Single-differential top quark pair production cross sections with running mass schemes at NLO

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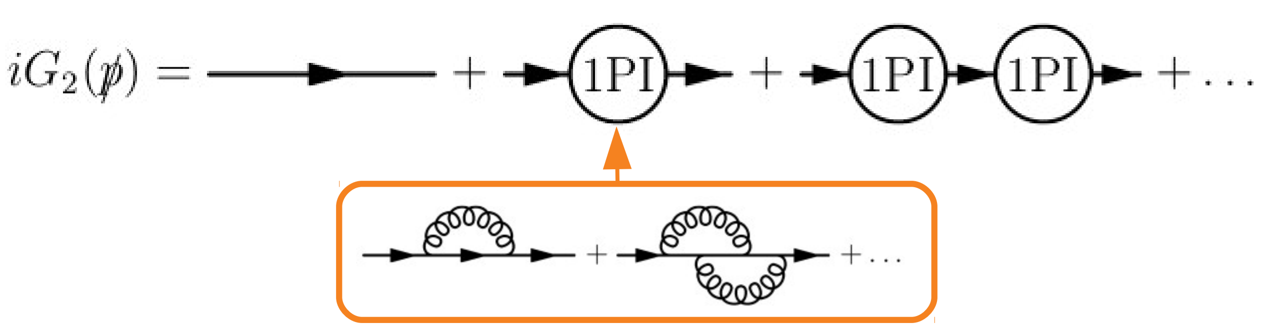
Renormalization of quark masses



- Understanding quark masses is important for precision SM studies → *renormalization scheme and -scale dependent quantities*
- Theoretically well-defined masses extracted from cross sections → *proper scale setting mandatory*
- Interpretation of MC top mass m_t^{MC} includes additional uncertainty $\mathcal{O}(0.5\ \text{GeV})$ in QCD
- Suitable *short-distance masses*: $\overline{m}_t(\mu_m)$ ($\overline{\text{MS}}$) or $m_t^{MSR}(R)$ (MSR)
  - For $\mu_m \gtrsim \overline{m}_t(\overline{m}_t)$; For $R \lesssim \overline{m}_t(\overline{m}_t)$

The running of the top quark mass

- Implementation of running MSR and $\overline{\text{MS}}$ masses into $t\bar{t}$ production cross sections: **HATHOR** (*inclusive, NNLO*) & **MCFM** v6.8 (*single-differential, NLO*)
- The pole and $\overline{\text{MS}}$ masses are related by

$$m_t^{pole} = \overline{m}_t(\mu_m)\left(1 + \sum_{n=1} \frac{\alpha_S(\mu_m)^n}{\pi^n} d_n(\mu_m)\right)$$

$\mu_m :\neq \mu_r$ in general!

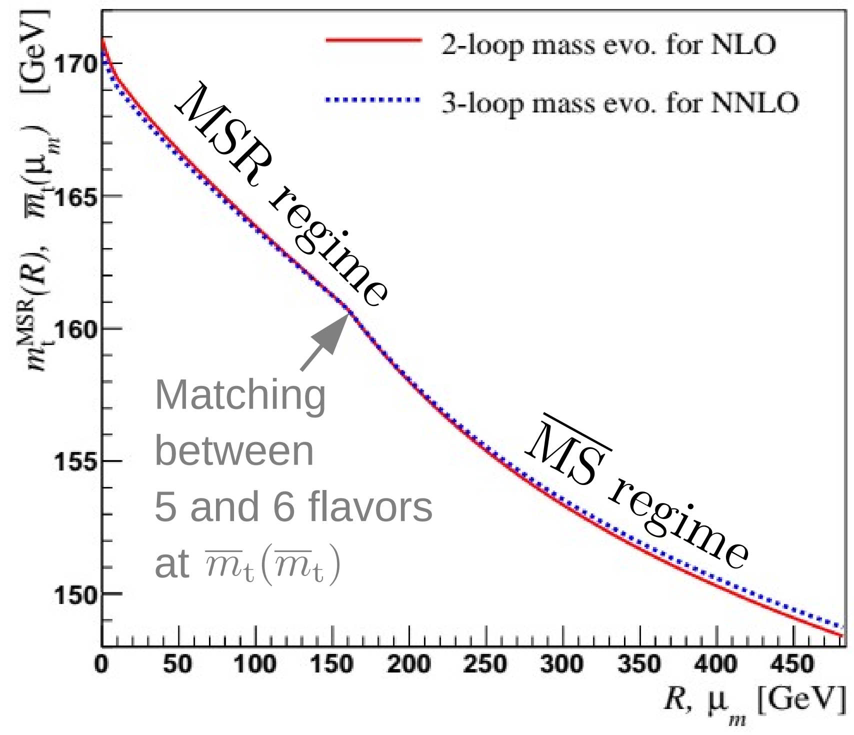
- MSR introduces a mass renormalization scale R, so that

