

Results on non-SUSY searches for physics beyond the Standard Model in pp collisions at CMS

– SUSY'12, Beijing –



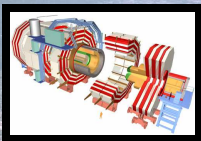
on behalf of CMS Collaboration

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16th August 2012

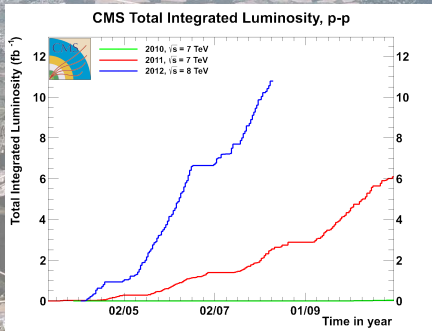


Outline



CMS

- 1 CMS Detector
- 2 Z' , W'
- 3 Heavy Neutrino
- 4 4th Generation
- 5 e^* , μ^*
- 6 LQ 1st 2nd 3rd
- 7 Extra Dimensions
- 8 ...



CMS Detector

Pixels
 Tracker
 ECAL
 HCAL
 Solenoid
 Steel Yoke
 Muons

SILICON TRACKER

Pixels ($100 \times 150 \mu\text{m}^2$)
 $\sim 1\text{m}^2$ $\sim 66\text{M}$ channels
 Microstrips ($80\text{--}180\mu\text{m}$)
 $\sim 200\text{m}^2$ $\sim 9.6\text{M}$ channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)

$\sim 76\text{k}$ scintillating PbWO_4 crystals

FRESHOWER

Silicon strips
 $\sim 16\text{m}^2$ $\sim 137\text{k}$ channels

STEEL RETURN YOKE

~ 13000 tonnes

SUPERCONDUCTING SOLENOID

Niobium-titanium coil
 carrying ~ 18000 A

HADRON CALORIMETER (HCAL)

Brass + plastic scintillator
 $\sim 7\text{k}$ channels

FORWARD CALORIMETER

Steel + quartz fibres
 $\sim 2\text{k}$ channels

MUON CHAMBERS

Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
 Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

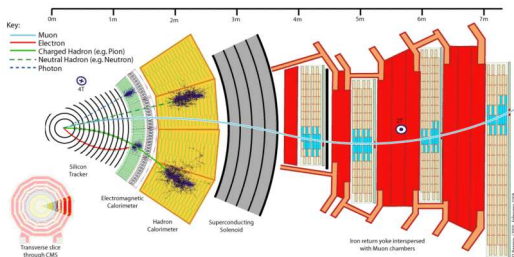
Total weight : 14000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

before we go for physics, we need to understand the physics objects (e , μ , τ , jets and E_T^{miss})...

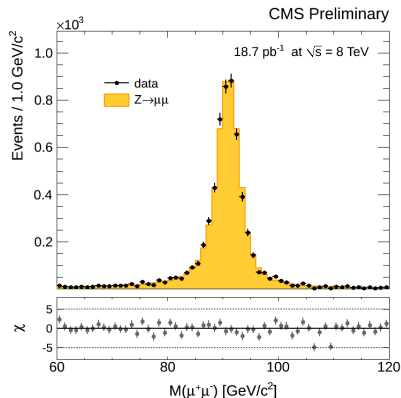
Muon Reconstruction

Muon in CMS:

track segment reconstructed in the muon chambers matched with track in silicon tracker



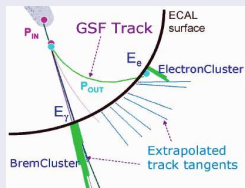
- Coverage: $|\eta| < 2.4$, $\eta = -\ln[\theta/2]$
- Tracking System Resolution:
 $\sigma_{p_T}/p_T \approx 0.015\% p_T \oplus 0.5\%$



- very nice agreement between Monte Carlo and Data
- there is a reason why we are called CMS

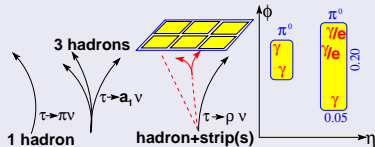
Physics Objects: e , τ , $jets$ and E_T^{miss}

Electron



- Gauss Sum Function
- Coverage:
 $|\eta| < 1.442$ &
 $1.556 < |\eta| < 2.5$
- Energy Resolution:
 $\frac{3\%}{\sqrt{E_T/\text{GeV}}}$

Tau

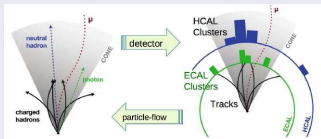


- Coverage: $|\eta| < 2.3$ Energy Scale: $< 3\%$

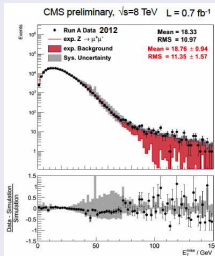
Particle Flow Jets

Particle Flow in CMS:

- reconstructs and identifies all stable particles within the detector
- builds jets using the *anti- κ_T* alg. which are: infrared & collinear safe



more details and examples are shown in back-up slides

 E_T^{miss} 

- Missing Energy in Transverse plane
- in CMS: negative vector sum of all particle candidates reconstructed with the PF algorithm
- signal efficiency for an E_T^{miss} cut can be estimated from signal MC

CMS BSM/Exotic Searches

Resonances/Leptons

- Contact Interaction: $\mu\mu$ CMS EXO-11-009
- Boosted $Z^0 \rightarrow \mu^+\mu^-$ CMS EXO-11-025
- e^*/μ^* CMS EXO-11-033/034
- ADD in ee CMS EXO-12-013

Jets

- Dark matter CMS EXO-11-059
- bjet resonances CMS EXO-11-008
- Three-jet resonance CMS EXO-11-060
- Dijet resonances CMS EXO-12-016
- Boosted VV, Vjet CMS EXO-11-095

Leptons & Jets

- LQ1($eejj + e\nu jj$) CMS EXO-11-027
- LQ2($\mu\mu jj + \mu\nu jj$) CMS EXO-11-028
- LQ3 to $\tau + b$ CMS EXO-12-002
- Heavy Majorana N to $\ell\ell$ CMS EXO-11-076
- VZ to $l + jets$ CMS EXO-11-081
- RS Graviton in $Z^0 Z^0(2l2q)$ CMS EXO-11-061

Long-Lived

- Stopped HSCP CMS EXO-11-020
- Displaced photons CMS EXO-11-035
- Fractionally charged CMS EXO-11-074
- Multiple charged CMS EXO-11-090
- Long-lived to displaced γ CMS EXO-11-101

top & 4th Generation

- $W' \rightarrow t\bar{t} + jet$ CMS EXO-11-056
- $B' \rightarrow bZ$ CMS EXO-11-066
- $Z' \rightarrow t\bar{t} + jet$ CMS EXO-11-006
- $Z' \rightarrow \tau^+\tau^-$ CMS EXO-11-031
- b'/t' inclusive CMS EXO-11-050/036/098
- $W' \rightarrow tb$ CMS EXO-12-001

8 TeV

- W' at 8 TeV CMS EXO-12-010
- Z' at 8 TeV CMS EXO-12-015
- Dijet at 8 TeV CMS EXO-12-016
- Heavy neutrino at 8 TeV CMS EXO-12-017
- Black holes at 8 TeV CMS EXO-12-009

$Z' \rightarrow e^+e^-/\mu^-\mu^+$: CMS EXO-12-015

Models:

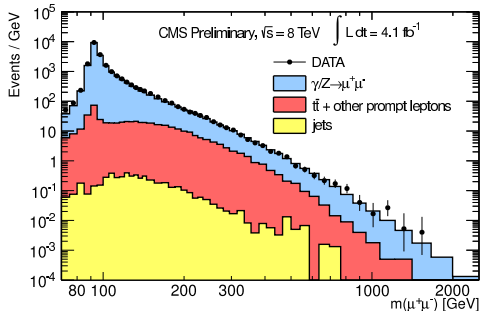
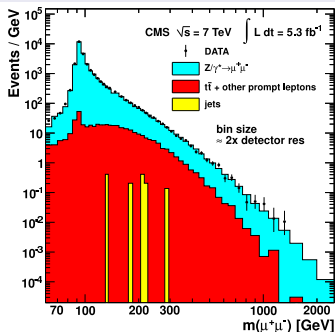
- Sequential Standard Model: Z'_{SSM}
- Grand Unified Theories: Z'_ψ

Background Contributions:

- $Z^0 \rightarrow \mu^+\mu^-$, $t\bar{t}$
- other prompt leptons: tW , WW , WZ , ZZ and $Z^0 \rightarrow \tau^+\tau^-$
- jets: one jet mis-reconstructed as a lepton

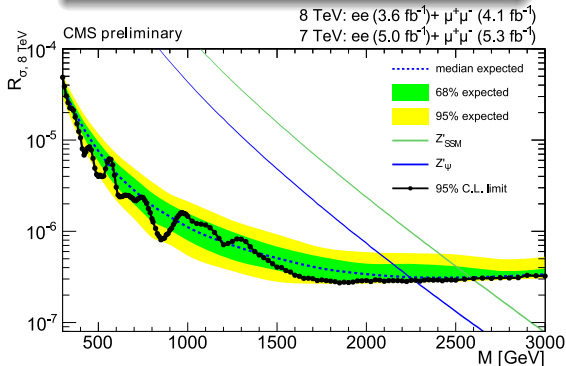
Event Selection:

- double leptons triggers
- with 2 isolated leptons
- e : $p_T > 35$ GeV/c and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- μ : $p_T > 45$ GeV/c and $|\eta| < 2.4$



$$Z' \rightarrow e^+e^-/\mu^+\mu^-$$

- unbinned likelihood function
- shape analysis of the dilepton mass



$$R_\sigma = \frac{pp \rightarrow Z' + X \rightarrow \ell\ell + X}{pp \rightarrow Z + X \rightarrow \ell\ell + X} \quad \ell = e, \mu$$

- eliminates uncertainty from integrated luminosity
- reduces dependence on experimental acceptance, trigger and selection efficiencies

Limits:

- $M(Z'_{SSM}) > 2590 \text{ GeV}/c^2$ at 95% C.L.
- $M(Z'_\psi) > 2260 \text{ GeV}/c^2$ at 95% C.L.

