Searches for Supersymmetry with Same-Sign Di-Leptons, b-tagged Jets and Missing Transverse Energy with the CMS Detector

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Abstract

The results of a search for new physics in events with two same-sign isolated leptons (electrons, muons), b tagged jets, and missing transverse energy in the final state are presented. The analysis is based on a data sample corresponding to an integrated luminosity of 3.95 fb^{-1} collected by the CMS experiment at the LHC with 8 TeV center of mass energy. The observed numbers of events agree with the Standard Model predictions and thus no evidence for new physics is found. The observations are used to set upper limits on possible new physics contributions and to constrain supersymmetric models.

Introduction

Events with same-sign lepton pairs from hadron collisions occur naturally in many new physics scenarios

- SUSY, tt production via di-quark resonances

Such events occur rarely in the Standard Model

- Only WW, WZ, ZZ, ttV can yield same-sign prompt $l^{\pm}l^{\pm}$
- Backgrounds are intrinsically low compared to searches involving all-hadronic final states as well as opposite-sign or single-lepton final states

Using 3.95 fb^{-1} of data produced by the LHC in 2012 before July, we report on the search of new physics in the same-sign di-lepton channel at CMS.

Physics Objects

Jets and E_T^{miss} are reconstructed based on the Particle-Flow technique (calorimeter + tracking)

- Anti-KT algorithm (d=0.5)
- p_T(Jet) > 40 GeV, $|\eta| < 2.4$

Total hadronic activity is characterized by the H_T observable:

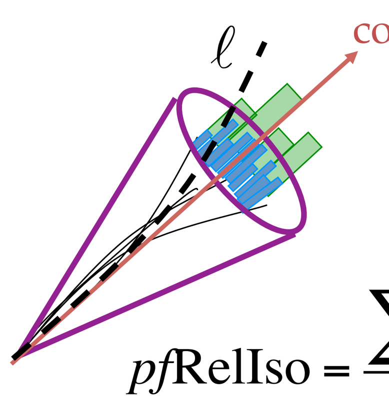
$$H_T = \sum_j^{\text{all jets}} |p_T^j|$$

The E_T^{miss} is calculated by summing vectorially over the transverse momenta of all of the reconstructed particle candidates in the event:

$$|\vec{E}_T^{miss}| = \left| \sum_j^{\text{all particles}} \hat{x}\left(p_T^j \cdot \cos(\varphi)\right) + \hat{y}\left(p_T^j \cdot \sin(\varphi)\right) \right|$$

Muons and electrons are reconstructed with standard techniques in CMS

- $|\eta| < 2.4$
- $p_T(\mu) > 20$ GeV, $p_T(e) > 20$ GeV



The relative isolation (RelIso) observable is used to distinguish prompt leptons from non-prompt ones:

$$pfRelIso = \frac{\sum_{\Delta R<0.3} P_T^{Track} + E_T^{ECAL} + E_T^{HCAL} - c}{P_T^{\ell}}$$

Signal Characteristics and Search Regions

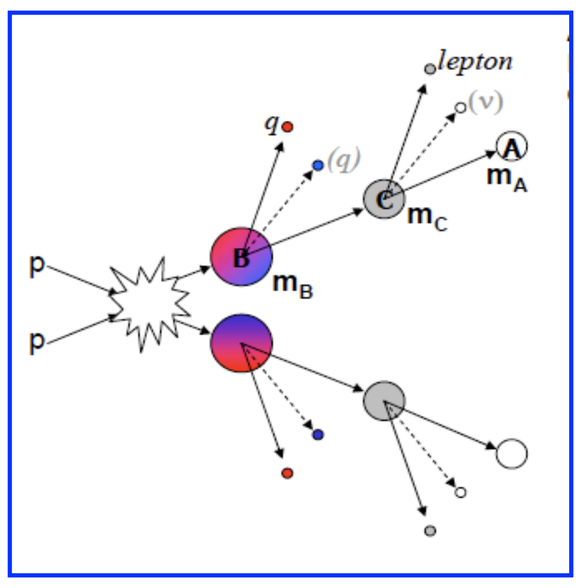
A: LSP *(dark-matter motivated; expect E_T^{miss})*
B: gluino/squark *(large σ; expect jets)*
C: chargino *(gives exclusive same-sign leptons)*

