Studying $t\bar{t}$ and $t\bar{t}j$ Events with MadGraph

Jarrett Fein
Jason Gombas
Sara Sawford
Reinhard Schwienhorst

Contribution to Snowmass paper: "Dependence of the top-quark mass measured in top-quark pair production on the parton distribution functions at the LHC and future colliders"

Michigan State University - MSU

Event Generation

- $t\bar{t}$ events generated at NLO using MadGraph (p p > t t~ [QCD])
- $t\bar{t}j$ events generated at NLO using MadGraph (p p > t t~ j [QCD])
- Two input parameters are varied, beam energy and top mass
- 10 million events (roughly) per mass/energy pair
- Top Masses (GeV): 171.0, 172.0, 172.5 (nominal), 173.0, 174.0
- Beam Energies (GeV): 4000, 6500, 6800, 7000, 50000
- A wider range of top masses had events generated, but are not included on the plots for the sake of clutter

Cuts Applied to $t\bar{t}j$

- pt (j) > 25 GeV
- eta (j) < 2.5
- Results in about 30% of total events containing 50% of total cross-section getting through

Cross-Section, Scale Variation, & PDF Variation

- Another set of events generated (1 million per mass/energy pair) with cuts built-in
- Cross-section, scale variation, and PDF variation calculated by MadGraph and reported in summary.txt file

```
------------------------------------------------------------
  Summary:
  Process p p > t t~ j [QCD]
  Run at p-p collider (7000.0 + 7000.0 GeV)
  Number of events generated: 100000
★ Total cross section: 4.630e+02 +- 2.4e+00 pb
------------------------------------------------------------
  Scale variation (computed from LHE events):
     Dynamical_scale_choice -1 (envelope of 9 values):
★       4.770e+02 pb  +9.6% -13.7%
  PDF variation (computed from LHE events):
     CT18NLO (59 members; using hessian method):
★       4.770e+02 pb  +3.8% -3.6%
------------------------------------------------------------
```

Plots

$t\bar{t}$ Events:

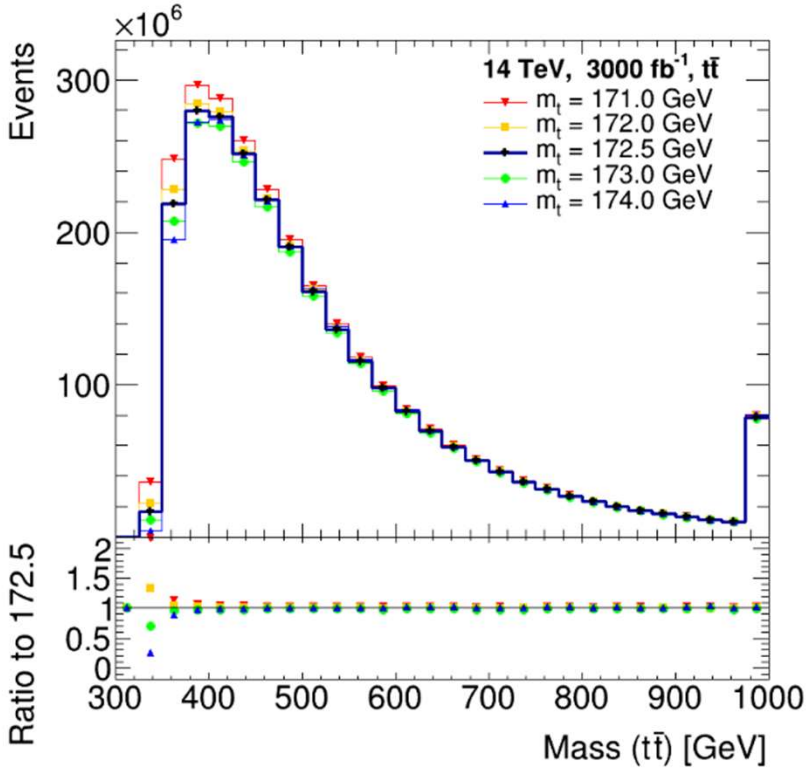
- pt (t and $\bar{t}$)
- pz ($t\bar{t}$)

$t\bar{t}j$ Events:

- mass ($t\bar{t}$)
- pt (t and $\bar{t}$)
- pz ($t\bar{t}$)
- rho ($t\bar{t}j$) (constant and variable binnings)
- PID (j)
- pt (j)

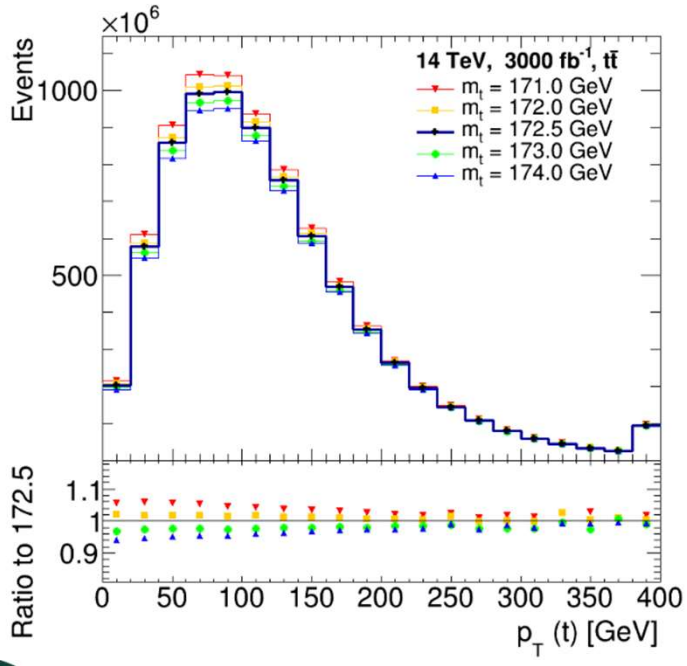
*others available as backup

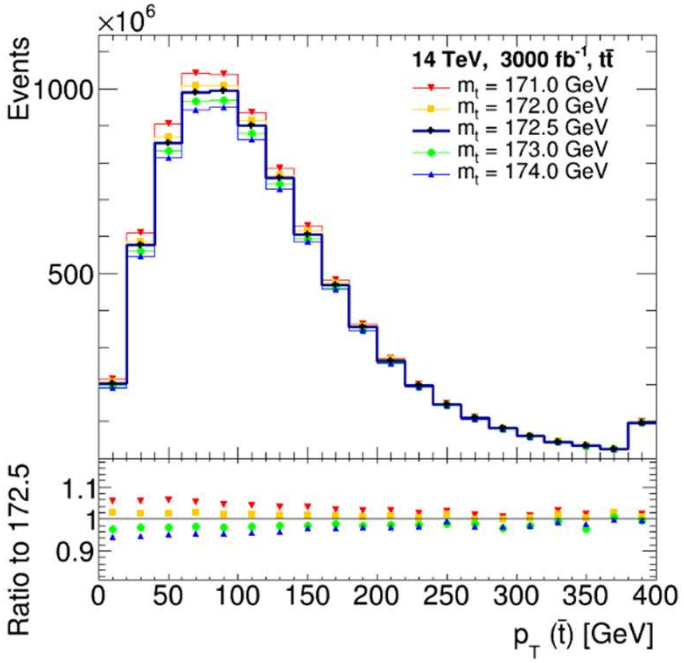
14 TeV mass ($t\bar{t}$) ($t\bar{t}$ Events)



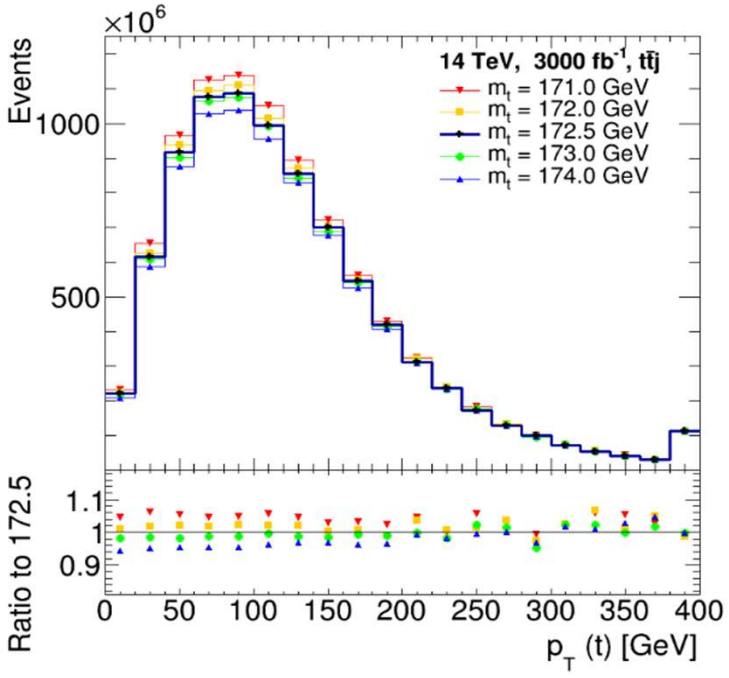
*all example plots shown come from energy 14 TeV with corresponding luminosity 3000 fb^{-1}

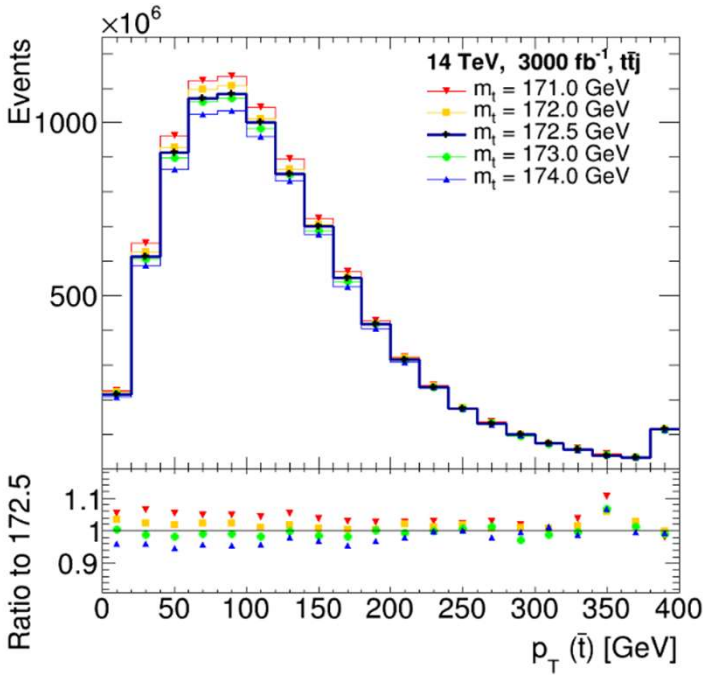
14 TeV pt (t and $\bar{t}$) ($t\bar{t}$ Events)





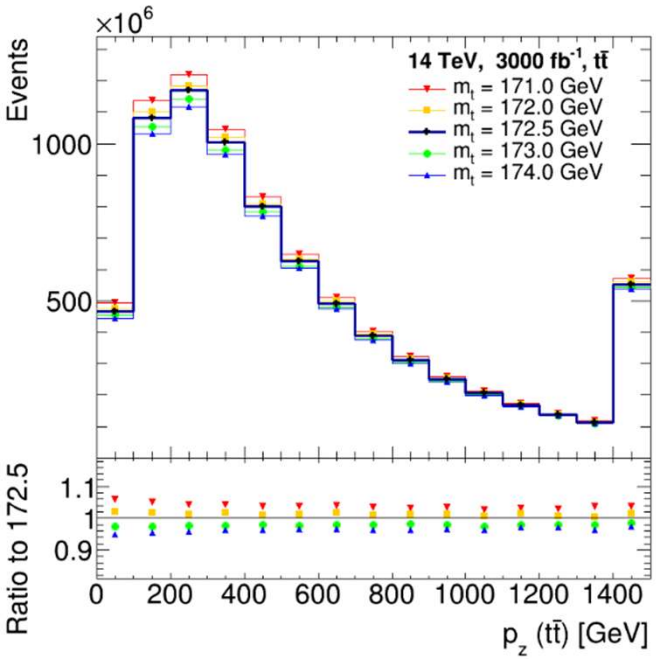
14 TeV pt (t and $\bar{t}$) ($t\bar{t}j$ Events)

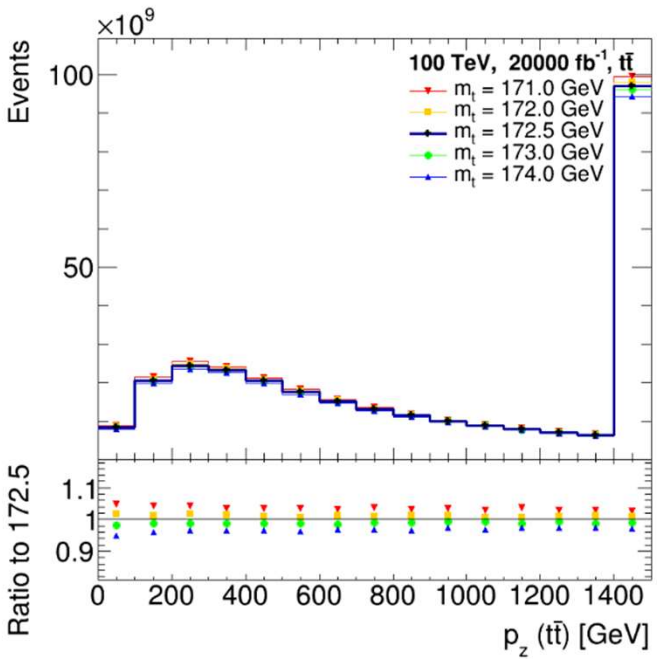




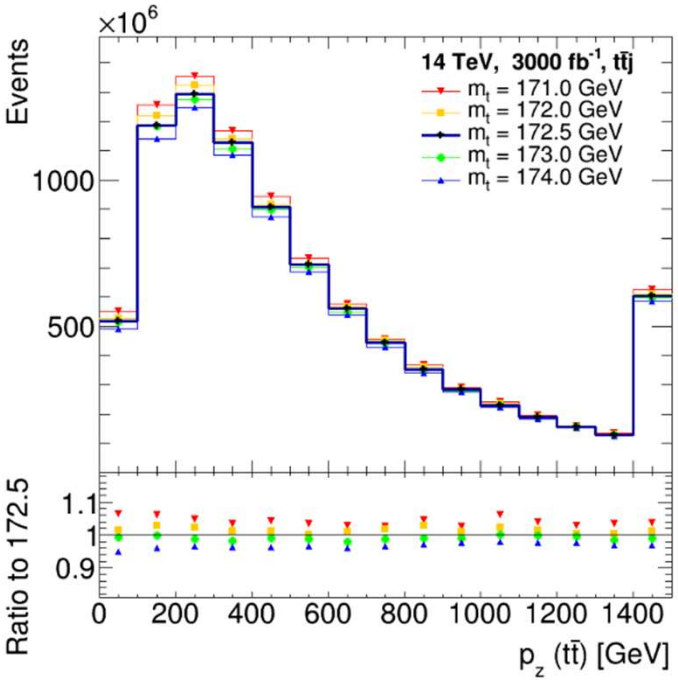
*these plots were generated prior to cuts