$W' \rightarrow \ell \nu$ with $\ell = e, \mu$: CMS EXO-12-010

• W' Models:

- right-handed with SM couplings
- left-handed (interference)
- Kaluza-Klein states
- excited W^* chiral boson

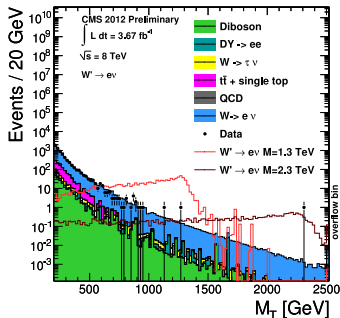
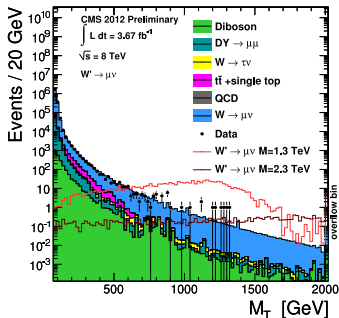
• Background Contributions:

- $W \rightarrow \ell \nu, WW, WZ, ZZ$
- $t\bar{t}, tW$ and $Z^0 \rightarrow \ell^+ \ell^-$

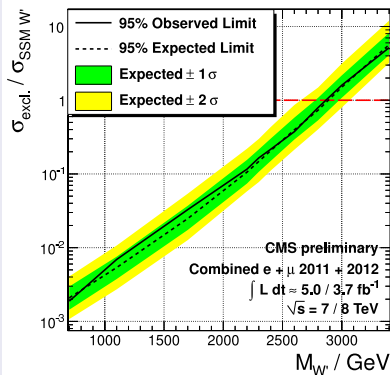
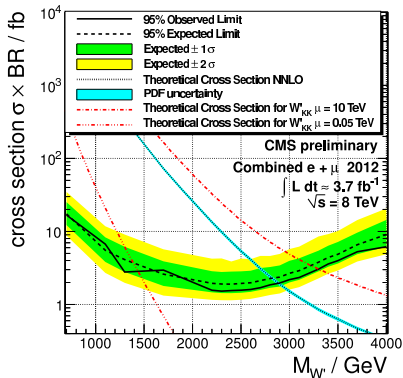
• Event Selection:

- e : $p_T > 90$ GeV/c
- μ : $p_T > 45$ GeV/c
- $p_{T\ell}$ and E_T^{miss} back-to-back

$$M_T = \sqrt{2 \cdot p_{T\ell}^\ell \cdot E_T^{miss} \cdot (1 - \cos \Delta\varphi_{\ell, \nu})}$$



$W' \rightarrow \ell \nu$ with $\ell = e, \mu$



- combined 2011 & 2012, e- and μ -channel:
 $M(W'_{\text{SSM}}) > 2.85 \text{ TeV}/c^2$ at 95% C.L.

more analyses are shown in back-up slides

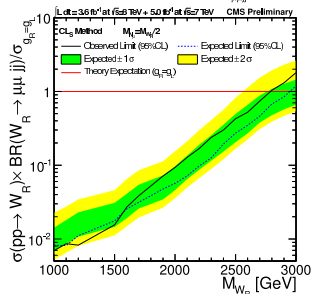
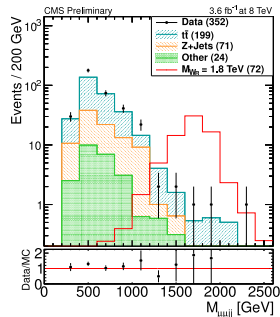
$W'_R \rightarrow N_{\ell\ell}$: CMS EXO-12-017

- W'_R Model:
 - Left-Right Symmetric Extensions to SM ($g_L = g_R$)
- decay mode:
 - $W'_R \rightarrow \ell_1 N_{\ell} \rightarrow \ell_1 \ell_2 W_R^* \rightarrow \ell_1 \ell_2 q q' \rightarrow \ell_1 \ell_2 j j$
(N_{ℓ} - heavy neutrino, j - reconstructed jet)
- Background Contributions:
 - $t\bar{t}, Z^0/\gamma^* \rightarrow \ell^+ \ell^-$
 - $W \rightarrow \ell \nu, tW, WW, WZ, ZZ$ (Others)

- Event Selection:
 - leading lepton: $p_T > 60$ GeV/c
 - sub-leading lepton: $p_T > 40$ GeV/c
 - ≥ 2 jets with $p_T > 40$ GeV/c
 - $M_{\ell\ell} > 200$ GeV/ c^2 and $M_{\ell\ell jj} > 600$ GeV/ c^2

Limits:

- $M(W'_R) > 2.8$ TeV/ c^2 at 95% C.L. in $\mu\mu jj$ channel



Heavy Neutrino - $W'_R \rightarrow N_{\ell}$: CMS EXO-12-017

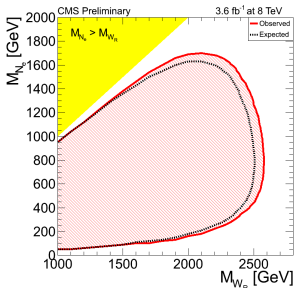
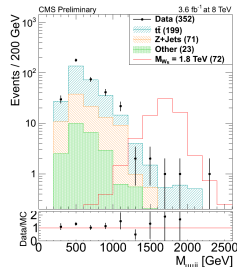
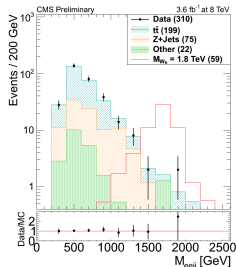
decay mode:

$$W'_R \rightarrow \ell_1 N_{\ell} \rightarrow \ell_1 \ell_2 W_R^* \rightarrow \ell_1 \ell_2 q q' \rightarrow \ell_1 \ell_2 j j$$

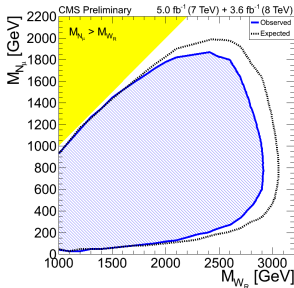
(N_{ℓ} - heavy neutrino, j - reconstructed jet)

Background Contributions:

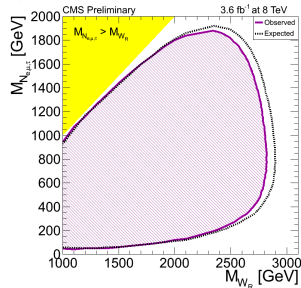
- $t\bar{t}, Z^0/\gamma^* \rightarrow \ell^+ \ell^-$
- $W \rightarrow \ell \nu, tW, WW, WZ, ZZ$ (Others)



available leptonic decay channels:
only N_e



available leptonic decay channels:
only N_{μ}



available leptonic decay channels:
 N_e, N_{μ}, N_{τ}

Heavy Majorana Neutrino: CMS EXO-11-076

Models:

- new massive neutrino state N
- $m_\nu \approx y_\nu^2 v^2 / m_N$
 y_ν - ν Yukawa coupling to Higgs;
 v - SM Higgs vacuum expectation

channel with $\ell = e, \mu$:

$$q\bar{q} \rightarrow W^\pm \rightarrow N\ell^\pm \rightarrow W^\mp \ell^\pm \ell^\pm \rightarrow q\bar{q}\ell^\pm \ell^\pm$$

Background Contributions:

- $WZ, ZZ, W\gamma, t\bar{t}W, W^\pm W^\pm qq$
- mis-identified lepton background

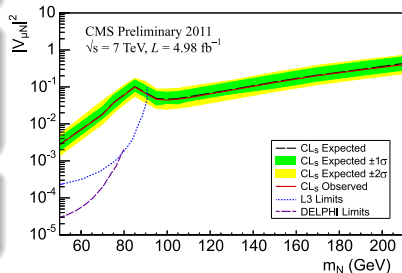
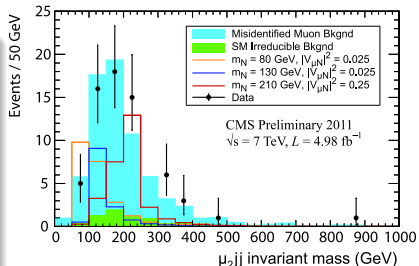
Event Selection:

- 2 ℓ with $p_T > 20(10)$ GeV/ c
- veto on the third ℓ
- at least 2 jets $p_T > 30$ GeV/ c
- $E_T^{miss} < 50$ GeV/ c

Limits at 95% C.L.

Majorana-neutrino mixing element:

$$m_N = 90 \text{ GeV}/c^2: |V_{\mu N}|^2 < 0.07 \text{ and } |V_{eN}|^2 < 0.22$$



$t'\bar{t}' \rightarrow bW^+\bar{b}W^-$: CMS EXO-11-050

• 4th Generation

- $m_{t'} > 350 \text{ GeV}/c^2$ - direct searches

• decay mode:

$$bW^+\bar{b}W^- \rightarrow b\ell^+\nu\bar{b}\ell^-\bar{\nu} \text{ with } \ell = e, \mu$$

• Background Contributions:

- $t\bar{t}, Z^0 \rightarrow \ell^+\ell^-$
- $Z^0 \rightarrow \tau^+\tau^-, WW, WZ, ZZ, tW$

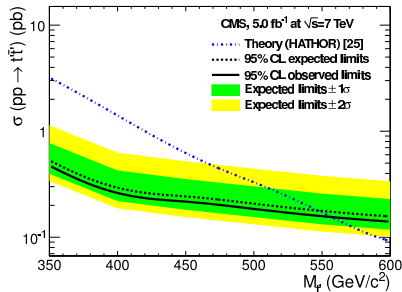
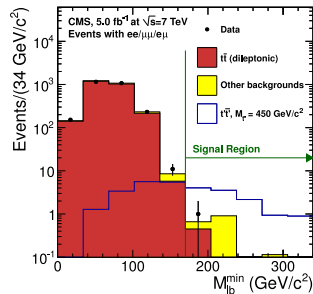
• Event Selection:

- two opposite-sign isolated leptons ($p_T > 20 \text{ GeV}/c$): $e^+e^-, e^\pm\mu^\mp$ or $\mu^+\mu^-$
- veto on Z^0/γ^*
- at least 2 b-tagged jets $p_T > 30 \text{ GeV}/c$
- $E_T^{\text{miss}} > 30 \text{ GeV}/c$
- M_{lb} : mass given by a lepton and b-tagged jet
- M_{lb}^{min} : minimum mass of the four possible M_{lb}

Limits

- $M(t') > 557 \text{ GeV}/c^2$ at 95% C.L.

more analyses are shown in back-up slides



4th Generation - Inclusive: CMS EXO-11-098

Model

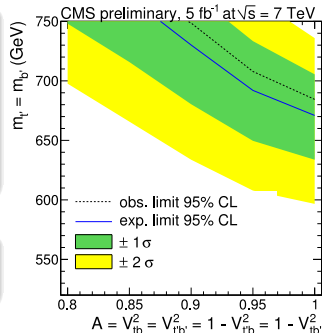
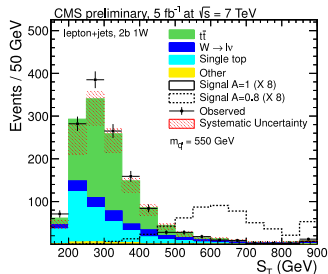
- $m_{b'} = m_{t'}$ and $A > 0.66$ where $V_{CKM}^{4 \times 4}$ parameter $\sqrt{A} = |V_{tb}| = |V_{t'b'}|$
- decay modes: $t' \rightarrow bW$ and $b' \rightarrow tW$ in:
 $t'b, t't', b't, b't', b'\bar{b'} \rightarrow bb\ nW$
- Background Contributions:
 - $t\bar{t}, tW, W \rightarrow \ell\nu$

