Planck 2018, Bonn, May 24 2018

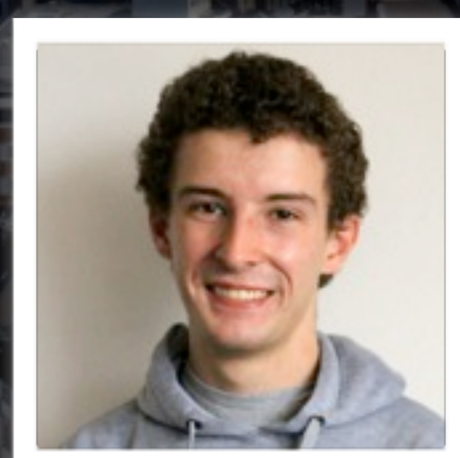
Witten's loop in the flipped SU(5)

revisited

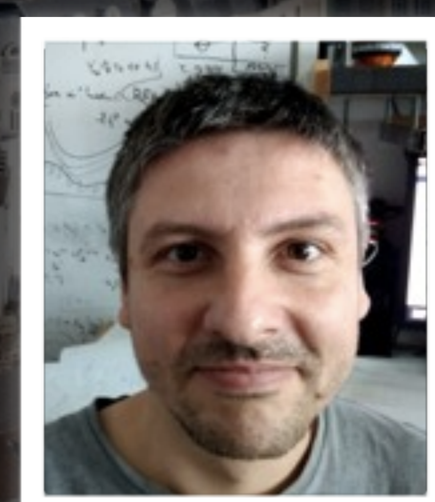
Michal Malinský

Institute of Particle and Nuclear Physics, Charles University in Prague

in collaboration with



Dylan Harries



Martin Zdráhal

The Witten's loop

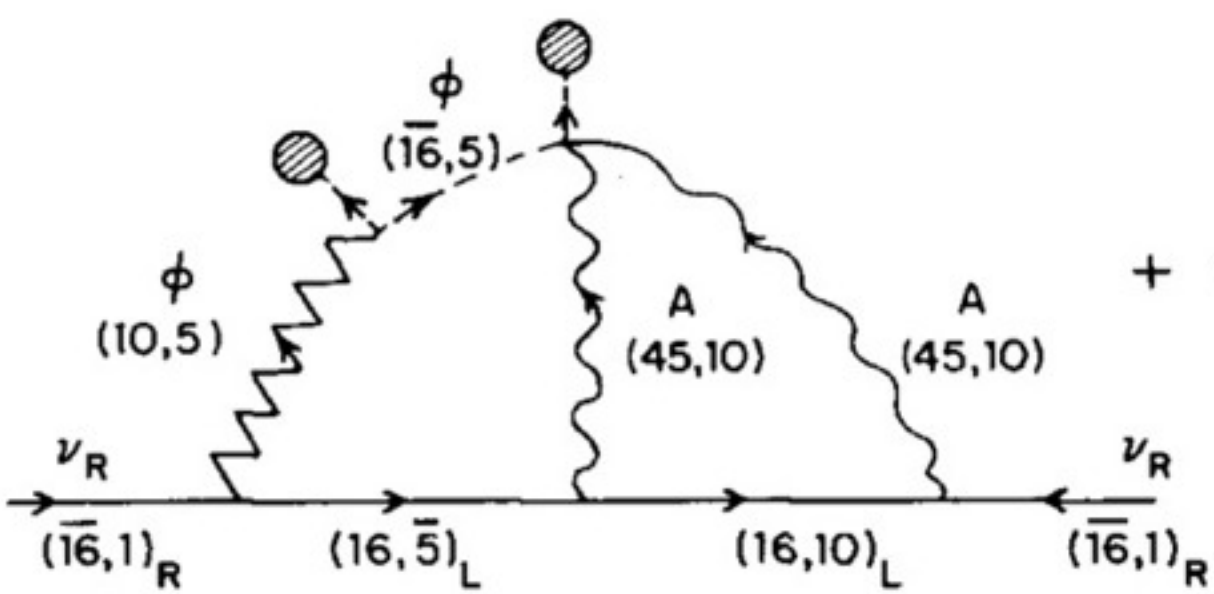
NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

Phys. Lett. B91 (1980) 81

Edward WITTEN [1]
Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, USA

Received 6 December 1979

Neutrino masses are discussed in the context of the O(10) grand unified theory. In the "minimal" form of this theory, with minimal Higgs and fermion content, the right-handed neutrinos acquire masses at the two loop level. The left-handed neutrino masses are correspondingly *larger* by a factor roughly $(\alpha/\pi)^{-2}$ than they would be if the right-handed neutrino could acquire mass at the tree level. In the simplest form of this theory, the neutrino mass matrix is proportional to the up quark mass matrix, and the neutrino mixing angles equal the usual Cabibbo angles. The neutrino masses will be roughly in the range $10^{0\pm2}$ eV depending on the strength of O(10) symmetry breaking, and on certain unknown ratios of masses and couplings of superheavy particles.



+ CROSSED

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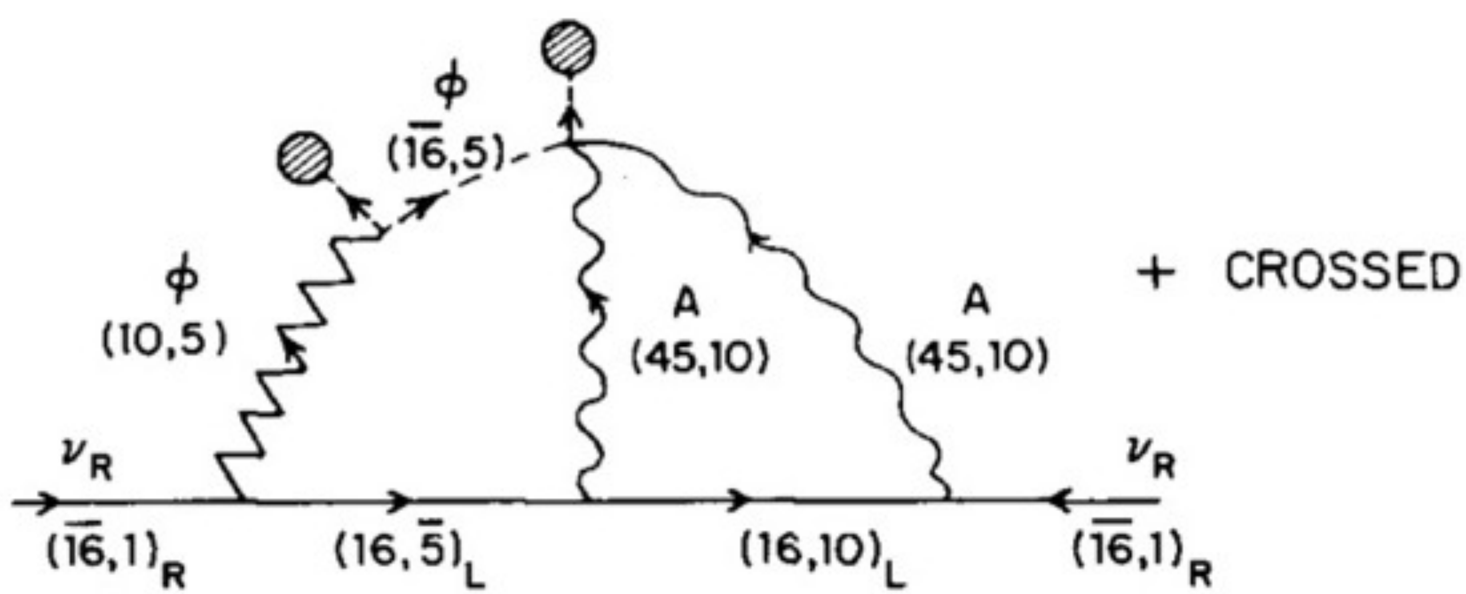

