



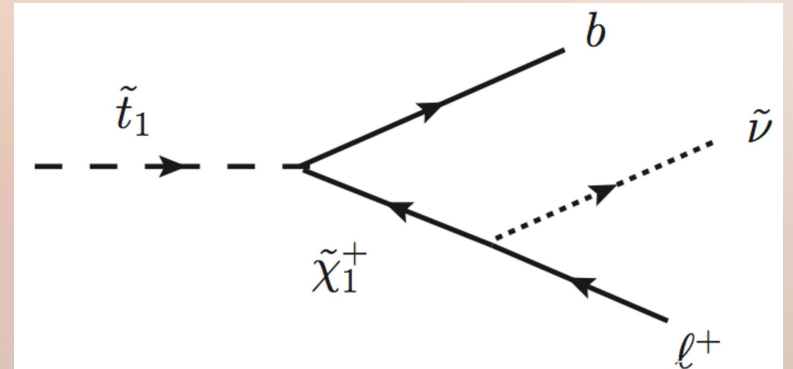
Search for scalar top in $\mu\tau$ final states

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University of Mississippi
For the DØ Collaboration



SuperSymmetry

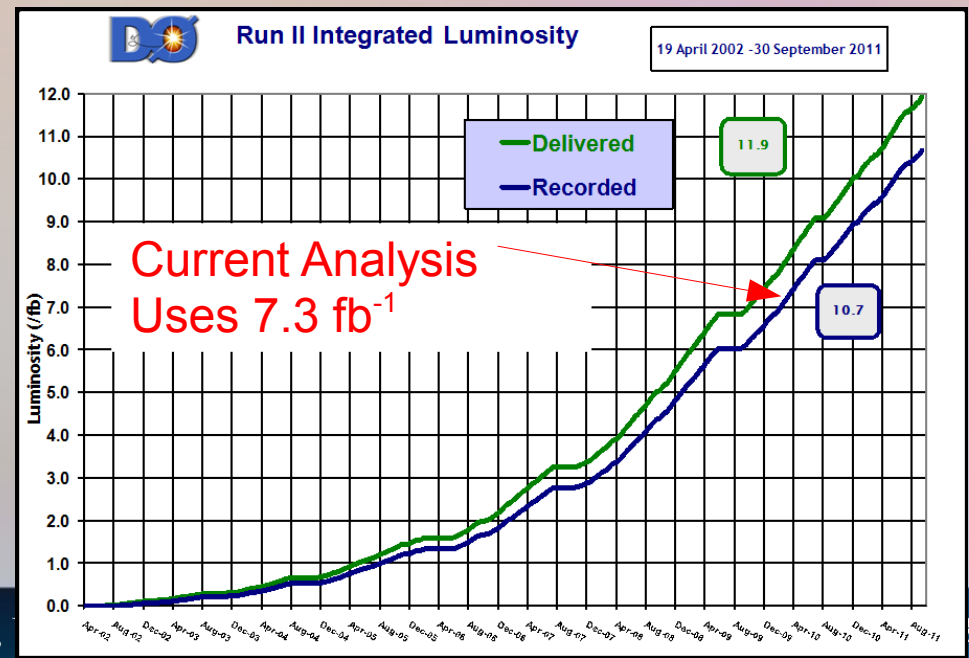
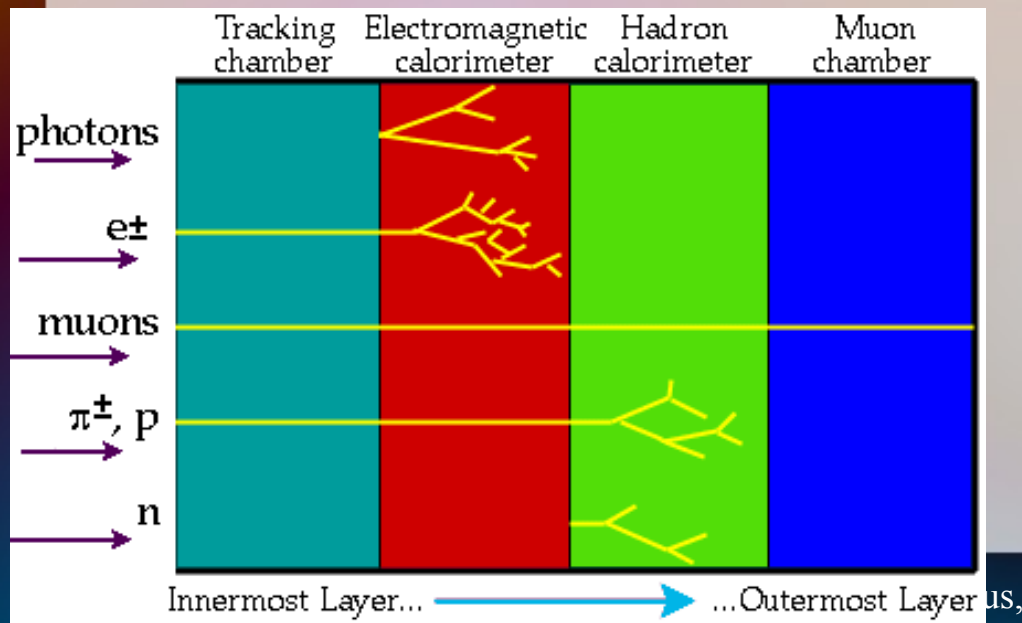
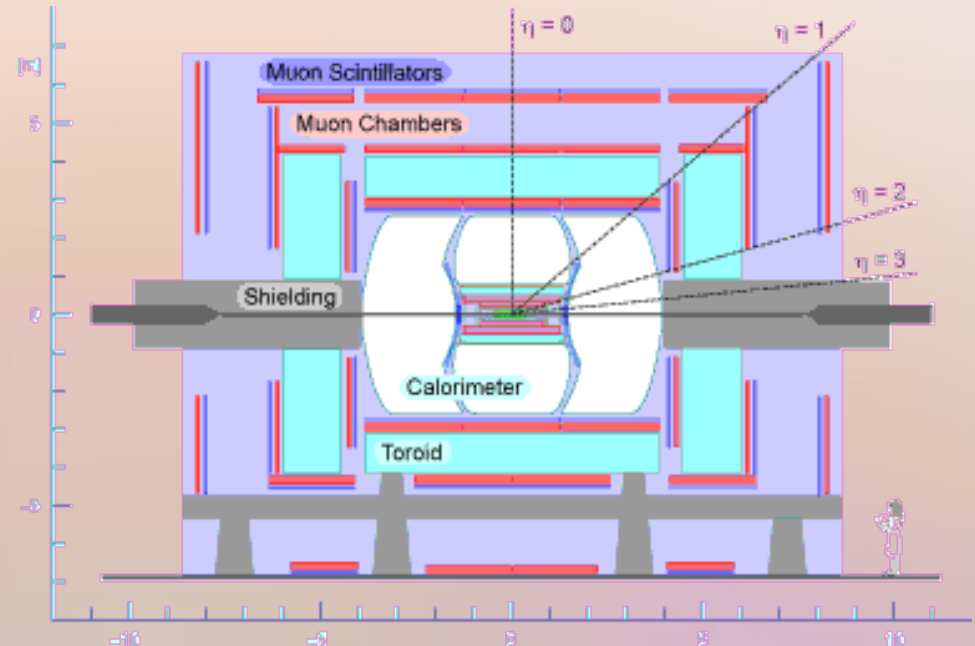
- Supersymmetric (SUSY) theories predict a scalar partner for every SM fermion
- As the top mass is much greater than the other SM fermion masses, some SUSY models predict stop lightest sfermion
 - If sneutrino lightest SUSY particle, and R-parity conserved, can have $\tilde{t} \rightarrow b \tilde{\chi}_1^+ \rightarrow b \ell^+ \tilde{\nu}$
- In this analysis, we search for pair produced scalar tops decaying to the final state $\tilde{t}\tilde{t} \rightarrow b \tilde{\chi}_1^+ \bar{b} \tilde{\chi}_1^+ \rightarrow b \tau \tilde{\nu} \bar{b} \mu \tilde{\nu}$





