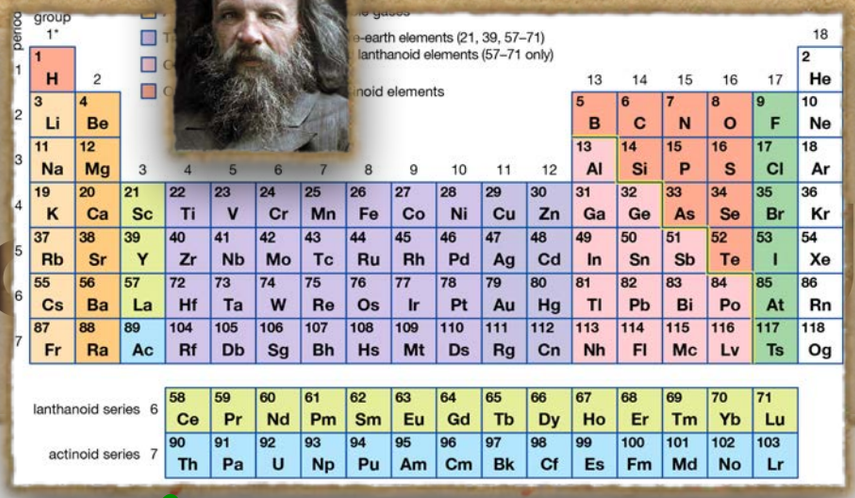


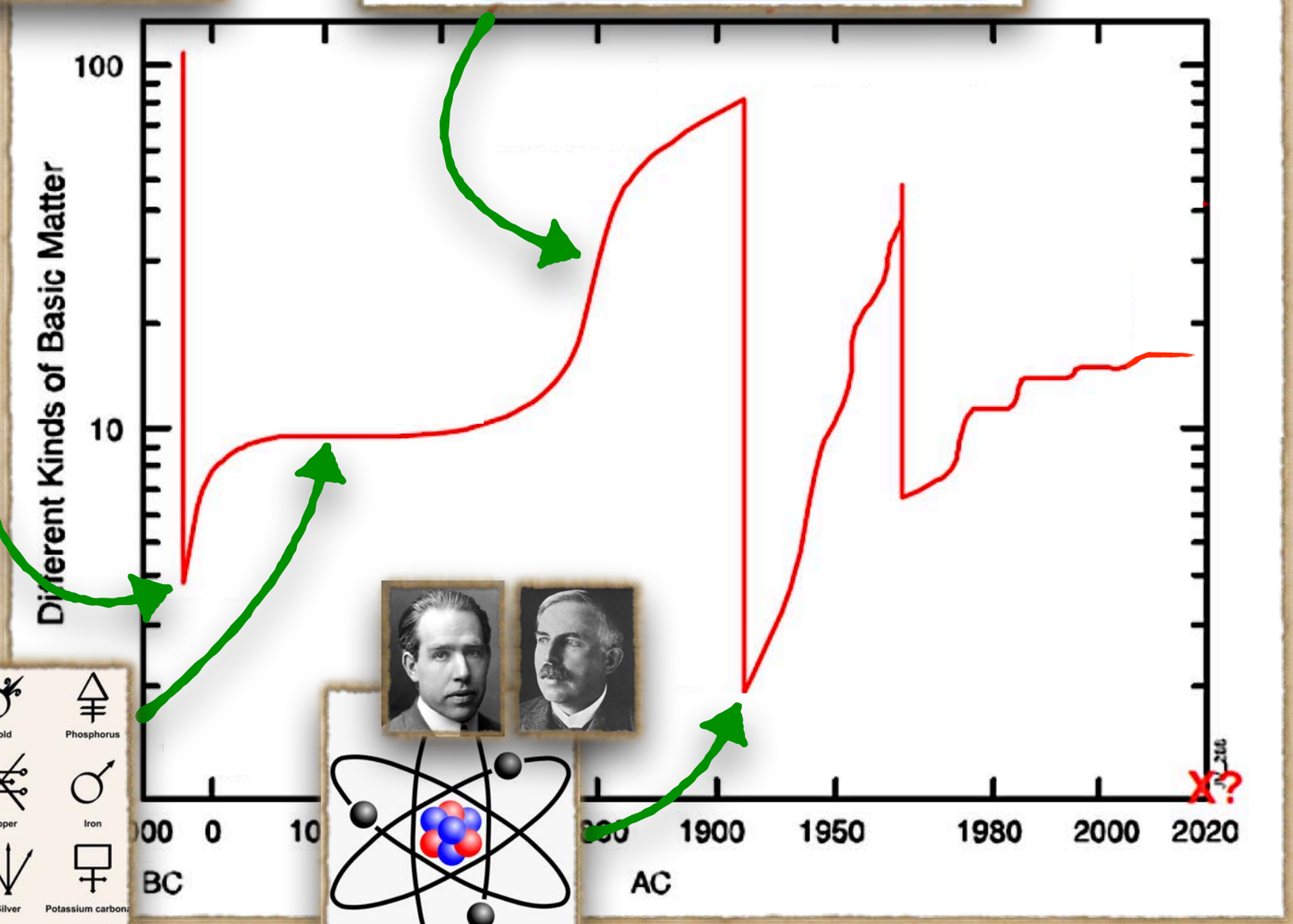
Credit: http://arxiv.org/abs/1311.1769

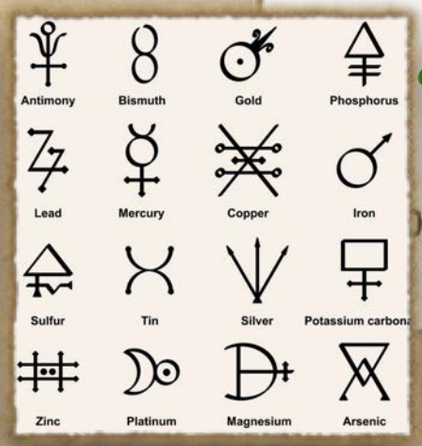
...oric ...niverse











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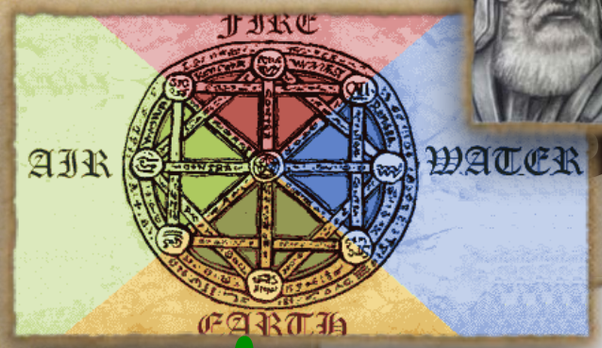

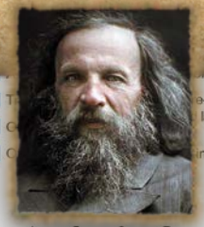

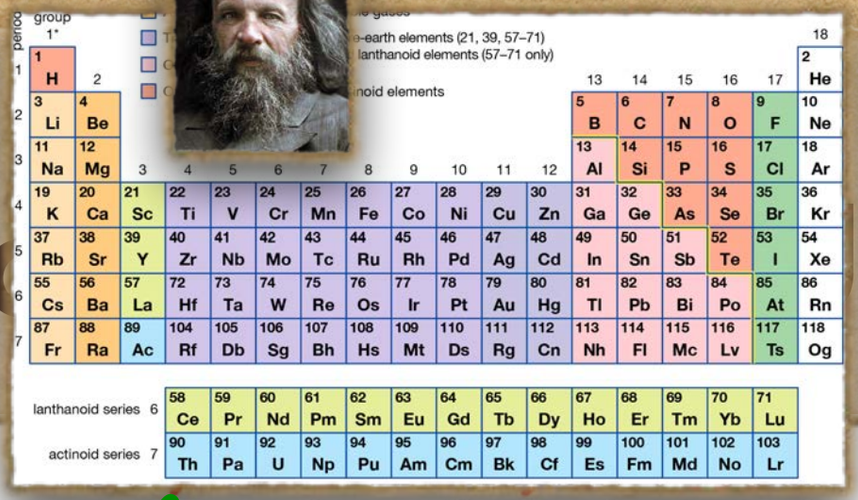

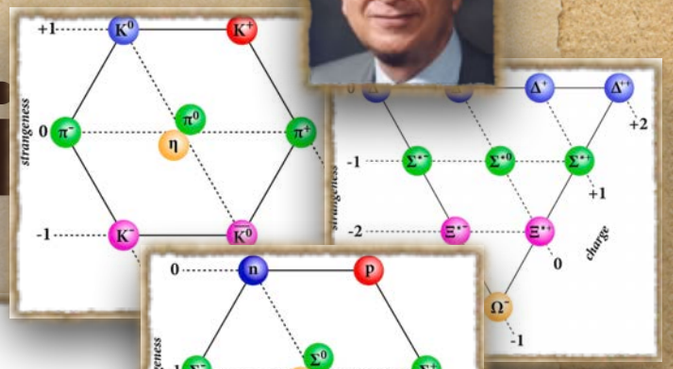

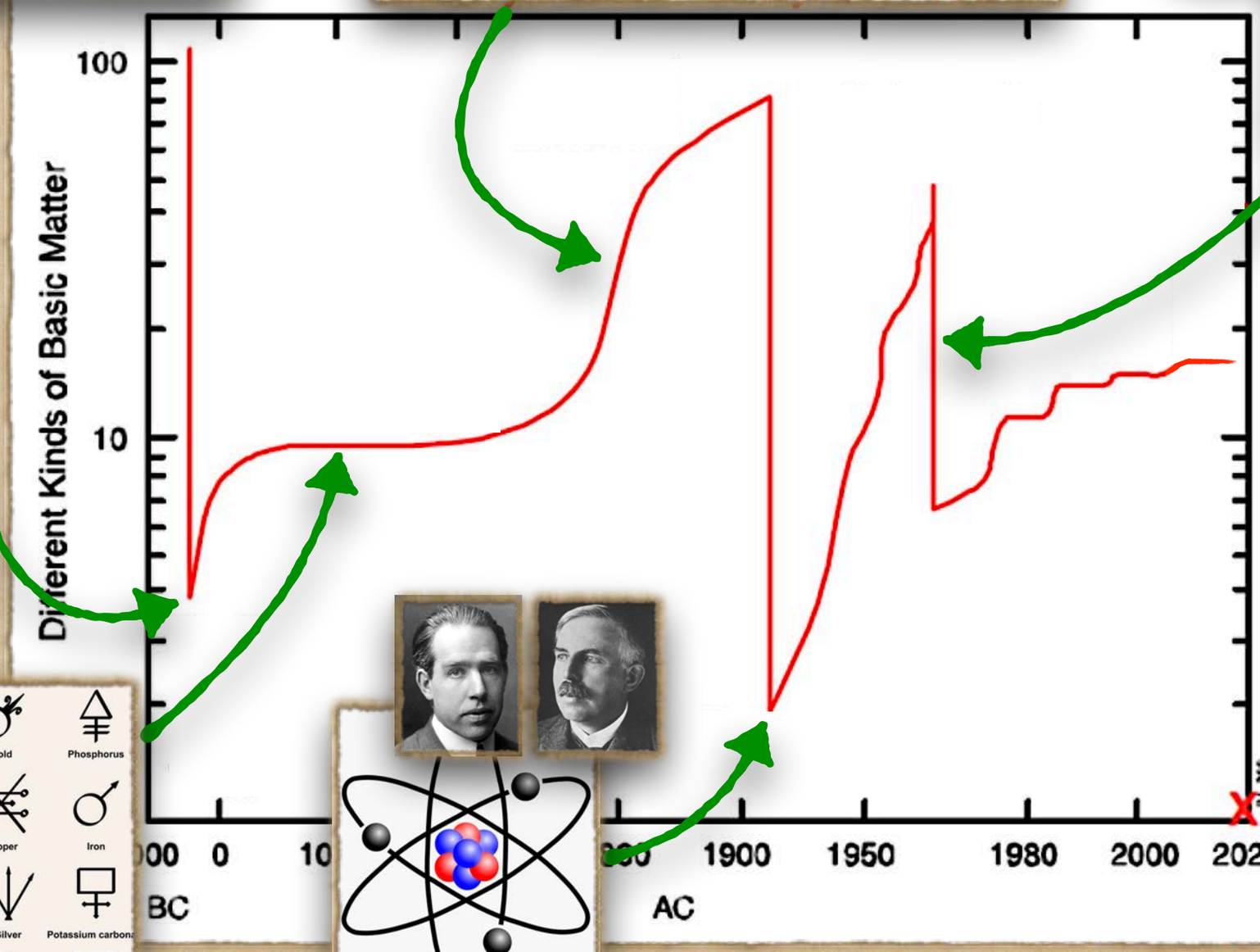

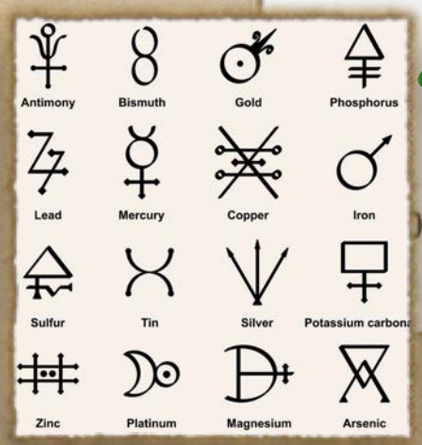

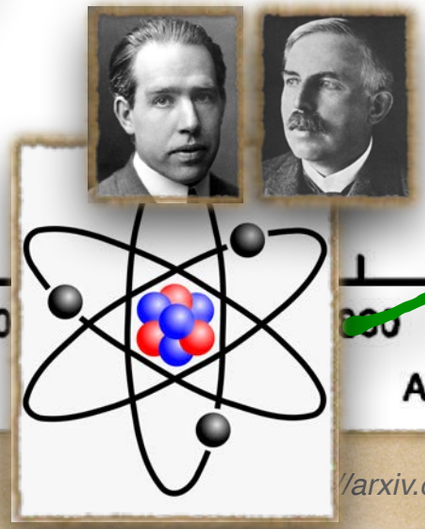

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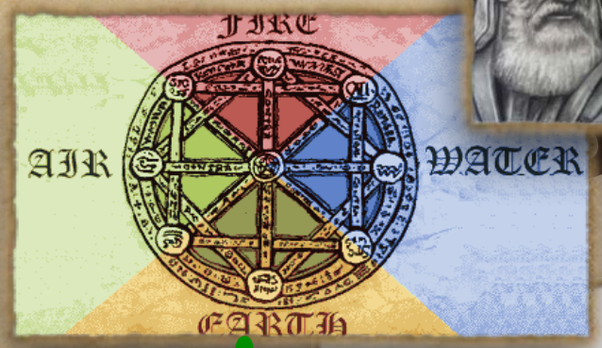

