Alternative methods for top quark mass measurements at the CMS

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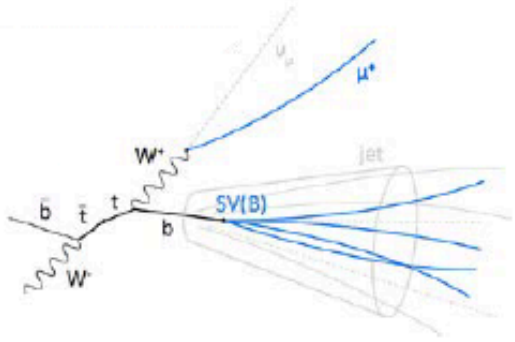
on behalf of the CMS Collaboration

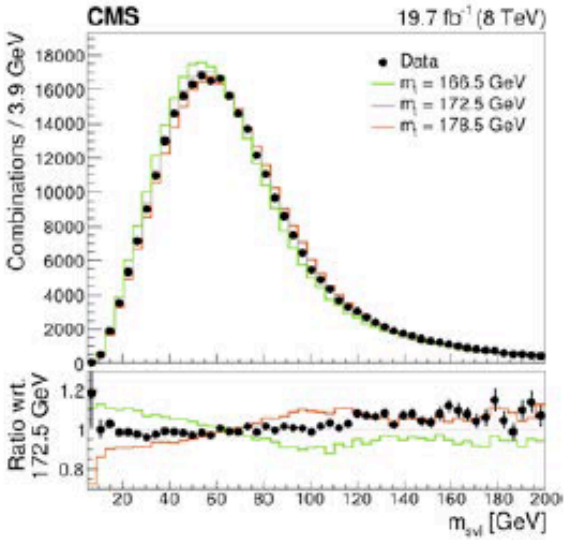
Introduction

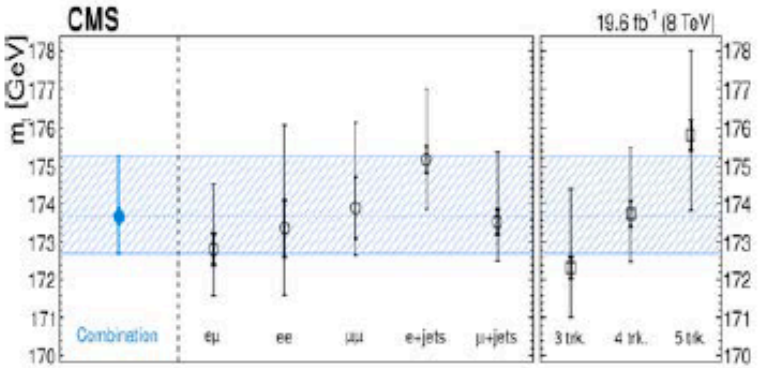
- Top quark mass
  - Fundamental parameter of the Standard Model(SM)
  - Provides strong self-consistency check of the electroweak theory
- m_t = 172.44 ± 0.13(stat) ± 0.47(syst) GeV
  - By the CMS collaboration
  - Using standard full kinematic reconstruction of the $t\bar{t}$ events
  - Reaching a precision of order 0.5 GeV(<0.3%)
- Standard measurement of top quark mass is constrained by
  - Jet energy uncertainties experimentally (~100-150 MeV)
  - Modeling of b-quark hadronization (~350 MeV)
  - Hard scattering process (~100-150 MeV)
  - ► may be complemented by alternative method!

