Study of exclusive two-photon production of W^+W^- pairs in pp collisions at 7 TeV, and constraints on anomalous quartic couplings in CMS

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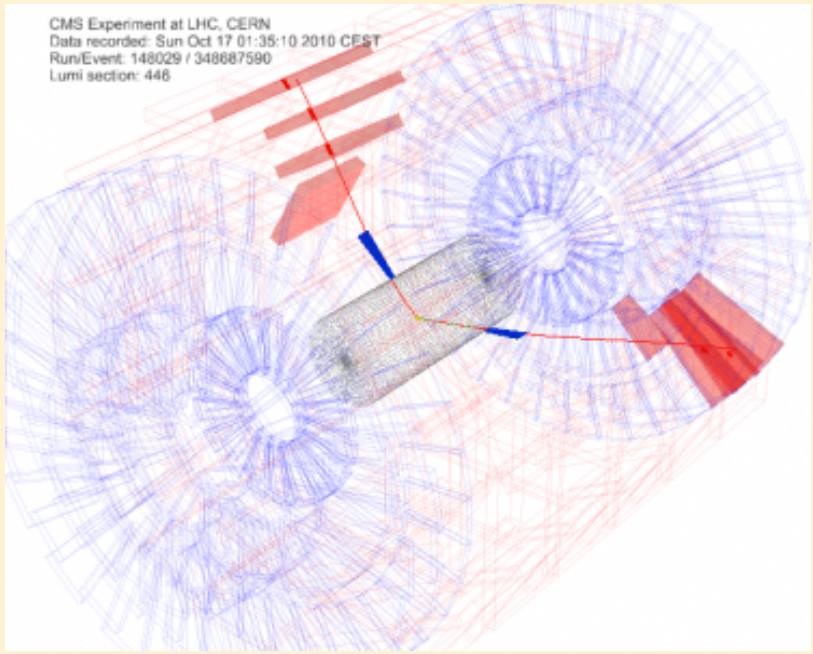
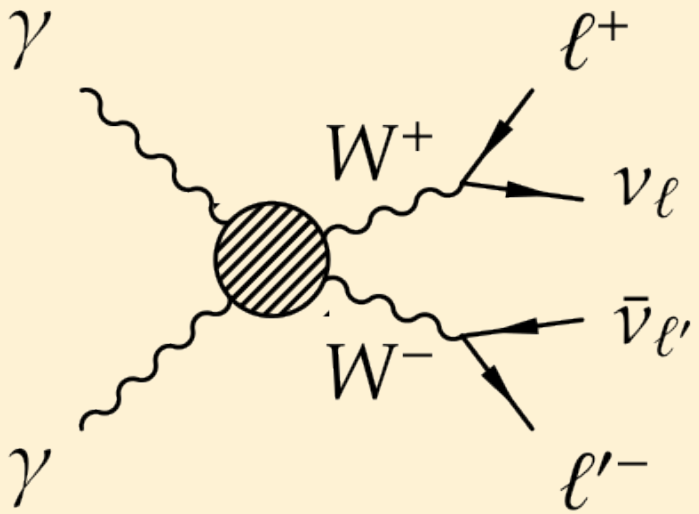
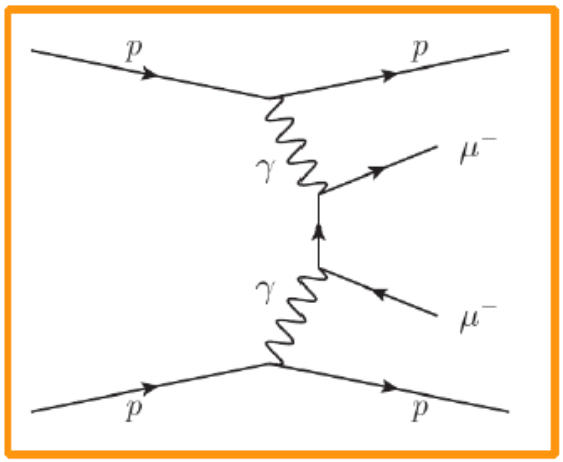




PHOTON 2013, LPNHE Paris

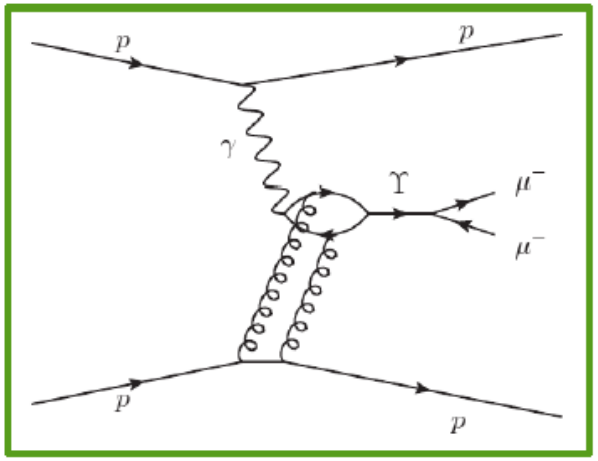
Exclusive production @ LHC

Two-photon production



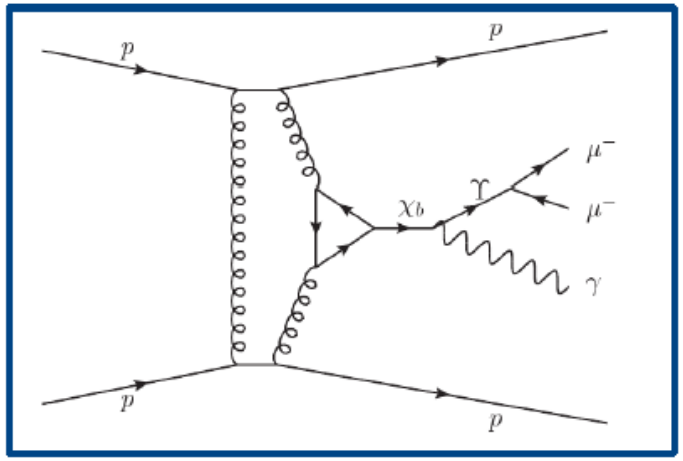
$\mu^+\mu^-$, e^+e^-, $\pi^+\pi^-$
W^+W^-, H^+H^-, $\tilde{l}^+\tilde{l}^-$, ...

Photo-production



ρ, J/Ψ, Υ, Z, ...

Central Exclusive Production

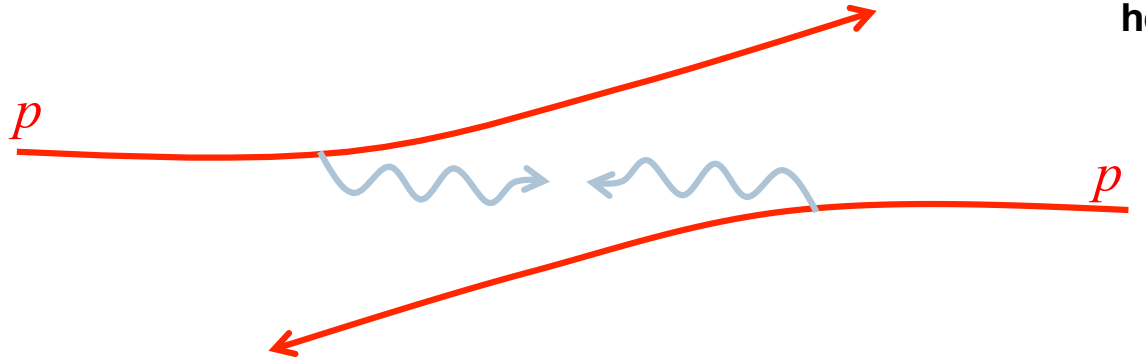


χ_c, χ_b, $\pi^+\pi^-$,dijets, $\gamma\gamma$,
Higgs, ...

