



Search for Exotic Resonances in Di-boson Final States

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for the

CMS Collaboration

Large Hadron Collider

- Energy frontier

- 2011

- 7 TeV

- 6.1 fb⁻¹

- 2012

- 8 TeV

- 23 fb⁻¹

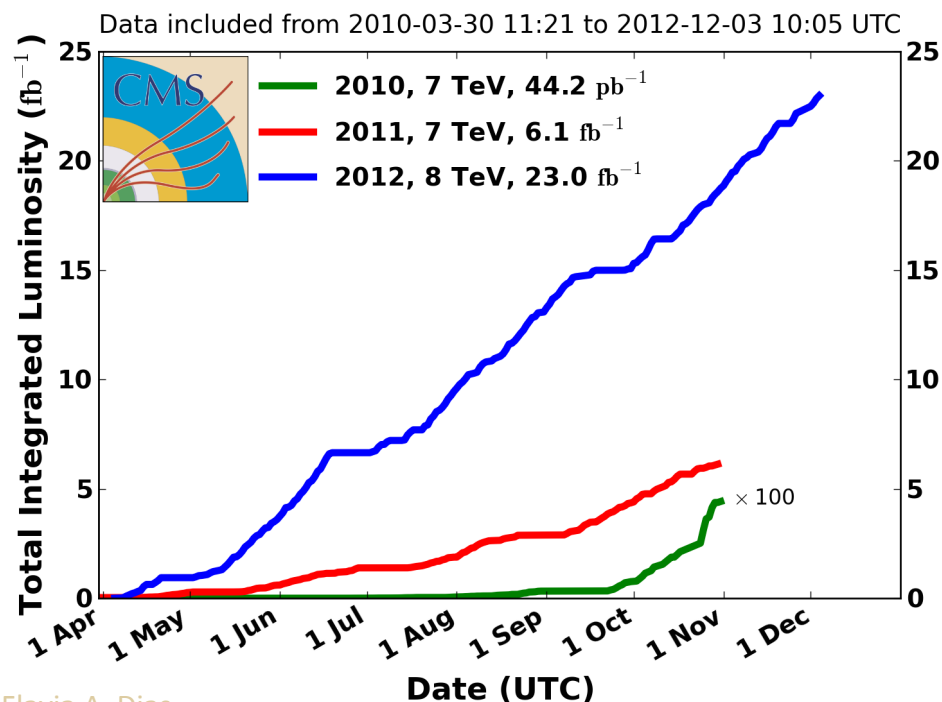
- Goals

- EWSB mechanism

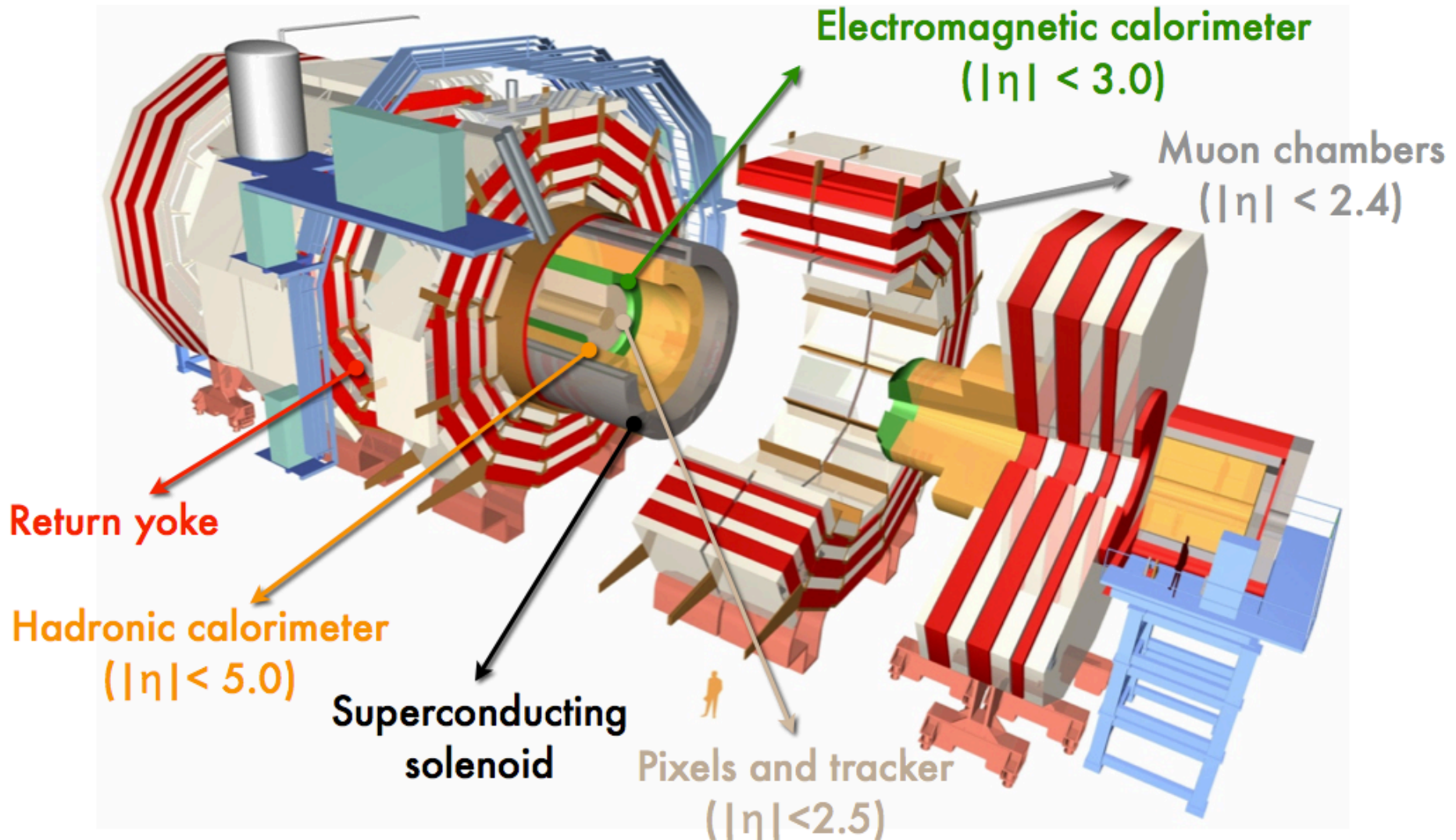
- Physics BSM



CMS Integrated Luminosity, pp



CMS Experiment



$$\eta = -\ln[\tan(\theta/2)]$$

θ – polar angle, ϕ – azimuthal angle

Exotic Di-boson Searches

- Historically connected to EWSB models
 - Not excluded if SM Higgs $m_H \sim 125$ GeV
- Several scenarios
 - Kaluza-klein gravitons (WW, ZZ)
 - Technicolor (WZ)
 - W' (WZ)
 - Compositeness
- Experimental aspects
 - Clean signature
 - Less constraints from precision EW measurements
 - Tight connection with VBF processes

