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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Measurement of WZ Production and search for WZ resonances with the CMS Detector

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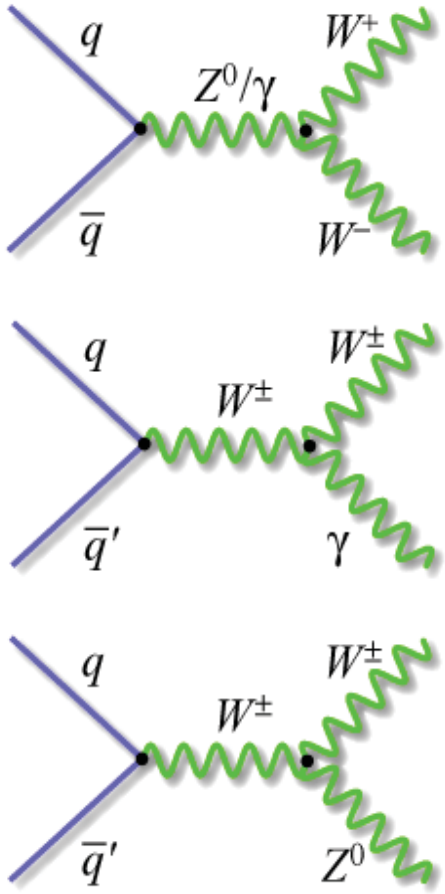
On behalf of the CMS Collaboration

20.9.2011.

Introduction

Diboson studies at the LHC

- Important test of the Standard Model
- Testing sensitivity to gauge boson interactions via trilinear gauge couplings (TGC) : $WWZ, WW\gamma$
- Coupling values are fully fixed in the SM by the gauge structure of the Lagrangian
  - deviation would indicate new physics
- WW and ZZ are Important irreducible background in Higgs searches



WZ process

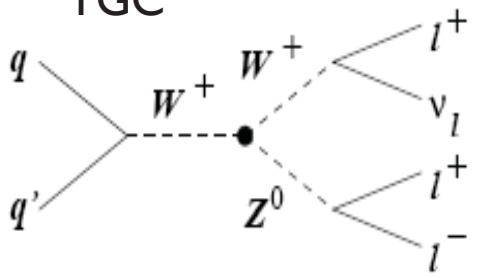
- Virtual off-shell W decay to W and Z via the WWZ vertex
  - small t-channel contribution
- Cross section
  - Theoretical (inclusive, NLO):

    $\sigma_{incl.NLO}$=17.53 ± 0.55(*pdf*) pb

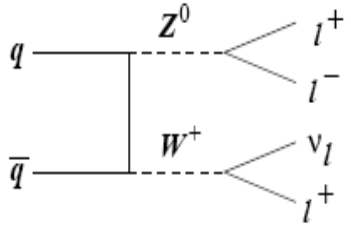
    for M_Z in [60,120] GeV range

- focusing on leptonic (e,μ) decay channels of W and Z boson
  - BR : ~1.5 , includes all four final states *eee*, *eeμ*, *μμe* and *μμμ*

TGC



t-channel



$$\mathbf{WZ} \rightarrow \ell^{\pm}\nu\ell'^{+}\ell'^{-} \; (\ell, \ell' = e, \mu)$$

WZ signal and backgrounds

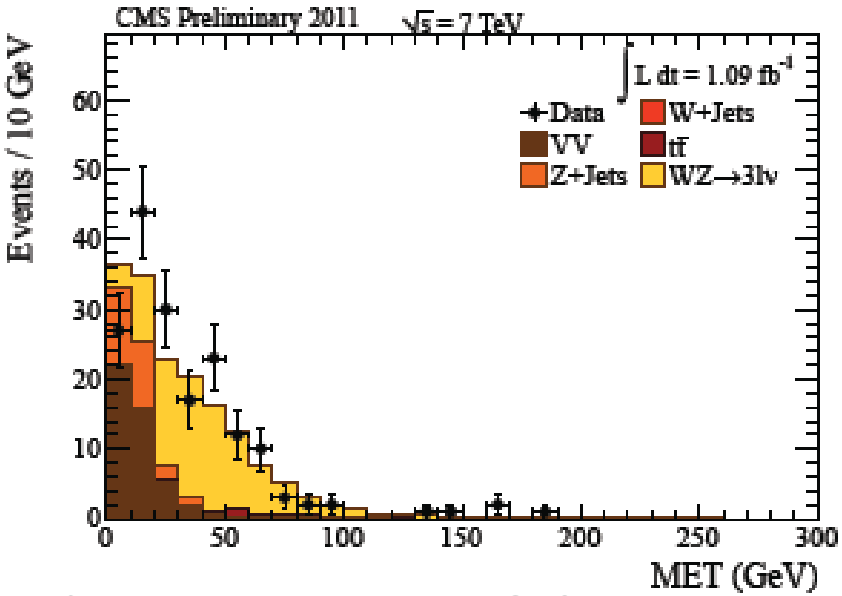
- WZ→3lν (e,μ) decay characterized by
  - a pair of same-flavor, opposite-charge, high-p_T leptons with an invariant mass corresponding to Z boson
  - third, high p_T lepton from W boson
  - significant amount of missing transverse energy (E_T^{miss}), associated to the escaping neutrino

