Probing the Standard Model with Forward Proton Tagging

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Objective

With this work we wanted to evaluate the feasibility of using the PPS experiment on the CMS detector at LHC-CERN to constrain the cross-section on the $\gamma\gamma \to \tau^+\tau^-$ interaction.

Introduction

The measurement of the physical properties of leptons, particles with half-integer spin that don't undergo strong interactions, is a crucial test to the Standard Model (SM).
The SM contains six different leptons, the electron, e, the muon, μ, the τ, τ and their respective neutrinos.
One of these physical properties is the so-called g-2, the anomalous magnetic moment, that can change the way leptons interact with photons.
Some smaller dedicated experiments have measured the anomalous magnetic moment for the lightest electron and muon:
As we can see in the the figure, these experiments yielded some tension between the observed g-2 and the SM prediction.
What about τ?
τ are, in principle, more sensitive to this difference, since they are more massive. But they are also more difficult to produce and very difficult to detect due to their fast and diverse decay... About 65% of all decays are hadronic modes decays.

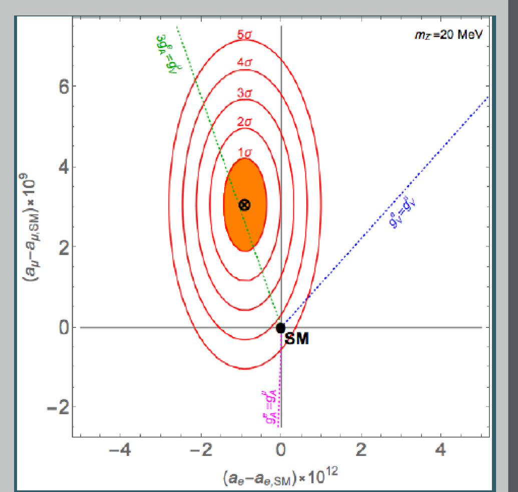

Figure: Measurements of the anomalous magnetic moment of electrons and muons showing some tension with the SM prediction

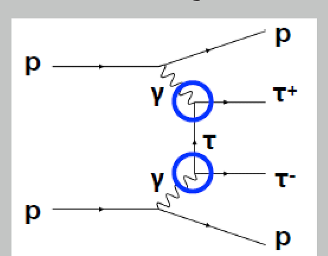

Figure: Feynman diagram of the $\gamma\gamma -> \tau + \tau -$ interaction

Decay Mode	Resonance	$\mathcal{B}$ [%]
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	10.8
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other hadronic modes		1.8
All hadronic modes		64.8

Figure: Decay modes of τ.

The Detectors - CMS and the PPS

In order to do this, we can use the PPS, Precision Proton Spectrometer experiment (with a strong LIP contribution, that collected more than $100fb^{-1}$ during Run2 of LHC) installed on the CMS, Compact Muon Solenoid, at LHC-CERN. The PPS already yielded some interesting physical results, particularly in $\gamma\gamma \to \mu^+\mu^-$, $\gamma\gamma \to e^+e^-$ [1] and $\gamma\gamma \to \gamma\gamma$ [2]. And there are also many ideas to study similar processes, like $\tau^+\tau^-$ [3]

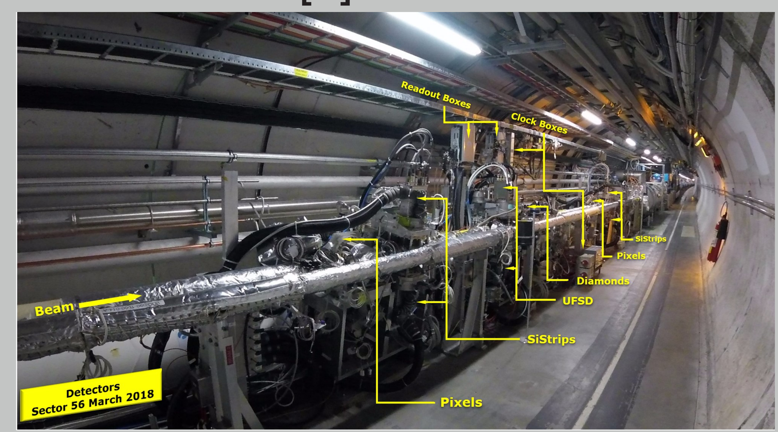

Figure: Picture of the inside of the tunnel, where we can see the PPS detectors labeled as Pixels

