Diffractive and exclusive processes in heavy ion collisions with CMS

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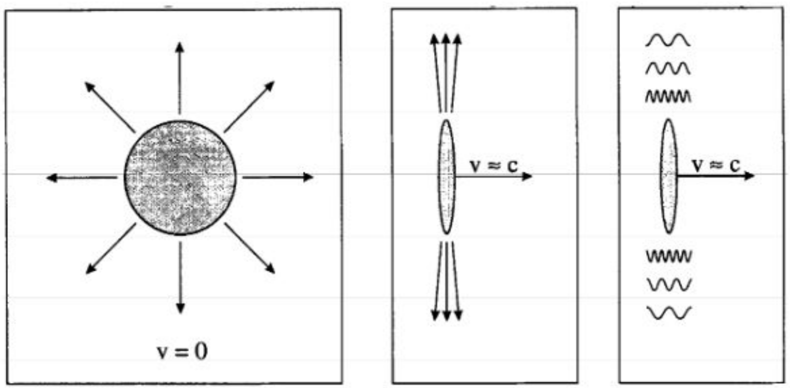
Photon exchange in ultrarelativistic heavy-ion collisions

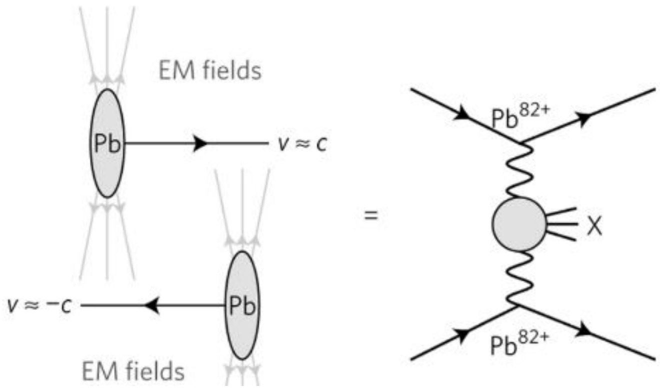
When b > 2R, there is no nuclear overlap.

Particles can still interact electromagnetically in this conguration!

Boosted charged particles are an intense source of photons.

Quasi-real photons in equivalent photon approximation (EPA) (*Weizsäcker-Williams* method).

