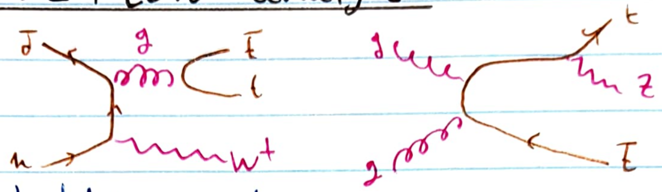
CMS EFFECTIVE FIELD THEORIES

5.1 EFT in measurements

→ Usually, measurements ⇒ searches. Sometime, searches (with negative results) ⇒ measurements of particular phase space

⊙ The CMS $pp \to t\bar{t}Z$ / $t\bar{t}W$ analysis:

→ Basic diagrams:



→ 2 strategies for identifying events:

1) "same sign" lepton pair
   → mostly for $t\bar{t}W$
   → 1 lepton from $W^\pm$ decay, one from $t/\bar{t}$ decay
2) three leptons:
   → mostly for $t\bar{t}Z$
   → 2 leptons from Z ($M(Z)$)
   → extra lepton from $t \to Wb$ / $W\nu$

⊙ $t\bar{t}W/t\bar{t}Z$ EFT interpretation

→ New physics can modify the cross-section of $t\bar{t}Z/t\bar{t}W$.

DEF An Effective Field Theory describes the effect of new physics at higher energy scale on observables at the lower energy scale we measure at. One uses non-renormalizable operators, suppressed by a high energy scale Λ:

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda}\sum_i c_i \mathcal{O}_i + \frac{1}{\Lambda^2}\sum_j c_j \mathcal{O}_j + \dots$$

↳ Effective, since only valid at energy $\ll \Lambda$

→ 1 at dim 5, 59 at dim 6, etc.

→ New physics represented by a blob 

→ $\mathcal{M} = \mathcal{M}_0 + c_1 \mathcal{M}_1 \Rightarrow \sigma(c_1) \propto |\mathcal{M}|^2 \propto s_0 + s_1 c_1 + s_2 c_2^2$

↳ If $c_1 < 0$, one can have $\sigma_{SM} > \sigma_{BSM}$ for some process.

→ Different EFT operators affect the interpretation of experimental data. EFT op. model deviations from SM

⊙ Outlook:

→ Effort to get EFT interpretation combining more measurements.

→ goal: get a pattern where small deviations collectively point towards new physics at higher energy scale.

5.2 EFT in searches

⊙ Dark Matter detection - direct:

→ Tiny energy transfers from DM ↔ SM.
Expect energy transfer ~ keV

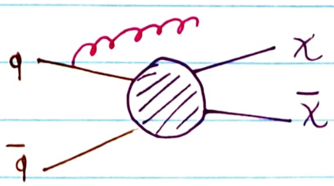
→ How to distinguish nuclear recoils from nuclear decay, radiation, etc?
Use phonons / heat, charge and light.

→ For spin-independent (SI) interactions:
→ scales with the # of nucleon A
For spin-dependent (SD) interactions:
→ scale with the spin of the nucleus

→ The neutrino coherent scattering limit is when the signal from DM interactions becomes indistinguishable from ν interactions

→ In EFT, $\exists$ operators linking DM with SM via heavy mediator.

⊙ Dark Matter direct production:



→ Creation of DM with EFT operators
like vector coupling $O_V = \Lambda^{-2}(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)$
axial vector coupling $O_A = \Lambda^{-2}(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)$

→ EFT approach always works in the limit where $m_{DM} \gg m_{recoil}$

→ Momentum transfer in production ~ EFT scale (less noise)
>< low energy in the direct detection experiments.

⊙ Beyond EFT's in production:

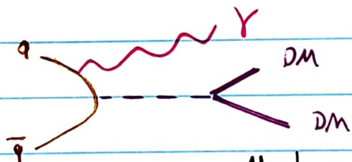
→ Since the LHC is probing energy $Q^2 \sim \Lambda^2$, one needs to go beyond EFT's.

