$\gamma\gamma \rightarrow WW$ and Anomalous Quartic Gauge Couplings at CMS

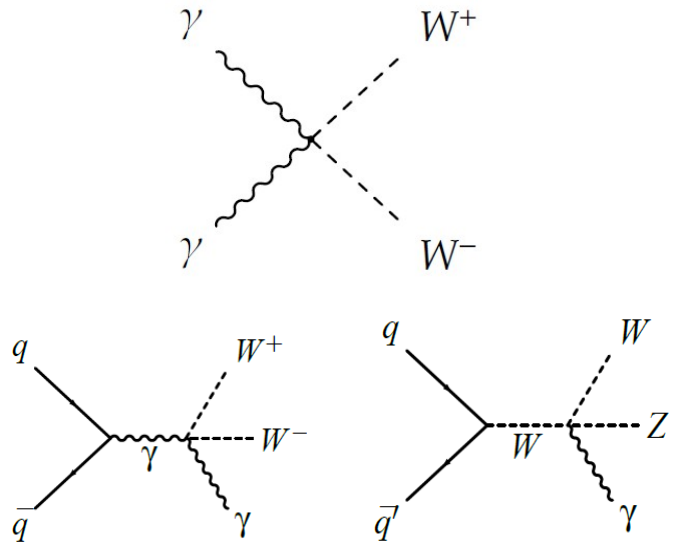
Jonathan Hollar (UCLouvain)
For the CMS Collaboration

EPS-HEP
July 19, 2013

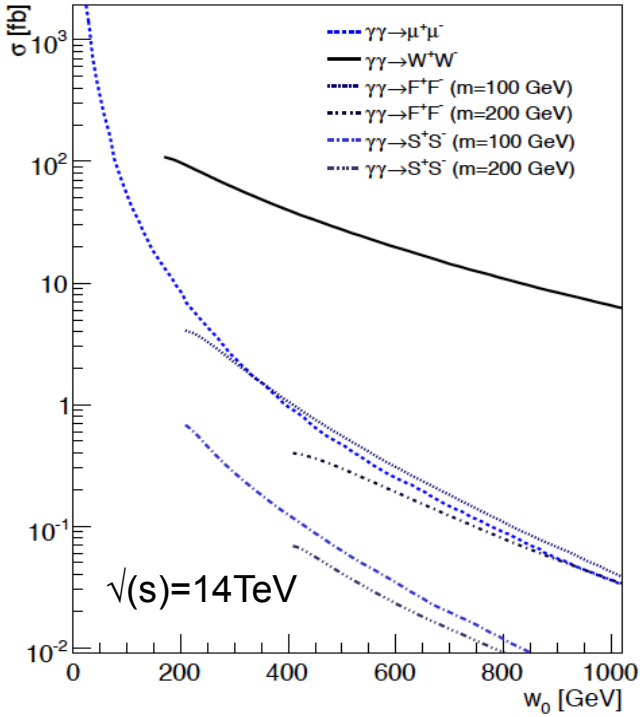
Quartic Gauge Couplings

- Fundamental prediction of the Standard Model electroweak sector
- Deviations from predictions would indicate new physics – typically parametrized in terms of Anomalous Quartic Gauge Couplings

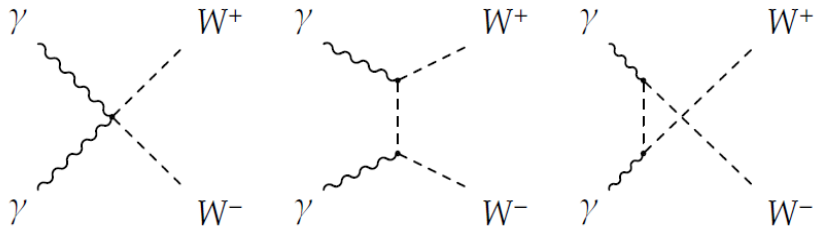
- At the LHC, quartic couplings can be studied via:
  - Boson scattering – for example $\gamma\gamma \rightarrow WW$
  - Tri-boson production – for example $WW\gamma$, $WZ\gamma$
  - Both types of analyses pursued in CMS



$\gamma\gamma \rightarrow WW$ at the LHC



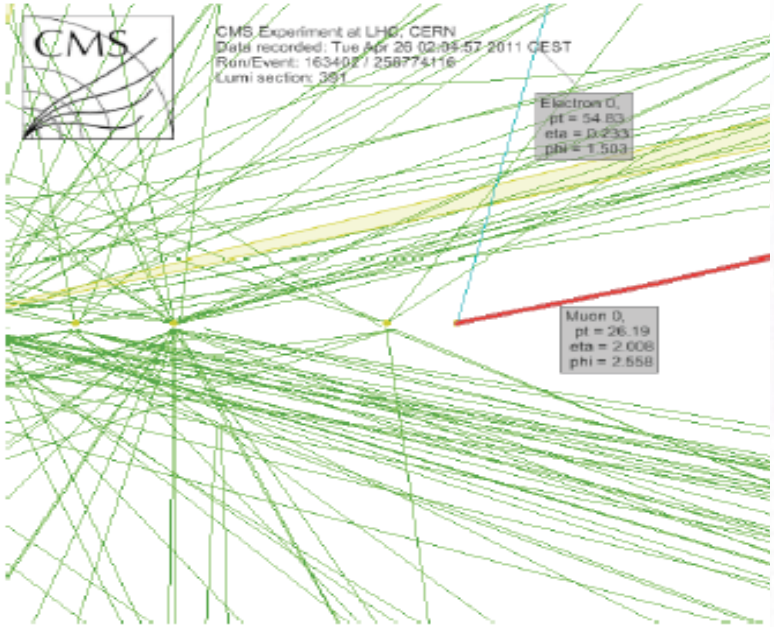
- Large cross section for high-energy $\gamma\gamma$ interactions at the LHC
  - $\gamma\gamma \rightarrow WW$ process has never before been observed



