

The Standard

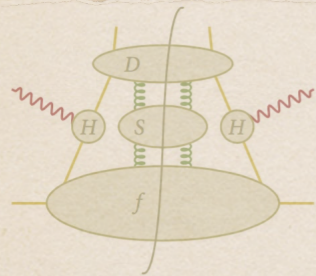


Figure 8.11: Factorisation in SIDIS: the bull diagram. All IR divergences are absorbed in the soft factor S, that hence only interacts with the TMD and FF. Note that the radiation comes from the hard subprocess.



Figure 5.8: All types of first order corrections to the DIS process. Real corrections are on the upper line; virtual on the lower line.

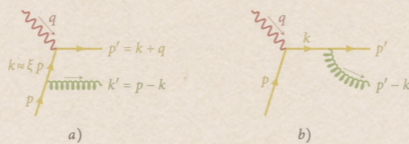


Figure 5.9: a) Initial state gluon radiation. b) Final state gluon radiation.

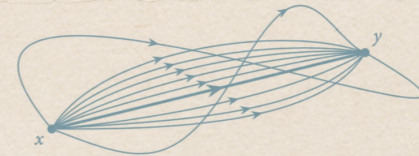
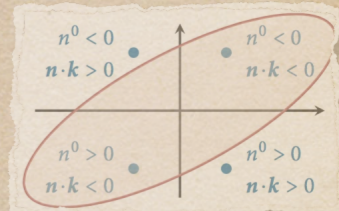


Figure 2.1: As a parallel transporter transforms in function of its path endpoints only, all paths shown will give rise to equivalent $U_{(y;x)}$'s, shifting a field at x to a field at y.



The Mikowskian loop integrals are then the same as the Euclidian ones, up to a possible sign difference:

$$\int \frac{d^\omega k}{(2\pi)^\omega} \frac{1}{(k^2 - \Delta)^n} = i \frac{(-)^n \Gamma(n - \frac{\omega}{2})}{(4\pi)^{\frac{\omega}{2}} \Gamma(n)} \Delta^{\frac{\omega}{2} - n}, \quad (\text{B.25a})$$

$$\left(\begin{array}{l} d \geq 2n \\ d \text{ even} \end{array} \right) = i \frac{\Delta^{\frac{d}{2} - n}}{(4\pi)^{\frac{d}{2}}} \frac{(-)^{\frac{d}{2}}}{(n-1)! (\frac{d}{2} - n)!} \left(\frac{1}{\epsilon} - \gamma_E + \sum_j \frac{1}{j} + \ln 4\pi - \ln \Delta \right),$$

$$\int \frac{d^\omega k}{(2\pi)^\omega} \frac{k^2}{(k^2 - \Delta)^n} = i \frac{(-)^{n+1} \omega \Gamma(n - \frac{\omega}{2} - 1)}{(4\pi)^{\frac{\omega}{2}} 2 \Gamma(n)} \Delta^{\frac{\omega}{2} + 1 - n}, \quad (\text{B.25b})$$

$$\left(\begin{array}{l} d \geq 2n - 2 \\ d \text{ even} \end{array} \right) = i \frac{\Delta^{\frac{d}{2} + 1 - n} \omega}{(4\pi)^{\frac{d}{2}} 2 (n-1)! (\frac{d}{2} + 1 - n)!} \left(\frac{1}{\epsilon} - \gamma_E + \sum_j \frac{1}{j} + \ln 4\pi - \ln \Delta \right)$$

$$\int \frac{d^\omega k}{(2\pi)^\omega} \frac{k^4}{(k^2 - \Delta)^n} = i \frac{(-)^n \omega(\omega+2) \Gamma(n - \frac{\omega}{2} - 2)}{(4\pi)^{\frac{\omega}{2}} 4 \Gamma(n)} \Delta^{\frac{\omega}{2} + 2 - n}, \quad (\text{B.25c})$$

$$\left(\begin{array}{l} d \geq 2n - 4 \\ d \text{ even} \end{array} \right) = i \frac{\Delta^{\frac{d}{2} + 2 - n} \omega(\omega+2)}{(4\pi)^{\frac{d}{2}} 4 (n-1)! (\frac{d}{2} + 2 - n)!} \left(\frac{1}{\epsilon} - \gamma_E + \sum_j \frac{1}{j} + \ln 4\pi - \ln \Delta \right)$$

We list some other common Minkowskian integrals:

$$\int \frac{d^\omega k}{(2\pi)^\omega} \ln(k^2 - a) = -\frac{i}{(4\pi)^{\frac{\omega}{2}}} \Gamma\left(-\frac{\omega}{2}\right) a^{\frac{\omega}{2}}, \quad (\text{B.26a})$$

$$\int \frac{d^\omega k}{(2\pi)^\omega} e^{ak^2 - ib \cdot k} = \frac{i}{(4\pi)^{\frac{\omega}{2}}} a^{-\frac{\omega}{2}} e^{\frac{b^2}{4a}}, \quad (\text{B.26b})$$

$$\int \frac{d^\omega k}{(2\pi)^\omega} \frac{1}{(-k^2)^\alpha} e^{-ib \cdot k} = \frac{i}{4^\alpha \pi^{\frac{\omega}{2}}} \frac{\Gamma(\frac{\omega}{2} - \alpha)}{\Gamma(\alpha)} \frac{1}{(-b^2)^{\frac{\omega}{2} - \alpha}}. \quad (\text{B.26c})$$

Model

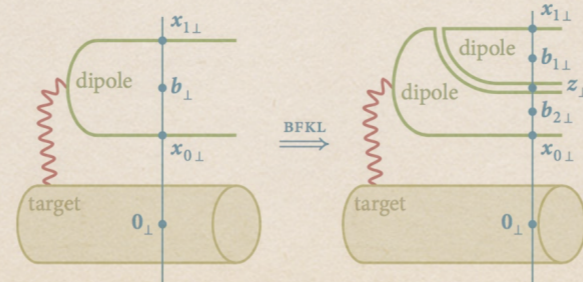
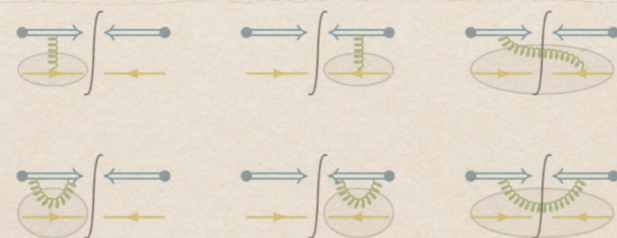


Figure 9.6: In the dipole picture, the BFKL evolution is an evolution in dipoles, i.e. new dipoles are created during the evolution. A gluon that is radiated from the dipole can be represented as two fundamental lines (see Equation 10.13). This essentially splits the dipole in two at the point z_\perp , as is illustrated in the second diagram.

$$\oint_C dx \cdot A = \int_\Sigma d\sigma \cdot (\partial \wedge A)$$



$$\begin{aligned} \text{tr}(t^a t^x t^b t^x) &= -\frac{1}{4N_c} \delta^{ab}, \\ \text{tr}(t^b t^x t^y) f_{axy} &= -i \frac{N_c}{4} \delta^{ab}, \\ \text{tr}(t^y t^z) f_{axy} f_{bzx} &= -\frac{N_c}{2} \delta^{ab}, \\ f_{xay} f_{ycz} f_{zbw} f_{wcx} &= \frac{N_c^2}{2} \delta^{ab}, \\ f_{awv} f_{xby} f_{yvw} f_{zvx} &= \frac{N_c^2}{2} \delta^{ab}, \\ f_{awv} f_{bwz} f_{xzy} f_{yvx} &= N_c^2 \delta^{ab}, \\ f_{xay} f_{ycz} f_{zbw} f_{wcx} &= \frac{N_c^2}{2} \delta^{ab}, \\ f_{vaw} f_{wbz} f_{xzy} f_{yvx} &= N_c^2 \delta^{ab}, \end{aligned}$$

and similarly for the seven remaining diagrams.

Building Bricks

Physics at the Femtoscale





**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"?**



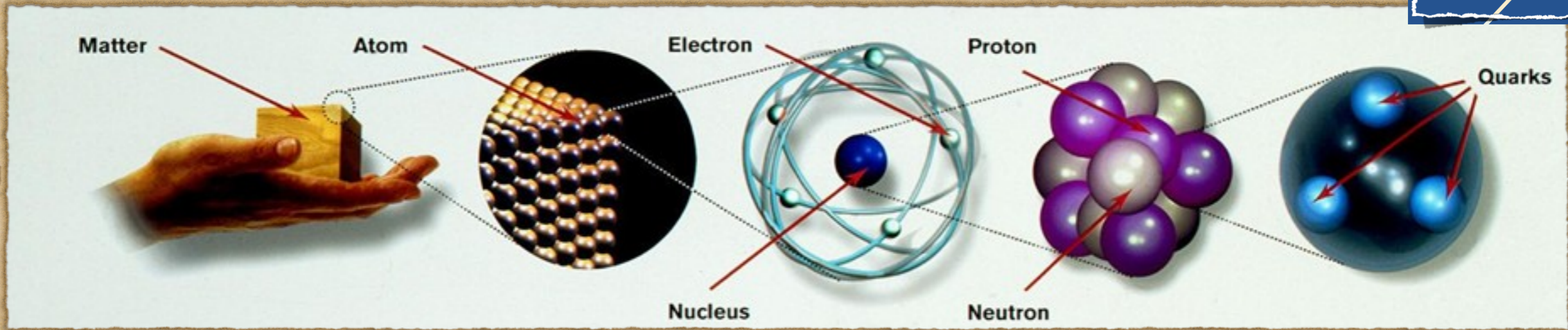
**What are we
made of?**

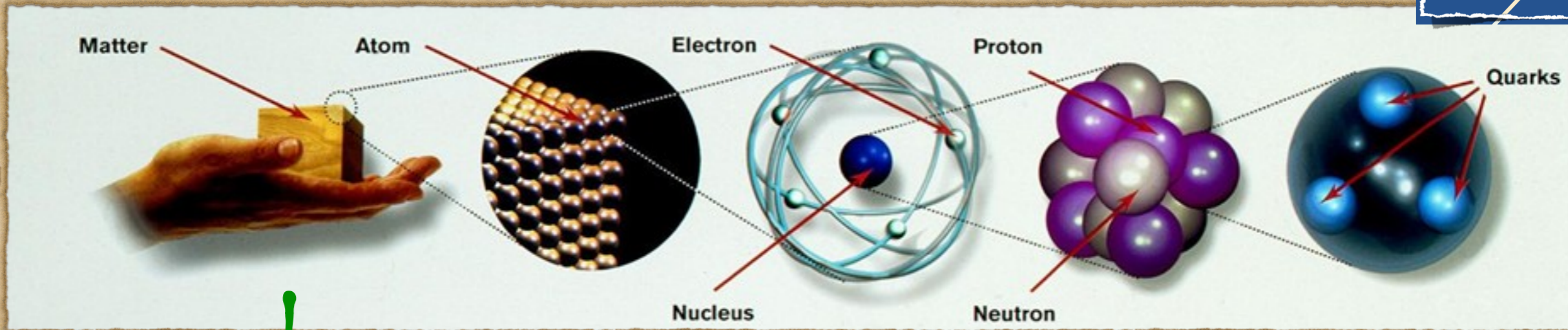
**What is the universe
made of?**

**Why does everything
just "work"?**



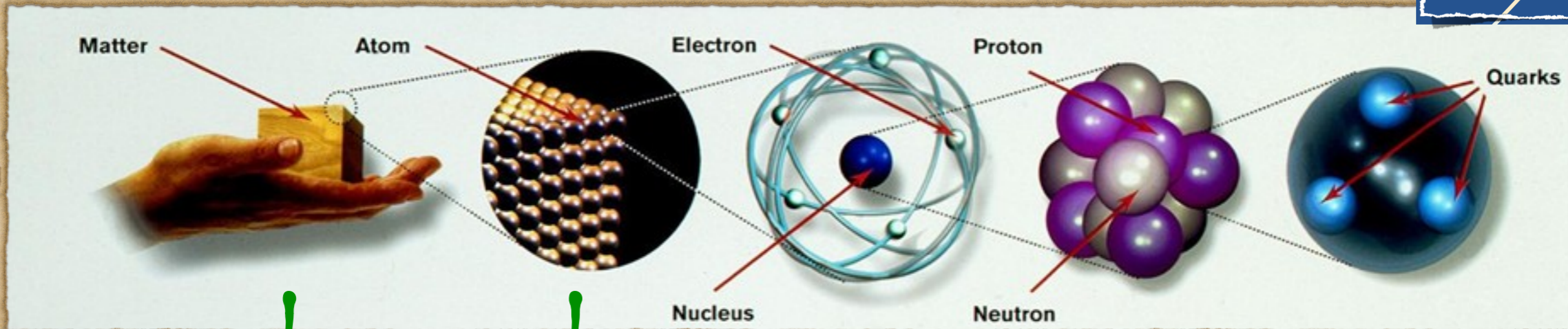
... ?





5cm

(10^{-2} m)

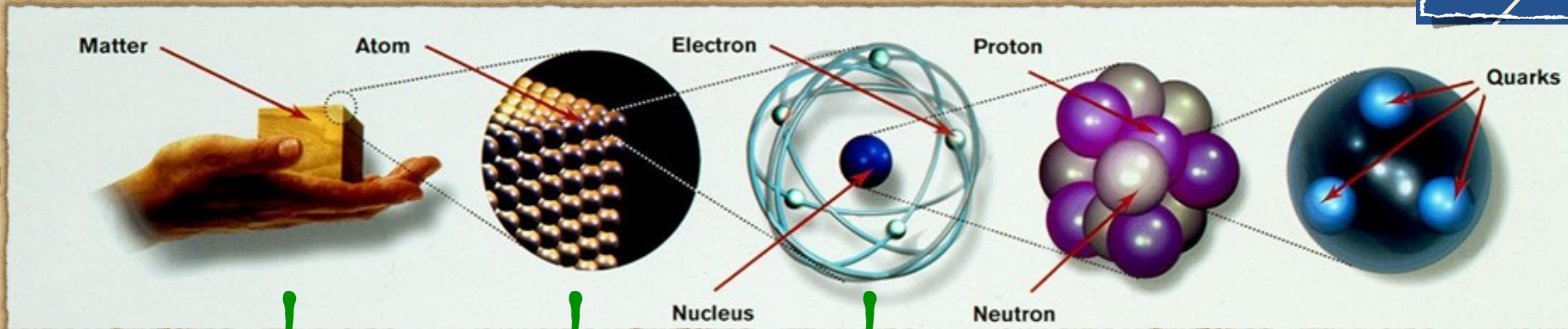


↓
5cm

(10^{-2} m)

