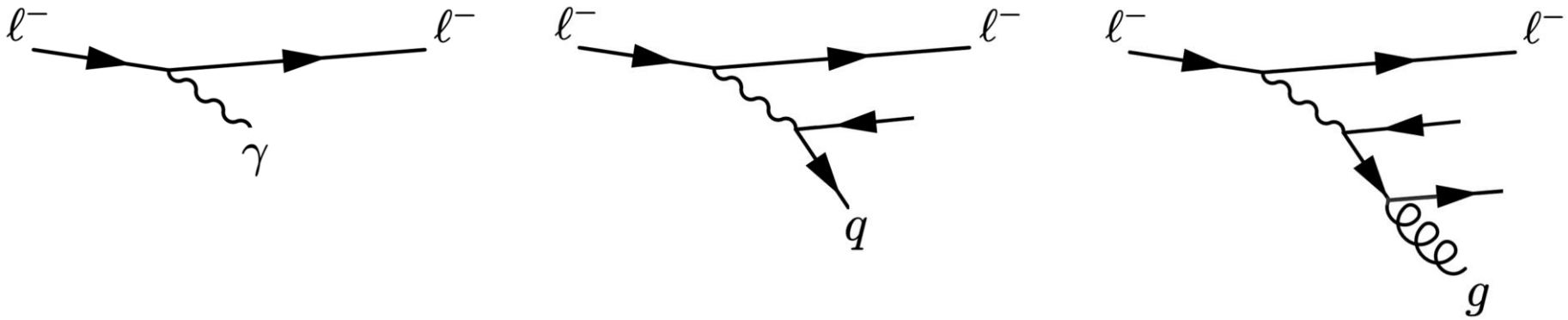
Colored Particle Production at Muon Collider

Tao Han, Matthew Low, Tong Arthur Wu, Keping Xie

arXiv:2502.20443

Partons in lepton



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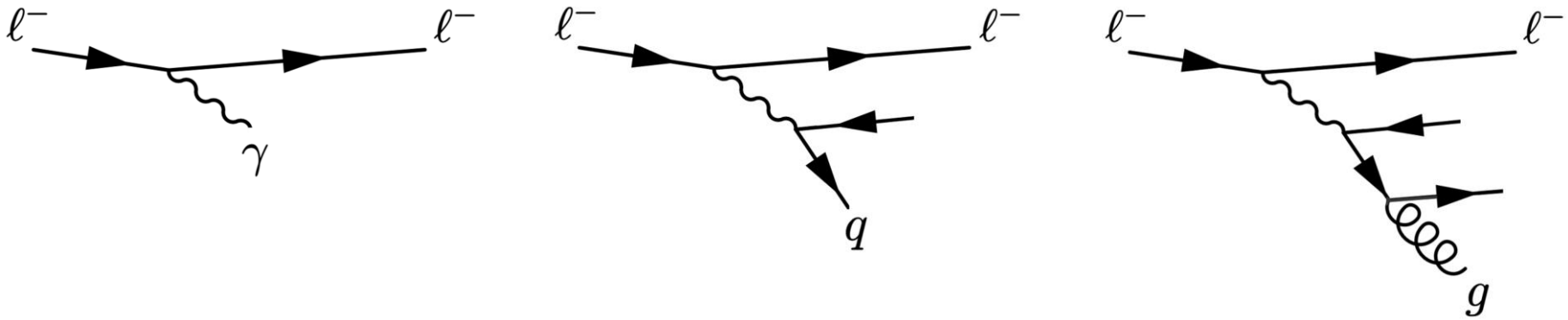
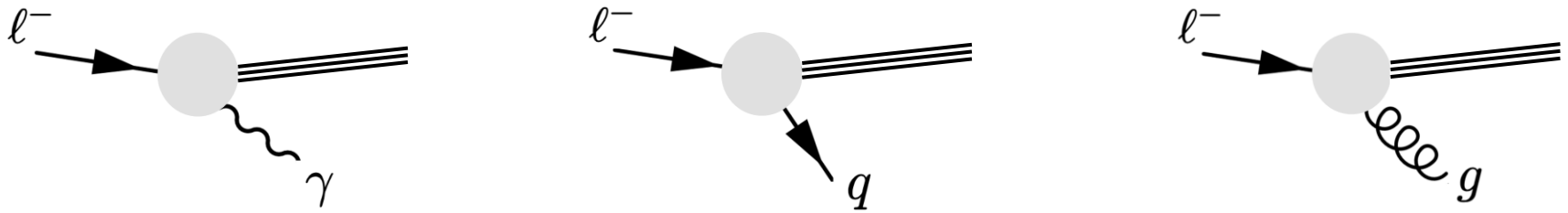


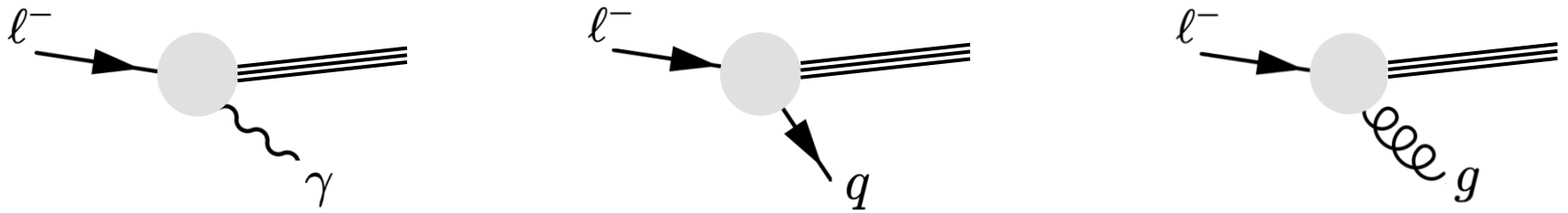
Lepton contains: photon, quark, gluon

$\Longrightarrow$ QCD production of all kind!

Parton distribution function



Parton distribution function



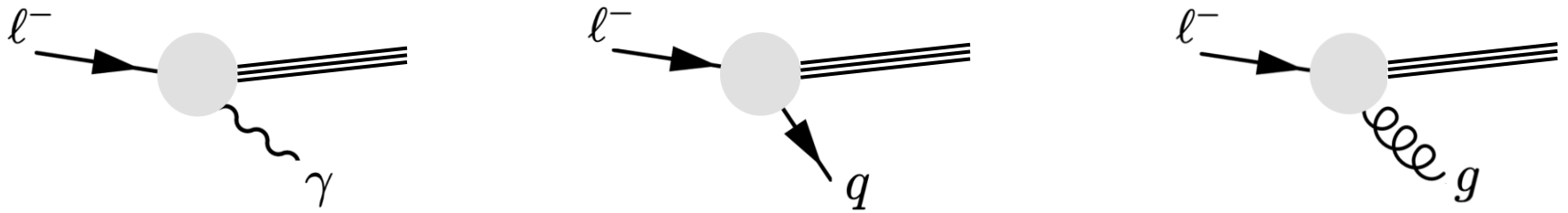
LO PDF:

$$f_{\mathrm{LO}}(x, Q^2) = \delta(1-x) + \frac{\alpha}{2\pi}\left(P(x)\log\frac{Q^2}{\mu^2} + \ldots\right)$$

Splitting function:

$$P_{\ell\ell}(x) = 2\frac{1+x^2}{(1-x)_+} + 3\delta(1-x)$$

Parton distribution function



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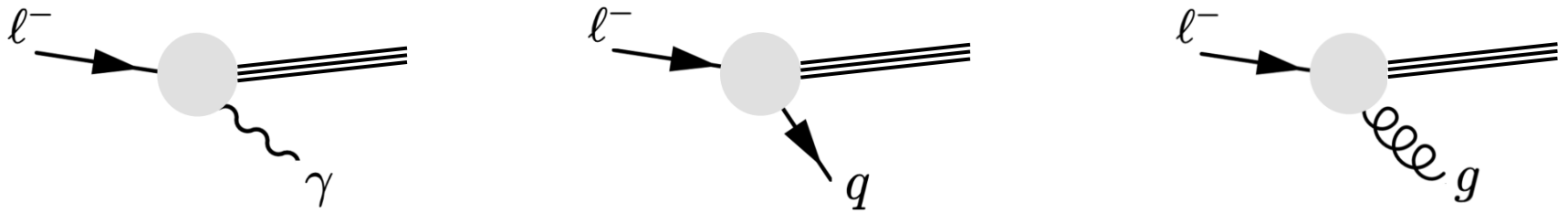
Resummed/factorized PDF:

$$f(x,Q^2) = \int_x^1 \frac{\mathrm{d}\xi}{\xi} f(\xi,\mu^2)\left[\delta(1-\tfrac{x}{\xi}) + \frac{\alpha}{2\pi}P(\tfrac{x}{\xi})\log\frac{Q^2}{\mu^2} + \ldots\right]$$

