
HOMER's
JOURNEY
TO THE CENTER OF THE MATTER
SAME PLANET. DIFFERENT WORLD.

'Matter Of Fact

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McGill University

Homer's Physics 101 - 28 November 2008

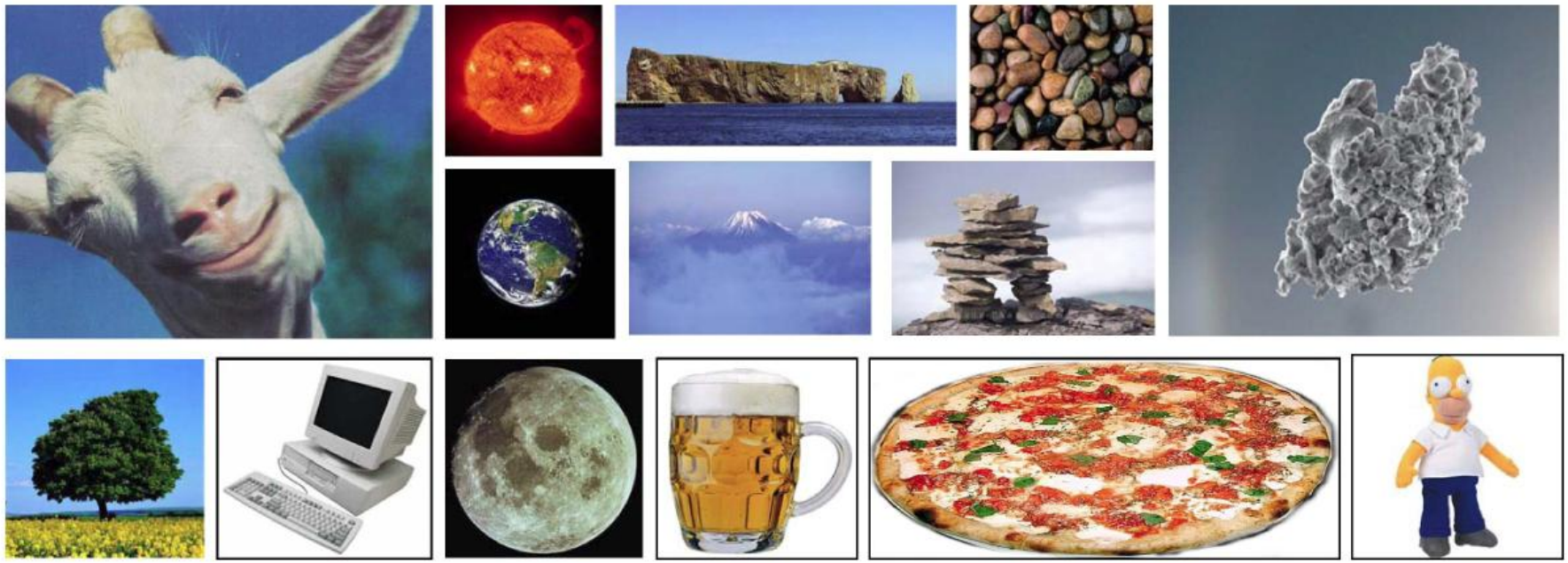
Particle physics & the structure of matter

What? Information on matter (and interactions)

How? Observe collisions and scattering

Question #1

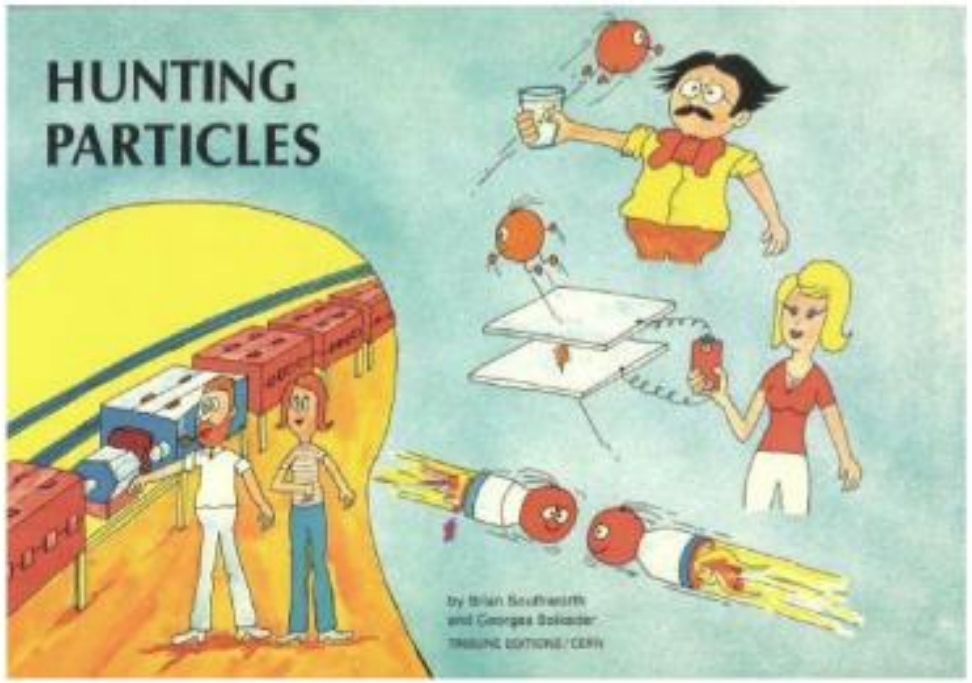
What do all those things have in common?



matter

Question #2

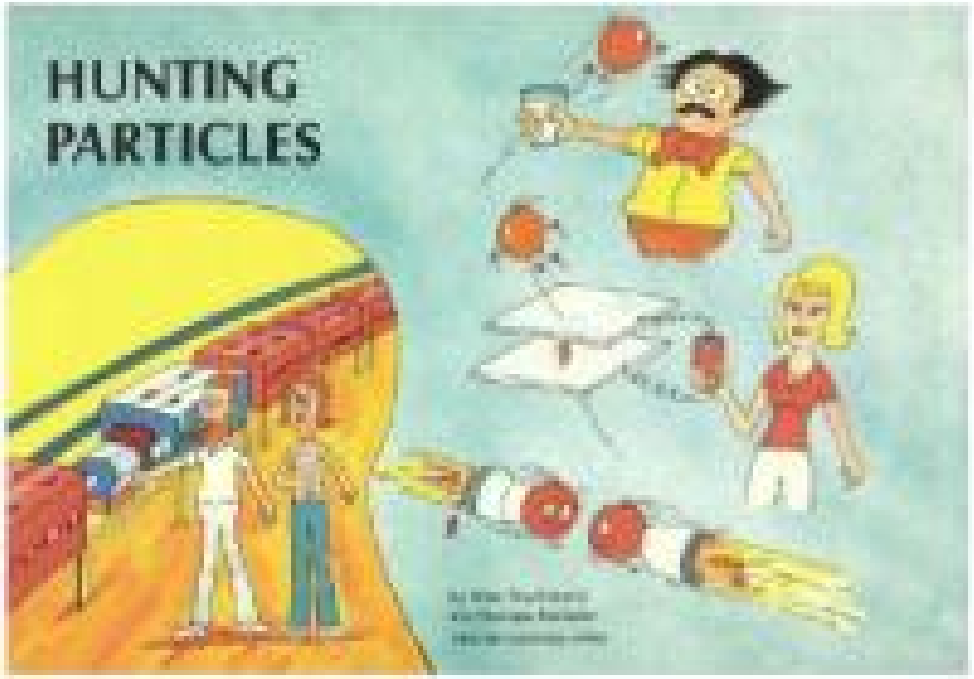
Why do particle physicists love to smash matter together and what kick do they really get out of it?



Control room of the ZEUS experiment

Question #2

Why do particle physicists love to smash matter together and what kick do they really get out of it?

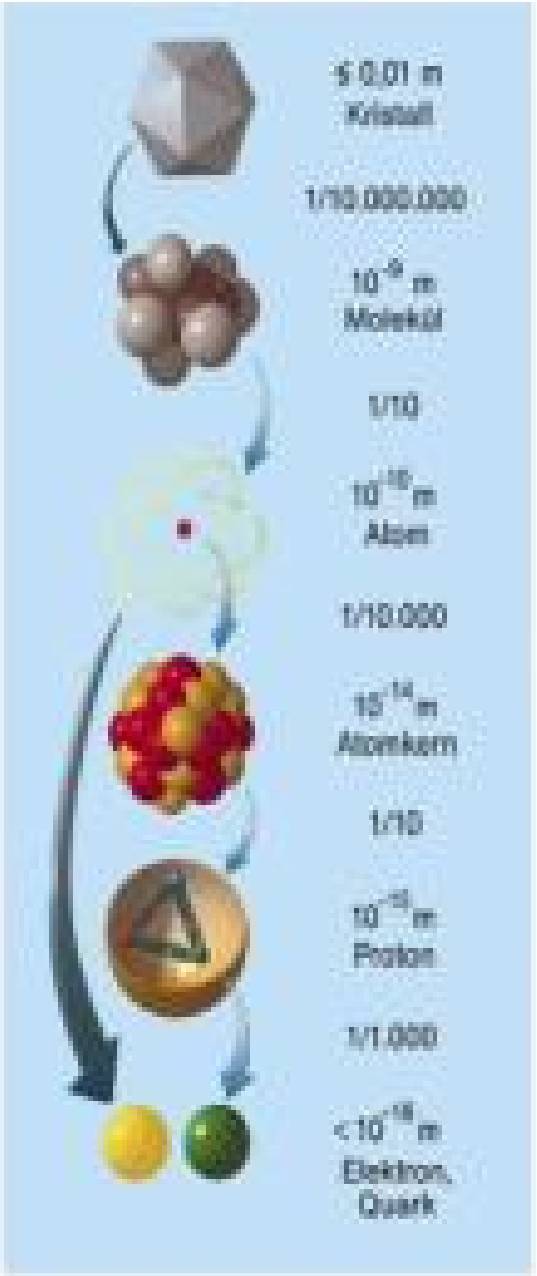


it's difficult, it's fascinating and it's fun

and also just like asking a child if he/she wants to see what's in the box

Question #3

What's the **matter**?



Cristal

↓

Molecule

↓

Atom

↓

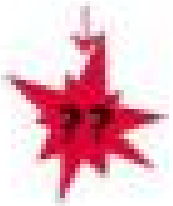
Nucleus

↓

Proton

↓

Parton



Goal:

go deep inside it

Matter

Science looks for patterns to discover the laws of nature.

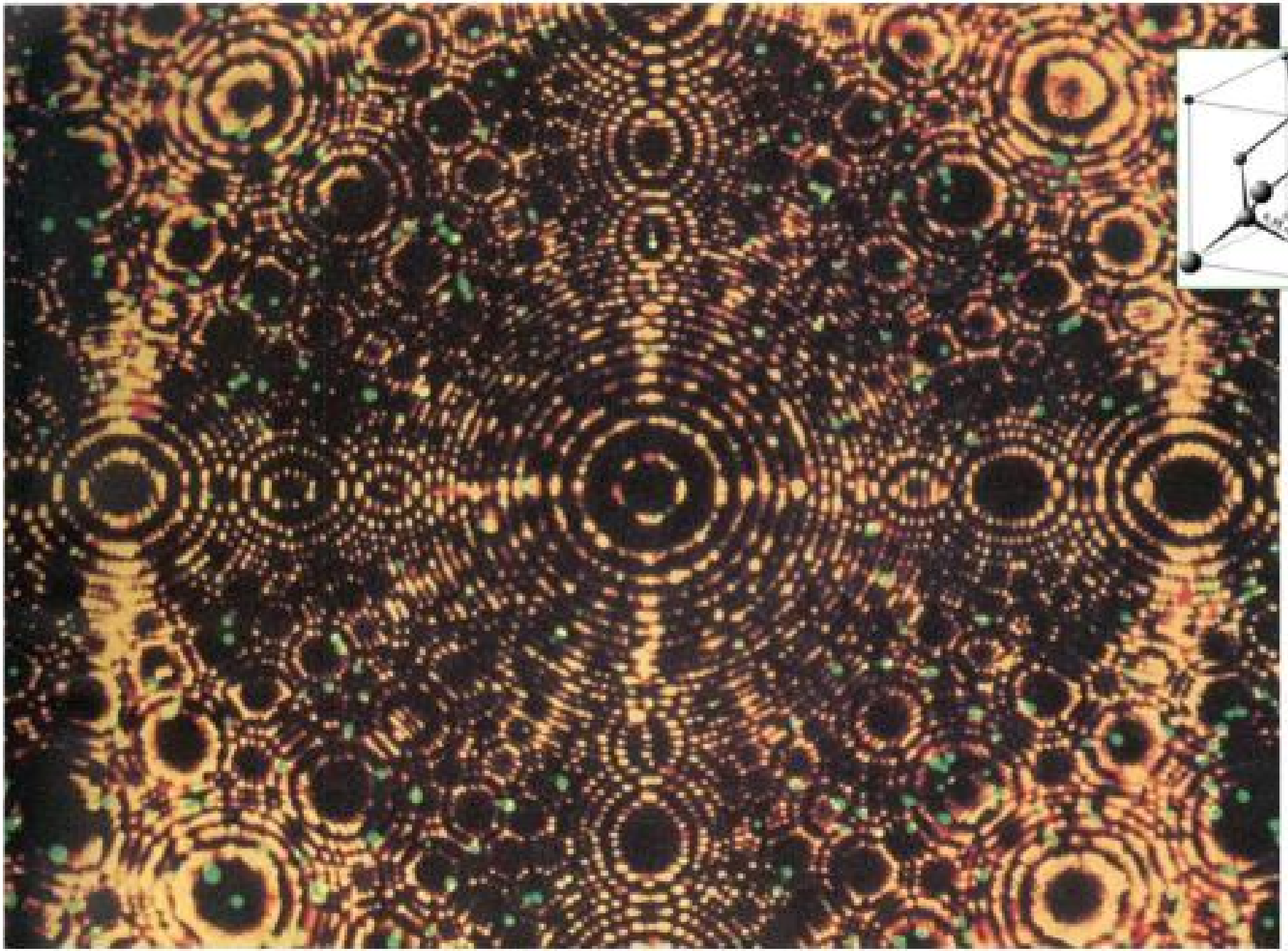
3 examples:

Galaxies

Snowflake

H_2O

Cristal



Demokritus

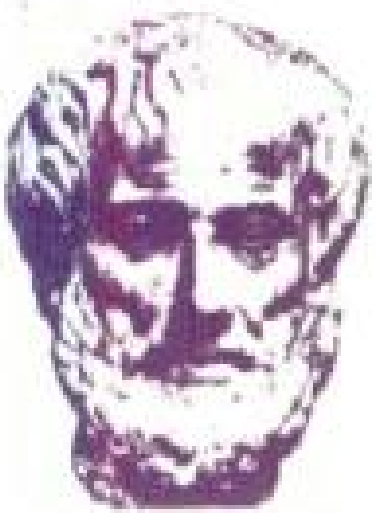
(around 460-371 BC)

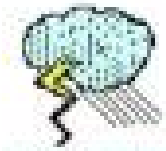
An object cannot be cut into smaller pieces indefinitely:
eventually it will be broken down to tiny particles.
These indivisible building blocks are called «***atomos***».
They would differ in shape, arrangement or position.
All objects would then be conglomerations of them.

