CMS Measurements of the Top Quark Mass and Width

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Outline

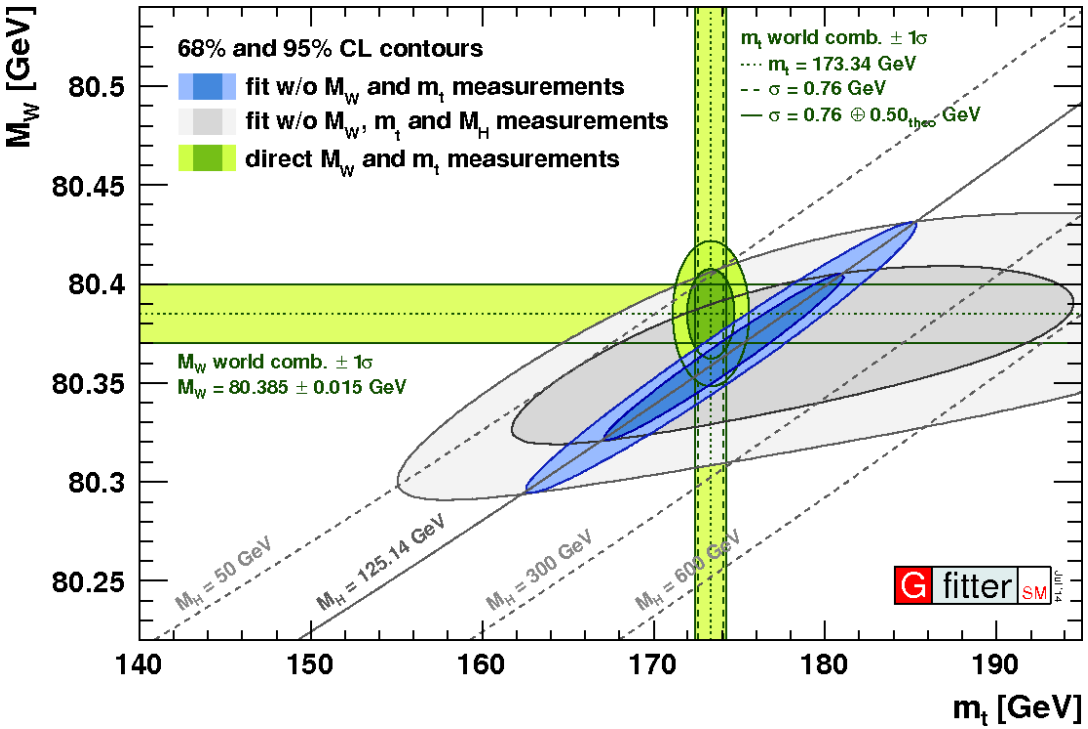
- Summary RunI Measurements
- 13 TeV measurements
- Alternative methods
- Top Width

EPS-HEP2017:
EPS Conference on High Energy Physics

July 7, 2017

Top Mass: Motivation

- Fundamental parameter of the SM
- m_{top} can be measured directly from the decay products (top quark decays well before hadronizing)
- m_{top} is close to the EWSB scale, so top quark might play a special role

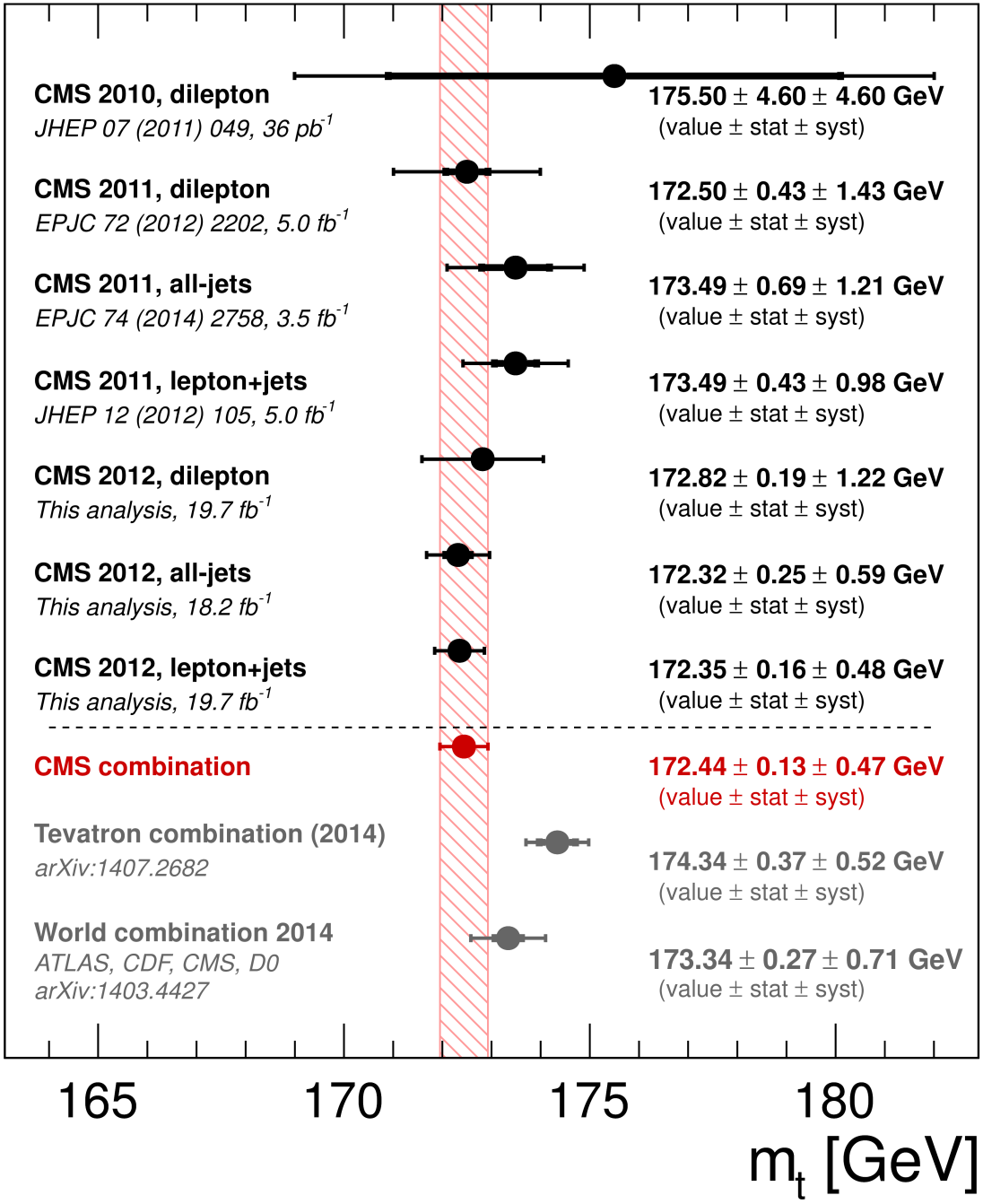


- Precise knowledge of m_{top} crucial for testing the consistency of the SM: participates in quantum loop radiative corrections to m_W constraining m_H
- m_{top} related with m_H and vacuum stability of SM

Top Mass: RunI Measurements (7 and 8 TeV)

