Photon-induced processes at ATLAS and CMS

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On behalf of ATLAS and CMS Collaborations
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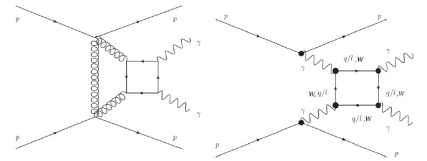
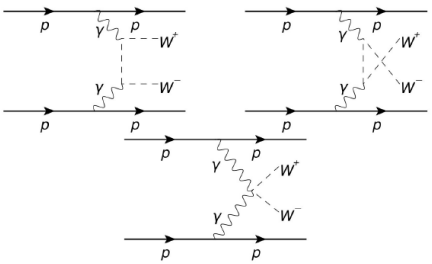
- Exclusive WW, ZZ production
- Exclusive dilepton production (with/without proton tagging)
- Exclusive $\gamma\gamma$ production
- Prospects: ALPs, anomalous coupling studies

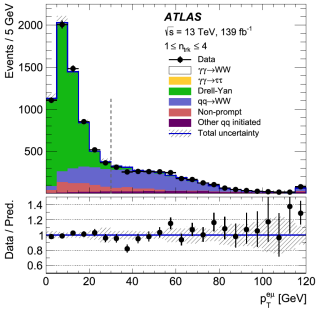
How can we measure photon-induced processes at the LHC?

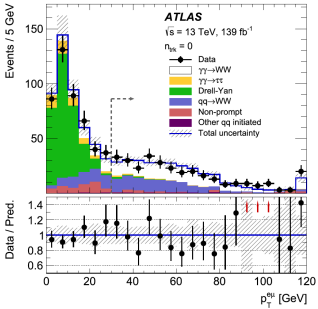


- Consider exclusive production of ee, $\mu\mu$ WW, $\gamma\gamma$, etc
- Dilepton production is a QED (γ-exchange) process
- In pp interactions, QCD production of $\gamma\gamma$ dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$ (similar for WW, ZZ, $Z\gamma$, $t\bar{t}$ production)
- At high masses, in pp interactions, possibility to select photon-induced events by tagging protons and by measuring high mass objects in CMS/ATLAS
- Pb Pb interactions: $\gamma\gamma$ exchanges enhanced by Z^4, measure low mass exclusive γ-induced processes ($\gamma\gamma$)

SM observation of exclusive photon-induced WW production (ATLAS)





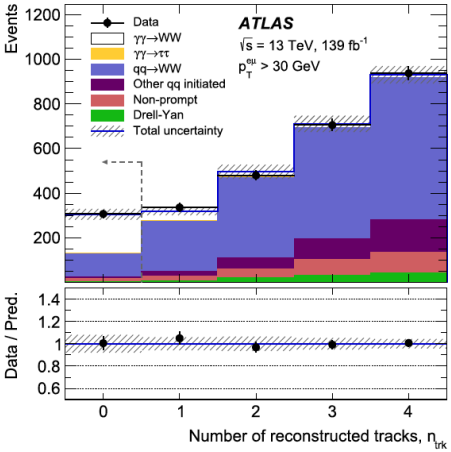


- Observation of photon induced WW production in pp collisions at $\sqrt{s}$ =13 TeV in ATLAS (Phys. Lett. B816 (2021) 136)

- Consider leptonic decays of W in one electron and one muon ($WW \to e\nu_e\mu\nu_\mu$) using 139 fb^{-1}
- Exclusive selection based on the number of tracks fitted to the primary vertex (outside e/μ)

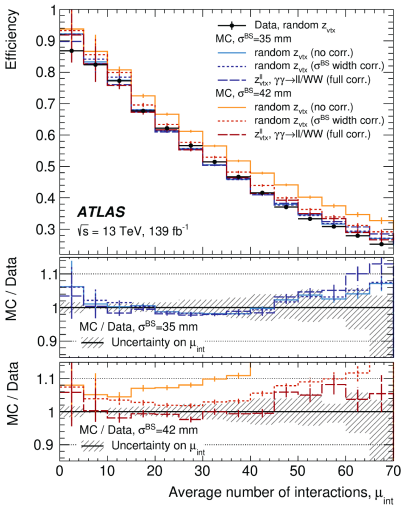
SM observation of exclusive photon-induced WW production (ATLAS)

- Observation of photon induced WW production in pp collisions at $\sqrt{s}$ =13 TeV in ATLAS (Phys. Lett. B816 (2021) 136)
- $\sigma(\gamma\gamma \to WW) = 3.13 \pm 0.31(\text{stat.}) \pm 0.28(\text{syst.})$ fb in detector acceptance in agreement with MC

