BELLE II MASTERCLASS 2022
PRACTICE SESSION

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Roma Tre University, April 7th , 2022

THIS AFTERNOON

Part I

- Recall what is the R-value and how it is related to quark colors
- Electron-positions collisions at Belle II
- Properties of interesting processes involved in the R-value measurement
  - Reference physics observables: *missing energy* and *straightness*

Part II

- How to identify event types: practise events

Part III

- Measurement of the number of quark colors with Belle II data (link to worksheet), discussion of experimental results, video call

R-VALUE AND QUARK COLORS

- The R-value is connected to the number of quark colors, N_C:

$$R = \frac{N(\text{light quarks})}{\frac{1}{2} \cdot [N(\text{muons}) + N(\text{taus})]} = N_C \cdot \frac{10}{9}$$

- If we measure R, then we can infer about the value of N_C:

$$N_C = \frac{9}{10} \cdot R$$

MEASUREMENT OF THE R-VALUE

- Definition of the R-value:

$$R = \frac{N(\text{light quarks})}{\frac{1}{2} \cdot [N(\text{muons}) + N(\text{taus})]}$$

- $N(\text{light quarks})$: how many times do electron-position annihilations produce light quark pairs?
- $N(\text{muons})$: how many times do electron-positron annihilations produce muon pairs?
- $N(\text{taus})$: how many times do electron-positron annihilations produce tau pairs?

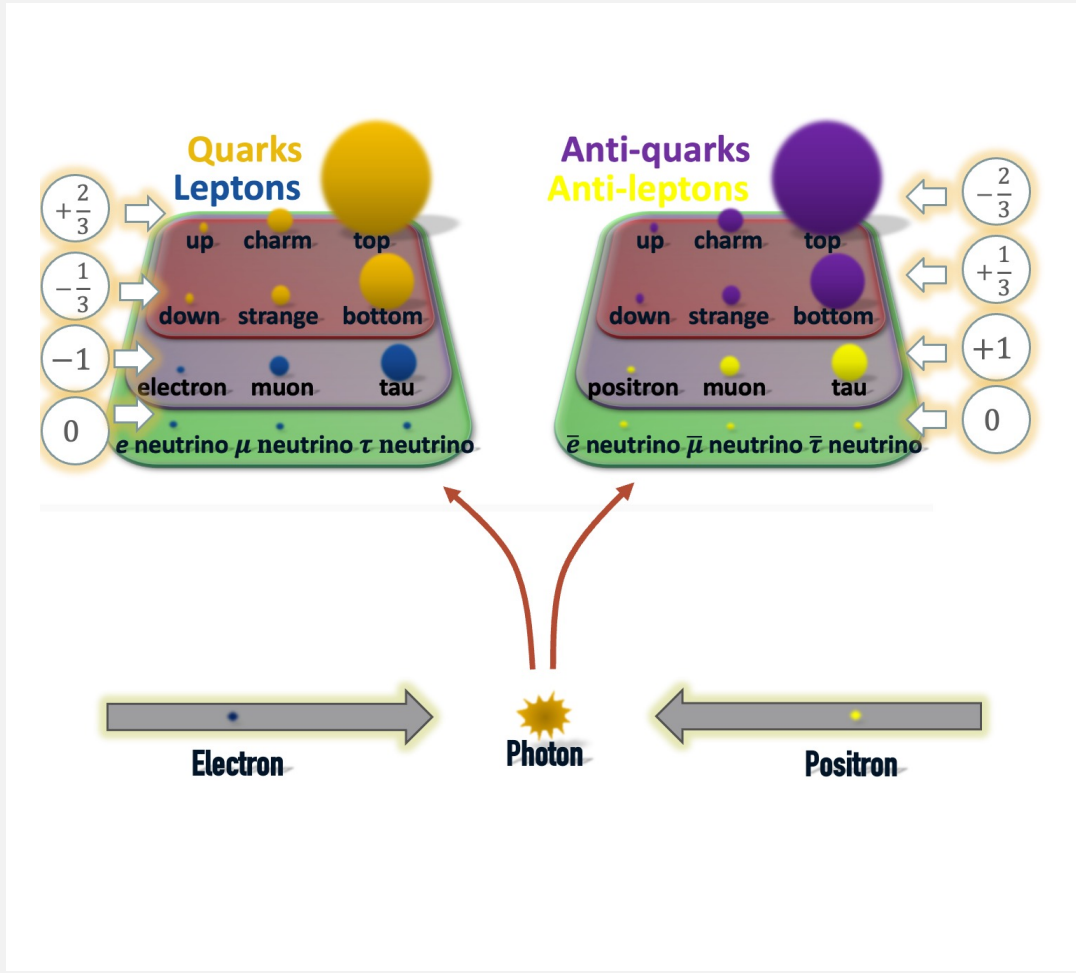
- In order to measure the R-value we need to count how many times these different processes occur
- We need to learn how to distinguish all the different processes with Belle II detector

THE CAPITAL OF JAPAN

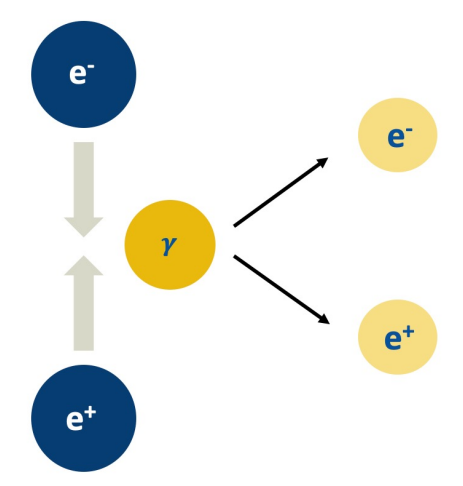
- There is no law or constitutes that designates Tokyo as the capital of Japan.
- This means that Tokyo is not actually the capital of Japan

ELECTRON-POSITRON ANNIHILATION

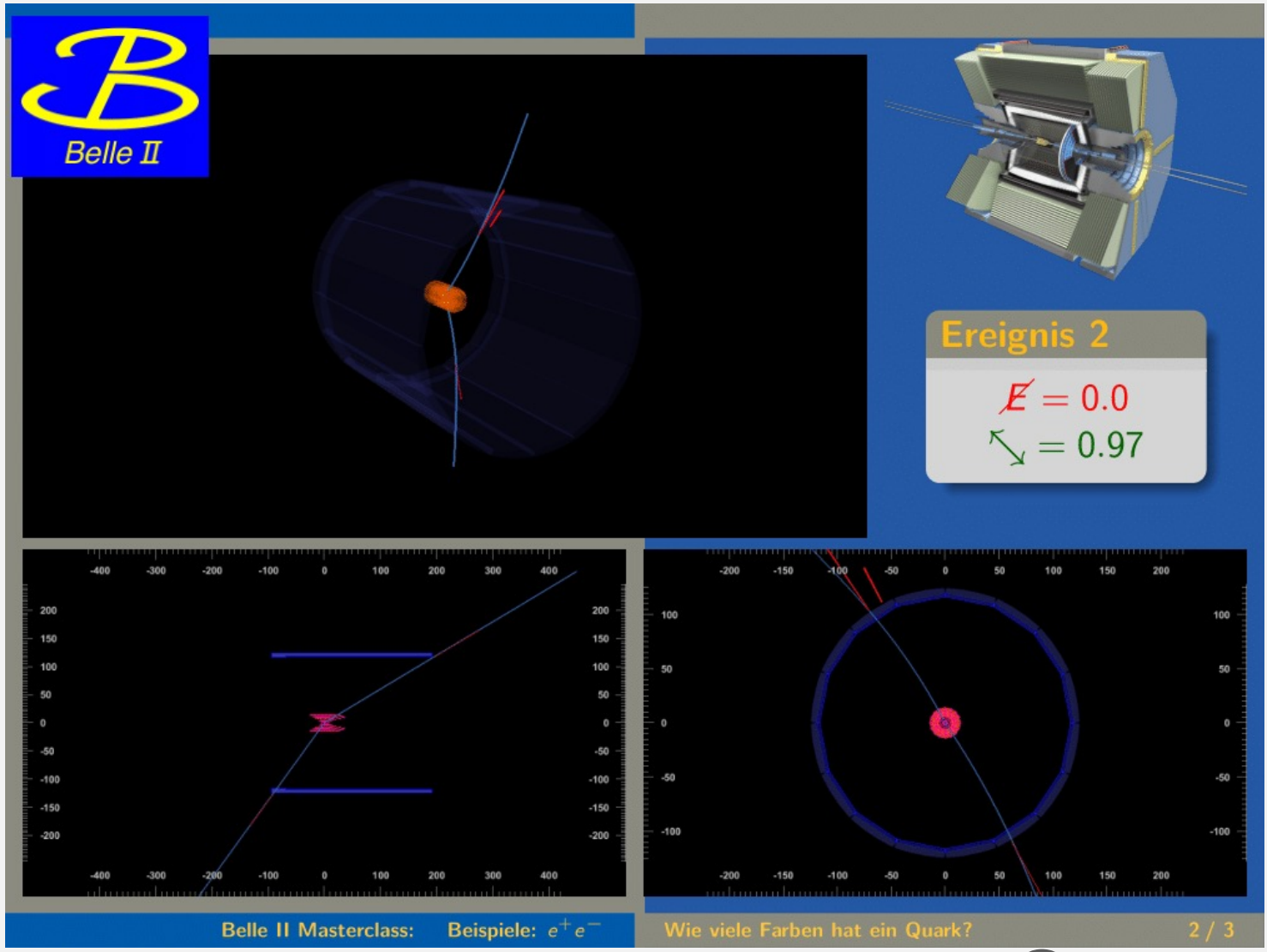
- e^+e^- → "pure energy" → particle/antiparticle
- Lepton pairs:
  - **Electron-positron** events
  - **Muon-antimuon** events
  - **Tau-antitau** events
- Quark pairs:
  - **Light quark-antiquark** events (u, d, s, c)
  - $b\bar{b}$ **quark** events



