LIP-STUDENTS-21-12

Searching for new physics by colliding light in the CMS experiment at the LHC

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Abstract. In the CMS Experiment there is a small forward detector, Precision Proton Spectrometer, that can identify and reconstruct very high energy photon-photon collisions, known as "light-by-light" scattering. Here is presented an analysis of a new Beyond Standard Model physics, Axion-Like Particle, and its predictions will be compared to the real CMS public data.

1 Introduction

1.1 Light-by-Light Scattering

Scattering, in physics, is a change in the direction of motion of a particle because of a collision with another particle. A collision can occur between particles that repel one another, and do not need to involve direct physical contact of the particles. Mateusz Dyndal said "According to classical electrodynamics, beams of light pass each other without being scattered. But if we take quantum physics into account, light can be scattered by light, even though this phenomenon seems very improbable". Using proton beams we're looking ate a very high energy photon-photon interactions. Photons, having neither mass nor charge, lack self interactions. However, because of the characteristics of the vacuum, photons with sufficient energy may fluctuate into particle-antiparticle pairs, thus giving rise to photon-photon interactions. When two photons interact in this way through an intermediate charged particle loop to create two different outgoing photons, the process is known as light-by-light (LbyL) scattering. The observation of this phenomenon has been sought after in laboratory experiments for decades. A full description can be found in [1].

1.2 Axion-Like Particles Model

The new physics model that will be analysed is The Axion-Like Particles Model. With the discovery of the Higgs boson, fundamental scalar particles in nature has received a very strong evidence, with that searches for additional (pseudo)scalar particles have thereby been attracting more interest in collider studies of physics beyond the Standard Model.[1] Axion-like particles (ALPs) are hypothetical pseudo scalar bosons that appear naturally in many extensions of the Sandard Model, often as pseudo nambu-Goldstone bosons. Axion-like particles being a hypothetical neutral, spin-0 particle, that should couple to photons is then an amazing opportunity to study light-by-light scattering.

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Next it is possible to see and compare the diagrams of light-by-light scattering according to the Standard Model and the Axion-like particles Model.

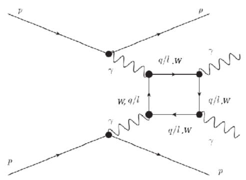
.5 

Figure 1. Standar Model(SM)

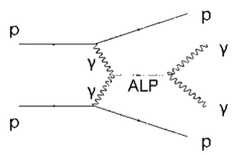
.5 

Figure 2. Axion-Like Particle (ALP)

Comparing the ALP model to the Standard Model the difference its clear, in the SM the particles would make a rectangular trajectory limiting the energy levels but in the ALP model that trajectory would be much more linear.

1.3 Precision Proton Spectrometer

The data that was analysed was gathered using the PPS detector,CMS has been successfully operating the Precision Proton Spectrometer (PPS) since 2016. PPS started as a joint CMS and TOTEM project, and then evolved into a standard CMS subsystem. Discussion with the machine groups has led to the identification of four locations suitable for the installation of movable proton detectors: at 196, 220, 234, and 420 m from the interaction point, on both sides.Acceptance studies indicate that having the beams cross in the vertical plane at the interaction point, as implemented after Long Shutdown 3, is vastly preferable over the present horizontal crossing. This gives access to centrally produced states X in the mass range 133 GeV2.7 TeV with the stations at 196, 220, and 234 m. The mass range becomes 43 GeV2.7 TeV if the 420 m station is included, which makes it possible to study central exclusive production of the 125 GeV Higgs boson. This is a major improvement with respect to the current mass range of 350 GeV2 TeV. The radiation background has also been studied. Radiation hardness is required for all components in the tunnel. Service work during short technical stops will not be possible. The irradiation dose rate will be very strongly peaked near the beam. This is a detector that allows the measurement of protons in the very forward regions on both sides of CMS in standard LHC running conditions, taking advantage of the machine magnets to bend the protons. [2]

2 Data Treatment

2.1 Even Selection

To mimic the CMS event selection, to correspond to the coverage of the detector, and also to reject background, or to avoid regions of low detection efficiency, there were applied some" cuts" to select the only events that pass the same criteria defined by the CMS paper.[3] The list of these cuts is presented down bellow:

- pT (each photon) > 200 GeV;
- $|\eta(eachphoton| < 2{,}5$;
- di-phoyon invariant mass > 350GeV;
- 0,070 < proton xi1 <0,1111;
- 0,070 < proton xi2 < 0,138;

For that, in the code, the value of the different variables was limited , most of the simulated events wouldn't pass the cuts as you can see in Table 1, right bellow. The cuts were applied to different masses and the results will be analysed in the following paragraphs.