Searches for VV resonances

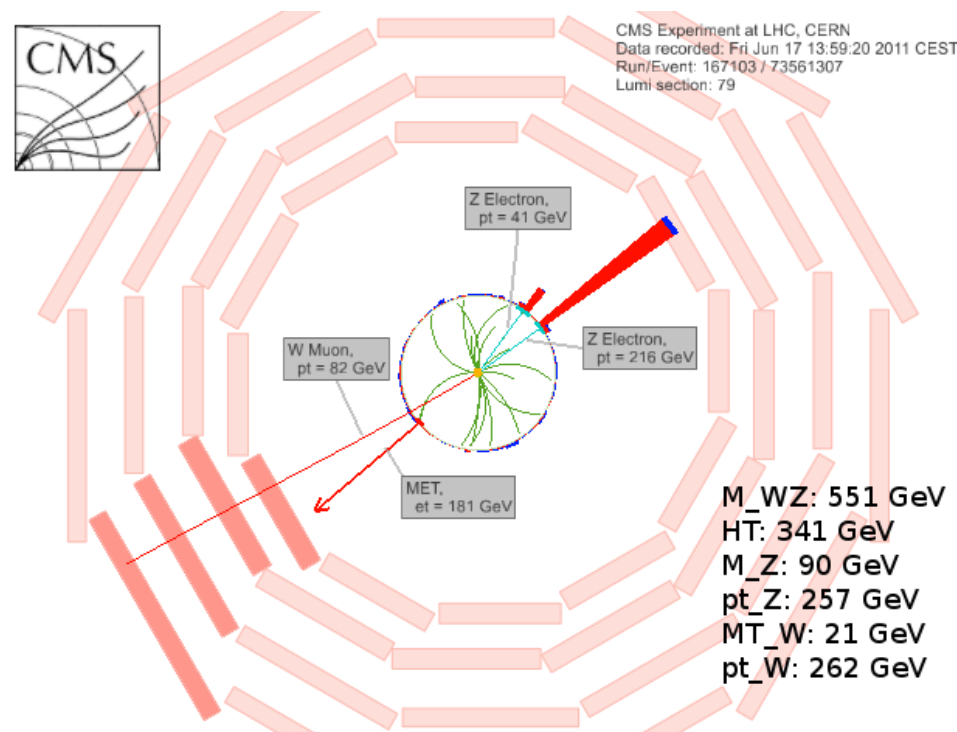
$WZ \rightarrow 3\ell + \text{MET}$

Phys. Rev. Lett. **109** (2012) 141801
arxiv: 1206.0433

- $W'/\rho_{\text{TC}} \rightarrow WZ \rightarrow 3\ell + \text{MET}$
 - 5 fb^{-1} of 7 TeV data (2011)

- Model interpretation

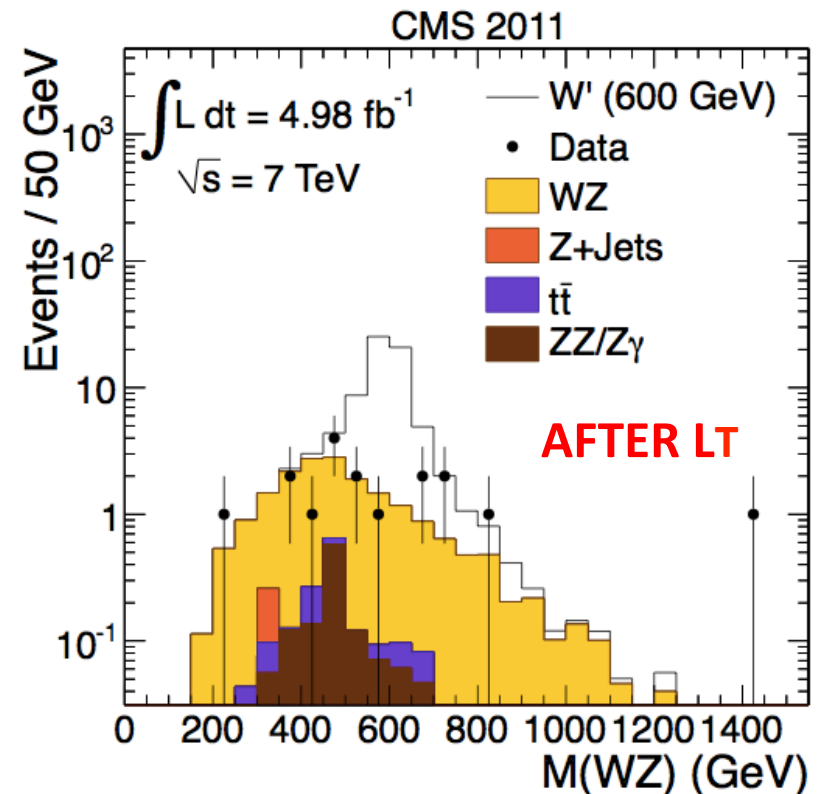
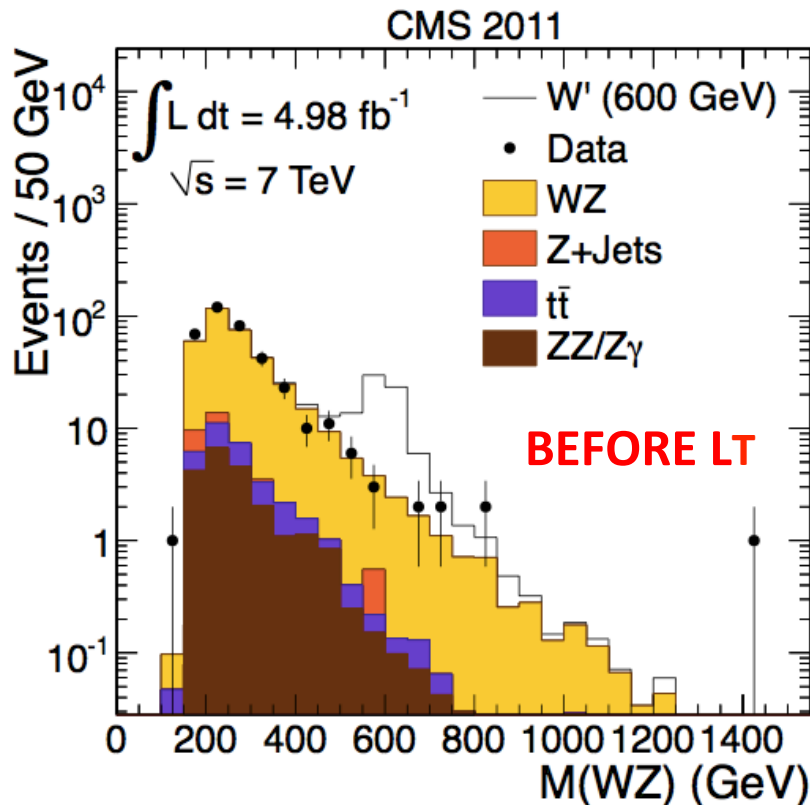
- Sequential Standard Model W'
- Low Scale Technicolor
 - Masses below 700 GeV
 - ρ_{TC} and a_{TC} can decay to WZ



$WZ \rightarrow 3\ell + \text{MET} - \text{Background}$

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- Monte-Carlo based estimation
 - MadGraph 5 + Pythia 6 for hadronization
 - NLO k-factors

