Effective Field Theory for Top Quark Physics

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Top 2010

June 4, 2010

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Cen Zhang and Scott Willenbrock
U. of Illinois at Urbana-Champaign

work in progress

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See also poster of

Celine Degrande, J.-M. Gerard,
C. Grojean, F. Maltoni, G. Servant

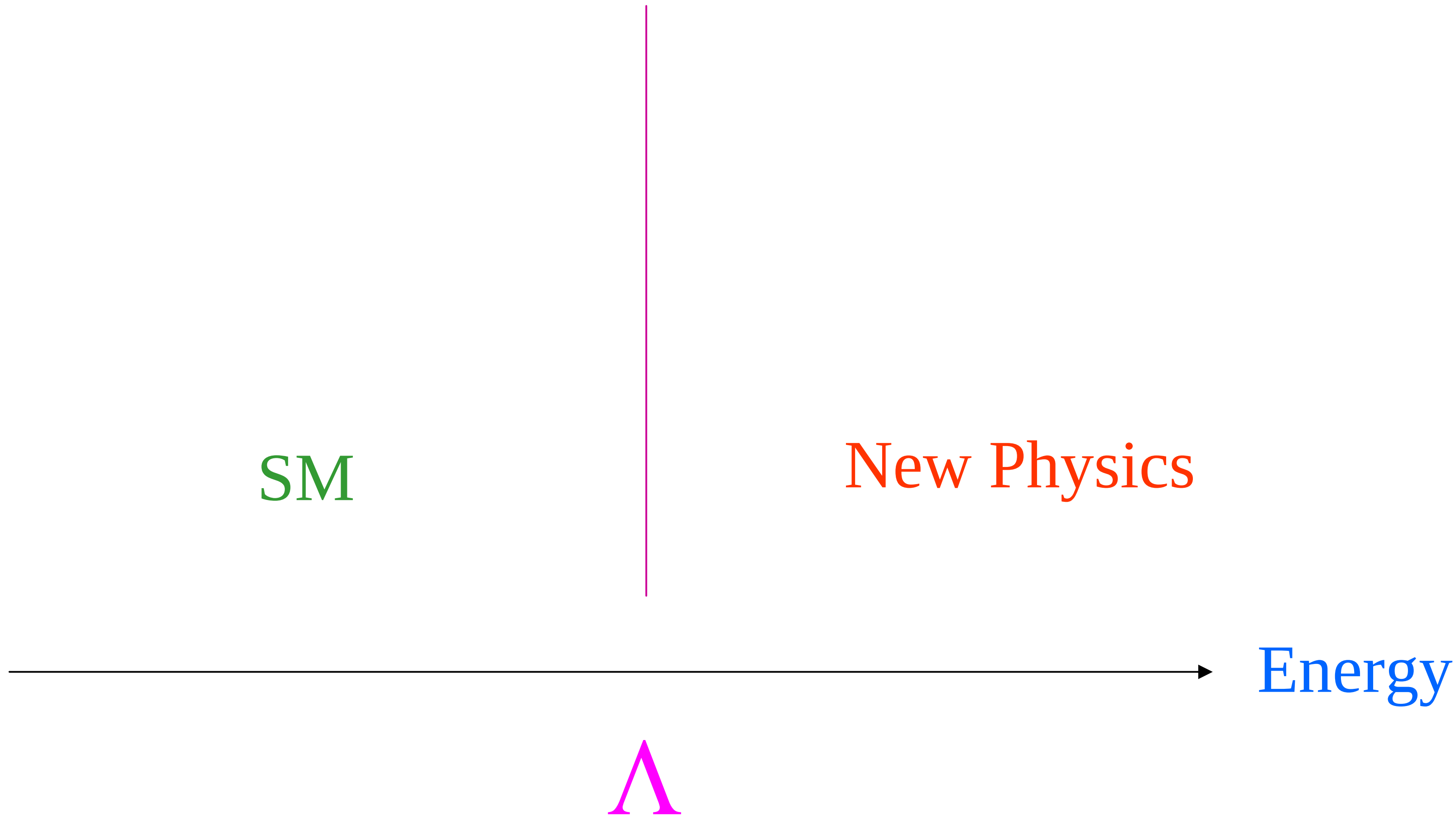
Two approaches to physics beyond the standard model:

1. Add new particles

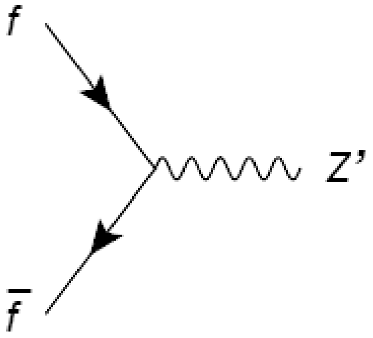
    Directly observe new physics

2. Add new interactions of SM particles

    How should we do this?