Parton distribution function



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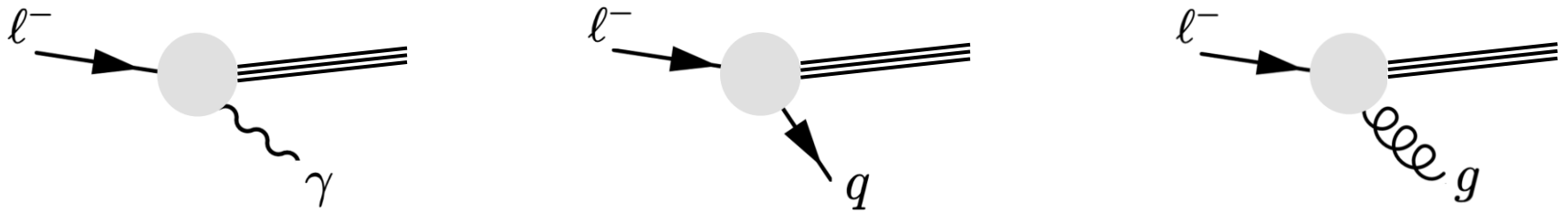
DGLAP equation:

$$\frac{\mathrm{d}f(x,\mu^2)}{\mathrm{d}\log\mu^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{\mathrm{d}\xi}{\xi} P(\tfrac{x}{\xi}) f(\xi,\mu^2) \quad \rightarrow \text{ solve } f$$

Parton distribution function



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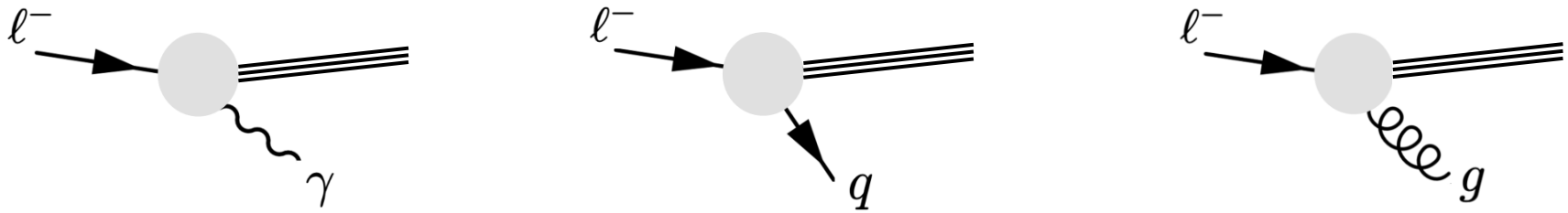
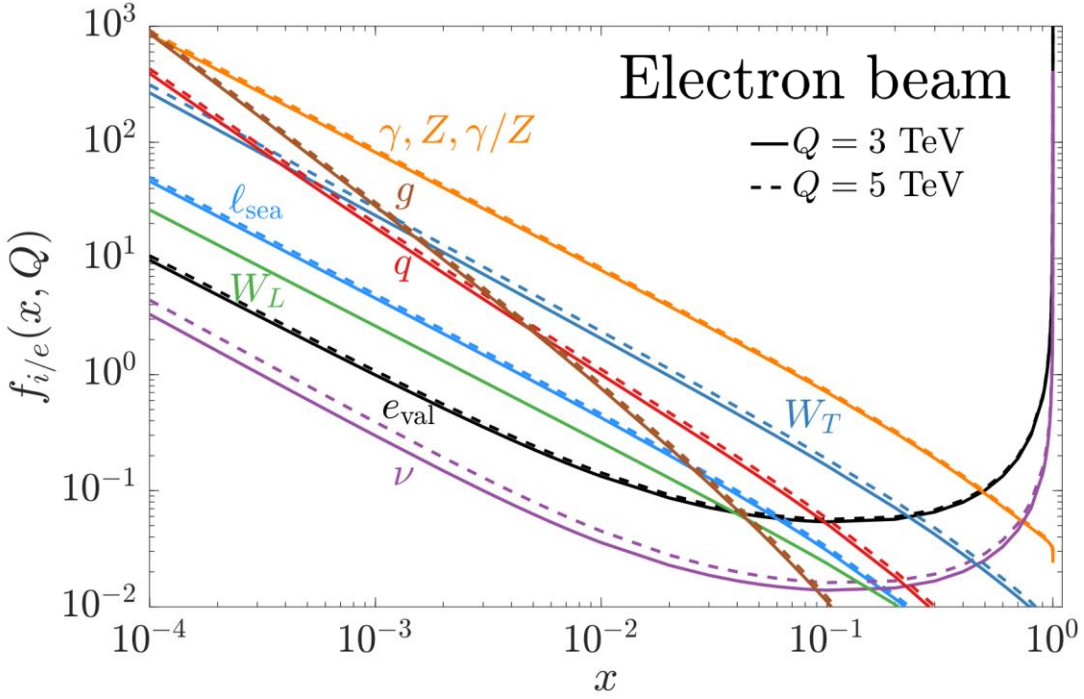
⟹ Semi-inclusive cross section: $\sigma(\ell^+\ell^-\to F+X) = \int \mathrm{d}x_1\mathrm{d}x_2\, f_a(x_1) f_b(x_2)\, \hat{\sigma}(ab\to F)$

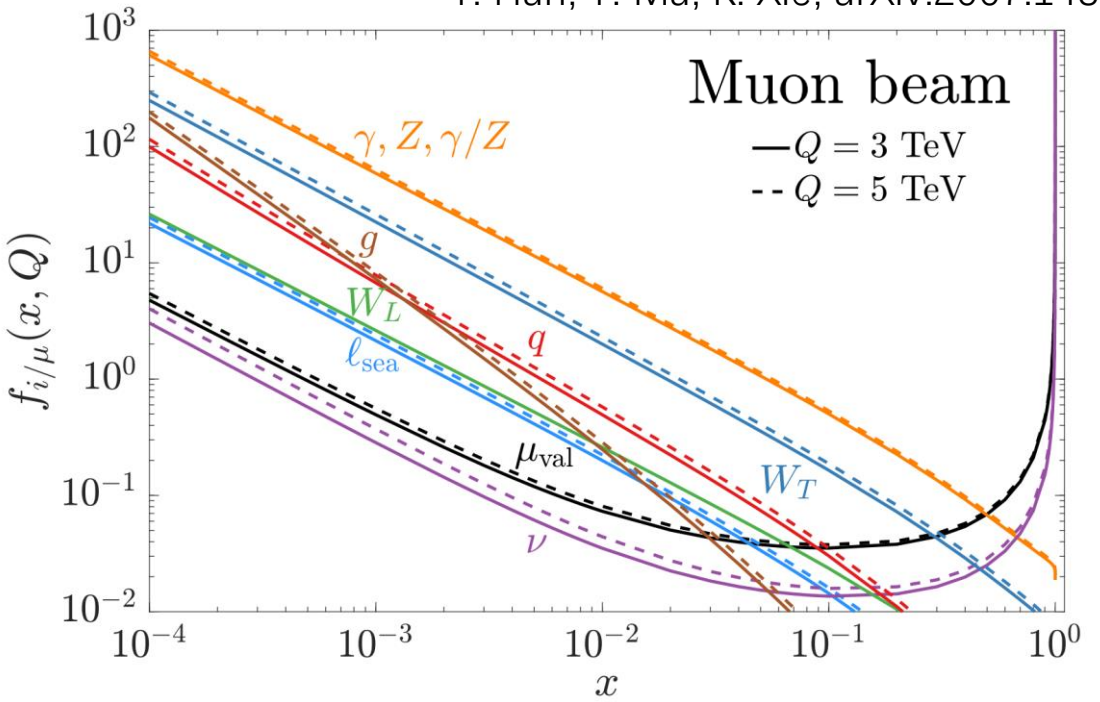
Parton distribution function



PDF:

T. Han, Y. Ma, K. Xie, arXiv:2007.14300





Colored BSM particles

	Model	Spin	$SU(3)_c$	$\lvert Q_e \rvert$	Current Limit
	Vector-like quark T	$\frac{1}{2}$	**3**	$\frac{2}{3}$	2.1 TeV
γ, Z, W, g, q →	Top squark $\tilde{t}$	0	**3**	$\frac{2}{3}$	1.3 TeV
	Scalar diquark D_6	0	**6**	$\frac{4}{3}$	7.5 TeV
γ, Z, W, g, q, l →	Leptoquark ℓ_q	0,1	**3**	$\frac{1}{3}$-$\frac{5}{3}$	1.4-2.0 TeV
	Leptogluon ℓ_g	$\frac{1}{2}$	**8**	1	2.5 TeV
	Octet scalar S_8	0	**8**	0	1.25 TeV
g, q →	Octet vector V_8	1	**8**	0	1.6 TeV
	Gluino $\tilde{g}$	$\frac{1}{2}$	**8**	0	2.2 TeV

Vector-like quark

$$\mathcal{L} = i\bar{T}\partial\!\!\!/ T - M_T\bar{T}T - g_s\bar{T}G\!\!\!/ T - \frac{2}{3}g'\bar{T}B\!\!\!/ T + \left(\kappa_W\frac{g}{\sqrt{2}}\bar{T}_L W_\mu^+\gamma^\mu b_L + \kappa_Z\frac{g}{2c_W}\bar{T}_L Z_\mu\gamma^\mu t_L - \kappa_H\frac{M_T}{v}\bar{T}_L H t_L + \text{h.c.}\right)$$

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model-independent

model-dependent

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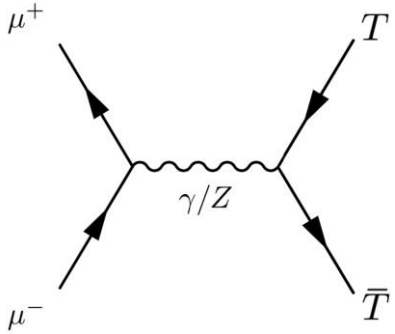
model-independent

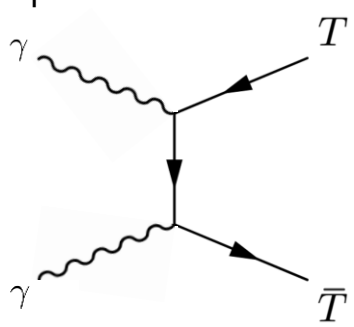
model-dependent

Pair production:

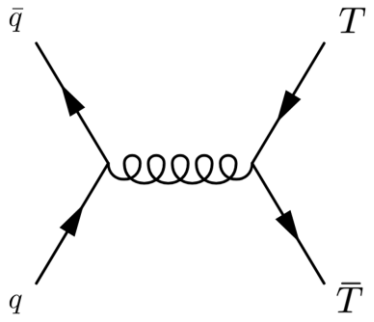
muon annihilation



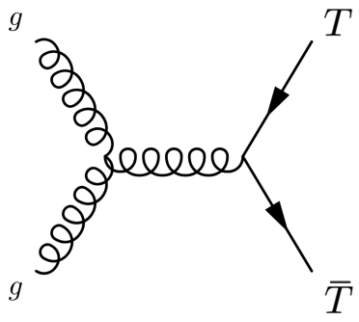
photon fusion



quark annihilation



gluon fusion



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model-independent

model-dependent

Pair production:

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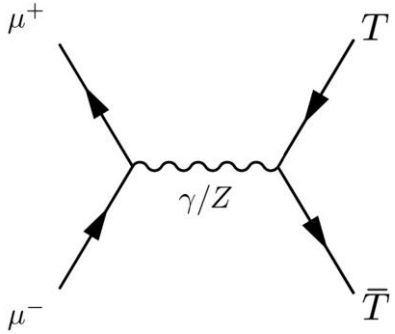

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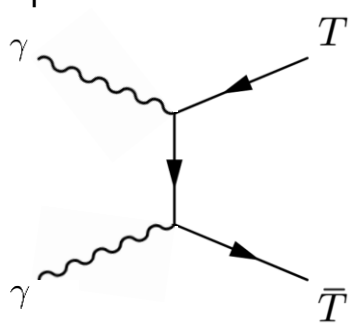

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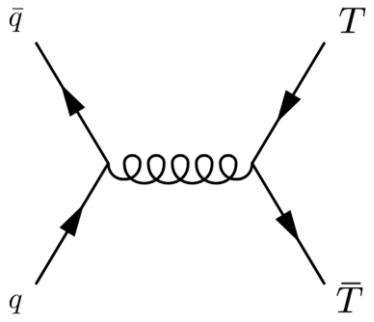

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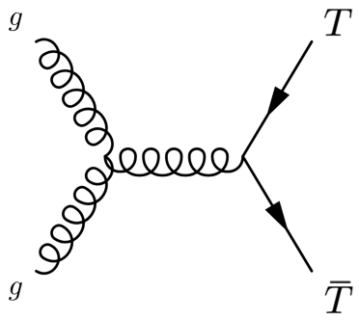
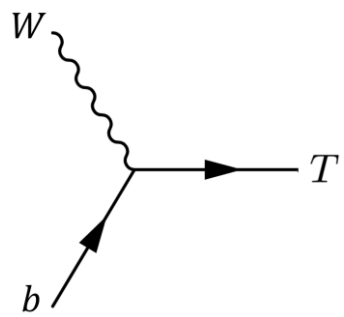
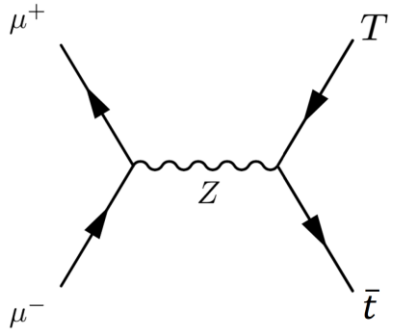


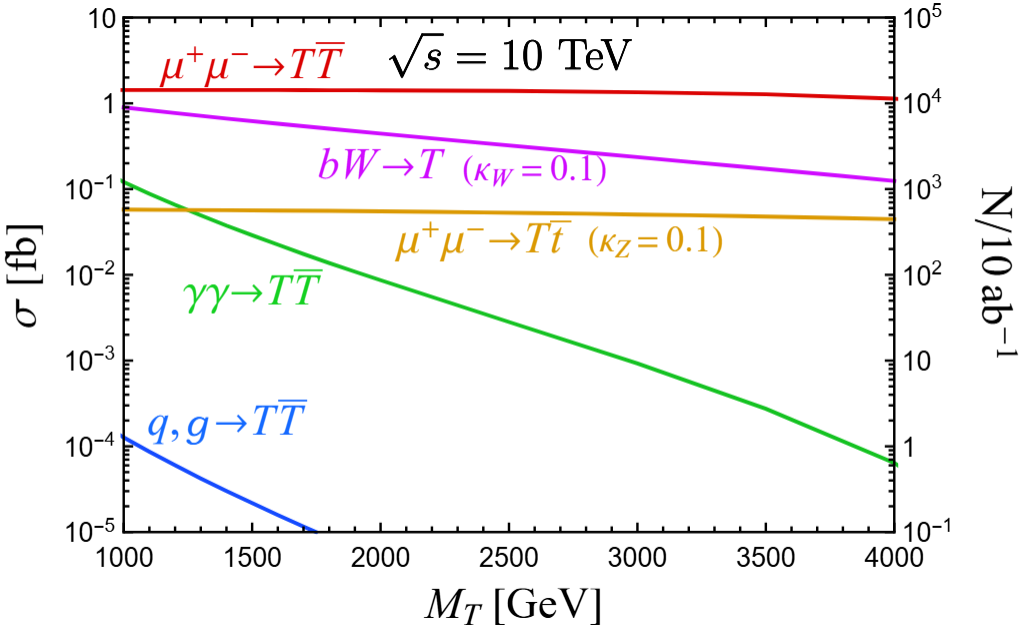
Single production:

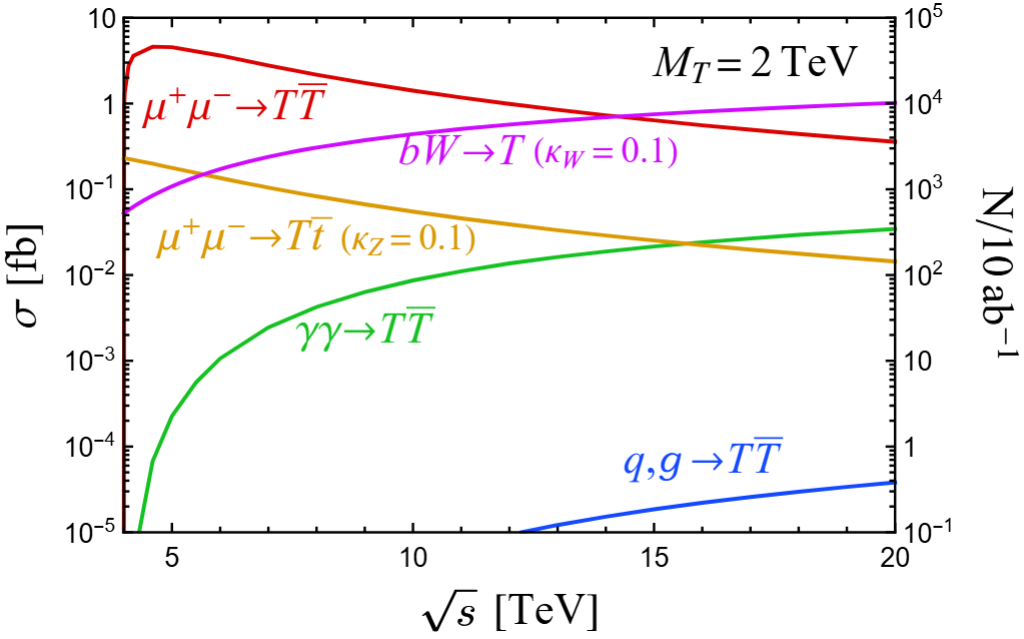




Vector-like quark

Cross section:





Vector-like quark

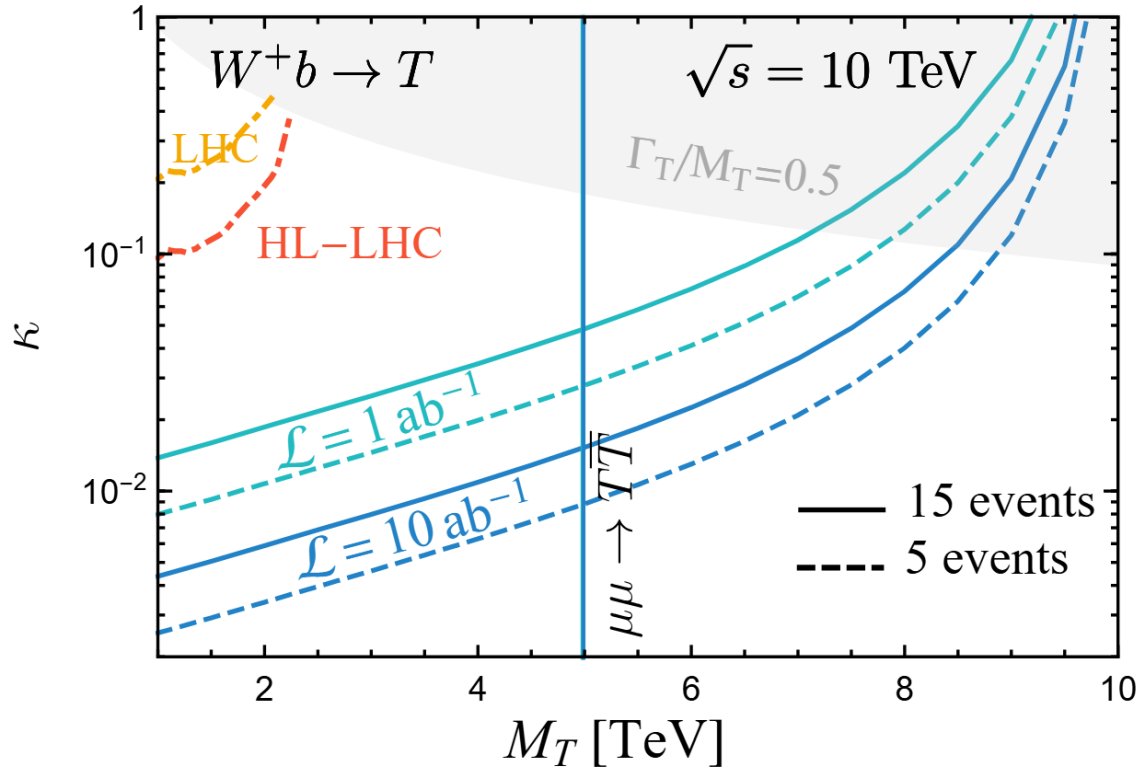
Sensitivity:

Decay channel: $T \to Wb$ (effectively background-free)

Fiducial cuts: $p_T^{\ell(j)} > 15\ \text{GeV}, \quad |\eta_{\ell(j)}| < 2.5, \quad \Delta R_{\ell j} > 0.4$

$0.85\ M_T < m_{Wb} < 1.15\ M_T$

Tagging efficiency: $\epsilon(b) = 70\%, \quad \epsilon(j) = 90\%$

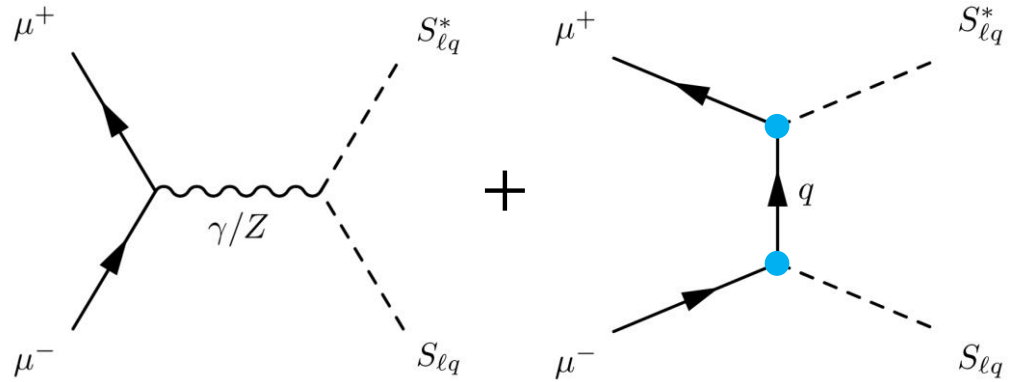


Scalar leptoquark

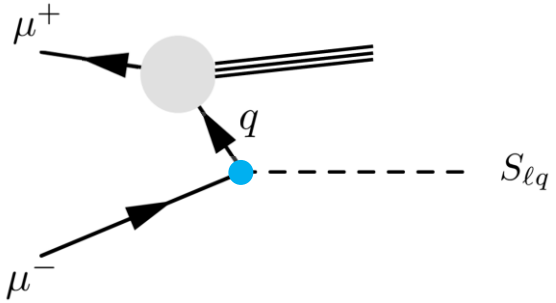
$$\mathcal{L}_{\ell q} = S_1^{1/3} \left(\lambda_R \bar{u}_R^c e_R + \lambda_L \bar{q}_L^c \ell_L \right)$$

