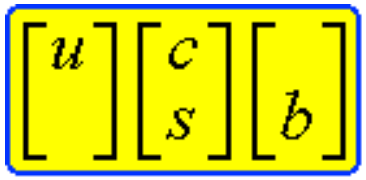


CMS SUSY searches

Finn Rebassoo
UCSB

Outline

- Quick phenomenological intro to SUSY
- Kinematics of SUSY particles
- Some SUSY analyses
  - muon+jets+MET
  - dilepton+jets+MET
- Analysis starter kit

Quick intro to SUSY

SUSY phenomenology

- SUSY: theory invariant w/ transformation *fermion* ↔ *boson*
- SUSY predicts spin $\Delta J = \pm\frac{1}{2}$ superpartner for each Standard Model particle

$q \rightarrow \tilde{q}$ $\quad$ $\gamma \rightarrow photino$

$l \rightarrow \tilde{l}$ $\quad$ $g \rightarrow gluino$

$W^{\pm} \rightarrow winos$ $\quad$ $H^{\pm} \rightarrow higgsino$

$Z \rightarrow zino$

Charginos, $\tilde{\chi}^{\pm}_{1,2}$, neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$ result from mixing of gauginos and higgsino

- If SUSY unbroken partner particles have same mass as SM particles, so SUSY must be broken!
- Minimal Supersymmetric Standard Model (MSSM) adds minimal possible number of particles to SM
  - Unknown process of symmetery breaking leads to ~100 parameters! Can't explore full parameter space

See backup slides for some good SUSY references

mSUGRA Model

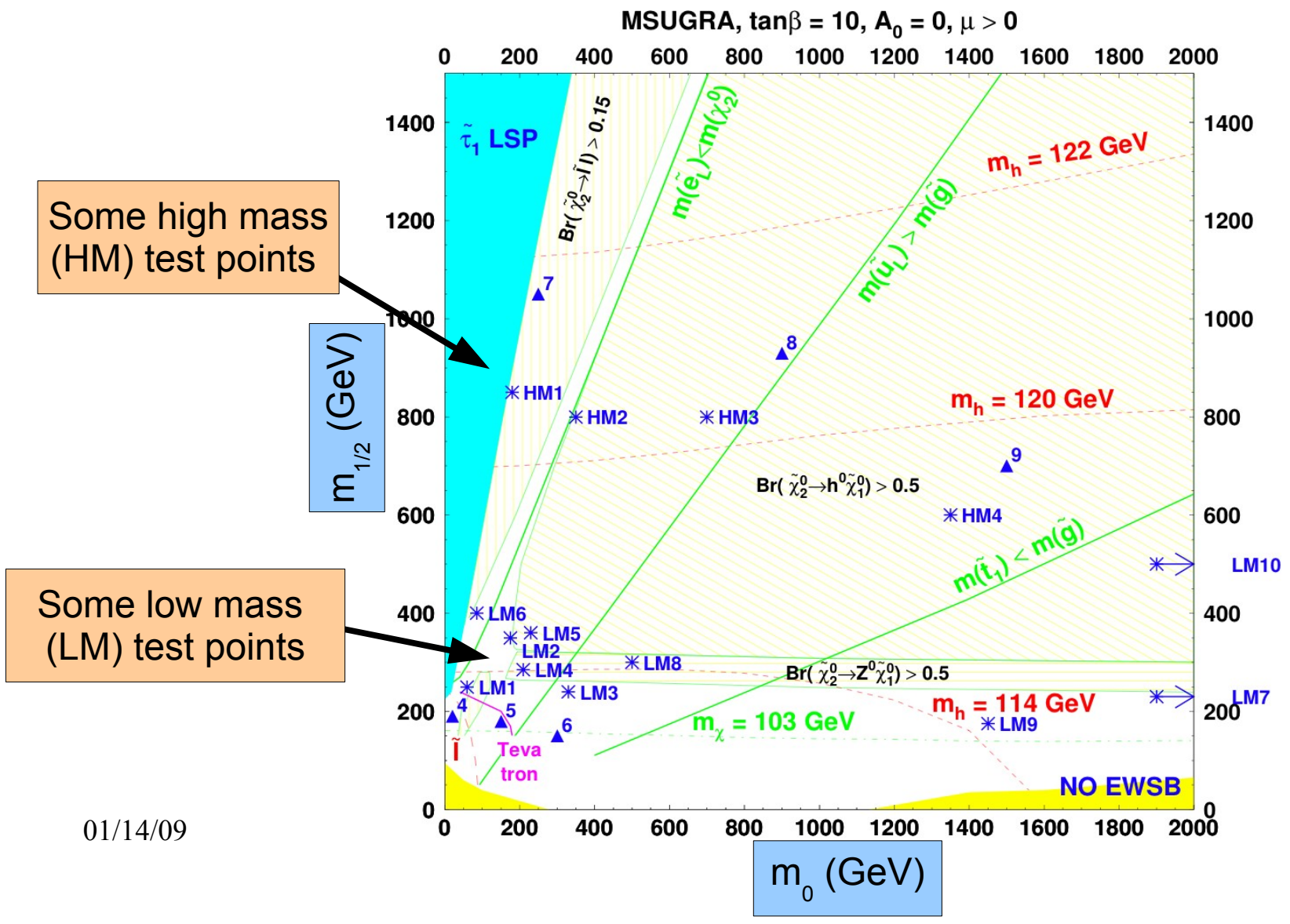
- Assumes symmetry breaking mediated by gravitational interaction
- Only 5 parameters: m_0, $m_{1/2}$, A_0, tan (β), sign(μ)
  - Small number of parameters means simpler to explore
- Main model studied in CMS
- Parameters determine: $m_{sparticles}$, $\sigma_{sparticles}$, $\frac{\Gamma_i}{\Gamma_{total}}$

$$m^2_{\tilde{u}_L} \simeq m^2_0 + 5.0 m^2_{1/2} + 0.35 \cos 2\beta M^2_Z$$

$$m^2_{\tilde{e}_L} \simeq m^2_0 + 0.49 m^2_{1/2} - 0.27 \cos 2\beta M^2_Z$$

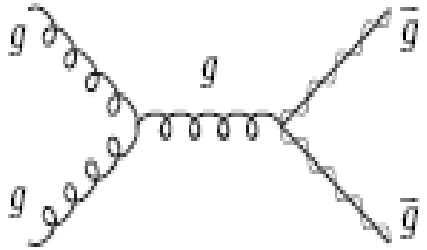
mSUGRA test points

- Parameter space still large. Choose test points in parameter space to study many different final-state signatures
- Kinematics of test points can be very different



R-Parity & lightest SUSY particle

- R-Parity, new quantum number in SUSY
  - $R = (-1)^{3(B-L)+2S}$
  - Preserves baryonic and leptonic conservation
  - Sparticles produced in pairs
  - Lightest SUSY Particle (LSP) stable



- LSP's interact weakly so can't detect directly
  - missing transverse energy (MET)
    - In general, $MET_{SUSY} > MET_{SM}$, b/c LSPs heavier than neutrinos
    - Common experimental signature when studying SUSY

