Searching for Compressed Supersymmetric Spectra at the Large Hadron Collider

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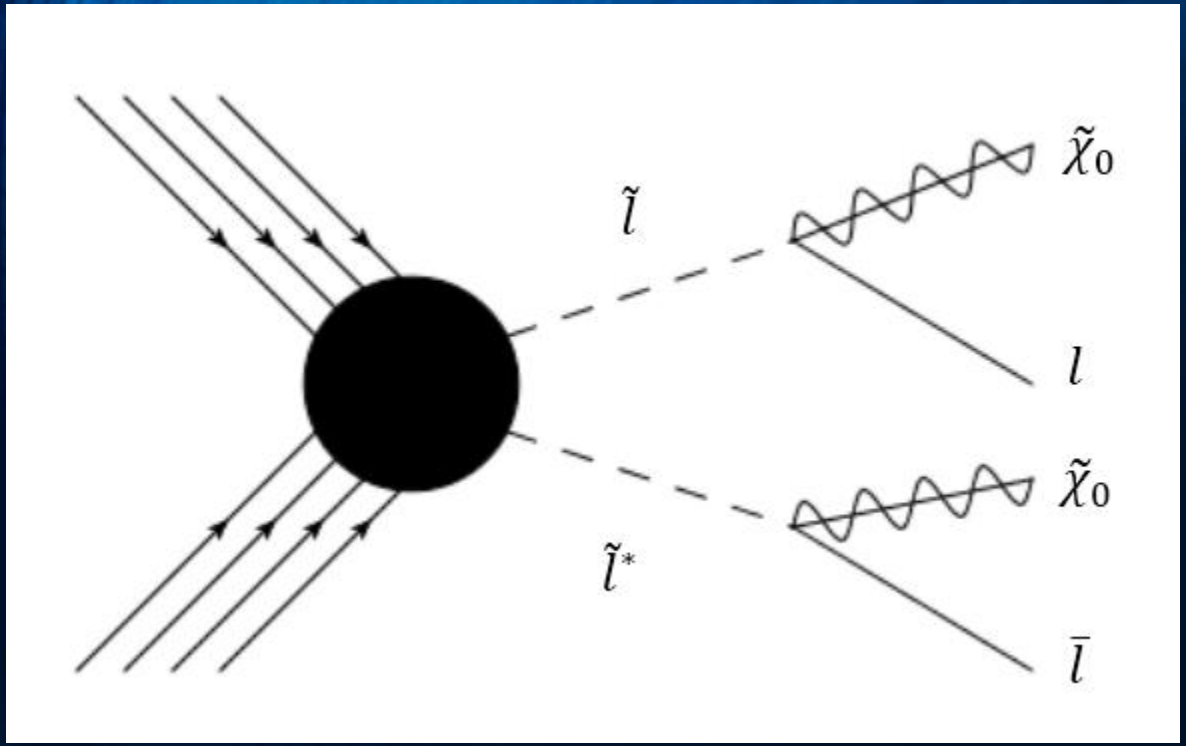
Overview

- Compressed mass spectra
- Background and Signal discrimination
- Cut Flow
- Optimization
- Findings

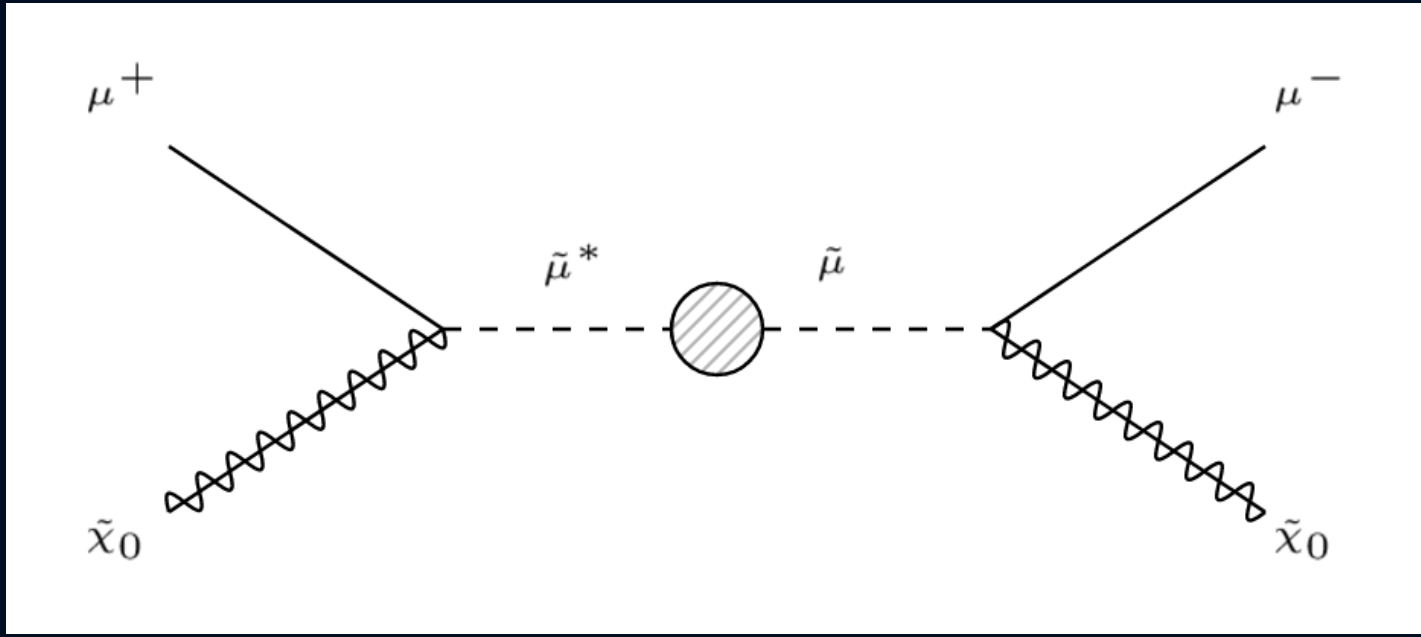
Compressed mass spectra

- The SUSY particles have degenerate mass, thus during their decay there isn't much energy left for the SM particles to emerge with
- Require an ISR jet to boost the soft leptons
- Baer et al. – Monojet + dilepton + Missing Et analysis(arXiv:1409.7058v2)



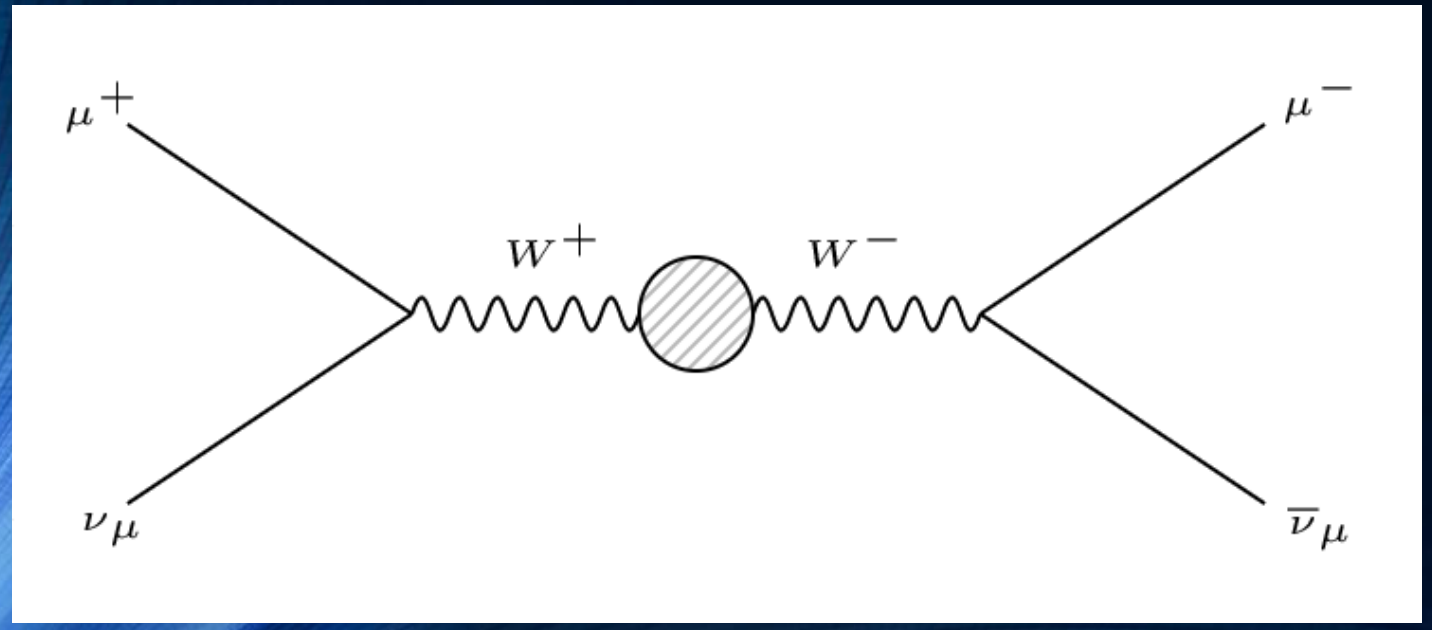
Event Topology

- Difficult to control BG in WW



Signal (slepton pair production) - Spin 0 (smuon), daughter is massive (100 GeV)

