Unitarity Constrains for EFT at LHC

Effects on Monojet Amplitudes

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SUSY 2016, 5 Jul 2016

Outline

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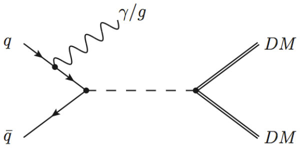
EFT Validity Problems

From UV to EFT: integrating OUT

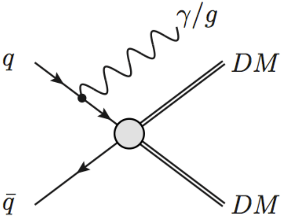
$$\mathcal{L}_{\rm UV} \supset -\frac{1}{2}M^2 S^2 - g_q \bar{q} q S - g_\chi \bar{\chi}\chi S + kin$$



Scalar Kinetic term can be neglected

$$-\frac{\partial \mathcal{L}_{\rm UV}}{\partial S} = M^2 S + g_q \bar{q} q + g_\chi \bar{\chi}\chi = 0$$

$$\mathcal{L}_{\rm EFF} \supset \frac{(g_q \bar{q} q + g_\chi \bar{\chi}\chi)^2}{M^2}$$



arXiv:1307.2253, 1402.1275

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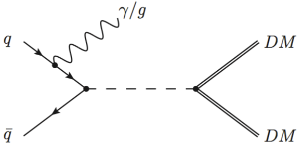

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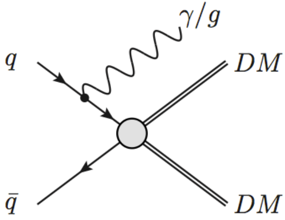

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EFT Validity Problems

From UV to EFT: propagator expansion

- Make UV calculation then expand propagator as power series

$$\frac{1}{Q_{\mathrm{tr}}^2 - M^2} = -\frac{1}{M^2}\left(1 + \frac{Q_{\mathrm{tr}}^2}{M^2} + \mathcal{O}\left(\frac{Q_{\mathrm{tr}}^4}{M^4}\right)\right)$$

- In both cases matching condition is

$$\frac{1}{\Lambda^2} = \frac{g_\chi g_q}{M^2}$$

In the latter case is easier to understand that the EFT validity requires

Validity Condition

$$Q_{\mathrm{tr}}^2 < M^2 = g_\chi g_q \Lambda^2$$

Problem

Validity condition depends on UV theory parameters

Another Problem

Matching (and so validity) condition depends on the UV completion which may not be unique

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Matrix Definition

$$S = \mathbb{I} + 2iT$$

$$M = 16\pi T$$

The matrix S satisfies the unitarity condition

$$S^\dagger S = \mathbb{I}$$

That means

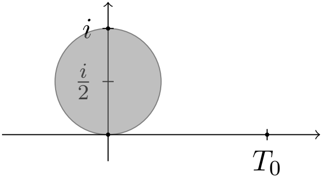
$$\sum_{j=1}^{n} |S_{i,j}|^2 = 1$$

This condition is usually rewritten for a specific entry as

$$|S_{i,j}|^2 \leq 1$$

- Let's consider the Amplitude of a fermion interacting through a Boson Mediator

$$M \propto \frac{1}{Q_{\text{tr}}^2 - M_{med}^2}$$



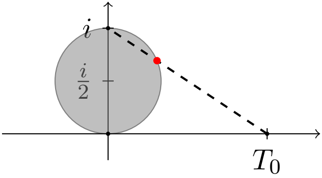
Problem

Amplitude does not lie on the Argand Circle

$$(1 - Im[\frac{M}{8\pi}])^2 + (Re[\frac{M}{8\pi}])^2 = 1$$

- If instead we include the width in the propagator

$$M \propto \frac{1}{Q_{\mathrm{tr}}^2 - M_{med}^2 - iM_{med}\Gamma}$$



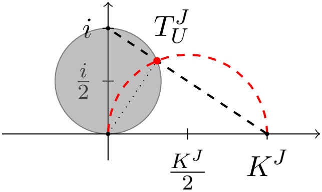
Solution

Amplitude is now unitary (if coupling is small)

- Alternative approach (no width)
- Enforce Unitarity by imposing

$$K^{-1} = (T^{-1} + i\mathbb{I}) = (T^{-1} + i\mathbb{I})^{\dagger} = K^{-1\dagger}$$

$$\left(T = \frac{M}{8\pi}\right)$$



K-Matrix Unitarization

$$K = Re[(T^{-1} + i\mathbb{I})^{-1}] = Re[T]$$

Unitarized amplitude

$$Re[T] = K = (T_U^{-1} + i\mathbb{I})^{-1}$$

Arxiv

1606.02722

Outline

Unitarity bounds

Toy Model

- Color, Flavor singlet
- Massless fermions
- Right-Handed interaction
- T-channel scalar exchange

$$\frac{1}{\Lambda^2}\bar{q}\gamma_\mu P_R q \bar{\chi}\gamma^\mu P_R \chi$$

Resulting Amplitude:

$$T_1 = \begin{pmatrix} \bar{q}q \to \bar{q}q & \bar{\chi}\chi \to \bar{q}q \\ \bar{q}q \to \bar{\chi}\chi & \bar{\chi}\chi \to \bar{\chi}\chi \end{pmatrix} = \frac{s}{12\pi\Lambda^2}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

