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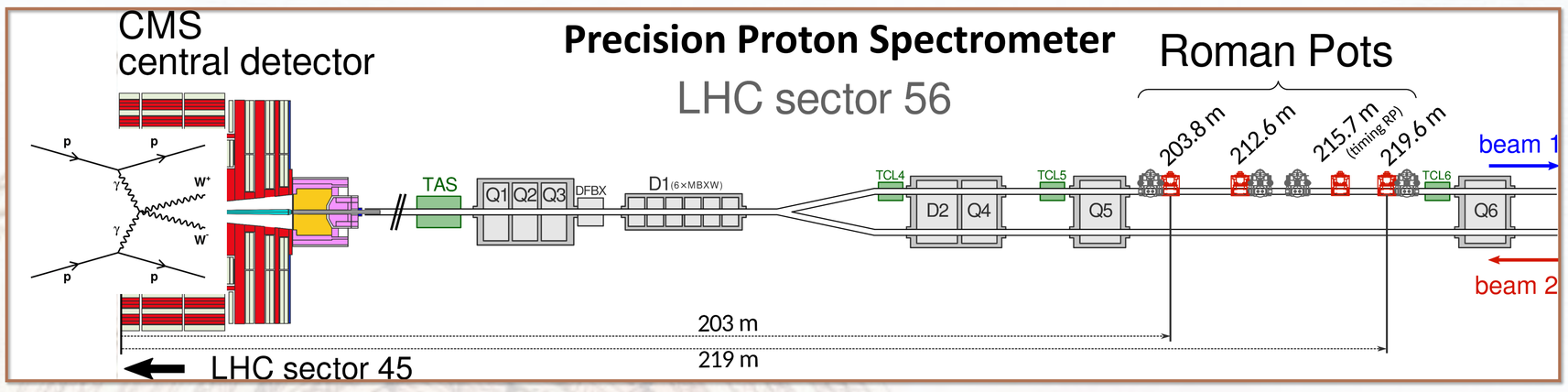
Search for high-mass exclusive γγ → WW and γγ → ZZ production in proton-proton collisions at √s = 13 TeV

INTRODUCTION

Final state: two bosons and scattered protons, which are reconstructed using PPS.
Fully hadronic decay modes of the W and Z bosons are studied: gauge bosons are produced with a large boost, decay products of each of the bosons are merged into a single large-area jet.
Within the **SM**, **quartic couplings involving two-photon production of charged ($W^{\pm}$) gauge bosons are allowed at tree level**. **The $\gamma\gamma \to ZZ$ process is not allowed at tree level** and only possible at higher order.
SM cross sections at $\sqrt{s} = 13$ TeV:

- $\gamma\gamma \to WW$: ~ 50 fb
- $\gamma\gamma \to ZZ$: ~ 0.05 fb

SM production concentrated at low values of the VV invariant mass, m(VV). Any significant signal over the prediction, particularly in the high m(VV) tails where the expected SM cross section is small, could indicate BSM physics.



The decay products of the boson pair, the so-called **central system**, are **detected by the CMS central detectors**, while the **protons** are **measured with the Precision Proton Spectrometer (PPS)**
The **Precision Proton Spectrometer** is a system of **near-beam tracking** and timing **detectors**, **located in Roman pots (RPs)** at about **200m from the CMS interaction point** [1]. The Roman Pots are movable near-beam devices that allow the detectors to be brought very close (within a few mm) to the beam without affecting the vacuum, beam stability, or other aspects of the accelerator operation. The PPS makes it possible to measure the 4-momentum of the scattered protons, along with their time-of-flight from the IP. The proton momenta are measured by two tracking stations on each arm of the spectrometer.

