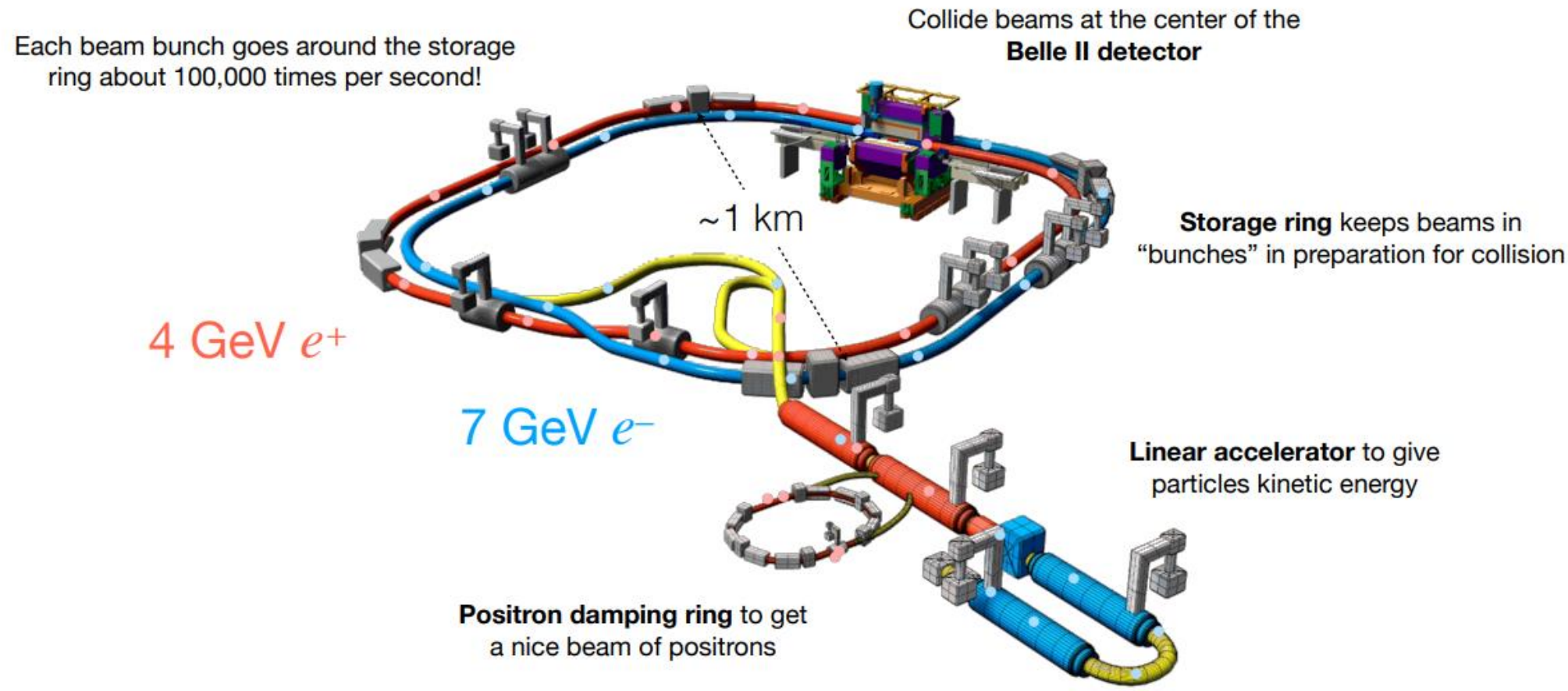
Analyzing Quark Colors in Belle II

Based on slides by Jake Bennett, University of Mississippi

Adapted by Kenneth Cecire, University of Notre Dame

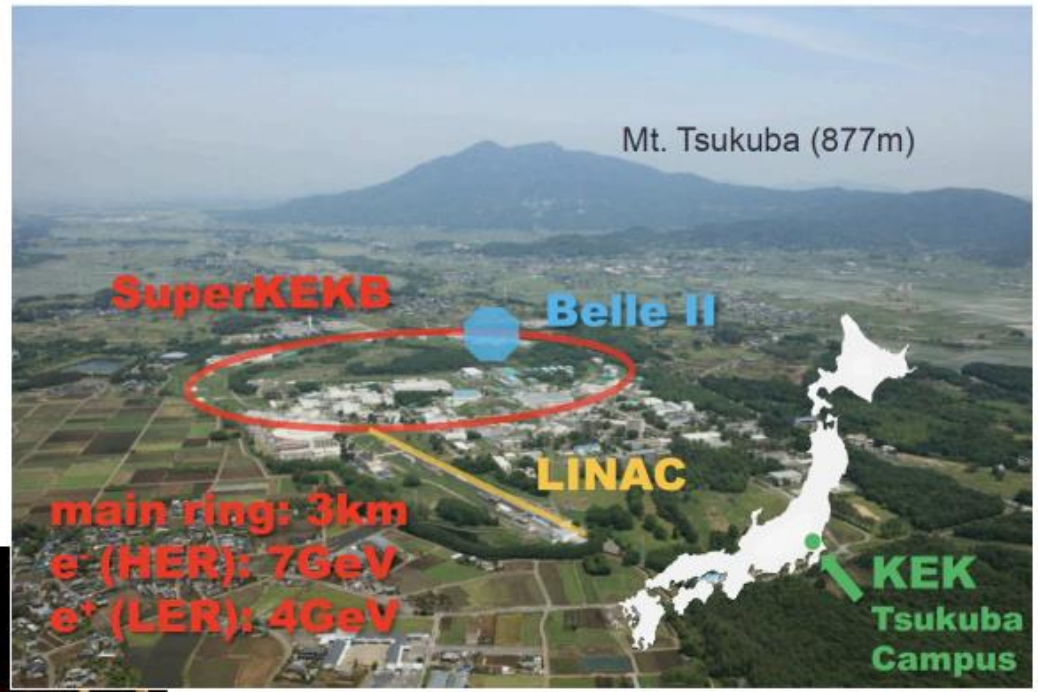
Super KEK-B and Belle II



The Belle II experiment in Tsukuba, Japan

Current Japanese era:
Reiwa
("beautiful harmony")
began on 1 May 2019,
following the Heisei era
("Achieving Peace")

令和



~1 hour train ride north of Tokyo
(shuto - "chief major city")

Pronounced "Nihon"
or "Nippon"

日本

Actually made up of about
14,000 islands!

さしみ　すし

Sashimi
(no rice!)

