Top quark mass measurement near threshold at future CEPC

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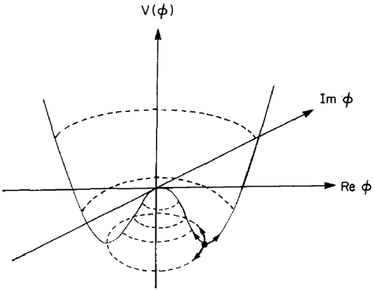
CONTENTS

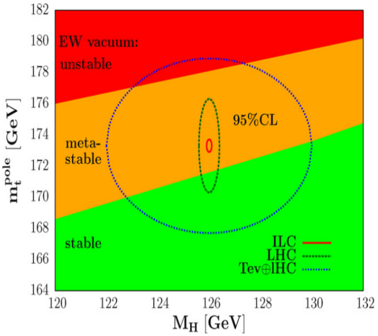
- Why we need precise top mass?
- Experimental measurement methods at $pp(p\bar{p})$ colliders
- $t\bar{t}$ threshold scan at future CEPC
- Conclusion

Why we need precise top mass?

The contour of top mass and Higgs mass.



$$V(r) = -\frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$



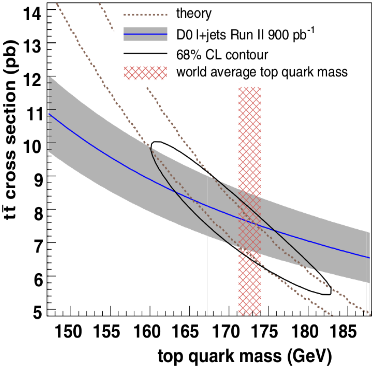
The contour of top mass and Higgs mass.

G. Degrassi et al., JHEP 08, 098 (2012), arXiv:1205.6497.; S. Alekhin, A. Djouadi, and S. Moch, Phys. Lett. B716, 214 (2012).

Experimental measurement methods at $pp(p\bar{p})$ colliders

How to determine the top mass?

- Kinematics reconstruction, lepton+jets, dilepton, full jets, single top etc..
- Comparing σ_{obs} to σ_{th}.



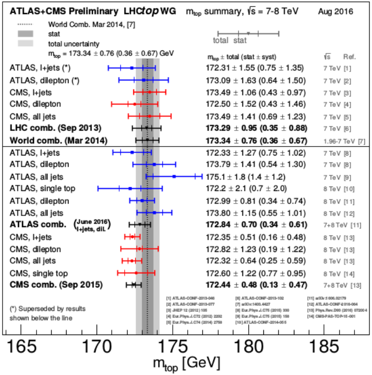
CMS PLB728, 496, (2013); D0 PLB703, 422, (2011);

Experimental measurement methods at $pp(p\bar{p})$ colliders

- Current top mass measurements:
  Monte Carlo mass: Monte Carlo simulation input mass,
  $\Delta m = m_{MC} - m_{pole} \leq 1$ GeV

D0(2016): $172.8^{+3.4}_{-3.2}$ GeV
CMS(2016): $173.8^{+1.7}_{-1.8}$ GeV
ATLAS(2016): 172.84 ± 0.70 GeV
World Average(2014): 173.34 ± 0.76 GeV

Theoretical sources:theoretical uncertainties? does top mass itself exist uncertainties?

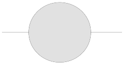


Ulrich Husemann, Progress in Particle and Nuclear Physics 95 (2017) 48-97

Short-distance top mass, potential subtracted(PS) mass

Recall:

The pole mass(long-distance) is defined at the pole of renormalized propagator:



$$= \frac{i}{\not{p} - m_R - \sum_R(\not{p})}$$

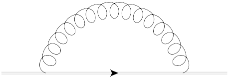
$$\Downarrow$$

$$\not{p}_{pole} = m_R + \sum{}_R(\not{p}_{pole})$$

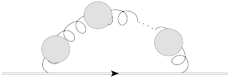
where m_R is the renormalized short-distance mass.

