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.

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Buchmueller, Wyler '86; Gradkowski, Iskrzynski, Misiak, Rosiek '10
Single top in the Standard Model EFT

Equally lots of work, beginning with anomalous couplings..

\[ \mathcal{L}_{\text{ew}} = - \frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W^- \mu + \text{h.c.} \]

\[ - \frac{g}{\sqrt{2}}  \frac{i \sigma^\mu \nu}{m_W} (g_L P_L + g_R P_R) t W^- \mu + \text{h.c.} \]

EFT correspondence:

\[ \delta V_L = \left( C_{\phi q}^{(3)} + \frac{g}{2} \text{Re} C_{\phi W} \right) \frac{v^2}{\Lambda^2}, \quad \delta q_L = \sqrt{2} C_{\phi W} \frac{v^2}{\Lambda^2}, \]

\[ \delta V_R = \frac{1}{2} C_{\phi q}^{(3)} \frac{v^2}{\Lambda^2}, \quad \delta g_R = \sqrt{2} C_{\phi W} \frac{v^2}{\Lambda^2} \]

- **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!