

ELEMENTARY PARTICLE PHYSICS

A BRIEF INTRODUCTION (PART I)

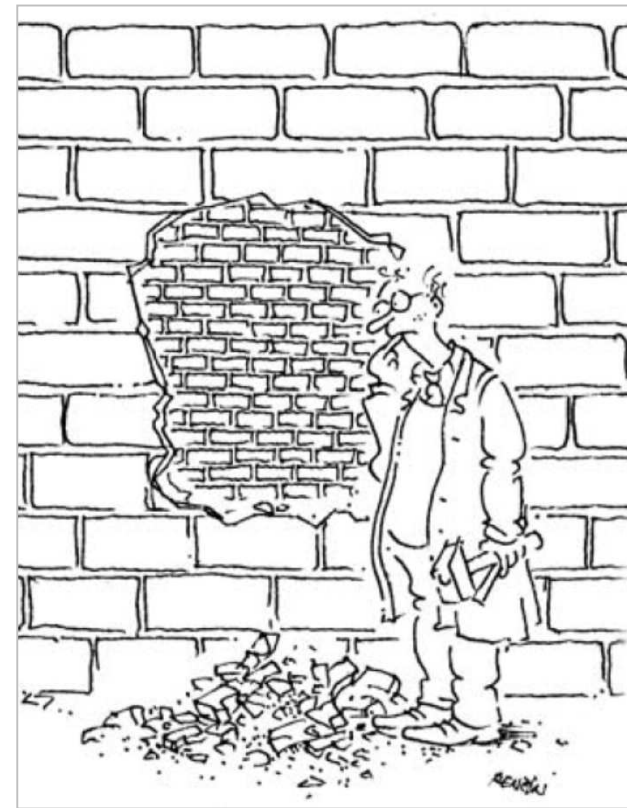
APRIL 2020 | HANS STRÖHER (FZ JÜLICH, UNIVERSITY OF COLOGNE)

Outline – EPP Video Lectures

- An introduction of Elementary Particle Physics (EPP) via video
- Lecturers: Hans Ströher, Irakli Keshelashvili, Detlev Gotta
- Time: Monday & Friday @ 2 pm (Jülich time) → 4 pm (Tbilisi)
- Outline:
 - A brief **introduction** (history ...)
 - The **tools** (accelerators, targets, detectors ... kinematics, ...)
 - The **particles** (hadrons, baryons, mesons)
 - The **fundamental particles** (quarks, leptons)
 - The **forces** (gravitation, nuclear forces)
 - The **fundamental interactions** (strong and electro-weak IA)
 - The **Standard Model** of EPP
 - Physics **Beyond the Standard Model** (BSM)
 - Spin-offs – **Applications** of EPP

Overall Information

Introduction – Prelude

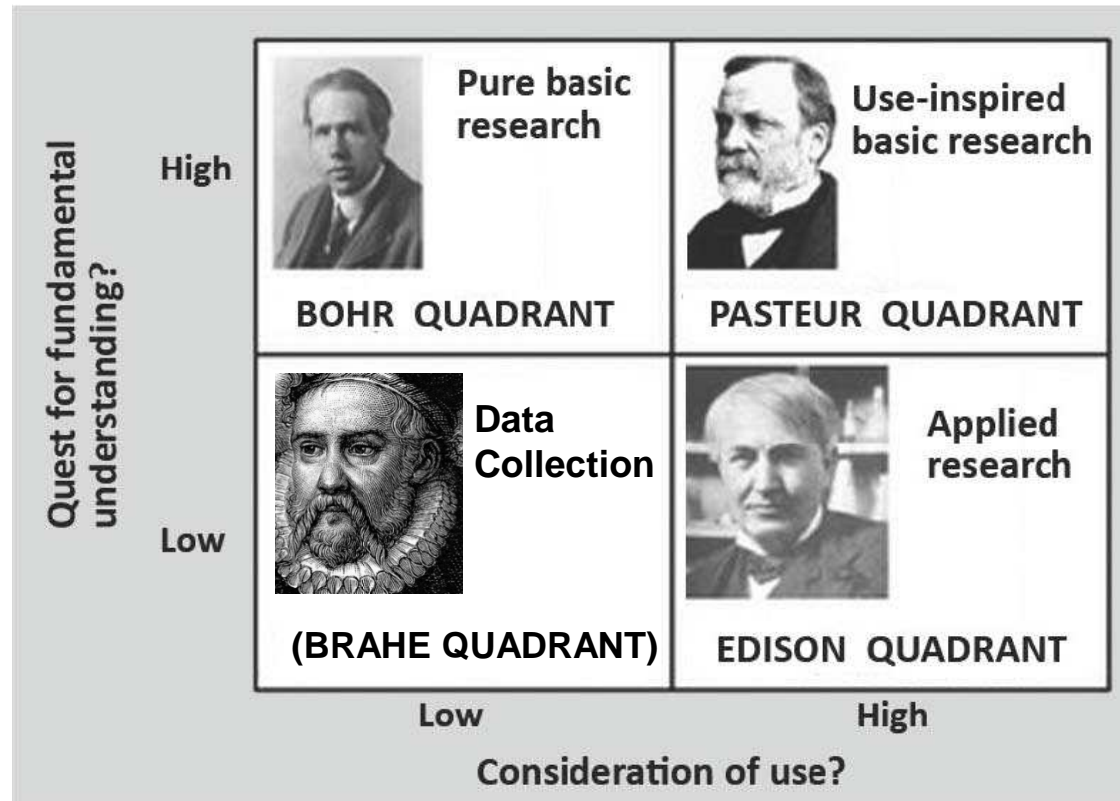


Science is driven by curiosity

- What we would like to know:
 - What are the **fundamental building blocks** of Nature?
 - Why are there **three generations** of fermions?
 - Are **neutrinos** their own antiparticle?
 - What are the **interactions** between the building blocks?
 - Do all **forces unify**?
 - Where does the **mass of the particles** originate?
 - What is **Dark Matter**? What is the origin of Dark Matter?
 - Or even **Dark Energy**?
 - Why is **antimatter** different from matter?
 - What is the origin of the **matter-antimatter asymmetry**?
 - Is the **proton** (ordinary matter) **stable**?
 - ...