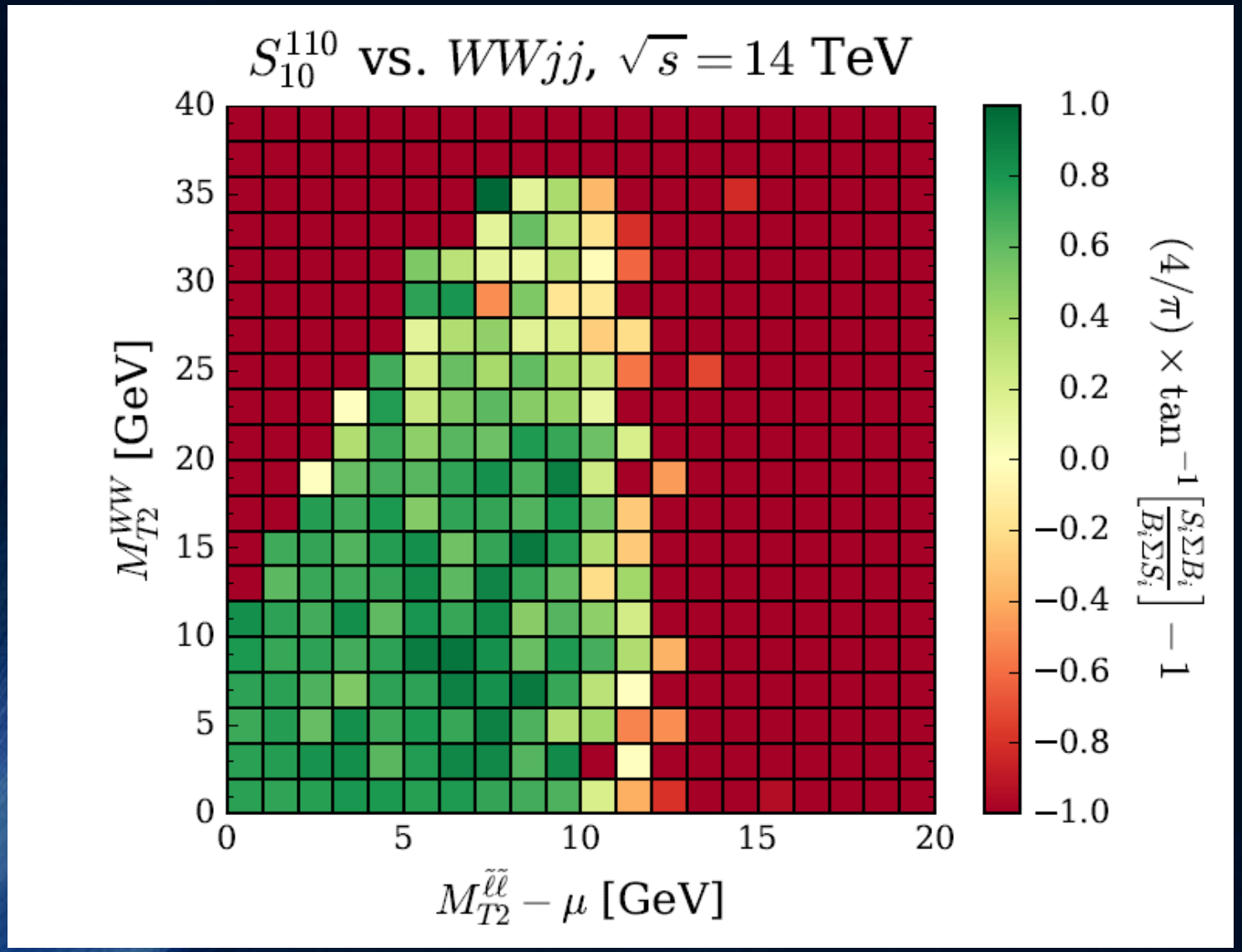
Background (WWjj) - Spin 1 (W boson), massless daughter (~ 0 GeV)

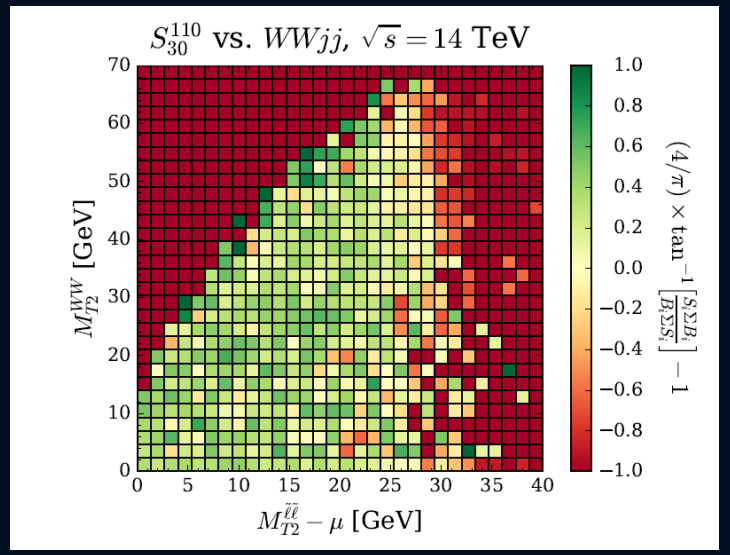


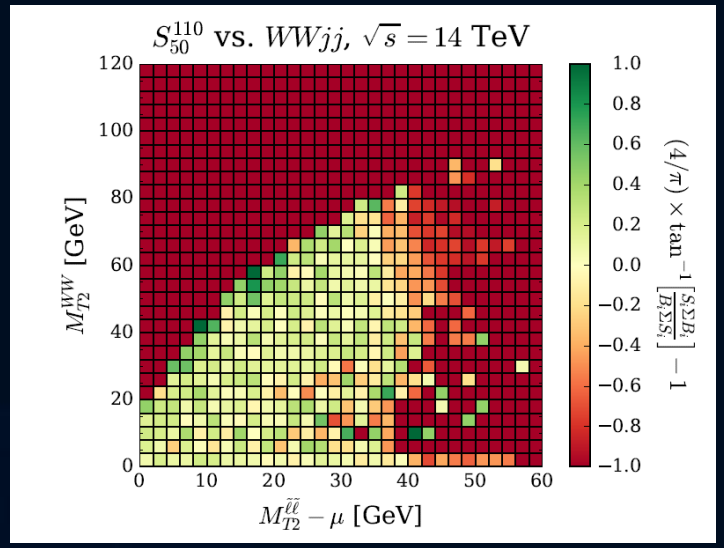
M_{T2} Statistic

- Estimator of a parent mass for a pair production event with missing transverse energy
- Suggested by Han,Liu (arXiv:1412:0618) for soft leptonic decay
- We propose comparing $M_{T2}^{\tilde{l}\tilde{l}} - \mu$ and M_{T2}^{WW}
- Can't be larger than the parent mass (if the hypothesis applies)

