New measurements on Photon-Photon interactions

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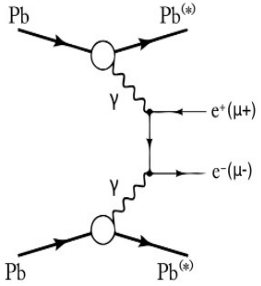
On behalf of ATLAS and CMS collaboration
8th June 2021

tifr
tata institute of fundamental research

9th Edition of the Large Hadron Collider Physics Conference

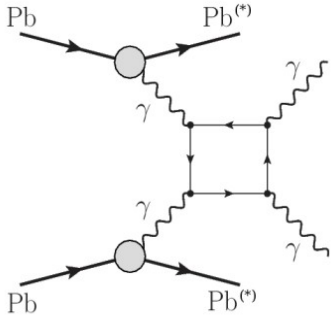
Photon-photon interactions

Exclusive dilepton production



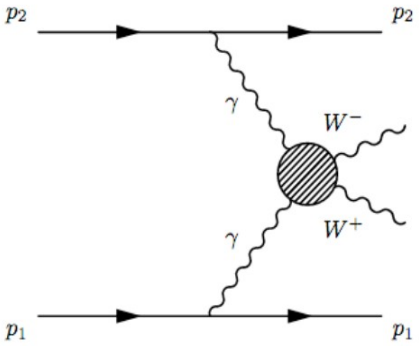
- Precision QED measurement
- Measure incoming photon fluxes

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.

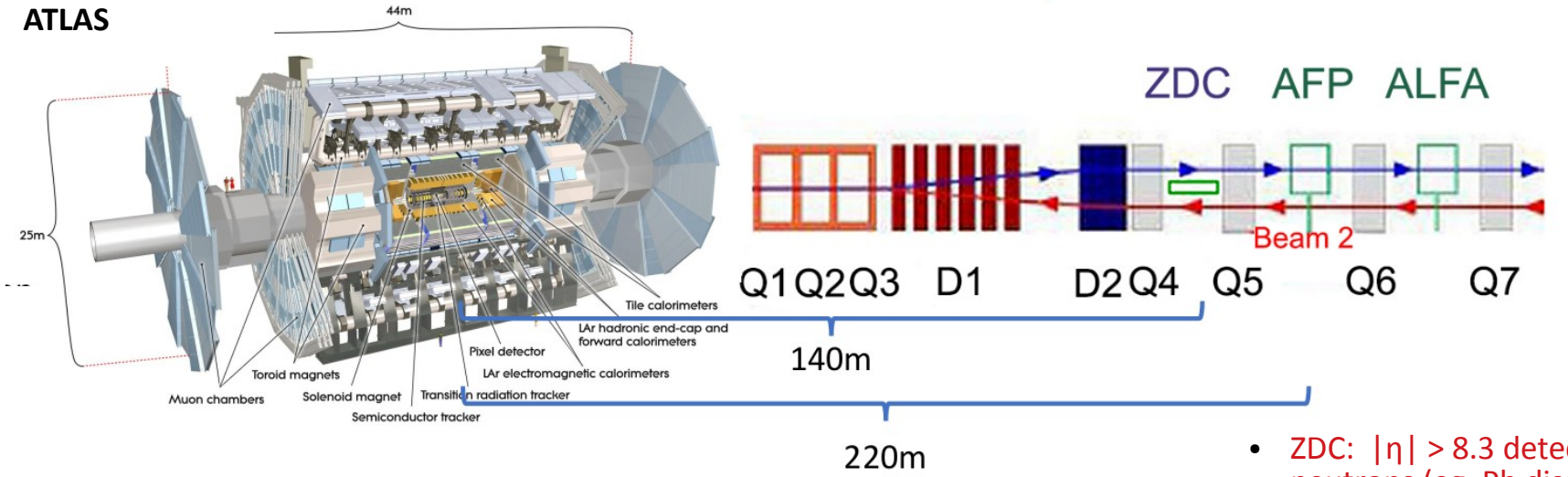
Exclusive production:

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

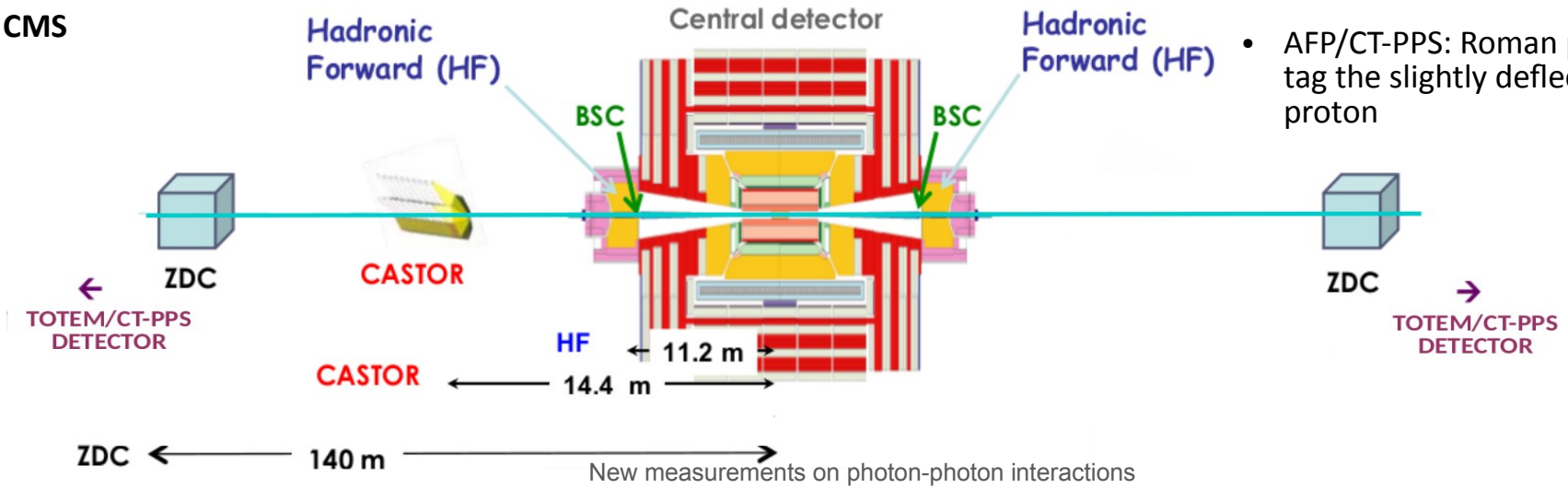
Results on proton-proton collision covered by Christophe Royon

ATLAS and CMS detectors

ATLAS

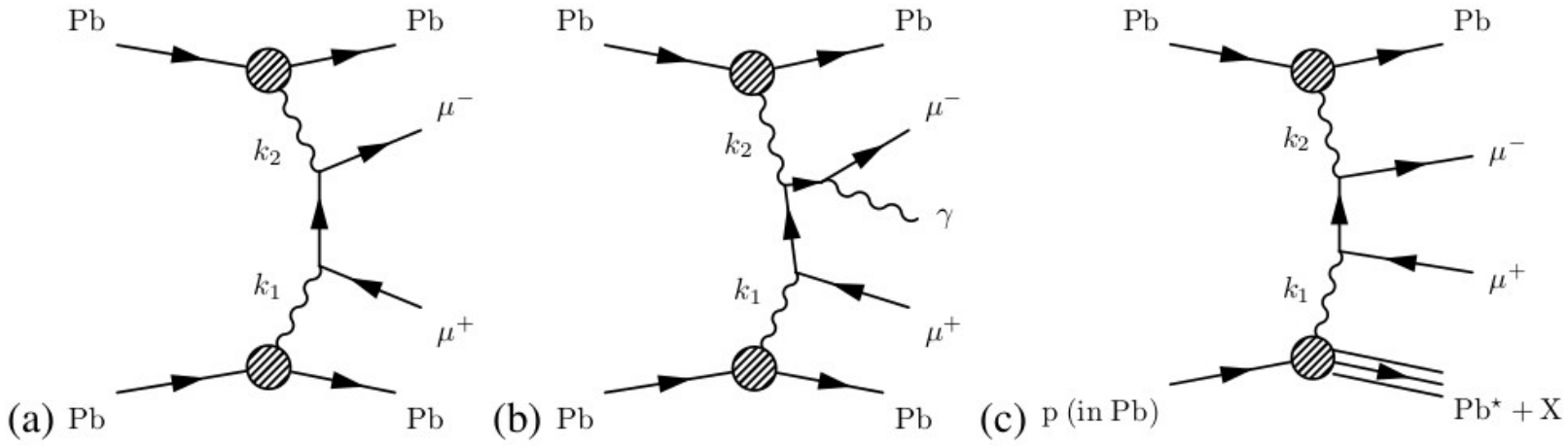


CMS

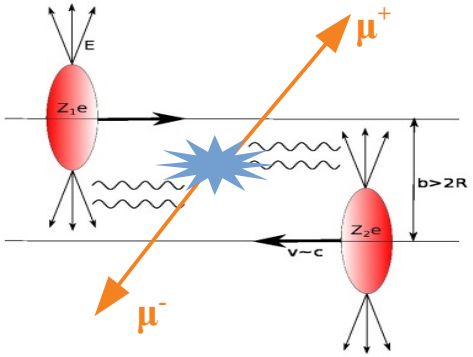


- ZDC: $|\eta| > 8.3$ detect neutrons (eg .Pb dissociation)
- AFP/CT-PPS: Roman pots to tag the slightly deflected proton

