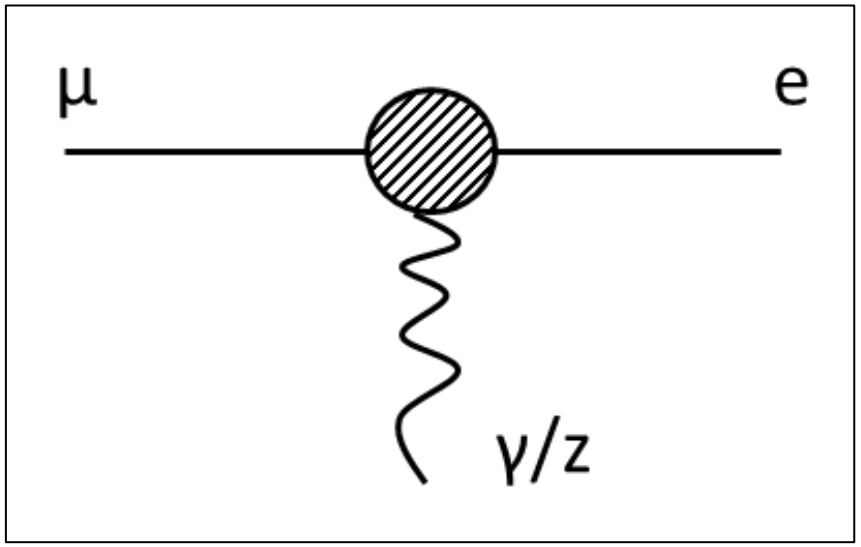
2ND RED LHC workshop

CIEMAT, Madrid, 9-11 mayo 2018

WHY IS cLFV A "BONA-FIDE" SIGNAL OF BSM-PHYSICS?



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IFIC-Valencia

FCNC AND FDNC PREDICTED IN SM AT LOOP LEVEL

Flavour Mixing in SM has its origin in the **MASS MATRICES** of fermions after Spontaneous Breaking of the Gauge Symmetry in the Yukawa sector

$$M \sim Y\, v,\ v = \langle \phi \rangle$$

- After Diagonalisation → **mismatch between Flavour and Mass Bases**.
What is observable is the relative diagonalising matrix for CC weak interactions of fermions mediated by $W^{\pm}$. For quarks → U(CKM) describing Flavour Mixing and CP-Violation.

- **CPV needs 3 families of fermions, first predicted, later observed**.

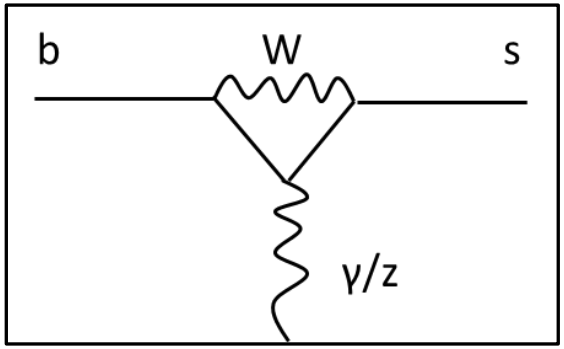
- Our subject refers to **NC interactions** mediated by γ/Z (W^0 component, in fact), not to CC ones. Due to $SU(2)_L$ symmetry and unitary U → GIM mechanism (need of charm!) $U^{+}U = I$ → **NEUTRAL CURRENTS ARE** naturally **DIAGONAL AND UNIVERSAL** in the Lagrangian (implying the same conclusion for Higgs Boson interactions)

→ **FCNC's forbidden at tree level. However, ALLOWED at loop level**!

PENGUINS WITH LONGITUDINAL W's:

$s \to d$, $b \to s$ and $\bar{d}\, d \neq \bar{s}\, s \neq \bar{b}\, b$

→ GIM "suppression" by non-degenerate masses of the $SU(2)_L$ partners u, c, t

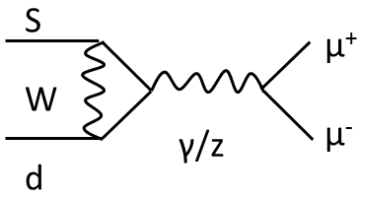


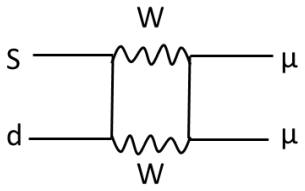
RARE PROCESSES OBSERVED

- RARE Processes, Decays and Mixings for Quarks, have been observed beyond any doubt. Many examples:

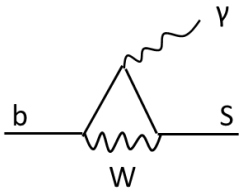
FCNC $K_L \rightarrow \mu^+ \mu^-$ ----------

$B_s \rightarrow \mu^+ \mu^-$

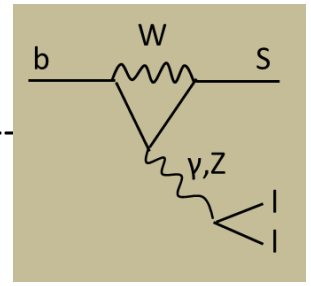




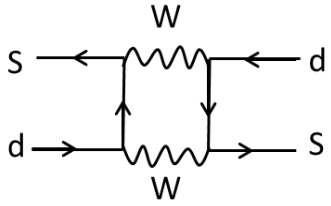
FCNC B → K(K*) γ ----------



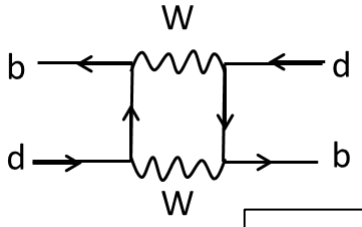
FCNC B → K(K*) μ μ, e e ----------



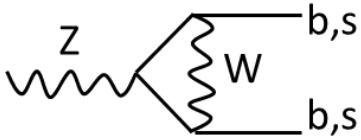
Δ S = 2 $K^0 - \bar{K}^0$ ---------- charm!



Δ B = 2 $B^0 - \bar{B}^0$ ----------



FDNC Z → $b\bar{b}$, $s\bar{s}$ ----------



t non-decoupling

- **Some of them "discovered" the top quark virtually before the real observation at Tevatron by means of "non-decoupling" effects.**

- Pending FCNC Z -> b nob at LHC ATLAS & CMS experiments

WHAT FOR LEPTONS ?

- **Flavour Mixing for Neutrinos** has been observed in Neutrino Flavour Oscillations with a **Mixing Matrix U(PMNS).**

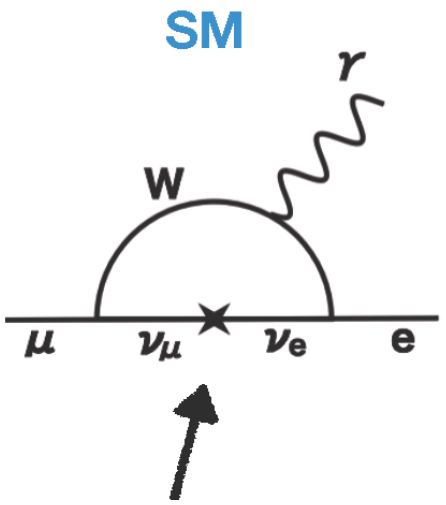
IFF U is Unitary $U^{+}U = I$, FCNC and FDNC should be

. Forbidden at tree level **. Allowed at loop level**

- In fact, Non-Universality of ν-Flavours calculated in the SM due to different masses of charged lepton partners.

AND FOR CHARGED LEPTONS?

- SM contribution is here strongly suppressed by GIM mechanism: the loop partners are neutrinos!



A word of caution for FDNC in semileptonic processes! Although gauge interactions of Quarks are chirality-conserving, they are NOT for Hadrons: **Scalar/Pseudoscalar mesons, Anomalous Dipole Moments of Baryons induce chirality-flip vertices and so amplitudes proportional to lepton mass!!!**

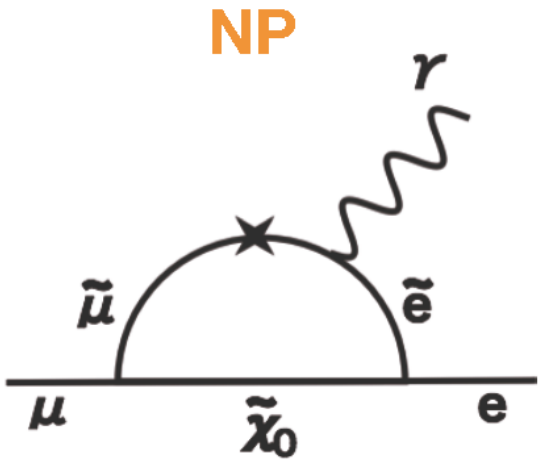
$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^{*}_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \simeq 10^{-54}$$