Kinematics of SUSY

Makeup of initial Susy particles in LMs

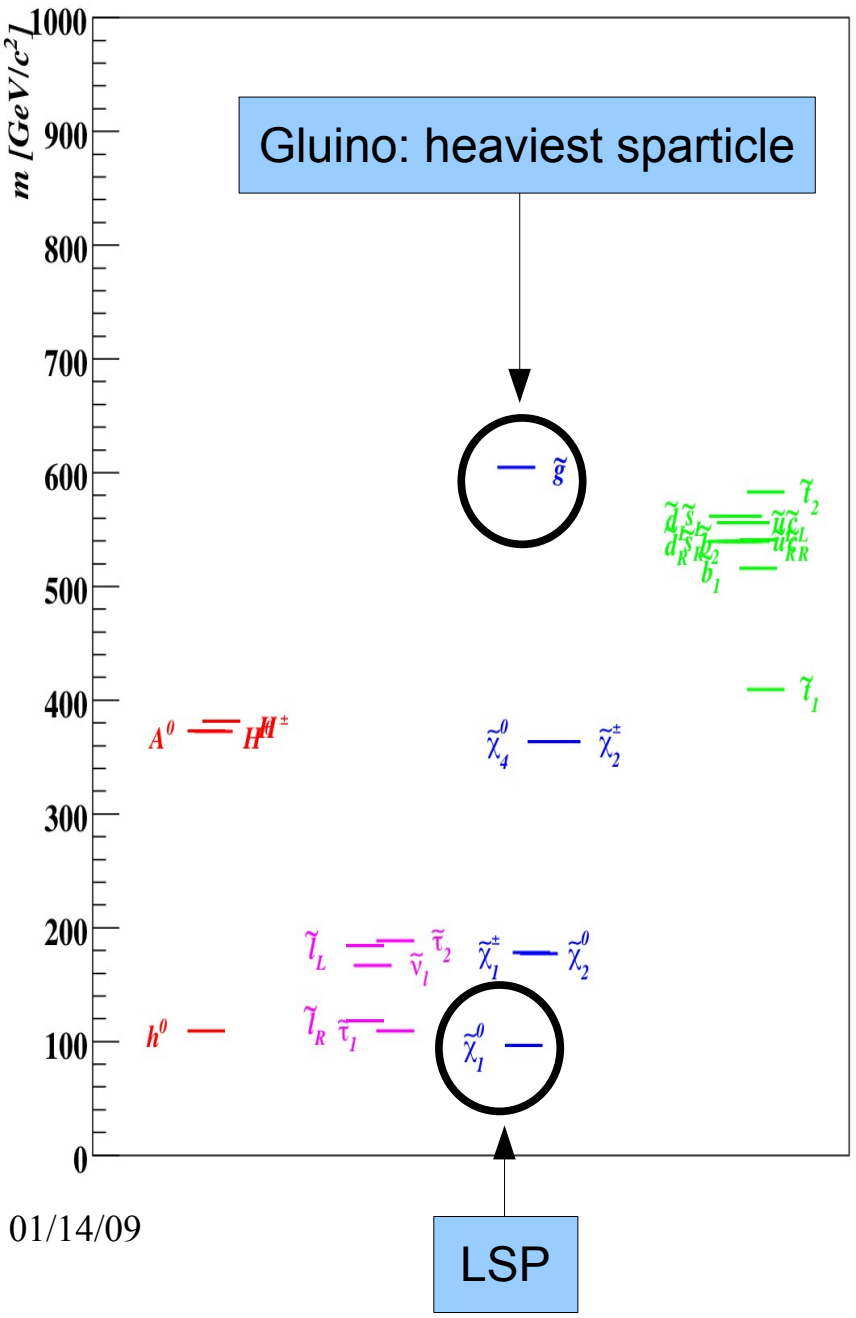
Squarks and gluinos primary initial particles produced from pp collision

Sample	gluino-gluino (%)	squark-squark (%)	gluino-squark (%)	antisquark-squark (%)	anti-squark gluino (%)	other (%)
LM1	11.2	12.3	42.1	16.2	7	11.2
LM2	8.2	17.5	40.9	15.3	5	13.1
LM3	15.6	10.6	43.3	12.1	7.1	11.3
LM4	10.8	13.8	43.2	14.6	6.3	11.3
LM6	6.1	20.4	38.5	15.1	4.4	15.5
LM8	14.7	12.2	42.8	10.6	5.6	14.1
LM9	64.4	0.1	4.6	0.1	0.6	30.2

