



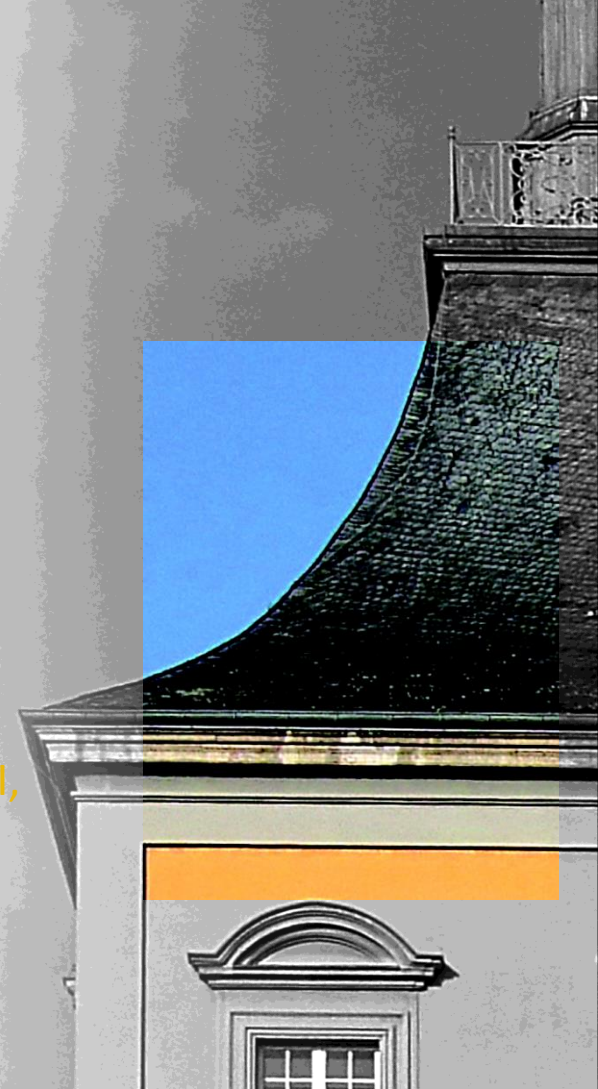
IMC STEERING MEETING:  
NOV. 12, 2021

# NEW MASTERCLASSES: HOW MANY COLORS DOES A QUARK COME IN?

**HENRIK JUNKERKALEFELD\***, SVENJA GRANDERATH,  
SEBASTIAN LÜLSDORF, BARBARA VALERIANI-KAMINSKI,  
FLORIAN BERNLOCHNER

Based on previous work of JANNIK STAMMNITZ,  
CHRISTIAN WESSEL, ECKHARD VON TÖRNE

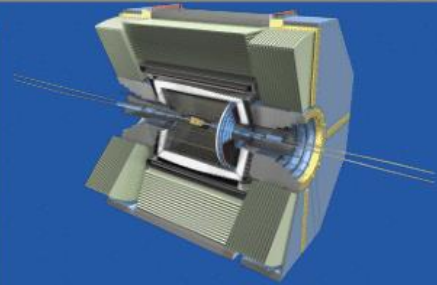
\* = [junkerkalefeld@physik.uni-bonn.de](mailto:junkerkalefeld@physik.uni-bonn.de)



- **Goal:** (very basic) masterclass that targets a scientifically very unexperienced audience without any knowledge of particle physics (i.e. pupils)
- **Idea:** Based on event displays, classify event as  $e^+e^- / \mu^+\mu^- / \tau^+\tau^- / \bar{q}q / \bar{b}b$
- Derive  $R$ -value: 
$$R = \frac{N(\bar{q}q)}{0.5 \cdot [N(\mu^+\mu^-) + N(\tau^+\tau^-)]} = N_c \cdot \sum_{\text{Quarks}} q_{\bar{q}q}^2 = N_c \cdot \frac{10}{9}$$
- Deduce **number of quark colors**
- We developed **several materials** (ATM in German, but translation is possible)
- **Successfully tested** this with a group of pupil

# EXAMPLE EVENT DISPLAY

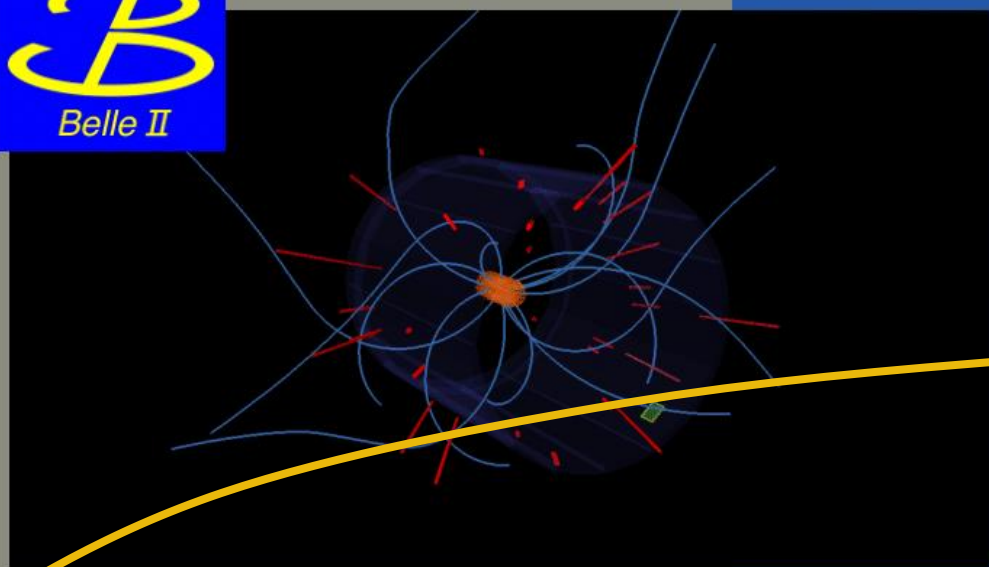
$$e^+e^- \rightarrow Y(4S) \rightarrow \bar{b}b$$



