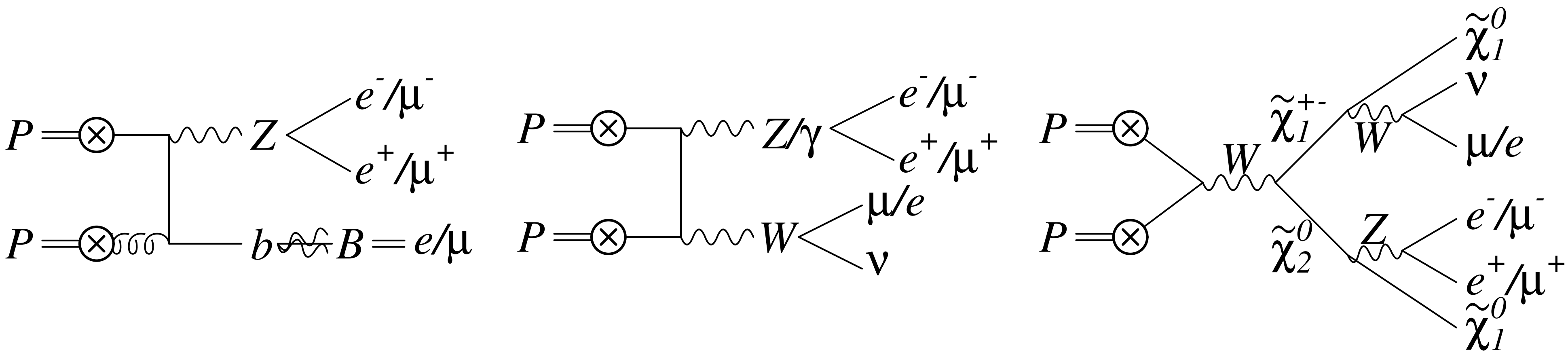
Trilepton Production at LHC

Standard model sources and beyond



Zack Sullivan

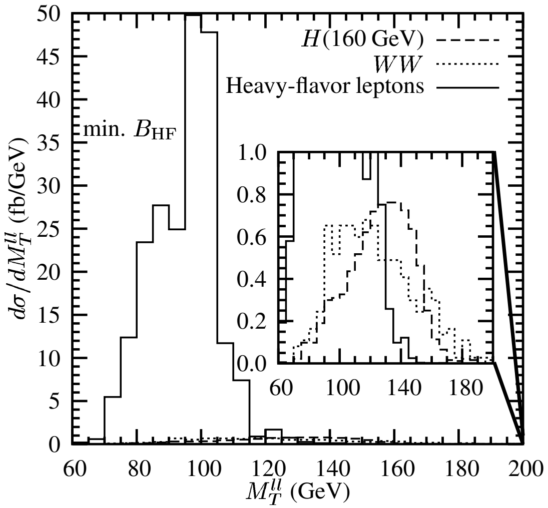
Illinois Institute of Technology

Based on Z.S., E. Berger, PRD 78, 034030 (08) (hep-ph:0805.3720)

Outline

1. Dileptons and trileptons at LHC
2. How heavy flavors (b, c) yield isolated leptons
3. SUSY signal vs. leptons from heavy flavors
4. Improved cuts
5. Conclusions

Motivation: Dileptons at LHC and b quark decays



Z.S.,E. Berger, PRD74, 033008 (06)

Higgs decays to W^+W^- to dileptons is expected to give the largest significance for $135 < M_H < 219$ GeV at LHC. ATLAS TDR V.2

A study of heavy-flavor (b, c) decay to leptons found $b\bar{b} + Wb\bar{b} + Wc$+single-top$+\ldots$ is $>50\times$the direct WW background.

Conclusion: Isolation does not remove leptons from heavy flavor decays!

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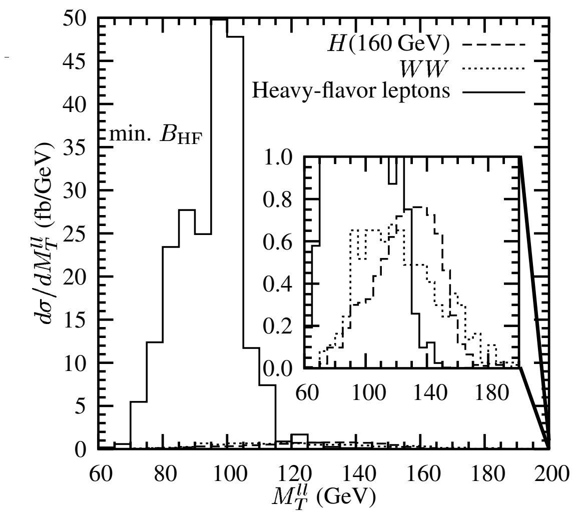

