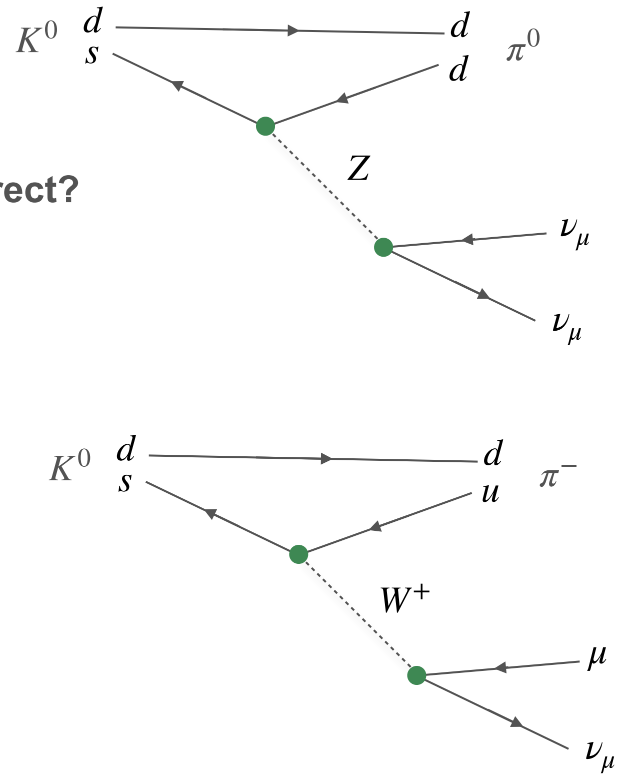
Introduction to Nuclear and Particle Physics

Lesson 9

weak interaction

Warm-up question 1

Which statement about the diagrams on the right is correct?



A) Both processes are valid.

B) The processes are both not valid because the strangeness is not conserved.

C) Quark mixing is part only of the W interaction. The upper diagram is not valid.

D) The charge is not conserved in the lower process. Only the upper diagram is valid.

Warm-up question 2

The diagonal elements of the CKM matrix are almost equal to 1…

A) Because the W-boson couples preferentially between particles of the same generation.

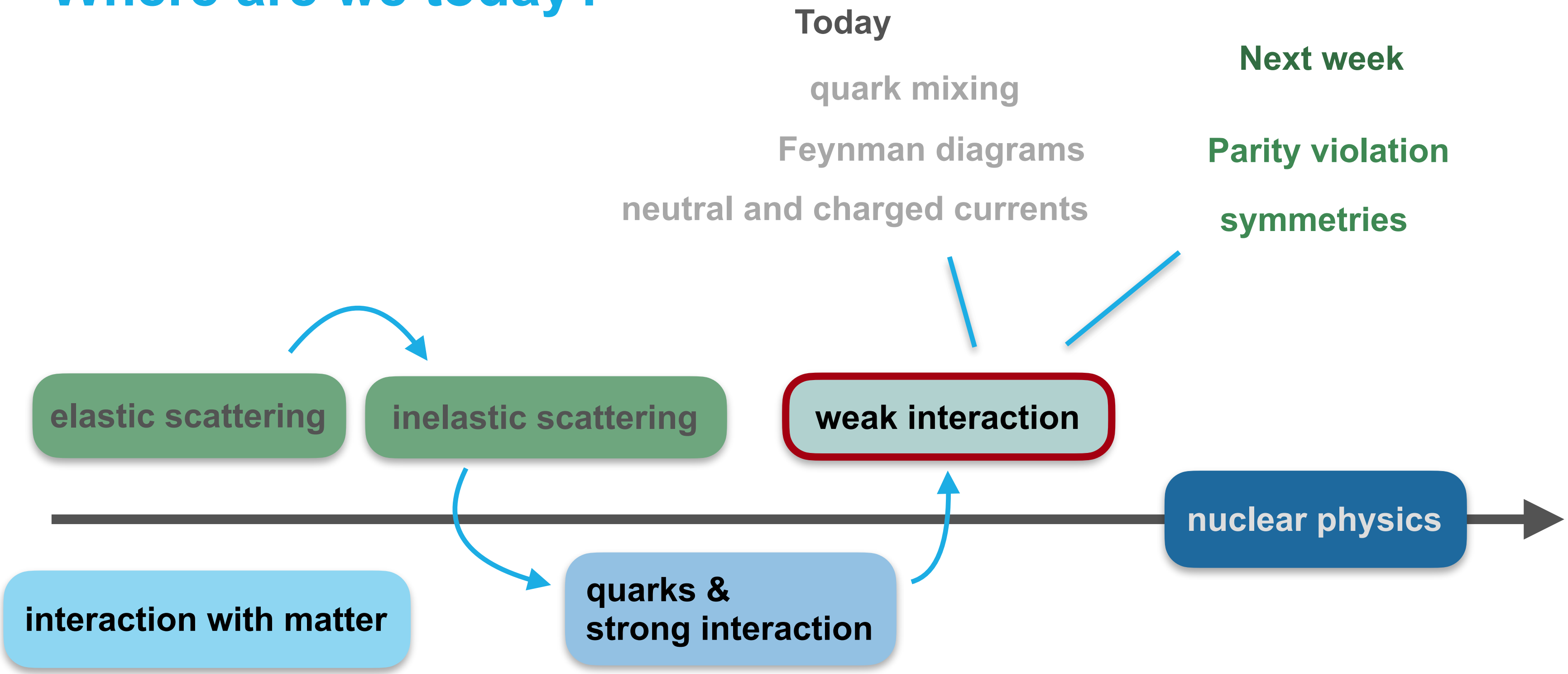
B) Because the W-boson couples preferentially between particles of the different generation.