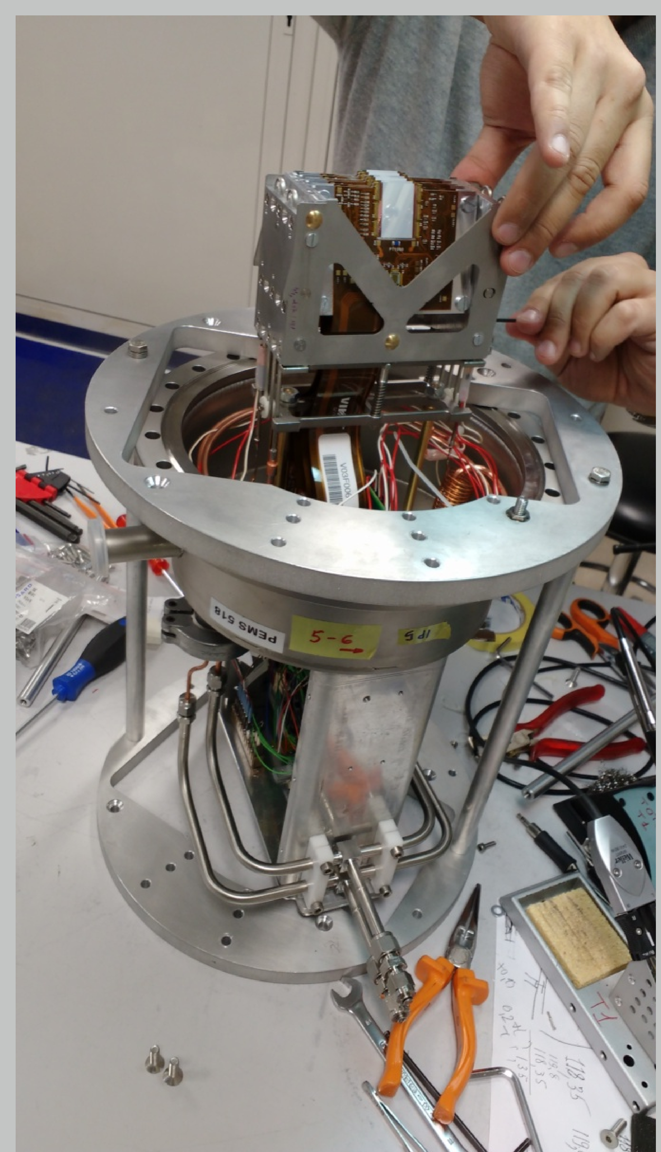

Figure: PPS pixels detectors being assembled

The method can schematically be put like this:

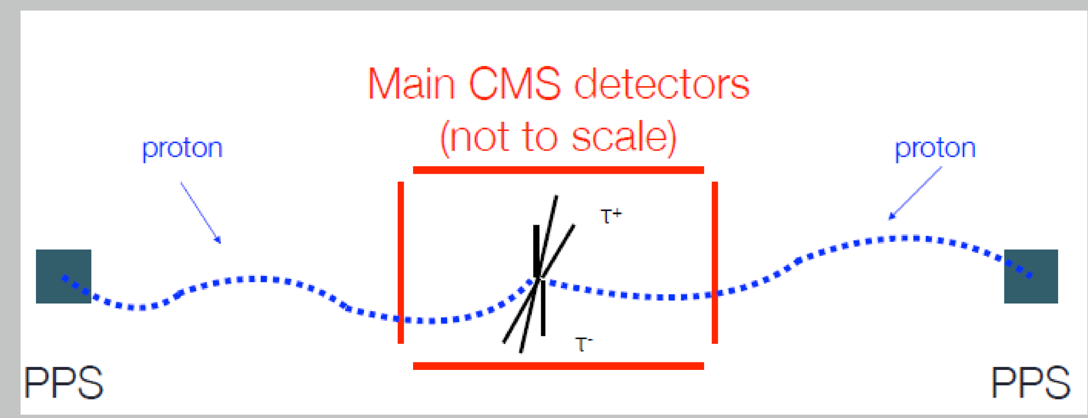

Figure: Schematic representation of the experiment

The central detectors of the CMS will reconstruct the τ and the PPS detectors will gather information about the protons. The total energy of the collision is 13TeV, and using the conservation of energy, the fractional momentum loss of the protons,ξ can be infered by how much the protons are deflected. And the dynamics (mass, M and rapidity, Y) of the protons and the τ produced, and reconstructed, can be related by:

$$M = \sqrt{s\xi_1\xi_2}$$

$$Y = \frac{1}{2}log\left(\frac{\xi_1}{\xi_2}\right)$$

Regarding the background, in the range we are looking at it comes mostly (80%) from QCD multi jets [4,5] Another issue arises when these events come in coincidence with protons from other collisions in the same bunch crossing (pile-up), since it can mimic the signal. In order to estimate this QCD contribution from data, same-sign τ candidates may be used, after a small correction to get the opposite-sign τ background.

