

Sensitivity to new high-mass particles decaying to $t\bar{t}$ in fully boosted regime at a 100 TeV collider

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100 TeV collider & BSM models with top decays

- 100 TeV collider can study physics beyond 10 TeV
- Many BSM models predict decays of heavy particles to $t\bar{t}$
 - top is heaviest known particle!
 - decays to “golden” channels (leptons, photons) can be suppressed
- Heavy means ~ 10 TeV mass range
- Such masses lead to highly boosted top decays $p_T(t) > 2\text{-}3$ TeV

Questions:

- How to measure $t\bar{t}$ resonances at the 10 TeV mass scale?:
 - separate decay particles cannot be “resolved”
 - “traditional” calorimetry
- What are sensitivity limits for a “generic” $t\bar{t}$ resonance using boosted techniques?



Current landscape of experimental searches

- **8 TeV: ATLAS & CMS** (CERN-PH-EP-2013-032, Phys.Rev.Lett. 111 (2013) 211804)
 - ATLAS:
 - A narrow leptophobic (narrow) Z' is excluded for $M < 1.7$ TeV
 - KK excitation is excluded up to $M = 2.1$ TeV
 - Upper limits: 0.03 pb up to 3 TeV
 - CMS:
 - Z' is excluded up to 2 TeV
 - KK excitation up to 2.5 TeV
 - → Methods: lepton+jets channel:
 - resolved+ some boosted technique (HepTopTagger)
- **14 TeV** for pp with 3000 fb^{-1} (Snowmass13, K.Agashe et al, arXiv:1309.7847)
 - Masses $< 4\text{-}5$ TeV could be excluded (depends on reconstruction scenario)
- **Region with $M > 5$ TeV is completely new territory for such searches**
- **Lepton+jets reconstruction will be very difficult due to large overlap of decay products (especially for e^+/e^-)**



MC simulation

- **Signal (LO QCD). PYTHIA8 for**

- $f\bar{f} \rightarrow Z0'$ with $M=8,10,12,14,16,18,20$ TeV. Code 3001. Pure Z' contribution. $\Gamma/M=3\%$
- $q\bar{q} \rightarrow g_{KK}$ with $M=8,10,12,14,16,18,20$ TeV. Code 5006. Pure g_{KK} contribution. $\Gamma/M=16\%$

- **Background processes:**

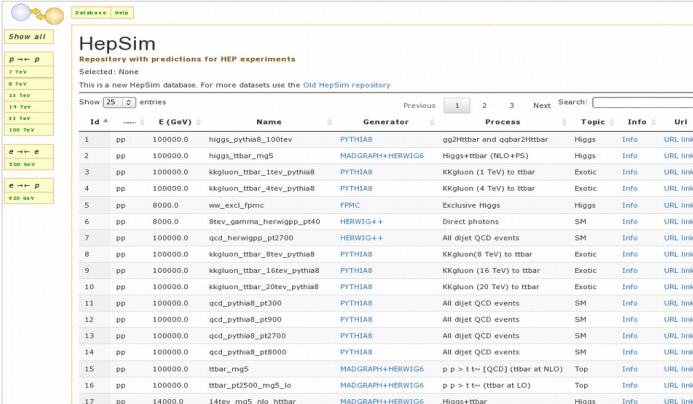
- PYTHIA8 and HERWIG++ for QCD backgrounds
 - NLOjet++ (NLO) to extract the k-factor (MSTW2008nlo68cl for PDF)
- SM $t\bar{t}$ process was generated with Madgraph (NLO+Herwig)
- PYTHIA8 for all SM boson processes (like Z/W+jets)
 - Not too realistic, but the usage of “realistic” ALPGEN should not change conclusions

- **All Monte Carlo samples are taken from the HepSim Monte Carlo repository:**

- <https://atlaswww.hep.anl.gov/hepsim/>

MC samples (100 TeV): qcd_herwigpp_pt2700, qcd_pythia8_pt2700, ttbar_pythia8_pt2700, pythia10tev_wjet2700, ttbar_pt2500_mg5, ttbar_pt2500_mg5_lo, zprime*_pythia8, kkgluon_ttbar_m*_pythia8