C) Because the W-boson couples preferentially between particles of the different charge

D) Because the CKM matrix must be hermitian

E) Because the CKM matrix must be unitarian

Where are we today?



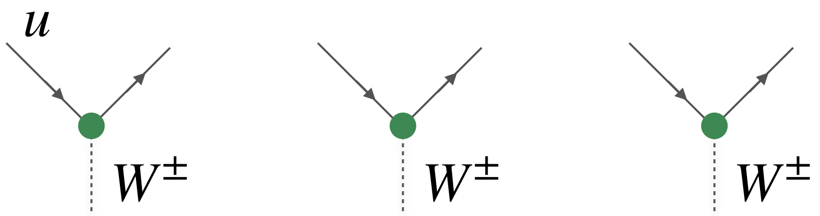
Recap - particles and their interactions

fermions ↓ bosons →

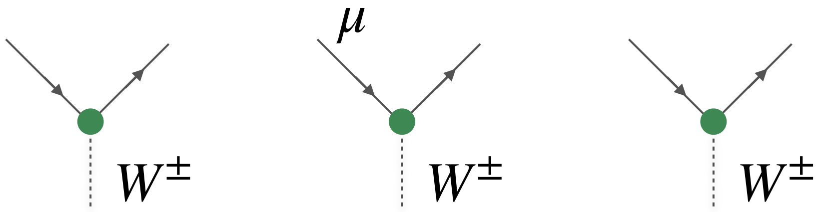
		electro-magnetic	weak		strong
		γ	$W^{\pm}$	Z	g
quarks	u c t d s b	X	X	X	X
charged leptons	e μ τ	X	X	X	
neutral leptons	ν_e ν_μ ν_τ		X	X	

Feynman rules for charged current interactions

Quark vertices



Lepton vertices

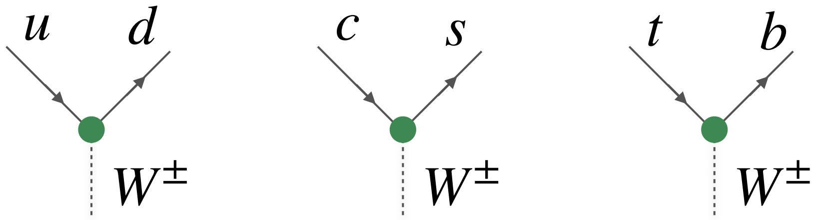


General rules:

- Fermion line goes through!
- Charge conservation
- Lepton number conservation
- Baryon number conservation