→ Present: studies of the SM physics and BSM searches by imposing exclusivity conditions using central detectors of CMS
→ Future: detect also (both) forward scattered protons with the proposed 'High Precision Spectrometer' (HPS)

LHC as a High Energy γγ Collider

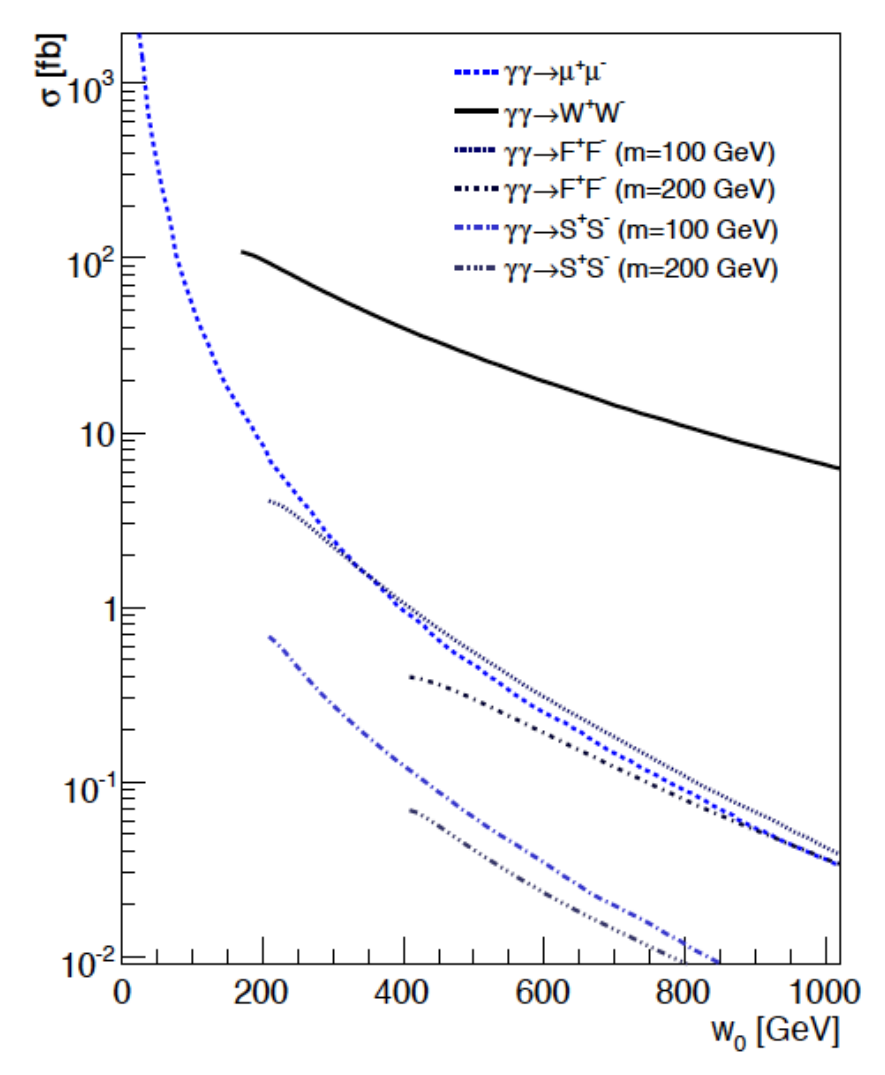
Phys. Rev. **D63** (2001) 071502(R)
hep-ex/0201027



Virtuality Q^2 of colliding photons vary between kinematical minimum = $M_p^2 x^2/(1-x)$ where x is fraction of proton momentum carried by a photon, and $Q^2_{\max} \sim 1/\text{proton radius}^2$

EQUIVALENT PHOTON APPROXIMATION (**EPA**) allows for representing a *pp* process involving the two-photon exchange, as a convolution of two photon fluxes and the **photon-photon** cross section at the γγ CM energy W (note that is just like use of pdf for partons…)

Two-photon pair production @ LHC



Production cross-sections determined completely by the particle mass and spin (& charge)

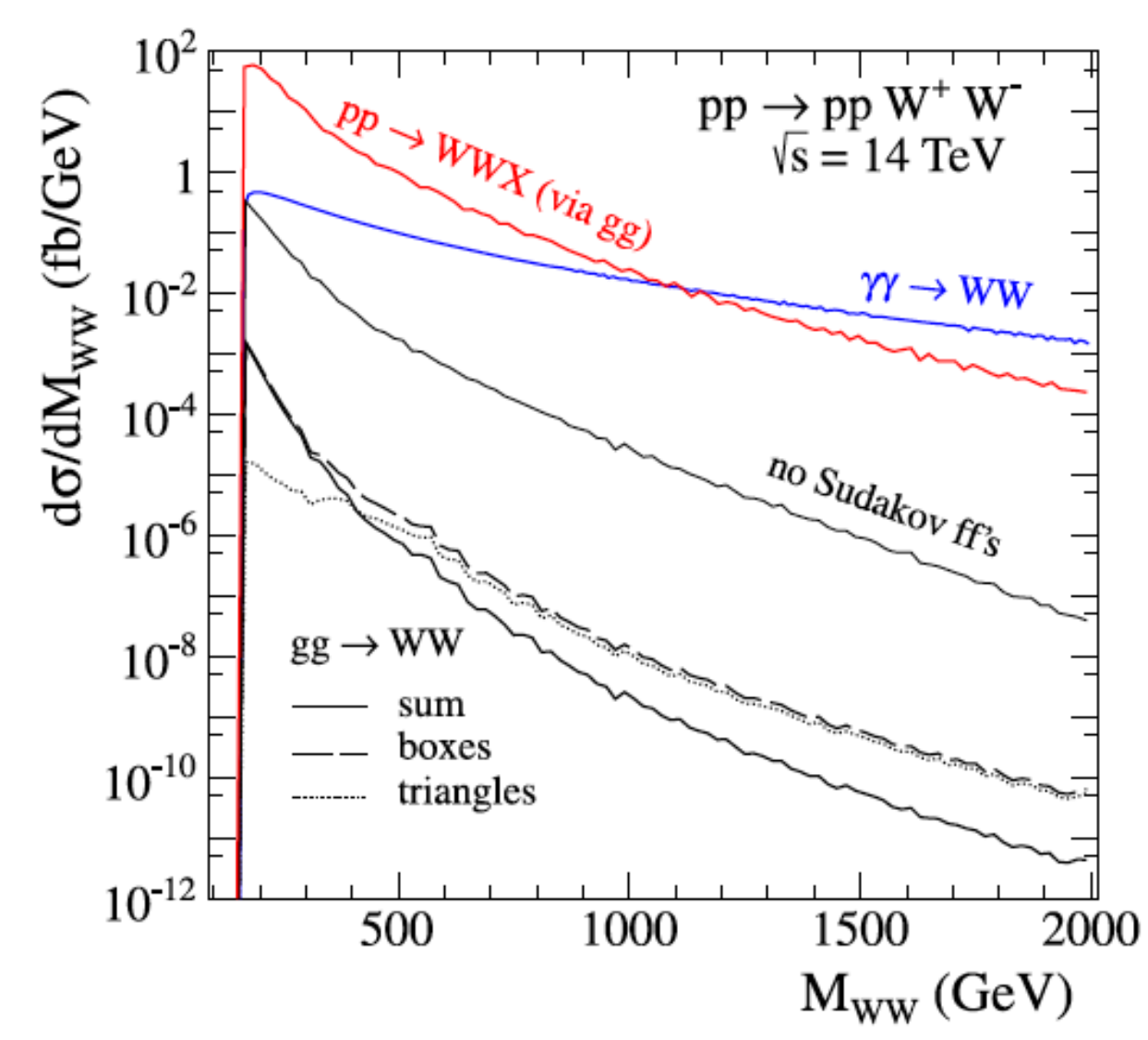
At low invariant γγ masses the μμ pairs dominate but at high energy WW pairs rule !

(Results for 14 TeV)

W_0 is a minimal γγ CM energy

arXiv:0908.2020v1 [hep-ph]

WW pair production @ LHC



At very high energy $\gamma\gamma$ wins over 'inclusive' production (even when production via qq is included) !