Fundamental questions

Introduction – Prelude



Curiosity-driven vs. use-inspired (basic) research

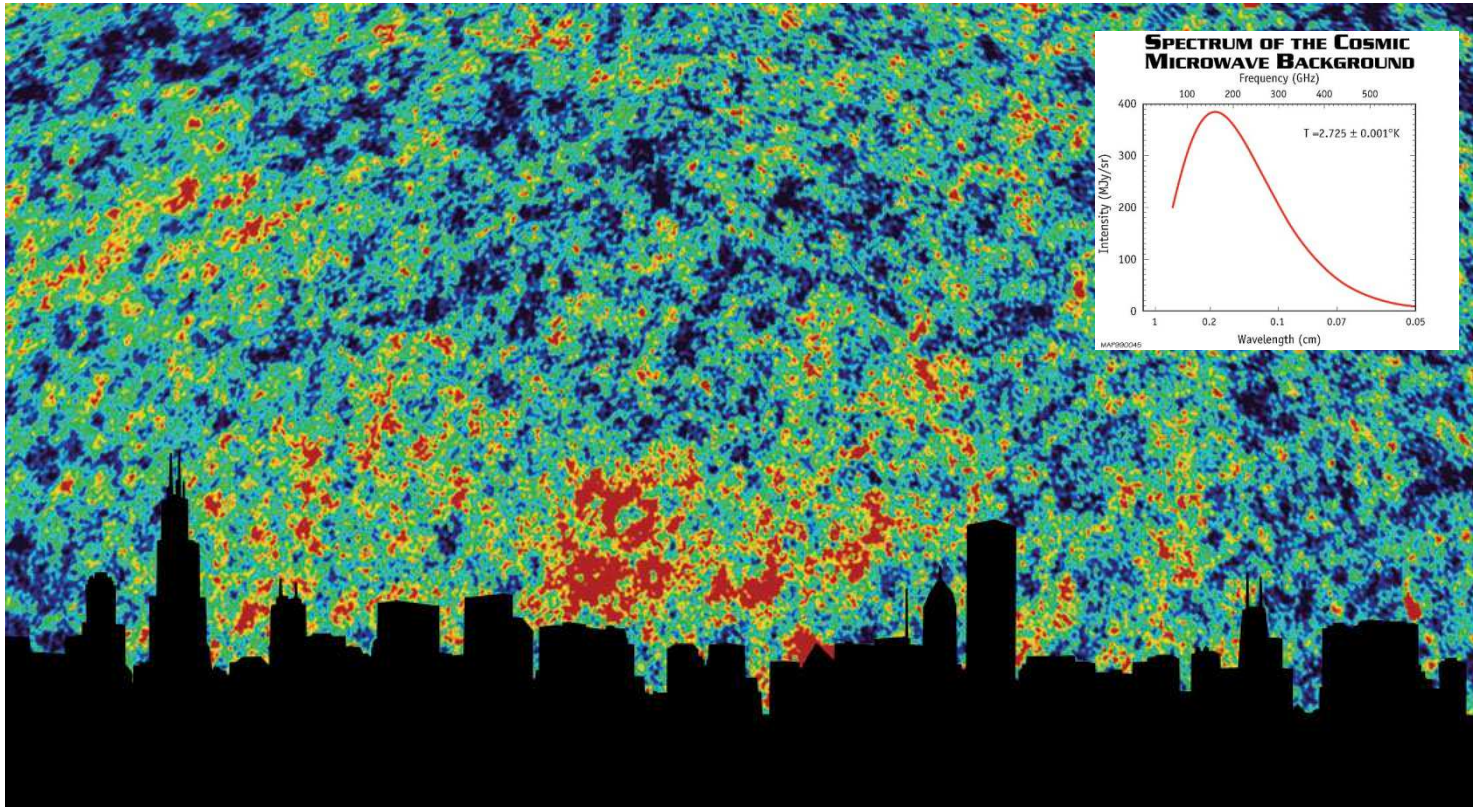
Introduction – Prelude



The *Milky Way* over monument valley

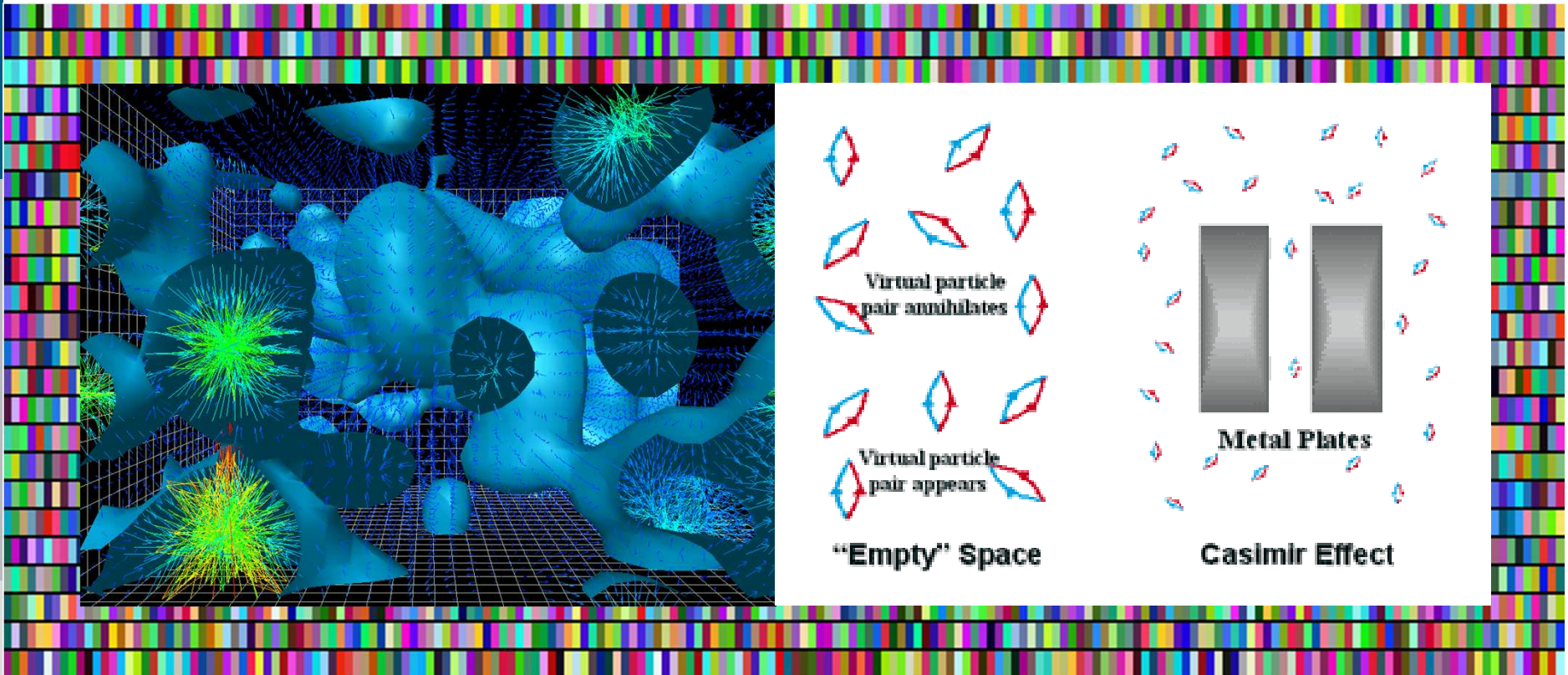
Mankind strives to understand **Nature** – from the very large ...

Introduction – Prelude



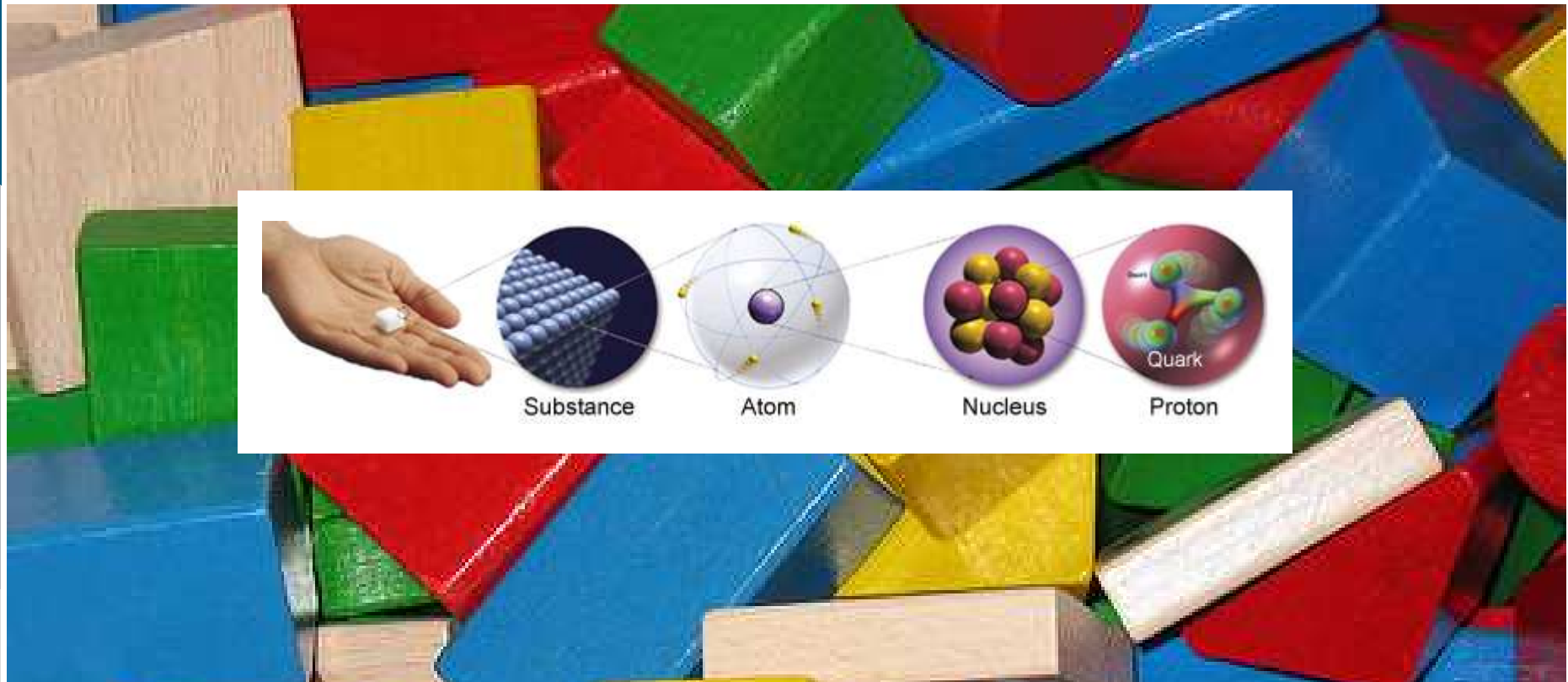
The Cosmic Microwave Background (CMB)

Mankind strives to understand Nature – from the very large ...



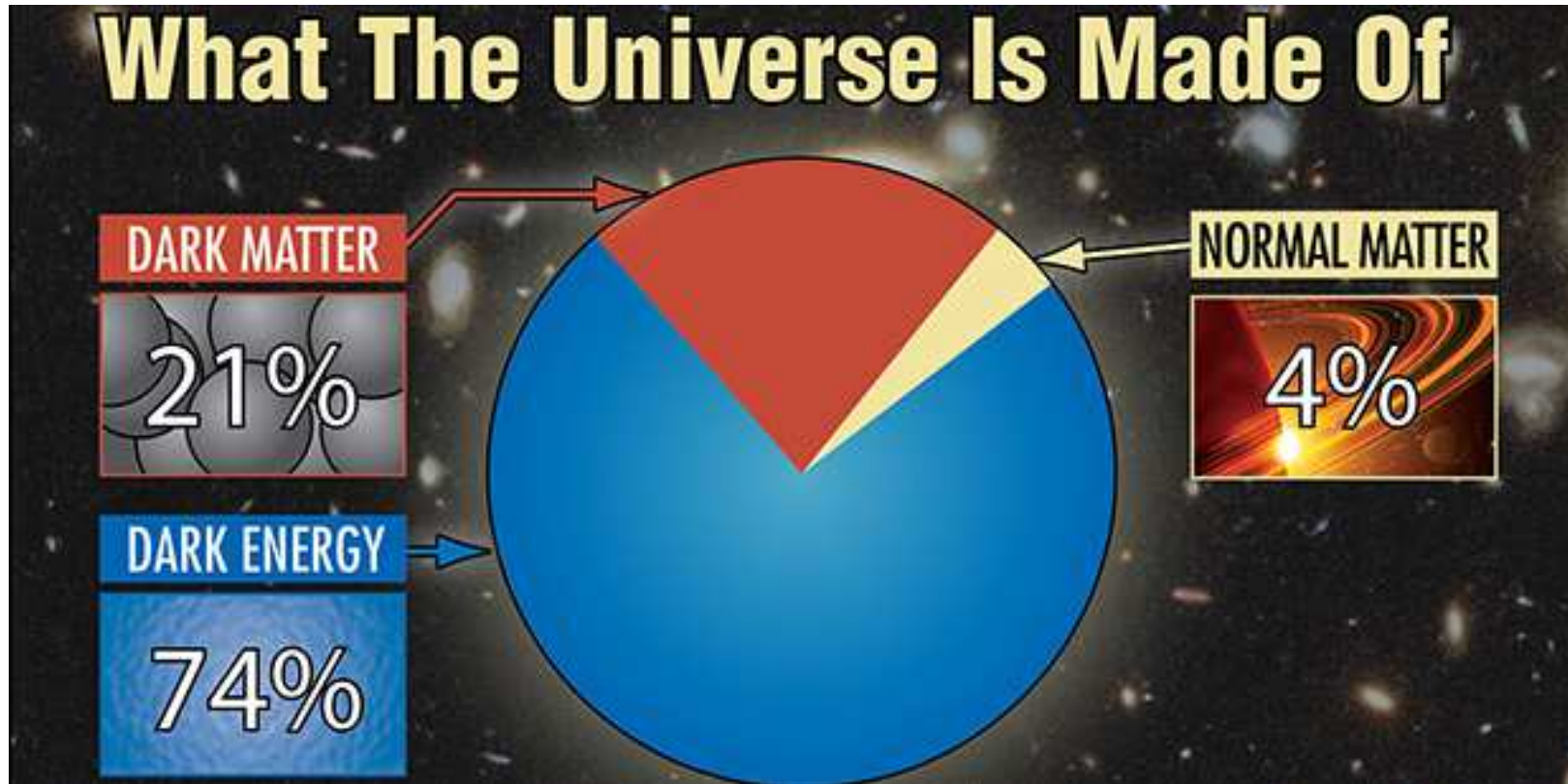
Vacuum Fluctuations (Simulation)

