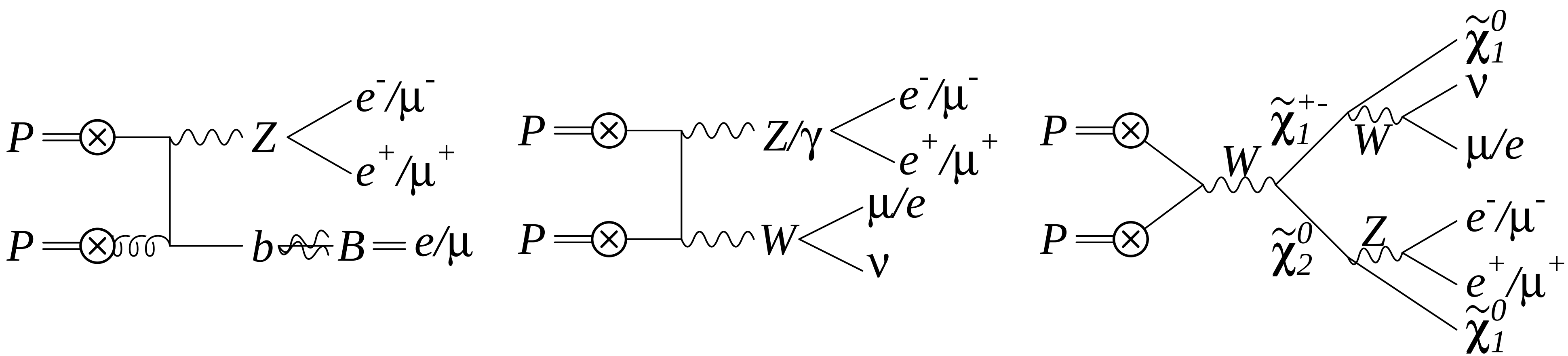
September 8, 2009

Estimates of Standard Model Backgrounds in Searches for New Physics – the Case of Isolated Leptons



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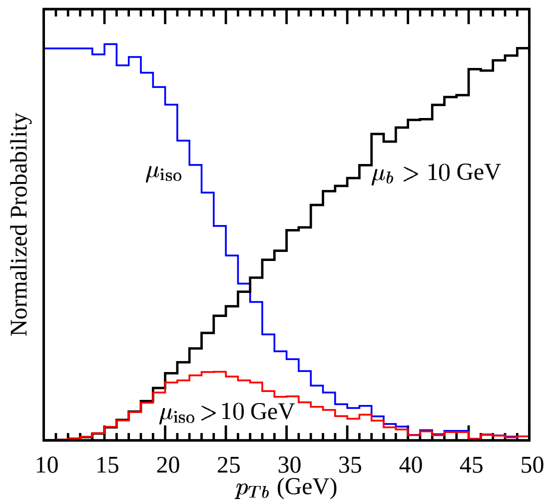
Based on E. Berger and Z. Sullivan, Phys Rev D **78**, 034030 (2008) and **74**, 033008 (2006)

Outline

1. Several (1, 2, ... N) *isolated* leptons are a signature for New Physics
2. Many Standard Model sources of isolated leptons
3. New: Isolated leptons from heavy flavor (b, c) decays and cuts that can be used to deal with this background
4. Dileptons and the Search for Higgs Bosons: Summary Berger and Sullivan, Phys Rev D **74**, 033008 (2006)
   - $H \to WW \to l^+l^-$ plus missing energy vs. leptons from Standard Model Sources at the LHC
5. Trileptons and the Search for Supersymmetry
   - $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ ("Golden" SUSY channel) vs. leptons from Standard Model Sources at LHC
6. Conclusions

Physics of isolated leptons from b decay



Prob. isolated μ w. $p_{T\mu} > 10$ GeV

$= $ Prob. producing muon

$\times$ Prob. B remnants missed

- Muons that pass isolation take substantial fraction of p_{Tb}
- Nearly all isolated muons point back to primary vertex.

C. Wolfe, CDF internal

- Isolation leaves $\sim 7.5 \times 10^{-3}$ μ/b $\gg 10^{-4}$ per light jet

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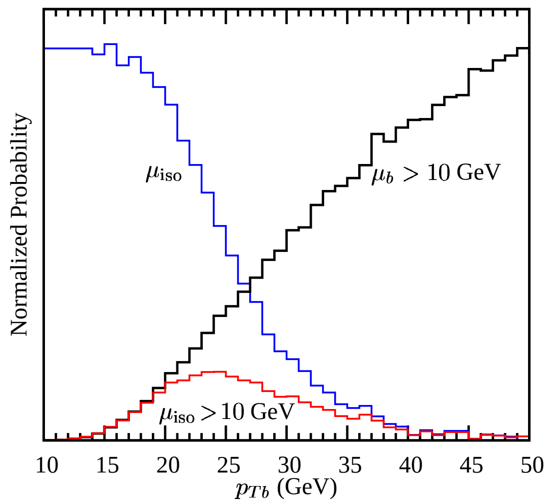