Feynman rules for charged current interactions

Quark vertices



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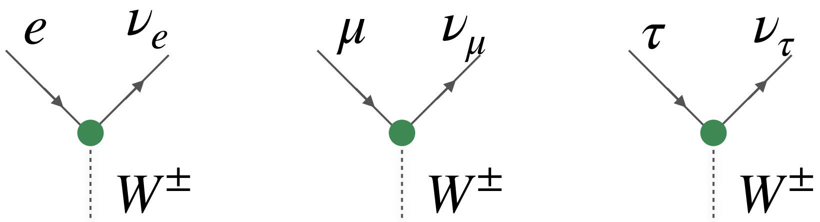

General rules:

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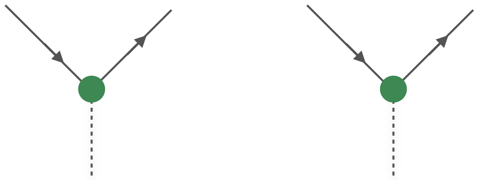
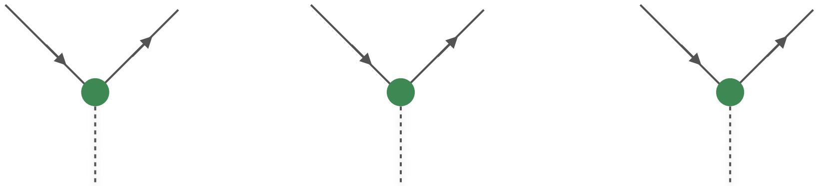
Feynman rules for neutral current interactions

Quark vertices - examples



Lepton vertices - examples



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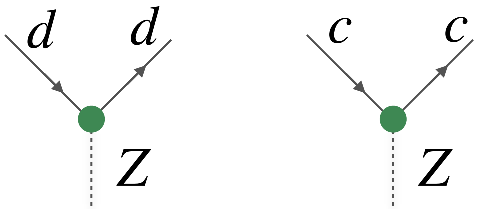
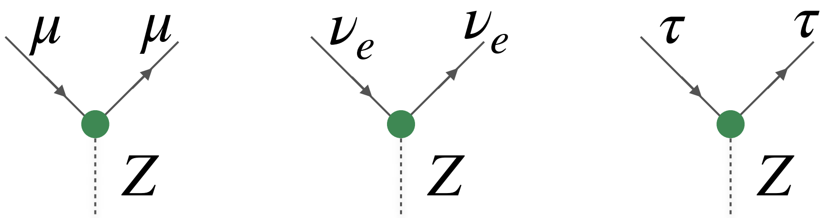


Lepton vertices - examples



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Quark mixing - question

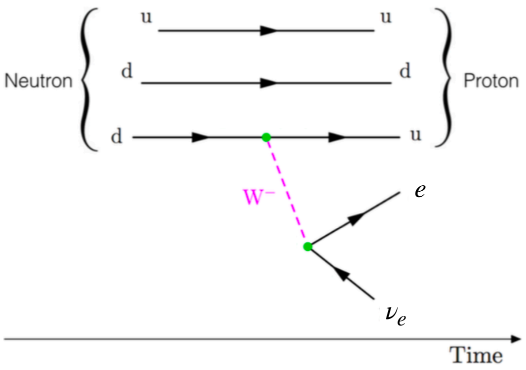
Have a look at the two Feynman diagrams on the left.
Which of the following statements is correct?

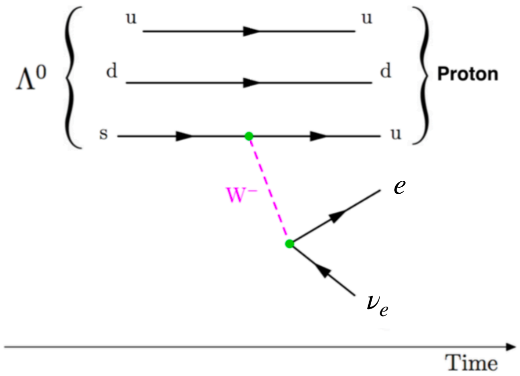
A) The upper diagram shows a β^+ decay.

B) The lower diagram is not possible, because the quark family number is not conserved in the s→u vertex.

C) The matrix element of the upper diagram is about 20 times smaller than the one of the lower diagram.

D) The matrix element of the lower diagram is about 5 times smaller than the one of the upper diagram.





