Standard model backgrounds at $\sqrt{s} = 100$ TeV

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Workshop on Physics at a 100 TeV Collider

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Introduction

Goals

- Describe well defined study and use it to gain intuition about
  - total and differential cross sections at $\sqrt{s}$=14TeV and $\sqrt{s}$=100TeV
  - distributions of reconstructed quantities (e.g. object multiplicity, H_T, MH_T) at 14TeV and 100TeV.
- Serve as reference for signal studies presented in later sessions.
- Initiate discussion – including discussion of utility of choices made for this study.

General Caveat

- I can't promise profound insights, but hopefully a starting point for discusssion.
- No systematic uncertainties provided for any results.

Overview of simulation

- Generation of samples with $\sqrt{s}$ = 14, 33, 100 TeV and pile-up (PU) of 0, 40, 140 for 2013 Snowmass Community Summer Study documented in

Event generation	arXiv:1308.1636
Detector simulation	arXiv:1309.1057
Grid implemenation	arXiv:1308.0843

Thanks to the all the authors, and especially John Stupak for his continued stewardship of the samples.

1. **Madgraph** [1] LO event generation.
2. **BRIDGE** [2] used to decay generated particles with flattened branching fractions, thereby providing sufficient statistics for rare decays.
3. **PYTHIA** [3] for parton shower and hadronization.
   - **Madgraph+PYTHIA jet matching** performed with five-flavor, MLM method in shower k_T scheme with matching scale of 80 (60) [40] GeV for processes including 2 (1) [0] top quarks.
4. **Delphes** [4] detector simulation.
5. **NLO k-factors** computed with **MCFM** [5].

[1] arXiv:1106.0522
[2] arXiv:hep-ph/0703031
[3] arXiv:hep-ph/0603175
[4] arXiv:1307.6346
[5] http://mcfm.fnal.gov

Overview of simulation II

Step 1 (Open Science Grid)

Generate with **MadGraph5** v1.5.10

→ LHE →

Step 2 (BNL/FNAL/OSG)

Decay generated Z,W,H,t with **BRIDGE** (flattened BRs)

→ **Shower/ hadronize** with **PYTHIA**

→ **Detector simulation** with **Delphes** v3.0.9

→ ROOT for end user

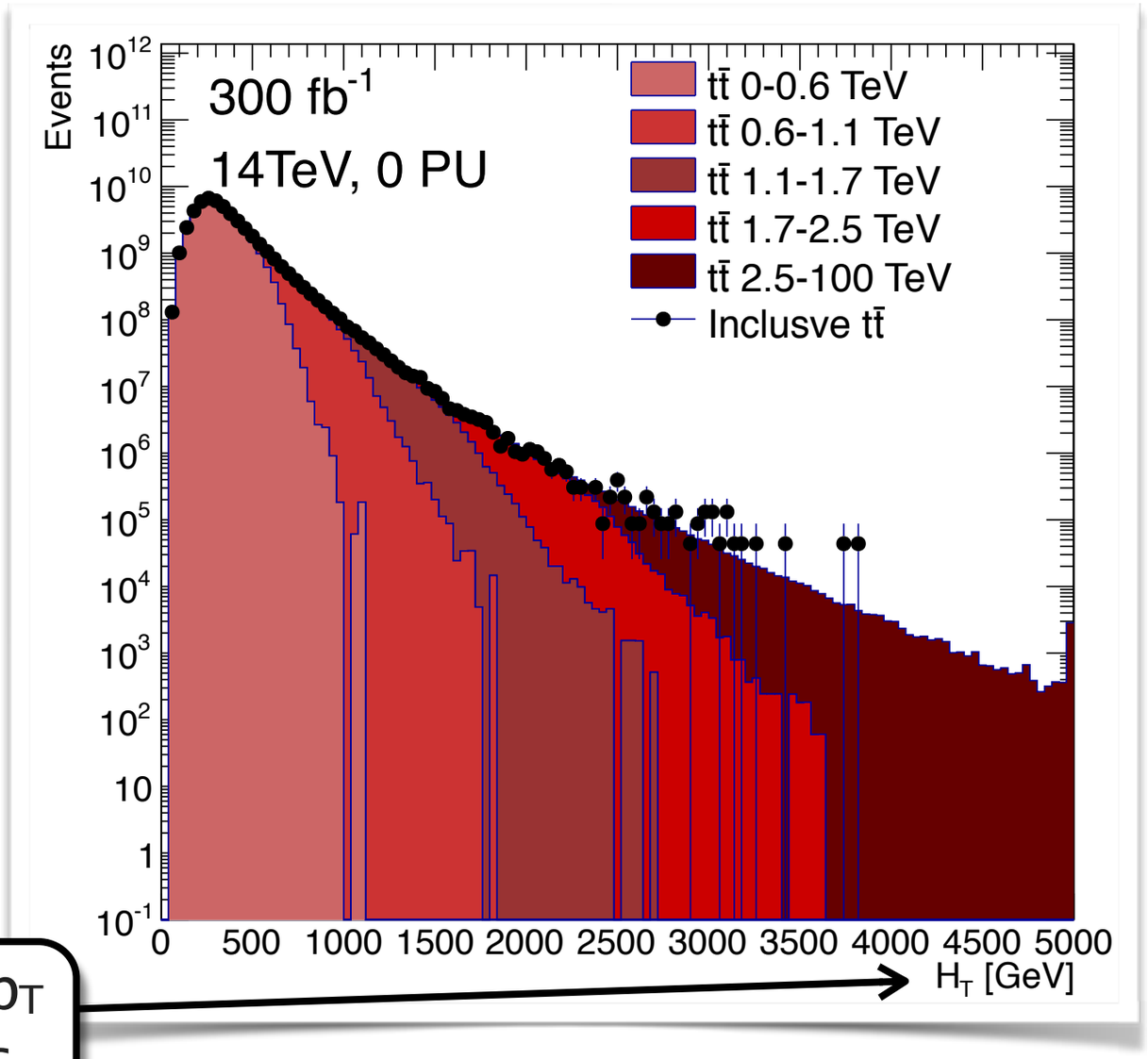
[http, SRM, XRootD] @ [FNAL, BNL UNL, ANL]

Binned event generation

- To obtain sufficient statistics for 3 ab^{-1}, weighted events **generated in bins of S_T*** (scalar sum of p_T of all generator-level particles).
- **Boundaries** for the α^{th} bin $[S_T^{min}{}_\alpha, S_T^{max}{}_\alpha)$ give one decade of cross section in each bin:

1. $S_T^{min}{}_1 \equiv 0$ GeV
2. $\sigma_1 \geq 0.9 \times \sigma_{tot}$
3. $\sigma\,(S_T^{max}{}_\alpha > S_T^* > S_T^{min}{}_\alpha) \geq 0.9 \times \sigma\,(S_T^* > S_T^{min}{}_\alpha)$
4. Final inclusive bin chosen so that $N_{gen} > 10 \times$ number of events expected in 3/ab.

- Comparison to inclusive sample validates approach and illustrates advantages.



$H_T \equiv$ scalar sum of the p_T of all reconstructed jets

NLO K-factors

- K-factors for dominant processes from **MCFM** [1] and **MadGraph +PYTHIA:**

$$K = \frac{\sigma^{\rm NLO}_{\rm MCFM}}{\sigma^{\rm LO}_{\rm MG\text{-}matched}}$$

- Sub-dominant processes given K=1.

Process	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 33$ TeV	$\sqrt{s} = 100$ TeV
$t\bar{t}$	1.24	1.10	0.96
$W^+ j$	1.17	0.85	0.74
$W^- j$	1.20	0.89	0.75
$Z^0 j$	1.17	0.87	0.76
γj	1.54	1.04	0.89
$W^+ W^-$	1.25	1.08	1.0
$W^+ Z^0$	1.24	1.06	0.95
$W^- Z^0$	1.26	1.09	0.97
$Z^0 Z^0$	1.37	1.29	1.21
$W^+ \gamma$	1.22	0.80	0.67
$W^- \gamma$	1.33	0.83	0.67
$Z^0 \gamma$	1.24	0.95	0.76
$\gamma\gamma$	1.34	1.08	0.98
tW^-	1.0	0.77	0.78
$\bar{t}W^+$	1.0	0.77	0.78
$t\bar{b}$	1.76	1.72	1.94
$\bar{t}b$	1.88	1.73	1.78
$\ell^+\ell^-$	1.20	1.16	1.20

[1] http://mcfm.fnal.gov

Sample organization

- Processes with similar cross sections grouped according to “particle containers”:
- All processes are exclusive.
- 4 generated particles in all datasets.
- Note that QCD is not included.

$$
\begin{aligned}
J &= \{g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}\} \\
L &= \{e^+, e^-, \mu^+, \mu^-, \tau^+, \tau^-, \nu_e, \nu_\mu, \nu_\tau\} \\
V &= \{W^+, W^-, Z^0, \gamma\} \\
T &= \{t, \bar{t}\} \\
H &= \{h^0\}
\end{aligned}
$$

Dataset Name	Main Processes	Final States	Order
Dominant Backgrounds			
B-4p, Bj-4p[a]	vector boson + jets	$V + nJ$	$\mathcal{O}(\alpha_s^n \alpha_w)$
BB-4p	divector + jets	$VV + nJ$	$\mathcal{O}(\alpha_s^n \alpha_w^2)$
TT-4p	top pair + jets	$TT + nJ$	$\mathcal{O}(\alpha_s^{2+n})$
TB-4p	top pair off-shell $T^* \to Wj$ + jets	$TV + nJ$	$\mathcal{O}(\alpha_s^{n+1} \alpha_w)$
TJ-4p	single top (s and t-channel) + jets	$T + nJ$	$\mathcal{O}(\alpha_s^{n-1} \alpha_w^2)$
LL-4p	off-shell $V^* \to LL$ + jets	$LL + nJ$ [$m_{ll} > 20$ GeV]	$\mathcal{O}(\alpha_s^n \alpha_w^2)$
Subdominant Backgrounds			
TTB-4p	top pair + boson	$(TTV + nJ), (TTH + nJ)$	$\mathcal{O}(\alpha_s^{2+n} \alpha_w)$
BLL-4p	off-shell divector $V^* \to LL$ + jets	$VLL + nJ$ [$m_{ll} > 20$ GeV]	$\mathcal{O}(\alpha_s^n \alpha_w^3)$
BBB-4p	tri-vector + jets, Higgs associated + jets	$(VVV + nJ), (VH + nj)$	$\mathcal{O}(\alpha_s^n \alpha_w^3)$
H-4p	gluon fusion + jets	$H + nJ$	$\mathcal{O}(\alpha_s^n \alpha_h)$
BJJ-vbf-4p	vector boson fusion + jets	$(V + nJ), (H + nJ)$ [$n \geq 2$]	$\mathcal{O}(\alpha_s^{n-2} \alpha_w^3)$

Sample organization II

- Bin boundaries, LO cross sections, numbers of generated events for major background modes:

S_T^* bin: $\alpha =$		1	2	3	4	5	6
Bj-4p	S_T^* (TeV)	$0-0.5$	$0.5-1.5$	$1.5-3.0$	$3.0-5.5$	$5.5-9.0$	$9.0-10^5$
	σ_α (pb)	485362.0	20395.9	635.88	47.62	3.48	0.36
	N_α ($\times 10^6$)	$25, 24$	$16, 15$	$11, 12$	$9.4, 9.7$	$7.6, 7.5$	$2.1, 2.0$
tt-4p	S_T^* (TeV)	$0-1.0$	$1.0-2.0$	$2.0-3.5$	$3.5-5.5$	$5.5-8.5$	$8.5-10^5$
	σ_α (pb)	29141.30	1777.28	185.22	18.92	2.39	0.277
	N_α ($\times 10^6$)	$7.6, 7.7$	$7.2, 7.2$	$7.3, 7.1$	$7.1, 7.0$	$13, 13$	$20, 20$
BB-4p	S_T^* (TeV)	$0-0.5$	$0.5-1.5$	$1.5-3.0$	$3.0-5.5$	$5.5-9.0$	$9.0-10^5$
	σ_α (pb)	2867.87	405.20	22.84	2.22	0.20	0.024
	N_α ($\times 10^6$)	$6.7, 6.9$	$5.9, 5.3$	$4.2, 4.0$	$1.1, 1.2$	$0.21, 0.2$	
tj-4p	S_T^* (TeV)	$0-1.0$	$1.0-2.0$	$2.0-4.0$	$4.0-7.0$	$7.0-10^5$	
	σ_α (pb)	2323.9	34.71	2.89	0.163	0.013	
	N_α ($\times 10^6$)	$6.9, 7.3$	$4.1, 4.3$	$3.0, 3.1$	$1.5, 1.5$	$0.18, 0.17$	

Delphes “Snowmass Detector”

arXiv:1309.1057

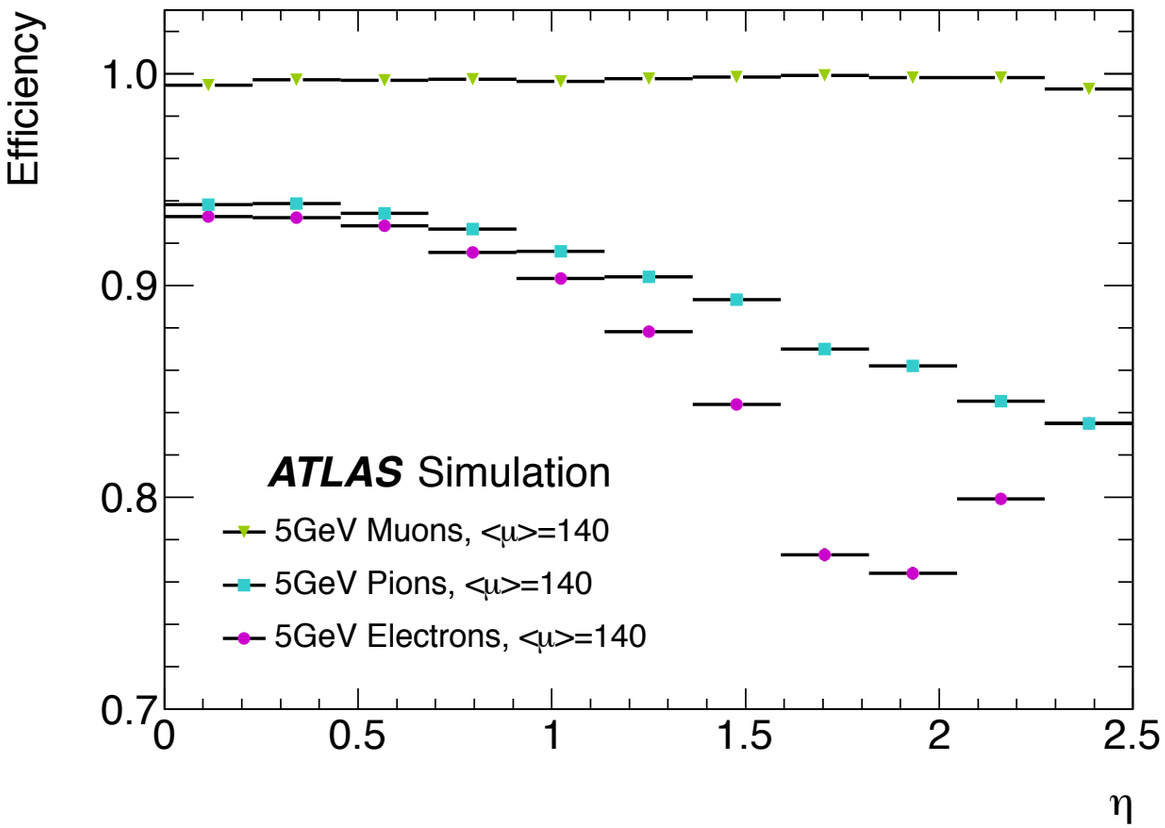
Guiding principles:

- **Our focus** was on reasonable simulation for HL-LHC with 140 pile-up (PU).
- Based on understanding of **current detectors** (ATLAS and CMS).
- For each sub-system, use **best expected performance** from ATLAS or CMS.
- Prefer ATLAS/CMS **public simulation studies**, where available.
  - If unavailable, extrapolate to higher PU based on **public detector notes**.
- Implicit assumption that we will **retain current performance**.

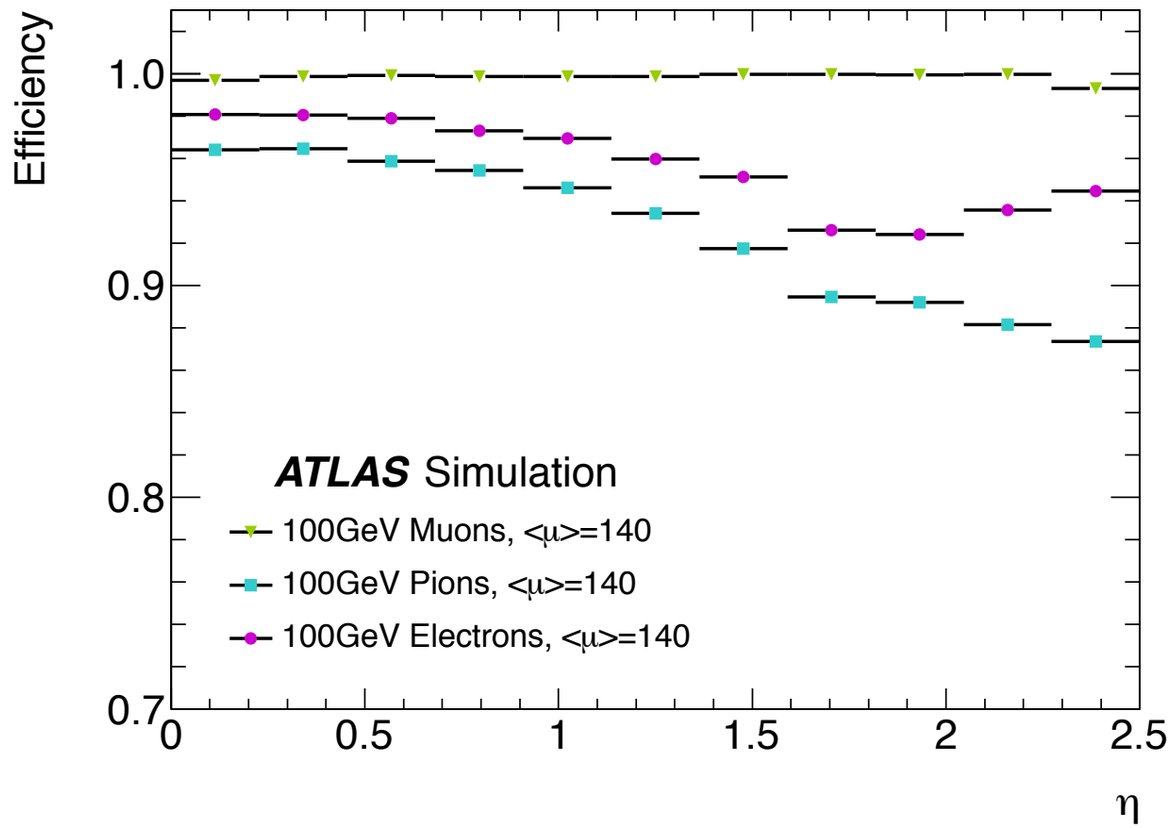
Caveats:

- Simulation is reasonable, but obviously speculative.
- E.g., tracking coverage will almost certainly be greater than $|\eta|<2.4$ used in this study — only affects reconstructed objects.

Tracking Performance



ATLAS LHCC-I-023



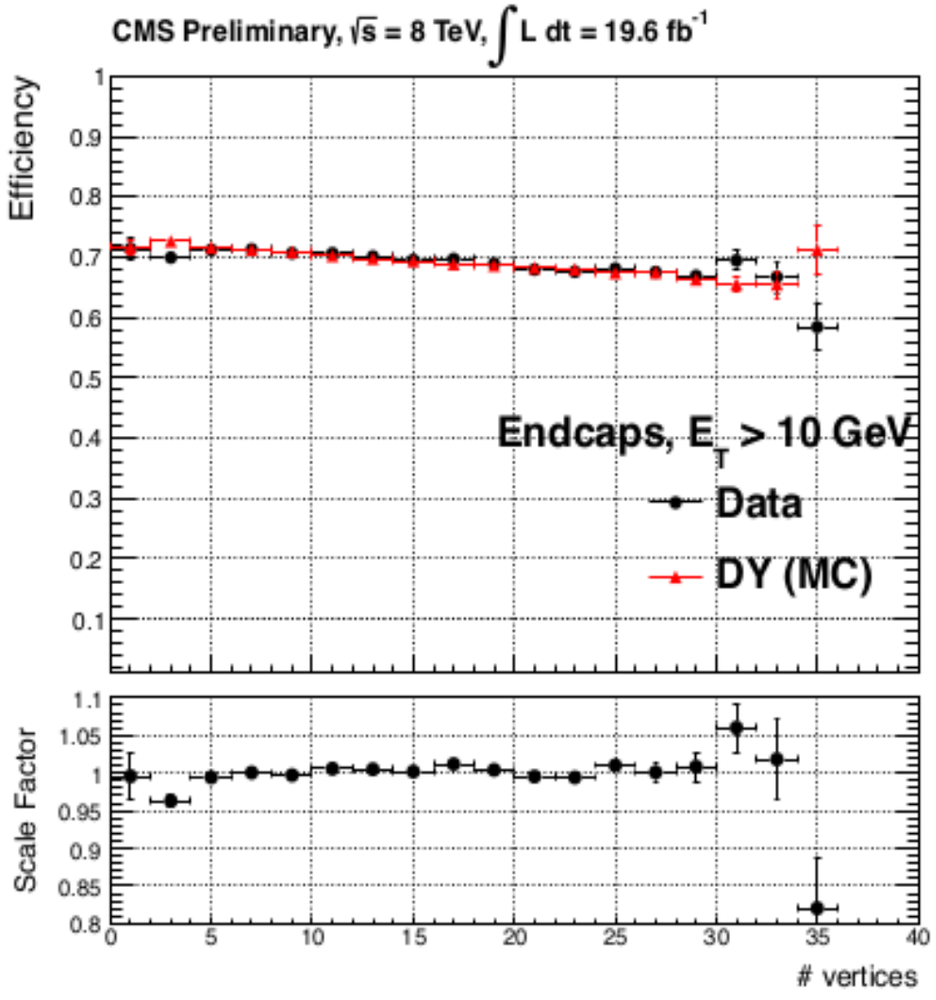
Expect ~85-95% tracking efficiency for pions at 140 PU.

Expect ~98% efficiency for muons at 140 PU.

Lepton Identification

Electron

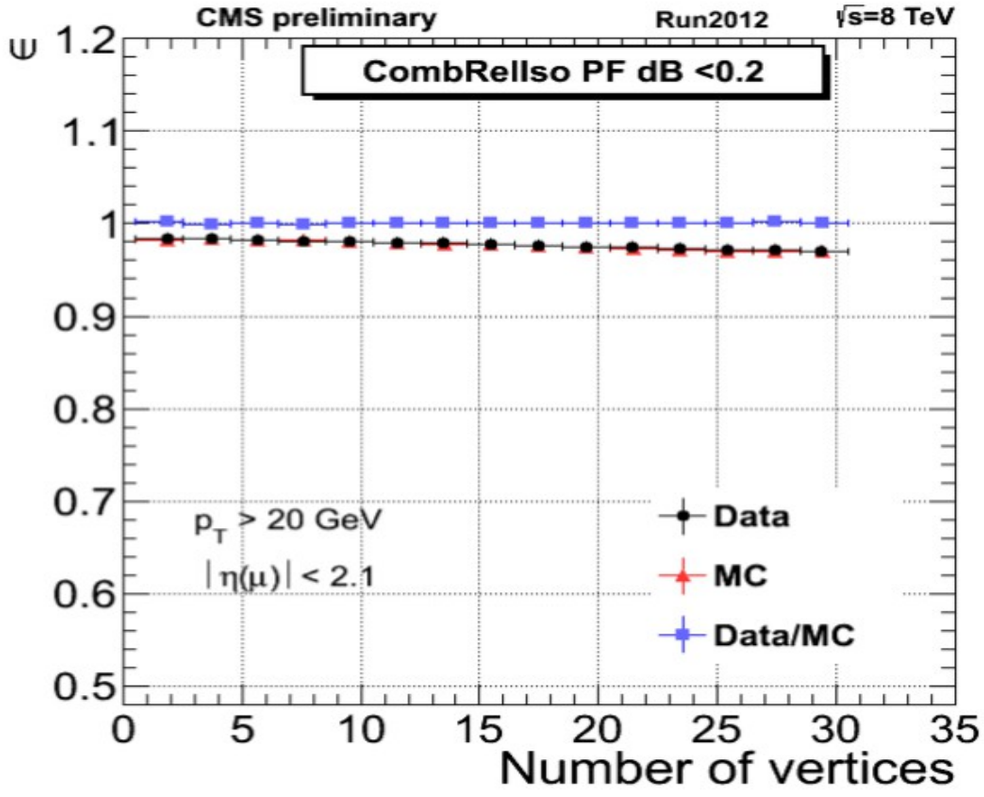
CMS-DP-2013-003



~65% efficiency in endcap
(~80% in barrel)

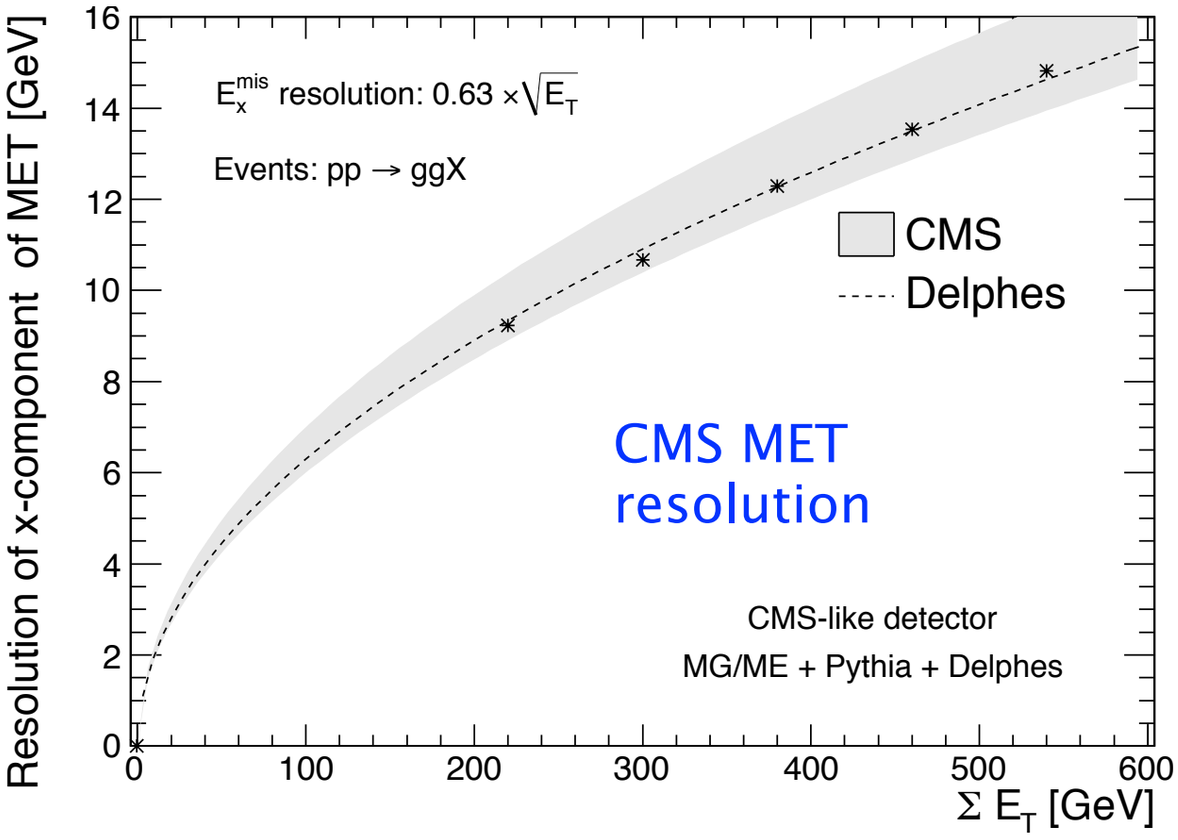
Muon

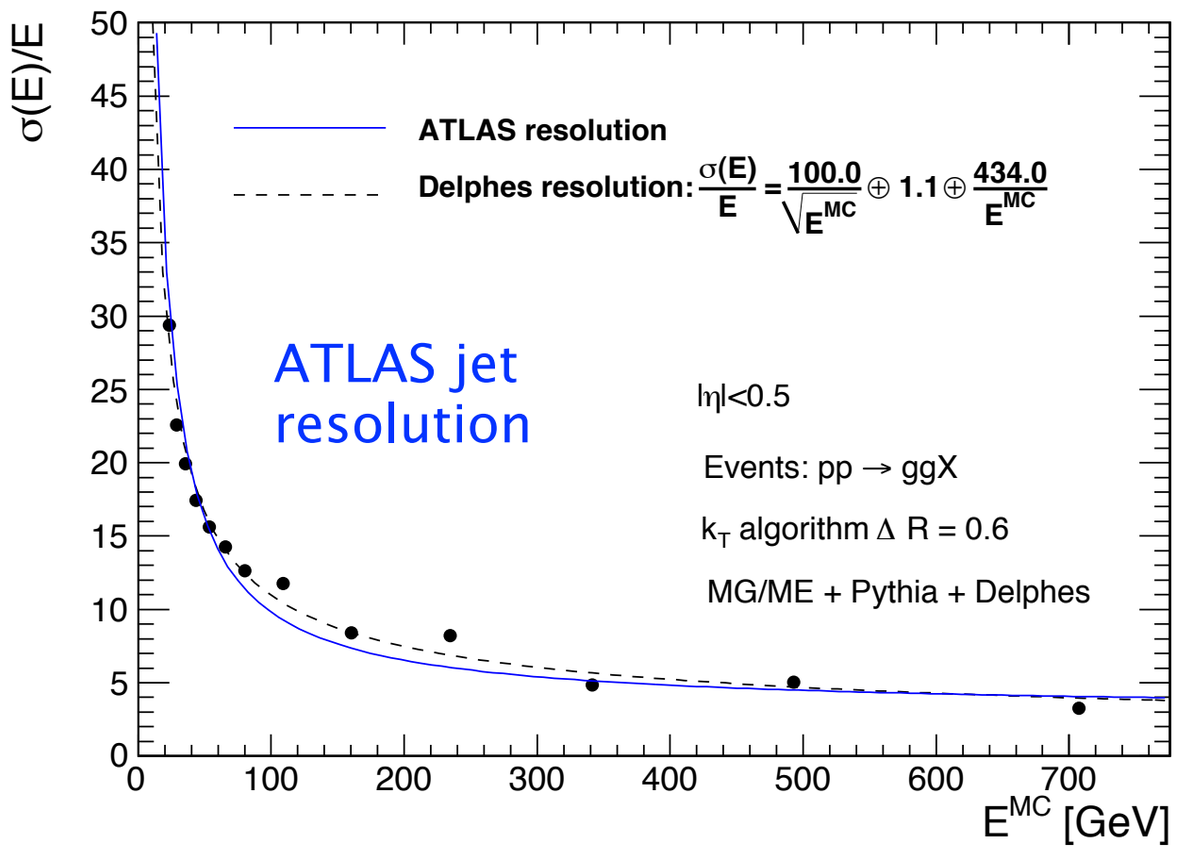
CMS-DP-2012-025



~95% efficiency at 50 PU
(consistent w/ CMS-TDR-011)

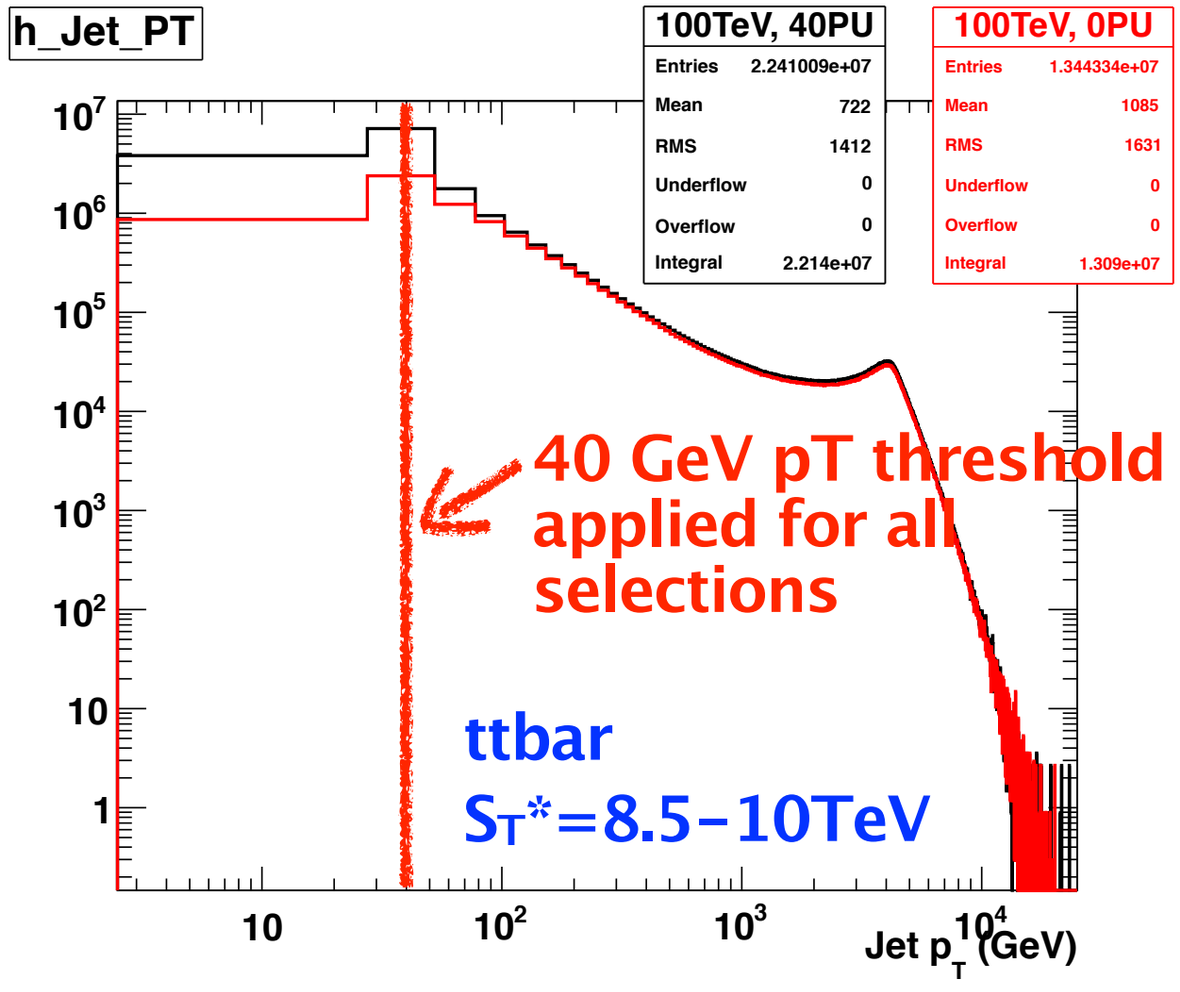
Jet and ME_T resolution





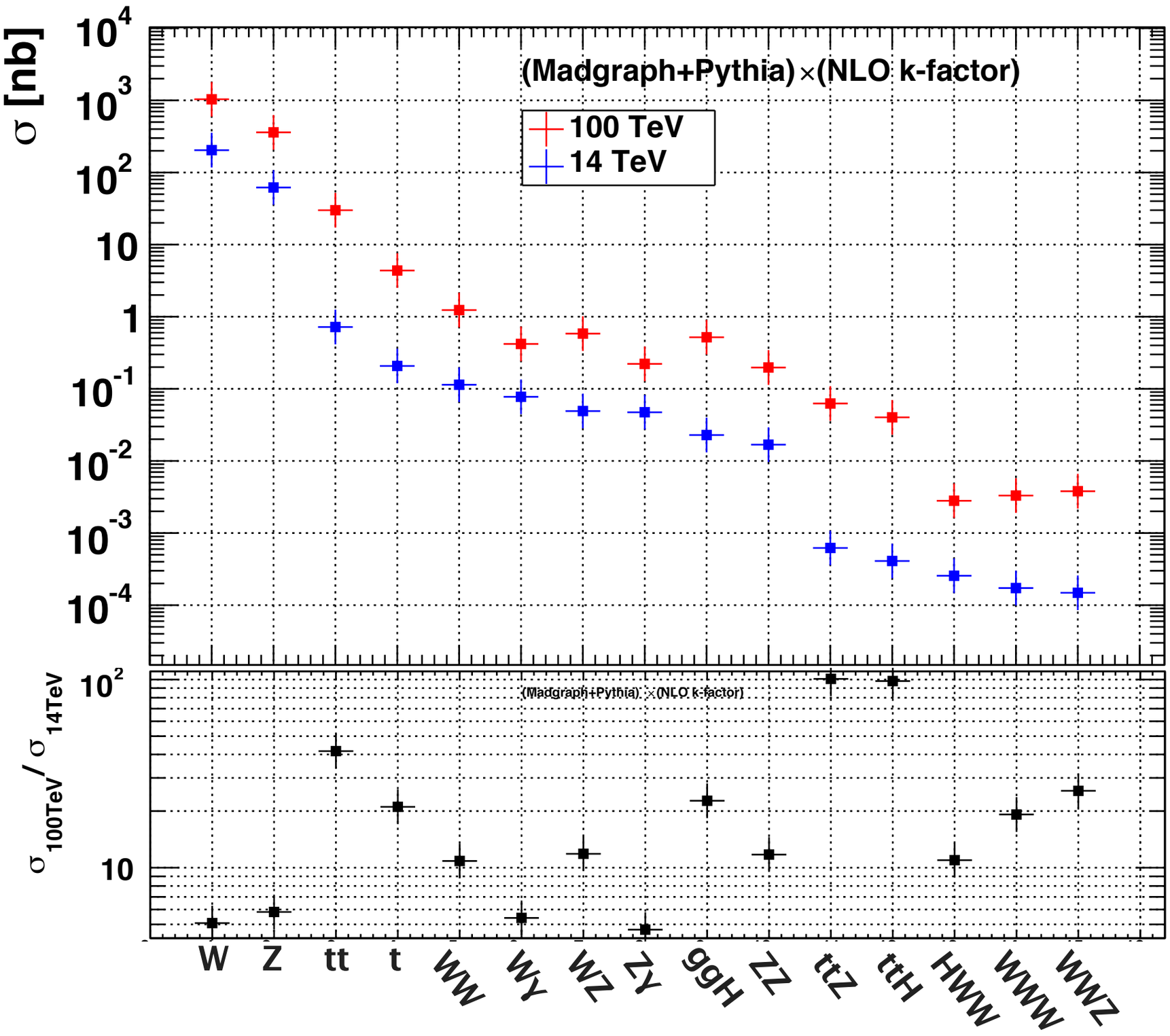
Pileup

- Pileup mixing is simple in **`Delphes`**.
- Pileup has small effect on reconstructed H_T and MH_T when these quantities are computed with 40 GeV jets.
- Focus on samples without pileup for simplicity.