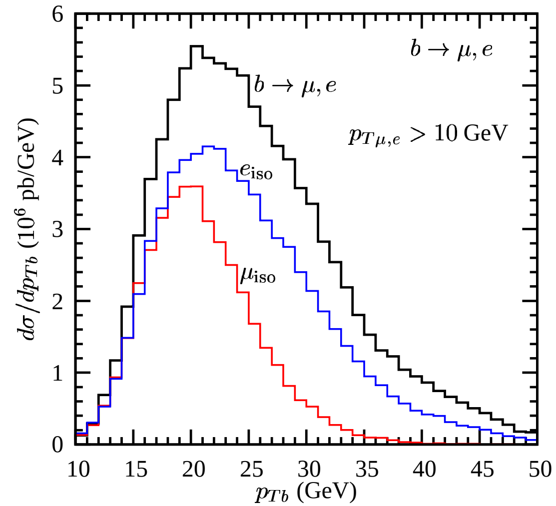

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Fold in $b\bar{b}$ cross section

- A large fraction of events with $b \to \mu/e$ have isolated μ/e
- Long tail that extends to large momentum, but
- $1/2$ of all isolated μ come from b with $p_{Tb} < 20$ GeV.

  It is common for analyses to start simulations with $p_{Tb} > 20$ GeV

Dileptons at the LHC

Higgs production and decay to WW

ATLAS-like study; 160 GeV Higgs (σ(fb))

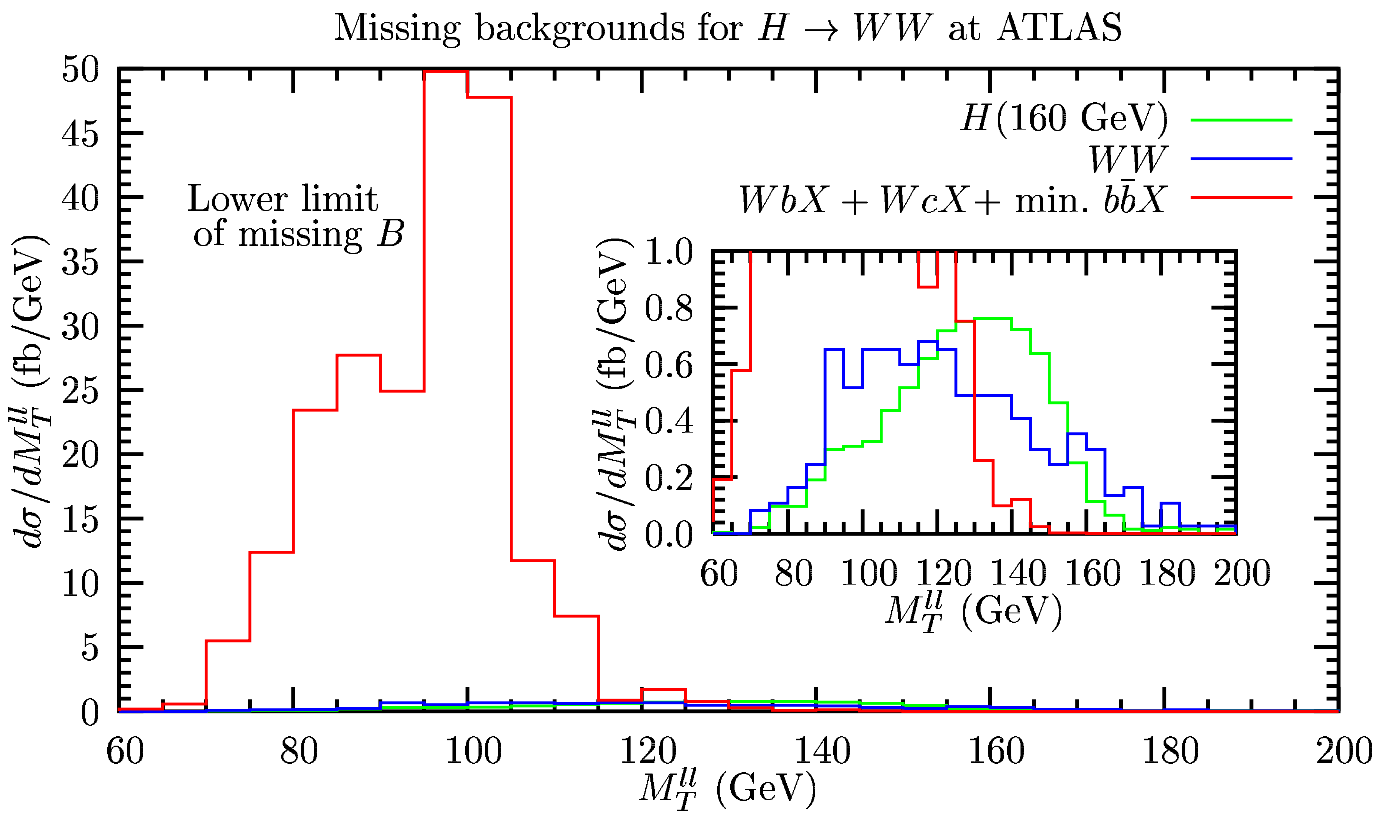
Cut level	$H \to WW$	WW	$b\bar{b}j^\star$	Wc	single-top	$Wb\bar{b}$	$Wc\bar{c}$
Isolated $l^+l^- > 10$ GeV	336	1270	> 35700	12200	3010	1500	1110
$E_{Tl_1} > 20$ GeV	324	1210	> 5650	11300	2550	1270	963
$\not{E}_T > 40$ GeV	244	661	> 3280	2710	726	364	468
$M_{ll} < 80$ GeV	240	376	> 3270	2450	692	320	461
$\Delta\phi < 1.0$	136	124	> 1670	609	115	94	131
$\|\theta_{ll}\| < 0.9$	81	83	> 1290	393	68	49	115
$\|\eta_{l_1} - \eta_{l_2}\| < 1.5$	76	71	> 678	320	48	24	104
Jet veto	41	43	> 557	175	11	12	7.4
$130 < M_T^{ll} < 160$ GeV	18	11	—	0.21	1.3	0.04	0.09