$$m_t^{MSR}(R) \xrightarrow{R\to 0} m_t^{pole} \quad \text{and}$$

$$m_t^{MSR}(R) \xrightarrow{R\to \overline{m}_t(\overline{m}_t)} \overline{m}_t(\overline{m}_t):$$

$$m_t^{pole} = m_t^{MSR}(R) + R\sum_{n=1} \frac{\alpha_S(R)^n}{\pi^n} d_n^{MSR}(R)$$

Decoupling coefficients: integrating the top quark out for $R \lesssim \overline{m}_t(\overline{m}_t)$ → *Natural MSR* (**MSRn**) [1]



The single-differential cross section

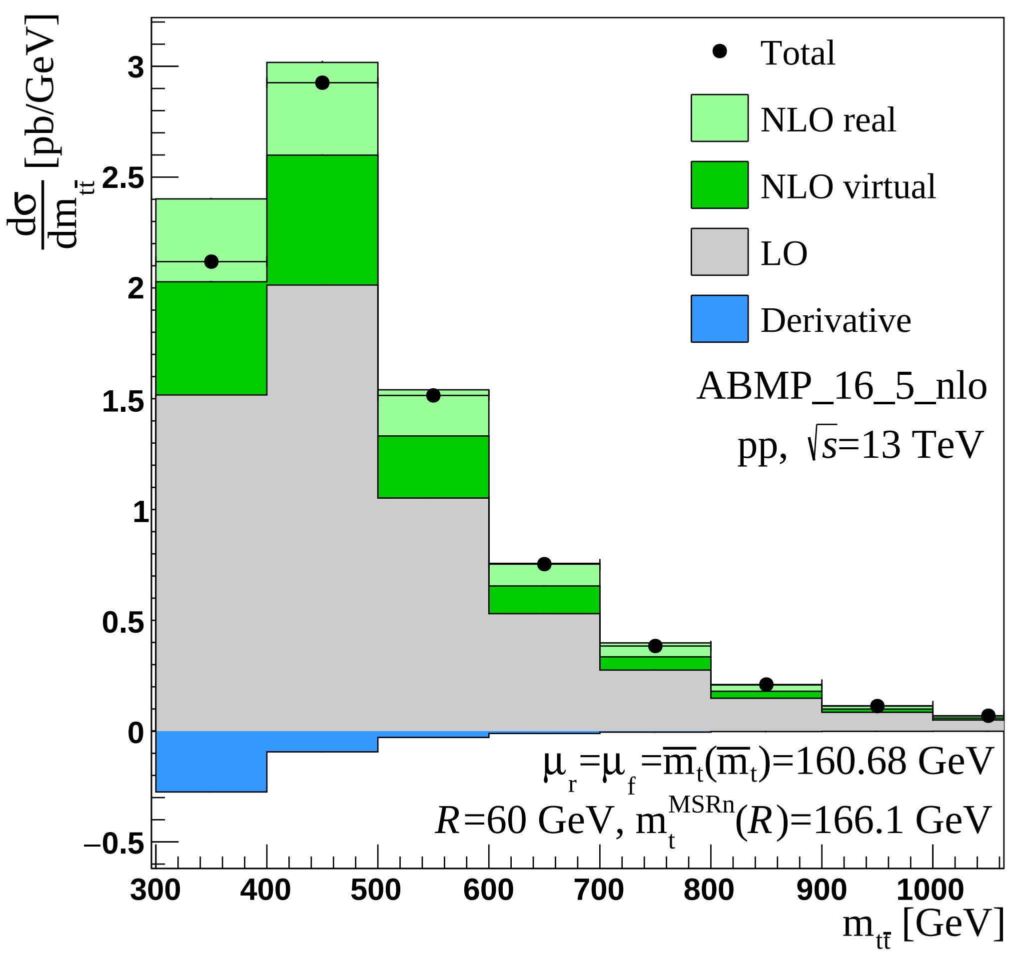
In the MSR regime:

$$\frac{d\sigma}{dm_{t\bar{t}}} = a_S(\mu_r)^2 \frac{d\sigma^{(0)}}{dm_{t\bar{t}}}(m_t^{MSR}(R), \mu_r) + a_S(\mu_r)^3 \frac{d\sigma^{(1)}}{dm_{t\bar{t}}}(m_t^{MSR}(R), \mu_r) + a_S(\mu_r)^3 d_1 R \frac{d}{dm_t}\left(\frac{d\sigma^{(0)}(m_t,\mu_r)}{dm_{t\bar{t}}}\right)\Bigg|_{m_t = m_t^{MSR}(R)}$$

Independent scales
- μ_f: factorization
- μ_r: renormalization
- R, μ_m: mass scales

In the $\overline{\text{MS}}$ regime:

$$\frac{d\sigma}{dm_{t\bar{t}}} = a_S(\mu_r)^2 \frac{d\sigma^{(0)}}{dm_{t\bar{t}}}(\overline{m}_t(\mu_m), \mu_r) + a_S(\mu_r)^3 \frac{d\sigma^{(1)}}{dm_{t\bar{t}}}(\overline{m}_t(\mu_m), \mu_r) + a_S(\mu_r)^3 d_1(\mu_m)\overline{m}_t(\mu_m) \frac{d}{dm_t}\left(\frac{d\sigma^{(0)}(m_t,\mu_r)}{dm_{t\bar{t}}}\right)\Bigg|_{m_t = \overline{m}_t(\mu_m)}$$

