Bounds on Neutrino-Scalar Coupling

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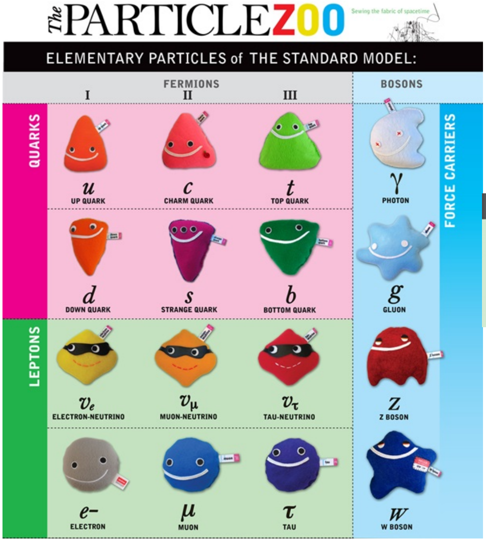
Universidade Estadual de Campinas (Unicamp)

Encontro Nacional de Física de Partículas e Campos

14 a 18 Setembro 2015, Caxambu, MG

SM is not the final chapter!



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http://www.particlezoo.net/

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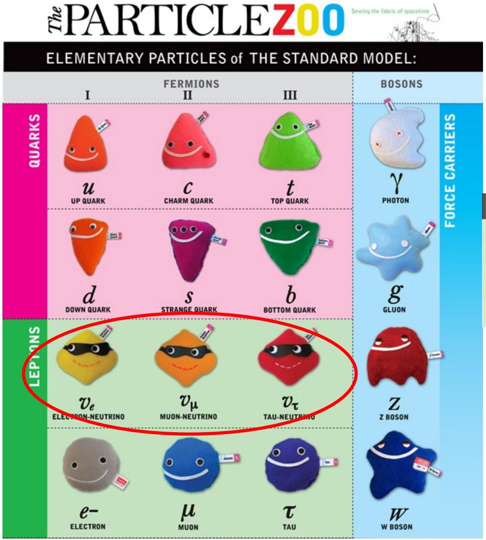

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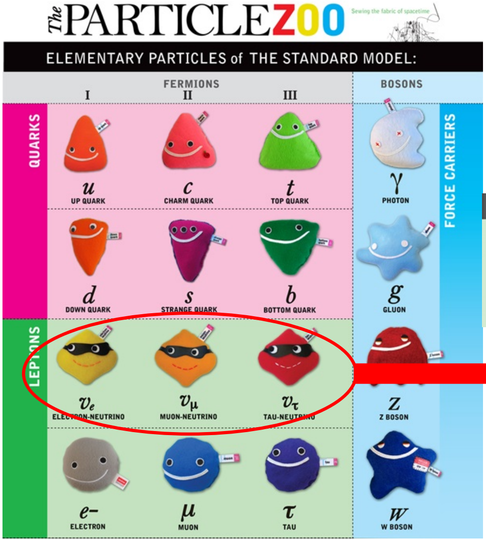

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Neutrinos have Mass!

And we don't know why

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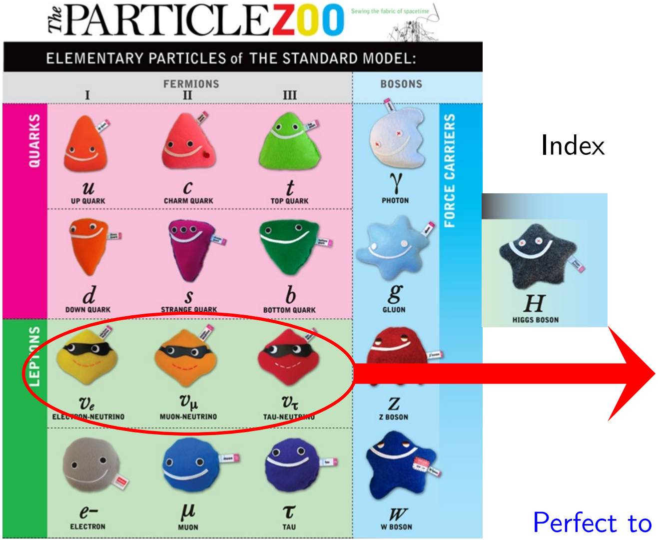

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Neutrinos have Mass!

And we don't know why

Perfect to look for new interactions/particles!

ν-Scalar interactions are interesting!

We assume a general Yukawa interaction with (only) neutrinos:

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$$\mathcal{L}_{\text{Yukawa}} = \frac{1}{2} g_{\alpha\beta} \overline{\nu}_\alpha \nu_\beta \phi_1 + \frac{i}{2} g'_{\alpha\beta} \overline{\nu}_\alpha \gamma_5 \nu_\beta \phi_2$$

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This interactions can be found in many models, e. g.

