Precision determination of the Wtb coupling in single top production

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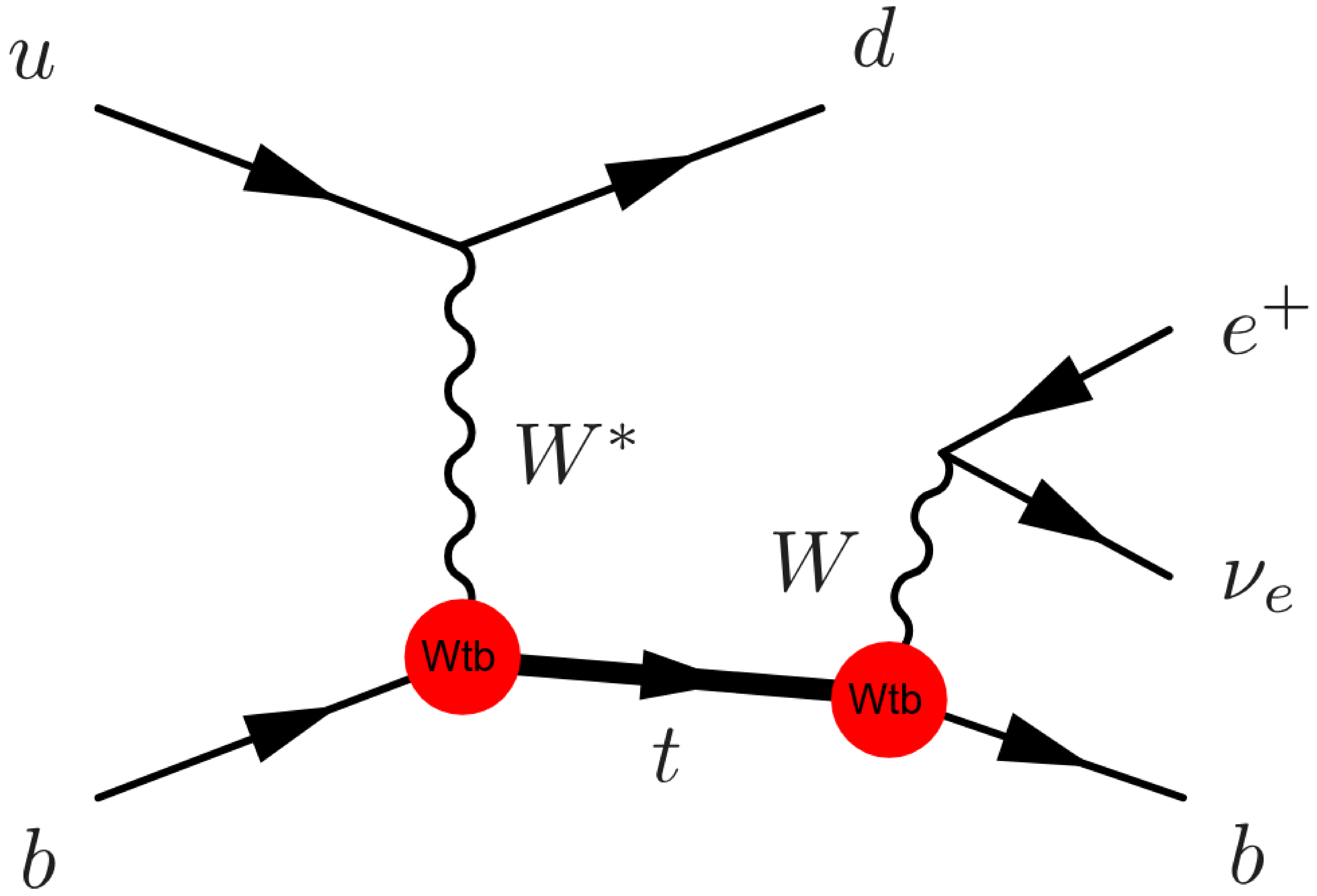
Wtb coupling in single top: the t-channel



What constitutes a theoretical precision determination?

Standard model precision calculations!

- fixed order (NLO, NNLO), resummation and parton shower
- Yes.. even at NLO it is not trivial..
  ... 4-flavor scheme, 5-flavor scheme, on-shell top, stable top, off-shell top, non-resonant contributions ...