- In an untagged analysis - protons may stay intact, or dissociate into an undetected low-mass system
  - Signal is the sum of both topologies: $pp \rightarrow p^{(*)}WWp^{(*)}$

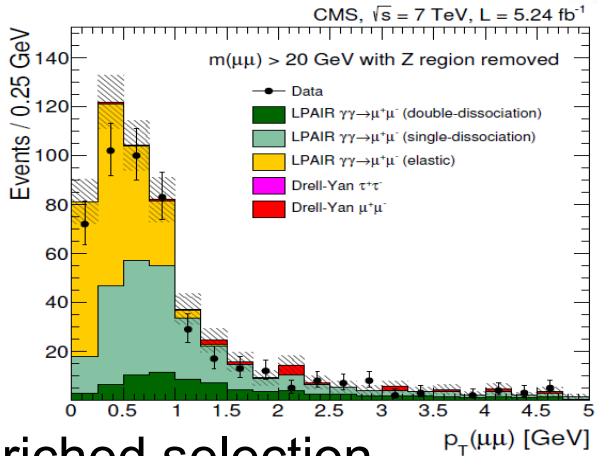
$\gamma\gamma \rightarrow WW$ analysis in CMS

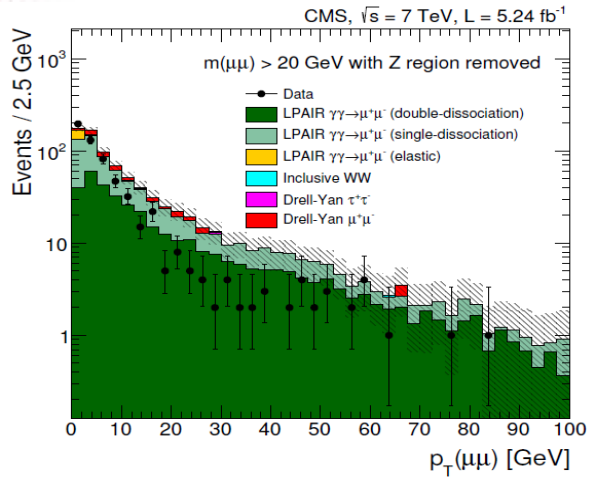
- Search for $\gamma\gamma \rightarrow WW$ performed using full 5fb^{-1} collected at 7TeV during 2011
- Consider only $WW \rightarrow \mu e$ (+ neutrinos) final state for signal
  - Same flavor channels have much larger backgrounds – use $\gamma\gamma \rightarrow \mu\mu$ as a control sample to constrain signal systematic and theory uncertainties
- "Exclusivity" defined by counting tracks on μe vertex – reduce sensitivity to pileup
  - Select events with 0 extra tracks and $p_T(\mu e) > 30$ GeV (SM signal region) and $p_T(\mu e) > 100$ GeV (AQGC search region)



$\gamma\gamma \to \mu\mu$ control samples

- Elastic-enriched selection with 0 extra tracks
  - Good agreement with predictions for $\gamma\gamma \to \mu\mu$ off the *Z* peak (LPAIR MC)
  - Use this sample to bound systematics from exclusivity, pileup modelling

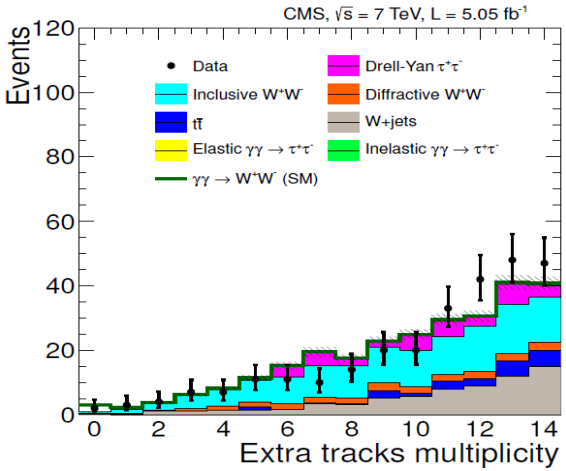


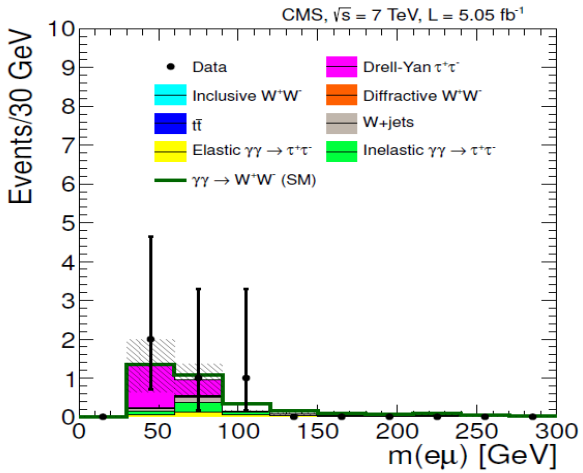


- Proton dissociation-enriched selection
  - Expect larger discrepancies from rescattering corrections not included in the MC simulation
- Derive a total normalization factor for (elastic + proton-dissociation)/elastic from high-mass dimuon data

