Multilepton SUSY Search with 35 pb^{-1} 2010 Data

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on behalf of the CMS Collaboration

SUSY11

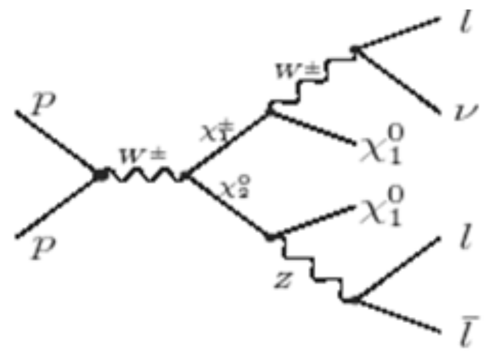
Outline for today

- Introduction
  - 2010 35 pb^{-1} analysis. Submitted to PRL
  - CMS public document.: SUS-10-008
- SUSY Searches with Leptons and Jets or MET
  - Multi-Leptons (≥3 Leptons)
- Conclusions.

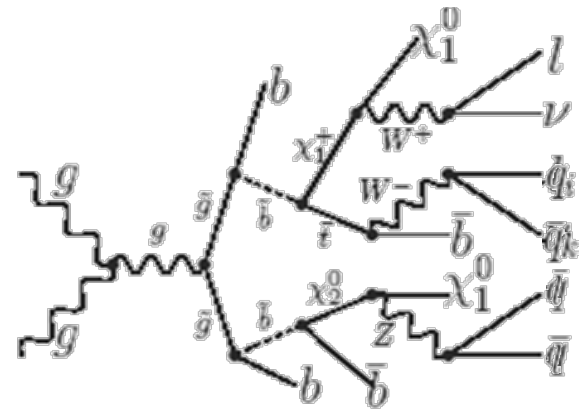
Multilepton SUSY Decays

- Leptons produced at the end of a chain of susy decays.
- Strongly coupled squarks and gluinos are generated in the proton collisions.
- Some combination of charginos, neutralinos, and sleptons decay to leptons and LSP (dark matter)
- Final state is ≥3 leptons with some combination of jets and MET

Tevatron



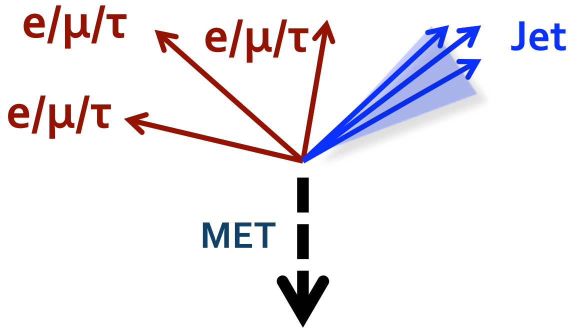
LHC



Searching for SUSY with Multi-Leptons

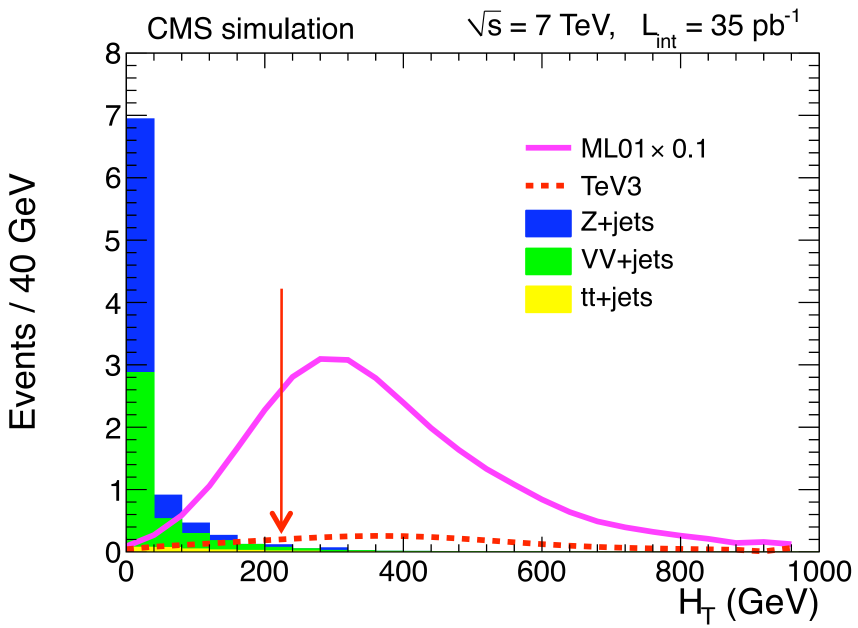
- Isolated Leptons (not from jet) are rare.
- SM events with ≥3 leptons are very rare!
  - Leptons isolated from jets come from gauge bosons $\gamma^*/Z^0/W^\pm$
  - Allow less stringent cuts on MET or Jets than other searches.
- Many SUSY scenarios produce ≥3 leptons.
  - Also large hadronic energy, MET or both.
- Reduce backgrounds with two variables:
  - MET: Missing transverse energy (neutrinos or LSP)
  - HT : $\Sigma\, p_T(\text{jet})$ with $p_T > 40$ GeV, $|\eta|<2.4$
  - Note: ≥3 leptons allow looser cuts on MET/H_T than ≥2

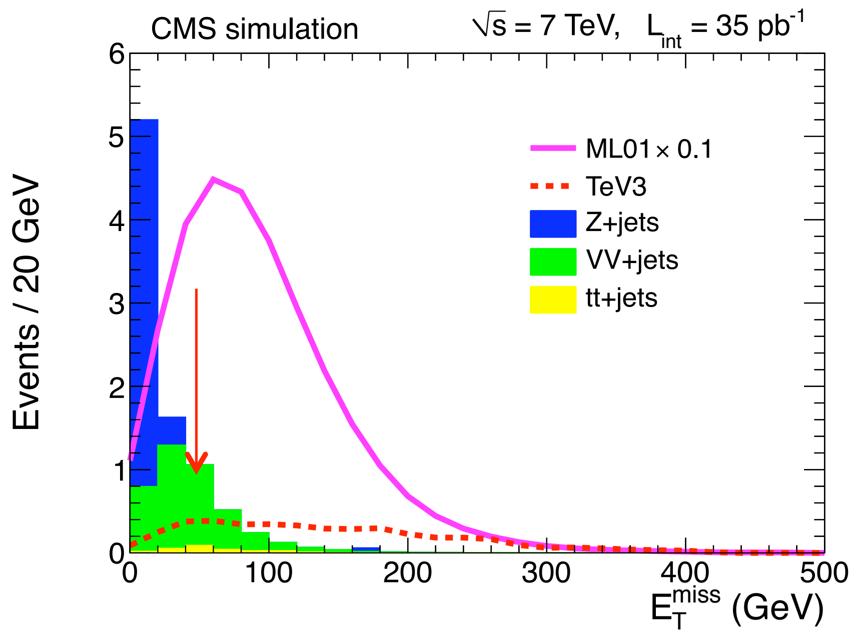
≥3 Leptons
(jets + MET)



Background reduction variables

Even after requiring 3 or more leptons, there are still some SM backgrounds. These can be removed by cutting on missing transverse energy or H_T.

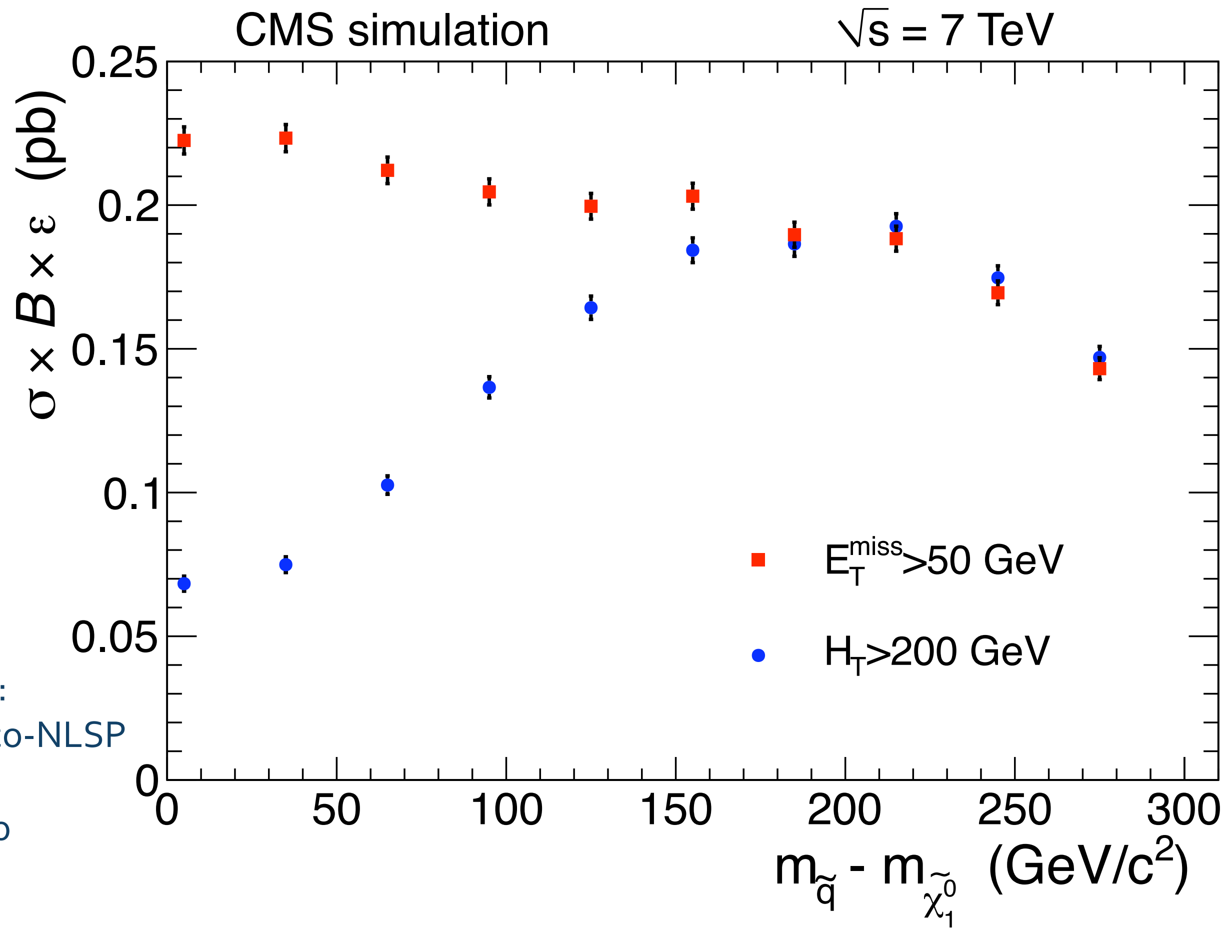




H_T is the total jet E_T for jets with E_T> 30 GeV

Background reduction variables

Beware, models vary. Not all of them have large H_T, not all have MET

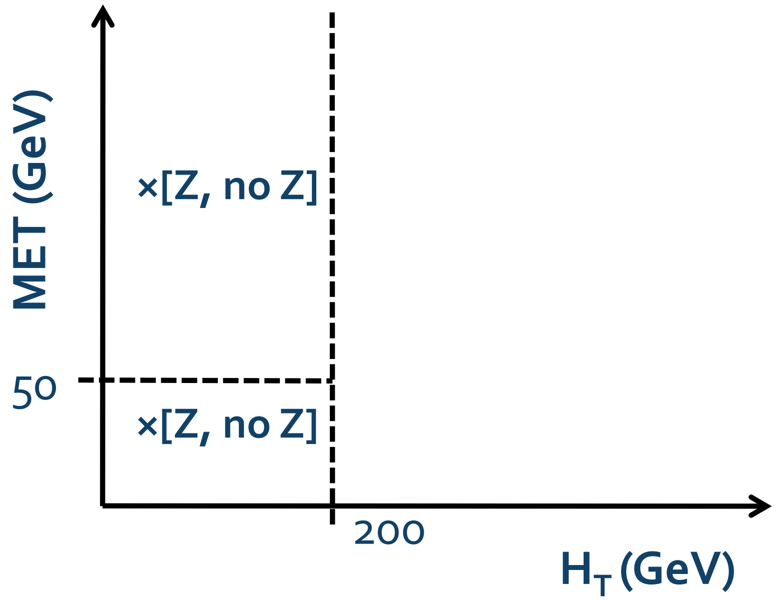


Example:
slepton co-NLSP
scenario
m(q)=500

Event selection

- Include 3 and ≥4 lepton combinations with ≤2 τ's
  - Use single e and single μ Triggers
  - Veto events where M(l+l-) < 12 GeV (J/ψ, Upsilon, Drell Yan)
  - Require ≥1 μ with pt > 15 GeV or ≥1 e with pt > 20 GeV

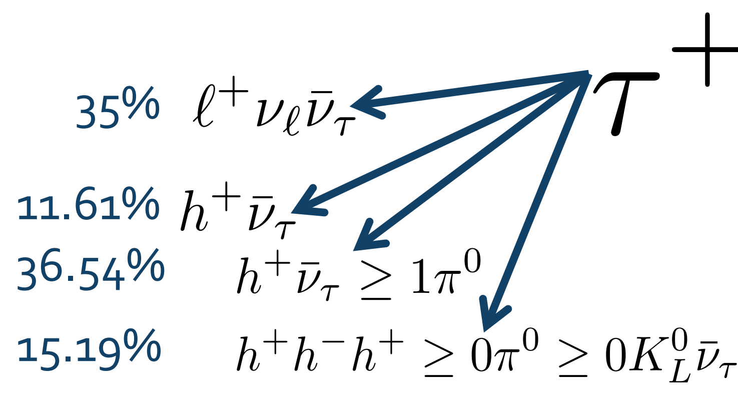
- Divide remaining events into 5 bins defined by background reducing variables.
  - H_T>200 GeV
  - MET>50 GeV
  - 75 GeV <M(l^+l^-)<105 GeV
- Channels with Z's or low MET and low HT are used to test background predictions.



Lepton Selection
(e, μ, τ)

- Electrons and Muons:
  - $p_T > 8$ GeV, $|\eta| < 2.1$
  - Identification:
    - Electrons ~90-95% efficient for pT > 20 GeV
      - HoverE, track shower match, shower shape.
    - Muons ~95% efficient for pT
      - Minimum ionizing and good match between tracker and muon detectors.

- Tau Leptons:
  - Tau are unstable and decay
  - Leptonic decays fall under e/μ
  - Single prong, no π^0
    - Isolated track
  - Single Prong with π^0 and 3 prong
    - "Shrinking Cone" algorithm (skinny jet)
  - Visible $p_T > 8$ GeV, $|\eta| < 2.1$