Measurements without jets

- Using Secondary vertices and leptons





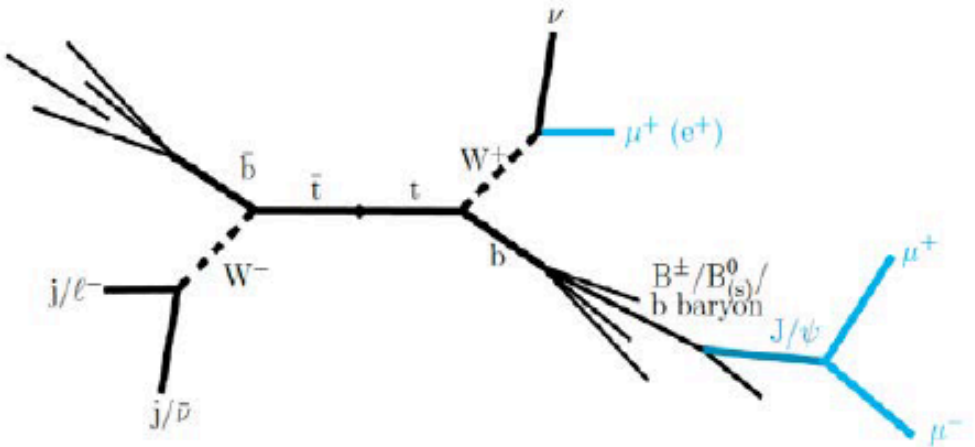


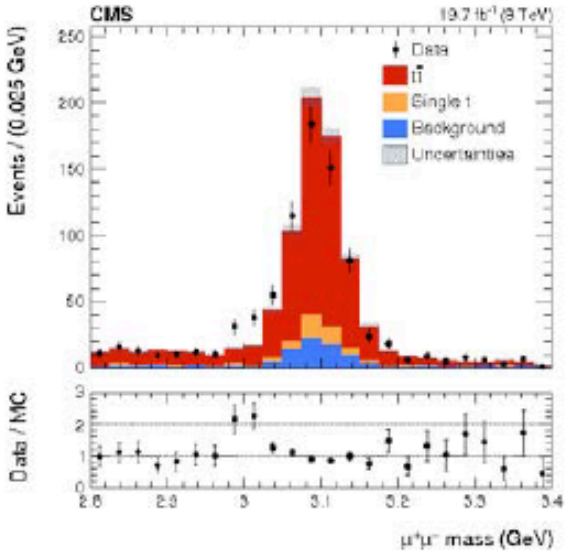
- Reconstruct secondary vertex from b-hadron decay and combine with a lepton from W
- m_{svl} is highly sensitive to m_t
- Higher momentum resolution, smaller corrections compared to jets
- Dominant systematics:
  - b fragmentation modeling ~1 GeV, top quark p_T ~800 MeV
- Fully complementary to standard methods

CMS TOP-12-030
Phys. Rev. D 93 (2016) 092006

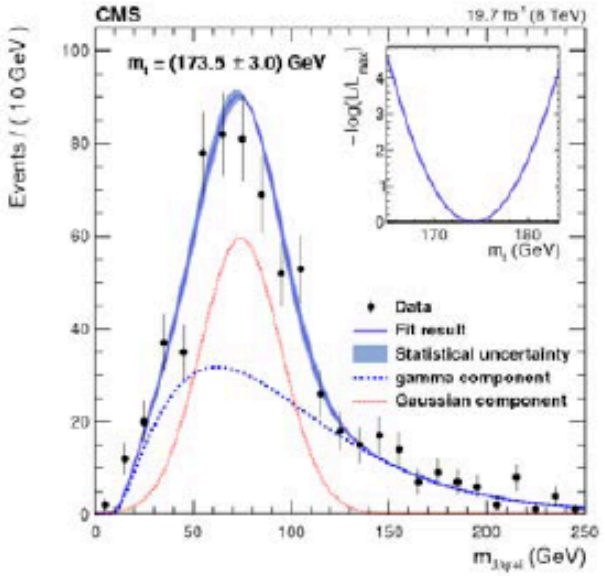
$m_t = 173.68 \pm 0.2(\text{stat}) \, ^{+1.58}_{-0.97}(\text{syst})$ GeV