Sushi (includes
vinegared rice)

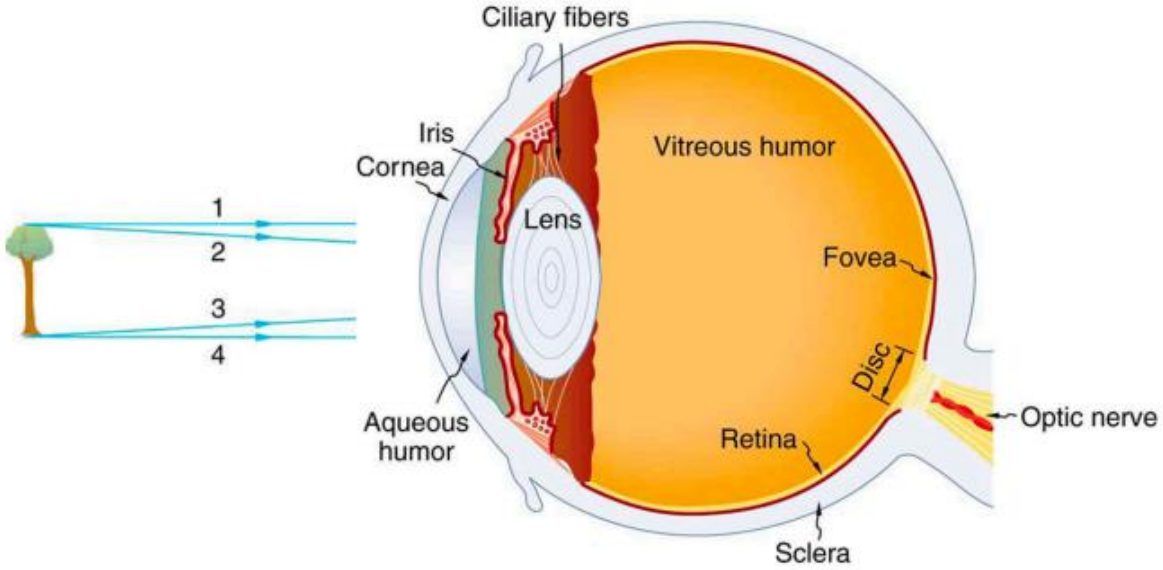
はし

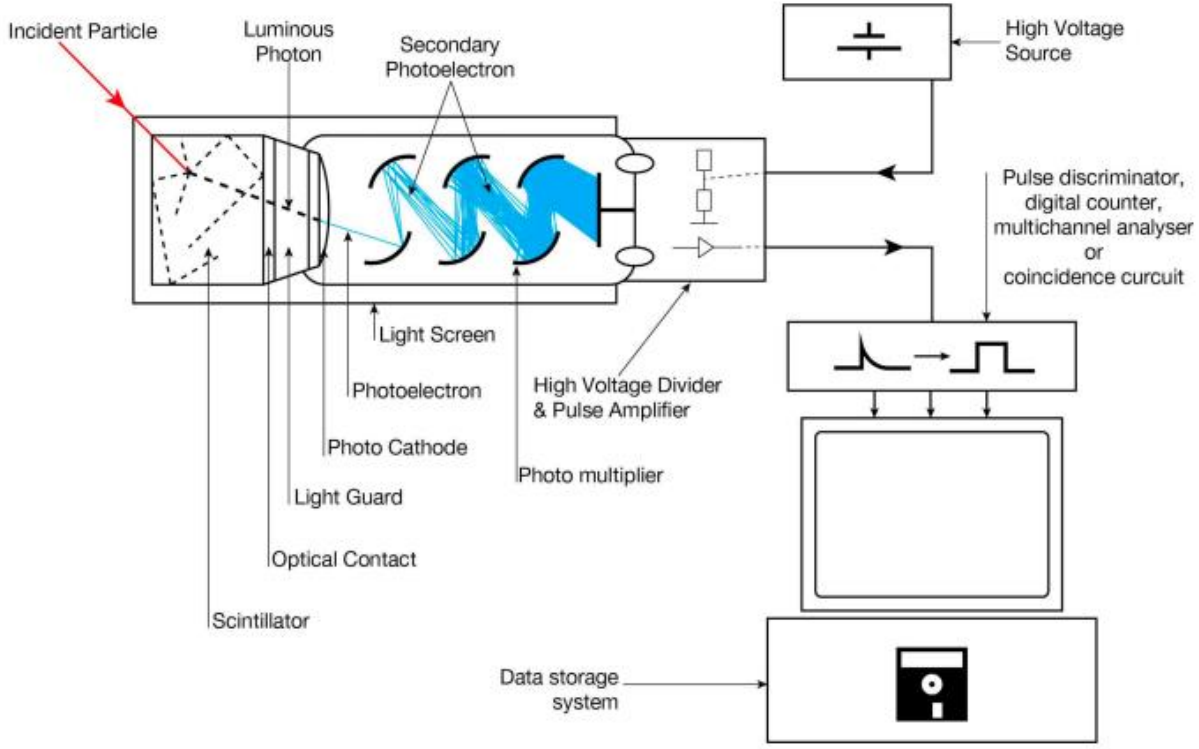
Hashi
(chopsticks)

Japan's Emperor Naruhito ascends
throne in traditional ceremony as he
becomes country's 126th emperor
(October 2019)

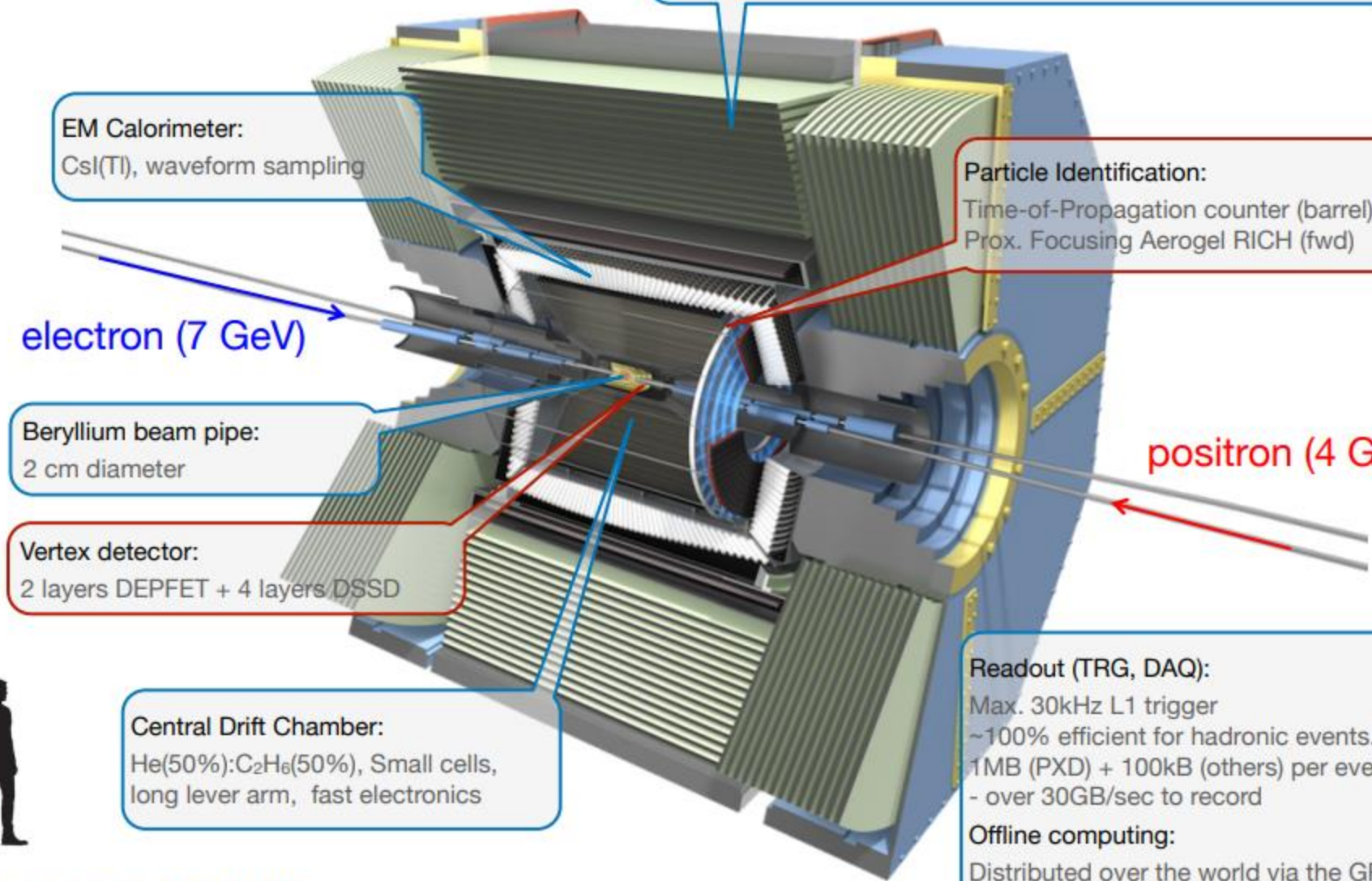
… but first, a simple(?) question: how are you observing these words?