SM
New Physics
Energy
Λ

Example: Z’ boson



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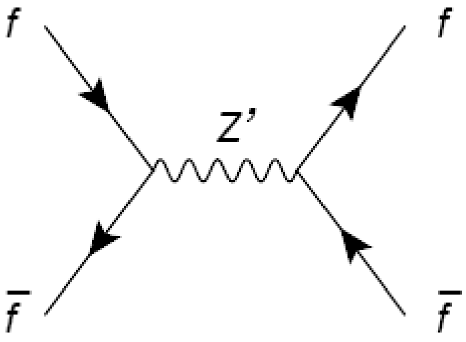

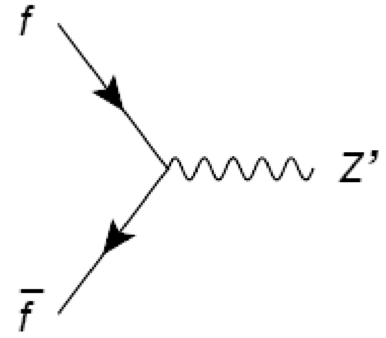

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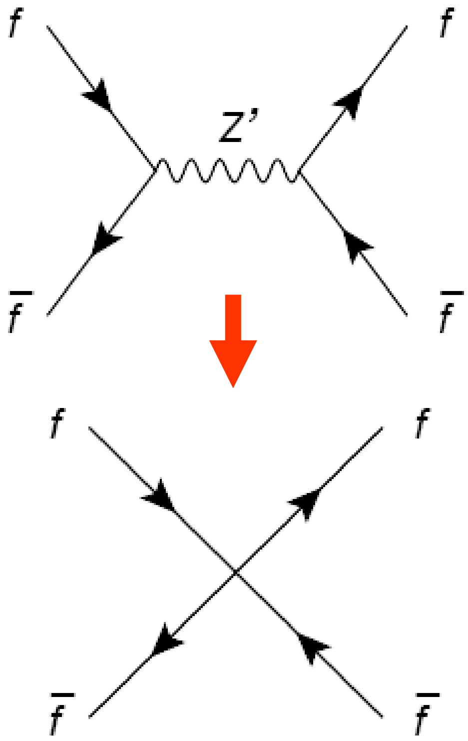

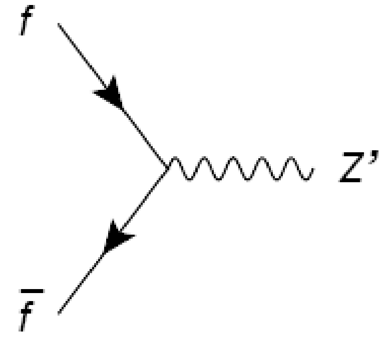

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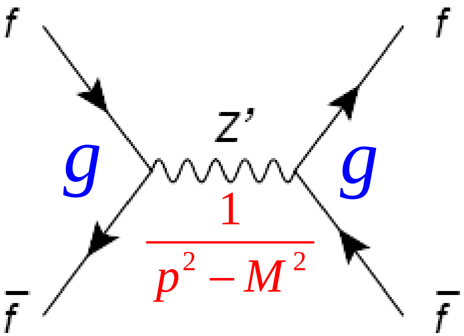
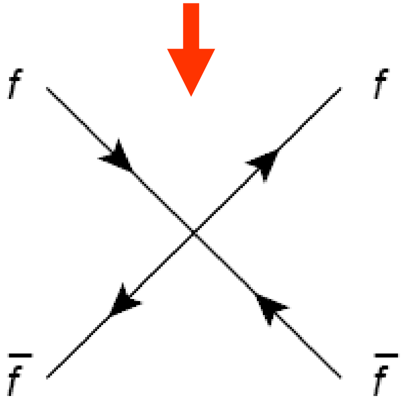
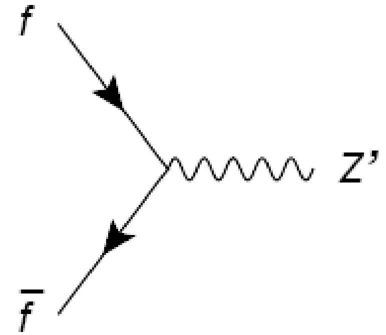
Example: Z' boson