Backgrounds - events with three leptons, genuine or fake

- Leptonic WZ decays containing τ-lepton
  - τ–decay can result with e,μ in final state
  - cross section proportional to the signal cross section (which we measure)
- Non-peaking (no genuine Z):
  - ttbar
  - W+jets, QCD(negligible)
- With genuine Z and third fake lepton:
  - Zγ and Z+jets (including Z+heavy quarks)
- With genuine Z and genuine third lepton: ZZ→4l
  - 4th lepton can escape detection, so a fraction of this background is irreducible
  - small production cross section

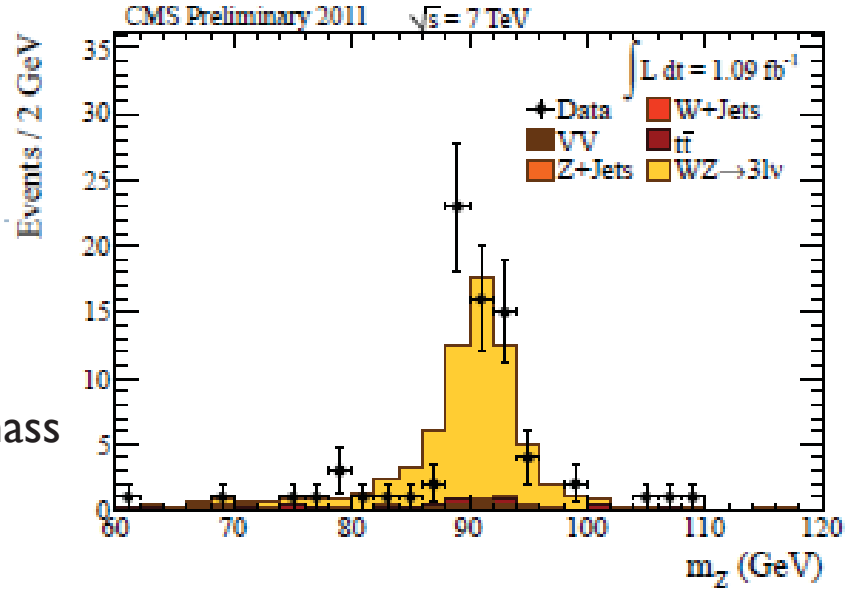
Event selection overview

- Analysis done separately for all four e and μ channel combinations
- Lepton selection
  - electrons: narrow shower in ECAL matched to a charged track
  - muons: track in the muon system and in the inner tracker matched
  - Isolation: require low energy in the cone around the lepton
  - $|\eta| < 2.5$ (electrons) or $|\eta| < 2.4$ (muons)
- Z selection
  - Opposite-charge same-flavor leptons with invariant mass in [60,120] GeV window
  - Kinematic cuts: leading lepton p_T>20(15) GeV, trailing lepton p_T> 10(15) GeV $Z \rightarrow ee$ ($Z \rightarrow \mu\mu$), tuned to trigger thresholds
- If second Z candidate found, event is vetoed (reduces ZZ background)
- W lepton selection:
  - tighter selection requirements than on Z leptons, p_T> 20 GeV
  - reduces backgrounds with fake third lepton and soft p_T spectrum
- Transverse missing energy (MET) > 30 GeV
  - discriminates against high p_T jets faking lepton(Z+jets), or photon conversion ($Z\gamma$)



Yields

Z invariant mass (all channels)



- expected and measured number of events after all selection criteria applied

(1.09 fb^{-1} statistics)

observed: 75 events

expected:73 events (MC)

Sample	$3e0\mu$	$2e1\mu$	$1e2\mu$	$0e3\mu$
$Z + Jets$	0.82	0.04	0.31	0.07
$Z \to bb + Jets$	0.04	0.06	0.00	0.10
$Z \to cc + Jets$	0.03	0.00	0.00	0.00
$t\bar{t}$	0.83	0.95	0.56	0.59
$ZZ \to 4\ell$	0.40	0.95	0.40	0.97
$V\gamma$	0.80	0.10	0.03	0.00
$W + Jets$	0.00	0.00	0.00	0.00
$WW \to 2\ell 2\nu + Jets$	0.02	0.04	0.00	0.00
Background	2.95	2.14	1.31	1.72
$WZ \to 3\ell\nu$	14.47	17.49	13.95	18.56
AllMC	17.42	19.62	15.26	20.28
Data	22	20	13	20

