Vgamma & gamma gamma

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for the ATLAS EXPERIMENT & CMS Collaborations

1. Cross section measurements
2. Resonance search
3. Rare decays
4. Light-by-light scattering

Why it could be interesting? (Vgamma & gamma gamma)

- Precise SM cross section measurements
- Vgamma sensitive to a triple gauge couplings
- Could be used for a BSM resonance production search
- Rare decays search
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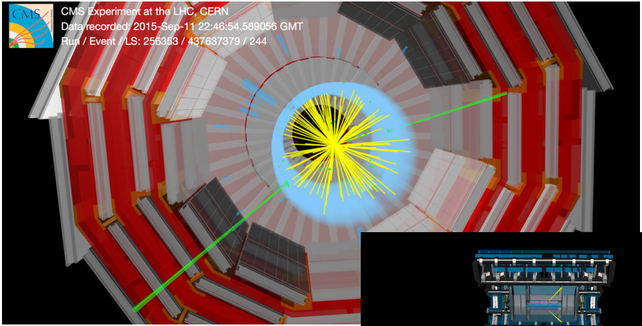
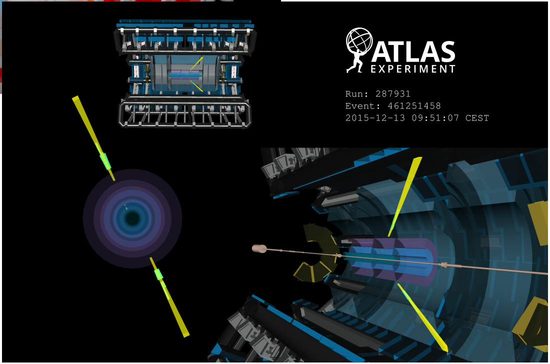
ATLAS & CMS detectors



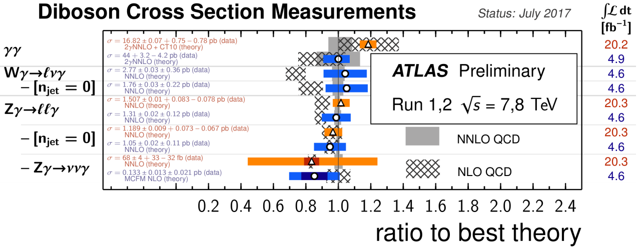
Better ECAL and momentum resolution

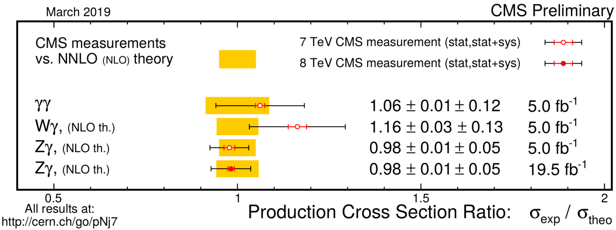


Better HCAL and muon system

More or less the same

Precise cross section measurements

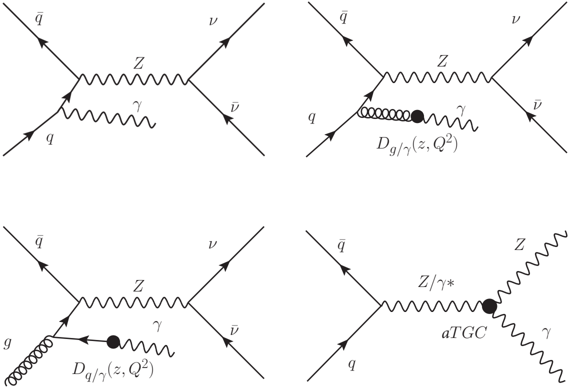




Accuracy of data is enough to distinguish NLO from NNLO.

Systematic uncertainties are dominant.

Why it could be interesting? $Z\gamma \to \nu\bar{\nu}\gamma$ example



$Z \to \nu\bar{\nu}$ channel is better for aTGC measurement than $Z \to$ hadr (large multijet background) or $Z \to \ell^+\ell^-$ (FSR and less branching ratio).