Pair production:

new channel in muon annihilation

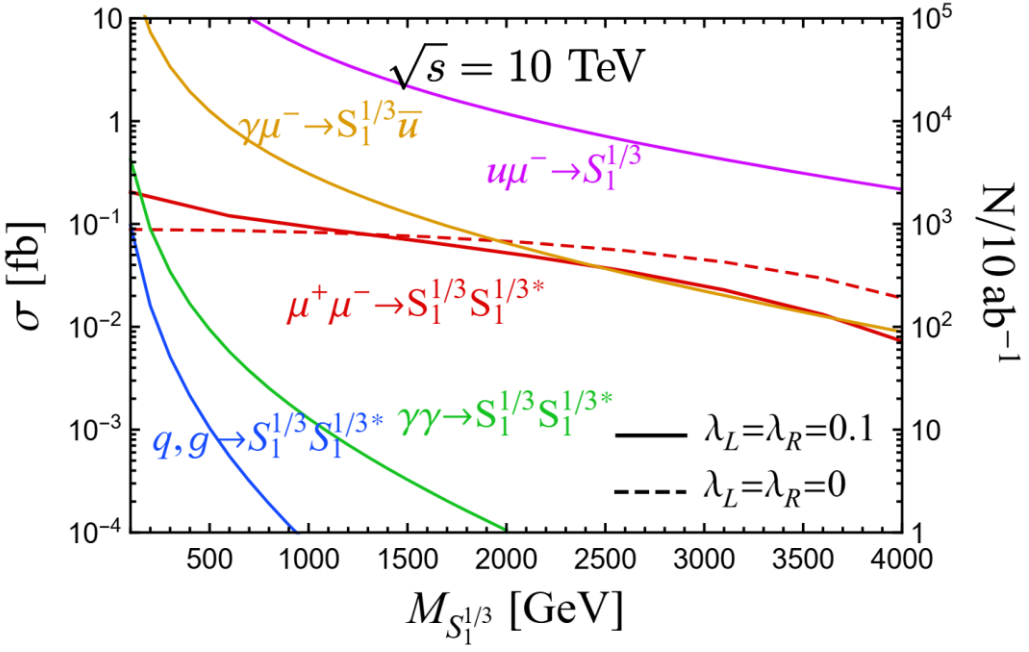


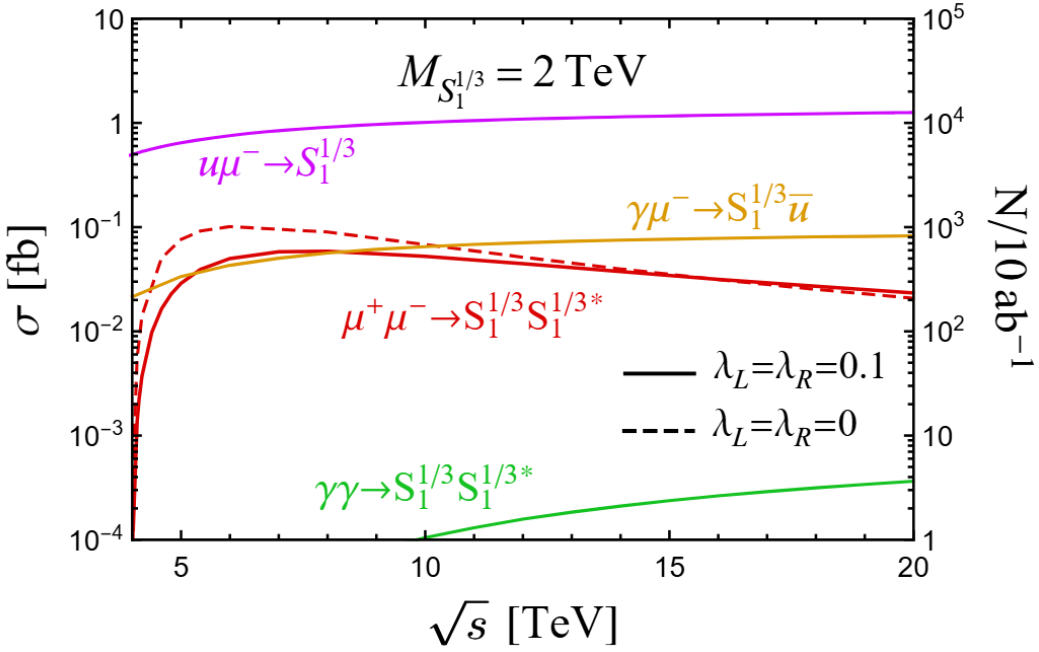
Single production:



Scalar leptoquark

Cross section:





Scalar leptoquark

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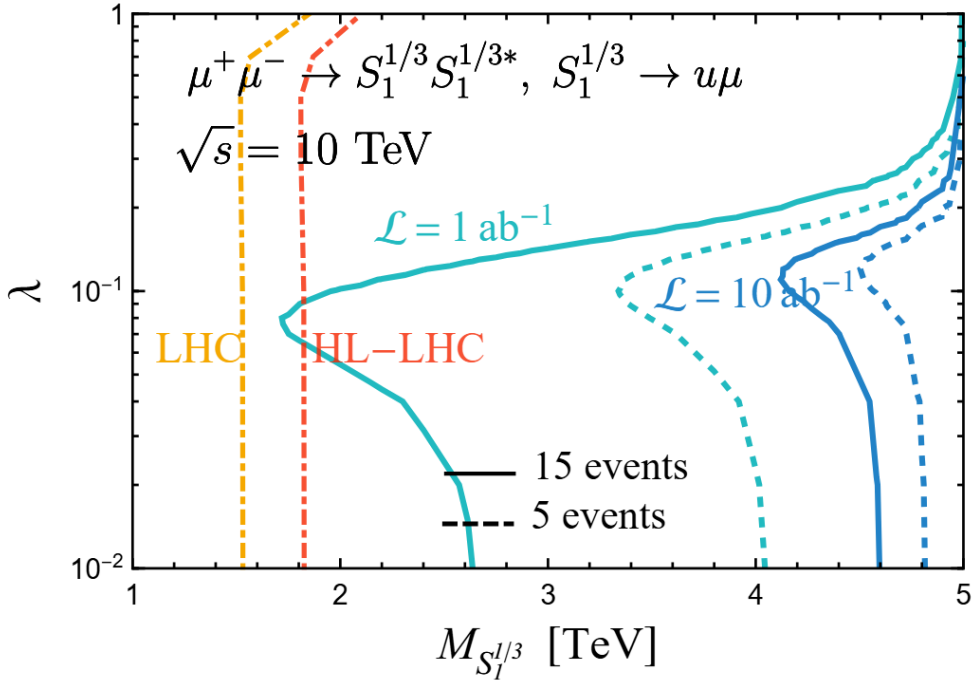
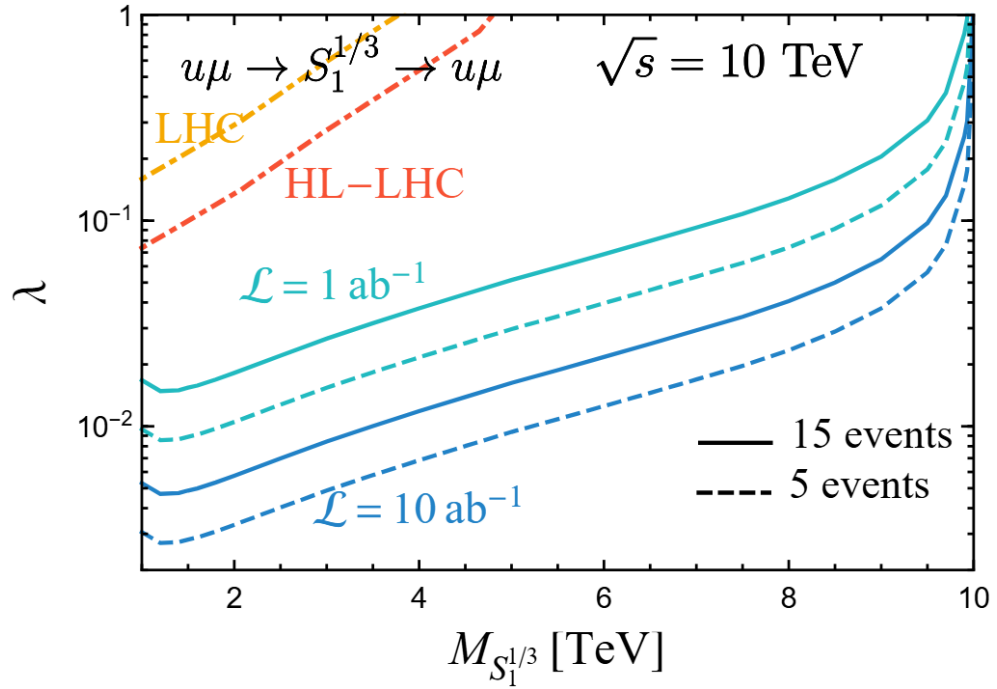
$0.85\ M_S < m_{u\mu} < 1.15\ M_S$