The biggest difference in the LHC analysis compared to our FNAL study is that cross sections are bigger, so the cuts are tighter.

- After the $\not{E}_T$ cut, all real power comes from the M_T^{ll} cut.
  Note $S/B \sim 1$ at LHC, but let's look at M_T^{ll} distribution

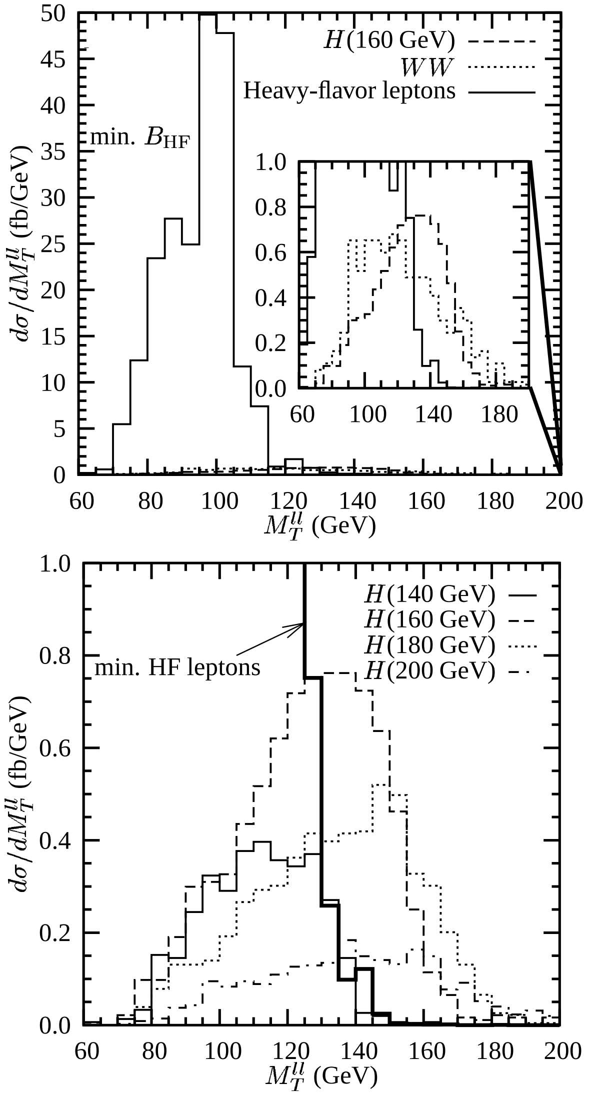
Transverse mass distribution after cuts

- Cannot reconstruct a Higgs boson mass peak from $H \to WW^* \to l^+l^-\nu\bar{\nu}$; use 'transverse mass' as an estimator; $M_T^{l\bar{l}} = \sqrt{2p_T^{l\bar{l}} E_T^{miss}(1-\cos(\Delta\phi))}$



- Heavy flavor background is more than 10 times previous estimates of backgrounds when $M_T^{l\bar{l}} < 110$ GeV; a tail extends into the signal region

The transverse mass distribution at ATLAS



The HF background starts off 50$\times$ the signal.

The M_T^{ll} peak is $\sim 2/3\, b\bar{b}j^\star$, $\sim 1/4\, Wc$!
$Wb\bar{b}$, $Wc\bar{c}$, single-top **all** are larger than WW.

The leading edge in M_T^{ll} covers $m_h = 140$ GeV, and it bisects larger Higgs masses.