Mass Discrimination between M_{T2} variables





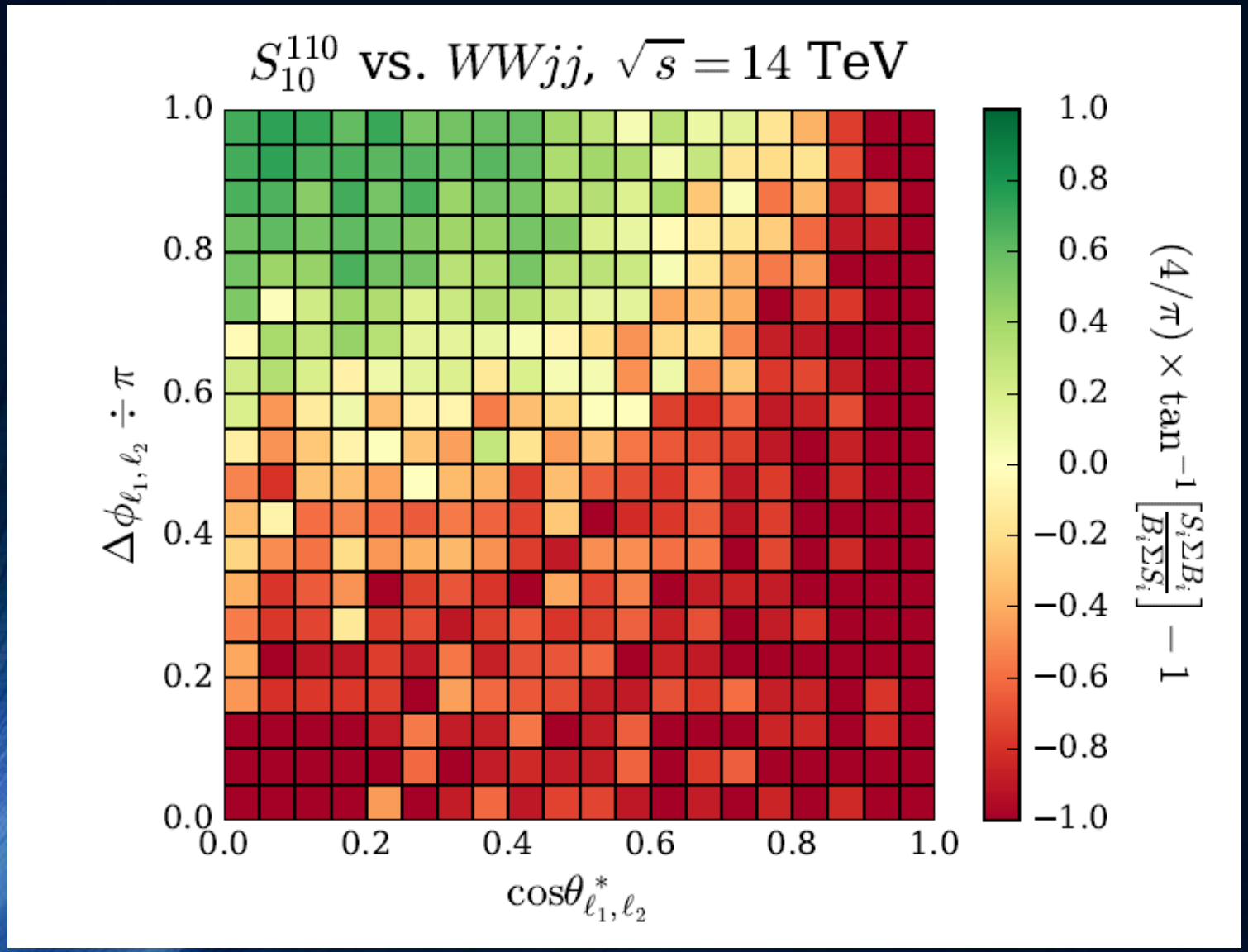


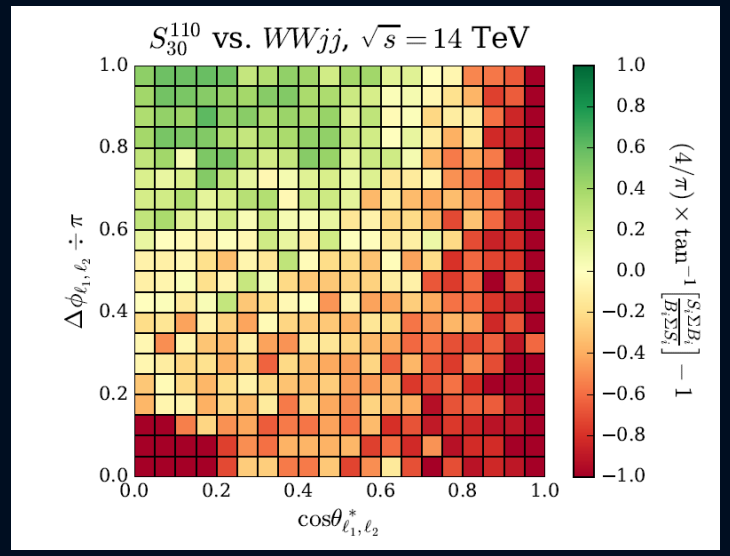
$\cos\theta^*{}_{l_1 l_2}$ statistic

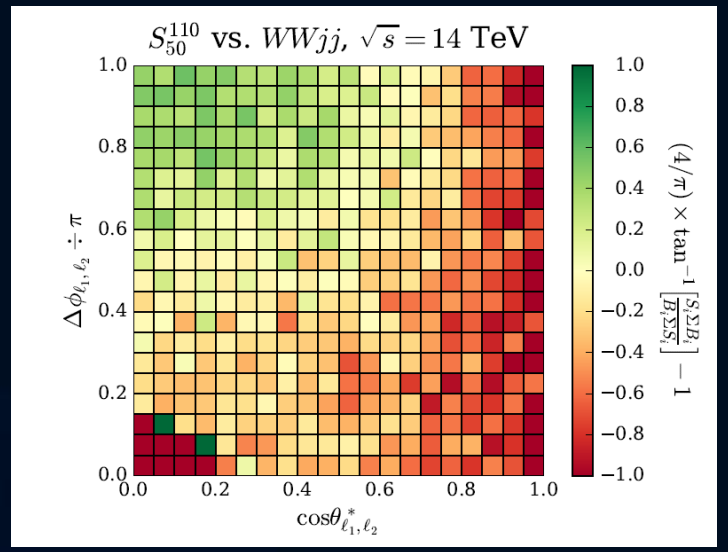
$$\cos\theta_{l_1 l_2}{}^* = \tanh\left(\frac{\Delta\eta_{l_1 l_2}}{2}\right), \Delta\eta_{l_1 l_2} = \eta_{l_1} - \eta_{l_2}$$

- The cosine of the polar angle between each lepton and the beam axis in the longitudinally boosted frame in which the psuedorapidities of the leptons are equal and opposite
- Utilize the mother particles' different spins to manifest angular correlations in the daughter particles
- WARNING : delta phi is influenced by the mass gap

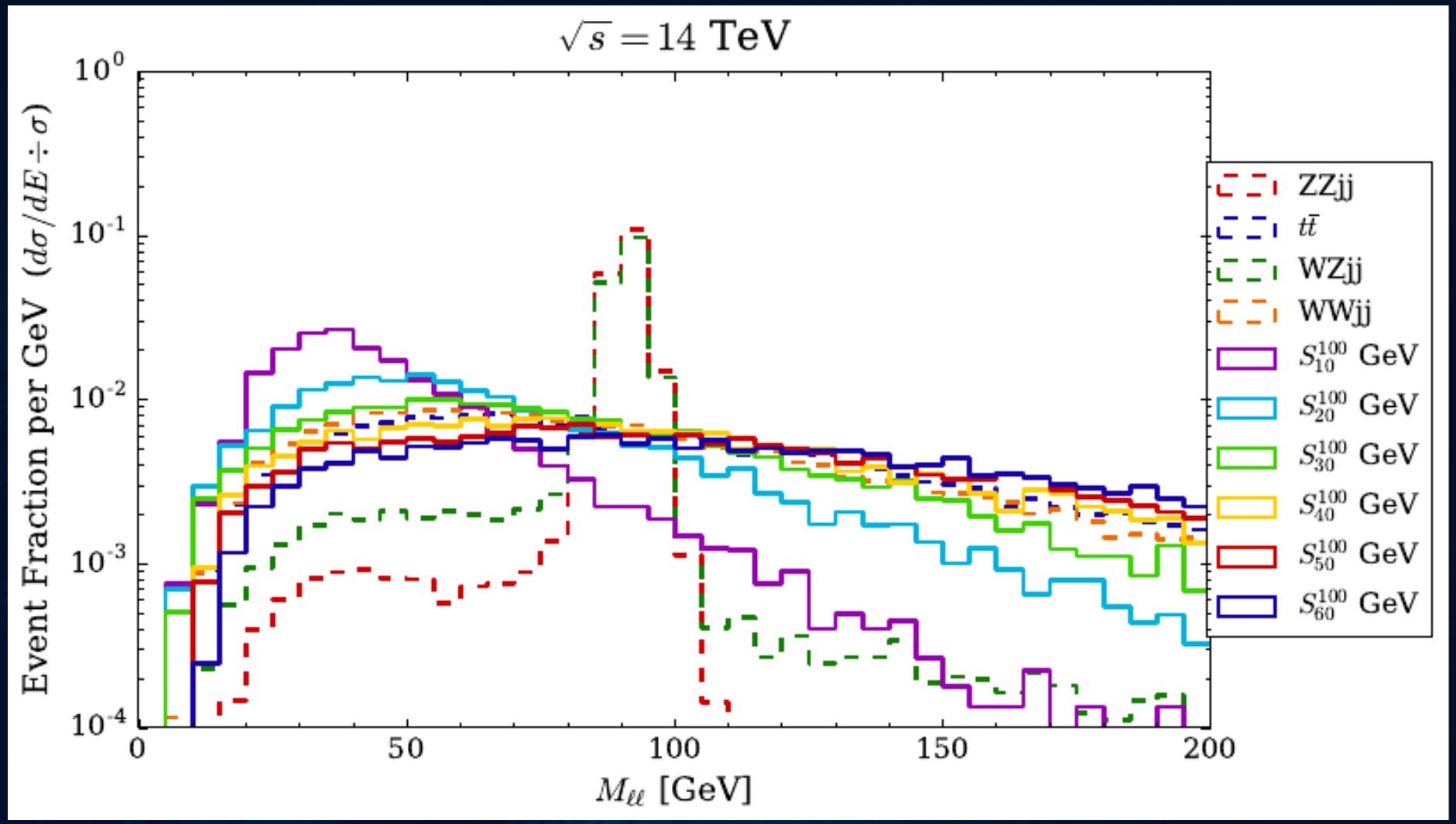
Spin Discrimination between angular variables