Background estimation

- Using the data-driven estimation method (the D0 matrix method) to estimate backgrounds with fake third lepton: Z+jets and ttbar

•efficiency factors ε_{tight} and p_{fake} estimated from data samples:

P_{fake} :
•isolation efficiency of fake leptons
•estimated on samples containing fake leptons (W+jets)

ε_{tight} :
•isolation efficiency of genuine leptons
•estimated with"Tag and Probe" method on Z→ee and Z→μμ

events with genuine W lepton

events with fake Wlepton

selection yield without W lepton isolation cut

$$N_{loose} = N_{lep} + N_{jet}$$

final selection yield (observed)

$$N_{tight} = \epsilon_{tight} N_{lep} + P_{fake} N_{jet},$$

MC

Type	$\epsilon_{tight} \cdot N_{lep}$	$P_{fake} \cdot N_{jet}$	True N_{lep}^{tight}
$3e0\mu$	20.24±4.76	1.76±0.67	14.47±3.80
$2e1\mu$	17.46±4.56	2.54±0.86	17.49±4.18
$1e2\mu$	11.40±3.67	1.60±0.58	13.95±3.73
$0e3\mu$	17.82±4.54	2.18±0.76	18.56±4.31

background

estimated number of events with isolated W lepton

Background estimation

- ZZ and Zγ estimated from MC
  - assuming 7.5%(ZZ) and 13%(Zγ) uncertainty on cross section

$$N_{backg} = p_{Fake} \cdot N_{Jet} + N_{bkg}^{ZZ} + N_{\mathbf{bkg}}^{Z\gamma}$$

- WZ decays to tau's considered as proportional to signal: $\sigma \, \alpha \, (1 - f_\tau)$

WZ→τ's fraction

Result: WZ cross section

- Signal Acceptance x efficiency $F = A \times \varepsilon = 20 - 25\%$ int. luminosity = 1.09 fb^{-1}
- Cross section calculation: lumi uncertainty – 6%

$$\sigma = (1 - f_\tau)\frac{N_{obs} - N_{backg}}{\mathcal{F} \cdot \rho \cdot \mathcal{L}}$$

data/MC corrections

channel	$N_{observed}$	cross section (pb)
$\sigma_{WZ \to eeev}$	22	$0.086 \pm 0.022(stat) \pm 0.007(syst) \pm 0.005(lumi)$
$\sigma_{WZ \to ee\mu\nu}$	20	$0.060 \pm 0.017(stat) \pm 0.005(syst) \pm 0.004(lumi)$
$\sigma_{WZ \to \mu\mu ev}$	13	$0.053 \pm 0.018(stat) \pm 0.004(syst) \pm 0.003(lumi)$
$\sigma_{WZ \to \mu\mu\mu\nu}$	20	$0.060 \pm 0.016(stat) \pm 0.004(syst) \pm 0.004(lumi)$

Combination of channels:

$$\sigma(pp \to \mathrm{WZ} + X) \times \mathcal{B}(\mathrm{Z} \to \ell\ell)\mathcal{B}(\mathrm{W} \to \ell\nu_\ell) = 0.062 \pm 0.009\ (\mathrm{stat.}) \pm 0.004\ (\mathrm{syst.}) \pm 0.004\ (\mathrm{lumi.})\ \mathrm{pb}.$$

WZ (inclusive, M_Z in [60,120] GeV) cross section measurement:

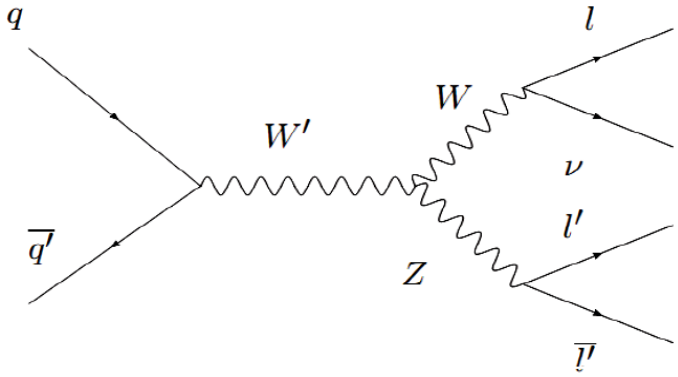
$$\sigma(pp \to \mathrm{WZ} + X) = 17.0 \pm 2.4\ (\mathrm{stat.}) \pm 1.1\ (\mathrm{syst.}) \pm 1.0\ (\mathrm{lumi.})\ \mathrm{pb}.$$