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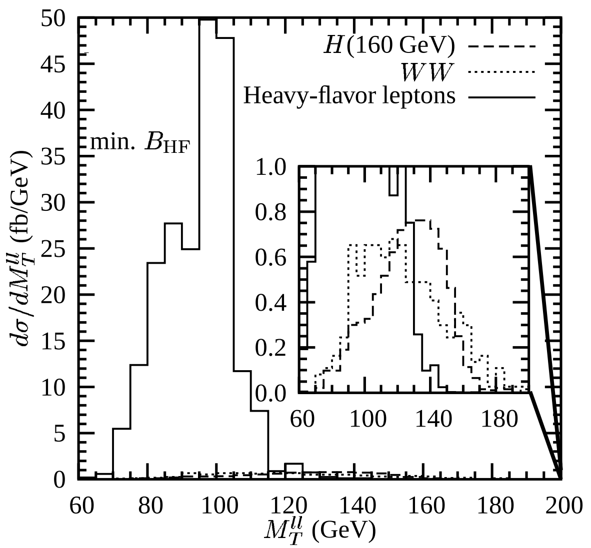

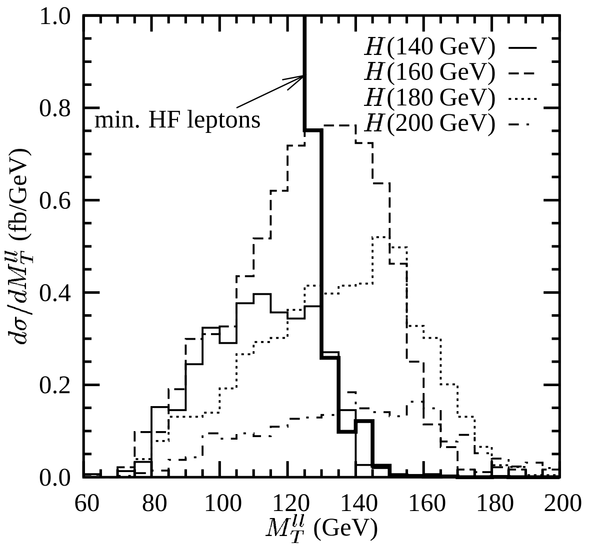

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ATLAS proposes a very tight cut:
$m_h - 30(40)$ GeV $< M_T^{ll} < m_h$
and attempts to extract the upper shoulder of $H \to WW$ from the upper shoulder of WW.

DØ cut $m_h/2 < M_T^{ll} < m_h - 10$ GeV — goes for peak.

Since the shapes for $m_h \gtrsim 160$ GeV are so similar, everything relies on counting events in the tails.

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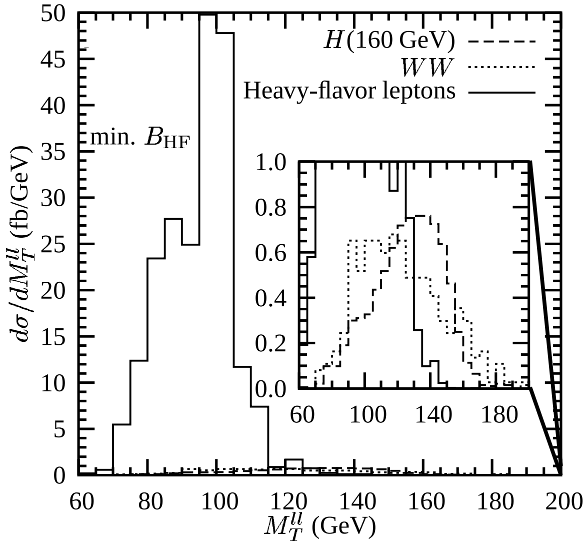