Two ways to “see” light





The Belle II detector



K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling

Particle Identification:
Time-of-Propagation counter (barrel)
Prox. Focusing Aerogel RICH (fwd)

electron (7 GeV)

positron (4 GeV)

Beryllium beam pipe:
2 cm diameter

Vertex detector:
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber:
He(50%):C_2H_6(50%), Small cells,
long lever arm, fast electronics

Readout (TRG, DAQ):
Max. 30kHz L1 trigger
~100% efficient for hadronic events.
1MB (PXD) + 100kB (others) per event
- over 30GB/sec to record

Offline computing:
Distributed over the world via the GRID

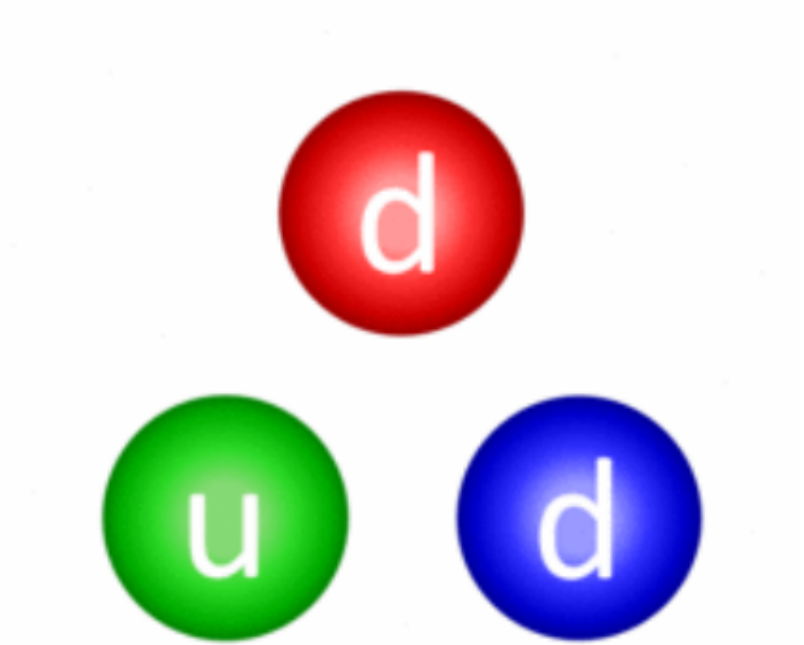
First new particle collider since the LHC
(intensity rather than energy frontier; e^+e^- rather than pp)

arXiv:1011.0352 [physics.ins-det]

Data Analysis!

Let's measure the number of quark colors

- Remember, they are not actually red, blue, or green… the "color" is a property that distinguishes quarks just like electric charge distinguishes electrons from positrons



A little math first…

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

The probability to create a quark pair ($e^+e^- \rightarrow q\bar{q}$):

$$\sigma_{total} = N_c \frac{4\pi\alpha^2 q^2}{3s}$$

Quark colors

Fine structure constant

Quark charges

Energy of beams

If there is more than one kind of quark, then we add one term like the right-hand term above for each kind:

$$\sigma_{total} = N_c \frac{4\pi\alpha^2 q_1^2}{3s} + N_c \frac{4\pi\alpha^2 q_2^2}{3s} + N_c \frac{4\pi\alpha^2 q_3^2}{3s} + \ldots = N_c \frac{4\pi\alpha^2}{3s} \sum_i q_i^2$$

A little math second…

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

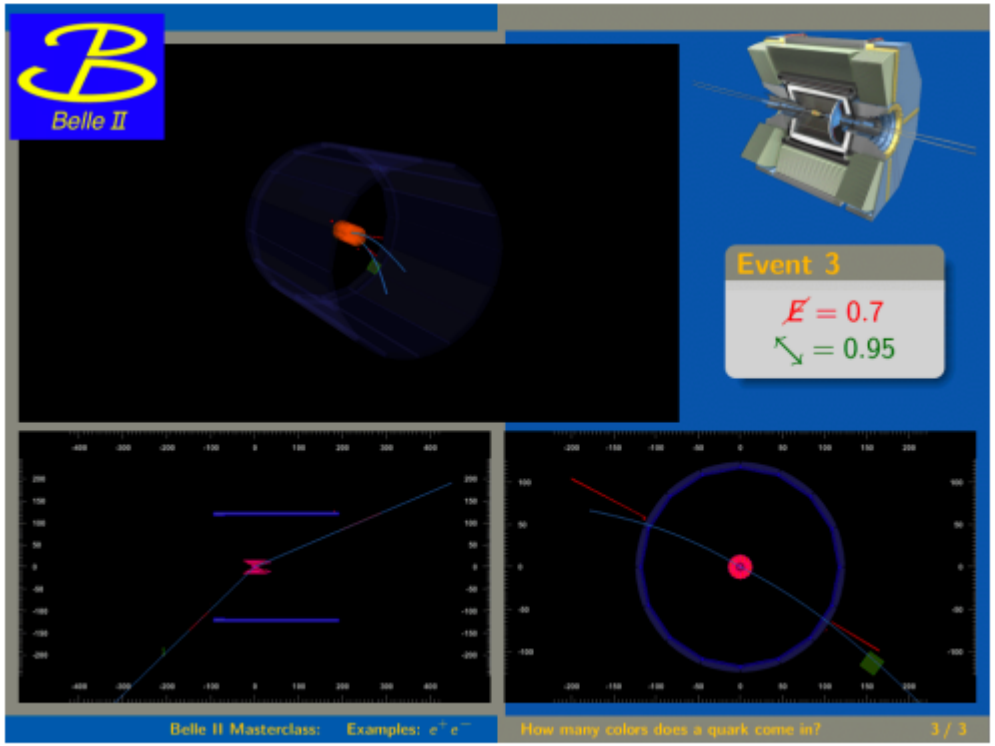
The ratio depends only on the number and charge of quarks!