Event Selection:

- leading lepton $p_T > 40$ GeV/c
- $E_T^{miss} > 40$ GeV/c
- at least 2 jets $p_T > 30$ GeV/c (one b-tagged jet)
- $S_T = E_T^{miss} + p_T^\ell + p_T^b + p_T^j + \sum_{i=0}^N p_T^{W_{q\bar{q}}^i}$
 - sum runs over reconstructed W_{had}

Limits

- $M(q') > 685$ GeV/c² at 95% C.L. where $q' = b', t'$



$\ell^\pm \ell^{*\mp} \rightarrow \ell^\pm \ell^\mp \gamma$: with $\ell = e, \mu$ CMS EXO-11-034

Model

- Excited Leptons Production via Contact Interactions (contact interaction scale Λ)

Background Contributions:

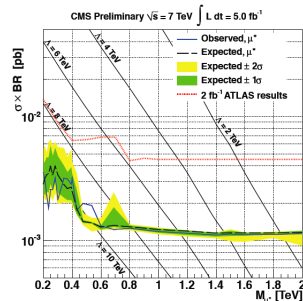
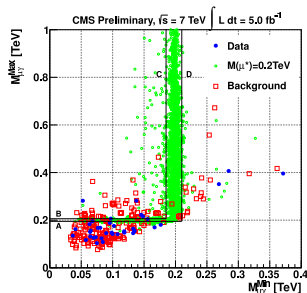
- $Z^0 \rightarrow \ell^\pm \ell^\mp, W \rightarrow \ell \nu$

Event Selection:

- 2 isolated leptons
- e : $p_T > 35(45)$ GeV/c EB(EE)
- μ : $p_T > 45(40)$ GeV/c
- γ : $E_T > 35$ GeV only EB ($|\eta| < 1.442$)
 $\Delta R(\gamma, \mu) > 0.7$ and $\Delta R(\gamma, e) > 0.5$
- $M_{\ell\gamma}^{\text{Max}} - M_{\ell\gamma}^{\text{Min}}$: signal region

Limits for $M_{e^*}(M_{\mu^*}) \in (0.6; 2)$ TeV/ c^2

- $\sigma \times BR$ less than 1.48-1.24 (1.31-1.11) fb
- for $M_{e^*} \approx M_{\mu^*}$ less than 0.73-0.60 fb
- $M(\ell^*) > 1.9$ TeV/ c^2 at 95% C.L. for $\Lambda = M(\ell^*)$



GMSB - displaced γ : CMS EXO-11-035

Model

- SUSY with **Gauge-Mediated Symmetry Breaking**
- Long Lived Particles: $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$
- signature: excess in E_T^{miss} and t_γ^{ECAL}

Background Contributions:

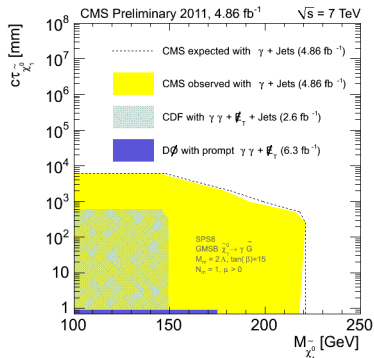
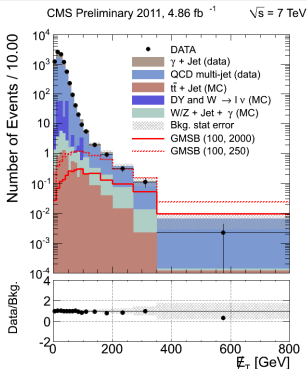
- QCD multi-jet, γ & jet, $Z^0\gamma$, $W^\pm\gamma$
- $t\bar{s}$, Z^0 , W^\pm

Event Selection:

- isolated γ : $E_T > 100$ GeV/c and $|\eta| < 1.4$
- three jets $p_T > 35$ GeV/c
- optimised cuts on γ shower shape and ECAL time

Limits

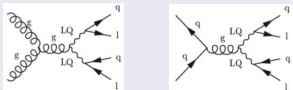
- $M(\tilde{\chi}_1^0) > 220$ GeV/ c^2 and $c\tau_{\tilde{\chi}_1^0} > 6000$ mm



LQ 1st 2nd Generation: CMS EXO-11-027/028

Models:

- Grand Unified Theories; composite models; technicolor; superstring-inspired E_6

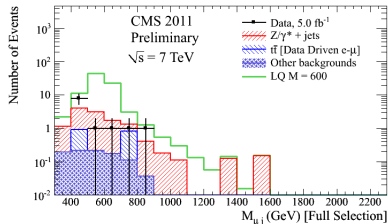


decay mode:

$LQLQ \rightarrow lqlq(\nu q)$ with $\ell = e, \mu$
 $\beta = BR(LQ \rightarrow lq)$

Background Contributions:

- $Z^0 \rightarrow \ell^\pm \ell^\mp, W \rightarrow \ell \nu, t\bar{t}$
- tW, QCD, WW, WZ, ZZ



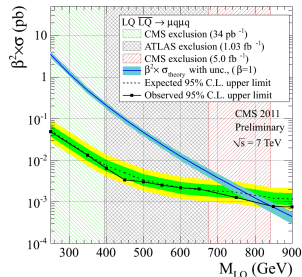
optimised selection

M_{LQ2} (GeV)	250	350	400	450	500	550	600	650	750	850
$S_T^{\mu\mu} > (\text{GeV})$	320	450	520	610	640	740	770	850	850	850
$M_{\mu\mu} > (\text{GeV})$	100	110	140	140	140	140	140	140	110	110
$\min M(\mu, \text{jet}) > (\text{GeV})$	70	130	150	170	260	350	350	350	510	510

Optimised Event Selection (e.g. $\mu\mu jj$):

- μ : $p_T > 40 \text{ GeV}/c$
- 2 jets with $p_T > 30 \text{ GeV}/c$
- $S_T > 250 \text{ GeV}/c$
(scalar p_T sum of the two μ and two jets)
- $\min M(\mu, \text{jet})$: smallest μj invariant mass which minimize the $M_{LQ} - M_{L\bar{Q}}$

more analyses are shown in back-up slides



LQ 3rd Generation: CMS EXO-12-002

Models:

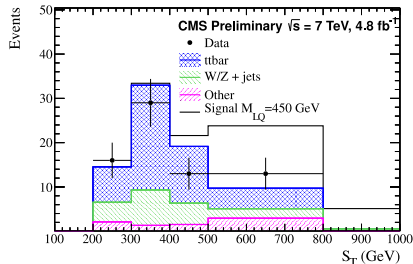
- Grand Unified Theories; composite models; technicolor; superstrings

decay mode:

$LQLQ \rightarrow \tau b \tau b \rightarrow \ell \tau_{had} b\text{-jet } b\text{-jet}$ with $\ell = e, \mu$ and $\beta = BR(LQ \rightarrow \tau b)$

Background Contributions:

- $t\bar{t}, Z^0 + nq \rightarrow \ell^\pm \ell^\mp + njets$,
 $W + nq \rightarrow \ell \nu + njets$
- WW, WZ, ZZ



Event Selection:

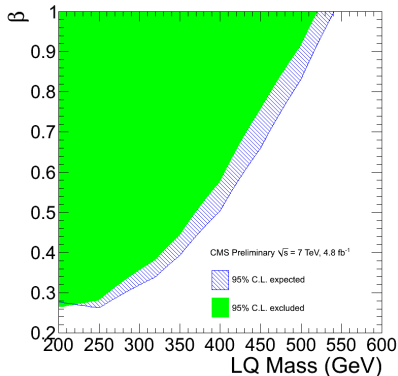
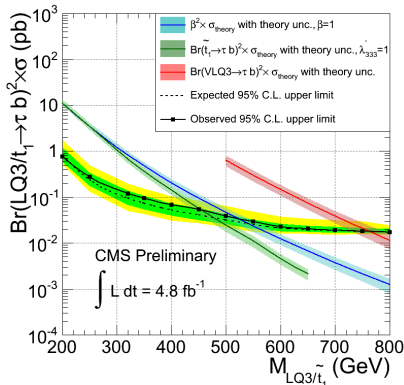
- ℓ : $p_T > 30$ GeV/c or τ : $p_T > 50$ GeV/c
- 2 b-tagged jets with $p_T > 30$ GeV/c
- $M(\tau_h, b\text{-jet})$ is chosen to minimize $M_{\ell b} - M_{\tau_h, bjet}$
- S_T : scalar p_T sum of the ℓ , τ_{had} and two b -jets

	$\mu + \tau$ channel	$e + \tau$ channel
$t\bar{t}$	$38.1 \pm 3.4 \pm 4.9$	$10.9 \pm 1.8 \pm 1.4$
W+jets/Z+jets	$11.6 \pm 0.1 \pm 2.6$	$8.4 \pm 0.1 \pm 1.8$
Z($\tau\tau/ll$)	$5.0 \pm 1.6 \pm 0.7$	$2.1 \pm 1.5 \pm 0.3$
diboson	$0.5 \pm 0.1 \pm 0.2$	$0.3 \pm 0.1 \pm 0.1$
Total Bkg.	$55.2 \pm 5.2 \pm 8.4$	$21.8 \pm 3.5 \pm 3.6$
Data	46	25
Signal (450 GeV)	$13.2 \pm 0.3 \pm 0.9$	$8.4 \pm 0.2 \pm 0.6$

	$\mu + \tau$ channel	$e + \tau$ channel
$t\bar{t}$	$27.0 \pm 3.0 \pm 3.5$	$6.9 \pm 1.4 \pm 0.9$
W+jets/Z+jets	$9.1 \pm 0.1 \pm 2.0$	$7.2 \pm 0.1 \pm 1.6$
Z($\tau\tau/ll$)	$5.0 \pm 1.6 \pm 0.7$	$2.1 \pm 1.5 \pm 0.3$
diboson	$0.4 \pm 0.1 \pm 0.1$	$0.2 \pm 0.1 \pm 0.1$
Total Bkg.	$41.5 \pm 4.8 \pm 6.3$	$16.4 \pm 3.1 \pm 2.9$
Data	36	17
Signal (500 GeV)	$6.75 \pm 0.14 \pm 0.45$	$4.37 \pm 0.11 \pm 0.29$
Signal (600 GeV)	$1.81 \pm 0.03 \pm 0.12$	$1.23 \pm 0.03 \pm 0.08$

LQ 3rd Generation

- limits estimated using the S_T variable
- because $\tilde{t}_1 \rightarrow \tau b$ has same signal signature one can estimate limits also on stop pair production



Limits

- LQ: $M(\text{LQ}) > 525(370) \text{ GeV}/c^2$ for $\beta = 1(0.5)$
- VectorLQ: $M(\text{LQ}) > 763 \text{ GeV}/c^2$ for $\beta = 1$

