what is lepton universality and what do we know about it ?

Lars Kolk

23. Januar 2020

Fakultät Physik

Einführung

Lepton Universality in the Standard Modell

Lepton Universality Tests

- The Electroweak Sector
- Pseudoscalar Mesons
- Meson Mixing

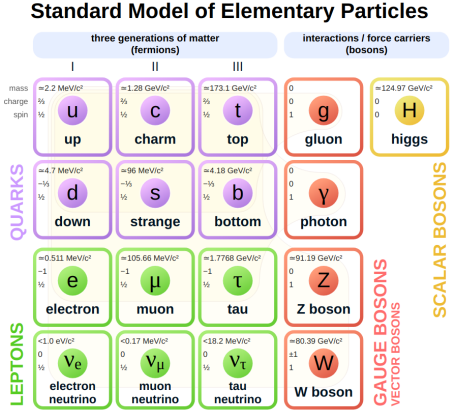
Beyond Standard Model: Leptoquarks

Conclusion

Lepton Universality in the Standard Modell

Standard Model (SM)

- gauge theory
- $SU(3)_C \otimes SU(2)_L \otimes U(1)_y$



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[1] https://en.wikipedia.org/wiki/Standard_Model

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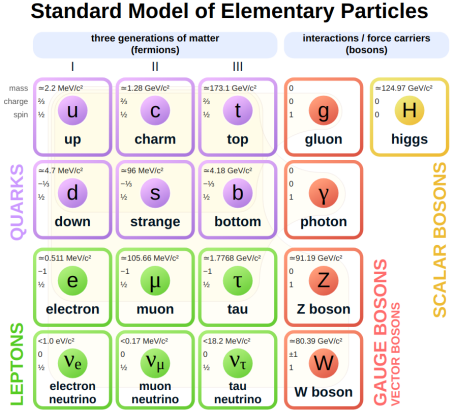
  - weak interaction



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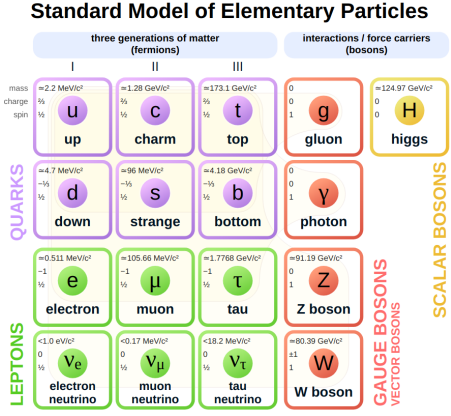
- twelve elementary fermions
  - six quarks
  - six leptons
  - three generations



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Standard Model (SM)

- gauge theory
- $SU(3)_C \otimes SU(2)_L \otimes U(1)_y \overset{SSB}{\rightarrow} SU(3)_C \otimes U(1)_{\text{QED}}$
  - Masses generated
  - Higgs-Boson
- twelve elementary fermions
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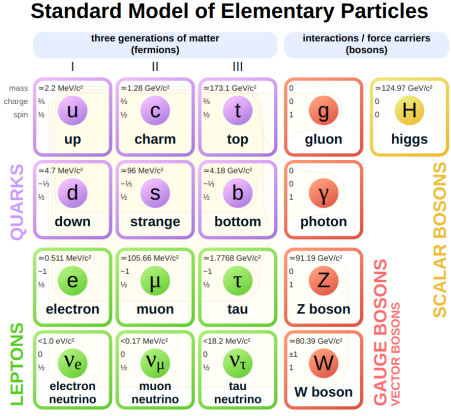
  - six leptons
  - three generations



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Leptons in the Standard Model

Particle	**Q** / e	**Mass** / MeV
electron (e)	-1	0.511
neutrino (ν_e)	0	0
muon (μ)	-1	105.66
neutrino (ν_μ)	0	0
tau (τ)	-1	1776.86
neutrino (ν_τ)	0	0

Electroweak Interaction

- Charged Currents (CC)
- $W^{\pm}$-Boson interactions
  - left handed fermions
  - right handed anti-fermions
  - → violates **C** and **P**