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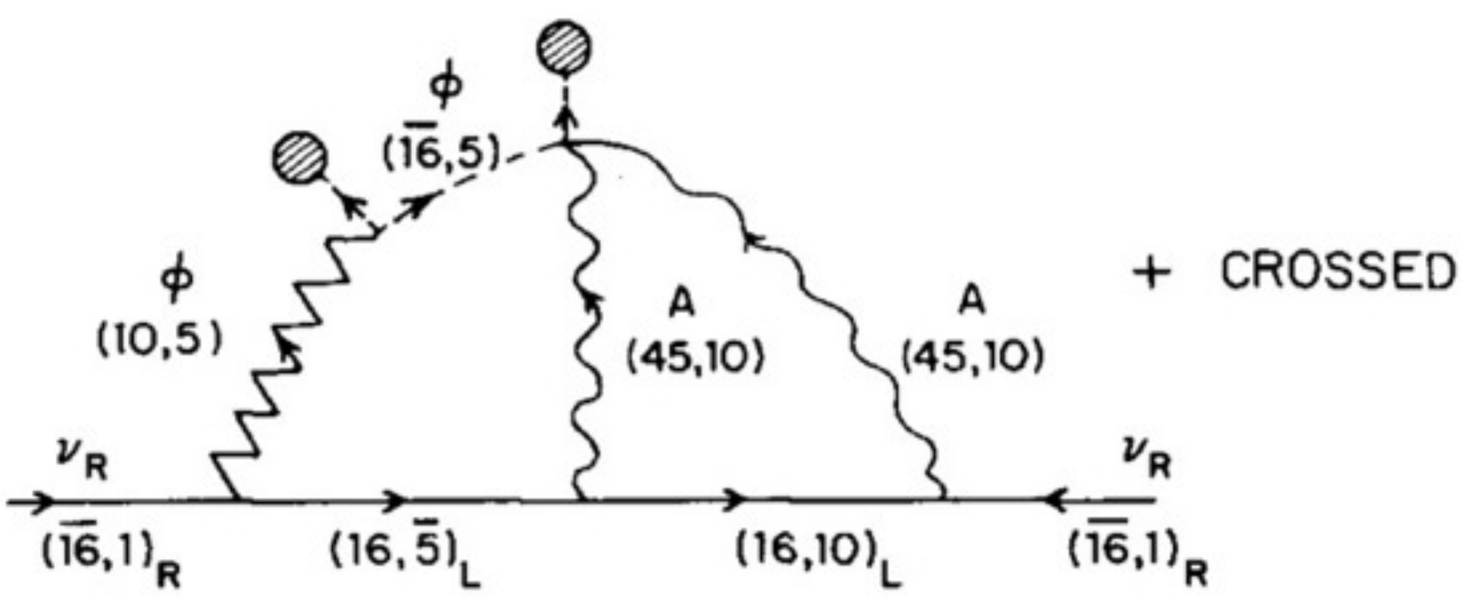
Not many true applications though!

Early 1980's: no need for a hierarchy of scales (seesaw vs. GUT)
stability issues in the minimal SO(10) scenario



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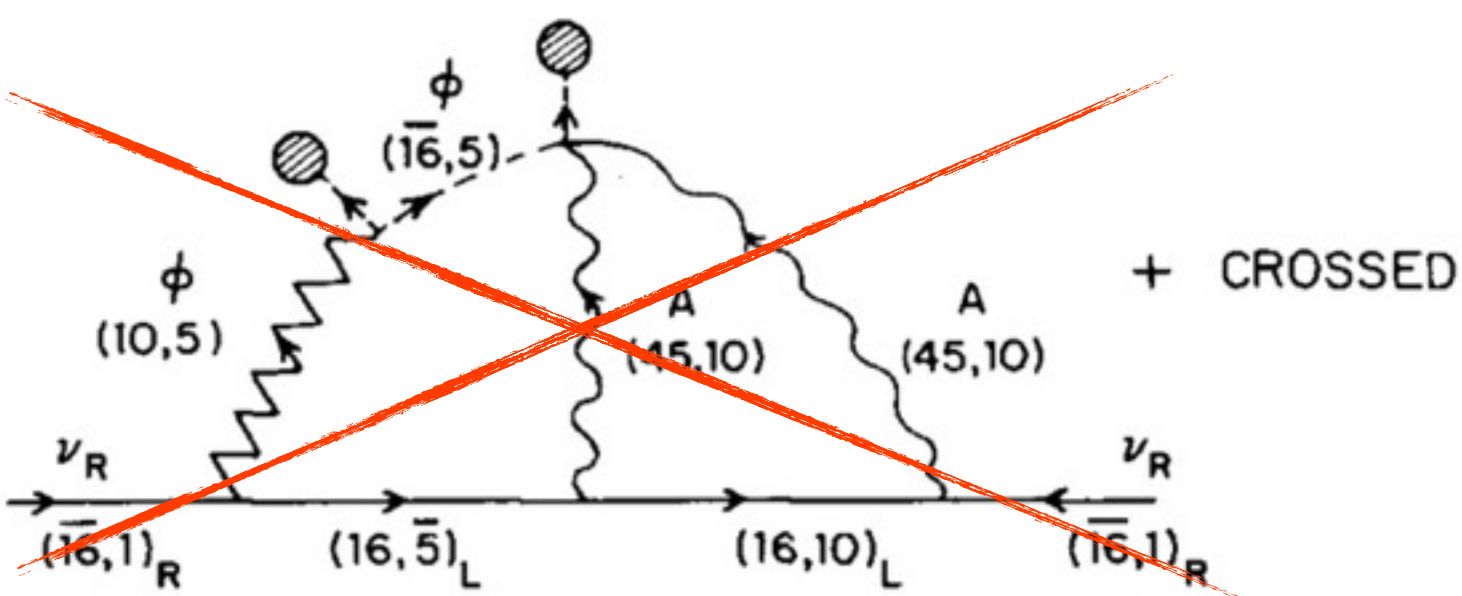