Nucl. Phys. B ***867*** *(2013) 61*

Proof-of-priciple

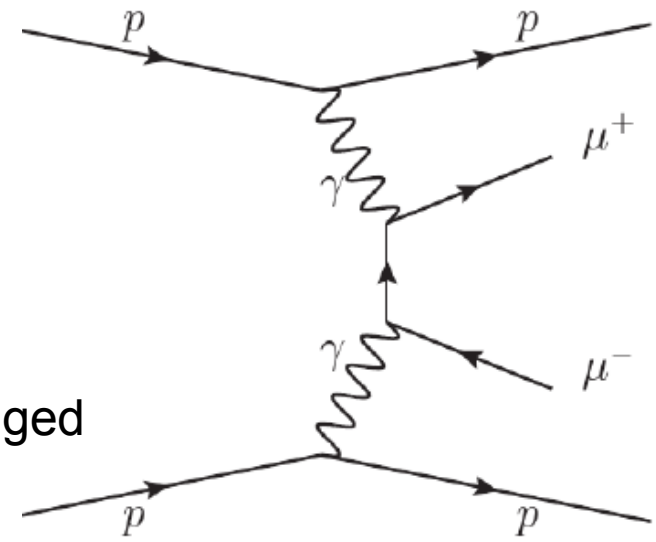
and

Calibration candle

CMS Collab. *"Exclusive photon-photon production of muon pairs in proton-proton collisions at $\sqrt{s}$ = 7 TeV"*, **JHEP 1201** (2012) 052

Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$

The first measurement focus on the dimuon channel – standard candle:

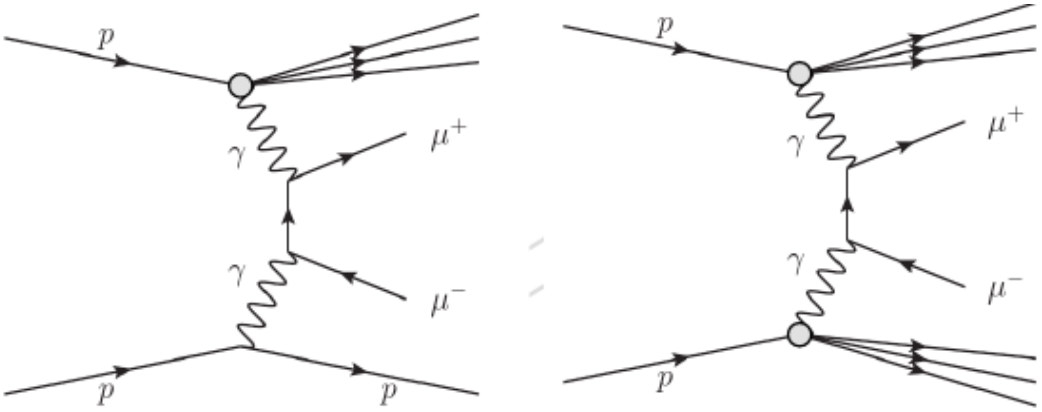


* ***Pure QED process:***
  - No PDF to account for
  - Small theoretical uncertainties

* ***Striking kinematic distributions:***
  - due to very small virtuality of the exchanged photons

* measured in previous experiments to be in agreement with the ME ***LPAIR generator***

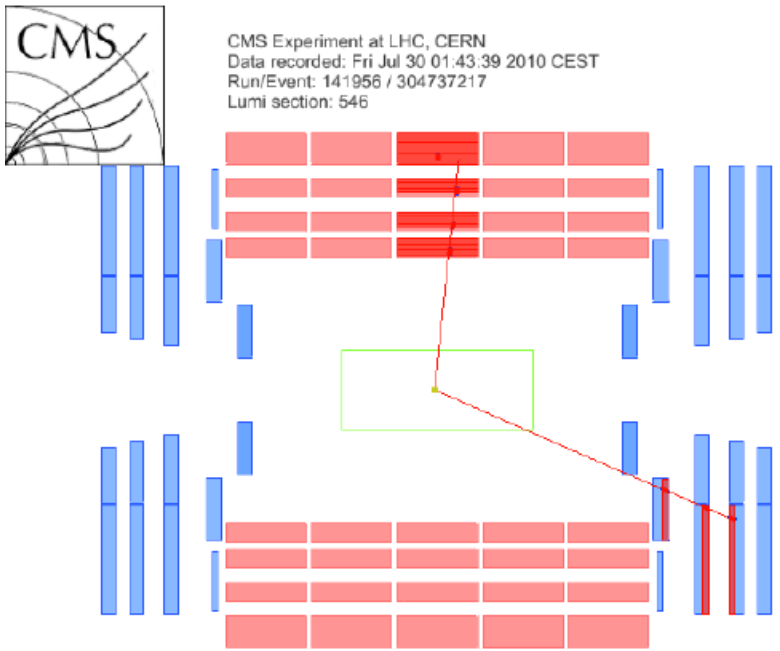
• Largest background arises from *semi-exclusive* **two-photon** production due to single and double proton dissociative (or inelastic) photon exchange:

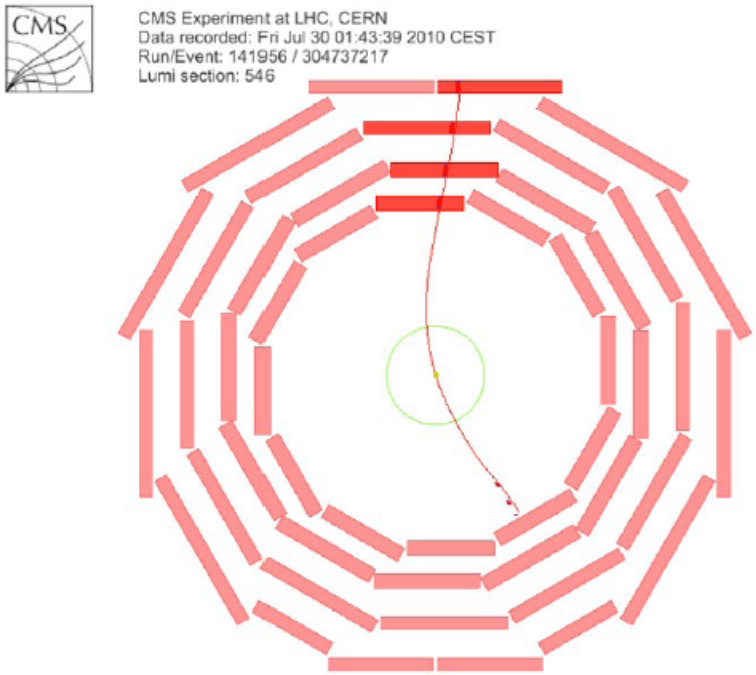


Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$

CMS-DP-2010-035

Candidates for $\gamma\gamma \rightarrow \mu\mu$ process:

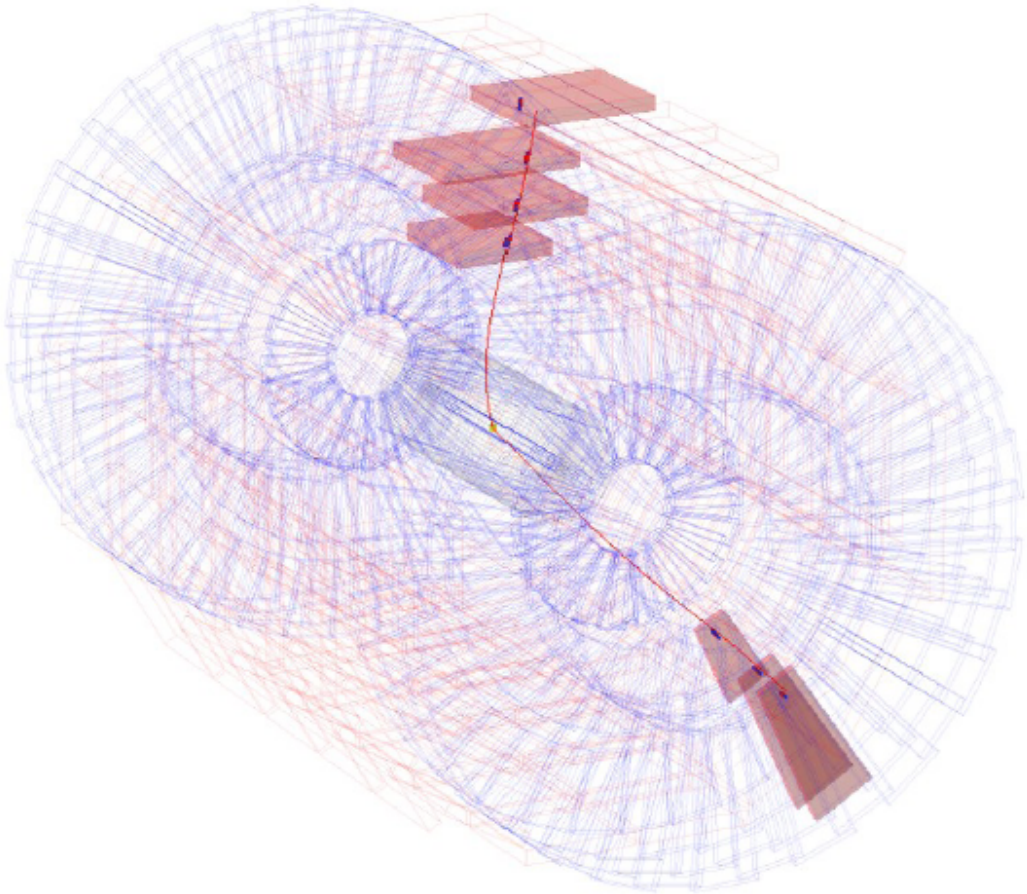




$$
\begin{aligned}
m &= 20.51 \pm 0.2 \text{ GeV} \\
\frac{\Delta\phi}{\pi} &= 0.98 \\
\Delta p_T &= 0.48 \text{ GeV}
\end{aligned}
$$

$$
\begin{aligned}
\text{track: } p_T &> 0 \text{ GeV} \\
\text{HCAL: } E &> 4 \text{ GeV} \\
\text{ECAL: } E &> 2.5 \text{ GeV}
\end{aligned}
$$