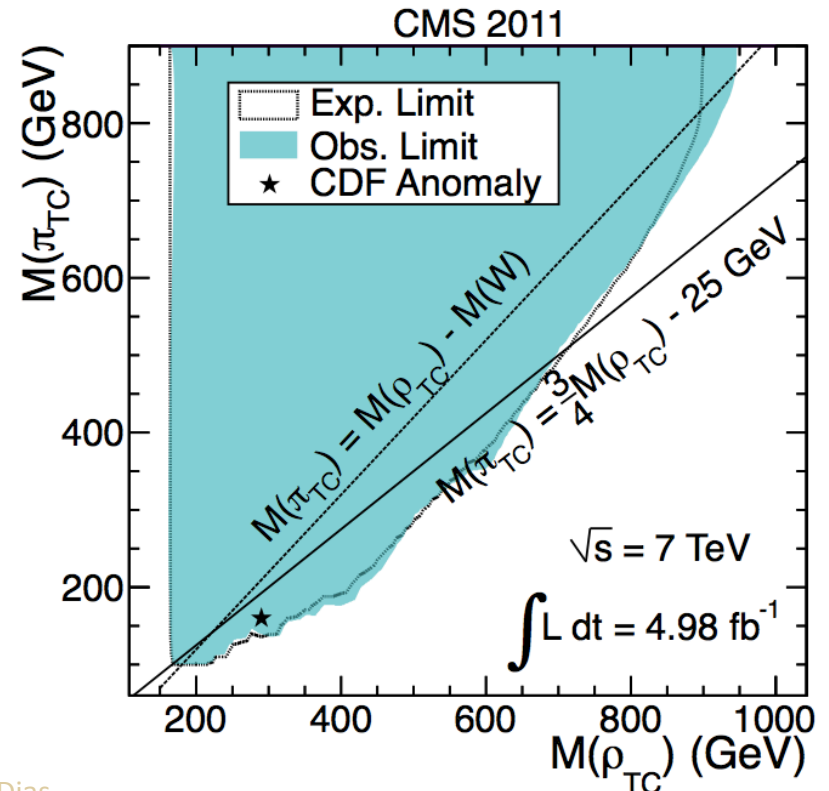
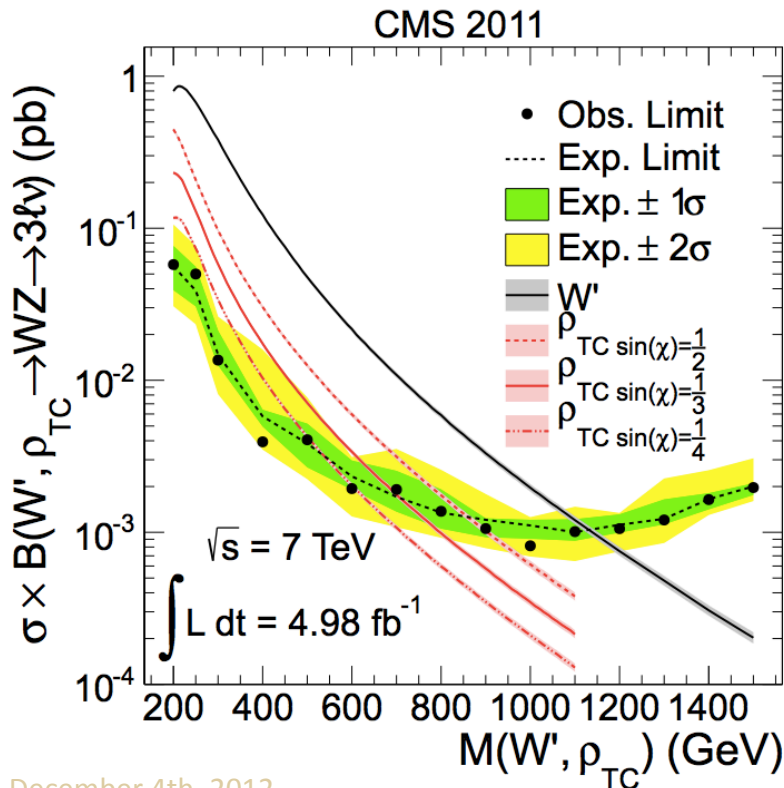


$WZ \rightarrow 3\ell + \text{MET} - \text{Limits}$

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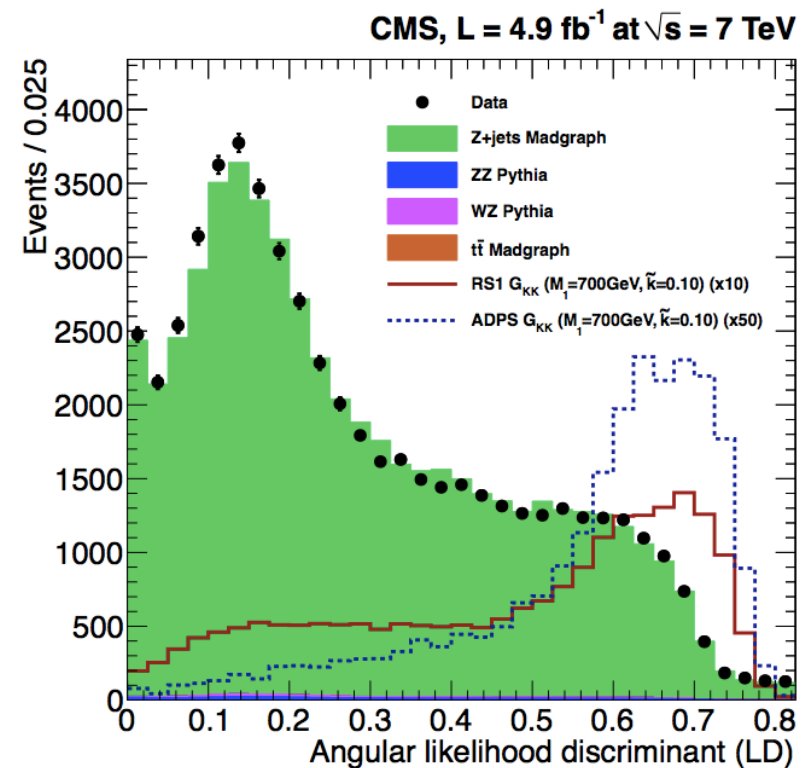
- 95% CL upper limits on cross section times branching fraction
 - $M(W') > 1143 \text{ GeV}$
 - LSTC, $(M(\pi_{\text{TC}}) = \frac{3}{4} M(\rho_{\text{TC}}) - 25 \text{ GeV}) \rightarrow M(\rho_{\text{TC}})$ excluded in 167 – 687 GeV range



$ZZ \rightarrow \ell\ell jj$

Submitted to *Phys. Lett. B*
arxiv: 1209.3807

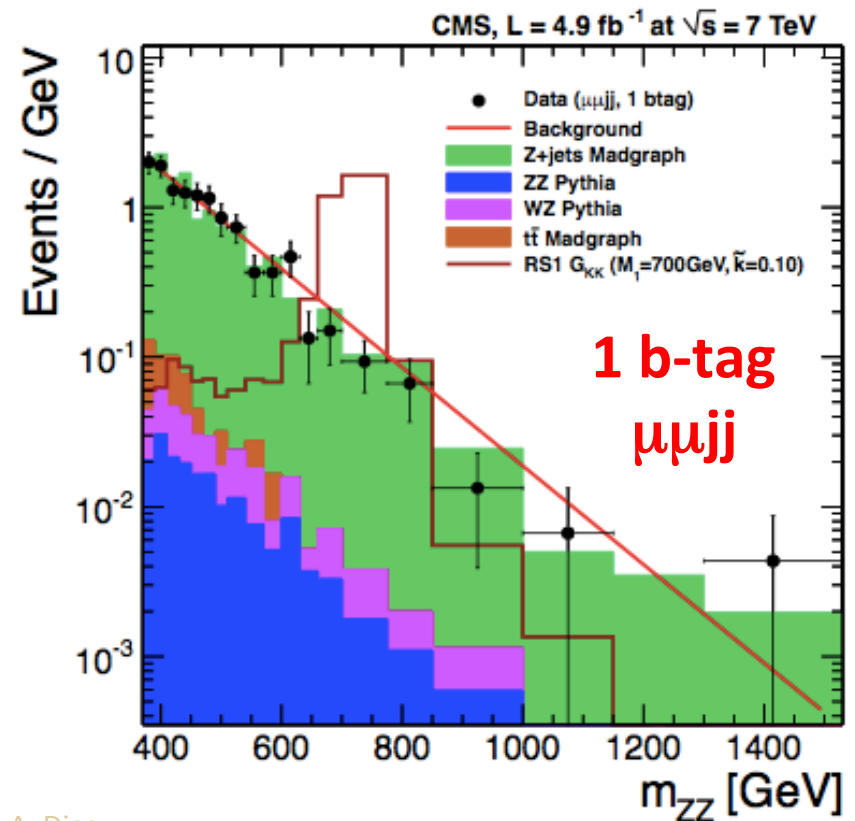
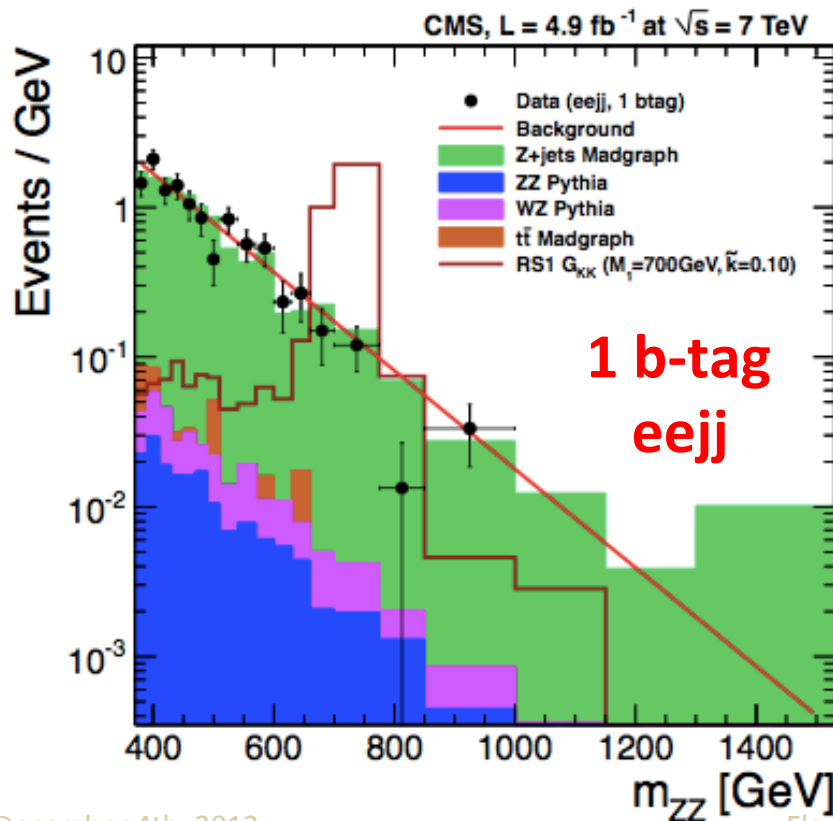
- $G_{KK} \rightarrow ZZ \rightarrow \ell\ell jj$
 - 5 fb⁻¹ of 7 TeV data (2011)
- Likelihood discriminator
 - Built from 5 helicity angles
 - Spin 2 particles
- Model interpretation
 - RS1 gravitons
 - Parameters: m_G and k/M_{Pl}
 - ADPS model (bulk gravitons)



