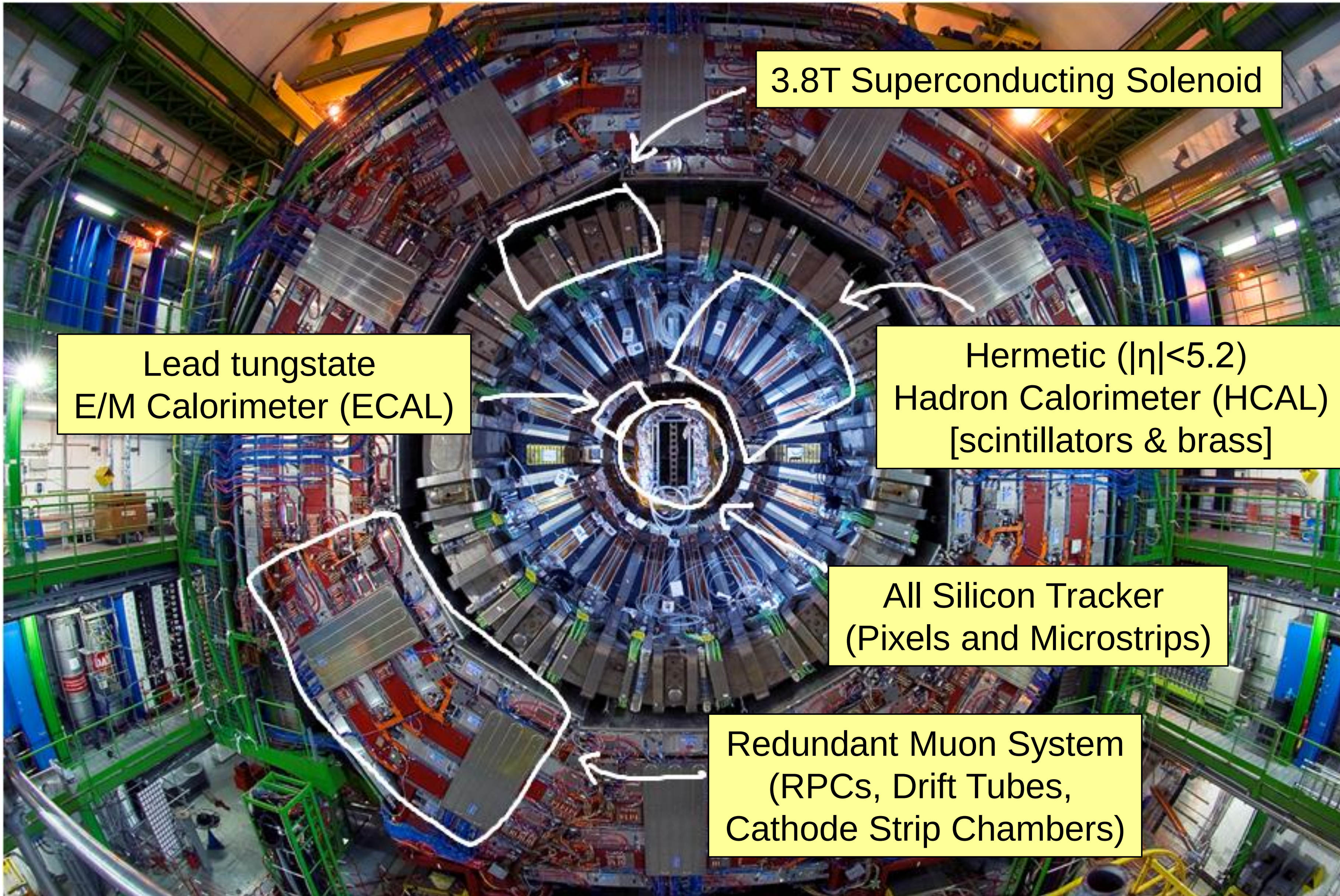
Search for Non-Resonant New Phenomena with the CMS Experiment

Christos Leonidopoulos (Fermilab)

International Europhysics Conference on High Energy Physics

20-27 July 2011, Grenoble

The CMS Detector



Highlights from 2010 analyses

Search for Pair Production of First-Generation Scalar Leptoquarks Using Events Containing Two Electrons And Two Jets Produced in pp Collisions at $\sqrt{s}$ = 7 TeV

Phys. Rev. Lett. 106, 201802 (2011)

Search for Pair Production of Second-Generation Scalar Leptoquarks in pp Collisions at $\sqrt{s}$ = 7 TeV

Phys. Rev. Lett. 106, 201803 (2011)

Search for First Generation Scalar Leptoquarks in the eνjj Channel in pp Collisions at $\sqrt{s}$ = 7 TeV

arXiv:1105.5237, submitted to Phys.Lett.B

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Search for Large Extra Dimensions in Dimuon Events in pp Collisions at sqrt(s) = 7 TeV

Physics Analysis Summary EXO-10-020

Search for Large Extra Dimensions in the Diphoton Final State at the Large Hadron Collider

arXiv:1103.4279, accepted by JHEP

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Search for New Physics in Highly Boosted Z0 Decays to Dimuons in pp Collisions at sqrt(s)=7 TeV

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Model Unspecific Search for New Physics in pp Collisions at sqrt(s) = 7 TeV

Physics Analysis Summary EXO-10-021

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Phys. Rev. Lett. 106, 201803 (2011)

Search for First Generation Scalar Leptoquarks in the eνjj Channel in pp Co...

Se...

- 2010 analyses made public before EPS 2011
- No evidence for New Physics

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

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Physics Analysis Summary EXO-10-021

W' searches with 2011 data

W': Overview

- Many beyond-the-SM theories predict new vector bosons: W' and Z'
  - GUT, SUSY, ED, Little Higgs, Technicolor, etc
  - "Natural" new particles to predict: any extension of SM gauge group introduces new vector bosons

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- W' Signatures
  - Leptonic: $e+\nu, \mu+\nu, \tau+\nu$
  - Bosonic: $WZ, W\gamma$
  - Hadronic: qq', $t\bar{b}$, ℓN_ℓ ($N_\ell \to qq'\ell'$)

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- Large W' mass opens up new channels
- Channels that are favored/suppressed: model-dependent

W': Overview

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  - "Natural" new particles to predict: any extension of SM gauge group introduces new vector bosons

Significantly larger integrated luminosity than published 2010 analyses

- W' Signatures
  - Leptonic: $e + \nu$, $\mu + \nu$, $\tau + \nu$
  - Bosonic: WZ, $W\gamma$
  - Hadronic: qq', $t\bar{b}$, ℓN_ℓ $(N_\ell \to qq'\ell')$

Considered by CMS for the first time

Results presented here for the first time outside CMS

$$W' \to \ell\nu$$

$W' \to \ell\nu$ model

Search for W' decaying to electron/muon and neutrino

- W': carbon copy of W (same couplings to fermions)
- Neutrino is light & stable
  - Important in context of L-R symmetric model
- No mixing between W' and other bosons (W, Z, Z')
- WZ channel also suppressed

$W' \to \ell\nu$: Analysis outline

Very similar event selection & analysis cuts for e, μ channels

- Trigger:
  - Highest p_T/E_T unprescaled single lepton trigger
  - Plus M_T condition for electron channel
- Only one (good quality) isolated high-p_T/E_T lepton
- Plus: "nothing else" in the event, i.e. lepton p_T and ME_T are similar in magnitude and back-to-back in xy plane

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Typical signal efficiencies

- > 80% in both electron & muon channels
- Fairly independent of W' mass

$W' \to \ell\nu \; (\ell = e, \mu)$ signature

Spectacular signature:

- One very energetic lepton in event ("straight track")
- Plus, "nothing else" in the event

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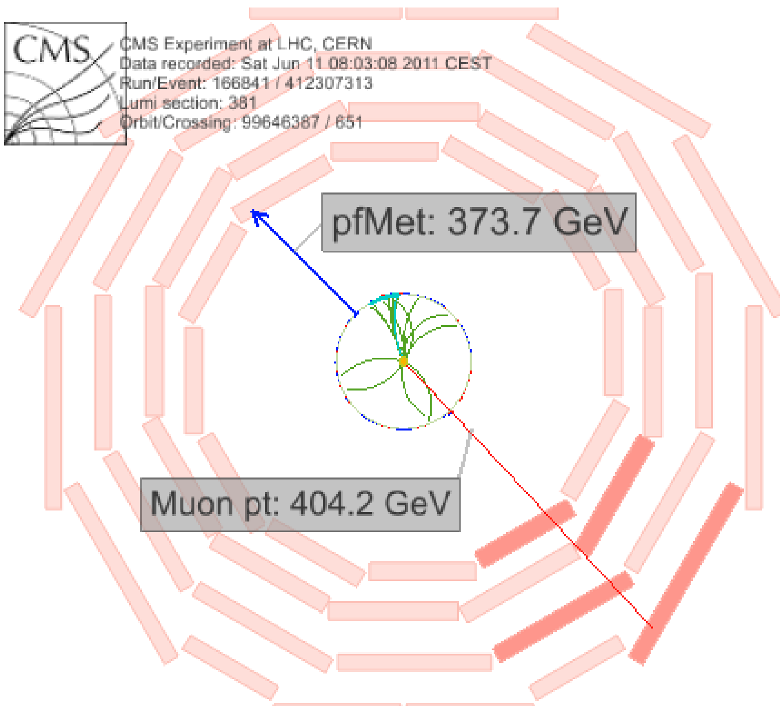
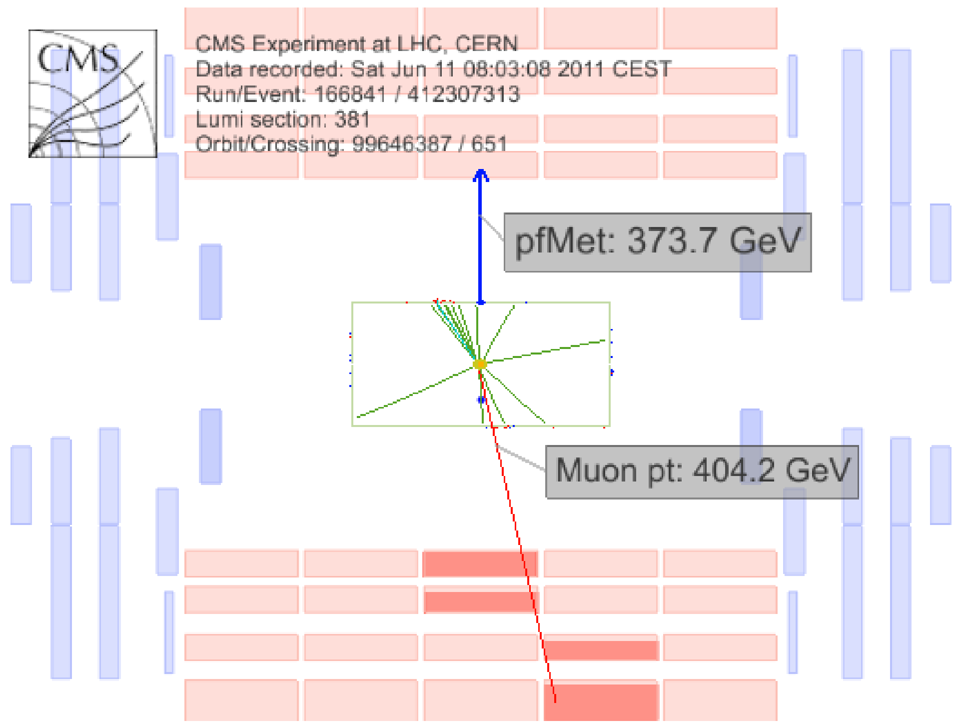
Muon channel: Event with M_T = 778 GeV





