



HOW MANY COLORS DOES A QUARK COME IN?

A MEASUREMENT USING DATA FROM THE BELLE II EXPERIMENT FOR
THE TEILCHENPHYSIK-MASTERCLASSES

Florian Bernlochner, Jochen Dingfelder, Svenja Granderath¹,
Henrik Junkerkalefeld, Sebastian Lülsdorf, Florin Martius,
Barbara Valeriani-Kaminski, Christian Wessel

¹granderath@physik.uni-bonn.de

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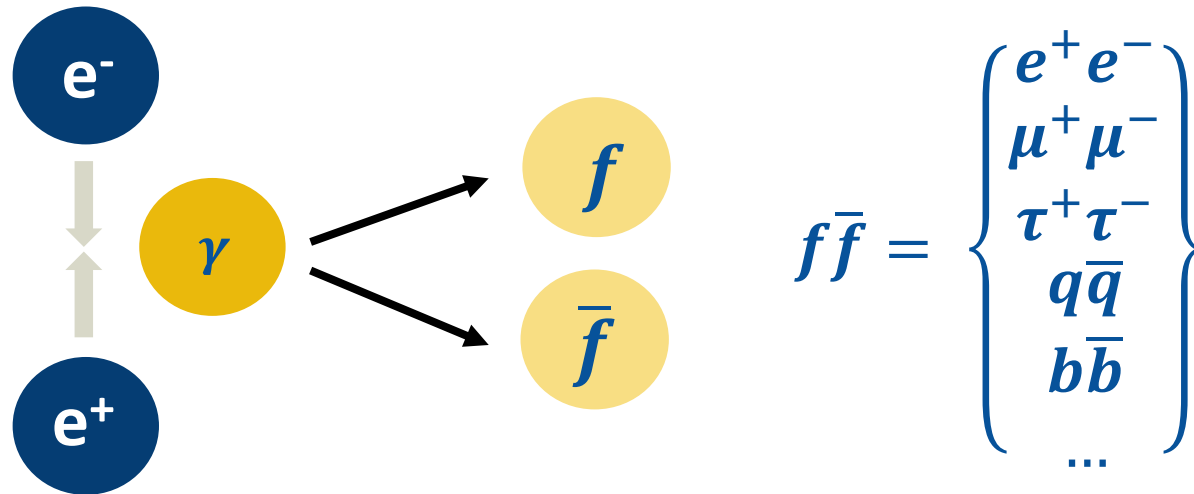
WHAT IS A MASTERCLASS?

- Offers high school students an insight into physics research
- Researchers spend one day with the students
- Combination of talks and hands-on work
- Netzwerk Teilchenwelt:
 - Organizes opportunities for students interested in particle physics
 - Developed a new masterclass based on Belle II data



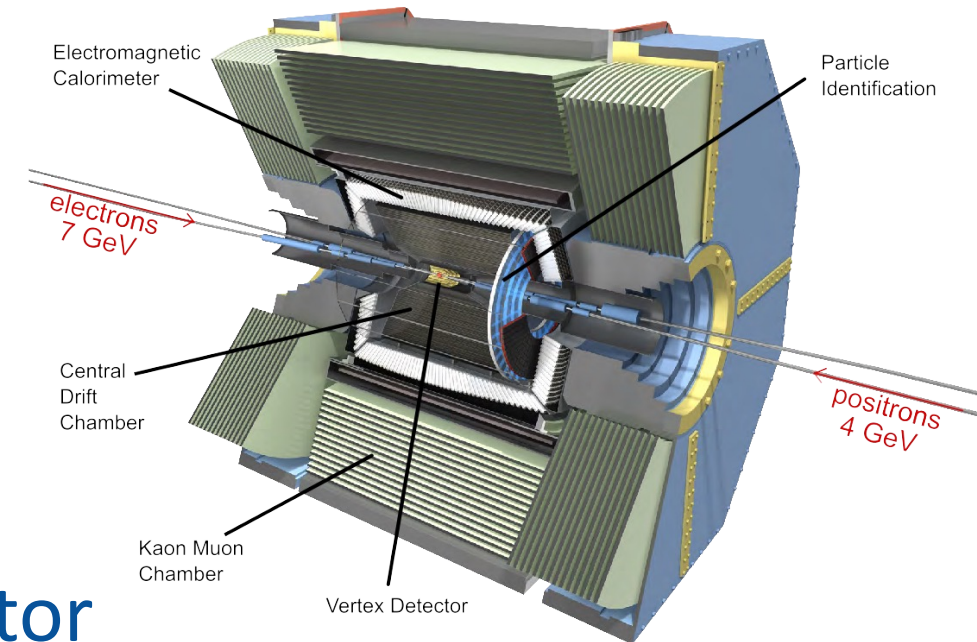
NETZWERK
TEILCHENWELT

- SuperKEKB accelerator located in Japan
- e^+e^- collider tuned to produce $B\bar{B}$ pairs
- Other processes occur also:



