v5

Search for Physics Beyond the Standard Model in Opposite-Sign Dilepton Events at CMS

Ben Hooberman, on behalf of the RA6 Team

Contents

Documentation

- CMS PAPER SUS-10-007: “Search for Physics Beyond the Standard Model in Opposite-Sign Dilepton Events at CMS”
  - ARC: Boaz Klima (chair), Colin Jessop, Luca Lista, Ritchie J. Patterson
- The paper contains 2 search approaches:
  - AN-2010/370: based on high p_T lepton triggers
  - AN-2010/373: based on H_T triggers
- NOTE:
  - Plots/tables in paper are marked: **PAPER**
  - Plots/tables seeking approval for supplementary material marked: **TWIKI**

CMS PAPER SUS-10-007

DRAFT
CMS Paper

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Search for Physics Beyond the Standard Model in Opposite-Sign Dilepton Events at CMS

The CMS Collaboration

DRAFT

Abstract

We present results of a search for physics beyond the Standard Model (SM) in final states with opposite-sign dileptons (e^+e^-, $e^\pm\mu^\mp$, $\mu^+\mu^-$) accompanied by hadronic jets and missing transverse energy. The search utilizes a 34 pb^{-1} data sample of 7 TeV proton-proton collisions collected by the CMS detector at the Large Hadron Collider in 2010. The search is based on a high P_T lepton trigger sample and an independent sample based on large hadronic activity triggers. Backgrounds are estimated using data-driven techniques and compared with SM Monte Carlo simulation. We find good agreement in the shapes of various relevant kinematic distributions between data and SM Monte Carlo. We find no evidence for anomalous event yield beyond SM expectations. An upper limit of 4.1 events at 95% confidence level is set on the non-SM contribution to our chosen signal region. We interpret the limit in the context of the CMSSM parameter space and find that the region excluded by our results exceeds those previously excluded by the Tevatron and LEP experiments. We also provide information to test whether specific models of physics beyond the SM are excluded by our results.

Analysis Notes

AN-2010/370

Available on CMS information server — CMS AN -2010/370

The Compact Muon Solenoid Experiment

Analysis Note

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15 November 2010 (v5, 21 January 2011)

Search for new physics in the opposite sign dilepton sample

D. Barge, C. Campagnari, P. Kalavase, D. Kovalskyi, V. Krutelyov, J. Ribnik

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W. Andrews, D. Evans, F. Golf, J. Mülmenstädt, S. Padhi, Y. Tu, F. Würthwein, A. Yagil, J. Yoo

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L. Bauerdick, I. Bloch, K. Burkett, I. Fisk, Y. Gao, O. Gutsche, B. Hooberman

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Abstract

We present the result of a search for new physics in the opposite-sign dilepton + jets + missing energy final state based on 34 pb^{-1} of 2010 CMS data. We find no evidence for an anomalous rate of events accompanied by large missing transverse energy and significant hadronic activity.

lepton trigger search

AN-2010/373

Available on CMS information server — CMS AN -2010/373

The Compact Muon Solenoid Experiment

Analysis Note

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16 November 2010 (v3, 14 January 2011)

Opposite sign di-lepton SUSY search at $\sqrt{s} = 7$ TeV

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Abstract

We present a search for Supersymmetry in opposite sign di-lepton final states using the data from 2010 proton-proton-running of the Large Hadron Collider. The final state signature consists of leptons, several hard jets and missing transverse energy. Since we observe good agreement of data to simulation and our background prediction methods, we conclude that there is no sign of flavour correlated di-lepton production accompanied by high jet activity and large missing transverse energy in the dataset of 34 pb^{-1}. We report an upper limit on the flavour correlated production of a new physics model within acceptance of our event selection.

H_T trigger search

Motivation

- Searches in multiple channels crucial for discovery/probing of SUSY
  - All-hadronic
  - Single lepton
  - Dilepton
    - Same-sign (SS)
    - **Opposite-sign (OS): focus of this analysis**
  - Multi-lepton

Signature with OS Dileptons

most NP scenarios with high xsec produced strongly, so leptons are produced in decays of heavy, colored objects → significant jet activity

LSP produced at end of decay chain escapes detection → significant missing E_T

signature: OS dileptons + jets + met

signature similar to tt → dilepton, but tends to have more hadronic activity and missing ET

Search Strategy

- Perform 2 complementary search approaches
  - Lepton trigger search: high p_T single/double lepton triggers
  - H_T trigger search: H_T triggers, extend sensitivity to lower p_T leptons
- For each search:
  - Define pre-selection to select pure tt → dilepton sample
  - Compare data/MC, validate data-driven methods in this background-dominated regime
  - Define signal region by adding requirements of large H_T, MET to pre-selection
  - Compare signal yields to MC predictions and data-driven background estimates:
    - Lepton trigger search: ABCD and p_T(ll) Template Methods
    - H_T trigger search: opposite-flavor (OF) subtraction

Contents

- Introduction and Overview
- **Lepton Trigger Search**
- H_T Trigger Search
- cMSSM Exclusion
- Conclusions

Pre-Selection

- Use selection from tt→dilepton x-sec measurement (Phys Lett B 695 (2011) 424–443) as baseline (colored text indicates changes w.r.t. this selection)
  - Require at least 1 single lepton or dilepton trigger
  - 2 OS leptons, well-identified and isolated, p_T > (20,10) GeV
    - Veto ee/μμ pairs in Z mass window

decreased 2nd lepton p_T cut due to possibility of soft leptons in SUSY

  - ≥ 2 JPT jets p_T > 30 GeV, $|\eta| < 2.5$
  - tcmet > 50 GeV, H_T (scalar sum selected jet p_T's) > 100 GeV
    - Tightened w.r.t. tt→dilepton selection (significant reduction in other backgrounds, eg. DY)
  - Minor changes to tt→dilepton selection:
    - $Z\rightarrow\mu\mu\gamma$ veto, muon $\sigma(p_T)/p_T < 0.1$, muon $|\eta| < 2.4$

Full selection and samples available in backup (slides 39-46)

Yields Passing Pre-Selection

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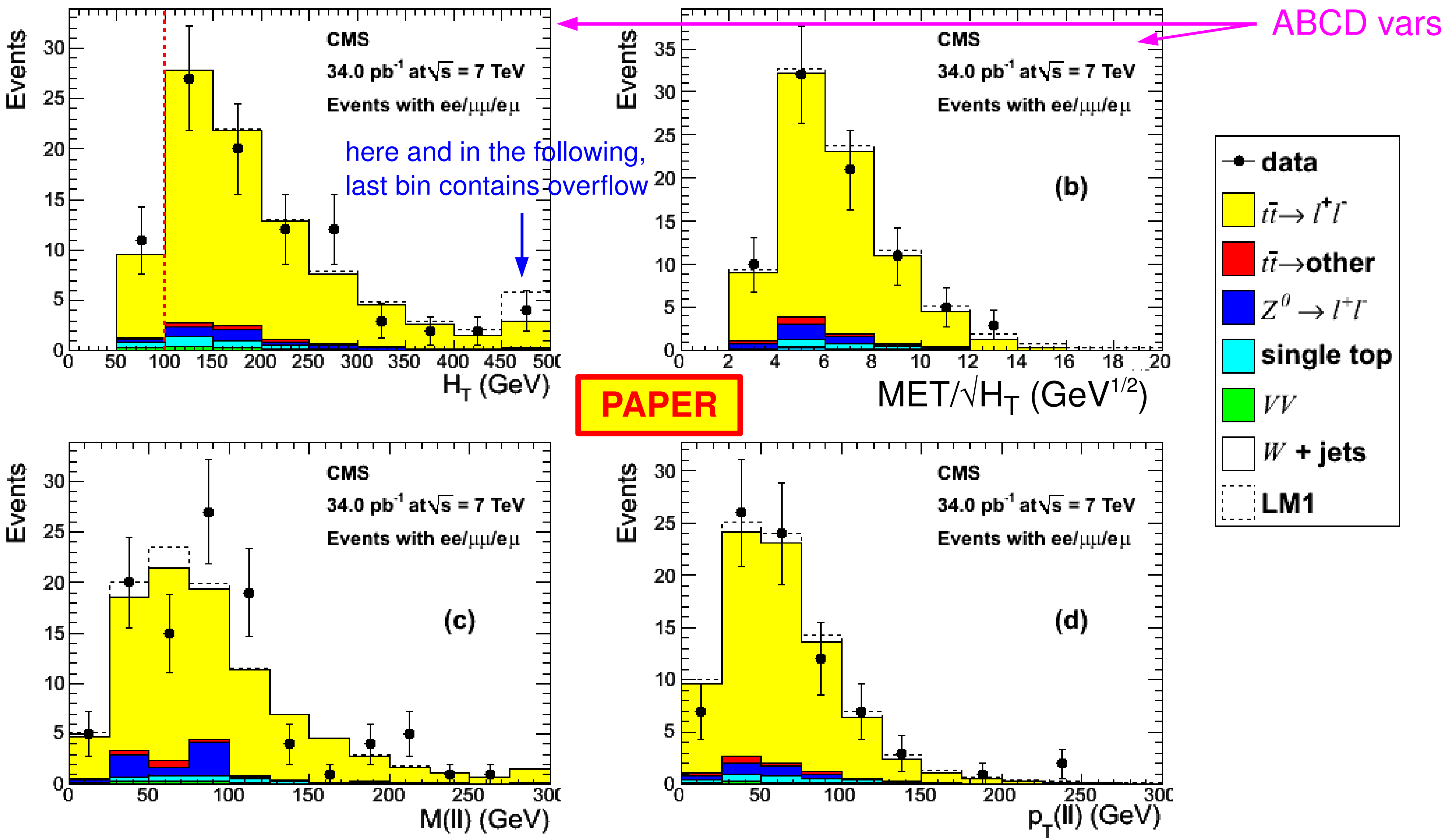
Sample	ee	$\mu\mu$	$e\mu$	tot
$t\bar{t} \to \ell^+\ell^-$	14.50 ± 0.24	17.52 ± 0.26	41.34 ± 0.40	73.36 ± 0.53
$t\bar{t} \to$ other	0.49 ± 0.04	0.21 ± 0.03	1.02 ± 0.06	1.72 ± 0.08
$Z \to \ell^+\ell^-$	1.02 ± 0.21	1.16 ± 0.22	1.20 ± 0.22	3.38 ± 0.37
$W^\pm$ + jets	0.19 ± 0.13	0.00 ± 0.00	0.09 ± 0.09	0.28 ± 0.16
W^+W^-	0.15 ± 0.01	0.16 ± 0.01	0.37 ± 0.02	0.68 ± 0.03
$W^\pm Z$	0.02 ± 0.00	0.02 ± 0.00	0.04 ± 0.00	0.09 ± 0.00
ZZ	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.05 ± 0.00
single top	0.46 ± 0.02	0.55 ± 0.02	1.24 ± 0.03	2.25 ± 0.04
total SM MC	16.85 ± 0.34	19.63 ± 0.34	45.33 ± 0.47	81.81 ± 0.67
data	15	22	45	82
LM0	10.67 ± 0.31	12.63 ± 0.34	17.81 ± 0.41	41.11 ± 0.62
LM1	2.35 ± 0.05	2.83 ± 0.06	1.51 ± 0.04	6.69 ± 0.09

MC errors statistical only

- Yields dominated by tt→dilepton (~90%)
- Good data/MC agreement in all channels

Data/MC Comparisons



- Observe good agreement between data and SM MC

Moving to Signal Region

- Observe good data/MC agreement in ttbar bulk→ proceed to search for NP in tails of ttbar
- Our signal region has been chosen based on
  - Astrophysical evidence→ large MET
  - Expect NP to have large $\sqrt{\hat{s}}$
  - Expect strong production of NP particles→ significant jet activity
- Signal region selected prior to examining data by adding requirements to pre-selection, such that O(1%) of tt → dilepton MC survives

(see BU slide 47)

  - **MET/$\sqrt{H_T}$ > 8.5 GeV$^{1/2}$**
  - **H_T > 300 GeV**
  - These variables are chosen since they are uncorrelated for tt → dilepton, allowing an ABCD data-driven background estimate

Data/MC Yields in Signal Region

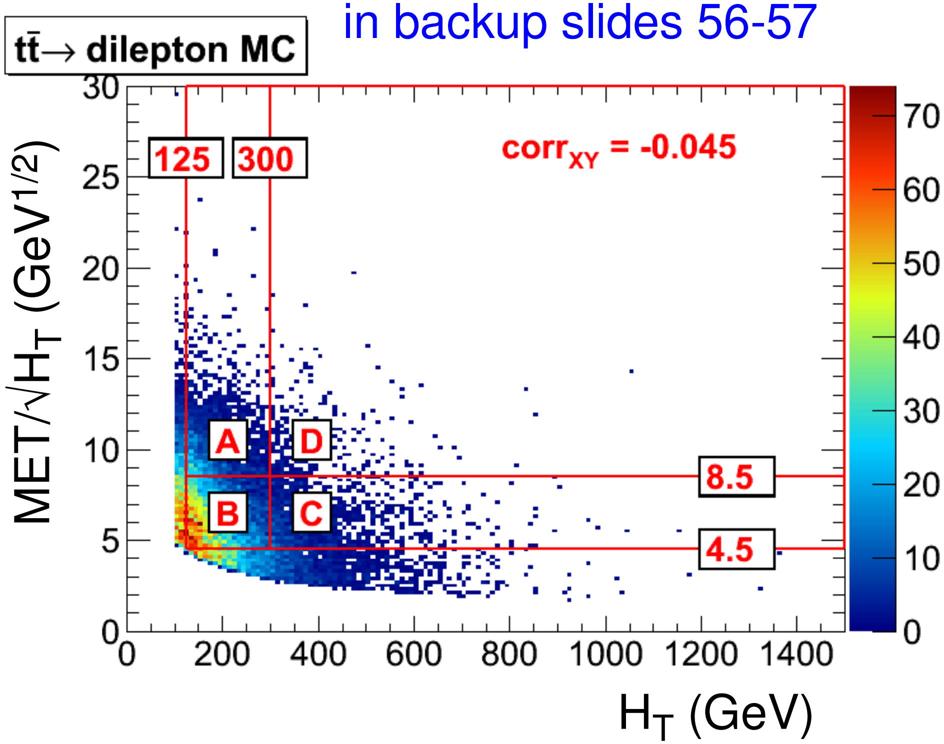
Sample	ee	$\mu\mu$	$e\mu$	tot
$t\bar{t} \to \ell^+\ell^-$	0.28 ± 0.03	0.22 ± 0.03	0.57 ± 0.05	1.07 ± 0.06
$t\bar{t} \to$ other	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.02 ± 0.01
$Z^0 \to \ell^+\ell^-$	0.04 ± 0.04	0.04 ± 0.04	0.04 ± 0.04	0.12 ± 0.07
$W^\pm$ + jets	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
W^+W^-	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.03 ± 0.01
$W^\pm Z^0$	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$Z^0 Z^0$	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
single top	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
total SM MC	0.34 ± 0.05	0.28 ± 0.05	0.65 ± 0.06	1.27 ± 0.10
data	0	0	1	1
LM0	2.37 ± 0.14	2.85 ± 0.15	3.41 ± 0.17	8.63 ± 0.27
LM1	1.24 ± 0.04	1.51 ± 0.04	0.81 ± 0.03	3.56 ± 0.06

TWIKI

- **Observe 1 event in signal region**, consistent with MC yield of 1.3
  - Signal event is eμ + 3 jets (more detail in backup, slides 48-51)
- Expected NLO yields: LM0 8.6, LM1 3.6
- We have verified using data-driven techniques that (see backup slides 52-55):
  - DY contribution is negligible (using $R_{out/in}$ method)
  - Contribution from fake leptons is negligible

Intro to ABCD Method

more details on ABCD method in backup slides 56-57

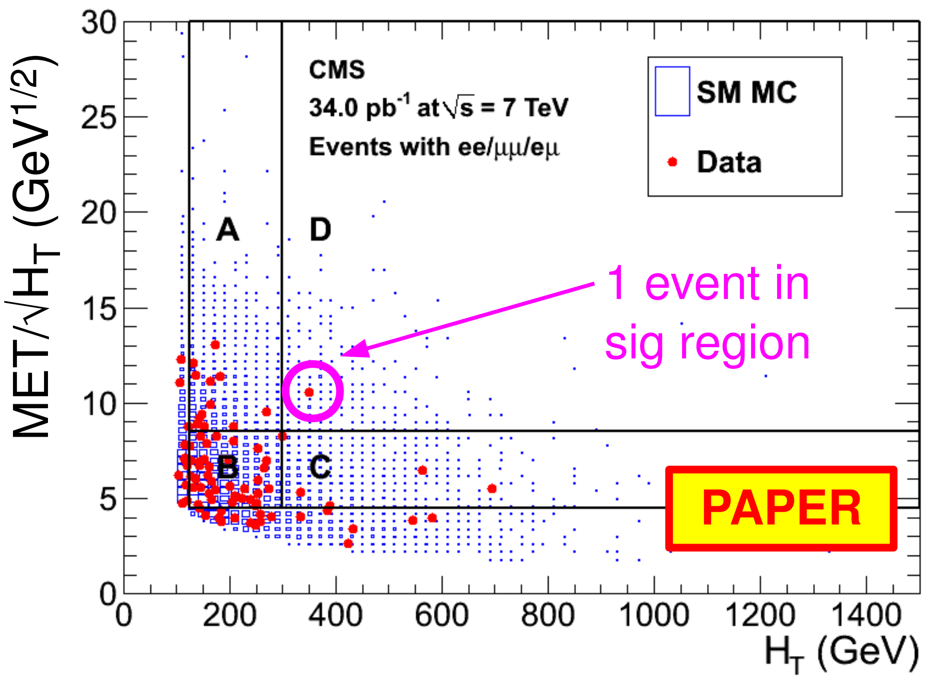


- Verified that chosen ABCD variables MET/$\sqrt{H_T}$, H_T are weakly correlated (5%)
- **A×C=B×D → predicted background yield in region D = A×C/B**
- Observed good agreement between **observed** and **predicted** MC yields
- Assess 20% uncertainty to cover: MC stats in closure test, non tt → dilepton backgrounds, variation of ABCD boundaries from hadronic energy scale uncertainty

MC Expected Yields 34 pb^{-1}

sample	A	B	C	D	A×C/B
$t\bar{t} \rightarrow \ell^+\ell^-$	8.44 ± 0.18	32.83 ± 0.35	4.78 ± 0.14	1.07 ± 0.06	1.23 ± 0.05
$Z^0 \rightarrow \ell^+\ell^-$	0.17 ± 0.08	1.18 ± 0.22	0.04 ± 0.04	0.12 ± 0.07	0.01 ± 0.01
SM other	0.53 ± 0.03	2.26 ± 0.11	0.23 ± 0.03	0.07 ± 0.01	0.05 ± 0.01
total SM MC	9.14 ± 0.20	36.26 ± 0.43	5.05 ± 0.14	$\boxed{1.27 \pm 0.10}$	$\boxed{1.27 \pm 0.05}$

ABCD Results



- Signal region yields:
  - Observe 1 event
  - 1.3 ± 0.8 (stat) ± 0.3 (syst) events predicted by ABCD method
- **Observed yield in agreement with ABCD prediction**
- Good data/MC agreement in all regions

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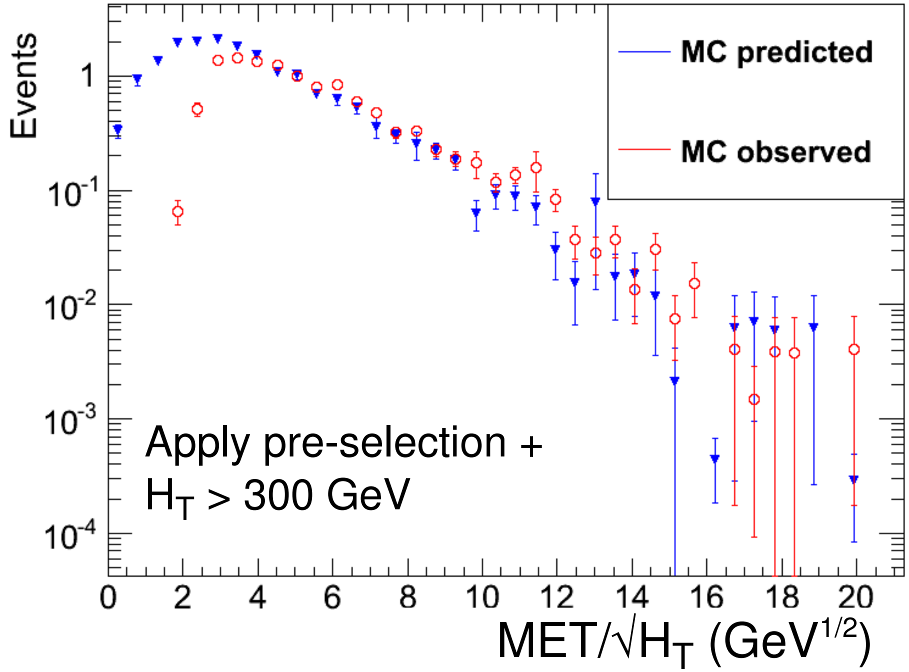
sample	N_A	N_B	N_C	N_D	$N_A \times N_C / N_B$
$t\bar{t} \to \ell^+\ell^-$	8.44 ± 0.18	32.83 ± 0.35	4.78 ± 0.14	1.07 ± 0.06	1.23 ± 0.05
$t\bar{t} \to$ other	0.12 ± 0.02	0.78 ± 0.05	0.16 ± 0.02	0.02 ± 0.01	0.02 ± 0.01
$Z \to \ell^+\ell^-$	0.17 ± 0.08	1.18 ± 0.22	0.04 ± 0.04	0.12 ± 0.07	0.01 ± 0.01
$W^\pm$ + jets	0.00 ± 0.00	0.09 ± 0.09	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
W^+W^-	0.11 ± 0.01	0.29 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	0.01 ± 0.00
$W^\pm Z$	0.01 ± 0.00	0.04 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZ	0.01 ± 0.00	0.02 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
single top	0.29 ± 0.01	1.04 ± 0.03	0.04 ± 0.01	0.01 ± 0.00	0.01 ± 0.00
total SM MC	9.14 ± 0.20	36.26 ± 0.43	5.05 ± 0.14	1.27 ± 0.10	1.27 ± 0.05
data	12	37	4	1	1.30 ± 0.78