Aristoteles

(around 384-322 BC)

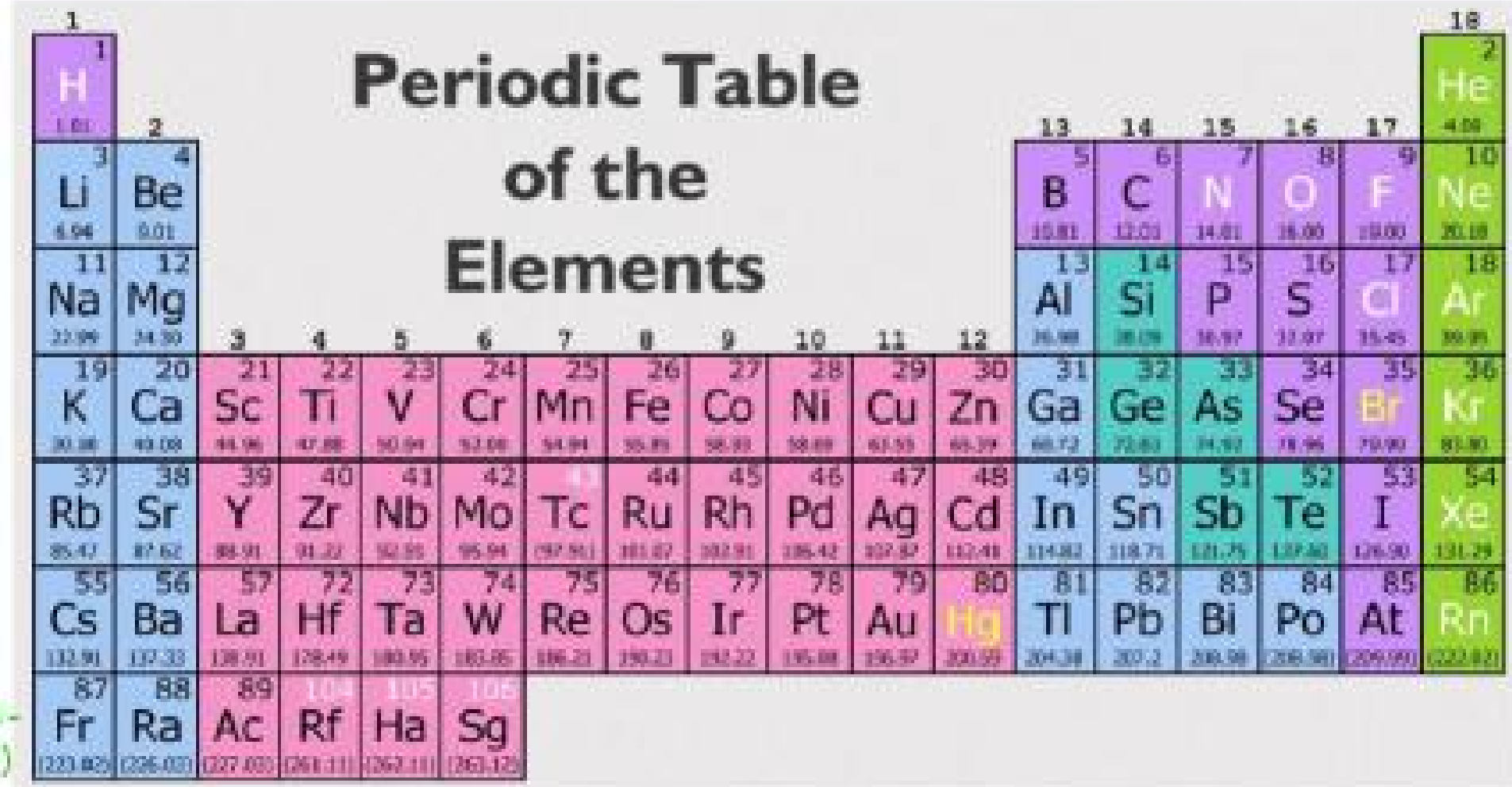
Aristotle did not believe in the atomic theory. In his view, matter consisted of four «elements»:





«qualities» described the basic properties of each element: dryness, wetness, heat and cold.

Dmitri Mendeleev

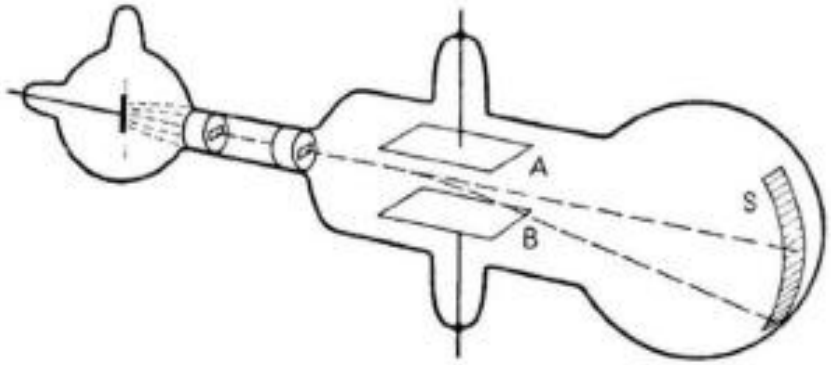


(1834-1907)

Joseph John Thompson

(1856-1940)

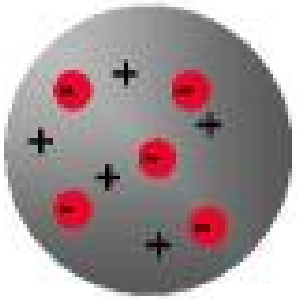
Thompson performed cathode ray experiments and tried to measure the velocity of these rays.



He demonstrated that the **electron** was a particle,
.. that it was charged and
.. that it was small.

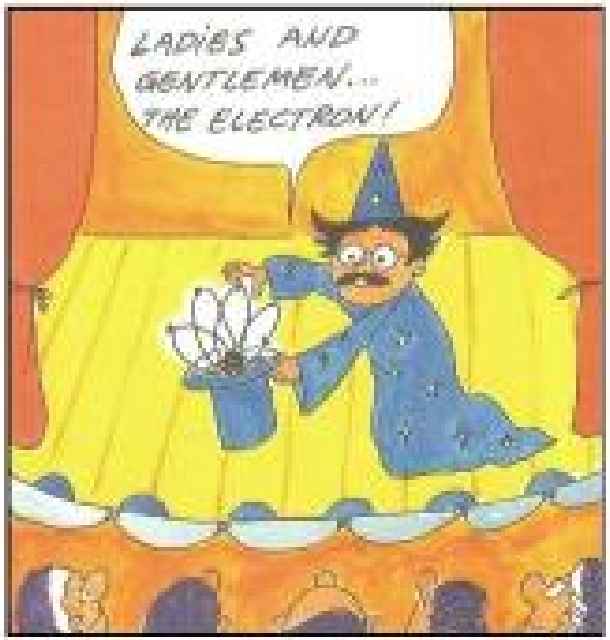
Atom Models

Thompson

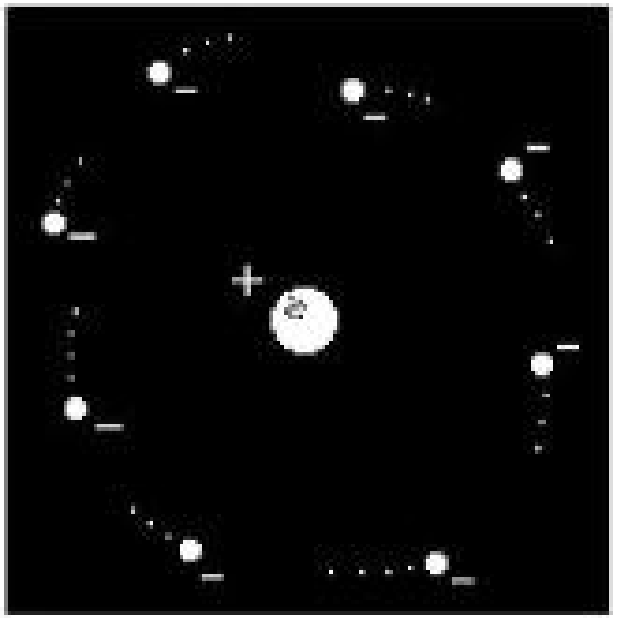


His «plum-cake» model of the atom: a sphere of positive charged matter in which electrons are imbedded.

Rutherford



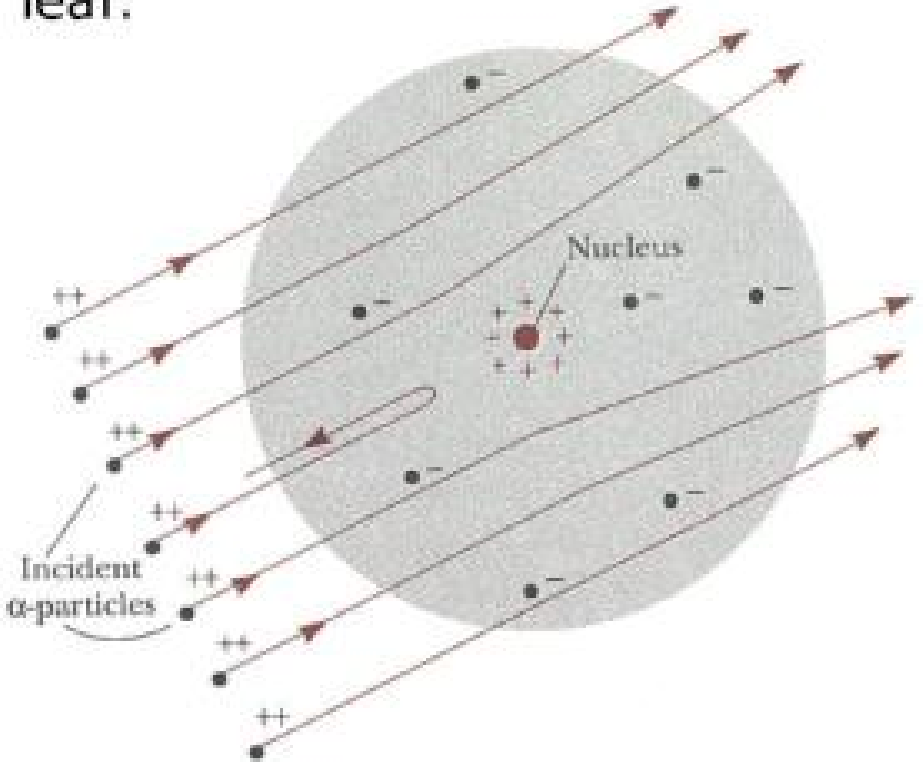
Negatively charged electrons would be circling around a positively charged **nucleus**.



Ernest Rutherford

(1871-1937)

alpha particles were scattered by a thin gold leaf.



But some were however scattered at very large angles!

Only a very strong field in the proximity of a **nucleus** could explain those observations.

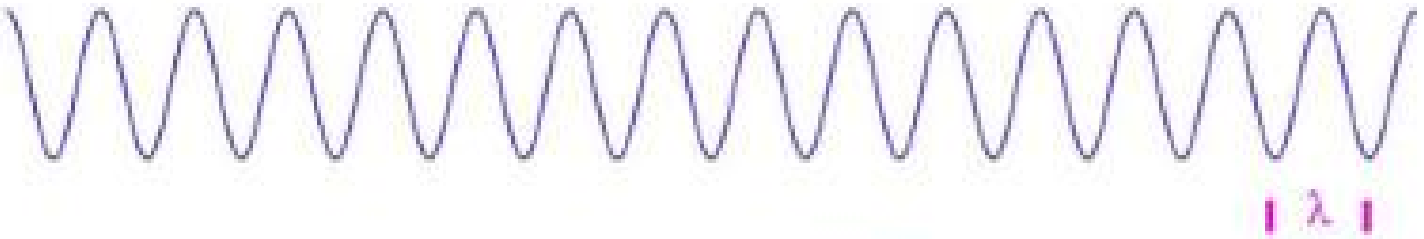
Louis de Broglie

(1892-1987)

Light is made of **photons**. A photon has no mass. Its energy E is given by:

$$E = h \cdot \nu$$

where **h** is the Planck constant and **ν** the frequency.



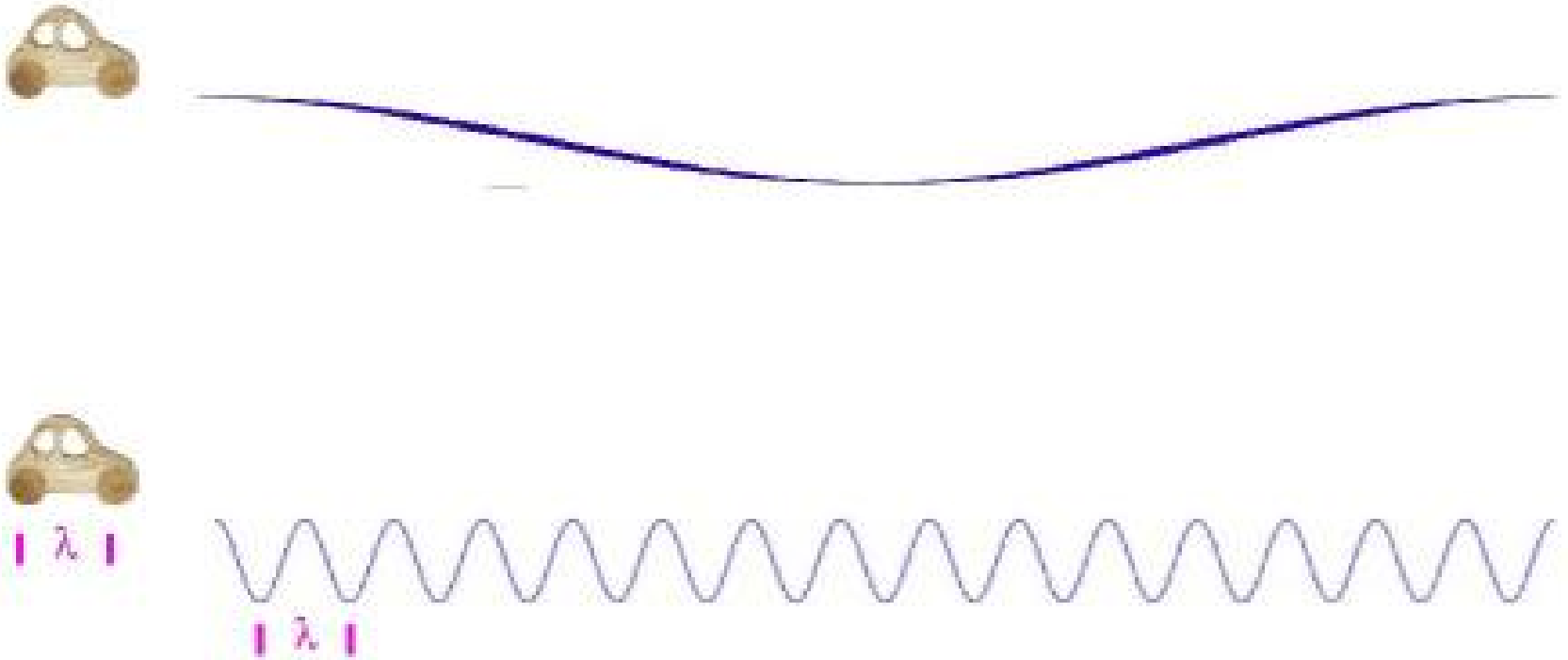
But photons behave as waves and particles!