m_B drives the production cross-section

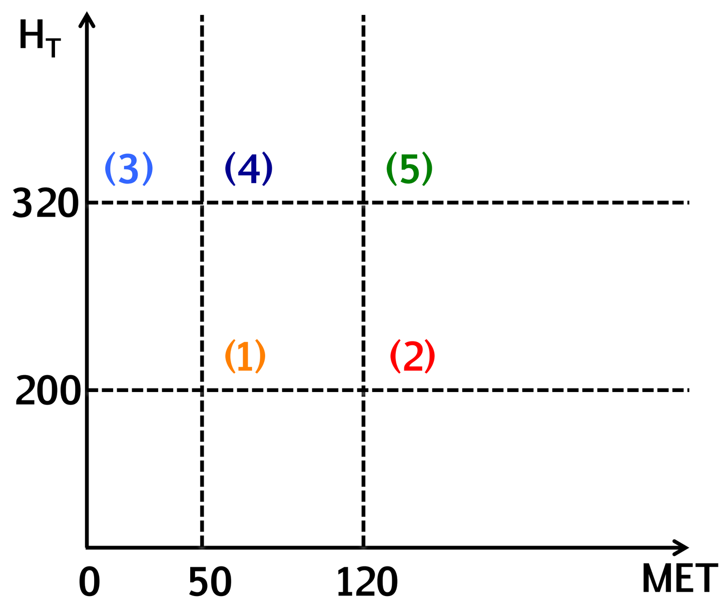
Δm_{BC} influences the total hadronic activity

Δm_{CA} influences the p_T of the leptons

Missing transverse energy (E_T^{miss}) is large so long as Δm_{BA} is large



Many search regions are designed to cover the various possibilities for Δm_{BC}, Δm_{CA}, Δm_{BA}



Background Classification

2 same-sign prompt leptons – small contribution – reasonably well understood → *taken from MC*	$qq \to qqW^{\pm}W^{\pm}$, $WZ, ZZ, WWW, t\bar{t}V$, $2\times(qq \to W^{\pm})$
2 opposite-sign prompt leptons and charge misidentification – small contribution – relying on MC is not safe → *derive from data*	$t\bar{t}$, tW, Drell-Yan, $W^{\pm}W^{\mp}$, WZ, ZZ
1 prompt lepton + 1 fake lepton – dominant contribution – relying on MC is not safe → *derive from data*	$(t\bar{t}, tW, tb) \to \ell\nu$ + jets W + jets, Drell-Yan + jets VV → ℓ + jets
2 fake leptons – sub-dominant contribution – relying on MC is not possible → *derive from data*	QCD $t\bar{t}$ (all-hadronic)

Background Estimation Methods for Fake Leptons

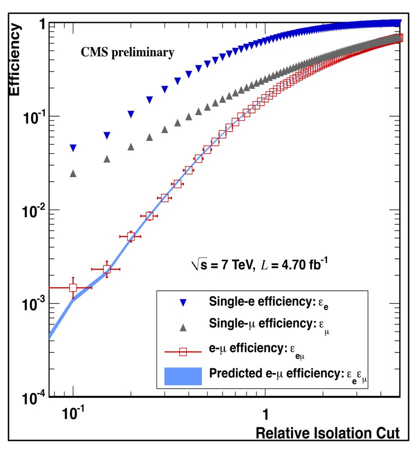
The Factorization Method

- **Double-Fake lepton background:** mostly comes from QCD multi-jet production.

- Select events with all analysis cuts applied except for those on isolation and E_T^{miss}. This defines the *preselection control region*, which is dominated by QCD

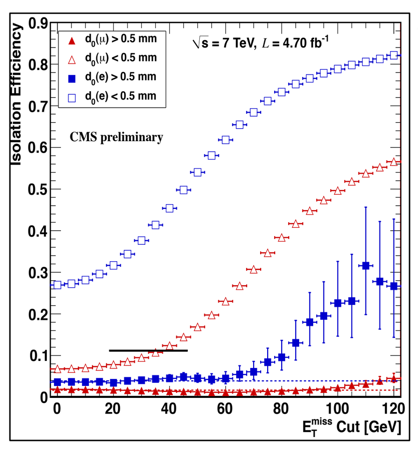
- Apply only isolation cut on electrons, calculate ε_e^{iso}
- Apply only isolation cut on muons, calculate ε_μ^{iso}
- Apply only E_T^{miss} cut, calculate $\varepsilon^{E_T^{miss}}$

