Study of the Differential Cross Section for the Production of a Top-Antitop Quark Pair with the CMS detector

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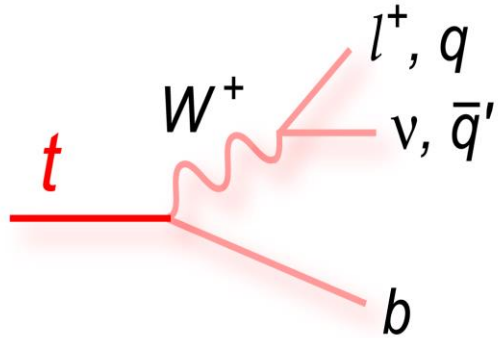
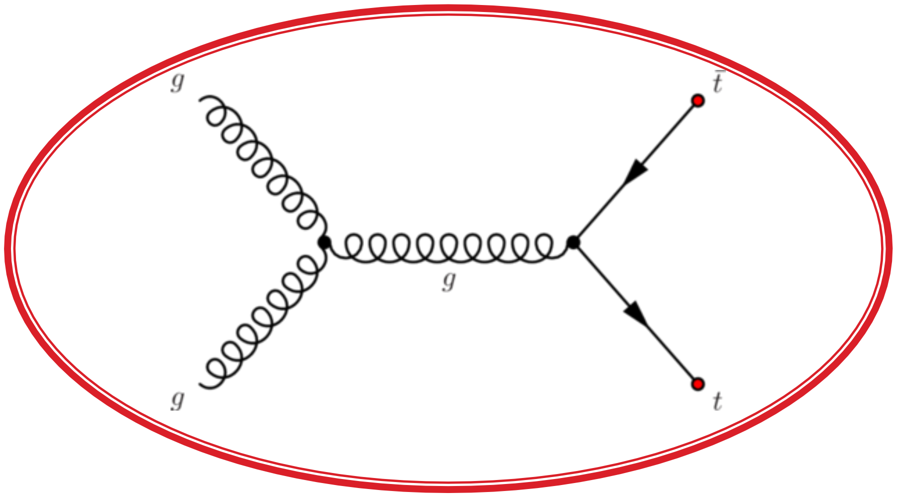
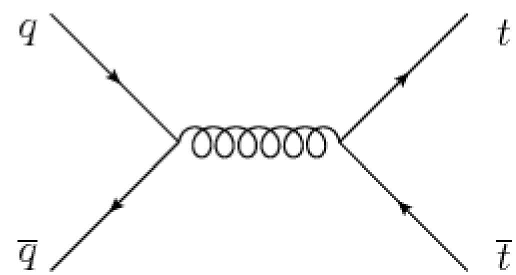
Top Quark

- Mass : 172.44 ± 0.13 $^{GeV}/_{c^2}$
- Top Quark decay
  - W⁺+ b ($\bar{t}$ → W⁻+ $\bar{b}$)
- Top pair production
  - $q + \bar{q} \rightarrow t + \bar{t}$
  - $g + g \;\rightarrow t + \bar{t}$





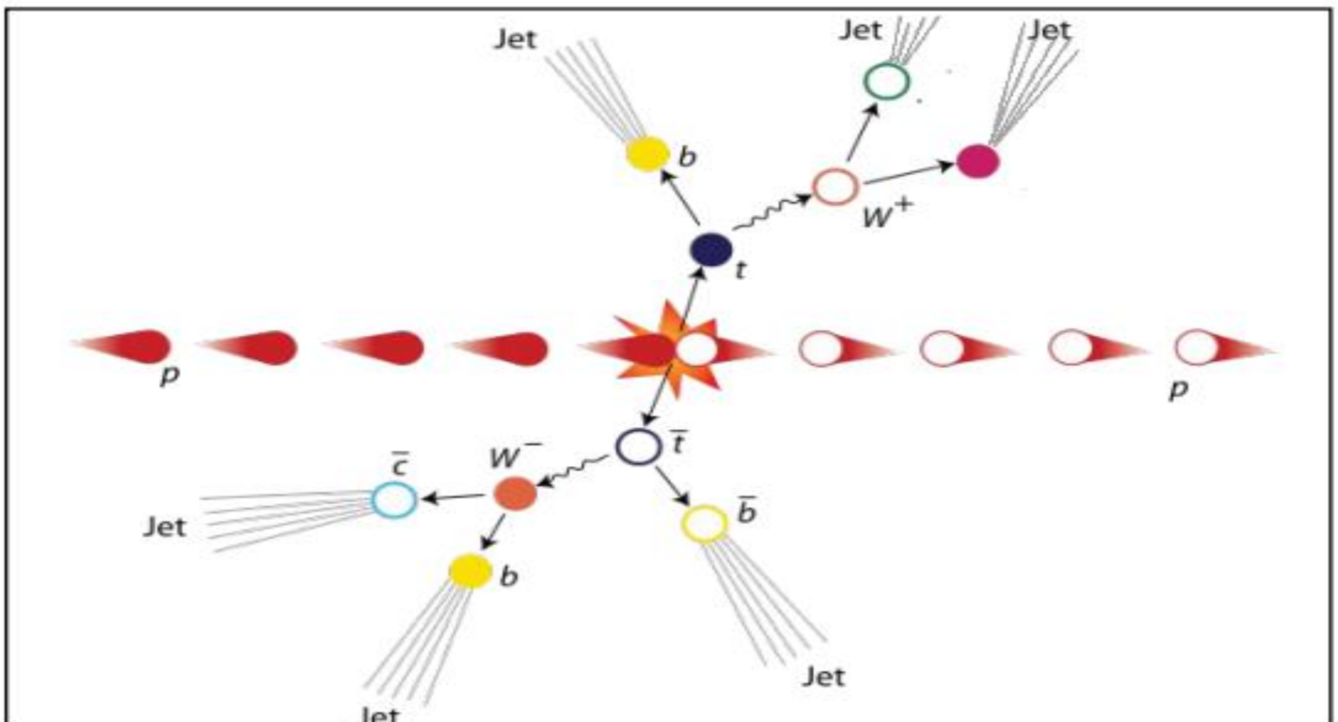
Gluon Fusion is dominant
at LHC



(b)

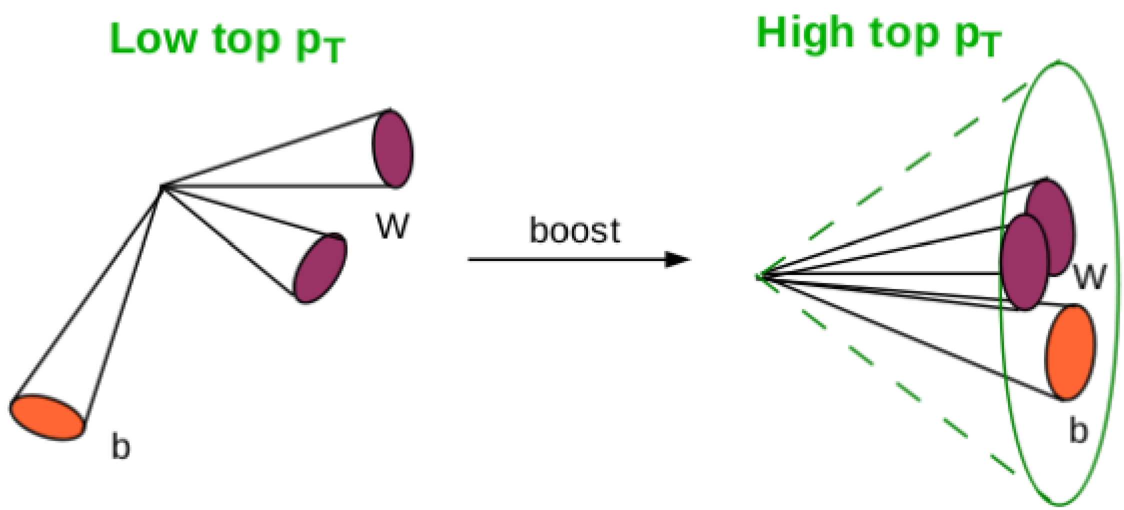
Top AntiTop system decay

1. $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow q\bar{q}b\, q"\bar{b}\bar{q}"$ (45.7%) (hadronic)
2. $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow q\bar{q}'bl^{-}\bar{\nu_{l}}\bar{b} + l^{+}\nu_{l}bq"\overline{q'''}\bar{b}$ (43.8%) (semileptonic)
3. $t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow l^{+}\nu_{l}b\, l'^{-}\bar{\nu}'\bar{b}$ (10.5%) (dileptonic)