**Ereignis 1**

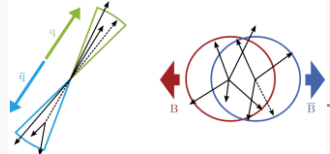
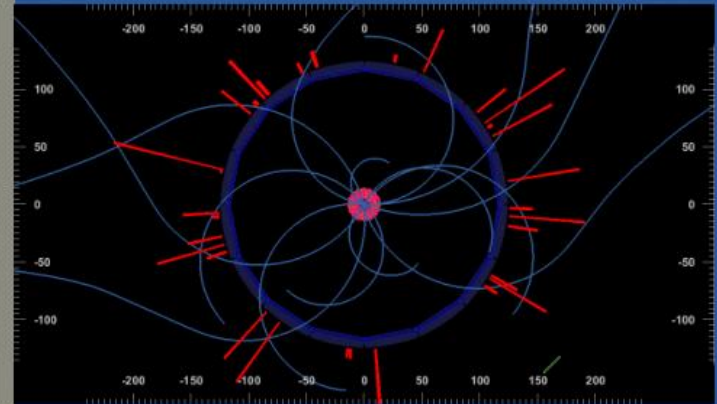
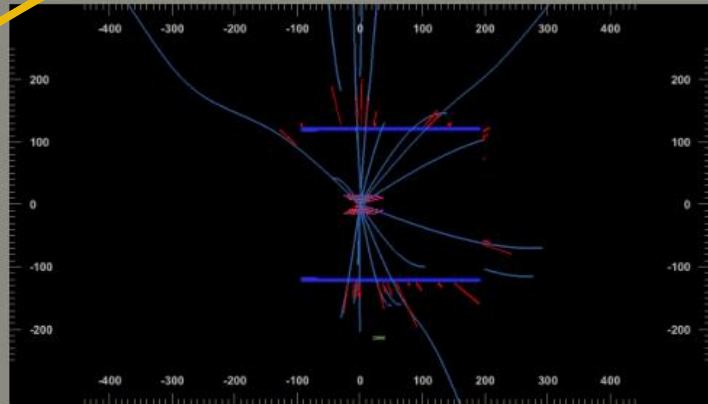
$\cancel{E} = 4.6$

$\swarrow = 0.06$



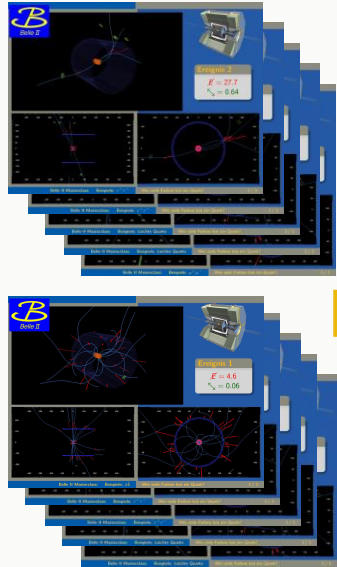
$m_{miss}^2$  as “missing energy” or  $\cancel{E}$

foxWolframR2 as “straightness” or  $\swarrow$





# PROCESS CLASSIFICATION AND QUARK COLOR EXTRACTION



Belle2 Masterclass - R-Wert Berechnung

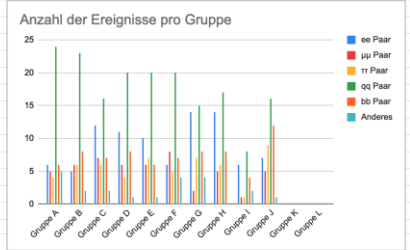
Datensatz K

Ereignis	Zugestellt	ee Paar	$\mu\mu$ Paar	$\tau\tau$ Paar	qq Paar	bb Paar	Anderes
1							
2							
3							
4							
5							
6							
7							
8							
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11							
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30							

