SUSY in SameSign DiLepton Channel

NPPD - Glasgow - 2011

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Outline

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3. Search regions
4. Lepton, MET and Jets selection
5. Background estimations
6. Tau Channels
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   - Testing the method
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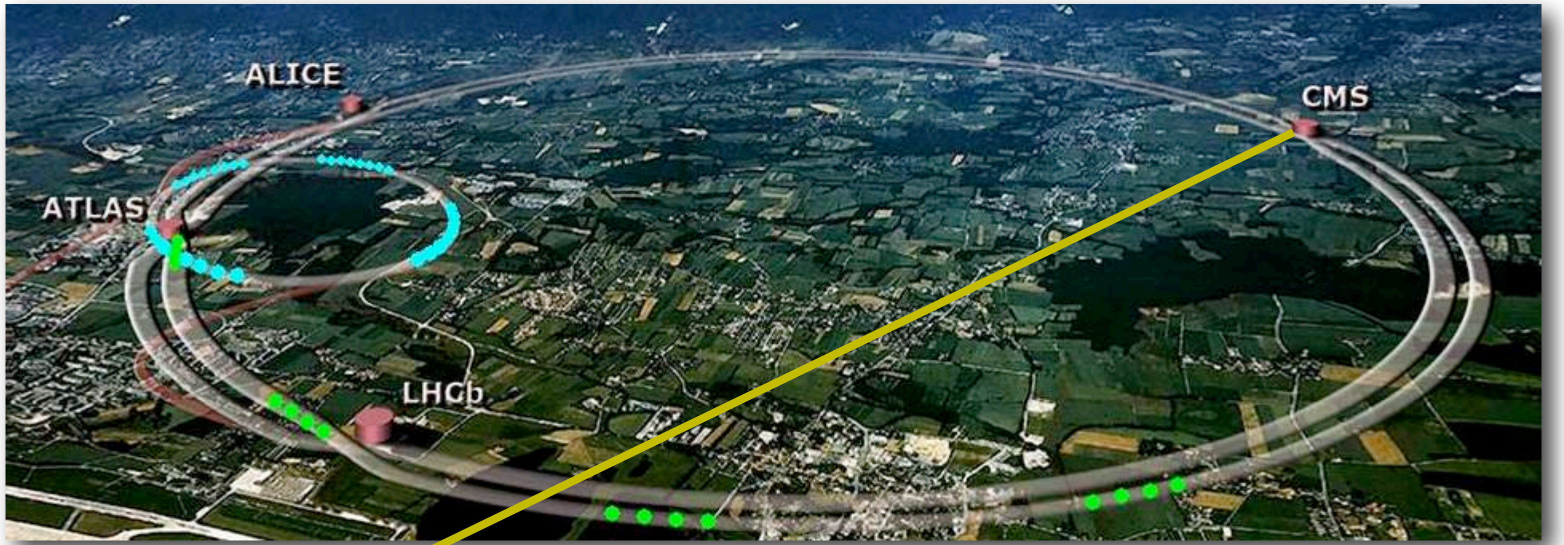
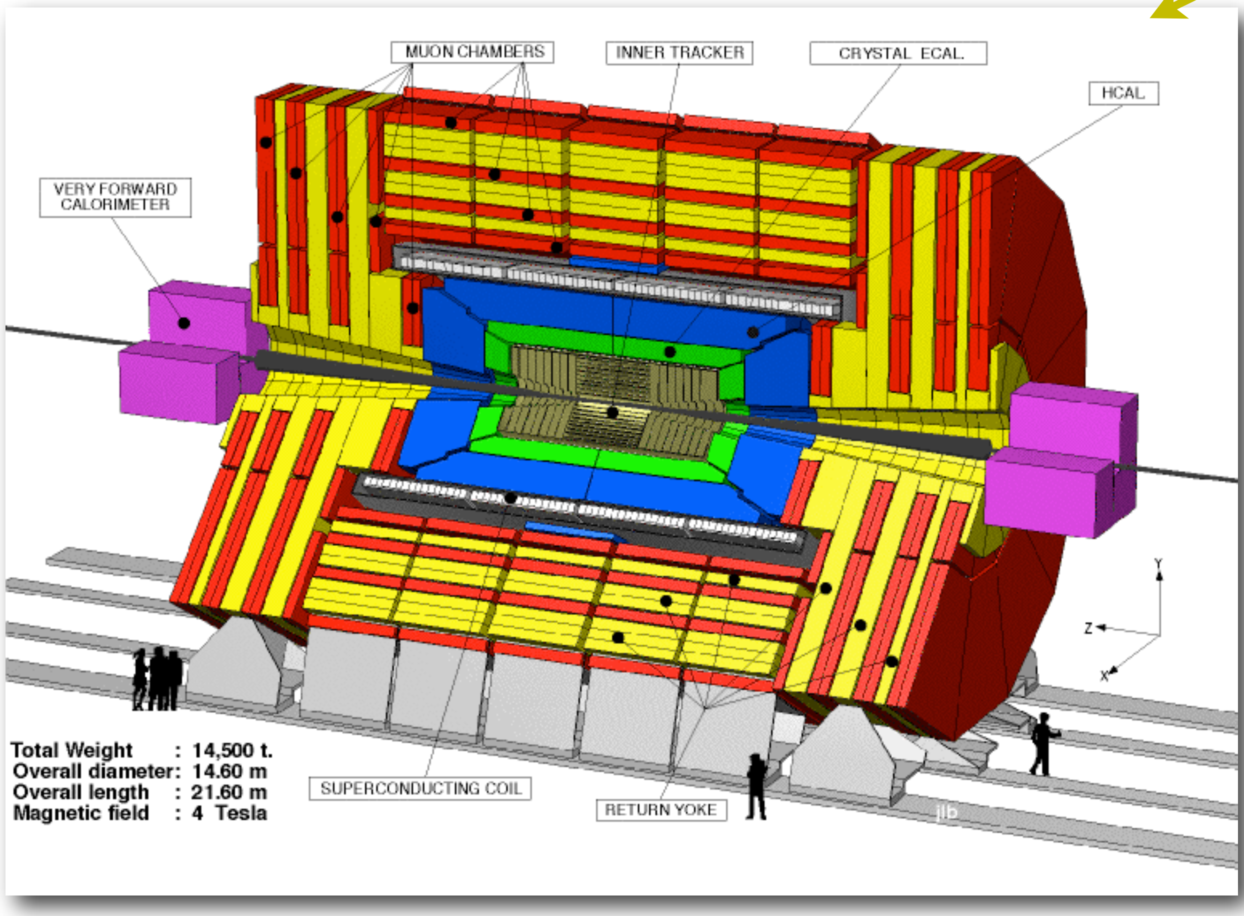
LHC and CMS

Nominal specs: 7TeV/beam,
$L = 10^{34} cm^{-1} s^{-2}$

2010 run: ~$35 pb^{-1}$
of 7TeV data



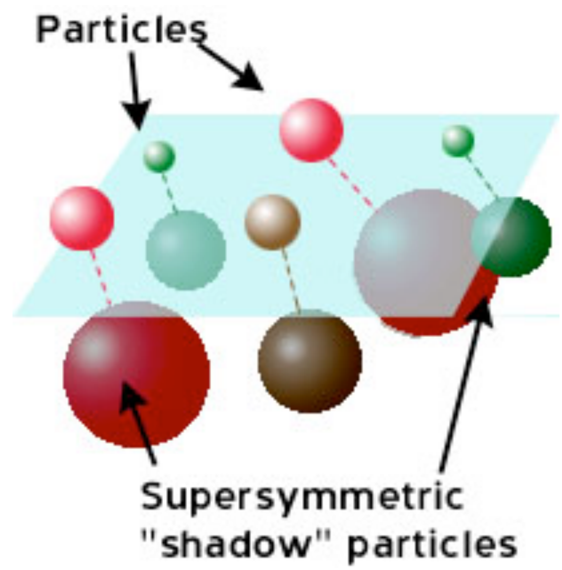


JINST3:S08004 (2008)

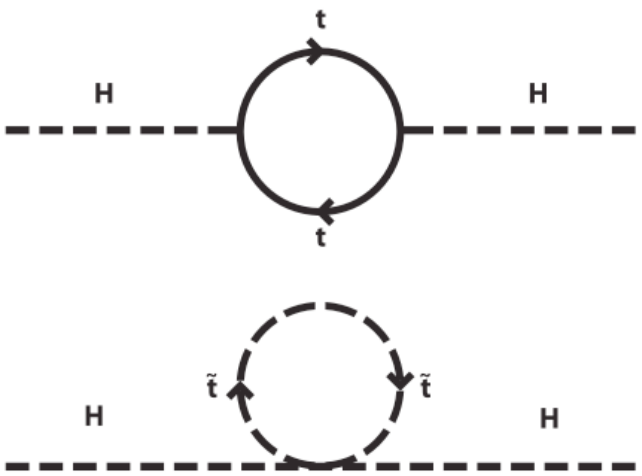
- 3.8 T solenoid magnet
- Silicon tracker (pixel and strips)
- Crystal ECAL $\sigma(E)/E = 3\%/\sqrt{E} \oplus 0.003$
- Brass/scintillator HCAL $\sigma(E)/E = 100\%/\sqrt{E} \oplus 0.05$
- Muon chambers $\sigma(p)/p < 10\%$ at 1TeV

