



# Introduction, Report, and Plans

Kalanand Mishra, Fermilab

*LPC Fellows Meeting*  
(March 26, 2013)

# Brief introduction



- Currently:

- RA at Fermilab CMS Center since 2008
- LPC Fellow for 2013

- Past:

- Ph.D. (2008), Univ. Cincinnati, BaBar experiment at SLAC
- Measured quark mixing (CKM) phase  $\gamma$  using  $B \rightarrow D^{(*)}K^{(*)}$  decay, set limits on CP violation in charm decays
- Cherenkov detector operations, hardware upgrade
- Developed particle identification

# Contribution to CMS detector calibration, upgrade



☑ Jet commissioning (JES, jet ID) with early data in 2008–10

- JES absolute calibration using Z+jet balance (included in the JINST paper on jet commissioning in CMS)

☑ Commissioning of electron with early data → calibration using Z peak

- Led Egamma electron reco, ID & trigger efficiency subgroup in 2008–10

☑ Led development of CMS Tag&Probe tool for lepton efficiency measurements

Calibration works for POGs resulted in  $\geq 5$  ANs + 1 PAS + 1 publication

New

Currently contributing to CMS Level-1 trigger upgrade (stages 1,1b,2)

- improvements in L1 calorimeter triggers
- muon isolation in L1

# Past physics analyses w/ significant involvement



**2010**  
36 pb<sup>-1</sup>

Inclusive W,Z cross  
section and properties

2 papers, published in JHEP



**2011**  
5 fb<sup>-1</sup>

M<sub>jj</sub> in W+2-jet events

Published in PRL



WW+WZ semi-leptonic:  
xsection & anomalous  
gauge couplings

Published in EJPC



H→WW semi-leptonic:  
excl. limit in 2M<sub>W</sub>-600 GeV

Submitted to EJPC, use data  
up to ICHEP12

Published or  
submitted in  
2013

**2011**  
5 fb<sup>-1</sup>

Jet substructure in dijet  
and W/Z+jet events

Submitted to JHEP (Ferbelized)

**2012**  
5-19 fb<sup>-1</sup>

H→WW semi-leptonic

Approved public results for  
ICHEP12, HCP12, Moriond13

# Physics contributions & accomplishments



**Inclusive W,Z analysis:** Co-led the Z analysis team, delivered the first cross section results for ICHEP 2010, and two papers with 3 pb<sup>-1</sup> & 36 pb<sup>-1</sup>. A high visibility analysis.

**M<sub>jj</sub> in W+jj analysis:** Co-led the analysis team; edited the paper. Exclude CDF bump & several models to explain the effect (technicolor, leptophobic Z'). A high visibility analysis.

**Diboson WW/WZ → ℓνjj:** Led the analysis effort, edited the paper. The most stringent limits on anomalous triple gauge couplings at a hadron collider, in some cases improving upon the LEP results.

**H → WW → ℓνjj:** Led the analysis effort. Exclude SM Higgs in mass range 170–600 GeV. Part of high mass Higgs paper. Important channel for 2012 analysis of VBF/ WW scattering.

**Jet substructure:** First comprehensive study of boosted jets in dijet and W/Z+jet events in CMS. Part of the 4-member of analysis team.

New



# People I work with: the lvjj team

Nural Akchurin<sup>1</sup>, **Jake Anderson<sup>2</sup>**, Chayanit Asawatangtrakuldee<sup>11</sup>, Andrea Benaglia<sup>3</sup>,  
Andrew Beretvas<sup>2</sup>, Jeffrey Berryhill<sup>2</sup>, Pushpa Bhat<sup>2</sup>, Sarah Boutle<sup>4</sup>, Chris Clarke<sup>5</sup>,  
Fabio Colombo<sup>3</sup>, Analu Custodio<sup>10</sup>, Jordan Damgov<sup>1</sup>, Leonardo Di Matteo<sup>3</sup>, Phil Duderø<sup>1</sup>,  
Ricardo Eusebi<sup>6</sup>, Pietro Govoni<sup>12</sup>, **Dan Green<sup>2</sup>**, Joey Goodell<sup>4</sup>, Robert Harr<sup>5</sup>, Pratima Jindal<sup>13</sup>,  
Ajay Kumar<sup>7</sup>, Kristina Krylova<sup>5</sup>, Kevin Lannon<sup>9</sup>, Sung-Won Lee<sup>1</sup>, Qiang Li<sup>11</sup>, Shuai Liu<sup>11</sup>,  
Wuming Luo<sup>9</sup>, Yajun Mao<sup>11</sup>, Kellen McGee<sup>5</sup>, **Kalanand Mishra<sup>2</sup>**, Md. Naimuddin<sup>7</sup>,  
Chris Neu<sup>4</sup>, Ilya Osipenkov<sup>6</sup>, Alexx Perloff<sup>6</sup>, Kirti Ranjan<sup>7</sup>, Sasha Sakharov<sup>5</sup>, Ram K  
Shivpuri<sup>7</sup>, Kevin Siehl<sup>5</sup>, Andre Sznajder<sup>10</sup>, **Nhan V. Tran<sup>2</sup>**, Zijun Xu<sup>11</sup>, Weimin Wu<sup>2</sup>,  
John Wood<sup>4</sup>, **Fan Yang<sup>2</sup>**, Francisco Yumiceva<sup>2</sup>, and Wei Zou<sup>11</sup>

<sup>1</sup> Texas Tech University, Lubbock, Texas, USA

<sup>2</sup> Fermi National Accelerator Laboratory, Batavia, Illinois, USA

<sup>3</sup> Milano-Bicocca University and INFN, Milan, Italy

<sup>4</sup> University of Virginia, Charlottesville, Virginia, USA

<sup>5</sup> Wayne State University, Detroit, Michigan, USA

<sup>6</sup> Texas A&M University, College Station, Texas, USA

<sup>7</sup> Delhi University, Delhi, India

<sup>8</sup> University of Nebraska at Lincoln, Nebraska, USA

<sup>9</sup> University of Notre Dame, Notre Dame, Indiana, USA

<sup>10</sup> Universidade do Estado do Rio de Janeiro (UERJ), Brazil

<sup>11</sup> Peking University, China

<sup>12</sup> CERN

<sup>13</sup> Princeton University, New Jersey, USA

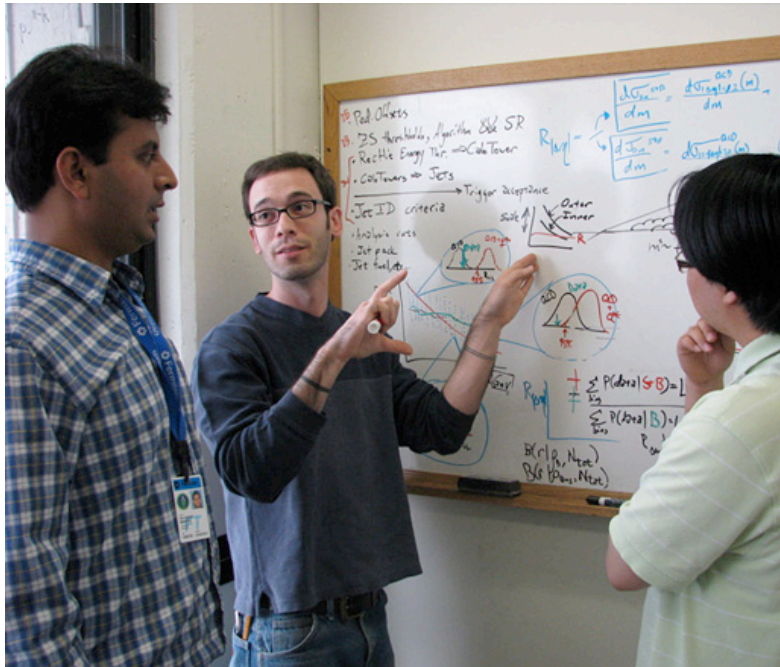
**Well established  
team, well oiled  
machinery**