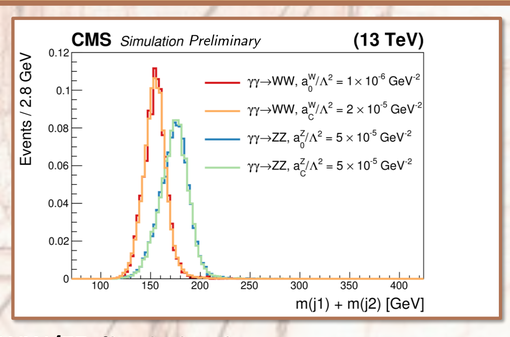
DATA & SIMULATION

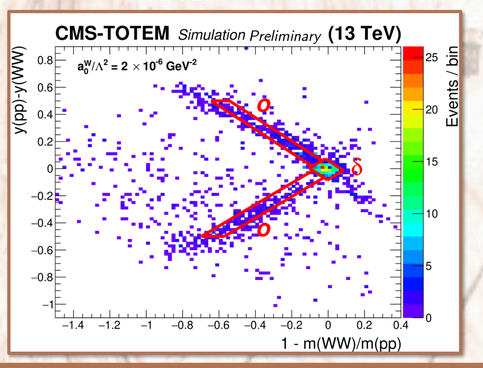
The analysis uses **data collected at $\sqrt{s} = 13$ TeV between 2016-2018**, amounting to a total integrated luminosity $L_{INT} = 100.0\ \mathrm{fb}^{-1}$.
BSM signal samples: simulated at LO with the Forward Physics Monte-Carlo (**FPMC**) generator [2] for both the $\gamma\gamma \to WW$ and $\gamma\gamma \to ZZ$ processes.
Backgrounds: main contribution from QCD multijet production (PYTHIA), **sub-leading contributions** from **W/Z+jets** (MADGRAPH) and $t\bar{t}$ (POWHEG). Protons, in background events, originate from pileup interactions (estimated from data, not simulated).
Particle interaction and propagation with the central CMS detectors modelled with GEANT4. Forward proton propagation simulated with the so-called 'direct' simulation [3].

SELECTION

Selection on **central variables**:

- ≥ 2 V-tagged AK8 jets ($\tau_{21}^{DDT} < 0.75$)
- $|\eta(j_1, j_2)| < 2.5$
- $p_T(j_1, j_2) > 200$ GeV
- $|\eta(j_1) - \eta(j_2)| < 1.3$
- $p_T(j_1)/p_T(j_2) < 1.3$
- $a = |1 - \Delta\phi(j_1 j_2)/\pi| < 0.01$
- 1126 GeV $< m(j_1 j_2) <$ 2500 GeV
- ≥ 1 proton per side of PPS
- $m^{pruned}(j_1, j_2)$ between 60 and 107 GeV





WW/ZZ discrimination:

- WW if $m(j_1) + m(j_2) < 166.6$ GeV

Proton matching: two signal regions defined
δ: two protons from signal
o: one proton mistakenly chosen from pileup

$$\xi = \frac{p_{nom} - p}{p_{nom}}$$

$$m(pp) = \sqrt{s\xi_1\xi_2}, y(pp) = \frac{1}{2}\ln\left(\frac{\xi_1}{\xi_2}\right)$$

BACKGROUND ESTIMATION

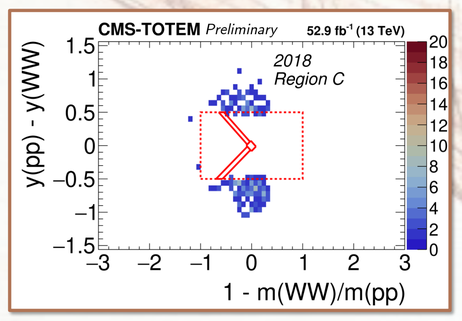
Data-driven background estimation: protons from pileup interactions are not well modelled by MC, using data is a necessity.

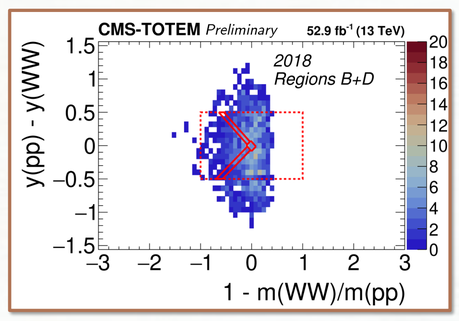
'ABCD' method:

- **Region A:** signal region & acoplanarity (a) cut
- **Region B:** signal region & inverted a cut
- **Region C:** unblinded region & a cut
- **Region D:** unblinded region & inverted a cut

$$N_A = \frac{N_B \cdot N_C}{N_D}$$

Consistent results when using a different sideband (e.g. pruned mass) or an event mixing approach. Precision limited by the low amount of events in region B.