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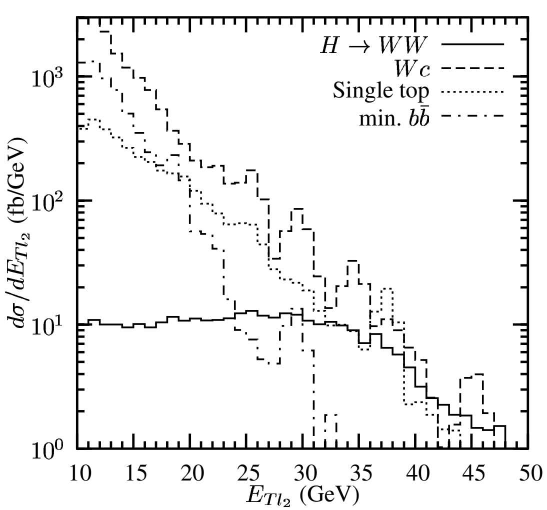
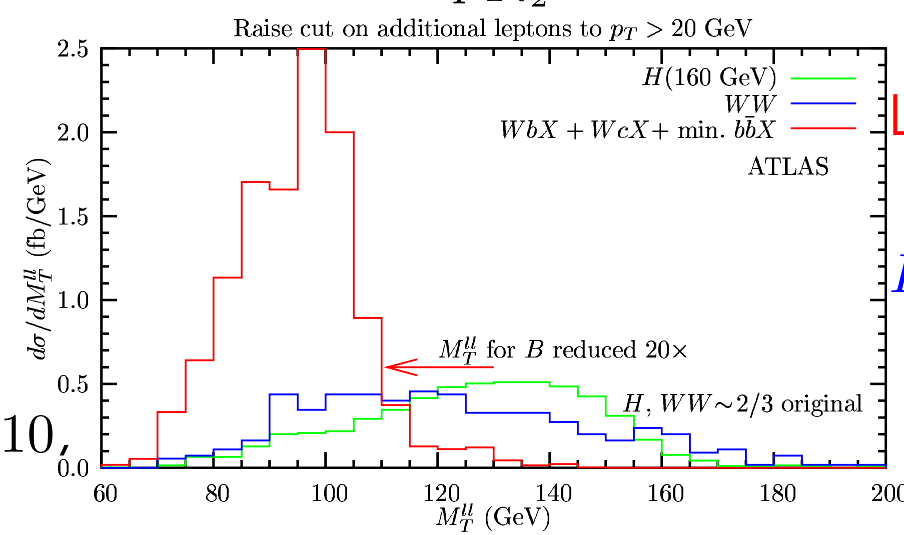


$b\bar{b} \to b\bar{b}/30$, $W{+}X \to W{+}X/10$,
$t{+}X \to t{+}X/5$

Solution: The second lepton p_T falls exponentially.

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

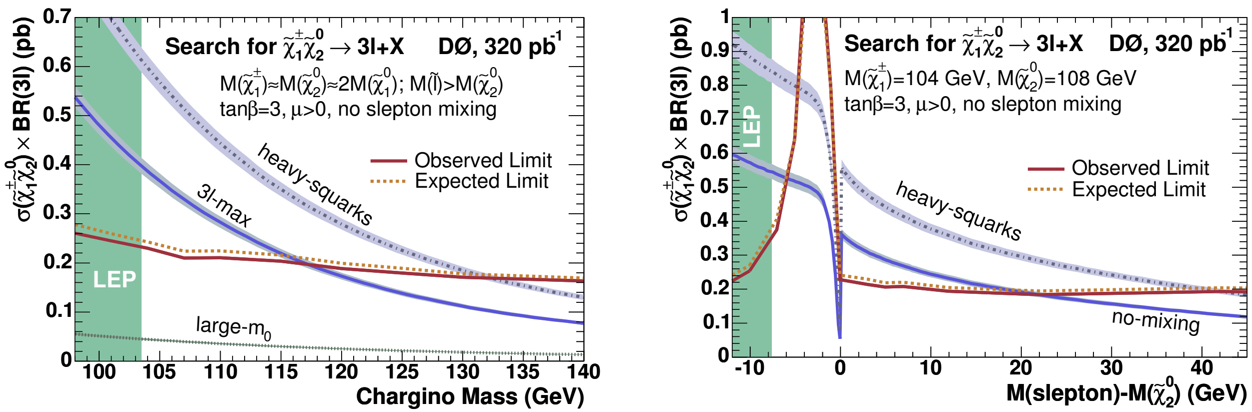


Leading edge 20 GeV lower!

$H \to WW$ survives!

SUSY trilepton production — the "golden channel"

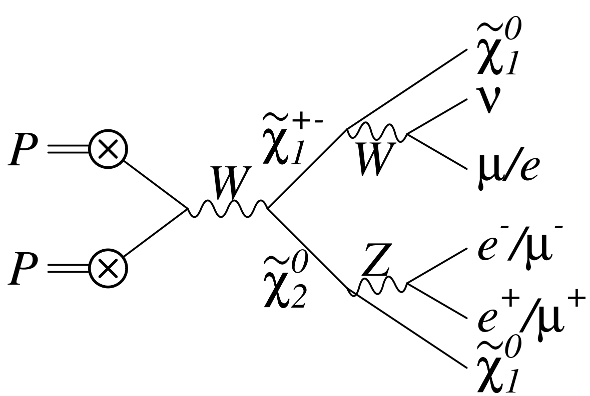
The measurement of trileptons plus missing energy is expected to be a clean probe of chargino and neutralino production.

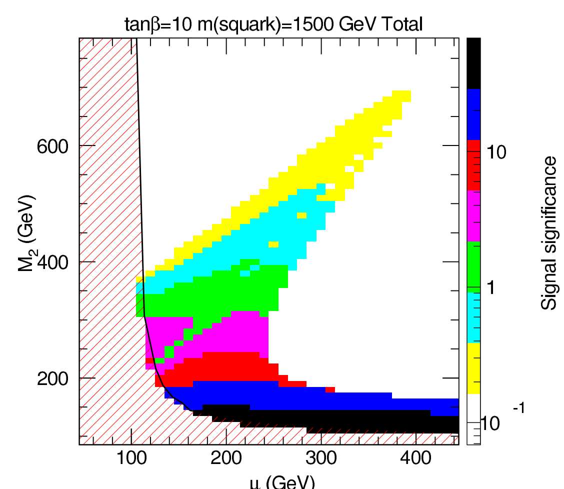


DØ, PRL95, 151805 (05)

DØ and CDF (PRD77,052002(08)) hope to both discover supersymmetry in an excess of trilepton events, and extract mass information.