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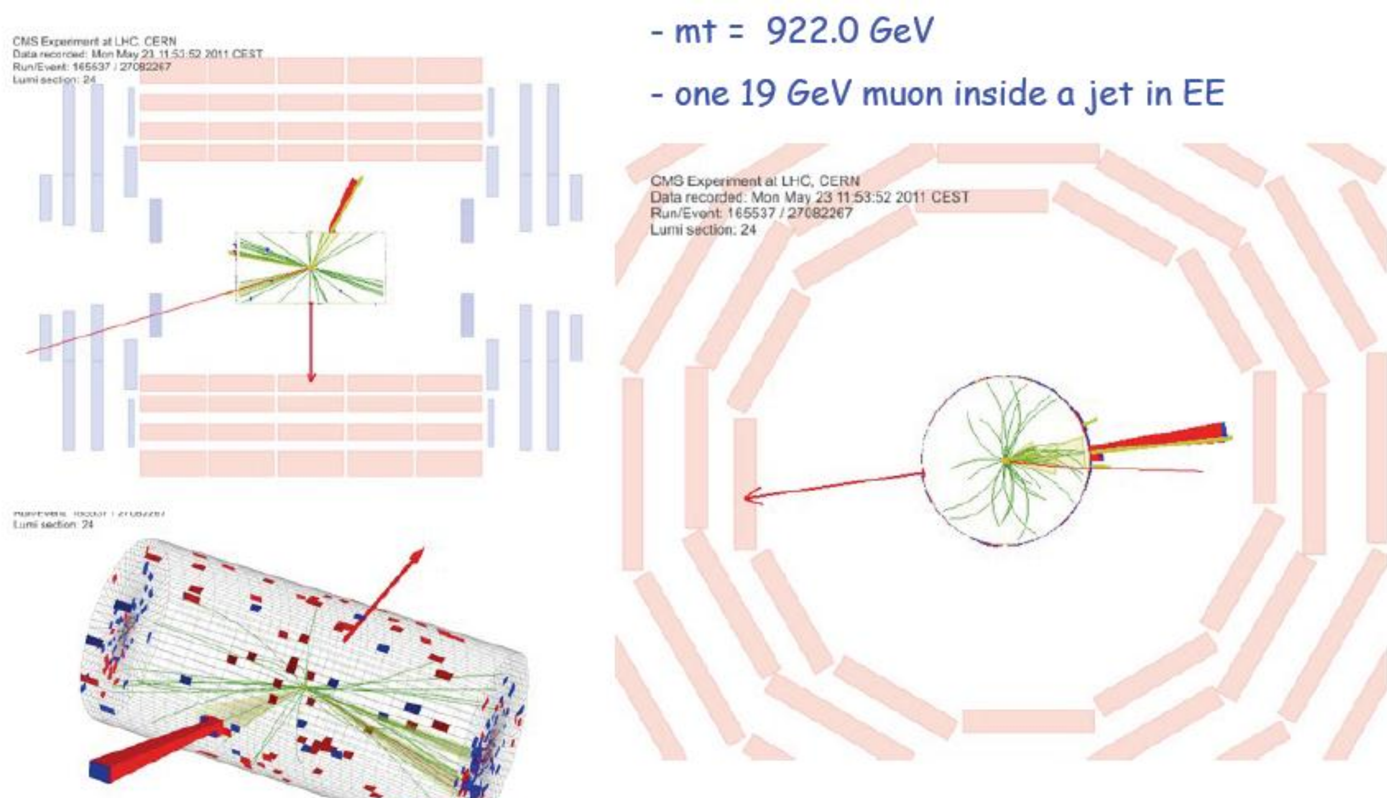


Electron channel: Event with M_T = 922 GeV

$$W' \rightarrow \ell \, N_\ell \, , N_\ell \rightarrow q q' \ell'$$

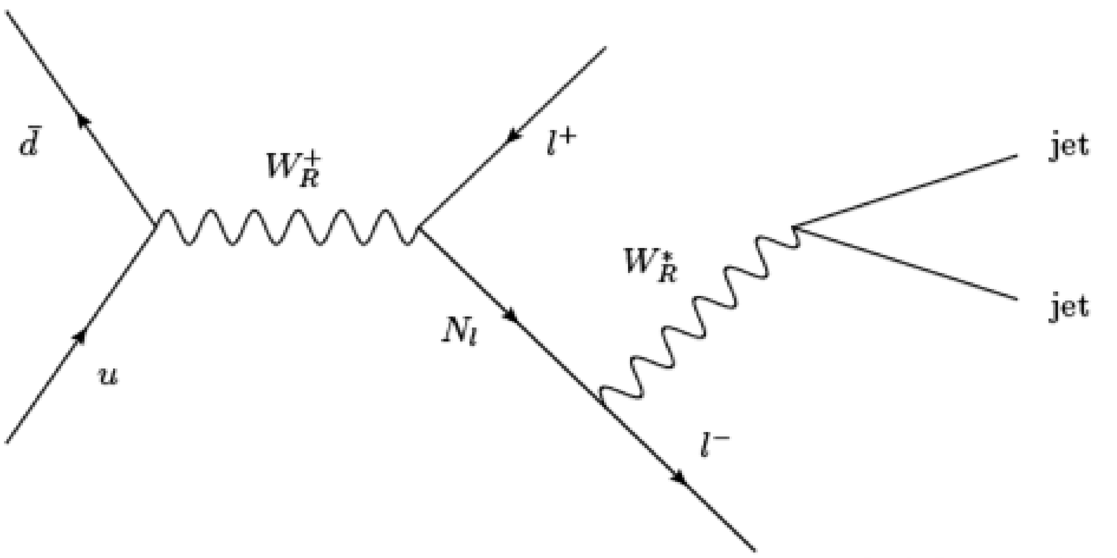
$W' \to \ell\, N_\ell\, (qq'\ell')$ model

Search for W' decaying to heavy neutrino plus lepton

- Coupling to right-handed (heavy) neutrino
- L-R symmetric model: restores parity at higher energies by introducing new heavy charged bosons
  - Parity violation explained by W, W' mass difference
- Massive neutrinos: "see-saw" mechanism

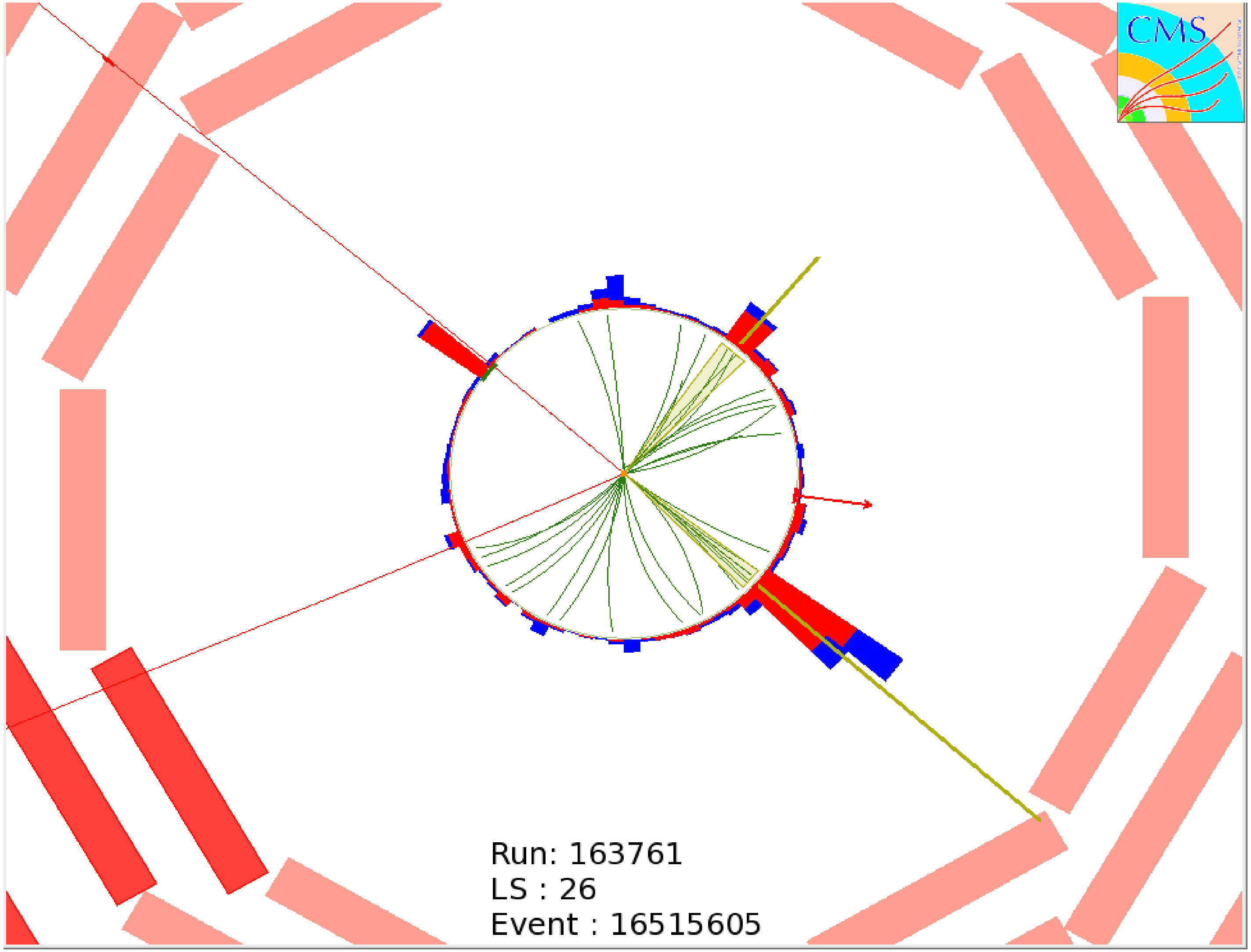
$W' \to \ell\, N_\ell\, (qq'\ell')$ model