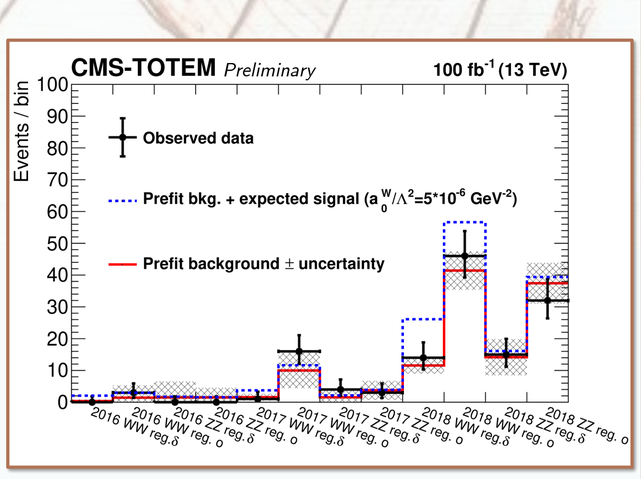


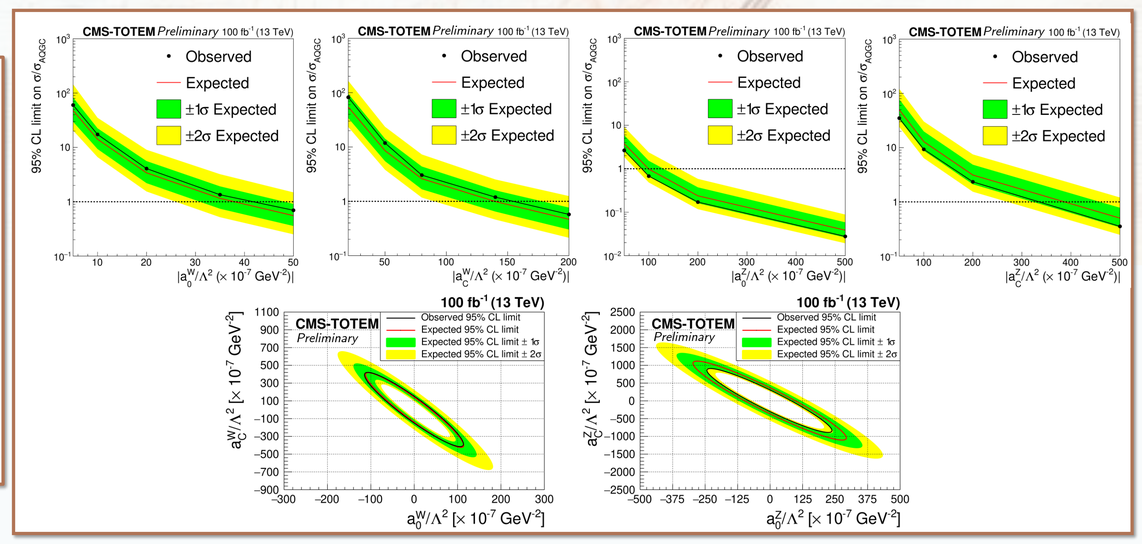


RESULTS

No excess with respect to the SM-only expectation found. **Upper limits on dimension-6 AQGC parameters** are set, both under the assumption of all other operators being zero and in a 2D plane. Limits are presented **with and without unitarization via clipping** at 1.4 TeV.
Results are also **converted to dimension-8 operators**, either following [4] or assuming all couplings to be zero but one.
Fiducial cross section limits are also derived in the region with $0.04 < \xi < 0.20, m(VV) > 1$ TeV:

$$\sigma(\mathrm{pp} \to \mathrm{pWWp}) < 67(53^{+34}_{-19})\ \mathrm{fb} \qquad \sigma(\mathrm{pp} \to \mathrm{pZZp}) < 43(62^{+33}_{-20})\ \mathrm{fb}$$