$ZZ \rightarrow \ell\ell jj$ – Background

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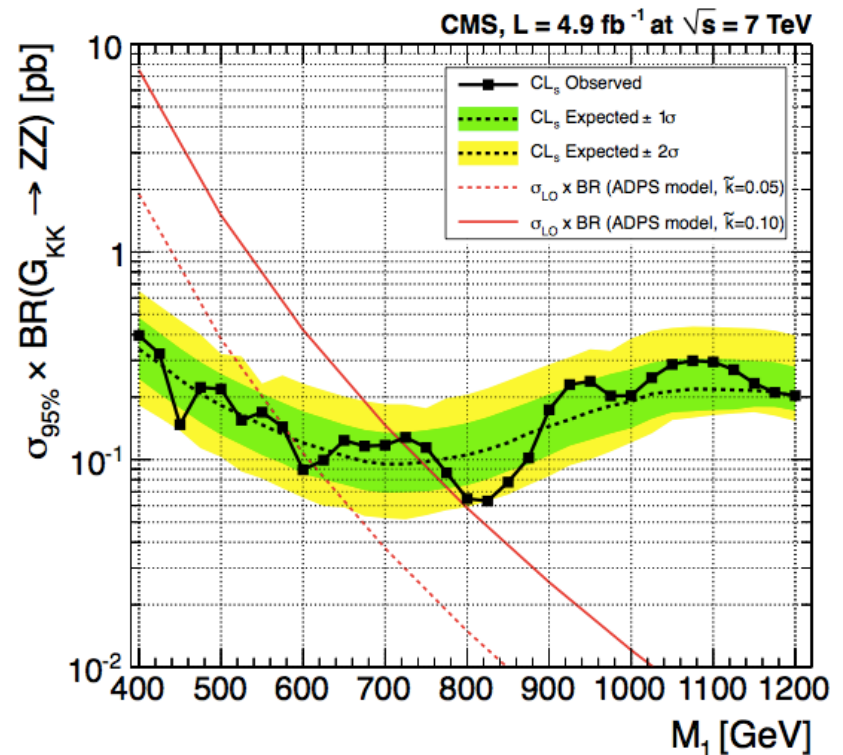
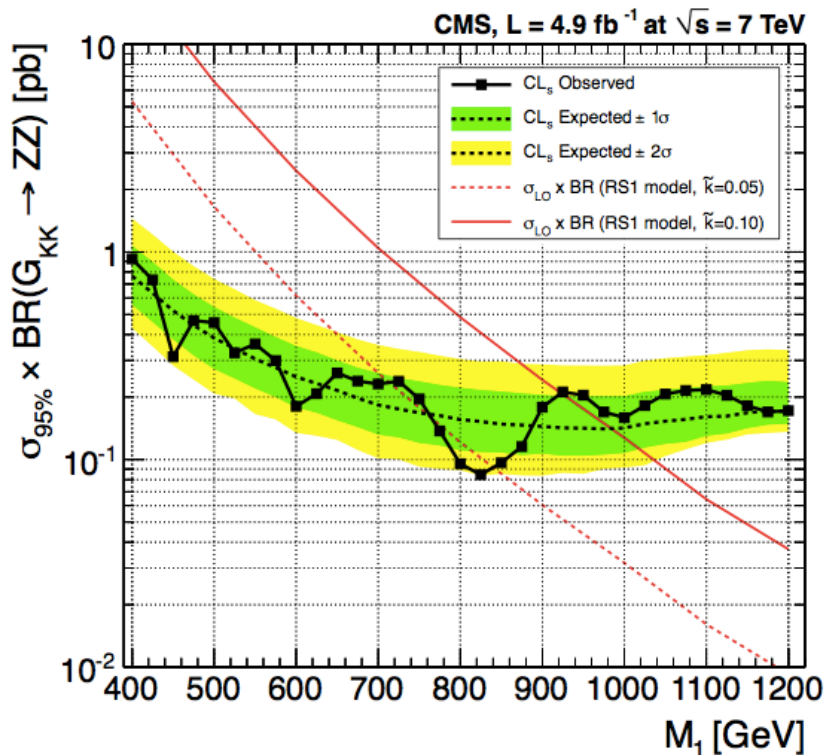
- Data-driven estimation
 - Sideband in M_{ZZ}
 - Division in b-tag categories



$ZZ \rightarrow \ell\ell jj$ – Limits

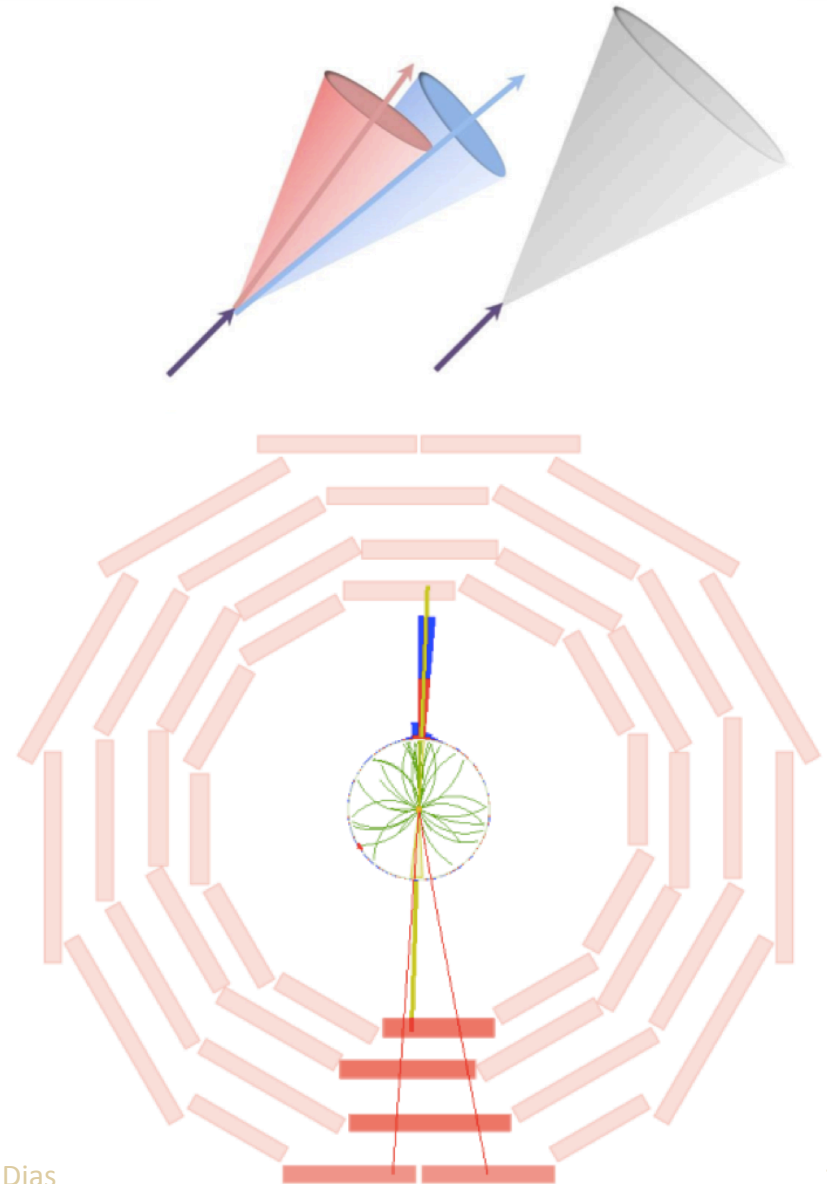
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- 95% CL upper limits on cross section times branching fraction
 - $M(G_{RS}) > 945$ GeV ($k/M_{Pl} = 0.1$)
 - $M(G_{bulk}) > 720$ GeV ($k/M_{Pl} = 0.1$)