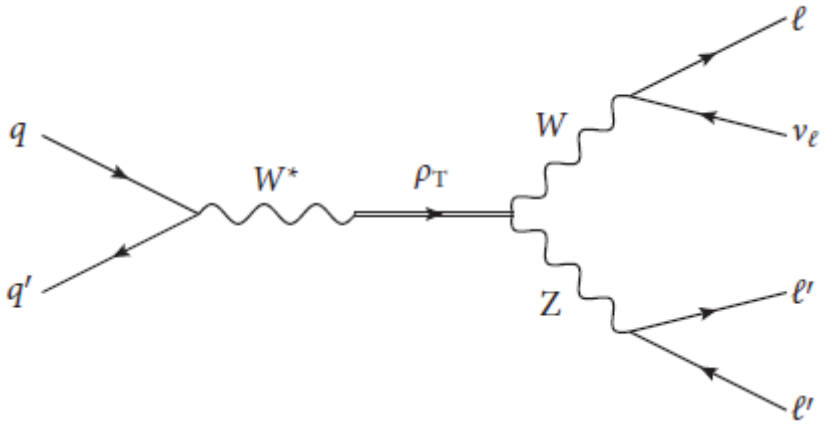
Good agreement with NLO σ =17.53 $\pm$ 0.55 pb

CMS PAS EWK-11-010

Search for WZ resonances

- W' and Technicolor WZ decay mode searches





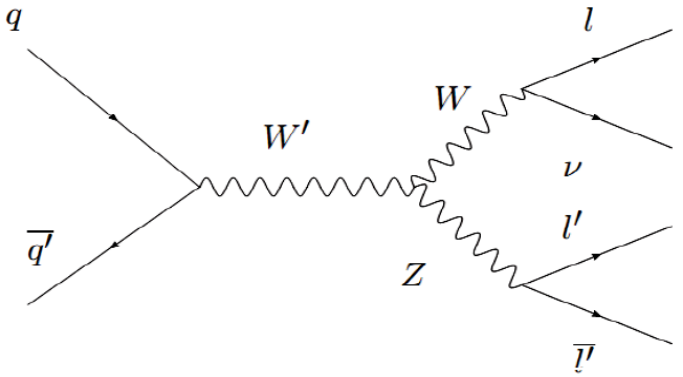
W prime : W'→WZ

- Extension of the Standard Model – heavy W boson-like resonance
  - current limit on Sequential SM W' search
    - Excluded $M_{W'} < 2.27$ TeV @95% C.L. (CMS) **CMS PAS EXO-11-024 (2011)**
    - Assumes that W'→WZ is suppressed (W' heavy analogue of SM W boson)

- W'→WZ search is complementary to leptonic decay search
  - W'→WZ BR is a factor ~2 smaller than W→ln BR
  - further reduced sensitivity due to leptonic BR of W and Z
  - leptonic decays suppressed in some models (enhancing vector boson channels)

- Test for W' evidence in [300,900] GeV range (100 GeV mass point intervals)

- Tevatron excludes W' masses between 188 and 520 GeV for SSM W'→WZ
  - [D0, Phys. Rev. Lett. 104, 061081 (2010)]

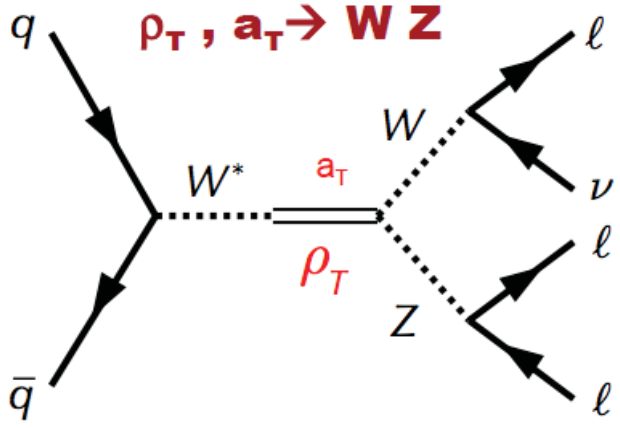


Technicolor

- Dynamical breaking of electroweak symmetry (QCD-like new dynamics)
- Walking gauge coupling – allows TC scale accessible at LHC energies (LSTC)
- Associated with problems linked to precision electroweak observables
  - Large S parameter contributions
  - Recently proposed that this can be suppressed if the lightest ρ_{TC} and its axial vector partner , a_{TC}, are nearly degenerate
    - K. Lane, S. Mrenna, Phys. Rev. D67 (2003)

- "Technicolor Strawman Model" – TCSM
  - Lightest ρ_{TC} and ω_{TC} are below 1 TeV and decay to γ, W, Z, π_{TC}
  - Very narrow resonances: Γ<5 GeV