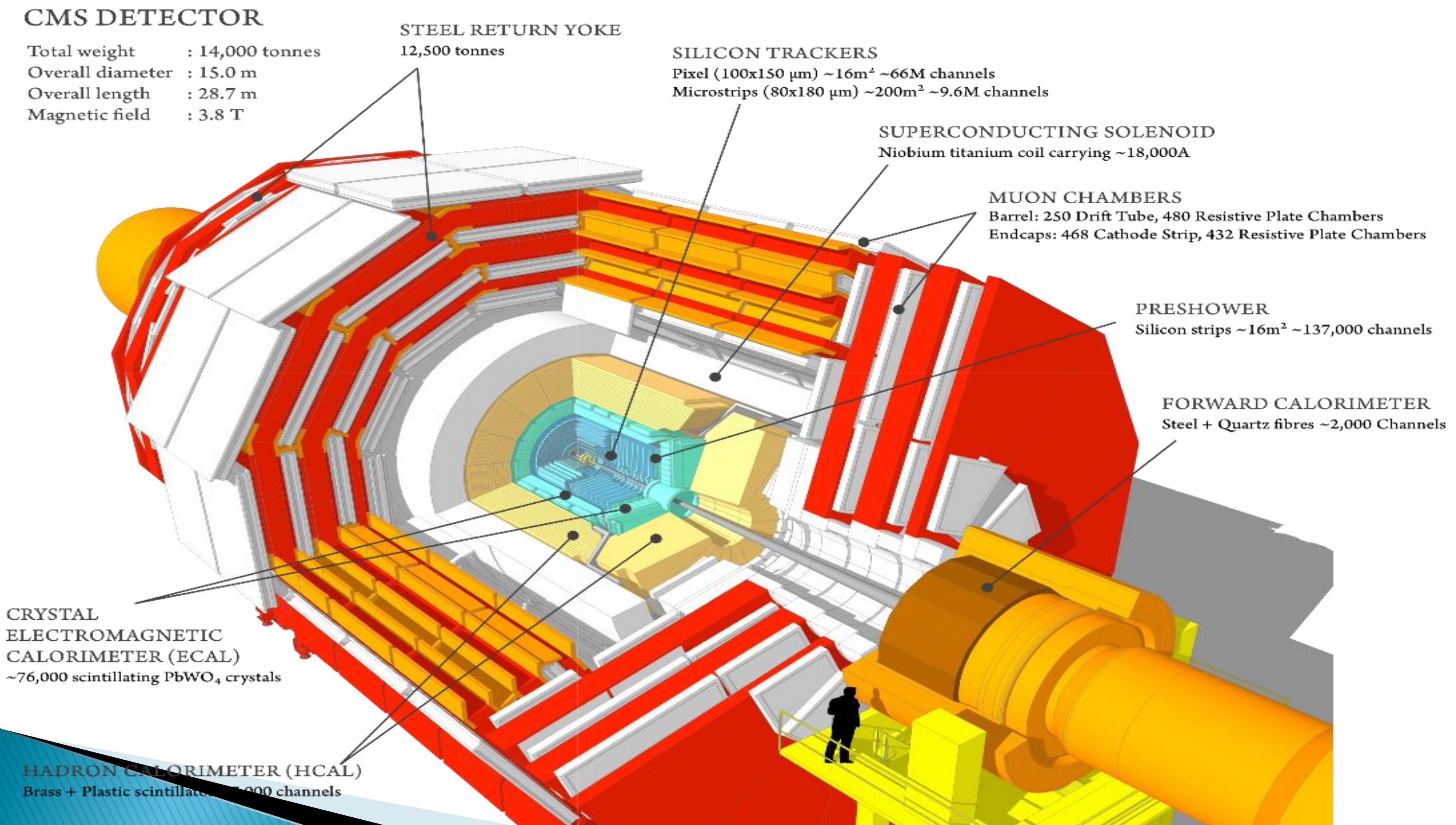
Boosted Jet

- Boosted jets are jets with high p_T (~400GeV)
- Aim is the reconstruction of two big jets that contain decay products of the top-antitop quark decay
- Why Boosted Jets?
  - Single “fat” jet: No combinatorial background
  - At high p_T^{top} the hadronic decay mode is easier to reconstruct than the leptonic
  - At high p_T where the theory is less precise→ boosted jets
- In order to identify boosted jets
  - use of sophisticated reconstruction techniques to identify the substructure within the “fat” jet
  - SoftDrop Technique



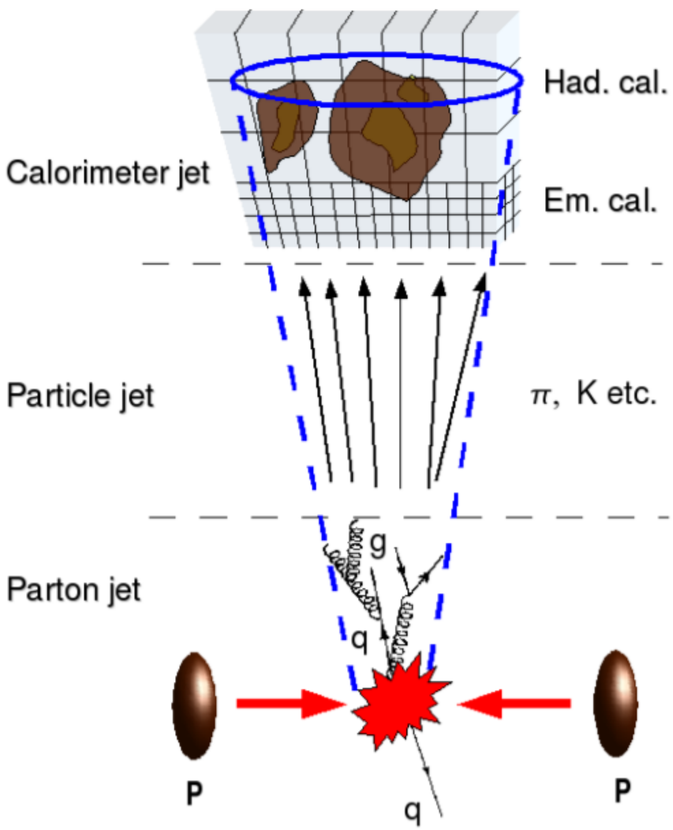
Compact Muon Solenoid Experiment

CMS is a general purpose detector and its goal is to investigate a wide range of physics



Analysis

Calculation of the ttbar differential cross section using the Unfolding method

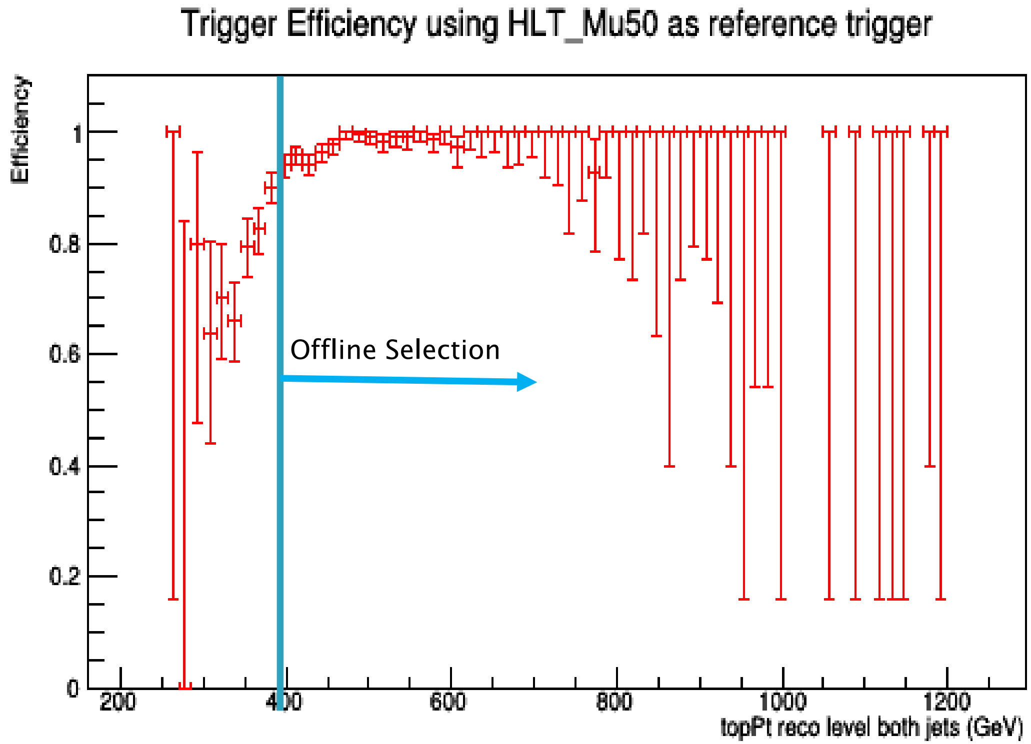


- Variable Levels
  - Parton Level: where collision occurs
  - Particle Level: Hadronization
  - Reconstructed Level: Data received from the detectors

- Variables that will be studied
  - Top P_T : Transverse momentum of the jet
  - Mass $t\bar{t}$ system

