New measurements on Photon-Photon interactions

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On behalf of ATLAS and CMS collaboration
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Photon-photon interactions

Exclusive dilepton production

- Precision QED measurement
- Measure incoming photon fluxes

Light-by-light scattering

- Rare process proceeds through charged loop in SM, sensitive to BSM
  - Constrain on axion-like-particle models.
  - Limits on anomalous four-photon coupling at high masses in proton-proton collision.

Exclusive W production

- Observation of rare SM process
- Measure quartic gauge boson coupling in proton-proton collision.

Exclusive production:
- No other particles in the final state.
- Intact protons (ions) in the final states (semi-exclusive: if proton(ion) p*(Pb*) dissociate).

Results on proton-proton collision covered by Christophe Royon

New measurements on photon-photon interactions
ATLAS and CMS detectors

- ZDC: $|\eta| > 8.3$ detect neutrons (e.g., Pb dissociation)
- AFP/CT-PPS: Roman pots to tag the slightly deflected proton

New measurements on photon-photon interactions
Exclusive dimuon production in PbPb collision

New measurements on photon-photon interactions
Exclusive dilepton production

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- Photon flux modeled by Equivalent photon approximation – impact parameter dependence of photon pT not considered.
- Produced dilepton system is back-to-back (acoplanarity \( \sim 0 \))

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Initial state effect or final state effect?

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Modification of dilepton pair in hadronic collision
Initial state effect or final state effect (QGP)?

- Described by lowest-order QED without medium effect
- Impact parameter dependence of initial photon $p_T$ considered.
- Better to study in UPC (without QGP medium).
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Excitation probability $\propto \frac{1}{(\text{impact parameter})^2}$

ZDC to classify dissociative events:
- 0n0n: no activity on both sides of ZDC
- Xn0n: activity on either side of the ZDC
- XnXn: activity on both sides

$0_{XnXn} < 0_{Xn0n} < 0_{0n0n}$


$\alpha$ distribution vs. neutron multiplicity at CMS

2018 PbPb data with 1.5 nb$^{-1}$ luminosity

- Core: Leading order QED
- Tail: FSR, multiple $\gamma$ interaction, $\gamma$ from one of the proton inside ion.
- Core $\alpha$ decoupled from tail

\[
\text{core : } c_1 e^{-\alpha/c_2 + c_3 \alpha^{0.25}},
\]
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\text{tail : } t_1 [1 + (t_2/t_3) \alpha]^{-t_3},
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**α distribution vs. neutron multiplicity at CMS**

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- **5.7σ (5.0 σ)** neutron multiplicity dependence of \( <\alpha_{\text{core}}^n > \) (\( < m_{\mu\mu} > \))
- Impact parameter dependence on initial photon pT

New measurements on photon-photon interactions
a) Signal: Breit-Wheeler process implemented in STARLIGHT and SuperChic MCs
b) Signal: Higher order final state (FSR), does not exist in STARLIGHT/SuperChic, estimated from Pythia8
c) Dissociative background: Used LPair 4.0
Dimuon acoplanarity for various nuclear breakup topology: ATLAS

2015 PbPb data with 0.48 nb$^{-1}$ luminosity

a) **Signal: Breit-Wheeler** process implemented in STARLIGHT and SuperChic MCs

b) **Signal: Higher order final state (FSR)**, does not exist in STARLIGHT/SuperChic, estimated from Pythia8

c) **Dissociative background:** Used LPair 4.0

- 0n0n described well by STARLIGHT + Pythia8 where there is no ZDC activity
- Xn0n, XnXn: Included LPair, gives better description where there is ZDC activity.
Data vs. STARLIGHT for $|y_{\mu\mu}|$ and initial photon energy: ATLAS

- Measured cross-section is consistent with STARLIGHT near dimuon rapidity $|y_{\mu\mu}| = 0$
- Excess in data increases with $|y_{\mu\mu}|$

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- Measured cross-section is consistent with STARLIGHT near dimuon rapidity $|y_{\mu\mu}| = 0$
- Excess in data increases with $|y_{\mu\mu}|$
- Incoming photon energies estimated $k_{1,2} = (1/2)m_{\mu\mu}\exp(\pm y_{\mu\mu})$
- Ratio unity ~ 10-20 GeV, Systematic differences observed at low and high $k_{1,2}$
Simultaneous fit to acoplanarity distribution performed to extract ZDC fractions

