Top-quark Pair Production in a Running Mass Scheme

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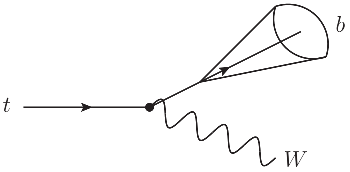
Top-Quark

The top-quark is unique in the sense that it is very massive and short lived.

This short lifetime gives access to properties as if it was a "free" quark.

Its production and decay can be treated perturbatively.



Top Mass

This perturbative property allows for very precise measurements of the mass.

The most recent measurements are

Tevatron:	$m_t = 173.2 \pm 0.87\text{GeV}$	[arXiv:1305.3929]
LHC:	$m_t = 173.3 \pm 1.4\text{GeV}$	[ATLAS-CONF-2012-095]

Direct Measurements

These mass measurements are direct measurements.

A variety of techniques are used:

- Template Method — F. Abe et.*al* [Phys.Rev., D50, 2966]
- Matrix Element Method — V.M. Abazov [Nature, 429, 638]
- Ideograms — V.M. Abazov [Phys.Rev., D75, 092001]

An important question is: Which mass do experiments measure?

Which Mass?

Mass in the Standard Model is a free parameter (not an observable).

In particular, the choice of renormalization scheme can affect the measured mass.

The direct measurements of the top-mass usually assume that it is the pole mass.

Which Mass?

The problem is partially that the pole mass is not a well defined physical quantity for a quark.

In addition, all direct measurements rely on matching with Monte Carlo (MC) simulations.

The extraction of the top-mass then relies on the models used in the MC simulations.

Monte Carlo Mass

It has been argued that what is really measured is a MC mass.

$$m_{pole} = m_{MC} + Q_o[\alpha_S(Q_o)c_1 + ...]$$

A.Hoang [Nucl.Phys.B, 185, 220]

With Q_o arguably $\mathcal{O}(1\text{GeV})$ and $\alpha_S, c_1 \sim \mathcal{O}(1)$ this gives an uncertainty of about 1GeV.

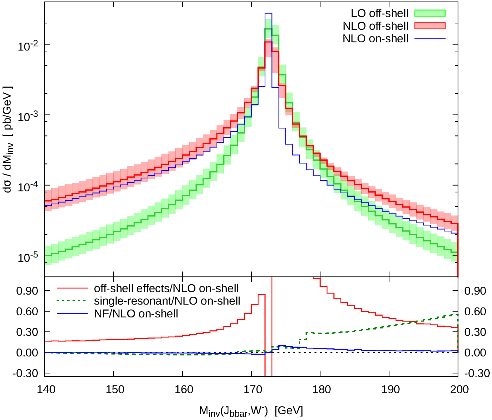
In addition, the pole mass suffers from a renormalon ambiguity which limits the accuracy to

$$\Lambda_{QCD} \sim 200\text{MeV}.$$

I.Bigi, et *al.* [Phys.Rev., D50, 2234]

Finite Width

The top-quark is not a stable particle, which means that finite width effects should be taken into account.



P.Falgari, A.Papanastasiou, A.Signer [arXiv:1303.5299]

Other Observables

A recent paper by CMS uses a description of the endpoints of various kinematic distributions to extract a mass for the top.

$$m_t = 173.9 \pm 0.9(\mathrm{stat.})^{+1.6}_{-2.0}(\mathrm{syst.})\mathrm{GeV}$$ CMS [arXiv:1304.5783].

This method does not depend as strongly on MC matching.

Compare Perturbative Quantities

Recently it was proposed to use the differential distribution

$$\mathcal{R}(m_{pole},\rho) = \frac{1}{\sigma_{t\bar{t}+1jet}}\frac{d\sigma_{t\bar{t}+1jet}}{d\rho}(m_{pole},\rho)$$

with

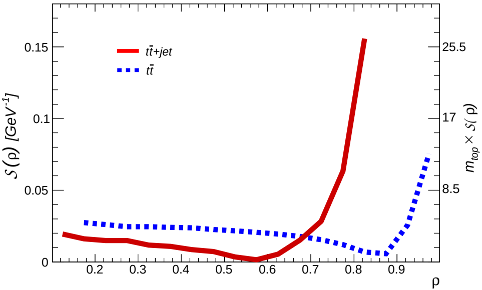
$$\rho = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}}.$$

S. Alioli et *al.* [Eur.Phys.J., C73, 2438]

This benefits from a having a well defined mass.