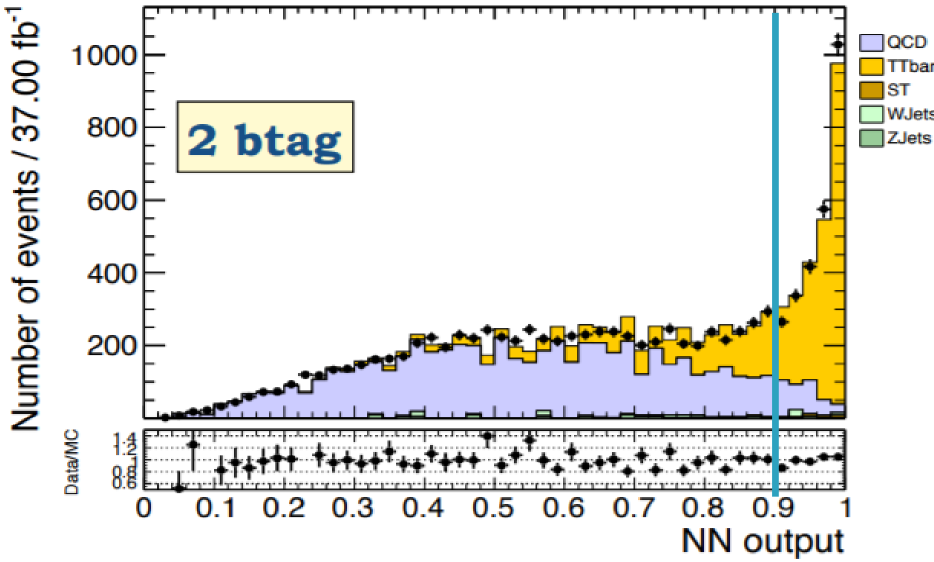
Trigger

- Level 1 Trigger
  - Scalar Sum of the Level 1 Jet p_T (H_T) > 175 GeV
- High Level Trigger
  - Aims to capture decay products of boosted top pair
  - $p_{T,1}$> 280 GeV and $p_{T,2}$ >200 GeV
  - Jet Mass > 30GeV
  - b tagging @ HLT



Selection

- Reco Cuts
  - Number of jets > 1
  - Jet P_T at reco level> 400 GeV
  - Leading and Subleading jets are b-tagged
  - Passes signal trigger
  - Multivariate analysis parameter (mva[1]) > 0.9
  - Mass leading, subleading jets [140, 200] GeV
- Parton Cuts
  - Jet P_T at parton level > 400 GeV
- Particle Cuts
  - Number of Jets > 1
  - Jet P_T at particle level > 400 GeV
  - Multivariate analysis parameter > 0.9
  - Mass of Jet in particle Level [140,200] GeV



[1]MVA: Neural Network

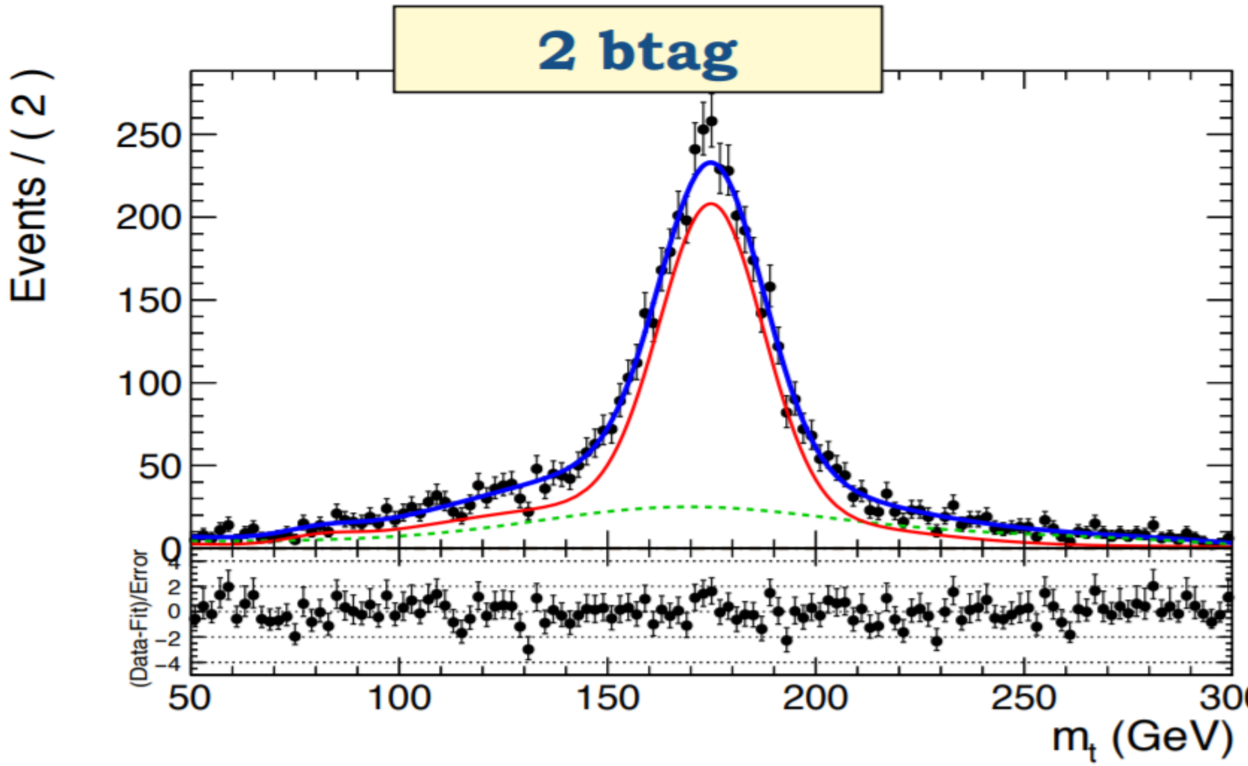
- Input to NN→ jet substructure properties
- Aim is the identification of boosted top-antitop pair
- mva > 0.9 clear signal over bkg

Fiducial Cross Section

$$S(x) = D(x) - N_{bkg}\, B(x)$$

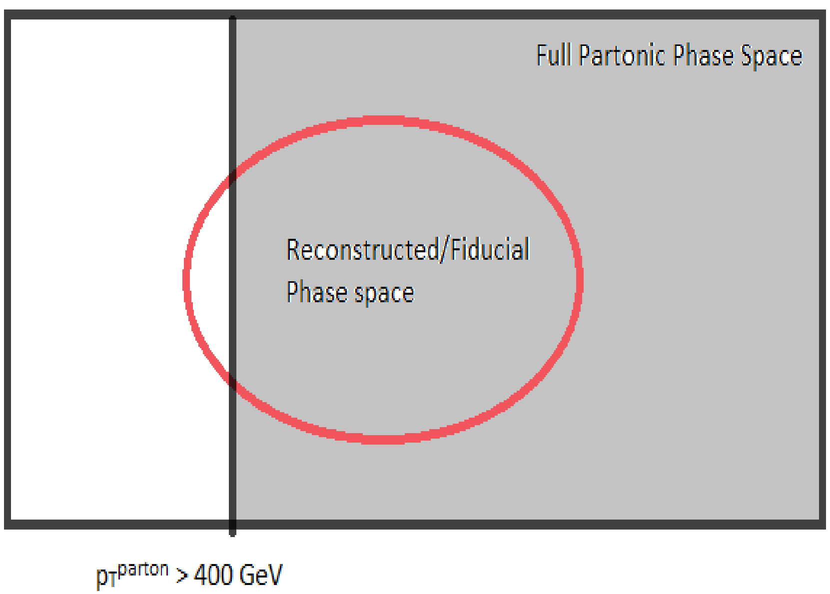
- $S(x)$ = signal
- $D(x)$ = data
- N_{bkg} = fitted bkg yield extended selection
- $B(x)$ = bkg template taken from 0-btag sample

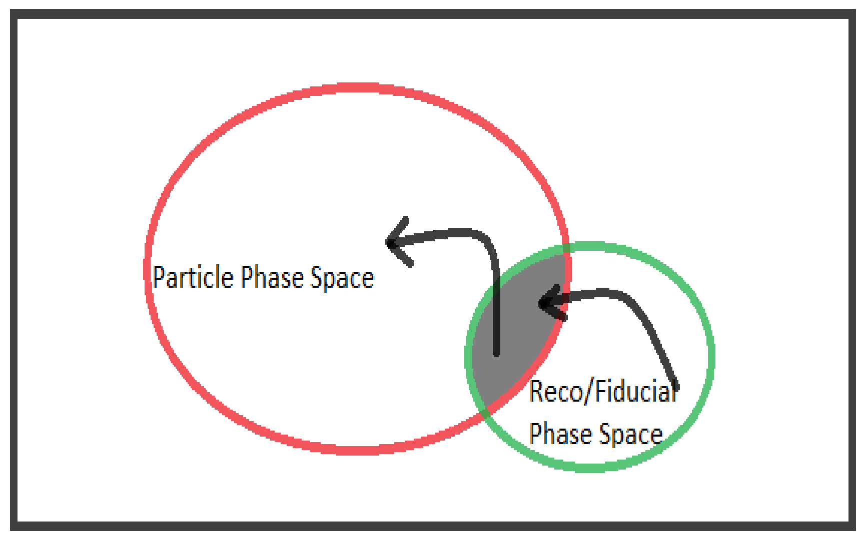
- The red fit is used to calculate the N_{bkg}