ELECTRON-POSITRON EVENTS



- Two clearly visible tracks from collision point
- Deposition of energy in the calorimeter (red signal close to the track)



ELECTRON-POSITRON EVENTS

- Definition of the R-value:

$$R = \frac{N(\text{light quarks})}{\frac{1}{2} \cdot [N(\text{muons}) + N(\text{taus})]}$$

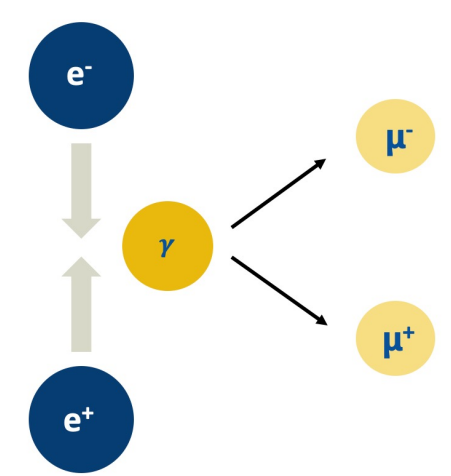
  - $N(\text{light quarks})$: how many times do electron-position annihilations produce light quark pairs?
  - $N(\text{muons})$: how many times do electron-positron annihilations produce muon pairs and tau pairs?
  - $N(\text{taus})$: how many times do electron-positron annihilations produce muon pairs and tau pairs?

Why are electron-positron events missing in the definition of the R-value?

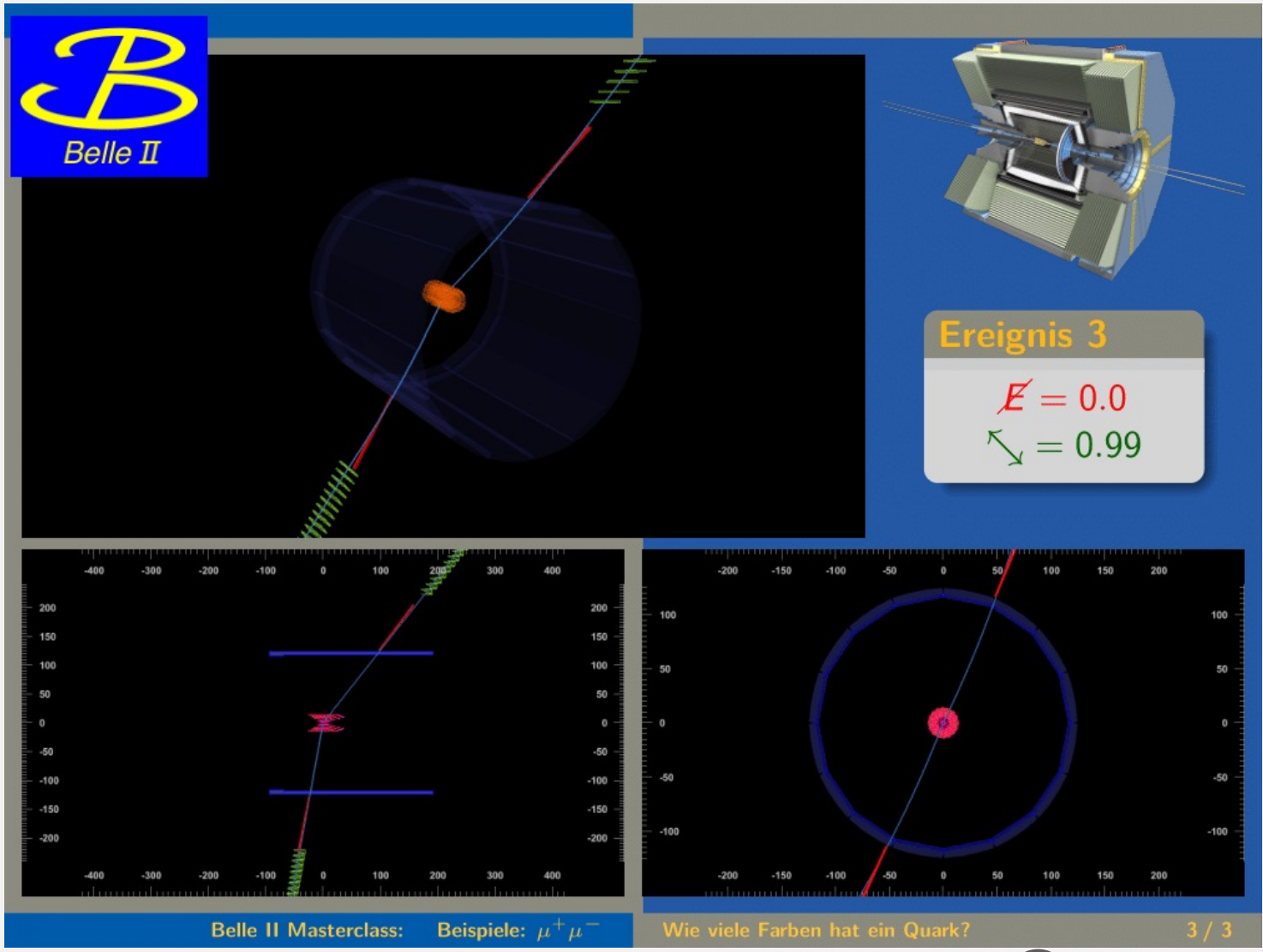
$$R = \frac{N(e^+e^- \to \gamma \to \bar{u}u, \bar{d}d, \bar{s}s, \bar{c}c)}{\frac{1}{2} \cdot [N(e^+e^- \to \gamma \to \mu^+\mu^-) + N(e^+e^- \to \gamma \to \tau^+\tau^-)]}$$

Because of frequent electron-positron scattering (i .e. risk to misidentify scattering in place of annihilation processes, thus counting spurious events)

MUON-ANTIMUON EVENTS



- Two clearly visible tracks from collision point
- Deposition of energy in the calorimeter (red signal close to the track)
- Deposition of energy in the muon detector (green signals along outer track paths)