After "Unitarizing":

$$T_1^U = \frac{1}{s^2 + 144\pi^2\Lambda^4}\begin{pmatrix} is^2 & -12\pi s\Lambda^2 \\ -12\pi s\Lambda^2 & is^2 \end{pmatrix}$$

Smooth cut-off at:

$$s \sim 12\pi\Lambda^2$$

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New Physics: Necessary (but not sufficient) condition

EFT breaks at an energy $\sqrt{s} \leq M_{med}$

Unitarity: Necessary (but not sufficient) condition

Use unitarized amplitude

Warning

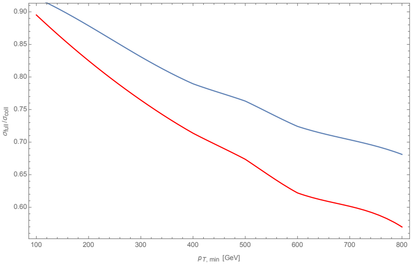
None of these conditions are sufficient, a priori

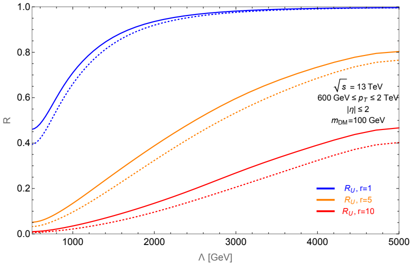
Outline

Unitarization and Monojet

Collinear Approximation

- $\sigma_{full}/\sigma_{coll}$, Gluon jets
- σ_U/σ, Quark + Gluon Jets





Collinear approx: $\sigma_{\bar{q}q\to j\bar{\chi}\chi}(s) = \sigma_{\bar{q}q\to\bar{\chi}\chi}(s(1-z))F_{q\to qg}(z,\theta)$

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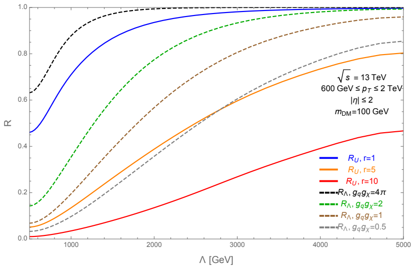
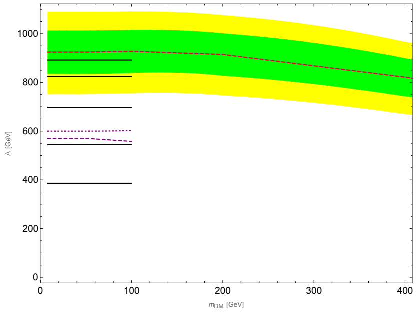
Unitarization and Monojet

Reinterpreting Collider Limits

- $\Lambda_U = \Lambda R_U^{1/4}(\Lambda_U, m_{DM})$
- $R_U = \sigma_U / \sigma_{EFT}$



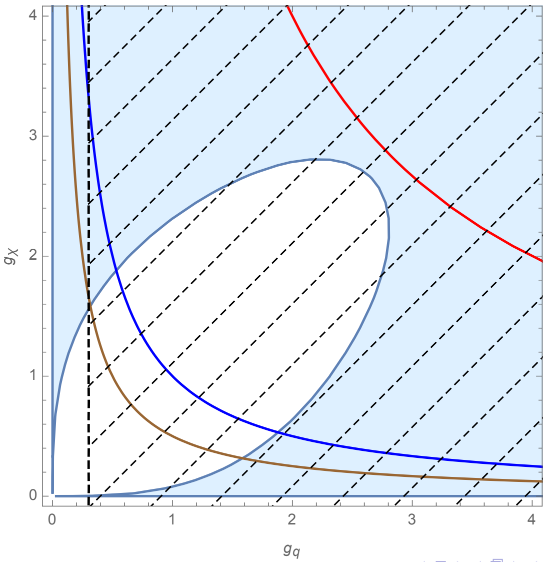


ATLAS 8 TeV

1502.01518

Unitarization and Monojet

UV parameter space



Summary

- EFT model independent but its validity is questionable at LHC
- Standard Framework is to truncate high energy events
  - Might be not enough to ensure unitarity bounds are satisfied
  - Small coupling region has low sensitivity
  - Unitarity Bounds might be not satisfied in the large coupling region
- Conclusions
  - EFT with truncation is ok for low couplings
  - High couplings region may need alternative/complementary analysis beyond EFT