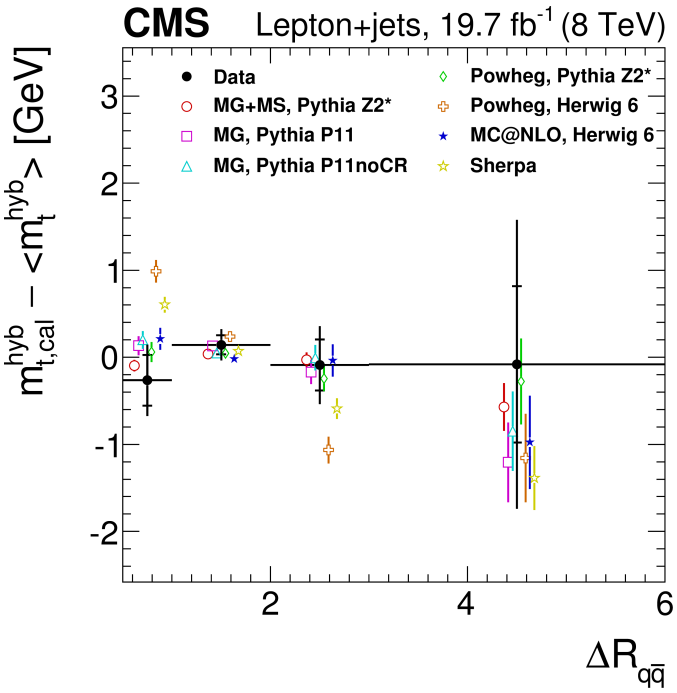
PRD 93 (2016) 072004

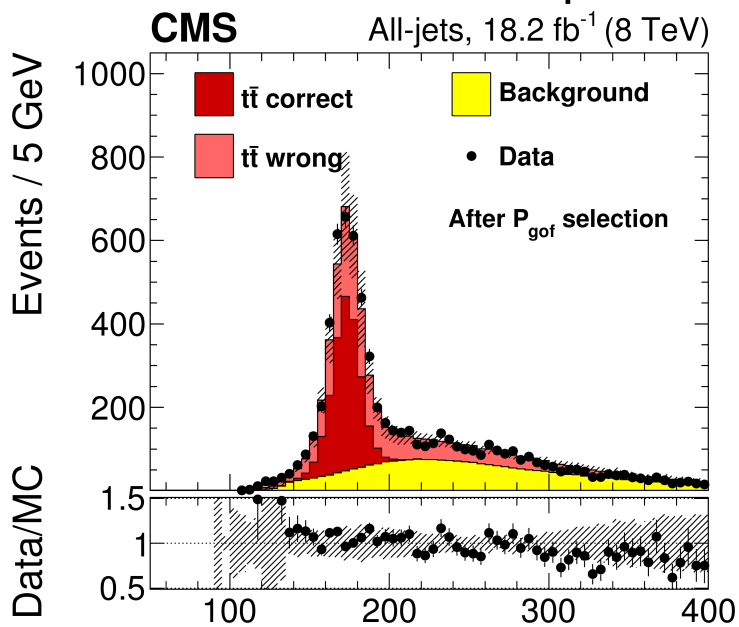
- All decay channels are pursued
  - provides consistency and precision
- Lepton+Jets and All Jets channels
  - in situ determination of jet energy scale factor (JSF)
  - similar systematic uncertainties
- Dilepton channel
  - Different color flow
  - Different main systematics: b-fragmentation and QCD modeling

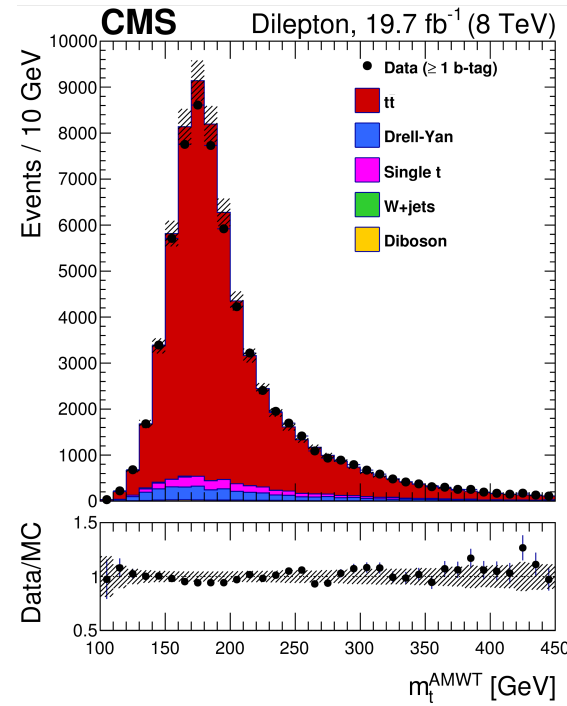


Top Mass: Measurements @ 8 TeV

- l+jets and all jets: fit of the decay products to a tt hypothesis and joint maximum likelihood to estimate m_{top} and JSF
- Dilepton: matrix weighting technique combined with an analytical algorithm to find solutions of the kinematic equations
- Most precise measurements in each of the decay channels







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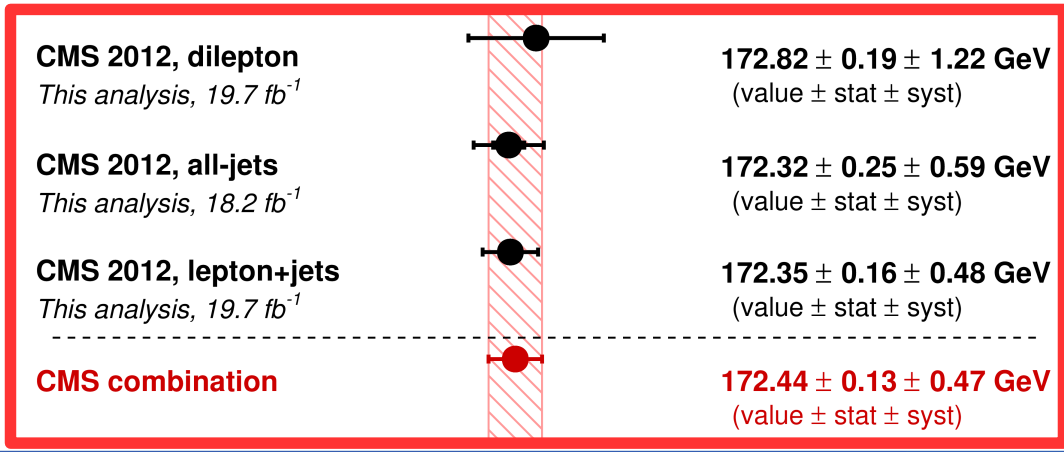
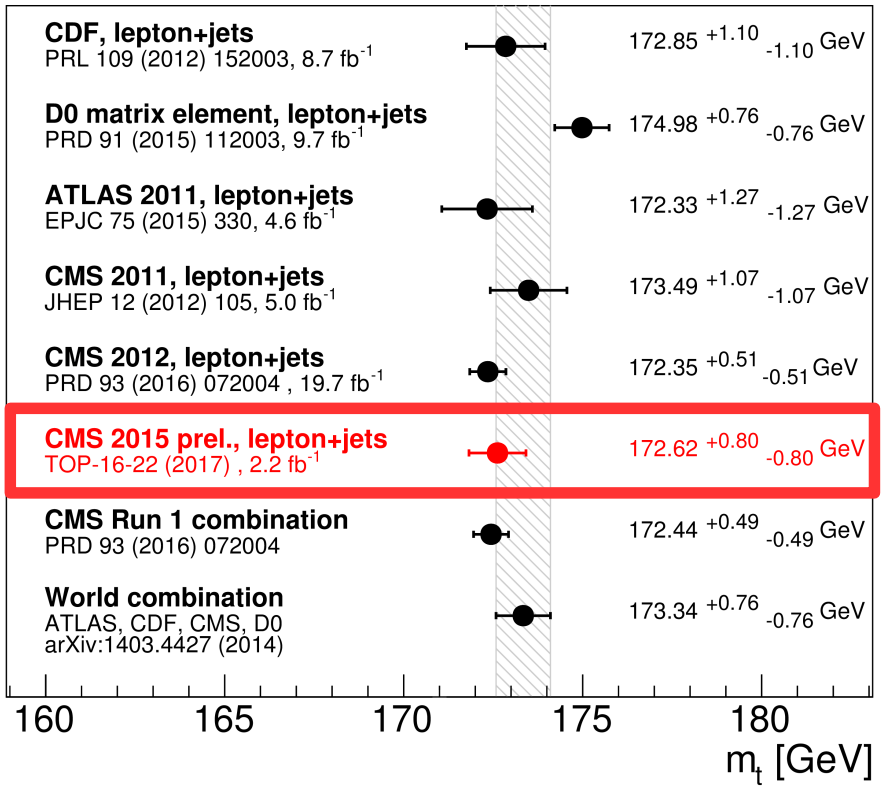
- Combination: $\delta m_{top}/m_{top}$ = 0.28%
  - 0.44% for 2014 world combination