Mass(GeV)	Simulated Events	Events Passing the "cuts"
0.95	952	41
0.95	958	36
0.95	952	41
1.00	100	5
1.00	961	65
1.00	943	61
1.25	991	211
1.25	991	203
1.25	945	96
1.50	994	62
1.50	996	76
1.50	945	90

Table 1. Number of Simulated Events and Number of events passing the "cuts".

3 Results

With the results of the "cuts" applied to the simulated ALP prediction data there's now the possibility to analyse some of the variables of the particles during and after the collision.

3.1 Comparing the energy levels in px and py variables:

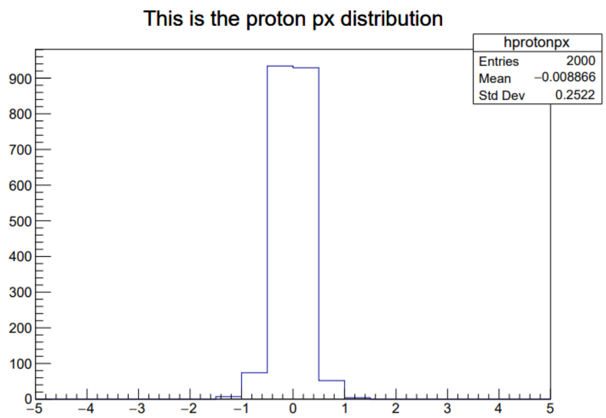


Figure 3. Number of Events px(GeV)

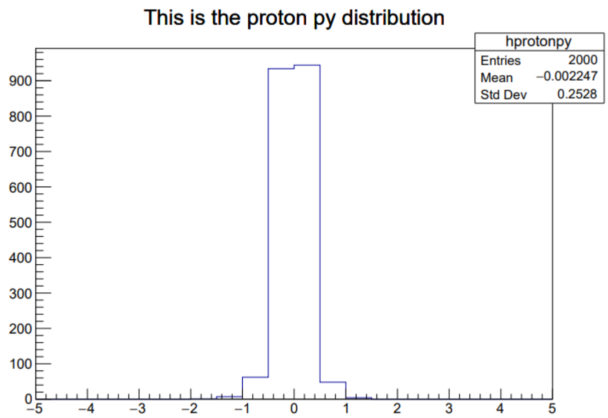


Figure 4. Number of Events py(GeV)

Knowing that the proton travels very close to the bean, it was expected that the values measured in the px and py variables would be very low.

Crossing px and py variables

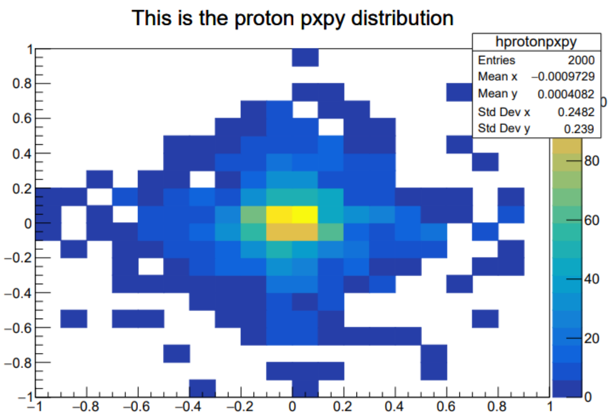


Figure 5. py(GeV) px(GeV)

Crossing the results of these to variables, as expected, they are very close to zero, this again occurs because of the distribution of the axes in the detector, being the pz variable the one with the biggest range of energy.