Quark mixing - question

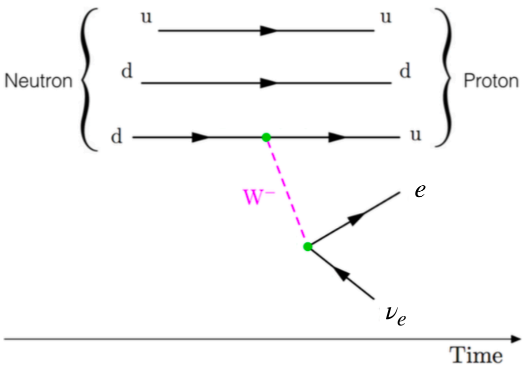
Have a look at the two Feynman diagrams on the left.
Which of the following statements is correct?

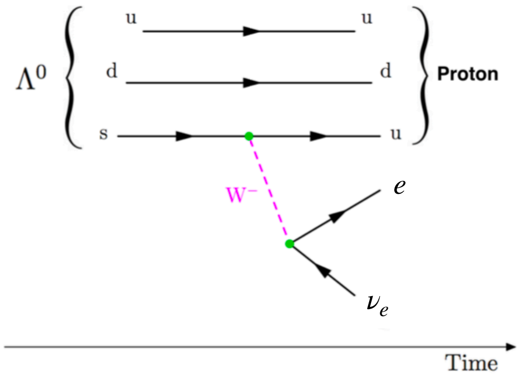
A) The upper diagram shows a β^+ decay. β^-!

B) The lower diagram is not possible, because the quark family number is not conserved in the s→u vertex.

C) The matrix element of the upper diagram is about 20 times smaller than the one of the lower diagram.

D) The matrix element of the lower diagram is about 5 times smaller than the one of the upper diagram.

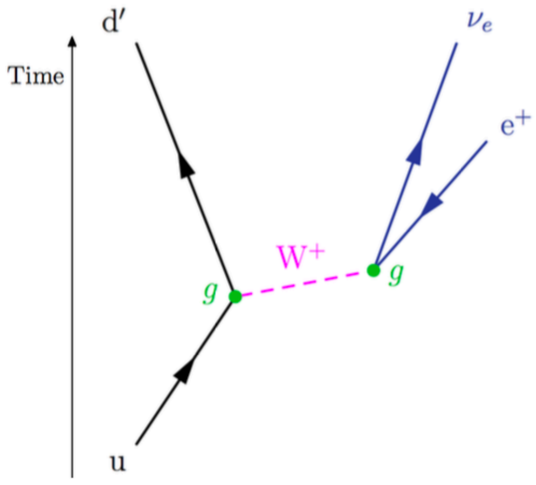




The CKM matrix

In weak current interactions, it is possible to mix between the quark generations.

But: The generation-changing reactions are suppressed.



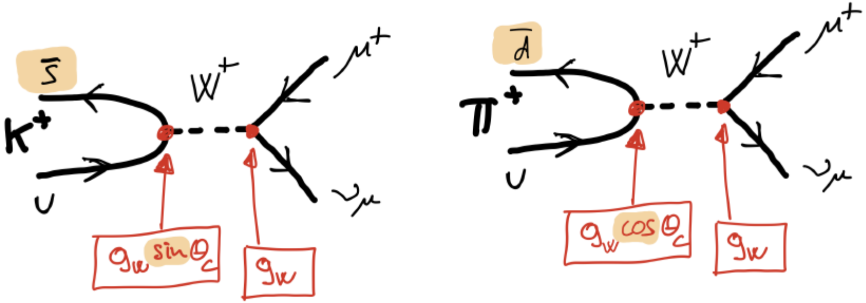
$$\begin{pmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{pmatrix}$$

$$\begin{bmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{bmatrix} = \begin{bmatrix} 0.97370 \pm 0.00014 & 0.2245 \pm 0.0008 & 0.00382 \pm 0.00024 \\ 0.221 \pm 0.004 & 0.987 \pm 0.011 & 0.0410 \pm 0.0014 \\ 0.0080 \pm 0.0003 & 0.0388 \pm 0.0011 & 1.013 \pm 0.030 \end{bmatrix}$$

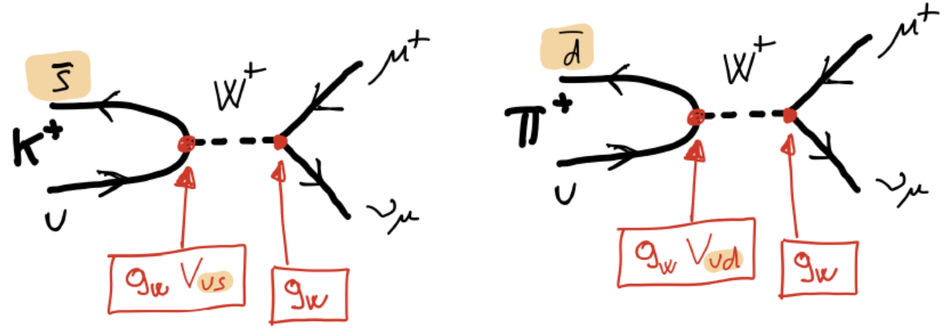
Cabibbo representation

The CKM matrix generalizes the Cabibbo notation to 3 quark generations.

Using Cabibbo notation (2x2 Matrix)



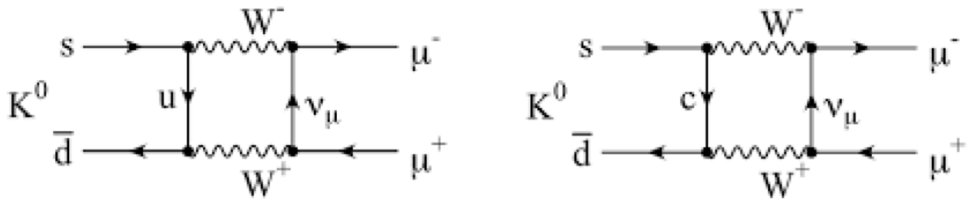
Using CKM-Matrix (3x3 Matrix)



θ_c is very small
$\Rightarrow$ mixing is suppressed.

Question 19 *(2 Points)*

Consider the two $K^0 \to \mu^+ + \mu^-$ diagrams as shown in the figure below. The amplitude of these diagrams depend on the Cabibbo angle Θ_C. Answer to the following questions:



A) The matrix element for the left diagram is $M_L \sim \sin\Theta_C \cos\Theta_C$ and for the right is $M_R \sim \sin\Theta_C \cos\Theta_C$.

B) The matrix element for the left diagram is $M_L \sim \cos\Theta_C \cos\Theta_C$ and for the right is $M_R \sim \sin\Theta_C \cos\Theta_C$.

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D) The $K^0 \to \mu^+\mu^-$ decay probability is given by $M_L + M_R$.

E) The $K^0 \to \mu^+\mu^-$ decay probability is given by $M_L^2 + M_R^2 + 2M_L M_R$.

F) The $K^0 \to \mu^+\mu^-$ decay probability is given by $M_L + M_R + 2M_L M_R$.

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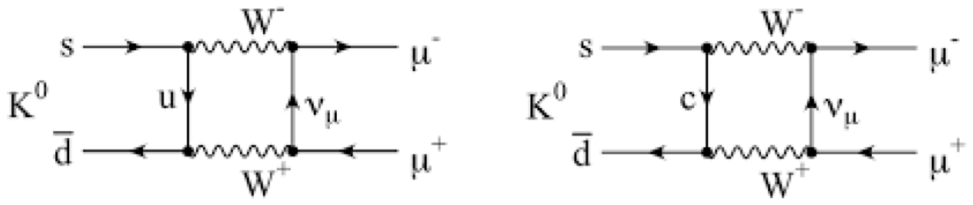

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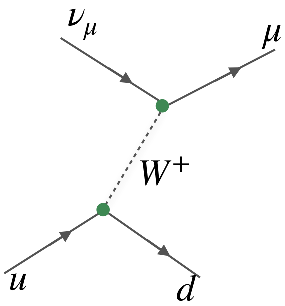
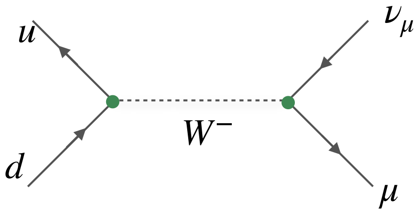
Group work - weak diagrams

Which of the following Feynman diagrams are valid?