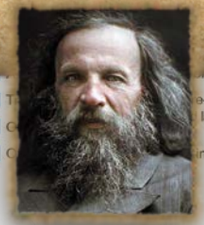

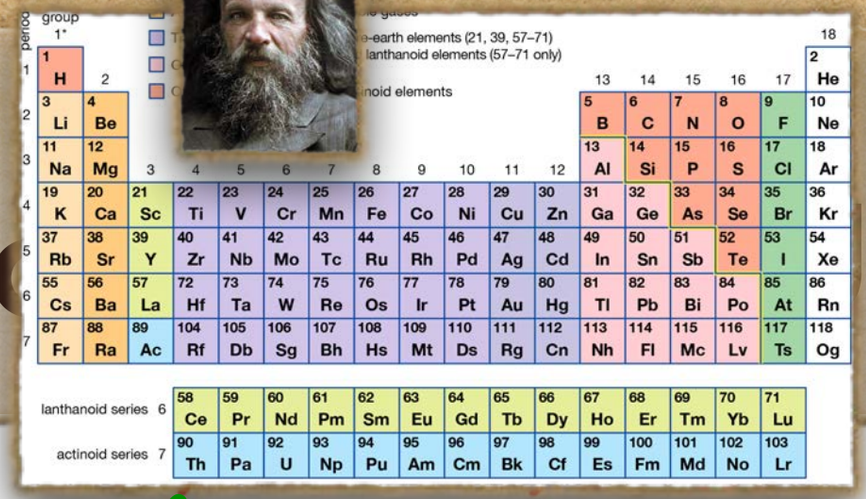

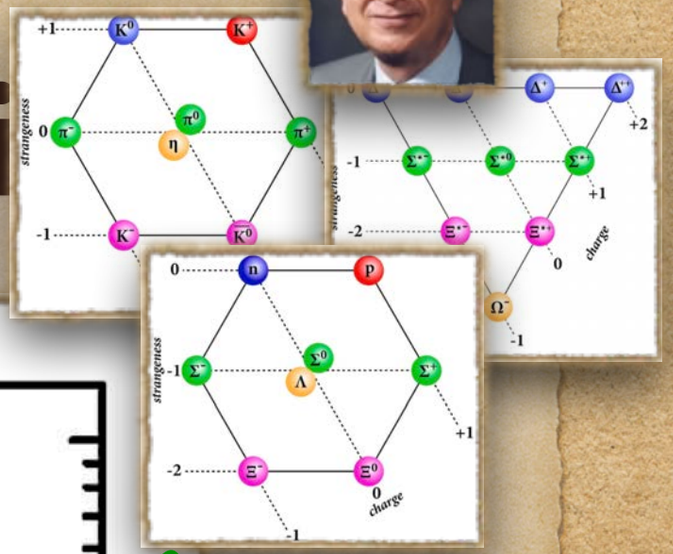

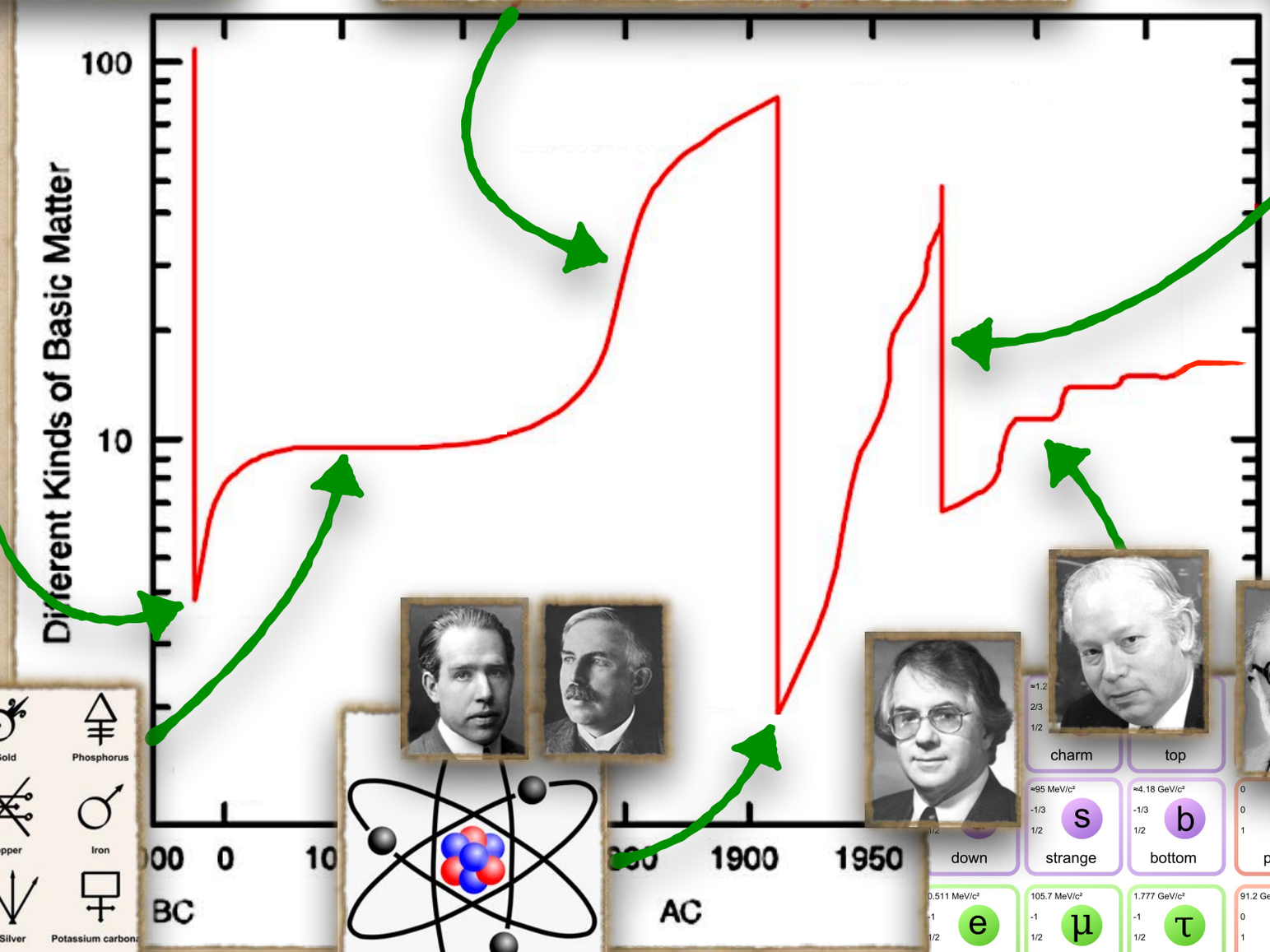

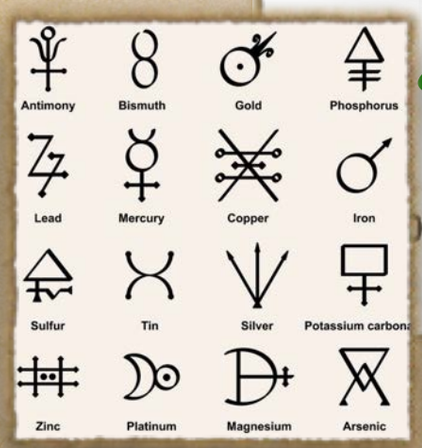

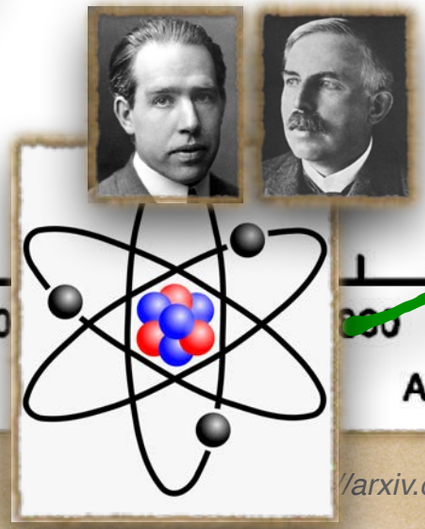

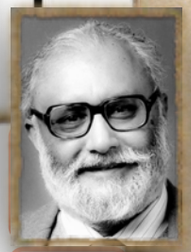

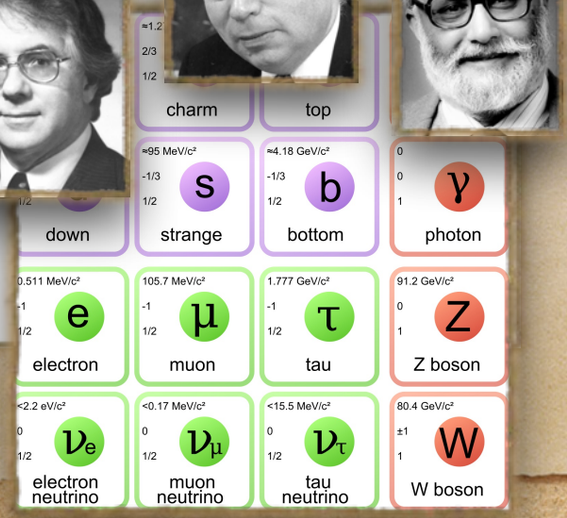

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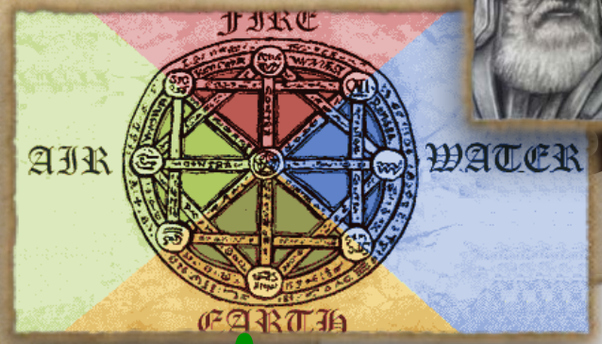
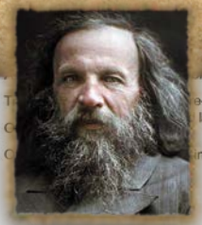
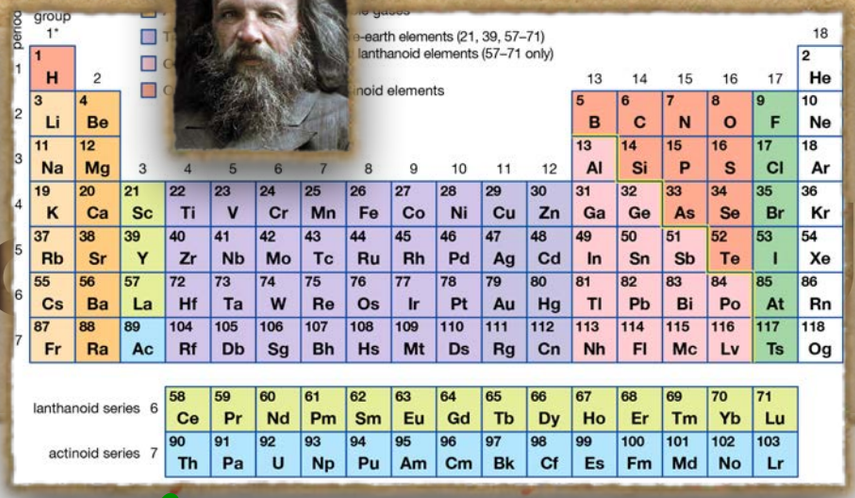
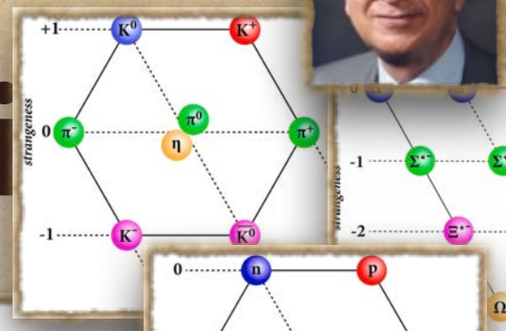
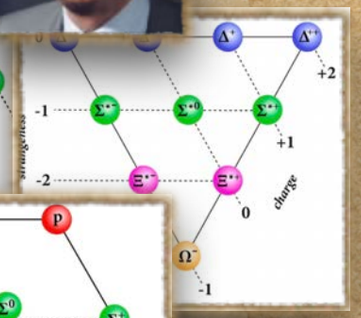
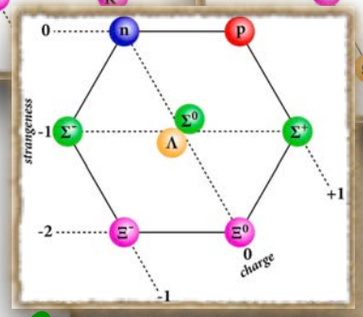