Using charmed mesons and leptons





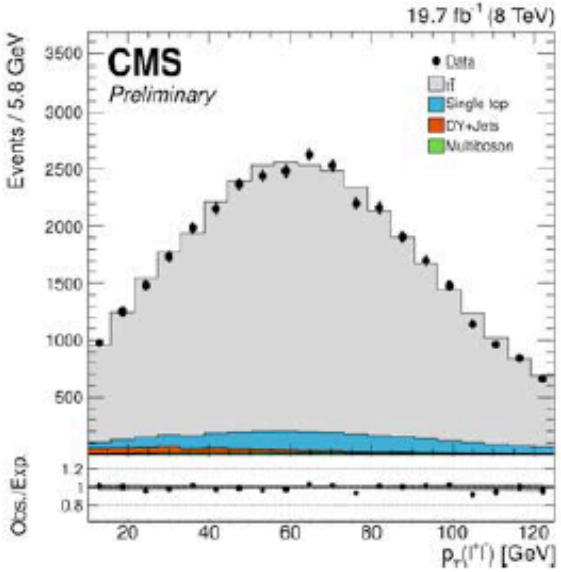
- Lepton + J/ψ invariant mass
- Small branching fractions
  - 666 available events in 8 TeV dataset
  - Statistical uncertainty of 3.0 GeV
  - However < 1 GeV systematic uncertainty
  - b-fragmentation ~0.3 GeV
- Limited by top p_T modeling, QCD scales
- Relevant experimental uncertainties < 100 MeV

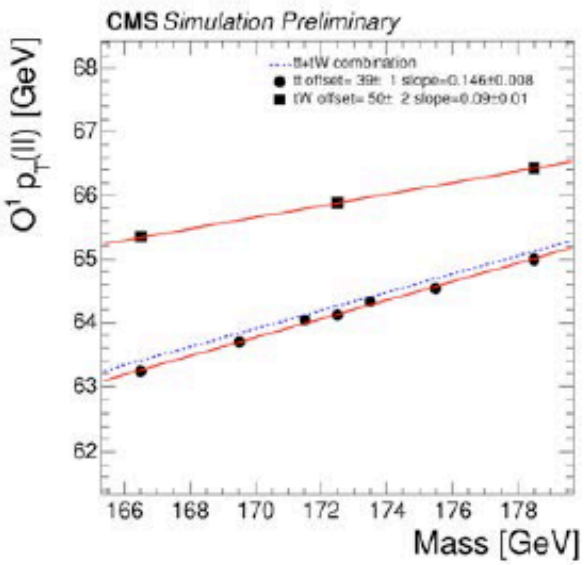


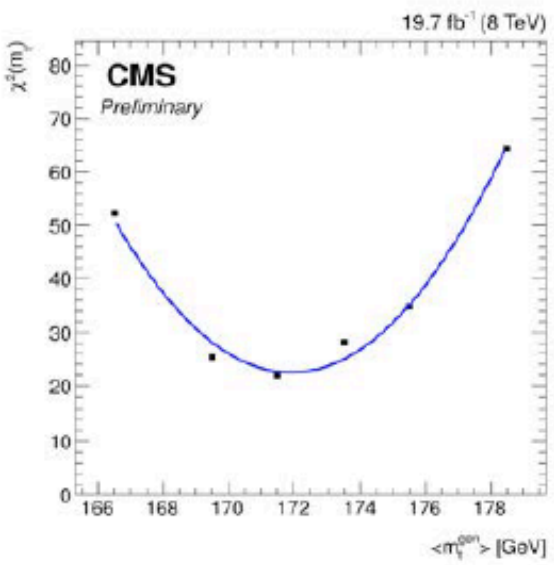
CMS TOP-15-014 arXiv:1608.03560, sub. to JHEP