Data samples & analysis program are public

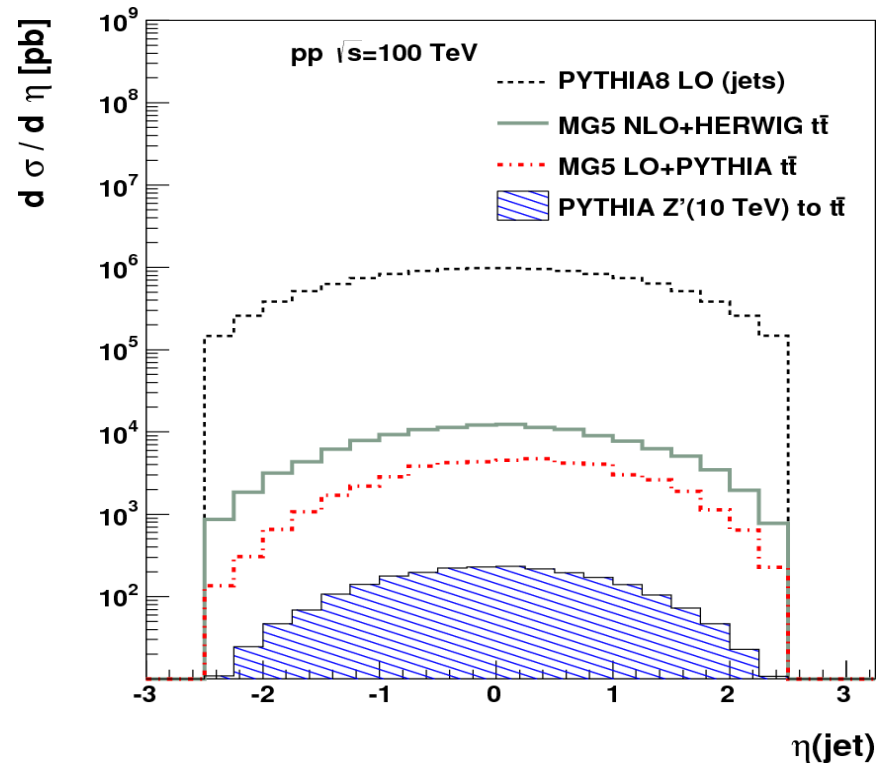
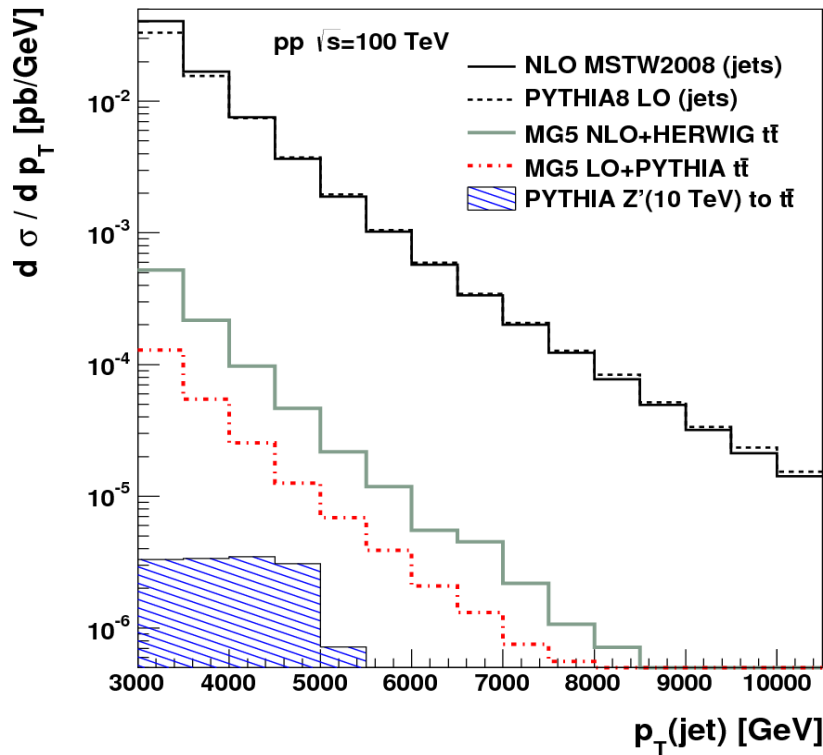