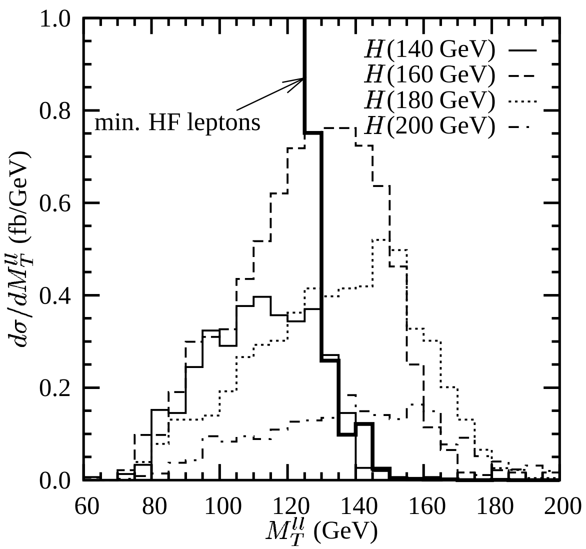

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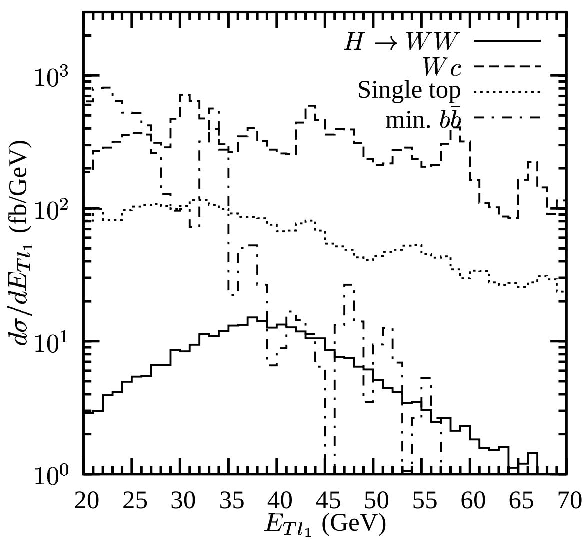
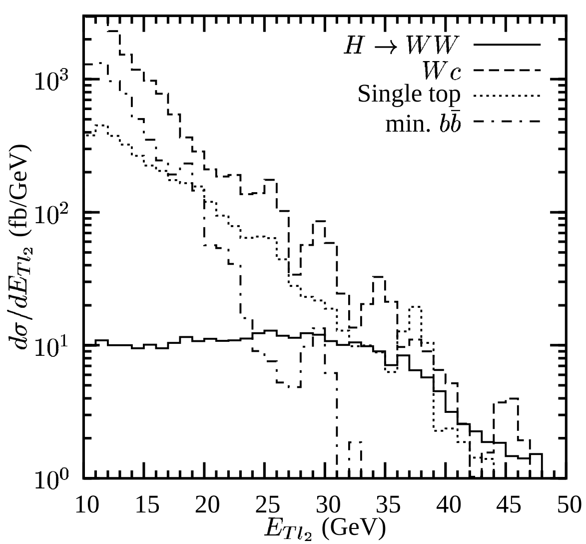
If WW were the only background, this might work.

Cannot predict to 10–20 GeV the position of HF leading edge.

However, can measure the HF background ... and maybe cut it.

One very effective new cut . . .





Most variations of cuts do not help much.

One could try to raise the cut on p_{Tl_1}.

- No help vs. anything with a W.
- Even $b\bar{b}$ does not decrease fast enough. Recall, an "isolated lepton" from a B is usually not soft compared to the B.

However, the second lepton p_T falls exponentially.

So raise the cut: $p_{Tl_2} > 10$ GeV $\Rightarrow p_{Tl_2} > 20$ GeV.

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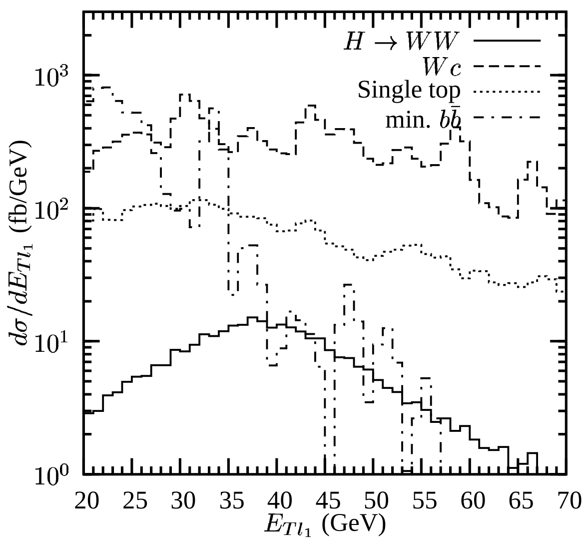