Exploit the intrinsic independence of isolation and E_T^{miss} cuts on QCD events. The efficiencies factorize:



Proof that isolation cuts factorize in data

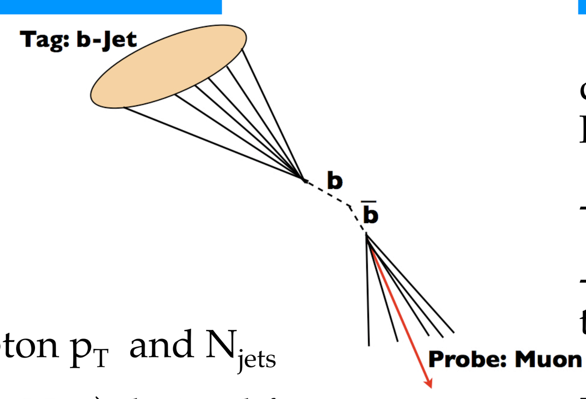
$$n_{\mu\mu} = N_{\mu\mu}^{preselected} \cdot \varepsilon_\mu^{iso} \cdot \varepsilon_\mu^{iso} \cdot \varepsilon^{E_T^{miss}}$$
$$n_{ee} = N_{ee}^{preselected} \cdot \varepsilon_e^{iso} \cdot \varepsilon_e^{iso} \cdot \varepsilon^{E_T^{miss}}$$
$$n_{e\mu} = N_{e\mu}^{preselected} \cdot \varepsilon_e^{iso} \cdot \varepsilon_\mu^{iso} \cdot \varepsilon^{E_T^{miss}}$$

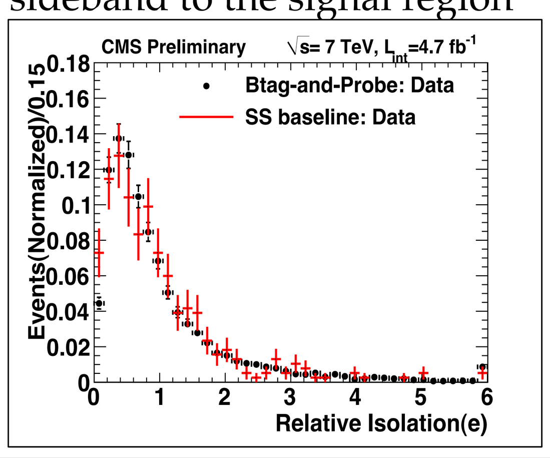


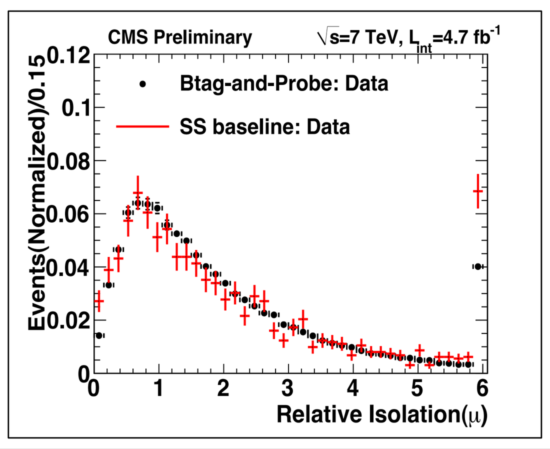
Proof that isolation and E_T^{miss} cuts factorize in data

The Btag-And-Probe Method

- **Single-Fake (+1 Prompt):** Dominant contribution is from Top events: a prompt lepton from W and another from b-decays
- Select a control sample by tagging a high purity b-jet and an away-lepton (targeting opposite b-jet)
- Measure isolation templates in bins of lepton p_T and N_{jets}
- Re-weight $\varepsilon(p_T, N_{jets})$ with probability $\omega(p_T, N_{jets})$ derived from tt-(MC) events
- Apply all analysis cuts, except for one lepton that is required to fail the isolation cut. This defines the *sideband region*
- Use measured isolation templates to extrapolate yields in the sideband to the signal region