Tagging efficiency: $\epsilon(\ell) = 90\%, \quad \epsilon(j) = 90\%$

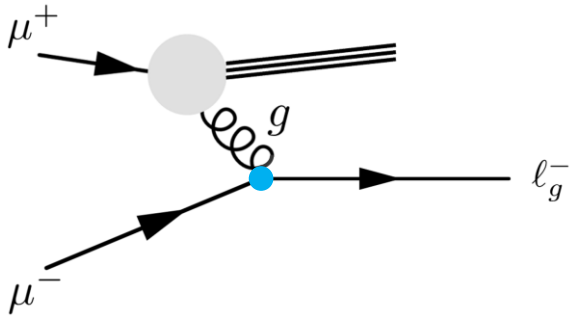




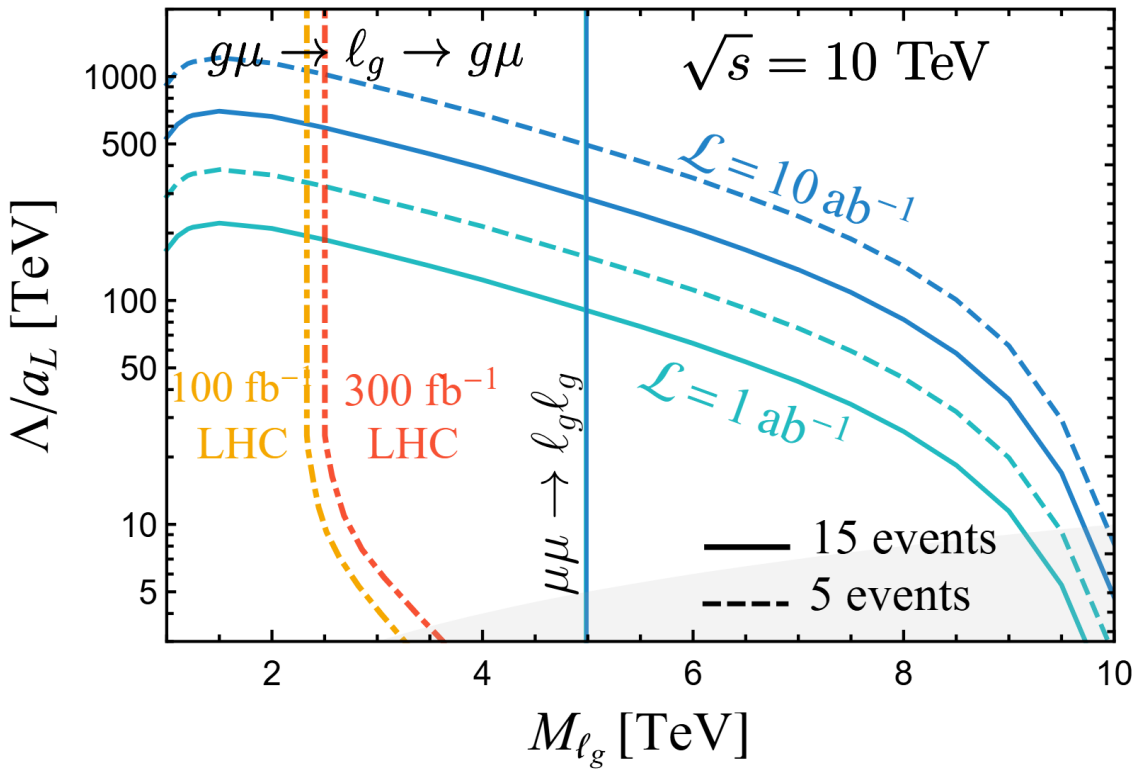
Leptogluon

$$\mathcal{L} = \bar{\ell}_g(i\not{D} - M_{\ell_g})\ell_g + \frac{g_s}{2\Lambda}\bar{\ell}_g^a\sigma^{\mu\nu}G^a_{\mu\nu}(a_L P_L + a_R P_R)\ell$$

Single production:



Sensitivity:



Vector octet

$$\mathcal{L} = -\frac{1}{4}F_{8,\mu\nu}F_8^{\mu\nu} + \frac{1}{2}M_V^2 V_{8,\mu}V_8^{\mu} + V_{8,\mu}\bar{t}\gamma^{\mu}(g_L P_L + g_R P_R)t$$

Vector octet

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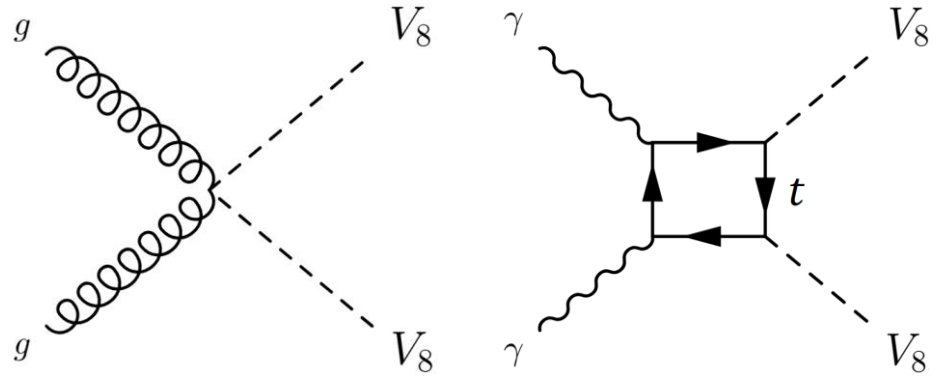
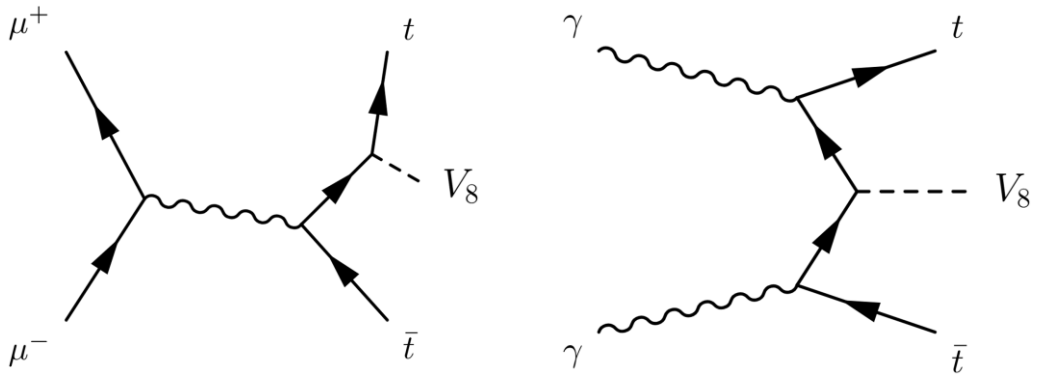
Pair production:

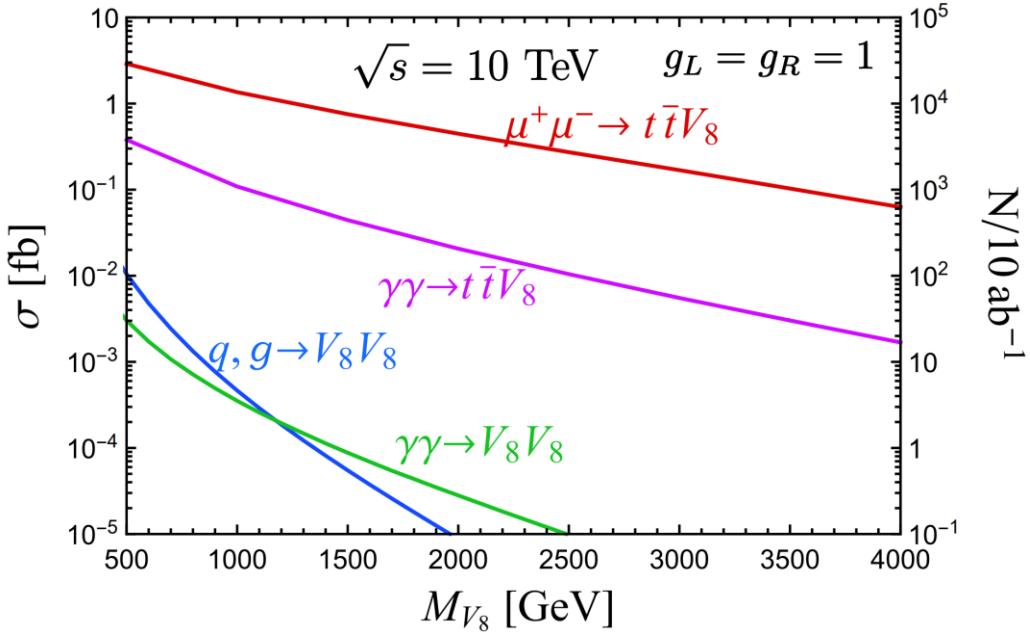


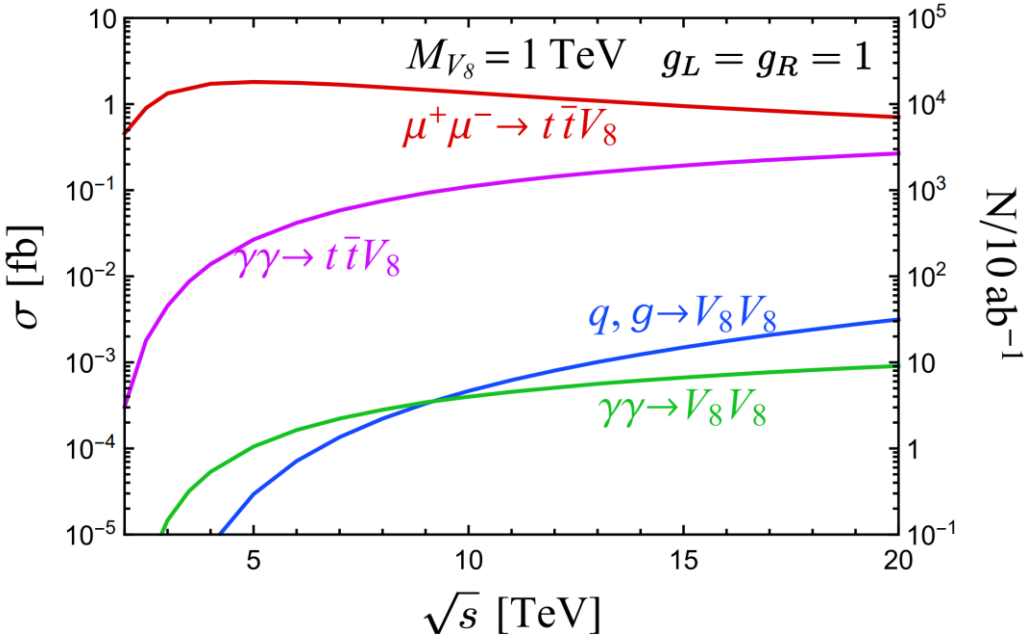
Single production:



Vector octet

Cross section:

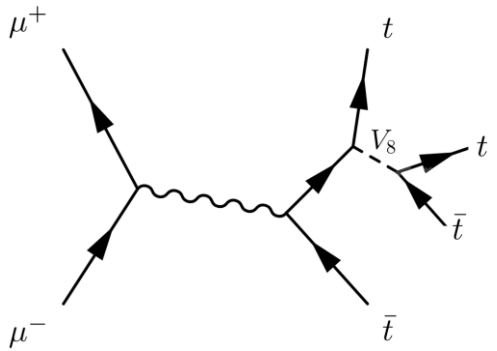




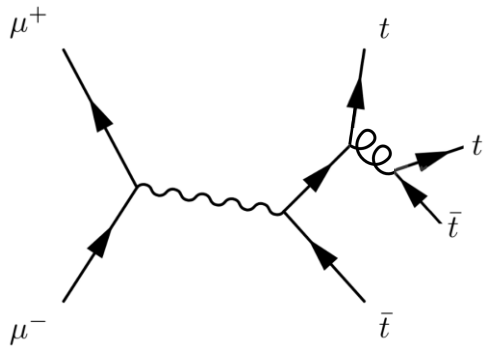
Vector octet

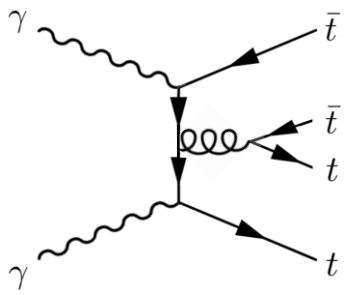
Sensitivity:

Signal:



Background:

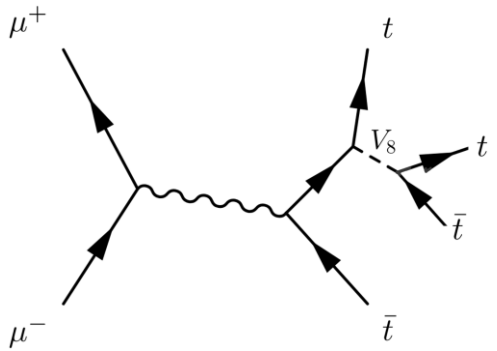




Vector octet

Sensitivity:

Signal:



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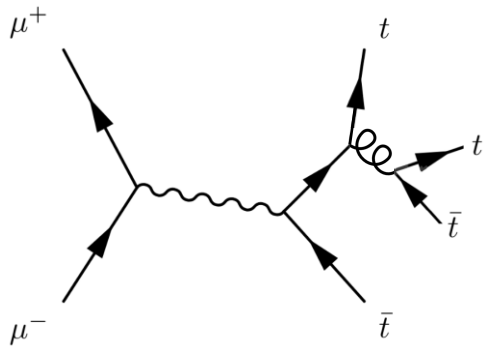
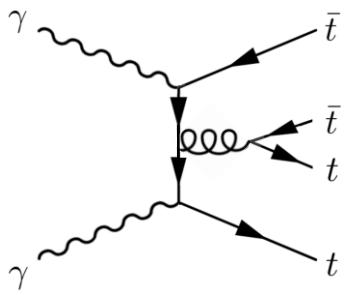
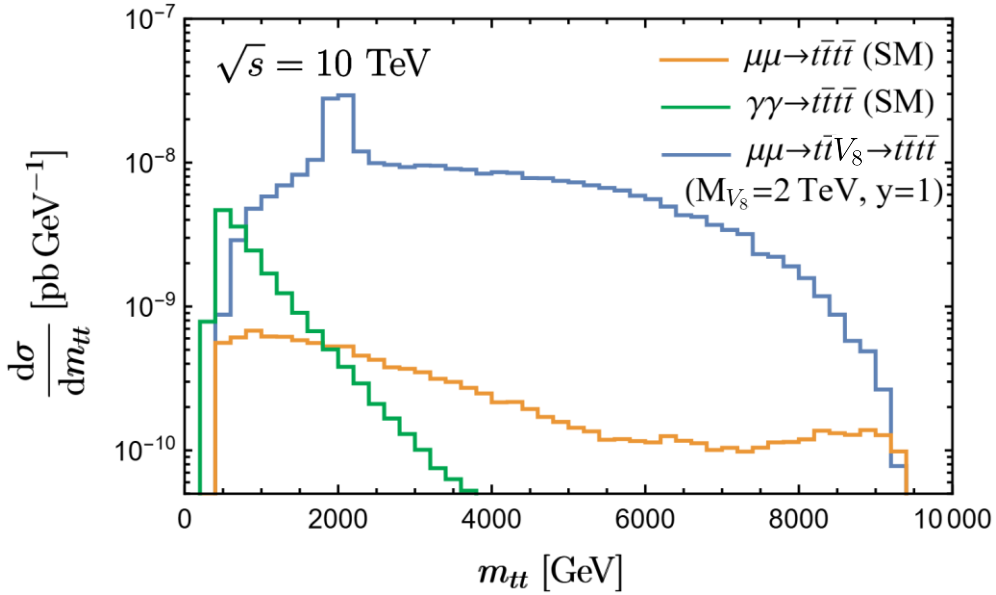