gluino-gluino dominates in LM9

gluino-squark most dominant for LM1, LM2, LM3 LM4, LM6, LM8

Mass spectrum of LM1



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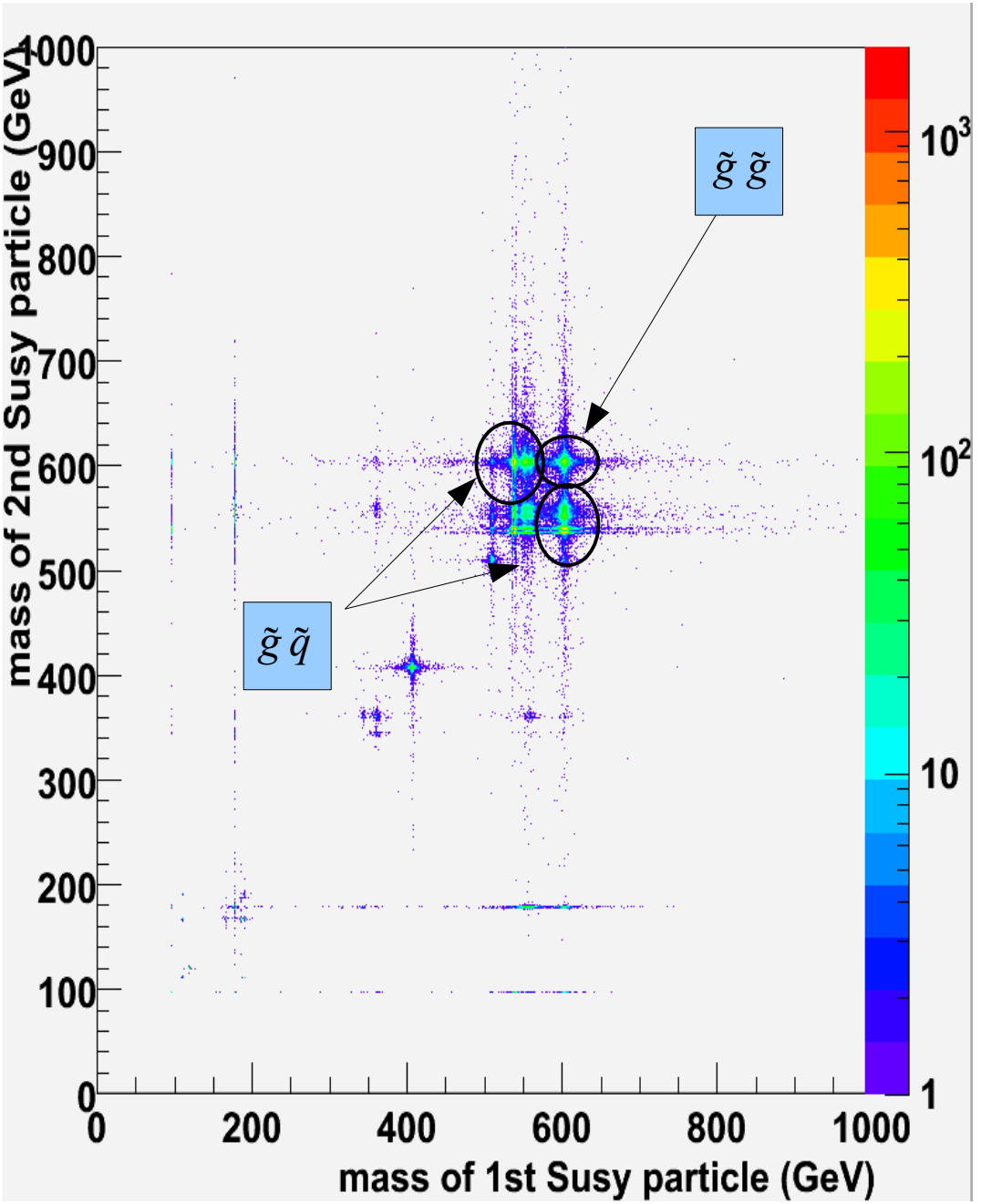
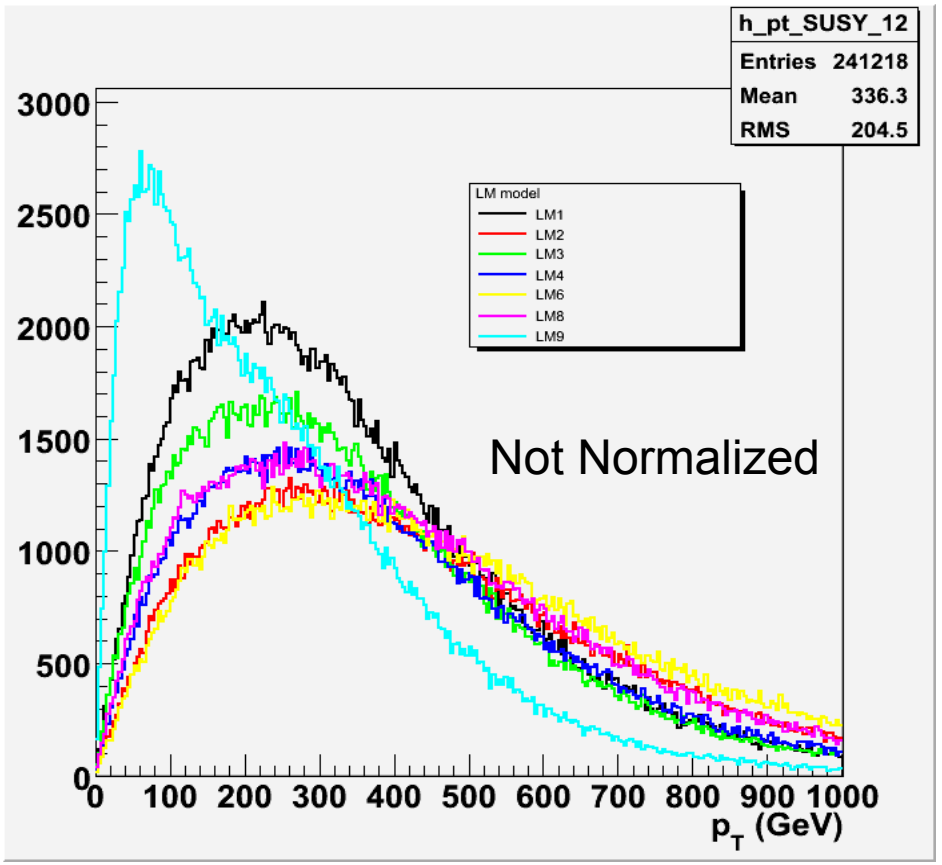


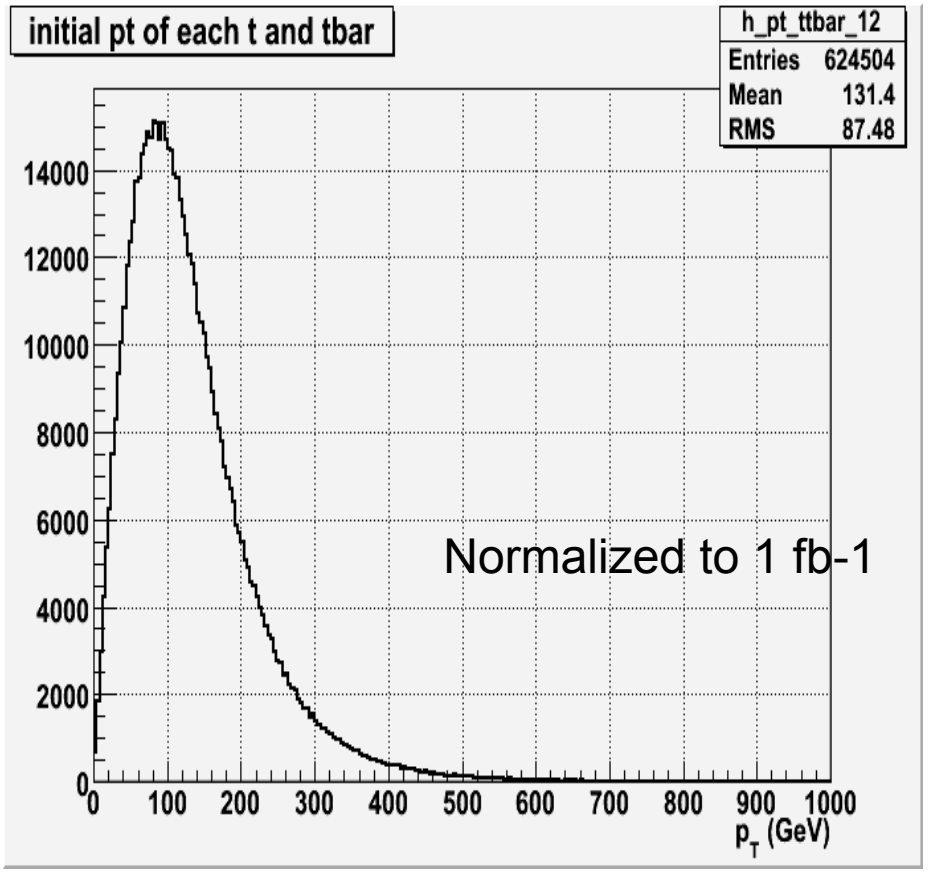
CMSSW_1_6_12

Gen p_T spectrum of initial particles, LM's vs. ttbar

Pt of each initial SUSY particle



Pt of each initial t and tbar



- Pt distribution of initial Susy particles hard for all LMs except LM9
- Pt spectrum of initial SUSY particles hard compared to pt spectrum of initial ttbar quarks (except in LM9)