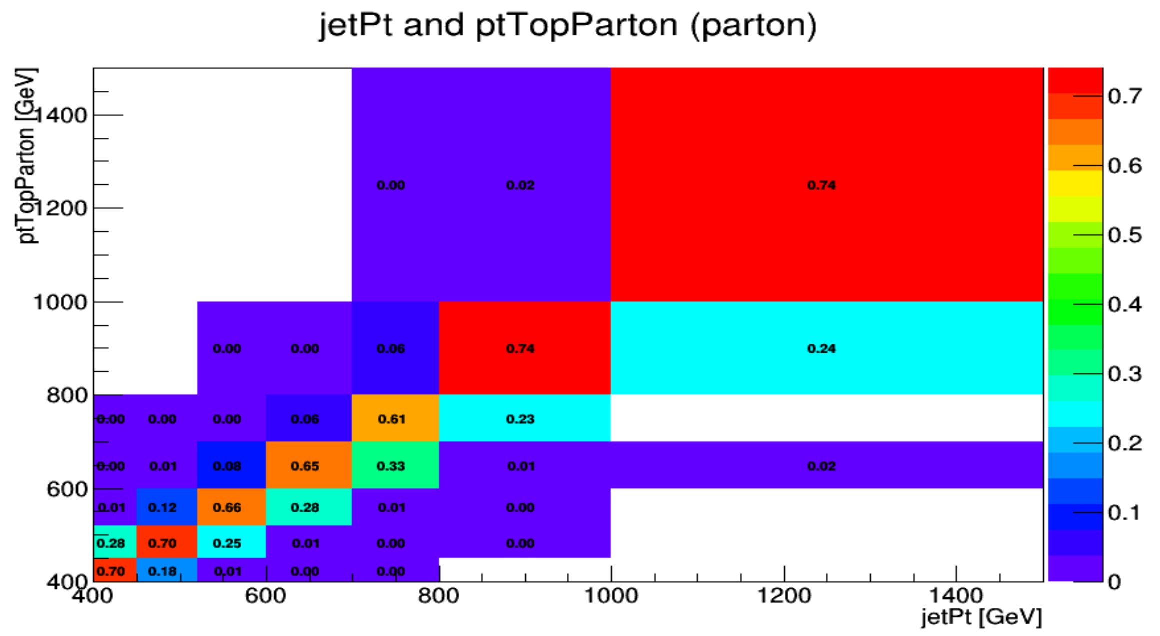
Unfolding

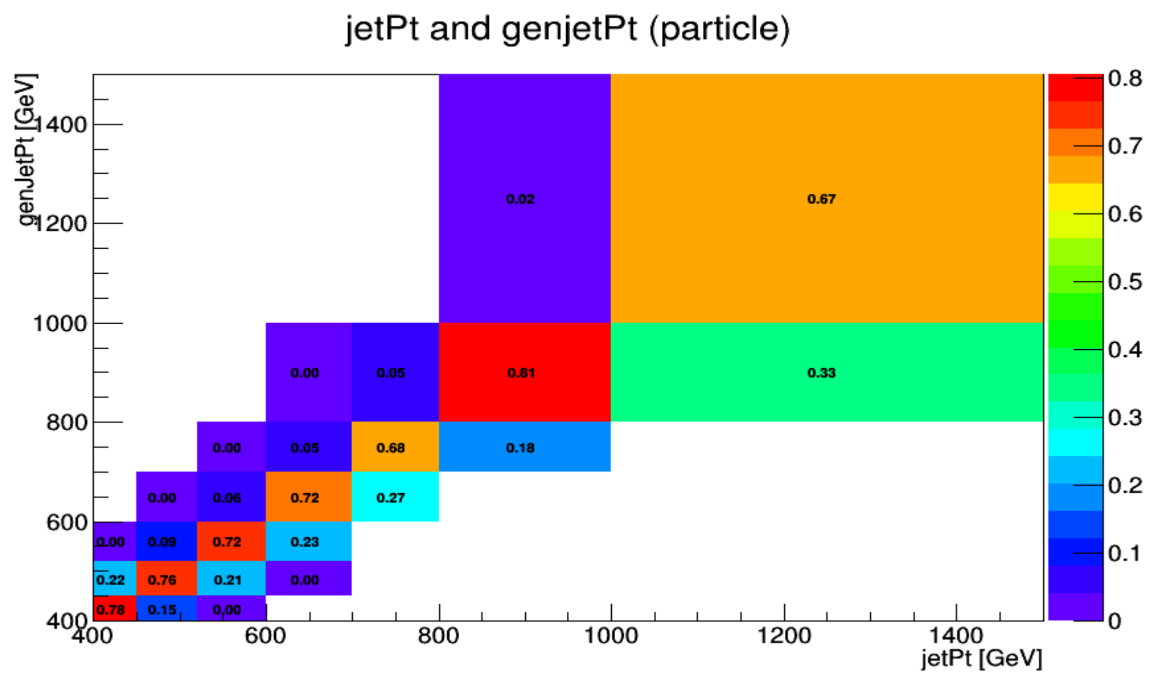
- Unfolding is a process that gives solution to the inverse problem
$$y = Ax \Rightarrow x = A^{-1}y + e \rightarrow finding\ x$$
- From measured distribution go to true distribution
- Best matching x is found by minimizing the L_1+L_2 function where
  - The L_1 is the least square minimization function
  - $L_2 \sim tau^2$ defines the regularization, where tau gives the strength of the regularization
- Falling spectrum
  - Migration effects between the bins
  - Use of extrapolation factor (=1/efficiency) to take into account the migration
- Extrapolation from Reconstructed level to Parton and Particle Phase Space





Response Matrices





Differential Cross Section

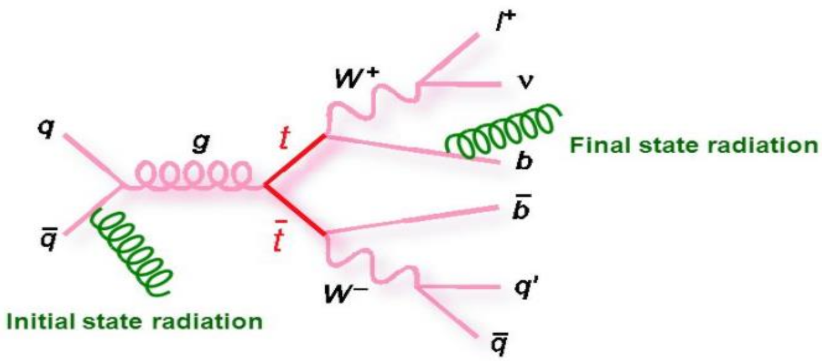
- Fiducial Cross Section
  - $\frac{dN}{dx} = \frac{S(x)}{L\Delta \mathrm{x}}$

- Parton Level:
  - $\left(\frac{dN}{dx}\right)_{parton} = \left(\frac{1}{a(x_{parton})}\right) R^{-1}(x_{parton}, x) \left(\frac{dN}{dx}\right)$
  - $a(x_{parton}) = signal\ efficiency\ \times acceptance$

- Particle Level:
  - $\left(\frac{dN}{dx}\right)_{parton} = \left(\frac{1}{a_2(x_{particle})}\right) R^{-1}(x_{particle}, x)(\frac{1}{a_1(x)}) \left(\frac{dN}{dx}\right)$
  - $a_1(x) = signal\ efficiency\ \times acceptance$
  - $a_2(x_{particle}) = signal\ efficiency\ \times acceptance$