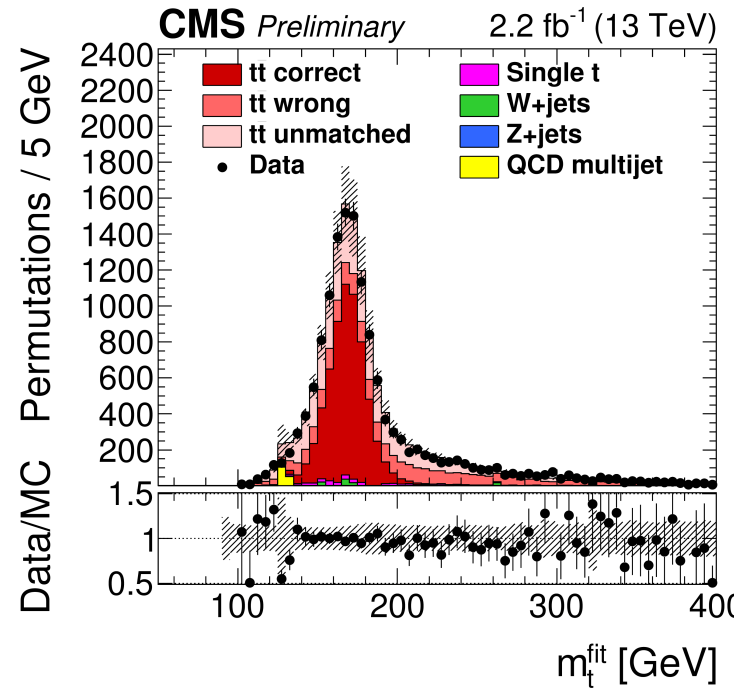


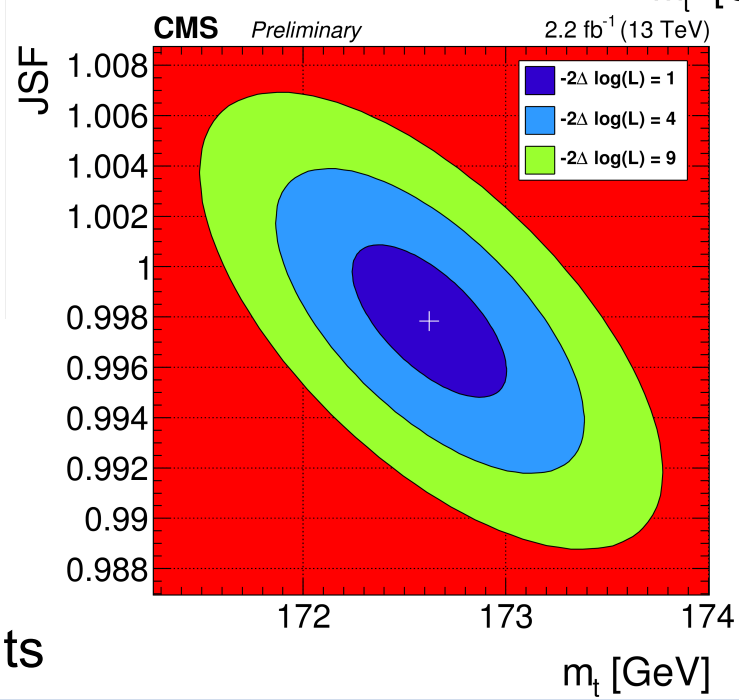
First Measurement @ 13 TeV

- Follows the 8 TeV measurement using μ+jets events
- Main systematics: JES and MC modeling

CMS-PAS-TOP-16-022



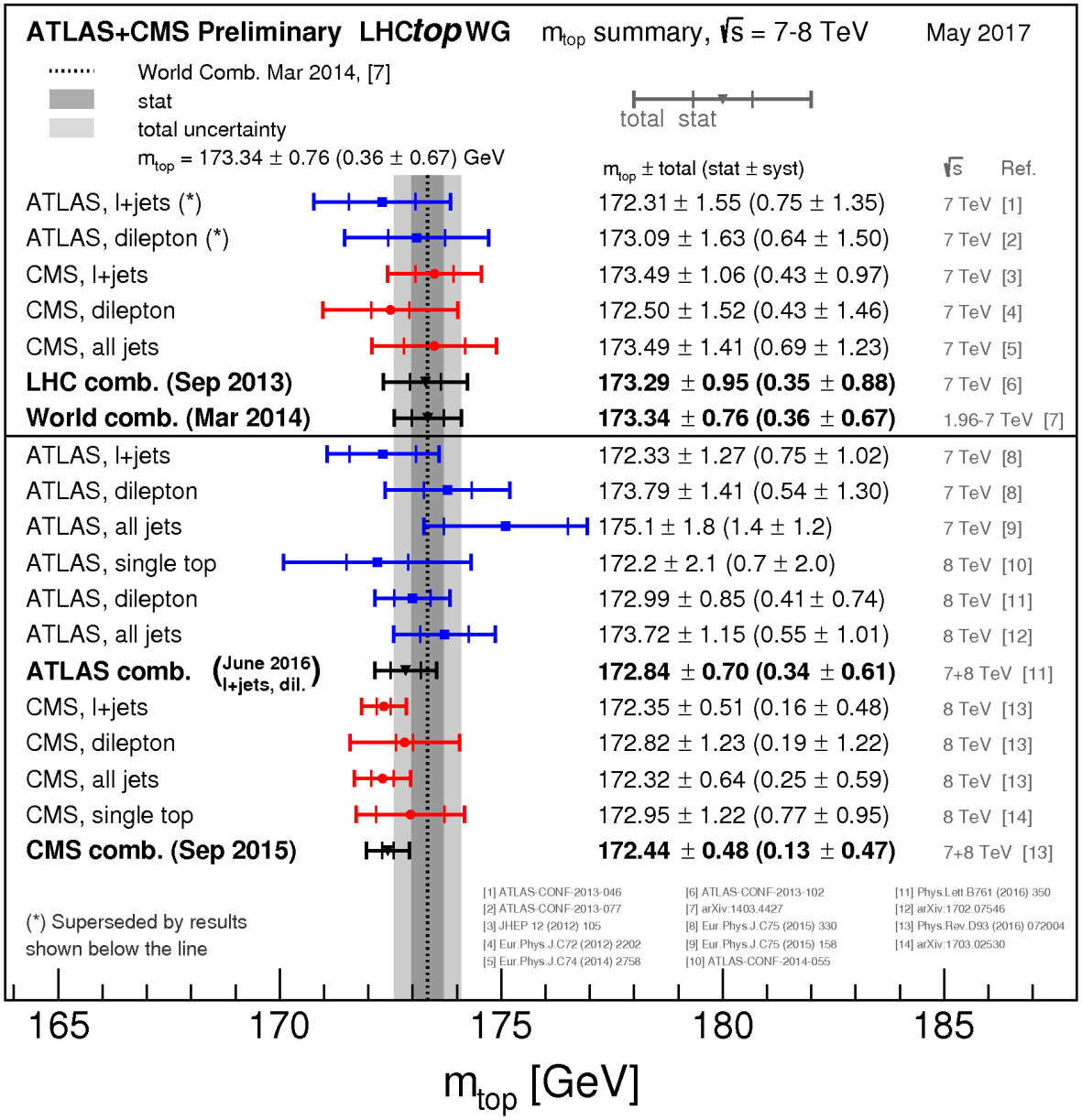




- Still not as precise as Run I measurement
  - new generators used in Run II still being tested/tuned (see details in E. Yazgan's talk)
- But in excellent agreement with other measurements

Top Mass: Current Status

- World combination reaching a precision of 0.5 GeV (<0.3%)
  - arXiv:1403.4427
- Precision limited by understanding of hadronization modeling
- Different ways to improve
- Use cleaner observables
  - Avoid jets
- Use theoretically calculable observables sensitive to the mass
  - σ(tt), m(lb)
- Constrain modeling systematics



Lepton + J/Ψ Events or Secondary Vertex @ 8 TeV

- Extract m_{top} from the invariant mass of J/ψ + lepton
  - Events in the main leptonic top quark decay where the b-quark decays via $b \rightarrow J/\psi + X \rightarrow \mu^+\mu^- + X$
  - Statistically limited (for now): 3.0 GeV
  - But no use of jets: syst. unc. < 1 GeV
  - Limited by top p_T modeling, QCD scales