- Neutral Currents (NC)
- Z-Boson, Photon
  - decays into $l\bar{l}$
  - never observed: $Z \rightarrow e^{\pm}\mu^{\mp}$

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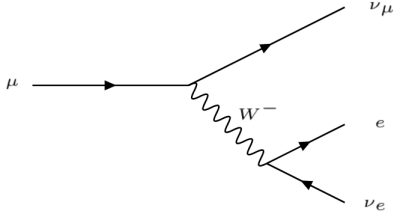

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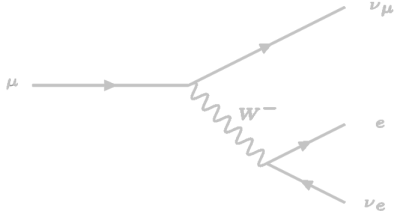

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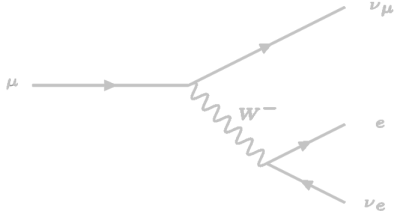

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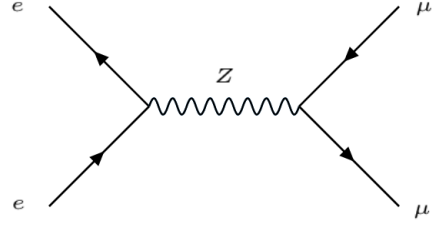
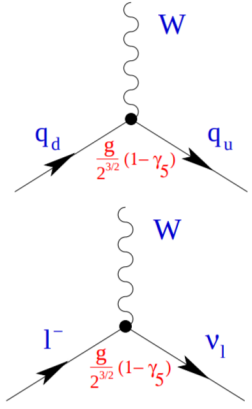


Charged Current

In the SM, the lagrangian for the charged current is [2]

$$\mathcal{L}_{CC} = \frac{g_1}{2\sqrt{2}} \left\{ W_\mu^\dagger \left[\bar{u}\gamma^\mu(1-\gamma^5)d + \bar{\nu}_e\gamma^\mu(1-\gamma^5)e \right] \right\}$$

- $g_1 = \frac{e}{sin(\theta_W)}$
- independent of mass



[2] arXiv:hep-ph/0502010

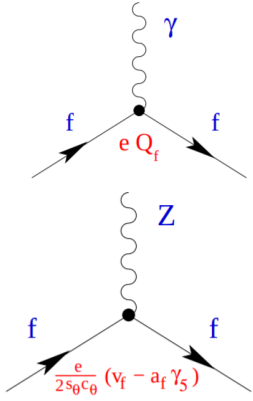
Neutral Current

In the SM, the lagrangian for the neutral current is [3]

$$\mathcal{L}_{\text{NC}} = \frac{g_2}{2\sin(\theta_W)} Z_\nu \sum_f \bar{f}\gamma^\mu \left(\nu_f - a_f\gamma_5\right) f$$

- $g_2 = \frac{e}{cos(\theta_W)}$
- independent of mass

	u	d	ν_e	e
$2\,v_f$	$1 - \frac{8}{3}\sin^2\theta_W$	$-1 + \frac{4}{3}\sin^2\theta_W$	1	$-1 + 4\sin^2\theta_W$
$2\,a_f$	1	-1	1	-1



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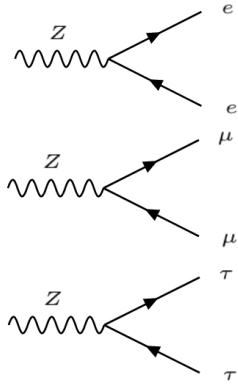
Lepton Universality

- charged and neutral currents studied:
  - inpependent of mass
  - constant coupling to all leptons

→ lepton flavour does not matter

Partial Width of the Z-Boson

- compare partial widths →ratios
  - no favoured flavour
  - → expect ratios near 1
- measurements [4] [5] :



