EFT analyses of New Physics searches: from nuclei to Higgses

RPP2015 January 2015

Martín González-Alonso

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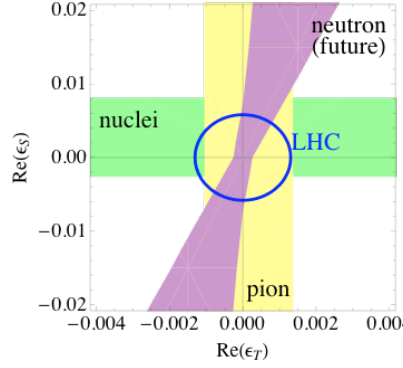

EFT analyses of New Physics searches: from nuclei to Higgses ... in 14 min!!

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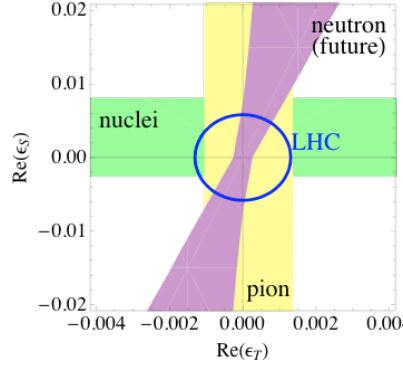

Some comments about...

EFT analyses of New Physics searches: from nuclei to Higgses ... in 14 min!!

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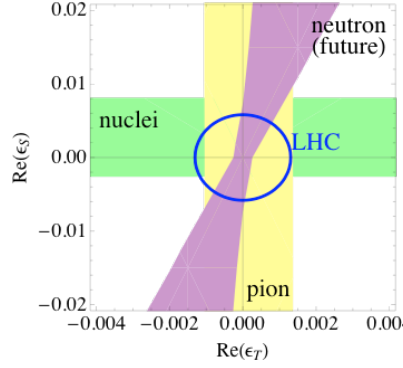


Introduction

- What's an EFT?
- Model-independent approach
  (not assumption indep.!!)
- Nice tool to study the interplay of diff. searches:
  E.g. Beta decays vs. LHC
- Finite # of indep. parameters in each process:
  E.g. Higgs decays
- EFT Limitations: light new particles
  E.g. Exotic Higgs decays

Effective Field Theory

Fields + Symmetries

- nuclei, e, ν;
- n, p, e, ν;
- u, d, e, ν;
- W, Z, …
- bSM?

+

- Lorentz;
- QED;
- SU(2) x U(1);
- Flavour sym.;
- B, L;

All terms allowed!

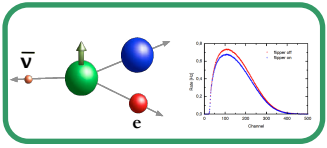
Example:

$$
\begin{aligned}
H_{V,A}^{(N)} &= \bar{e}\gamma_\mu(C_V + C_V'\gamma_5)\nu\bar{p}\gamma_\mu n \\
&\quad -\bar{e}\gamma_\mu\gamma_5(C_A + C_A'\gamma_5)\nu\bar{p}\gamma_\mu\gamma_5 n + \text{H.c.} \\
H_{S,P}^{(N)} &= \bar{e}(C_S + C_S'\gamma_5)\nu\bar{p}n + \text{H.c.} \\
H_T^{(N)} &= \bar{e}\frac{\sigma_{\lambda\mu}}{\sqrt{2}}(C_T + C_T'\gamma_5)\nu\bar{p}\frac{\sigma_{\lambda\mu}}{\sqrt{2}}n + \text{H.c.}
\end{aligned}
$$

$$\mathcal{L}_{eff.} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum \alpha_i \mathcal{O}_i$$

[In collaboration with Cirigliano, Graesser, Naviliat-Cuncic, Martin-Camalich, Isidori, Marzocca, Greljo, …]

Beta decays



$N \to N' e^{\pm} \nu$

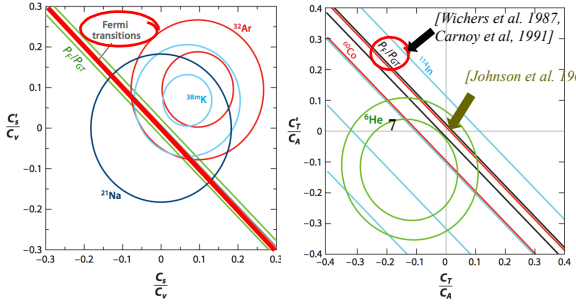
Precise data
+
Precise SM predictions

[Remember… $V_{ud} = 0.97425(22)$]