Study CP violation
Look for new physics

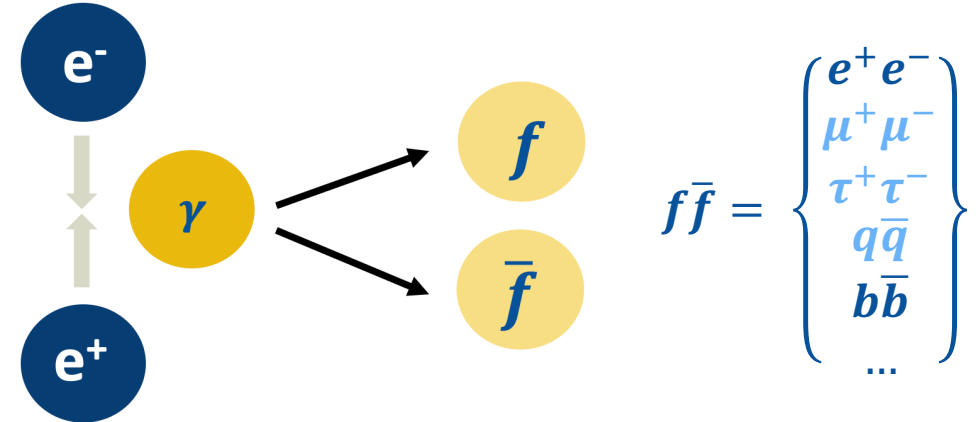
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- Decay products detected by Belle II detector

- By counting frequency of processes can determine R value:

$$R = \frac{N(q\bar{q})}{0.5 N(\tau^+\tau^- + \mu^+\mu^-)}$$



- R value determined by **electric quark charges** and **number of colors**:

$$R = N_c \sum_{\text{quarks}} q_{q\bar{q}}^2 = \frac{10}{9} N_c$$

- Can determine the number of quark color charges

COMPONENTS

1. Introductory talks



COMPONENTS

1. Introductory talks

2. Worksheet



Belle II Masterclass What happens in e^+e^- collisions? Quark colors and the R value

Exercise a)

According to the calculation of above's example, try to answer the following: What is the frequency of occurrence for the following particle-antiparticle pairs:

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}) = \boxed{}_{XY}$$

$$N(e^+e^- \rightarrow \gamma \rightarrow s\bar{s}) = \boxed{}_{XY}$$

$$N(e^+e^- \rightarrow \gamma \rightarrow \tau^+\tau^-) = \boxed{}_{XY}$$

Exercise b)

Maybe you already spotted some regularities. Let's turn this around: For which particle-antiparticle pairs is the frequency of occurrence given by the following?

$$N(e^+e^- \rightarrow \gamma \rightarrow P\bar{P}) = \left(\frac{2}{3}\right)^2 \cdot XY = \frac{4}{9} \cdot XY \quad P = \boxed{} \boxed{} \boxed{}$$

Exercise c)

To be able to create a particle-antiparticle pair, the energy needs to be sufficiently high. Let's assume that we build a particle accelerator that produces enough energy in the collision point to (only) produce u -, d - and s -quarks (+ anti quarks). What is the total frequency of occurrence of the overall quark production in this case? **Hint:** You might want to calculate this in a couple of steps on a note pad.

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}) = \boxed{}_{XY}$$


How does this change when we increase the collision energy sufficiently such that the production of c -quarks becomes possible as well?

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}) = \boxed{}_{XY}$$

COMPONENTS

1. Introductory talks
2. Worksheet
3. Interactive quizzes

What is the electric charge of the tau-lepton?



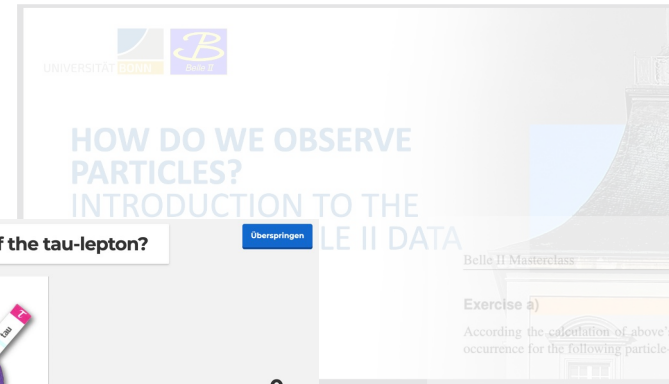
18

0 Antworten

▲ +2/3 e ◆ -1 e

● +1 e ■ -1/3 e

Überspringen



UNIVERSITÄT BONN

HOW DO WE OBSERVE PARTICLES?
INTRODUCTION TO THE BELLE II DATA

Belle II Masterclass What happens in e^+e^- collisions? Quark colors and the R value