Search for W' decaying to heavy neutrino plus lepton



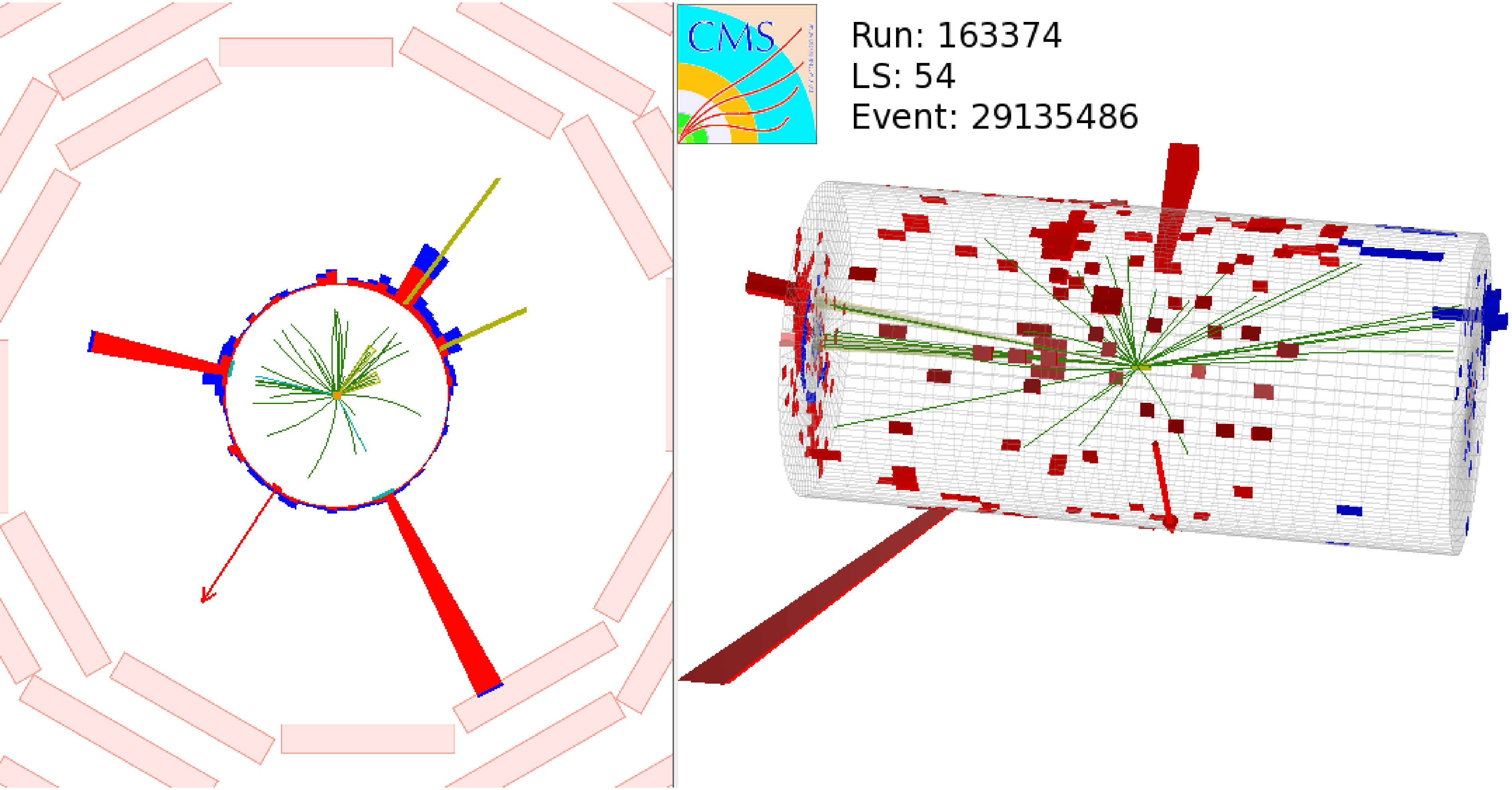
- No L-R mixing: heavy neutrino decays via $W_R{}'$
- Cross-section: depends on $W_R{}'$, N_ℓ masses (assuming $W_L{}'$ couplings)
- Final state: two (same-flavor) leptons plus two jets

$W' \rightarrow \ell\, N_\ell\, (qq'\ell')$ signature



Muon channel: Event with $M_{\mu\mu}$ = 331 GeV, $M_{\mu\mu jj}$ = 881 GeV

$W' \to \ell\, N_\ell\, (qq'\ell')$ signature



Electron channel: Event with M_{ee} = 264 GeV, M_{eejj} = 1009 GeV

$W' \to \ell\, N_\ell\, (qq'\ell')$: Analysis outline

Very similar event selection & analysis cuts for e, μ channels

- Single-lepton triggers
- Two (good quality) isolated leptons
- Two anti-k_T ($\Delta R = 0.5$) jets
- Ensure no jet-lepton overlaps
- Remove Z/Drell-Yan by applying $M_{\ell\ell}$ cut

$W' \to \ell\, N_\ell\, (qq'\ell')$: Analysis outline

Very similar event selection & analysis cuts for e, μ channels

- Single-lepton triggers
- Two (good quality) isolated leptons
- Two anti-k_T ($\Delta R = 0.5$) jets
- Ensure no jet-lepton overlaps
- Remove Z/Drell-Yan by applying $M_{\ell\ell}$ cut

Typical signal efficiencies

- 70-75% in $eejj$ channel
- 75-80% in $\mu\mu jj$ channel
- Assuming $m(N_\ell) > m(W_R{}')/2$

Background estimations

Background estimation

- $W' \to \ell\nu$: sideband fit of M_T spectrum
  - Find "signal-free" region of M_T spectrum (off-peak W)
  - Fit and use parameters to model background shape
  - Extrapolate function to "region of interest" (M_T tail)
  - Estimate background in signal region w/o relying on MC
- $W' \to \ell\, N_\ell$: combination of data- and MC-based estimates
  - Major backgrounds: top and Z +jets
    - ➢ Use MC shapes, normalize to data
  - Other backgrounds:
    - ➢ QCD: determine from data
    - ➢ W +jets, dibosons: use MC prediction

(Transverse*) Mass distributions

(*) $M_T = \sqrt{2 \cdot (p_T^{\mu} \cdot c) \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\mu,\nu})}$

$e + MET$ transverse mass

2011 analysis: 1.03 fb^{-1}

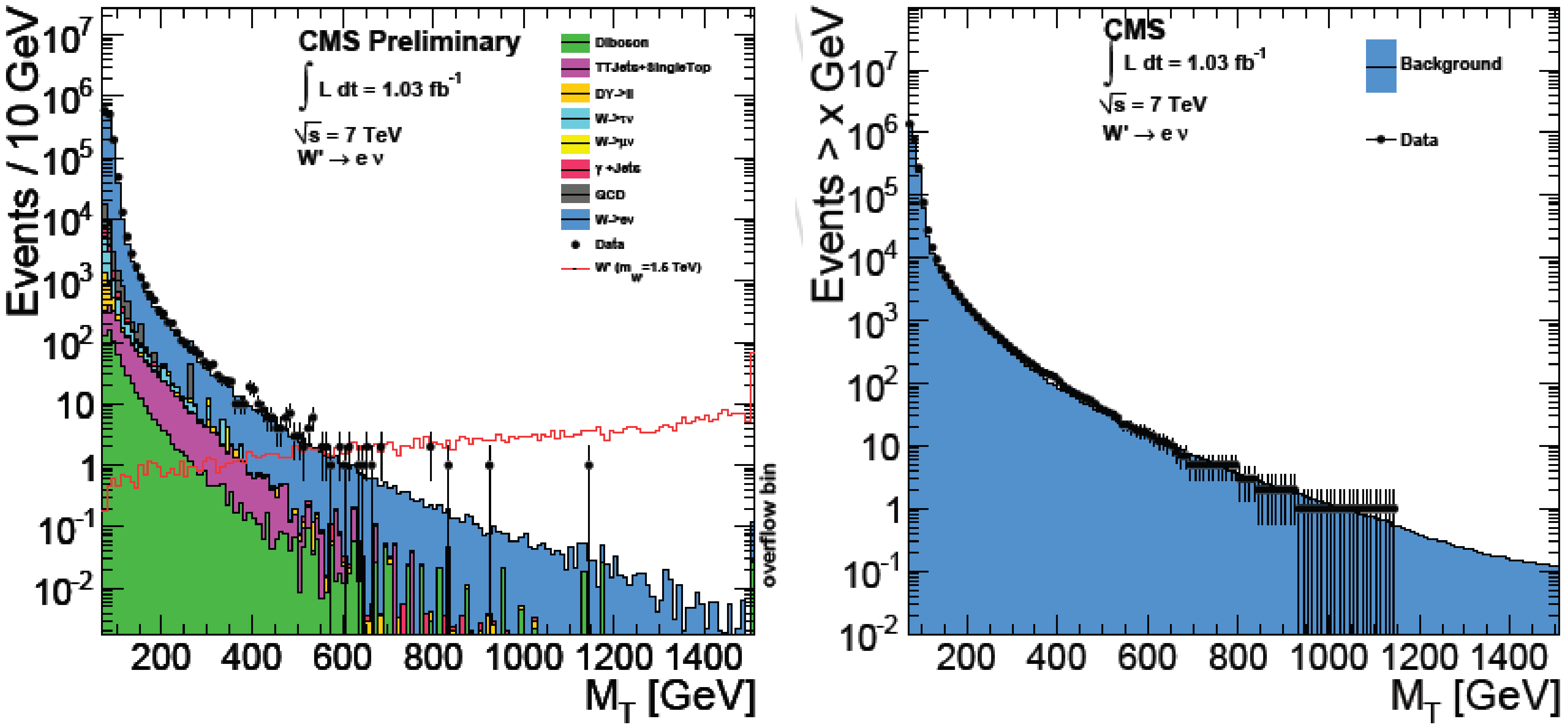


Figure 2: Transverse mass distribution (left) and cumulative distribution (right) for the electron channel.