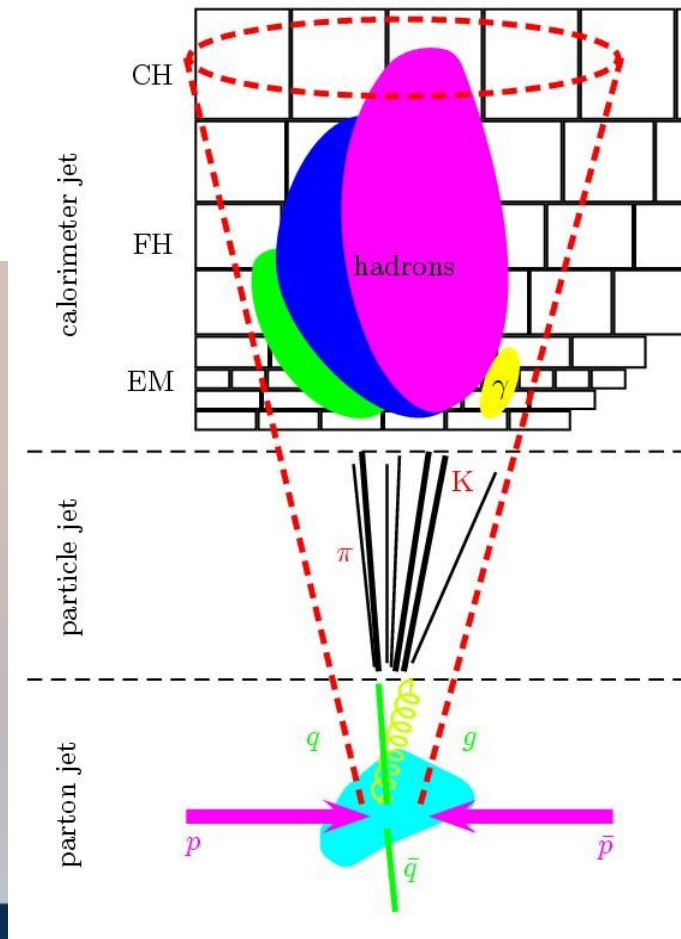
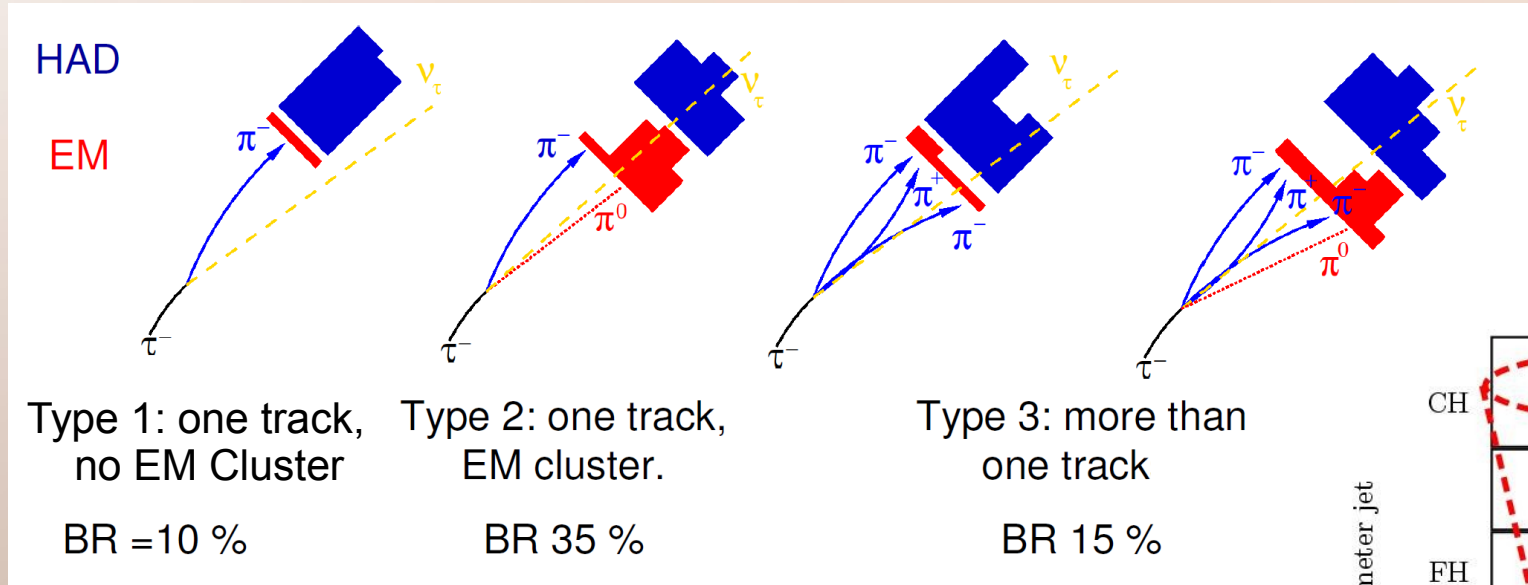
The DØ Experiment

- A multipurpose particle detector
- Innermost detectors are the trackers, followed by calorimetry and muon chambers





Tau and Jet Reconstruction

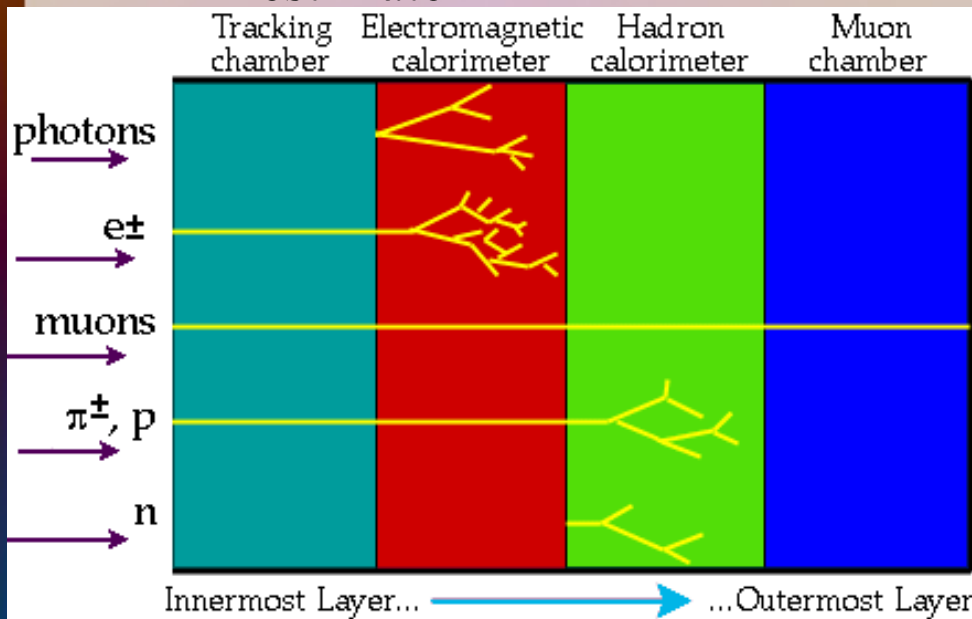
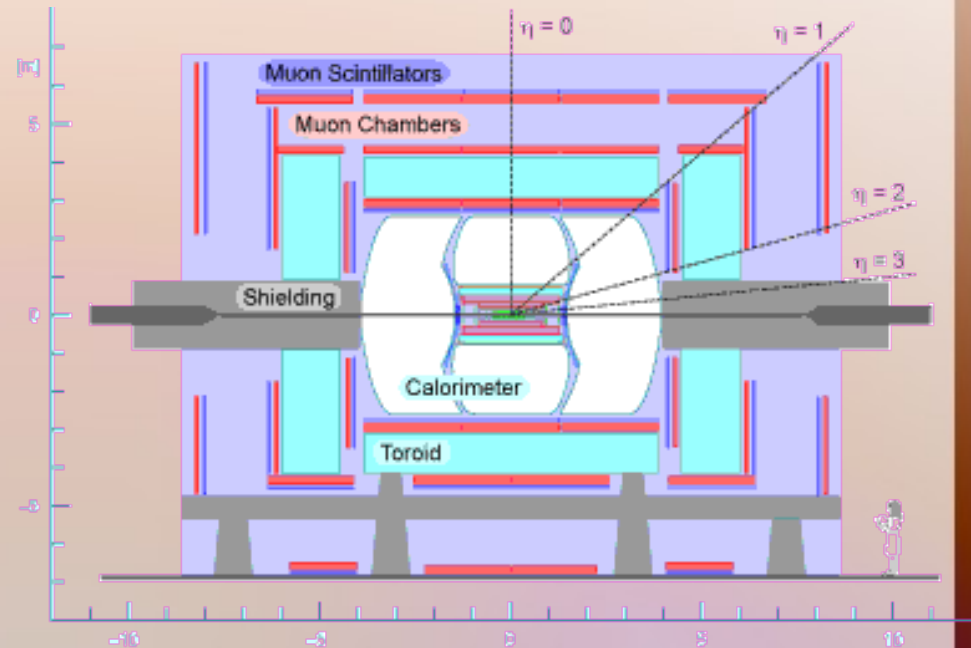