Plethora of processes (nuclear & neutron) and observables!

$$
\begin{aligned}
H^{(N)}_{V,A} &= \bar{e}\gamma_\mu(C_V + C'_V\gamma_5)\nu\bar{p}\gamma_\mu n \\
&\quad -\bar{e}\gamma_\mu\gamma_5(C_A + C'_A\gamma_5)\nu\bar{p}\gamma_\mu\gamma_5 n + \text{H.c.} \\
H^{(N)}_{S,P} &= \bar{e}(C_S + C'_S\gamma_5)\nu\bar{p}n + \text{H.c.} \\
H^{(N)}_{T} &= \bar{e}\frac{\sigma_{\lambda\mu}}{\sqrt{2}}(C_T + C'_T\gamma_5)\nu\bar{p}\frac{\sigma_{\lambda\mu}}{\sqrt{2}}n + \text{H.c.}
\end{aligned}
$$

[Jackson, Treiman & Wyld'1957]



[Severijns & Naviliat-Cuncic, 2011]

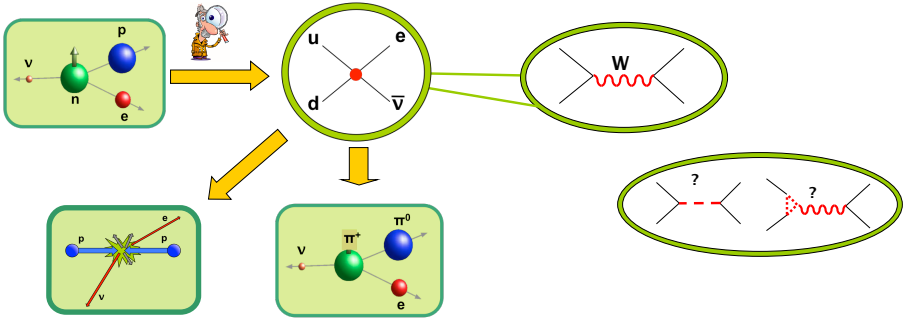
Question:

Comparison with pion decay?
LHC?

?

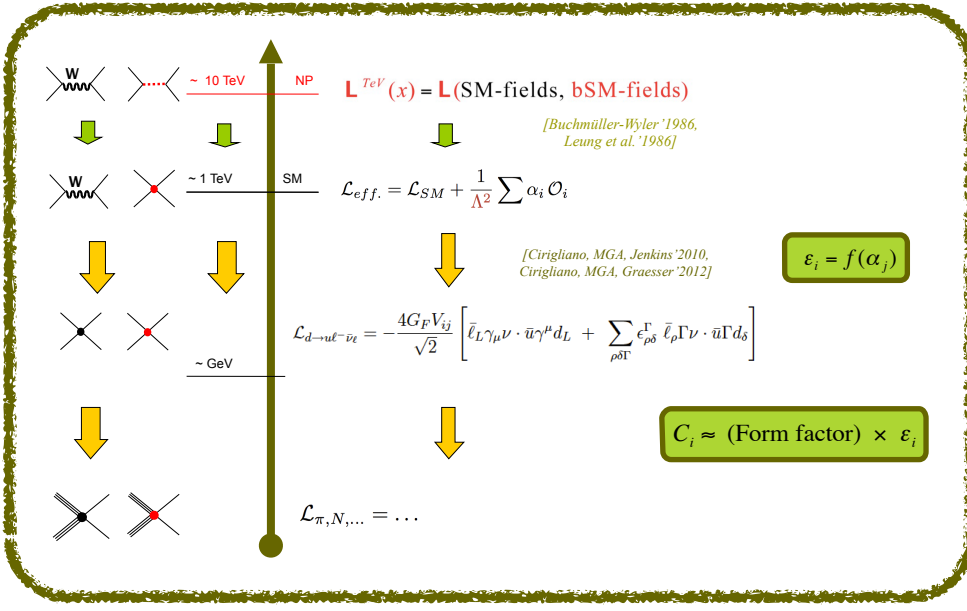
Beta decays vs LHC

- What about pion decays? LHC searches?