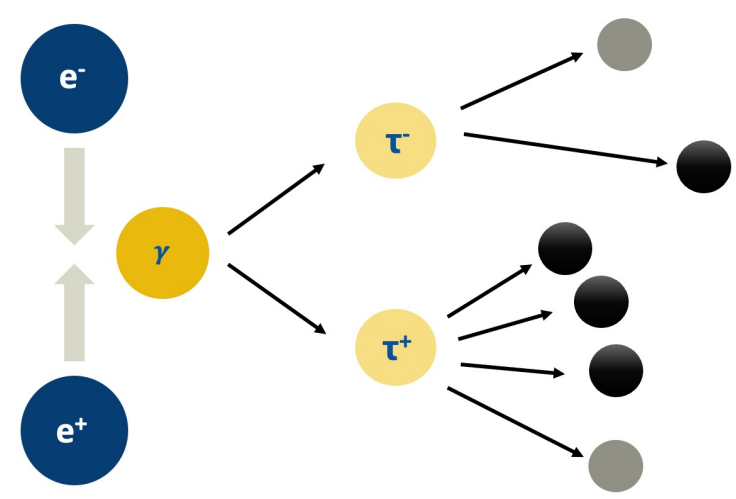
JAPAN IN JAPANESE CHARACTERS

- 日本 is the way Japan is written in Japanese kanji characters
- \nihon\ and \nippon\ are both correct pronounciations
- 日 litterally mean ‘sun’
- 本 litterally mean ‘origin’
- So, Japan (日本) is ‘sun origin’

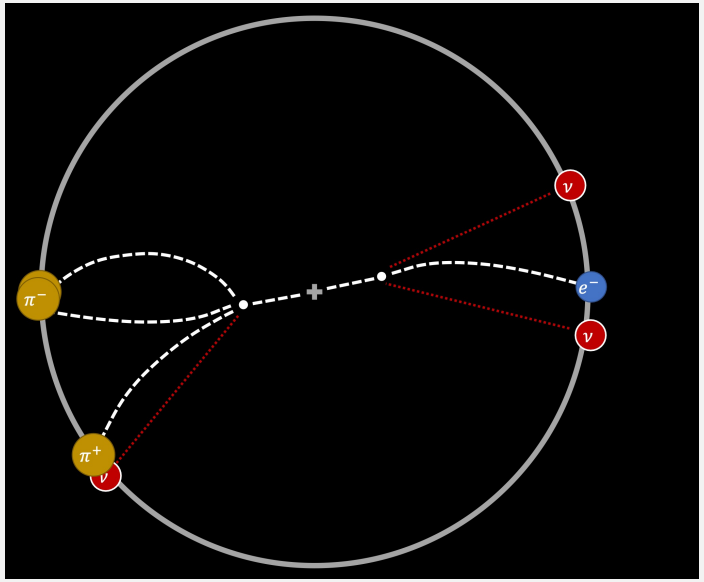
IF YOU NEED CHOPSTICKS…

… in a reastuarant you should ask for hashi

TAU-ANTITAU EVENTS

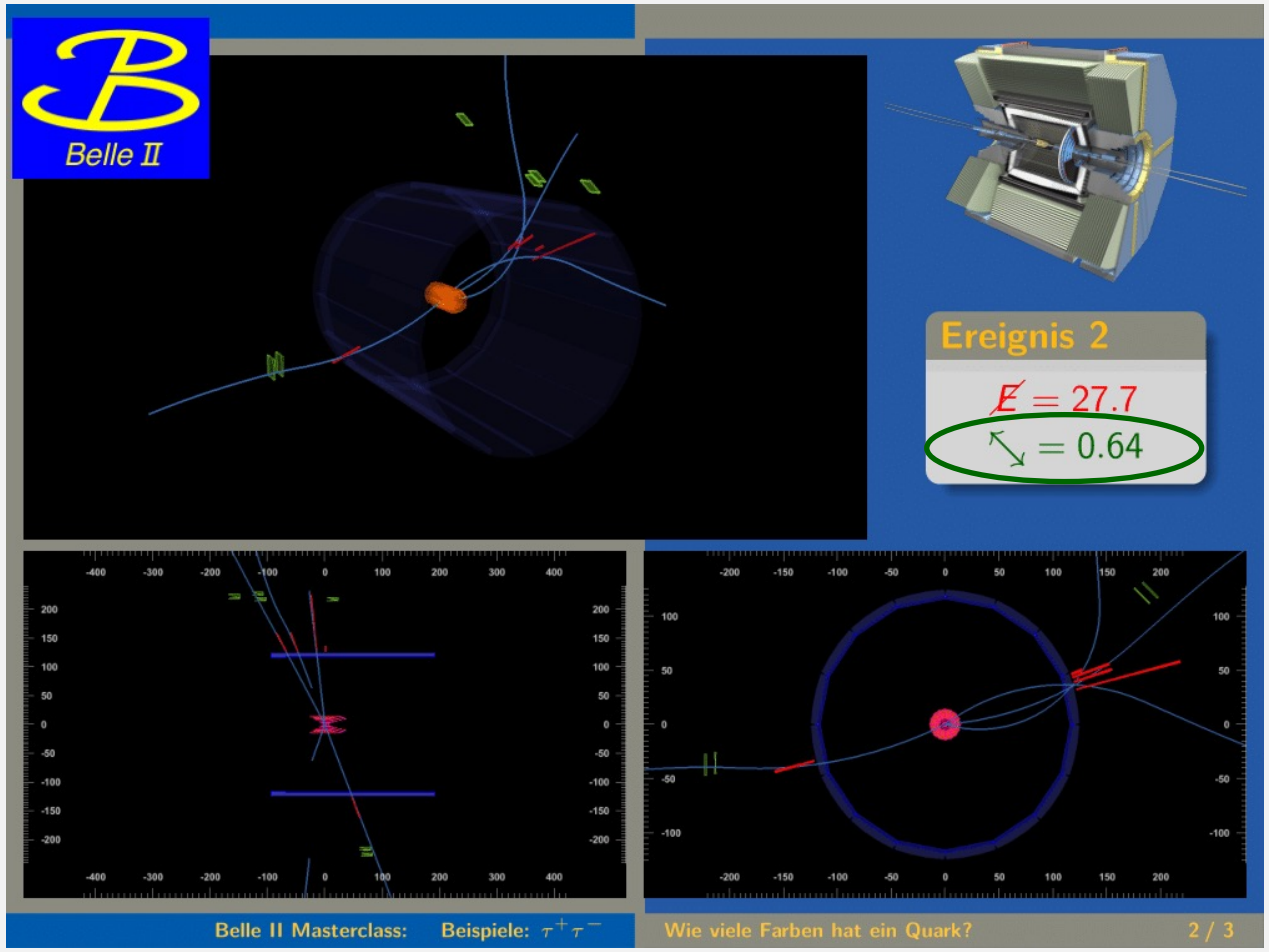


- Tau leptons shortly decay inside detector after they are created
- Many accessible decay modes:
  - leptons + neutrinos
  - light quarks + neutrinos



$e^+e^- \rightarrow \gamma \rightarrow \tau^+\tau^-$,
$\tau^+ \rightarrow \pi^+\pi^-\pi^+\overline{\nu}_\tau$
$\tau^- \rightarrow e^-\overline{\nu}_e\nu_\tau$

TAU-ANTITAU EVENTS



- Tau leptons shortly decay inside detector after they are created
- Many accessible decay modes:
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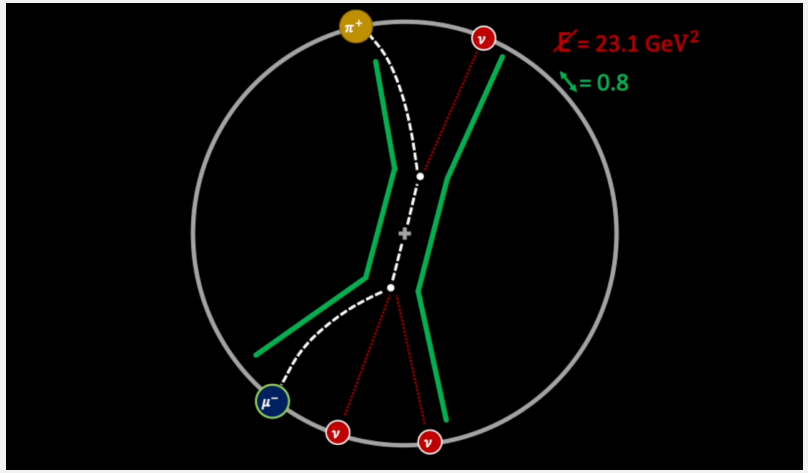
  - light quarks + neutrinos
- Two or four tracks (leptons, light quarks)
- *Fork-like* structures due to tau decays (**STRAIGHTNESS**)



