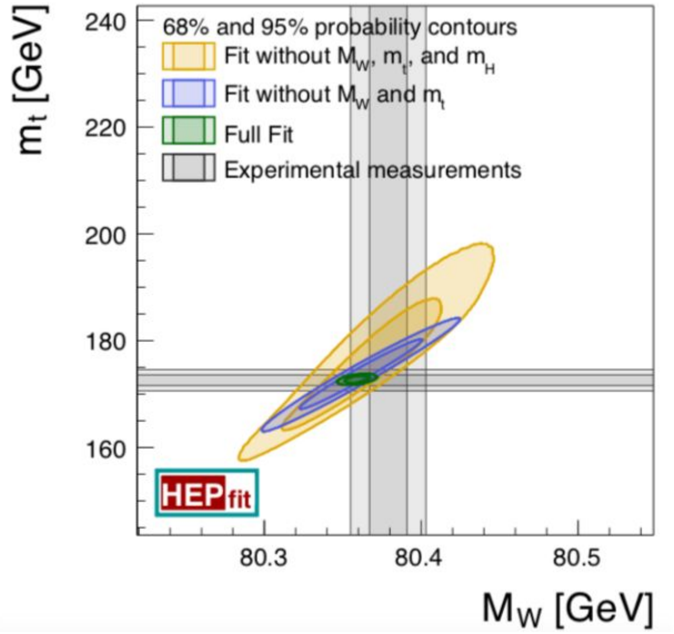
Top (pole) mass combination

with
valencian ATLAS top mass group
and
Sebastian Wuchtrel, Matteo Defranchis (CMS)

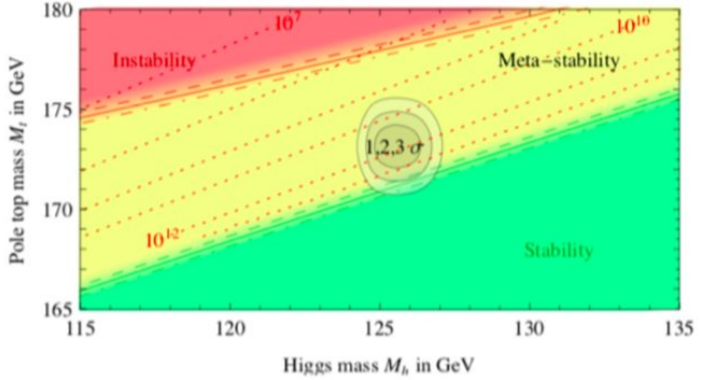
Top mass - intro

The top quark mass (Mtop) is a free fundamental parameter of the Standard Model (SM)

arXiv: 2112.07274 … or the updated version arXiv: 2204.04204



JHEP 08 (2012) 098

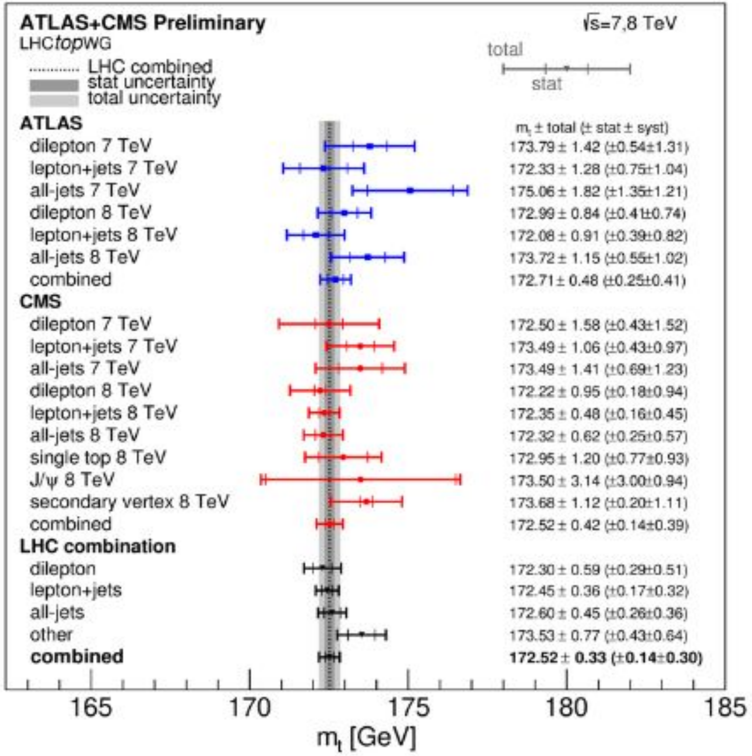


Mtop precise determination is important per-se and its value is relevant in:

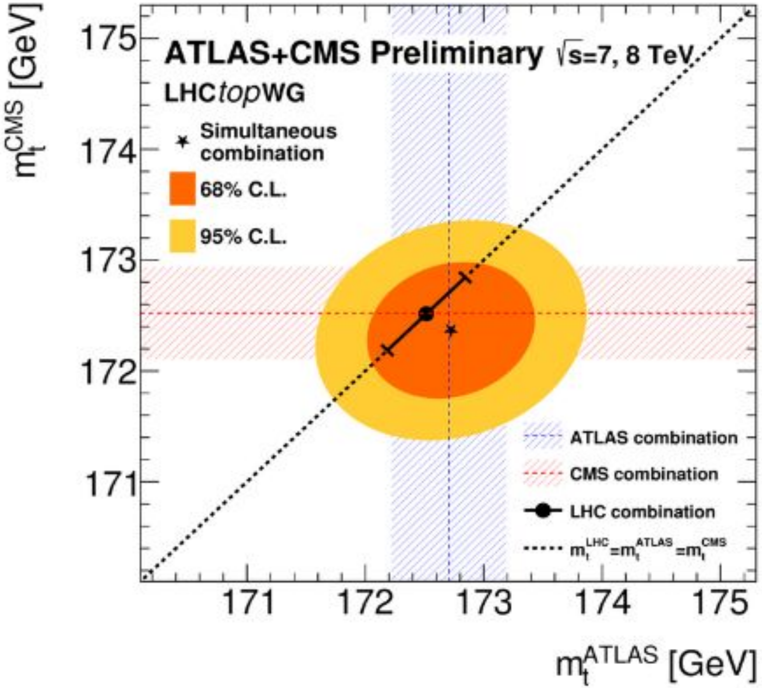
- consistency checks in the SM
- possible new physics scenarios (top-quark being the heaviest SM particle)

GeV/subGeV precision in Mtop highly desirable

Top mass(es) - status



[End-of-2023 result]



Recent combination of ATLAS & CMS results on direct top-mass measurement has 0.33 GeV **experimental** uncertainty

Top mass(es) - definitions

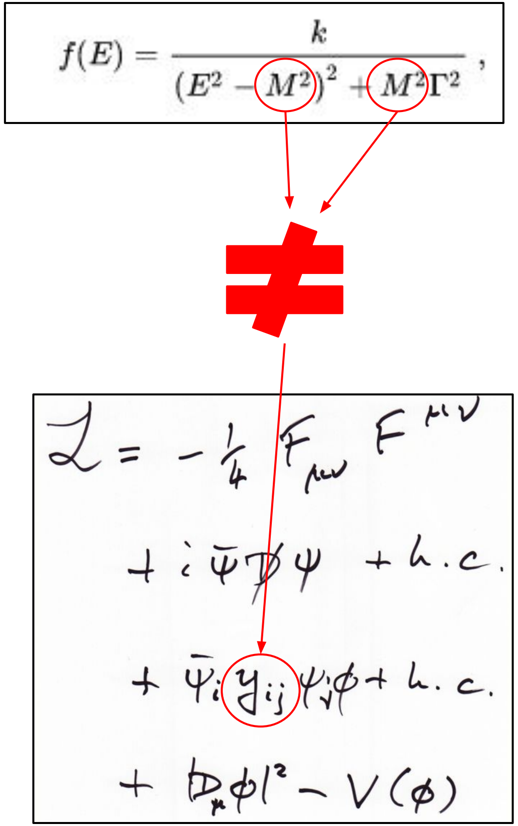
What about theoretical uncertainties?

To compute/evaluate these precisely, a well defined theoretical scheme is needed.

Direct top-mass measurements are usually hard to interpret in a well defined theoretical scheme:

- typically obtained from a data-to-MC comparison at detector-level
- the top-quark mass in the MC (MtopMC) is not precisely defined theoretically
    - mtopMC usually a parameter in a Breit-Weigner distribution for top MC resonance
    - an analytical connection to a SM-parameter not available yet