**Supervisor  
at FNAL:  
Jeffrey  
Berryhill**

# Activities at LPC



- 1) Taught/facilitated CMSDAS jet short & long exercises in 2010, 2011, 2012, and 2013 including the ones at Pisa and Taipei
- 2) Regularly help LPC-based students with physics & data analysis



<http://lpc.fnal.gov/>

- 3) Mentored a number of undergrad and graduate students at LPC

**2013:** Kevin Siehl (Wayne State), Cristian Vega (Universidad San Francisco de Quito, **UG**)

**2012:** Wei Zou (Beijing), Ajay Kumar (Delhi), Kevin Siehl (Wayne State), Geoffrey Fatin (Buffalo, **UG**), Joseph Flanigan (Wayne State, **UG**)

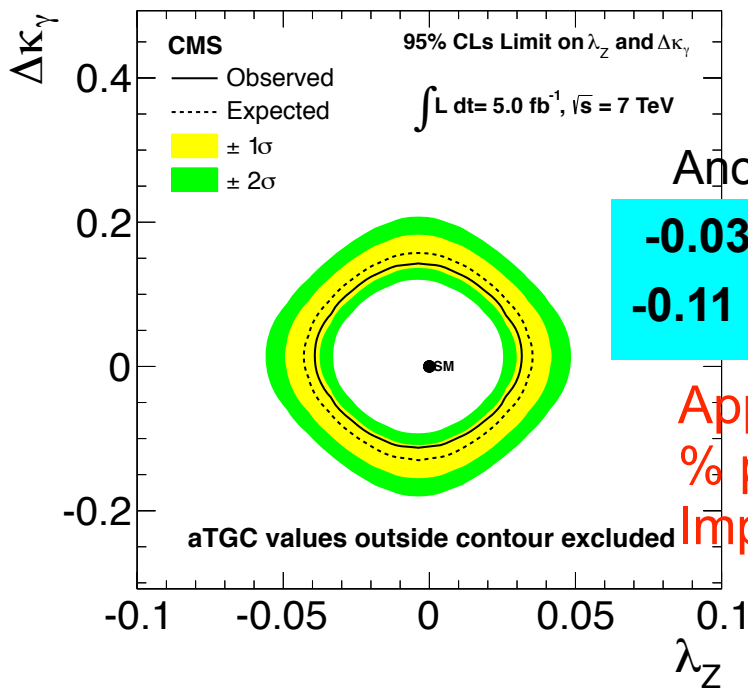
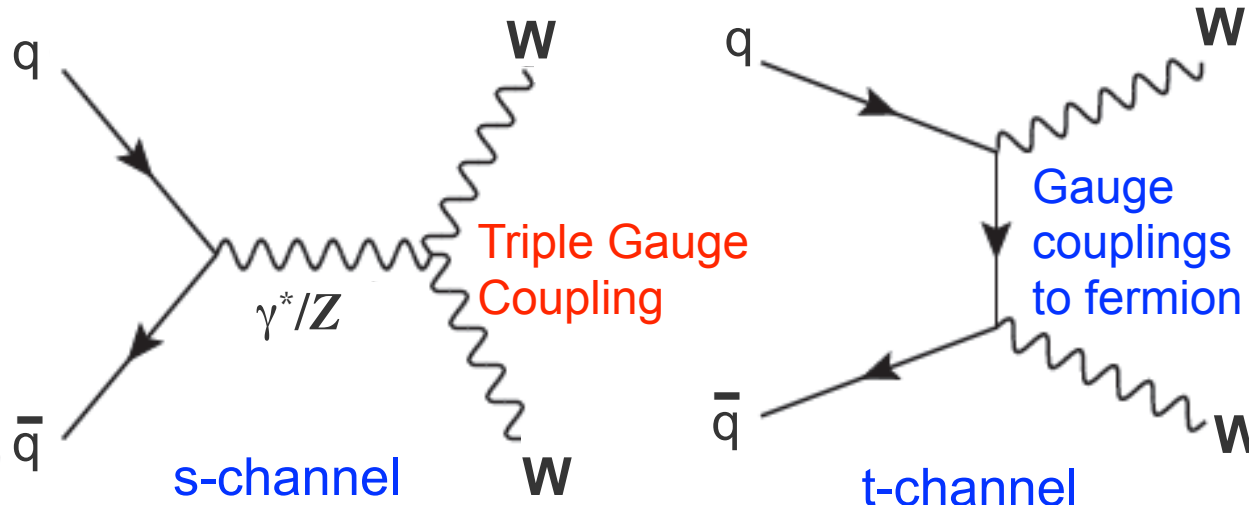
**2011:** Kristina Krylova (Buffalo, **UG**), Kellen McGee (Johns Hopkins, **UG**)

**2008–10:** Mikhail Makouski (Kansas State), Sunil Bansal (Panjab, India), Mehmet Deliomeroğlu (Bogazici, Turkey), Kittikul Kovitanggoon (Texas Tech), David Bjergaard (Johns Hopkins, **UG**)

# Physics analysis: my research focus

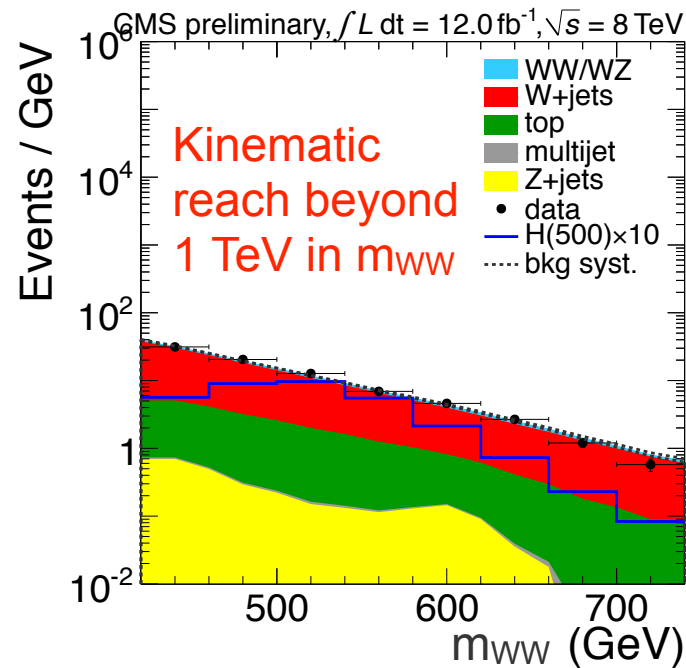


**Semi-leptonic  
WW channel is  
most sensitive to  
anomalous TGC  
and high mass  
WW resonances**



**Anomalous TGC**  
 $-0.038 < \lambda_Z < 0.030$   
 $-0.11 < \Delta\kappa_\gamma < 0.14$

Approaching a few  
% precision.  
Improved over LEP.