CMS and ATLAS hope to do the same.





W. Vandelli, thesis

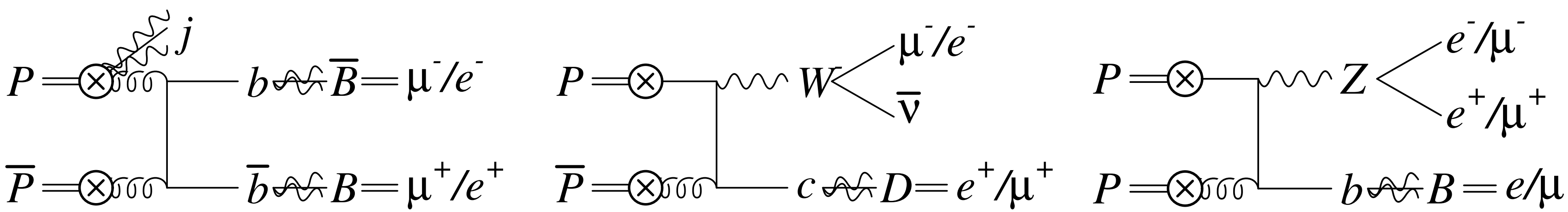
The missing pieces to multi-leptons+$\not\!\!E_T$

$H \to WW$ and $\tilde{\chi}_1^+ \tilde{\chi}_2^0$ signals share the common trait of multiple leptons plus missing transverse energy.

Experimental collaborations have spent significant time modeling (and measuring) backgrounds to these processes, including both real Standard Model physics and complicated experimental effects (e.g., jet fakes, misreconstruction, etc.)

In all cases, the background to multilepton signatures from the decays of heavy-flavor quarks (b, c) have been declared "obviously" insignificant.

Is this really true? The real physical processes below do not matter?



The (nearly) universal beliefs

Common wisdom says . . .

"The $b\bar{b}$ contamination (for our signal) is suppressed because the soft and typically non-isolated leptons from B decays are rejected by our lepton selection." — published reference withheld

— Therefore, we can ignore it.

"Even if the leptons did pass our isolation cuts, we could just cut them out by looking for secondary vertices"

— multiple names withheld

— We can always reject the events with better reconstruction.

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Both of these beliefs have reasonable sounding foundations.

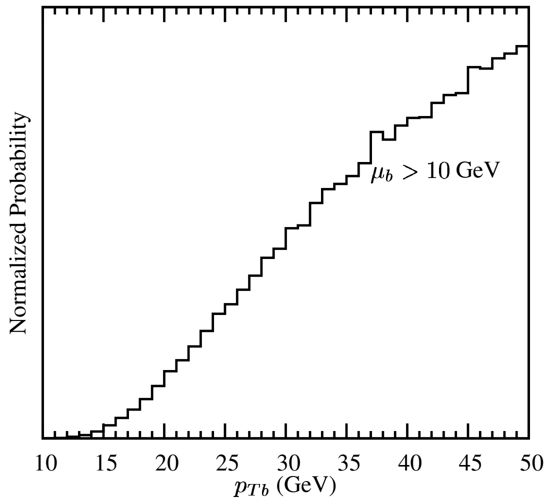
Both have been used as justification to ignore leptons from b and c decays as possible backgrounds.

Both have led to analyses which have misunderstood the dominant backgrounds in their samples.

Let's see why this arose. . .

The physics of isolated leptons from heavy-flavor decays

Physics of isolated leptons from b decay



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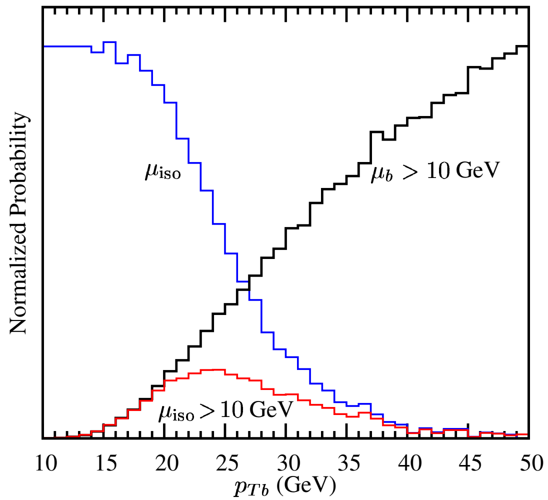

Prob. isolated muon

$= $ Prob. producing muon

$\times$ Prob. B remnants missed

- Muons that pass isolation take nearly all p_T
- ~Nearly all isolated muons point back to primary vertex.

