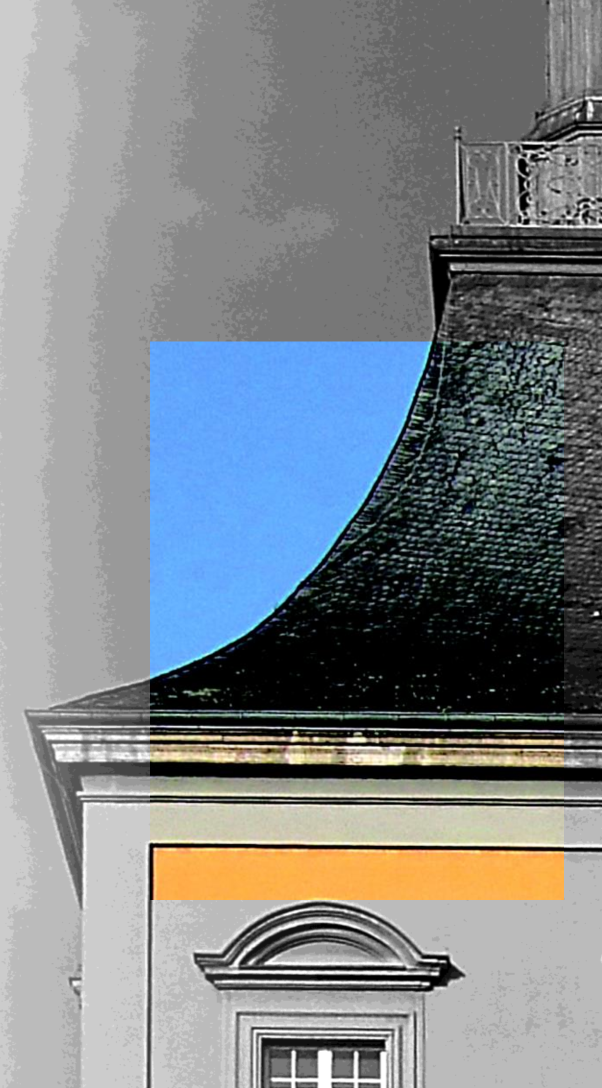
INTRODUCTION TO THE ANALYSIS OF BELLE II DATA (PT 2)

BELLE-II MASTERCLASS



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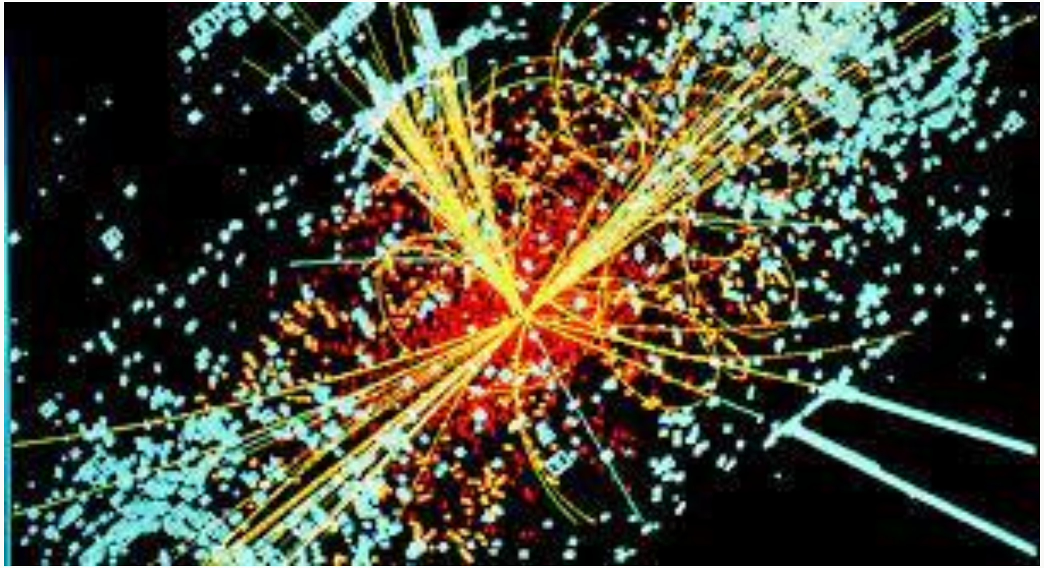
Belle II

AIM:

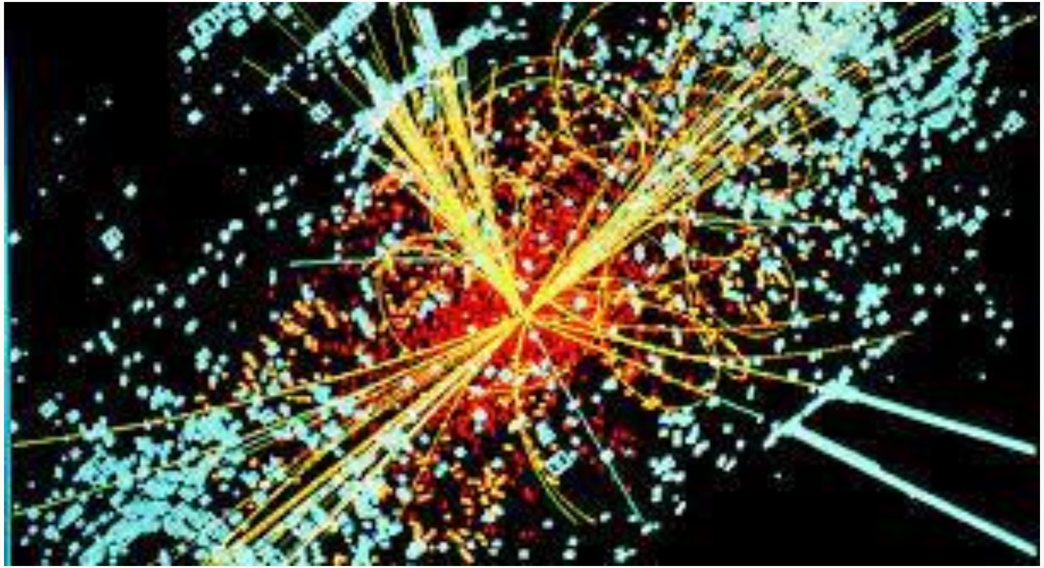
LEARN TO DIFFERENTIATE INDIVIDUAL EVENTS IN THE DETECTOR

PARTICLE COLLISIONS



PARTICLE COLLISIONS

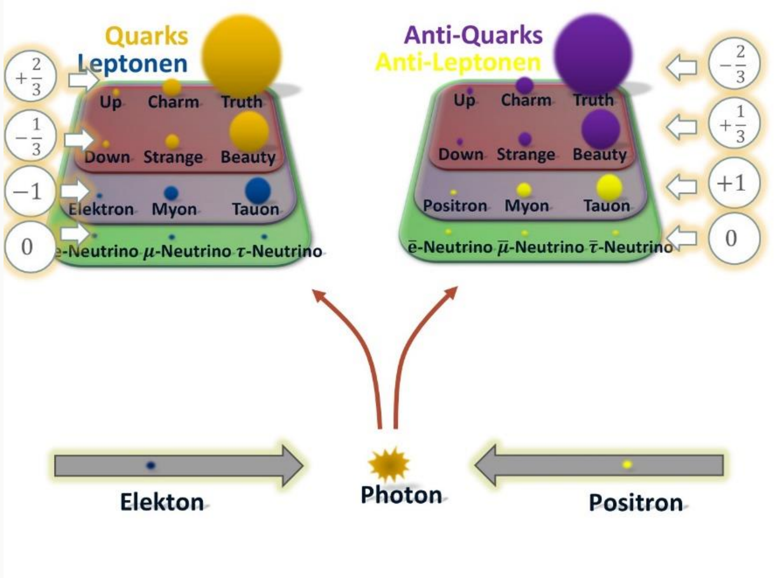
- What happens here actually?



PARTICLE COLLISIONS

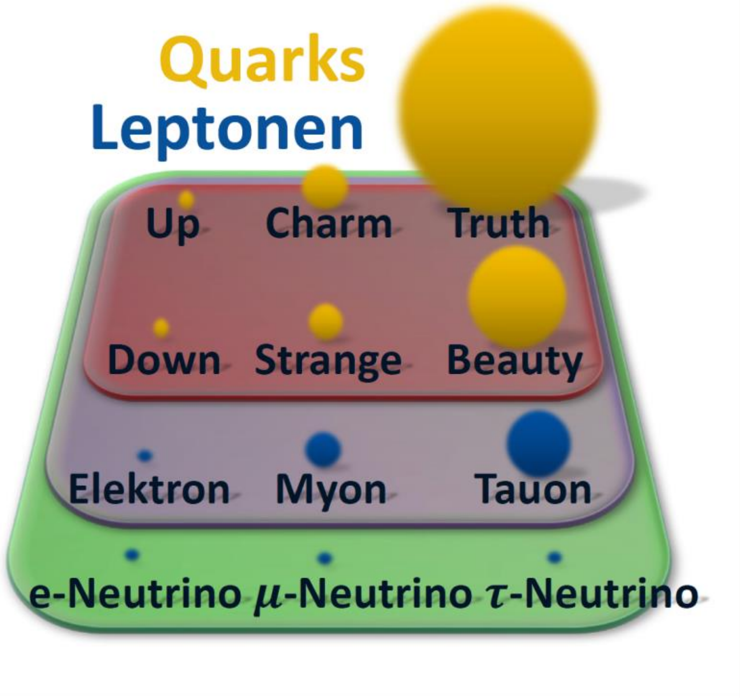
- Electrons are *annihilated* -> photons.
- Particle/antiparticle events are created.

→ Analysis



PARTICLE COLLISIONS

- What are the possible outcomes?
  - Electron/positron events
  - Muon/antimuon events
  - Tauon/antitauon events
  - Light quark/antiquark events
  - b quark/b antiquark events



PARTICLE COLLISIONS

- Two questions:
  - How to identify and differentiate the events?
  - Which events can we use for analysis?

WHICH EVENTS CAN WE USE FOR ANALYSIS?

- The R-value

$$R = \frac{N\left(e^+e^- \to \gamma \to u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}\right)}{\frac{1}{2}\cdot\left[N\left(e^+e^- \to \gamma \to \mu^+\mu^-\right) + N\left(e^+e^- \to \gamma \to \tau^+\tau^-\right)\right]} = 10/3$$

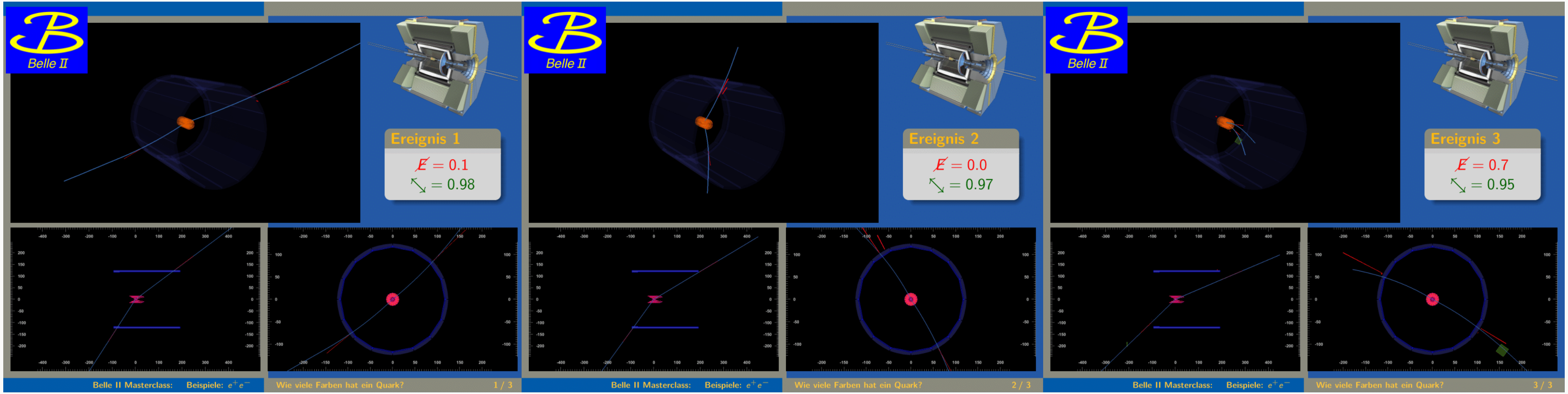
WHICH EVENTS CAN WE USE FOR ANALYSIS?

- But what about…
  - Electron/positron events?
  - b quark/b antiquark events?