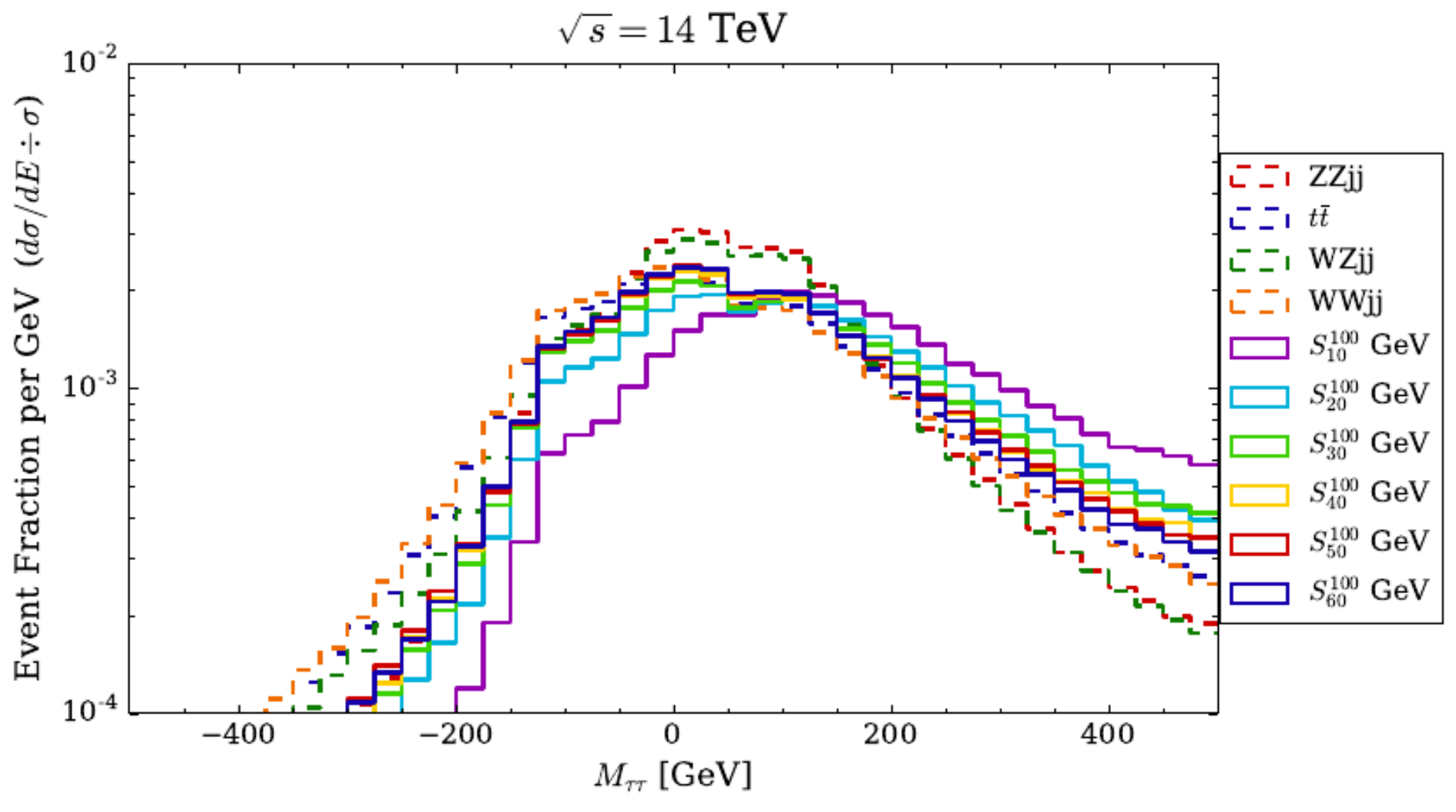




Mass of a reconstructed dilepton



Mass of a reconstructed ditau

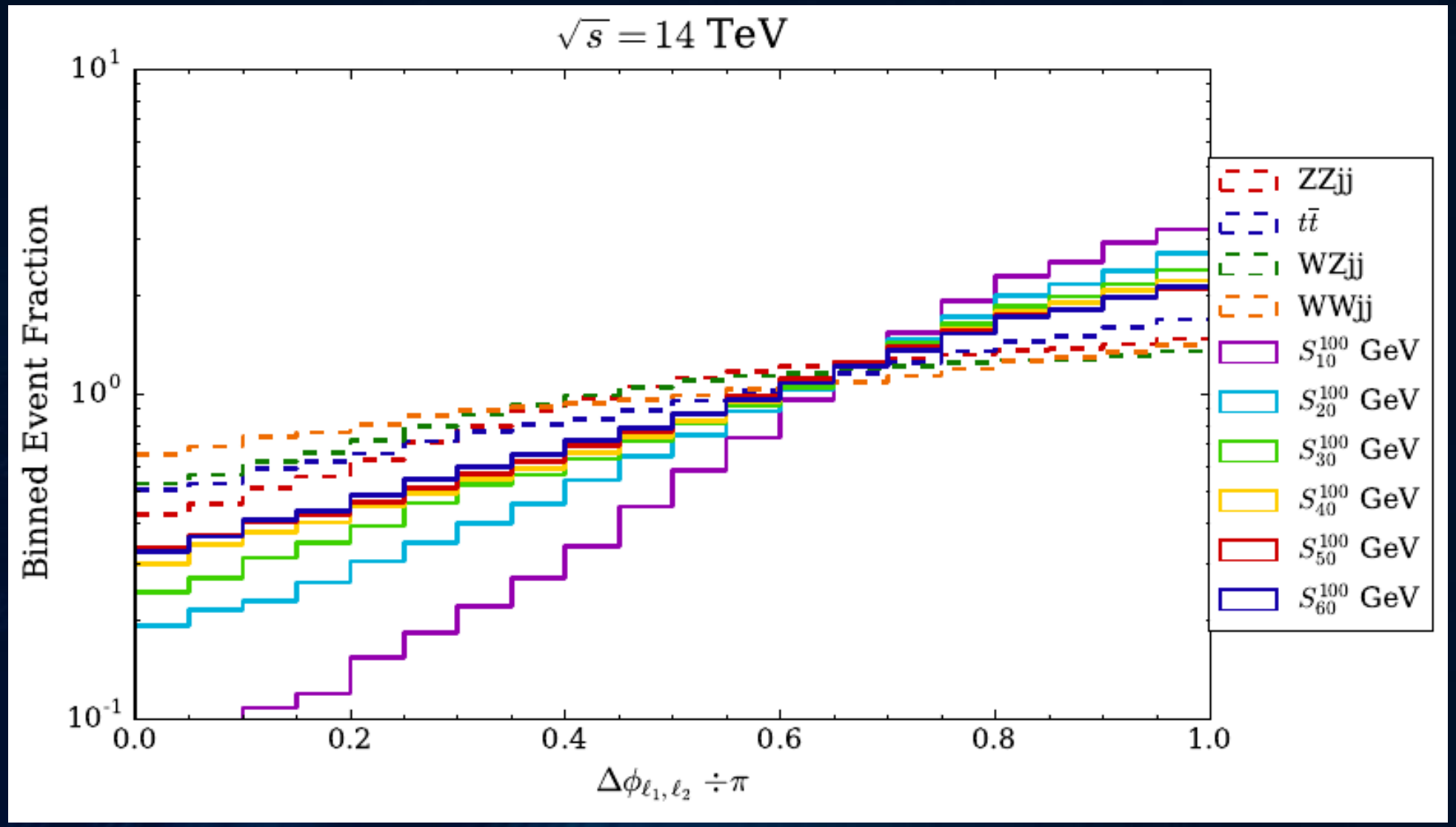


Ditau mass statistic

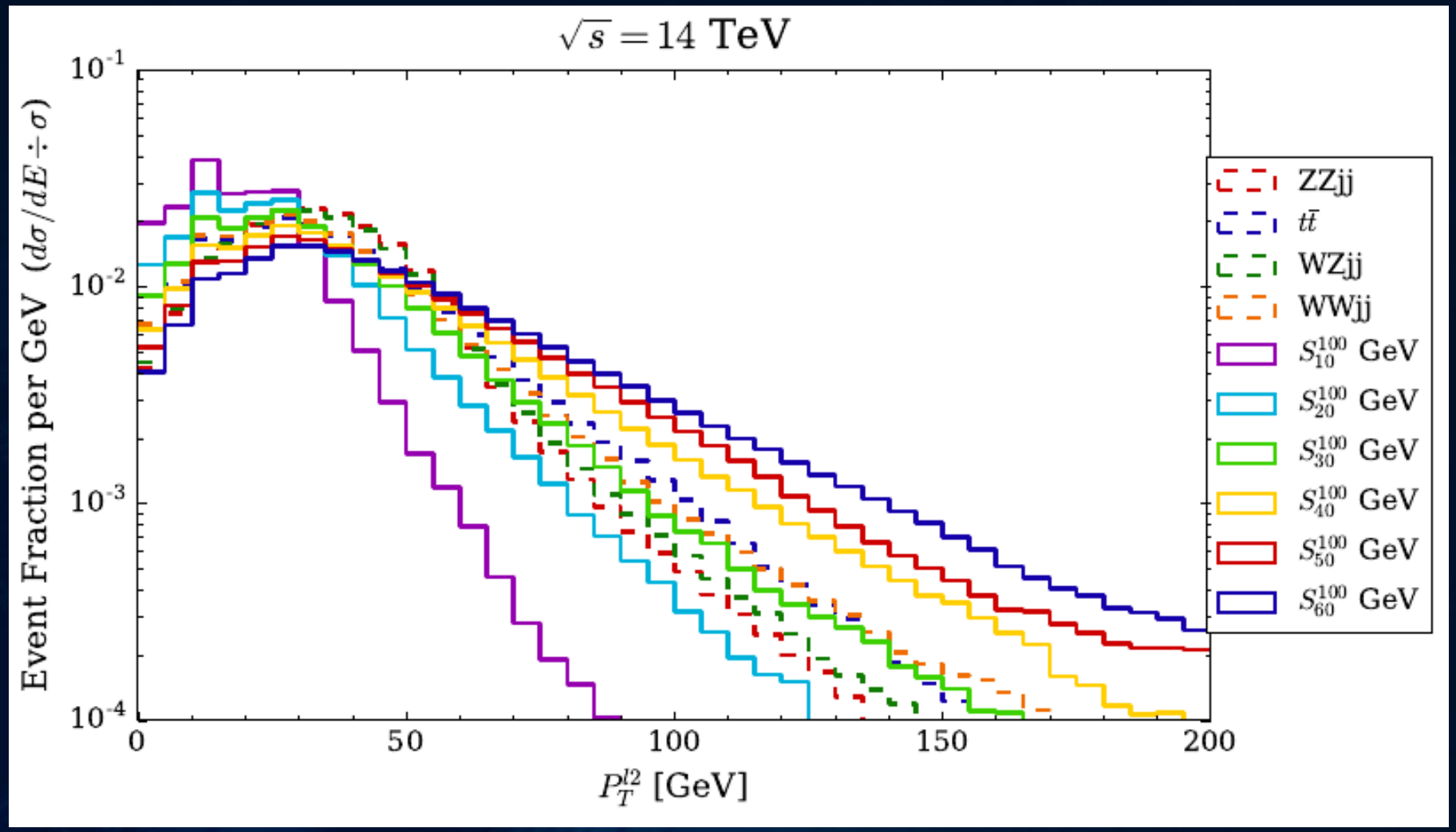
- Previously used by Dr. Baer in similar analysis, this statistic recreates the mass of a tau pair that decays fully leptonically (with 4 neutrinos)

- $m_{\tau\tau} = -m_{l_1 l_2} \frac{\left(\vec{P}_T^{l_1} \times \vec{P}_T^{j}\right) . \left(\vec{P}_T^{l_2} \times \vec{P}_T^{j}\right)}{\left|\vec{P}_T^{l_2} \times \vec{P}_T^{l_2}\right|^2}$
- Proven to be valuable kinematic discriminant for cutting background

