International Particle Physics Masterclass with the Belle II Experiment

THE UNIVERSITY of MISSISSIPPI

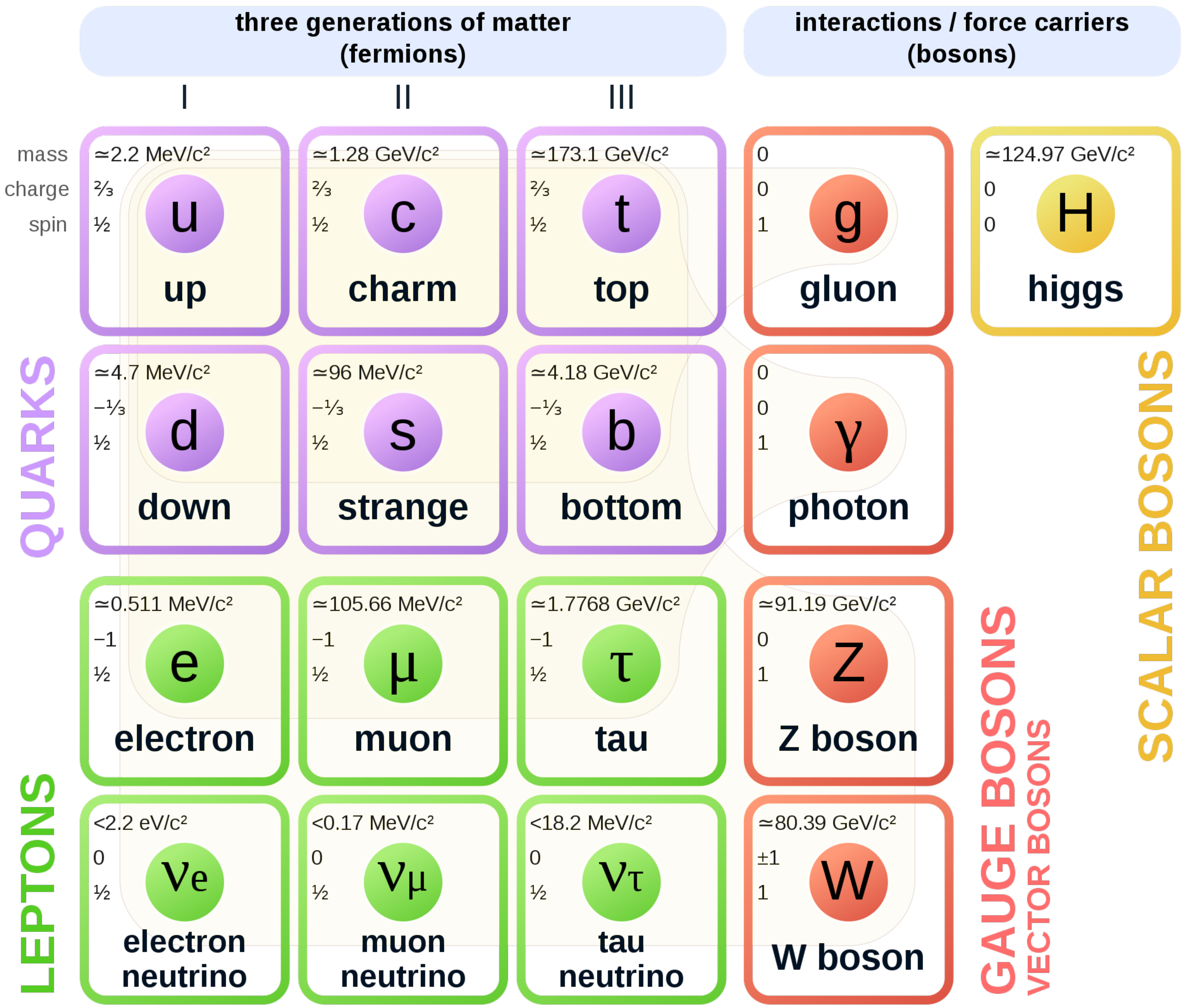
QuarkNet

INTERNATIONAL MASTERCLASSES

hands on particle physics

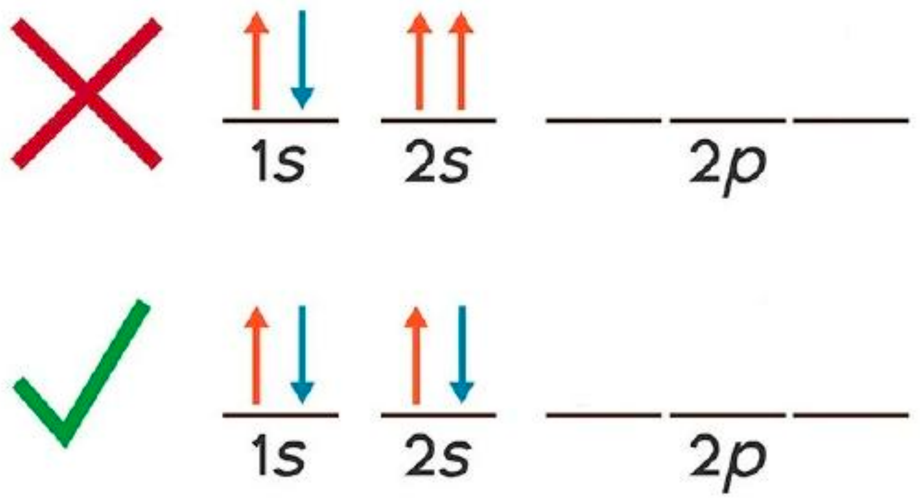
Belle II

Standard Model of Elementary Particles



- The Standard Model of particle physics includes:
  - Six quarks and six antiquarks
  - Six leptons and six antileptons
  - "Gauge bosons" that mediate the strong, weak, and electromagnetic forces
  - Higgs boson
- Matter is made up of different combinations of quarks and leptons
  - Proton = uud
  - Neutron = udd
  - Hydrogen = proton+neutron+electron