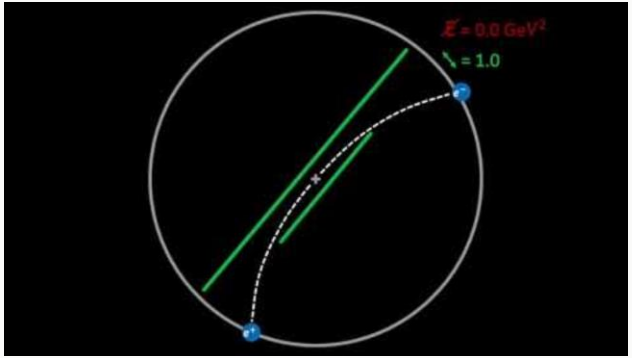
EVENT DISCRIMINATION – EVENT DISPLAYS

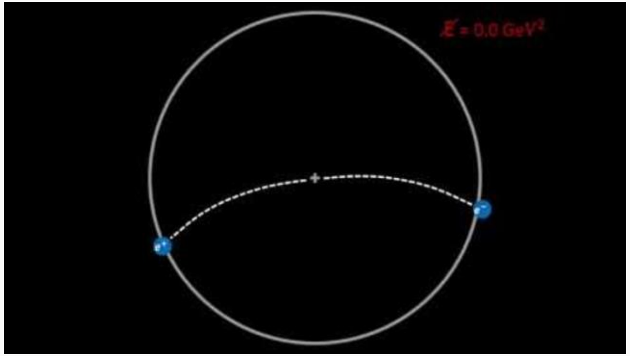
1. Electron/positron events
2. Muon/antimuon events
3. Tauon/antitauon events
4. Light quark/antiquark events
5. b quark/b antiquark events

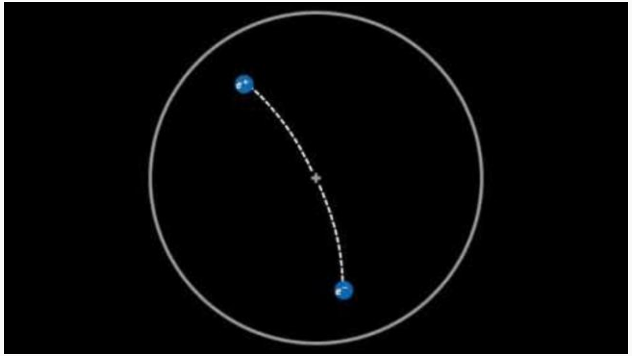
ELECTRON/POSITRON EVENTS



ELECTRON/POSITRON EVENTS







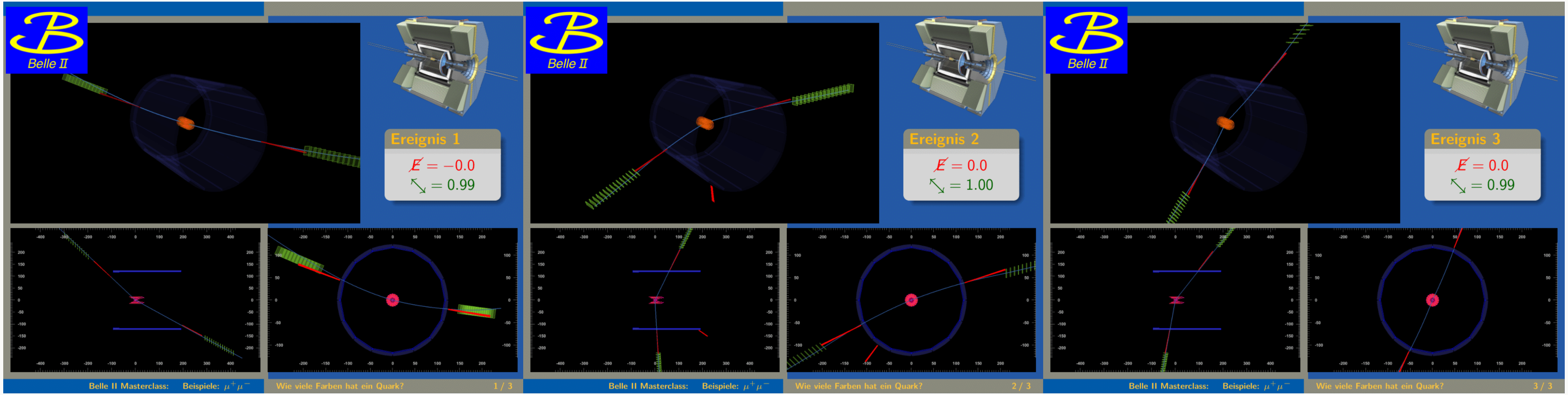
ELECTRON/POSITRON EVENTS

- Two clearly recognisable tracks
- Red energy deposits (in the calorimeter)
- No or only a few green detections
- Little missing energy
- Large straightness

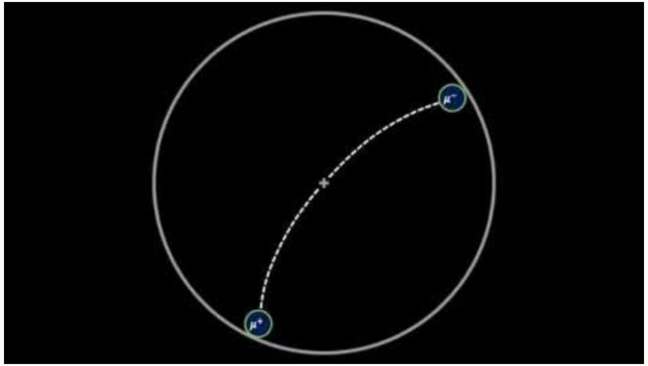
ELECTRON/POSITRON EVENTS

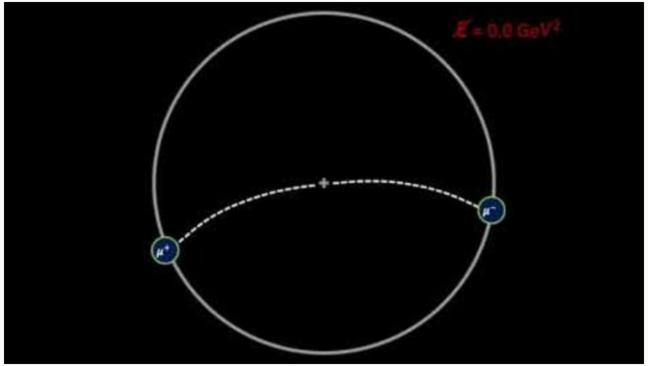
- Why are electron/positron events missing in our formula for the R-value?
  - Scattering instead of annihilation.
  - Muons are far more easier to distinguish.