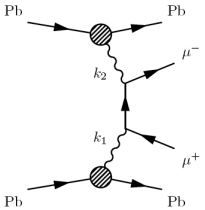


SM observation of exclusive photon-induced *WW* production (ATLAS): difficulty to detect exclusive events at high luminosity

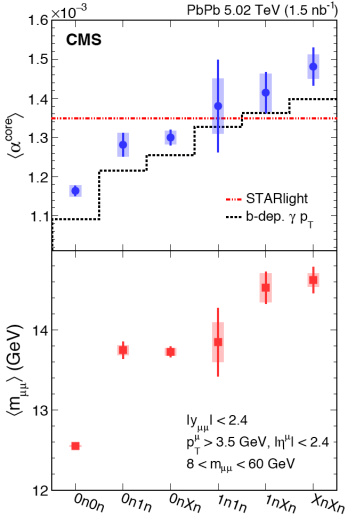
- Number of pile up events increases at the LHC
- Efficiency of detecting exclusive *WW* events decreases fast as a function of the number of pile up events
- The solution is to detect and measure intact protons in the final state in oder to ensure exclusivity (see next slides)



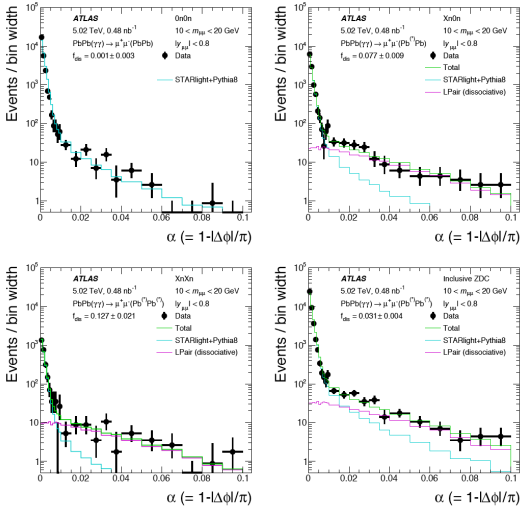
Exclusive dilepton production in Pb Pb interactions (CMS)



- $\gamma\gamma \to \mu\mu$ exclusive process: good sensitivity to Pb EM form factors and can probe higher order effects (FSR, Coulomb interactions)
- Dependence on forward neutron multiplicity as a function of $m_{\mu\mu}$ and $\alpha = 1 - |\Delta\phi_{\mu\mu}|/\pi$ (related to Pb dissociation) for $p_{T,\mu}$ >3.5 GeV and $8 < m_{\mu\mu} < 60$ GeV, $|y_{\mu\mu}|$ <2.4 (ArXiv:2011.05239)

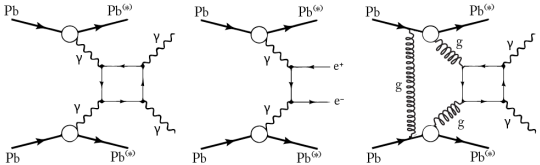


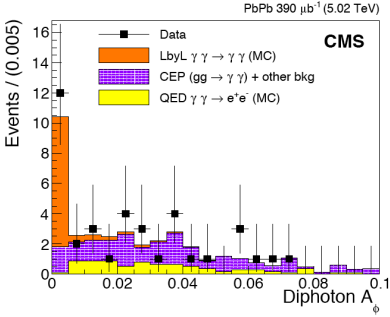
Exclusive dilepton production in Pb Pb interactions (ATLAS)



- Muon pair with $P_{T\mu} > 4$ GeV, $|\eta_\mu| < 0.4$, $M_{\mu\mu} > 10$ GeV, $P_{T\mu\mu} > 2$ GeV
- Description of $0n0n$ data → Pythia8+Starlight include FSR effects ($0n0n$ means no neutron detected in Zero Degree Calorimeter (ZDC))
- Description of $XnXn$ data → dissociative background using LPAIR ($XnXn$ means at least 1 neutron detected in ZDC)
- Measurement important to take into account higher order effects (ArXiv:2011.12211)

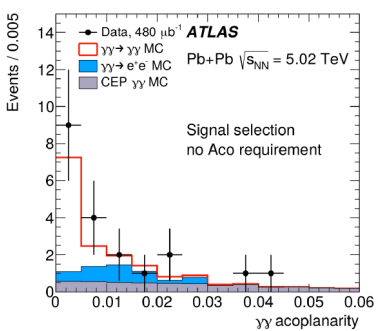
Light by light scattering in Pb Pb collisions (CMS)

