# Cross Sections for ttH production with the Top Quark MS Mass

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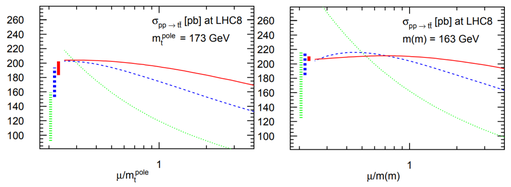
## Motivation

- **Pole Mass**
  - Used in state-of-the-art simulations
  - Quarks as asymptotic states
  - Intrinsic uncertainty of the order of $\Lambda_{\text{QCD}}$
- **$\overline{\text{MS}}$ Mass**
  - Energy dependence of mass ($m_q(\mu_R)$)
  - **Improved convergence** and **smaller scale dependences** compared to pole mass shown for $t\bar{t}$ production

$$\frac{i}{p - m_0 - \delta m}$$




[Dowling, Moch, Eur.Phys.J.C 74 (2014)]

**Goals:** Improvement of scale uncertainties, study of systematic effects

## Calculation of the Cross Section

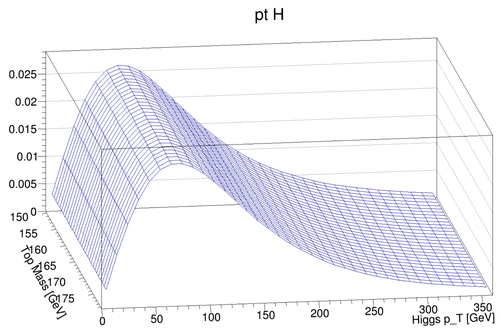
Using the relationship

$$m_t^{\text{pole}} = m(\mu_R)\left(1 + \frac{\alpha_s}{\pi} d_1 + \ldots\right)$$

$\sigma\left(m_t^{\text{pole}}\right)$ is used to calculate $\sigma\left(m\left(\mu_R\right)\right)$

$$\frac{d\sigma\left(m\left(\mu_R\right)\right)}{dX} = \left(\frac{\alpha_s}{\pi}\right)^2 \frac{d\sigma^{(0)}\left(m\left(\mu_R\right)\right)}{dX} + \left(\frac{\alpha_s}{\pi}\right)^3 \left\{ \frac{d\sigma^{(1)}\left(m\left(\mu_R\right)\right)}{dX} + d_1 m\left(\mu_R\right) \frac{d}{dm_t} \left( \frac{d\sigma^{(0)}\left(m_t\right)}{dX} \right)\Big|_{m_t = m(\mu_R)} \right\} + O\left(\alpha_s^2\right) \quad (1)$$

- Mass derivative is estimated **numerically**
  - **Advantage**: Independent of the physics process
  - **Disadvantage**: Computationally demanding
- 2D differential cross-sections
- Derivative approximated with simulations of $\Delta m_t = 0.5$ GeV
- **Renormalization Scale Uncertainty**: Variation $\mu_R = \{\frac{1}{2}, 2\}$

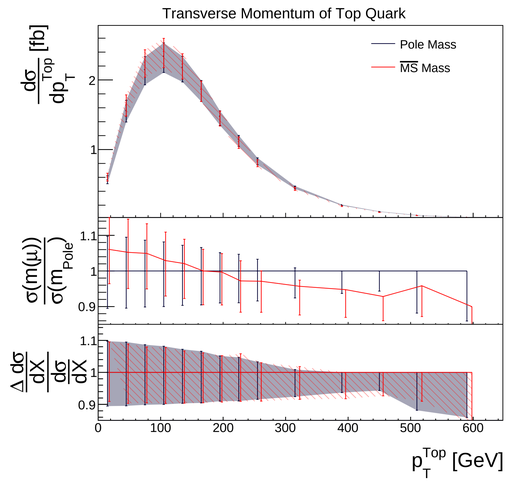


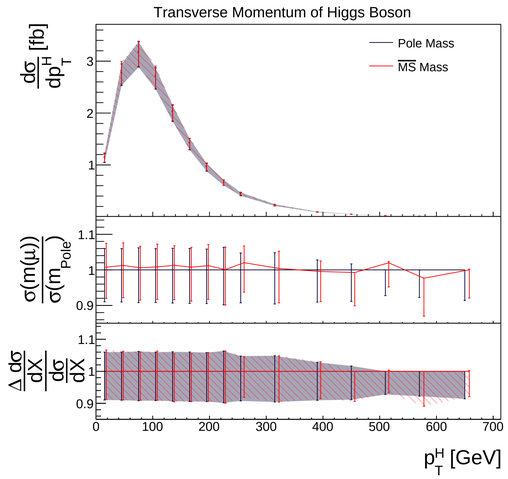

## References

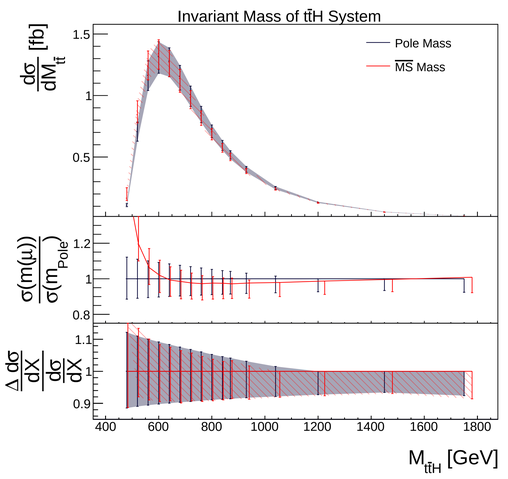
[1] Matthew Dowling and Sven-Olaf Moch. Differential distributions for top-quark hadro-production with a running mass. *Eur. Phys. J.*, C74(11):3167, 2014.

## Differential ttH Cross Sections

- Comparisons: pole mass and $\overline{\text{MS}}$ mass schemes
- **Distributions studied**:
  - $p_T$, $y$ of top quarks and Higgs boson
  - Invariant masses: $M_{t\bar{t}}$, $M_{t\bar{t}H}$
- **Transverse momentum ($p_T$) of the top quarks**
  - Shape difference (slope) covered by scale uncertainties
  - Negligible uncertainty reduction in low $p_T$ bins
- **Transverse momentum ($p_T$) of the Higgs boson**
  - Similar shape across wide range of $p_T$
  - Similar scale uncertainties
- **Invariant Mass of $t\bar{t}H$ System**
  - Significant shape differences in low $M_{t\bar{t}H}$ region
  - Uncertainty reduction in $600\text{ GeV} < M_{t\bar{t}H} < 1200\text{ GeV}$
  - **Near threshold: Uncertainty in $\overline{\text{MS}}$ scheme increased!**
- $\overline{\text{MS}}$ mass defined in perturbative theory
  ⇒ **known disadvantages close to the threshold!**




## Conclusion and Outlook

- First study of $t\bar{t}H$ production with top quark running mass!
- Impact on reduction of scale uncertainties small
  - Largest impact on $M_{t\bar{t}H}$
- Behavior of the Higgs boson barely influenced by the QCD running of the top quark
- Publication in preparation for submission to journal!
- **Outlook**: QCD+EWK running, MSR mass