Mankind strives to understand Nature – from the very large to the very small



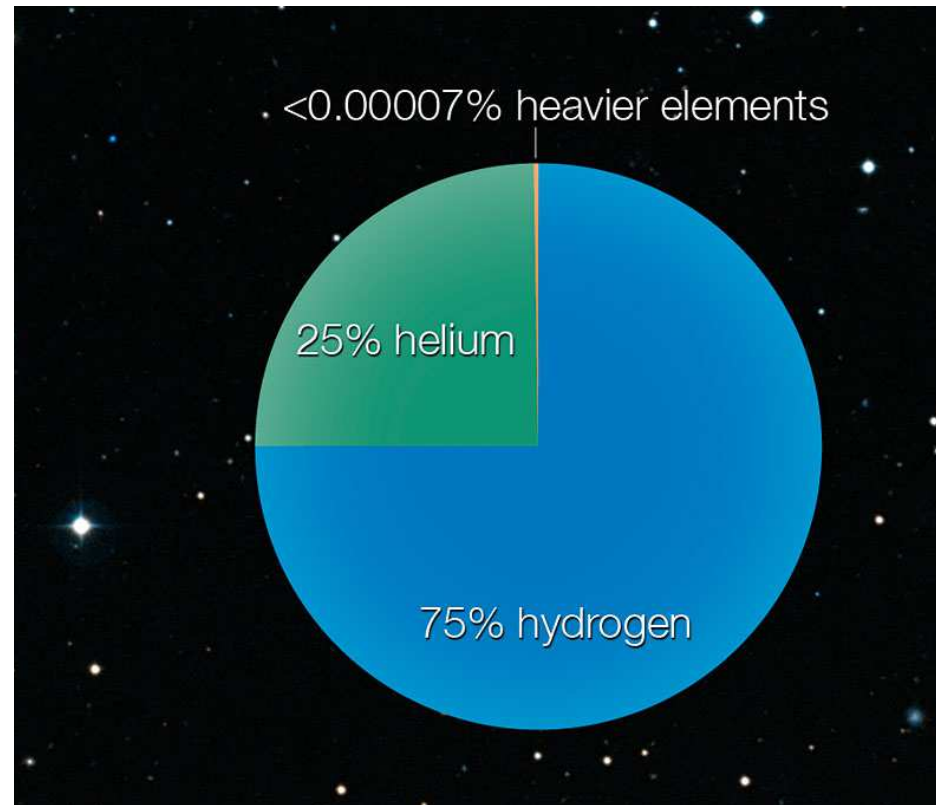
The building blocks of matter

There is a **connection** between the *very large* and the *very small*



What we know and what we don't know

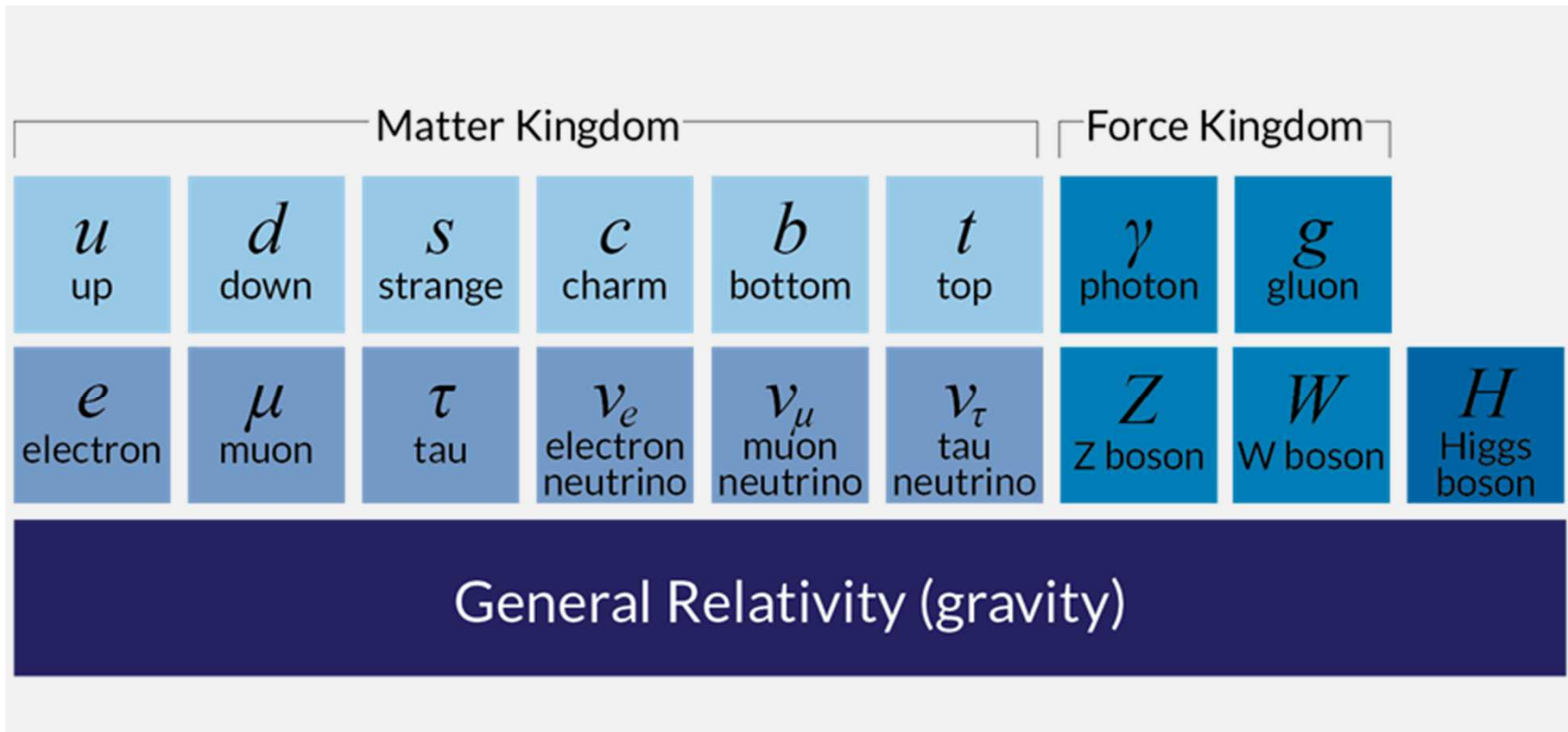
This talk is only about a **tiny fraction** of the energy content of the Universe



What we know and what we don't know

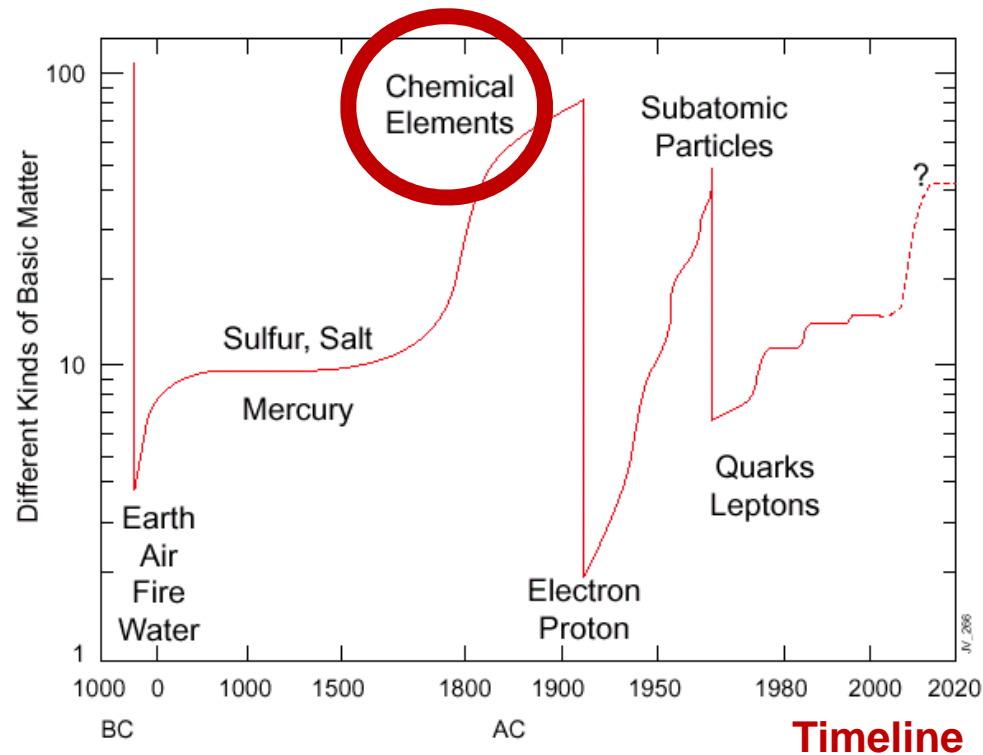
Matter is essentially hydrogen and helium (+ a tiny fraction of heavy nuclei)

