What is a particle?

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Motivation & challenge:

→ explain it to a high school student in 45 min

If a high school student asks physicists what a particle is, he/she might get very different answers, including

a) particle is what we see in the detector

b) a point-like object with mass and various charges

c) an irreducible representation of the Poincare group

d) a (collapsed) wave function

e) a minimum excitation of a quantum field

I discuss strong and weak points of these definitions in an open search for the best approach.

1. a pointlike object with mass and charges (table of elementary particles)

\+
- introduces players
- can compare with periodic table of elements
- mysteries of Standard model
- connection to energy content of the Universe

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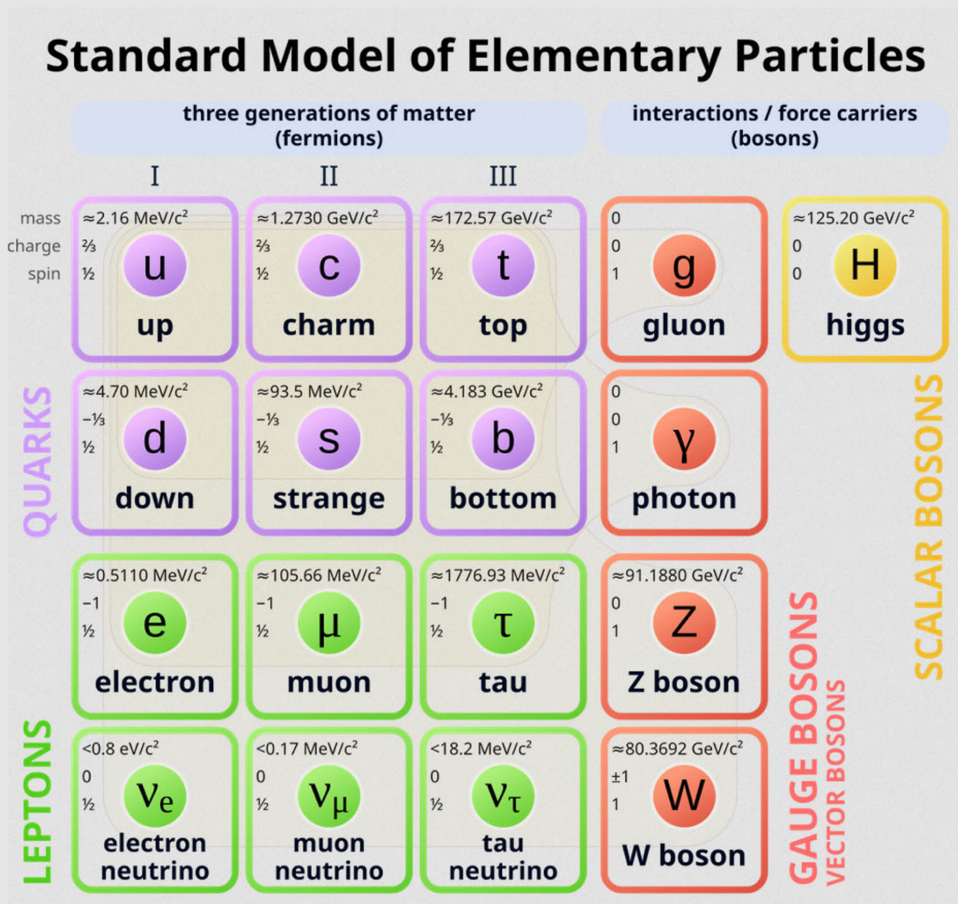
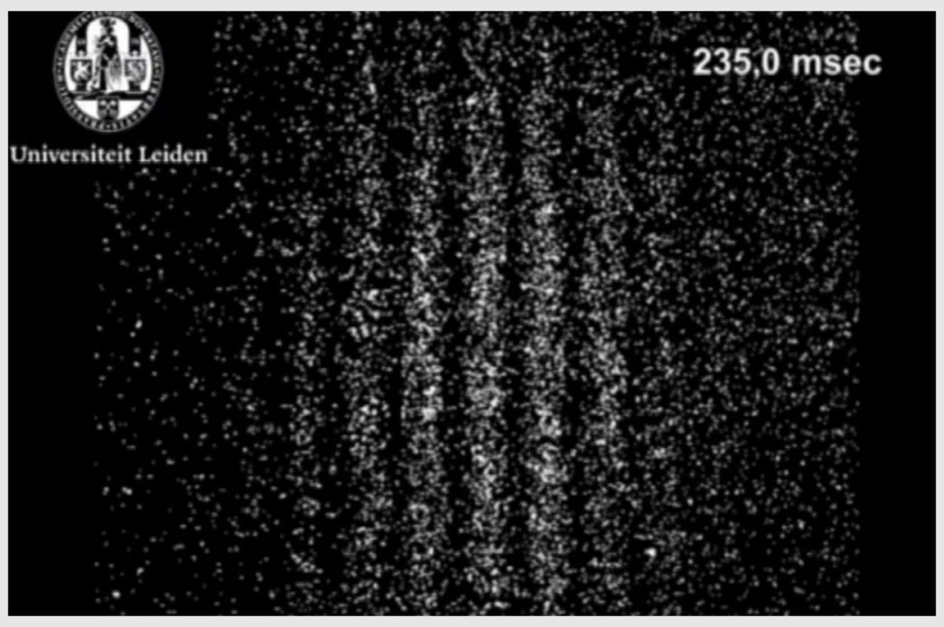
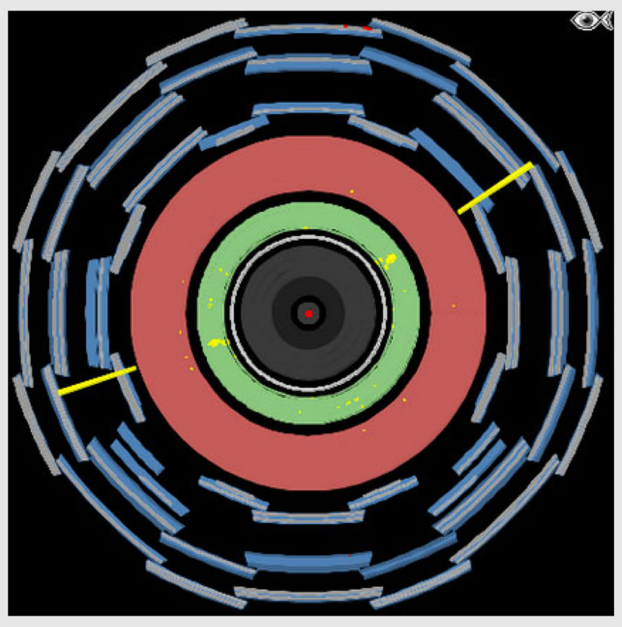
- remains at the surface
- difficulty with spin
- difficulty with many charges
- difficulty with gauge