One-loop example:

$$\sum{}_R^{(1)}(m_R) \;=$$



$$+ \ldots +$$



$$+ \ldots$$

$$= m_R \sum_{n=0}^{\infty} c_n \alpha_s^{n+1}(m_R). \quad \mathrm{Resulting:} \quad \delta \mathrm{m_{pole}} \sim \Lambda_{\mathrm{QCD}},$$

what this means?

Short-distance top mass, potential subtracted(PS) mass

- Potential Subtracted(PS) mass:

  Defining $\delta m(\mu_f) = -\frac{1}{2}\delta V(r,\mu_f) = -\frac{1}{2}\int_{|\vec{q}|<\mu_f} \frac{d^3\vec{q}}{(2\pi)^3}\tilde{V}(\vec{q})$

  $\Longrightarrow \quad m_{PS}(\mu_f) = m_{pole} - \delta m(\mu_f),$

$$m_{PS}(\mu_f) = m_R\left(1 + \sum_{n=0}^{\infty} c_n \alpha_s^{n+1}(m_R)\right) - \mu_f \sum_{n=0}^{\infty} c'_n \alpha_s^{n+1}(m_R)$$

  - Conspicuously, the coefficients c_n and c'_n have the same divergent form as $n \to \infty$ and cancel exactly!
  - The remained finite terms are unambiguity!
  - Setting $\mu_f = 0$, $m_{PS} = m_{pole}$!

Short-distance top mass, potential subtracted(PS) mass

Pole mass vs PS mass

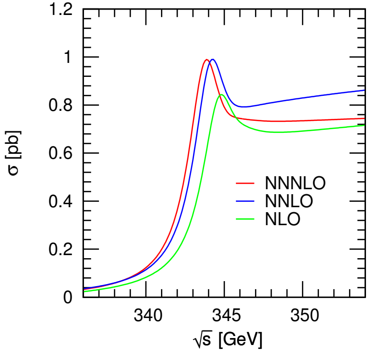


Fig. 1 pole mass → unstable peak location

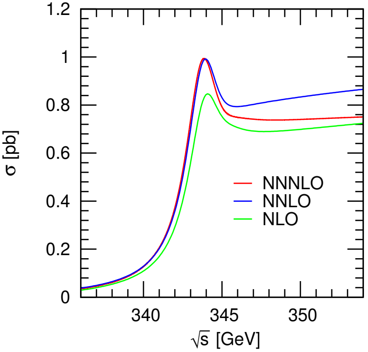


Fig. 2 PS mass → stable peak location

- Observed cross section

$$\sigma^{obs}_{t\bar{t}}(\sqrt{s}) = \int_0^{\infty} d\sqrt{s'}\, G(\sqrt{s'}, \sqrt{s}) \cdot \int_0^1 dx \mathcal{F}(x, s^{'}) \sigma^{th}_{t\bar{t}}(\sqrt{s'}(1-x)),$$

$\mathcal{F}(x, s^{'})$: the initial state radiation(ISR) factor.

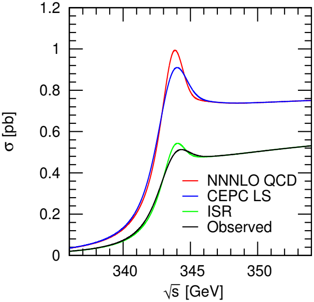
(E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. 41, 466 (1985), [Yad. Fiz.41,733(1985)])

Input mapameters:

$m_{PS}(\mu_f = 20 \text{ GeV}) = 171.5 \text{ GeV},$

α_s=0.1185,

$\Gamma_t = 1.33 \text{ GeV}.$



Various corrected cross sections.
Luminosity spectrum=bremsstrahlung+synchrotron radiation