Introduction – Prospect



F. Wilczek (Nobel Laureate Physics 2004): „Core Theory“ of physics

Introduction – History



A historical account of the number of **matter-constituents**

Introduction – History

Key

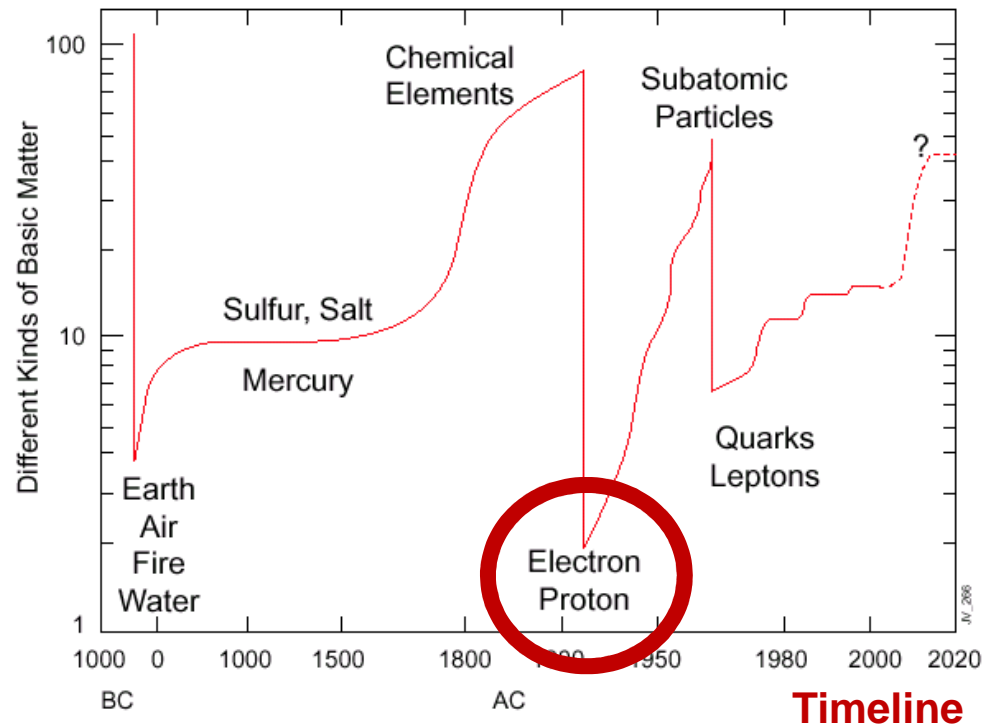
Atomic #
Symbol
Exact Name

1 H <small>Hydrogen</small>																	2 He <small>Helium</small>						
3 Li <small>Lithium</small>	4 Be <small>Beryllium</small>																	5 B <small>Boron</small>	6 C <small>Carbon</small>	7 N <small>Nitrogen</small>	8 O <small>Oxygen</small>	9 F <small>Fluorine</small>	10 Ne <small>Neon</small>
11 Na <small>Sodium</small>	12 Mg <small>Magnesium</small>																	13 Al <small>Aluminum</small>	14 Si <small>Silicon</small>	15 P <small>Phosphorus</small>	16 S <small>Sulfur</small>	17 Cl <small>Chlorine</small>	18 Ar <small>Argon</small>
19 K <small>Potassium</small>	20 Ca <small>Calcium</small>	21 Sc <small>Scandium</small>	22 Ti <small>Titanium</small>	23 V <small>Vanadium</small>	24 Cr <small>Chromium</small>	25 Mn <small>Manganese</small>	26 Fe <small>Iron</small>	27 Co <small>Cobalt</small>	28 Ni <small>Nickel</small>	29 Cu <small>Copper</small>	30 Zn <small>Zinc</small>	31 Ga <small>Gallium</small>	32 Ge <small>Germanium</small>	33 As <small>Arsenic</small>	34 Se <small>Selenium</small>	35 Br <small>Bromine</small>	36 Kr <small>Krypton</small>						
37 Rb <small>Rubidium</small>	38 Sr <small>Strontium</small>	39 Y <small>Yttrium</small>	40 Zr <small>Zirconium</small>	41 Nb <small>Niobium</small>	42 Mo <small>Molybdenum</small>	43 Tc <small>Technetium</small>	44 Ru <small>Ruthenium</small>	45 Rh <small>Rhodium</small>	46 Pd <small>Palladium</small>	47 Ag <small>Silver</small>	48 Cd <small>Cadmium</small>	49 In <small>Indium</small>	50 Sn <small>Tin</small>	51 Sb <small>Antimony</small>	52 Te <small>Tellurium</small>	53 I <small>Iodine</small>	54 Xe <small>Xenon</small>						
55 Cs <small>Cesium</small>	56 Ba <small>Barium</small>	*	71 Lu <small>Lutetium</small>	72 Hf <small>Hafnium</small>	73 Ta <small>Tantalum</small>	74 W <small>Tungsten</small>	75 Re <small>Rhenium</small>	76 Os <small>Osmium</small>	77 Ir <small>Iridium</small>	78 Pt <small>Platinum</small>	79 Au <small>Gold</small>	80 Hg <small>Mercury</small>	81 Tl <small>Thallium</small>	82 Pb <small>Lead</small>	83 Bi <small>Bismuth</small>	84 Po <small>Polonium</small>	85 At <small>Astatine</small>	86 Rn <small>Radon</small>					
87 Fr <small>Francium</small>	88 Ra <small>Radium</small>	*	103 Lr <small>Lawrencium</small>	104 Rf <small>Rutherfordium</small>	105 Db <small>Dubnium</small>	106 Sg <small>Seaborgium</small>	107 Bh <small>Bohrium</small>	108 Hs <small>Hassium</small>	109 Mt <small>Mitnerium</small>	110 Ds <small>Darmstadtium</small>	111 Rg <small>Roentgenium</small>	112 Cn <small>Copernicium</small>		114 Fl <small>Flerovium</small>		116 Lv <small>Livermorium</small>							
		*	57 La <small>Lanthanum</small>	58 Ce <small>Cerium</small>	59 Pr <small>Praseodymium</small>	60 Nd <small>Neodymium</small>	61 Pm <small>Promethium</small>	62 Sm <small>Samarium</small>	63 Eu <small>Europium</small>	64 Gd <small>Gadolinium</small>	65 Tb <small>Terbium</small>	66 Dy <small>Dysprosium</small>	67 Ho <small>Holmium</small>	68 Er <small>Erbium</small>	69 Tm <small>Thulium</small>	70 Yb <small>Ytterbium</small>							
		*	89 Ac <small>Actinium</small>	90 Th <small>Thorium</small>	91 Pa <small>Protactinium</small>	92 U <small>Uranium</small>	93 Np <small>Neptunium</small>	94 Pu <small>Plutonium</small>	95 Am <small>Americium</small>	96 Cm <small>Curium</small>	97 Bk <small>Berkelium</small>	98 Cf <small>Californium</small>	99 Es <small>Einsteinium</small>	100 Fm <small>Fermium</small>	101 Md <small>Mendelevium</small>	102 No <small>Nobelium</small>							

Pauli-principle at work

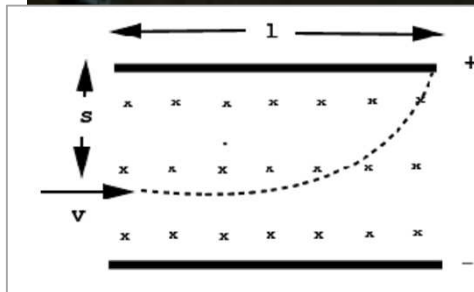
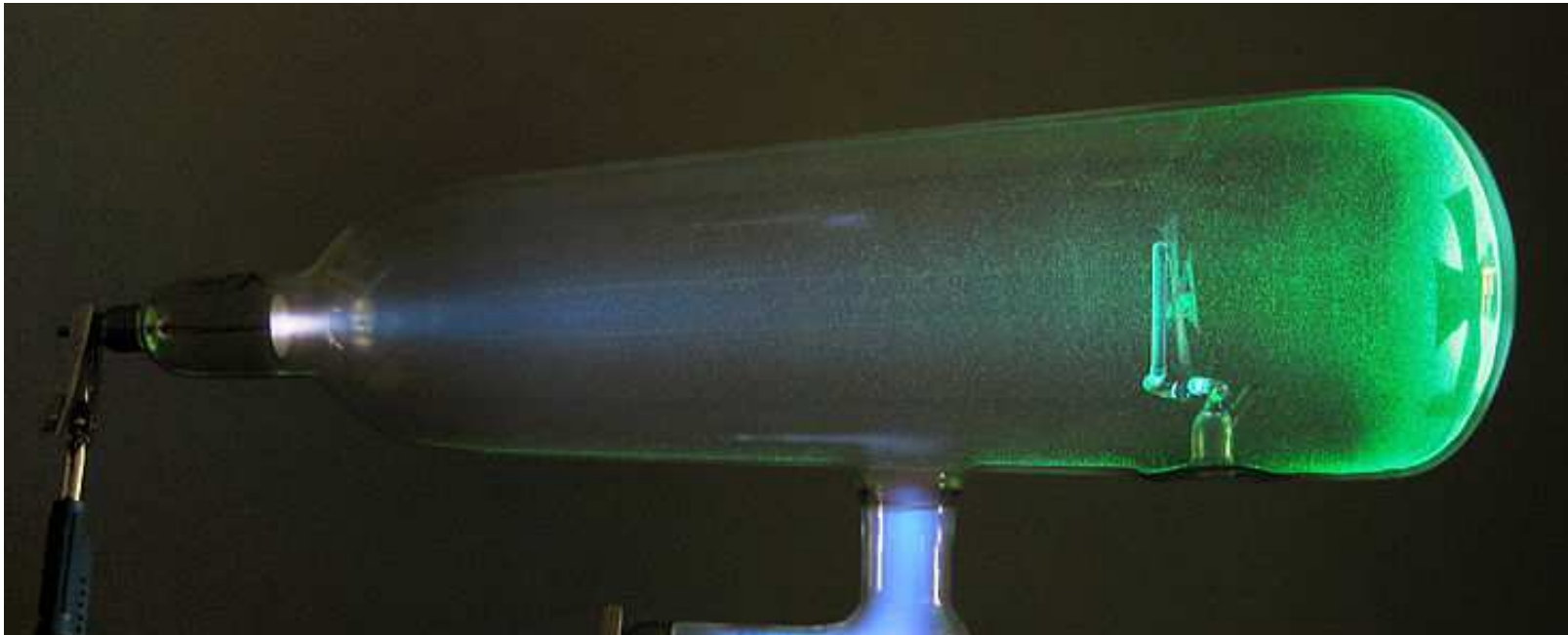
Periodic Table of Elements

Introduction – History



The up's and down's in the number of matter constituents

Introduction – History

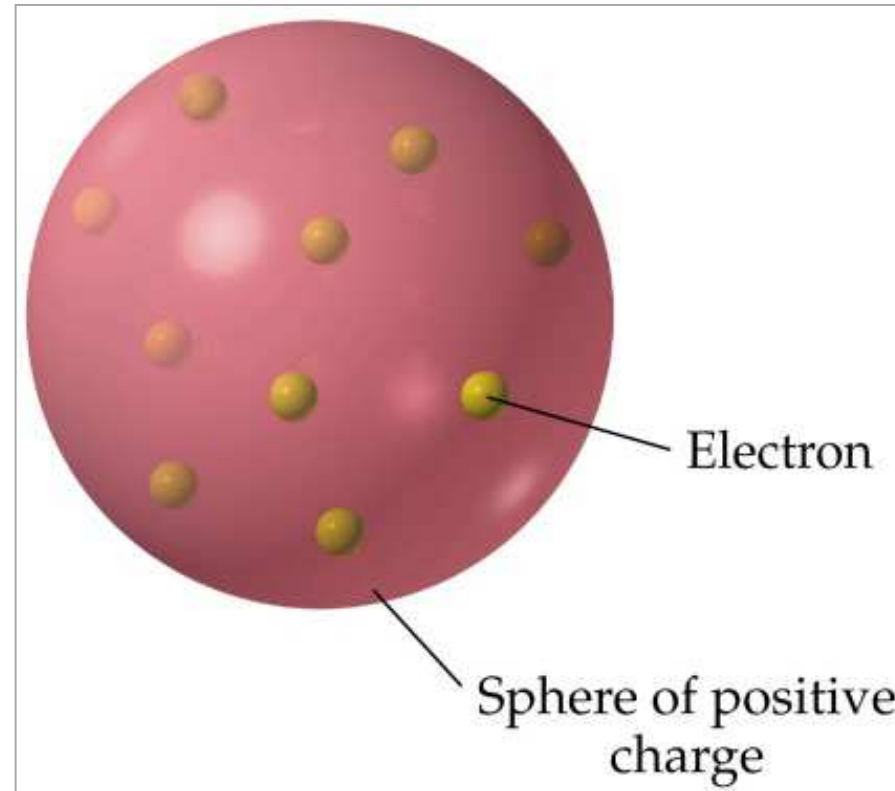


$$\frac{e}{m} = \frac{2sE}{l^2 H^2}$$

[The charge-to-mass ratio of cathode rays, e/m]
The charge-to-mass ratio of hydrogen ion