Majoron and Related [1]

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Two Higgs Models [2]:

[2] arXiv:1507.07550 [hep-ph]

It is possible to probe New Physics on Leptonic Decay

The idea is to use Mesons Leptonic Decays,

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Meson

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lepton

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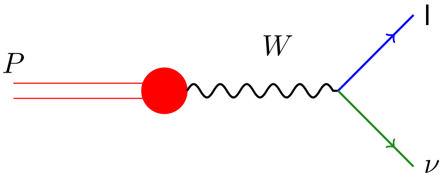

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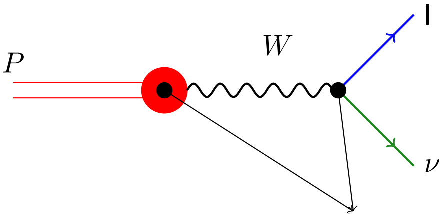

$$\Gamma(P \rightarrow l\nu) \sim G_F^2$$

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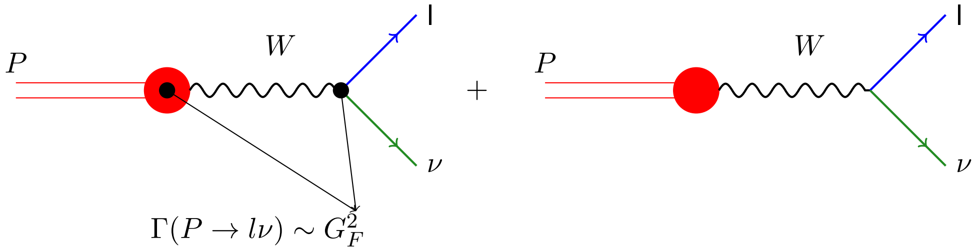
$$P \to l + \nu_m + \phi$$



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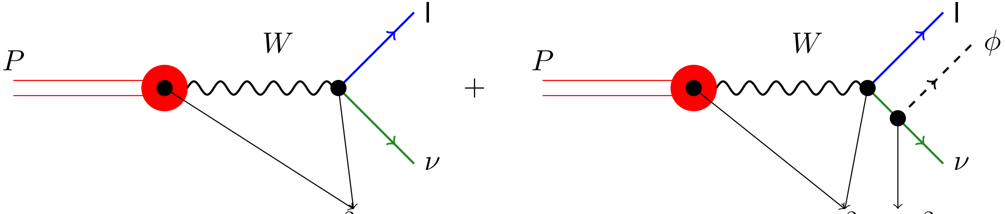

$$\Gamma(P \to l\nu) \sim G_F^2 \qquad \Gamma(P \to l\nu\phi) \sim G_F^2 |g_{lm}|^2$$

New couplings are small Corrections to known physics

$$\Gamma_{\text{tot}} = \Gamma(P \to l\nu) + \Gamma(P \to l\nu\phi)$$

Decay Rate (P rest Frame)

New couplings are small Corrections to known physics

$$\Gamma_{\text{tot}} = \Gamma(P \to l\nu) + \Gamma(P \to l\nu\phi)$$

Can't be observed on this experiment

New couplings are small Corrections to known physics

$$\Gamma_{\text{tot}} = \Gamma(P \to l\nu) + \Gamma(P \to l\nu\phi)$$

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SM

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New Physics

$$\Gamma_{\text{tot}} = \Gamma(P \to l\nu)\,(1 + A_{Pl}\, g_l^2)$$

New couplings are small Corrections to known physics

$$\Gamma\left(P \to l\nu\right) = \frac{G_F^2 f_P^2 |V_{qq'}|^2 m_p^3}{8\pi}\left(\frac{m_l}{m_p}\right)^2 \left[1 - \left(\frac{m_l}{m_p}\right)^2\right]^2$$

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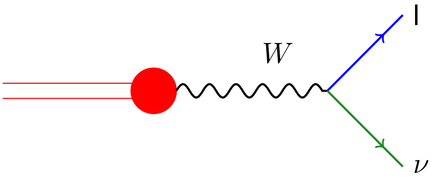

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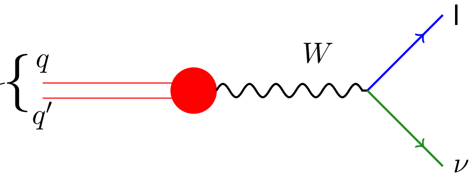

CKM matrix Element

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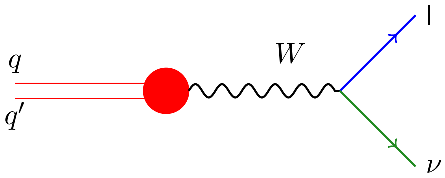

Chiral suppression

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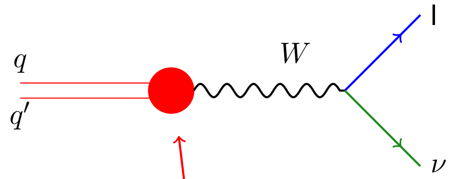

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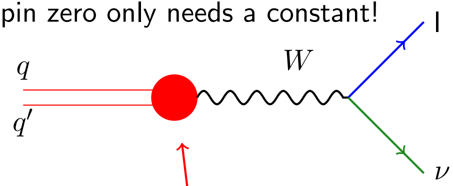
Meson Decay Constant

New couplings are small Corrections to known physics

Spin zero only needs a constant!



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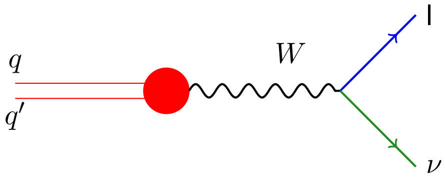

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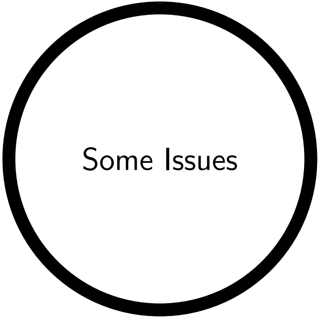
More on that later...

Meson Decay Constant

We don't know everything!



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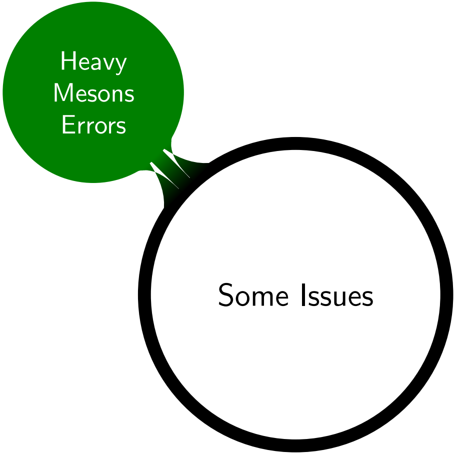
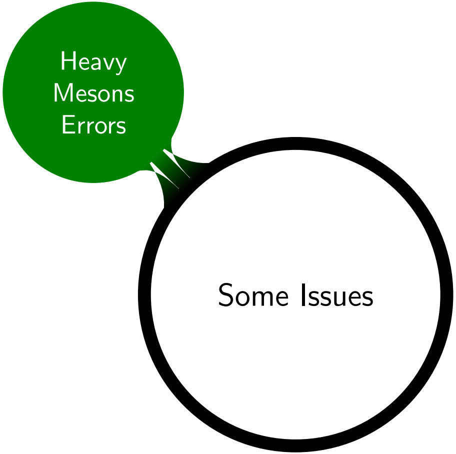


We don't know everything!

Reach up to 25%...



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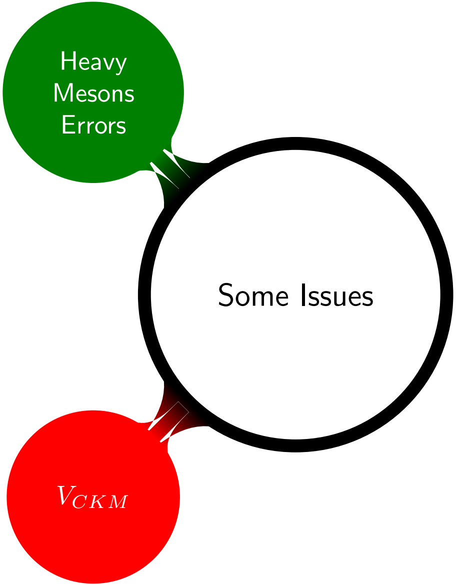

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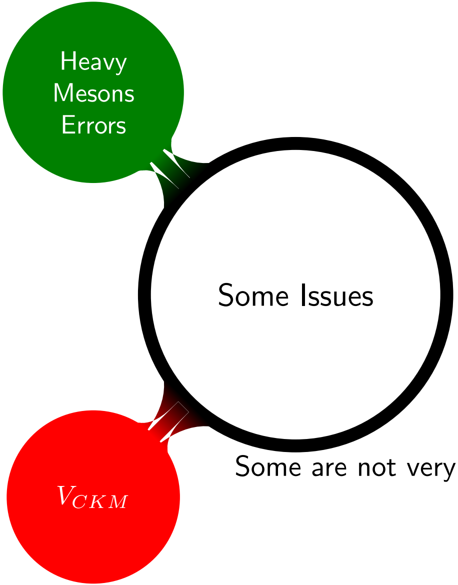