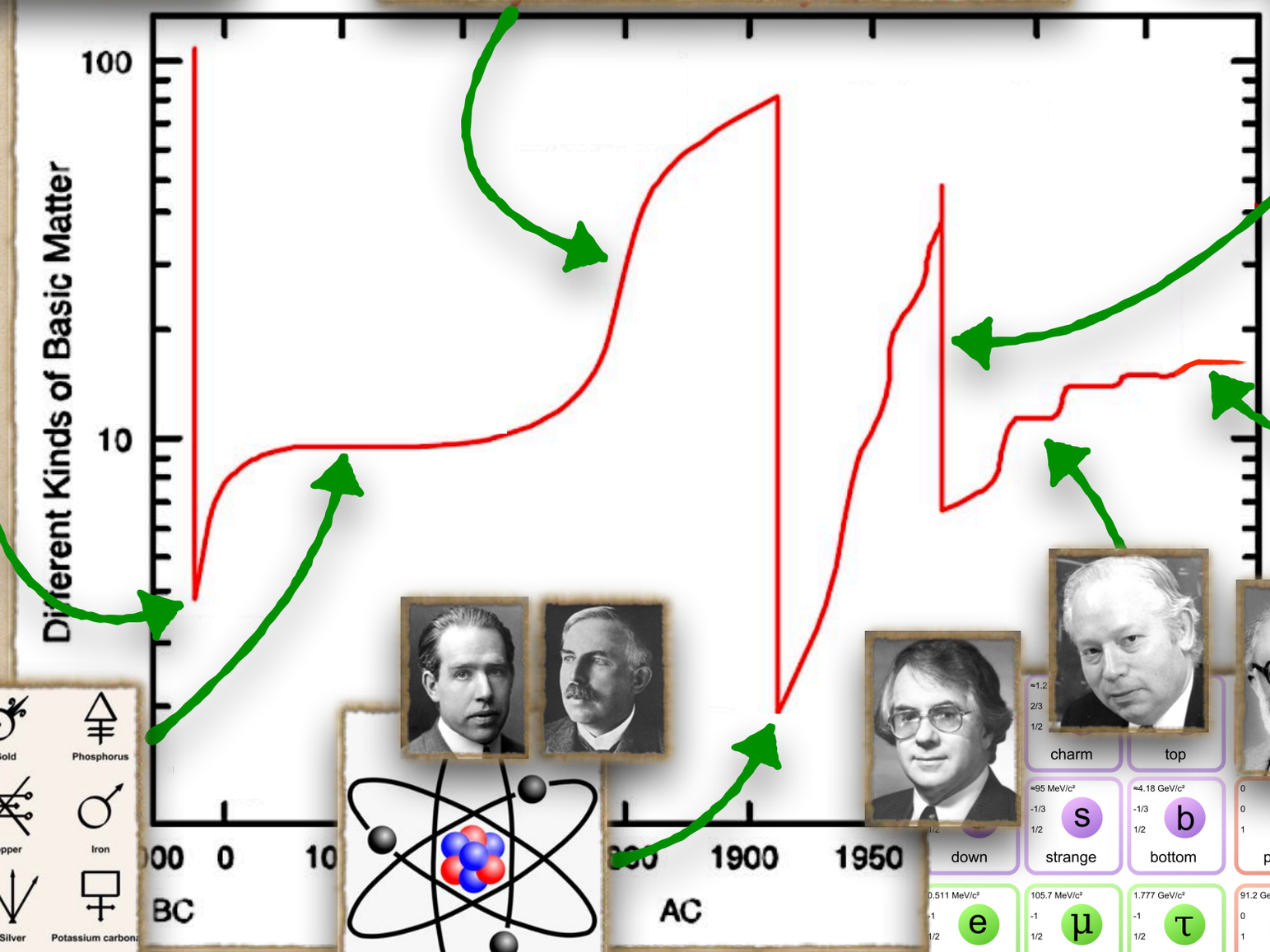


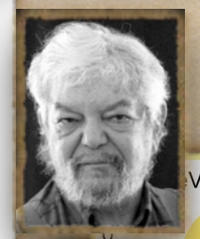


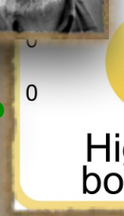


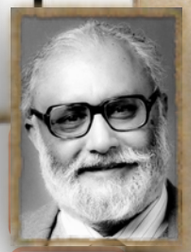


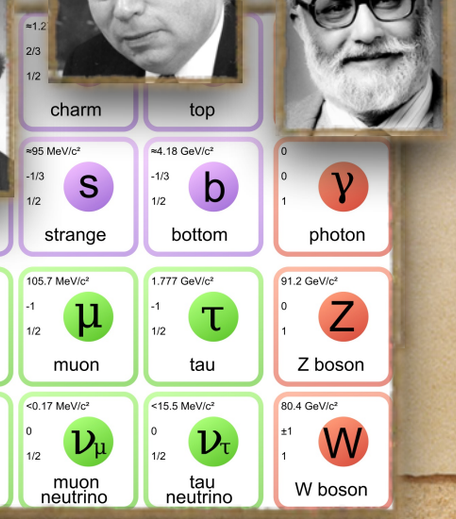






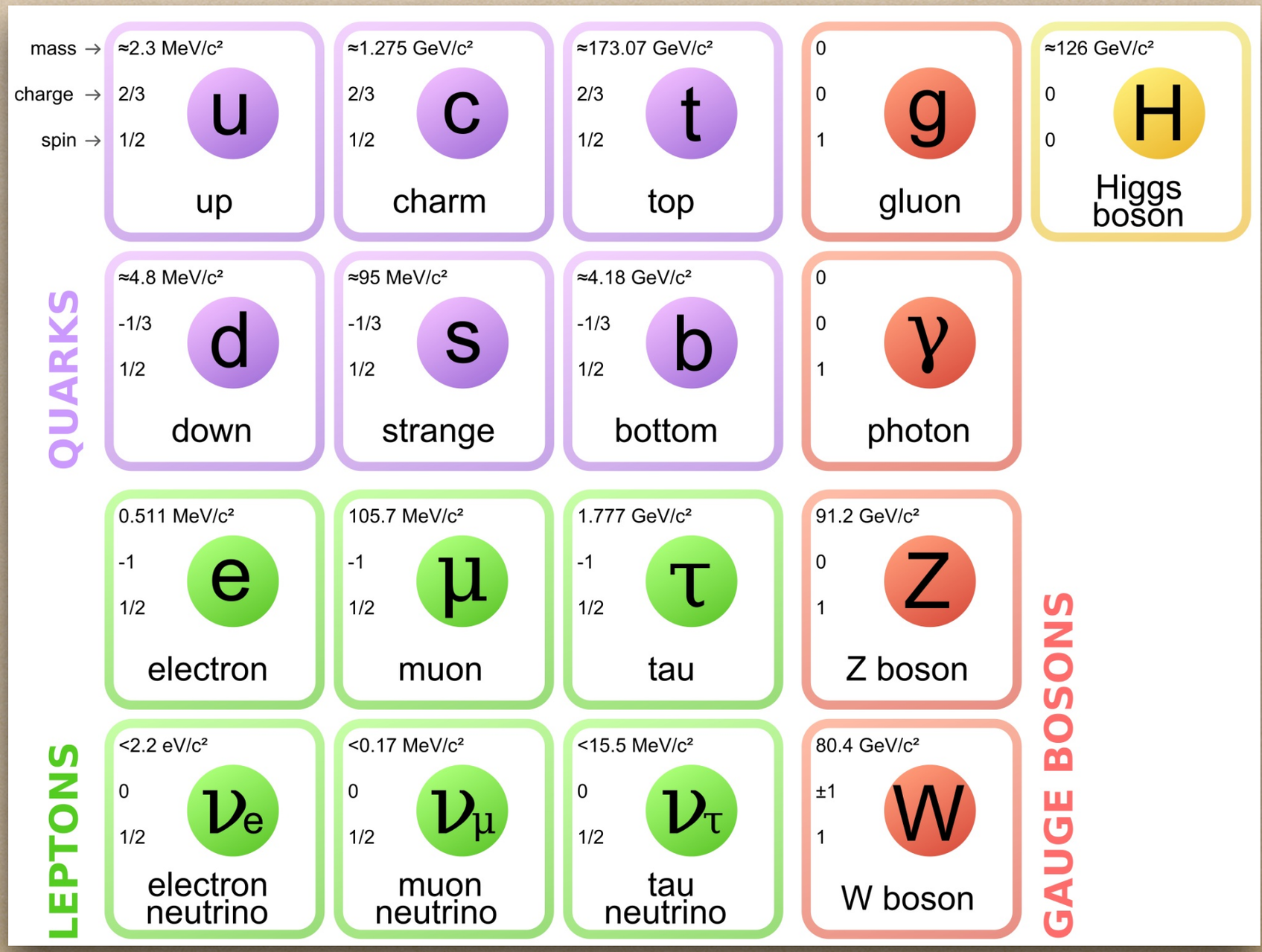






17 particles

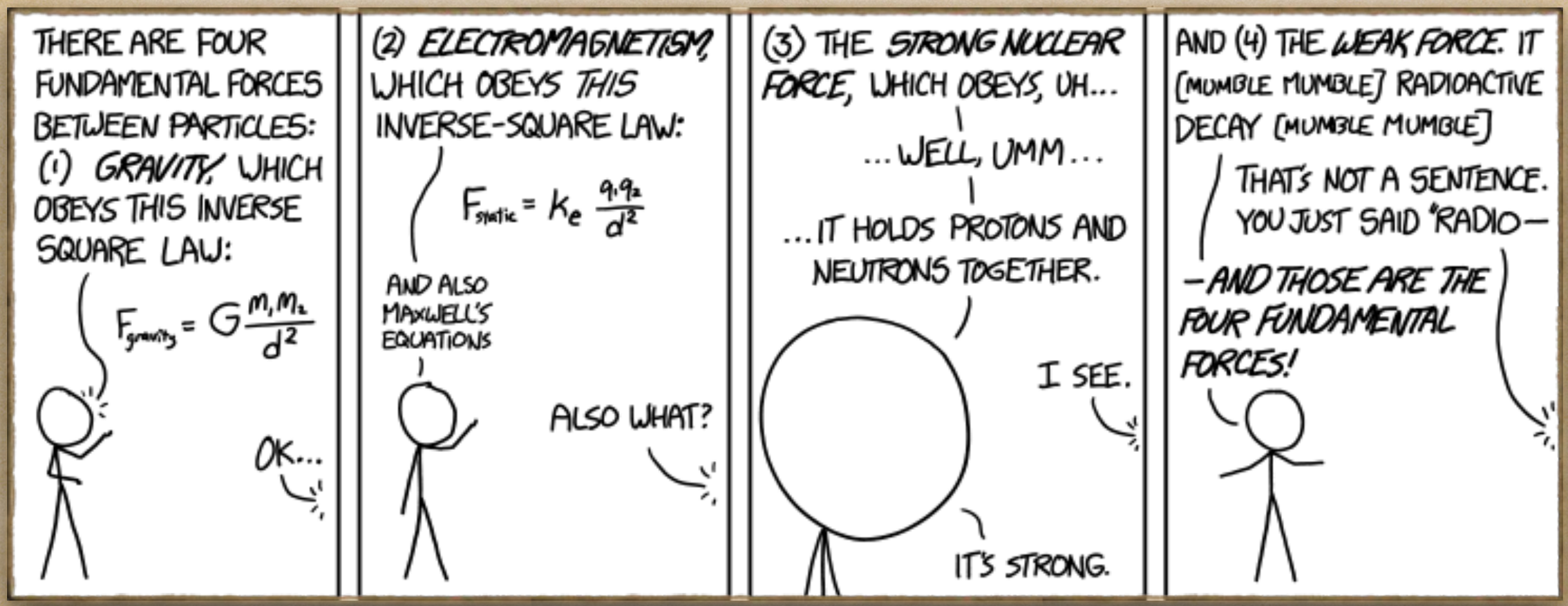
The Standard Model



4

High Energy

High Energy Physics



How do we do it?

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Black Box Mechanism:

we know what we put in
we measure what comes out
use statistics to deduce what happened in between

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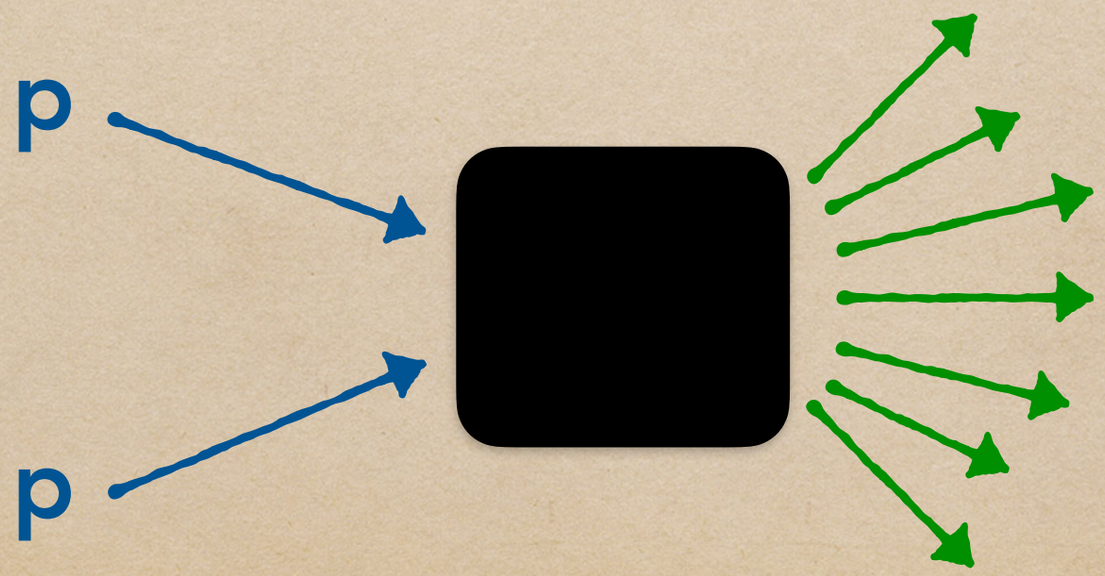

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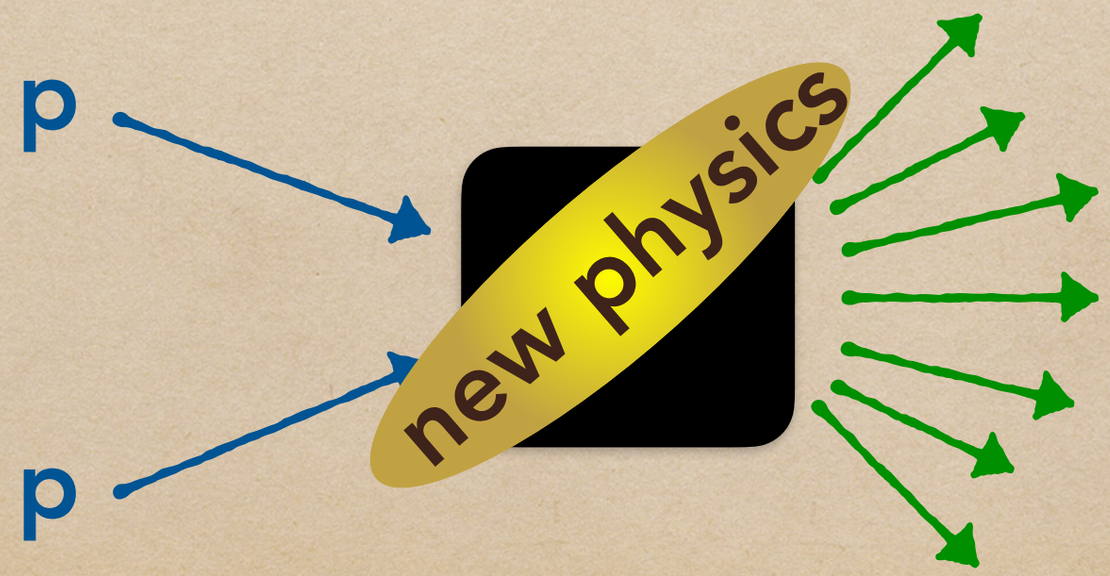

Statistics!

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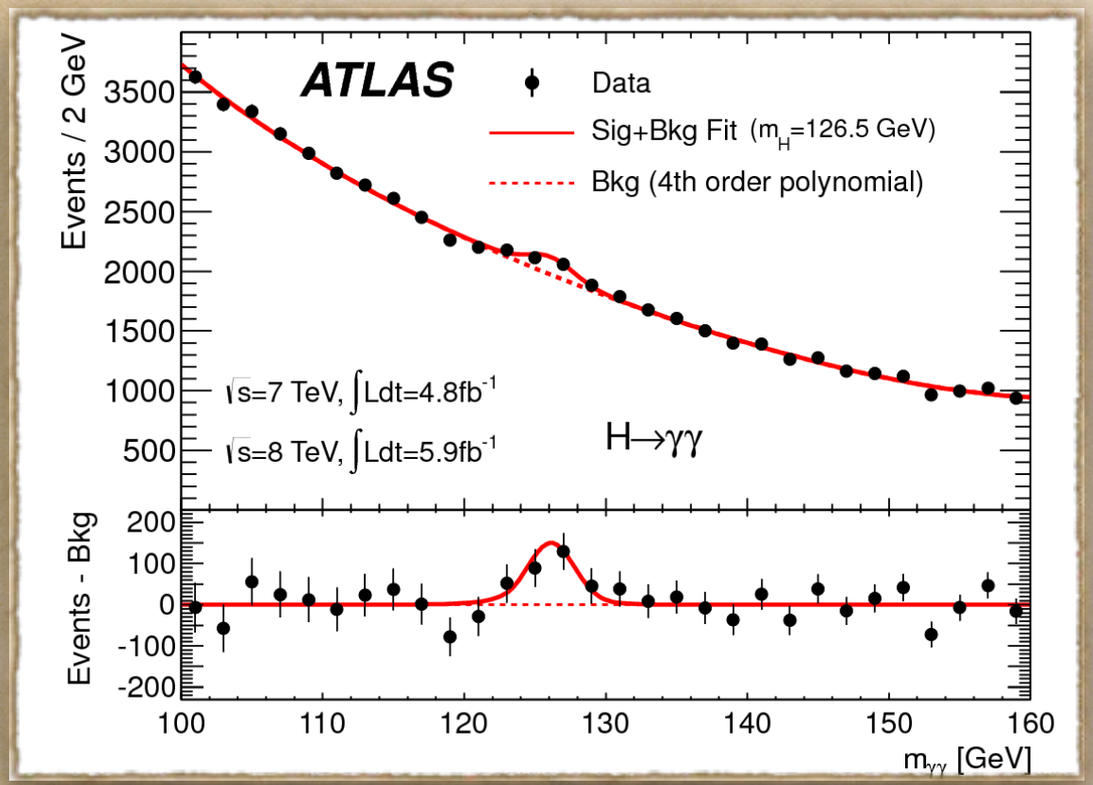
Higgs found!



