Fizika leptokvarkov

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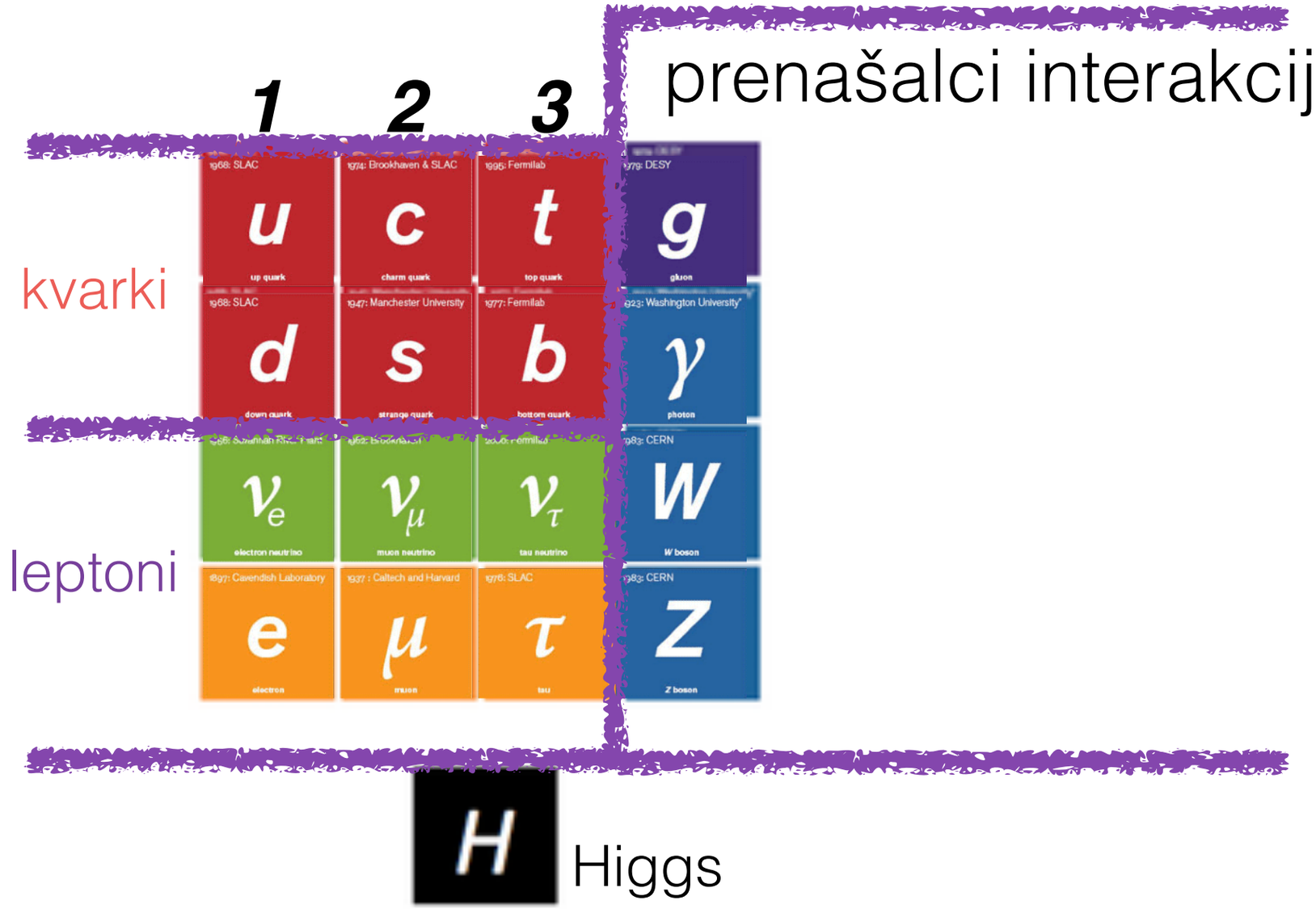
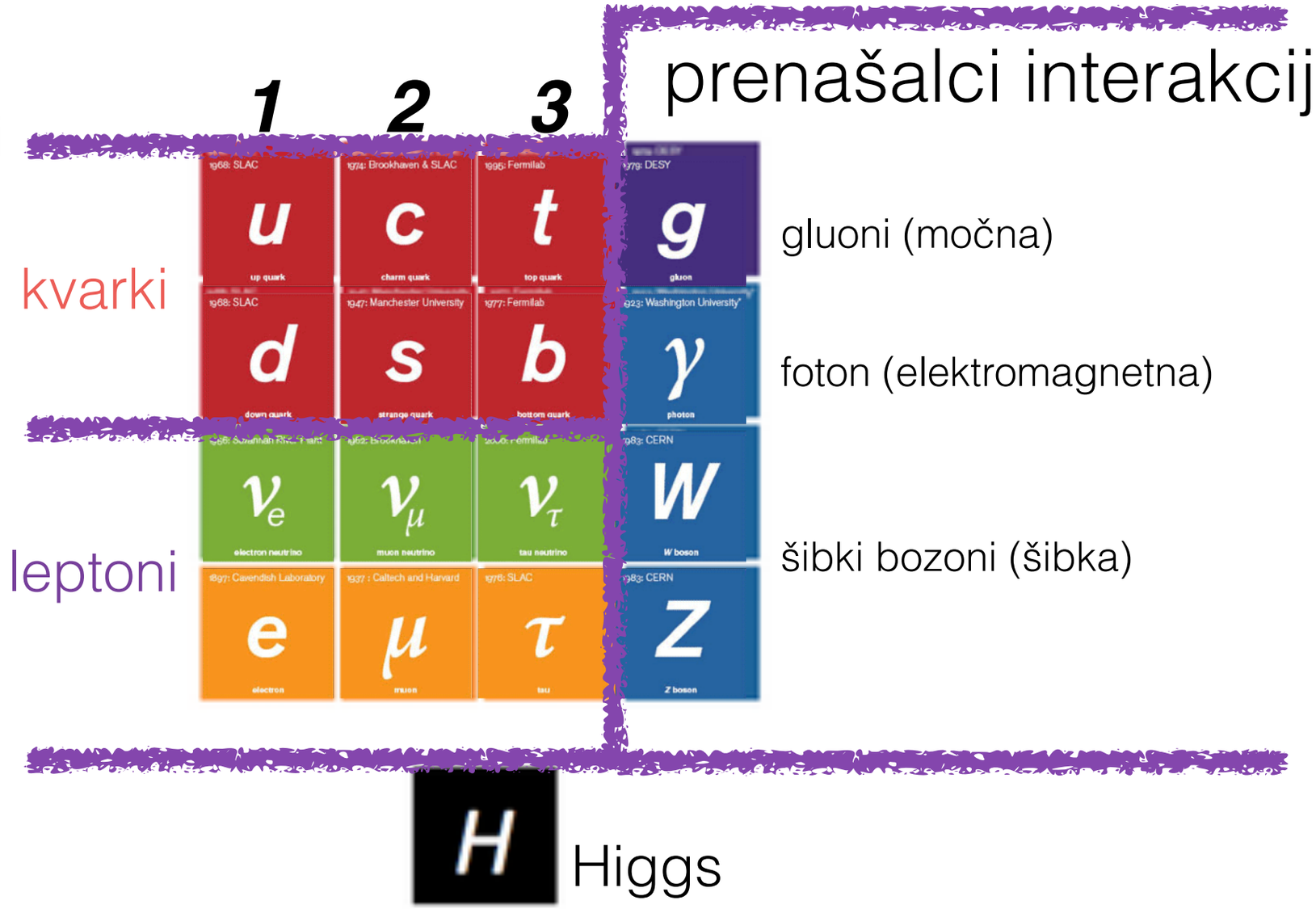
Standardni model