Dijets at $\sqrt{s} = 8$ TeV: CMS EXO-12-016

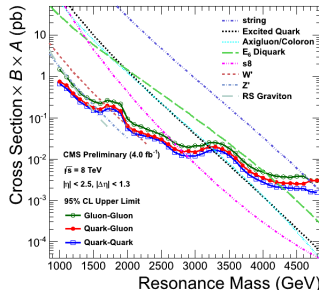
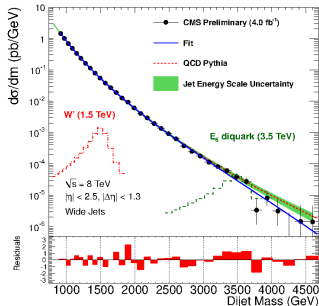
- Models with a narrow s -channel dijet resonance:
 - strings, diquarks, excited quarks, axigluons, colorons s_8 , W' , Z' , Randall-Sundrum gravitons...
- final states with $q\bar{q}$, qq , $\bar{q}\bar{q}$, qg and/or gg
- Background Contributions:
 - QCD multijet production - fit parametrization:

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3} \ln(x)}$$
 with $x = m_{jj}/\sqrt{s}$ and four free parameters P_i

- Event Selection:
 - $jets$: $p_T > 30$ GeV/ c and $|\eta| < 2.5$
 - 2 "wide jets": jet-grooming algorithm with $|\eta| < 2.5$ and $\Delta\eta_{jj} < 1.3$ and $m_{jj} > 890$ GeV/ c

Limits

- estimated with pseudo-experiments generated using background shapes (fit)



Randall-Sundrum Gravitons: CMS EXO-11-061

Models:

- graviton propagates in the extra dimension, leading to a Kaluza-Klein tower of states
- parameters: M_G and k/M_{Pl} (ratio of the 5d curvature to reduced Plack mass)

final state:

$$G^* \rightarrow Z^0 Z^0 \rightarrow q\bar{q}\nu\bar{\nu}$$

$$M_T^G = \sqrt{2p_T^{jet} E_T^{miss} (1 - \cos \Delta\varphi(jet, E_T^{miss}))}$$

Background Contributions:

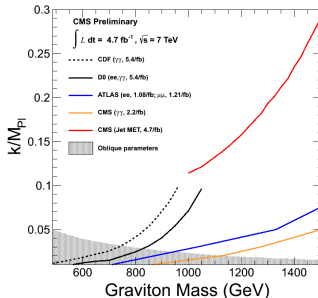
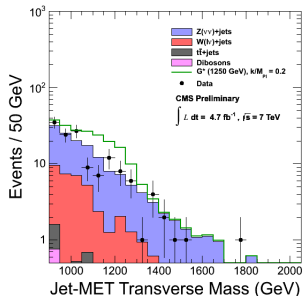
- $Z^0 + nq \rightarrow \nu\bar{\nu} + njets$, $W + nq \rightarrow \ell\nu + njets$
- $t\bar{t}$, WW , WZ , ZZ

Event Selection:

- only 2 jets with $\Delta\varphi > 2.8$ (veto QCD)
- leading jet $p_T > 200$ GeV/c and $m_j > 70$ GeV/c²
- $E_T^{miss} > 300$ GeV and $M_T^G > 900$ GeV/c²
- veto on isolated e or μ (veto $W \rightarrow \ell\nu$)

Limits at 95% C.L. for $M_G \in (1000; 1500)$ GeV/c²

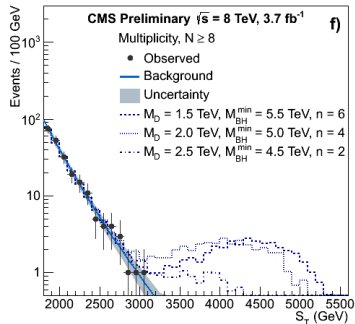
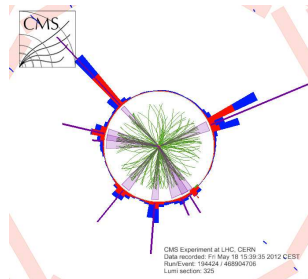
- σ in range 0.047 to 0.021 pb; k/M_{Pl} in range 0.11 to 0.29



Microscopic BH: CMS EXO-12-009

- Extra dimensions:
production with almost no mass \Rightarrow they do not grow, like cosmic black holes, but rather evaporate
- signature: large number of energetic final state particles, $\sim 75\%$ in jets
- Background Contributions: *QCD*

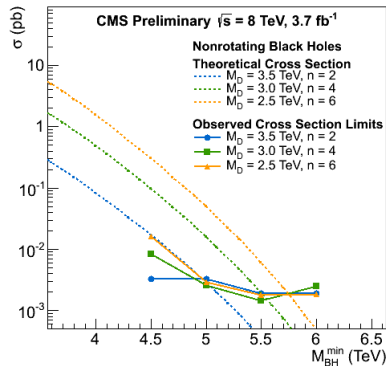
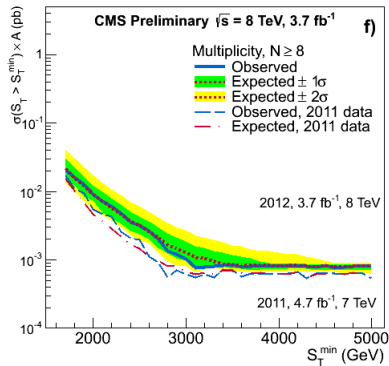
- Event Selection:
 - isolated leptons $p_T > 50$ GeV/c
 - isolated γ with $E_T > 50$ GeV/c
 - at least 2 jets with $p_T > 50$ GeV/c and $|\eta| < 2.6$
 - S_T - discriminating variable
(scalar p_T sum of jets, leptons, photons with $p_T > 50$ GeV/c and $E_T^{miss} > 50$ GeV)



Microscopic BH

- 95% C.L. model independent limits
- counting experiments with $S > S_T^{\min}$
- events with ≥ 8 jets of $p_T > 50$ GeV/c

- 95% C.L. dependent on n extra dimensions
- signal cross-sections: BLACKMAX generator
- M_{BH}^{\min} : minimum bh mass



ADD Extra Dimensions - e^+e^- : CMS EXO-12-013

Model:

- Arkani-Hamed, Dimopoloulos, Dvali
- signature: Kaluza-Klein excitations of the graviton
 \Rightarrow enhance σ for fermion and boson pair

Background Contributions:

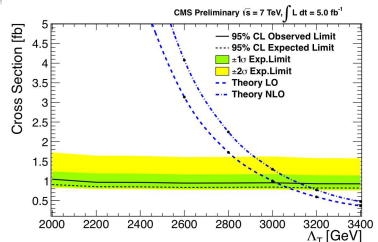
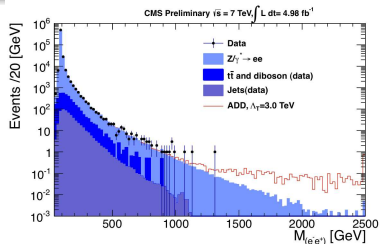
- $Z^0/\gamma^* \rightarrow e^+e^-$
- $t\bar{t}$, WW , WZ , ZZ , other multi-jets backgrounds

Event Selection:

- two isolated e : $p_T > 35(40)$ GeV/ c EB(EE)
- optimized M_{ee} cut to expected sensitivity:
 $M_{ee} > 1.3$ TeV/ c^2

$ee, \mathcal{L} = 4.98 \text{ fb}^{-1}$			
Mass region [TeV]	N_{obs}	Background expectation	Signal exp. $\Lambda_T = 3.0 \text{ TeV}$
Control regions			
0.12–0.20	13017	12587 ± 2166	-
0.20–0.40	2924	2912 ± 470	-
0.40–0.60	211	225 ± 37	15
0.60–0.80	42	40.6 ± 6.8	3
0.80–1.00	12	9.2 ± 1.2	1.3
1.00–1.30	2	3.17 ± 0.5	1.2
Signal region			
> 1.30	1	0.79 ± 0.15	4.4

similar analysis was performed also in $\mu^+\mu^-$ channel for 2.3 fb^{-1} so far (CMS EXO-11-087)



Monojet & Monophoton: CMS EXO-11-059

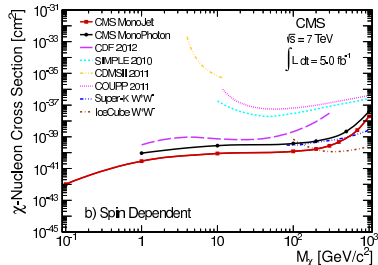
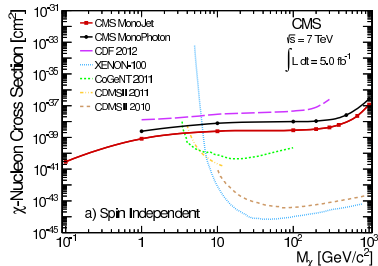
• Signal:

- Dark matter particle: χ - a Dirac fermion
- ADD Extra Dimensions

• Event Selection (e.g. Monojet):

- one jet: $p_T > 110$ GeV/c
- $E_T^{miss} > 200$ GeV/c
- no more than 2 jets with $p_T > 30$ GeV/c
- lepton veto: no ℓ with $p_T > 10$ GeV/c

E_T^{miss} (GeV/c) \rightarrow	≥ 250	≥ 300	≥ 350	≥ 400
Process	Events			
$Z(\nu\nu)+jets$	5106 ± 271	1908 ± 143	900 ± 94	433 ± 62
$W+jets$	2632 ± 237	816 ± 83	312 ± 35	135 ± 17
$t\bar{t}$	69.8 ± 69.8	22.6 ± 22.6	8.5 ± 8.5	3.0 ± 3.0
$Z(\ell\ell)+jets$	22.3 ± 22.3	6.1 ± 6.1	2.0 ± 2.0	0.6 ± 0.6
Single t	10.2 ± 10.2	2.7 ± 2.7	1.1 ± 1.1	0.4 ± 0.4
QCD Multijets	2.2 ± 2.2	1.3 ± 1.3	1.3 ± 1.3	1.3 ± 1.3
Total SM	7842 ± 367	2757 ± 167	1225 ± 101	573 ± 65
Data	7584	2774	1142	522
Expected upper limit non-SM	779	325	200	118
Observed upper limit non-SM	600	368	158	95



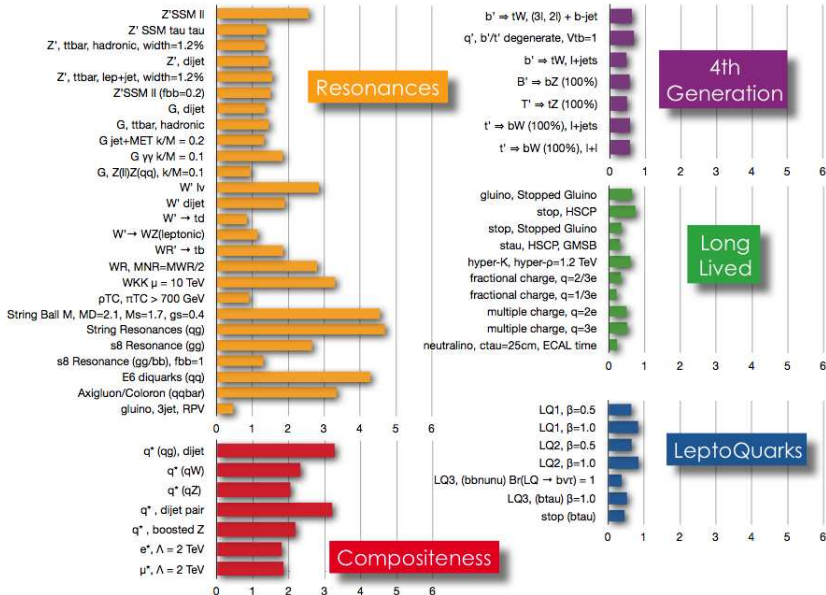
instead of conclusions...