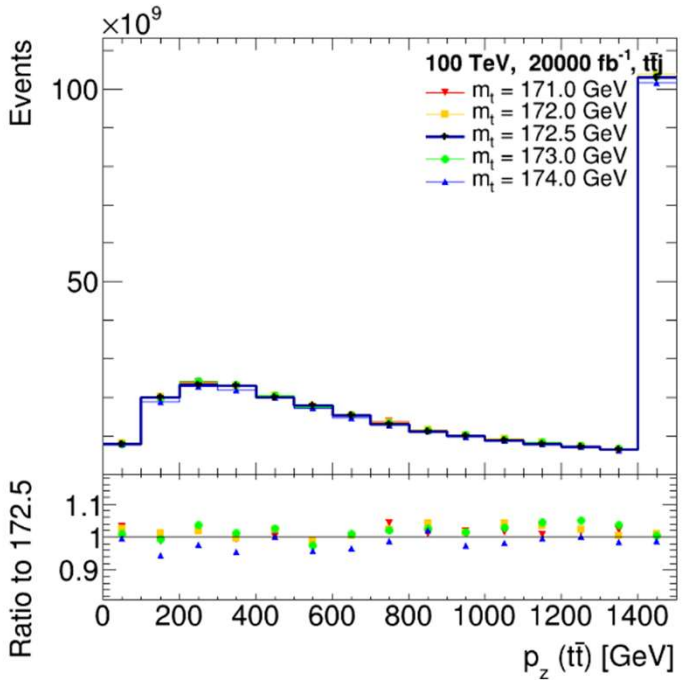
14 & 100 TeV pz ($t\bar{t}$) ($t\bar{t}$ Events)





14 & 100 TeV pz ($t\bar{t}$) ($t\bar{t}j$ Events)

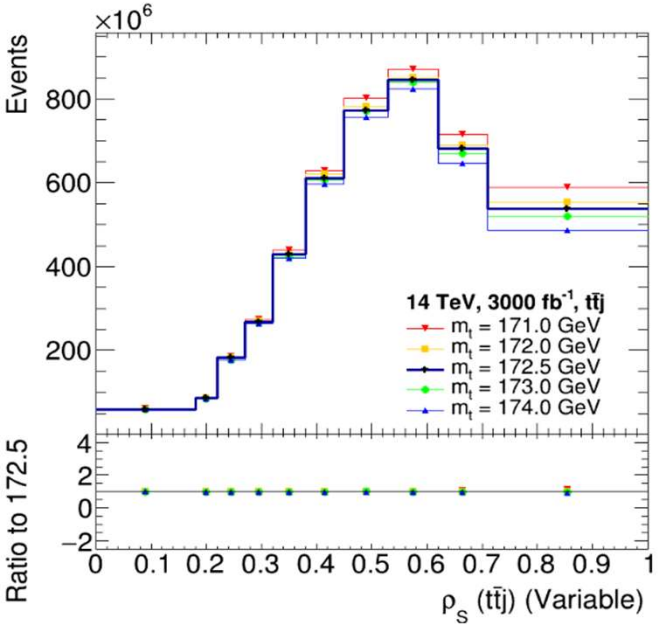


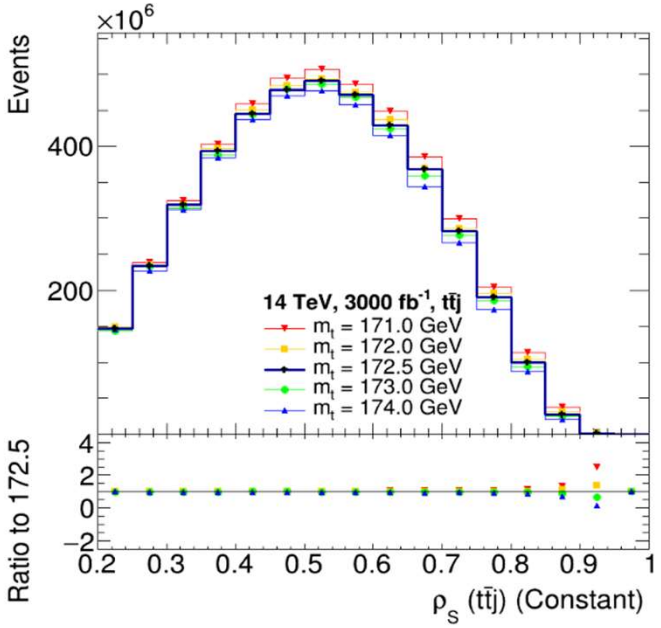


*these plots were generated prior to cuts

14 TeV rho ($t\bar{t}j$)

$$\rho = 2 * 170/\sqrt{((e_t + e_{t\sim} + e_j)^2\text{-}(px_t + px_{t\sim} + px_j)^2\text{-}(py_t + py_{t\sim} + py_j)^2\text{-}(pz_t + pz_{t\sim} + pz_j)^2)}$$

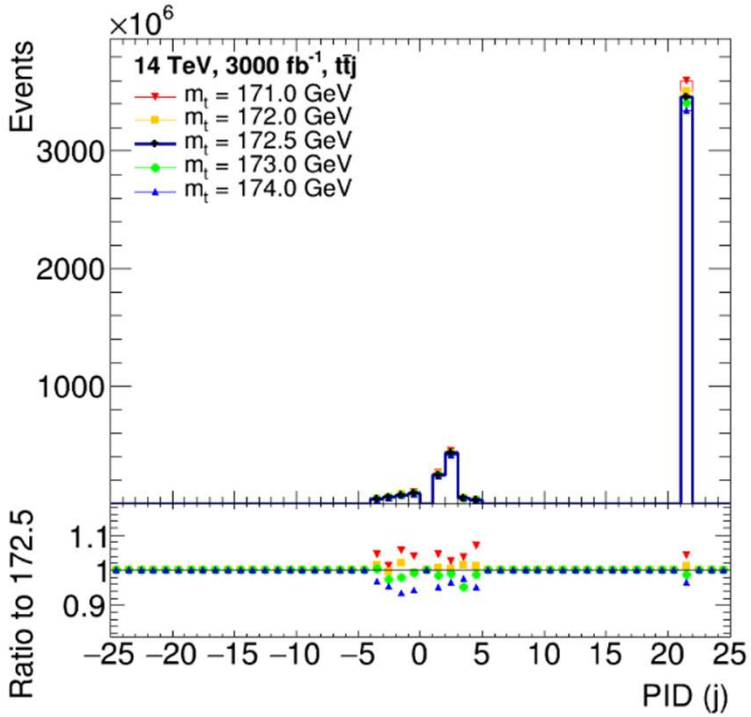




Variable binning comes from another study: "Phenomenology of $t\bar{t}j + X$ production at the LHC" (Link)

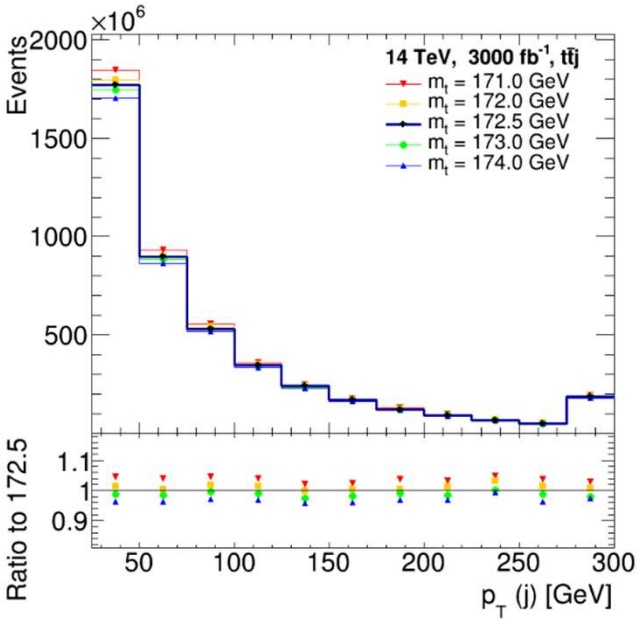
*these plots were generated after cuts

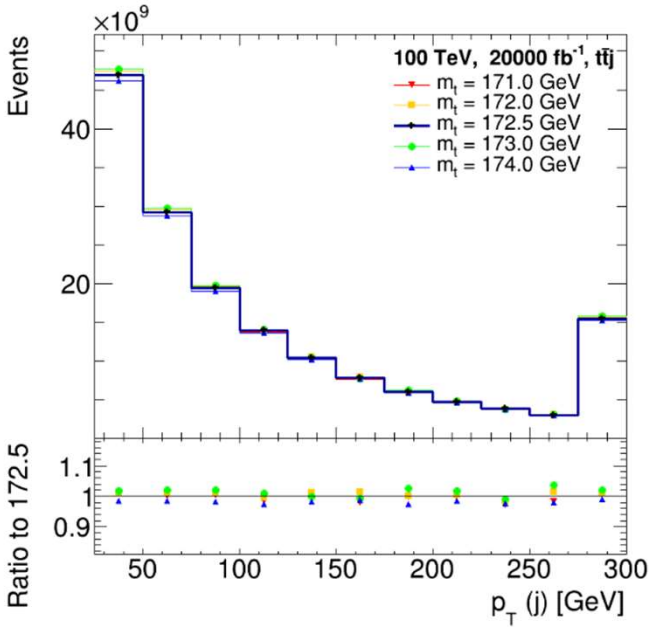
14 TeV PID (j)



*this plot was generated after cuts

14 & 100 TeV pt (*j*)





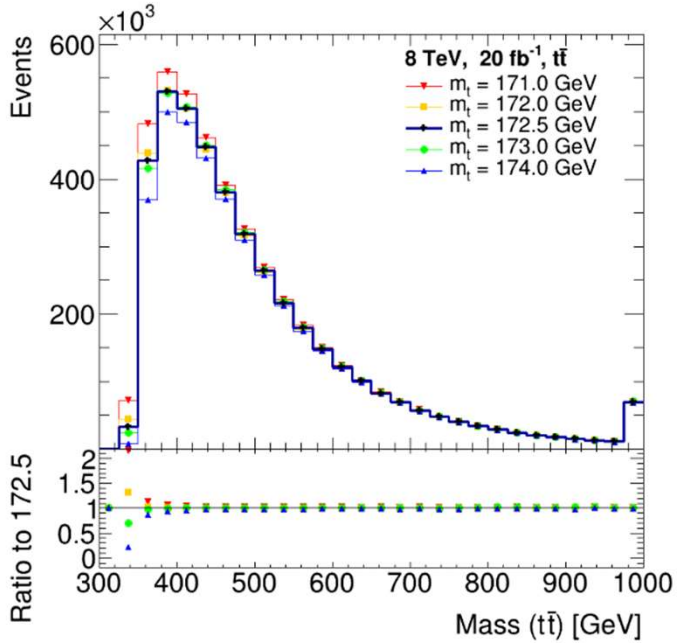
*these plots were generated after cuts

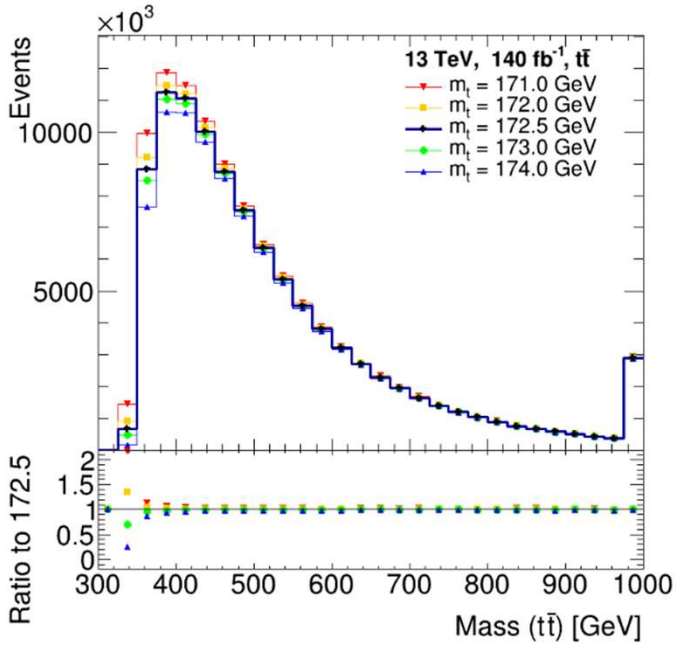
Conclusions

- Most sensitive to top mass at low mass ($t\bar{t}$) and high rho ($t\bar{t}j$)
- Distributions used in the $t\bar{t}$ mass fit