Belle2 Masterclass - R-Wert Berechnung

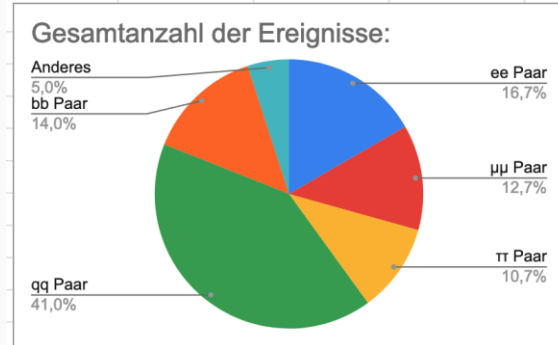
Ereignistyp

Gruppe	ee Paar	$\mu\mu$ Paar	$\tau\tau$ Paar	qq Paar	bb Paar	Anderes
Gruppe A	6	5	4	24	6	5
Gruppe B	5	6	6	23	8	2
Gruppe C	12	7	6	16	7	2
Gruppe D	11	6	4	20	8	1
Gruppe E	10	6	7	20	6	1
Gruppe F	6	8	5	20	7	4
Gruppe G	14	2	7	15	8	4
Gruppe H	14	5	6	17	8	0
Gruppe I	6	1	1	8	4	2
Gruppe J	7	5	9	16	12	1
Gruppe K	0	0	0	0	0	0
Gruppe L	0	0	0	0	0	0
Summe:	50	38	32	123	42	15



## Result website:

All entries are automatically summarized and counted

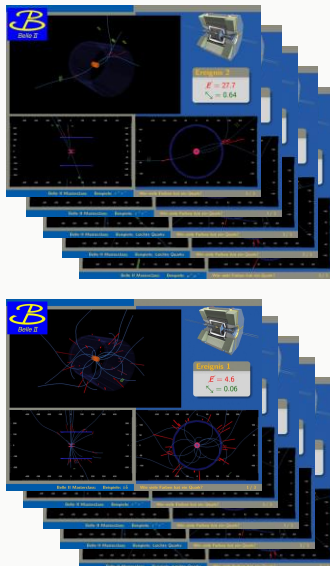
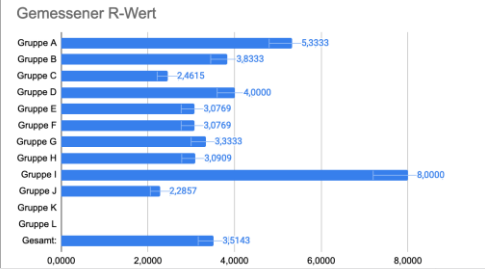


Pupils get sets of 50 – 100 events

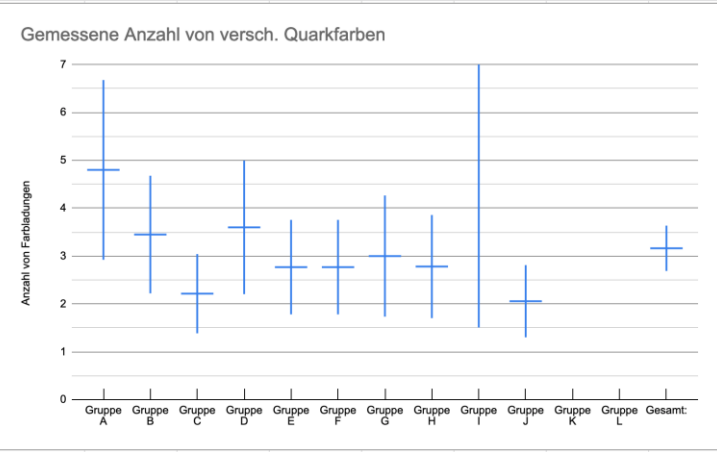
Events are classified and filled in online



# PROCESS CLASSIFICATION QUARK COLOR EXTRACTION



	Farbanzahl	Unsicherheit
jeder Gruppe		
Gruppe A	4,8000	1,8762
Gruppe B	3,4500	1,2286
Gruppe C	2,2154	0,8272
Gruppe D	3,6000	1,3943
Gruppe E	2,7692	0,9866
Gruppe F	2,7692	0,9866
Gruppe G	3,0000	1,2649
Gruppe H	2,7818	1,0764
Gruppe I	7,2000	5,6921
Gruppe J	2,0571	0,7528
Gruppe K	#DIV/0!	#DIV/0!
Gruppe L	#DIV/0!	#DIV/0!
<b>Gesamt:</b>	<b>3,1629</b>	<b>0,4735</b>

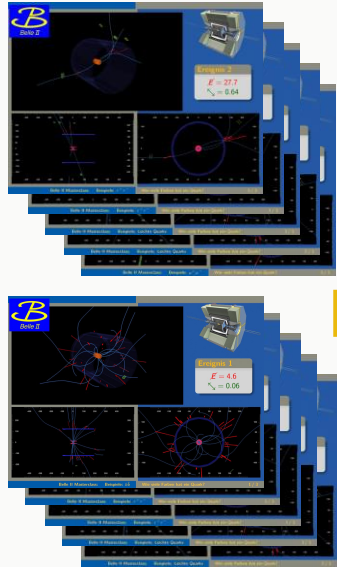


Pupils get sets of 50 – 100 events

Events are classified and filled in online

Result website: The number of quark colors (derived from the  $R$ -value) is calculated for each group individually and all combined (with statistical errors)

# PROCESS CLASSIFICATION AND QUARK COLOR EXTRACTION



Belle2 Masterclass - R-Wert Berechnung

Daten Bearbeiten Ansicht Einfügen Format Daten Tools Add-ons Hilfe Letzte Än... Freigeben