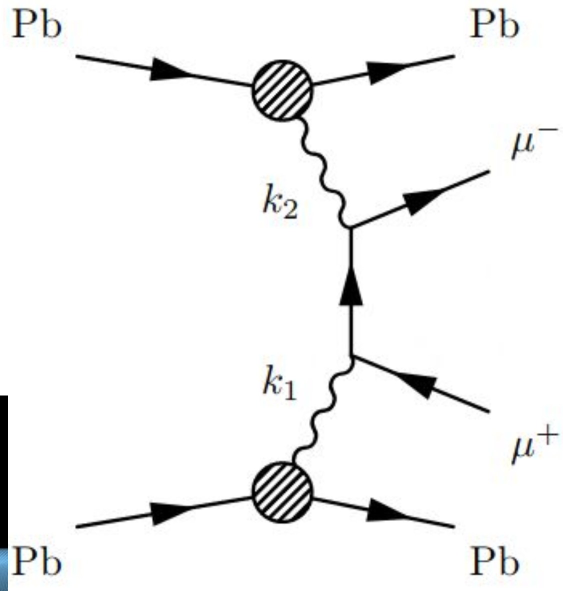




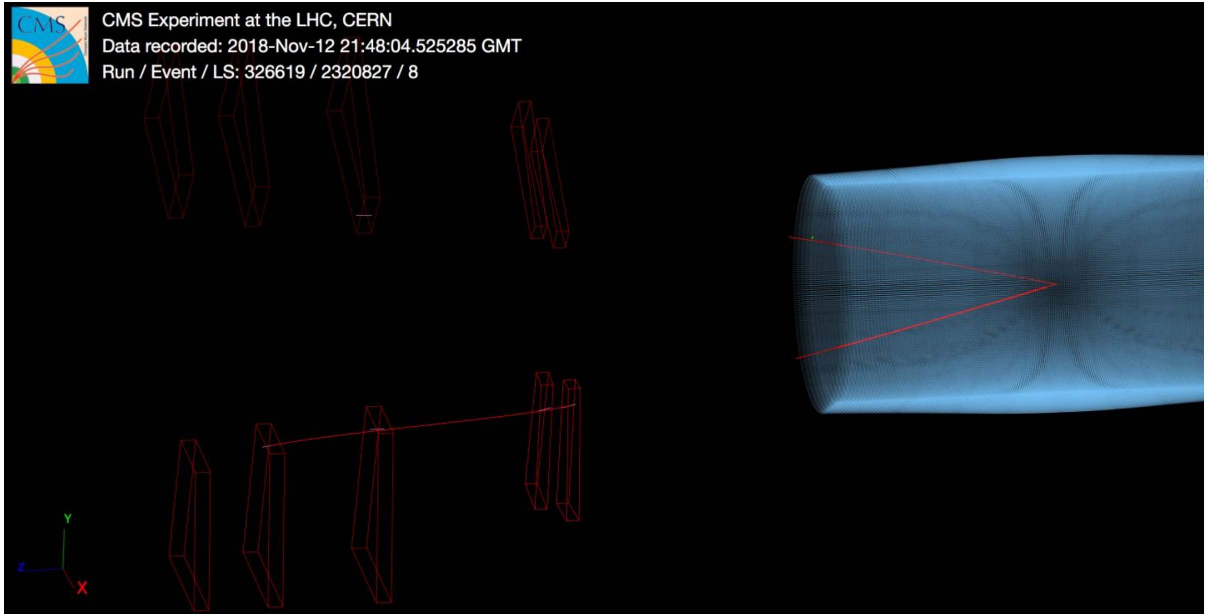
Exclusive dimuon production in PbPb collisions

Elementary QED process $\gamma\gamma \rightarrow \mu^+\mu^-$ → *Can be used as standard candle process.*

- Constrain photon flux modeling
- Sensitivity to higher-order effects (FSR, Coulomb interactions)

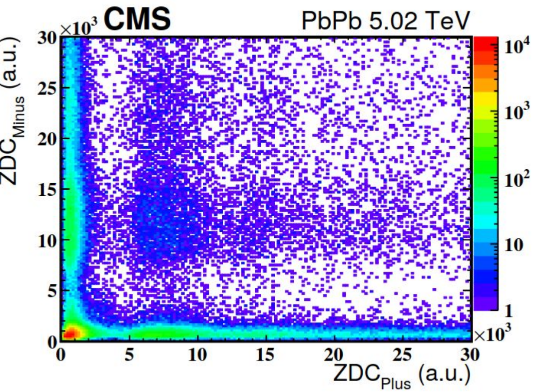


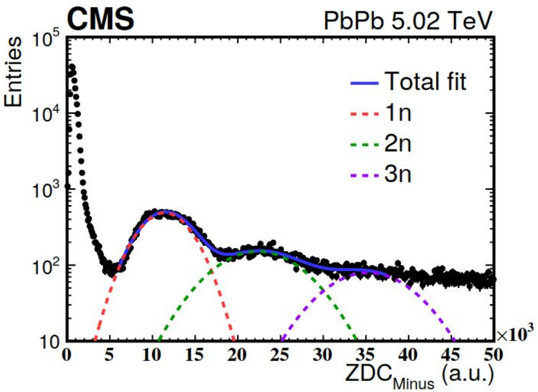
Clean experimental signature

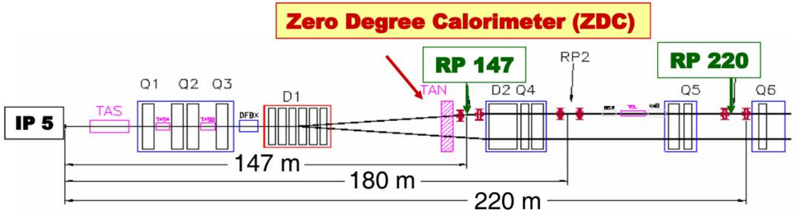


Forward neutron multiplicity ⇔ impact parameter "filter"

Softer photon-exchange in addition to hard scattering → forward neutrons from nuclear breakup
Events can be categorized w.r.t. Zero Degree Calorimeter (**ZDC**) activity (0n0n, 0nXn, XnX n, with X = 1, 2, ...)