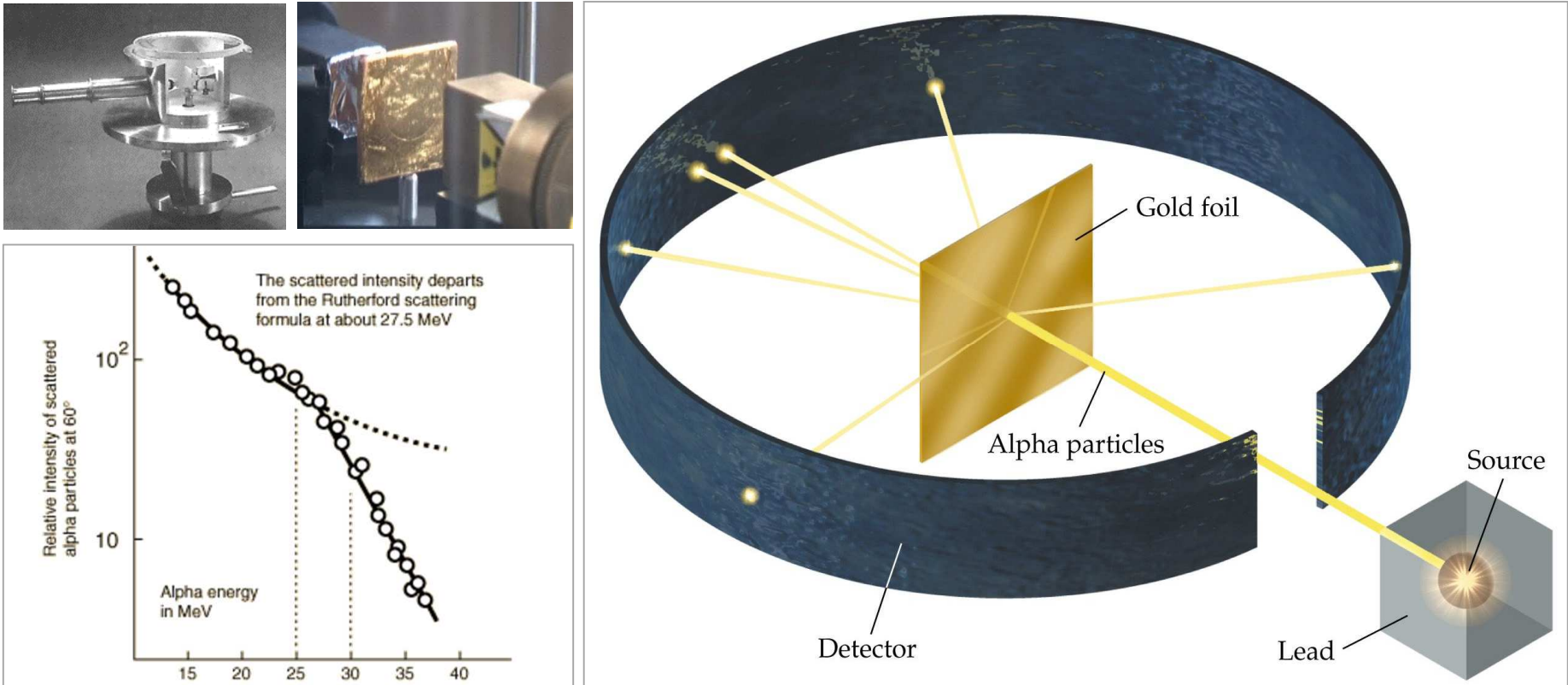
$$= \frac{1.76 \times 10^{11}}{9.65 \times 10^7}$$
$$\approx 1800.$$

„Cathode rays“ → discovery of the **electron**



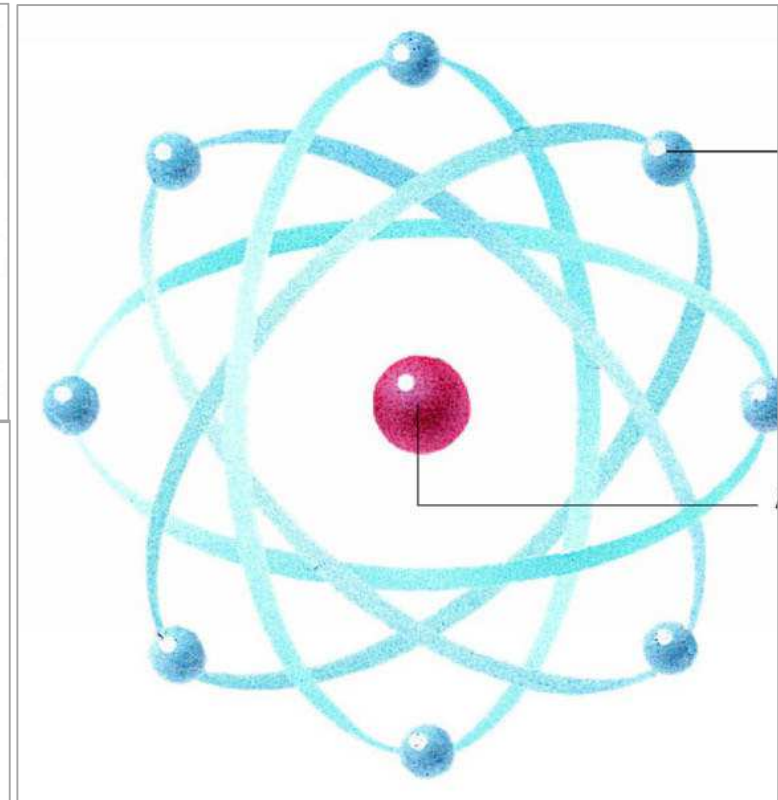
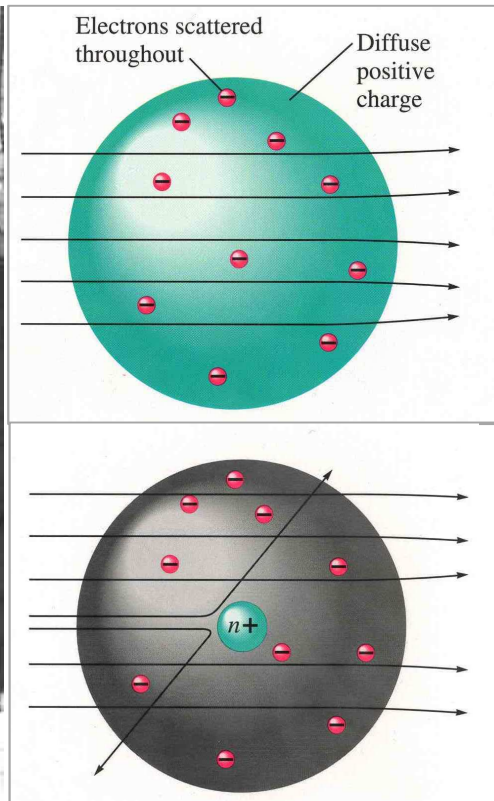
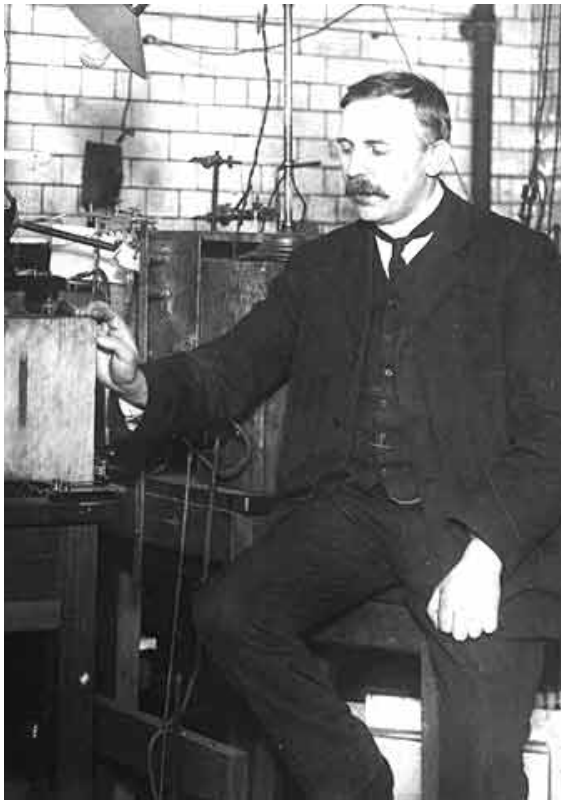
Discovery of the **electron** (J.J. Thomson, 1897) → Thomson's atom-model

Introduction – History



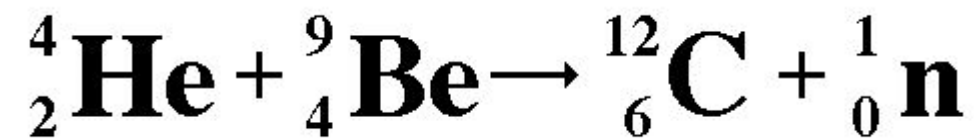
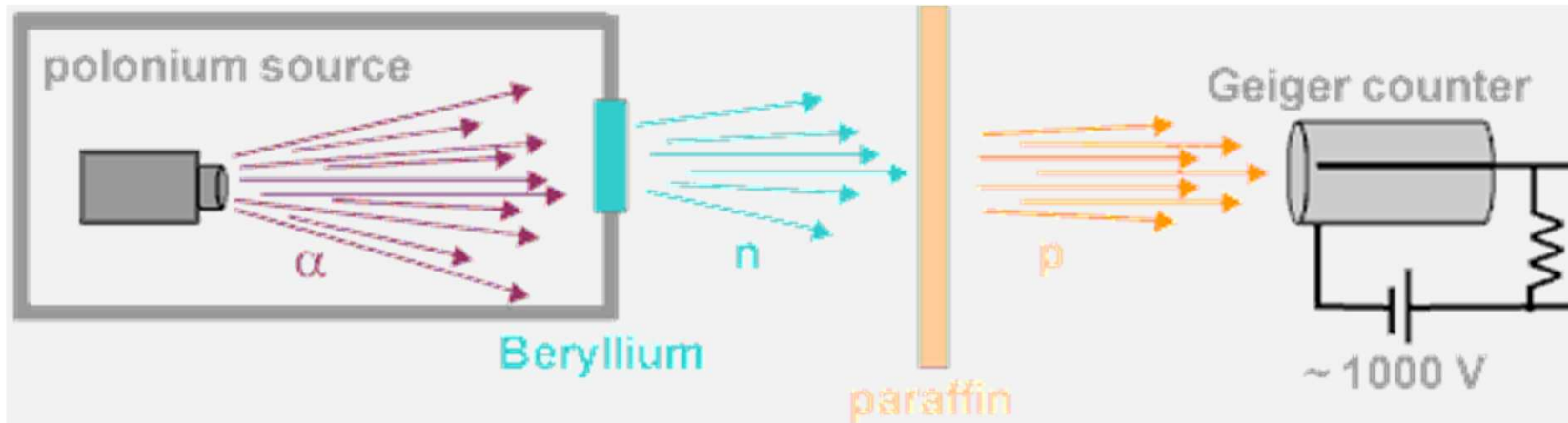
Discovery of the atomic nucleus (E. Rutherford, 1911) → new atomic model