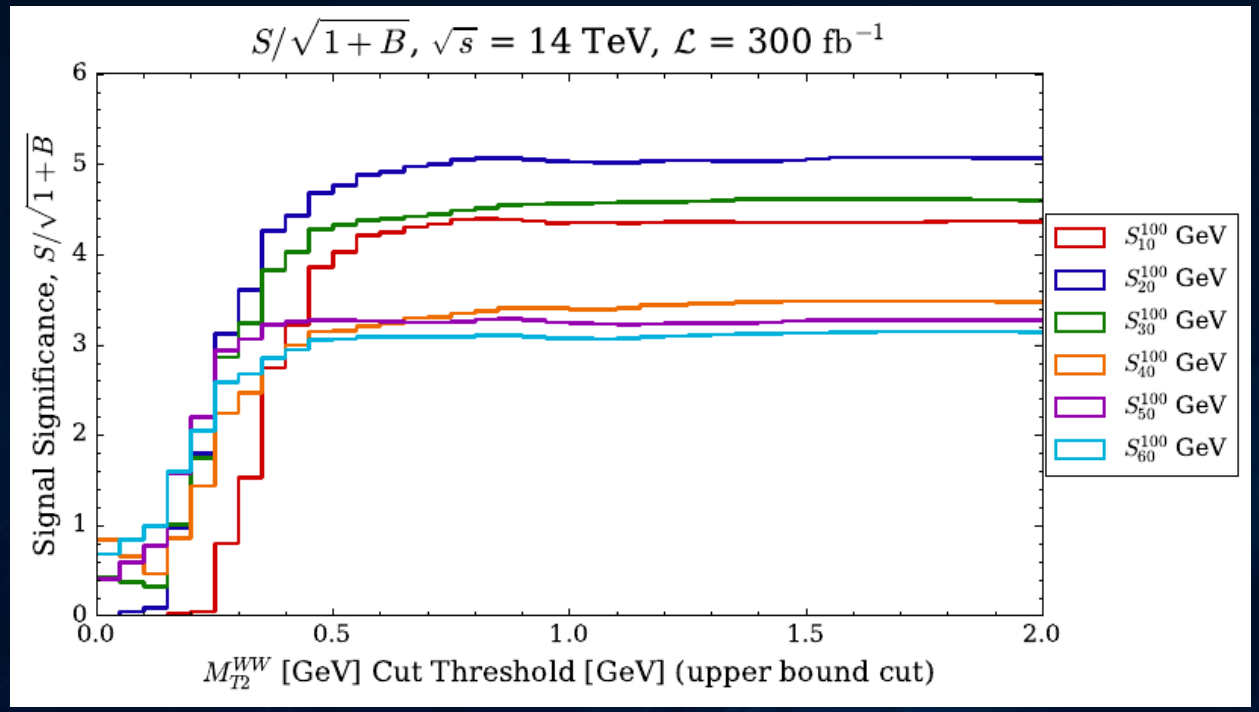
Azimuthal angle between the dileptons

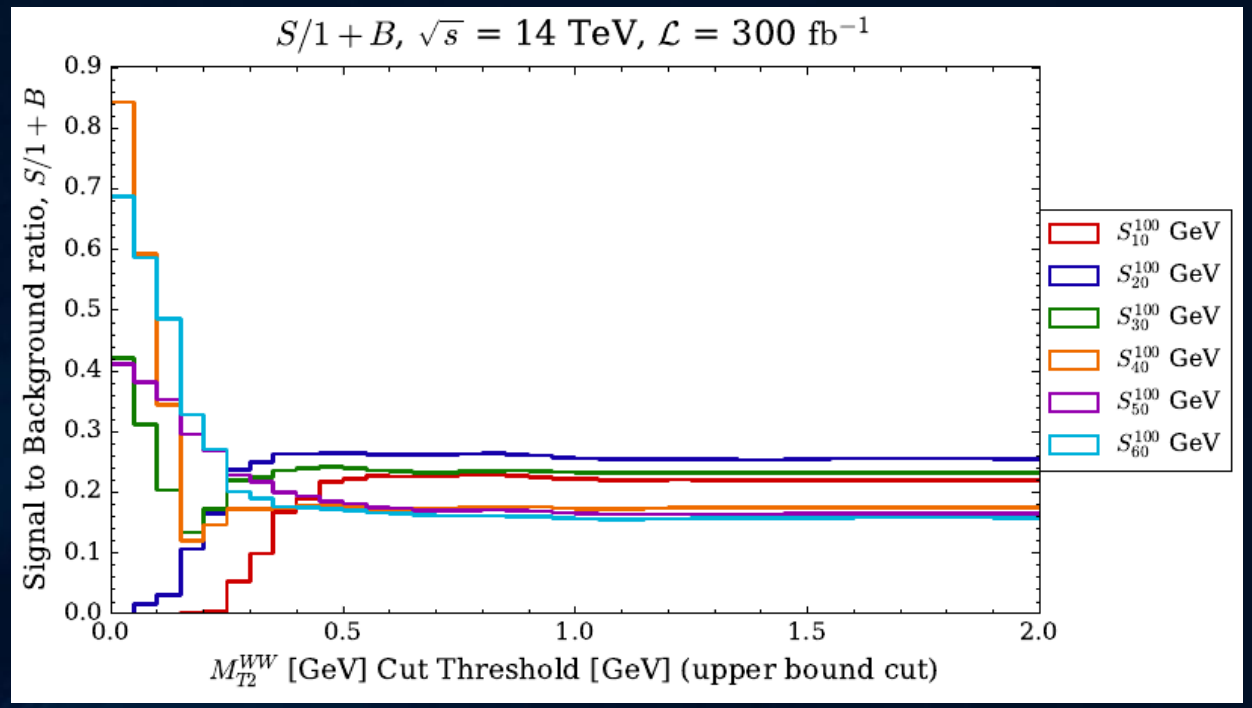


Transverse momentum of the sub-leading lepton



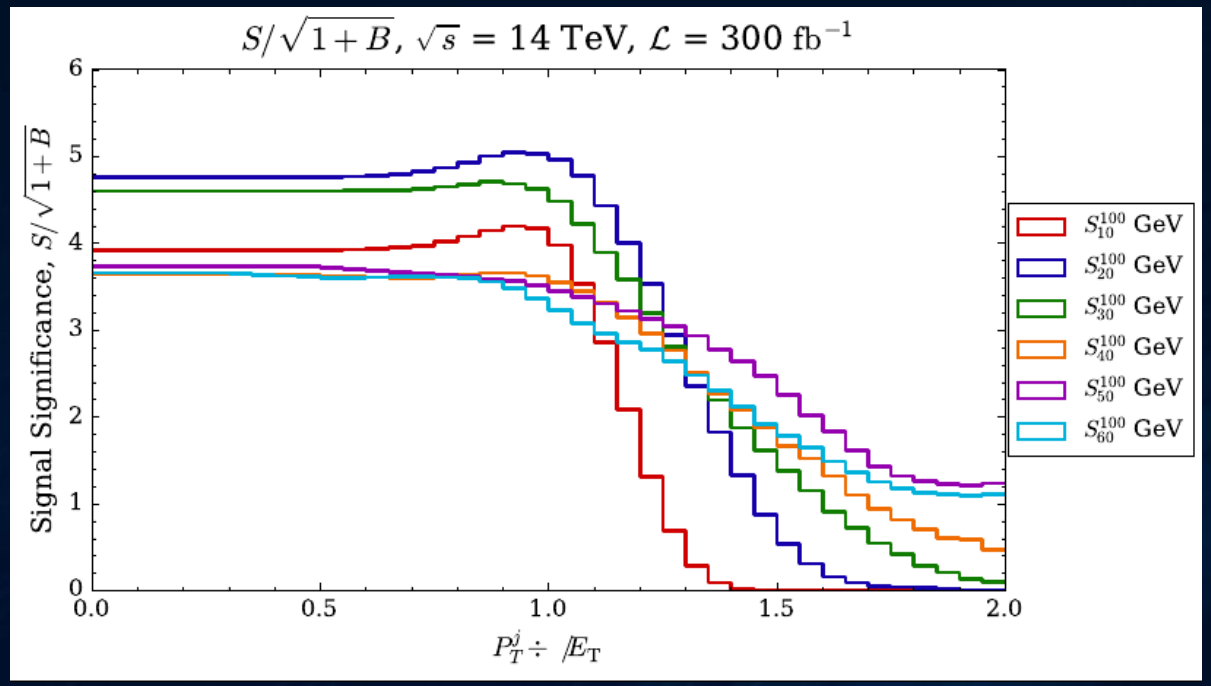
Statistical significance and S/B ratio

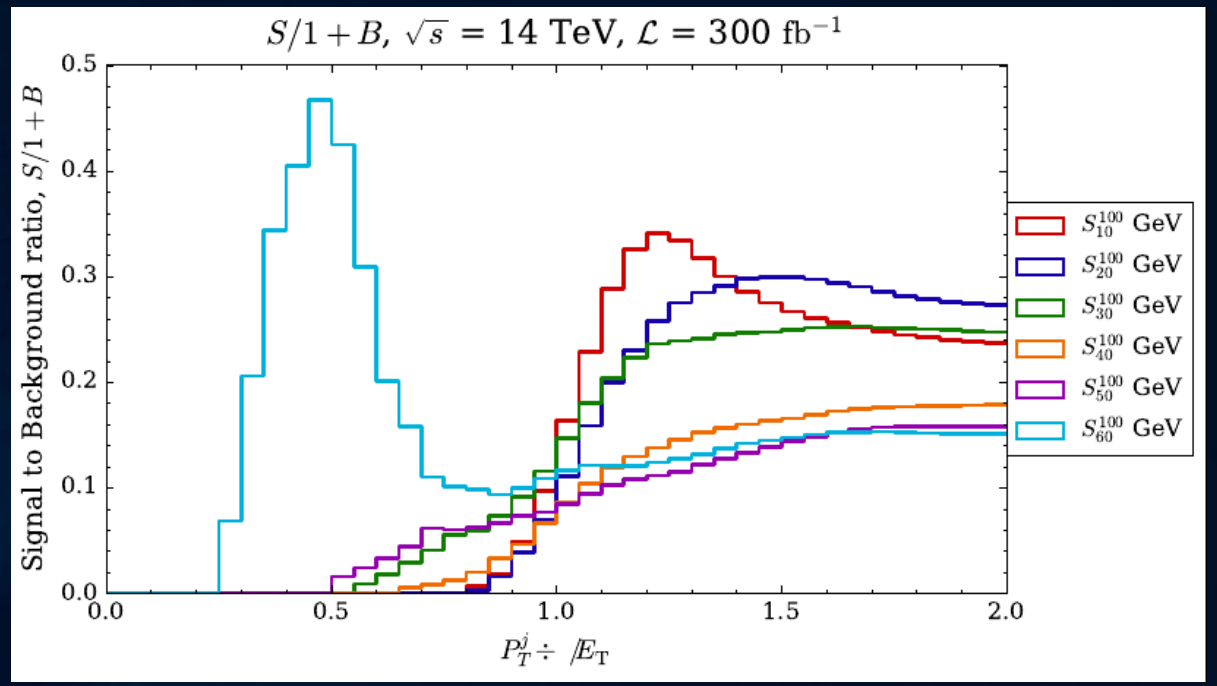




$M_{T2}^{WW} < 1$ GeV

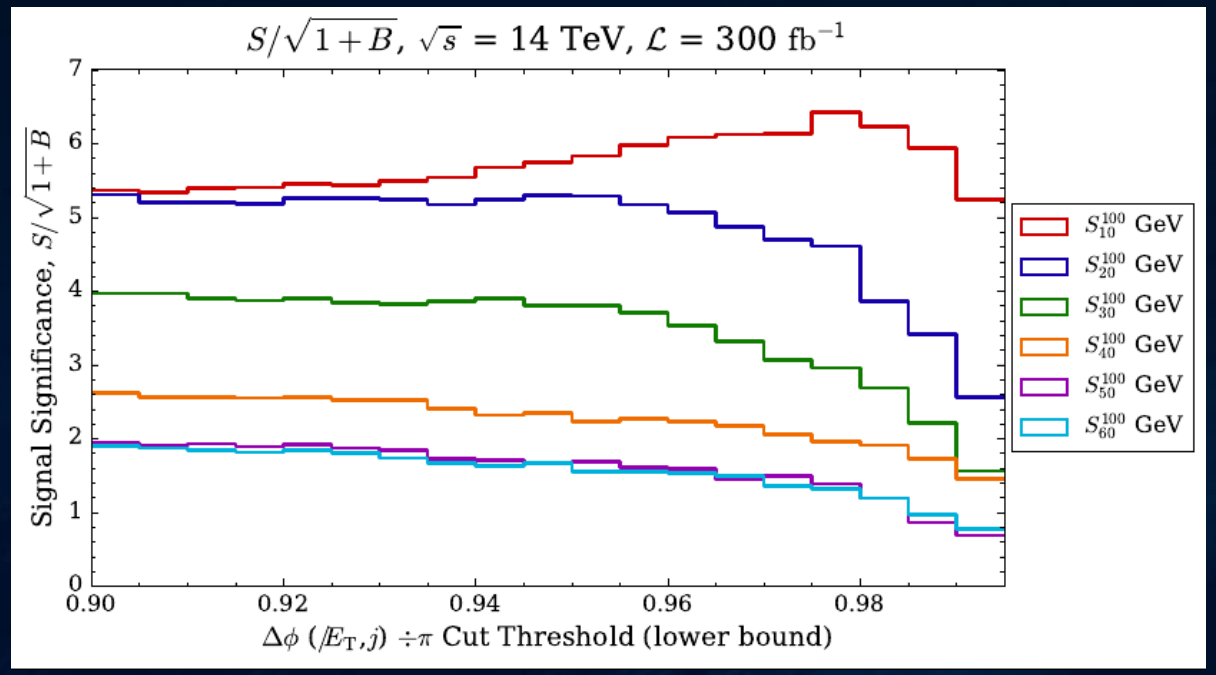
Statistical significance and S/B ratio

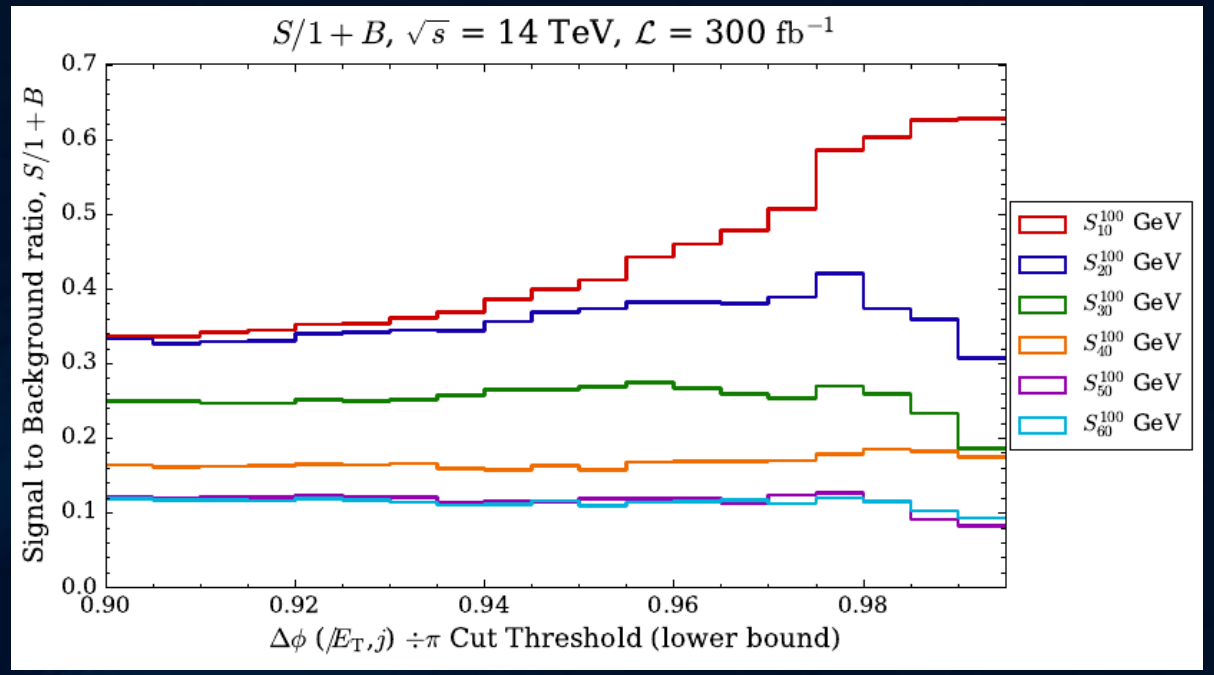




0.8 < PT / MET < 1.4

Statistical significance and S/B ratio





(Delta phi between MET and j) / π > 0.95

Tertiary cuts for smaller mass gaps

Selection	$t\bar{t}jj$	$ZZjj$	$WZjj$	$WWjj$	S_{10}^{110}	S_{20}^{110}	S_{30}^{110}	S_{40}^{110}	S_{50}^{110}	S_{60}^{110}
$M_{T2}^{WW} < 1$ GeV	2.4×10^{-1}	3.9×10^{-3}	7.0×10^{-2}	8.6×10^{-1}	2.7×10^{-1}	3.0×10^{-1}	2.8×10^{-1}	2.1×10^{-1}	2.0×10^{-1}	1.9×10^{-1}
$0.8 < P_T^j \div \not{E}_T < 1.4\}$	1.9×10^{-1}	3.3×10^{-3}	3.6×10^{-2}	6.0×10^{-1}	2.7×10^{-1}	2.7×10^{-1}	2.1×10^{-1}	1.5×10^{-1}	1.1×10^{-1}	1.2×10^{-1}
$\Delta\phi(\not{E}_T, j) \div \pi > 0.95$	1.4×10^{-1}	2.7×10^{-3}	2.3×10^{-2}	4.4×10^{-1}	2.6×10^{-1}	2.3×10^{-1}	1.6×10^{-1}	1.0×10^{-1}	6.7×10^{-2}	6.6×10^{-2}