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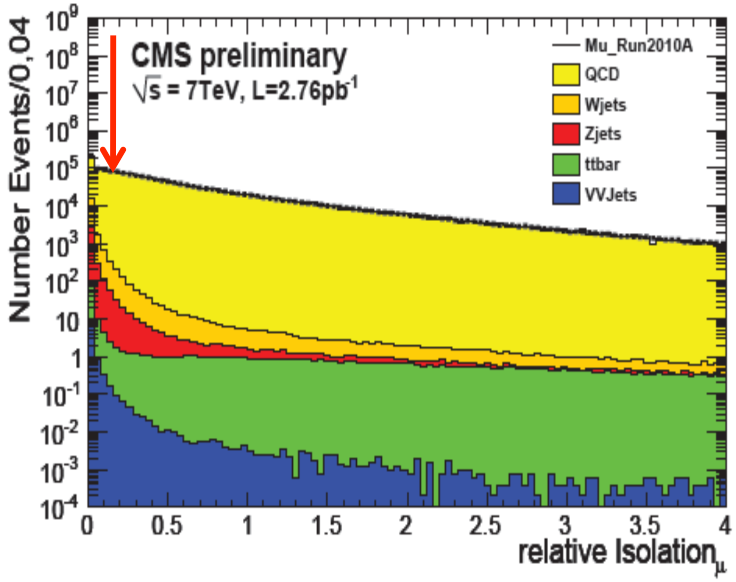
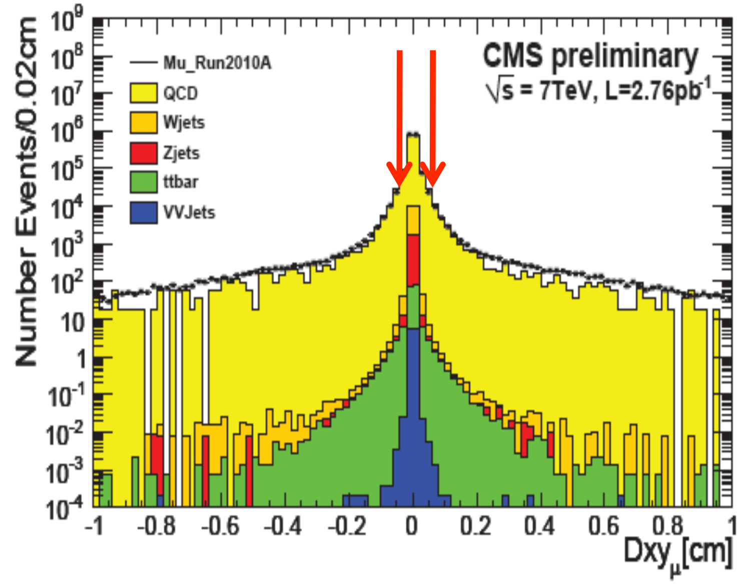
Removing Leptons from Jets

- Isolated from jets.
  - Sum transverse energy in cone around lepton from tracks.
  - Require energy in cone to be small compared to the lepton.
- Not displaced from collision.
  - Leptons from jets can start farther from interaction vertex
  - Require lepton to have small "impact parameter"





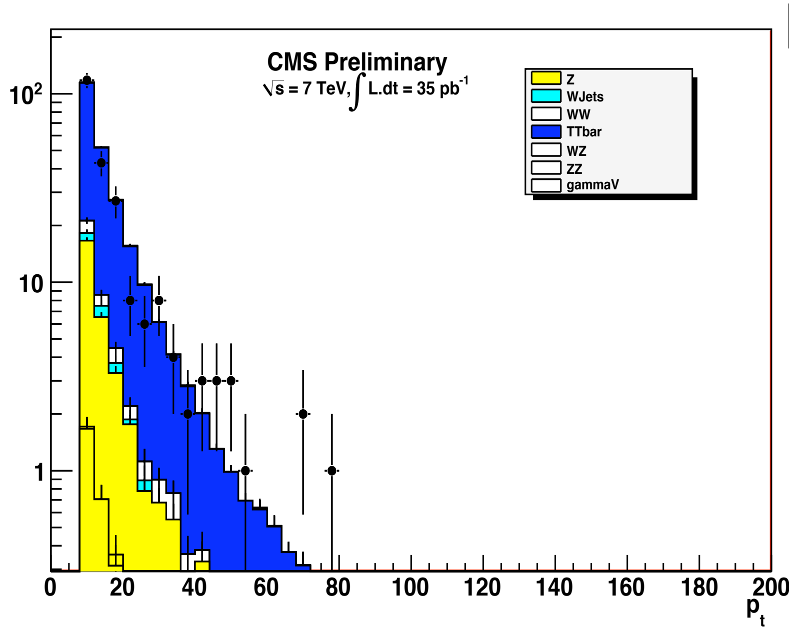
Background Predictions

- Some are directly from Monte Carlo (MC)
  - Irreducible backgrounds: WZ+Jets, ZZ+Jets
    - Corrected to match efficiency measurements.
    - Small cross sections.
- Some are from MC with Data Controls or Scale Factors
  - Including TTbar and FSR from dileptons
    - Correct MC to match efficiency measurements
- The rest are completely "Data Driven"
  - Z+Jets, WW+Jets, W+Jets, QCD
    - No MC required.