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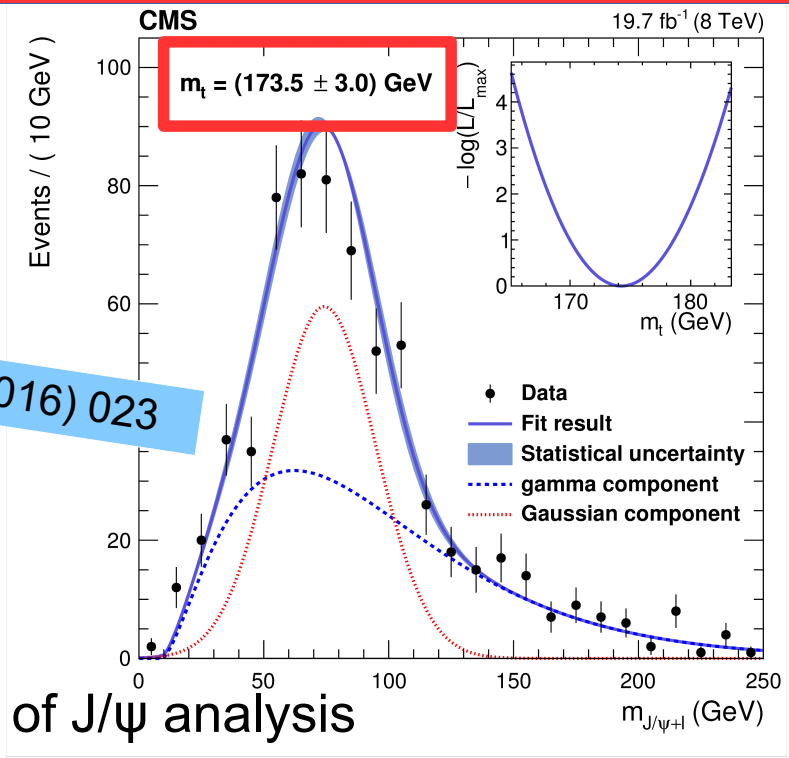

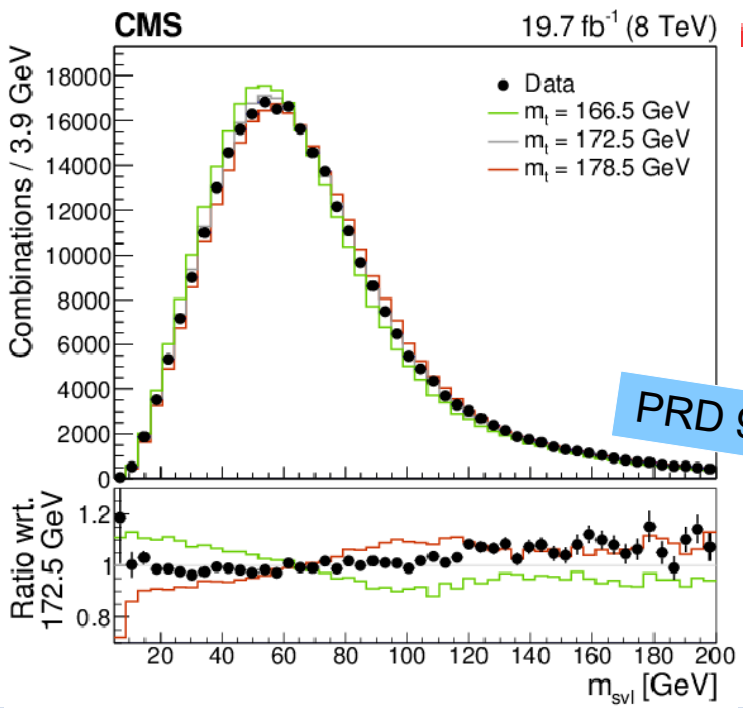

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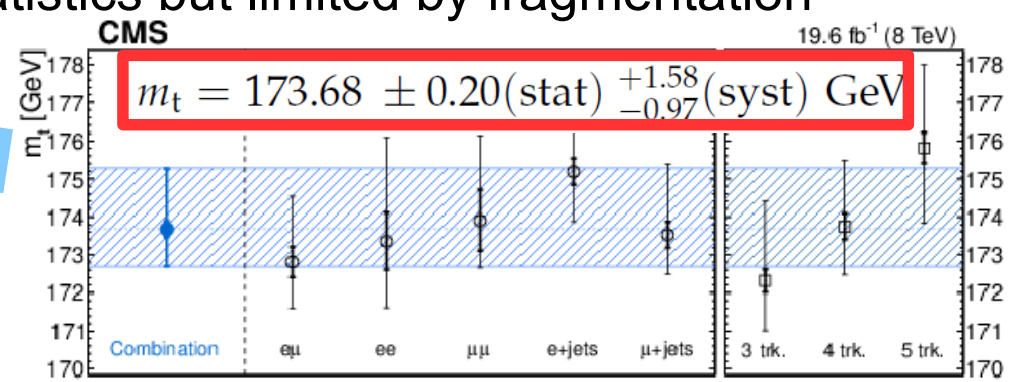
- More general version of J/ψ analysis
  - Invariant mass of lepton and secondary vertex used as observable (in bins of SV track multiplicity)
  - Gain in statistics but limited by fragmentation

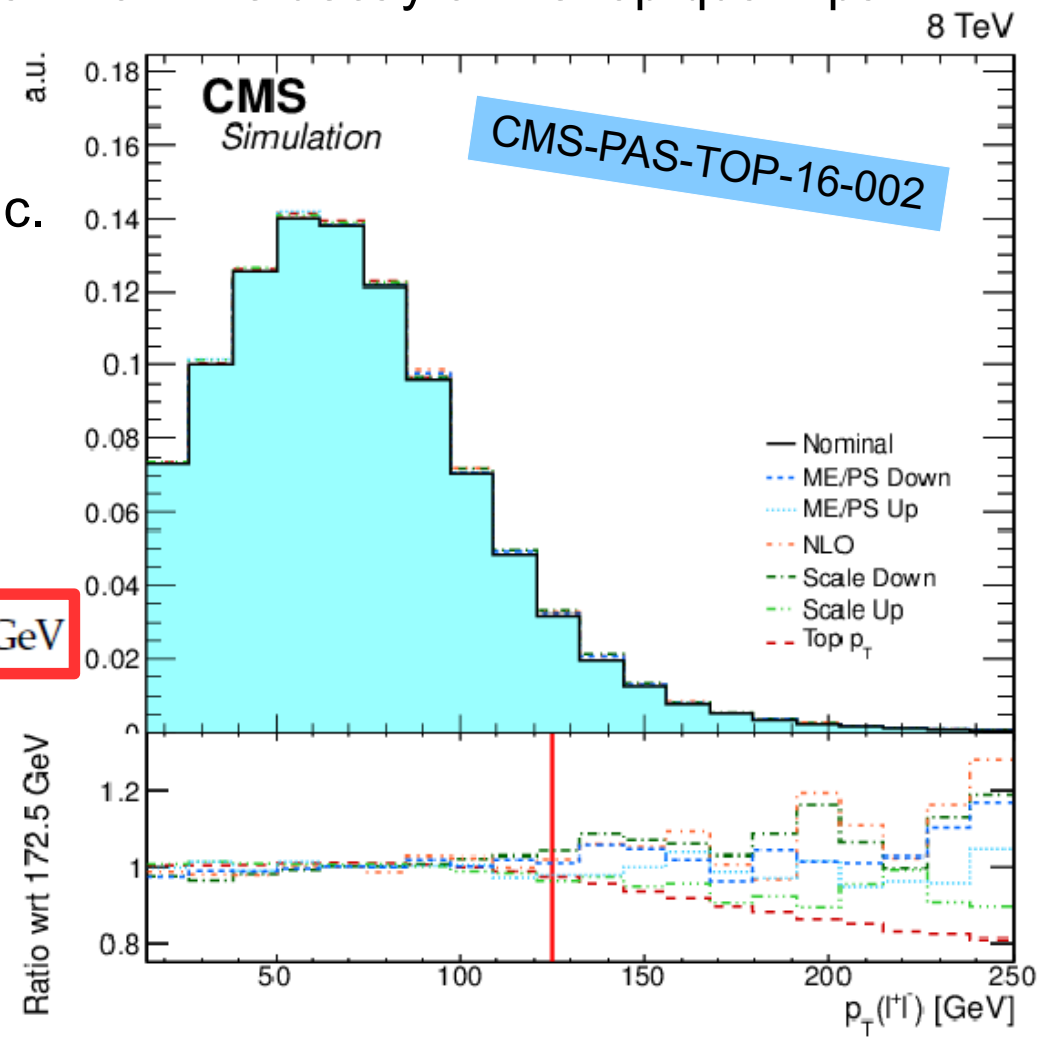


Top Mass from Leptonic Observables @ 8 TeV

- Dilepton channel
- The transverse momentum of the lepton pair from the decay of the top quark pair is chosen to extract the top quark mass
- Clean but overwhelmed by μ_R, μ_F scale unc.
- Based on LO Madgraph (Run I MC)
  - Expected to improve using NLO+PS
- After the calibration with simulated events

$$m_t = 171.7 \pm 1.1\,(\text{stat.}) \pm 0.5\,(\text{exp.})\ ^{+2.5}_{-3.1}\,(\text{th.})\ ^{+0.8}_{-0.0}\,(p_T\,(\text{t}))\ \text{GeV}$$