Introduction – History



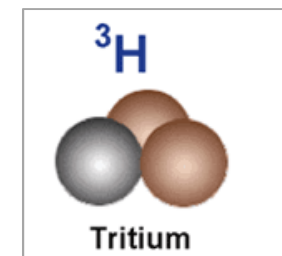
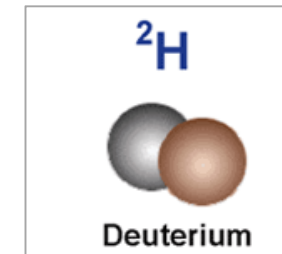
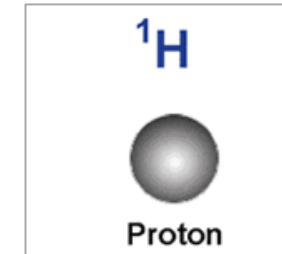
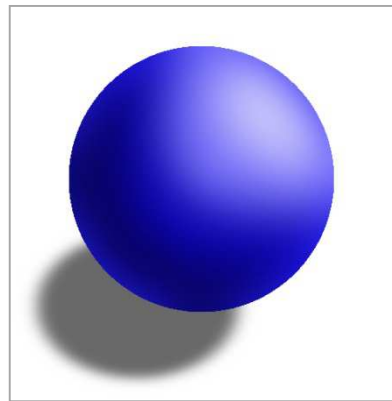
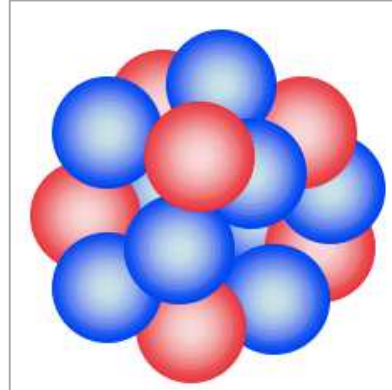
Discovery of the atomic nucleus (E. Rutherford, 1911) → new atomic model

Introduction – History



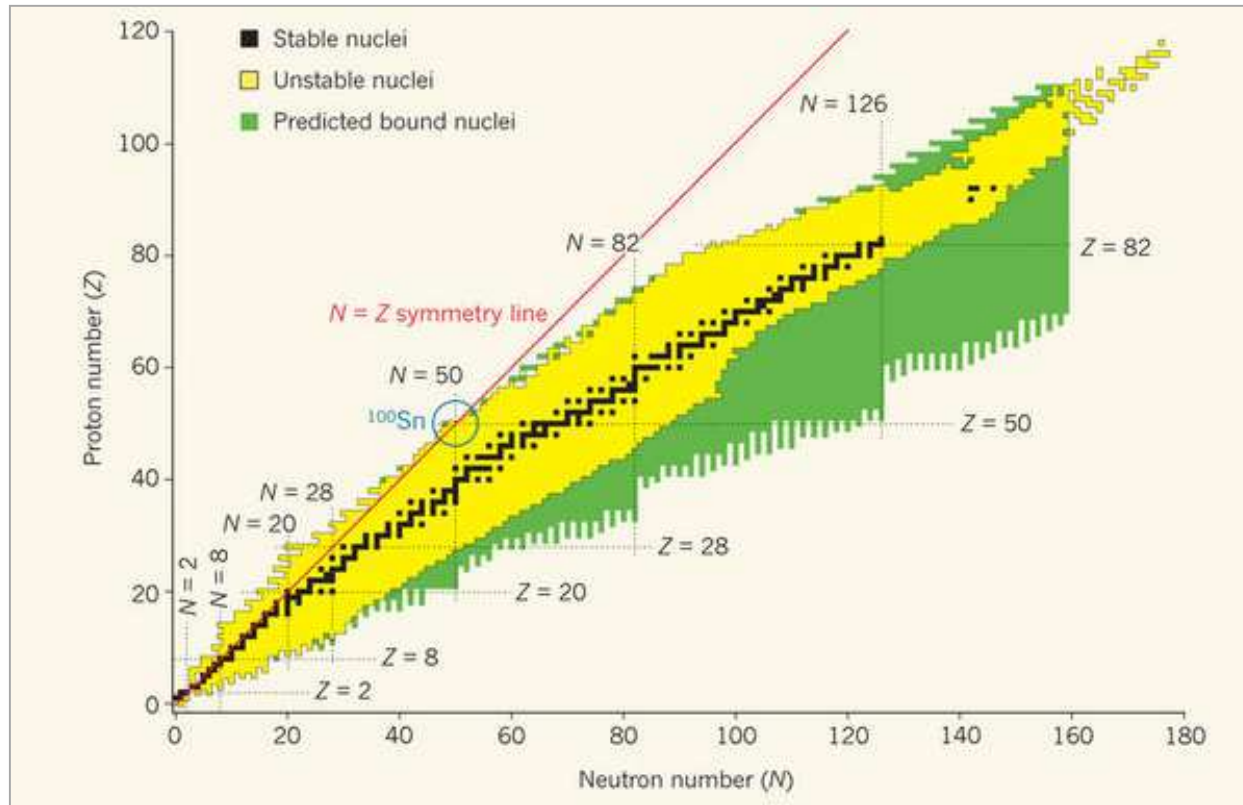
Discovery of the neutron (J. Chadwick, 1932) → structure of the nucleus

Introduction – History



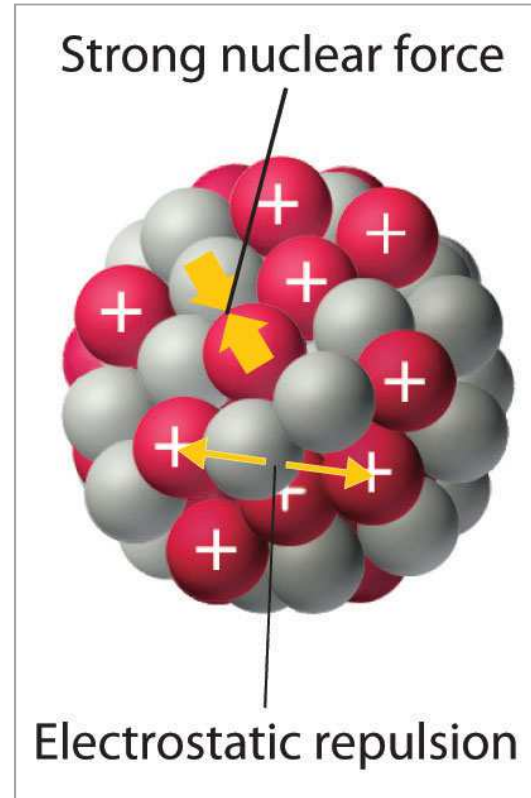
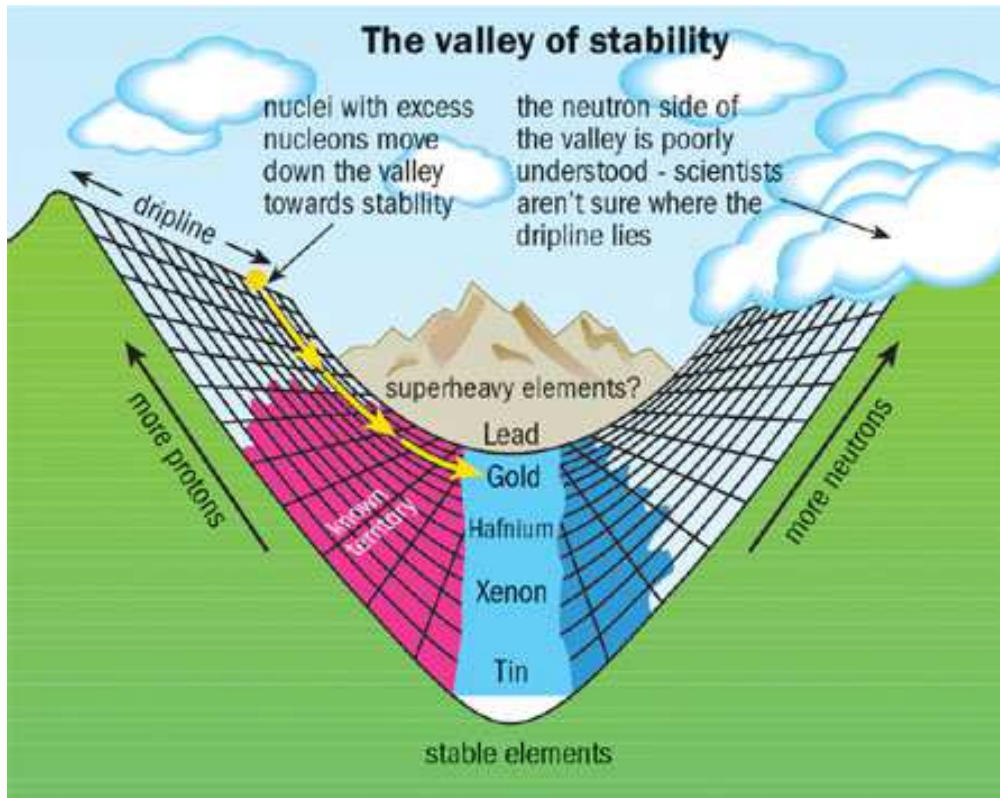
Discovery of the **neutron** (J. Chadwick, 1932) → isotopes