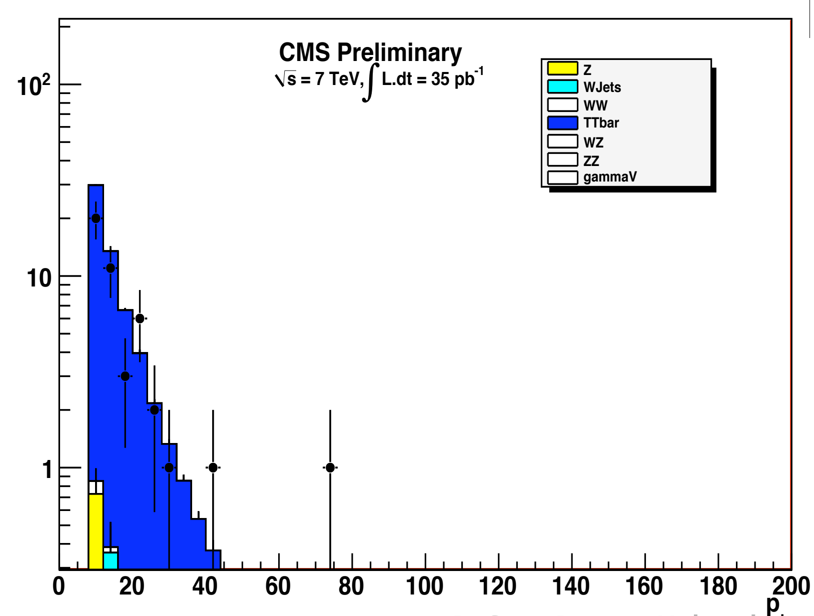
TTbar Background

- Obtained from Monte Carlo but validated in control data.
  - Compare MC to relevant distributions in data dominated by TTbar.
- Compare non-isolated tracks in $e^+\mu^-$ events (multiple entry)
  - Look at large and small impact parameter
  - Related to # of fake leptons, # of b-jets

$e^+\mu^-$: p_t of Tracks with $|d_{xy}(BS)| < 0.02$ cm



$e^+\mu^-$: p_t of Tracks with $|d_{xy}(BS)| > 0.02$ cm

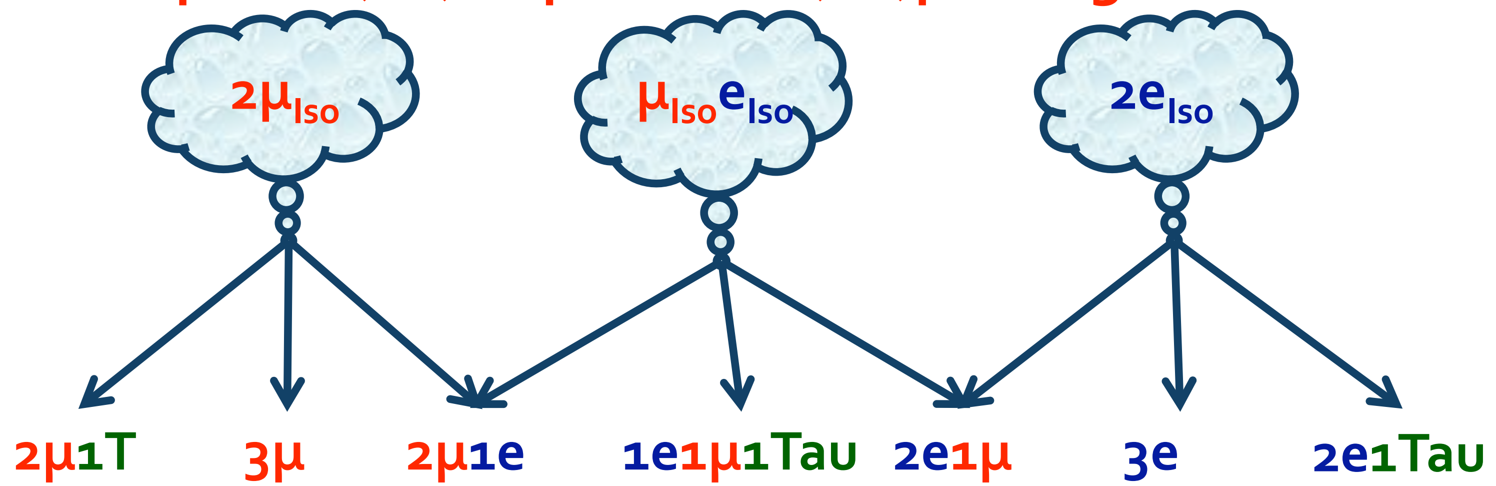


Data Driven Background Predictions

- Number e/μ from jets proportional to number k/π from jets.
  - Count isolated tracks to imply number of leptons from jets.
  - Determine conversion factor in di-jet data.
  - Use impact parameter distribution of tracks to understand systematic.
- Use isolation side band for fake Tau background.
  - Use di-jet data to parameterize conversion factor.
  - Use region beyond sideband to understand systematic.