Total NLO cross sections

- Process dependence of σ_{100}/σ_{14} reflects parton luminosities.
- gluon–gluon luminosity increases more than other parton–parton luminosities.
- VH processes absent for technical reasons, but are small search backgrounds

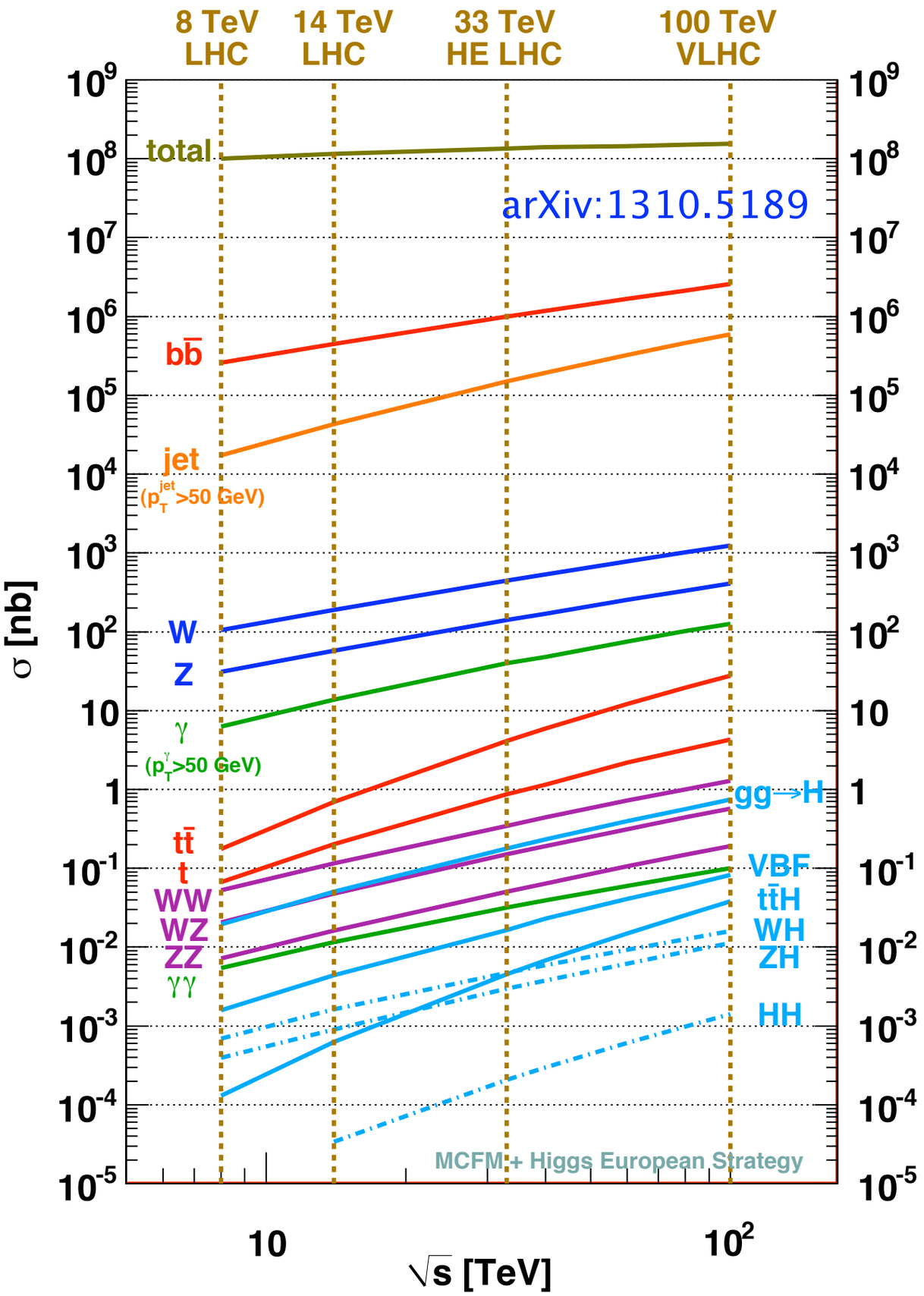


σ vs. $\sqrt{s}$

- Evolution of NLO cross sections with $\sqrt{s}$ from Snowmass QCD report [1] computed with MCFM.
- Excellent agreement with numbers on previous slide serve as sanity check.
- Note: the double parton scattering cross section is 15 mb and independent of $\sqrt{s}$.
- At 100 TeV, bb production will accompany ~20% of events through DPS because

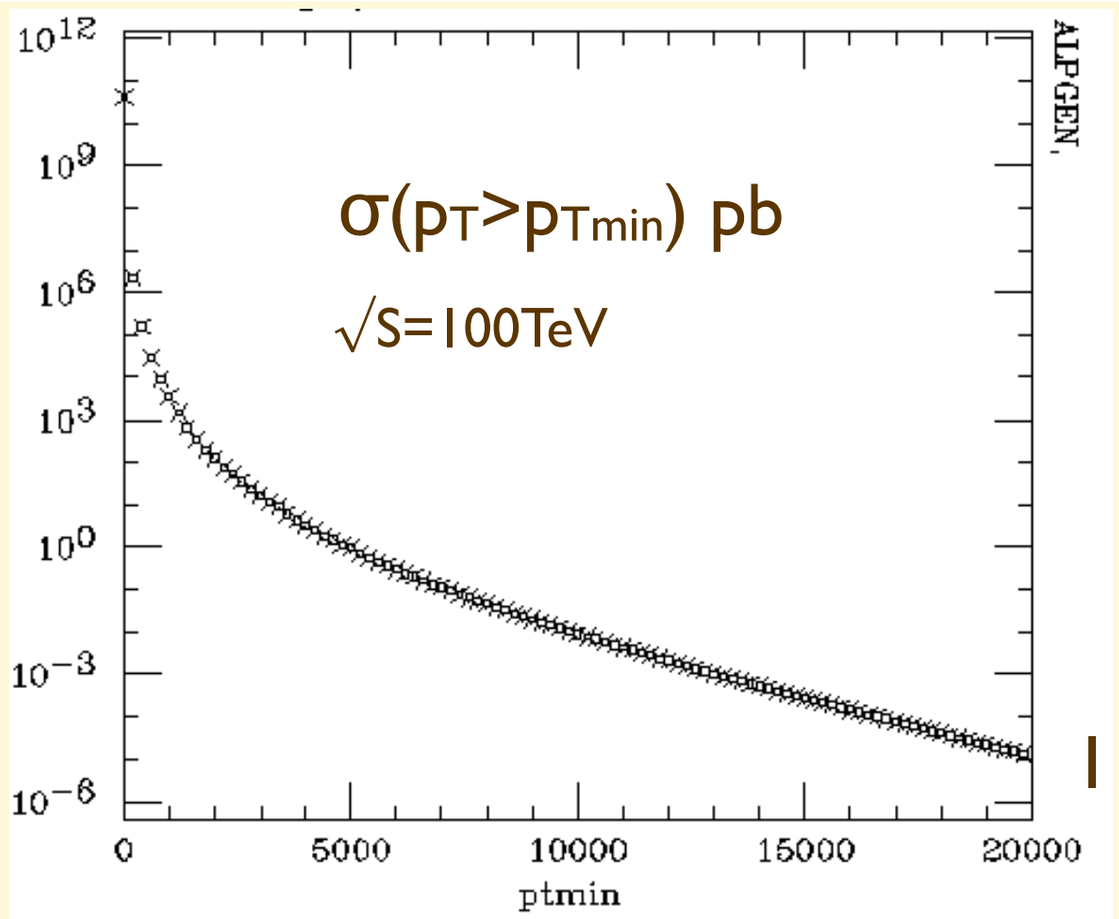
$$\sigma_{X,b\bar{b}} \simeq \frac{\sigma_X \sigma_{b\bar{b}}}{\sigma_{\mathrm{DPS}}} \simeq \sigma_X \cdot \frac{3\ \mathrm{mb}}{15\ \mathrm{mb}}$$

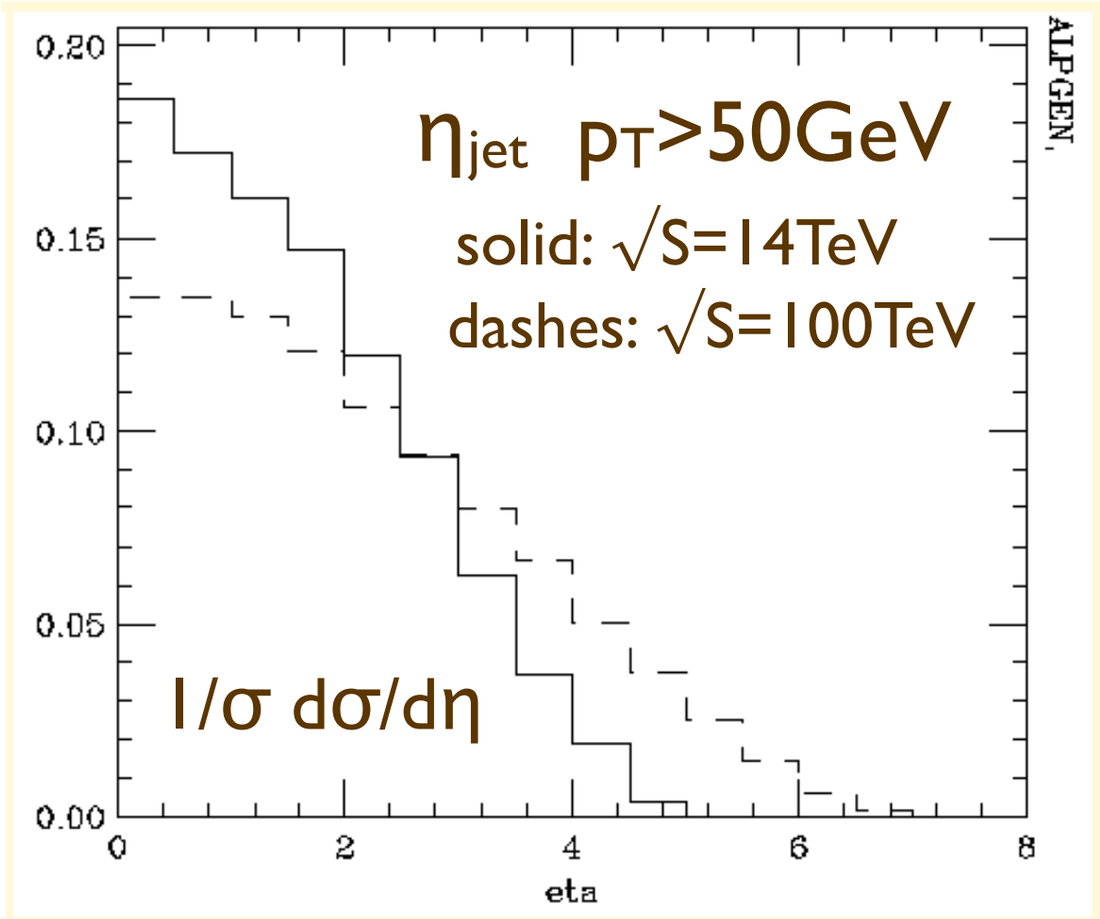
[1] arXiv:1310.5189



QCD

- From Michelangelo Mangano: Future Hadron Colliders meeting, Nov 26, 2013.
- Parton level study of QCD from ALPGEN.





Inclusive distributions for 14 and 100 TeV

- Focus on multiplicity and energy-scale variables.

Y-axis units are either:

(i) effective cross section in fb per 125 GeV bin

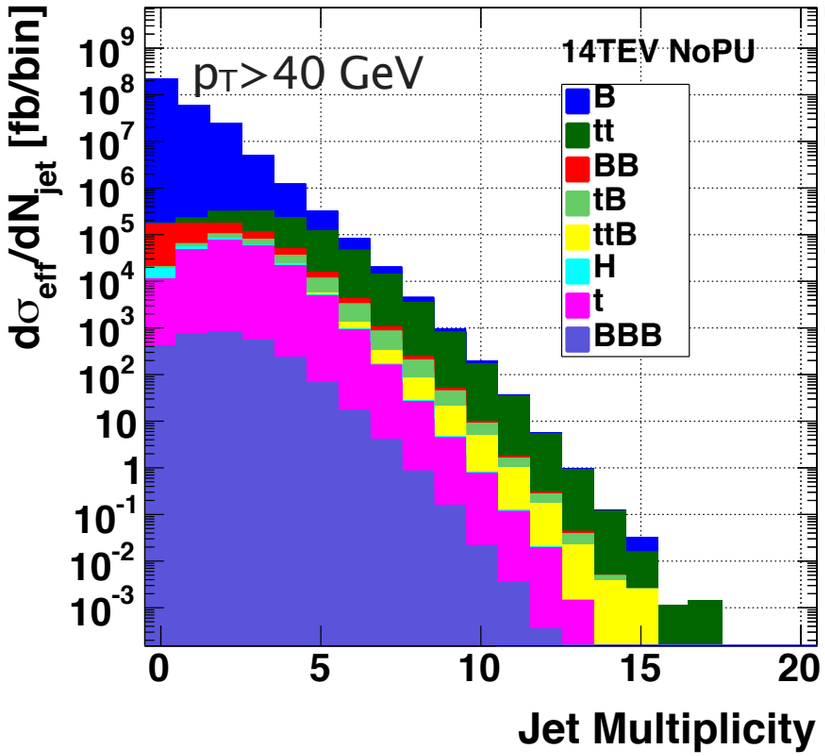
(ii) expected counts in 300 fb^{-1} per 125 GeV bin

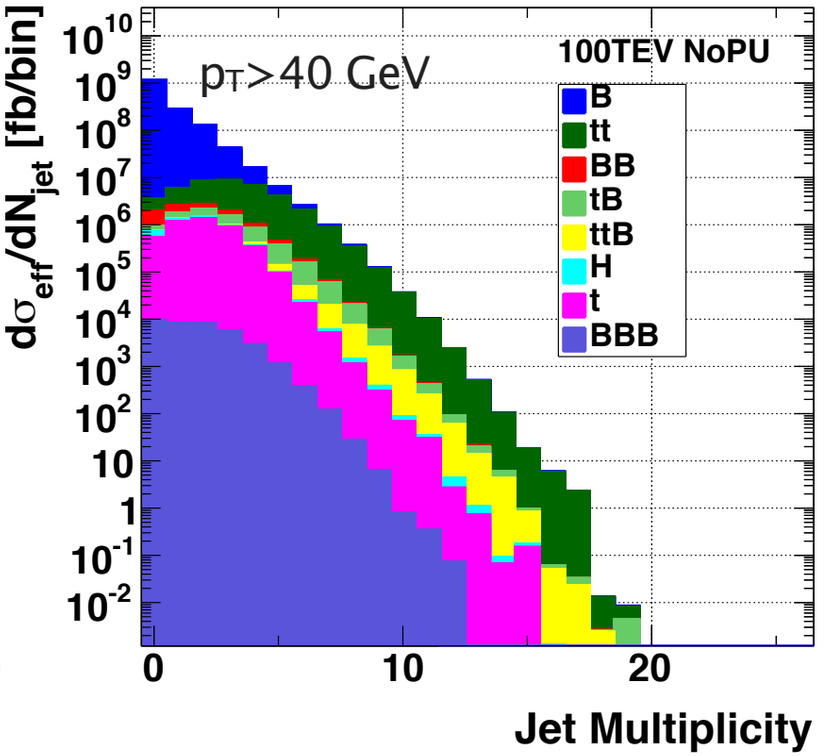
Inclusive Jets

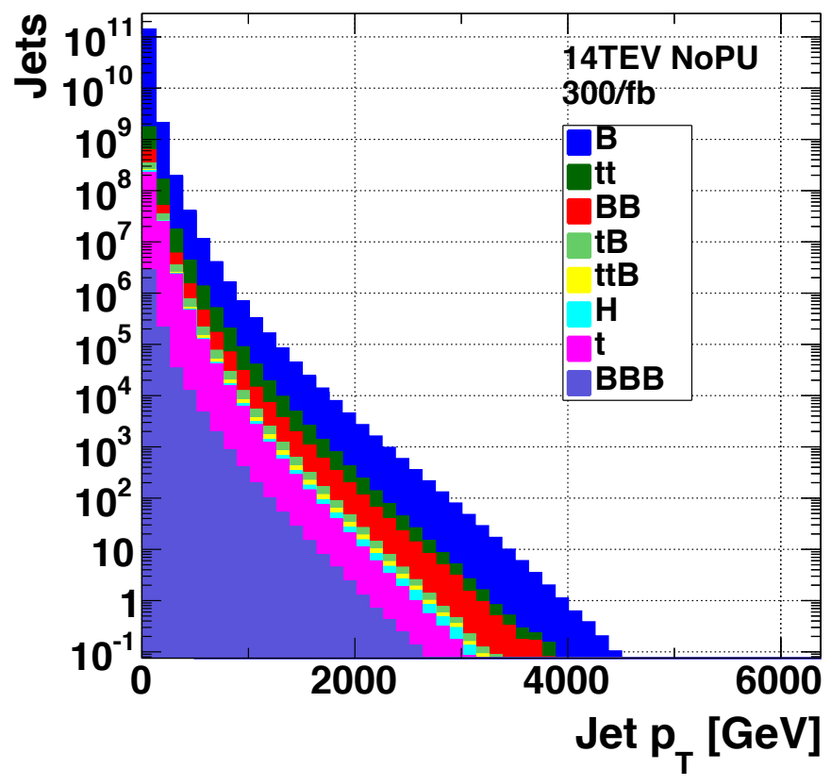
- p_T>40 GeV
- |η|<2.4
- anti-k_T jets with 0.5 distance parameter.
- At most 3 radiated jets/ event from **Madgraph**, most jets in event from PYTHIA parton shower.

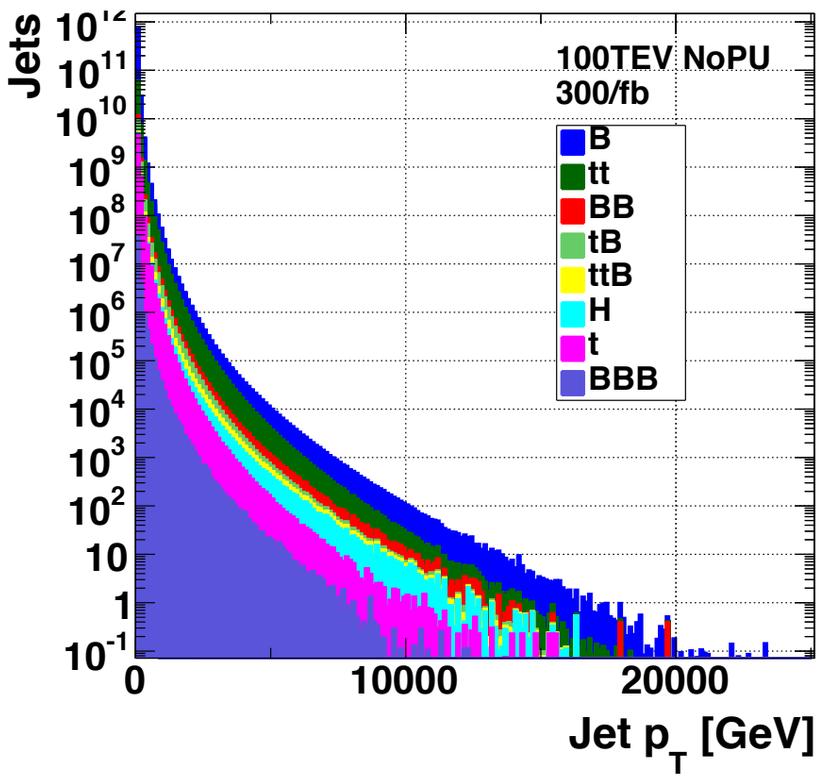
1 ab^{-1}, √s=100TeV

- 100 events with 17 jets
- 100 jets with p_T=10TeV







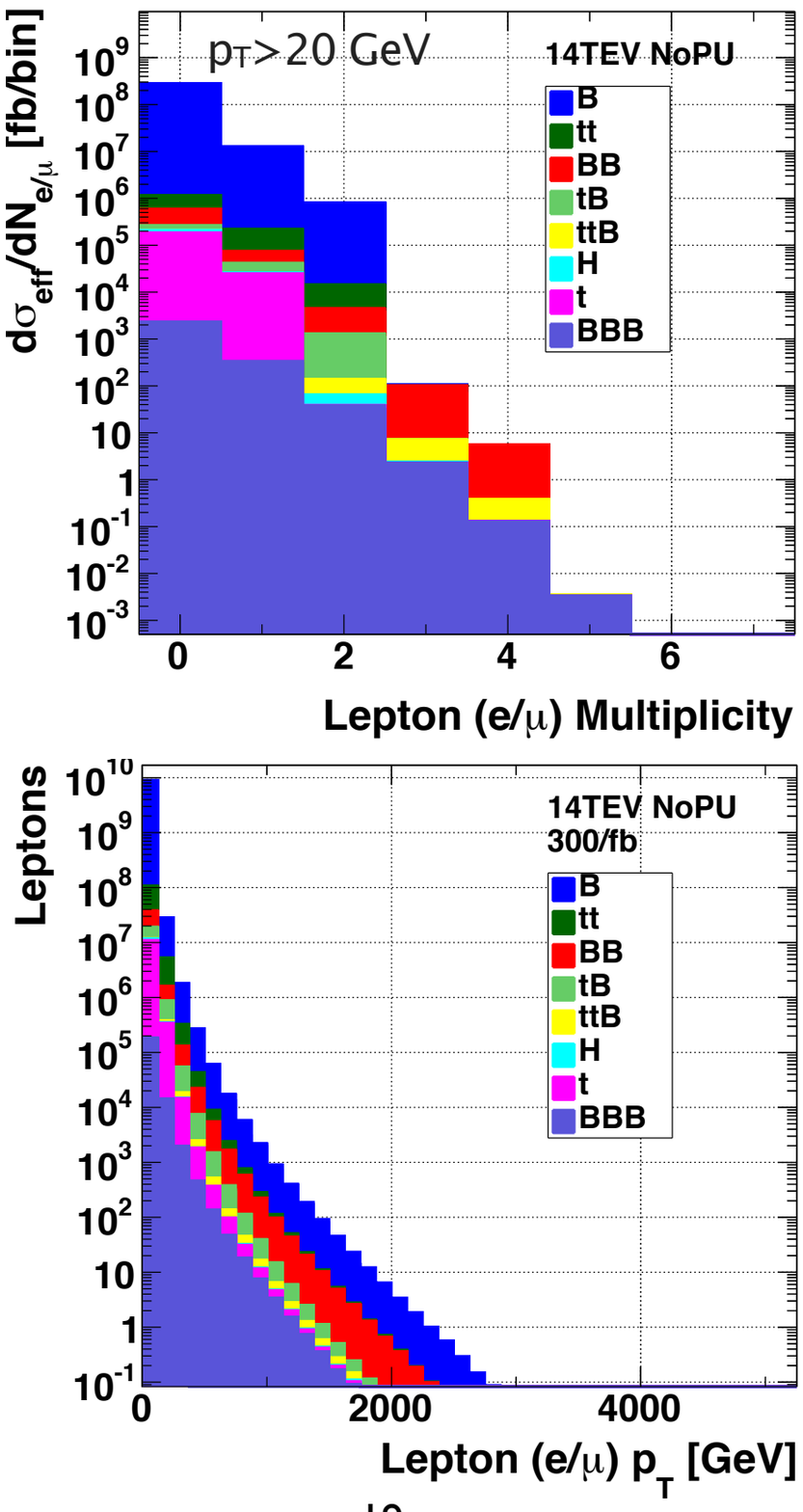


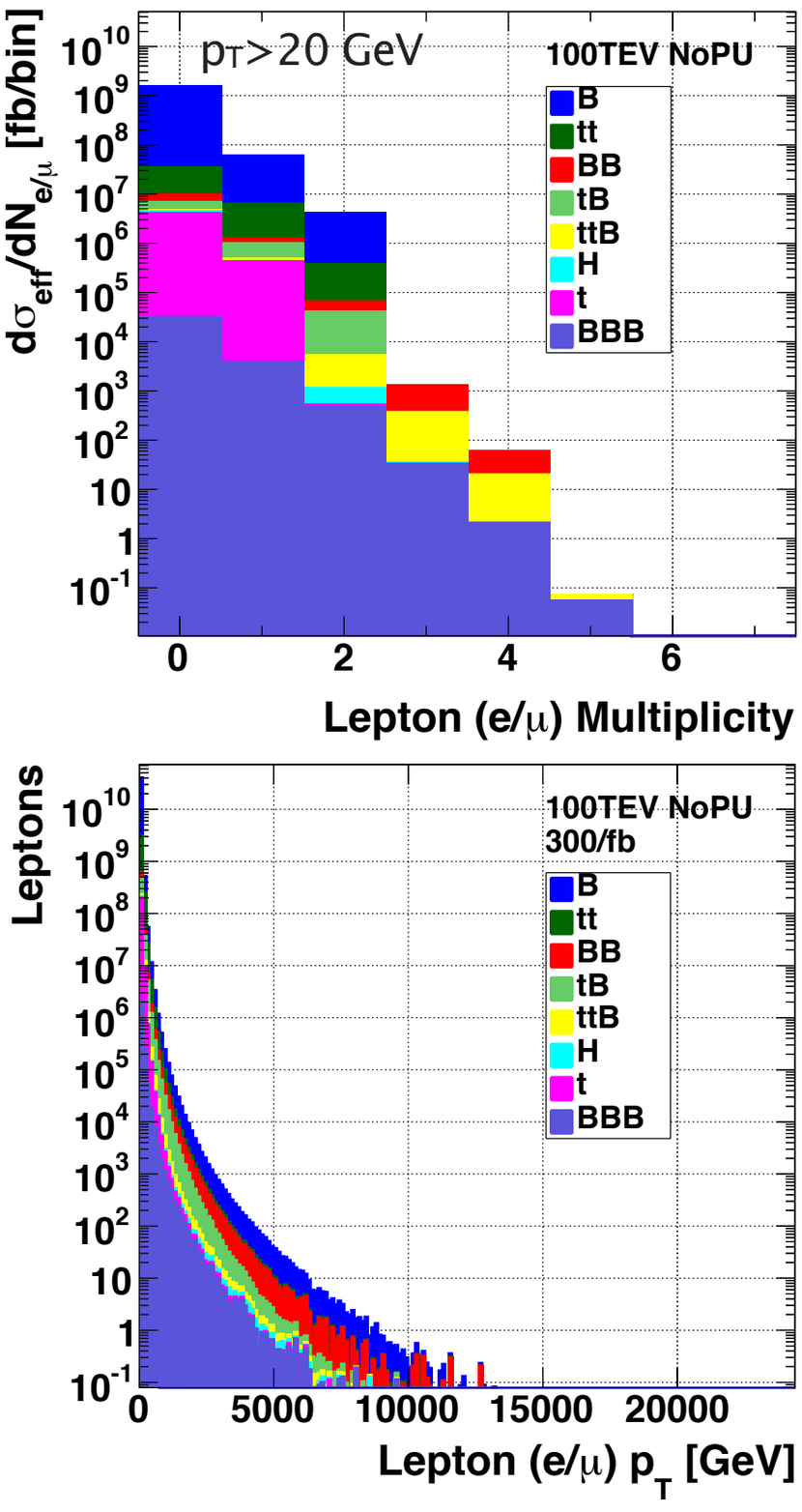
Inclusive Leptons

- Leptons = e, μ
- p_T>20 GeV
- |η|<2.1
- Reconstruction efficiency and isolation applied in Delphes.

1 ab^{-1}, √s=100TeV

- 100 evts w/ 5 leptons





Inclusive H_T and MH_T

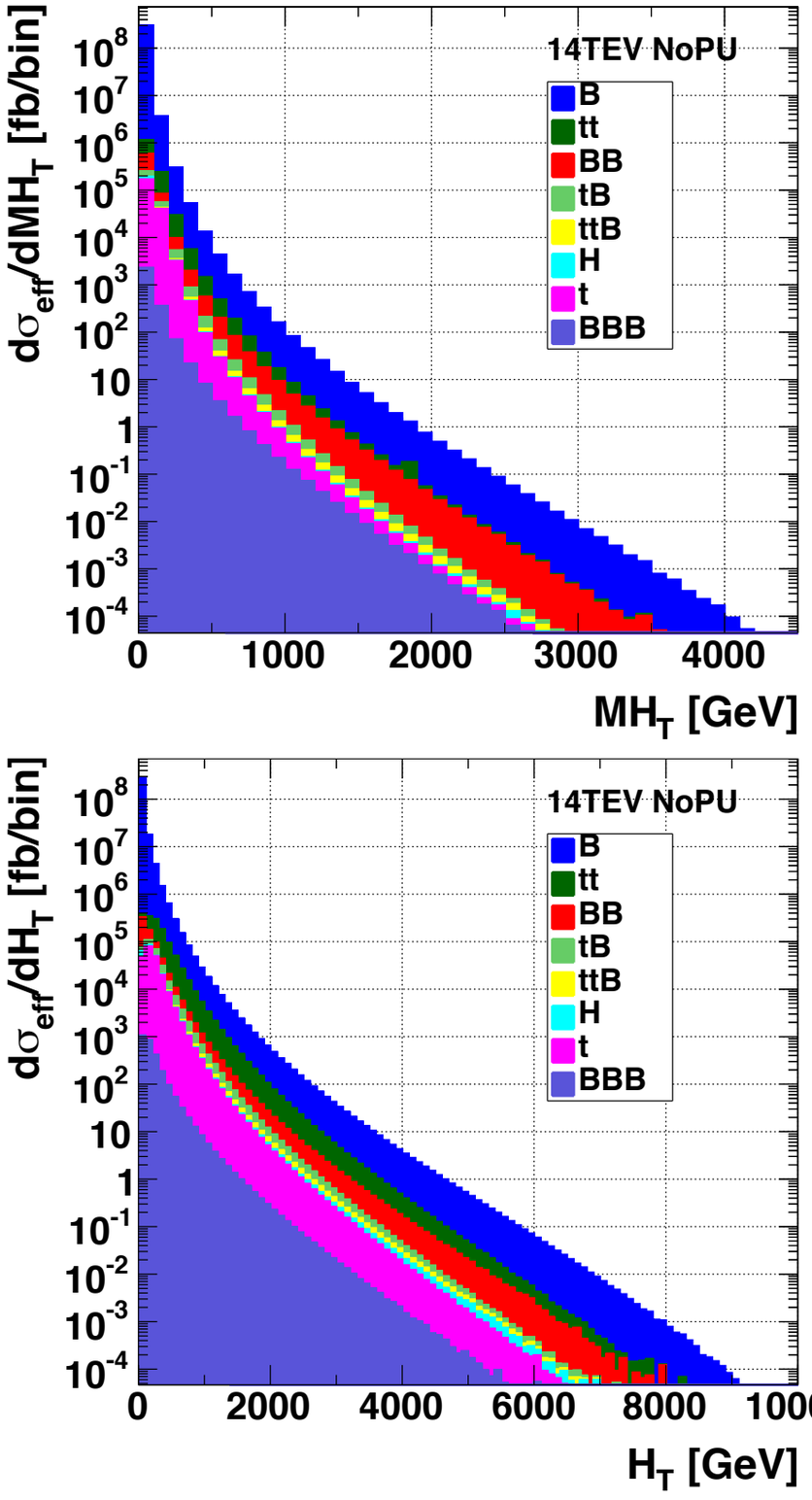
- No selection applied.
- Jets p_T>40 GeV.

$$\mathrm{MH_T} = \sum_{\mathrm{jets}} -\vec{p}_{\mathrm{T}}$$

$$\mathrm{H_T} = \sum_{\mathrm{jets}} |p_{\mathrm{T}}|$$

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ H_T=20TeV
- 100 evts w/ MH_T=8TeV



Comparison of distributions for 14 and 100 TeV by process

- Focus on multiplicity and energy-scale variables.

Y-axis units are either:

(i) effective cross section in fb per 125 GeV bin

(ii) expected counts in 300 fb^{-1} per 125 GeV bin

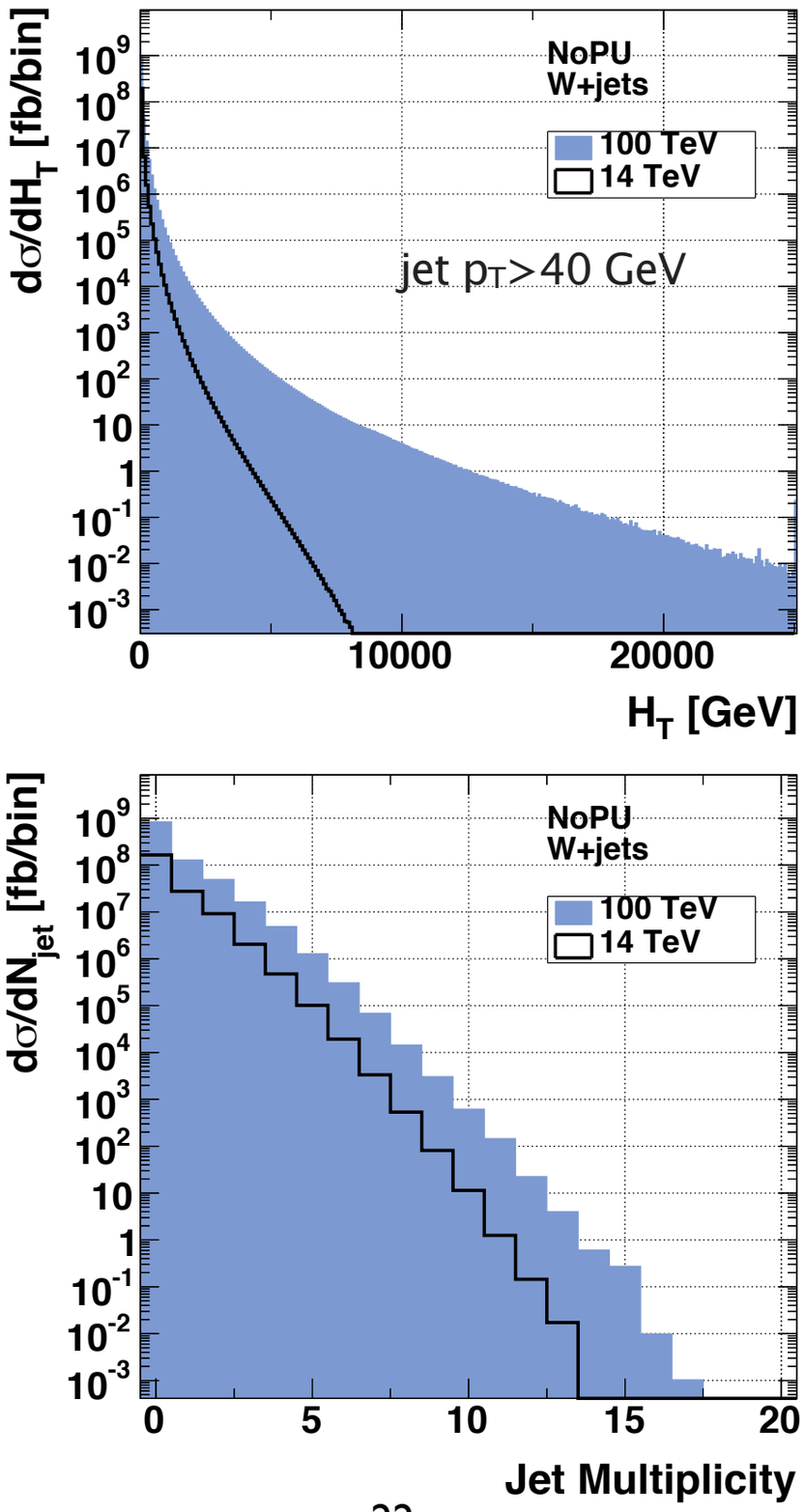
- **All basic distributions** (N_{jet}, N_{lepton}, N_{b-jet}, Jet p_T, Lepton p_T, B-jet p_T, H_T, MH_T) for all processes included in appendix.