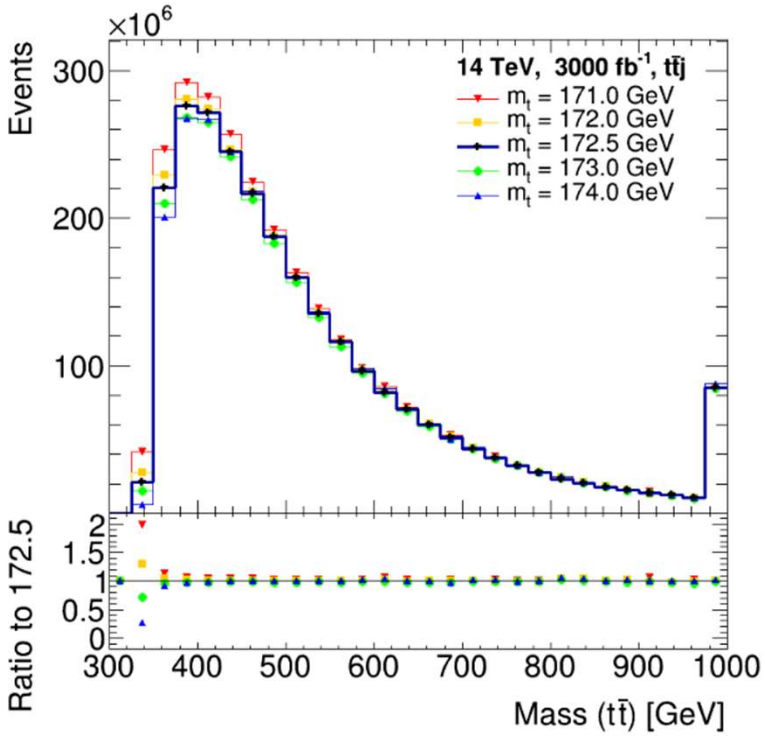
- Information will be used as part of an update to our Snowmass paper: “Dependence of the top-quark mass measured in top-quark pair production on the parton distribution functions at the LHC and future colliders”

8 & 13 TeV mass ($t\bar{t}$) ($t\bar{t}$ Events)



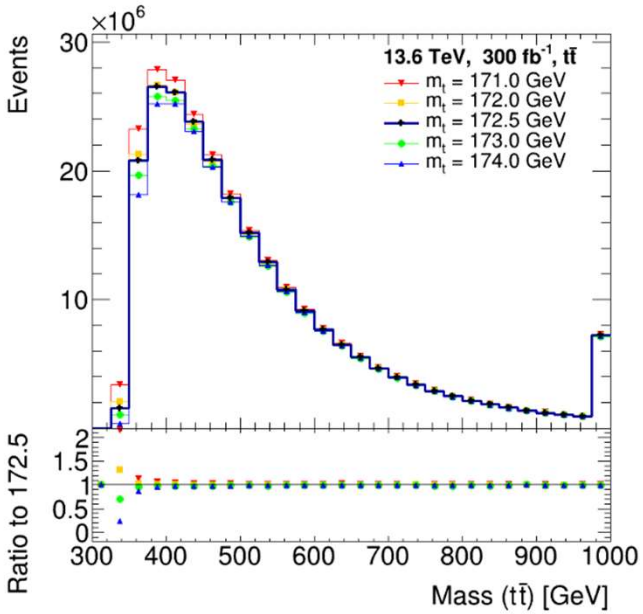


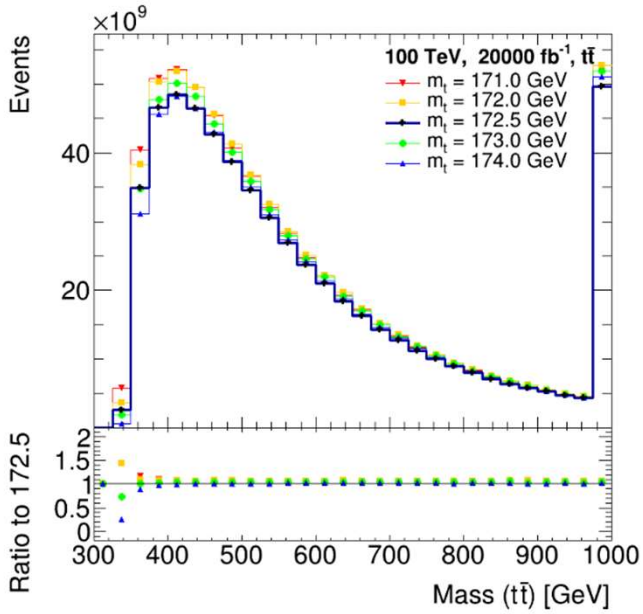
14 TeV mass ($t\bar{t}$) ($t\bar{t}j$ Events)



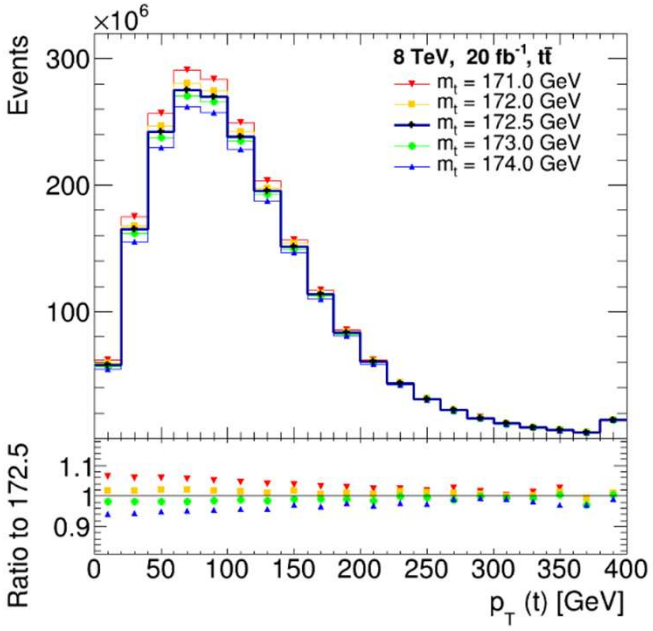
*this plot was generated prior to cuts

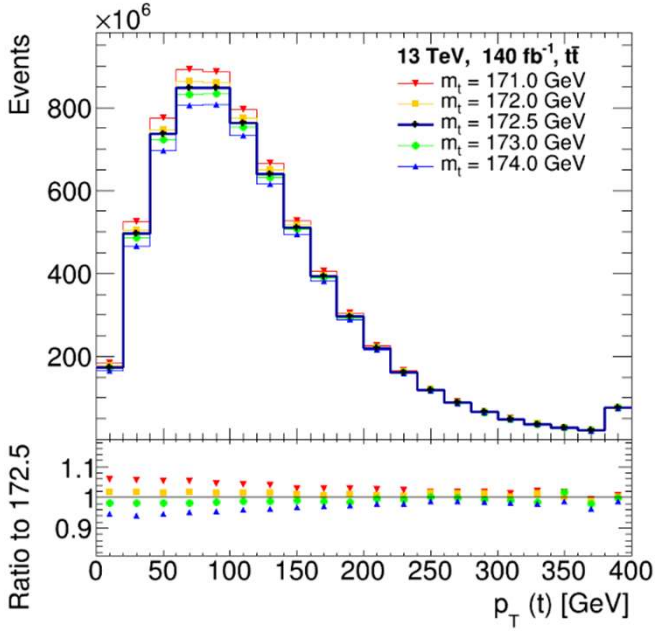
13.6 & 100 TeV mass ($t\bar{t}$) ($t\bar{t}$ Events)



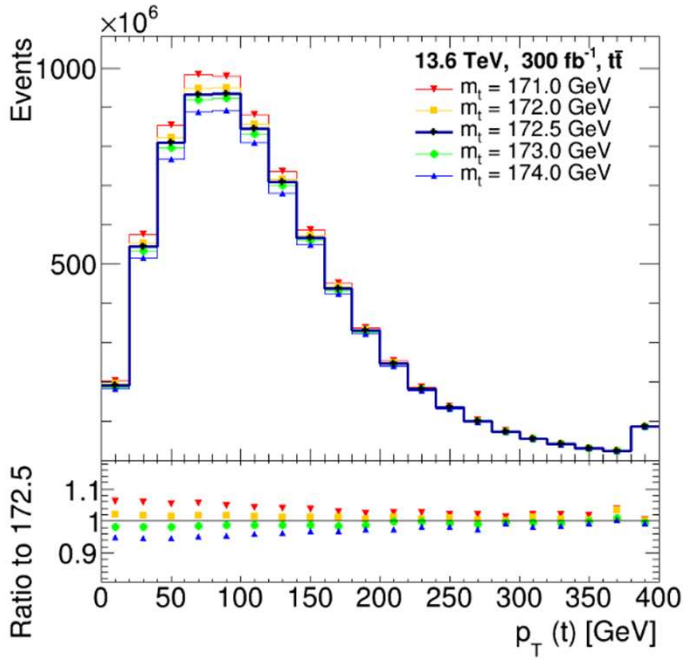


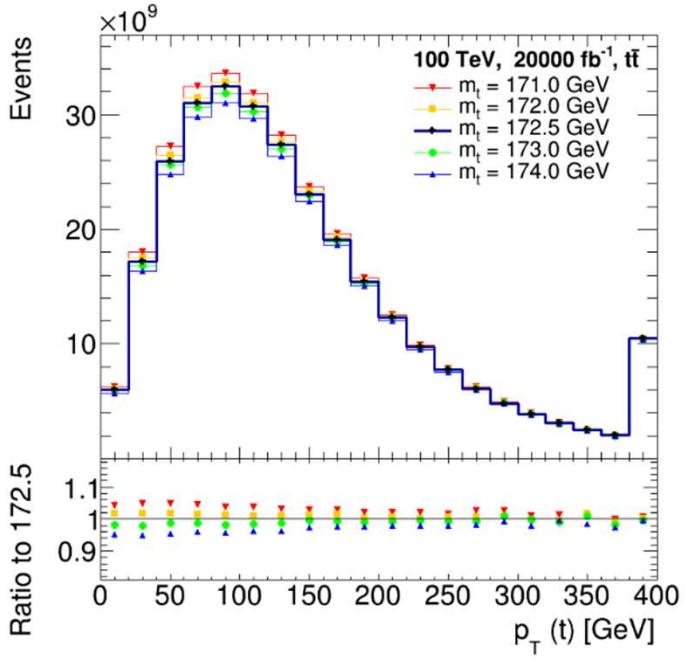
8 TeV & 13 TeV pt (t) ($t\bar{t}$ Events)



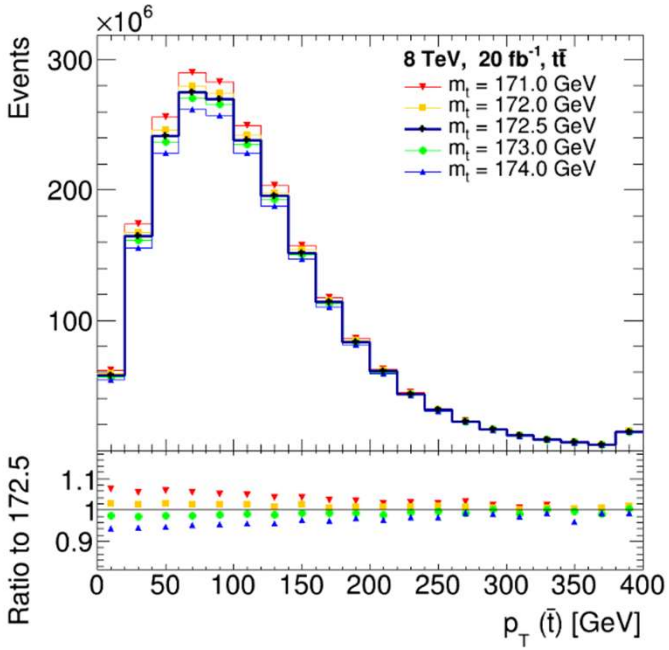


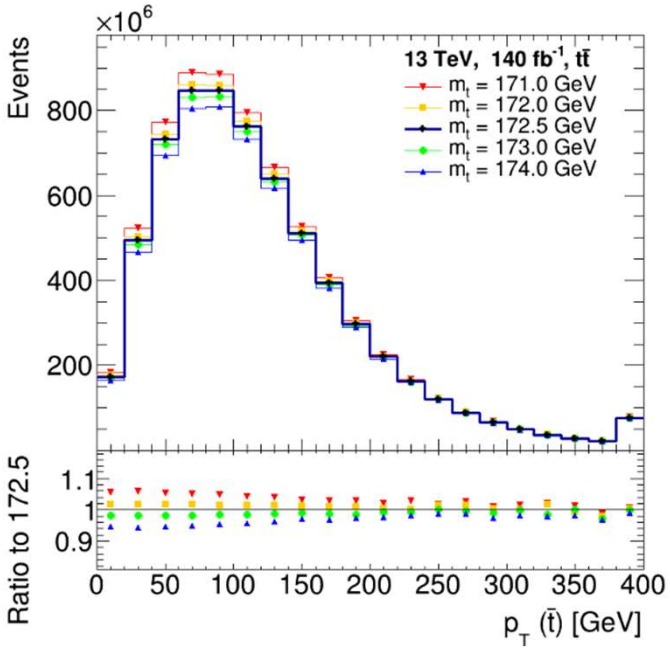
13.6 TeV & 100 TeV pt (t) ($t\bar{t}$ Events)



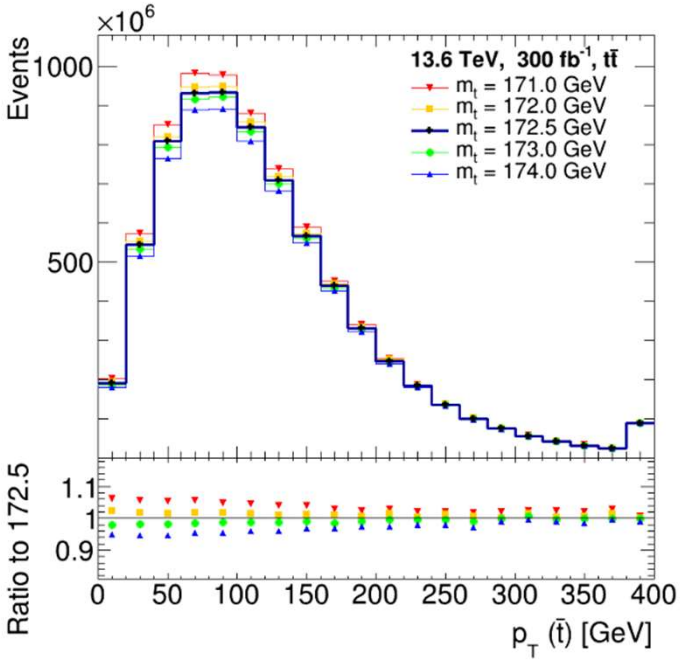


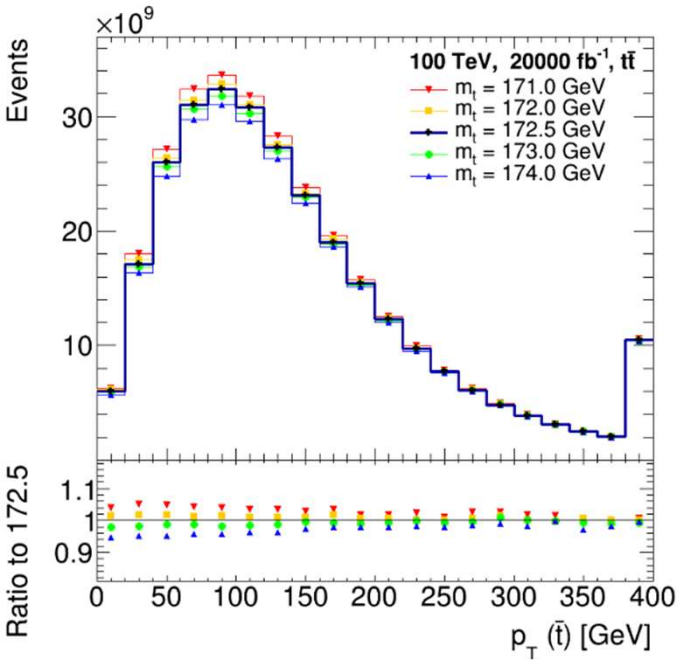
8 TeV & 13 TeV pt ($\bar{t}$) ($t\bar{t}$ Events)