F.A.P.P. -> NEW BSM-PHYSICS

NEW PHYSICS ILLUSTRATIONS FOR cLFV

1) To avoid neutrino mass suppression in the loop,

- **GO TO SUSY NEUTRALINO**
- **MIXING OF SLEPTONS**



2) Any mechanism Violating Unitarity $U(PMNS)^{+}U(PMNS) \pm I$:

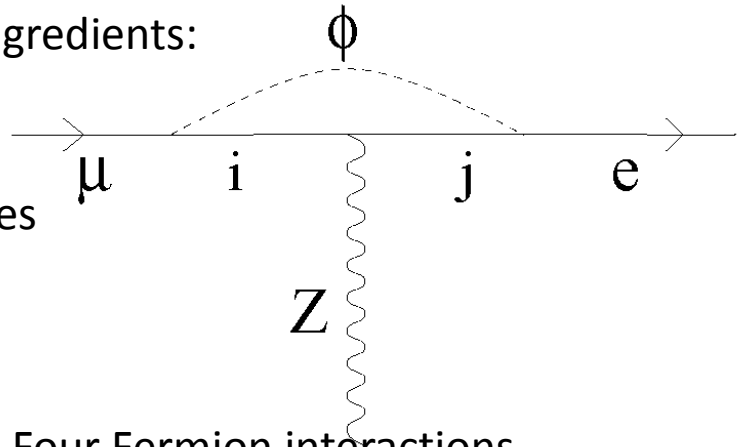
. Even at tree level: Multi-Higgs, Leptoquarks, Z', ...

. "Natural" connection to the origin of neutrino mass:
P. Minkowski claim → U(PMNS) is NOT unitary ← **see-saw mechanism**

. However (Tommasini, Barenboim, J. B., Jarlskog 1995)
The **mixing between light and heavy scales** is given by the ratio of the two mass scales, so **there is a "decoupling" effect**.
How generating **true "non-decoupling"** effects? Two ingredients:

i) Longitudinal $W^{\pm}$ contribution

ii) Singular Mass Matrix of ν_L AND N_R^c → degeneracies



3) No model → **Effective Interactions**

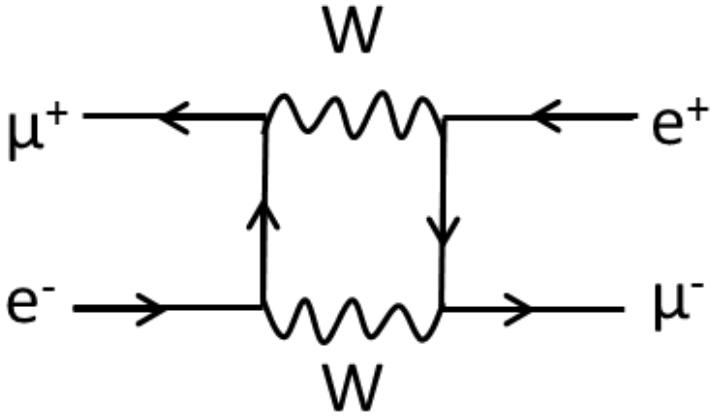
Transition Dipole Moments, Dimension-6 non-diagonal Four Fermion interactions, ...

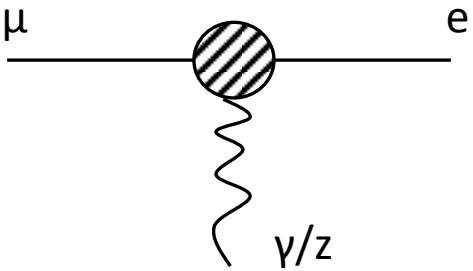
cLFV DECAYS/MIXINGS

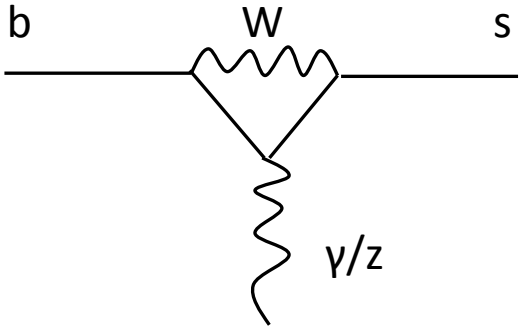
Various cLFV processes currently studied or to be studied