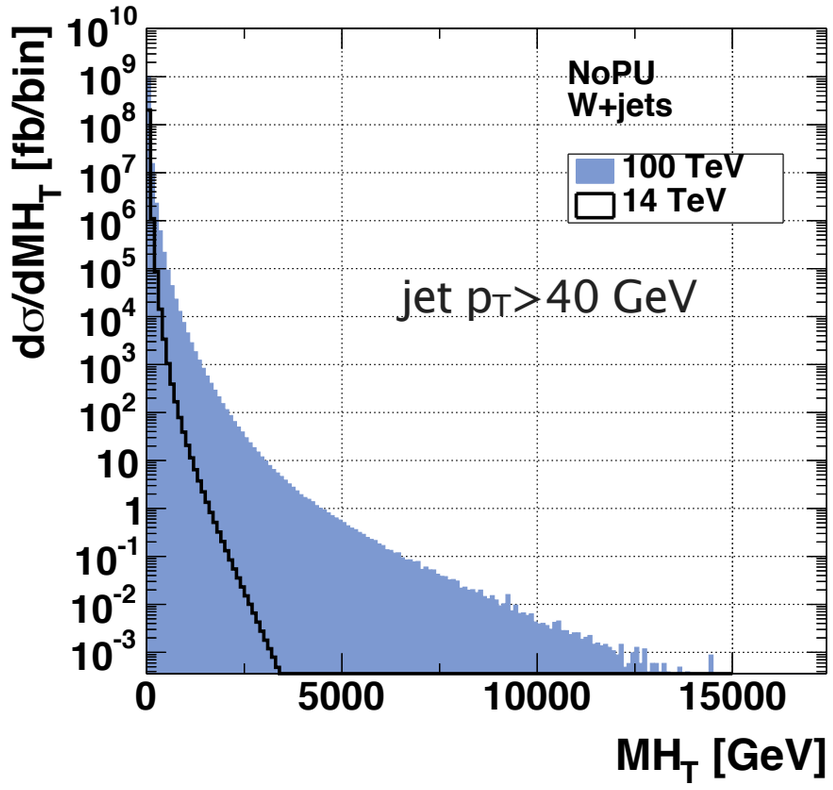
W + Jets

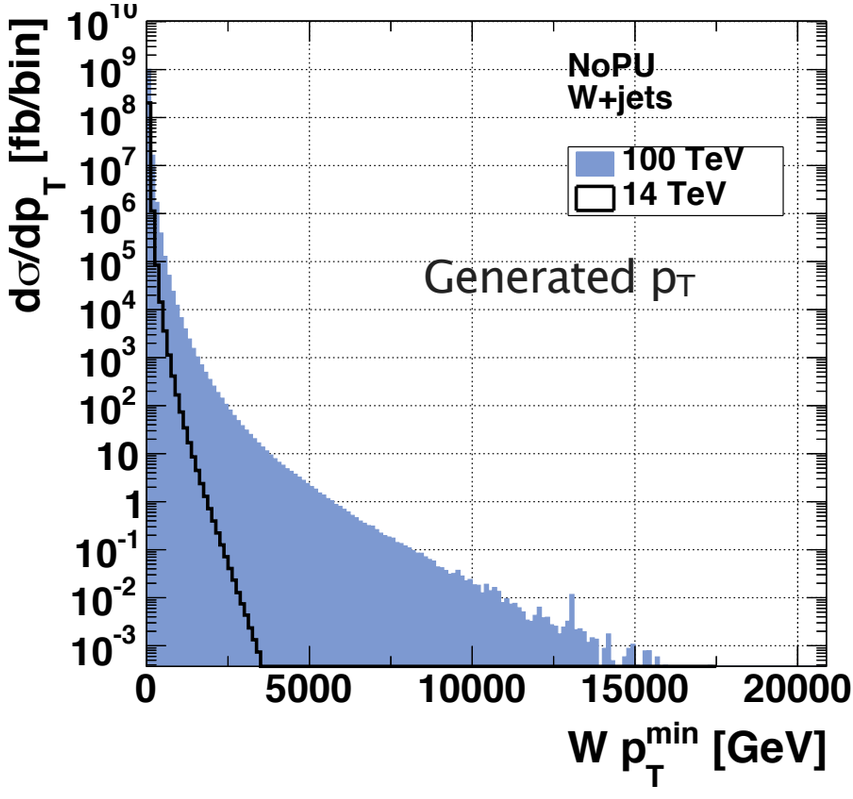
- V+jets is primary background.
- $\sigma_{Wjets} \approx 1\ \mu b$

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ W p_T=8TeV
- 100 evts w/ MH_T=7TeV





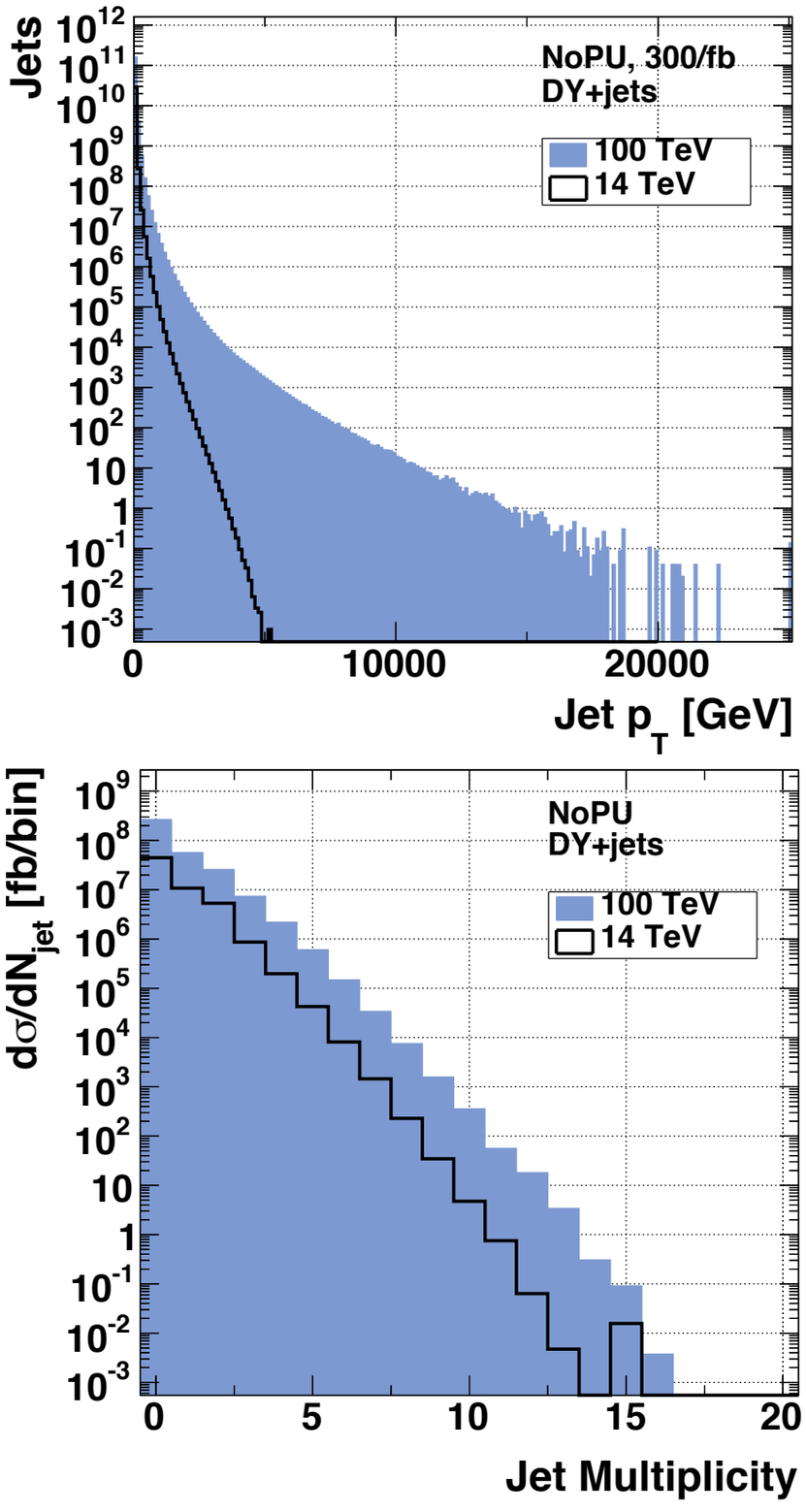


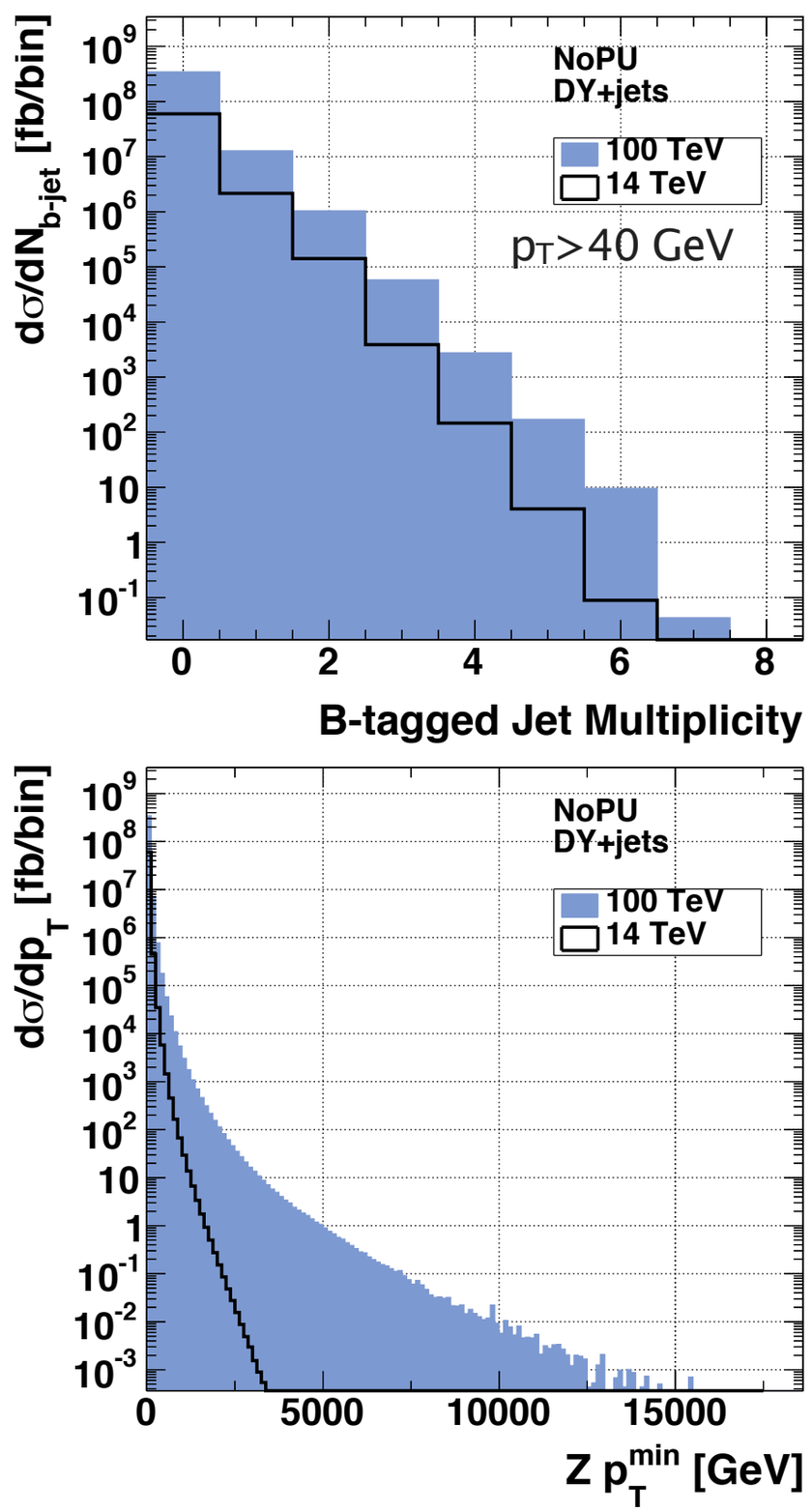
Drell-Yan + Jets

- V+jets is primary background.
- $\sigma_{DY} \approx \sigma_W/2.9$
- B-jet multiplicity should probably

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ Z p_T=7TeV
- 100 evts w/ MH_T=5TeV



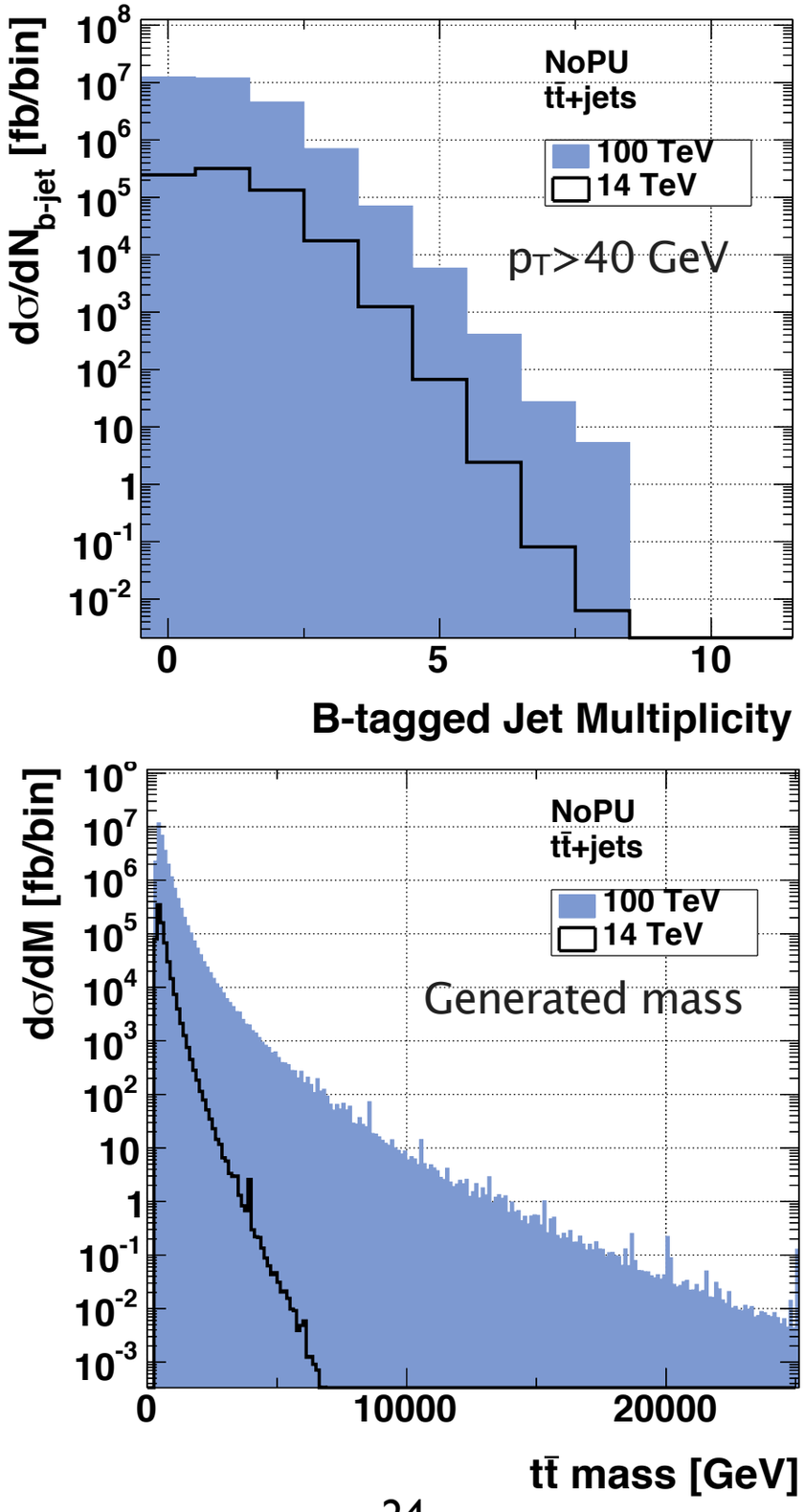


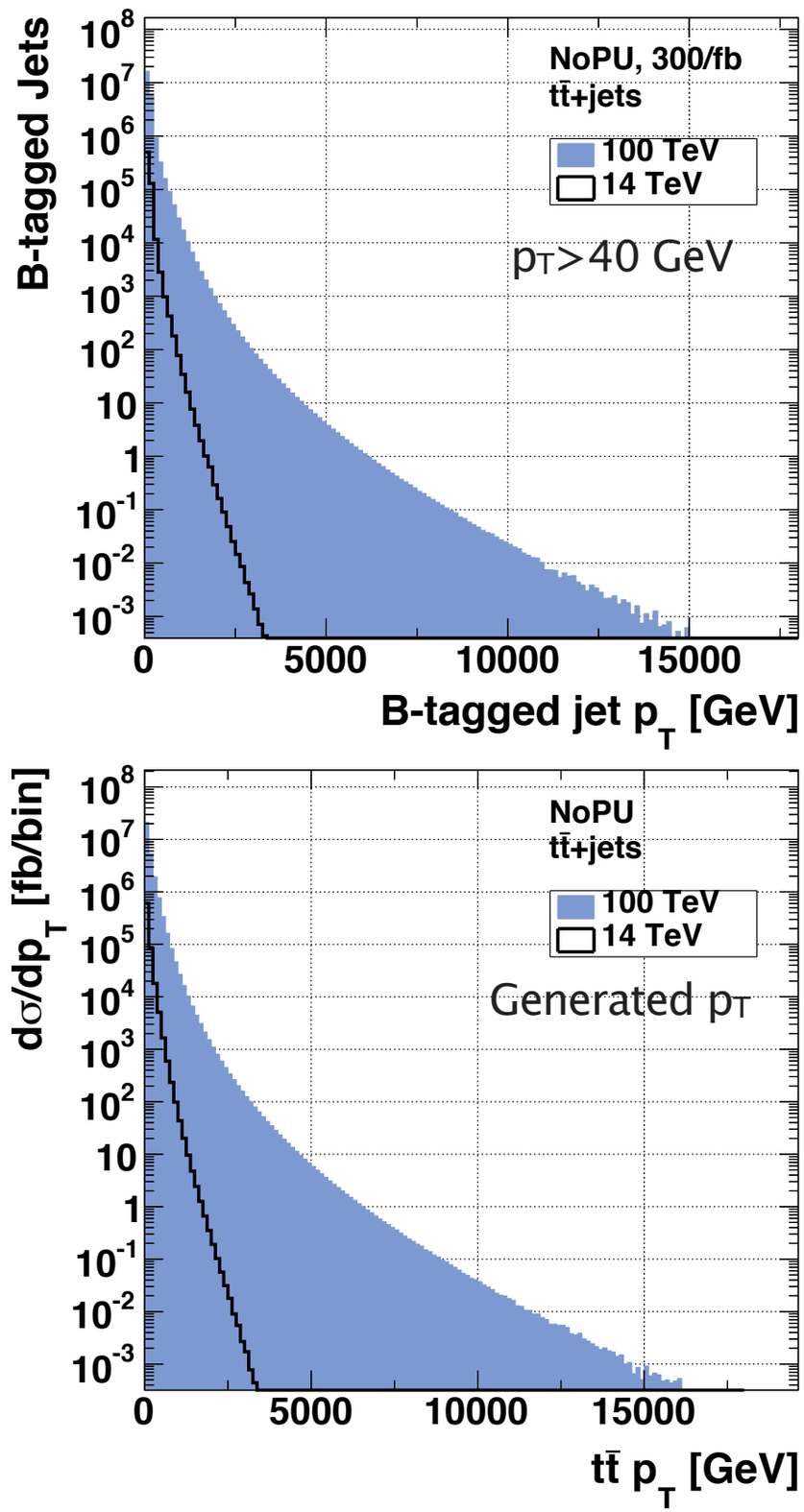
$t\bar{t}$ + Jets

- $\sigma_{tt} \approx \sigma_{DY}/12$
- $M_{tt} \approx H_T$
- Roughly equal to W+jets at high H_T.

1 ab^{-1}, $\sqrt{s}$=100TeV

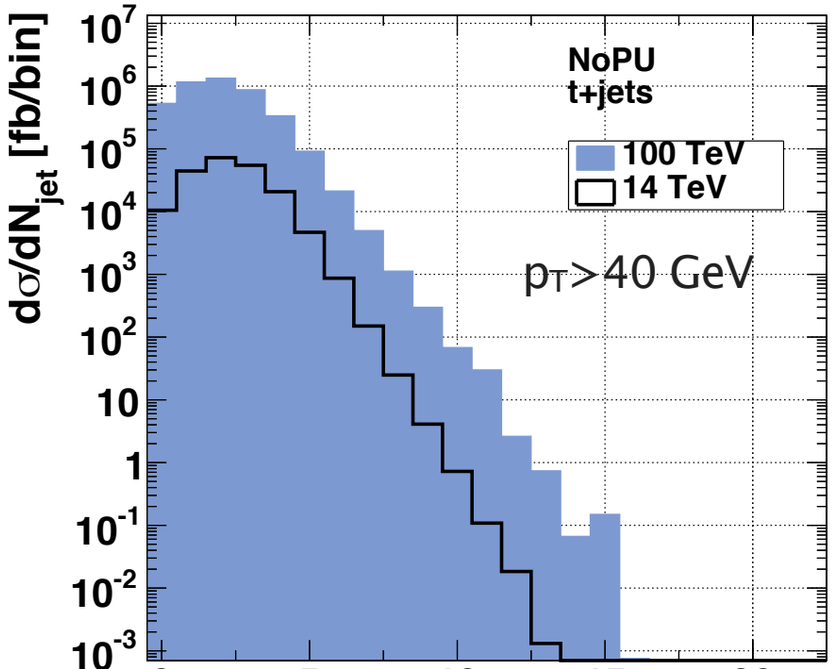
- 100 evts w/ M_{tt} =16TeV
- 100 evts w/ tt p_T=8TeV

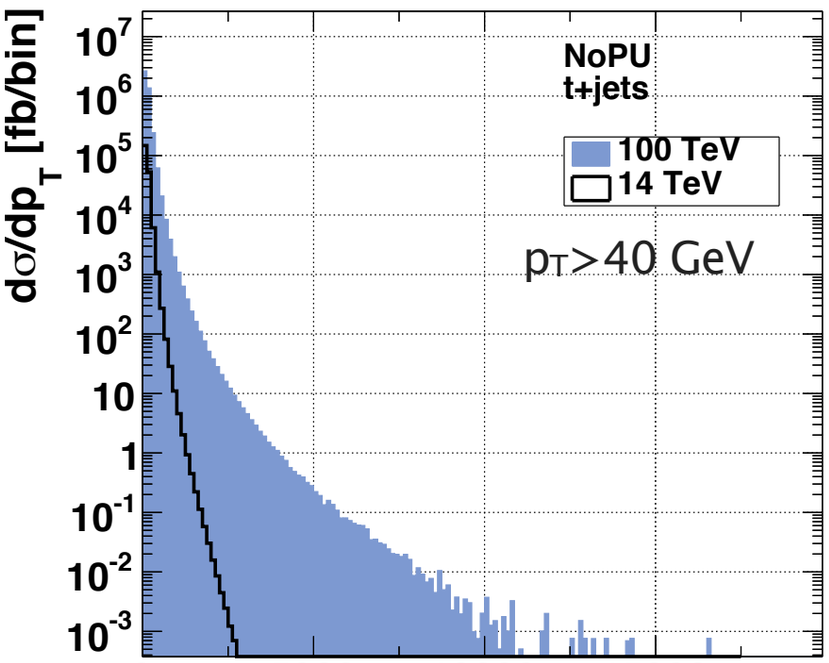


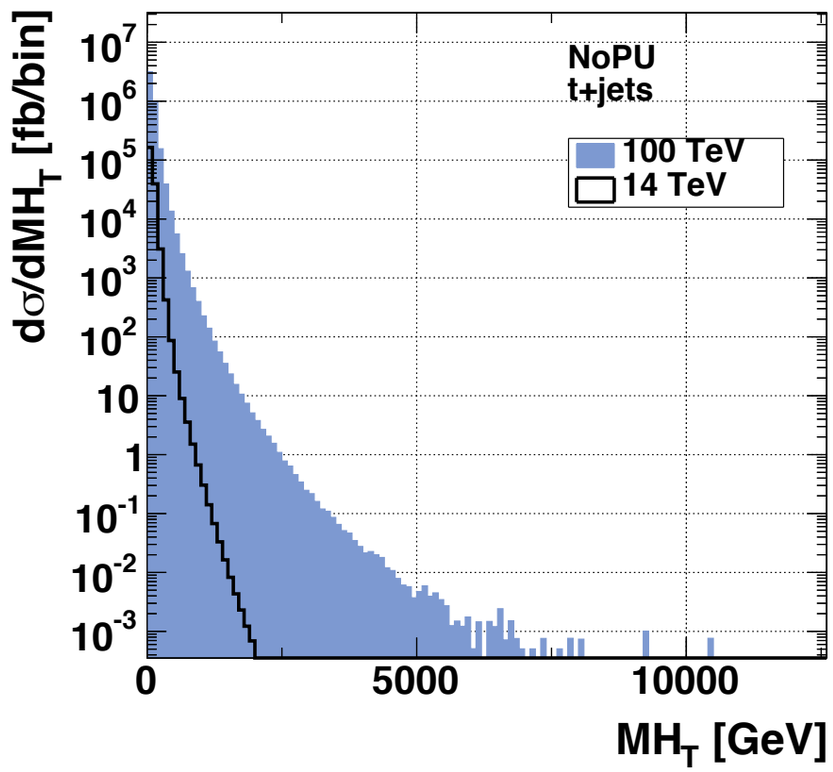


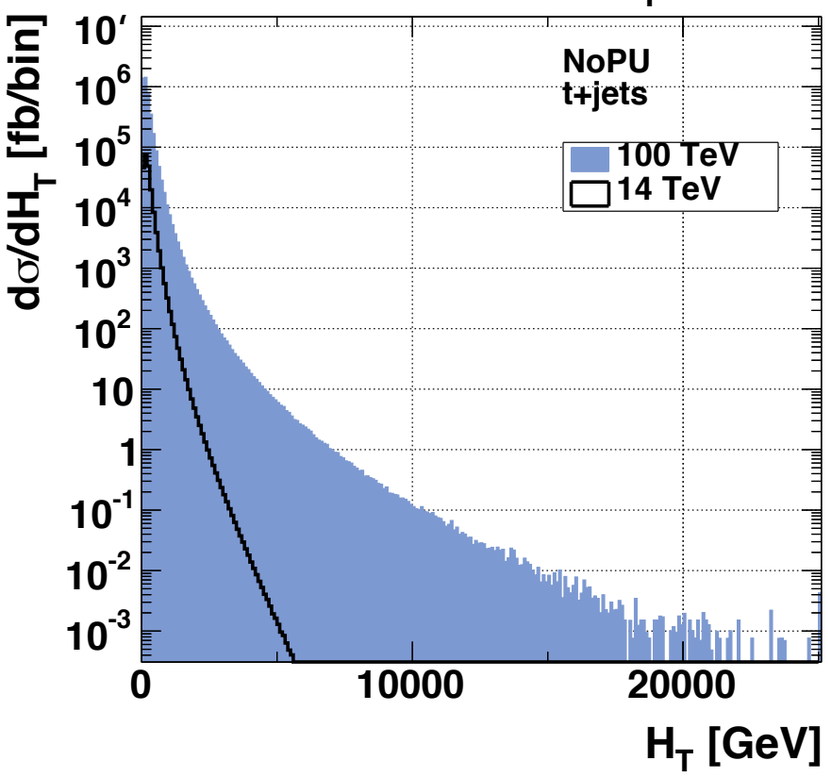
t + Jets

- $\sigma_t \approx \sigma_{tt}/3.5$









1 ab^{-1}, $\sqrt{s}$=100TeV

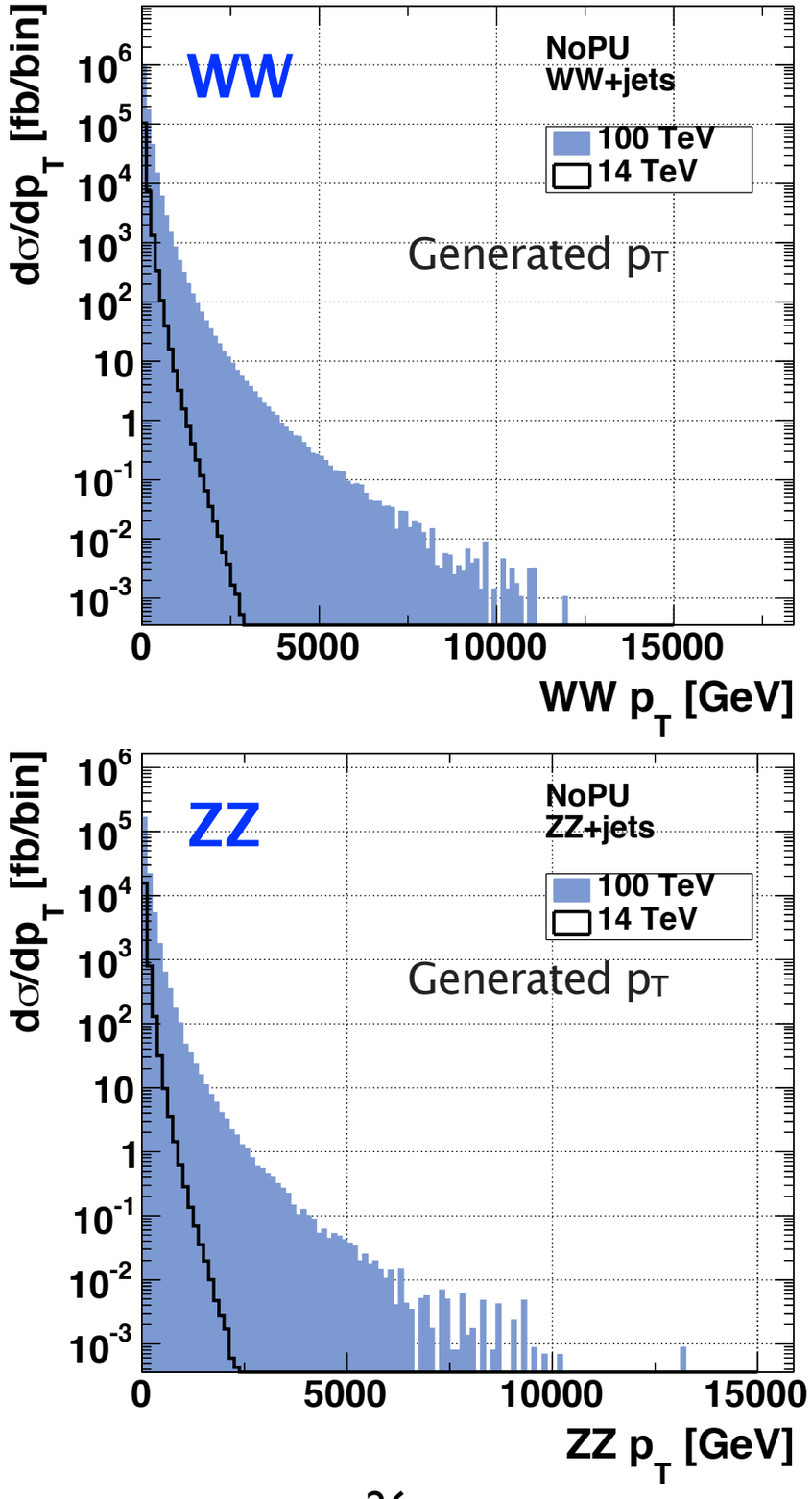
- 100 evts w/ MH_T=3TeV
- 100 evts w/ H_T=10TeV

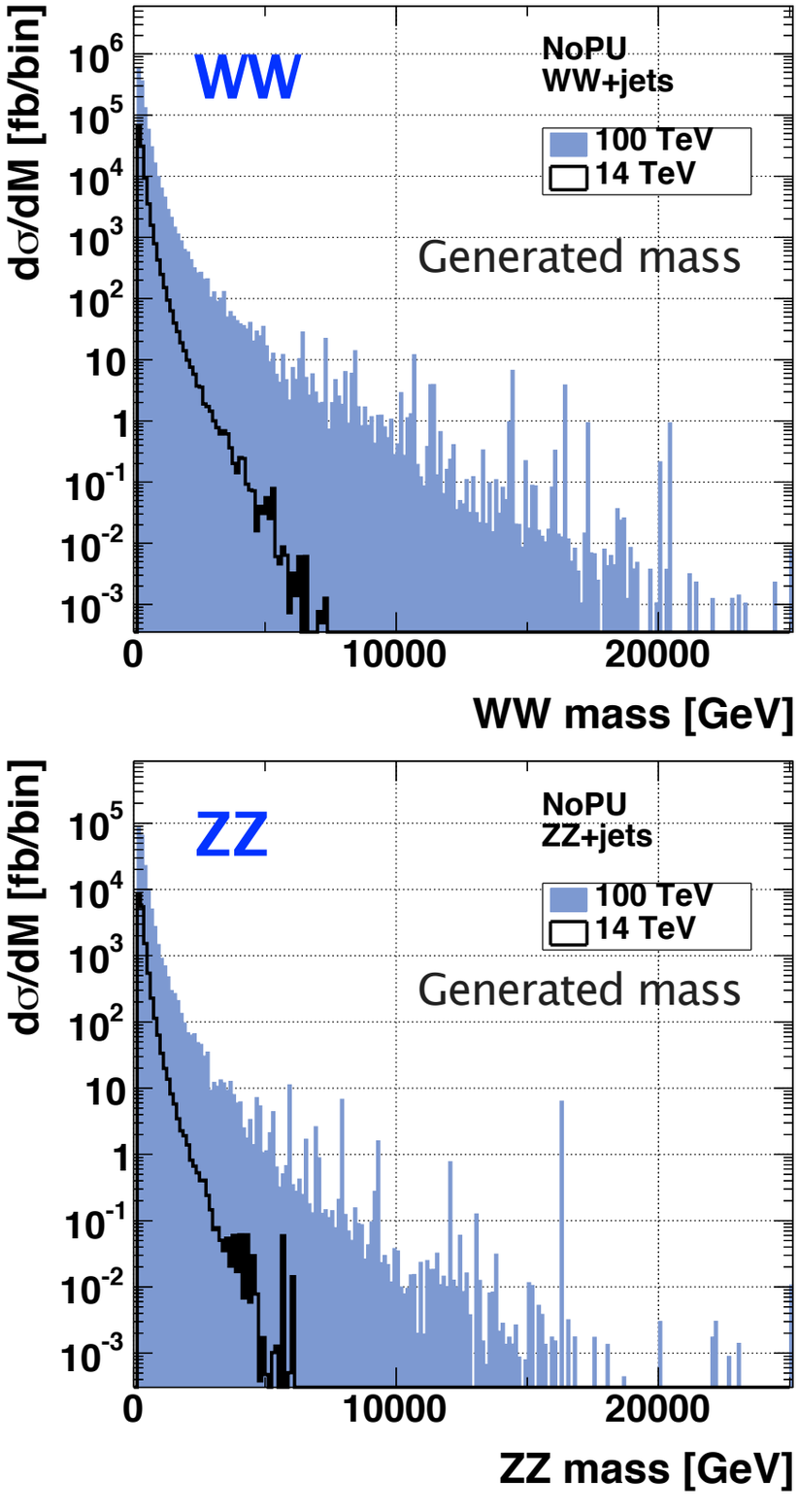
VV + Jets

- $\sigma_{WW} \approx \sigma_{tt}/24$
- $\sigma_{ZZ} \approx \sigma_{WW}/6$
- Probe WW scattering out to 10 TeV.

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ M_{WW}=10TeV
- 100 evts w/ M_{ZZ}=8TeV



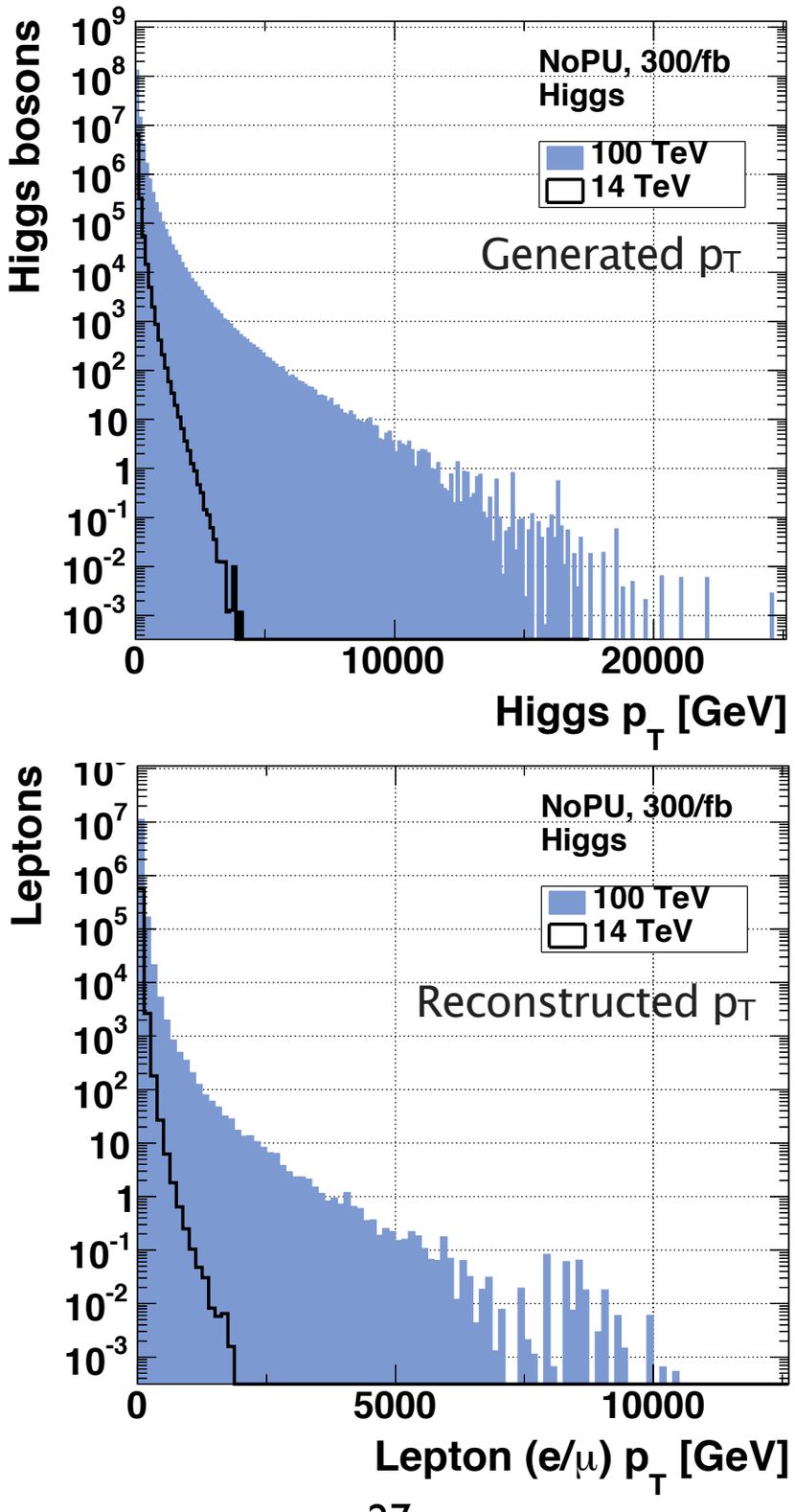


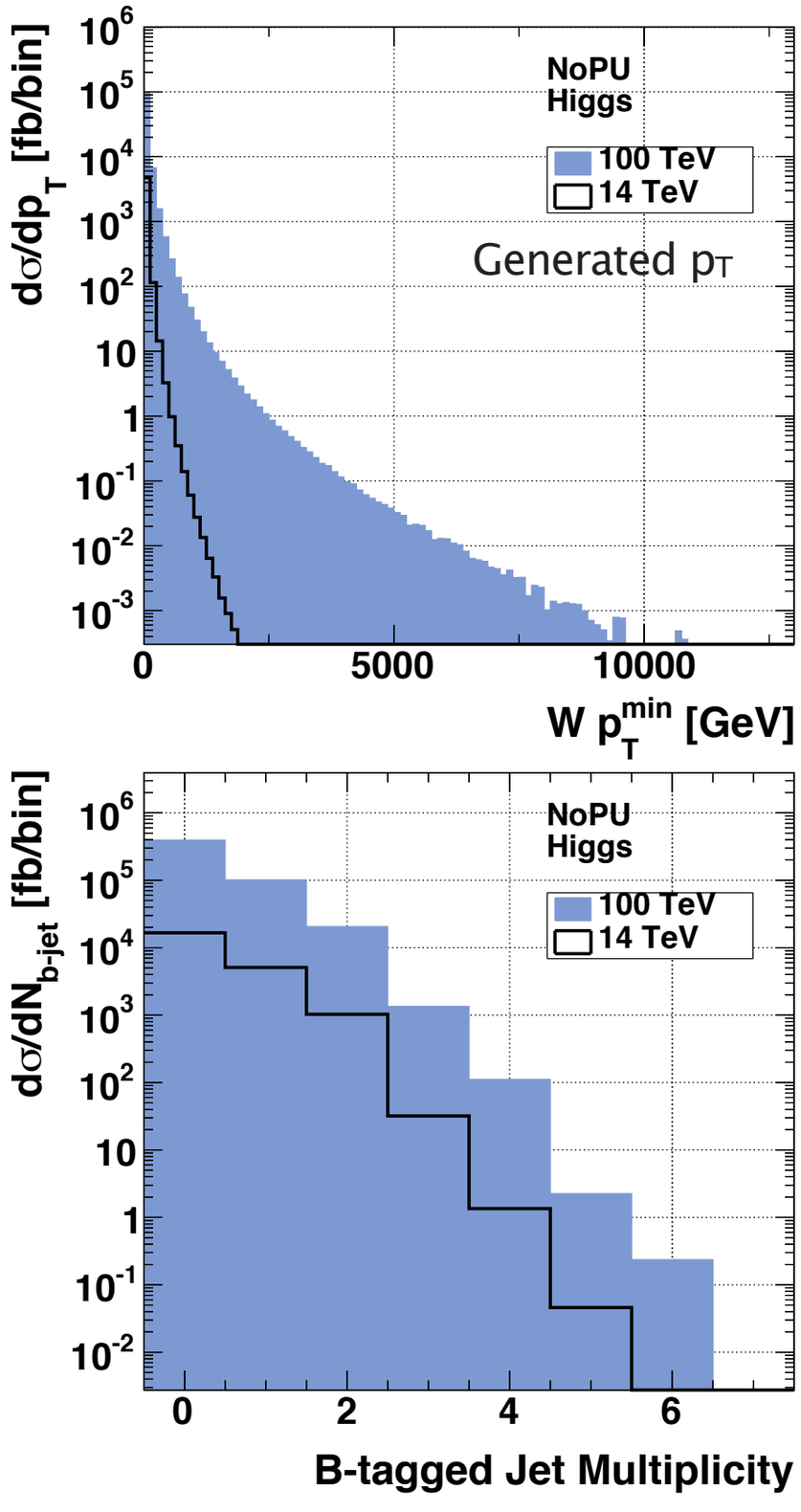
gg→H

- Higgs production via gluon fusion.
- $\sigma_{ggH} \approx \sigma_{WW}/2.4$
- $\sigma_{ggH} \approx \sigma_{WZ}$