Exclusivity conditions



In (very) low luminosity era:
2 muons and "nothing else"
in the tracker and calorimeters

In 2010, each event of interest can be accompanied by extra "PileUp" events
within the same bunch crossing:
~ 2-3 pileup interactions

In 2011, roughly 7-10 PU per crossing

Restricting the analysis to single interactions only would have reduced the data sample to <1% of the total in 2011 → **impose exclusivity using tracking only**

Exclusive $\gamma\gamma \rightarrow W^+W^-$ production at $\sqrt{s} = 7$ TeV

Available on the CERN CDS information server

CMS PAS FSQ-12-010

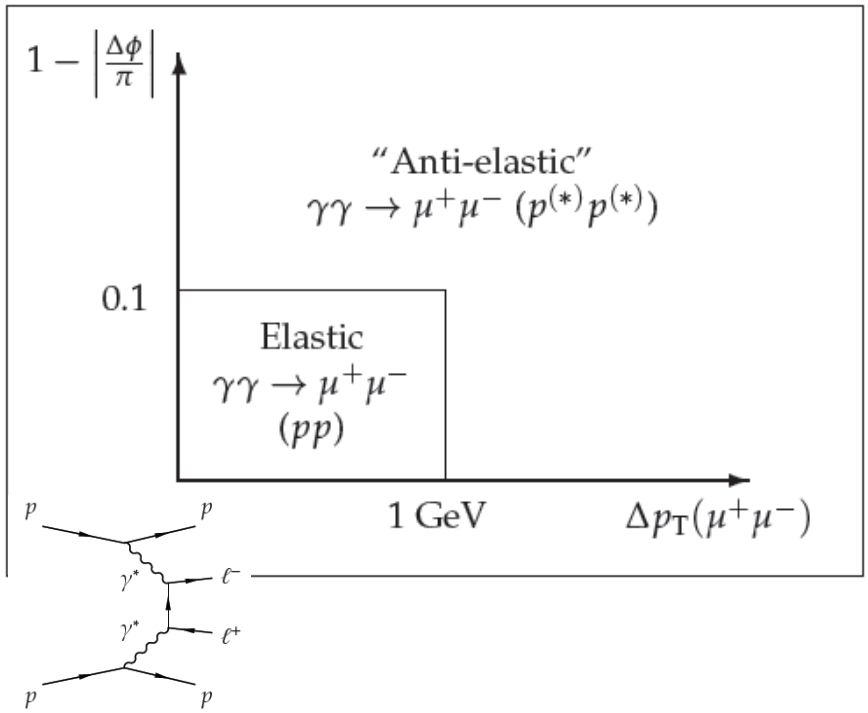
CMS Physics Analysis Summary

Contact: cms-pag-conveners-fsq@cern.ch

2013/02/20

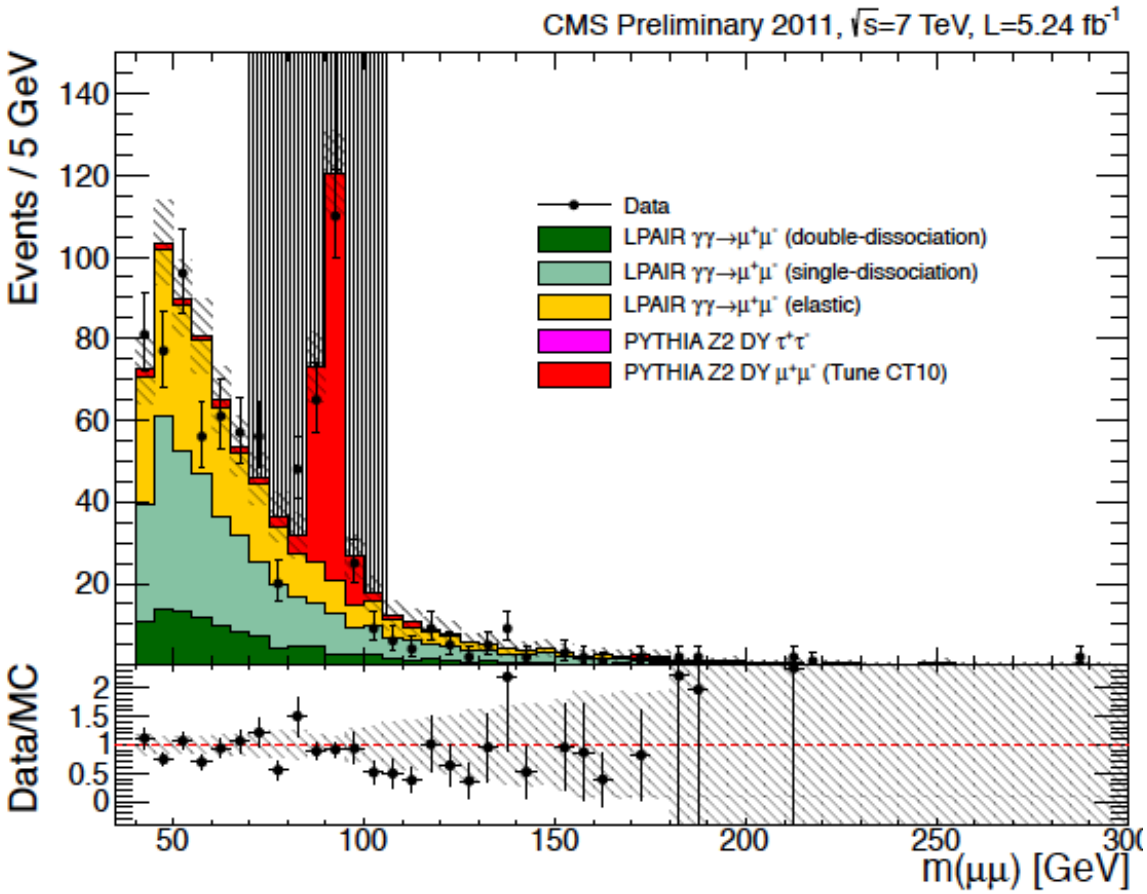
Study of exclusive two-photon production of W^+W^- pairs in pp collisions at 7 TeV, and constraints on anomalous quartic couplings

$\mu\mu$ calibration candle



- Use Δp_T and $|1-\Delta\phi/\pi|$ to select regions enriched in elastic or inelastic events
  - Same cuts as used for 2010 $\gamma\gamma \to \mu\mu$ cross-section paper
- Also separate Z peak region (76-105GeV) to check modeling of Drell-Yan
  - $\gamma\gamma \to Z$ is suppressed at tree-level , exclusive Z is expected to be <1fb including branching fraction