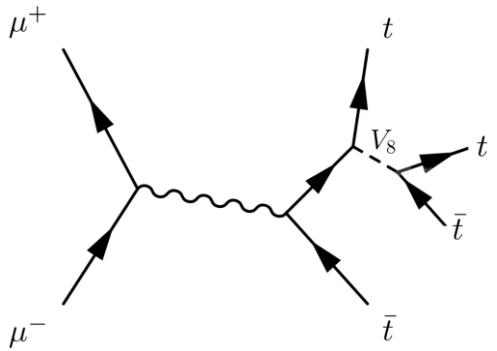
Combinatorial mass:



Vector octet

Sensitivity:

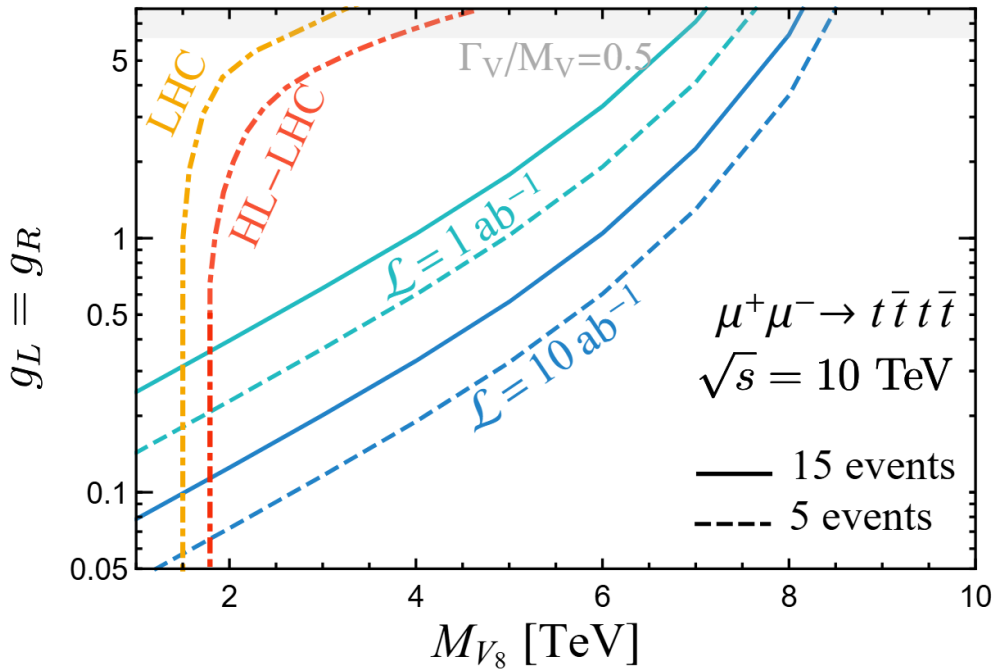
Signal:



Fiducial cuts: $|\eta_t| > 2.5, \quad \Delta R(t,t) > 0.4$

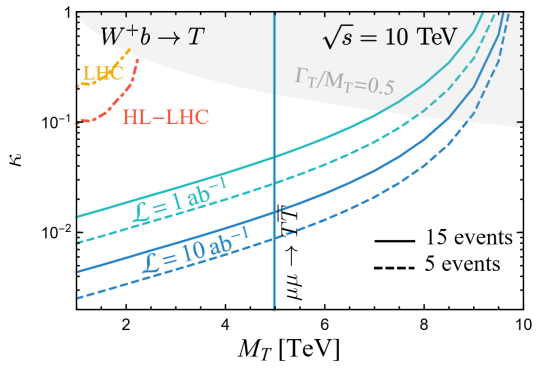
$0.9M_{V_8} < m_{tt} < 1.1M_{V_8}$

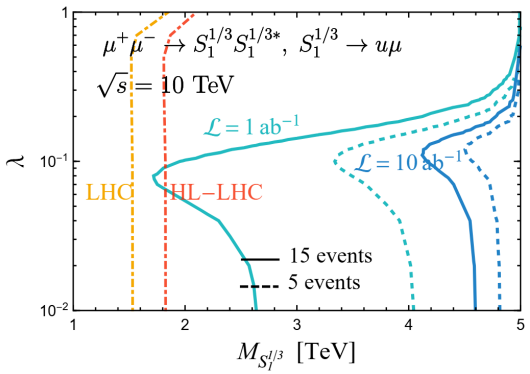
Tagging efficiency: $\epsilon(t) = 50\%$

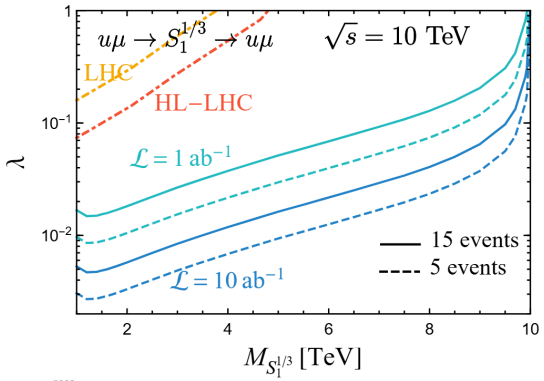


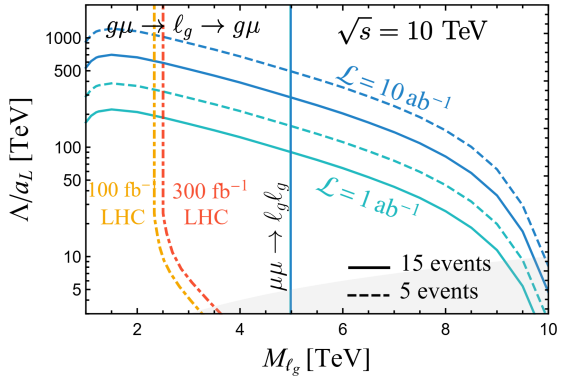
Conclusion

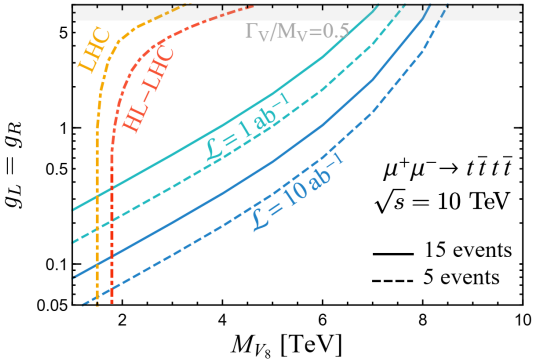
- Muon collider has excellent reach for a wide variety of colored particles!

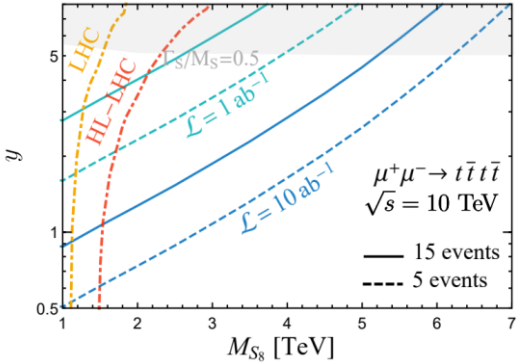


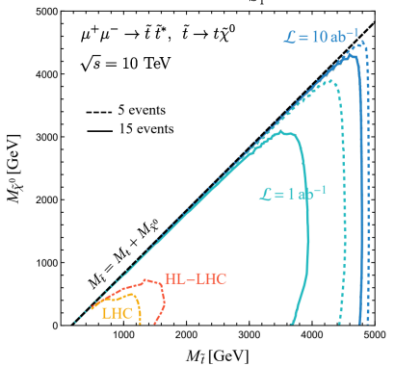












T. Han, M. Low, A. Wu, K. Xie, arXiv:2502.20443

Thank you!