High Energy Physics

Search for new physics in dileptons at CMS

Claudio Campagnari

UC Santa Barbara

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Why dileptons?

Why dileptons?

- Why not?

Why dileptons?

- Why not?
- We do not know what the new TeV-scale physics is
  - If there is such a thing....
- Dilepton final states are not where pre-LHC conventional-wisdom told us to place our bets
  - SUSY in jets and MET
- But we should look everywhere
- And it doesn't look like conventional-wisdom was that good
- Now becoming "fashionable" because sensitive to some theoretically attractive scenarios
  - "Natural SUSY"

What’s good about dileptons?

- Relatively clean
  - Few well defined sources in SM
  - Easier to “buy” claim of NP?
- Rich
  - Many possible signatures (fun program to work on)

Why dileptons + Missing ET?

- We know that there is dark matter
- Thus, searches that I am most interested in are those with MET
- SUSY or not SUSY

Why dileptons + MET + jets?

- High cross-section → strong production
- Strong production → quarks/gluons in final state
- New physics states at high mass → lots of H_T

Dilepton final states to study

- $Z \rightarrow ee$, $Z \rightarrow \mu\mu$ + MET + jets
- Opposite sign (but not Z) + MET + jets
- Same sign + MET + jets

Z + MET + jets

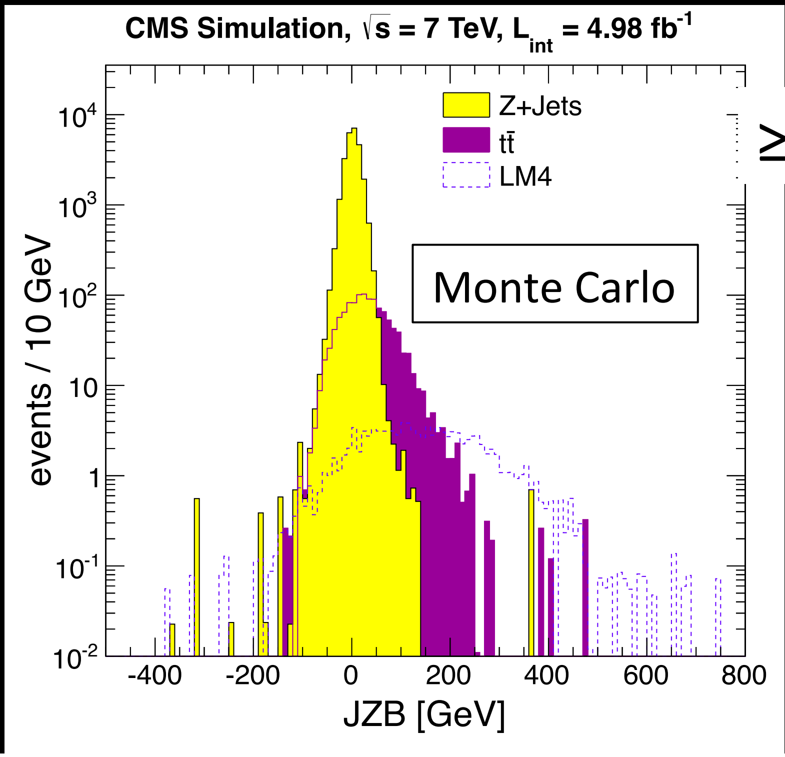
arXiv:1204.3774

- No Z production with real MET
  - Except rare processes eg pp → ZZ , Z→ee Z→νν
- Backgrounds are
  1. MET from jet mismeasurements in Z+jets
  2. pp → tt → dileptons with dileptons whose inv mass happens to be consistent with Z
     - Easy to estimate from eμ events
- Two methods for MET mismeasurements
  1. Jet-Z-Balance (JZB)
  2. MET templates from γ+jets events

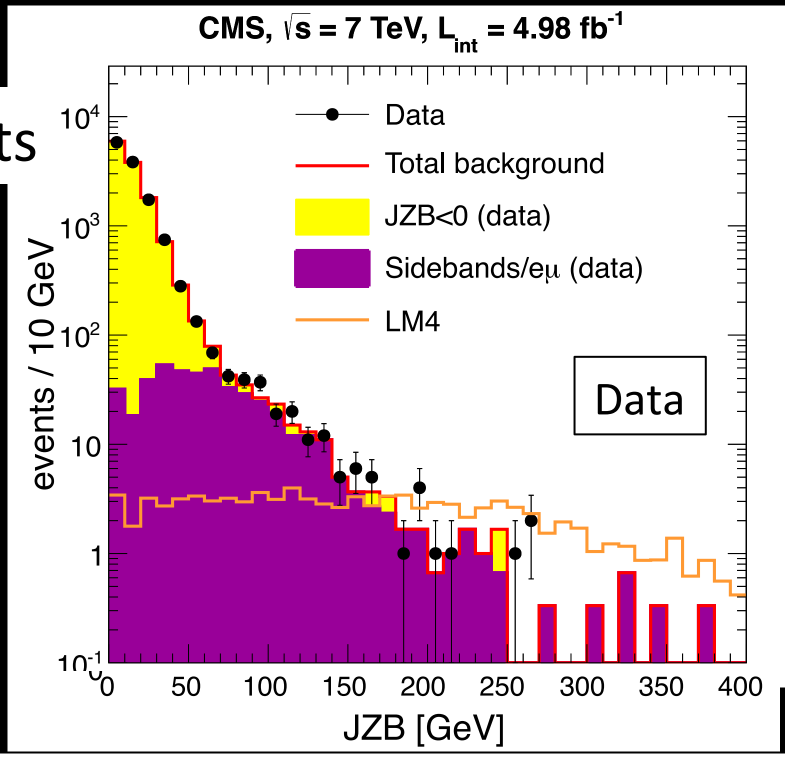
JZB method

$$\text{JZB} = \left|\sum_{\text{jets}} p_{\text{T}}\right| - \left|\vec{p}_{\text{T}}^{\,(\text{Z})}\right| \approx \left|-\vec{E}_{\text{T}}^{\text{miss}} - \vec{p}_{\text{T}}^{\,(\text{Z})}\right| - \left|\vec{p}_{\text{T}}^{\,(\text{Z})}\right|.$$

- JZB symmetric about zero for Z+jet BG
- Mostly positive for SUSY
- Normalize BG in JZB>0 with observation in JZB<0

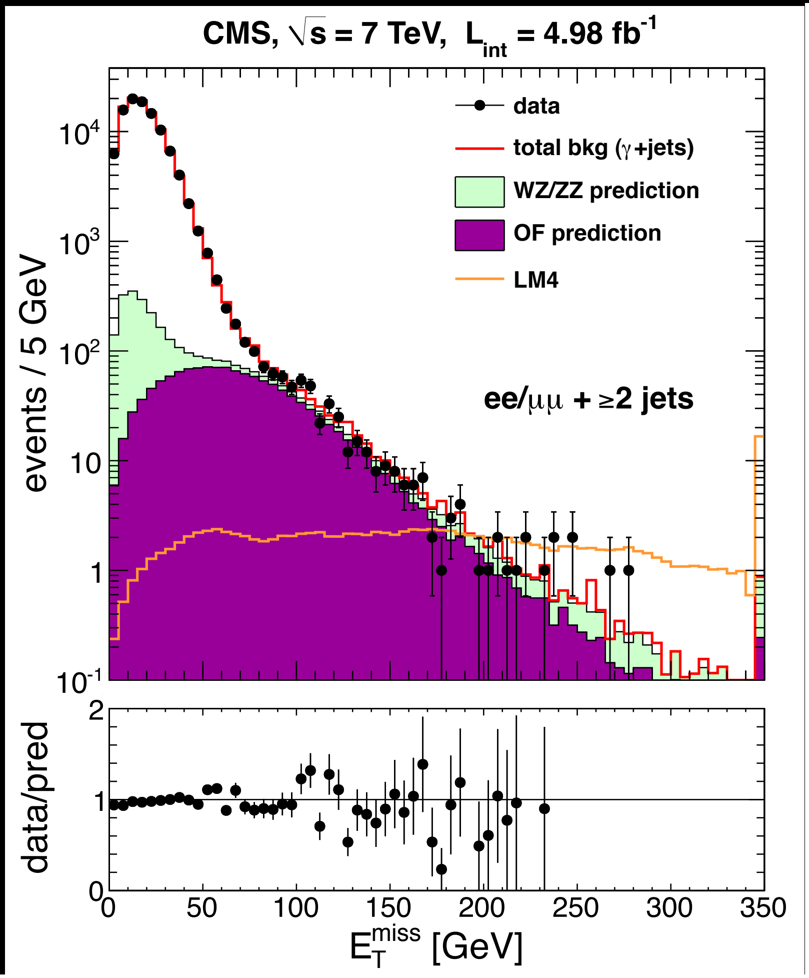


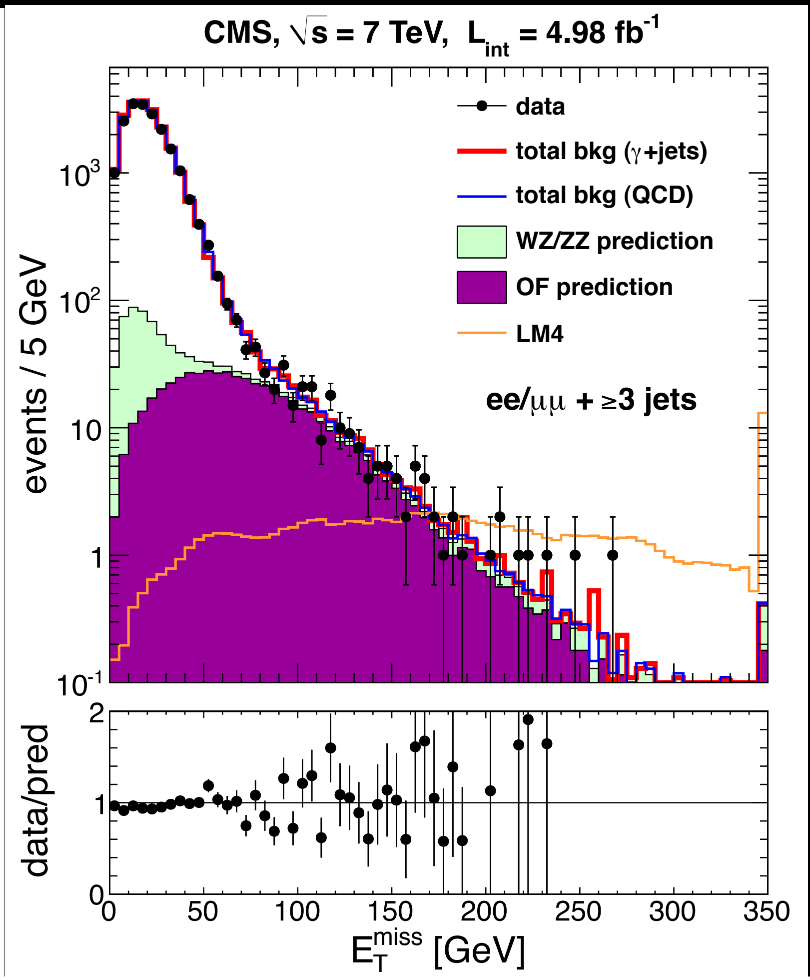
≥3 jets



MET templates method

- Measure MET as a function of N_{jets}, H_T in γ+jets
- Transfer this measurement to Z+jets





No excess of events at high JZB/MET

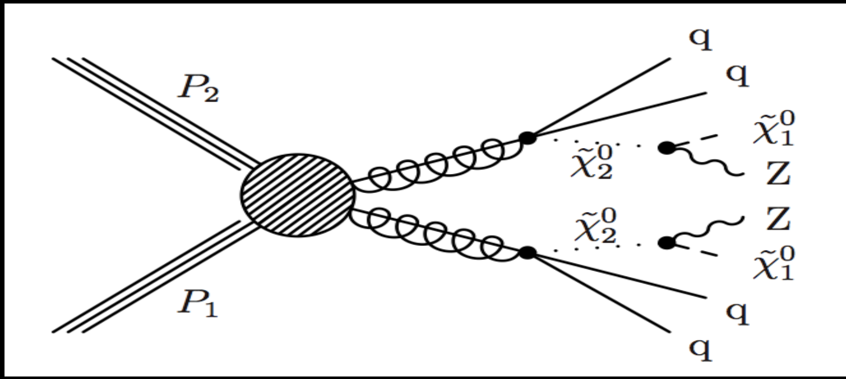
JZB results, 3 or more jets

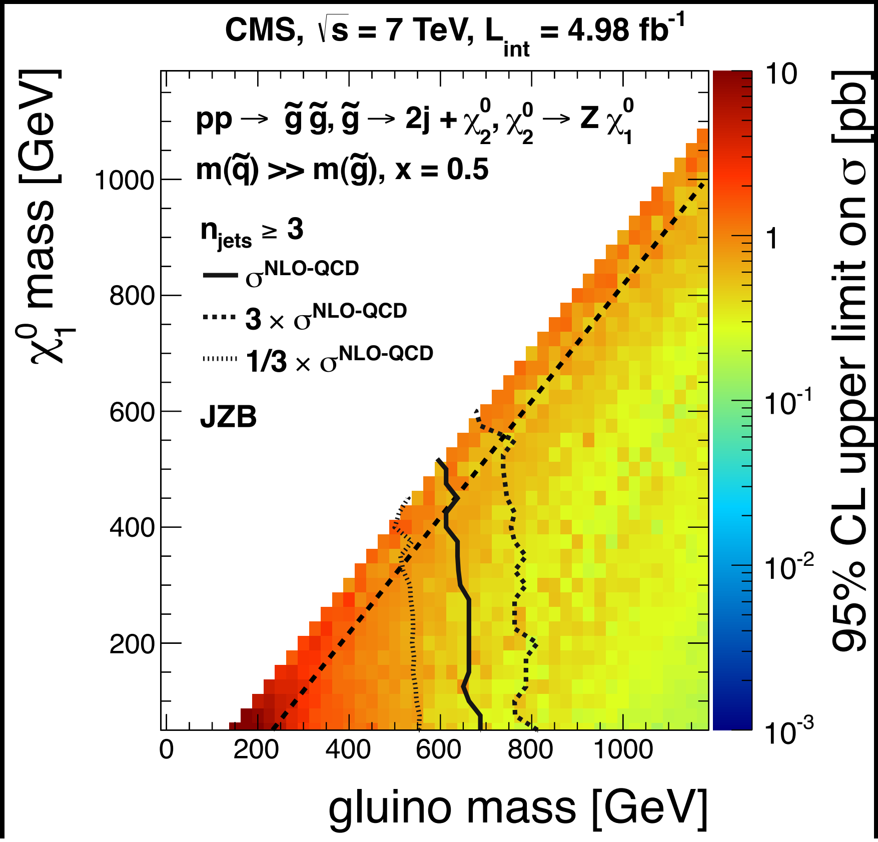
	JZB > 50 GeV	100 GeV	150 GeV	200 GeV	250 GeV
Z bkg	$97 \pm 13 \pm 38$	$8 \pm 3 \pm 3$	$2.7 \pm 1.8 \pm 0.8$	$1.0 \pm 1.0 \pm 0.3$	0
Flavor-symmetric	$311 \pm 10 \pm 45$	$81 \pm 5 \pm 12$	$19 \pm 3 \pm 3$	$7 \pm 2 \pm 1$	$2.0 \pm 0.8 \pm 0.3$
Total bkg	$408 \pm 16 \pm 59$	$89 \pm 6 \pm 12$	$22 \pm 3 \pm 3$	$8 \pm 2 \pm 1$	$2.0 \pm 0.8 \pm 0.3$
Data	408 (203,205)	88 (52,36)	21 (13,8)	5 (3,2)	3 (2,1)

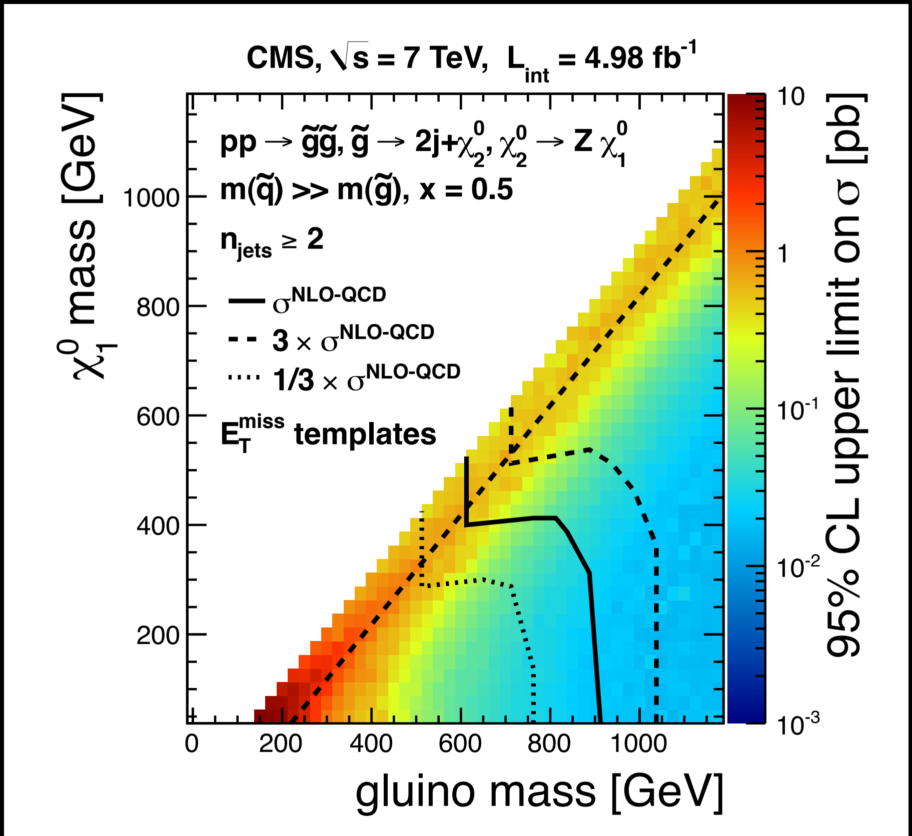
Template results, 2 or more jets

	$E_T^{miss} > 30$ GeV	$E_T^{miss} > 60$ GeV	$E_T^{miss} > 100$ GeV	$E_T^{miss} > 200$ GeV	$E_T^{miss} > 300$ GeV
Z bkg	15070 ± 4825	484 ± 156	36 ± 12	2.4 ± 0.9	0.4 ± 0.3
OF bkg	1116 ± 101	680 ± 62	227 ± 21	11 ± 3.2	1.6 ± 0.6
VZ bkg	269 ± 135	84 ± 42	35 ± 17	5.3 ± 2.7	1.2 ± 0.7
Total bkg	16455 ± 4828	1249 ± 174	297 ± 30	19 ± 4.3	3.2 ± 1.0
Data	16483 (8243,8240)	1169 (615,554)	290 (142,148)	14 (8,6)	0

Simplified model interpretation

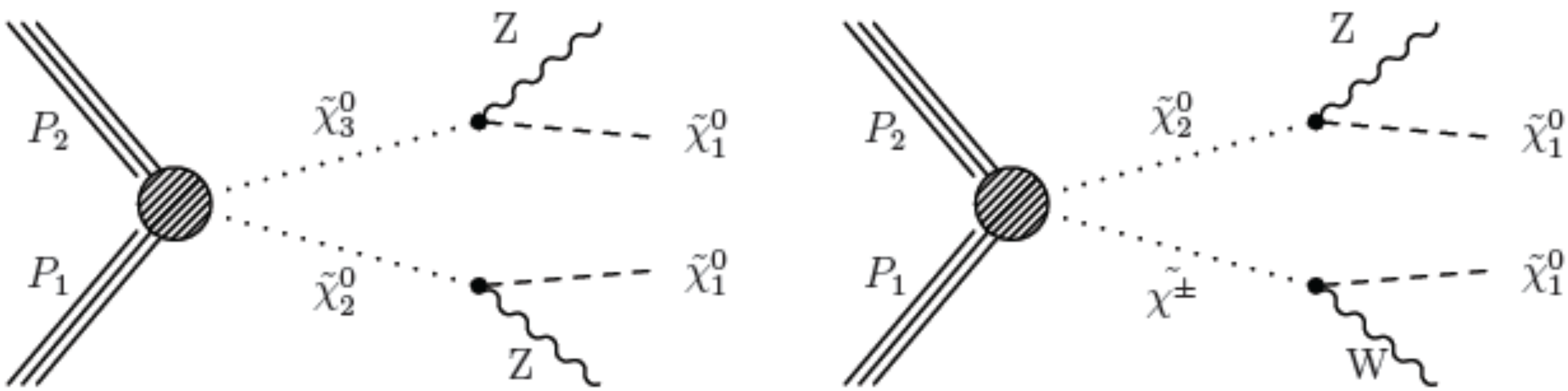






A more interesting interpretation

- The data sample is large enough that we start to be sensitive to ewk-ino pair production



one Z→ll, one Z→jj

Z→ll, W→jj

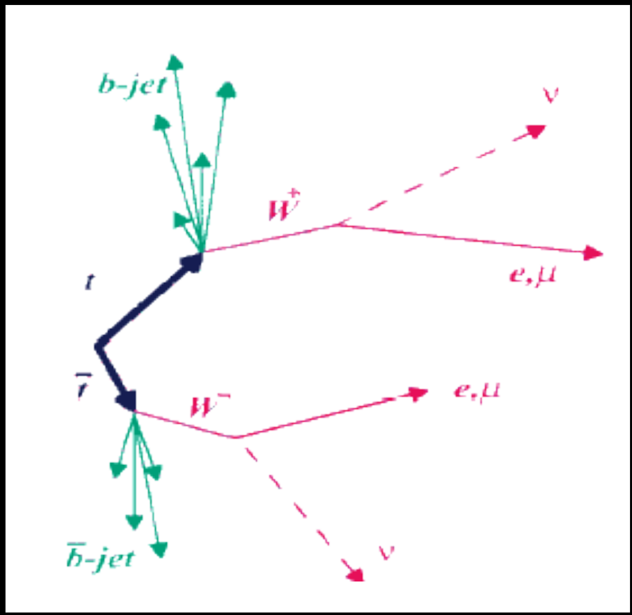
- In the process of combining with multilepton searches…..stay tuned….results soon

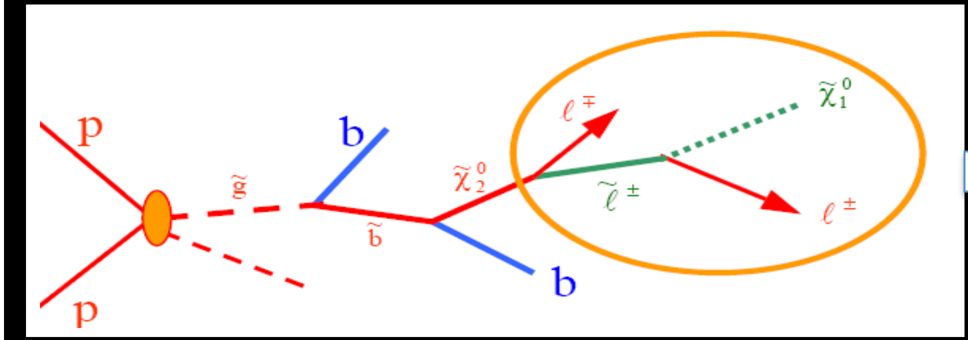
Opposite sign, not a Z

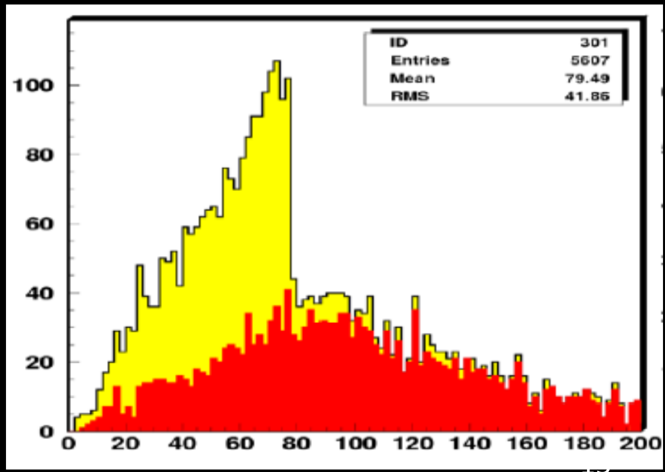
SUS-11-011

(to be submitted in ~ 1 week)

- Background from ttbar
- Two handles
  - Go to high H_T, high MET
  - Edge in dilepton mass in SUSY cascades







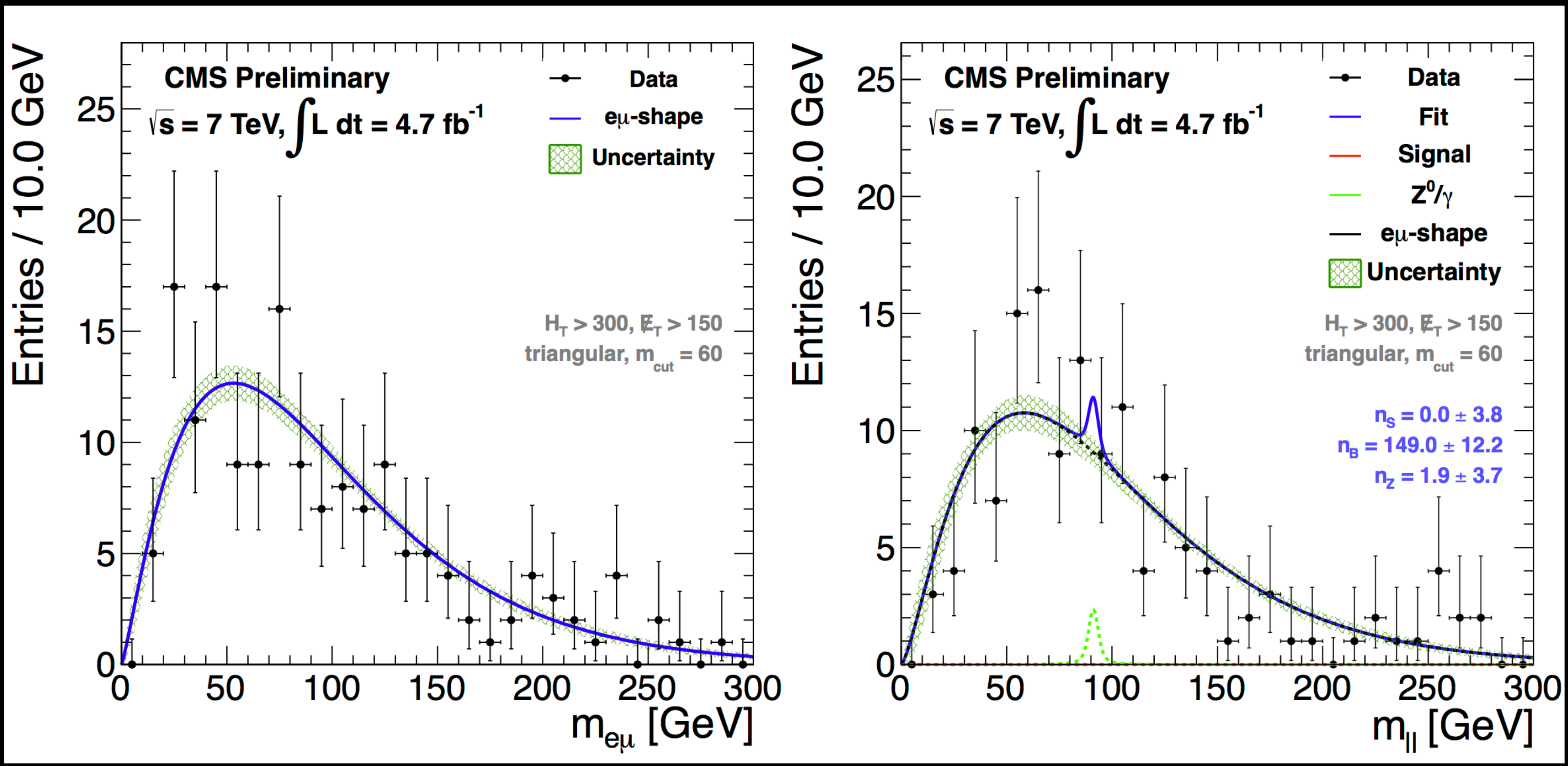
$M(l^+l^-)$

Dilepton edge search

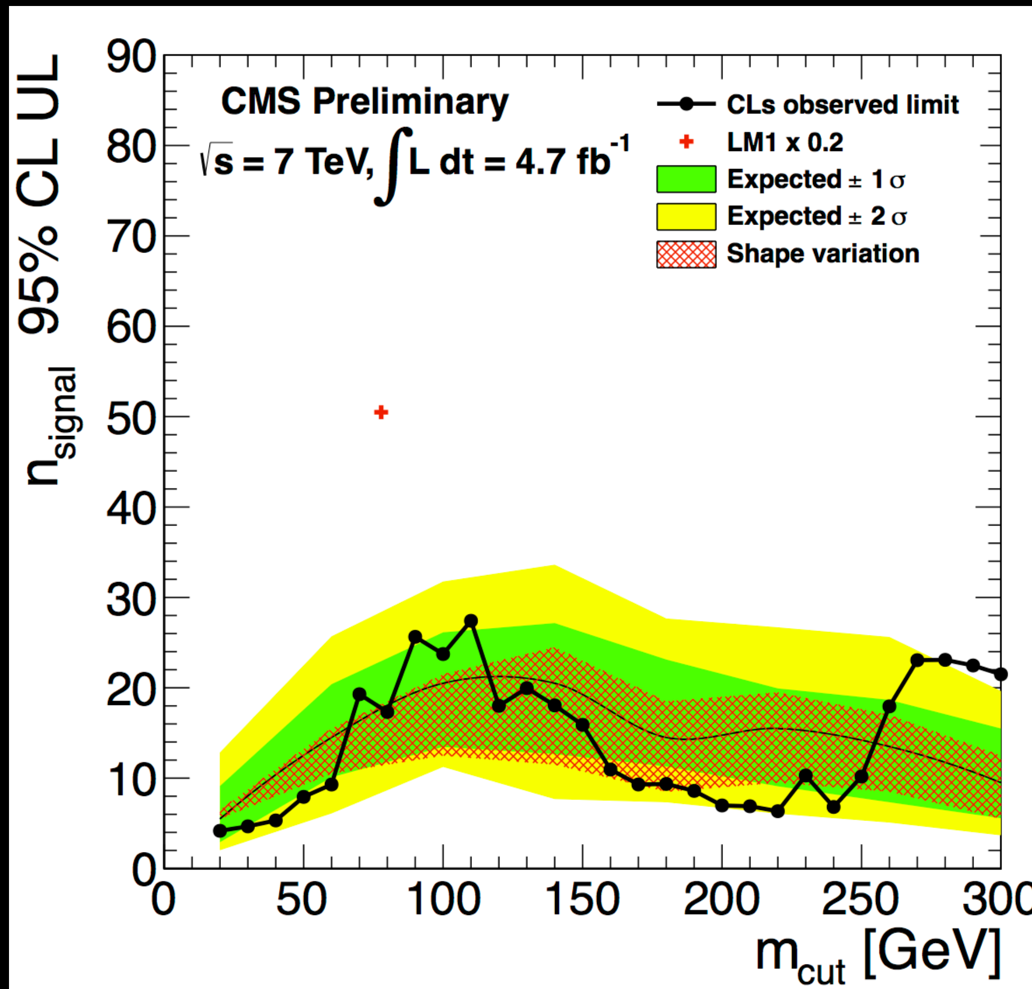
$P_T > (20,10)$
≥ 2 jets
$H_T > 300$
MET > 150

eμ sample.
Don't expect an edge.
Used to calibrate ee/μμ sample

ee/μμ sample.
Hope to see an edge.
Nothing exciting



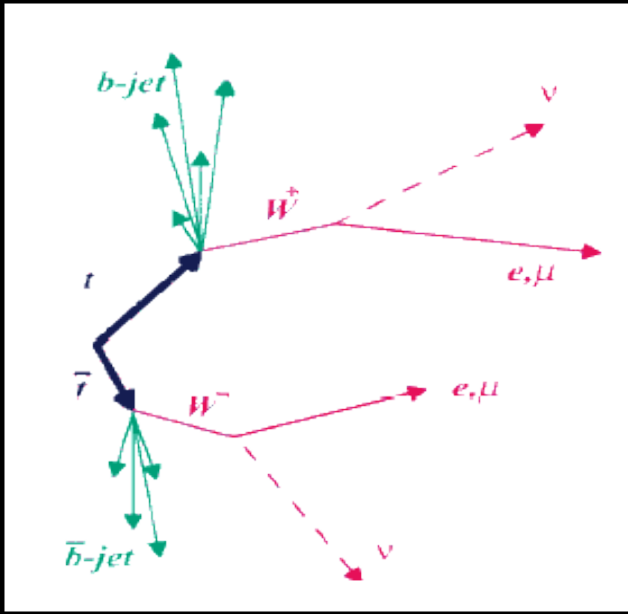
Dilepton edge search limit



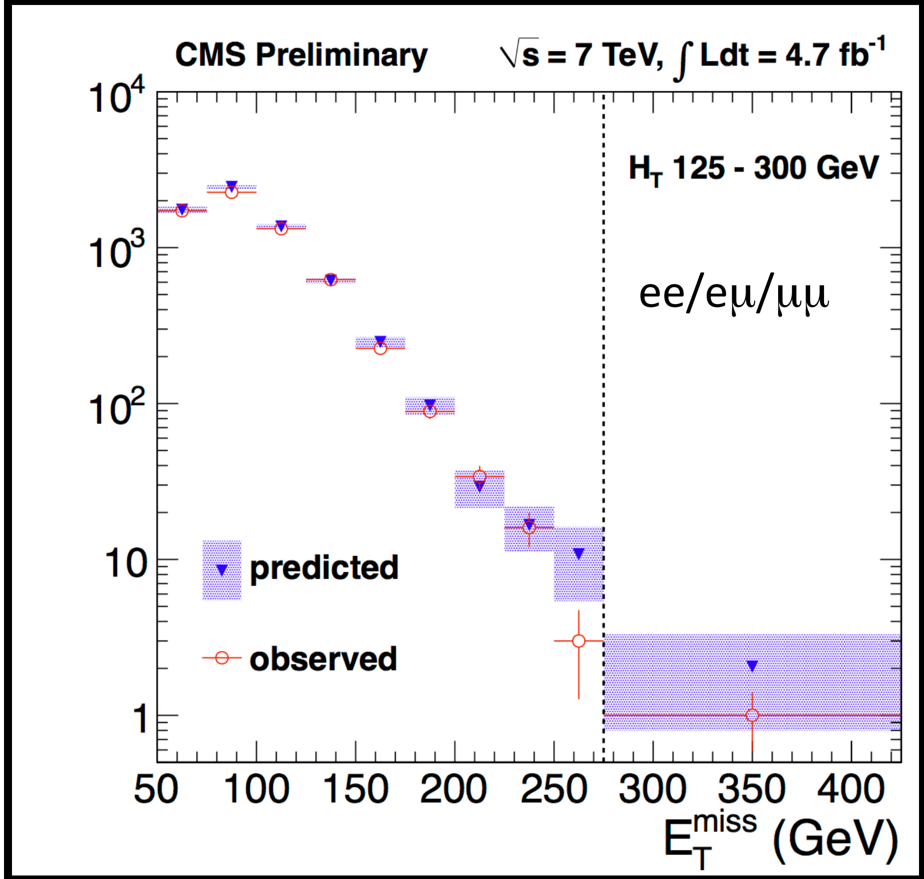
Limit on number of events as a function of the position of the edge

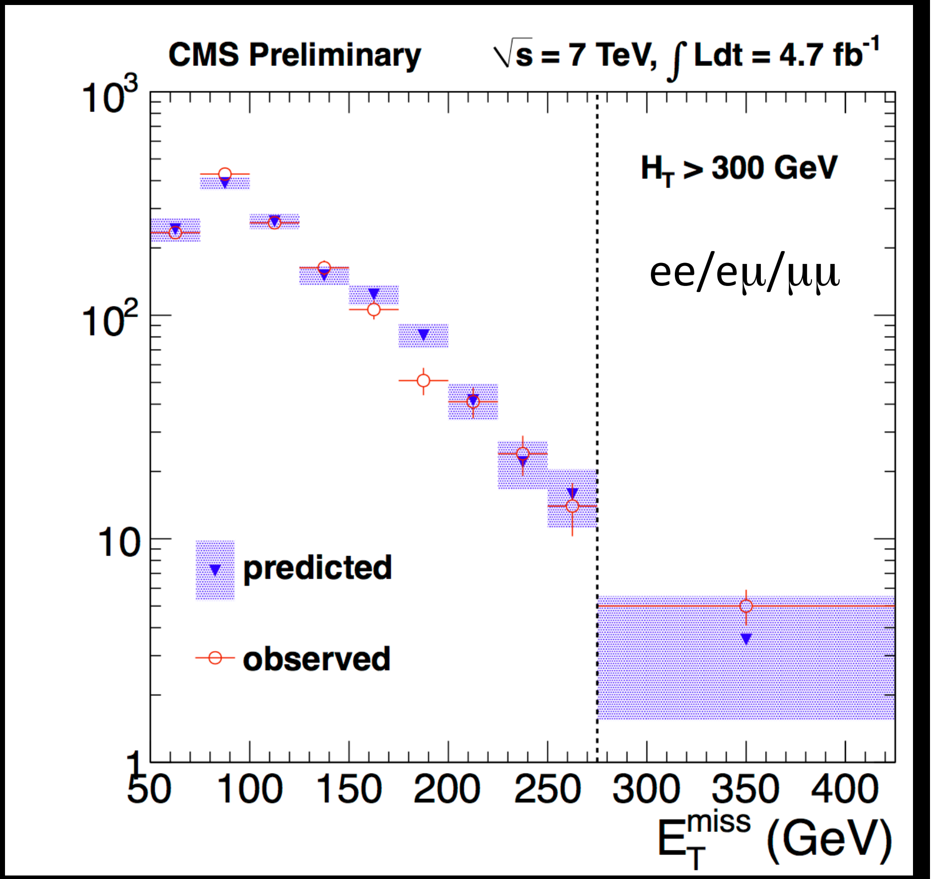
High H_T, high MET search

- Count events at high H_T, high MET
- Compare with BG
- Data driven $P_T(ll)$ BG estimate:
  - In the limit of perfect detector and no W polarization $MET=P_T(\nu\nu)=P_T(ll)$
  - Use $P_T(ll)$ to predict MET
  - Drawback: will calibrate away all signals where MET only comes from W decays (!)



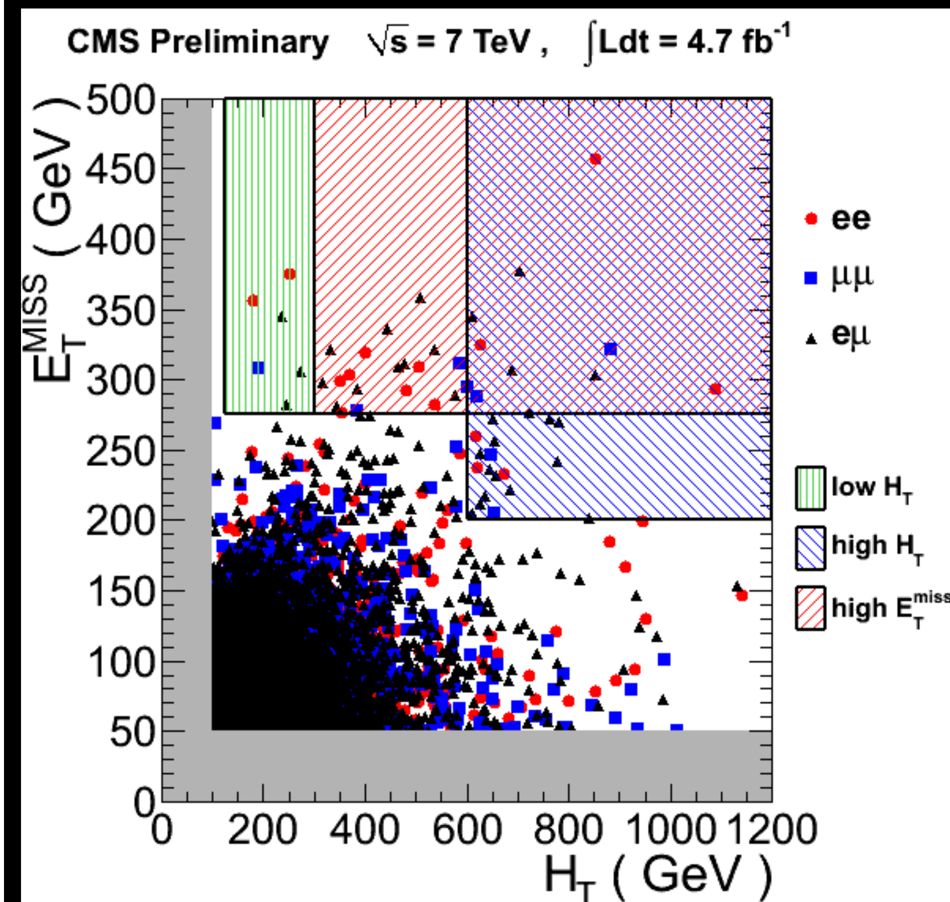
MET distributions predicted by $P_T(ll)$ method

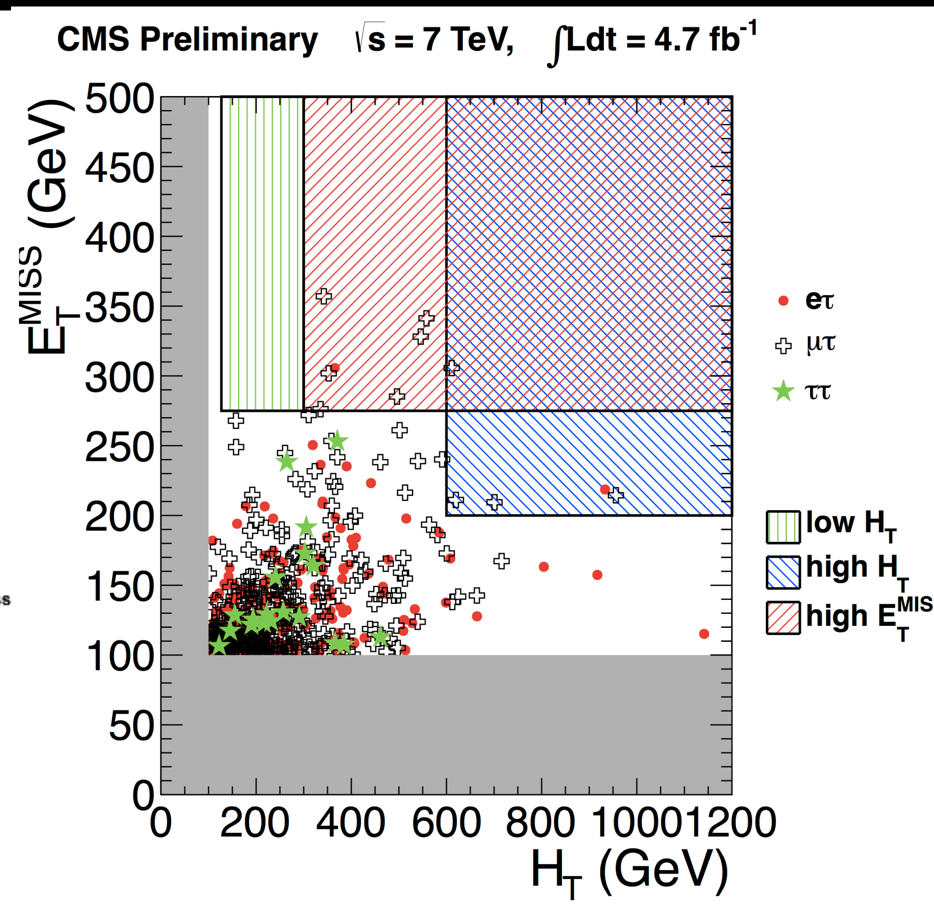




Works pretty well

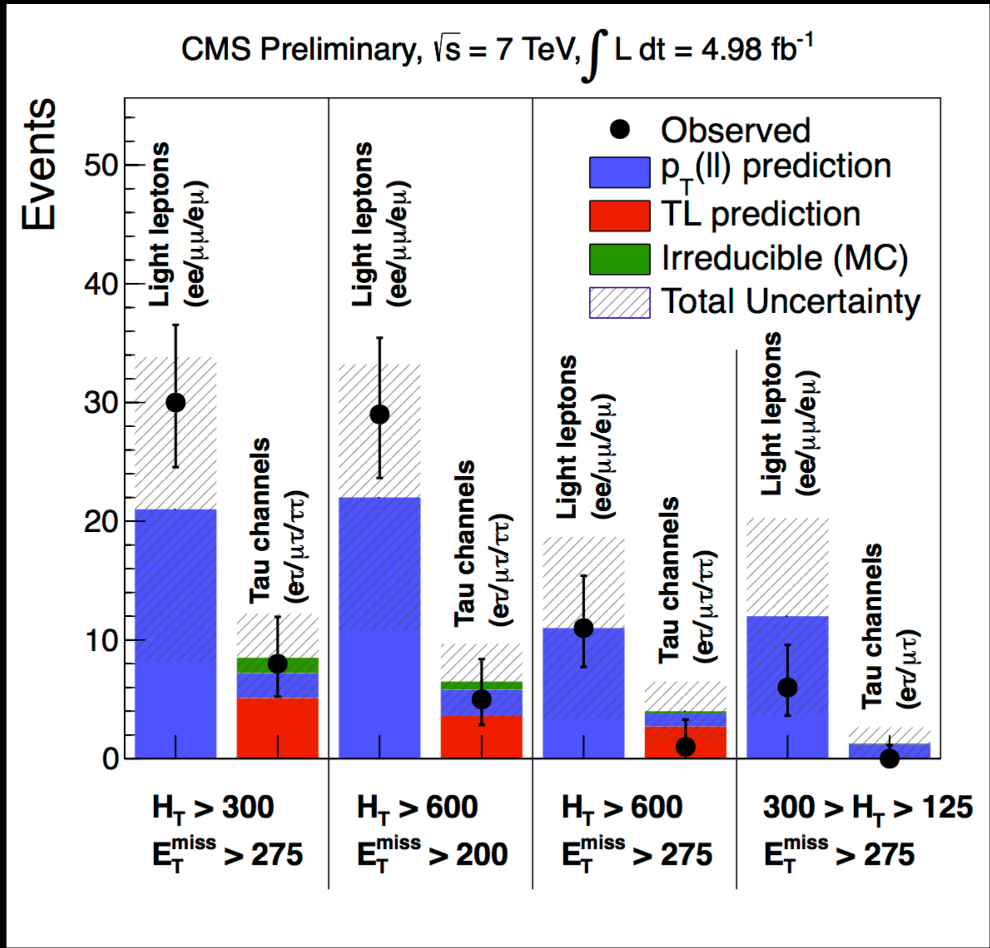
High MET/H_T search





Define several signal regions

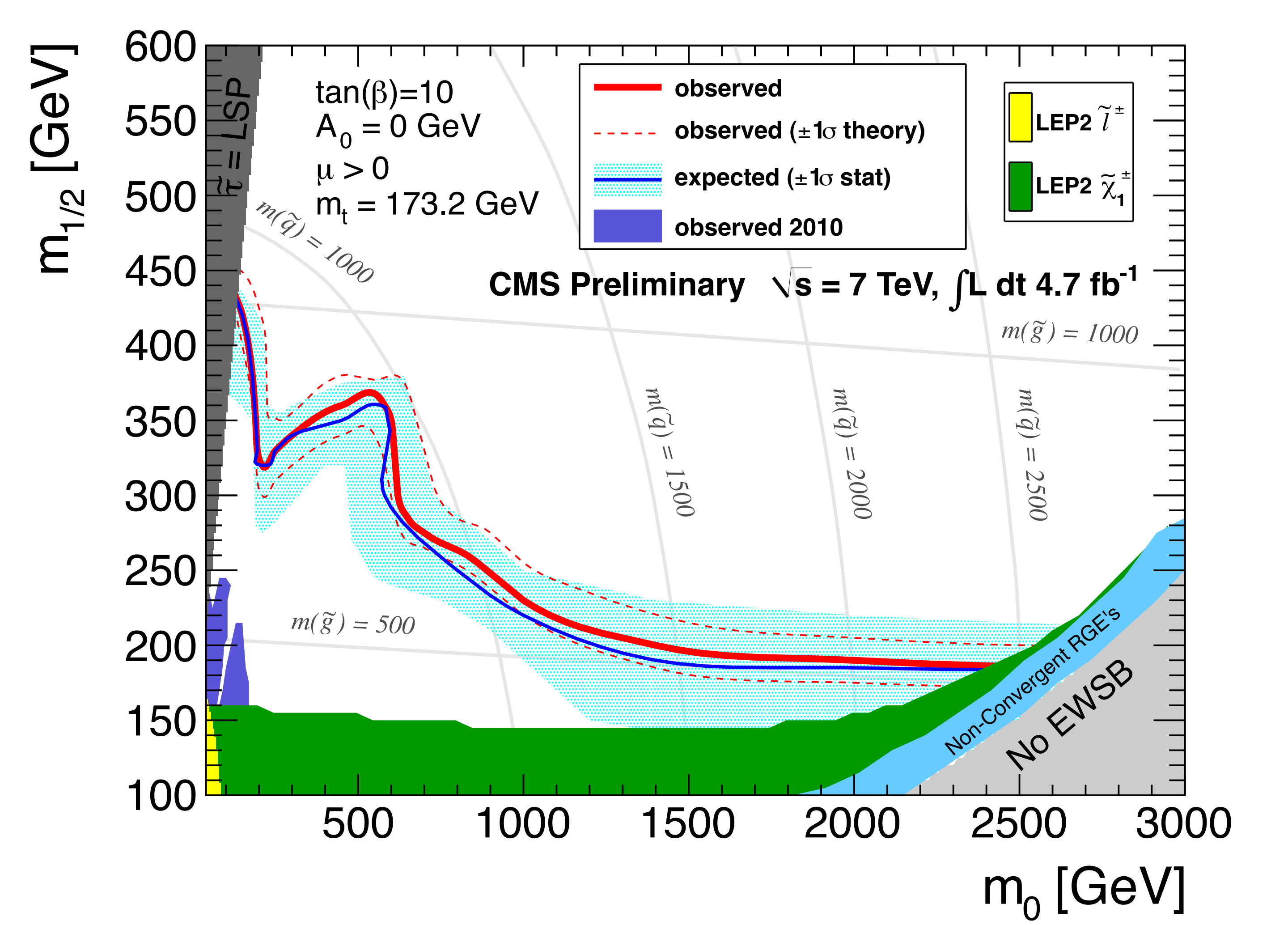
High MET/H_T search



No excess of events

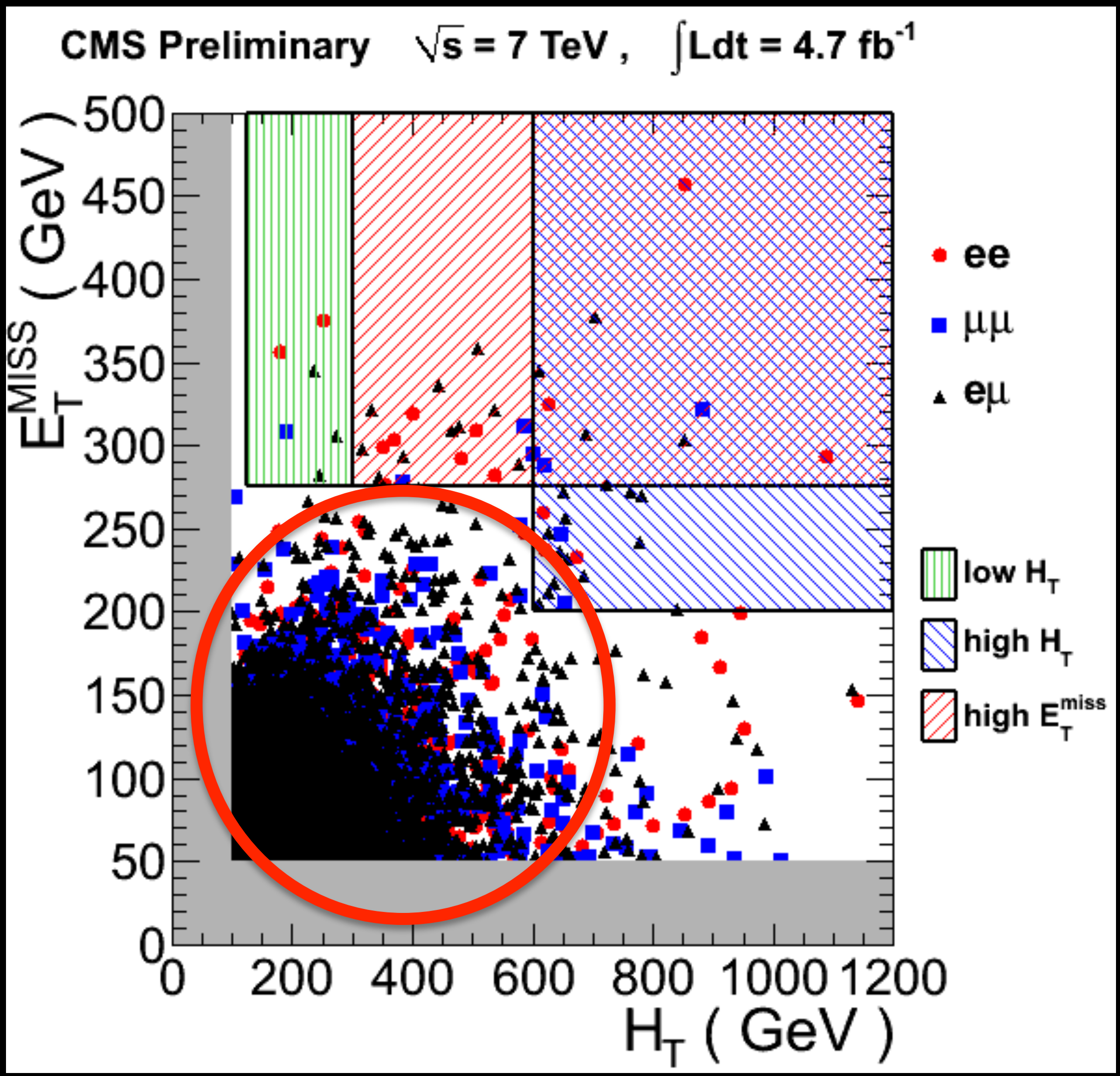
(Also agrees with MC, BTW)

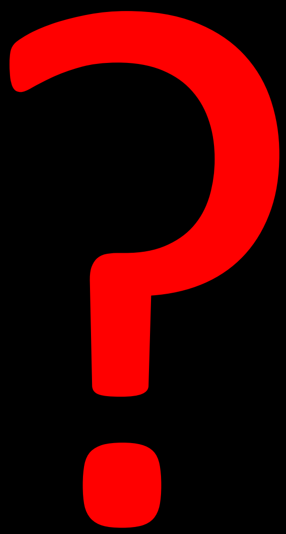
Interpretation in cMSSM



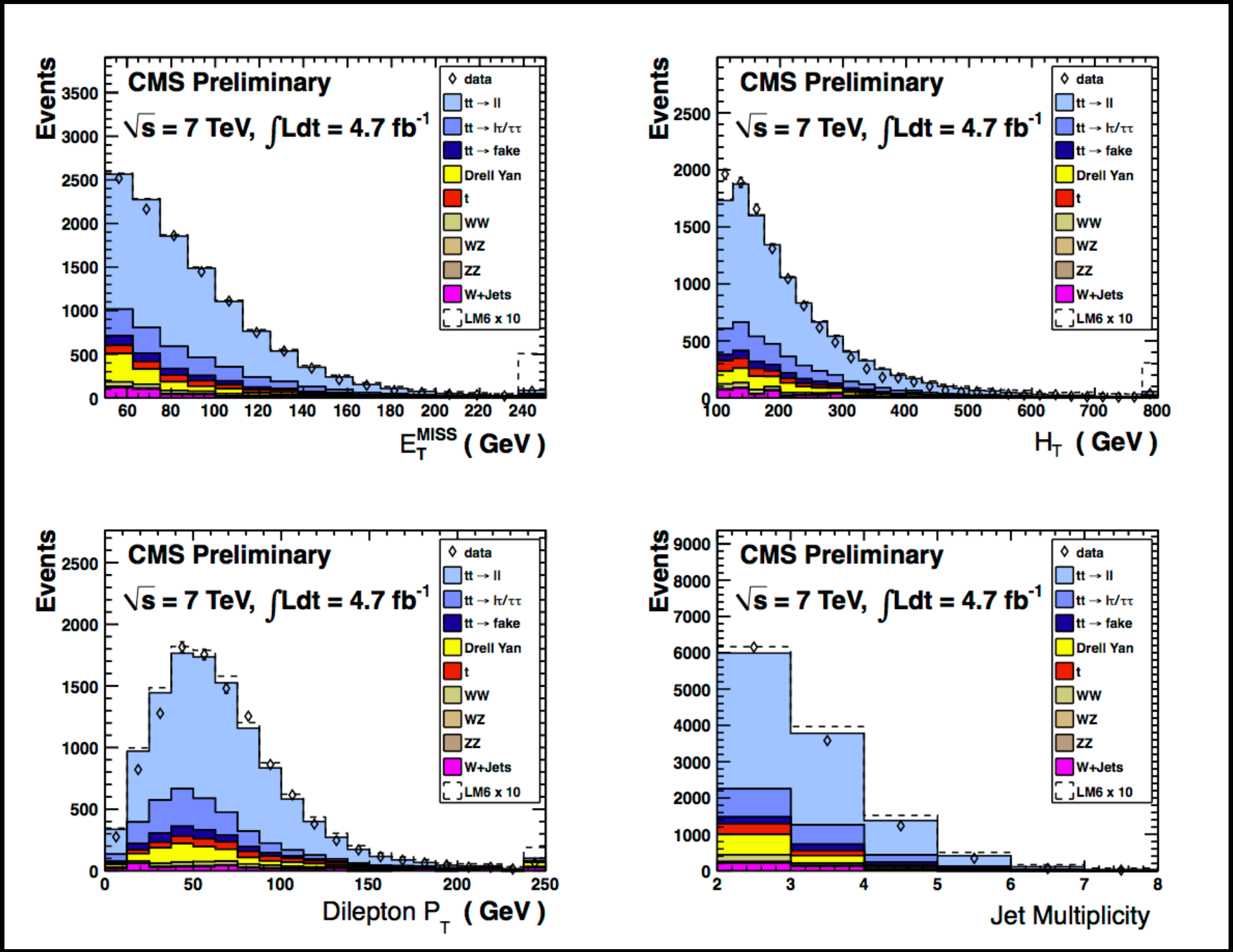
From high MET/H_T search, ee/eμ/μμ

Nothing in the tails, what about the bulk?



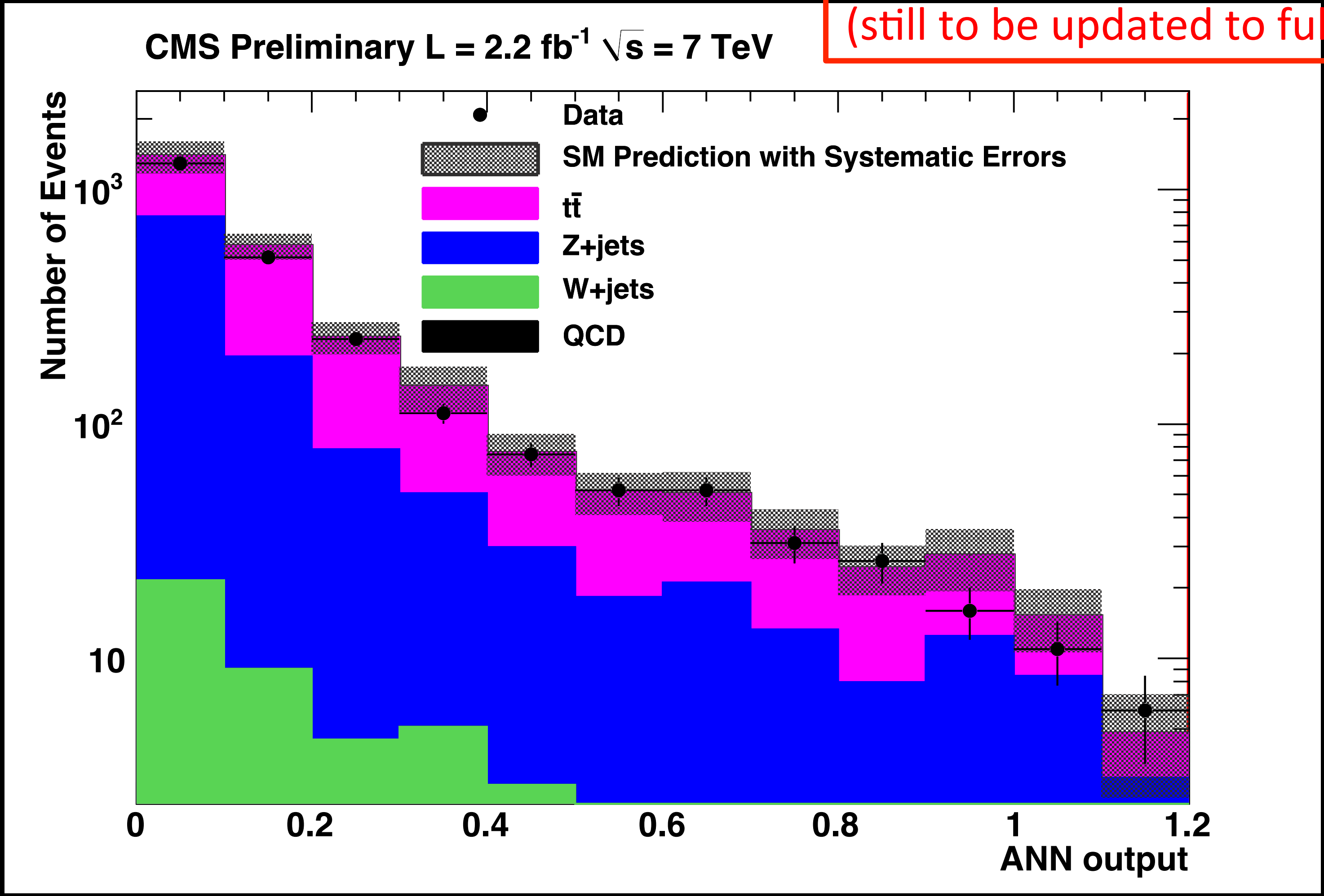


Kinematical distributions look ~ ”as expected”



SUS-11-018

(still to be updated to full statistics)



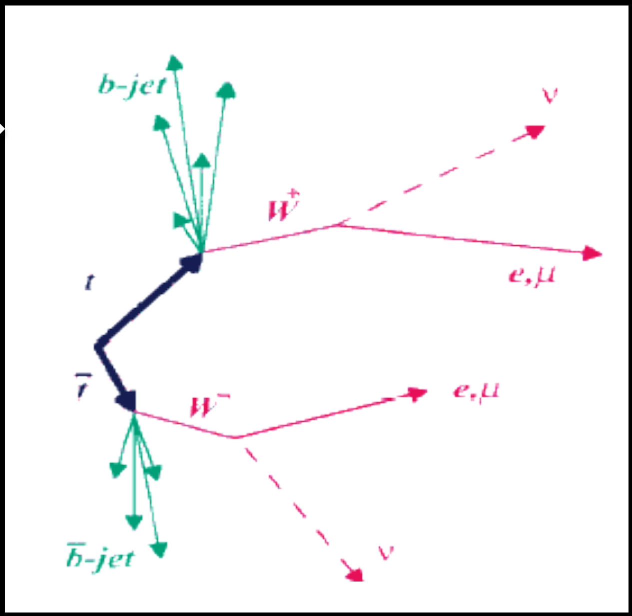
Neural Net for OS events (Z and non-Z) trained to differentiate SM from “standard” SUSY signature.

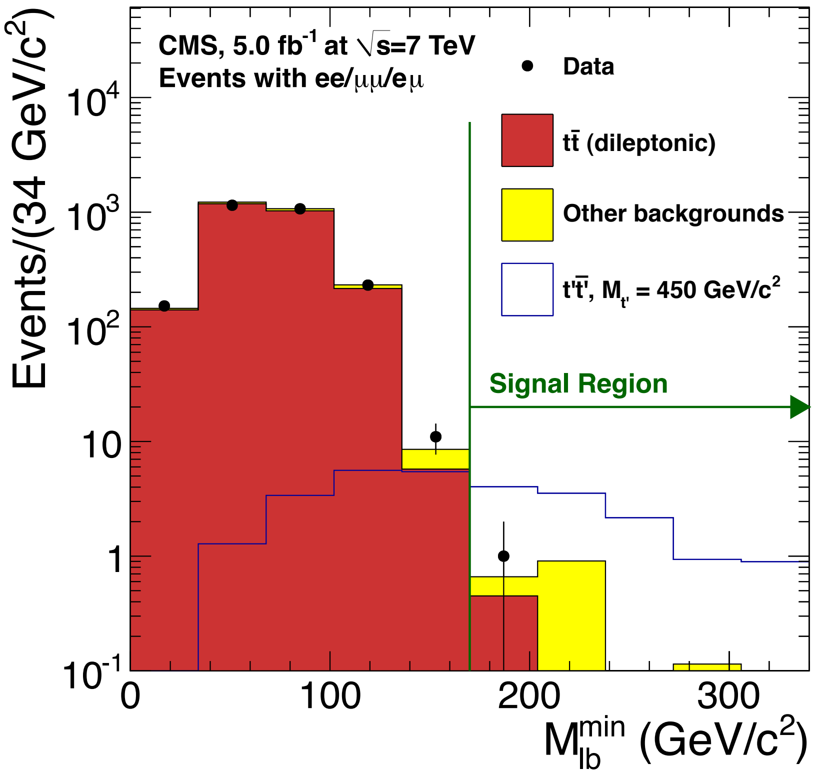
No sign of anything out of ordinary

OS dileptons – a twist

arXiv:1203.5410

- b-jets and leptons come from top decay
- $M(lb) < M_{top}$
- Look for events with two btagged jets where M(lb) is inconsistent with top
- Kills the top BG, without needing high MET, high H_T

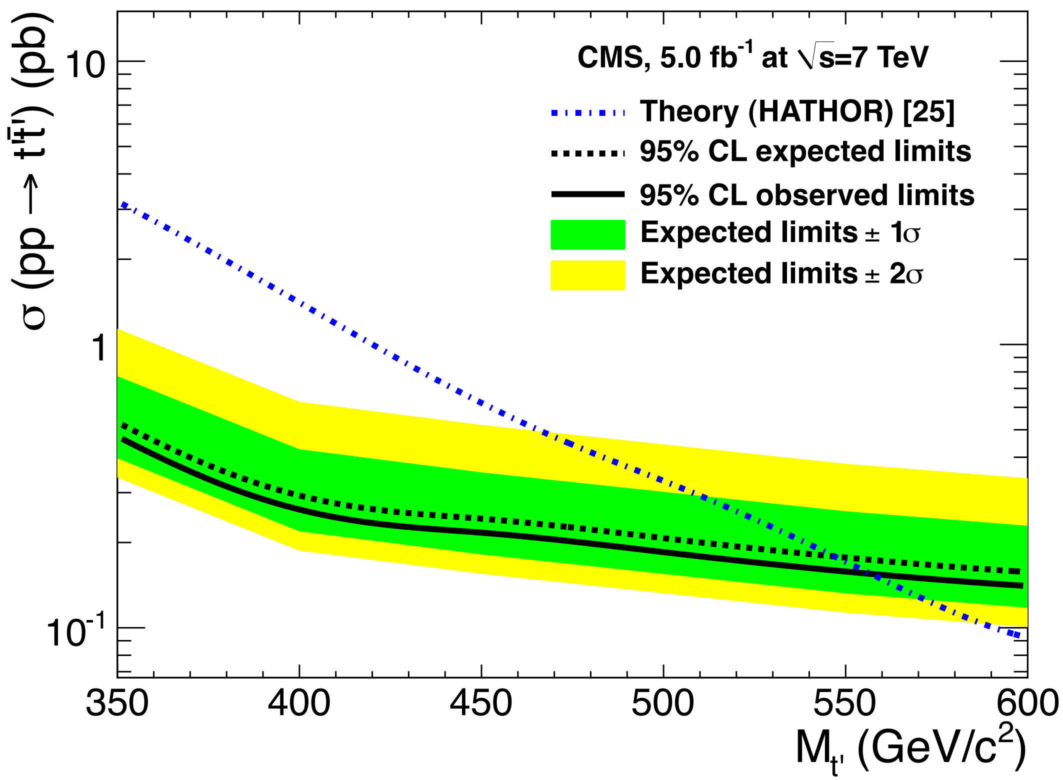




Interpreted as a limit on t' pair production

M(t') < 557 GeV
(l+jets limit is 560 GeV)

A cut on min-M(lb) kills the BG.
But there is no signal….

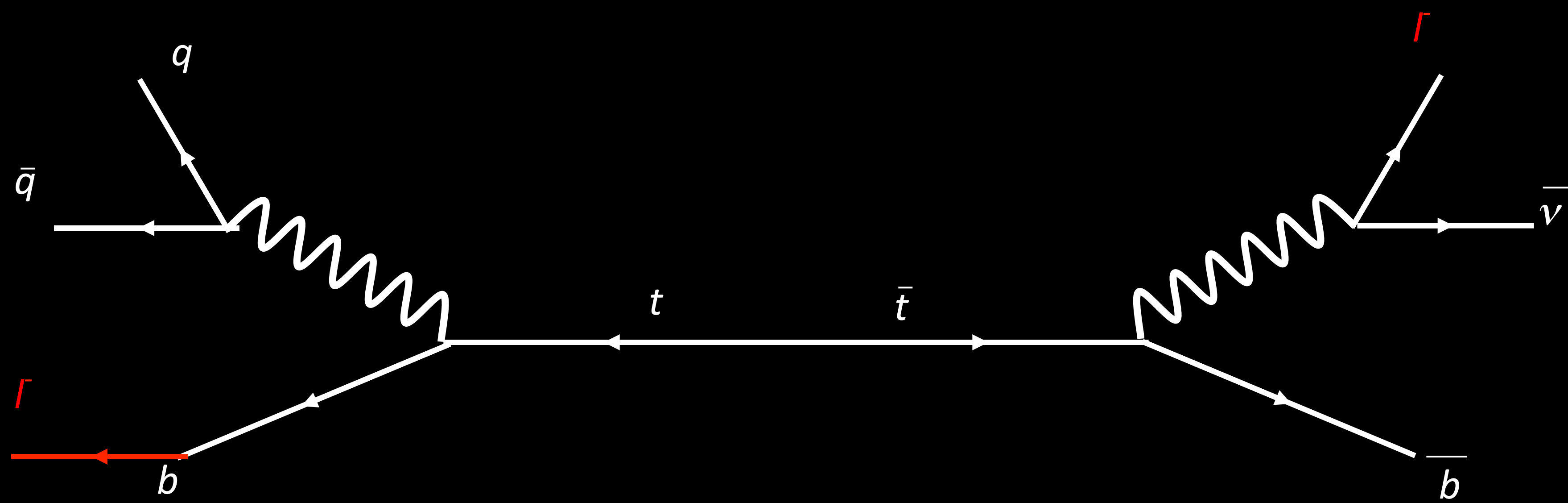


Same Sign Dileptons

SUS-11-011
(sent to arxiv today)

- Much lower background than OS
- Because ttbar is almost gone
- Generically "more sensitive"

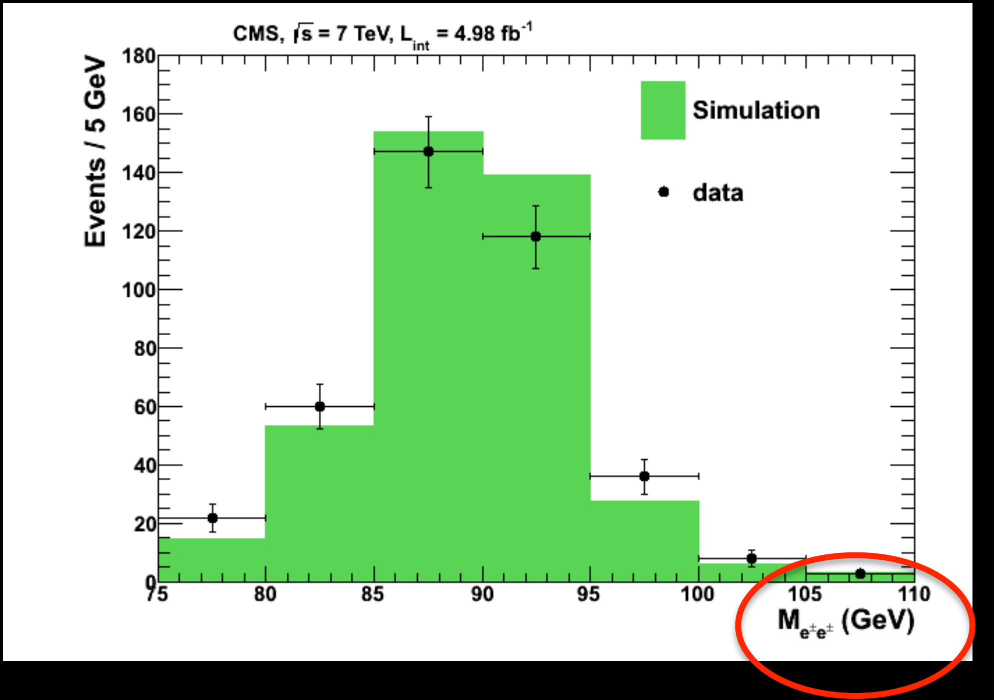
Same-sign: ttbar is not totally gone



- One lepton from W decay
- A second "*fake*" lepton (mostly from bottom decay)
- Estimate BG *in situ* from rate of events with non-isolated second leptons
- <u>This is the main background</u>

Other backgrounds

- Rare SM processes (ttW, ttZ, VVV, SS-WW,…)
  - From MC
- OS dileptons where the charge is mismeasured
  - ~ 10^{-3} "charge flip" probability for electrons
  - From OS data + MC "flip probability" verified by looking at SS Z→ee peak (!)

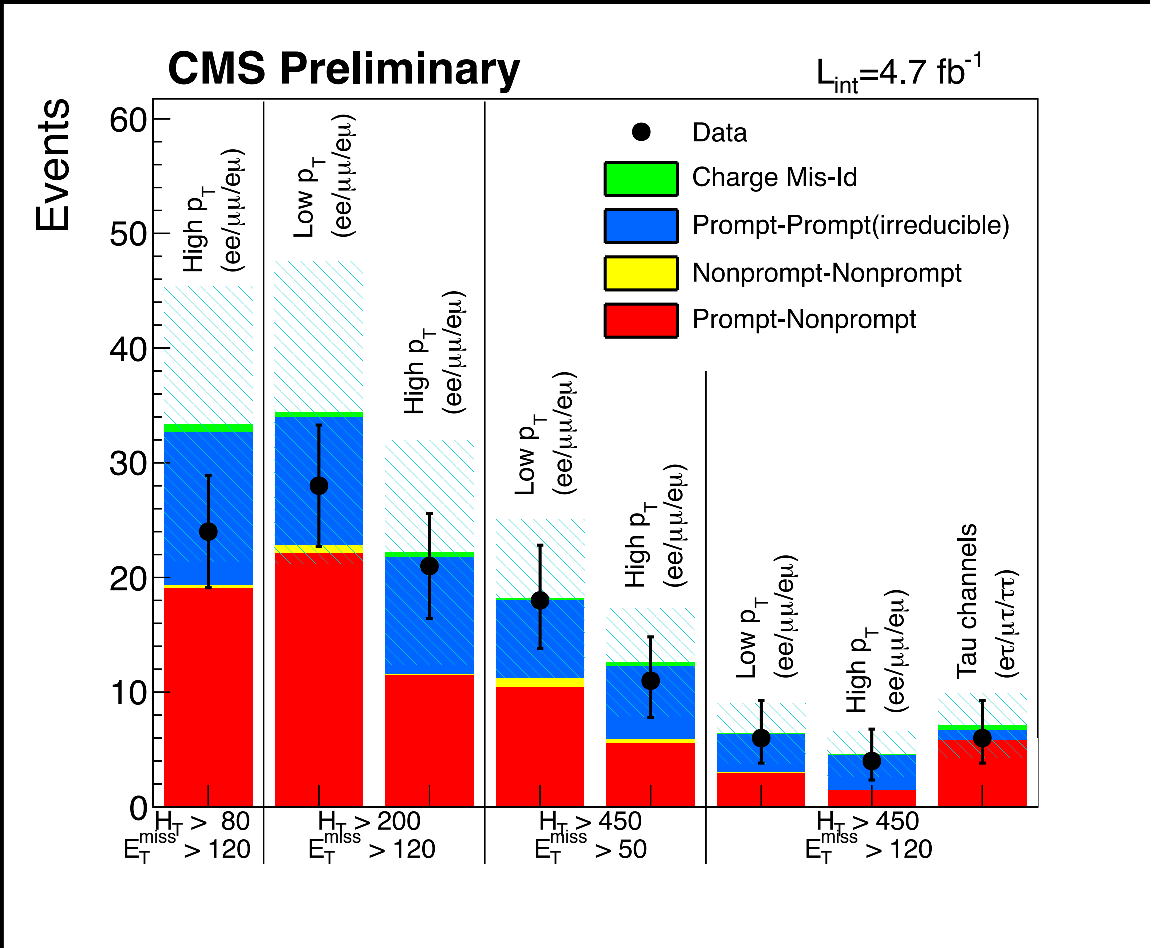


Same Sign results

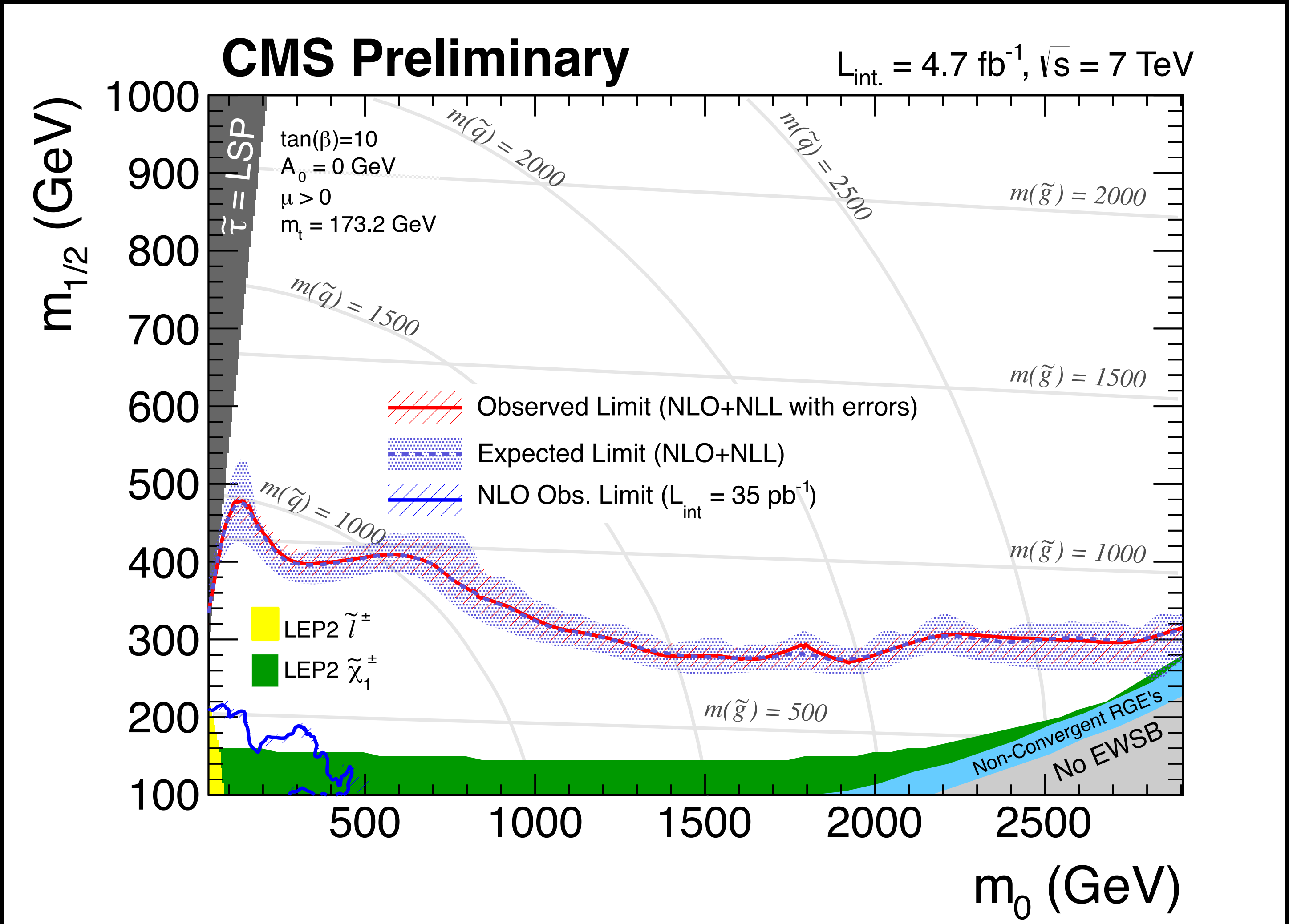
- Many signal regions
  - Low P_T … P_T>(10,5)
  - High P_T … P_T>(20,10)
  - With & without taus
  - Different H_T/MET
  - Always ≥ 2 jets

- **No excess anywhere**

- Note that rare SM are important
  - Esp at high H_T



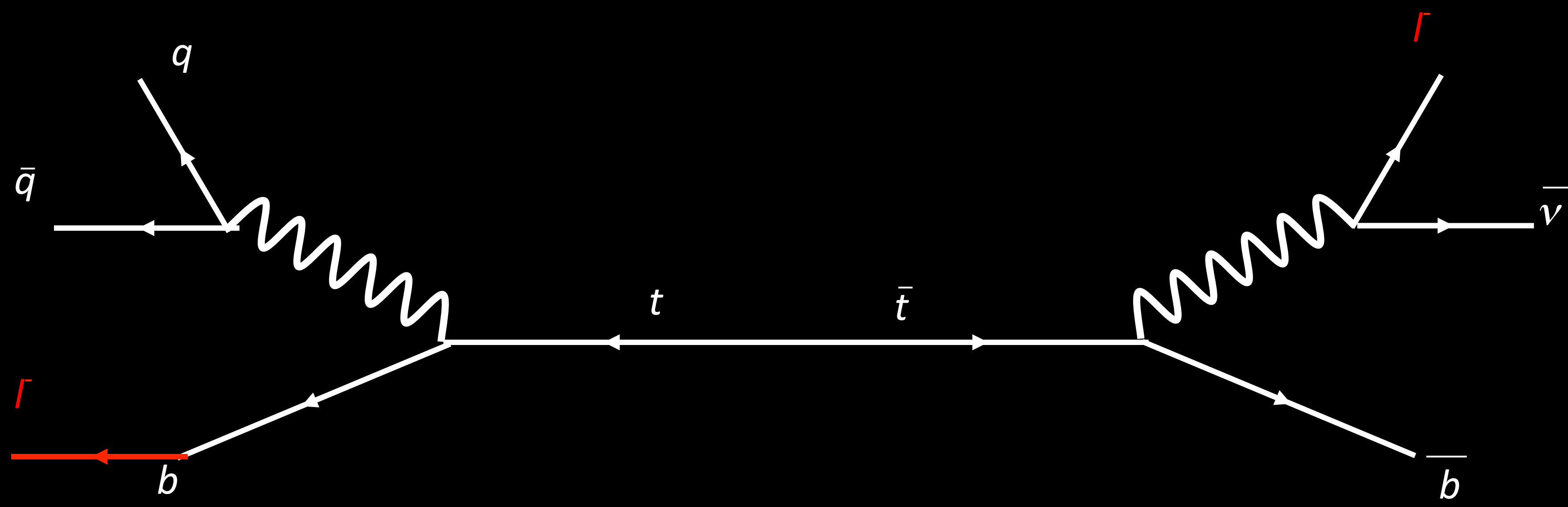
SS interpretation in the cMSSM



One of the most sensitive channels at high m_0

Add b-tagging to SS

arXiv:1205.3933

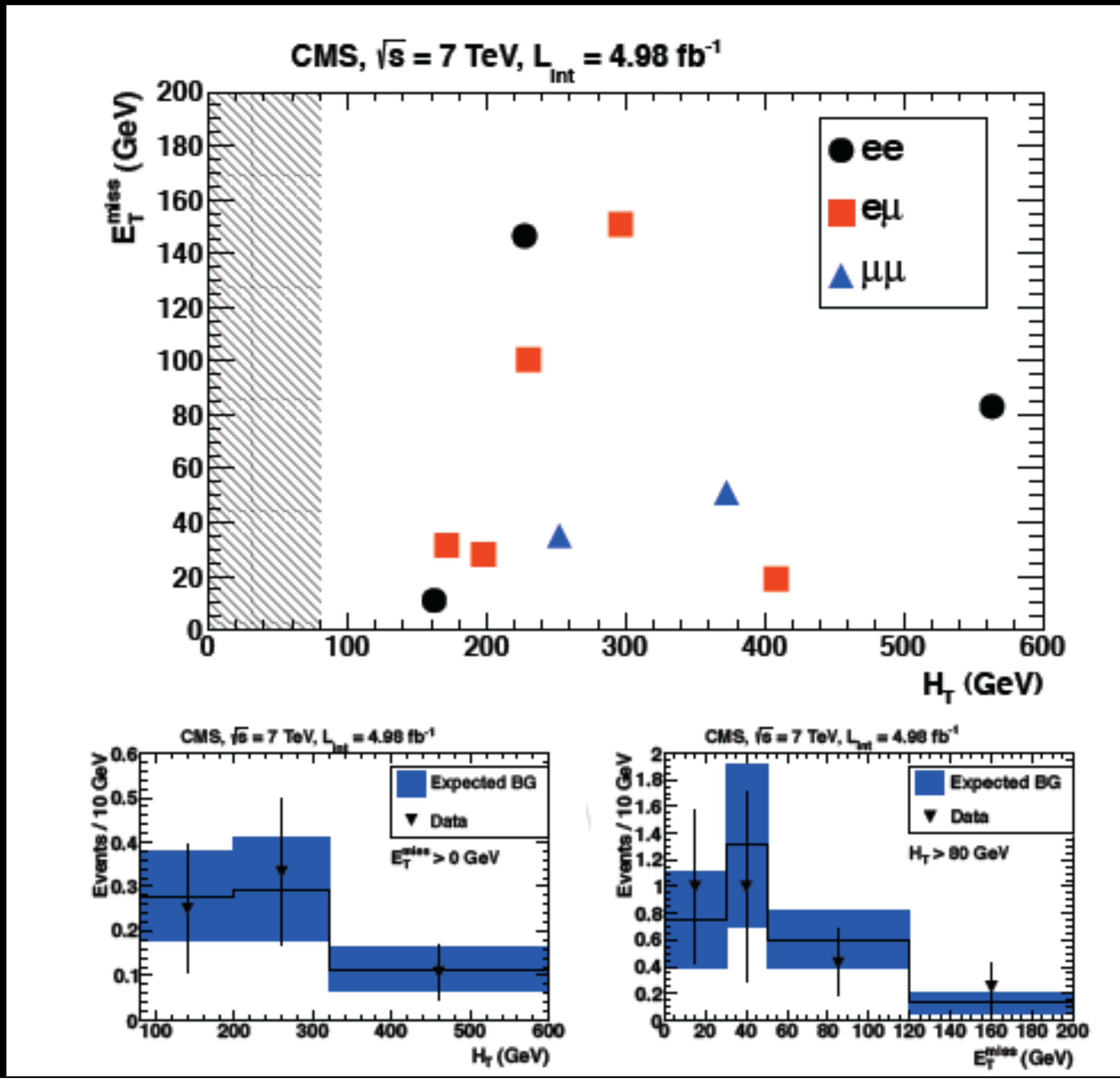


- It is impossible for the two b-quarks in a ttbar event to give <u>two</u> btagged jets <u>and</u> one fake isolated lepton
- **<u>The fake BG is reduced considerably</u>**

SS + 2 btags + MET

- Signature sensitive to final states with multiple top quarks/W bosons and possibly LSPs
- Increase P_T requirements on leptons to > 20 GeV
  - Appropriate for leptons from top/W
- Define signal regions with varying H_T/MET requirements

SS + 2 btags results



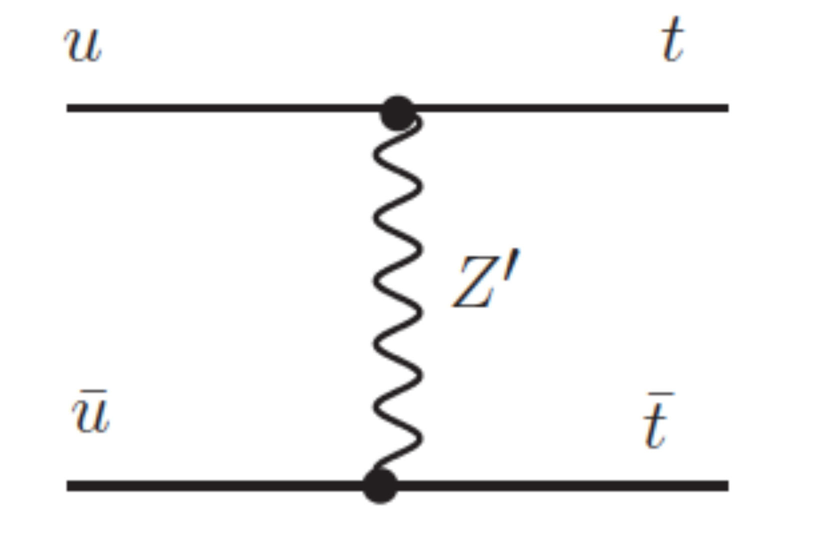
SS + 2 btag results

	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
No. of b-tags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Charge-flip BG	1.4 ± 0.3	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.03 ± 0.01	0.008 ± 0.004	0.20 ± 0.05
Fake BG	4.7 ± 2.6	3.4 ± 2.0	1.8 ± 1.2	0.3 ± 0.5	1.5 ± 1.1	0.8 ± 0.8	0.15 ± 0.45	0.15 ± 0.45	1.6 ± 1.1
Rare SM BG	4.0 ± 2.0	3.4 ± 1.7	2.2 ± 1.1	0.6 ± 0.3	2.1 ± 1.0	1.1 ± 0.5	0.4 ± 0.2	0.12 ± 0.06	1.5 ± 0.8
Total BG	10.2 ± 3.3	7.9 ± 2.6	4.5 ± 1.7	1.0 ± 0.6	3.9 ± 1.5	2.0 ± 1.0	0.6 ± 0.5	0.3 ± 0.5	3.3 ± 1.4
Event yield	10	7	5	2	5	2	0	0	3

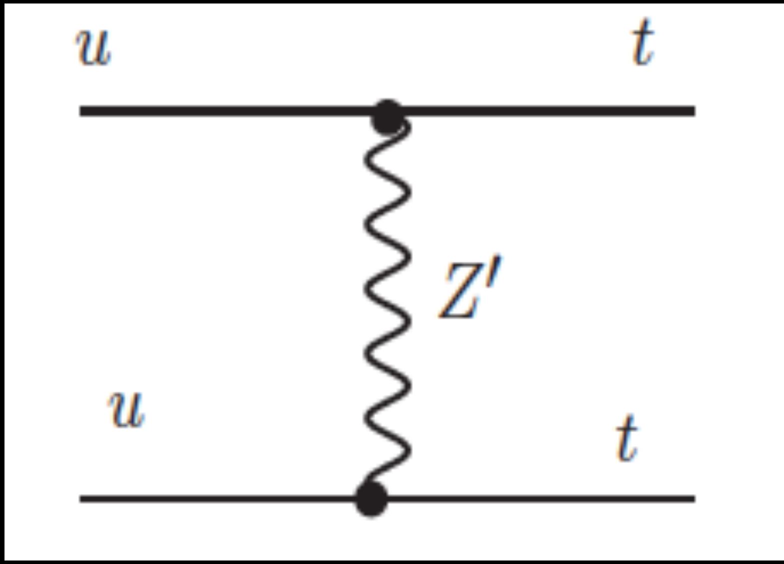
- Very low BG: Only 10 events, even with no MET cut and minimal H_T
- **No excess anywhere**

Interpretation: same-sign-top

- Interesting because many proposals to explain A_{FB} in ttbar at TeVatron lead to large pp→tt rates at the LHC
- eg Z' model of Berger et al (xxxxxxx)

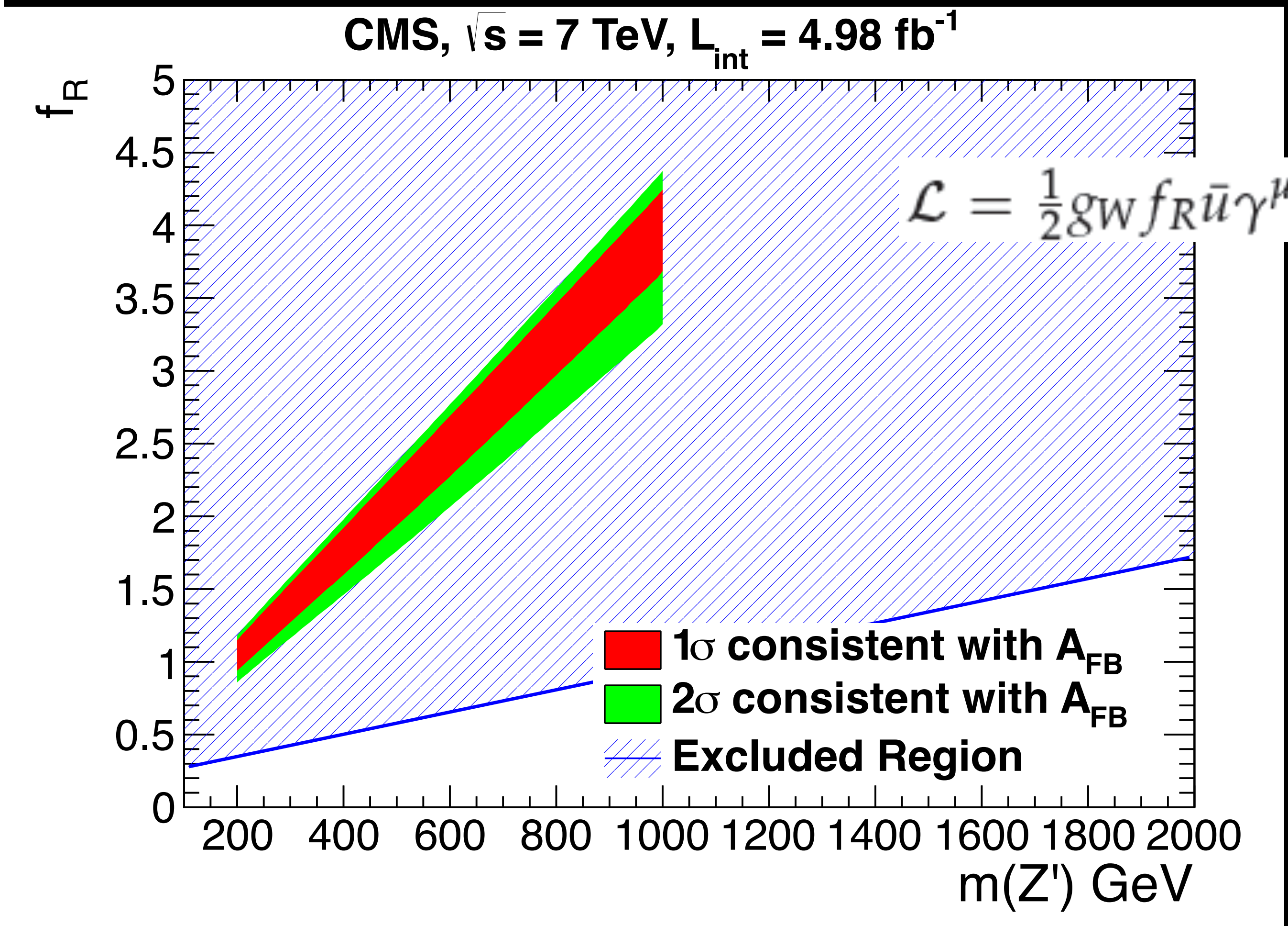


This can cause A_{FB}



This makes SS tops

Same sign tops: σ(pp→tt) < 0.61 pb



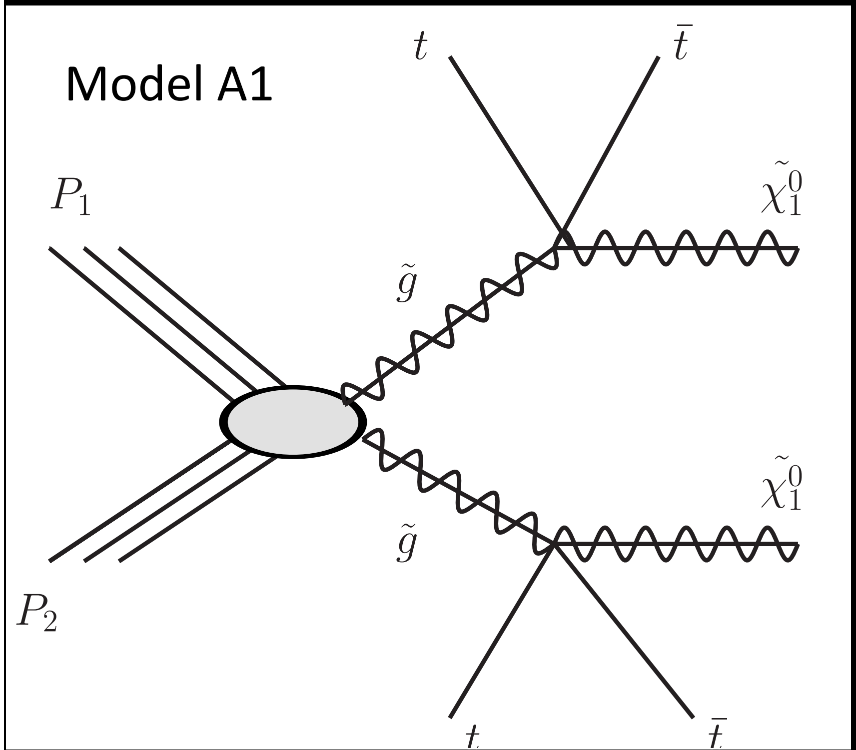
$$\mathcal{L} = \frac{1}{2} g_W f_R \bar{u} \gamma^\mu (1+\gamma^5) t Z'_\mu + \text{h.c.}$$

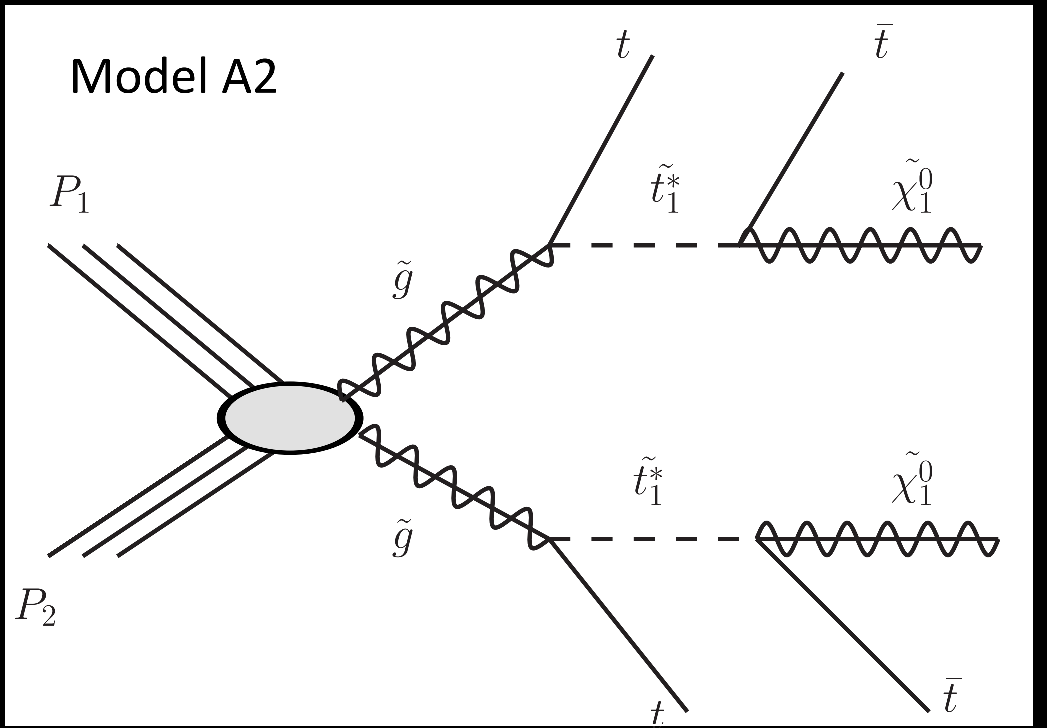
This model is excluded by a huge margin

SUSY models with third generation squarks

- Much interest in looking for SUSY 3rd generation
- To preserve naturalness the stop cannot be too heavy
- Canonical jets+MET searches great for gluino, light squarks. Not so much for stops
- SS + btags one of the most sensitive channels

3rd generation models probed (stop)



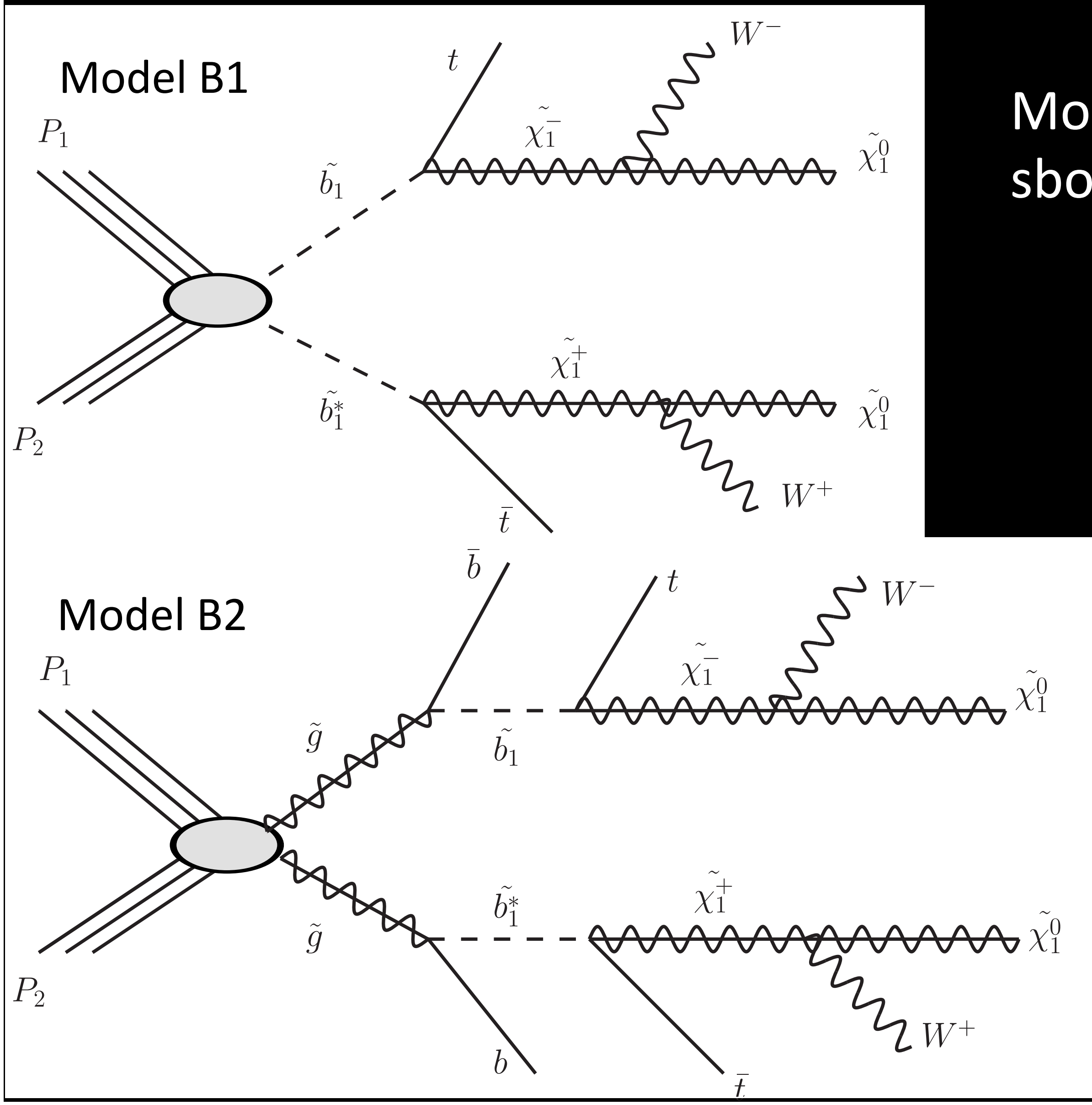


These would be the dominant gluino decay modes if the stop was the lightest squark.

Model A1: heavyer virtual stop

Model A2: lighter on-shell stop

3rd generation models probed (sbottom)



Model B1:
sbottom pair production

Model B2:
sbottom production via gluino decay

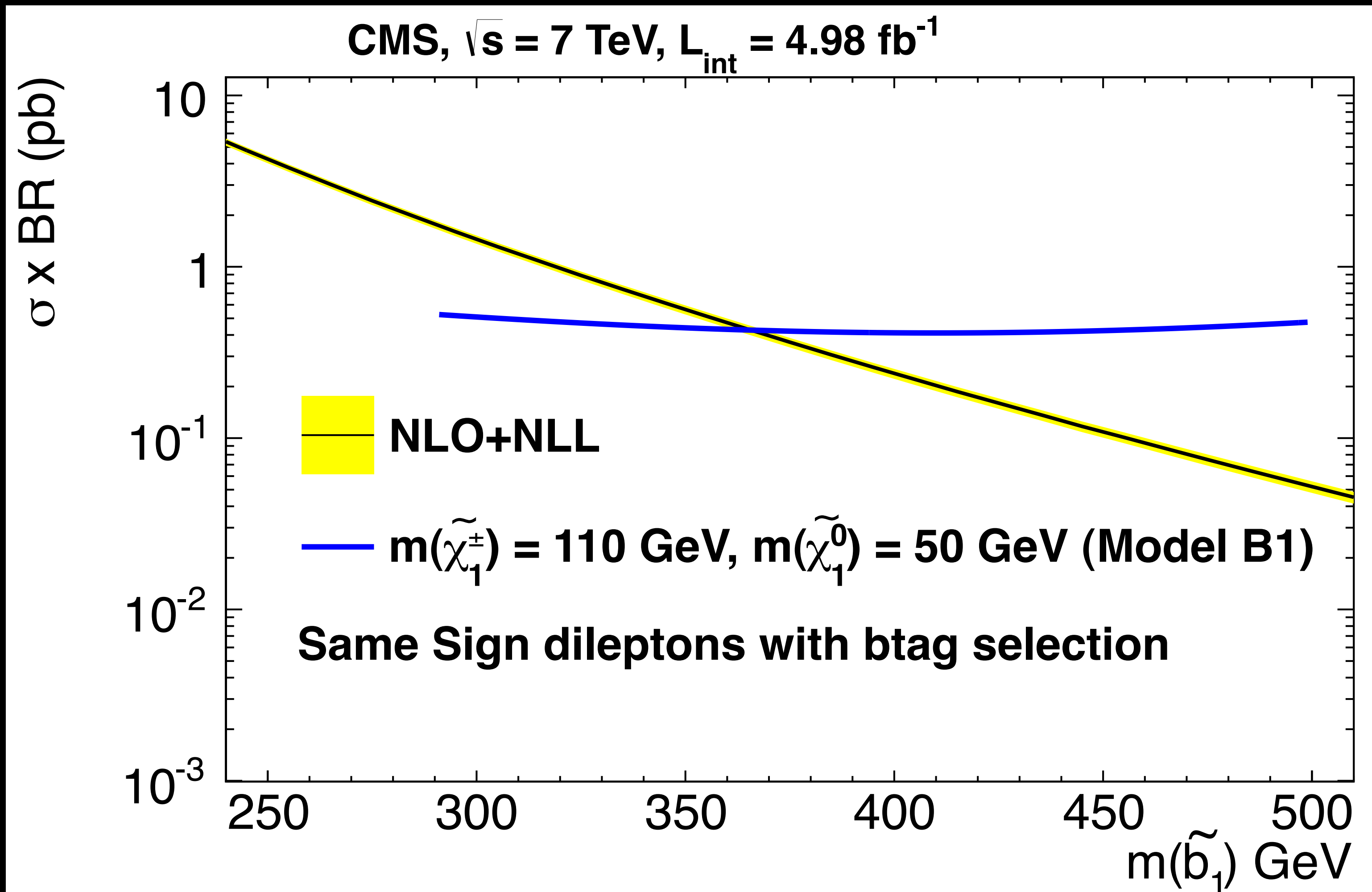
Would be favored gluino decay if sbottom was Lightest squark

Exclusions

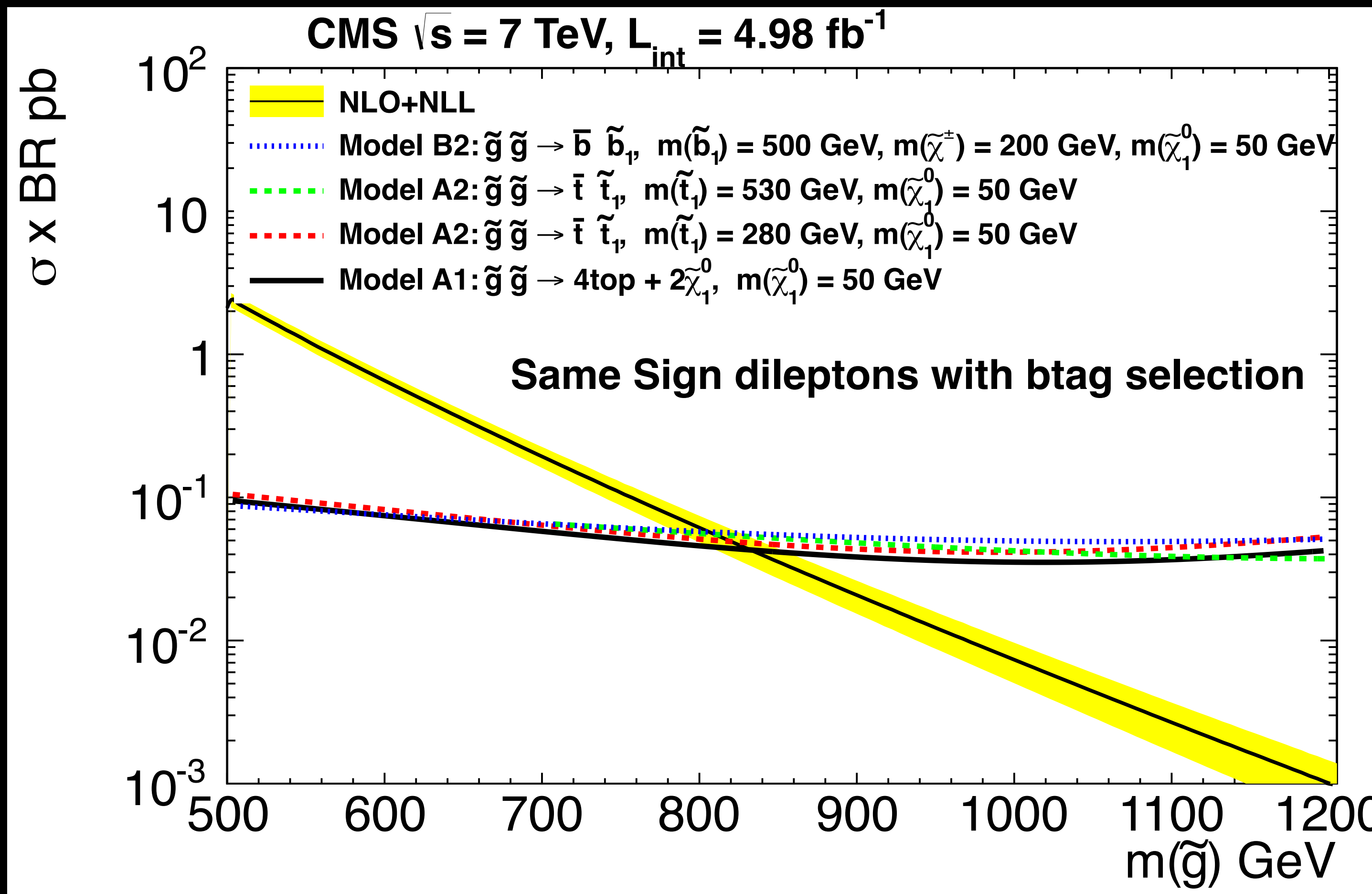
- Exclude gluinos below about 800 GeV for all allowed mass parameters of stop, LSP, etc
  - Small BG → loose cuts → little loss of sensitivity near kinematical boundaries
- Exclude sbottoms below 370 GeV
  - For the assumed sbottom decay chain

$\tilde{b}_1 \to t\tilde{\chi}_1^-$ $\tilde{\chi}_1^- \to W^-\tilde{\chi}_1^0.$

Model B1 exclusion: sbottom pair production



Gluino exclusions for models A1, A2, B2



Communicating the results

- cMSSM, Simplified Models
- How to make results most useful to the community?
  - eg: theorist has a new model; is it already excluded by a published search that did not explicitly test this new model?
- Lots of discussions/workshops
- Phenomenologists have been doing this since forever

Outreach

Introduced in CMS dilepton papers to encourage reuse of our results. Becoming more accepted in CMS. Consistent with recent Les Houches recommendations arXiv:1203.2489

1. Present clear definitions of signal regions
2. Present event yields, background predictions with uncertainties
   - Upper limits on number of events beyond SM
3. Present clear instructions on how to do an approximate detector simulation so that anybody can interpret the results for they favorite model

Outreach example (from 2010 Same Sign Dilepton Search)

JHEP 1106:077,2011

Abstract

The results of searches for new physics in events with two same-sign isolated leptons, hadronic jets, and missing transverse energy in the final state are presented. The searches use an integrated luminosity of 35 pb^{-1} of pp collision data at a centre-of-mass energy of 7 TeV collected by the CMS experiment at the LHC. The observed numbers of events agree with the standard model predictions, and no evidence for new physics is found. To facilitate the interpretation of our data in a broader range of new physics scenarios, information on our event selection, detector response, and efficiencies is provided.

It is in the abstract.
To emphasize that this is a major part of the scientific result in the paper

8 Interpretation of Results

One of the challenges of signature-based searches is to convey information in a form that can be used to test a variety of specific physics models. In this section we present additional information that can be used to confront models of new physics in an approximate way by generator-level simulation studies that compare the expected number of events in 35 pb^{-1} with our upper limits shown in Table 2.

The kinematic requirements described in Section 4 are the first key ingredients of such studies. The H_T variable can be approximated by defining it as the scalar sum of the p_T of all final-state quarks (u, d, c, s, and b) and gluons with $p_T > 30$ GeV produced in the hard-scattering process. The E_T^{miss} can be defined as the magnitude of the vector sum of the transverse momentum over all non-interacting particles, *e.g.*, neutrinos and LSP. The ratio of the mean detector responses for H_T and E_T^{miss} as defined above, to their true values are 0.94 ± 0.05, and 0.95 ± 0.05, respectively, where the uncertainties are dominated by the jet energy scale uncertainty. The resolution on these two quantities differs for the different selections. In addition, the E_T^{miss} resolution depends on the total hadronic activity in the event. It ranges from about 7 to 25 GeV for events with H_T in the range of 60 to 350 GeV. The H_T resolution decreases from about 26% at 200 GeV to 19% for 300 GeV and to 18% for 350 GeV. The H_T resolution was measured in simulation using the LM0 reference model, while the E_T^{miss} resolution was measured in data.

Tells you how to calculate HT and MET from parton level
Tells you what the response and the resolution on these quantities is

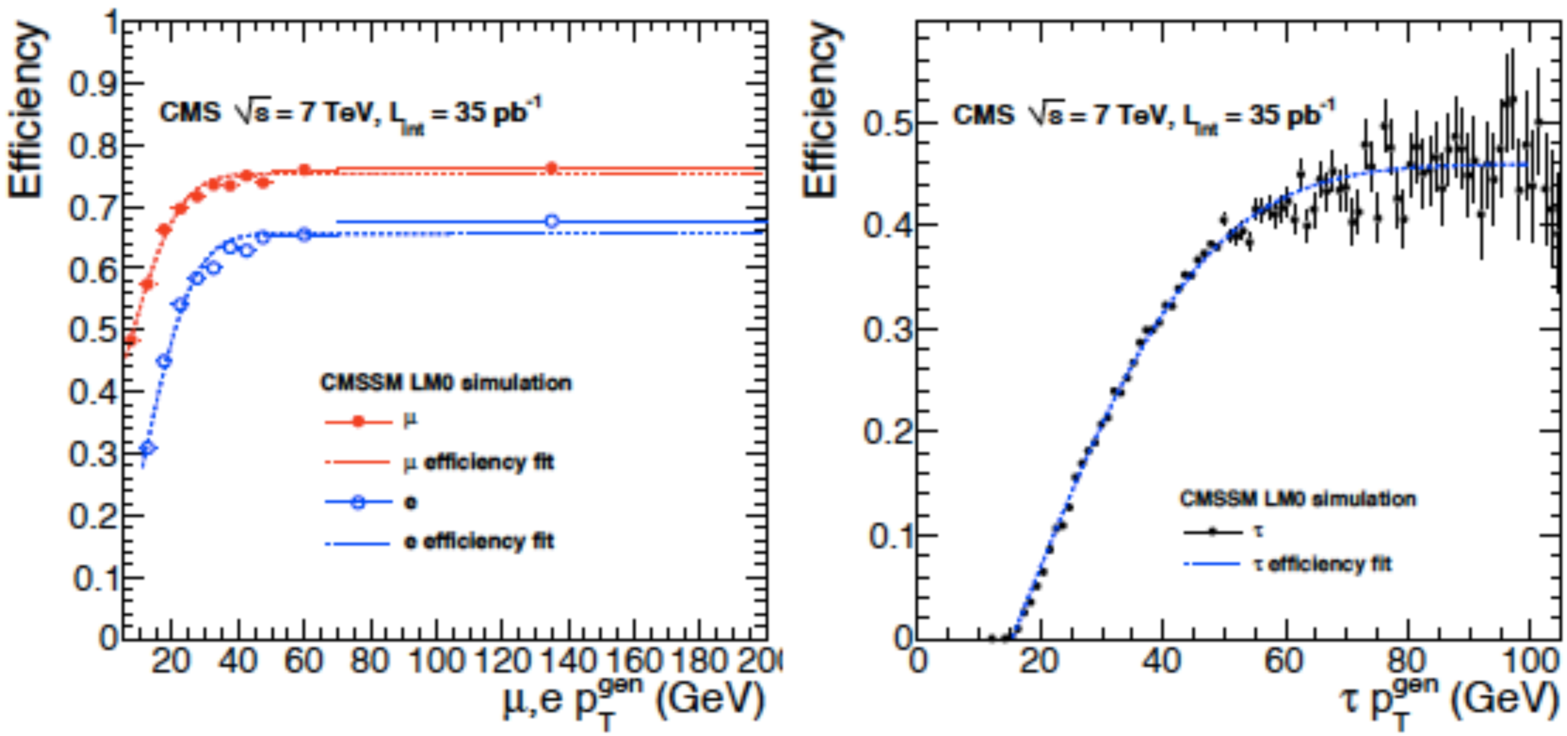


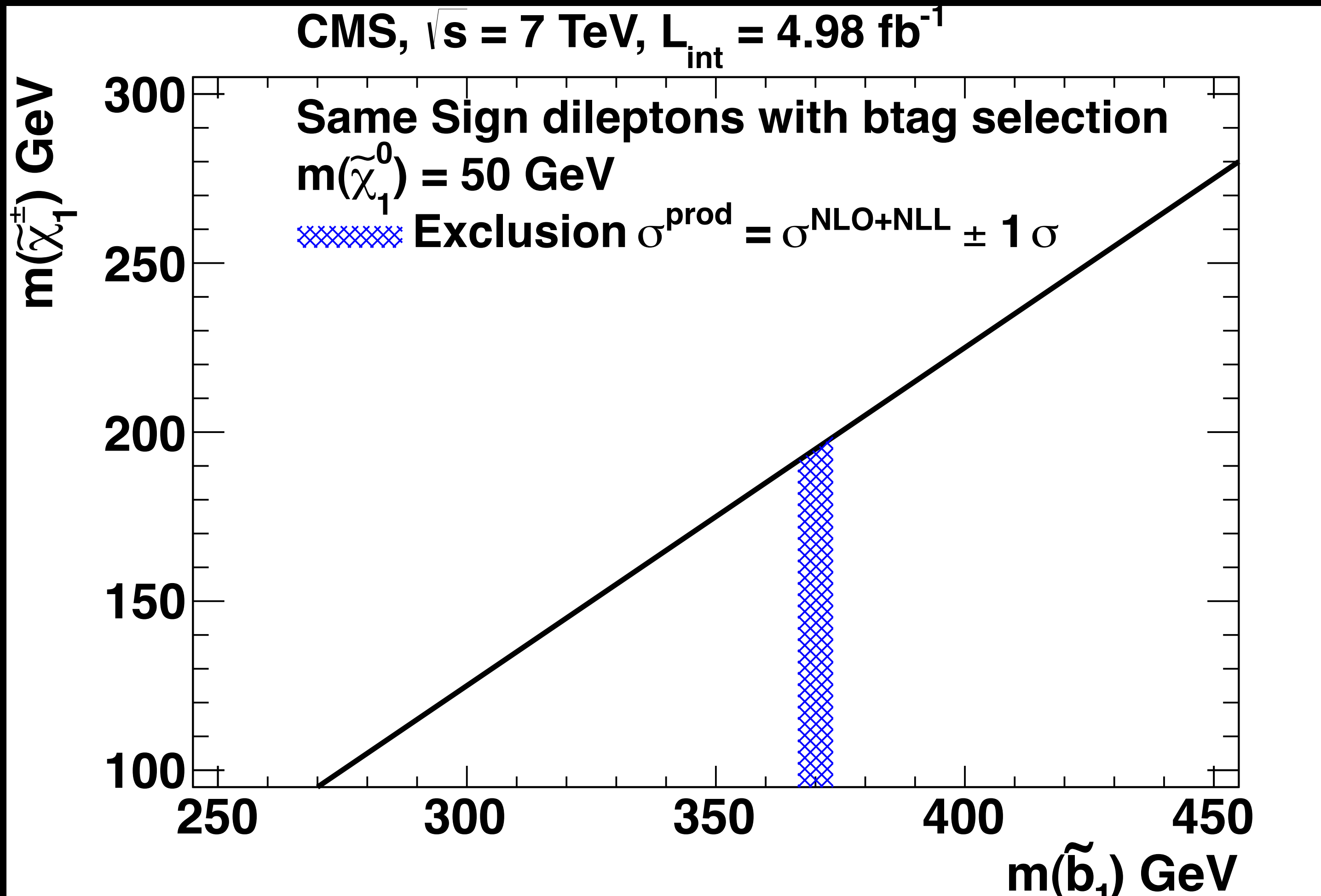
Figure 9: Electron, muon (left) and τ_h (right) selection efficiencies as a function of p_T. The results of the fits described in the text are shown by the dotted lines.

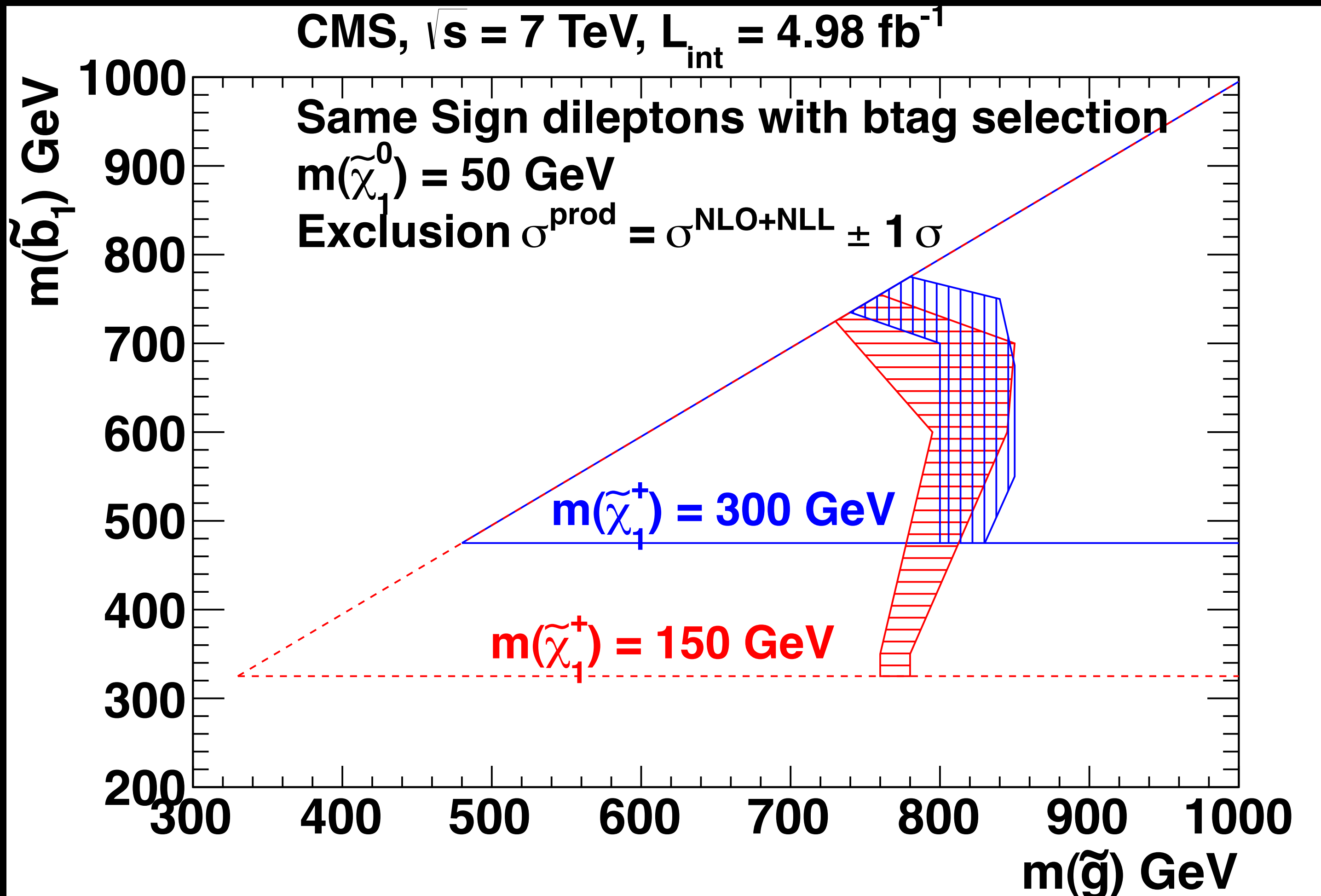
Gives you efficiency parametrizations

Outlook for 2012

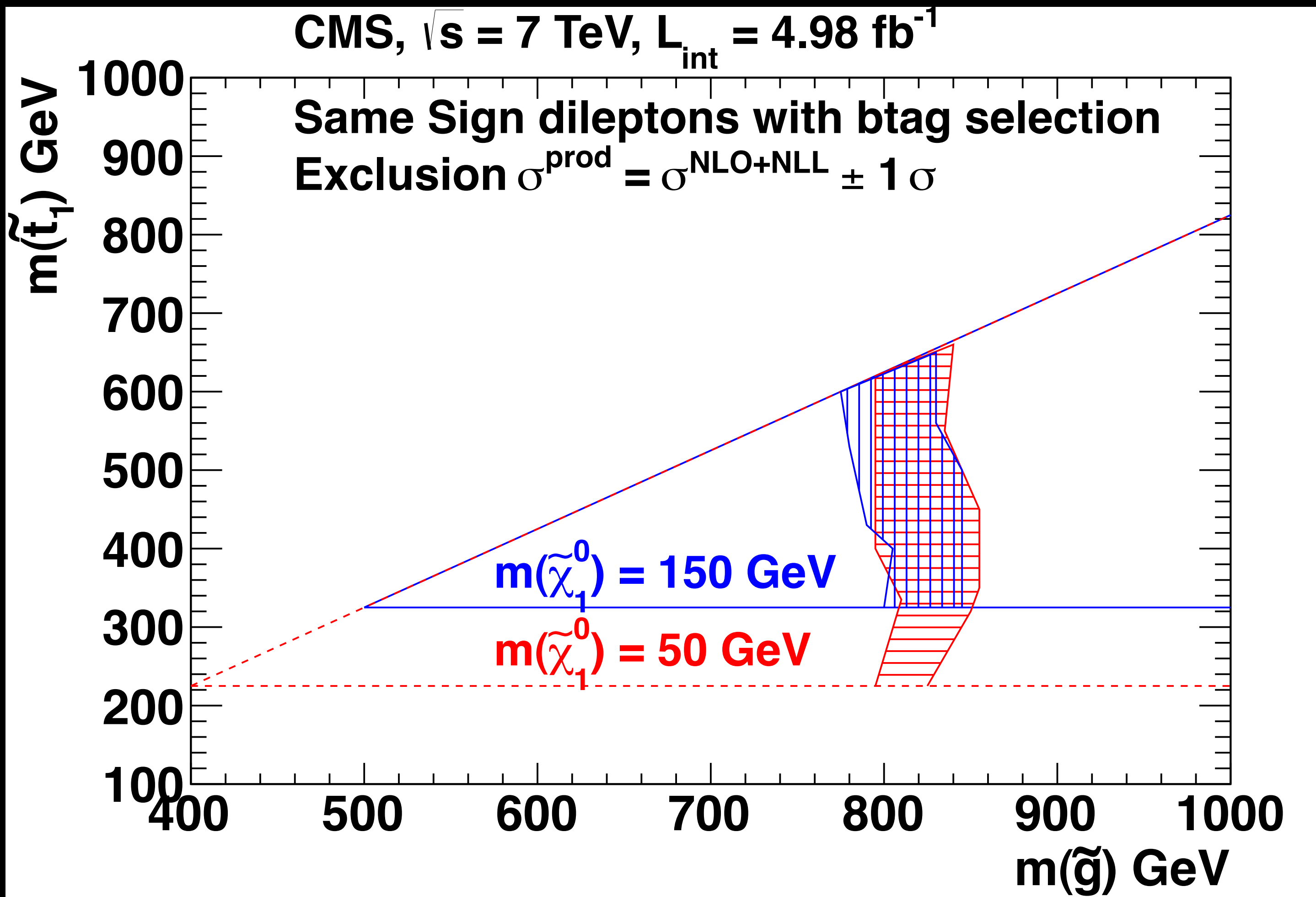
- More luminosity, a little more energy
- Unlikely that this will turn some of these null results into *splendid discoveries*
- Nevertheless, many of these are worth repeating
  - SS + btags will challenge "natural susy"
  - Will become really sensitive to ewkinos
- Need to also look in different corners of phase space
  - Many btags
  - Many jets
  - More taus

The end

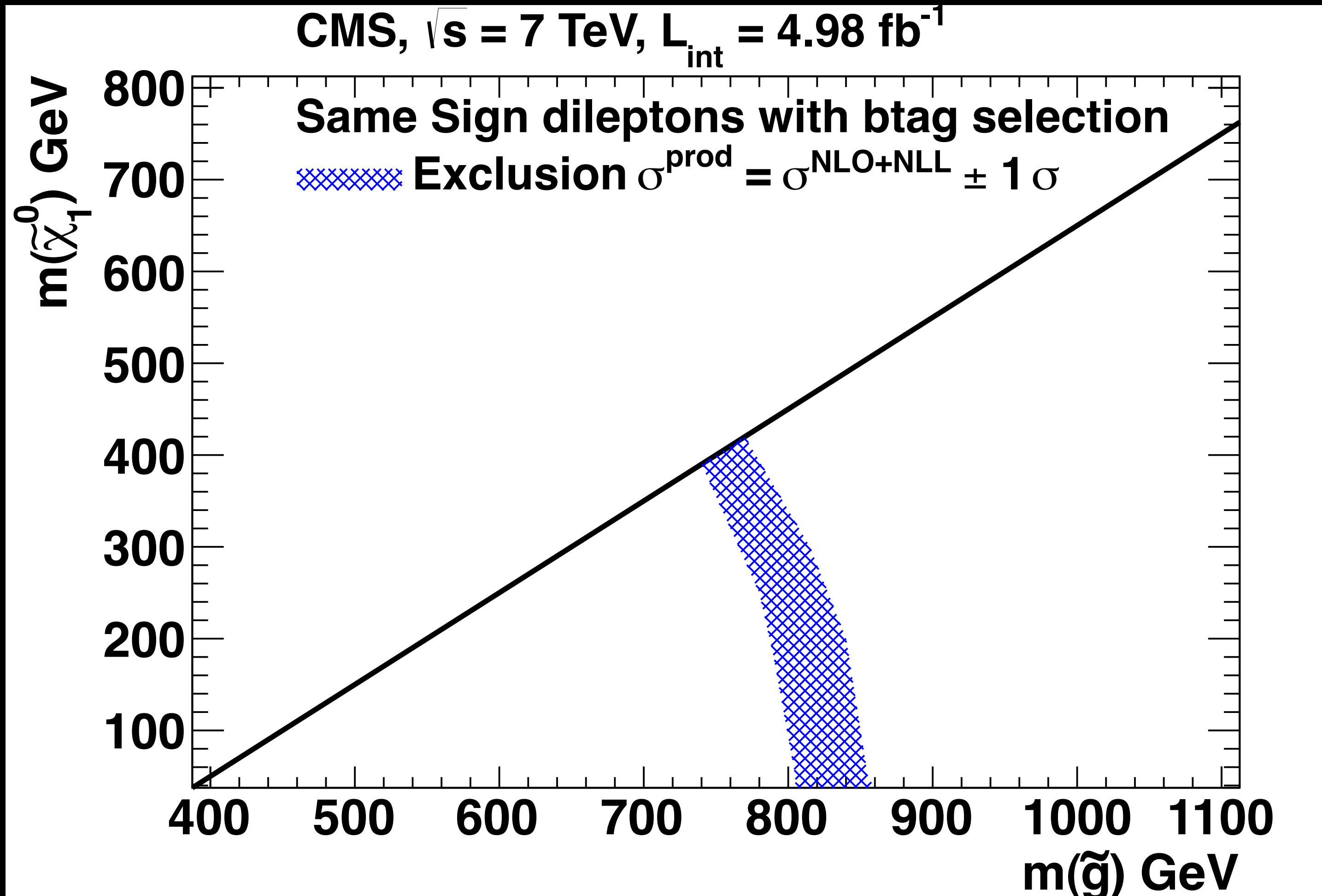

CMS, √s = 7 TeV, L_{int} = 4.98 fb^{-1}
Same Sign dileptons with btag selection
$m(\tilde{\chi}_1^0)$ = 50 GeV
Exclusion $\sigma^{prod} = \sigma^{NLO+NLL} \pm 1\,\sigma$
$m(\tilde{\chi}_1^{\pm})$ GeV
300
250
200
150
100
250
300
350
400
450
$m(\tilde{b}_1)$ GeV



CMS, √s = 7 TeV, L_int = 4.98 fb^-1
Same Sign dileptons with btag selection
m(χ̃^0_1) = 50 GeV
Exclusion σ^prod = σ^NLO+NLL ± 1 σ
m(χ̃^+_1) = 300 GeV
m(χ̃^+_1) = 150 GeV
m(b̃_1) GeV
m(g̃) GeV
1000
900
800
700
600
500
400
300
200
300
400
500
600
700
800
900
1000



CMS, √s = 7 TeV, L_int = 4.98 fb^-1
Same Sign dileptons with btag selection
Exclusion σ^prod = σ^NLO+NLL ± 1 σ
m(χ̃₁⁰) = 150 GeV
m(χ̃₁⁰) = 50 GeV
m(t̃₁) GeV
m(g̃) GeV
1000
900
800
700
600
500
400
300
200
100
400
500
600
700
800
900
1000


CMS, √s = 7 TeV, L_int = 4.98 fb^-1
Same Sign dileptons with btag selection
Exclusion σ^prod = σ^NLO+NLL ± 1 σ
m(χ̃₁⁰) GeV
m(g̃) GeV
100
200
300
400
500
600
700
800
400
500
600
700
800
900
1000
1100