# Top quark mass measurements using $t\bar{t} + 1jet$ events in the ATLAS detector at 7, 8 and 13 TeV

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## The Standard Model

The Standard Model (SM) of particle physics (Fig.1) is the theoretical framework which describes the interactions among particles at subatomic level.

The SM assumes that matter and its interactions can be described by elementary particles which do not have structure and are characterized by their quantum numbers.

The SM is a powerful theory that describes a huge variety of physics processes. However, it has limitations that point to the need for searching more complete theories.

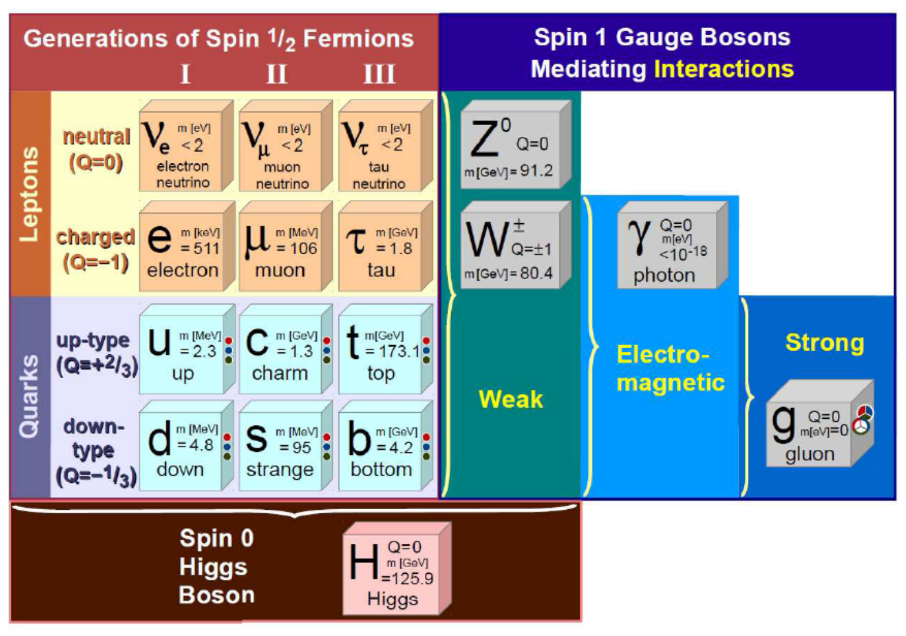

Figure 1: SM elementary particles and their properties

## The ATLAS detector

In order to test the SM and search for physics beyond it several experiments have been carrying on. The data used in this analysis has been produced in pp collisions at the LHC and collected by the ATLAS experiment (Fig.2).

The ATLAS experiment at the CERN Large Hadron Collider (LHC) is a multi-purpose particle detector with a forward-backward symmetric cylindrical geometry. I is 44x25 m and it is made of layers of sub-detectors.