## Plans for the rest of the year



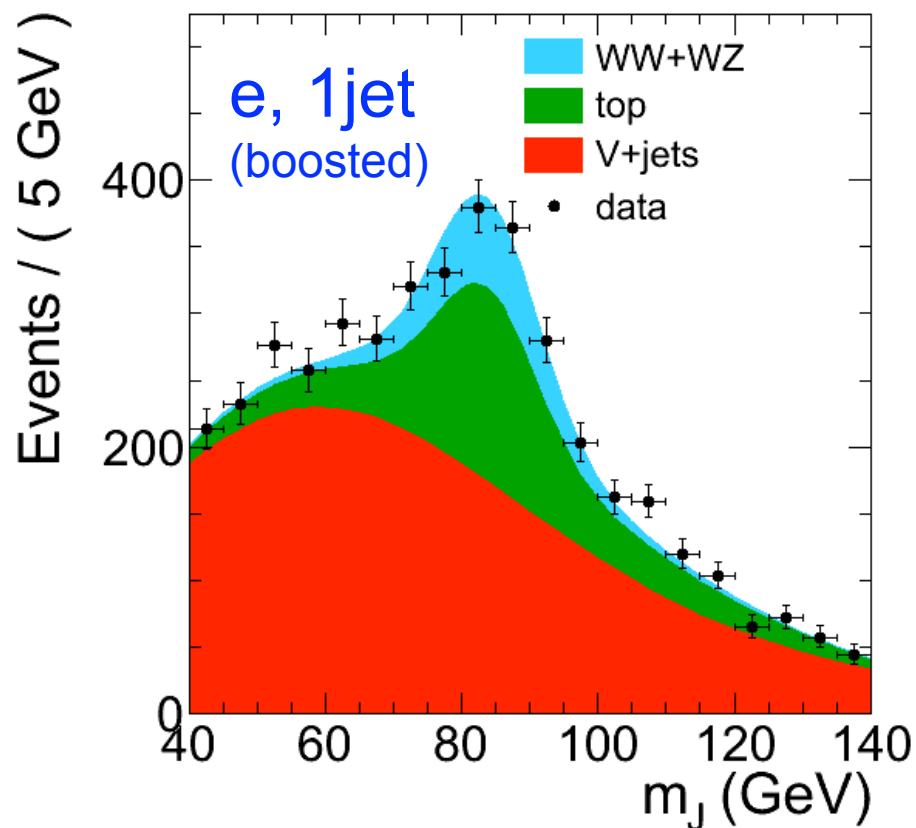
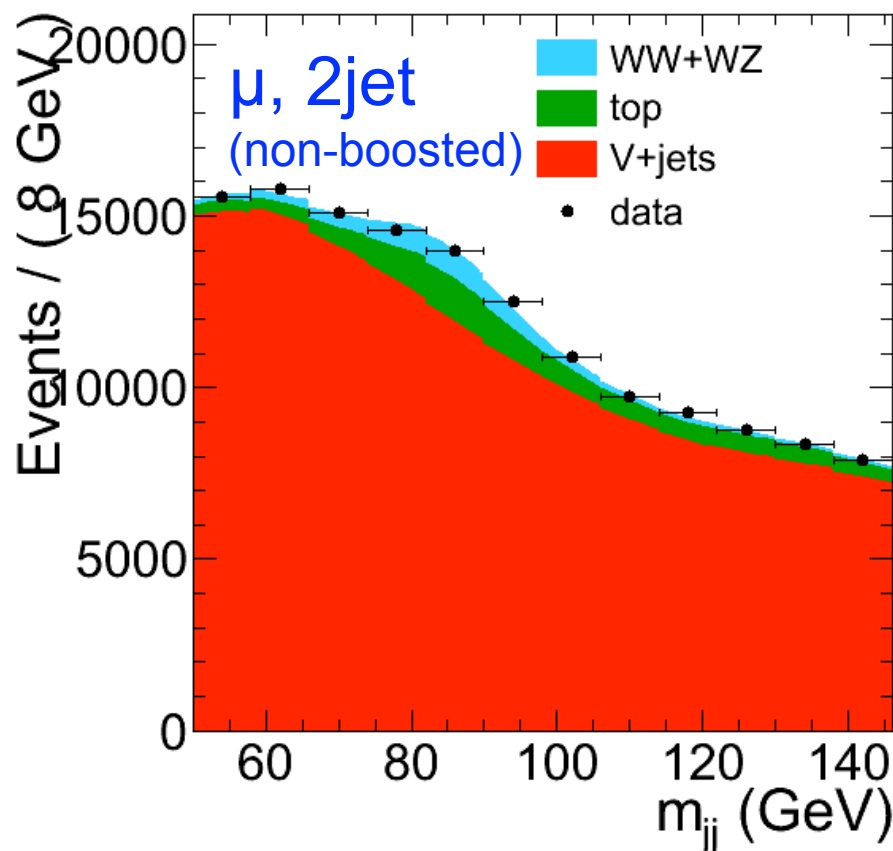
- ◆ Push the current 8 TeV analysis to publication
  - extend  $m_{WW}$  mass range  $>1$  TeV for Higgs/BSM analysis
  - probe triple gauge couplings at the percent level
  
- ◆ Focus now on a deeper probe of EWSB using  $WW+2$  tag jets events in VBF topology
  - First establish VBF production of  $WW$
  - Check if data consistent with  $H(125)$  unitarized  $WW \rightarrow WW$  scattering, probe quartic gauge couplings
  