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 Higgs w/ p_T=5TeV



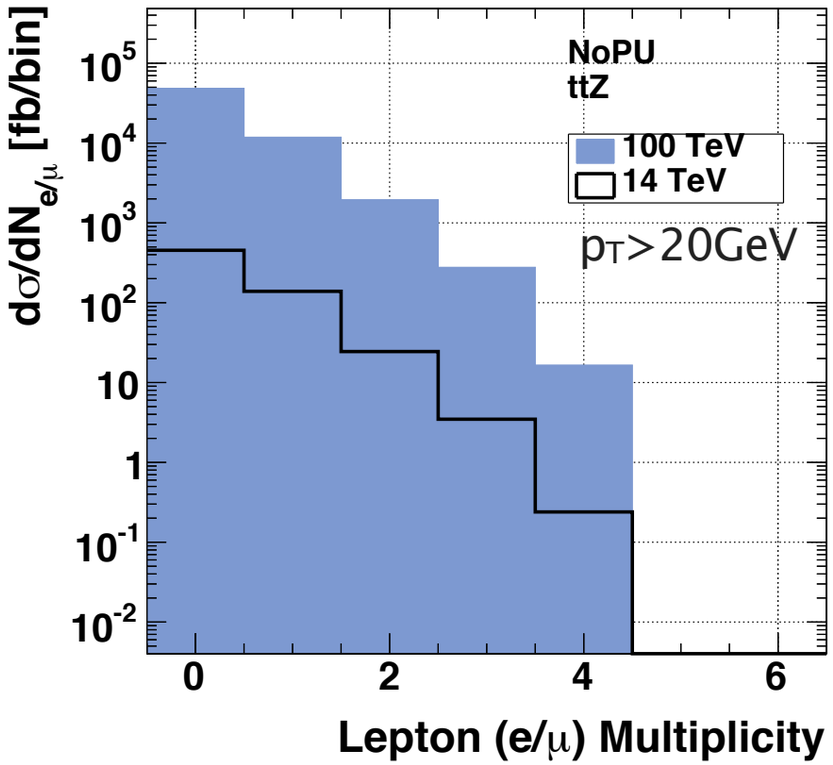


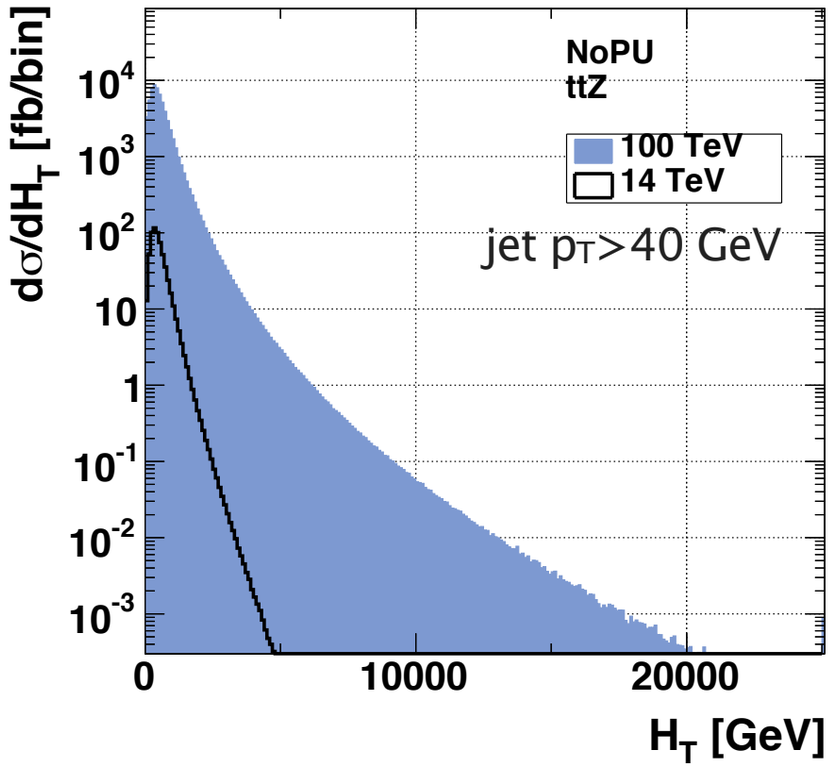
ttZ

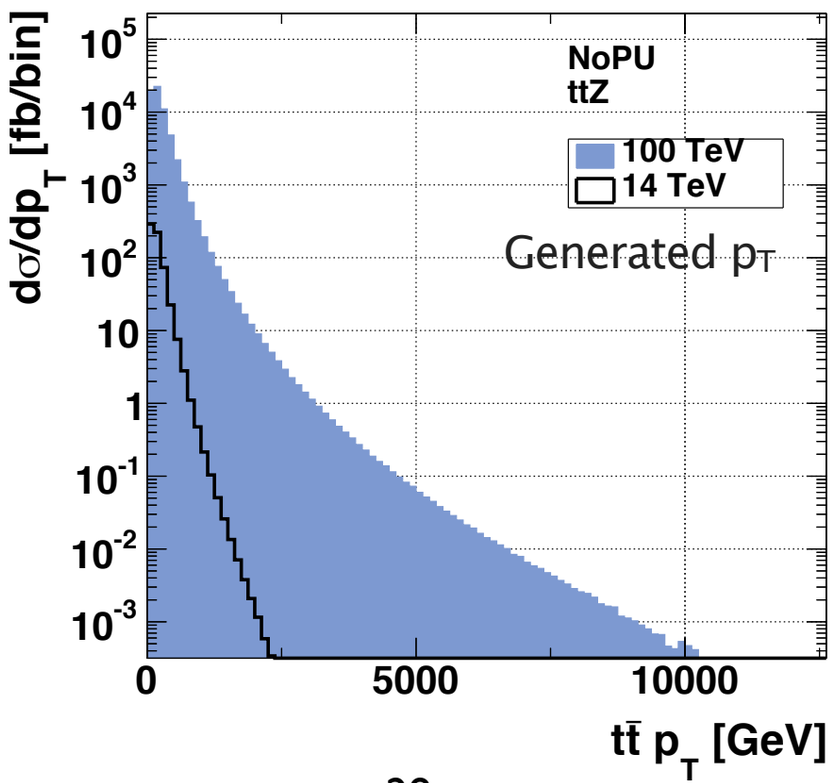
- $\sigma_{ttZ} \approx \sigma_{ZZ}/3.2$

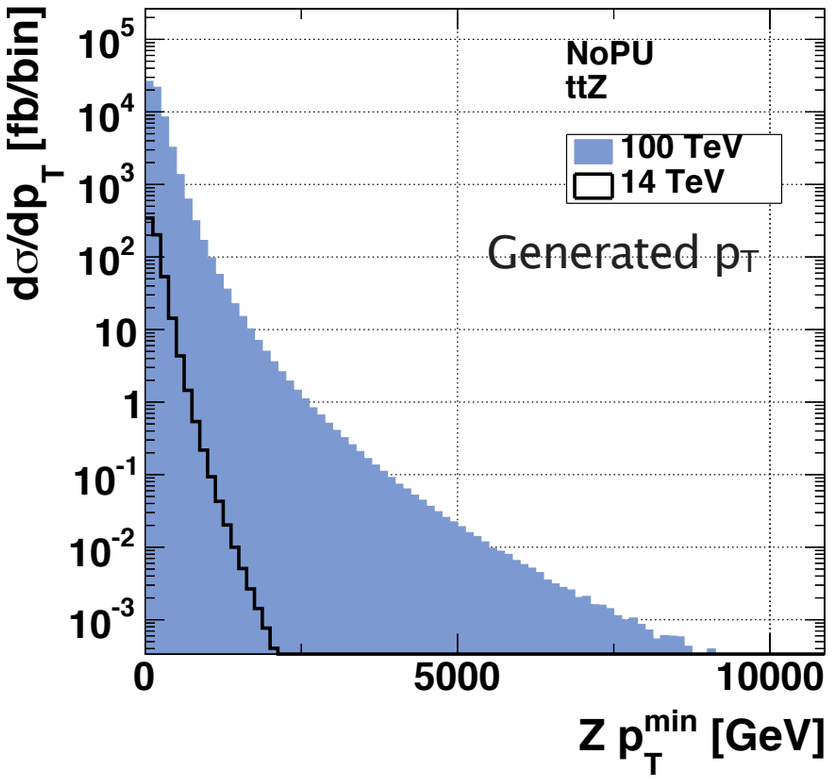
1 ab^{-1}, $\sqrt{s}$=100TeV
- 300k evts w/ SS leptons

300 fb^{-1}, $\sqrt{s}$=14TeV
- 900 evts w/ SS leptons







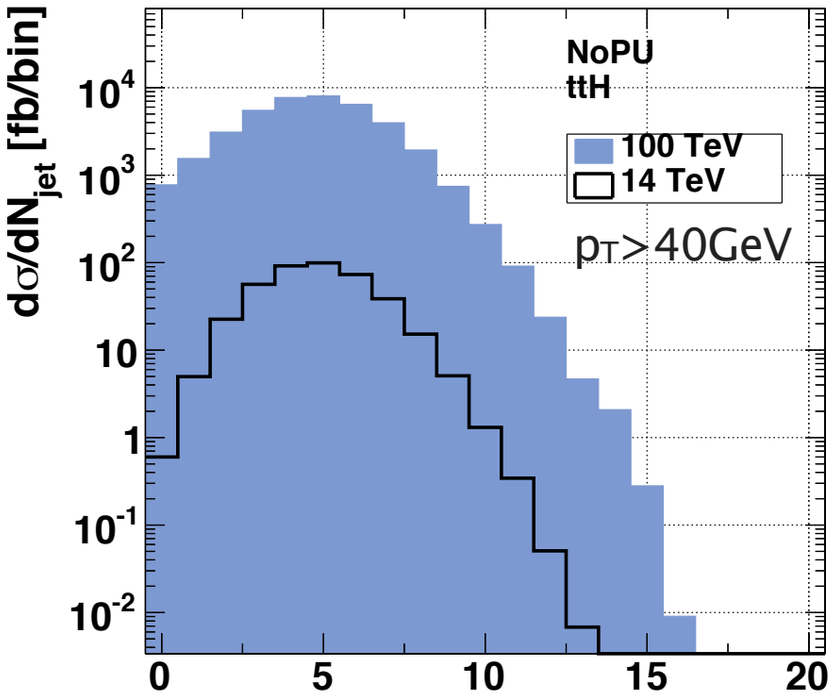


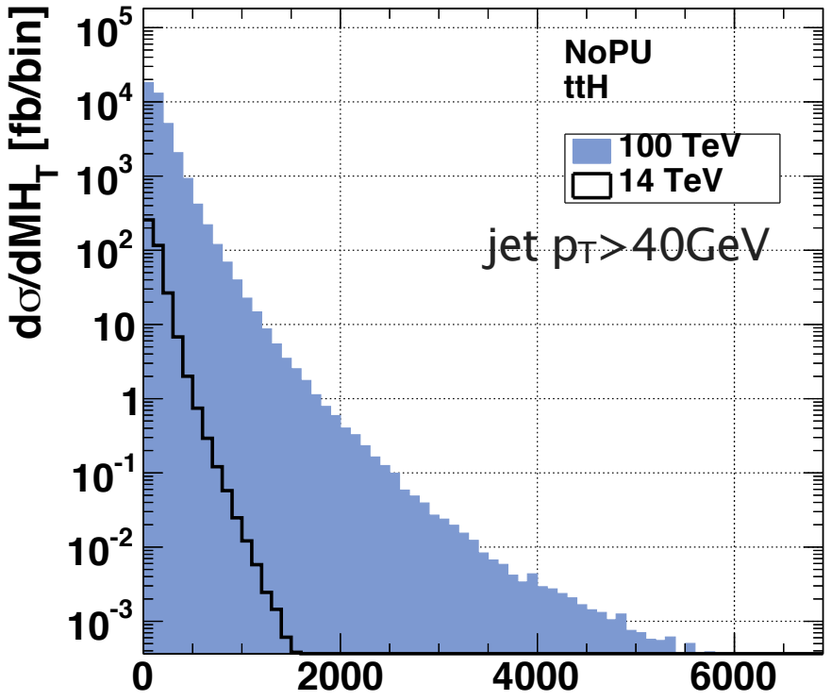
ttH

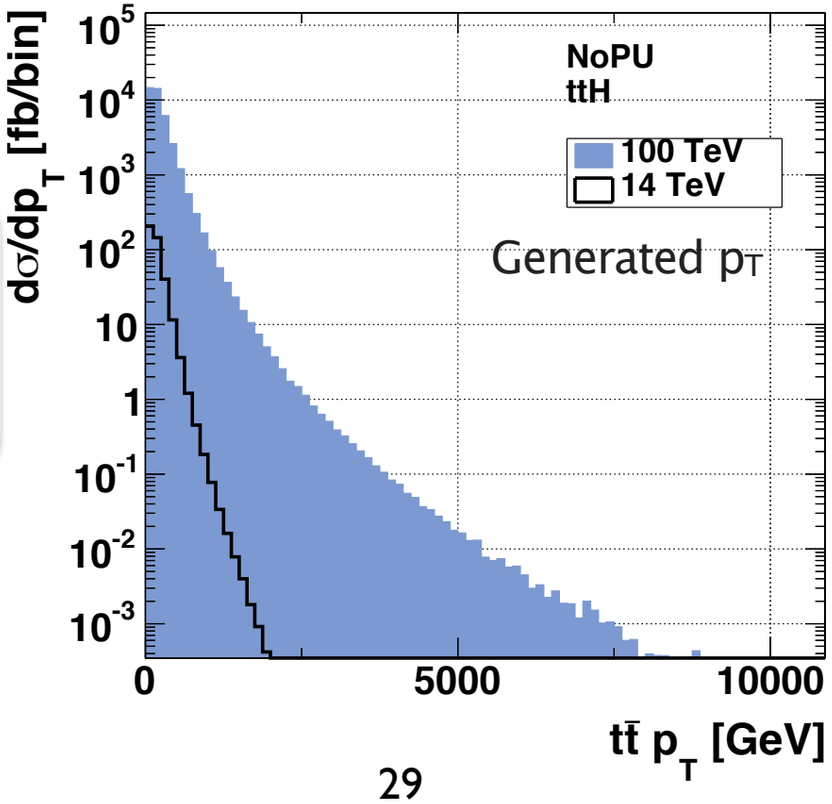
- $\sigma_{ttH} \approx \sigma_{ttZ}/1.6$
- Because of gg luminosity, $\sigma_{ttH} > \sigma_{VH}$ at 100 TeV.
- More jets, fewer leptons than ttZ.
- ttH H–spectrum harder than ttZ Z–spectrum.

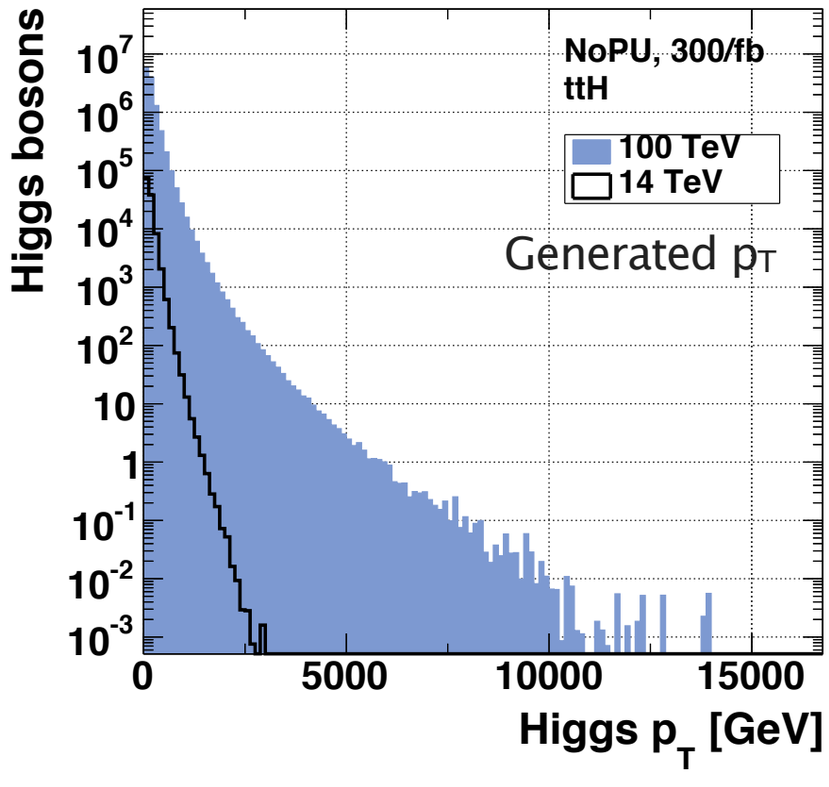
1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ MH_T=2.5TeV