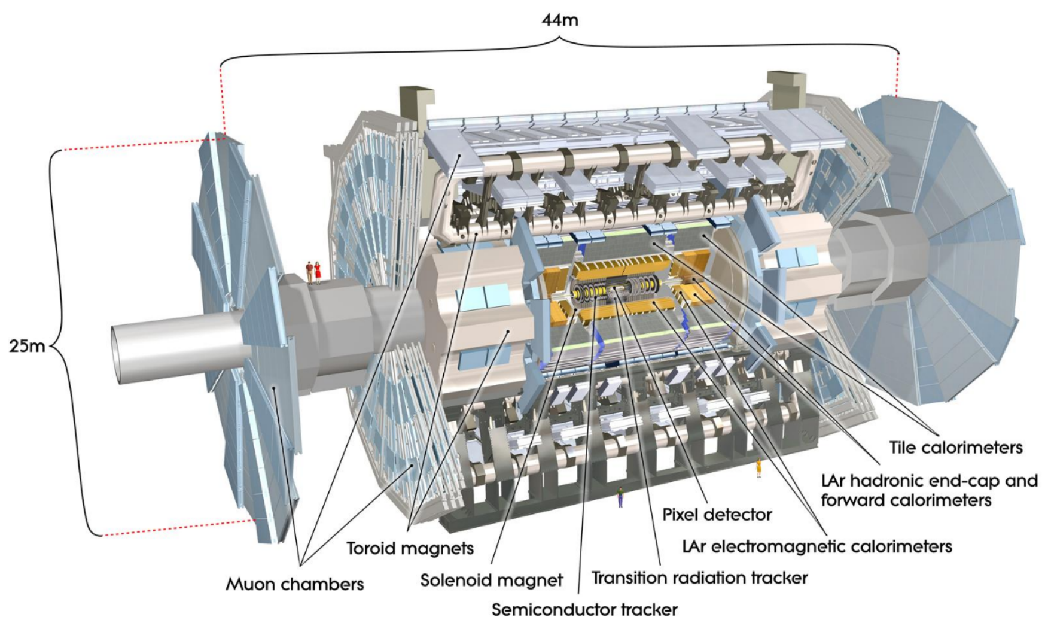

Figure 2: The ATLAS detector with all its sub-detectors labeled

## Importance of a precise top quark mass measurement

The top quark mass is one of the fundamental parameters in the SM and a high precision measurement of this quantity has a great importance by its own. Furthermore, an increase in the precision is key to test the validity of the SM and plays an important role in the search for BSM physics. Figures 3 and 4 show two of these tests that highly depend in the top quark mass measurement.

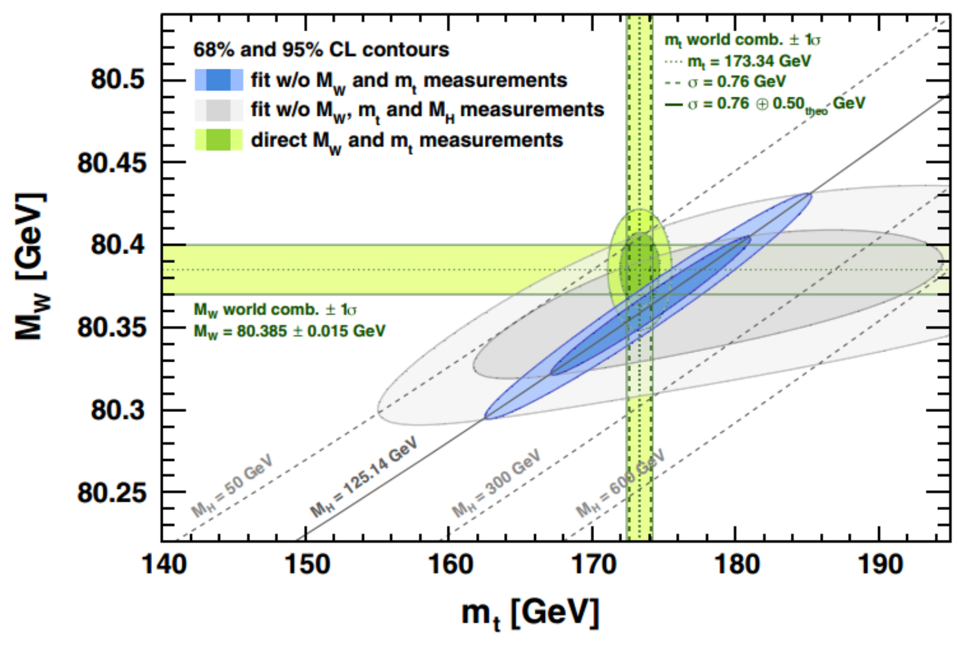

Figure 3: Higgs, W and top quark mass compatibility within the SM.