Susy Analysis Examples

Prototype muon + jets + MET analysis

- Based on Biallass et al., CMS Analysis note AN 2008/034
- All samples are from CSA07, w/ $\sqrt{s} = 14\,TeV$
- Signal: LM1 (see paper for LM2, LM4 as well)
- Backgrounds
  - W and Z
  - WW, WZ, and ZZ
  - t tbar
  - QCD multijets

Explanation of Cuts

Quantity	Value
HLT path	HLT1MuonIso, HLT2MuonIso, HLT2MuonNonIso
μ: p_T	> 20 GeV/c
μ: isol	$\sum_{\Delta R<0.3} p_T(trks) < 6$ GeV/c
μ: tracker and μ hits	≥ 12
μ: χ^2/ndof	< 3
μ: $\lvert\eta\rvert$	< 2.1 rad
Jets used: $\lvert\eta\rvert$	≤ 2.5 rad
Presel. MET: $E_T^{\rm miss}$	≥ 100 GeV
Top 3 leading jets: p_T	≥ 80 GeV
p_T^{j1}	> 200 GeV
p_T^{j2}	> 150 GeV
$\lvert\Delta(\phi(\mu, E_T^{\rm miss}))\rvert$	> 0.8 rad
$\lvert\Delta(\phi(jet_{1,2,3}, E_T^{\rm miss}))\rvert$	> 0.6 rad
Final MET: $E_T^{\rm miss}$	> 250 GeV

Explanation of Cuts

Muon acceptance and Identification cuts

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b/c generally $MET_{SUSY} > MET_{SM}$

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Jets in SUSY events generally have higher pt

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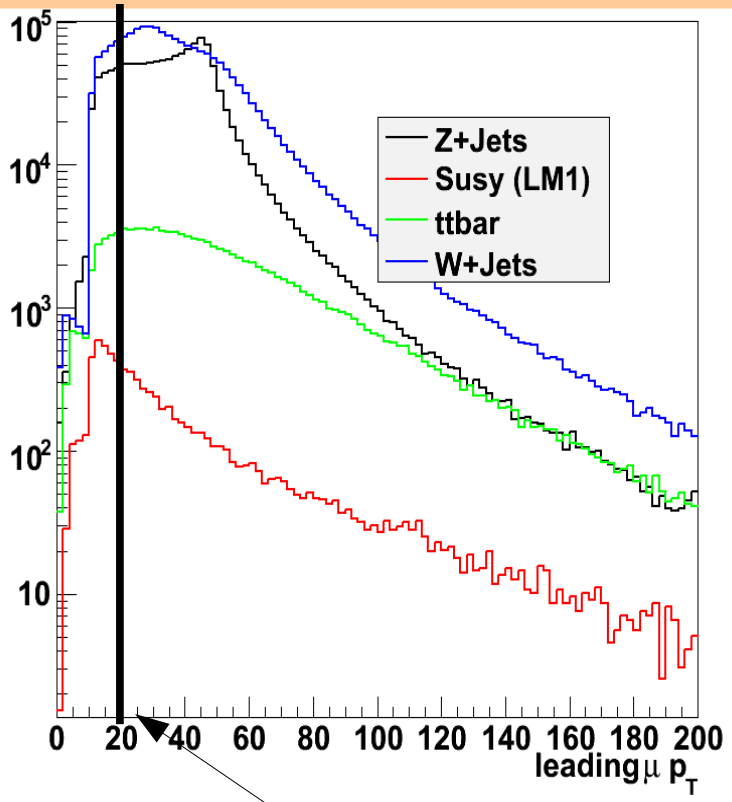
Final MET: E_T^{miss}	> 250 GeV

Angular cuts: make sure MET not from mismeasurement

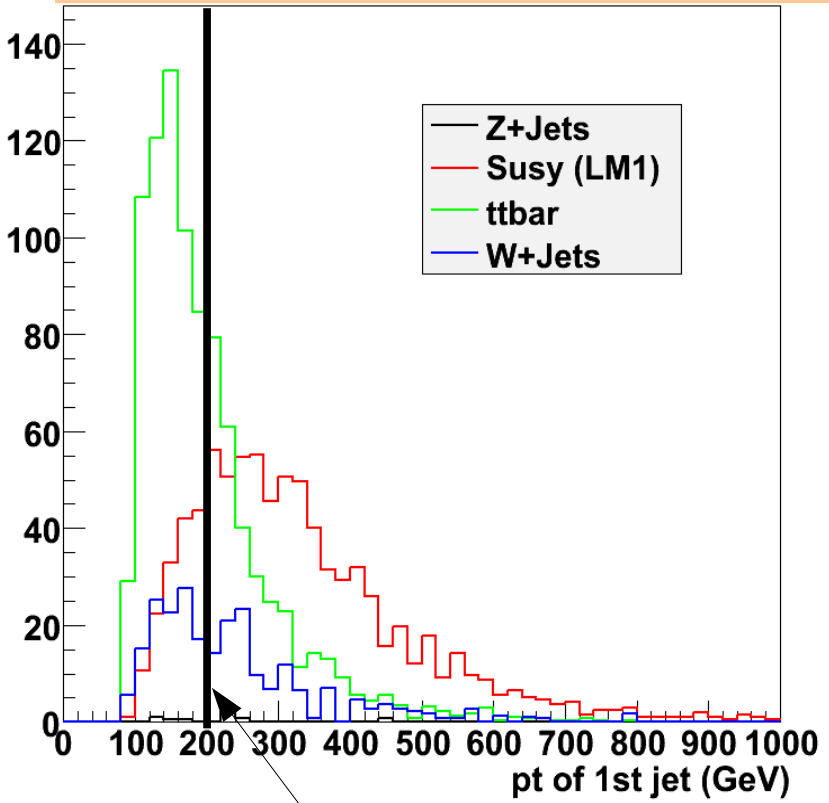
Testing Cuts

$p_T^{\mu_1}$ after HLT & μ cuts (except p_T^{μ} cut)



Raising cut above 20 GeV doesn't improve S/B

p_T^{j1} after all cuts up to p_T^{j1} cut



Cut at 200 GeV gets rid of a lot of ttbar, minimal amount of signal

- Backgrounds not summed

Efficiency and Yield

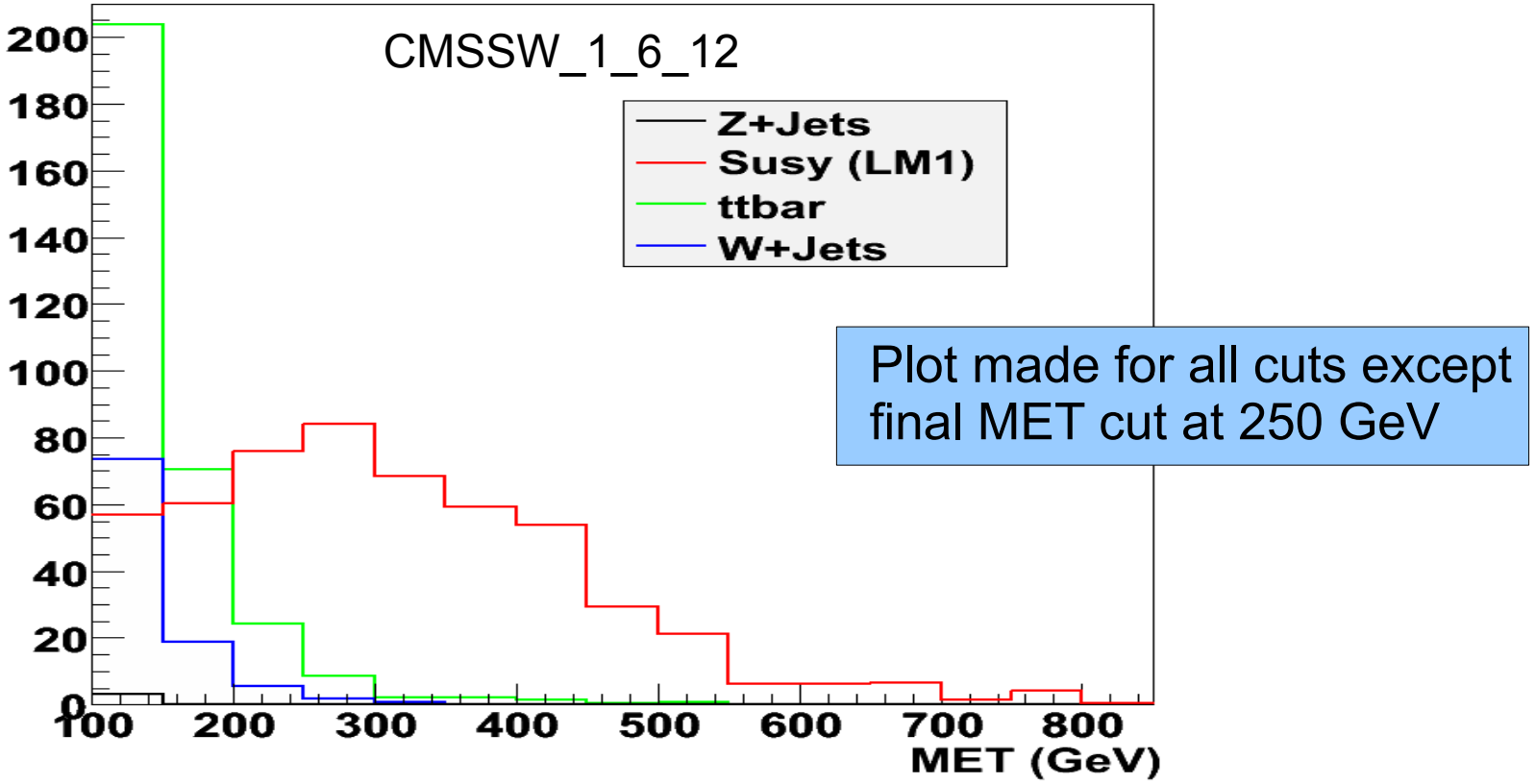
Cut	LM1 Number passing cuts	ttbar Number passing cuts	LM1 Cut Effic. (%)	ttbar Cut Effic. (%)
NoCuts	$61.1e+03$	$8.28e+05$	-	-
HLT	$8.88e+03$	$1.24e+05$	14.5	14.9
μ acceptance and identification	$5.42e+03$	$9.80e+04$	61.1	79.0
Top 3 leading jets: $p_T \geq 80$	$2.15e+03$	$1.05e+04$	40.5	10.5
Presel. MET: $E_T^{\text{miss}} \geq 100$	$1.96e+03$	$3.56e+03$	91.1	34.1
Angular correlations	$8.36e+02$	$9.22e+02$	42.9	25.8
$p_T^{j1} \geq 200$	$6.84e+02$	$3.43e+02$	81.6	37.7
$p_T^{j2} \geq 150$	$5.37e+02$	$2.13e+02$	79.0	62.8
Final MET: $E_T^{\text{miss}} > 250$	$3.45e+02$	$1.29e+01$	64.3	6.5

Yields Normalized to 1 fb^{-1}

- LM1 Signal: 345 events
- Background:
  - For ttbar: 12.9 events
  - For W+ jets: 2.76 events
  - For Z + jets: 0 events

Note: Number of background events not integers b/c of event weighting

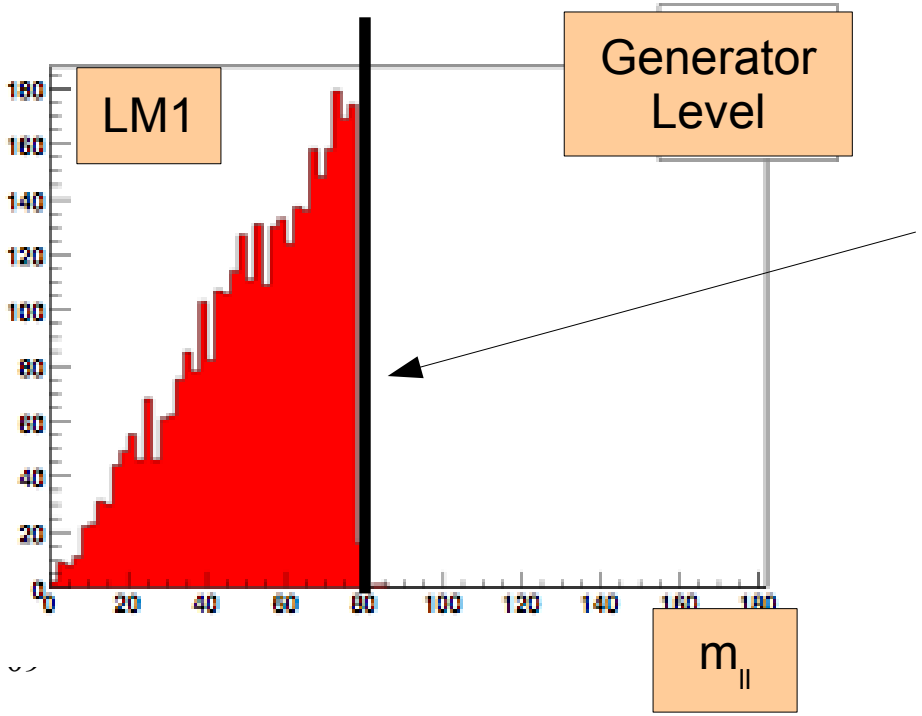
Final MET distribution



- Backgrounds summed. Signal overlaid
- Able to differentiate signal from background
- Next Step: Study data-driven methods for backgrounds

Di-lepton + Jets + MET Analysis

- Karapostoli, Sphicas, CMS Analysis note AN 2008/038
  - All samples used from CSA07, w/ $\sqrt{s} = 14\,TeV$
- Look at "mass peak" of leptons from $\tilde{\chi}_2^0 \rightarrow l^{\pm}\, l^{\mp}\, \tilde{\chi}_1^0$
- LSP missing, m_{ll}^{max} shape characterized by triangle function



Mass edge given by:

$$m_{ll}^{max} = m_{\tilde{\chi}_2^0}\sqrt{1-\frac{m_{\tilde{l}_R}^2}{m_{\tilde{\chi}_2^0}^2}}\sqrt{1-\frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{l}_R}^2}}$$

Backgrounds

Dominant Background

- Flavor-symmetric background
  - Produces ee/μμ and eμ final states w/ equal probability
  - Comes from ttbar, WW, uncorrelated SUSY, etc.

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Dominant Background

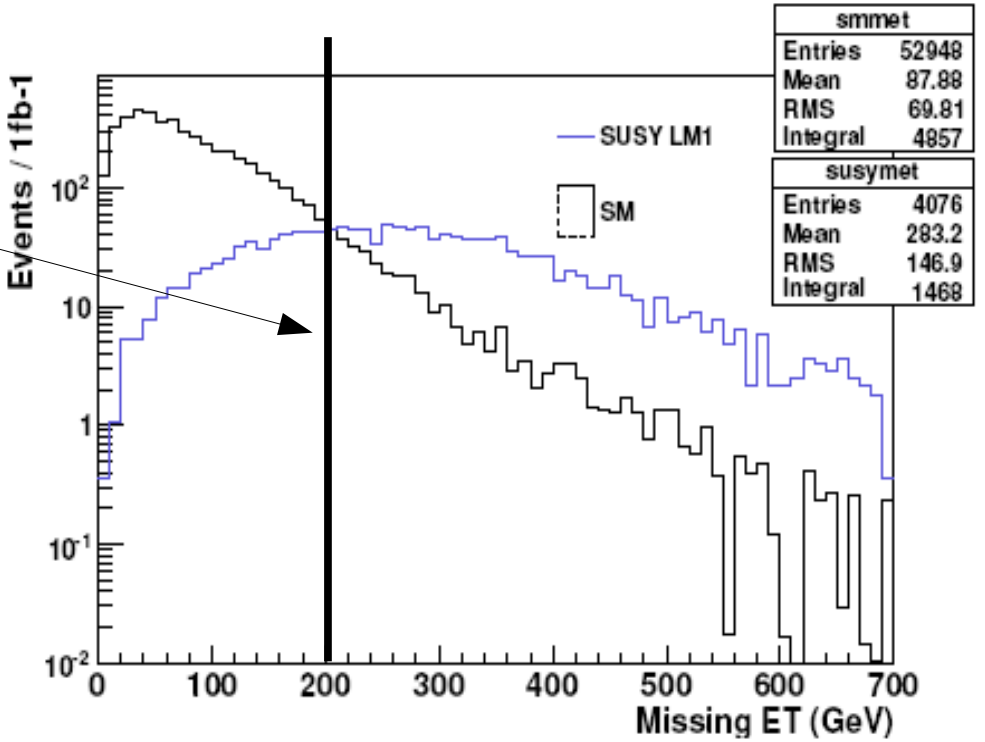
- Flavor-symmetric background
  - Produces ee/μμ and eμ final states w/ equal probability
  - Comes from ttbar, WW, uncorrelated SUSY, etc.

Other Backgrounds

- Flavor-asymmetric background
  - SUSY background $\tilde{\chi}_4^0 \to \tilde{l}^{\pm}\, l^{\mp}$, $\tilde{\chi}_3^0 \to Z\, \tilde{\chi}_2^0$, $\tilde{\chi}_4^0 \to Z\, \tilde{\chi}_1^0$, etc.
  - Direct slepton slepton production: $p\, p \to \tilde{l}^{\pm}\, \tilde{l}^{\mp}$
- Z-boson decays accounted for by term in final fit
- Decays from heavier gauginos and background from fake leptons is small and estimated in error analysis

Cuts

- Trigger Path is HT+MET
  - $\epsilon_{Trigger} = \frac{Num\ events\ passing\ analysis\ cuts + trigger\ bit\ on}{Num\ events\ passing\ analysis\ cuts} = 98\,\%$
- 2 opposite sign (OS) and isolated leptons (e^+e^- or $\mu^+\mu^-$) w/ $p_T^l > 10\,GeV$ and $|\eta^l| < 2.4$
- At least 3 jets w/ $E_T^{jet} > 30\,GeV$ and $|\eta^{jet}| < 3$
- $E_T^{j1} > 120\,GeV$, $E_T^{j2} > 80\,GeV$
- $E_T^{miss} > 200\,GeV$



See backup slides for lepton isolation and identification criteria as well as more info on jets