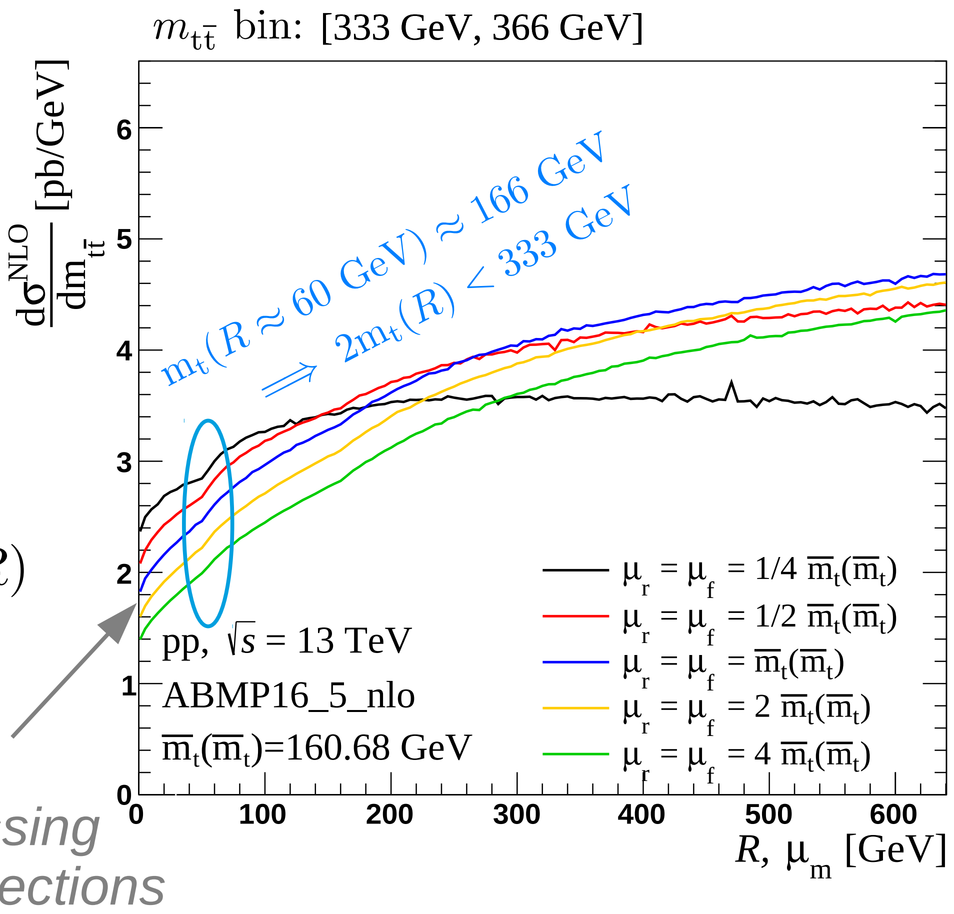


Also $d\sigma/dp_T(\bar{t})$ and $d\sigma/dy(\bar{t})$ available

Investigating independent scale behavior

- Studying $d\sigma/dm_{t\bar{t}}$ as a function of R, μ_m in small $m_{t\bar{t}}$ bins and varying μ_r, μ_f permits novel investigations of dynamical scale dependency
- Low μ_r, μ_f lead to quick stabilization of NLO predictions near distribution peak
- Recommend scales $R \sim 60 - 100$ GeV for extracting $m_t^{MSR}(R)$ e.g. $R = 80$ GeV $\approx \overline{m}_t(\overline{m}_t)/2$

Low-R region subject to missing Coulomb corrections



Extraction of the top quark MSR mass from CMS data at 13 TeV

- $m_t^{MSR}(R)$ extracted from the data of [2] at $R = 80$ GeV, evolved to reference values at $R \in \{1, 2\}$ GeV and $\overline{m}_t(\overline{m}_t)$ [1]
- Fit- and (μ_r, μ_f) uncertainties correspond to $R = 80$ GeV
- R-uncertainty from difference in evolved values when starting R varied ± 20 GeV
- Lowest $m_{t\bar{t}}$ bin has highest mass sensitivity, but requires understanding of threshold effects (Coulomb + soft) for future precision studies
- At $\mu_r = \mu_f = \mu \equiv \overline{m}_t^{MSR}(80)$, agreement with CMS $\overline{\text{MS}}$ [2] and ATLAS MSR [3]
- Stability investigations confirmed by setting μ_r, μ_f to $\mu/2$ near threshold

Scales (μ_r, μ_f) in bins (1,2,3,4) extracted from [2]	$m_t^{MSR}(80)$ [GeV]	$m_t^{MSR}(1)$ [GeV]	$m_t^{MSR}(2)$ [GeV]	$\overline{m}_t(\overline{m}_t)$ [GeV]	Fit [GeV]	(μ_r, μ_f) [GeV]	(R) [GeV]
(μ, μ, μ, μ)	167.7	173.2	173.0	163.3	$^{+0.6}_{-0.6}$	$^{+0.4}_{-0.6}$	$^{+0.4}_{-0.5}$
$(-, \mu, \mu, \mu)$	165.0	170.5	170.3	160.7	$^{+2.1}_{-2.1}$	$^{+6.7}_{-9.8}$	$^{+0.5}_{-0.5}$
$(\frac{\mu}{2}, \mu, \mu, \mu)$	169.3	174.8	174.6	164.8	$^{+0.5}_{-0.5}$	$^{+0.2}_{-0.4}$	$^{+0.2}_{-0.3}$

Dynamical scales decrease uncertainty

[1] A. Hoang *et al.*, doi:10.1007/JHEP04(2018)003
[2] CMS Collaboration, doi:10.1016/j.physletb.2020.135263
[3] ATLAS Collaboration, ATL-PHYS-PUB-2021-034

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