- Jets and τ both reconstructed in calorimeter
- NNs used to separate τ from jets, e
 - Jets wider than τ , more tracks



Muons and Missing Energy

- Muons are reconstructed by matching tracks in central tracker to hits in tracking system outside calorimeter
 - Calorimeters absorb other particles
 - Use central track for momentum estimate



- Missing Transverse Energy (MET) negative vector sum of calorimeter energy with μ , τ , jet corrections
 - Possibly from particle missed in detector
 - Can arise from mismeasurement



Signal Generation

- We consider 2 separate scenarios of stop production and decay
 - Either wino or higgsino like charginos
 - Wino-like $\text{BR}(\tilde{\chi}_1^+ \rightarrow \mu \tilde{\nu}) \approx \text{BR}(\tilde{\chi}_1^+ \rightarrow \tau \tilde{\nu}) = 0.3$ vs
Higgsino-like $\text{BR}(\tilde{\chi}_1^+ \rightarrow \mu \tilde{\nu}) = 0.1$, $\text{BR}(\tilde{\chi}_1^+ \rightarrow \tau \tilde{\nu}) = 0.8$
 - Max MSSM Higgsino-like BR found using SUSY-HIT
- Scan over space of stop and sneutrino masses
- Signal generated with MADGRAPH/MADEVENT + PYTHIA, corrected to NLO PROSPINO stop production cross sections

Standard Model Backgrounds

- Backgrounds for this analysis include

- Z+jets, diboson(WW,WZ,ZZ), tt, W+jets, and multijet

- All but multijet from MC

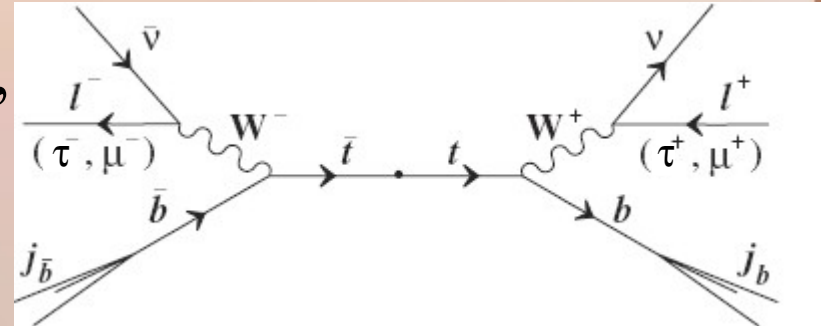
- Z + jets, $t\bar{t}$, W+jets estimated with ALPGEN+PYTHIA MC

- W and Z corrected to NLO cross sections from MCFM,

- $t\bar{t}$ corrected to approximate next-to-next-to-NLO

- Diboson backgrounds estimated using PYTHIA corrected to NLO MCFM calculations

- Multijet arises when a muon comes from a jet (as in b-decay), and narrow jet fakes tau





Multijet Background Estimate

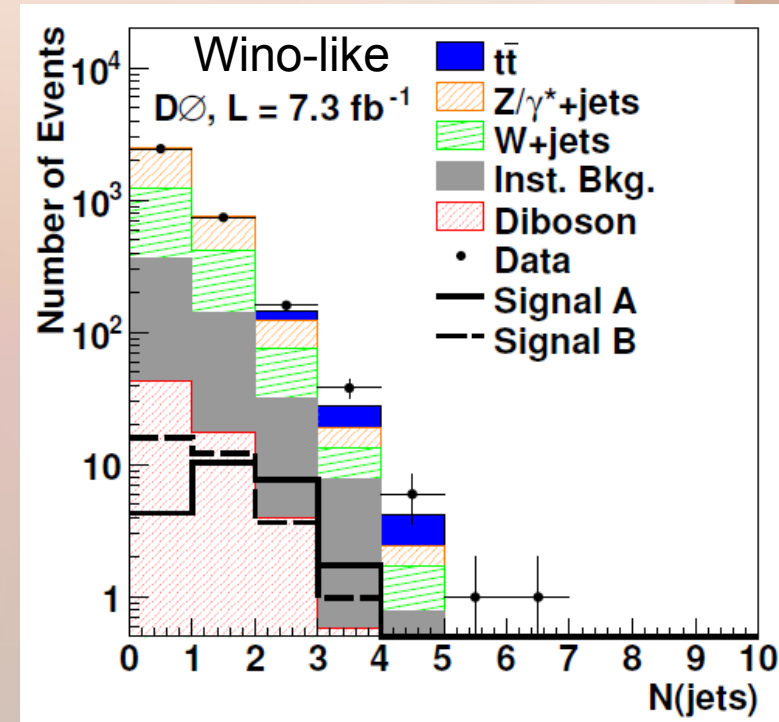
- Estimate by reversing isolation cuts on μ and τ
 - Require anti-isolated leptons be opposite charged (OS)
- Normalize anti-isolated sample to multijet in data using like sign (LS) sample
 - Expect LS and OS QCD samples to have same ratio, ρ , of isolated to anti-isolated events
 - Measure ρ in LS sample for each tau type, apply it to OS sample to get multijet estimate
- We use MC to correct multijet estimate for small amount of real $\mu\tau$ in LS and anti-isolated samples

$$N_{multijet}(OS) = \rho \times (N_{\tau QCD}^{Data}(OS) - N_{\tau QCD}^{MC}(OS))$$
$$\rho = \frac{N_{\tau}^{Data}(LS) - N_{\tau}^{MC}(LS)}{N_{QCD}^{Data}(LS) - N_{QCD}^{MC}(LS)}$$



Event Selection

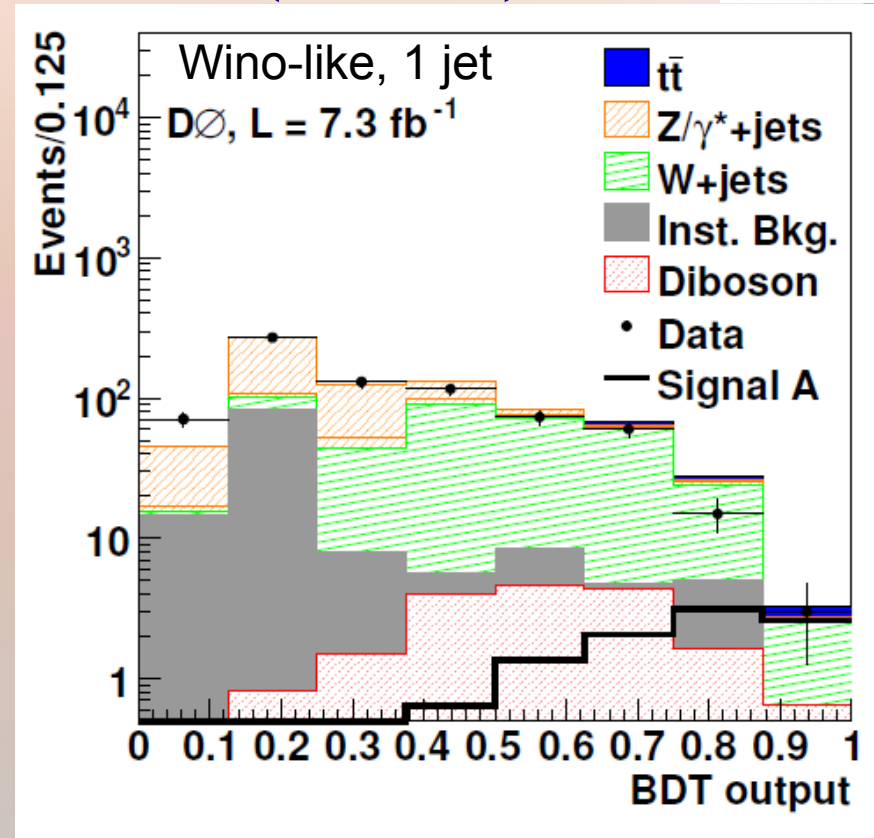
- We look for events with oppositely charged, isolated μ & τ , and at least one jet
 - Signal A($m_{\tilde{t}}, m_{\tilde{\nu}}$) = (180, 60) GeV
 - Signal B($m_{\tilde{t}}, m_{\tilde{\nu}}$) = (120, 80) GeV
 - We pick these mass points as signal properties most sensitive to stop mass, $\Delta m(\tilde{t}, \tilde{\nu})$
- Require $\Delta\phi(\text{MET}, \text{lepton}) > 0.5$, removes Z + jet
- Require $\Delta R(\mu, \text{jet}) > 0.5$ to reduce multijet, W+jet
- 893 events pass cuts, 905.1 ± 9.6 expected