Exclusive dimuon production in PbPb collision



Exclusive dilepton production



- Electromagnetic field treated as quasi real photons.
  Quasi-real photons, Q ~ 1/R ~ 0.06 GeV (Pb)
- Photon flux modeled by Equivalent photon approximation
  – impact parameter dependence of photon pT not considered.
- Produced dilepton system is back-to-back (acoplanarity ~ 0)

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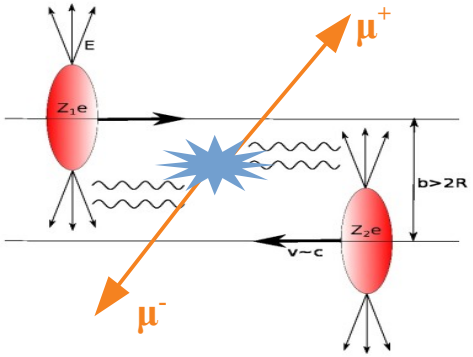

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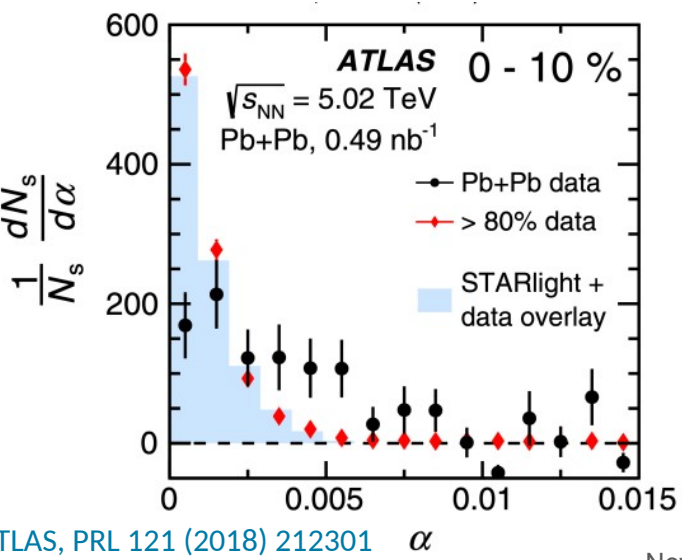
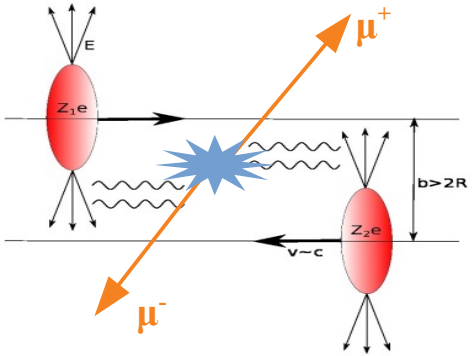
Modification of dilepton pair in hadronic collision
Initial state effect or final state effect?



ATLAS, PRL 121 (2018) 212301

Exclusive dilepton production



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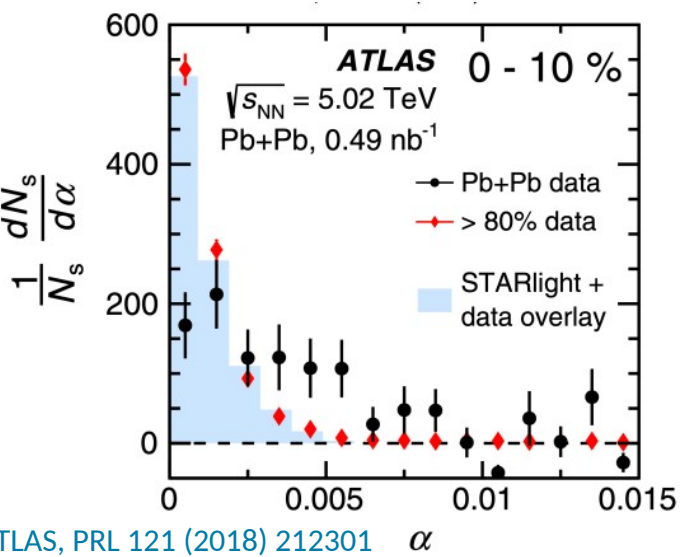
Modification of dilepton pair in hadronic collision
Initial state effect or final state effect (QGP) ?



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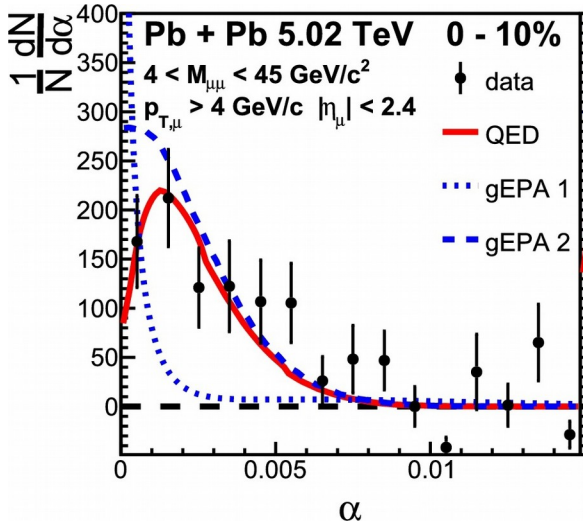
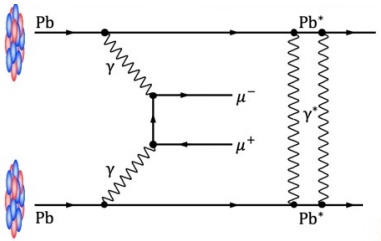


Zha et al., PLB 800 (2020) 135089

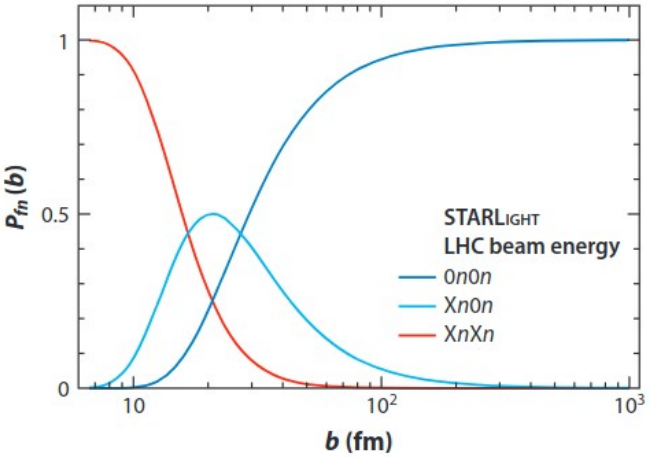
- Described by lowest-order QED without medium effect
- Impact parameter dependence of initial photon pT considered.
- Better to study in UPC (without QGP medium).