Some are not very precise

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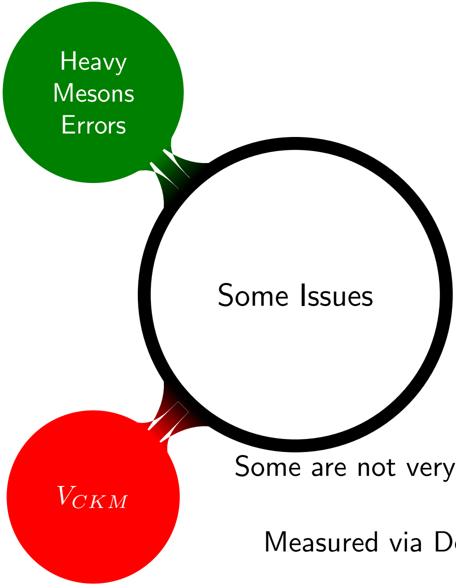

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Measured via Decays

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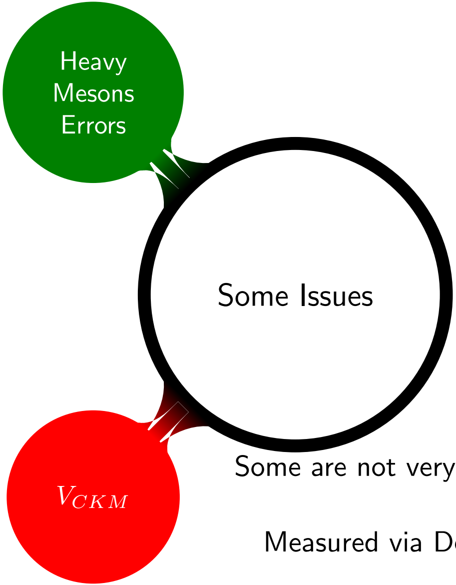

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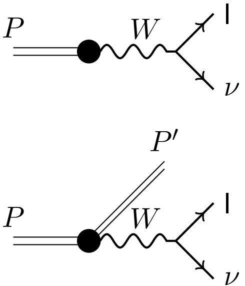

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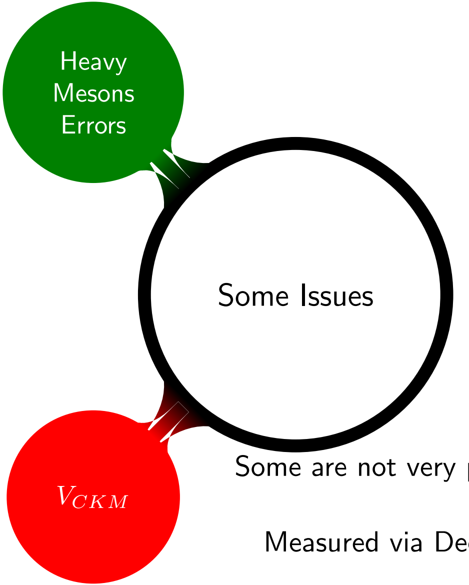

$$\Gamma \sim |V_{\rm CKM}|^2(1 + \text{corrections})$$

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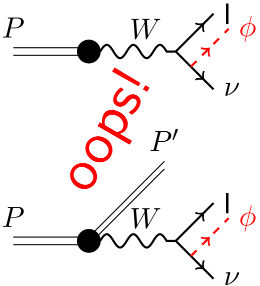

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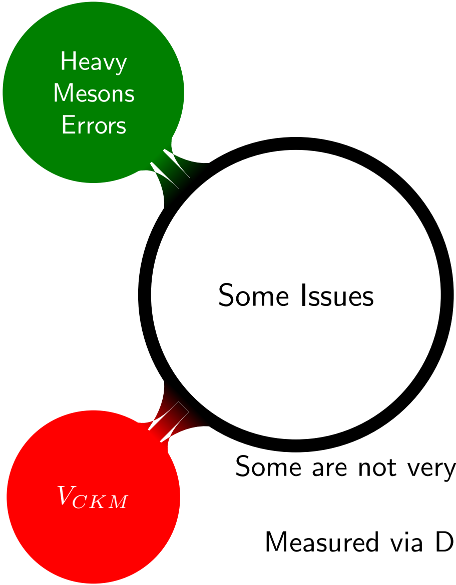

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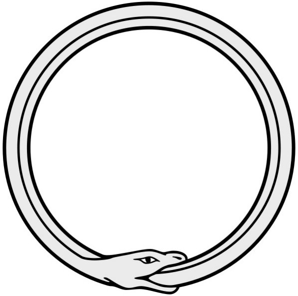