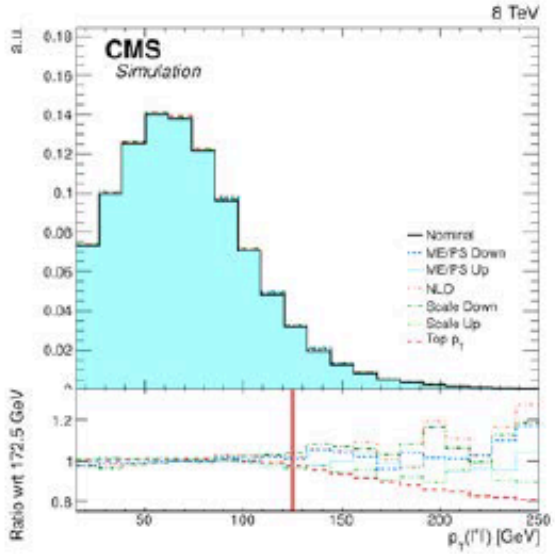
m_t = 173.5 ± 3.0(stat) ± 0.9(syst) GeV

Using lepton kinematics









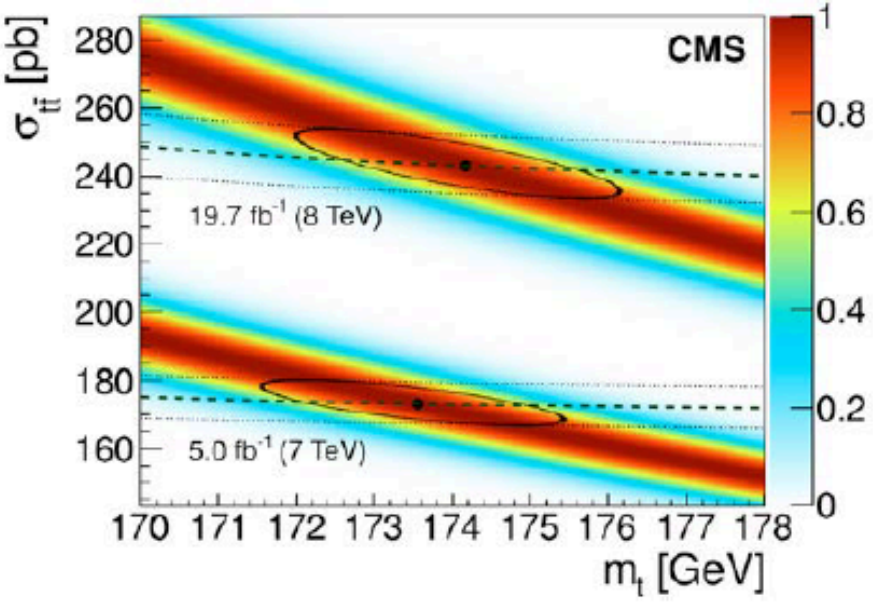
- Dilepton kinematics proposed by Frixione and Mitov (2014)
- $p_T(l^+l^-)$ found to show highest sensitivity to top mass
- Loss of sensitivity when unfolding
- Dominant systematics:
  - Using only leading order MC in Run I (8TeV), QCD scales
  - Top quark p_T mismodeling has a large impact
  - Experimentally limited only by lepton momentum scale

CMS TOP-16-002

$m_t = 171.7 \pm 1.1(\text{stat}) \pm 0.5(\text{exp}) \,^{+2.5}_{-3.1}(\text{theo}) + 0.8(\text{top } p_T)$ GeV

Using theoretically calculable observables

- Inclusive production cross section



- Pole mass extraction from the inclusive $t\bar{t}$ production cross-section reaching < 2 GeV (at 7 and 8 TeV) and ~2.5 GeV (at 13 TeV) precision
- Mass-dependence can be calculated at NNLO+NNLL
- Cross section limited by luminosity uncertainty