Charge Misidentification Method

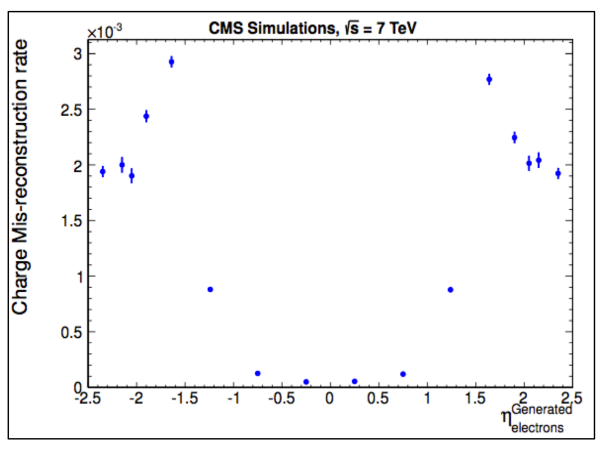
- **Opposite sign prompt lepton:** Sub-leading background due to charge misidentification – only relevant for electrons. For muons, it is negligible.

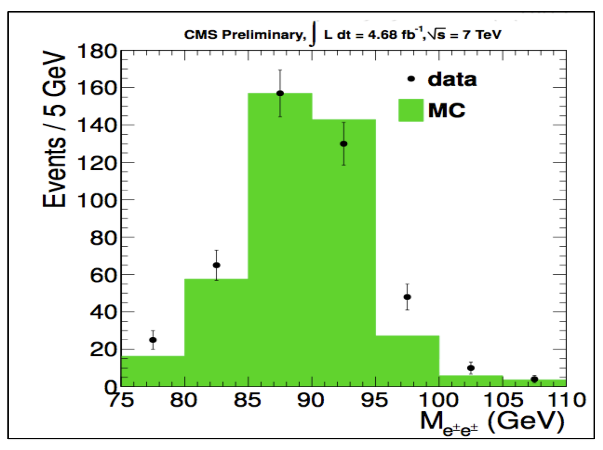
- Select a control region Z peak ± 15 GeV