$\Delta\phi(\ell_1, j) \div \pi > 0.5$	7.8×10^{-2}	2.2×10^{-3}	1.9×10^{-2}	3.7×10^{-1}	2.5×10^{-1}	2.1×10^{-1}	1.4×10^{-1}	8.9×10^{-2}	6.0×10^{-2}	6.0×10^{-2}
Events at $\mathcal{L} = 300$ fb^{-1}	23.4	0.7	5.7	111.3	75.0	63.0	42.0	26.7	18.0	18.0
$S \div B$	-	-	-	-	0.53	0.45	0.30	0.19	0.13	0.13
$S \div \sqrt{B}$	-	-	-	-	6.3	5.3	3.5	2.2	1.5	1.5
Poisson Significance	-	-	-	-	6.0	5.2	3.6	2.5	1.9	1.9

Muon reconstruction @ 5 GeV

5 GeV muon	S_{10}^{110}	S_{20}^{110}	S_{30}^{110}
Events at $\mathcal{L} = 300\ \mathrm{fb}^{-1}$	90.0	72.0	42.0
$S \div B$	0.64	0.51	0.30
$S \div \sqrt{B}$	7.6	6.1	3.5
Poisson Significance	7.1	5.8	3.6

Conclusion

- Collider searches are weakened(due to softness of decay products)
- Can be improved by a transverse boost, plus dedicated cuts
  - Monojet + 2l + missing transverse energy provides best option
- Mass/Spin discrimination with MT2(WW vs $(\tilde{l}\tilde{l} - \mu)$) & $\cos\theta^*{}_{l_1 l_2}$

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- Dr. Jason Kumar
- Dr. Pearl Sandick
- Dr. Tathagata Ghosh
- Dr. Patrick Stengel
- NSF
- PHENO 2017

- All 1D and 2D histogram plots and event selection analysis done using software packages AEACuS and RHADAManTHUS available at: joelwalker.net

Thank you!