- Relationship of $M_{\pi TC}$ and $M_{\rho TC}$ significantly affects BR ($\rho_{TC} \rightarrow WZ$)
- If $M_{\rho TC} > 2 * M_{\pi TC}$, WZ BR is reduced ~10x
- For $M_{\rho TC} < M_{\pi TC} + M_W$, WZ BR is ~100%
  - D0 excluded $M_{\rho TC}$ in [208,409] GeV



Technicolor

- TC test on [300-500] GeV TCSM mass points
  - assumed parameter set from "Les Houches" study
  - not excluded by other experiments while accessible below 5fb^{-1}

$$M_{\pi_{TC}} = \frac{3}{4} \cdot M_{\rho_{TC}} - 25\,GeV$$

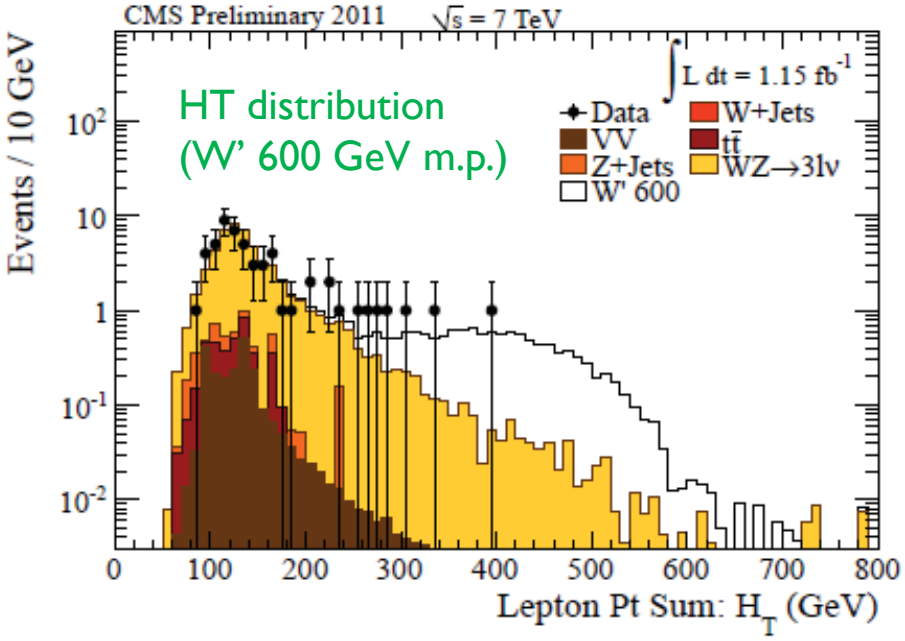
$$M(a_{TC}) = 1.1 M(\rho_{TC}) \qquad M(\rho_{TC}) = M(\omega_{TC})$$

Parameter Set	$M(\rho_{TC}) = M(\omega_{TC})$	$M(a_{TC})$	$M(\pi_{TC})$	$M_V = M_A$	$\sigma \times BR$(fb)
A	300	330	200	300	42.9
B	400	440	275	400	12.9
C	500	550	350	500	5.2

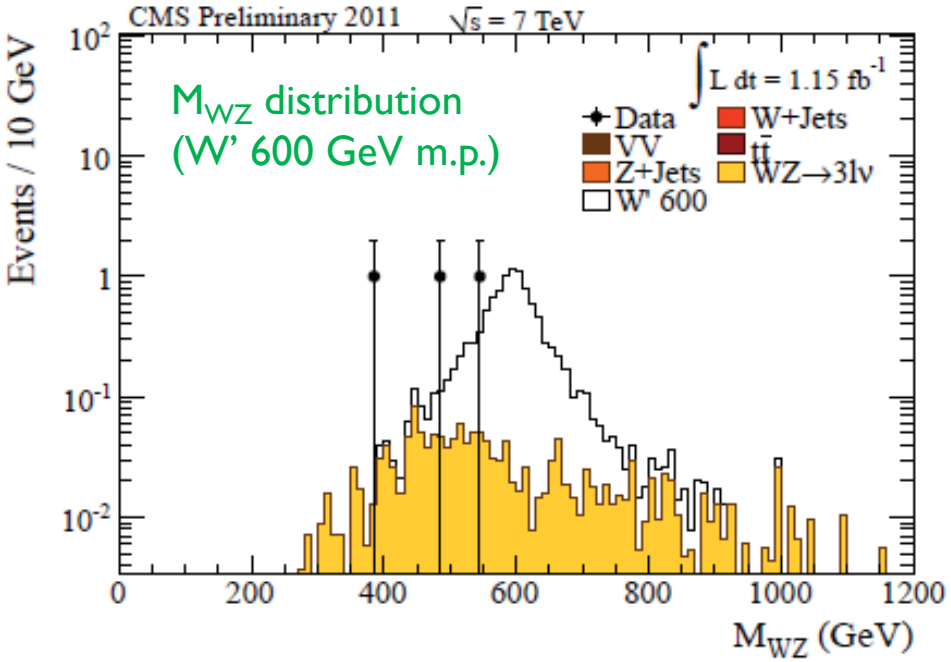
(WZ)

