Fake Ratios for a Same-Sign Double Lepton SUSY Search

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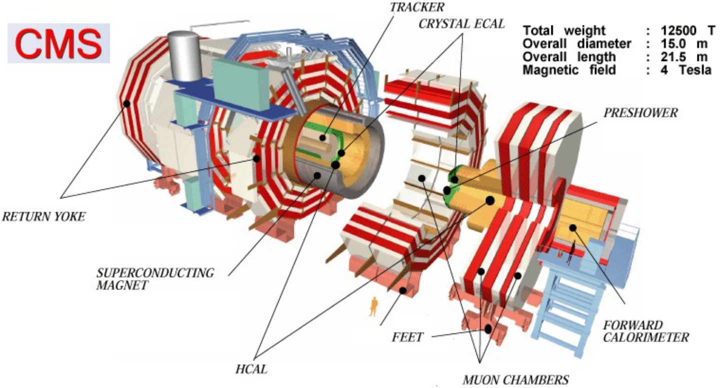
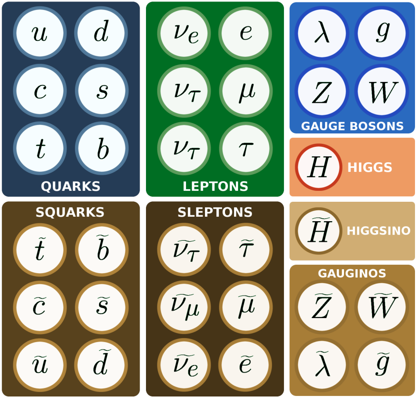
Outline

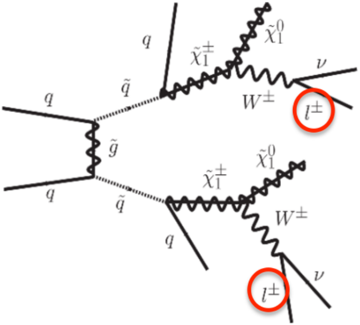
- Introduction to CMS and SUSY
- Selection
- Validation Plots
- Methodology of Fake Rate Measurements
- Results

CMS - Compact Muon Solenoid



Supersymmetry



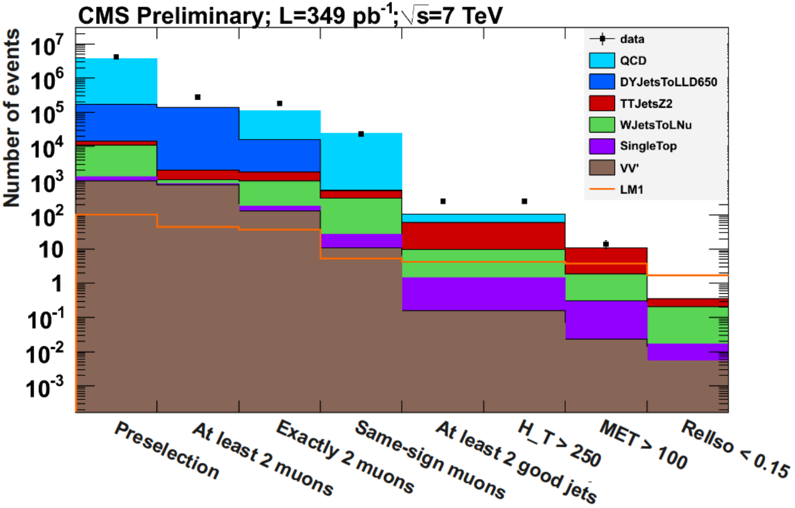


- Symmetry between fermions and bosons
- Each SM particle has superpartner with spin that differs by $\frac{1}{2}$
- R-parity is conserved $R = (-1)^{3(B-L)+2S}$
- Lightest SUSY particle (LSP) is stable $\rightarrow$ Missing E_T (MET)

