Top quark mass measurement from b-jet energy spectrum

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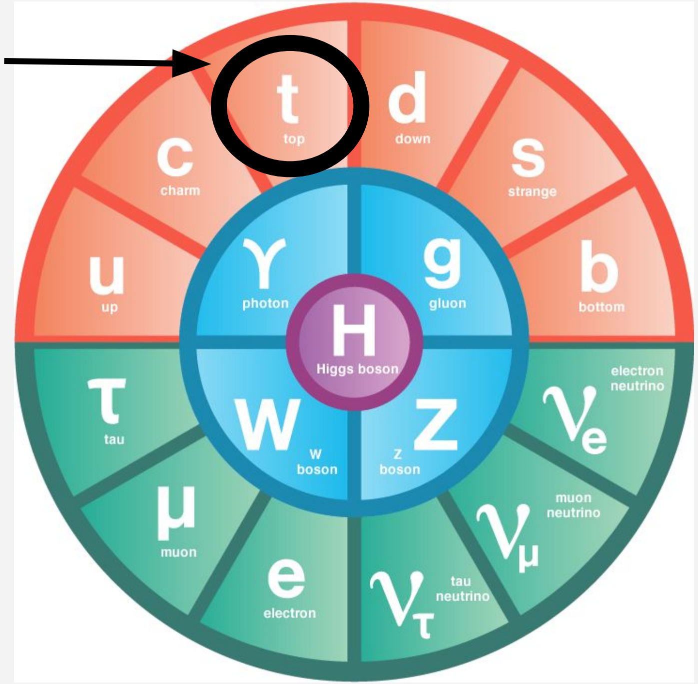
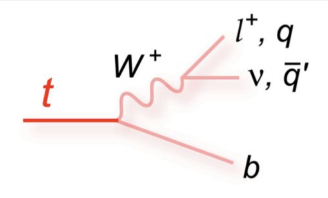
Problem Overview

- Why Top quark mass is important to measure?
  - Standard Model parameter
  - It provides an indirect constraint on m_W
- Normally, we would measure the top quark mass by reconstructing the kinematics of the top decay products (for example this analysis)
- However, in this analysis, we measure it through the **b-jet energy spectrum**



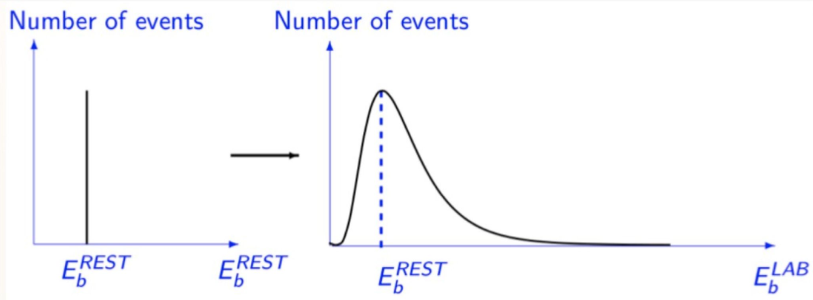
Setup



- The top-quark is the only fermion heavy enough to produce an on-shell W boson in its decay hence allowing a 2-body electroweak decay
- We can derive a simple relation between the masses of the 3 particles involved:

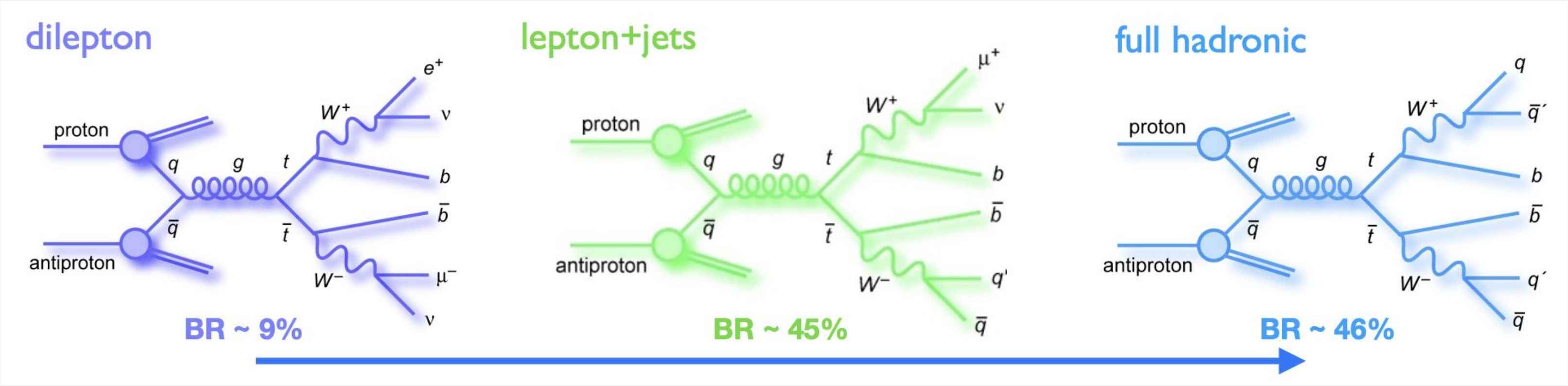
$$m_t = E_b^{\text{Rest}} + \sqrt{m_W^2 - m_b^2 + E_b^{\text{Rest}\,2}}.$$

- Assuming the top to be unpolarized, the peak position of the b-quark energy distribution in the lab frame [can be shown](#) to be independent of the boosts of the top quarks and hence related to the peak position in the top rest frame → allows us to use E_b^{Rest} to measure m_t



Physics Process

- There are 3 possible modes:



→ We will focus on the eμ dilepton channel (because it's the cleanest and easiest)

- Backgrounds
  - Main background: single top-quark production in association with a W boson (tW)
  - Other backgrounds: W+jets, Drell–Yan, diboson, and tt +boson

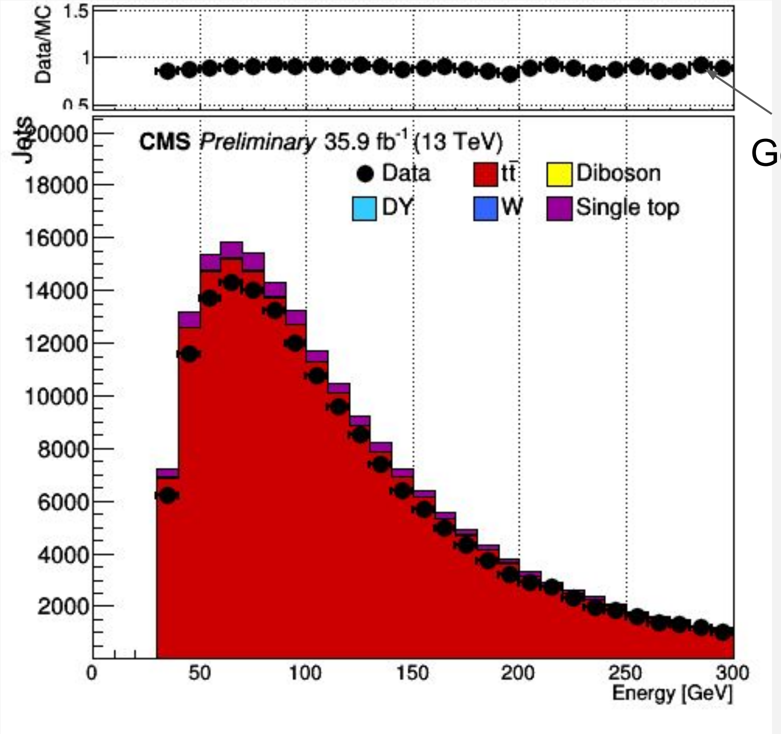
Event Selection

- Triggers:
  - Mu8_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL
  - Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL
- Leptons:
  - 1 isolated muon & 1 isolated electron
  - Opposite charge → constrained by charge conservation
  - p_T>20GeV and $|\eta|\leq 2.4$ → to remain within detector coverage
  - $M_{e\mu}$>12GeV → to remove DY->tautau->eμ background events
- Jets:
  - njets≥2 with p_T>30GeV and $|\eta|\leq 2.4$
  - 1 or 2 b-tagged jets (IVF>0.8484) → to accommodate imperfect b tagging efficiency