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Exercise b)

Maybe you already spotted some regularities. Let's turn this around: For which particle-antiparticle pairs is the frequency of occurrence given by the following?

$$N(e^+e^- \rightarrow \gamma \rightarrow P\bar{P}) = \left(\frac{2}{3}\right)^2 \cdot XY = \frac{4}{9} \cdot XY \quad P = \boxed{} \boxed{} \boxed{}$$

Exercise c)

To be able to create a particle-antiparticle pair, the energy needs to be sufficiently high. Let's assume that we build a particle accelerator that produces enough energy in the collision point to (only) produce u -, d - and s -quarks (+ anti quarks). What is the total frequency of occurrence of the overall quark production in this case? **Hint:** You might want to calculate this in a couple of steps on a note pad.

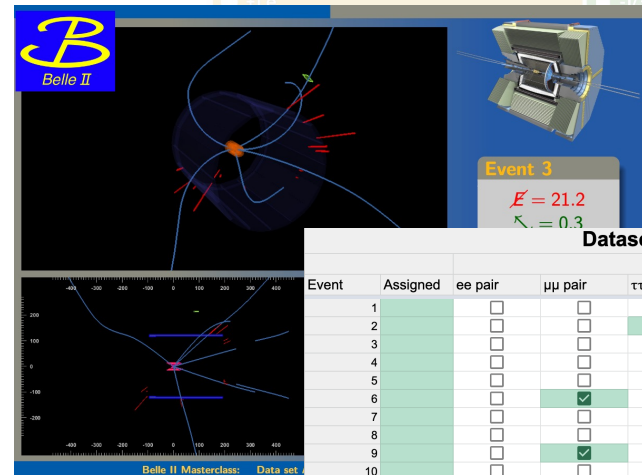
$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}) = \boxed{} XY$$

How does this change when we increase the collision energy sufficiently such that the production of c -quarks becomes possible as well?

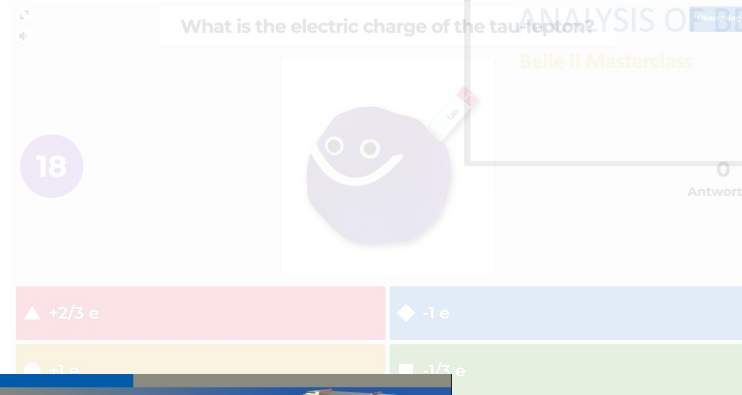
$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}) = \boxed{} XY$$

COMPONENTS

1. Introductory talks
2. Worksheet
3. Interactive quizzes
4. Data Analysis



Event	Assigned	Event type					
		ee pair	$\mu\mu$ pair	$\tau\tau$ pair	qq pair	bb pair	Other
1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
5	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
11	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
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19	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



Belle II Masterclass: What happens in e^+e^- collisions? Quark colors and the R value

Exercise a)
 According to the calculation of above's example, try to answer the following: What is the frequency of occurrence for the following particle-antiparticle pairs:

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}) = \boxed{} XY$$

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$$N(e^+e^- \rightarrow \gamma \rightarrow c^+\bar{c}^-) = \boxed{} XY$$

Exercise b)
 Maybe you already spotted some regularities. Let's turn this around: For which particle-antiparticle pairs is the frequency of occurrence given by the following?

$$N(e^+e^- \rightarrow \gamma \rightarrow P\bar{P}) = \left(\frac{2}{3}\right)^2 \cdot XY = \frac{4}{9} XY \quad P = \boxed{} \boxed{} \boxed{}$$

Exercise c)
 To be able to create a particle-antiparticle pair, the energy needs to be sufficiently high. Let's assume that we build a particle accelerator that produces enough energy in the collision point to (only) produce u - and s -quarks (+ anti quarks). What is the total frequency of occurrence of the overall quark production in this case? Hint: You might want to calculate this in a couple of steps on a note pad.

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}) = \boxed{} XY$$

How does this change when we increase the collision energy sufficiently such that the production of c -quarks becomes possible as well?