No excess (compared to bgd expectations) observed in data

$\mu + MET$ transverse mass

2011 analysis: 1.13 fb^{-1}

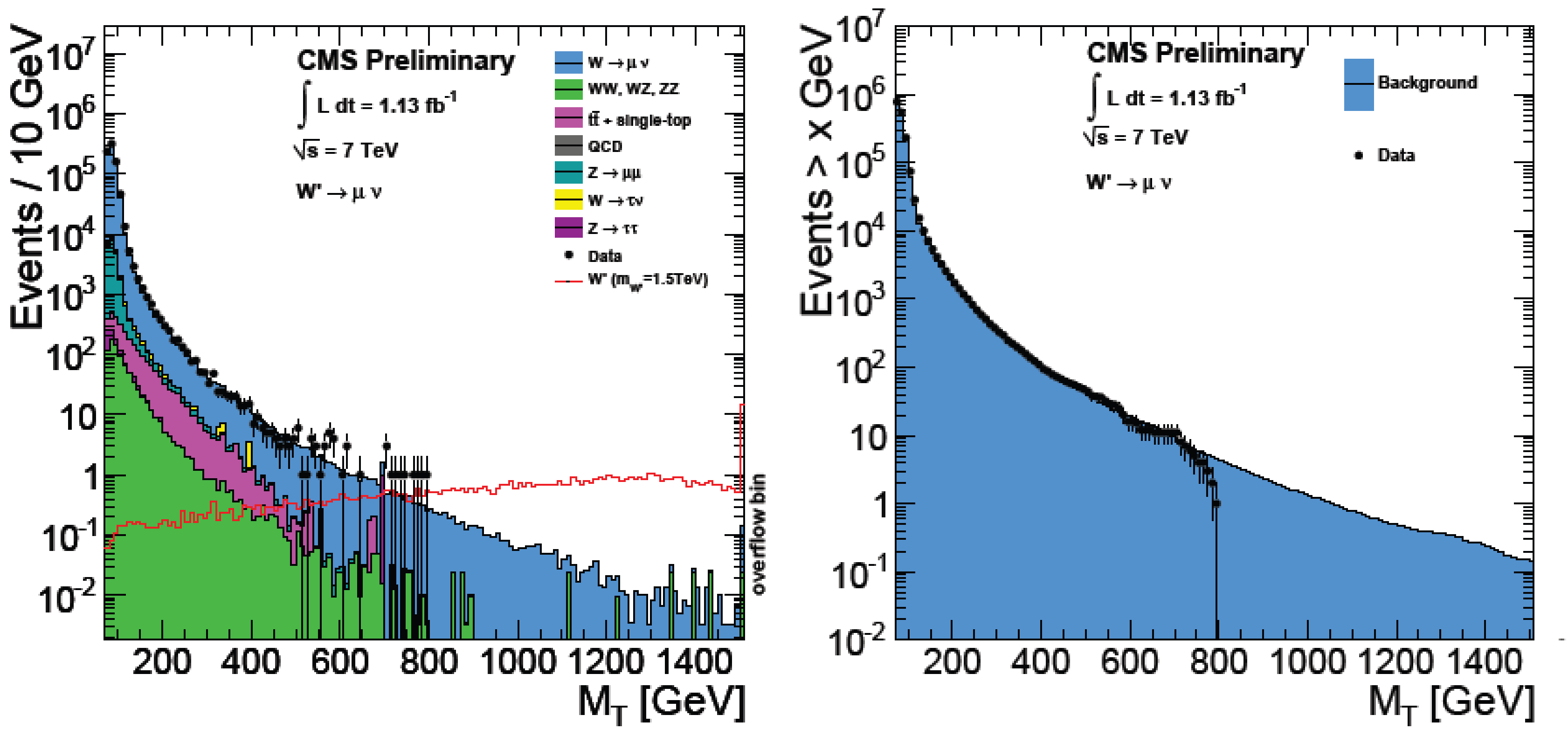


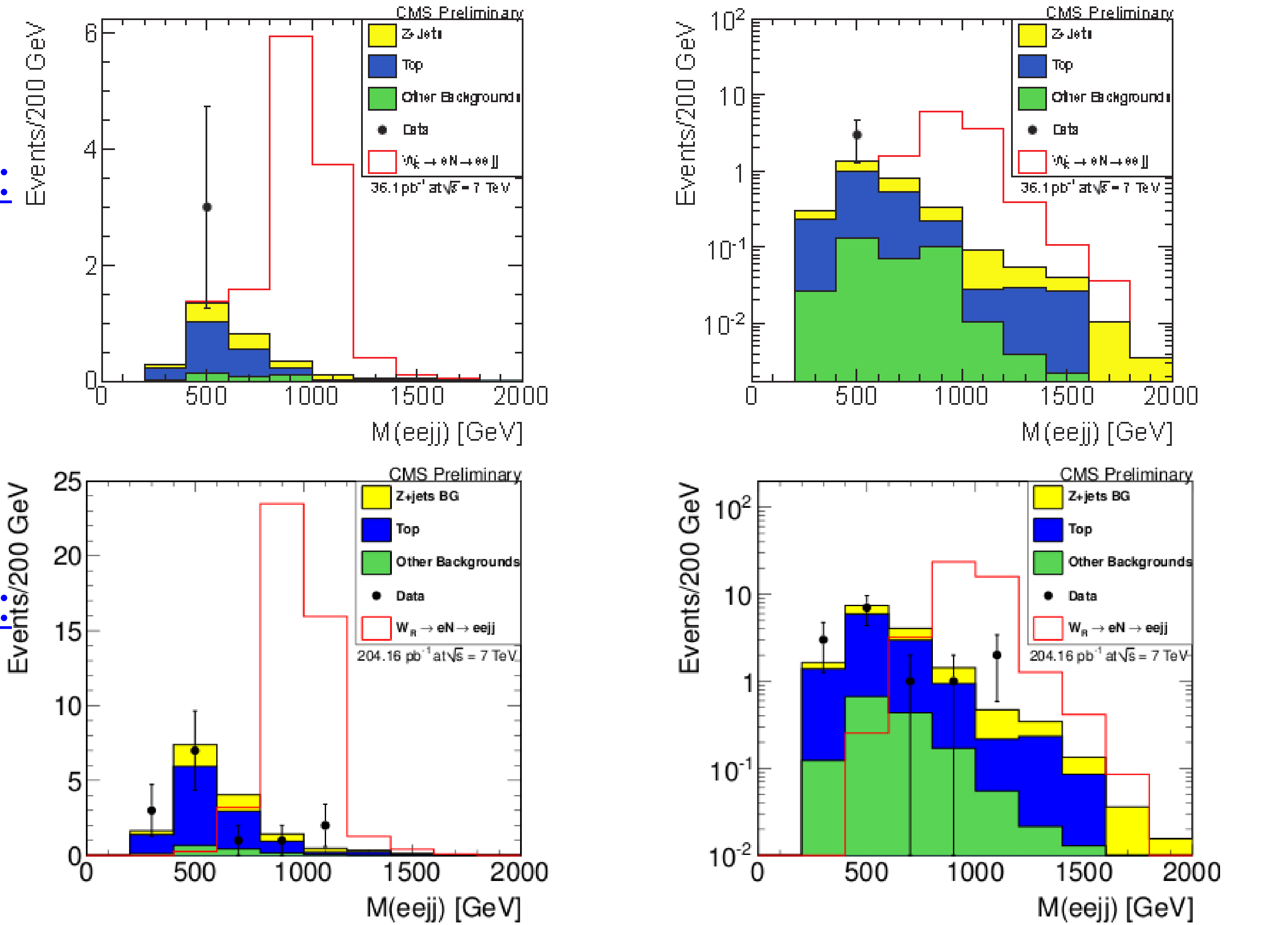
Figure 3: Transverse mass distribution (left) and cumulative distribution (right) for the muon channel.

No excess (compared to bgd expectations) observed in data

eejj invariant mass

2010 analysis: 36 pb^{-1}

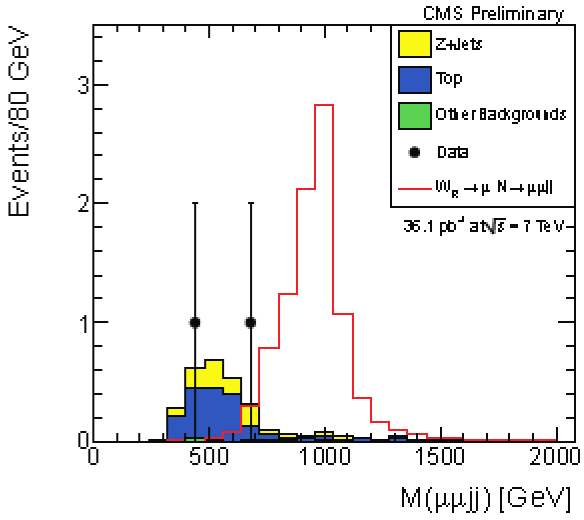
2011 analysis: 204 pb^{-1}

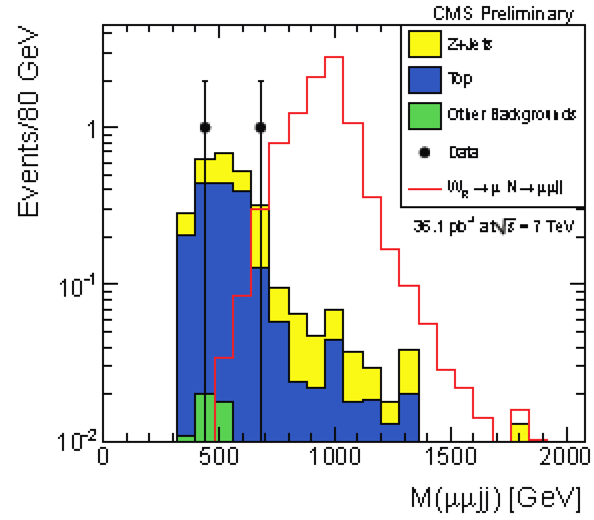


No excess (compared to bgd expectations) observed in data

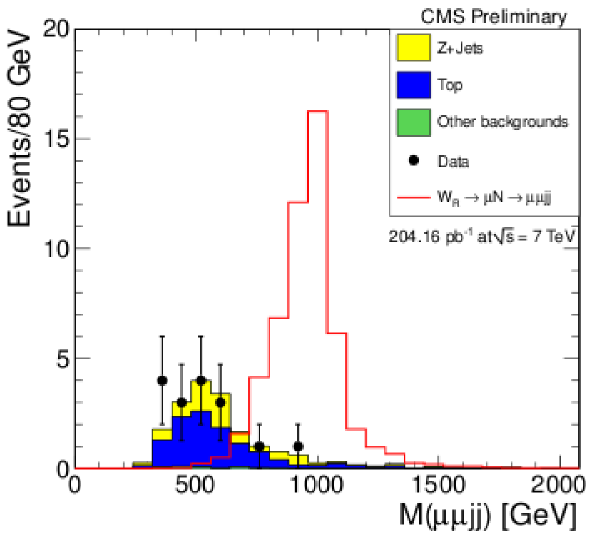
$\mu\mu jj$ invariant mass

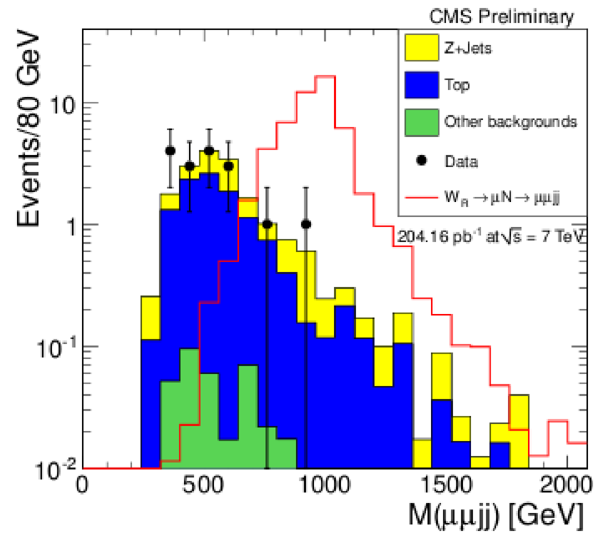
[2010 analysis:](#)
36 pb^{-1}





[2011 analysis:](#)
204 pb^{-1}





No excess (compared to bgd expectations) observed in data

Systematic Uncertainties

Systematic uncertainties

Long list of systematic uncertainties considered (see backup)

Major systematics summarized here

- $W' \to \ell\,\nu$
  - PDF/k-factor uncertainties
  - Muon p_T resolution for very energetic muons
  - Uncertainties related to background determination

- $W' \to \ell\,N_\ell$
  - Jet-energy scale
  - PDF/k-factor uncertainties
  - Initial & final state radiation

Statistical analysis & Exclusion limits

Setting Exclusion Limits

- Look for excess of events at tail of mass distributions
- No signal observed

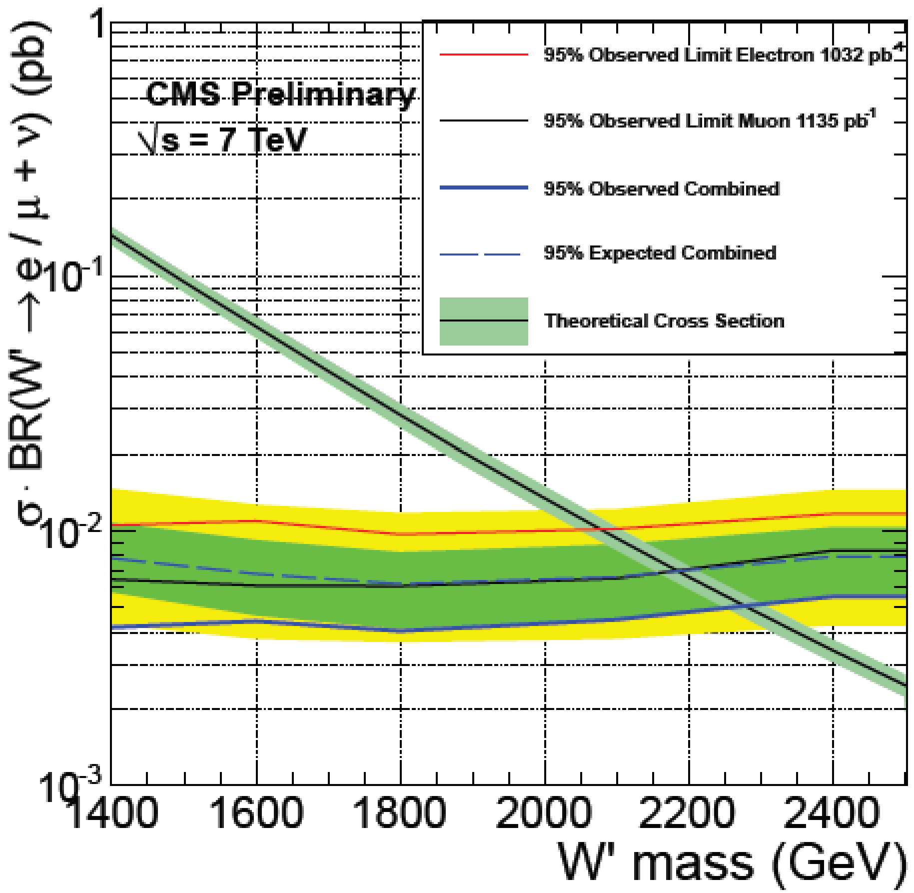
  ☹

- Simple "event-counting" experiments
  - What is the number of <u>expected</u> signal events?
  - What is the number of <u>expected</u> background events?
  - What is the number of <u>observed</u> events in the data?