↓
1Å

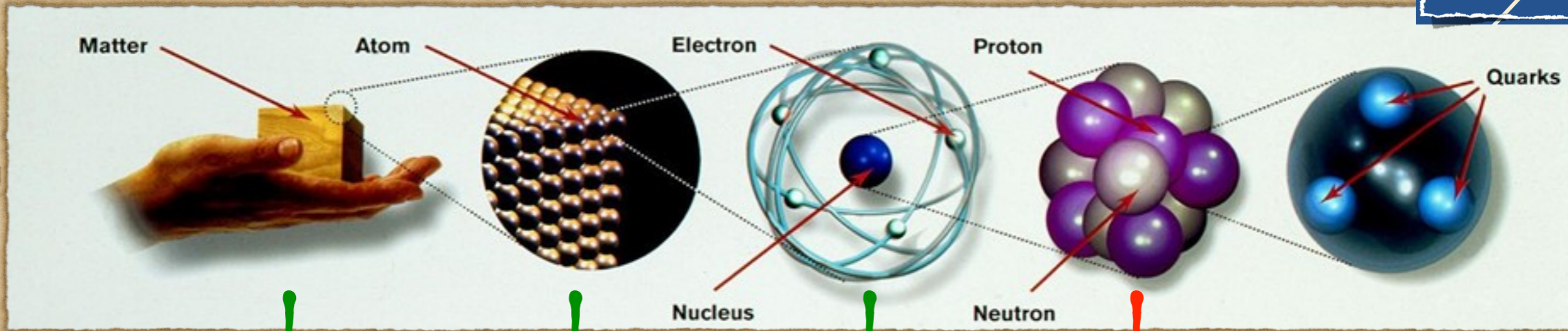
(10^{-10} m)



↓
5cm
(10^{-2} m)

↓
1Å
(10^{-10} m)

↓
0.01pm
(10^{-14} m)



5cm

(10^{-2} m)

1Å

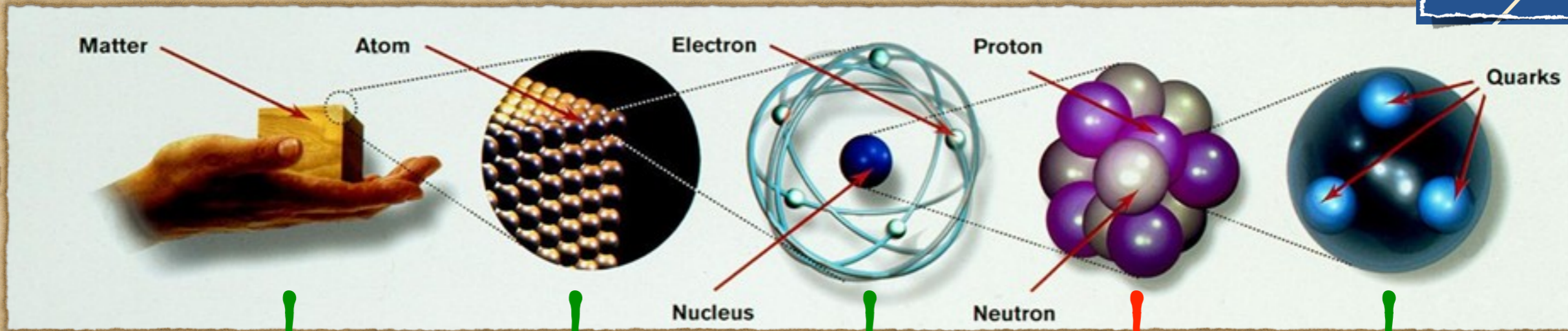
(10^{-10} m)

0.01pm

(10^{-14} m)

Femto!

(10^{-15} m)



↓
5cm
(10^{-2} m)

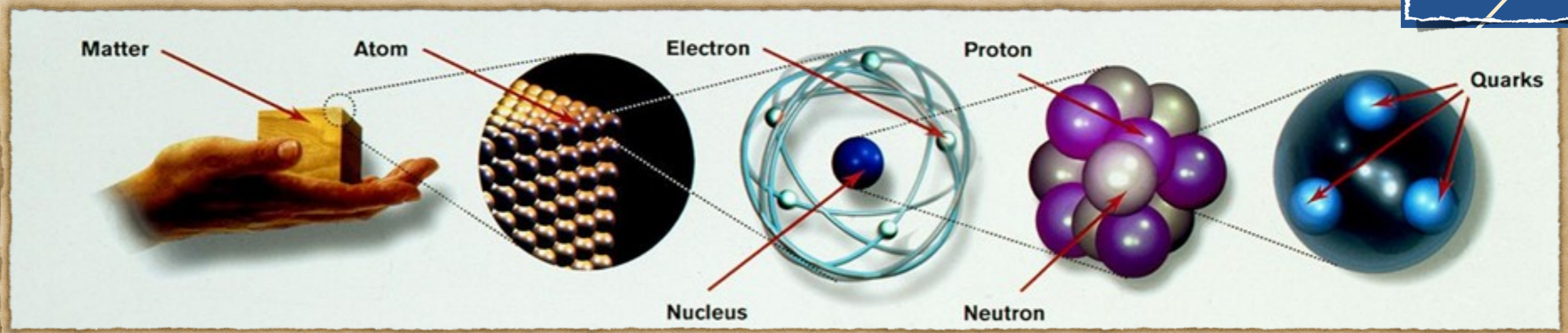
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1Å
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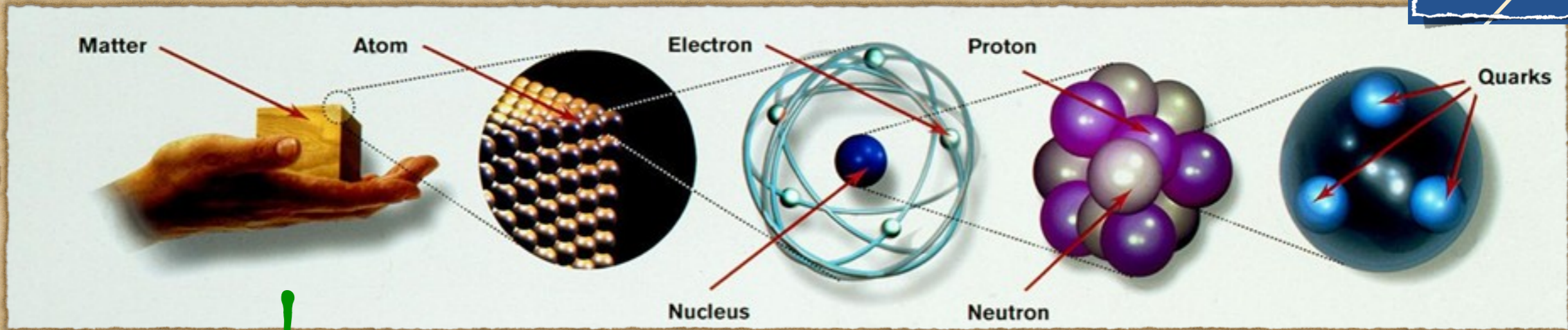
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0.01pm
(10^{-14} m)

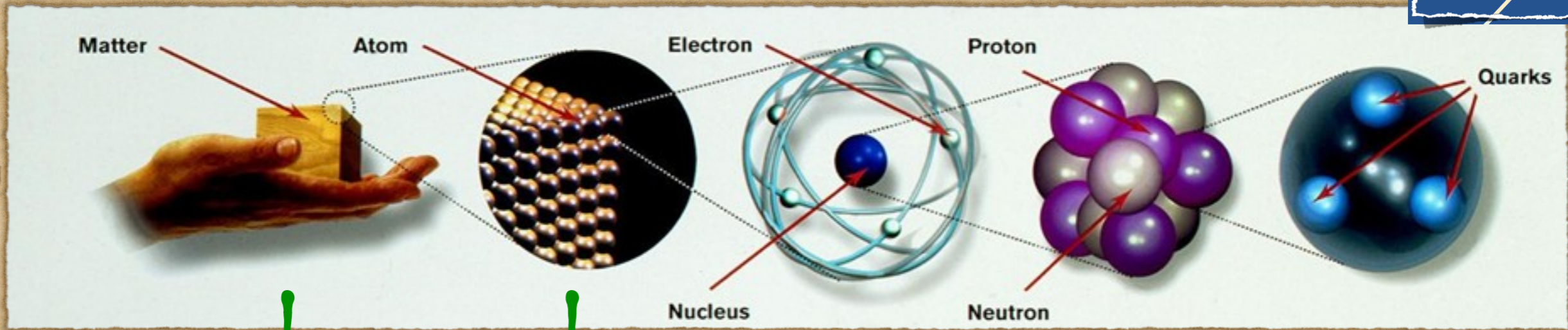
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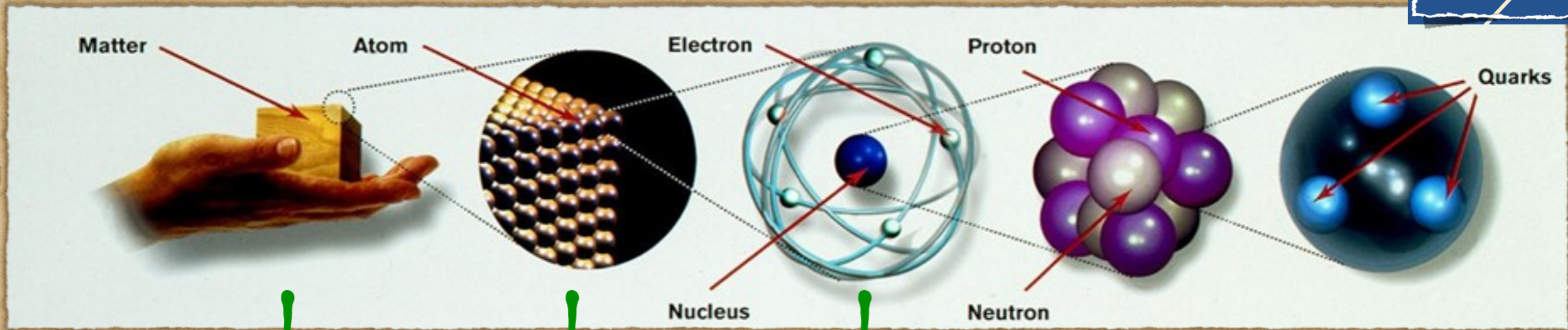
↓
1am
(10^{-18} m)

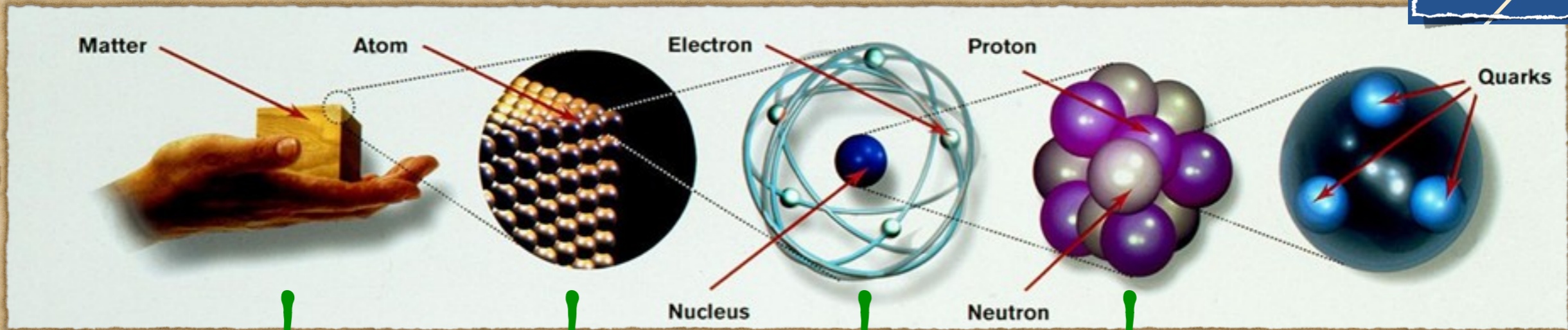
Femto!
(10^{-15} m)