Boosted Topologies

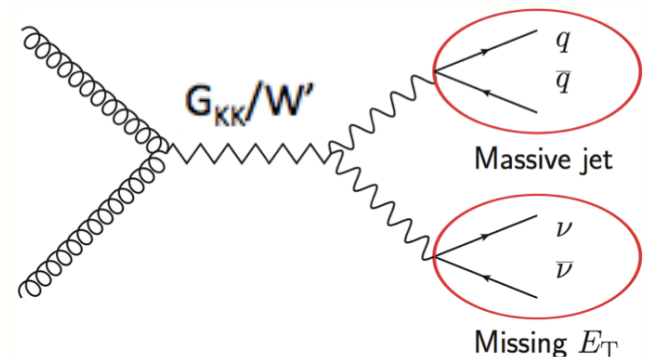
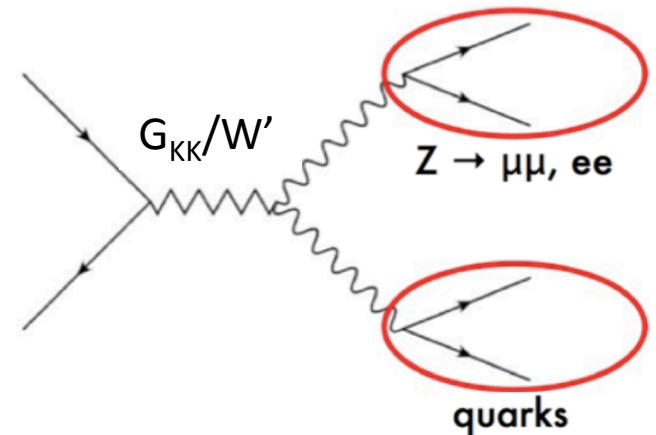
- Traditional techniques lose sensitivity at higher masses
 - Jet merging
 - ❑ Boosted monojet with mass of original decaying particle
 - Alternative lepton isolation
 - ❑ Avoids self veto of dilepton system from heavy particle



$VZ \rightarrow \ell\ell/\nu\nu + j$

Submitted to *JHEP*
arxiv: 1211.5779

- $W'/G_{KK} \rightarrow WZ/ZZ \rightarrow \ell\ell/\nu\nu + j$
 - 5 fb⁻¹ of 7 TeV data (2011)
- Hadronic products merging
 - Single massive jet
- $V \rightarrow$ jet either W or Z
 - Anti- k_T with $R = 0.7$
 - Selection on the jet mass
- Model interpretation
 - RS1 gravitons
 - SSM W'

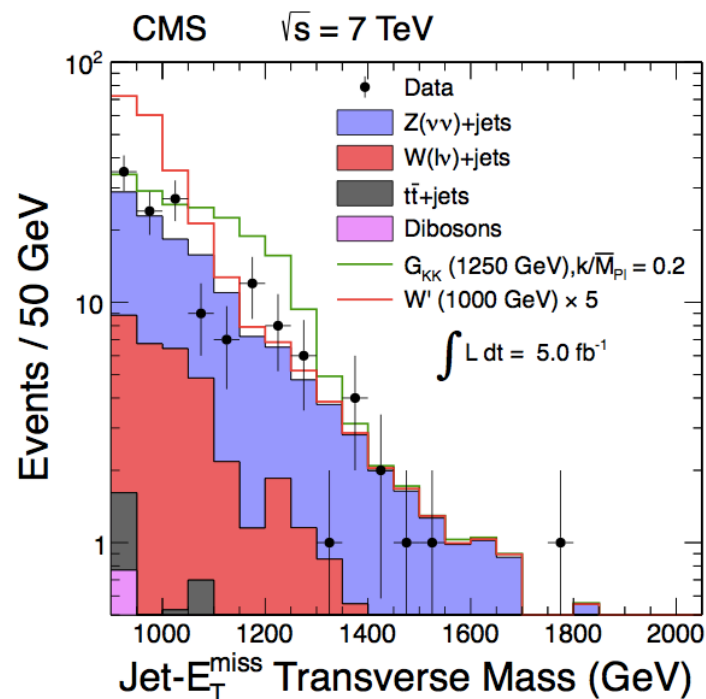
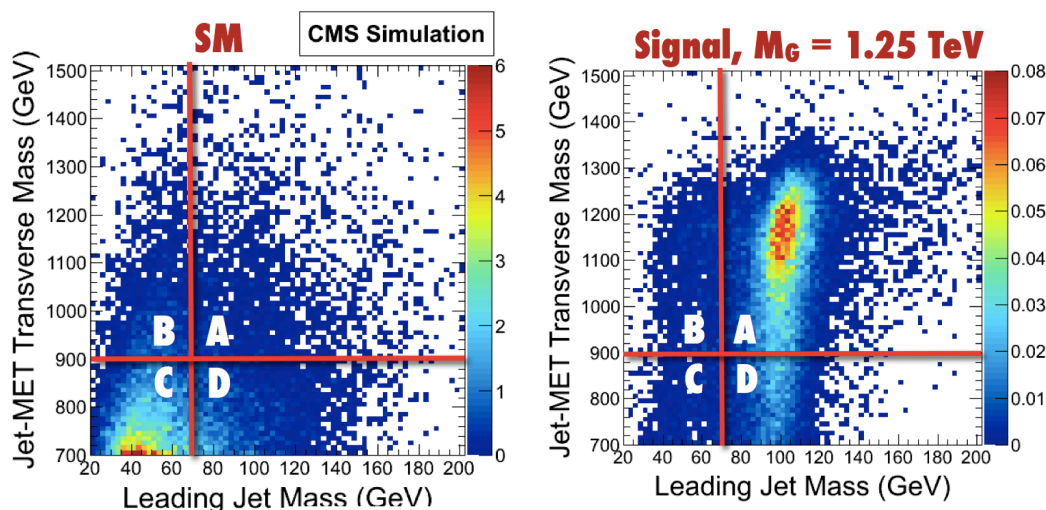


VZ \rightarrow $\nu\nu + j$ – Background

Submitted to *JHEP*
arxiv: 1211.5779

- Jet + MET channel
 - Data-driven estimation
 - ABCD method
 - $M_{\text{jet}} > 70$ GeV
 - $M_{\text{T}}^{\text{G}} > 900$ GeV

