Top Quark Running Mass in $t\bar{t}H$ production

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DESY

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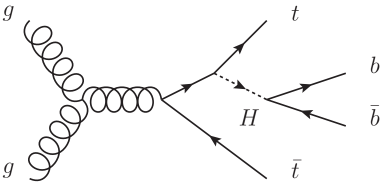
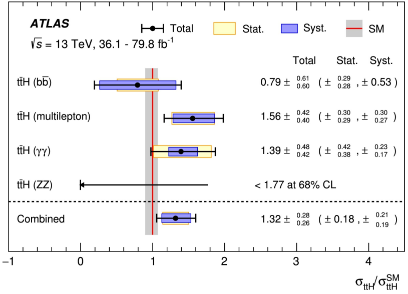
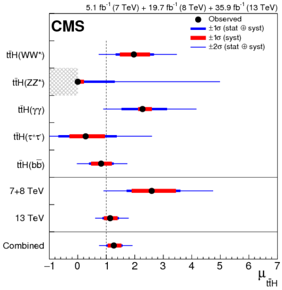
- In SM : one Higgs field giving mass to W,Z, and coupling to fermions
- Coupling is $\propto \frac{m_t}{v}$
- Direct measurement of top-Higgs Yukawa coupling with $t\bar{t}H$



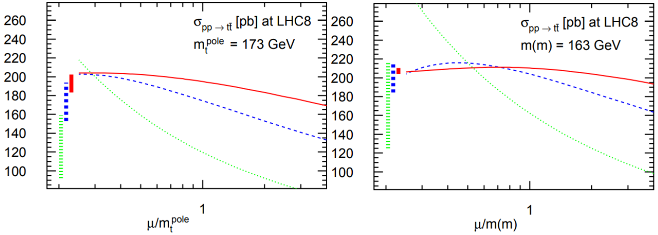
Discovery $t\bar{t}H$

- Summer 2018: Observation of $t\bar{t}H$ in combination of decay channels
- First observation of Higgs coupling to fermion
- ATLAS 6.3 (5.1) σ, CMS CMS 5.2 (4.2) σ
- Some analyses are already systematically limited





- **Pole mass**:
  - Quarks as asymptotic states
  - Intrinsic uncertainty of the order of Λ_{QCD}
- **Running Mass** ($\overline{\mathrm{MS}}$):
  - Improved convergence and smaller scale dependences of XS for $t\bar{t}$
  - Shown for $t\bar{t}$ production in [arXiv:1001.3987], [arXiv:1305.6422]



Calculation of differential XS with Top Quark Running Mass

- Starting from pole mass (on-shell) description:

$$\frac{d\sigma\left(m_t^{\text{pole}}\right)}{dX} = \left(\frac{\alpha_s}{\pi}\right)^2 \frac{d\sigma^{(0)}\left(m_t^{pole}\right)}{dX} + \left(\frac{\alpha_s}{\pi}\right)^3 \frac{d\sigma^{(1)}\left(m_t^{\text{pole}}\right)}{dX} + O\left(\alpha_s^2\right)$$

- Using the relation between pole mass and running mass:

$$m_t^{\text{pole}} = m(\mu_r)\left(1 + \frac{\alpha_s}{\pi} d_1 + \left(\frac{\alpha_s}{\pi}\right)^2 d_2 + \dots\right)$$

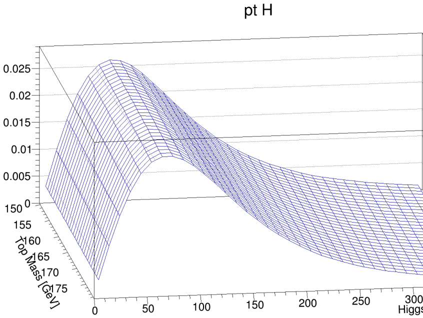
- We derive the expression for differential cross section in $\overline{MS}$ scheme:

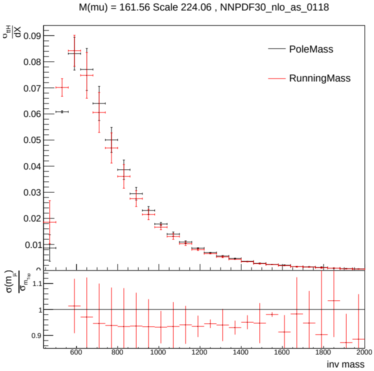
$$\frac{d\sigma\left(m\left(\mu_r\right)\right)}{dX} = \left(\frac{\alpha_s}{\pi}\right)^2 \frac{d\sigma^{(0)}\left(m\left(\mu_r\right)\right)}{dX}$$
$$+ \left(\frac{\alpha_s}{\pi}\right)^3 \left\{ \frac{d\sigma^{(1)}\left(m\left(\mu_r\right)\right)}{dX} + d_1 m\left(\mu_r\right) \frac{d}{dm_t}\left(\frac{d\sigma^{(0)}\left(m_t\right)}{dX}\right)\bigg|_{m_t=m(\m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

  - **Mass derivative of the Born-level cross section required**

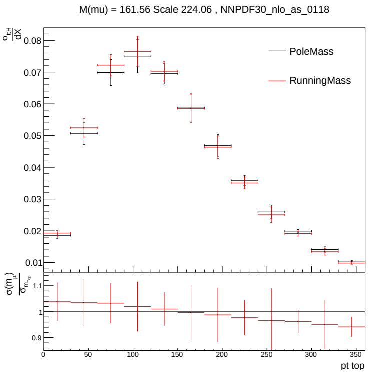
- Mass derivative is estimated numerically
- Born XS calculated with MG5aMC@NLO
- Derivative is approximated with simulations of $\Delta m_t = 0.5\text{GeV}$

$$\frac{d}{dm_t}\left(\frac{d\sigma^{(0)}(m_t)}{dX}\right) \approx \frac{\frac{d\sigma^{(0)}(m_t)}{dX} - \frac{d\sigma^{(0)}(m_t+\Delta m)}{dX}}{\Delta m}$$

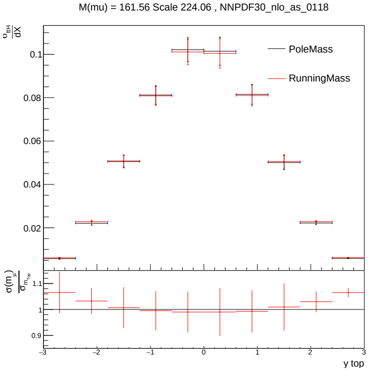



M(mu) = 161.56 Scale 224.06 , NNPDF30_nlo_as_0118
PoleMass
RunningMass
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
1.1
1
0.9
600
800
1000
1200
1400
1600
1800
2000
inv mass

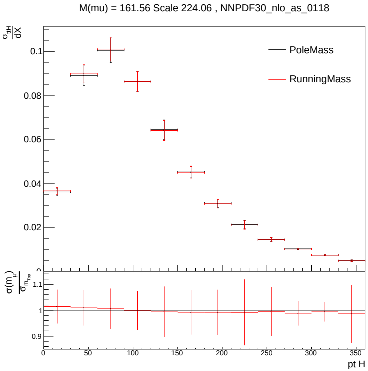
Differential Cross Sections
Top Quark p_T



Rapidity of the Top Quarks



Behavior of the Higgs boson



Summary and Conclusion

- **Summary**:
  - $t\bar{t}H$ is important for probing the Yukawa-coupling
  - Analyses systematically limited in several channels already now
  - Top quark running mass
- **Conclusion**:
  - The running mass has influence on $t\bar{t}H$ production
  - Difference between pole and running mass inside scale uncertainties
  - Top Quark distributions show partially large shape differences
  - Higgs boson distributions invariant

BACKUP