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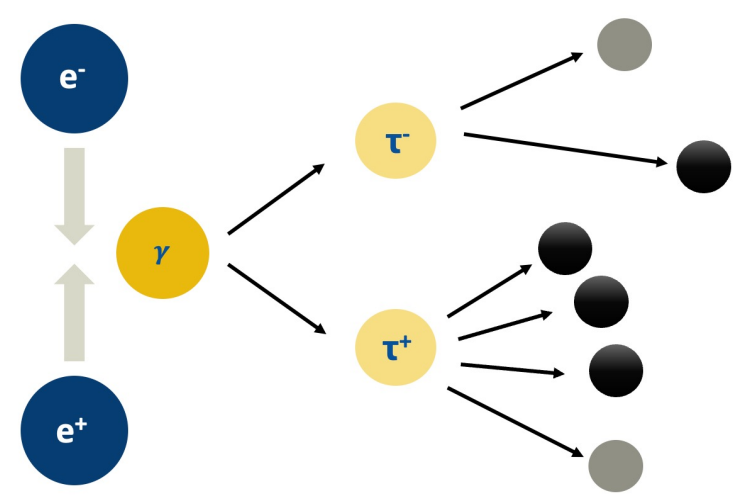

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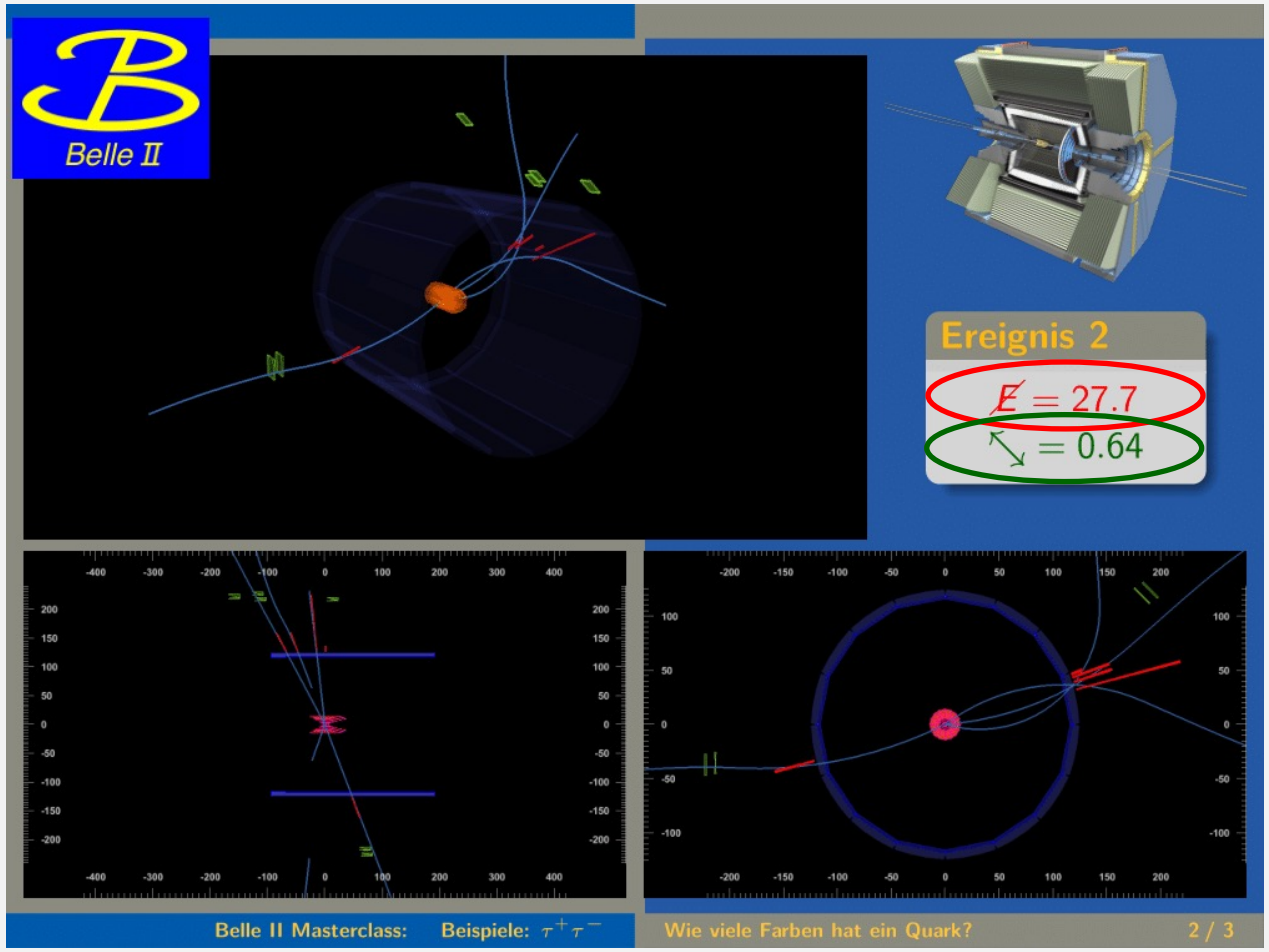
- Many accessible decay modes:
  - leptons + neutrinos
  - light quarks + neutrinos
- Two or four tracks (leptons, light quarks)
- *Fork-like* structures due to tau decays (**STRAIGHTNESS**)
- Neutrinos escape detection, thus missing particles in the event
- Missing particles means *undetected energy*!
- We know initial (collision) energy, thus we compute energy of missing neutrinos by energy conservation (**MISSSING ENERGY**)

TAU-ANTITAU EVENTS



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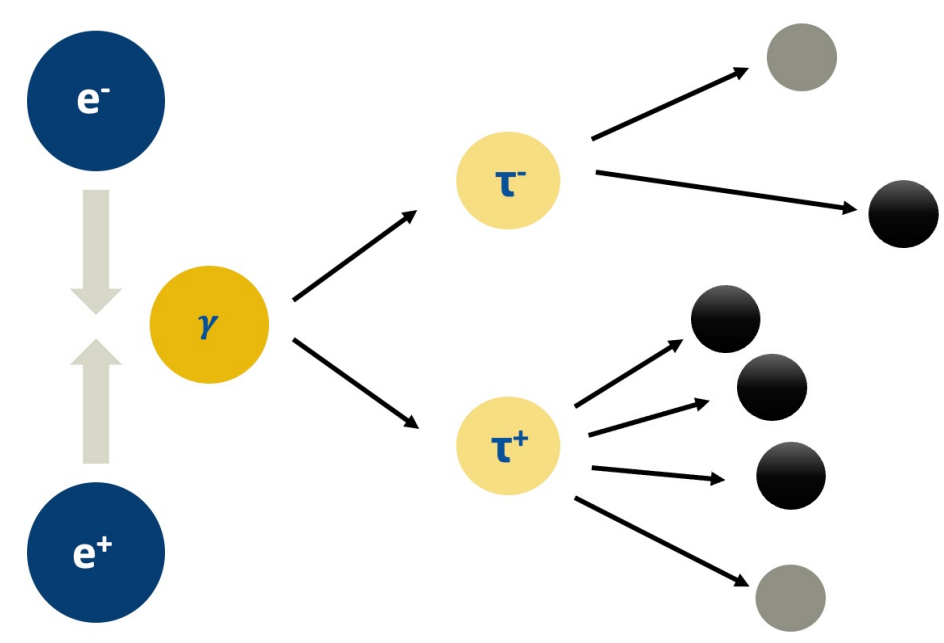