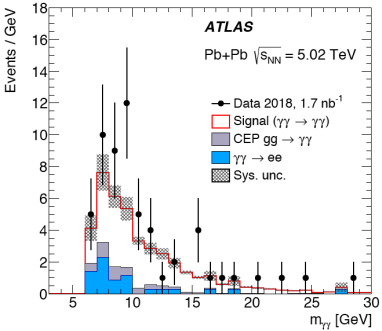




- Signal: two γ back-to-back, background: electrons misreconstructed as γ and QCD $gg \to \gamma\gamma$
- CMS 2015 selection: $E_{T_\gamma} > 3$ GeV, $|\eta| < 2.4$, $m_{\gamma\gamma} > 5$ GeV, $p_{T,\gamma\gamma}$ <1 GeV, acoplanarity <0.01
- 14 candidates, estimated background: 4.0±0.1 (PLB 797 (2019) 134826)

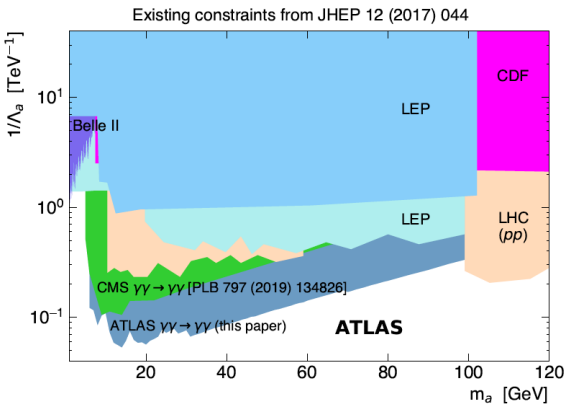
Light by light scattering in Pb Pb collisions (ATLAS)

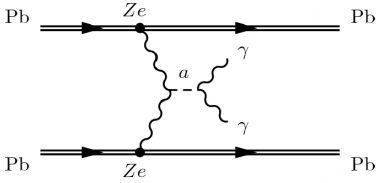




- ATLAS 2015 selection: $E_{T_\gamma} > 3$ GeV, $|\eta| < 2.37$, $m_{\gamma\gamma} > 6$ GeV, $p_{T,\gamma\gamma} < 2$ GeV, acoplanarity < 0.01
- 13 candidates, estimated background: 2.6 ± 0.7 (Nature physics 13 (2017) 852)
- ATLAS 2018 with similar selection: 59 events with an expected background of 12 ± 3: 8.2σ observation of light-by-light scattering (PRL 123 (2019) 052001)

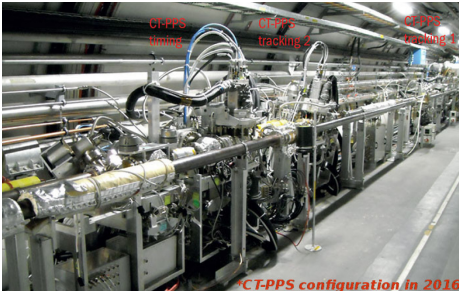
Light by light scattering in Pb Pb: constraint on ALP (ATLAS/CMS)

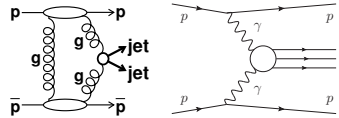


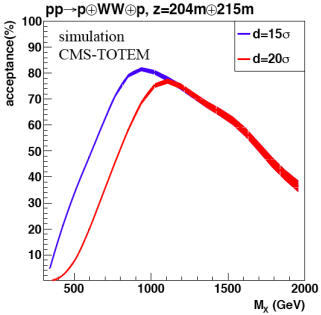


- Pb Pb interactions lead to sensitivity to ALPs at low masses (resonance) since the γ-exchange cross section is enhanced by a factor Z^4
- Complementarity with *pp* running: sensitivity at high mass (PPS/AFP acceptance starts at $\sim$400 GeV)