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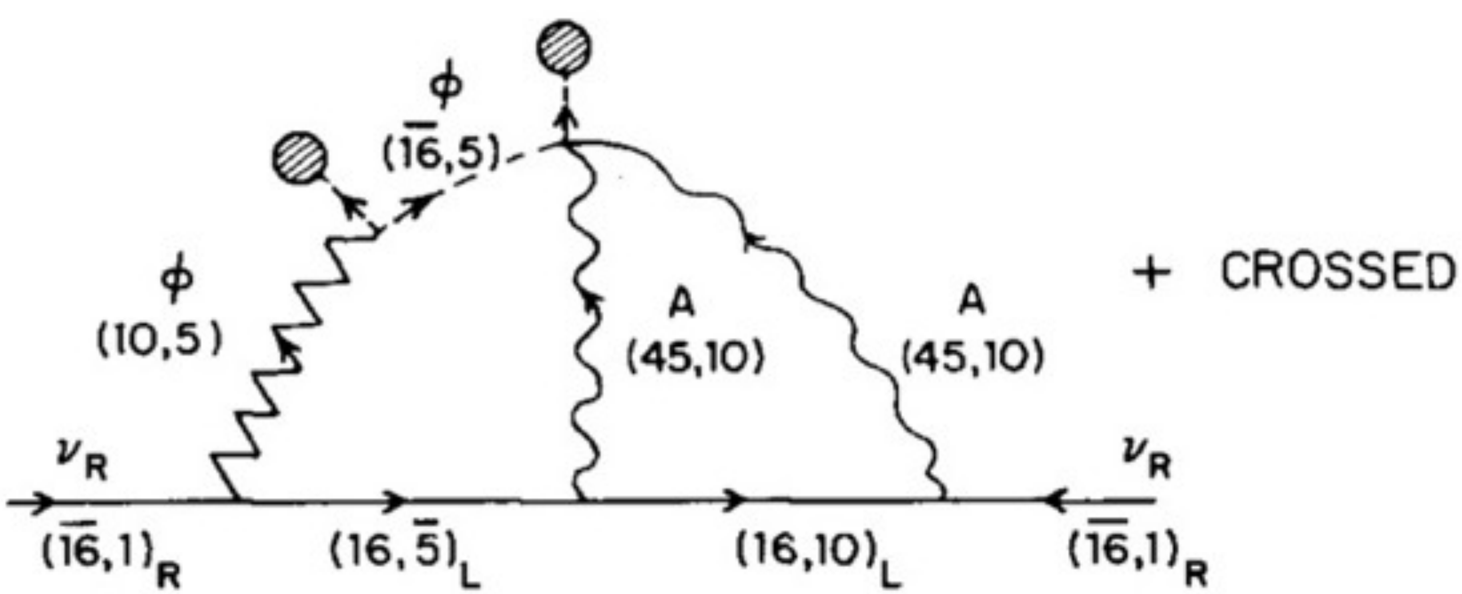
Few exceptions: super-split supersymmetry - scalars at the GUT scale

Bajc, Senjanovic, Phys. Lett.B610 (2005) 80



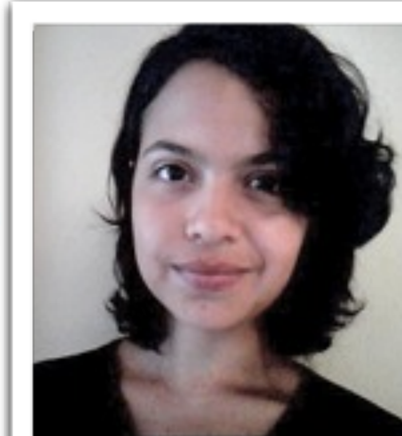
Witten's loop in the flipped SU(5)

PHYSICAL REVIEW D **89,** 055003 (2014)

Witten's mechanism in the flipped $SU(5)$ unification

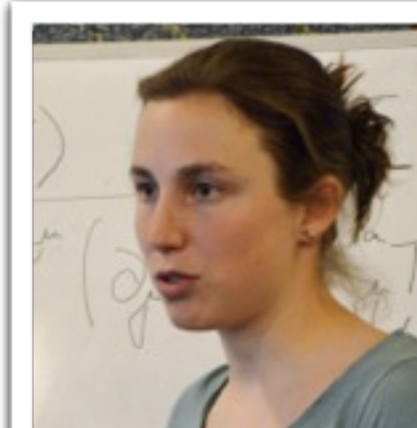
Carolina Arbeláez Rodríguez[*]

Centro de Física Teórica de Partículas, Instituto Superior Técnico, Universidade Técnica de Lisboa, Avenida Rovisco Pais 1, 1049-001, Lisboa Portugal and AHEP Group, Instituto de Física Corpuscular–C.S.I.C./Universitat de València Edificio de Institutos de Paterna, Apartado 22085, E–46071 València, Spain



Helena Kolešová[†]

Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, 180 00 Praha 8, Czech Republic and Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 115 19 Praha 1, Czech Republic



Michal Malinský[‡]

Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, 180 00 Praha 8, Czech Republic

(Received 3 October 2013; published 3 March 2014)

We argue that Witten's loop mechanism for the right-handed Majorana neutrino mass generation identified originally in the $SO(10)$ grand unification context can be successfully adopted to the class of the simplest flipped $SU(5)$ models. In such a framework, the main drawback of the $SO(10)$ prototype—in particular, the generic tension among the gauge unification constraints and the absolute neutrino mass scale—is alleviated, and a simple yet potentially realistic and testable scenario emerges.

see also G.K.Leontaris and J.D.Vergados, PLB 258 (1991), 111

Flipped SU(5) crash course

SO(10) ⊃ SU(5) x U(1)z

Matter: $16_M \ni (10, +1)_M \oplus (\overline{5}, -3)_M \oplus (1, +5)_M$

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Standard: $Y = T_{24}$ $\quad u^c, Q, e^c \quad d^c, L \quad \nu^c$

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Symmetry breaking: $16_H \ni (10,+1)_H$ SU(5) x U(1) to the SM

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Gauge sector: $45_G \ni (24,0)_G \oplus (1,0)_G \ni \overset{X',Y'}{(3,2,-\tfrac{1}{6})_G} + h.c.$

RH neutrino masses in the flipped SU(5)