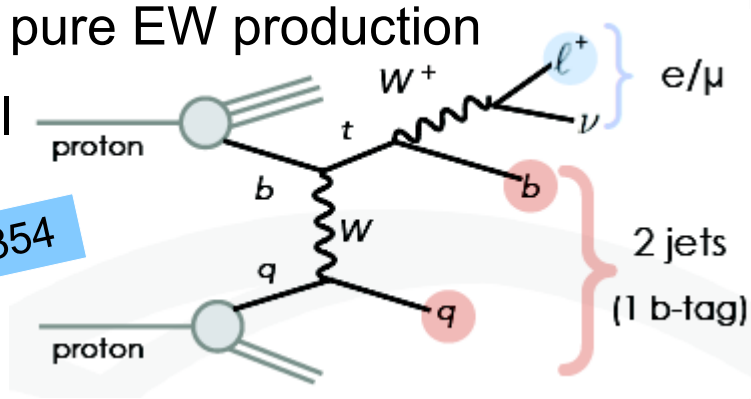
- Signal modeling is the dominant systematic uncertainty

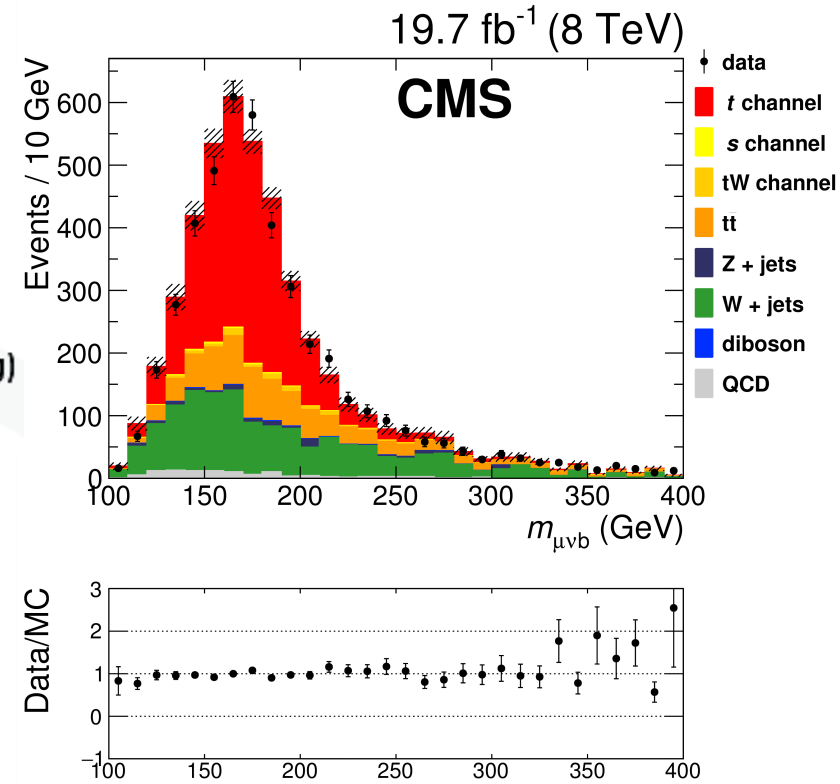


Top Mass from Single Top (t-channel) @ 8 TeV

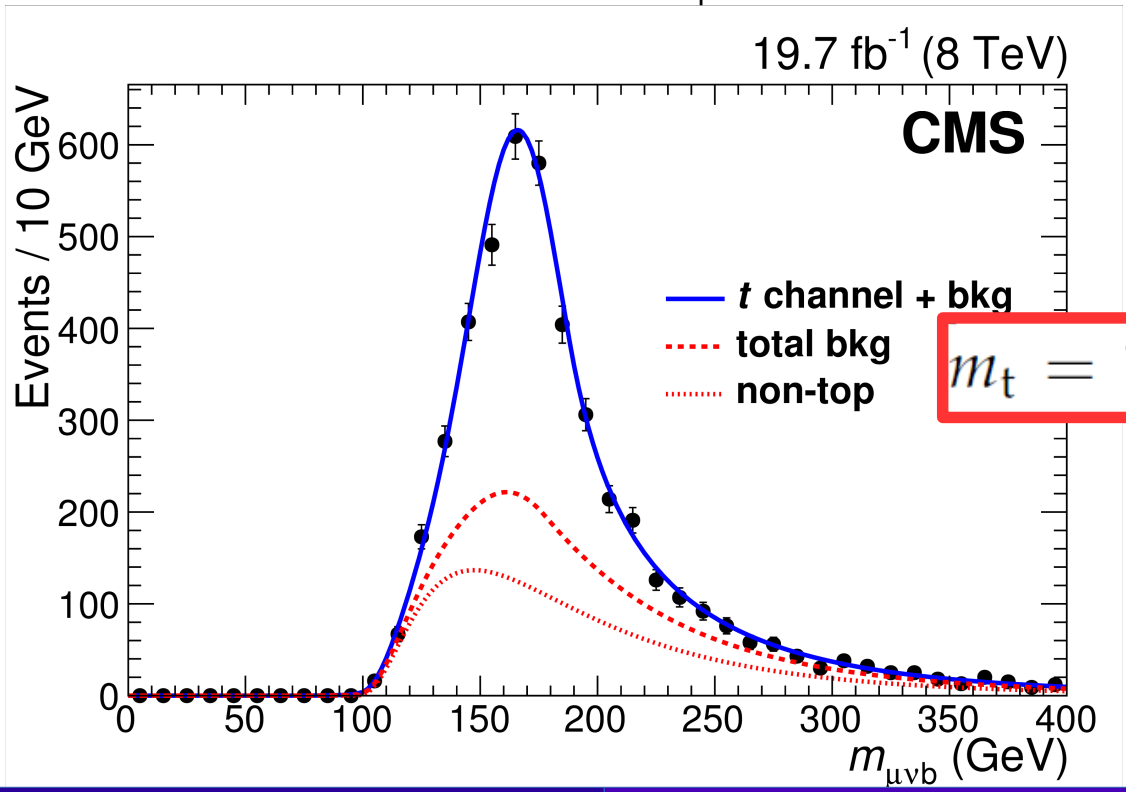
- Analyses targeting alternative topologies can give further insights, e.g. pure EW production
- Single top t-channel

