Finding particles like at CERN

Lesson idea for a double period (90 min) · physics, age 14–18 · teacher notes

> This lesson idea has not been tested in a classroom yet. Corrections and experience reports are welcome: info@idlecollider.com

WHAT STUDENTS SHOULD TAKE AWAY

- Matter and forces are described by a small set of particles (Standard Model); they differ hugely in mass.
- Energy can become mass ($E = mc^2$): a particle only appears once the collision energy is high enough.
- A detector does not see particles directly. It records tracks and energy deposits in layers, and the pattern identifies the particle.
- A game is a model: students name what is real and what is simplified.

WHAT YOU NEED

- One iPhone per group of two or three with “Idle Collider: Higgs Hunt” installed (free; the first ring is enough, no purchase needed). There is no Android or web version yet.
- Install before the lesson. The opening film (1 min) and the introduction can be skipped; sound and haptics can be switched off in the settings (gear icon).
- The game needs no account and no internet connection and collects no data. The one optional purchase can be blocked with Screen Time on school devices.
- The worksheet (page 2), one per group.

LESSON PLAN

Time	Phase	What happens
10 min	**Start**	Show an event display (from the game or a public ATLAS/CMS image; check the image licence). Question: “What do you see, and how could one tell which particle this was?” Collect guesses.
35 min	**Collect**	Groups play ring 1 and fill in table A. Tapping in time with the beam gives more data; data buys beam energy, and new particles appear as the energy rises. Expect six to nine particles in this time (see page 3).
15 min	**Look closely**	Task B: open a found particle in the codex, look at its recorded event, sketch it and mark tracks and energy deposits. Tapping parts of the picture explains them.
20 min	**Discuss**	Task C in plenary: thresholds and $E = mc^2$, which layer stops which particle, the invisible neutrino.
10 min	**Reality check**	What is real, what is simplified (table on page 3)? Optional homework: who records a W, a Z or a Higgs boson by next week? The accelerator keeps running while the app is closed.

Worksheet: Finding particles like at CERN

Names: _____ Date: _____

You run a particle accelerator. The more energy your beam has, the heavier the particles that can appear in a collision. Your detector records what flies out.

A · COLLECT (ABOUT 35 MINUTES)

Play and upgrade your accelerator. For every new particle: open the codex (book icon), tap the particle and fill in a row.

Particle	Symbol	Mass	Appears from (beam energy)	Rarity tier

B · LOOK CLOSELY

Open one of your particles in the codex and look at a recorded event (tap parts of the picture for explanations). Sketch it here. Mark: (1) a curved track, (2) an energy deposit in a calorimeter, (3) the collision point.