Energy levels on the pz variable

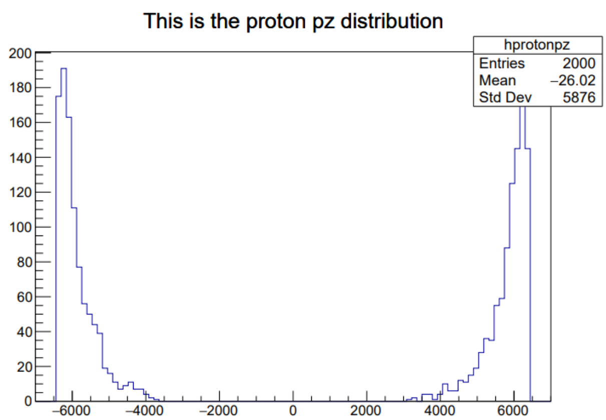


Figure 6. Number of Events pz(GeV)

Analysing Figure6 we can see that the energy levels are a lot higher in the pz variable. This variable being the one that measures the energy in the axe of most motions of the particles this result only makes sense.

3.2 Transversal Momentum

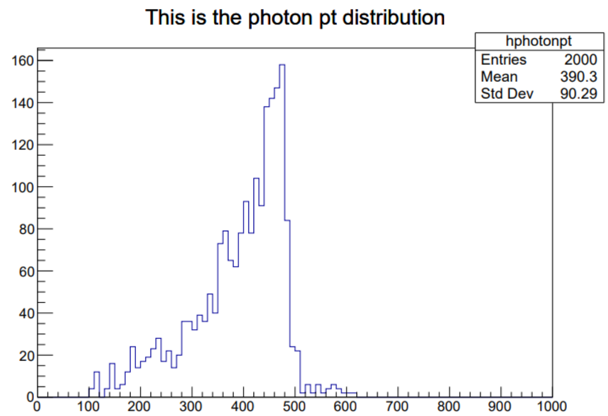


Figure 7. Number of Events pz(GeV)

Looking at the transversal momentum (pT) of the the photon we can see that making the cut, accordingly to the Axion-Like Particle Model, at 200 GeV most of the events are included by this cut, here we can see that a great part of the simulated events is being analysed with this model.