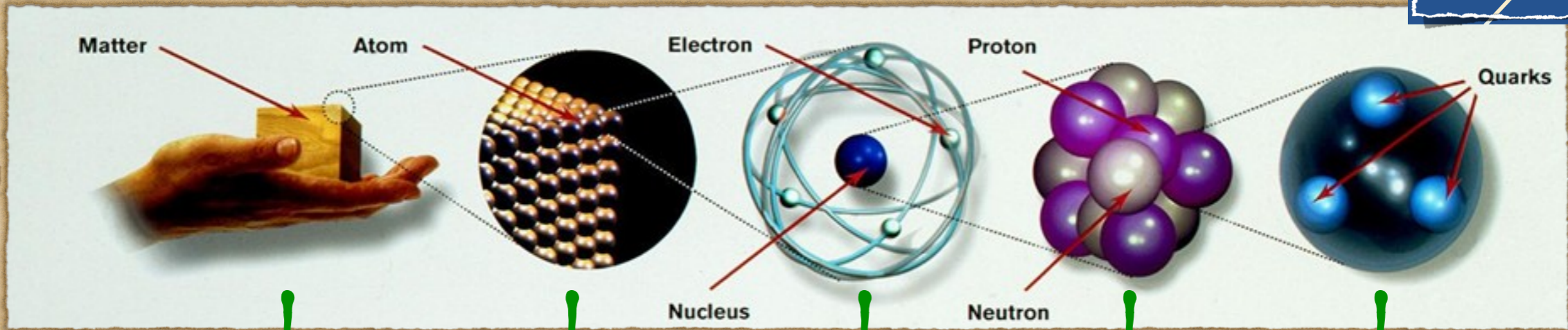




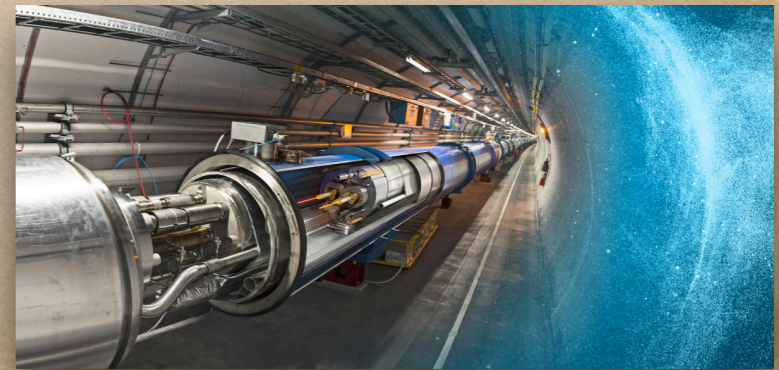




Credit: CERN

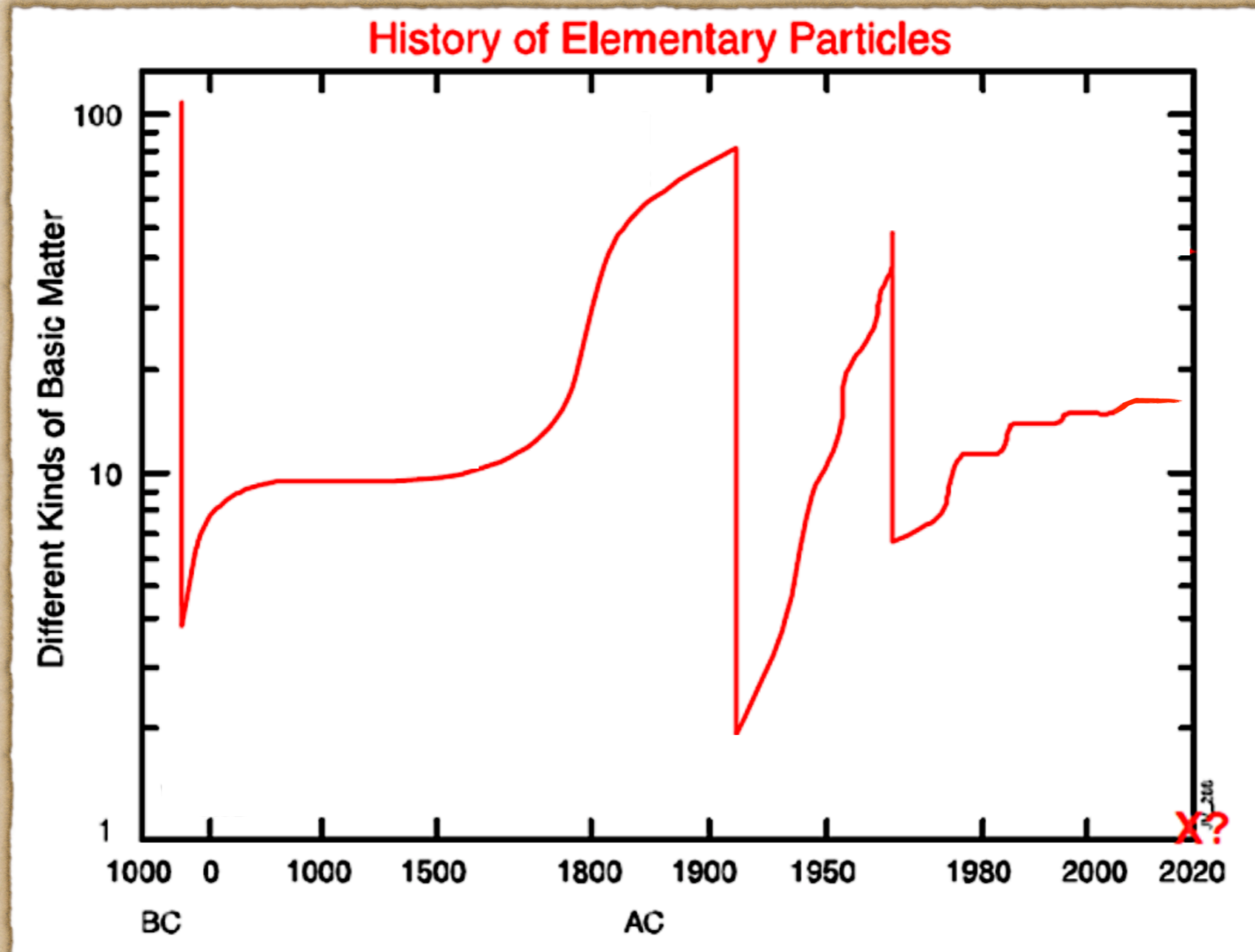


Credit: CERN

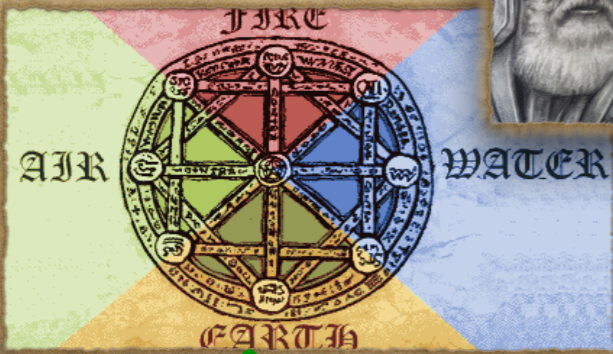


Credit: CERN

Basic Bricks of the Universe

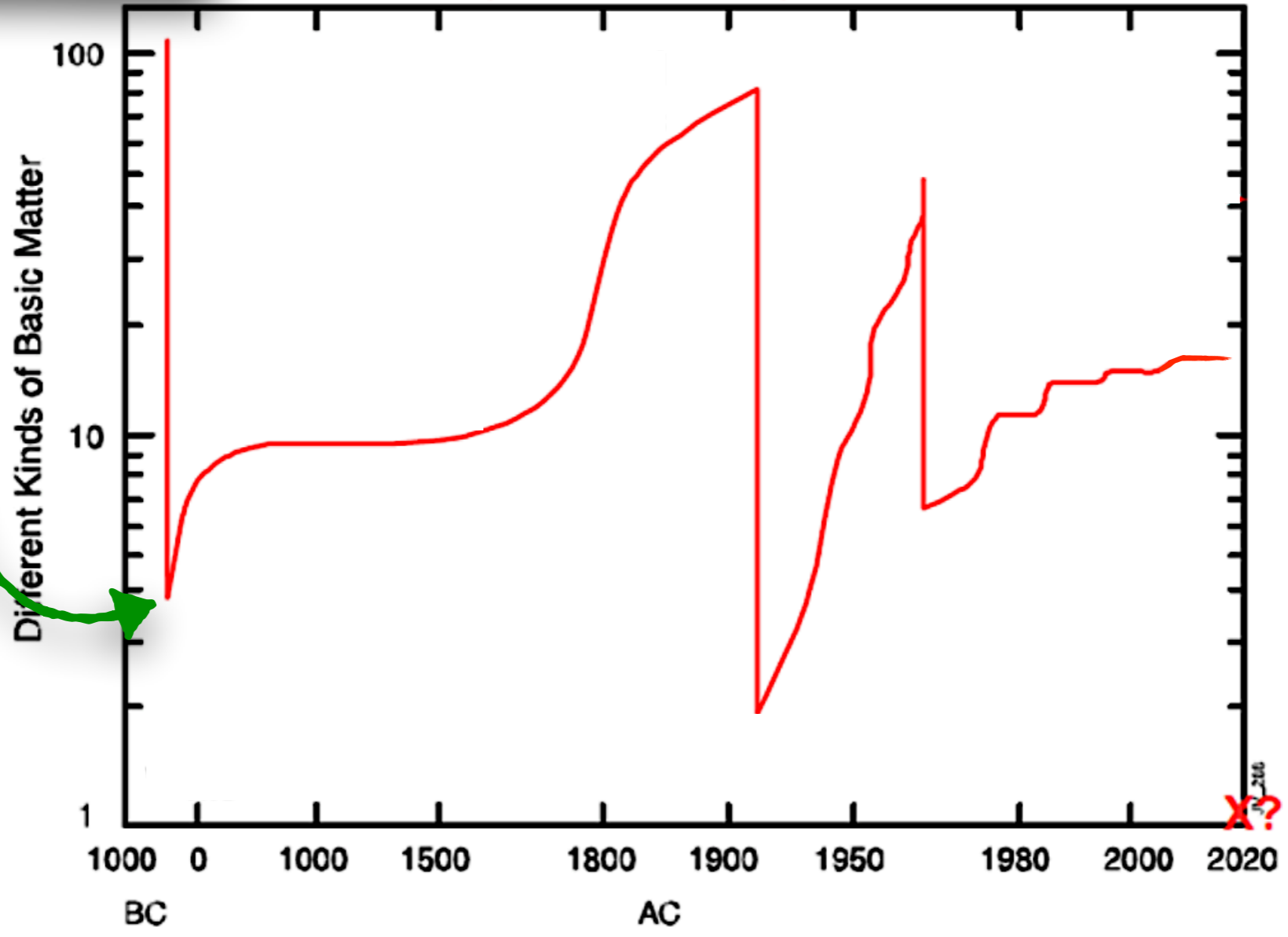


Credit: <http://arxiv.org/abs/1311.1769>

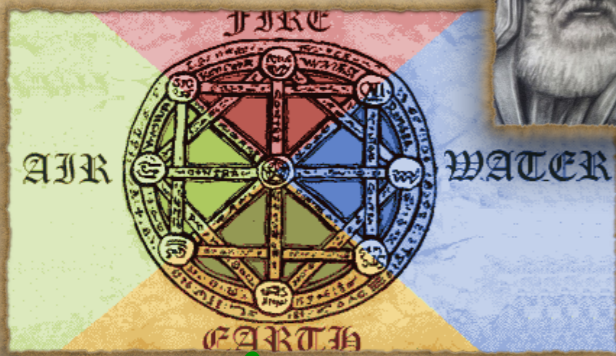


Bricks of the Universe

History of Elementary Particles

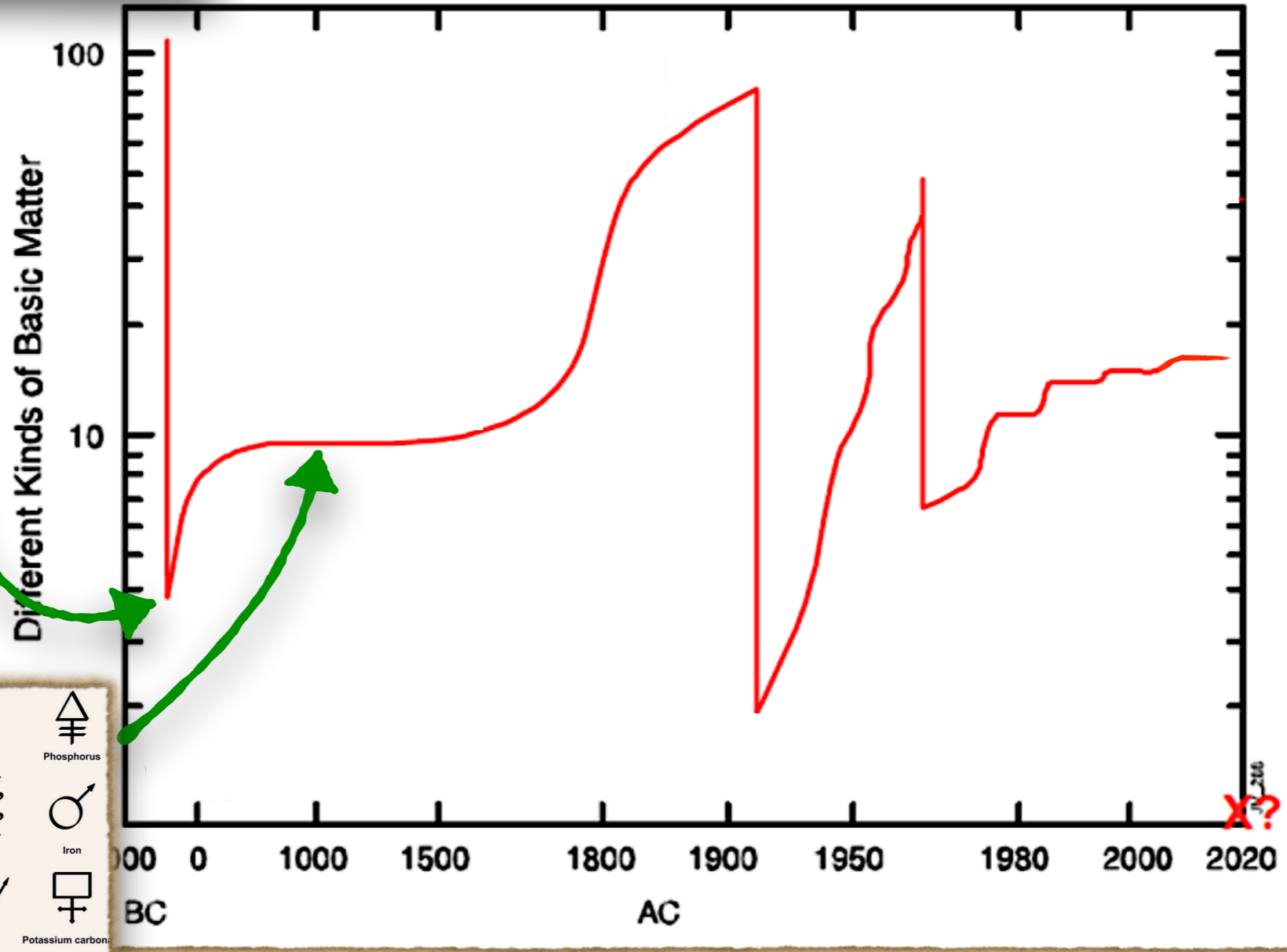


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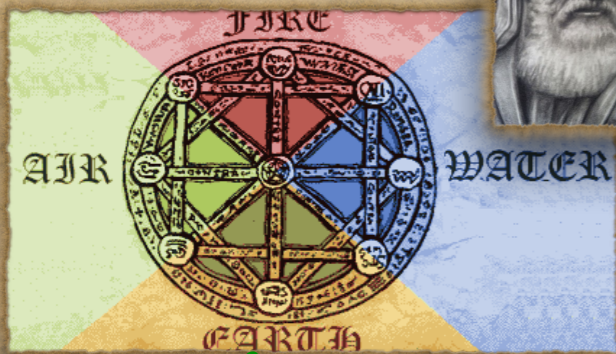
Bricks of the Universe

History of Elementary Particles



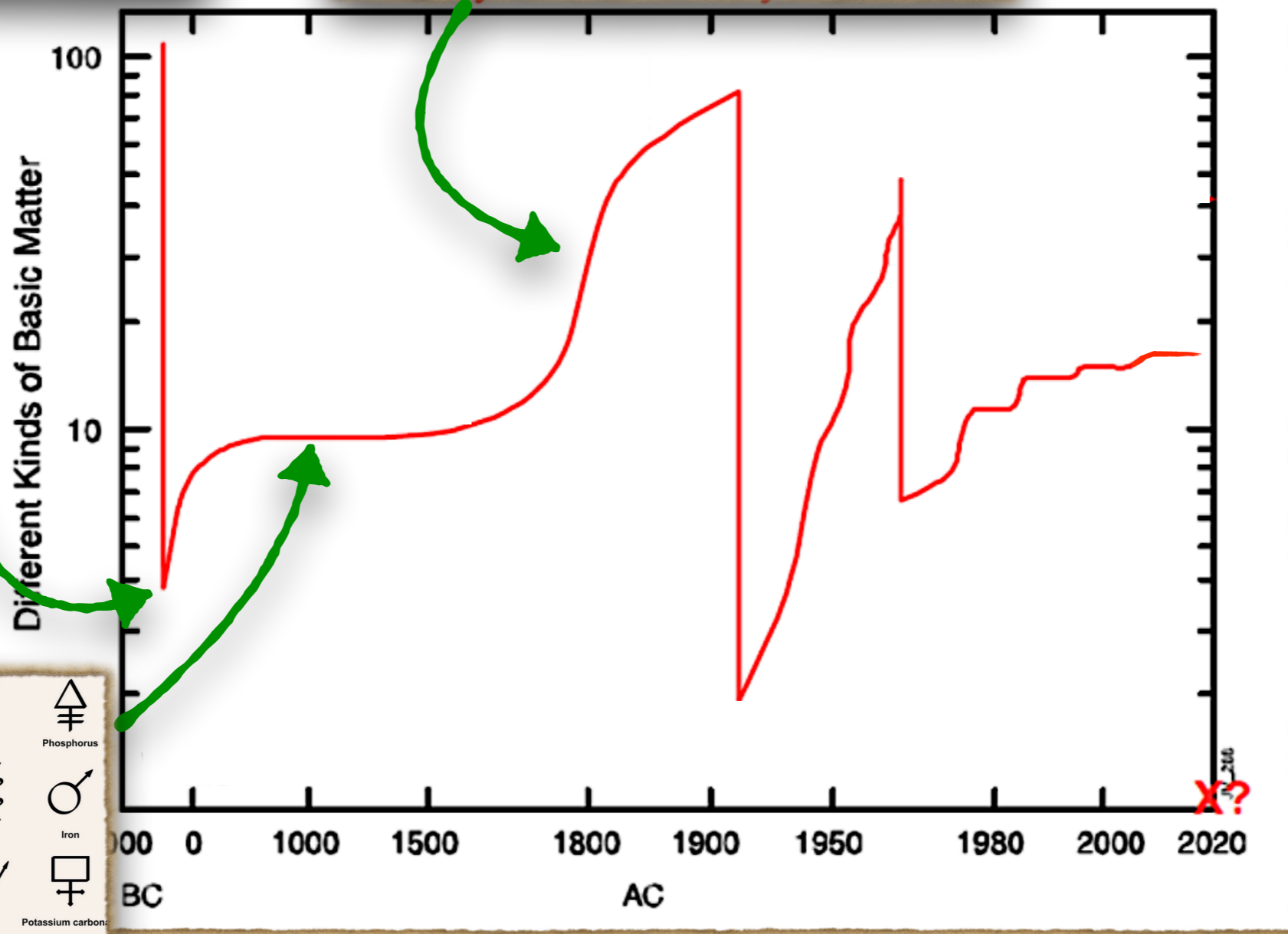
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|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
| Zinc | Platinum | Magnesium | Arsenic |