EPJC 77 (2017) 354





- Fit to the reconstructed m_{top} of the top candidates



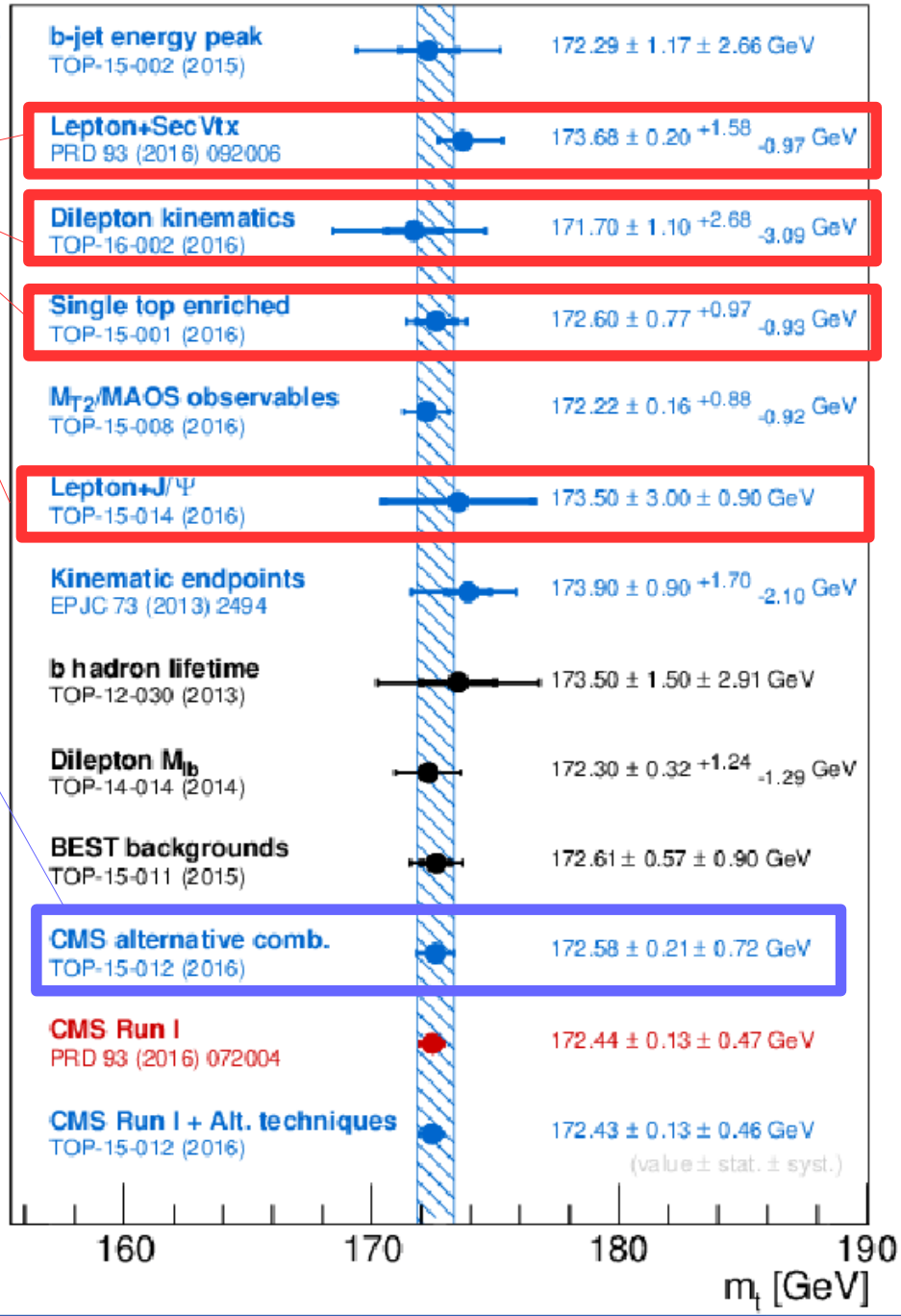
$$m_t = 172.95 \pm 0.77\,(\text{stat})^{+0.97}_{-0.93}\,(\text{syst})\ \text{GeV}$$

- JES is the main systematic uncertainty

Top Mass: Combination Alternative Measurements

CMS-PAS-TOP-15-012

- Only few alternative methods shown here
  - Others are available
- All measurements combined using BLUE
  - 0.4% precision, comparable with the combination of standard methods
  - Similar exp. unc. but larger theoretical
- When combining with standard methods not large improvement due to correlations between the main syst. uncertainty
- How to increase the impact
  - Decrease the size of the correlations using less sensitive techniques
  - Decrease the size of the correlated terms data-based constraints



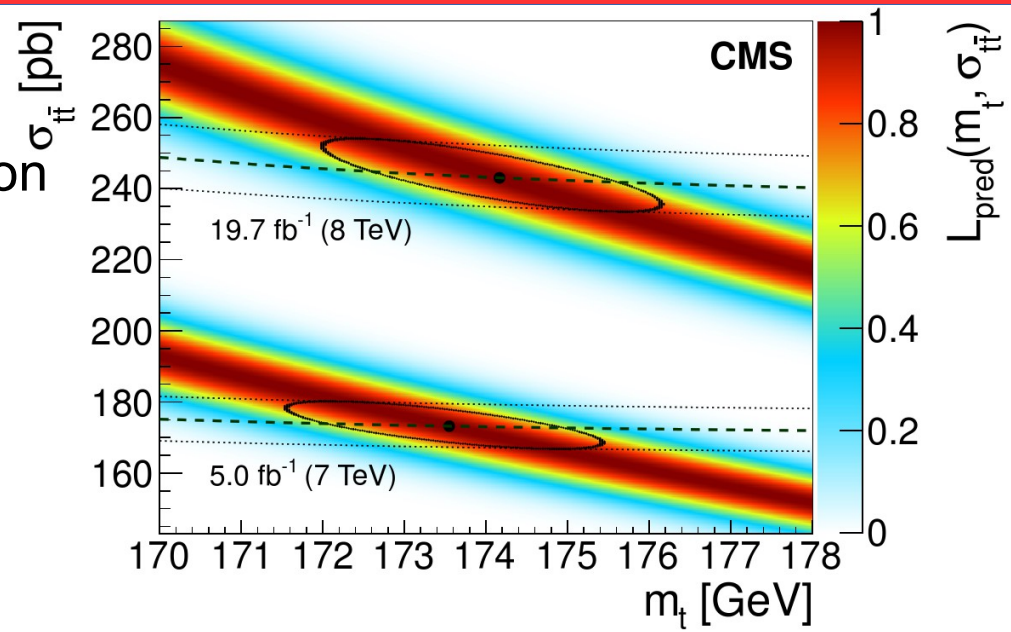
Top Pole Mass

JHEP 08 (2016) 029

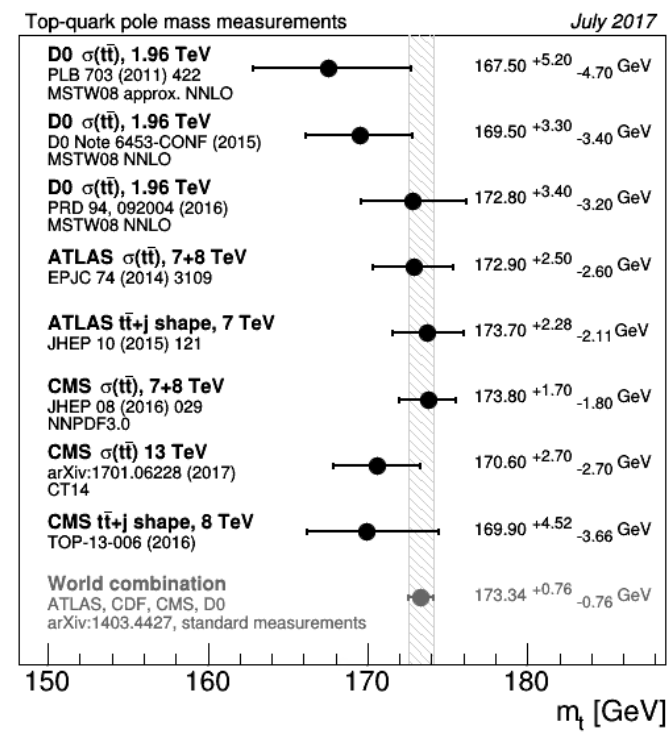
- Extract m_{top} from production cross section
- Calculate mass dependence at NNLO
- 1% precision, not yet competitive with direct measurements

$$m_t^{pole} = 173.8^{+1.7}_{-1.8}\ \text{GeV}$$

PDF set: NNPDF3.0 (consistent results with CT14 and MMHT2014)



- Could reach 0.5% precision with 5% and 2% theory and experimental unc., respectively (CMS-PAS-FTR-16-006).
- Main systematics: PDF, luminosity
- 13 TeV l+jets x-sect measurement (details in T. Arndt's talk) yields 170.6 ± 2.7 GeV (using CT14 PDF)