- most of the analyses were designed as model independent as possible - *one can have the number of events in data and the background prediction which can be compared with its signal prediction*
- there were many "stones" turned in CMS Exotic searches (and not only)
- so far, under the "stones", there was nothing that could explain $\sigma/\sigma_{SM}(H \rightarrow \gamma\gamma) = 2.1 \pm 0.6$
- where to go from here...
 - many final states with $e, \mu, \tau, \gamma, \text{jets}, E_T^{\text{miss}}, W, Z$ have been checked
- time to be more specific in our searches, the Higgs "door" is already open
- it is also time to prepare analyses with the new boson plus the physics objects above
 - for 35 fb^{-1} integrated luminosity at the Christmas time
 - and for 13 TeV (~ 2015) and 14 TeV (~ 2016)
- by the way, we have already 10 fb^{-1} recorded so far this year
congratulation to the operation crew at P5

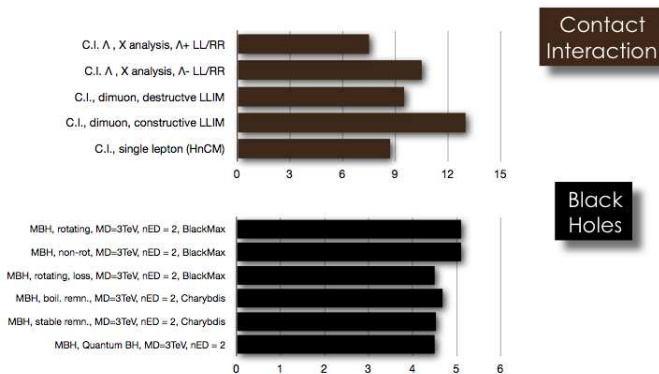
*apologise to my colleagues that did not see their analyses today, time is a difficult variable
please take a moment or two, and look also in back-up slides to see many other nice analyses*

Back-Up Slides

Overview from CMS Exotic Searches I



Overview from CMS Exotic Searches II



an "Exotic" test, even for the Great Wall



- many of us were yesterday at the Great Wall (the rest are happy with the SM)
- this is one of the many pictures taken yesterday (I shoot ~ 100 of them)
- do you see anything special in this picture?
(the famous: *what is wrong in this picture?*)
- let's restrict the search area:
do you know that there is camel in this picture? do you see a camel in this picture? a real camel (BSM), not the Great Wall (tails in the SM)

an "Exotic" test, even for the Great Wall



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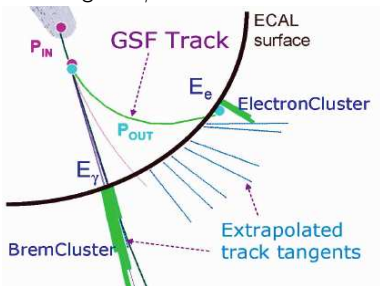


- what about in this picture? ohh jaa...
- don't worry if you did not see it first time, I needed also 3 shots of the same side of the Great Wall to see the exotic camel
- so far we look mostly where we expect to have no SM backgrounds... the $H \rightarrow \gamma\gamma$ was seen on top of a huge background... what about challenging ourselves to more delicate phase-space regions? what about the eagle?

Electron Reconstruction

Electron in CMS:

an ECAL cluster matched with a track reconstructed using the **Gauss Sum Function** and adding the γ radiation from Brem Clusters

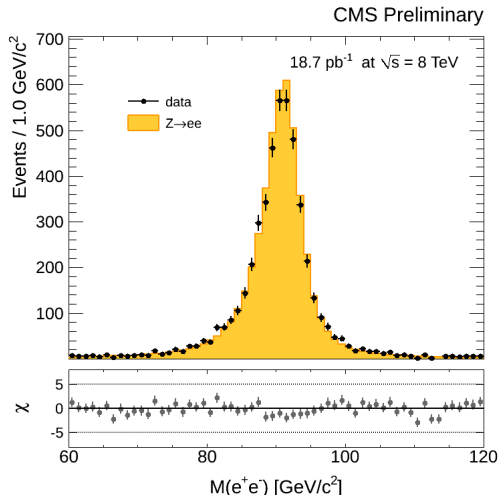


- Coverage:

- ECAL: $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$

- Energy Resolution: $\frac{3\%}{\sqrt{E_T/\text{GeV}}}$

- $E_T = 45 \text{ GeV}$:
 $\sigma_{E_T}/E_T = 0.44\%$
 $\sigma_{E_T} = 0.2 \text{ GeV}$

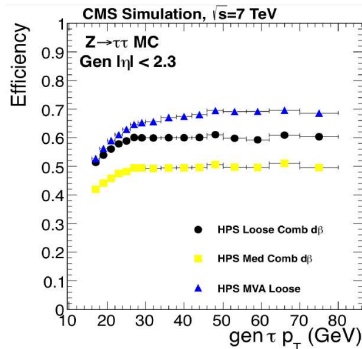
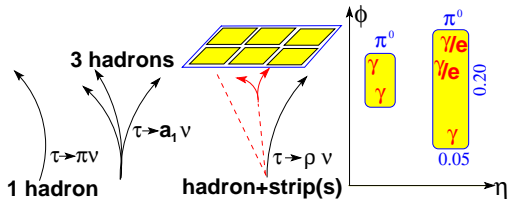


- again nice agreement between Monte Carlo and Data
- we could even call ourselves CEMS ☺

Tau Reconstruction

Taus in CMS:

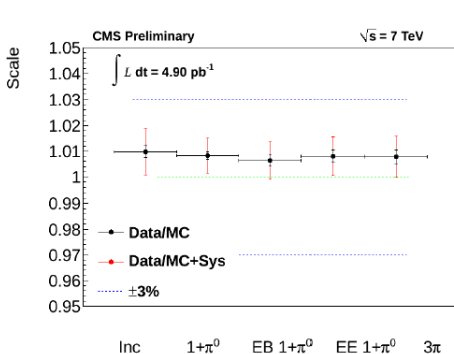
reconstructed using the **Hadron Plus Strips** algorithm



- decays in 1- or 3-prongs (π^\pm)
- e & γ clustered in strips: π^0 reconstruction (the mass has to be compatible with an a_1 or ρ hypothesis)
- cleaning with MVA discriminators for: e^- and μ^- -rejection and I isolation corrected for pile-up

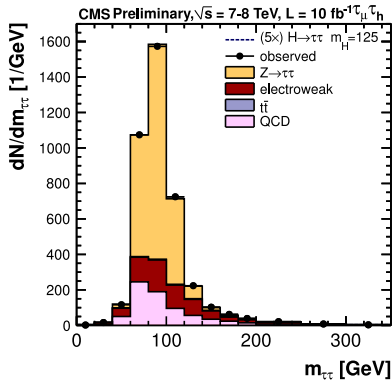
- different isolations are used
 - corrected for pile-up ($d\beta$)
 - and combining the Tracker, ECAL and HCAL information in working points: Loose, Medium, MVA Loose
- 70% efficiency and 5% fake rate

Tau Reconstruction



EB: ECAL barrel
EE: ECAL end caps

- Coverage: $|\eta| < 2.3$
- Energy Scale: $< 3\%$

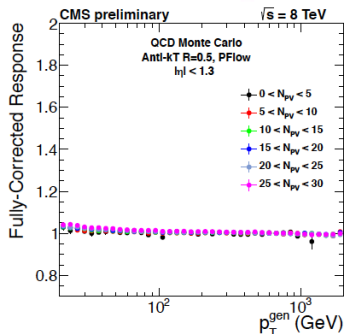
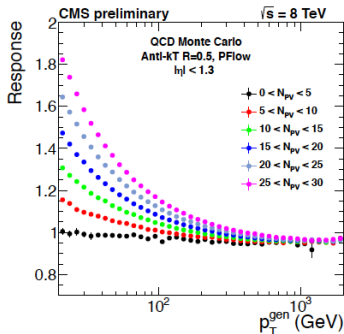
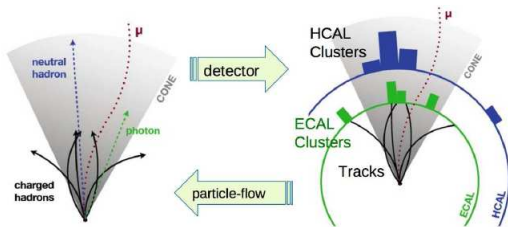


- one τ decaying into μ and second one into τ 1- or 3-prongs
- "electroweak" combines contributions from W^\pm , $Z^0 \rightarrow \ell^\pm \ell^\mp$ with $\ell = e, \mu$, WW , WZ and ZZ

PFJets Reconstruction

Particle Flow in CMS:

- reconstructs and identify all stable particles within the detector (e , γ , μ , charged & neutral hadrons)
- builds jets using the *anti- κ_T* alg. which are: infrared & collinear safe
- coverage: $|\eta| < 2.4$ for most analyses



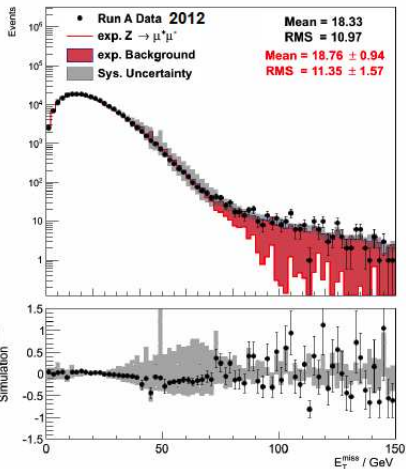
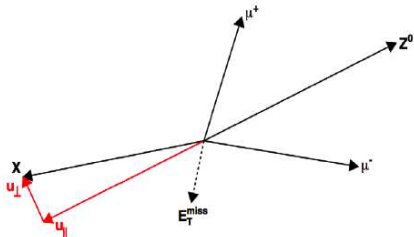
- after all corrections:
an independent of pile-up (N_{PV}) good reconstruction of the generated p_T jets

MET Reconstruction

Missing Energy in Transverse plane in CMS:

the negative vector sum of all particles candidates reconstructed with the PF algorithm

CMS preliminary, $\sqrt{s}=8$ TeV $L = 0.7 \text{ fb}^{-1}$



- best events to check MET and its resolution: $Z^0 \rightarrow \mu^+ \mu^-$
- mean of the distribution of $-u_{\parallel}/q_T$ measures the MET response (sets the scale), where q_T is Z^0 momentum
- RMS widths of $-u_{\parallel} - q_T$ and u are used to measure the MET resolution