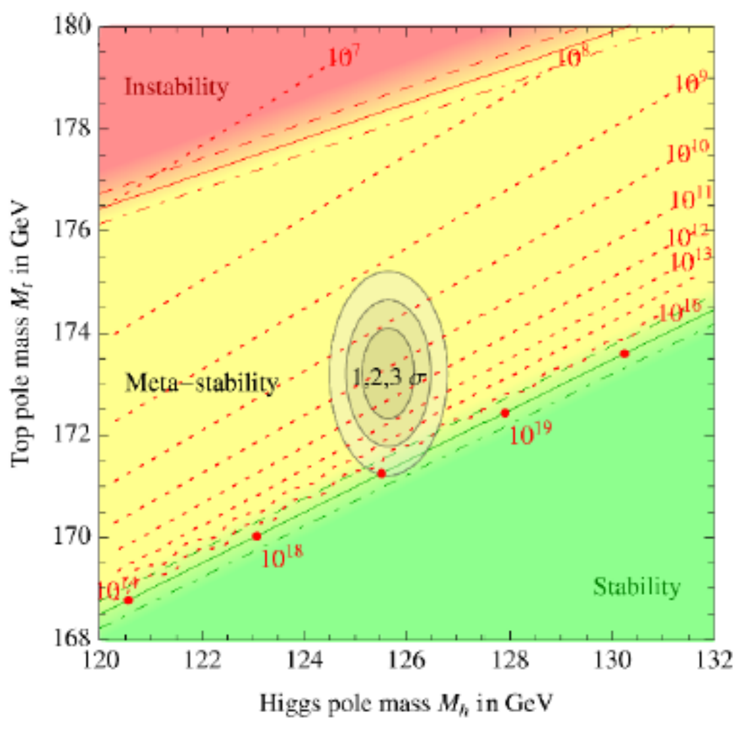

Figure 4: Regions of stability and instability of SM vacuum in the $m_{top}$-$M_H$ plane.

The most precise methods to measure this quantity are based on the kinematic reconstruction of top decay products and have reached a precision of $\Delta m_{top} \leq 1$ GeV. However, these methods have a theoretical uncertainty associated with their interpretation which is estimated to be between 0.5 and 1 GeV. Alternative methods with a good theoretical definition as well as a good experimental precision are needed.

## Observable definition with $t\bar{t} + 1jet$ events

A novel method that has been used to measure the top quark mass was defined for the first time in Ref. [1]. It extracts the top quark mass from the (normalized) differential distribution of the $t\bar{t} + 1jet$ cross section with respect to the inverse of the invariant mass of the final state ( $\sqrt{s_{t\bar{t}+1jet}}$ ). More formally, the following dimensionless distribution is used:

$$\mathcal{R}(m_t^{pole}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1jet}} \frac{d\sigma_{t\bar{t}+1jet}}{d\rho_s}(m_t^{pole}, \rho_s)$$

where $\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1jet}}}$ and $m_0$ is set to $m_0 = 170$ GeV . The extra jet is required to have a $p_T > 50$ GeV to make the observable infrared safe.

The $\mathcal{R}$ observable has been computed at next to leading order (NLO) in quantum chromodynamics (QCD) in well defined mas schemes [1, 2] .The shape of the observable as well as its sensitivity to $m_t$ is shown in Fig.5 and Fig.6 . The extra jet in the topology greatly improves the sensitivity in the top quark mass.

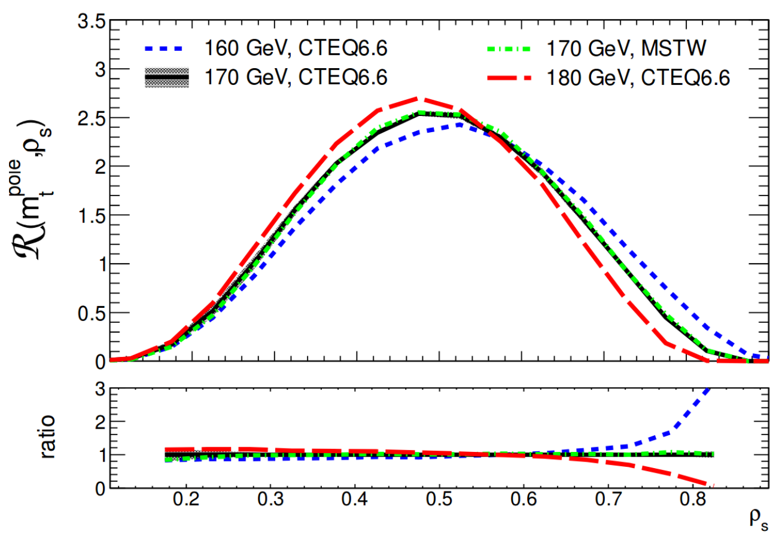

Figure 5: Normalised differential cross section $\mathcal{R}(m_t^{pole}, \rho_s)$ calculated at 7 TeV for different masses and PDF sets.