C. Wolfe, CDF internal

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

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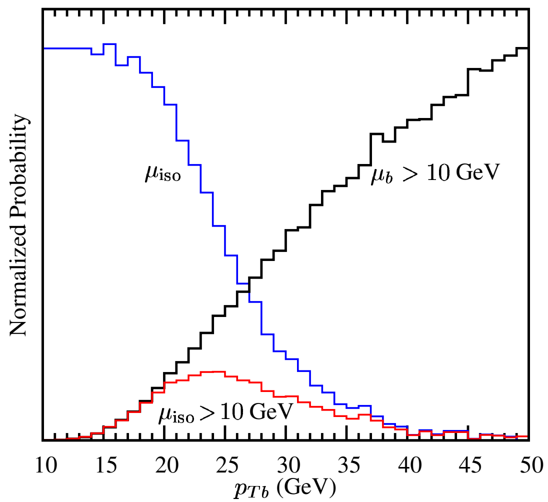

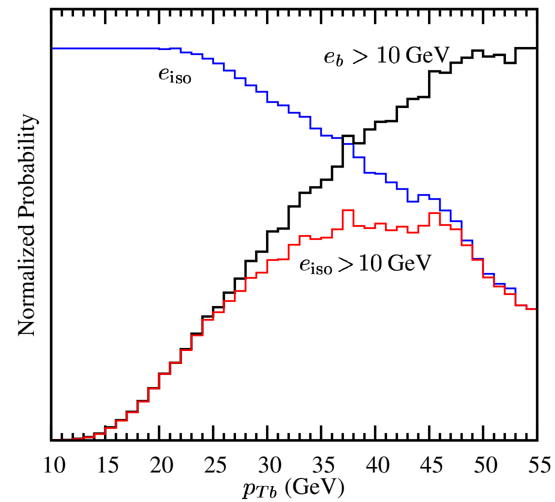

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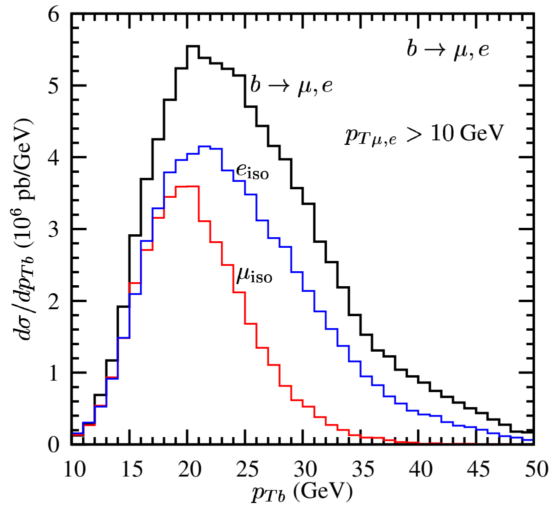
Harder b's can give isolated e's, because e cuts must allow more energy in the calorimeter

It is difficult to reduce this without losing efficiency for primary e.

Isolation is not extremely effective for leptons from b decay.

Isolated leptons from b/c production & decay



Fold in $b\bar{b}$ production.

- A large fraction of events with $b \to \mu/e$ have isolated μ/e.

  More isolated e than μ per b.

- $1/2$ 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.

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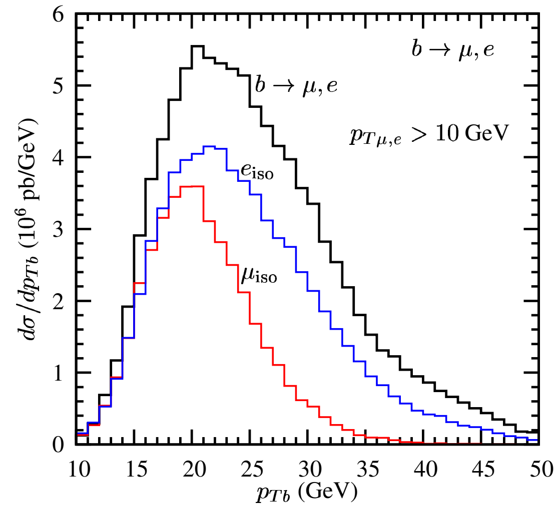

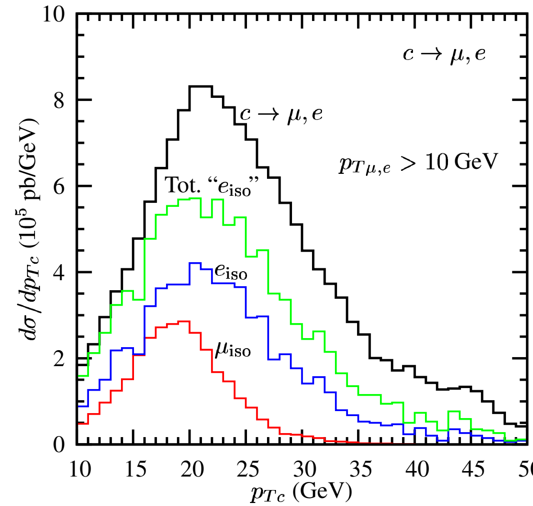

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Fold in $c\bar{c}$ production.

The story repeats for c decays

1 twist: D decays have many pions

$\pi^{\pm}$ fake e at $\sim 10^{-4}$

$\Rightarrow$ Large "e_{iso}" rate

Measuring isolated leptons from heavy flavors

We understand exactly where and how the isolated leptons arise from heavy flavor decays.

So far we have seen simulations that predict rates of $\sim 0.5\%/b$.