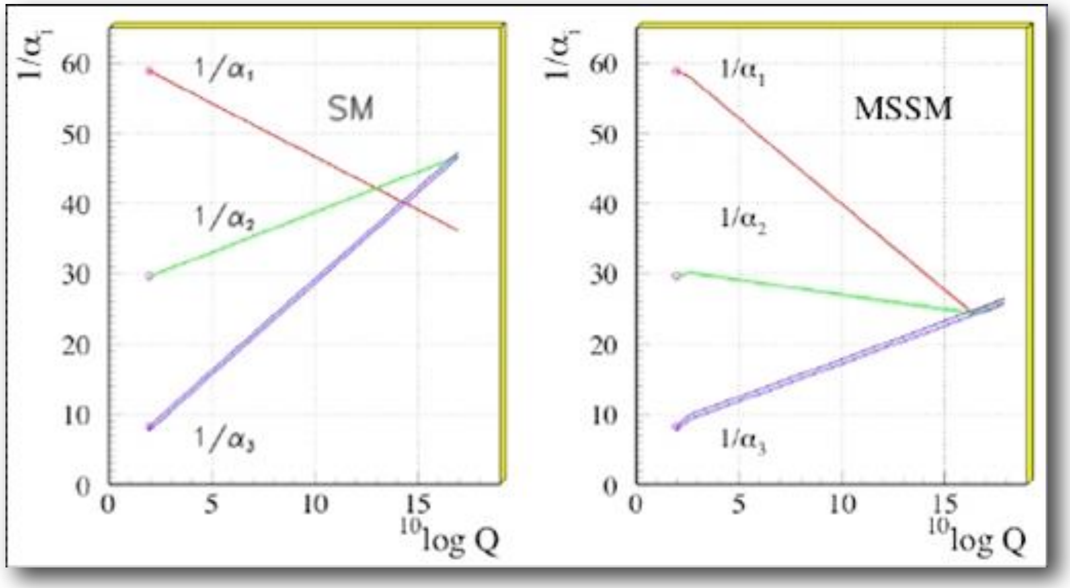
Motivation for SUSY

Spacetime symmetry that relates particles of a given spin to new particles that differ by half spin
→For every SM particle there is a new SUSY particle
Fermions have bosonic superpartners and vice versa

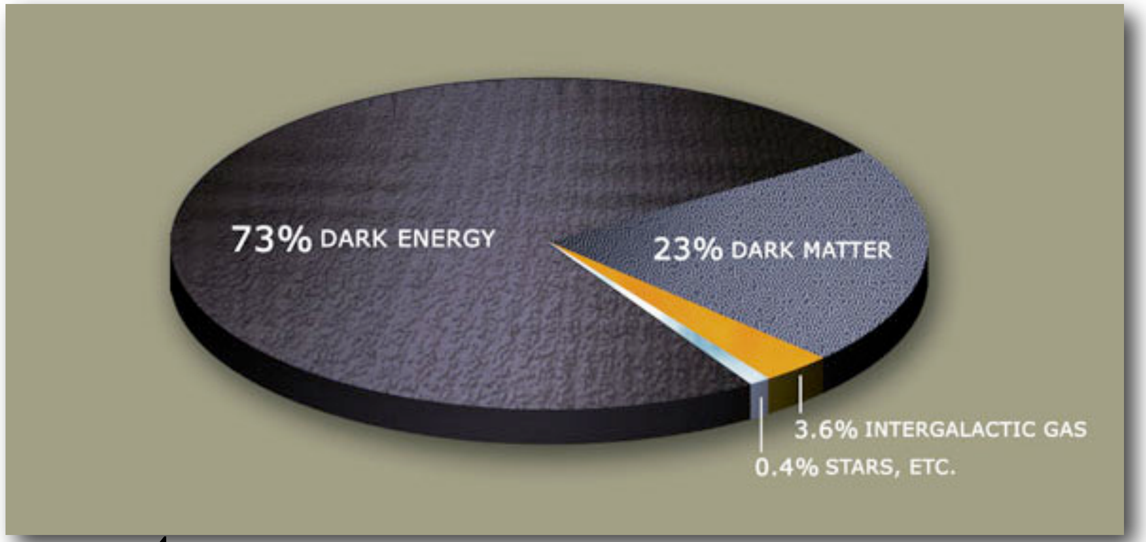


Theoretically interesting because it solves the hierarchy problem and provides unification of the forces at the GUT scale





SUSY can also provide a good DM candidate...which can manifest itself as MET at a hadron collider experiment



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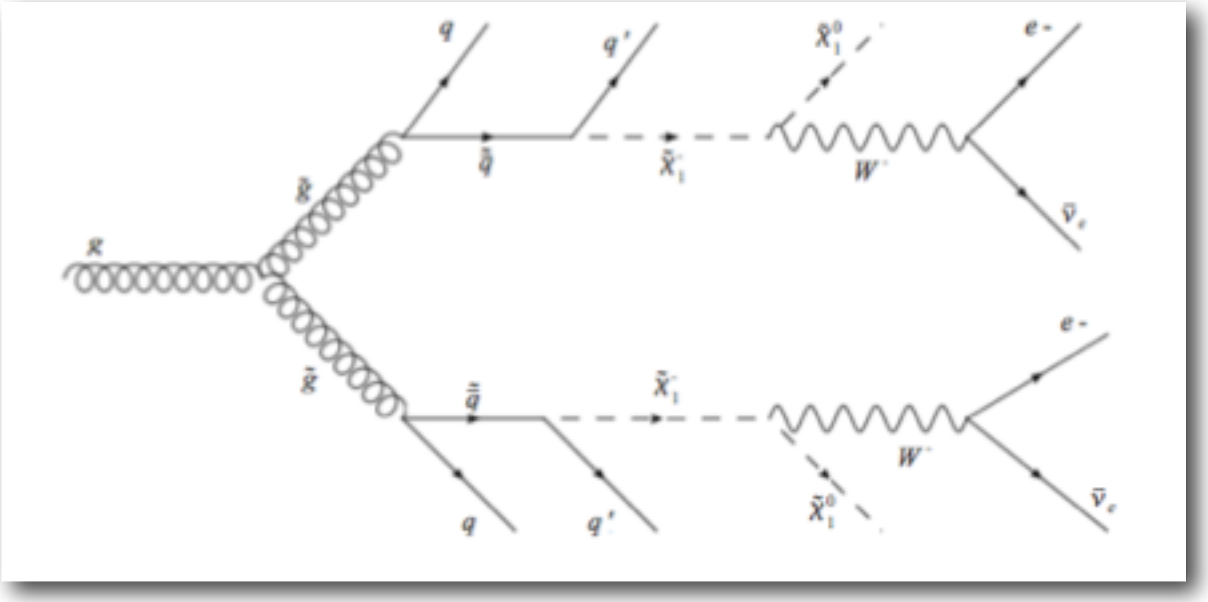
Same sign lepton pairs are rare in SM processes but are common in NP

In addition to the usual MET and jets of a 'standard' SUSY event, we request also the presence of isolated SSDL

Depending on LSP and chargino mass we would expect soft lepton p_T spectra.
Large values of tanß can produce τ in the final states



Example of SUSY cascade to jets, MET and 2 same sign electrons

This provides a clean analysis with minimal background however, the signal is also low so care must be taken with any events passing the selections

Search regions

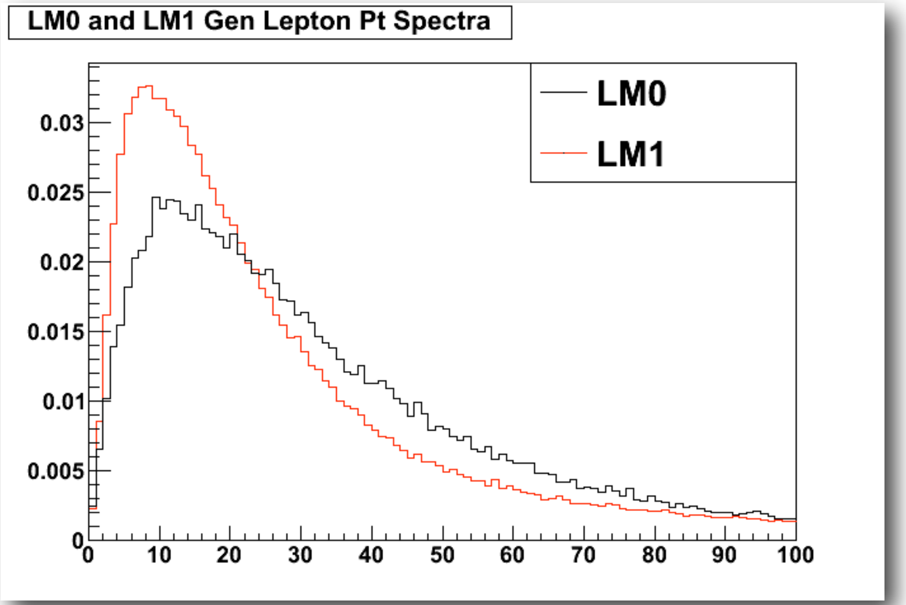
The analysis is performed in 2 separate regions to cover as much parameter space as possible