- ◆ Continue ramping up on CMS Level-1 trigger upgrade

I elaborate on each of these topics in the following slides

# Glimpse of currently ongoing 8 TeV analysis



## WW production in semi-leptonic final state

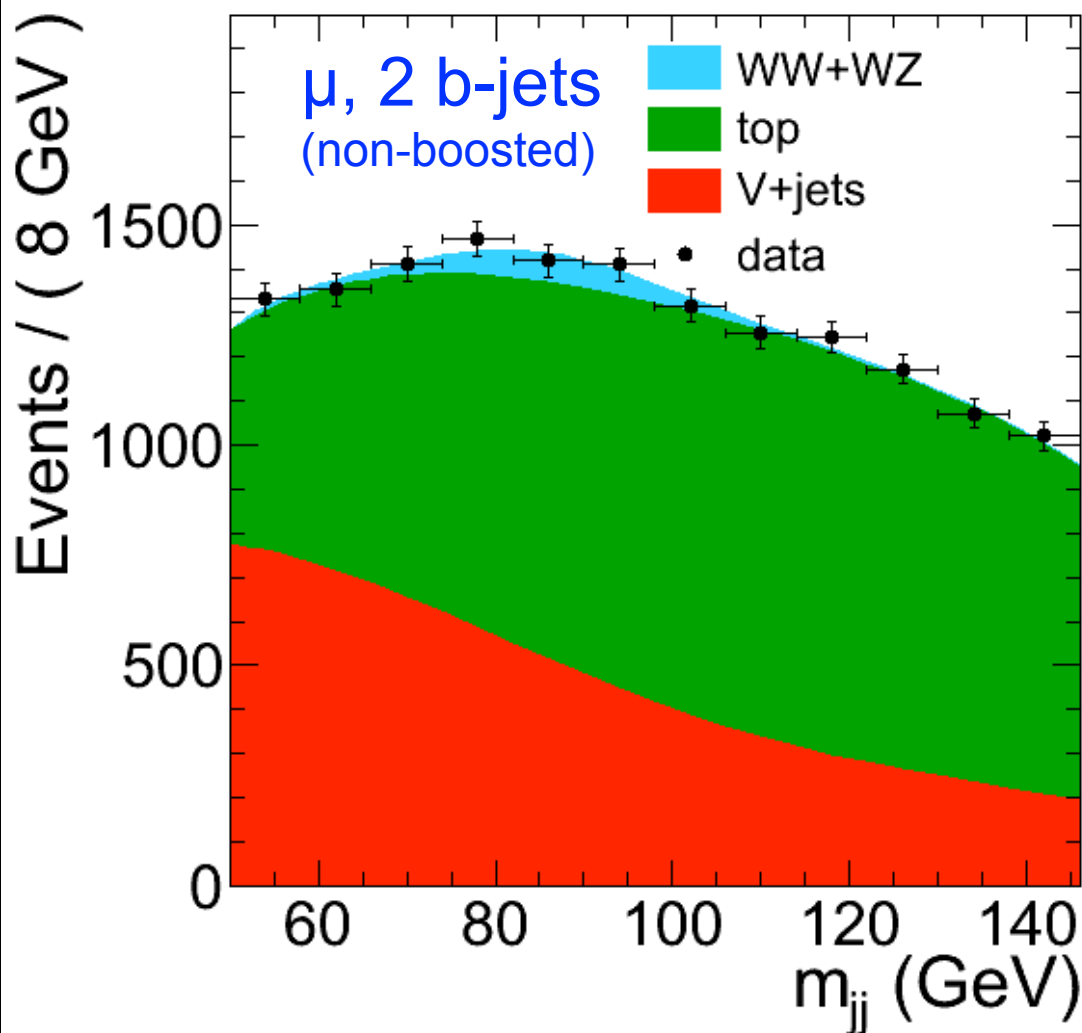


Found 9000 diboson events in 8 TeV data, with purity 5–15%

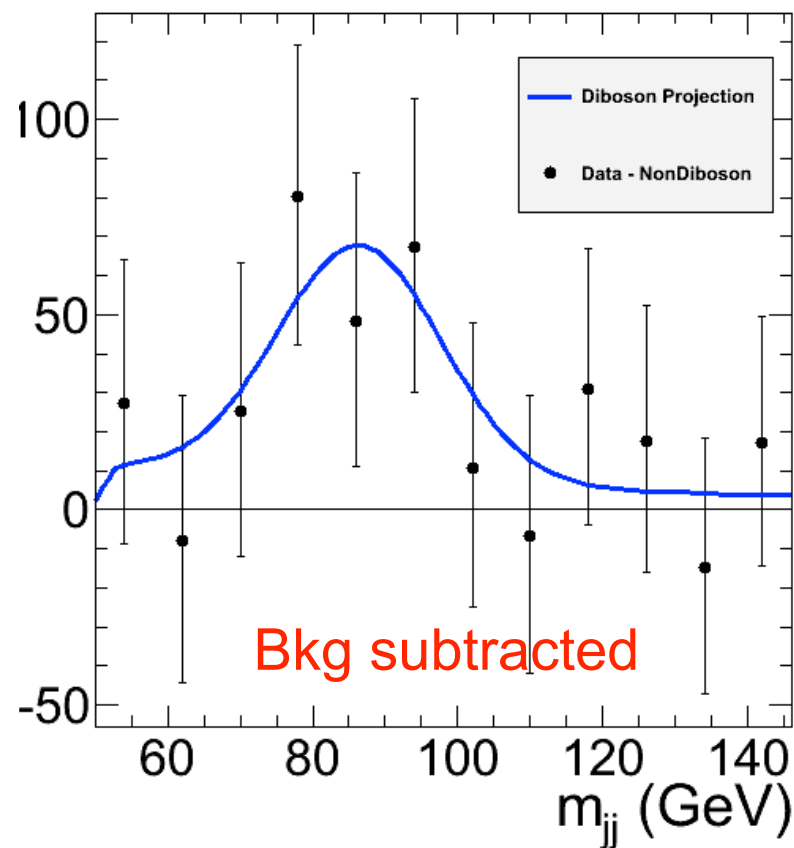
# Glimpse of current analysis II



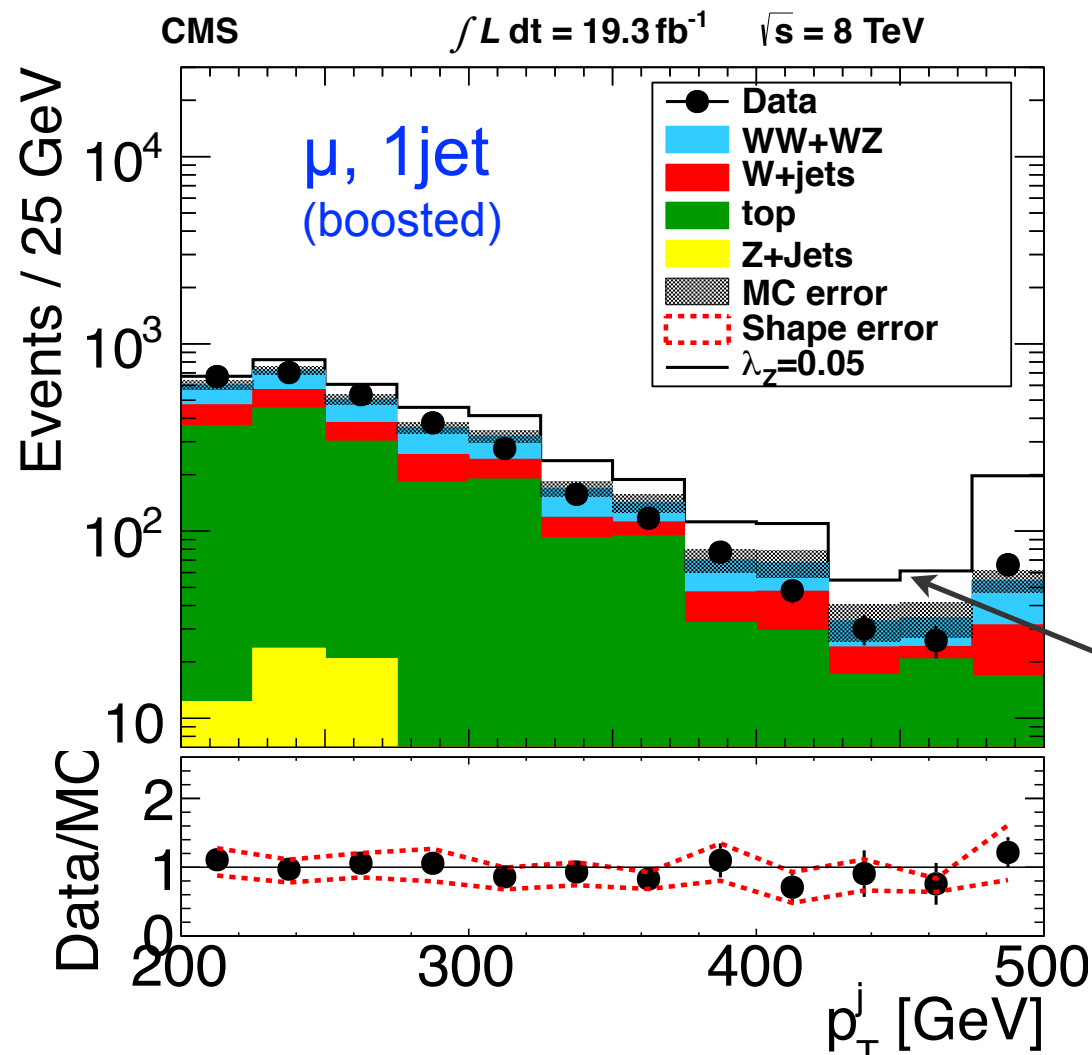
Hints of  $WZ(\rightarrow bb)$  production.



Good proxy for  $WH(\rightarrow bb)$ .