Tree level: $10_M Y_{50} 10_M \langle 50_H \rangle$

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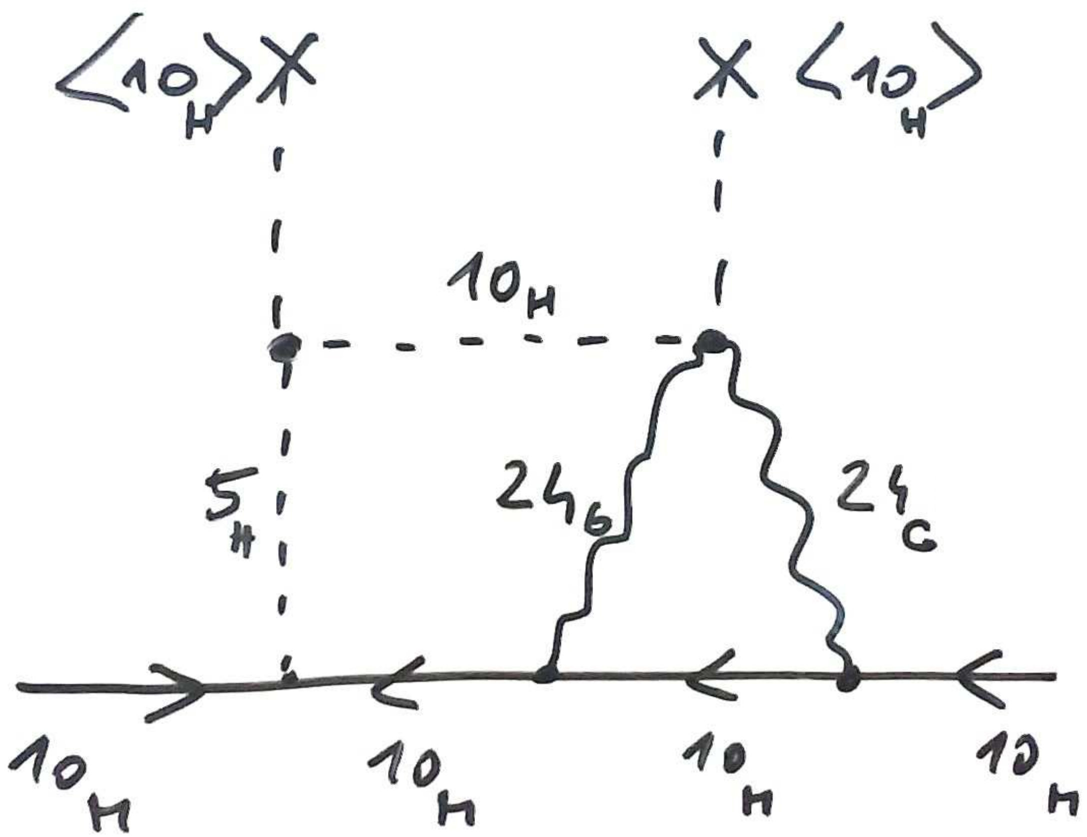

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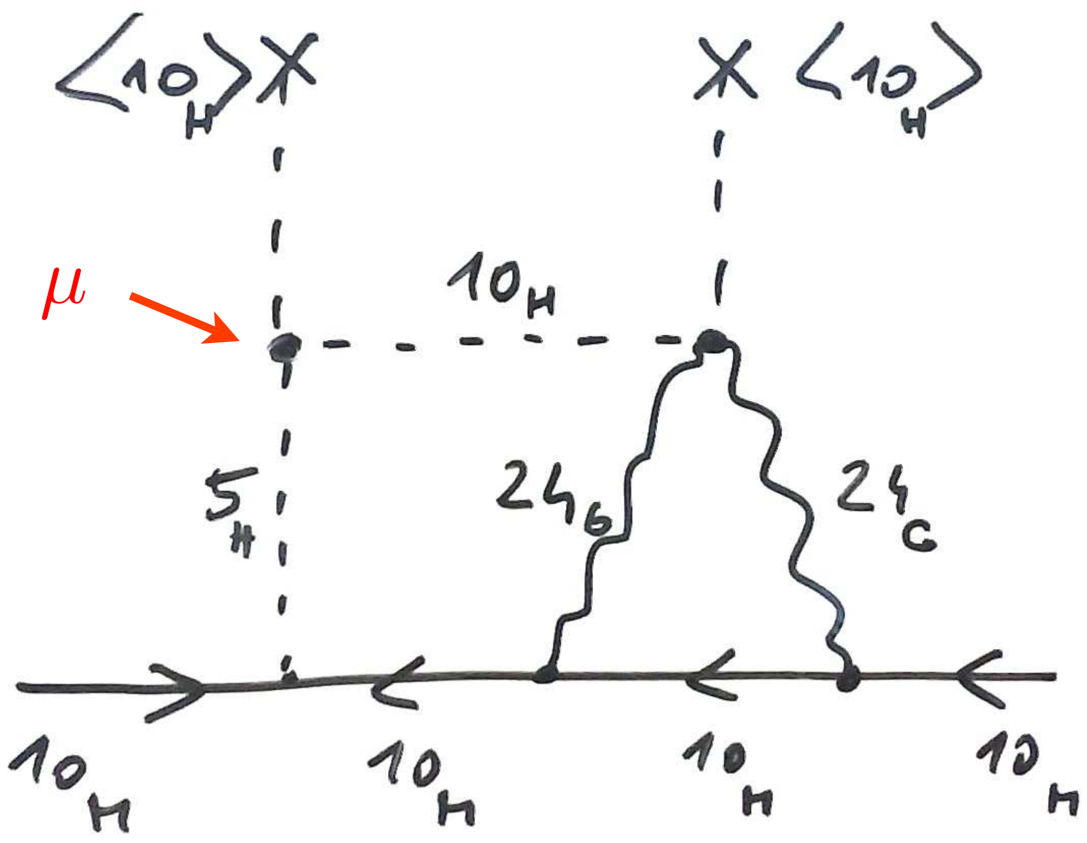
μ



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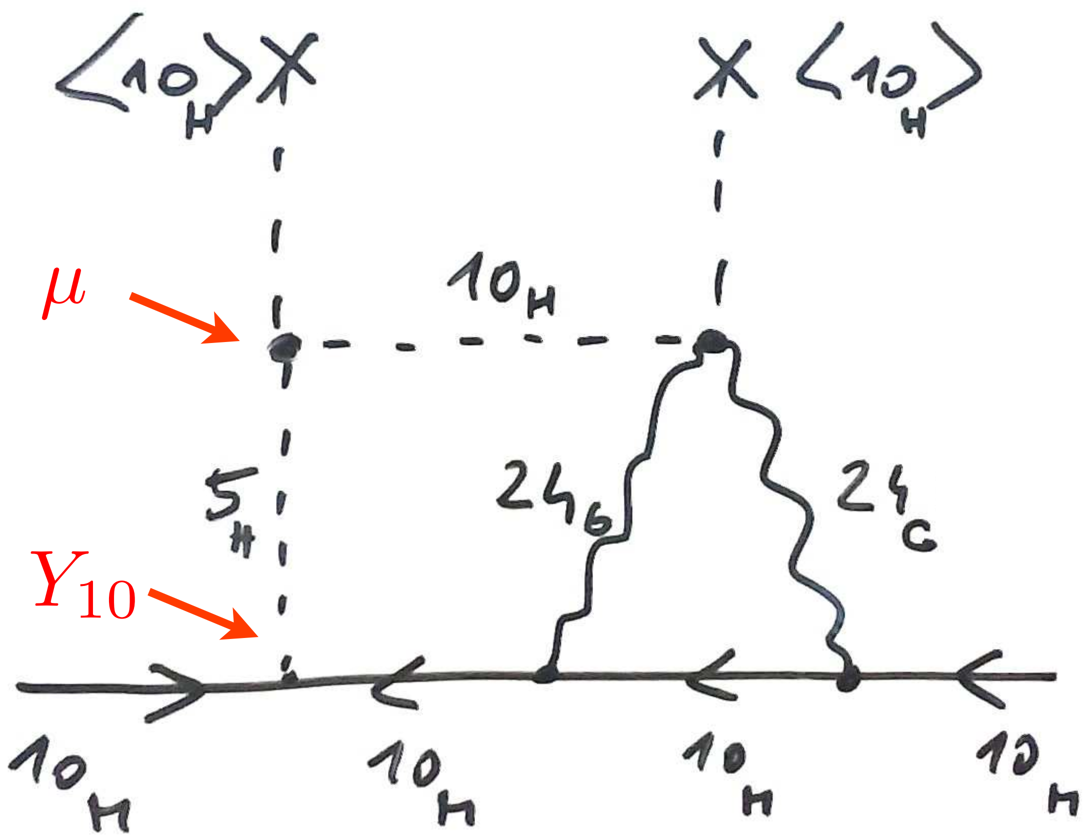