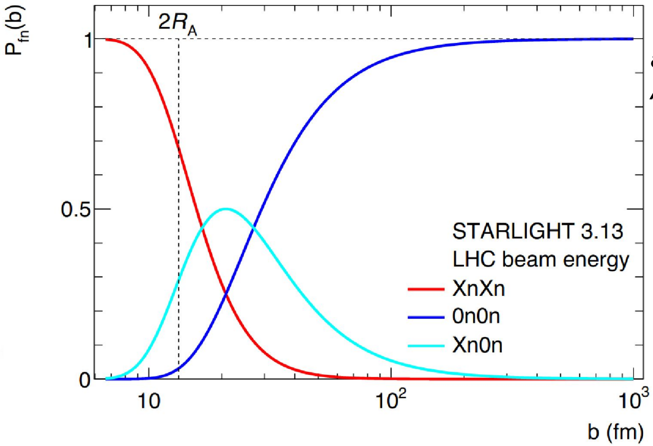






Phys. Rev. Lett. 127, 122001 (2021)

arXiv:2011.05239, Phys. Rev. Lett. 127, 122001 (2021)



arXiv:2005.01872, S. Klein, P. Steinberg, Ann. Rev. Nucl. Part. Sci. 70 (2020) 323

Selection of a specific ZDC topology is also filtering on a range of impact parameters.

Xn0n or XnXn select smaller impact parameters than 0n0n!

Significant dependence of impact parameter with forward neutron multiplicities.

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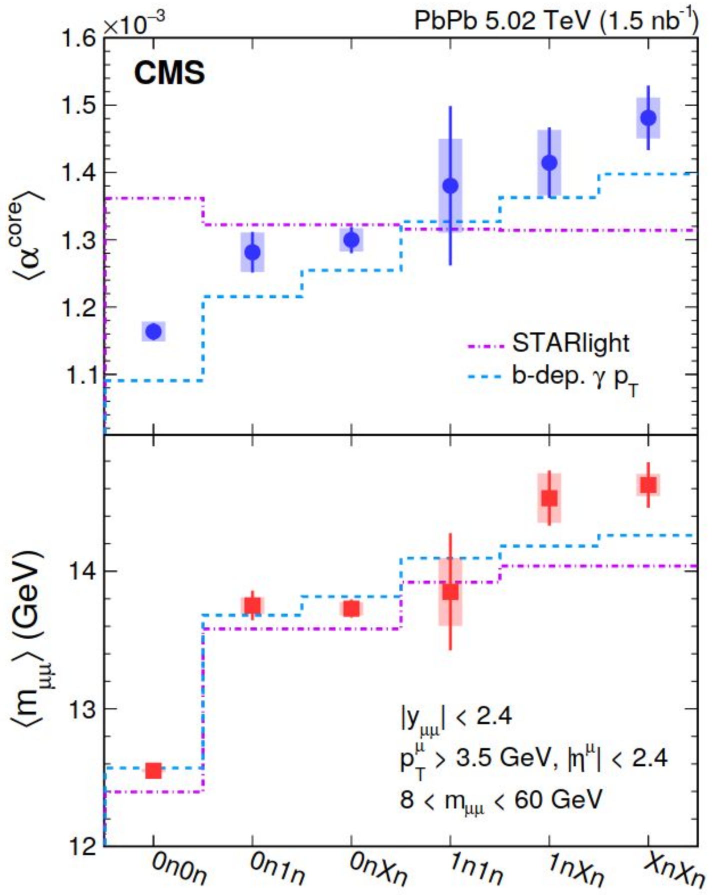


- Each muon has $p^{\mu}_T > 3.5$ GeV, $|\eta^{\mu}| < 2.4$, and the pair $8 < m^{\mu\mu} < 60$ GeV, $|y^{\mu\mu}| < 2.4$.
- Strong correlation between neutron multiplicities with $\langle m^{\mu\mu}\rangle$ and the mean value of the acoplanarity $\alpha = 1 - |\Delta\varphi^{\mu\mu}|/\pi$ near the back-to-back region ($\langle\alpha_{core}\rangle$).
- Comparison to **STARlight** (pure back-to-back muon pairs, no initial-state p_T ``kicks'')
- Data agrees with QED calculation ***only when it incorporates the b-dependence of the initial photon pT (``kicks'')*** (**blue line**, calculation by J. Brandenburg, W. Li, L. Ruan, Z. Tang, Z. Xu, S. Yang, W. Zha, arXiv:2006.07365)