The screenshot shows the HepSim repository interface. It features a search bar, a table of samples, and navigation controls. The table lists various Monte Carlo samples with columns for ID, energy (E in GeV), name, generator, process, topic, and URL. The first few rows of the table are as follows:

ID	E (GeV)	Name	Generator	Process	Topic	Info	URL
1	pp 100000.0	higgs_pythia8_100tev	PYTHIA8	gg2ttbar and qqbar2ttbar	Higgs	Info	URL link
2	pp 100000.0	higgs_ttbar_mg5	MADGRAPH+HERWIG6	Higgs+ttbar (NLO+PS)	Higgs	Info	URL link
3	pp 100000.0	kkgluon_ttbar_1tev_pythia8	PYTHIA8	KKgluon (1 TeV) to ttbar	Exotic	Info	URL link
4	pp 100000.0	kkgluon_ttbar_4tev_pythia8	PYTHIA8	KKgluon (4 TeV) to ttbar	Exotic	Info	URL link
5	pp 8000.0	ww_excl_fmrc	FMRC	Exclusive Higgs	Higgs	Info	URL link
6	pp 8000.0	ltex_gamma_herwigpp_pt40	HERWIG++	Direct photons	SM	Info	URL link
7	pp 100000.0	qcd_herwigpp_pt2700	HERWIG++	All djet QCD events	SM	Info	URL link
8	pp 100000.0	kkgluon_ttbar_8tev_pythia8	PYTHIA8	KKgluon (8 TeV) to ttbar	Exotic	Info	URL link
9	pp 100000.0	kkgluon_ttbar_16tev_pythia8	PYTHIA8	KKgluon (16 TeV) to ttbar	Exotic	Info	URL link
10	pp 100000.0	kkgluon_ttbar_20tev_pythia8	PYTHIA8	KKgluon (20 TeV) to ttbar	Exotic	Info	URL link
11	pp 100000.0	qcd_pythia8_pt300	PYTHIA8	All djet QCD events	SM	Info	URL link
12	pp 100000.0	qcd_pythia8_pt500	PYTHIA8	All djet QCD events	SM	Info	URL link
13	pp 100000.0	qcd_pythia8_pt700	PYTHIA8	All djet QCD events	SM	Info	URL link
14	pp 100000.0	qcd_pythia8_pt8000	PYTHIA8	All djet QCD events	SM	Info	URL link
15	pp 100000.0	ttbar_mg5	MADGRAPH+HERWIG6	p p > t t- [QCD] (ttbar at NLO)	Top	Info	URL link
16	pp 100000.0	ttbar_pt2500_mg5_lo	MADGRAPH+HERWIG6	p p > t t- (ttbar at LO)	Top	Info	URL link
17	pp 14000.0	14tev_mg5_nlo_ttbar	MADGRAPH+HERWIG6	Higgs+ttbar	Higgs	Info	URL link

Heavy particles decaying to $t\bar{t}$ at a 100 TeV collider. S.Chekanov et. al (ANL)