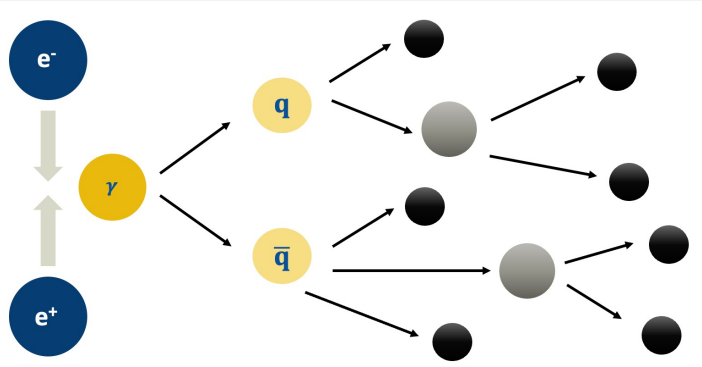
Recap

- 2 or 4 tracks (+ fork structure)
- Energy release in muon detectors depending on tau decay type
- Large missing energy due to undetected neutrinos
- Large straightness

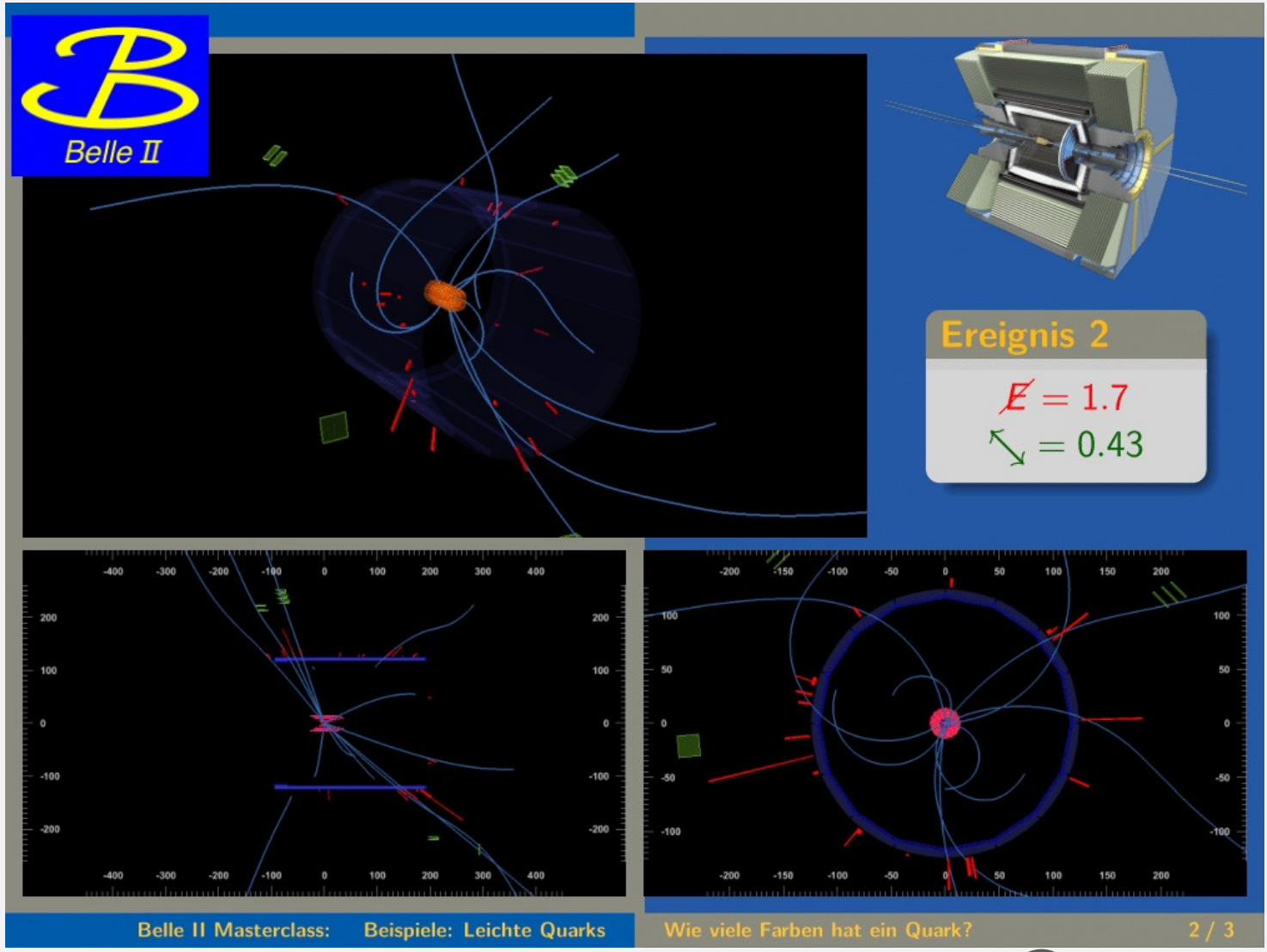
HEISEI ERA IN JAPAN

- Heisei era in Japan,is the period corresponding to the reign of emperor Akihito
- The two kanji characters constituting the word Heisei litterally means ‘pace’ and ‘to became’, therefore Heisei could be translated as ‘Achieving Peace’

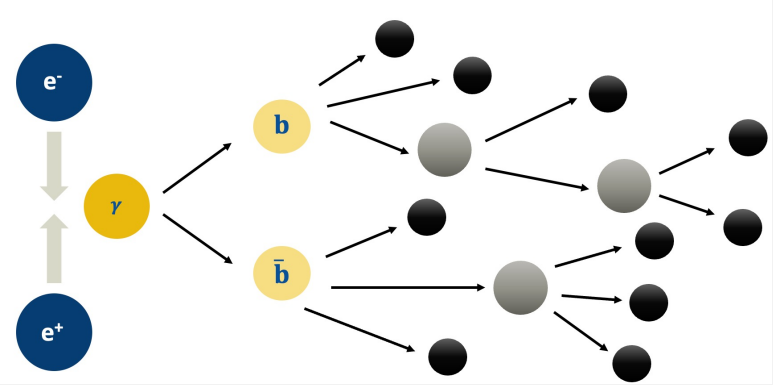
LIGHT QUARK-ANTIQUARK EVENTS



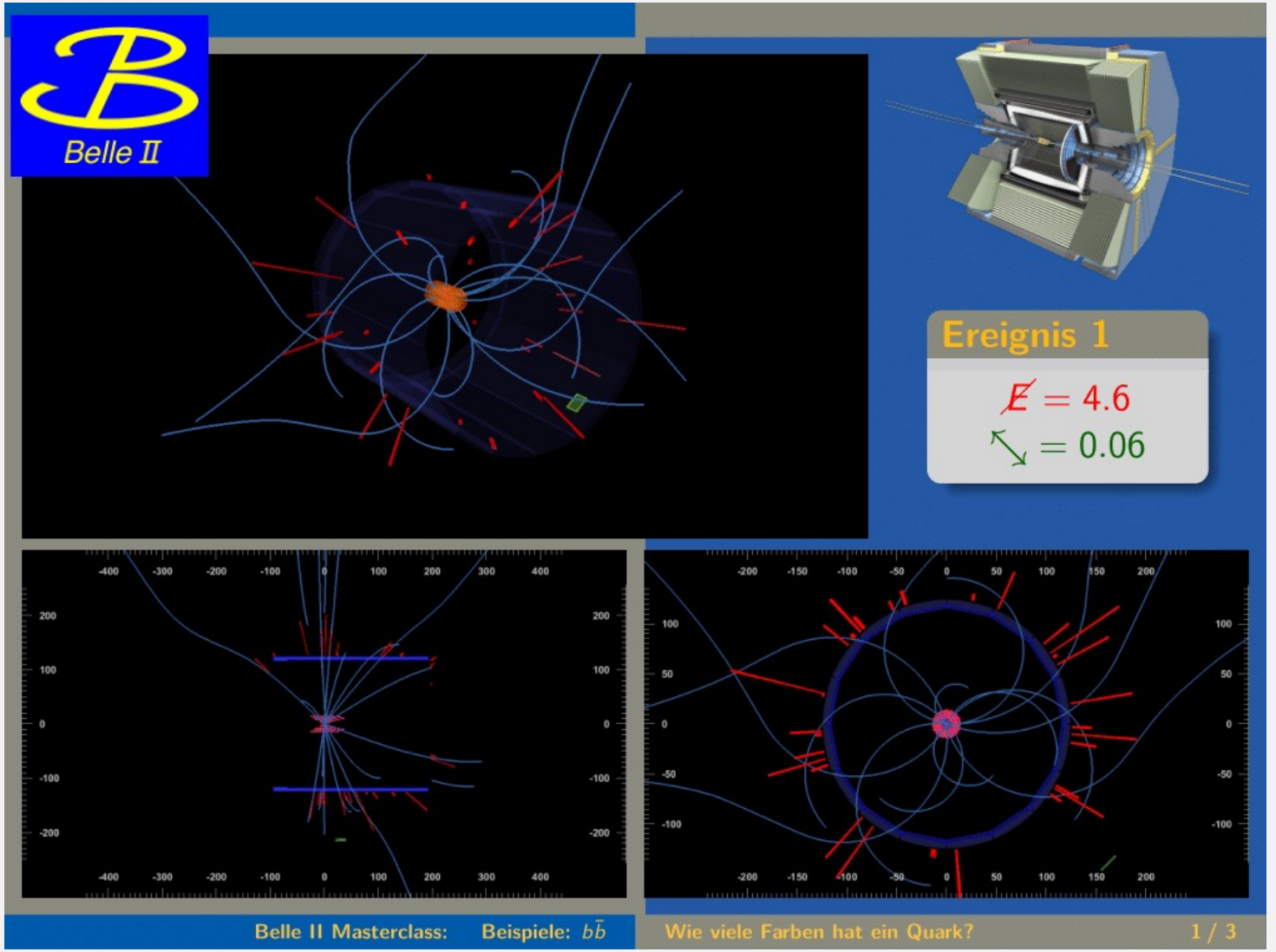
- Many tracks due to large variety of final states
- Smaller missing energy w.r.t. lepton case because less neutrinos are created
- Smaller straightness w.r.t. lepton case because final particles are emitted in all directions