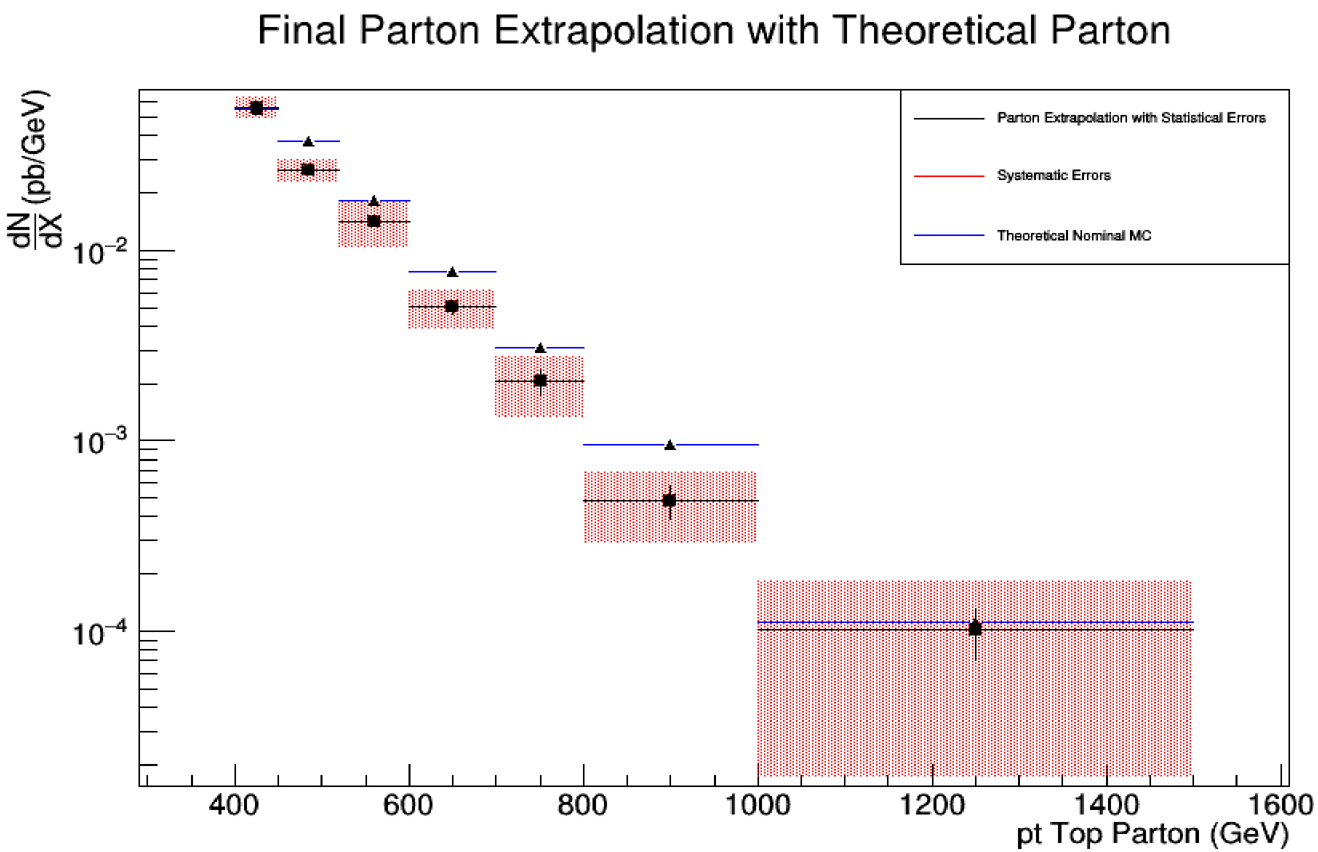
Uncertainties

- Focus on theoretical uncertainties
- Experimental
  - Statistics
  - Jet Energy Scale
  - Jet Energy Resolution
  - B tagging efficiency

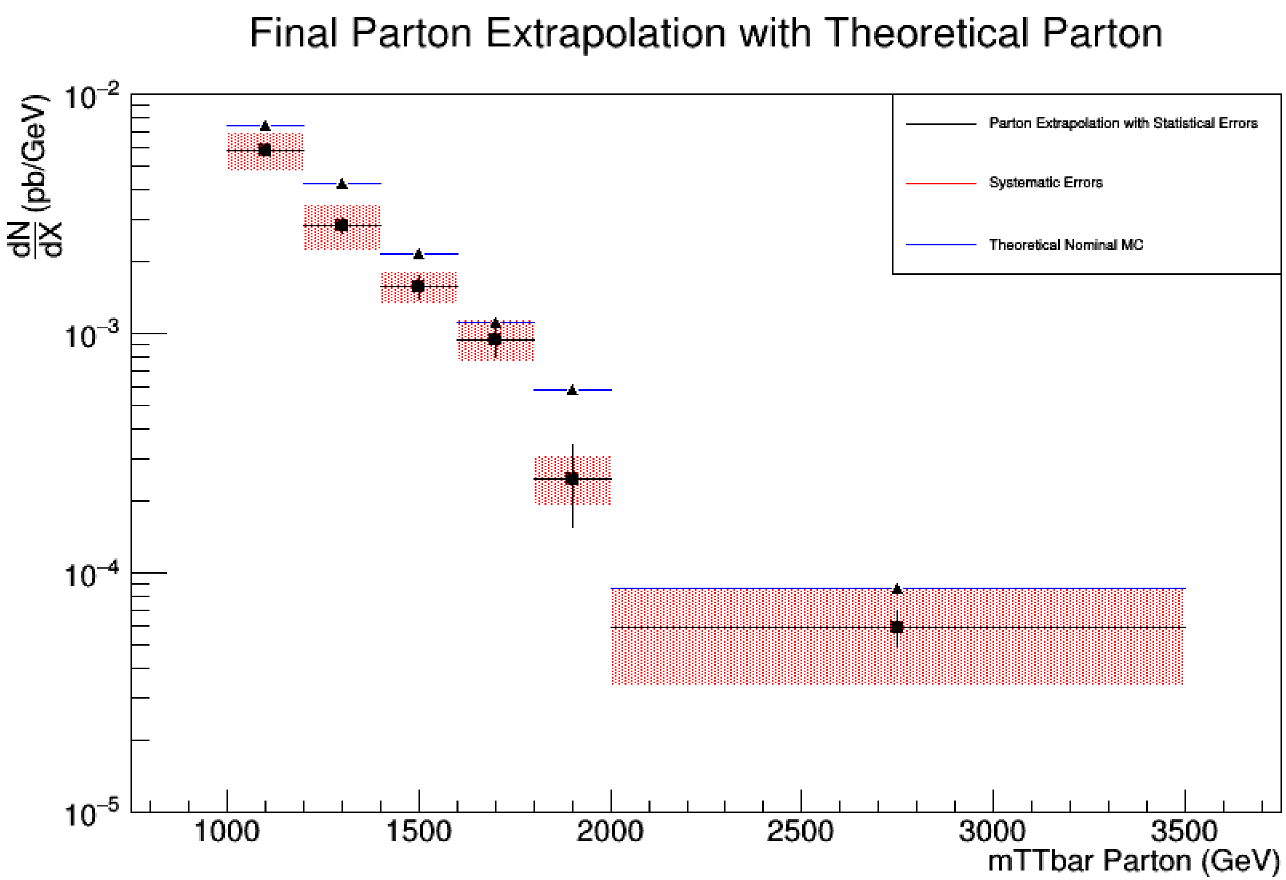


- Theory Uncertainties
  - Affect the extrapolation factors and the response matrix for the unfolding procedure
    - ISR (Initial State Radiation)
    - FSR (Final State Radiation)
    - CMS Tuned set of MC parameters for Pythia 8

