SCET BSM for Leptoquarks

Bianka Meçaj
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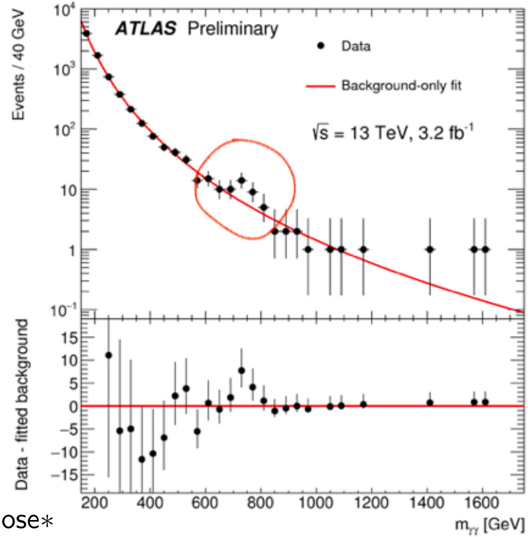
A new heavy resonance?

In case of a new heavy resonance. How would we describe it?



Illustrative purpose∗

What's next?

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- Separate scales $\Rightarrow$ logs of large ratios : $\alpha_s^n \log^{2n}(\frac{M}{v})$
- A tower of infinite number of effective operators for $M \sim \Lambda$

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SCET as the EFT

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- Assign a field for each direction of momentum flow: $(p^+, p^-, p_\perp)$

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- Describe it by means of non-local EFT $\Longrightarrow$ $SCET$ build all the gauge invariant (sub)leading order non-local operators, fields dressed up by Wilson lines.

$$\Psi_{n_i}(x) = \frac{\not{n}_i \bar{\not{n}}_i}{4} \underbrace{\left(P \exp \left[i \sum_k g^{(k)} \int_{-\infty}^{0} ds \bar{n}_i \cdot G_{n_i}^{(k)}(x + s\bar{n}_i) \right] \right)^{\dagger}}_{\textit{Wilson line}} \psi(x)$$

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- Construct an heavy field effective Lagrangian

Heavy Scalar Effective Lagrangian

- Treat the heavy scalar momentum as: $p_\phi^\mu = M_\phi v^\mu + k_\phi^\mu$, where $v^\mu = (1,0,0,0)$ and $\Delta k \sim \Lambda_{QCD}$

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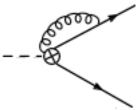

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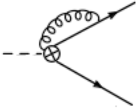

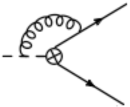

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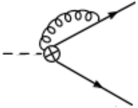

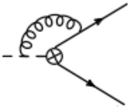

$$Z_S = 1 + \frac{C_F}{2\pi}\alpha_s\frac{1}{\epsilon}$$

Scalar Leptoquark $S_1(3, 1, -\frac{1}{3})$

Application to Leptoquarks

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Only **three** leading order operators:

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- Effects of NP in **three** dimensionless Wilson coefficients.

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Scalar Leptoquark $S_1(3,1,-\frac{1}{3})$+ν_R

$$\mathcal{O}^R_{u\ell} = \bar{u}^c_{R,n_1}\ell_{R,n_2}S_1^* + (n_1 \leftrightarrow n_2)$$
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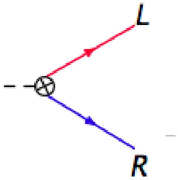

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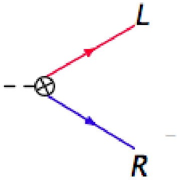
- Fermion number violated at $\mathcal{O}(\lambda^2)$



Operators for $S_1(3,1,-\frac{1}{3})$ at sub-leading order

Two jet operator-Lagrangian

$$\mathcal{L}_{SCET}^{(\lambda^3)} = \frac{1}{\Lambda} \sum_{j=1,2} \int_0^1 du \left[C_1^{(j)}{}_{Ld}^{LR} \mathcal{O}^{(j)}{}_{Ld}^{LR} + C_1^{(j)}{}_{Q\nu}^{LR} \mathcal{O}^{(j)}{}_{Q\nu}^{LR} + C_1^{(j)}{}_{d\nu}^{R} \mathcal{O}^{(j)}{}_{d\nu}^{R} \right]$$
$$+ \frac{1}{\Lambda} C_1^{(0)}{}_{Ld}^{LR} \mathcal{O}^{(0)}{}_{Ld}^{LR} + \frac{1}{\Lambda} C_1^{(0)}{}_{Q\nu}^{LR} \mathcal{O}^{(0)}{}_{Q\nu}^{LR} + h.c$$

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Two jet operators

$$
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Operators for $S_1(3,1,-\frac{1}{3})$ at sub-leading order

Two jet operators **conserve the fermion number** $\Rightarrow$ no mixing between $\mathcal{L}^{(\lambda^2)}_{SCET}$ and $\mathcal{L}^{(\lambda^3)}_{SCET}$

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Operators for $S_1(3,1,-\frac{1}{3})$ at sub-leading order

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3-jet operators further suppressed by the phase space!