Properties of quarks



$$\Delta^{++}(u\uparrow u\uparrow u\uparrow)$$

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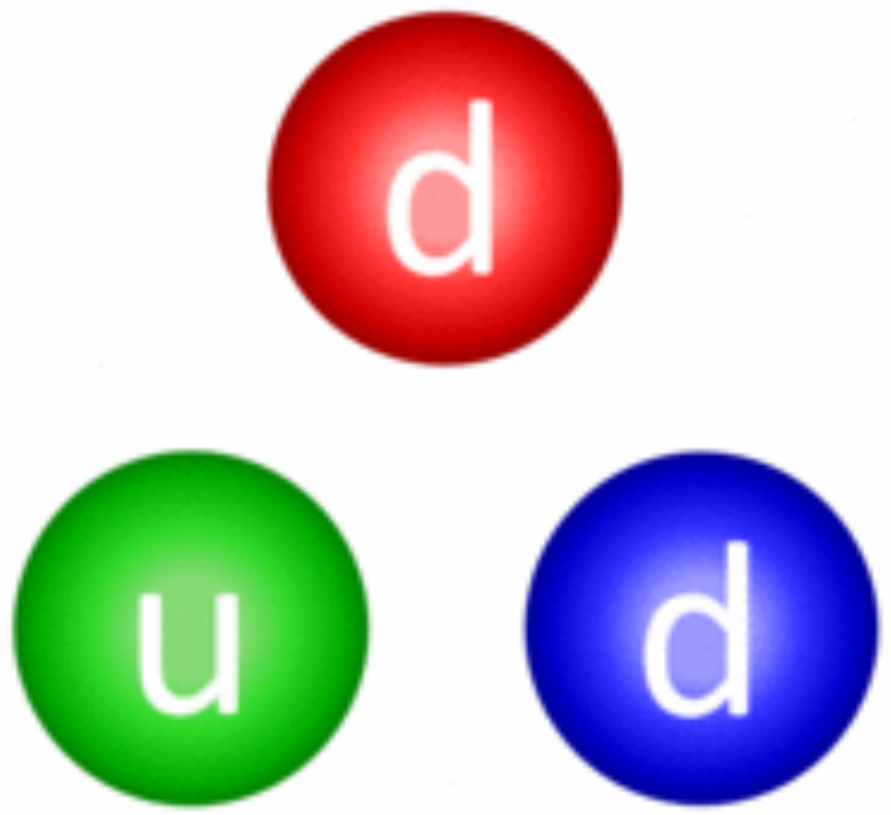
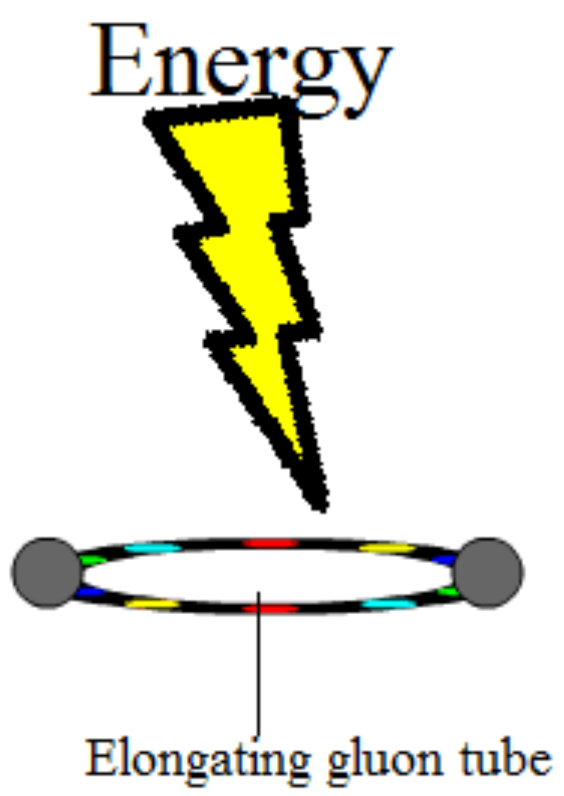
- Problem: the quark model appears to violate Pauli's exclusion principle, which states that identical fermions (spin 1/2 particles) cannot occupy the same state (e.g. atomic orbitals)
  - Δ^{++} must contain three up-type quarks in an identical state!

- Solution by Greenberg (1964): quarks have an additional property that contributes to their wave function - color
  - Not actually color as we know it, but a property of the quarks, like a charge
  - Mediator of the interaction is the gluon, which also carries color!

- Quarks are confined to colorless hadrons





Let's measure the number of quark colors

- For every additional quark color, the probability to create a quark increases

Fine structure constant

Quark colors

Quark charges

The probability to create a quark pair ($e^+e^- \rightarrow q\bar{q}$): $\sigma_{total} = N_c \frac{4\pi\alpha^2 q^2}{3s}$

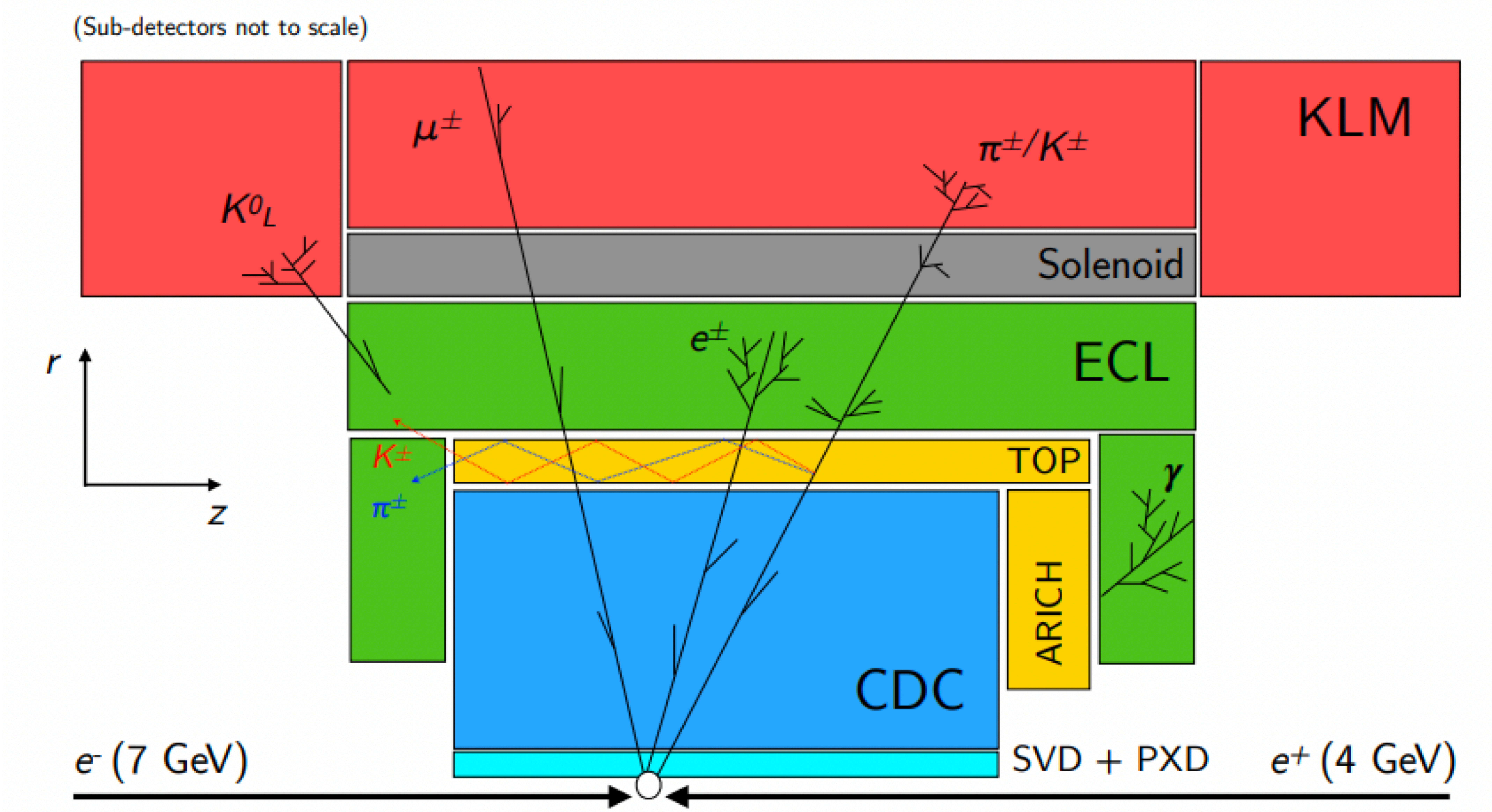
Energy of beams

The probability to create a muon pair ($e^+e^- \rightarrow \mu^+\mu^-$): $\sigma_{total} = \frac{4\pi\alpha^2}{3s}$

The ratio depends only on the number and charge of quarks!

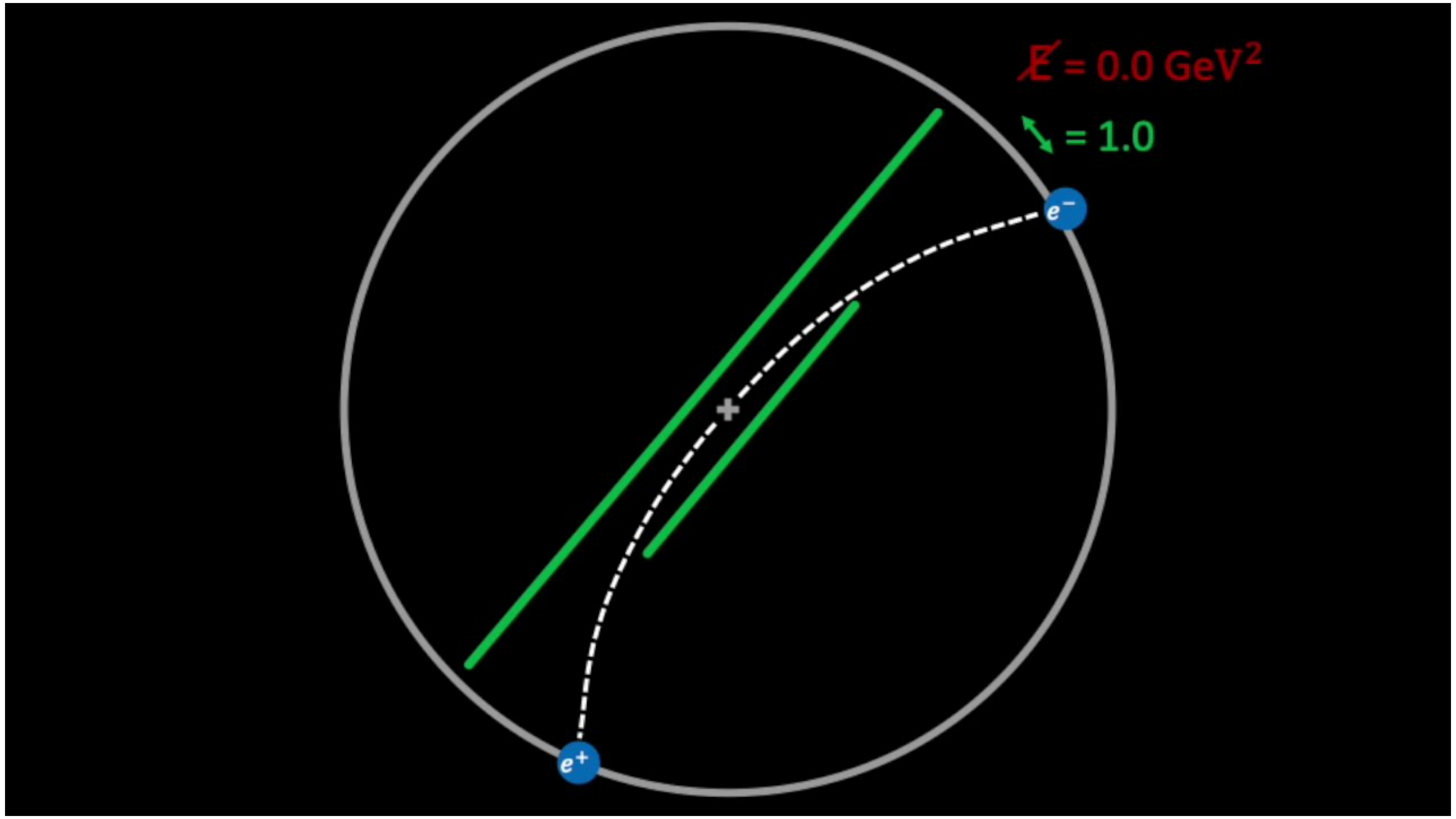
$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} = N_c \sum_i q_i^2$$