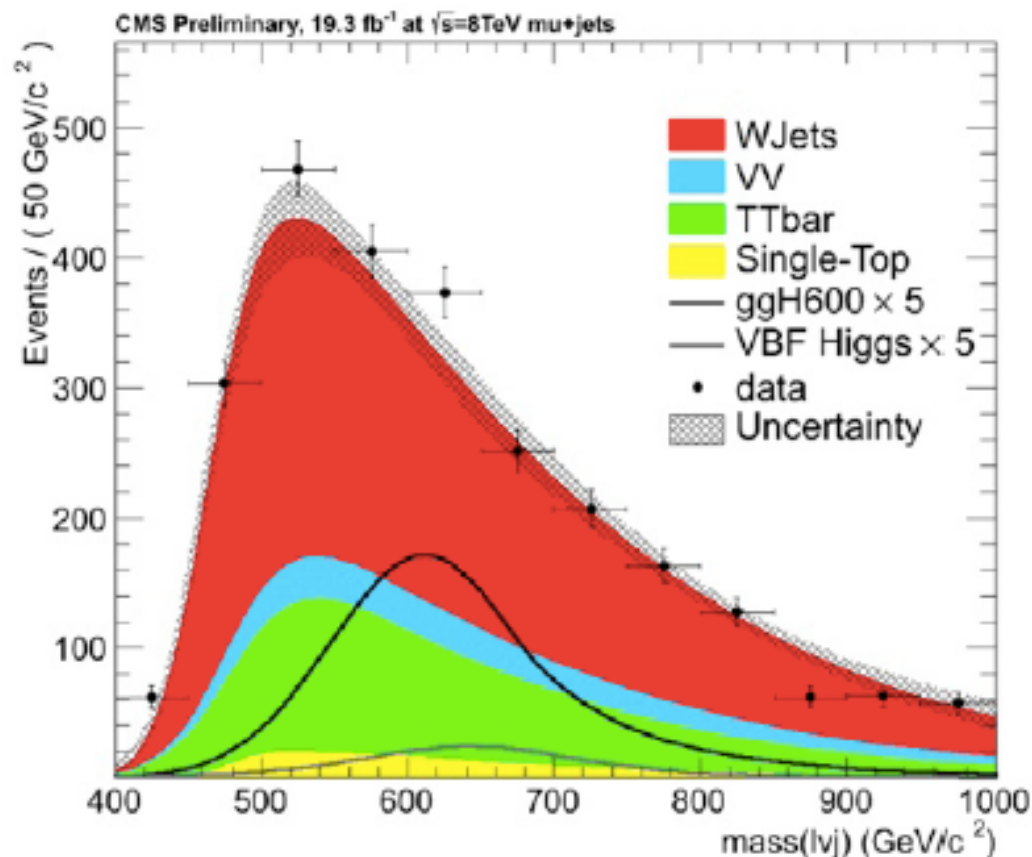
# Glimpse of current analysis III



Limits on anomalous gauge couplings

Expect to constrain triple gauge coupling measurements to the % level. Already have world's best limit/measurement.

# Glimpse of current analysis IV



Probe WW invariant mass up to 1 TeV and beyond in the boosted regime (i.e., a single merged fat jet from W)

More details in the presentation in Higgs PAG

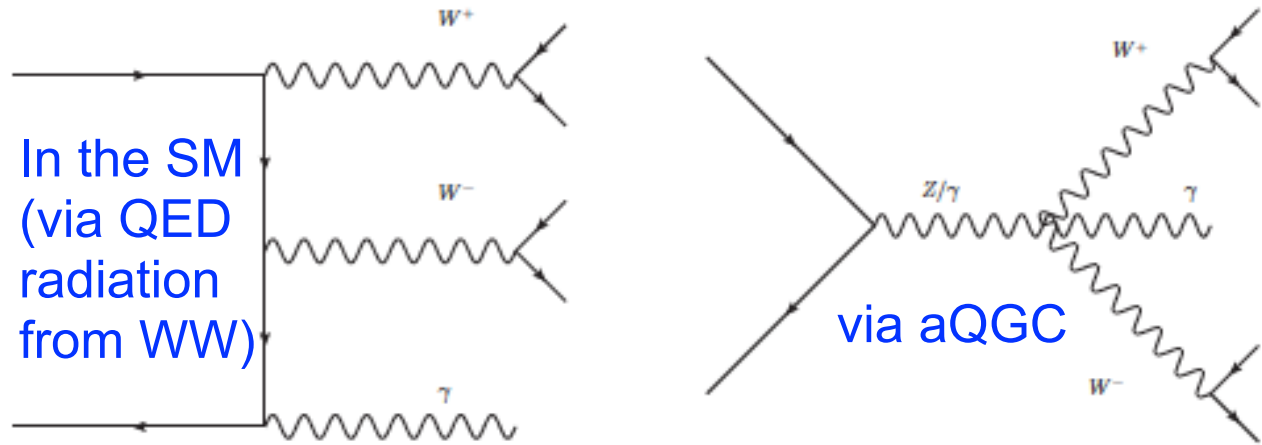
<https://indico.cern.ch/getFile.py/access?contribId=2&sessionId=6&resId=0&materialId=slides&confId=227892>



# Multi boson production and quartic couplings

## WW $\gamma$ production at LHC

- SM production is highly suppressed
- By a factor of  $\sim 2000$  compared to WW



New

Observed:  $-3.0 \times 10^{-5} < a_0^W / \Lambda^2 < 3.0 \times 10^{-5}$     Observed:  $-5.0 \times 10^{-5} < a_c^W / \Lambda^2 < 4.5 \times 10^{-5}$   
 Expected:  $-2.5 \times 10^{-5} < a_0^W / \Lambda^2 < 2.5 \times 10^{-5}$     Expected:  $-4.5 \times 10^{-5} < a_c^W / \Lambda^2 < 4.0 \times 10^{-5}$

LEP limits

$W^+W^-\gamma$	$a_0^W$	$-0.020 \text{ GeV}^{-2} < a_0^W / \Lambda^2 < 0.020 \text{ GeV}^{-2}$
$W^+W^-\gamma$	$a_c^W$	$-0.053 \text{ GeV}^{-2} < a_c^W / \Lambda^2 < 0.037 \text{ GeV}^{-2}$

We improve upon LEP limits on aQGC by a factor of 1000 !!!

# Thinking of future: weak interaction @ high E

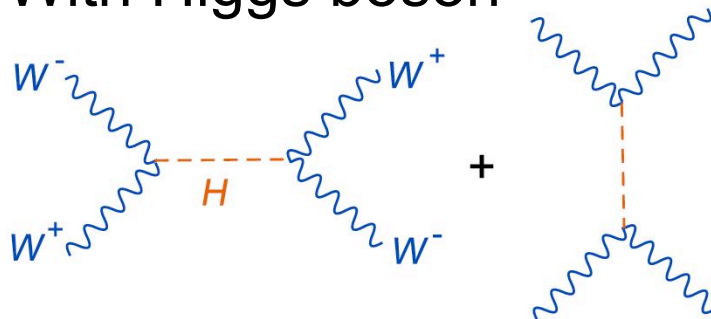


Without Higgs boson, WW scattering becomes divergent

$$= \frac{g^2 E^2}{2m_W^2} (1 + \cos \theta)$$

unitarity violated:  
grows as  $E^2$

With Higgs boson



$$= -\frac{g^2 E^2}{2m_W^2} (1 + \cos \theta)$$

no problem now!

Higgs exchange needed to prevent **unitarity** violation in WW scattering at high energies or **New Phenomena** possible. With 20/fb,  $lvjj$  sensitive to weakly produced NP at 1 TeV.

Ballestrero et al, JHEP 1205, 083 (2012) [arXiv:1203.2771]