2. ... it is what we see in the detector



Individual photons recorded by an intensified CCD camera [1]



High energy photons in ATLAS detector [2]

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- straightforward description of reality
- stimulates philosophy: can instruments alone reveal nature of reality?

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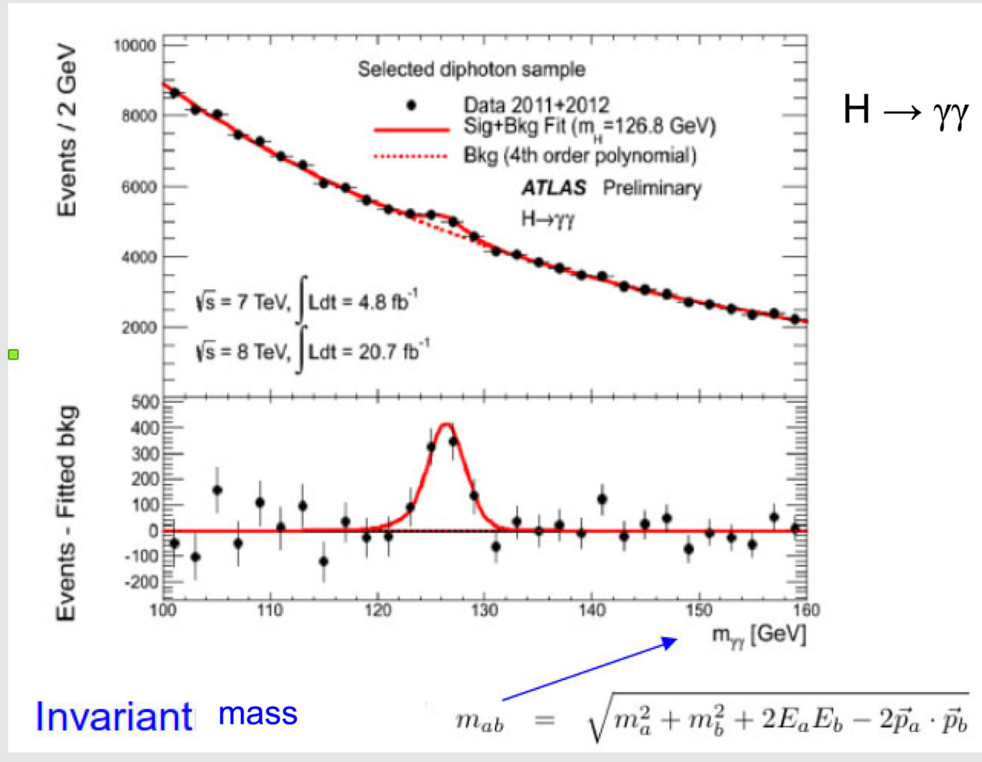
- not the particle we see but the signal it generates
- does not explain things, need of theoretical picture