Event Selection

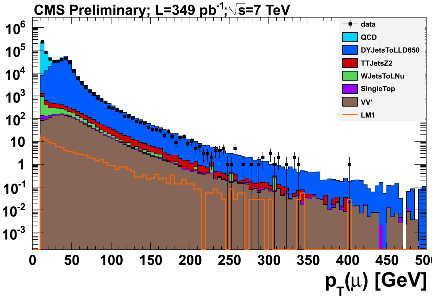
- Bunches of protons collide up to 40 million times per second
- Trigger system selects potentially interesting events only
- Amount of data that must be analysed is still huge
- Aim: Filter out SS (same-sign) dilepton events
- SUSY selection
  - Exactly 2 SS leptons
  - $MET > 100\ GeV$ ($MET = |\sum_i \vec{p}_{T,i}|$) (because LSP leaves undetected)
  - $H_T > 250\ GeV$ ($H_T = \sum |\vec{jet}_{p_T}|$)
- From 1 million events we select ~ 1

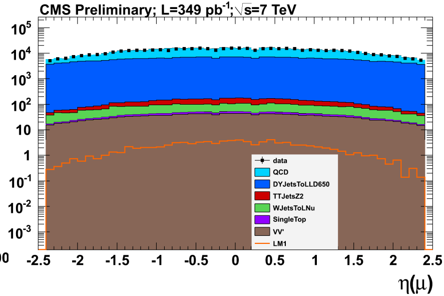
Event selection

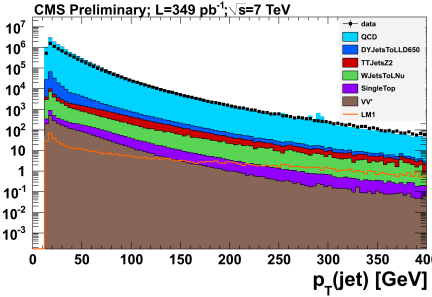


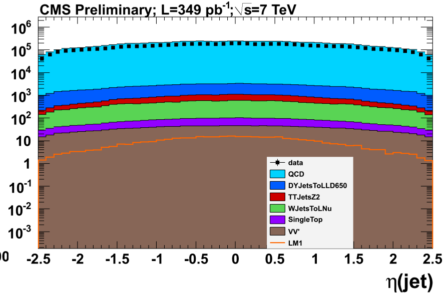
After the SUSY selection, a SUSY scenario (orange line) and SM are well separated

Validation plots

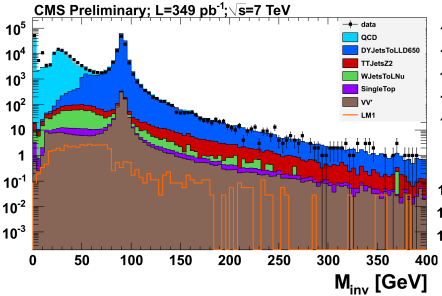


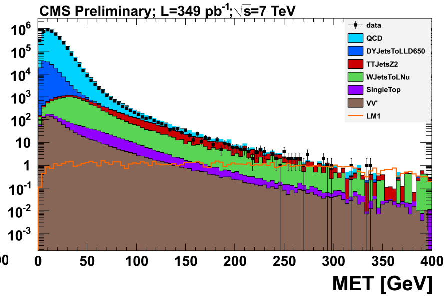






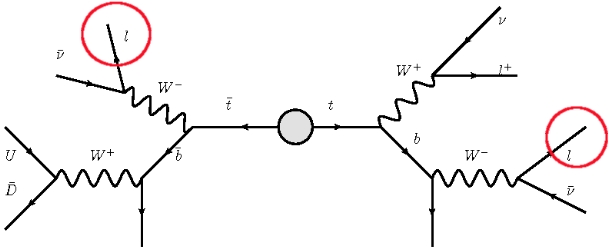
Validation plots





$$M_{inv}(\mu_1\mu_2) = \sqrt{E^2 - ||\vec{p}_{\mu_1\mu_2}||^2}$$
$$p_{\mu_1\mu_2} = p_{\mu_1} + p_{\mu_2}$$

Background



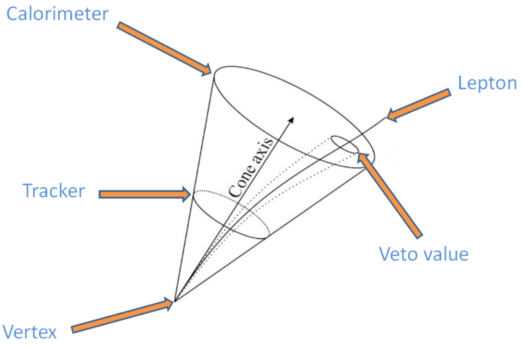
- Fake leptons
  - heavy flavour decay (diagram)
  - leptons from γ conversions
  - jets taken as leptons
- Prompt leptons - from W decay in $t\bar{t}$ (diagram) or from SS chargino decay in SUSY
  - There is no SS prompt di-lepton production in SM
- Isolated SS dileptons are very rare in SM but
  - $t\bar{t}$ and W + jets - one fake and one prompt lepton
  - QCD - both leptons are fake
- Estimate background by extrapolating relative isolation