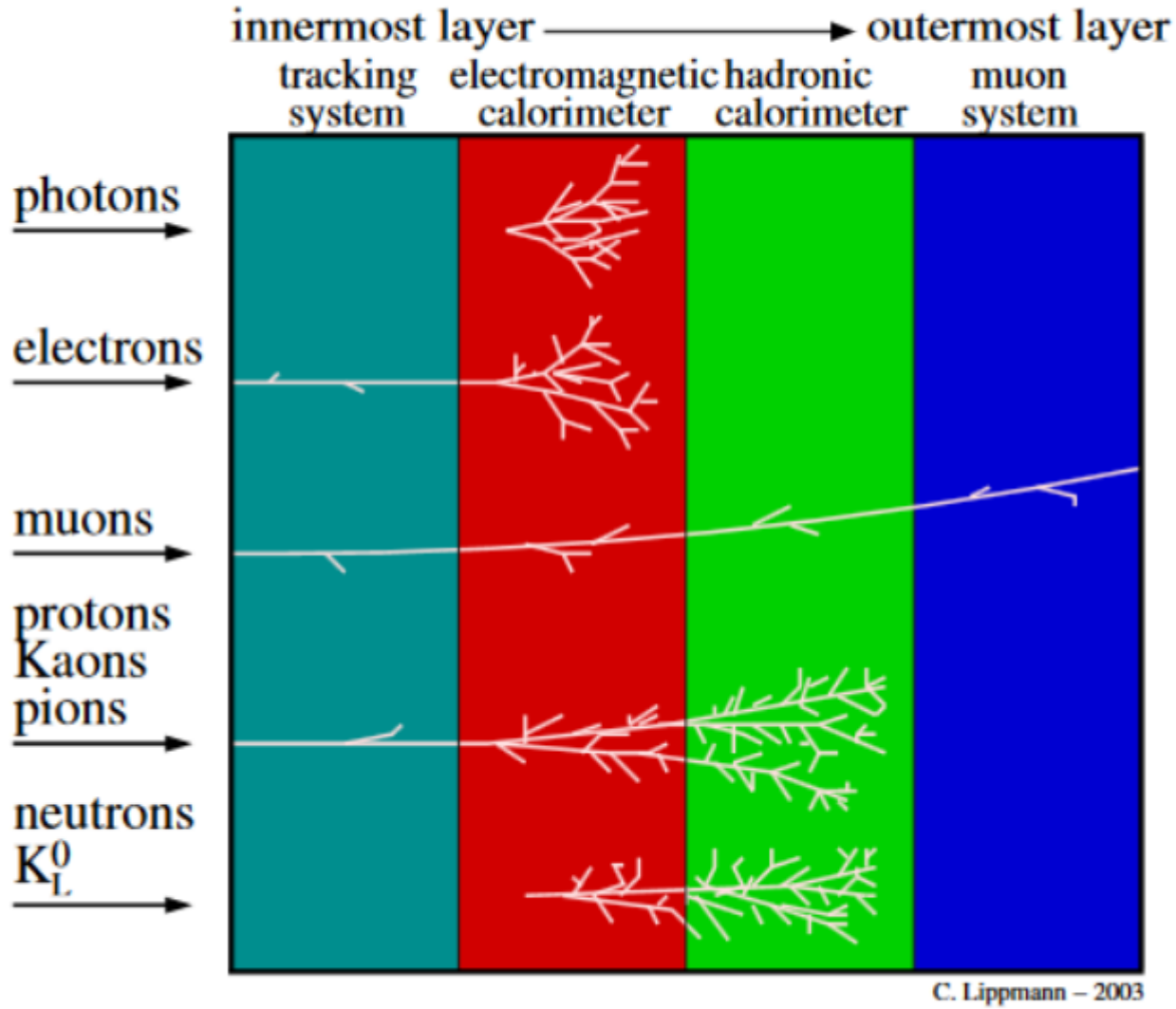
$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} = \frac{N_c \frac{4\pi\alpha^2}{3s} \sum_i q_i^2}{\frac{4\pi\alpha^2}{3s}} = N_c \sum_i q_i^2$$

This must mean something!

Classifying events

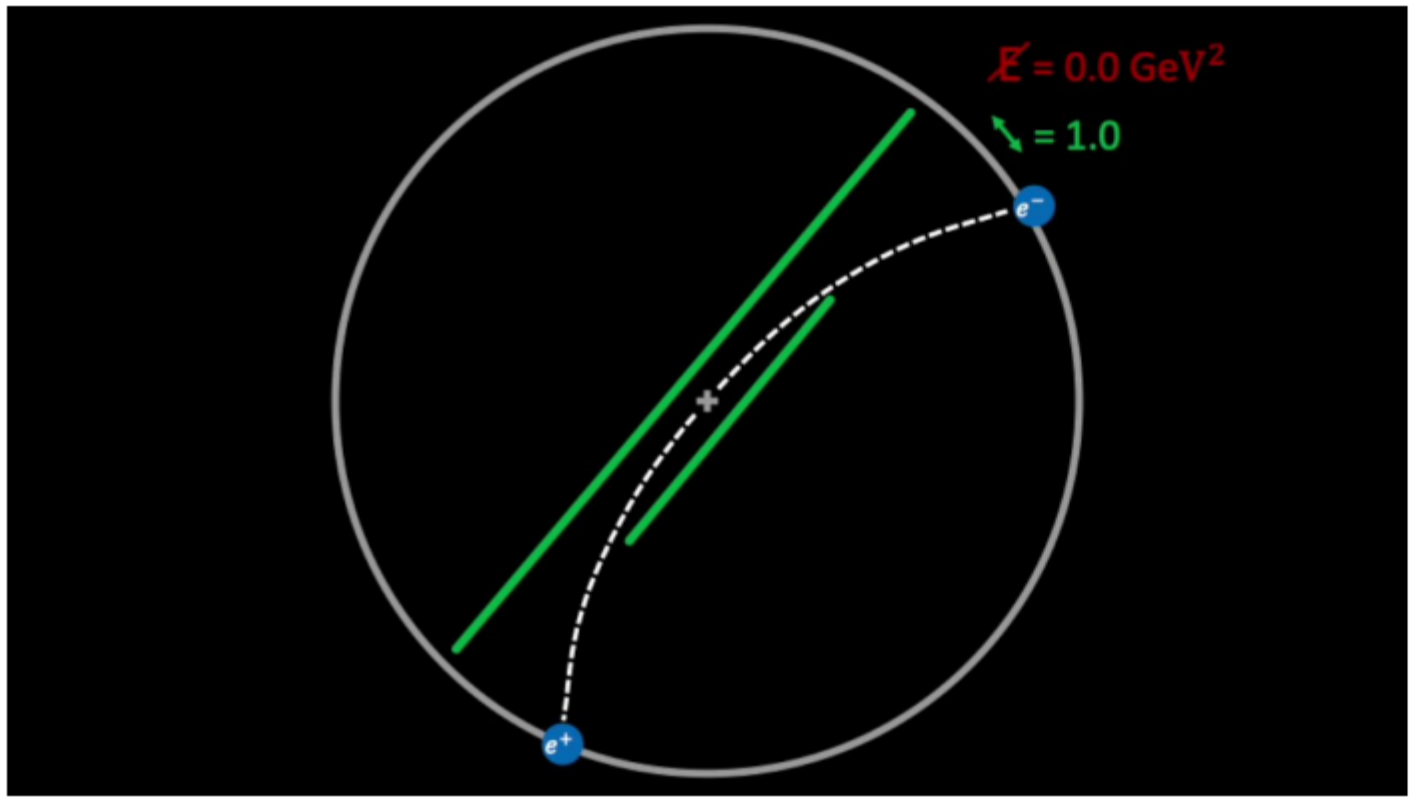
- Particles will produce unique signatures in the different detector components
  - Distribution of energy also unique