$$F = 3.23 \pm 0.53.$$

$\gamma\gamma \to WW \to \mu e$ backgrounds





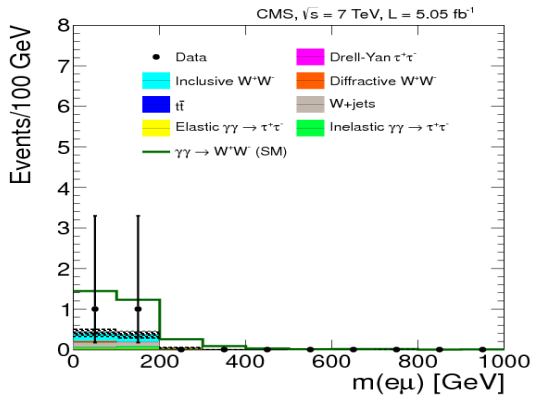
- Background predictions are checked from sideband control regions in number of extra tracks and $p_T(\mu e)$

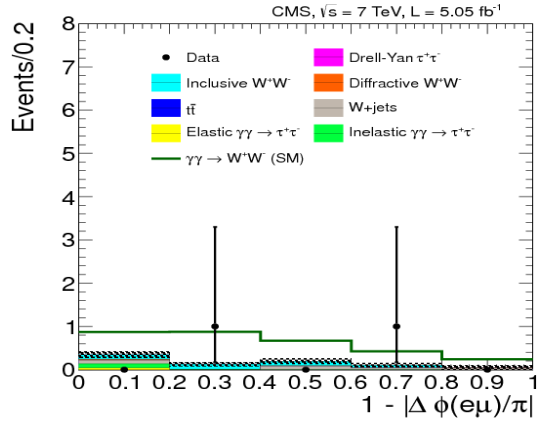
Region	Background process	Data	Sum of backgrounds	$\gamma\gamma \to W^+W^-$ signal
1	Inclusive W^+W^-	43	46.2 ± 1.7	1.0
2	Inclusive Drell-Yan $\tau^+\tau^-$	182	256.7 ± 10.1	0.3
3	$\gamma\gamma \to \tau^+\tau^-$	4	2.6 ± 0.8	0.7

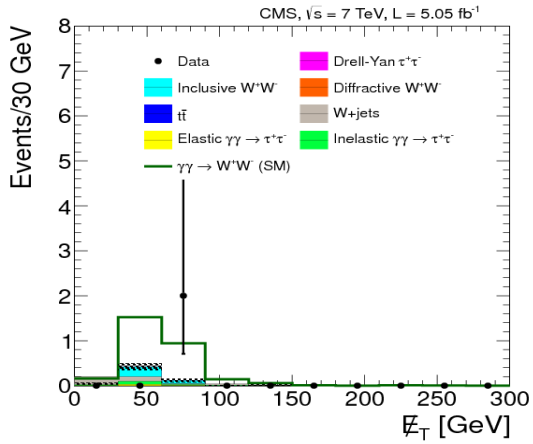
- Nominal background estimate: 0.84±0.15
- Consistent results obtained with several MC and data-driven (ABCD, same-sign events, tau-embedding) methods

$\gamma\gamma \to WW$ signal region

- For the SM signal region with $p_T(\mu e)$>30GeV:
  - Expected:
    - 2.2±0.4 (signal)
    - 0.84±0.15 (bkg)
  - Observed: 2 events
- Obtain a cross section times branching fraction and upper limit for a SM-like signal:



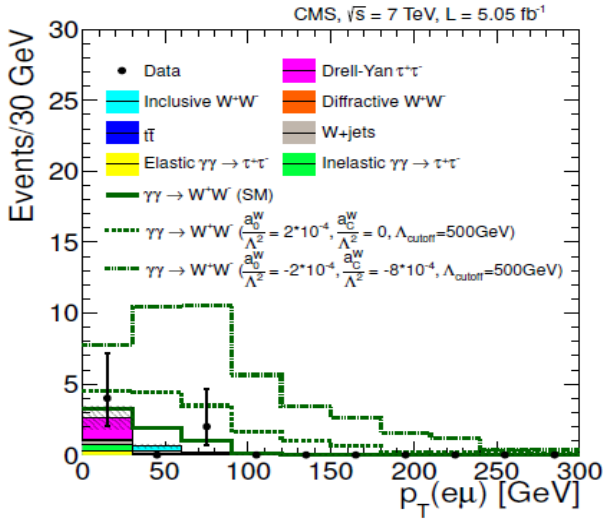


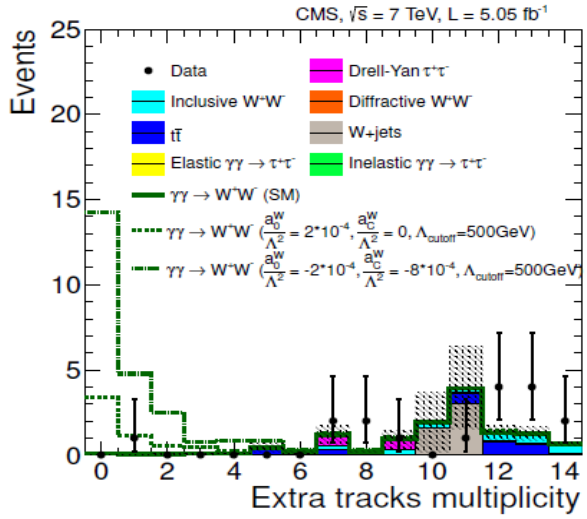


$$\sigma(\mathrm{pp} \to \mathrm{p}^{(*)}\mathrm{W}^+\mathrm{W}^-\mathrm{p}^{(*)} \to \mathrm{p}^{(*)}\mu^{\pm}\mathrm{e}^{\mp}\mathrm{p}^{(*)}) = 2.2^{+3.3}_{-2.0}\,\mathrm{fb},$$

$$\sigma(\mathrm{pp} \to \mathrm{p}^{(*)}\mathrm{W}^+\mathrm{W}^-\mathrm{p}^{(*)} \to \mathrm{p}^{(*)}\mu^{\pm}\mathrm{e}^{\mp}\mathrm{p}^{(*)}) < 10.6\,\mathrm{fb}.$$

AQGC search region





- For $p_T(\mu e)$ > 100 GeV and 0 extra tracks
  - 0.14 events expected (SM)
  - 0 events observed

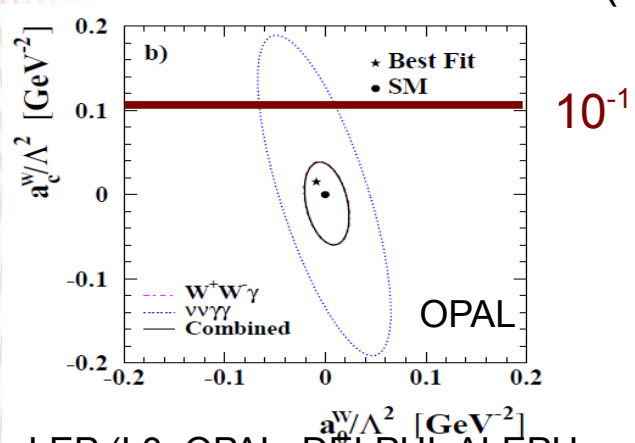
- Set a model-independent limit on the partial cross section times branching fraction

$$\sigma(\mathrm{pp} \to \mathrm{p}^{(*)}\mathrm{W}^+\mathrm{W}^-\mathrm{p}^{(*)} \to \mathrm{p}^{(*)}\mu^{\pm}\mathrm{e}^{\mp}\mathrm{p}^{(*)}) < 1.9\,\mathrm{fb}.$$

For $p_T(\mu,e)$ > 20 GeV, $|\eta(\mu,e)|$ < 2.4, $p_T(\mu e)$ > 100 GeV

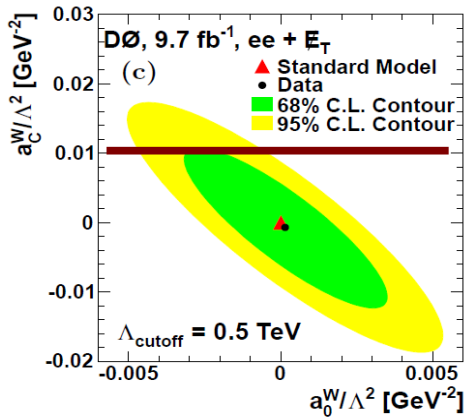
$\gamma\gamma \rightarrow WW$ AQGC limits

- Interpret results in terms of LEP-like "dimension-6" $\gamma\gamma WW$ AQGC's
  - Strong unitarity violation for high-energy $\gamma\gamma$ interactions – give limits both with and without form factors (Λ = 500 GeV) to preserve unitarity



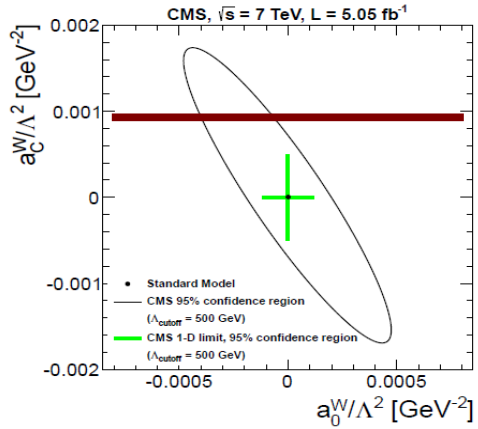
10^{-1}

LEP (L3, OPAL, DELPHI, ALEPH $WW\gamma$ + $WW \rightarrow \gamma\gamma$)