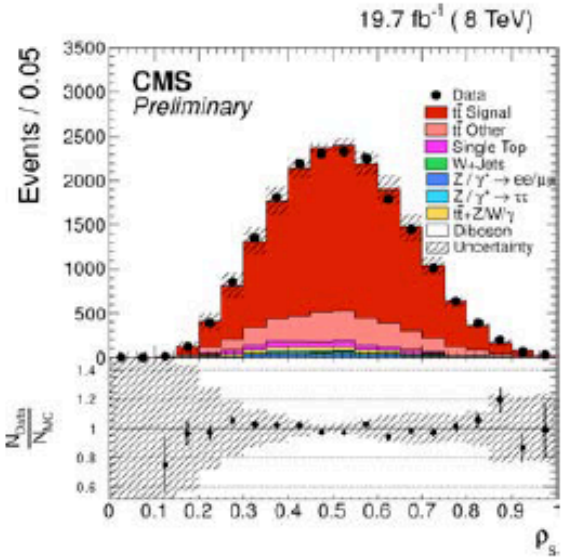
CMS TOP-13-004 arXiv:1603.02303

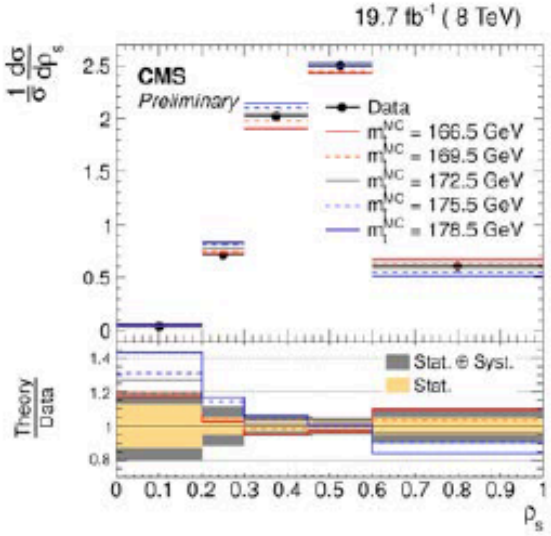
$m_t = 173.8\ ^{+1.7}_{-1.8}$ GeV (at 7 and 8 TeV)

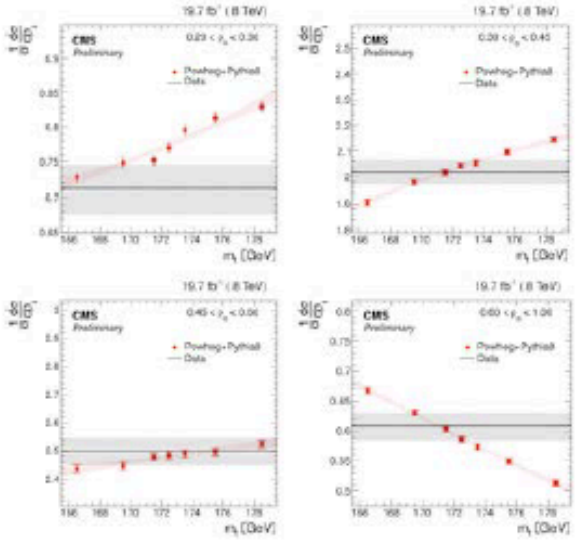
$m_t = 173.8\ ^{+2.7}_{-2.3}$ GeV (at 13 TeV)

CMS TOP-16-006

$t\bar{t}$+jet invariant mass







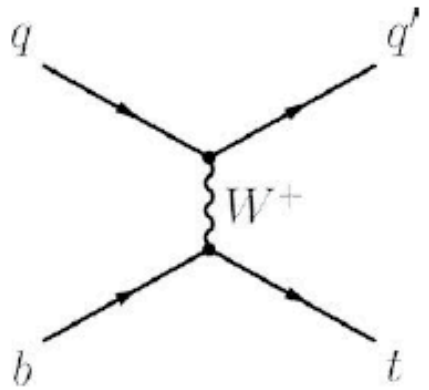
- Study $t\bar{t}$ events with at least one additional jet
- Measure differential cross section vs. $\rho_s = 2 \cdot m_0 / m(t\bar{t}, \text{jet})$
- Unfold to particle level using MadGraph+PY6
- Compare particle-level measurement with POWHEG prediction at NLO
- Dominant systematics:
  - POWHEG $t\bar{t}$+jet modeling(theo): $^{-1.6}_{+3.5}$ GeV
  - Q^2 scale: $^{+1.0}_{-2.8}$ GeV