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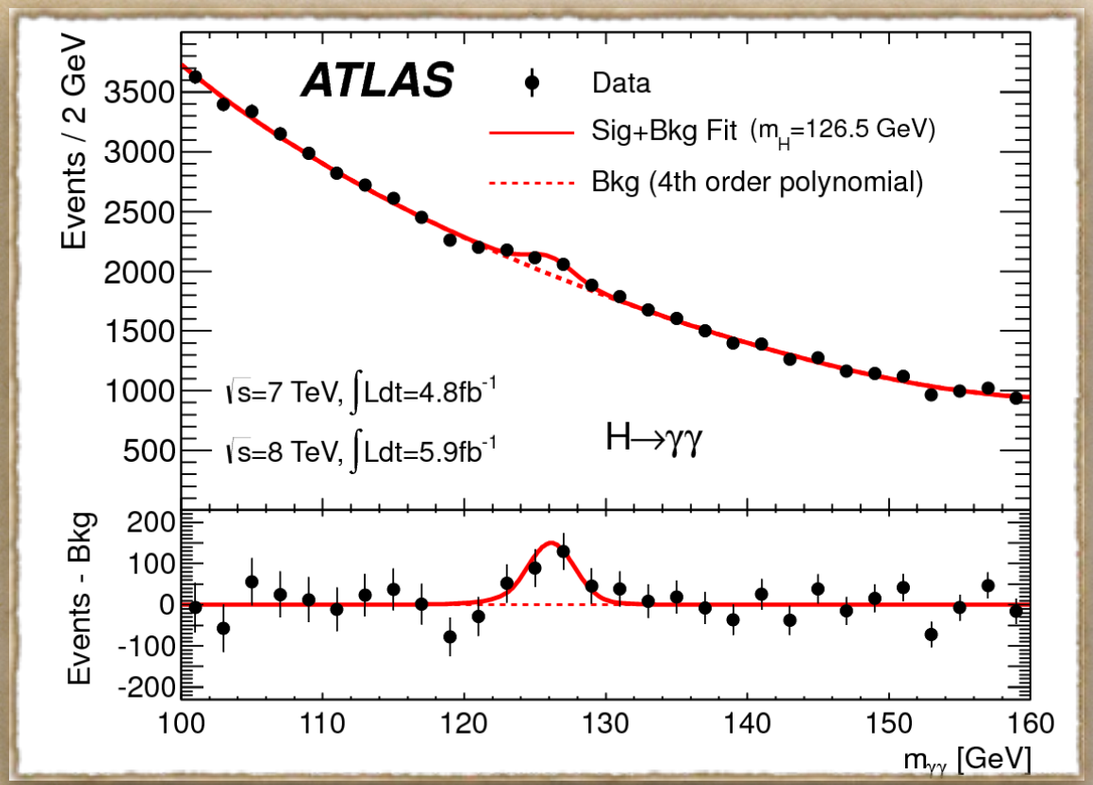
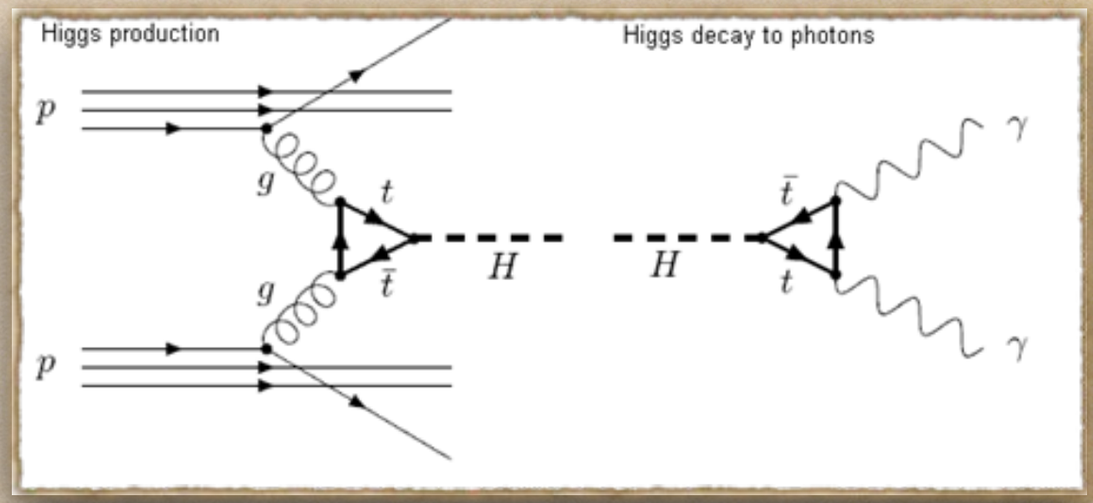


Example process



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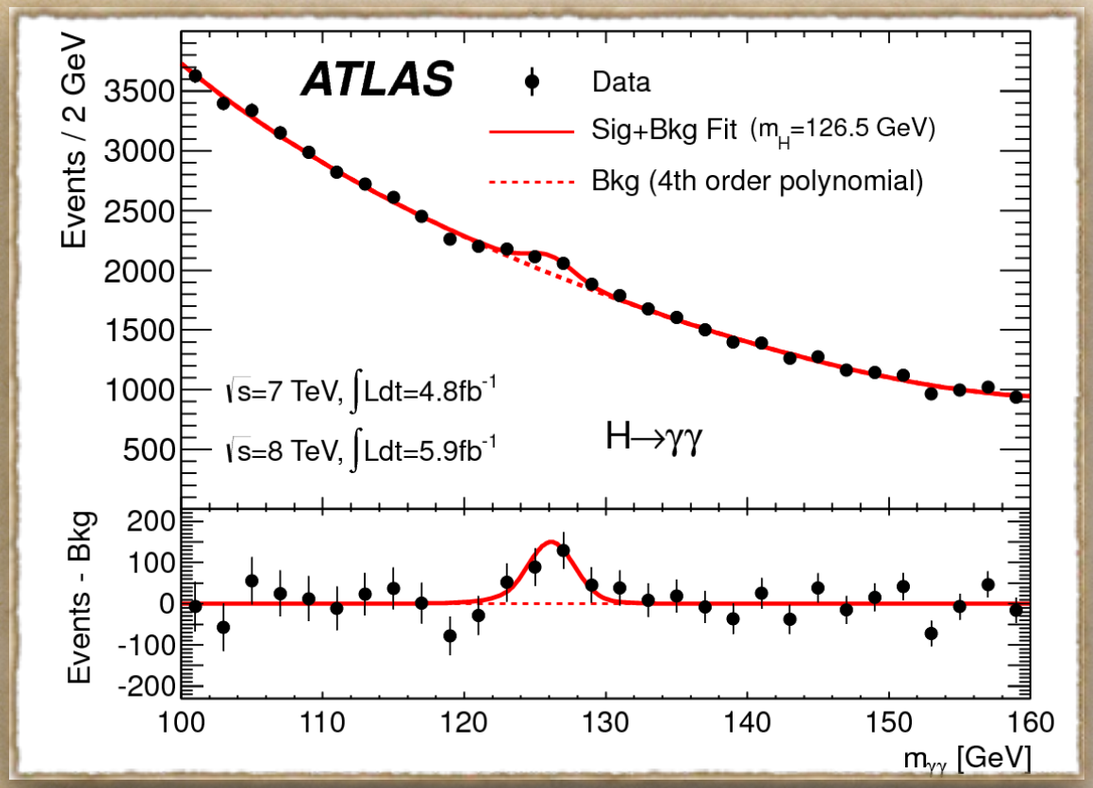

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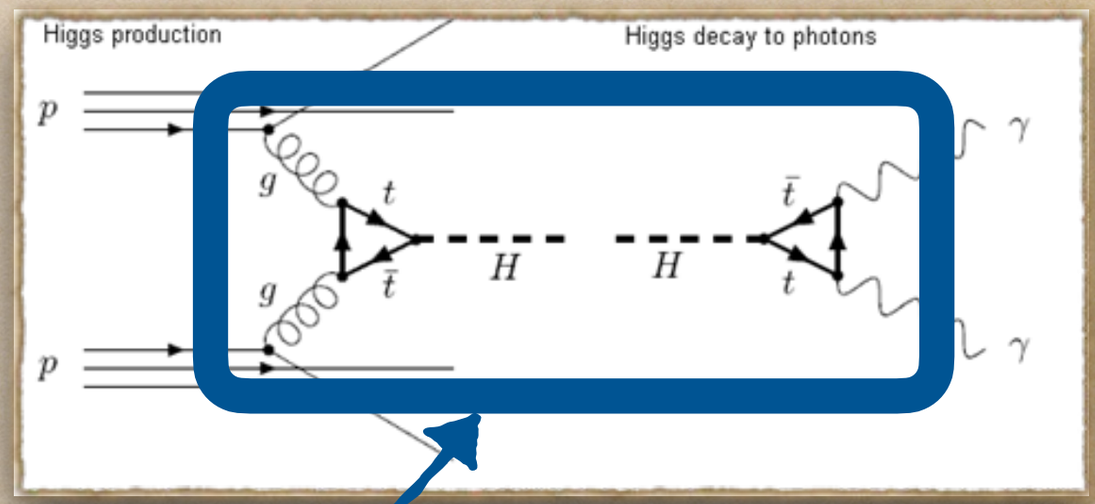
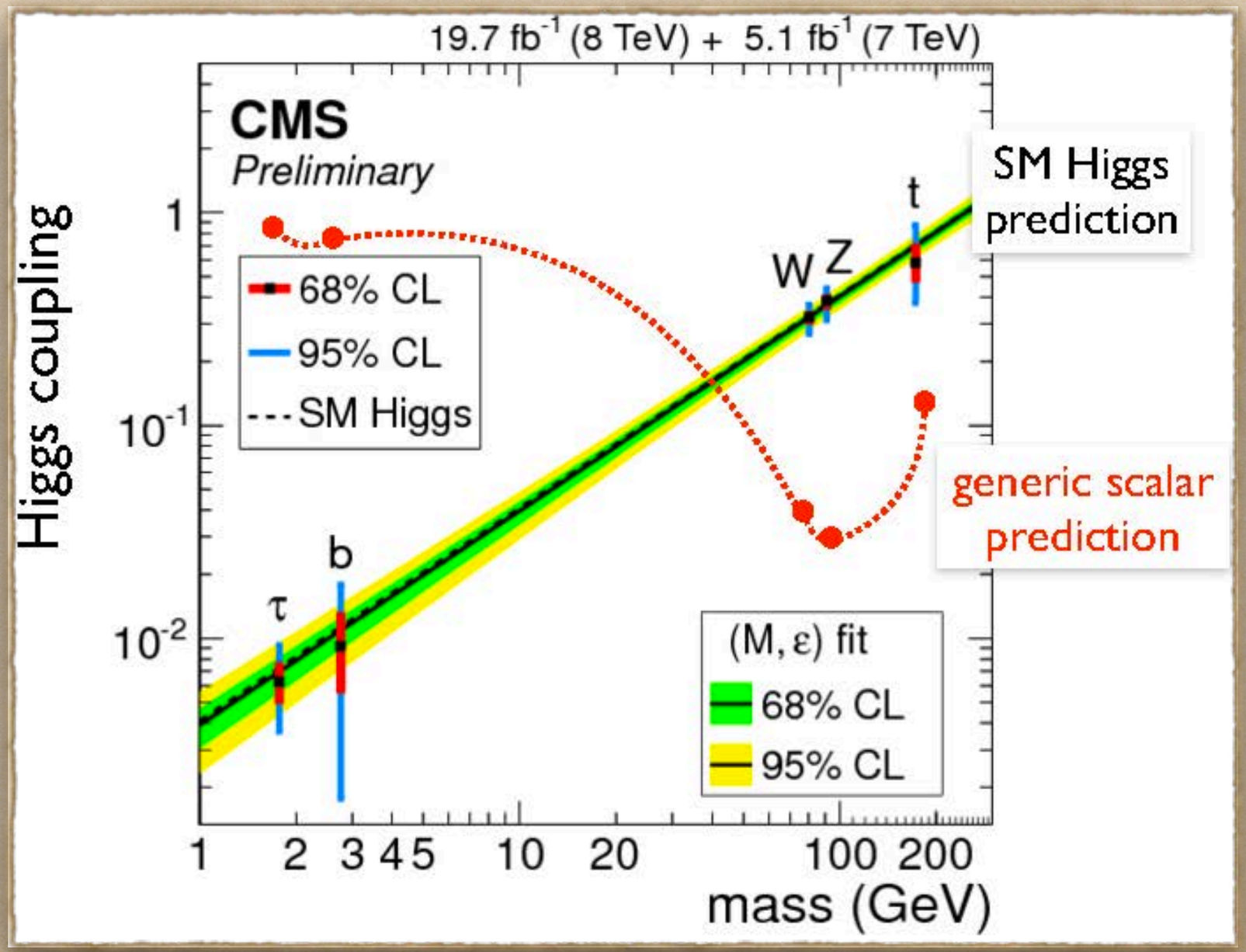


Black box:

Can be everything; we don't know (Higgs, photon, gluon, ….)

Use **statistics** and **probability** to peek into process

It walks like a Higgs...



Inside the Black Box

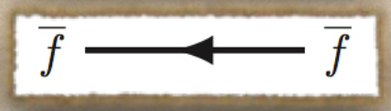
Feynman diagrams

Inside the Black Box

Feynman diagrams

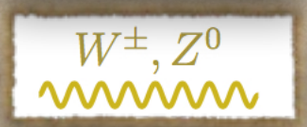
Notations

quark, lepton 

antiquark, antilepton 

photon 

gluon 

weak boson 

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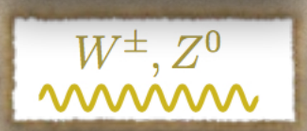
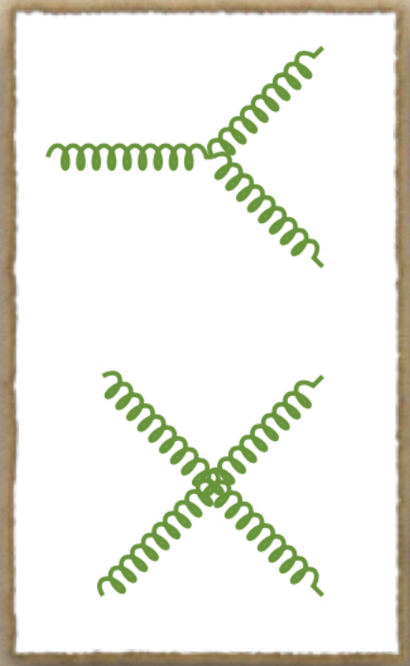
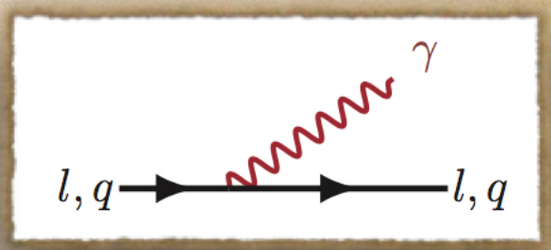
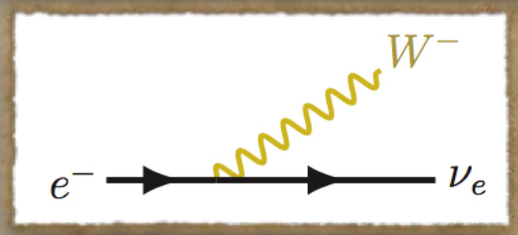
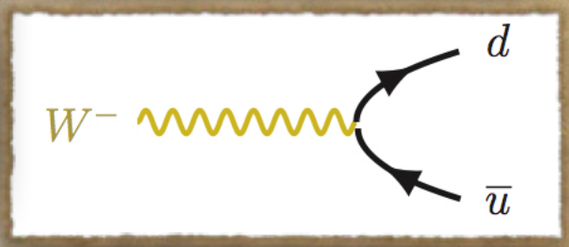


Interactions









5

The Future

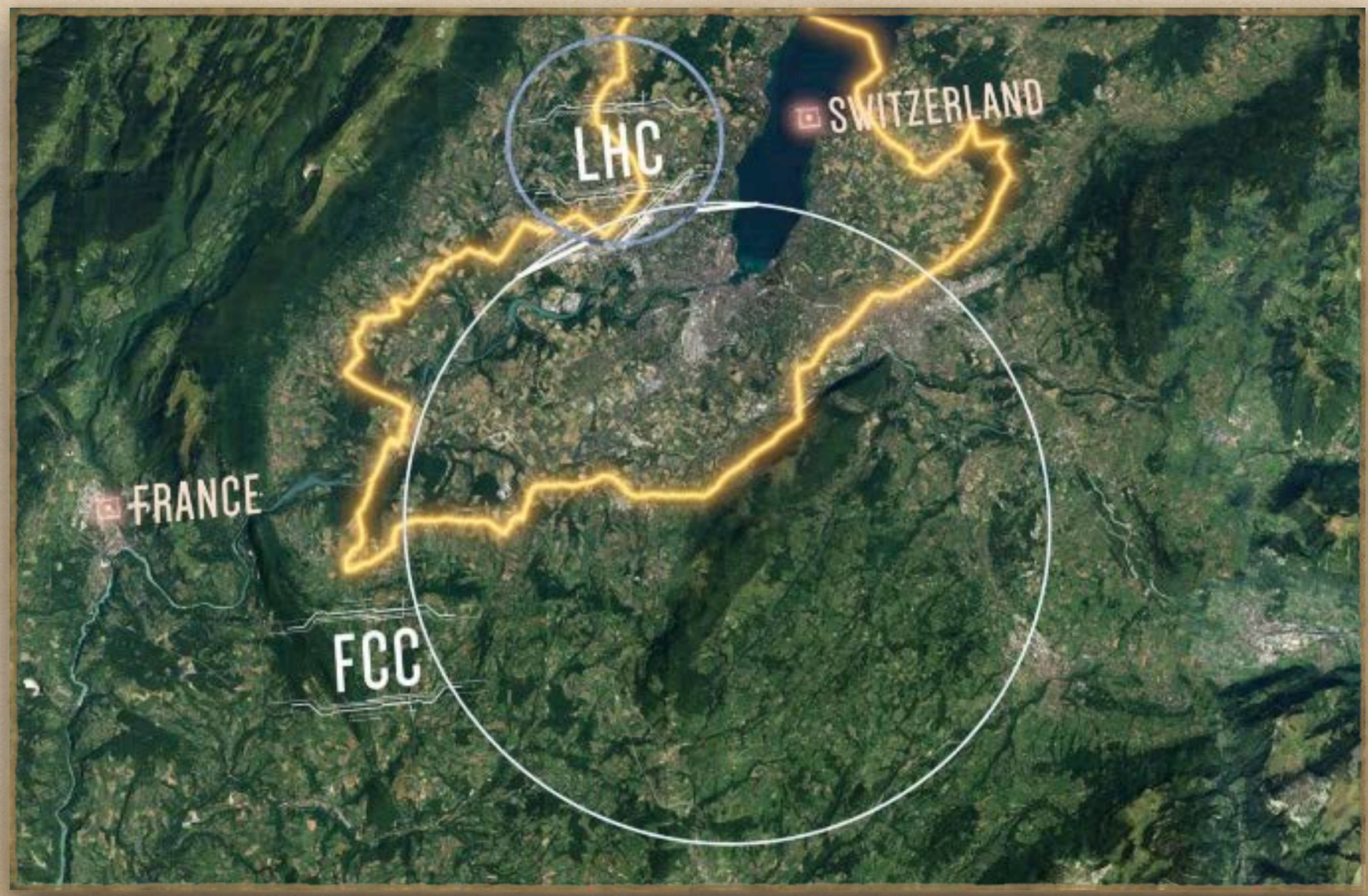
Expanding the search...