$\gamma\gamma \rightarrow \tau^+\tau^-$ scattering

arXiv:2206.05192, submitted to PRL

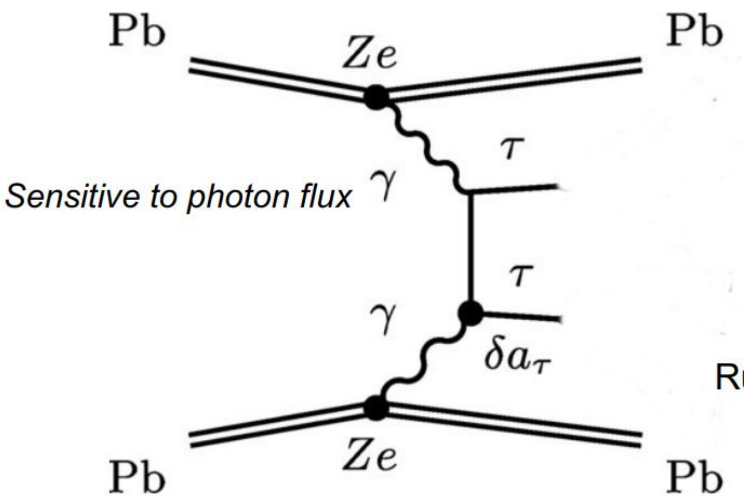
- Current best candidate for $a_\tau = (g_\tau-2)/2$ determination
- LHC can improve the sensitivity on a_τ relative to LEP stringest limits.
- Anomalous τ lepton electric can be constrained as well (following BELLE measurements)

(DELPHI)

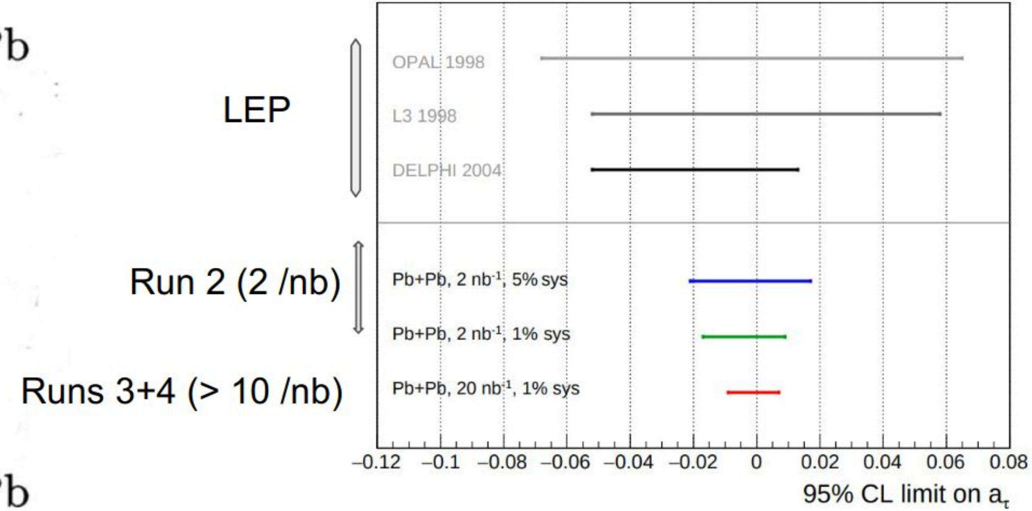
$-0.052 < a_\tau^{exp} < 0.013$

(SM theo)

$a_\tau^{th} = 0.00117721 \pm 0.00000005$



τ lepton photoproduction in ultraperipheral collisions (UPC)



Phys. Lett .B 809 (2020) 135682 (2002.05503)
Phys. Rev. D 102 (2020) 113008 (1908.05180)

$\gamma\gamma \to \tau+\tau-$ scattering

$\tau+\tau-$ signal regions can be then defined based on the lepton and/or hadron multiplicity:

- dilepton: the lowest reco efficiency
- 1l +1 track: main bkg due to μμ, ee
- ***1l +3 tracks: clean with high enough yield (channel used by CMS)***

Muon selection:

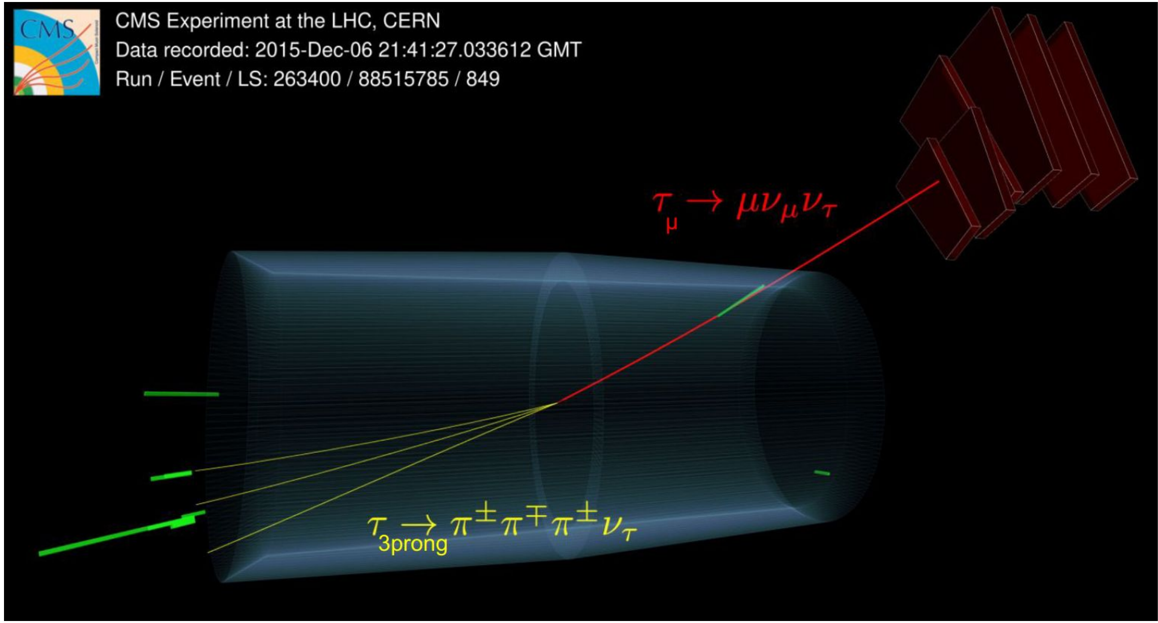
$$p_T > 3.5\,\text{GeV for } |\eta| < 1.2$$
$$p_T > 2.5\,\text{GeV for } 1.2 < |\eta| < 2.4$$

Charged-particle track selection:

$$p_T > 0.5\,\text{GeV for the leading}$$
$$p_T > 0.3\,\text{GeV for the (sub-)subleading}$$
$$|\eta| < 2.5$$

Three-prong selection:

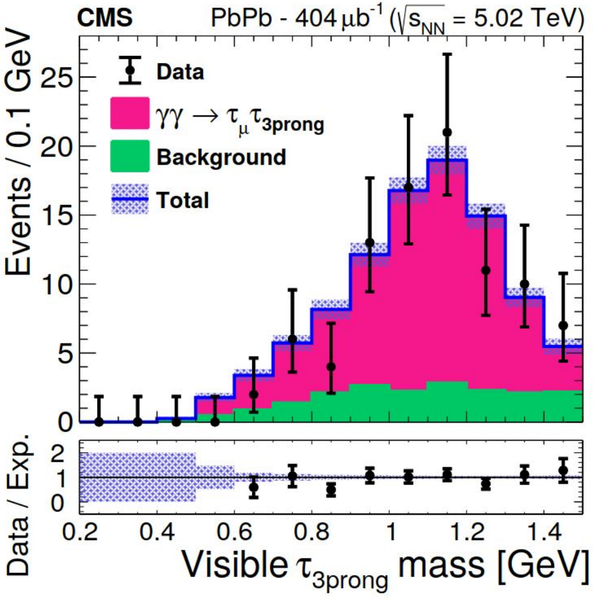
$$p_T^{vis} > 2\,\text{GeV and } 0.2 < m_\tau^{vis} < 1.5\,\text{GeV}$$