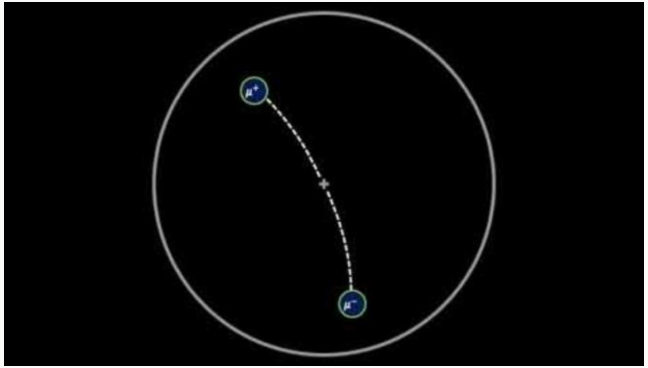
MUON/ANTIMUON EVENTS



MUON/ANTIMUON EVENTS

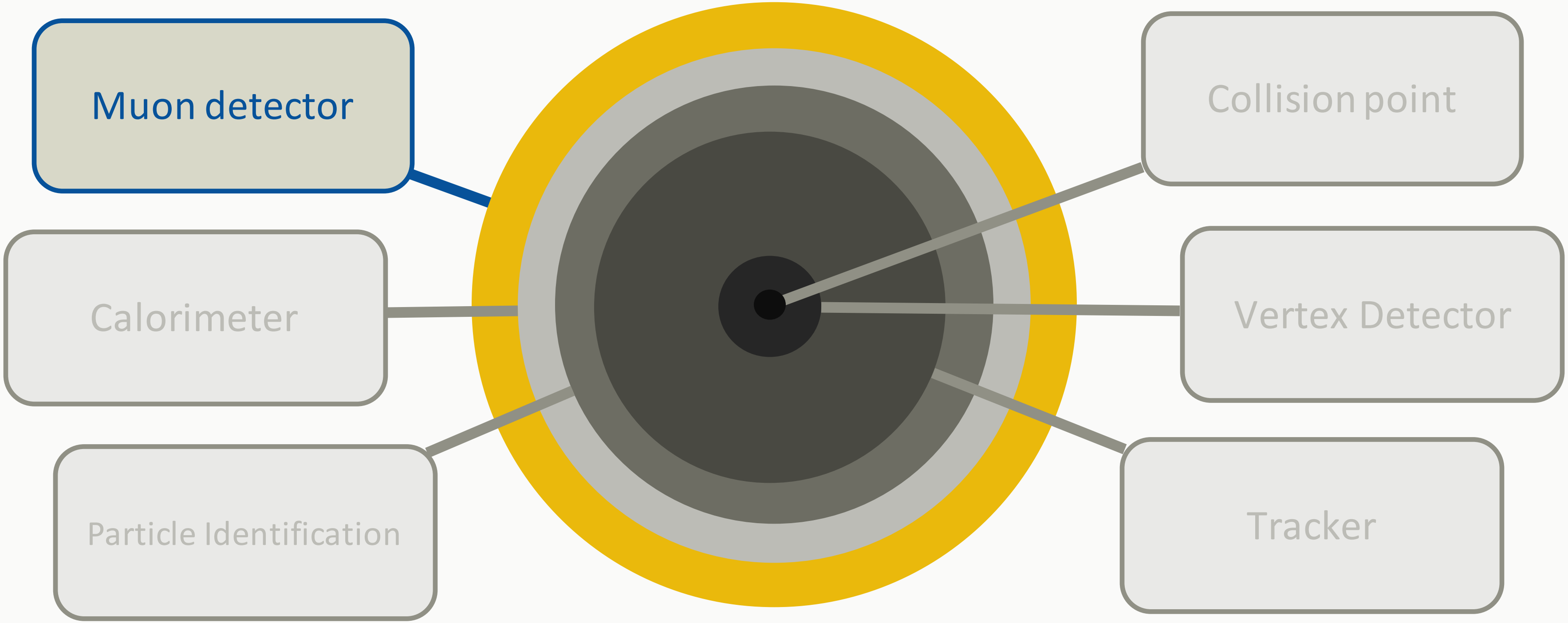






WHERE DO THESE SIGNALS COME FROM?

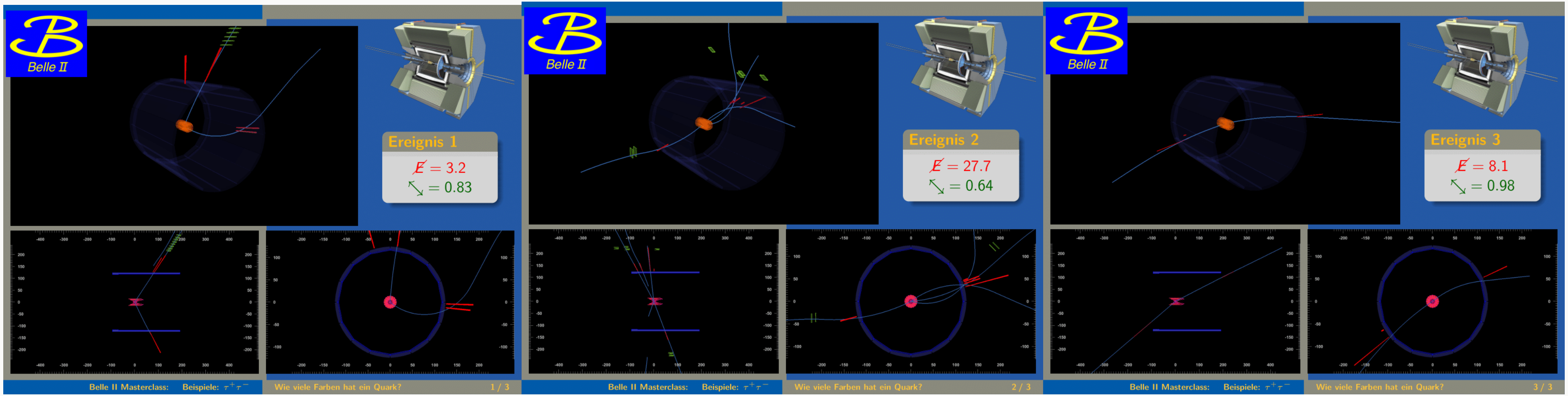
– Detector using the onion-shell principle around the collision point



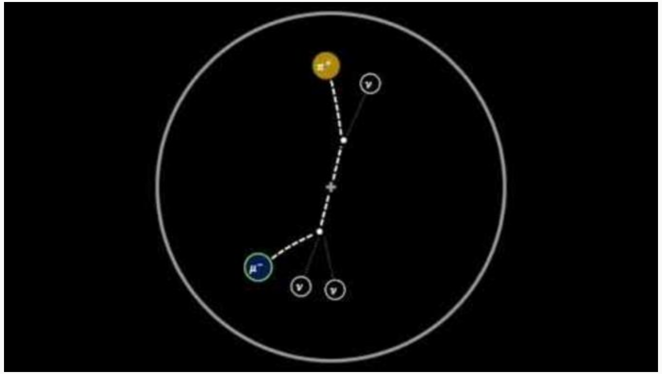
MUON/ANTIMUON EVENTS

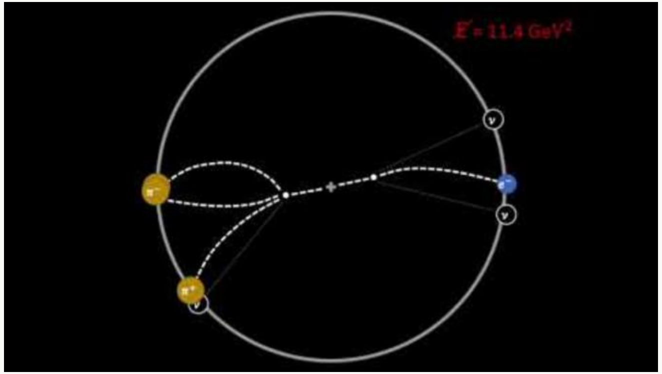
- Events are very easy to recognize due to the characteristic track
- Two clear tracks
- Green detections (Breakthrough electromagnetic calorimeter)
- Little missing energy
- Large straightness