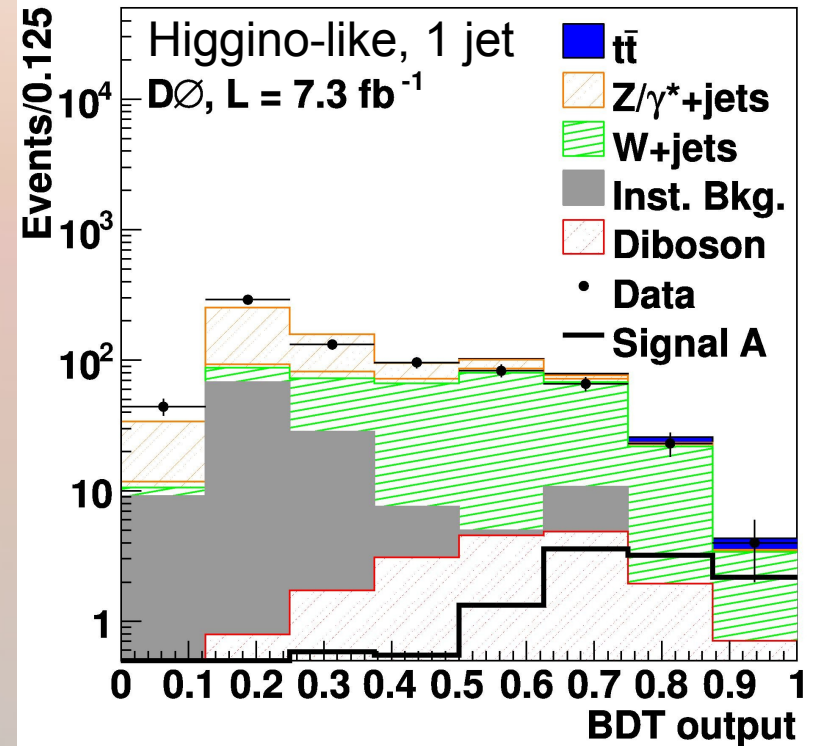
Boosted Decision Tree (BDT)

- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
- We train BDTs for wino-like charginos



Boosted Decision Tree (BDT)

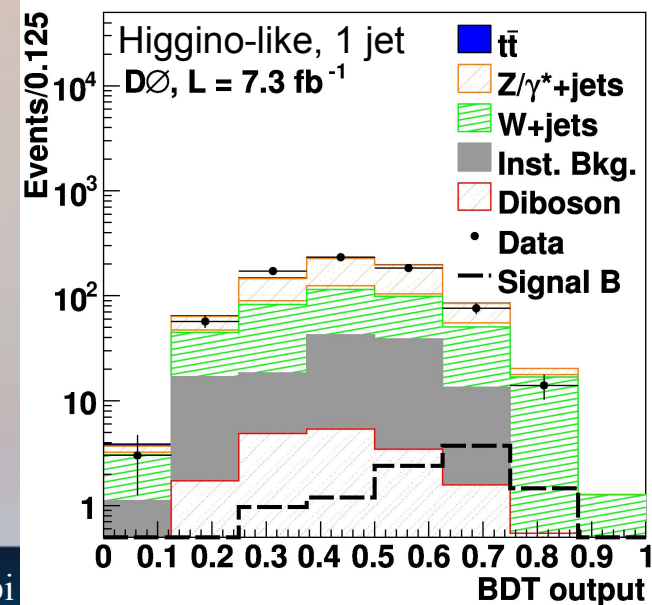
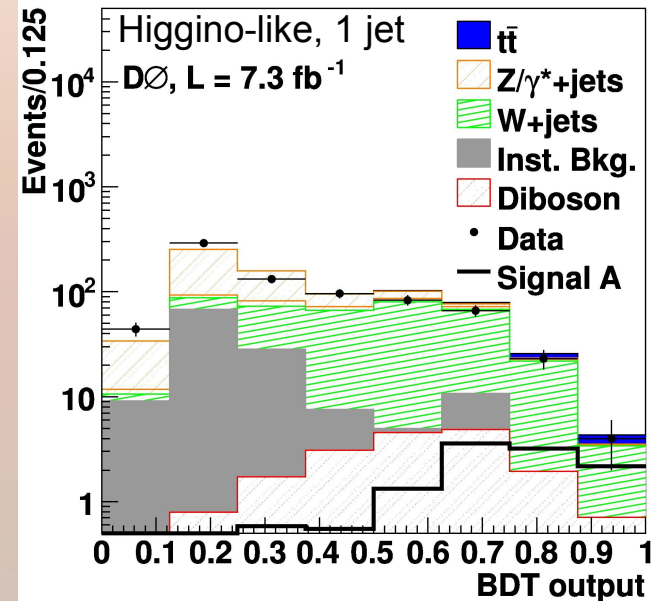
- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
- We train BDTs for wino-like charginos and Higgsino-like charginos separately





Boosted Decision Tree (BDT)

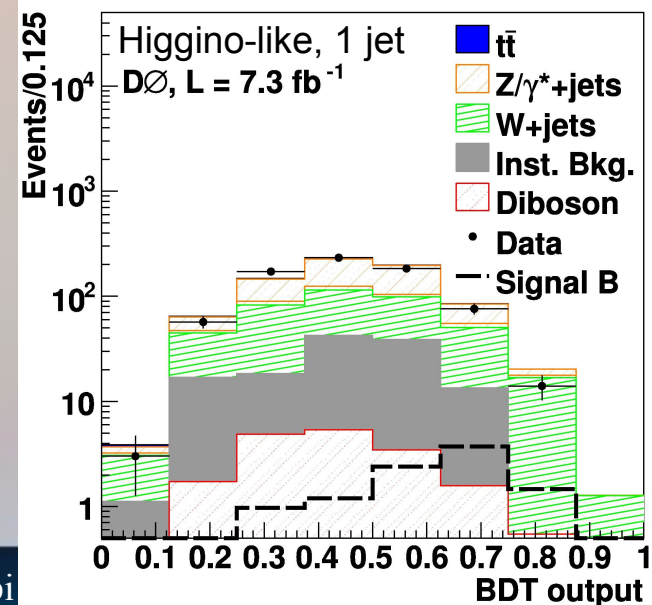
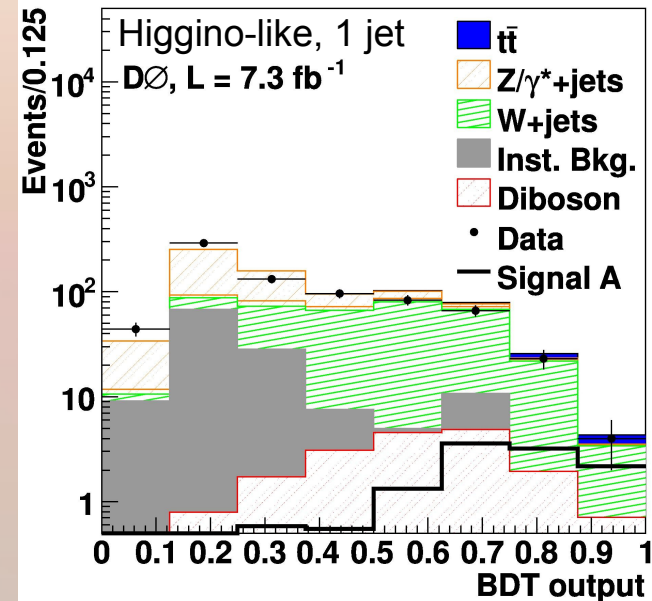
- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
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- BDTs trained for each stop/sneutrino mass point