# Upgrade activities

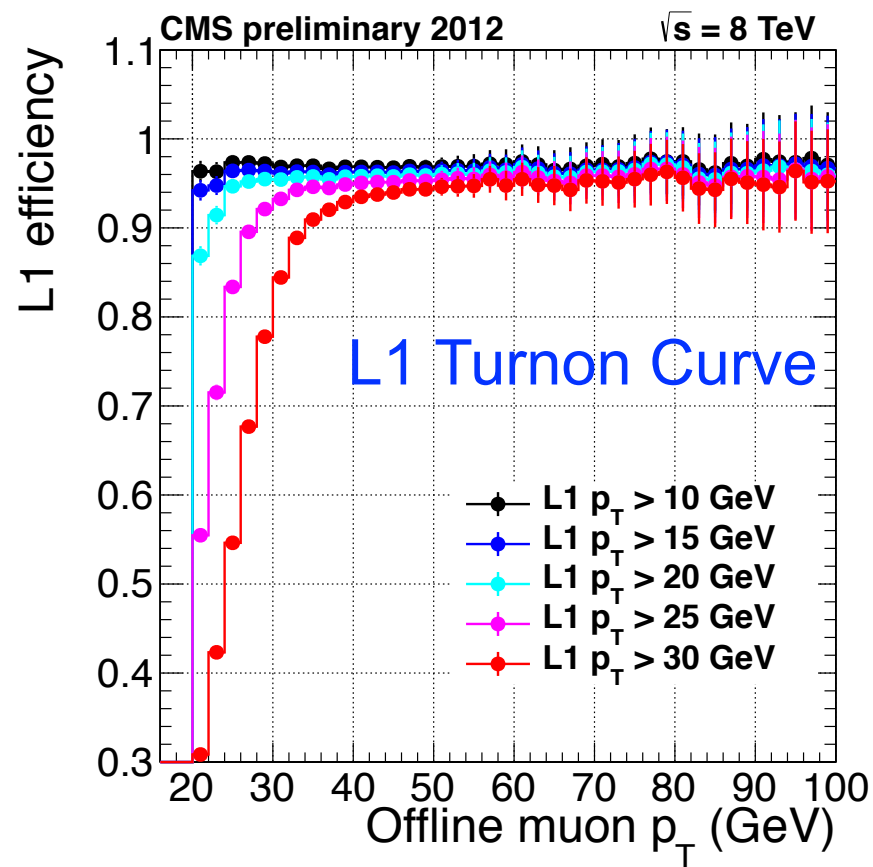
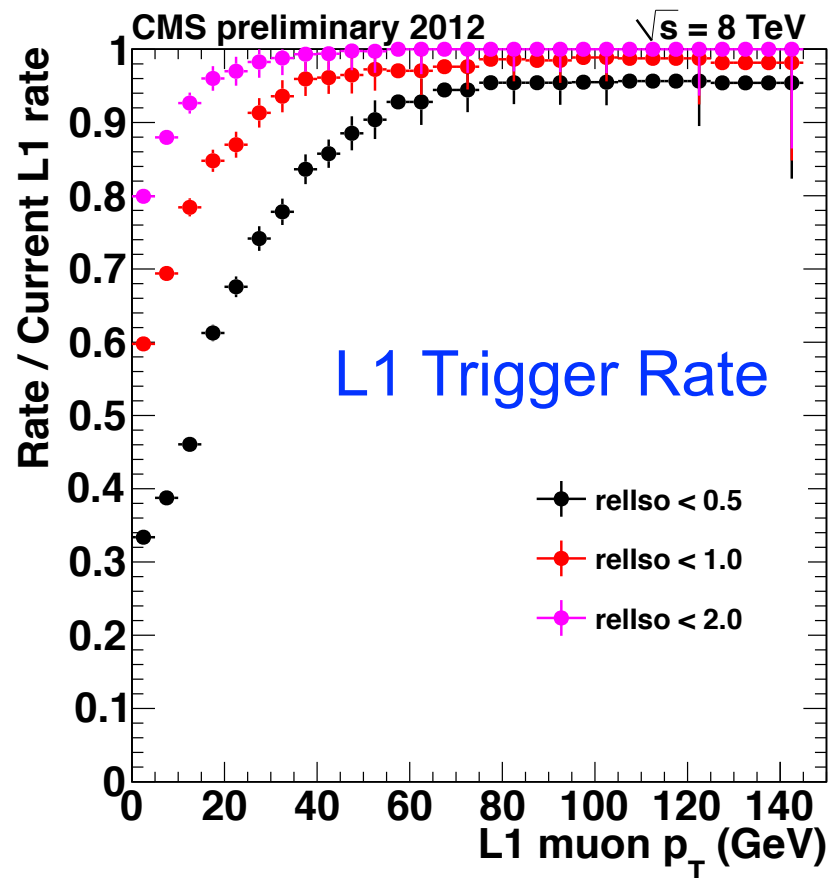


- The current Level-1 triggers will severely compromise CMS physics capability at 14 TeV, 50–100 pileup
  - E.g., single lepton threshold at HLT to go up to ~50 GeV
  - Will lose most of W,Z,top, Higgs events
  - Similar issues with jet, MET, tau, b-tag, cross triggers
- Having painfully dealt with the HLT rate increase of  $\ell+jj$  triggers, I decided to invest my effort on L1 upgrade
  - Working closely w/ Andres Osorio (FIT & LPC) and Sergo
  - I focus on improvement from applying calorimeter isolation to L1 muons
  - Goal is to improve L1 objects in calorimeter by doing pileup subtraction and better algorithms
  - We started with performance studies, rate and efficiency computation etc, provided feedback for L1 upgrade TDR

# Example: L1 muon isolation



## Performance for “non-isolated” muons



Actual rate reduction is only 10–20% because significant fraction of L1 muons are already pretty isolated in calorimeter.

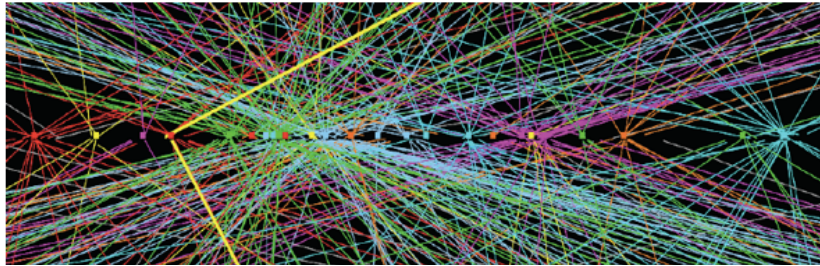
# BOOST project / jet substructure



<https://twiki.cern.ch/twiki/bin/view/Main/BOOST2012-pileup>

Jet substructure performance at high luminosity  
BOOST 2012 working group

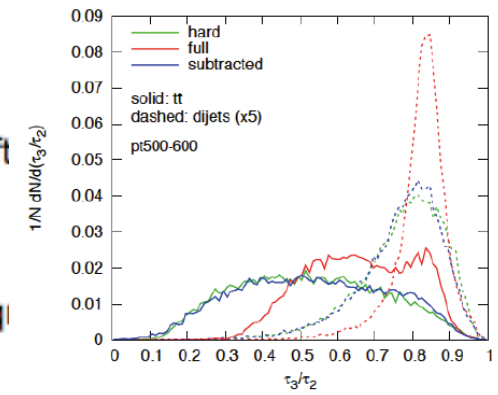
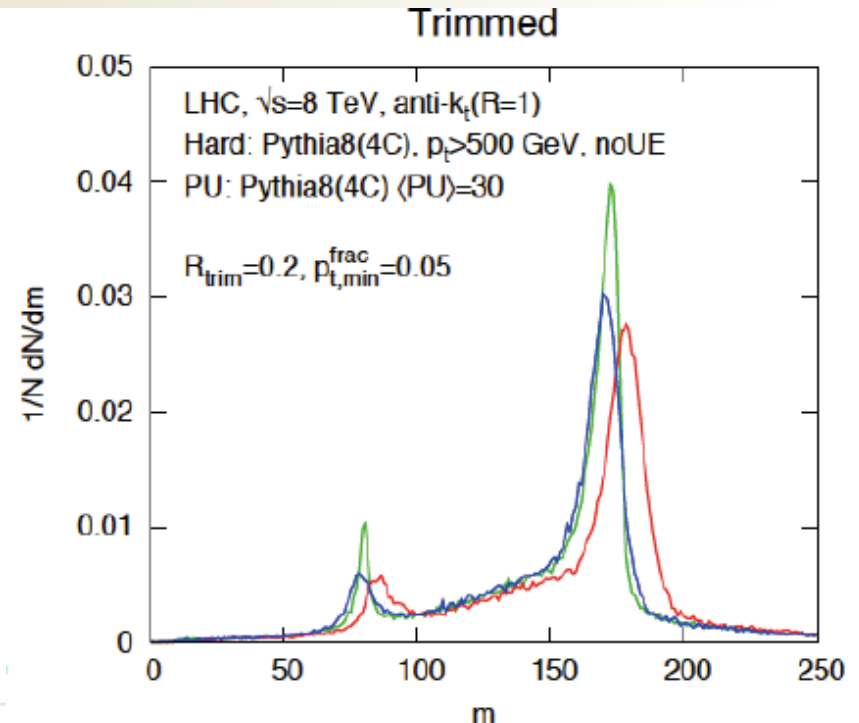
Conveners: Gregory Soyez and Ariel Schwartzman



## Pile-up subtraction plus grooming

Coordinator: Mishra Kalanand

- Study the application of jet-areas pile-up subtraction during grooming
- Compare jet substructure performance with the use of pile-up subtraction after grooming (CMS approach)
- Consider all luminosity scenarios separately
- Figures of merit include: mass vs. number of vertices, mass resolution,  $S/\sqrt{s}$  etc.