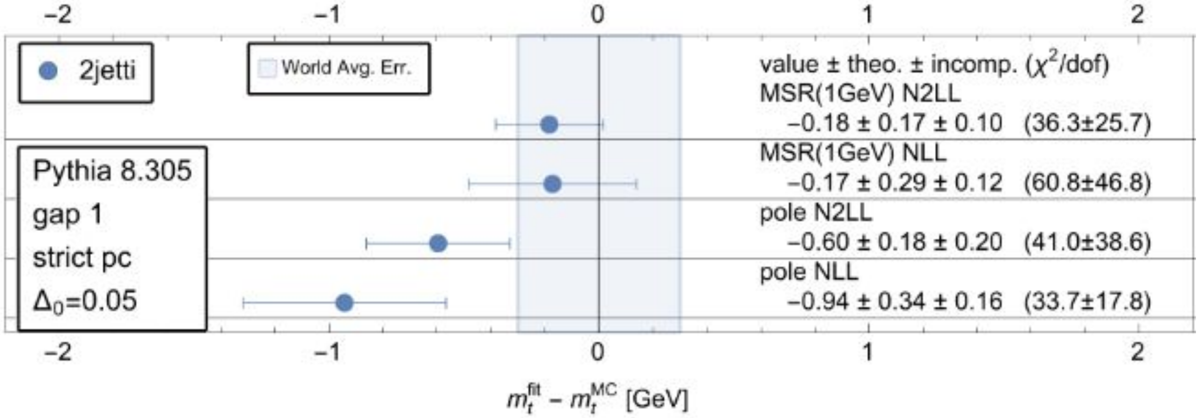
So far estimated/used 0.5-1GeV theo uncertainty on direct top-quark mass measuremens



Top mass(es) - strategies

Two options possible:

- work on the MtopMC-to-Mtop relation:
    - typically for theorists
    - short range masses, MSR renormalization scheme, MtopMC calibration…



arxiv:2309.00547

- for experimentalists
    - extract the top-quark mass directly in a well defined theoretical way:
        - compare measured cross-sections to fixed-order (beyond QCD LO) theoretical calculations

Top mass(es) - status v2

In the last 10 years many analyses pursued the measurement of the top-quark pole mass:

- ATLAS ttbar+1jet @ 7 TeV (Adrian)
- ATLAS ttbar+1jet @ 8 TeV (myself)

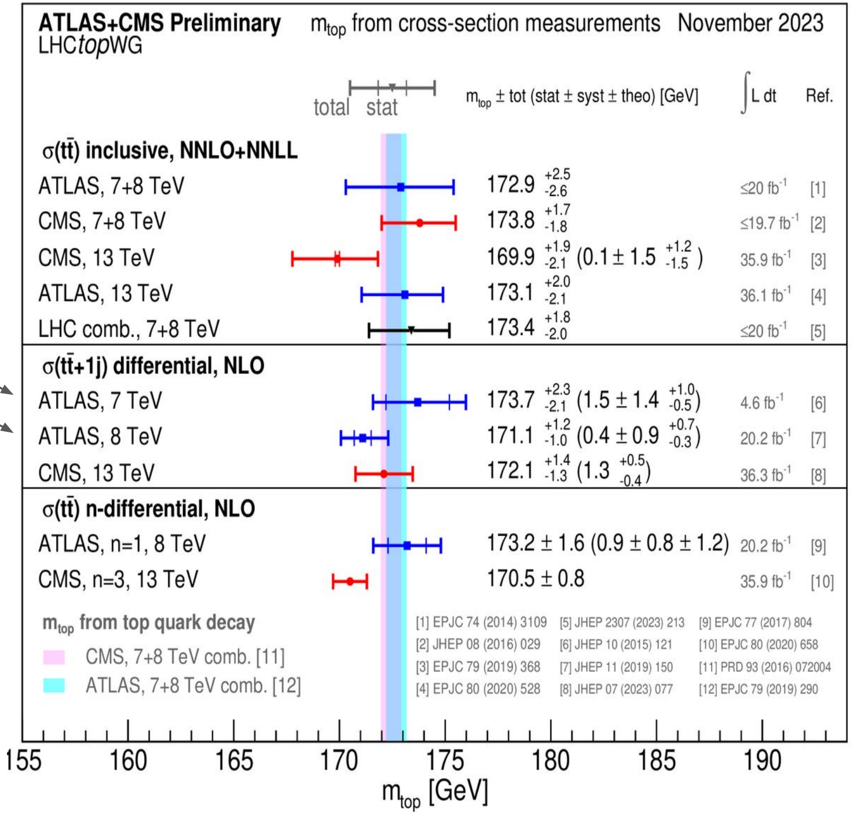
The most precise measurements of Mtop at their respective LHC energies

ATLAS 13TeV results are coming soon…

- ATLAS ttbar1jet+CRs @ 13 TeV, semileptonic (Alberto)
- ATLAS ttbar+1jet @ 13 TeV, dileptonic (Luis)

CMS also following ATLAS (and Valencian!) example with nice ideas and results at 13TeV

Full uncertainty (<u>included theo</u>) at ~1-1.5GeV



Top mass combination - intro

Single pole mass measurements are reaching their design potential

- it gets very hard / impossible to get better
- already started “trading” syst. unc. to stat. unc. with profile likelihood fits

Next step is to start considering combinations.

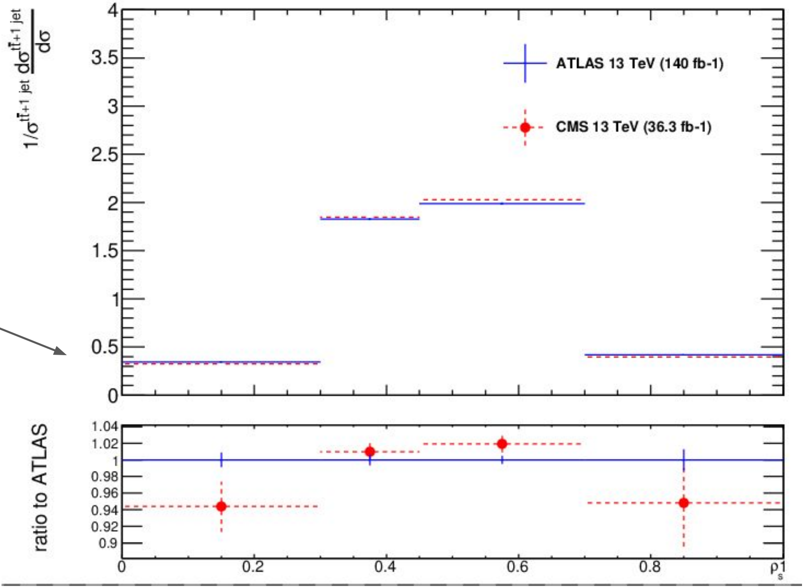
A “posteriori” combinations, taking mass values directly has been done since ages:

- not the perfect option, but often the only available in the past
- full potential of analyses typically not fully explored
    - full information on systematics is lost when one number is given to represent the impact of a systematic effect (i.e. no shape effects on observable)

If one aims at the most precise and accurate Mtop determination, this is not ideal.

Better to combine the cross sections from which Mtop is extracted, and then extract Mtop from a fit to theoretical predictions

Top mass combination - ingredients



The tt+1jet observable (R) has been used successfully to measure Mtop:

- highest precision on Mtop for a single-observable measurement

What is needed for a Mtop measurement:

- measured observables (unfolded)
  - experiment-dependent
    - if possible, common fiducial/truth-level cuts
- covariance matrices for each uncertainty source
    - contain all the needed information on correlations
- theory predictions (at least NLO)
  - renormalization scheme is defined and uncertainties can be defined well
  - independent on the experiment (if no changes for truth-level cuts)

$$X^2 = [\text{Rmeas} - \text{Rtheo(Mtop)}] \times \text{COV}^{-1} \times [\text{Rmeas} - \text{Rtheo(Mtop)}]$$

Top mass combination - strategies

Both ATLAS and CMS have results at 8TeV (and something at 13TeV)

- can use HEP/published information to combine single-observable measurements
  - caveats on what is available apply…
    - analyses in the past did not foresee combinations and did not publish all necessary information

- ATLAS and CMS are developing also multi-observables fits for 13TeV
  - use profile likelihood fits
    - have information on bin contents and bin-content variations for each uncertainty source -> full measurement information
  - can combine likelihood functions directly, as ATLAS and CMS events measured events are independent

Top mass combination - status

So far:

- brought together ATLAS and CMS people interested (~5 people)

- collecting material from what is public:
  - CMS thought about combination ahead and has more information
  - ATLAS did not think so much ahead for 8TeV result (my fault…)
    - currently trying to get ~5year old information back…

- discussing software choice
  - available on the market:
    - BLUE
      - faster/lessCPU
    - Convino
      - more functionalities
      - slower,but still ok

from a 2016 talk

	BLUE	BLUE tool	Convino
Absolute uncertainties	X	X	X
Relative uncertainties		*	X
Log-normal priors			X
Can combine ‘sim. fit measurements’			X
Access to pulls of all estimates	X	X	X
Access to pulls of all uncertainties			X
Automated correlation scans		X	X
Creates figures for scans		X	X
Creates LaTeX tables		X	#
CPU time (for about 200 parameters)	<<10 min	<10 min✣	~10 min
Statistical bias	Neyman	Neyman	Pearson Neyman❖

Conclusions

Mtop is a free SM parameter and its important to measure it precisely and accurately

Great development in last ~10years in improving theoretical uncertainties on measured values (both theorists and experimentalists)

Single-analysis measurements getting to their maximum potential:

- ~1/1.5GeV total uncertainty on single-analysis

Combination of ATLAS and CMS measurements is a promising way to get an even better result:

- currently setting up team, software and analysis inputs