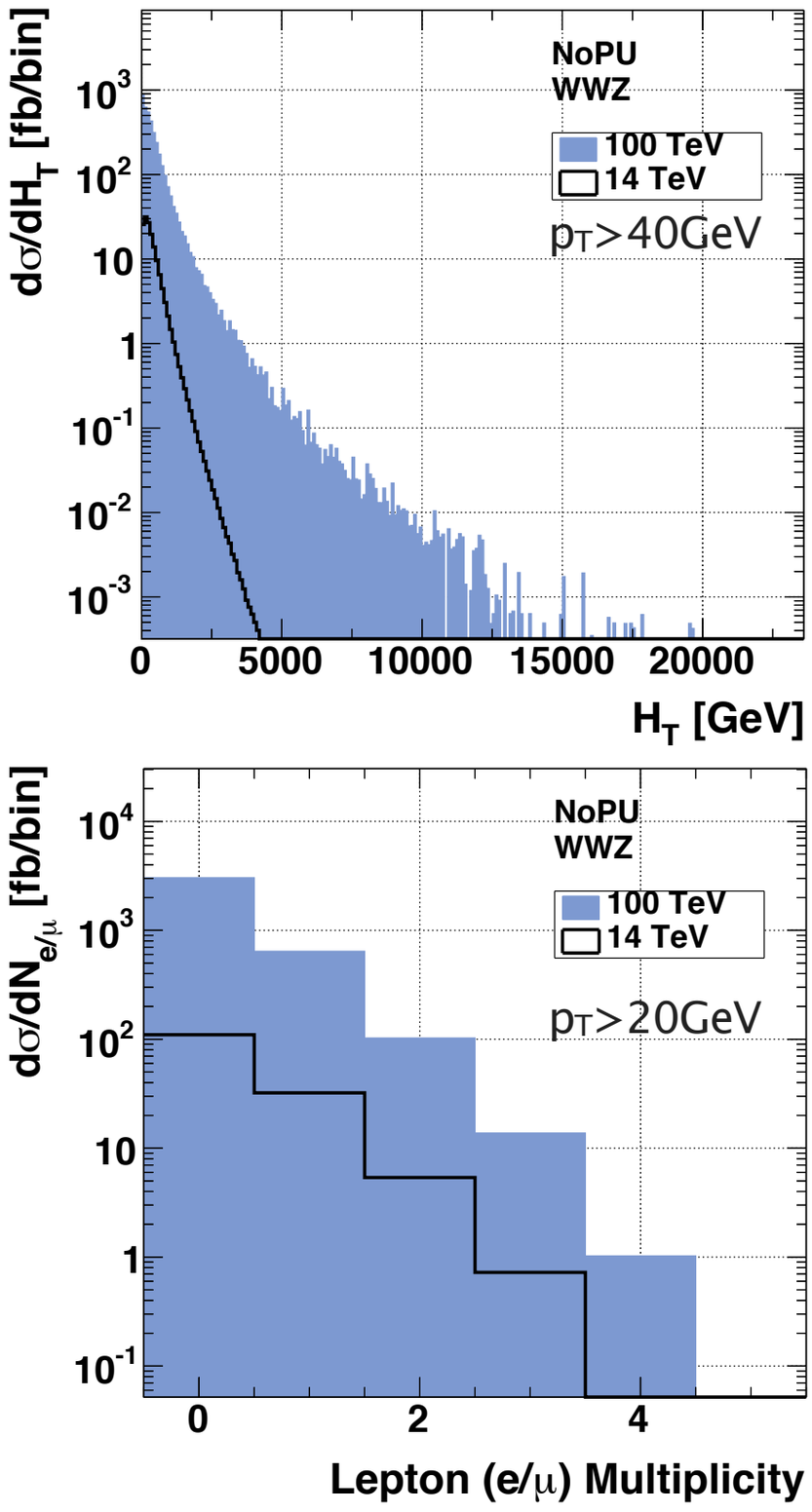


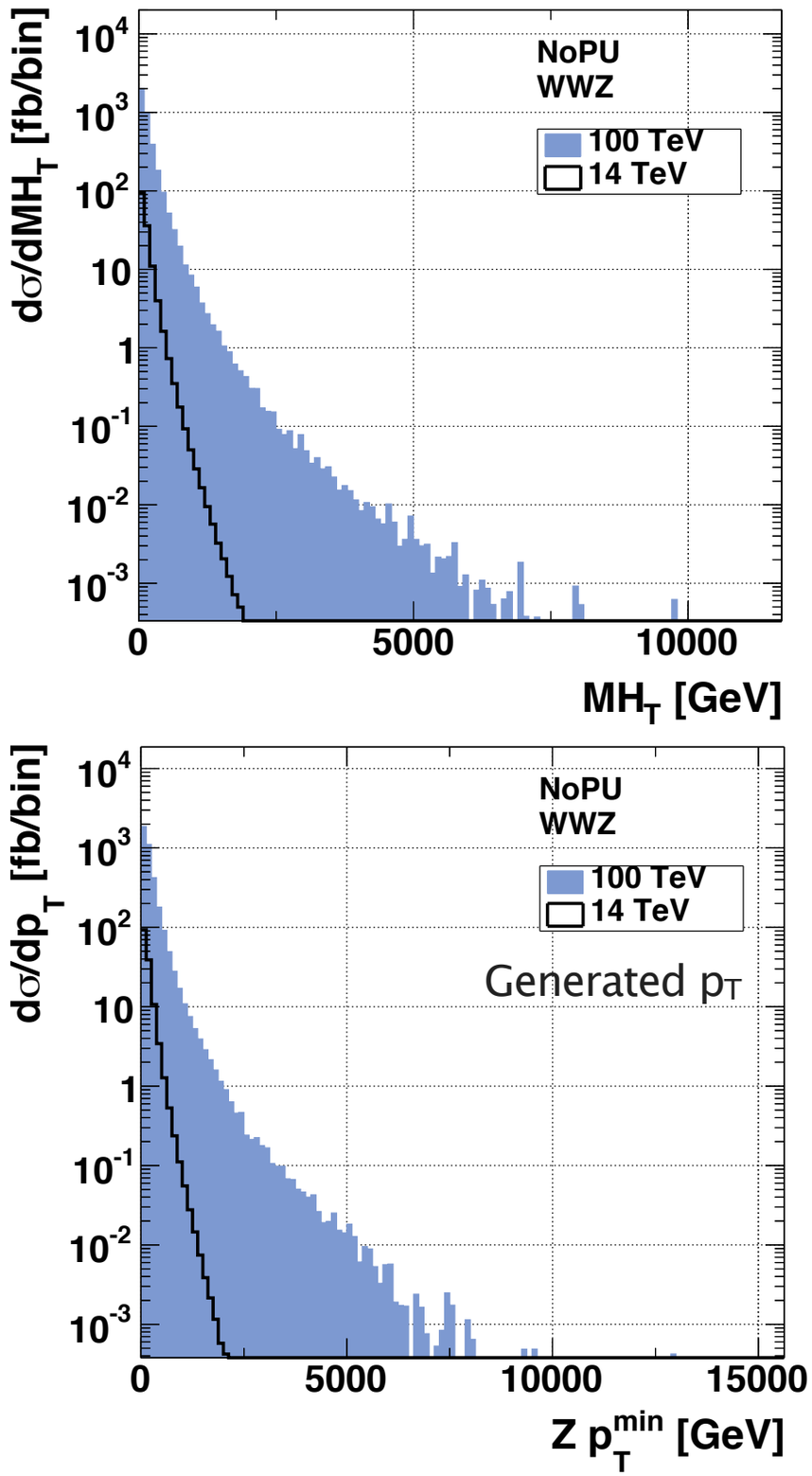
WWZ

- $\sigma_{WWZ} \approx \sigma_{ttH}/10.6$

1 ab^{-1}, $\sqrt{s}$=100TeV

- 10k evts SS leptons



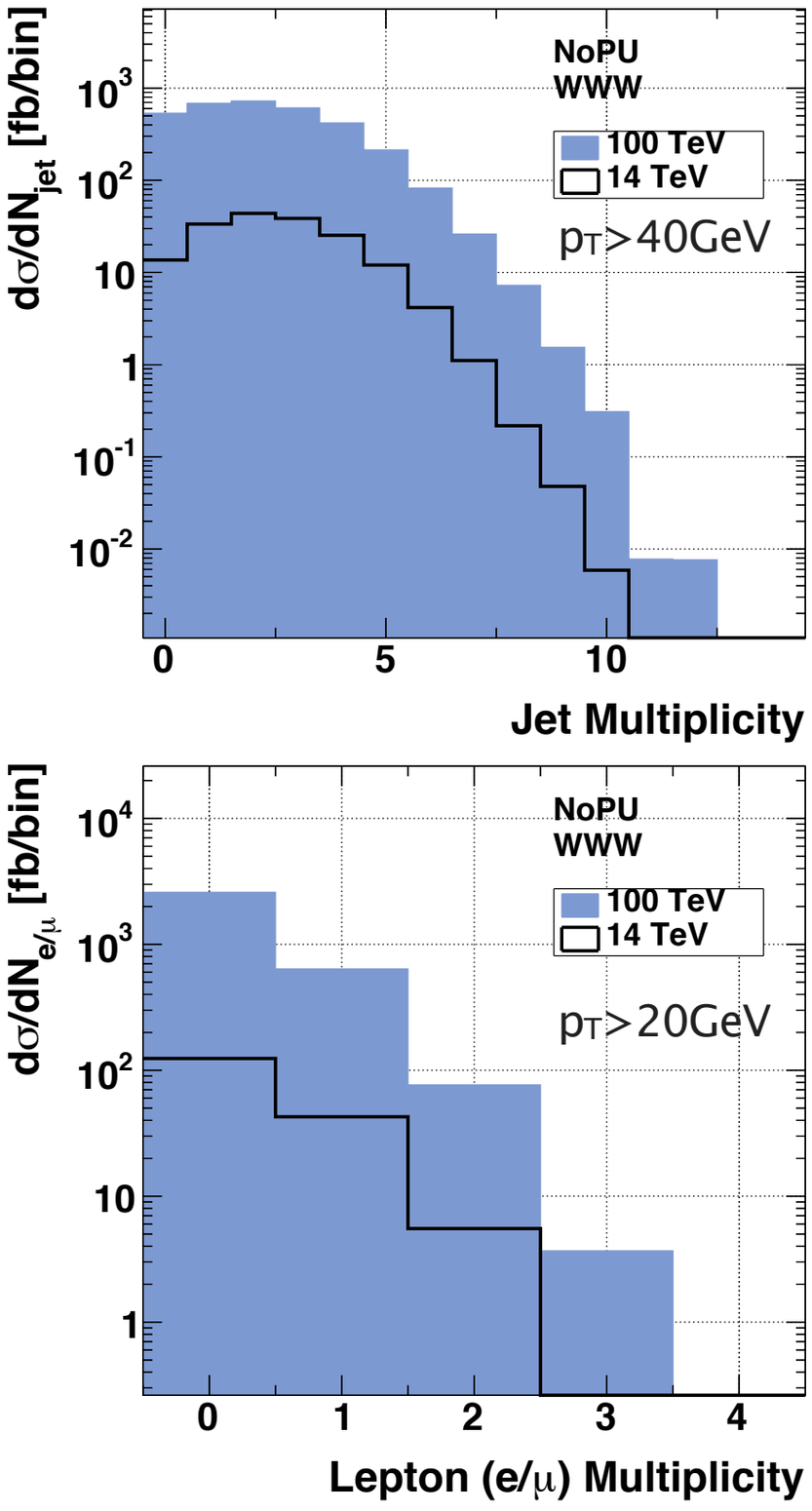


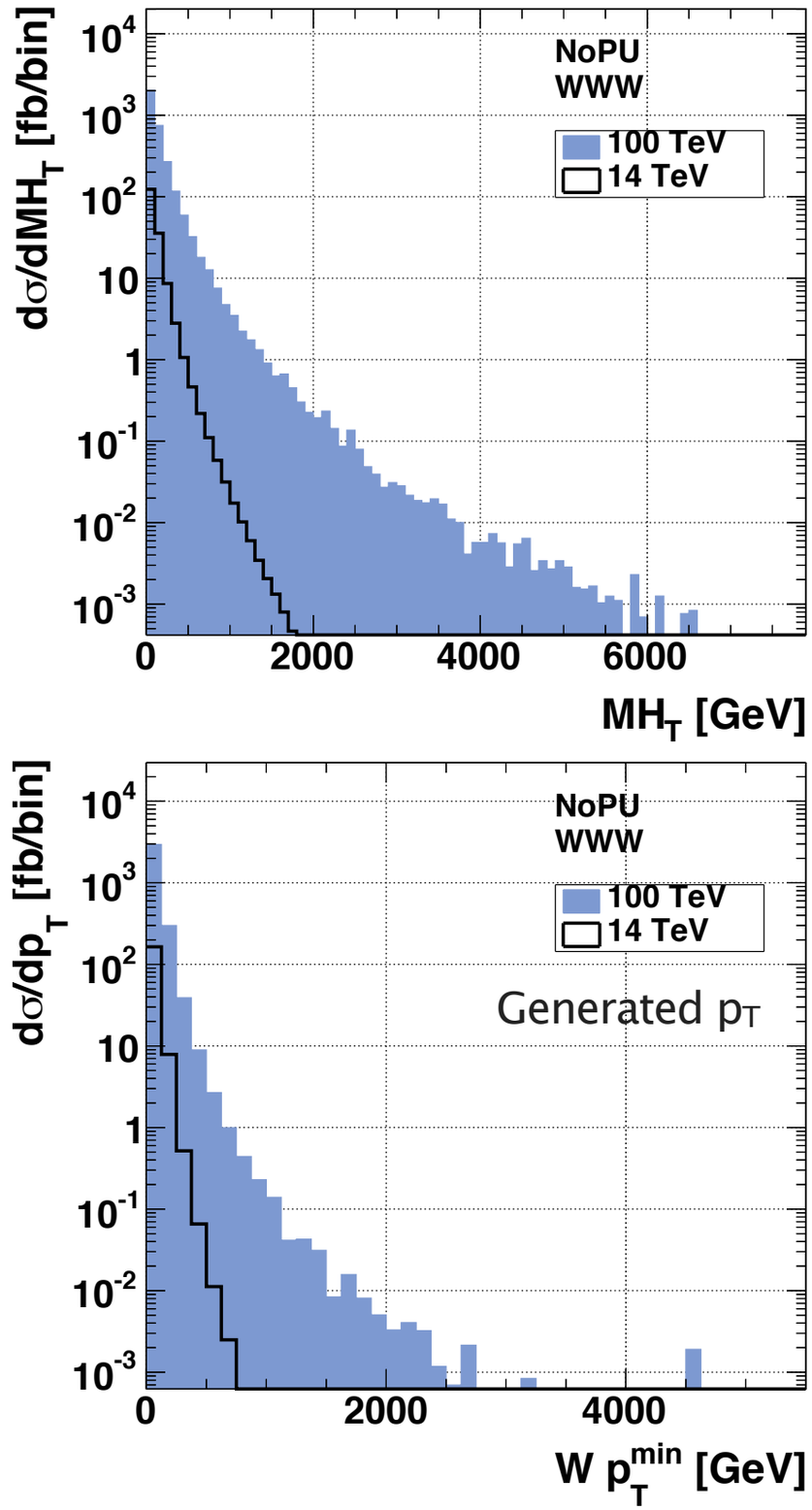
WWW

- $\sigma_{WWW} \approx \sigma_{WWZ}/1.2$

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts with W p_T^{min}=1TeV



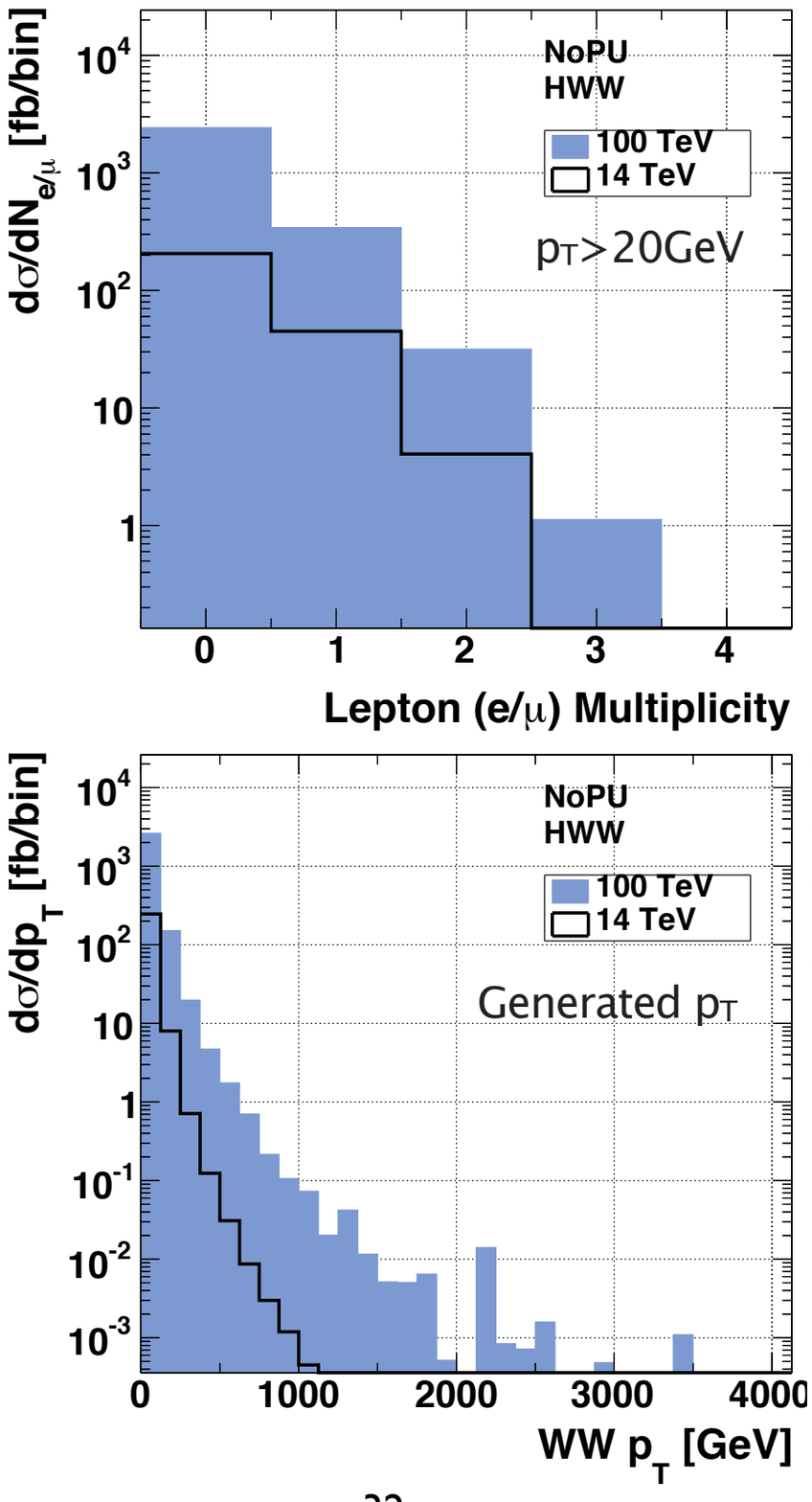


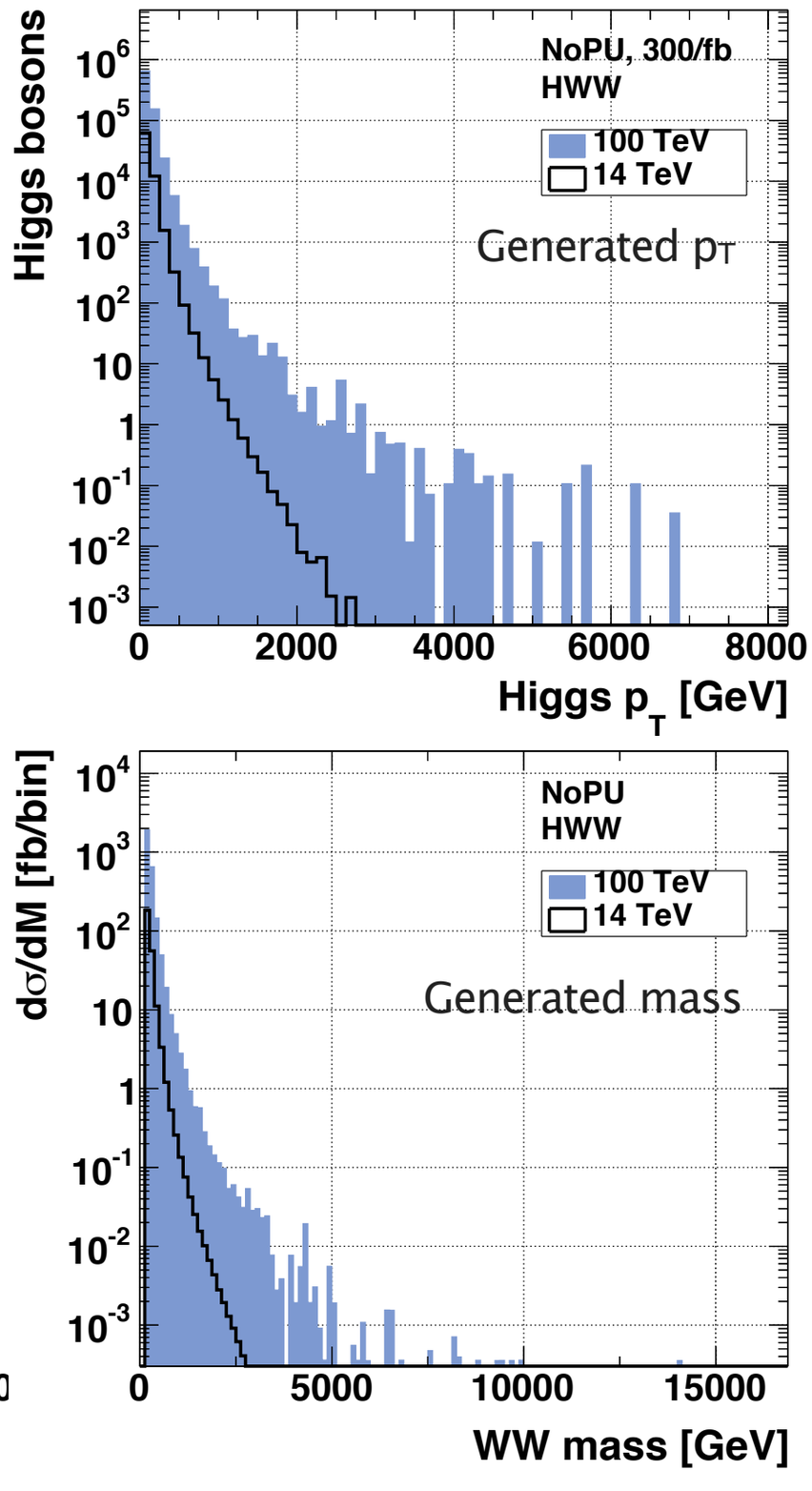
HWW

- $\sigma_{HWW} \approx \sigma_{WWZ}/1.4$

1 ab^{-1}, $\sqrt{s}$=100TeV

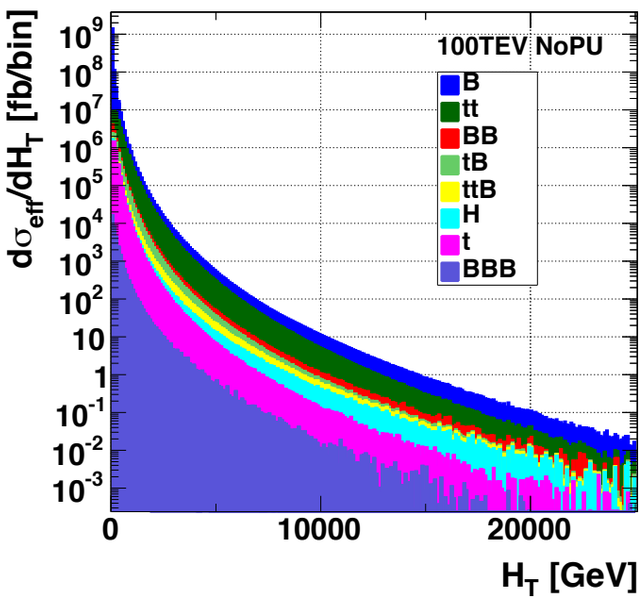
- 100 evts with WW mass =2TeV

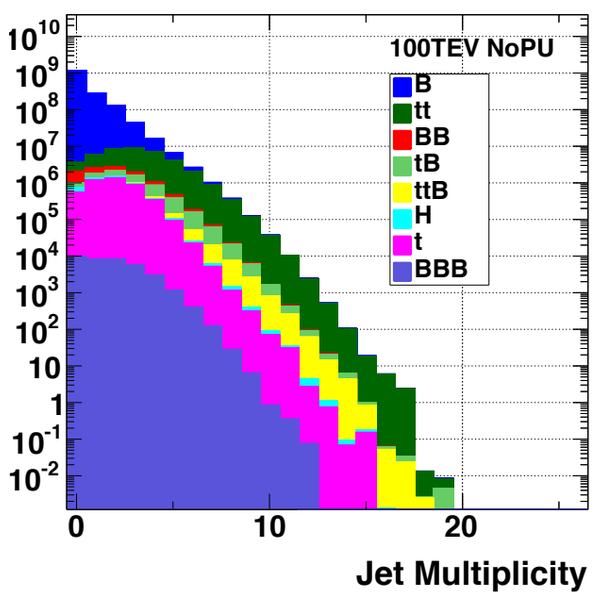


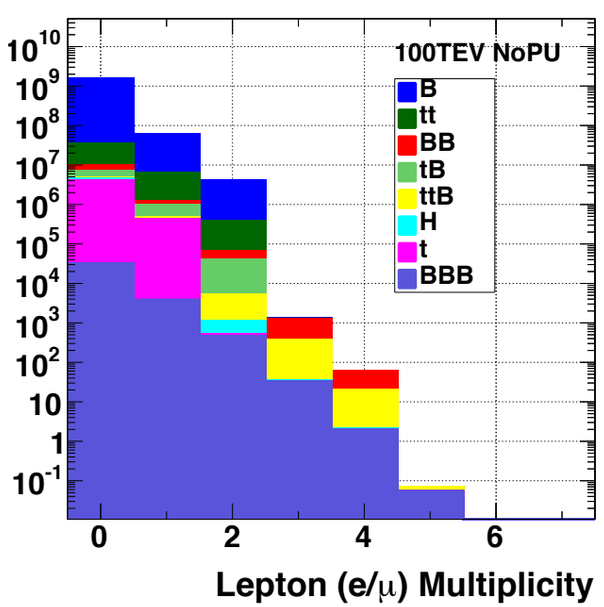


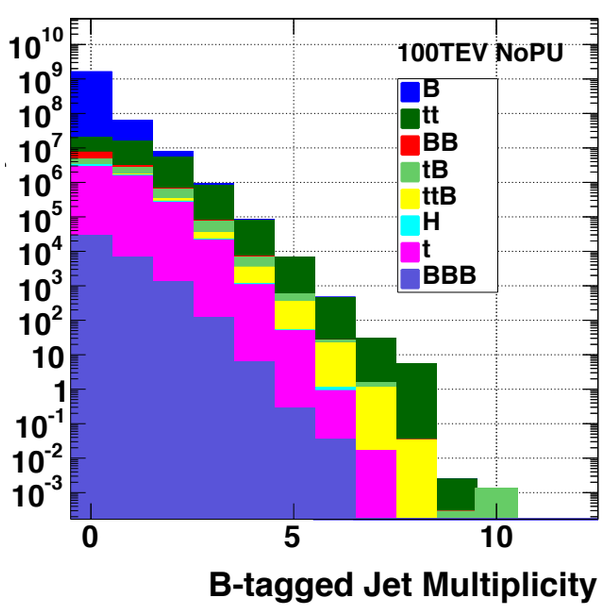
Application of basic event selection

Selection	H	N	N	N
Had	>2.5 TeV	>8	0	≥2
1Lep	>2.5 TeV	>4	≥1	–
3Lep	>1.0 TeV	>3	≥3	–



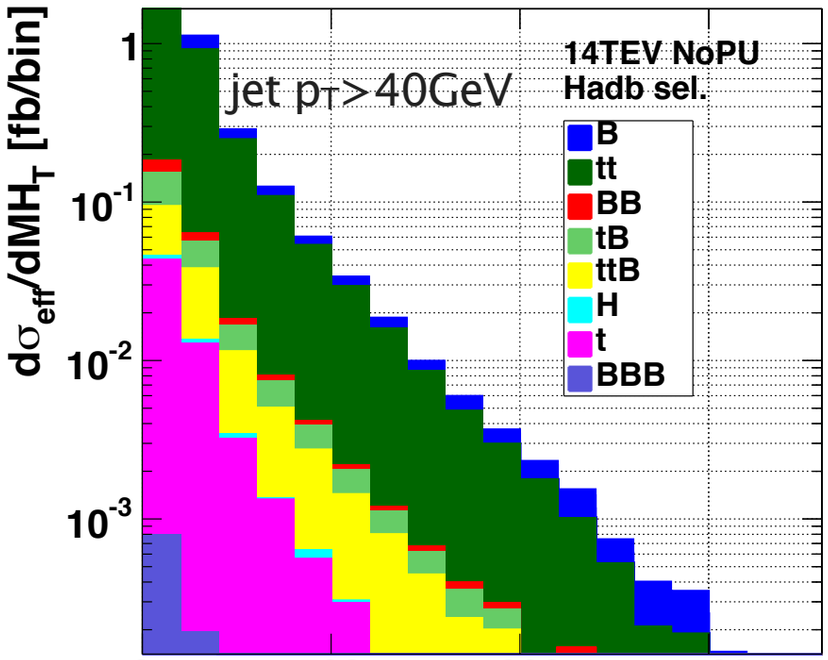


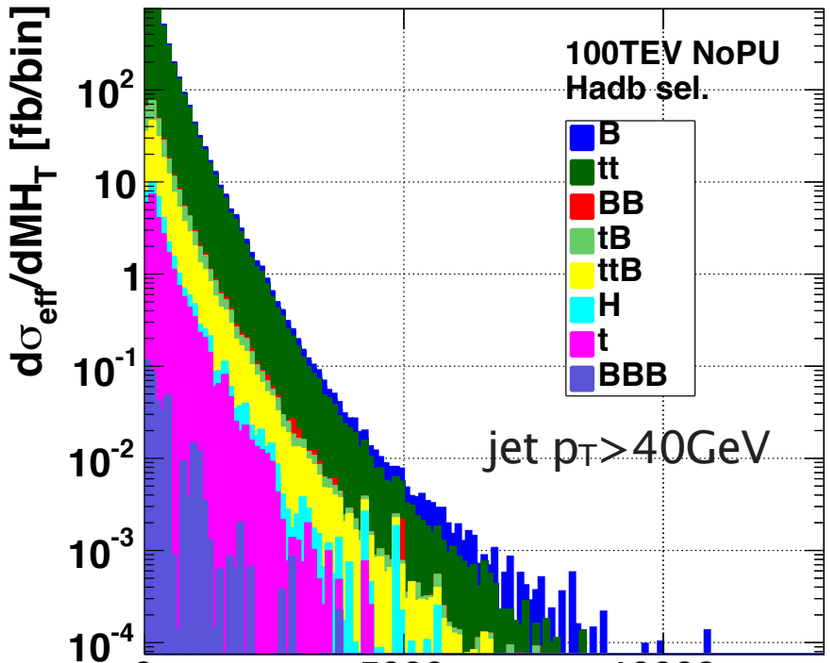




Hadronic selection

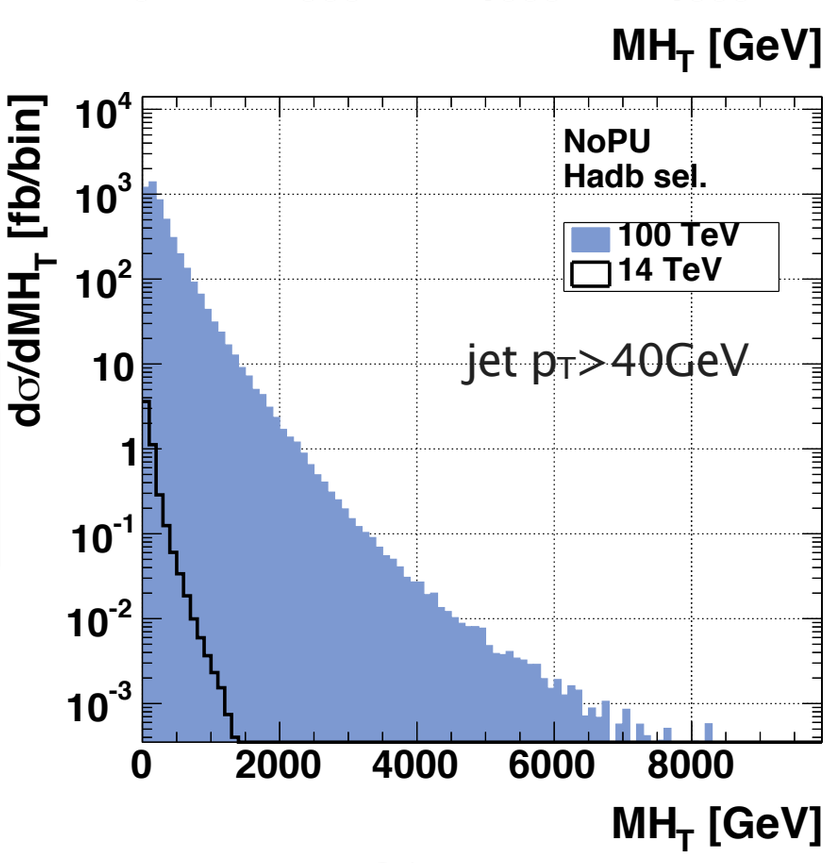
- Dominant backgrounds at 8 TeV are Z→νν and semi-leptonic tt.
- Simple selection does not use hadronic top rejection methods.

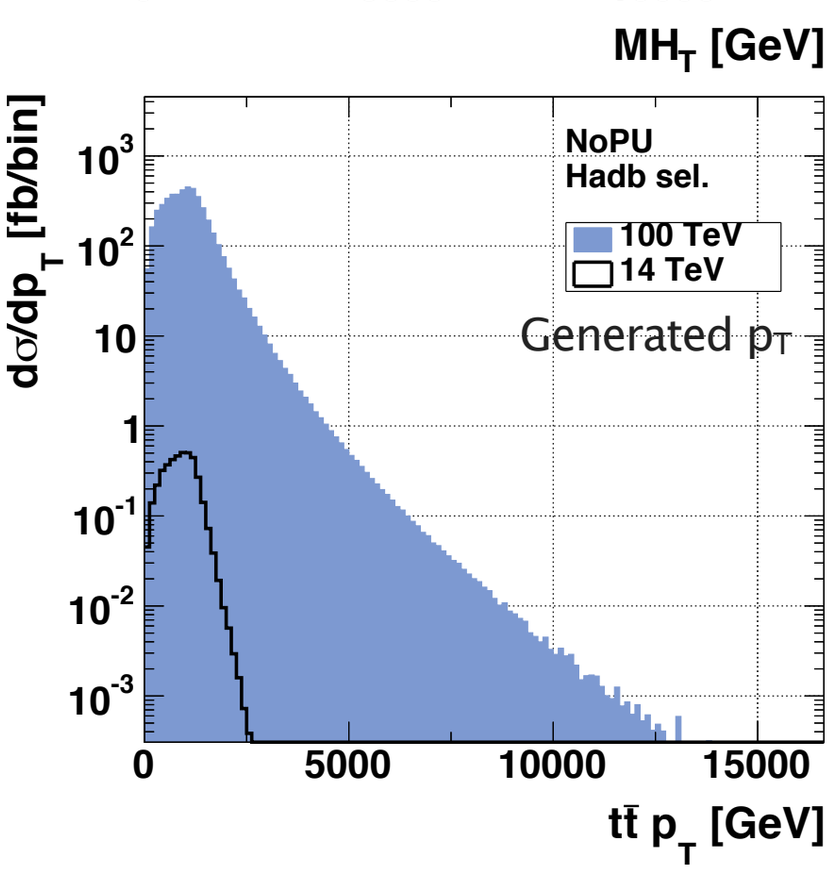




1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ MH_T=3TeV



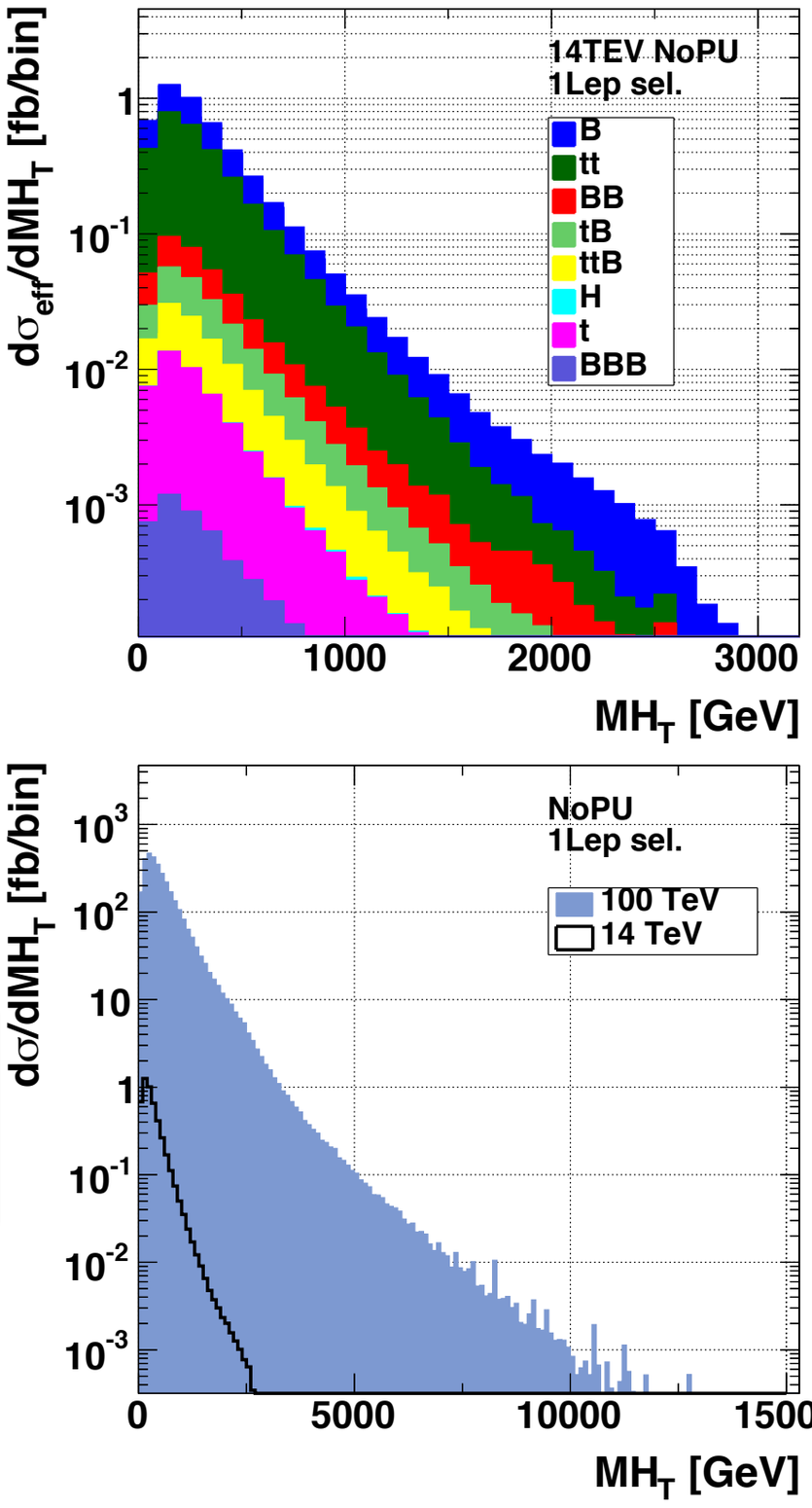


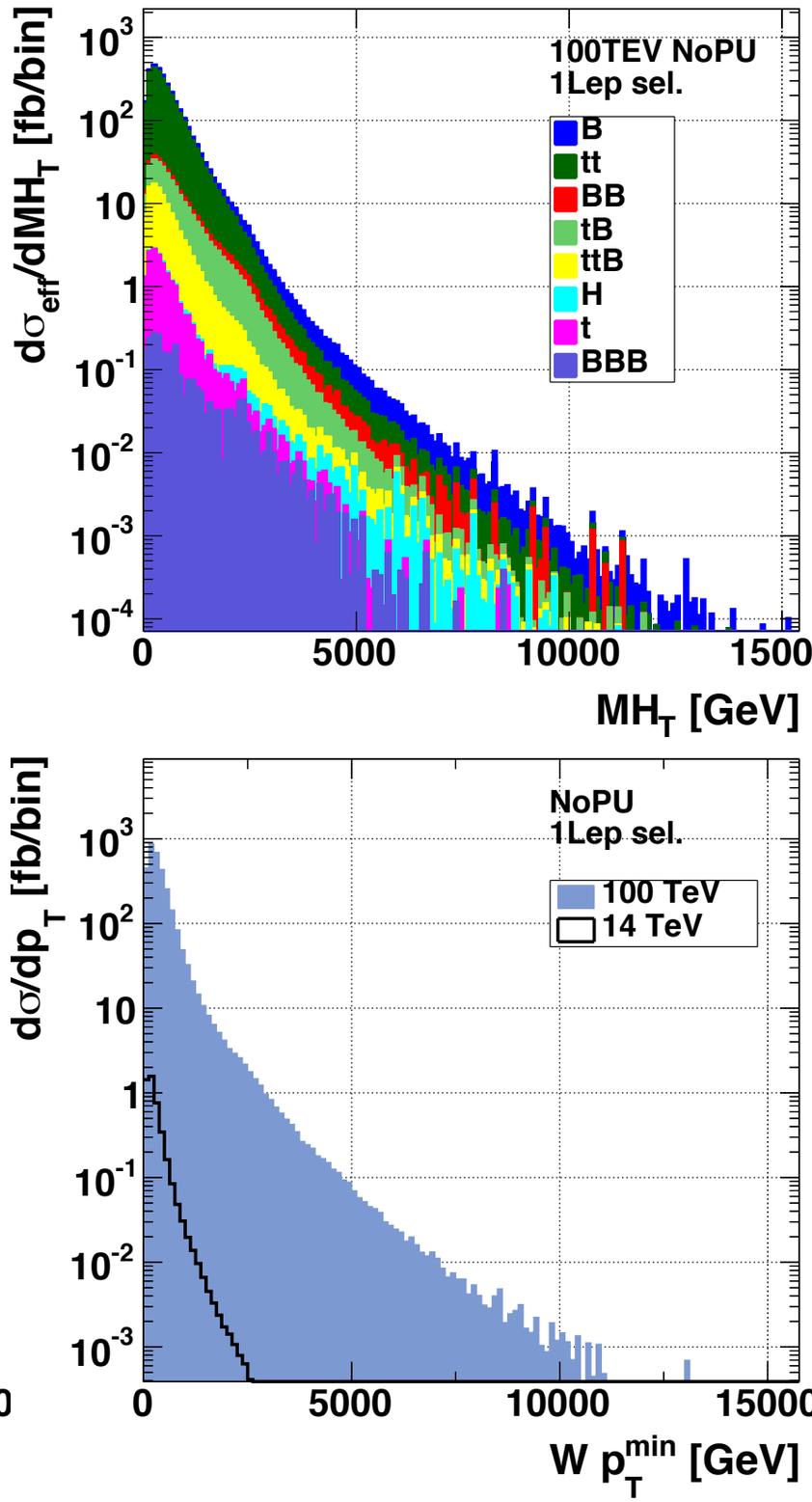
1-lepton selection

- Dominant backgrounds at 8 TeV are tt and W +jets.
- No M_T- or BDT-based background rejection in this study.

1 ab^{-1}, $\sqrt{s}$=100TeV

- 100 evts w/ MH_T=5TeV



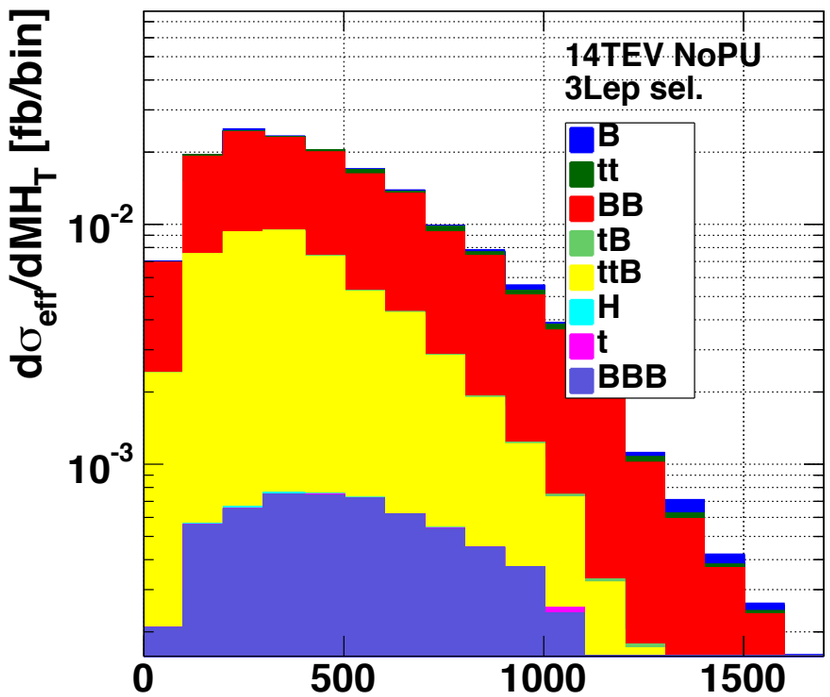


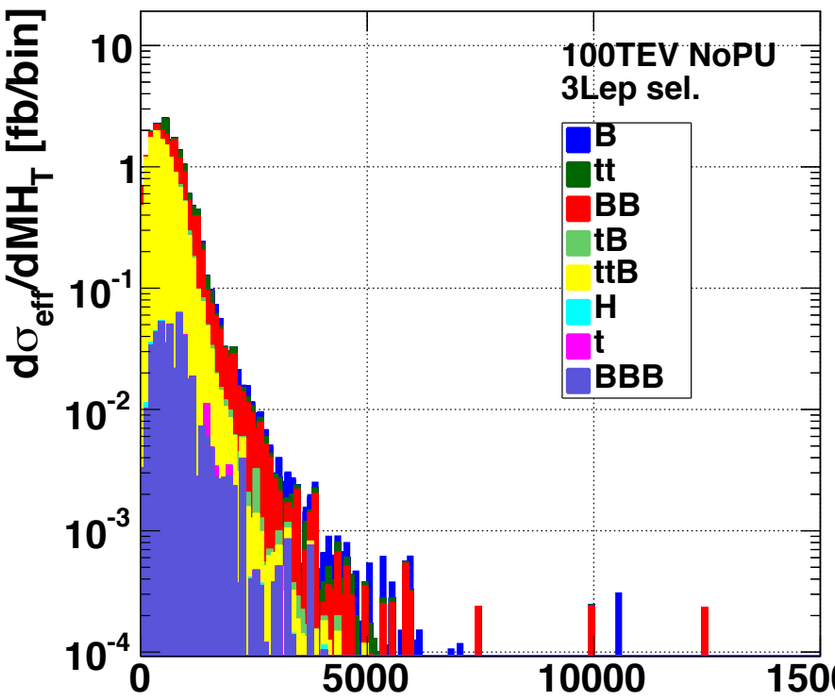
3-lepton selection

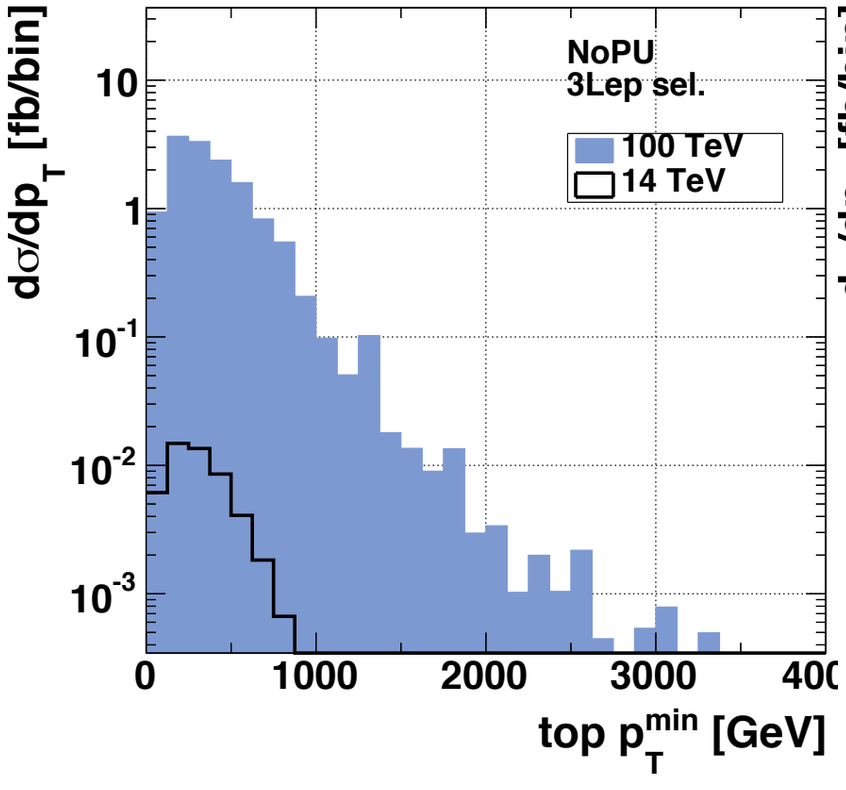
- Fake leptons not included in this study.

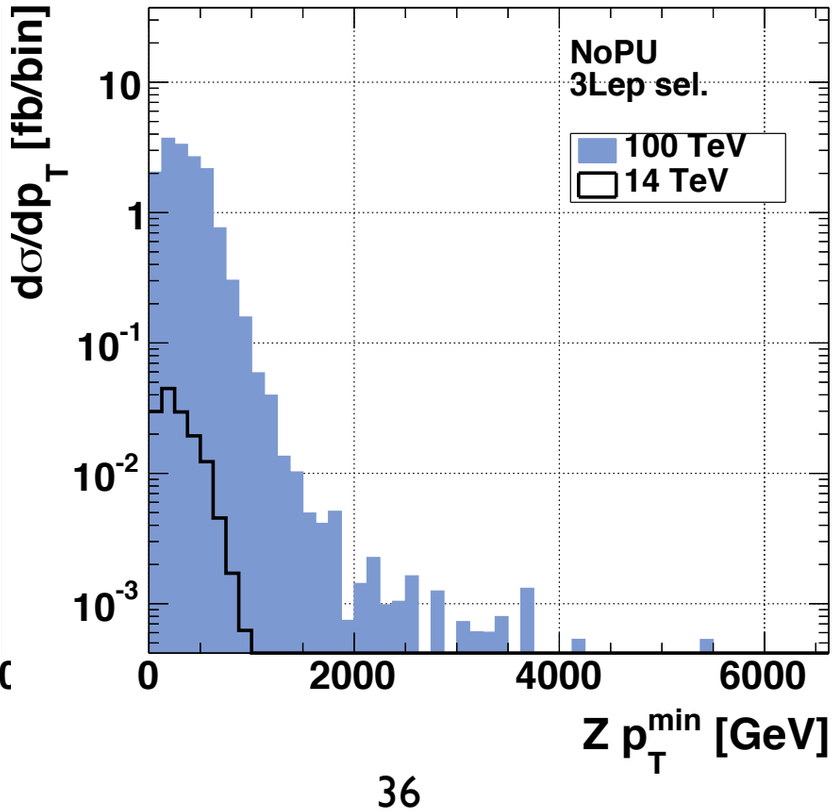
1 ab^{-1}, $\sqrt{s}$=100TeV

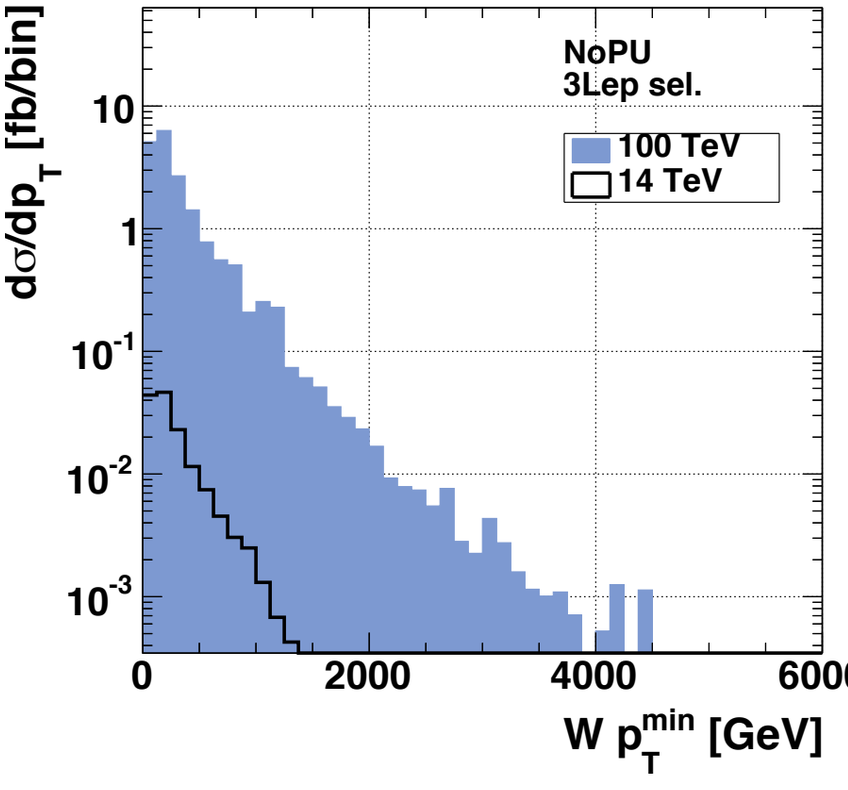
- 100 evts w/ MH_T=2TeV











Summary

- We **simulated an array of SM processes** at $\sqrt{s}$=14 and 100 TeV spanning 6 orders of magnitude in cross section.
  - These samples are (can be made) available for general use — please contact me if interested.

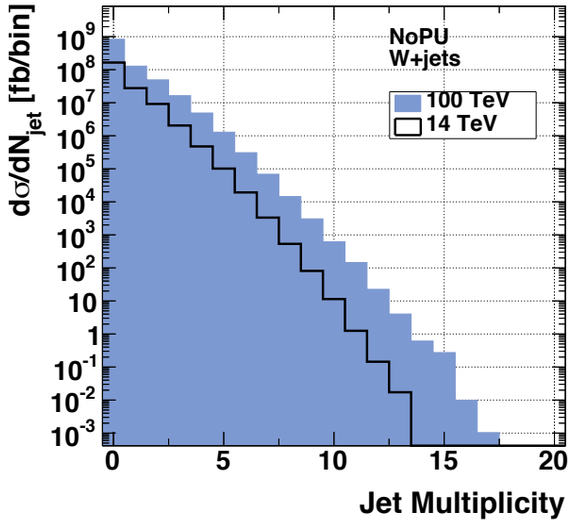
- Based on these samples, we **compare effective cross sections** as functions of several variables at 14 TeV and 100 TeV for many of these processes.

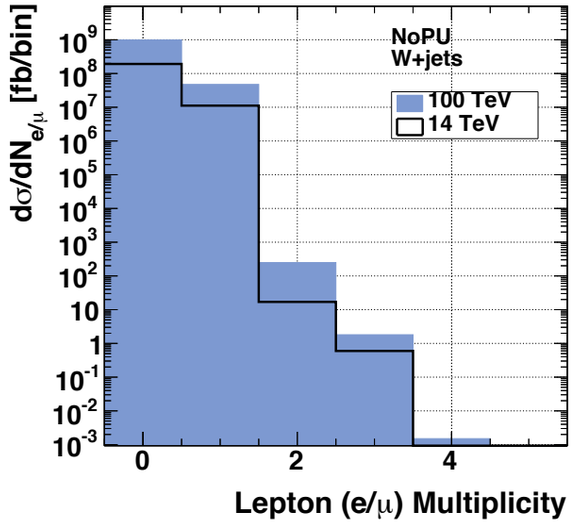
- We hope this study will serve as
  - a **reference for signal studies** presented in later sessions.
  - a **starting point for future discussions**.

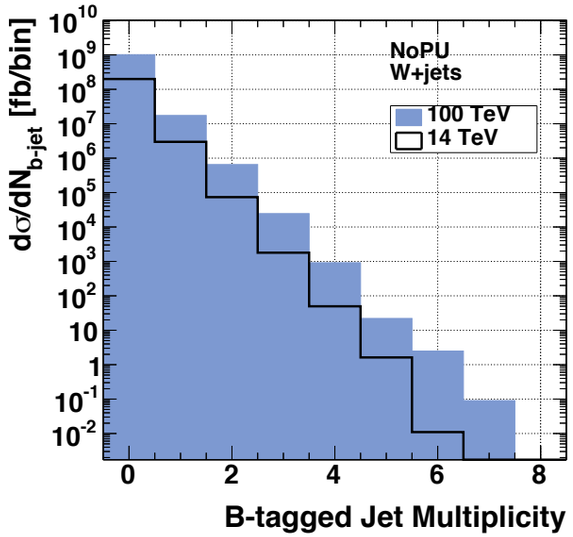
Appendix

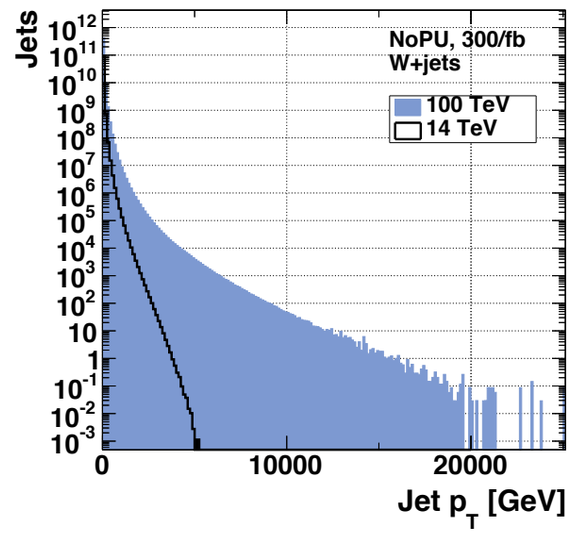
- Comparisons of N_{jet}, N_{lepton}, N_{b-jet}, Jet p_T, Lepton p_T, B-jet p_T, H_T, MH_T for all processes.