DØ has computed the same efficiency w/ a full detector simulation and cuts. DØ, Note 4390

CDF has reported Jet20 data have more 10–20 GeV muons than predicted from jets as a result of B decays. S. Chung, talk 4/22/05

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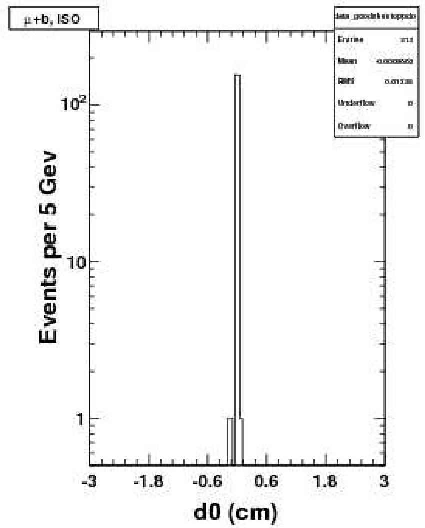
For a first measurement we suggested looking at a sample of μ recoiling against tagged b-jets.

Collin Wolfe looked at samples of μ and B using 2 fb^{-1} of CDF data:

1. The ratio of isolated muons to the measured 1 b-tag cross section is 0.5%!
2. $> 99\%$ of the isolated muons point back at the primary vertex!



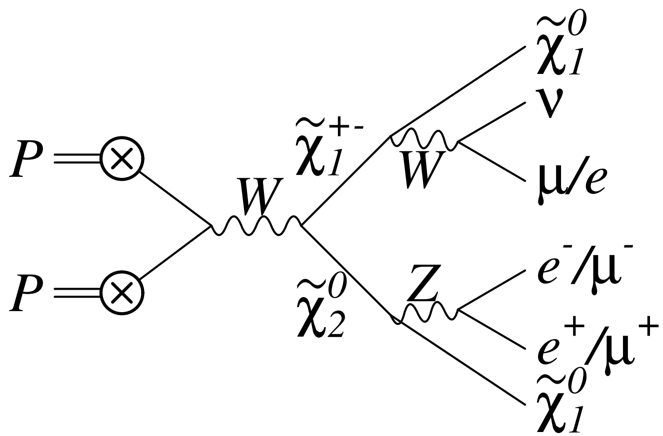
$\mu_{\rm iso}$ impact parameter, C. Wolfe

This does not extrapolate directly to the signals we wish to study. Full simulations including cut-dependent correlations are necessary. . .

Trileptons at LHC

The foil:
SUSY chargino/neutralino production

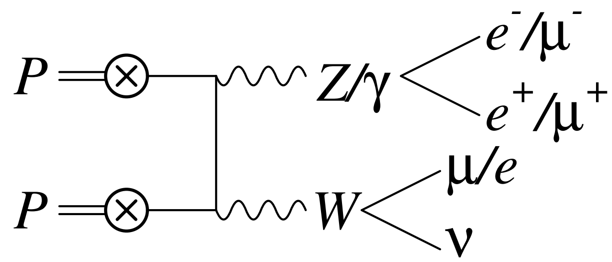
Motivation: Trileptons at LHC



$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to l^+l^-\,l^{\pm}+\not{E}_T$ is a golden signature of supersymmetry.

CMS and ATLAS both have analyses designed to observe this signal.

CMS TDR V.2&Note 2006/113; ATLAS CSC 7



WZ was expected to be the largest source of low-p_T trileptons at LHC.

$W\gamma^*$ has not previously been included.

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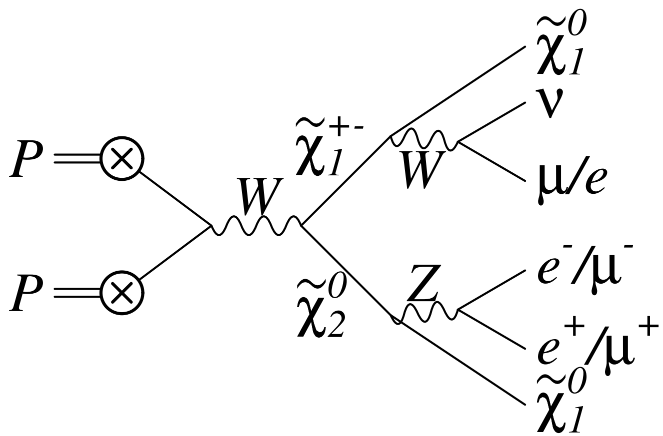

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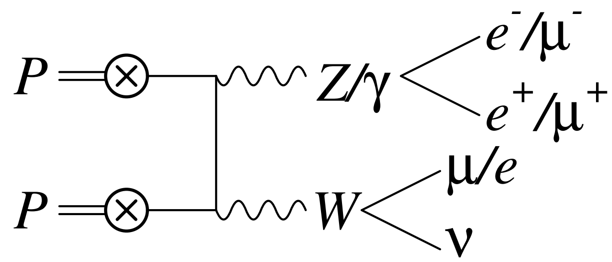

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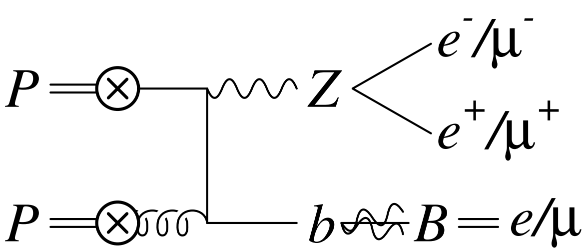


How important are leptons from heavy flavor (b, c) decays?