- Limit setting
  - Bayesian method with flat prior for signal cross section
  - $W' \longrightarrow \ell\nu$: using "sliding" search window
  - $W' \longrightarrow \ell N_\ell$: using fixed search window

Exclusion limit: $e/\mu + ME_T$

- Fully correlated luminosity uncertainty
- Fully uncorrelated background uncertainty



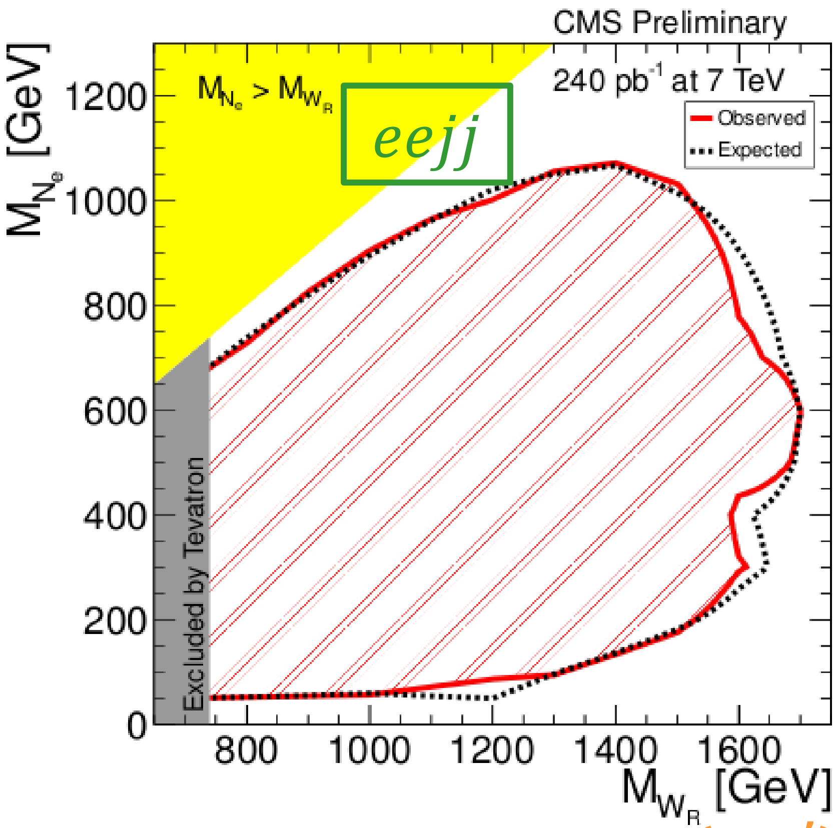
W' mass (GeV)	σ_{theor} (pb)	Exp. Limit (pb)	Obs. Limit (pb)
1400	0.1440	0.0078	0.0042
1600	0.0633	0.0068	0.0044
1800	0.0285	0.0062	0.0040
2100	0.0094	0.0066	0.0045
2400	0.0034	0.0079	0.0055

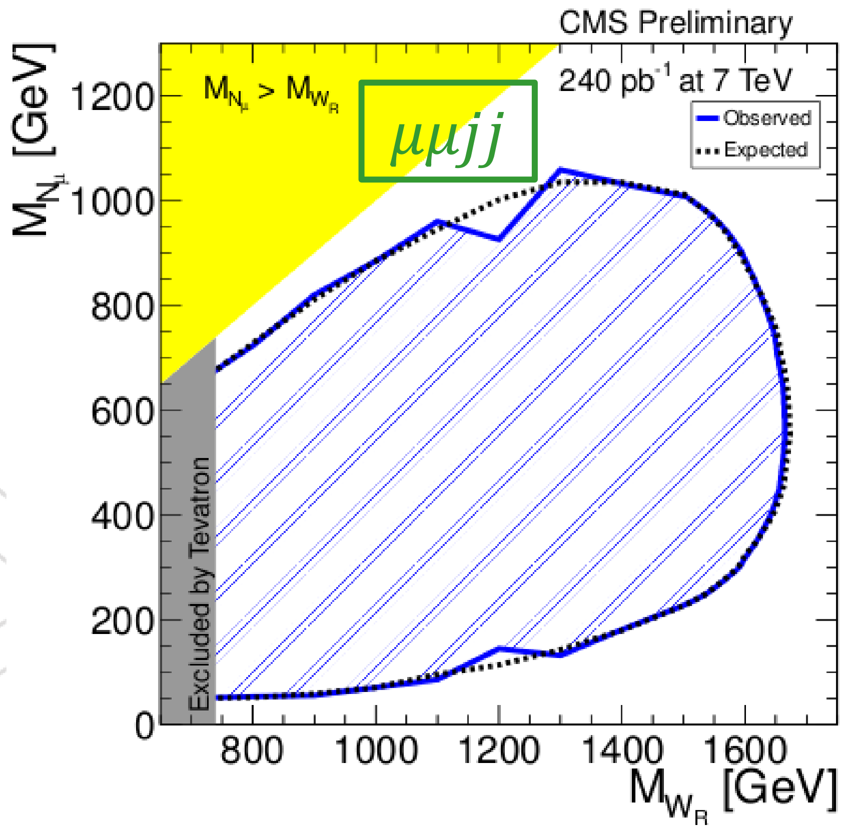
Combined limit in SSM:
Expected: $m(W') > 2.20$ TeV
Observed: $m(W') > 2.27$ TeV

Significant improvement over 2010 result (1.58 TeV)

Exclusion limits: W_R', N_ℓ mass plane

- Reconstruction, ID uncertainties between 2010, 2011: uncorrelated
- All other uncertainties: correlated





- Lower bound on $m(W_R')$ extends up to 1.7 TeV
- Significant improvement over TeVatron limit (780 GeV)

Summary

This just in

Search for pair production of a fourth-generation t' quark in the lepton-plus-jets channel with the CMS experiment

$$t'\bar{t}' \to WbW\bar{b} \to \ell\nu bq\bar{q}\bar{b}$$

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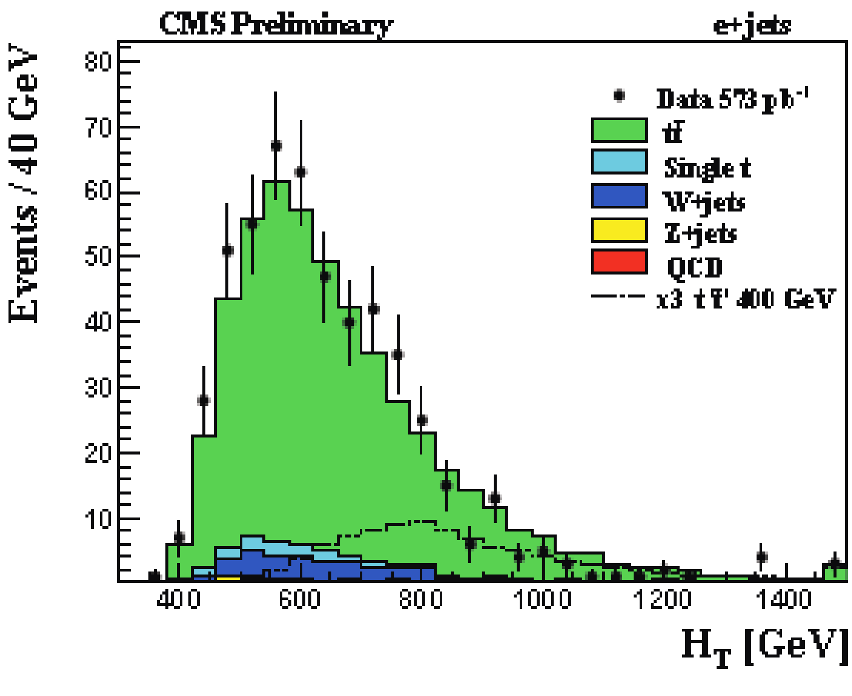

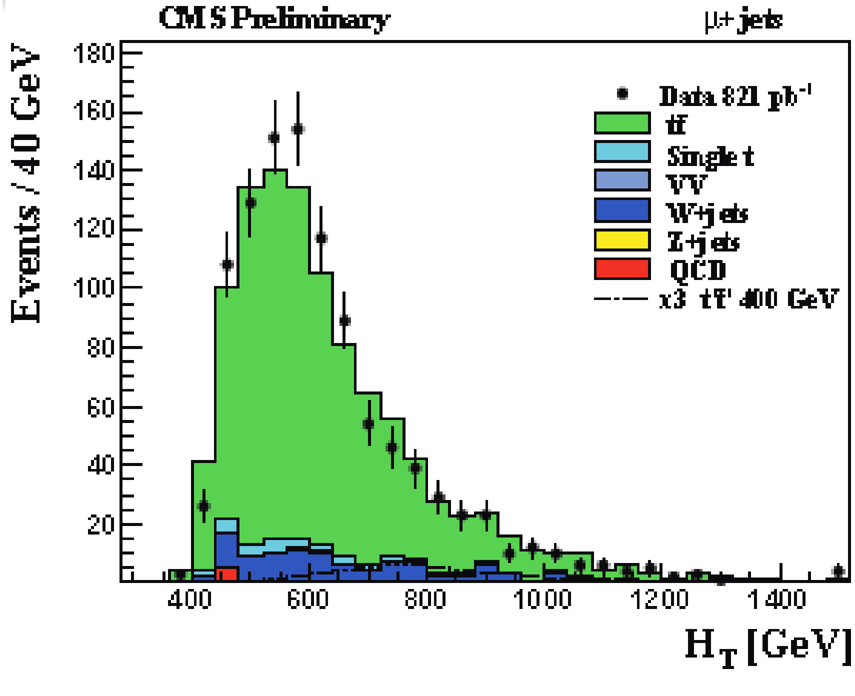

Search for pair production of a fourth-generation t' quark in the lepton-plus-jets channel with the CMS experiment

$$t'\bar{t}' \to WbW\bar{b} \to \ell\nu bq\bar{q}\bar{b}$$

A search is presented for the pair production of a fourth-generation t' quark and its antiparticle in proton-proton collisions at $\sqrt{s} = 7$ TeV provided by the Large Hadron Collider. The data were collected by the CMS detector during the 2011 collider run. The t' quark is assumed to decay exclusively to a W boson and a b quark. The search is carried out using events with a single isolated electron or muon, large missing transverse momentum, and at least four jets with large transverse momenta, one of which must be identified as originating from the fragmentation of a b quark. The data analyzed correspond to an integrated luminosity of 573 pb^{-1} for the electron channel and 821 pb^{-1} for the muon channel. No significant excess over standard model expectations is observed. Assuming strong pair production of t' quarks, a lower limit is set on the t' quark mass of 450 GeV at 95% confidence level.