Relative Isolation

Definition:

$$RelIso = (TrackIso + EcalIso + HcalIso)/p_T$$

Loose: RelIso<1.0
Tight: RelIso<0.15



Methodology - Tight-to-Loose-Method

- Two samples are defined, regarding isolation criteria:
  - Loose leptons - leptons with $RelIso < 1$
  - Tight leptons - leptons with $RelIso < 0.15$ (all tight leptons are also loose)
- ASSUMPTION: a prompt lepton that is loose, has a probability **p** of also being tight
- ASSUMPTION: a fake lepton that is loose, has a probability **f** of also being tight
- The number of events with one tight lepton and one loose lepton will follow from N_{pp}, N_{pf} and N_{ff} using simple combinatorics

$$N_{t10} = 2p(1-p)N_{pp} + [p(1-f) + f(1-p)]N_{fp} + 2f(1-f)N_{ff}$$

Relations

In general, the number of events with all the possibilities for the leptons passing/failing the tight criteria can be derived in terms of the different contributions N_{pp}, N_{pf} and N_{ff} via A

$$\begin{pmatrix} N_{pp} \\ N_{pf} \\ N_{fp} \\ N_{ff} \end{pmatrix} = A(p, f) \begin{pmatrix} N_{t00} \\ N_{t01} \\ N_{t10} \\ N_{t11} \end{pmatrix}$$

Main idea behind this method:

By measuring **p** and **f** in control regions and then N_{t00}, N_{t01}, N_{t10}, N_{t00} with the SUSY selection, we can easily invert the previous relation and obtain an estimation of N_{pf} and N_{ff}, which are the backgrounds, as well as N_{pp}, which is the signal

The prompt and fake ratios are measured in different p_T bins. The algebra is a bit more complicated, but conceptually it is the same idea.

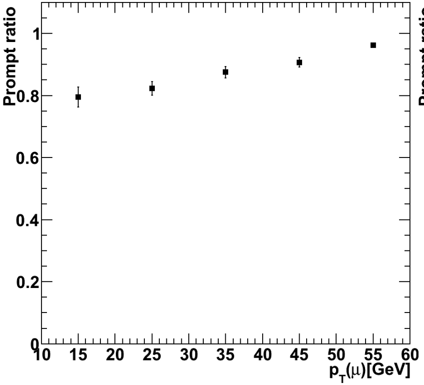
Algebra:

$$A = \begin{pmatrix} f_1 f_2 & -(1-f_1)f_2 & -f_1(1-f_2) & (1-f_1)(1-f_2) \\ -f_1 p_2 & (1-f_1)p_2 & f_1(1-p_2) & -(1-f_1)(1-p_2) \\ -p_1 f_2 & (1-p_1)f_2 & p_1(1-f_2) & -(1-p_1)(1-f_2) \\ p_1 p_2 & -(1-p_1)p_2 & -p_1(1-p_2) & (1-p_1)(1-p_2) \end{pmatrix}$$

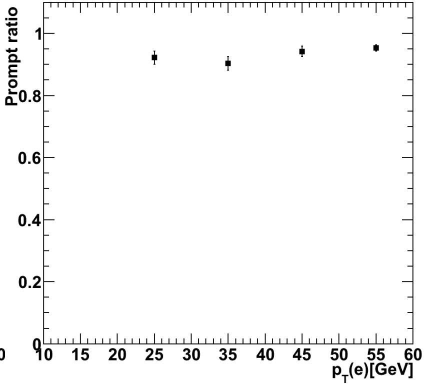
$$\begin{pmatrix} N_{pp} \\ N_{pf} \\ N_{fp} \\ N_{ff} \end{pmatrix} = \frac{A}{(p_1-f_1)(p_2-f_2)} \begin{pmatrix} N_{t00} \\ N_{t01} \\ N_{t10} \\ N_{t11} \end{pmatrix}$$

sum over all bins $\Rightarrow$ $N_{xy} = \sum_{p_{T1},\eta_1,p_{T2},\eta_2}$, x,y=p,f