It could be that all forms of matter also have properties of waves, with:

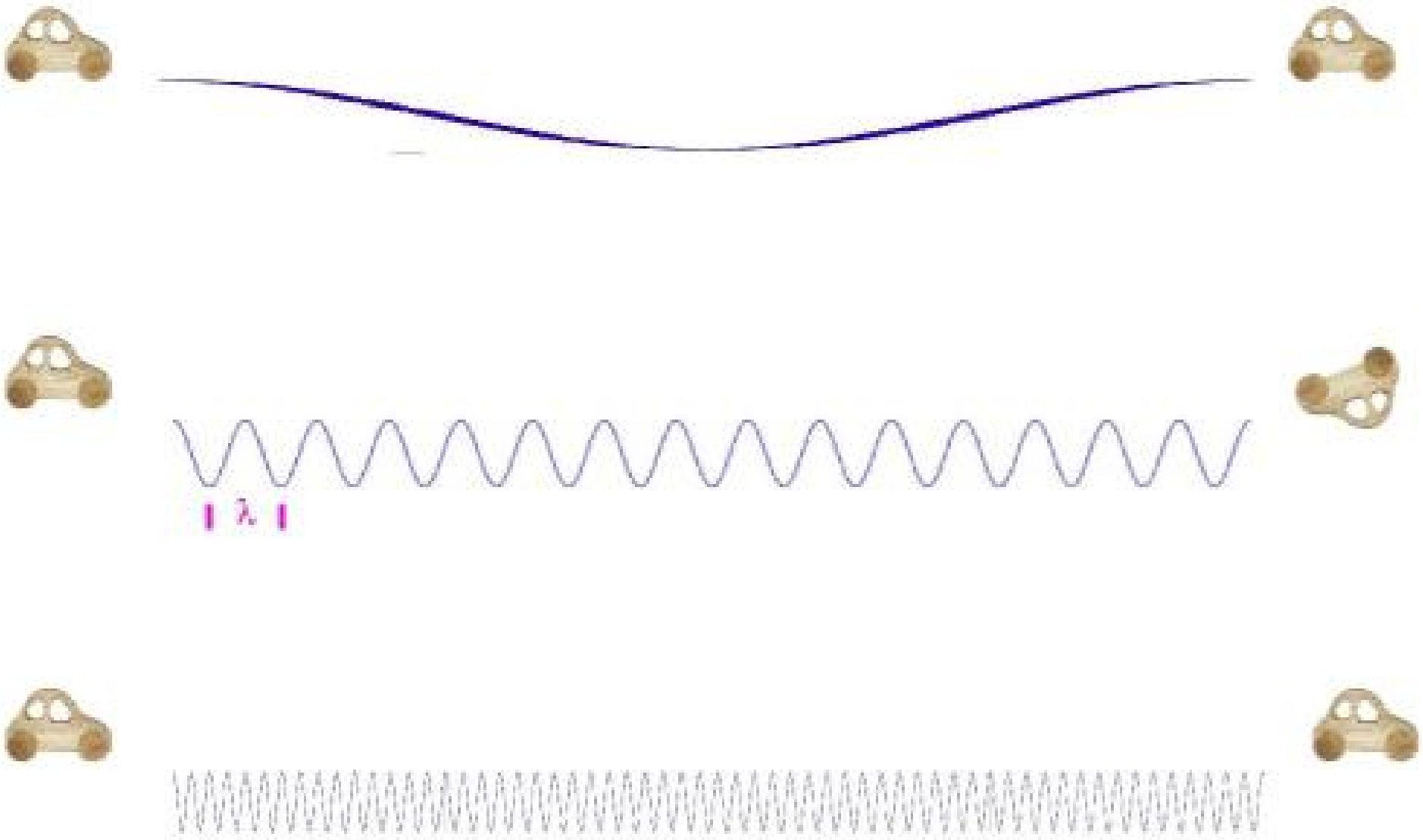
$$\lambda = \frac{h}{p}$$

p is the particle momentum and **λ** the wave length associated to **p**, i.e. the higher the energy/momentum, the shorter the wave length.