- Select events with same-sign and opposite sign dileptons in the control region

- The ratio of these two numbers defines the charge misidentification rate

- Extrapolate to the search regions

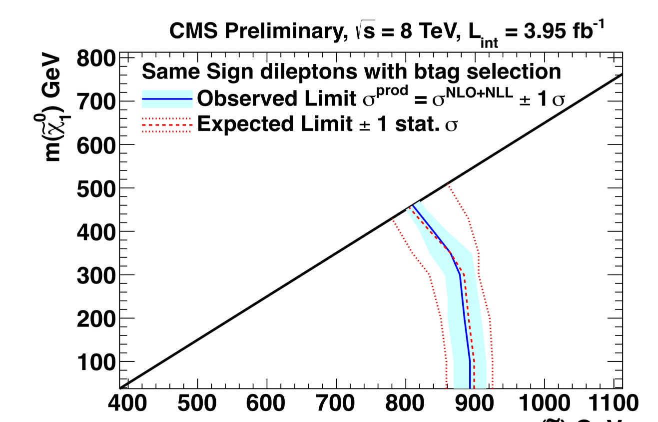


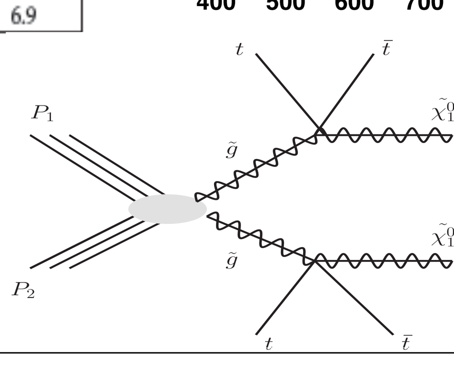


Summary of Results

	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	++/−−	++/−−	++/−−	++/−−	++/−−	++/−−
E_T^{miss}	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Charge-flip BG	0.05 ± 0.01	0.35 ± 0.08	0.11 ± 0.03	0.02 ± 0.01	0.01 ± 0.01	0.18 ± 0.05
Fake BG	0.33 ± 0.36	2.46 ± 2.16	0.77 ± 0.82	0.20 ± 0.33	0.08 ± 0.52	1.36 ± 1.12
Rare SM BG	1.01 ± 0.62	2.95 ± 1.56	1.77 ± 1.03	0.71 ± 0.51	0.24 ± 0.40	2.24 ± 1.27
Total BG	1.39 ± 0.72	5.76 ± 2.67	2.64 ± 1.32	0.93 ± 0.61	0.33 ± 0.66	3.78 ± 1.69
Event yield	1	4	2	1	1	4
N_{UL} (13% unc.)	3.7	5.5	4.5	3.8	4.2	6.4
N_{UL} (20% unc.)	3.8	5.6	4.7	3.9	4.3	6.6
N_{UL} (30% unc.)	4.0	6.0	4.9	4.2	4.6	6.9

- No excesses observed in any signal region
- Set upper limits with 95% CL

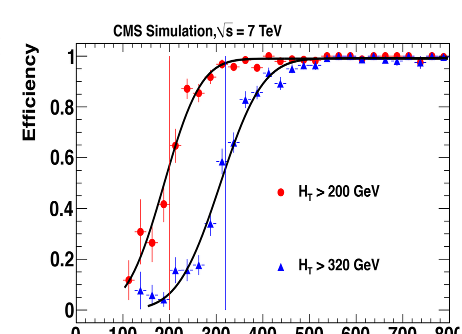


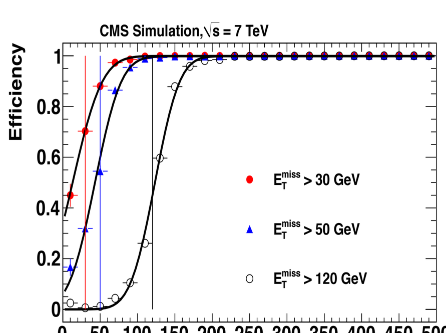


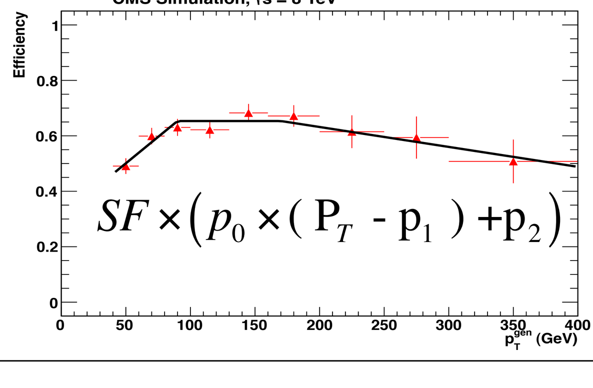
In order to make the result of this search meaningful in a broader context, we provide a parameterization of the experimental signal acceptance

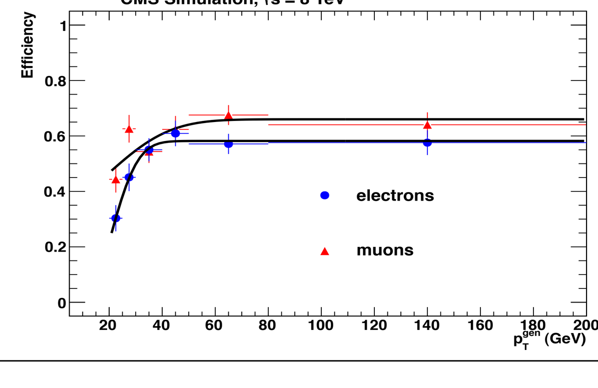
Lepton efficiencies: $\varepsilon(x) = \varepsilon_\infty erf\left(\frac{P_T - C}{\sigma}\right) + \varepsilon_C\left(1 - \text{erf}\left(\frac{P_T - C}{\sigma}\right)\right)$

H_T/E_T^{miss} efficiencies: $\varepsilon(x) = 0.5\varepsilon_\infty\left(1 + \text{erf}\left(\frac{X - X_{1/2}}{\sigma}\right)\right)$









References

CMS-SUS-12-017

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12017