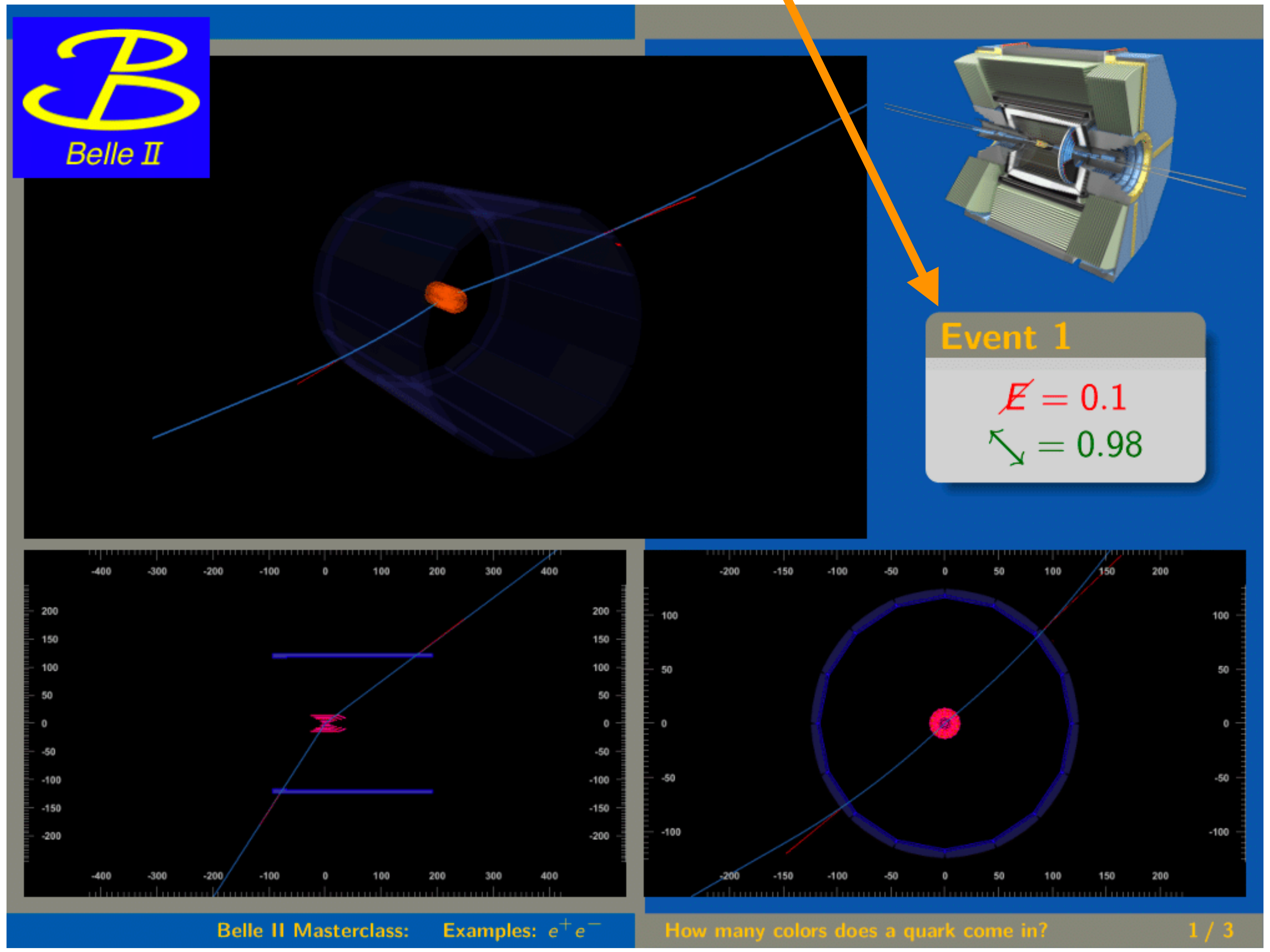
Classifying events



Electron/positron events

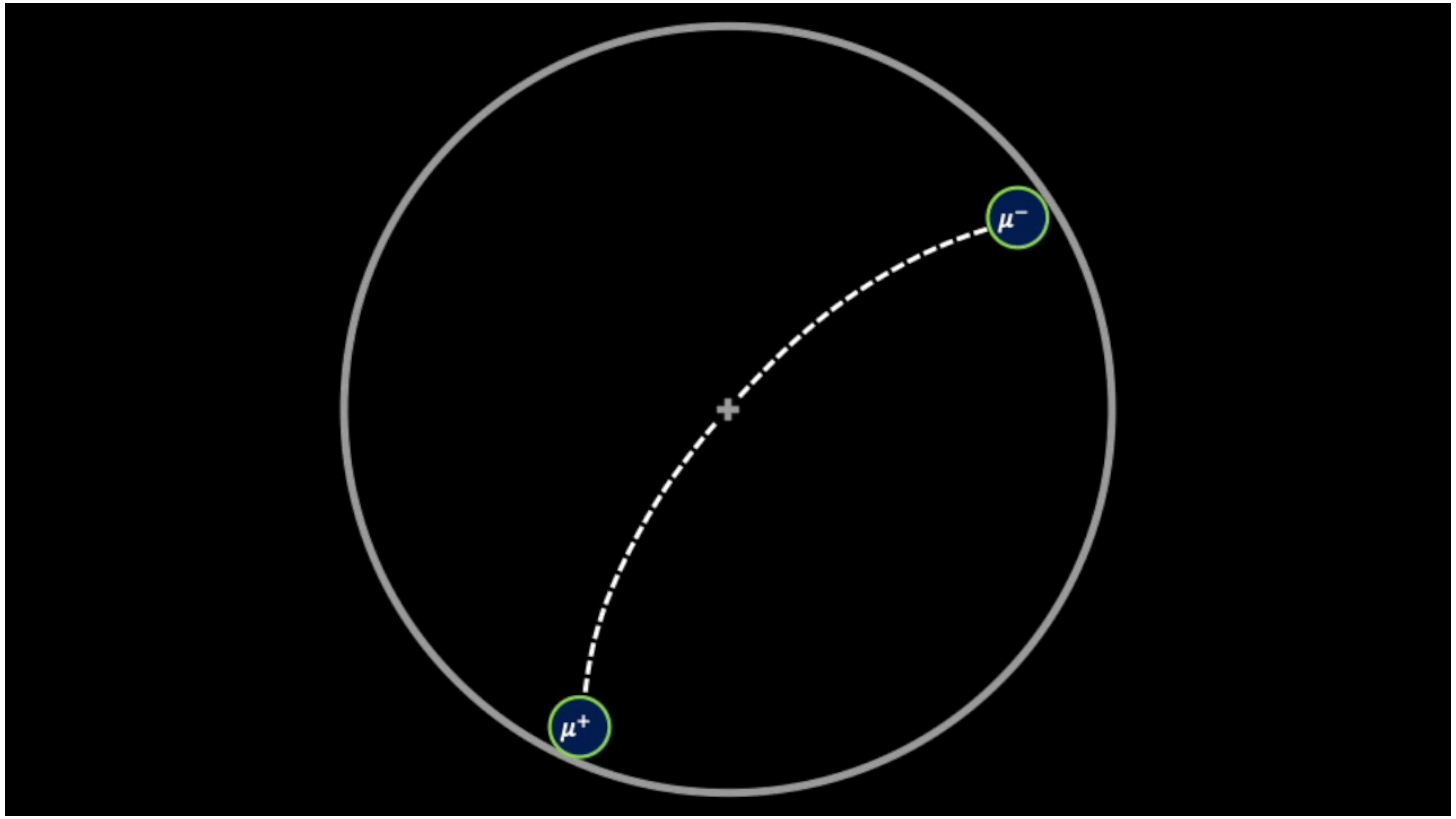
- (almost) always exactly two tracks that are clearly visible in the detector
- (almost) always fully captured by inner detector components
- do not decay in the detector, so very little missing energy and high straightness