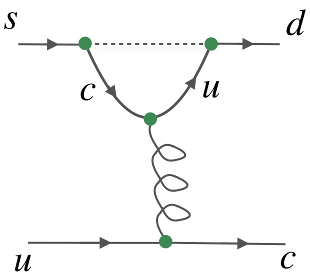
A)



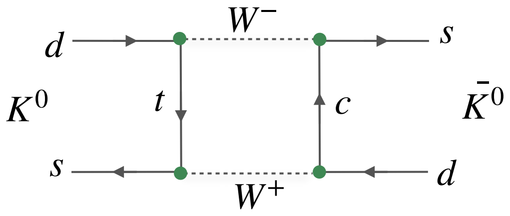
C)



E)



B)



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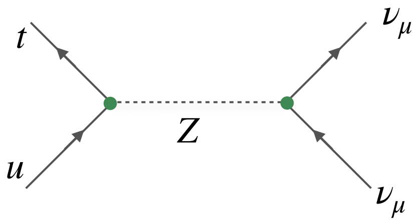

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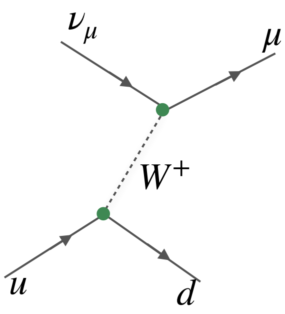
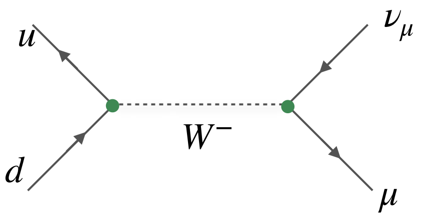
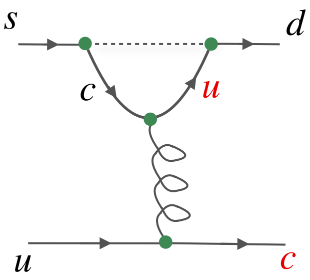


Wrong charge of W

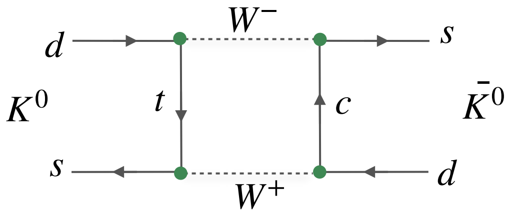


π^- decay

E)

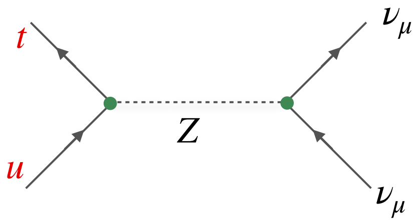


strong interaction does not change flavour!



Kaon oscillation

D)



Z boson does not mix quark generations!

Group Activity

MC questions from exams

Question 6 (*2 Points*) Consider the following hypothetical process

$$\nu_\tau + \mathrm{p} \rightarrow \tau^+ + \mathrm{n}.$$

Which conservation law(s) is(are) violated in this process?

- ☐ Charge.
- ☐ Energy.
- ☐ Linear momentum.
- ☐ Angular momentum.
- ☐ Lepton number.
- ☐ Baryon number.
- ☐ None of the listed laws is violated.

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Question 10 *(2 Points)*

A particle having non-zero strangeness ...

- ☐ ... can decay into a particle of zero strangeness only via the weak interaction.
- ☐ ... can decay into a particle of zero strangeness only via the strong interaction.
- ☐ ... can not decay into a particle of zero strangeness.
- ☐ ... can not be created from a strong process when colliding particles with zero strangeness.
- ☐ ... can be produced from a strong process when colliding particles of zero strangeness only if more than one particle with non-zero strangeness are produced in the final state.

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The weak interaction…

- ☐ …is weaker than the electromagnetic interaction only at high energy due to the large W-boson mass.
- ☐ …is much weaker than the electromagnetic interaction only at low energy due to the large W-boson mass.
- ☐ …has similar coupling constants as the electromagnetic interaction.