$$\frac{1}{p^2 - M^2}$$



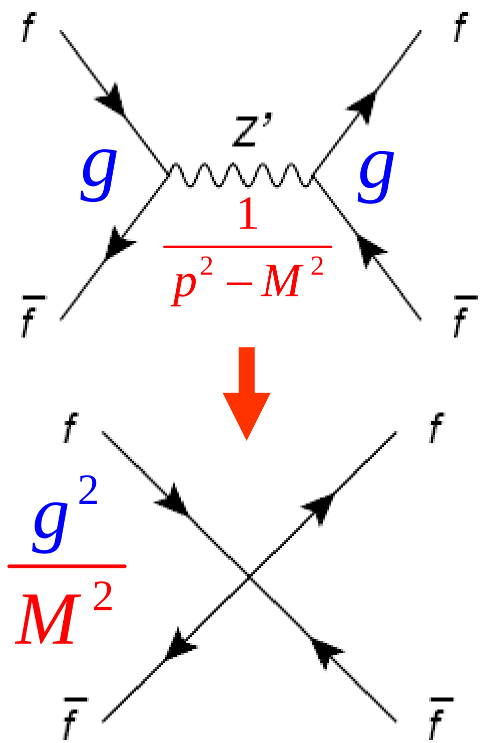


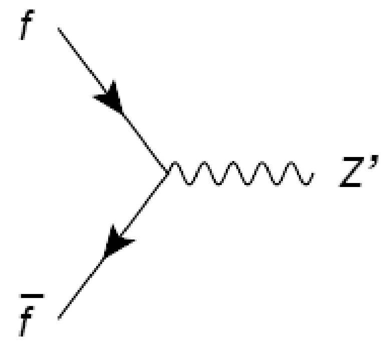
New Physics

Energy

$$\Lambda = M$$

Example: Z' boson





New Physics

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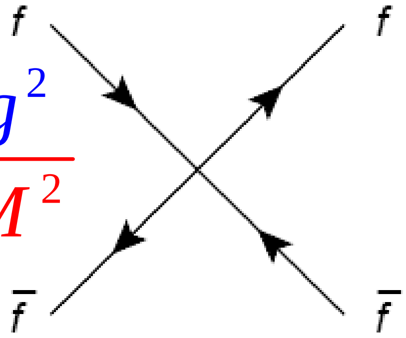
Example: Z' boson

$$\frac{g^2}{M^2}$$



$$L = L_{SM} + \frac{g^2}{M^2}\bar{\psi}\psi\bar{\psi}\psi$$

Dimensional analysis

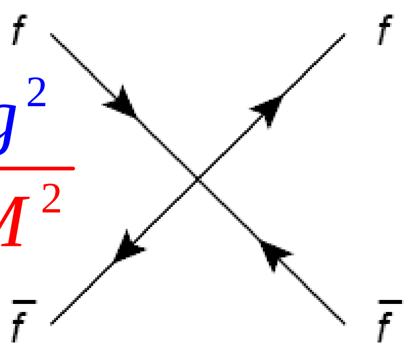
$$\hbar = c = 1$$

$$\dim A^{\mu} = 1$$

$$\dim \phi = 1$$

$$\dim \psi = 3/2$$

$$\frac{g^2}{M^2}$$



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$$\dim = \qquad \leq 4 \qquad\qquad 6$$

Dimensional analysis

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$$L = L_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

$$\dim = \qquad \le 4 \qquad\qquad 6$$

Dimensional analysis

$$\hbar = c = 1$$

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Effective Field Theory

$$L = L_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

Weinberg 1979

$$\dim = \quad \leq 4 \qquad\qquad 6$$

Leung, Love, Rao 1984
Buchmuller, Wyler 1986

Bad news: >60 operators

Effective Field Theory $$L = L_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

Weinberg 1979

$$\mathrm{dim} = \quad \leq 4 \qquad\qquad 6$$

Good news: only a few operators contribute to top physics

Leung, Love, Rao 1984
Buchmuller, Wyler 1986

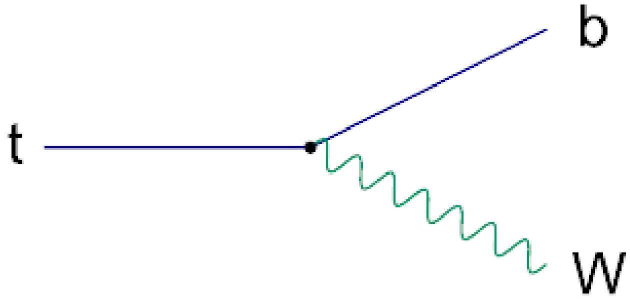
Bad news: >60 operators

Effective Field Theory $$L = L_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

Weinberg 1979

$\mathrm{dim} =$ ≤ 4 6

Top decay



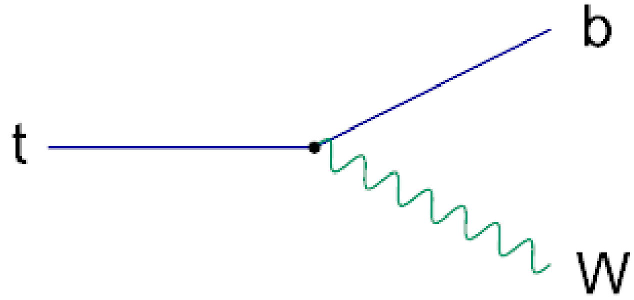
$$F_0 = \frac{m_t^2}{m_t^2 + 2m_W^2} = 0.7$$

$$F_L = \frac{2m_W^2}{m_t^2 + 2m_W^2} = 0.3$$

$$F_R = 0$$

$m_b = 0$

Top decay



$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$$

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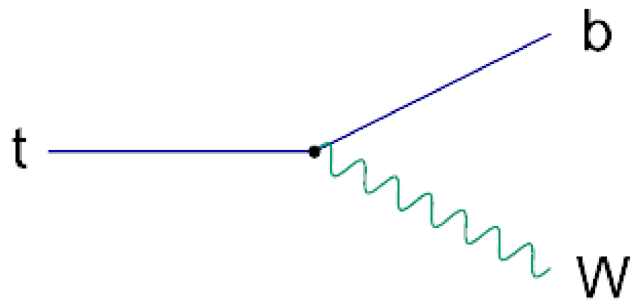
Top decay