Data MC comparison

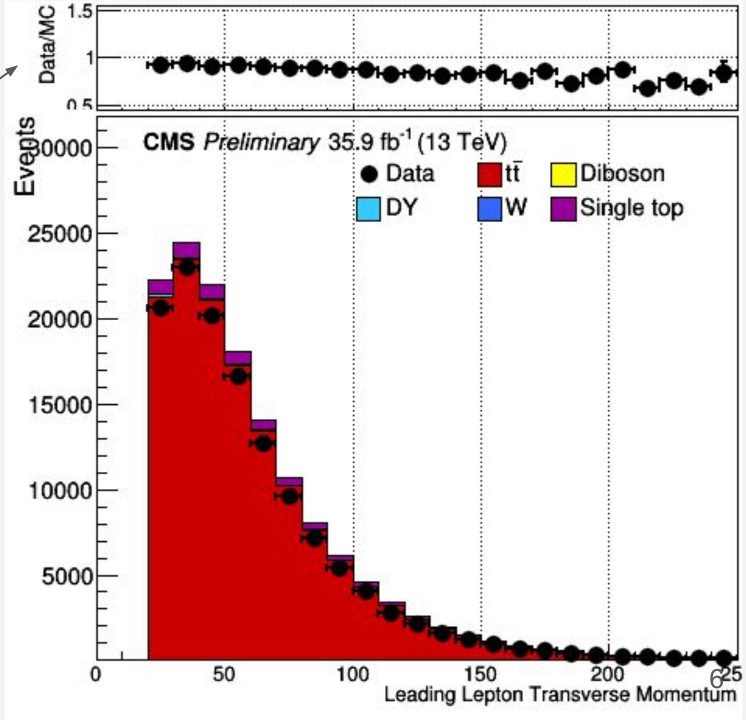
Majority of events after cuts is t-tbar signal 👍