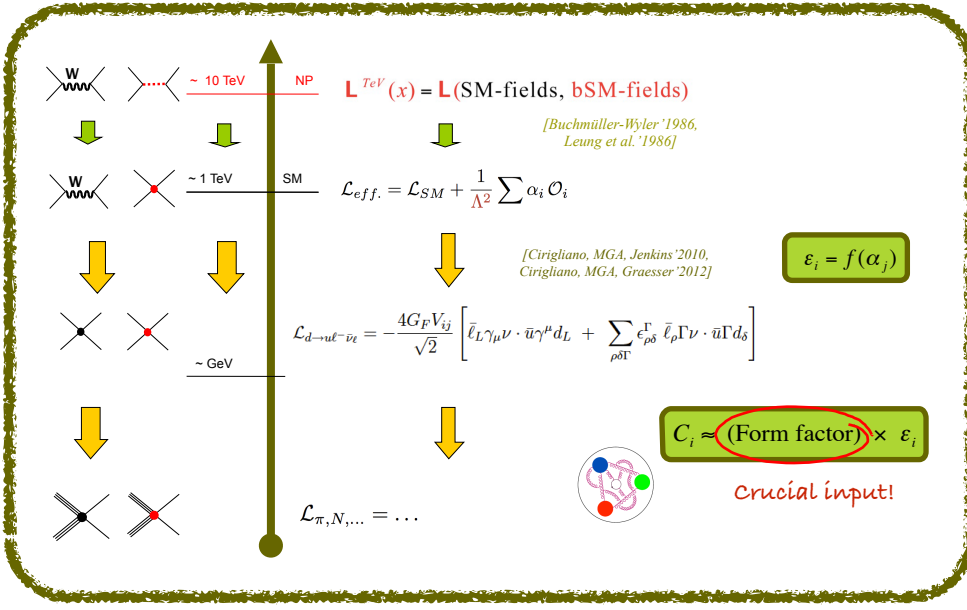


Recipe: Build & match the corresponding EFTs.