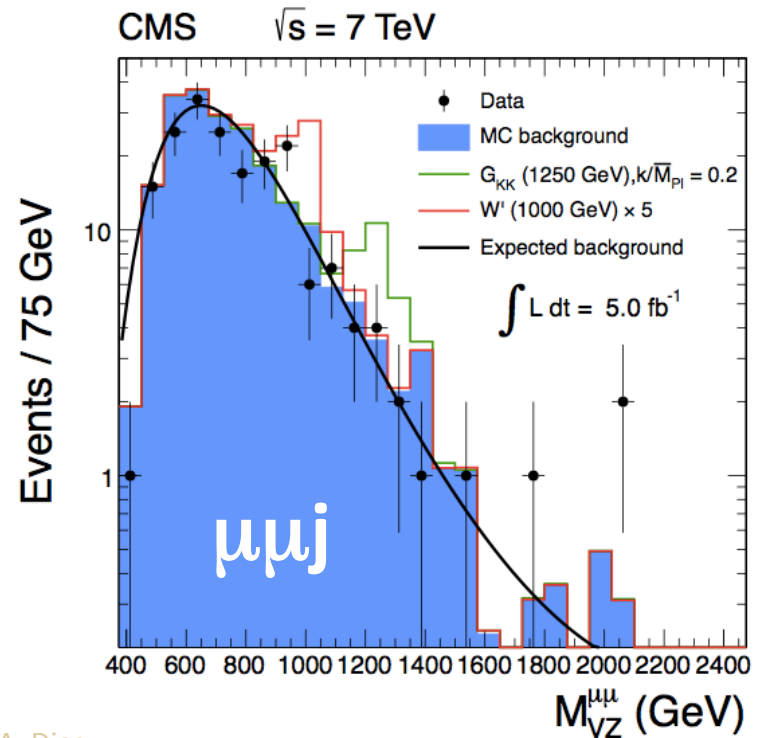
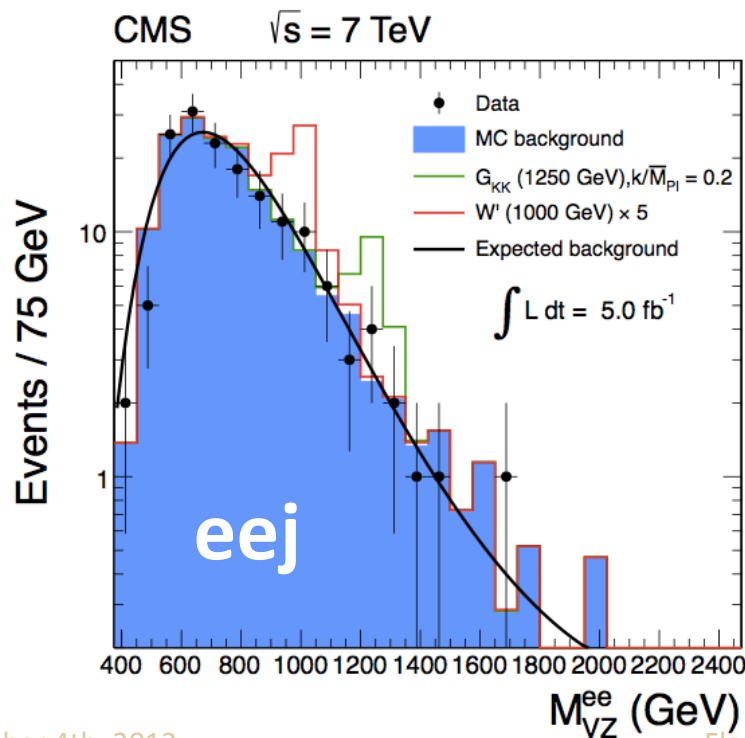
$$M_{\text{T}}^{\text{G}} = \sqrt{2 p_{\text{T}}^{\text{jet}} \cancel{E}_{\text{T}} \left[1 - \cos \Delta\phi(\text{jet}, \cancel{E}_{\text{T}}) \right]}$$



$VZ \rightarrow \ell\ell + j$ – Background

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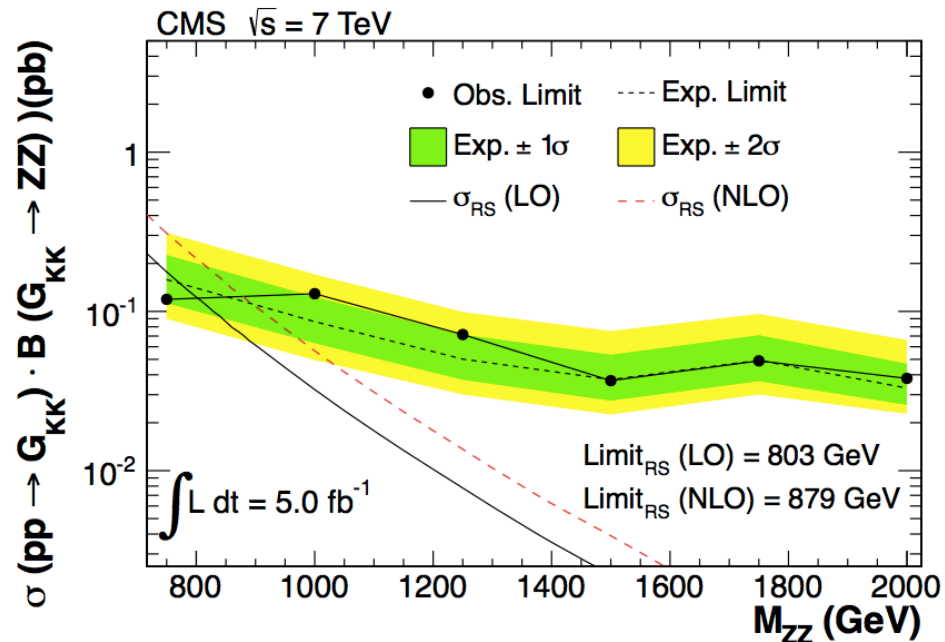
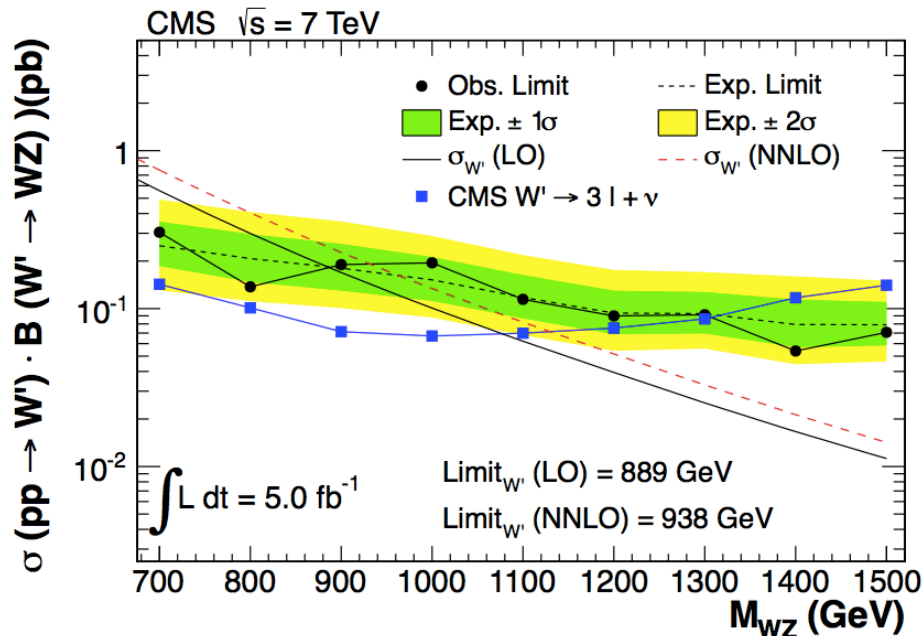
- Di-lepton + jet channel
 - $65 < M_{\text{jet}} < 120$ GeV
 - Data-driven estimation
 - M_{jet} sideband ($30 < M_{\text{jet}} < 65$ GeV)