Kinematic distributions

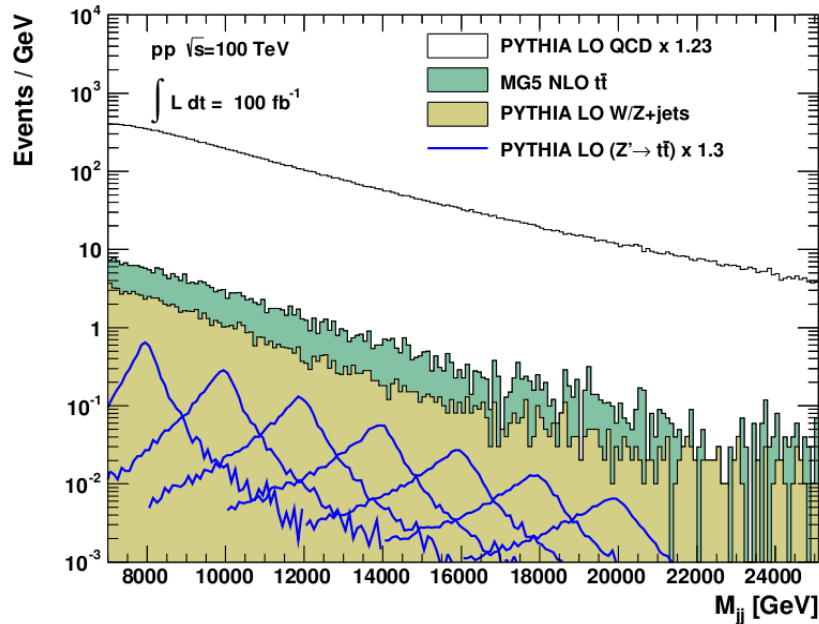


- Jets reconstructed using antiKT5 ($R=0.5$) from FastJet
- $p_T(\text{jet}) > 2.7$ TeV and $|\eta| < 2.5$
- The k-factor for dijets is $\sim 10\%$, but larger for $t\bar{t}$
- The distributions look as expected, with a harder p_T spectrum for Z'(10 TeV)

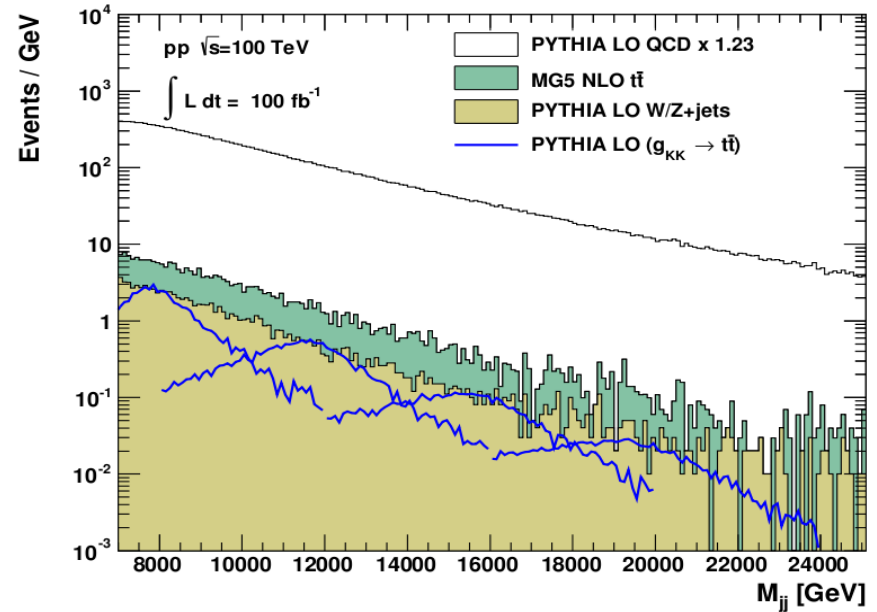


Dijet invariant mass for 100 fb^{-1}

$$Z' \rightarrow t\bar{t}$$



$$g_{KK} \rightarrow t\bar{t}$$

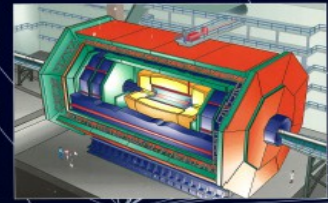


- Look at 2 leading jets above $p_T > 2.7 \text{ TeV}$.
 - all decay channels. Semileptonic decays are included
- Z' model leads to narrow signal ($\Gamma/M \sim 3\%$)
- g_{KK} is wider ($\Gamma/M \sim 16\%$) and has larger cross section

Signal(Z')/Bkg ~ 0.001

Not That Obvious:

How to reduce QCD (reducible) and $t\bar{t}$ (irreducible) background for back-to-back jet events?