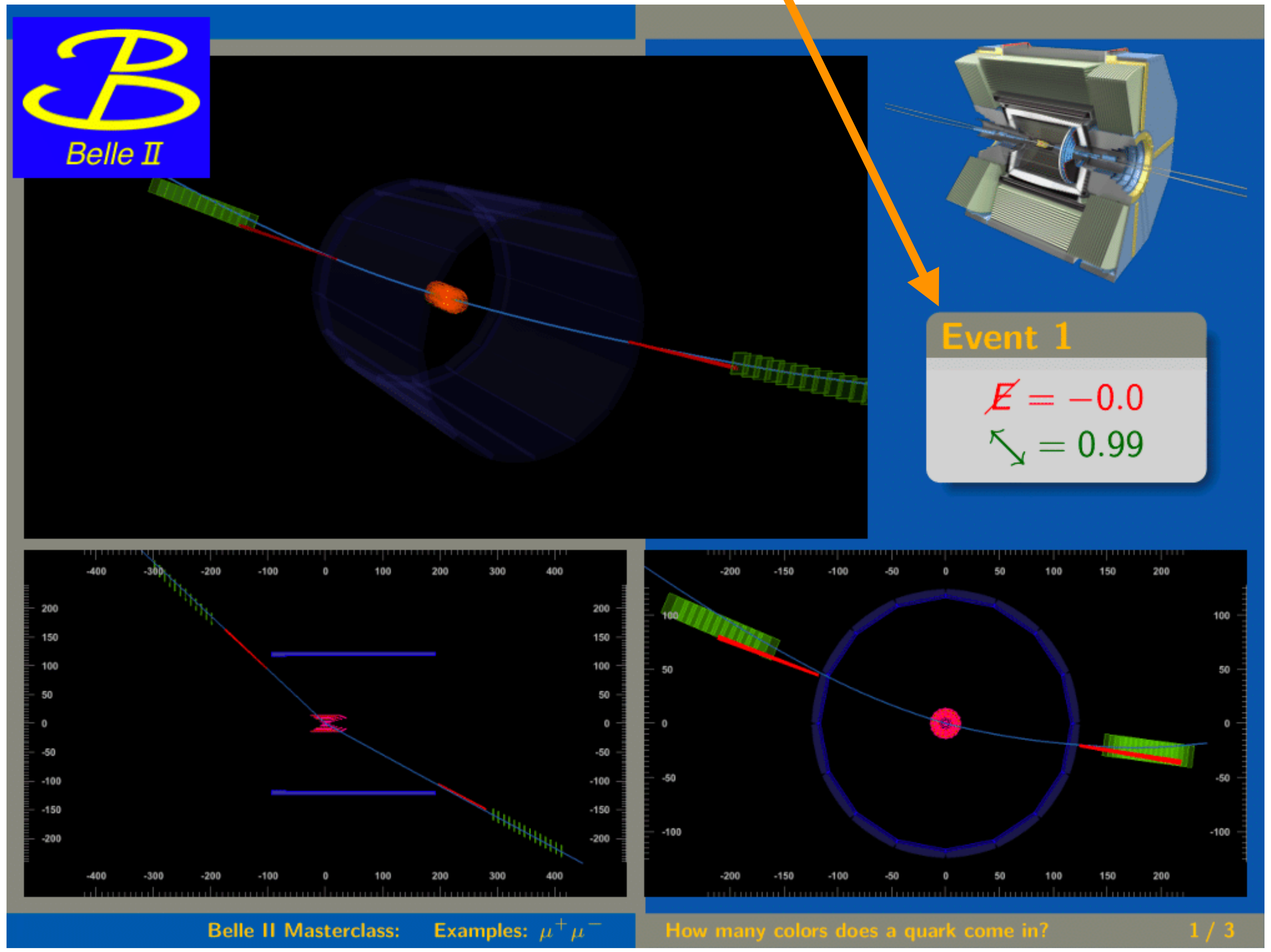




Muon/antimuon events

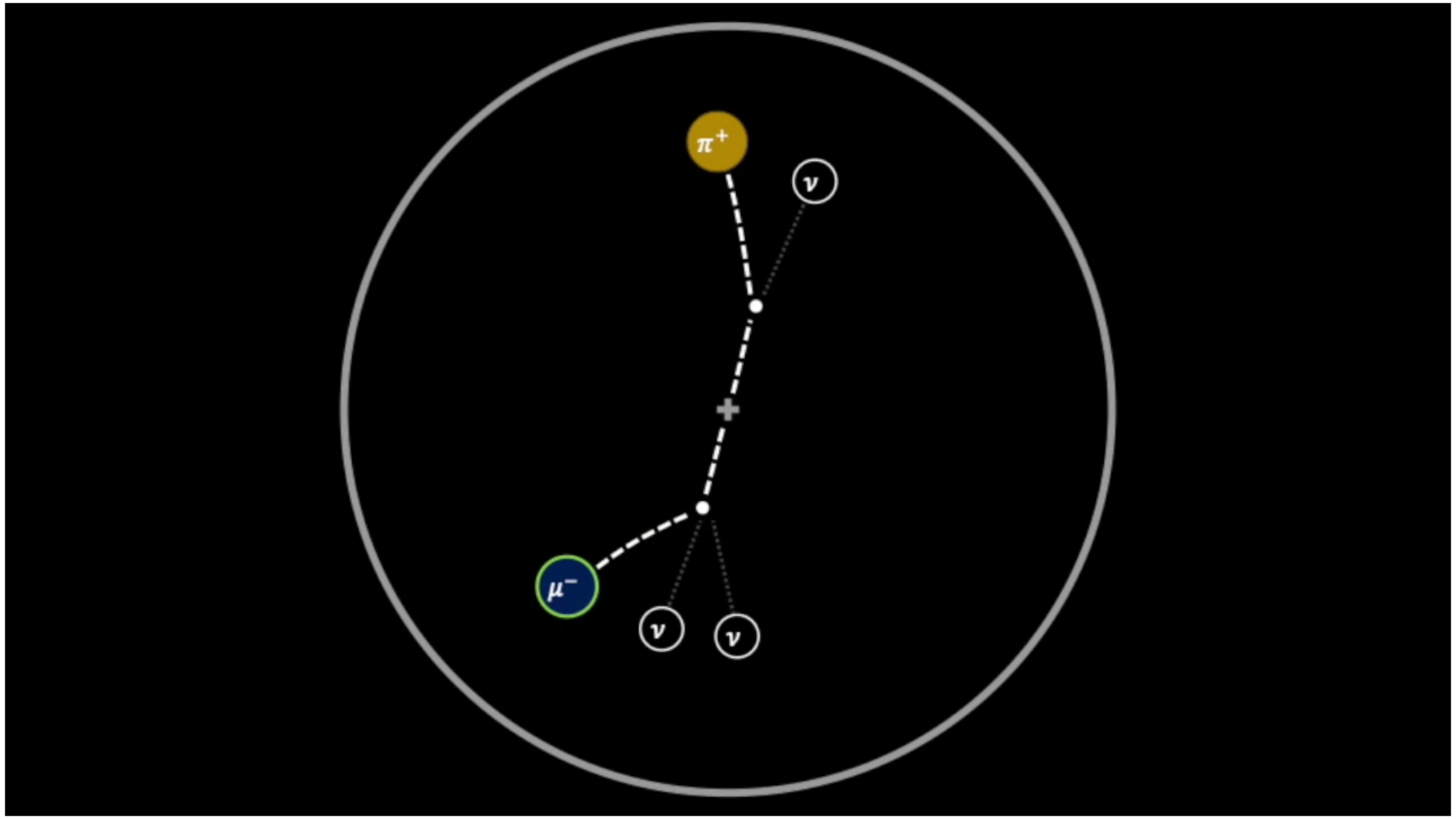
- (almost) always exactly two tracks that are clearly visible in the detector
- (almost) <u>never</u> fully captured by inner detector components - detected in KLM
- do not decay in the detector, so very little missing energy and high straightness