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Question 18 *(5 Points)*

Classify the following experimentally observed processes into strong, electromagnetic and weak interactions.

$$\begin{array}{ll} (a) & \pi^- \to \pi^0 + e^- + \bar{\nu}_e \\ (b) & \gamma + p \to \pi^+ + n \\ (c) & \bar{p} + p \to \pi^+ + \pi^- + \pi^0 \\ (d) & D^- \to K^+ + \pi^- + \pi^- \\ (e) & \Lambda + p \to K^- + p + p \end{array}$$

$$|D^-\rangle = |d\bar{c}\rangle$$
$$|\Lambda^0\rangle = |uds\rangle$$

(a)	☐ strong	☐ electromagnetic	☐ weak
(b)	☐ strong	☐ electromagnetic	☐ weak
(c)	☐ strong	☐ electromagnetic	☐ weak
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(a)	☐ strong	☐ electromagnetic	■ weak
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(c)	■ strong	☐ electromagnetic	☐ weak
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Website with many example Feynman diagrams

http://hst-archive.web.cern.ch/archiv/HST2002/feynman/examples.htm

Warm-up question 1

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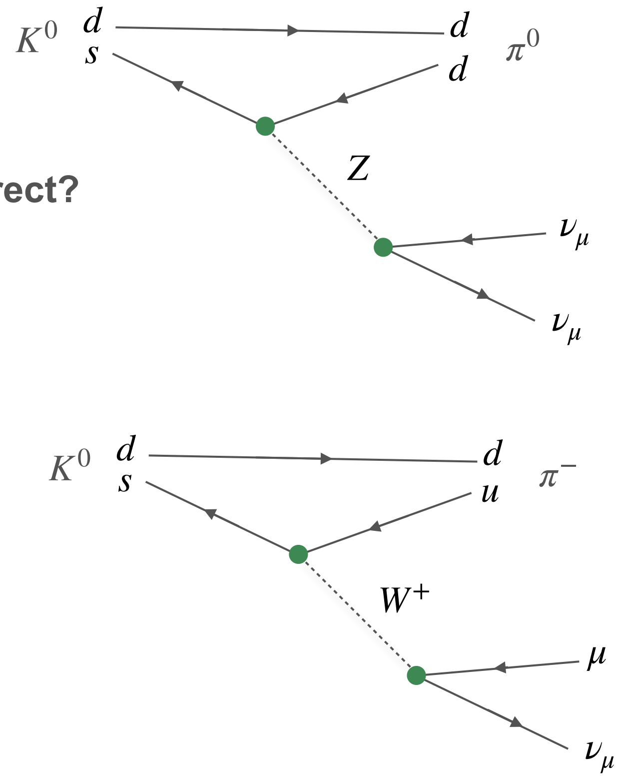

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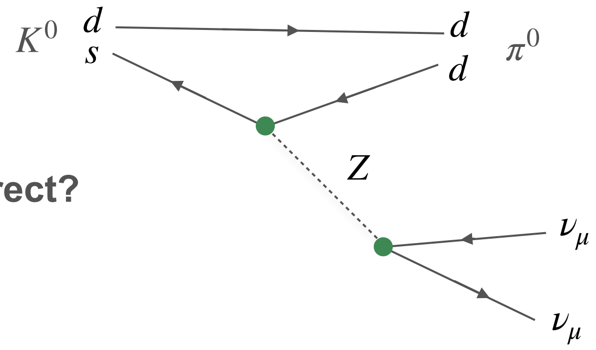

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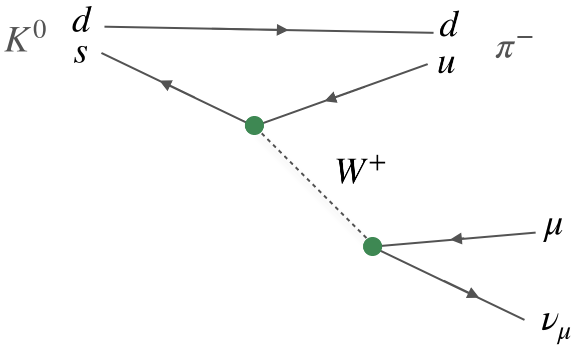

Warm-up question 2

The diagonal elements of the CKM matrix are almost equal to 1…

A) Because the W-boson couples preferentially between particles of the same generation.

B) Because the W-boson couples preferentially between particles of the different generation.

C) Because the W-boson couples preferentially between particles of the different charge

D) Because the CKM matrix must be hermitian

E) Because the CKM matrix must be unitarian

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