DEF: HT = Scalar sum of jet energy

Leptonic trigger region

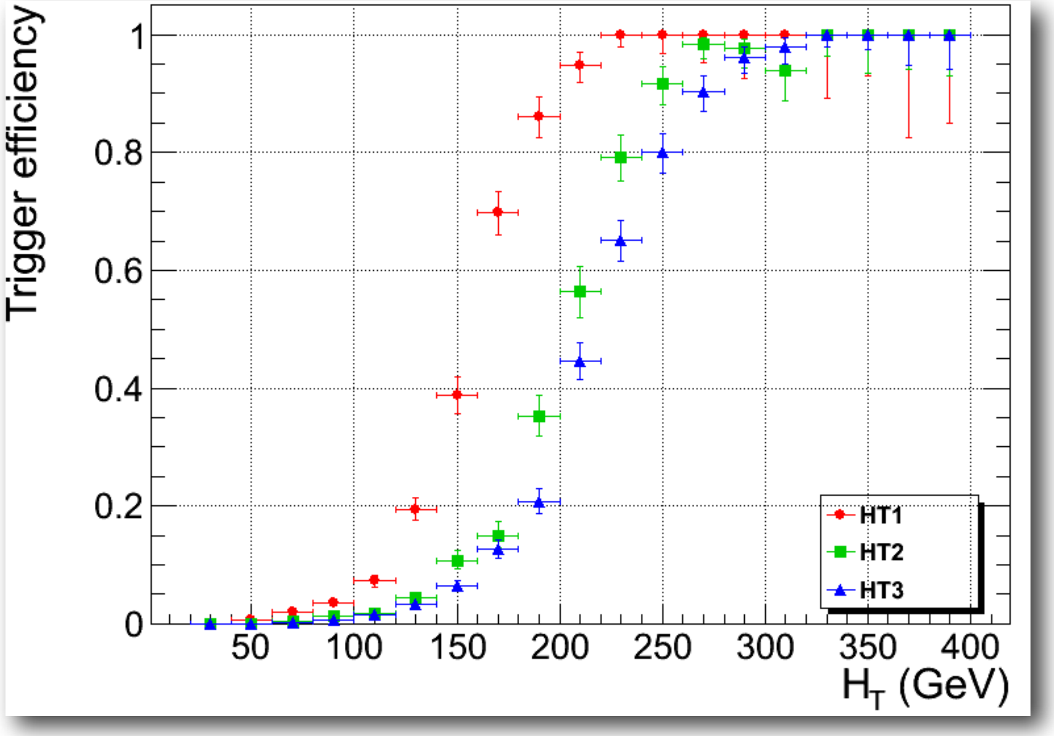
The choice of leptonic trigger allows for sensitivity to lower H_T regions of the parameter space

Events are selected with near 100% efficiency using single and double e/μ triggers



Hadronic trigger region

The hadronic trigger region allows access to low lepton P_T regions



H_T trigger vs H_T for 3 data taking periods. Measured with data taken with μ triggers.

Object selection

The object requirements are as follows in the leptonic trigger region and the H_T trigger (scalar sum of jet energy) region

Leptonic trigger:

Electrons and muons (isolated):

- P_T>20 GeV and second lepton with P_T>10 GeV

Jets / HT / MET (baseline):

- Require n_{jets} > 1
- H_T > 60 GeV
- MET > 30 GeV (for ee and μμ)
- MET > 20 GeV (for eμ)

(2 search regions):

- MET > 80 GeV
- HT > 200 GeV

H_T trigger:

Electrons and muons (isolated):

- μ P_T>5 GeV
- e P_T>10 GeV

Taus:

- P_T > 15 GeV

Jets / HT / MET:

- Require n_{jets} > 1
- H_T > 300 GeV (350 GeV in τ channels)
- MET > 30 GeV (50 GeV in τ channels)

(Detailed ID in backup)

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Background Estimations

SM processes leading to SSDL type final states are minimal and represent a contribution of a few % to the total background

Backgrounds are dominated by:

1. 1 lepton being faked - heavy flavour decay/e from γ conversion/decays in flight..
2. Double fake from QCD multijet

Background evaluation methods:

- Hadronic trigger: track fake-fake and prompt-fake events separately. Use *preselection*, *sidebands* and *BTag-and-probe* as control regions
- τ channels - *tight* - *loose* method
- Leptonic trigger: use *tight* - *loose* method (see backup)

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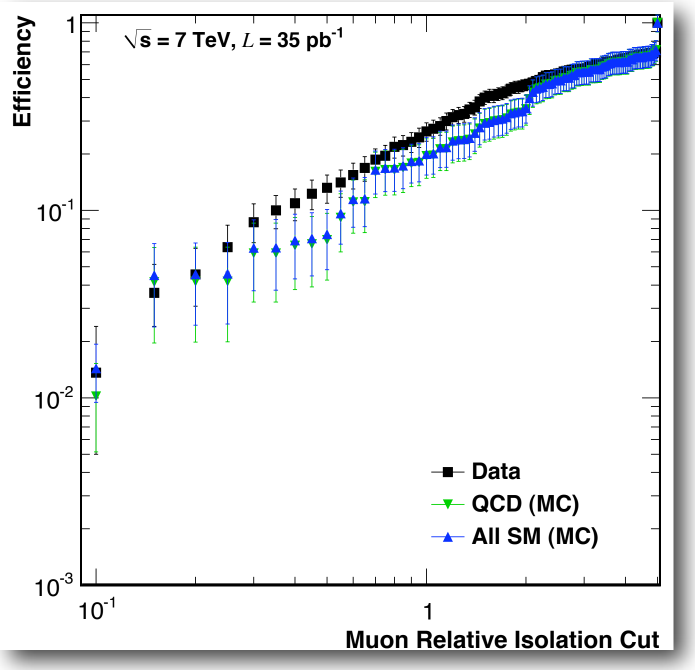
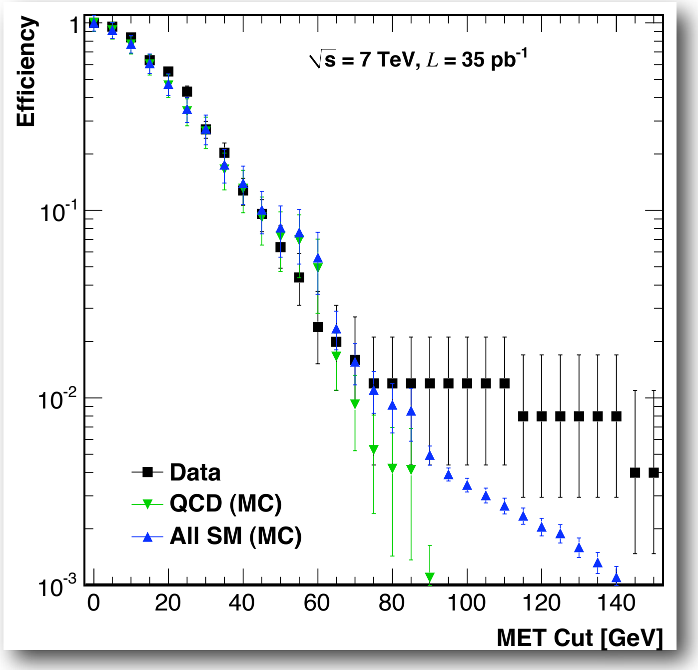
Hadronic trigger background evaluation

pre-selection: Apply all analysis cuts except MET and RelIso (mainly fake - fake (QCD))

$$n_{\mu\mu} = N_{\mu\mu}^{preselected} \times \varepsilon_{\mu}^{2} \times \varepsilon_{MET} = 0.08$$
$$n_{ee} = N_{ee}^{preselected} \times \varepsilon_{e}^{2} \times \varepsilon_{MET} = 0.02$$
$$n_{e\mu} = N_{e\mu}^{preselected} \times \varepsilon_{e}\varepsilon_{\mu} \times \varepsilon_{MET} = 0.08$$





Isolation and MET cut efficiencies for SSDL events in QCD multijet. Inclusion of all SM illustrates that the curve is unbiased to prompt lepton background

sideband: Apply all analysis cuts and require 1 non-iso lepton (mainly ttbar with non-iso lepton from b-jet)

BTag and Probe: 1 bjet and 1 lepton pointing away (dR > 1)
Use this to measure iso efficiency for leptons from b-jets

$$n_{\mu\mu} = (N_{\mu\mu}^{sideband} - N_{\mu\mu}^{presel} \times 2\varepsilon_{\mu}(1-\varepsilon_{\mu})\varepsilon_{MET}) \times \varepsilon_{\mu}^{(b)} = 0.20$$
$$n_{ee} = (N_{ee}^{sideband} - N_{ee}^{presel} \times 2\varepsilon_{e}(1-\varepsilon_{e})\varepsilon_{MET}) \times \varepsilon_{e}^{(b)} = 0.06$$
$$n_{e\mu} = (N_{e\mu}^{sideband} - N_{e\mu}^{presel} \times \varepsilon_{e}(1-\varepsilon_{\mu})\varepsilon_{MET}) \times \varepsilon_{\mu}^{(b)} = 0.11$$
$$n_{\mu e} = (N_{\mu e}^{sideband} - N_{\mu e}^{presel} \times \varepsilon_{\mu}(1-\varepsilon_{e})\varepsilon_{MET}) \times \varepsilon_{e}^{(b)} = 0.16$$

Total prompt - fake and fake - fake (signal region): 0.70±0.30

τ channels

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In the context of the hadronic trigger search we can also include τ + lepton channels in the analysis

Background evaluation - use same method as leptonic trigger analysis

1 good lepton + 1 fake

$B(i,j)=\Sigma_i(T_j,L!T_i) \times FR_i + \Sigma_j(T_i,L!T_j) \times FR_j$

$+ \Sigma_{i,j} (L!T_i,L!T_j) \times FR_i \times FR_j$ 2 fake leptons

$+ \Sigma OS(T_i,T_j) \times MC_i \times MC_j$ 2 good leptons with charge misidentification