There are MANY potential processes:

bZ/γ, $b\bar{b}Z/\gamma$, cZ/γ, $c\bar{c}Z/\gamma$, $b\bar{b}W$, $c\bar{c}W$, $t\bar{t}$, tW, $t\bar{b}$

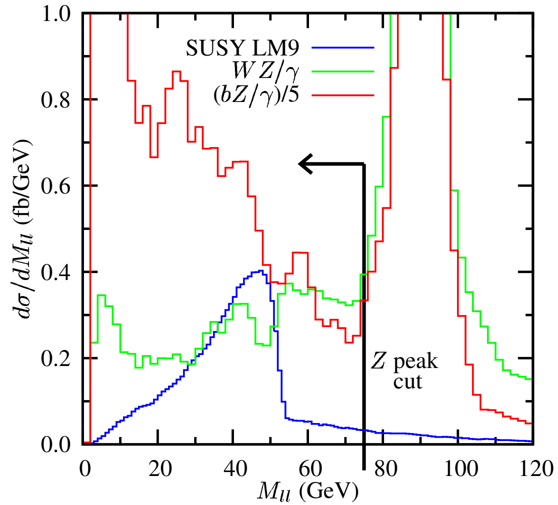
NOTE: All photons are virtual, and split to l^+l^-

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

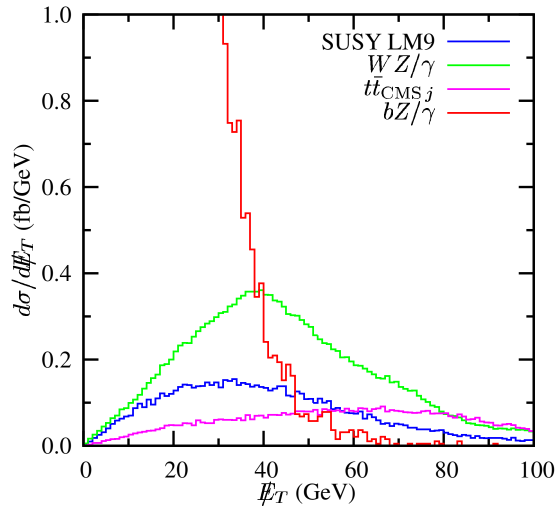


Z+heavy flavor decays are $10\times$ $WZ/\gamma + t\bar{t}$!

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/γ+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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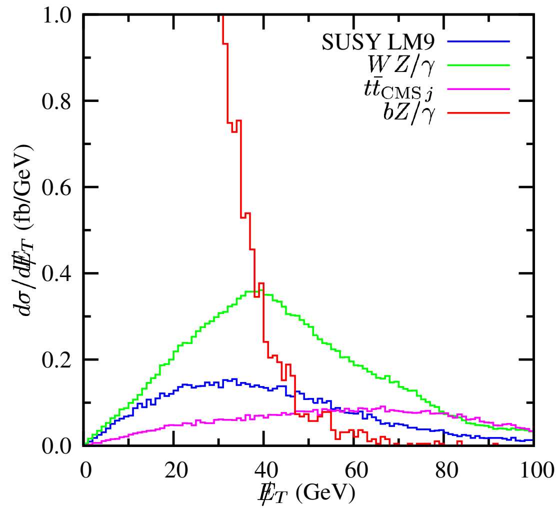

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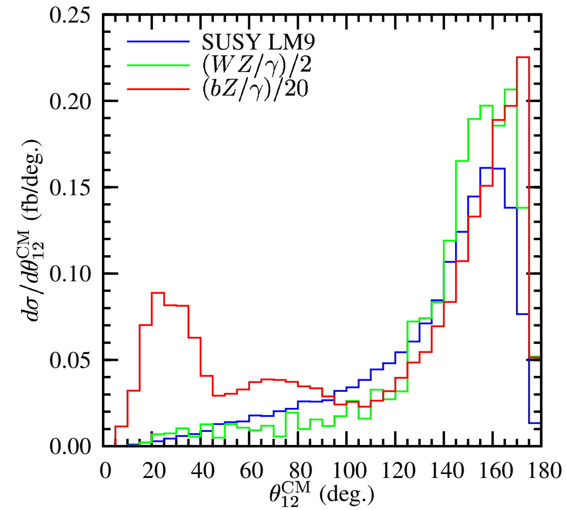
$\not\!\!E_T$ is poorly measured

Angular correlations



Angles measured extremely well

All combinations different ($\theta_{12}^{\mathrm{CM}}$ shown)

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

Reduces B by 30% for 5% loss of S

Not optimized

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

Channel	$N^l = 3$, NoJets	$M_{ll}^{\rm OSSF} < 75$ 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

Pure QCD background to trileptons

CMS estimates $jjj \to lll < 5$ events in 30 fb^{-1}

What about $b\bar{b}b\bar{b}$, $b\bar{b}c\bar{c}$, $c\bar{c}c\bar{c}$?