The SM predicted cross-section,σ is $0.16fb$, for $\xi > 0.03$ and $pT(\tau) > 100GeV$, so ,with the current data, we will be searching for cross sections much higher than the SM prediction.

Bibliography

[1] JHEP 07 (2018) 153; [2] CMS-PAS-EXO-18-014; [3] JHEP 11 (2010) 060; [4] JHEP 02 (2017) 048; [5] JHEP 09 (2018) 007.

Conclusion and Future Perspectives

With this method we were able to determine that this is a feasible way to constrain the cross-section (σ) of this type of interaction by

$$N_{signal} = (e \times A) \times L \times \sigma$$

But in order to achieve the SM predicted cross section of $\sigma = 0.16fb$ more data needs to be used, along with improvement of the acceptance rate, either by more accurately relate the protons detected with the produced τ, or to better distinguish the signal and the background through more systematic methods.

Now, looking ahead...

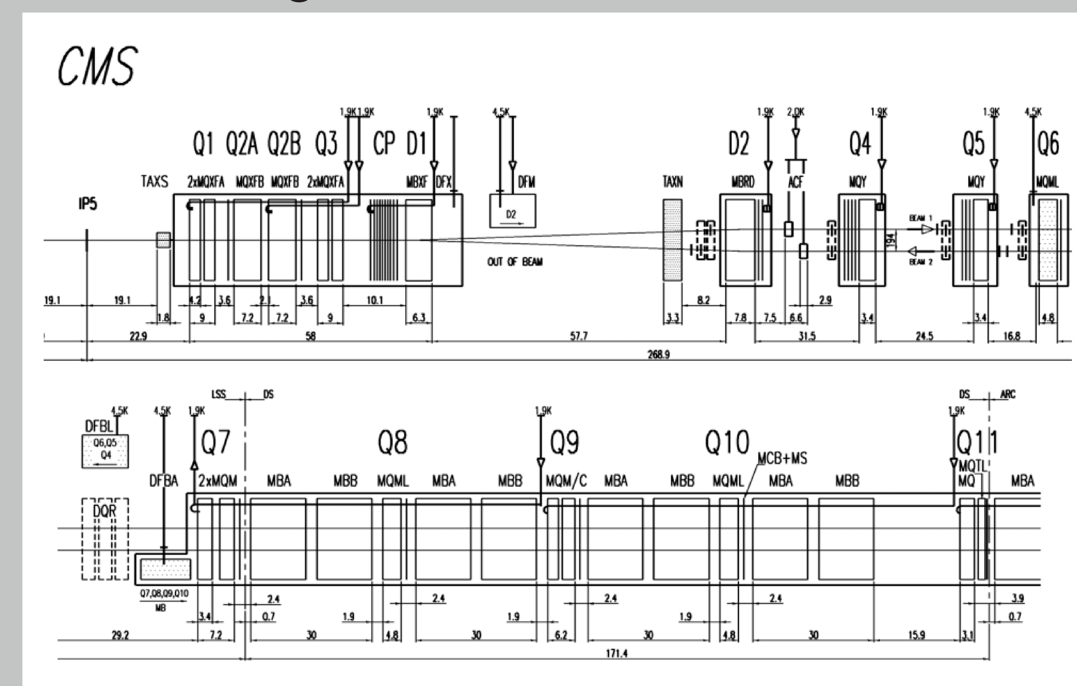

Figure: The CMS beamline at the future HL-LHC

During LHC Run3 (starting in 2022), the PPS will continue to operate with improved timing and tracking detectors. By the end of Run 3, the total available luminosity should be on the order of $300fb^{-1}$, about 3 times higher than Run2

After Run 3, the current PPS system will be removed, in order to re-configure the tunnel for the HL-LHC ("High Luminosity LHC") program.

At the HL-LHC the PPS will accumulate up to $4000fb^{-1}$ of data, about 40 times the data collected during Run2. With enough data, instead of only looking for excesses above the SM, it would be possible to precisely measure these processes.