The way particle physicists see short-lived particles [3]

3. irreducible representation of Poincare group

\+ Precise definiton

− Seems too formal to explain

4. a (collapsed) wave (function)

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- double slit experiment goes to the heart of QM mysteries
- connects to „what we see in the detector“
- goes to the probabilistic nature of QM

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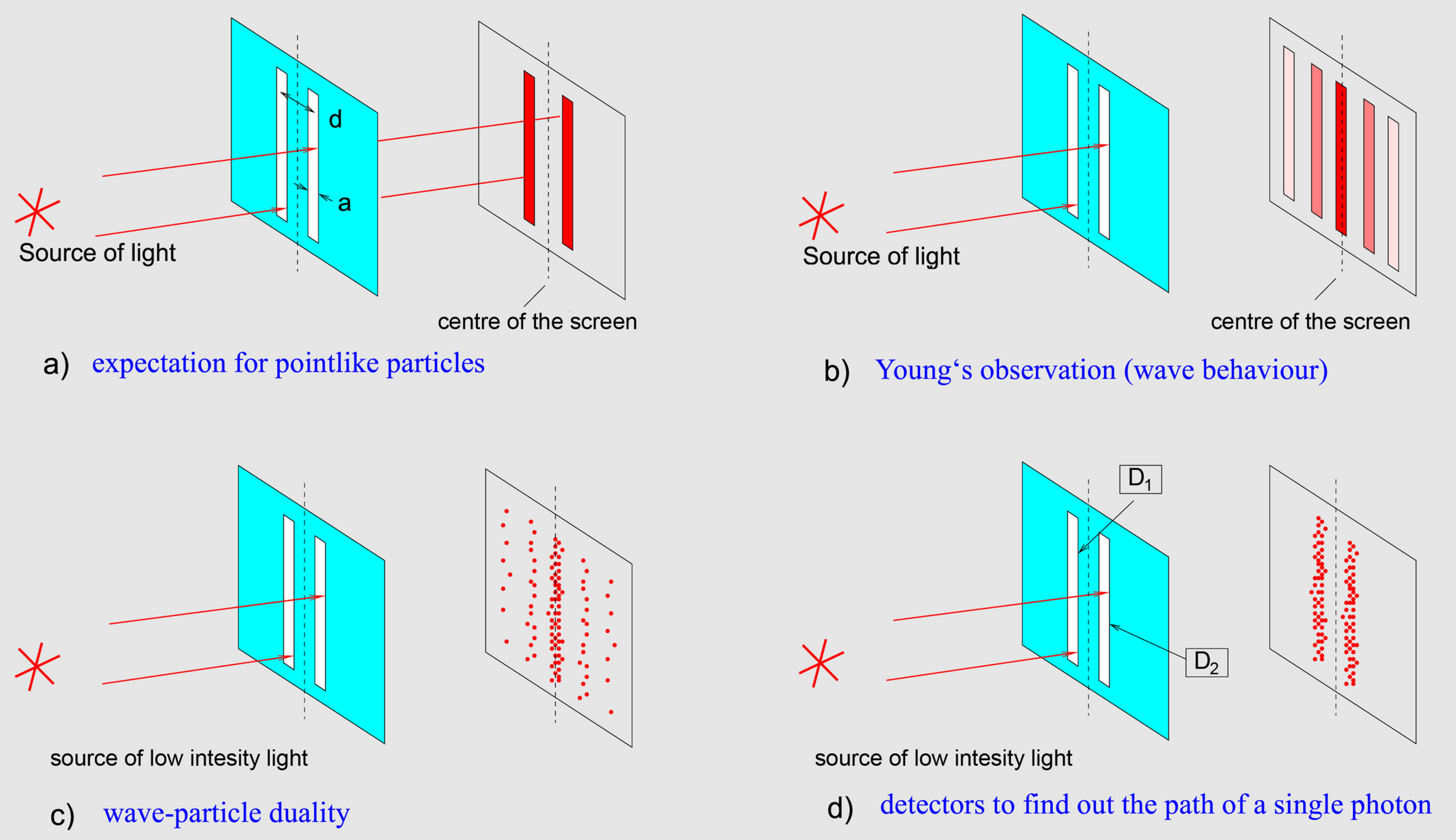
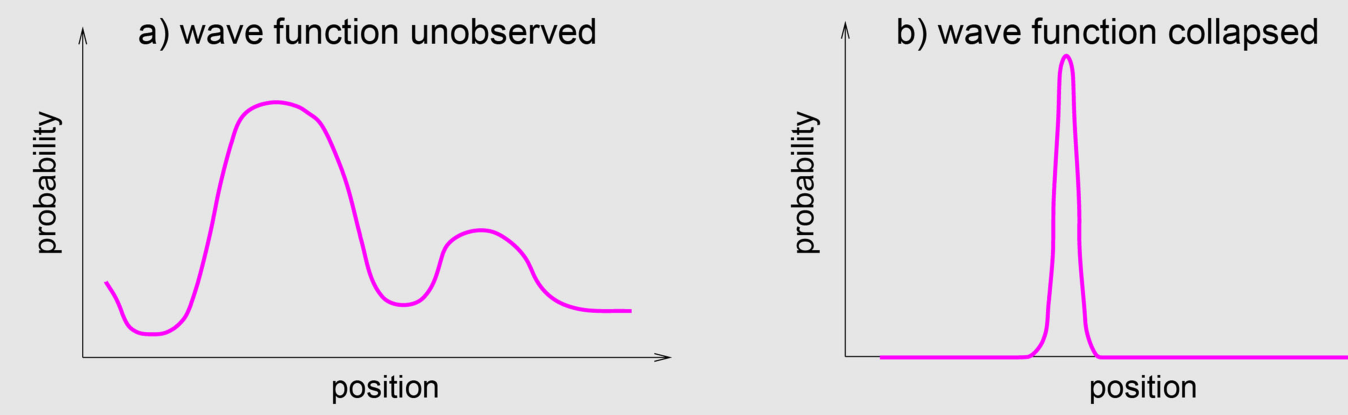
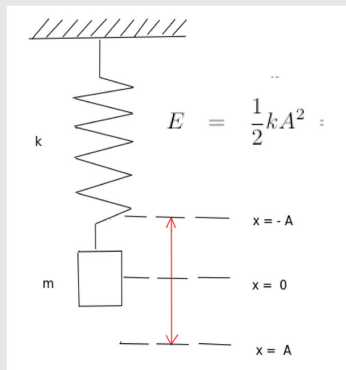