It was argued that it could be competitive in precision.

Compare Perturbative Quantities



It was found that the sensitivity to the top mass could become quite large.

$$\left|\frac{\Delta\mathcal{R}}{\mathcal{R}}\right| \approx \left(m_{pole} \times S(\rho)\right) \left|\frac{\Delta m_{pole}}{m_{pole}}\right|$$

Compare Perturbative Quantities

Another option is to compare the production cross-section with the predicted quantity from calculations.

This provides a result that is well defined

$$m_{pole} = 173.3 \pm 2.8\text{GeV}$$ Alekhin, Djouadi, Moch [Eur. Phys. J., C73, 2438]

This agrees well with direct measurements but has larger errors.

Choice of Renormalization Scheme

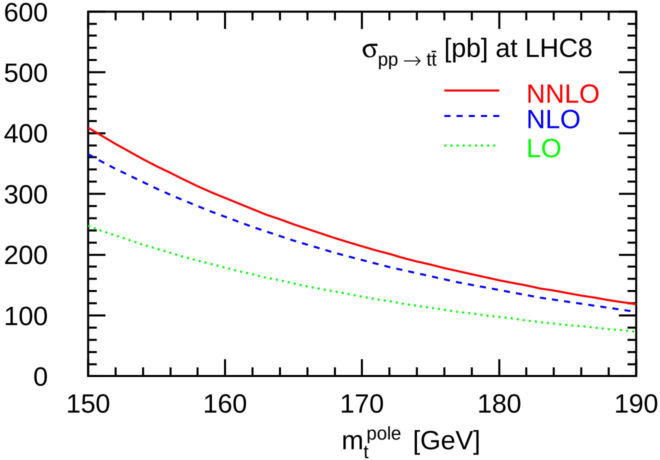
The mass obtained from the cross-section was actually computed in the $\overline{\mathrm{MS}}$ scheme.

Using the perturbative relation between the $\overline{\mathrm{MS}}$ and pole masses, gives the pole mass.

$$m_{pole} = \overline{m}(\overline{m}) \left(1 + \frac{\alpha_s}{\pi} d_1 + \left(\frac{\alpha_s}{\pi}\right)^2 d_2 + \mathcal{O}(\alpha_s^3)\right)$$

Why use the $\overline{\mathrm{MS}}$ scheme?

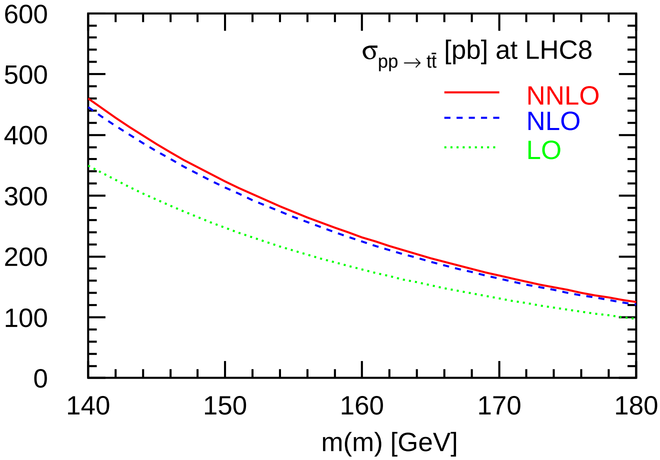
Total Cross-Section



M.D. and S.Moch [arXiv:1305.6422]

The NNLO corrections represent a 12% increase in the cross-section.

Total Cross-Section



M.D. and S.Moch [arXiv:1305.6422]

The NNLO corrections represent a 3% increase in the cross-section.

Differential Cross-Sections

Differential cross-sections are now being measured at the LHC.

CMS [Eur.Phys.J., C73 2339]

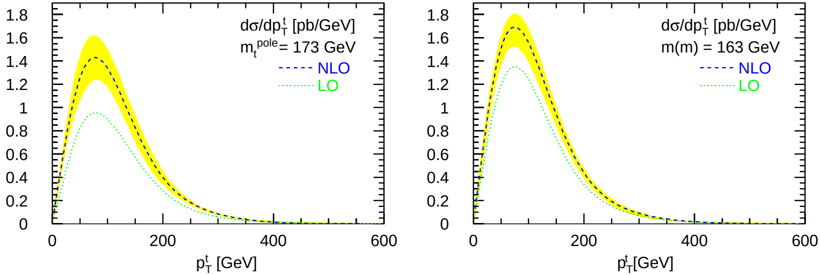
ATLAS [Eur.Phys.J., C73 2261]

The same improvements hold when moving from the pole mass to $\overline{\mathrm{MS}}$ scheme.