Dimension-6

Coupling	Observed (expected) 95% CL upper limit	Clipping
$\lvert a_0^W/\Lambda^2\rvert$	4.3 (3.9) $\times 10^{-6}$ GeV^{-2}	-
$\lvert a_C^W/\Lambda^2\rvert$	1.6 (1.4) $\times 10^{-5}$ GeV^{-2}	-
$\lvert a_0^Z/\Lambda^2\rvert$	0.9 (1.0) $\times 10^{-5}$ GeV^{-2}	-
$\lvert a_C^Z/\Lambda^2\rvert$	4.0 (4.5) $\times 10^{-5}$ GeV^{-2}	-
$\lvert a_0^W/\Lambda^2\rvert$	5.2 (5.1) $\times 10^{-6}$ GeV^{-2}	1.4 TeV
$\lvert a_C^W/\Lambda^2\rvert$	2.0 (2.0) $\times 10^{-5}$ GeV^{-2}	1.4 TeV

Dimension-8 – vanishing WWγZ coupling

Coupling	Observed (expected) 95% CL upper limit	Clipping
$\lvert f_{M,0}/\Lambda^4\rvert$	16.2 (14.7) TeV^{-4}	-
$\lvert f_{M,4}/\Lambda^4\rvert$	90.9 (82.6) TeV^{-4}	-
$\lvert f_{M,0}/\Lambda^4\rvert$	19.5 (19.2) TeV^{-4}	1.4 TeV
$\lvert f_{M,4}/\Lambda^4\rvert$	110 (108) TeV^{-4}	1.4 TeV

Dimension-8 – all couplings zero but one

Coupling	Observed (expected) 95% CL upper limit	Clipping
$\lvert f_{M,0}/\Lambda^4\rvert$	66.0 (60.0) TeV^{-4}	-
$\lvert f_{M,1}/\Lambda^4\rvert$	245.5 (214.8) TeV^{-4}	-
$\lvert f_{M,2}/\Lambda^4\rvert$	9.8 (9.0) TeV^{-4}	-
$\lvert f_{M,3}/\Lambda^4\rvert$	73.0 (64.6) TeV^{-4}	-
$\lvert f_{M,4}/\Lambda^4\rvert$	36.0 (32.9) TeV^{-4}	-
$\lvert f_{M,5}/\Lambda^4\rvert$	67.0 (58.9) TeV^{-4}	-
$\lvert f_{M,7}/\Lambda^4\rvert$	490.9 (429.6) TeV^{-4}	-
$\lvert f_{M,0}/\Lambda^4\rvert$	79.8 (78.2) TeV^{-4}	1.4 TeV
$\lvert f_{M,1}/\Lambda^4\rvert$	306.8 (306.8) TeV^{-4}	1.4 TeV
$\lvert f_{M,2}/\Lambda^4\rvert$	11.9 (11.8) TeV^{-4}	1.4 TeV
$\lvert f_{M,3}/\Lambda^4\rvert$	91.3 (92.3) TeV^{-4}	1.4 TeV
$\lvert f_{M,4}/\Lambda^4\rvert$	43.5 (42.9) TeV^{-4}	1.4 TeV
$\lvert f_{M,5}/\Lambda^4\rvert$	83.7 (84.1) TeV^{-4}	1.4 TeV
$\lvert f_{M,7}/\Lambda^4\rvert$	613.7 (613.7) TeV^{-4}	1.4 TeV

References

- [1] CMS and TOTEM Collaborations, "CMS-TOTEM Precision Proton Spectrometer", Technical Report CERN-LHCC-2014-021, TOTEM-TDR-003, CMS-TDR-13, 2014.
- [2] M. Boonekamp et al., "FPMC: a generator for forward physics", arXiv:1102.2531, 2011.
- [3] CMS and TOTEM Collaborations, "Proton reconstruction with the Precision Proton Spectrometer in Run 2", arXiv:2210.05854, 2022.
- [4] O. J. P. Éboli and M. C. Gonzalez-Garcia, "Classifying the bosonic quartic couplings", Phys. Rev. D 93 (2016) 093013, 2016.

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