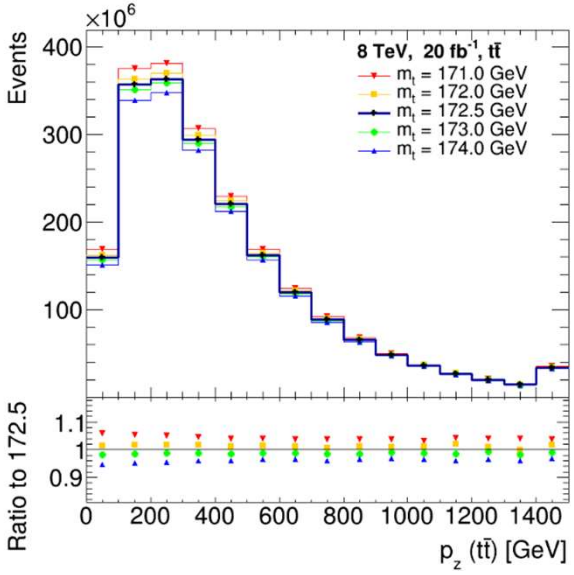


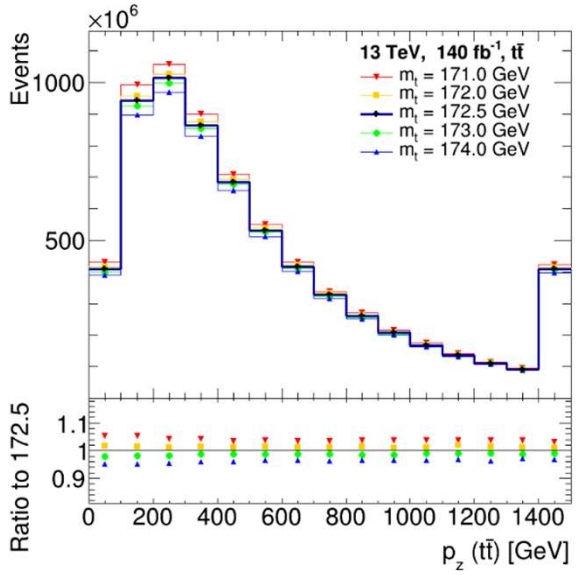
13.6 TeV & 100 TeV pt ($\bar{t}$) ($t\bar{t}$ Events)

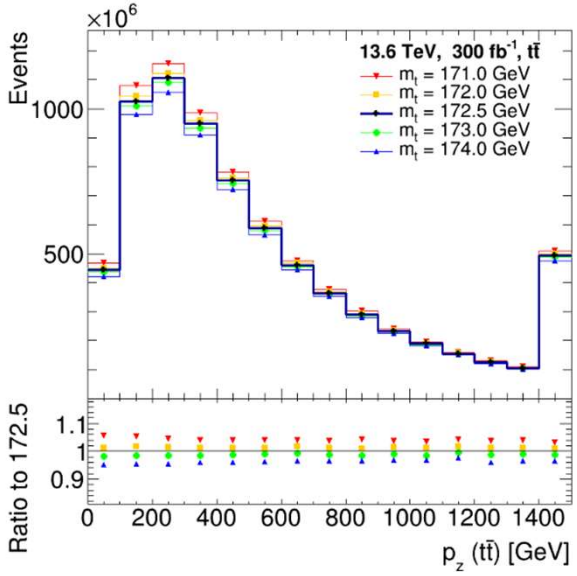




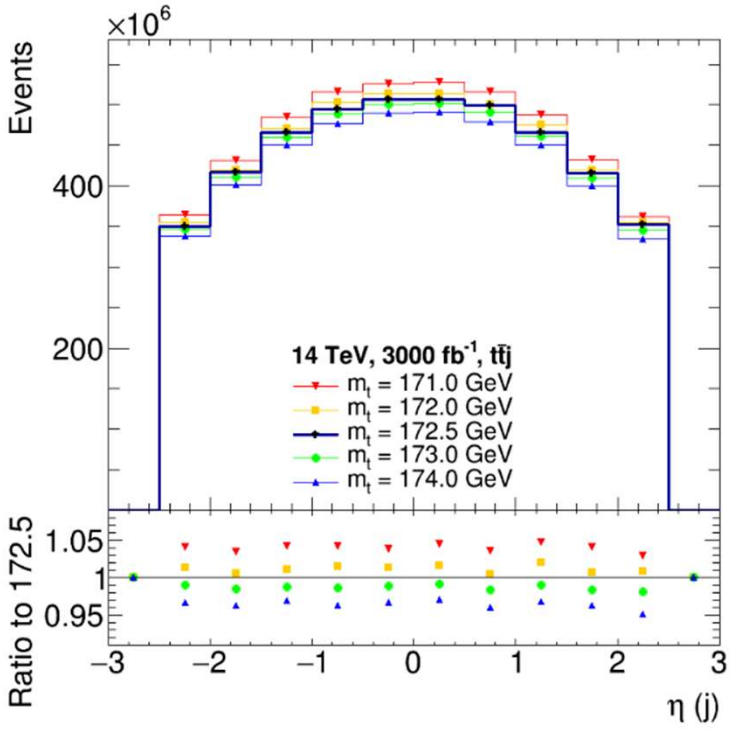
8, 13, & 13.6 TeV pz ($t\bar{t}$) ($t\bar{t}$ Events)





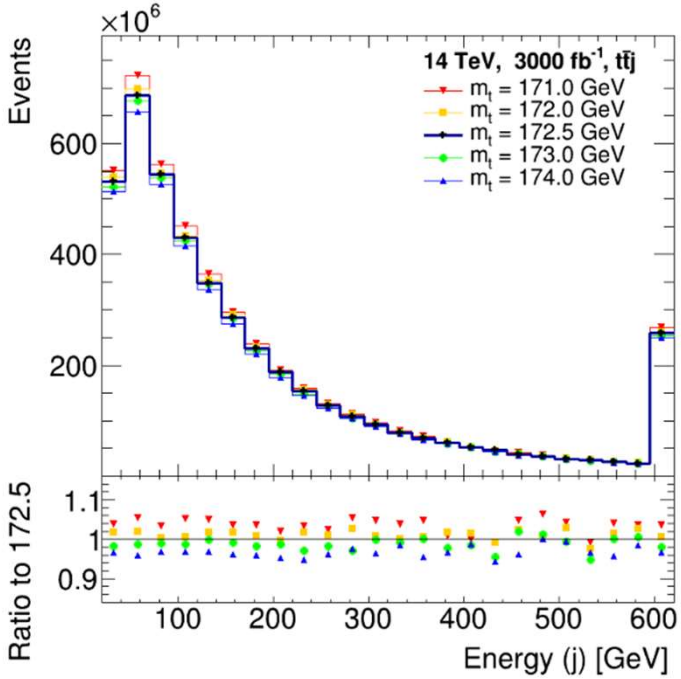


14 TeV eta (*j*)



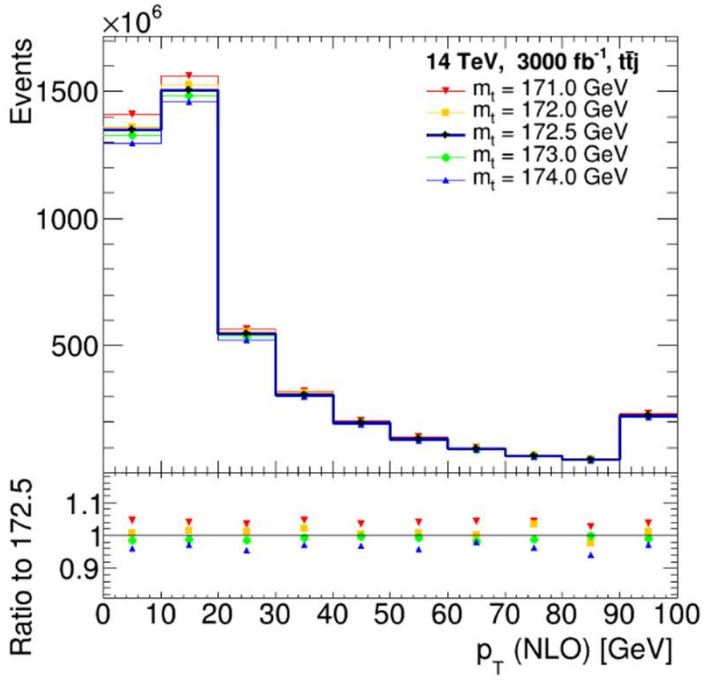
*this plot was generated after cuts

14 TeV energy (j)



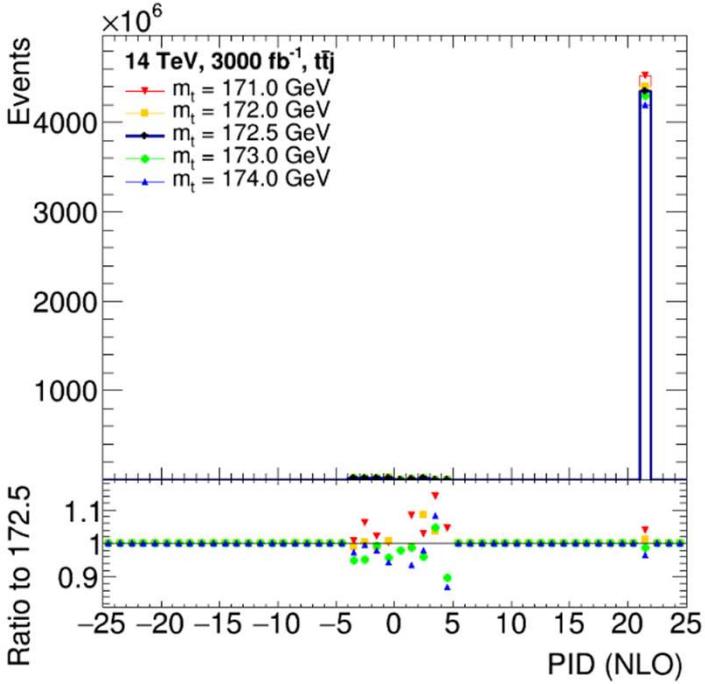
*this plot was generated after cuts

14 TeV pt (nlo)



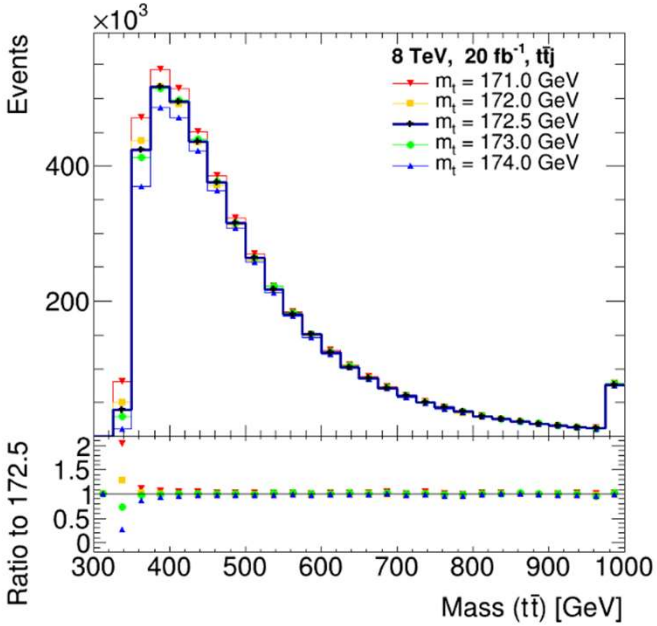
*this plot was generated after cuts

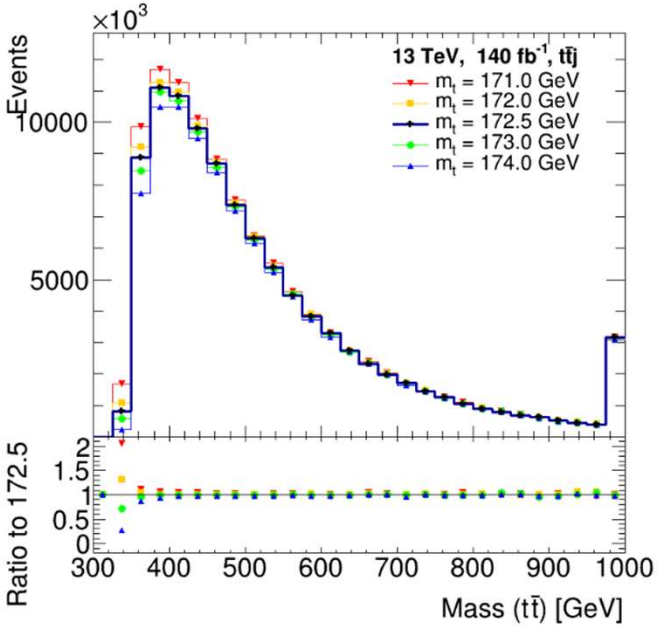
14 TeV PID (nlo)