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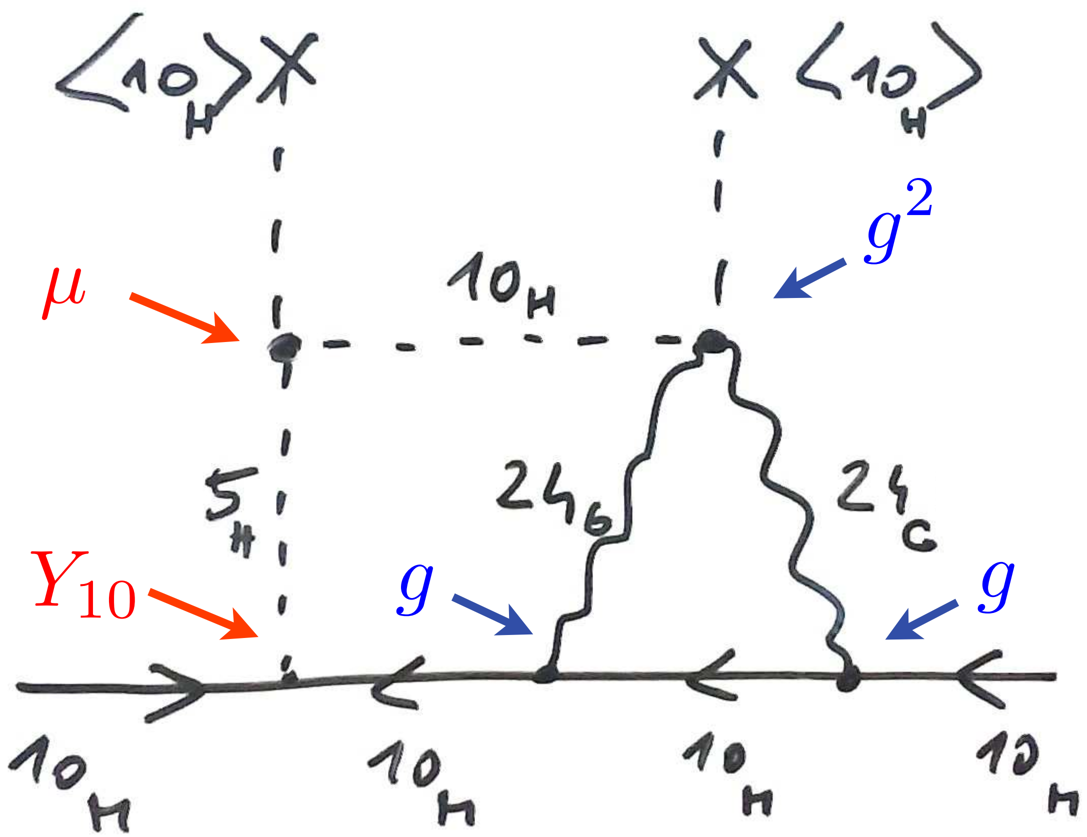

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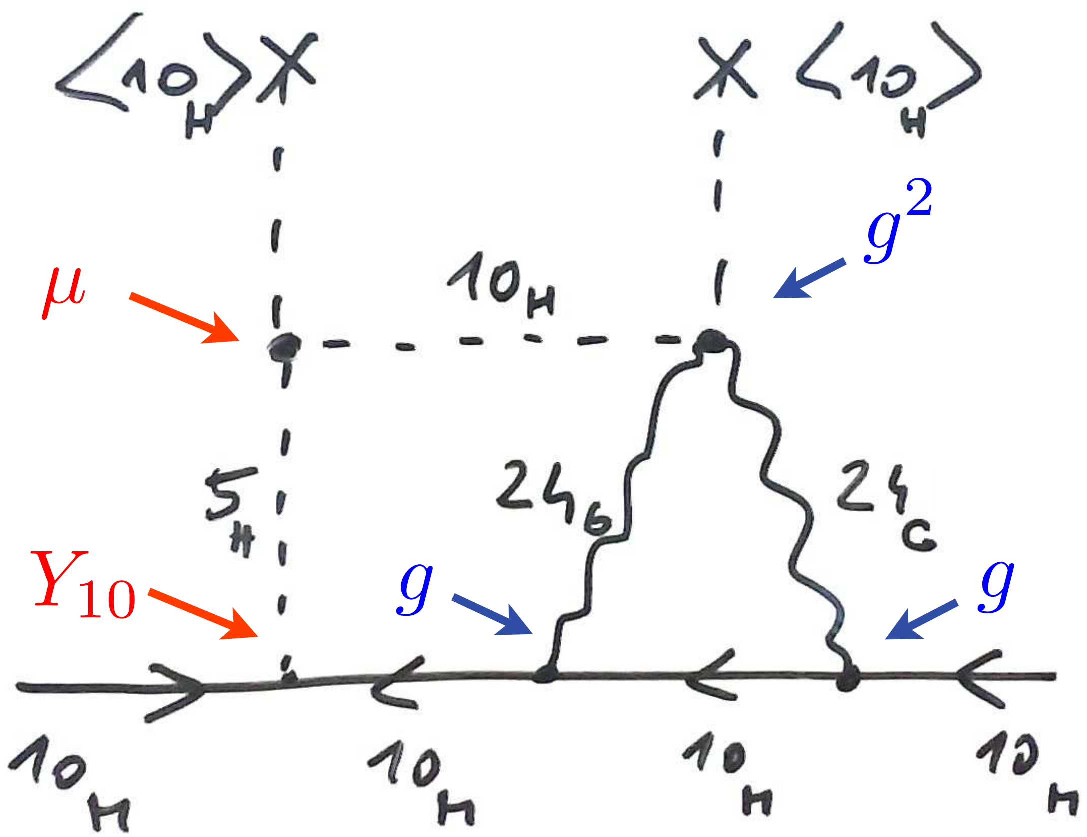

$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu Y_{10} \frac{\langle 10_H \rangle^2}{M_X^2} K(\ldots)$$

O(1) factor depending on the details of the heavy spectrum

Seesaw - the key to phenomenology

$$M_\nu^D m_\nu^{-1} (M_\nu^D)^T = M_M$$

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Feature 1 : absolute neutrino mass scale

LHS: ~ $\begin{pmatrix} 10^4 & 0 & 0 \\ 0 & 5\times 10^8 & 0 \\ 0 & 0 & 5\times 10^{13} \end{pmatrix}$ GeV for $U_\nu = 1$ and $m_1 = 8 \times 10^{-2}$ eV

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Feature 2 : Flavour structure constrained (U_ν)

D_ν^{-1} looks like $\begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix}$ GeV^{-1} !!!