Standardni model

Opis fizike na dolžinski skali 10^{-18} m



Interakcije so določene s simetrijskimi lastnostmi umeritvene grupe

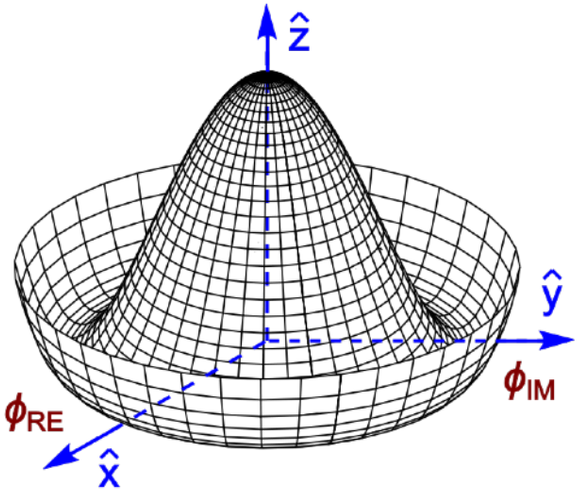
$$SU(3)_{\mathrm{RGB}} \otimes SU(2)_L \otimes U(1)_Y$$

Tri enakovredne kopije kvarkov in leptonov.

Standardni model

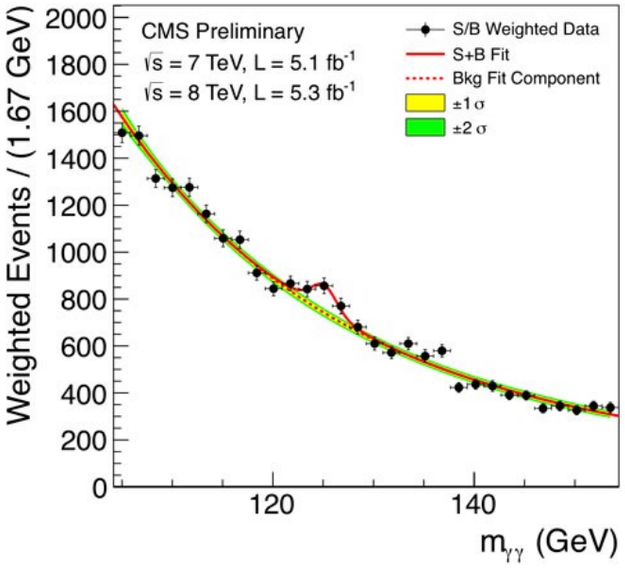
Higgsov mehanizem - osnovno stanje ima manj simetrije od enačb gibanja

Higgs (1964)



Mase prenašalcev interakcij, kvarkov in leptonov

Englert in Higgs (2012)

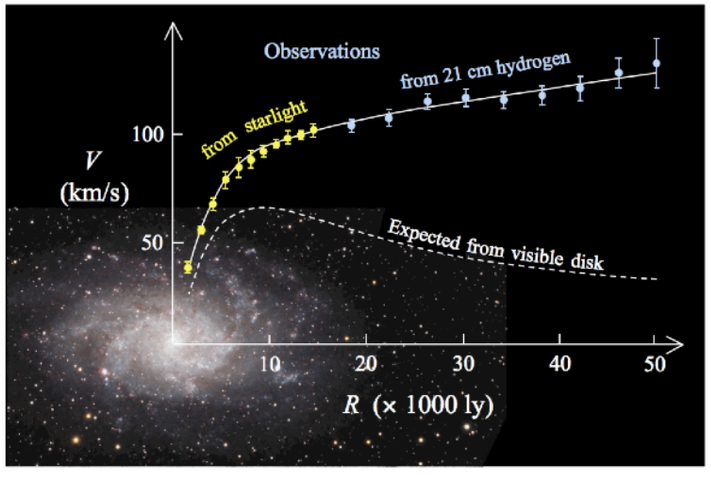


Odkritje 2012, ATLAS, CMS

Standardni model in nova fizika

Standarni model ni celotna zgodba:

- manjkajoče mase nevtrinov
- ne vsebuje temne snovi
- ne opiše gravitacije
- kvantizacija naboja



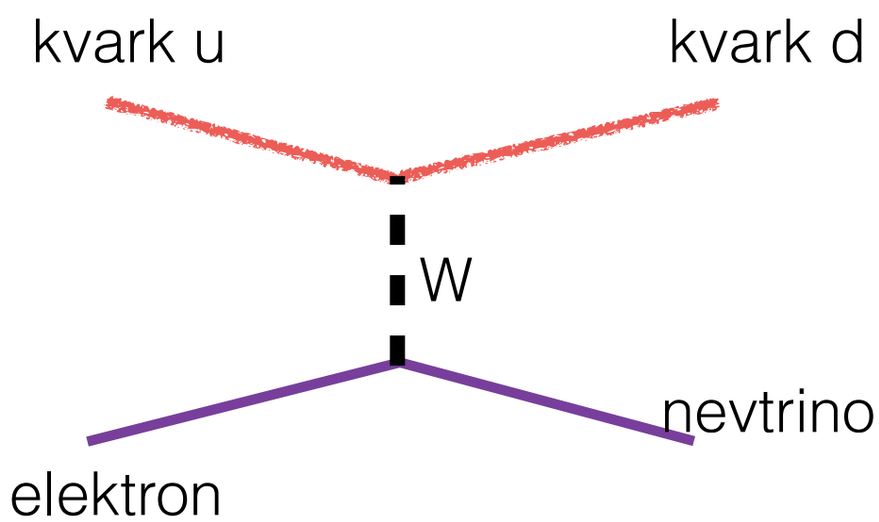
rotacijska krivulja galaksije

Hipotetična razširitev Standardnega modela: <u>teorija poenotenja</u>

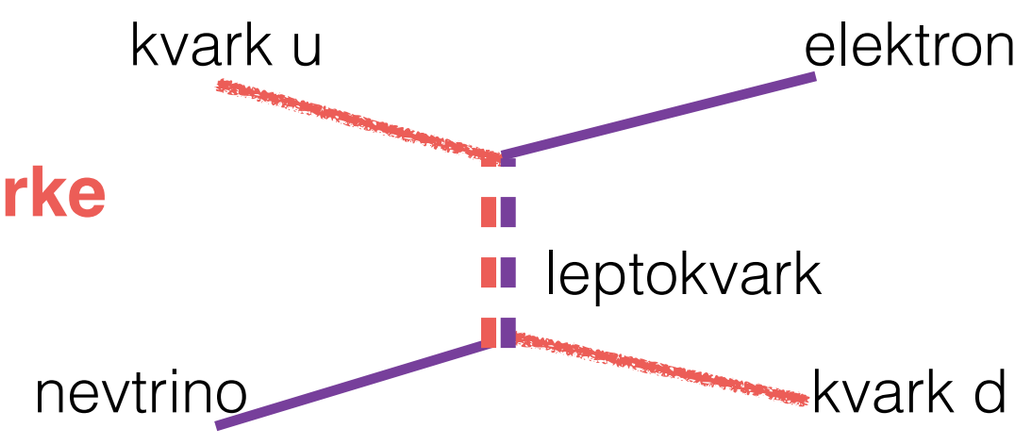
- poenotenje interakcij na razdalji 10^{-30} m (Georgi-Glashow, 1974)
- kvantizira naboj, lahko razloži mase nevtrinov
- zabrisana ločnica med kvarki in leptoni
- **leptokvarki**, novi prenašalci interakcij

Leptokvarki

V Standardnem modelu se leptoni in kvarki pogovarjajo le posredno, preko prenašalcev sil.