Intro to p_T(ll) Template Method

- In tt→dilepton charged leptons and neutrinos from W decay have similar p_T spectrum: use p_T(ll) to model $p_T(\nu\nu)$ (ie. MET) (V. Pavlunin, PRD 81, 035005 (2010))
- Rescale p_T(ll) distribution by **K** to account for MET cut in pre-selection

SM MC (34 pb^{-1})

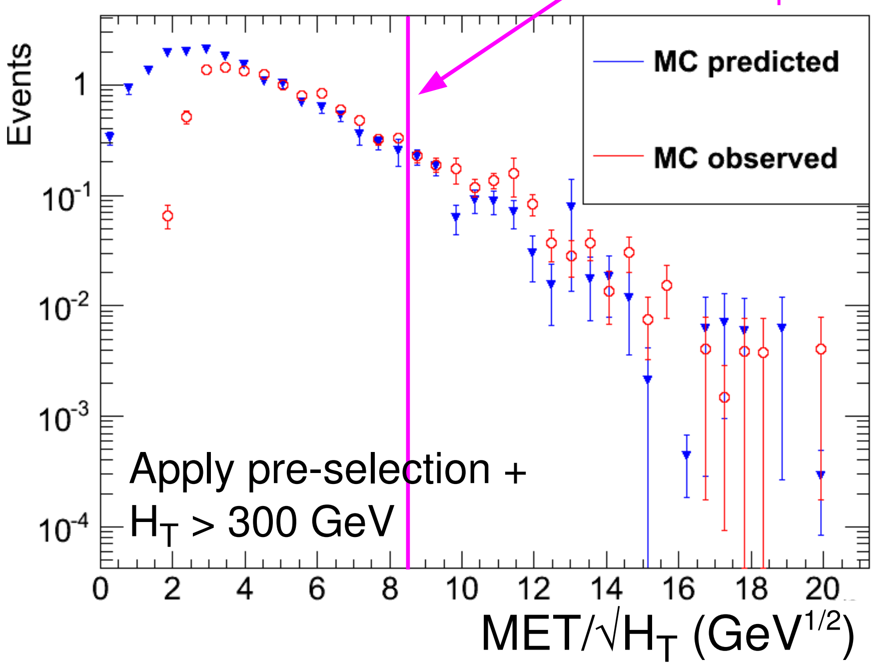


Take scale factor from MC (K = 1.5)

$$K = \frac{\int_0^\infty \mathcal{N}(P_T(\ell\ell))\ \ dP_T(\ell\ell)}{\int_{50}^\infty \mathcal{N}(P_T(\ell\ell))\ \ dP_T(\ell\ell)}$$

- **tt → dilepton MET distribution is modeled approximately by the rescaled p_T(ll) distribution**

$p_T(ll)$ Method MC Closure Test



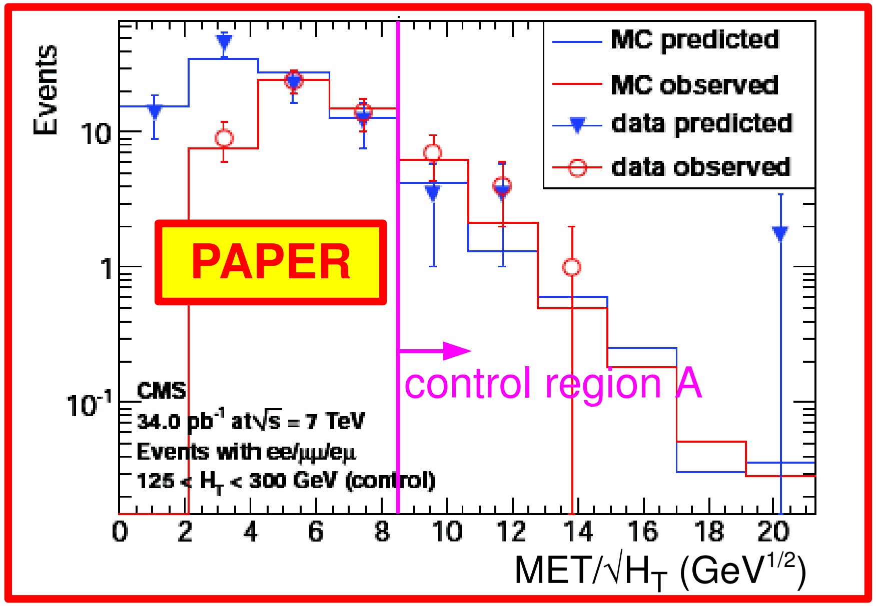
	MC Yield in Sig Region (34 pb^{-1})
Observed	1.27 ± 0.10
Predicted	0.92 ± 0.09

- Observed yield: #events $MET/\sqrt{H_T} > 8.5\ GeV^{1/2}$
- Predicted yield: = $K \times$ #events $p_T(ll)/\sqrt{H_T} > 8.5\ GeV^{1/2}$
- Prediction must be corrected further by factor KC = 1.4 ± 0.4
  - Due mainly to W polarization effects and also depends on hadronic energy scale, uncertainty dominated by hadronic energy scale uncertainty

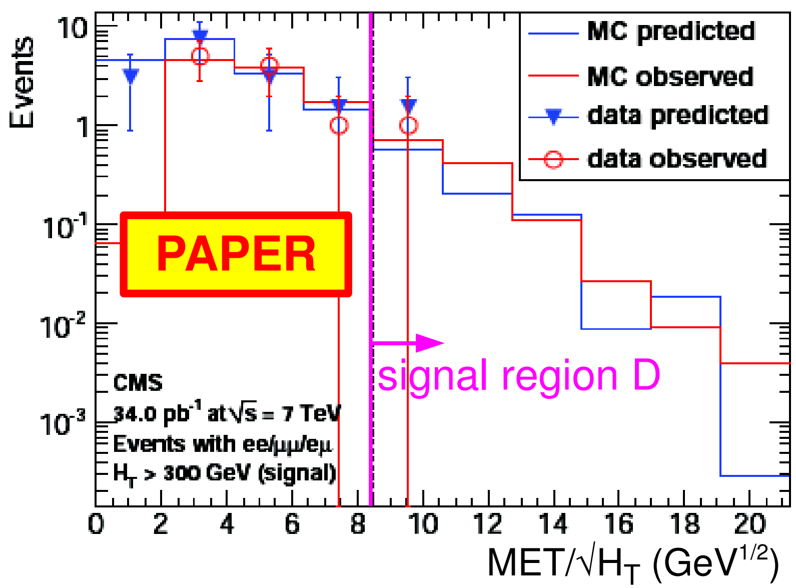
(more details on $p_T(ll)$ method in BU slides 58-64)

p_T(ll) Results: Control Region A

control region: 125 < H_T < 300 GeV



signal region: H_T > 300 GeV



	Control Region		Signal Region	
	Predicted	Observed	Predicted	Observed
total SM MC	6.45	9.14	0.92	1.27
data	9.0 ± 6.0	12	2.1 ± 2.1	1

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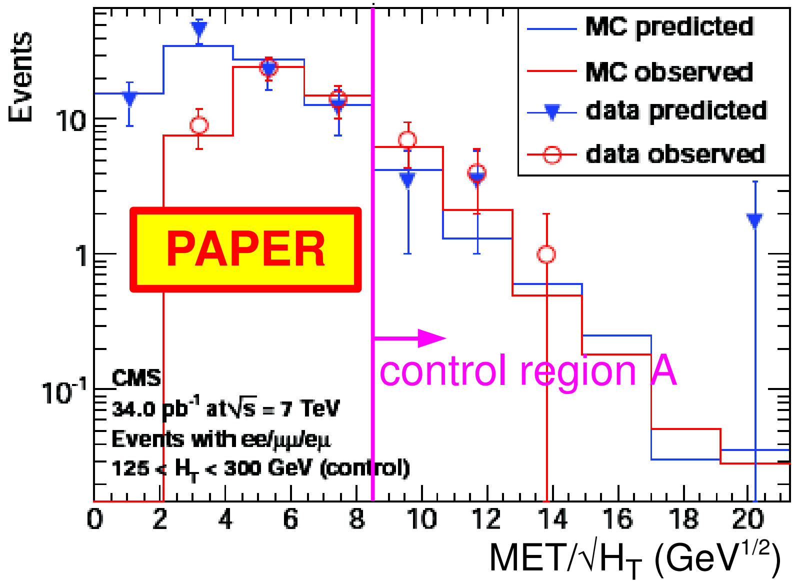
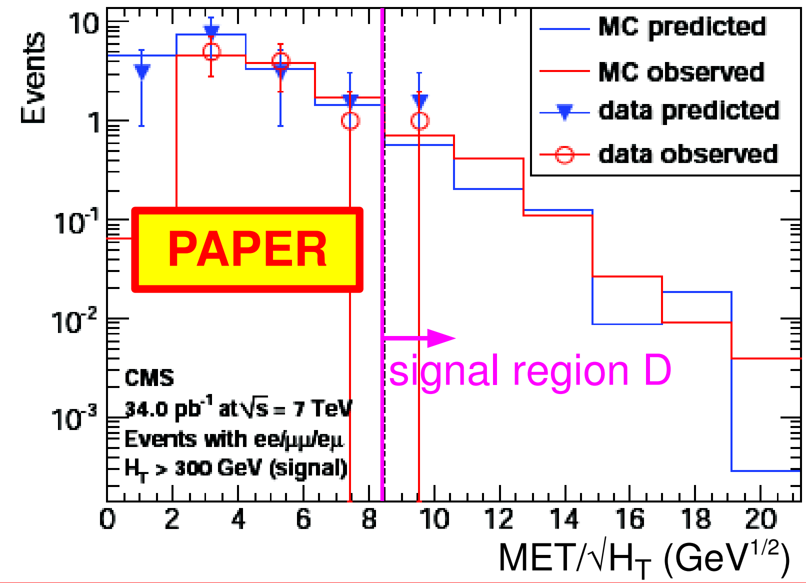
- First, validate method in control region A → observe good agreement between predicted and observed yields in region expected to be background dominated
- Next, move to signal region → observed yield **(1 event)** is consistent with predicted yield: **2.1 ± 2.1 (stat) ± 0.6 (syst)**

p_T(ll) Results: Signal Region D

control region: $125 < H_T < 300$ GeV



signal region: $H_T > 300$ GeV



	Control Region		Signal Region	
	Predicted	Observed	Predicted	Observed
total SM MC	6.45	9.14	0.92	1.27
data	9.0 ± 6.0	12	2.1 ± 2.1	1

PAPER

- First, validate method in control region A → observe good agreement between predicted and observed yields in region expected to be background dominated
- Next, move to signal region → observed yield **(1 event)** is consistent with predicted yield: **2.1 ± 2.1 (stat) ± 0.6 (syst)**

Acceptance/Efficiency Systematics

- Lepton selection
  - Trigger: compare yields assuming 100% efficiency vs. yields using trigger efficiency model (<1%) (see slides 65-68)
  - ID/iso: assess using T&P on Z data/MC (2%) (see slide 69)
- Jet/MET: assess by varying hadronic energy scale by ±5%
  - Uncertainty very final-state dependent: tt → dilepton (27%), LM0 (14%), LM1 (6%) (see slide 70)
- Luminosity (11%)

Summary (lepton trigger search)

- Yields in signal region
  - **Observed yield: 1 event**
  - **MC predicts: 1.3 events**
  - **ABCD method predicts: 1.3 ± 0.8 (stat) ± 0.3 (syst) events**
  - **p_T(ll) method predicts: 2.1 ± 2.1 (stat) ± 0.6 (syst) events**

- We have not observed NP → set UL on non-SM contribution to yield in signal region
- Take as best estimate of background yield the weighted average of the 2 data-driven methods: **N_{BKG} = 1.4 ± 0.8**
- 95% CL Bayesian upper limit on non-SM contribution to signal region: **4.1 events**
  - This UL is not very sensitive to choice of N_{BKG} and $\sigma(N_{BKG})$ (see backup slide 71)
- Expected yields 8.6 ± 1.6 for LM0, 3.6 ± 0.5 for LM1 (uncertainty from jet/MET, lumi, dilepton selection)

Contents

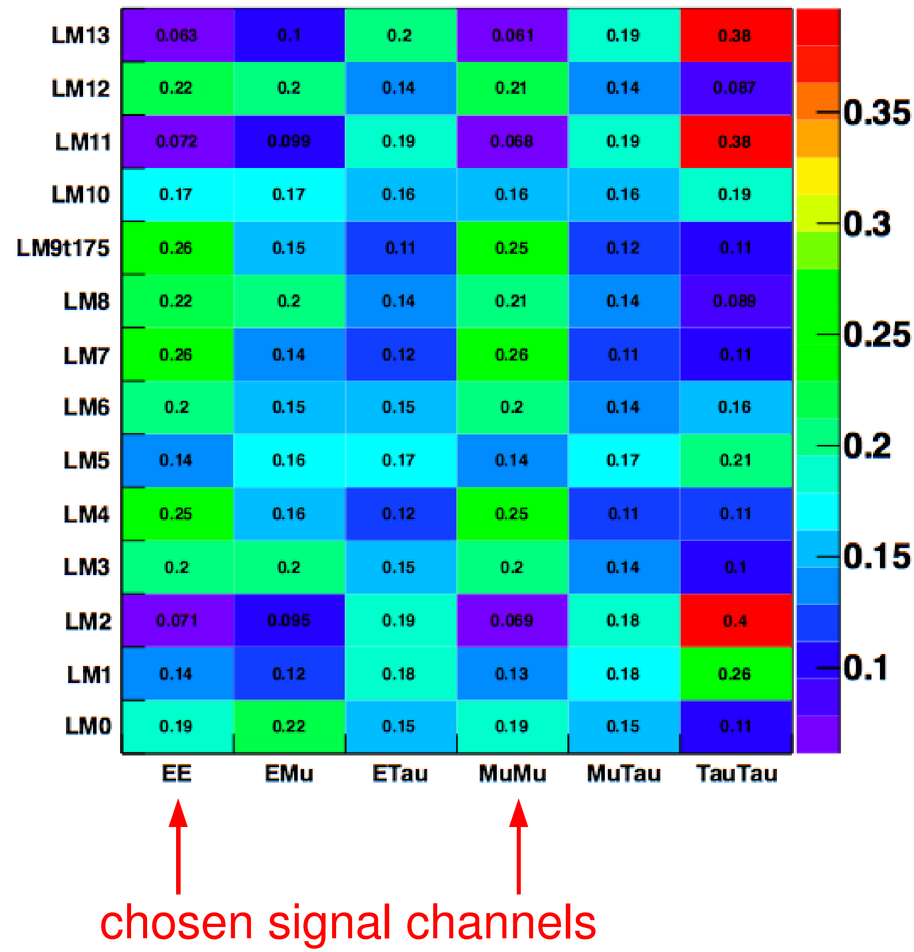
- Introduction and Overview
- Lepton Trigger Search
- **H_T Trigger Search**
- cMSSM Exclusion
- Conclusions

Overview of H_T Trigger Search

- Independent analysis in similar kinematic regime but with:
  - Different trigger path (hadronic triggers) motivated by sensitivity to low p_T leptons
  - Different reconstruction objects (fully PFlow-based)
  - Different background estimation method (OF subtraction)
    - In tt → dilepton, the 2 lepton flavors are uncorrelated → $N(ee) + N(\mu\mu) = N(e\mu)$ (modulo differences in electron vs. muon selection efficiency)
    - Restrict search to same-flavor ($ee+\mu\mu$) final states, use $e\mu$ yield to predict tt → dilepton background
    - Method also predicts other backgrounds with un-correlated lepton flavors (eg. DY → $\tau\tau$, WW), and will subtract NP with un-correlated lepton flavors

Event Selection

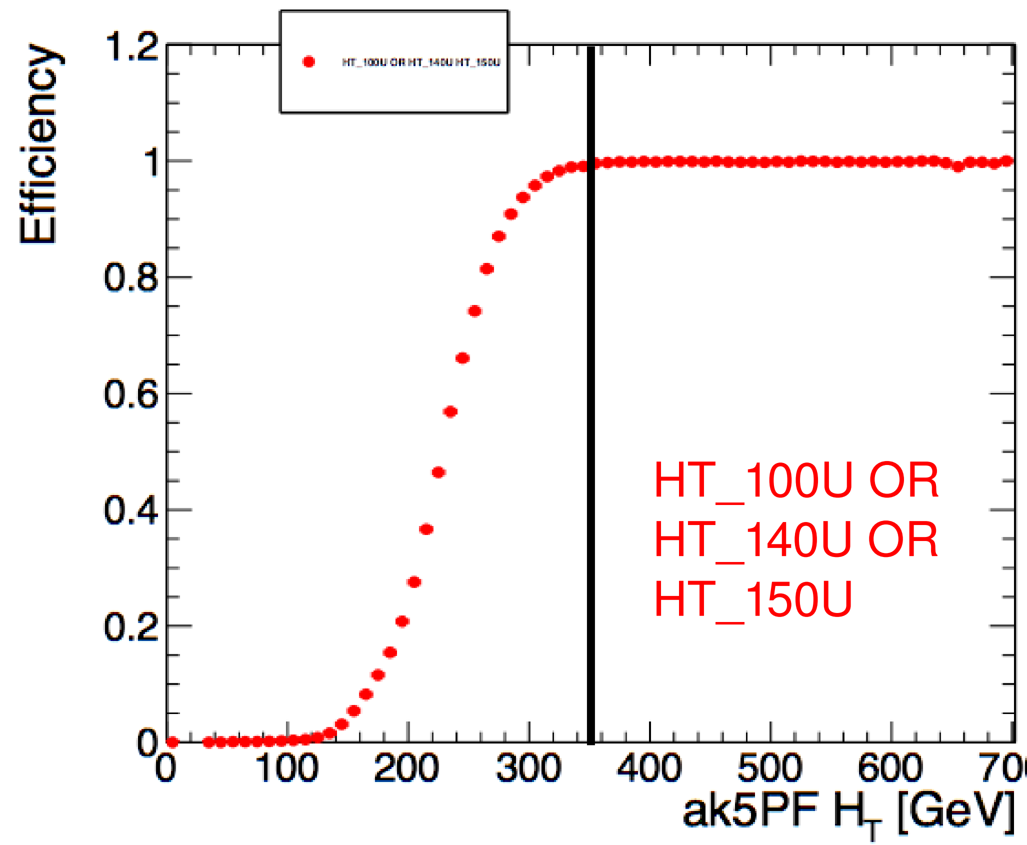
- Trigger
  - 100U OR 140U OR 150U
- Leptons
  - 2 p_T > 10 GeV, well-identified and isolated OS same-flavor leptons
  - eμ pairs used for bkg estimate
- Jets
  - $\geq$2 jets, p_T > 30 GeV, $|\eta|$ < 3
- Signal region: add requirements H_T > 350 GeV, MET > 150 GeV



(object selection details on slide 74)

Trigger

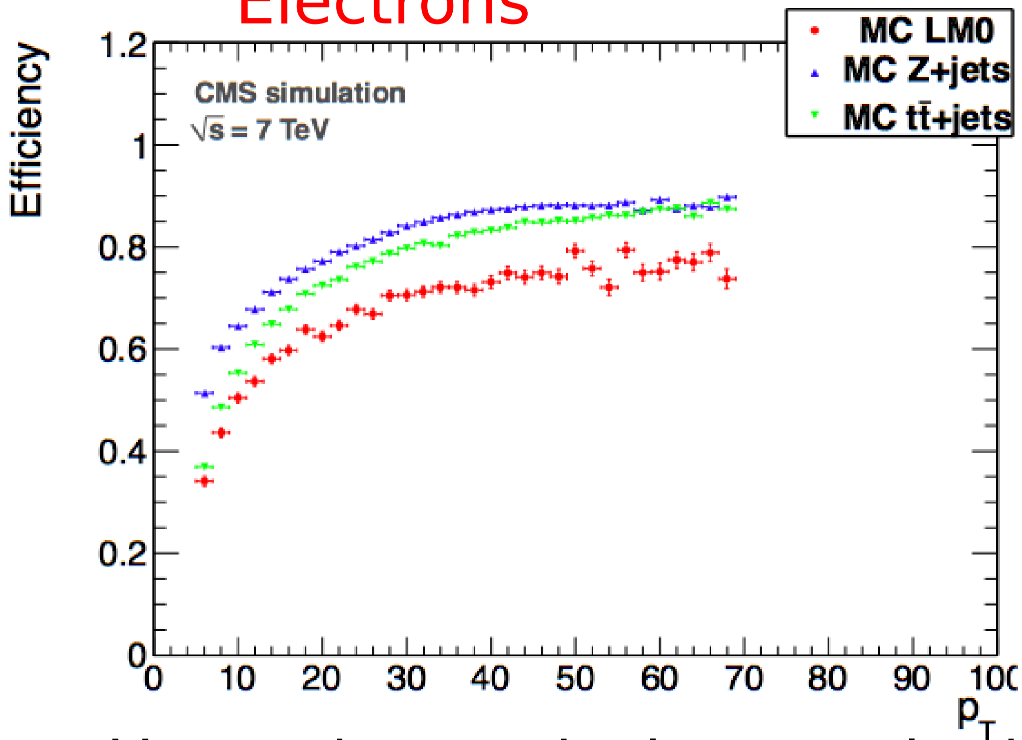
- HT_100U OR HT_140U_v* OR HT_150U_v*
- Measure the efficiency on the muon stream
- Trigger is fully efficient for an offline cut at $H_T > 350$ GeV
- This trigger turn-on point defines the H_T cut
- Slow turn-on due to better resolution of pfjets
- We assume 1% as systematic uncertainty on signal yield