Control the impact parameter in UPC with ZDC

- In PbPb collisions, soft photon might excite Pb, leading to forward neutrons
- Excitation probability ∝ 1/ (impact parameter)^2



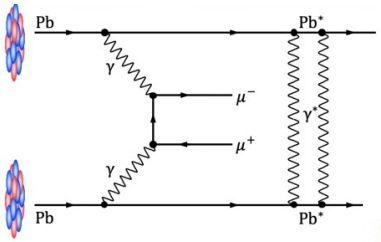
Ann. Rev. Nucl. Part. Sci. 70 (2020) 323



CMS, arXiv: 2011.05239

Control the impact parameter in UPC with ZDC

- In PbPb collisions, soft photon might excite Pb, leading to forward neutrons
- Excitation probability ∝ 1/ (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
  - $b_{XnXn} < b_{Xn0n} < b_{0n0n}$



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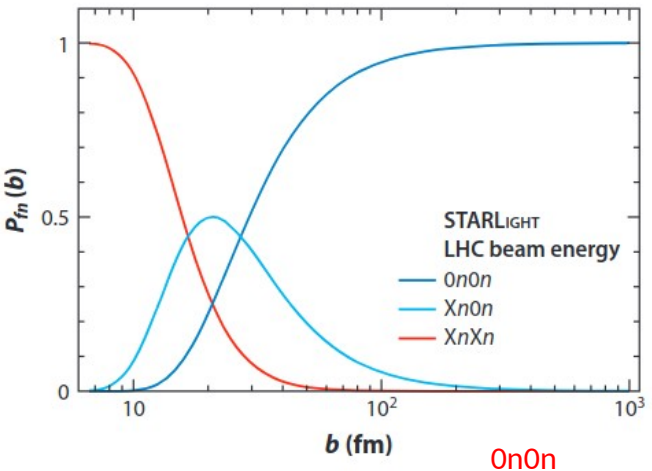

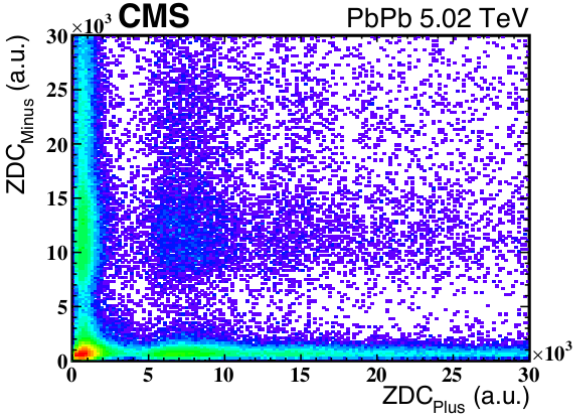

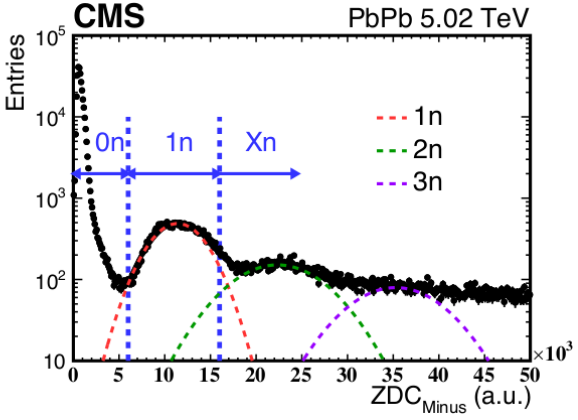

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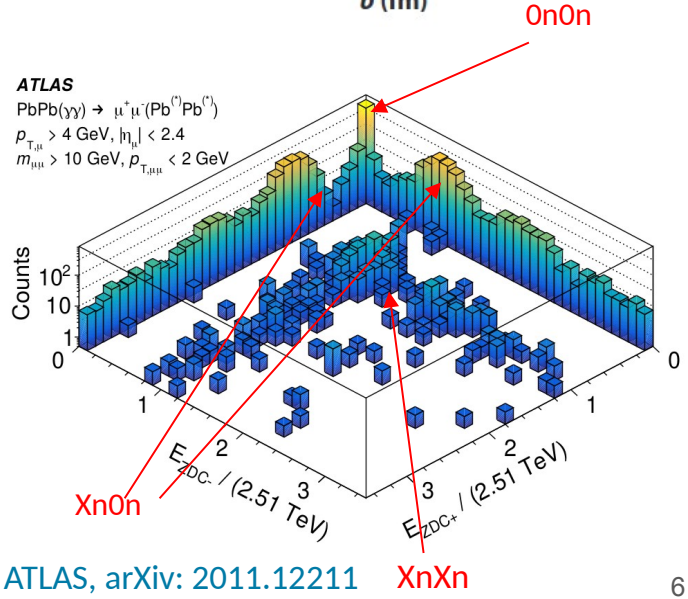

ATLAS, arXiv: 2011.12211

α distribution vs. neutron multiplicity at CMS

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

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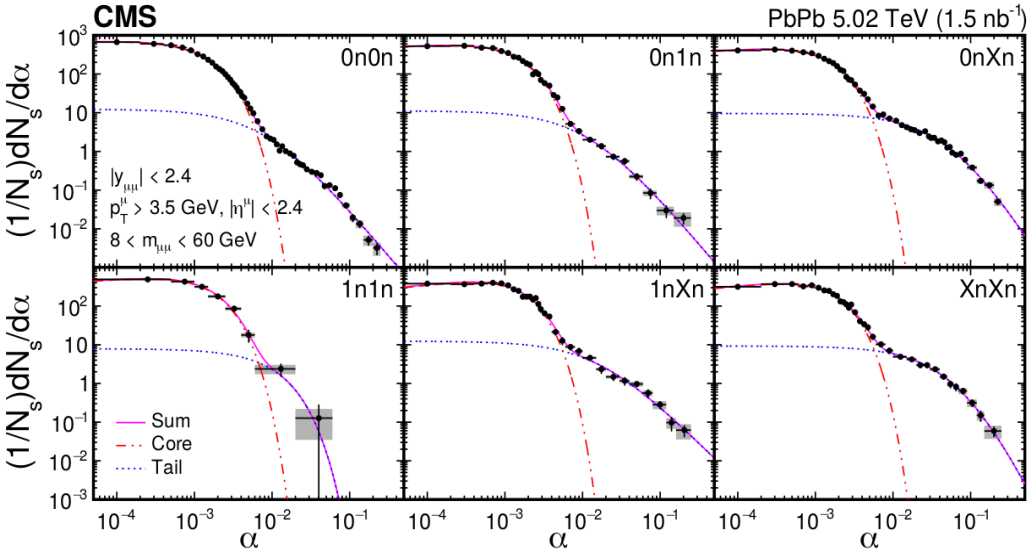

- Core: Leading order QED
- Tail: FSR, multiple γ interaction,
  γ from one of the proton inside ion.
- Core α decoupled from tail

$$\text{core} : c_1 e^{-\alpha/c_2 + c_3 \alpha^{0.25}},$$

$$\text{tail} : t_1 [1 + (t_2/t_3)\alpha]^{-t_3},$$

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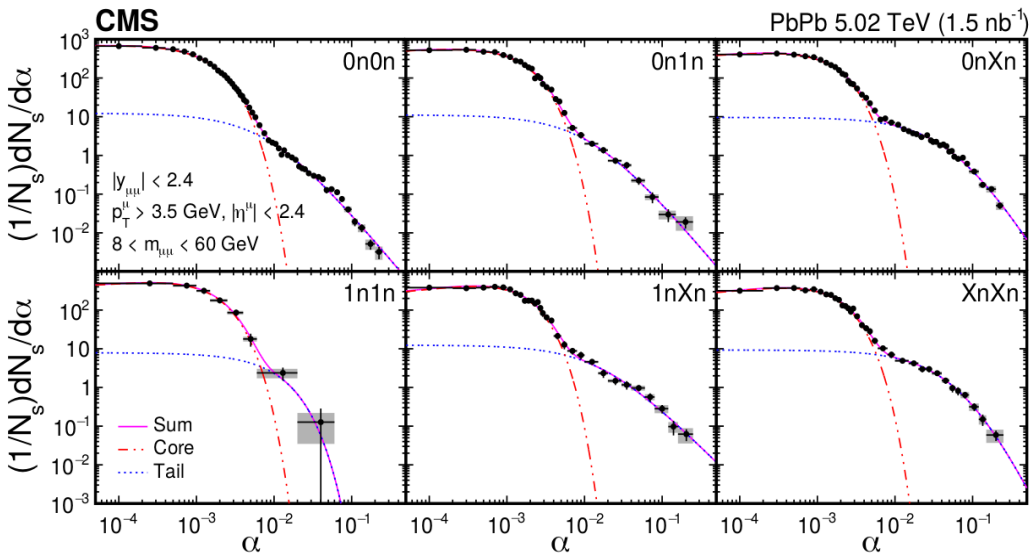