Expanding the search...

Bigger, larger, better

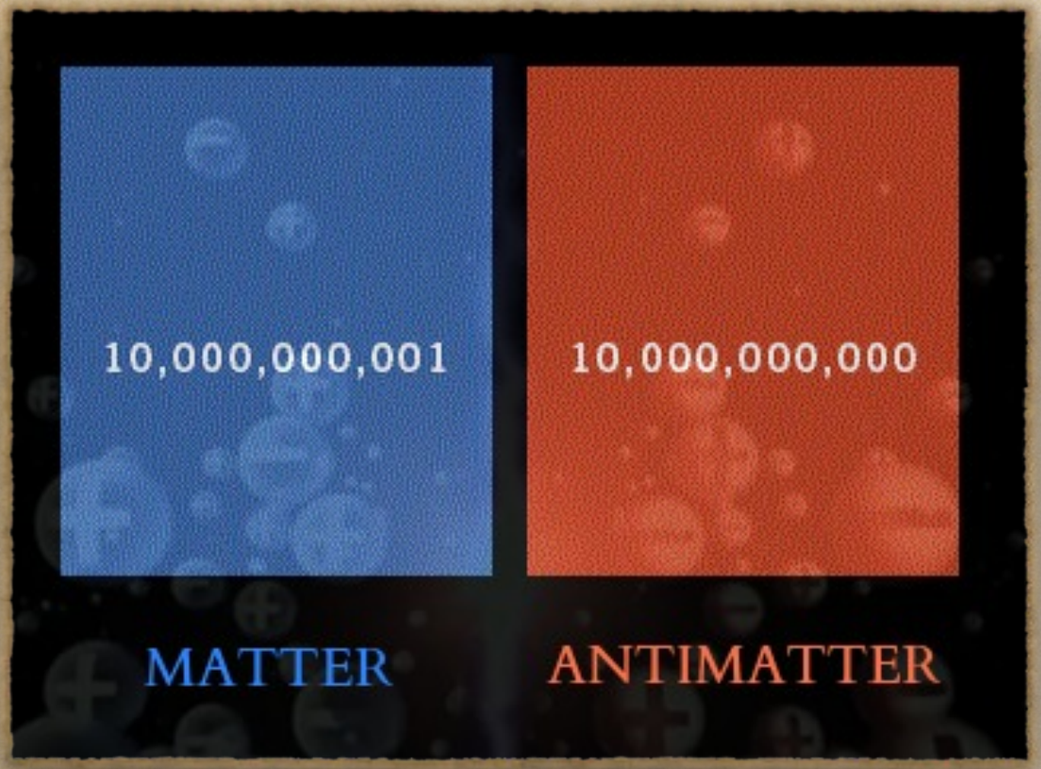
Expanding the search...

Bigger, larger, better

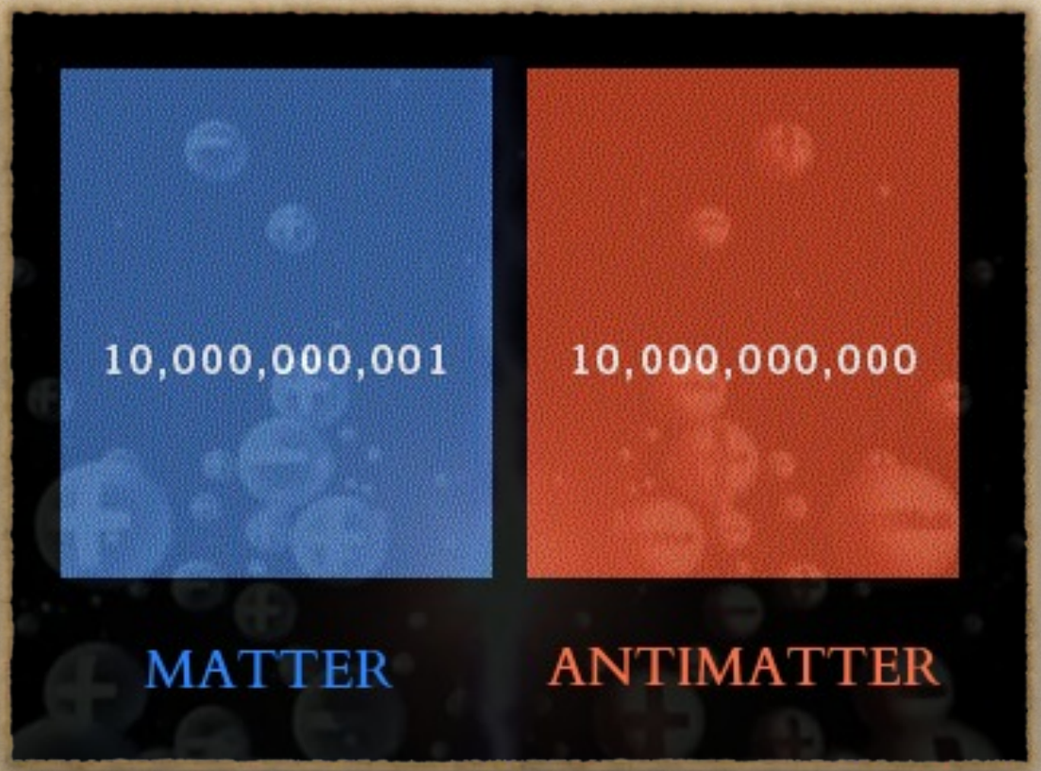


(Anti)Matter Asymmetry

(Anti)Matter Asymmetry

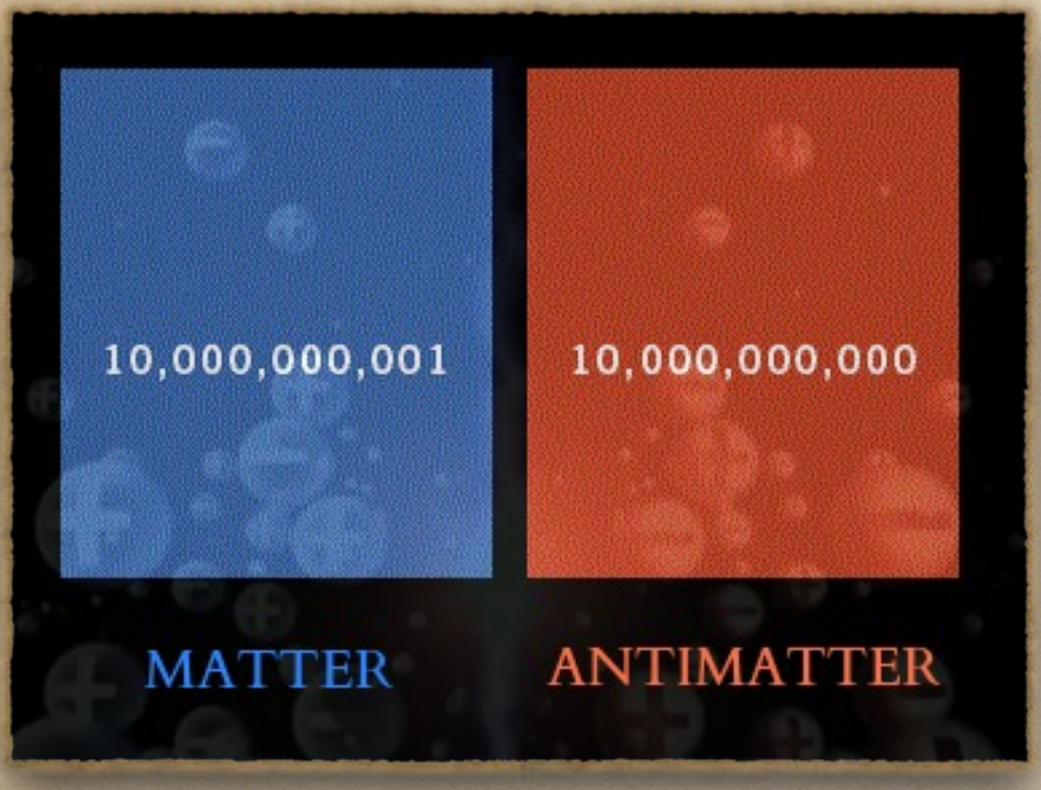


(Anti)Matter Asymmetry



Hidden somewhere far?

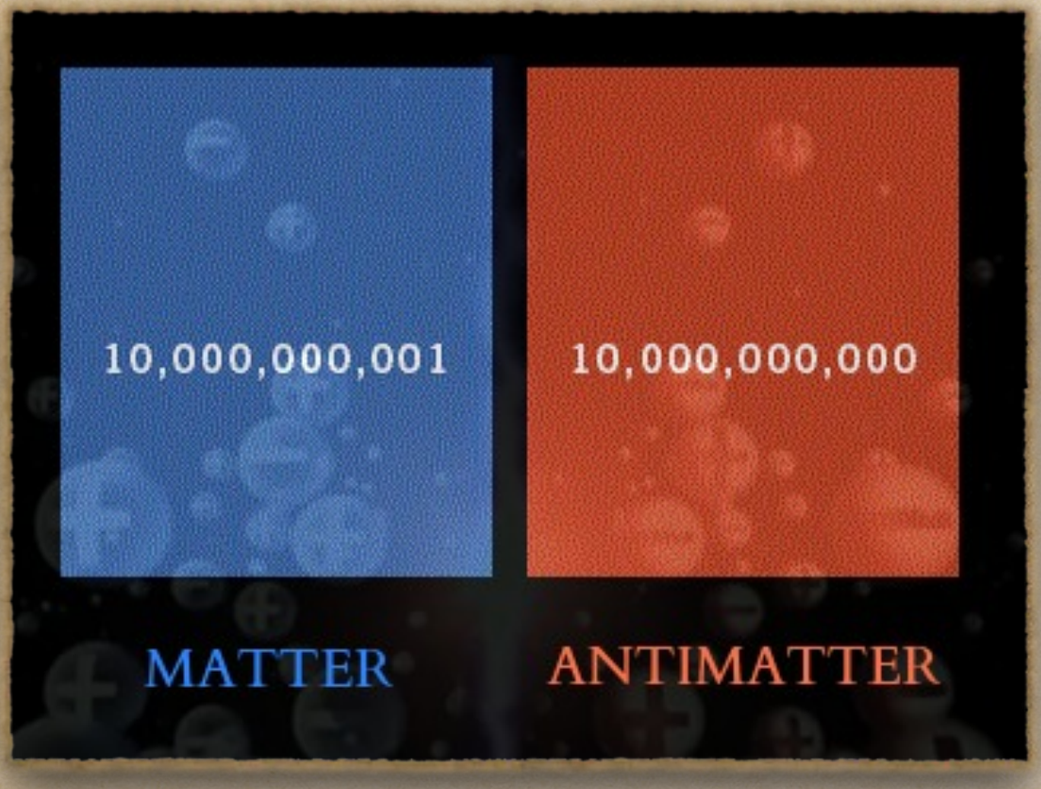
(Anti)Matter Asymmetry



Hidden somewhere far?

Created asymmetrically?

(Anti)Matter Asymmetry

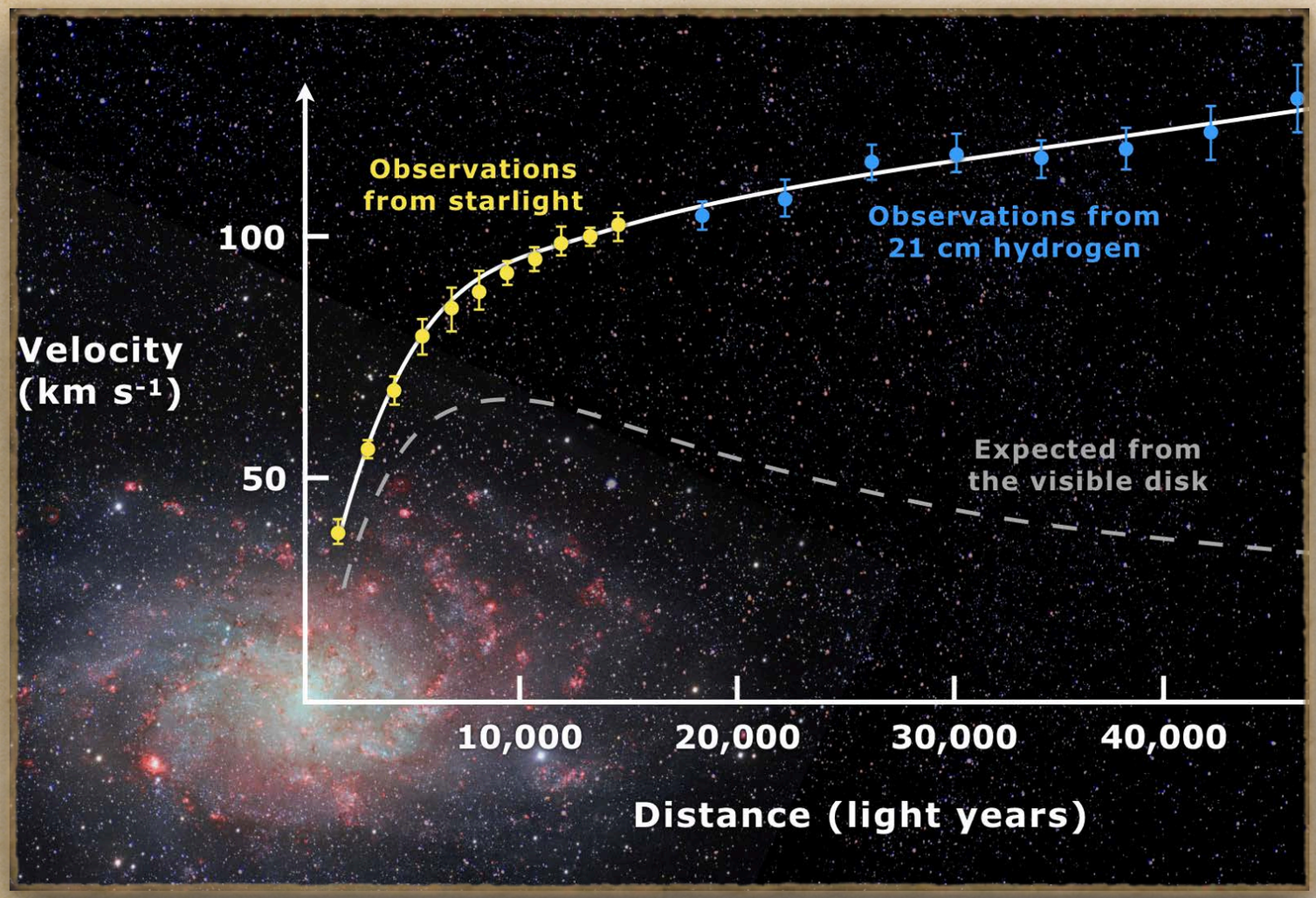


Hidden somewhere far?