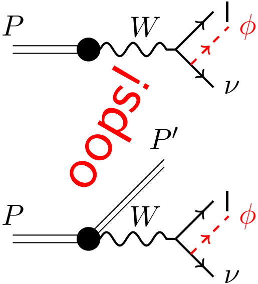

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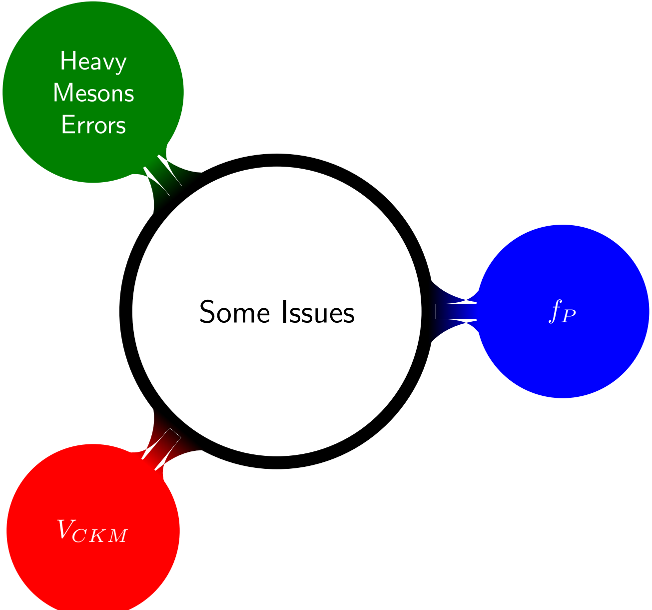
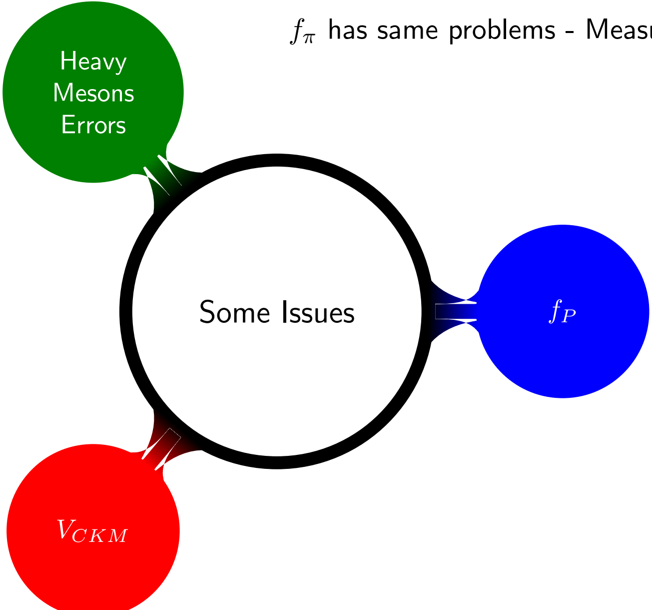


We don't know everything!

f_π has same problems - Measured via decays



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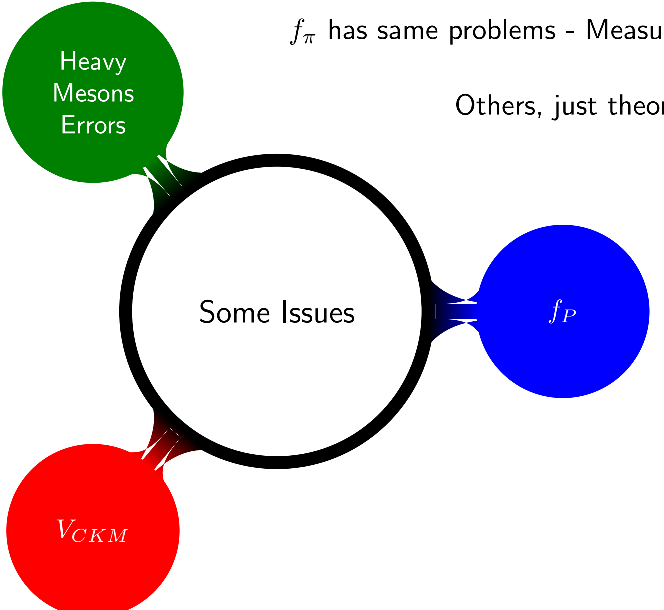
f_π has same problems - Measured via decays

Others, just theoretical!



Today it is possible!

Lattice QCD[3]

[3] Eur. Phys. J. C **74**, no. 9, 2890 (2014)

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Lattice QCD[3]

	f_P[MeV]
π	130.2(1.4)
K	156.3(0.9)
D	209(3.3)
D_s	250(7)
B	186(4)

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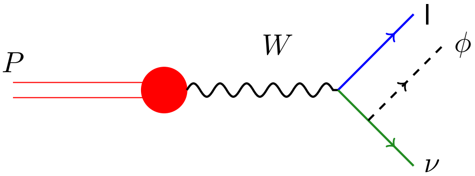
Very Recent!