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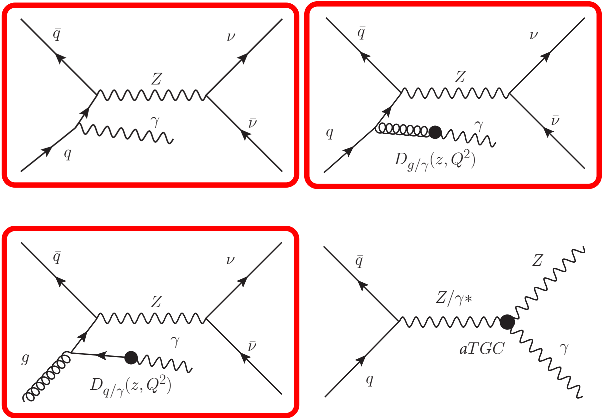

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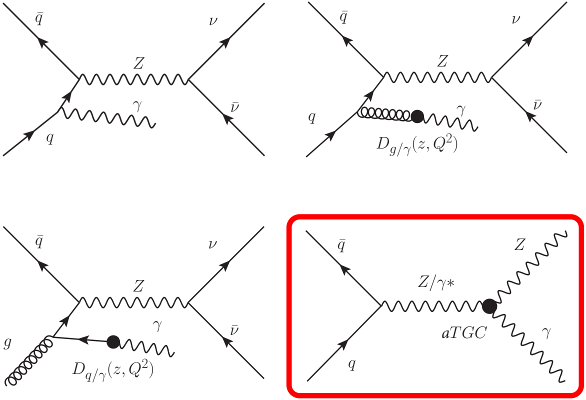

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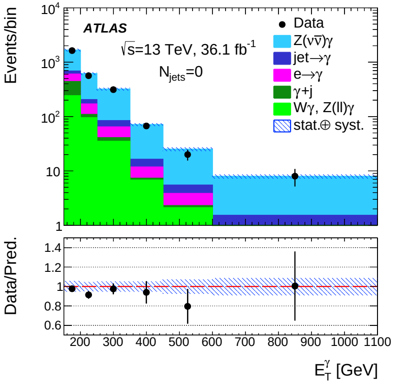
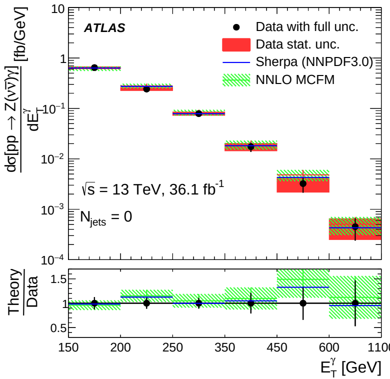
ATLAS, $\sqrt{s} = 13$ TeV, $\mathcal{L} = 36.1\,\text{fb}^{-1}$





The contribution from aTGCs increases with the E_T of the photon, and the measurement of $Z\gamma$ production is found to have the highest sensitivity to aTGCs by restricting the search to the portion of the extended fiducial region with $E_T > 600$ GeV.

arXiv:1810.04995

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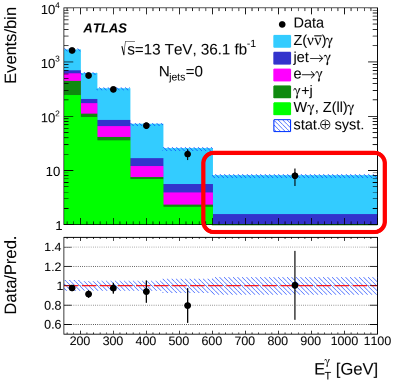

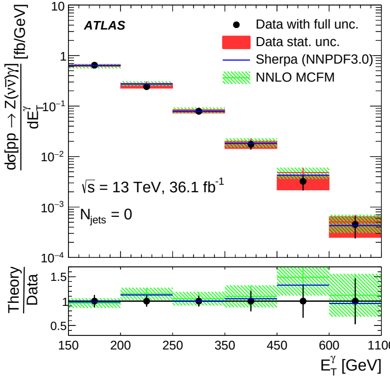

The contribution from aTGCs increases with the E_T of the photon, and the measurement of $Z\gamma$ production is found to have the highest sensitivity to aTGCs by restricting the search to the portion of the extended fiducial region with $E_T > 600$ GeV. More statistics needed.