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



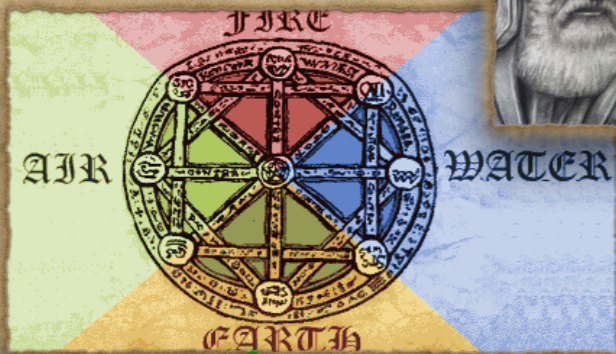
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|-------------------|----|----|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|
| group | 1* | 2 | transition elements | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 18 | |
| 1 | H | | | | | | | | | | | | | | | | | He | |
| 2 | Li | Be | | | | | | | | | | | | | | | | Ne | |
| 3 | Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar | |
| 4 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr | |
| 5 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe | |
| 6 | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn | |
| 7 | Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og | |
| lanthanoid series | | | 6 | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | | |
| actinoid series | | | 7 | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr | | |

Universe



| | | | |
|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
| Zinc | Platinum | Magnesium | Arsenic |

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

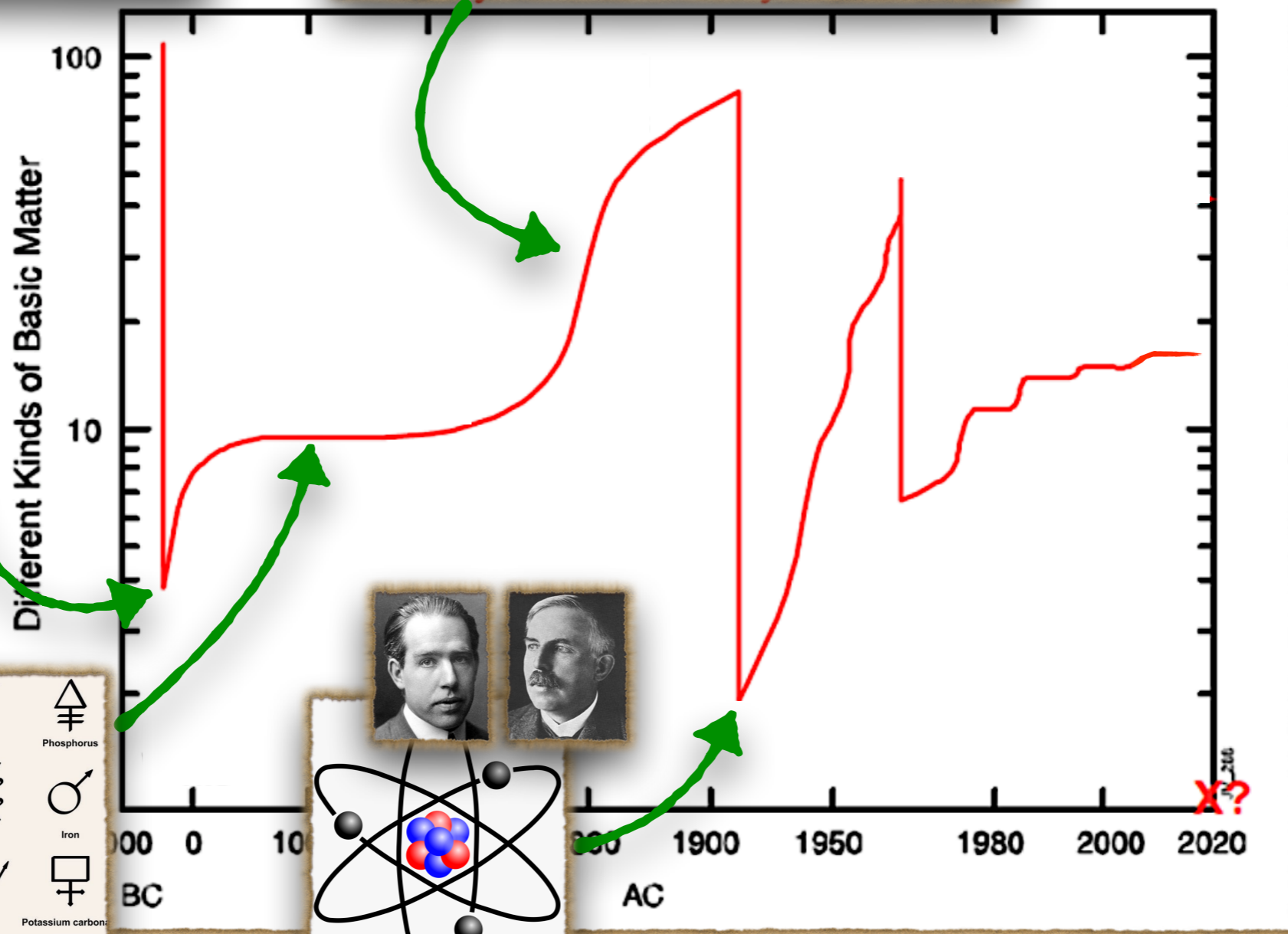


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|--------|----|----|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| group | 1* | 2 | transition elements | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 18 |
| period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | H | | | | | | | | | | | | | | | | | He |
| 2 | Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| 3 | Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| 4 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 5 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| 6 | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| 7 | Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |

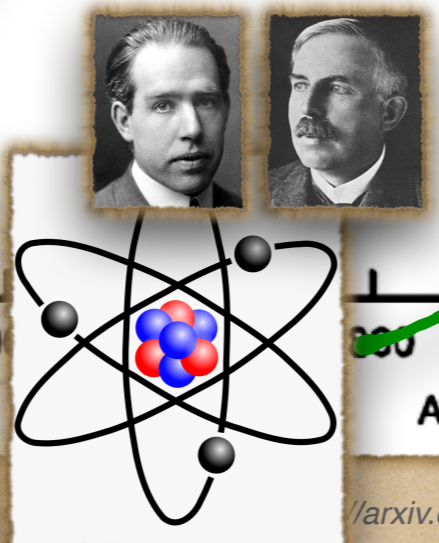
lanthanoid series 6
 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu

actinoid series 7
 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

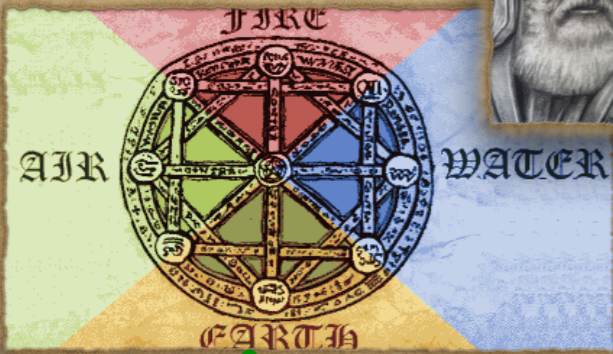
Origin of the Universe



| | | | |
|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
| Zinc | Platinum | Magnesium | Arsenic |

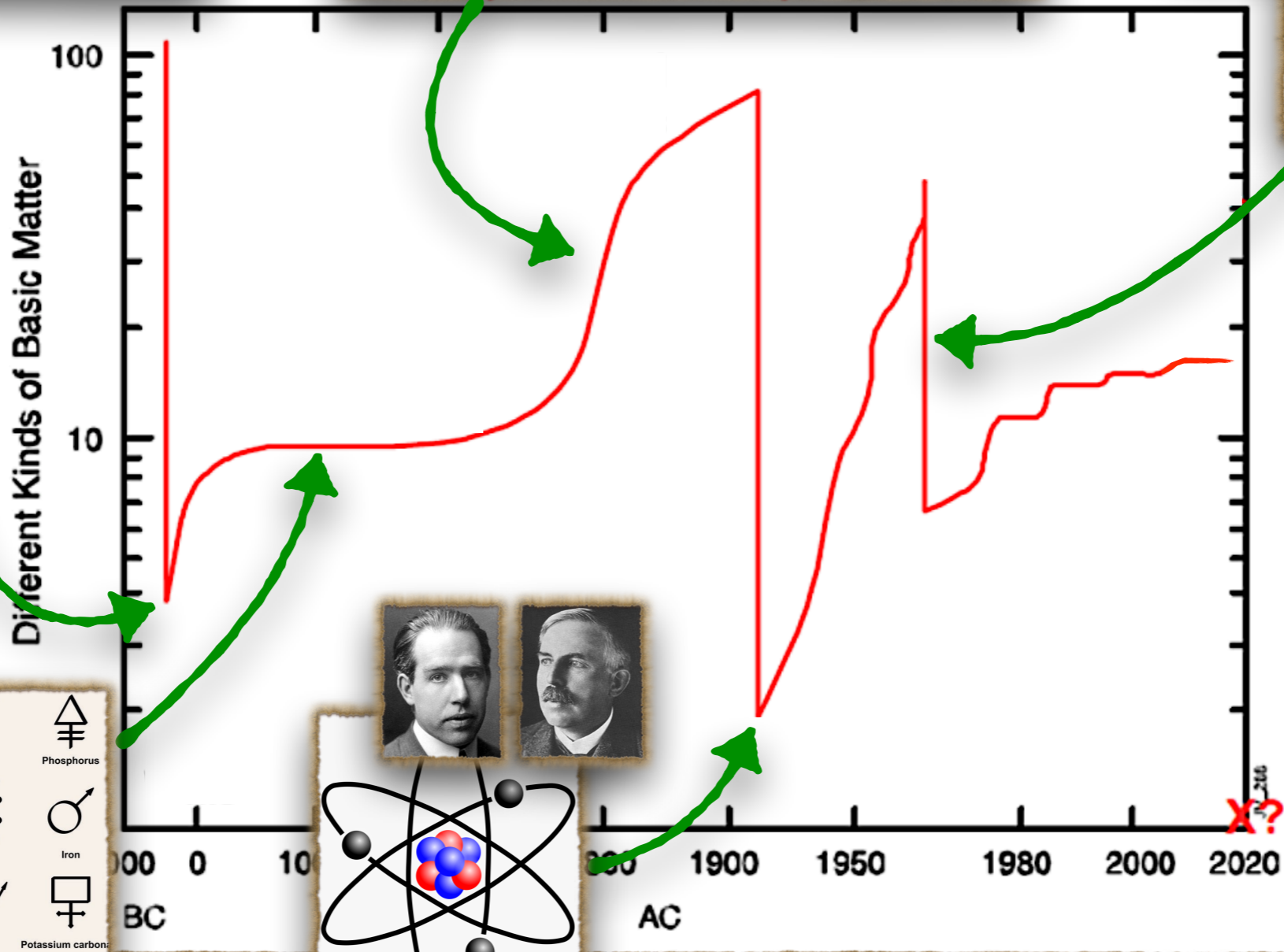
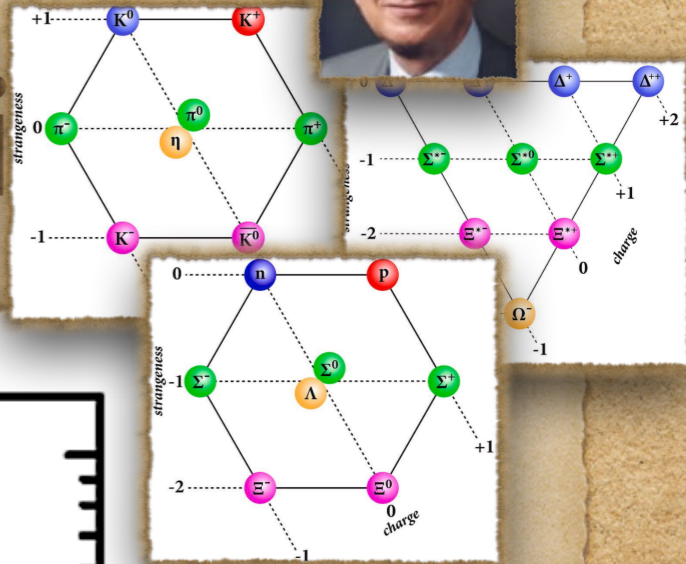


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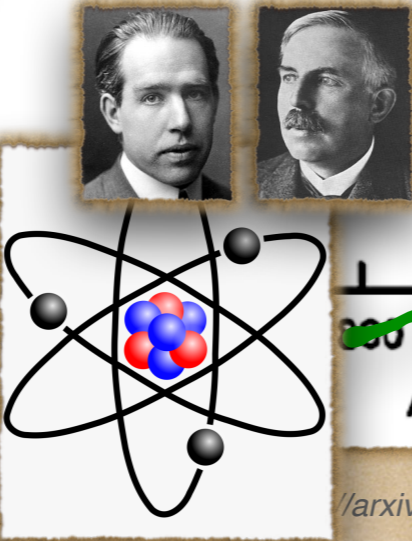


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|-------|----|----|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| group | 1* | 2 | transition elements | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | H | | | | | | | | | | | | | | | | | He |
| 2 | Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| 3 | Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| 4 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 5 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| 6 | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Hg | Tl | Pb | Bi | Po | At | Rn | |
| 7 | Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |

lanthanoid series 6
 Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
 actinoid series 7
 Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