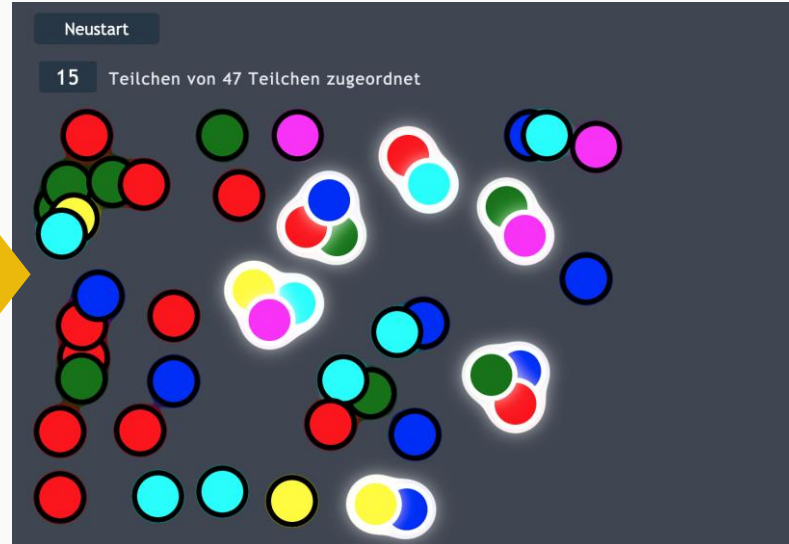
100% 123 Arial 10

WABR

Datensatz K

Ereignis	Zugeteilt	ee Paar	$\mu\mu$ Paar	$t\bar{t}$ Paar	$q\bar{q}$ Paar	$b\bar{b}$ Paar	Anderes
1		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input 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"/>
3		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input 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"/>
5		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6		<input checked="" type="checkbox"/>	<input 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 type="checkbox"/>	<input type="checkbox"/>
8		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9		<input checked="" type="checkbox"/>	<input 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 type="checkbox"/>	<input type="checkbox"/>
11		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input 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 type="checkbox"/>
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15		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18		<input checked="" type="checkbox"/>	<input 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 type="checkbox"/>	<input type="checkbox"/>
20		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Gruppe F Gruppe G Gruppe H Gruppe I



Pupils get sets of 50 – 100 events

Events are classified and filled in online

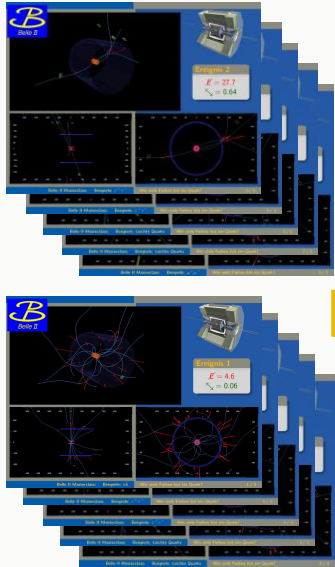
Interactive color-combination minigame:

Directly learn what “three colors” mean





# PROCESS CLASSIFICATION AND QUARK COLOR EXTRACTION



Belle2 Masterclass - R-Wert Berechnung

Daten Bearbeiten Ansicht Einfügen Format Daten Tools Adressen Hilfe Letzte An...

Freigeben

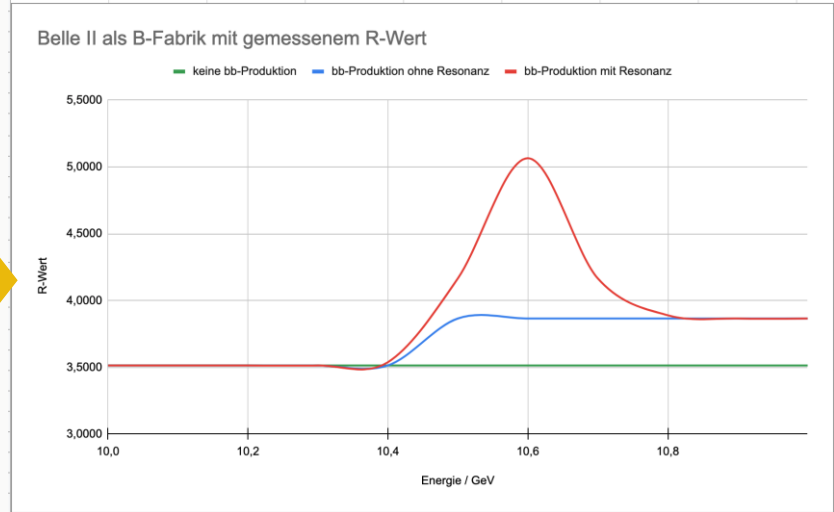
100% 133 Anzeig

Datensatz K

Ereignis	Zugestell	ee Paar	$\mu\mu$ Paar	$t\bar{t}$ Paar	qq Paar	bb Paar	Anderes
1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input 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 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 type="checkbox"/>
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21	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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24	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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27	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Gruppe F Gruppe G Gruppe H Gruppe I

Erkunden



Pupils get sets of 50 – 100 events

Events are classified and filled in online

Result website: Bonus: It is shown how *B* mesons are produced favorably at Belle II based on event classification of pupils