The magic of U_ν - BNV nucleon decays

$\Gamma(p \to \pi^0 \ell_\alpha^+)$	$\Gamma(p \to \pi^+ \overline{\nu})$	$\Gamma(n \to \pi^- \ell_\alpha^+)$	$\Gamma(n \to \pi^0 \overline{\nu})$
$\Gamma(p \to K^0 \ell_\alpha^+)$	$\Gamma(p \to K^+ \overline{\nu})$	$\Gamma(n \to K^- \ell_\alpha^+)$	$\Gamma(n \to K^0 \overline{\nu})$
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(no flavour ambiguity!)

$$\Gamma(p \to K^+ \overline{\nu}) = 0$$

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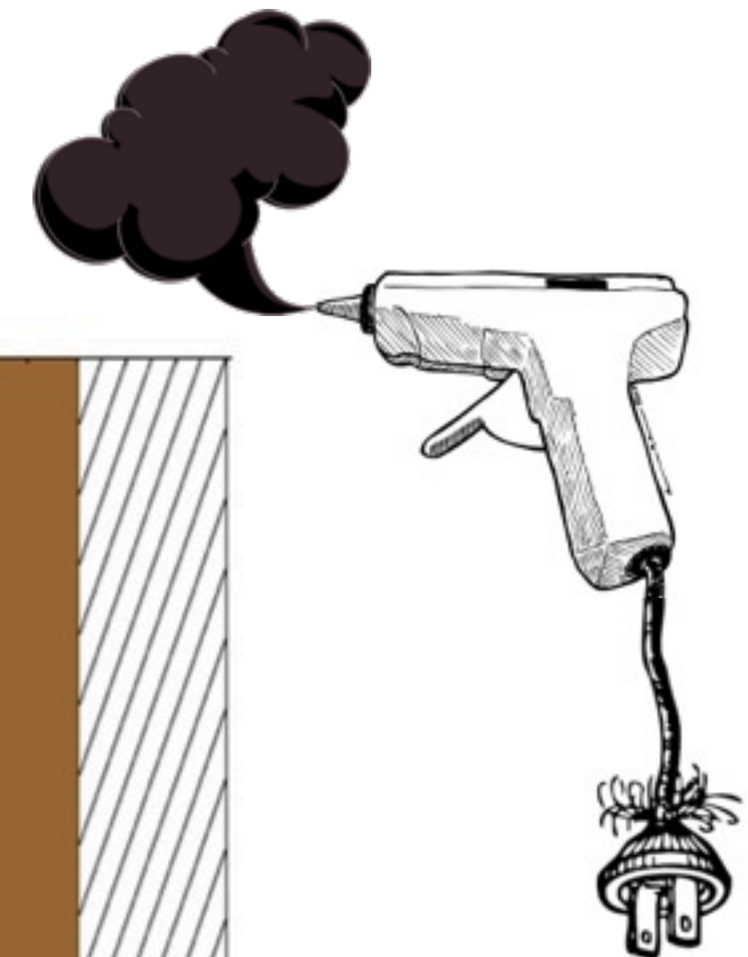
If we knew U_ν there would be a **prediction for ALL BNV channels!!!**

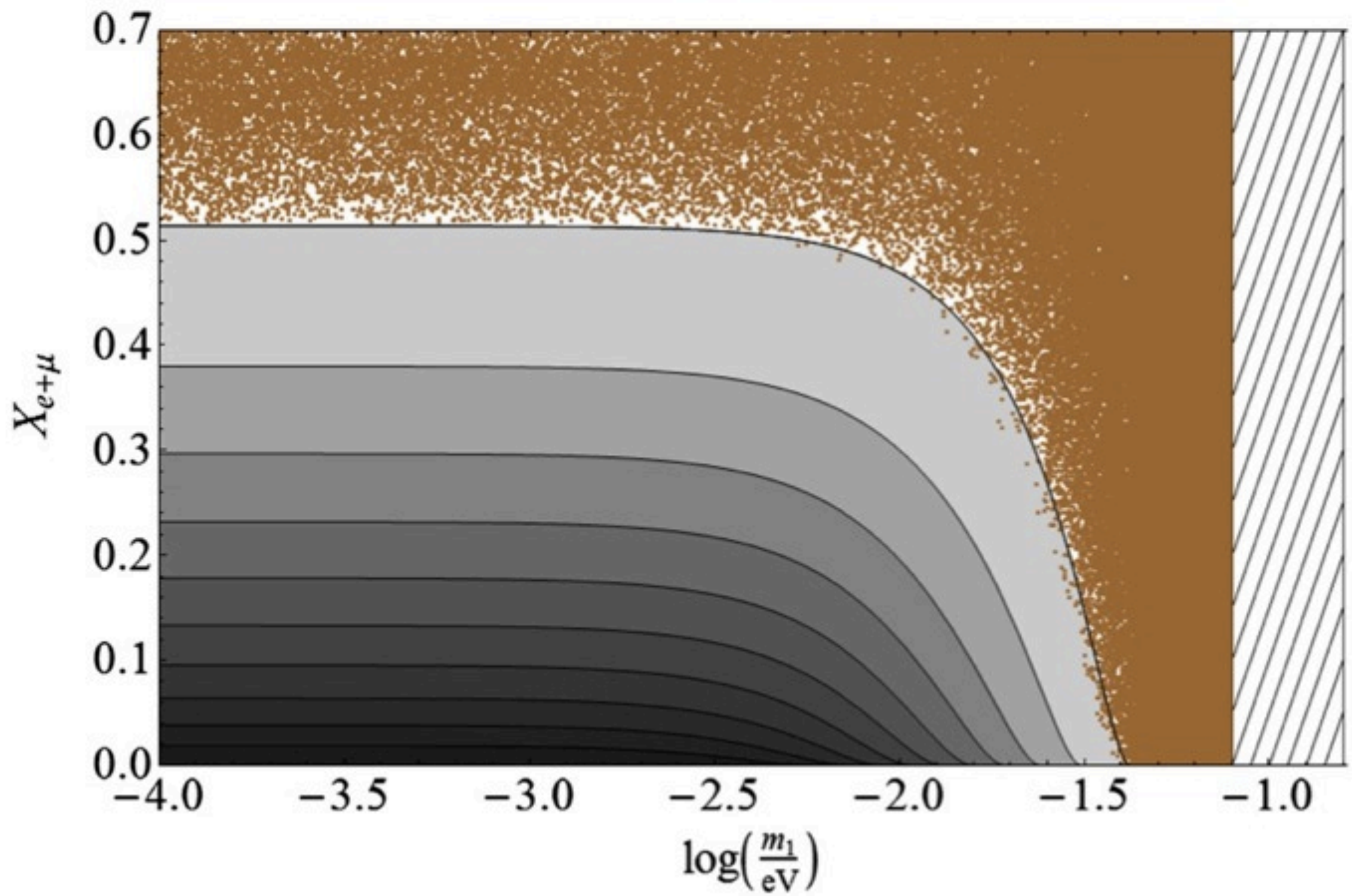
Proton decay into to neutral mesons+charged leptons