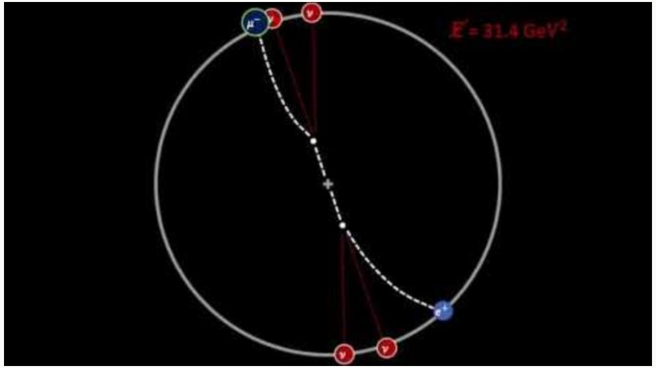
TAUON/ANTITAUON EVENTS



TAUON/ANTITAUON EVENTS







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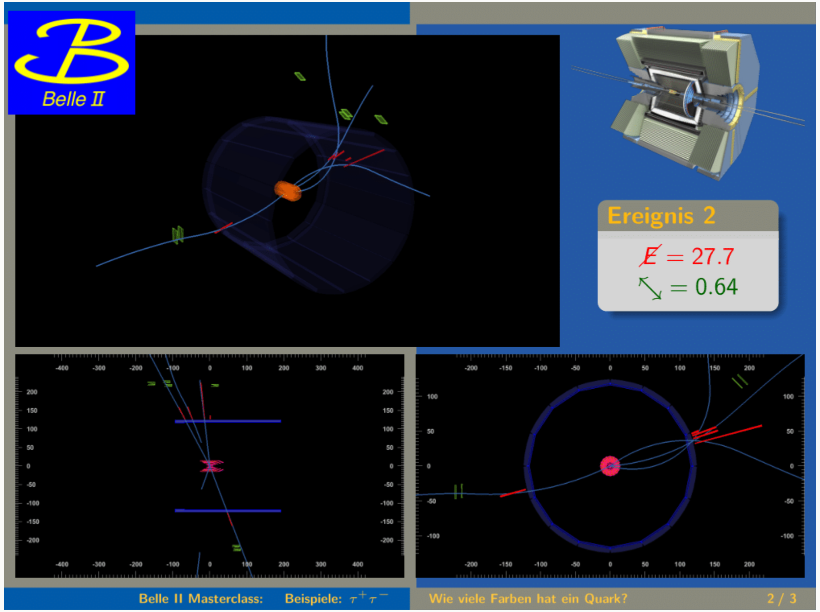
MISSING ENERGY: $\not{E}$

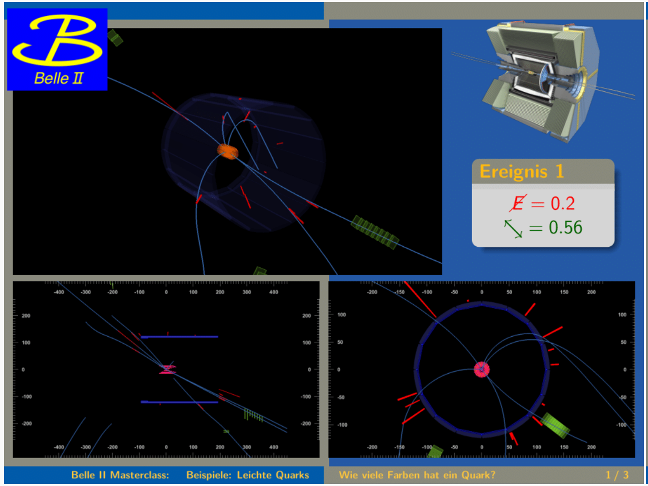


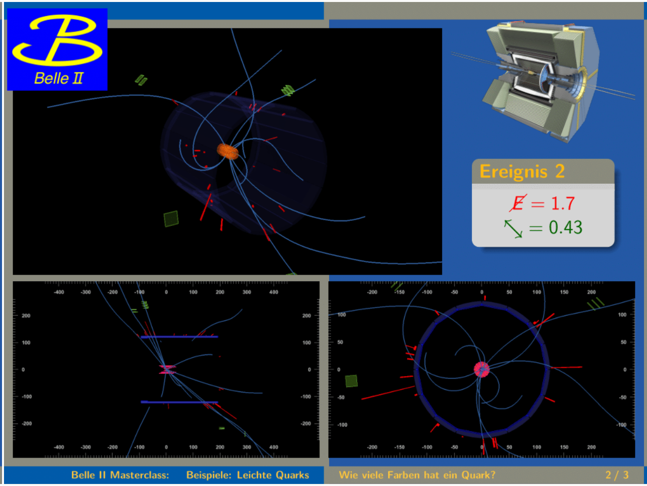
- We know the energy in the accelerator (initial state)
- Energy-momentum conservation
- Neutrinos -> $\not{E}$ in GeV^2
- Neutrinos don't interact & therefore cannot be detected -> particles are missing

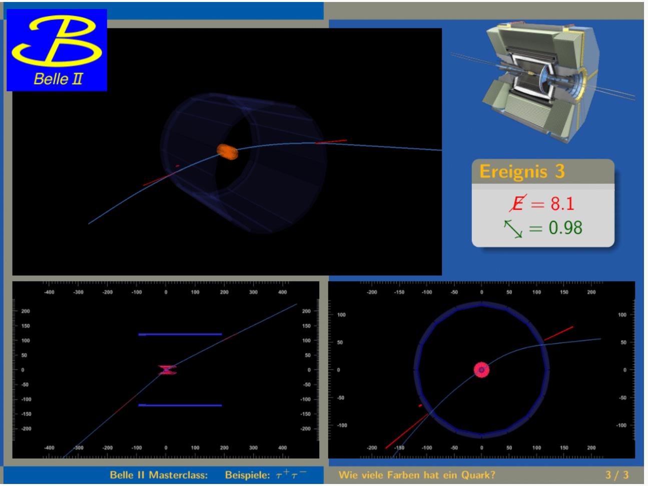
TAUON/ANTITAUON EVENTS

- Decay just after production in the detector
- Decay products are important
  - Electron and muon + neutrinos (leaving undetected)
  - Light quarks + neutrino
- A lot of missing energy (due to neutrinos)
- Large straightness