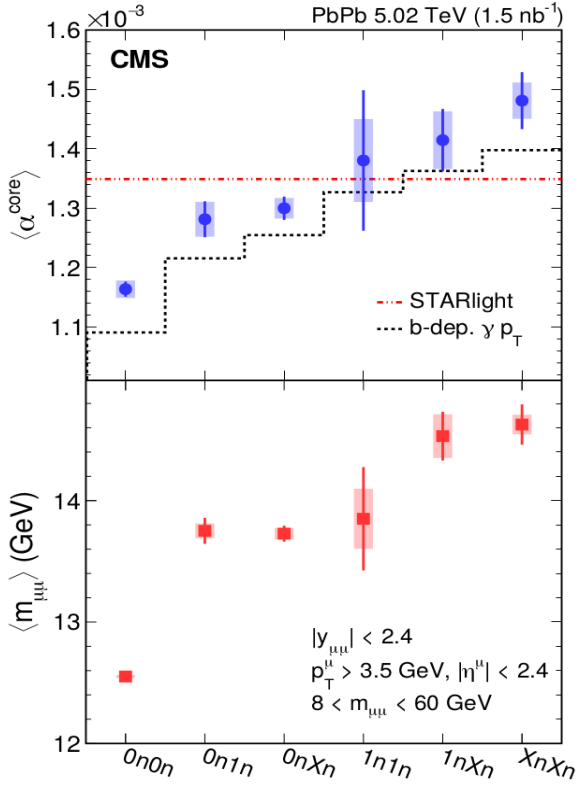

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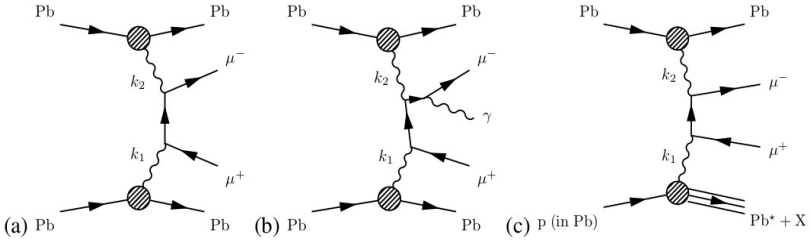
- **5.7σ (5.0 σ)** neutron multiplicity dependence of **$\langle\alpha^{core}\rangle$ ($\langle m_{\mu\mu} \rangle$)**
- Impact parameter dependence on initial photon pT

Dimuon acoplanarity for various nuclear breakup topology: ATLAS

ATLAS, arXiv: 2011.12211

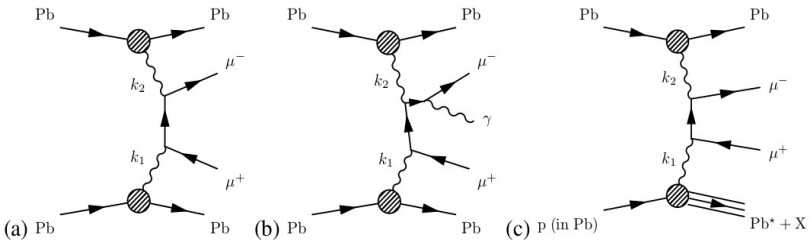


a) Signal: Breit-Wheeler process implemented in STARLIGHT and SuperChic MCs
b) Signal: Higher order final state (FSR) , does not exist in STARLIGHT/SuperChic, estimated from Pythia8
c) Dissociative background: Used LPair 4.0

Dimuon acoplanarity for various nuclear breakup topology: ATLAS

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

ATLAS, arXiv: 2011.12211



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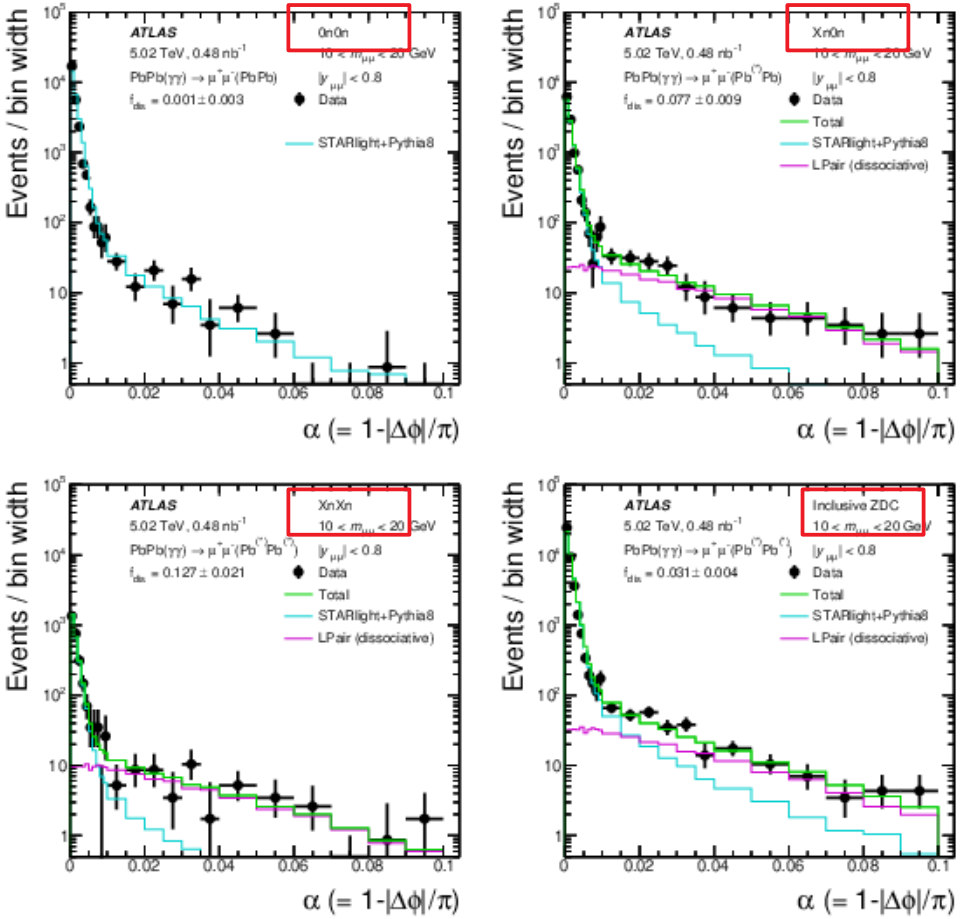
c) Dissociative background: Used LPair 4.0

- 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

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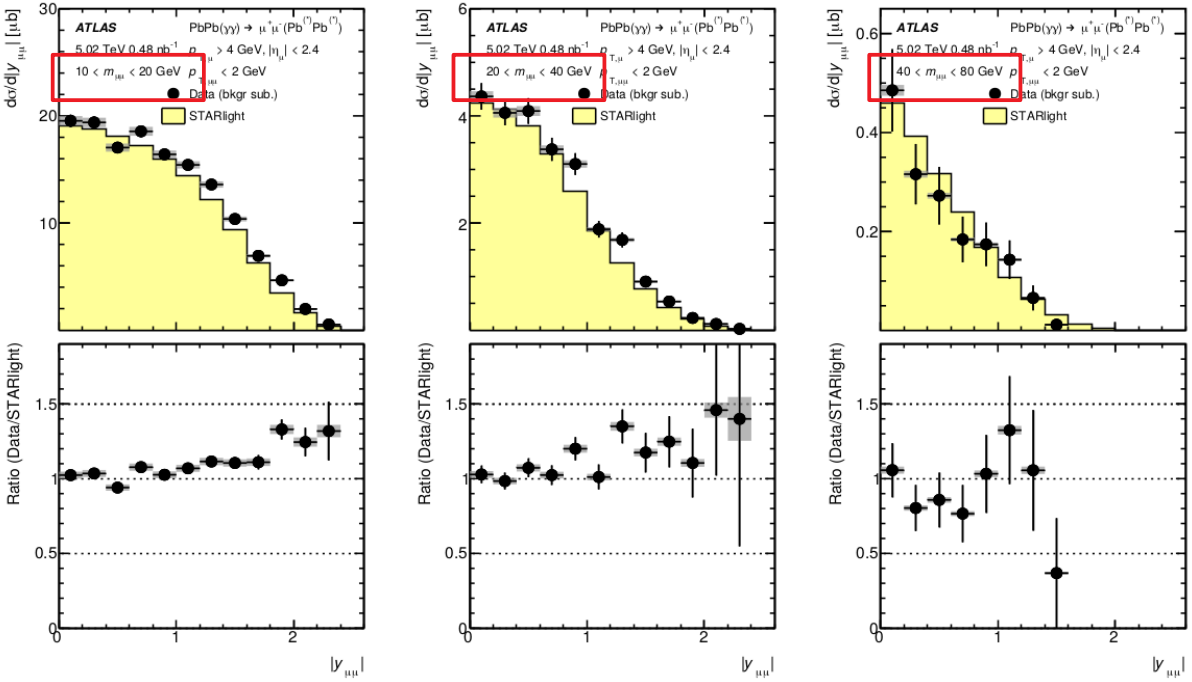