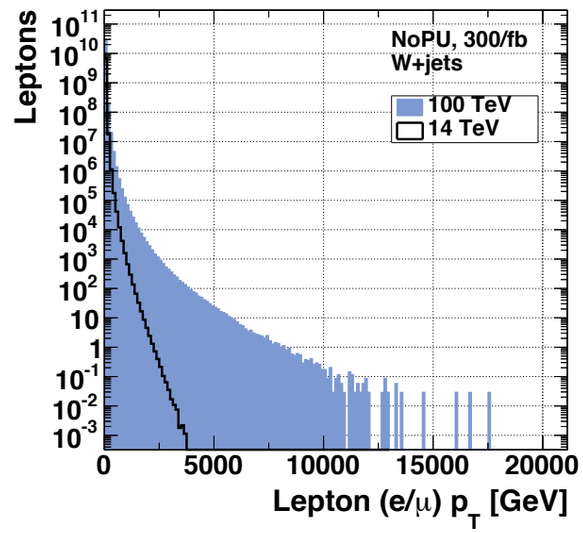
W+jets

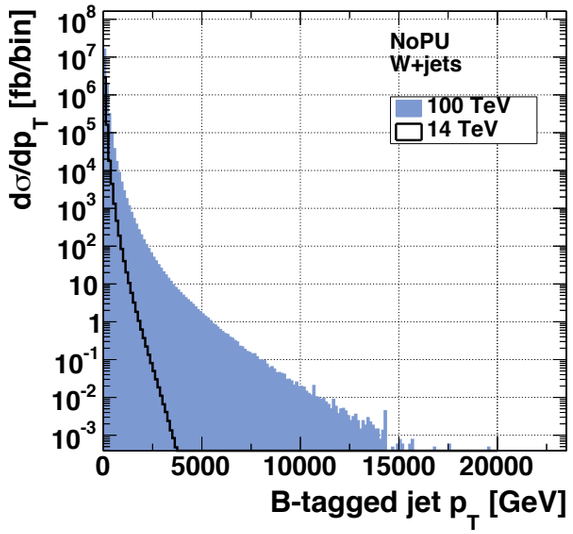

NoPU
W+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

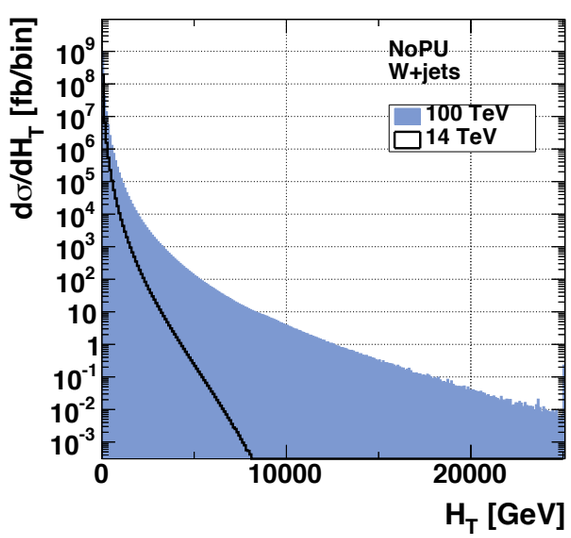

NoPU
W+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

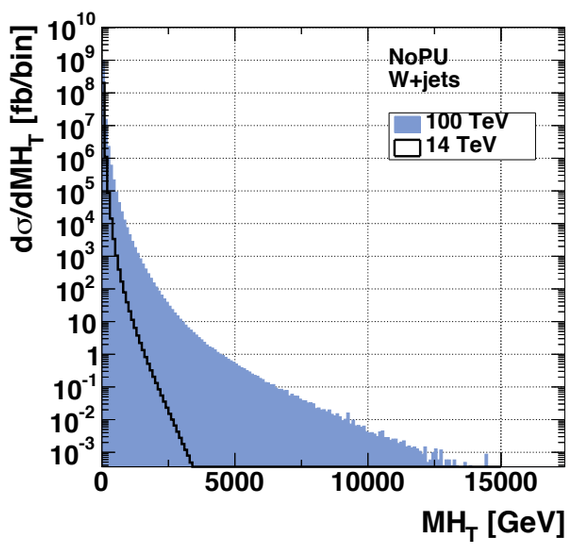

NoPU
W+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
W+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

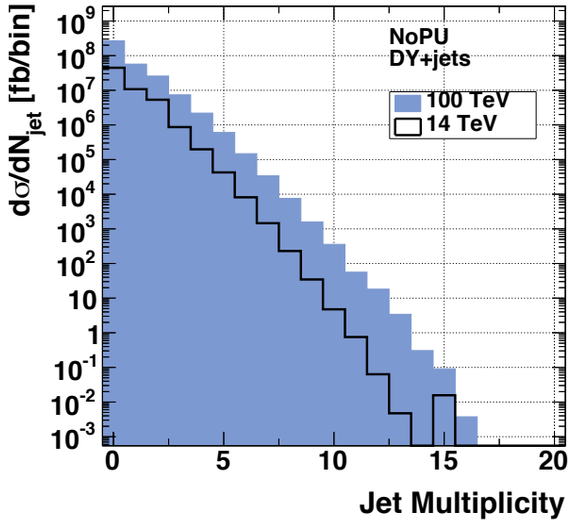

NoPU, 300/fb
W+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

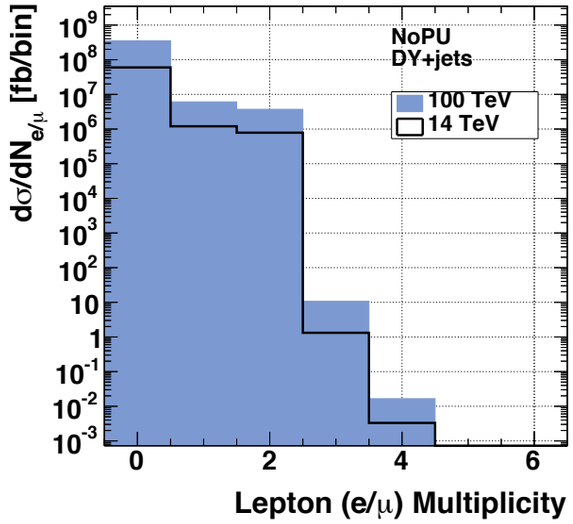

NoPU
W+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

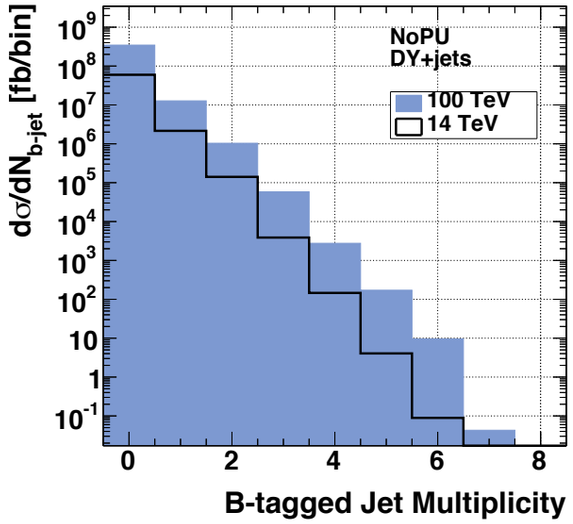

NoPU
W+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

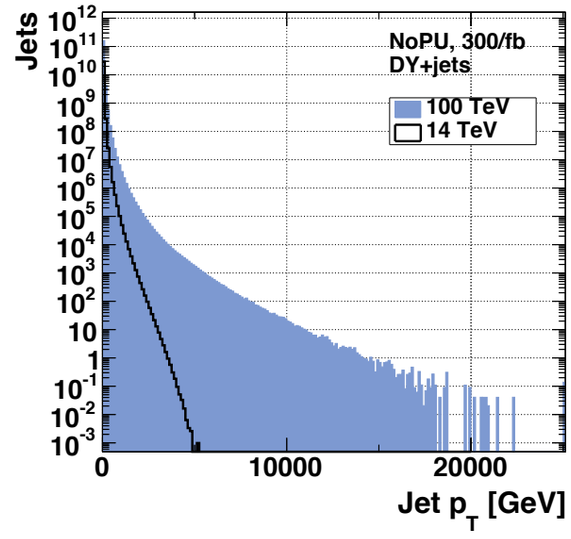

NoPU
W+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

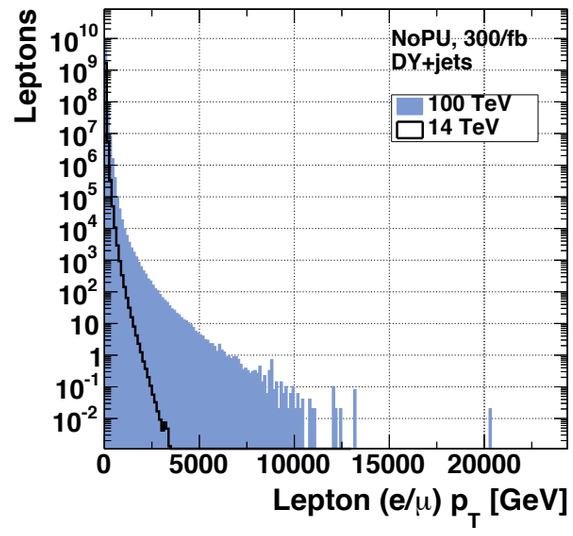
DY+jets

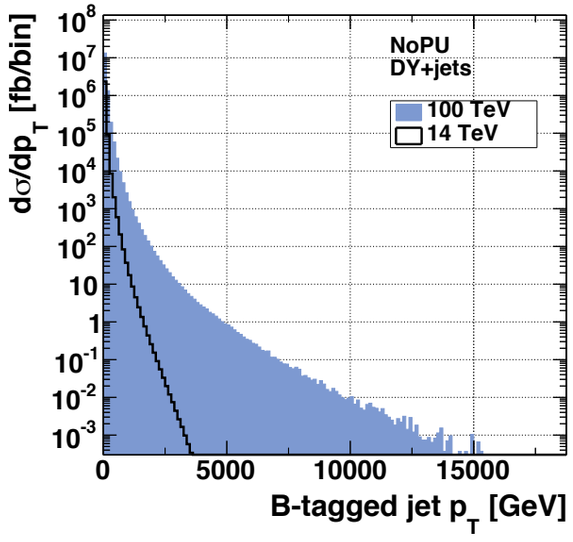

NoPU
DY+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

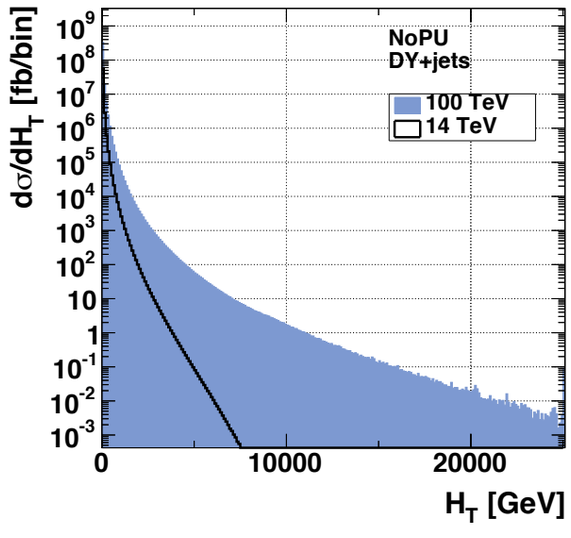

NoPU
DY+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

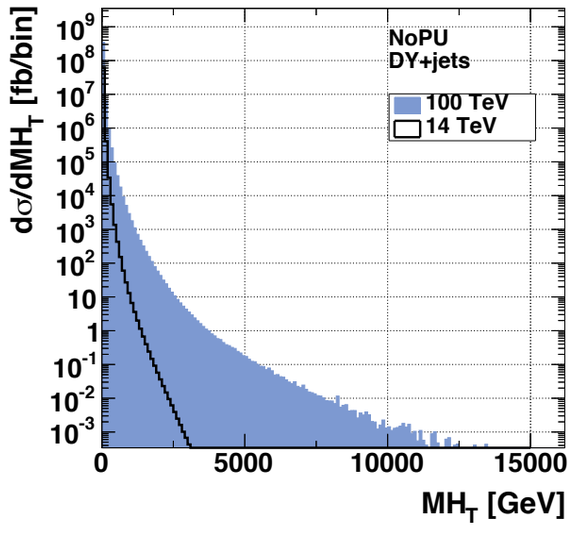

NoPU
DY+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
DY+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

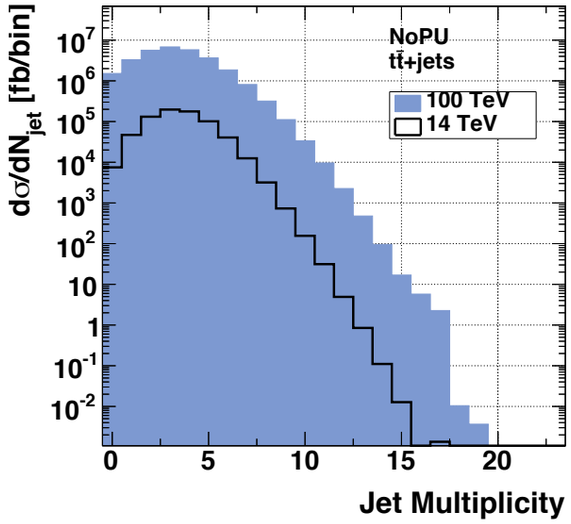

NoPU, 300/fb
DY+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

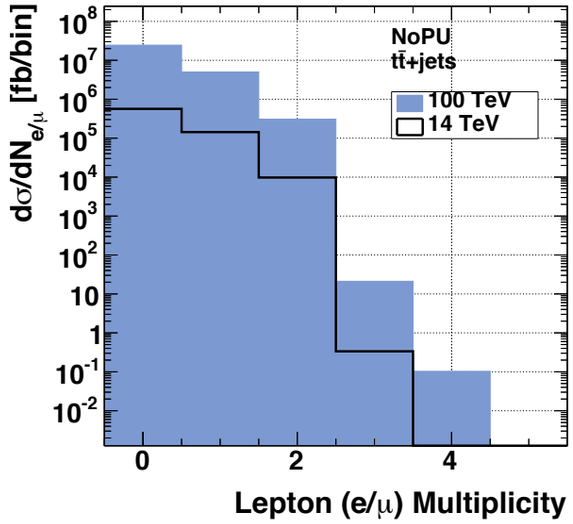

NoPU
DY+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

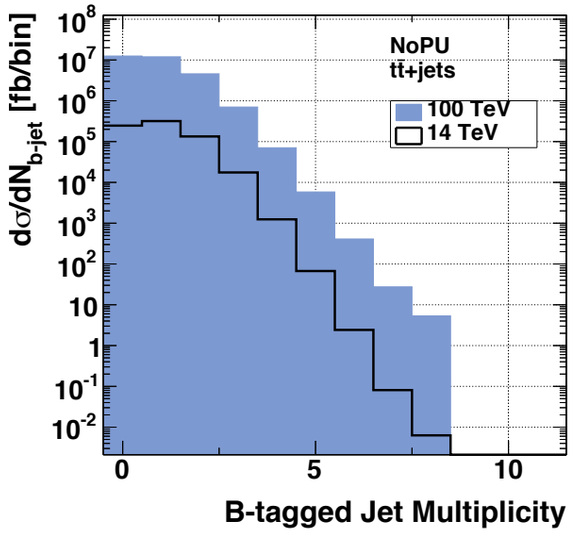

NoPU
DY+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

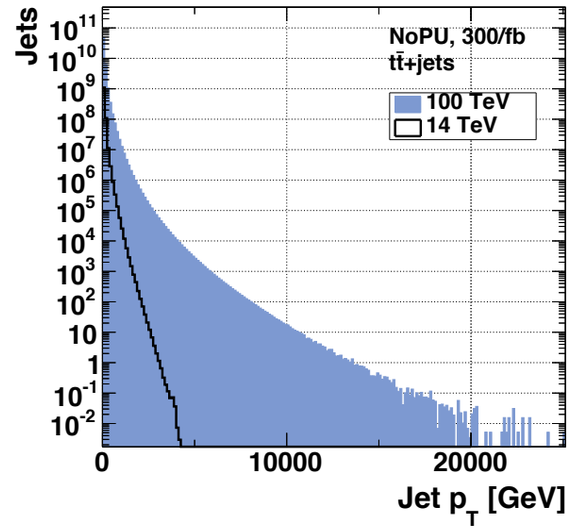

NoPU
DY+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

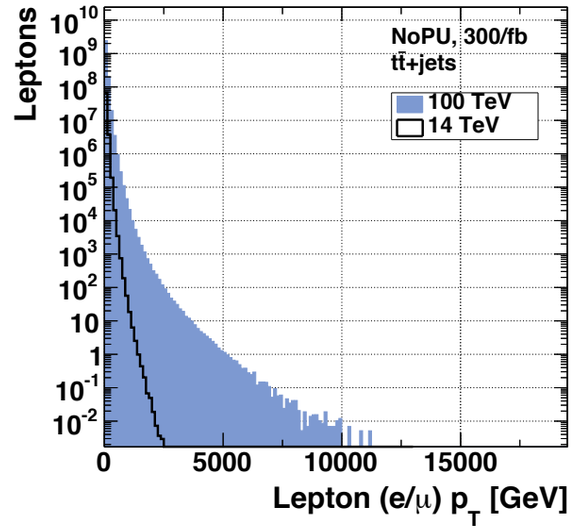
tt+jets

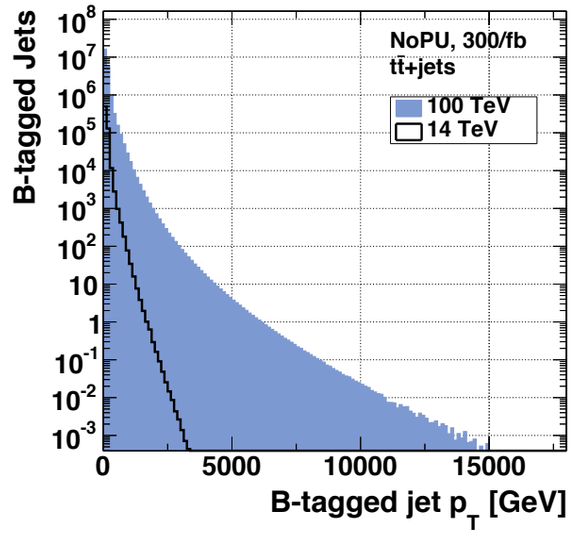

NoPU
tt̄+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

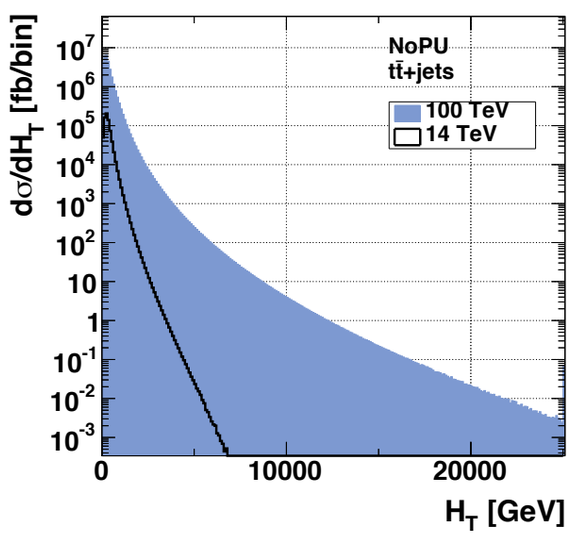

NoPU
tt̄+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

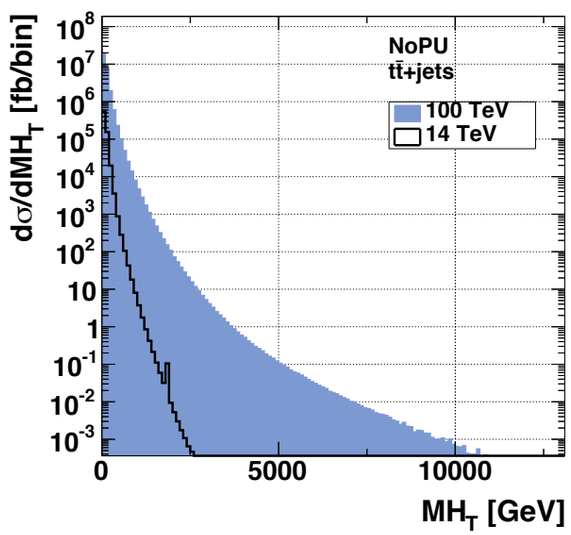

NoPU
tt̄+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
tt̄+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

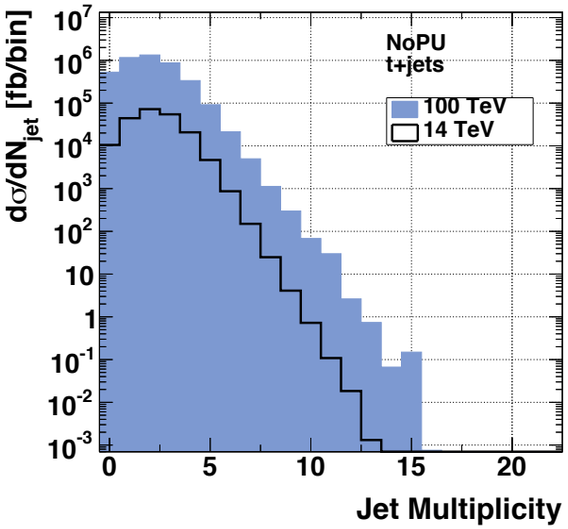

NoPU, 300/fb
tt̄+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

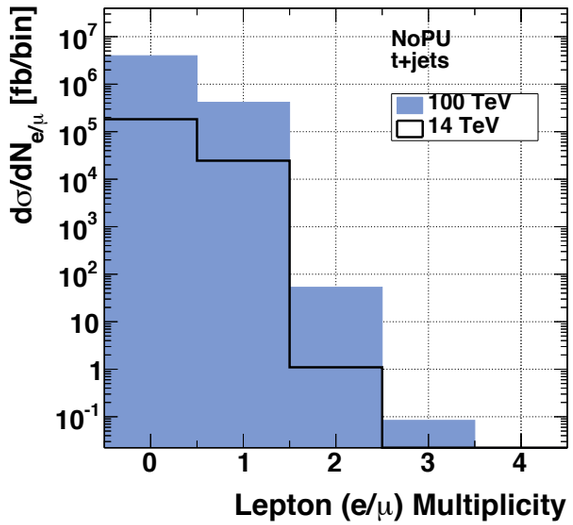

NoPU, 300/fb
tt̄+jets
100 TeV
14 TeV
B-tagged Jets
B-tagged jet p_T [GeV]

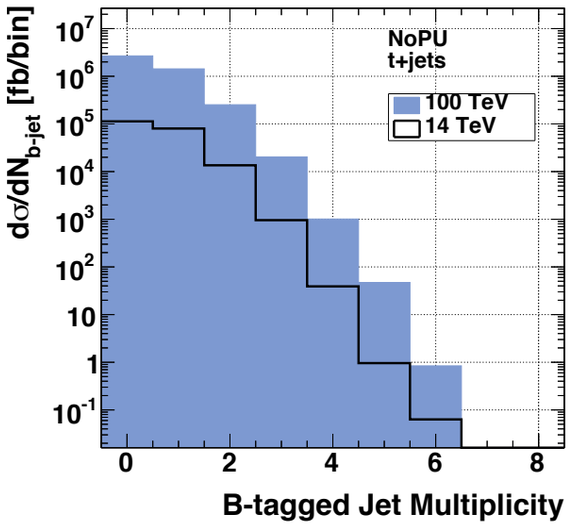

NoPU
tt̄+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

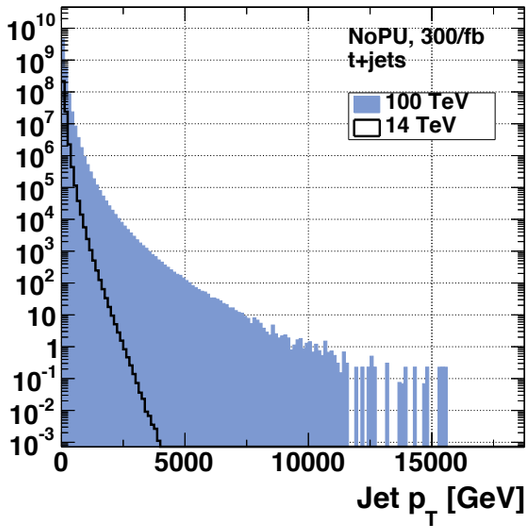

NoPU
tt̄+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

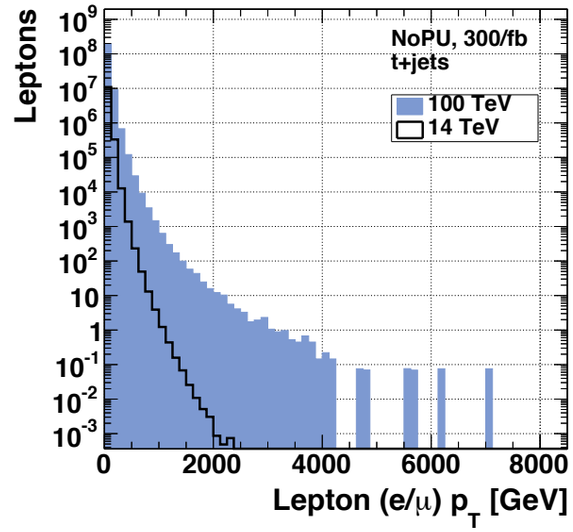
t+jets

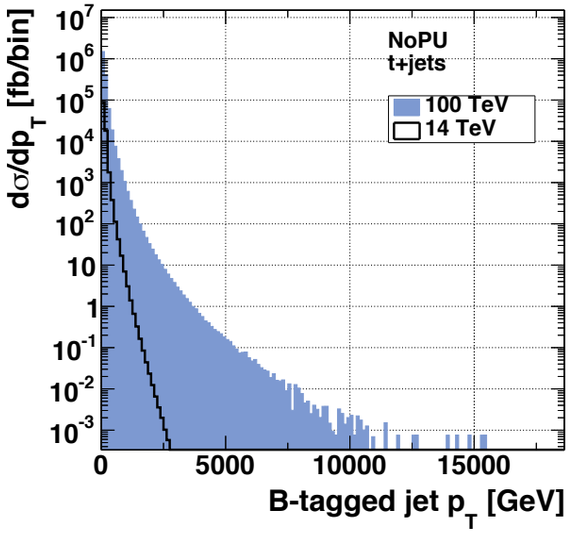

NoPU
t+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

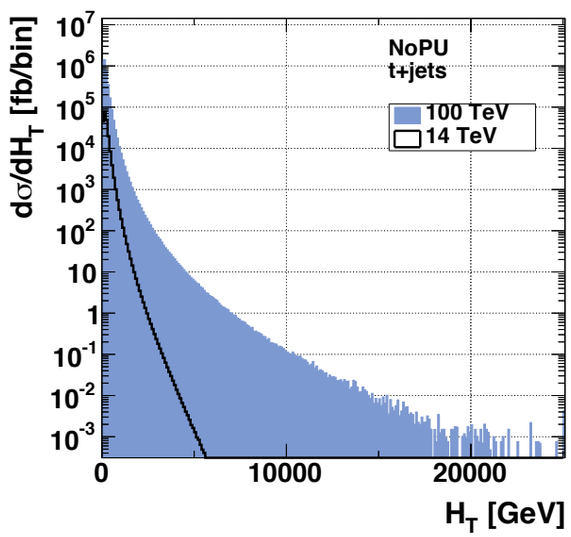

NoPU
t+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

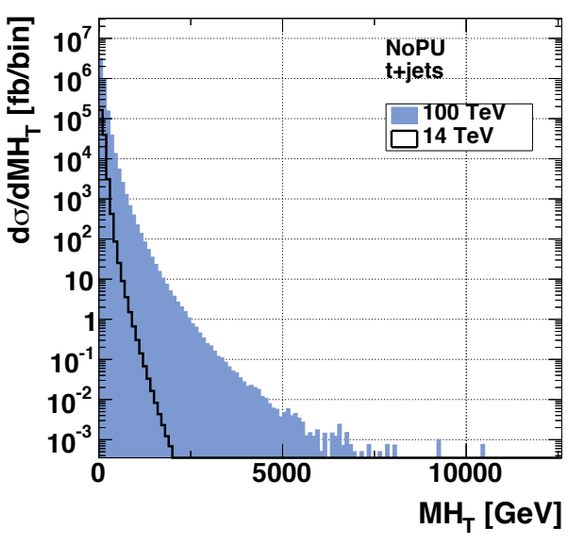

NoPU
t+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
t+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

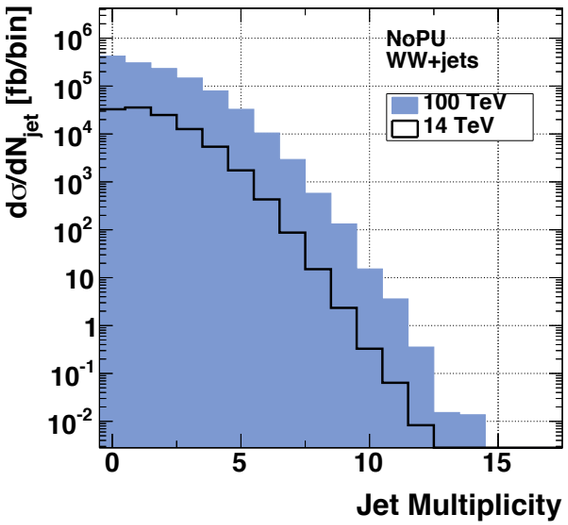

NoPU, 300/fb
t+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

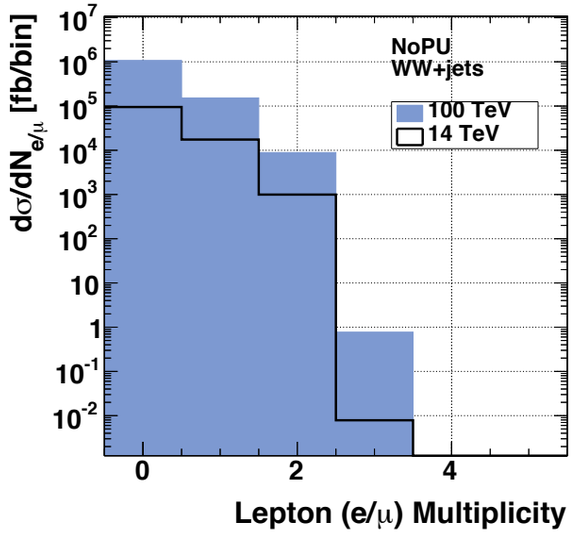

NoPU
t+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

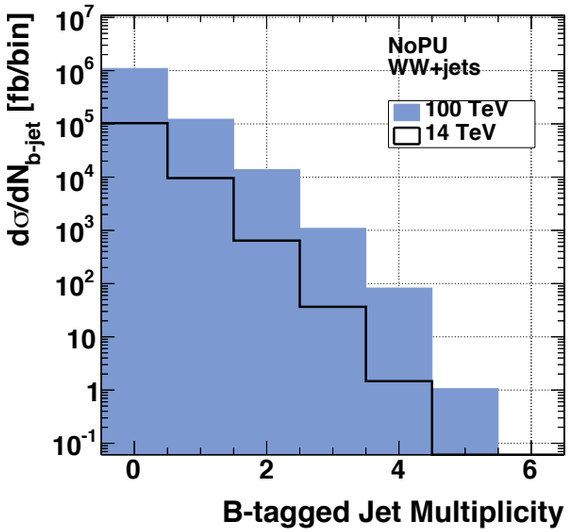

NoPU
t+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

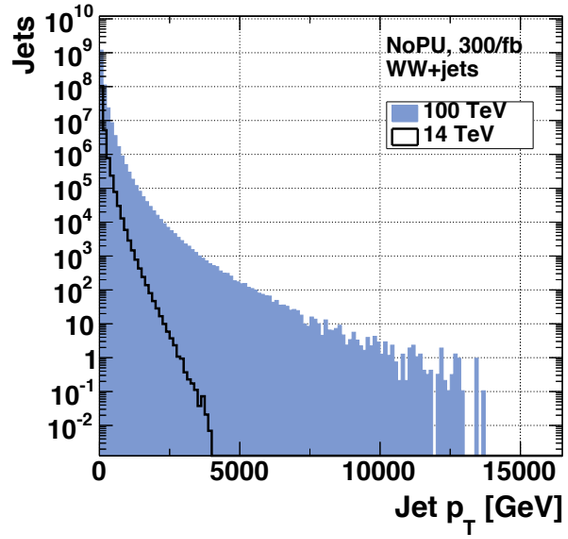

NoPU
t+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

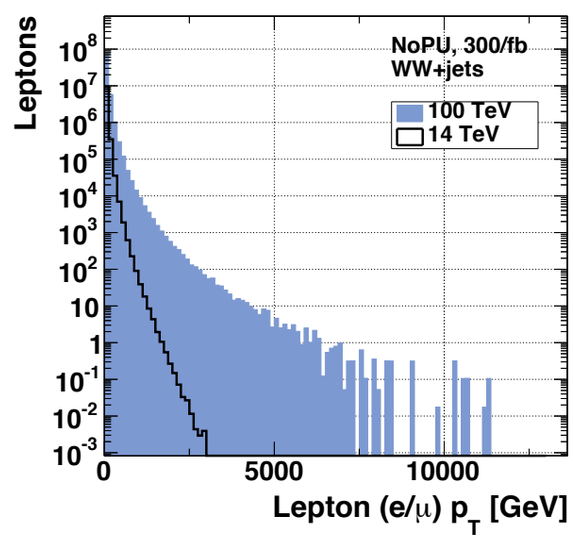
WW

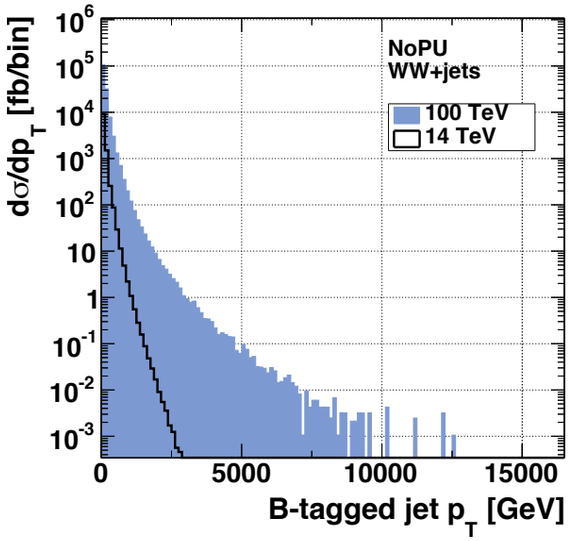

NoPU
WW+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

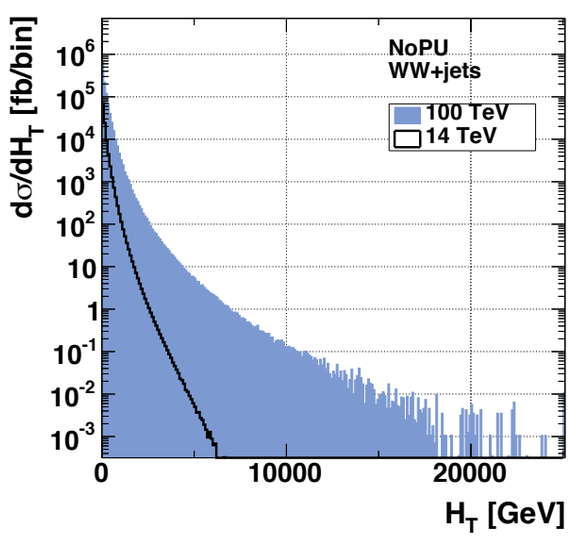

NoPU
WW+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

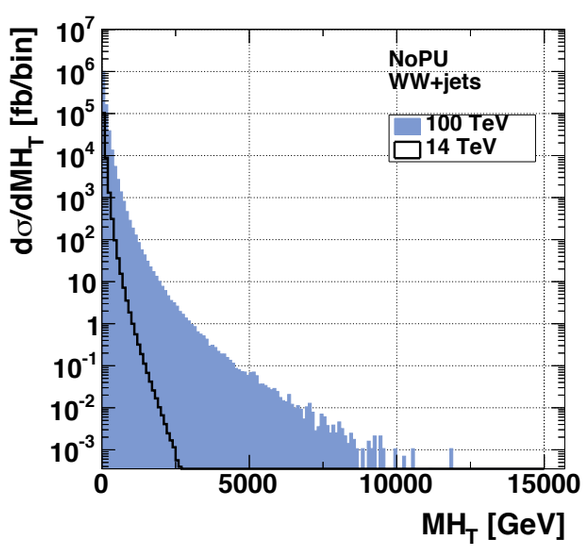

NoPU
WW+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
WW+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

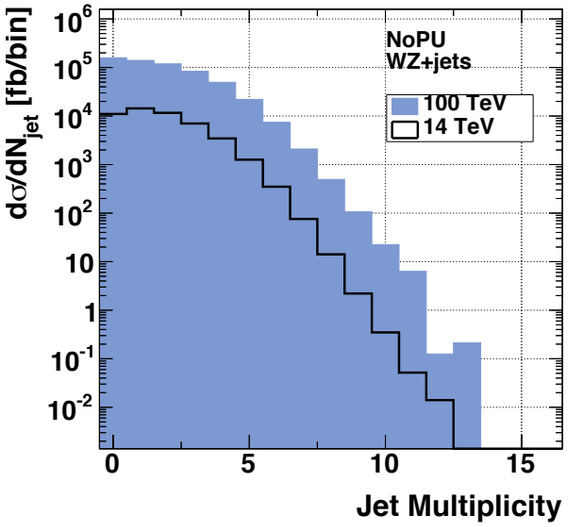

NoPU, 300/fb
WW+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

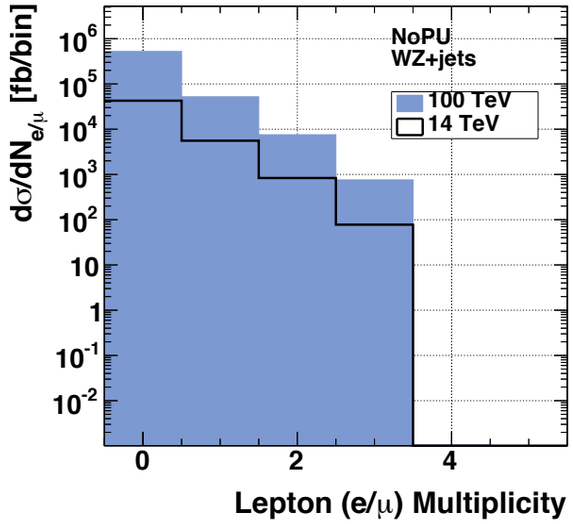

NoPU
WW+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

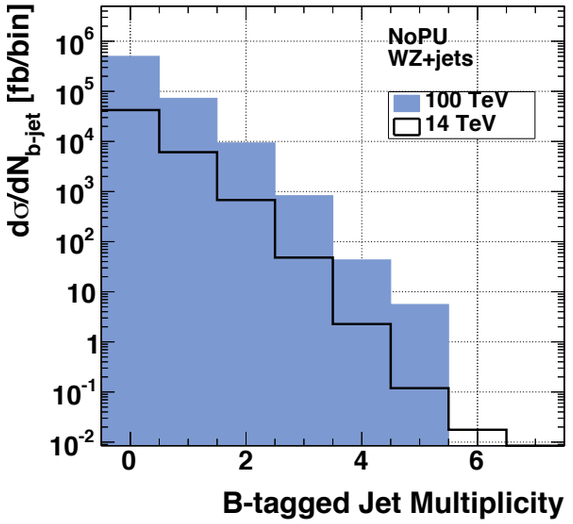

NoPU
WW+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

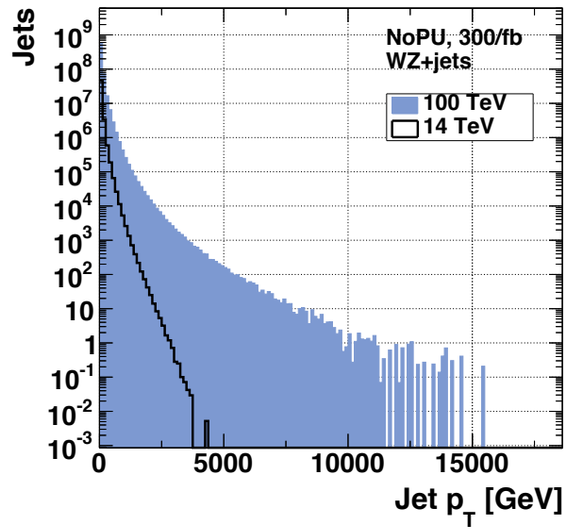

NoPU
WW+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

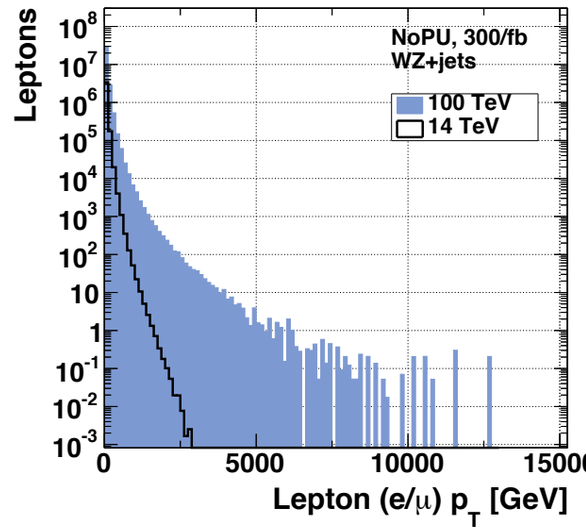
WZ

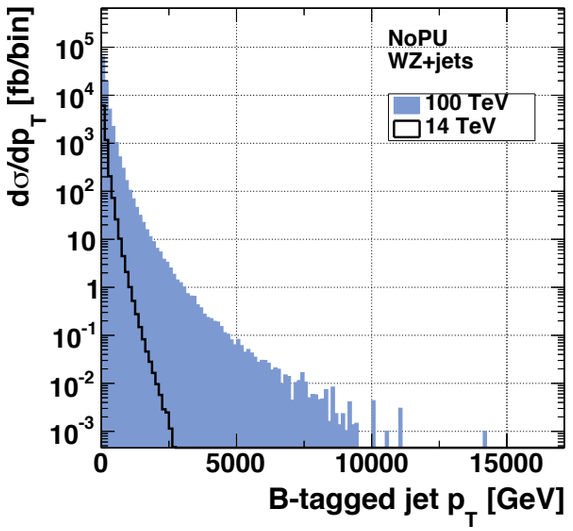

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

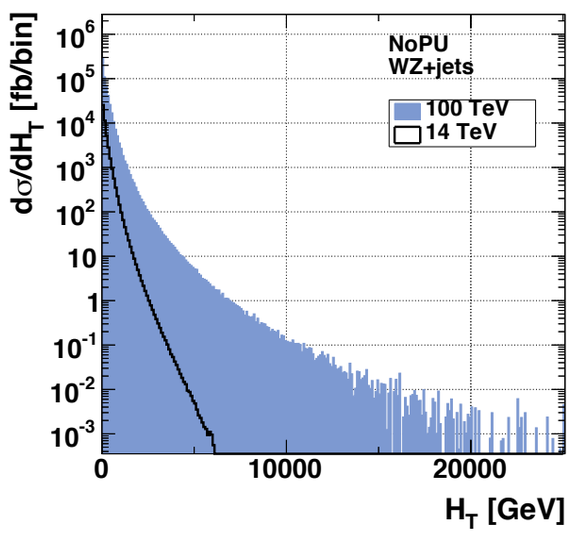

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

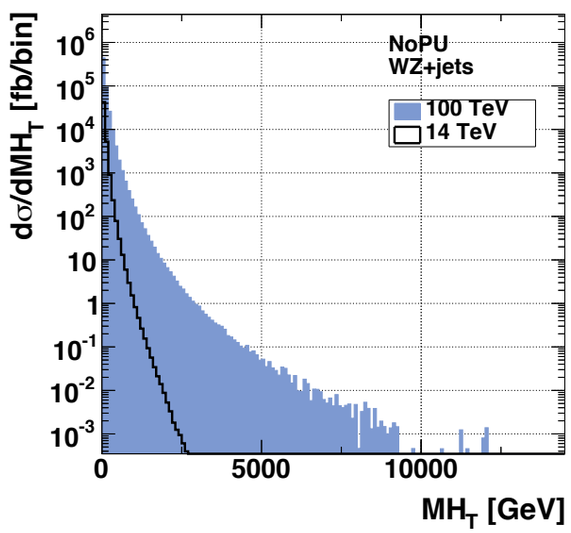

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
WZ+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