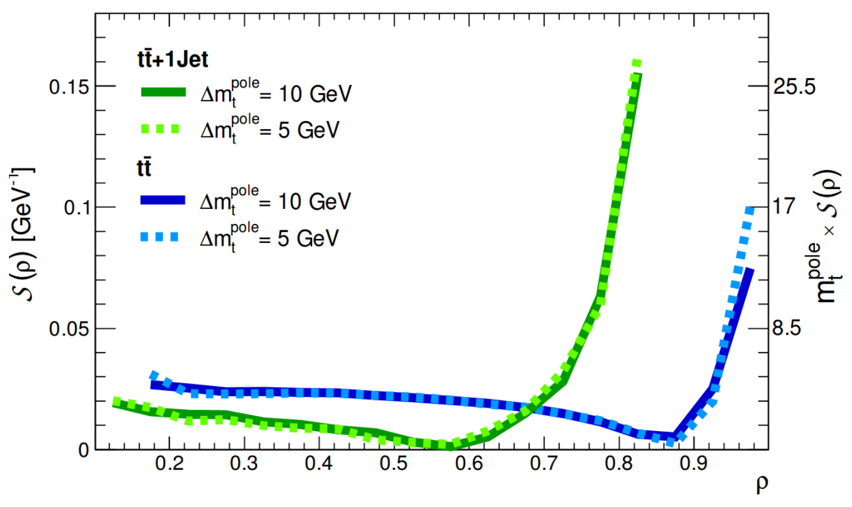

Figure 6: Sensitivity of $\mathcal{R}(m_t^{pole}, \rho_s)$ to the top quark mass. This sensitivity is compared to a similar observable that use the $t\bar{t}$ topology.

## Top quark mass measurement results at 7 and 8 TeV

The first measurement of the top-quark pole mass with this method was performed using the data produced in 7 TeV pp collisions at the LHC and collected by the ATLAS detector, corresponding to a luminosity of L = 4.6 fb$^{-1}$ [3]. The resulting distribution for the observable is shown in Fig.7 and the extracted top quark mass was:

$$m_t^{pole} = 173.7 \pm 1.5(\text{stat.}) \pm 1.4(\text{syst.})^{+1.0}_{-0.5}(\text{theory})\ \text{GeV}$$

A recent analysis using the data at a center of mass energy of 8 TeV has been recently published [4]. The resulting measurement improved all the sources of uncertainties due to an increase in the luminosity (L = 20.2 fb$^{-1}$), a better understanding of the ATLAS detector and an optimisation of the methodology. The resulting distribution is shown in Fig.8 and the extracted top quark mass was:

$$m_t^{pole} = 171.1 \pm 0.4(\text{stat.}) \pm 0.9(\text{syst.})^{+0.7}_{-0.3}(\text{theory})\ \text{GeV}$$

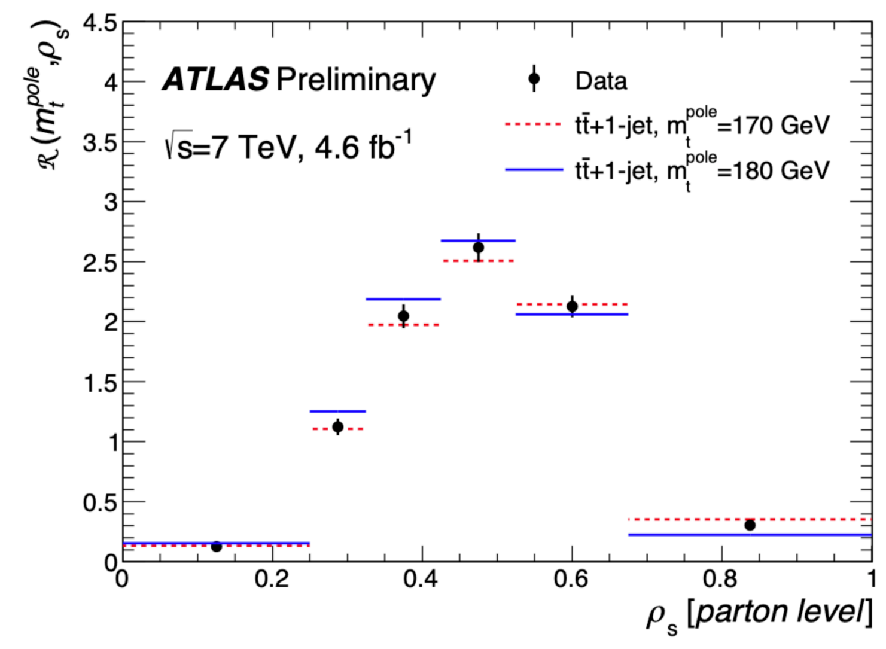

Figure 7: Final $\mathcal{R}(m_t^{pole}, \rho_s)$ distribution for the 7 TeV measurement in [3].