Event Selection

- Extension of the WZ cross section measurement selection
  - using the same integrated luminosity
  - 1.15 fb^{-1} ± 3% (updated)
- Adding $H_T \equiv \sum p_T^{\ell}$ and WZ mass window cut for each mass point
  - Optimized for $S/\sqrt{S+B}$ to give best expected limit



Event Selection



M_{WZ} distribution
(W' 600 GeV m.p.)

Sample	H_T Cut (GeV)	N_{Bkg}	N_{Sig}	Data
W′ 300 GeV	140	22	96	24
W′ 400 GeV	190	8	45	12
W′ 500 GeV	250	3	19	7
W′ 600 GeV	300	2	9	3
W′ 700 GeV	340	0.9	5	1
W′ 800 GeV	380	0.6	3	1
W′ 900 GeV	480	0.2	1	0
ρ_{TC} 300 GeV	160	14	12	18
ρ_{TC} 400 GeV	210	6	5	10
ρ_{TC} 500 GeV	280	2	4	4

expected and observed number of events after HT selection cut is applied

Background estimation

- Background contributions for each mass point

total estimation using MC

Mass point	Window (GeV)	N_{ZJets}	$N_{t\bar{t}}$	N_{ZZ}	$N_{V\gamma}$	N_{WZ}	N_{BkgMC}	N_{Bkg}
W′ 300	259-353	0.0	0.2	0.2	0.1	7.6	8.0	9.8
W′ 400	323-472	0.1	0.0	0.1	0.0	3.3	3.4	4.3
W′ 500	412-575	0.0	0.0	0.0	0.0	1.2	1.3	1.4
W′ 600	496-688	0.0	0.0	0.0	0.0	0.6	0.6	0.6
W′ 700	590-795	0.0	0.0	0.0	0.0	0.2	0.2	0.2
W′ 800	681-900	0.0	0.0	0.0	0.0	0.2	0.2	0.2
W′ 900	787-997	0.0	0.0	0.0	0.0	0.1	0.1	0.1
ρ_{TC} 300	253-352	0.0	0.2	0.1	0.0	5.4	5.7	7.0
ρ_{TC} 400	347-455	0.1	0.0	0.0	0.0	1.9	2.0	2.5
ρ_{TC} 500	430-555	0.0	0.0	0.0	0.0	0.7	0.7	0.8