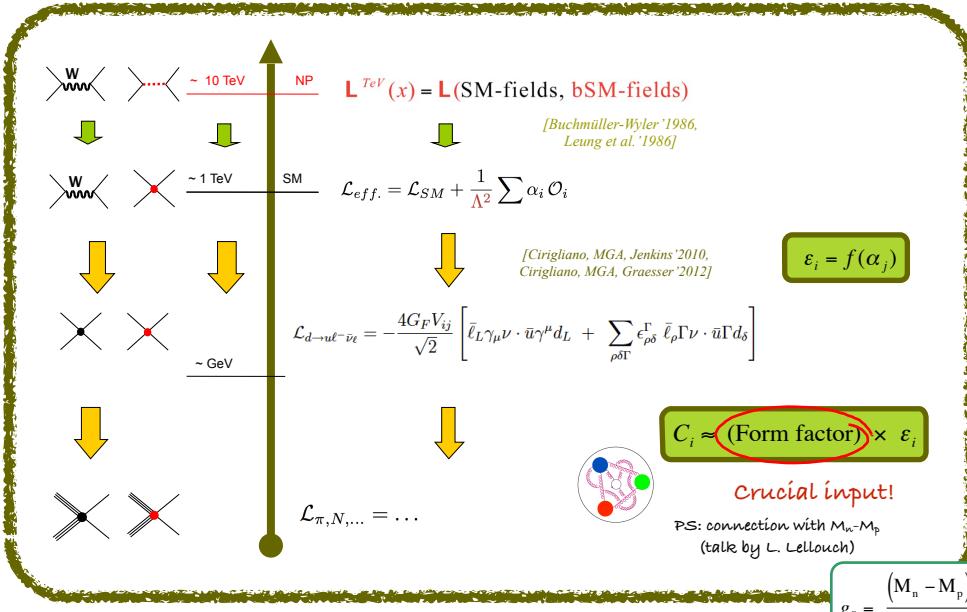
Beta decays vs LHC



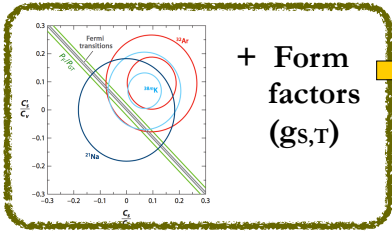
Beta decays vs LHC



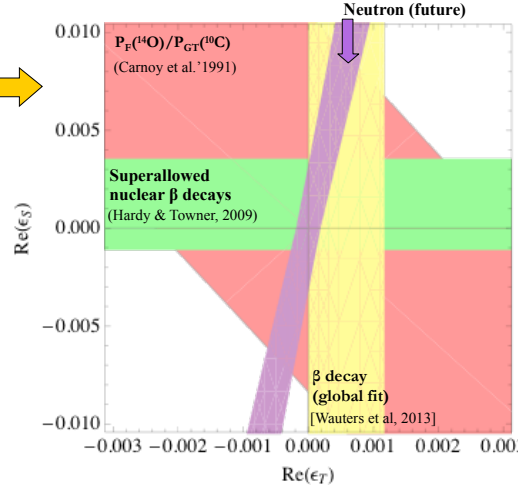
Beta decays vs LHC



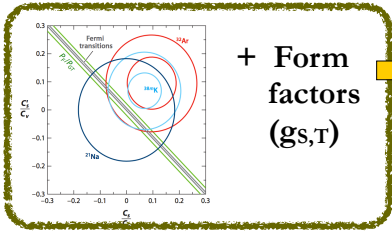
Beta decays vs LHC



+ Form factors ($g_{S,T}$)



Beta decays vs LHC



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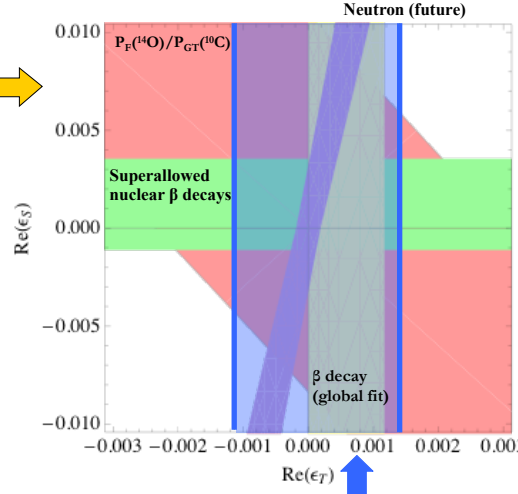
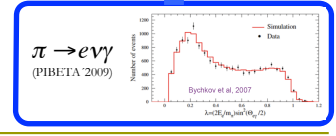
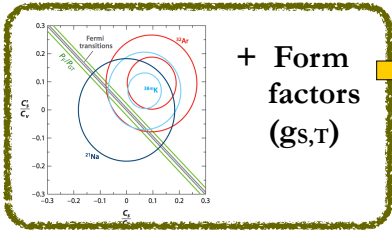
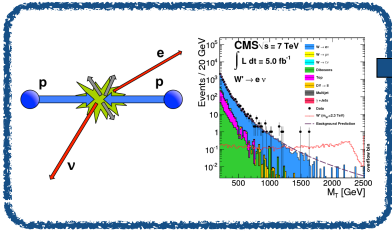