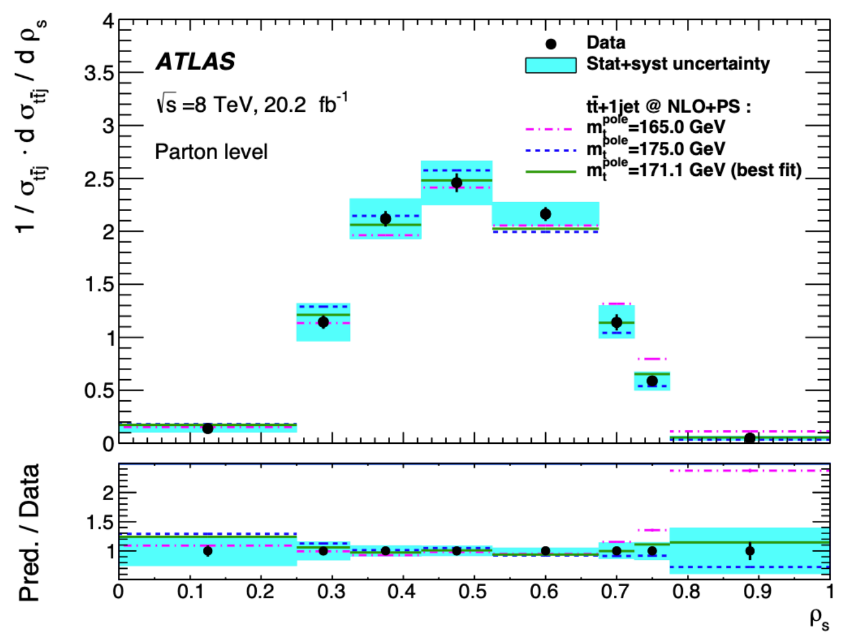

Figure 8: Final $\mathcal{R}(m_t^{pole}, \rho_s)$ distribution for the 8 TeV measurement in [4].

## Prospects for a 13 TeV measurement

The 13 TeV analysis is currently ongoing for the semileptonic and dileptonic final state of the $t\bar{t} + 1jet$ system. Unfortunately, the ATLAS data and MC can not be shown until the final result is published. Nevertheless, Fig.9 and 10 show how the observable behaves at 13 TeV . These plots have been produced at the generator level without detector simulation.

The total integrated luminosity of the 13 TeV run is much larger than in the previous runs (L = 150 fb$^{-1}$). This increase in luminosity plus the increase in the $\sigma_{t\bar{t}+1jet}$ cross section at 13 TeV has lead to $\sim 30$ times more events than in the previous measurement. In addition, several changes in the methodology have been introduced. For example, a new event reconstruction algorithm (KLFitter) and new calculations of the MC events using a dynamic estimation of the factorisation and renormalisation scales of QCD are being tested. We expect that these changes will improve all the uncertainty sources (in our examples, stat. , syst. and theory respectively). Our goal is to reach a precision between 0.5 and 1 GeV using the full 13 TeV Run 2 ATLAS dataset.