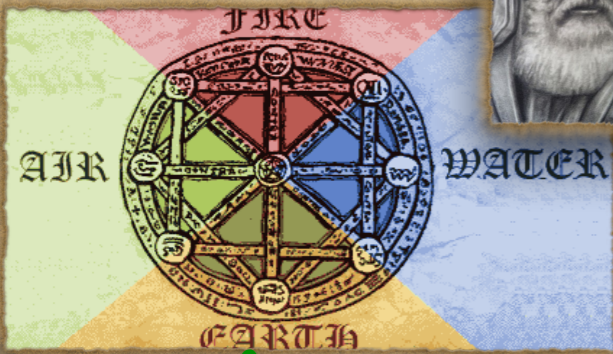


| | | | |
|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
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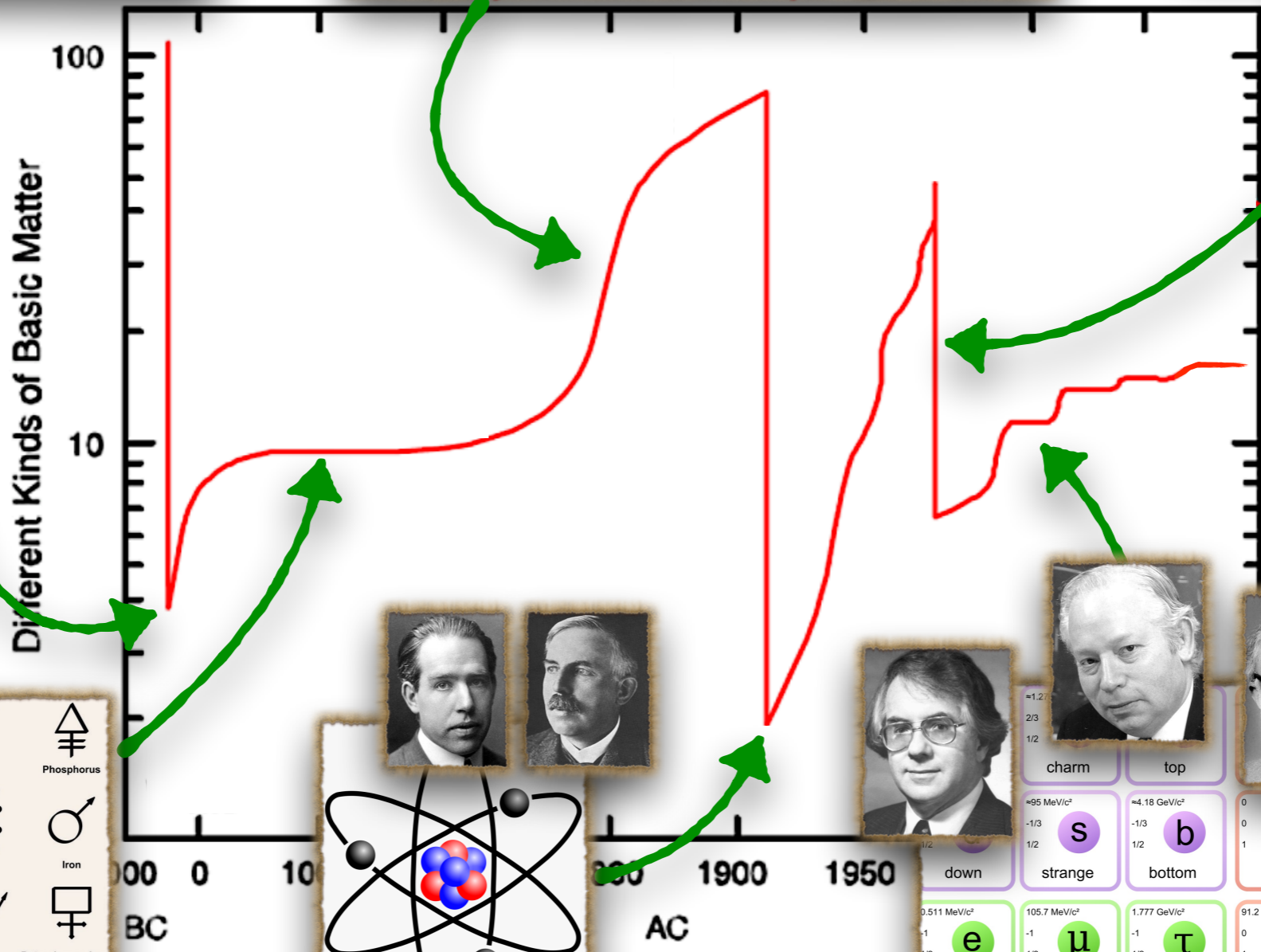
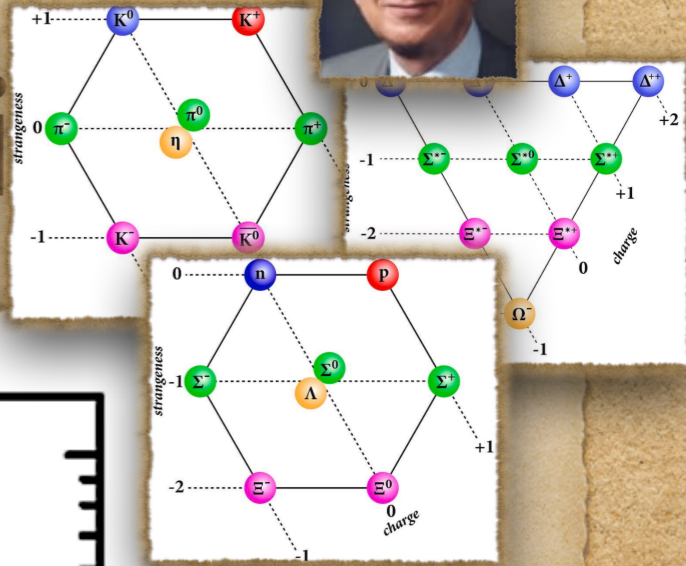


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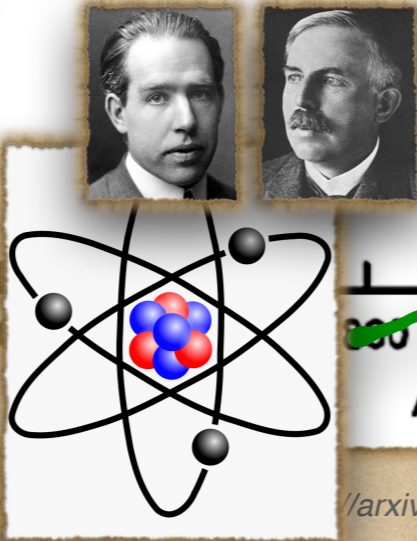
X?



| | | | | | | | | | | | | | | | | | | | |
|-------------------|----|----|-------------------------------------|----|----|----|----|----|----|----|----|----|----------------------------------|----|----|----|----|----|----|
| group | 1* | 2 | transition elements (21, 39, 57-71) | | | | | | | | | | lanthanoid elements (57-71 only) | | | | | | 18 |
| 1 | H | | | | | | | | | | | | | | | | | | He |
| 2 | Li | Be | | | | | | | | | | | | | | | | | Ne |
| 3 | Na | Mg | | | | | | | | | | | | | | | | | Ar |
| 4 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr | |
| 5 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe | |
| 6 | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn | |
| 7 | Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og | |
| lanthanoid series | | | 6 | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | | |
| actinoid series | | | 7 | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr | | |

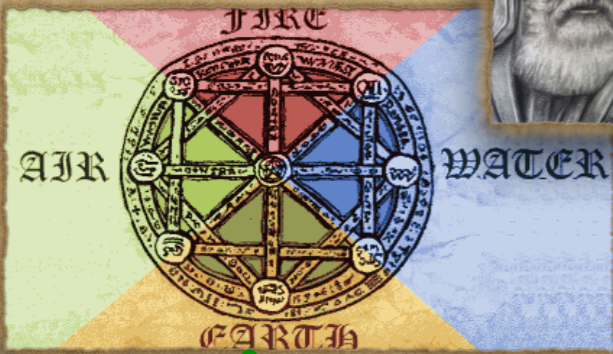


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|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
| Zinc | Platinum | Magnesium | Arsenic |



| | | |
|-------------------|---------------|--------------|
| | | |
| charm | top | photon |
| | | |
| strange | bottom | Z boson |
| | | |
| electron | muon | tau |
| | | |
| electron neutrino | muon neutrino | tau neutrino |
| | | |
| W boson | W boson | W boson |

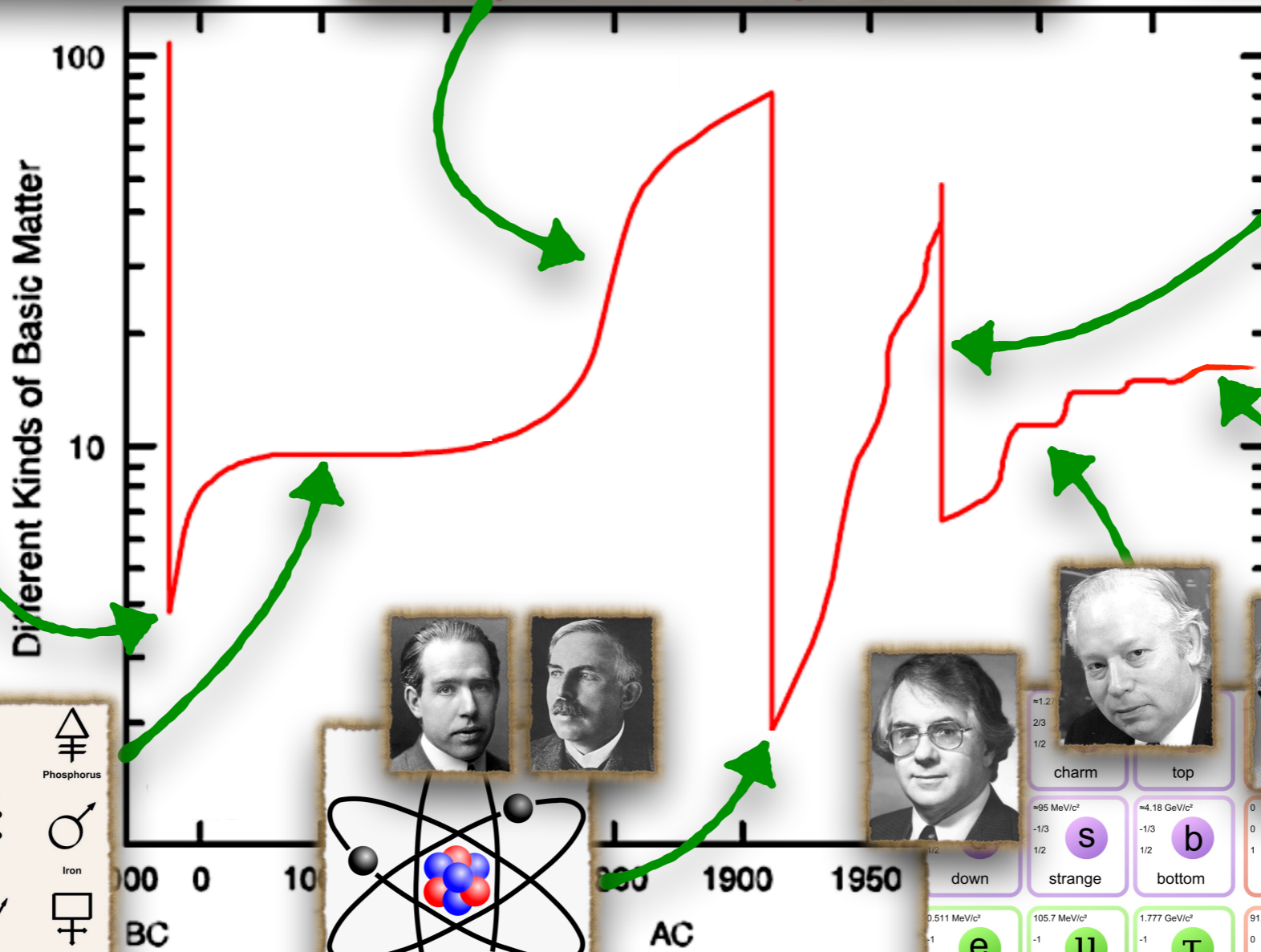
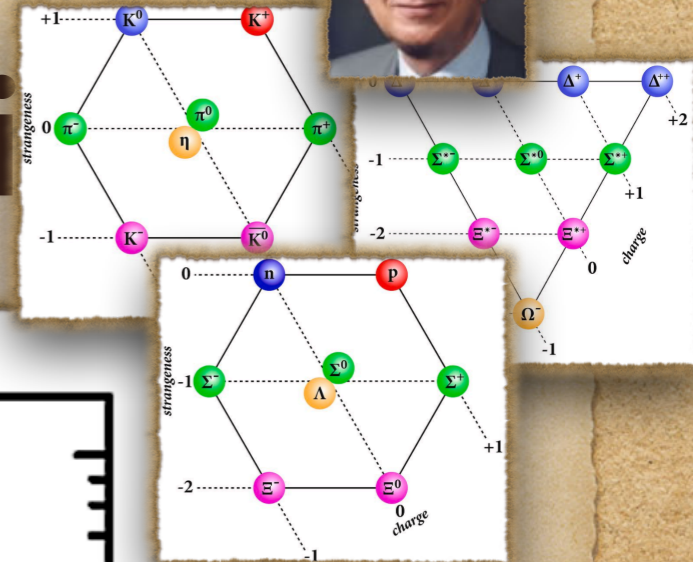
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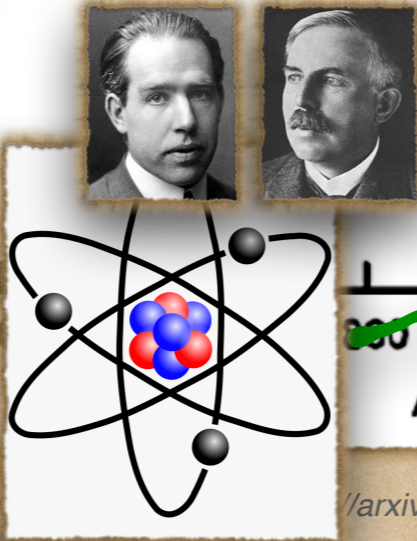
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|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 2 | | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 18 | |
| 1 | H | | | | | | | | | | | He | | | | | | |
| 2 | 3 | 4 | | | | | | | | | | | 10 | | | | | |
| 3 | Li | Be | | | | | | | | | | | Ne | | | | | |
| 4 | 11 | 12 | | | | | | | | | | | 18 | | | | | |
| 5 | Na | Mg | | | | | | | | | | | Ar | | | | | |
| 6 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| 7 | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| 8 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 |
| 9 | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| 10 | 55 | 56 | 57 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 |
| 11 | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| 12 | 87 | 88 | 89 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 |
| 13 | Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |

lanthanoid series 6
 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
 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

actinoid series 7

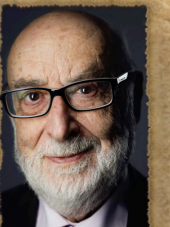


| | | | |
|----------|----------|-----------|------------|
| | | | |
| Antimony | Bismuth | Gold | Phosphorus |
| | | | |
| Lead | Mercury | Copper | Iron |
| | | | |
| Sulfur | Tin | Silver | Potassium |
| | | | |
| Zinc | Platinum | Magnesium | Arsenic |



[/arxiv.org/abs/1311.1769](https://arxiv.org/abs/1311.1769)

| | | |
|-------------------|---------------|--------------|
| | | |
| charm | top | photon |
| | | |
| strange | bottom | Z boson |
| | | |
| electron | muon | tau |
| | | |
| electron neutrino | muon neutrino | tau neutrino |
| | | |
| W boson | W boson | W boson |



v/c^2
H
 Higgs boson



17

particles



A portion of the periodic table of elements, showing the first few rows and columns. The elements are arranged in a grid, with their symbols and atomic numbers. The table is labeled with 'group' and 'period'.



Different Kinds of Basic Matter



A table of chemical symbols and names. The symbols are arranged in a grid, with their corresponding element names below them. The elements listed are Antimony, Bismuth, Gold, Phosphorus, Lead, Mercury, Copper, Iron, Sulfur, Tin, Silver, Potassium carbon, Zinc, Platinum, Magnesium, and Arsenic.

A table of particle properties. The table lists various particles and their properties, including mass, charge, and spin. The particles listed are charm, top, down, strange, bottom, photon, electron, muon, tau, Z boson, electron neutrino, muon neutrino, tau neutrino, and W boson.

$E=mc^2$
H
Higgs boson



What is a particle?





Particles

Fundamental Forces

THERE ARE FOUR FUNDAMENTAL FORCES BETWEEN PARTICLES:

(1) GRAVITY, WHICH OBEYS THIS INVERSE SQUARE LAW:

$$F_{\text{gravity}} = G \frac{m_1 m_2}{d^2}$$

OK...