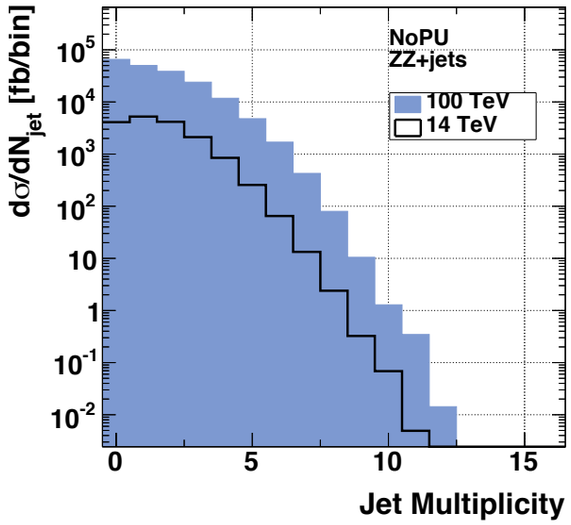

NoPU, 300/fb
WZ+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

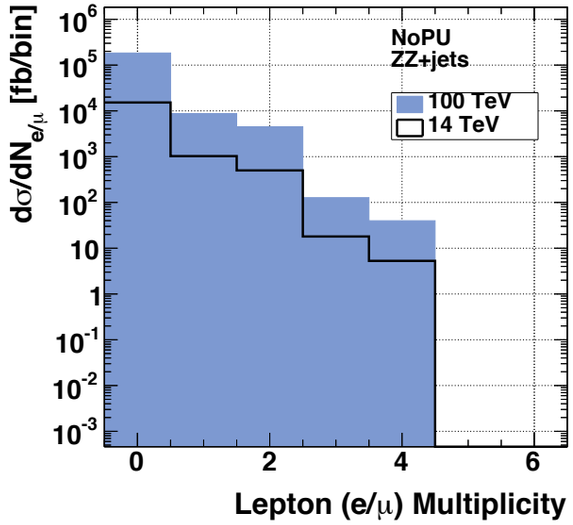

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

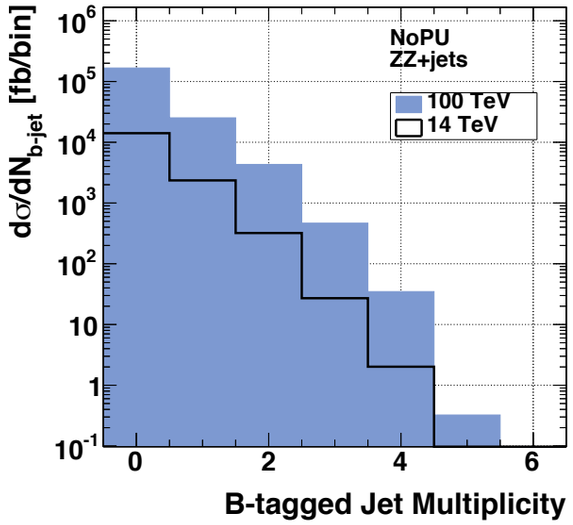

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

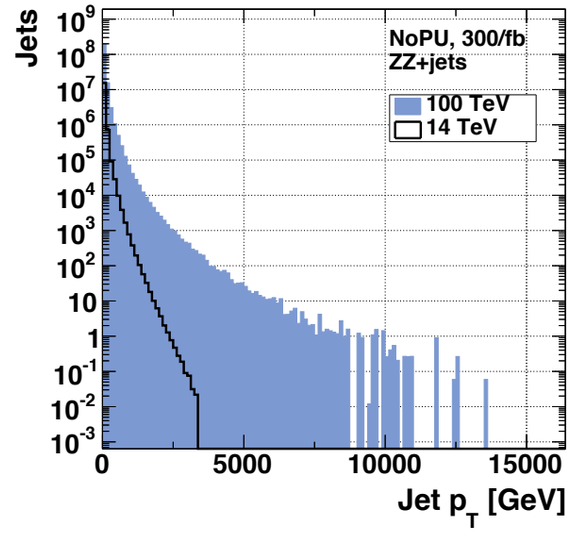

NoPU
WZ+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

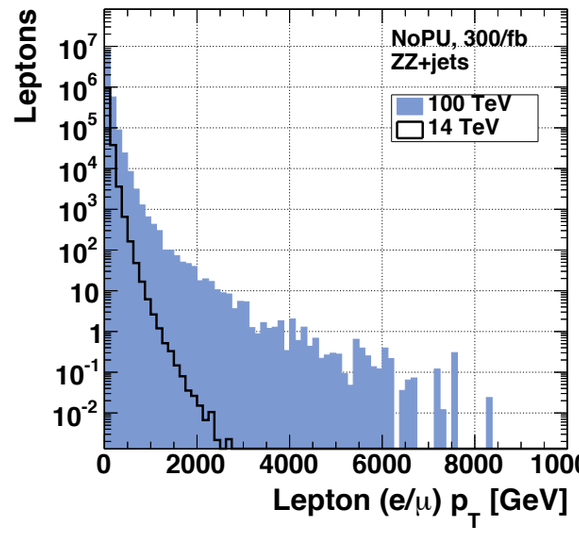
ZZ

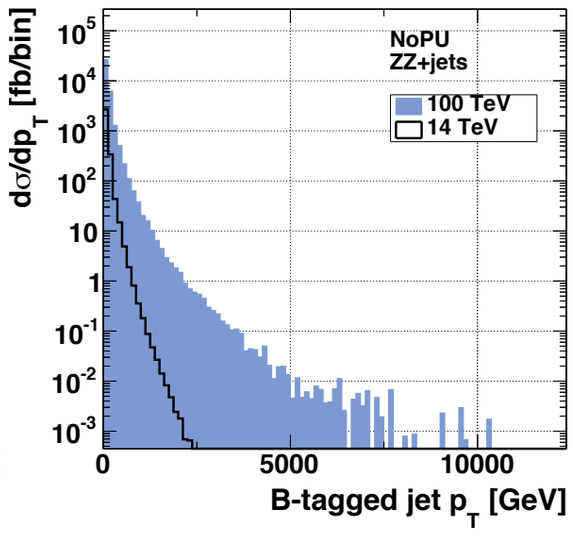

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

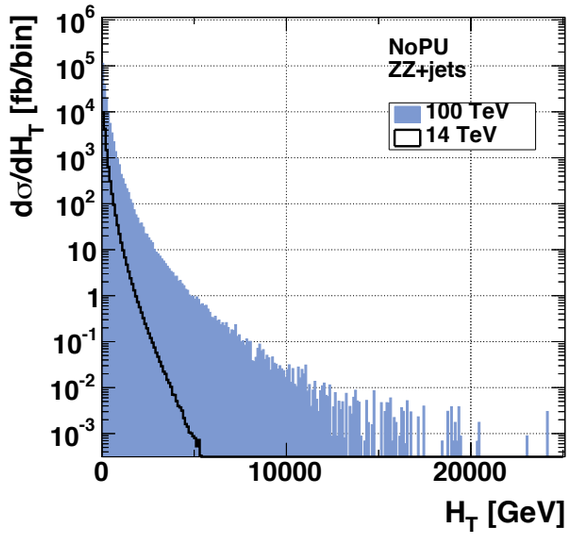

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

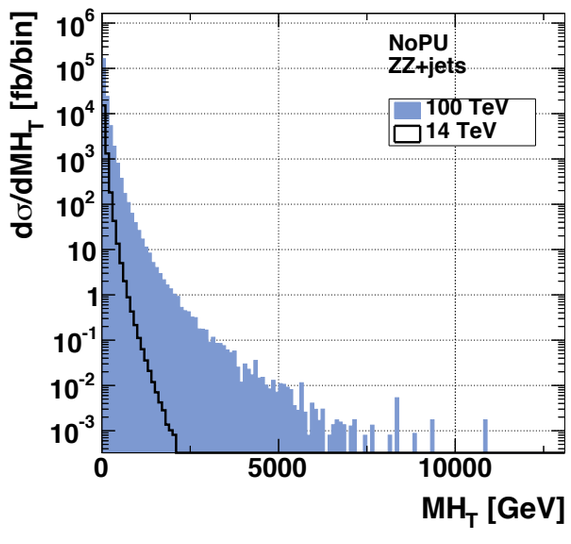

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
ZZ+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

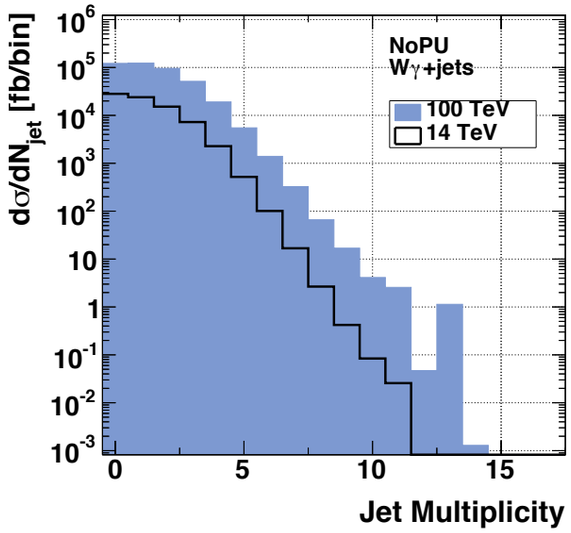

NoPU, 300/fb
ZZ+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

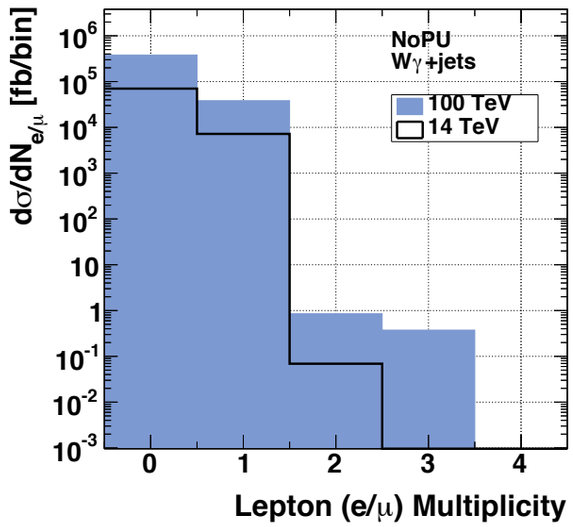

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

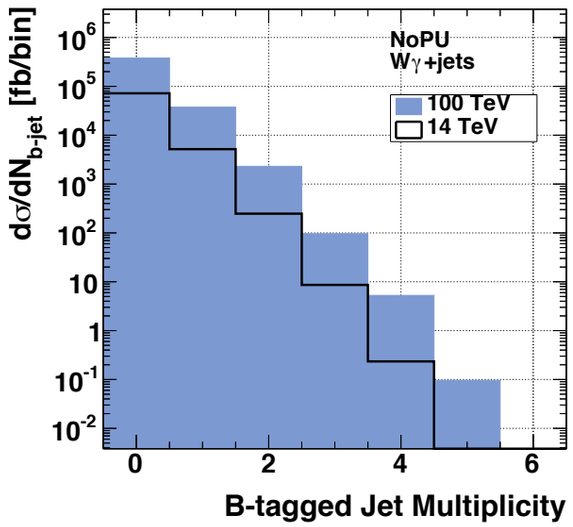

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

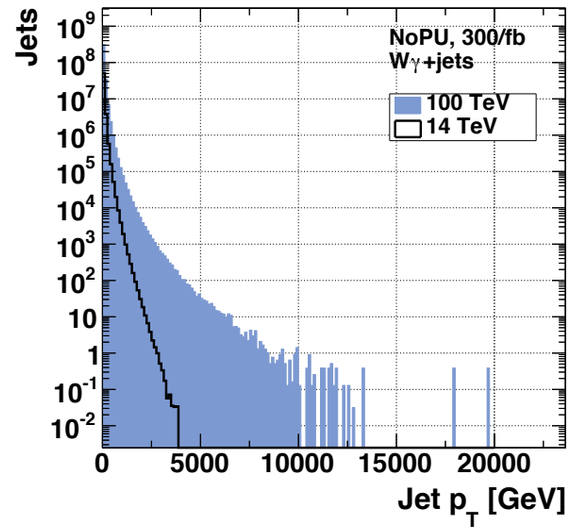

NoPU
ZZ+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

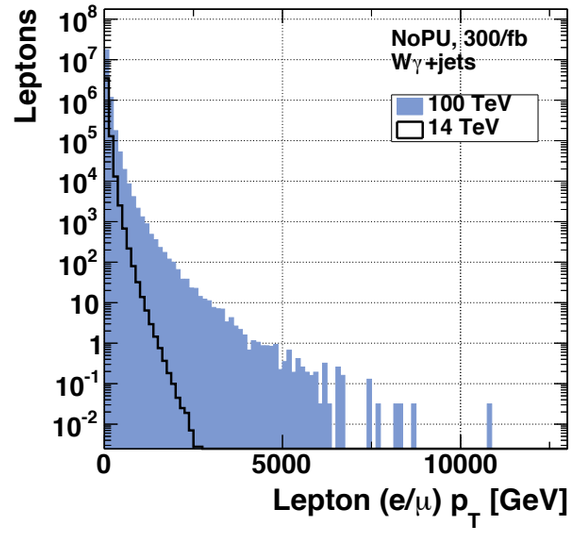
Wγ

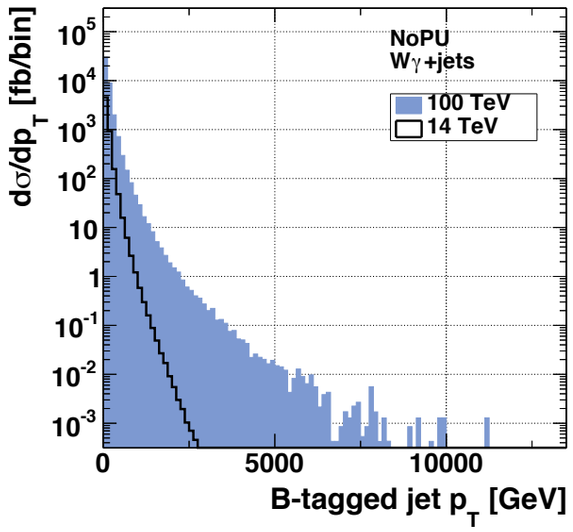

NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

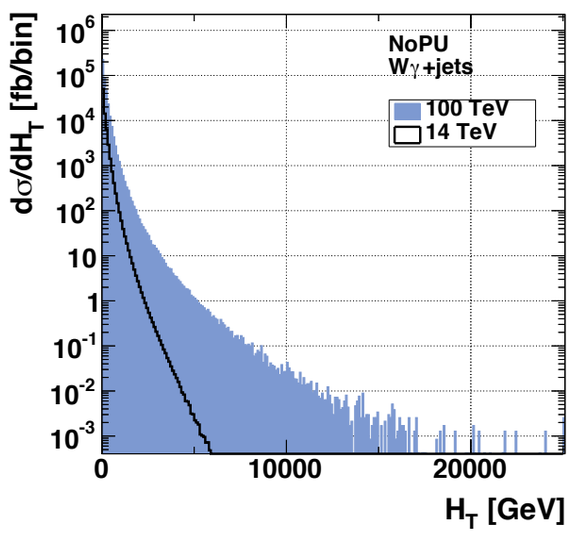

NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

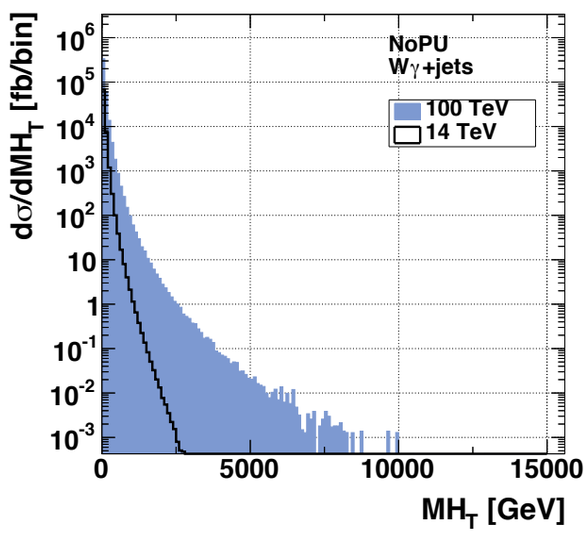

NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
Wγ+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

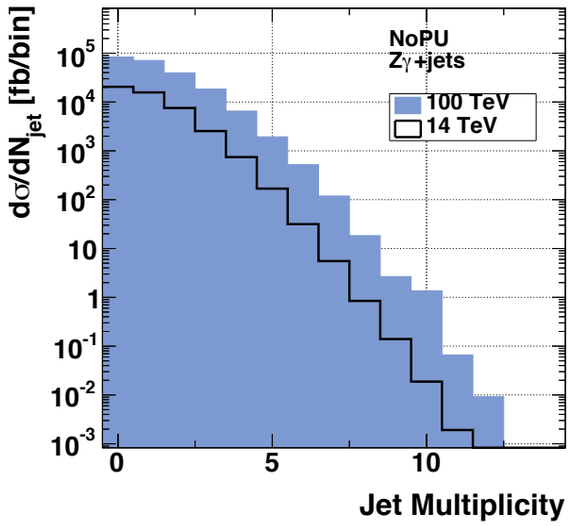

NoPU, 300/fb
Wγ+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]


NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]


NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]


NoPU
Wγ+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

Zγ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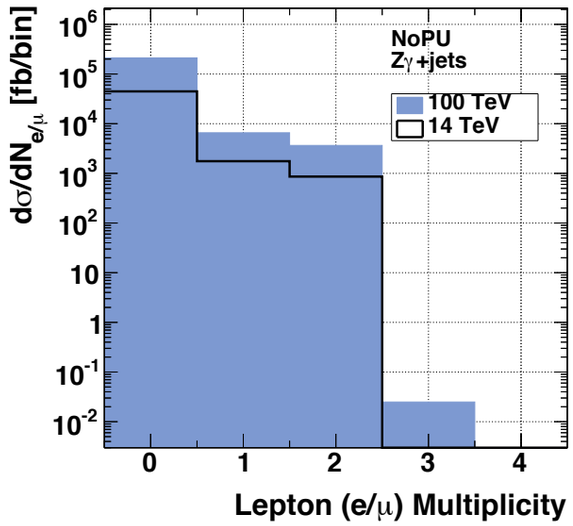
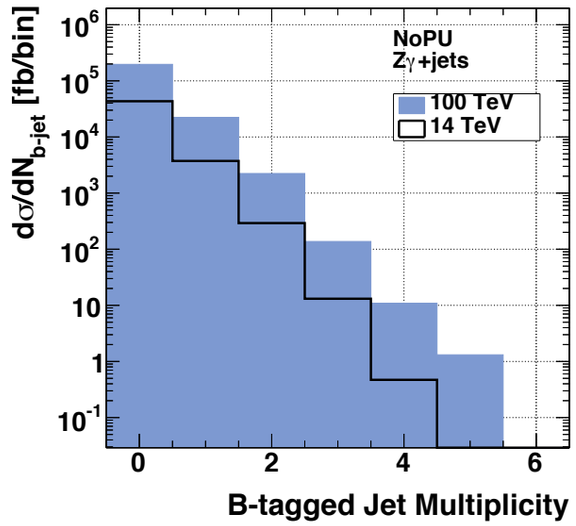
Zγ+jets
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity


NoPU
Zγ+jets
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity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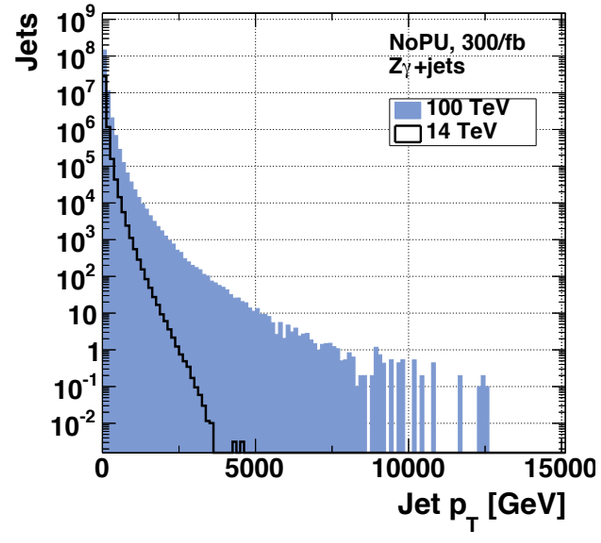
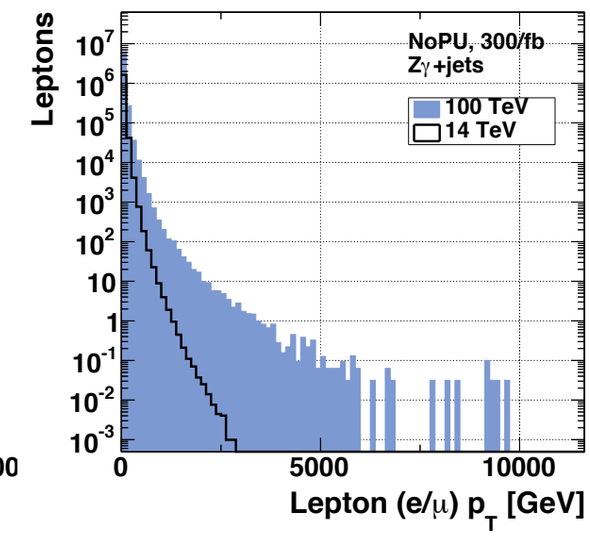
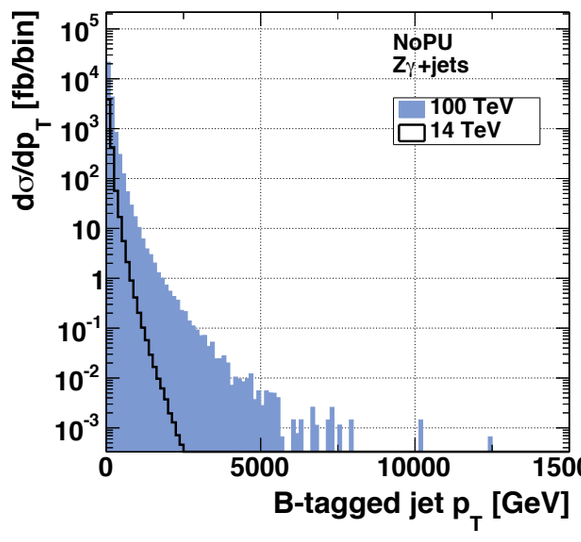
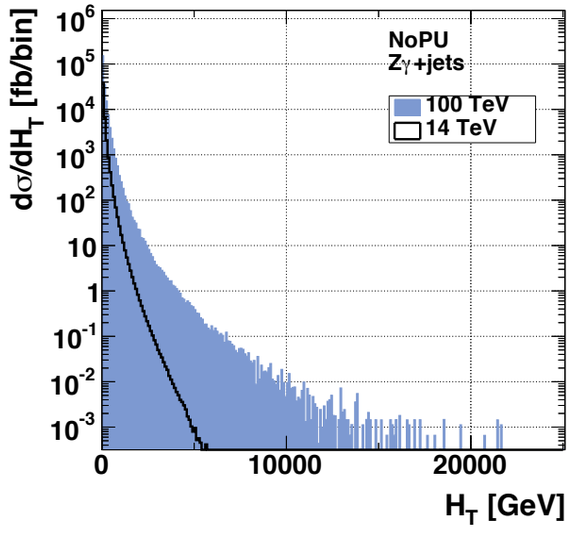
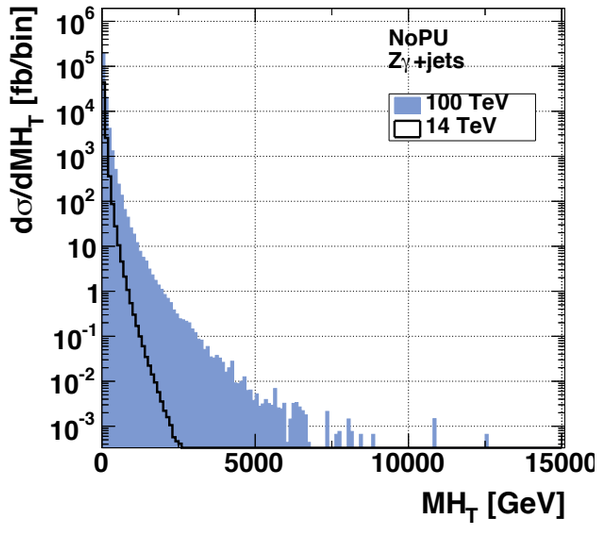
Zγ+jets
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
Zγ+jets
100 TeV
14 TeV
Jets
Jet p_T [GeV]

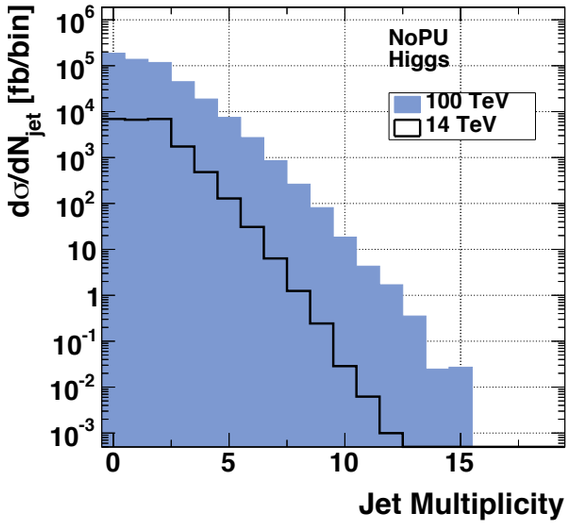

NoPU, 300/fb
Zγ+jets
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

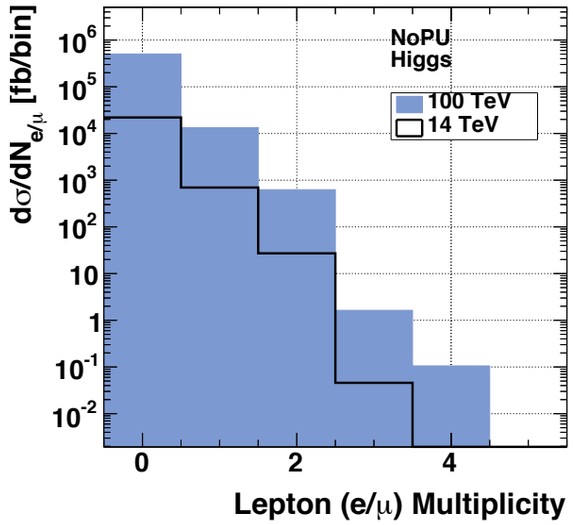

NoPU
Zγ+jets
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

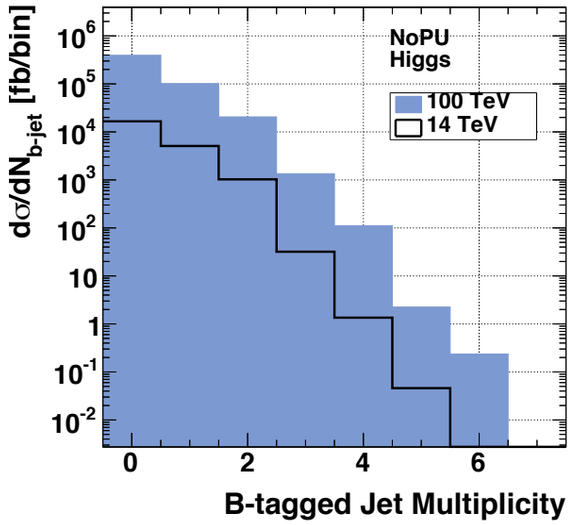

NoPU
Zγ+jets
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

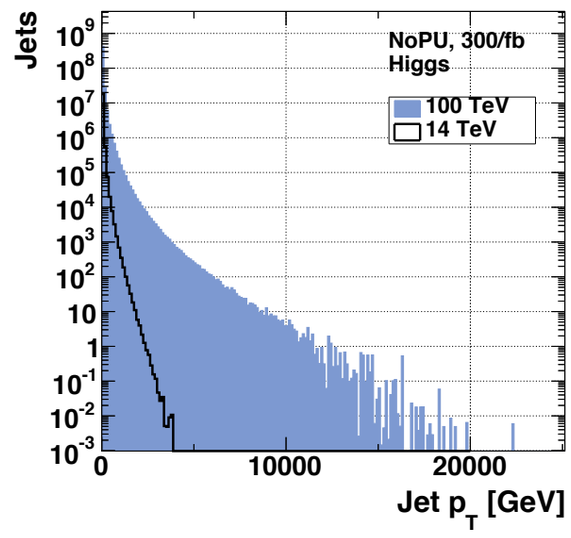

NoPU
Zγ+jets
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

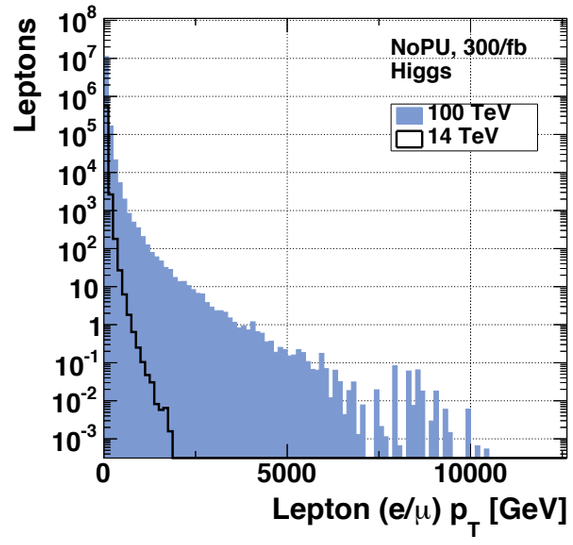
ggH

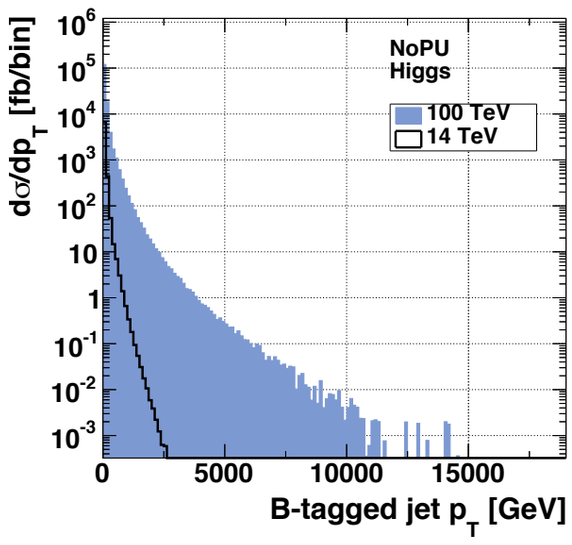

NoPU
Higgs
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

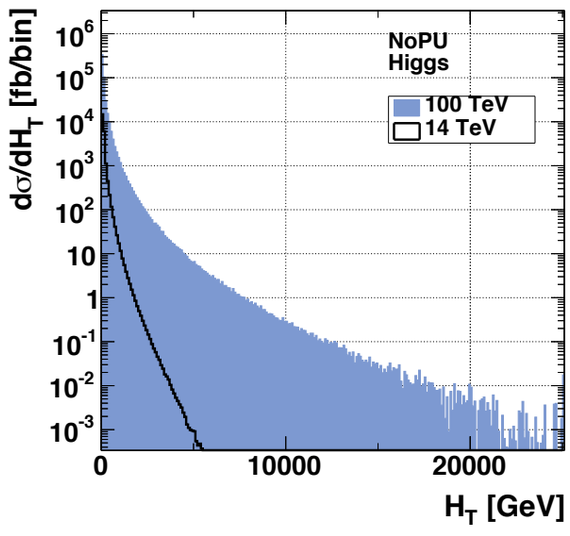

NoPU
Higgs
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

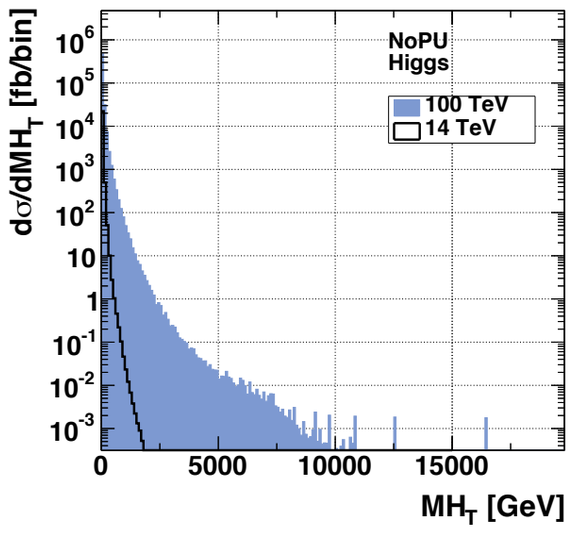

NoPU
Higgs
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
Higgs
100 TeV
14 TeV
Jets
Jet p_T [GeV]