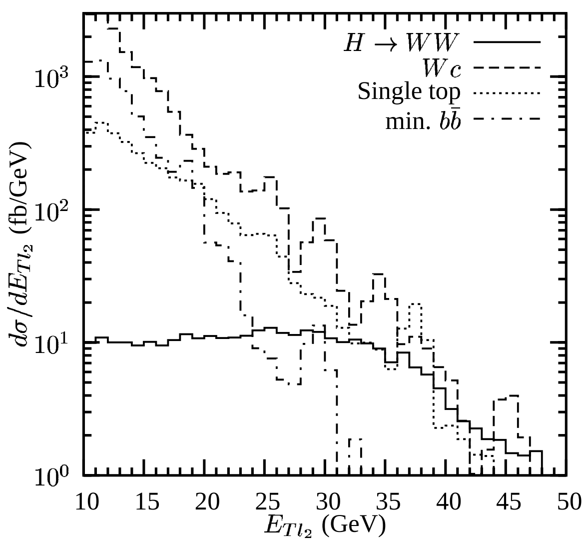

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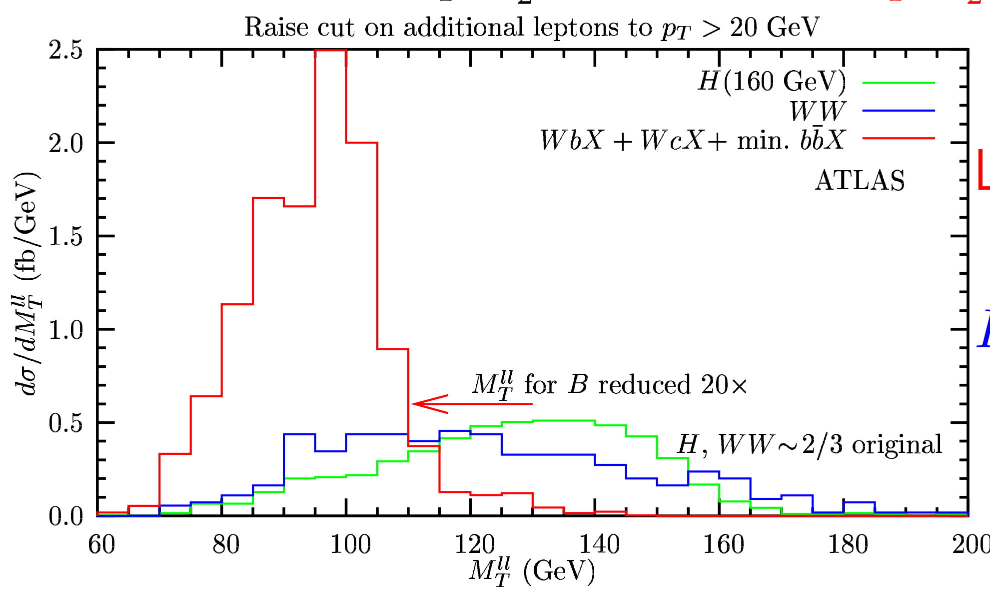


Leading edge 20 GeV lower!

$H \to WW$ survives!

$b\bar{b} \to b\bar{b}/30$, $W+X \to W+X/10$, $t+X \to t+X/5$

Trileptons at LHC
SUSY chargino/neutralino production

SUSY particle masses

We examined the trilepton SUSY signal and the SM backgrounds for 4 SUSY points (all masses in GeV units):

	$\widetilde{\chi}_1^0$	$\widetilde{\chi}_2^0$	$\widetilde{\chi}_1^{\pm}$
LM1	96.8	178.3	178.1
LM7	90.5	154.8	154.8
LM9	68.7	121.7	122.3
SU2	112.5	171.3	164.0

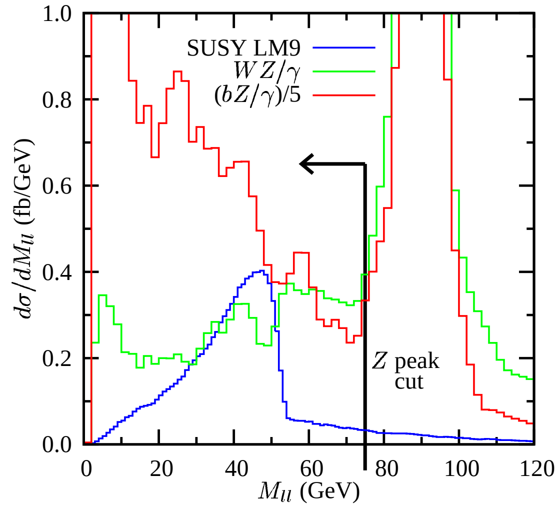
- LM1, LM7, and LM9 are the SUSY points investigated by CMS. They are a subset that exhibits a large trilepton signature from $\widetilde{\chi}_1^+ \widetilde{\chi}_2^0$ decay.
- ATLAS point SU2 is in the focus point region of mSUGRA parameter space.
- These may already be excluded by WMAP, $b \to s\gamma$, or other data. We use them to make contact with the CMS and ATLAS simulations.

Trileptons: SUSY & SM at CMS w/ 30 fb^{-1}

Channel	$N^l = 3$, NoJets	$M_{ll}^{\rm OSSF} < 75$ GeV
LM9	248	243
LM7	126	123
LM1	46	44
WZ/γ	1880	538
$t\bar{t}$	1540	814
tW	273	146
$t\bar{b}$	1.1	1.0
bZ/γ	14000	6870
cZ/γ	3450	1400
$b\bar{b}Z/\gamma$	8990	2220
$c\bar{c}Z/\gamma$	4680	1830
$b\bar{b}W$	9.1	7.6
$c\bar{c}W$	0.19	0.15

Analysis cuts:

- 3 leptons
- No jets ($E_{Tj} > 30$ GeV)
- Remove Z peak (demand $M_{ll}^{\rm OSSF}) < 75$ GeV

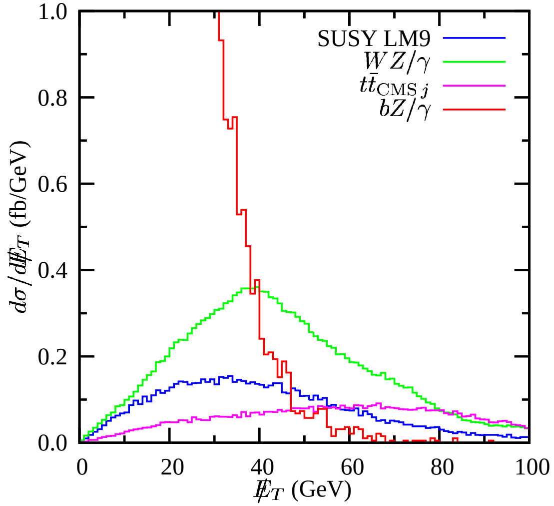


Z+heavy flavor decays are $10\times\ WZ/\gamma + t\bar{t}$!