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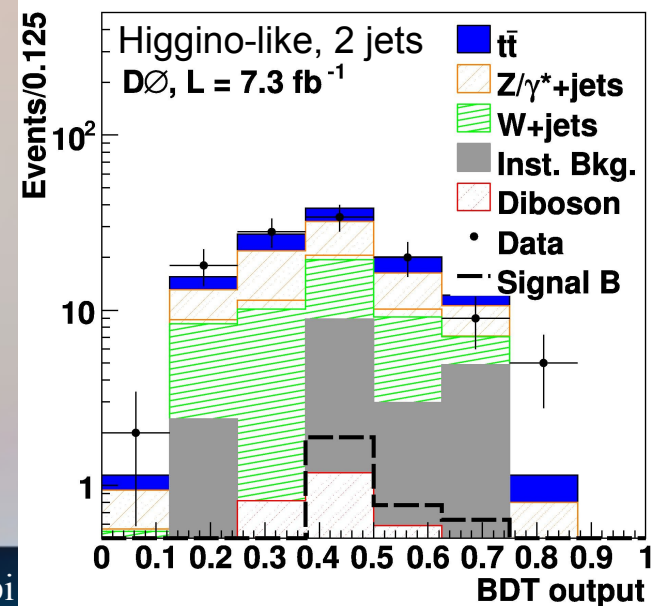
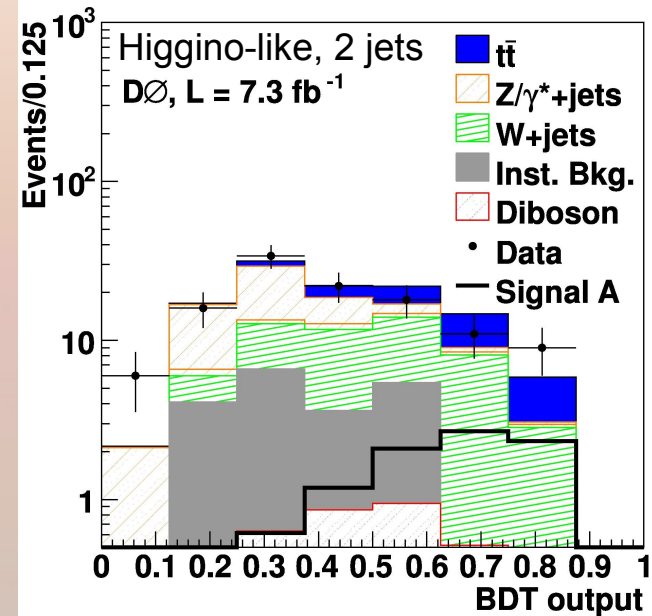
- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
- We train BDTs for wino-like charginos and Higgsino-like charginos separately
- BDTs trained for each stop/sneutrino mass point
- Train separate BDTs for 1 jet,





Boosted Decision Tree (BDT)

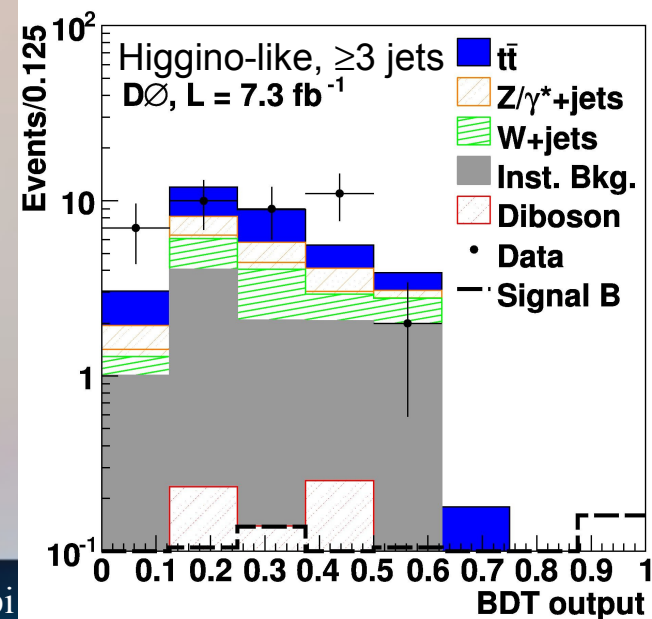
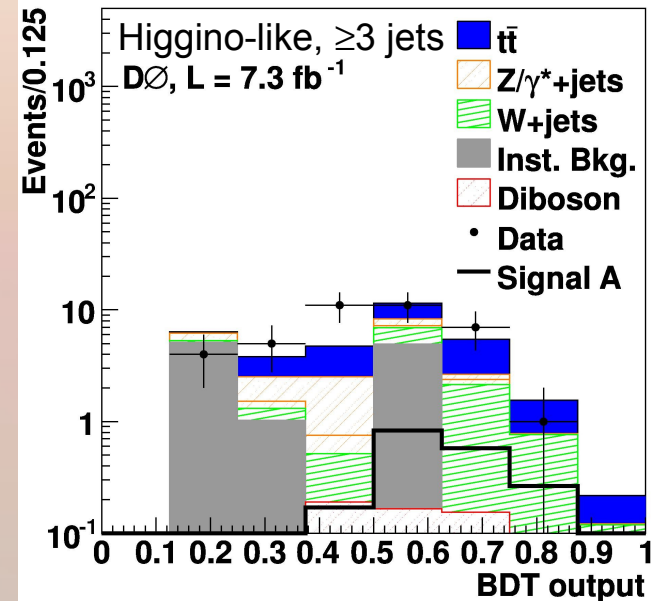
- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
- We train BDTs for wino-like charginos and Higgsino-like charginos separately
- BDTs trained for each stop/sneutrino mass point
- Train separate BDTs for 1 jet, 2 jet,





Boosted Decision Tree (BDT)

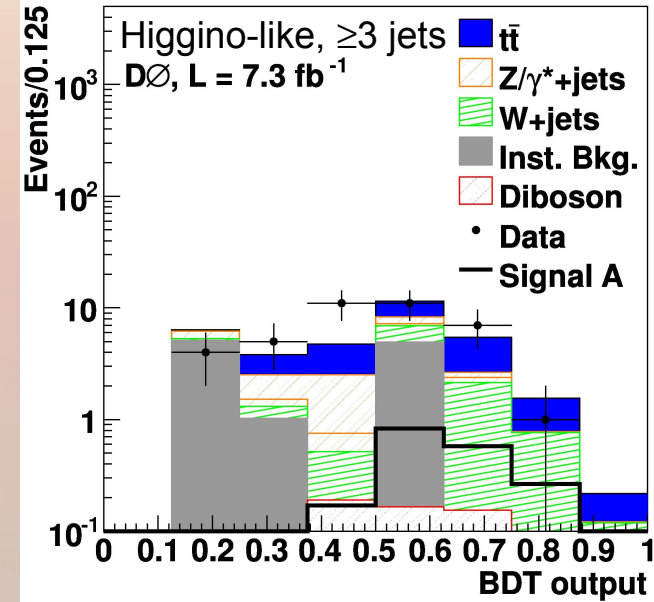
- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
- We train BDTs for wino-like charginos and Higgsino-like charginos separately
- BDTs trained for each stop/sneutrino mass point
- Train separate BDTs for 1 jet, 2 jet, and 3 or more jet bins





Boosted Decision Tree (BDT)