[5] arXiv:hep-ex/0509008
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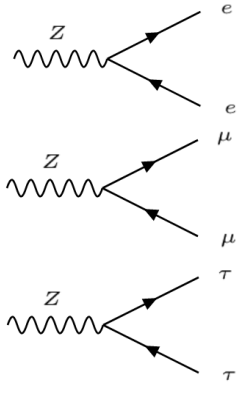

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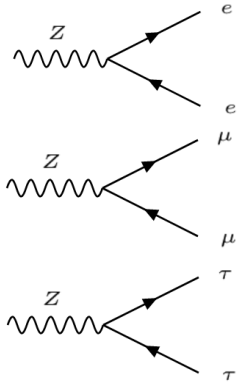

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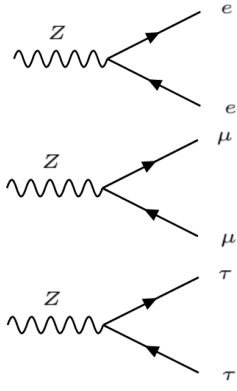

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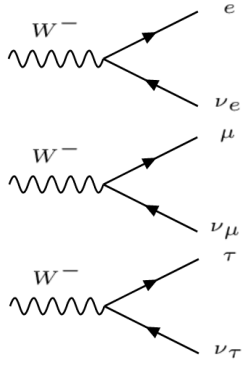

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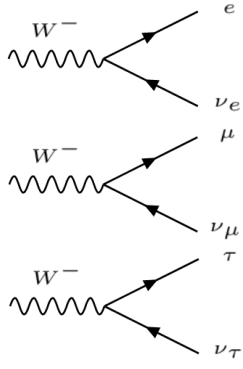

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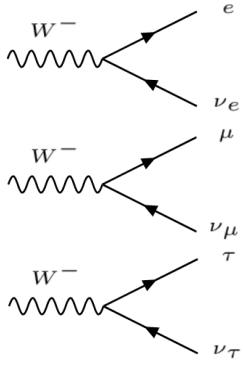

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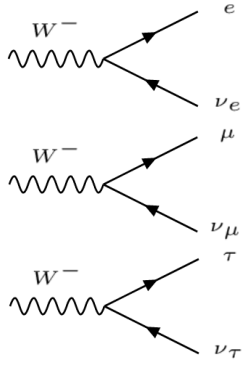

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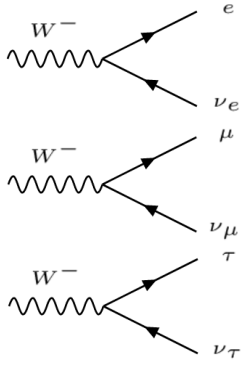
- $\approx 2.3\sigma$ deviation!



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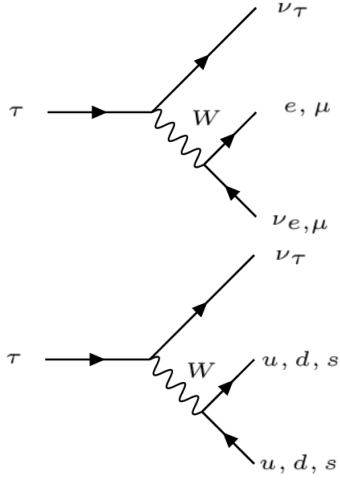
Difficulty: tau reconstruction

- channels
  - τ_l
  - τ_{had}



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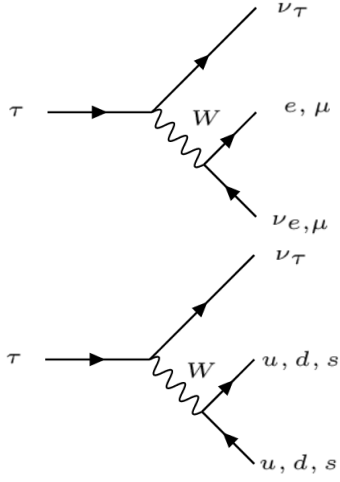
  - no visible jets
  - decay products form pions