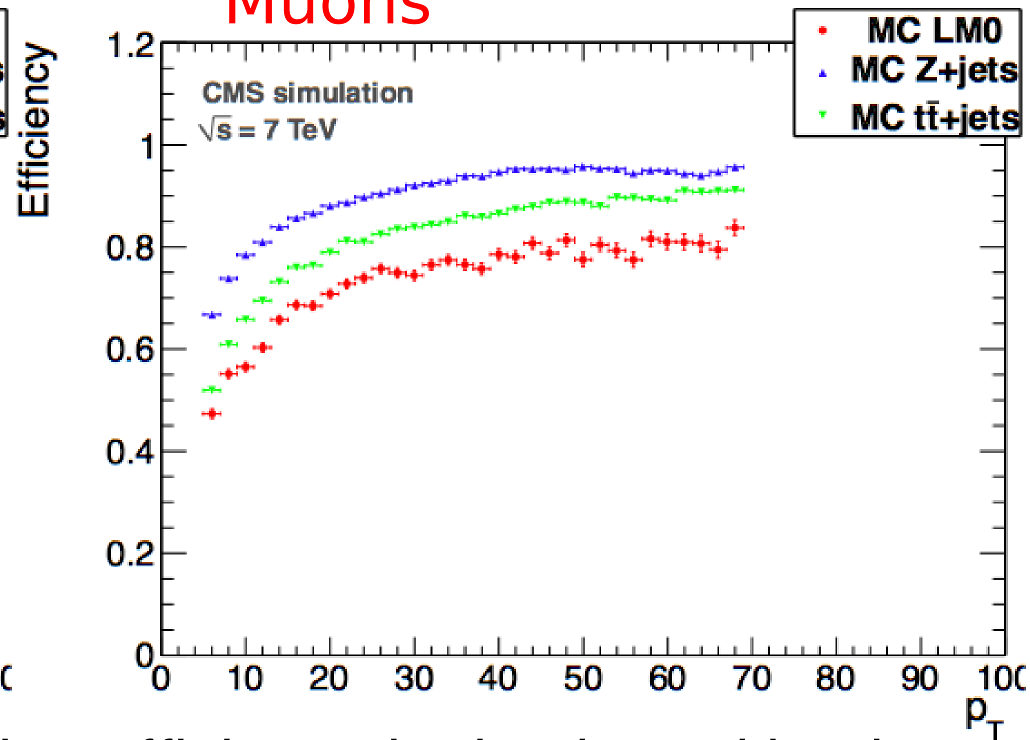
HLT path	Thresh. [GeV]	Pathname	ϵ
H_T	100	HLT_HT100U	$99.8 \pm 0.1\%$
H_T	140	HLT_HT140U	$99.7 \pm 0.1\%$
H_T	150	HLT_HT150U	$99.7 \pm 0.1\%$

Lepton Efficiency

Electrons



Muons



- Uncertainty on the lepton selection efficiency is dominated by the uncertainty on the hadronic activity (model dependent)
- Measured efficiency using T&P on the Z
  - Good agreement with simulation
  - Find similar efficiency as in lepton trigger search

	Data	Monte Carlo
electron	$0.88 \pm 0.004(\text{stat}) \pm 0.02(\text{syst})$	$0.87 \pm 0.002(\text{stat})$
muon	$0.94 \pm 0.002(\text{stat}) \pm 0.02(\text{syst})$	$0.93 \pm 0.002(\text{stat})$
ratio	$1.07 \pm 0.005(\text{stat}) \pm 0.05(\text{syst})$	$1.052 \pm 0.003(\text{stat})$

Signal Region Definition

Process	ee	$\mu\mu$	$e\mu$	total
$t\bar{t}$	0.38 ± 0.04	0.49 ± 0.05	0.76 ± 0.06	1.63 ± 0.09
$Z + \text{jets}$	0.0 ± 0.07	0.05 ± 0.07	0.11 ± 0.07	0.16 ± 0.1
$W + \text{jets}$	0.0 ± 0.32	0.0 ± 0.32	0.0 ± 0.32	0.0 ± 0.32
Di-boson	0.01 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.06 ± 0.02
Total background	0.38 ± 0.33	0.56 ± 0.33	0.93 ± 0.33	1.87 ± 0.34
Data	0	0	1	1
LM0	3.35 ± 0.17	3.86 ± 0.18	4.46 ± 0.19	11.67 ± 0.31
LM1	1.64 ± 0.04	2.0 ± 0.05	1.0 ± 0.03	4.65 ± 0.07

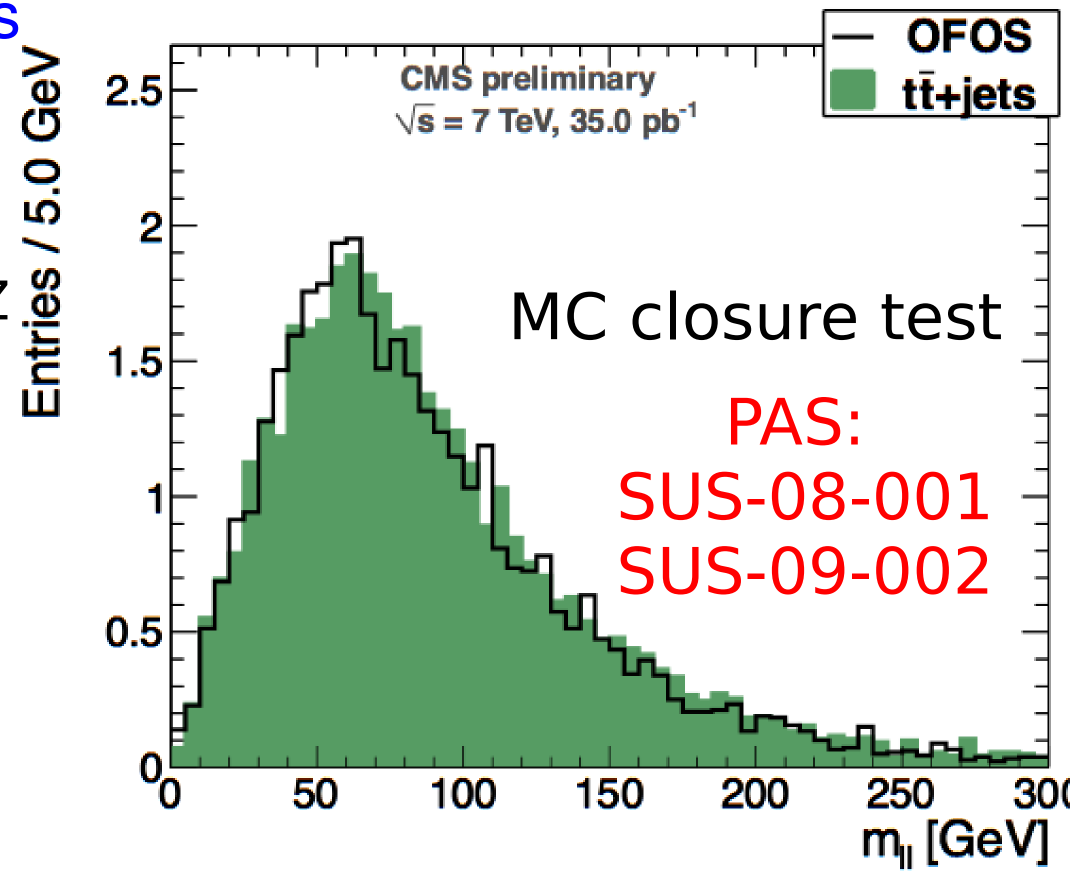
- Signal region: H_T > 350 GeV, MET > 150 GeV, 2 p_T > 10 GeV OS ee/μμ leptons
  - Chosen a priori based on simulation (expect ~1 event from SM MC)
  - Dominant background is tt → dilepton (~90%): far away from large background Z+jets, W+jets, QCD
- **Observe 0 events in ee+μμ channels, consistent with MC (0.9 events)**
- High sensitivity (similar to lepton trigger search) to LM0 and LM1 (7.2 and 3.6 ee+μμ events, respectively)
  - Overlap with lepton trigger search to 35%-60% for LM0, LM1

Opposite Flavour Subtraction

- Predict number of tt → dilepton ee and μμ events from eμ events →

$$n_{ee} = \frac{1}{2} n_{e\mu} r_{\mu e}, \quad n_{\mu\mu} = \frac{1}{2} \frac{n_{e\mu}}{r_{\mu e}}$$

- Only relies on efficiency ratio $r_{\mu e}$ = eff(e) / eff(μ)
  - Using efficiency from T&P on the Z
  - 5% systematic due to difference between Z vs. top events
- MC closure: observe good agreement between MC predicted vs. observed



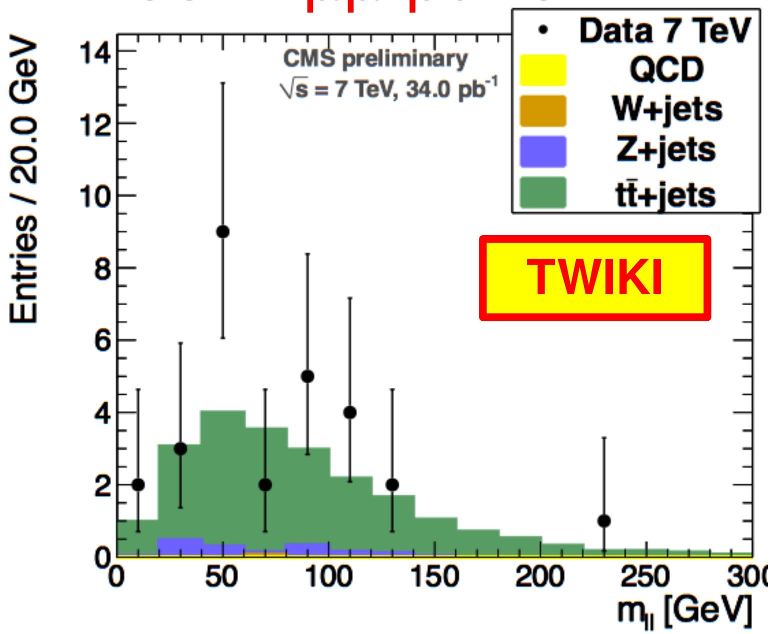
MC closure test

PAS:
SUS-08-001
SUS-09-002

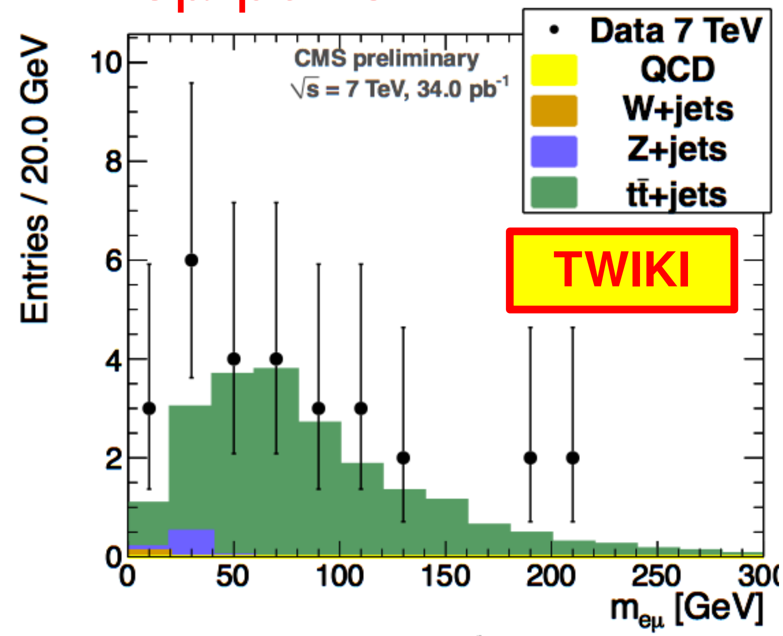
$$\boxed{n_{ee} = 16.9 \pm 2.8(\text{stat.}) \;\; (16.2\ \text{MC}), \quad n_{\mu\mu} = 19.8 \pm 3.3(\text{stat.}) \;\; (21.5\ \text{MC})}$$

Results in Control Region

ee + μμ pairs



eμ pairs



- Control region: 100 < H_T < 350 GeV, MET > 80 GeV and p_T > (20,10) OS leptons, lepton triggers
  - tt → dilepton dominant in this region
- Observe 25 ee+μμ events compared to predicted yield from OF subtraction 25.0 ± 5.0 with a fake contribution of 1.0± 0.5
  - **Prediction well in agreement with observed yield in control region**

$$n_{ee} = \frac{1}{2} n_{e\mu} r_{\mu e}, \quad n_{\mu\mu} = \frac{1}{2} \frac{n_{e\mu}}{r_{\mu e}}$$

PAPER

	Control Region	
Process	ee	$\mu\mu$
$t\bar{t}$ from $e\mu$	11.7 ± 2.4	13.4 ± 2.8
Fake leptons	0.5 ± 0.3	0.4 ± 0.2
Total predicted	12.2 ± 2.4	13.8 ± 2.8
Total observed	10	15
SM MC	8.4 ± 0.2	10.5 ± 0.3

Results in the Signal Region

signal region:
$H_T > 350$ GeV,
MET > 150 GeV,
2 $p_T > 10$ GeV OS leptons

	Signal Region	
Process	ee	$\mu\mu$
$t\bar{t}$ from $e\mu$	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Fake leptons	0	0
Total predicted	$0.4^{+1.0}_{-0.4}$	$0.5^{+1.2}_{-0.4}$
Total observed	0	0
SM MC	0.38 ± 0.08	0.56 ± 0.07
LM0	3.4 ± 0.2	3.9 ± 0.2
LM1	1.6 ± 0.1	2.0 ± 0.1

PAPER

- Observe 0 events in ee and μμ channels
- Few predicted fake leptons even without MET cut
  - Predicted fakes 0.1 ± 0.1 due to 1 event in eμ channel (50% syst)
- 1 event in eμ channel → OF subtraction predicted yield:
  - $0.9^{+2.2}_{-0.8}$ (stat) $\pm$ 0.05 (syst)
- MC signal yield 0.9
- **Everything is consistent with the SM in the signal region**

Summary (H_T trigger search)

- Yields in signal region
  - **Observed yield: 0 events**
  - **MC predicts: 0.9 events**
  - **OF subtraction predicts: $0.9^{+2.2}_{-0.8}$ (stat) ± 0.05 (syst) events**
- Observe no excess → set Bayesian 95% CL limit (Log-normal prior)
- Different interpretations
  - ee+μμ: 0 observed events → UL = 3.0 events
  - ee+μμ+eμ: generic limit in all 3 channels assuming 1 event is signal (most conservative) → UL = 4.8 events
- At the two LM points we expect at NLO
  - LM0 ee+μμ: 7.2 ± 1.6 (ee+μμ+eμ: 10.9 ± 2.4),
  - LM1 ee+μμ: 3.6 ± 0.7 (ee+μμ+eμ: 4.2 ± 0.8)
    - Uncertainty from hadronic energy scale, lepton efficiency, lumi

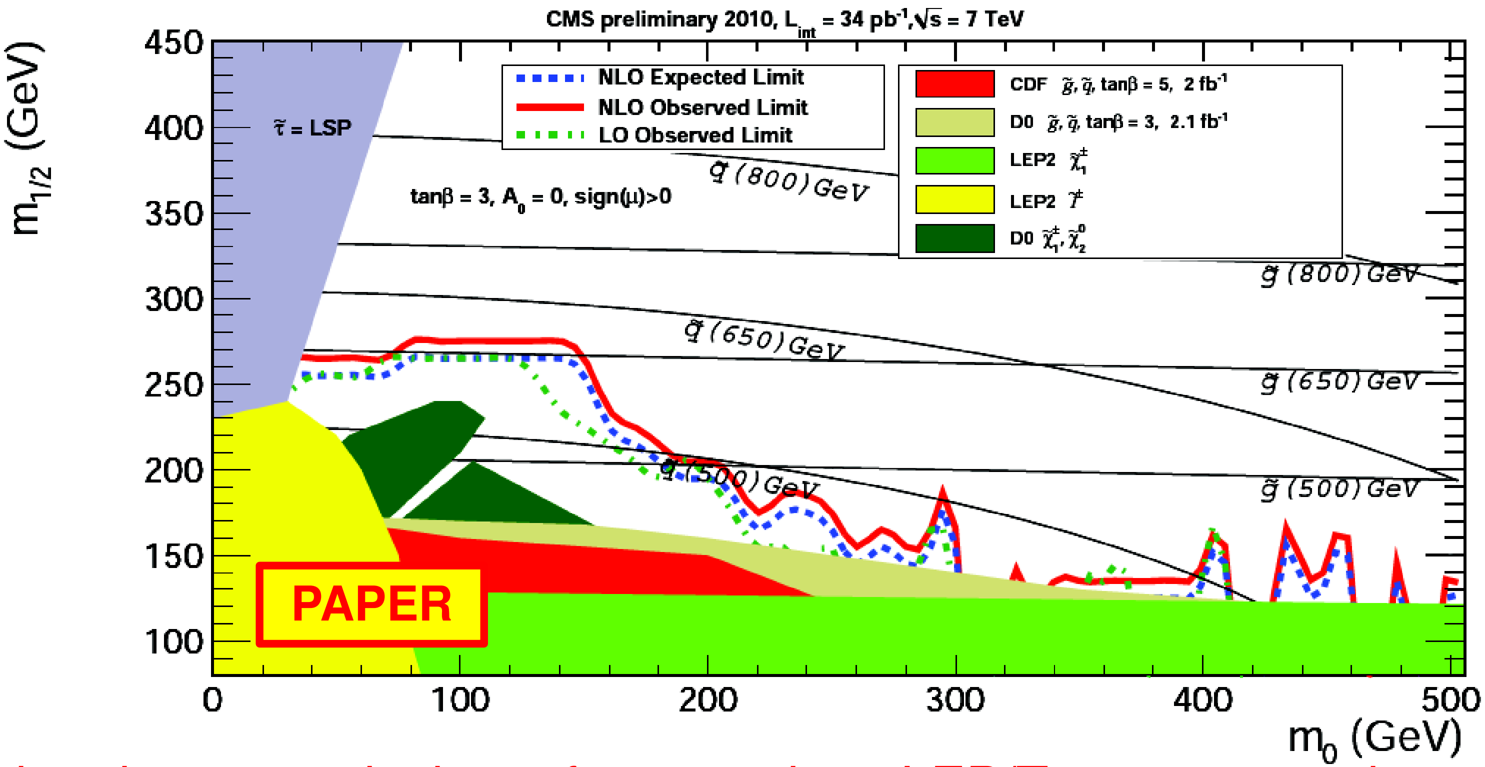
Contents

- Introduction and Overview
- Lepton Trigger Search
- H_T Trigger Search
- **cMSSM Exclusion**
- Conclusions

cMSSM Exclusion

- Perform exclusion in cMSSM m_0-$m_{1/2}$ parameter space
  - Show results based on lepton trigger search, find similar sensitivity for H_T trigger search
- Set tanβ=3, A=0, sign $\mu > 0$, scan m_0-$m_{1/2}$ space in 10 GeV steps
- At each scan point, calculate acceptance uncertainty from:
  - Hadronic energy scale
  - PDF uncertainty
  - k-factor uncertainty due to renormalization/factorization scale
  - Lumi uncertainty and dilepton selection efficiency uncertainty
  - Total uncertainty ~0.2-0.3
- Calculate 95% CL UL at each point, consider excluded if yield > UL
  - Verified that signal contamination has negligible impact on exclusion

cMSSM Exclusion Results



- Excluded region exceeds those from previous LEP/Tevatron searches
- NOTE: this is NOT the final version of the plot
  1) The Tevatron/LEP curves were taken from the hadronic analysis recently submitted for publication. It was discovered that SOME of them are wrong. When these are globally fixed for the SUSY group they will be updated.
  2) We're slightly improving the procedure for the exclusion curve at large m0 to better reflect our measurement
  3) We (authors) think that the expected limit curve should be removed because there is not enough granularity and statistics in the scan to make a meaningful distinction between expected and observed NLO, and the plot is too busy as it is... but this is still up for the discussion.

Additional Info for Model Testing

- We want to provide enough info to allow others to check if their chosen model is ruled out by our upper limit $\rightarrow$ required info:
  - Selection described in paper
  - Lepton ID efficiencies (see slide 83)
    - Muons: 95%
    - Electrons: 63% (p_T = 10 GeV) – 91% (p_T > 30 GeV)
  - Lepton isolation efficiencies (depends on final state) (see slide 84)
    - For tt $\rightarrow$ dilepton
      - p_T = 10 GeV: 83% (muons), 89% (electrons)
      - p_T > 60 GeV: >95%
    - For SUSY isolation efficiency can be significantly less due to increased hadronic activity
      - For example, for LM0, LM1 efficiency decreases ~5-10% per lepton
  - H_T, MET/$\sqrt{H_T}$ response/resolution (see slide 85)

Conclusions

- Performed search for new physics in OS dilepton + jets + MET channel
- Observed no evidence for NP
  - Lepton trigger search: observed 1 event in signal region
  - H_T trigger search: observed 0 events in signal region
  - Both results consistent with MC expectations and data-driven background predictions → set UL on non-SM event yields
- Performed exclusion in cMSSM parameter space
- Provided additional information on efficiencies, responses, etc. to allow others to check if their models are ruled out by our observations

Additional Material

Details of Lepton Trigger Search

Data/json

- Data: ExpressStream v3 of PVT certification 34.0 pb^{-1}
  - /EG/Run2010A-Sep17ReReco_v2/RECO
  - /Mu/Run2010A-Sep17ReReco_v2/RECO
  - /Electron/Run2010B-PromptReco-v2/RECO
  - /Mu/Run2010B-PromptReco-v2/RECO

MC Samples

- TTJets_TuneD6T_7TeV-madgraph-tauola_Fall10-START38_V12-v2
- WJets-madgraph_Spring10-START3X_V26_S09-v1 1)
- DYJetsToLL_TuneD6T_M-50_7TeV-madgraph-tauola_Fall10-START38_V12-v2
- DYToEE_M-10To20_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- DYToEE_M-20_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- DYToMuMu_M-10To20_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- DYToMuMu_M-20_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- DYToTauTau_M-10To20_TuneZ2_7TeV-pythia6-tauola_Fall10-START38_V12-v1
- DYToTauTau_M-20_TuneZ2_7TeV-pythia6-tauola_Fall10-START38_V12-v1
- WWTo2L2Nu_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- WZTo3LNu_TuneZ2_7TeV-pythia6_Fall10-START38_V12-v1
- ZZtoAnything_TuneZ2_7TeV-pythia6-tauola_Fall10-START38_V12-v1
- TToBLNu_TuneZ2_tW-channel_7TeV-madgraph_Fall10-START38_V12-v2
- TToBLNu_TuneZ2_s-channel_7TeV-madgraph_Fall10-START38_V12-v1
- TToBLNu_TuneZ2_t-channel_7TeV-madgraph_Fall10-START38_V12-v2
- LM0_SUSY_sftsht_7TeV-pythia6_Fall10-START38_V12-v1
- LM1_SUSY_sftsht_7TeV-pythia6_Fall10-START38_V12-v1

Event Cleaning

- Scraping cut: if there are ≥ 10 tracks, require at least 25% of them to be high purity.
- Require at least one good vertex:
  - not fake
  - ndof > 4
  - $|\rho| < 2$ cm
  - $|z| < 24$ cm.

Trigger Selection

- For data, require ee event to pass at least 1 single- or double-electron trigger, require μμ to pass at least 1 single- or double-muon trigger, require eμ to pass at least 1 single-electron, 1 single-muon, or 1 e-μ cross trigger
- Apply model of trigger efficiency to MC

- single-muon triggers
  - HLT_Mu5
  - HLT_Mu7
  - HLT_Mu9
  - HLT_Mu11
  - HLT_Mu13_v1
  - HLT_Mu15_v1
  - HLT_Mu17_v1
  - HLT_Mu19_v1
- double-muon triggers
  - HLT_DoubleMu3
  - HLT_DoubleMu3_v2
  - HLT_DoubleMu5_v1

- single-electron triggers
  - HLT_Ele10_SW_EleId_L1R
  - HLT_Ele10_LW_EleId_L1R
  - HLT_Ele10_LW_L1R
  - HLT_Ele10_SW_L1R
  - HLT_Ele15_SW_CaloEleId_L1R
  - HLT_Ele15_SW_EleId_L1R
  - HLT_Ele15_SW_L1R
  - HLT_Ele15_LW_L1R
  - HLT_Ele17_SW_TightEleId_L1R
  - HLT_Ele17_SW_TighterEleId_L1R_v1
  - HLT_Ele17_SW_CaloEleId_L1R
  - HLT_Ele17_SW_EleId_L1R
  - HLT_Ele17_SW_LooseEleId_L1R
  - HLT_Ele17_SW_TighterEleIdIsol_L1R_v1
  - HLT_Ele17_SW_TighterEleIdIsol_L1R_v2
  - HLT_Ele17_SW_TighterEleIdIsol_L1R_v3
  - HLT_Ele20_SW_L1R
  - HLT_Ele22_SW_TighterEleId_L1R_v2
  - HLT_Ele22_SW_TighterEleId_L1R_v3
  - HLT_Ele22_SW_TighterCaloIdIsol_L1R_v2
  - HLT_Ele27_SW_TightCaloEleIdTrack_L1R_v1
  - HLT_Ele32_SW_TightCaloEleIdTrack_L1R_v1
  - HLT_Ele32_SW_TighterEleId_L1R_v1
  - HLT_Ele32_SW_TighterEleId_L1R_v2

- double-electron triggers
  - HLT_DoubleEle15_SW_L1R_v1
  - HLT_DoubleEle17_SW_L1R_v1
  - HLT_Ele17_SW_TightCaloEleId_Ele8HE_L1R_v1
  - HLT_Ele17_SW_TightCaloEleId_Ele8HE_L1R_v2
  - HLT_Ele17_SW_TightCaloEleId_SC8HE_L1R_v1
  - HLT_DoubleEle10_SW_L1R
  - HLT_DoubleEle5_SW_L1R
- e-μ cross triggers
  - HLT_Mu5_Ele5_v1
  - HLT_Mu5_Ele9_v1
  - HLT_Mu11_Ele8_v1
  - HLT_Mu8_Ele8_v1
  - HLT_Mu5_Ele13_v1
  - HLT_Mu5_Ele13_v2
  - HLT_Mu5_Ele17_v1
  - HLT_Mu5_Ele17_v2

Electron Selection

Electron candidates are RECO GSF electrons passing the following requirements:

- $|\eta| < 2.5$.
- SuperCluster $E_T > 10$ GeV.
- The electron must be ecal seeded.
- VBTF90 identification[3].
- Transverse impact parameter with respect to the beamspot $< 400\ \mu$m.
- $Iso \equiv E_T^{\mathrm{iso}}/\mathrm{Max}(20\ \mathrm{GeV}, P_T) < 0.15$. E_T^{iso} is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3. A 1 GeV pedestal is subtracted from the ecal energy deposition in the EB, however the ecal energy is never allowed to go negative.
- Electrons with a tracker or global muon within ΔR of 0.1 are vetoed.
- The number of missing expected inner hits must be less than two[4].
- Conversion removal via partner track finding: any electron where an additional GeneralTrack is found with $Dist < 0.02$ cm and $\Delta \cot\theta < 0.02$ is vetoed[4].
- Cleaning for ECAL spike (aka Swiss-Cross cleaning) has been applied at the reconstruction level (CMSSW 38x).

Muon Selection

Muon candidates are RECO muon objects passing the following requirements:

- $|\eta| < 2.4$.
- Global Muon and Tracker Muon.
- χ^2/ndof of global fit < 10.
- At least 11 hits in the tracker fit.
- Transverse impact parameter with respect to the beamspot $< 200\ \mu$m.
- $Iso \equiv E_T^{\rm iso}/{\rm Max}(20\ {\rm GeV}, P_T) < 0.15$. $E_T^{\rm iso}$ is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3.
- At least one of the hits from the standalone muon must be used in the global fit.
- Require tracker $\Delta P_T/P_T < 0.1$. This cut was not in the original top analysis. It is motivated by the observation of poorly measured muons in data with large relative P_T uncertainty, giving significant contributions to the $\not{E}_T$.

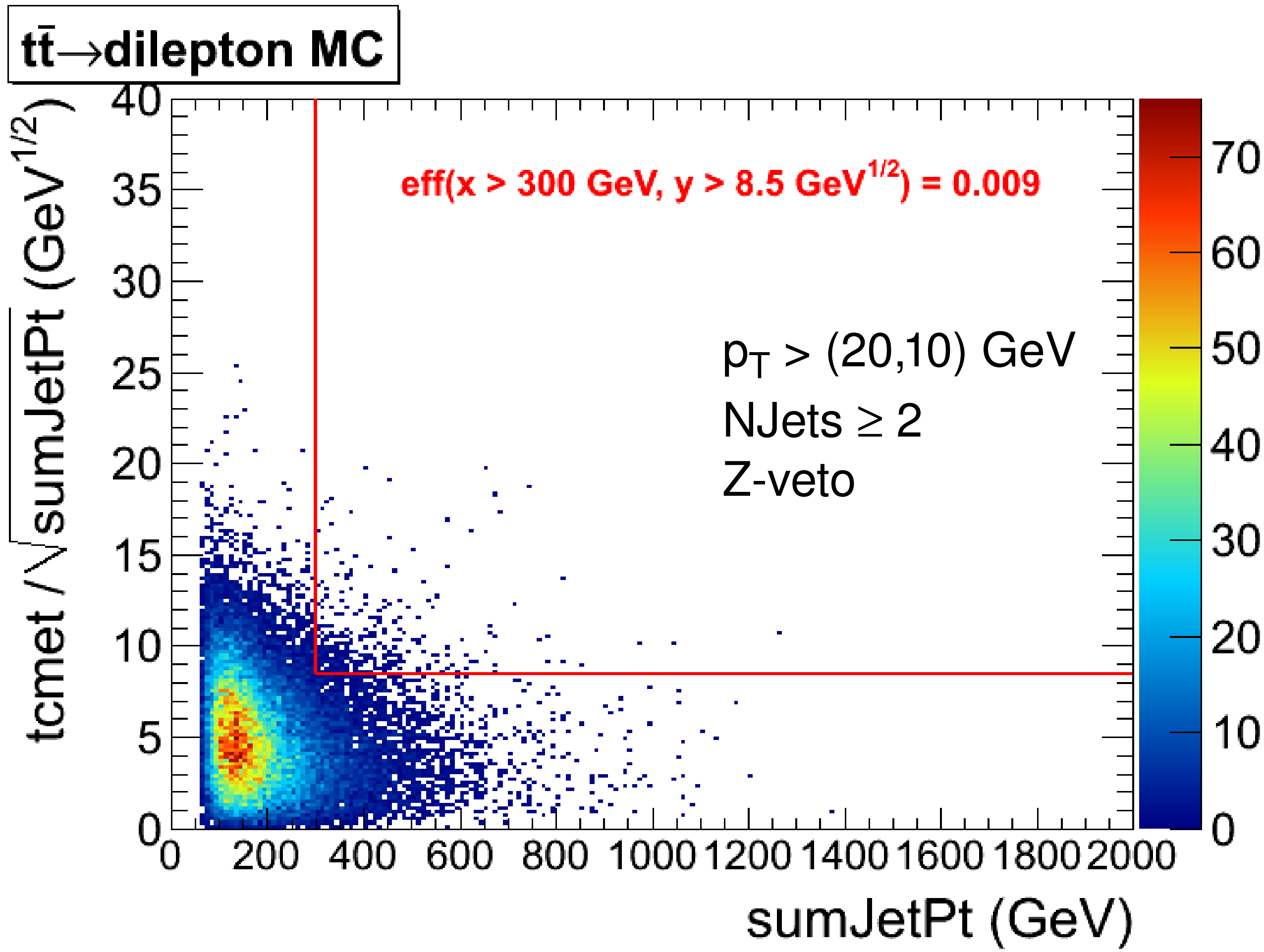
Jet Selection

- JPT jets
- L2L3-corrected pT > 30 GeV
- $|\eta| < 2.5$
- Pass caloJET ID
- Veto jets $\Delta R < 0.4$ from any lepton pT > 10 GeV passing full analysis selection

Dilepton Selection

- If more than 2 leptons pass analysis selection, choose pair which maximizes p_T(lep1) + p_T(lep2)
- Veto ee/$\mu\mu$ pairs 76-106 GeV
- Veto lepton pairs mass < 10 GeV (poorly modeled in MC)
- $Z \to \mu\mu\gamma$ veto:
  - Check for ECAL energy associated to muon. If E > 6 GeV, add energy to muon and recompute $\mu\mu$ mass. If M($\mu\mu$) 76-106 GeV, reject event.

Definition of Signal Region



- Efficiency to pass chosen sumJetPt, tcmet/√(sumJetPt) cuts is ~1%

Signal Event

- eμ + 3 jets event (148864 225 267767817)
- pfmet/tcmet are consistent, pfjets/JPT's are consistent

Table B.1: Summary of the objects in the candidate event.

	P_T (GeV)	η	ϕ	b-tagged?	value
muon	136.	0.046	-0.206		
electron	88	0.389	2.529		
Jet 1 (jpt)	267	-0.161	2.709	Y	
Jet 2 (jpt)	42	0.786	-0.739	N	
Jet 3 (jpt)	40	0.192	-1.025	N	
SumJetPt (jpt)					350 GeV
Jet 1 (pf)	263	-0.165	2.709	Y	
Jet 2 (pf)	49	0.727	-0.723	N	
Jet 3 (pf)	34	0.117	-1.020	N	
SumJetPt (pf)					347 GeV
tcMET	198		-0.557		
pfMET	194		-0.503		
$P_T(\ell\ell)$	65		0.354		
$M(\ell\ell)$					217 GeV
MT2 (tcMet)					42 GeV
MT2J (tc+JPT)					97 GeV
Mass (tc+JPT)					159 GeV
Meff (tc+JPT)					771 GeV

Cross-Check: tcmet vs. pfmet

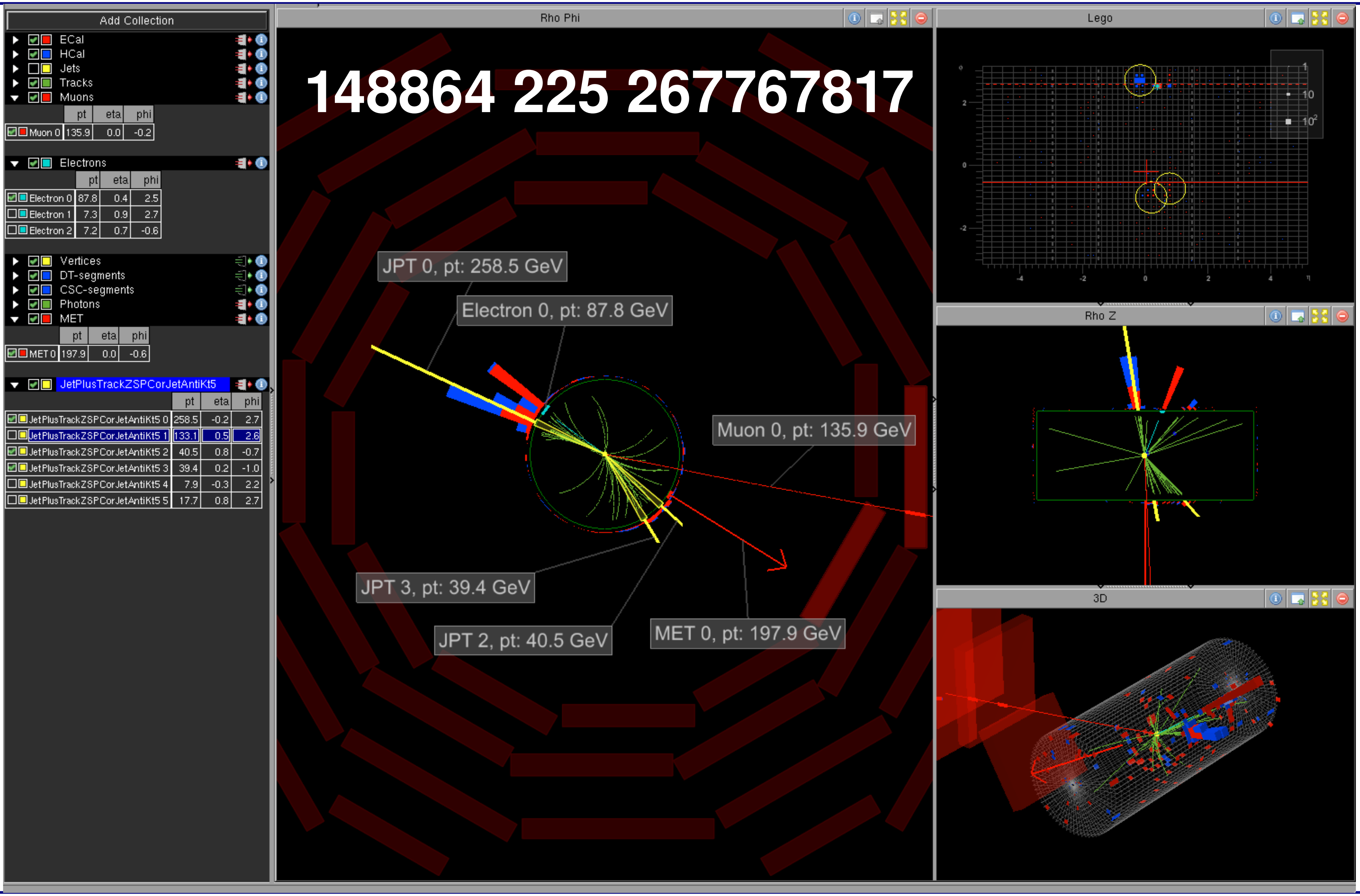
Yields passing pre-selection using MET > 50 GeV cut using given MET algorithm

Sample	ee	mm	em	tot
tcmet	15	22	45	82
pfmet	16	22	42	80

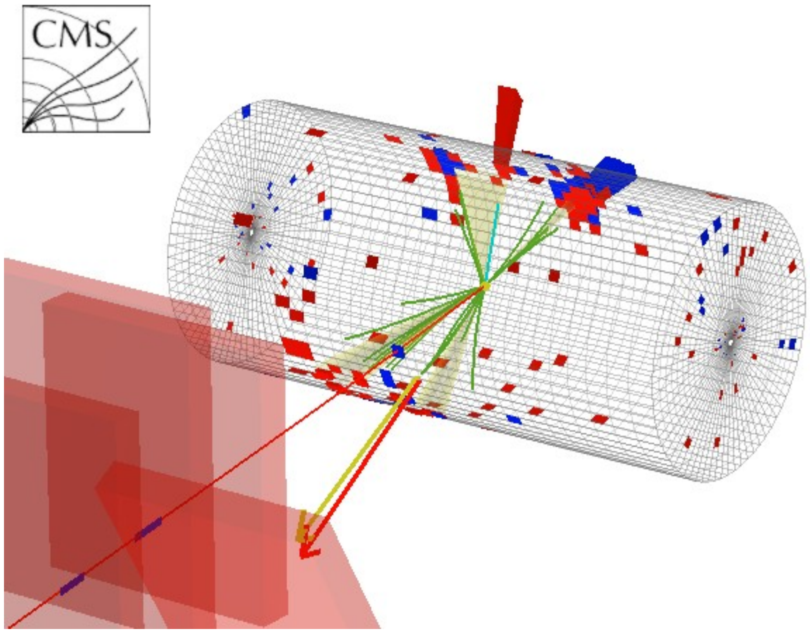
Yields in ABCD regions using given MET algorithm

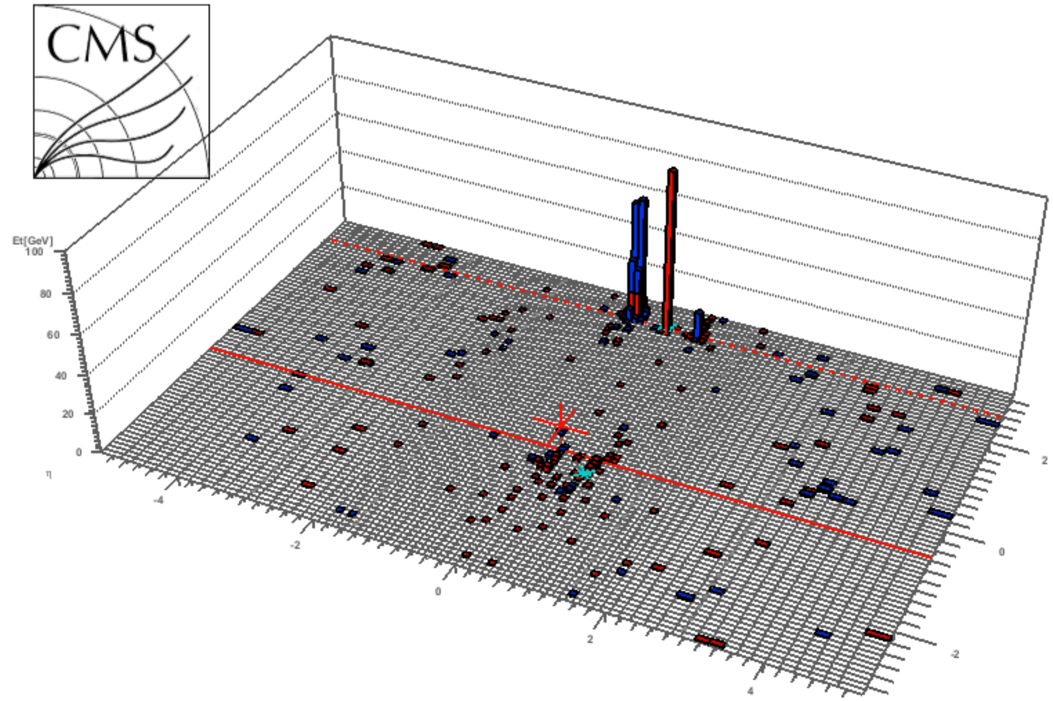
sample	A	B	C	D	A X C / B
tcmet	12	37	4	1	1.30 +/- 0.78
pfmet	11	35	3	1	0.94 +/- 0.63

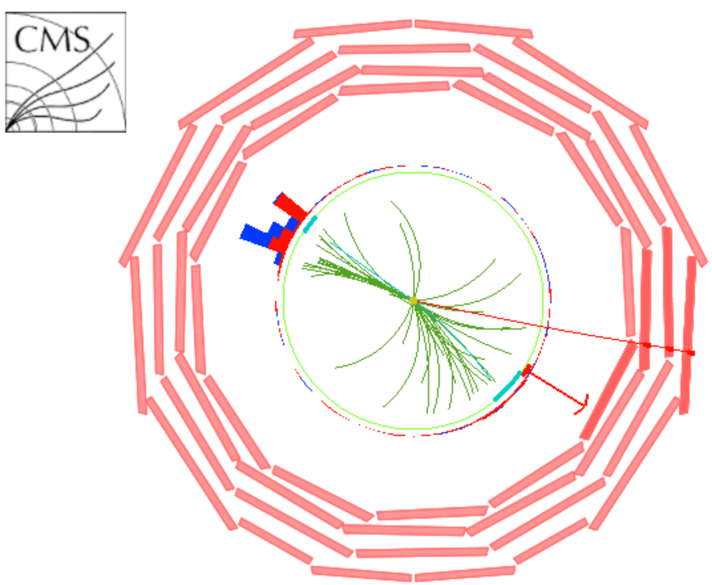
Signal Event



Signal Event







148864 225 267767817

DY Estimate in Signal Region

- Estimate DY yield in signal region using data-driven technique (same as for tt → dilepton cross section analysis)

$$N_{DY} = R_{out/in} \left(N_Z(ee+\mu\mu) - N_Z(e\mu) \right)$$

predicted DY yield

ratio of Nevents outside:inside Z peak in Z MC

Nevents in data inside Z peak in ee, mm, em channels

Observe 0 events inside Z peak ($N_Z(ee)=N_Z(\mu\mu)=N_Z(e\mu)=0$) → predicted DY yield in signal region is 0

Fake Rate Method

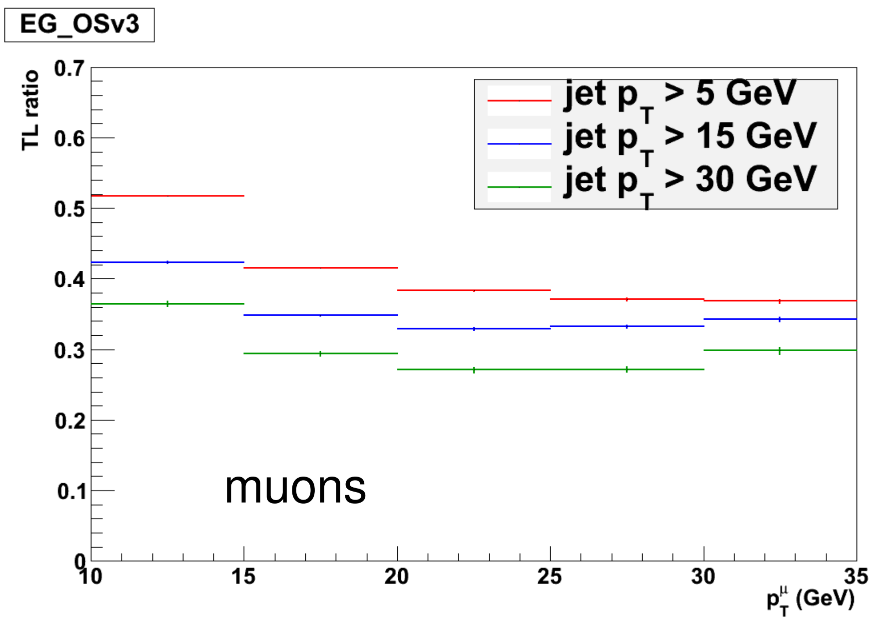
- Single fakes ($t\bar{t} \rightarrow$ other & W+jets) are expected to be very small from MC (total contribution to signal region is 0.04 from MC)
- Single fakes are expected to have a small contribution to ABCD and $p_T(ll)$ data-driven methods, which are taken into account with scale factors/uncertainties
- We verify our assumption that the single fakes are small using the data-driven "fake rate" method used in ttbar analysis (CMS AN-2010/257)
  - Single-fake estimate: observe 0 events with (1 selected lepton + 1 FO) in sig region
    - FR estimate $0.0^{+0.4}_{-0.0}$
    - (error is conservative estimate, based on what we would assess if we had seen 1 event with 1 lepton + 1 FO)
  - Double-fake estimate: observe no events with 2 FO's in signal region
    - FR estimate = $0.00^{+0.04}_{-0.00}$
  - **Observe no FO's in data in signal: our data-driven estimate of contribution of fakes to signal region is therefore zero**

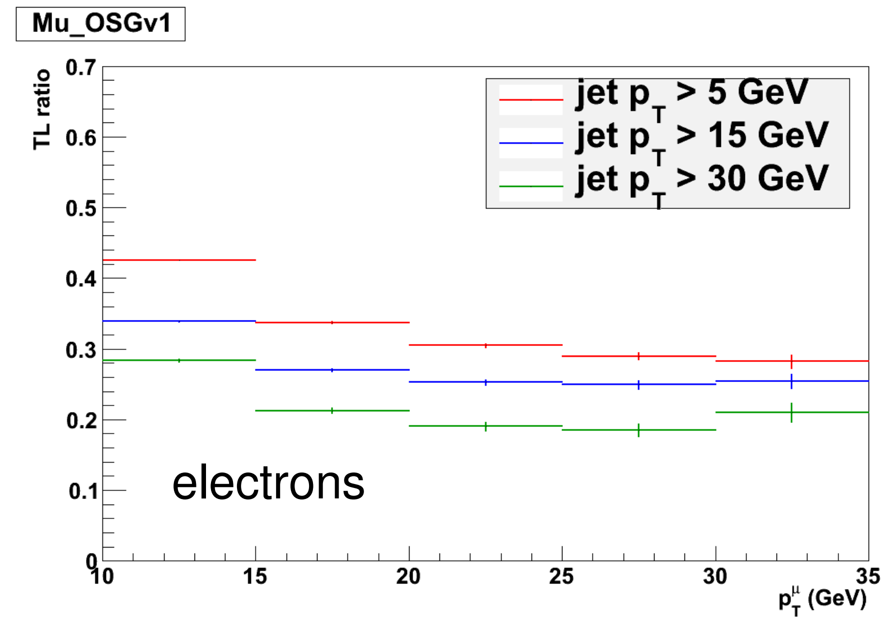
Closure Test of the FR in MC

- Use FR from QCD MC obtained in the same way as was done for data to “predict” the number of lepton+fake observed in the ttbar and W+jets MC
- This was done for the preselection, yields normalized to 35 pb-1
- Total observed fakes consistent with prediction within 50% systematic uncertainty

	Observed	Predicted
ttbar	1.74 ± 0.08 (stat)	2.1
W+jets	0.29 ± 0.17 (stat)	0.8
sum	2.03 ± 0.19 (stat)	2.9

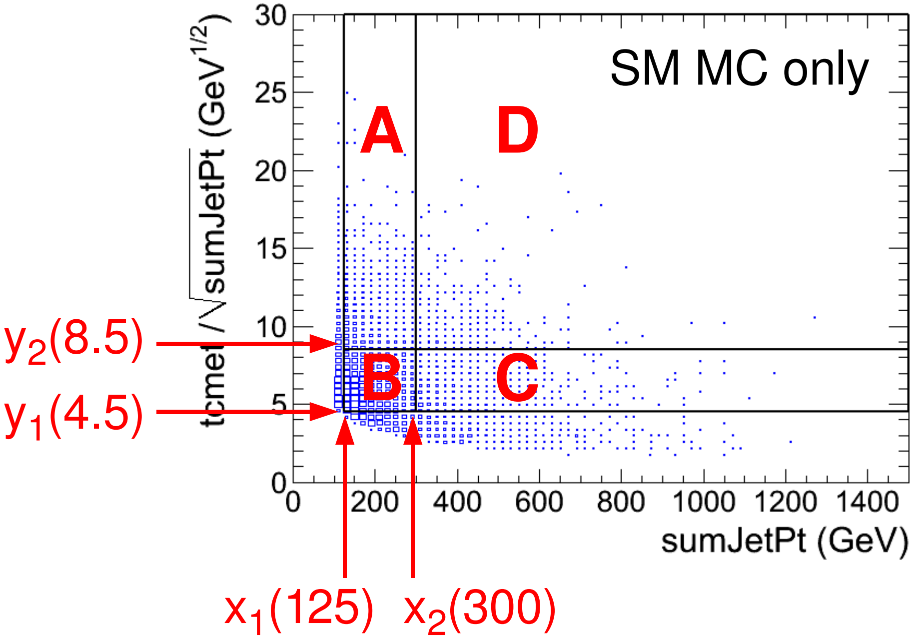
Jet p_T dependence of Fake Rate





- Fake rates obtained by varying the minimum pT requirement on the highest uncorrected pT caloJET separated by $\Delta R > 1$ from the "lepton"

Systematics of ABCD Method



x_1	x_2	y_1	y_2	Observed/Predicted
nominal	nominal	nominal	nominal	1.00 ± 0.08
+5%	+5%	+2.5%	+2.5%	1.08 ± 0.11
+5%	+5%	nominal	nominal	1.04 ± 0.10
nominal	nominal	+2.5%	+2.5%	1.03 ± 0.09
nominal	+5%	nominal	+2.5%	1.05 ± 0.10
nominal	-5%	nominal	-2.5%	0.95 ± 0.07
-5%	-5%	+2.5%	+2.5%	1.00 ± 0.08
+5%	+5%	-2.5%	-2.5%	0.98 ± 0.09

- Assess systematic by varying the boundaries from nominal values by an amount determined by energy scale uncertainty (±5% for x-var, ±2.5% for y-var), check effect on ratio observed:predicted signal yield
- Variations in observed/predicted are consistent within ~10%: assess corresponding systematic uncertainty

ABCD MC Closure Test

MC Expected Yields 34 pb^{-1}

sample	A	B	C	D	PRED
$t\bar{t} \rightarrow \ell^+\ell^-$	8.44 ± 0.18	32.83 ± 0.35	4.78 ± 0.14	1.07 ± 0.06	1.23 ± 0.05
$Z^0 \rightarrow \ell^+\ell^-$	0.17 ± 0.08	1.18 ± 0.22	0.04 ± 0.04	0.12 ± 0.07	0.01 ± 0.01
SM other	0.53 ± 0.03	2.26 ± 0.11	0.23 ± 0.03	0.07 ± 0.01	0.05 ± 0.01
total SM MC	9.14 ± 0.20	36.26 ± 0.43	5.05 ± 0.14	$\boxed{1.27 \pm 0.10}$	$\boxed{1.27 \pm 0.05}$

observed signal yield

predicted signal yield

- x, y variables un-correlated for tt→dilepton background → A×C=B×D → predict yield in sig region D as A × C / B
- Observe good agreement between MC observed and predicted yields
- Assess 20% uncertainty to cover: MC stats in closure test, non-tt→dilepton backgrounds, variation of observed/predicted due to smearing of ABCD boundaries by hadronic energy scale uncertainty

Systematic Uncertainties of $p_T(ll)$ Method

- We traced the origin of the discrepancy in the MC closure test to the following effects, which spoil correspondence between MET and $p_T(ll)$
  - W polarization: neutrino p_T > lepton p_T **(dominant effect)**
  - Lepton selection (p_T and cuts)
  - MET scale not =1, MET resolution worse than $p_T(ll)$ resolution
  - $W \rightarrow \tau \rightarrow l$ decays do not have $p_T(ll) \sim$ MET
  - Non-ttbar backgrounds (especially DY)
    - This contribution will be estimated separately using $R_{out/in}$ method (next slide)
- **Apply correction factor KC = 1.4 ± 0.4 (uncertainty due primarily to hadronic energy scale uncertainty)**

Estimate of DY Contamination of $p_T(ll)$ Background Prediction

- DY yield in signal region is very small due to large MET requirement (MC expected yield = 0.12)
- However, high p_T Z + jets events can enter $p_T(ll)$ control region, artificially increasing data-driven prediction of $p_T(ll)$ method
- Estimate DY contamination to $p_T(ll)$ control region using same method as ttdilepton analysis CMS AN-2009/023: $R_{out/in}$ method
- In signal region, observe 0 events inside Z mass window $\rightarrow$ **predicted DY yield in signal region is 0**
- Also apply $p_T(ll)$ method to ABCD control region A, where we find:

$$\boxed{\mathbf{N_{DY} = R_{out/in}\,(\,N_Z(ee+\mu\mu) - N_Z(e\mu)\,) = 1.3 \pm 0.9}}$$

$R_{out/in} = 0.3 \pm 0.2$(stat) (ratio of yield outside:inside Z mass window in DY MC)

N_Z = event yield in data inside Z mass window. $N_Z(ee+\mu\mu) = 4$, $N_Z(e\mu) = 0$.

Systematics of $p_T(ll)$ Method

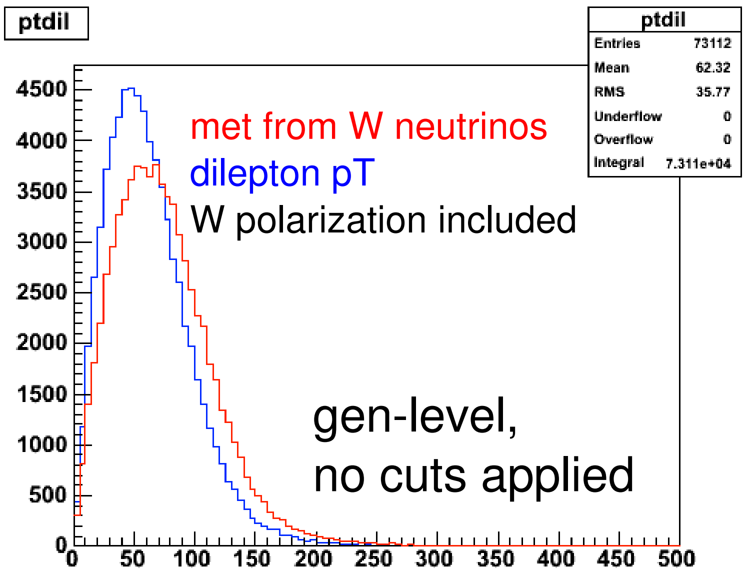
Table 3: Test of the data driven method in Monte Carlo under different assumptions. See text for details.

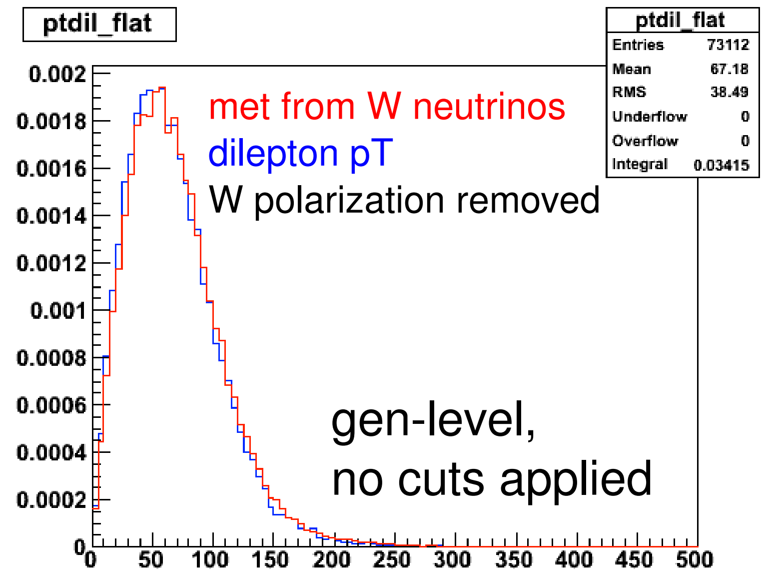
	True $t\bar{t}$ dilepton included	$t \to W \to \tau$ included	other SM included	GEN or RECOSIM	Lepton P_T and η cuts	Z veto	$\not{E}_T > 50$	obs/pred
1	Y	N	N	GEN	N	N	N	1.90
2	Y	N	N	GEN	Y	N	N	1.64
3	Y	N	N	GEN	Y	Y	N	1.59
4	Y	N	N	GEN	Y	Y	Y	1.55
5	Y	N	N	RECOSIM	Y	Y	Y	1.51
6	Y	Y	N	RECOSIM	Y	Y	Y	1.58
7	Y	Y	Y	RECOSIM	Y	Y	Y	1.38

- Several effects spoil the correspondence between $p_T(ll)$ and MET
  - W polarization: neutrino p_T > lepton p_T (dominant effect, see backup)
  - Lepton selection (p_T and cuts)
  - MET scale not =1, MET resolution worse than $p_T(ll)$ resolution
  - $W \to \tau \to l$ decays do not have $p_T(ll) \sim$ MET
  - Non-ttbar backgrounds (in particular DY, this contribution will be estimated separately using the $R_{out/in}$ method)
  - Top spin correlations
- Assess scale factor/systematic uncertainty by checking stability of ratio observed:predicted signal yield while varying the selection.
  - This will be assessed using 38X MC, in the following we do not apply a correction

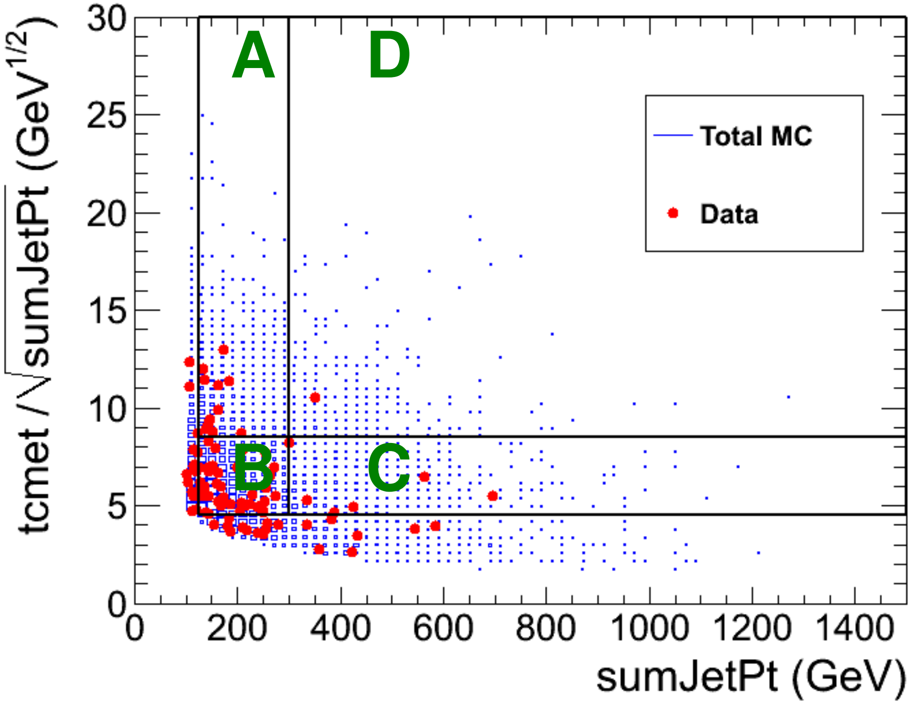
Effect of W Polarization

- 1) W's from top decay are polarized
- 2) costheta* (angle between charged lepton and W velocity in W CM frame) distribution is peaked at negative values
- 3) Charged lepton is emitted preferentially anti-parallel to W velocity
- 4) Leptons are softer in pt than neutrinos
- 5) met from W neutrinos > dilepton pt
- If we remove this effect by reweighting the costheta* distribution, we get reasonable agreement between met from W neutrinos and dilepton pT
- **Disagreement between met, dilepton pt at gen-level is due to effects of W polarization**



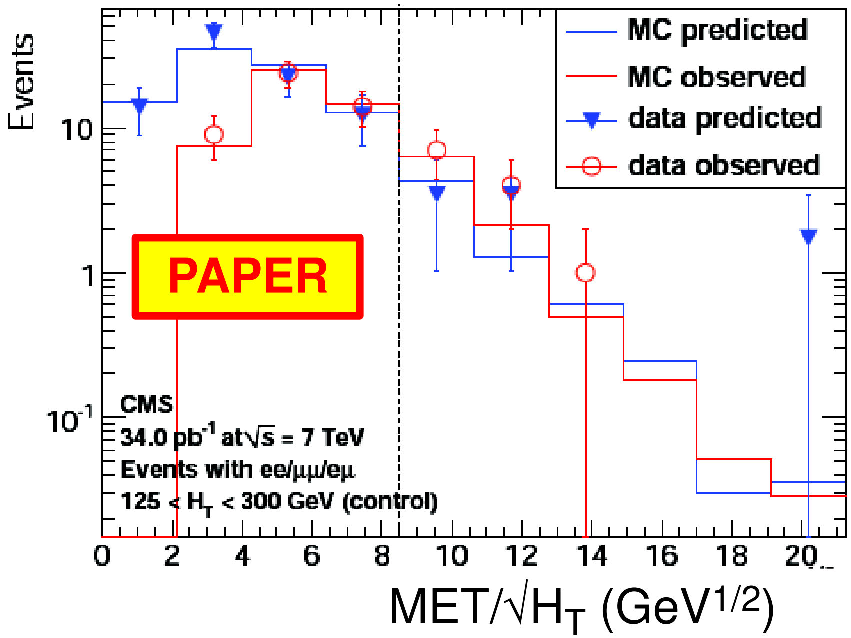


Dilepton p_T Template Application



- First, use $p_T(ll)$ method to predict yield in control region A which we expect to be dominated by background
- Next, use $p_T(ll)$ method to predict yield in signal region D

$p_T(ll)$ Template Results: Control Region A



Yields in Control Region A **PAPER**

	Predicted	Observed
total SM MC	6.45	9.14
data	9.0 ± 6.0	12

Predicted yield $N(A) = K \times KC \times (N(A') - N_{DY}(A')) = 9.0 \pm 6.0$ (stat)

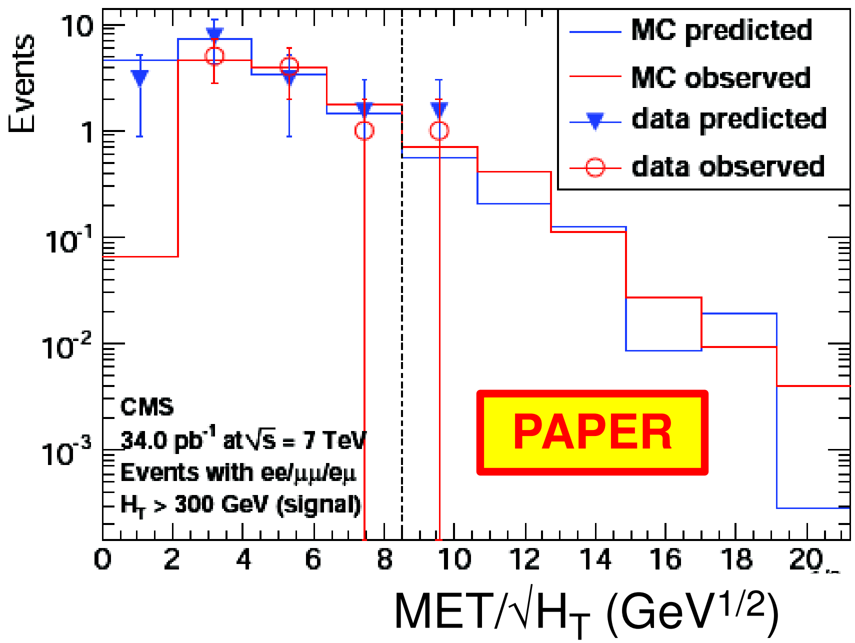
$N(A') = 5$: observed yield in region A' ($125 < H_T < 300$ GeV, $pT(ll)/\sqrt{H_T} > 8.5$ GeV$^{1/2}$)

$N_{DY}(A') = 1.3 \pm 0.9$: estimated DY contribution in A' using $R_{out/in}$ method

$K = 1.7$: pT(ll) scaling factor from MC

$KC = 1.4$: observed/predicted scaling factor from MC

- Observe agreement between predicted vs. observed yields in control region A$\rightarrow$ proceed to predict yield in signal region D



Yields in Signal Region D **PAPER**

	Predicted	Observed
total SM MC	0.92	1.27
data	2.1 ± 2.1	1

Predicted yield $N(D) = K \times KC \times (N(D') - N_{DY}(D')) = 2.1 \pm 2.1$ (stat)

$N(D') = 1$: observed yield in region D' ($H_T > 300$ GeV, $pT(ll)/\sqrt{H_T} > 8.5$ GeV$^{1/2}$)

$N_{DY}(D') = 0$: estimated DY contribution in D' using $R_{out/in}$ method

$K = 1.4$: $p_T(ll)$ scaling factor from MC

$KC = 1.4$: observed/predicted scaling factor from MC

- Observe agreement between predicted vs. observed yields in signal region D

Trigger Efficiencies (ee)

Source	#Probes (2TT)	#Probes (TP)	#Probes (TF)	Efficiency
DY MC	1853.439	0.157	9.832	0.995 ± 0.0017
W+Jets MC	0.328	0.010	0.000	1.000 ± 0.3757
DATA	1460	0	22	$\boxed{0.985 \pm 0.003}$

run < 144000

Table 9: Yields in the mass window for the 15 GeV electron trigger without ID.

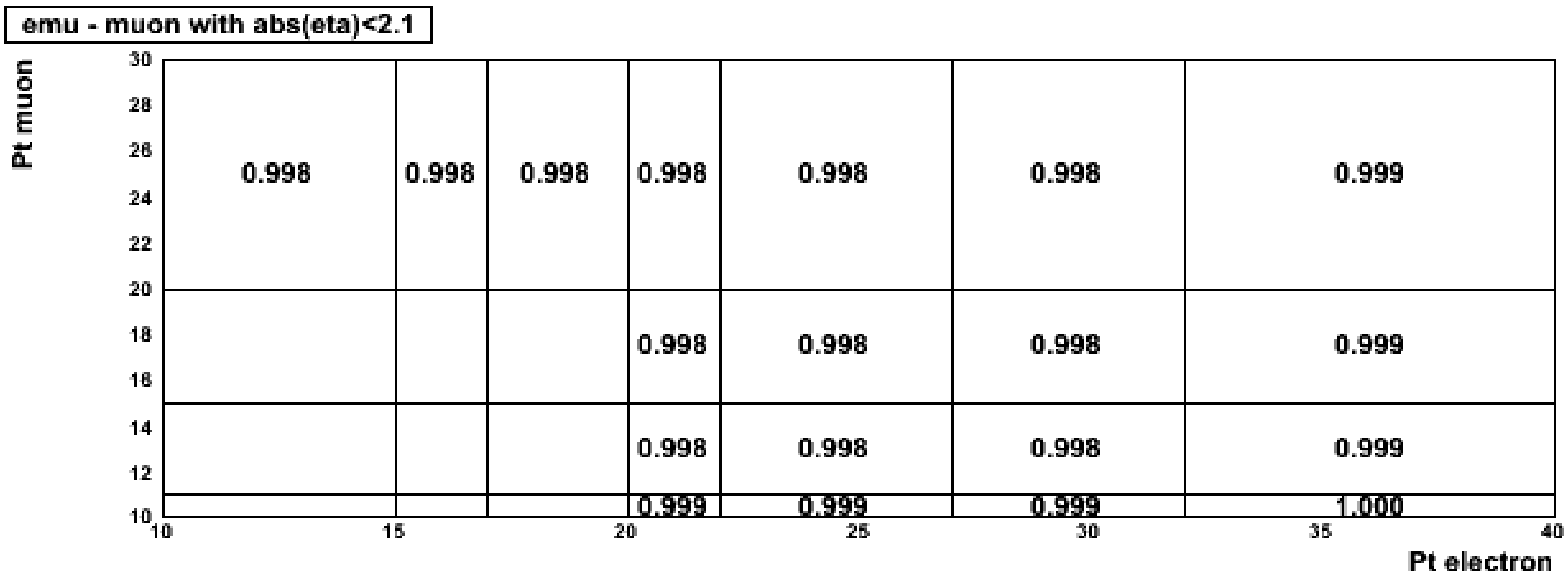
Source	#Probes (2TT)	#Probes (TP)	#Probes (TF)	Efficiency
DATA (15 GeV ID)	417	1	4	0.991 ± 0.005
DATA (20 GeV)	417	0	5	$\boxed{0.988 \pm 0.005}$

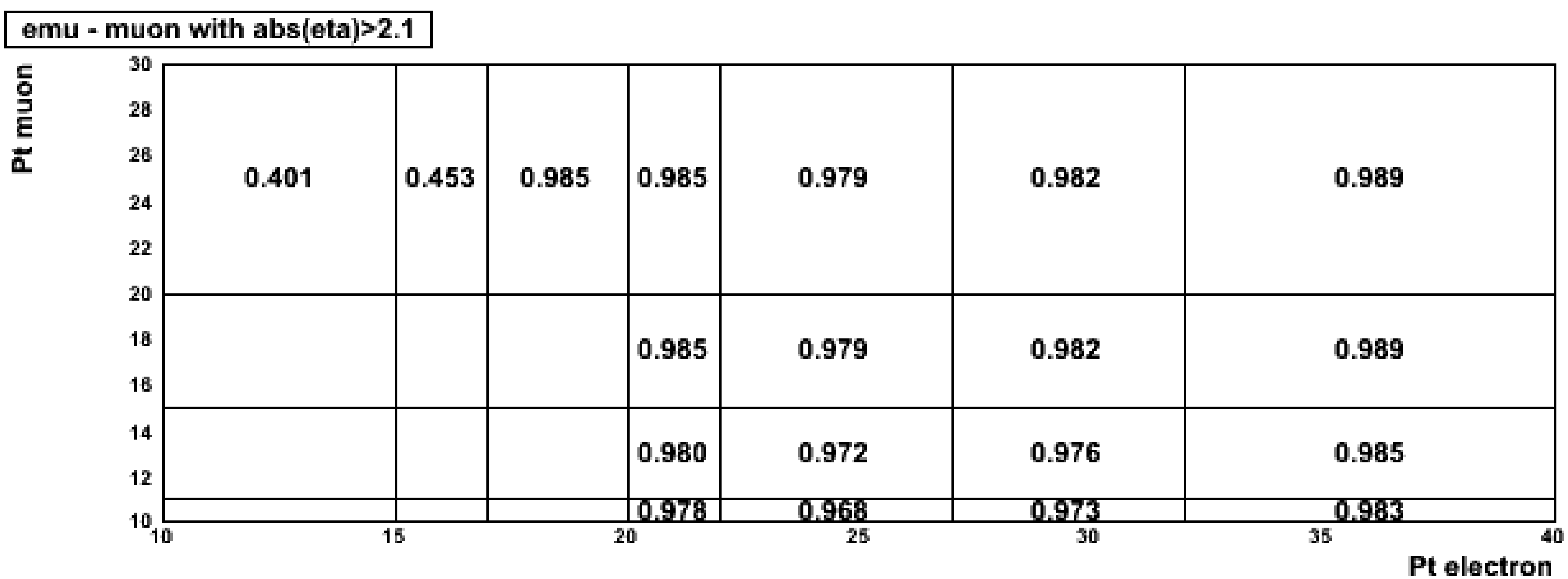
run > 144000

Table 10: Yields in the mass window for electron triggers including ID and higher threshold.

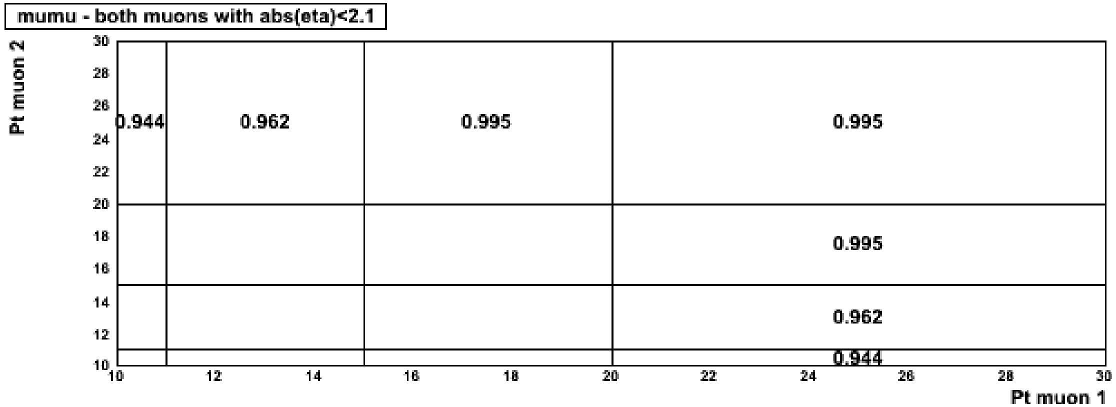
- Material from CMS AN-2010/274
- Single electron triggers have efficiency >98%
  - Efficiency for at least 1 of 2 electrons to fire: $1-(1-\varepsilon)^2 \sim 100\%$

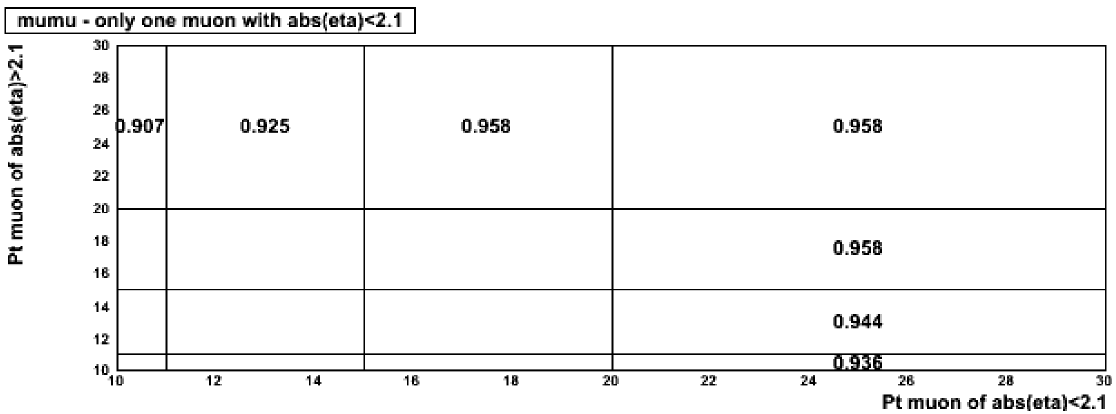
Trigger Efficiencies (eμ)

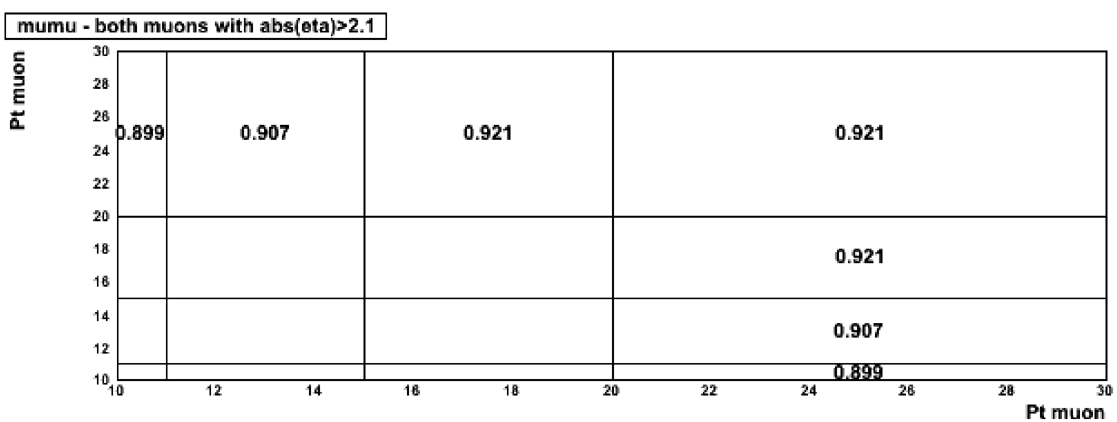




Trigger Efficiencies (μμ)







Trigger Efficiency Uncertainty

- Trigger efficiency for 2 leptons $p_T > (20,10)$ GeV is close to 1, since there are 2 chances to pass single lepton triggers which each have high efficiency
- Measure single-lepton trigger efficiencies using same T&P technique used for ttbar (CMS AN-201-/274)
- Apply to MC a simplified model of trigger efficiency based on lepton flavors (ee, $\mu\mu$, eμ), lepton p_T, and η (for muons only) (results in backup)
- Evaluate uncertainty by comparing yield in signal region assuming 100% trigger efficiency (unweighted sig yield) vs. efficiency from trigger model (weighted sig yield), assess the difference as the systematic uncertainty
  - tt → dilepton 0.3%, LM0 0.6%, LM1 0.6%
- **Trigger efficiency uncertainties less than 1%**

Z T&P ID/iso Efficiency

Electron

pt		10-15	15-20	20-40	40-	Total
id+iso / iso	35 /pb data	0.696 ± 0.096	0.919 ± 0.035	0.928 ± 0.009	0.932 ± 0.009	0.925 ± 0.007
	DY+WJets	0.778 ± 0.0632	0.892 ± 0.0249	0.932 ± 0.0050	0.943 ± 0.0048	0.934 ± 0.0037
id+iso / id	35 /pb data	0.889 ± 0.074	0.966 ± 0.024	0.992 ± 0.003	0.996 ± 0.002	0.991 ± 0.002
	DY+WJets	0.942 ± 0.0392	0.956 ± 0.0170	0.982 ± 0.0027	0.994 ± 0.0016	0.987 ± 0.0018

Muon

pt		10-15	15-20	20-40	40-	Total
id+iso / iso	35 /pb data	1.000 ± 0.049	1.000 ± 0.014	0.966 ± 0.006	0.955 ± 0.007	0.962 ± 0.005
	DY+WJets	0.978 ± 0.0186	0.981 ± 0.0093	0.984 ± 0.0023	0.985 ± 0.0023	0.984 ± 0.0017
id+iso / id	35 /pb data	0.950 ± 0.049	0.971 ± 0.020	0.980 ± 0.005	0.995 ± 0.002	0.987 ± 0.003
	DY+WJets	0.935 ± 0.0305	0.945 ± 0.0154	0.976 ± 0.0028	0.993 ± 0.0016	0.982 ± 0.0018

data/MC agree to ~2%

Jet/MET Scale Uncertainties

- Very final-state dependent: final state with lots of jets and MET less sensitive than one with jets and MET near threshold
- Use method from tt→dilepton analysis (CMS AN-10-258) to evaluate acceptance uncertainty for ttbar, LM0, LM1, assuming 5% uncertainty in CMS hadronic energy scale
    - ttbar: 8% (pre-selection), 27% (signal region selection)
    - LM0: 14% (signal region selection)
    - LM1: 6% (signal region selection)

Upper Limits: Dependence on NBKG and Uncertainty

All upper limits computed from bayes.f*: 1 observed event, 0 uncertainty on signal acceptance, 95% CL, integration upper limit 30, step size 0.02

Background

0.0 ± 0.0: UL = 4.754

1.0 ± 0.0: UL = 4.123
1.0 ± 0.1: UL = 4.127
1.0 ± 0.4: UL = 4.183
1.0 ± 0.7: UL = 4.215

1.5 ± 0.0: UL = 3.952
1.5 ± 0.4: UL = 4.001
1.5 ± 0.7: UL = 4.078
1.5 ± 1.0: UL = 4.119

*J. Conway, http://www-cdf.fnal.gov/physics/statistics/code/bayes.f.

Signal Contamination

- Signal contamination tends to dilute the significance of an excess by inflating the background prediction
- Effects of signal contamination depend strongly on the signal, and we don't know what the signal looks like
- Using multiple, independent data-driven techniques adds redundancy and achieves sensitivity to larger region of NP phase space
  - Consider NP scenario with pT(ll) ~ MET: observe excess using ABCD method but not using pT(ll) template method
- Quote expected results for LM0, LM1: signal contamination is present but does not hide the presence of the signal

MC Expected Results (34 pb^{-1})

	Yield	ABCD	$P_T(\ell\ell)$
SM only	1.3	1.3	0.9
SM + LM0	9.9	6.1	2.4
SM + LM1	4.8	1.8	1.6

Details of H_T Trigger Search

Object Selection

Muons	Cut
p_T	$\geq 5.$
$\|\eta\|$	≤ 2.4
GlobalPromptTight	
TrackerMuon	
Number of hits	≥ 11
Number of pixel hits	≥ 1
Number of matches	≥ 2
Impact par. XY(PV)	≤ 0.02
Impact par. Z(PV)	≤ 1
Combined relative isolation	≤ 0.2

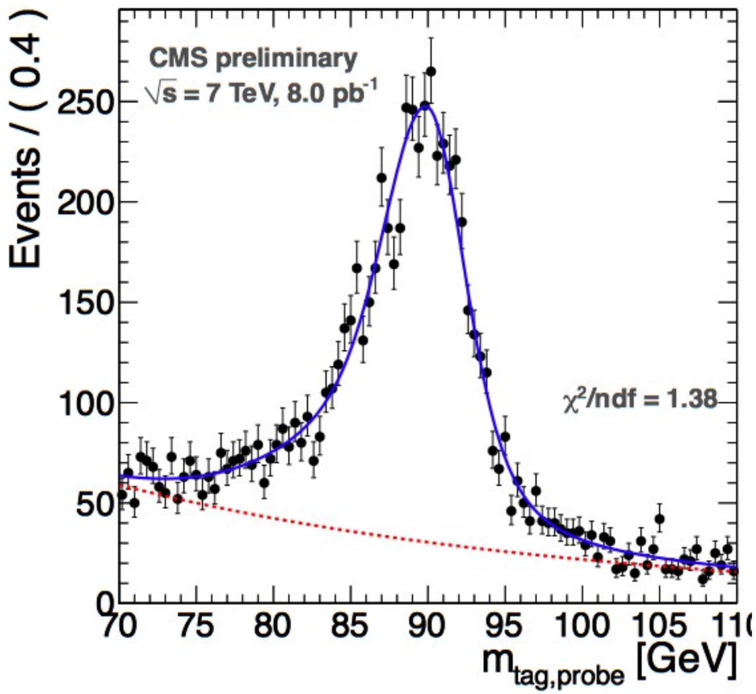
Electrons	Cut
p_T	$\geq 5.$
$\|\eta\|$	≤ 2.4
Mva cut	≥ 0.4
Lost hits	≤ 1
Impact par. XY(PV)	≤ 0.04
Impact par. Z(PV)	$\leq 1.$
Isolation	≤ 0.2

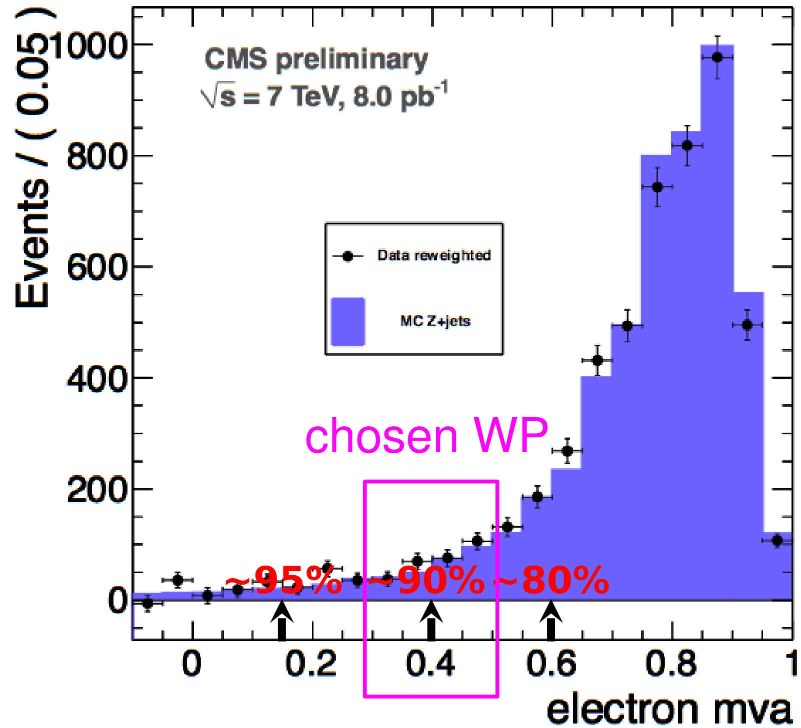
- All primary data streams
- Require good vertex (!Fake, ndf > 4, |z| < 24 cm, ρ < 2 cm)
- Beam scraping removal (25% high purity tracks)

- Jets $|\eta| < 3$, $p_T > 30$ GeV
- antikt5 jet algorithm
- Corrected up to level 3 using jet energy corrections
- Loose PFJetID as recommended
- pfMET

Electron ID

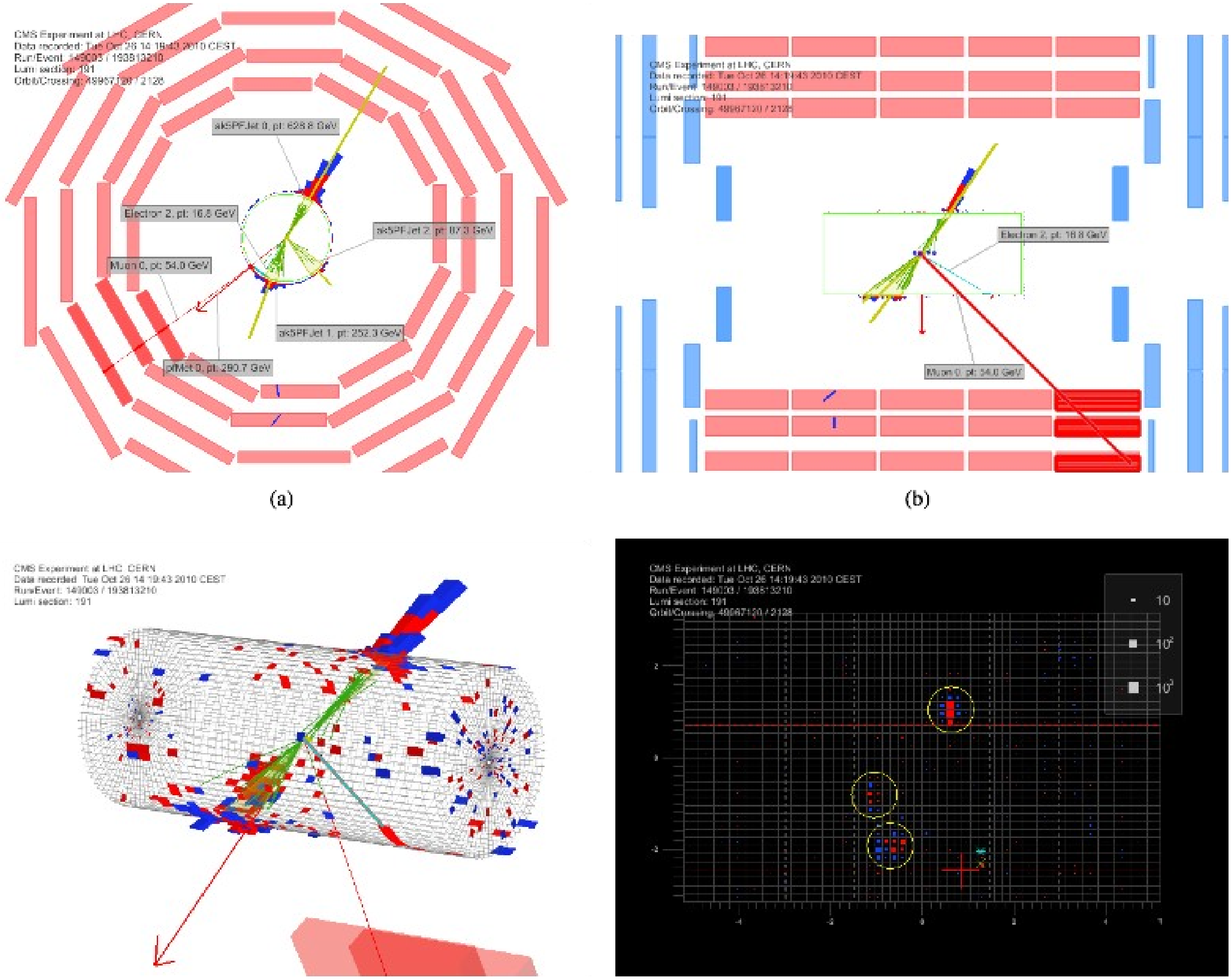
sPlot: http://arxiv.org/abs/physics/0402083v3





- ID can be done via BDT (energy momentum comparison, track quality, geometrical quantities)
- One can choose desired working point depending on analysis
- Good agreement to MC (similar results J/Ψ from particle flow commissioning)

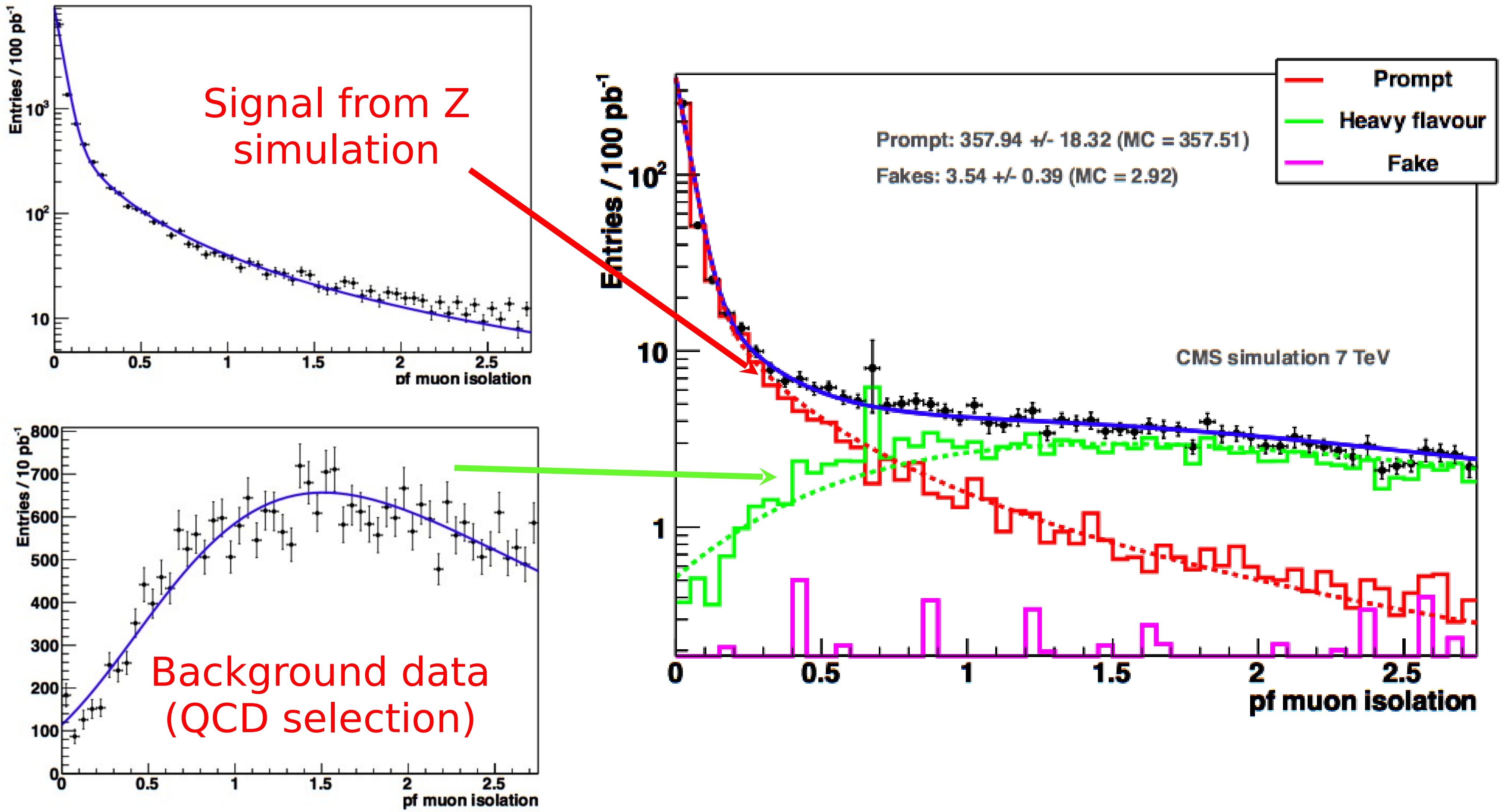
eμ Event Display



(a) (b) (c) (d)

run lumi event: 149003 191 193813210

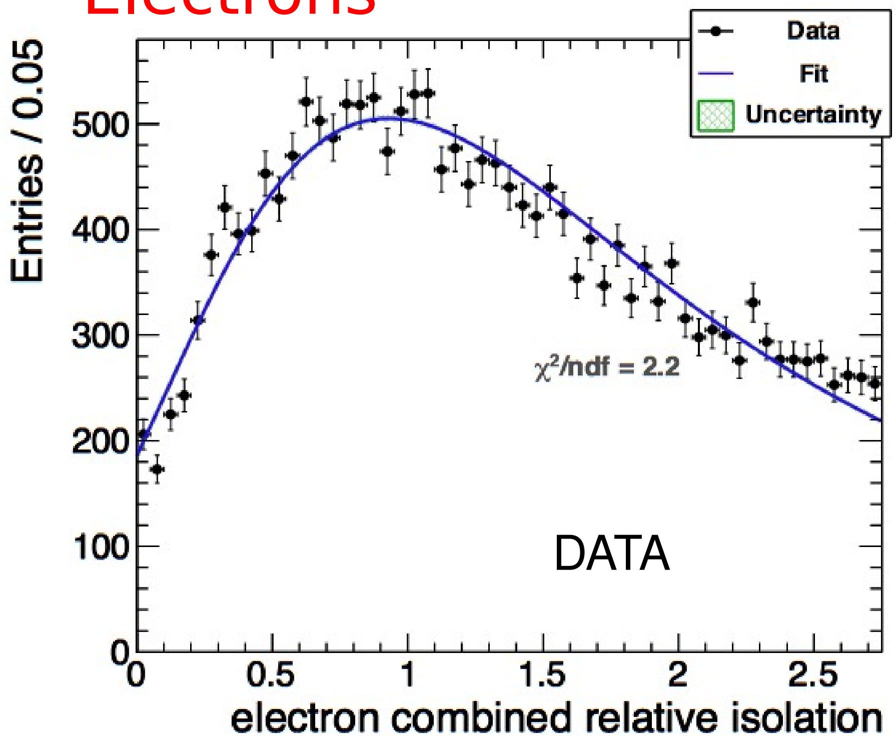
Fake Lepton Background Method



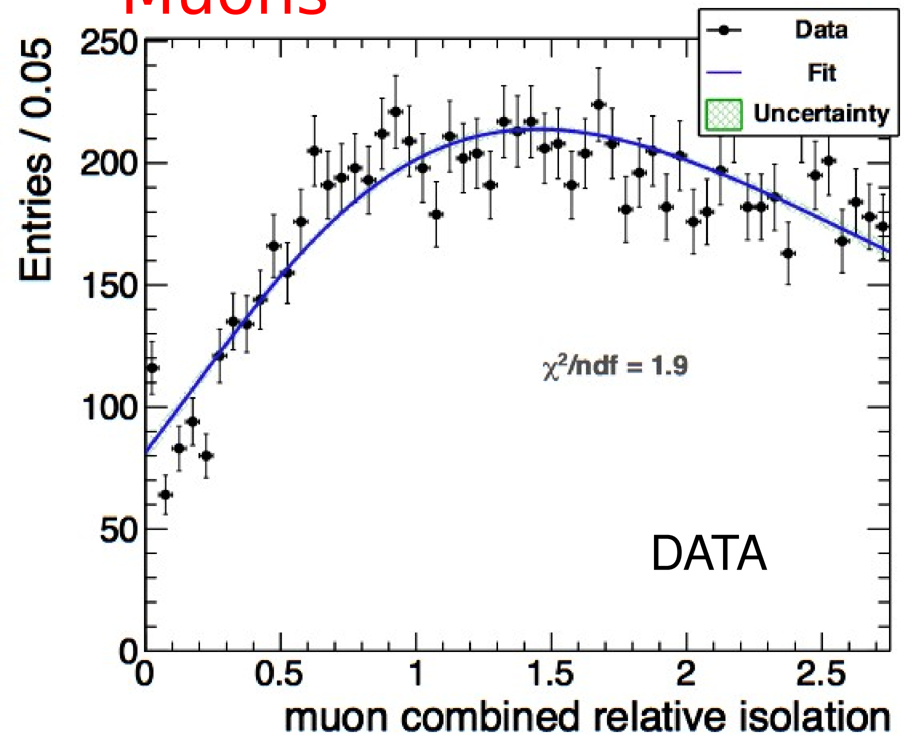
Allows to extract the purity of the lepton selection in the final sample!

Background Templates

Electrons

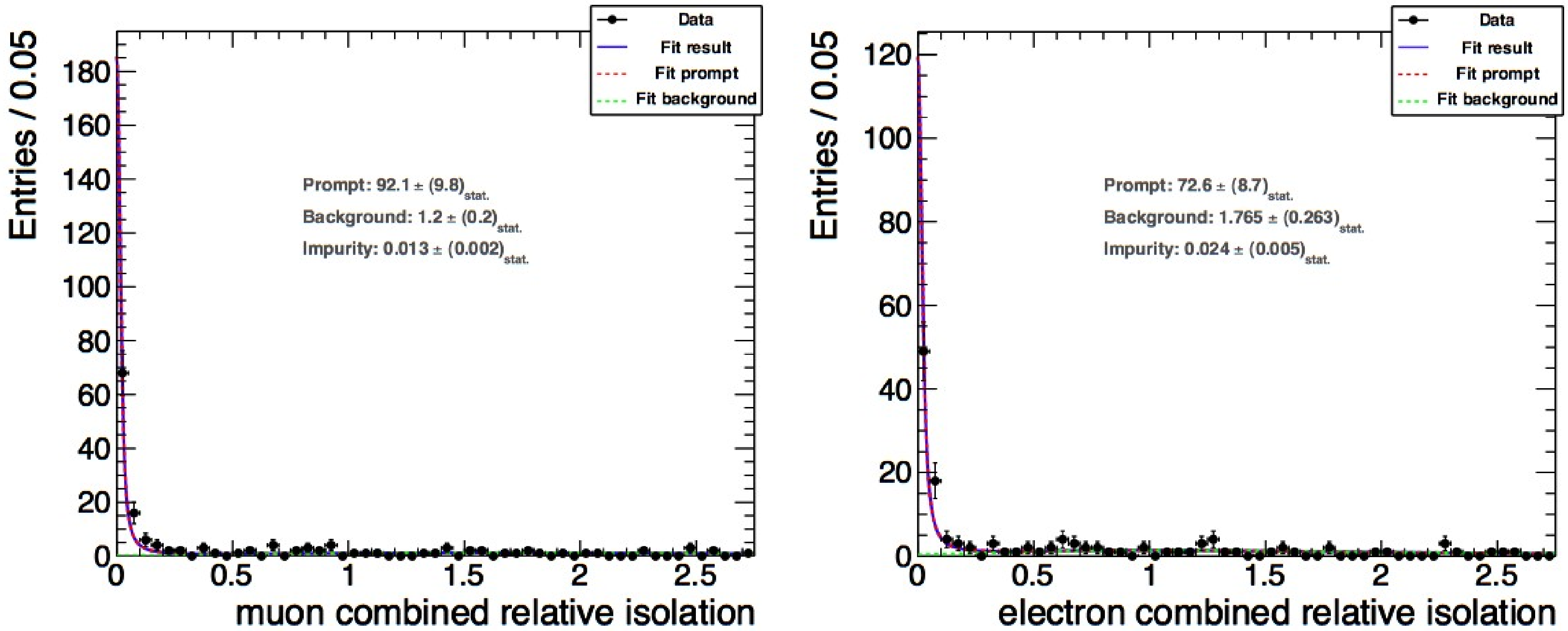


Muons



- Data driven fake template (H_T > 200 GeV, MET < 20 GeV, exactly one lepton with all identification cuts)
  - Dominated by QCD, but still some signal contamination left at low isolation
- Fakes are a subdominant background suppressed by H_T and MET cuts anyway
  - In total 50% systematic uncertainty

Fit in control region



- Very high purity as expected $H_T > 100$, MET > 80 and 20 (10) OS leptons
  - Slightly lower purity in electron channel

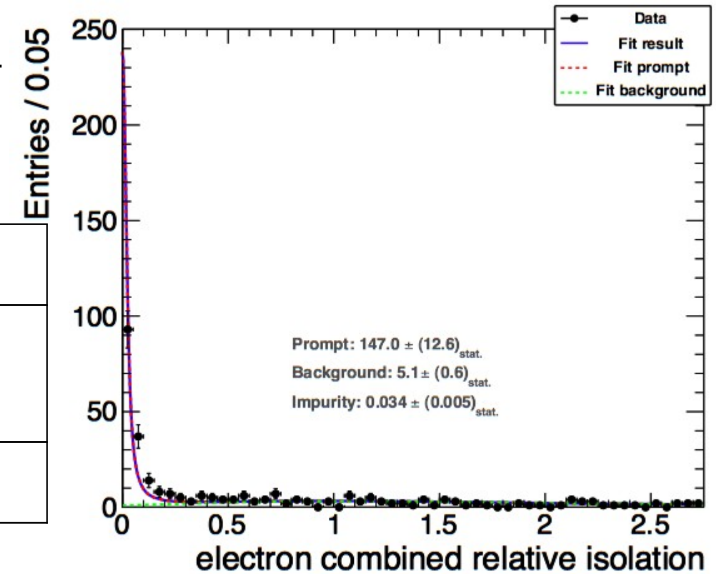
$$n_{f_{ee}} = 2n_{ee} \cdot I_e$$
$$n_{f_{\mu\mu}} = 2n_{\mu\mu} \cdot I_\mu$$
$$n_{f_{e\mu}} = n_{e\mu} \cdot I_e + n_{e\mu} \cdot I_\mu$$

- Number of fake events calculated using impurity
  - Impurity is similar to expectation in simulation

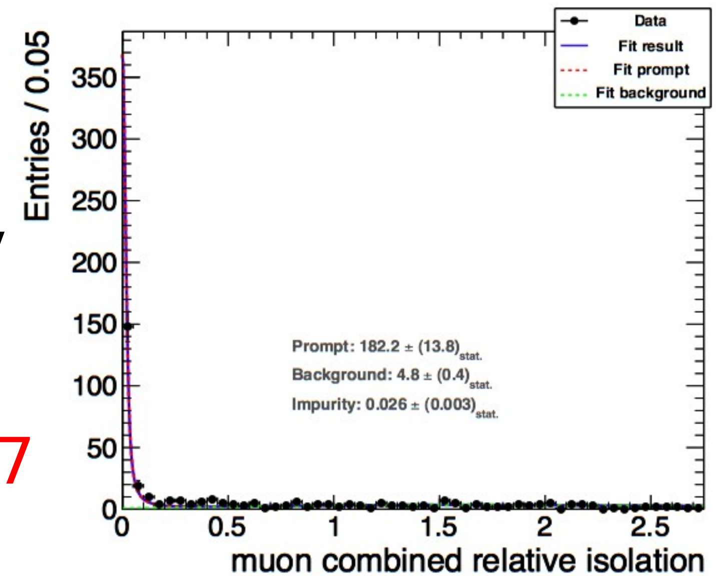
Closure test in simulation

- Closure test on simulation
- 35 pb^{-1} of pseudo data with MET > 50 GeV, H_T > 100 GeV, 20 (10) GeV

Fit	Electrons	Muons
Prompt	147.0 ± 12.6 (151)	182.2 ± 13.8 (178)
Fake	5.1 ± 0.6 (4)	4.8 ± 0.4 (3)