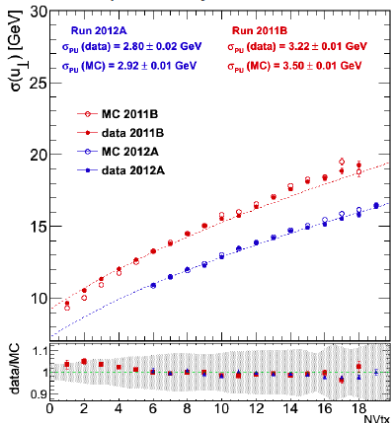
- good agreement between MC and data

MET Reconstruction

Missing Energy in Transverse plane in CMS:

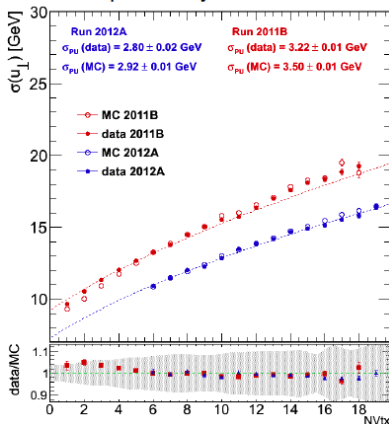
the negative vector sum of all particles candidates reconstructed with the PF algorithm

CMS preliminary



- again good agreement between MC and data
- evolution with PU can be predicted

CMS preliminary



- better in 2012A due to changes in energy reconstruction (2012B will follow)

$Z' \rightarrow \tau^- \tau^+$: CMS EXO-11-031

Models:

- Sequential Standard Model: Z'_{SSM}
- Grand Unified Theories: Z'_ψ
- Z' - could prefer the coupling to 3rd generation
- channels: $\tau_e \tau_\mu$, $\tau_e \tau_{had}$, $\tau_\mu \tau_{had}$, $\tau_{had} \tau_{had}$

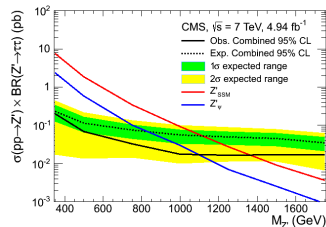
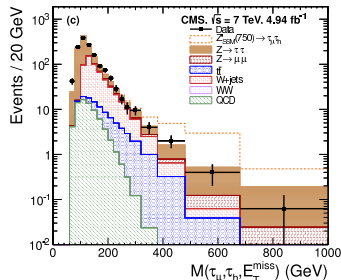
Background Contributions:

- $Z^0 \rightarrow \ell^- \ell^+$ with $\ell = e, \mu, \tau$
- $t\bar{t}$, W , WW , WZ , QCD

Process	$\tau_e \tau_\mu$	$\tau_e \tau_h$	$\tau_\mu \tau_h$	$\tau_h \tau_h$
$Z \rightarrow \tau^+ \tau^-$	$816 \pm 58 \pm 44$	$462 \pm 56 \pm 24$	$804 \pm 53 \pm 44$	$30.9 \pm 3.6 \pm 4.3$
$Z \rightarrow \mu^+ \mu^-$	—	—	$20.8 \pm 8.3 \pm 1.1$	—
$Z \rightarrow e^+ e^-$	—	$220 \pm 24 \pm 11$	—	$0.66 \pm 0.33 \pm 0.22$
$W + Jets$	$83 \pm 15 \pm 7$	$181 \pm 36 \pm 13$	$459 \pm 26 \pm 29$	$5.8 \pm 1.7 \pm 1.1$
WW	$55.6 \pm 1.4 \pm 1.9$	—	$24.6 \pm 0.8 \pm 0.8$	—
WZ	$5.6 \pm 0.35 \pm 0.22$	—	—	—
$t + \bar{t}$	$9.6 \pm 1.2 \pm 0.7$	$10.8 \pm 2.8 \pm 0.9$	$46.2 \pm 6.9 \pm 3.7$	$0.00 \pm 0.76 \pm 0.15$
QCD	$45.1 \pm 3.3 \pm 9.0$	$185 \pm 31 \pm 19$	$72 \pm 18 \pm 8$	$467 \pm 26 \pm 67$
Total	$1015 \pm 60 \pm 45$	$1058 \pm 77 \pm 35$	$1427 \pm 63 \pm 53$	$504 \pm 26 \pm 67$
Observed	1044	1043	1422	488

Limits

- $M(Z'_{SSM}) > 1.4 \text{ TeV}/c^2$ at 95% C.L.
- $M(Z'_\psi) > 1.1 \text{ TeV}/c^2$ at 95% C.L.



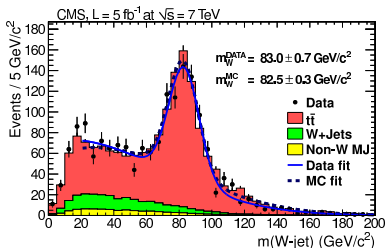
$Z' \rightarrow t\bar{t}$: CMS EXO-11-006

• "Model":

- Z' resonance with a narrow width (1% of $M_{Z'}$)
- t - full hadronic channel (3+3 jets)
- boosted t - decay products inside one jet

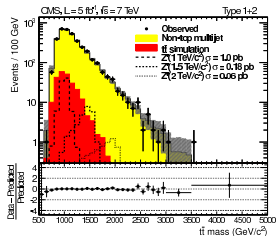
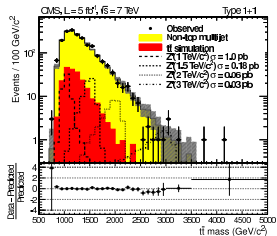
• Event Selection:

- single hadronic jet trigger
- one t reconstructed in each hemisphere
- Type 1: all 3 jets merged into a single "hard" jet
two jets with $p_T > 350$ GeV/c and $|\eta| < 2.5$
- Type 2: only 2 jets are merged in a jet
 $p_{T\text{ jet1}} > 350$ GeV/c, $p_{T\text{ jet2}} > 200$ GeV/c,
 $p_{T\text{ jet3}} > 30$ GeV/c and $|\eta| < 2.5$



• Background Contributions:

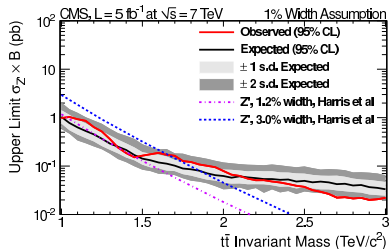
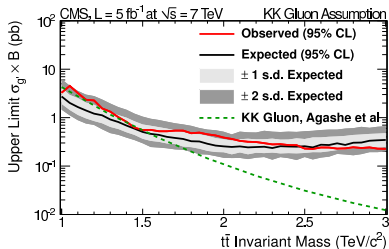
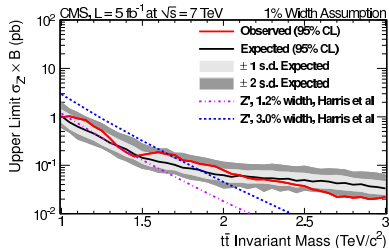
- $t\bar{t}$
- QCD multijet production



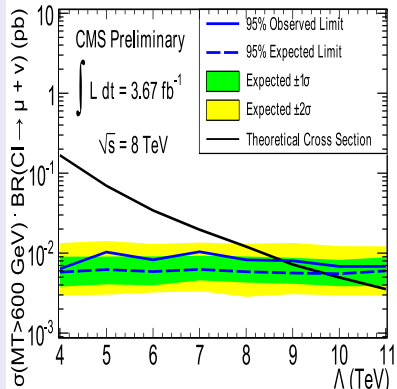
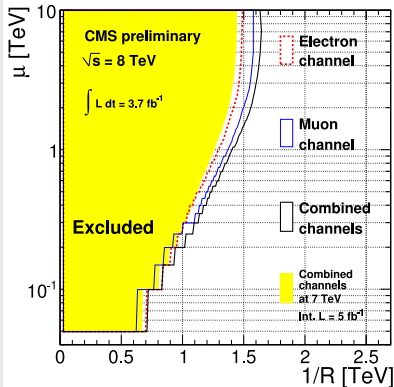
$$Z' \rightarrow t\bar{t}$$

	1+1	1+2
Expected SM $t\bar{t}$ events	194 ± 106	129 ± 80
Expected non-top multijet events	1546 ± 45	2271 ± 130
Total expected events	1740 ± 115	2400 ± 153
Observed events	1738	2423

- model-independent limits on production cross-section



$W' \rightarrow \ell \nu$ with $\ell = e, \mu$



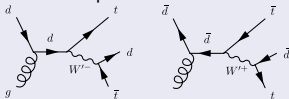
- 95% C.L. on split universal extra dimensions parameters μ and $1/R$
- considering W_{KK}^2 width

- four-fermion contact interaction (Helicity-Non-Conserving model)
- preon binding energy scale: $\Lambda > 8.7 \text{ TeV}$ at 95% C.L.

$tW' \rightarrow t + \bar{t} + d$: CMS EXO-11-056

• W' Models:

- associated production with t

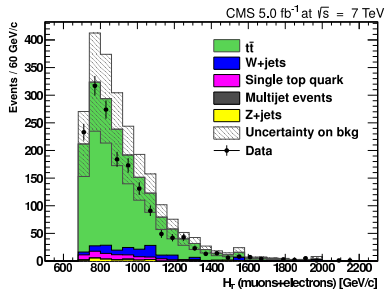
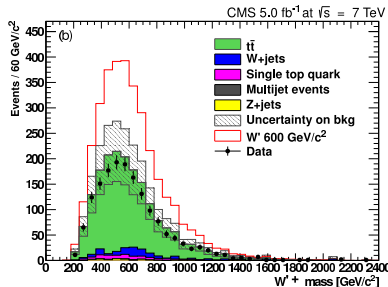


• Background Contributions:

- $t\bar{t}$, tW
- $W \rightarrow \ell\nu$, $Z^0 \rightarrow \ell^+\ell^-$

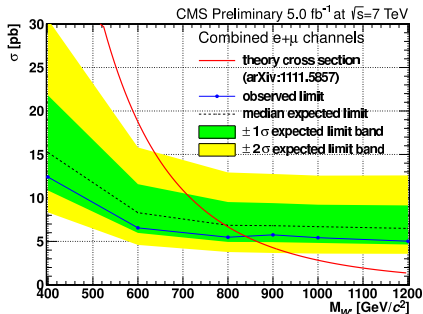
• Event Selection:

- single lepton and/or single lepton & 3 jets trigger
 - one isolated lepton
 - e : $p_T > 45$ GeV/c and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
 - μ : $p_T > 42$ GeV/c and $|\eta| < 2.1$
 - ≥ 5 jets with $p_T > 35$ GeV/c and $|\eta| < 2.5$
 - $p_{T, \text{jet1}} > 180$ GeV/c, $p_{T, \text{jet2}} > 90$ GeV/c
 - at least 1 b-tagged jet
 - $E_T^{\text{miss}} > 20$ GeV
 - $H_T > 700$ GeV/c
- (scalar sum of p_T jets, lepton and E^{miss})



$$tW' \rightarrow t + \bar{t} + d$$

- LHC-type CL_s method: one-sided prole likelihood ratio test statistics and applies a Frequentist treatment of nuisance parameters