A tiny and incomplete list of some recent results:

(partial) NNLO: Brucherseifer, Caola, Melnikov '14 (stable top); Berger, Gao, Yuan, Zhu '16 '17 (on-shell but with decay), IBP reduction for full result: Assadolimani, Kant, Tausk, Uwer '14; NNLL threshold resummation: Kidonakis '12

NLO 4/5-flavor, on-shell (in MCFM): Campbell, Ellis, Tramontano '04; Campbell, Frederix, Frixione, Maltoni, Tramontano '09; Campbell, Ellis '12; (in POWHEG and aMC@NLO): Frederix, Re, Torrielli '12; NLO off-shell + non-resonant + parton shower: Prestel, Torrielli, Papanastasiou, Frederix, Frixione, Hirschi, Maltoni '13 '16; NLO with analytic transverse momentum dependent resummation: Cao, Sun, Bin Yan, C.P. Yuan, F. Yuan '18

What else do we need?

Standard model Effective Field Theory (SMEFT) precision calculations!

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_k \sum_i \frac{C_{i,k}}{\Lambda^k} \mathcal{O}_{i,k}$$

- Using the effective field theory framework allows us to better quantify deviations and constrain concrete models like SUSY.

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar l_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar l_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar l_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar e_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde\varphi\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar q_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar q_p\sigma^{\mu\nu}u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar q_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar q_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar u_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar d_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar q_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p\gamma^\mu d_r)$

Buchmueller, Wyler '86; Gradkowski, Iskrzynski, Misiak, Rosiek '10

Single top in the Standard Model EFT

Equally lots of work, beginning with anomalous couplings..

$$\mathcal{L}_{tbW} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\big(V_L P_L + V_R P_R\big)\,t\,W_{\mu}^{-} + \text{h.c.}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\big(g_L P_L + g_R P_R\big)\,t\,W_{\mu}^{-} + \text{h.c.}$$

EFT correspondence:

$$\delta V_L = \left(C_{\phi q}^{(3)*} + \frac{g}{2}\text{Re}\,C_{qW}\right)\frac{v^2}{\Lambda^2}\,, \quad \delta g_L = \sqrt{2}C_{dW}^{*}\frac{v^2}{\Lambda^2}\,,$$
$$\delta V_R = \frac{1}{2}C_{\phi\phi}^{*}\frac{v^2}{\Lambda^2}\,, \quad \delta g_R = \sqrt{2}C_{uW}\frac{v^2}{\Lambda^2}$$

- *LO EFT, anomalous couplings: Aguilar-Saavedra '08 '09; Bach, Ohl '12*
- *Analysis and fit to observables, specific model interpretation: Cao, Bin Yan, Yu, Zhang '15*
- *further work, up to including NLO EFT: Zhang, Willenbrock '11; Franzosi, Zhang '15; Zhang '14 '16*
- *connection to flavor physics and low energy precision measurements: Alioli, Cirigliano, Dekens, Vries, Mereghetti '17*

tl;dr: SMEFT has also reached the level of NLO! (very necessary!)

Is there anything left to do?

Yes.

- Inclusive NNLO to NLO corrections are about 1-2%.
  " We found a difference of ~1% on the NNLO cross sections"
  Berger, Gao, Yuan, Zhu '16
- NLO SMEFT calculation (Zhang '16) in the framework MadGraph5_aMC@NLO using the on-shell approximation. This means $\mathcal{O}(\Gamma_T/m_t)$ effects are neglected. Also top decay spin correlations only approximately included. But has PS!

What am I working on?

- **Analytical** calculation of **off-shell** single top production with **full decay** (and full spin correlations) of top and W
- Inclusion of all relevant EFT operators at NLO
- Implementation in MCFM: introduce b-jet tagging, complex mass scheme

How far am I? Spent two/three months on the setup and simplifications (millions of terms with an off-shell top!). Results are meanwhile compact.
Last steps: "understand" renormalization, implement b-jet tagging in MCFM.

Last slide.

- Single top **incredibly** active field. **The** process to study the Wtb coupling.
- Lots of room for precision improvements:
  - full NNLO calculation and check of currently disagreeing results
  - NLO SMEFT: off-shell, full decay spin correlations, analytic computation in MCFM
- Establish contact with experimentalists so NLO EFT improvements get actually used!