# MASTERCLASS SCHEDULE (INDICO) AND ADDITIONAL MATERIAL

MONDAY, JULY 19



9:00 AM	→ 9:30 AM	Begrüßung	30m
9:30 AM	→ 10:00 AM	<b>Das Standardmodell der Teilchenphysik: Was wir wissen</b> Speaker: Henrik Junckerkalefeld (University of Bonn)	30m
10:00 AM	→ 10:45 AM	<b>Was passiert bei e+e- Kollisionen? Quarkfarben und der R-Wert</b> Speaker: Lültsdorf Sebastian (University of Bonn)	45m
10:45 AM	→ 11:00 AM	Pause	15m
11:00 AM	→ 11:15 AM	<b>Das Standardmodell der Teilchenphysik: Was wir nicht wissen</b> Speaker: Henrik Junckerkalefeld (University of Bonn)	15m
11:15 AM	→ 11:45 AM	<b>Wie beschleunigt und misst man Teilchen?</b> Speaker: Svenja Granderath (University of Bonn)	30m
11:45 AM	→ 12:00 PM	Pause	15m
12:00 PM	→ 12:15 PM	<b>Netzwerk Teilchenwelt stellt sich vor</b> Speaker: Barbara Valeriani-Kaminski (University of Bonn)	15m
12:15 PM	→ 12:30 PM	<b>Quiz</b> Speaker: Sebastian Lültsdorf (University of Bonn)	15m

TUESDAY, JULY 20



9:00 AM	→ 9:15 AM	Begrüßung	15m
9:15 AM	→ 10:00 AM	<b>Einführung in die Analyse der Belle II-Daten</b> Speaker: Sebastian Lültsdorf (University of Bonn)	45m
10:00 AM	→ 10:30 AM	<b>Übungsaufgabe</b> Speakers: Svenja Granderath (University of Bonn), Henrik Junckerkalefeld (University of Bonn)	30m
10:30 AM	→ 10:45 AM	Pause	15m
10:45 AM	→ 12:15 PM	<b>Datenanalyse: Wie viele Farben hat denn jetzt ein Quark?</b> Speakers: Henrik Junckerkalefeld (University of Bonn), Sebastian Lültsdorf (University of Bonn), Svenja Granderath (University of Bonn)	1h 30m
12:15 PM	→ 12:35 PM	<b>Ergebnisdiskussion</b> Speaker: Henrik Junckerkalefeld (University of Bonn)	20m
12:35 PM	→ 12:50 PM	<b>Quiz</b> Speaker: Svenja Granderath (University of Bonn)	15m
12:50 PM	→ 1:00 PM	<b>Feedbackrunde</b>	10m



# TWO INTRODUCTORY TALKS

MONDAY, JULY 19

9:00 AM → 9:30 AM	Begrüßung	30m
9:30 AM → 10:00 AM	Das Standardmodell der Teilchenphysik: Was wir wissen Speaker: Henrik Junckerkalefeld (University of Bonn)	30m
10:00 AM → 10:45 AM	Was passiert bei e+e- Kollisionen? Quarkfarben und der R-Wert Speaker: Lülsdorf Sebastian (University of Bonn)	45m
10:45 AM → 11:00 AM	Pause	15m
11:00 AM → 11:15 AM	Das Standardmodell der Teilchenphysik: Was wir nicht wissen Speaker: Henrik Junckerkalefeld (University of Bonn)	15m
11:15 AM → 11:45 AM	Wie beschleunigt und misst man Teilchen? Speaker: Svenja Granderath (University of Bonn)	30m
11:45 AM → 12:00 PM	Pause	15m
12:00 PM → 12:15 PM	Netzwerk	15m
12:15 PM → 12:30 PM	Spezial	15m
12:30 PM → 12:45 PM	...	...
12:45 PM → 1:00 PM	...	...
1:00 PM → 1:15 PM	...	...
1:15 PM → 1:30 PM	...	...
1:30 PM → 1:45 PM	...	...
1:45 PM → 2:00 PM	...	...
2:00 PM → 2:15 PM	...	...
2:15 PM → 2:30 PM	...	...
2:30 PM → 2:45 PM	...	...
2:45 PM → 3:00 PM	...	...

## Introductory presentation:

- Why particle physics?
- What do we know? (introduction of important particles and forces)
- How (often) are they produced?
- What is still a mystery?



**Quarks**  
Up Charm Truth  
Down Strange Beauty  
Elektron Myon Tauon

**Leptonen**

**Kraft-Teilchen**  
Gluon  
Z-Boson  
W-Boson  
Graviton  
Majorana?

**DAS STANDARDMODELL - NOCH LÄNGST NICHT ALLES KLAR**

- Wie können wir die **Gravitation** mit unserem SM vereinen?
- Wieso ist die **Materie-Antimaterie Symmetrie** gebrochen?
- Aus welchen Teilchen besteht **dunkle Materie**?
- **Wie können wir solche Fragen beantworten?**

**Dark Matter?**

**RH-Neutrino(s)?**

**LH-Neutrinos**

**Mathematical symbols:**  $\frac{2}{3}$ ,  $\frac{1}{3}$ ,  $-1$ ,  $0$

# TWO INTRODUCTORY TALKS

MONDAY, JULY 19

9:00 AM	→ 9:30 AM	Begrüßung	30m
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12:00 PM	→ 12:15 PM	Netzwerk Teilchenwelt stellt sich vor Speaker: Barbara Valeriani-Kaminski (University of Bonn)	15m
12:15 PM	→ 12:30 PM	Quiz Speaker: Sebastian Lülsdorf (University of Bonn)	15m

## Second presentation:

- What is a particle accelerator/collider?
- How do we measure and distinguish particles?