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

Summary

Summary

- Search for W' in $\ell + ME_T$ final state carried out with 1.1 fb^{-1} of 2011 data
- Search for right-handed W' (in $\ell\ell jj$ final state) carried out with 240 pb^{-1} of 2010-11 data

- No excess above SM background expectations is observed in data distributions

- A lower bound has been set on the W' mass, assuming SM-like couplings and no interference with other bosons:
  - $m(W') > 2.27$ TeV $\ell + MET$
  - $m(W_R') > 1.70$ TeV (for $m_{N_\ell} \sim 500$ GeV) $\ell\ell jj$

- Significant improvement over 2010 limits

Summary

TWiki > CMSPublic Web > PhysicsResults > PhysicsResultsEXO (18-Jul-

CMS Exotica Public Physics Results

- CMS Exotica Public Physics Results
  - Journal Publications

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

Search for W′ in the leptonic channels in pp Collisions at sqrt(s) = 7 TeV

The CMS Collabo

Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at $\sqrt{s}$=7 TeV

The CMS Collaboration

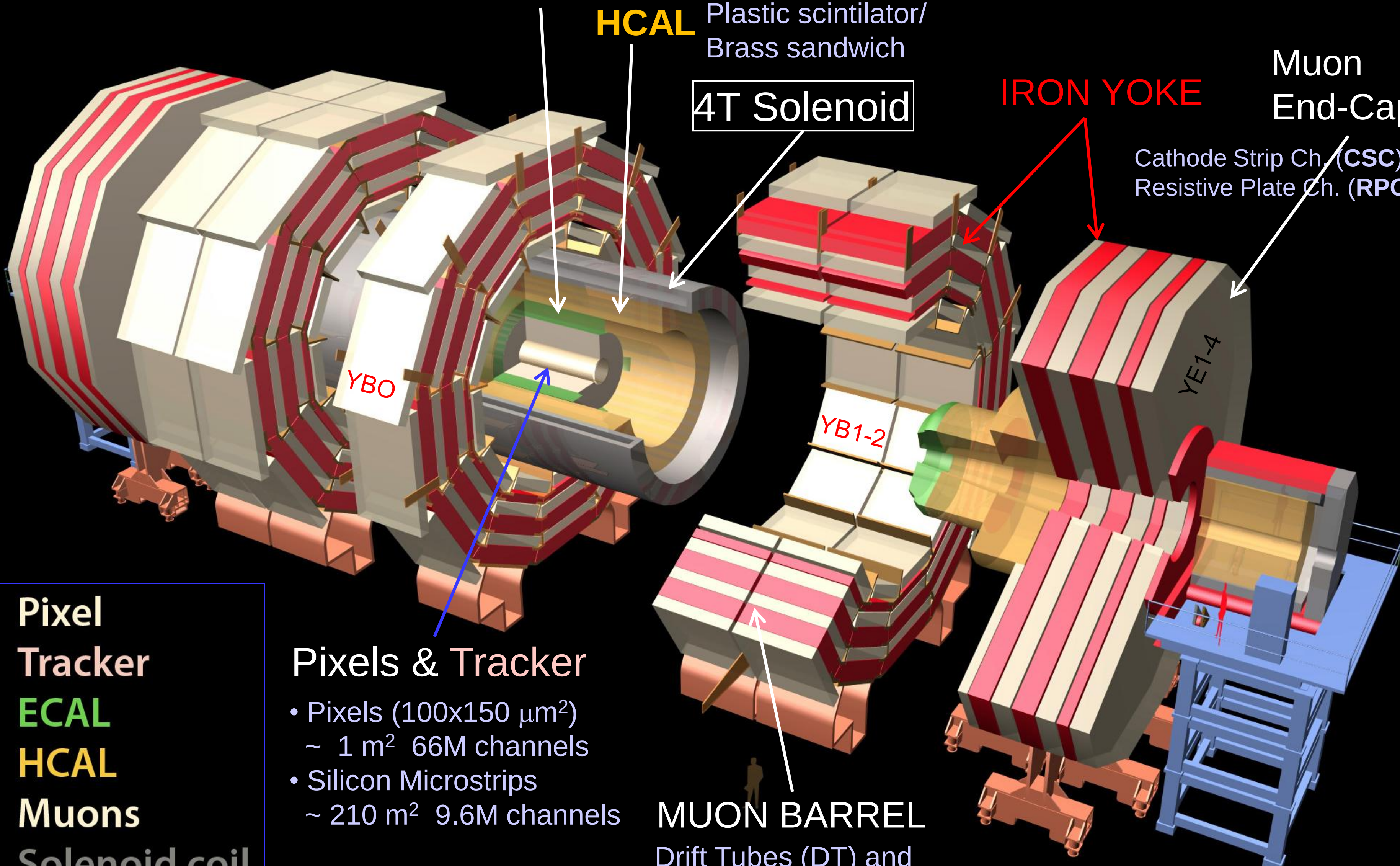
- A lower bound has been set on the W' mass, assuming SM-like couplings and no interference with other bosons:
  - $m(W') > 2.27$ TeV $\ell + MET$
  - $m(W_R{}') > 1.70$ TeV (for $m_{N_\ell} \sim 500$ GeV) $\ell\ell jj$

- Significant improvement over 2010 limits

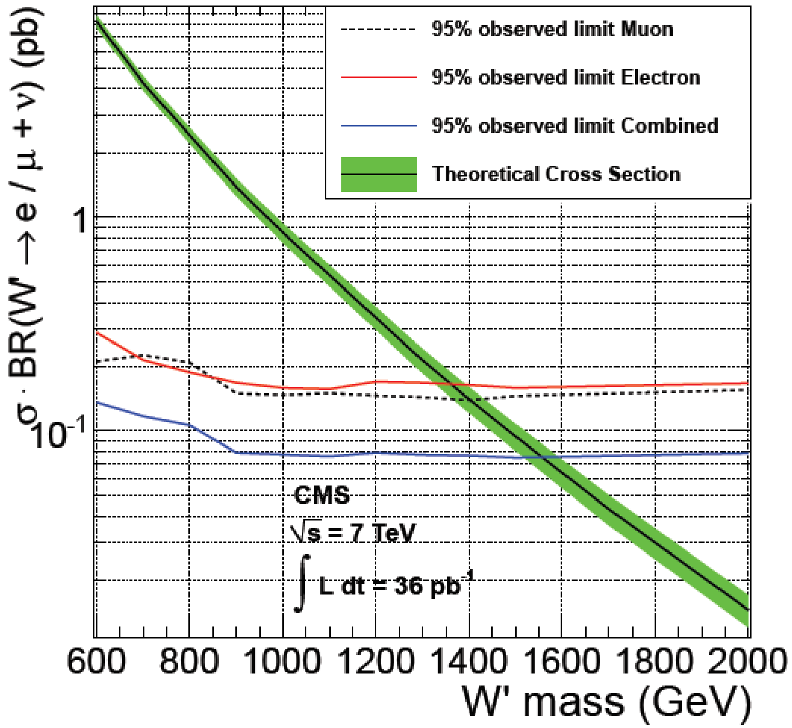
Backup

Total weight 14000 t
Overall diameter 15 m
Overall length 21.6 m

CMS



$W' \longrightarrow \ell\nu$ search results in 2010



Phys. Lett. B698: 21 – 39 (2011)
Phys. Lett. B701: 160 – 179 (2011)

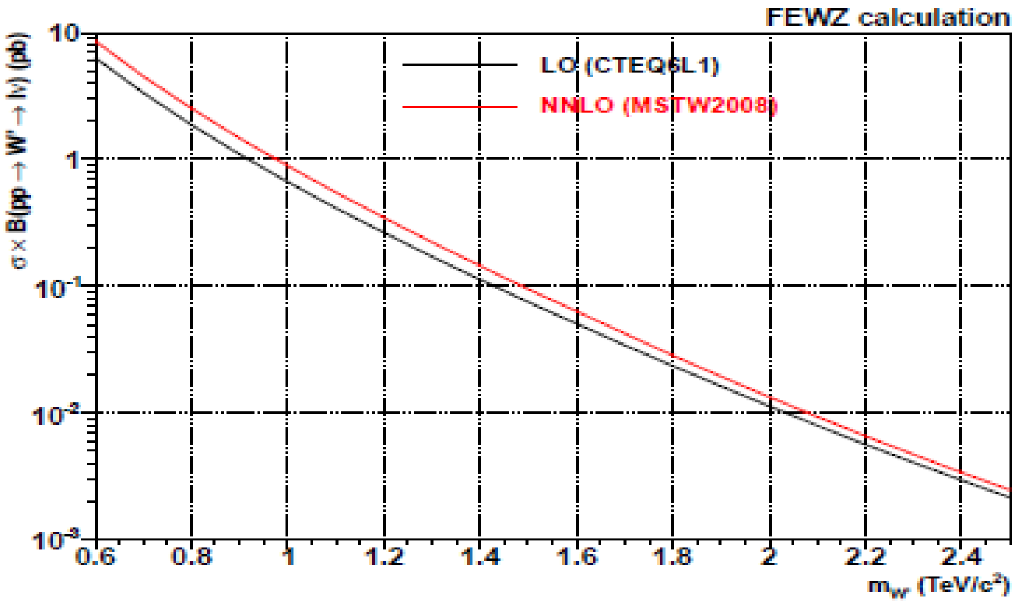
Limits	Electron (TeV)	Muon (TeV)	Combined (TeV)
CDF (5.3 fb^{-1} , 2 TeV)	1.12	–	
CDF (107 pb^{-1}, 1.8 TeV)		0.66	
CMS (36 pb^{-1}, 7 TeV)	1.36	1.40	1.58
Atlas (36 pb^{-1}, 7 TeV)	1.37	1.29	1.49

NNLO k-factor for W' production

- Signal samples generated with PYTHIA6 in LO
- Determination of NNLO k-factors for each W´ mass point using FEWZ 2.0

  (see: http://gate.hep.anl.gov/fpetriello/FEWZ.html)
- Calculated LO cross-section for CTEQ6L1 (used for generation) and NNLO cross-section for MSTW2008 PDF-sets for masses 600-2500 GeV in steps of 100 GeV
- Analysis uses NNLO = LO × k-factor

$$K^{NNLO}_{Factor} = \frac{\sigma_{FEWZ}(NNLO; MSTW2008)}{\sigma_{FEWZ}(LO; CTEQ6L1)}$$