We cannot simulate this directly in our lifetimes ($\sim 10^3$ CPU years)

Estimate 3 sources of $b\bar{b}b\bar{b}$ for 30 fb^{-1}

1. Direct $b\bar{b}b\bar{b}$: $\sim$500 events
   Use $Wb\bar{b}$ to estimate $P(b \to \mu_{\rm iso})$: $\sigma_{b\bar{b}b\bar{b}} \times (7.5 \times 10^{-3})^3$
2. Multiple interactions: $\sim$600 events
   10 interactions $\times \sigma^2_{b\bar{b}} / \sigma^{\rm Tot}_{\rm inelastic}$
3. Multiple scattering, gluon splitting: $\sim 10^3$ events

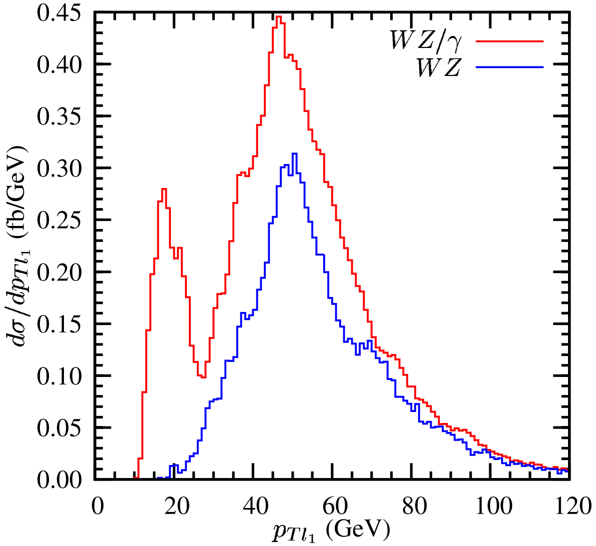
Note that K factors could be as high as 5.5

A. Del Fabbro, D. Treleani, PRD66, 074012 (02)

Scaling results from Z.S., E.L. Berger, PRD 74, 033008 (06),
the $\not{E}_T$ cut should remove nearly all of these.

Importance of the virtual photon

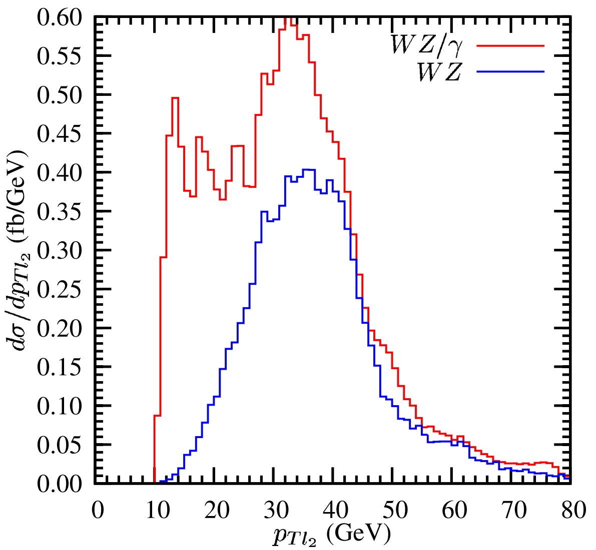
Simulations of WZ based on PYTHIA do not include virtual photons.

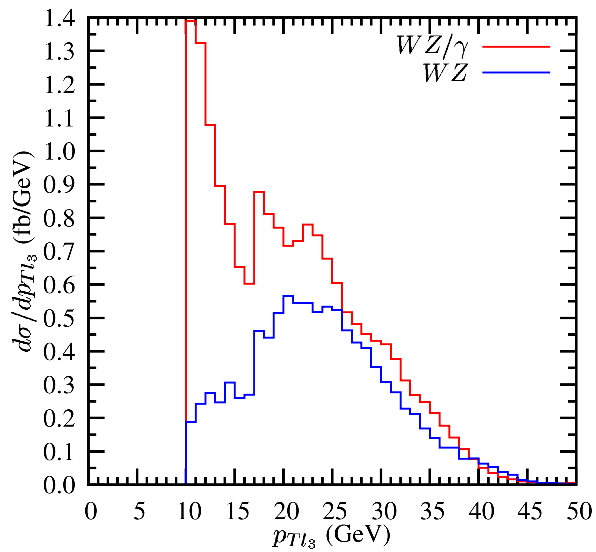


Nearly $1/2$ of the trilepton background from WZ/γ is from $W\gamma^*$ alone.

Matrix elements that include virtual photons are important when observing low-p_T leptons.

(p_{Tl} spectra after M_{ll}^{OSSF} cut)





Significance of SUSY point LM9 in 30 fb^{-1}

1. Our calculations are LO.
   NLO K-factors are large (1.5–2) on most processes,
   BUT, jet veto will reduce this.

2. ISR is not well determined
   The rate of > 30 GeV jets can be changed by a factor of 4
   depending on assumptions in PYTHIA about ISR.

We present our calculation, and one that scales down B by 4 to show the range of possible significances

	$N^l = 3$, NoJets	$M_{ll}^{\mathrm{OSSF}} < 75$ GeV	$\not\!\!E_T > 30$ GeV	Angular cuts
$S/\sqrt{B}_{\mathrm{LM9}}$	1.33	2.07(1.79)	3.93(3.74)	3.94(3.79)
$S/\sqrt{B}_{\mathrm{LM9}}^{\mathrm{CMS}\ j}$	2.63	4.09(3.54)	7.78(7.39)	7.79(7.49)

(Parentheses include leptons from fakes from CMS Table 6, Note 2006/113)

We will not know which ISR estimate is correct until we measure it at LHC

Conclusions

(Z.S., E. Berger, PRD 78, 034030 (08) (hep-ph:0805.3720))

1. Heavy-flavor (b, c) decays to leptons dominate low-p_T isolated leptons at LHC
   Trileptons from Z/γ^*+heavy flavors (HF) $\sim 10\times$ all other backgrounds
2. When modeling low-p_T leptons, virtual photons cannot be ignored
   $WZ/\gamma^* \sim 1.7 \times WZ$ after cuts
3. Raising minimum p_T is not viable for SUSY signal, but other cuts work:
   (a) Require $\not\!\!E_T > 30$ GeV, $Z/\gamma^* + \mathrm{HF} \rightarrow Z/\gamma^* + \mathrm{HF}/30$ Hard to measure low $\not\!\!E_T$
   (b) Impose cuts on well-measured angles, Z/γ^*+HF reduced by 30%
4. Overall normalization is dominated by assumptions regarding ISR
   Huge uncertainties in effectiveness of jet veto
   If large ISR exists, may want to loosen jet veto to recover SUSY signal
   ISR questions will be resolved with initial data from LHC

Any signal that has low-p_T leptons MUST consider the background from heavy flavor (b, c) decays

What have we learned about leptons from heavy-flavor (b,c) decays?