# Involvement with Snowmass 2013 activities



## Snowmass 2013: Energy Frontier Workshop on QCD Physics

31 January 2013  
Fermilab  
US/Central timezone

Search

13:00

**Scale choices for complex processes**

Kalanand MISHRA

WH11NE (Sunrise), Fermilab

13:00 - 13:40

To the Snowmass QCD report, I am contributing to sections on jet substructure (boosted systems), and scale choice and jet veto in top/Higgs/electroweak processes.

◆ I am also helping the local LPC based effort on performance studies for future high luminosity LHC detectors.

## Other miscellaneous contributions



### Anomalous Quartic Gauge Couplings

from 30 September 2013 to 02 October 2013 (Europe/Berlin) *TU Dresden*  
Europe/Berlin timezone

I'm in the organizing committee of this international workshop (along with Christophe Grojean, Matt Herndon, Barbara Jaeger, Sabine Lammers, Yurii Maravin, Juergen Reuter, Thomas Schoerner-Sadenius, Anja Vest)

### ASPEN 2014: "Frontiers in Particle Physics: From Dark Matter to the LHC and Beyond"

I'm in the organizing committee (along with Kyle Cranmer, Michele Papucci, Tomer Volansky, Jure Zupan)

## Repeat: plans for the rest of the year



- Publish the current ongoing analyses with full 8 TeV data
  - push the  $m_{WW}$  mass range up to 1 TeV for Higgs analysis
  - probe triple gauge couplings at the percent level
  
- Focus on a deeper probe of EWSB using WW+ 2-tag jet events in VBF topology
  - Need to first establish VBF production of WW
  - Check if data consistent with H(125) unitarized WW→WW scattering, probe quartic gauge boson couplings
  - Probe existence of weakly produced WW resonances
  
- Continue ramping up on CMS Level-1 trigger upgrade

**End of Report ! Thank You for your attention.**

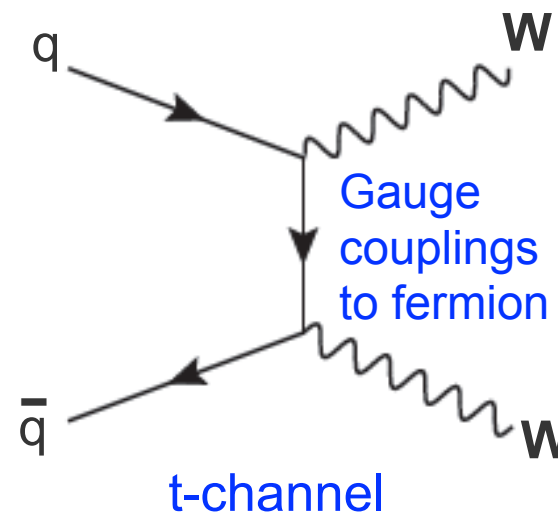
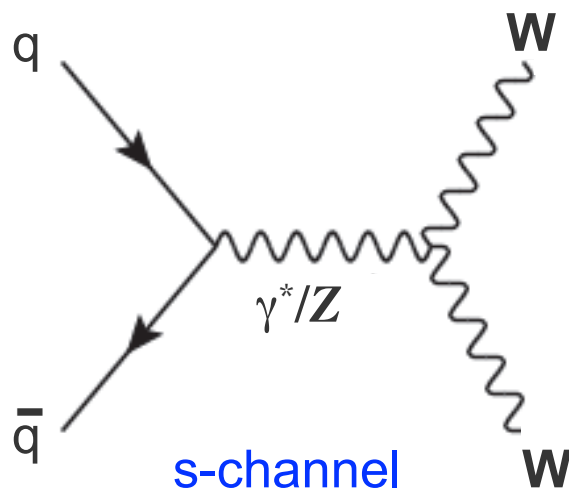
**BACKUP SLIDES**

# WW production and TGC



Need to measure WW production rate first !

WW production  
at Leading Order:



- Each diagram is divergent but the sum is finite !!!
- Higher order contribution is large:  $\sim 60\%$  of the LO !  
(see backup for details, if interested)



# Anomalous couplings in WW/WZ production

5 independent couplings remain after assuming basic symmetry

$$\mathcal{L}_{anom} = ig_{WWZ} \left[ \Delta g_1^Z (W_{\mu\nu}^* W^\mu Z^\nu - W_{\mu\nu} W^{*\mu} Z^\nu) + \Delta \kappa^Z W_\mu^* W_\nu Z^{\mu\nu} + \frac{\lambda^Z}{M_W^2} W_{\rho\mu}^* W_\nu^\mu Z^{\nu\rho} \right] + ig_{WW\gamma} \left[ \Delta \kappa^\gamma W_\mu^* W_\nu \gamma^{\mu\nu} + \frac{\lambda^\gamma}{M_W^2} W_{\rho\mu}^* W_\nu^\mu \gamma^{\nu\rho} \right],$$

## Equal coupling (HISZ) parametrization

$$\Delta \kappa_Z = \Delta g_1^Z - \Delta \kappa_\gamma \cdot \tan^2 \theta_W \quad \lambda_Z = \lambda_\gamma = \lambda$$

Further assume that  $\Delta g_1^Z = 0$  (SM), leaves two parameters:  $\lambda_Z$ ,  $\Delta \kappa_\gamma$

Coupling	Particle Data Group Fit
$\Lambda_\gamma$	$0.028^{+0.020}_{-0.021}$
$\Lambda_Z$	$0.088^{+0.060}_{-0.057}$
$\Delta g_1^Z$	$0.016^{+0.022}_{-0.019}$
$\Delta \kappa_\gamma$	$0.027^{+0.044}_{-0.045}$
$\Delta \kappa_Z$	$0.026^{+0.059}_{-0.056}$