- Measured cross-section is consistent with STARLIGHT near dimuon rapidity $|y_{\mu\mu}| = 0$
- Excess in data increases with $|y_{\mu\mu}|$

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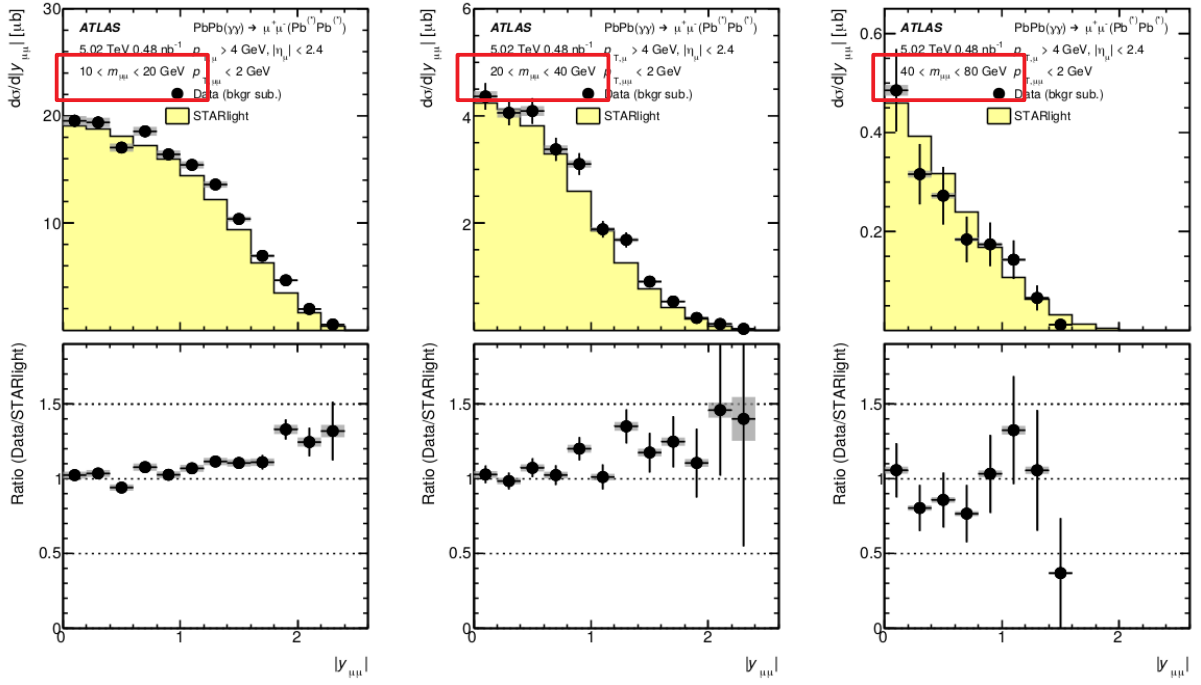

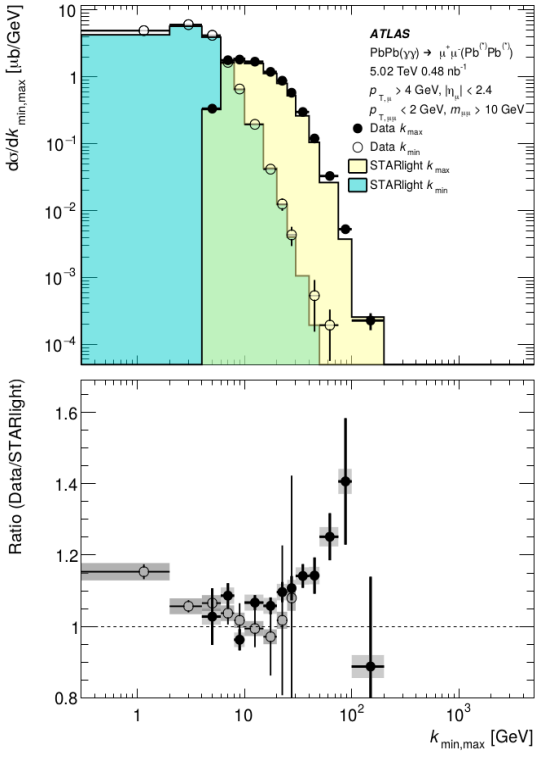

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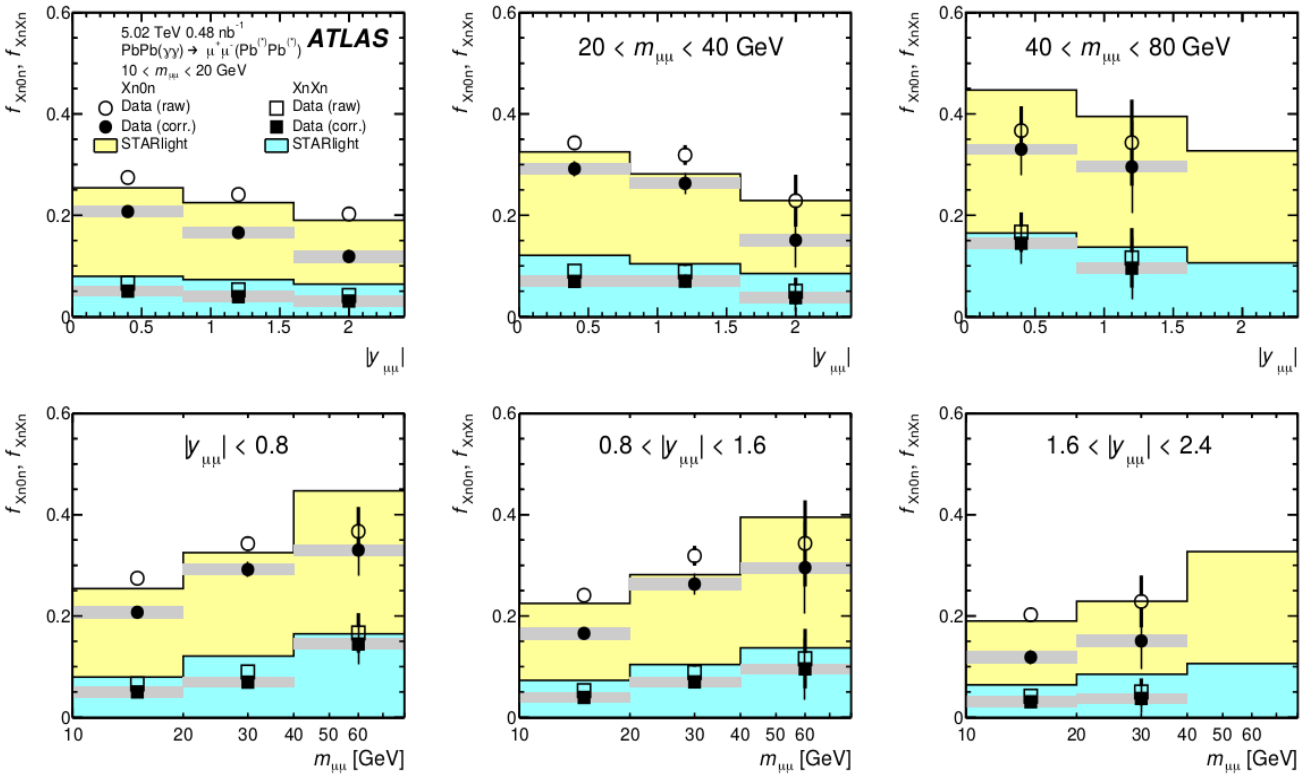
- Excess in data increases with $|y_{\mu\mu}|$

- Incoming photon energies estimated

$$k_{1,2} = (1/2) m_{\mu\mu} \exp(\pm y_{\mu\mu})$$

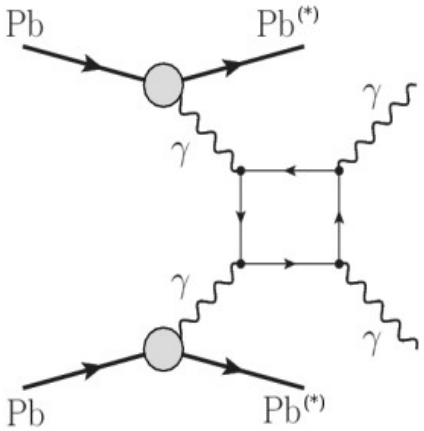
- Ratio unity ~ 10-20 GeV, Systematic differences observed at low and high $k_{1,2}$

ZDC fractions vs. $y_{\mu\mu}$ and $m_{\mu\mu}$



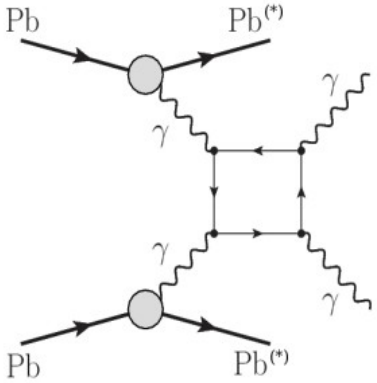
- Simultaneous fit to acoplanarity distribution performed to extract ZDC fractions
- STARLIGHT MC over predict the rate of forward activity
- Use of this measurement will allow for improved modeling of photon fluxes and reduction of uncertainties for measurements of rarer processes!