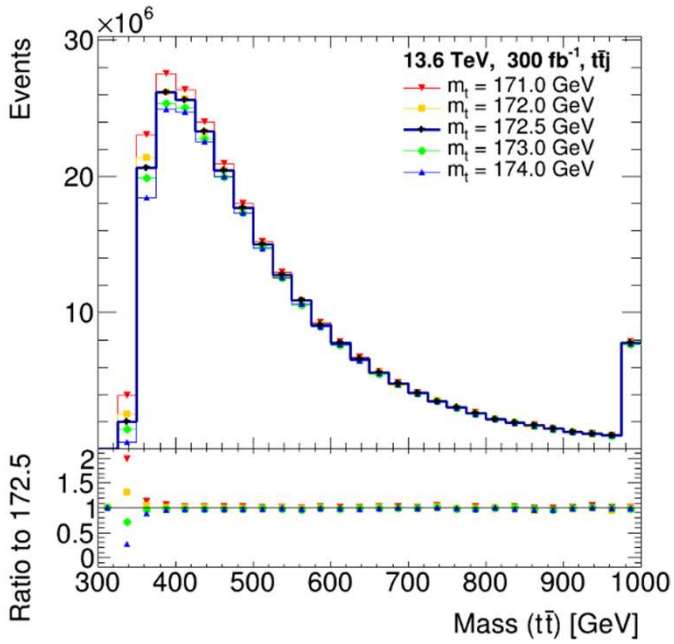
*this plot was generated after cuts

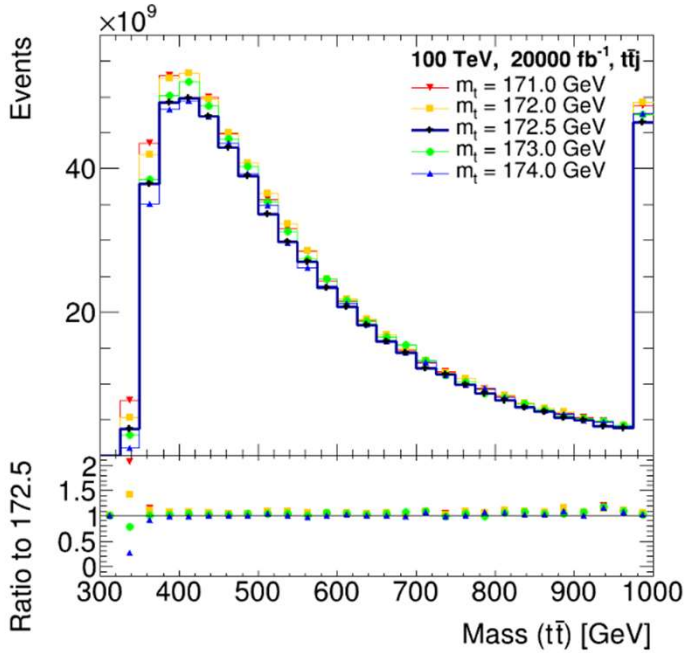
8 & 13 TeV mass ($t\bar{t}$) ($t\bar{t}j$ Events)



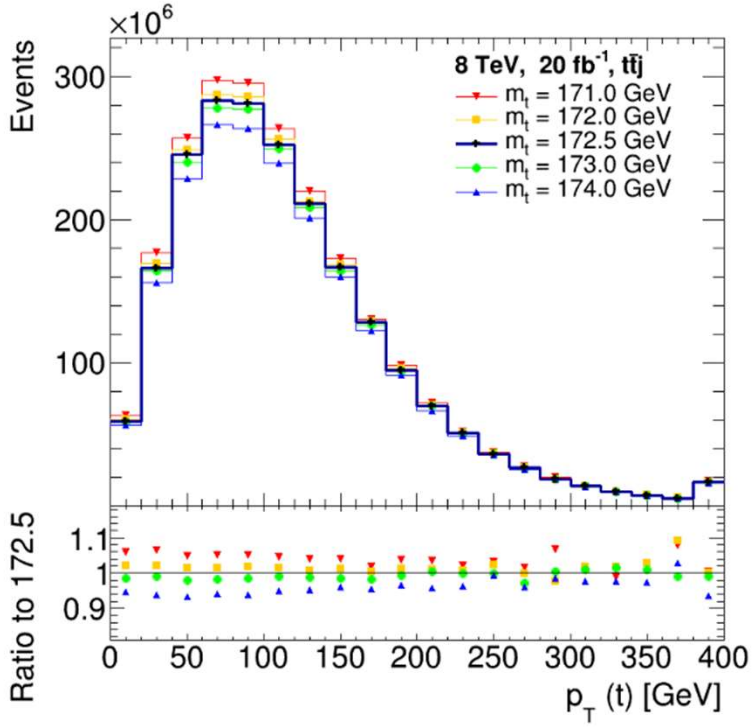


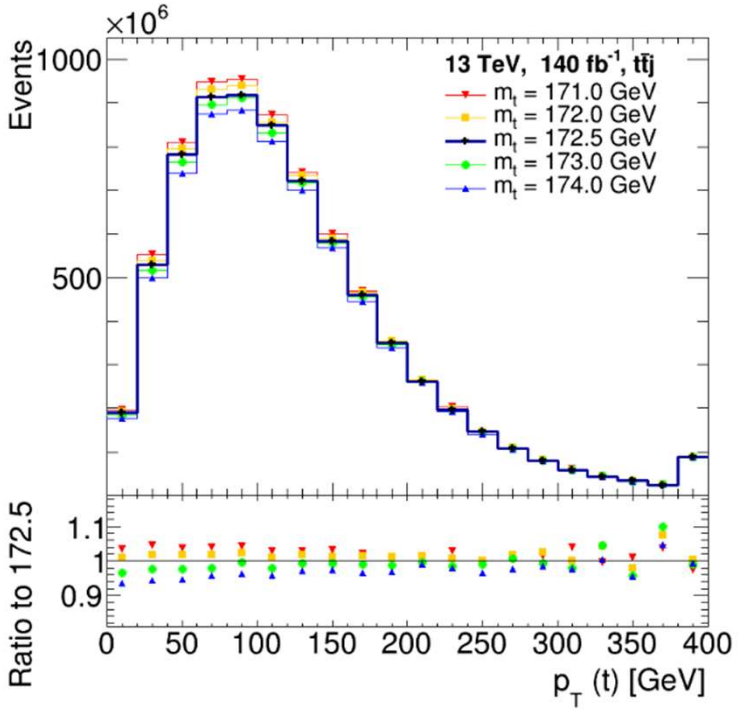
13.6 & 100 TeV mass ($t\bar{t}$) ($t\bar{t}j$ Events)



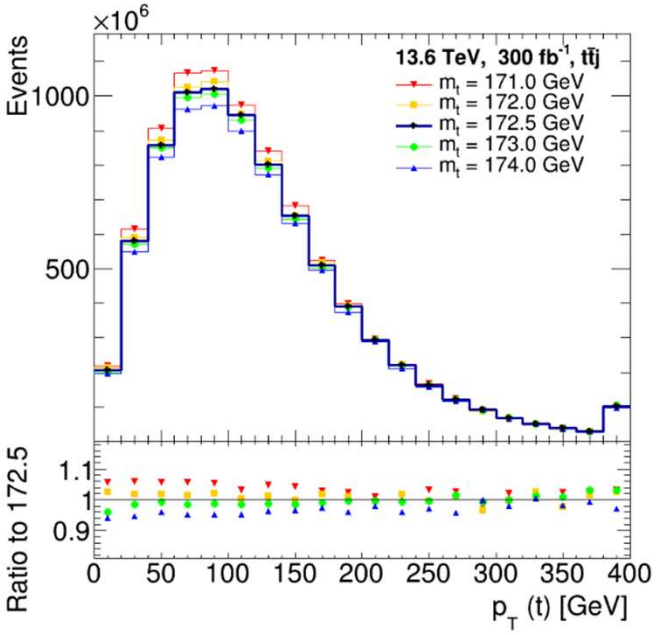


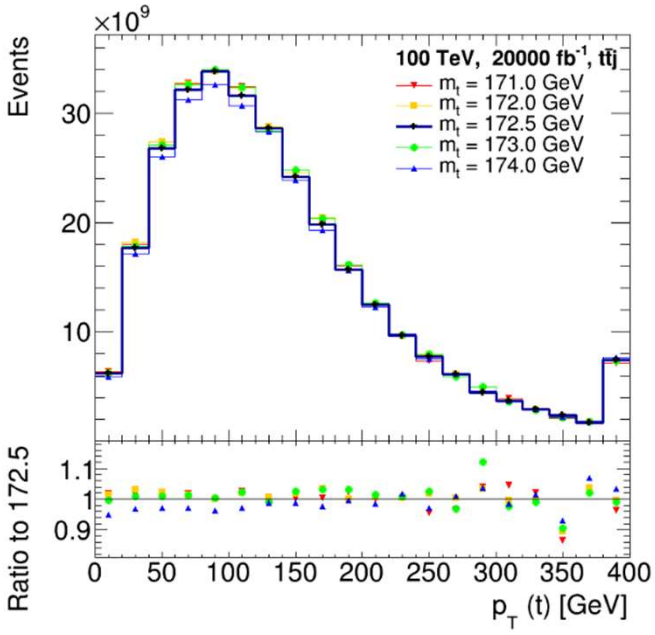
8 TeV & 13 TeV pt (t) ($t\bar{t}j$ Events)



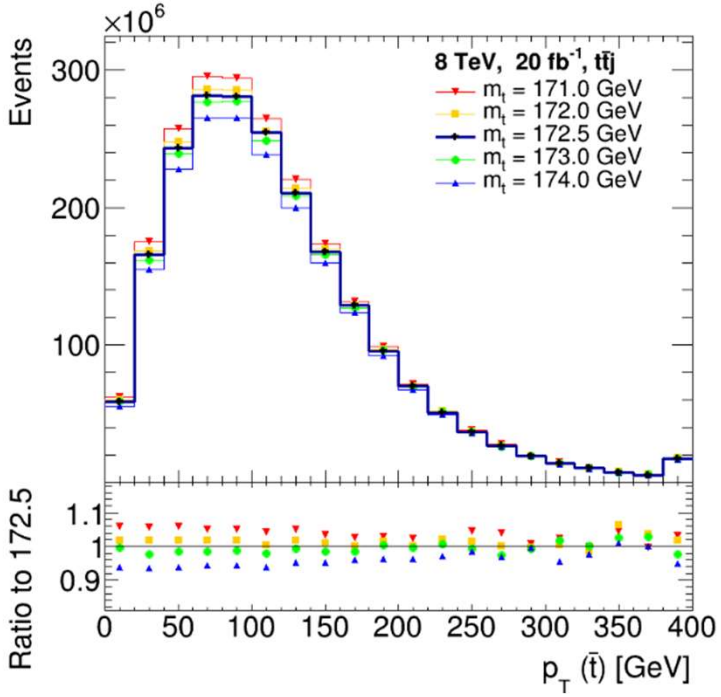


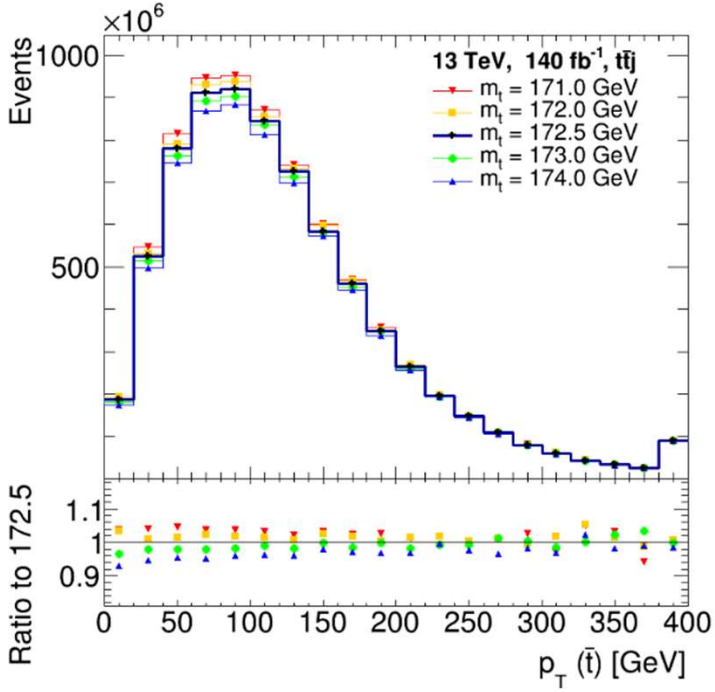
13.6 TeV & 100 TeV pt (t) ($t\bar{t}j$ Events)



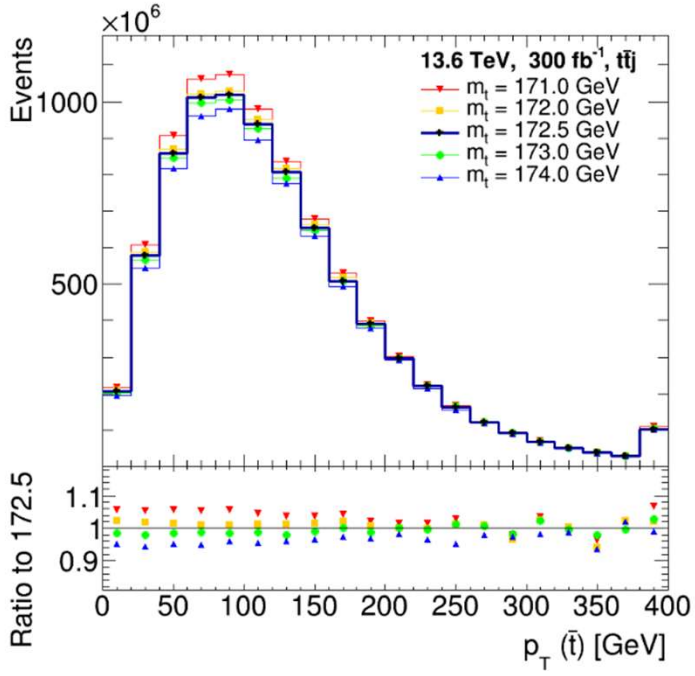


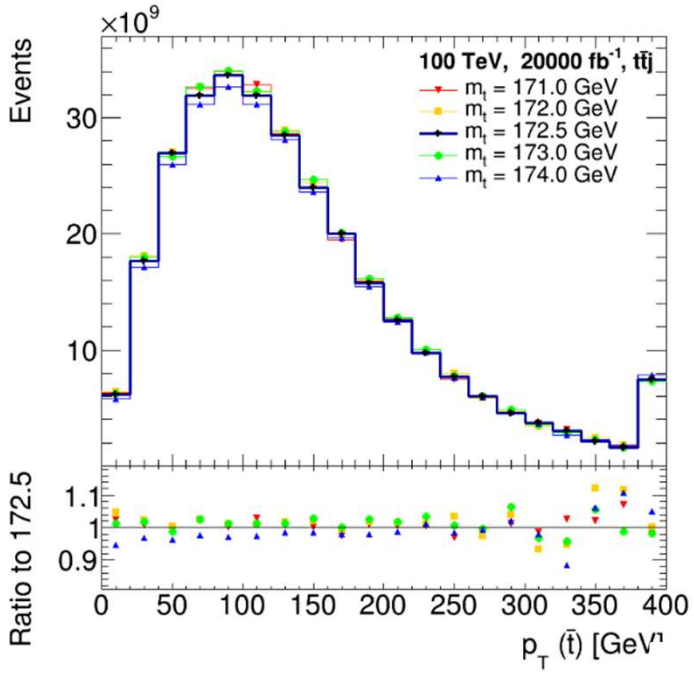
8 TeV & 13 TeV pt ($\bar{t}$) ($t\bar{t}j$ Events)