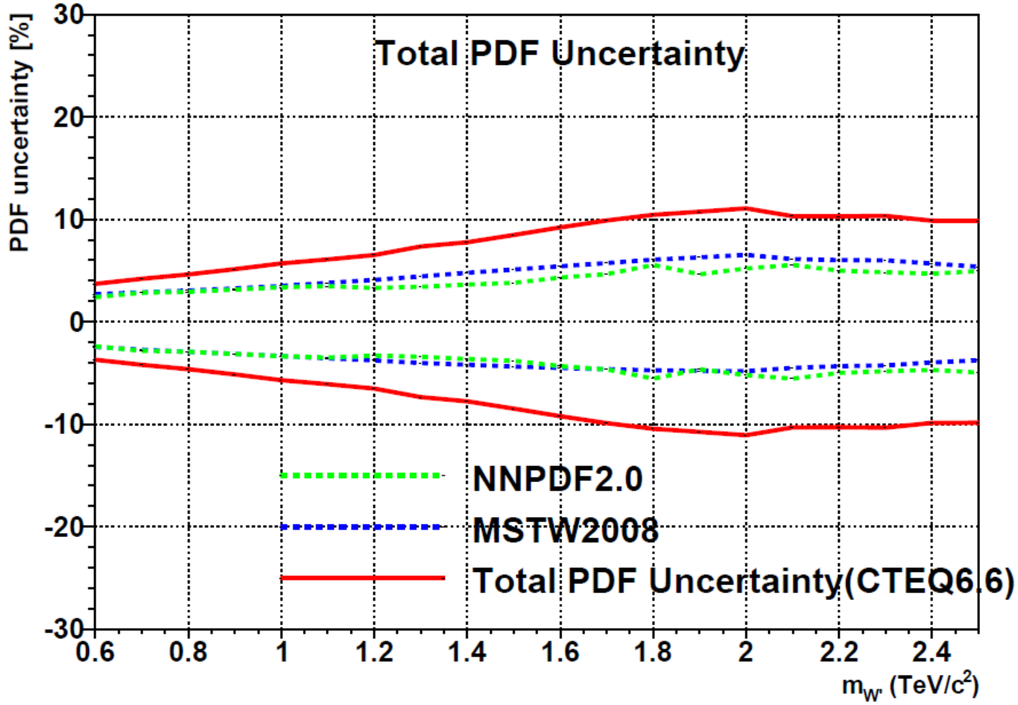


PDF uncertainties

Three different PDF sets (PDF4LHC recommendation, end of 2010)

i=MSTW2008, CTEQ66, NNPDF2.0

$$\Delta F_{\text{tot}} = \frac{1}{2}\left(\max_i\left(F^i + (\Delta F^i_{\text{PDF}+\alpha_s})_+\right) - \min_i\left(F^i - (\Delta F^i_{\text{PDF}+\alpha_s})_-\right)\right)$$



Background estimation

- $W' \to \ell\nu$: sideband fit of M_T spectrum
  - Find "signal-free" region of M_T spectrum (off-peak W)
  - Fit and use parameters to model background shape
  - Extrapolate function to "region of interest" (M_T tail)
  - Estimate background in signal region w/o relying on MC

Tested several fitting functions

Function 1:

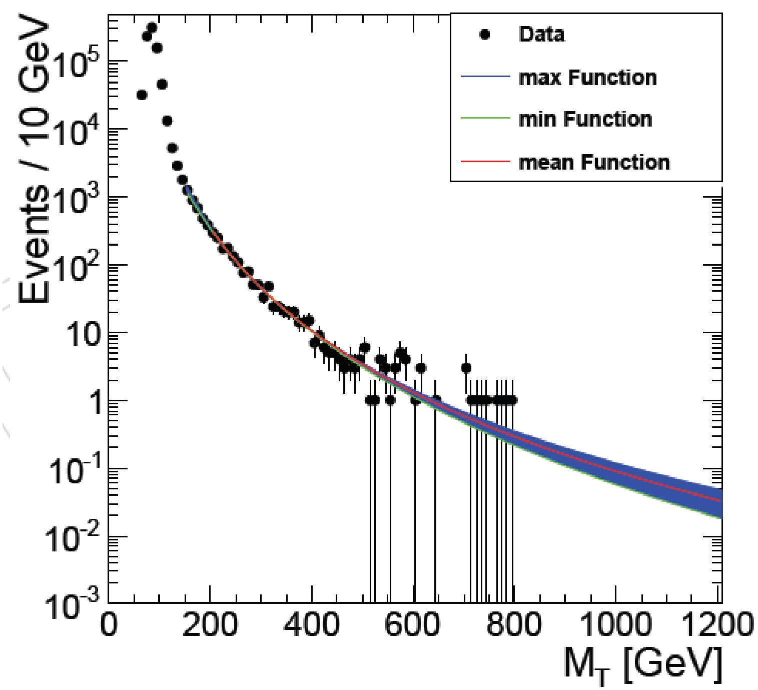
$$\frac{a}{(x+b)^c}$$

Function 2:

$$\frac{a}{(x^2+b\cdot x+c)^d}$$

Function 3:

$$\frac{a(1+x)^b}{(x^{c+d\cdot \log x})}$$



Example: muon channel

Background estimation

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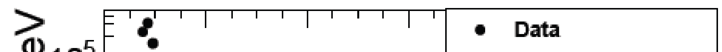
  - Find "signal-free" region of M_T spectrum (off-peak W)
  - Fit and use parameters to model background shape
  - Extrapolate function to "region of interest" (M_T tail)
  - Estimate background in signal region w/o relying on MC



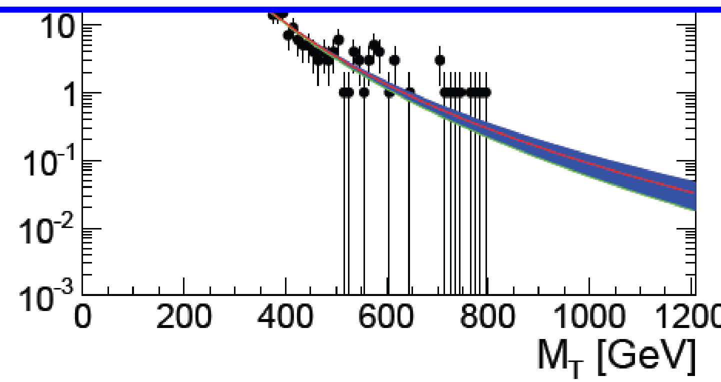
- Variations of sideband width and different functions give slightly different predictions for background at large M_T : systematic uncertainty
- Impact of fit parameters uncertainty on extrapolation: statistical uncertainty
- MC-Data difference: minor effect (including Sudakov corrections, a ~15-20% effect)

Function 2:

$$\frac{a}{(x^2 + b \cdot x + c)^d}$$

Function 3:

$$\frac{a(1+x)^b}{(x^{c+d \cdot \log x})}$$



Example: muon channel

Systematic uncertainties: $\ell + ME_T$

Signal

Systematic uncertainty	Value	Impact on signal
Luminosity	6 %	6 %
Muon p_T resolution and Momentum scale	0.14 TeV^{-1} (pT) 0.4% (scale)	10 %
MET resolution, hadronic component	10 %	2 %
Muon trigger efficiency	3 %	3 %
Combined electron efficiency (trigger, ID and reconstruction)	2 %	2 %
Electron energy scale	1% EE, 3% EC	<1%

Background

Taking into account uncertainties due to fit parameter errors in extrapolation, sensitivity of fit on range of sideband, choice of fitting function and discrepancy between MC and sideband fit prediction

Systematic uncertainties: $\ell\ell jj$

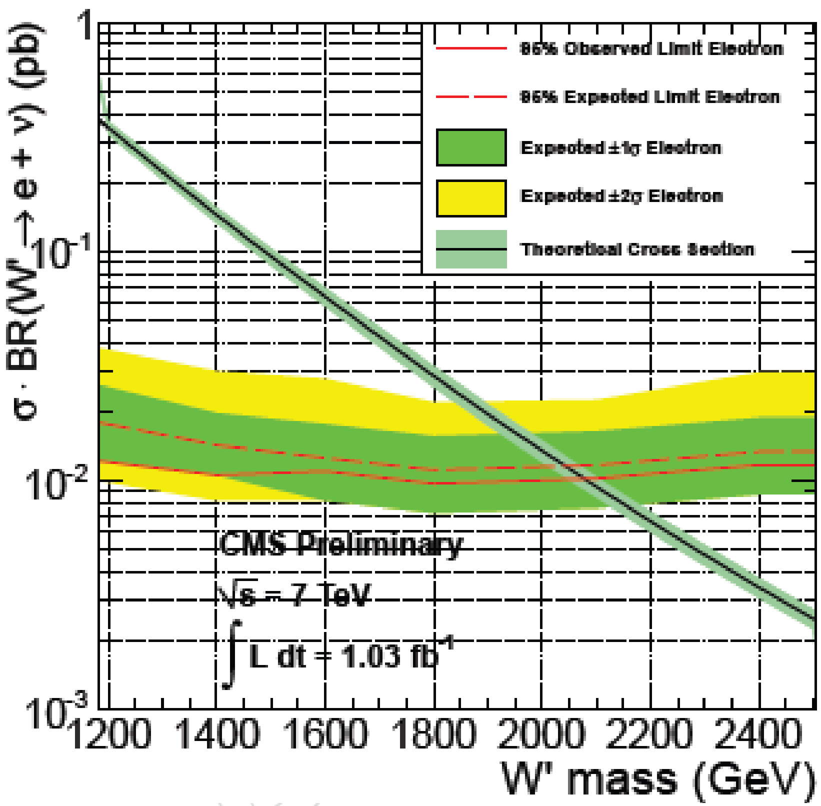
Electron Channel

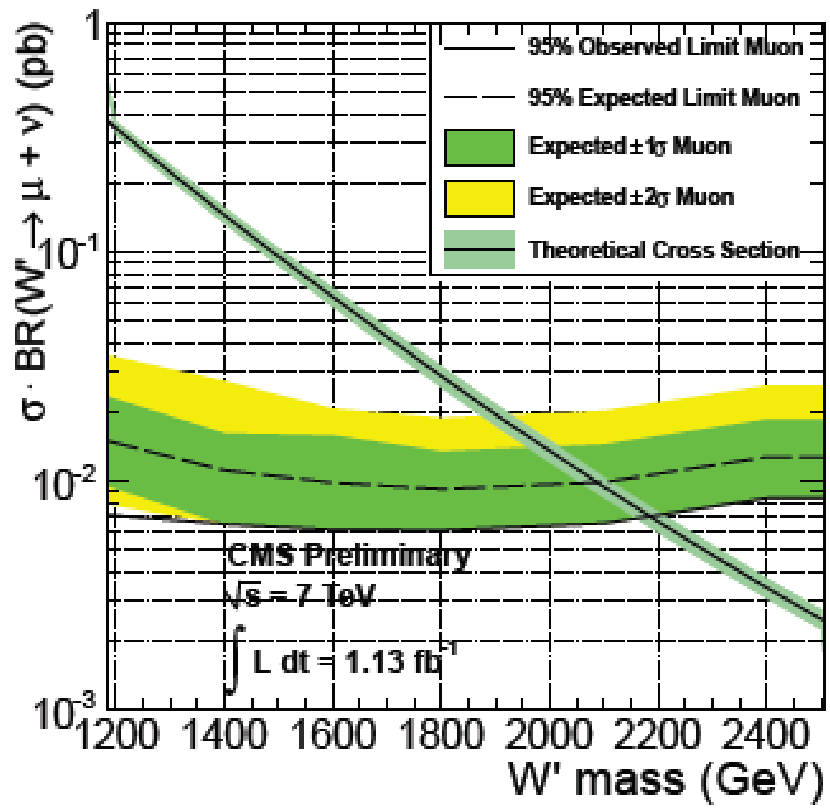
Systematic Uncertainty	Signal	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±2-20%	±11%	±5%	–	±12%	±7%
Electron Energy Scale	±1-3%	±4%	±3%	–	±9%	±4%
Electron Reco/ID/Iso	±10%	±10%	±10%	–	±10%	±10%
Normalization	±6%	±12%	±7%	–	±6%	±8%
Simulation Statistics	±1-7%	±5%	±4%	–	±7%	±5%
Theoretical	±5%	±13%	±19%	–	±13%	±14%
QCD estimate	–	–	–	±18%	–	±3%
Total	±12-25%	±24%	±23%	±18%	±25%	±23%