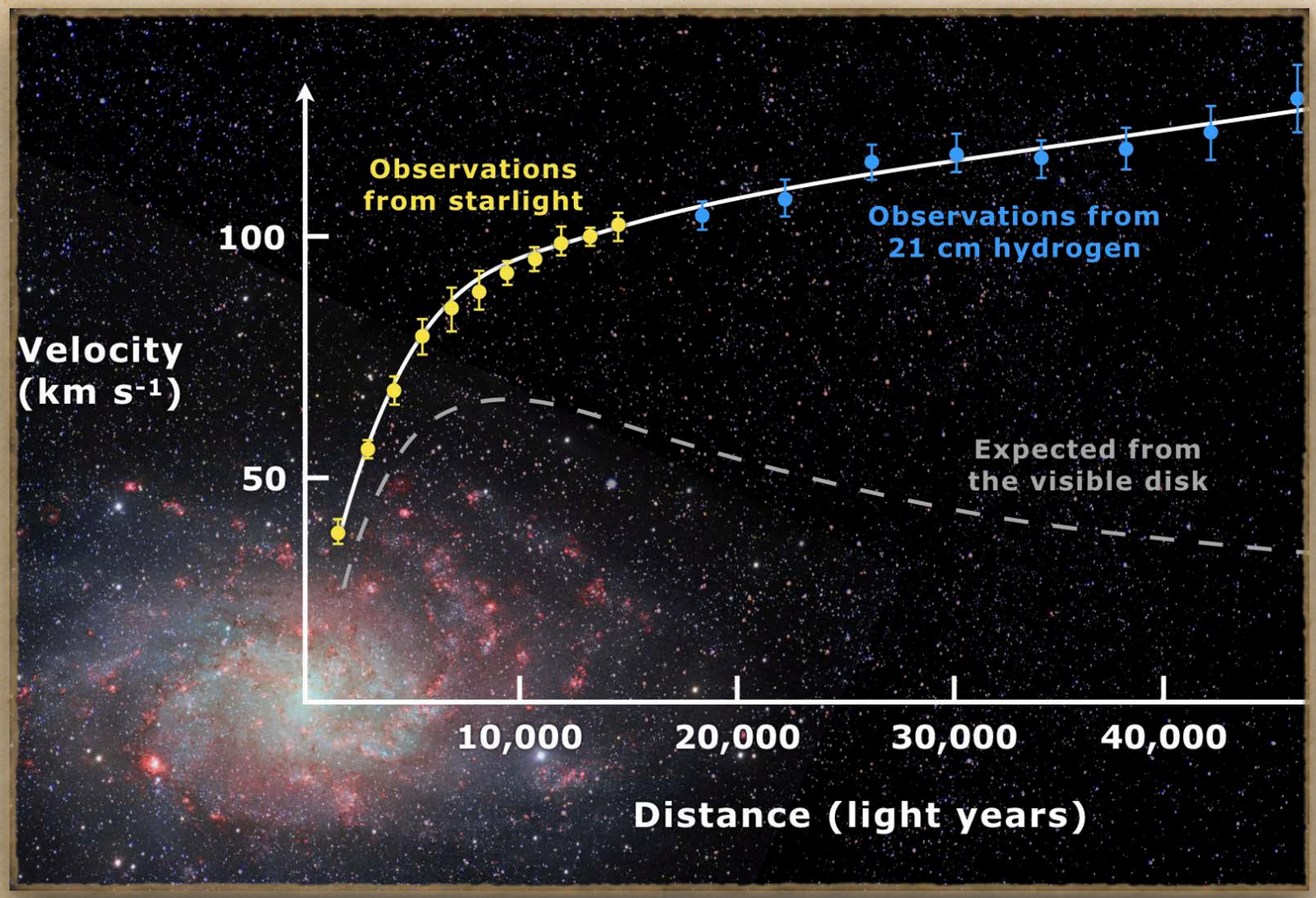
Created asymmetrically?

Asymmetric decay?

Dark Matter

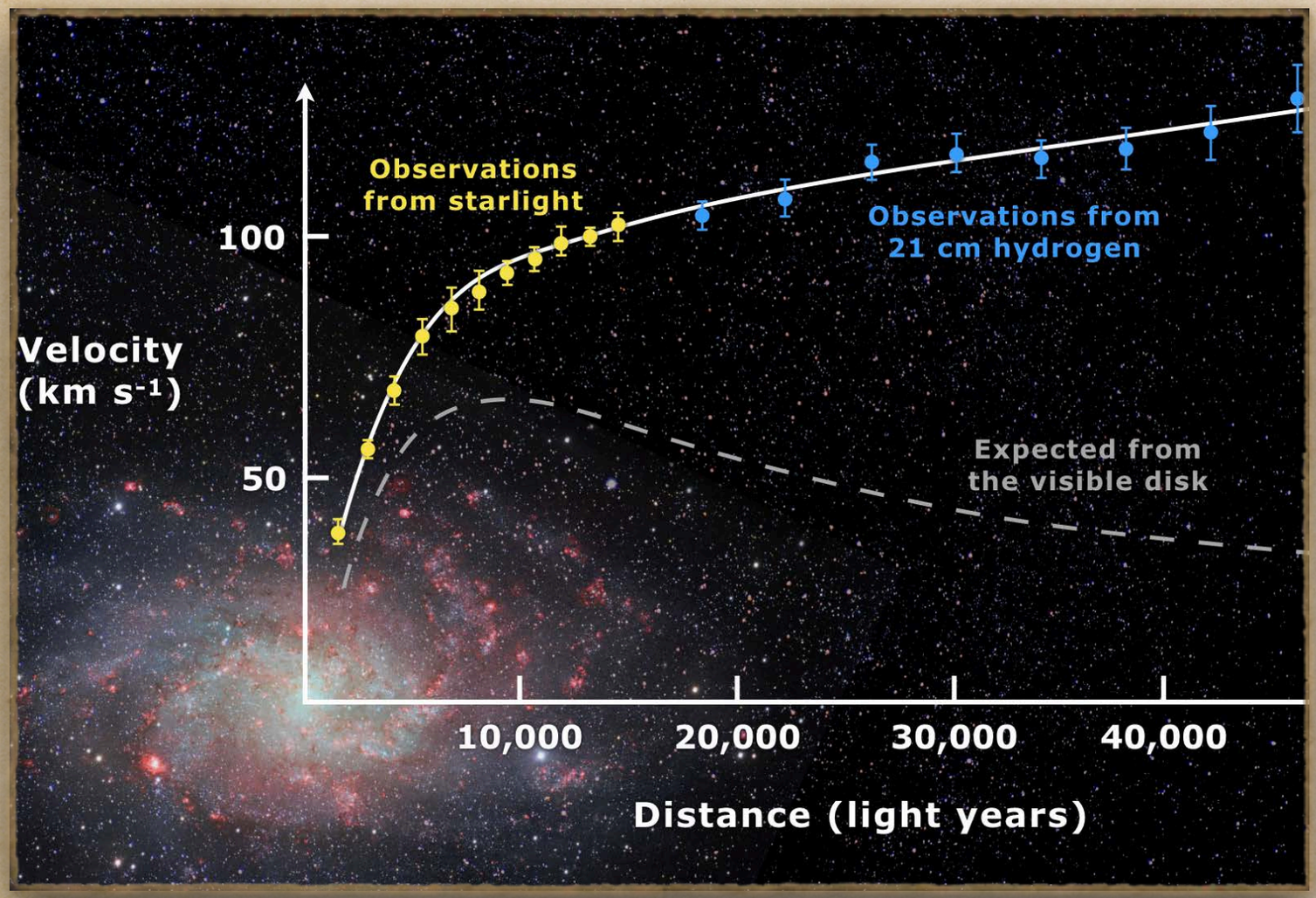

Observations
from starlight
Observations from
21 cm hydrogen
Expected from
the visible disk
Velocity
(km s-1)
100
50
10,000
20,000
30,000
40,000
Distance (light years)

Dark Matter



Black holes?

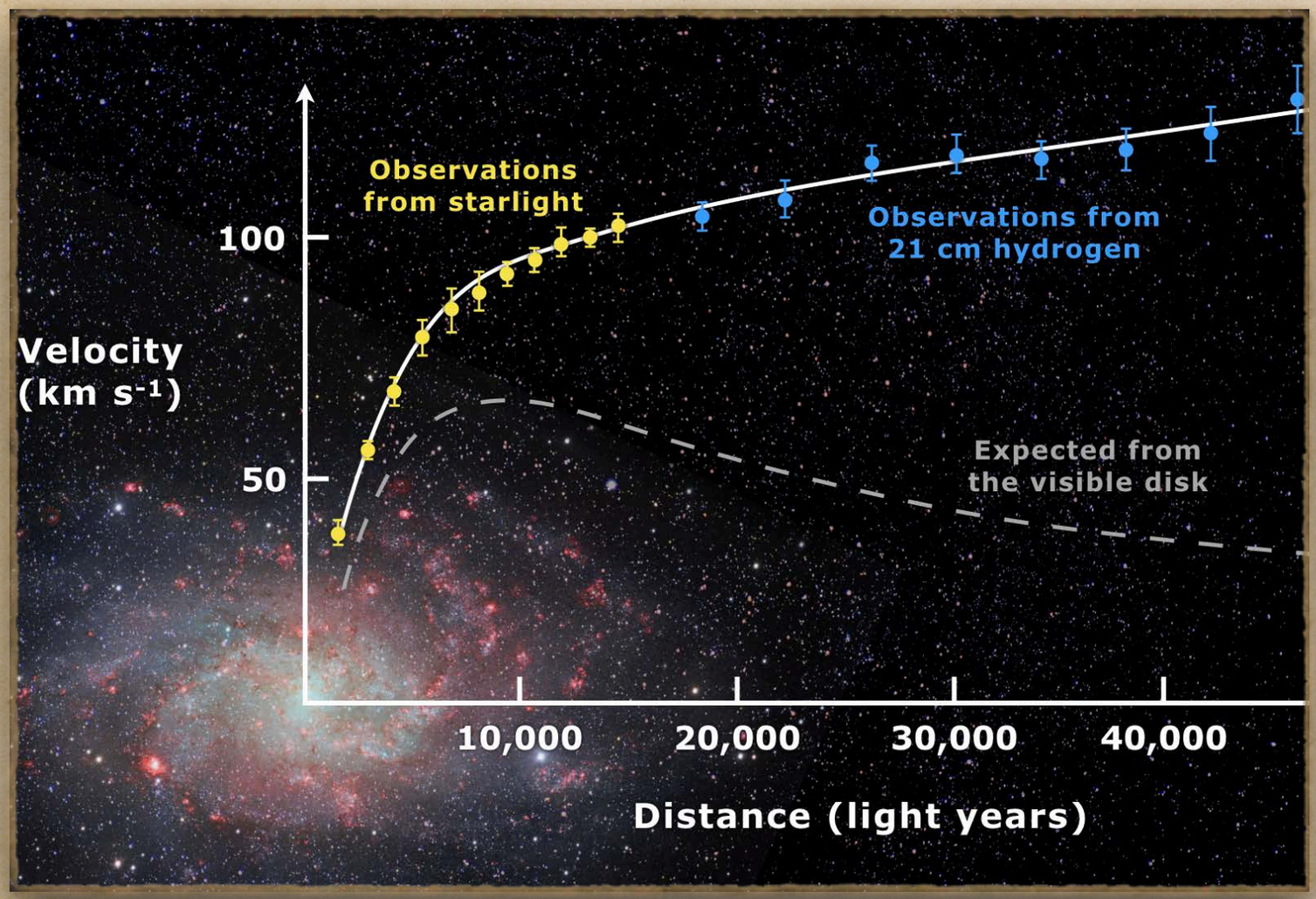
Dark Matter



Black holes?

WIMPs?

Dark Matter



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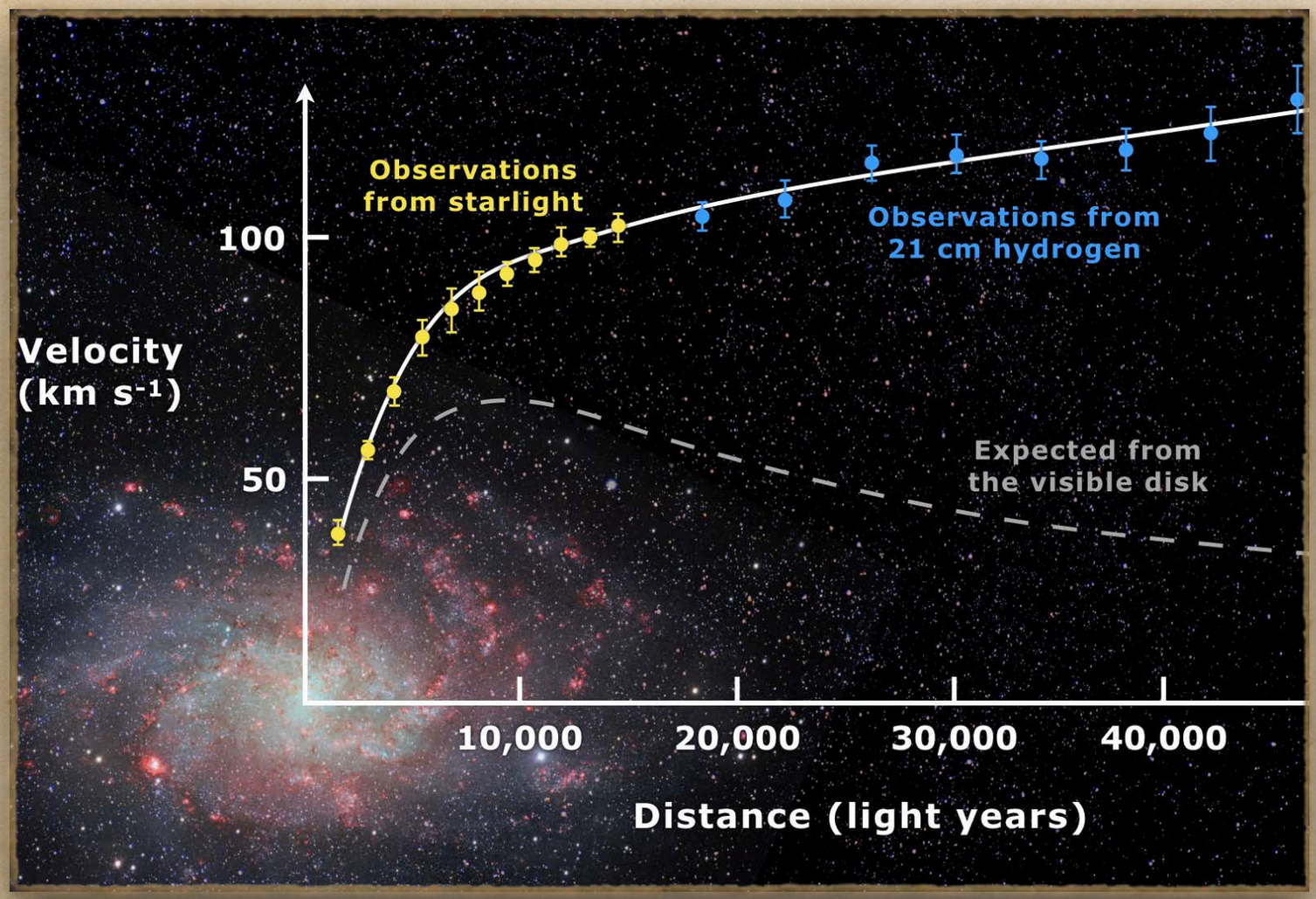
Sterile neutrinos?