Data Driven Predictions

- Use 2L data as a seed to predict ≥3L background
  - Example: 2e(SS) to predict 2e(SS)μ background



- Apply background estimation procedures to seeds.
  - Predict e or μ from jet using isolated track (~40% systematic)
  - Predict fake Tau using isolation side band. (~30% systematic)

Background Tests

- $\mu^+\mu^-\mu^\pm$ (MET < 50 GeV, H_T <200 GeV, with Z candidate)

Obs	SM Total	Data Driven	TTbar	WZ(ZZ) +Jets	FSR
2	1.8±0.3	1.1	0.01	0.7	0

- $\mu^+\mu^-e^\pm$ (MET < 50 GeV, H_T<200 GeV, with Z Candidate)

Obs	SM Total	Data Driven	TTbar	WZ(ZZ)+Jets	FSR
2	1.4 ± 1.1	0.7	0.005	0.5	0.2

- $\mu^+\mu^-T^\pm$ (MET < 50 GeV, H_T<200 GeV, with Z Candidate)

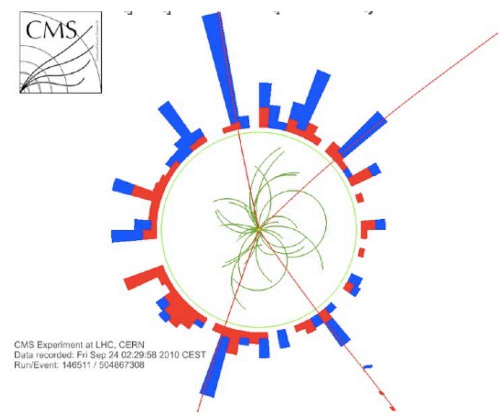
Obs	SM Total	Data Driven	TTbar	WZ(ZZ) +Jets	FSR
43	56 ± 12	55.8	0.02	0.25	0.3

Observations and Backgrounds

Observed and Predicted are Consistent

Channel	Before MET cut: ΣSM	Before MET cut: Data	After MET cut: ΣSM	After MET cut: Data
	3-lepton channels			
ll(OS)e	4.4 ± 1.5	6	0.1 ± 0.1	0
ll(OS)μ	4.7 ± 0.5	6	0.10 ± 0.1	0
ll(OS)T	123 ± 16	127	0.4 ± 0.1	0
ll(OS)τ	484 ± 77	442	–	–
ll′T	1.7 ± 0.7	3	0.4 ± 0.2	2
ll′τ	11.2 ± 2.5	10	–	–
ll(SS)l′	0.2 ± 0.1	0	0.2 ± 0.1	0
ll(SS)T	0.7 ± 0.4	3	0.1 ± 0.1	0
ll(SS)τ	3.0 ± 1.1	3	–	–
Σ lll(T)	135 ± 16	145	1.3 ± 0.2	2
Σ lll(τ)	507 ± 77	467	–	–
lTT	48 ± 9	30	0.4 ± 0.1	0
Channel	4-lepton channels			
llll	0.2 ± 0.1	2	0	0
lllT	0.1 ± 0.1	0	0	0
lllτ	0.1 ± 0.1	0	–	–
llTT	0.0 ± 0.1	0	0	0
llττ	3.2 ± 0.7	5	–	–
Σ llll(T)	0.3 ± 0.1	2	0	0
Σ llll(τ)	3.5 ± 0.7	5	–	–

Famous ZZ(4μ) event here (over 5,000 views on YouTube) First saw it Sunday 10/10/2010



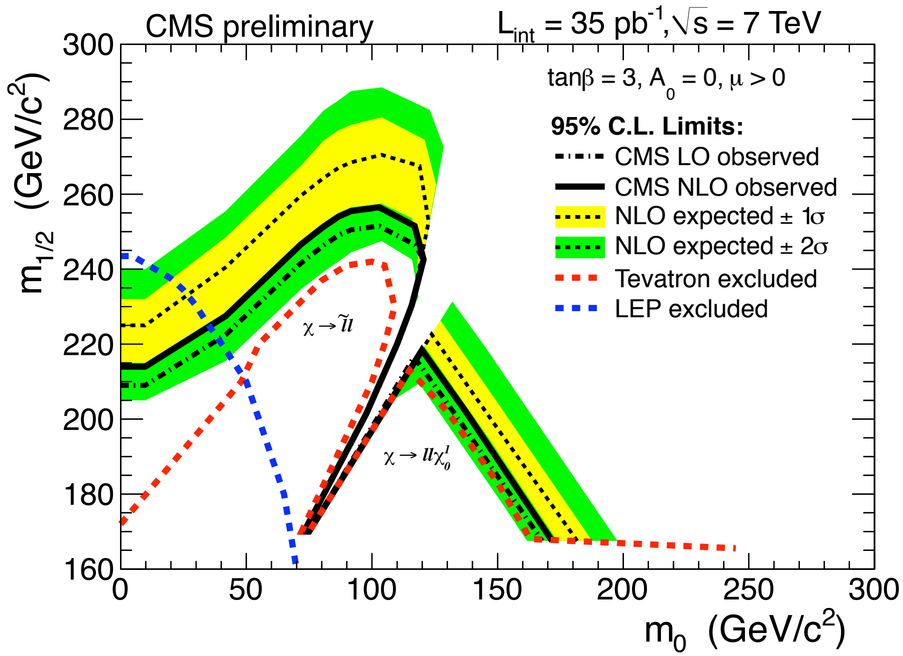
Multi-Lepton Summary Table

No statistically significant deviation from the standard Model.