Prompt Ratio for Muons & Electrons

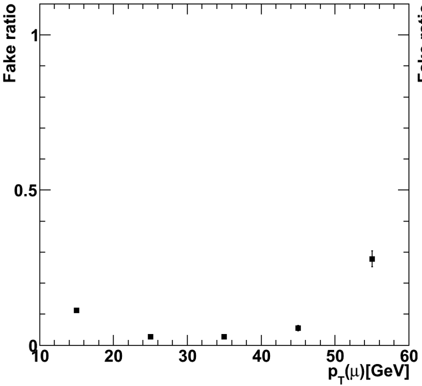


Prompt ratio for muons

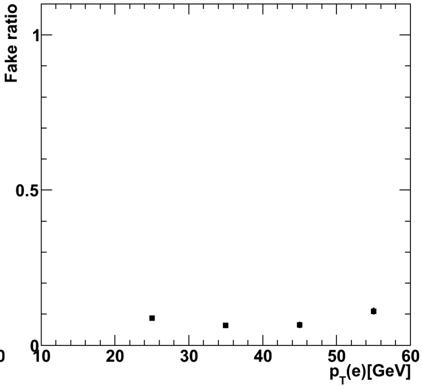


Prompt ratio for electrons

Fake Ratio for Muons & Electrons



Fake ratio for muons



Fake ratio for electrons

Results - Event Yield after SUSY Selection

Counting over Data
$(N_{t00}, N_{t10}, N_{t01}, N_{t11})$ $\rightarrow$ *Prediction*

	$\mu\mu$	$e\mu$	ee	total
MC	0.95±0.37	1.07±0.33	0.32±0.13	2.34±0.5
Pred. (TL)	1.94±0.57	1.4±0.42	0.39±0.19	3.73±0.73
Data (1.1fb)	1±1	2±1.4	0	3±1.7
Signal (LM1)	13.4±1.3	18.3±1.7	5.6±0.9	37.3±2.3

Summary

- SUSY Cut Flow for discovery established (leptonic channel)
- Validation of MC successful
- Background estimation established (Tight-to-Loose method)
- Prompt/ fake ratios for e/μ binned in p_T
- No excess found in data yet (1.1 $\frac{1}{fb}$)
- Looking forward to more data $\rightarrow$ exciting times! :-)

Thank you for your attention!

Backup

Relative isolation

Muon selection:

$$RelIso = (TrackIso + EcalIso + HcalIso)/p_T$$

Loose: RelIso<1.0
Tight: RelIso<0.15

Electron selection:

$$RelIso = (TrackIso + max(0., EcalIso - 1) + HcalIso)/p_T \; (Barrel)$$

$$RelIso = (TrackIso + EcalIso + HcalIso)/p_T \; (Endcap)$$

Loose: RelIso<1.0 (Barrel), Reliso<0.6 (Endcap)
Identification: El.ID cuts defined in the "90% efficiency working point"(WP90)

Tight: RelIso<0.15
Identification: El.ID cuts defined in the "80% efficiency working point"(WP80)

Methodology - single lepton events

- Assumption: fake ratios are universal and can be applied to other backgroungds
    - p - prompt ratio; probability that a prompt loose lepton is also tight (≈ 1)
    - f - fake ratio; probability that a fake loose lepton is also tight (≈ 0)
    - N_l - total number of leptons passing loose criteria
    - N_p - number of prompt leptons
    - N_f - number of fake leptons
    - N_{t0} - number of events where no lepton passes tight criteria
    - N_{t1} - number of events where one lepton passes tight criteria
- N_p and N_f not directly measurable; related to N_{t0} and N_{t1}

Methodology - single lepton events

$$\left.\begin{array}{c} N_x,\ x=p,f \\ N_{tx},\ x=0,1 \\ p \\ f \end{array}\right\} \rightarrow \text{Depend on } \eta, p_T!$$

$$N_l = N_p + N_f = N_{t0} + N_{t1}$$

Relations:

$$\begin{array}{l} N_{t0} = (1-p)N_p + (1-f)N_f \\ N_{t1} = pN_p + fN_f \end{array} \Rightarrow \begin{array}{l} N_p = \frac{1}{p-f}[(1-f)N_{t1} - fN_{t0}] \\ N_f = \frac{1}{p-f}[pN_{t0} - (1-p)N_{t1}] \end{array}$$