- **μ-decay/process: podium** — **Sensitivity**
  - μ→ eγ (MEG@ PSI) — 4×10^{-14}
  - μN→ eN (COMET@ J-PARC, Mu2e@ Fermilab, DeeMe@J-PARC) — $\sim 10^{-17}$
  - μ→ eee (Mu3e@PSI) — $\sim 10^{-15}$
- **τ- decay**
  - τ →lγ, τ →3l, τ →lV^0, τ →lhh,… (Belle, BaBar, LHCb, Belle II)
- **Higgs/Z-decay**
  - H→ μe/μτ/eτ, Z→ μe/μτ/eτ (CMS/ATLAS)
- **Kaon decay**
  - $K^+ \rightarrow \pi^+ \mu^+ e^-$, $K_L^0 \rightarrow \mu^\pm e^\pm$,…
- **Many others**
  - Mu(μ^+e^-) - $\bar{\text{M}}$u(μ^-e^+)
  - Like $K^0 - \bar{K}^0 \rightarrow \Delta F = 2$

. **The Muonium-Antimuonium Δ L_μ = 2 Mixing** is particularly attractive because it is, for leptons, analogous to ΔS = 2 $K^0 - \bar{K}^0$ mixing. A proposal at FNAL seeks to reach a 10^{-14} sensitivity in the Mixing Probability.




μ
e
γ/z


b
W
s
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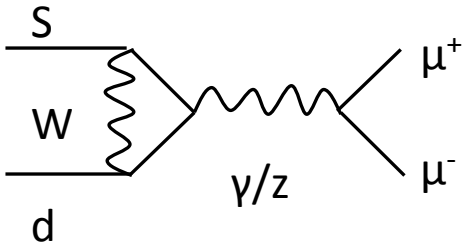
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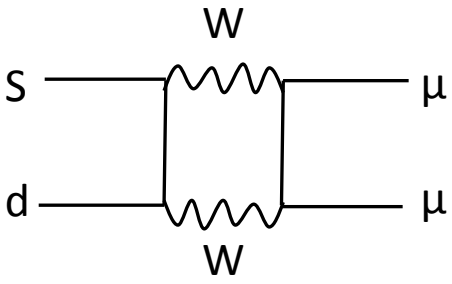
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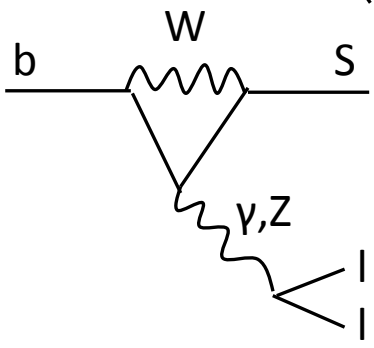
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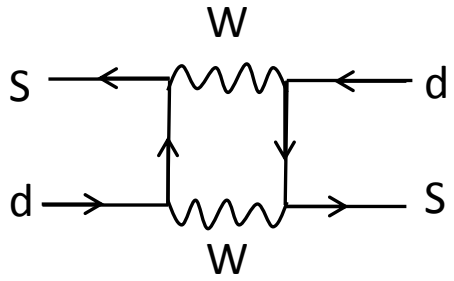
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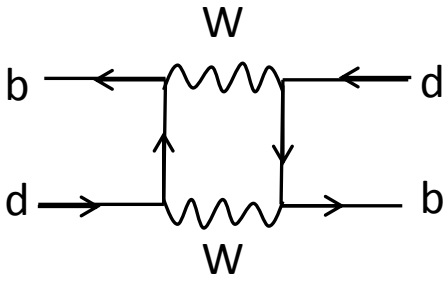
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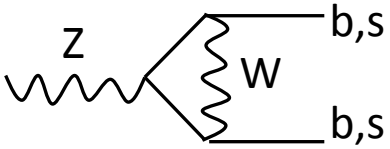
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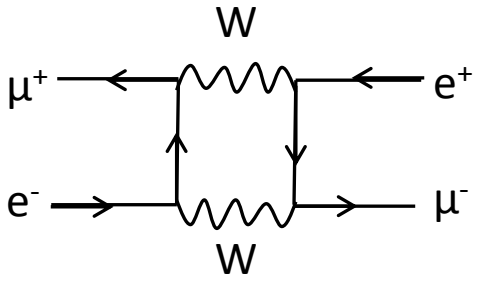
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