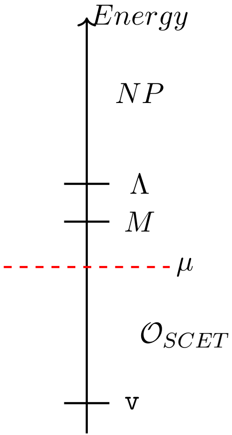
Scalar Leptoquark $S_3(3,3,-\frac{1}{3})$

Lagrangian at leading order:

$$\boxed{\mathcal{L}^{(\lambda^2)}_{SCET} = C_{3}{}^{L}_{QL}\mathcal{O}^{L}_{QL} + h.c}$$

$$\mathcal{O}^{L}_{QL} = \bar{Q}^{c,a}_{L,n_1}\epsilon^{a,b}L^{b}_{L,n_2}S_3^{*} + (n_1 \leftrightarrow n_2)$$

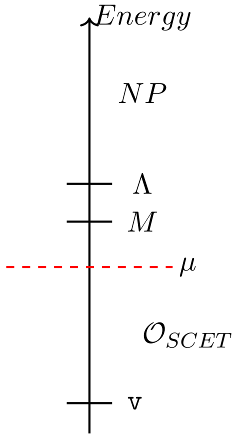
$+5$ more operators at sub-leading order!



Run the scale to resume the logs

$$\mu\frac{d}{\mu}\mathcal{O}_{SCET} = \Gamma(\alpha, M, \mu)\,\mathcal{O}_{SCET}$$

- Anomalous dimensions from the renormalization of the *operators*



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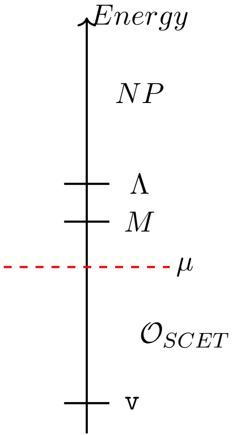

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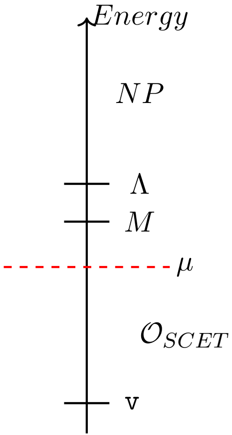

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- Numerically solve the above RGE to estimate the effects from the high scale M-the mass of the leptoquark

Leading order effects on the decay rates of the singlet S_1

Assume an S_1 with mass $M \sim 5TeV$.

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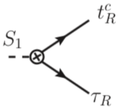

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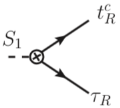

$$\frac{\Gamma(S_1 \to t_R^c \tau_R)_{resum}}{\Gamma(S_1 \to t_R^c \tau_R)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.19$$

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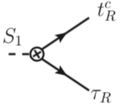

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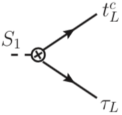

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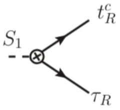
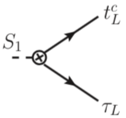


$$\frac{\Gamma(S_1 \to t^c_R \tau_R)_{resum}}{\Gamma(S_1 \to t^c_R \tau_R)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.19$$



$$\frac{\Gamma(S_1 \to t^c_L \tau_L)_{resum}}{\Gamma(S_1 \to t^c_L \tau_L)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.25$$

Leading order effects on the decay rates of the singlet S_1

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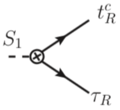

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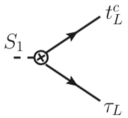
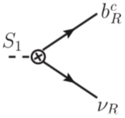


$$\frac{\Gamma(S_1 \to t_L^c \tau_L)_{resum}}{\Gamma(S_1 \to t_L^c \tau_L)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.25$$



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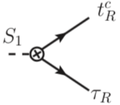

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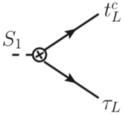
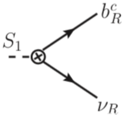


$$\frac{\Gamma(S_1 \to t_L^c \tau_L)_{resum}}{\Gamma(S_1 \to t_L^c \tau_L)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.25$$



$$\frac{\Gamma(S_1 \to b_R^c \nu_R)_{resum}}{\Gamma(S_1 \to b_R^c \nu_R)_{fix}} \to \frac{|C(m_b)|^2 - |C(M_{S_1})|^2}{|C(m_b)|^2} \sim 0.92$$

Leading order effects on the decay rates of the triplet S_3

$$\boxed{\mathcal{L}_{SCET}^{(\lambda^2)} = C_{3}{}^{L}_{QL}\mathcal{O}^{L}_{QL} + h.c}$$

$$\mathcal{O}^{L}_{QL} = \bar{Q}^{c,a}_{L,n_1}\epsilon^{a,b}L^{b}_{L,n_2}S_3^{*} + (n_1 \leftrightarrow n_2)$$

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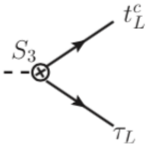

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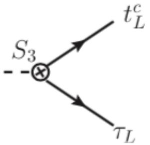

$$\frac{\Gamma(S_3 \to t^c_L \tau_L)_{resum}}{\Gamma(S_3 \to t^c_L \tau_L)_{fix}} \to \frac{|C(m_t)|^2 - |C(M_{S_1})|^2}{|C(m_t)|^2} \sim 0.12$$

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Thank you!