10^{-2}

Tevatron (D0, $\gamma\gamma \rightarrow WW$)



10^{-3}

LHC (CMS, $\gamma\gamma \rightarrow WW$)

$$-0.00015 < a_0^W/\Lambda^2 < 0.00015\,\text{GeV}^{-2} \quad (a_C^W/\Lambda^2 = 0, \Lambda_{\text{cutoff}} = 500\,\text{GeV}),$$
$$-0.0005 < a_C^W/\Lambda^2 < 0.0005\,\text{GeV}^{-2} \quad (a_0^W/\Lambda^2 = 0, \Lambda_{\text{cutoff}} = 500\,\text{GeV}).$$

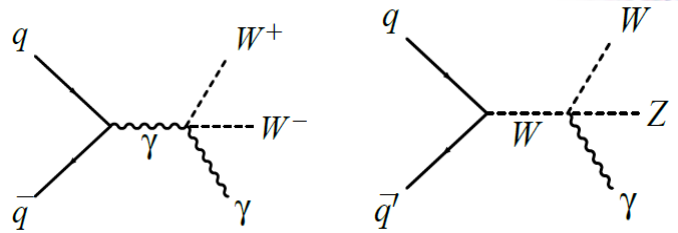
Limits are ~100x beyond LEP, ~20x beyond Tevatron (with Λ=500GeV)

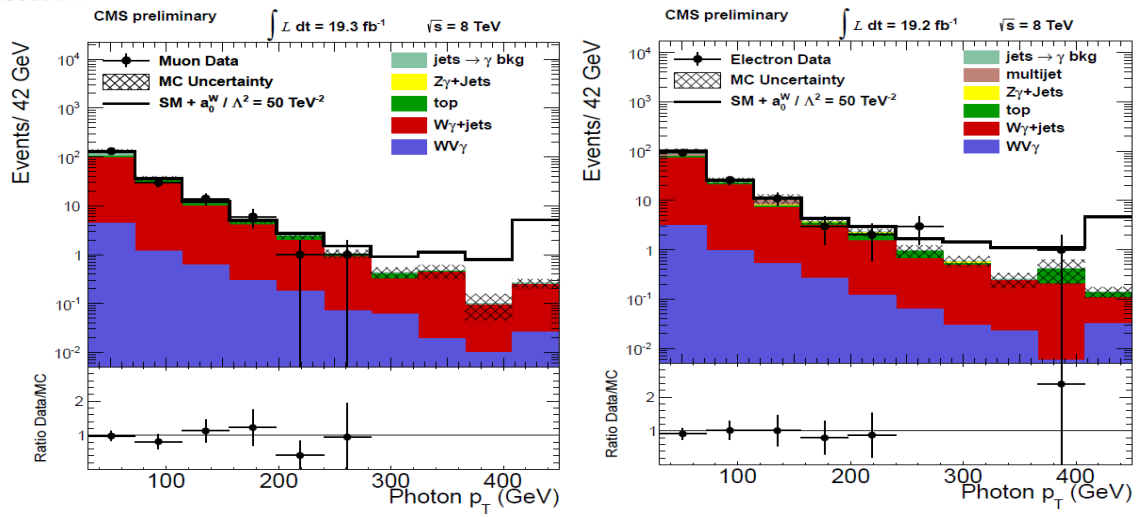
$$-4.0 \times 10^{-6} < a_0^W/\Lambda^2 < 4.0 \times 10^{-6}\,\text{GeV}^{-2} \quad (a_C^W/\Lambda^2 = 0, \text{no form factor}),$$
$$-1.5 \times 10^{-5} < a_C^W/\Lambda^2 < 1.5 \times 10^{-5}\,\text{GeV}^{-2} \quad (a_0^W/\Lambda^2 = 0, \text{no form factor}).$$

No-FF limits are ~100x beyond Tevatron (with no form factor)

$WZ\gamma$ and $WW\gamma$ at CMS

- New - first LHC search for $WV\gamma$ tri-boson production (where $V = W$ or Z decaying to dijets)
  - Analysis performed in the lepton + dijet + photon + missing E_T final state
  - Based on the full 20fb^{-1} dataset collected at 8 TeV