9:00 AM	→ 9:15 AM		15m
9:15 AM	→ 9:30 AM		15m
10:00 AM	→ 10:30 AM		30m
10:30 AM	→ 10:45 AM		15m
10:45 AM	→ 11:15 AM		30m
11:15 AM	→ 11:45 AM		30m
11:45 AM	→ 12:00 PM		15m
12:00 PM	→ 12:15 PM		15m
12:15 PM	→ 12:30 PM		15m
12:30 PM	→ 12:45 PM		15m
12:45 PM	→ 1:00 PM		15m

UNIVERSITÄT **BONN**

- Im Endeffekt:
- Gerade Strecken zum Beschleunigen
- Gekrümmte Strecken zum Ablenken
- Kennt ihr Beispiele für Ringbeschleuniger?

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- Geladene Teilchen hinterlassen elektrische Signale
- Daraus können Spuren rekonstruiert werden
- Zusätzlich kann der Vertex definiert werden

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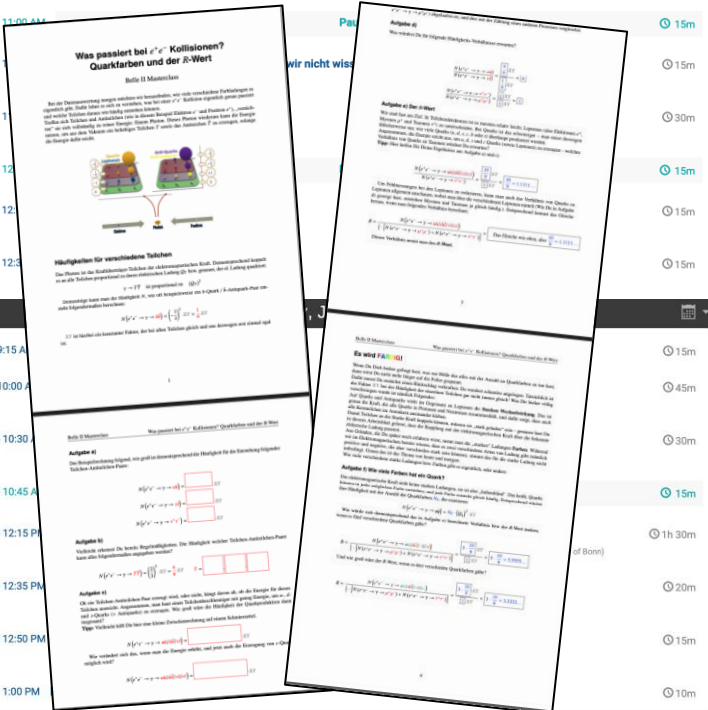
- Kalorimeter:
- Die meisten Teilchen verlieren gesamte Energie
- Und werden hier gestoppt
- Myondetektor:
- Myonen interagieren kaum und verlassen das Kalorimeter
- Hinterlassen Signal im Myondetektor



MONDAY, JULY 19	
9:00 AM → 9:30 AM	Begrüßung 30m
9:30 AM → 10:00 AM	Das Standardmodell der Teilchenphysik: Was wir wissen 30m Speaker: Henrik Junkerkaletfeld (University of Bonn)
10:00 AM → 10:45 AM	Was passiert bei e+e- Kollisionen? Quarkfarben und der R-Wert 45m Speaker: Lülsdorf Sebastian (University of Bonn)
10:45 AM → 11:00 AM	15m
11:00 AM → 11:15 AM	15m
11:15 AM → 11:45 AM	30m
11:45 AM → 12:00 PM	15m
12:00 PM → 12:15 PM	15m
12:15 PM → 12:30 PM	15m
9:00 AM → 9:15 AM	15m
9:15 AM → 10:00 AM	45m
10:00 AM → 10:30 AM	30m
10:30 AM → 10:45 AM	15m
10:45 AM → 12:15 PM	1h 30m
12:15 PM → 12:35 PM	20m
12:35 PM → 12:50 PM	15m
12:50 PM → 1:00 PM	10m

## Work sheet:

➤ Autodidactic derivation of expected  $R$ -value and its dependence of the quark colours



The work sheet contains several sections:

- Section 1: Was passiert bei e+e- Kollisionen? Quarkfarben und der R-Wert**

Bei der Teilchenphysik gehen wir davon aus, dass die Teilchen aus den Quarks und Leptonen bestehen. Die Quarks sind in drei Farben unterteilt: Rot, Grün und Blau. Die Leptonen sind in drei Familien unterteilt: Elektronen, Myonen und Tauonen. Die Quarks sind in drei Familien unterteilt: Up, Down, Charm, Strange, Bottom und Top. Die Leptonen sind in drei Familien unterteilt: Elektronen, Myonen und Tauonen.