$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu} \longrightarrow L_{eff} = i\frac{C_{tW}}{\Lambda^2}v\left(\bar{b}\sigma^{\mu\nu}(1+\gamma_5)t\right)\partial_\nu W^-_\mu$$

$$F_0 = \frac{m_t^2}{m_t^2 + 2m_W^2}$$

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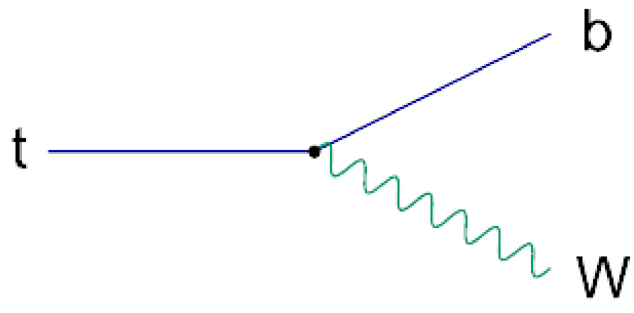

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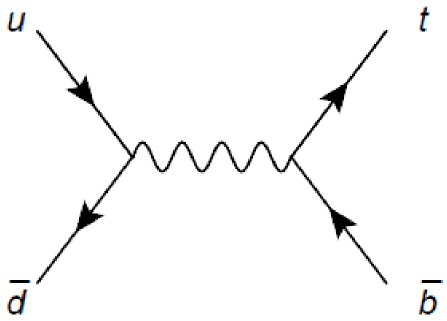
$$\begin{aligned} F_0 &= \frac{m_t^2}{m_t^2+2m_W^2} - \frac{4\sqrt{2}C_{tW}v^2}{\Lambda^2}\frac{m_t m_W(m_t^2-m_W^2)}{(m_t^2+2m_W^2)^2} \\ F_L &= \frac{2m_W^2}{m_t^2+2m_W^2} + \frac{4\sqrt{2}C_{tW}v^2}{\Lambda^2}\frac{m_t m_W(m_t^2-m_W^2)}{(m_t^2+2m_W^2)^2} \\ F_R &= 0 \end{aligned}$$

Single top



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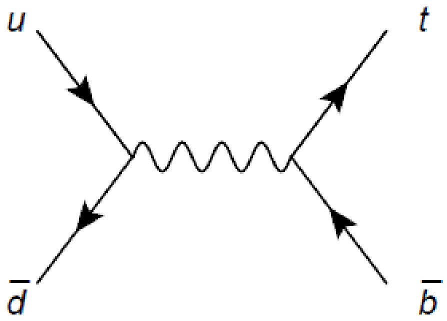
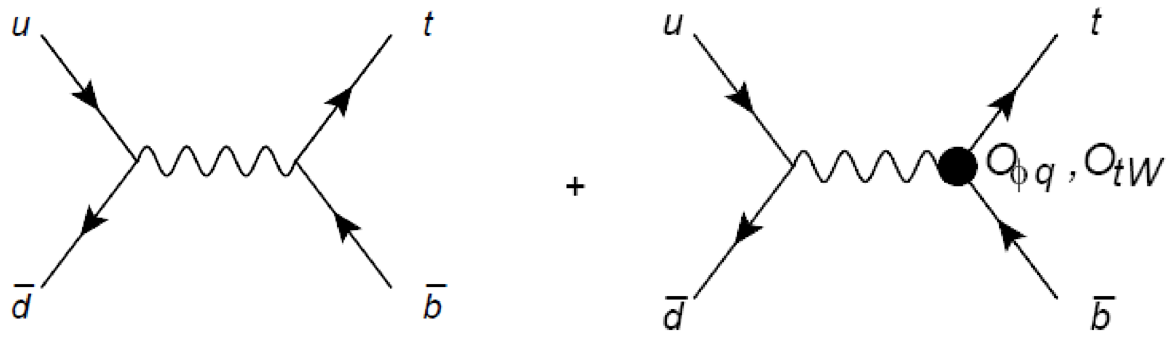


$$O_{tW} \quad = \quad (\bar{q}\sigma^{\mu\nu}\tau^{I}t)\tilde{\phi}W^{I}_{\mu\nu} \longrightarrow L_{eff} = i\frac{C_{tW}}{\Lambda^2}v\left(\bar{b}\sigma^{\mu\nu}(1+\gamma_5)t\right)\partial_\nu W^{-}_{\mu}$$