$t\bar{t}$ threshold scan at CEPC

- χ^2 fitting:

$$\chi^2 = \sum_{i=1}^{n} \frac{[N_i - \mu_i(m_t)]^2}{\mu_i(m_{t0})},$$

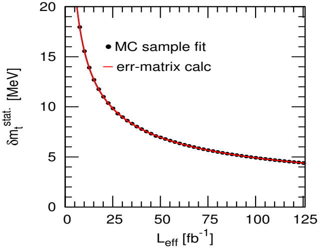
N_i: observed events, obtained by Poisson sampling with expectation $\mu_i(m_{t0})$.

$$\mu_i = [\epsilon_{sig} \cdot Br_{\mathrm{Wb}} \cdot \sigma_{t\bar{t}}^{obs}(\sqrt{s_i}, m_t) + \sigma_{BG}] \cdot \mathscr{L}^i \\ \sim \mathscr{L}_{eff}^i \cdot Br_{\mathrm{Wb}} \cdot \sigma_{t\bar{t}}^{obs}(\sqrt{s_i}, m_t),$$

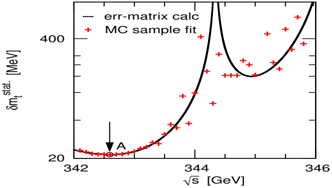
$\mathscr{L}_{eff}^i = \mathscr{L}_i \cdot \epsilon_{sig}$: the effective luminosity for ith energy point,
$Br_{\mathrm{Wb}} = 1$.
σ_{BG}: back grounds from W^+W^-, ZZ, ZH decays, etc.,
$\mid \mathrm{M}_{W,b} - \mathrm{m}_t \mid \leq \triangle \mathrm{M}_t \backsim$ 15 - 35 GeV, suppressed,negligible.

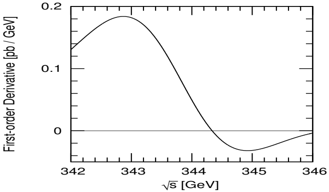
- The statistical uncertainty(Hesse error matrix in MINUIT)
- One energy point, data driven method

$$\delta m_t^{stat.} = \sqrt{\frac{\sigma(\sqrt{s}, m_t)}{\mathscr{L}_{eff}}} \cdot \left[\frac{2d\sigma(\sqrt{s}, m_t)}{d\sqrt{s}}\right]^{-1}.$$



Relationship between the statistical error and luminosity.





Stat. error&first-order derivative

$t\bar{t}$ threshold scan at CEPC

- Top PS mass extraction at CEPC:

$$\delta m_t^{stat.} \simeq 7 \text{ MeV} \quad (\mathscr{L}_{\text{eff}} = 50 \text{ fb}^{-1})$$

$$\delta m_t^{theory} = \delta\sigma(m_t, \sqrt{s}) \cdot [\frac{\partial\sigma(m_t, \sqrt{s})}{\partial m_t}]^{-1} \simeq 26 \text{ MeV}.$$

NNNLO QCD: $\delta\sigma_{obs}^{theory} \sim 3\%$.

Converting into pole mass:

$m_t^{pole} = 173.294 \pm 0.03$(theory+stat.+syst.) $\pm \mathcal{O}(0.2)$ GeV.

colliders	$\delta m_t^{\text{stat.}}$ [MeV]
$\text{CEPC}^{N_p=1}_{\mathscr{L}_{eff}=50fb^{-1}}$	7
$\text{FCC-ee}^{N_p=10}_{\mathscr{L}_{total}=100fb^{-1}}$	15.5
$\text{ILC}^{N_p=10}_{\mathscr{L}_{total}=100fb^{-1}}$	18
$\text{CLIC}^{N_p=10}_{\mathscr{L}_{total}=100fb^{-1}}$	21

A summary of statistical uncertainties for various colliders, N_p refers to the numbers of fit energy points.

Martin Beneke, Phys. Rev. Lett. 115, 192001 (2015)

Conclusion

- PS mass is adopted.
- Experimental scheme at CEPC:
  - Threshold scan
  - One energy point scheme
  - Data driven method
- Top PS mass is extracted within $\mathcal{O}(30)$ MeV at future CEPC, $\mathscr{L}_{eff} = 50\ fb^{-1}$.

Thank You!