**Häufigkeiten für verschiedene Teilchen**

Die Wahrscheinlichkeit, dass ein Teilchen ein bestimmtes Teilchen ist, ist durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist, gegeben durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist.

$$R = \sum_i N_i \sigma_i / \sigma_{\text{had}} = \sum_i N_i \frac{4\pi\alpha^2 Q_i^2}{3s} / \frac{4\pi\alpha^2}{3s} = \sum_i N_i Q_i^2$$
- Section 2: Aufgabe II**

Die Wahrscheinlichkeit, dass ein Teilchen ein bestimmtes Teilchen ist, ist durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist, gegeben durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist.

$$R = \sum_i N_i Q_i^2 = 3 \cdot \frac{2}{3} + 3 \cdot \frac{1}{3} = 2 + 1 = 3$$
- Section 3: Aufgabe III**

Die Wahrscheinlichkeit, dass ein Teilchen ein bestimmtes Teilchen ist, ist durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist, gegeben durch die Wahrscheinlichkeit, dass es ein bestimmtes Teilchen ist.

$$R = \sum_i N_i Q_i^2 = 3 \cdot \frac{2}{3} + 3 \cdot \frac{1}{3} = 2 + 1 = 3$$

# KAHOOT QUIZZES

Quizzes ([day 1](#), [day 2](#)) that playfully probe the gained knowledge:

- of particle physics in general
- with respect to the  $R$ -value
- of the Belle II detector and its interaction with different particles

The image displays two overlapping Kahoot! quiz screenshots and a schedule for Tuesday, July 20. The top-left screenshot shows a quiz titled 'Was von den Folgenden ist ein richtiges Elementarteilchen?' with options: Proton, Helium, Myon, and Die äußere muskulöse Denker-Statue. The top-right screenshot shows a quiz titled 'Wie man Elektronen und Positronen auf eine Kreisbahn?' with options: elektrischer Spannung, Stromtransformatoren, Platten, and Plasmazonen. The bottom screenshot is a schedule for Tuesday, July 20, with a quiz at 12:35 PM by Svenja Granderath.

Time	Activity	Speaker	Duration
9:00 AM	Begrüßung		15m
9:15 AM	Einführung in die Analyse der Belle II-Daten	Sebastian Lülldorf (University of Bonn)	45m
10:00 AM	Übungsaufgabe	Svenja Granderath (University of Bonn), Henrik Junkerkalefeld (University of Bonn)	30m
10:30 AM	Pause		15m
10:45 AM	Datenanalyse: Wie viele Farben hat denn jetzt ein Quark?	Henrik Junkerkalefeld (University of Bonn), Sebastian Lülldorf (University of Bonn), Svenja Granderath (University of Bonn)	1h 30m
12:15 PM	Ergebnisdiskussion	Henrik Junkerkalefeld (University of Bonn)	20m
12:35 PM	Quiz	Svenja Granderath (University of Bonn)	15m
12:50 PM	Feedbackrunde		10m

# MATERIAL TO INTRODUCE DIFFERENT PROCESSES

MONDAY, JULY 19		
9:00 AM	→ 9:30 AM	Begrüßung
9:30 AM	→ 10:00 AM	Das Standardmodell der Teilchenphysik: Was wir wissen Speaker: Henrik Junkerkaletfeld (University of Bonn)
10:00 AM	→ 10:45 AM	Was passiert bei $e^+e^-$ Kollisionen? Quarkfarben und der R-Wert Speaker: Lülsdorf Sebastian (University of Bonn)
10:45 AM	→ 11:00 AM	Pause
11:00 AM	→ 11:15 AM	Das Standardmodell der Teilchenphysik: Was wir nicht wissen Speaker: Henrik Junkerkaletfeld (University of Bonn)
11:15 AM	→ 11:45 AM	Wie beschleunigt und misst man Teilchen? Speaker: Svenja Granderath (University of Bonn)
11:45 AM	→ 12:00 PM	Pause
12:00 PM	→ 12:15 PM	Netzwerk Teilchenwelt stellt sich vor Speaker: Barbara Valeriani-Kaminski (University of Bonn)
12:15 PM	→ 12:30 PM	Quiz Speaker: Sebastian Lülsdorf (University of Bonn)
TUESDAY, JULY 20		
9:00 AM	→ 9:15 AM	Begrüßung
9:15 AM	→ 10:00 AM	Einführung in die Analyse der Belle II-Daten Speaker: Sebastian Lülsdorf (University of Bonn)
10:00 AM	→ 10:30 AM	Übungsaufgabe Speakers: Svenja Granderath (University of Bonn), Henrik Junkerkaletfeld (University of Bonn)
10:30 AM	→ 10:45 AM	Pause
10:45 AM	→ 12:15 PM	Datenanalyse: Wie viele Farben hat denn jetzt ein Quark? Speakers: Henrik Junkerkaletfeld (University of Bonn), Sebastian Lülsdorf (University of Bonn), Svenja Granderath (University of Bonn)
12:15 PM	→ 12:35 PM	Ergebnisdiskussion Speaker: Henrik Junkerkaletfeld (University of Bonn)
12:35 PM	→ 12:50 PM	Quiz Speaker: Svenja Granderath (University of Bonn)
12:50 PM	→ 1:00 PM	Feedbackrunde