- We train BDT to separate signal from SM background
 - Inputs checked for data/MC agreement with Kolmogorov-Smirnov test
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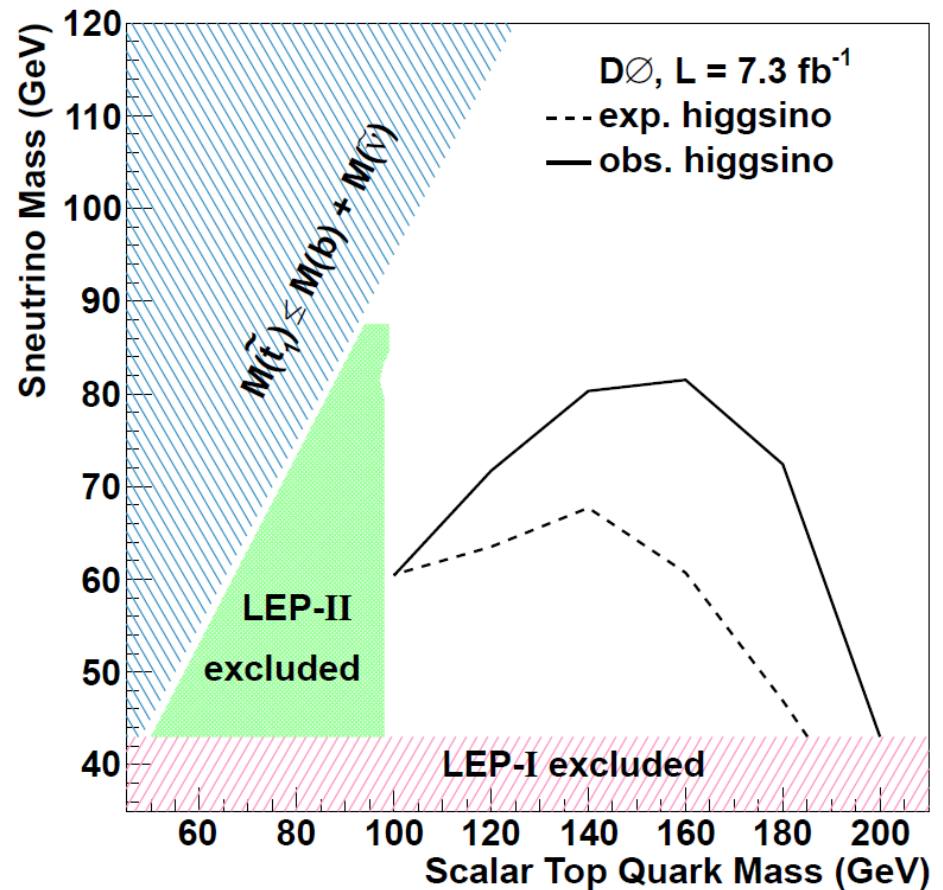
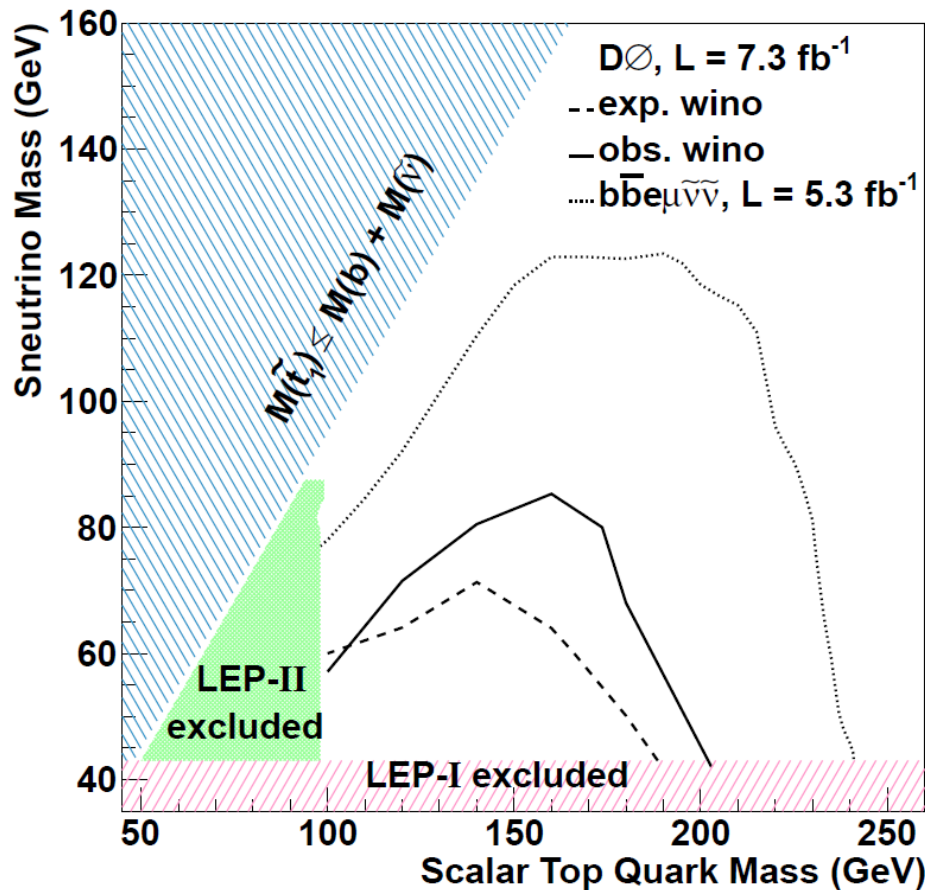


	Wino scenario			Higgsino scenario		
	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$
Signal A	S_T	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\text{Mass}(\mu, \tau)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	H_T
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^τ	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\text{Mass}(\mu, \tau)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$	$\text{Mass}(\text{lept}, \text{jet})$	$M_T(\tau, \cancel{E}_T)$	$\text{Mass}(\mu, \text{jet})$
Signal B	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\eta(\mu, \tau)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \tau)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$	S_T	$\eta(\text{leading jet})$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\eta(\tau)$	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \cancel{E}_T)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	$\text{Mass}(\mu, \text{jet})$	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\Delta\phi(\tau, \cancel{E}_T)$



Limits

- No excess found, proceed to set limits
 - Exclude $m_{\tilde{\tau}} < 200$ GeV for $m_{\tilde{\nu}} = 40$ GeV

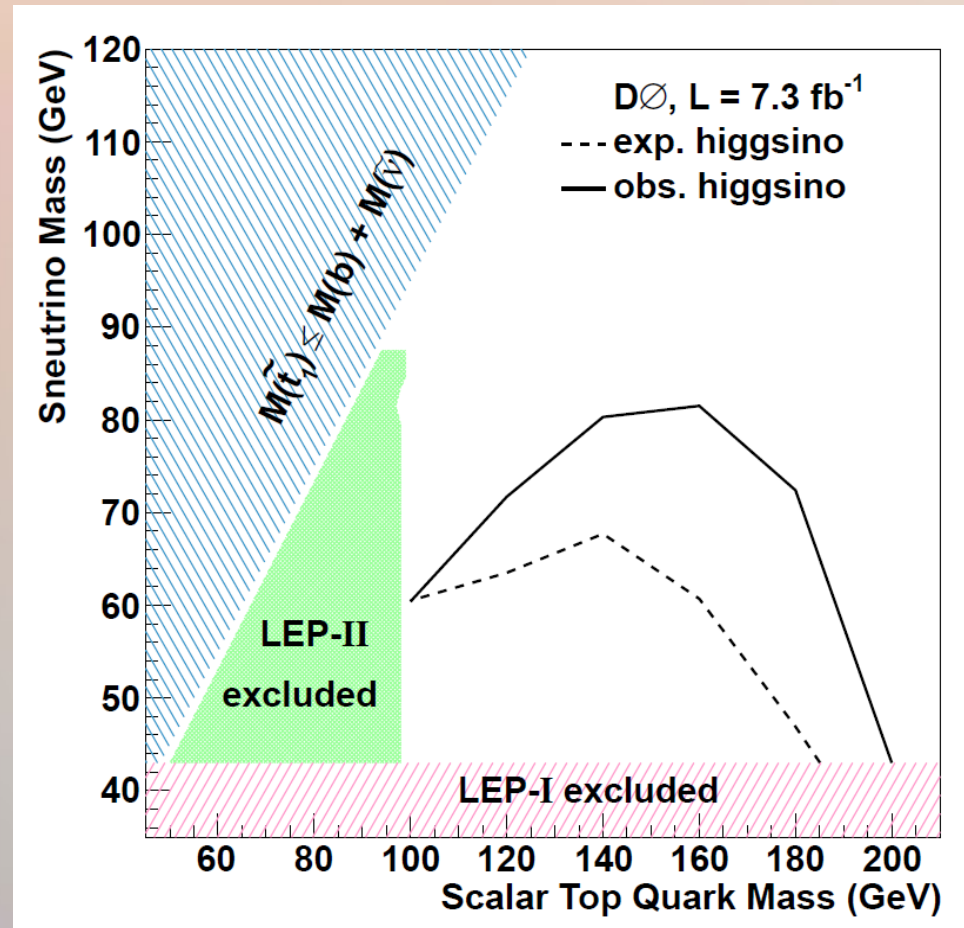




Conclusion/Summary

Phys. Lett. B 710, 578 (2012). arXiv:1202.1978 [hep-ex]

- First limits placed on scalar top production decaying to τ from the Tevatron
- Find 893 data events passing selection cuts
 - Expect 905.1 ± 9.6 background events
- BDTs used to separate signal and background
- Exclude $m_{\tilde{t}} < 200$ GeV for $m_{\tilde{\nu}} = 40$ GeV