B-Jet Energy



Good MC agreement

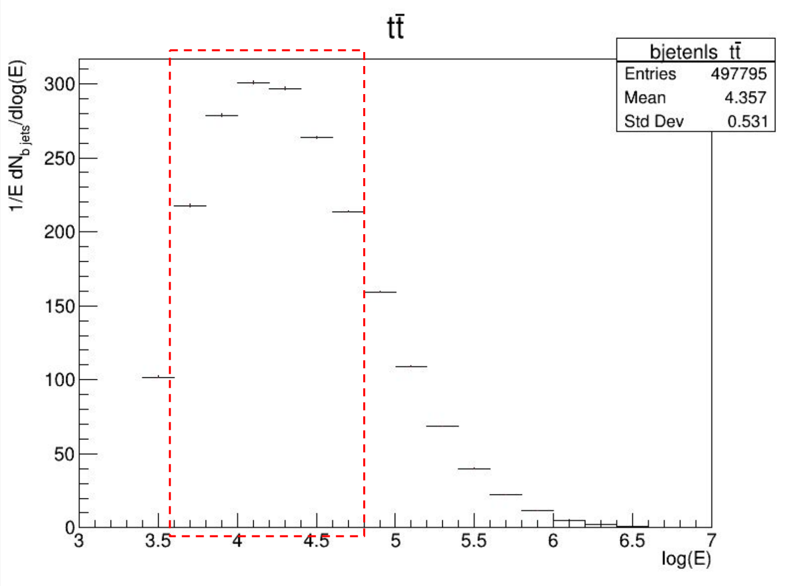
Lepton p_T

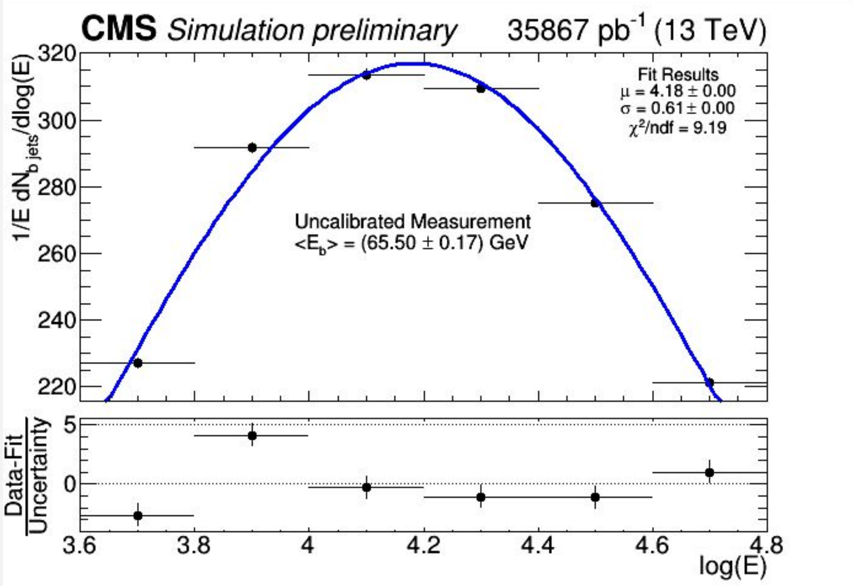


Fit Calibration

MC simulation, using top mass of 172.5 GeV.

- Gaussian Fit → Mean used as the measurement of B-jet energy (E_b)
- Measure E_b and compare with the expected value
- Calibrate the measured value accordingly