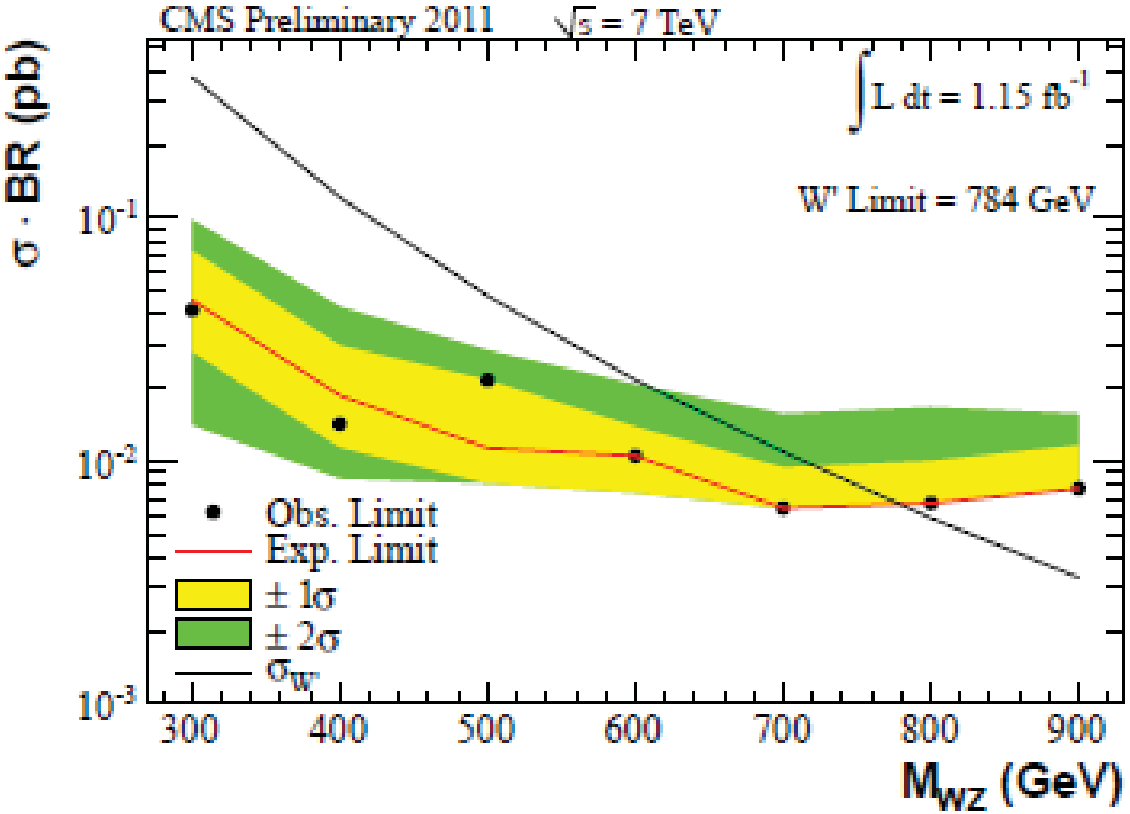
search window used per mass point

total estimation using data driven method + MC

Limits: W' mass

- 95% C.L on cross section x BR, using bayesian statistics and flat prior on the signal
- $M_{W'} > 784$ GeV @ 95% C.L