Dark Matter



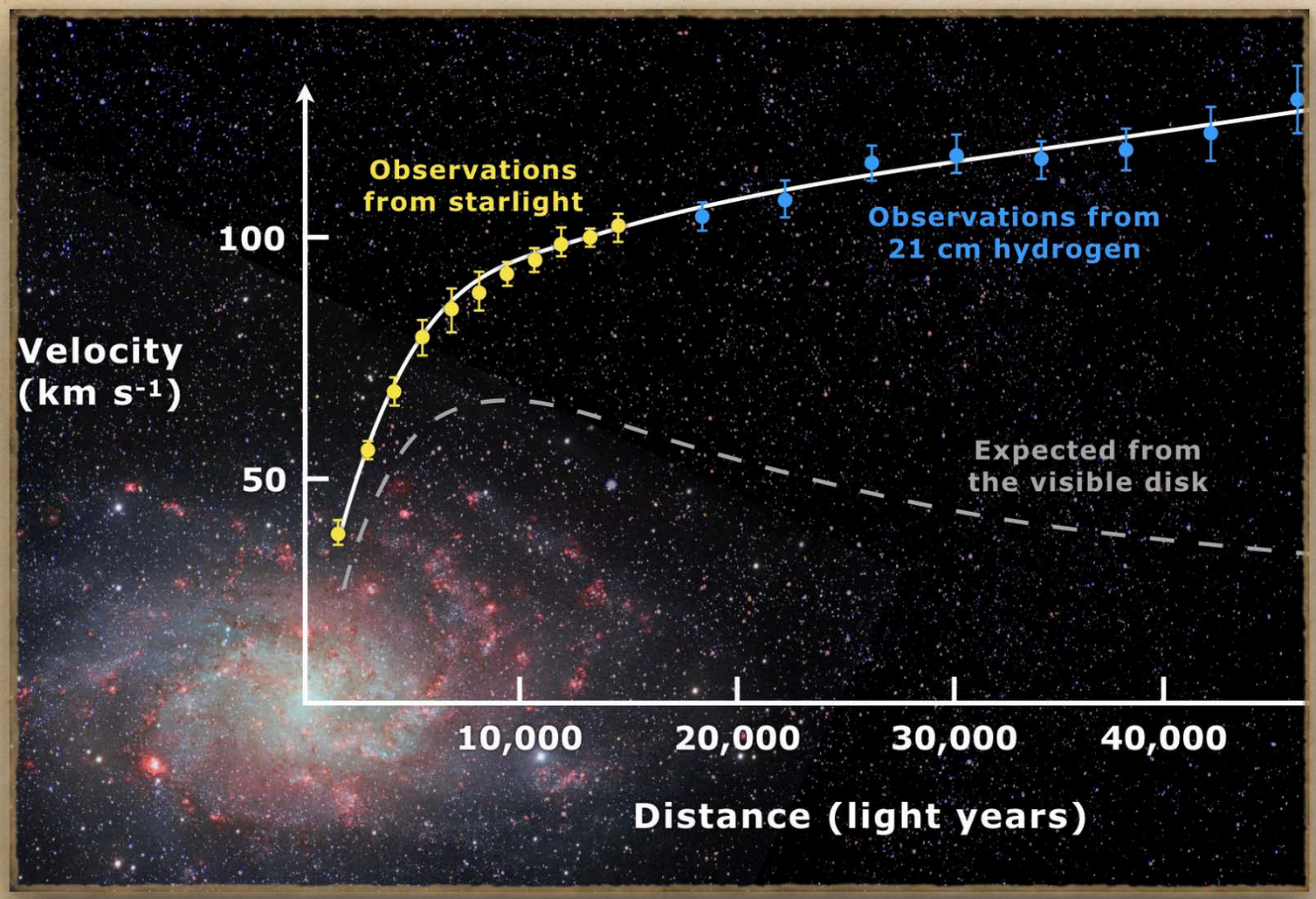
Black holes?

WIMPs?

Sterile neutrinos?

Gravity behaves different at large scales?

Dark Matter



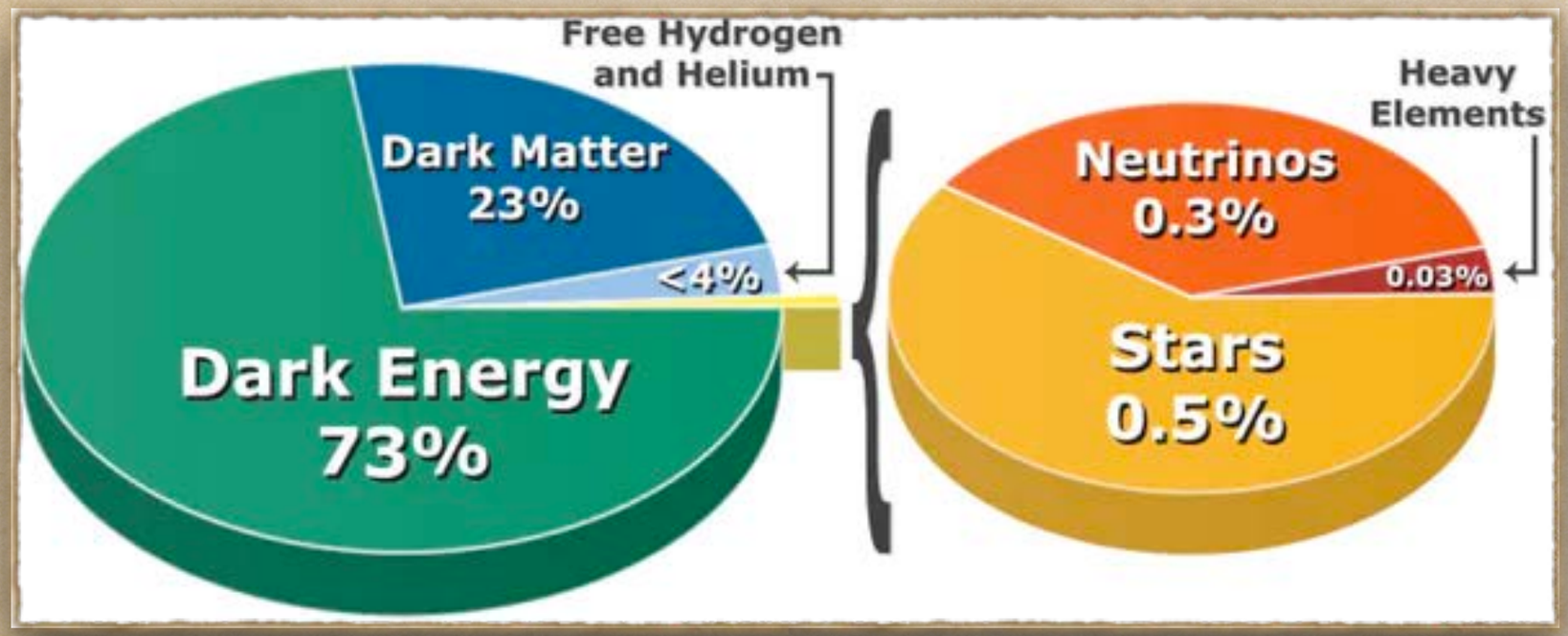
Black holes?

WIMPs?

Sterile neutrinos?

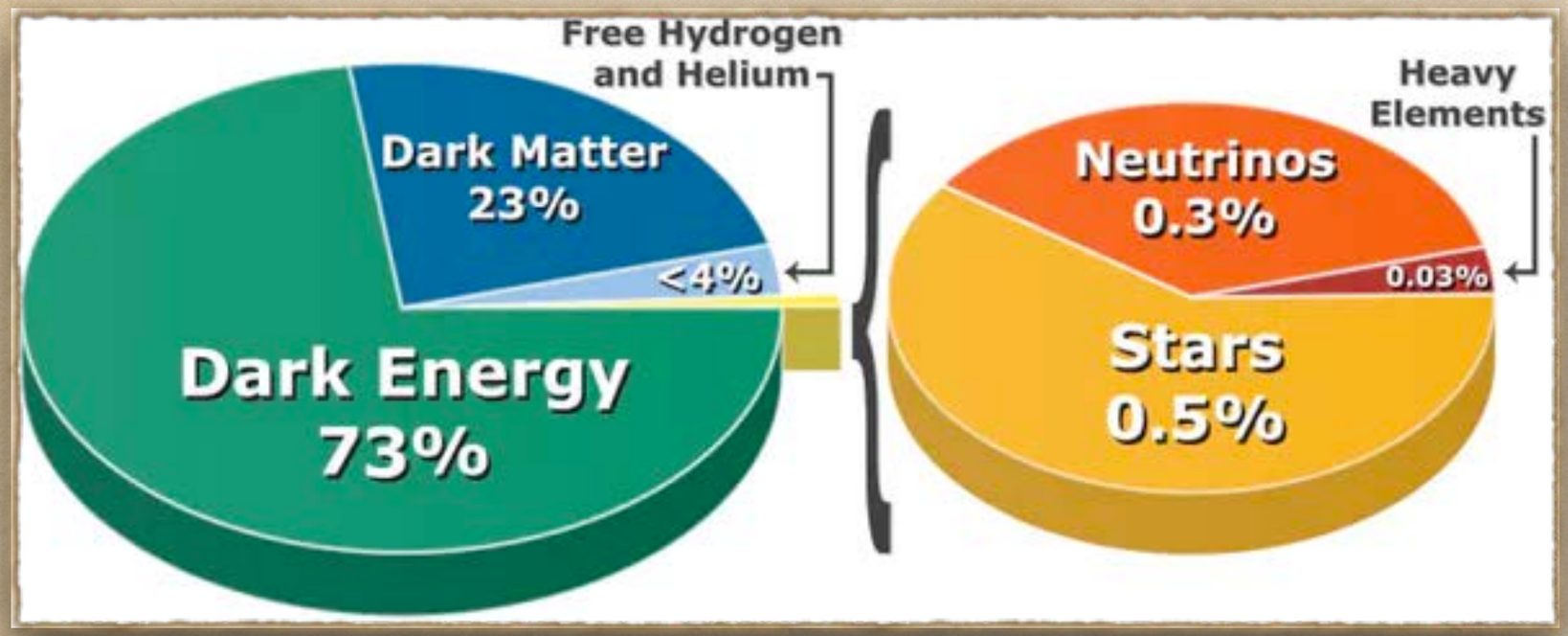
Gravity behaves different at large scales?

Dark Energy


Free Hydrogen
and Helium
Dark Matter
23%
<4%
Dark Energy
73%
Heavy
Elements
Neutrinos
0.3%
0.03%
Stars
0.5%

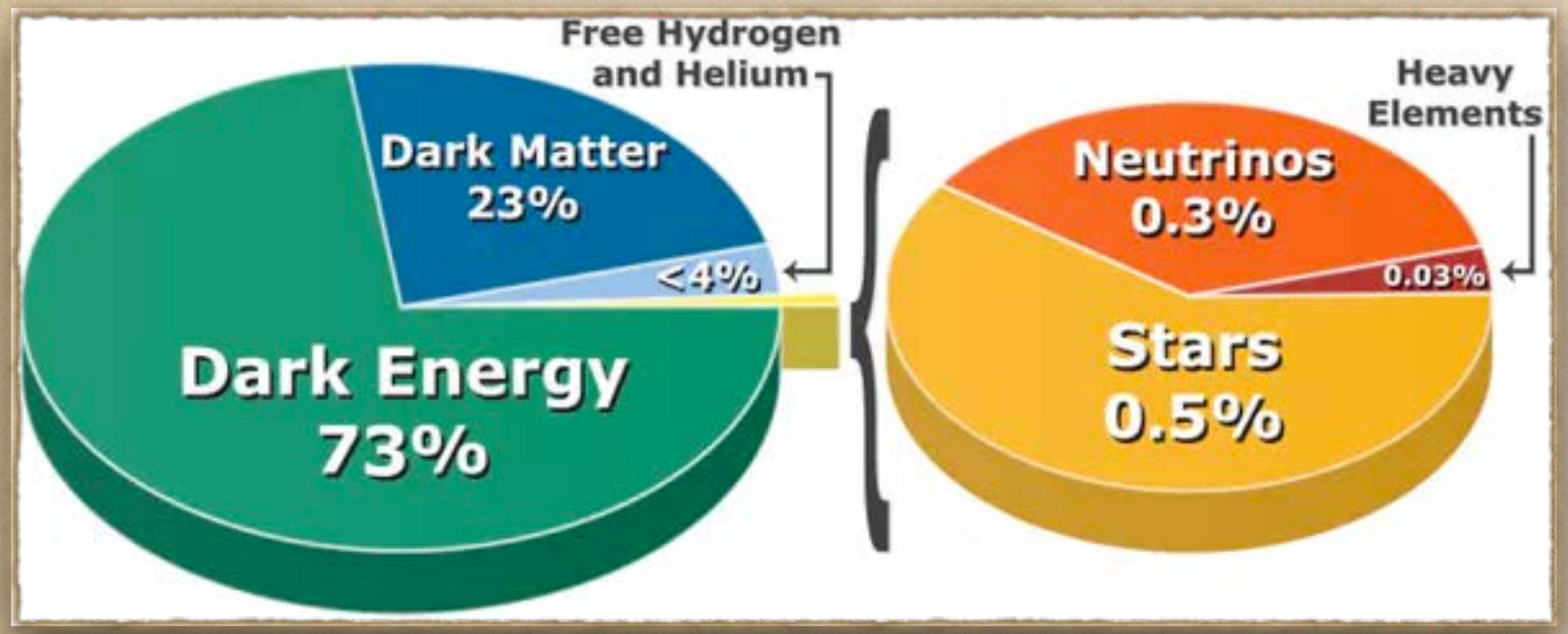
Dark Energy

Variable energy field?



Dark Energy

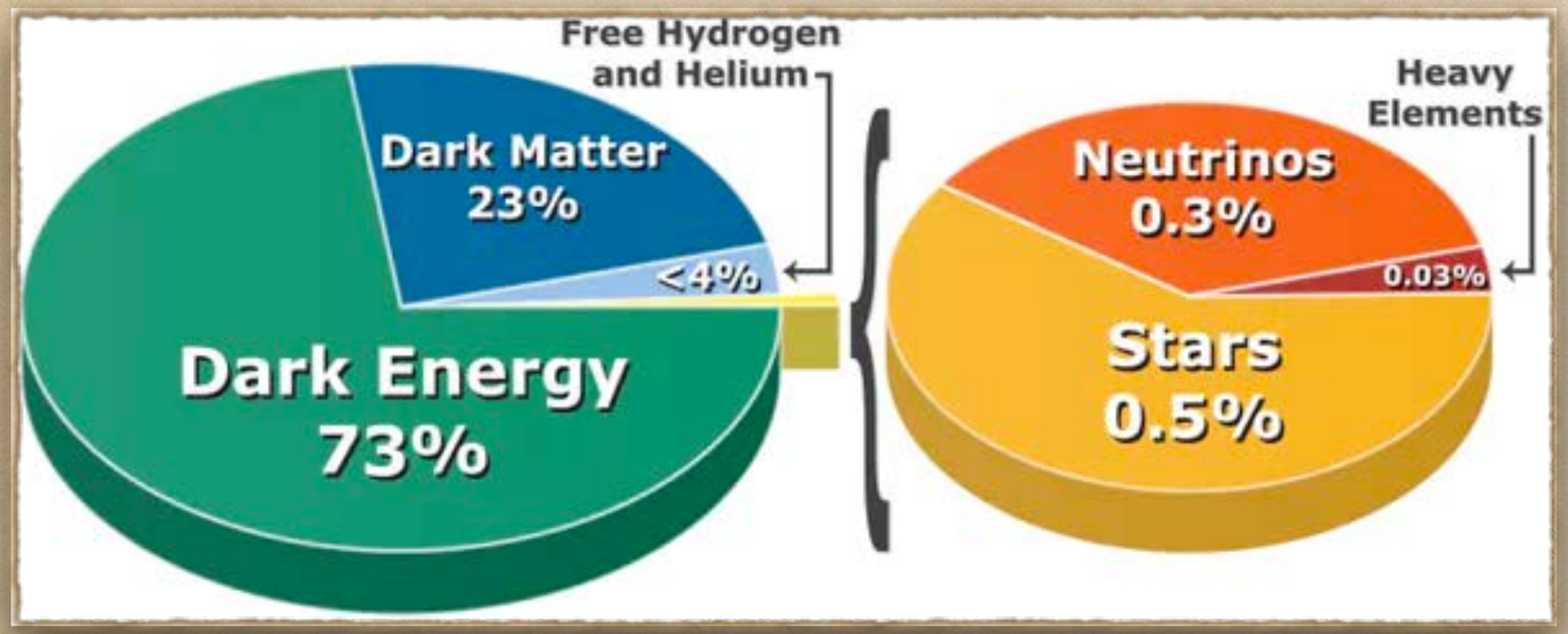
Variable energy field?