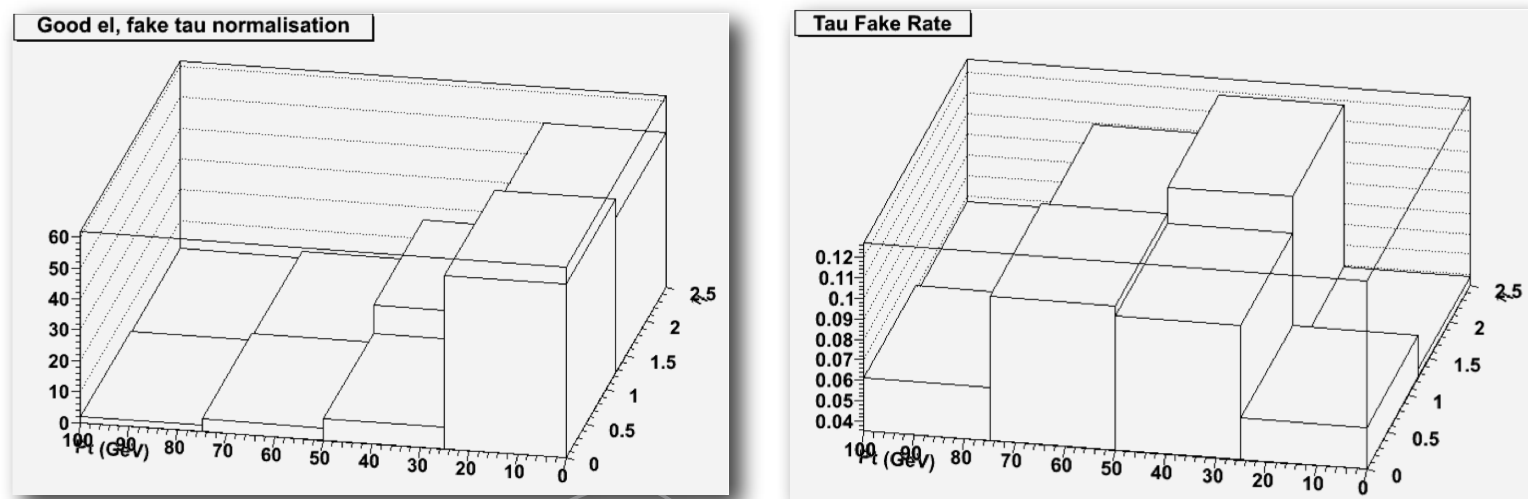
$\mathrm{Eff}(\eta,p_T)=T(\eta,p_T)/L(\eta,p_T)$
$FR(\eta,p_T)=\mathrm{Eff}/(1-\mathrm{Eff})$

We change the definition of loose from isolation, to TauID discriminators

Approximations	ττ	eτ	μτ
Term 1	✗	consider only fake τ	Consider only fake τ
Term 2	✓	✗	✗
Term 3	✗	✗	✗

Testing the method

Test the background evaluation method by relaxing the H_T and MET cuts



Example in eτ channel of the normalisation and fake rate (loosened HT > 50 and no MET cut for both).

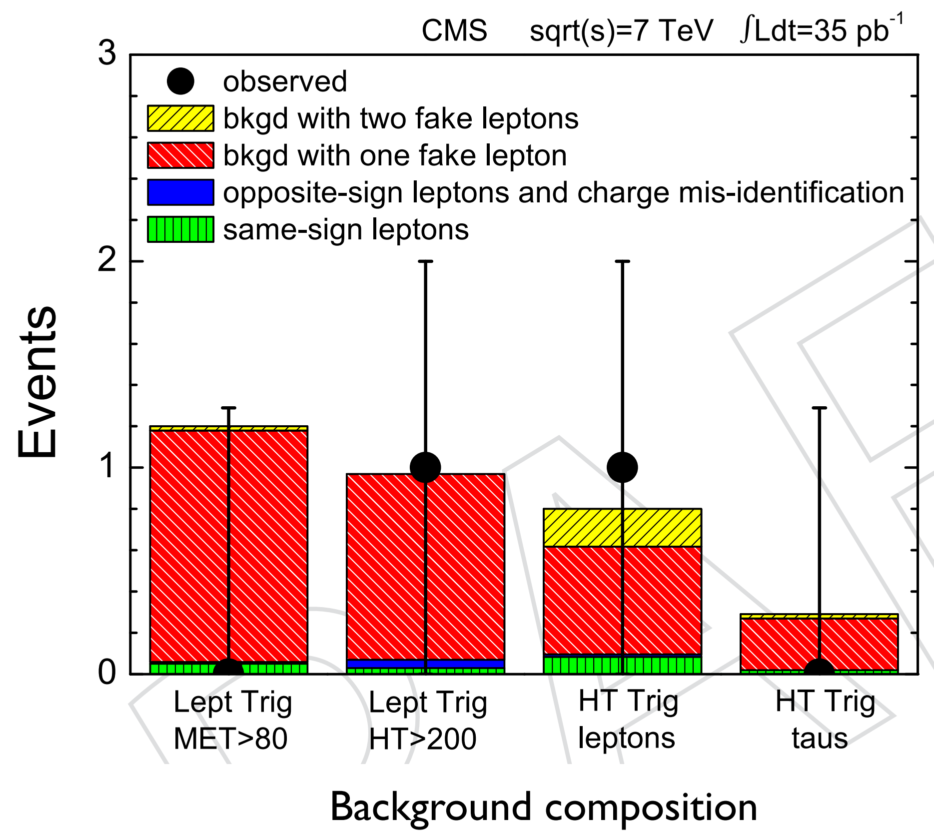
	Simulation Only SM BKG		Data Relaxed selection	
Channel	Observed	Predicted	Observed	Predicted
$\tau\tau$	0.08±0.03	0.15±0.15	14	14.0±4.3±2.6
$e\tau$	0.35±0.12	0.30±0.11	1	0.8±0.4±0.1
$\mu\tau$	0.47±0.15	0.49±0.20	2	2.9±0.6 ±0.4

An extra 10% is added in quadrature to eτ and μτ to account for the approximation used

The systematic error is evaluated by considering the prediction obtained when using HT > 150 GeV (with respect to HT > 300 GeV) for the fake rate

Results

Search Region	ee	$\mu\mu$	$e\mu$	total	95% C.L. UL Yield
Lepton Trigger					
$\not\!\!E_T > 80$ GeV					
MC	0.05	0.07	0.23	0.35	(7.3 for LM0)
BG predicted	**0.23 ± 0.35**	**0.23 ± 0.26**	**0.74 ± 0.55**	**1.2 ± 0.8**	
observed	**0**	**0**	**0**	**0**	**3.1**
$H_T > 200$ GeV					
MC	0.04	0.10	0.17	0.32	(9.6 for LM0)
BG predicted	**0.71 ± 0.58**	**0.01 ± 0.24**	**0.25 ± 0.27**	**0.97 ± 0.74**	
observed	**0**	**0**	**1**	**1**	**4.4**
H_T Trigger					
Low-p_T					
MC	0.05	0.16	0.21	0.41	(9.1 for LM0)
BG predicted	**0.10 ± 0.07**	**0.30 ± 0.13**	**0.40 ± 0.18**	**0.80 ± 0.31**	
observed	**1**	**0**	**0**	**1**	**4.5**
	$e\tau$	$\mu\tau$	$\tau\tau$	total	95% C.L. UL Yield
τ enriched					
MC	0.36	0.47	0.08	0.91	(2.0 for LM0)
BG predicted	**0.10 ± 0.10**	**0.17 ± 0.14**	**0.02 ± 0.01**	**0.29 ± 0.17**	
observed	**0**	**0**	**0**	**0**	**3.4**



BG predicted are results of the prediction methods previously discussed.
The MC prediction is also shown.
No evidence for excess over background is observed and 95% CL are set.