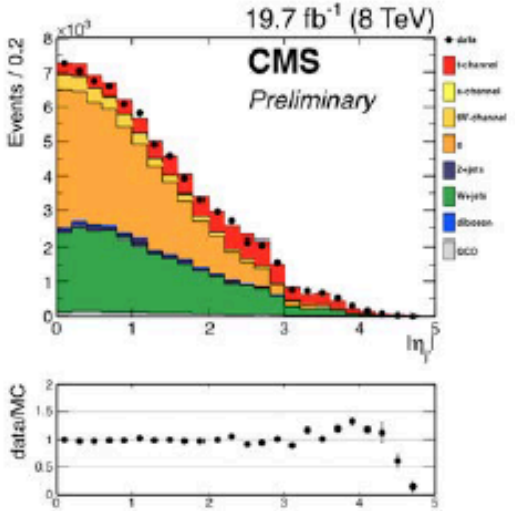
CMS TOP-13-006

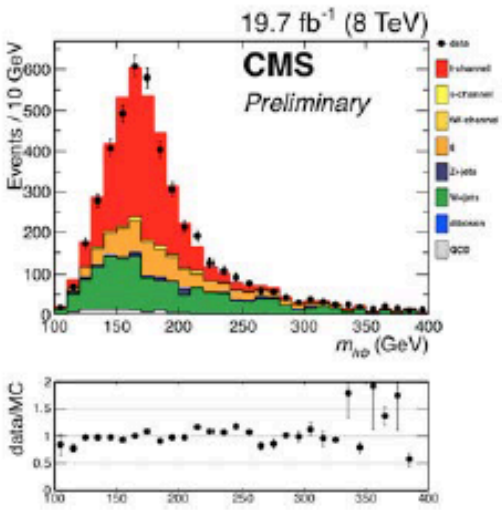
$m_t = 169.9 \pm 1.1(\text{stat}) \,^{+2.5}_{-3.1}(\text{syst}) \,^{+3.6}_{-1.6}(\text{theo})$ GeV

Measurements in alternative topologies

- Singl-top production events







- A top quark is reconstructed from the muon, E_T^{miss}, and b-jet(m_{lvb})
- Enrich selection in single top requiring a forward jet: $|\eta_j| > 2.5$
  - 71% t-channel single top, $t\bar{t} < 10\%$
- Extended unbinned maximum likelihood fit to m_{lvb}
  - Crystal Ball shapes(signal) + Novosibirsk function(background)
- EWK mediated
  - Different color reconnection, hard scattering and pdfs
- Dominant systematics:
  - Jet energy scales: $^{+0.68}_{-0.61}$ GeV
  - Background modeling: ±0.39 GeV
- Good agreement with measurements from $t\bar{t}$ events

$m_t = 172.60 \pm 0.77(stat)\ ^{+0.97}_{-0.93}(syst)$ GeV CMS TOP-15-001

Summary and Prospects

- Standard measurements
  - ~500 MeV precision
  - Working on LHC Run I combination
  - Precision is limited by our ability to model the signal, particularly b-quark hadronization
  - Jet-energy uncertainties are dominant on experimental side

- Alternative methods
  - Provide insights by different systematics
  - Contribute to understanding of modeling
  - Give consistent results with standard methods so far
  - Expecting improvements with 13TeV data