Muon Channel

Systematic Uncertainty	Signal	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±0.5-20%	±4%	±7%	–	±10%	±5%
Muon Energy Scale	±0-3%	±5%	±3%	–	±4%	±4%
Muon Reco/ID/Iso	±6-10%	±1%	±0.5%	–	±0.5%	±1%
Trigger Efficiency	±0.3%	±0.3%	±0.3%	–	±0.3%	±0.3%
Normalization	±6%	±12%	±8%	–	±6%	±8%
Simulation Statistics	±1-7%	±4%	±3%	–	±9%	±3%
Theoretical	±5%	±13%	±19%	–	±13%	±14%
QCD estimate	–	–	–	±25%	–	±0.1%
Total	±10-25%	±19%	±22%	±25%	±22%	±17%

Exclusion limits: $e/\mu + ME_T$





Electron channel

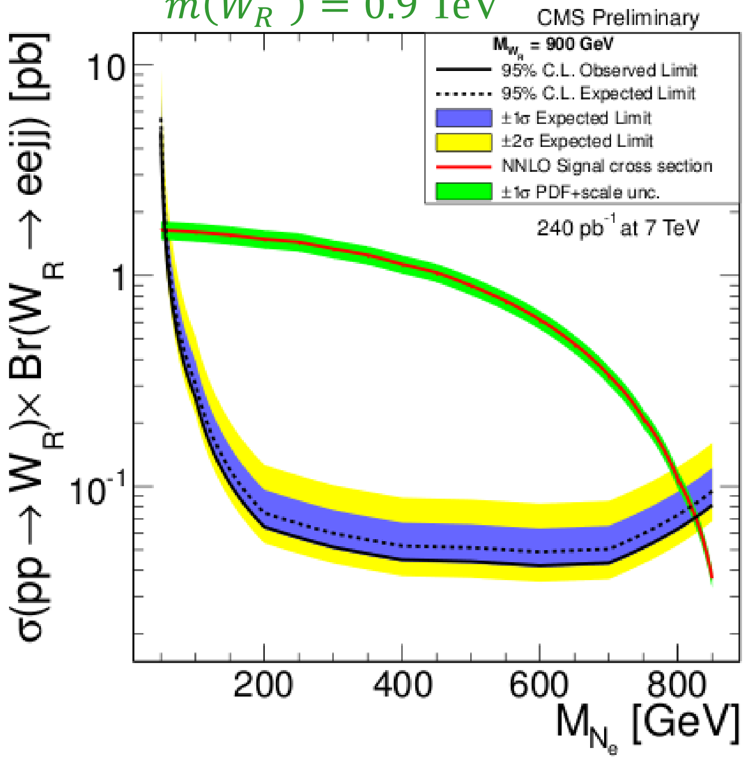
W' mass (GeV)	M_T (GeV)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	σ_{theor} (pb)	Exp. Limit (pb)	Obs. Limit (pb)
1400	1000	53.838 ± 3.707	2.227 ± 1.124	1	0.144	0.014	0.011
1600	1100	23.681 ± 1.630	1.438 ± 0.798	1	0.063	0.013	0.011
1800	1100	12.021 ± 0.735	1.438 ± 0.798	1	0.029	0.011	0.010
2100	1100	3.764 ± 0.242	1.438 ± 0.798	1	0.009	0.012	0.010
2400	1100	1.193 ± 0.087	1.438 ± 0.798	1	0.003	0.013	0.012

Muon channel

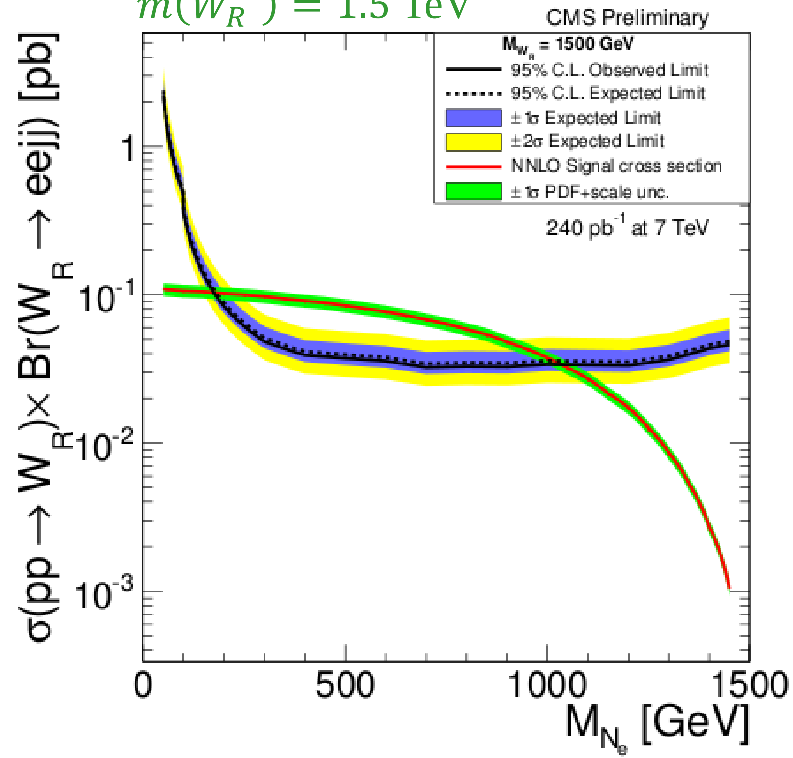
W' mass (GeV)	M_T (GeV)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	σ_{theor} (pb)	Exp. Limit (pb)	Obs. Limit (pb)
1400	1000	68.665 ± 7.320	2.014 ± 1.402	0	0.144	0.011	0.006
1600	1050	31.932 ± 3.403	1.621 ± 1.182	0	0.063	0.010	0.006
1800	1100	14.455 ± 1.540	1.316 ± 1.002	0	0.029	0.009	0.006
2100	1100	4.435 ± 0.473	1.316 ± 1.002	0	0.009	0.010	0.007
2400	1100	1.249 ± 0.133	1.316 ± 1.002	0	0.003	0.013	0.008

Exclusion limits: *eejj*

$m(W_R{}') = 0.9$ TeV



$m(W_R{}') = 1.5$ TeV



$m(W_R{}') = 1.0$ TeV

$m(N_\ell) = 0.5$ TeV

Electron Channel (2010, 36 pb^{-1})

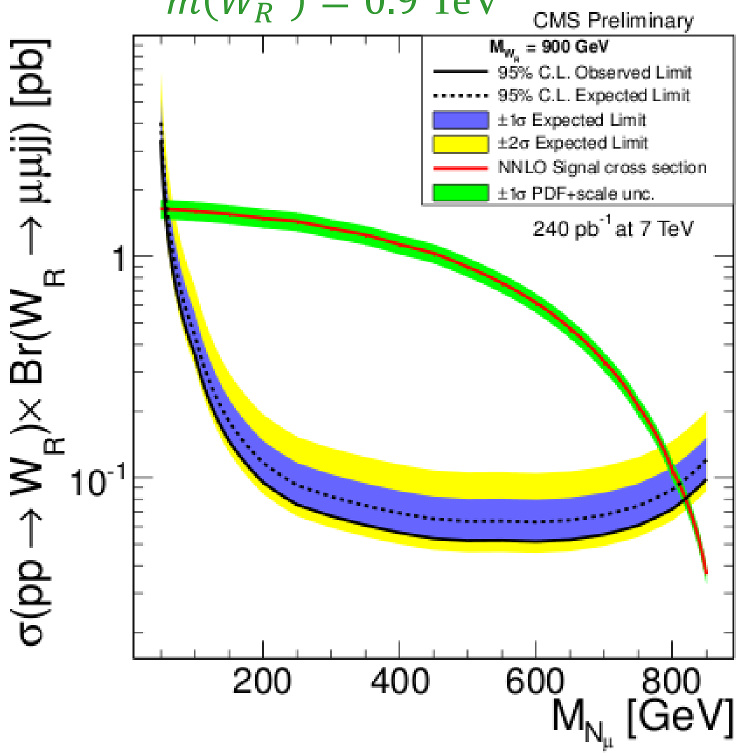
Data	Signal	$(\epsilon \times A)(\%)$	Tot. BG	$t\bar{t}$	Z+jets	Other
3	10	52	1.9 ± 0.5	1.0	0.6	0.2

Electron Channel (2011, 204 pb^{-1})

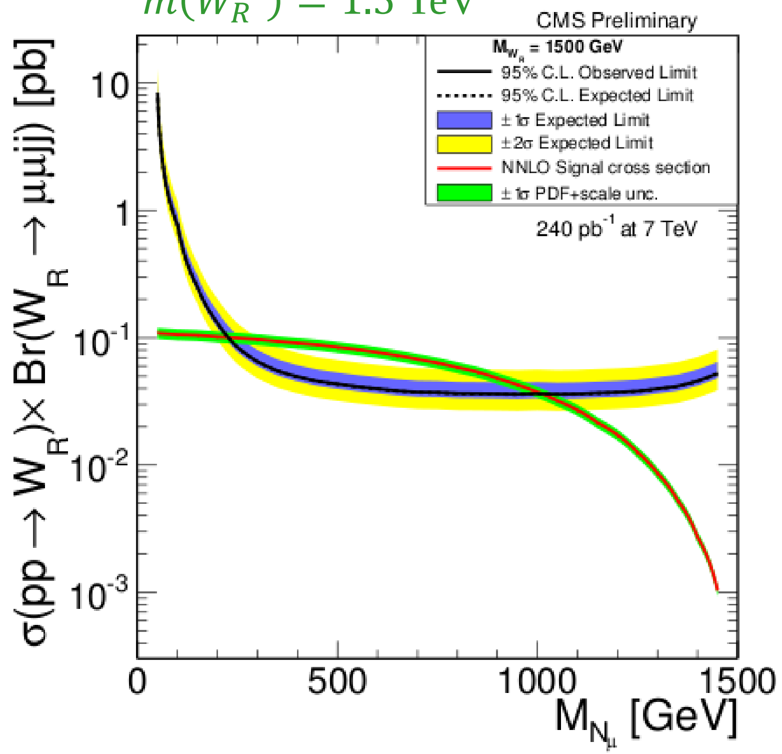
Data	Signal	$(\epsilon \times A)(\%)$	Tot. BG	$t\bar{t}$	Z+jets	Other
8	45	44	9.4 ± 2.0	5.7	2.7	1.0

Exclusion limits: $\mu\mu jj$

$m(W_R{}') = 0.9$ TeV



$m(W_R{}') = 1.5$ TeV



$m(W_R{}') = 1.0$ TeV

$m(N_\ell) = 0.6$ TeV

Muon Channel (2010, 36 pb^{-1})

Data	Signal	$(\epsilon \times A)(\%)$	Tot. BG	$t\bar{t}$	Z+jets	Other
1	9	56	1.6 ± 0.4	0.9	0.6	0.1

Muon Channel (2011, 204 pb^{-1})

Data	Signal	$(\epsilon \times A)(\%)$	Tot. BG	$t\bar{t}$	Z+jets	Other
5	52	55	9.9 ± 2.2	5.5	4.0	0.4