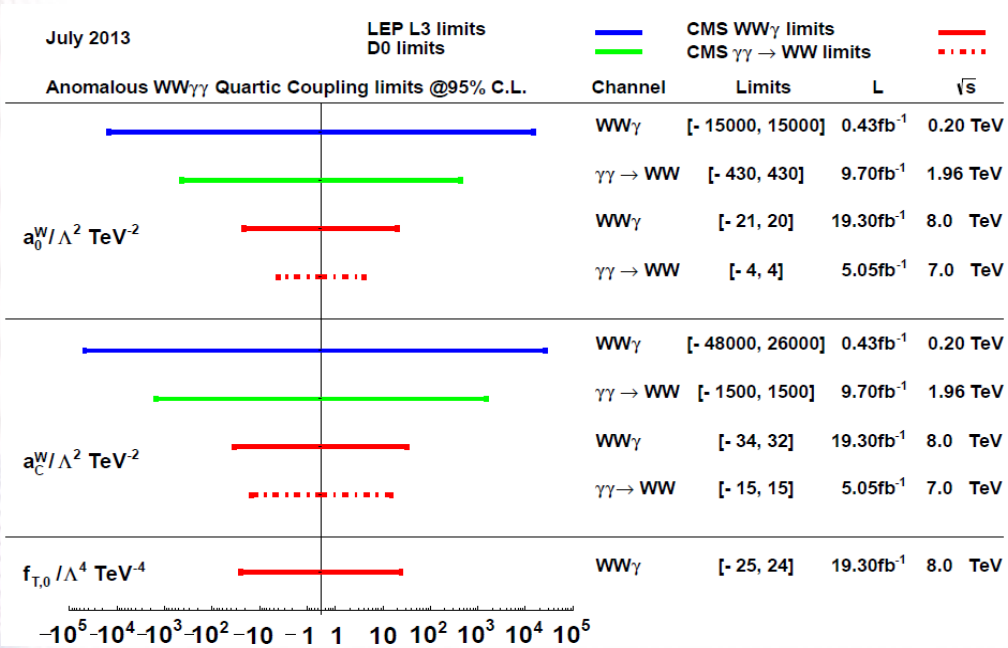


- Cross section limits obtained are 3.4x the Standard Model prediction
- Photon p_T is used as the variable to set limits on AQGC's
  - For additional details see talk by Chia-Ming Kuo

$WV\gamma$ AQGC limits

- Interpret results in terms of both dimension-6 and dimension-8 (linear) anomalous $WW\gamma\gamma$ and $WWZ\gamma$ couplings
  - No form factors used

$$
\begin{aligned}
-21 < a_0^W/\Lambda^2 < 20\,\mathrm{TeV}^{-2},\\
-34 < a_C^W/\Lambda^2 < 32\,\mathrm{TeV}^{-2},\\
-25 < f_{T,0}/\Lambda^4 < 24\,\mathrm{TeV}^{-4}\\
-12 < \kappa_0^W/\Lambda^2 < 10\,\mathrm{TeV}^{-2},\\
-18 < \kappa_C^W/\Lambda^2 < 17\,\mathrm{TeV}^{-2}.
\end{aligned}
$$



Limits shown with no form factors

- Limits on $WW\gamma\gamma$ couplings are significantly beyond Tevatron
- First limits on the (CP-conserving) $WWZ\gamma$ couplings κ_c^W, κ_0^W

Summary

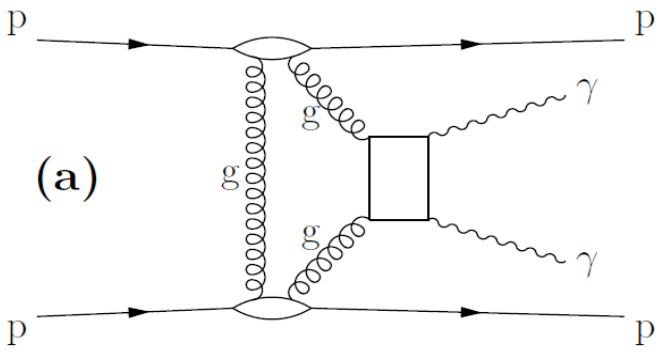
- The investigation of quartic gauge boson couplings at the LHC is underway
- CMS has searched for $\gamma\gamma \to WW$ production in the $e\mu$ final state using 5fb^{-1} collected at 7 TeV
  - For the SM signal region with $p_T(\mu e)$>30GeV: 2 events observed, with 2.2±0.4 signal, 0.84±0.15 background expected
  - Limits on anomalous quartic $\gamma\gamma WW$ couplings are ~20-100x more stringent than previous results obtained at LEP/Tevatron
- CMS has searched for $WW\gamma$ and $WZ\gamma$ production in the lepton + photon + dijets + missing E_T final state using 20fb^{-1} collected at 8 TeV
  - Limits are set on the CP-conserving anomalous quartic $WWZ\gamma$ couplings κ_c^W, κ_0^W for the first time

arXiv:1305.5596, To appear in JHEP ($\gamma\gamma \to WW$)
CMS PAS-SMP-13-009 ($WV\gamma$)

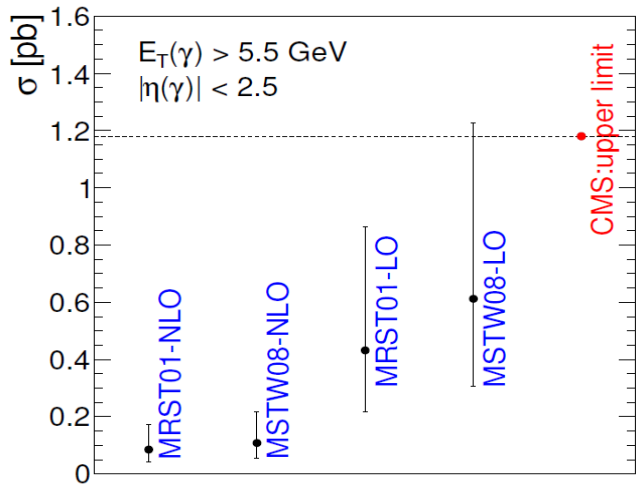
Additional material

Exclusive $\gamma\gamma$

- First search for exclusive diboson production at 7 TeV by CMS
  - Expected to be dominated by strong Central Exclusive Production
  - Based on 36pb^{-1} collected in 2010