Cao, Wudka 2006
Cao, Wudka, Yuan 2007

Single top



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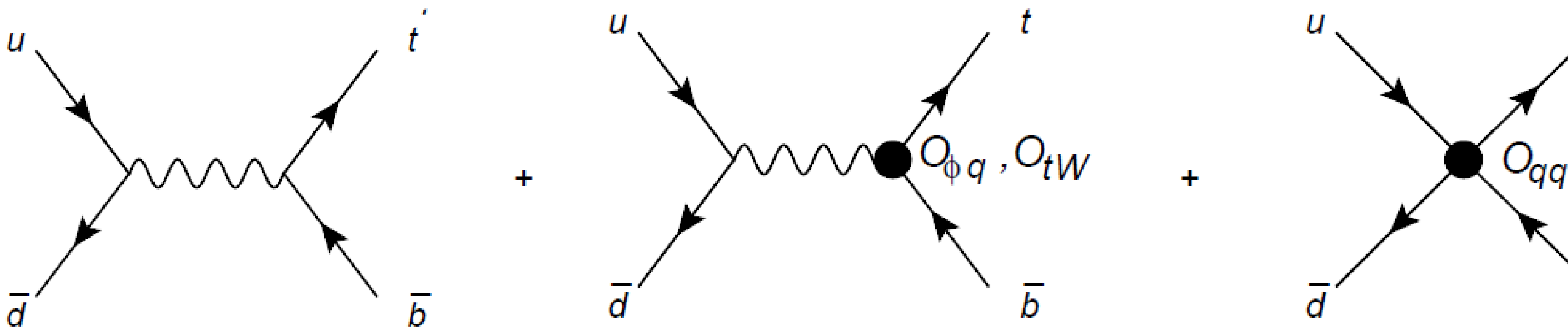

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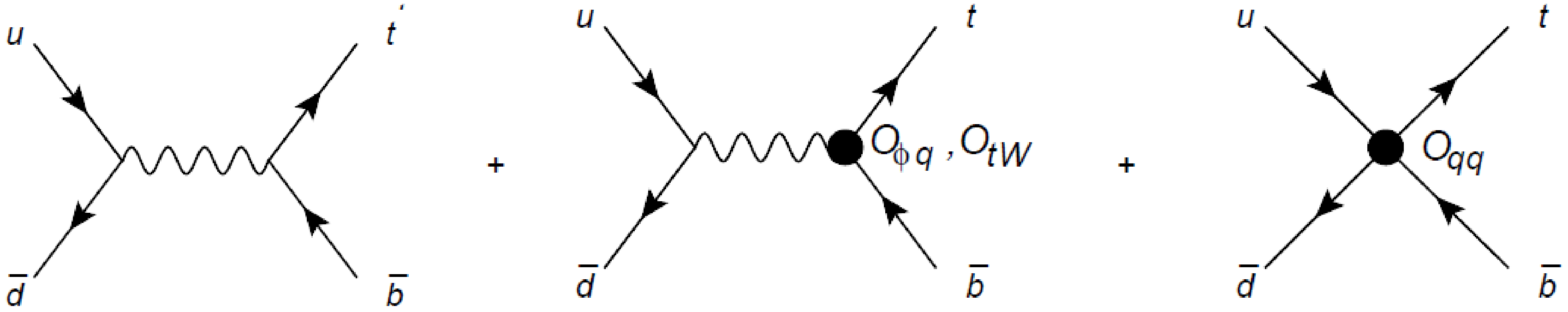

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Strategy:

O_{tW} from t decay

$O_{\phi q}$ O_{qq} from s-, t-channel single top:

Vertex function approach

Kane, Ladinsky, Yuan 1992

Aguilar-Saavedra 2008, 2009

Vertex function approach

Kane, Ladinsky, Yuan 1992

Aguilar-Saavedra 2008, 2009

- **General form of *Wtb* vertex:**

$$\Gamma^{\mu}_{Wtb} = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^{\mu} \left[f_1^L P_L + f_1^R P_R \right] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_{\nu} \left[f_2^L P_L + f_2^R P_R \right] \right\}$$

Vertex function approach

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Form factors: functions of Q^2

Vertex function approach

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Form factors: functions of Q^2

Equivalently:

$$L_{tWb} = \frac{g}{\sqrt{2}} W_{\mu}^{-} \bar{b}^{\circ\ \mu} \left(f_1^L P_L + f_1^R P_R \right) t - \frac{g}{\sqrt{2} M_W} \partial_{\nu} W_{\mu}^{-} \bar{b} \sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R \right) t$$

Vertex function approach

Kane, Ladinsky, Yuan 1992

Aguilar-Saavedra 2008, 2009

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Effective field theory $V_{tb} + C_{\phi q} \frac{v^2}{\Lambda^2}$ $\sqrt{2} C_{tW} \frac{v^2}{\Lambda^2}$

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$$\boxed{\text{Effective field theory approach provides rationale for neglecting some f's, setting others to constants}}$$

Effective field theory

Vertex function approach

- Well motivated and provides guidance
- SU(3)xSU(2)xU(1) gauge invariant
- Includes contact interactions
- Valid for top and bottom off shell
- Can calculate radiative corrections