LEP combination  
@ 95% CL

$[-0.026, 0.208]$

$[-0.063, 0.115]$

Tevatron (DØ)  
arXiv:1208.5458

$\lambda_Z$ :  $[-0.039, 0.042]$

$\Delta \kappa_\gamma$ :  $[-0.049, 0.124]$

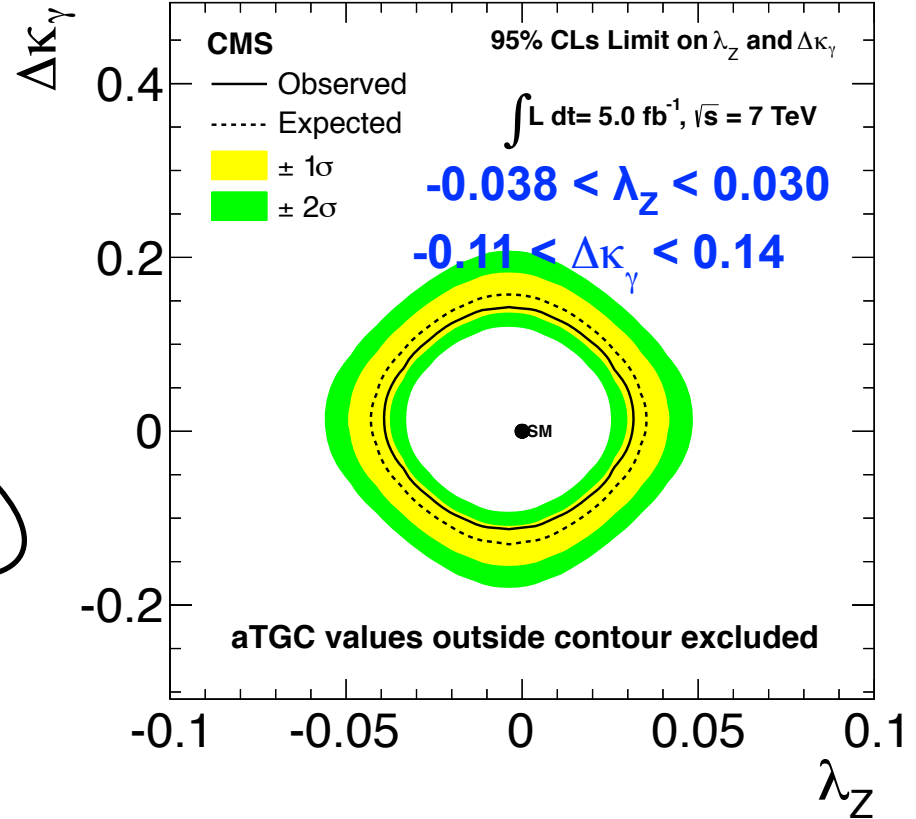
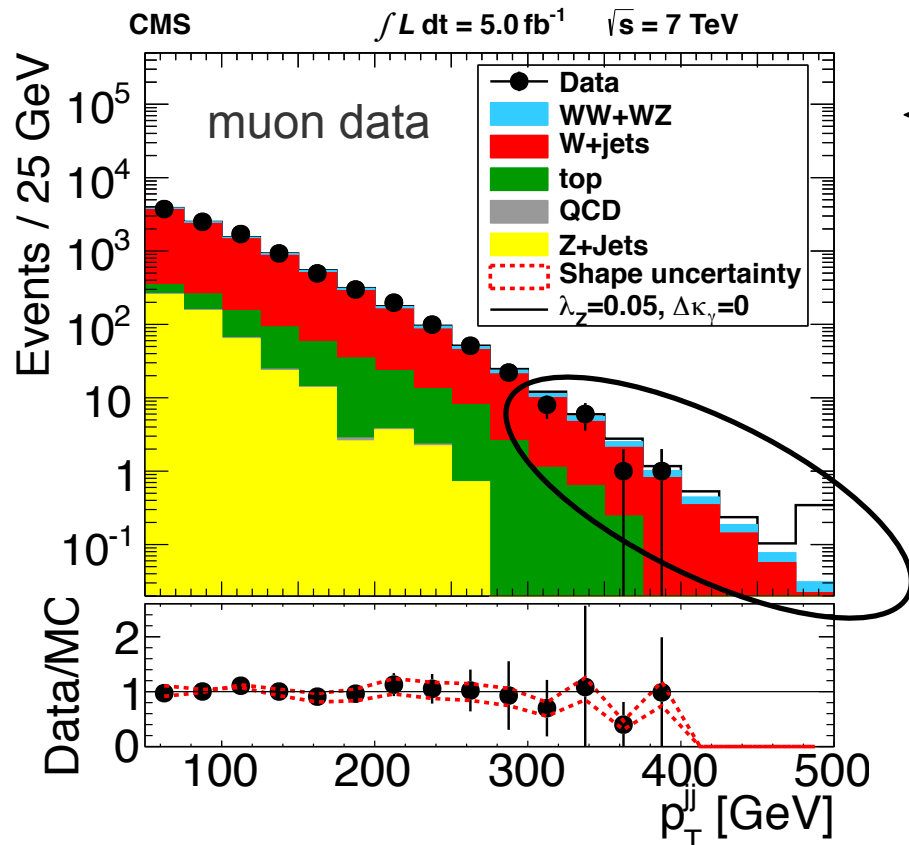
Note: assumes form  
factor of 2 TeV

ATLAS (arXiv:1208.1390)  $\lambda_Z$ :  $[-0.057, 0.093]$ ,  $\Delta \kappa_\gamma$ :  $[-0.37, 0.57]$



# Limits from $WW/WZ \rightarrow \ell \nu qq$ measurement

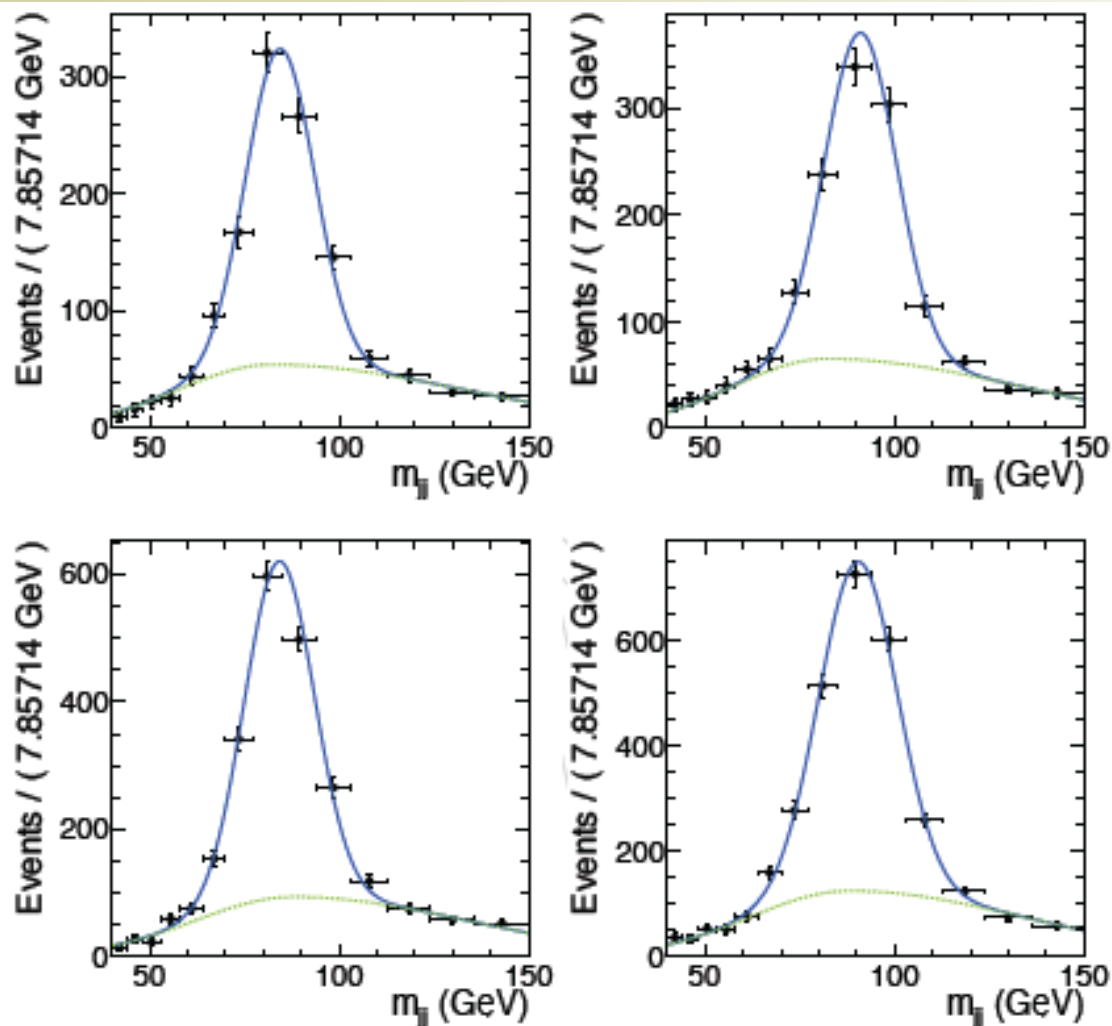
Use hadronic W  $p_T$  as the observable



Anomalous couplings show up in high  $p_T$  tails. Model using MCFM.

Improve upon the LEP limit in some cases.

# Shape of dijet mass in WW and WZ events



AN-12-224 v8  
pp 37

Figure 28: Diboson shape in the b-tagged sample: Projections of the fit to the diboson MC samples using the selected parameterization. Left is WW: right is WZ: top is electrons: bottom is muons.