Roman pot detectors from PPS/AFP installed in the tunnel



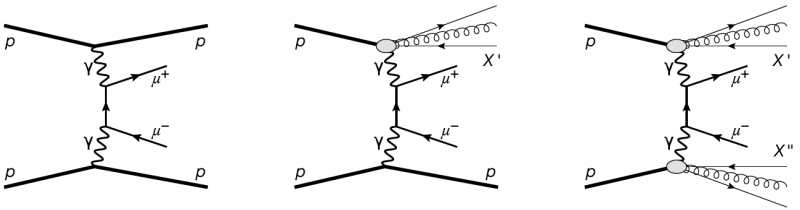




- Good acceptance at high mass in standard runs (PPS in CMS, AFP in ATLAS)
- Roman pots inserted routinely in every run without issues

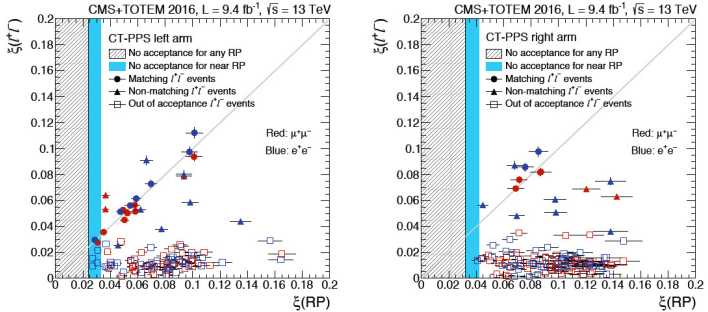
Quasi-exclusive $\mu\mu$ and ee production in ATLAS and in CMS-TOTEM

- Turn the LHC into a $\gamma\gamma$ collider at high luminosity: flux of quasi-real photons under the Equivalent Photon Approximation, dilepton production dominated by photon exchange processes
- ATLAS and CMS TOTEM-Precision Proton Spectrometer: Tag one of the two protons
- The dilepton mass acceptance of PPS/AFP starts at about $\sim$400 GeV $\rightarrow$ expect very small number of double tagged events
- The two first diagrams are signal, the last one background



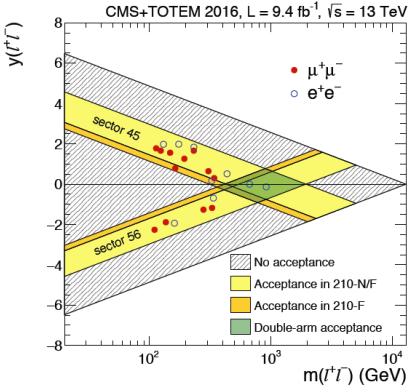
Observed signal (CMS)

- First measurement of semi-exclusive dilepton process with proton tag
- PPS works as expected (validates alignment, optics determination...)
- 17 (resp. 23) events are found with protons in the PPS acceptance and 12 (resp. 8) $< 2\sigma$ matching in the $\mu\mu$ (resp. ee) channel
- Significance $> 5\sigma$ for observing 20 events for a background of 3.85 ($1.49 \pm 0.07(stat) \pm 0.53(syst)$ for $\mu\mu$ and $2.36 \pm 0.09(stat) \pm 0.47(syst)$ for ee)



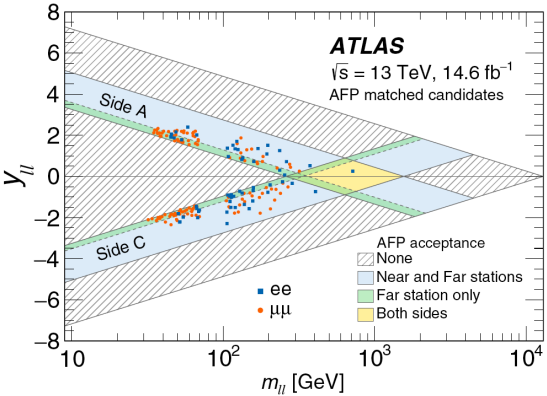
Summary of 20 candidates properties (CMS)

- Dimuon invariant mass vs rapidity distributions in the range expected for single arm acceptance
- No event at higher mass that are double tagged: The two dielectron events in the acceptance region are compatible with pile up contamination (2.36 events expected)
- Highest mass event: 917 GeV
- JHEP 1807 (2018) 153

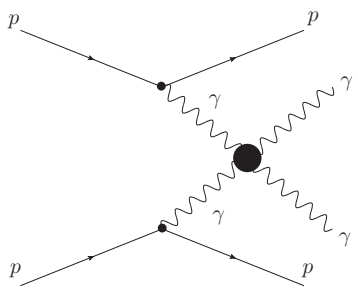


Observed signal (ATLAS)