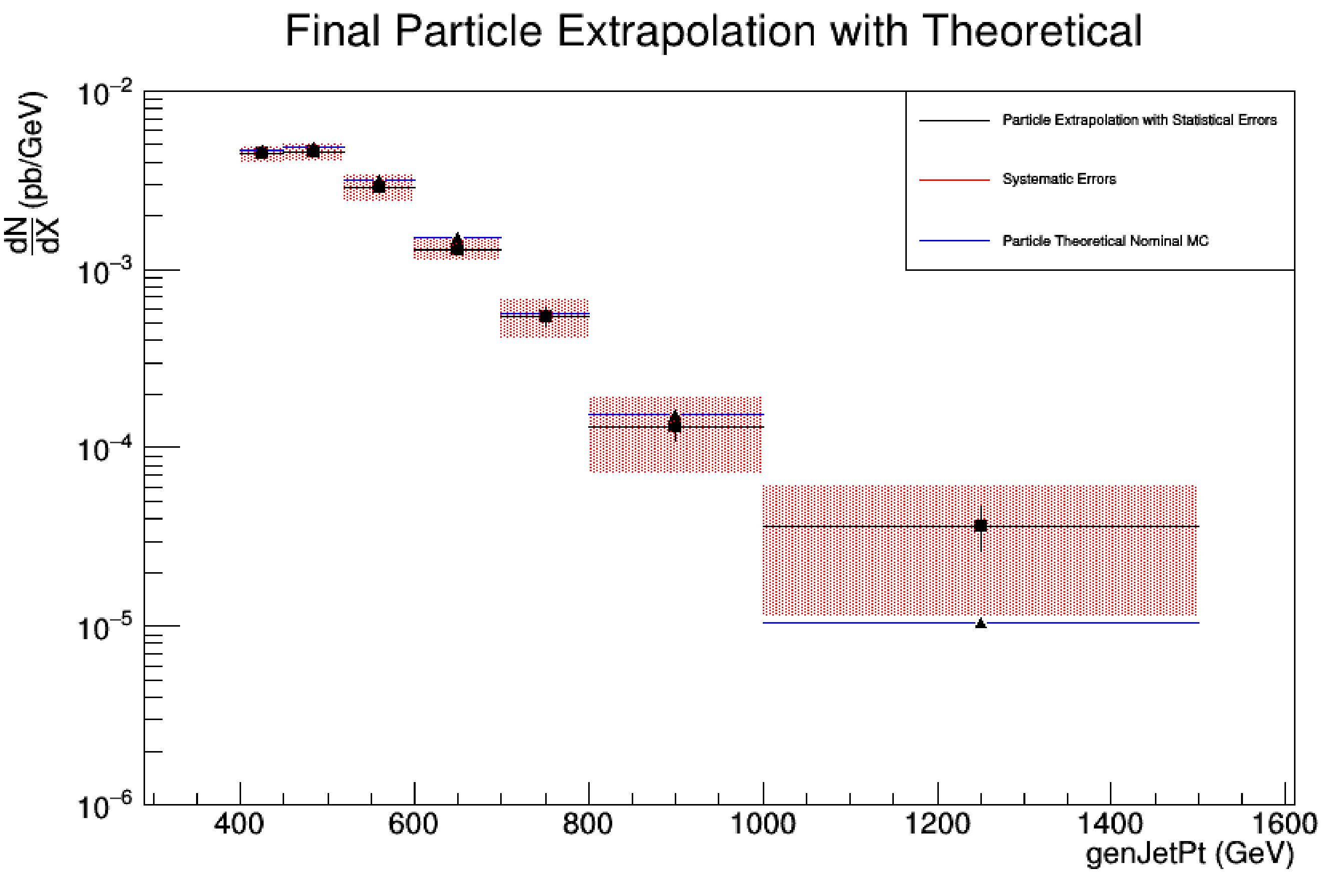
Top P_T Parton Extrapolation



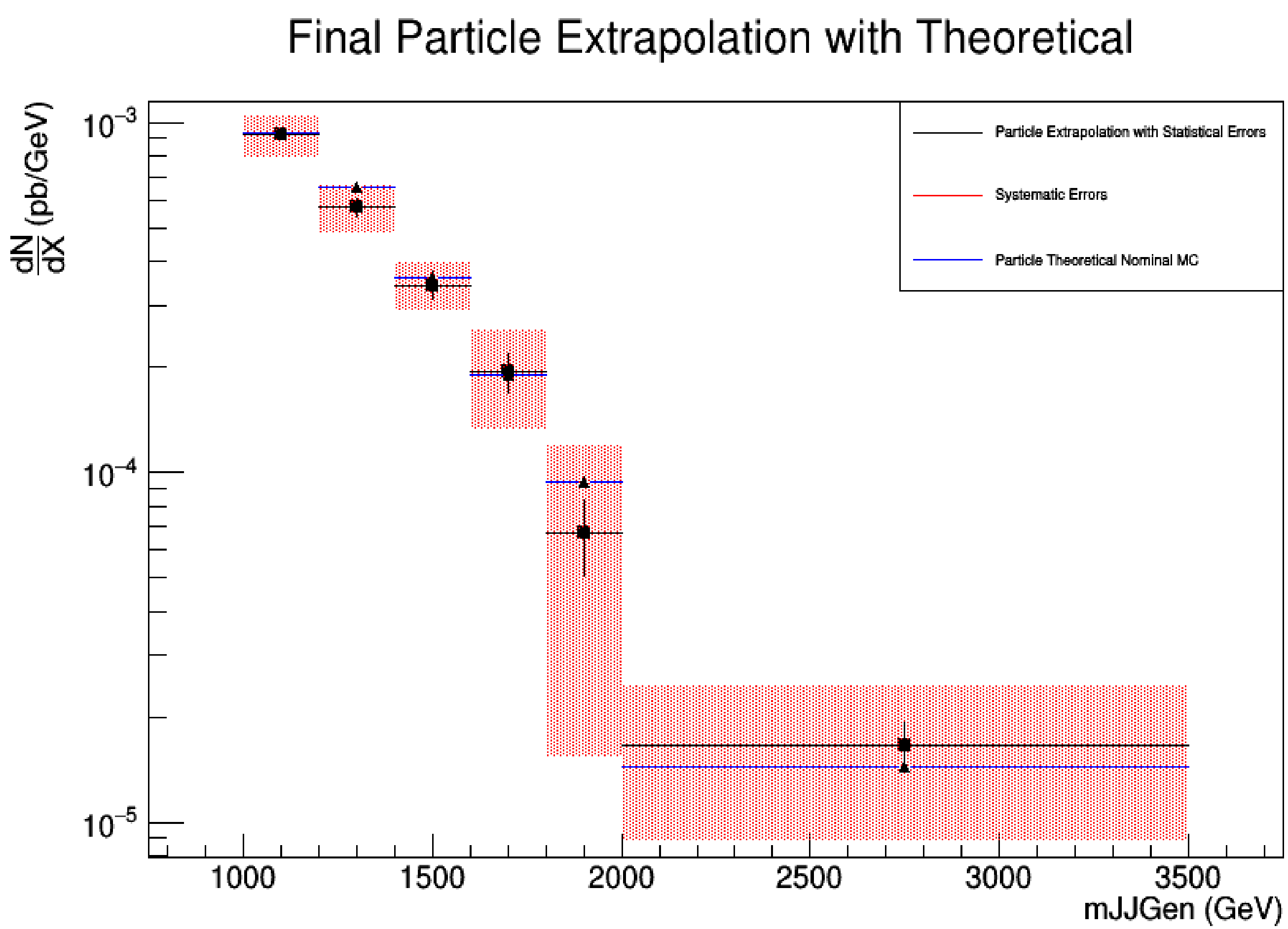
Mass $t\bar{t}$ Parton Extrapolation



Top P_T Particle Extrapolation



Mass $t\bar{t}$ Particle Extrapolation



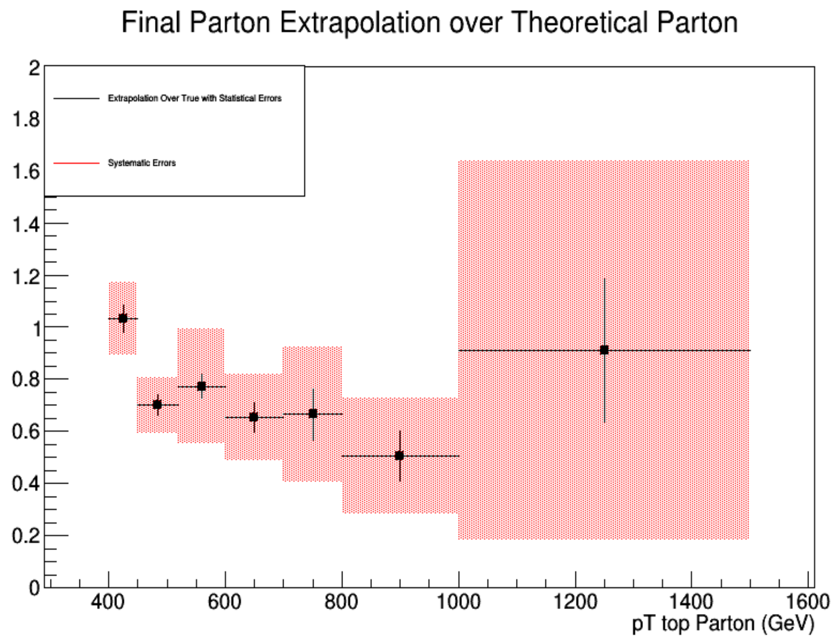
Conclusions

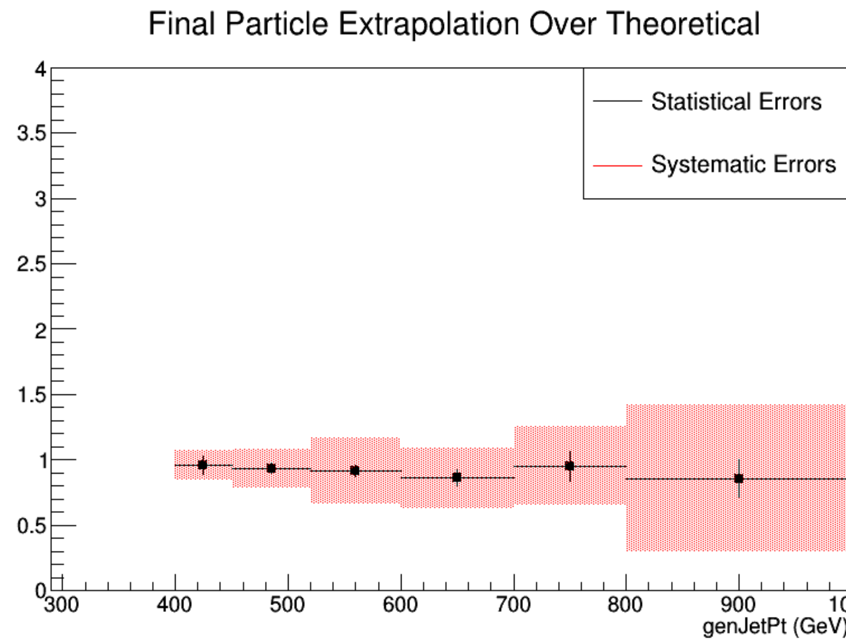
- We have studied the $t\bar{t}$ production in pp collisions at 13TeV Energy recorded by the CMS detector
- Differential cross sections have been presented at parton and particle levels
- Comparison with theory predictions show consistent shapes but systematically lower cross section in data *(this is a known effect, also reported by ATLAS and other CMS measurements)*
- Focus on the unfolding of the measured cross sections to the parton and particle levels and investigation of the impact of the theoretical (simulation) uncertainties