Our particle: _____

C · THINK

1. The electron has a mass of 0.511 MeV, but it only appears from 1.022 MeV. Why? Check your idea with the muon.

2. Sort your particles by mass. How many electrons weigh as much as one proton?

3. The photon leaves no track in the inner detector, the electron does. What is the difference between the two?

4. Which particles get all the way to the outermost layer of the detector? What happens to the others?

5. Sometimes the display reports “missing energy”. Where could energy have gone that the detector does not see?

Answer key and notes

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THE 13 PARTICLES OF RING 1

Particle	Symbol	Mass	Appears from	First find after about	Fact shown in the game
Photon	γ	0	–	at once	Massless and always moving at the speed of light. Carries the electromagnetic force.
Electron	e^-	511.0 keV	1.022 MeV	at once	Created in pairs with its antiparticle, the positron. This takes at least 1.022 MeV.
Pion	π	139.6 MeV	139.6 MeV	12 min	The lightest hadron, a quark–antiquark pair. Mediates the force between protons and neutrons in the nucleus.
Muon	μ	105.7 MeV	211.3 MeV	15 min	A heavy electron, created in pairs with the antimuon. Lives only 2.2 microseconds – and still reaches the ground thanks to time dilation.
Kaon	K	493.7 MeV	493.7 MeV	19 min	Contains a strange quark. In 1964 kaons showed that matter and antimatter are not exact mirror images.
Proton	p	938.3 MeV	938.3 MeV	21 min	Three quarks bound by gluons. Over 99% of its mass is binding energy, not quark mass.
J/ψ meson	J/ψ	3.097 GeV	3.097 GeV	27 min	Discovered at two laboratories at once in 1974 – the “November Revolution” that proved the existence of the charm quark.
Tau	τ	1.777 GeV	3.554 GeV	29 min	The heaviest lepton, almost twice as heavy as a proton, created in pairs with the antitau. Decays after about 0.3 trillionths of a second.
B meson	B	5.279 GeV	5.279 GeV	31 min	Contains a bottom quark. It is used to study why the universe contains more matter than antimatter.
W boson	W	80.36 GeV	80.36 GeV	73 min	Carries the weak force and makes radioactive beta decay possible. Discovered at CERN in 1983.
Z boson	Z	91.19 GeV	91.19 GeV	80 min	The neutral sibling of the W. Its decay width shows there are exactly three light neutrino types.
Higgs boson	H	125.1 GeV	125.1 GeV	2.5 h	At the real LHC it appears about once per billion collisions – far more often here. Its field gives other particles their mass.
Top quark	t	172.6 GeV	172.6 GeV	2.3 h	About as heavy as a gold atom. Decays before it can bind – the only “bare” quark.

“First find” is the simulated median of active playing time for a casual player (taps on half of the beam crossings); practised groups are roughly twice as fast. W, Z, Higgs and top are out of reach in one lesson.

REAL, SIMPLIFIED, INVENTED

Real	Names, symbols and masses of the 13 particles in ring 1 (Particle Data Group values). The principle of the event display: curved tracks of charged particles in a magnetic field, energy deposits in calorimeters, muons in the outer chambers, missing energy from neutrinos. Pair creation thresholds for electron, muon and tau.
Simplified	How often particles appear: at the real LHC a Higgs boson is produced about once per billion collisions, in the game far more often. The LHC collides protons at a fixed energy of several TeV; the game lets the energy grow from below 1 MeV so that thresholds become visible. Tapping “in time” stands for the trigger, which really decides automatically.
Invented	Rings 3 to 7 (around a continent, the Earth, the Moon’s orbit, the Sun, the heliosphere) are fiction; ring 2, the FCC, is a real plan. The 13 particles from ring 2 onwards are hypothetical and labelled as such in the game. Neither is needed for this lesson.

Answers to the worksheet

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C · THINK

1. Electrons are created in pairs with their antiparticle, the positron. The energy must cover two masses: 2 × 0.511 MeV = 1.022 MeV ($E = mc^2$). Muon: 2 × 105.7 MeV = 211.3 MeV. The tau follows the same rule (2 × 1.777 GeV = 3.554 GeV).
2. 938.27 MeV ÷ 0.511 MeV ≈ 1836 electrons. For comparison: a Higgs boson (125.1 GeV) weighs as much as about 133 protons.
3. Charge. The tracking detector only sees charged particles, which ionise its material; their tracks bend in the magnetic field. The neutral photon first shows up when it deposits its energy in the electromagnetic calorimeter.
4. Muons. Electrons and photons are stopped in the electromagnetic calorimeter, hadrons such as pions, kaons and protons in the hadronic calorimeter. Muons pass through both and are measured again in the muon chambers outside.
5. Neutrinos, for example from the decay of a W boson, leave the detector without a trace. One notices them because the momenta of the visible particles do not add up to zero across the beam direction.

POSSIBLE EXTENSIONS

- Resonance: J/ψ and Z can be “tuned in” by lowering the beam energy to their mass. Why does a particle appear more often at exactly this energy?
- Statistics: every recorded event has a significance in σ. What does “5 σ” mean for a discovery?
- Scale: the LHC ring is 26.7 km long. How long does a proton at nearly the speed of light need for one lap, and how many laps is that per second? (about 89 µs, about 11,000 laps)