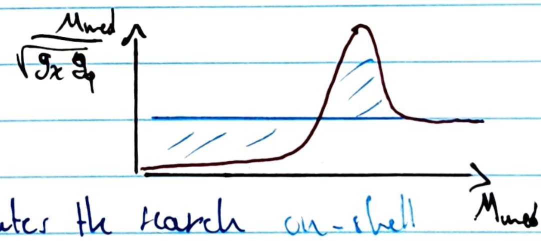
1) Truncation

→ Simply not consider collisions with $Q^2 < M_{med}^2 = g_\chi g_q \Lambda^2$
↳ no creation of mediator
↳ clumsy since Λ is determin by the analysis without truncation
→ loose a lot a sensitivity, especially at high mass

2) Simplified models

→ Explicit mediator :





→ Find 3 regimes
→ for $M_{med}^2 \gg Q^2$: EFT limit
→ for $M_{med}^2 \sim Q^2$: EFT underestimates the search on-shell
→ for $M_{med}^2 < Q^2$: EFT overestimate the search off-shell

→ Low DM mass easy to produce at LHC if the $M_{med} \sim$ TeV

⊙ Conclusion :

→ EFTs good for direct detection : → low recoil energies
→ need to look for more operators

→ EFTs not so good for DM production at colliders :
→ exclusions of suppression scale
→ beyond EFTs : simplified models.

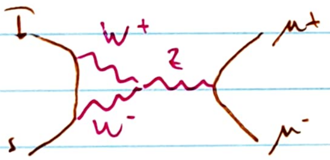
5.3 Flavour physics

→ Hadrons are complex due to QCD high bond at low energy, but they offer some advantages:

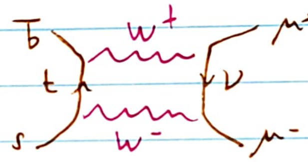
1) no FCNC at tree level in the SM
   ↳ suppressed
2) CP violation in the weak sector
3) Many rare decays ↦ leptons
   ↳ clean signals

→ Heavy particles (BSM) can alter the (loopy) decay.

⊙ Example: $B^0_s \to \mu\mu$: $B^0_s = (\bar{b}\ s)$

→ 

(SM)



→ Example of BSM: one of the $W^\pm \mapsto X^+$, or $Z \mapsto X^0$

→ Very rare decay: $\mathcal{B}(B^0_s \to \mu\mu) \sim 10^{-9}$

→ EFT approach: ok since $m \sim$ GeV
→ 4 fermions interactions: b, s, μ, μ:

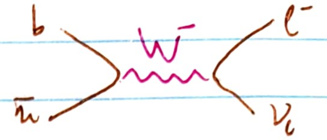
$$\mathcal{L}_{eff} = -\left(\frac{1}{M^2_{L,SM}} + \frac{1}{M^2_L}\right)(\bar{s}_L \gamma_\mu b_L)\bar{\ell}\gamma_\mu\gamma_5 \ell - \frac{1}{M^2_R}(\bar{s}_R \gamma_\mu b_R)\bar{\ell}\gamma_\mu\gamma_5 \ell$$
$$- \frac{1}{M^2_S}(\bar{s}\gamma_5 b)\bar{\ell}\ell - \frac{1}{M^2_P}(\bar{s}\gamma_5 b)\bar{\ell}\gamma_5 \ell + h.c.$$

From observation, we can set the following constraints:
$M_L, M_R \gtrsim 30$ TeV $\qquad M_S, M_P \gtrsim 150$ TeV

⚠ we assumed coupling $\theta = 1$

⊙ Example: $B^\pm \to \tau\nu$ $B^- = (b\ \bar{u})$

→ Tree level: $\mathcal{B}(B^+ \to \tau^+\nu) \sim 10^{-4}$

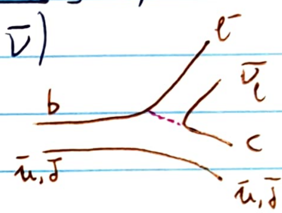


→ Any charged particle coupling to quarks and leptons can alter this decay.

⊙ Tau anomalies:

→ ex: $B \to D^{(*)}\tau\nu$ with $R_D^{SM} \equiv \dfrac{\mathcal{B}(\bar{B} \to D\tau\bar{\nu})}{\mathcal{B}(\bar{B} \to D\ell^-\bar{\nu})} = 0{,}3$

$R_{D^*}^{SM} = 0{,}25$, prediction from the CKM matrix



→ testing lepton universality

→ Complicated background

Currently, ~ 3σ deviation!

⊙ Global picture:

→ One can use EFT to make the global fit better.

↳ Consider $O_{b_X \ell_Y} = (\bar{s}\gamma_\mu P_X b)(\bar{\ell}\gamma_\mu P_Y \ell)$ with $X, Y \in \{L, R\}$

→ Provide hint for BSM, by introducing (for instance) Z' and LQ a leptoquark with both a baryon and lepton number: