Top quark mass measurement in $t\bar{t}$ events using a $J/\psi \to \mu^+\mu^-$ in the final state (Run2 and HL-LHC)

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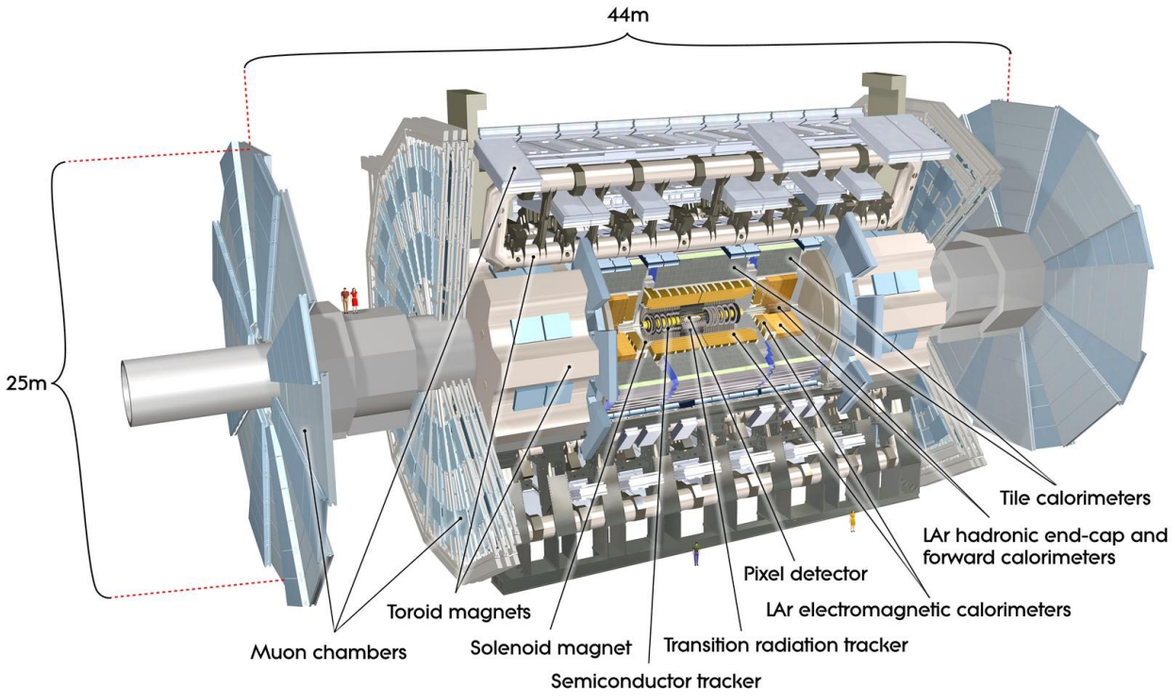
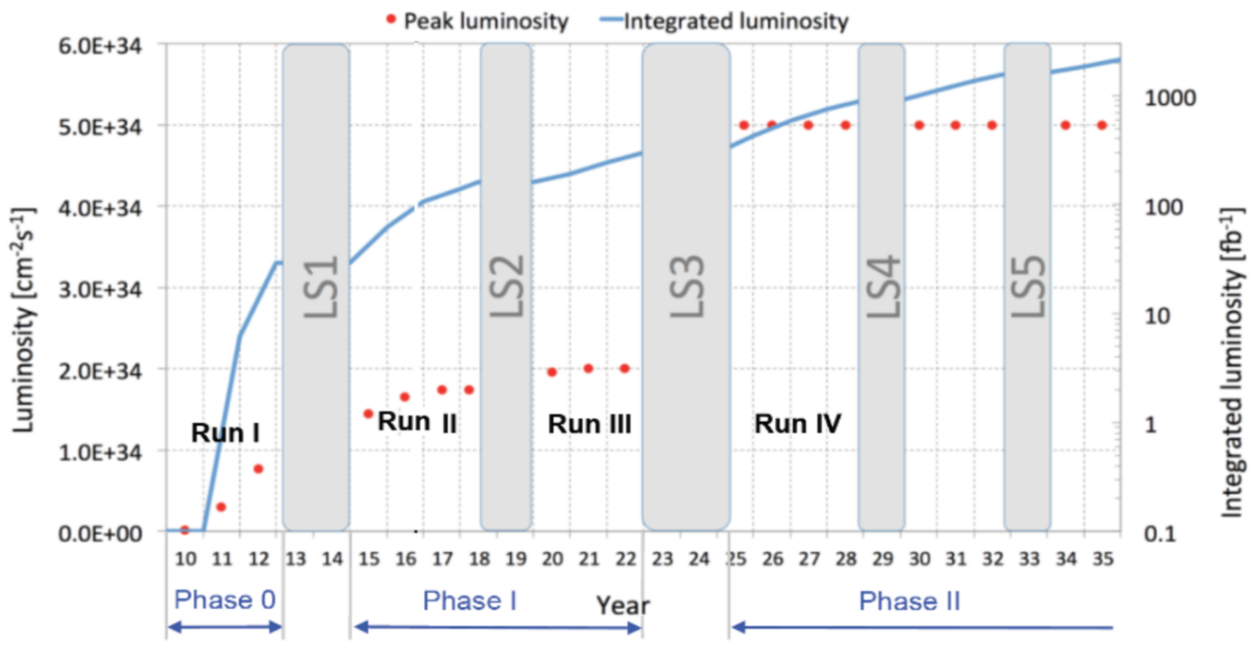
ATLAS experiment at CERN

Large Hadron Collider (LHC) is a particle collider with a center-of-mass energy of $\sqrt{s}$ = 13 TeV for Phase I. These collisions occur every 25 ns.



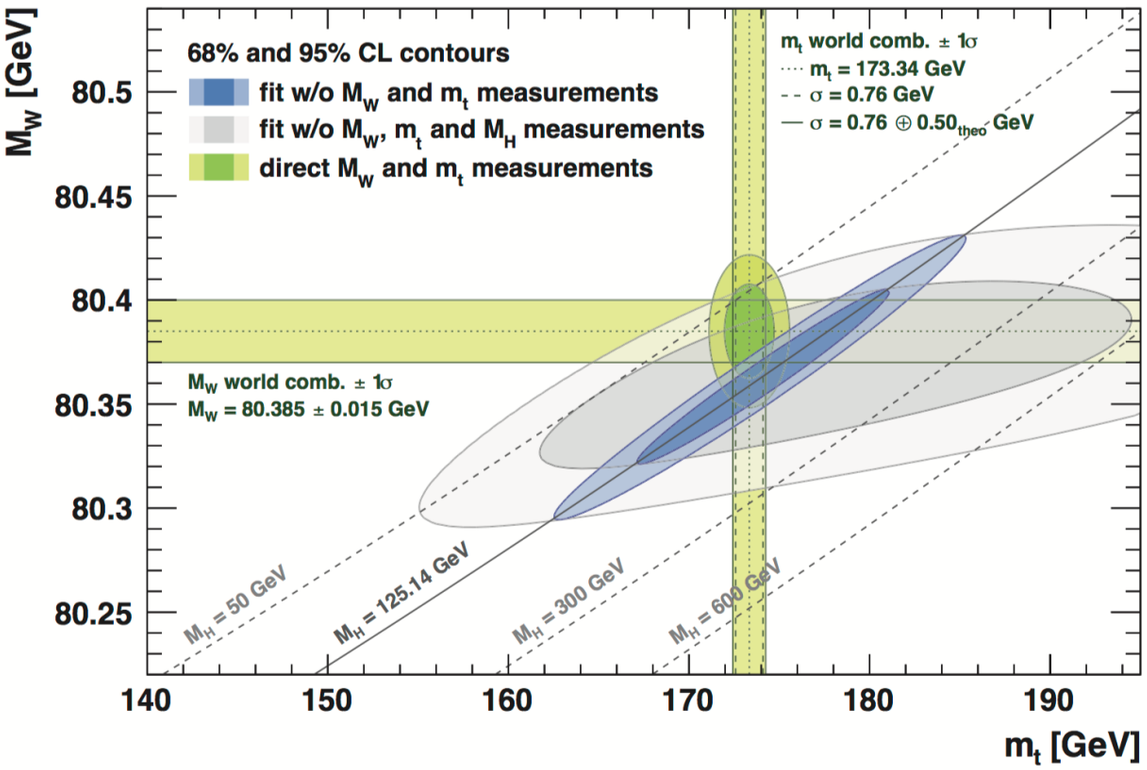


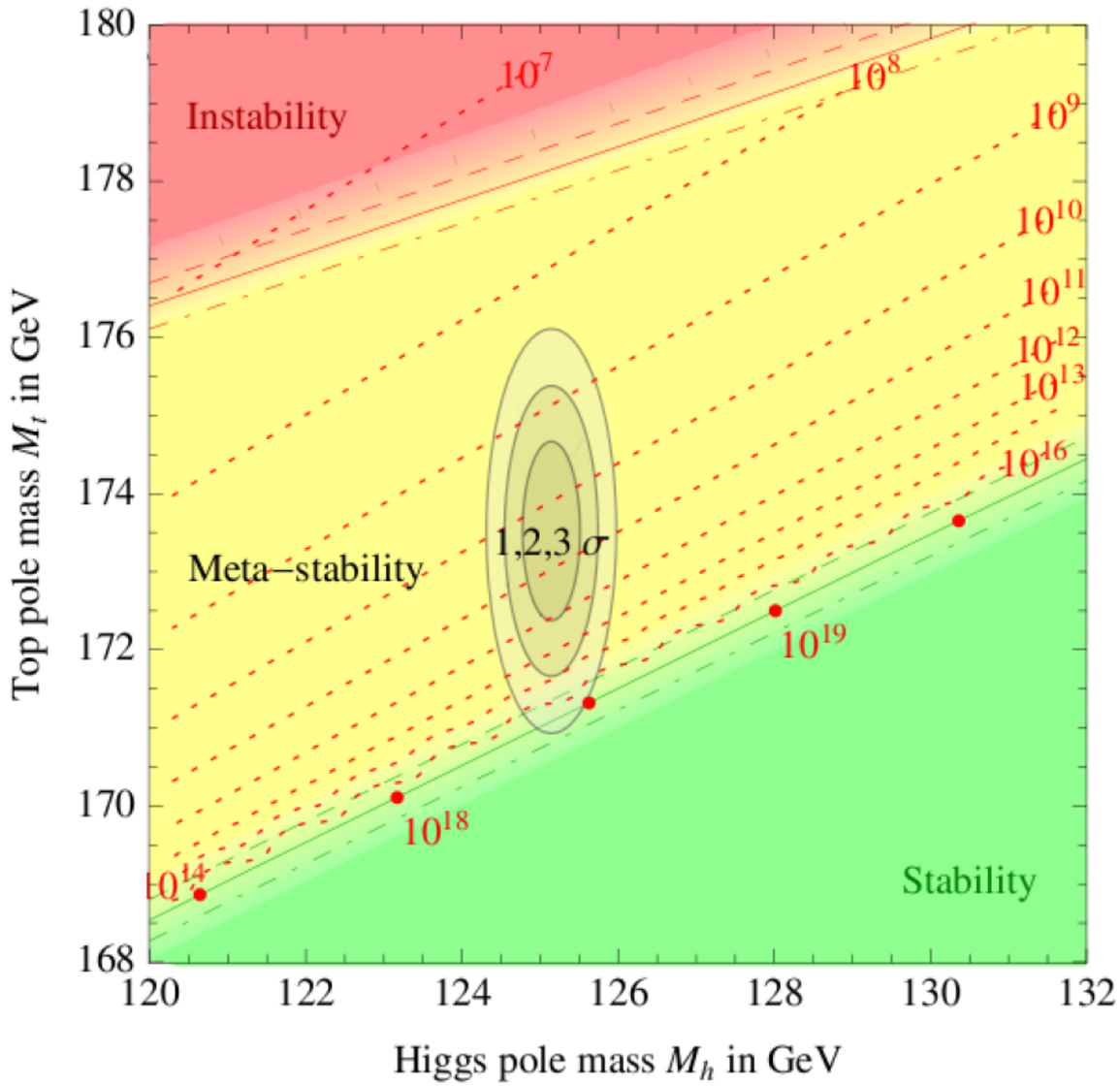
ATLAS (**A** **T**oroidal **L**hc **A**pparatu**S**):

- Onion-like detector: inner detector, electromagnetic and hadronic calorimeters, muon spectrometer
- Integrated luminosity for Run2: 2015+2016 (36fb^{-1}), 2017 (86.3fb^{-1}), 2018 (148.5fb^{-1})
- HL-LHC: $\sqrt{s}$ = 14 TeV; integrated luminosity till 2035 (3000 fb^{-1})

Top quark mass

- **The top quark mass is a fundamental parameter of the standard model**
  - Relation with the W and H masses: test the coherence of the standard model
  - Relation with the vacuum instability: possible that the Higgs potential is in a meta-stable state after the symmetry breaking, and is going to stable phase via a tunnel effect.





- **What are we really measuring?**
  Because of the radiative corrections, the mass that we measure is still a matter of debate, is it the pole mass (calculated from cross sections measurements) or a MC mass (defined in the top quark decay of the Monte Carlo generator) ?

Experimental measurements

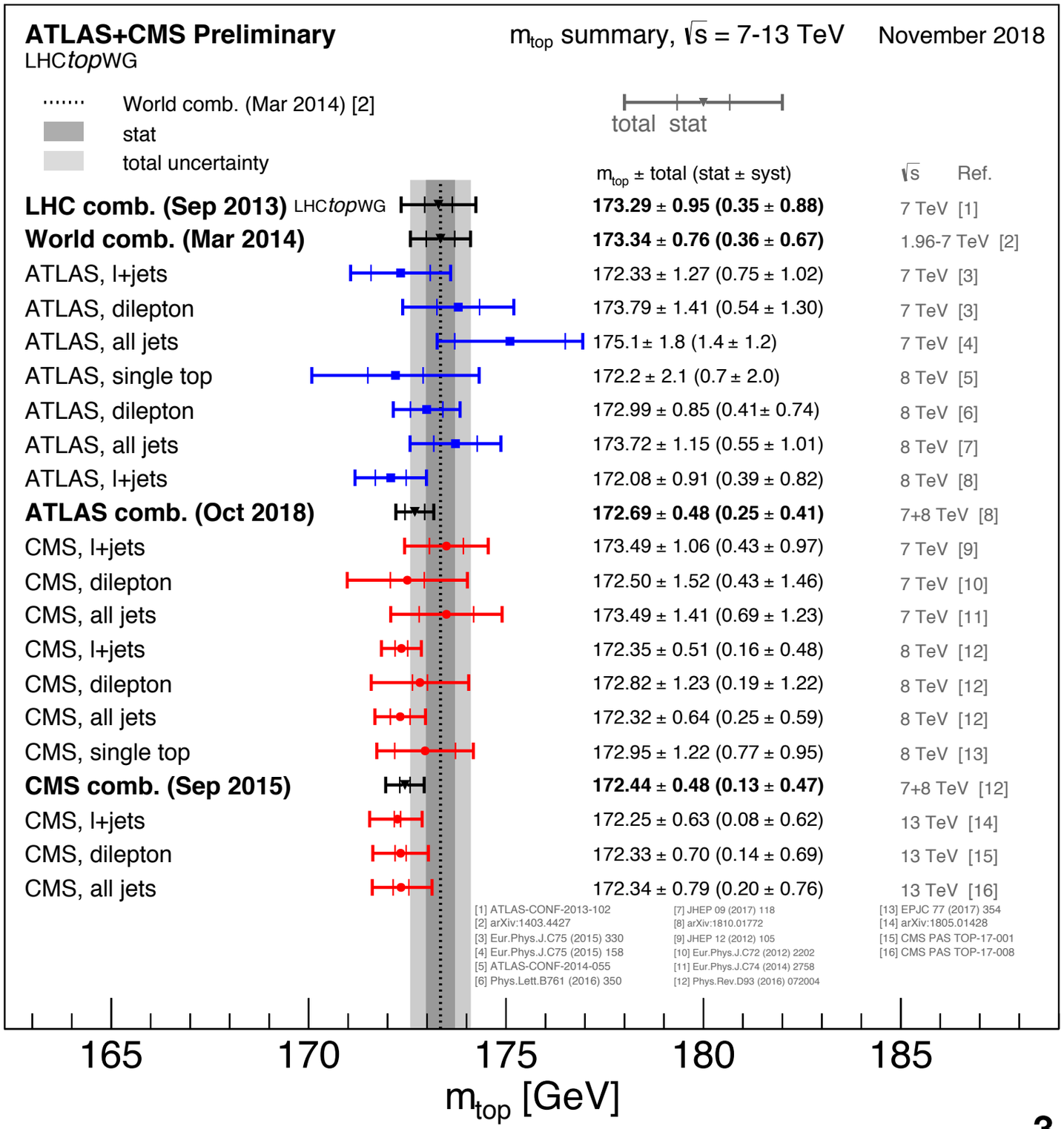
- m_t = 173.34 ± 0.36 (stat.) ± 0.67 (syst.) GeV (World Comb. 2014)

- σ(syst.) limited by our knowledge of the Jet Energy Scale (JES)

- σ(syst.) is also limited by some modeling uncertainties

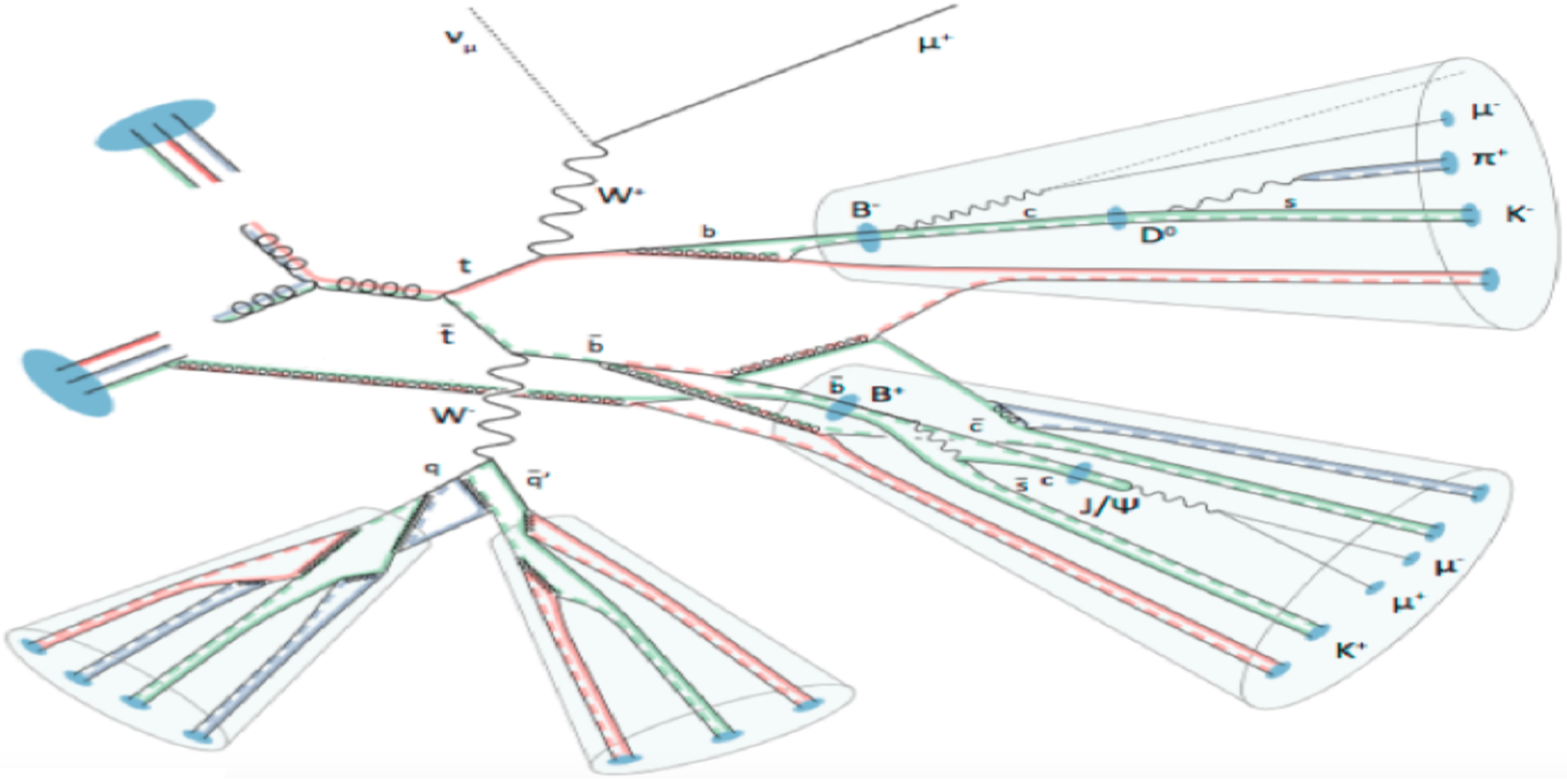
- Solution: Use alternative methods (non-jet based direct reconstruction measurement) and calculate the invariant mass $M_{lepton+X}$, X being inside a b-jet:
  - soft muon
  - J/ψ mesons
  - D mesons

⟶ less sensitive to the JES, but sensitive to the modeling of the b quark disintegration



Top quark production and decay modes

- The most massive elementary particle ⟶ important coupling to the Higgs boson
- Very short lifetime ($\tau \sim 5 \times 10^{-25}$ s) ⟶ decays before hadronization ($\tau \sim 2 \times 10^{-24}$ s) ⟶ possibility of studying this quark as a bare quark
- 2 production modes: $t\bar{t}$ pairs (~ 75 %), single top (~ 25 %)
- t ⟶ Wb ~100%, decay channels: fully hadronic (46%), leptons+jets (44%), dileptons (10%)



Final state considered : $J/\psi, BR(b \to J/\psi \to \mu^+\mu^-) \sim 7 \cdot 10^{-4}$

$D^0, BR(b \to \mu D^0 \to \mu K\pi) \sim 5.9 \cdot 10^{-3}$

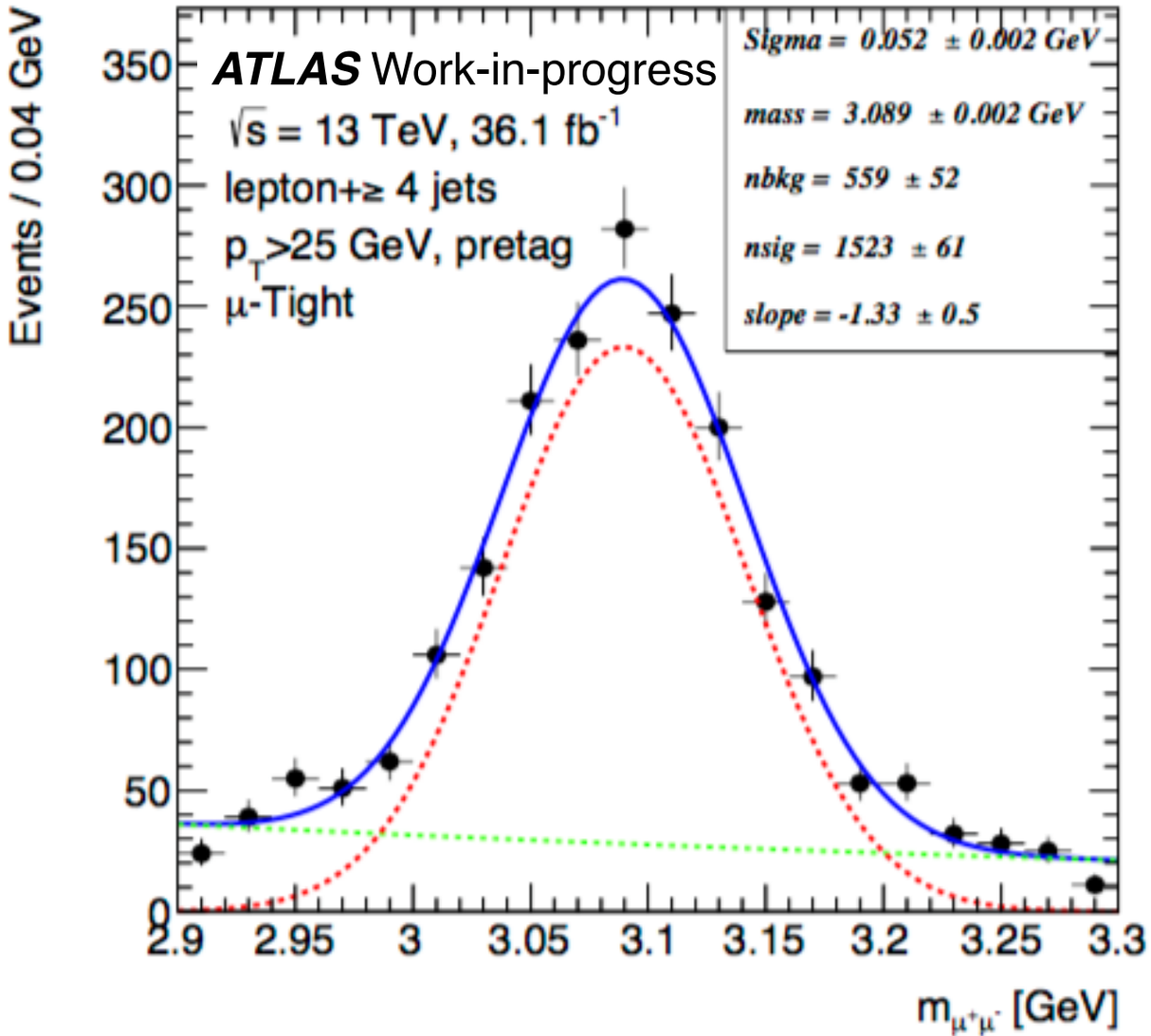
$D^*(2010)^+, BR(b \to D^*(2010)^+ \to D^0\pi) \sim 2.2 \cdot 10^{-2}$

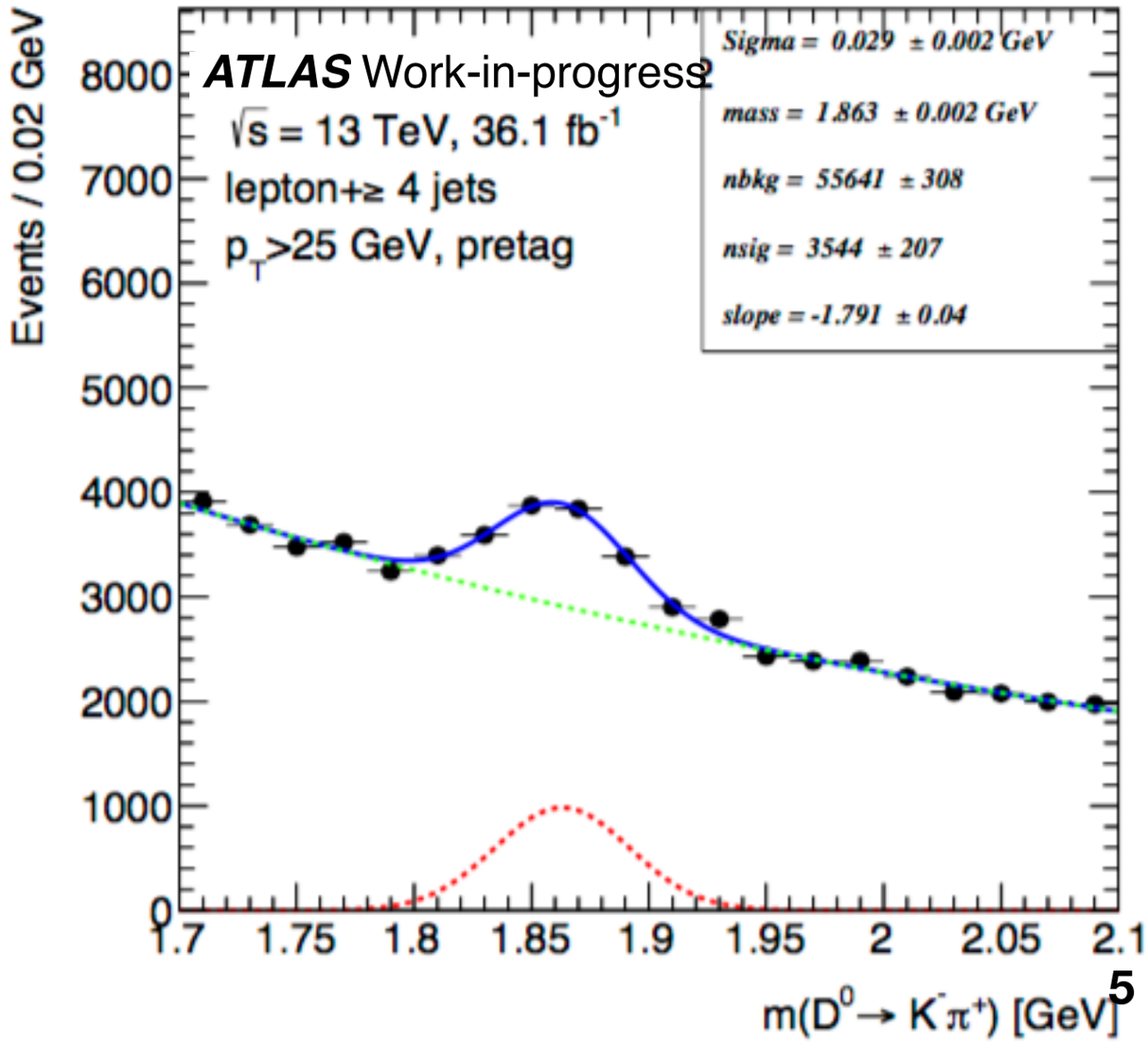
Reconstruction of charmed mesons (Run2)

We select lepton+jets events in data and in MC (tt, single top, and other backgrounds)

2 soft μ with opposite electric charges
1 cand. in $2.9 < m(\mu\mu) < 3.3$ GeV
$p_T(J/\psi) > 8$ GeV
$\tau(J/\psi) > 0$ ps
1523 J/ψ

A soft μ with three leading p_T tracks
μ and K the same electric charge
Permutations for K and π candidates
$p_T(trk_1)$, $p_T(trk_2) > 3$ GeV
1 cand. in $1.7 < m(trk_{1,2}) < 2.1$ GeV
$p_T(D^0) > 8$ GeV
3544 D^0





Reconstruction of charmed mesons

- CERN yellow report for the beginning of 2019, it gathered all the analyses (ATLAS/CMS/theorists) projected with the HL-LHC data at 14 TeV (luminosity 3000 fb^{-1})
- Only ATLAS top quark mass uncertainty projection prepared for the Yellow Report

arXiv:1902.04070v2 [hep-ph]

Preselection:

Leptons: pT>25 GeV and |η| < 4

Jets: pT>25GeV and |η| < 4.5

First selections:

2 soft μ with opposite electric charges

no refit to a common vertex

6×10^6 dimuon pairs at this level

Final selections:

1 cand. in $2.9 < m(\mu\mu) < 3.3$ GeV

$\Delta R(\mu, jet) < 0.5$, $\Delta R(\mu, \mu) < 0.8$

$p_T(J/\psi) > 8$ GeV, $\tau(J/\psi) > 0$ ps

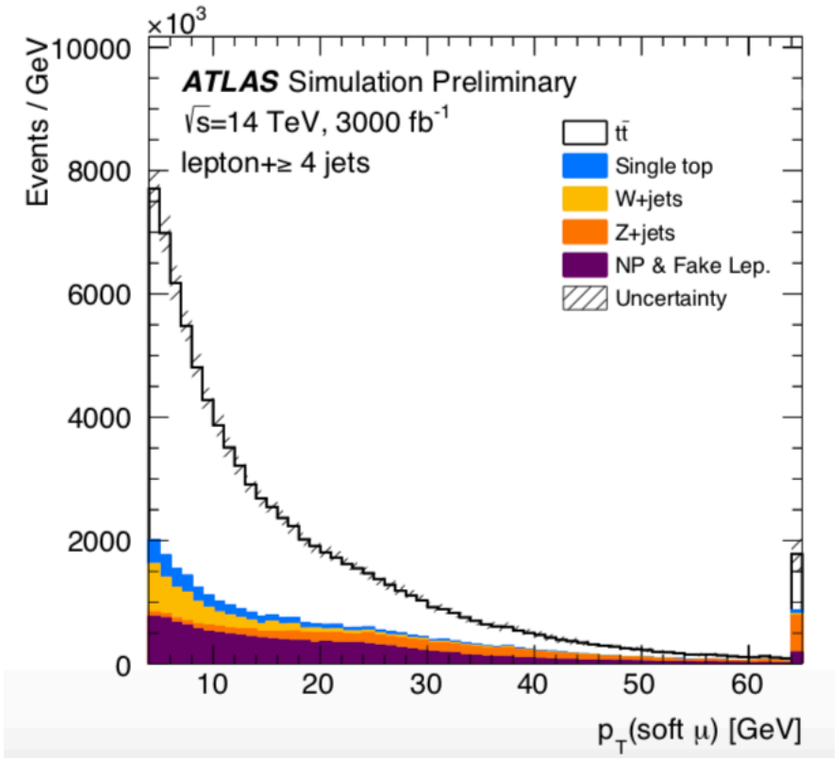
2×10^5 candidates

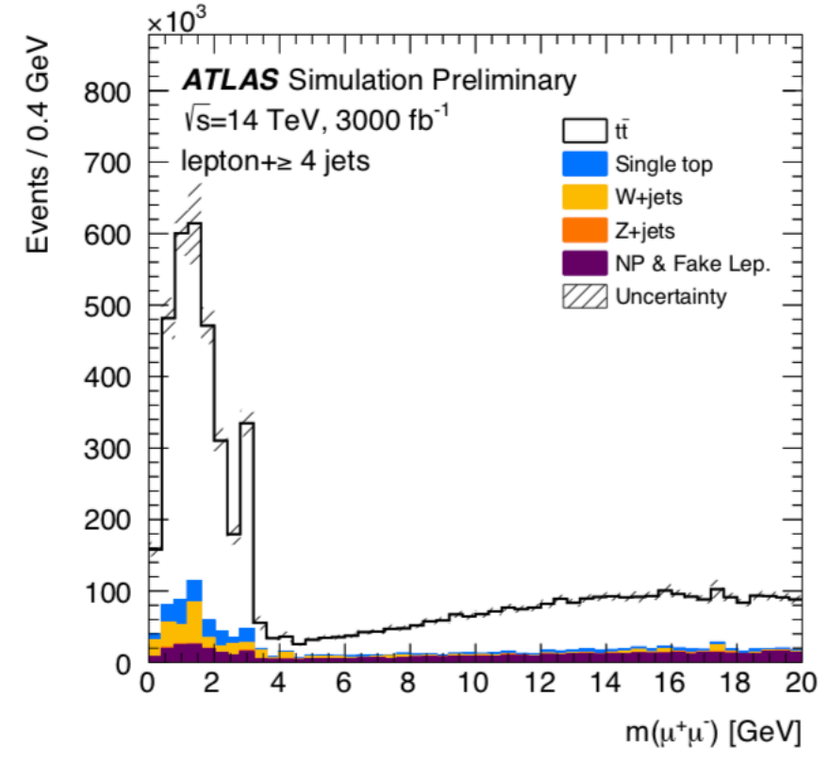
Event rate: ~70 events per fb^{-1} at 14 TeV.

Increase in events:

18% higher (due to higher cross-section)

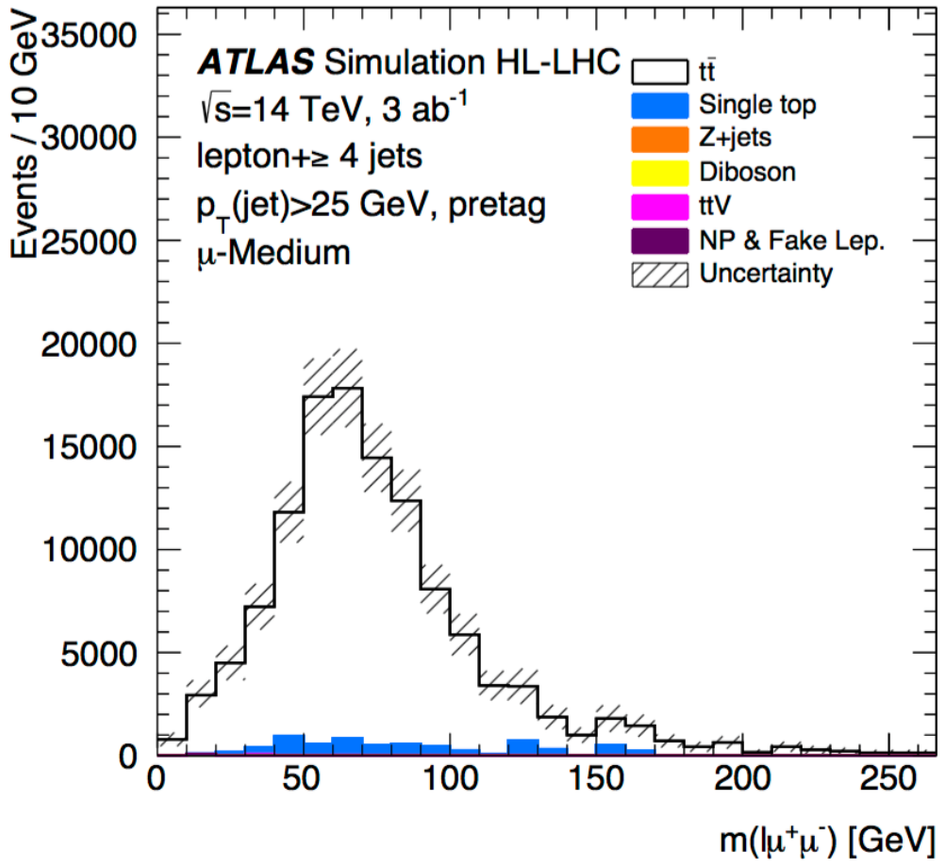
10% more events (due to increase in |η| coverage)

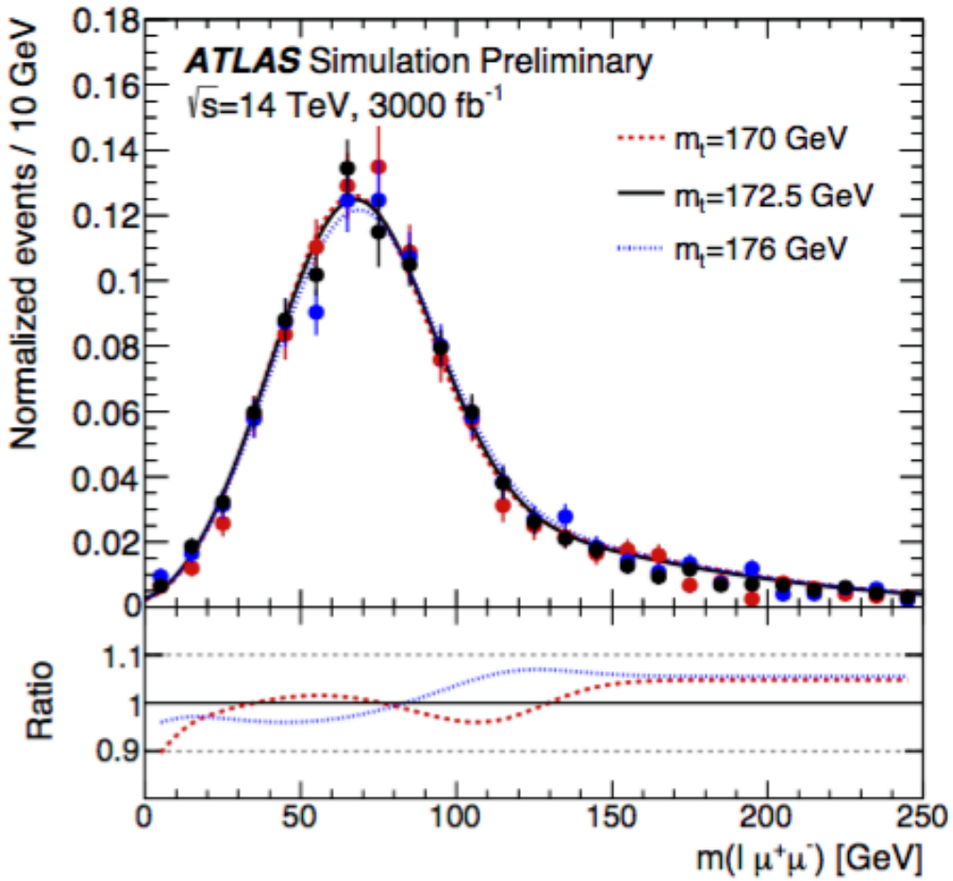




Top quark mass measurement for HL-LHC

- The mass of the system (isolated lepton+charmed meson) is sensitive to the top quark mass
- Build templates each one having a different m_{top} prediction + calibration





- Systematic uncertainties:
- modeling : MC tt samples: generator + hadronization + b-fragmentation + b-production
- detector: ~100 variations of the analysis by changing energy, resolution, efficiencies, etc…

Projection of uncertainties of mtop (HL-LHC): Yellow report

"Standard Model Physics at the HL-LHC and HE-LHC" arXiv:1902.04070v2 [hep-ph]

Projection to 3000 fb^{-1} based on preliminary results from 2015+2016 studies with a J/ψ or a soft muon in the final state (***ATL-COM-PHYS-2017-1116***)

Statistical uncertainty: 0.14 GeV

Systematic uncertainty: 0.48 GeV

modeling :
dominated by b- fragmentation and production

experimental :
dominated by JES

Total syst. uncertainty ~0.5 GeV :
⟶ dominated by systematics
⟶ trade some of statistical uncertainty with syst. uncertainty to get a lower syst.

Source of uncertainty	$\sigma(m_{\text{top}})$ [GeV]
Statistical uncertainty	0.14
Method uncertainty	0.11
Signal modelling uncertainties	
$t\bar{t}$ NLO modelling	0.06
$t\bar{t}$ PS and hadronisation	0.05
$t\bar{t}$ b-production	0.24
$t\bar{t}$ b-fragmentation	0.11
Initial- and final-state radiation	0.04
Underlying event	0.02
Colour reconnection	0.02
Background modelling uncertainties	0.10
Experimental uncertainties	
Jet energy scale (JES)	0.31
b-jet energy scale (b-JES)	0.06
Jet energy resolution (JER)	0.13
Jet vertex fraction	0.02
Electrons	0.03
Muons	0.09
Pile-up	0.04
Total Systematic uncertainty	0.48
Total	0.50

Conclusions

Top quark mass is an important parameter of the standard model

m_t = 173.34 ± 0.36 (stat.) ± 0.67 (syst.) GeV (World Comb. 2014)

Alternative methods: Select a soft-μ, a J/ψ or D mesons in the final state
⟶ not sensitive to the JES, but to the b-quark disintegration

Full Run 2 analysis is in progress ⟶ end of thesis 2020

Projection of uncertainties done for the Yellow Report:
- Done using soft-μ and J/ψ analyses
- dominated by systematics related to b (as expected)
- σ(total) = 0.5 GeV; σ(stat.) = 0.14 GeV; σ(syst.) = 0.48 GeV
- CMS results:
  σ(total) = 0.58 GeV; σ(stat.) = 0.24 GeV; σ(syst.) = 0.53 GeV