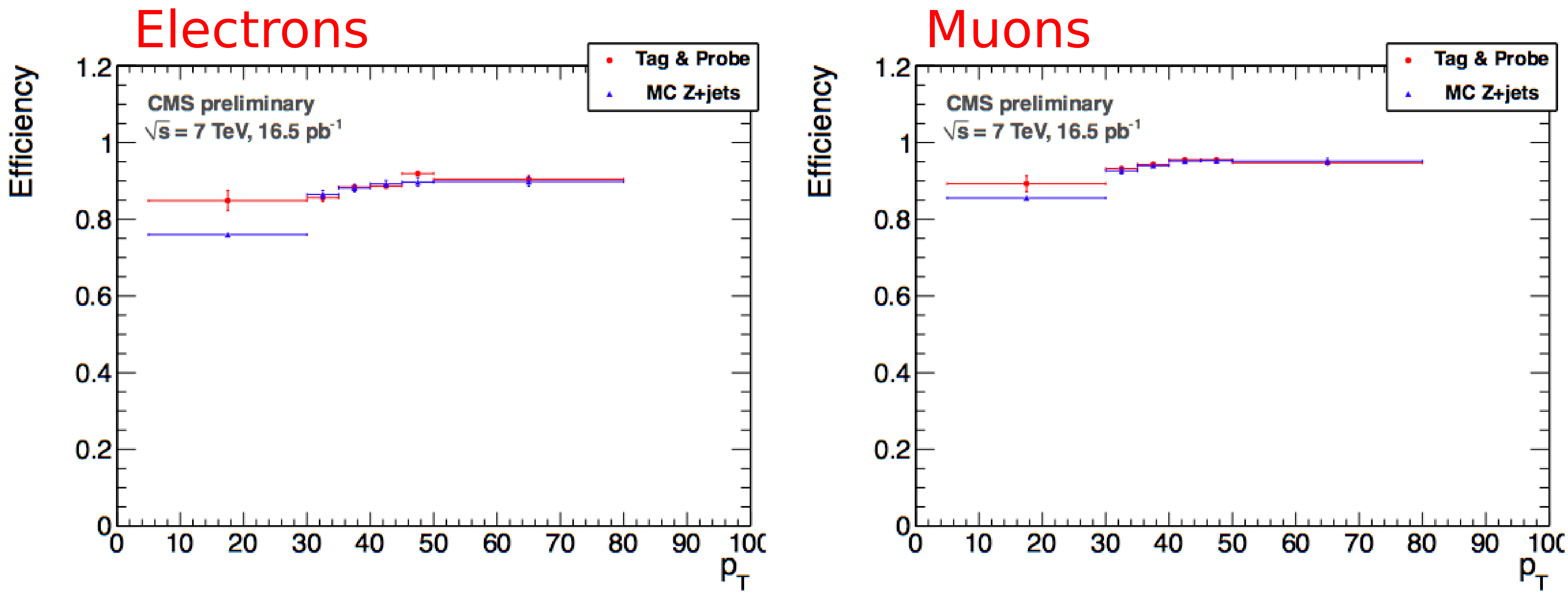


- We observe good agreement in simulation
- From these numbers the impurity is determined
- Number of fake events by multiplying impurity to the number of candidate leptons in selection



Closure test on first data: AN-2010/167

Lepton efficiency measurement

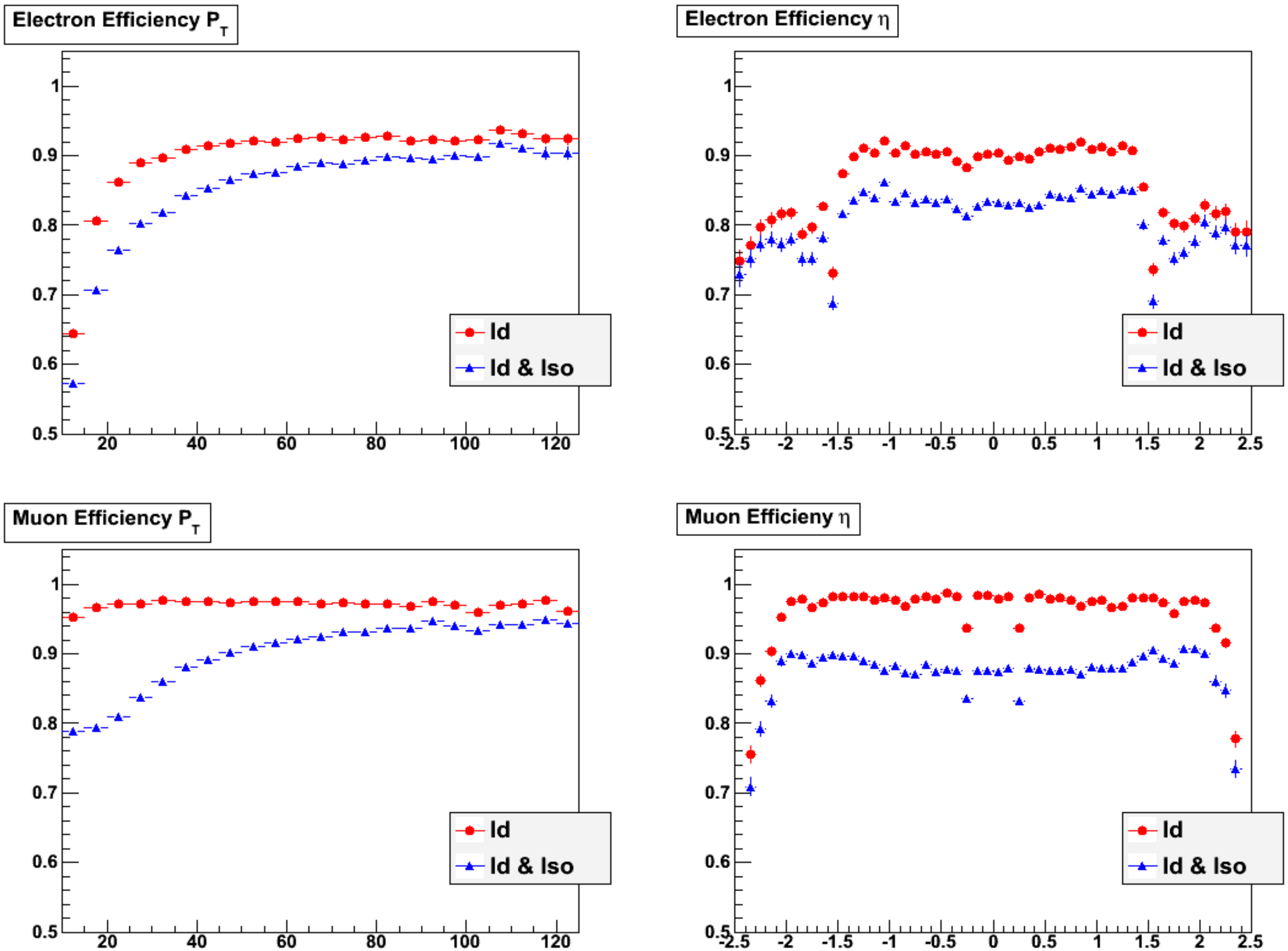


- Tag and probe on the Z using tracks and superclusters as probe via fit
- Efficiency on the bulk of Z production is well in agreement with simulation
- Use the ratio of electron to muon efficiency in the opposite flavour subtraction

	Data	Monte Carlo
electron	$0.88 \pm 0.004(\text{stat}) \pm 0.02(\text{syst})$	$0.87 \pm 0.002(\text{stat})$
muon	$0.94 \pm 0.002(\text{stat}) \pm 0.02(\text{syst})$	$0.93 \pm 0.002(\text{stat})$
ratio	$1.07 \pm 0.005(\text{stat}) \pm 0.05(\text{syst})$	$1.052 \pm 0.003(\text{stat})$

Additional Info for Model Testing

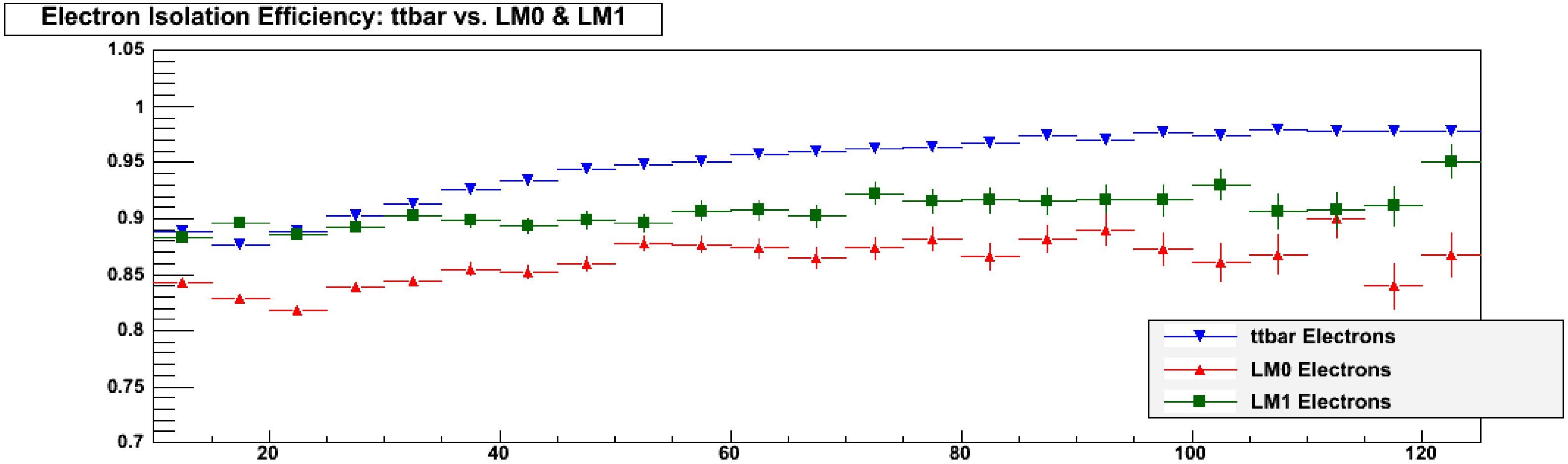
Lepton Selection Efficiencies

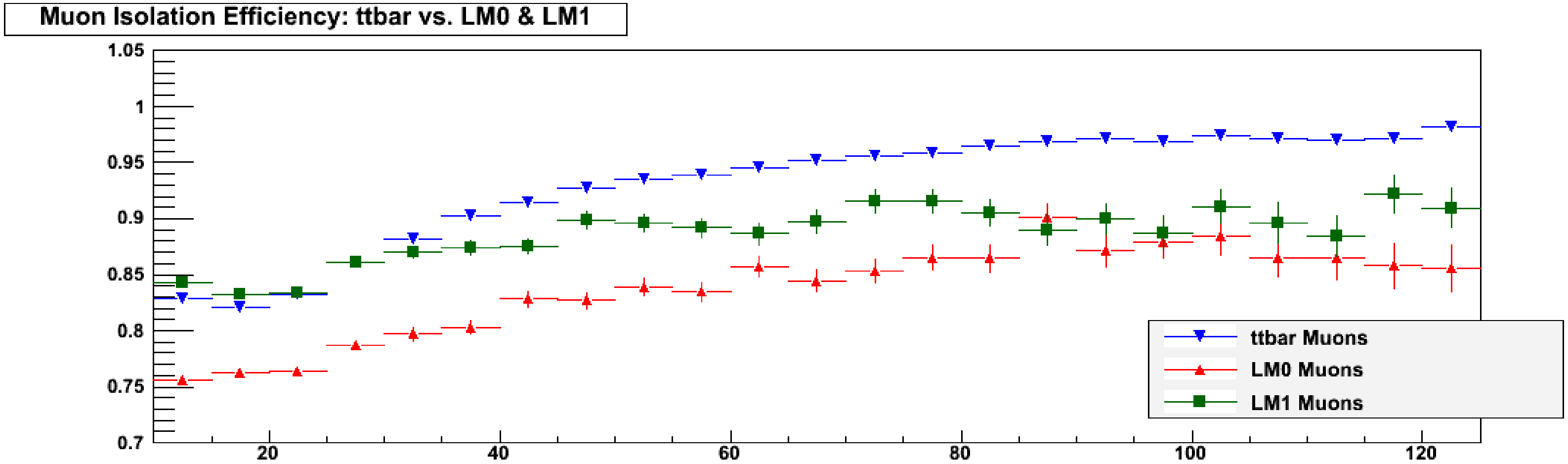


- ID/iso efficiencies for $t \rightarrow W \rightarrow l$ and $t \rightarrow W \rightarrow \tau \rightarrow l$ in ttbar MC

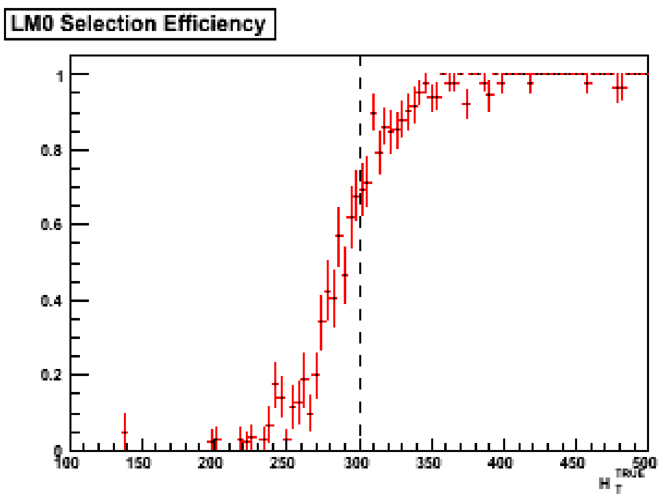
Isolation Efficiency

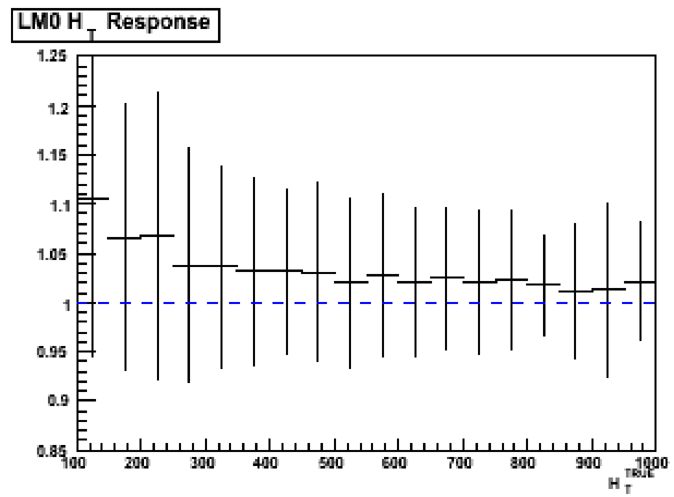
- Isolation efficiency depends on final state jet activity
  - Observe difference of ~5-10% per lepton ttbar vs. LM0, LM1



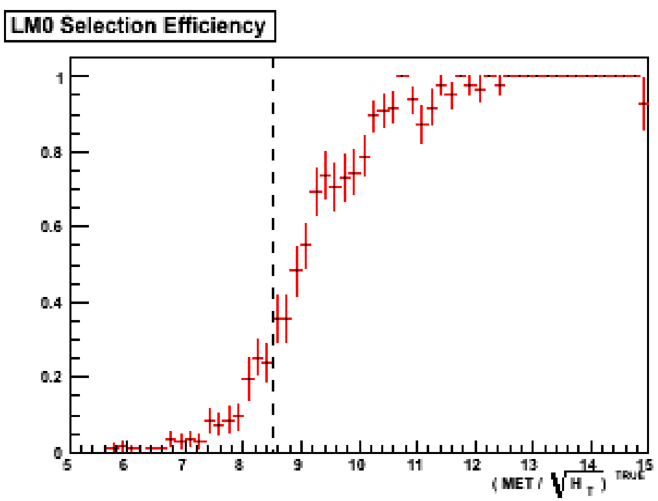


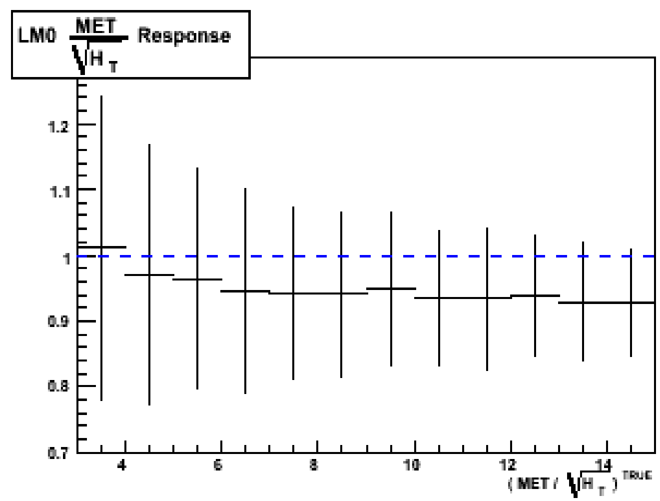
Efficiency/Response Curves





average sumJetPt response 1.02 with RMS 11%

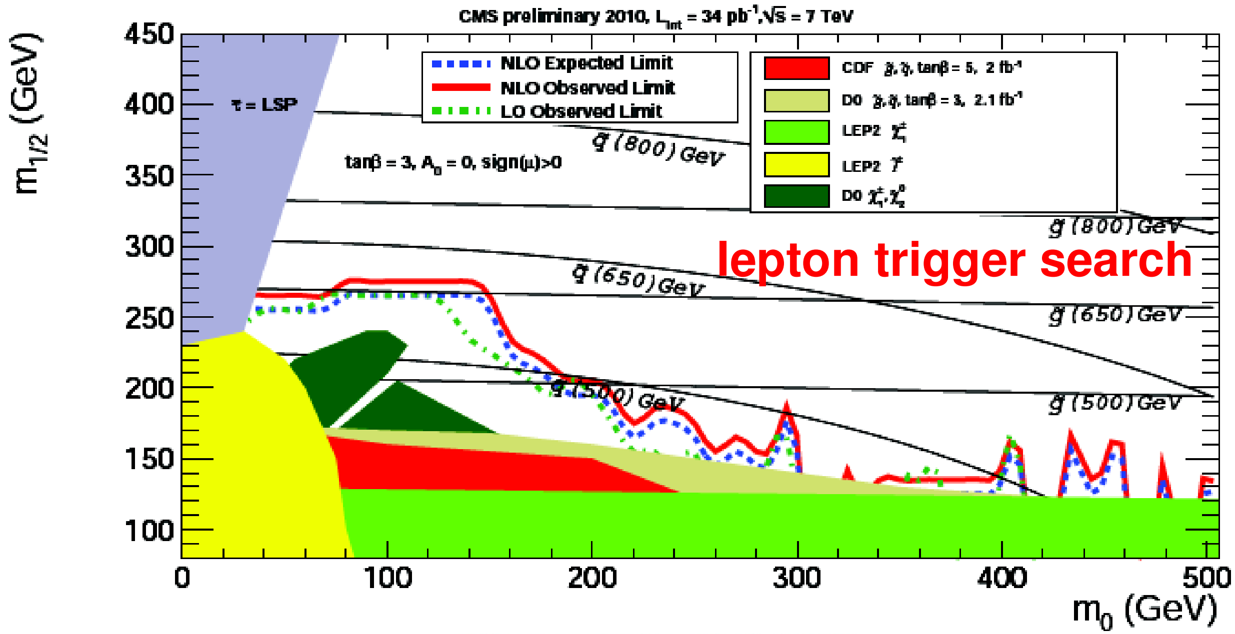


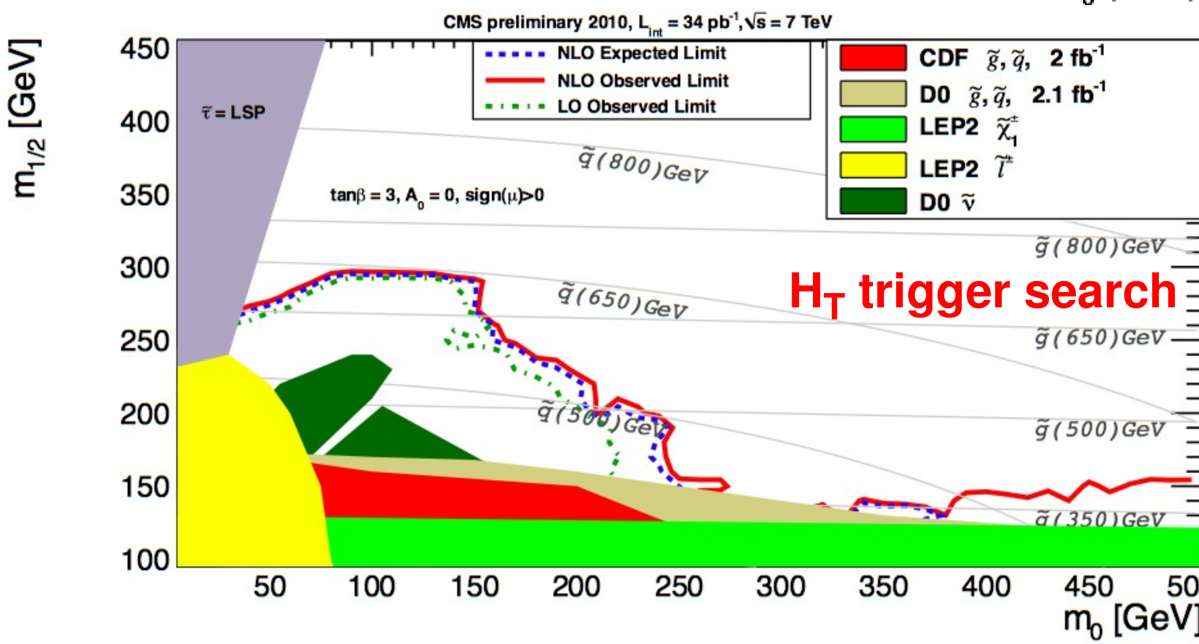


average MET/$\sqrt{H_T}$ response 0.94 with RMS ~14%

- Plot efficiency and response (reco quantity/gen quantity) as a function of gen quantity
- LM0 shown, but efficiency/response doesn't depend strongly on underlying physics

Comparison of cMSSM Exclusion Regions





Comparison of cMSSM Exclusion Regions