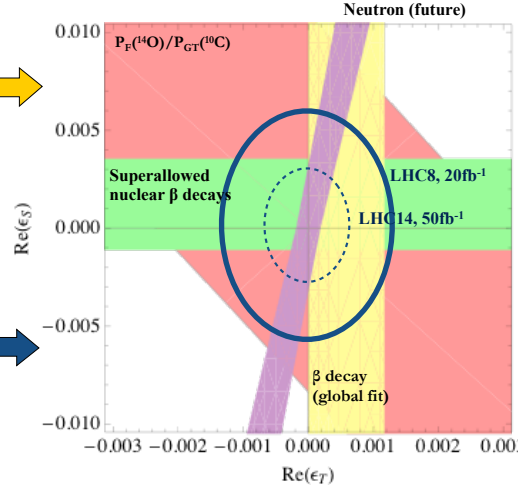


Beta decays vs LHC



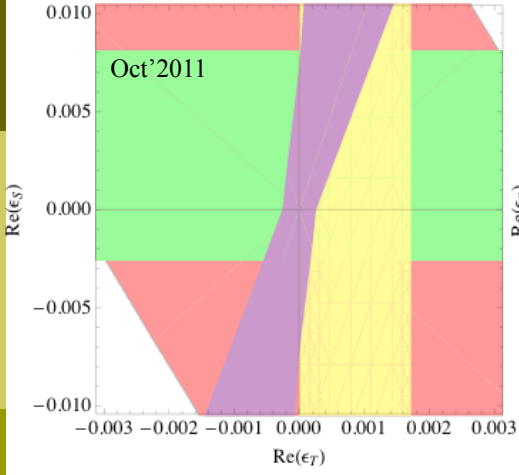
+ Form factors ($g_{S,T}$)

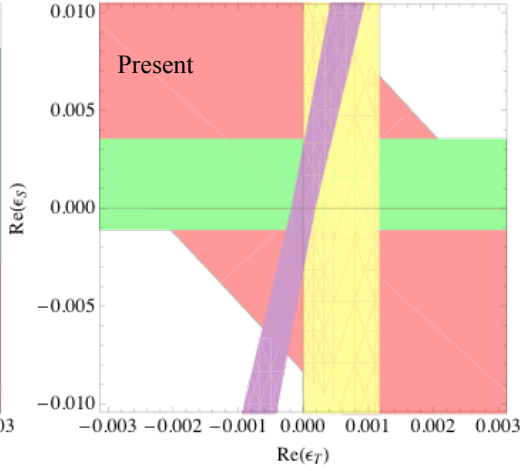




[MGA & Naviliat-Cuncic, Ann. Phys. 525 (2013)*]*
[Cirigliano, MGA & Graesser, JHEP1302 (2013*)]*
[Bhattacharya, Cirigliano, Cohen, Filipuzzi, MGA, Graesser, Gupta, Lin, PRD85 (2012*)]*

Beta decays vs LHC

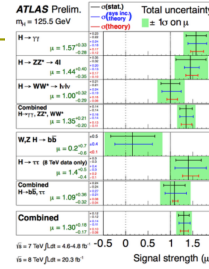




- We are benefiting here from the advance in the FF determinations!
- Conclusion: S,T are at least ~1000x weaker than the V-A Fermi interaction.

$$\varepsilon_i \sim \frac{M_W^2}{M_{NP}^2} \rightarrow M_{NP} \sim 2 \text{ TeV}$$

EFTs and Higgs decays



- Finite # of parameters: useful to analyze future Higgs data (systematic generalization of the "signal-strength framework")
- Instead of Wilson coefficients (basis dependent and linear vs non-linear) we propose a set of pseudo-observables.

Example:

$$h \to e^+e^-\mu^+\mu^-$$

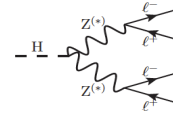
$$\mathcal{A}_{n.c.} = i\frac{2m_Z^2}{v_F}\sum_{f=f_L,f_R}\sum_{f'=f'_L,f'_R}(\bar{f}\gamma_\mu f)(\bar{f}'\gamma_\nu f')\mathcal{T}^{\mu\nu}(q_1,q_2)$$

$$\mathcal{T}^{\mu\nu}(q_1,q_2) = \left[F_1^{ff'}(q_1^2,q_2^2)g^{\mu\nu} + F_3^{ff'}(q_1^2,q_2^2)\frac{q_1\cdot q_2\, g^{\mu\nu} - q_2{}^\mu q_1{}^\nu}{m_Z^2} + F_4^{ff'}(q_1^2,q_2^2)\frac{\varepsilon^{\mu\nu\rho\sigma}q_{2\rho}q_{1\sigma}}{m_Z^2}\right]$$

$$F_1^{ff'}(q_1^2,q_2^2) = \kappa_{ZZ}\frac{g_Z^f g_Z^{f'}}{P_Z(q_1^2)P_Z(q_2^2)} + \frac{\epsilon_{Zf}}{m_Z^2}\frac{g_Z^{f'}}{P_Z(q_2^2)} + \frac{\epsilon_{Zf'}}{m_Z^2}\frac{g_Z^f}{P_Z(q_1^2)}$$