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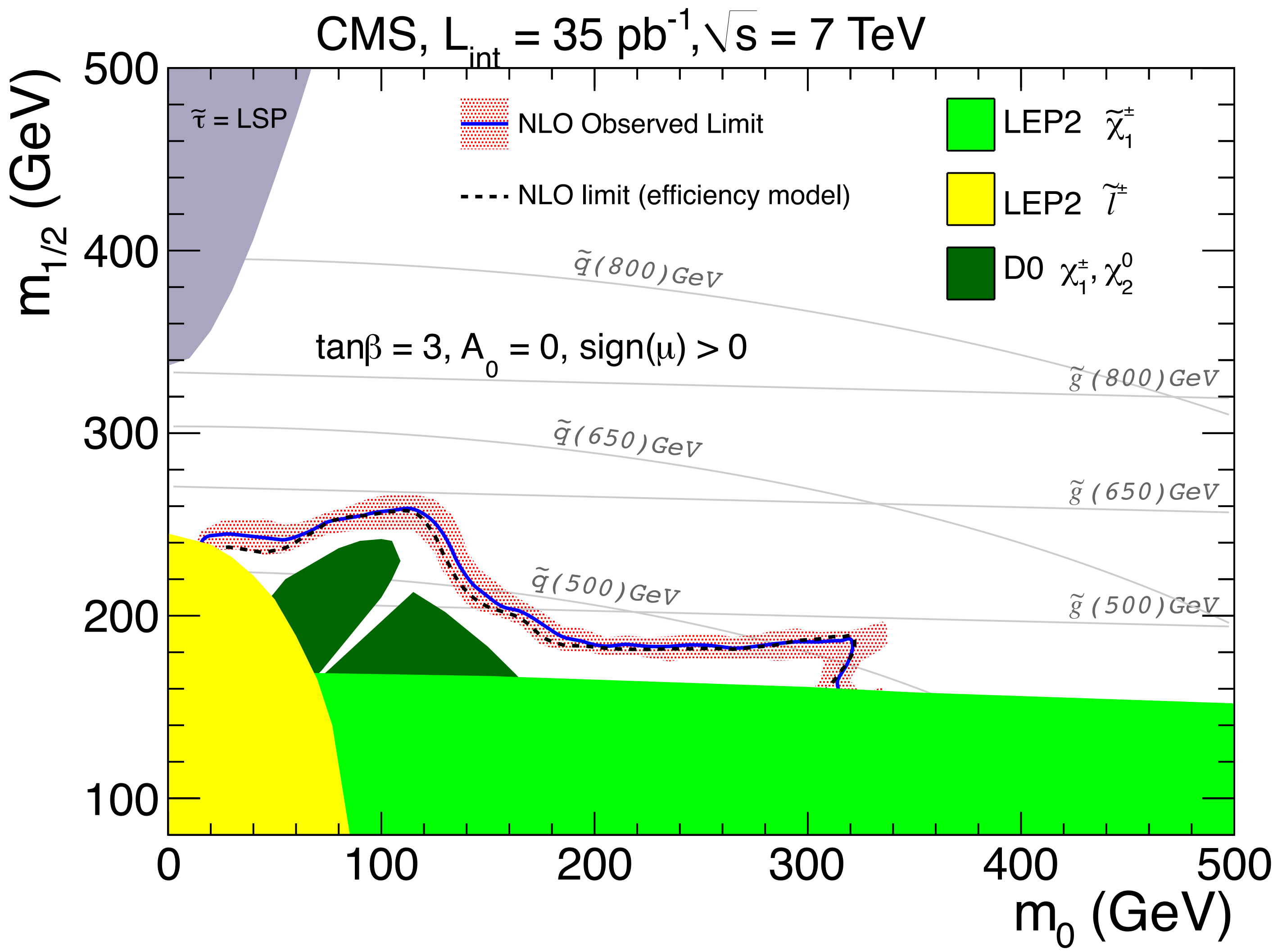
Summary and 2011 prospects

2010:

- $35pb^{-1}$ @ 7TeV of LHC data collected with CMS - SSDL analysis with 2 trigger strategies across 6 channels
- SUSY analysis done with full 2010 dataset ($35pb^{-1}$)
- No excess found
- 95% CL upper limit



Exclusion in the m_0 - $m_{1/2}$ plane. Width of red band shows theoretical uncertainty. The effects of using a simple efficiency model are show in blue.

For 2011:

- Update trigger strategy for new $10^{32\text{-}33}$ regime
- Present a new exclusion (or better..) by the summer conferences

BACKUP

Object selection

The object requirements are as follows in the leptonic trigger region and the H_T trigger region

Leptonic trigger:

Electrons and muons:

- P_T>20 GeV and second lepton with P_T>10 GeV
- RelIso < 0.1 for P_T > 20 GeV
- IsoSum < 2 GeV for P_T < 20 GeV

Jets / HT / MET (baseline):

- Require n_{jets} > 1
- H_T > 60 GeV
- MET > 30 GeV (for ee and μμ)
- MET > 20 GeV (for eμ)

(2 search regions):

- MET > 80 GeV
- HT > 200 GeV

H_T trigger:

Electrons and muons:

- μ P_T>5 GeV
- e P_T>10 GeV
- RelIso < 0.15

Taus:

- P_T > 15 GeV
- PF τ with shrinking cone

Jets / HT / MET:

- Require n_{jets} > 1
- H_T > 300 GeV (350 GeV in τ channels)
- MET > 30 GeV (50 GeV in τ channels)

(Detailed ID in backup)

Lepton IDs

- VBTF_ID 80:
  - $\sigma i \eta i \eta < 0.01$ in the barrel and < 0.03 in the endcap.
  - $d\phi_{in} < 0.06$ in the barrel and < 0.03 in the endcap.
  - $d\eta_{in} < 0.004$ in the barrel and < 0.007 in the endcap.
- $|d0_{corrected}| < 0.02$ (taken with respect to the beamspot).
- Hit pattern and conversion rejections:
  - Number of missing hits in the inner tracker layers = 0.
  - $dcot < 0.02$ and $dist < 0.02$ of clostest approach to conversion partner.
- Charge consistency requirement: CTF, GSF and SuperCluster charges must all be equal.
- $RelIsolation_{dR<0.3} < 0.15$, where $RelIsolation$ is defined as: $RelIsolation_{dR<0.3} = (trackIso + ecalIso + hcalIso) / p_T$ in the endcaps ($|\eta| > 1.56$) and as: $RelIsolation_{dR<0.3} = (trackIso + max(0., ecalIso - 1) + hcalIso) / p_T$ in the barrel ($|\eta| < 1.44$).

- Tau identification and selection: shrinking cone PF taus are considered with the following discriminators:
  - *leadingTrackFinding*
  - *leadingPionCut*
  - *byIsolationUsingLeadingPion*
  - *againstMuon*
  - *againstElectron*
  - signalChHadrons=1 or signalChHadrons=3
  - TauIdByTaNCfrHalfPercent

- Muon identification and selection: both tracker and global muons are considered.
  - Global track $\chi^2 / n.d.f < 10$.
  - Number of valid tracker hits > 10.
  - $|d0_{corrected}| < 0.02$ (taken with repsect to the beamspot).
  - Valid stand-alone hits > 0.
  - $RelIsolation_{dR<0.3} < 0.15$

Leptonic trigger background evaluation - Tight Loose method

In theory:

1 good lepton + 1 fake

$$B(i,j)=\Sigma_i(T_j,L!T_i) \times FR_i + \Sigma_j(T_i,L!T_j) \times FR_j$$

$$+ \Sigma_{i,j}(L!T_i,L!T_j) \times FR_i \times FR_j$$

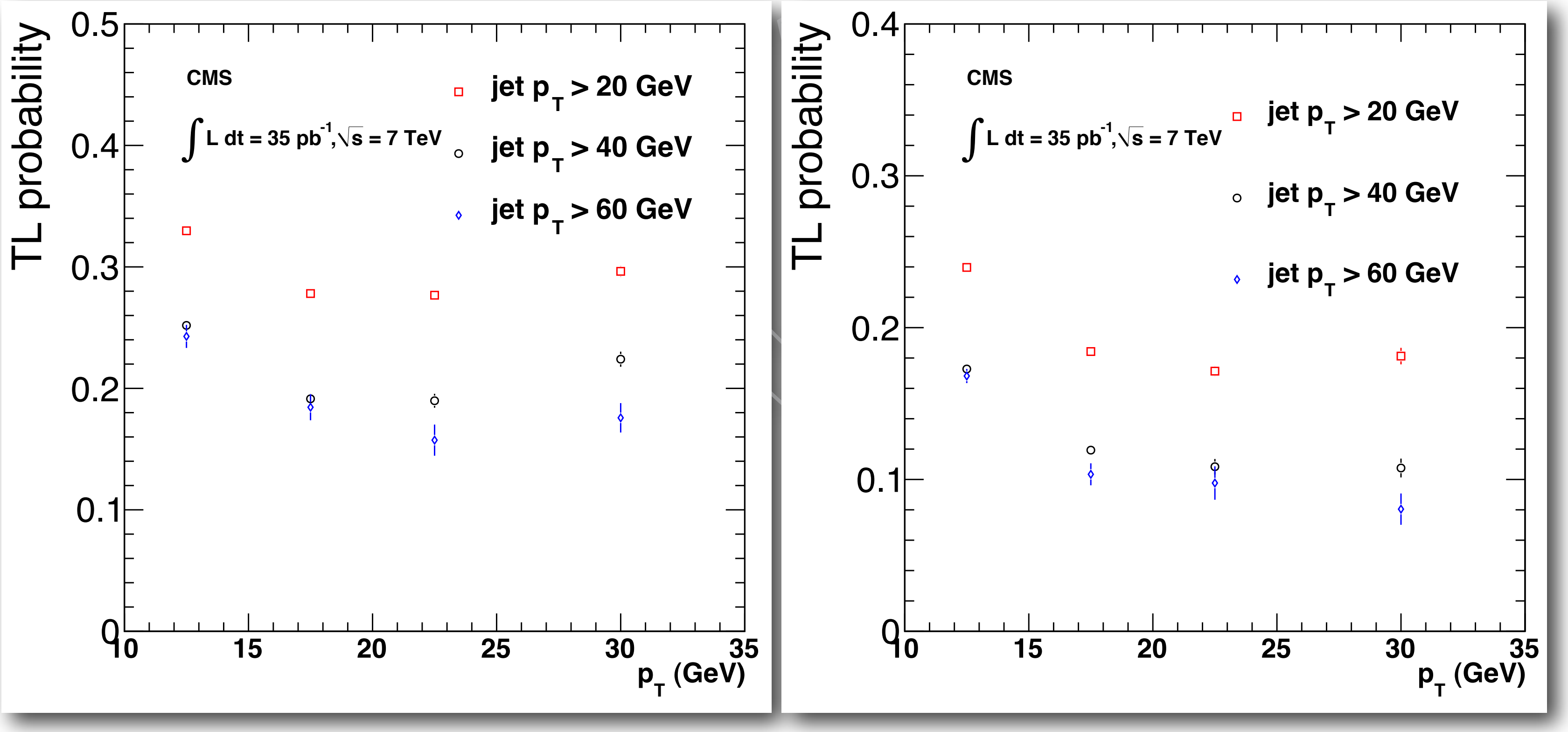
2 fake leptons

$$+ \Sigma OS(T_i,T_j) \times MC_i \times MC_j$$

2 good leptons with charge misidentification

$$Eff(\eta,p_T)=T(\eta,p_T)/L(\eta,p_T)$$
$$FR(\eta,p_T)=Eff/(1-Eff)$$

For the leptonic trigger analysis, we take loose to require less iso (RelIso < 0.4)



e (left) and μ (right) tight/loose probability from QCD multijet with different jet requirements