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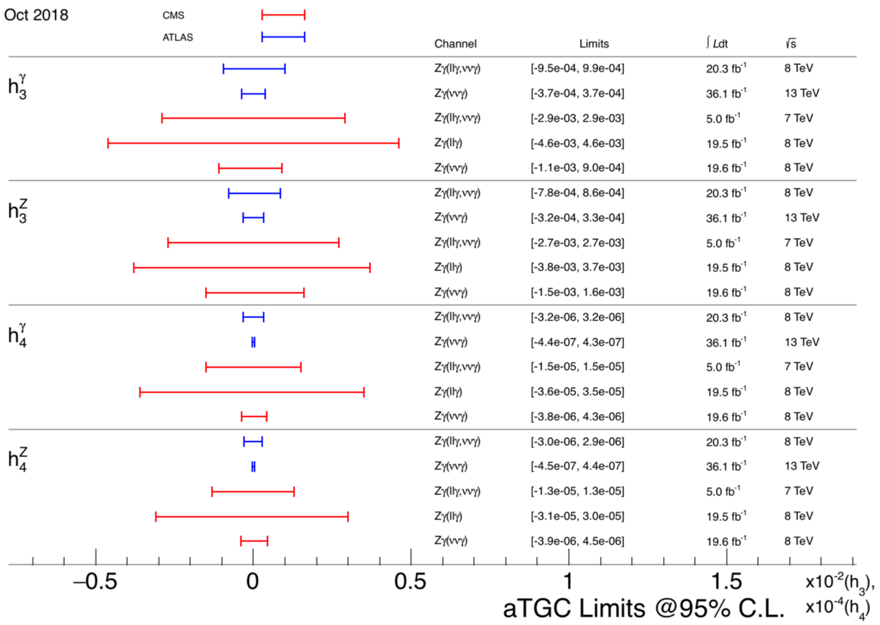
Limits on neutral aTGC $Z\gamma\gamma$ and $ZZ\gamma$ couplings



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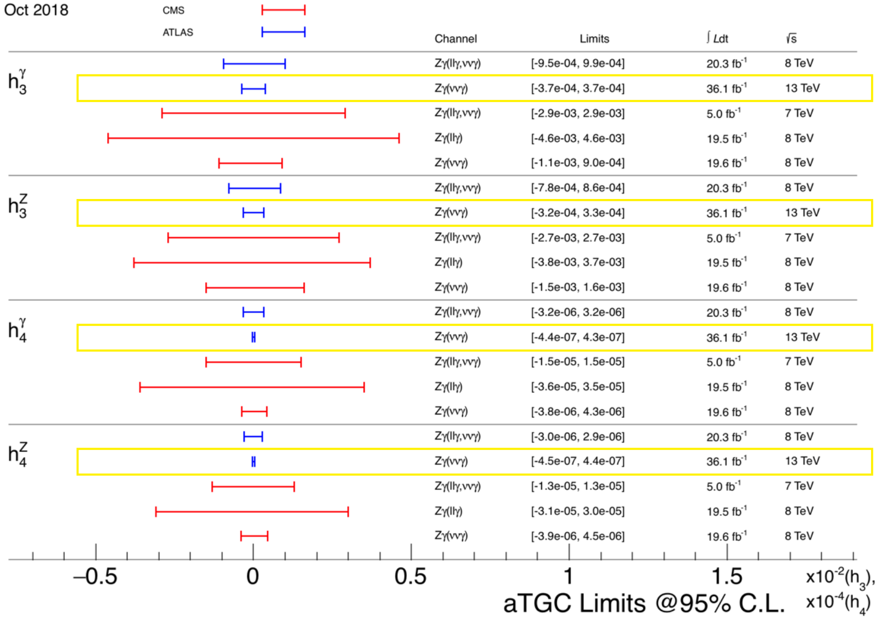