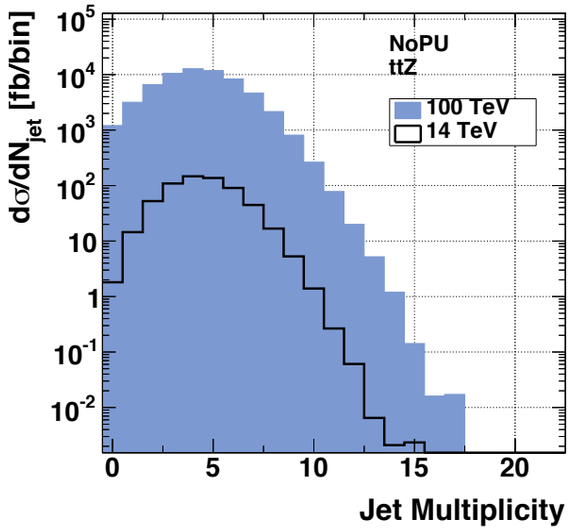

NoPU, 300/fb
Higgs
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

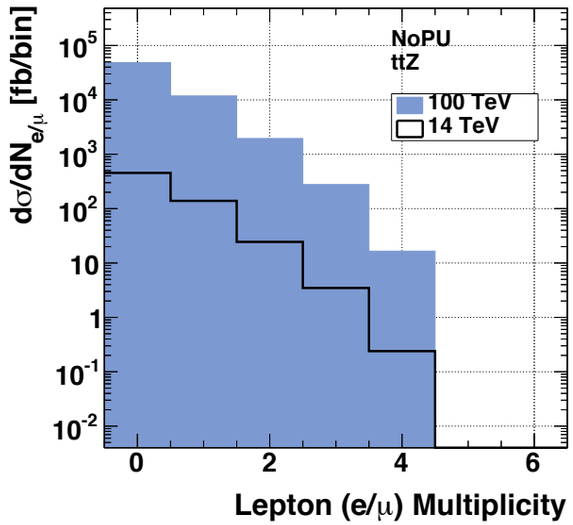

NoPU
Higgs
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

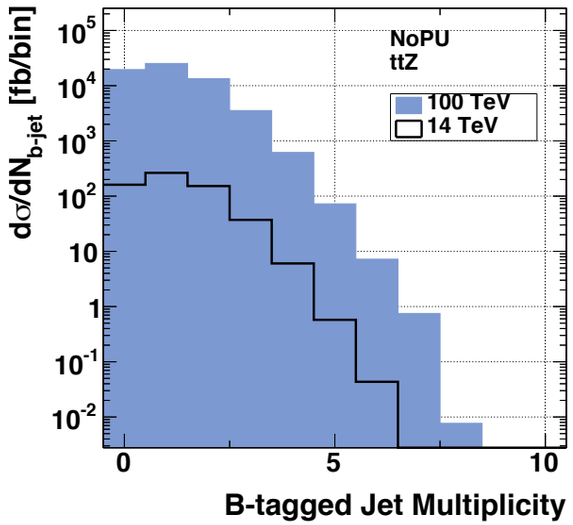

NoPU
Higgs
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

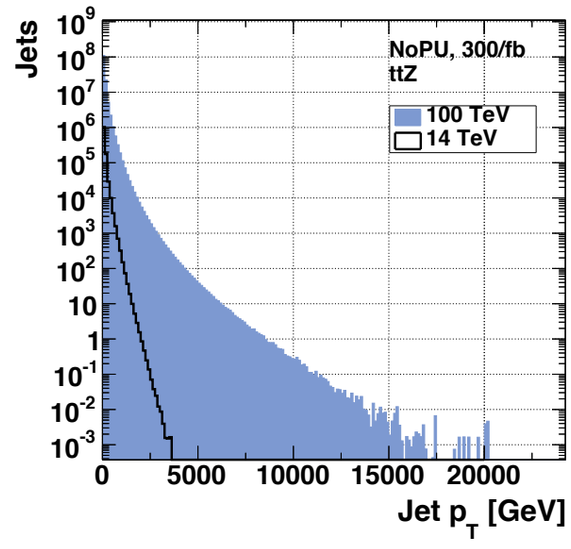

NoPU
Higgs
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

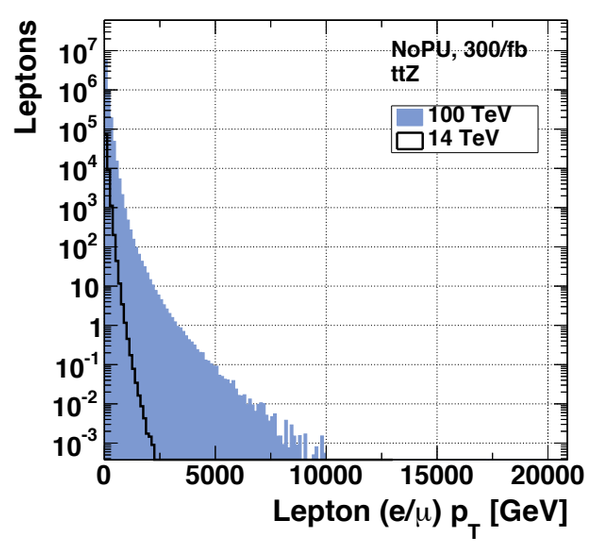
ttZ

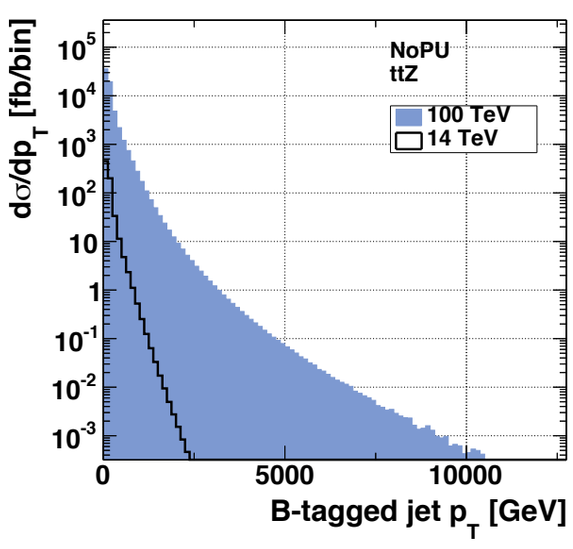

NoPU
ttZ
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

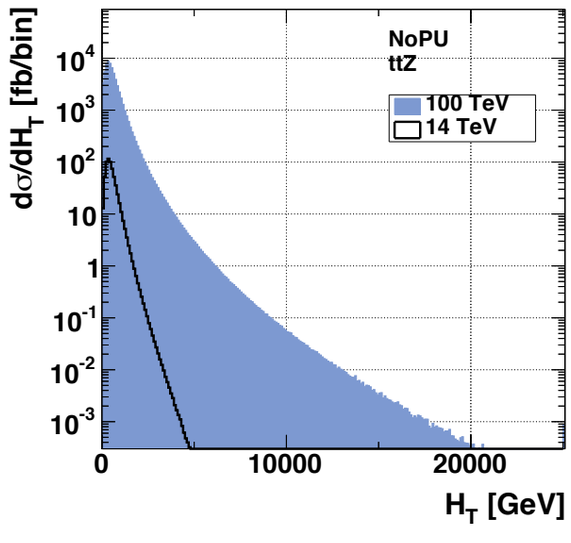

NoPU
ttZ
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

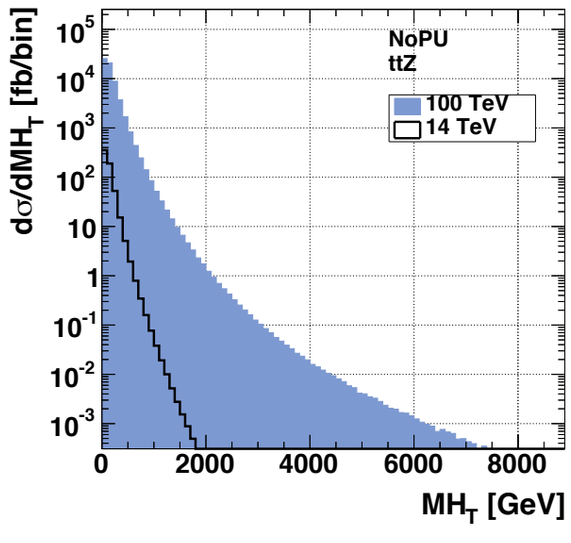

NoPU
ttZ
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
ttZ
100 TeV
14 TeV
Jets
Jet p_T [GeV]

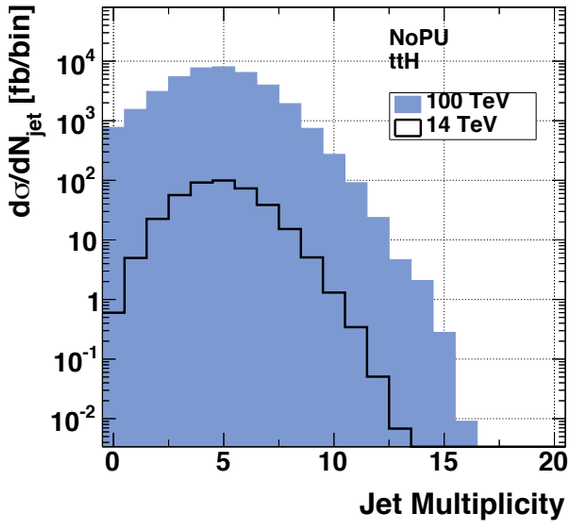

NoPU, 300/fb
ttZ
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

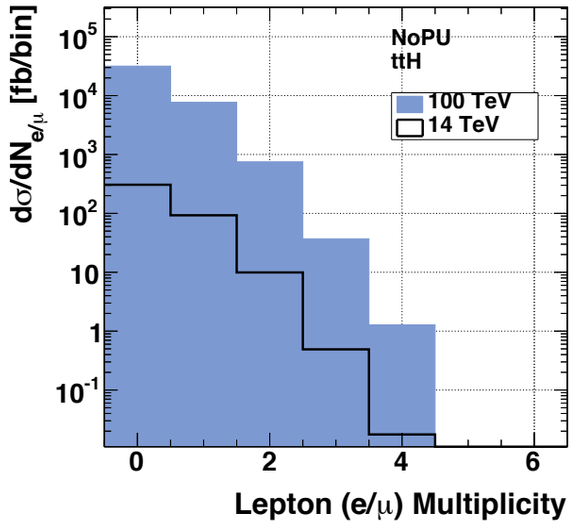

NoPU
ttZ
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

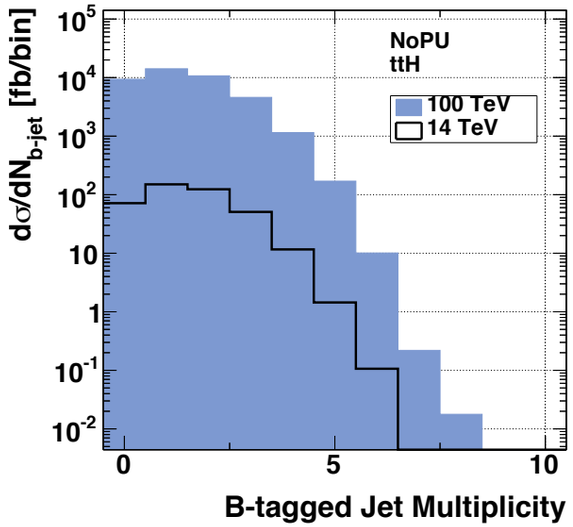

NoPU
ttZ
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

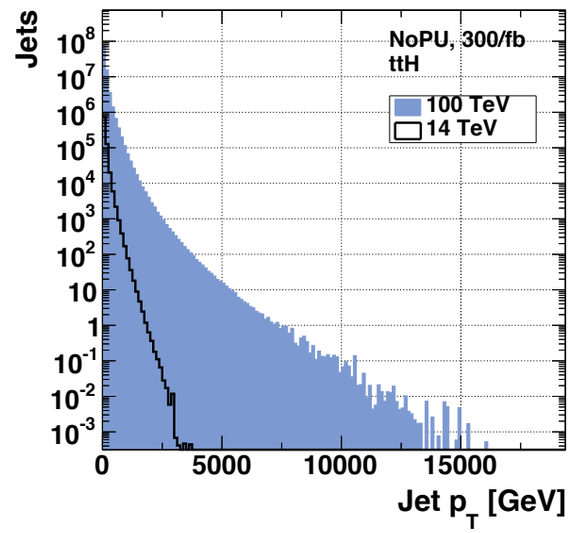

NoPU
ttZ
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

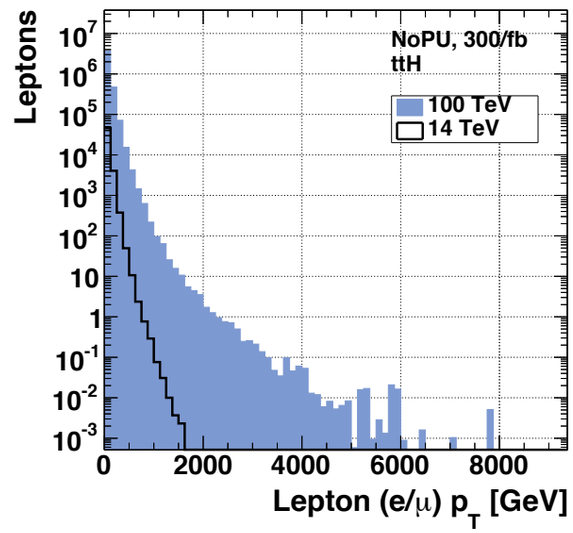
ttH

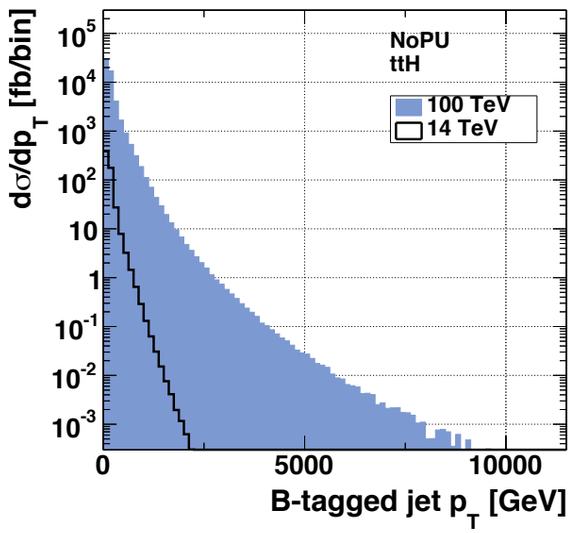

NoPU
ttH
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

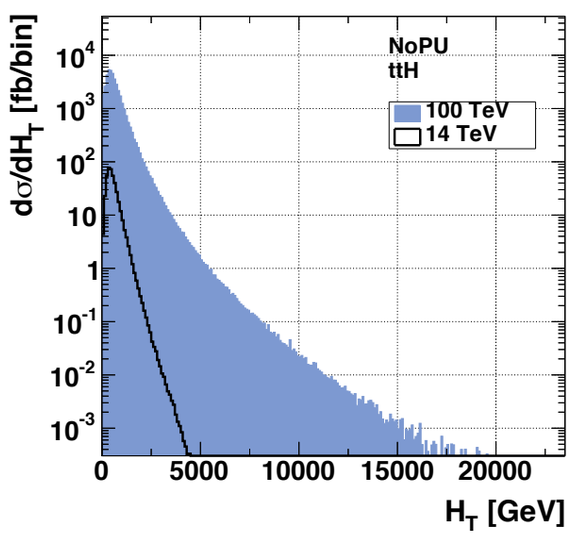

NoPU
ttH
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

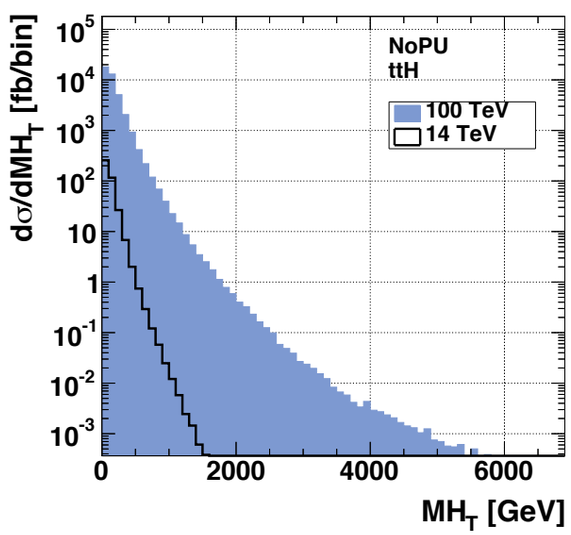

NoPU
ttH
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
ttH
100 TeV
14 TeV
Jets
Jet p_T [GeV]

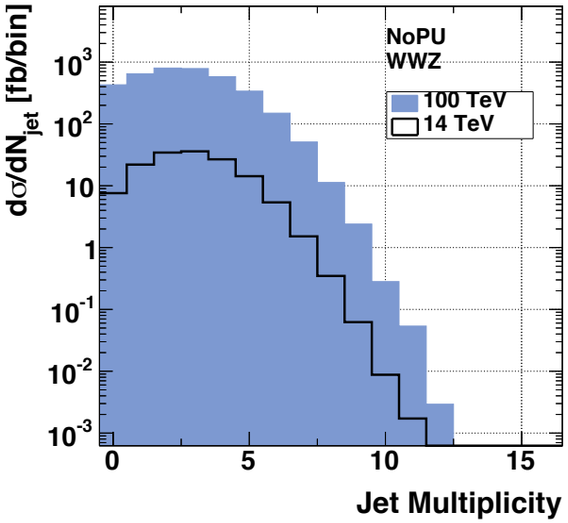

NoPU, 300/fb
ttH
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

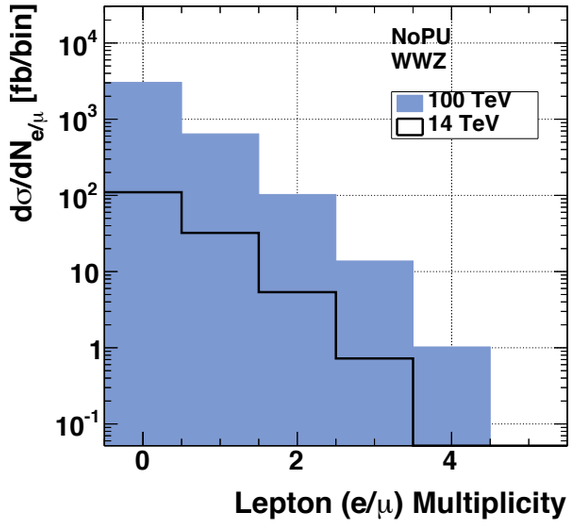

NoPU
ttH
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

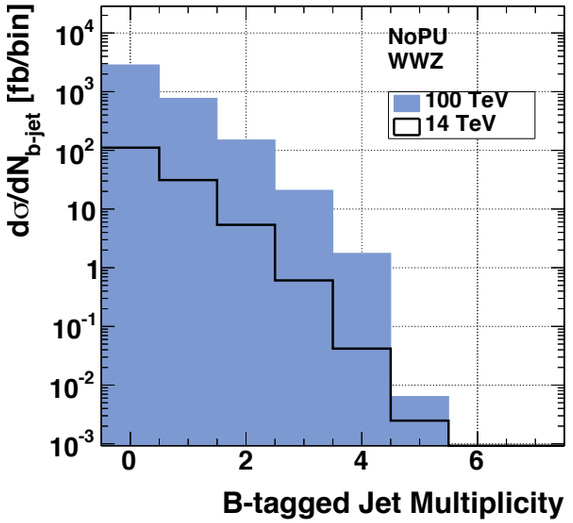

NoPU
ttH
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

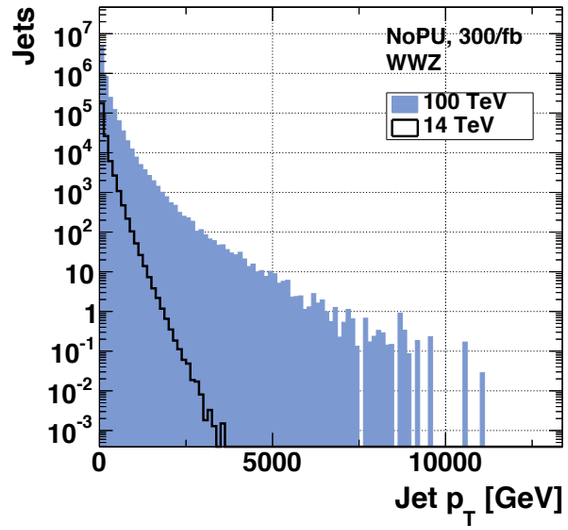

NoPU
ttH
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

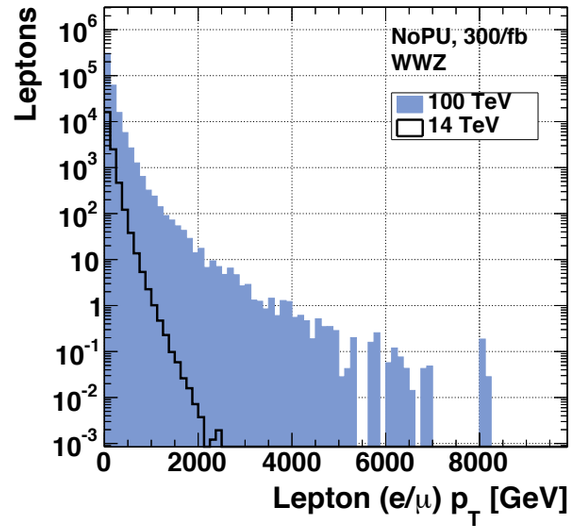
WWZ

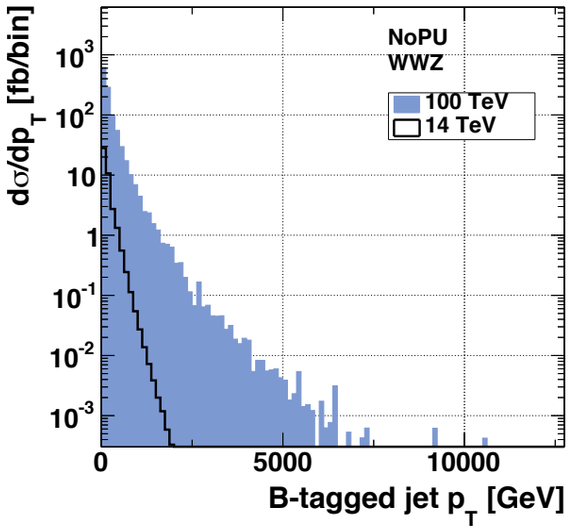

NoPU
WWZ
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

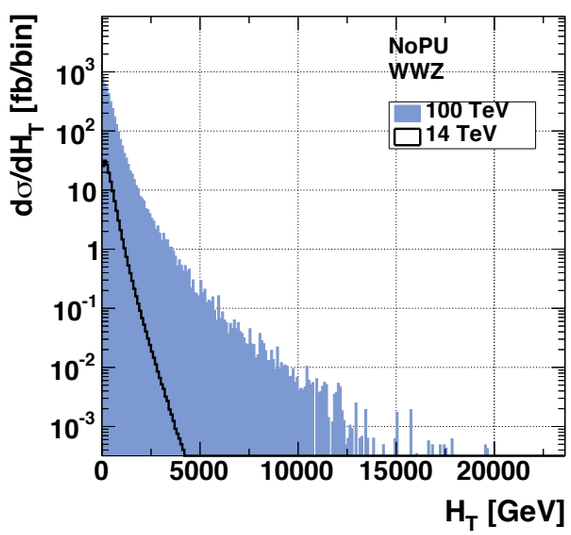

NoPU
WWZ
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

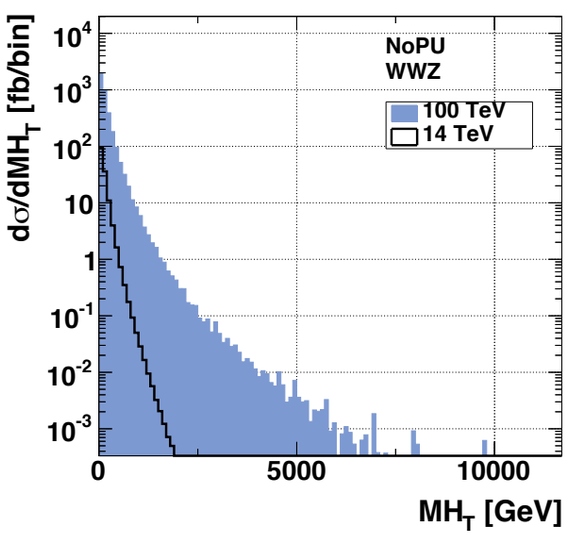

NoPU
WWZ
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


NoPU, 300/fb
WWZ
100 TeV
14 TeV
Jets
Jet p_T [GeV]

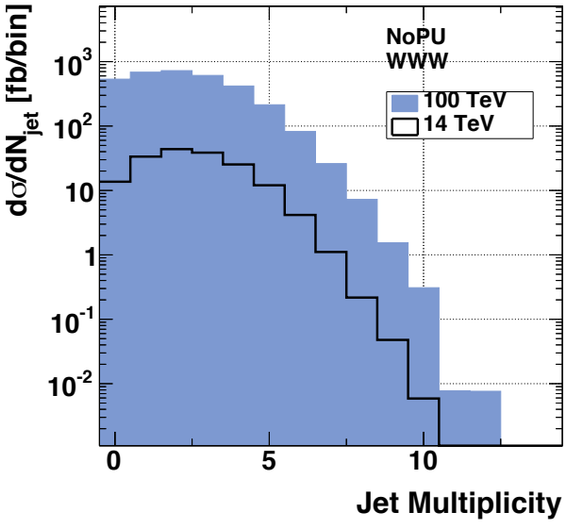

NoPU, 300/fb
WWZ
100 TeV
14 TeV
Leptons
Lepton (e/μ) p_T [GeV]

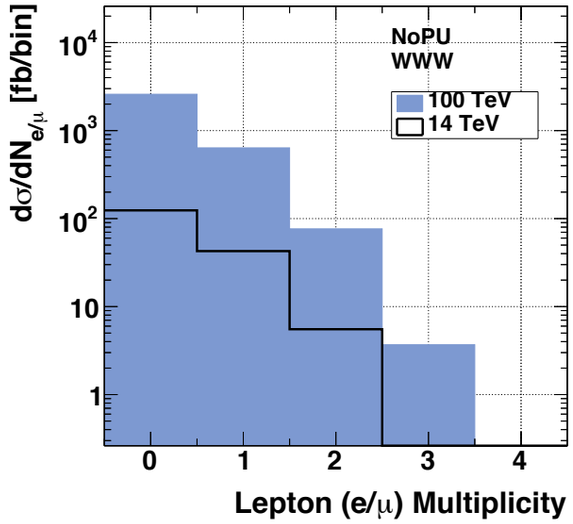

NoPU
WWZ
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

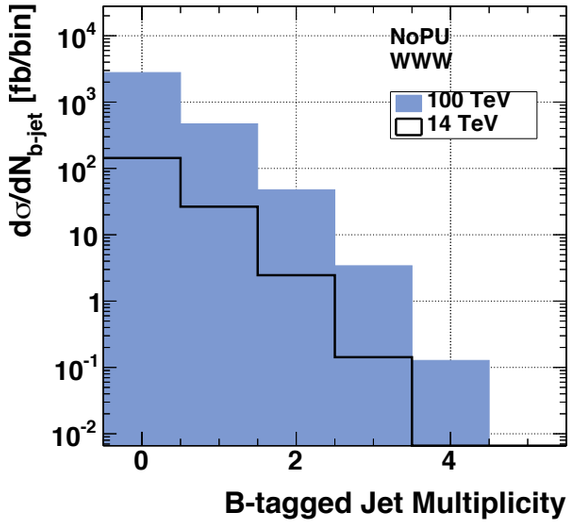

NoPU
WWZ
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

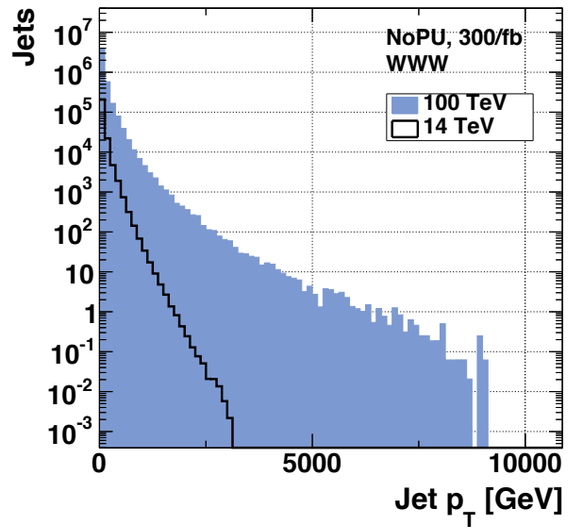

NoPU
WWZ
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

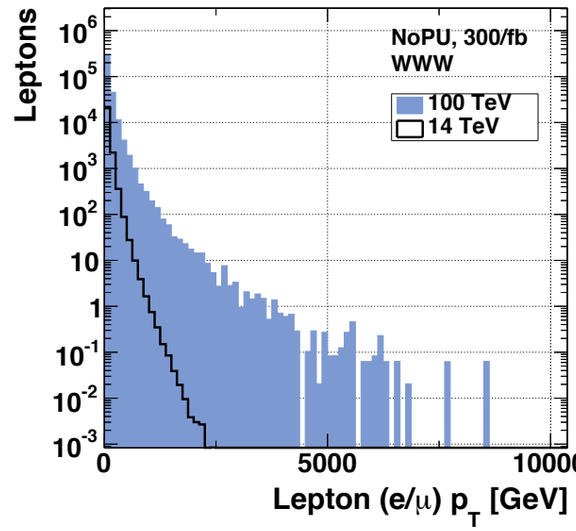
WWW

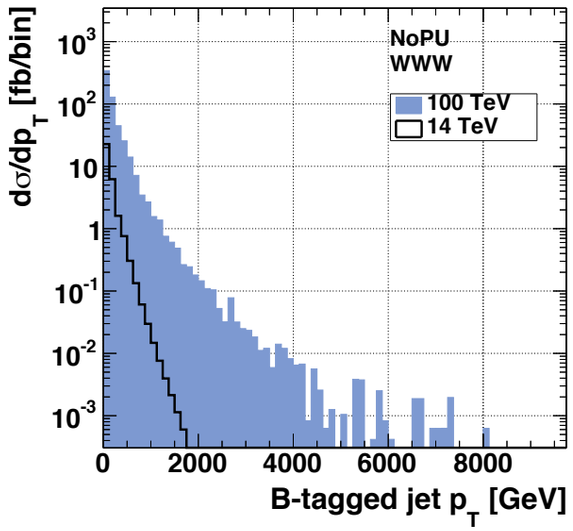

NoPU
WWW
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

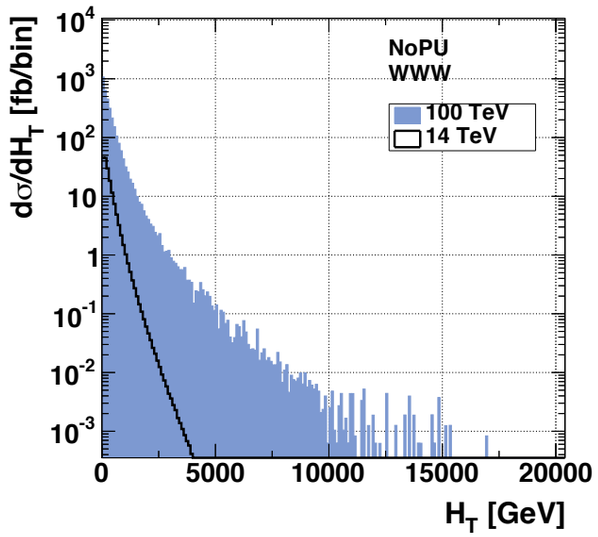

NoPU
WWW
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

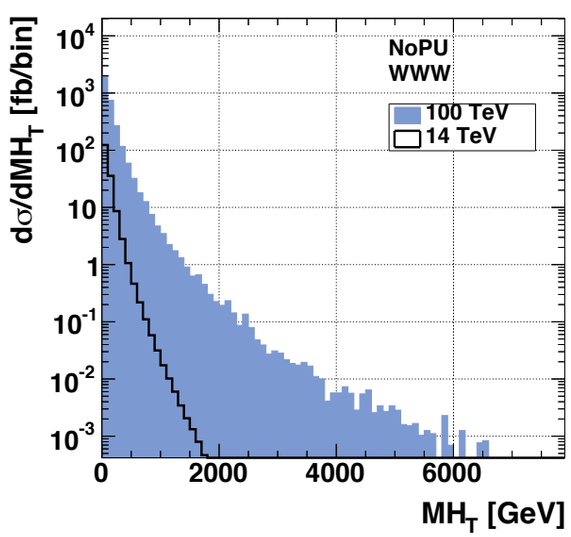

NoPU
WWW
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


Jets
NoPU, 300/fb
WWW
100 TeV
14 TeV
Jet p_T [GeV]

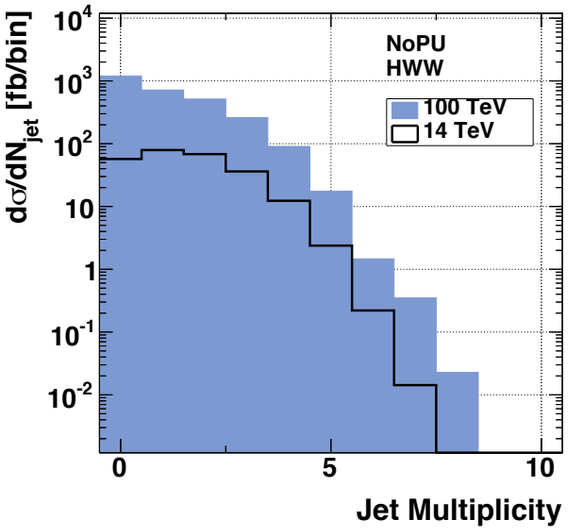

Leptons
NoPU, 300/fb
WWW
100 TeV
14 TeV
Lepton (e/μ) p_T [GeV]

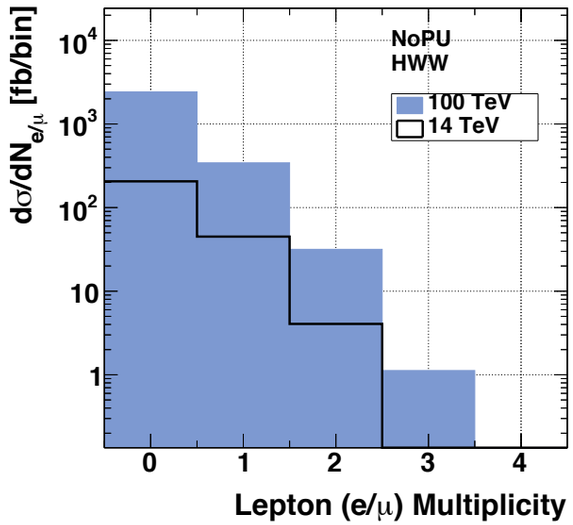

NoPU
WWW
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]

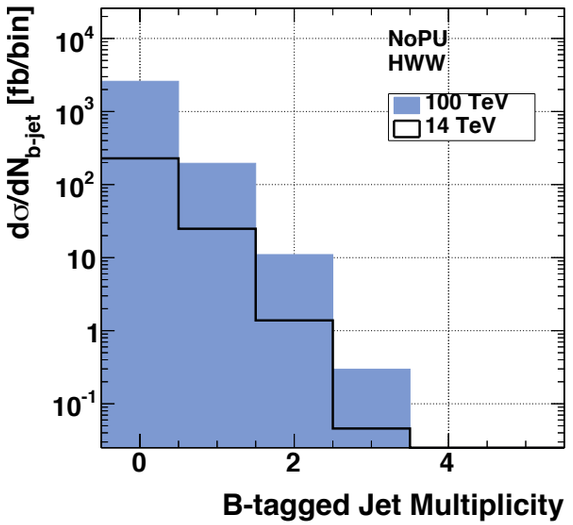

NoPU
WWW
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]

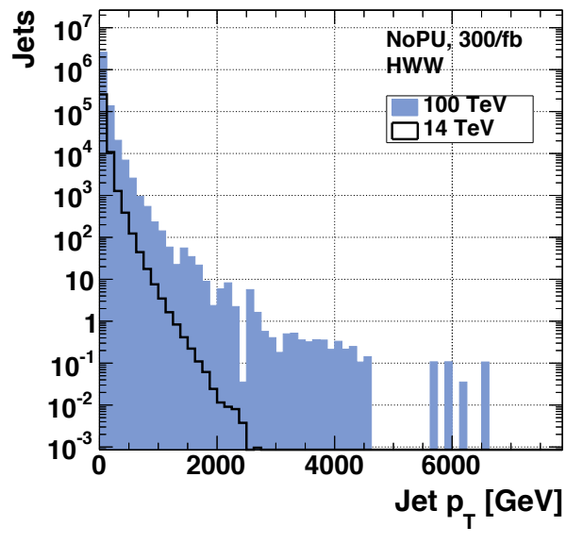

NoPU
WWW
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]

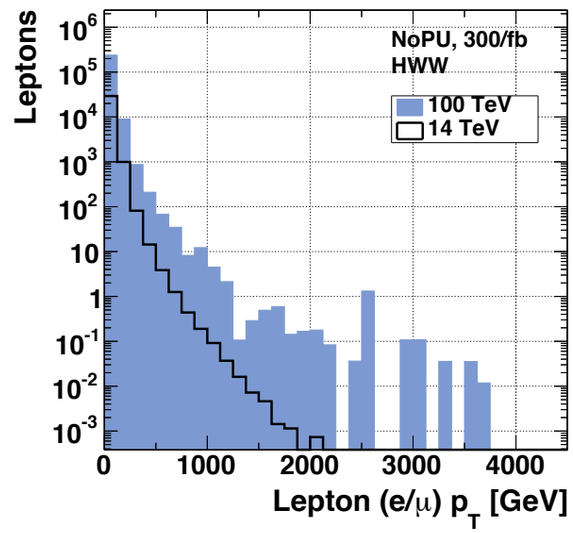
HWW

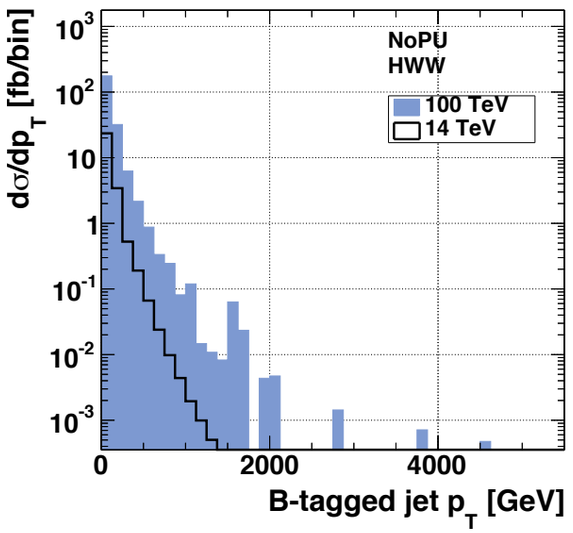

NoPU
HWW
100 TeV
14 TeV
dσ/dN_jet [fb/bin]
Jet Multiplicity

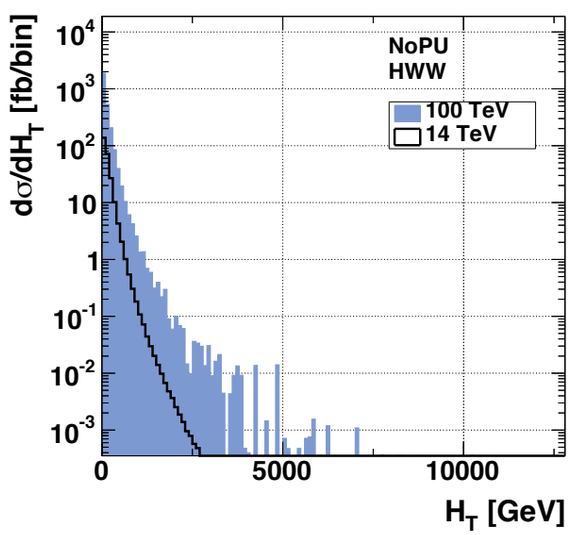

NoPU
HWW
100 TeV
14 TeV
dσ/dN_e/μ [fb/bin]
Lepton (e/μ) Multiplicity

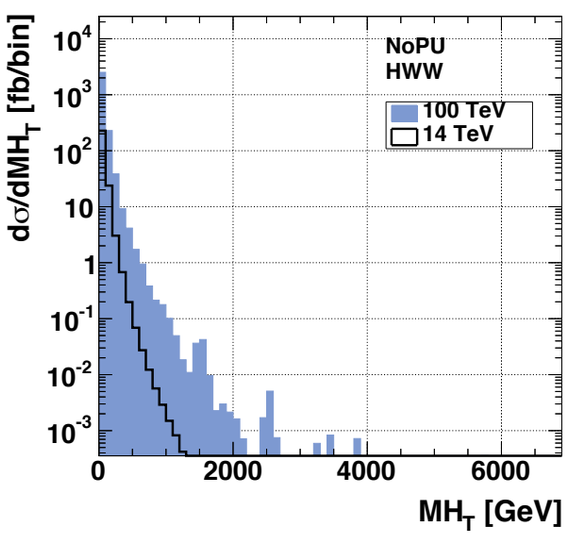

NoPU
HWW
100 TeV
14 TeV
dσ/dN_b-jet [fb/bin]
B-tagged Jet Multiplicity


Jets
NoPU, 300/fb
HWW
100 TeV
14 TeV
Jet p_T [GeV]


Leptons
NoPU, 300/fb
HWW
100 TeV
14 TeV
Lepton (e/μ) p_T [GeV]


NoPU
HWW
100 TeV
14 TeV
dσ/dp_T [fb/bin]
B-tagged jet p_T [GeV]


NoPU
HWW
100 TeV
14 TeV
dσ/dH_T [fb/bin]
H_T [GeV]


NoPU
HWW
100 TeV
14 TeV
dσ/dMH_T [fb/bin]
MH_T [GeV]