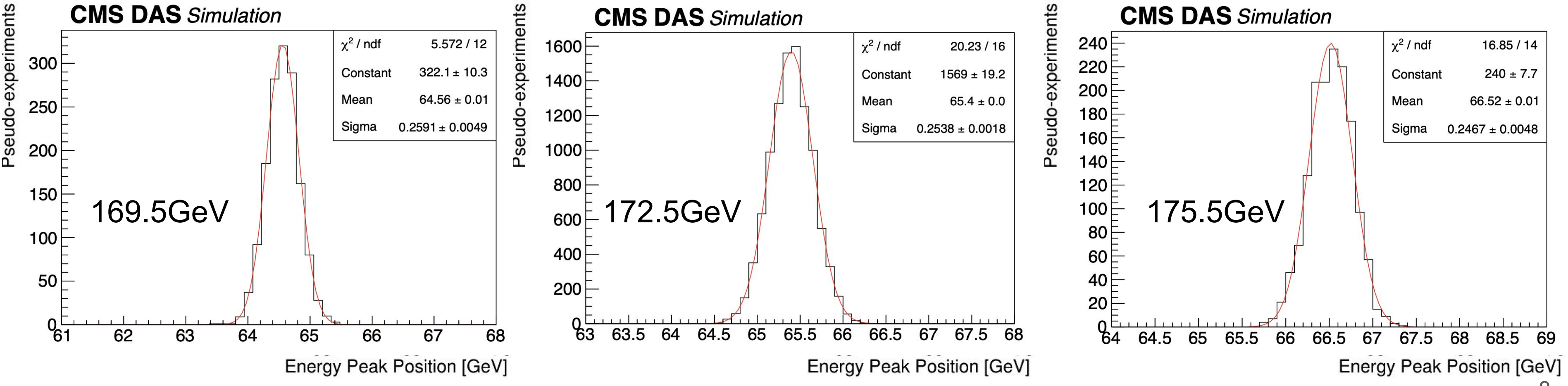
region is approx. Gaussian

Fitting the b-jet energy spectrum

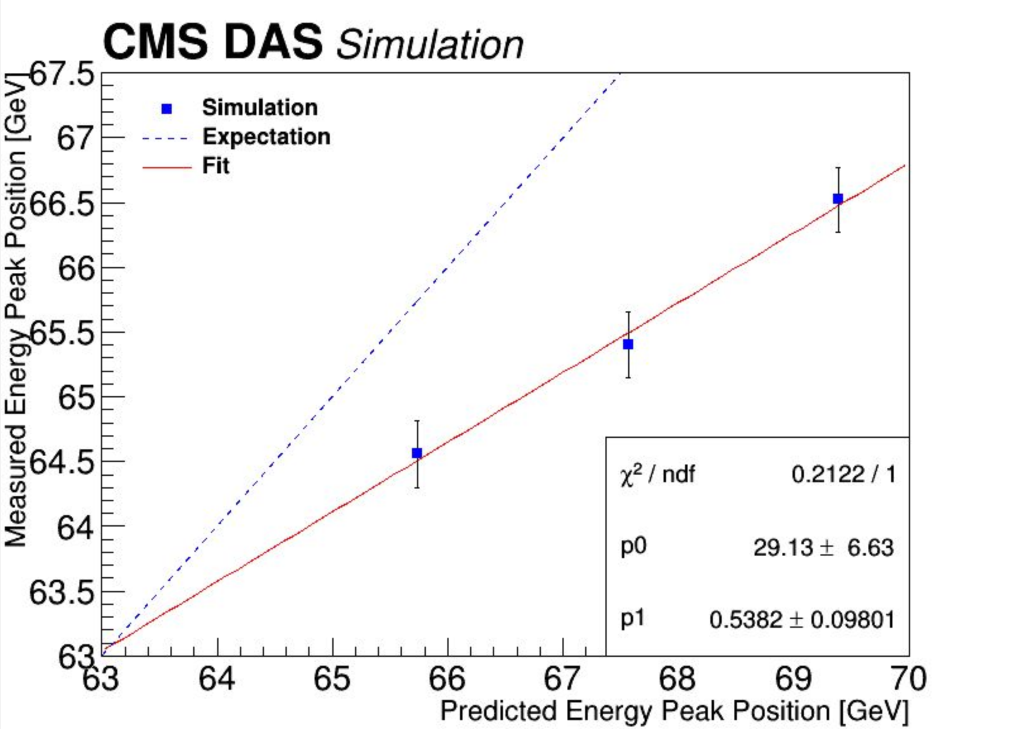
$$E_{b,peak} = \frac{m_b^2 - m_W^2 + m_t^2}{2m_t^2}$$

Pseudo Experiments

- MC simulations for 3 different values of top masses
- Apply Poissonian fluctuations to the measurement using MC ~ 1500 times
- Obtain 1500 means, fit with Gaussian



Fit of the Calibration Function



Expectation: $E_{b,measured} = E_{b,theoretical}$

Bias is introduced in the event selections and B-jet energy measurements. We account for the difference in theoretical vs. measured and create a linear calibration function.

$$E_{b,measured} = p_0 + p_1 * E_{b,theoretical}$$

$$\downarrow$$

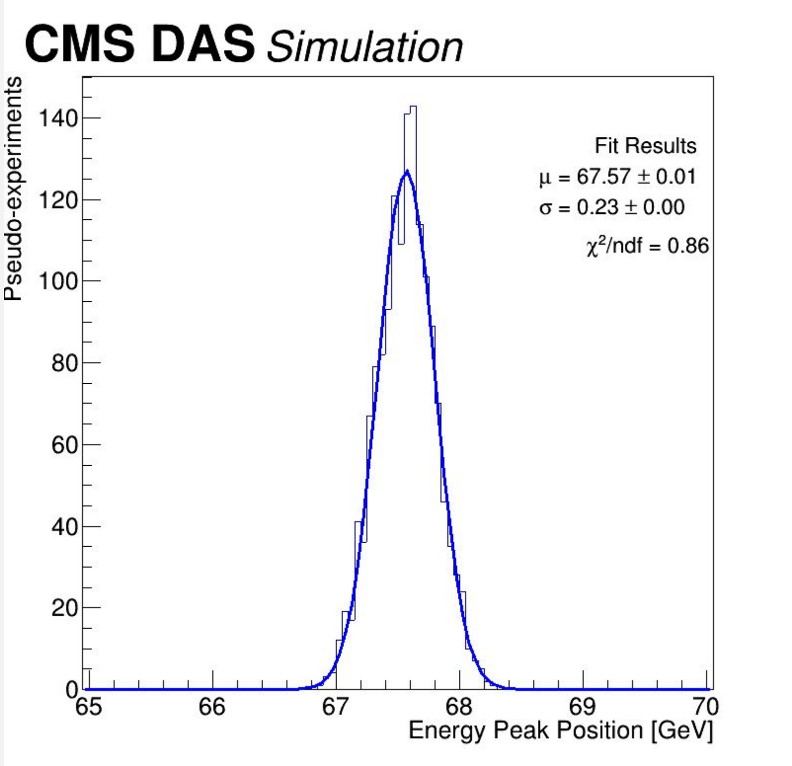
$$E_{b,theoretical} = \frac{E_{b,measured} - p_0}{p_1}$$