$VZ \rightarrow \ell\ell/\nu\nu + j$ – Limits

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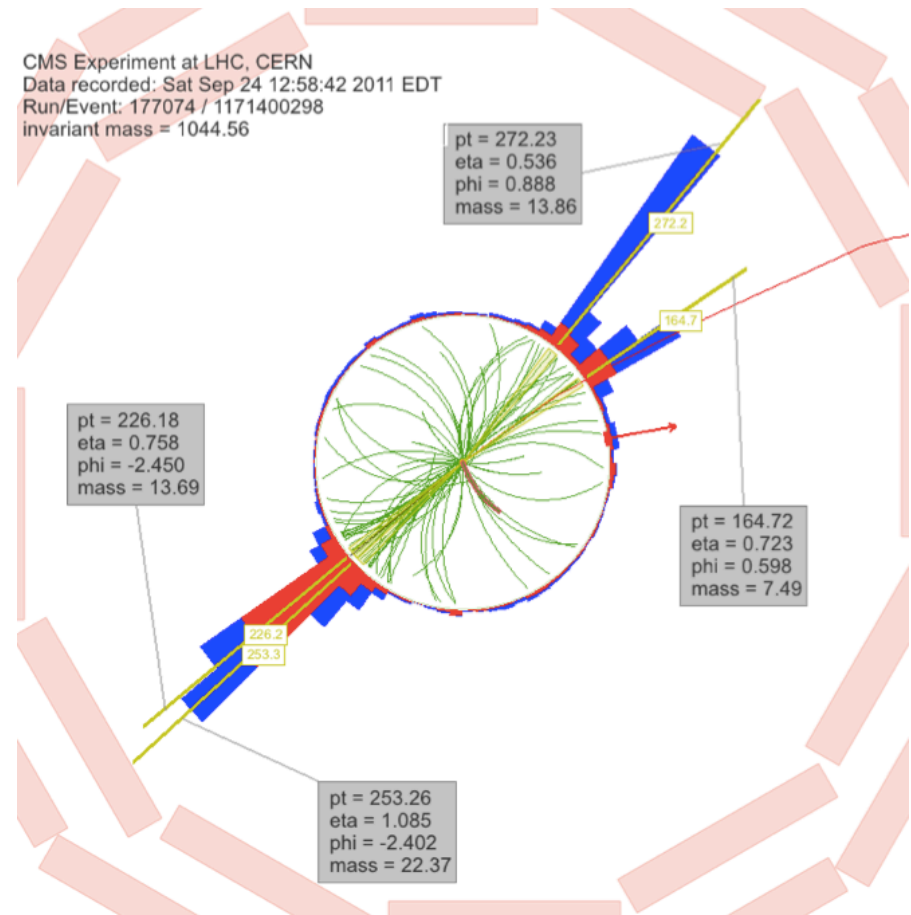
- 95% CL upper limits on cross sections times branching fraction
 - W' excluded in 700 – 938 GeV range (NNLO)
 - RS1 gravitons excluded in 750 – 879 GeV range for $k/M_{Pl} = 0.05$ (NLO)



VV \rightarrow Dijet

EXO-11-095

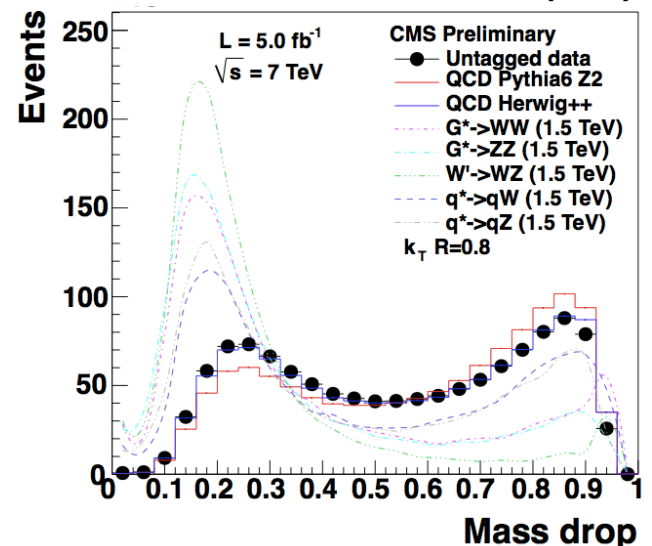
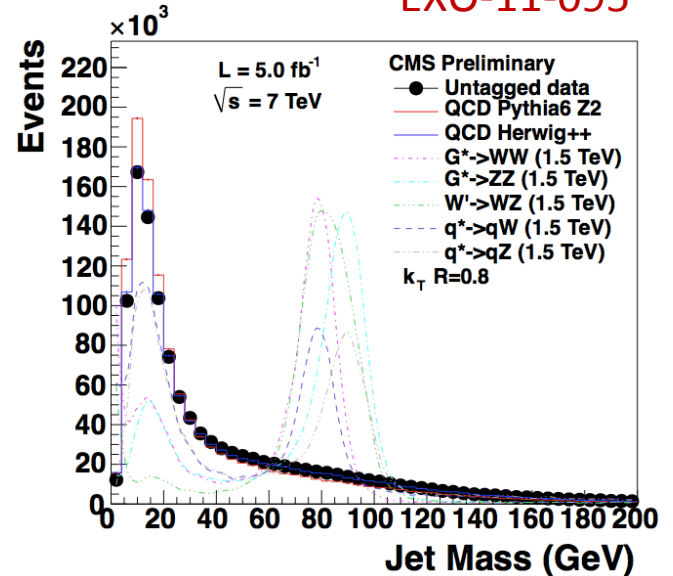
- $W'/G_{KK} \rightarrow WZ/WW/ZZ \rightarrow jj$
 - 5 fb⁻¹ of 7 TeV data (2011)
- Model interpretation:
 - RS1 gravitons
 - SSM W'
- VV \rightarrow Di-jet topology
 - Jet substructure for QCD suppression
 - W/Z tag on jets
 - Peak in the di-jet invariant mass on top of falling distribution



VV \rightarrow Di-jet – V-tag

EXO-11-095

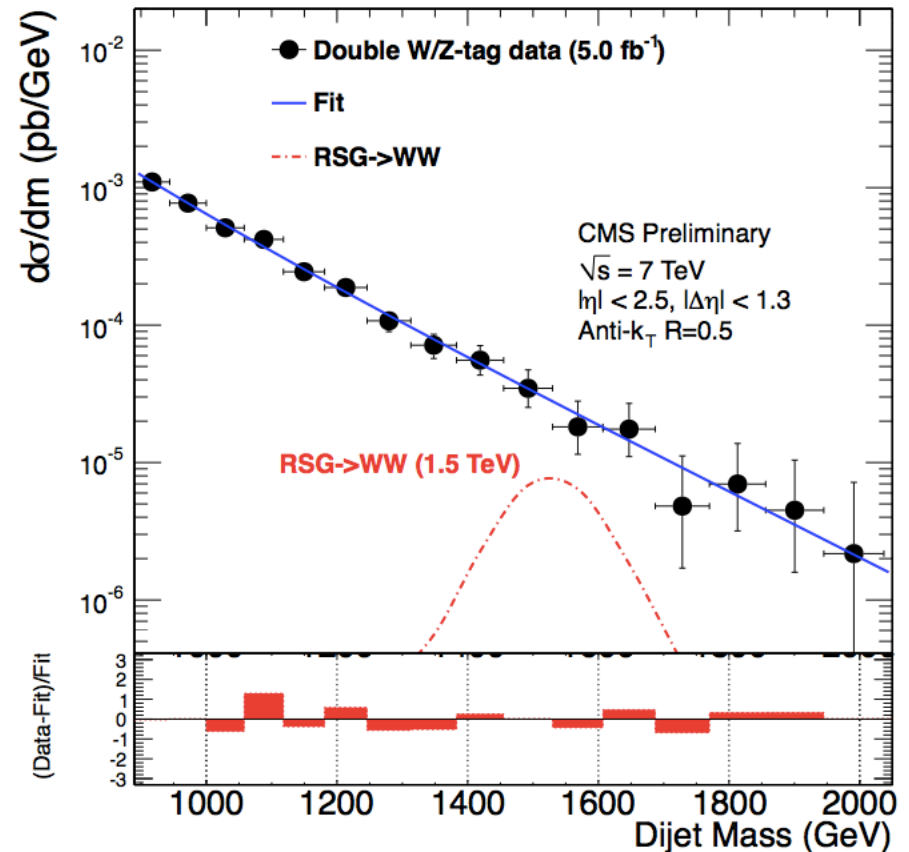
- Cambridge-Aachen with $R = 0.8$
+ pruning
 - Soft and wide angle particles ignored
 - $N_{\text{subjets}} = 2$
 - $70 < M_{\text{jet}} < 100 \text{ GeV}$
 - $m_1/m_{\text{jet}} < 0.25$ (mass drop)
- Evident discriminant power of the pruned jet mass and mass drop