Background estimation:

$N_{signal} = N_P^{pass} = pN_p$ - Prompt signal

$N_{contam} = N_f^{pass} = fN_f$ - Fakes passing tight cuts

Methodology - dilepton events

- Notation: N_{xy},x,y=p,f where first label refers to lepton with higher p_T
- N_{pp} - number of events with both prompt leptons
- N_{pf} - number of events with one prompt and one fake lepton
- N_{ff} - number of events with both fake leptons
- N_{txy} (x,y=0,1) - number of events with 0,1,or 2 leptons passing tight cuts
- Functions of lepton kinematics

$$\left.\begin{array}{l} N_{xy},\ x,y=p,f \\ N_{txy},\ x,y=0,1 \\ p_{xy},\ x,y=l_1,l_2 \\ f_{xy},\ x,y=l_1,l_2 \end{array}\right\} \rightarrow \text{Depend on: } p_{T1}, p_{T2}, \eta_1, \eta_2$$

Dilepton events

- $N_l = N_{pp} + N_{fp} + N_{ff} = N_{t11} + N_{t10} + N_{t01} + N_{t00}$
- $N_{t00} = (1 - p_1)(1 - p_2)N_{pp} + (1 - p_1)(1 - f_2)N_{pf} + (1 - f_1)(1 - p_2)N_{fp} + (1 - f_1)(1 - f_2)N_{ff}$
- $N_{t10} = p_1(1 - p_2)N_{pp} + p_1(1 - f_2)N_{pf} + f_1(1 - p_2)N_{fp} + f_1(1 - f_2)N_{ff}$
- $N_{t01} = (1 - p_1)p_2 N_{pp} + (1 - p_1)f_2 N_{pf} + (1 - f_1)p_2 N_{fp} + (1 - f_1)f_2 N_{ff}$
- $N_{t11} = p_1 p_2 N_{pp} + p_1 f_2 N_{pf} + f_1 p_2 N_{fp} + f_1 f_2 N_{ff}$

Event selection (SUSY)

- Triggers: lepton triggers
- Cleaning cuts - No of good vertex > 0
- HBHE noise filter
- Pure tracks
- No of good leptons > 1 (ee, eμ, $\mu\mu$)
- No of good leptons $= 2$ (ee, eμ, $\mu\mu$)
- Is same-sign (ee, eμ, $\mu\mu$)
- M_{inv}(SS ll) > 5 GeV
- SSPrimary vertex Z< 1 cm
- $|M_{inv}$(OS ll) $- MZ| > 15$ GeV
- No of Jets > 1
- H_T(particle flow) > 250 GeV
- MET (particle flow)> 100 GeV
- RelIso1 < 0.15
- RelIso2 < 0.15

Muon selection

- $p_T > 10$ GeV
- $|\eta| < 2.4$
- Reduced $\chi^2 < 10$
- Is Global and Tracker muon
- NoOfTrackerHits > 10
- No of valid silicon Hits > 10
- $|d0_{corr}| < 0.02$ (z-distance with respect to beam spot)
- Valid Stand Alone Hits > 0
- ecalvetoDep < 4 GeV
- hcalvetoDep < 6 GeV

Loose:
Relative Isolation < 1.0 (cone R = 0.3)
Tight:
Relative Isolation < 0.15 (cone R = 0.3)

Electron selection

- $p_T > 20$ GeV
- $|\eta| < 2.4$
- Exclude η-gap $(1.47 < |\eta| < 1.57)$
- $|d0_{corr}| < 0.02$(z-distance with respect to beam spot)
- No μ within $\Delta R < 0.1$
- Conversion rejection (from 80% eff working point)
- ECAL driven seed
- Charge(GSF) = Charge(CTF) = Charge(ScPix)

Loose RelIso $<$ 1.0/ 0.6 (Barrel/ Endcap) VBTF-IDc 90 == 5 || 7
Tight RelIso $<$ 0.15 VBTF-IDc 80 == 5 || 7

Jet selection

- $p_T > 30 GeV$
- $|\eta| < 2.5$
- Ak5Jets: loose ID (L2 & L3; PF)
- ΔR to electrons > 0.4
- ΔR to muons > 0.4