(2) ELECTROMAGNETISM, WHICH OBEYS THIS INVERSE-SQUARE LAW:

$$F_{\text{static}} = k_e \frac{q_1 q_2}{d^2}$$

AND ALSO MAXWELL'S EQUATIONS

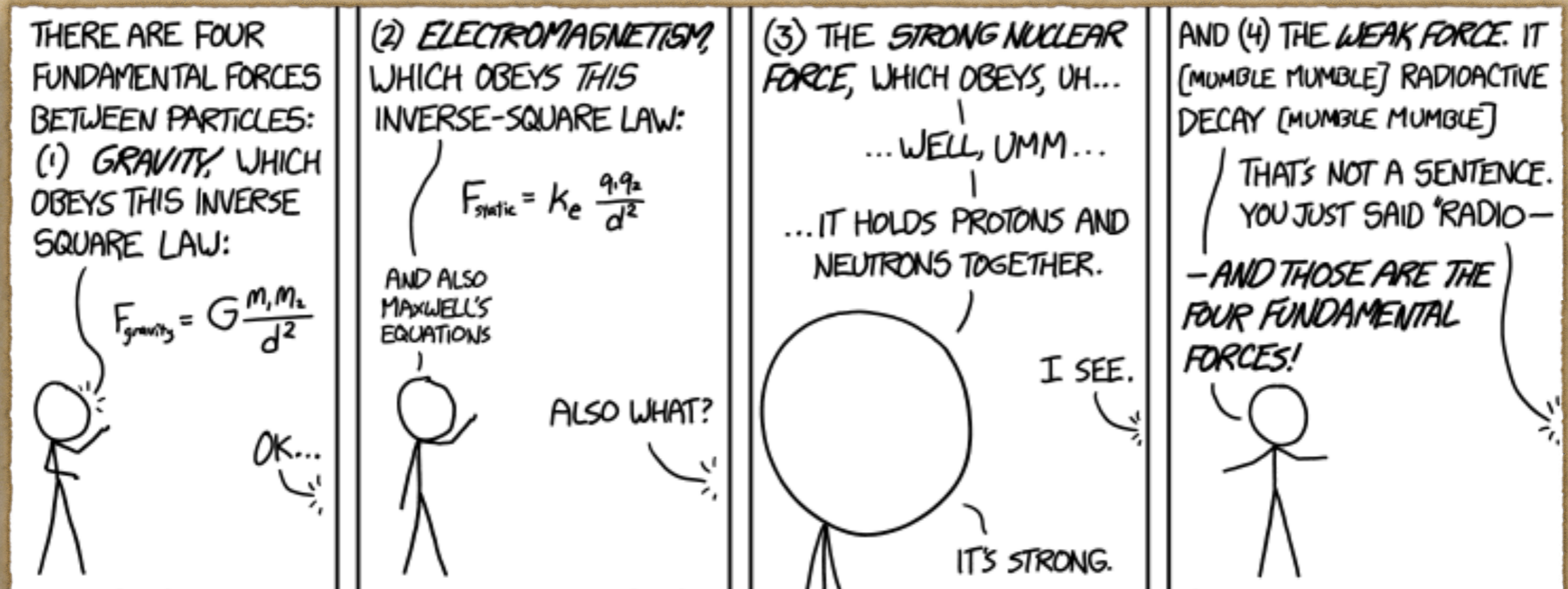
ALSO WHAT?

(3) THE STRONG NUCLEAR FORCE, WHICH OBEYS, UH...
...WELL, UMM...
...IT HOLDS PROTONS AND NEUTRONS TOGETHER.

I SEE.

IT'S STRONG.

AND (4) THE WEAK FORCE. IT [MUMBLE MUMBLE] RADIOACTIVE DECAY [MUMBLE MUMBLE]
THAT'S NOT A SENTENCE. YOU JUST SAID 'RADIO-
-AND THOSE ARE THE FOUR FUNDAMENTAL FORCES!



Elementary Particles

- Three types:
 - **Fermions:** matter particles
 - **Bosons:** force carriers ("exchange particles")
 - **Higgs:** special guy
- Difference lies in **spin**

Elementary Particles

- Two types of matter particles:
 - **Leptons:** electrons, muons, taus, and neutrinos
 - **Quarks:** don't exist alone, but combine to form hadrons (composite particles)
- Four fundamental forces:
 - **Electromagnetic:** exchanged by photon
 - **Weak:** exchanged by W^+ , W^- , Z^0
 - **Strong:** exchanged by gluons
 - **Gravity:** exchanged by graviton

Elementary Particles

- Two types of matter particles:
 - **Leptons:** electrons, muons, taus, and neutrinos
 - **Quarks:** don't exist alone, but combine to form hadrons (composite particles)

Three very cool and quantisable and not 'totally ignorable'

- ~~Four fundamental forces:~~
 - **Electromagnetic:** exchanged by photon
 - **Weak:** exchanged by W^+ , W^- , Z^0
 - **Strong:** exchanged by gluons
 - ~~**Gravity:** exchanged by graviton~~

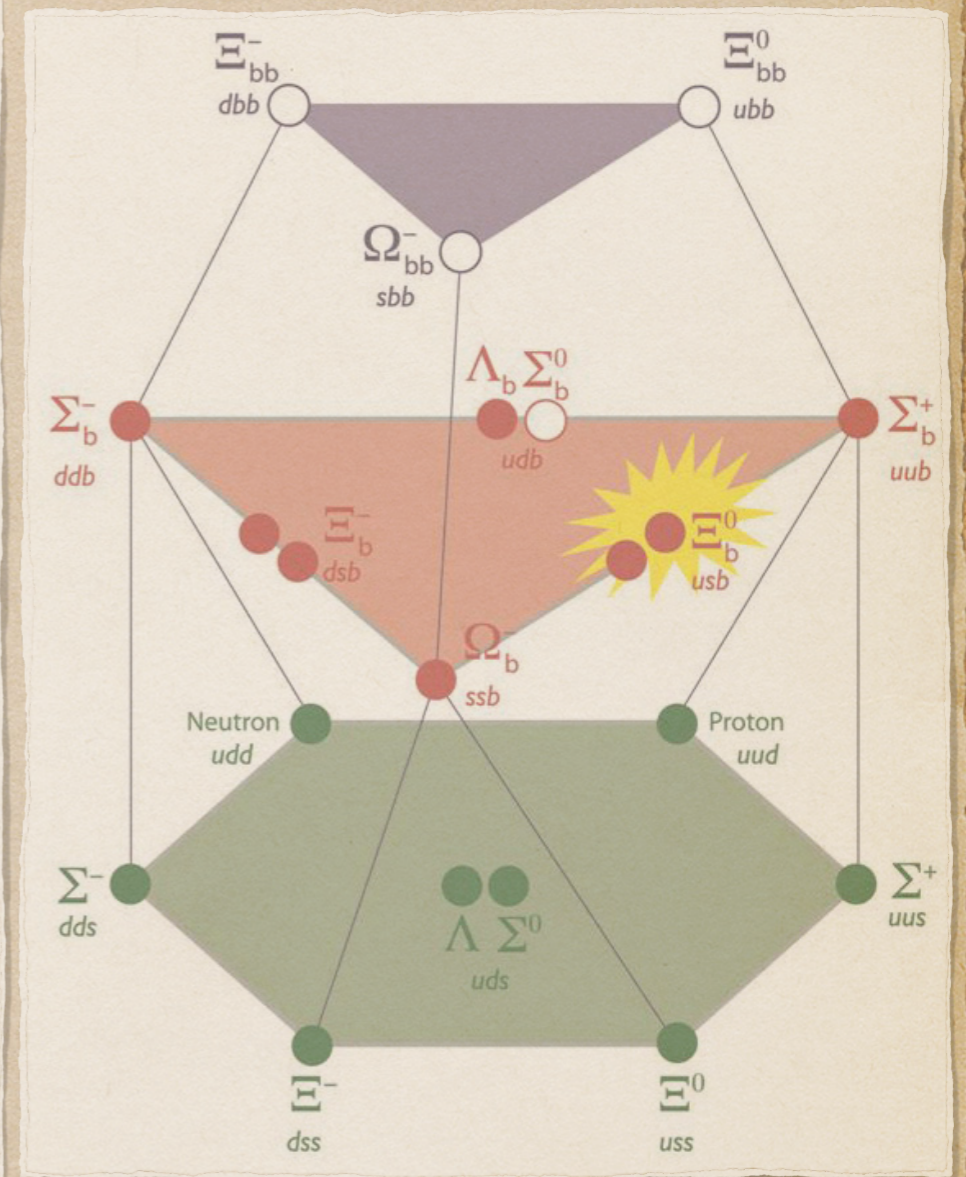
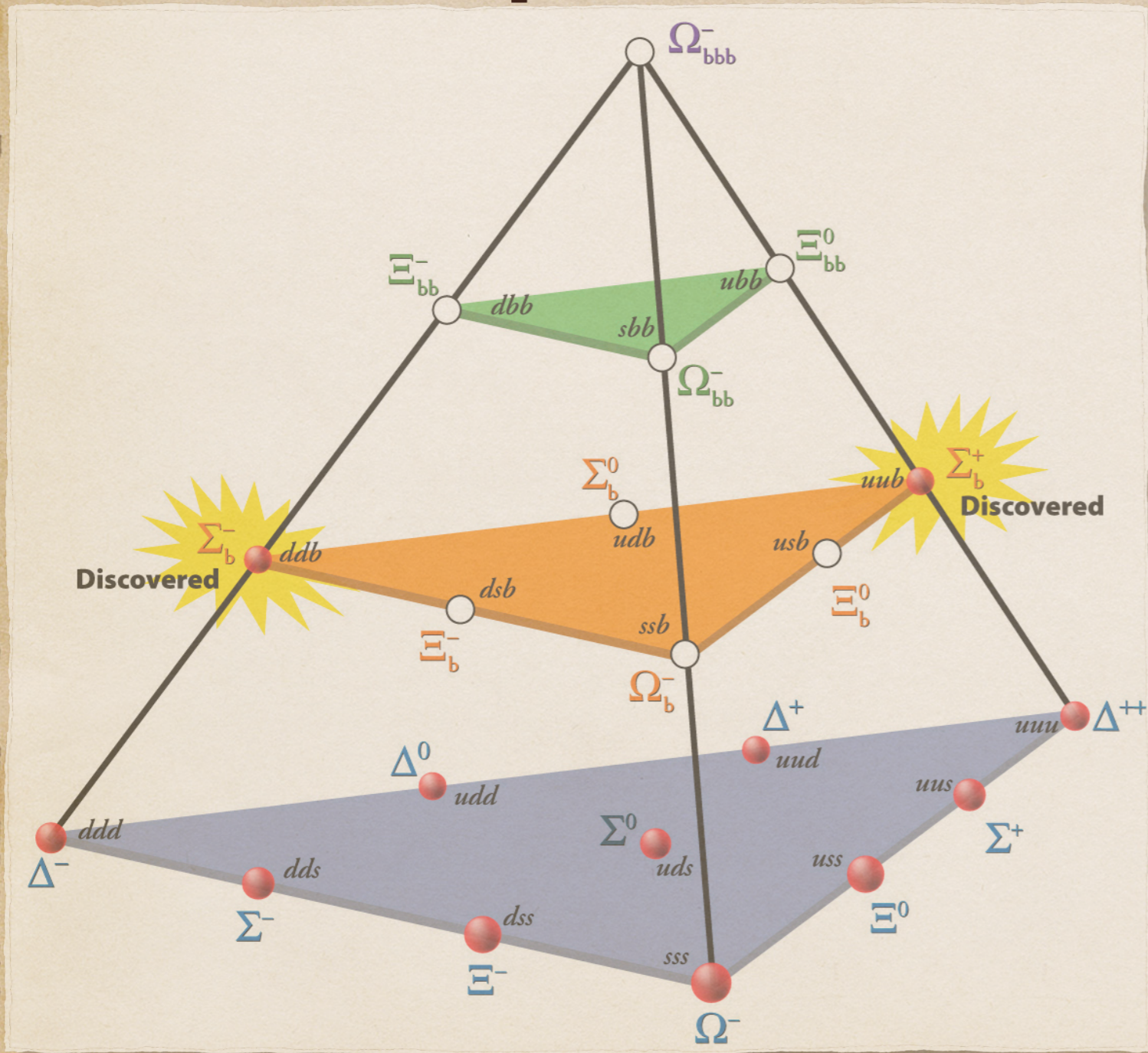
Particle Properties

- Every force comes with an associated charge. If a certain particle does not have this charge, it will not interact with this force.
 - Electromagnetic charge
 - Weak hypercharge
 - Colour (strong force)
- Fermions come in 3 families, the difference between the families being the mass.

Elementary: The SM

| | mass → | charge → | spin → | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------|-------------------------------|----------|--------|---------------------------|-------------------|---------------------------------|--------|-------|-----------------------------|---------------|----------------------------------|--------|-------|------------------------------|--------------|------------------------|---------|---|----------------------------|----------|-------------------------------|---|---|---|----------|-------------|--|--|
| QUARKS | $\approx 2.3 \text{ MeV}/c^2$ | $2/3$ | $1/2$ | u | up | $\approx 1.275 \text{ GeV}/c^2$ | $2/3$ | $1/2$ | c | charm | $\approx 173.07 \text{ GeV}/c^2$ | $2/3$ | $1/2$ | t | top | 0 | 0 | 1 | g | gluon | $\approx 126 \text{ GeV}/c^2$ | 0 | 0 | 0 | H | Higgs boson | | |
| | $\approx 4.8 \text{ MeV}/c^2$ | $-1/3$ | $1/2$ | d | down | $\approx 95 \text{ MeV}/c^2$ | $-1/3$ | $1/2$ | s | strange | $\approx 4.18 \text{ GeV}/c^2$ | $-1/3$ | $1/2$ | b | bottom | 0 | 0 | 1 | γ | photon | | | | | | | | |
| | $0.511 \text{ MeV}/c^2$ | -1 | $1/2$ | e | electron | $105.7 \text{ MeV}/c^2$ | -1 | $1/2$ | μ | muon | $1.777 \text{ GeV}/c^2$ | -1 | $1/2$ | τ | tau | $91.2 \text{ GeV}/c^2$ | 0 | 1 | | Z | Z boson | | | | | | | |
| | $< 2.2 \text{ eV}/c^2$ | 0 | $1/2$ | ν_e | electron neutrino | $< 0.17 \text{ MeV}/c^2$ | 0 | $1/2$ | ν_μ | muon neutrino | $< 15.5 \text{ MeV}/c^2$ | 0 | $1/2$ | ν_τ | tau neutrino | $80.4 \text{ GeV}/c^2$ | ± 1 | 1 | | W | W boson | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| LEPTONS | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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Composite: Particle Zoo



source: http://www.fnal.gov/pub/inquiring/physics/discoveries/images/BaryonChart_MR.jpg
<http://physicsworld.com/blog/Baryons%20Fermilab.jpg>



Interactions



How do we do it?

How do we do it?