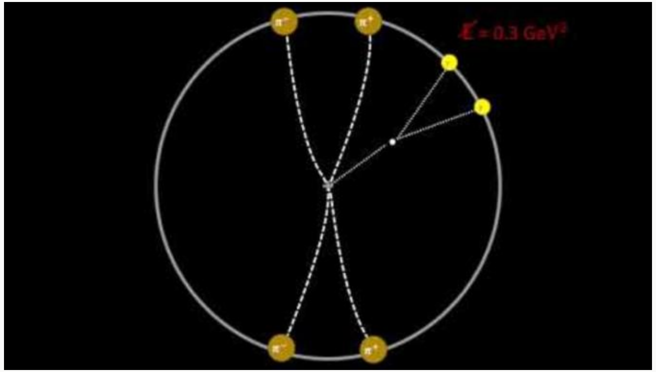
LIGHT QUARK/ANTIQUARK EVENTS

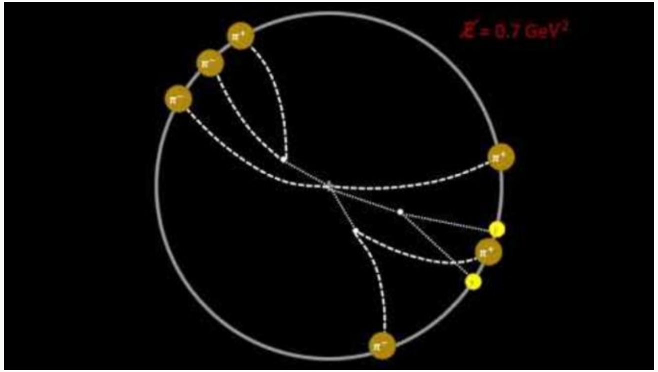


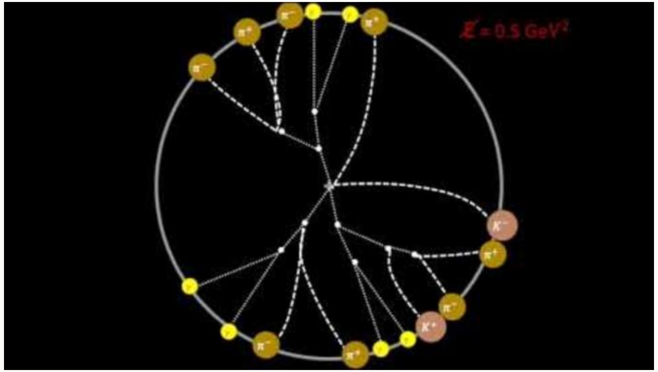




LIGHT QUARK/ANTIQUARK EVENTS



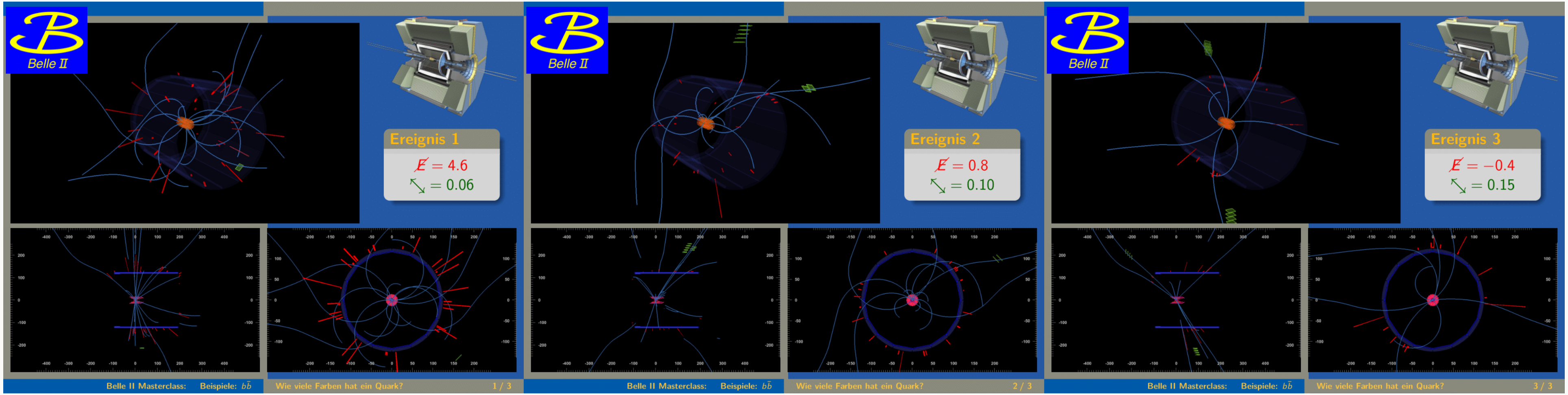




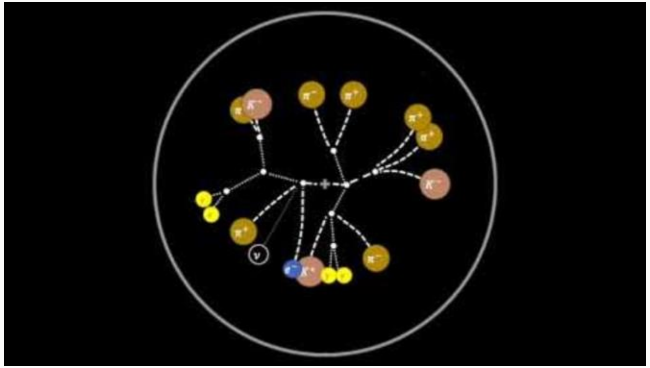
LIGHT QUARK/ANTIQUARK EVENTS

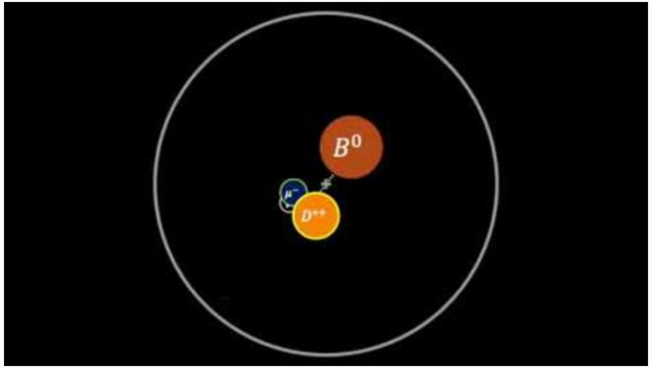
- Variety of possible events
- Distinction from tauon/antitauon or “heavy” b/anti-b quark events difficult
- Less neutrinos -> less missing energy
- If many tracks: larger straightness compared to b/anti-b quark events