CMS PAS EXO-11-041

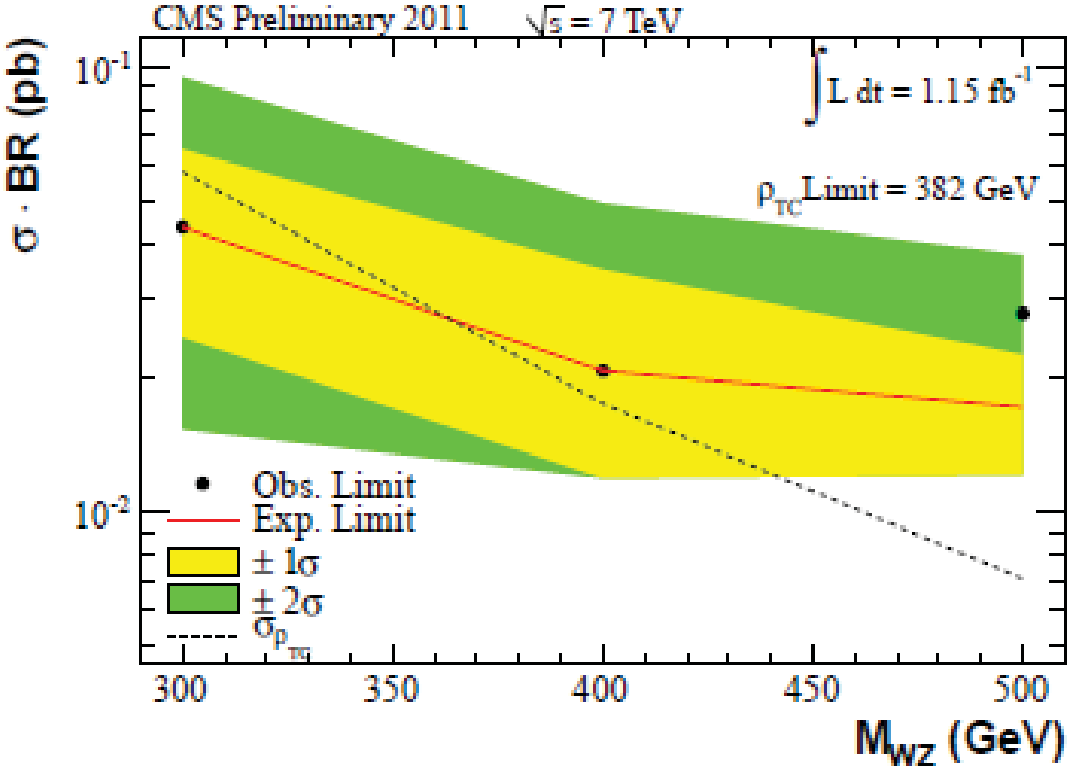


Limits: ρ_{TC} mass

- for parameter space $M_{\pi_{TC}} = \frac{3}{4} \cdot M_{\rho_{TC}} - 25\,GeV$

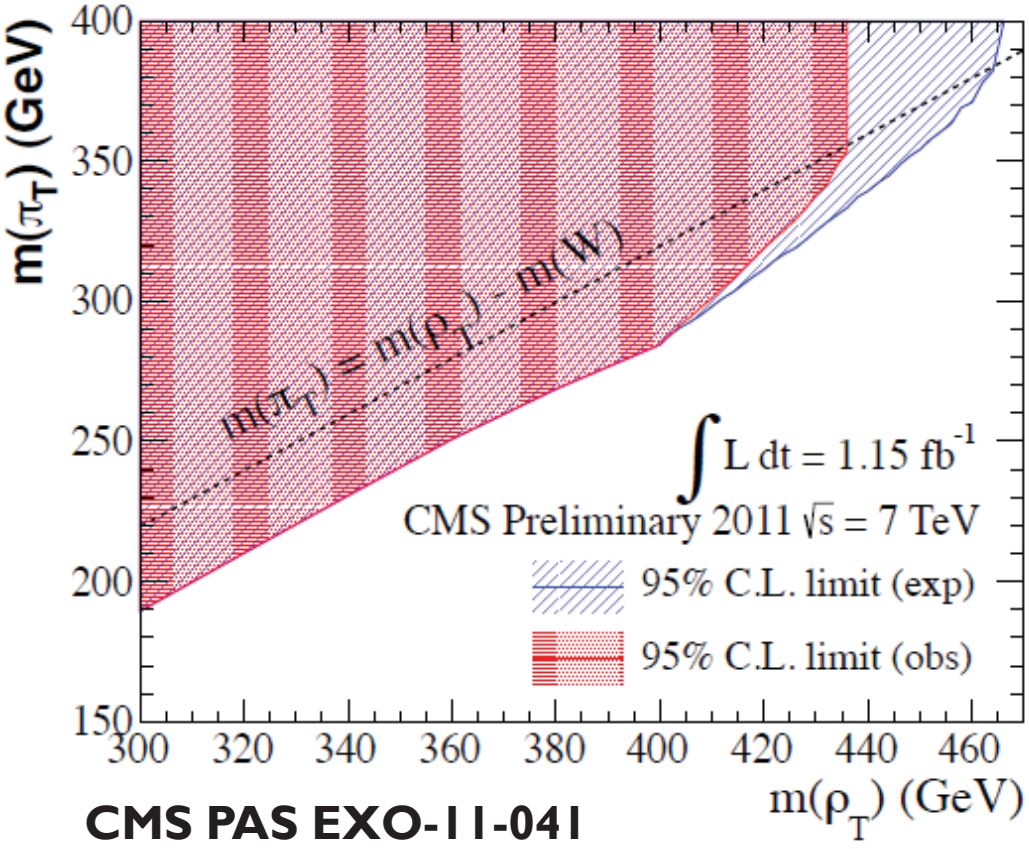
- $M\rho_{TC}$ > 382 GeV @ 95% C.L.

CMS PAS EXO-11-041



Limits: ρ_{TC} and π_{TC} parameter space

- $M_{\rho TC}$ > 436 GeV @ 95%.C.L.
  - for the parameter space $M_{\rho TC} < M_{\pi TC} + M_W$ (WZ BR ~100%)



CMS PAS EXO-11-041

Summary

- Measurement of SM WZ cross section in leptonic decay modes

$$\sigma(pp \to \mathrm{WZ} + X) = 17.0 \pm 2.4\ (\mathrm{stat.}) \pm 1.1\ (\mathrm{syst.}) \pm 1.0\ (\mathrm{lumi.})\ \mathrm{pb}.$$

  - agreement with SM predictions

- We searched for resonances in context of W' and Technicolor

- 95% C.L. W' mass exclusion limit: $M_{W'} > 784$ GeV
- 95% C.L. Exclusion limits on Technicolor:
  - excluded $M_{\rho TC} > 387$ GeV (LH parameter space)
  - excluded $M_{\rho TC} > 426$ GeV ($M_{\rho TC} < M_{\pi TC} + M_W$)
  - currently best experimental limits

- Planning improved results with the full 2011 dataset

BACKUP

Results

- Summary of expected and observed event yields and limits

Mass point	Window (GeV)	N_{BkgMC}	ϵ_{Sig} (%)	N_{Sig}	Data	Exp. Limit (pb)	Obs. Limit (pb)
W′ 300	259-353	8.0	20 ± 1	76	7	0.0459	0.0417
W′ 400	323-472	3.4	31 ± 2	39	2	0.0186	0.0142
W′ 500	412-575	1.3	33 ± 2	17	4	0.0113	0.0215
W′ 600	496-688	0.6	36 ± 2	8	1	0.0105	0.0105
W′ 700	590-795	0.2	42 ± 2	5	0	0.0064	0.0064
W′ 800	681-900	0.2	40 ± 2	3	0	0.0067	0.0067
W′ 900	787-997	0.1	35 ± 2	1	0	0.0077	0.0077
ρ_{TC} 300	253-352	5.7	17.3 ± 0.9	11	6	0.0436	0.0436
ρ_{TC} 400	347-455	2.0	22 ± 1	4	2	0.0207	0.0207
ρ_{TC} 500	430-555	0.7	22 ± 1	1	3	0.0172	0.0279