References

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- "MT2 To the Rescue…" Zhenyu Han and Yandong Liu, https://arxiv.org/abs/1412.0618
- "Monojet plus soft dilepton…", Howard Baer et al., https://arxiv.org/abs/1409.7058
- "Draw Feynman…", https://feynman.aivazis.com/

Questions?

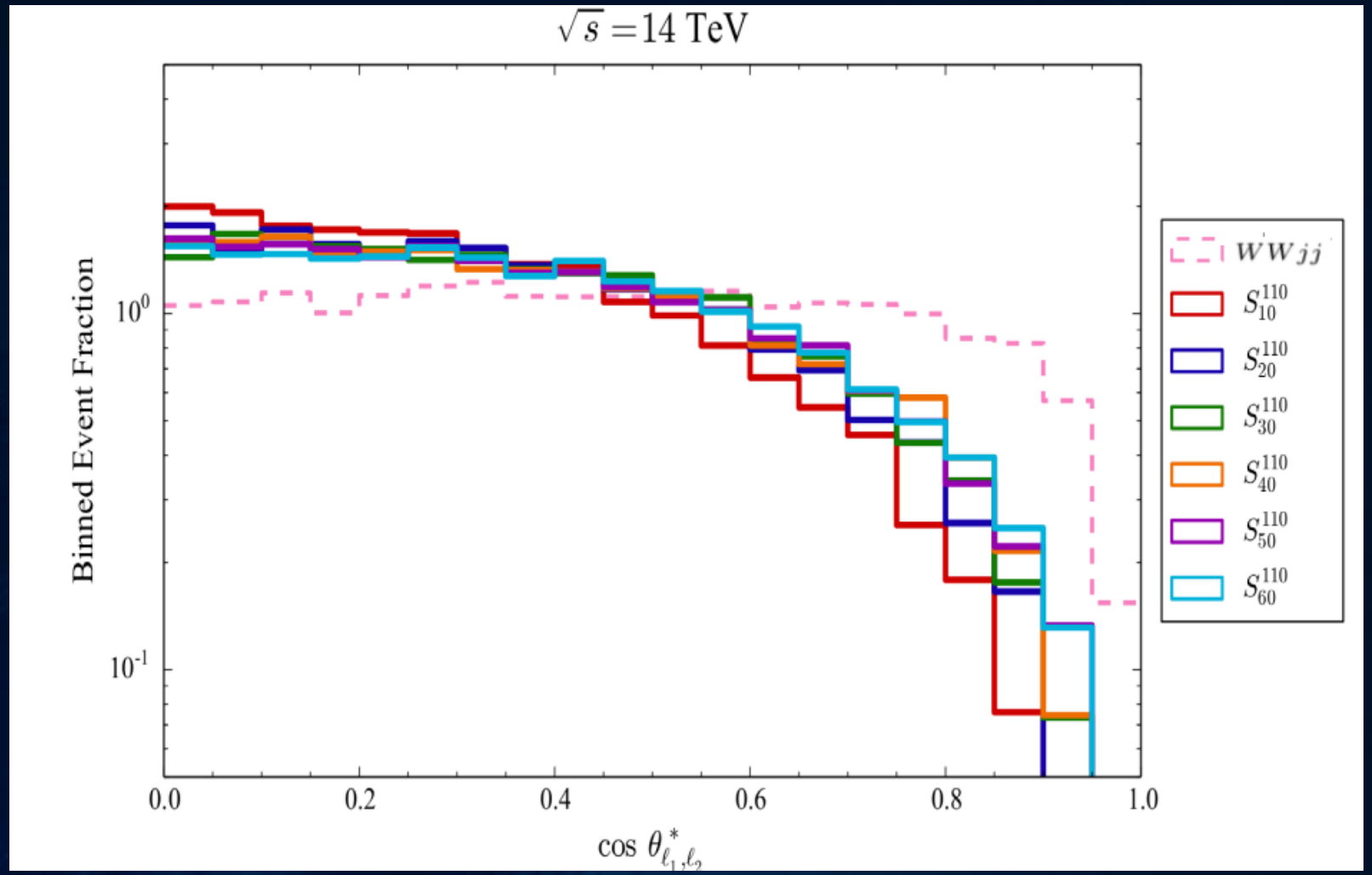
Secondary cuts for all mass gaps

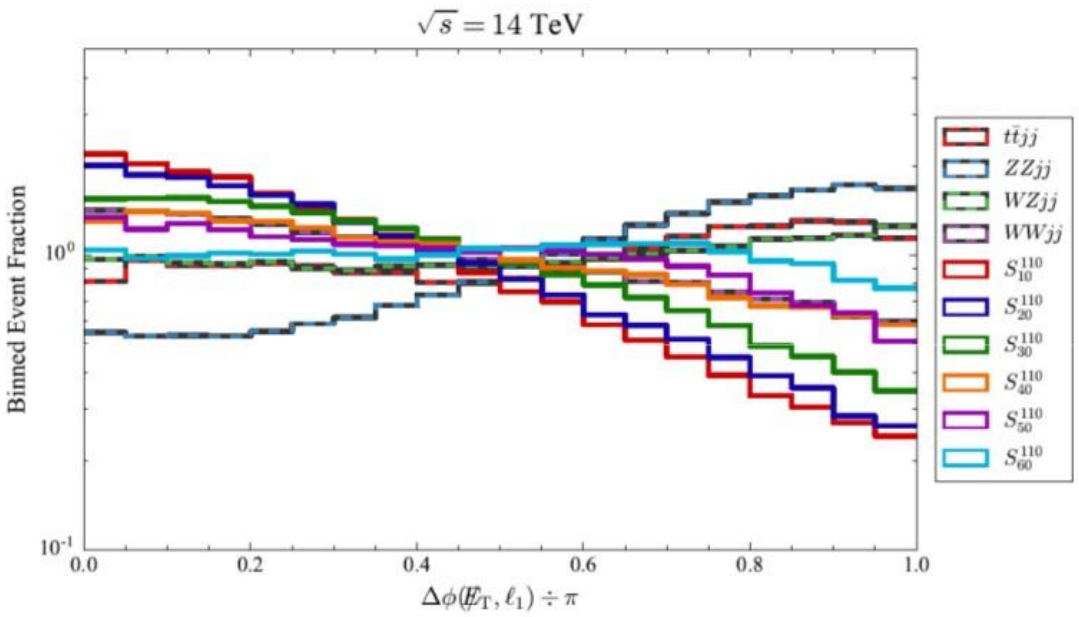
Selection	$t\bar{t}jj$	$ZZjj$	$WZjj$	$WWjj$	S_{10}^{110}	S_{20}^{110}	S_{30}^{110}	S_{40}^{110}	S_{50}^{110}	S_{60}^{110}
Matched Production	6.1×10^5	1.3×10^4	4.2×10^4	9.5×10^4	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2
τ-veto	5.4×10^5	1.2×10^4	4.0×10^4	8.9×10^4	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2	1.9×10^2
OSSF muon	3.5×10^3	3.2×10^2	5.8×10^2	5.1×10^2	3.9×10^1	6.8×10^1	8.1×10^1	8.8×10^1	8.9×10^1	9.1×10^1
only 1J $P_T > 30$	6.6×10^2	9.4×10^1	1.5×10^2	1.1×10^2	7.6×10^0	1.3×10^1	1.6×10^1	1.7×10^1	1.7×10^1	1.8×10^1
Jet b-veto	1.9×10^2	8.0×10^1	1.4×10^2	1.1×10^2	7.5×10^0	1.3×10^1	1.6×10^1	1.7×10^1	1.7×10^1	1.8×10^1
$\not{E}_T > 100$ GeV	3.2×10^1	4.3×10^0	7.8×10^0	1.7×10^1	1.3×10^0	2.1×10^0	2.5×10^0	3.4×10^0	3.8×10^0	4.8×10^0
Jet $P_T > 100$ GeV	1.2×10^1	1.4×10^0	4.0×10^0	1.0×10^1	1.3×10^0	1.8×10^0	1.8×10^0	1.9×10^0	1.8×10^0	1.9×10^0
$m_{\ell\ell} \notin M_Z \pm 10$ GeV	1.1×10^1	1.0×10^{-1}	1.0×10^0	8.9×10^0	1.2×10^0	1.5×10^0	1.6×10^0	1.6×10^0	1.5×10^0	1.7×10^0
$m_{\tau\tau} > 175$ GeV	4.8×10^0	2.0×10^{-2}	3.3×10^{-1}	4.5×10^0	8.1×10^{-1}	9.0×10^{-1}	9.3×10^{-1}	9.3×10^{-1}	9.3×10^{-1}	9.6×10^{-1}
$\not{E}_T > 175$ GeV	7.5×10^{-1}	8.3×10^{-3}	9.9×10^{-2}	1.3×10^0	2.9×10^{-1}	3.5×10^{-1}	3.5×10^{-1}	3.1×10^{-1}	3.2×10^{-1}	3.5×10^{-1}
Jet $P_T > 175$ GeV	3.7×10^{-1}	6.6×10^{-3}	8.7×10^{-2}	1.2×10^0	2.9×10^{-1}	3.3×10^{-1}	3.3×10^{-1}	2.6×10^{-1}	2.6×10^{-1}	2.7×10^{-1}