Luminosity 5.0 fb^{-1}			
	Cross section [pb]	μ +jets	e+jets
$t\bar{t}$	154	888 ± 276	734 ± 204
Single top	85	40 ± 20	32 ± 16
W+jets	31314	49 ± 25	64 ± 32
Z+jets	3048	12 ± 6	8 ± 4
Multijets		-	5 ± 5
Total background		989 ± 279	843 ± 209
Signal W' 600 GeV/c^2 mass	18.2	858	723
Data		904	726

Limits:

- $M(W') > 839 \text{ GeV}/c^2$ at 95% C.L.
for coupling constant values $g_L = 0$ and $g_R = 2$

$W'^+ \rightarrow t\bar{b}$ and $W'^- \rightarrow \bar{t}b$: CMS EXO-12-001

- W' Model:

- various couplings: W'_R , W'_L and W'_{mixed}

- decay mode:

- $t \rightarrow bW^+ \rightarrow b\ell^+\nu$ with $\ell = e, \mu$

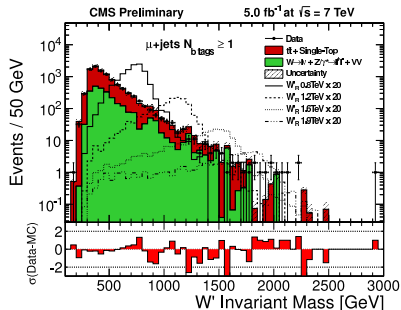
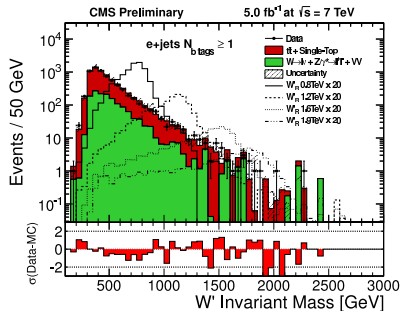
- Background Contributions:

- $t\bar{t}$, tW
- $W \rightarrow \ell\nu$, $Z^0/\gamma^* \rightarrow \ell^+\ell^-$, WW , WZ , ZZ

- Event Selection:

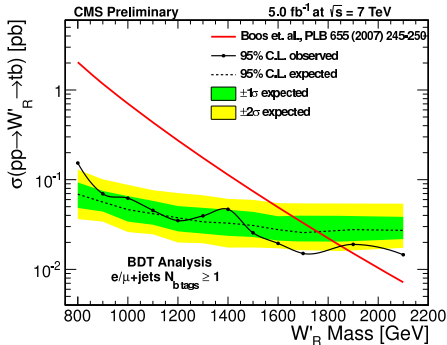
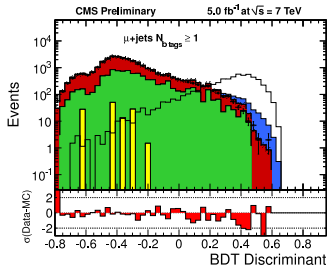
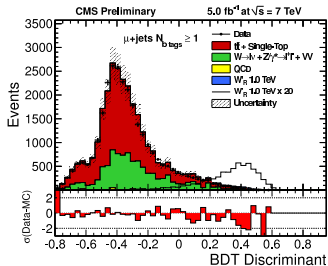
- single isolated lepton or single lepton with E_T^{miss} and jets trigger
- one isolated lepton
- e : $p_T > 35$ GeV/c and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- μ : $p_T > 32$ GeV/c and $|\eta| < 2.1$
- ≥ 5 jets with $p_T > 35$ GeV/c and $|\eta| < 2.5$
- $p_{T,jet1} > 100$ GeV/c, $p_{T,jet2} > 40$ GeV/c
- at least 1 b-tagged jet
- $E_T^{miss} > 20$ GeV in μ -channel and 35 GeV in e -channel

- Signal (illustration) scaled by a factor of 20



$W'^+ \rightarrow t\bar{b}$ and $W'^- \rightarrow \bar{t}b$

- BDT discriminant trained for each mass point
- individual kinematics, event kinematics and angular variables

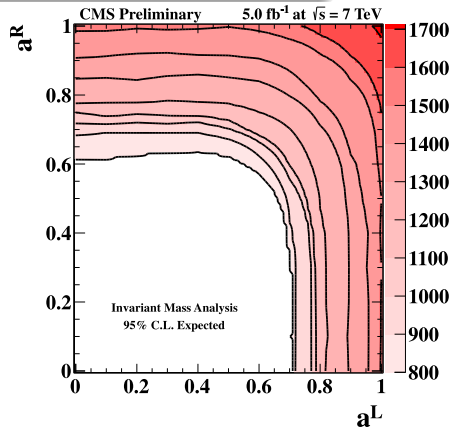
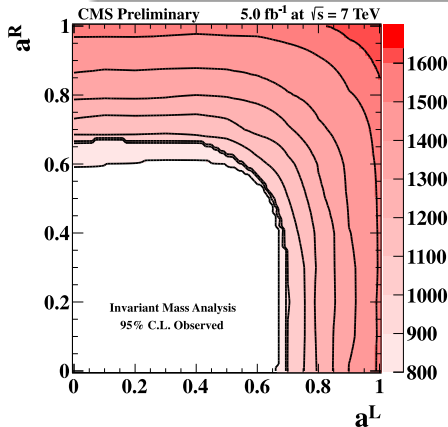


Limits:

- $M(W'_R) > 1.85 \text{ TeV}/c^2$ at 95% C.L.
and $M(W'_L)$ - no interference with SM included
- on left- and right-handed couplings

$W'^+ \rightarrow t\bar{b}$ and $W'^- \rightarrow \bar{t}b$

- BDT discriminant trained for each mass point
- input: individual kinematics, event kinematics and angular variables



Limits:

- on left- and right-handed couplings
- z-axis: $M(W')$ in GeV/c²

$W', \rho_{TC} \rightarrow WZ \rightarrow 3\ell\nu$ with $\ell = e, \mu$: CMS EXO-11-041

• W' Models:

- Sequential Standard Model
- Technicolor

$$M(\pi_{TC}) = 3/4 M(\rho_{TC}) - 25 \text{ GeV}/c^2$$

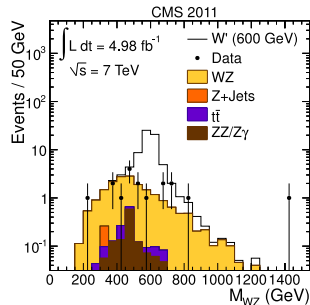
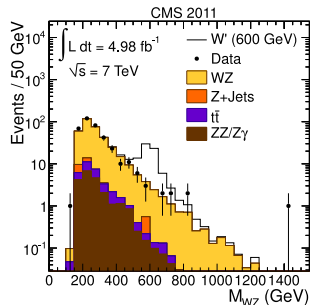
$$M(\rho_{TC}) < M(\pi_{TC}) + M_W$$

• Background Contributions:

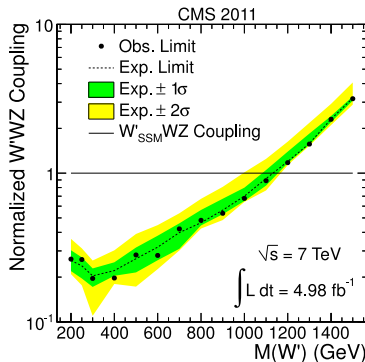
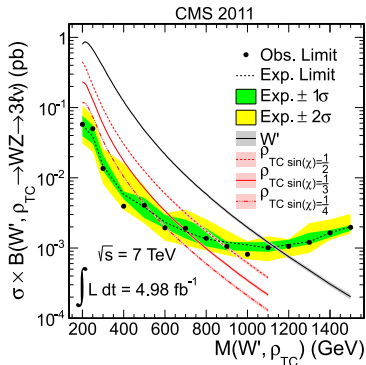
- $WZ, ZZ/Z\gamma$
- $t\bar{t}, Z^0 \rightarrow \ell^+\ell^-$

• Event Selection:

- double leptons (same flavour) trigger
- two isolated leptons
- $e(Z^0)$: $p_T > 20(10) \text{ GeV}/c$ and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- $\mu(Z^0)$: $p_T > 15(15) \text{ GeV}/c$ and $|\eta| < 2.4$
- $m_{\ell^+\ell^-} \in (60; 120) \text{ GeV}/c^2$ and veto on second Z^0 pair
- $\ell(W^\pm)$: $p_T > 20 \text{ GeV}/c$
- $E_T^{\text{miss}} > 30 \text{ GeV}$
- L_T scalar sum of the transverse momenta of the charged leptons - optimized for each mass point
 - for $600 \text{ GeV}/c^2$ mass point: $L_T > 290 \text{ GeV}/c$
 - M_{WZ} w/o L_T cut (up) and with L_T cut (down)



$W', \rho_{TC} \rightarrow WZ \rightarrow 3\ell\nu$ **with** $\ell = e, \mu$



$M(W'/\rho_{TC})$	L_T	WZ	N_{Bkg}^{MC}	Data	ϵ_{sig}
(GeV)	(GeV)	Mass Window (GeV)			(%)
500	230	450–550	8.1 ± 0.5	9	41 ± 1
600	290	540–660	3.4 ± 0.1	2	45 ± 1
700	360	620–780	1.79 ± 0.09	2	48 ± 1
800	400	710–890	1.02 ± 0.07	1	52 ± 2
900	400	760–1040	1.03 ± 0.07	0	61 ± 2
1000	400	820–1180	0.77 ± 0.06	0	65 ± 2
1100	400	890–1310	0.55 ± 0.05	0	63 ± 1
1200	400	940–1460	0.42 ± 0.04	0	58 ± 1
1300	400	1020–1580	0.34 ± 0.04	0	50 ± 1
1400	400	1110–1690	0.18 ± 0.03	0	36 ± 1
1500	400	1200–1800	0.13 ± 0.02	0	30 ± 1

Limits:

- $M(W'_{SSM}) > 1143 \text{ GeV}/c^2$ at 95% C.L.
- $M(\pi_{TC}) = 3/4 M(\rho_{TC}) - 25 \text{ GeV}/c^2$
excluded: $M(\rho_{TC}) \in (167; 687) \text{ GeV}/c^2$ at 95% C.L.
- $M(\rho_{TC}) < M(\pi_{TC}) + M_W$
excluded: $M(\rho_{TC}) \in (180; 938) \text{ GeV}/c^2$ at 95% C.L.