3 Eur. Phys. J. C **74**, no. 9, 2890 (2014)

It is a Three body Decay

Finally, Beyond SM:



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Following Barger, Keung and Pakvasa[4]

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Calculated the corrections $A_{Pl}(m_\phi)$

[4] Phys. Rev. D **25**, 907 (1982).

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$$d\Gamma(P \to l\nu\phi) = \Gamma_{l\nu} \frac{\left(x^2+\epsilon^2+6x\epsilon-\beta x-\beta\epsilon\right)\lambda^{1/2}(x,\epsilon,\beta)}{x^2(x-\epsilon)^2} \frac{g_l^2}{32\pi^2} dx$$

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$$\lambda(x,y,z) = x^2 + y^2 + z^2 - 2xy - 2xz - 2zy$$

Kinematic Function

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Leptonic Decay rate

for neutrino with Squared mass x

$$\Gamma_{l\nu} = \frac{G_F^2 f_P^2 |V_{qq'}|^2 m_p^3}{8\pi}[x + \alpha - (x-\alpha)^2]\lambda^{1/2}(1, x, \alpha)$$

$$\alpha = \frac{m_l^2}{m_P^2}$$

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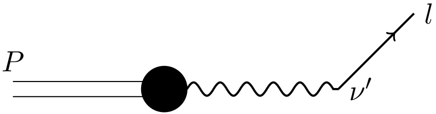
⬇

Three body and Yukawa

[4] Phys. Rev. D **25**, 907 (1982).

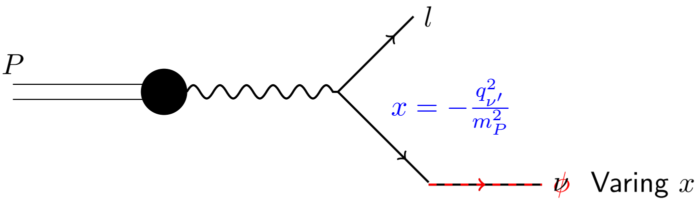
It is like a virtual twobody!



ν' is virtual!

$$x = -\frac{q_{\nu'}^2}{m_P^2}$$

x varies angles and M^2_{miss}



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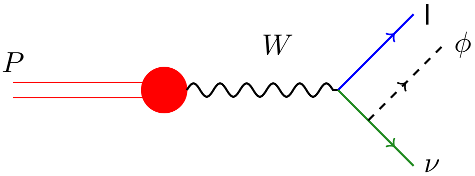
Infrared Divergent!!

[4] Phys. Rev. D **25**, 907 (1982).

It is not Divergent



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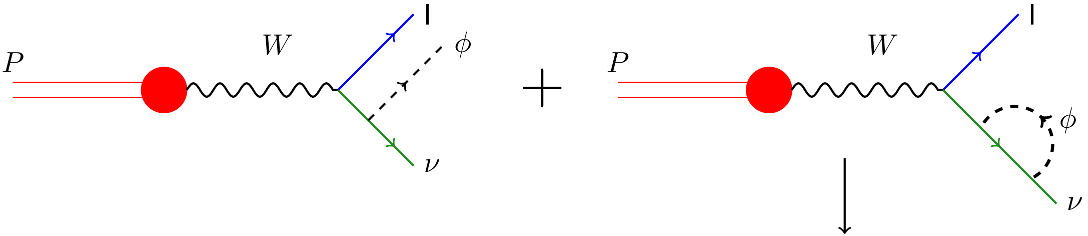

$$\sum_s u^{(s)}\overline{u}^{(s)} \approx \not{p}\left[1-\frac{g_l^2}{32\pi^2}Log\left(\frac{(m_P^2-m_l^2)^2}{4m_\phi^2 m_P^2}\right)\right]$$

Decays from π, K, D^+, D_s, B

Using a χ^2:

$$\chi^2 = \sum_{P,l} \frac{\left[\Gamma_{Pl}(1 + A_{Pl} g_l^2) - a_{Pl}\right]^2}{\sigma_{Pl}^2}$$

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Experimental Data 8 Decays:

π, K, D^+, D_s, B

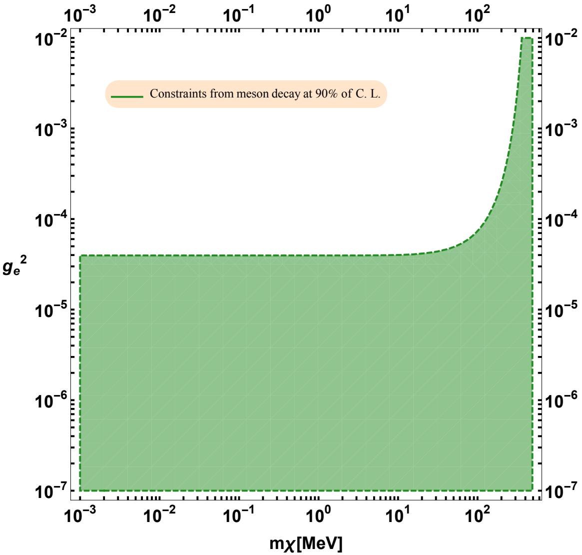
[5] PDG Chin. Phys. C 38, 090001 (2014).