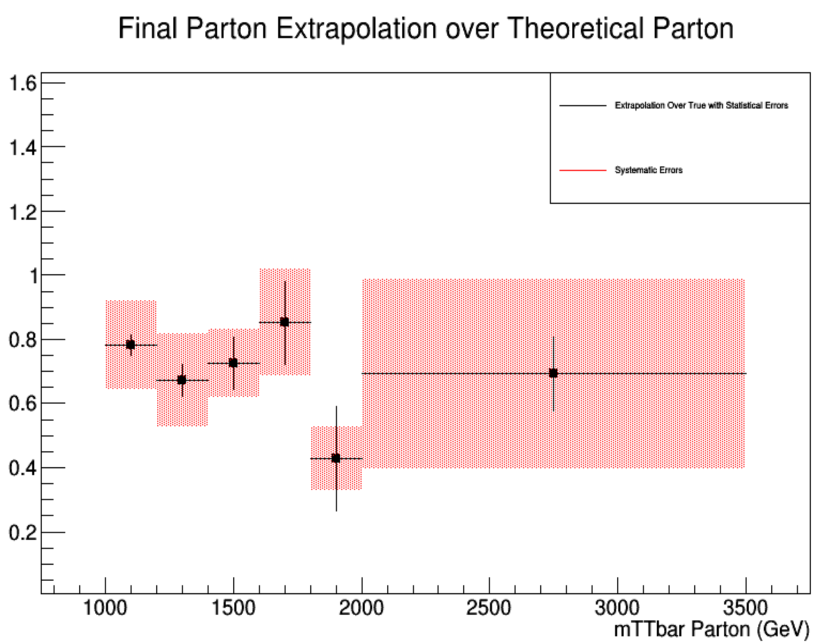
Thank you for your attention

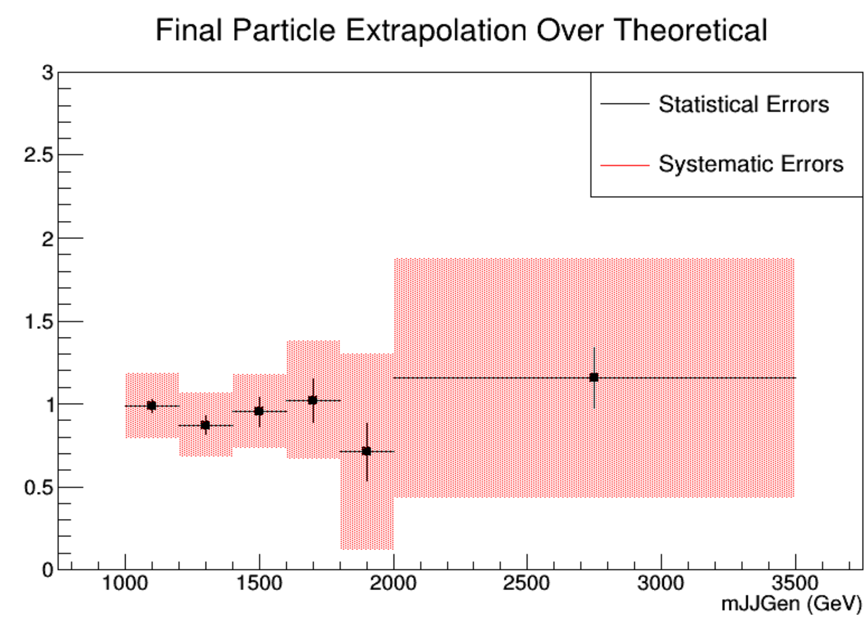
Backup Slides

Ratio of Extrapolated vs Theoretical

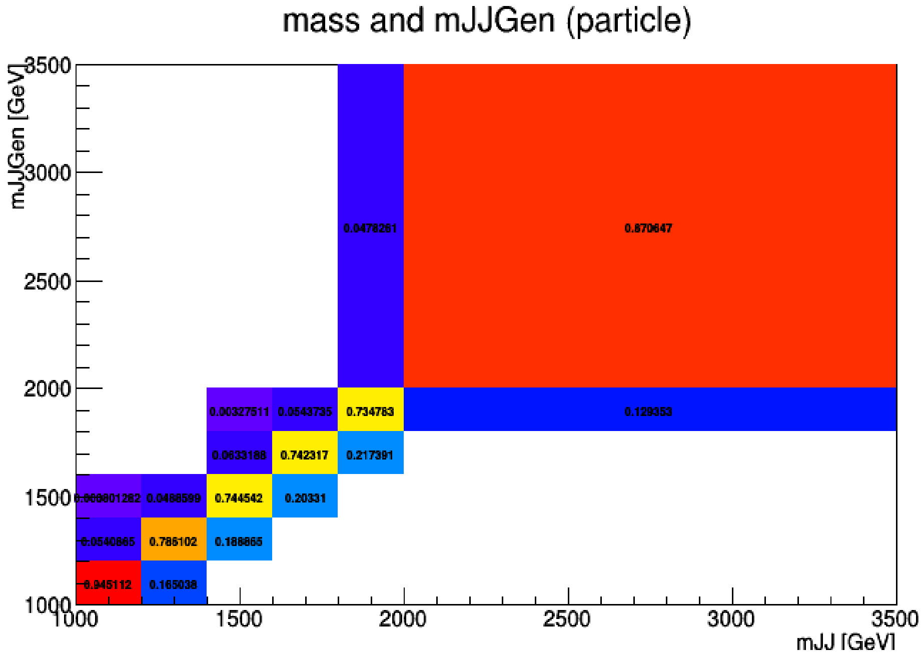


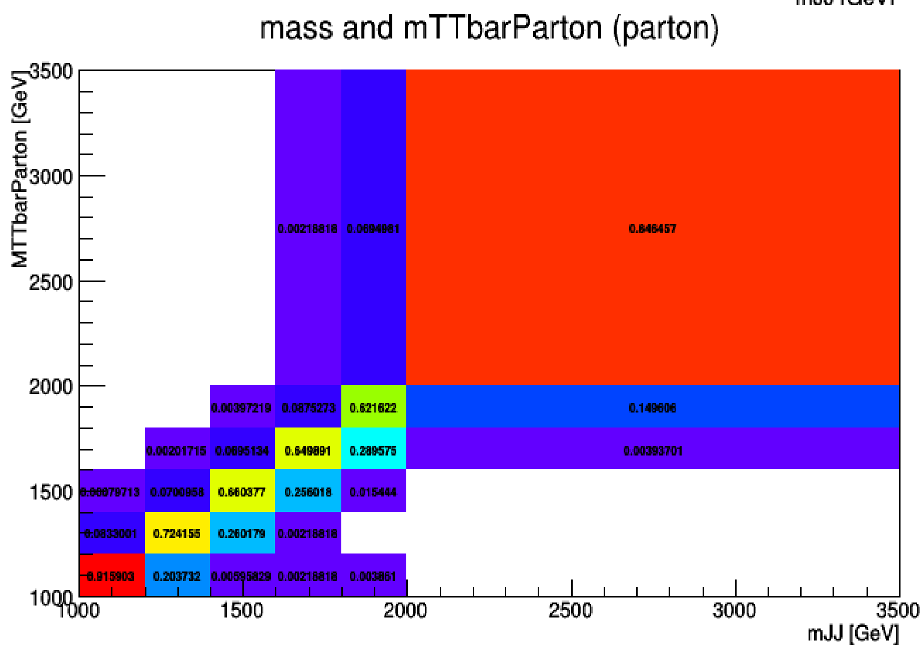






Mass top-Antitop response matrices





Soft Drop Technique

- Reconstruct the jet mass by removing soft contributions from pileup and collinear emissions