Wavelength

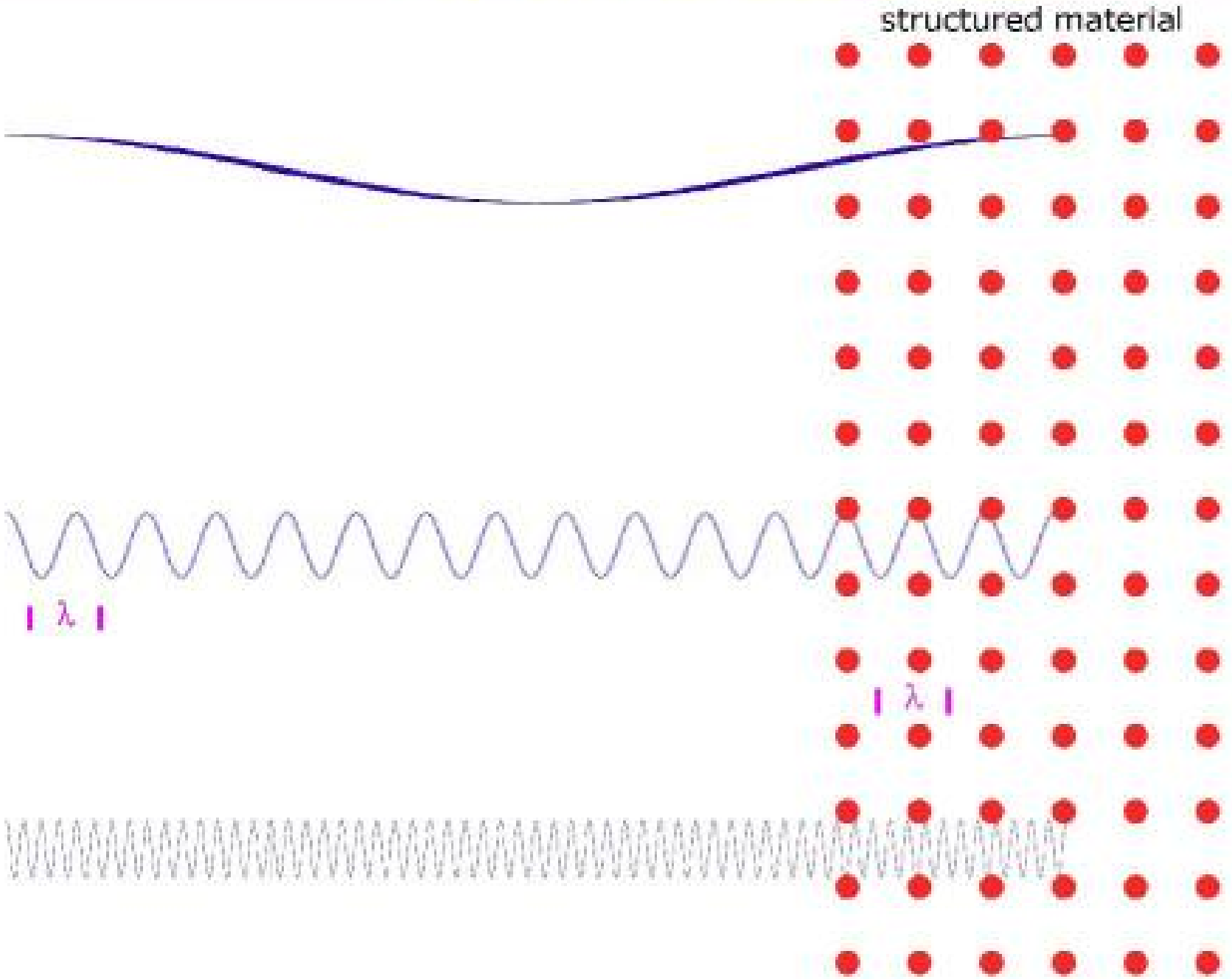


Wavelength

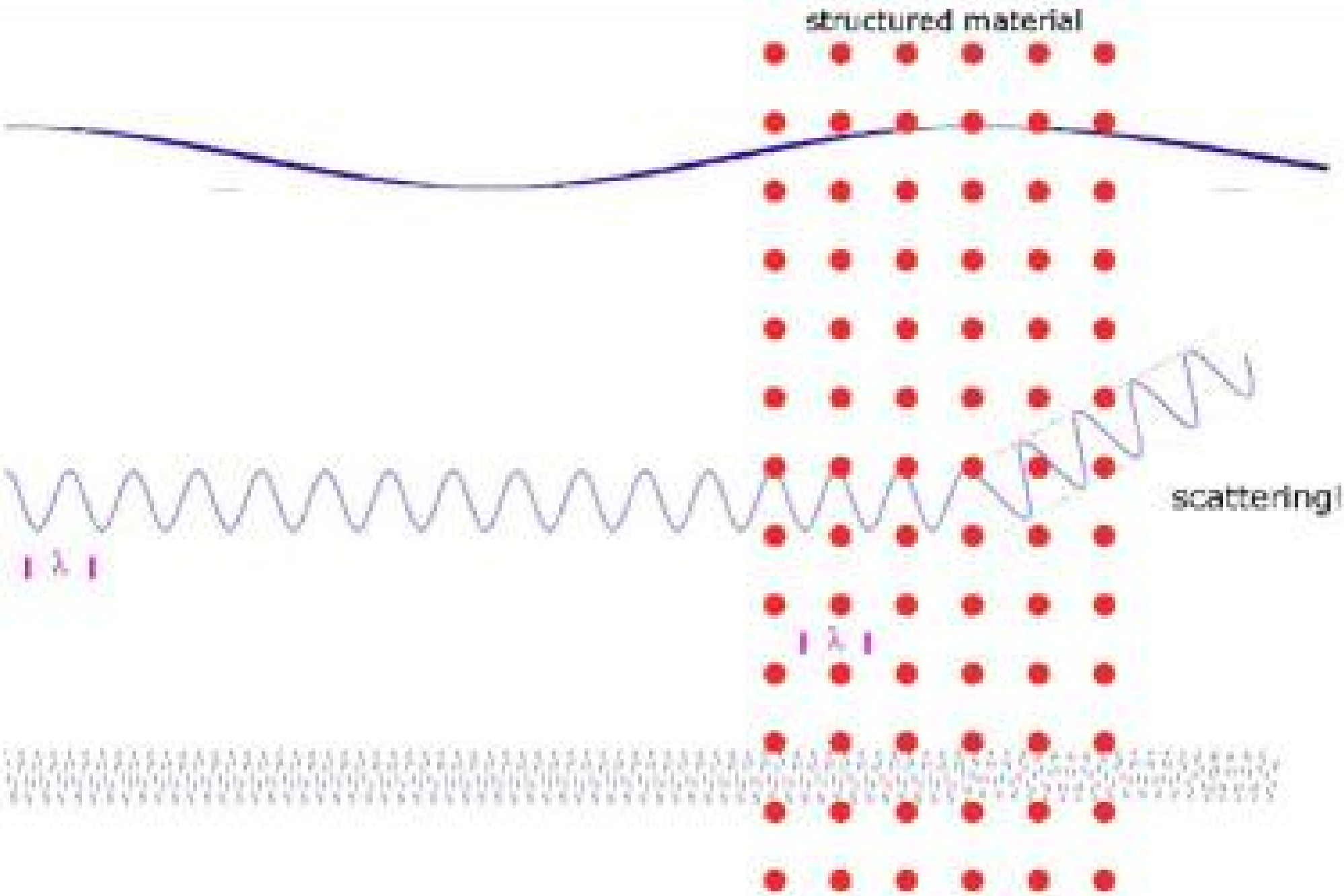


Wavelength

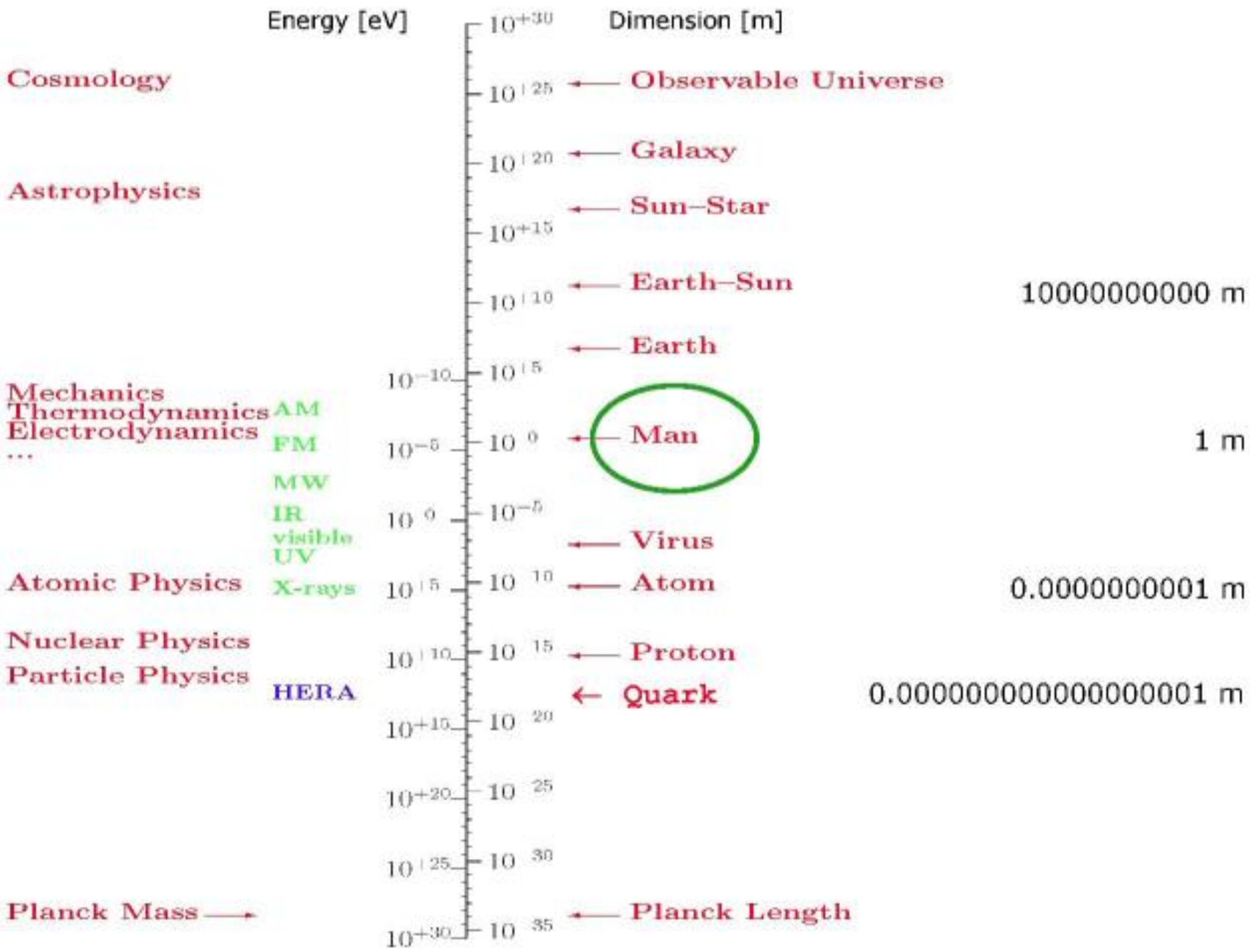
Wavelength



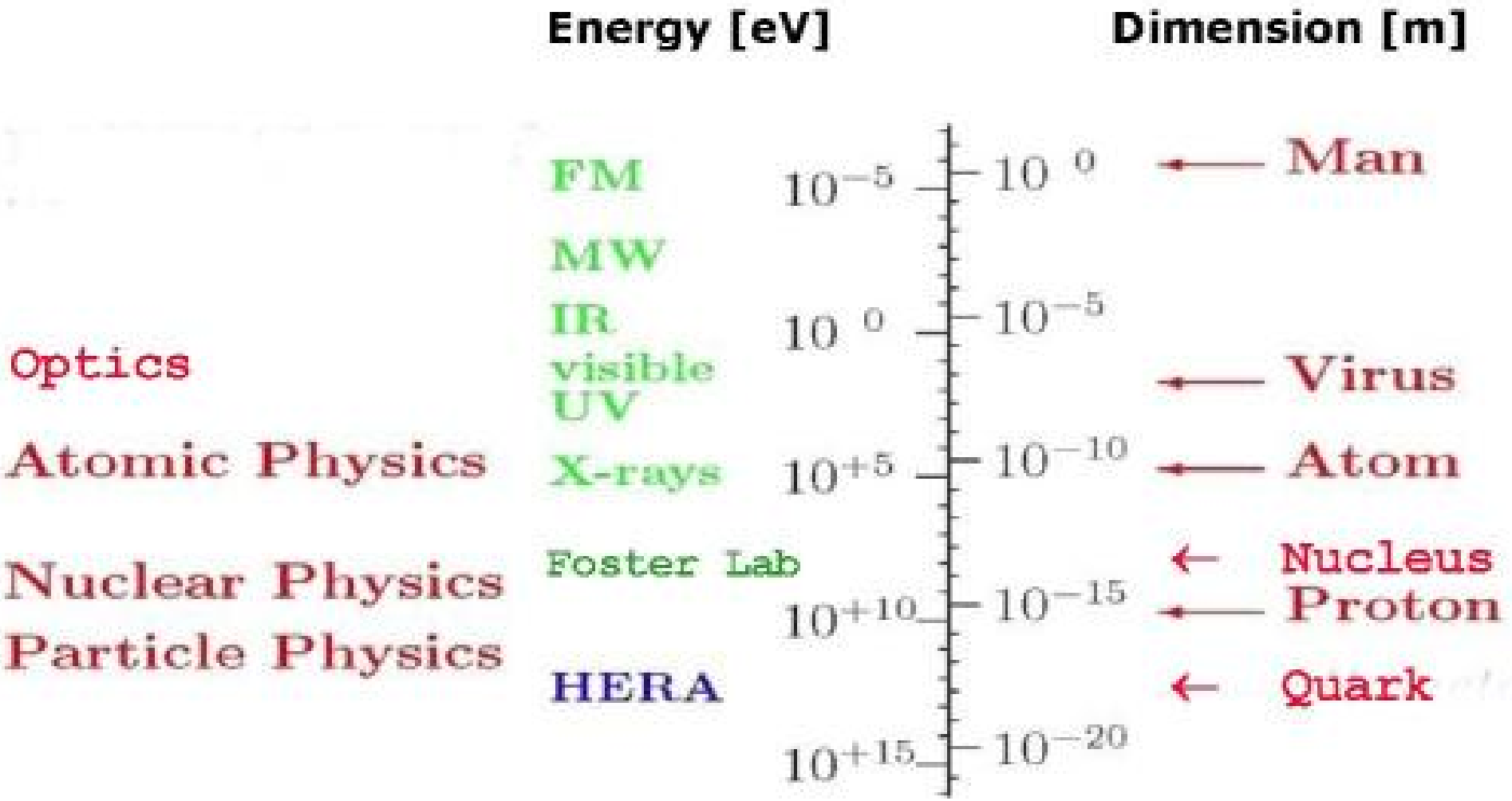
Wavelength



A Matter of Scale

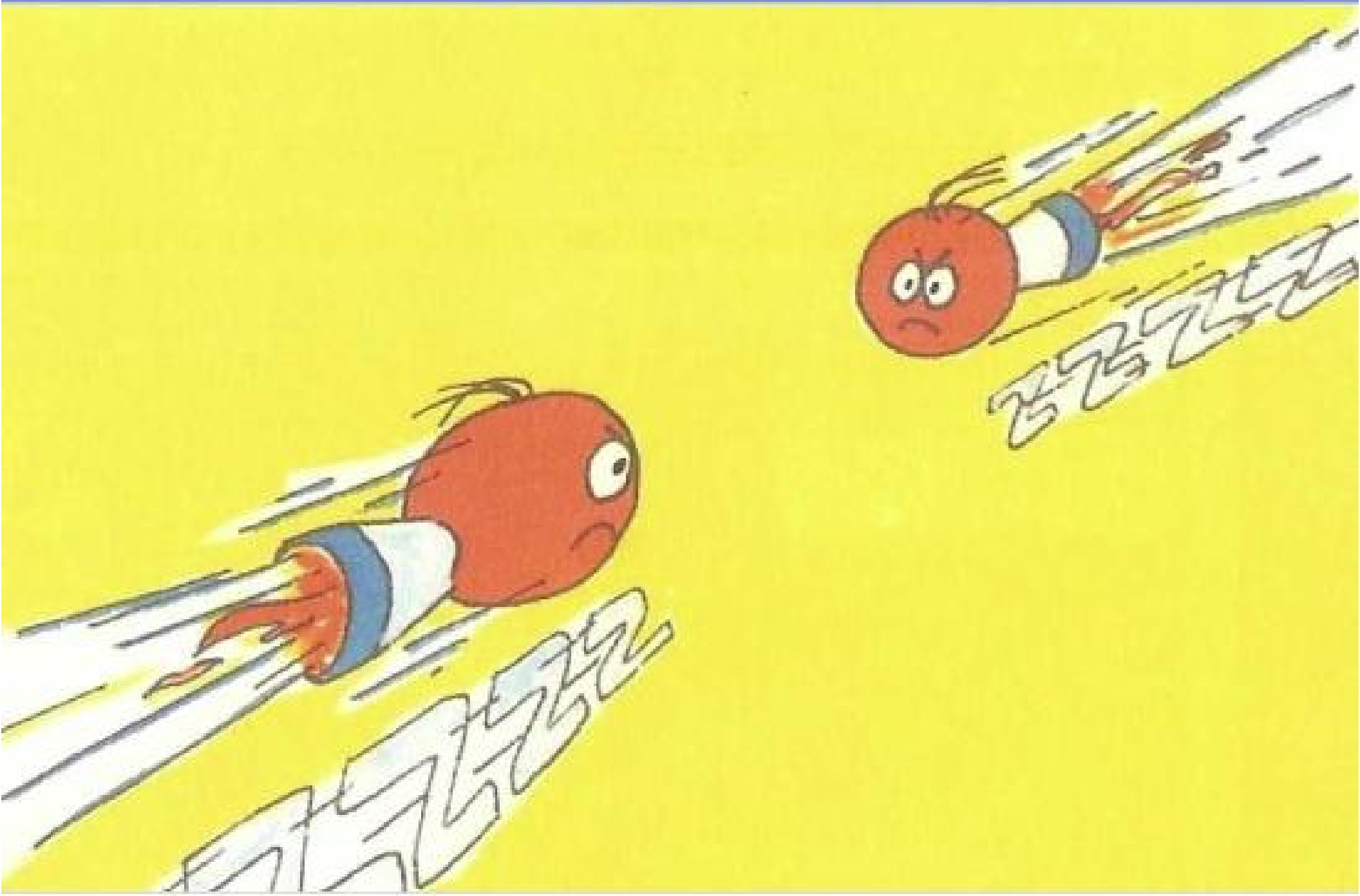


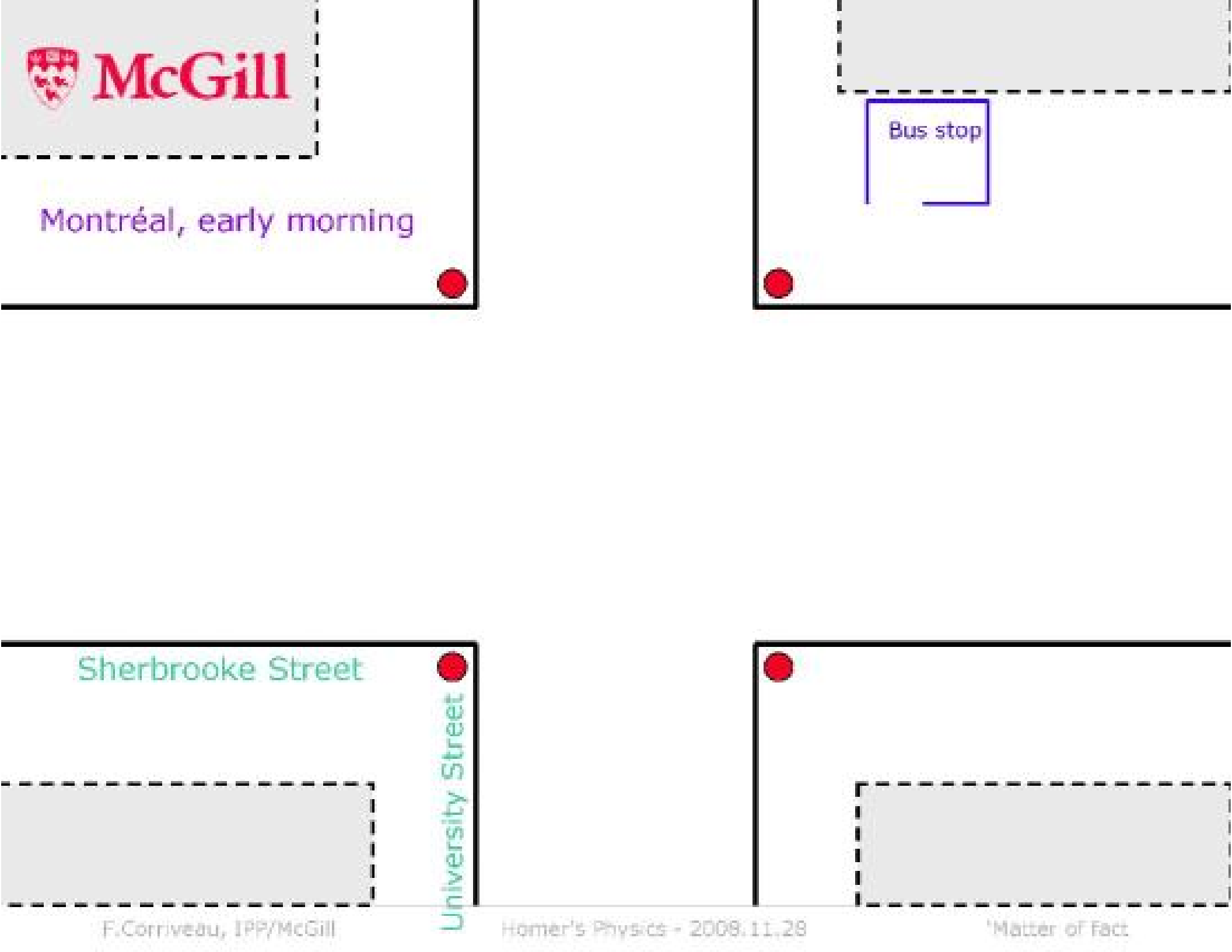
Zooming In



The higher the energy, the deeper we can probe

Collisions



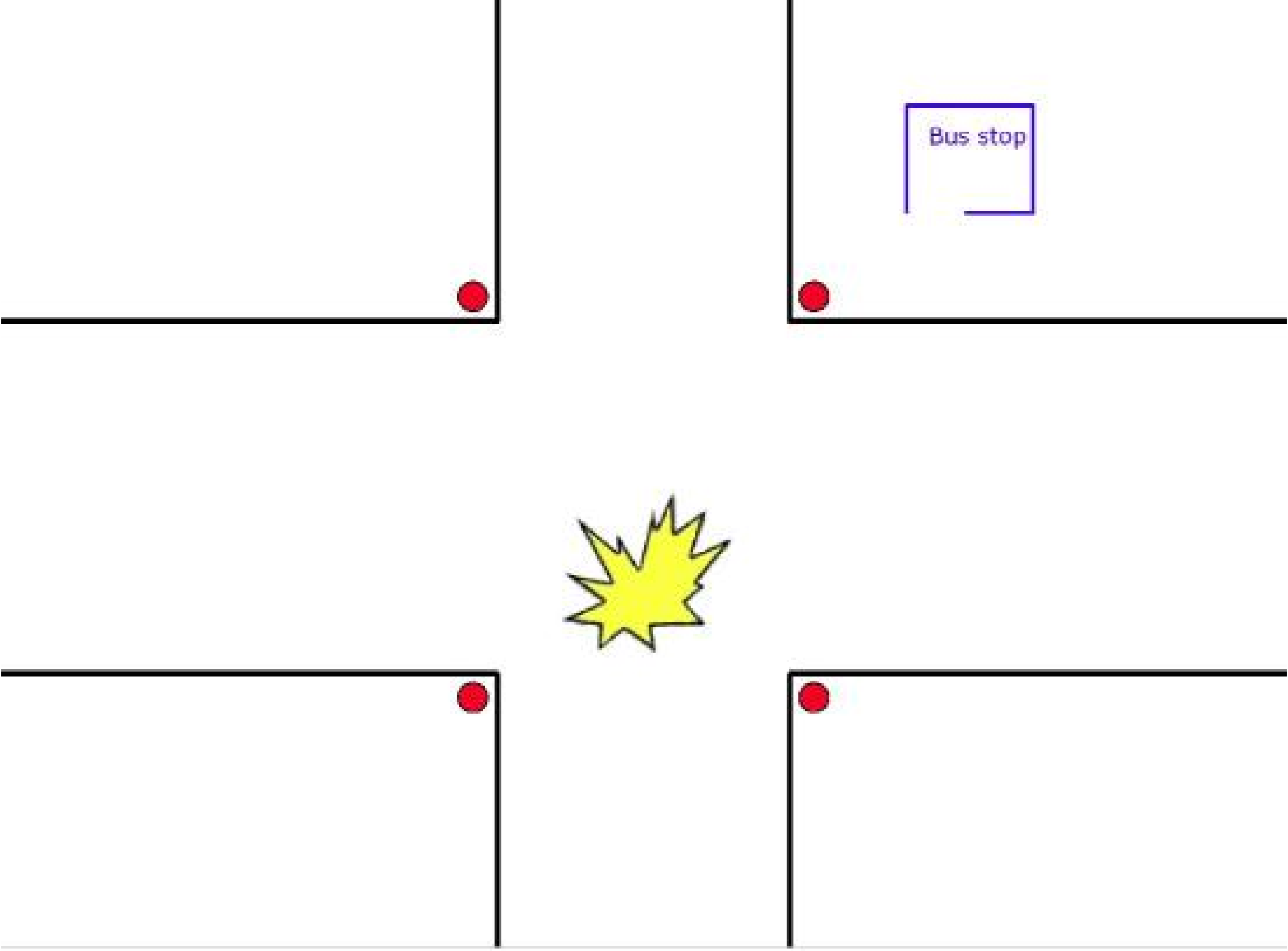

McGill
Montréal, early morning
Bus stop
Sherbrooke Street
University Street

McGill

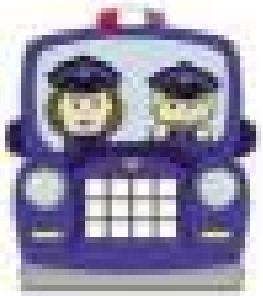
Bus stop

Sherbrooke Street