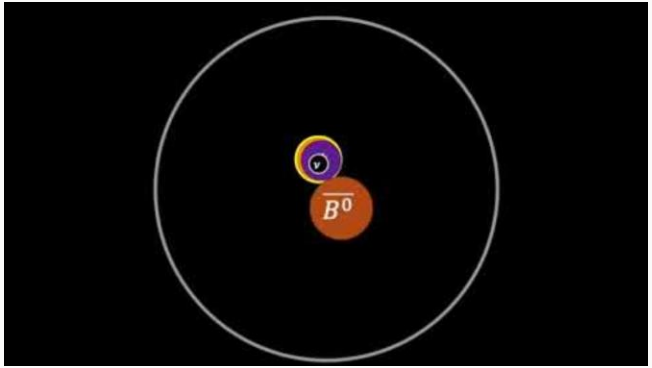
B QUARK/B ANTIQUARK EVENTS



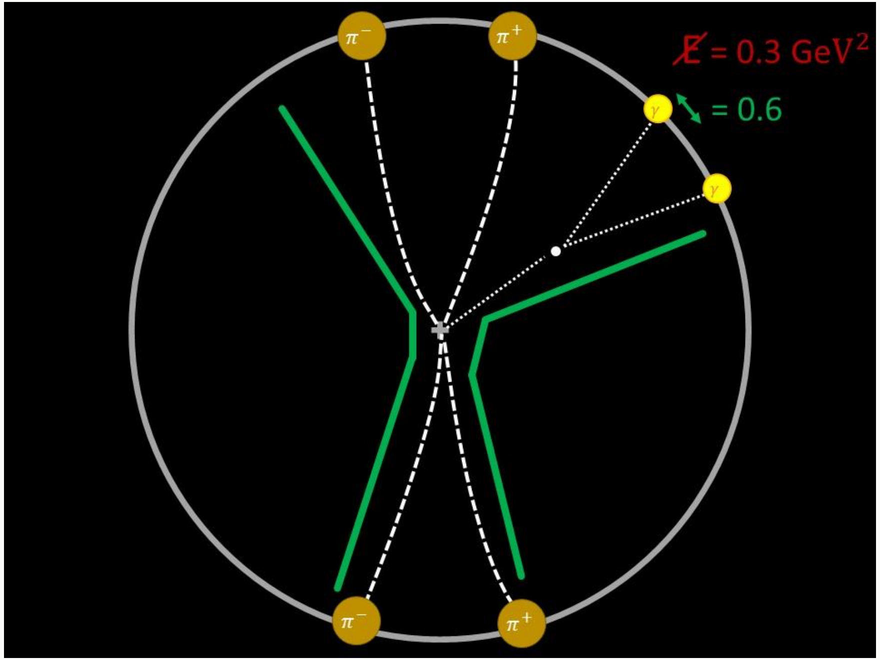
B QUARK/B ANTIQUARK EVENTS

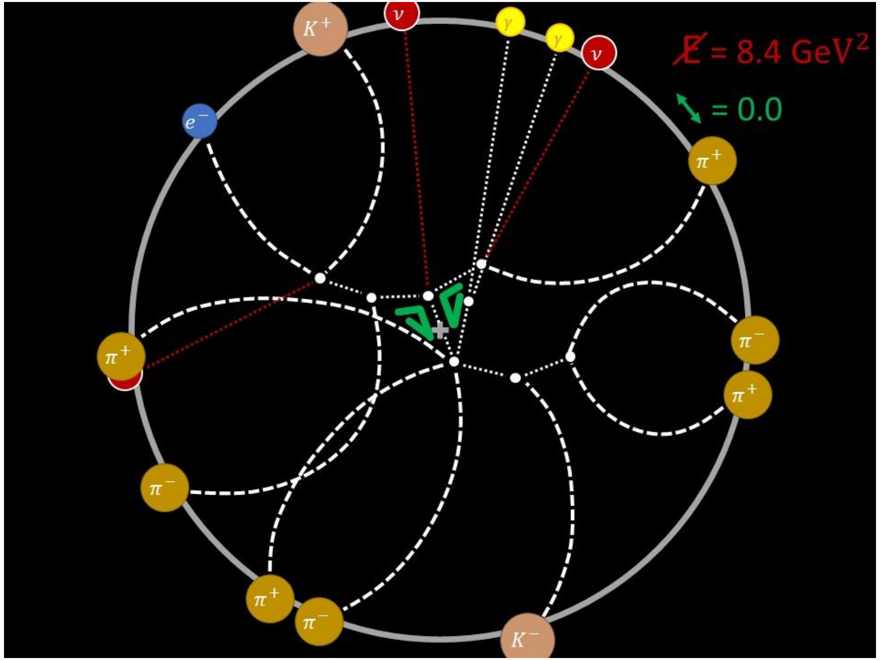




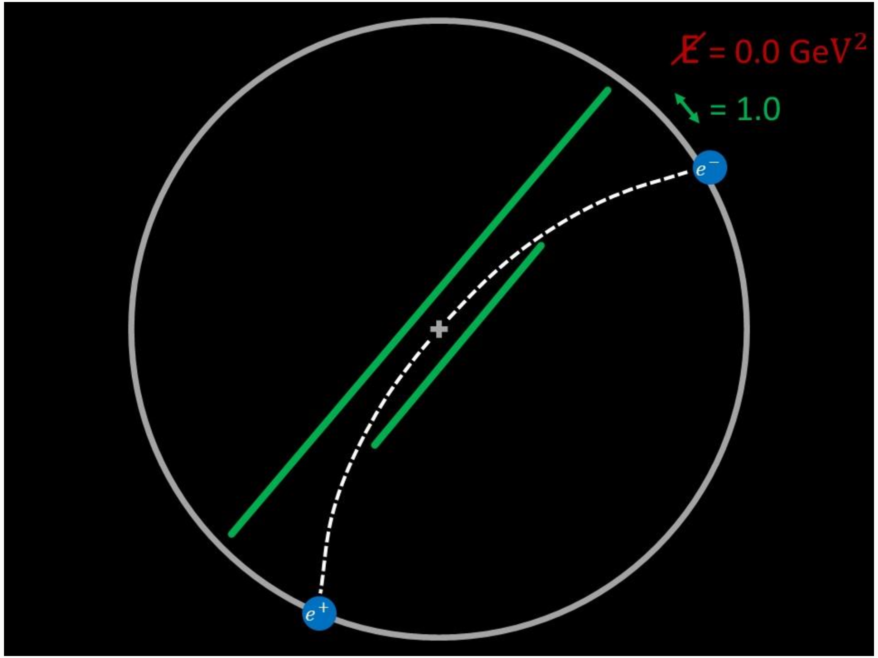


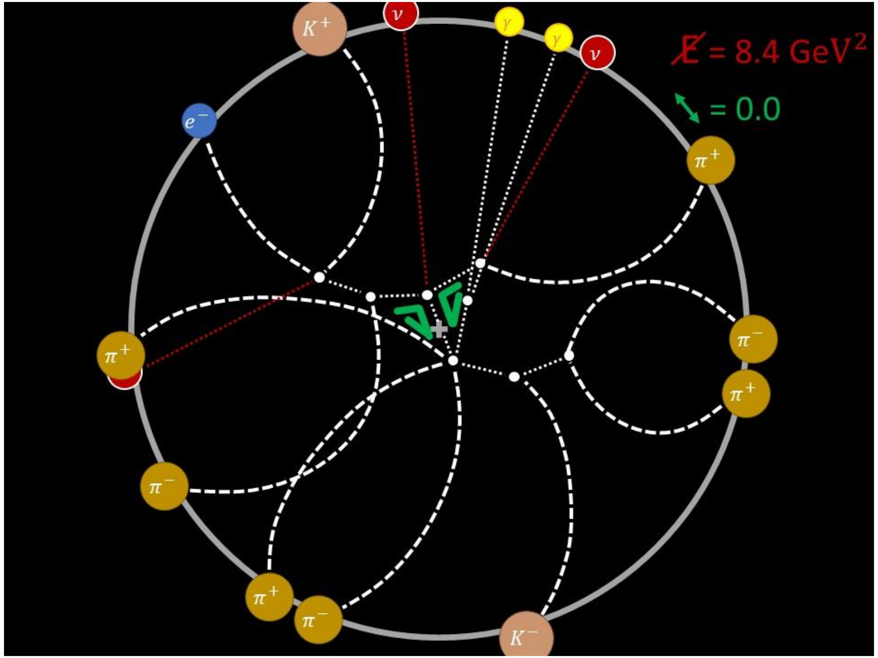
STRAIGHTNESS: ⤡
LIGHT QUARKS AND B QUARKS IN COMPARISON





STRAIGHTNESS: ⤡
LIGHT QUARKS AND B QUARKS IN COMPARISON





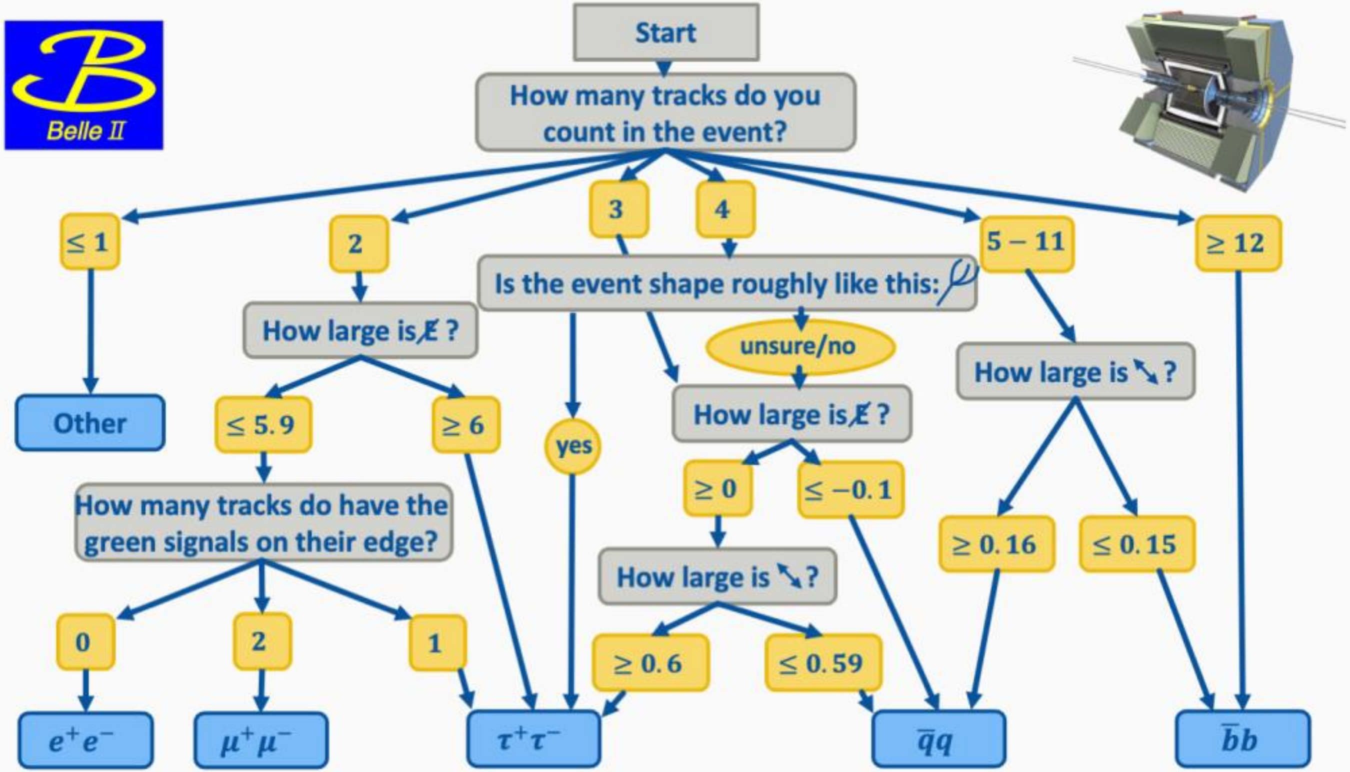
B QUARK/B ANTIQUARK EVENTS

- The heaviest particles in the Belle II detector decay "quickly" in all directions
- A lot of energy -> many particles -> many tracks
- Collision energy of SuperKEKB accelerator almost equal to energy of first “B-mesons”, i.e. mesons that contain b-quarks
- Belle-II experiment -> “B-factory”: produces often b/anti-b quarks at resonance energy
- Smaller straightness than in light quark/antiquark events

B QUARK/B ANTIQUARK EVENTS

- b quark/b antiquark events are also not included in R-value calculation
  - Resonance events

SUMMARY


Start
How many tracks do you count in the event?
≤ 1
2
3
4
5 – 11
≥ 12
Is the event shape roughly like this:
unsure/no
yes
How large is $\not{E}$?
≤ 5.9
≥ 6
How many tracks do have the green signals on their edge?
0
2
1
How large is $\not{E}$?
≥ 0
≤ −0.1
How large is ⤡ ?
≥ 0.6
≤ 0.59
How large is ⤡ ?
≥ 0.16
≤ 0.15
Other
e^+e^-
$\mu^+\mu^-$
$\tau^+\tau^-$
$\bar{q}q$
$\bar{b}b$

SUMMARY

3 main criteria:

1. # tracks
2. Missing energy: $\not{E}$
3. Straightness: ⤡

&

Visual measures (muons, tauons)

Thanks for your attention!

Now it's your turn!

Open the website & start with example events!