Unlikely to have both
$\Gamma(p \to \pi^0 e^+)$ and $\Gamma(p \to \pi^0 \mu^+)$
arbitrarily suppressed



K

growing



C.Arbelaez-Rodriguez, H.Kolešová, MM, PRD89

How about K?

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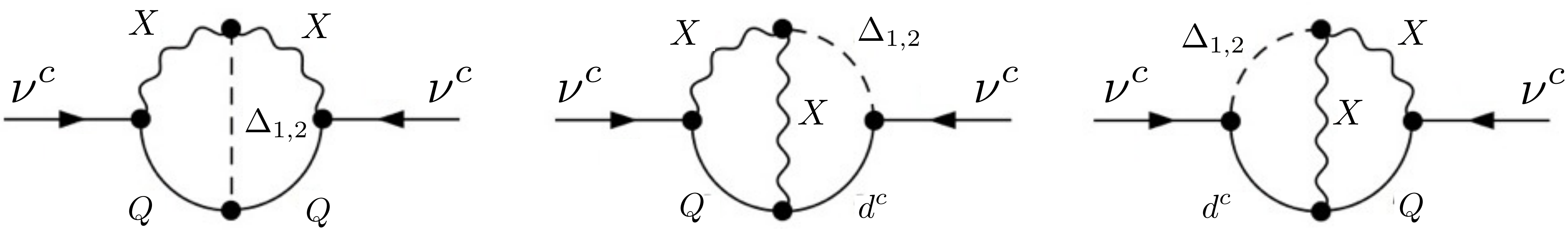
D. Harries, MM, M. Zdráhal 2018 (in preparation)

$$M_M = \Sigma_{1\text{-loop}}(0) + \dots$$

Broken phase (massive) perturbation theory, unitary gauge:



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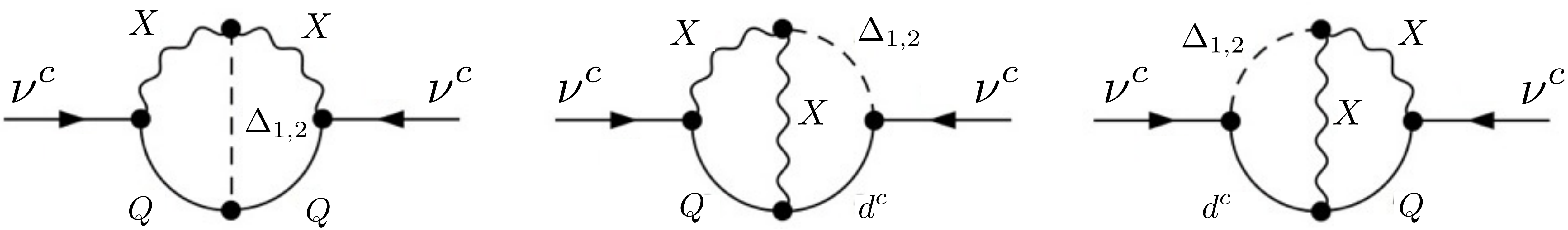

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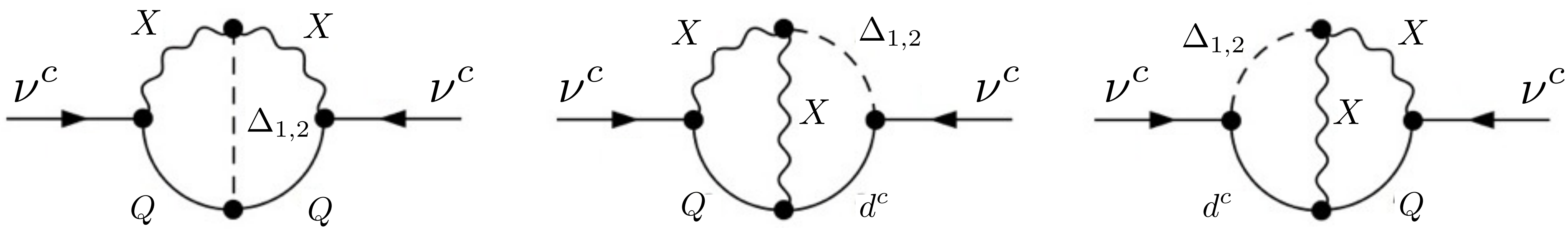

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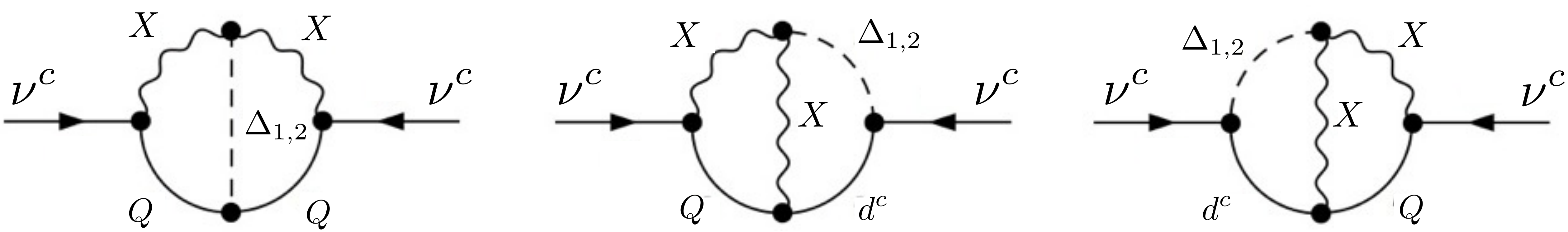

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- Each single graph is UV divergent. No d=4 counterterm - Σ(0) must be finite!
- Beware of possible IR divergences - internal fermions essentially massless!