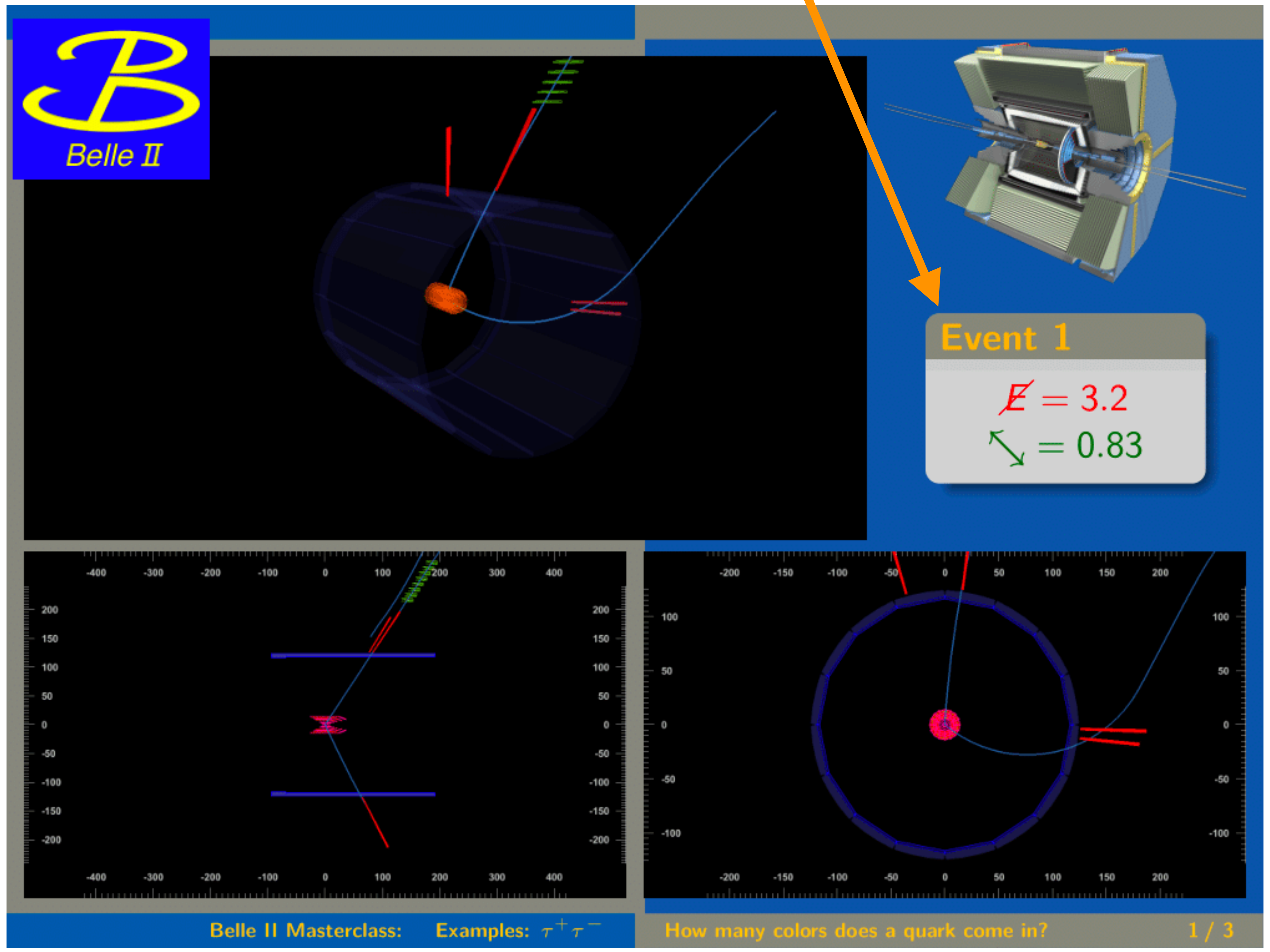




Tauon/antitauon events

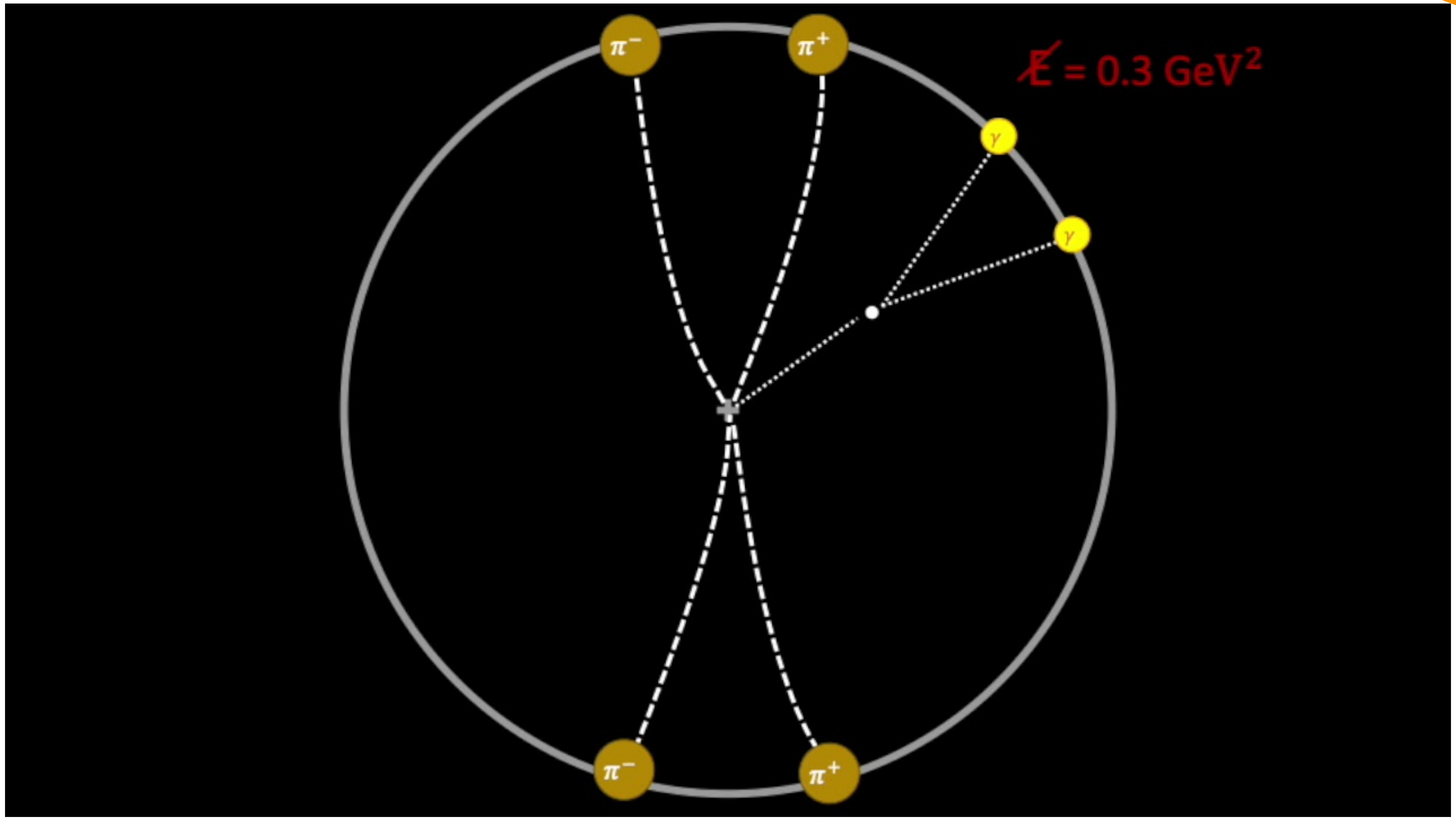
- decay very quickly into (usually) two or three tracks (often one track vs. three tracks)
- usually includes at least one muon track
- decay products include neutrinos, which are not detected, leading to lots of missing energy