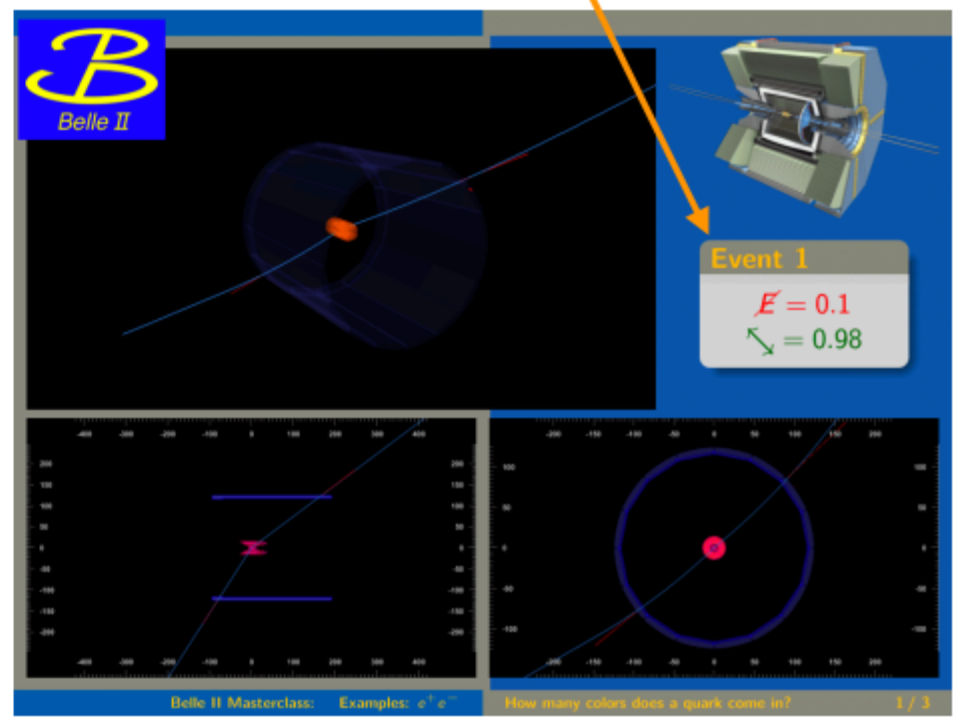




Electron/positron events

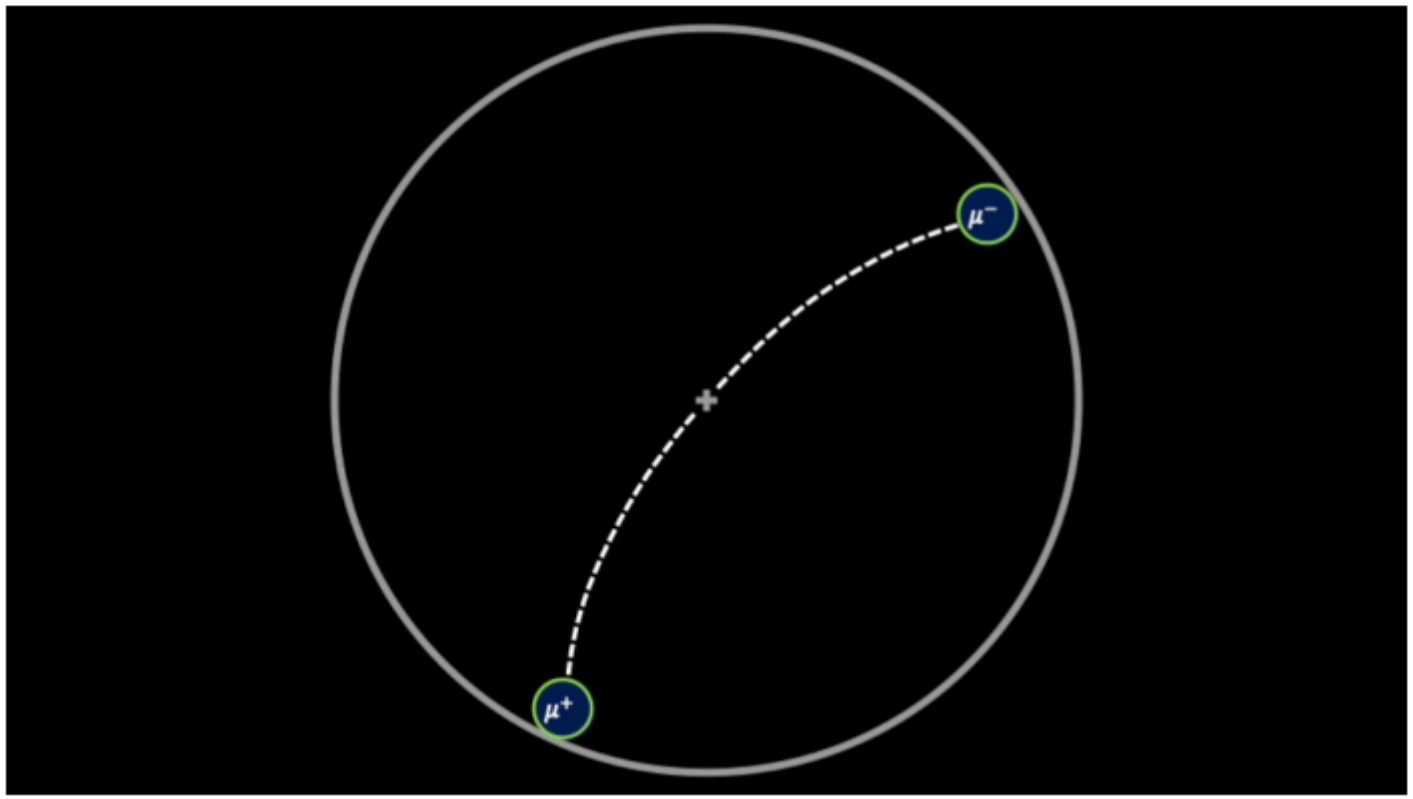
- (almost) always exactly two tracks that are clearly visible in the detector
- (almost) always fully captured by inner detector components
- do not decay in the detector, so very little missing energy and high straightness