Closure Test

$$E_{b,theoretical} = \frac{E_{b,measured} - p_0}{p_1}$$

Closure test on MC sample

- Theoretical: 67.57 GeV
- Measured: 67.57 GeV



Systematics & results

Experimental sources of uncertainties –

- Jet Energy Corrections
  - JEC uncorrelated groups
  - JEC in-situ correlated groups
  - JEC inter-calibration
  - JEC pile-up
  - Jet energy resolution
  - Flavor JES
  - bJES
- Pileup
- Lepton efficiency
- B-tagging efficiency
- Fit Calibration
- Non-tt background

Theoretical sources of uncertainties –

- Modeling hard scattering process
  - Parton distribution functions (PDF)
  - Renormalization and factorization scales
  - Matrix element generator
  - Top p_T reweighting
  - Generator modelling
- Modeling non perturbative QCD
  - Underlying events
  - Color reconnection

– Blue uncertainties are the one we calculated.

Evaluation of Systematic Uncertainties

- Vary parameters for each source (rest constant)

  ⇩

  Two distribution of BJet Energy

- Get peak energy for both distributions

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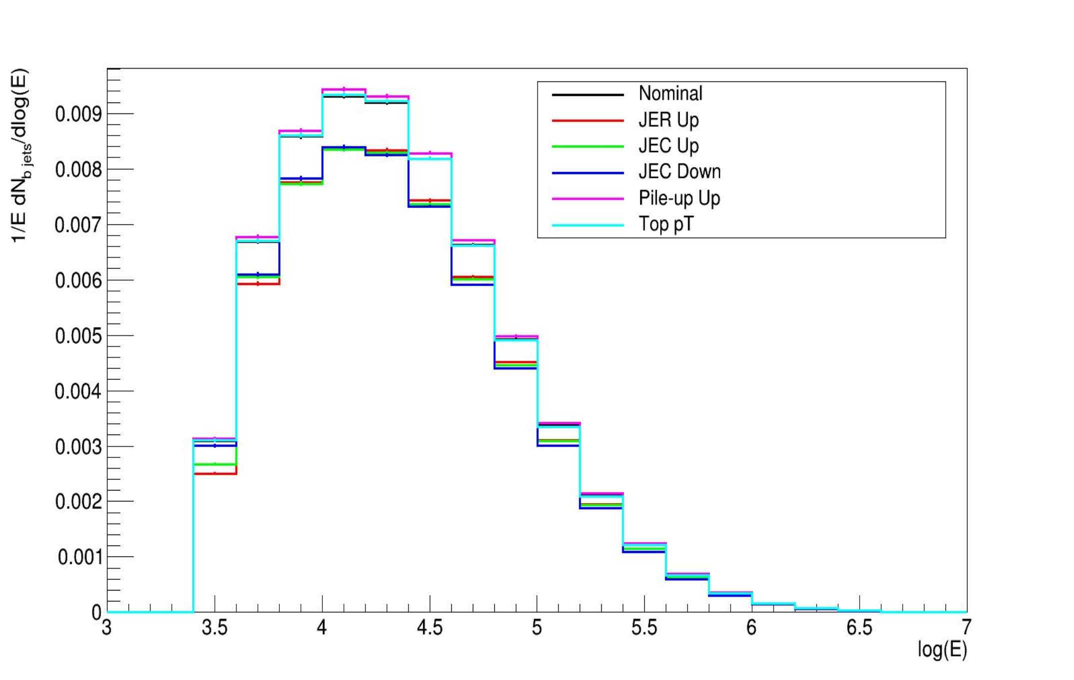
  top mass
  (2-body decay calculation)