Light-by-light scattering

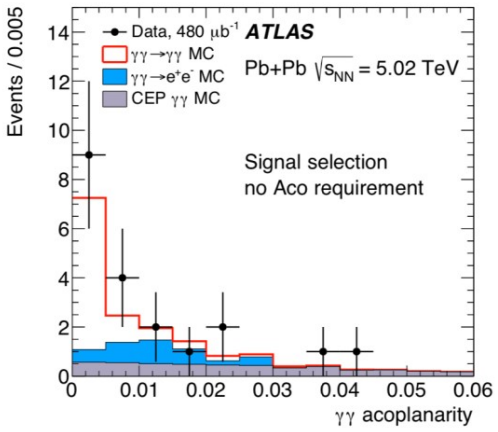


Light-by-light scattering

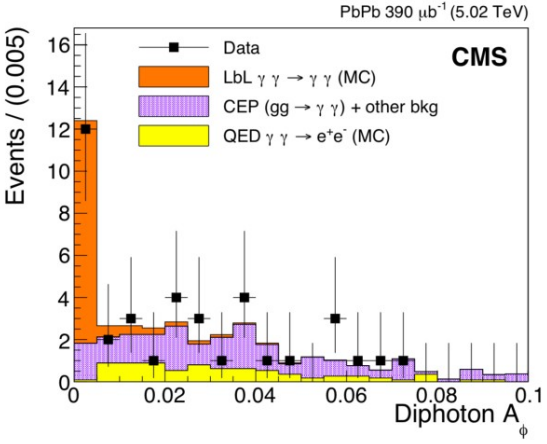
- Evidence for light-by-light (γγ → γγ) scattering provided by ATLAS and CMS using 2015 PbPb data with luminosity 480 μb^{-1} and 390 μb^{-1}
- Exclusive γγ → γγ sensitive to physics signals beyond the SM such as axion-like particles.
- Observed γγ → γγ 8.2σ by ATLAS using 2018 PbPb data with luminosity 1.7 nb^{-1}
- ATLAS: 2015 + 2018 differential measurement in this talk.



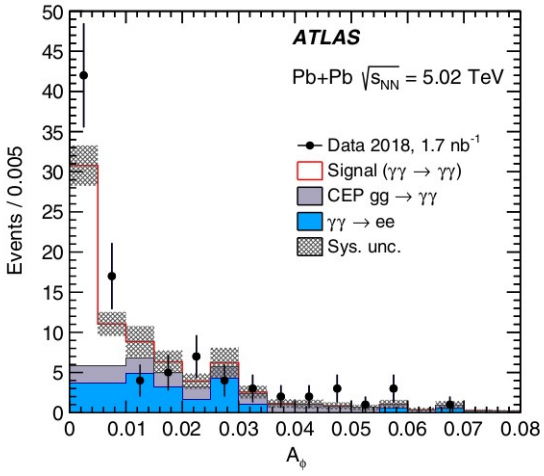
ATLAS Nature Phys 13 (2017) 852



CMS Phys Lett B 797 (2019) 134826

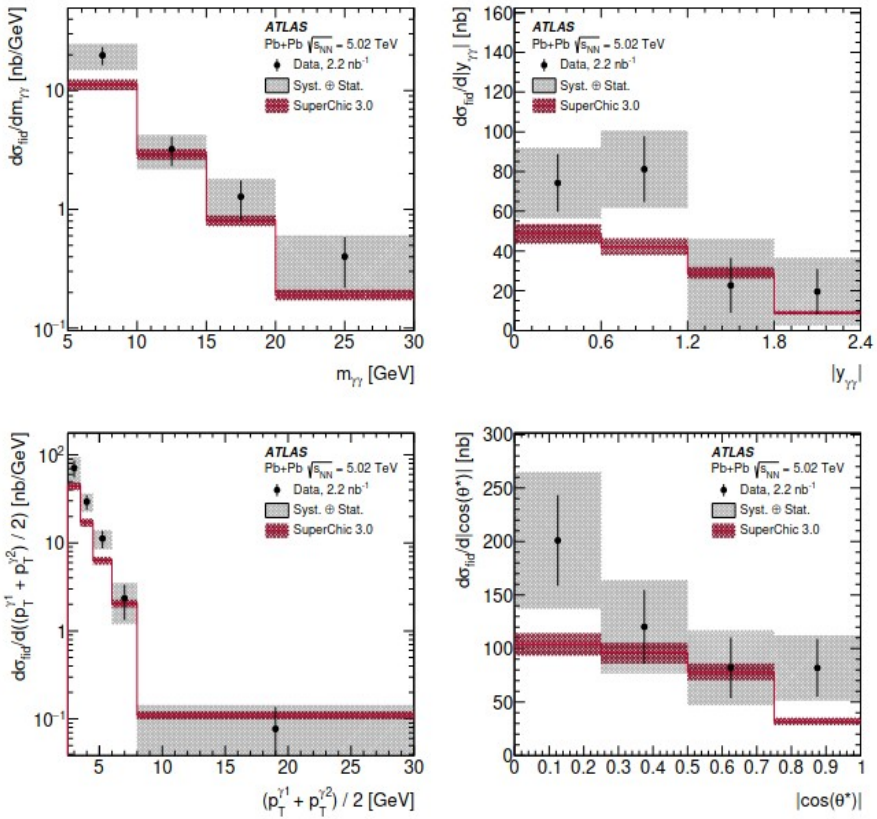


ATLAS Phys. Rev. Lett. 123 (2019) 052001



Light-by-light scattering : ATLAS (2015 + 2018)

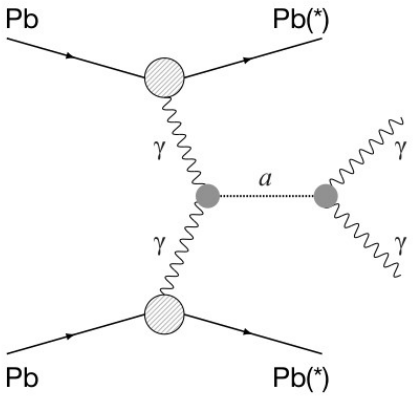
ATLAS JHEP 03 (2021) 243



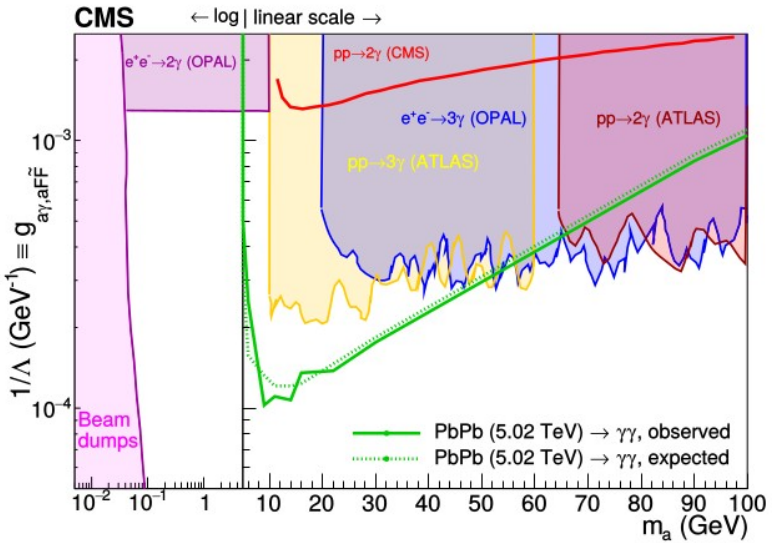
Unfolded differential cross section distributions.
Overall normalization disagreement.