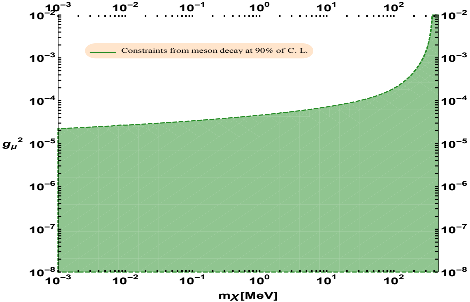
[6] BESIII Collaboration, Phys. Rev. D 89, no. 5, 051104 (2014)

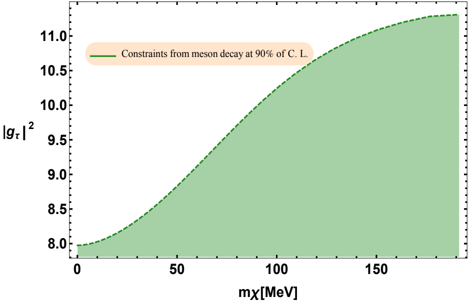
[7] BaBar Collaboration, arXiv:1003.3063 [hep-ex].

[8] Belle Collaboration, JHEP 1309, 139(2013).

Bounds on π, K, D^+, D_s, B







Continuous peaks = $l\nu\phi$ decay

Heavy Neutrino Search allows to use this calculations too!

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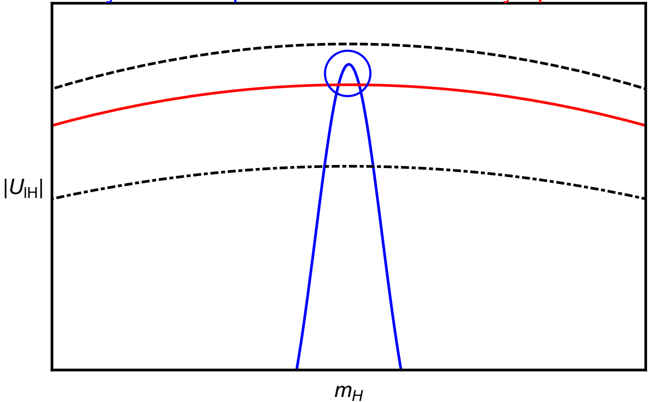
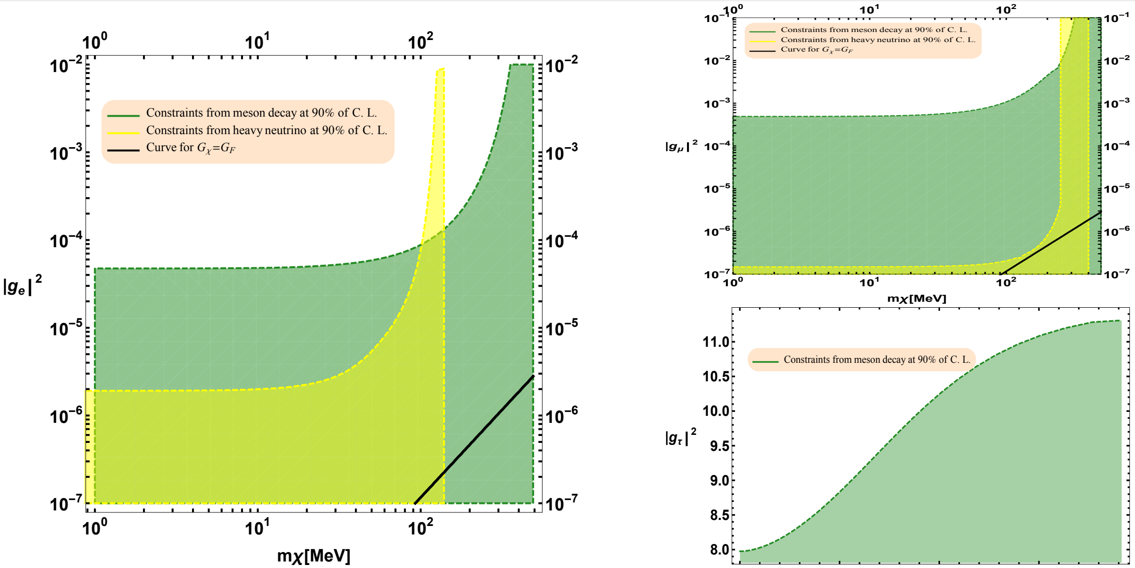
The three body decay mimic a continuos mass spectrum of heavy neutrino

They look for peaks on the SM decay spectrum



Using Heavy Search from π, K [8,9]



[8] D. I. Britton et al., Phys. Rev. D 46, 885 (1992).
[9] A. V. Artamonov et al. [E949 Collaboration], arXiv:1411.3963 [hep-ex].