Double slit experiment



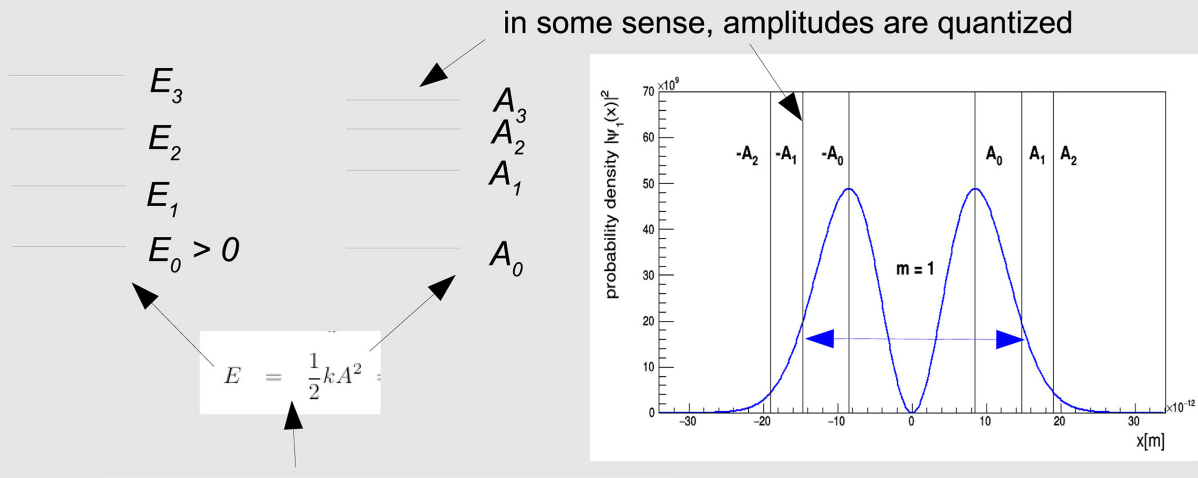
Collapse of the wavefunction

5. a minimum excitation of quantum field (example: photon in a box)