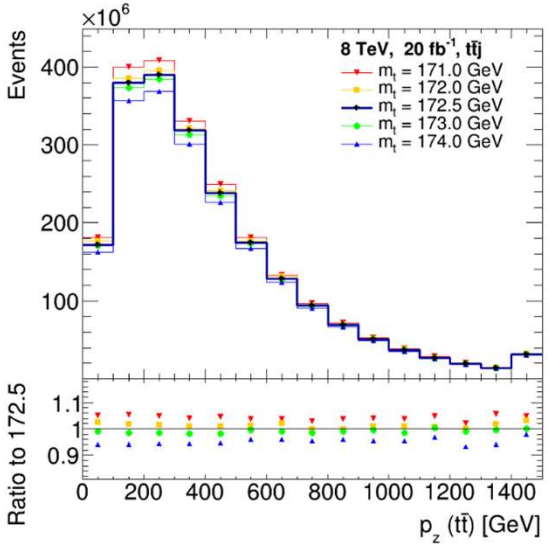


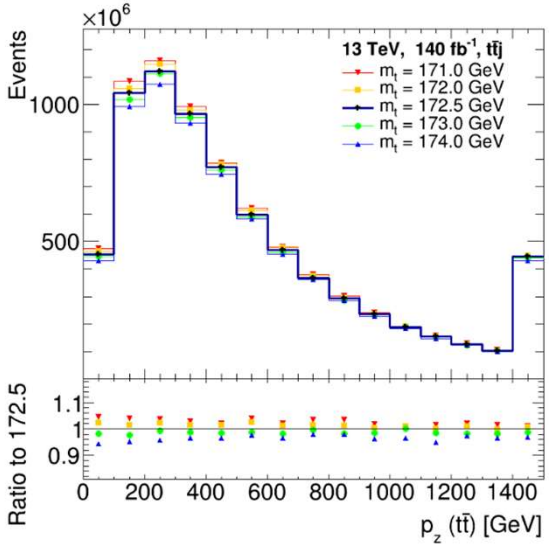
13.6 TeV & 100 TeV pt ($\bar{t}$) ($t\bar{t}j$ Events)

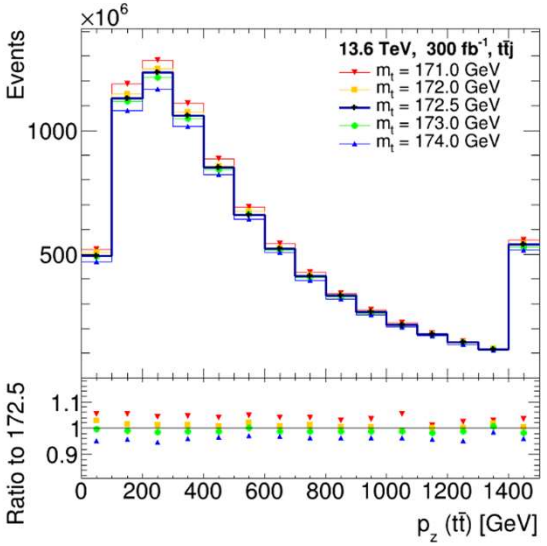




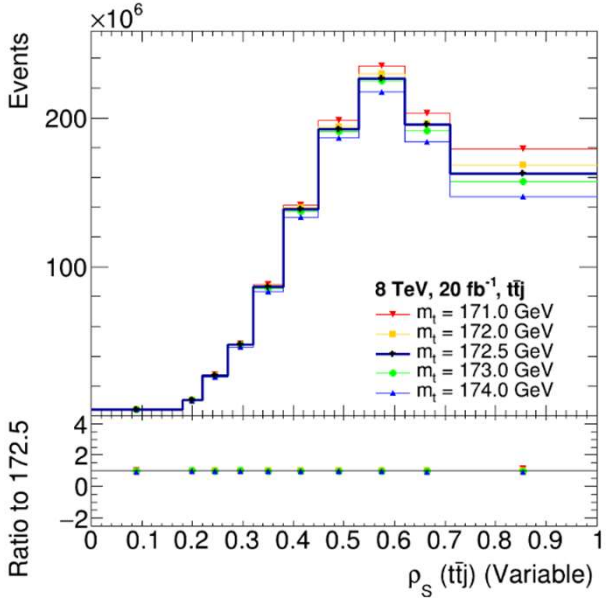
8, 13, & 13.6 TeV pz ($t\bar{t}$) ($t\bar{t}j$ Events)

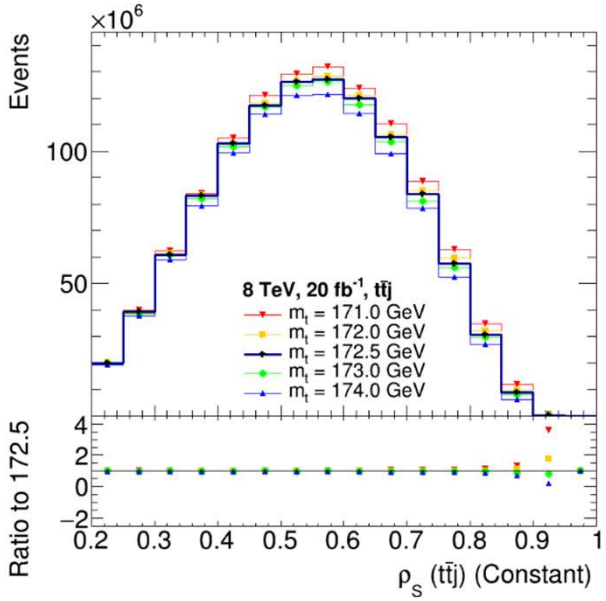




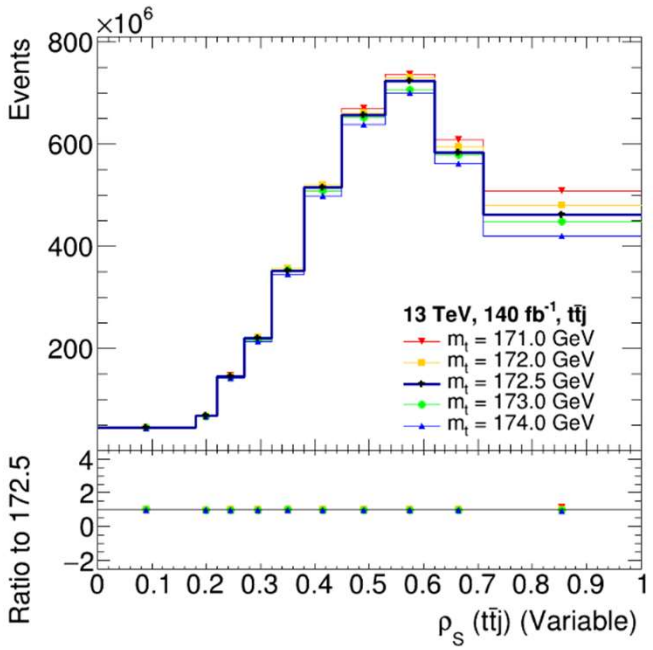


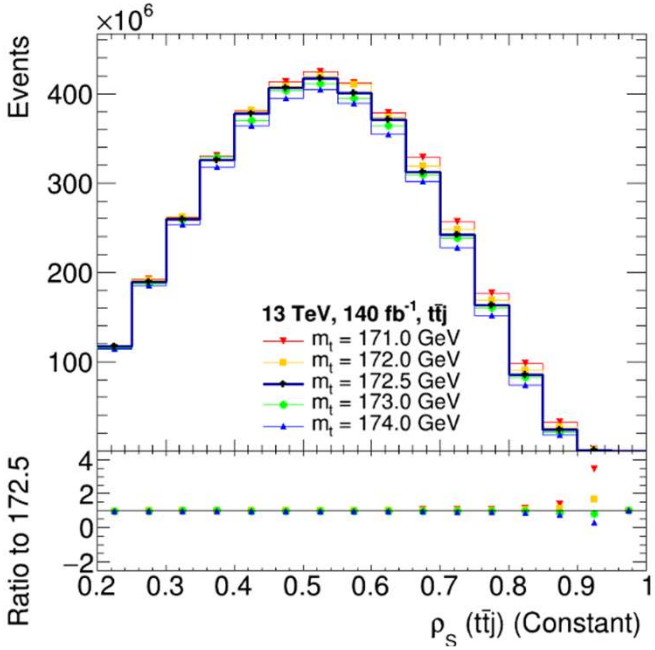
8 TeV rho ($t\bar{t}j$)



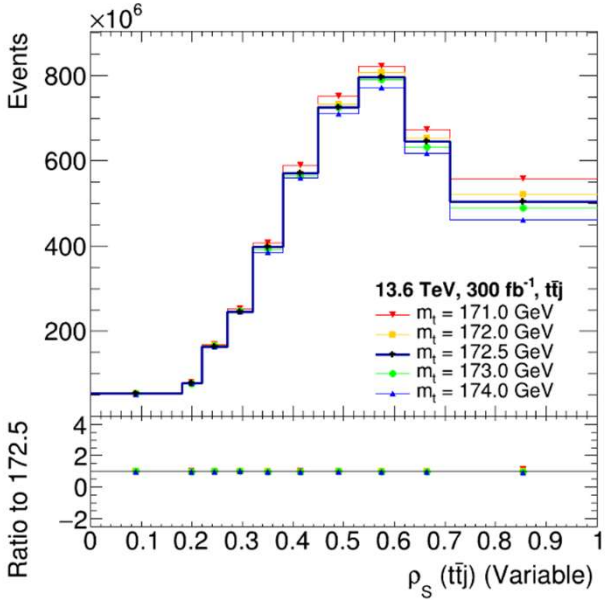


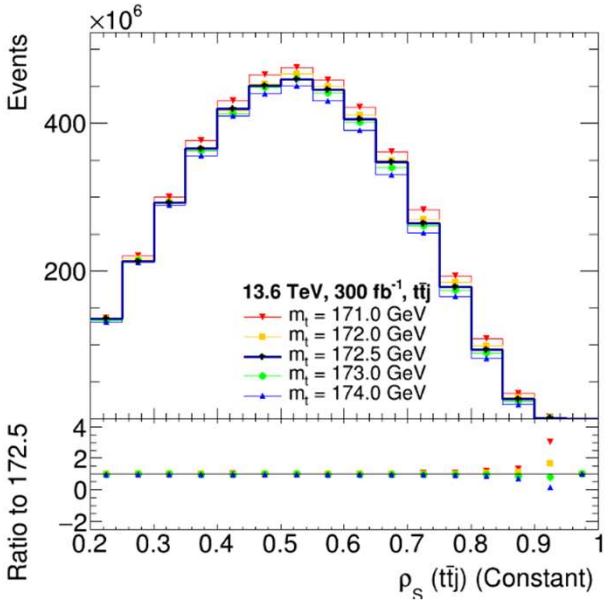
13 TeV rho ($t\bar{t}j$)



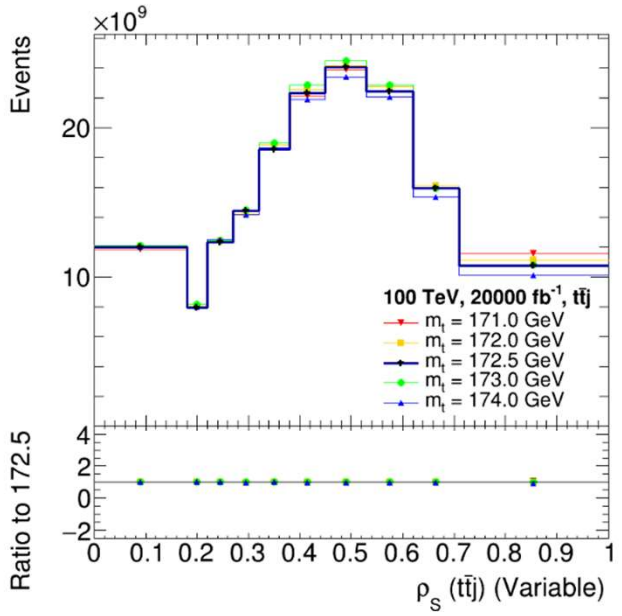


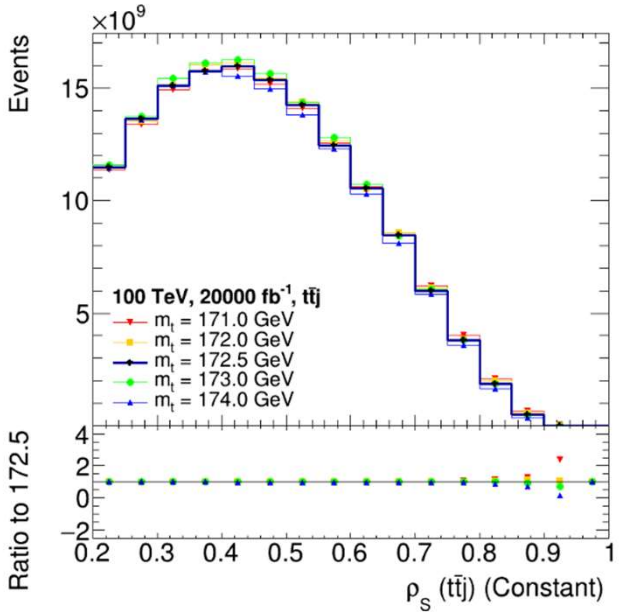
13.6 TeV rho ($t\bar{t}j$)