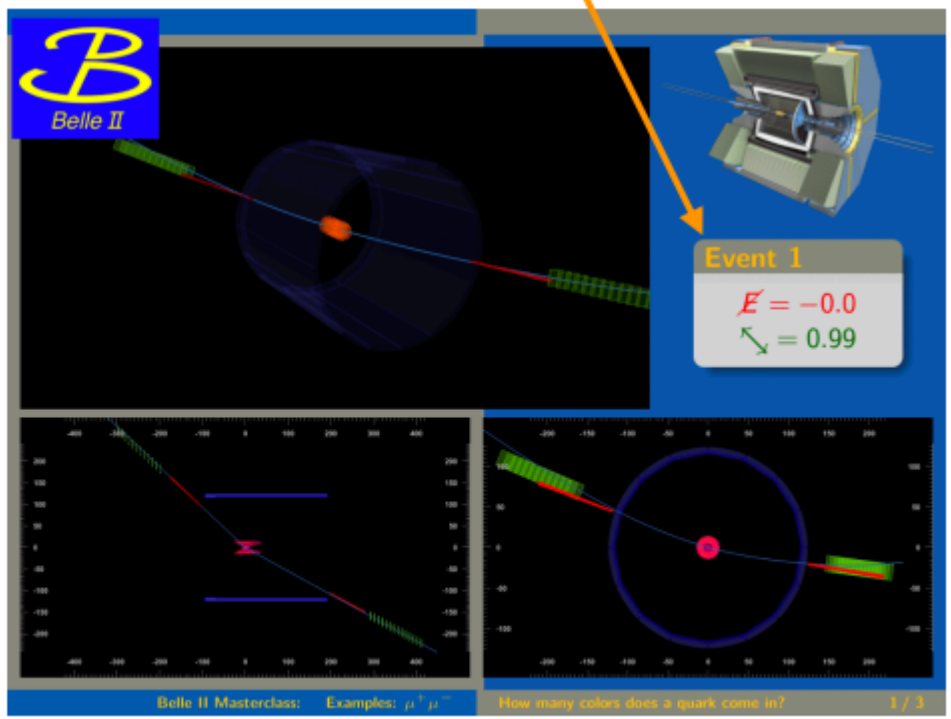




Muon/antimuon events

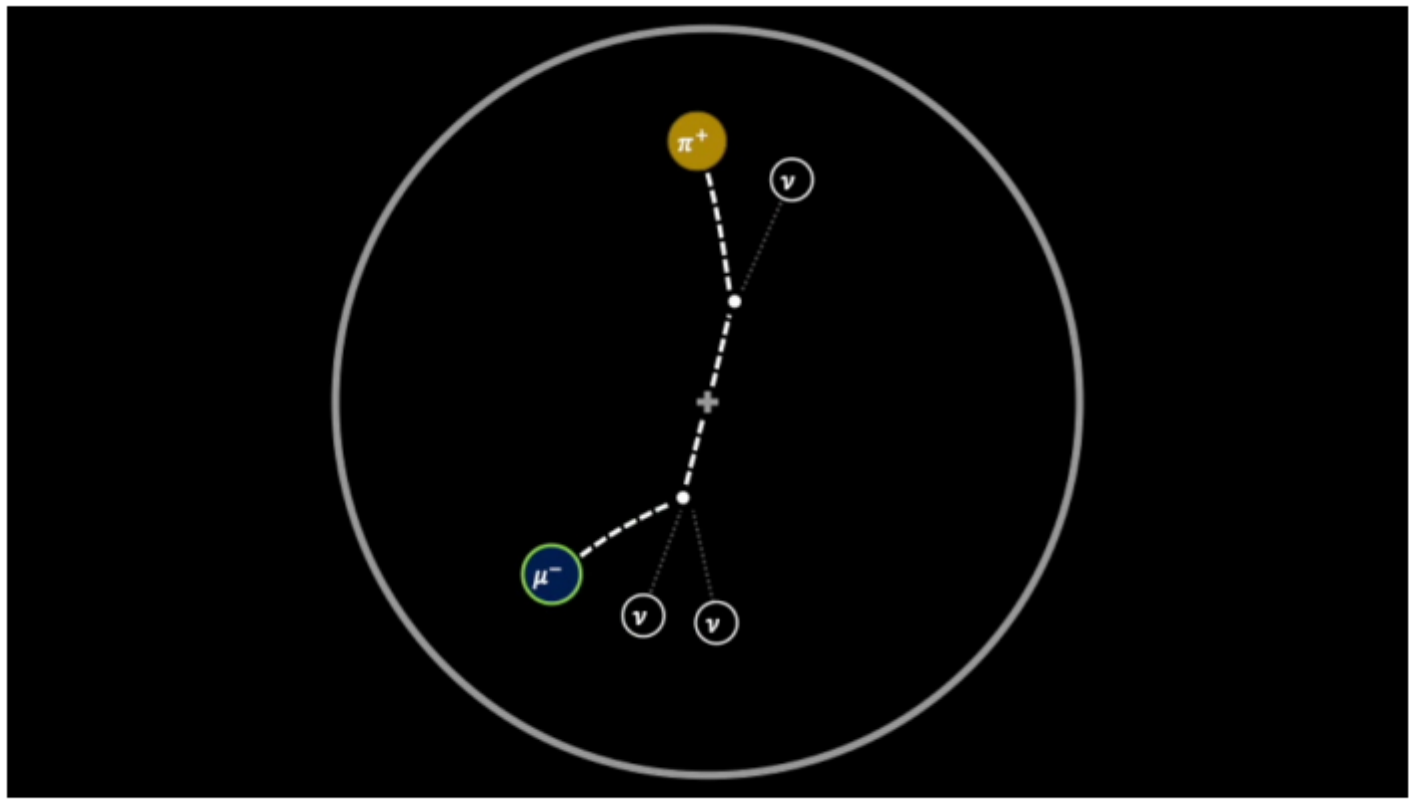
- (almost) always exactly two tracks that are clearly visible in the detector
- (almost) never fully captured by inner detector components - detected in KLM (outer detector)
- do not decay in the detector, so very little missing energy and high straightness

