Light-by-light scattering and high mass dilepton production in UPC

Krzysztof Cieśla
on behalf of the ATLAS and CMS collaborations

11th Large Hadron Collider Physics Conference
22-26 May 2023
Photon-induced processes in heavy ions

- Accelerated particles surrounded by photons
- Equivalent photon approximation
- Photon-photon interactions possible in Pb+Pb collisions at the LHC
  - Cross-section scales with $Z^4$
  - Cleaner events (compared to $pp$)

$pp$ results @ TeV scale: see Anna’s talk
Motivation

- Various types of photon-photon interactions possible, including:
  - Light-by-light ($\gamma\gamma \rightarrow \gamma\gamma$) scattering:
    - Forbidden at tree-level
    - Tested indirectly in electron/muon g-2 measurements
    - Clean channel to study anomalous gauge couplings and BSM searches
  - Dilepton ($\gamma\gamma \rightarrow l^+l^-$) production:
    - Abundant rate → precision test of QED and initial photon flux modelling
    - Background for other processes
ATLAS and CMS detectors
Measurement of light-by-light scattering


Main background:
- Central exclusive production \( gg \rightarrow \gamma\gamma \)
- Misidentified electrons from \( \gamma\gamma \rightarrow ee \)
- Dedicated control regions used

Integrated fiducial cross-section:
- Measurement: \( \sigma_{fid} = 120 \pm 46 \) (stat.) \( \pm 28 \) (syst.) \( \pm 12 \) (theo.) nb
- Prediction\(^a\): \( \sigma_{fid} = 116 \pm 12 \) (stat.) nb

\(^a\)PRL 111, 080405 (2013)
Measurement of light-by-light scattering

\[ \sigma_{fid} = 120 \pm 17(\text{stat.}) \pm 13(\text{syst.}) \pm 4(\text{lumi.}) \text{ nb} \]

- Measurement:
- SuperChic prediction: 78 ± 8 nb
- Data to SuperChic ratio: 1.54 ± 0.32

Differential cross-section:
- Uncertainties dominated by statistics
- No significant differences between predictions and data
Measurement of light-by-light scattering

- Combining ATLAS+CMS measurements in a „common” fiducial phase-space
- The averaged cross-section consistent within about two standard deviations with the SM predictions

\[
Pb + Pb (\gamma\gamma) \rightarrow Pb^{(*)} + Pb^{(*)} \gamma\gamma \text{ at } \sqrt{s_{NN}} = 5.02 \text{ TeV}
\]

ATLAS, \(L_{\text{int}} = 2.2 \text{ nb}^{-1}\)
JHEP 03 (2021) 243

CMS, \(L_{\text{int}} = 0.39 \text{ nb}^{-1}\)

**Average**
\(L_{\text{int}} = 2.6 \text{ nb}^{-1}\)

\[\sigma_{\text{meas.}}^{\text{fid.}} \text{ [nb]}\]

\[
\begin{align*}
\text{ATLAS} & : 120 \pm 17 \pm 14 \\
\text{CMS} & : 91 \pm 36 \pm 24 (\dagger) \\
\text{Average} & : 115 \pm 15 \pm 11 \\
\end{align*}
\]

(\dagger) Scaled to fiducial region
Axion-like particle search
JHEP 03 (2021) 243

- Main background: $gg \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow l^+l^-$, SM $\gamma\gamma \rightarrow\gamma\gamma$
- MC prediction with STARlight
- ALP mass range: 5-90 GeV (CMS) and 6-100 GeV (ATLAS)

* Does not include newest $pp$ results: arXiv:2304.10953
$\gamma \gamma \rightarrow \tau \tau$ production


- First observation of $\gamma \gamma \rightarrow \tau \tau$ production in hadron collisions by ATLAS and CMS.
- Targets $\mu + 3$prong (CMS) or $\mu + 3$prong, $\mu + 1$prong and $\mu + e$ (ATLAS) decays
- CMS: $\sigma_{fid} = 4.8 \pm 0.6 (\text{stat.}) \pm 0.5 (\text{syst.}) \text{ mb}$
- ATLAS: $\mu_{\tau \tau} = 1.03^{+0.06}_{-0.05}$
Constraints on $\tau$ anomalous magnetic moment


- $a_\tau = (g_\tau - 2)/2$ poorly constrained experimentally $\rightarrow$ can be sensitive to BSM
- ATLAS and CMS provide their first constraints on $a_\tau$
- ATLAS precision competitive with DELPHI@LEP limits

![Graph showing constraints on $a_\tau$](image-url)
Background: dissociative dimuon production $\gamma\gamma \rightarrow \mu\mu$ production

- Background: dissociative dimuon production $\rightarrow$ emission of forward neutrons $\rightarrow$ importance of ZDC
- Presence of forward neutrons affects the impact parameter dependence of the two-photon flux
- Modelling with STARlight+Pythia (FSR) and LPair (dissociation)
$\gamma\gamma \rightarrow \mu\mu$ production


- Measurement:
  $\sigma_{fid} = 34.1 \pm 0.3 \text{ (stat.)} \pm 0.7 \text{ (syst.)} \, \mu b$
- STARlight: 32.1 $\mu b$ + Pythia: 30.8 $\mu b$
- Hints of larger fluxes of photons in the initial state
First measurement of the dependence of $\gamma\gamma \rightarrow \mu\mu$ production on the multiplicity of forward neutrons

CMS observes a significant impact parameter dependence of the initial photon $p_T$ (not grasped by STARlight)
• Similar techniques as in ATLAS $\mu\mu$ UPC measurement, but with notable advances:
  • Higher statistics from 2018 data
  • Extended fiducial region
• $\sigma_{fid} = 215 \pm 1^{stat.} + 23^{syst.} - 20^{lumi.} \mu$b
• STARlight: 196.9 $\mu$b, SuperChic: 235.1 $\mu$b
Summary

- Rich physics programme of UPC collisions at the LHC
- Standard Model tests:
  - Observation of LbyL scattering
  - Measurement of $\gamma \gamma \rightarrow ll$ processes
  - First constrains on anomalous magnetic moment $a_T$
- BSM searches:
  - The best limits on ALP production in mass range 5-100 GeV
- Very good prospects for LHC Run3 and beyond
Backup