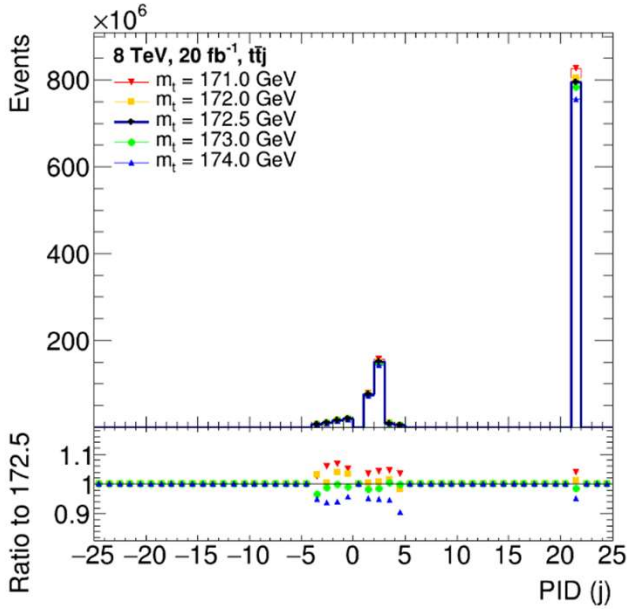


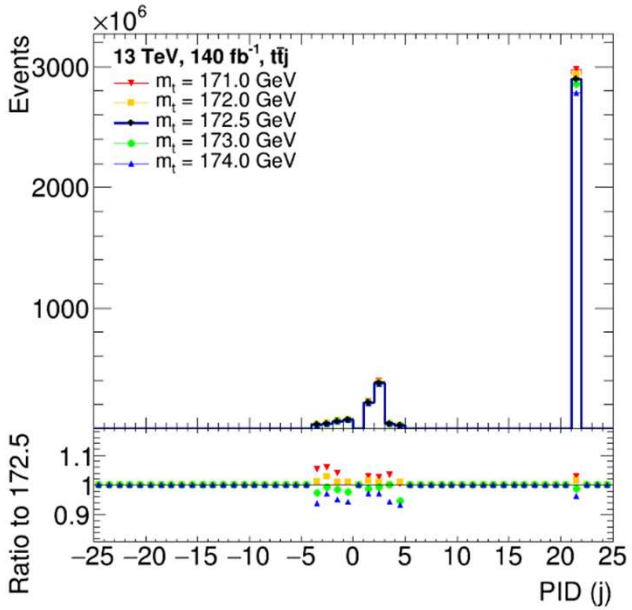
100 TeV rho ($t\bar{t}j$)



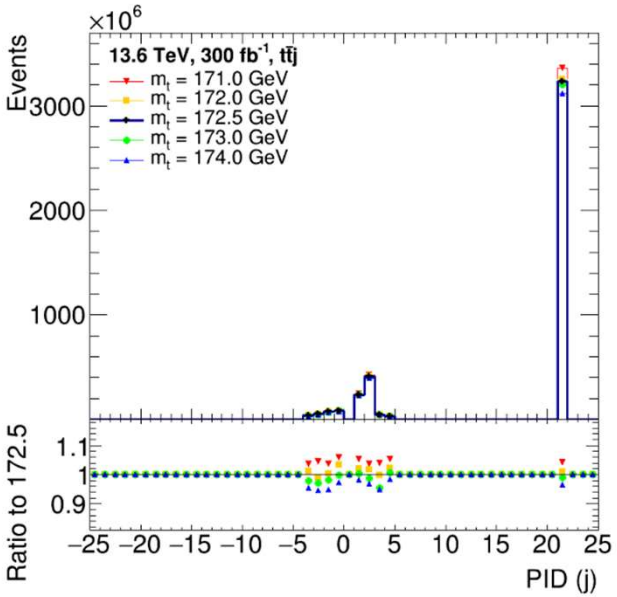


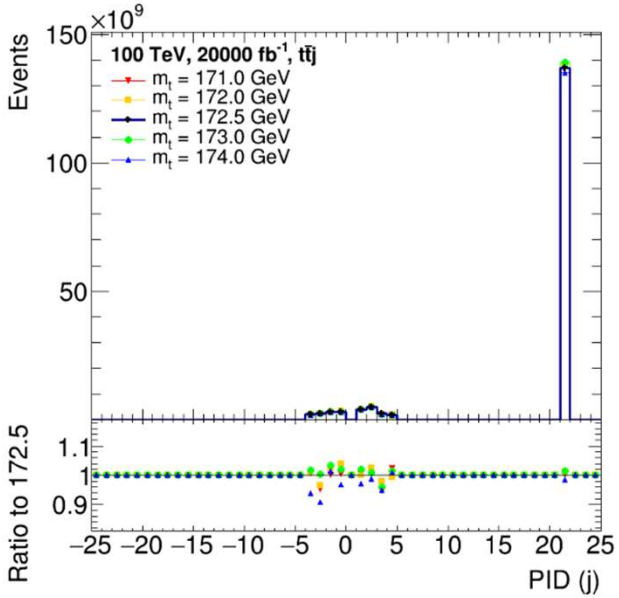
8 & 13 TeV PID (*j*)


×10^6
Events
8 TeV, 20 fb^-1, tt̄j
m_t = 171.0 GeV
m_t = 172.0 GeV
m_t = 172.5 GeV
m_t = 173.0 GeV
m_t = 174.0 GeV
800
600
400
200
Ratio to 172.5
1.1
1
0.9
−25 −20 −15 −10 −5 0 5 10 15 20 25
PID (j)

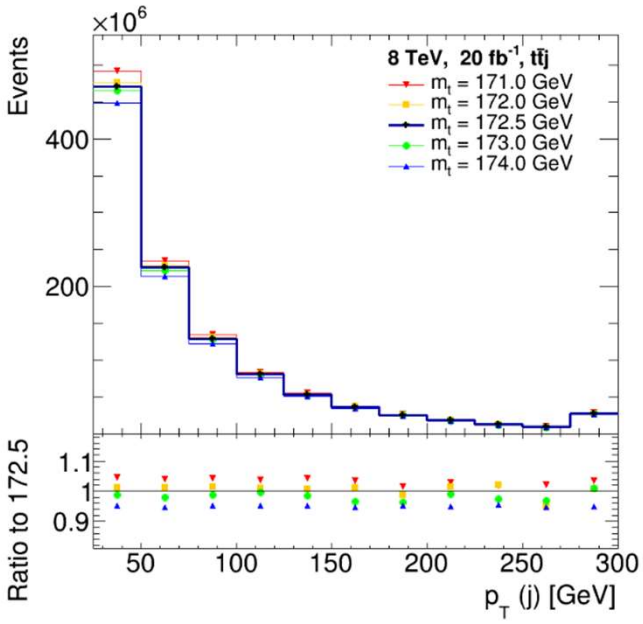

×10^6
Events
13 TeV, 140 fb^-1, tt̄j
m_t = 171.0 GeV
m_t = 172.0 GeV
m_t = 172.5 GeV
m_t = 173.0 GeV
m_t = 174.0 GeV
3000
2000
1000
Ratio to 172.5
1.1
1
0.9
−25 −20 −15 −10 −5 0 5 10 15 20 25
PID (j)

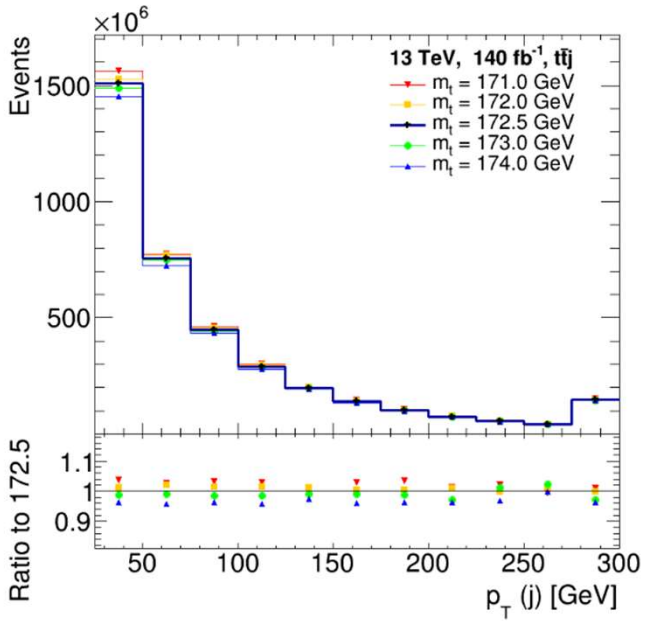
13.6 & 100 TeV PID (*j*)

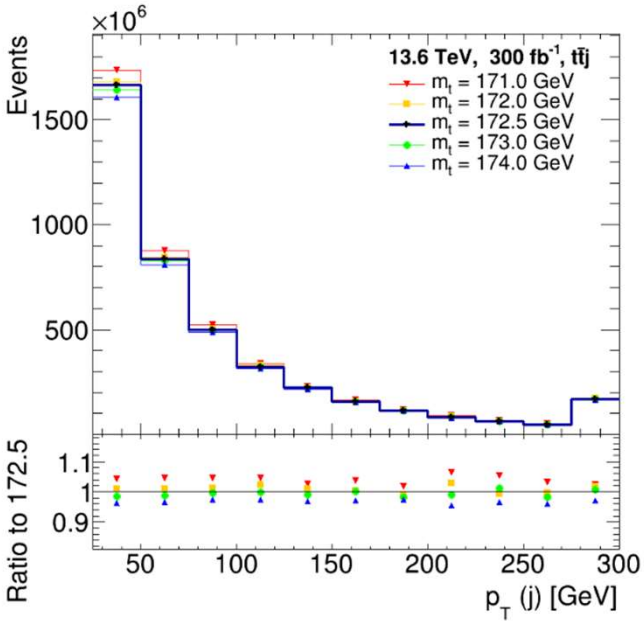




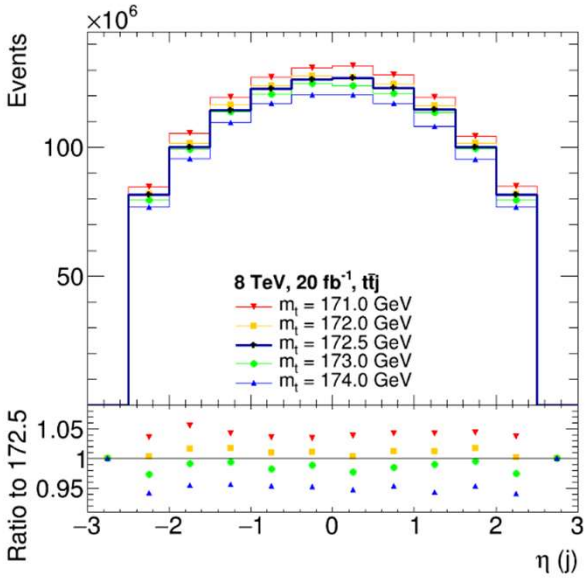
8, 13, & 13.6 TeV pt (*j*)

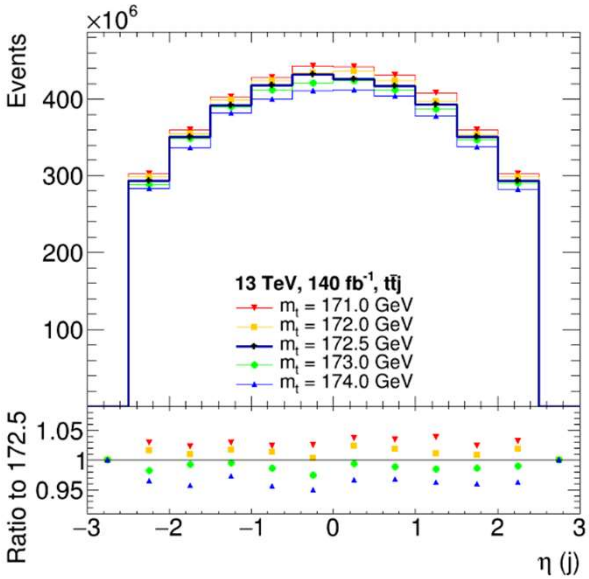




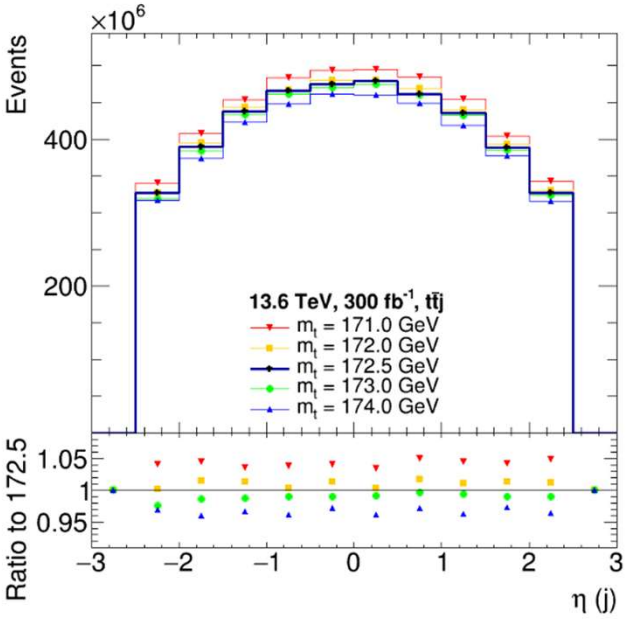


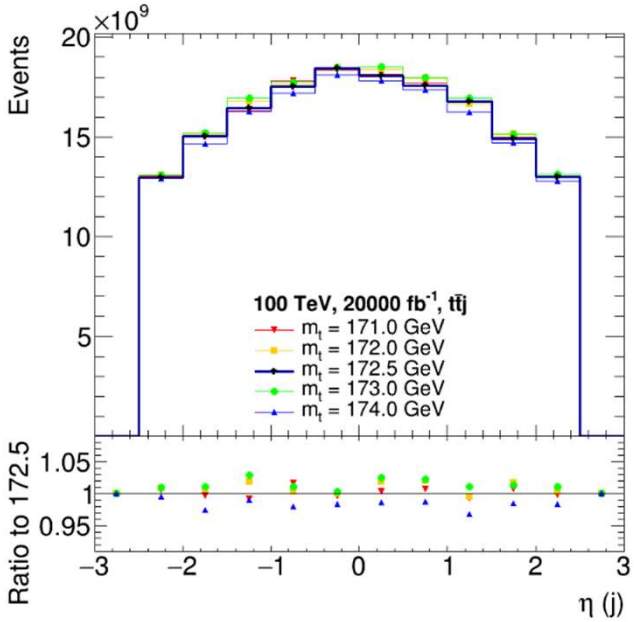
8 & 13 TeV eta (*j*)