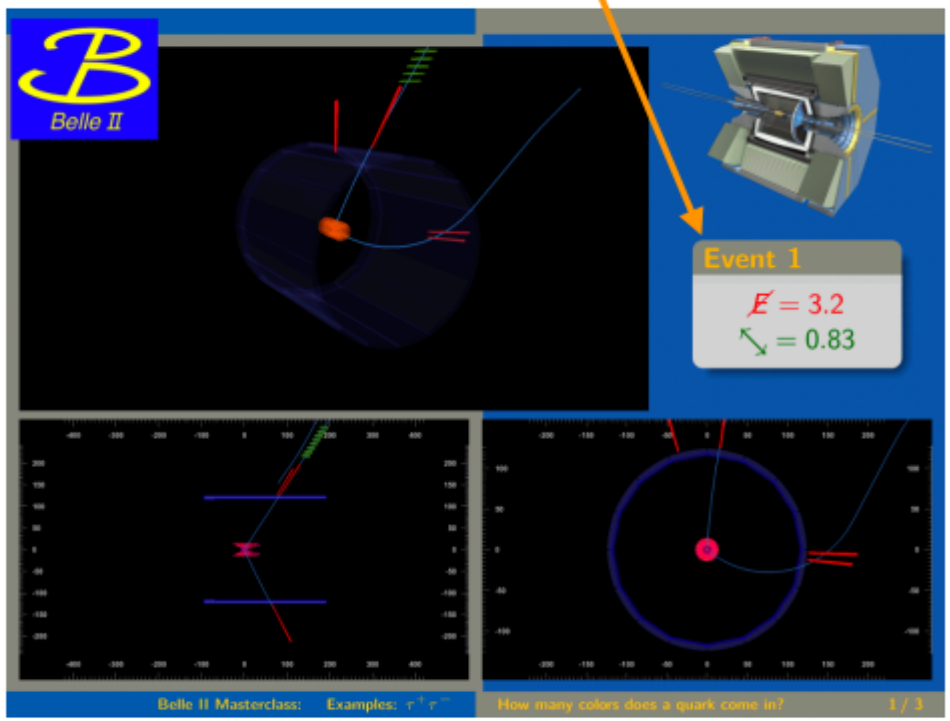




Tau/antitau events

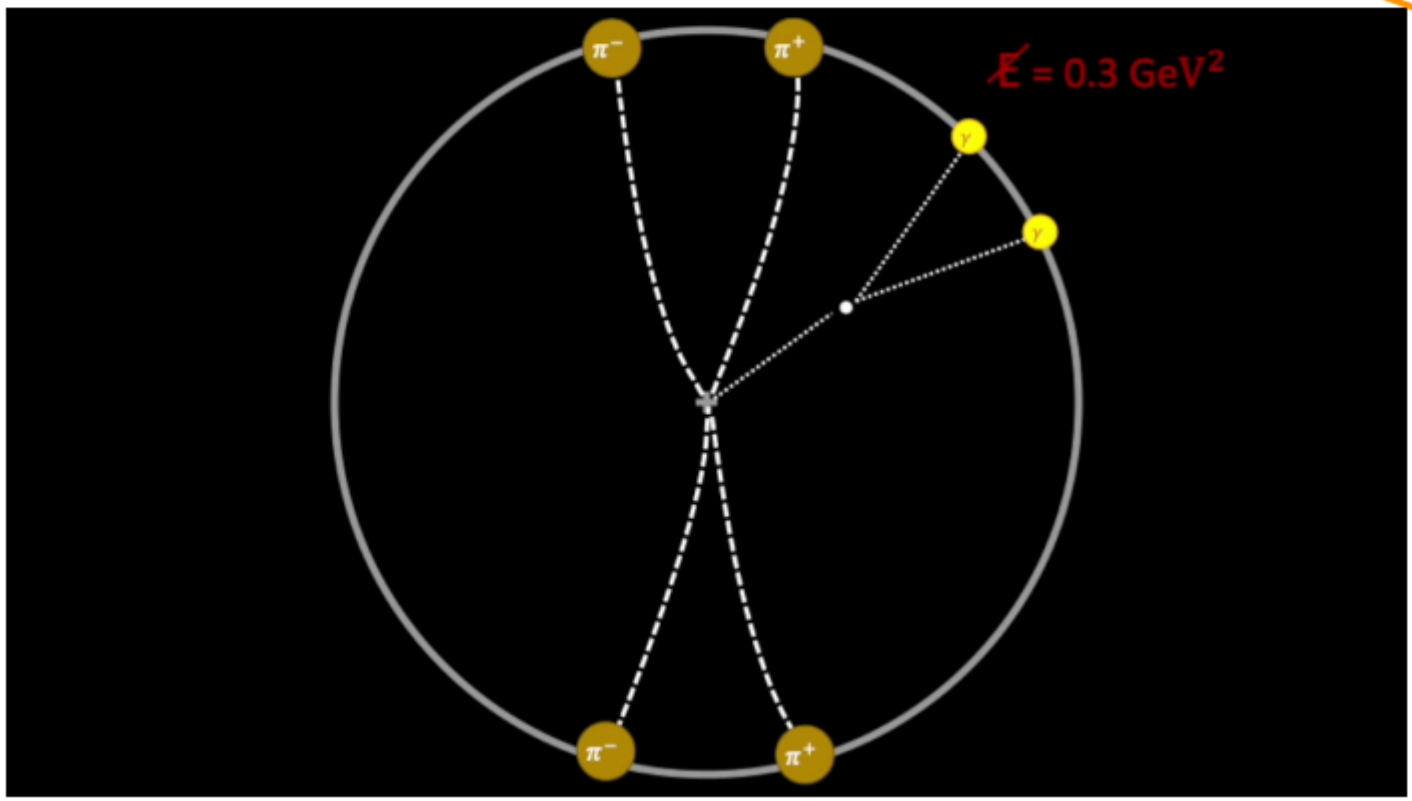
- decay very quickly into (usually) two or three tracks (often one track vs. three tracks)
- usually includes at least one muon track
- decay products include neutrinos, which are not detected, leading to lots of missing energy