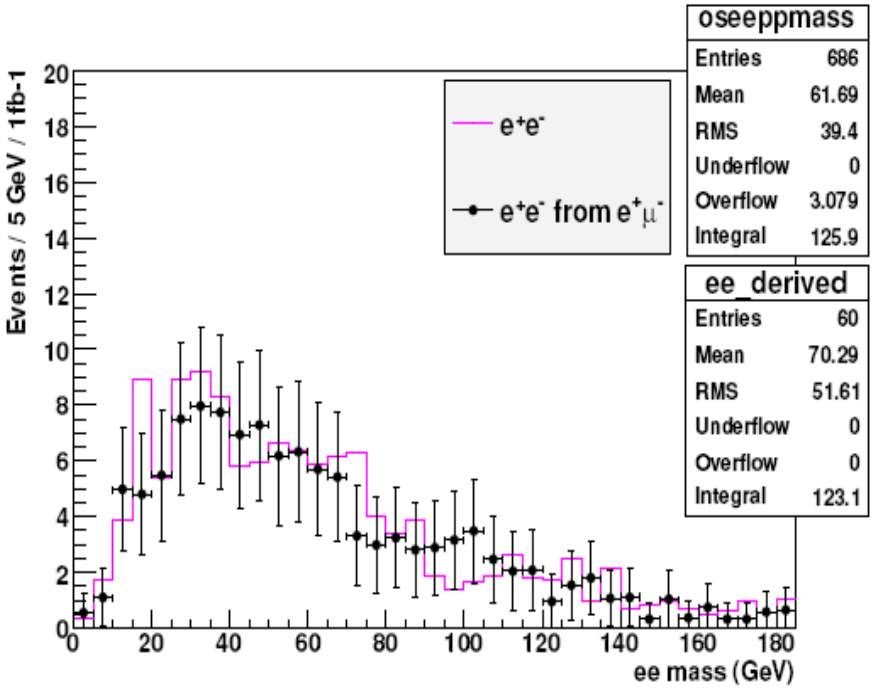
Flavor-asymmetric background from data

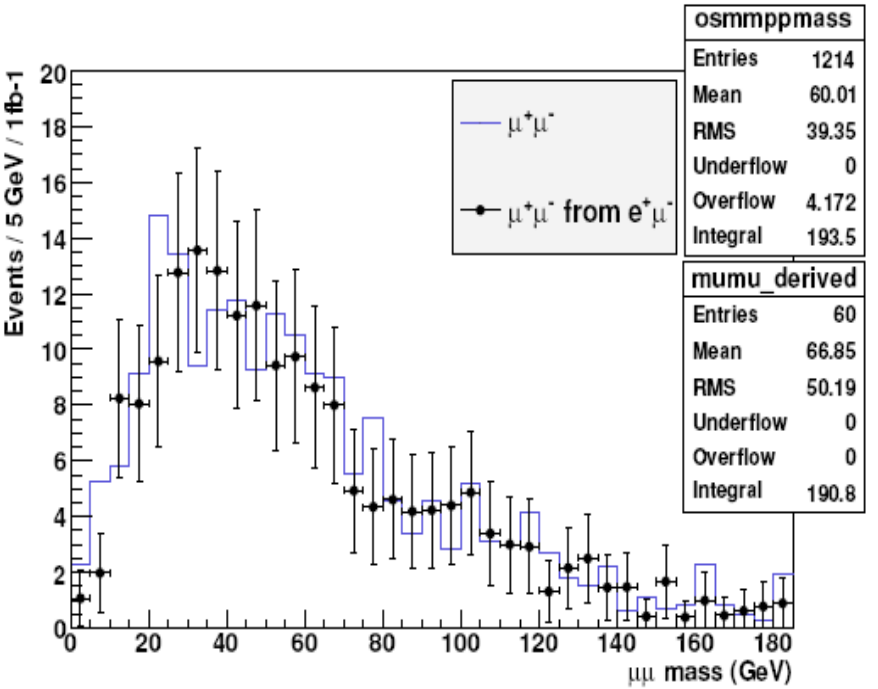
- Can predict size and shape of ee/μμ background from eμ

Must know ratio of electron to muon efficiencies

$$N(ee) = \frac{1}{2} \times \frac{\epsilon^e}{\epsilon^\mu} \times N(e\mu) \qquad N(\mu\mu) = \frac{1}{2} \times \frac{\epsilon^\mu}{\epsilon^e} \times N(e\mu)$$

- Predicted background matches well with MC





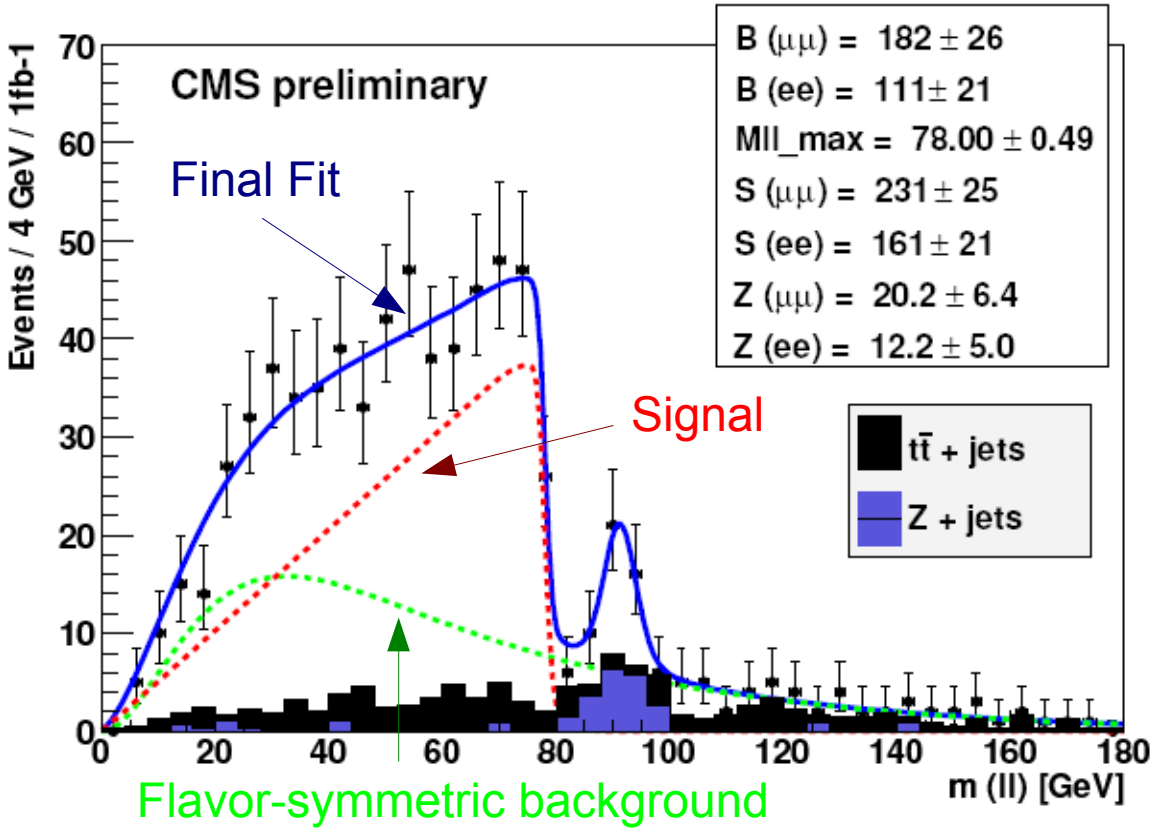
Final Fit

- Fit function: $F(m) = N_{sig} S(m) + N_{bkg} B(m) + N_Z Z(m)$

Signal Model, intended to fit for endpoint value

Describes flavor-symmetric background. Modeled from eμ shape in data

Describes Z-peak



Endpoint final fit values

$$m_{ee}^{max} = 77.90 \pm 1.07 \pm 0.36\ GeV/c^2$$

$$m_{\mu\mu}^{max} = 78.03 \pm 0.75 \pm 0.18\ GeV/c^2$$

$$m_{ll}^{max}(TH) = 78.15\ GeV/c^2$$

Analysis Starter Kit (I)

- Can reproduce analyses results shown above using ROOT ntuples already created
  - Only need to know ROOT!
- Root ntuples created using configurableAnalysis tool
  - For configurableAnalysis description see:

https//twiki.cern.ch/twiki/bin/view/CMS/WorkBookConfigurableAnalysis

- Twiki site dedicated to description of ntuples:

https//twiki.cern.ch/twiki/bin/view/CMS/WorkBookConfigurableAnalysisNtupler

- Twiki site provides location of ntuples, documentation on content, and example macros for running

Analysis Starter Kit (II)

- ROOT ntuples produced in CMSSW_1_6_12 from CSA07 samples:
  - LM1, LM2, LM3, LM4, LM6, LM8, LM9
  - WW, WZ, ZZ
  - Muon-skimmed soups
    - Soups contain Z+jets, W+jets, ttbar, and more
- We are in the process of making more ntuples in CMSSW 2_2_x.