$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}) = \boxed{} XY$$

COMPONENTS

1. Introductory talks
2. Worksheet
3. Interactive quizzes
4. Data Analysis
5. Discussion



HOW DO WE OBSERVE PARTICLES? INTRODUCTION TO THE ANALYSIS OF BELLE II DATA

Belle II Masterclass

What happens in e^+e^- collisions? Quark colors and the R value

Exercise a)

According to the calculation of above's example, try to answer the following: What is the frequency of occurrence for the following particle-antiparticle pairs:

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$$N(e^+e^- \rightarrow \gamma \rightarrow u\bar{u}[d\bar{d}][s\bar{s}]) = \dots XY$$

How does this change when we increase the collision energy sufficiently such that the production of ...

Dataset B

Event	Assigned	ee pair	$\mu\mu$ pair	$\tau\tau$ pair	qq pair	bb pair
1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
6		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
7		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
11		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
12		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
14		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
15		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
16		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
17		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
18		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

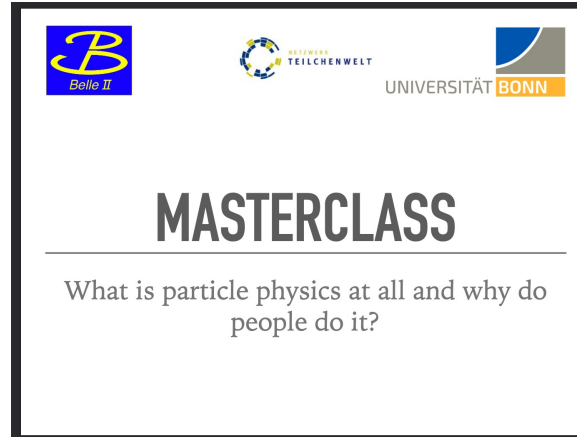
Measured Number of Quark Colors

Group	Number of quark colors
Group A	4
Group B	3.5
Group C	2.5
Group D	3.3
Group E	2
Group F	2.3
Group G	3.8
Group H	2.3
Group I	2.7
Group J	1.8
Group K	
Group L	
Group M	
Group N	
Total	2.8

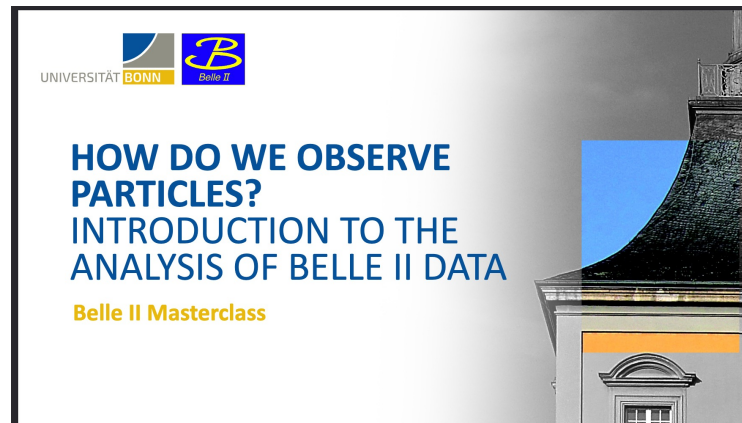
All material available in English and German

- Introduce students to particle physics and relevant concepts
- Start with familiar concepts and bring students to same level
- Prepare them for measurement
- Give opportunity to ask questions

1st Talk:

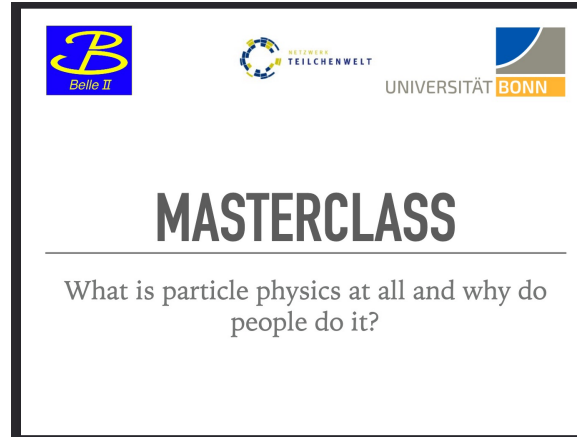


2nd Talk:



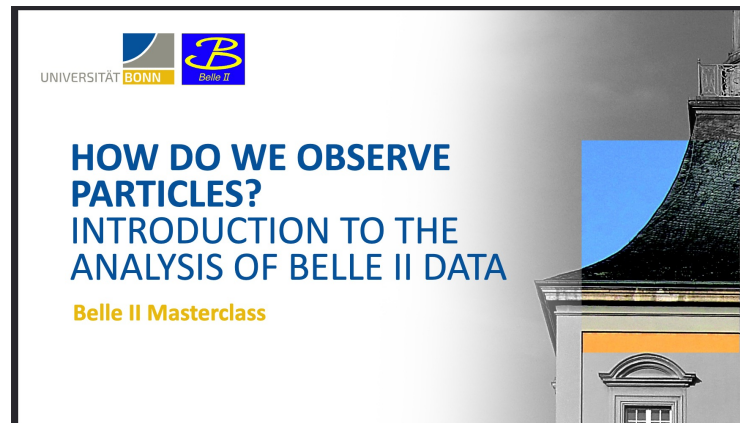
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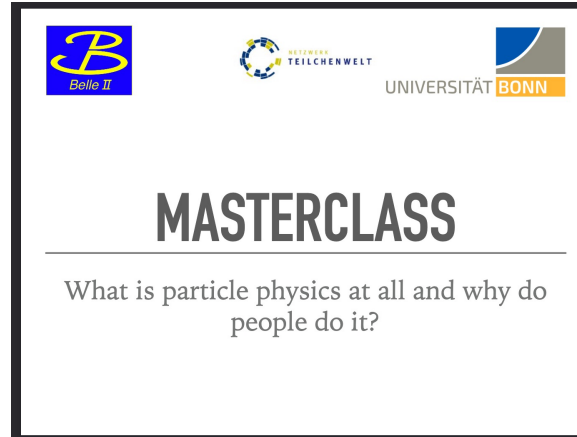
- History and status of Standard Model
- Mass-energy equivalence
- Open questions

2nd Talk:



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- Start with familiar concepts and bring students to same level
- Prepare them for measurement
- Give opportunity to ask questions

1st Talk:



- History and status of Standard Model
- Mass-energy equivalence
- Open questions

2nd Talk:



- Particle accelerators
- Particle detectors
- Distinguishing processes

- Step-by-step introduction to
 - relationship between frequency of process and electric charge
 - the R value
 - its dependence on number of colors
- Allows for discussion amongst students and deeper understanding of concepts

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- Interactive quizzes about
- Particle physics concepts
- Belle II detector
- R value
- Competitive and playful way to check understanding

What is the electric charge of the tau-lepton? Überspringen

18 


0 Antworten

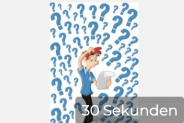
▲ +2/3 e


◆ -1 e

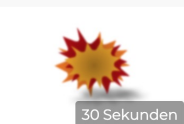
● +1 e


■ -1/3 e

4 - Quiz  30 Sekunden
What are neutrons made of?


5 - Quiz  30 Sekunden
Which force cannot be unified with the Standard Model at the moment?

6 - Quiz  30 Sekunden
How do the three generations of quarks differ?

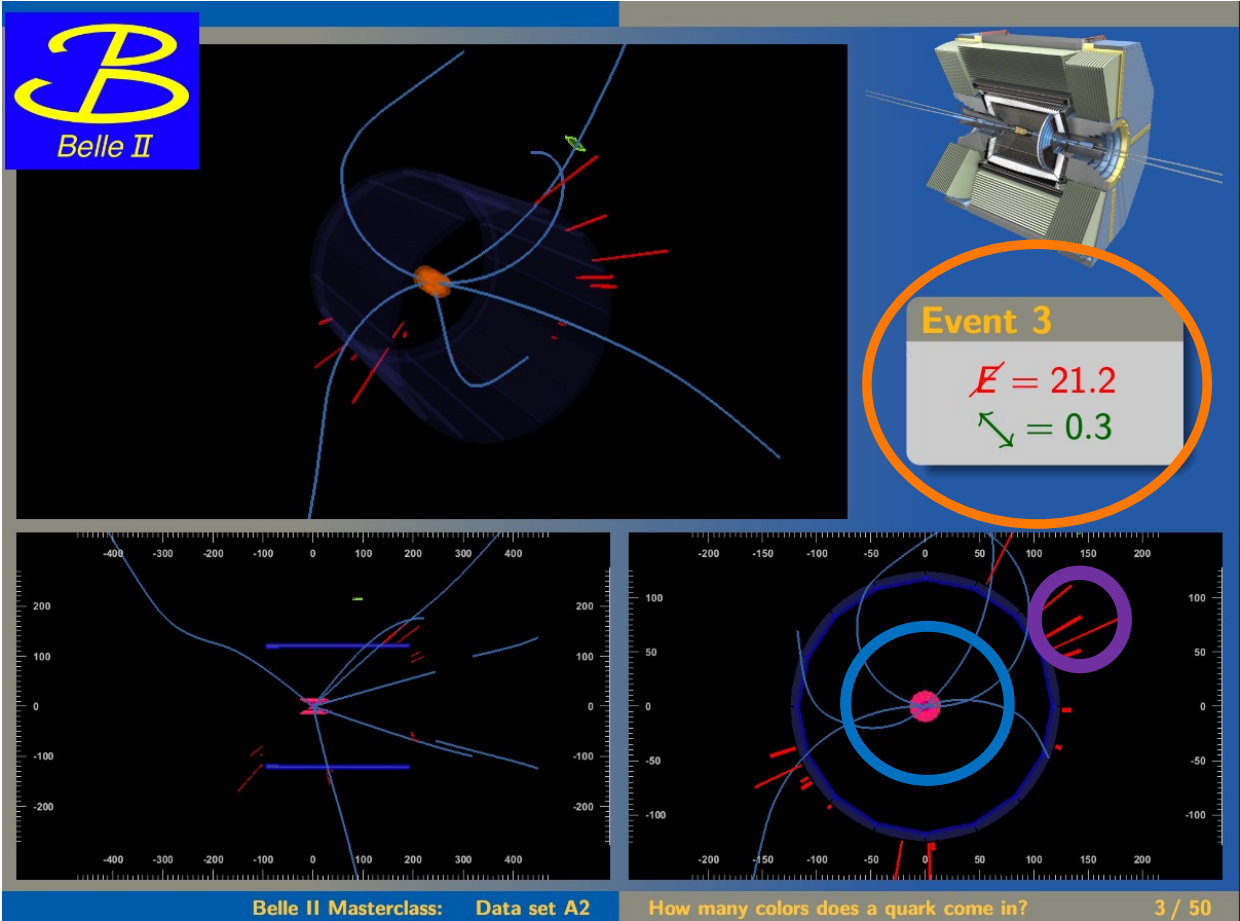
7 - Quiz  30 Sekunden
What is always created according to particle physics when matter is produced out of energy?