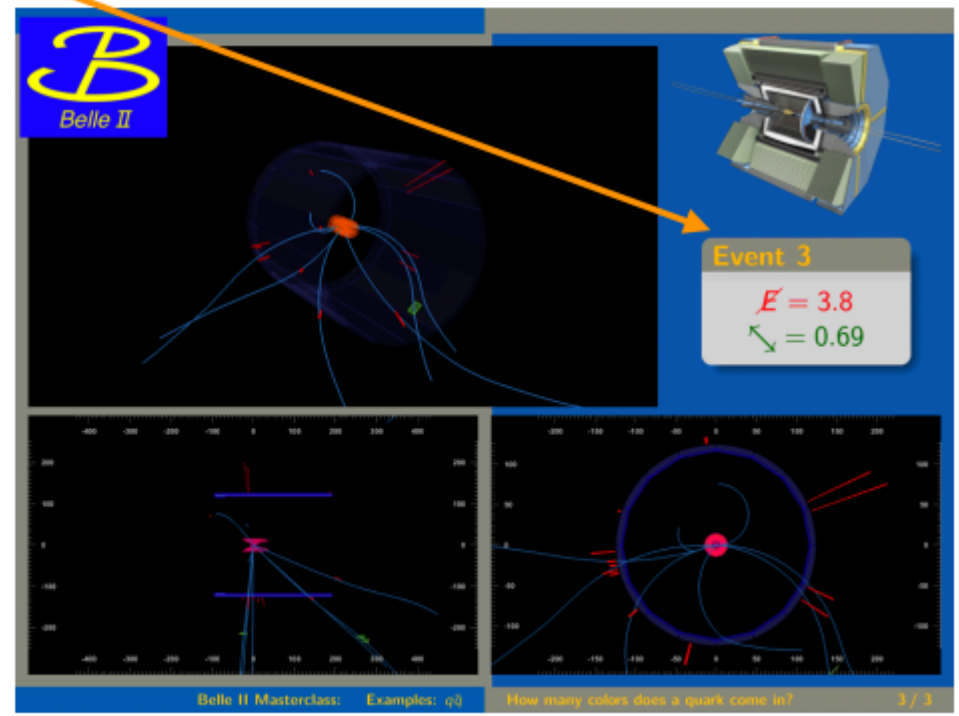




light quark/antiquark events

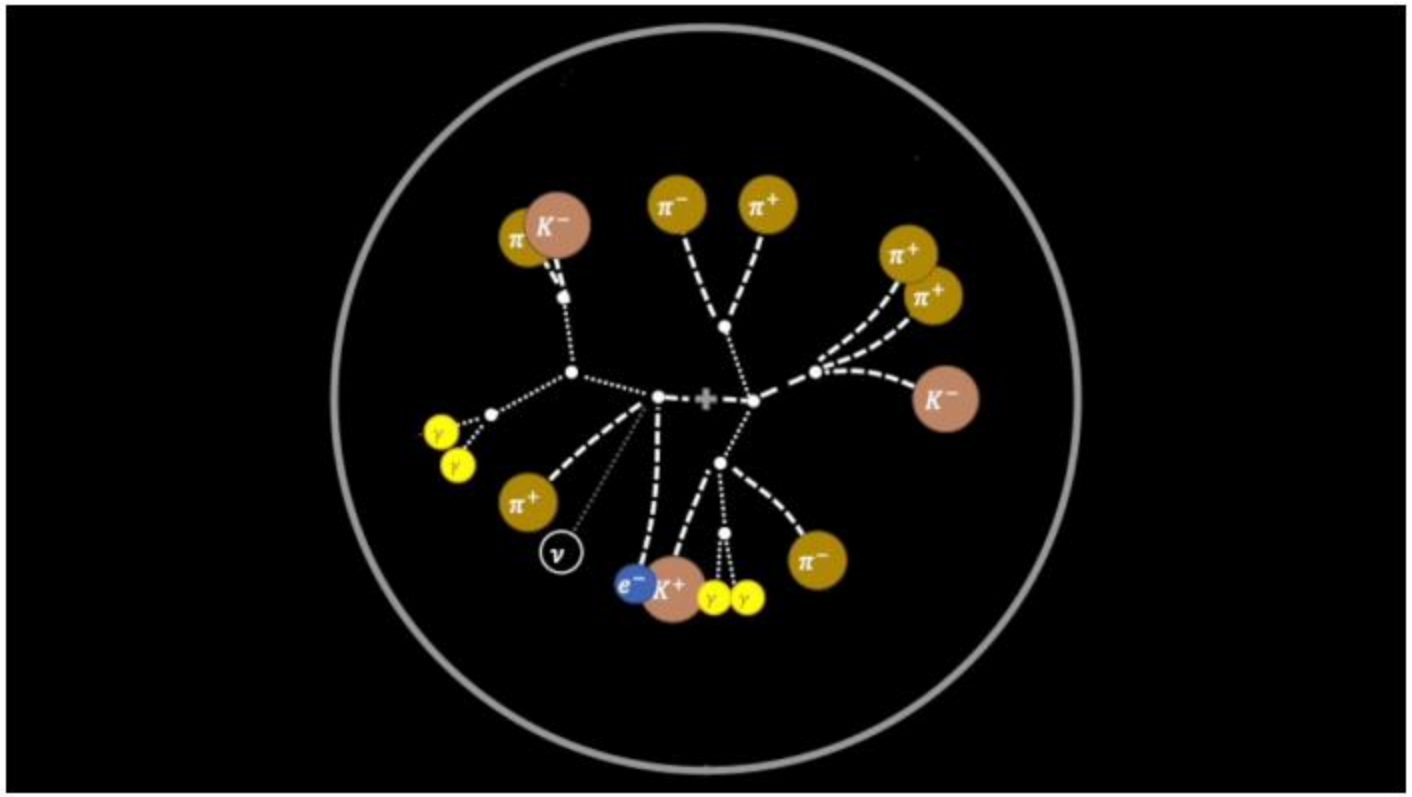
- many possible final states! (usually not one track vs. three tracks)
- fewer neutrinos so not much missing energy
- usually less straight than tau/antitau events

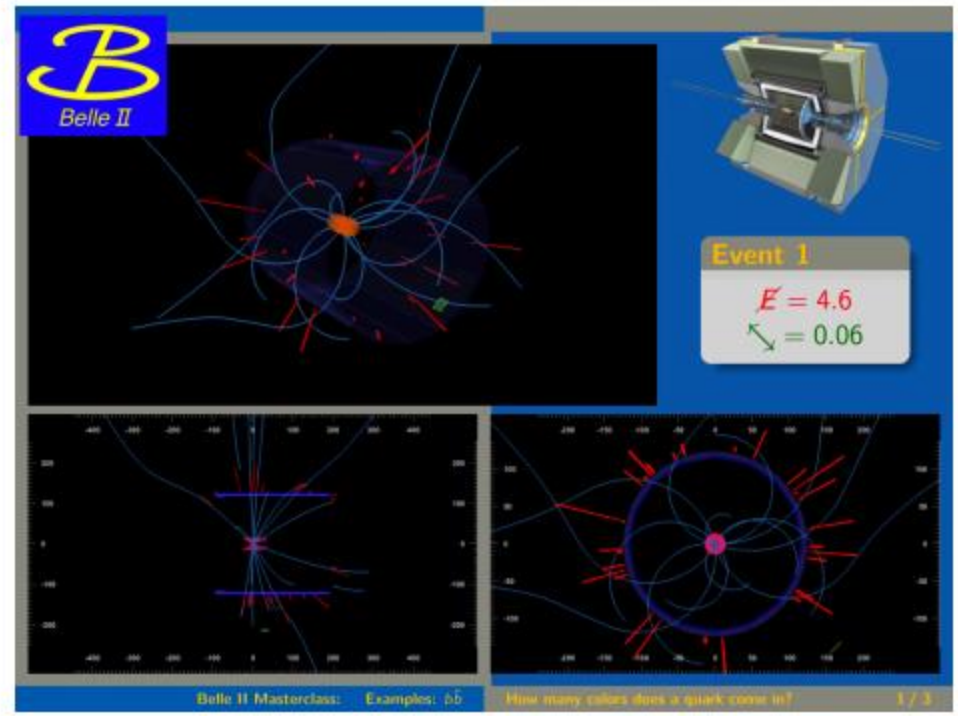




b/anti-b events

- 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 you be the physicist!

- Practice
- Analyze events
- Record results
  - Take care! Live, open spreadsheet!