	After Lepton ID Requirement					MET > 50 GeV		H_T > 200 GeV		ML01 Signals	
	Z +jets	$t\bar{t}$	V V +jets	ΣSM	Data	ΣSM	Data	ΣSM	Data	MET > 50	H_T > 200
Channel	3-lepton channels										
ll(OS)e	1.7	0.1	1.2	4.4 ± 1.5	6	0.1 ± 0.1	0	0.2 ± 0.1	1	121.4	141.5
ll(OS)μ	2.83	0.2	1.7	4.7 ± 0.5	6	0.10 ± 0.1	0	0.1 ± 0.1	0	123.6	120.8
ll(OS)T	121.5	0.5	0.7	123 ± 16	127	0.4 ± 0.1	0	–	–	80.5	–
ll(OS)τ	476	2.7	3.9	484 ± 77	442	–	–	0.6 ± 0.2	1	–	68
ll′T	0.72	0.5	0.2	1.7 ± 0.7	3	0.4 ± 0.2	2	–	–	18.6	–
ll′τ	4.7	2.9	0.6	11.2 ± 2.5	10	–	–	0.4 ± 0.1	1	–	12.3
ll(SS)l′	0.13	0.1	0.0	0.2 ± 0.1	0	0.2 ± 0.1	0	0	0	2.8	2.8
ll(SS)T	0.25	0.0	0.1	0.7 ± 0.4	3	0.1 ± 0.1	0	–	–	9.0	–
ll(SS)τ	1.4	0.0	0.1	3.0 ± 1.1	3	–	–	0.0 ± 0.1	0	–	6.9
Σ lll(T)	127.1	1.4	3.8	135 ± 16	145	1.3 ± 0.2	2	–	–	355.9	–
Σ lll(τ)	486.8	6.0	7.5	507 ± 77	467	–	–	1.3 ± 0.3	3	–	349.5
lTT	47.1	0.33	0.1	48 ± 9	30	0.4 ± 0.1	0	–	–	8.0	–
Channel	4-lepton channels										
llll	0	0	0.2	0.2 ± 0.1	2	0	0	0	0	163.9	149.2
lllT	0	0	0.1	0.1 ± 0.1	0	0	0	–	–	62.3	–
lllτ	0	0	0.1	0.1 ± 0.1	0	–	–	0	0	–	33.2
llTT	0	0	0	0.0 ± 0.1	0	0	0	–	–	20.6	–
llττ	3.1	0.1	0.1	3.2 ± 0.7	5	–	–	0	0	–	16.8
Σ llll(T)	0	0	0.3	0.3 ± 0.1	2	0	0	–	–	246.8	–
Σ llll(τ)	3.1	0.1	0.4	3.5 ± 0.7	5	–	–	0	0		199.2

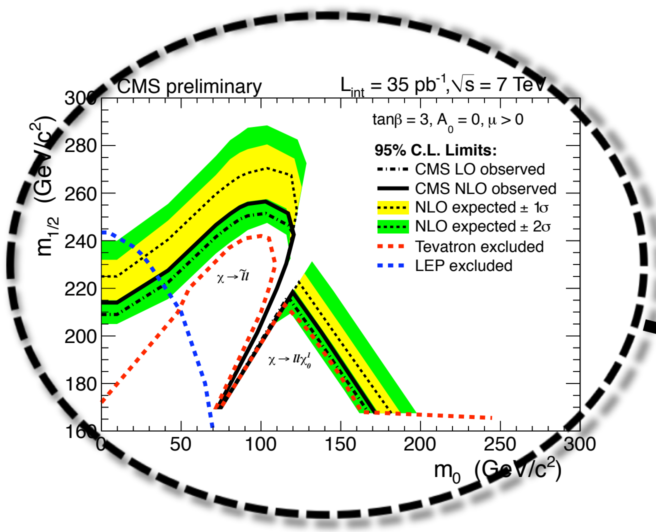
95% Excluded Scenarios cMSSM tan(β)=3

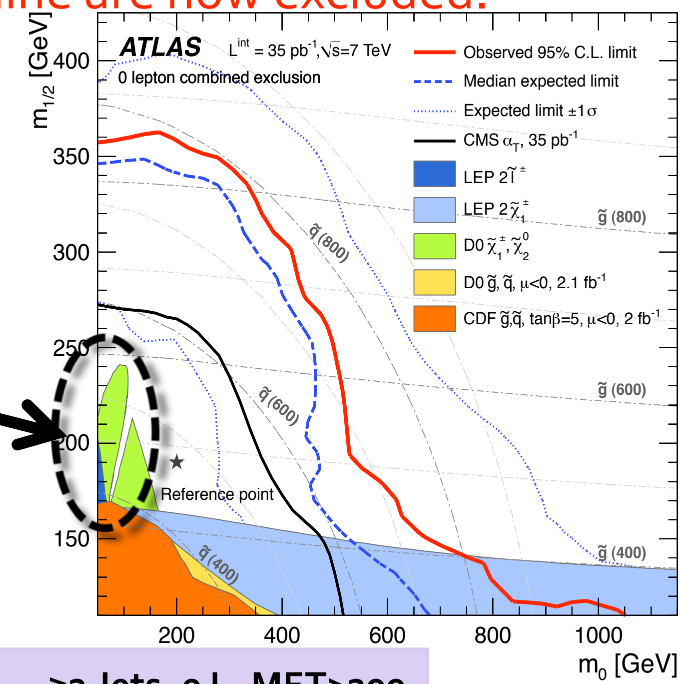
- cMSSM
  - Popular scenario that reduces SUSY parameters down to 5.
    - M0, M1/2, a0, sign(μ), tan(β)
  - Standard to compare experiments, but not realistic model.
  - Mass scenarios below solid black line are now excluded.