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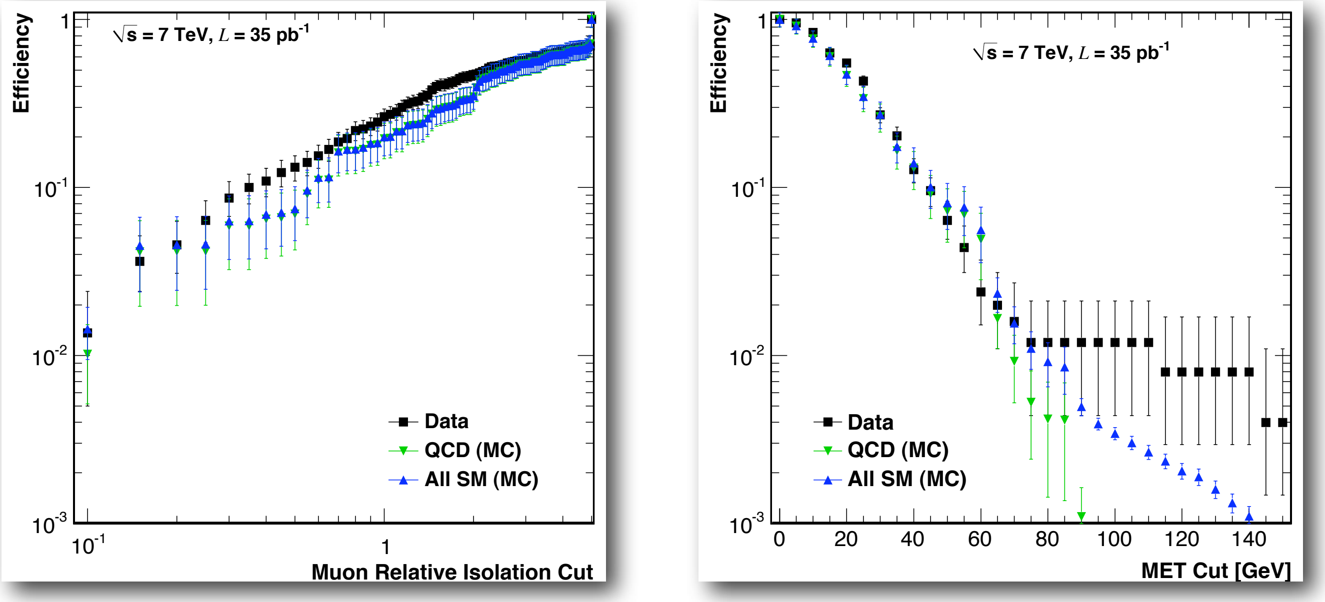
Hadronic trigger background evaluation

pre-selection: Apply all analysis cuts except MET and RelIso (mainly fake - fake (QCD))

$N_{\mu\mu}^{preselected} = 223$
$N_{ee}^{preselected} = 6$
$N_{e\mu}^{preselected} = 78$

$$n_{\mu\mu} = N_{\mu\mu}^{preselected} \times \varepsilon_\mu^2 \times \varepsilon_{MET} = 0.08$$
$$n_{ee} = N_{ee}^{preselected} \times \varepsilon_e^2 \times \varepsilon_{MET} = 0.02$$
$$n_{e\mu} = N_{e\mu}^{preselected} \times \varepsilon_e\varepsilon_\mu \times \varepsilon_{MET} = 0.08$$



Isolation and MET cut efficiencies for SSDL events in QCD multijet. Inclusion of all SM illustrates that the curve is unbiased to prompt lepton background

sideband: Apply all analysis cuts and require 1 non-iso lepton (mainly ttbar with non-iso lepton from b-jet)

$N_{\mu\mu}^{sideband} = 11$
$N_{ee}^{sideband} = 2$
$N_{e\mu}^{sideband} = 6$
$N_{\mu e}^{sideband} = 5$

BTag and Probe: 1 bjet and 1 lepton pointing away (dR > 1)
Use this to measure iso efficiency for leptons from b-jets

$$n_{\mu\mu} = (N_{\mu\mu}^{sideband} - N_{\mu\mu}^{presel} \times 2\varepsilon_\mu(1-\varepsilon_\mu)\varepsilon_{MET}) \times \varepsilon_\mu^{(b)} = 0.20$$
$$n_{ee} = (N_{ee}^{sideband} - N_{ee}^{presel} \times 2\varepsilon_e(1-\varepsilon_e)\varepsilon_{MET}) \times \varepsilon_e^{(b)} = 0.06$$
$$n_{e\mu} = (N_{e\mu}^{sideband} - N_{e\mu}^{presel} \times \varepsilon_e(1-\varepsilon_\mu)\varepsilon_{MET}) \times \varepsilon_\mu^{(b)} = 0.11$$
$$n_{\mu e} = (N_{\mu e}^{sideband} - N_{\mu e}^{presel} \times \varepsilon_\mu(1-\varepsilon_e)\varepsilon_{MET}) \times \varepsilon_e^{(b)} = 0.16$$

Total prompt - fake and fake - fake (signal region): 0.70±0.30

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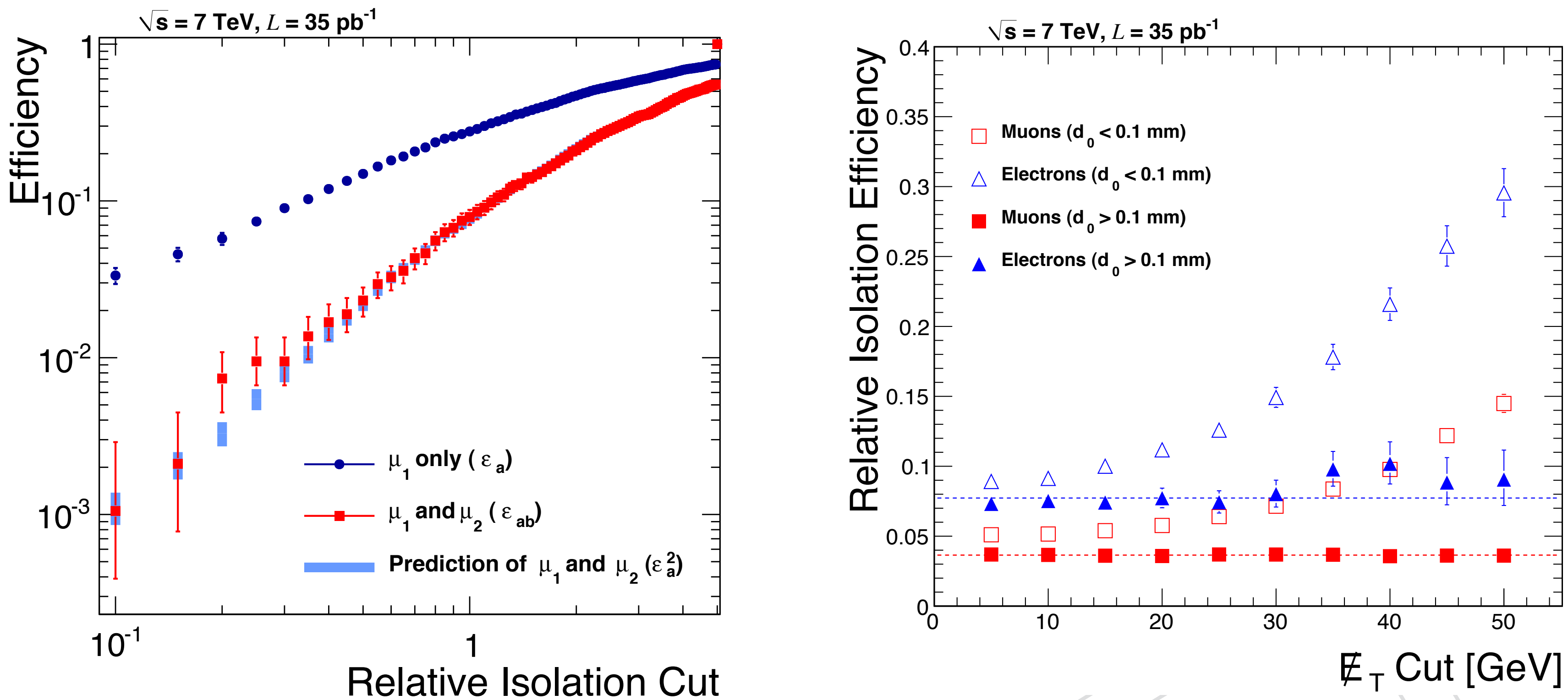


Figure 4: (Left) Demonstration that the lepton isolation efficiencies on the two leptons are independent of each other, and thus factorize. Only the di-muon sample is shown here. (Right) Demonstration that the RelIso efficiency is independent of $\not{E}_T$ once leptons from W decays are vetoed via the track impact parameter requirement. For more details, see text.