$\gamma\gamma$ example

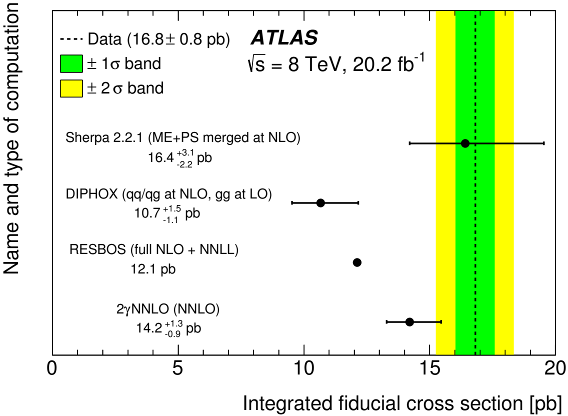
High-energy photon pairs at the LHC are famous for two things:

- First, as a dependable decay channel of the Higgs boson.
- Second, for triggering some discussions in the scientific community in late 2015 due to seeming the excess above Standard Model predictions presented by both ATLAS and CMS collaborations. Unfortunately excess disappeared after analysis of larger dataset.

▸ Improving our understanding of photon pairs

People prefer to look into visible discrepancies but probably now the time of precise measurement begins. Precise calculations of already well known effects are also important.

Measured fiducial cross section compared to the predictions from Sherpa 2.2.1, Diphox, Resbos and 2γNNLO.



$$\sigma_{\text{tot}}^{\text{fid.}} = 16.8 \pm 0.1\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.3\,(\text{lumi})\ \text{pb} = 16.8 \pm 0.8\,\text{pb}\ (4.8\%).$$

arXiv:1704.03839

Resonance search

Today SM is considered at most an effective theory. Many physicists believe that SM should eventually break down. For example, because it does not include gravity.

A common trait of new physics theories that extend the SM is their inclusion of new gauge bosons or resonances that couple to the SM fields and may thus decay into pairs of the respective fermions and bosons. Thus constructed resonances can decay, for example, into pairs of observable bosons.

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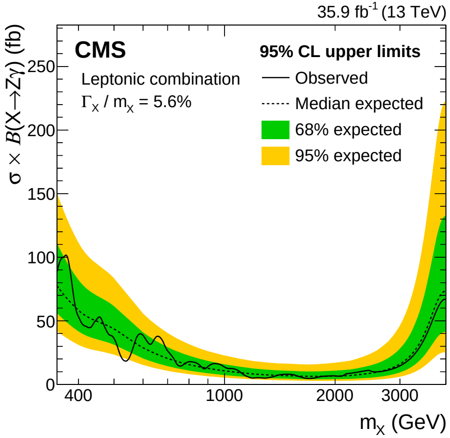
Problem: The null results. . .

There's always hope.

Leptonic channel



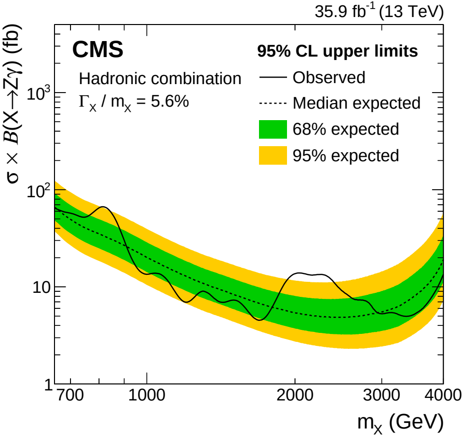
Advantage: Good background rejection leads to better sensitivity at lower signal masses (till $\simeq$ 350 MeV).

Disadvantage: Low statistics at high invariant masses.

Main source of systematics: e/γ energy resolution (μ momentum resolution) $\simeq 10\%$

arXiv:1712.03143

Hadronic channel



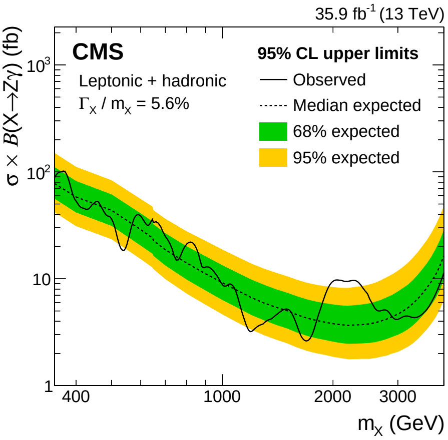
Z are identified using a large-radius jet.