Leptokvark združuje **leptone** in **kvarke**

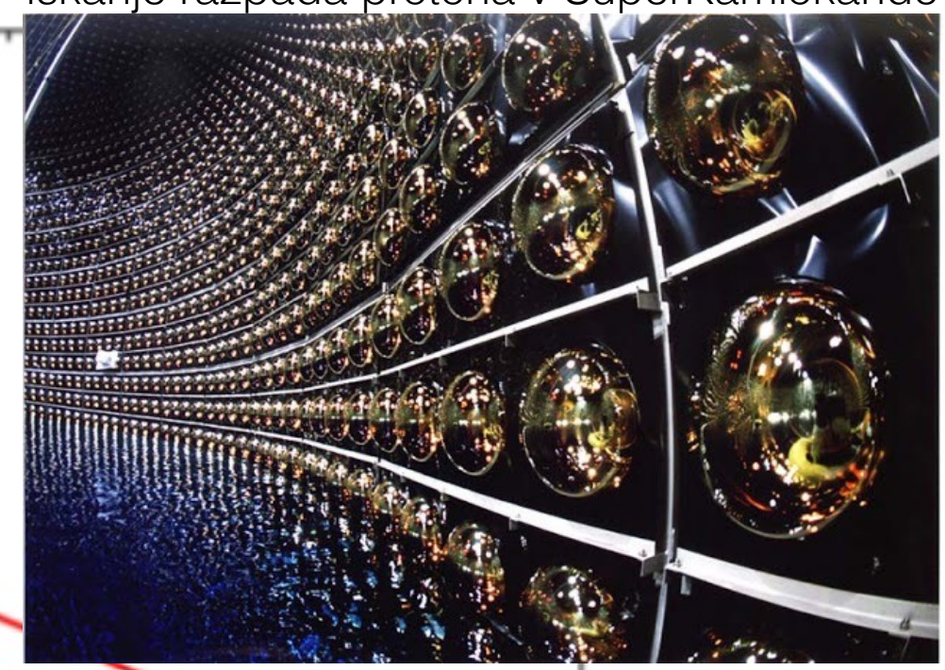


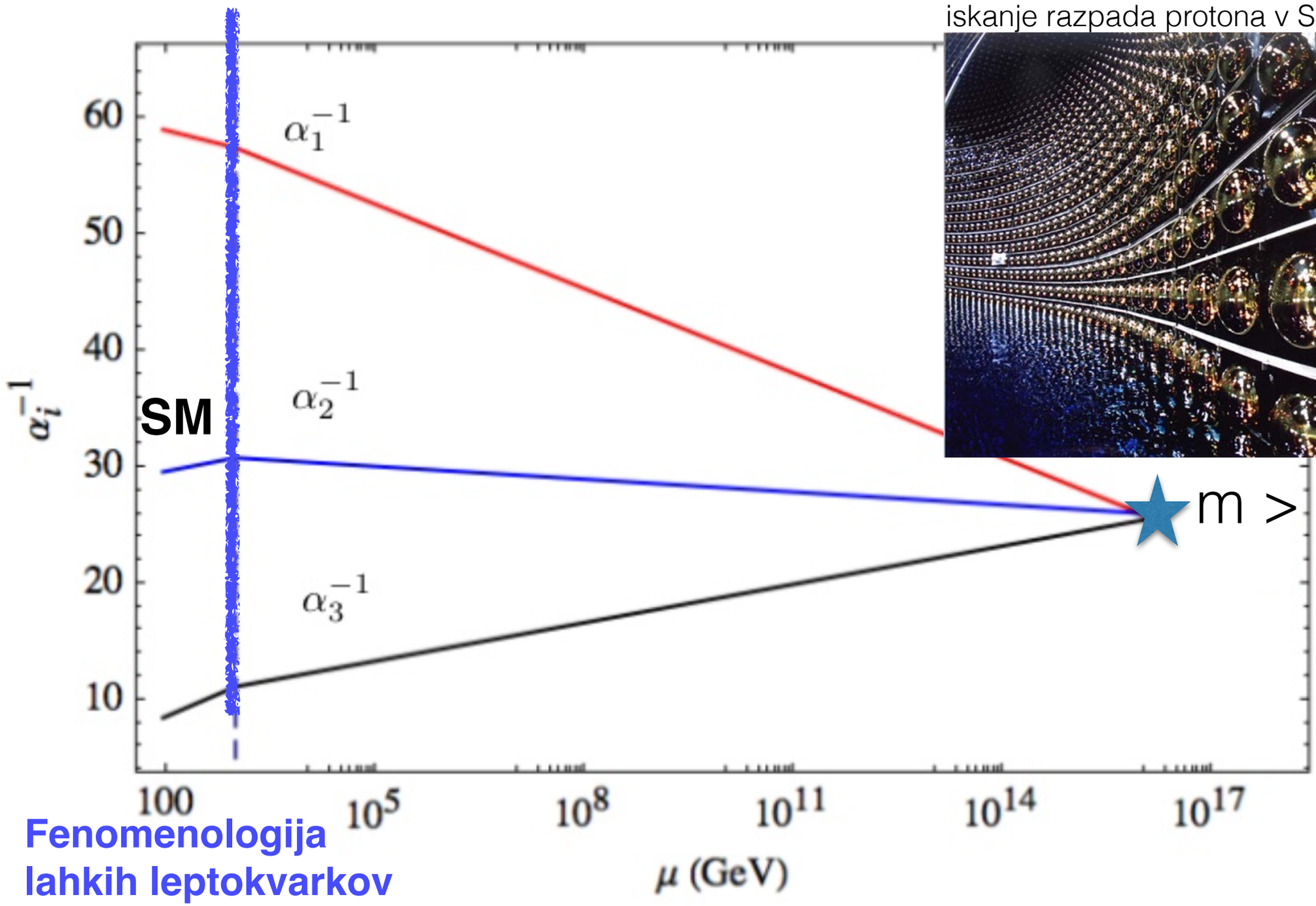
V kakšnih procesih lahko zaznamo leptokvarke? Kako spremenijo lastnosti poznanih osnovnih delcev? Kakšen bi bil pomen odkritja?