Introduction – History



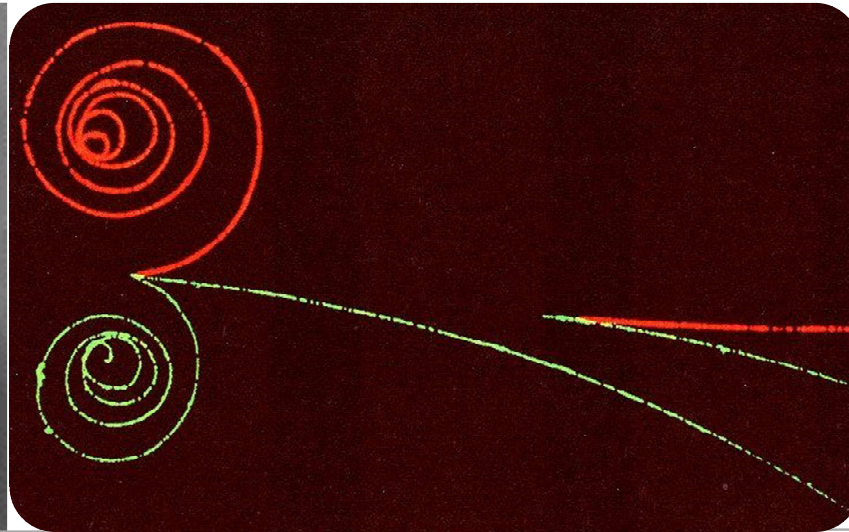
The „Table of Isotopes“

Introduction – History

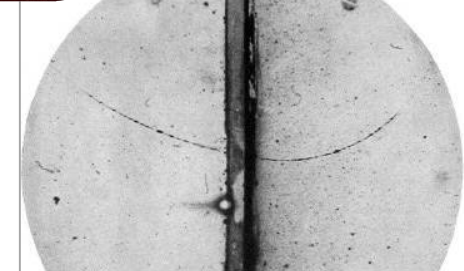


The „Valley of Stability“

Introduction – History

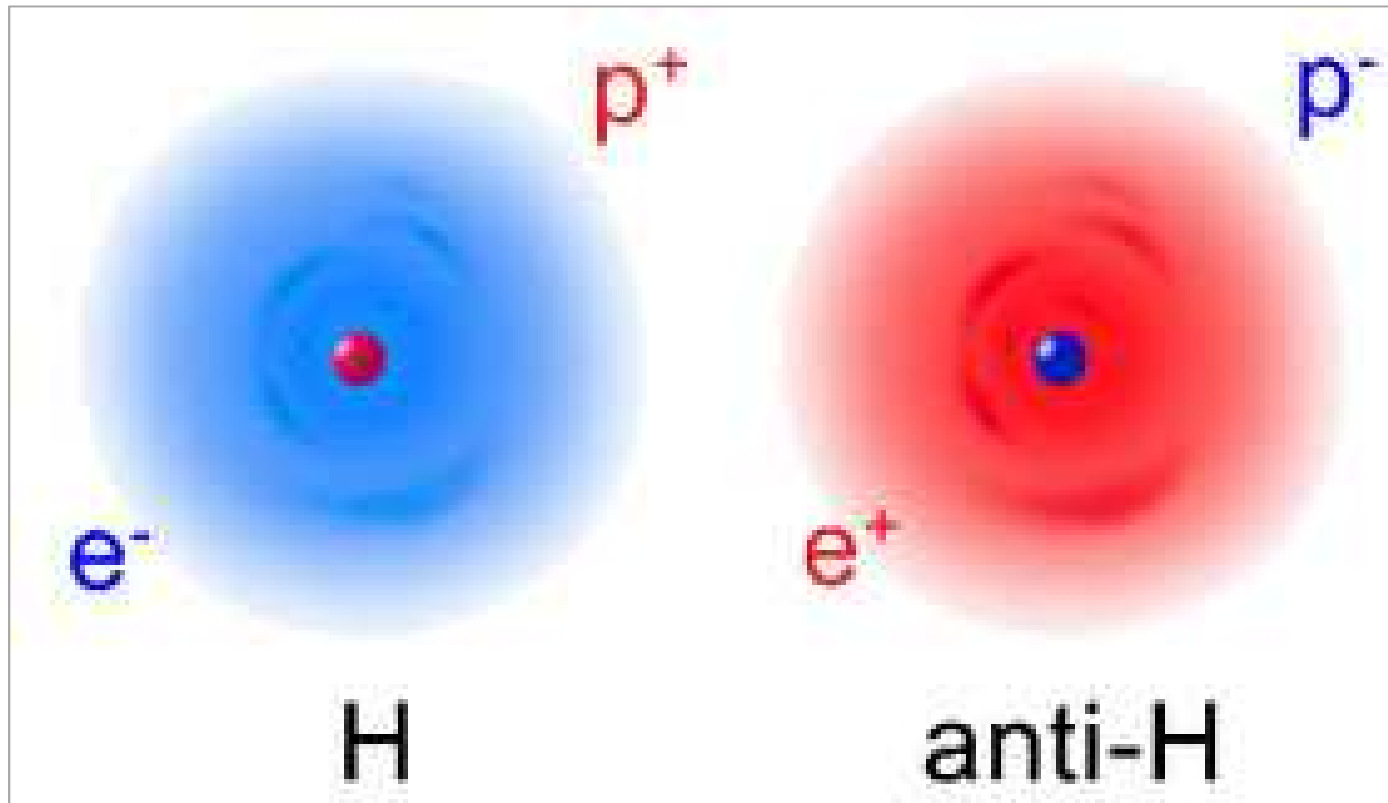


$$(i\gamma \cdot \partial - m)\psi = 0$$



Discovery of antiparticles (P.A.M. Dirac, 1928, C.D. Anderson, 1932)

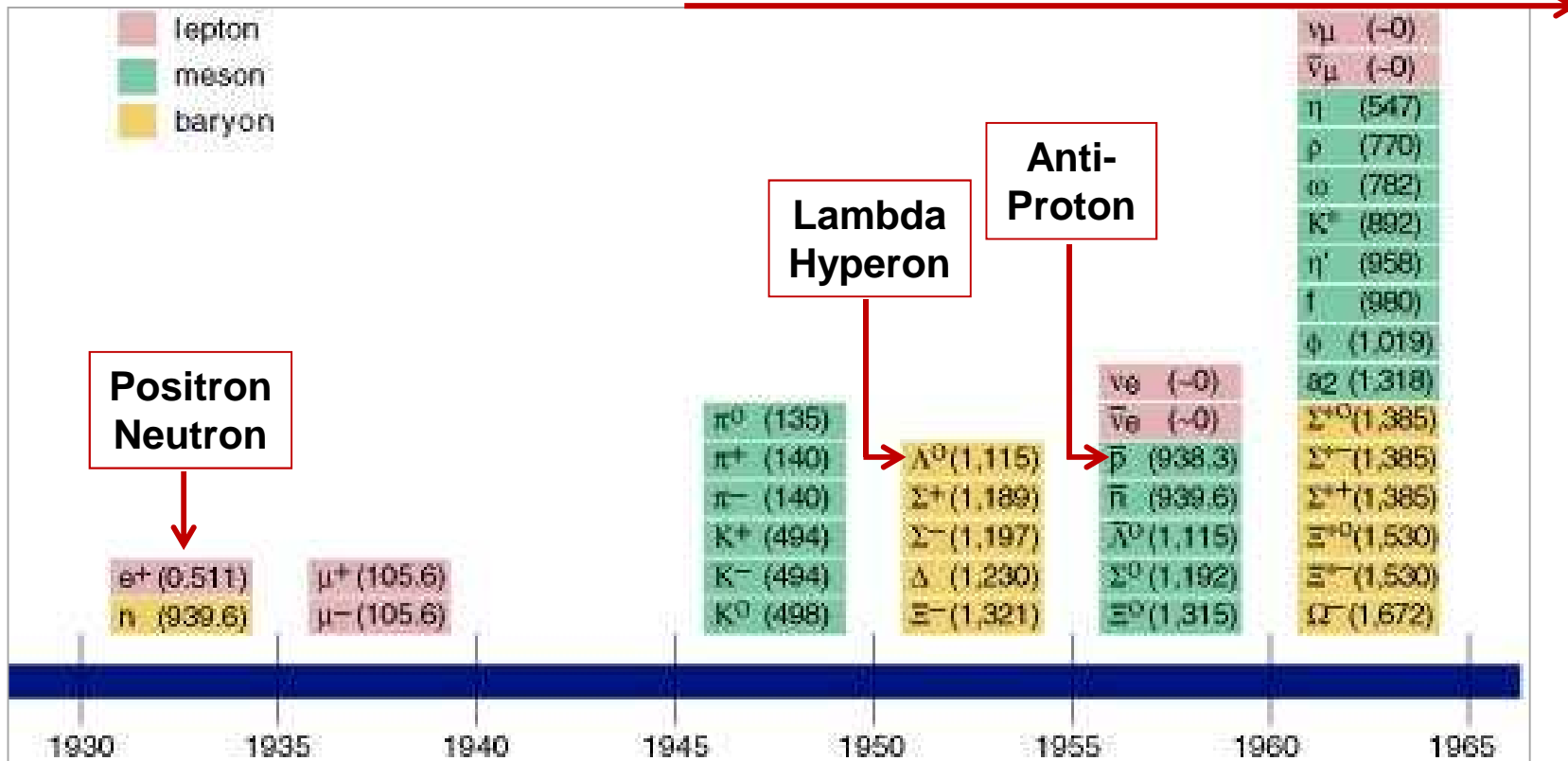
Introduction – History



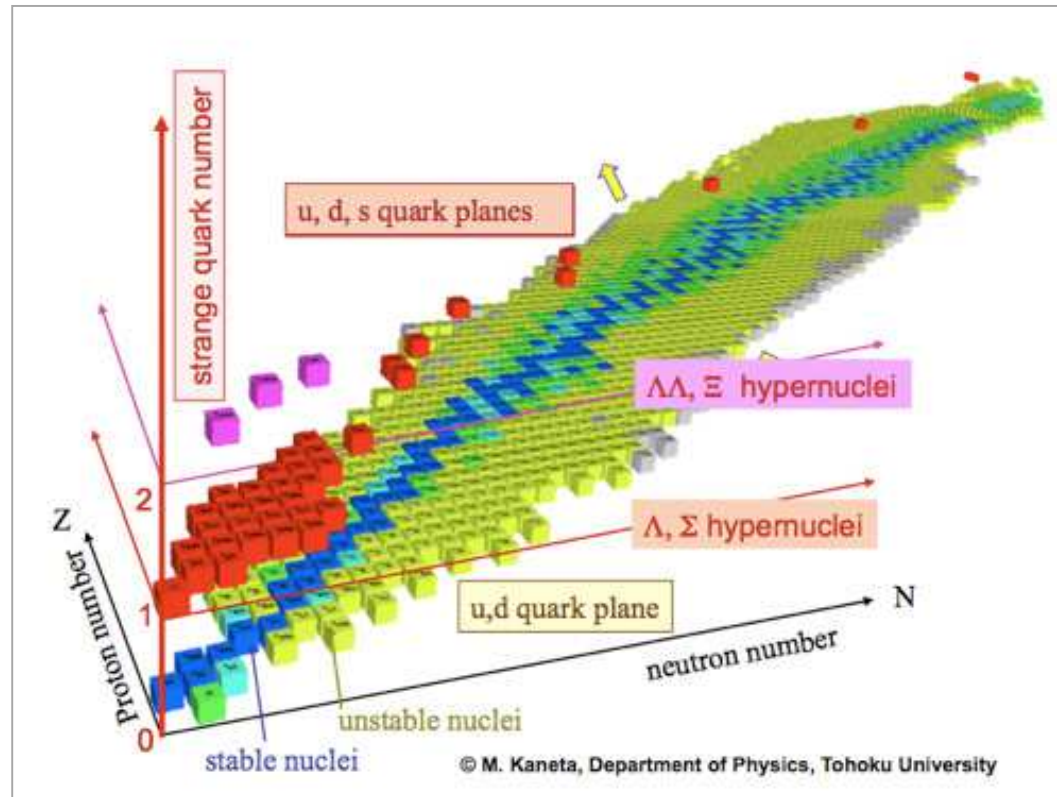
Duplication: matter and anti-matter

Introduction – History

The era of accelerators ...