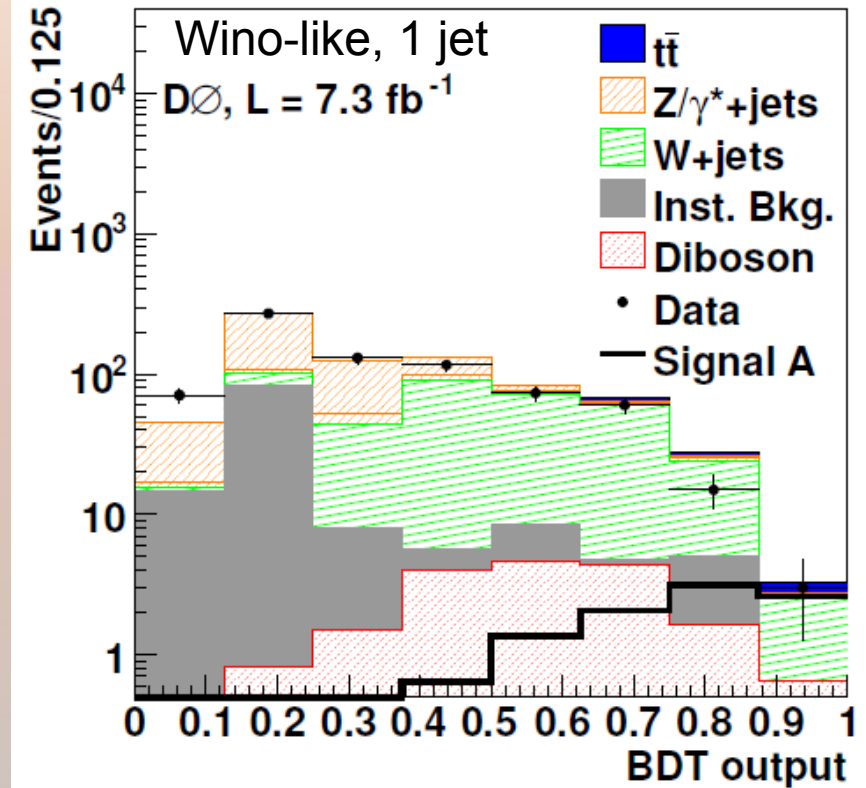


Backup Slides



BDT Training and Inputs

- We train separate BDTs for wino-like and Higgsino-like chargino scenarios
- Three BDTs for each scenario per mass point
 - 1 jet, 2 jet, and more than 2 jets
 - Table shows 5 most significant variables for Signals A, B

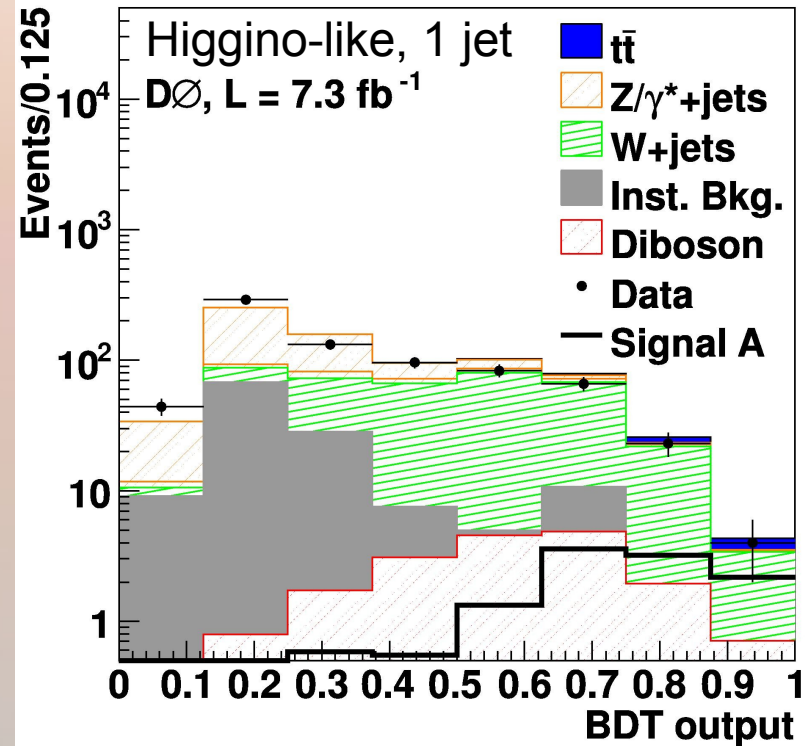


	Wino scenario			Higgsino scenario		
	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$
Signal A	S_T	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	Mass(μ, τ)	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	Sig(\cancel{E}_T)	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	H_T
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^τ	Sig(\cancel{E}_T)	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	Mass(μ, τ)
	Mass(lept, jet)	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$	Mass(lept, jet)	$M_T(\tau, \cancel{E}_T)$	Mass(μ, jet)
Signal B	Sig(\cancel{E}_T)	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\eta(\mu, \tau)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \tau)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	Sig(\cancel{E}_T)	S_T	$\eta(\text{leading jet})$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\eta(\tau)$	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \cancel{E}_T)$
	Mass(lept, jet)	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	Mass(μ, jet)	Mass(lept, jet)	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\Delta\phi(\tau, \cancel{E}_T)$



Boosted Decision Tree (BDT)

- We train BDT to separate signal from SM background
- BDTs trained for each stop/sneutrino mass point
- We train separate BDTs for wino-like and Higgsino-like chargino scenarios
- Samples split into thirds for training, testing, limit setting
 - Check inputs for data/MC agreement with Kolmogorov-Smirnov test

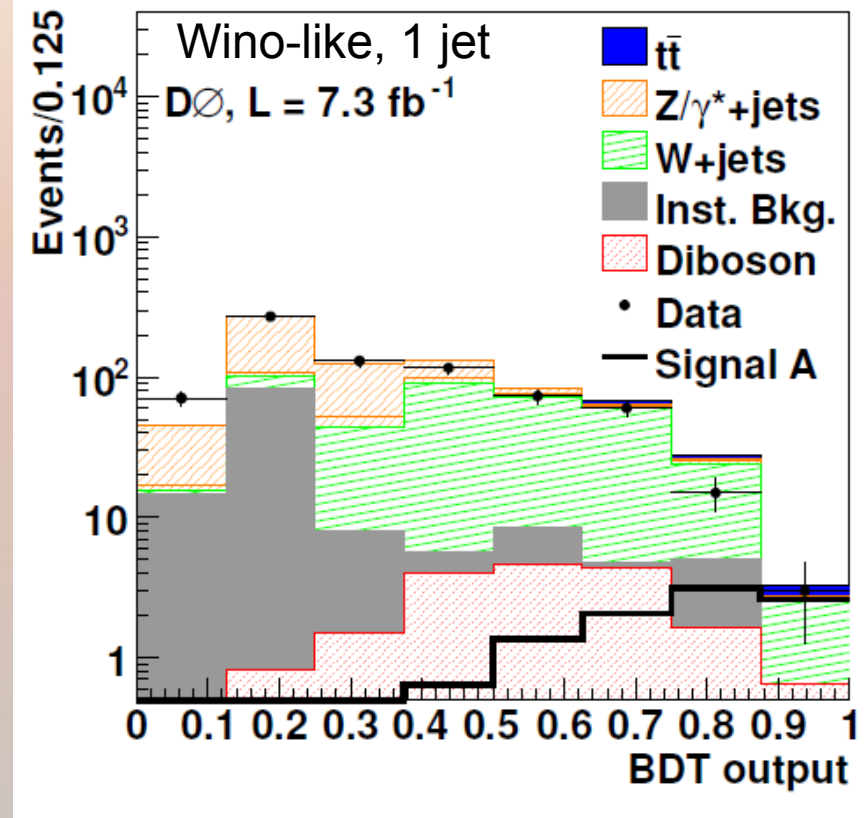


	Higgsino scenario		
	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$
Signal A	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\text{Mass}(\mu, \tau)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	H_T
	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\text{Mass}(\mu, \tau)$
	$\text{Mass}(\text{lept}, \text{jet})$	$M_T(\tau, \cancel{E}_T)$	$\text{Mass}(\mu, \text{jet})$
Signal B	$\Delta\eta(\mu, \tau)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \tau)$
	S_T	$\eta(\text{leading jet})$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	$\eta(\tau)$	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$	$\Delta\phi(\mu, \cancel{E}_T)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$	$\Delta\phi(\tau, \cancel{E}_T)$



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- We train separate BDTs for wino-like and Higgsino-like chargino scenarios
- Separate BDTs are trained for each mass point for 1 jet, 2 jet, and 3 or more jet events