Extra figures

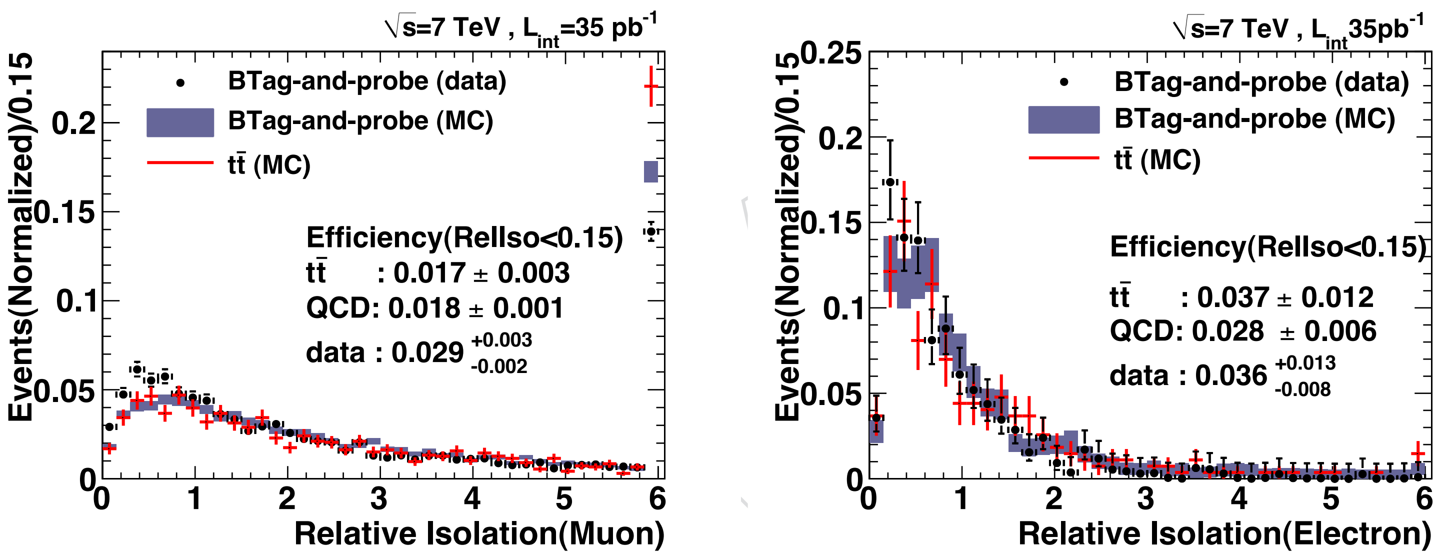


Figure 5: Isolation variable distributions obtained with the BTag-and-probe method for muons (left) and electrons (right). Efficiencies for the RelIso $>$ 0.15 (first bin in the distributions shown) are explicitly quoted.

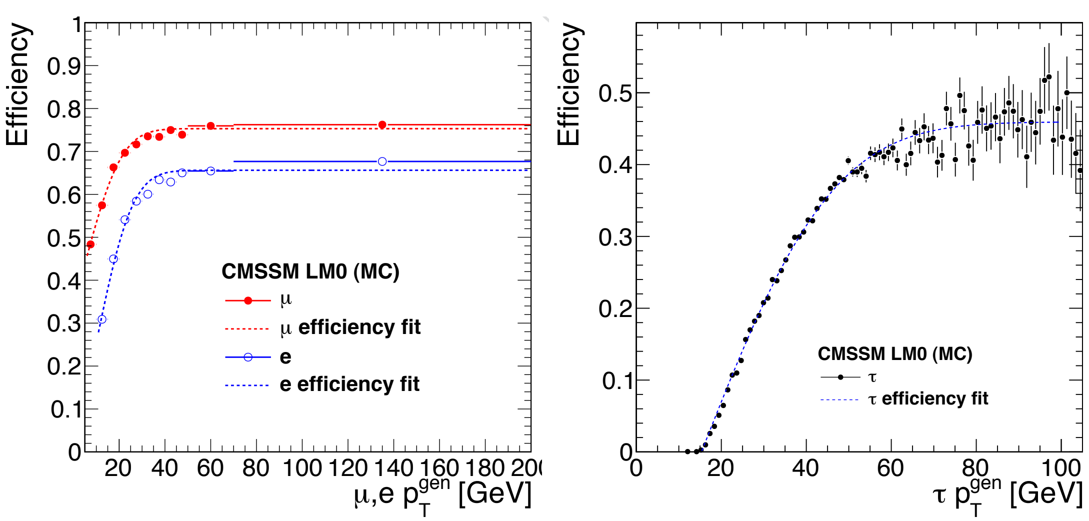


Figure 8: Electron, muon (left) and τ selection efficiencies as a function of P_T.

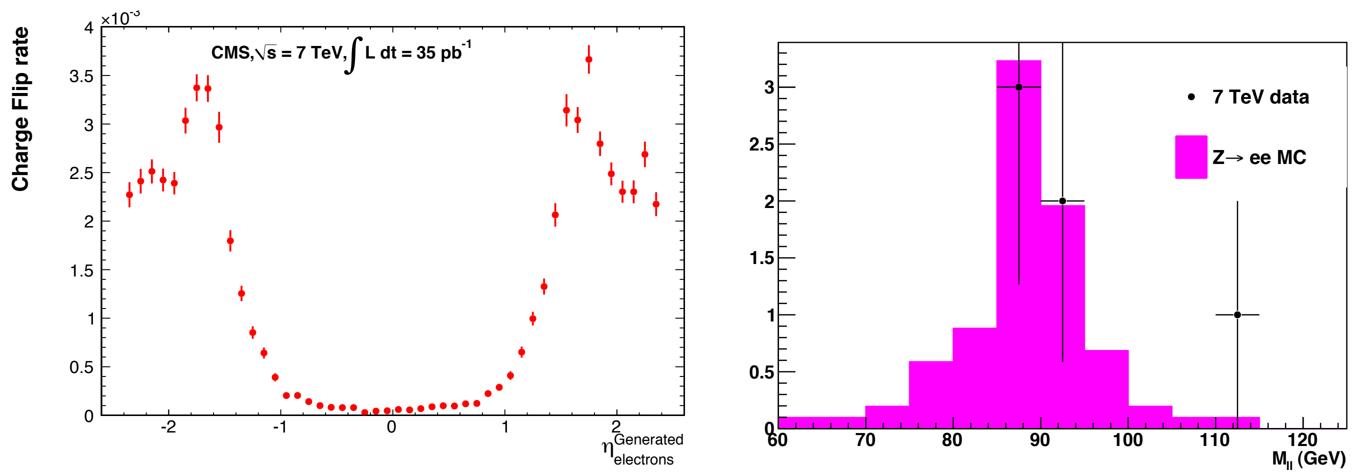
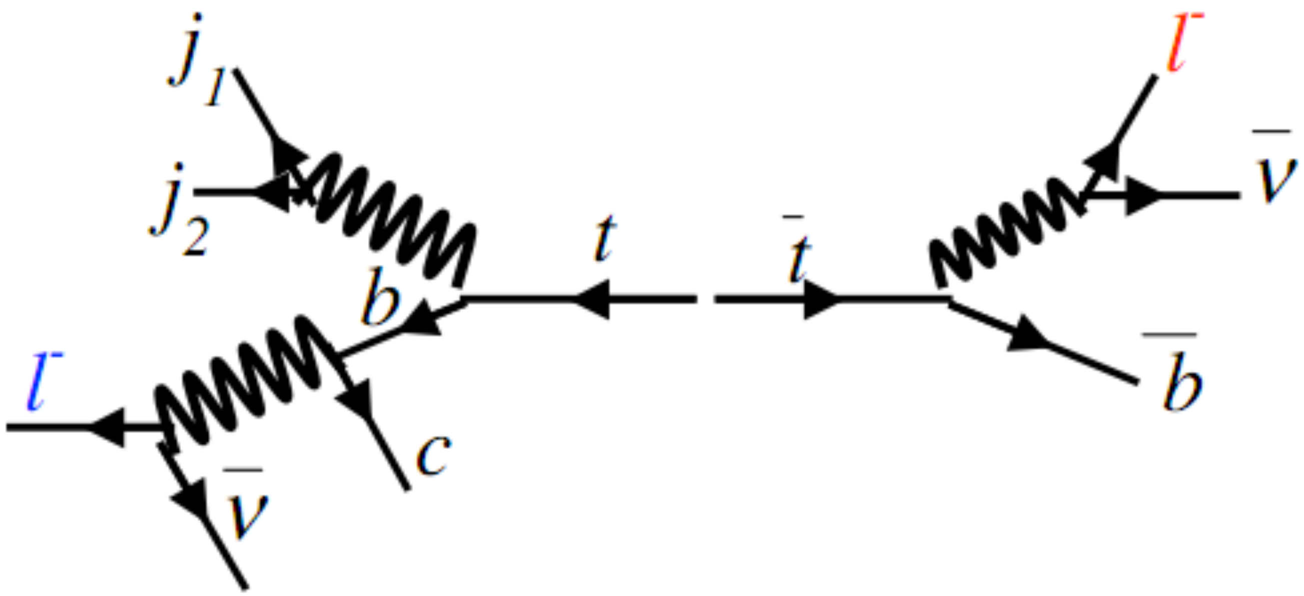


Figure 6: (Left) The probability to mismeasure the electron charge as a function of η in the P_T range 10$-$100 GeV, as obtained from Monte Carlo simulation. (Right) Same-sign ee invariant mass distribution in data compared with $Z \rightarrow ee$ Monte Carlo expectations.