- Observation of quasi-exclusive di-lepton (e and μ) by ATLAS using 14.6 fb^{-1} at 13 TeV
- 57 (123) events are observed in ee ($\mu\mu$) channels $> 5\sigma$ evidence
- $\sigma_{ee+p} = 11.0 \pm 2.6$ (stat) ± 1.2 (syst) ± 0.3 (lumi) fb and $\sigma_{\mu\mu+p} = 7.2 \pm 1.6$ (stat) ± 0.9 (syst) ± 0.2 (lumi) fb
- PRL 125 (2020) 261801



Search for quartic $\gamma\gamma\gamma\gamma$ anomalous coupling

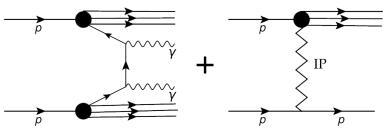


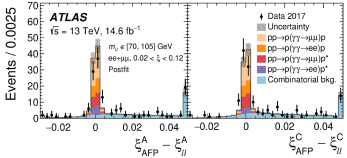
- Search for production of two photons and two intact protons in the final state: $pp \to p\gamma\gamma p$

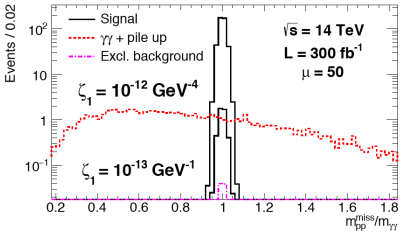
- Additional channels: WW, ZZ, γZ, $t\bar{t}$
- Possible larger number of events than expected in SM due to extra-dimensions, composite Higgs models, axion-like particles
- Anomalous couplings can appear via loops of new particles coupling to photons or via resonances decaying into two photons
- JHEP 1806 (2018) 131; JHEP 1502 (2015) 165; Phys.Rev. D89 (2014) 114004; Phys.Rev. D81 (2010) 074003; Phys.Rev. D78 (2008) 073005

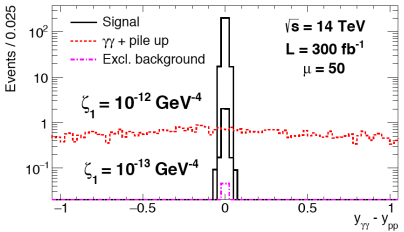
Removing pile up at the LHC

- Advantage of tagging protons: negligible background after matching mass/rapidity of photon and proton systems
- Use fast timing detectors in the case of *WW* production and *W*s decaying leptonically

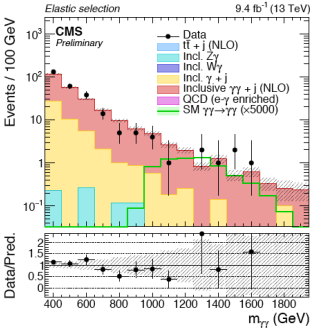


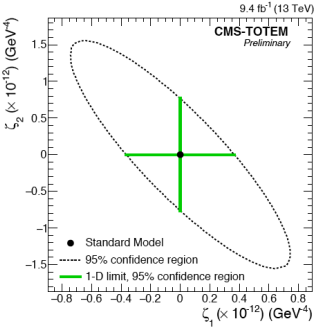






Looking for $\gamma\gamma\gamma\gamma$ anomalous quartic couplings (CMS)





- Search for two isolated γ in CMS, back-to-back, and 2 intact protons in PPS (matching in mass and rapidity the diphoton): $M_{\gamma\gamma} > 350$ GeV, $p_{T,\gamma} > 75$ GeV, acoplanarity < 0.005
- Results are compatible with background hypothesis: 1st limits on quartic anomalous couplings $|\zeta_1| < 3.7\ 10^{-13}$ GeV^{-4} and $|\zeta_2| < 7.7\ 10^{-13}$ GeV^{-4} (PAS EXO-18-014)
- Study in progress with full luminosity >100 fb^{-1} accumulated, stay tuned!

Conclusion

- First observation by ATLAS of the exclusive production of WW bosons in photon-induced processes in pp collisions
- Exclusive dilepton production in Pb Pb collisions measured by ATLAS and CMS and study of Pb dissociation by measuring neutrons in ZDC
- Light-by-light scattering observed both by ATLAS and CMS in Pb Pb collisions that lead to the first ALP limits in the medium mass range
- Observation of quasi-exclusive dilepton production in ATLAS/CMS with one proton tagged, and first limits on photon quartic anomalous couplings by PPS
- >100 fb^{-1} of data with intact protons being analyzed, stay tuned!
- See talk by Ruchi in the heavy ions/QCD session