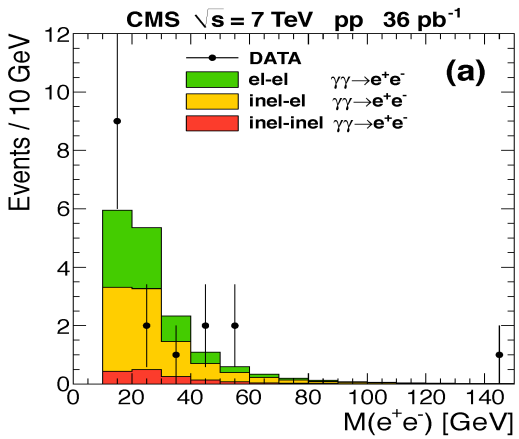
- 0 events observed - limits set on exclusive plus quasi-exclusive $pp \to p(*)\gamma\gamma p(*)$
  - Start to exclude upper end of theory predictions

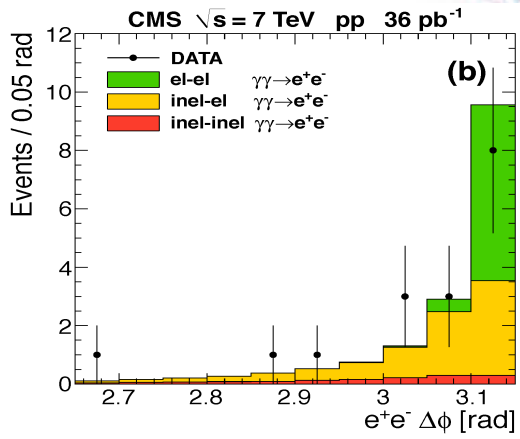


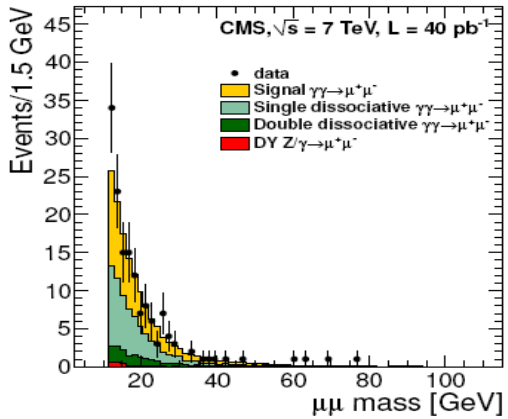
JHEP 1211 (2012) 080

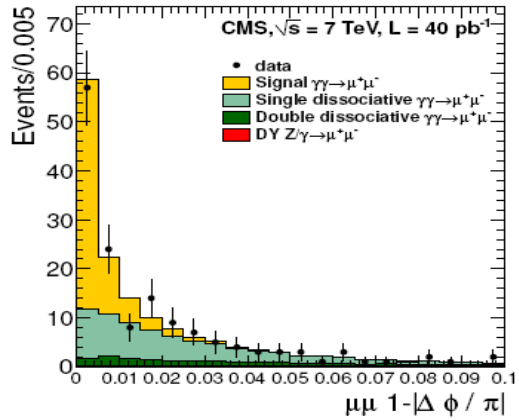
$\gamma\gamma \to ll$

- Standard candle processes used to validate exclusivity selection
- Measured in both $\mu\mu$ and *ee* channels in 2010 data
- Reasonable agreement with LPAIR MC in shapes and normalization