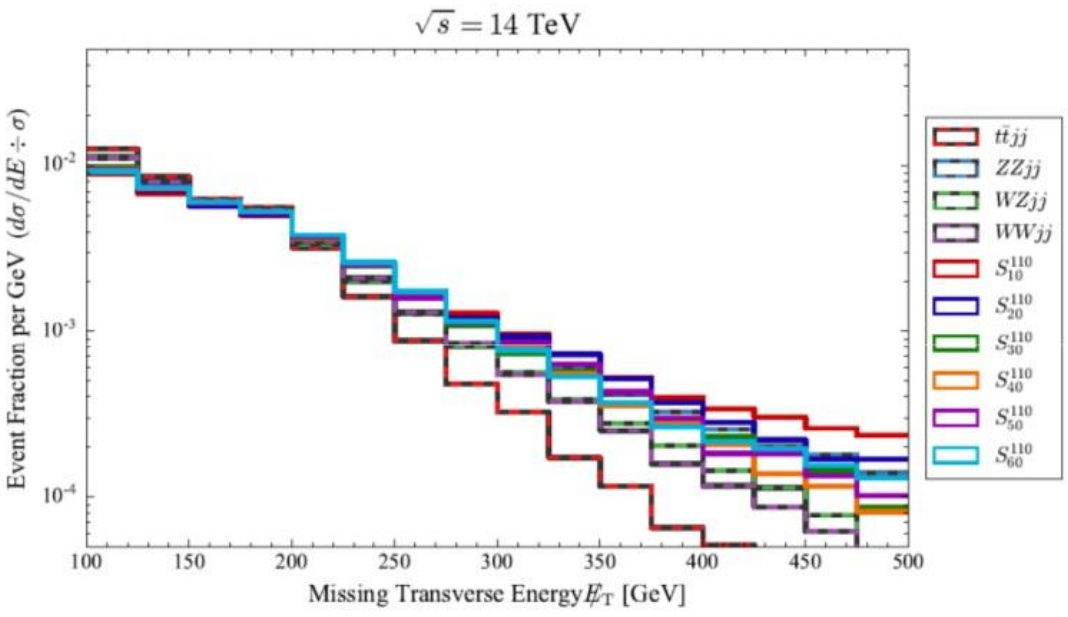
Tertiary cuts for larger mass gaps

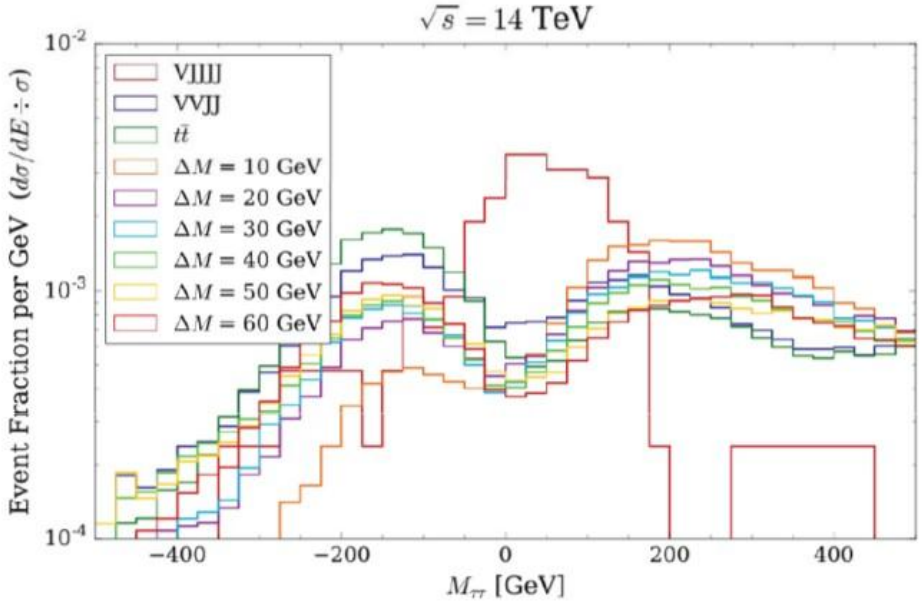
Selection	$t\bar{t}jj$	$ZZjj$	$WZjj$	$WWjj$	S_{10}^{110}	S_{20}^{110}	S_{30}^{110}	S_{40}^{110}	S_{50}^{110}	S_{60}^{110}
$M_{T2}^{WW} < 1$ GeV	2.4×10^{-1}	3.9×10^{-3}	7.0×10^{-2}	8.6×10^{-1}	2.7×10^{-1}	3.0×10^{-1}	2.8×10^{-1}	2.1×10^{-1}	2.0×10^{-1}	1.9×10^{-1}
$0.8 < P_T^j \div \not{E}_T < 1.8\}$	2.1×10^{-1}	3.9×10^{-3}	5.6×10^{-2}	7.5×10^{-1}	2.7×10^{-1}	3.0×10^{-1}	2.7×10^{-1}	1.9×10^{-1}	1.7×10^{-1}	1.7×10^{-1}
$\Delta\phi(\not{E}_T, \ell_1) \div \pi < 0.8$	1.8×10^{-1}	3.9×10^{-3}	5.4×10^{-2}	7.2×10^{-1}	2.7×10^{-1}	3.0×10^{-1}	2.6×10^{-1}	1.9×10^{-1}	1.6×10^{-1}	1.6×10^{-1}
$\Delta\phi(\ell_1, \ell_2) \div \pi > 0.5$	1.5×10^{-1}	2.7×10^{-3}	3.1×10^{-2}	5.6×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	1.6×10^{-1}	1.2×10^{-1}	1.4×10^{-1}
$P_T^{\ell 2} > 40$ GeV	3.9×10^{-2}	0	1.1×10^{-2}	2.3×10^{-1}	2.0×10^{-2}	8.1×10^{-2}	9.4×10^{-2}	8.7×10^{-2}	8.4×10^{-2}	9.4×10^{-2}
Events at $\mathcal{L} = 300$ fb^{-1}	11.8	0.0	3.4	68.5	6.0	24.3	28.2	26.1	25.2	28.2
$S \div B$	-	-	-	-	0.07	0.29	0.34	0.31	0.30	0.34
$S \div \sqrt{B}$	-	-	-	-	0.7	2.7	3.1	2.9	2.8	3.1
Poisson Significance	-	-	-	-	1.2	2.8	3.2	3.0	2.9	3.2

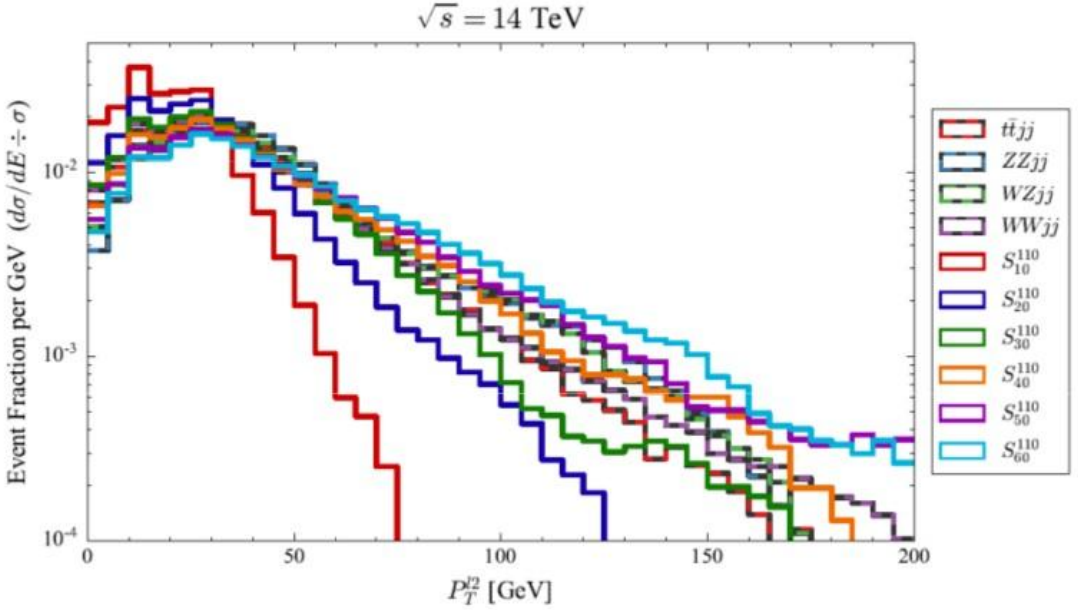
$\cos\theta^*{}_{l_1 l_2}$




$\sqrt{s} = 14$ TeV
Binned Event Fraction
$\Delta\phi(\not{E}_T, \ell_1) \div \pi$
$t\bar{t}jj$
$ZZjj$
$WZjj$
$WWjj$
S_{10}^{110}
S_{20}^{110}
S_{30}^{110}
S_{40}^{110}
S_{50}^{110}
S_{60}^{110}


$\sqrt{s} = 14$ TeV
Event Fraction per GeV $(d\sigma/dE \div \sigma)$
Missing Transverse Energy $\not{E}_T$ [GeV]
$t\bar{t}jj$
$ZZjj$
$WZjj$
$WWjj$
S_{10}^{110}
S_{20}^{110}
S_{30}^{110}
S_{40}^{110}
S_{50}^{110}
S_{60}^{110}


$\sqrt{s} = 14$ TeV
Event Fraction per GeV $(d\sigma/dE \div \sigma)$
$M_{\tau\tau}$ [GeV]
VJJJJ
VVJJ
$t\bar{t}$
$\Delta M = 10$ GeV
$\Delta M = 20$ GeV
$\Delta M = 30$ GeV
$\Delta M = 40$ GeV
$\Delta M = 50$ GeV
$\Delta M = 60$ GeV


$\sqrt{s} = 14$ TeV
Event Fraction per GeV $(d\sigma/dE \div \sigma)$
P_T^{j2} [GeV]
$t\bar{t}jj$
$ZZjj$
$WZjj$
$WWjj$
S_{10}^{110}
S_{20}^{110}
S_{30}^{110}
S_{40}^{110}
S_{50}^{110}
S_{60}^{110}