Lahki in težki leptokvarki

Lahki leptokvarki z maso okrog 1000 GeV so na dosegu LHC in preciznih meritev

iskanje razpada protona v SuperKamiokande



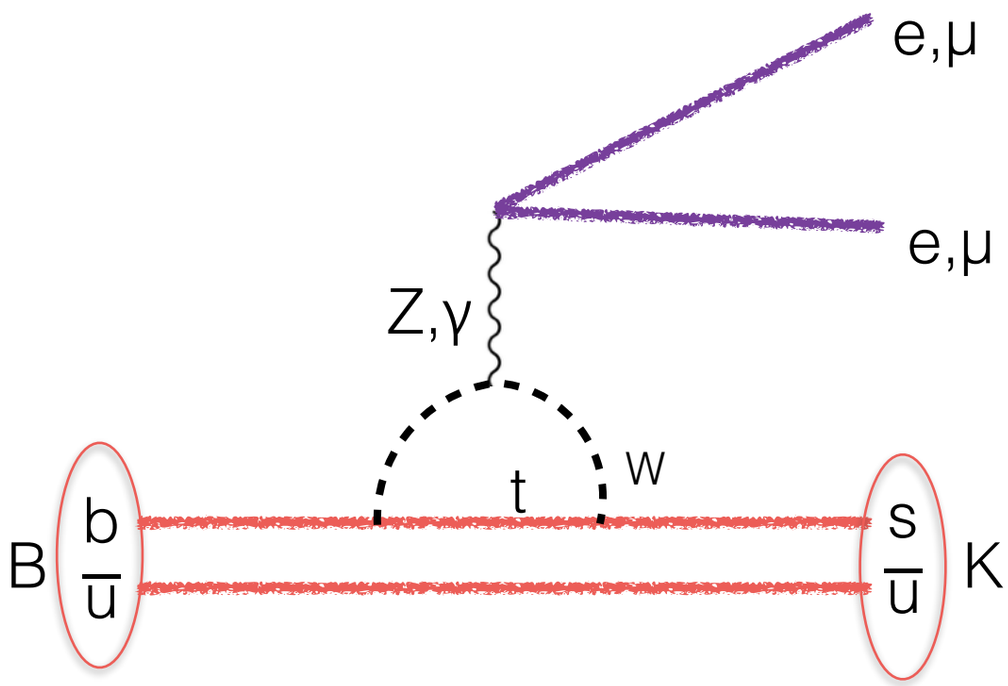


m > 10^{12} GeV

Fenomenologija lahkih leptokvarkov

Na sledi leptokvarkom

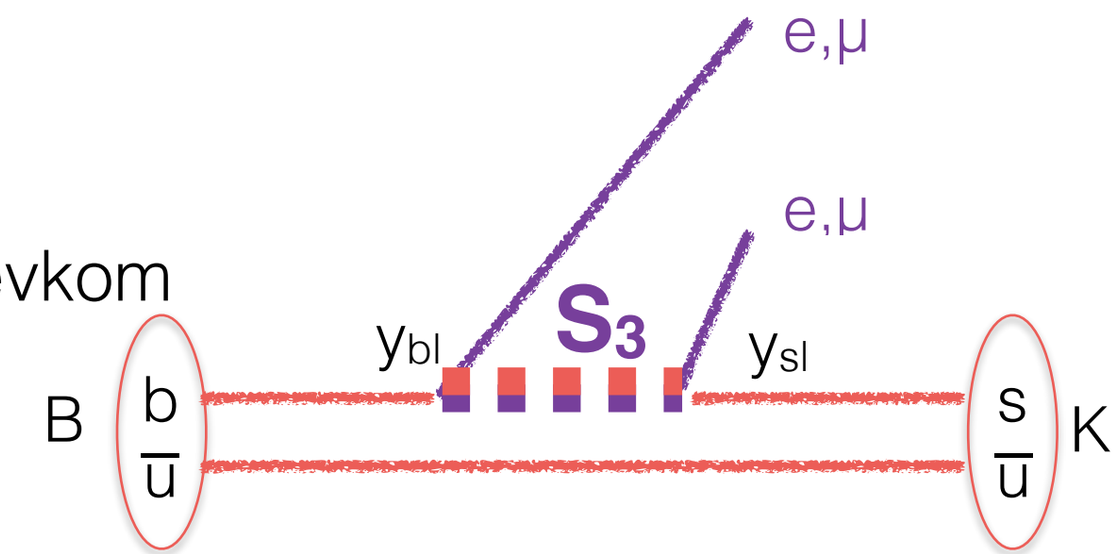
primer virtualnih efektov



Standardni model: Verjetnosti za razpad mezona B v končno stanje Ke^+e^- in $K\mu^+\mu^-$ sta enaki - univerzalnost leptonov

Eksperiment (LHCb): $P(K\mu^+\mu^-)$: $P(Ke^+e^-) = 0{,}75 \pm 0{,}12$

Neujemanje lahko razložimo s prispevkom leptokvarka, npr. z leptokvarkom S_3



V preglednem članku smo zbrali možne prispevkov leptokvarkov v redkih razpadih.

LQ	$d_j \to d_i \ell^- \ell'^+$ decays	$u_j \to u_i \ell^- \ell'^+$ decays
S_3	$c^{LL} = -\frac{v^2}{2m_{\rm LQ}^2} y_{3\,j\ell'}^{LL} y_{3\,i\ell}^{LL*}$	$c^{LL} = -\frac{v^2}{2m_{\rm LQ}^2} (V^T y_3^{LL})_{j\ell'} (V^T y_3^{LL})^*_{i\ell}$
R_2	$c^{LR} = \frac{v^2}{4m_{\rm LQ}^2} y_{2\,\ell j}^{LR} y_{2\,\ell' i}^{LR*}$	$c^{LR} = \frac{v^2}{4m_{\rm LQ}^2} (y_2^{LR} V^\dagger)_{\ell j} (y_2^{LR} V^\dagger)^*_{\ell' i}$ $c^{RL} = \frac{v^2}{4m_{\rm LQ}^2} y_{2\,i\ell'}^{RL} y_{2\,j\ell}^{RL*}$ $g^{LL} = 4h^{LL} = -\frac{v^2}{4m_{\rm LQ}^2} y_{2\,j\ell}^{RL*} (y_2^{LR} V^\dagger)^*_{\ell' i}$ $g^{RR} = 4h^{RR} = -\frac{v^2}{4m_{\rm LQ}^2} y_{2\,i\ell'}^{RL} (y_2^{LR} V^\dagger)_{\ell j}$
$\tilde{R}_2$	$c^{RL} = \frac{v^2}{4m_{\rm LQ}^2} \tilde{y}_{2\,i\ell'}^{RL} \tilde{y}_{2\,j\ell}^{RL*}$	
$\tilde{S}_1$	$c^{RR} = -\frac{v^2}{4m_{\rm LQ}^2} \tilde{y}_{1\,j\ell'}^{RR} \tilde{y}_{1\,i\ell}^{RR*}$	
S_1		$c^{LL} = -\frac{v^2}{4m_{\rm LQ}^2} (V^T y_1^{LL})_{j\ell'} (V^T y_1^{LL})^*_{i\ell}$ $c^{RR} = -\frac{v^2}{4m_{\rm LQ}^2} y_{1\,j\ell'}^{RR} y_{1\,i\ell}^{RR*}$ $g^{LL} = -4h^{LL} = \frac{v^2}{4m_{\rm LQ}^2} y_{1\,j\ell'}^{RR} (V^T y_1^{LL})^*_{i\ell}$ $g^{RR} = -4h^{RR} = \frac{v^2}{4m_{\rm LQ}^2} (V^T y_1^{LL})_{j\ell'} y_{1\,i\ell}^{RR*}$
U_3	$c^{LL} = \frac{v^2}{2m_{\rm LQ}^2} x_{3\,i\ell'}^{LL} x_{3\,j\ell}^{LL*}$	$c^{LL} = \frac{v^2}{m_{\rm LQ}^2} (V x_3^{LL})_{i\ell'} (V x_3^{LL})^*_{j\ell}$
V_2	$c^{LR} = -\frac{v^2}{2m_{\rm LQ}^2} x_{2\,j\ell'}^{LR} x_{2\,i\ell}^{LR*}$ $c^{RL} = -\frac{v^2}{2m_{\rm LQ}^2} x_{2\,j\ell'}^{RL} x_{2\,i\ell}^{RL*}$ $g^{LR} = \frac{v^2}{2m_{\rm LQ}^2} x_{2\,j\ell'}^{RL} x_{2\,i\ell}^{LR*}$ $g^{RL} = \frac{v^2}{2m_{\rm LQ}^2} x_{2\,j\ell'}^{LR} x_{2\,i\ell}^{RL*}$	$c^{LR} = -\frac{v^2}{2m_{\rm LQ}^2} (V^T x_2^{LR})_{j\ell'} (V^T x_2^{LR})^*_{i\ell}$
$\tilde{V}_2$		$c^{RL} = -\frac{v^2}{2m_{\rm LQ}^2} \tilde{x}_{2\,j\ell'}^{RL} \tilde{x}_{2\,i\ell}^{RL*}$
$\tilde{U}_1$		$c^{RR} = \frac{v^2}{2m_{\rm LQ}^2} \tilde{x}_{1\,i\ell'}^{RR} \tilde{x}_{1\,j\ell}^{RR*}$
U_1	$c^{LL} = \frac{v^2}{2m_{\rm LQ}^2} x_{1\,i\ell'}^{LL} x_{1\,j\ell}^{LL*}$ $c^{RR} = \frac{v^2}{2m_{\rm LQ}^2} x_{1\,i\ell'}^{RR} x_{1\,j\ell}^{RR*}$ $g^{LR} = -\frac{v^2}{m_{\rm LQ}^2} x_{1\,i\ell'}^{LL} x_{1\,j\ell}^{RR*}$ $g^{RL} = -\frac{v^2}{m_{\rm LQ}^2} x_{i\ell'}^{RR} x_{1\,j\ell}^{LL*}$	