	Effective field theory	Vertex function approach
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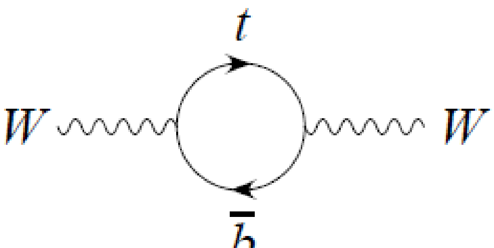
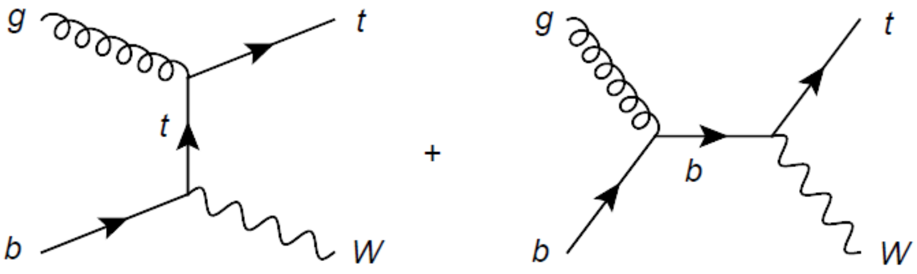


Wt production



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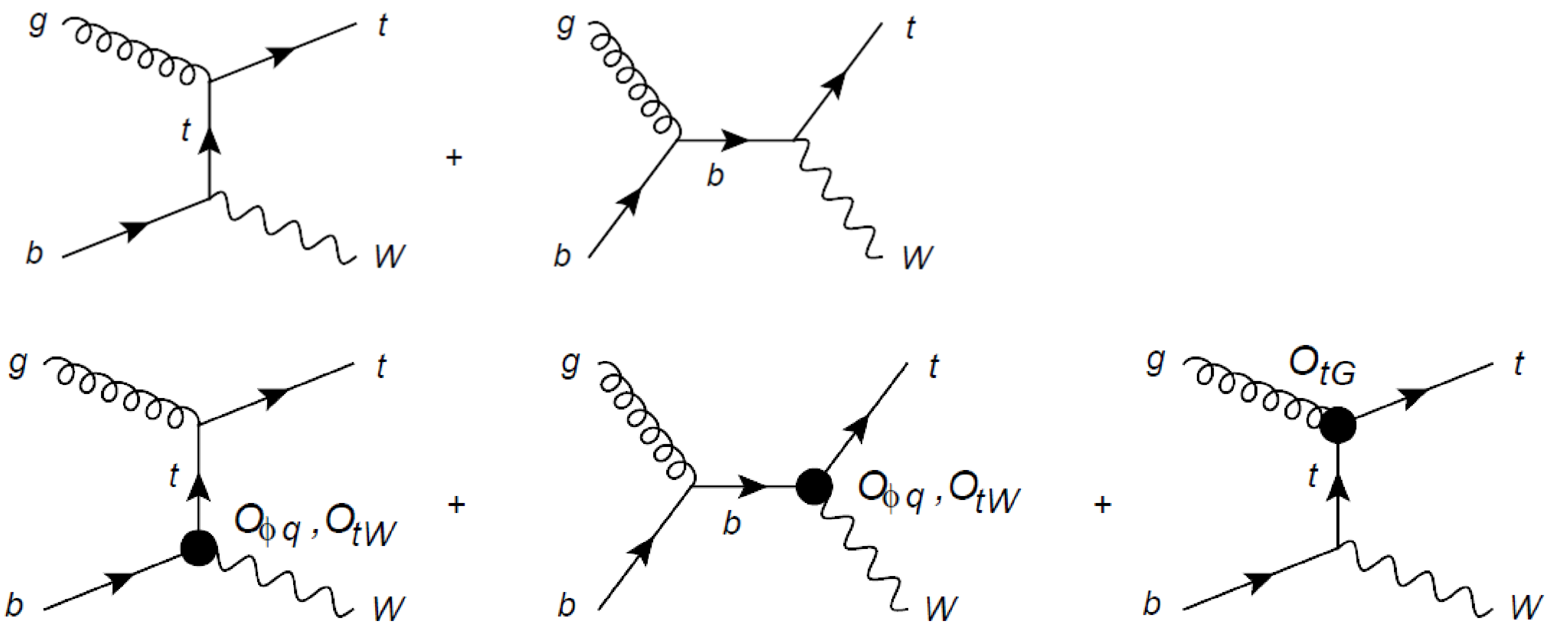