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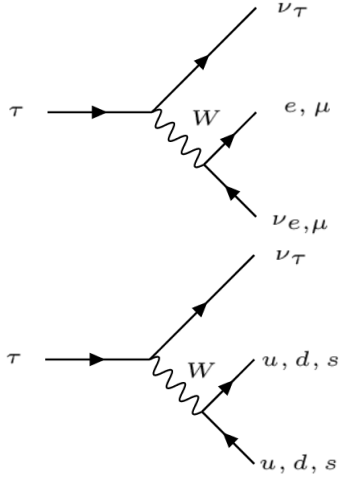

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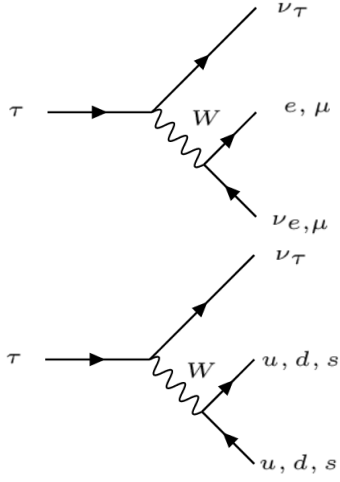
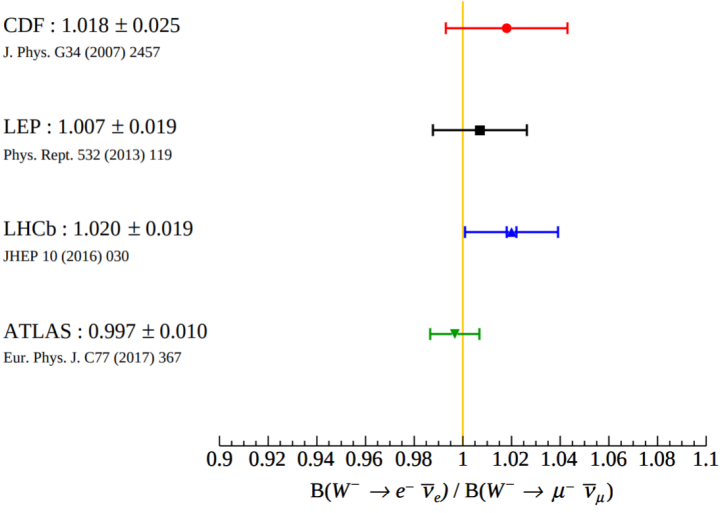
- may be cause of deviation

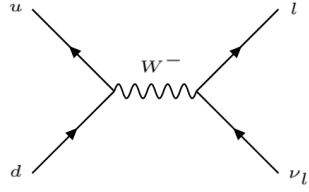


Branching Ratios of the $W^{\pm}$-Boson



Pseudoscalar Mesons

- study decay of π^-
  - composed of $d, \bar{u}$
  - Spin 0



-

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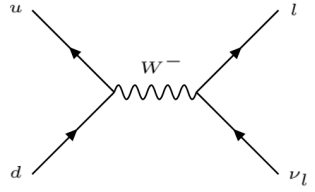

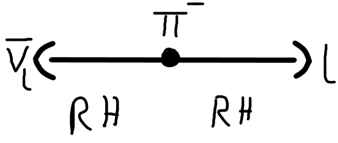

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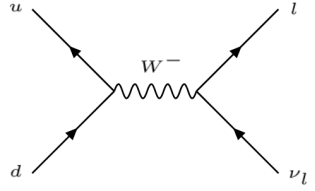

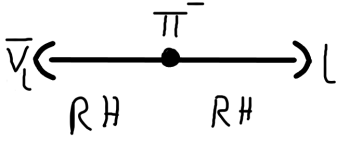

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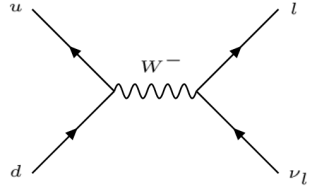
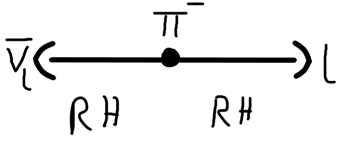
$$= (1.2352 \pm 0.0001) \cdot 10^{-4}$$