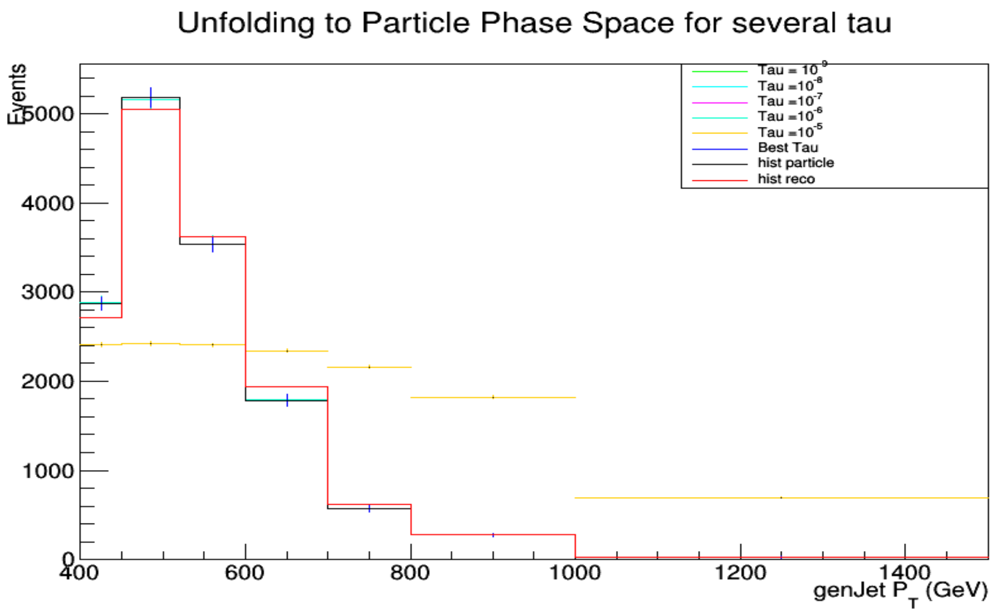
$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \times \left(\frac{\Delta \mathrm{R}_{12}}{R}\right)^{\beta}$$

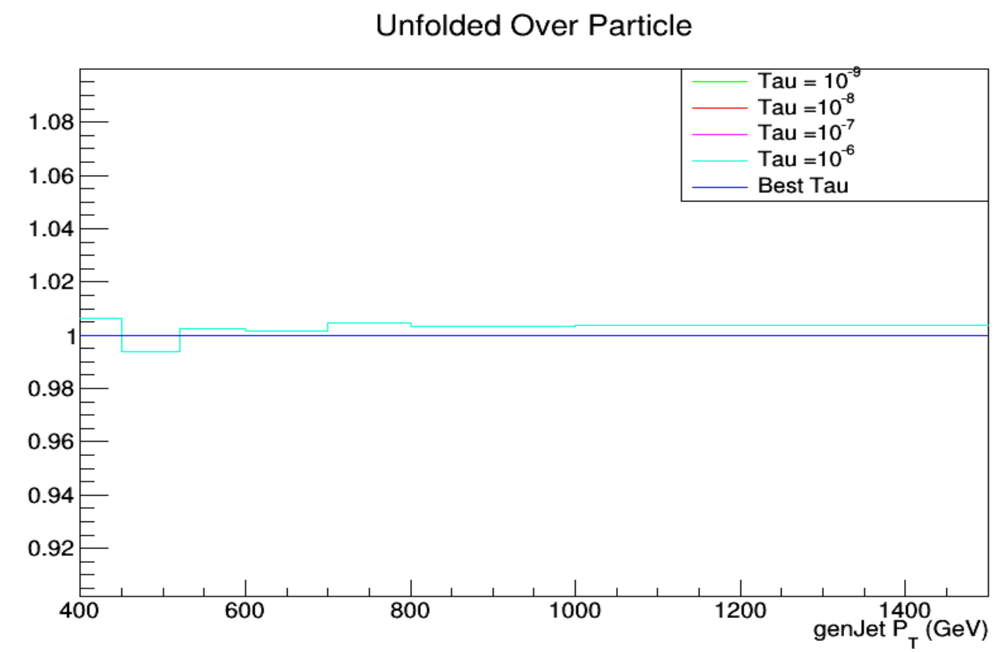
- At CMS the $z_{cut} = 0.1$ and $\beta = 0$
- This means that $\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > 0.1$ → when the technique goes backwards to "check" the jet, it keeps only the the objects that have a p_T no smaller than 10% of the "central" p_T of the jet
- This happens in order to suppress the contribution from secondary sources

τ_N : N-subjettiness

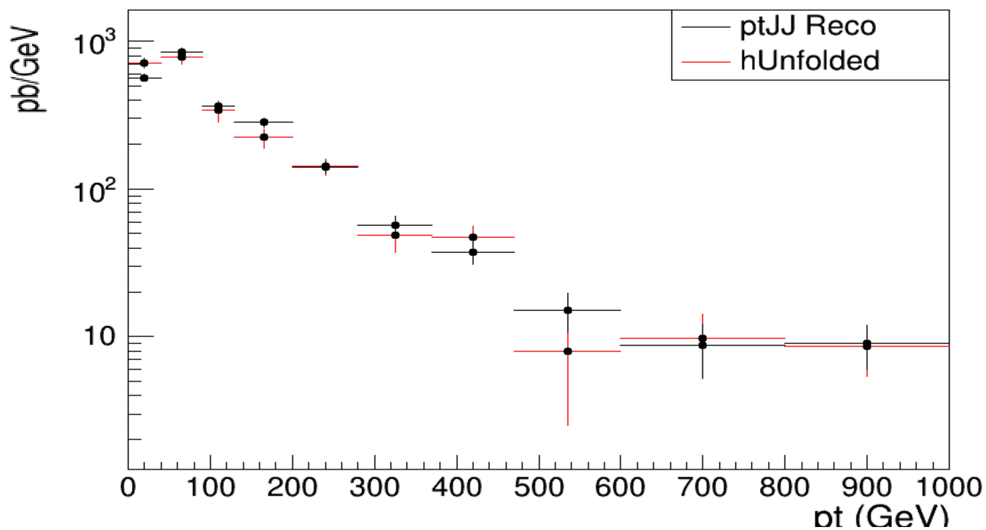
- The NN combines the $\tau_{1,}\tau_2,\tau_3$ of the two leading jets, where τ_N is the subjetiness and N is the number of prong jets
- Prong jets are the number of jets that determine the substructure of the boosted jet
- $\tau_i = \frac{1}{\sum_k p_{TK} R} \sum_k p_{TK} \min(\Delta R_{1K}, \ldots \Delta \mathrm{R}_{iK})\, , where\ i = 1,2,3$
- Normaly $\tau_1 > \tau_2 > \tau_3$
  - Small τ_i means that the i-jets are more possible to be seen

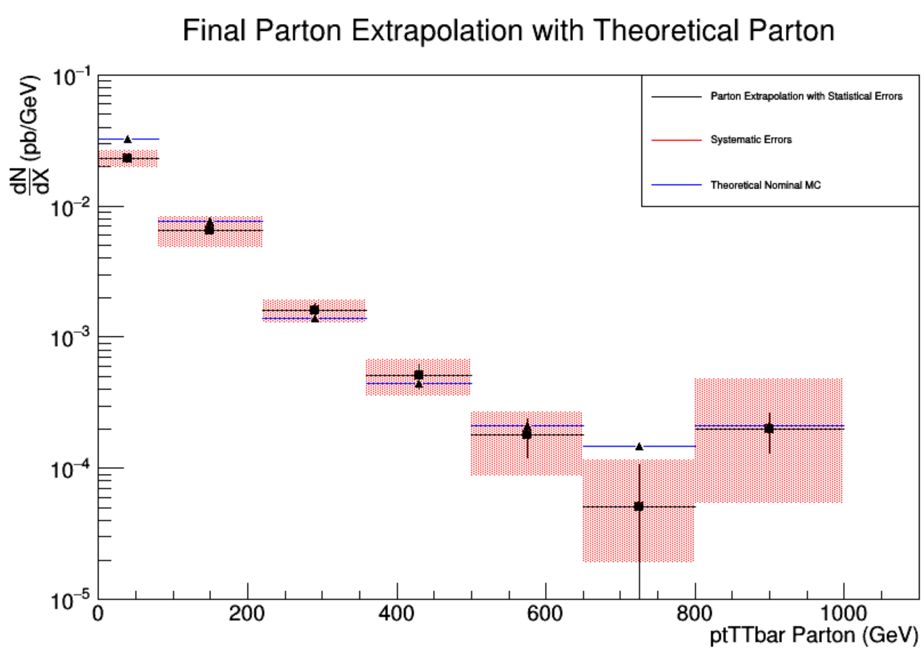
Closure Tests





P_t ttbar Parton Extrapolation





P_t ttbar Particle Extrapolation