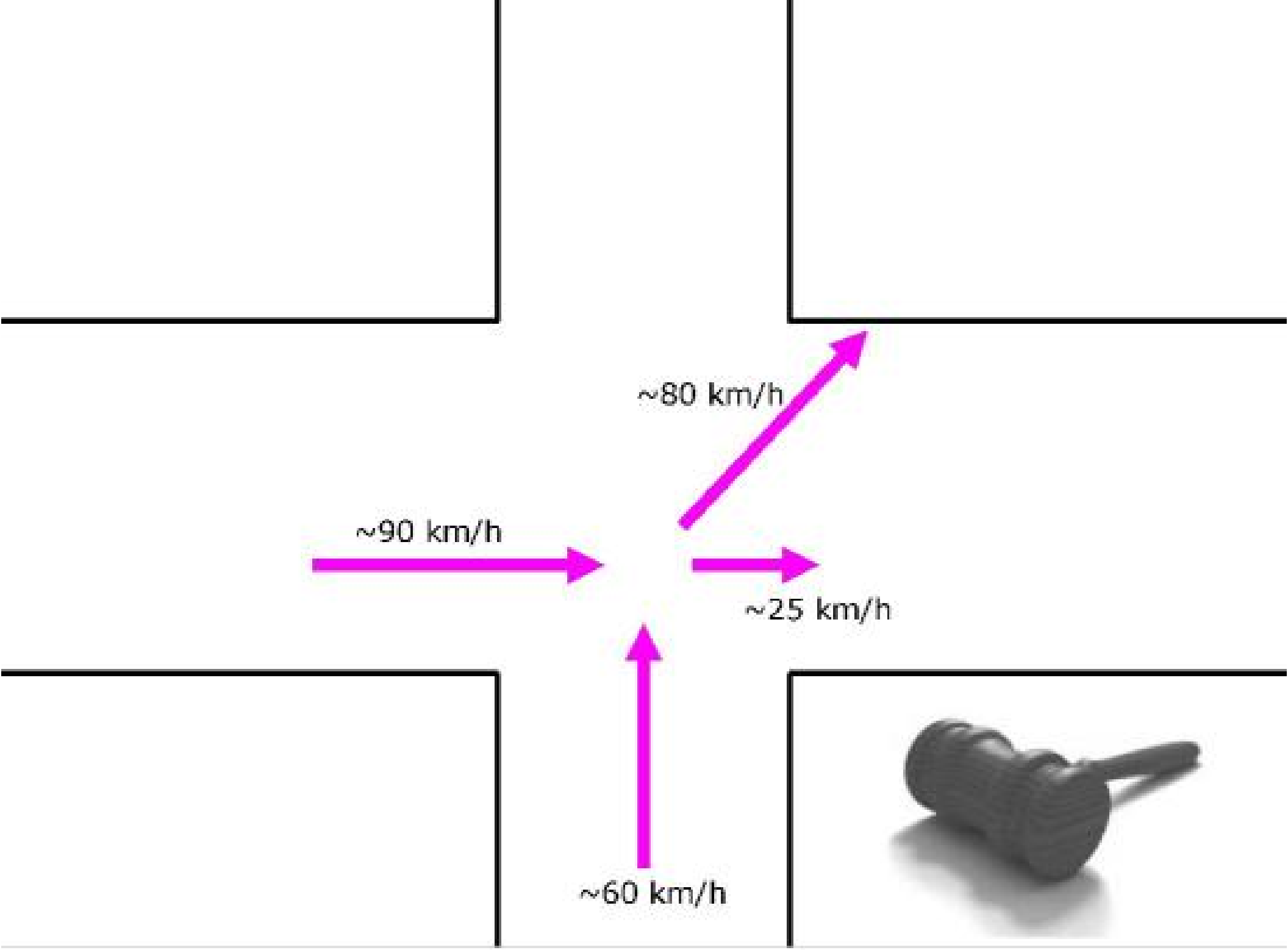
University Street


Bus stop


Bus stop



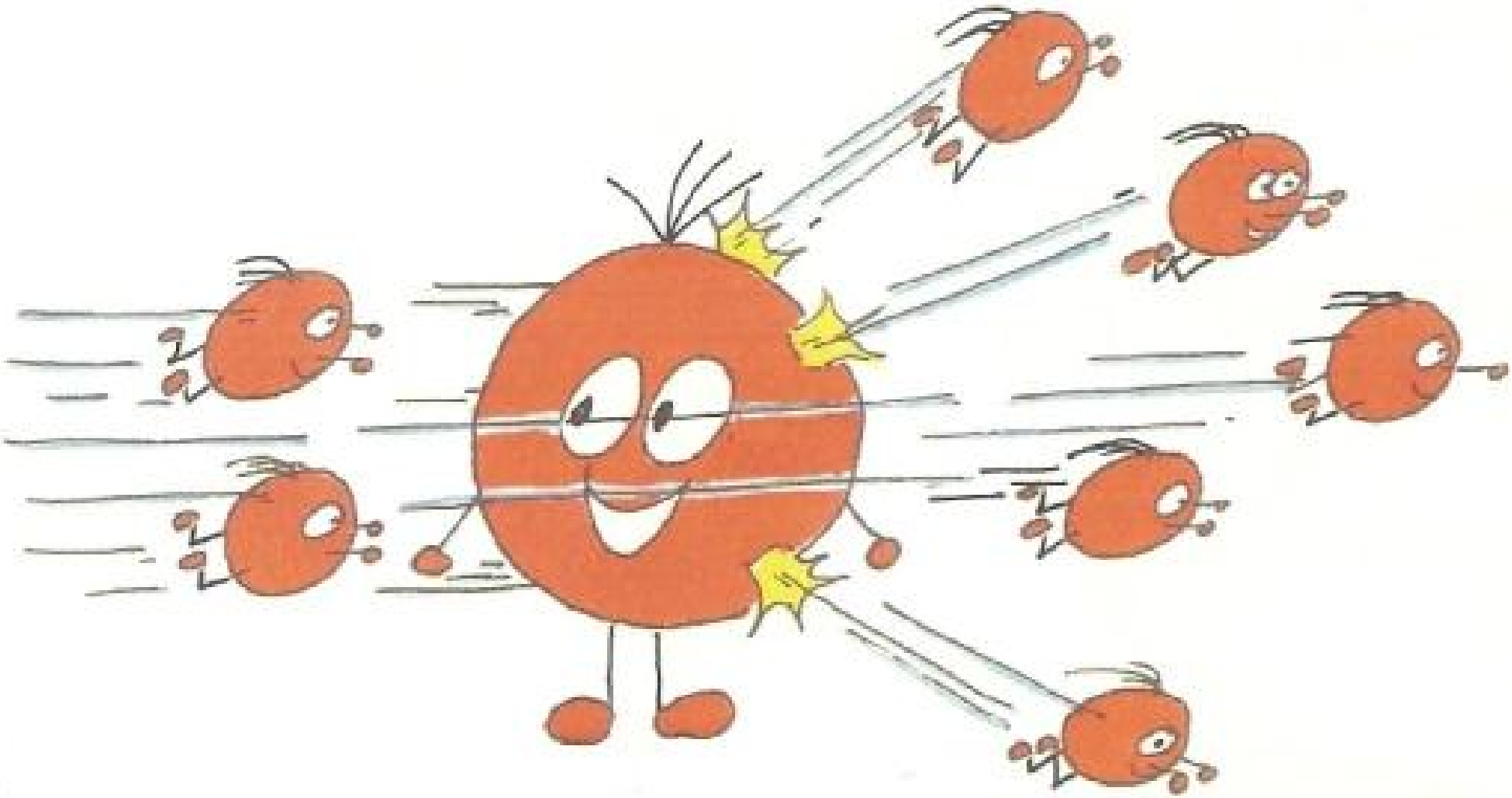

Bus stop


~80 km/h
~90 km/h
~25 km/h
~60 km/h

When Worlds Collide

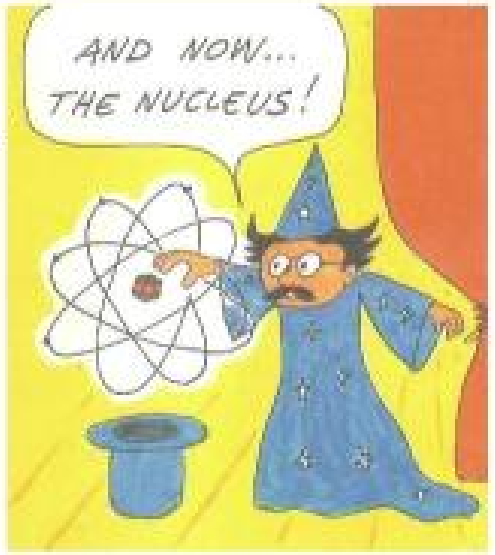
Scattering

PARTICLES HAVE BEEN FIRED AT OBJECTS AND THE WAY THEY HAVE BOUNCED OFF HAS BEEN STUDIED

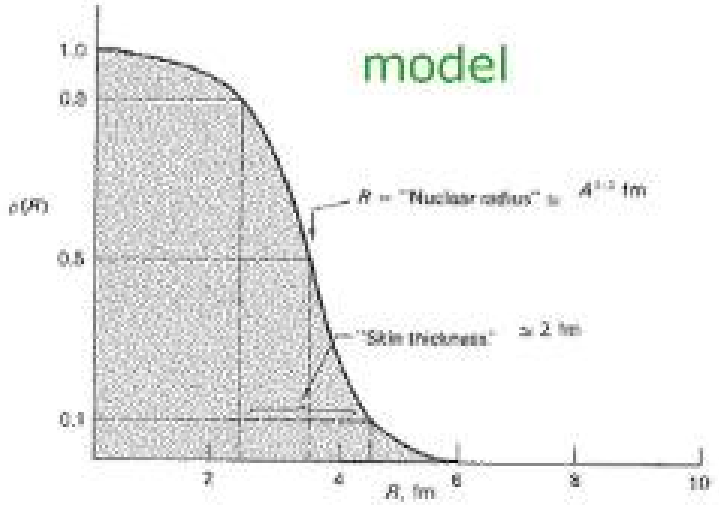


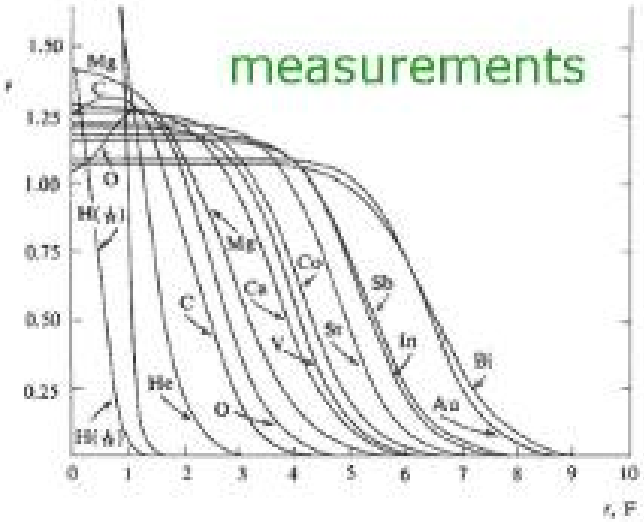
The Nucleus

The nucleus is made of tightly bound nucleons, the protons and the neutrons:



electron elastic scattering provides nuclear charge density distributions:

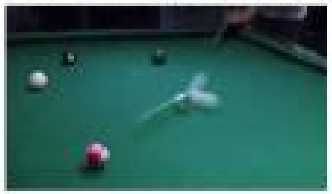




Nucleus and Nucleons

Electron-**nucleus** scattering

low p: elastic scattering

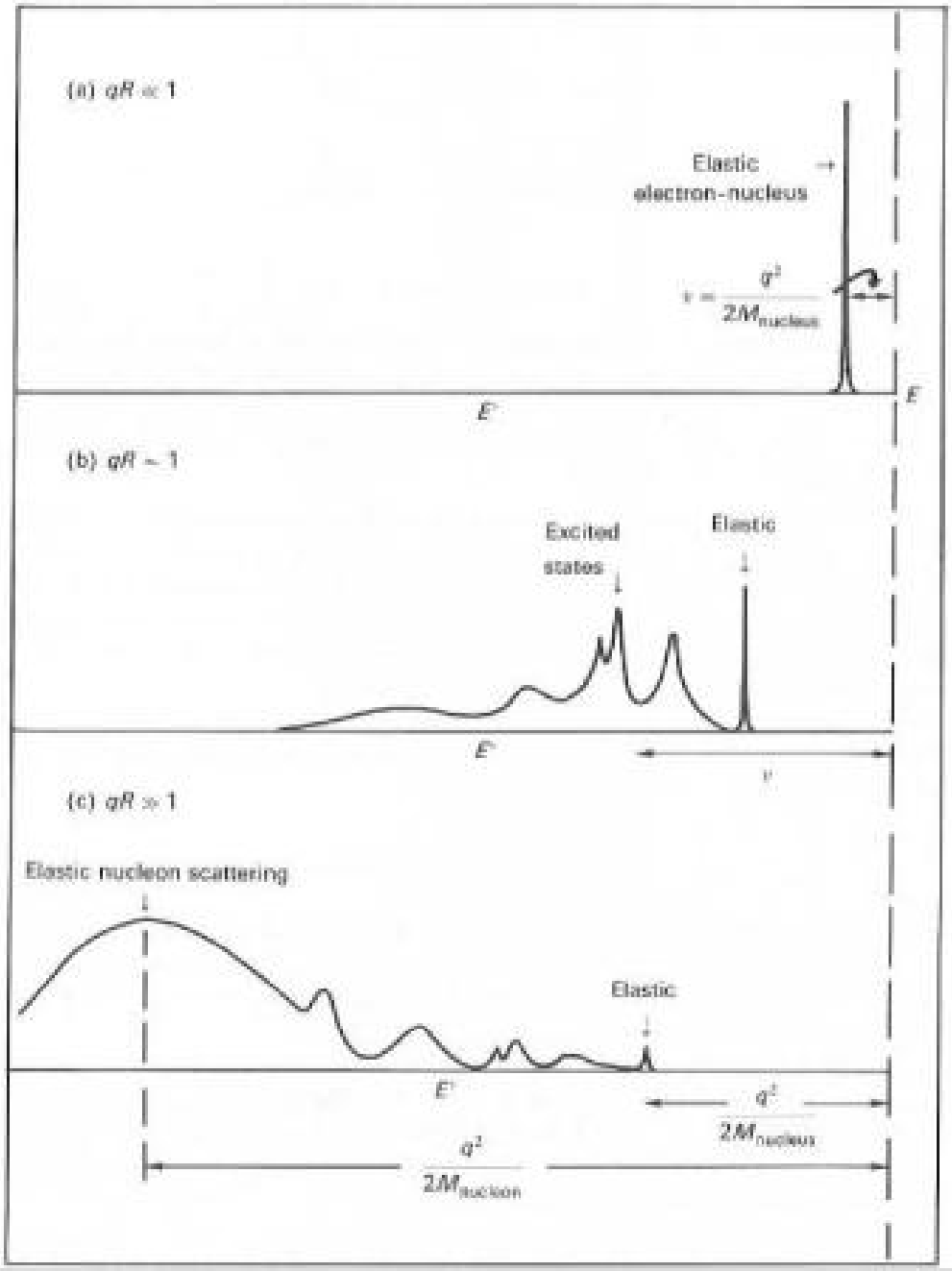


middle p: nuclear resonances

high p: nucleons are ejected

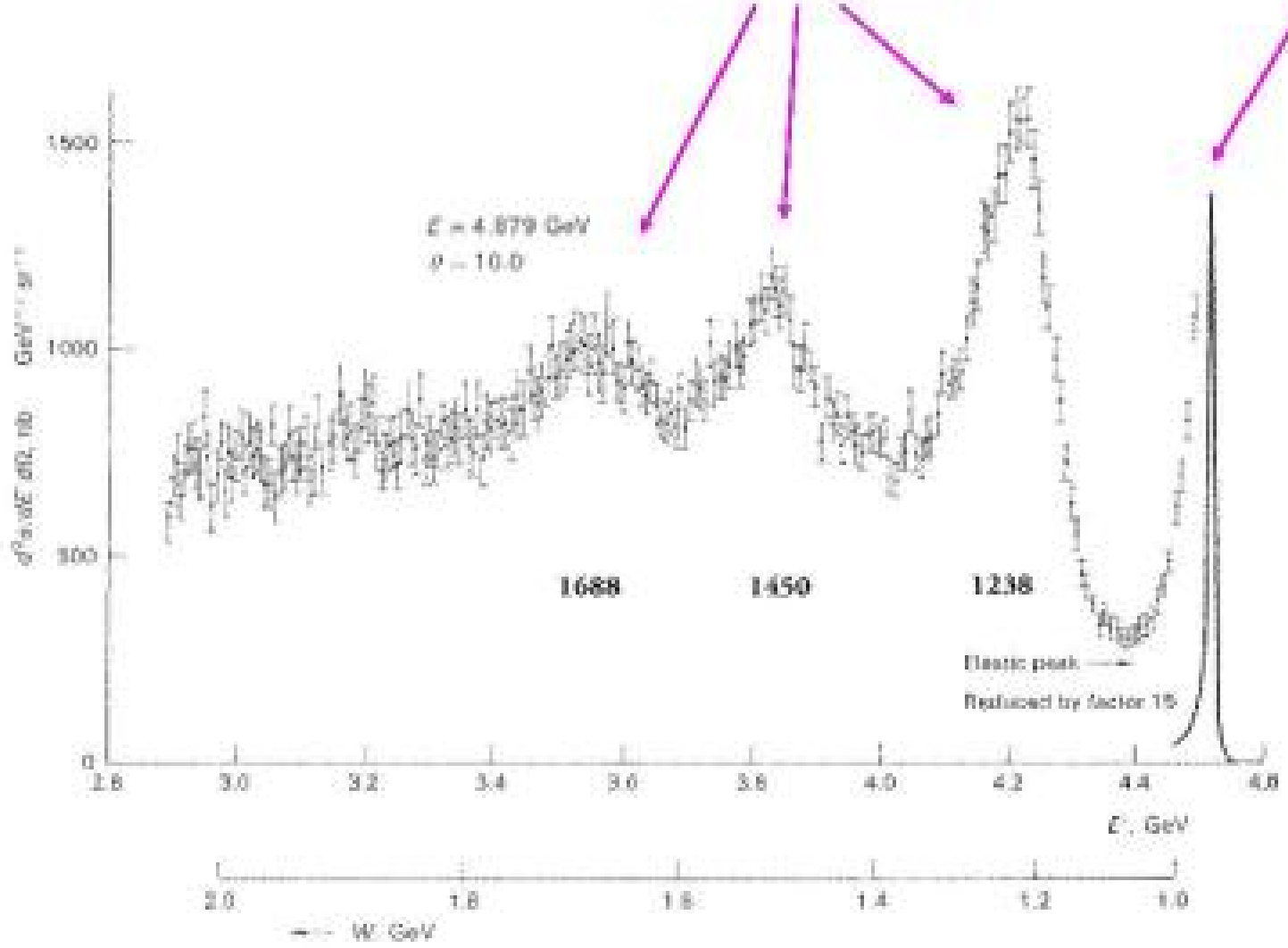
De Broglie's law: the electron "wavelength" λ reaches the size of a nucleon. We then probe the **nucleus content!**

electron momentum increases



The Proton

Electron-**proton** scattering at DESY (1968) - besides elastic collisions, excitation nucleon resonances are also observed.

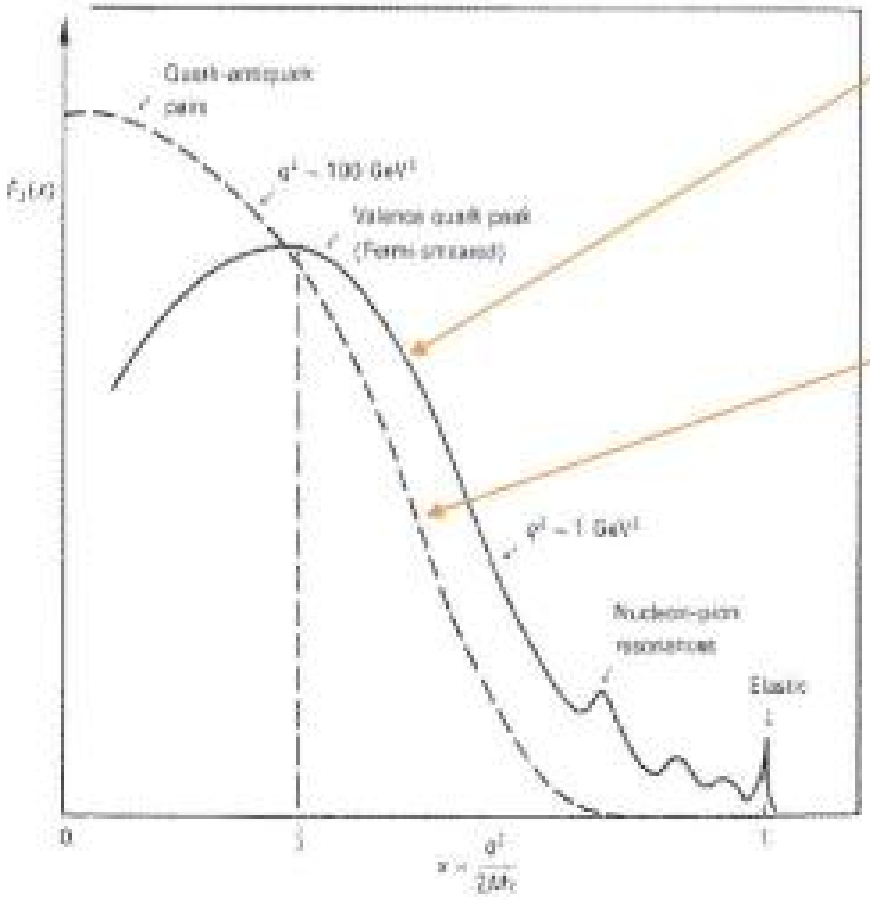


Proton and Quarks

Similarly to electron-nucleus collisions,
study electron-**proton** collisions as function of **p** and **x** :

p is the momentum transfer in the reaction

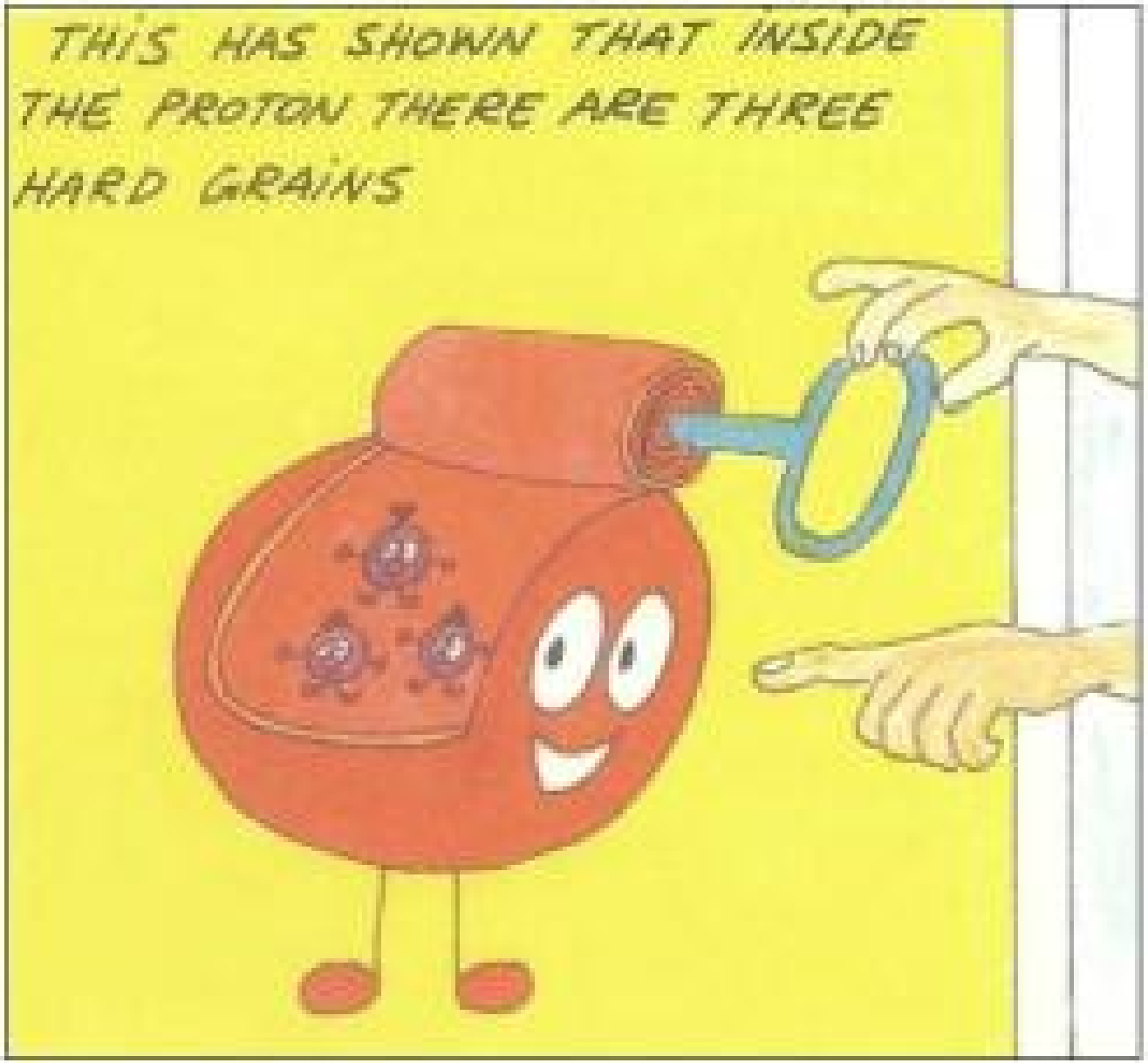
x is the "contributing" fraction of the nucleon



low p: the continuum peaks around **x**=1/3, indicating that 3 valence quarks exist, i.e. one quark is hit at any one time.

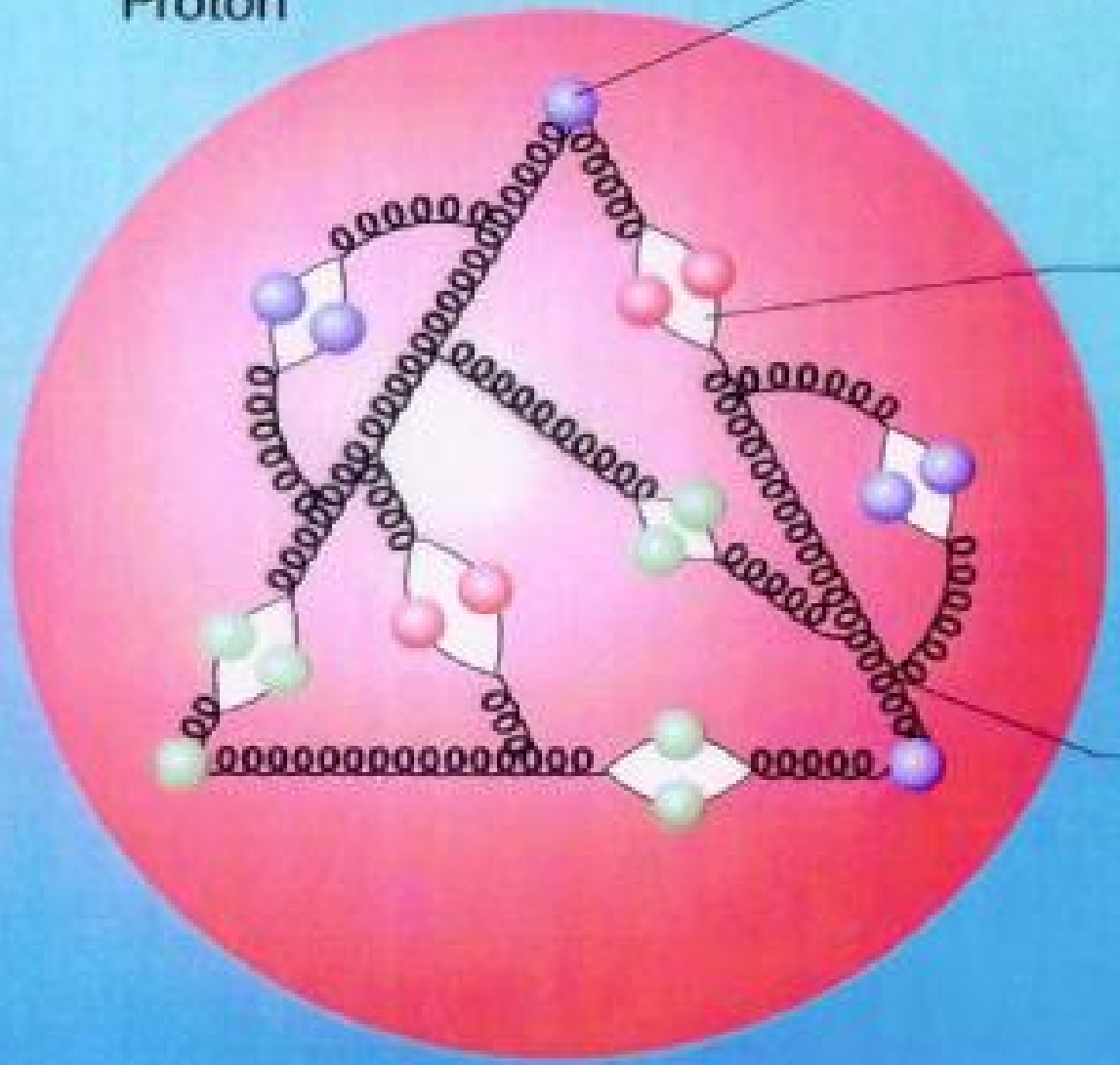
high p: as the momentum increases, single peaks vanish and the distribution shifts to lower **x** values → probe other quarks inside the nucleon.