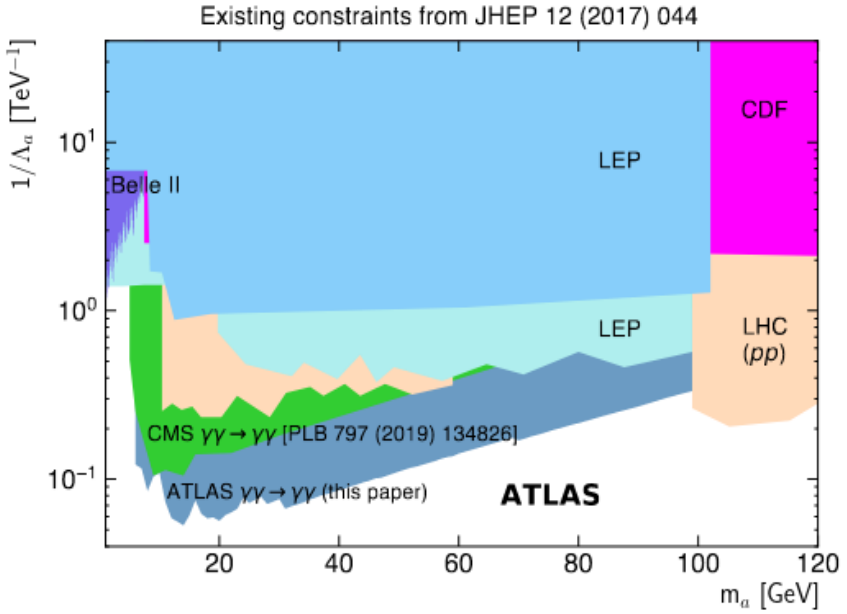
- ATLAS 2015+ 2018 PbPb data, luminosity 2.2 nb^{-1}
- Two photons with p_T > 2.5 GeV
- diphoton invmass $m_{\gamma\gamma}$ > 5 GeV
- **Reduce background from γγ → e^+e^-**
  - Veto on tracks with pT > 100 MeV
  - Veto on pixel tracks with pT > 50 MeV with 0.5 eta of photon
- **Reduce background from 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 → γγ**
  - A_Φ: $(1-\Delta\Phi/\Pi)$ < 0.01
- **Measured fiducial cross-section**
  120 ± 17 (stat.) ± 13 (syst.) ± 4 (lumi.) nb
  Superchic MC: 78 ± 8 nb
  Data to theory ratio: 1.5 ± 0.32

Search for axion like particles : ATLAS and CMS



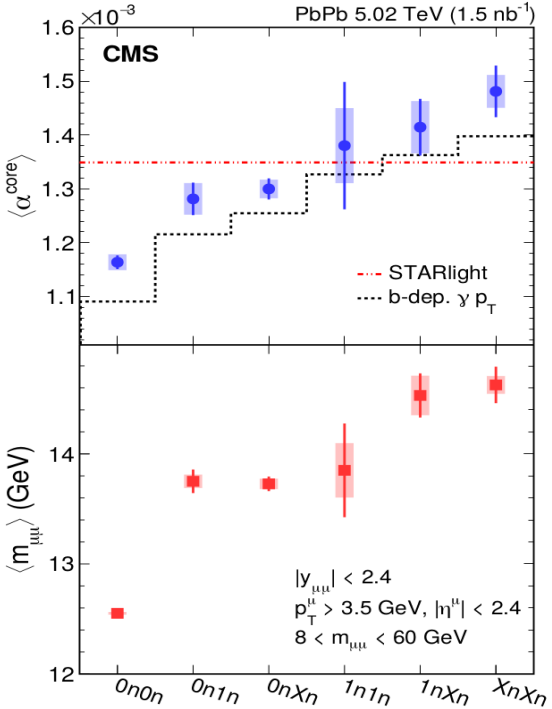
- The measured diphoton invariant mass distribution used to search for pseudoscalar axion-like particles γγ → a → γγ
- ALP samples for masses generated from STARLIGHT
  - ATLAS : 6-100 GeV , CMS : 5-90 GeV
- No significant ALP excess observed in data above LbL+ backgrounds
- Cross-sections above 2 to 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 $\langle\alpha^{core}\rangle$
- b dependence on initial photon pT



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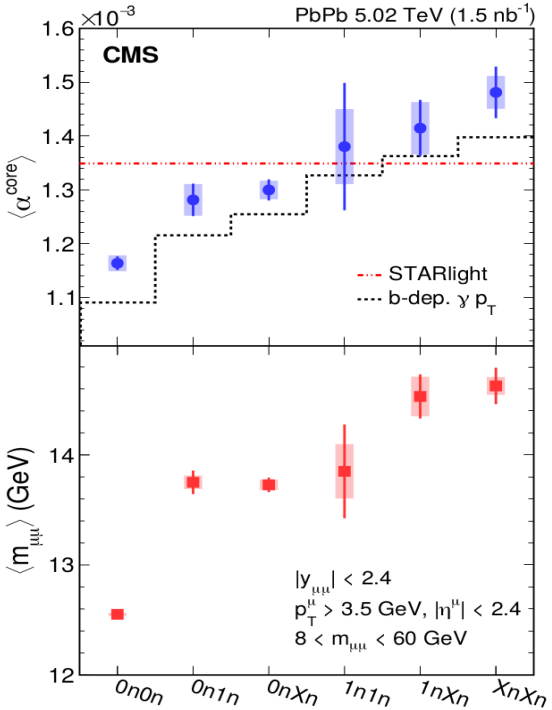
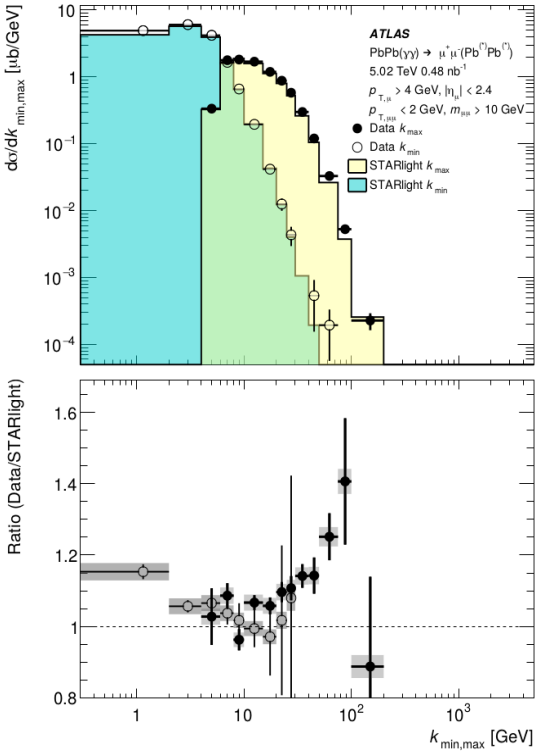


- Systematic differences between data and STARLIGHT observed.
- Important input for precise photon flux estimation.