Zero-momentum two-loop integrals: M.J.G.Veltman, J.Van der Bij, Nucl. Phys. B231, 205 (1984)

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D. Harries, MM, M. Zdráhal 2018 (in preparation)

$$\mathcal{L}_{\rm int} \ni \Big[\frac{g_5^2}{2}\epsilon^{\beta\alpha}V_G X^\mu_\alpha X_{\mu\beta}\overline{D}^\dagger + \frac{g_5}{\sqrt{2}}X_{\mu\alpha}\overline{d^c_{L_I}}\gamma^\mu q^\alpha_{L_I} + \frac{g_5}{\sqrt{2}}\epsilon^{\beta\alpha}X_{\mu\alpha}\left(\overline{q_{L_I}}\right)_\beta\gamma^\mu\nu^c_{L_I}$$
$$- 8Y_{10}^{IJ}d^{cT}_{L_I}C^{-1}\nu^c_{L_J}T - 4Y_{10}^{IJ}\epsilon_{\alpha\beta}(q^\beta_{L_I})^T C^{-1}q^\alpha_{L_J}T + h.c.\Big]$$

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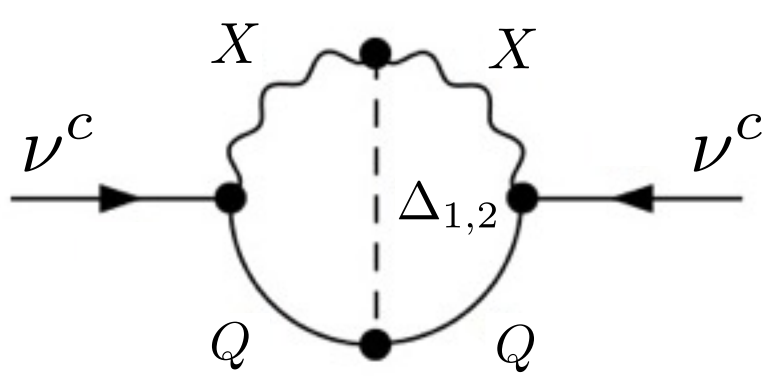

$$i\Sigma_0^P(0) = i^4 i^5\int\frac{d^4p}{(2\pi)^4}\int\frac{d^4q}{(2\pi)^4}\gamma_\rho\frac{1}{-\not{q}}\frac{1}{\not{p}}\gamma_\mu\frac{1}{(p+q)^2-m_S^2}\frac{-g^{\mu\nu}+\frac{1}{M_V^2}p^\mu p^\nu}{p^2-M_V^2}\frac{-g^\rho_\nu+\frac{1}{M_V^2}q_\nu q^\rho}{q^2-M_V^2}$$

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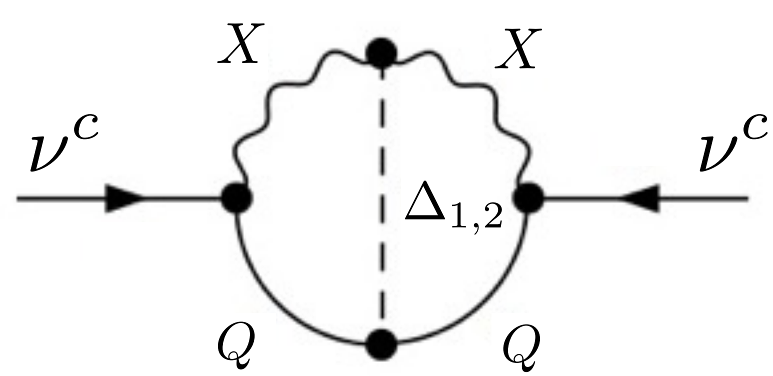


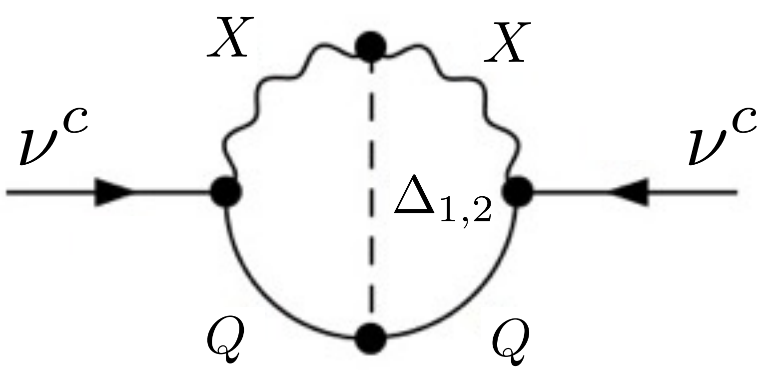
$$i\Sigma_0^P(0) = i^4 i^5\int\frac{d^4p}{(2\pi)^4}\int\frac{d^4q}{(2\pi)^4}\gamma_\rho\frac{1}{-\not{q}}\frac{1}{\not{p}}\gamma_\mu\frac{1}{(p+q)^2-m_S^2}\frac{-g^{\mu\nu}+\frac{1}{M_V^2}p^\mu p^\nu}{p^2-M_V^2}\frac{-g^\rho_\nu+\frac{1}{M_V^2}q_\nu q^\rho}{q^2-M_V^2}$$

UV divergences (in dim. reg.): $-\frac{M_\Delta^4}{4M_X^4\varepsilon^2}-\frac{3M_\Delta^4}{4M_X^4\varepsilon}+\frac{M_\Delta^4\log\left(M_\Delta^2\right)}{2M_X^4\varepsilon}+\frac{3}{2\varepsilon}$

How about K?

D. Harries, MM, M. Zdráhal 2018 (in preparation)

$$\mathcal{L}_{\rm int} \ni \Big[\frac{g_5^2}{2}\epsilon^{\beta\alpha}V_G X^\mu_\alpha X_{\mu\beta}\overline{D}^\dagger + \frac{g_5}{\sqrt{2}}X_{\mu\alpha}\overline{d^c_{L_I}}\gamma^\mu q^\alpha_{L_I} + \frac{g_5}{\sqrt{2}}\epsilon^{\beta\alpha}X_{\mu\alpha}\left(\overline{q_{L_I}}\right)_\beta\gamma^\mu\nu^c_{L_I}$$
$$- 8Y^{IJ}_{10} d^{cT}_{L_I}C^{-1}\nu^c_{L_J}T - 4Y^{IJ}_{10}\epsilon_{\alpha\beta}(q^\beta_{L_I})^T C^{-1}q^\alpha_{L_J}T + h.c.\Big]$$



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Exactly cancelled among the three topologies!

Results

D. Harries, MM, M. Zdráhal 2018 (in preparation)

$$M_M \lesssim 10^{-2} M_X \times 10^{-1} \times 3 \sum_{i=1,2} (U_\Delta)_{i1} (U^*_\Delta)_{i2}\, I\left(\frac{m^2_{\Delta_i}}{m^2_X}\right)$$

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A lower limit on $\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$

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Preliminary

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Thanks for your kind attention!