Two additional cuts: $\not\!\!E_T$ and angular correlations

Leptons from SUSY decays are SOFT $\Rightarrow$ Cannot raise p_{Tl} cut.

Missing E_T



$Z/\gamma+$heavy flavors – no intrinsic $\not\!\!E_T$

Comes from misreconstruction,
energy lost down beam pipe

Natural $\not\!\!E_T$ in SUSY points low as well

$\tilde{\chi}_1^0$'s partially balance out

A $\not\!\!E_T$ cut demanding
$\not\!\!E_T > 30$–40 GeV is very effective

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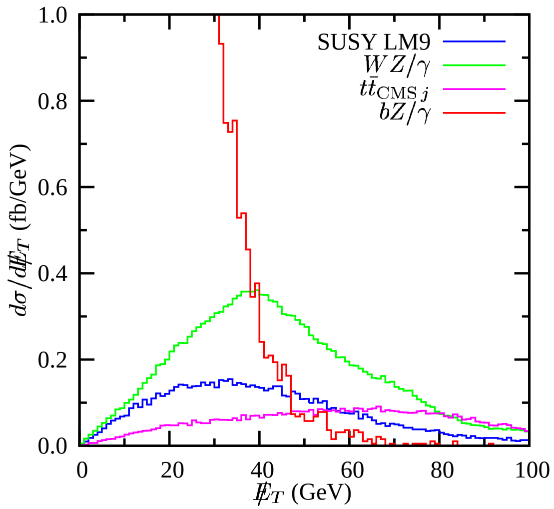

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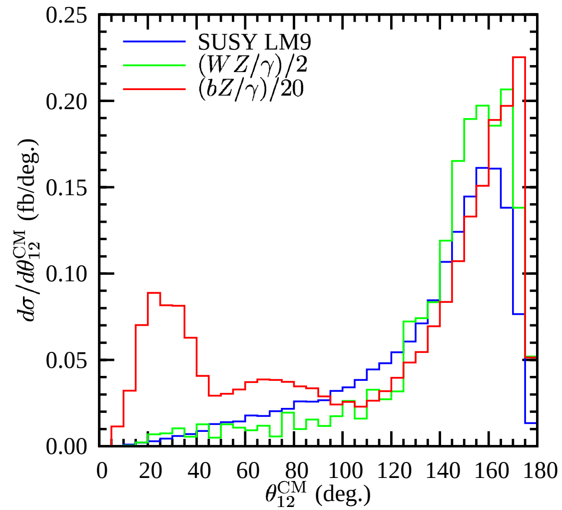
Caution: $\not\!\!E_T$ is poorly measured

Angular correlations



Angles measured extremely well

All combinations different (θ_{12}^{CM} shown)

Demand $\theta_{12}^{\text{CM}} > 45^\circ$, $\theta_{13}^{\text{CM}} > 40^\circ$, $\theta_{23}^{\text{CM}} < 160^\circ$