$b'\bar{b}' \rightarrow tW^-\bar{t}W^+$: CMS EXO-11-036

- 4th Generation

- $m_{b'} > 480 \text{ GeV}/c^2$ - ATLAS

- decay mode:

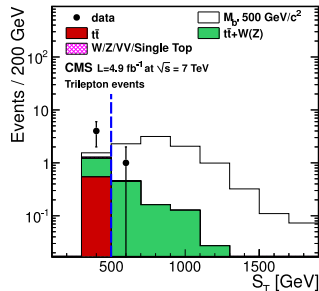
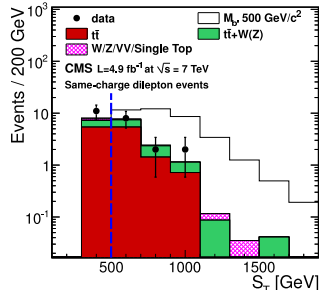
$$tW^-\bar{t}W^+ \rightarrow bW^+W^- \quad bW^-W^+ \rightarrow \ell^\pm \ell^\pm (\ell^\pm)X$$

- Background Contributions:

- $t\bar{t}$, $t\bar{t}Z^0$, $t\bar{t}W^\pm$
- tW , WW , WZ , ZZ , W^\pm , Z^0/γ^*

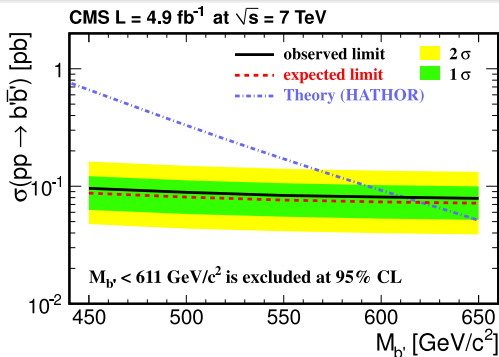
- Event Selection:

- two same-sign or three isolated leptons
 $p_T > 20 \text{ GeV}/c$
- veto on Z^0/γ^*
- at least 4 jets (2jets) $p_T > 25 \text{ GeV}/c$
(one b-tagged jet)
- $S_T > 500 \text{ GeV}/c$
(scalar p_T sum of jets, leptons and E_T^{miss})



$$b'\bar{b}' \rightarrow tW^-\bar{t}W^+$$

- LHC-type CL_S method: one-sided prole likelihood ratio test statistics and applies a Frequentist treatment of nuisance parameters



Sources	Same-charge dilepton	Trilepton
Same-charge dilepton with a charge-misidentified electron, or a misidentified or non-isolated lepton (from data)	7.8 ± 2.8	
Prompt same-charge dilepton, or trilepton (simulated)	3.6 ± 0.6	0.78 ± 0.21
Background sum	11.4 ± 2.9	0.78 ± 0.21
Observed yield in data	12	1

Limits:

- $M(b') > 611 \text{ GeV}/c^2$ at 95% C.L.

$T' \rightarrow tZ^0$: CMS EXO-11-005

- Vector-like Charged Quarks

- charge: $2/3$, $BR : \sim 100\%$

- decay mode:

$$T' \bar{T}' \rightarrow tZ^0 \bar{t}Z^0 \rightarrow bW^+ Z^0 \bar{b}W^- Z^0$$

- Background Contributions:

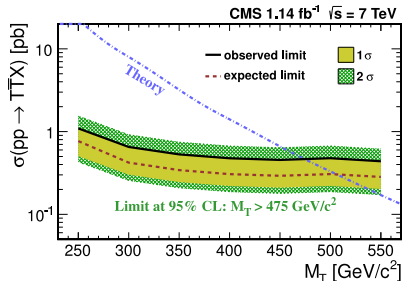
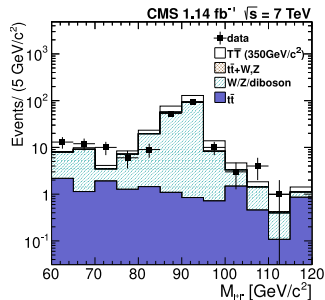
- $t\bar{t}$, WW , WZ , ZZ , tW , Z^0 , W^\pm
- $t\bar{t}Z^0$, $t\bar{t}W^\pm$

- Event Selection:

- double leptons trigger
- e : $p_T > 20$ GeV/c and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- μ : $p_T > 15$ GeV/c and $|\eta| < 2.4$
- at least one Z^0/γ^* : $m_{\ell\ell} \in (60; 120)$ GeV/c²
- at least 3 leptons
- at least 2 jets $p_T > 25$ GeV/c and $|\eta| < 2.4$
- $R_T > 80$ GeV/c
(scalar p_T sum of all jets and leptons, except the 2 highest p_T ones)

Limits

- $M(T') > 475$ GeV/c² at 95% C.L. (Bayesian)



$B' \rightarrow bZ^0$: CMS EXO-11-066

- Vector-like Charged Quarks

- charge: $-1/3$, $BR: \sim 100\%$

- decay mode:

$$B' \bar{B}' \rightarrow bZ^0 \bar{b}Z^0$$

- Background Contributions:

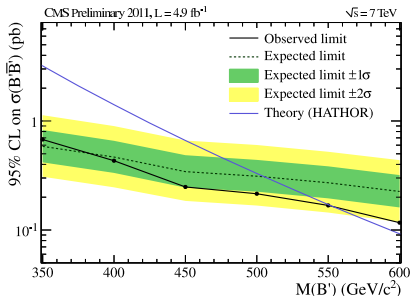
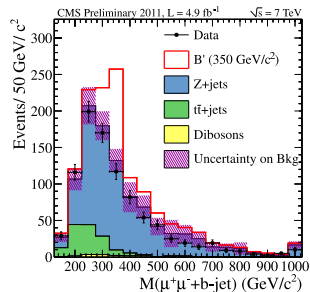
- $t\bar{t}$, WW , WZ , ZZ , tW , Z^0 , W^\pm
- $t\bar{t}Z^0$, $t\bar{t}W^\pm$

- Event Selection:

- double leptons trigger
- e : $p_T > 25$ GeV/c and $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- μ : $p_T > 20$ GeV/c and $|\eta| < 2.1$
- at least one Z^0/γ^* : $m_{\ell^+\ell^-} \in (60; 120)$ GeV/c² with $p_T > 95$ GeV/c
- at least 2 jets $p_T > 30$ GeV/c and $|\eta| < 2.4$
- at least one b-tagged jet with $p_T > 65$ GeV/c

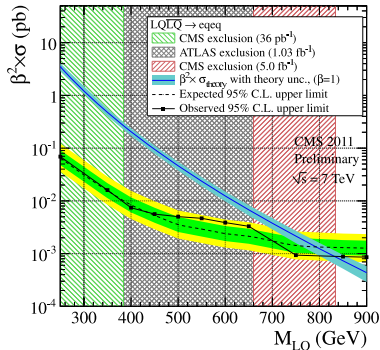
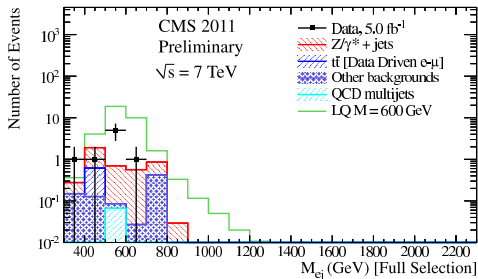
Limits

- $M(B') > 550$ GeV/c² at 95% C.L. (Frequentist)



LQ 1st 2nd: CMS EXO-11-028

● LQ : - first generation ej

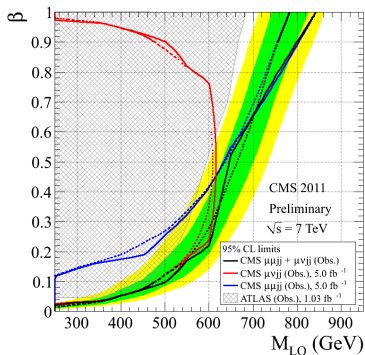
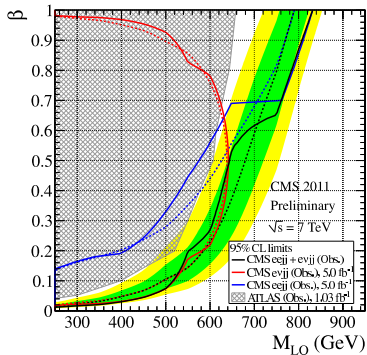


Limits:

● $M(QL) > 840(650)$ GeV/ c^2 for $\beta = 1(0.5)$

LQ 1st 2nd Generation

- LHC-type CL_s method: one-sided prole likelihood ratio test statistics and applies a Frequentist treatment of nuisance parameters
- limits consistent also with calculations using the Bayesian approach



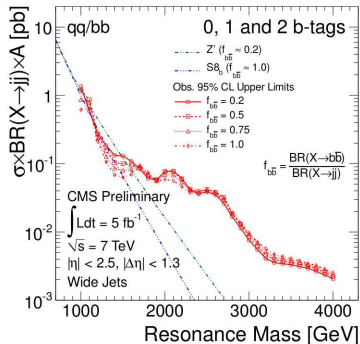
Limits

- ej : $M(LQ) > 830(640)$ GeV/ c^2 for $\beta = 1(0.5)$
- μj : $M(LQ) > 840(650)$ GeV/ c^2 for $\beta = 1(0.5)$

Dijets at $\sqrt{s} = 7$ TeV

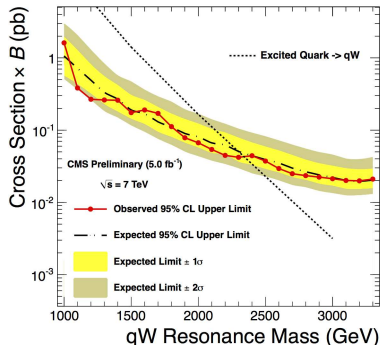
0/1/2 b-jets: CMS EXO-11-008

- additional limits on:
 - Z'
 - Randall-Sundrum gravitons ($b\bar{b}$)
 - $S8_b$



1/2 W^\pm/Z^0 : CMS EXO-11-095

- additional limits on:
 - excited quarks (qW^\pm, qZ^0)
 - Randall-Sundrum gravitons (WW, ZZ)
 - $W'(WZ)$



Fractionally Charged Particles: CMS EXO-11-074

- No Specific Model:

- particles with $q = 1e/3$ or $q = 2e/3$, and a lifetime of a few ns or more
- a non-negligible fraction of these particles can escape the detector without decaying

- Background Contributions:

- cosmic ray μ
- pp collisions - control region from $Z^0 \rightarrow \mu^+ \mu^-$

- Event Selection:

- single isolated μ trigger
- one isolated μ : $p_T > 40$ GeV/c and $|\eta| < 1.5$
- at least 6 dE/dx measurements in inner tracker
- $d_{xy} < 0.1$ cm and $d_z < 0.5$ cm
- low ionizing hits: $dE/dx < 2$ MeV/cm
- $N_{hits}^{dE/dx} \geq 6$ (veto SM backgrounds)

Cosmic ray background estimate	1.0 ± 0.32
pp collisions uncorrelated background estimate	$0.04^{+0.07}_{-0.04}$
pp collisions uncorrelated background estimate	$0^{+4.6}_{-0}$
Observed events in signal sample data	1

Limits at 95% C.L.

- $M_{q=1/3} > 210$ GeV/c² and $M_{q=2/3} > 330$ GeV/c²