$$E = \frac{1}{2}m\omega^2 x(t)^2 + \frac{1}{2}m\dot{x}(t)^2 = \frac{1}{2}kA^2$$

classical oscillator (HO)



$$E = E_n = \hbar\omega(m + \tfrac{1}{2}), \quad m = 0, 1, 2, 3, \ldots$$

quantum oscillator

electric field (standing wave)

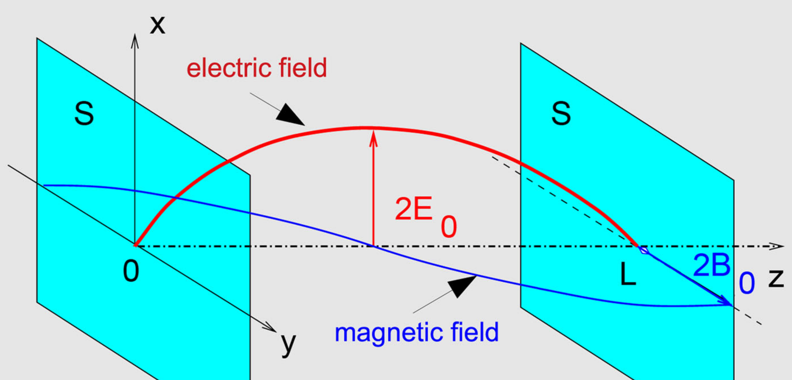
$$\vec{E} = 2E_0\cos\omega t\,\sin kz\,\vec{i} = 2E_0\,q(t)\,\sin kz\,\vec{i}.$$

energy

$$E = \frac{1}{2}M\omega^2 q^2(t) + \frac{1}{2}M\dot{q}^2(t) \qquad M = 2\frac{\epsilon_0 LSE_0^2}{\omega^2}$$

equivalent to classical HO if $q(t) \leftrightarrow x(t)$

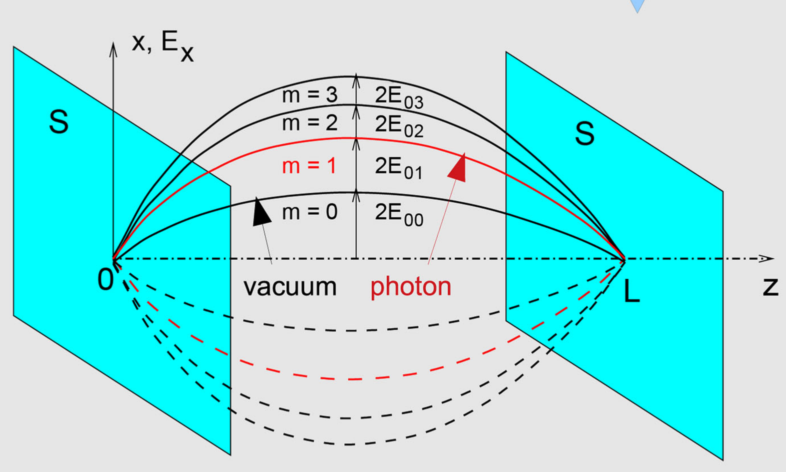
$$E = \frac{1}{2}m\omega^2 x(t)^2 + \frac{1}{2}m\dot{x}(t)^2$$



fundamental mode

standing elmag. wave is formally equivalent to classical HO

quantize like HO



\+
- based on relatively familiar classical oscillator and classical standing wave
- quantization the same as for HO

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- quantization of HO challenging
- translation from x(t) to q(t) and E_x
- only noninteracting photon

photon is quantized electromagnetic wave with minimum amplitude (m = 1 state)

References:

- [1] Leiden University video: https://www.youtube.com/watch?v=MbLzh1Y9POQ
- [2] IPPOG ATLAS Masterclass, https://atlas.physicsmasterclasses.org/en/zpath_lhcphysics3.htm
- [3] ATLAS experiment preliminary analysis of H -> γ γ in 2012.
- [4] Section 5 was partially inspired by Matt Strassler's blog Of particular significance.