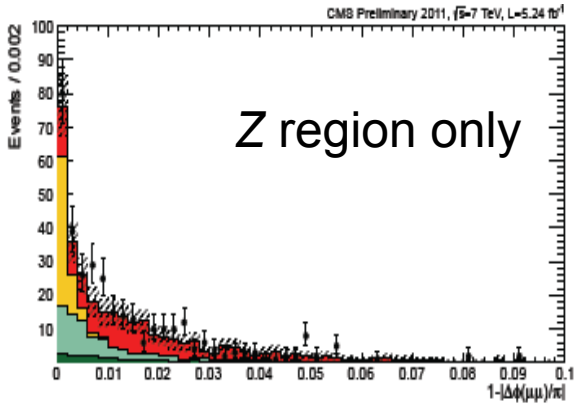
$\mu\mu$ elastic region

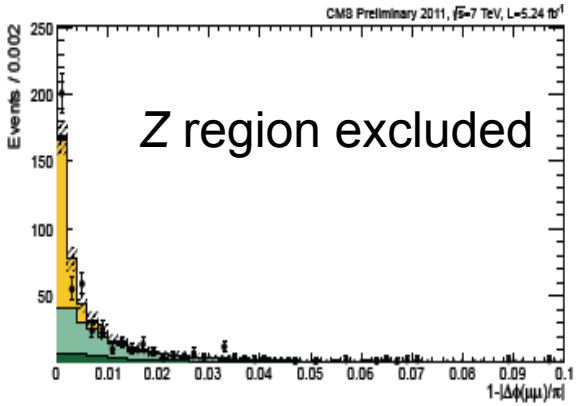


- Total event yields in elastic $\mu\mu$ region
  - Data: 820
  - MC: 906
  - Ratio: 0.91±0.04

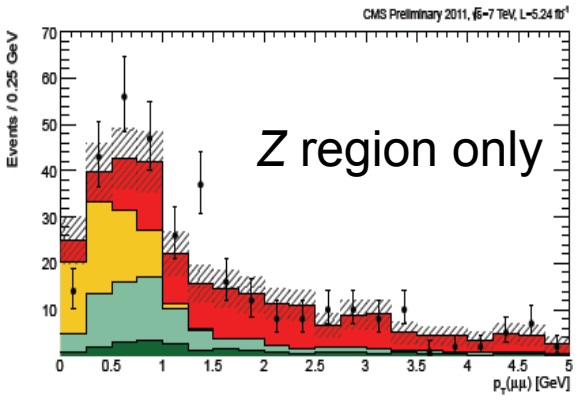
$\mu\mu$ control plots – elastic region

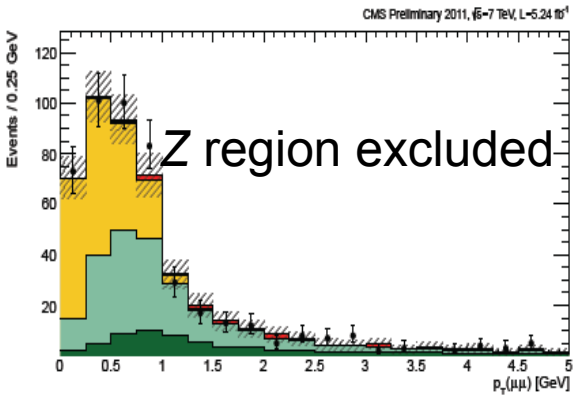
- Compare acoplanarity, $p_T(\mu\mu)$, $\Delta p_T(\mu\mu)$ distributions for events with 0 extra tracks





- Generally good description, both in and out of the Z region

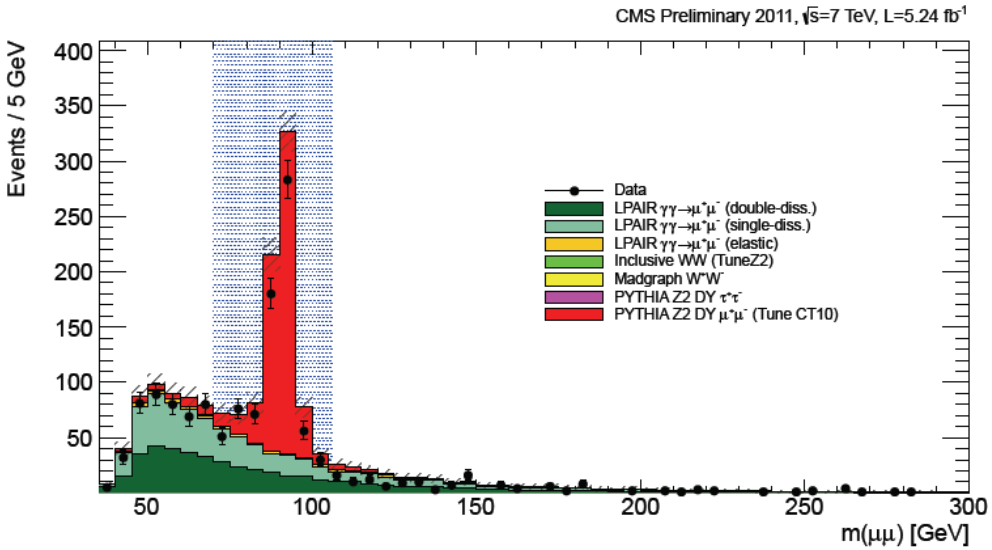




  - Shaded bands indicate MC statistical errors

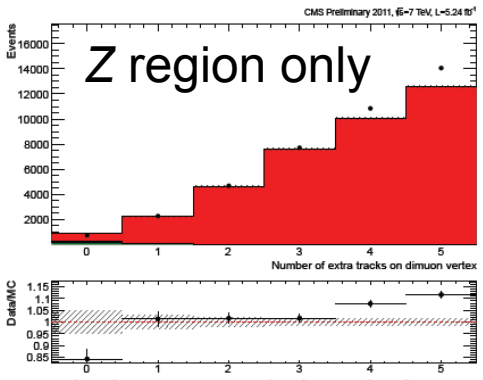
$\mu\mu$ control plots – anti-elastic region

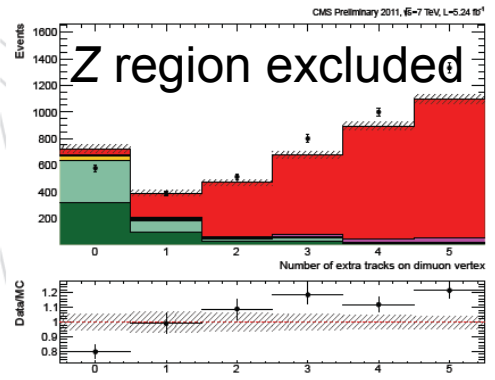
- From MC, expect inelastic yield to be several x elastic at high mass
  - But at high p_T/mass inelastics may be suppressed by – "rescattering" (production of additional soft particles rejected by the extra tracks veto) ⇒ extract the total/elastic ratio from the $\mu\mu$ data



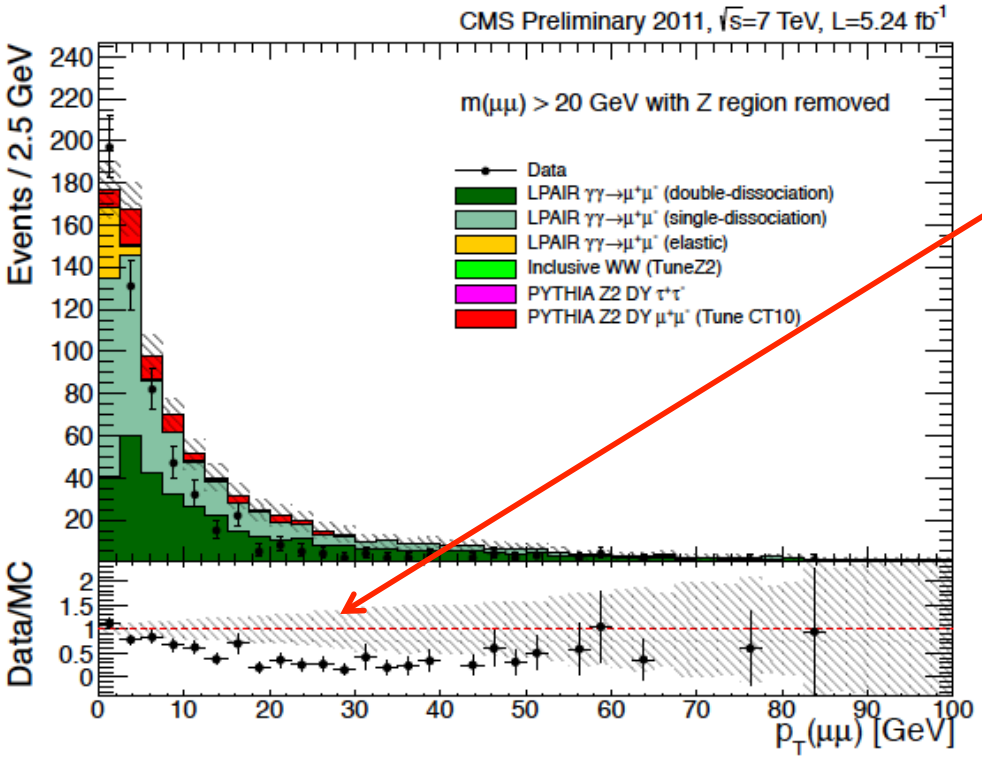
- Invert the acoplanarity and Δp_T cuts to select a region enriched in inelastic events