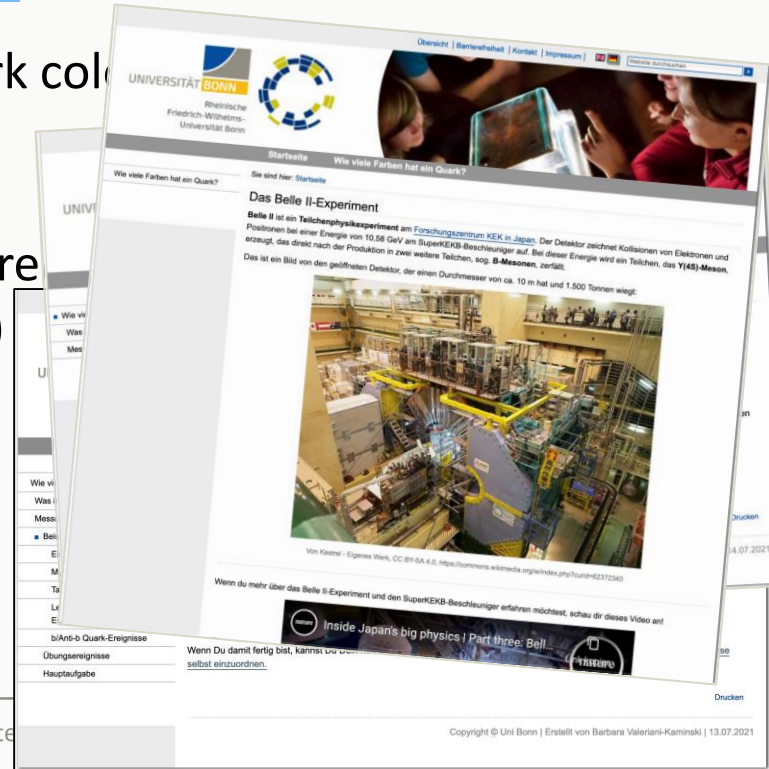
## Introduction of event displays and pupil's exercise:

- How can we distinguish the different processes and why?
- Why can't we use  $e^+e^-$  and  $\bar{b}b$  events to get the  $R$ -value?
- Concept of `foxWolframR2` aka "straightness"
- Concept of  $m_{\text{miss}}^2$  aka "missing energy"

# SELF-EXPLANATORY WEBSITE

Pupils are guided through the exercise by a [website](#) that links the tasks

- The [general task](#) (measuring the number of quark colors)
- The [R-value](#) is introduced in a [work sheet](#)
- [Example events](#) are presented in which the differences are outlined (event displays and **stopmotion videos**)







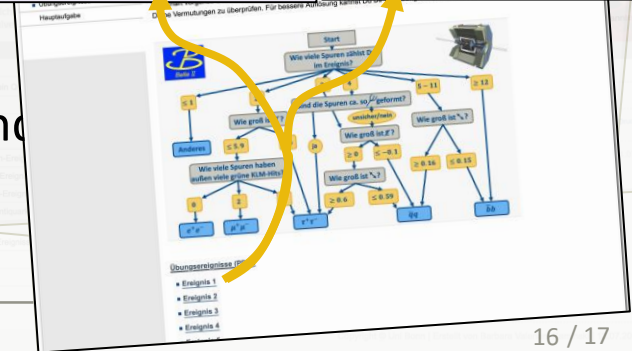
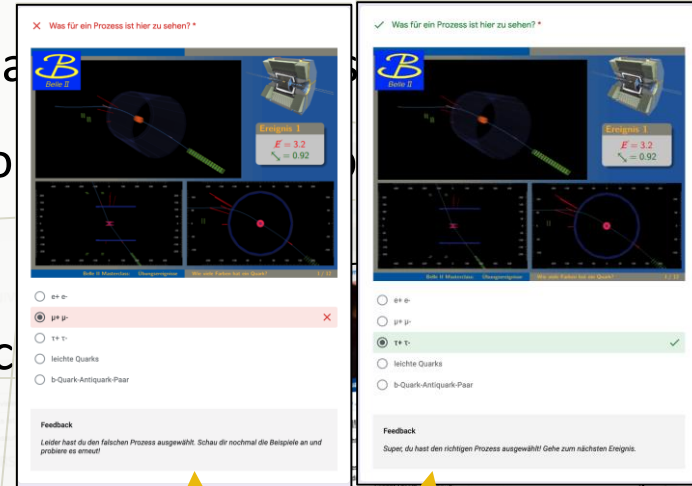
The diagram consists of six white circles arranged in a 2x3 grid on a black background. Each circle has a small white plus sign in its center. A yellow rectangular box is positioned in the center, containing two mathematical expressions. Dotted yellow lines connect the corners of this box to the centers of the four middle circles (top-left, top-right, bottom-left, and bottom-right).

$$e^+ e^- \rightarrow \gamma \rightarrow \ell^+ \ell^-$$

$$e^+ e^- \rightarrow \gamma \rightarrow \bar{q} q / \bar{b} b$$

Pupils are guided through the exercise by a [website](#) that

- The [general task](#) (measuring the number of quark collisions)
- The [R-value](#) is introduced in a [work sheet](#)
- [Example events](#) are presented in which the differences are outlined (event displays and **stopmotion videos**)
- [12 practice events](#) are available with [direct feedback](#)
- [Several datasets](#) for the main exercise are available and



# SUMMARY

- **Complete masterclass is developed and finished.** It ran like a clockwork.
- Several materials & **different tasks** are available to ensure **variety** for pupil
- Measurement is based on statistics, so the results actually improve the more events are evaluated ⇒ encourages joint work in **international masterclasses**