$$F_3^{ff'}(q_1^2,q_2^2) = \epsilon_{ZZ}\frac{g_Z^f g_Z^{f'}}{P_Z(q_1^2)P_Z(q_2^2)} + \epsilon_{Z\gamma}\left(\frac{eQ_{f'}g_Z^f}{q_2^2P_Z(q_1^2)} + \frac{eQ_f g_Z^{f'}}{q_1^2P_Z(q_2^2)}\right) + \epsilon_{\gamma\gamma}\frac{e^2Q_fQ_{f'}}{q_1^2q_2^2}$$

$$F_4^{ff'}(q_1^2,q_2^2) = \epsilon_{ZZ}^{CP}\frac{g_Z^f g_Z^{f'}}{P_Z(q_1^2)P_Z(q_2^2)} + \epsilon_{Z\gamma}^{CP}\left(\frac{eQ_{f'}g_Z^f}{q_2^2P_Z(q_1^2)} + \frac{eQ_f g_Z^{f'}}{q_1^2P_Z(q_2^2)}\right) + \epsilon_{\gamma\gamma}^{CP}\frac{e^2Q_fQ_{f'}}{q_1^2q_2^2}$$

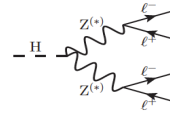


IMP:
g_Z^f are pseudo-observables (Z→ff)

$$\mathcal{A} = i\sum_{f=f_L,f_R} g_Z^f\,\varepsilon_\mu\,\bar{f}\gamma^\mu f$$

[MGA, Greljo, Isidori & Marzocca, 2014]

EFTs and Higgs decays



$h \to e^+ e^- \mu^+ \mu^-$ → 11 pseudo-obs.

$h \to e^+ \nu_e \mu^- \bar{\nu}_\mu$ → 7 pseudo-obs.

$h \to 2e2\nu, 2\mu2\nu$ → + 2 pseudo-obs

→

$h \to 4\mu$

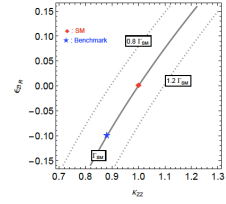
$h \to 4e$

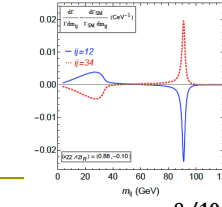
$h \to \gamma\gamma$

$h \to e^+ e^- \gamma$

$h \to \mu^+ \mu^- \gamma$

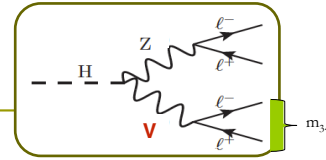
- Linear EFT: 20 ==> 14 parameters
- Flavor universality + CP + Custodial sym: 20 => 15 => 10 => 7
- The pseudo-obs. can be extracted from kinematic distributions
- The pseudo-observables can be expressed in any particular EFT. E.g. Linear EFT ==> Correlation with Higgsless processes!





[MGA, Greljo, Isidori & Marzocca, 2014]

EFT limitations…

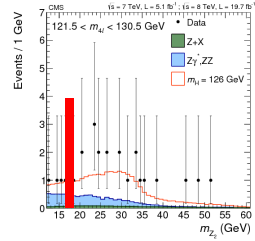


- Light new particles are not ruled out!
  (historical example: neutrino!)

- Exotic Higgs decays?
  - Tiny Γ_h ;
  - O(500,000) Higgses produced at LHC7+LHC8!
  - BR(h➔BSM) could be as large as O(20-50%);
    [Belanger et al'2013, Giardino et al'2013, Ellis & You'2013, …]
  - Can be connected with some anomalies (g-2).

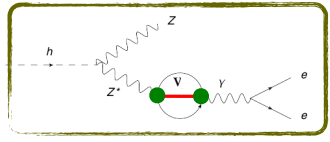
- Low-energy QCD effects can be important;

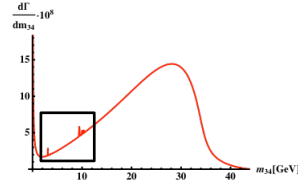
- Discovery potential: worth searching!
  Current cuts: 12 GeV!



More spectacular signals!