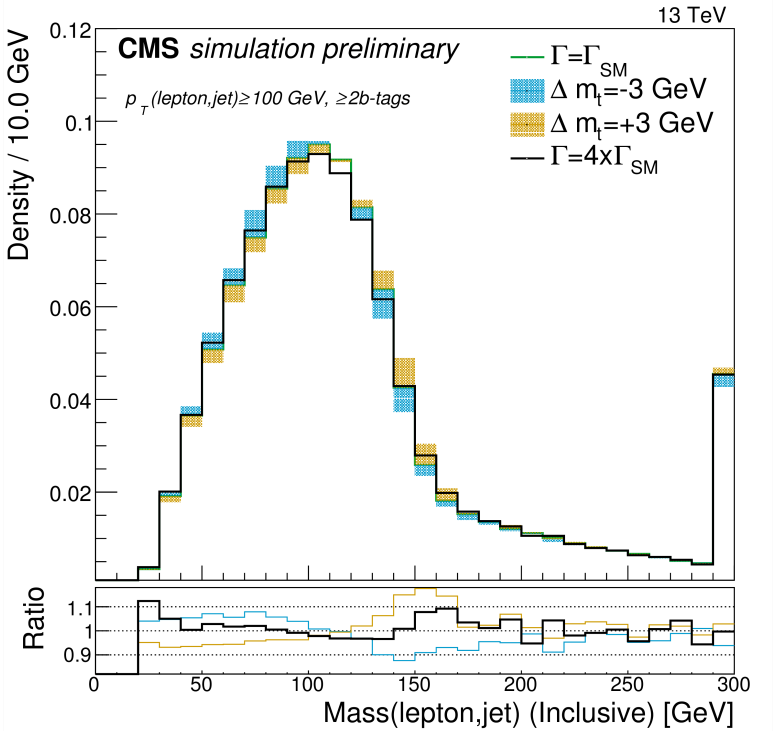


Top Width

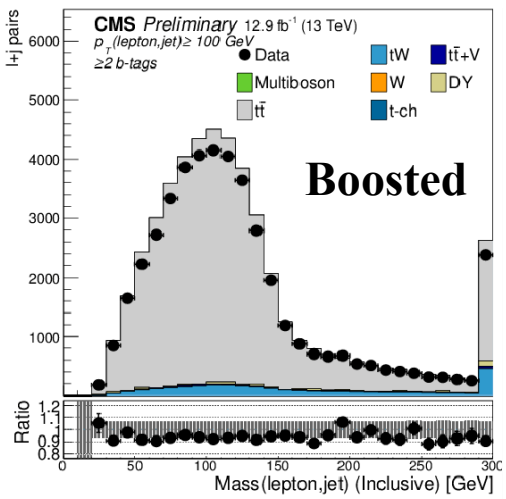
- Less tested of the top quark properties!
- Dilepton channel

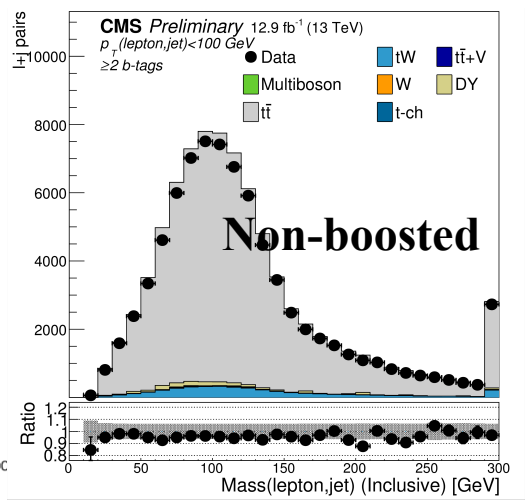
CMS-PAS-TOP-16-019

- Reconstructed mass of the decay products (lepton and b) is used as observable to probe variations in Γ_t
- Observable compared to the simulated expectations for different Γ_t scenarios using a likelihood technique



- MC modeling main systematic uncertainty

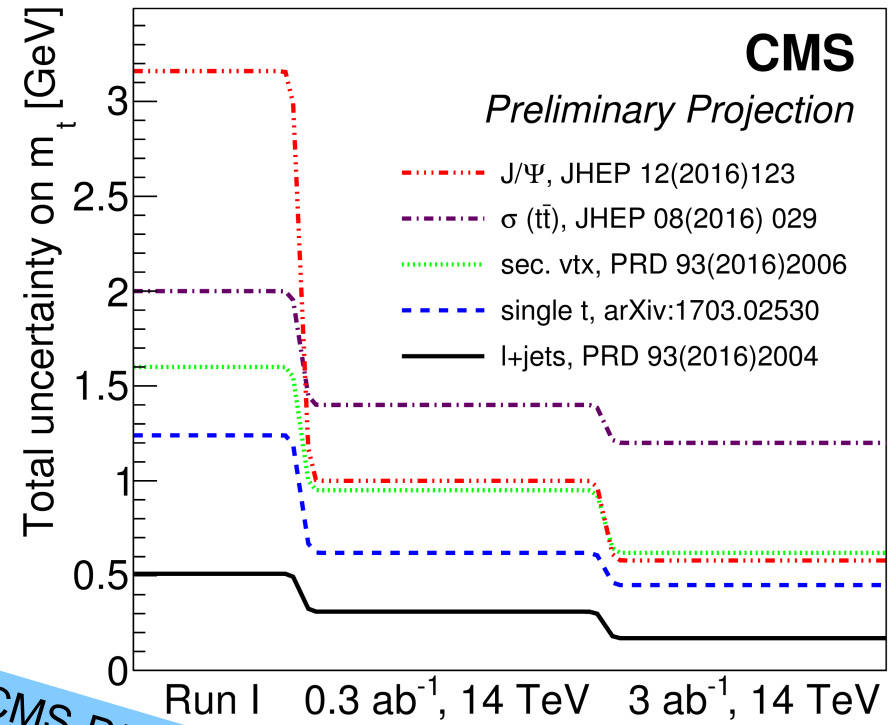




- For a SM-like top quark hypothesis:
  - Observed limit: $0.6 \leq \Gamma_t \leq 2.5$ GeV, expected limit: $0.6 \leq \Gamma_t \leq 2.4$ GeV
  - Γ_t (NLO) = 1.35 GeV
- Indirect measurement Phys. Lett. B 736 (2014) 33
  - $\Gamma_t = 1.36 \pm 0.02$ (stat) +0.14-0.11 (syst)

Summary

- In Run I, CMS measured m_{top} in all decay channels with different complementary methods. The combination produced the most precise measurement to date
- Level of precision reached in m_{top} (<0.3%) impressive but comes from many years of continuous improvements
- Combination of alternative methods yields similar precision as standard methods
- First measurement at 13 TeV already available
- Outlook: ultimate precision of $0(10^2)$ MeV expected when merging measurements and experiments, accounting for correlations, and improving the MC modeling



CMS-PAS-FTR-16-006

- The first direct bounds on Γ_t at the LHC has been achieved
  - Most precise performed to date

Thank you

for your

attention!

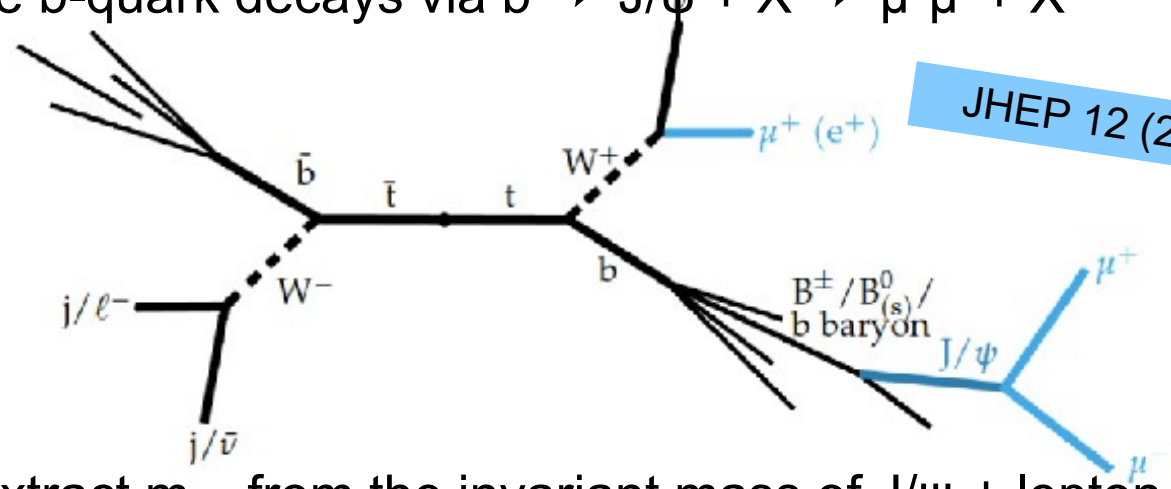
http://cms-results.web.cern.ch/cms-results/public-results/publications/TOP/MASS.html

Back-up

Slides

Lepton(s) + J/Ψ Events @ 8 TeV

- Select events in the main leptonic top quark decay where the b-quark decays via b → J/ψ + X → $\mu^+\mu^-$ + X