VV → Di-jet – Background

EXO-11-095

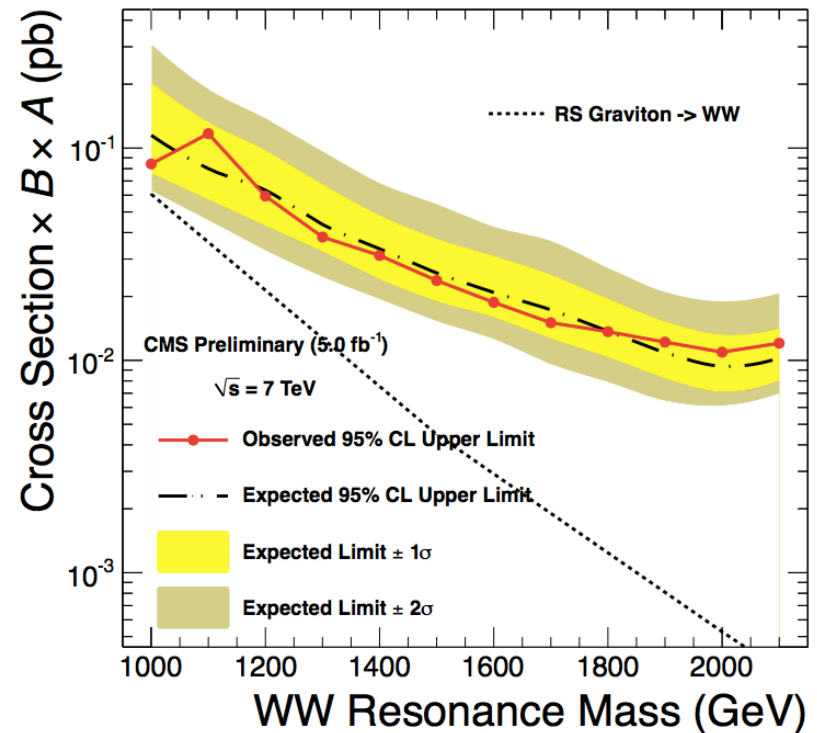
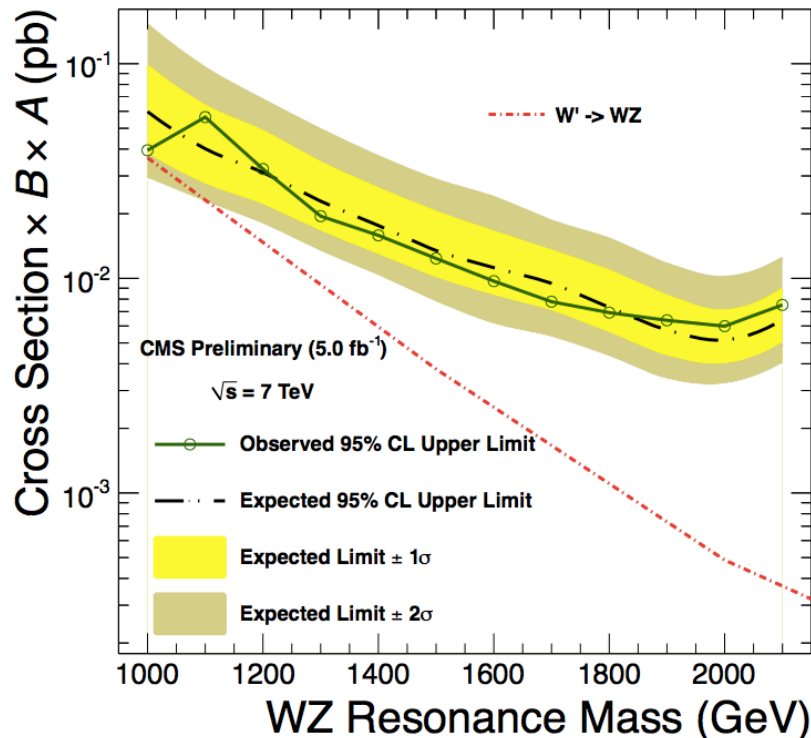
- Shape parameterization for di-jet background
- In limit setting
 - Background fit parameters obtained by best signal + background fit to the data points for each signal hypothesis



$VV \rightarrow$ Di-jet – Limits

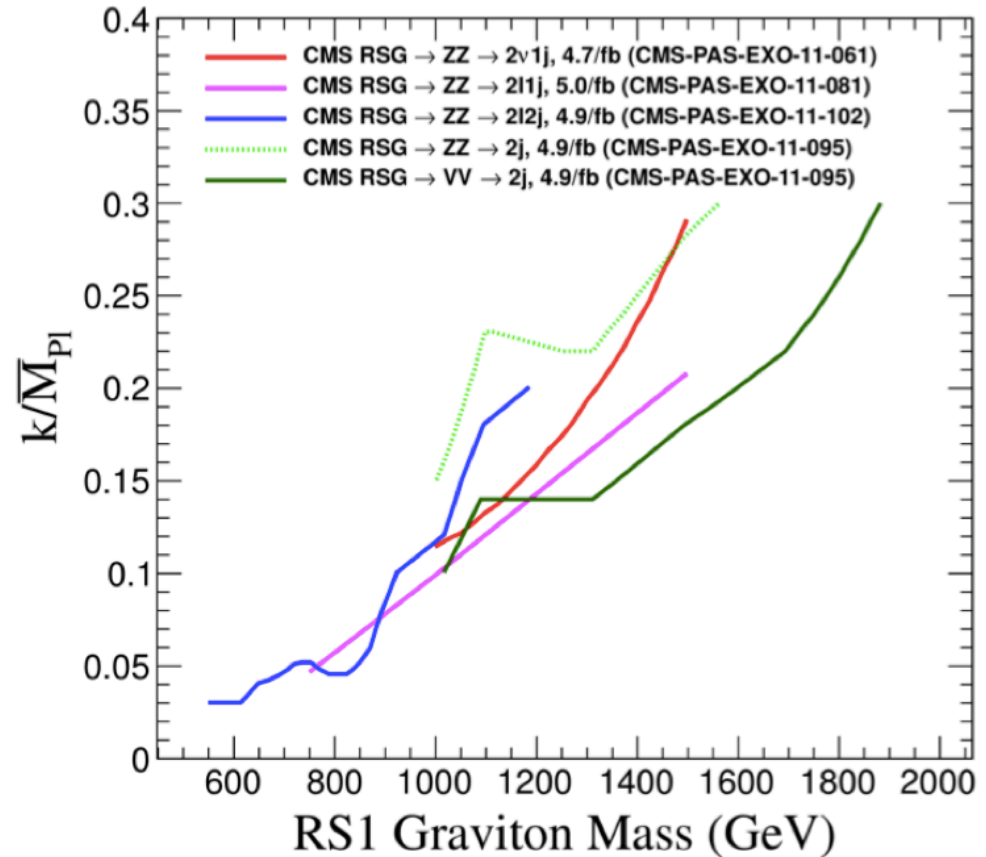
EXO-11-095

- 95% CL limits on di-jet resonance cross section
- No sensitivity to RS gravitons with $k/M_{\text{Pl}} = 0.1$ or W' models with current datasets
- Most stringent cross section limits in the channel to date



RS Gravitons \rightarrow VV – CMS Limits

- Narrow width approximation
 - Resonance width much smaller than experimental resolution
- Stringent limits for RS gravitons in VV channels
- Complementarity between results in different channels



Summary

- Searches for exotic resonances decaying to a pair of vector bosons have been performed at the CMS experiment
- Stringent upper limits in several models:
 - Technicolor
 - Randall-Sundrum gravitons
 - Sequential Standard Model W'
- Advances on jet substructure algorithms allow channels with boosted hadronic objects have good performance and sensitivity
- More results with 2012 data to come. Stay tuned!

Documentation

- All public CMS exotic searches:

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

- $WZ \rightarrow$ trileptons

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- $ZZ \rightarrow$ di-leptons + di-jets

arxiv: 1209.3807

- $VZ \rightarrow$ di-lepton / MET + jet

arxiv: 1211.5779

- $VV \rightarrow$ di-jet

<http://cdsweb.cern.ch/record/1458050/files/EXO-11-095-pas.pdf>

BACKUP SLIDES