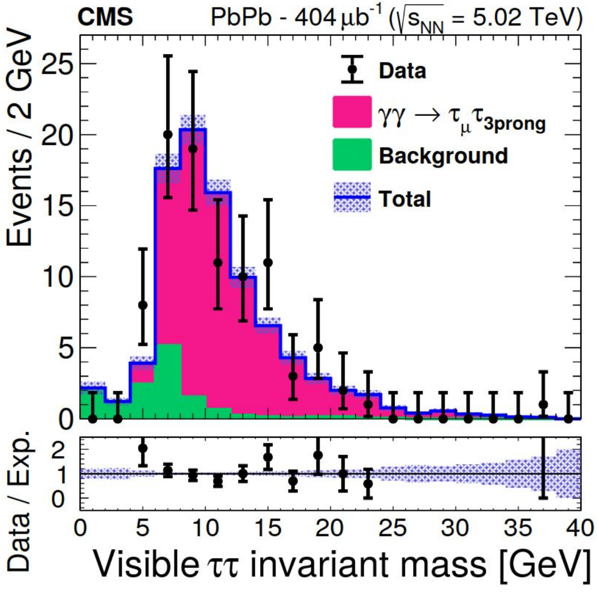


$\gamma\gamma \rightarrow \tau^+\tau^-$ observed by both CMS and ATLAS

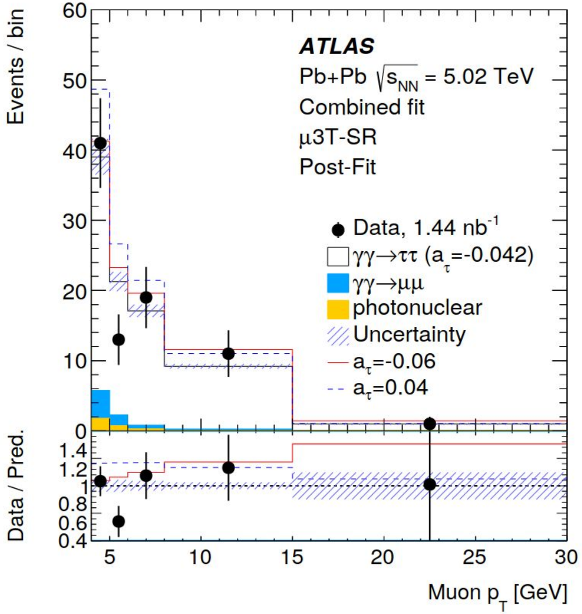
- Muon+3-prong decays (***CMS***) or muon+3-prong, muon+1-prong, muon+electron (***ATLAS***)
- *Observation established by both CMS and ATLAS experiments.*
- Background (estimated via ABCD method): heavy quark photoproduction, meson production via photon-photon and photon-nuclear.