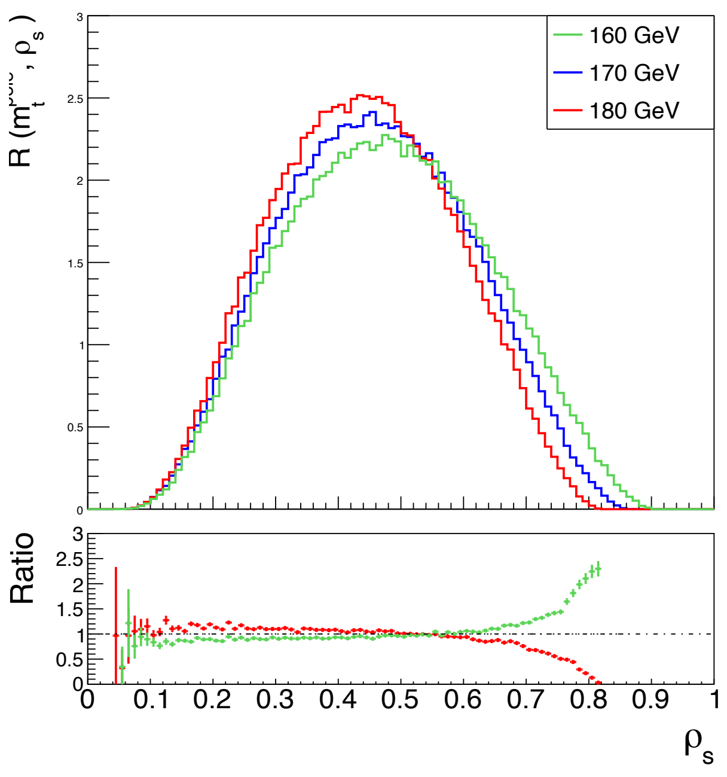

Figure 9: Normalised differential cross section $\mathcal{R}(m_t^{pole}, \rho_s)$ calculated at 13 TeV for different masses.

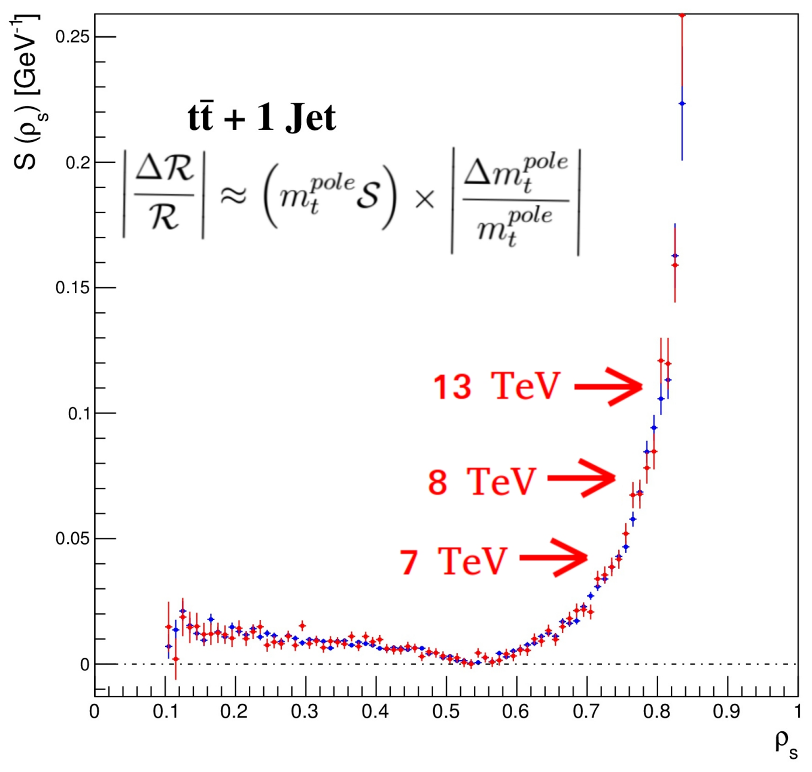

Figure 10: Sensitivity of $\mathcal{R}(m_t^{pole}, \rho_s)$ to the top quark mass using 13 TeV simulated data. The red arrows represent the increase in the sensitivity in each analysis.

### References

[1] Simone Alioli, Patricia Fernandez, Juan Fuster, Adrian Irles, S Moch, Peter Uwer, and Marcel Vos. A new observable to measure the top-quark mass at hadron colliders. The European Physical Journal C, 73(5):2438, 2013.

[2] J Fuster, A Irles, D Melini, P Uwer, and M Vos. Extracting the top-quark running mass using $t\bar{t}$+ 1-jet events produced at the Large Hadron Collider. The European Physical Journal C, 77(11):794, 2017.

[3] ATLAS Collaboration. Determination of the top-quark pole mass using $t\bar{t}$ + 1-jet events collected with the ATLAS experiment in 7 TeV pp collisions. CERN-PH-EP-2015-100.

[4] ATLAS Collaboration. Measurement of the top-quark mass in $t\bar{t}$ + 1-jet events collected with the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV. Journal of High Energy Physics, 2019(11)