8 - Quiz  30 Sekunden
Why is this considered to be a "problem"?

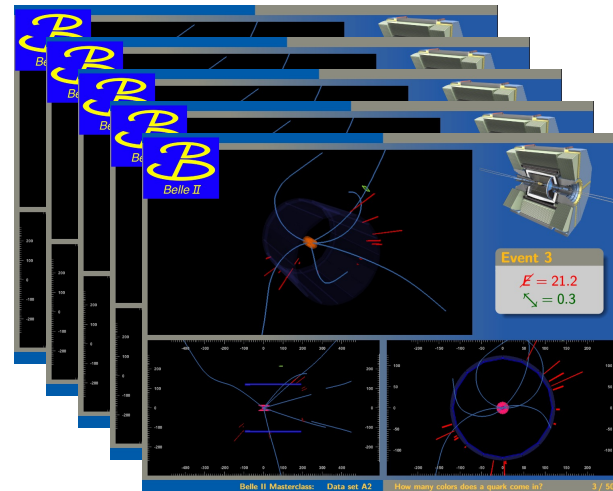
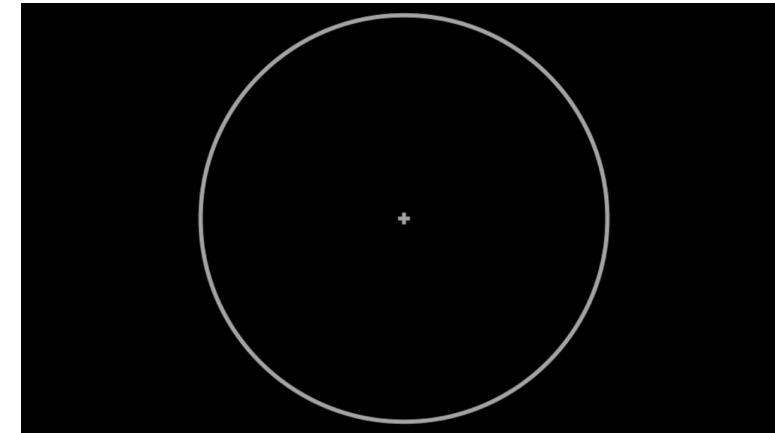
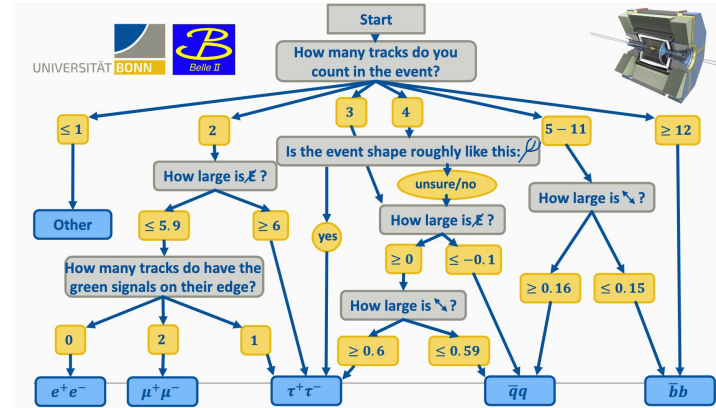
MEASUREMENT OF R VALUE