Advantage: Large statistics helps at larger signal masses (from $\simeq$ 700 MeV till 4 TeV).

Main source of systematics: jet energy/mass scale (3-4%) and various identification efficiencies (depending on events class b-tagged/τ-tagged/Untagged).

arXiv:1712.03143

Combined results

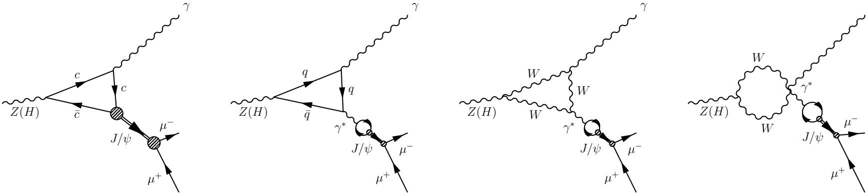


Combined results in terms of upper limits on the product of the production cross section and the branching fraction to $Z\gamma$ for narrow spin-0 resonances with masses between 0.35 and 4.0 TeV today are the most stringent limits on such resonances.

arXiv:1712.03143

Search for rare decays of Z/H to $J/\psi + \gamma$ (CMS)

pp, $\sqrt{s} = 13\,\text{TeV}$, $\mathcal{L} = 35.9\,\text{fb}^{-1}$



Feynman diagrams for $Z(H) \to J/\psi\gamma$ decay. The left-most diagram shows the direct and the remaining diagrams the indirect processes.

$$\mathcal{B}_{\text{SM}}(Z \to J/\psi\gamma) = \left(9.0^{+1.5}_{-1.4}\right) \times 10^{-8}$$
$$\mathcal{B}_{\text{SM}}(H \to J/\psi\gamma) = \left(3.0^{+0.2}_{-0.2}\right) \times 10^{-6}$$

arXiv:1810.10056

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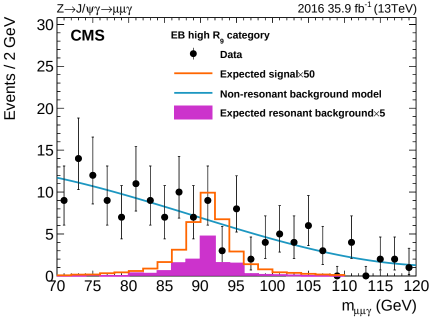
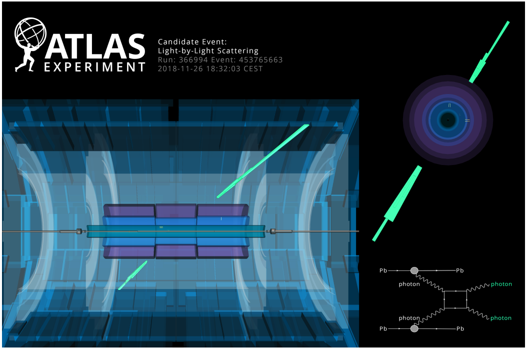


Fit to nonresonant background using a lowest-order unbiased function to describe the three-body invariant mass $m_{\mu\mu\gamma}$ distribution observed in data for the $Z \to J/\psi\gamma$ channel.

$$\mathcal{B}(Z \to J/\psi\gamma) < 1.4 \times 10^{-6} \text{ (15 times grater SM)}$$
$$\mathcal{B}(H \to J/\psi\gamma) < 7.6 \times 10^{-4} \text{ (260 times grater SM)}$$

arXiv:1810.10056

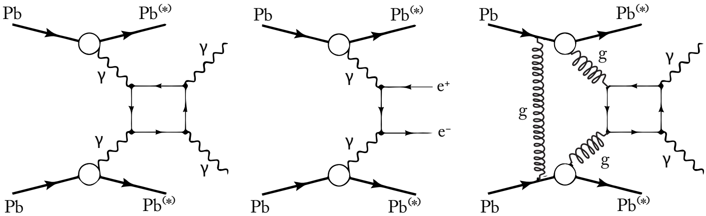


The ATLAS Collaboration has reported the observation of light-by-light scattering $\gamma\gamma \to \gamma\gamma$, with a significance beyond 8 standard deviations. $1.73\,\mathrm{nb}^{-1}$ of data collected in November 2018 (Pb+Pb collisions, $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$) was used for this analysis. 59 candidate events are observed for a background expectation of 12 ± 3 events.