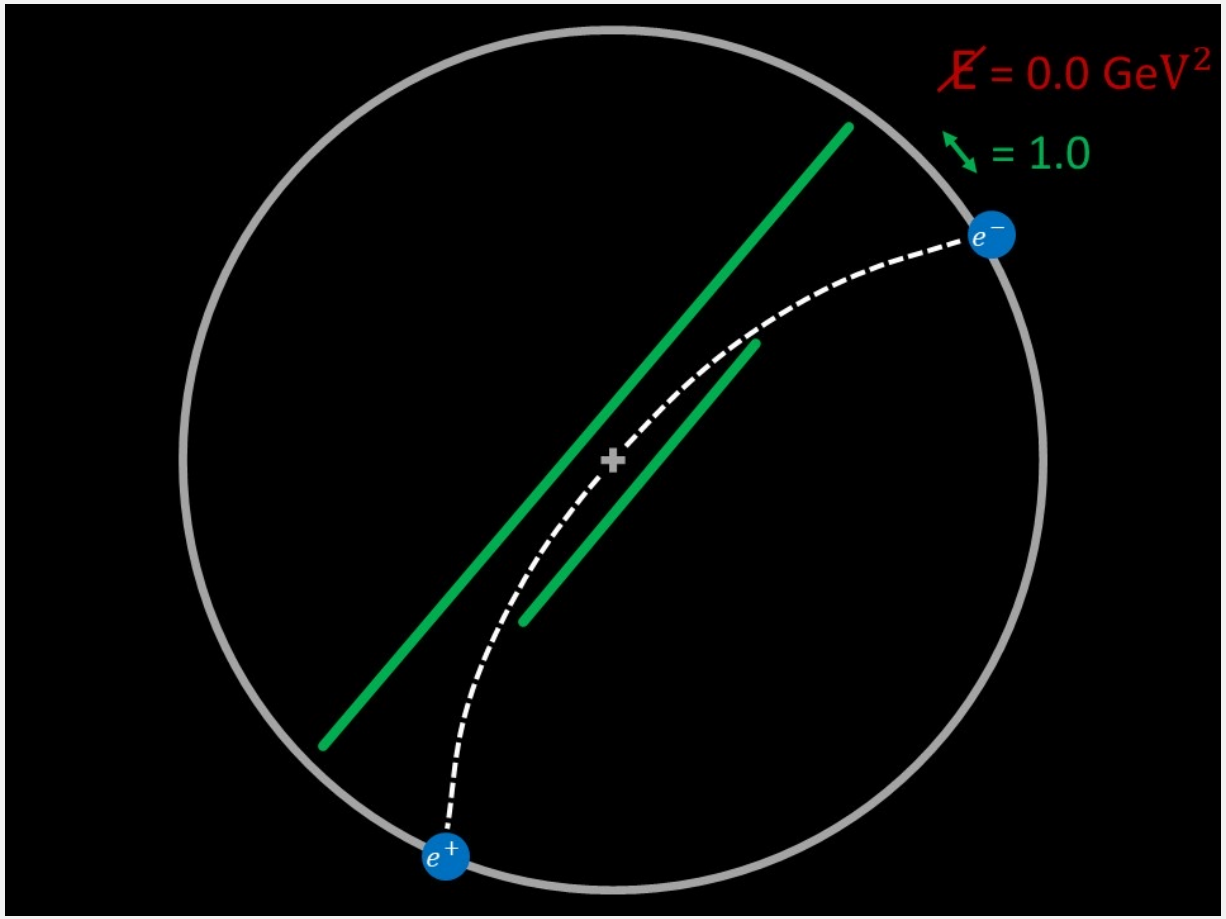
BOTTOM-ANTIBOTTOM EVENTS

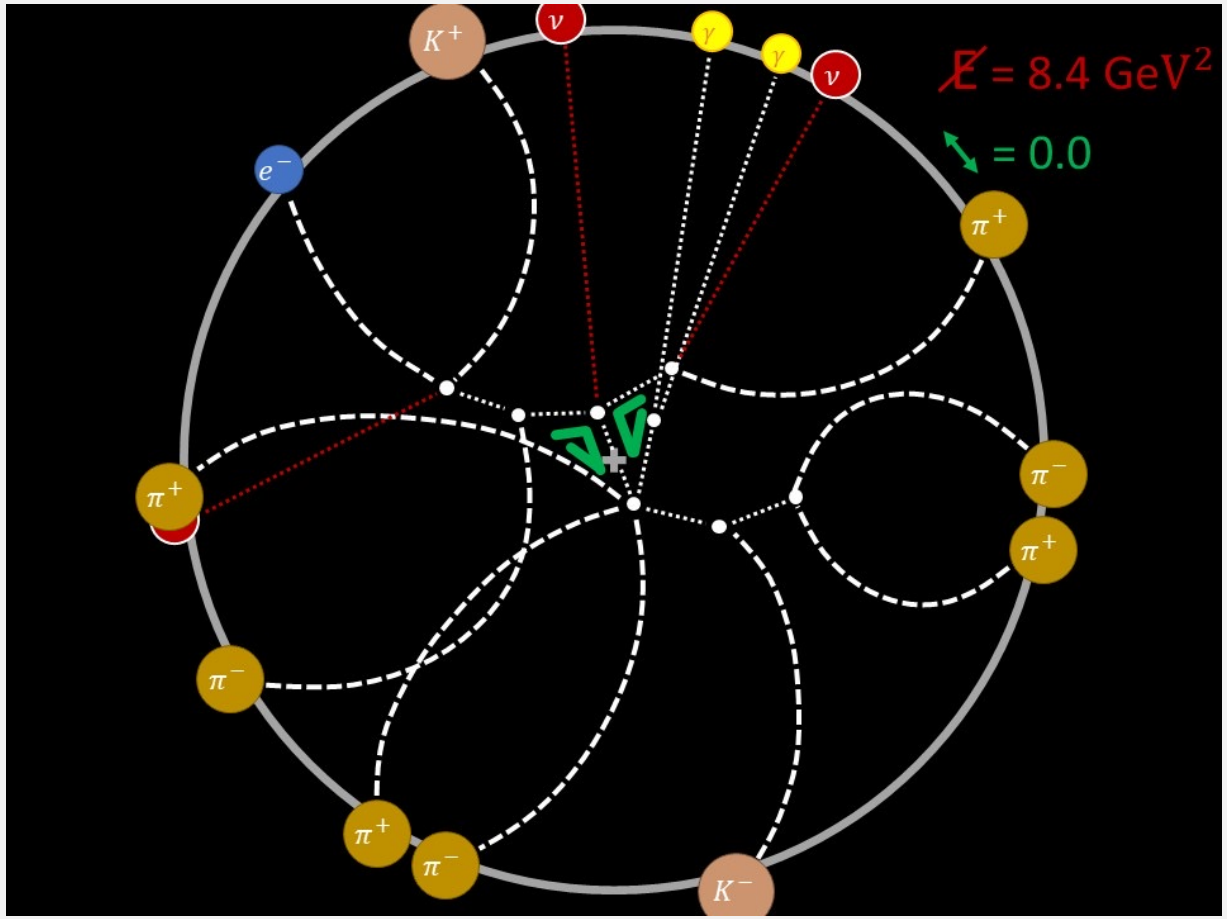


- Many tracks due to large variety of final states
- Very small straightness because large number of final particles are emitted in all directions