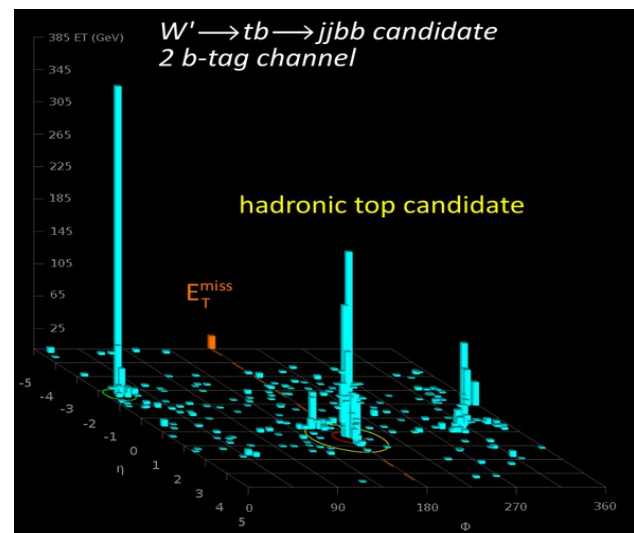
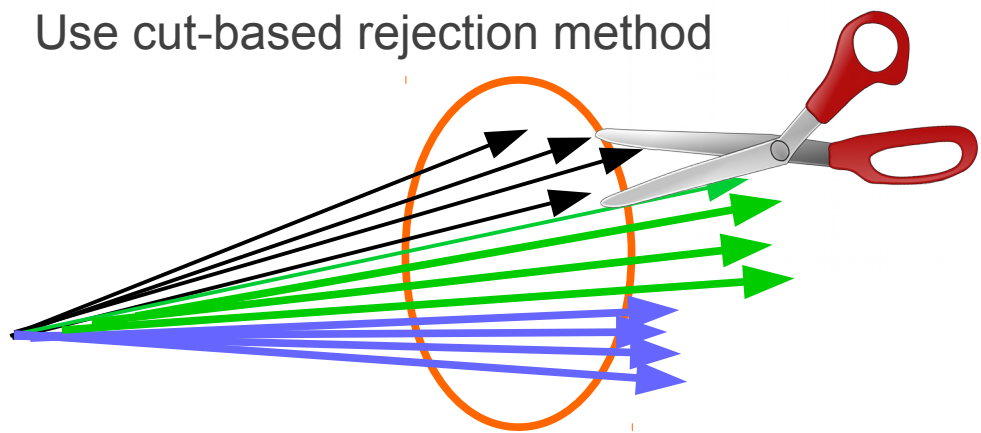


SOLENOIDAL DETECTOR COLLABORATION
SOX

Discriminating variables

- Use jet substructure signatures (SSC-SR-1217 TDR 1992 p 3-26)
- Tremendous recent progress in advancing such approach
- Most basic variables used in this study:
 - Jet mass
 - τ_{32} and τ_{21} (N-subjettiness jet characteristics)
 - Jet shapes (eccentricity)
 - $\sqrt{d_{12}}$ splitting scale
 - R^{eff} effective jet radius (weighted with energy radial distance to jet center)
 - b-tagging
 - high- p_T muons
- Use cut-based rejection method

