Prospects For Photon-Photon Measurements with CMS PPS

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On behalf of the CMS collaboration
Introduction

The LHC was built as a discovery machine, but we’ve found a way to do precision physics

- The CMS Precision Proton Spectrometer (PPS) provides an opportunity for new searches and measurements
- Possibility of a very strong background suppression using intact protons
- Outline
  1. Short description of PPS
  2. First physics results
  3. Prospects: Anomalous Couplings, Axion-Like Particles, etc.
CMS Precision Proton Spectrometer

- LHC magnets bend scattered protons outside of the beam envelope
- Detect protons at about ± 200 m from IP5
- Near and far stations on both sides
- Reconstruct $\xi = 1 - p_f / p_i$
- Central system mass acceptance $350 \text{ GeV} < M_X < 2 \text{ TeV}$
- Collected $\sim 10 \text{ fb}^{-1}, 40 \text{ fb}^{-1}, 58 \text{ fb}^{-1}$ in 2016, 2017, 2018 respectively

https://cds.cern.ch/record/1753795
Layout of PPS
Detectors - Year By Year

2016
- TOTEM silicon strip detectors
  - Single track capability

2017
- One station with silicon strips, one station with 3D pixels
  - Pixel detectors with multi-tracking capability
  - UFSD timing (one per side)

2018
- All stations with 3D pixel detectors
  - 3D pixel detectors
  - Diamond timing detectors (one per side)
PPS Alignment

Alignment Procedure

- RP moved very close to beam for alignment fill
- Use low luminosity, elastic runs for reference
- Correct physics run to reference runs
- Full documentation at CERN-TOTEM-NOTE-2017-001
Available Phase Space

CMS+TOTEM Preliminary 2016, $\sqrt{s} = 13$ TeV

LHC Run-II, pre-TS2

$\beta^* = 0.4$ m

$\alpha_x = 370$ $\mu$rad

No acceptance

Acceptance in 210-N/F

Acceptance in 210-F

Double arm acceptance

$m(\text{central system}) = \sqrt{s_{1/2}}$ (GeV)

$Y(\text{central system}) = \frac{1}{2} \log(\xi_{1/2})$
Luminosity

40% of luminosity recorded

88% of luminosity recorded

92% of luminosity recorded
Dilepton Analysis

First observation of the process at high mass using intact protons

Observed 13 signal events (5.1σ) consistent with the SM expectation

Performed at normal optics and pileup conditions

Proof that the alignment, optics, trigger, proton tagging, etc are working
Anomalous Quartic Gauge Couplings

- Photon induced processes with intact protons in forward regions
- Exclusive processes with a very clean signal
- PPS provides the best sensitivity to anomalous couplings due to proton tagging
Motivations for AQGC

- Warped Extra Dimensions solve hierarchy problem of the SM
- Predicted by Composite Higgs, Kaluza Klein, Extra Dimensional models
- Couplings can be probed independently of models
- Effective 4-photon couplings $\zeta_i \sim 10^{-14} - 10^{-13}$ GeV$^{-4}$ possible
Backgrounds

- Requesting two protons identified in forward detectors + two converted photons in central detector
- All backgrounds considered (DPE diphoton production, $H \to \gamma\gamma$, exclusive $\gamma\gamma$ production, dilepton + dijet misidentification, PU, Drell-Yan, ...)
- Pileup is the main source of background
The LHC collides packets of protons

- PU causes interference from particles generated at unrelated vertices
- For conditions of the LHC in 2016, can have up to 60 PU vertices
Dealing with pileup

\[ \gamma \gamma \]

\[ p \]

\[ p \]

\[ \zeta_1 = 10^{-12} \text{ GeV}^4 \]

\[ \zeta_1 = 10^{-13} \text{ GeV}^4 \]

Events

\[ L = 300 \text{ fb}^{-1} \]

\[ \mu = 50 \]

\[ \tilde{t} = 14 \text{ TeV} \]

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Potential For Limits

Cross section scales as a function of the coupling values $\zeta_1, \zeta_2$

$$\frac{d\sigma}{d\Omega} = \frac{1}{16\pi^2 s} \left( s^2 + t^2 + st \right)^2 \left[ 48 (\zeta_1)^2 + 40 \zeta_1 \zeta_2 + 11 (\zeta_2)^2 \right]$$

- Based on 9.41 fb$^{-1}$ of data from 2016
- Assume signal and background obey a Poisson distribution
- Assume expected background is 0 and observed events is 0

$$\sqrt{48\zeta_1^2 + 40\zeta_1\zeta_2 + 11\zeta_2^2} \geq 5.8 \times 10^{-13}\text{GeV}^{-4}$$
Search For Axion-Like Particles

We can study the production of ALPs via photon exchange with intact protons

- Study the production of ALPs via photon exchange with intact protons
- Sensitivity is enhanced since ALP production rate increases with $m_{\gamma\gamma}$
- PPS provides sensitivity that is competitive and complimentary to other collider searches above 600 GeV
- Existing limits on ALP production$^1$

$^1$ JHEP 1806 (2018) 131
Summary

- With its 2016 operation, PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at a high luminosity hadron collider on a regular basis.
- First observation of $\gamma\gamma \rightarrow \ell\ell$ with single proton tag.
- Prospects for anomalous couplings, ALP searches, and more.
- PPS has $> 110$ fb$^{-1}$ and has plans for Run 3.
Questions?
Standard Model $\gamma\gamma$ Exclusive Production

- QED process dominates at high $m_{\gamma\gamma}$
- Cross section is well known
- $W$ boson loop is the most significant at high $m_{\gamma\gamma}$

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Dispersion Matrix

Proton kinematics defined by:
• transferred momentum, \( t \equiv (p_f - p_i)^2 \);
• fractional momentum loss, \( \xi \equiv (|p_f| - |p_i|)/|p_i| \).

Proton acceptance in the detectors depends on the machine optics parameters:
Leading terms for "standard" LHC optics:
• \( x \approx D_x(\xi) \xi \); 
• \( y \approx L_y(\xi) \Theta_y \).

Proton transport description:
\[ T = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \\ \xi^* \end{pmatrix}. \]