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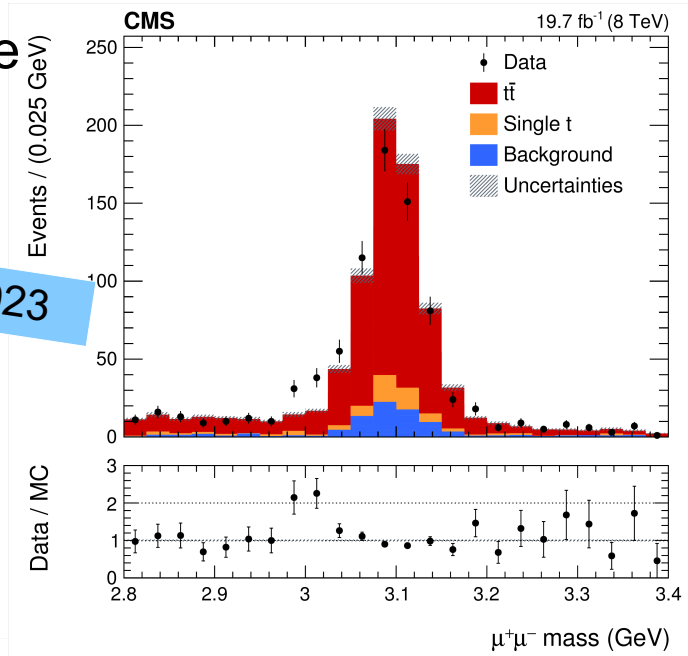
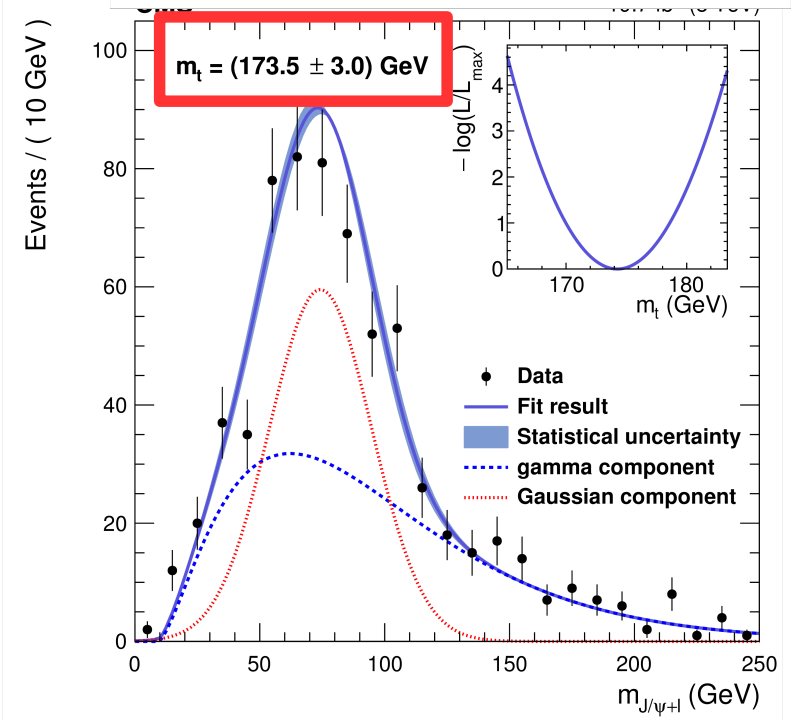
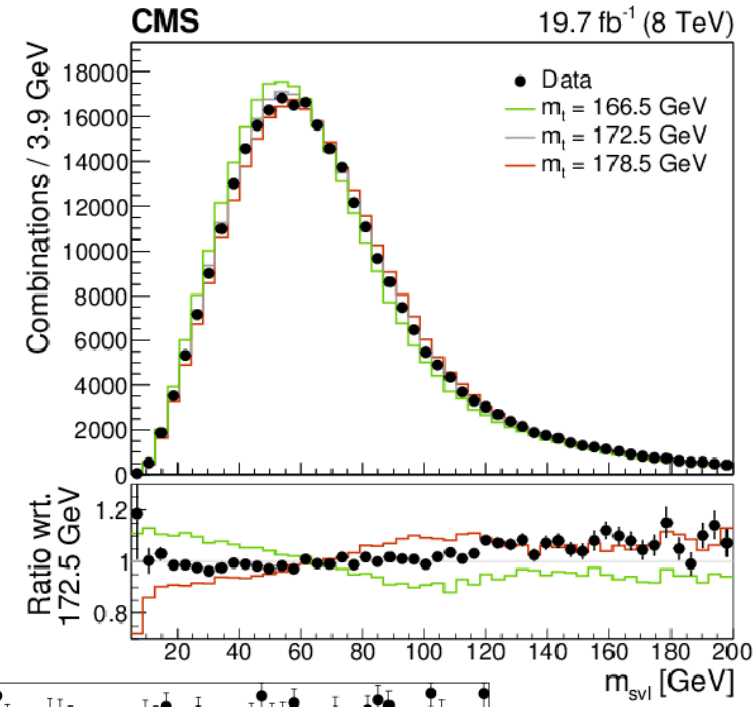


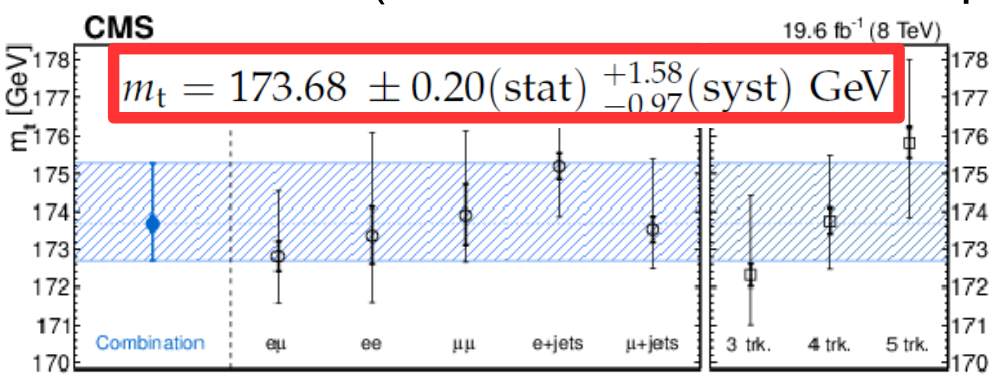
- Extract m_{top} from the invariant mass of J/ψ + lepton
- Very small BR ⇒ statistically limited (for now)
  - 666 events ⇒ stat. unc. of 3.0 GeV
- But no use of jets to build observable
  - Avoid JES/bJES
  - Systematic uncertainty < 1 GeV
  - Limited by top p_T modeling, QCD scales

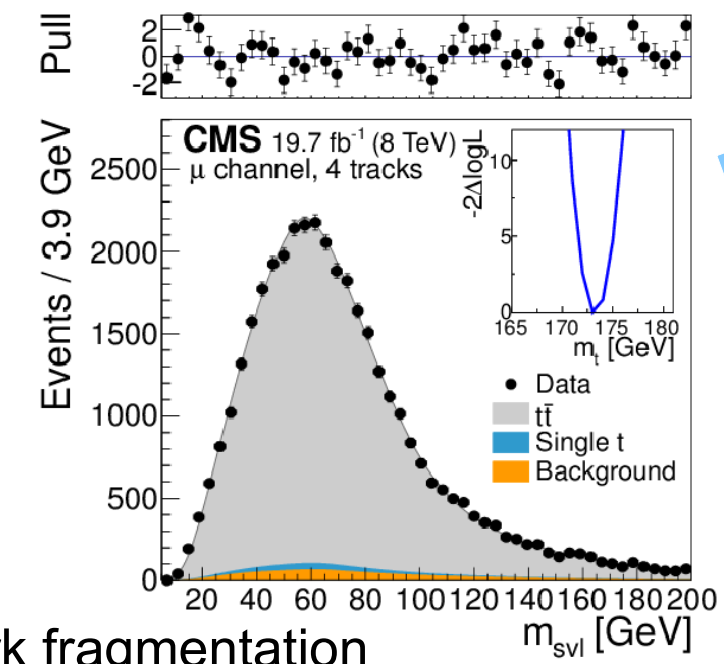


Lepton + Secondary Vertices @ 8 TeV

- More general version of J/ψ analysis
- Sensitivity to m_{top} from leptons (e/μ) and via decay lengths of charged hadrons (from b-quark decay)
  - Stronger sensitivity to m_{top} without inclusion of jets
- Semileptonic and dileptonic channels
- Invariant mass of lepton and secondary vertex used as observable (in bins of SV--track multiplicity)







PRD 93 (2016) 092006

- Experimental uncertainties <500 MeV
- Dominant systematic: top quark p_T and b-quark fragmentation