- **δE = ½ (E_up - E_down)**

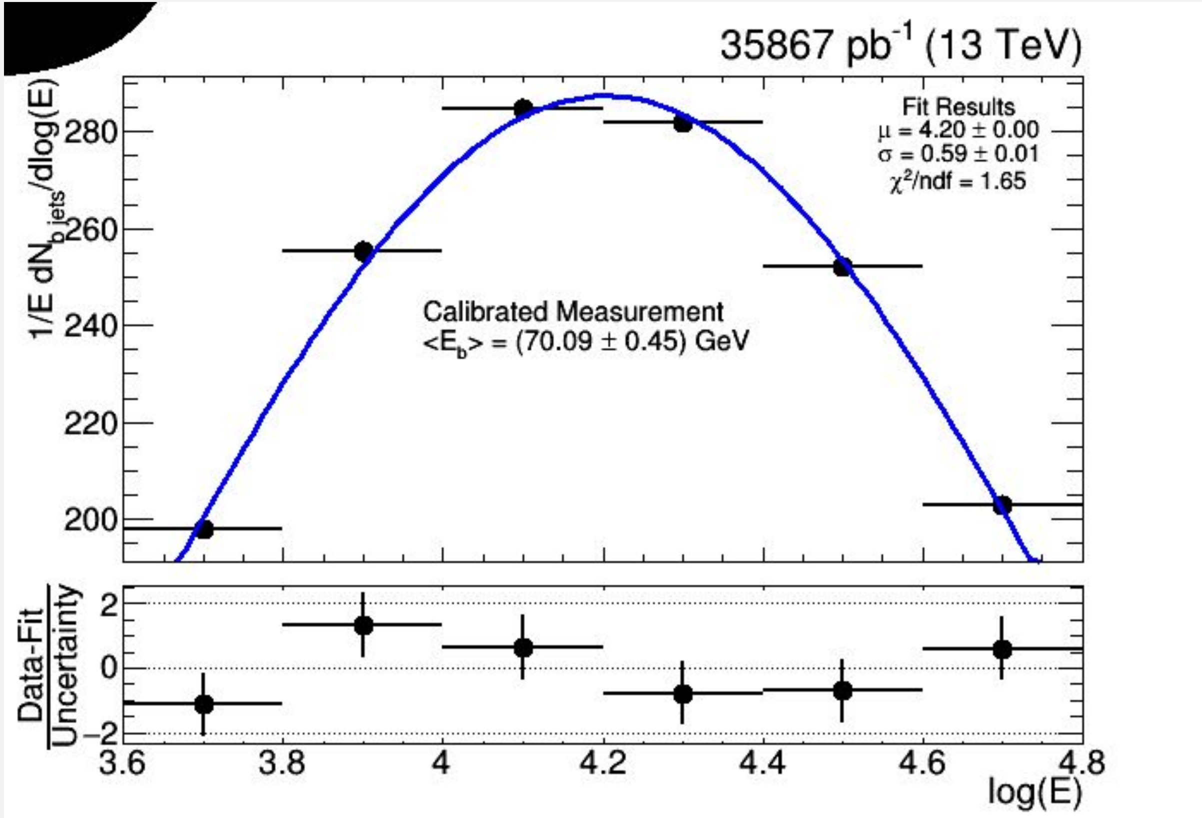
  δm = ½ (m_up - m_down)



Breakdown of systematic uncertainties

Source	δE_{peak} (GeV)	δm_t (GeV)
● Jet energy corrections (JEC)	1.7808	2.9272
● Jet energy resolution (JER)	1.4984	2.4637
● Top p_T reweighting	0.1681	0.2767
● Pile-up	0.0041	0.0069
● Lepton efficiency	0.0153	0.0252
❖ Total	2.0136	3.0124