Fundamental property of space?

Dark Energy

Variable energy field?

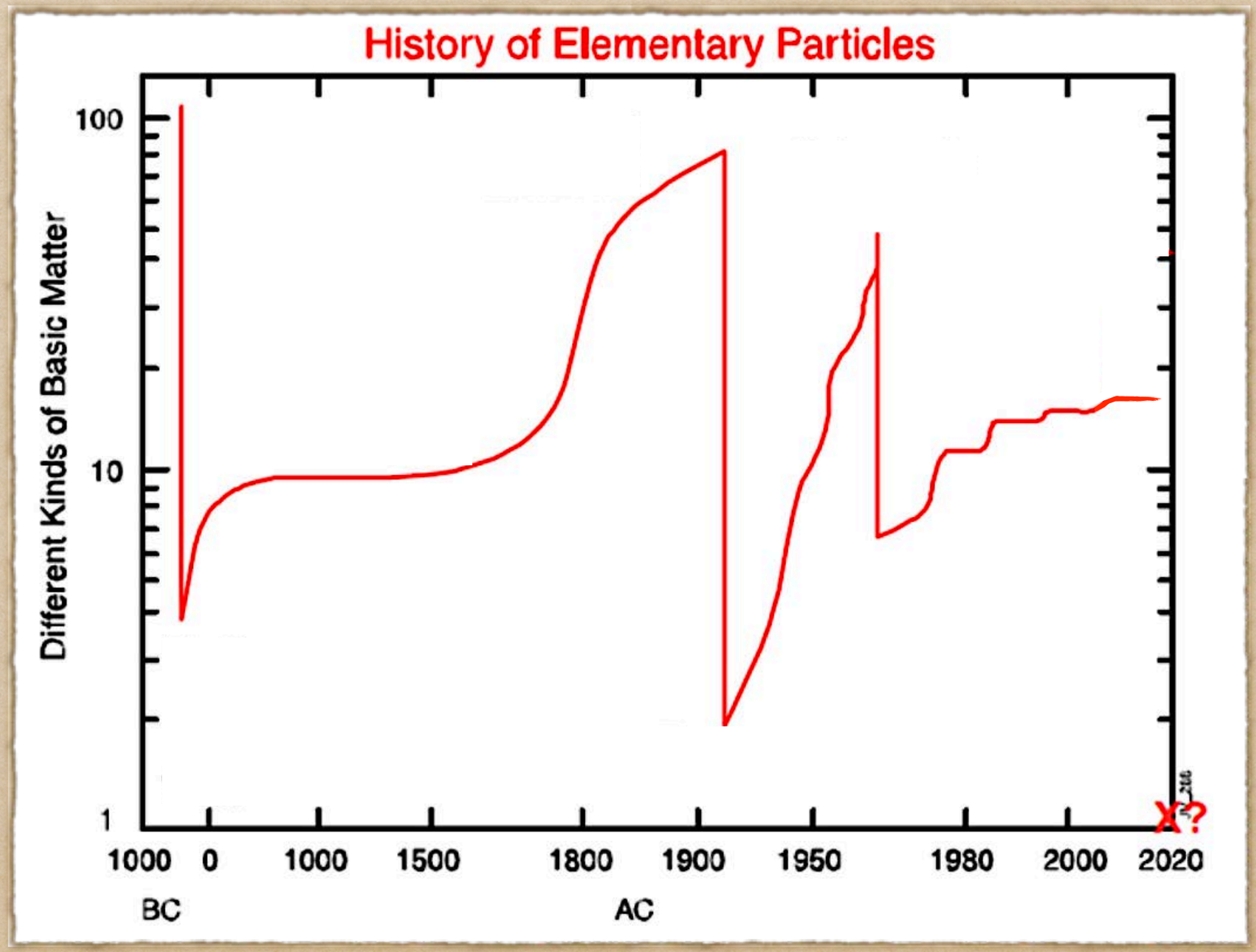


Fundamental property of space?

Gravity behaves different at large scales?

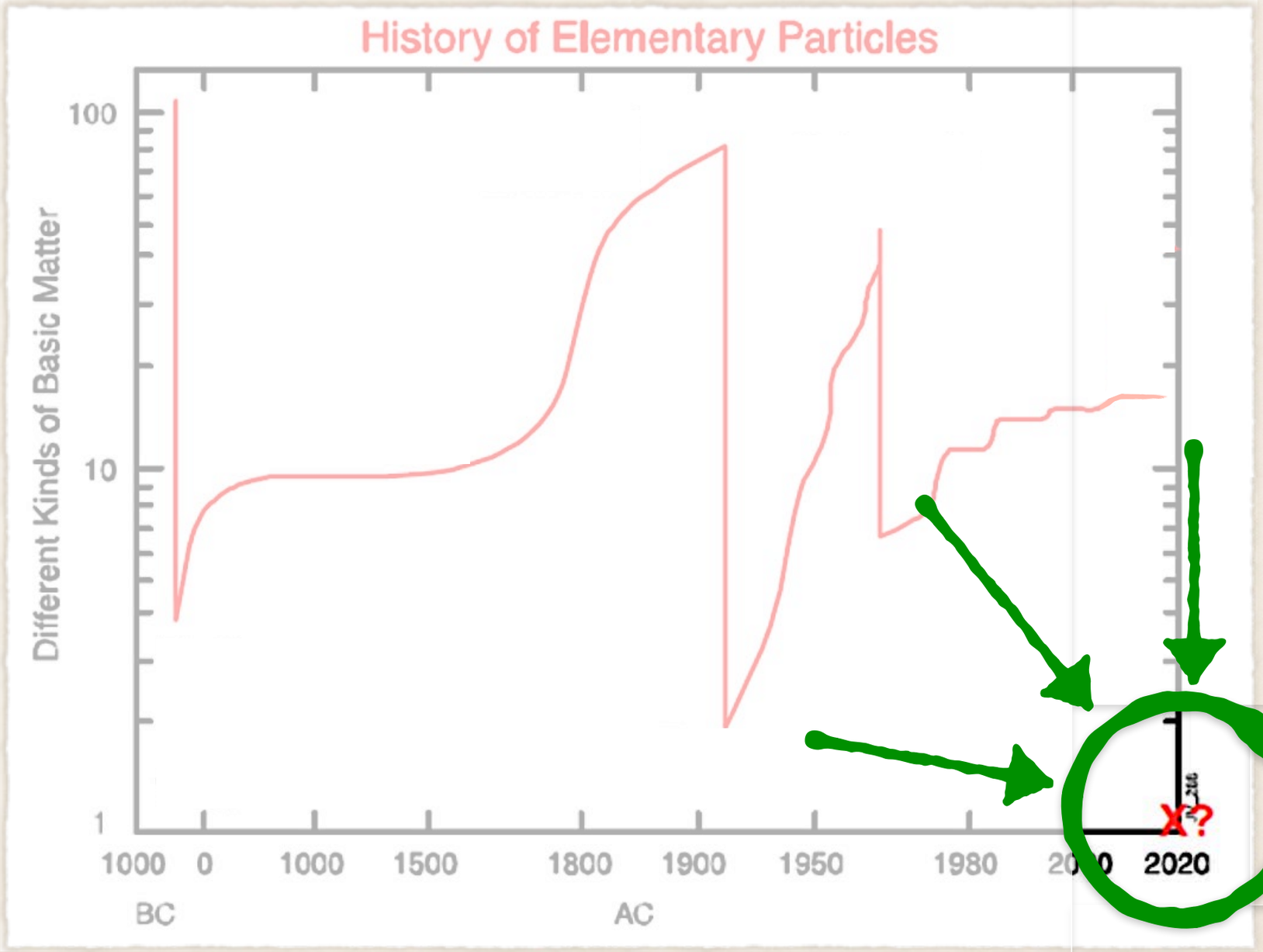
One more thing..

Basic Bricks of the Universe



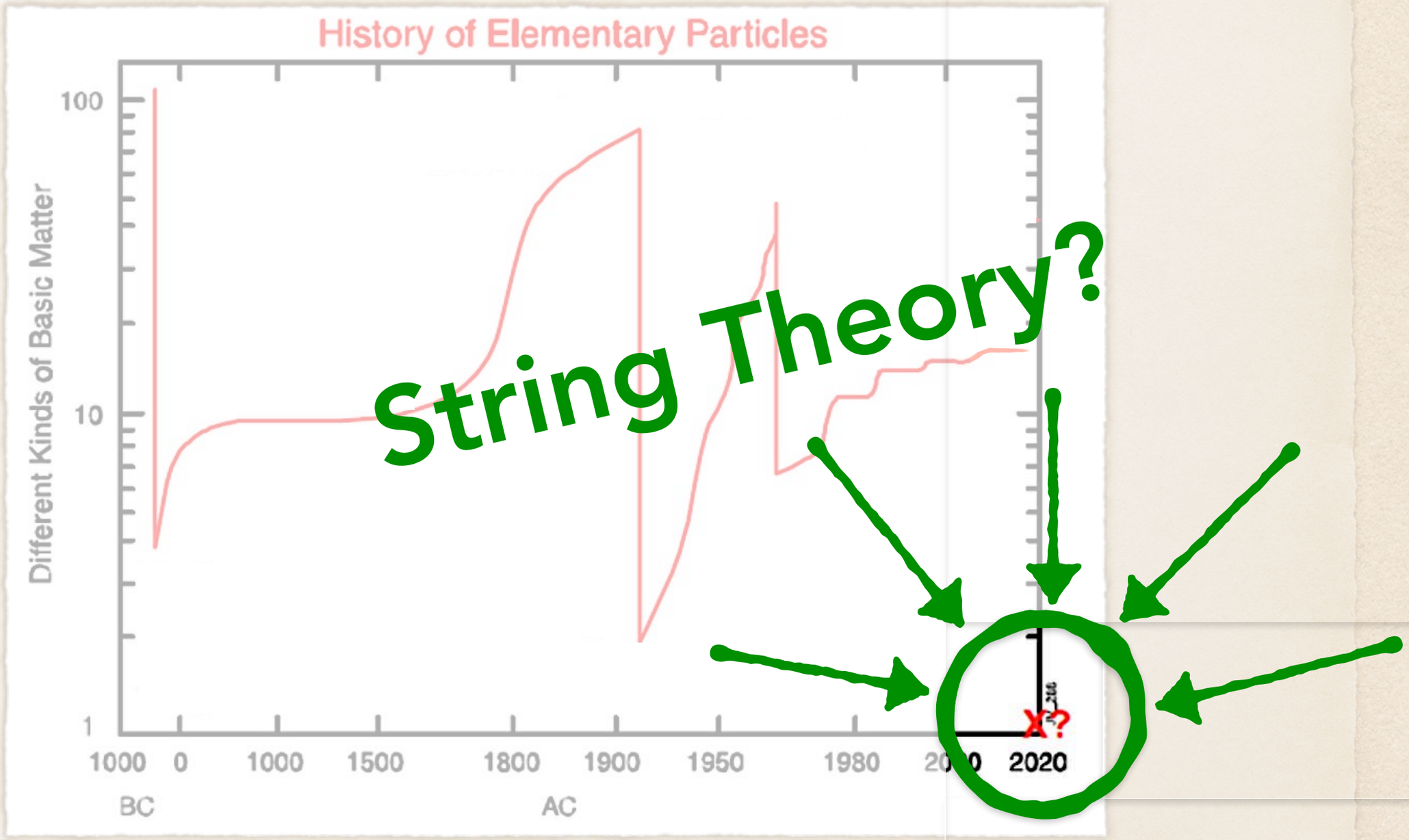
Credit: http://arxiv.org/abs/1311.1769

Basic Bricks of the Universe



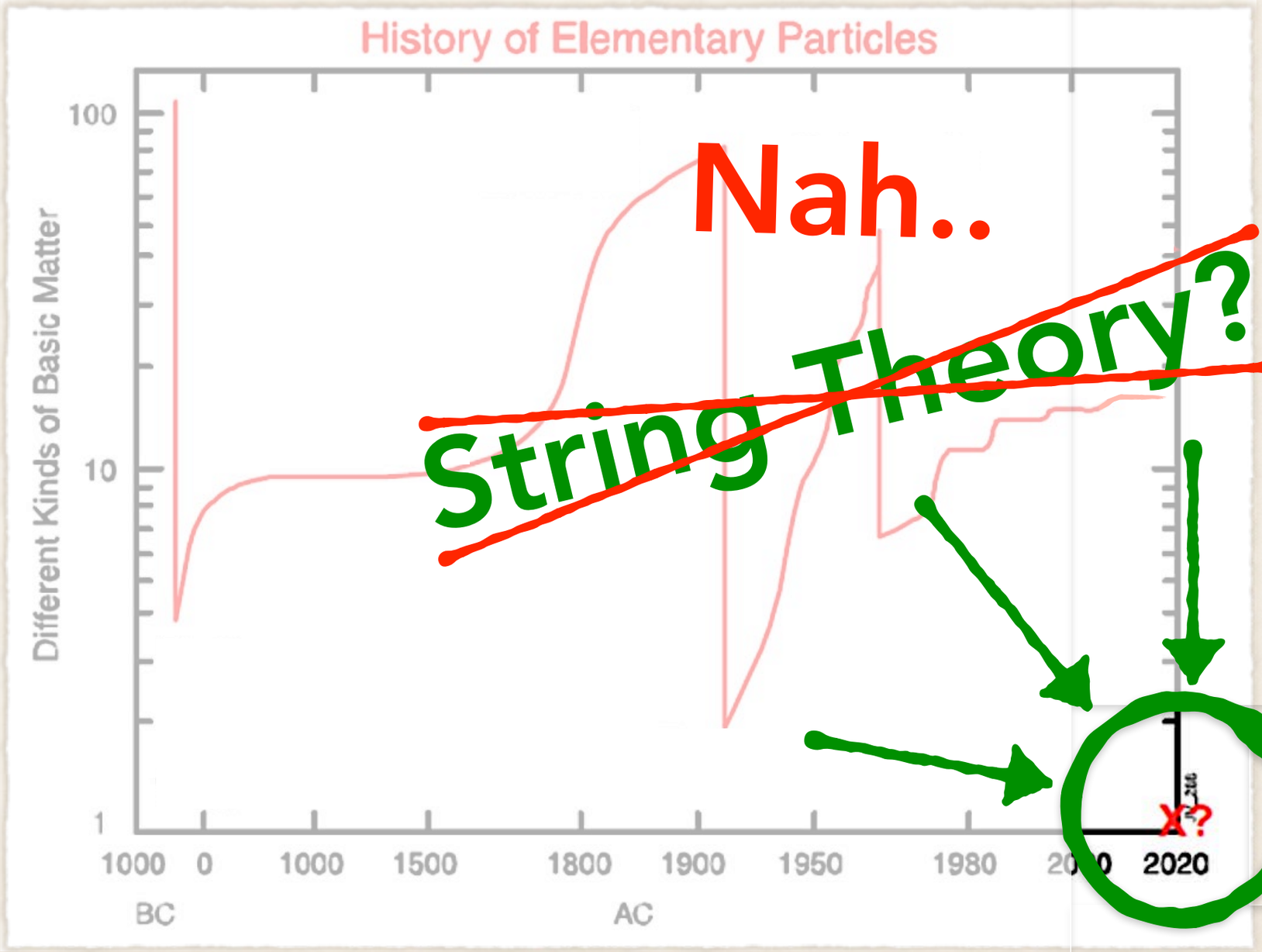
Credit: http://arxiv.org/abs/1311.1769

Basic Bricks of the Universe



Credit: http://arxiv.org/abs/1311.1769

Basic Bricks of the Universe



Credit: http://arxiv.org/abs/1311.1769

These are open questions
left to be explored...

Thank you for your attention

Questions?

=> frederikvanderveken@gmail.com