4 Comparing Results to the Real CMS data

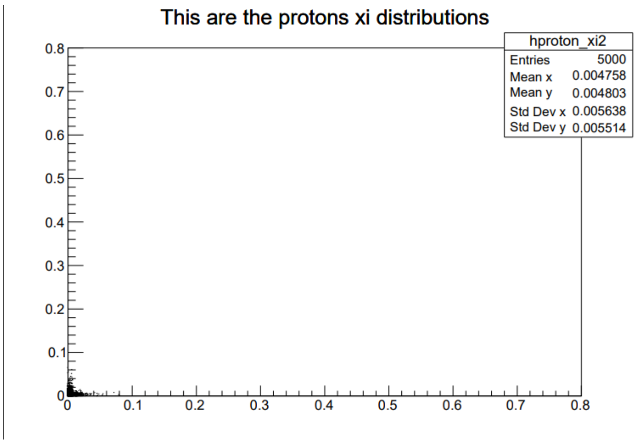


Figure 8. Standard Model Prediction

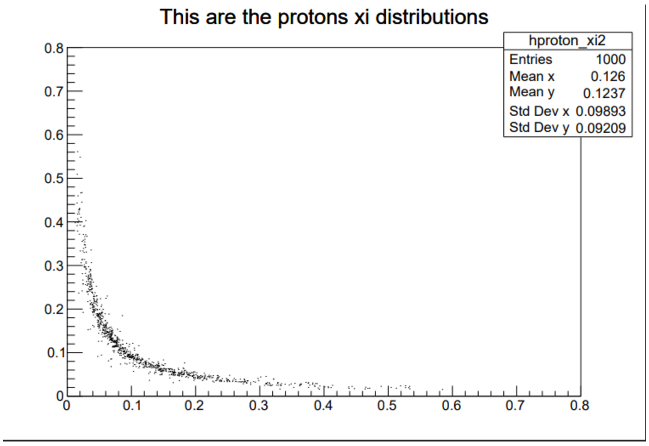


Figure 9. Simulated ALP Prediction

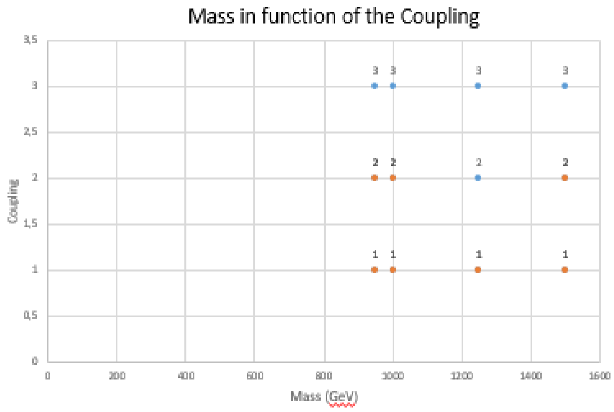


Figure 10. Mass in function of coupling , blue dots above the cross section limit, orange dots bellow the cross section limit.

The xi variable is the percentage of energy lost in the scattering. In each axe there's represented the lost of energy of one of the photons. First is presented the Sandard Model prediction for the percentage of energy lost, for both protons and next we have the simulated Axion-Like Particle prediction with the cuts. Analysing the ALP prediction it is possible to approximate the energy lost "line" to a mathematical function, this meaning that the energy lost by the two photons involved in the collision is proportional to one another, making it easier to understand and predict other collisions of the same type.

Mass (GeV)	Cross section	Coupling
950	0.474237645	1
950	1.653444676	2
950	4.306722689	3
1000	0.5	1
1000	2.705515088	2
1000	5.886532344	3
1250	1.3839556	1
1250	5.325933401	2
1250	12.2625641	3
1500	0.267670683	1
1500	1.373493976	2
1500	4.095238095	3

Table 2. Cross Section results accordingly to coupling and masses.

5 Cross Section

To calculate the cross section for different masses, we divided the number of events passing the cuts, presented before, same one's used in the CMS paper [1], by the total number of simulated events, And then multiply that by the theoretical prediction for the cross section for the Axion-Like Particle model.

In the paper cited before, CMS measures an upper limit of 3.0 femtobarns for the cross limit. In the graphic down below with the mass in function off the coupling its possible to conclude that, being the blue dots above the cross section limit, almost half of the results is above the limit of 3.o fb.

Most of the results above the cross section limit happened with a coupling of 3, with only one exception as we can see in Table2.

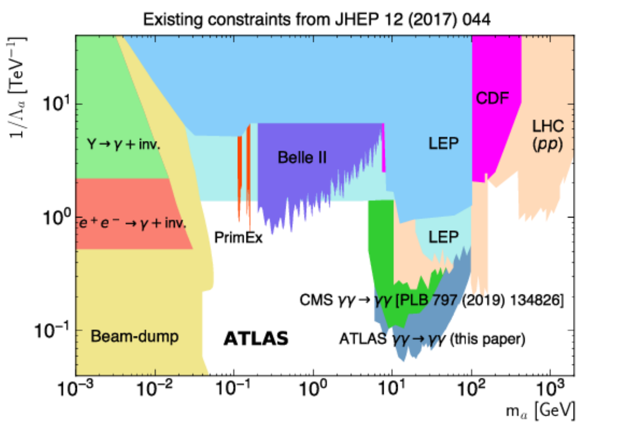


Figure 11. Existing constrains from JHEP 12 (2017)

Comparing to the limits of other experiments, it's safe to say that the results presented above are very near the LHC area, just a little bit bellow that.

6 Conclusions

In conclusion we can say that, even tho, the Standard Model predicts something much less than a 3.0 femtbarns, if new physics like ALP exists, this analysis as good sensitivity to find it. Like ALP there are other new physics models that also try to analyse this events. The data sample base that was used for this paper was only of 9.4 fb-1, by the end of LHC Run 3 there should be 20 to 30 times mores data available, so in the future it will be possible to test smaller couplings for the ALPS.

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References

[1] CMS, T. Collaborations (2020)
[2] C. Collaboration (????)
[3] D. d'Enterria, CERN, EP Department, CH-1211 Geneva, Switzerland (2021), [Online]