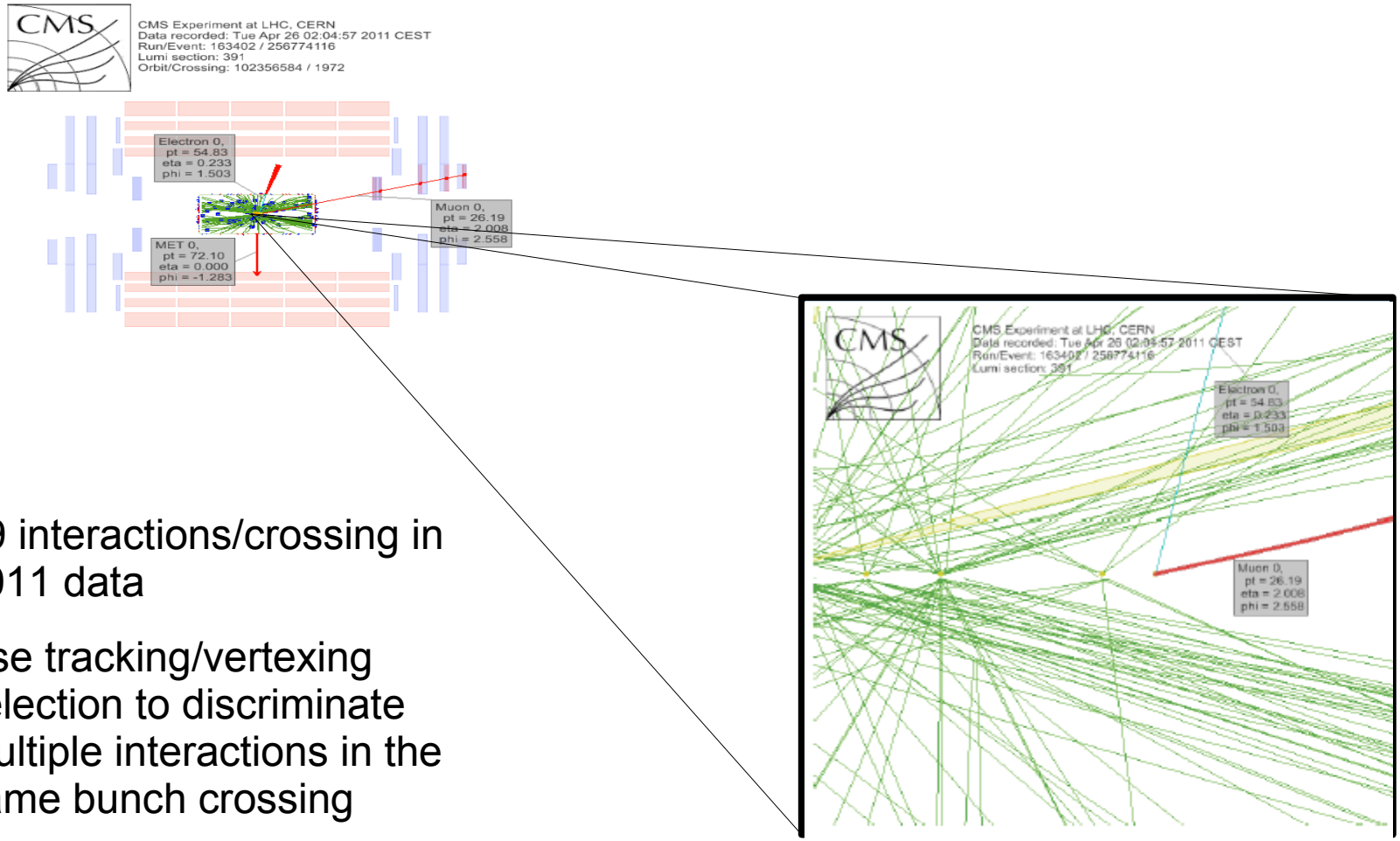






JHEP 1201 (2012) 052
JHEP 1211 (2012) 080

Life with pileup

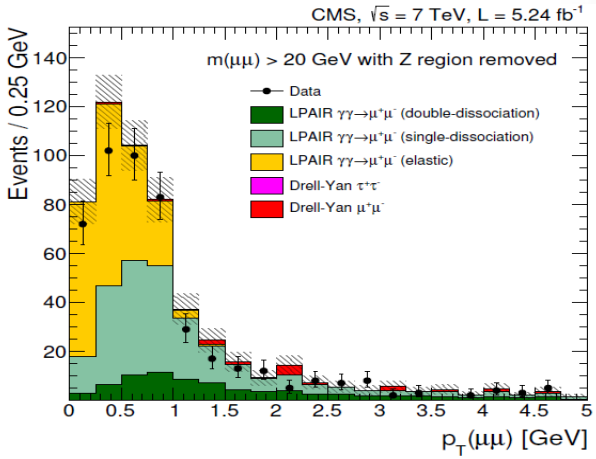


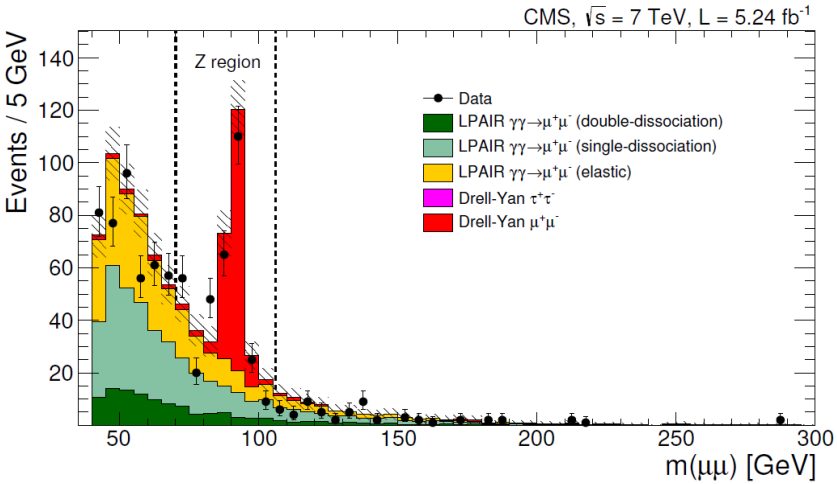
- ~9 interactions/crossing in 2011 data
- Use tracking/vertexing selection to discriminate multiple interactions in the same bunch crossing

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ12010

$\gamma\gamma \to \mu\mu$ control samples (I)

- Elastic-enriched selection with 0 extra tracks
  - Good agreement with predictions for $\gamma\gamma \to \mu\mu$ off the *Z* peak (LPAIR MC)
  - Use this sample to bound systematics from exclusivity, pileup modelling





- On the *Z* peak
  - Yields consistent with expected residual Drell-Yan background