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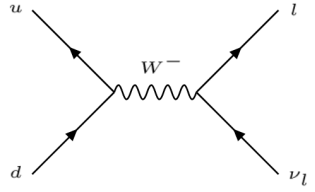

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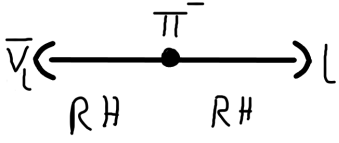
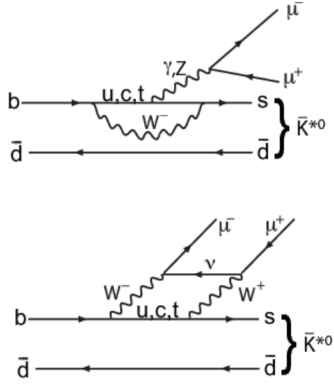


- measured :
  - $\frac{\Gamma_{\pi^-\to e^-\bar{\nu}_e}}{\Gamma_{\pi^-\to\mu^-\bar{\nu}_\mu}} = (1.230 \pm 0.004)\cdot 10^{-4}$

R_K and R_{K^*}

- anomalies in $\bar{B}^0 \to \bar{H} l \bar{l}$
  - $H = K, K^*$



[7] arXiv:1406.6482

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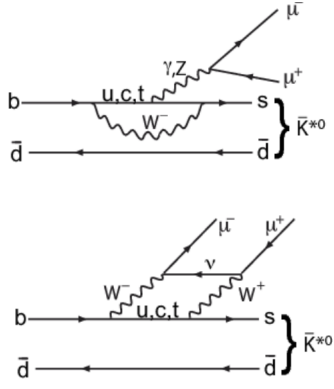

[7] arXiv:1406.6482

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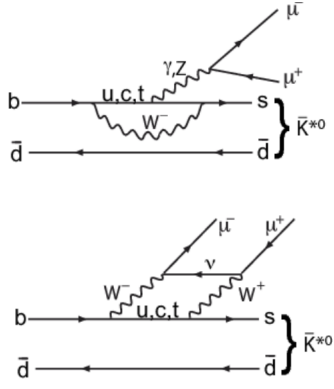

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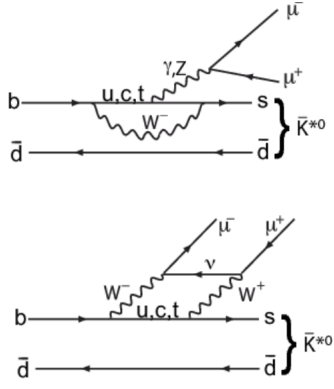
- Potential lepton flavour-violation (2.6σ)
- Leptoquarks may be the answer to this!



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Beyond the Standard Modell: Leptoquarks

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[9] Phys. Lett. B 191 (1987) 442

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How LQs can contribute to R_K and R_{K^*}

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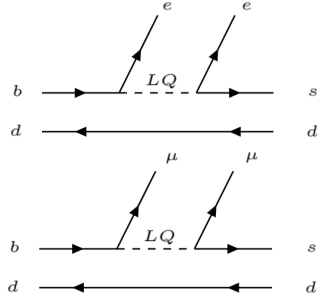

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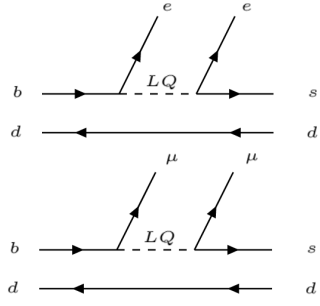

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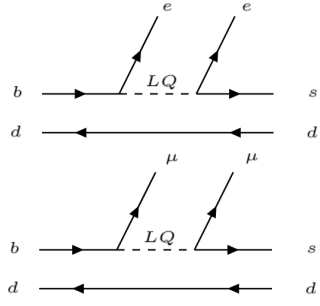

Conclusion

- Lepton Universality:
  - Interaction of gauge bosons and leptons is flavour-independent
- Most tests correspond to LU
- R_K and R_{K^*}: 2.6σ deviaton
- Leptoquarks may explain R_K and R_{K^*}