Dominant ttbar background



Others:
Electron charge flip
WZ/ZZ/Wgamma… from MC
= ~10% of total background for leptonic channels

Groups and status

Multiple groups have contributed to this analysis:

Lepton triggered AN 2010/247,257

D. Barge, C. Campagnari, P. Kalavase, D. Kovalskyi, V. Krutelyov, J. Ribnik
University of California, Santa Barbara
W. Andrews, D. Evans, F. Golf, J. Mülmenstädt, S. Padhi, Y. Tu, F. Würthwein, A. Yagil, J. Yoo
University of California, San Diego
L. Bauerdick, I. Bloch, K. Burkett, I. Fisk, Y. Gao, O. Gutsche, B. Hooberman
Fermi National Accelerator Laboratory, Batavia, Illinois

H_T triggered ee, μμ, eμ. AN 2010/372,378,379

P. Avery, M. Chen, D. Dobur, A. Drozdetskiy, Yu Fu, I. Furic, B. Kim, A. Korytov, K. Matchev, G. Mitselmakher, L. Muniz, Y. Pakhotin, R. Remington, N. Skhirtladze, D. Wang, J. Yelton
University of Florida, Gainesville, Florida, U.S.A.

Independent cross check of ee, μμ, eμ. AN 2010/375

Hamed Bakhshian[1], Alicia Calderon[2], Gigi Cappello[3], Massimiliano Chiorboli[3], Javier Cuevas[4], Guenther Dissertori[5], Ali Fahim[1], Javier Fernandez[4], Lara LLoret[4], Patricia Lobelle[2], Jesus Marco[2], Pablo Martinez[2], Predrag Milenovic[5], Filip Moortgat[5], Pascal Nef[5], Luc Pape[5], Teresa Rodrigo[2], Frederic Ronga[5], Leonardo Sala[5], Benjamin Stieger[5], Konstantinos Theofilatos[5], Daniel Treille[5], Alessia Tricomi[3], Rocio Vilar[2], and Matthias Weber[5]

[1] IPM, Tehran, Iran
[2] Santander, IFCA, CSIC-Universidad de Cantabria, Spain
[3] Catania, INFN Sezione di Catania, Italy
[4] Oviedo, Universidad de Oviedo, Spain
[5] ETH Zurich, Zurich, Switzerland

H_T triggered hadronic τ. AN 2010/168,300

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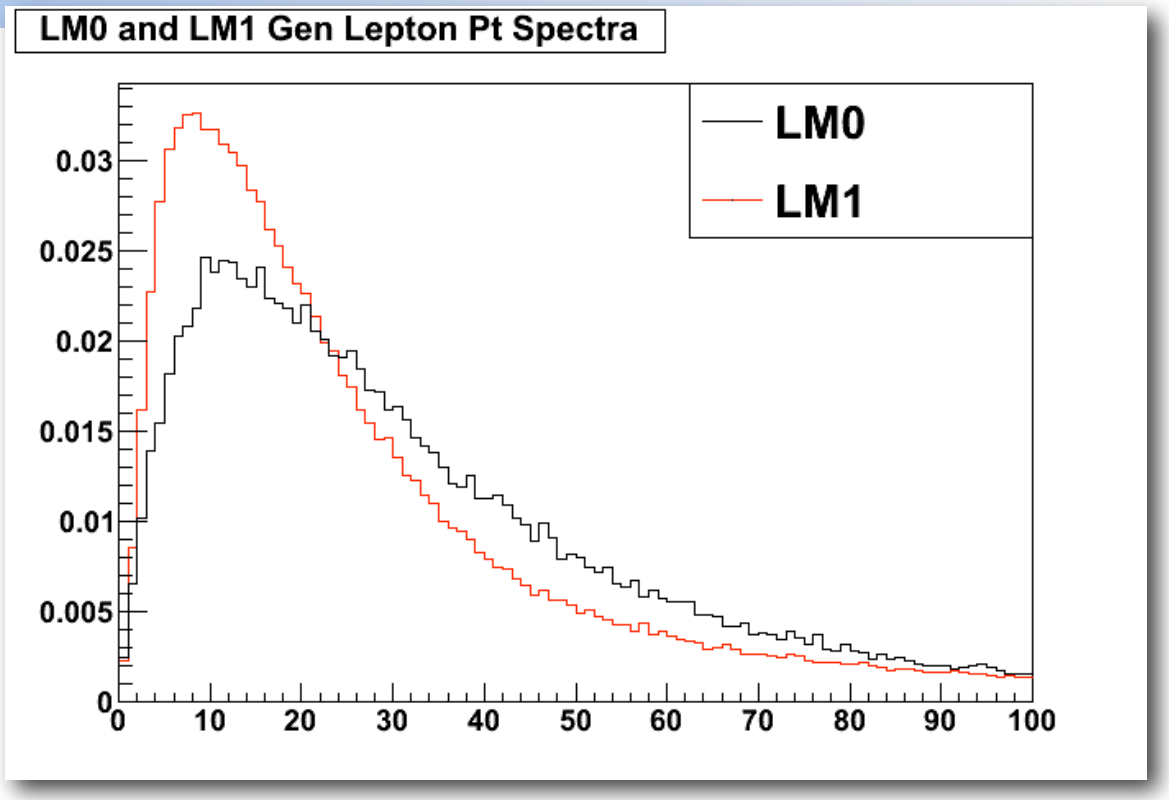
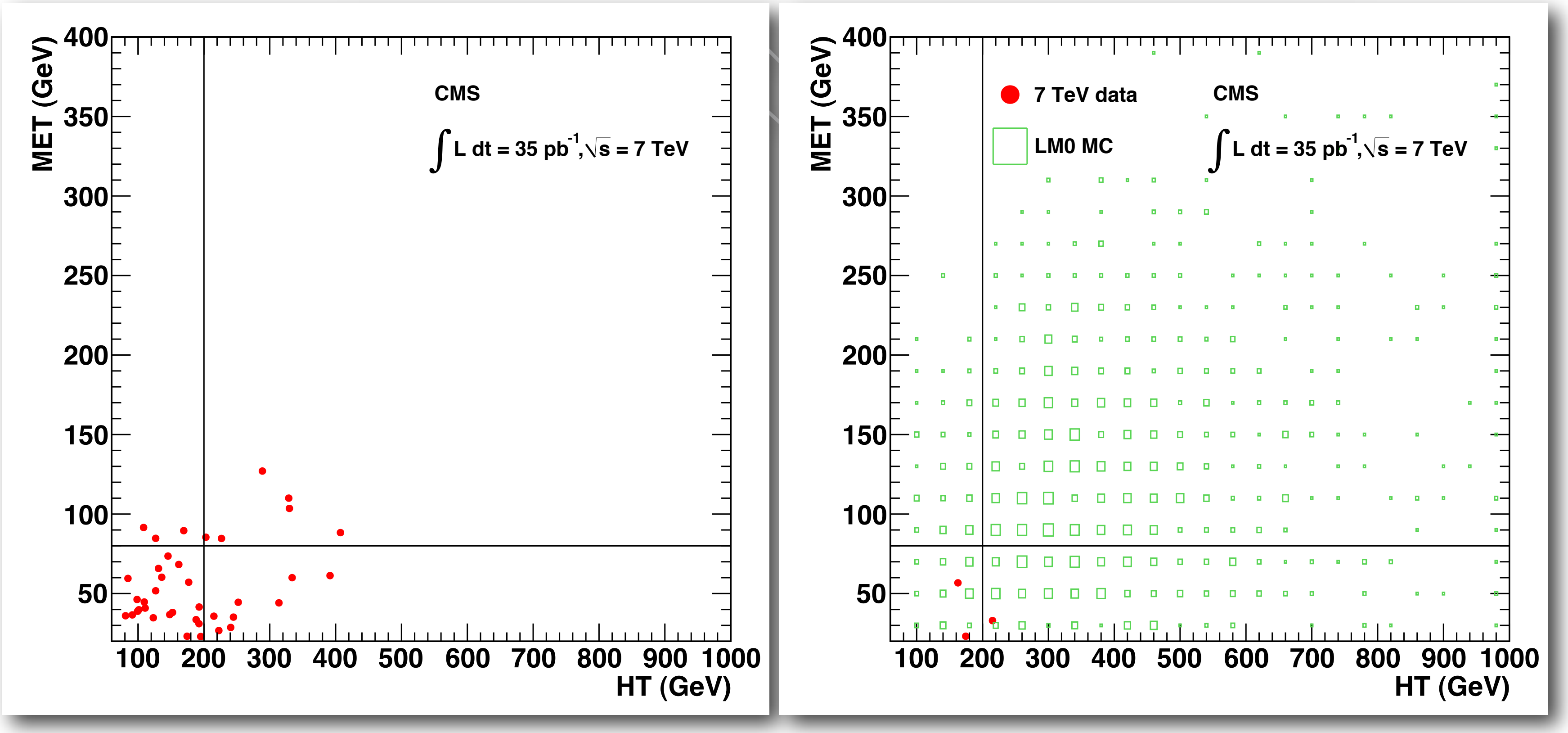
[2] Universidad De Los Andes, Bogota, Colombia
[3] INFN e Dipartimento di Fisica, Perugia, Italy
[4] University of Wisconsin, Madison, United States

Combined in PAS SUS-10-004 and approved.

Search regions





MET vs H_T - Baseline selection. Left: background in data where one lepton is required to be isolated. Right: 3 observed events with LM0 distribution