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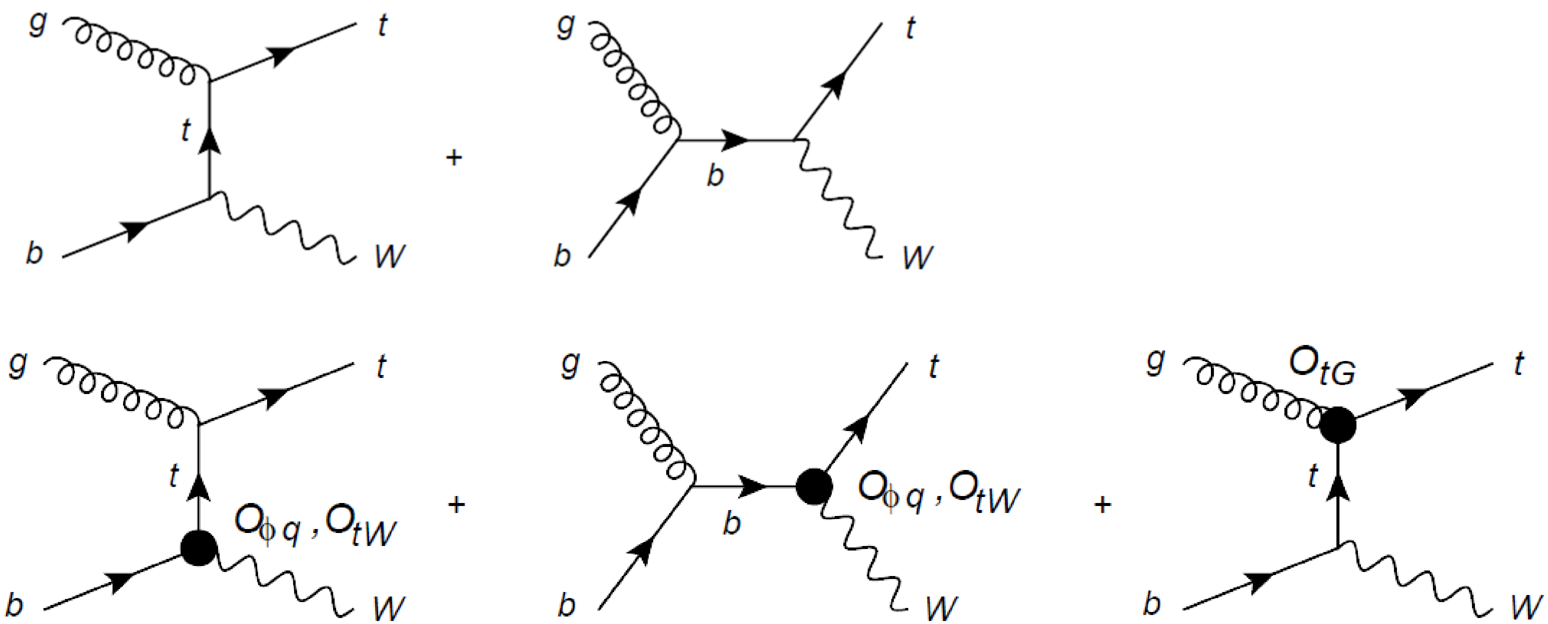


Strategy:

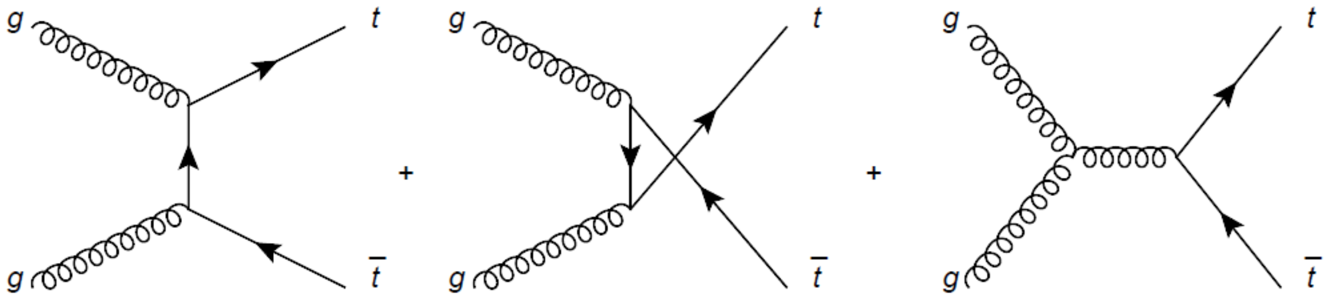
O_{tW} from t decay

$O_{\phi q}$ O_{qq} from s-, t-channel single top

O_{tG} from Wt

Cho, Simmons 1995

Top pair production



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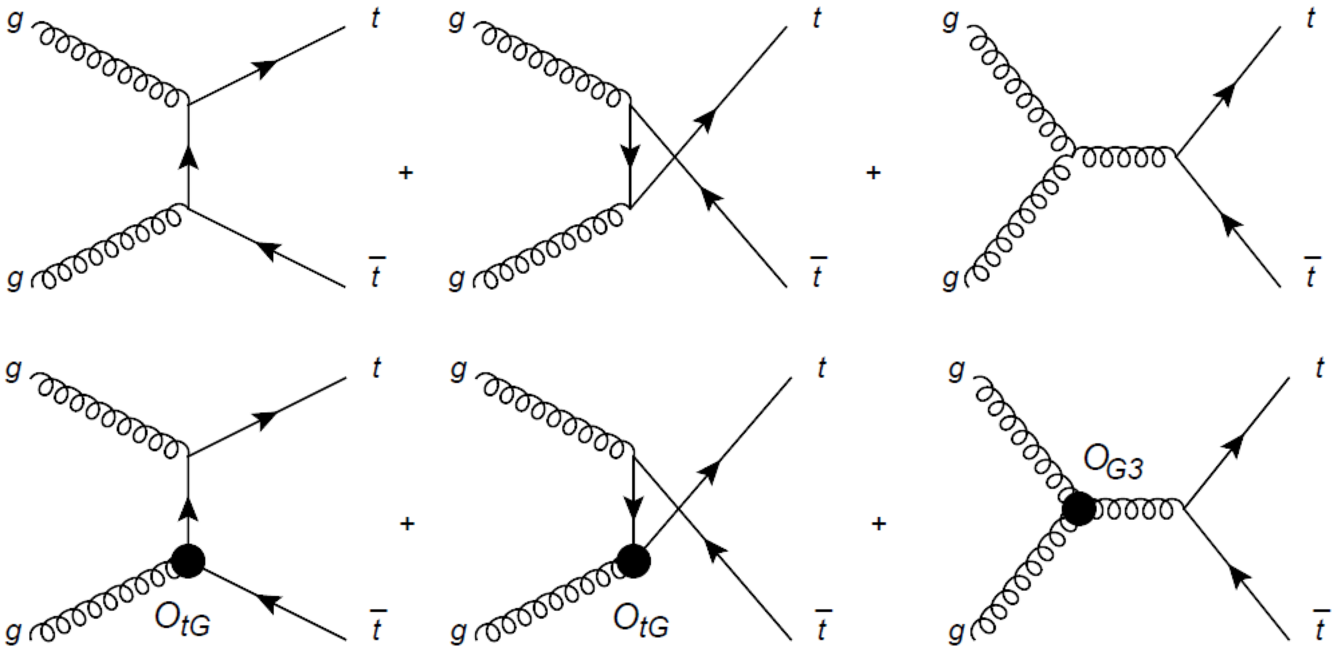
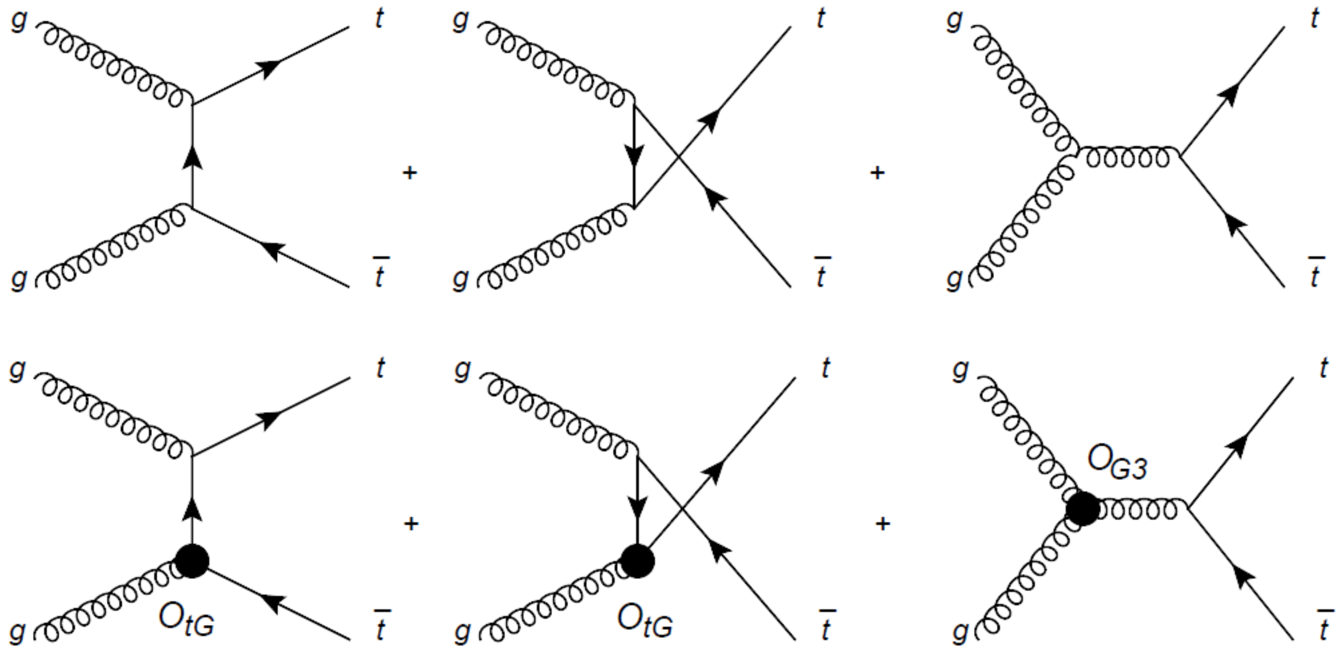


Cho, Simmons 1995

Top pair production



Strategy:

O_{tW}		from t decay
$O_{\phi q}$	O_{qq}	from s-, t-channel single top
O_{tG}		from Wt
O_{G3}		from tt

Conclusion

$$L_{eff}$$

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$$L_{eff}$$