Black Box Mechanism:

we know what we put in

we measure what comes out

use statistics to deduce what happened in between

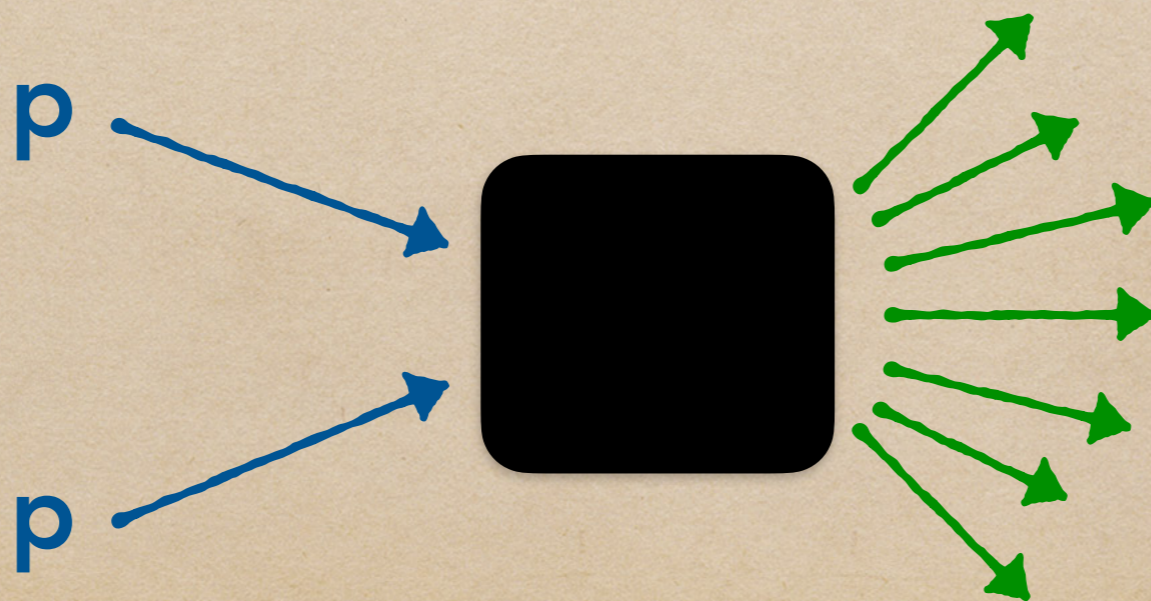
How do we do it?

Black Box Mechanism:

we know what we put in

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use statistics to deduce what happened in between



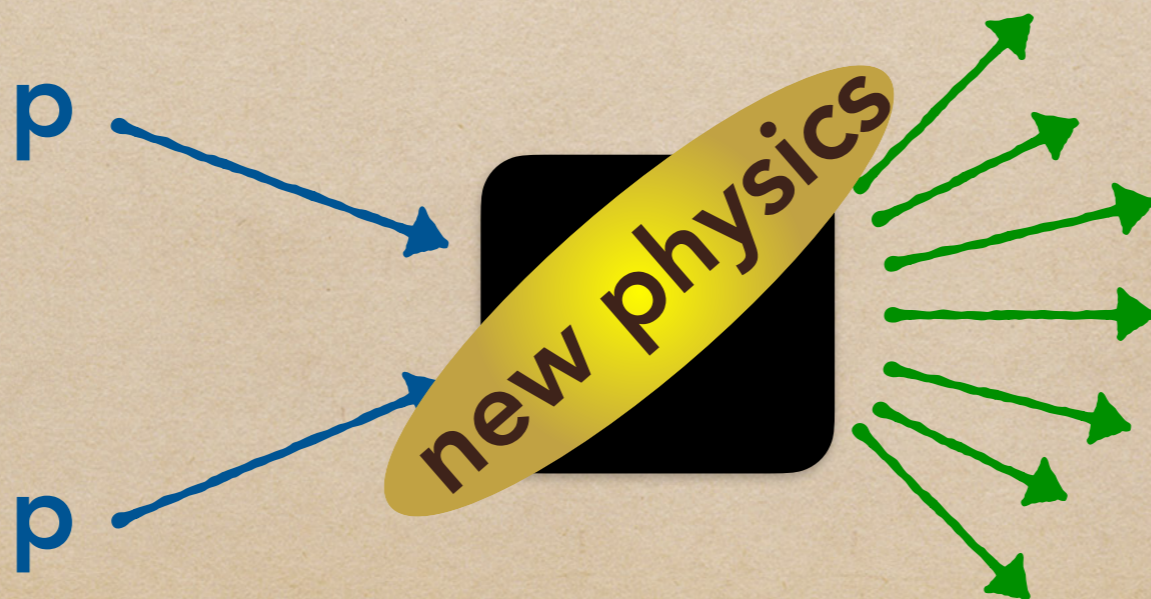
How do we do it?

Black Box Mechanism:

we know what we put in

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use statistics to deduce what happened in between

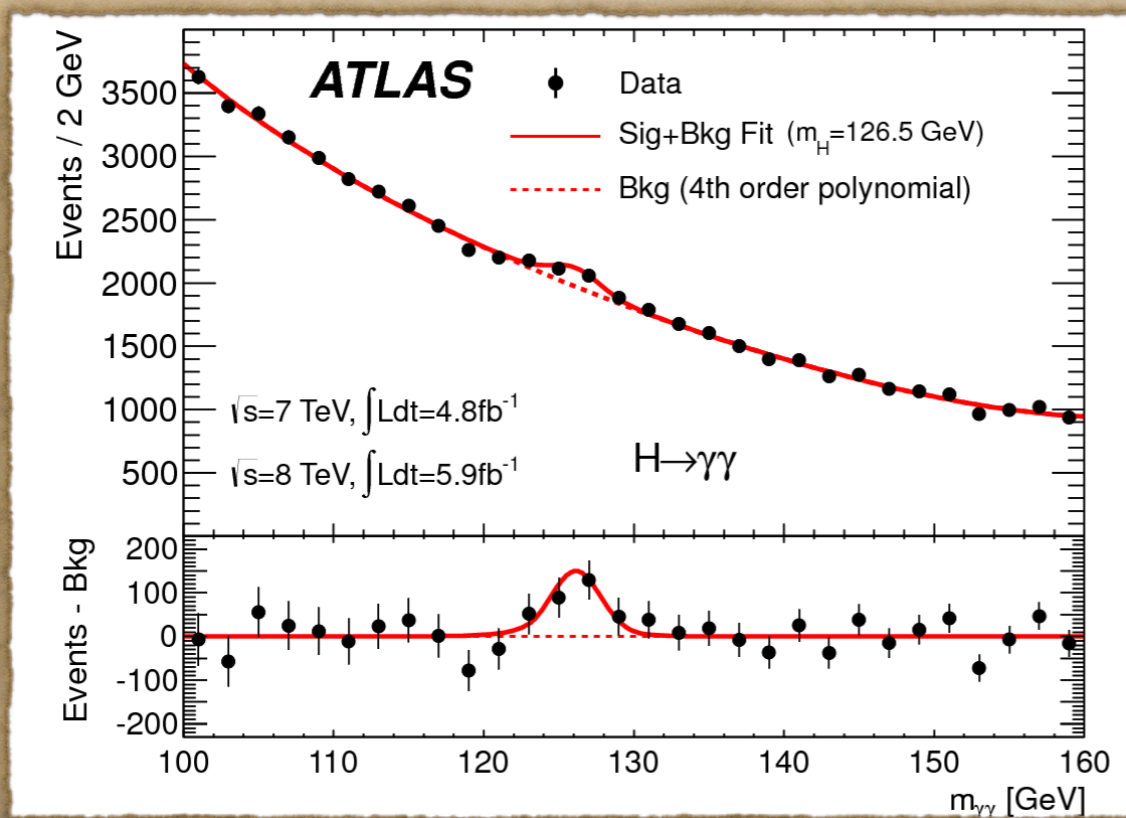




Statistics!

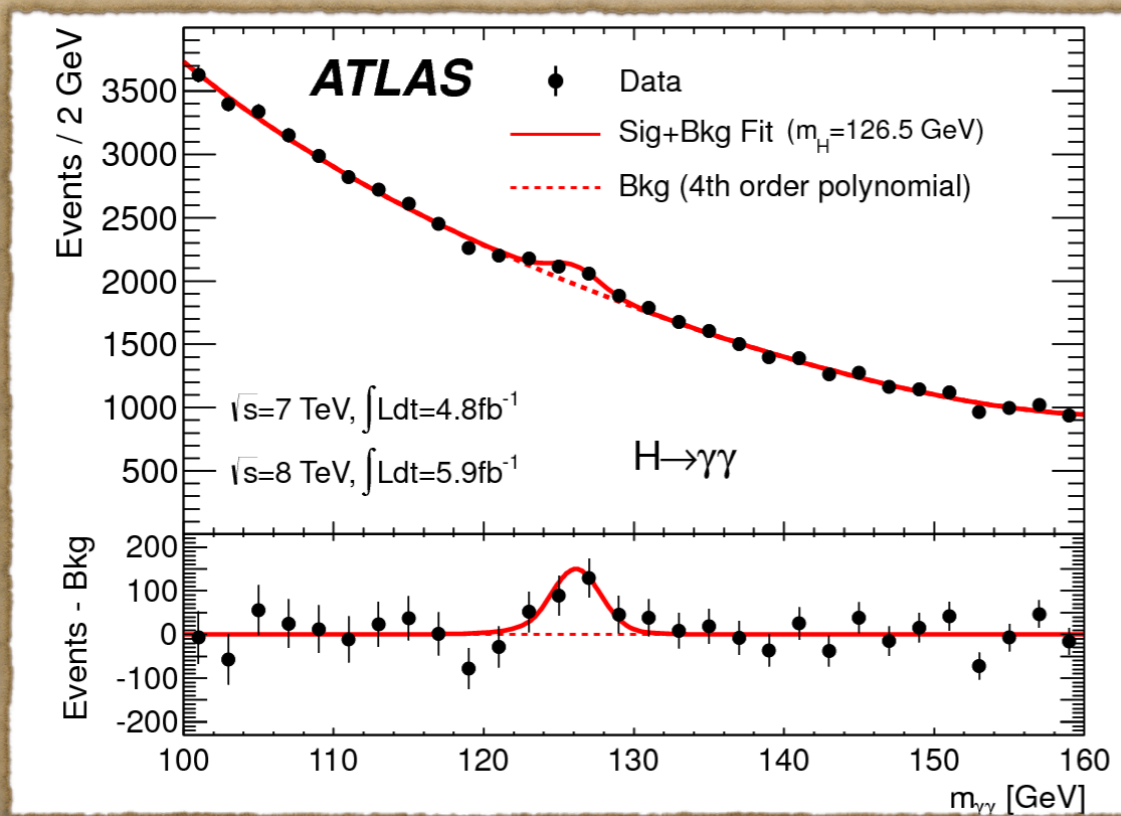
Statistics!

Higgs found!

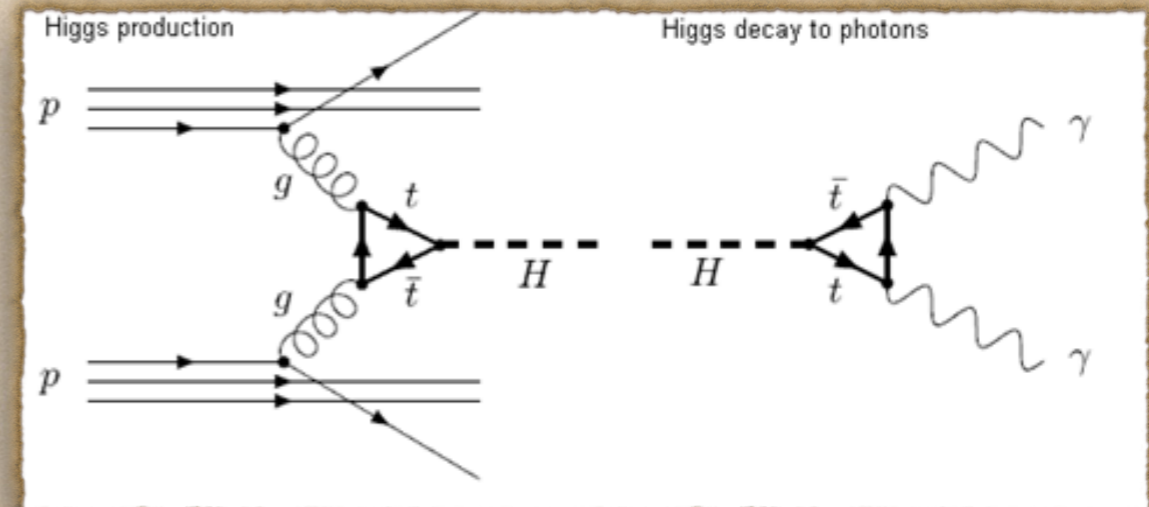


Statistics!

Higgs found!

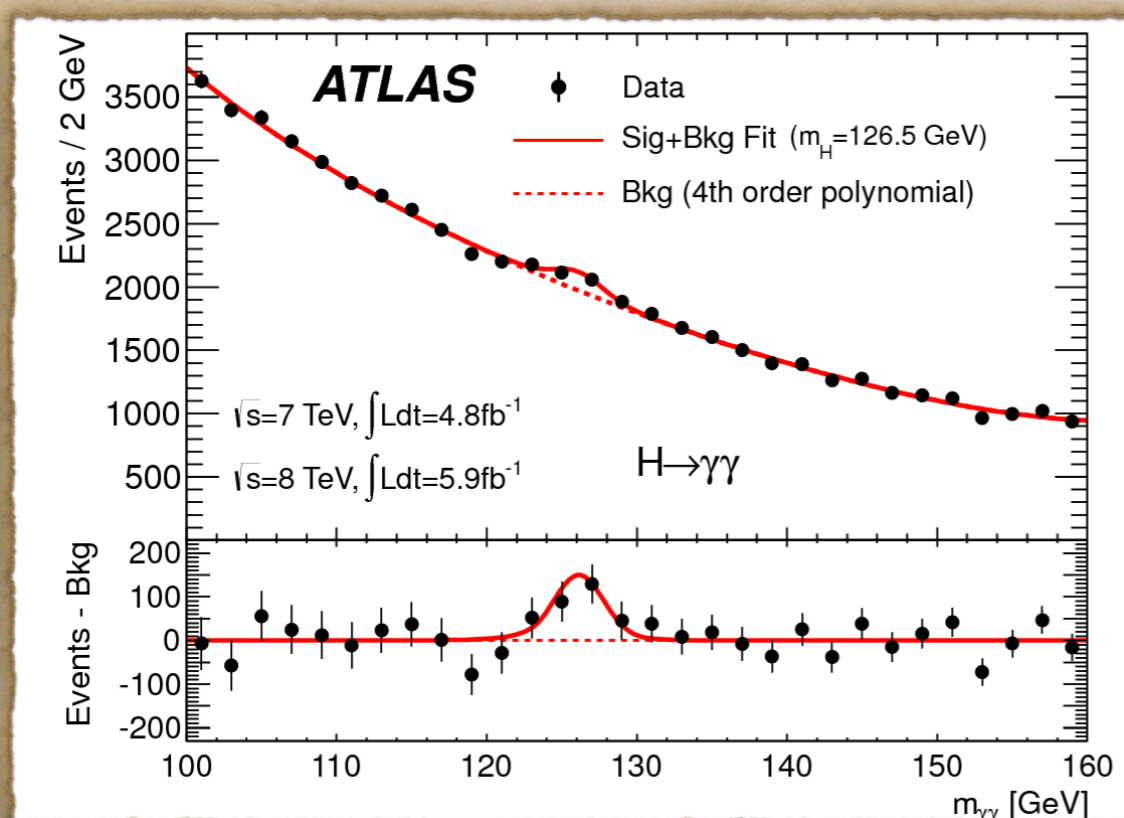


Example process

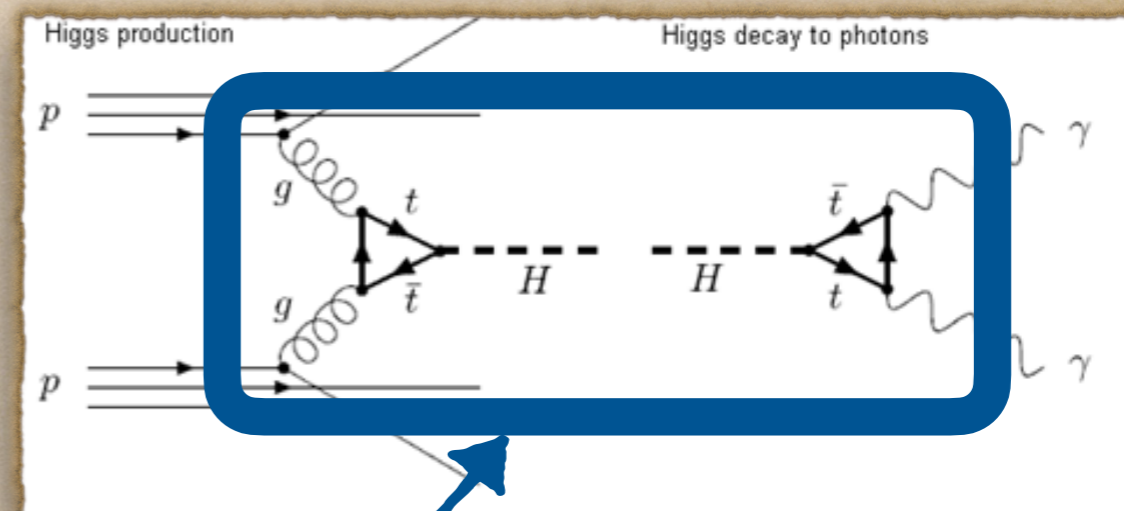


Statistics!