95% Excluded Scenarios (Other Signatures)

+ **cMSSM**
  + Mass scenarios below solid red line are now excluded.





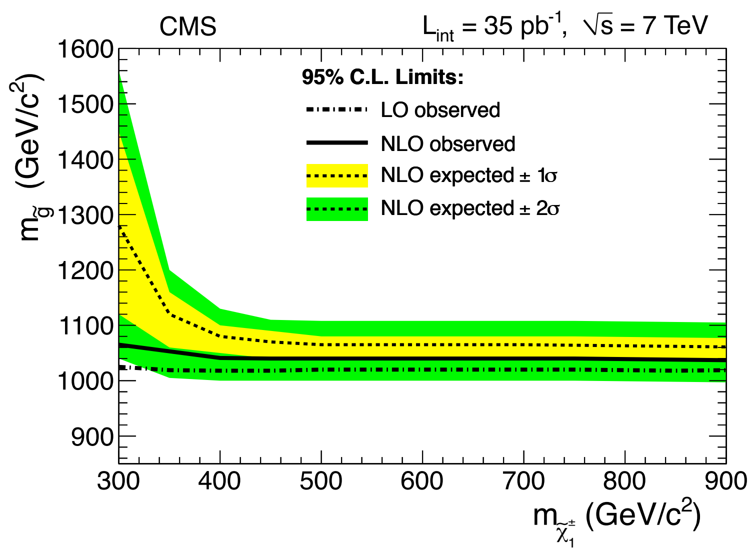
So Why are we doing multileptons?

SUSY Scenario Examples	≥3L	≥2 Jets, 0 L, MET>200
Slepton co-NLSP	~100%	0%
Leptonic R-parity violating	~100%	0%
mSUGRA (M0=60, M1/2=190)	~23%	11.4%
mSUGRA (M0=200, M1/2=250)	~1.8%	35%

cMSSM isn't friendly to multileptons, but other scenarios are.

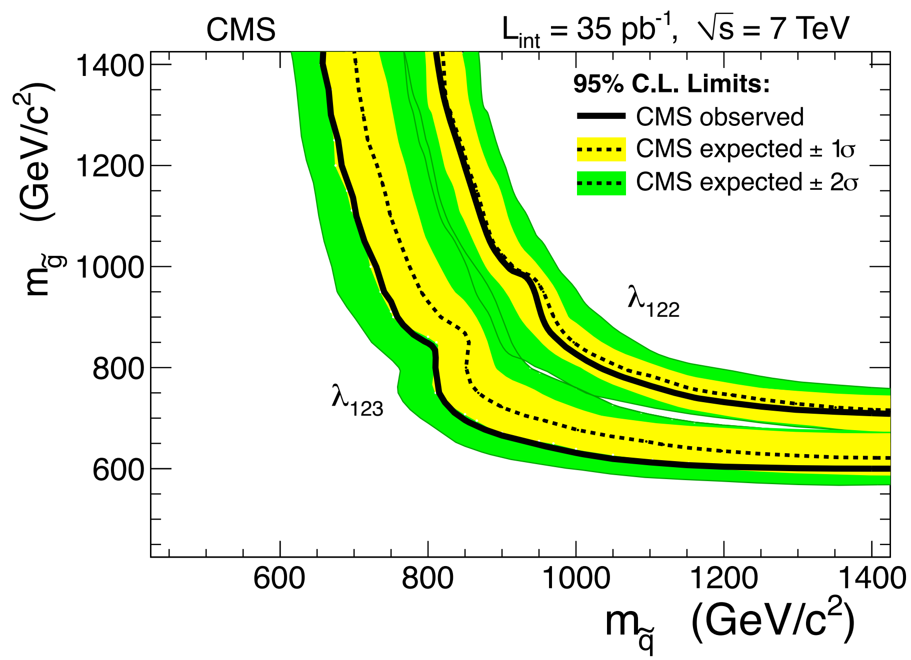
95% Excluded Scenarios (Multi-Leptons)

- Slepton co-NLSP
  - Sleptons have ~ the same mass, and are closest to the lightest SUSY particle which happens to be a gravitino.
  - At least 4 leptons produced per event.
  - Mass scenarios below solid line are now excluded.
  - Tevatron only excluded gluino mass < 400 GeV



95% Excluded Scenarios (Multi-Leptons)

- R-parity violation
  - R-parity is conserved in most SUSY scenarios. But it might be violated.
  - If violated leptonically, can be 4 or more leptons produced per event.
  - Two curves for two different scenariois.
    - λ123 contains 2L+2Tau
    - λ122 contain no Tau.
  - Mass scenarios below solid line are now excluded.



Conclusions

- Presented SUSY in multi-leptons with 35 pb^{-1} 2010 CMS data.
  - Use combination of MC and data-driven SM background predictions
  - Make use of control objects to understand/control fake rate systematics.
  - Results consistent with the standard model.
  - Set new limits on slepton co-NLSP topology and R-Parity violating SUSY.
- The 35 pb^{-1} data consistent with the SM, and constrained the range of many SUSY possibilities beyond the reach of the Tevatron.
- More data is here 2 fb^{-1}!!! The search continues.