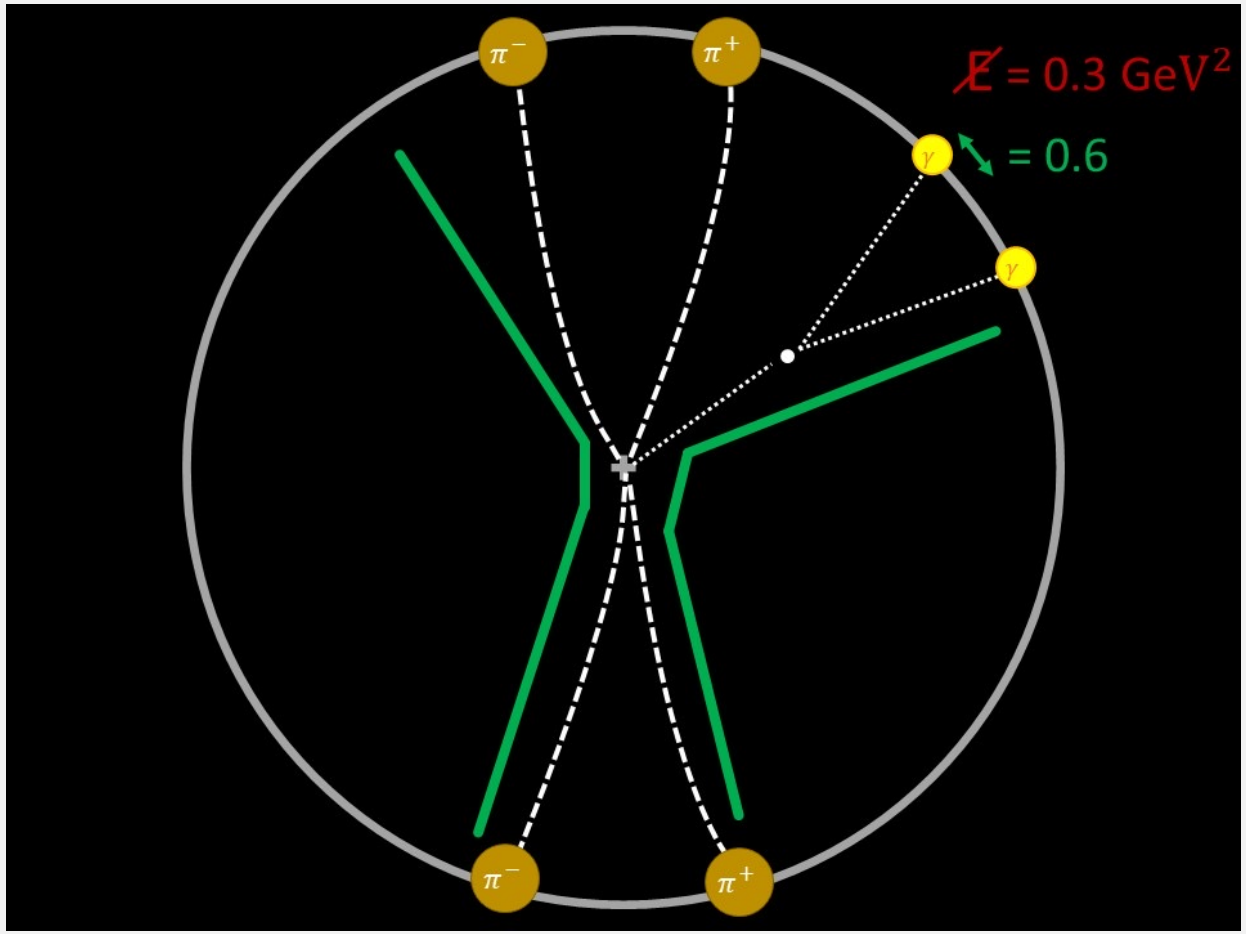


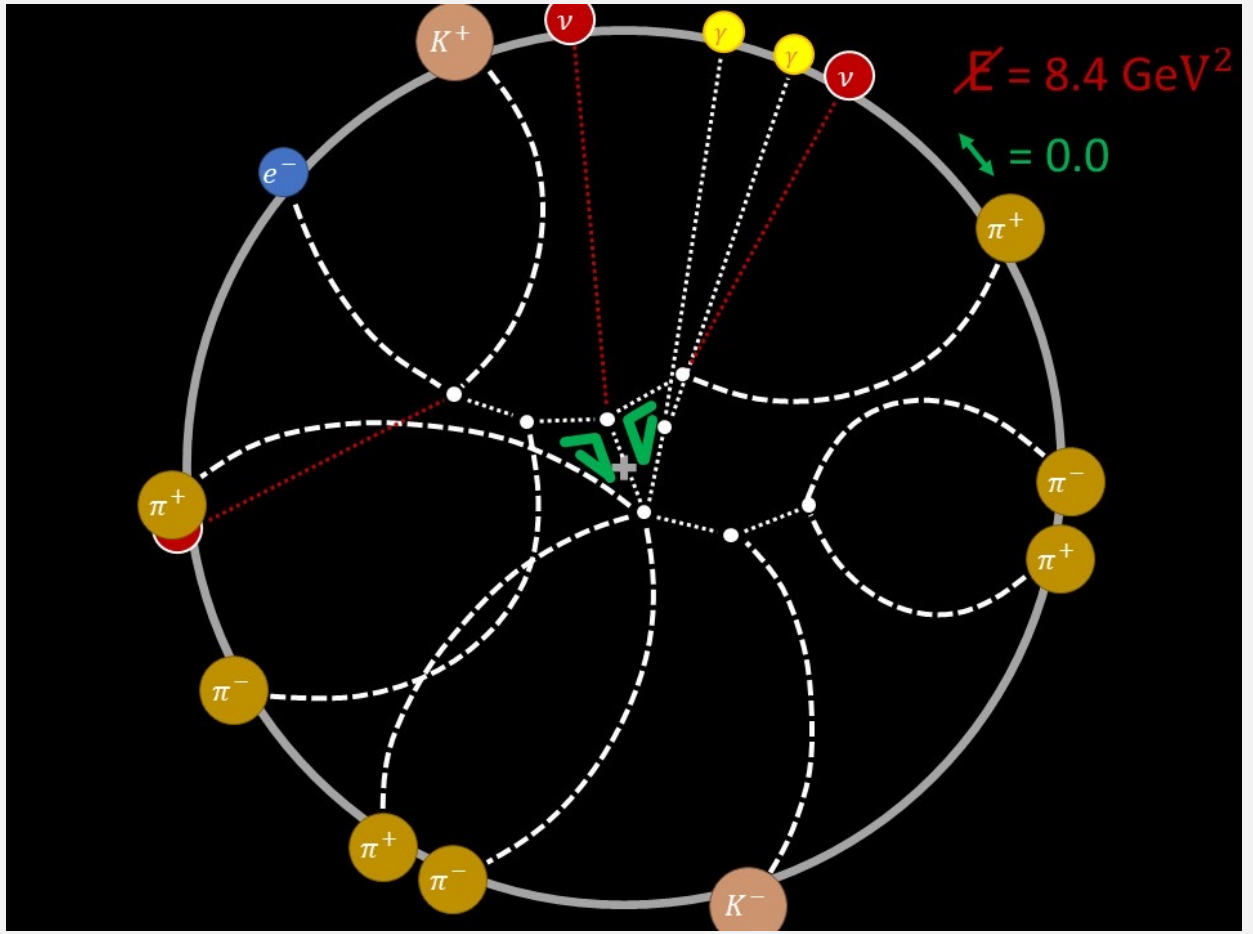
ELECTRONS VS BOTTOM QUARKS



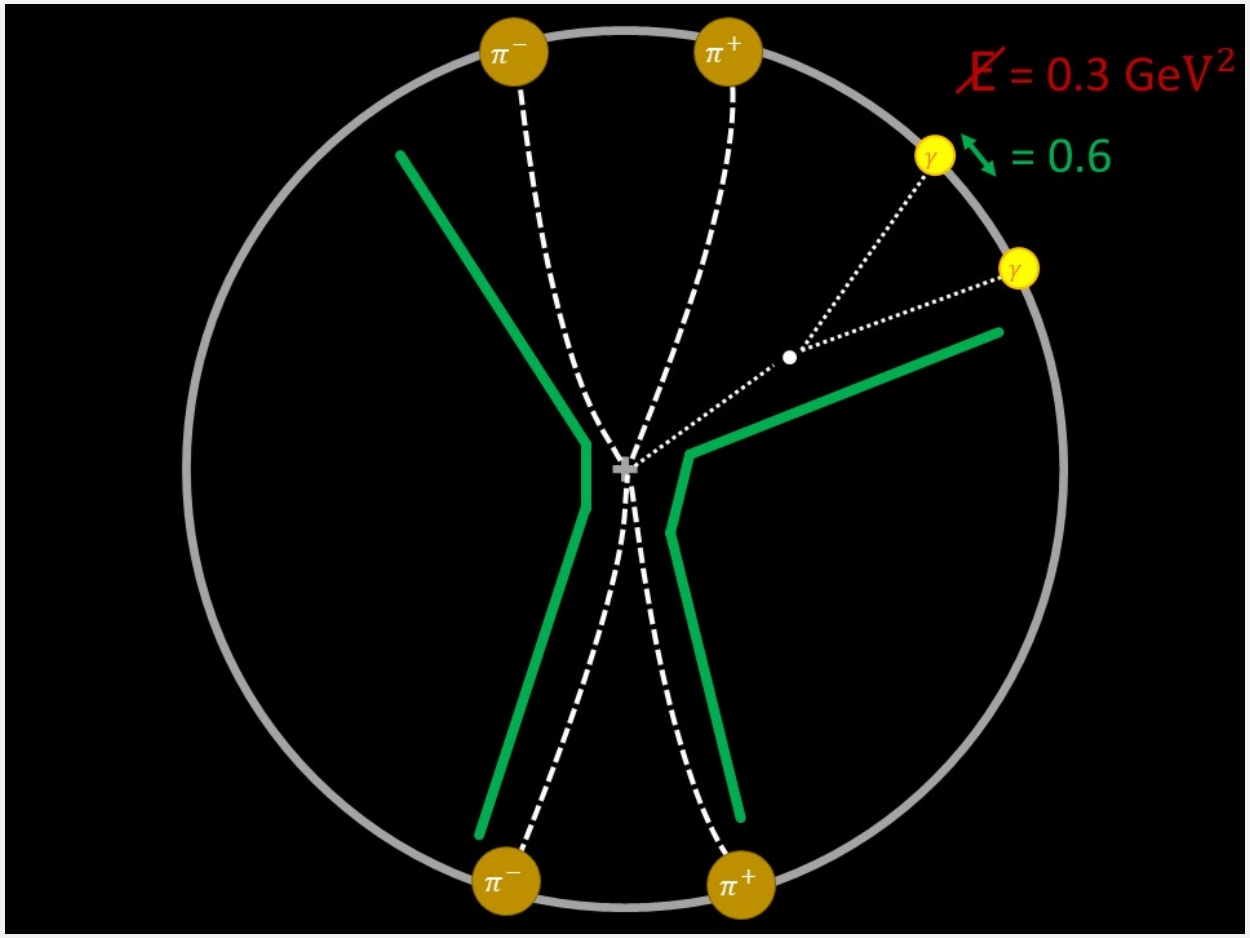