Fit on data



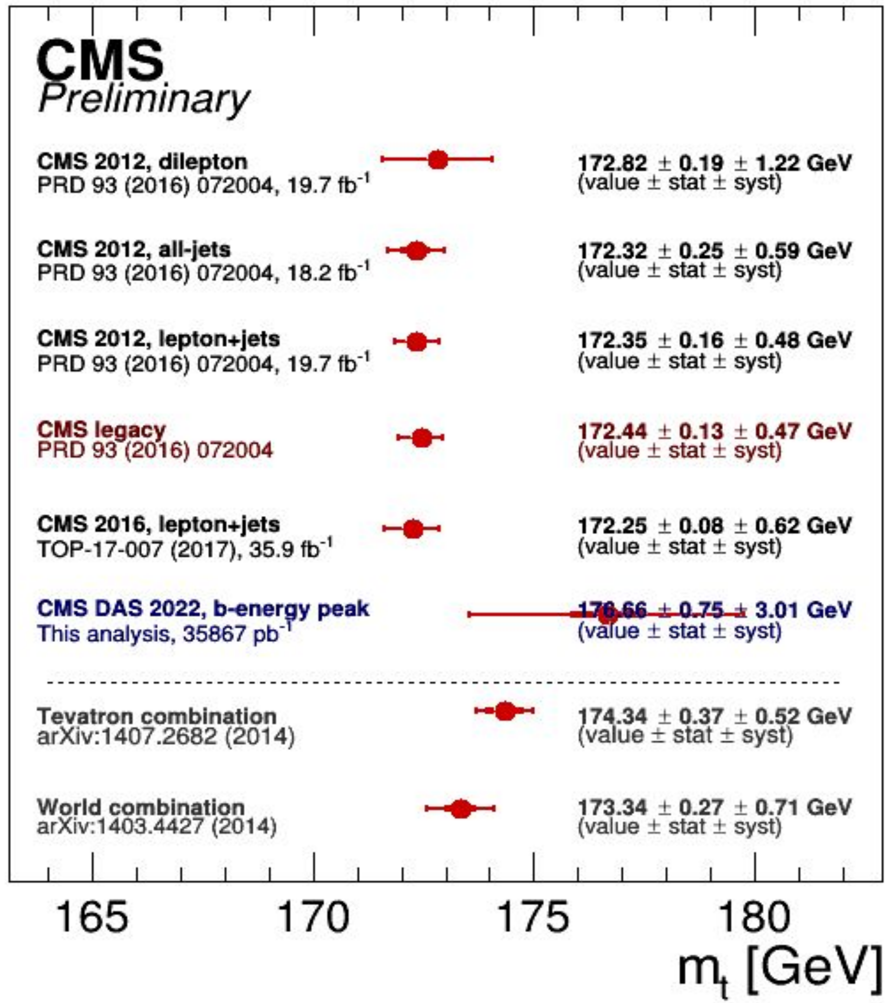
Real Data:

- E_peak measured: 70.09 GeV
- M_top measured: 176.66 GeV
- Statistical uncertainty: 0.75
- Final calibrated measurement w/ statistical uncertainty:
  176.66 +- 0.75 GeV

Results

We measured Top mass using the B-Jet energy peak in the tt di-lepton channel with 35.9 fb^{-1} of 2016 data:

176.66 ± 0.75 (stat.) ± 3.01 (syst.) GeV



Further Improvements

- The bias/shift could be caused by the choice of the fit range, the choice of fit function, the calibration, the b jet energy measurement, etc. if time allows we could do more studies on this and understand better the biases/differences. The uncertainties we have are very large and can cover the difference.
- For ways to reduce the uncertainties and improve the results. we should think about where are our current dominant systematics come from - JEC and JER. So more precise measurements of JEC/JER, to reduce our dominant systematics. Furthermore, we can start looking at the other channels (going from emu channel to ee, mumu, and also include the single lepton channel, etc.)
- For the data fit, right - the pull is not perfect and there is certainly a trend. If given more time we could study more on the fit range, fit function, and study their impacts on the final results, to be more confident, etc.
- **How to improve the analysis?** looking at your systematic breakdowns, and thinking about how to reduce the dominant systematic uncertainty, then the subdominant, etc.