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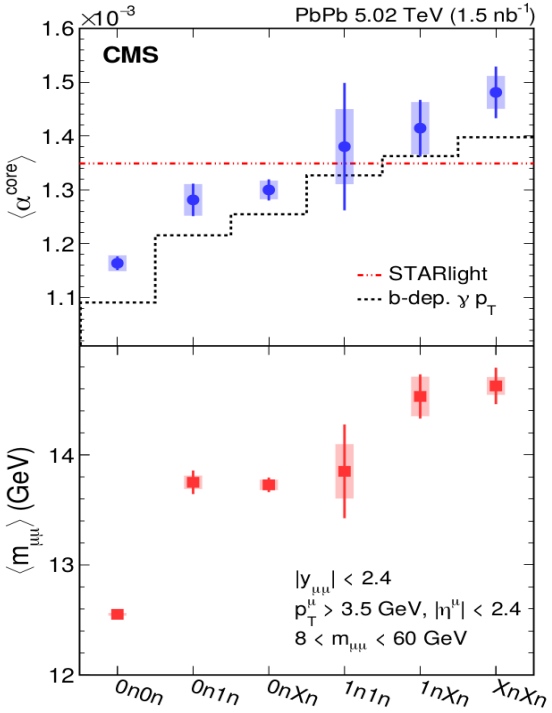
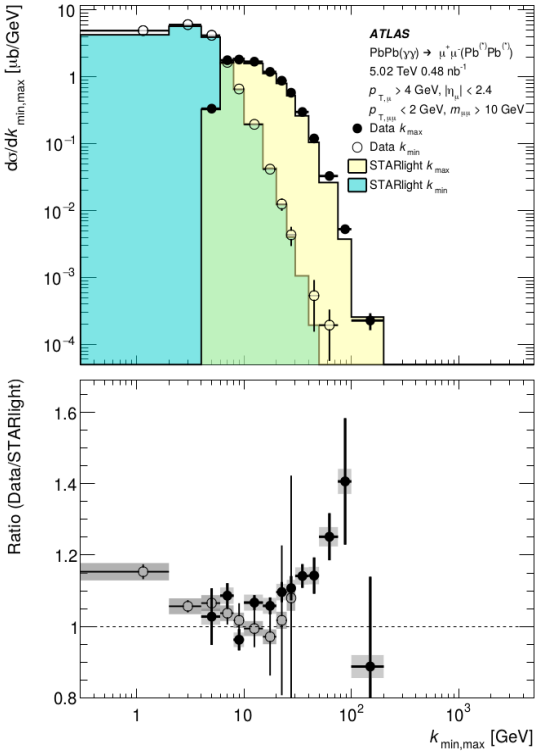
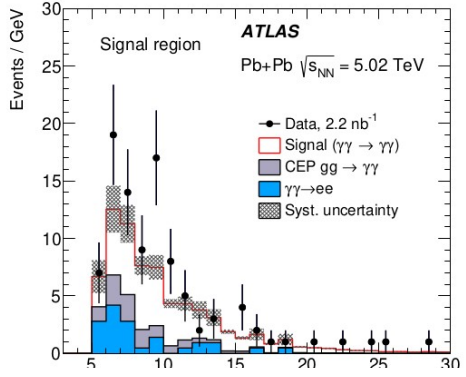
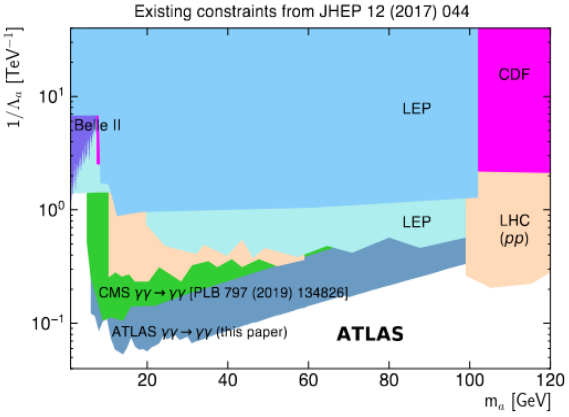


- Systematic differences between data and STARLIGHT observed.
- Important input for precise photon flux estimation.



- Observation of light-by-light scattering.
- Most stringent constraint on ALPS by PbPb UPC.



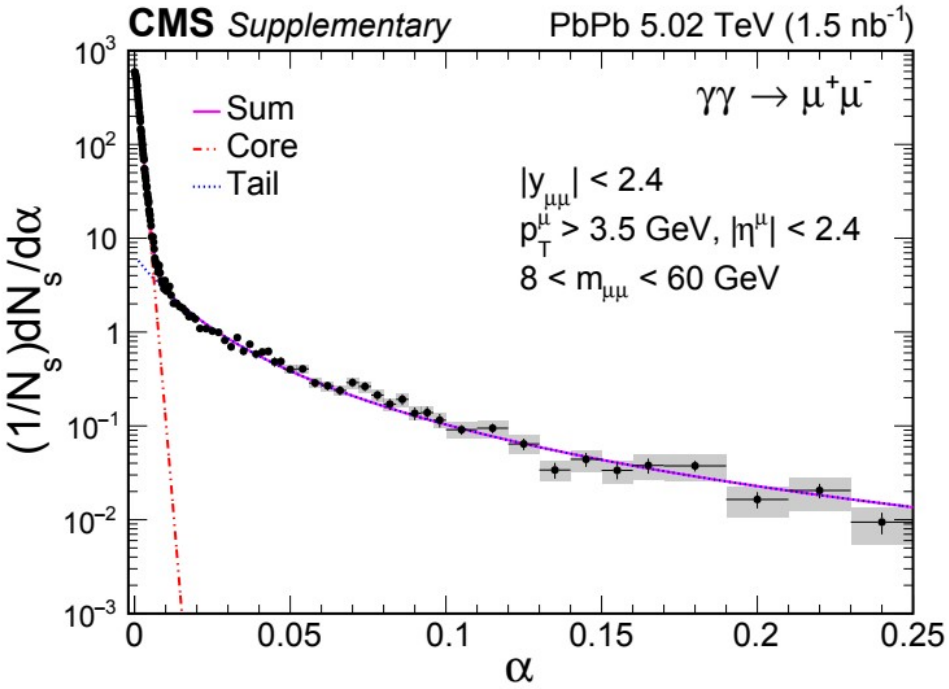


Backup

α distribution vs. neutron multiplicity at CMS

CMS, arXiv: 2011.05239

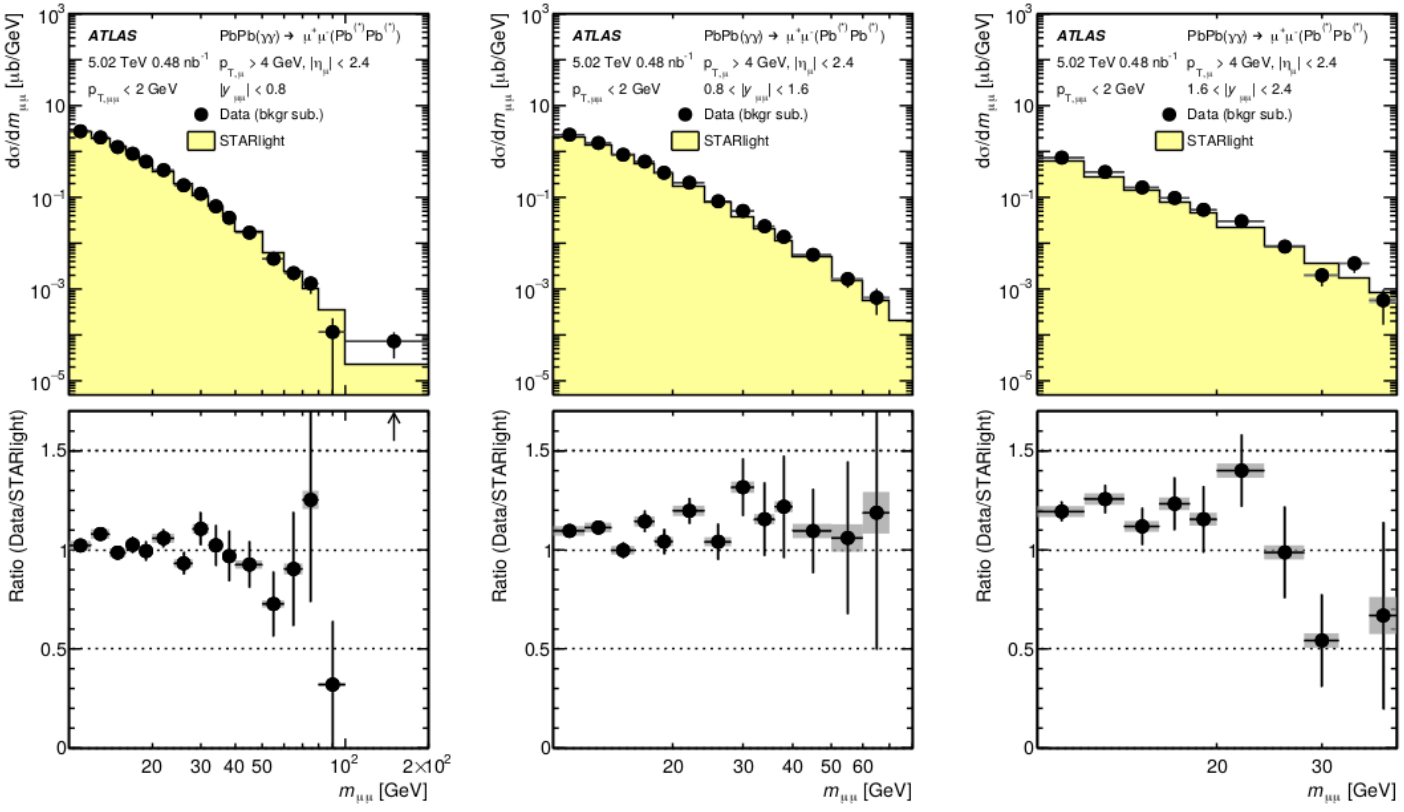
2018 PbPb data with 1.5 nb^{-1} luminosity



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

Data vs. STARLIGHT for $m_{\mu\mu}$: ATLAS

ATLAS, arXiv: 2011.12211



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