- Overall find a deficit of ~28% compared to MC prediction with no rescattering





$\mu\mu$ – anti-elastic region



- Further investigation – deficit mainly at high-mass/high-p_T of the pair
  - Expected to be the region most affected by *rescattering* corrections
- Derive a "data-driven" scale factor for total (in data) $\gamma\gamma\to\mu\mu$ /elastic $\gamma\gamma\to\mu\mu$ in MC with m($\mu\mu$)>160 GeV:

$$F = \left.\frac{N_{\mu\mu\ data} - N_{DY}}{N_{elastic}}\right|_{m(\mu^+\mu^-)>160\ \mathrm{GeV}}$$

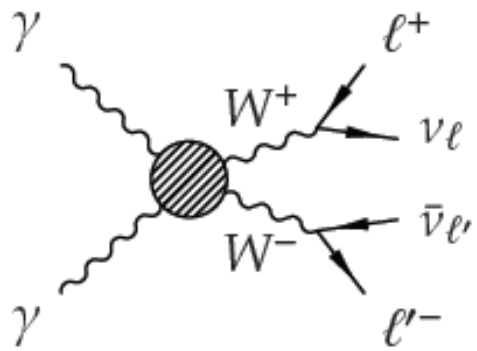
- Apply this to renormalize the $\gamma\gamma\to WW$ and $\gamma\gamma\to\tau\tau$ samples in the μe analysis

$$F = 3.23 \pm 0.50\ (\mathrm{stat.}) \pm 0.36\ (\mathrm{syst.})$$

$\gamma\gamma \rightarrow WW \rightarrow \mu e \nu\nu$

Notation

- Fully exclusive (or "elastic"): events in which both protons stay intact
  - Theoretically clean QED-like production
- Quasi-exclusive (or "inelastic" or "proton dissociation"): events in which one or both protons fragment into an undetected low-mass system $p^{(*)}$
  - Larger uncertainties, possible rescattering corrections
- Cannot separate the two contributions in a counting experiment, therefore signal is defined to include both:



$$pp \to p^{(*)} W^+ W^- p^{(*)}$$

AQGCs

- In order to consider the anomalous couplings in the $\gamma\gamma \to W^+W^-$, we introduce a model to the CalcHEP event generator with the following effective Lagrangians
- Local $U(1)_{em}$ and global $SU(2)_c$ invariance imposed; these are genuine quartic couplings independent of the gauge ones (à la LEP):

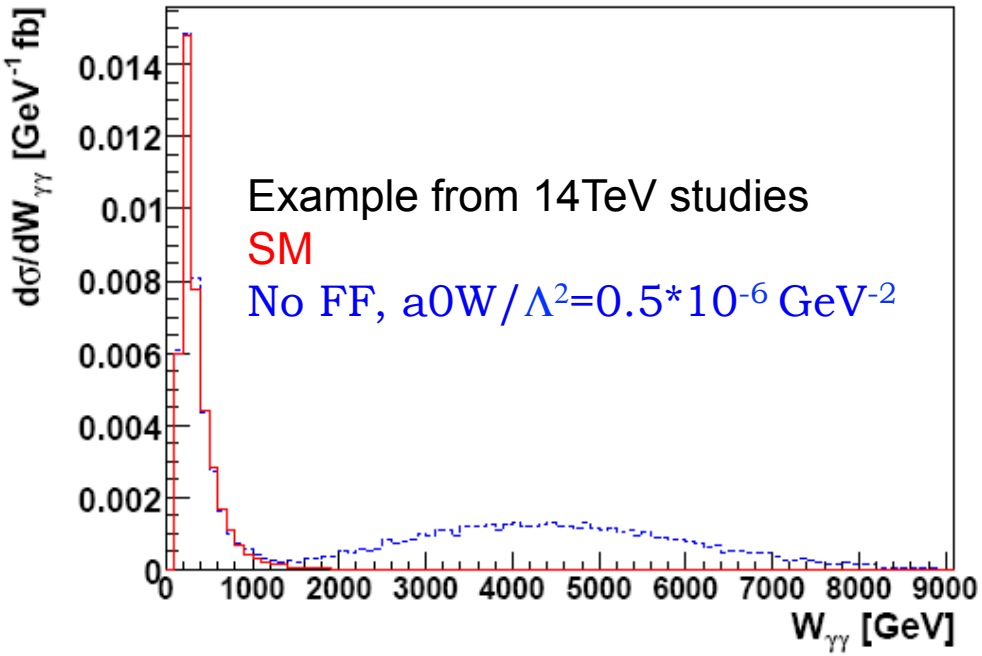
$$L_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_{\alpha} - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^{\alpha}Z_{\alpha}$$

$$L_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_{\beta} - W^{-\alpha}W^+_{\beta}) - \frac{e^2}{16\cos^2\Theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^{\alpha}Z_{\beta}$$

- Where Λ is the scale for new physics, which is set in this analysis to 500 GeV

Form Factors

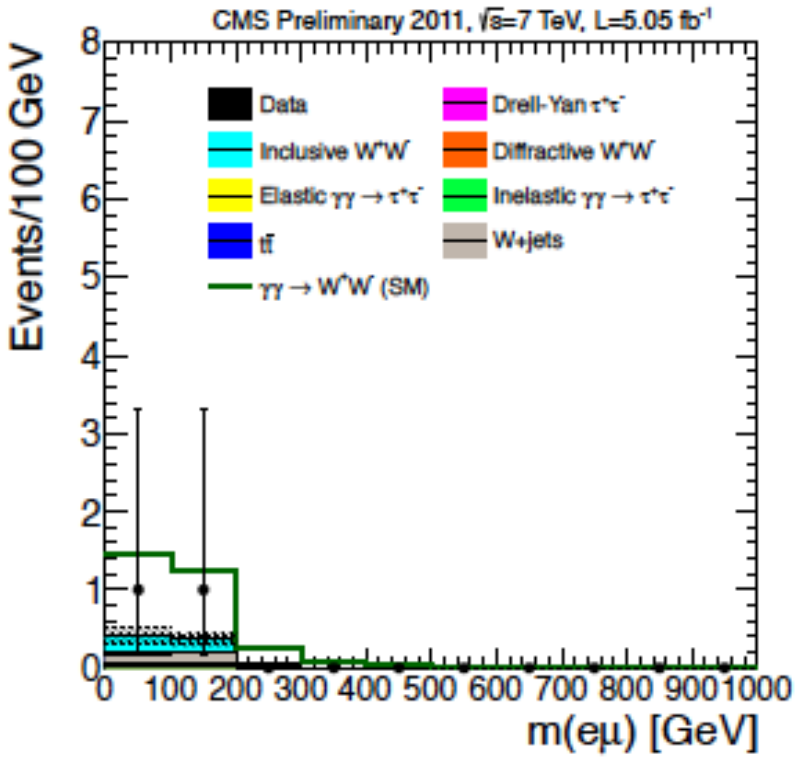
- AQGC terms make the $\gamma\gamma \rightarrow W^+W^-$ cross section rise quadratically with energy – unitarity is violated for high energy $\gamma\gamma$ interactions
- Due to this behavior, form factors are introduced in order to tame this rising of the cross section, and guarantee unitarity. In this analysis we introduce the form factors as