Higgs found!



Example process

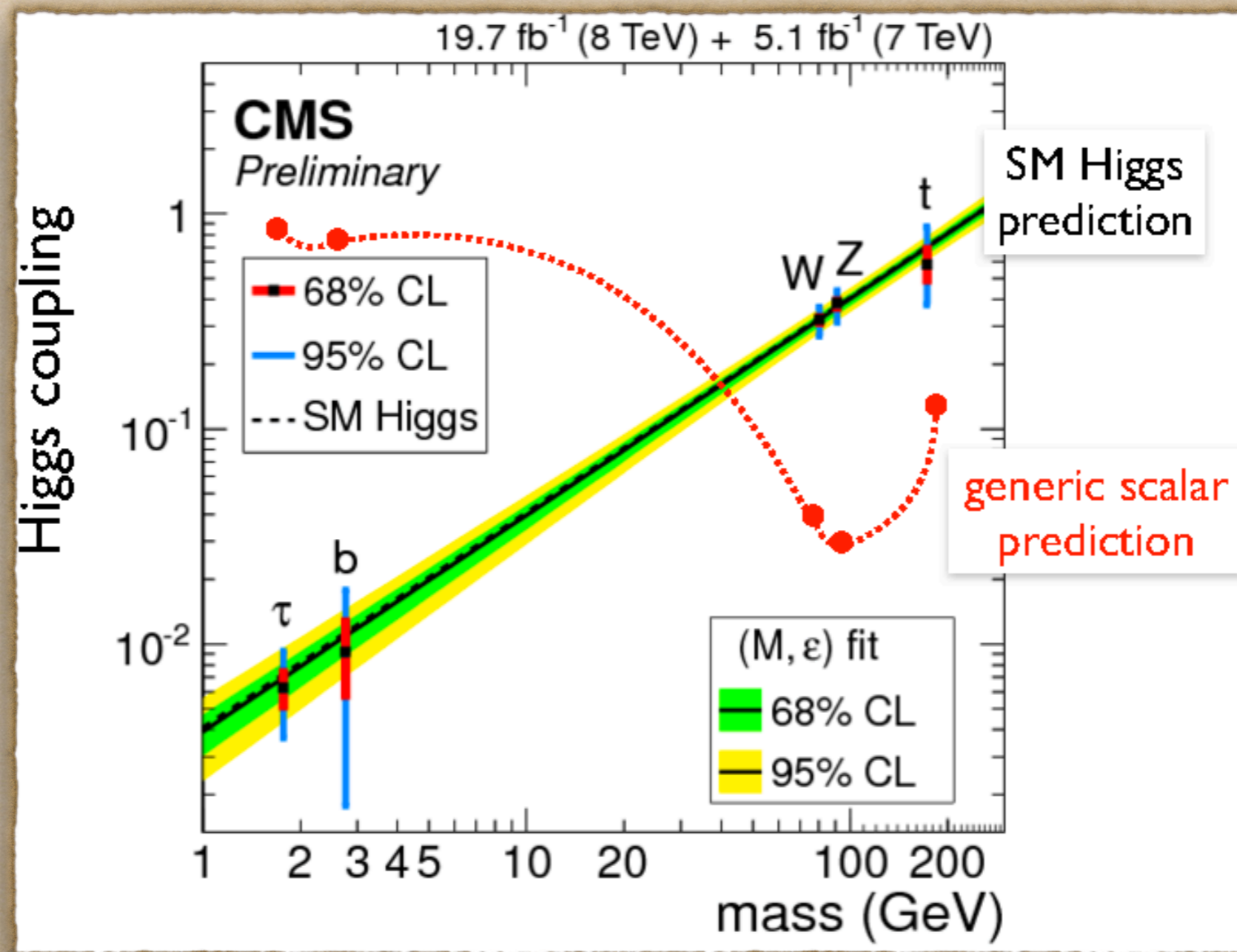


Black box:

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 |  |

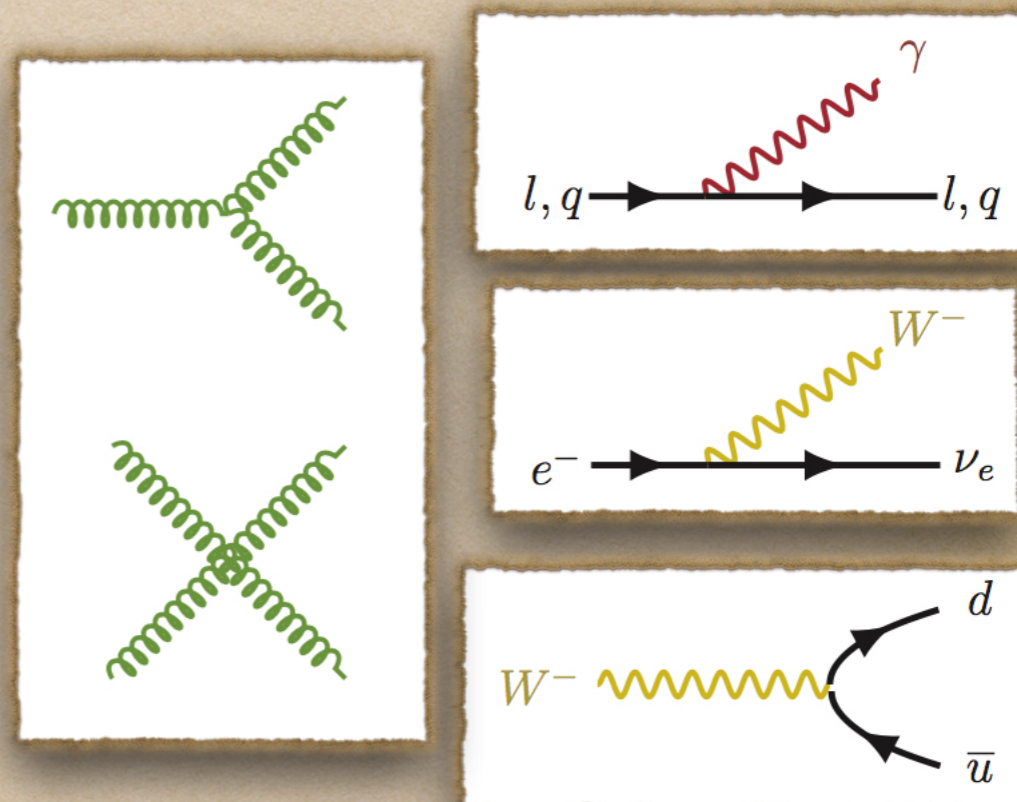
Inside the Black Box

Feynman diagrams

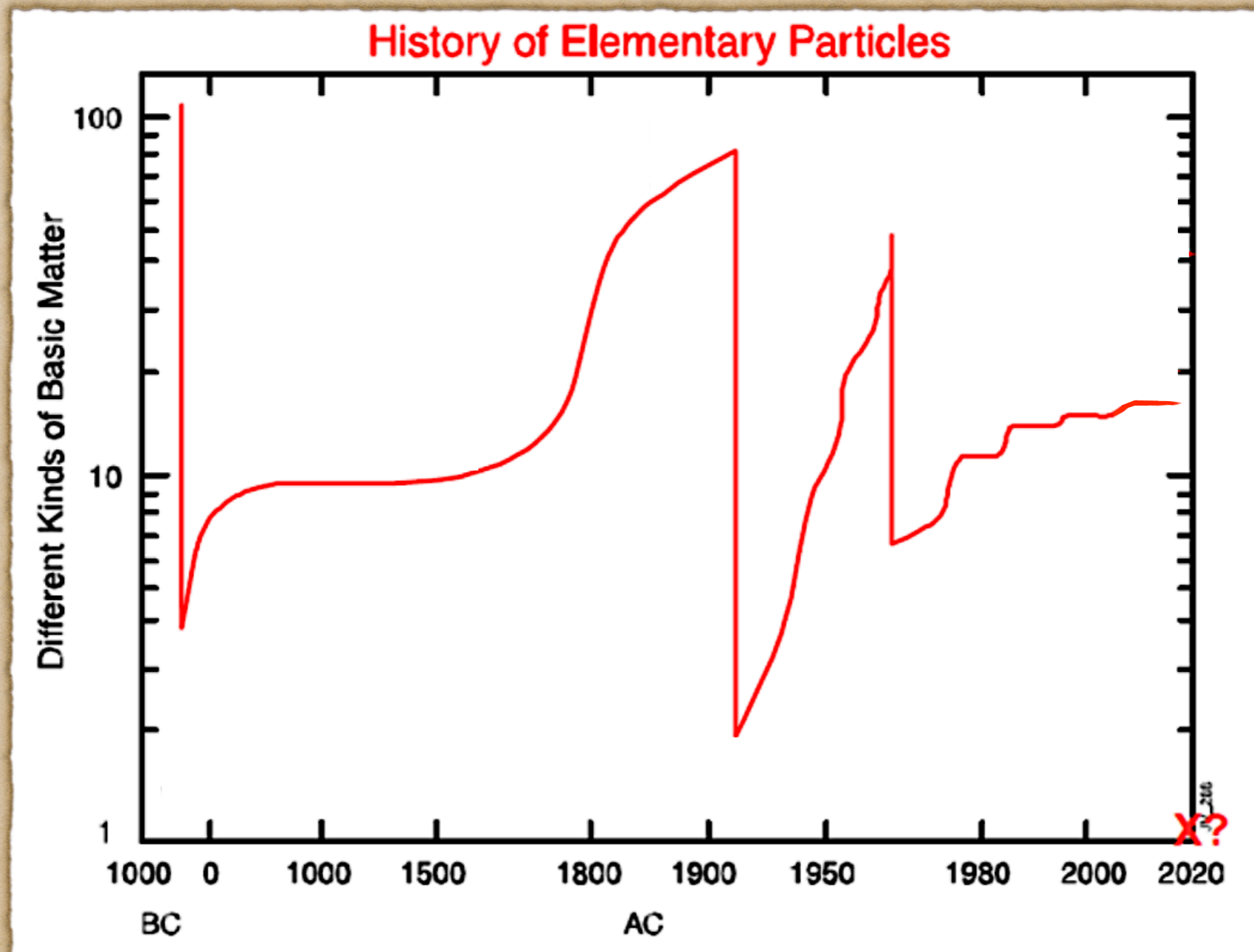
Notations

| | |
|-----------------------|---|
| quark, lepton |  |
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| photon |  |
| gluon |  |
| weak boson |  |

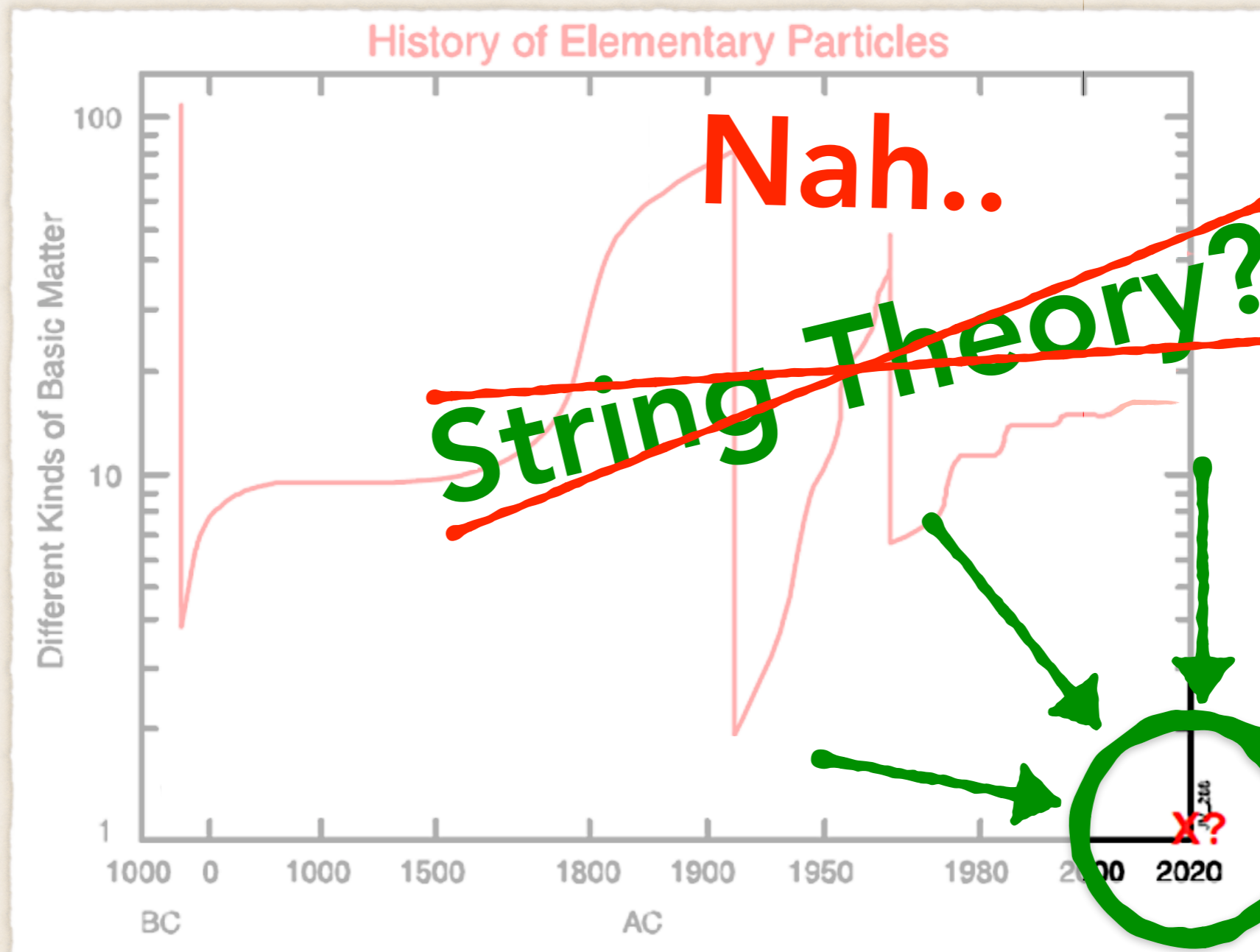
Interactions



Basic Bricks of the Universe



Basic Bricks of the Universe



This is one of many open questions
left to be explored...

Thank you for your attention

Questions?

=> frederik@cern.ch