×10^6
Events
100
50
8 TeV, 20 fb^-1, tt̄j
m_t = 171.0 GeV
m_t = 172.0 GeV
m_t = 172.5 GeV
m_t = 173.0 GeV
m_t = 174.0 GeV
Ratio to 172.5
1.05
1
0.95
−3
−2
−1
0
1
2
3
η (j)

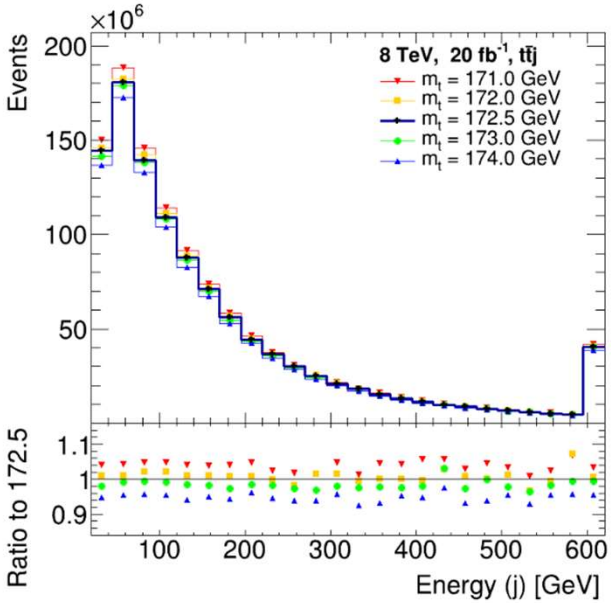

×10^6
Events
400
300
200
100
13 TeV, 140 fb^-1, tt̄j
m_t = 171.0 GeV
m_t = 172.0 GeV
m_t = 172.5 GeV
m_t = 173.0 GeV
m_t = 174.0 GeV
Ratio to 172.5
1.05
1
0.95
−3
−2
−1
0
1
2
3
η (j)

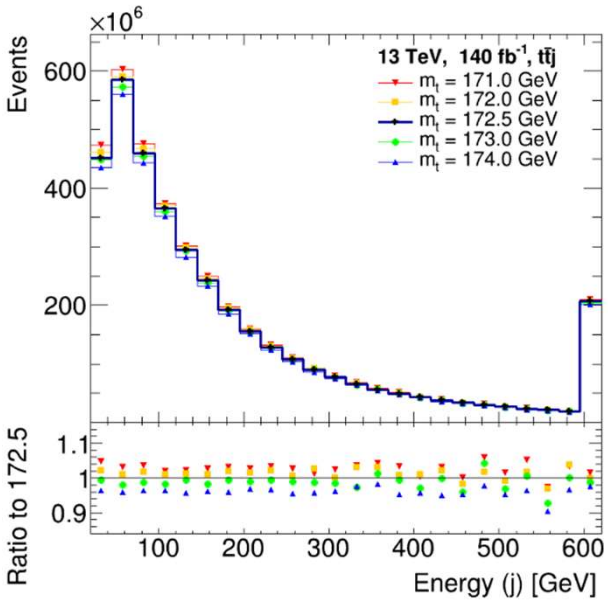
13.6 & 100 TeV eta (j)



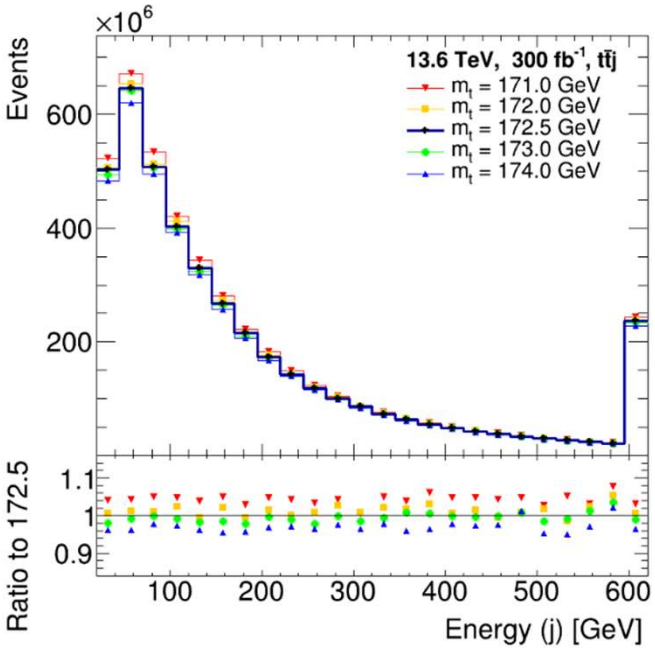


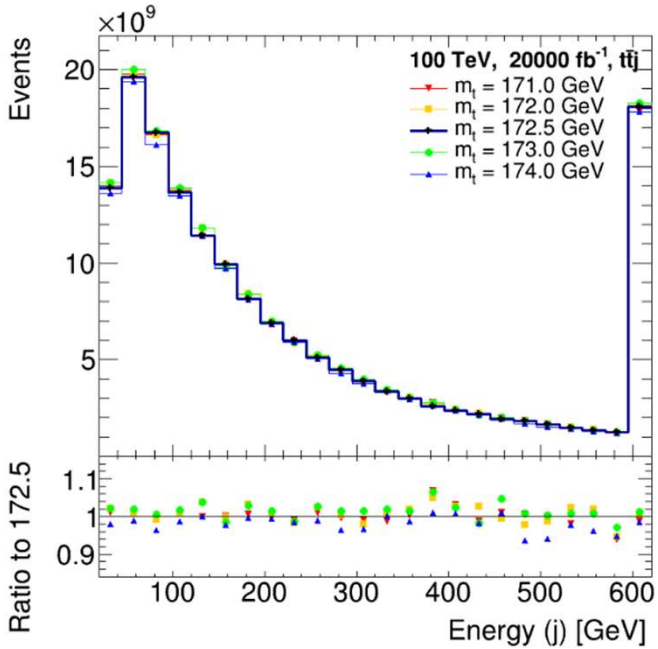
8 & 13 TeV energy (*j*)



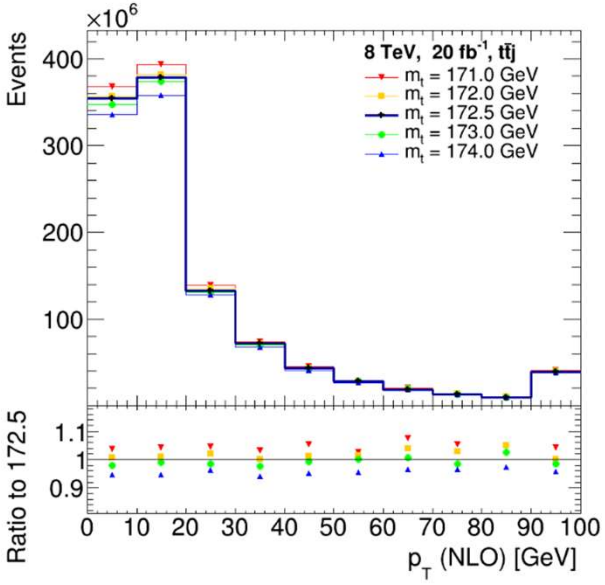


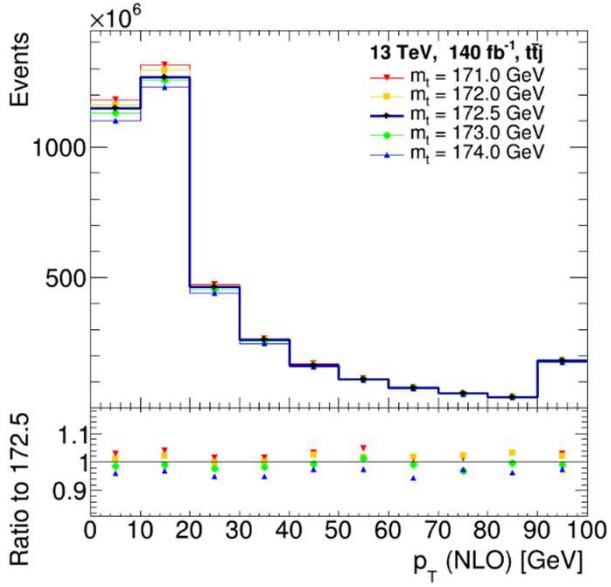
13.6 & 100 TeV energy (j)



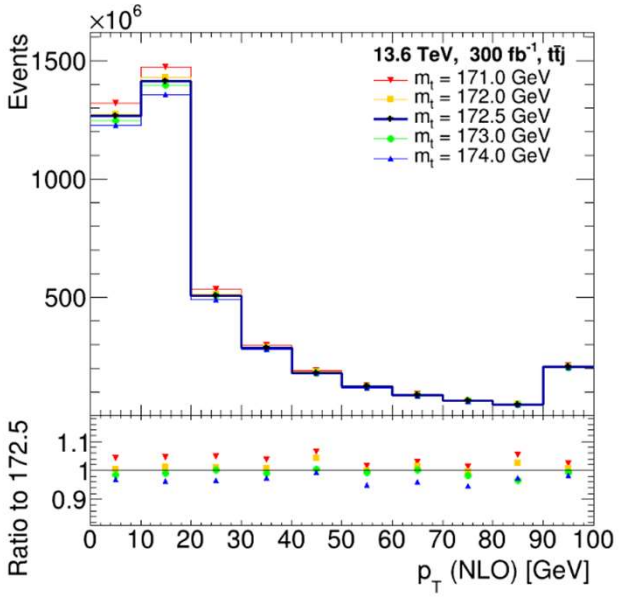


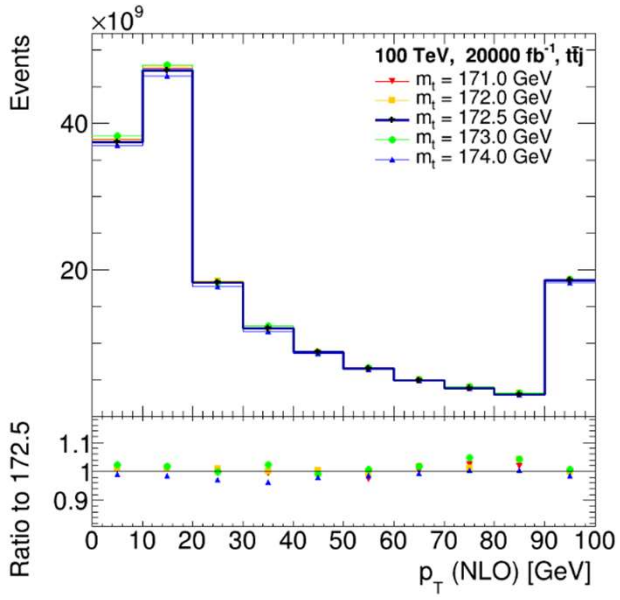
8 & 13 TeV pt (nlo)



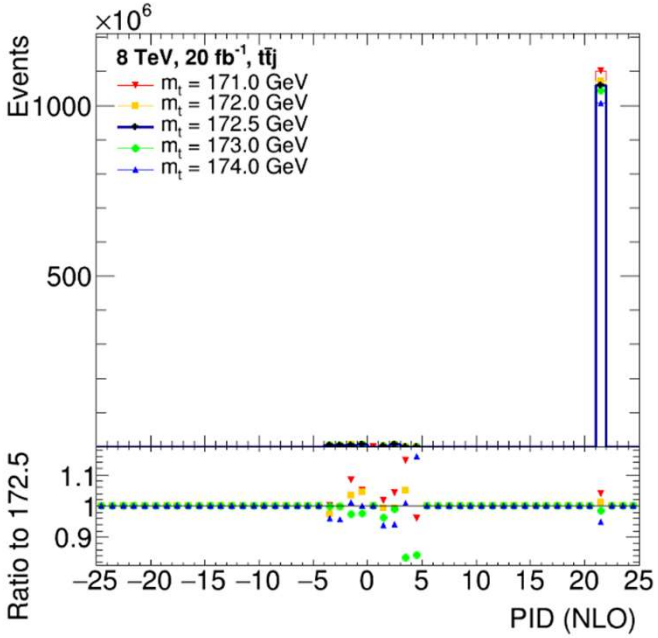


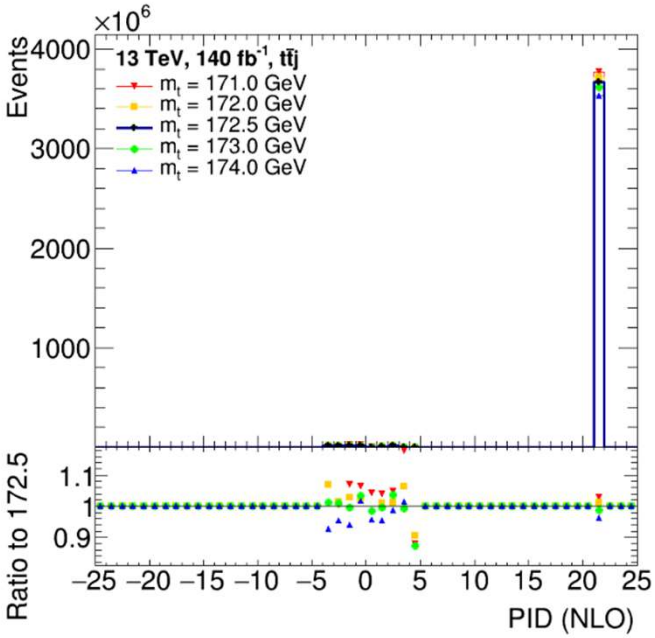
13.6 & 100 TeV pt (nlo)





8 & 13 TeV PID (nlo)





13.6 & 100 TeV PID (nlo)