Reduces B by 30% for 5% loss of S

Not optimized

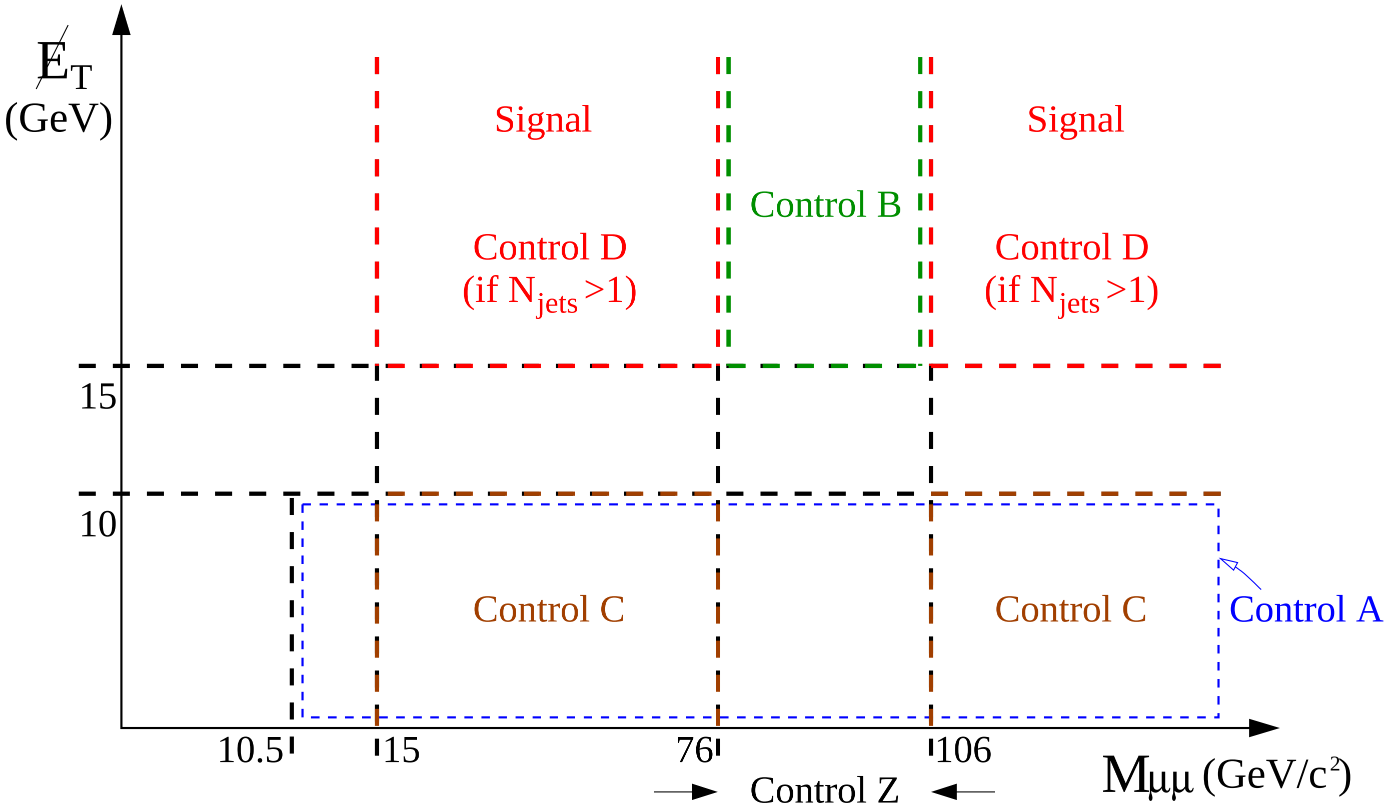
Trileptons: SUSY & SM at CMS (+new cuts)

Channel	$N^l = 3$, NoJets	$M_{ll}^{\mathrm{OSSF}} < 75$ GeV	$\not{E}_T > 30$ GeV	Angular cuts
LM9	248	243	160	150
LM7	126	123	89	85
LM1	46	44	33	32
WZ/γ	1880	538	325	302
$t\bar{t}$	1540	814	696	672
tW	273	146	123	121
$t\bar{b}$	1.1	1.0	0.77	0.73
bZ/γ	14000	6870	270	177
cZ/γ	3450	1400	45	35
$b\bar{b}Z/\gamma$	8990	2220	119	103
$c\bar{c}Z/\gamma$	4680	1830	69	35
$b\bar{b}W$	9.1	7.6	5.6	5.3
$c\bar{c}W$	0.19	0.15	0.12	0.11

Control regions defined by CDF

Control regions defined by CDF in their dilepton and trilepton search

Search for new physics in $\mu\mu + e/\mu + \not{E}_T$, Phys Rev **D79**, 052004 (2009)



Trileptons at CDF

Expected and observed trilepton event yields, in the control regions and the SUSY signal region. The expected SUSY signal event yield is for the SIG2 mSUGRA scenario. Phys Rev **D79**, 052004 (2009)

Region	DY	HF	Fakes	Diboson	$t\bar{t}$
Control Z	0.2 ± 0.2	-	2.5 ± 1.2	0.26 ± 0.06	-
Control A	0.3 ± 0.2	6 ± 3	7.6 ± 3.8	0.25 ± 0.08	-
Control B	-	-	0.2 ± 0.1	0.094 ± 0.009	-
Control C	0.2 ± 0.2	3 ± 2	2 ± 1	0.10 ± 0.06	-
Control D	-	-	0.02 ± 0.01	0.003 ± 0.002	0.011 ± 0.008
Signal Reg.	**-**	$\mathbf{0.06 \pm 0.04}$	$\mathbf{0.2 \pm 0.1}$	$\mathbf{0.15 \pm 0.06}$	**-**

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Region	**Total SM expected**	**SUSY expected**	**Observed**
Control Z	3 ± 1	0.06 ± 0.01	4
Control A	14 ± 4	0.08 ± 0.02	16
Control B	0.3 ± 0.1	0.10 ± 0.03	0
Control C	5 ± 2	0.06 ± 0.02	8
Control D	0.03 ± 0.01	0.04 ± 0.02	0
Signal Reg.	$\mathbf{0.4 \pm 0.1}$	$\mathbf{1.7 \pm 0.4}$	$\mathbf{1}$