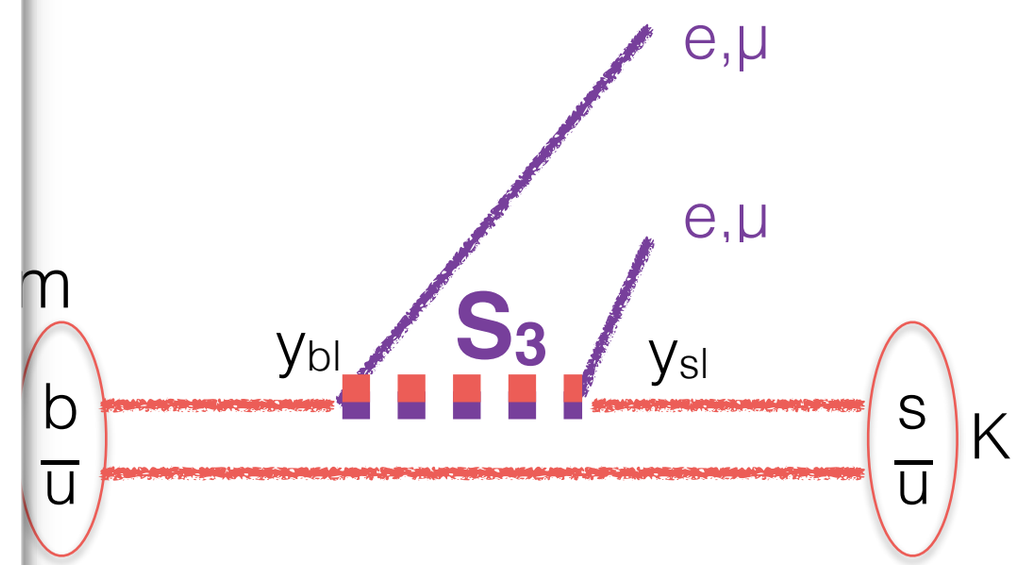
Table 4: Tree-level Wilson coefficients of LQ models in rare semileptonic decays. Values quoted are valid at the matching scale taken to be the LQ mass $m_{\rm LQ}$. We have not explicitly written the lepton and quark flavor indices on the Wilson coefficients, as introduced in the operator basis. For example, a table entry for c^{LL} stands for $c^{LL}_{ij;\ell\ell'}$. V and U are CKM and PMNS matrices, respectively. The electroweak vacuum expectation value is $v = 246$ GeV.

okvarkom

fektov

rdni model: Verjetnosti za razpad
a B v končno stanje Ke+e- in Kμ+μ-
ki - univerzalnost leptonov