- Need to count occurrences of processes
- Introduce event displays 
- Explain how to categorise events based on:
 - Number of tracks
 - Energy deposits in calorimeter and muon detector
 - Missing energy and straightness

$$R = \frac{N(q\bar{q})}{0.5 N(\tau^+\tau^- + \mu^+\mu^-)}$$



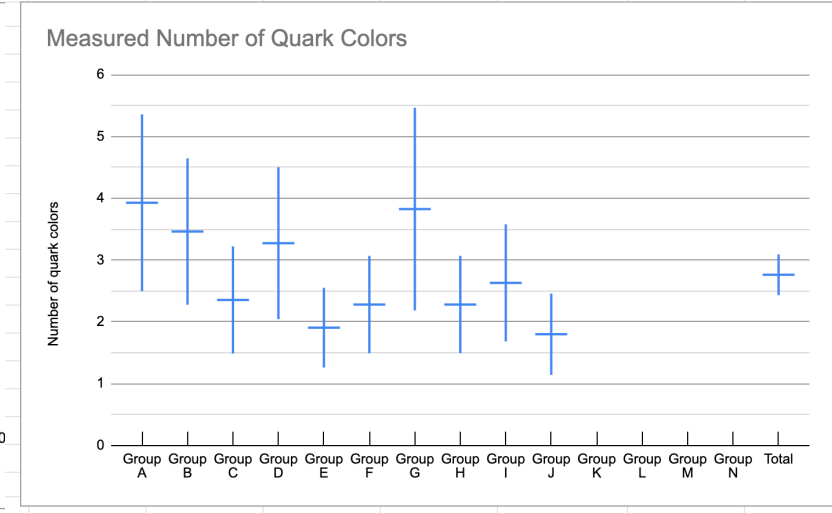
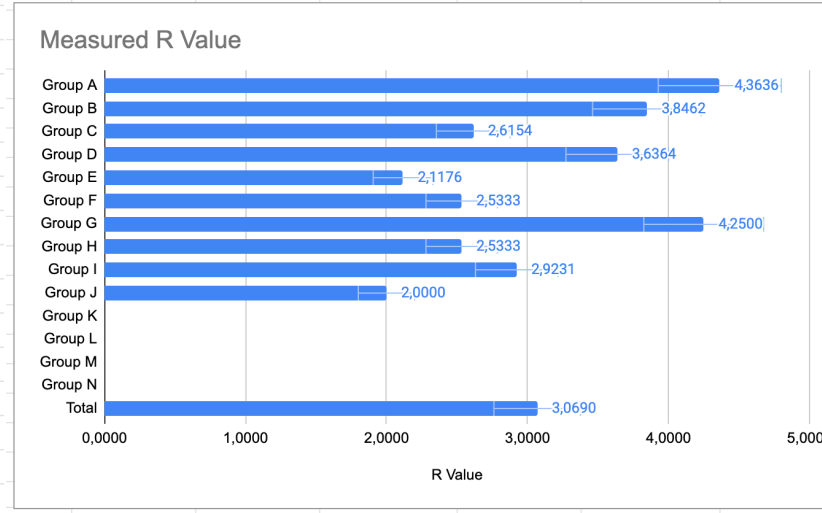
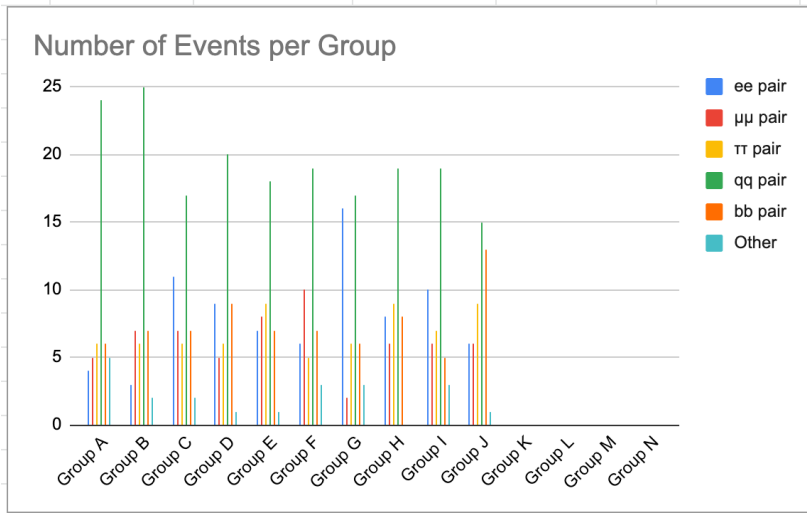
- One set of 50-100 events per pair of students
- Assistance:
 - Flow chart
 - Example videos of processes
 - Practice exercises
- Categorise events in spreadsheet