We have computed this at NLO using

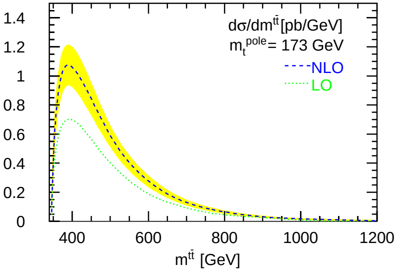
$$\begin{aligned} \frac{d\sigma(m(\mu_r))}{dX} &= \left(\frac{\alpha_s}{\pi}\right)^2 \frac{d\sigma^{(0)}(m(\mu_r))}{dX} + \left(\frac{\alpha_s}{\pi}\right)^3 \left\{ \frac{d\sigma^{(1)}(m(\mu_r))}{dX} \right. \\ & \left. \quad + d_1 m(\mu_r) \frac{d}{dm_t} \left(\frac{d\sigma^{(0)}(m_t)}{dX} \right) \bigg|_{m_t = m(\mu_r)} \right\} \\ & \quad + \mathcal{O}(\alpha_s^4)\,. \end{aligned}$$

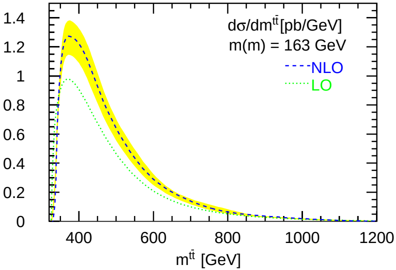
p_t Cross-section



M.D. and S.Moch [arXiv:1305.6422]

$m^{t\bar{t}}$ Cross-section





M.D. and S.Moch [arXiv:1305.6422]

$m^{t\bar{t}}$ Cross-section

Very close to threshold, the differential cross-section diverges.

This is due to the presence of a $\frac{1}{\sqrt{1-4\frac{m_t^2}{(m^{t\bar{t}})^2}}}$ in the derivative term.

This behaviour indicates a breakdown of fixed-order perturbation theory and bound-state effects need to be included.

Summary

The top mass measured by experiments isn't necessarily the pole mass.

Work is being done to understand the difference between the MC mass and pole mass.

Similarly, perturbative observables are being looked at and give an unambiguous mass determination.

Using the $\overline{\mathrm{MS}}$ scheme improves convergence and scale dependence.

Outlook

We are working on integrating this within MCFM so that experiments have access to the distributions.

Higher order corrections and finite width effects need to be included in differential cross-sections.

N.Kidonakis [Phys.Rev., D82, 114030]

V.Ahrens et *al.* [Phys.Lett., B687, 331]

A.Denner et *al.* [JHEP, 1210, 110]

The theoretical uncertainty is not as prevalent at an e^+e^- collider where approximations to the N^{3}LO corrections are known.

M.Beneke et *al.* [Phys.Lett., B668, 143]

A.Hoang [Phys.Rev., D69, 034009]

A.Penin and M.Steinhauser [Phys.Lett., B538, 335]

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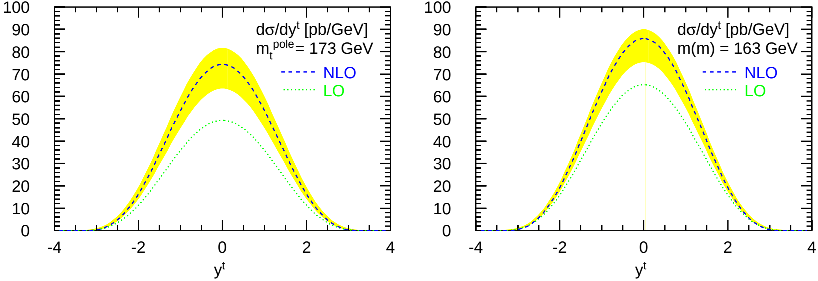

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