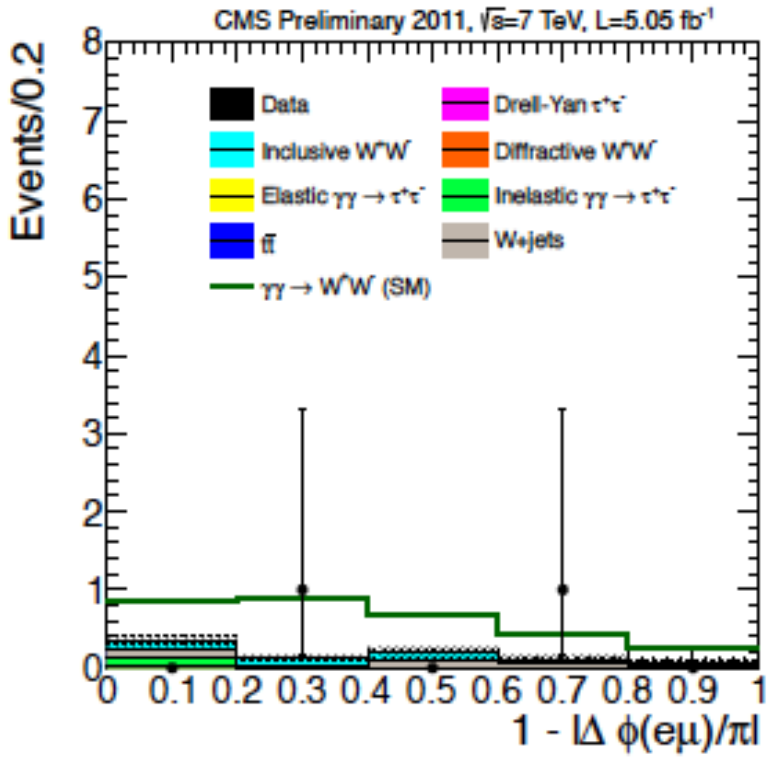


$$G_{\gamma\gamma WW} = \left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda^2}\right)^{-p}$$

arXiv:0807.1121

SM signal region (0 extra tracks, $p_T(e\mu)$>30 GeV)

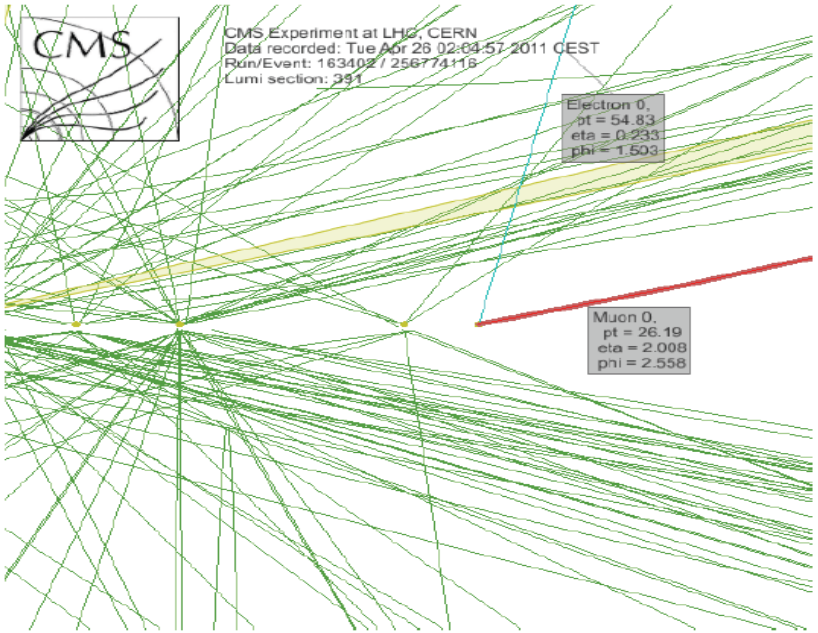


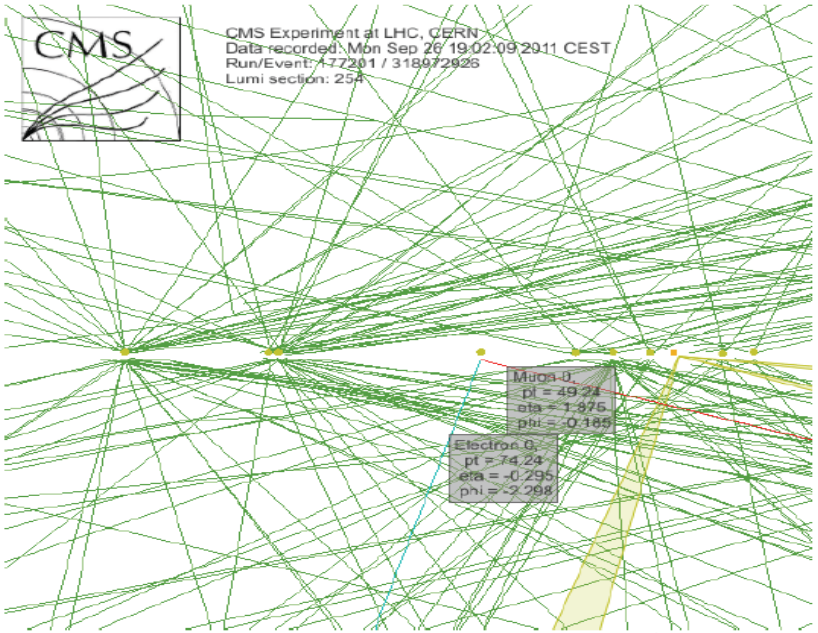


- Expected bkg: 0.8
- Expected signal: 2.2±0.5
- Observed in data: 2 events

SM Signal region: First EVER $\gamma\gamma \rightarrow WW$ events

Reminder: NO extra tracks are allowed on a di-lepton vertex



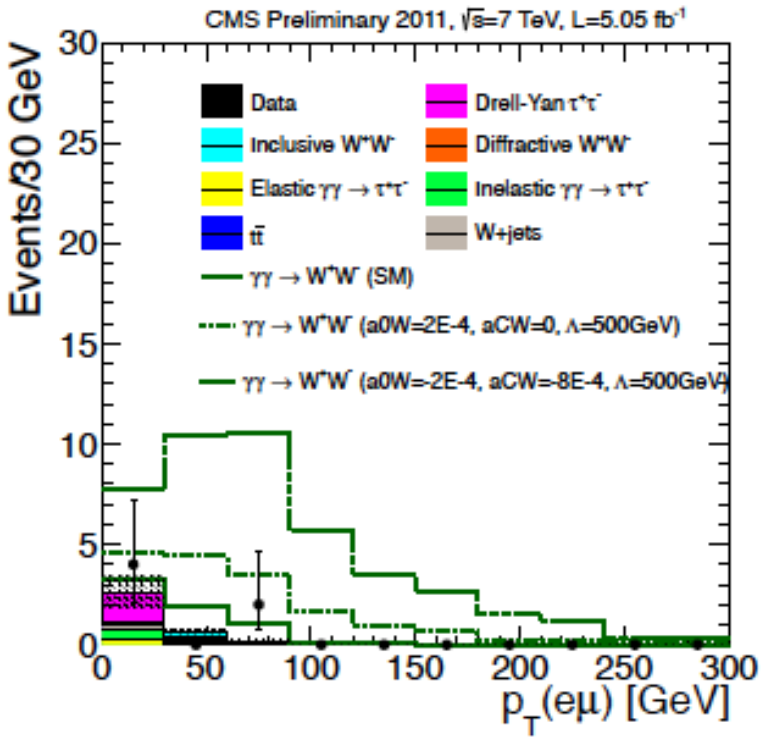


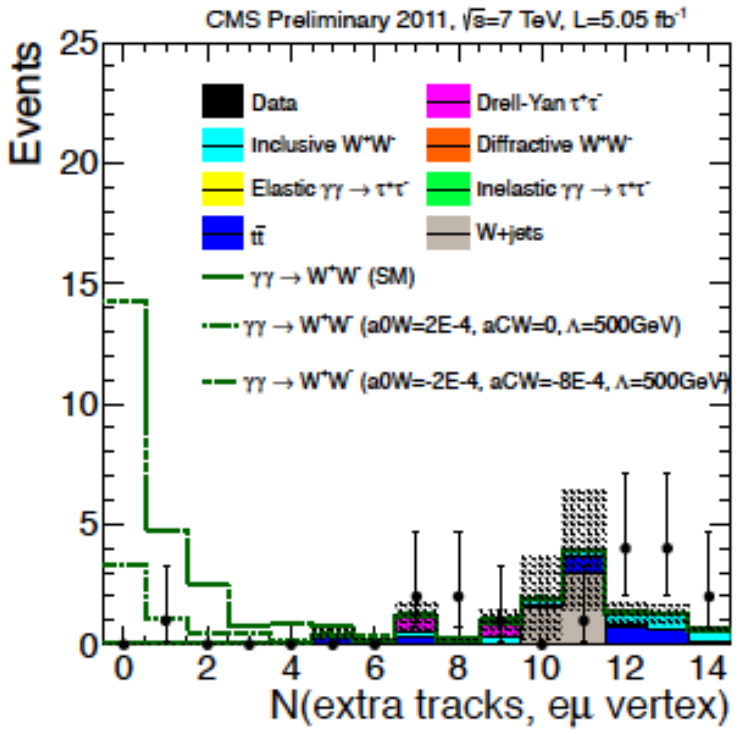
Variable	Event 1	Event 2
Run	163402	177201
LumiSection	391	254
Event number	256774116	318972926
$m(\mu^{\pm}e^{\mp})$ [GeV]	85.5	190.3
$1 - \lvert\Delta\phi(\mu^{\pm}e^{\mp})/\pi\rvert$	0.66	0.33
$p_T(\mu^{\pm})$ [GeV]	26.2	49.2
$E_T(e^{\pm})$ [GeV]	54.8	74.2
$\eta(\mu^{\pm})$	2.01	1.88
$\eta(e^{\pm})$	0.23	-0.30