Dataset B							
Event	Assigned	Event type					
		ee pair	μμ pair	ττ pair	qq pair	bb pair	Other
1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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4	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
5	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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14	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
16	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

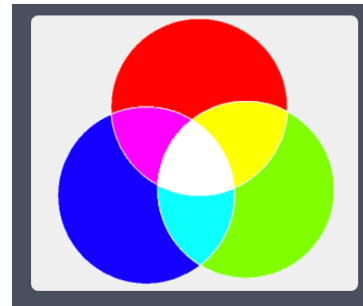
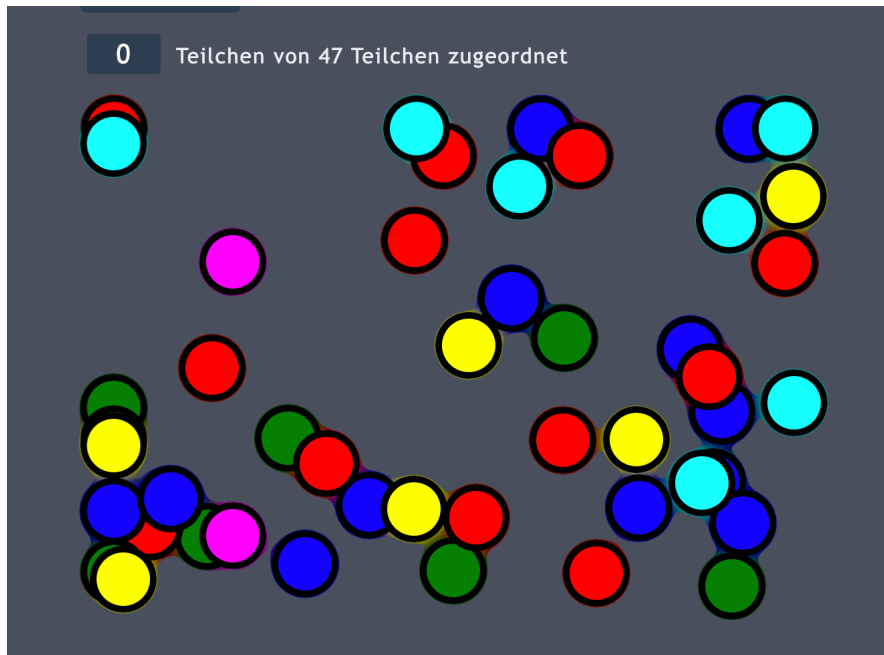
DISCUSSION OF RESULTS

- Automatic calculation of R value and number of quark colors for each group
- Error calculation included and results also combined
- Shows importance of statistics and proper error propagation in particle physics

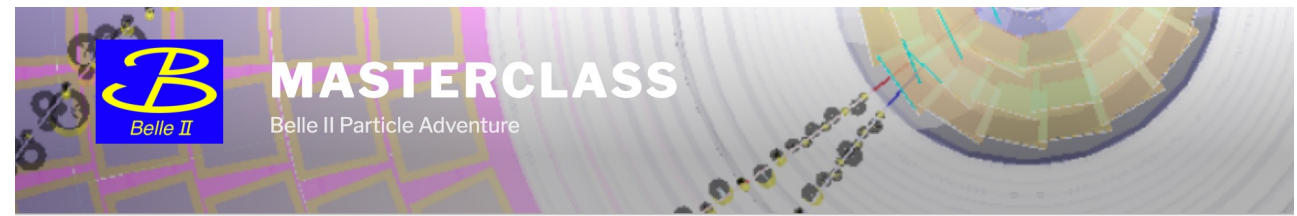


EXPLORE RESULT

- Lastly introduce meaning behind concept of three colors using game
- Drag-and-drop coloured quarks into colorless bound states



- Masterclass fully developed and tested multiple times
- All material available in English and German
- Students are guided through masterclass using website



Home Intro Belle II Reconstruct B mesons Measure quark colors Events

HOW MANY COLORS DOES A QUARK COME IN?

The e
coupl
either
force,
color

Today
color

How many colors does a quark come in?

What is the R-value?

Example Events

Practice Task: Try it out!

Main Task

Additional material for tutors

weak force is the photon. It
magnetic charge. This charge can
exchange particle of the strong
to particles that carry a so called

termine the number of possible
data of the **Belle II experiment**.

To that end we should first approach the subject from the theoretical side. To start with we should take a look at the so called *R*-value.

- What is the R-value?



Thank you for your attention!

English: <https://belle2.ijs.si/public/home/quark-colors/>

German: <https://www.pi.uni-bonn.de/outreach/netzwerk-teilchenwelt/belle2-masterclass/>