riment (LHCb): P(Kμ+μ-) :
-) = 0,75 ± 0,12



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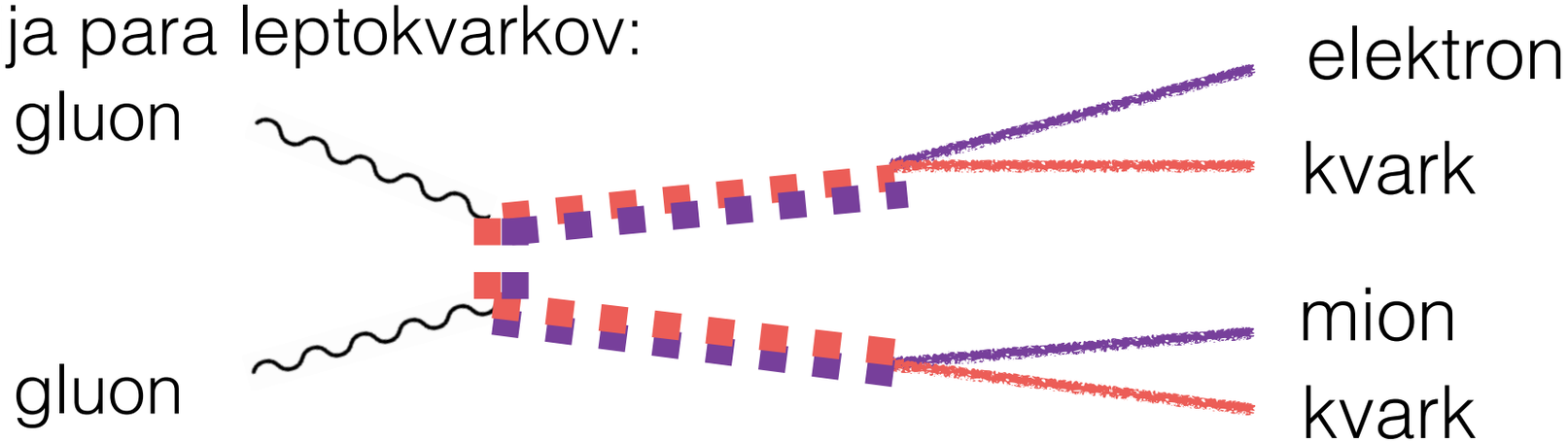
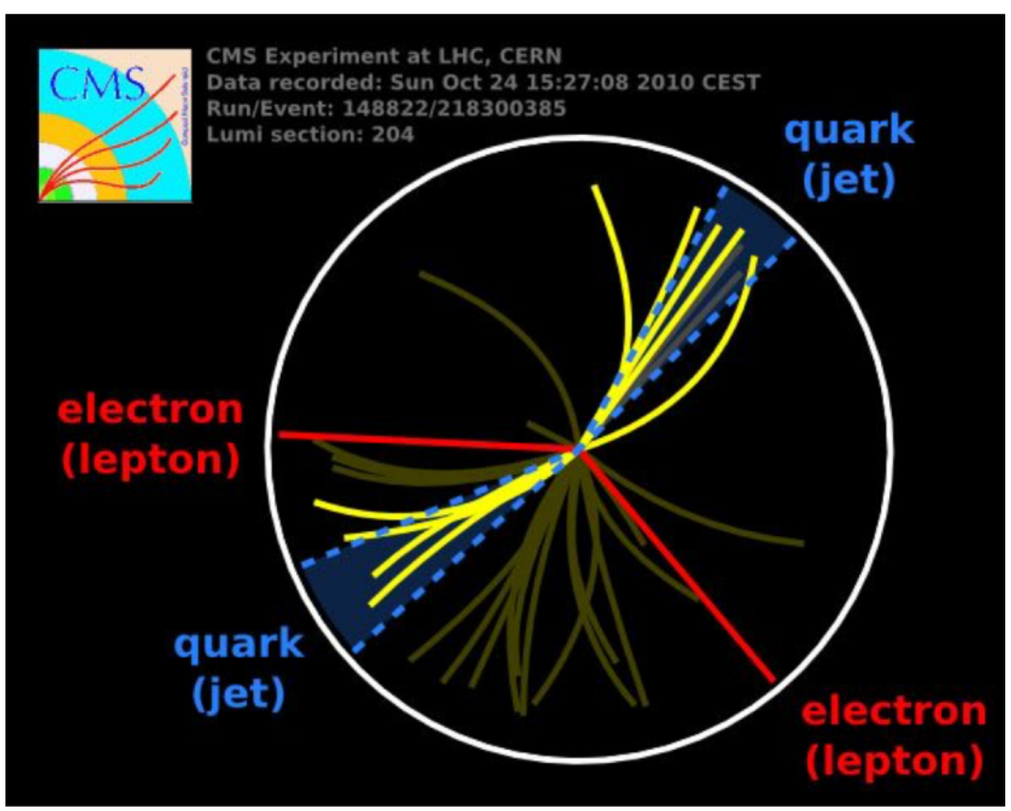
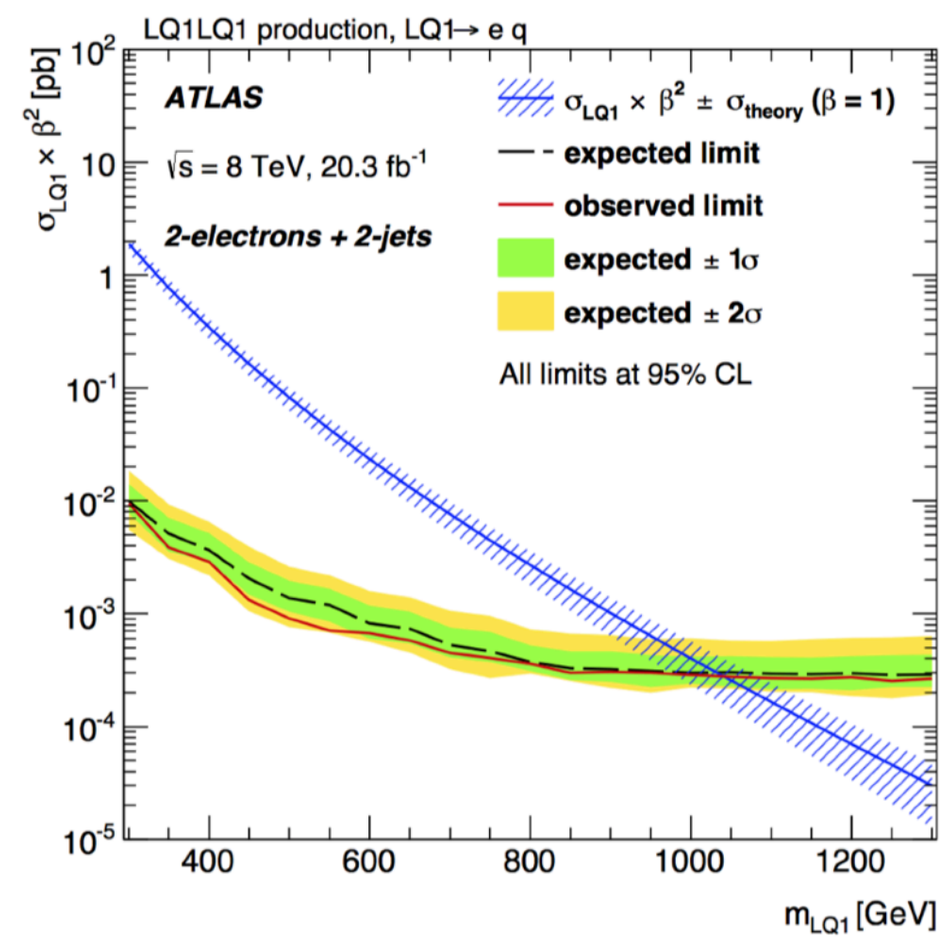
Leptokvarki na LHC

Pri velikih energijah trkov na LHC se lahko tvorijo realni leptokvarki z maso okrog 1000 GeV, ki razpadejo v leptone in hadronske curke

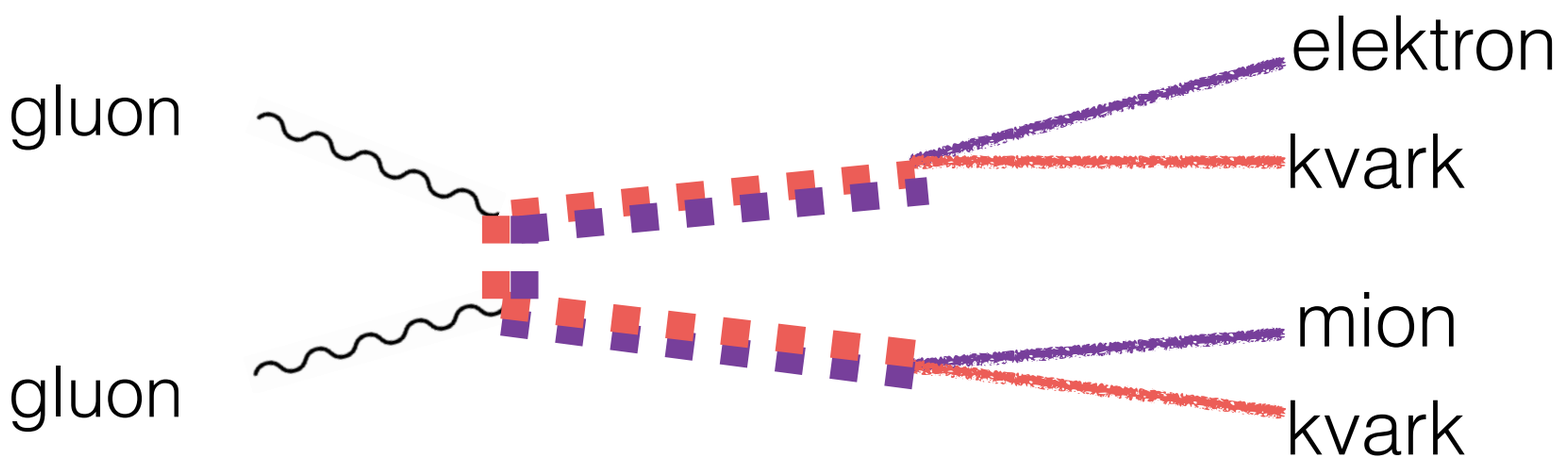
Produkcija para leptokvarkov:

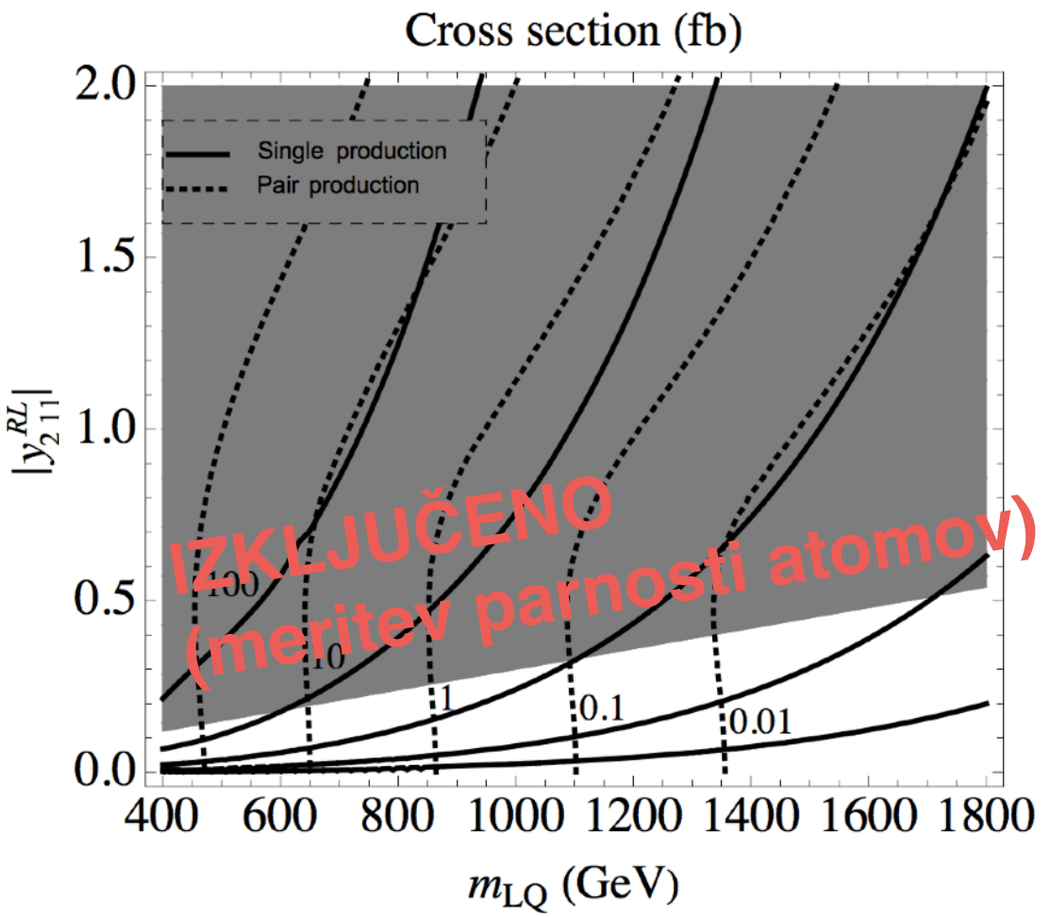






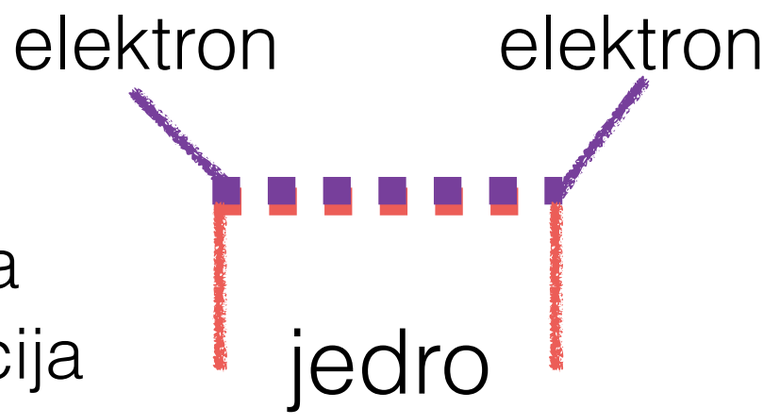
Leptokvarki na LHC





Prepletenost različnih fizikalnih procesov

Celostna analiza izboljša ločljivost.