- Event displays and single/double lepton information for the two selected events

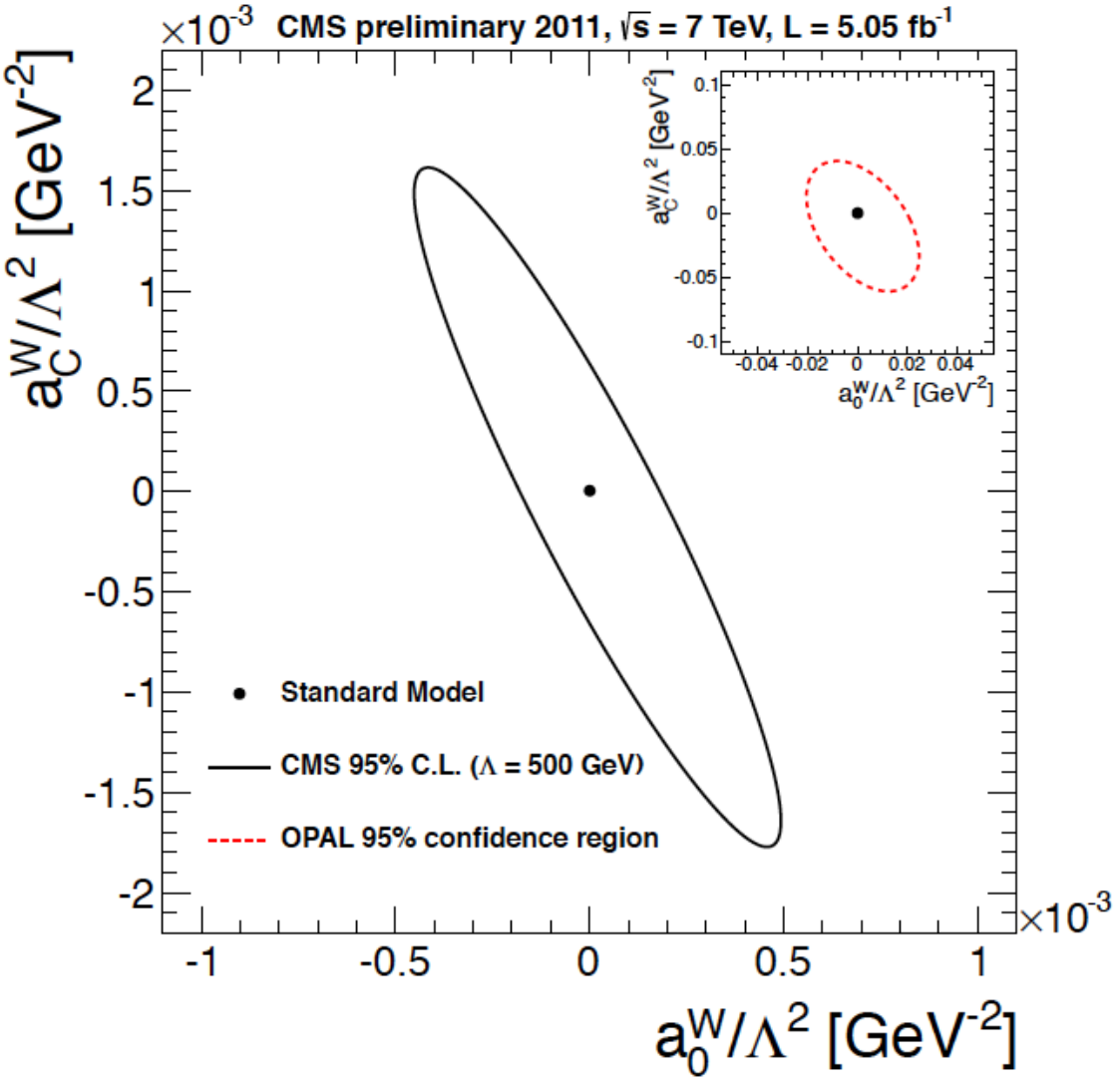
Search for anomalous signal…

The $p_T(\mu^{\pm}e^{\mp})$ distribution for events with zero extra tracks is shown in Figure 12. In the AQGC search region $p_T(\mu^{\pm}e^{\mp}) > 100$ GeV, zero events are observed in data, consistent with the Standard Model expectation of 0.14, dominated by $pp \to p^{(*)}W^+W^-p^{(*)}$.





Exclusion limits…



Summary & what next ?

Using 2011 data at 7 TeV CMS made first ever evidence of $\gamma\gamma \rightarrow WW$!
$\rightarrow$ Limits on aQGCs improved by two orders of magnitude with respect to LEP2 (and Tevatron)

Repeat it in 2015 @ 13 TeV – sensitivity to aQGCs should be 10 times better wrt to present results

In 2016 hopefully High Precision Spectrometer (HPS) starts running:

- **Yet more sensitive studies of the $\gamma\gamma$WW couplings will be possible, as well for $\gamma\gamma$ZZ; even in case U(1)xSU(2) gauge invariant models** (as discussed by *O. Nachtmann et al.*) **!**

- **Search of new heavy charged particles:**
  - **Stable, 'heavy muons' (completely model independent, a la LEP) up to about 400 GeV (LEP limits are at 100 GeV)**
  - **Unstable, non-strongly interacting particles (very model dependent, like sleptons or charginos)**

We must make the best of out of LHC !

Exclusive WW

Abstract

A search for exclusive or quasi-exclusive W^+W^- production by two-photon exchange, $pp \to p^{(*)}W^+W^-p^{(*)}$, at $\sqrt{s} = 7$ TeV is reported using data collected by the CMS detector corresponding to an integrated luminosity of 5.05 fb^{-1}. Events are selected by requiring a $\mu^\pm e^\mp$ vertex with no associated charged tracks, and dilepton transverse momentum $p_T(\mu^\pm e^\mp) > 30$ GeV. Two events passing all selection requirements are observed in the data, compared to a Standard Model expectation of 2.2 ± 0.5 signal events with 0.84 ± 0.13 background. The tail of the dilepton transverse momentum distribution, with $p_T(\mu^\pm e^\mp) > 100$ GeV, is studied for deviations from the Standard Model. No events are observed in this region, and the resulting upper limits are compared to predictions involving anomalous quartic gauge couplings.

Limits on anomalous quartic couplings

Table 6: Signal efficiency of all trigger, reconstruction, and analysis selections, relative to the acceptance [$p_T(\mu, e) > 20$ GeV, $|\eta(\mu, e)| < 2.4$, $p_T(\mu^{\pm}e^{\mp}) > 100$ GeV] for the SM and for four representative values of the anomalous couplings a_0^W/Λ^2 and a_C^W/Λ^2, with and without form factors.

a_0^W/Λ^2	[GeV^{-2}]	0	2×10^{-4}	-2×10^{-4}	7.5×10^{-6}	0
a_C^W/Λ^2	[GeV^{-2}]	0	0	-8×10^{-4}	0	2.5×10^{-5}
Λ	[GeV]	-	500	500	No form factor	No form factor
Efficiency		$30.5 \pm 5.0\%$	$29.8 \pm 2.1\%$	$31.3 \pm 1.8\%$	$36.0 \pm 1.7\%$	$36.3 \pm 1.8\%$