[MGA & G. Isidori, 2014
Davoudiasl et al'2012-2013,
Curtin et al'2013,
Falkowski & Vega-Morales, 2014, …]

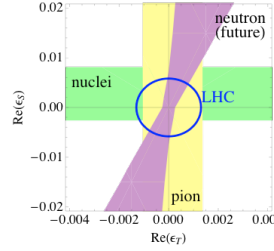




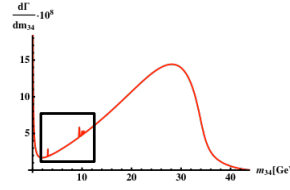
Summary

- Nice tool to study the interplay of diff. searches:
  E.g. Beta decays vs. LHC
- Finite # of indep. parameters in each process:
  E.g. Higgs decays
- EFT Limitations: light new particles
  E.g. Exotic Higgs decays

Effective Field Theory
=
Fields + Symmetries



Merci beaucoup!



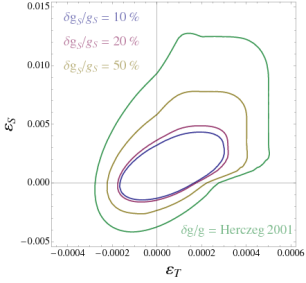
[In collaboration with Cirigliano, Graesser, Naviliat-Cuncic, Martin-Camalich, Isidori, Marzocca, Greljo, ...]

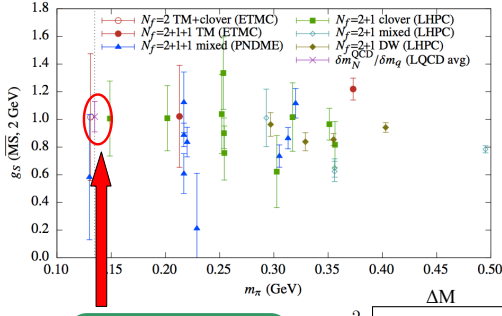
Backup slides

Example: beta decays

$C_i \sim g_i \times \varepsilon_i$

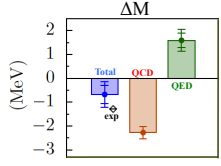
- Non-standard form factors: $\langle p(p_p)|\, \bar{u}\, d\, |\, n(p_n)\rangle \;=\; g_S(q^2)\; \bar{u}_p(p_p)\, u_n(p_n)$





$$g_S = \frac{\left(M_n - M_p\right)_{QCD}}{m_d - m_u}$$

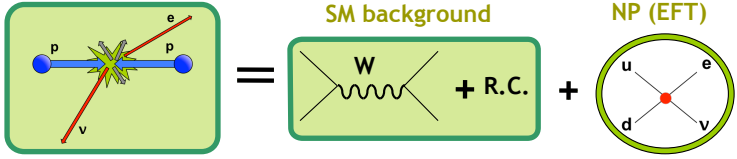
$$\partial_\mu\,(\bar{u}\gamma^\mu d) = -i(m_d - m_u)\bar{u}d$$



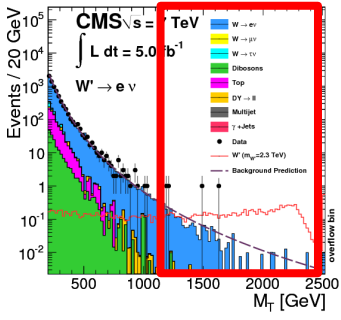
[MGA & Martin Camalich, Phys. Rev. Lett. 112 (2014)]

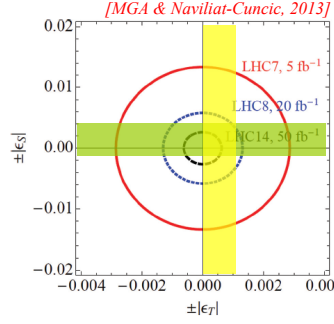
[BMW'13]

LHC limits on $\varepsilon_{S,T}$



$$N_{pp\to e\nu X}\left(m_T^2 > m_{T,cut}^2\right) = \varepsilon \times \mathrm{L} \times \sigma_{pp\to e\nu X}\left(m_T^2 > m_{T,cut}^2\right) = \varepsilon \times \mathrm{L} \times \left(\sigma_W + \sigma_S\,\varepsilon_S^2 + \sigma_T\,\varepsilon_T^2\right)$$





PS: Similar interplay in the near future