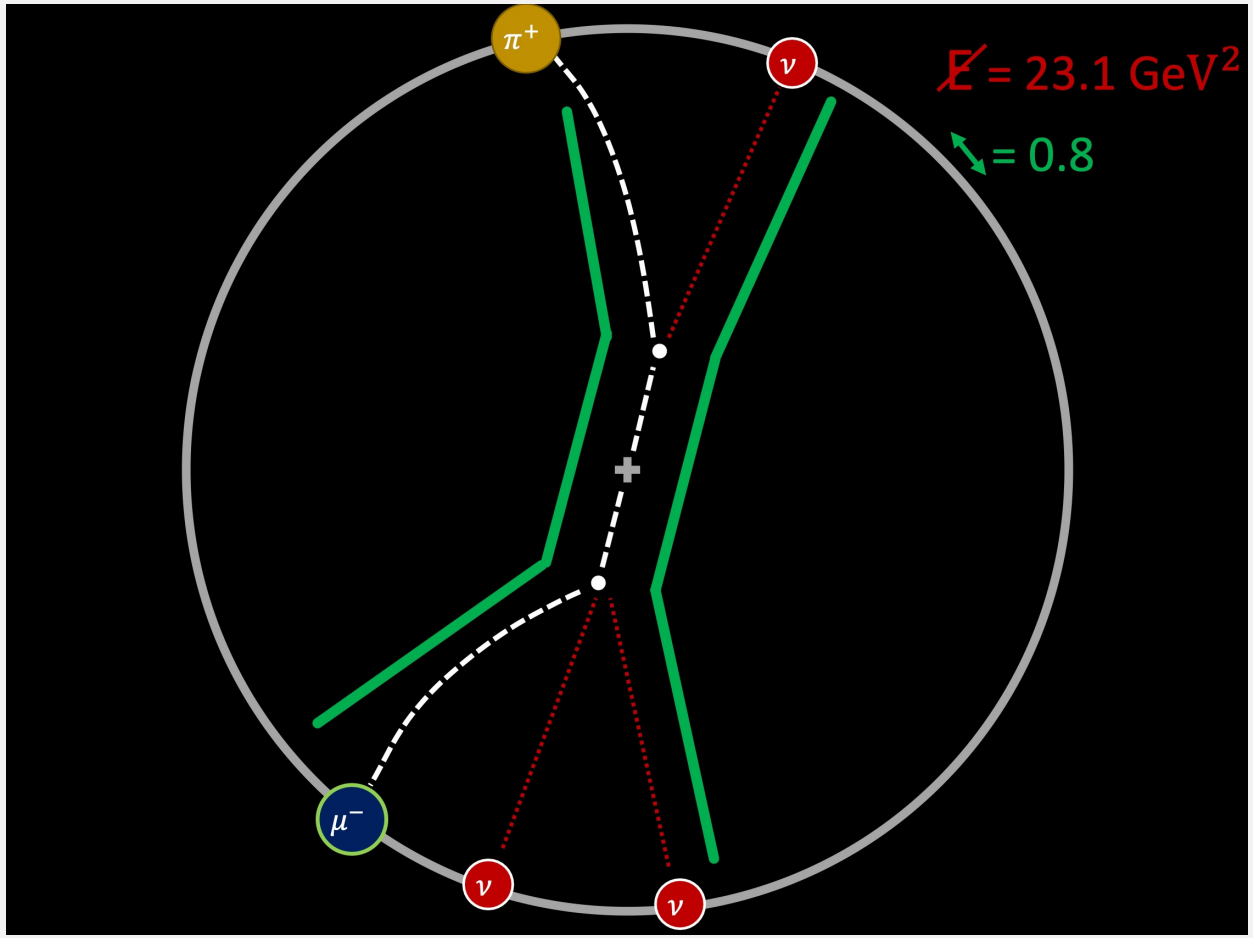
LIGHT QUARKS VS BOTTOM QUARKS





LIGHT QUARKS VS TAUS





[Link to YouTube example vids]

[Link to practise events]