Nucleon



Actually ..

Proton Model



Valenzquark

(3 valence quarks): **uud**

Quark-Antiquark-Paar

(sea quarks)

Gluon

(gluons)

Accelerators

Colliders:

- proton-proton

Tevatron (Fermilab, Chicago)

LHC (CERN, Geneva)

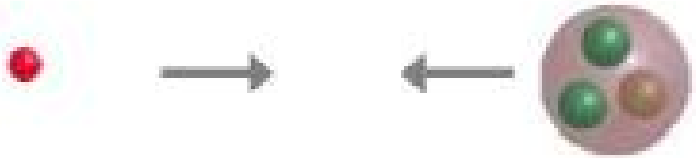
→ lots of energy available

- electron-electron

LEP (CERN, Geneva)

→ precision measurements

- electron-proton

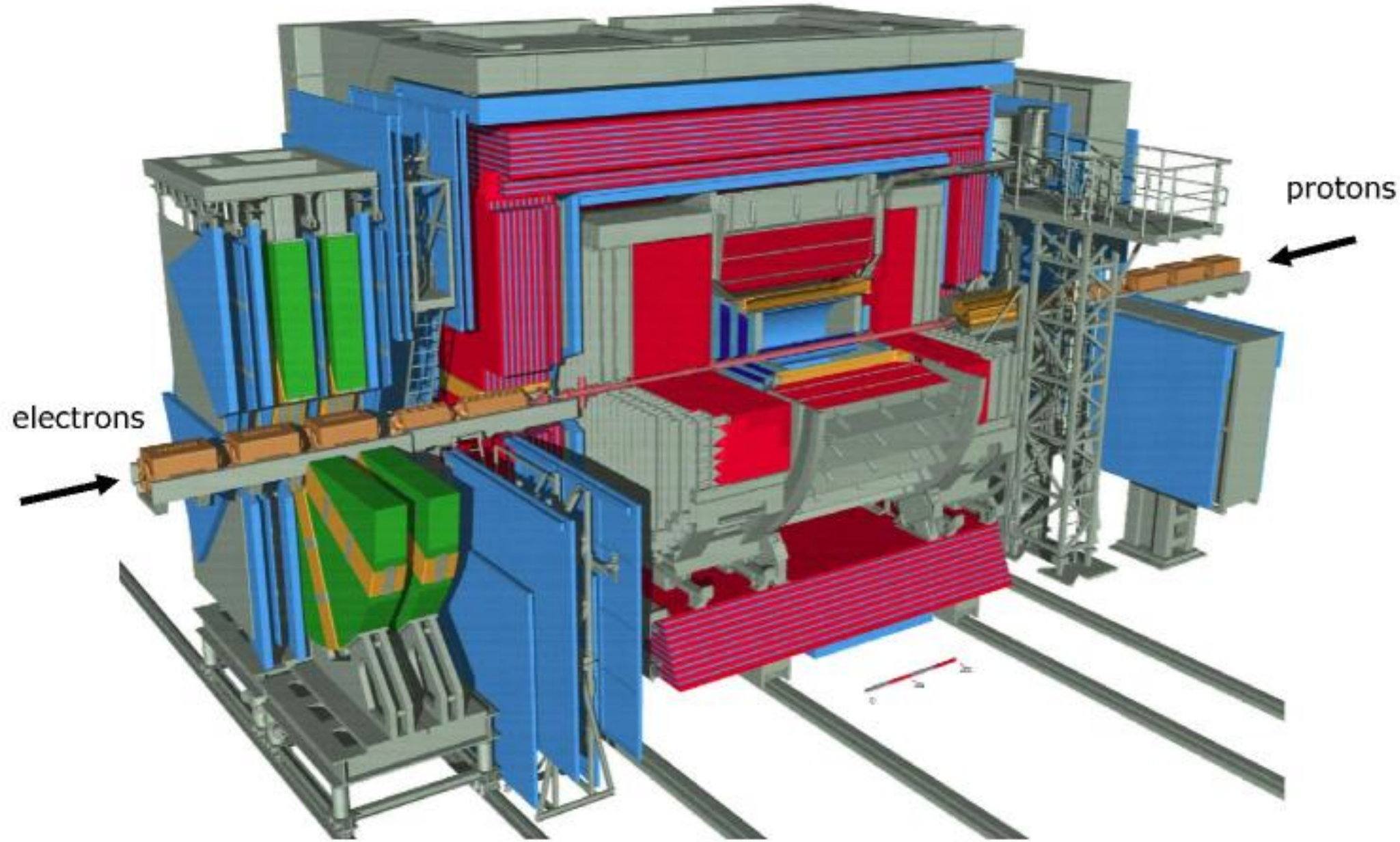


HERA (DESY, Hamburg)

→ structure of the proton!

HERA Accelerator

ZEUS Detector



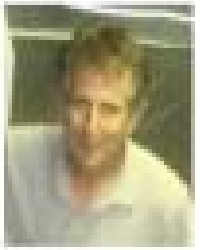
ZEUS Collaboration

McGill over the years:

4 Professors


D.Stairs


P.Patel


D.Hanna

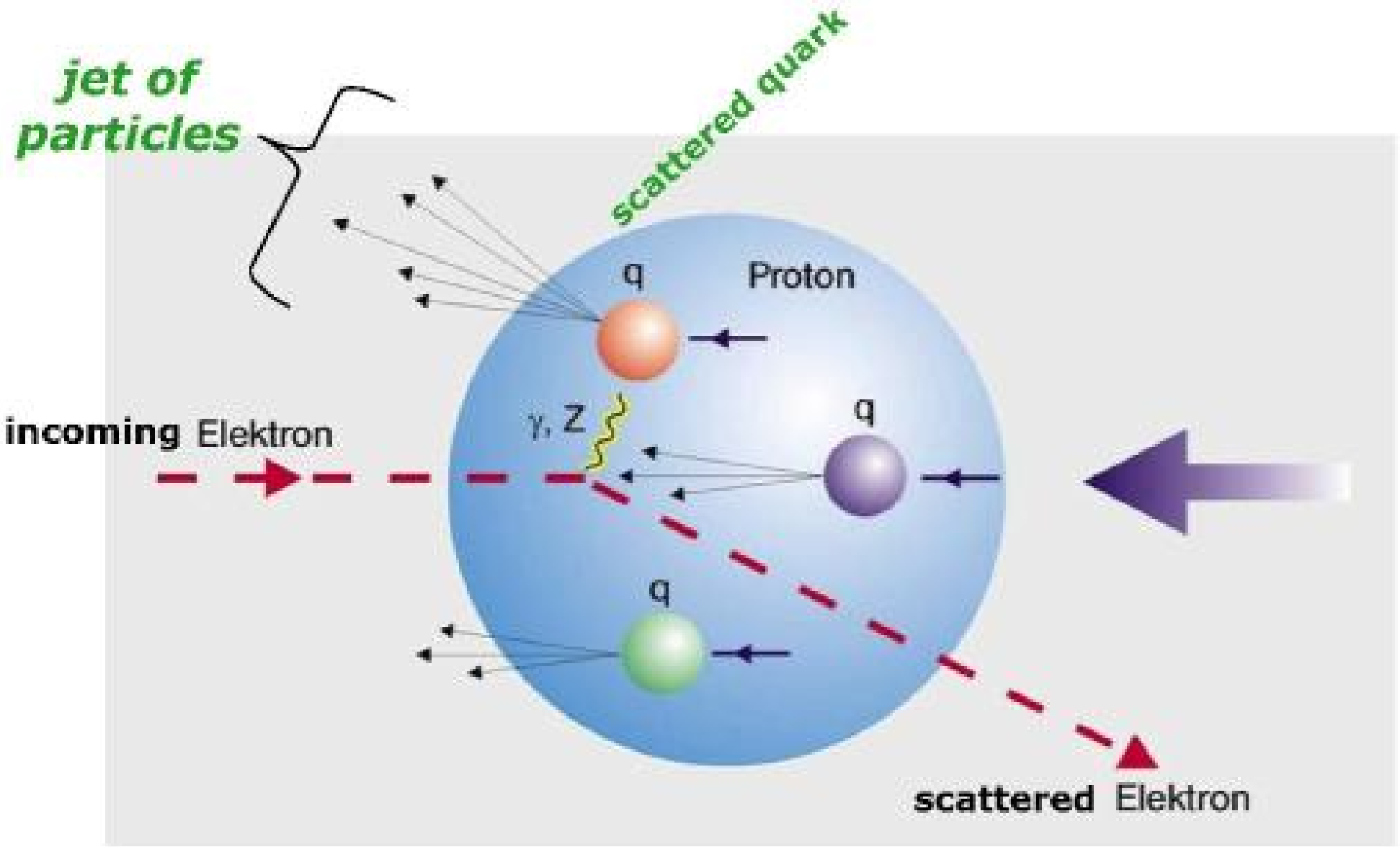

F.Corriveau

12 Research Associates

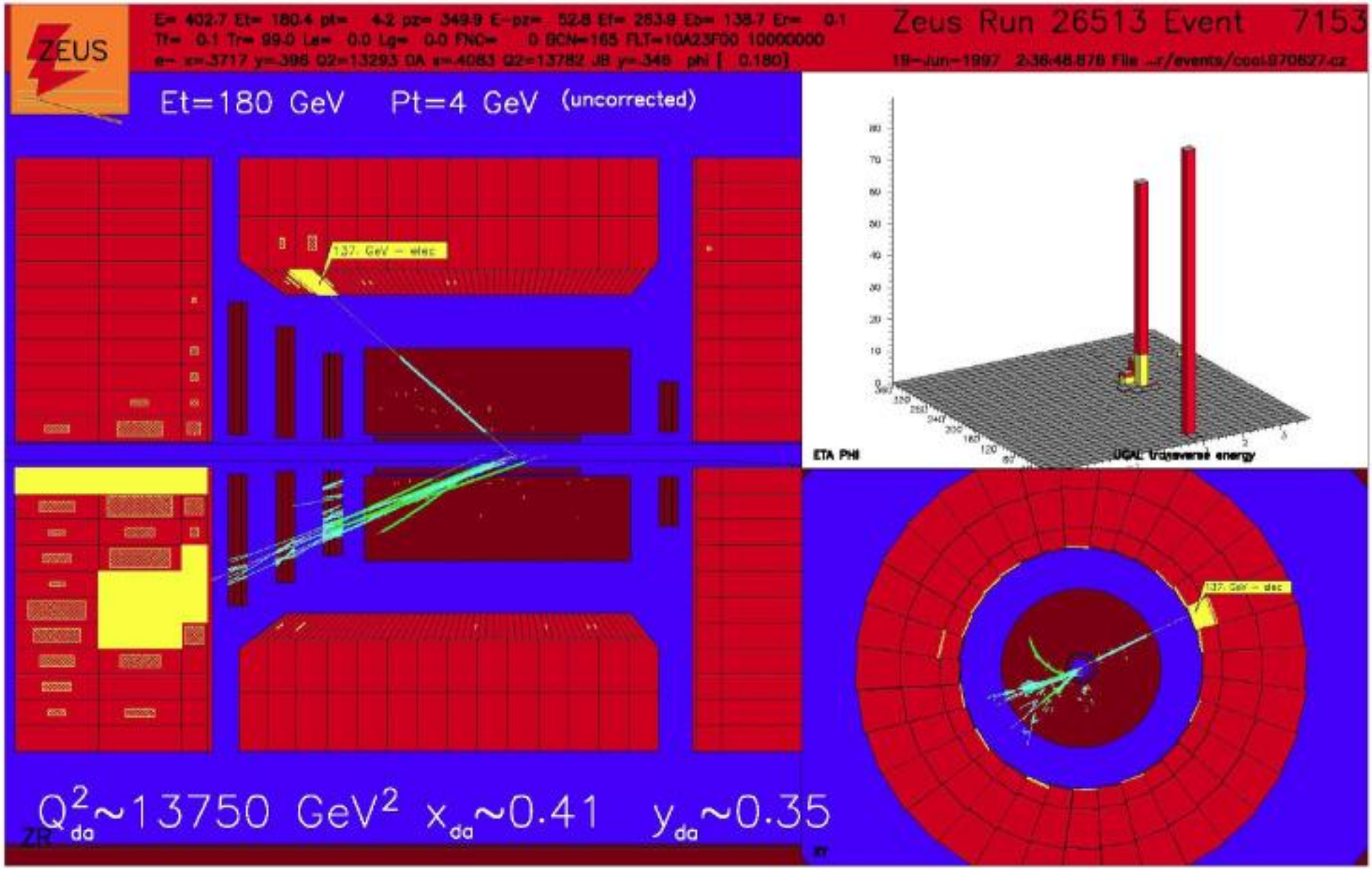
15 Graduate Students

20+ Summer Students

Electron-Proton Collisions



One Such ZEUS Event



ZEUS Measurements

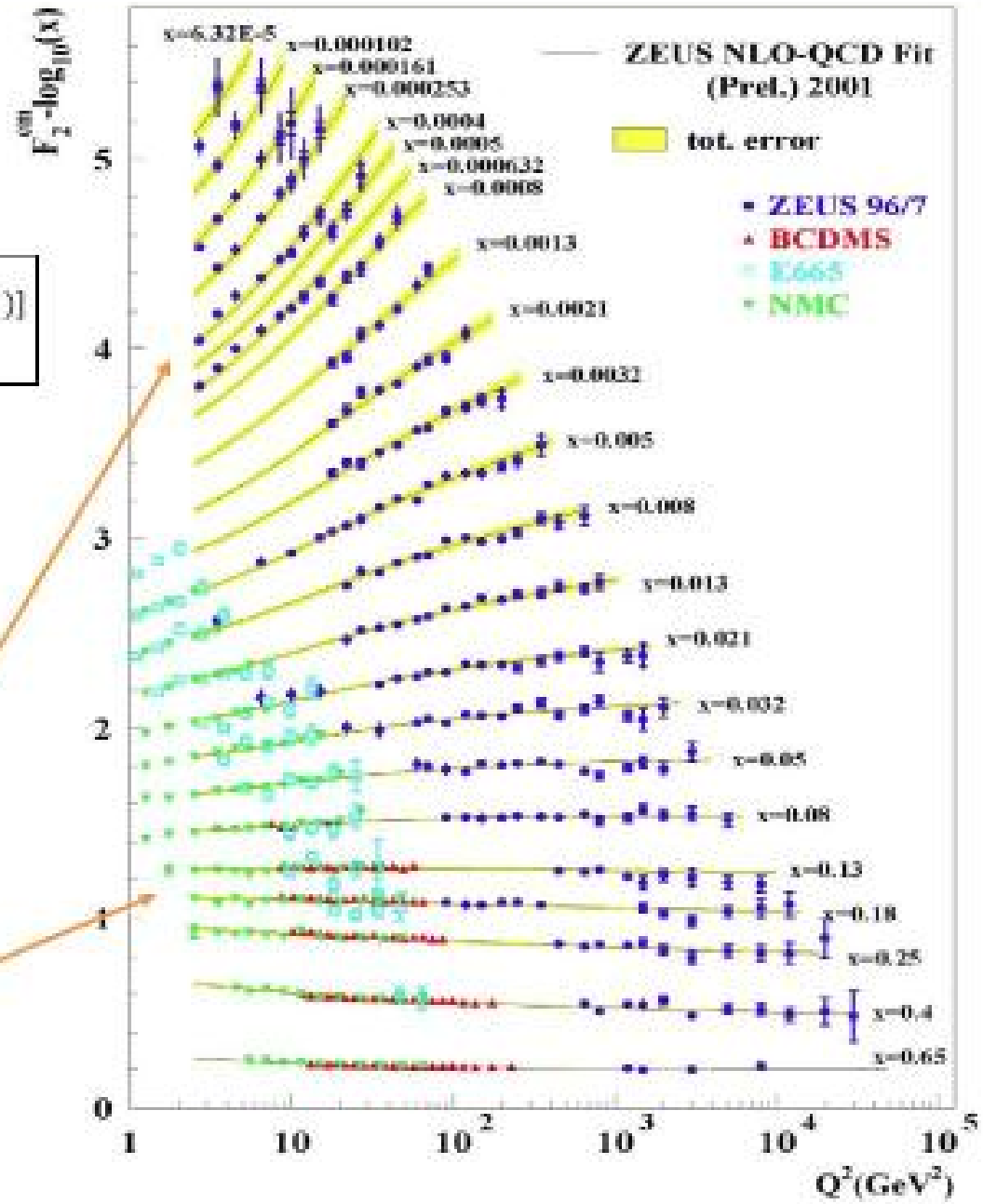
Differential cross-sections:

$$\frac{d^2\sigma(e^\pm)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2) \mp Y_- xF_3(x,Q^2)]$$
$$\text{où } Y_\pm = 1 \pm (1-y)^2$$

The proton structure is well constrained by the HERA data.

Scaling breaks → **gluons**

Flat = "scaling" → **quarks**



Mapping the Proton

World data used
(including ZEUS)

↓

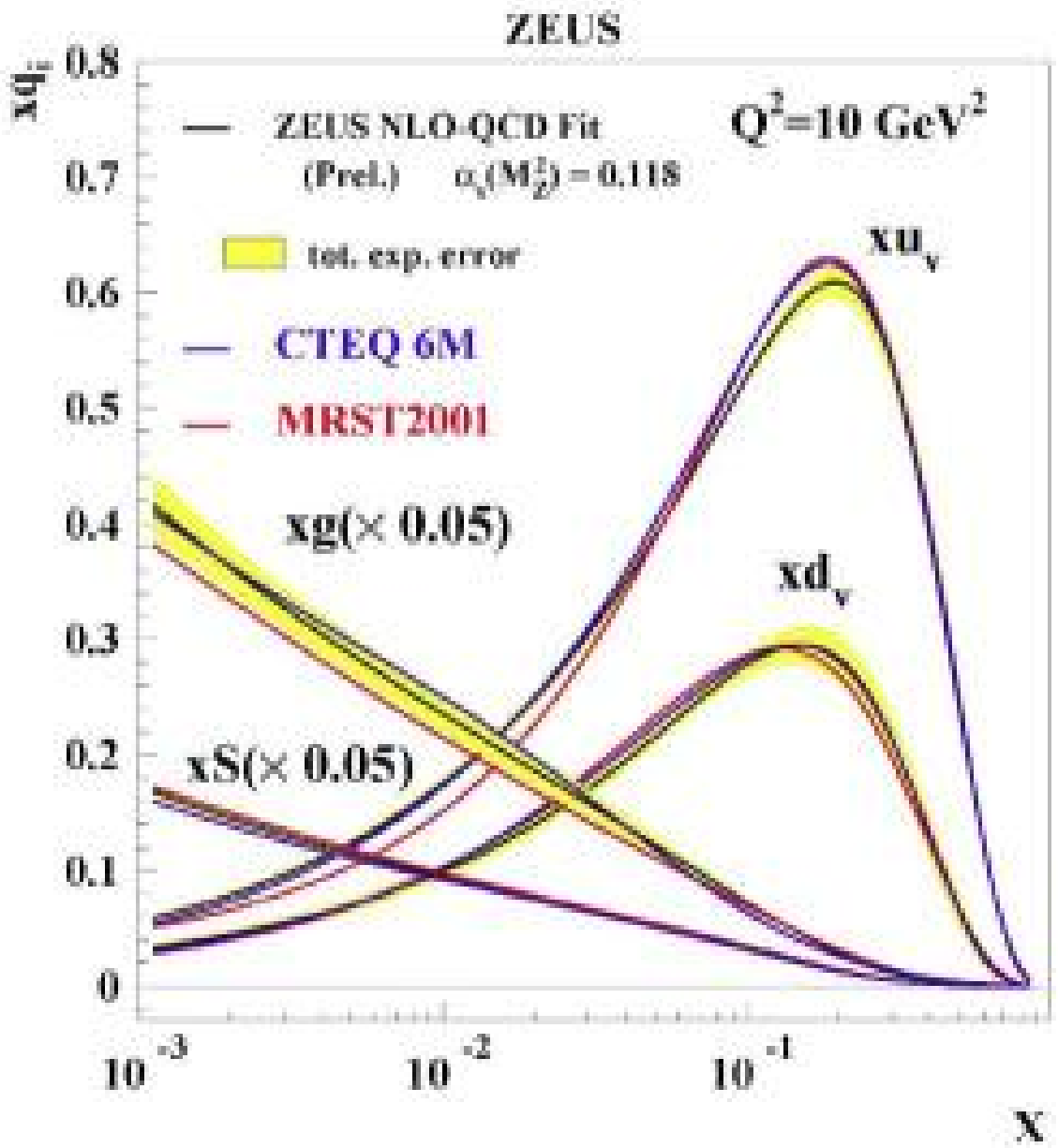
quark & gluon momentum distributions

↓

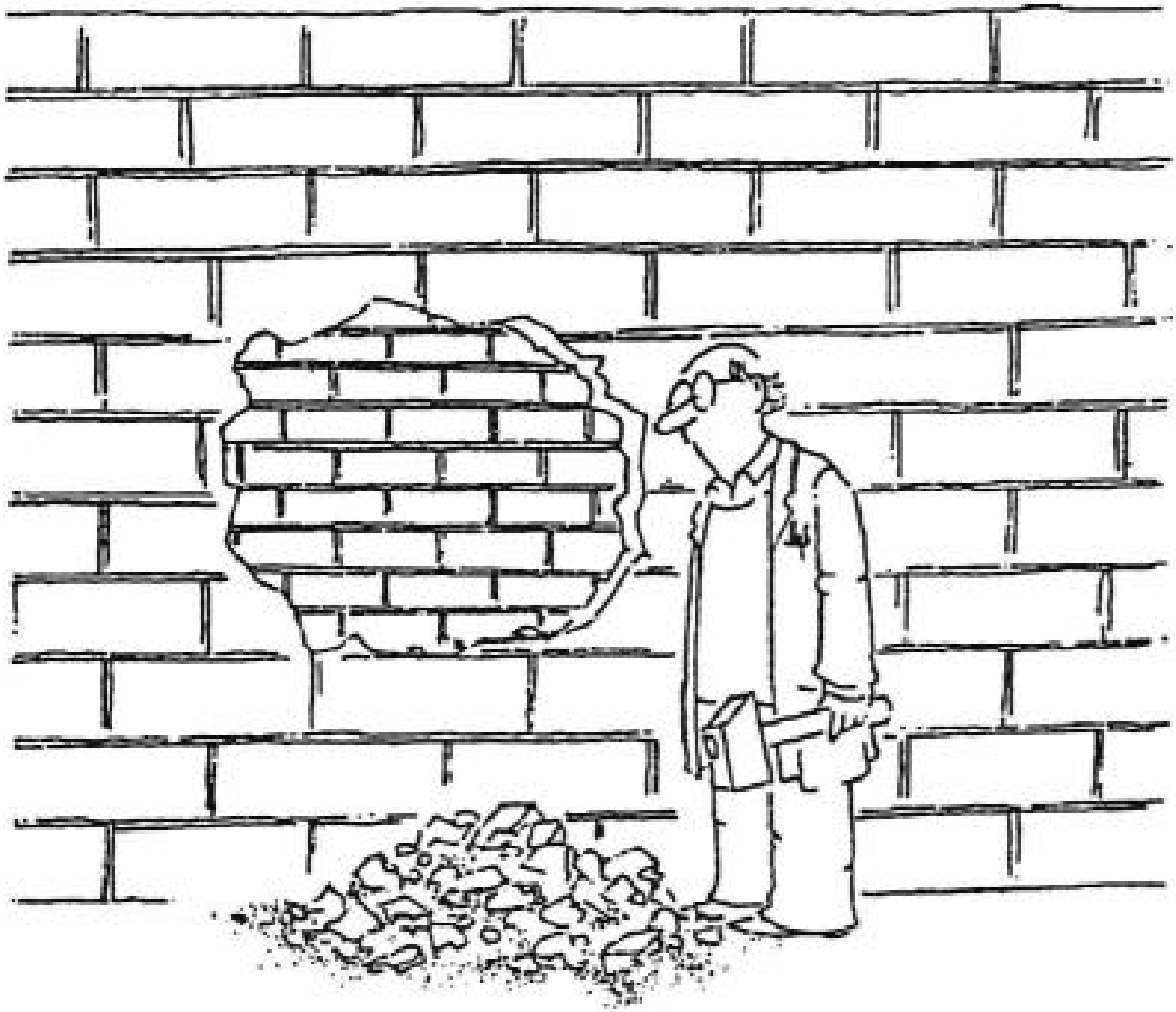
or how the quarks and gluons are distributed in momenta within the proton

↓

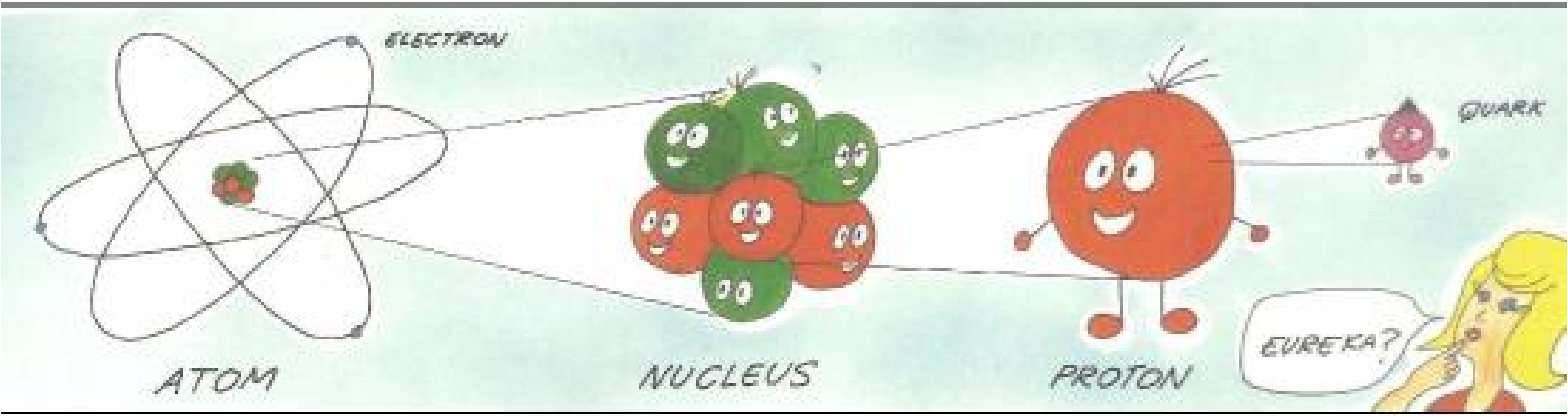
will be much needed by the Large Hadron Collider (LHC)!



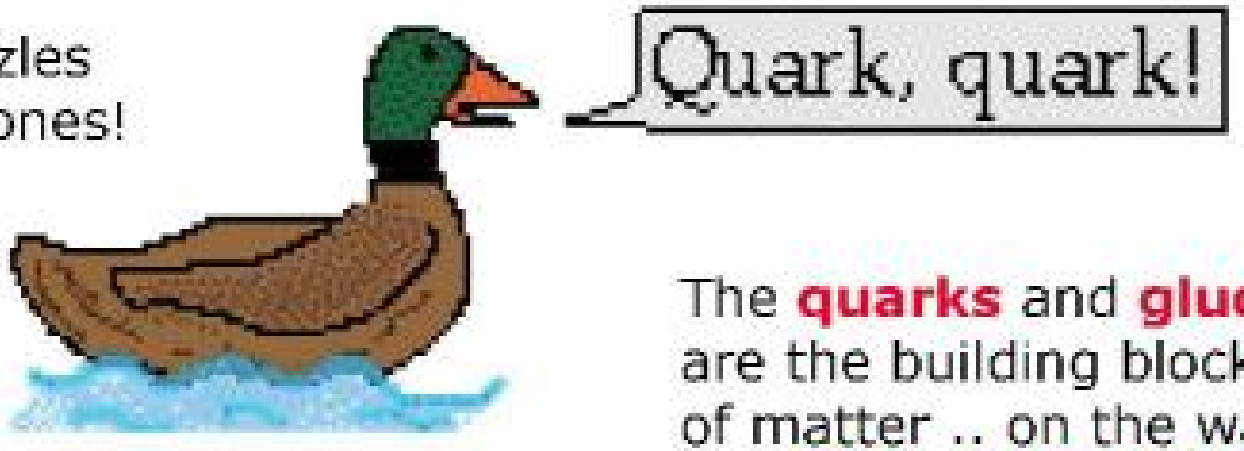
Smaller, Smallest?



Conclusions



Each step of the quest towards the infinitely small has solved puzzles .. and revealed new ones!



The **quarks** and **gluons** are the building blocks of matter .. on the way to a **Grand Unification** of all known forces.

Suggested Web Readings

The Particle Aventure	**http://particleadventure.org/**
Dancing Quarks	**http://quarkdance.org/**
HERA at DESY:	
Into the Heart of Matter	**http://www.desy.de/f/hera/engl/**
The ZEUS Experiment at HERA	**http://www-zeus.desy.de/**