Conclusions

- Many interesting ongoing analyses in CMS SUSY group
- CMS SUSY group welcomes new people
  - No need for analysis experience!
  - Contact SUSY conveners Oliver Buchmeller oliver.buchmeller@cern.ch, Jeff Richman richman@charm.physics.ucsb.edu

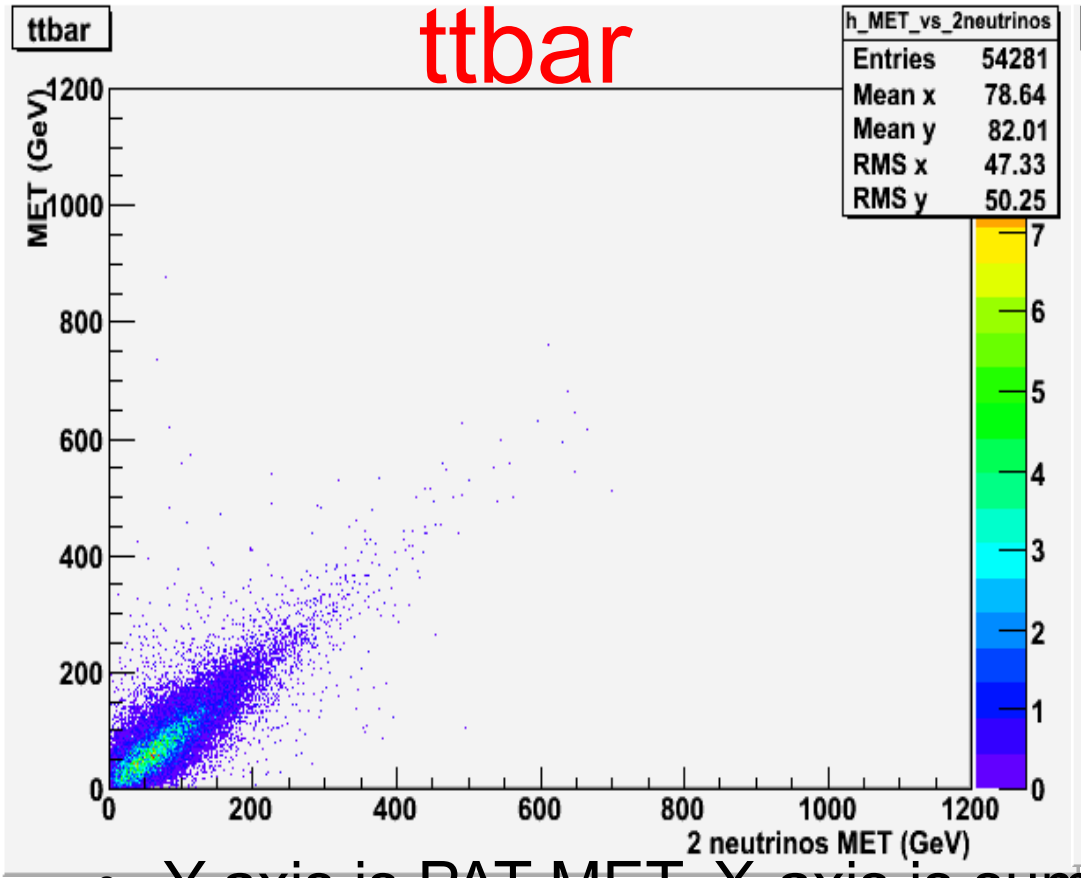
Backup Slides

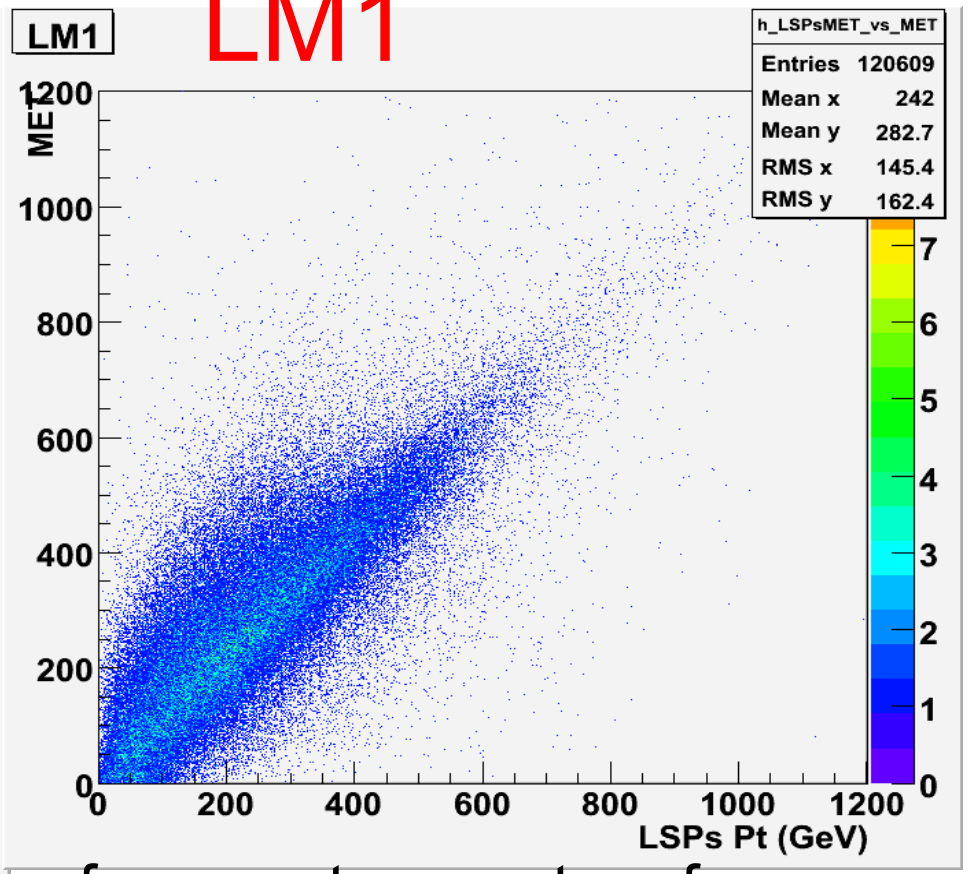
SUSY references

- Supersymmetry in Particle Physics – I. Aitchinson
- Weak Scale Supersymmetry - H. Bauer and X. Tata
- Supersymmetry Primer – S. Martin hep-ph/9709356

Examples using MC truth info.

PAT MET vs. Gen MET





- Y-axis is PAT MET, X-axis is sum of momentum vector of neutrinos or LSPs projected onto the transverse plane
- Correlation relatively good

CMSSW_1_6_12

Di-lepton cuts

Quantity	Value
HLT path	HT+MET
electron id	tight
μ: tracker and μ hits	> 8
μ: χ^2	< 10
μ: $\Delta p_T / p_T$	< 0.5
lepton: isol	$\sum_{0.015<\Delta R<0.2}(p_T^{trks}/p_T^{lep}) < 0.2$ GeV/c
lepton: p_T	> 10GeV/c
Jets used: $\|\eta\|$	≤ 3 rad
Top 3 leading jets: p_T	≥ 30 GeV
p_T^{j1}	> 120 GeV
p_T^{j2}	> 80 GeV
E_T^{miss}	> 250 GeV

Note: All jet energies referred to in this analysis are corrected

- Additional Jet requirements
  - Charged energy fraction > 0.005
  - For iso *e* within ΔR = 0.05 of jet, $\frac{Shared\ energy\ of\ e\ ,\ jet}{energy\ of\ \ jet} < 0.7$

Functional Form of Fit

$$F(m) = N_{sig} S(m) + N_{bkg} B(m) + N_Z Z(m)$$

$$S(m) = \sum_i T(m_i) \times \exp\left(-\left(\frac{1}{2}\right)\left(\frac{m - m_i}{\sigma(m_i)}\right)^2\right)$$

$$B(m) = \sum_i m^{\alpha_i} \exp(-\kappa \beta_i m)$$

Z-peak PDF is determined with a Voigtian of central Z mass and width