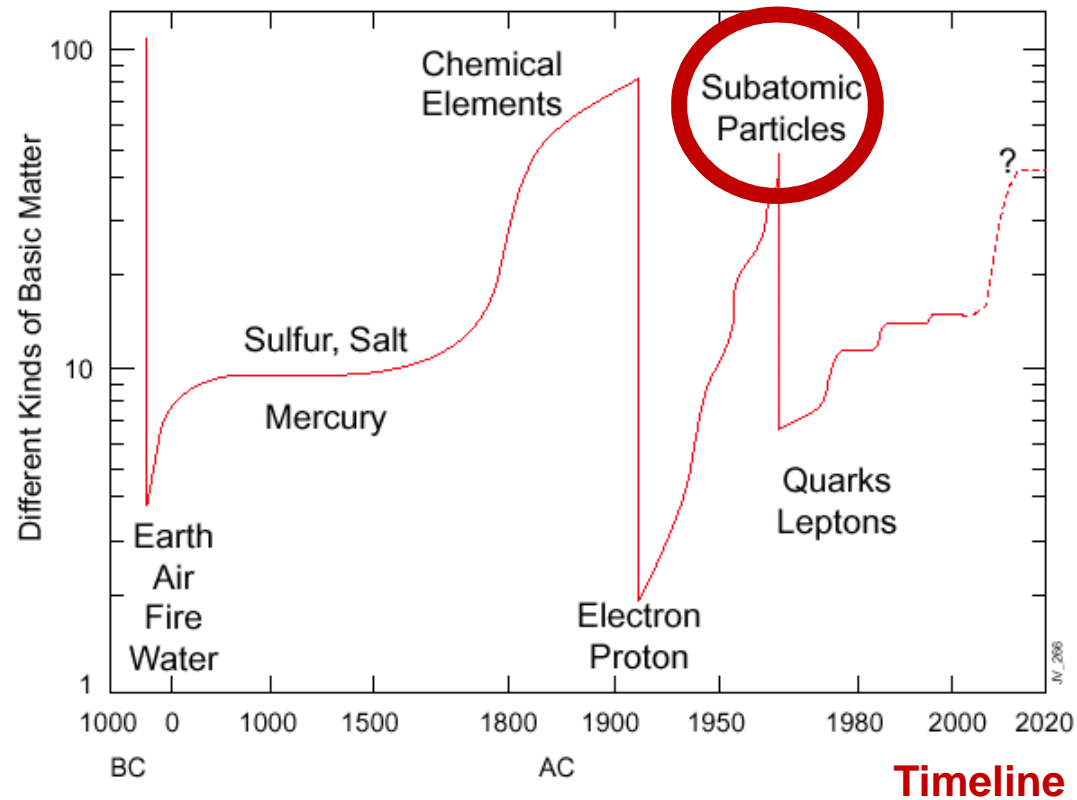
Observation of a „zoo“ of sub-atomic particles and anti-particles



“Hypernuclei”

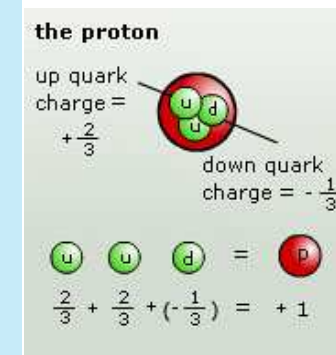
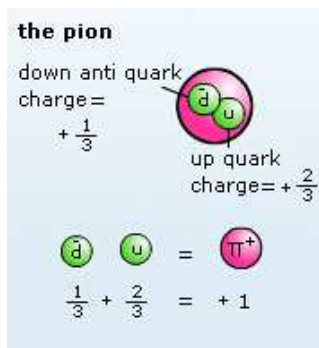
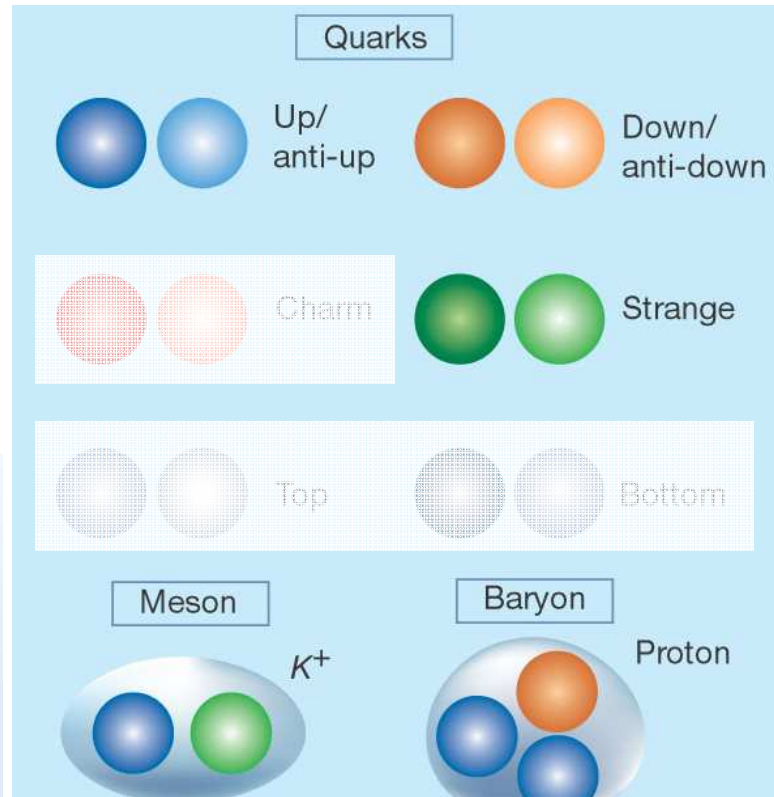
The extended „Table of Isotopes“

Introduction – History



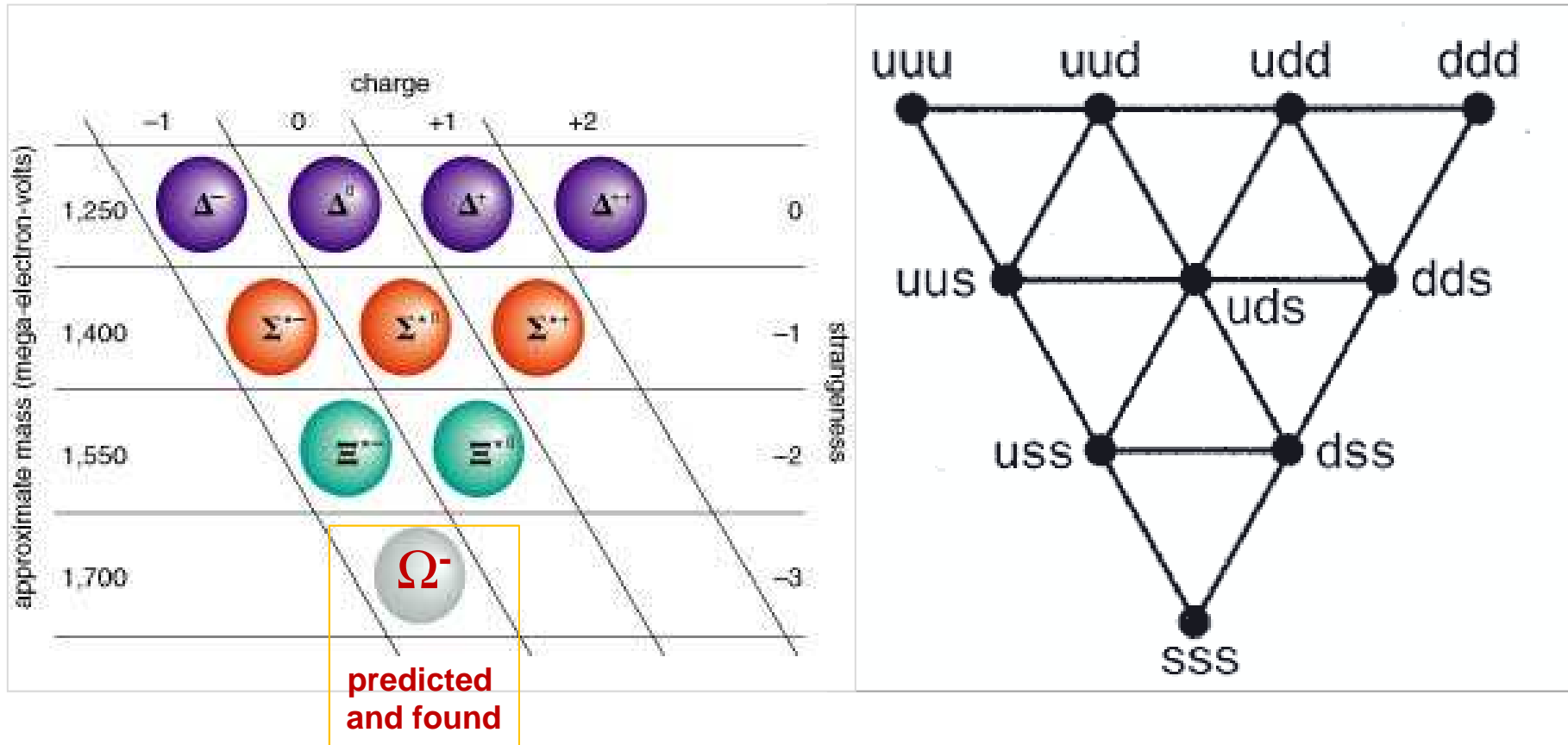
The up's and down's in the number of matter constituents

Introduction – History



M. Gell-Mann and G. Zweig (1964): Quarks („Aces“)

Introduction – History



Hadrons (baryons & mesons) appear in „multiplets“: all members found



გმადლობთ