arXiv:2206.05192, submitted to PRL





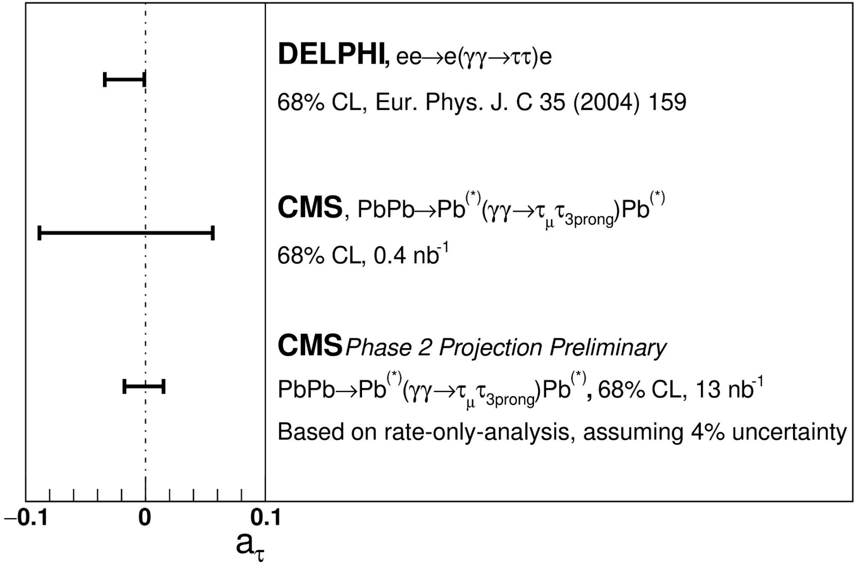
ATLAS, arXiv:2204.13478



New constraints on anomalous magnetic moment

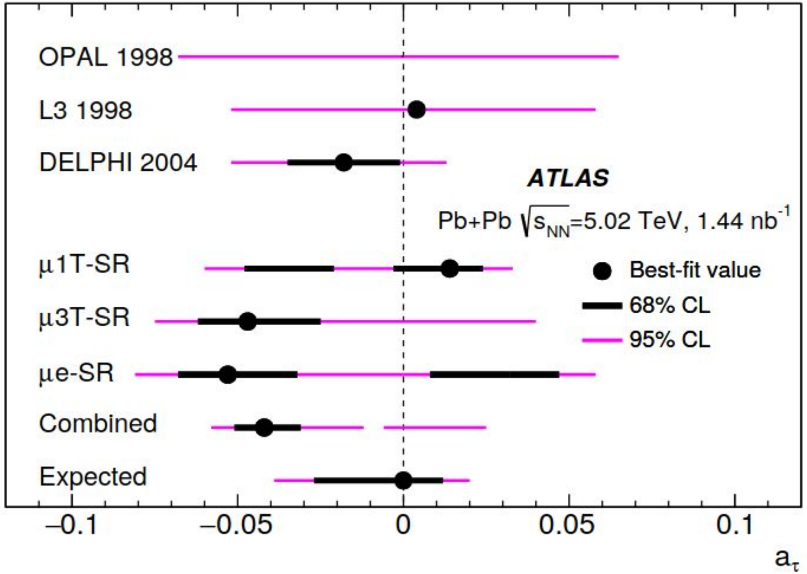
- Both ATLAS and CMS provide their first constraints on aTau.
- ATLAS limits (stat.-dominated) are competitive with DELPHI limits.
  → Excellent prospects for ATLAS and CMS for Run-3 and beyond.

CMS limits ***arXiv:2206.05192, submitted to PRL***



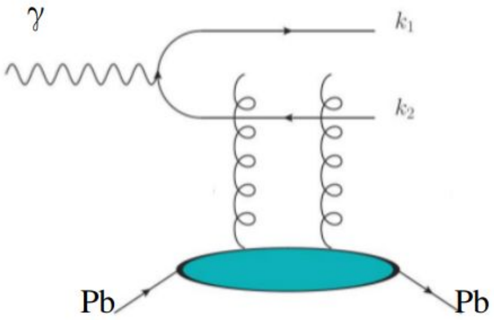
$$a_\tau = 0.001^{+0.055}_{-0.089}$$ @ 68% CL

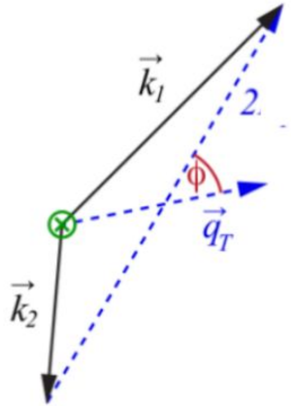
ATLAS limits
arXiv:2204.13478



Exclusive dijet photoproduction in PbPb collisions

Direct probe of elliptic gluon Wigner distribution (*Hatta, et al, PRL* 116, 202301 (2016))





Vector sum of 2 jets:

$$\vec{Q}_T = \vec{k}_1 + \vec{k}_2$$

Vector difference of 2 jets:

$$\vec{P}_T = \frac{1}{2}(\vec{k}_1 - \vec{k}_2)$$

Using QT as a proxy for the recoil momentum of Pb target

Measure angle φ between QT and PT vectors.

Gluon polarization effects can be probed by analyzing 2nd Fourier moment *v2*

$$v_2 = \langle \cos(2\phi) \rangle,$$

$$\cos(\phi) = \vec{Q}_T \cdot \vec{P}_T / (\| \vec{Q}_T \| \cdot \| \vec{P}_T \|)$$

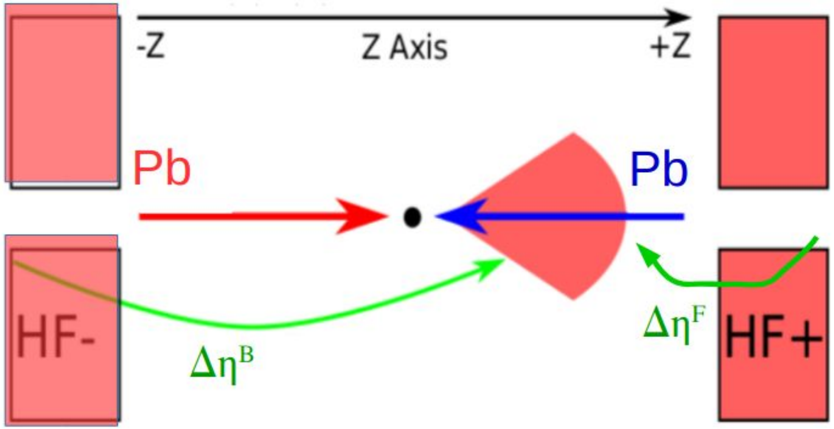
Hatta, et al, PRL 116, 202301 (2016)

Event selection

- anti-kT R = 0.4 particle-flow jets.