STARLIGHT MC over predict the rate of forward activity

Use of this measurement will allow for improved modeling of photon fluxes and reduction of uncertainties for measurements of rarer processes!
Light-by-light scattering
Evidence for light-by-light ($\gamma\gamma \rightarrow \gamma\gamma$) scattering provided by ATLAS and CMS using 2015 PbPb data with luminosity 480 $\mu$b$^{-1}$ and 390 $\mu$b$^{-1}$.

Exclusive $\gamma\gamma \rightarrow \gamma\gamma$ sensitive to physics signals beyond the SM such as axion-like particles.

Observed $\gamma\gamma \rightarrow \gamma\gamma$ 8.2$\sigma$ by ATLAS using 2018 PbPb data with luminosity 1.7 nb$^{-1}$.

ATLAS: 2015 + 2018 differential measurement in this talk.


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- ATLAS 2015+ 2018 PbPb data, luminosity 2.2 nb⁻¹
- Two photons with $p_T > 2.5$ GeV
- Diphoton invmass $m_{\gamma\gamma} > 5$ GeV

- **Reduce background from $\gamma\gamma \rightarrow e^+e^-$**
  - Veto on tracks with $p_T > 100$ MeV
  - Veto on pixel tracks with $p_T > 50$ MeV with 0.5 eta of photon

- **Reduce background from calorimeter noise and cosmic**
  - Diphoton $p_T(\gamma\gamma) < 1$ GeV for $m_{\gamma\gamma} < 12$ GeV
  - Diphoton $p_T(\gamma\gamma) < 2$ GeV for $m_{\gamma\gamma} > 12$ GeV

- **Reduce background from gg $\rightarrow \gamma\gamma$**
  - $A_\Phi : (1-\Delta\Phi/\Pi) < 0.01$

- Measured fiducial cross-section
  - $120 \pm 17$ (stat.) $\pm 13$ (syst.) $\pm 4$ (lumi.) nb
  - Superchic MC: $78 \pm 8$ nb
  - Data to theory ratio: $1.5 \pm 0.32$

Unfolded differential cross section distributions. Overall normalization disagreement.
Search for axion like particles: ATLAS and CMS

- The measured diphoton invariant mass distribution used to search for pseudoscalar axion-like particles $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- ALP samples for masses generated from STARLIGHT
  - ATLAS: 6-100 GeV, CMS: 5-90 GeV
- No significant ALP excess observed in data above LbL+ backgrounds
- Cross-sections above 2 to 70 nb are excluded at the 95% CL in 6-100 GeV mass interval at ATLAS
- Most stringent constraint in this mass region by PbPb UPC at LHC
Summary

- Observed strong $b$ dependence of $\langle \alpha^{\text{core}} \rangle$
- $b$ dependence on initial photon $p_T$
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- $b$ dependence on initial photon $p_T$
- Systematic differences between data and STARLIGHT observed.
- Important input for precise photon flux estimation.
Summary

- Observed strong dependence of \( \alpha^{\text{core}} \)
- \( b \) dependence on initial photon pT
- Systematic differences between data and STARLIGHT observed.
- Important input for precise photon flux estimation.
- Observation of light-by-light scattering.
- Most stringent constraint on ALPS by PbPb UPC.
New measurements on photon-photon interactions
2018 PbPb data with 1.5 nb\(^{-1}\) luminosity

- Core: Leading order QED
- Tail: FSR, multiple \(\gamma\) interaction, \(\gamma\) from one of the proton inside ion.
- Core \(\alpha\) decoupled from tail
- Data: \(\langle \alpha^{\text{core}} \rangle = (1227 \pm 7 \text{ (stat)} \pm 8 \text{ (syst)}) \times 10^{-6}\)
- STARLIGHT: \(1350 \times 10^{-6}\)

New measurements on photon-photon interactions
Data vs. STARLIGHT for $m_{\mu\mu}$: ATLAS

- Overall increase in data for higher $|y_{\mu\mu}|$

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