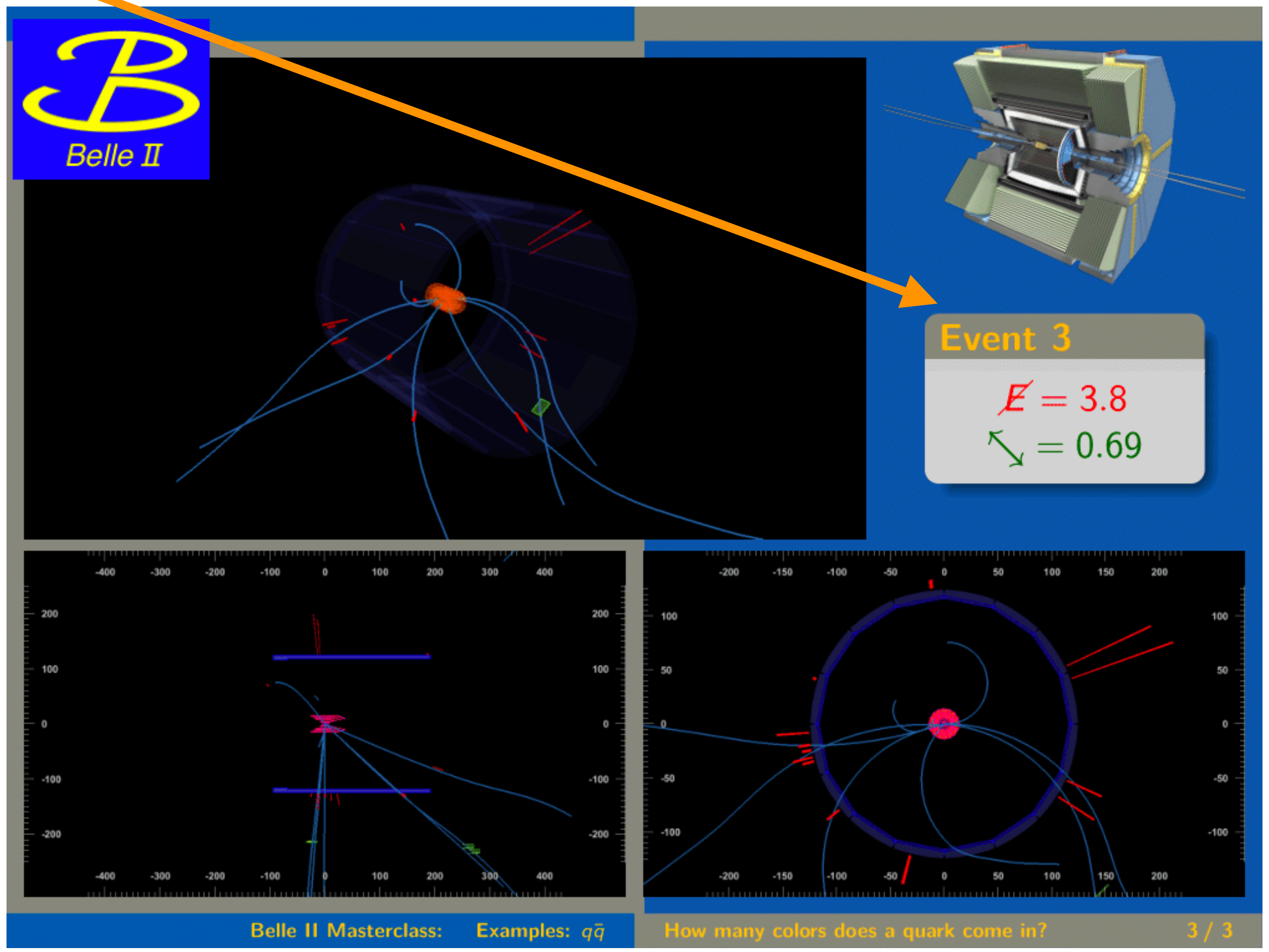




light quark/antiquark events

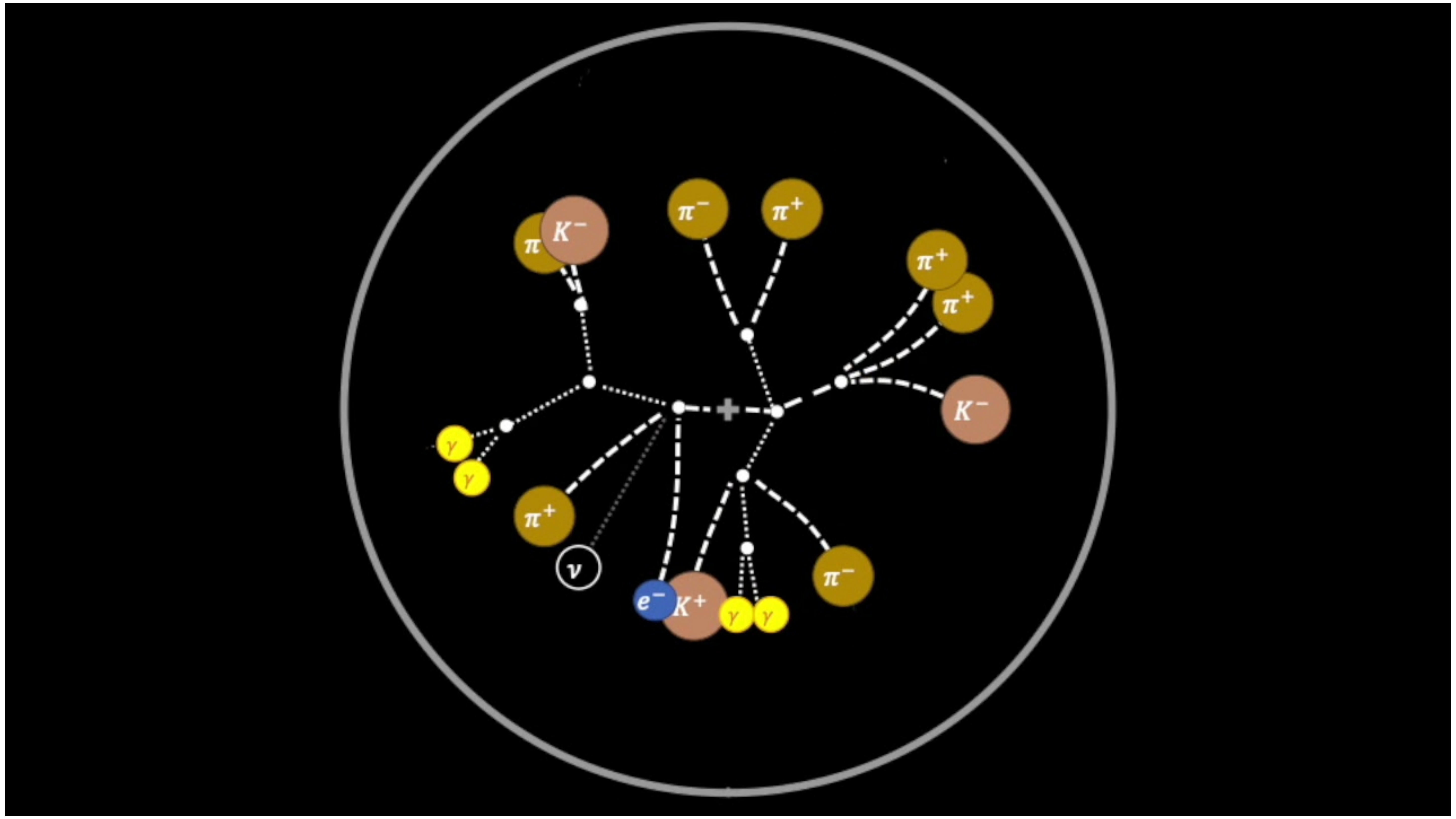
- many possible final states! (usually not one track vs. three tracks)
- fewer neutrinos so not much missing energy
- usually less straight than tau/antitau events

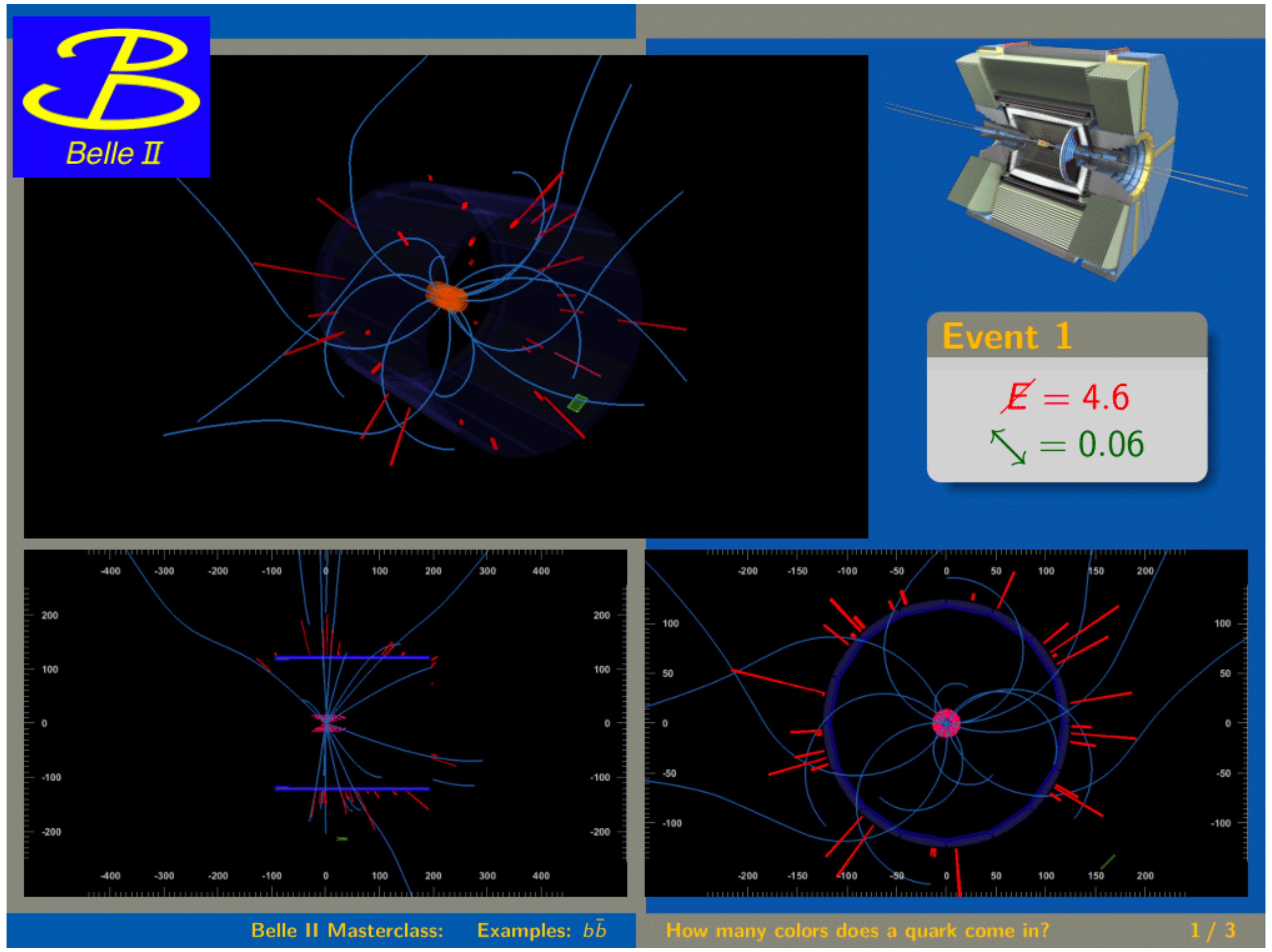




b/anti-b events

- decay very quickly into (usually) many tracks
- relatively low straightness because $\Upsilon(4S) \rightarrow B\bar{B}$ and no “extra” particles
- can decay to neutrinos, so possibly high missing energy





Now it's your turn to be the scientist!

- Navigate to https://belle2.ijs.si/public (it's already open in the browser at your station!)
  - Look through the practice events and use this chart to help make a decision
  - When you are ready, move to the main task