Heavy Search Uses Lepton Spectrum → much better

Conclusions

We improved the bounds on the constants!

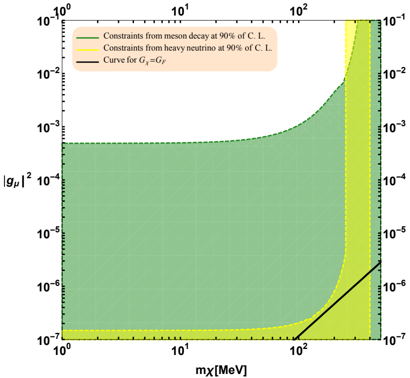
Our Results are valid up to $m_\phi \sim 100$ MeV

Constants	Our Results	[10]	[11]
$\|g_e\|^2$	$< 1.9 \times 10^{-6}$	$< 4.4 \times 10^{-5}$	$< 1.6 \times 10^{-5}$
$\|g_\mu\|^2$	$< 1.9 \times 10^{-7}$	$< 3.6 \times 10^{-4}$	
$\|g_\tau\|^2$	< 7.5	$< 2.2 \times 10^{-1}$	

Table: Limits setting $m_\phi = 0$.

[10] A. P. Lessa and O. L. G. Peres, Phys. Rev. D 75, 094001 (2007).

[11] J. B. Albert et al. [EXO-200], Phys. Rev. D 90, no. 9, 092004 (2014).



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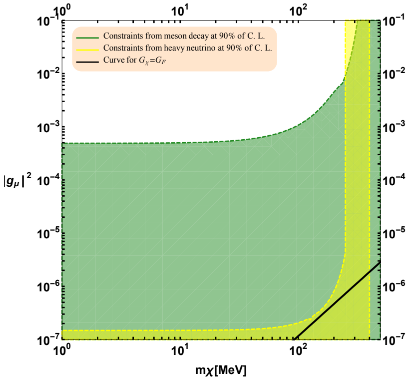

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Agradecimentos:

Fapesp CNPQ

Unicamp (IFGW)

Advisor, Professors and friends

Backup Slides

Backup Slides

We need second order corrections..

Radiative Corrections[2]!

Tree Level

Lepton Radiative Corrections

$$\Gamma\left(P \to l\nu(\gamma)\right) = \Gamma^{(0)} \left(1 + 2\frac{\alpha_{el}}{\pi}\log\left(\frac{m_z}{m_\rho}\right)\right)\left[1 + \frac{\alpha_{el}}{\pi} F\left(\frac{m_l}{m_P}\right)\right] \times \left\{1 - \frac{\alpha_{el}}{\pi} G(m_\rho, m_P, m_l)\right\}$$

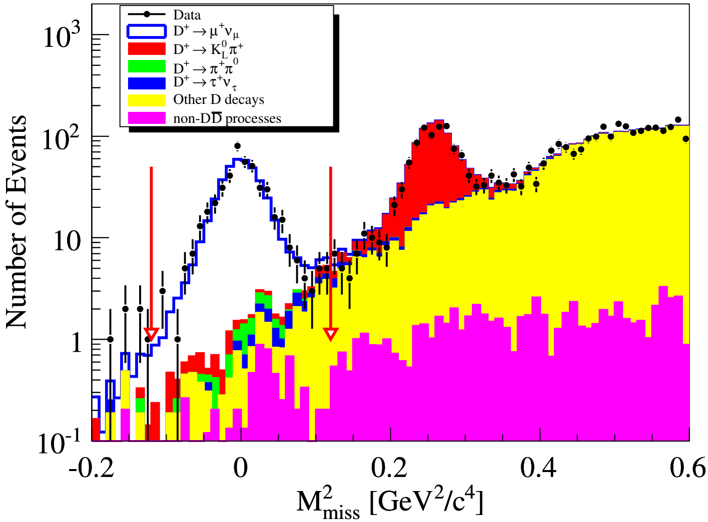
Low Distance Radiative Corrections

High Distance Radiative Corrections

[2] W. J. Marciano and A. Sirlin, Phys. Rev. Lett. **71**, 3629 (1993).

Missing Energy Allows Probe New Physics

$$x \neq 0$$



Bounds on π, K, D^+, D_s, B