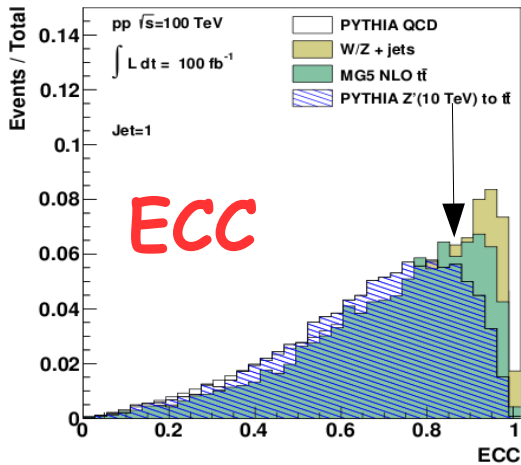
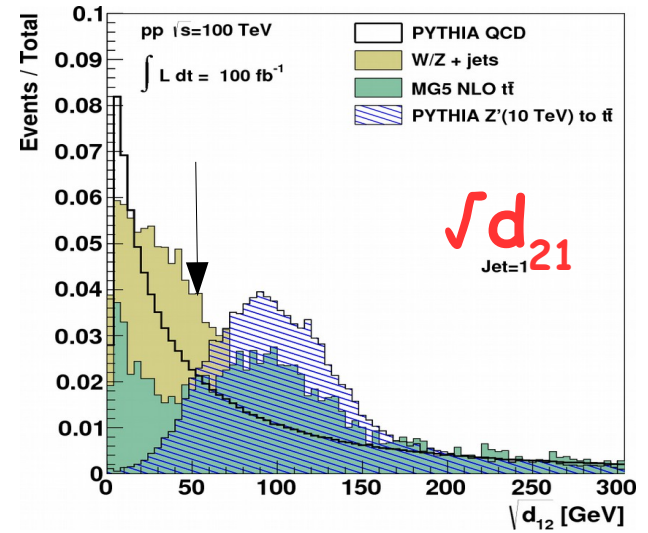
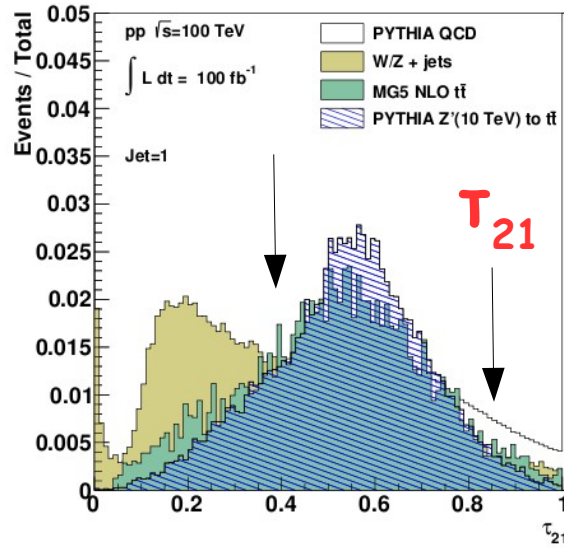
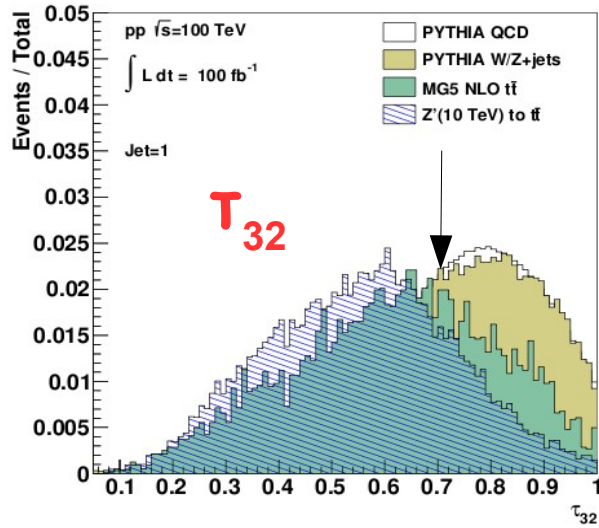
J.Thaler, K. Van Tilburg, JHEP 1103:015, 2011
 S.C., J.Proudfoot, Phys. Rev. D81 (2010) 114038
 J. M. Butterworth, B. E. Cox, and J. R. Forshaw, Phys. Rev. D65 (2002) 96014



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Discriminating variables (lead. jet)



- $T_{32} > 0.75$ reduces QCD and boosted W/Z
- $T_{21} < 0.3$ reduces W/Z
- $T_{21} > 0.8$ reduces QCD background
- $\sqrt{d_{12}} > 50$ GeV reduces QCD, W/Z, some $t\bar{t}$

Correlation between variables:

~10% for T_{32} , T_{21} , mass

~30% correlation between d_{12} mass, ECC

Summary

- Limit extraction is still in progress
- We hope to finish this study in 1 week and present it at the “Next step..” meeting at FNAL