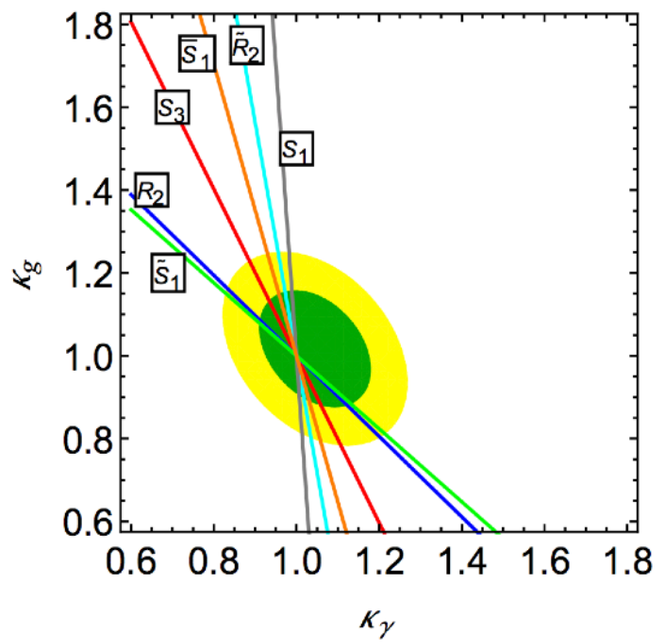


produkcija para

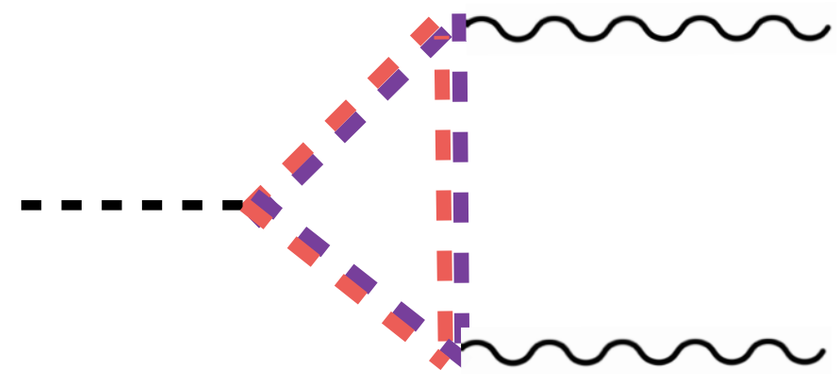
enojna produkcija

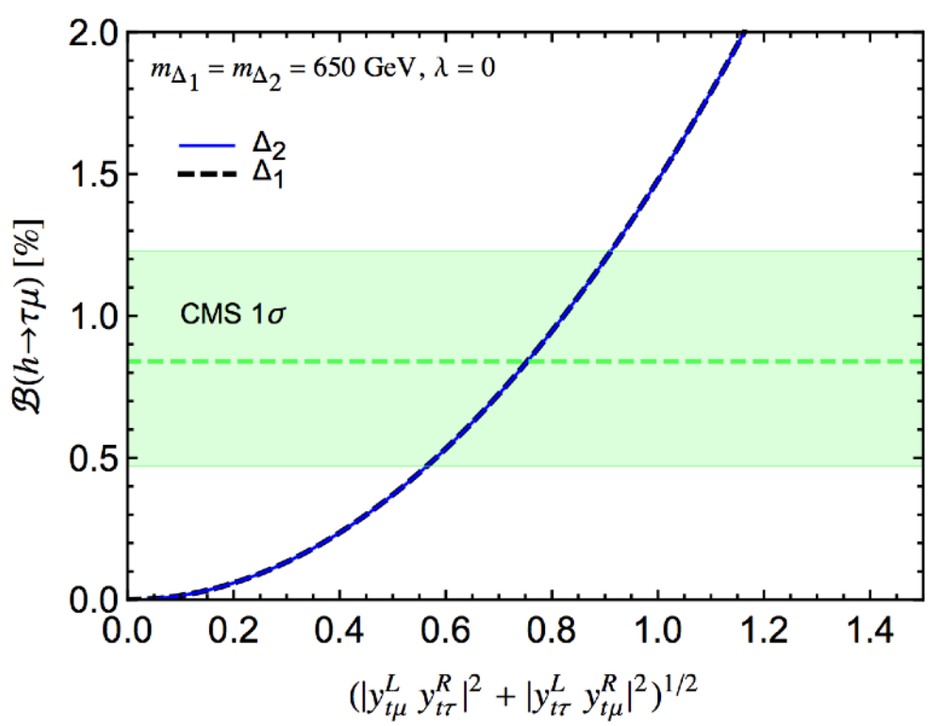
Leptokvarki na LHC

Študija razpadov Higgsovega bozona omogoča diskriminacijo med leptokvarki.

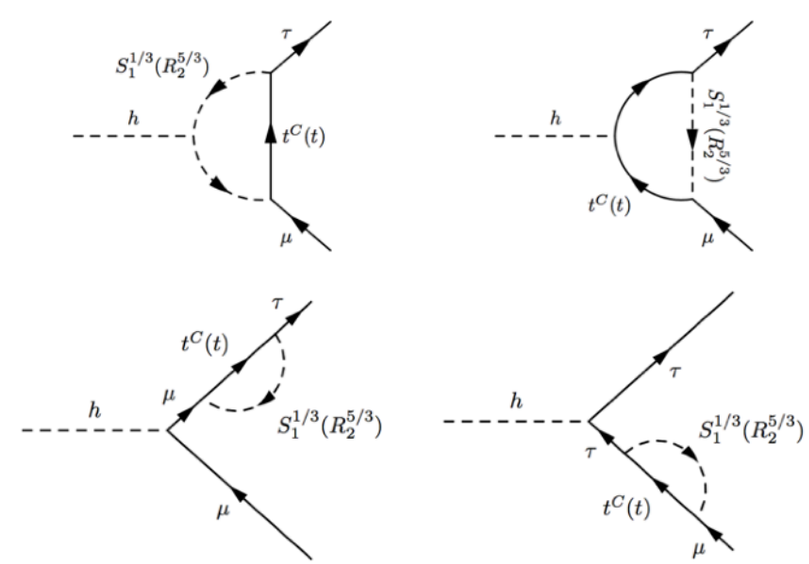


h→γγ, h→gg

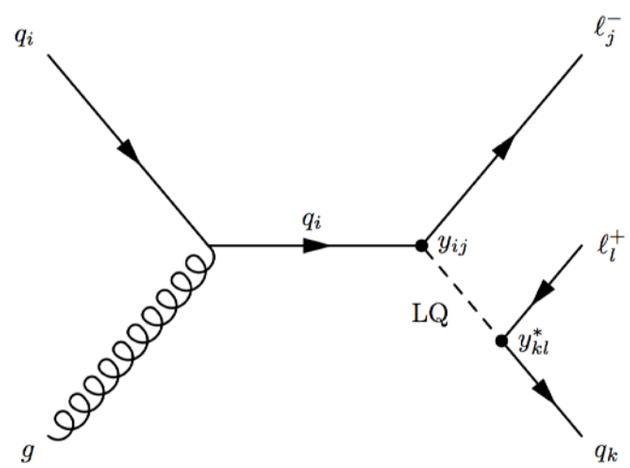




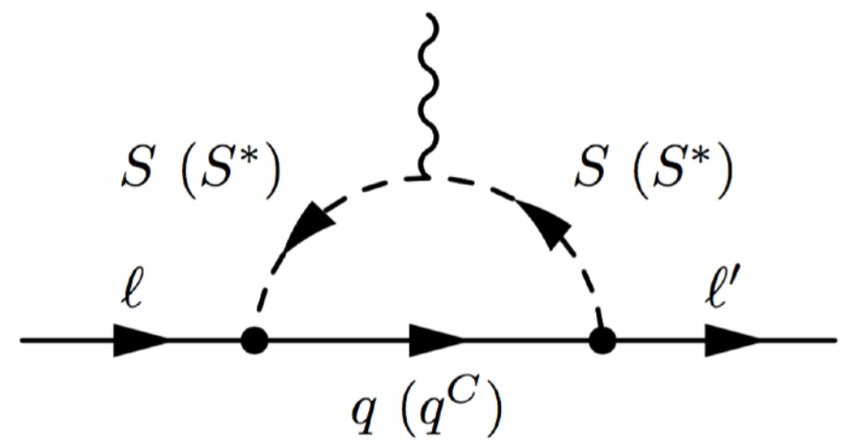
Prepovedani razpadi: h→μτ



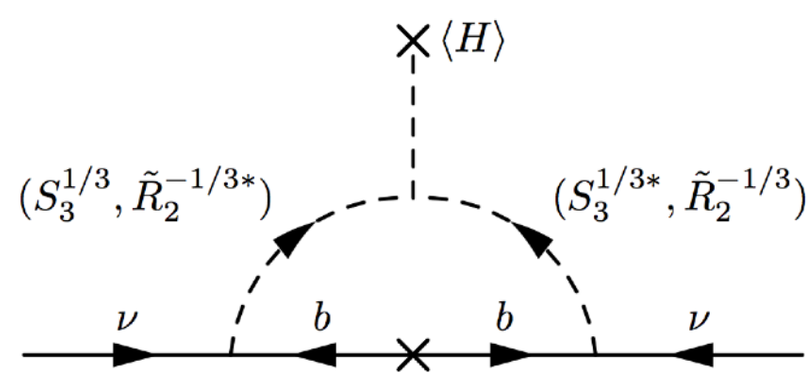
Ples realnih in virtualnih efektov leptokvarkov



enojna produkcija



magnetni moment miona



mase nevtrinov

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