Common wisdom: Leptons from heavy flavor decays are strongly suppressed by isolation cuts. We can ignore them.

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  This is surprisingly insensitive to cut details or collider construction.

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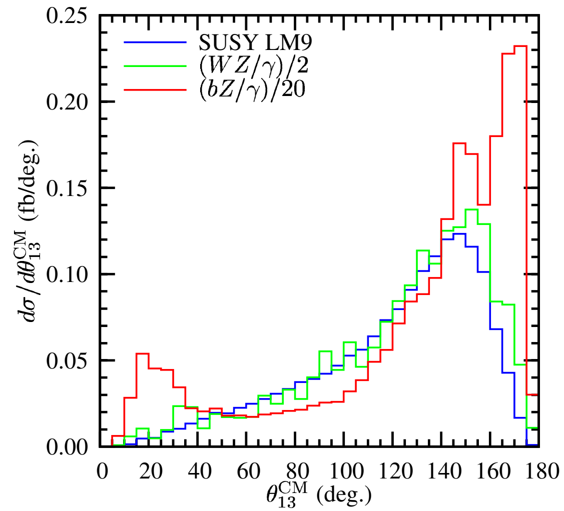
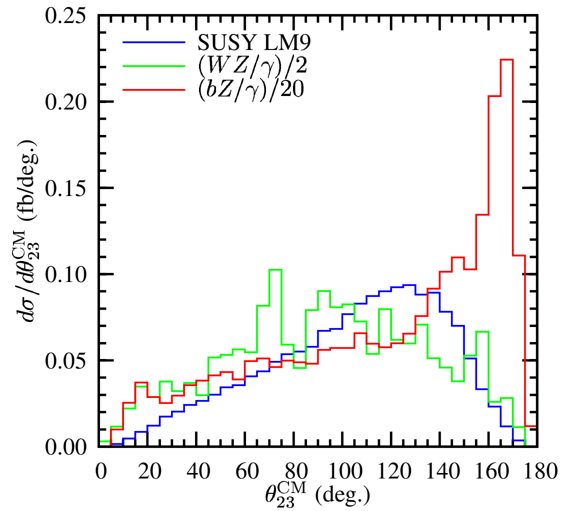
We propose modest tweaks to the cuts to remove these backgrounds. But, we better measure them *in situ* first!

BACKUPS

Other angular correlations

Angles are well-measured, and defined in the trilepton CM frame.





Suggested cut: $\theta_{13}^{\mathrm{CM}} > 40°$

Suggested cut: $\theta_{23}^{\mathrm{CM}} < 160°$

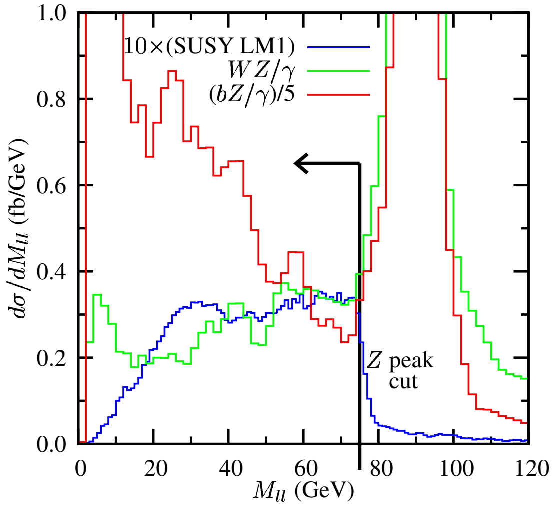
These cuts are almost free, and not optimized.

5% signal decrease, but 30% backgound decrease

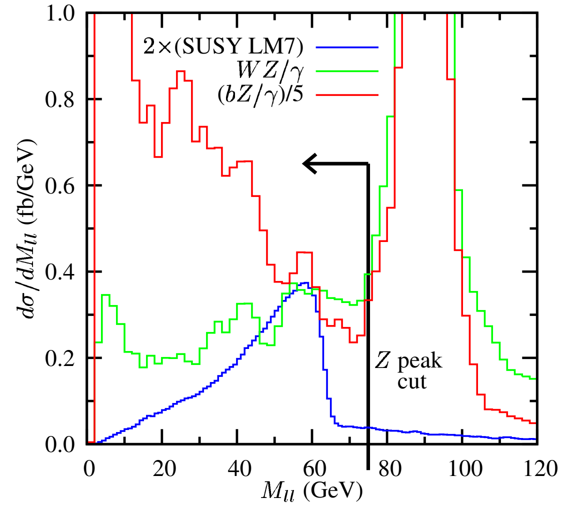
CMS SUSY points LM1, LM7

Representative opposite-sign same-flavor (OSSF) invariant masses

LM1



LM7



Signal endpoint above Z-peak cut and signal is small

LM7 similar to LM9, but smaller