arXiv:1904.03536

Light-by-light scattering

Similar to well known Delbrück scattering (γ diflection and photon splitting in nucleus Coulomb field).



Light-by-light scattering ($\gamma\gamma \to \gamma\gamma$, left), QED dielectron ($\gamma\gamma \to e^+e^-$, centre), and central exclusive diphoton ($gg \to \gamma\gamma$, right) production in ultraperipheral Pb+Pb collisions.

Interest: Sensitive to new physics in charged loops.
Problems: $\sim O(\alpha^4)$, high η for products, pileup, relatively low γ energies for trigger and reconstruction, QED dielectron and QCD backgrounds.

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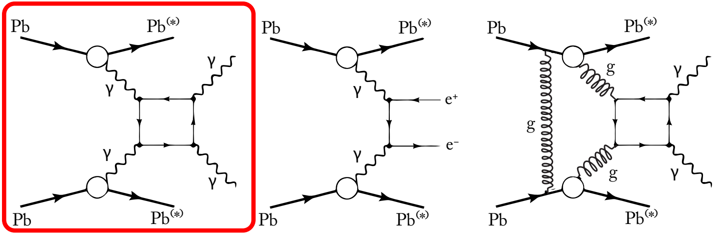

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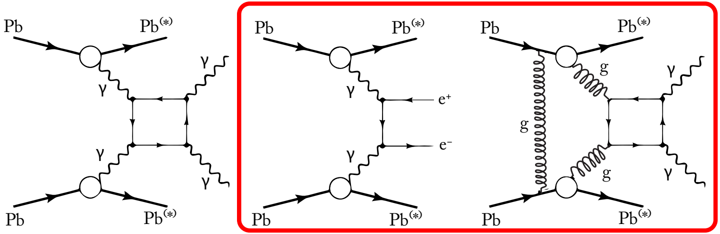

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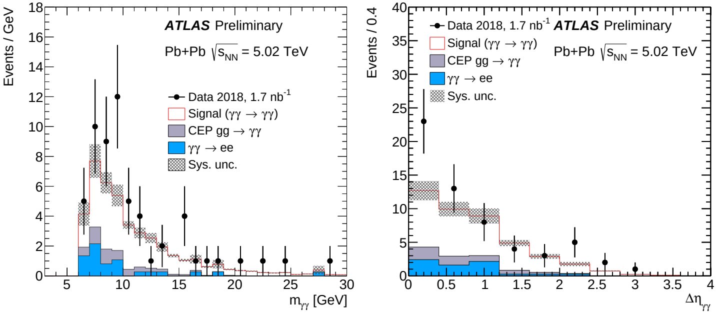

Kinematic distributions for $\gamma\gamma \to \gamma\gamma$ event candidates: diphoton invariant mass and diphoton pseudorapidity difference. Data (points) are compared to the sum of signal and background expectations (histograms). New channel for tests!

$$\sigma_{\text{fid.}} = 78 \pm 13\,(\text{stat.}) \pm 7\,(\text{syst.}) \pm 3\,(\text{lumi.})\,\text{nb}$$

$$\sigma_{\text{th.}} = 50 \pm 5\,\text{nb}, \quad \text{experiment}/\text{prediction} = 1.53 \pm 0.33$$

arXiv:1904.03536

Conclusion

- Many tests on "Vgamma & gamma gamma" included precise measurement were completed recently.
- Light-by-light scattering is observed on LHC.
- This presentation could not cover all interesting topics. Please see "ATLAS experiment — public results" and "CMS Physics Results" pages for more information. And of course more results and new challenges will come soon.

▸ ATLAS experiment public results

▸ CMS Physics Results