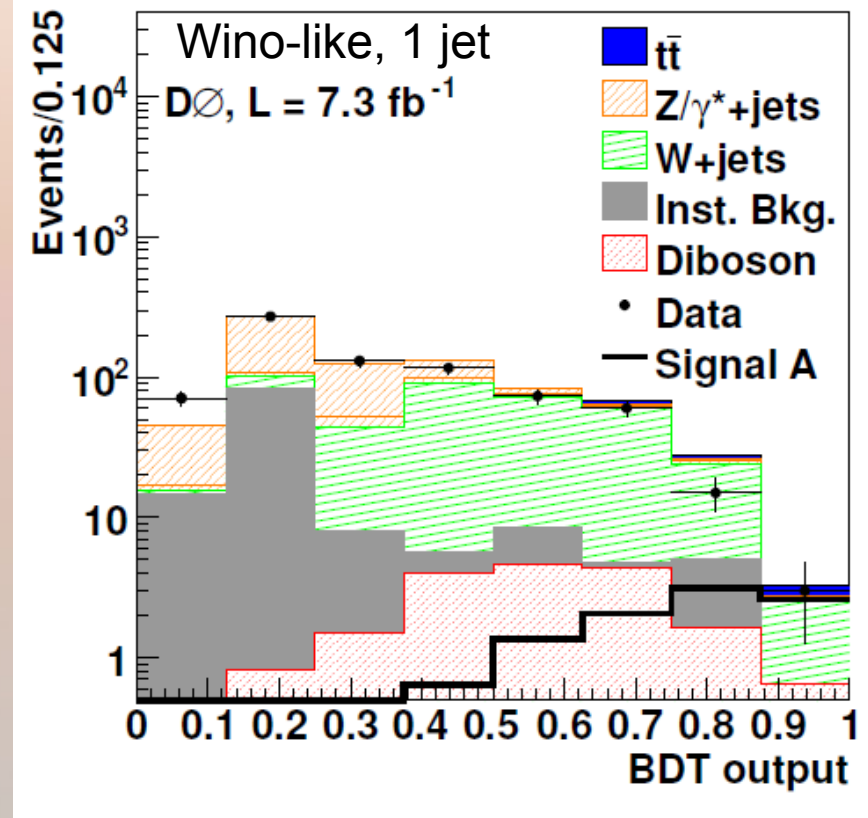


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Signal A	S_T	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^{τ}
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$
Signal B	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	$\text{Mass}(\mu, \text{jet})$



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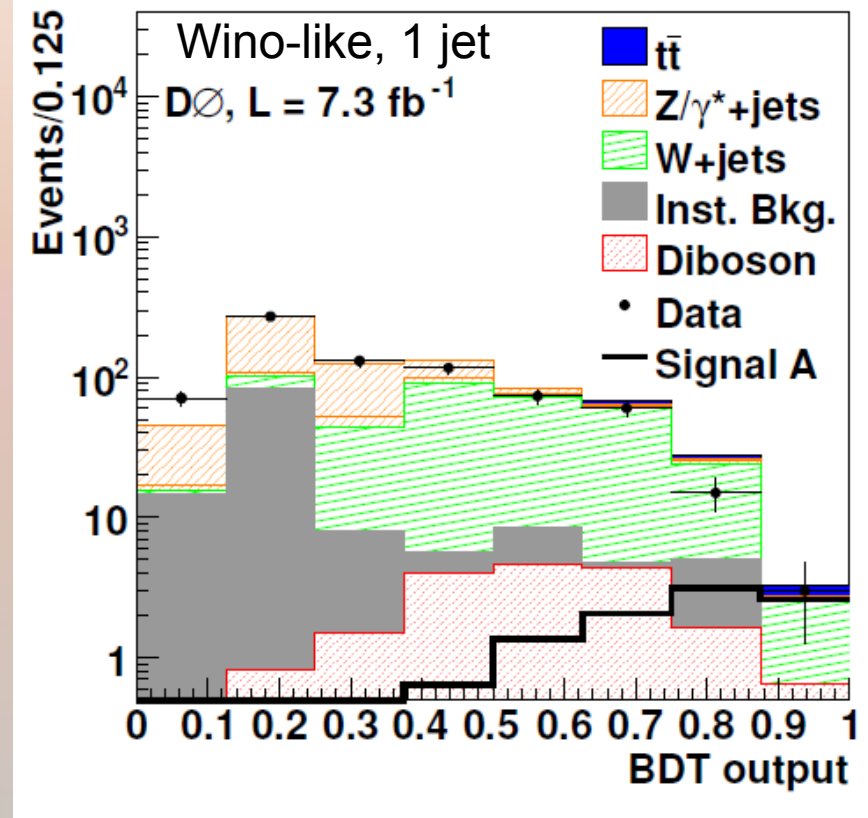


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	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^τ
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$
Signal B	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	$\text{Mass}(\mu, \text{jet})$



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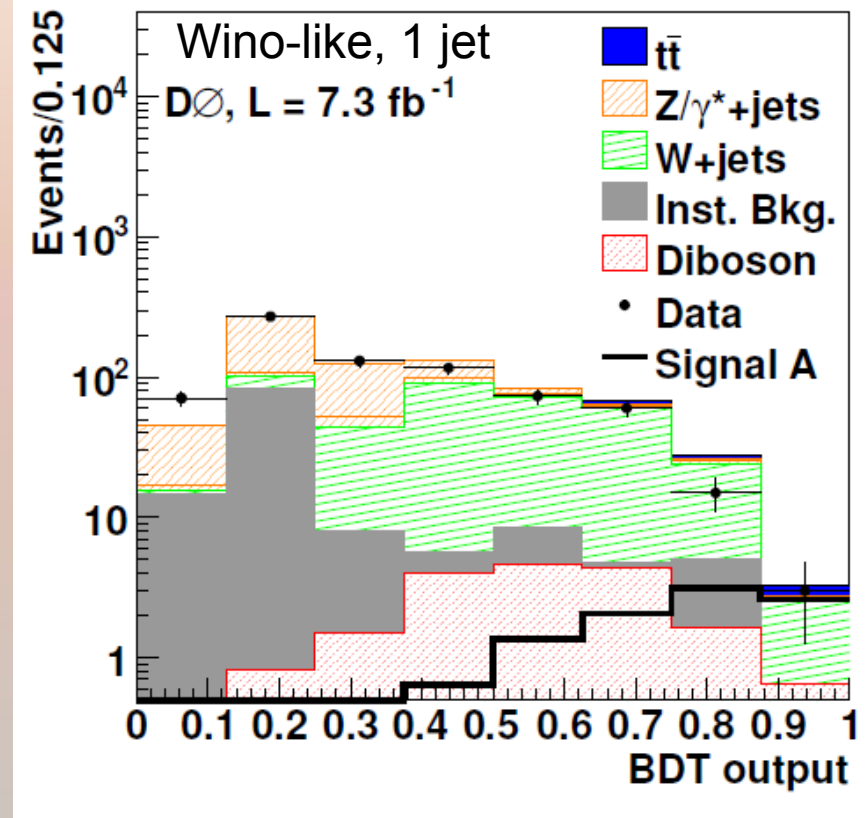


	Wino scenario		
	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$
Signal A	S_T	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^τ
	Mass(lept, jet)	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$
Signal B	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	Mass(lept, jet)	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	Mass(μ, jet)



Boosted Decision Tree (BDT)

- We train BDT to separate signal from SM background
- BDTs trained for each stop/sneutrino mass point
- We train separate BDTs for wino-like and Higgsino-like chargino scenarios
- Separate BDTs are trained for each mass point for 1 jet, 2 jet, and 3 or more jet events



	Wino scenario		
	$N(\text{jets})=1$	$N(\text{jets})=2$	$N(\text{jets})\geq 3$
Signal A	S_T	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\text{leading jet})$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$	$\Delta\mathcal{R}^{\max}(\tau, \text{jet})$
	$M_T(\mu, \cancel{E}_T)$	$\Delta\phi(\mu\tau, \cancel{E}_T)$	E_T^{τ}
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\max}(\mu, \text{jet})$	$p_T(\text{leading jet})$
Signal B	$\text{Sig}(\cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$	$\Delta\phi^{\min}(\text{jet}, \cancel{E}_T)$
	$\eta(\tau)$	$\eta(\text{leading jet})$	$\text{Sig}(\cancel{E}_T)$
	S_T	$\Delta\mathcal{R}^{\min}(\tau, \text{jet})$	$\Delta\phi(\mu + \tau, \cancel{E}_T)$
	$\Delta\phi(\mu, \tau)$	$\Delta\phi(\text{next-to-leading jet}, \cancel{E}_T)$	$\Delta\phi(\text{leading jet}, \cancel{E}_T)$
	$\text{Mass}(\text{lept}, \text{jet})$	$\Delta\mathcal{R}^{\min}(\mu, \text{jet})$	$\text{Mass}(\mu, \text{jet})$