- Two jets with $|\eta| < 2.4$, $p_T^{lead} > 30$ GeV and $p_T^{sublead} > 30$ GeV > 20 GeV.

- Hadronic activity is vetoed in backward and forward regions
(2.8 < $|\eta|$ < 5.2) above the calorimeter noise threshold.



Symmetric PbPb beams: ***which Pb ion emits a pomeron and which one emits a photon?***

Enrich sample in gamma-pomeron -> dijet interactions by selecting dijet boosted topologies (*cf* **RAPGAP** simulation).

Rapidity gap definition:

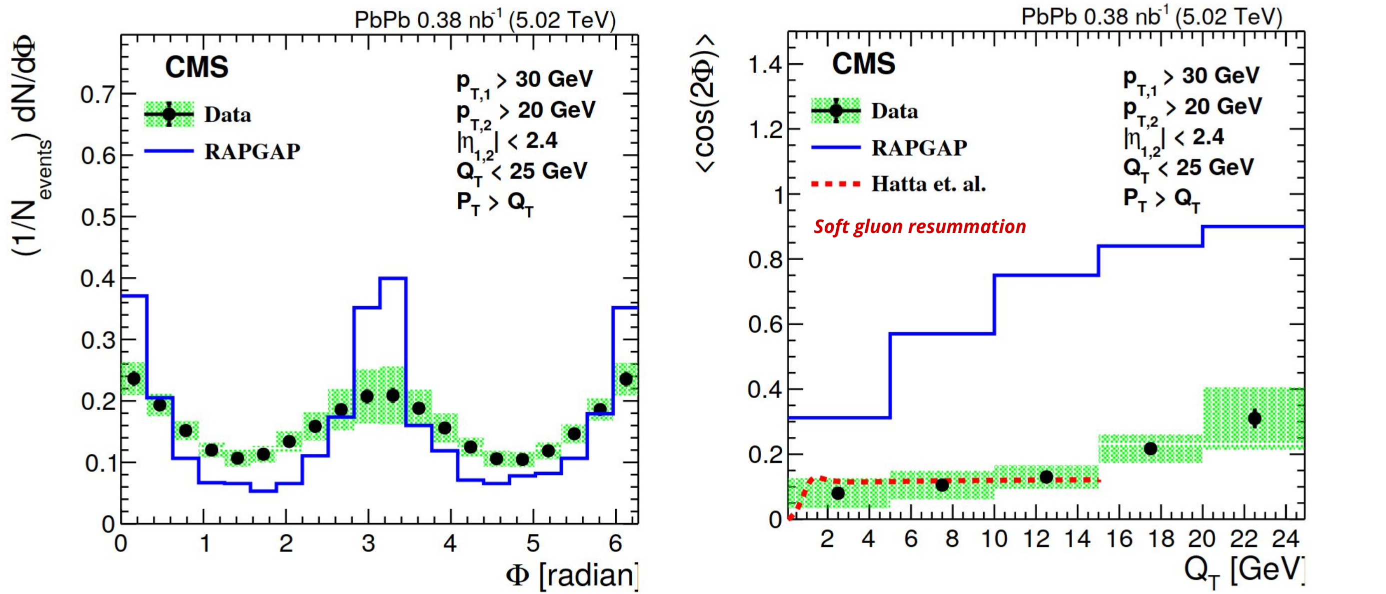
A forward gap $\Delta\eta^F = 2.4 - \eta max$, where ηmax is the η of the farthest track with $p_T > 0.2$ GeV (*associated to pomeron exchange).*

A larger backward gap $\Delta\eta^B > \Delta\eta^F$ (*associated to the photon exchange)*

Symmetrized configuration is analyzed and combined

Fully corrected (unfolded)

arXiv:2205.00045, submitted to PRL



RAPGAP (photon flux reweighted to Pb photon flux, pomeron exchange *a la* HERA) does not properly describe the angular correlations between Q_T and P_T.

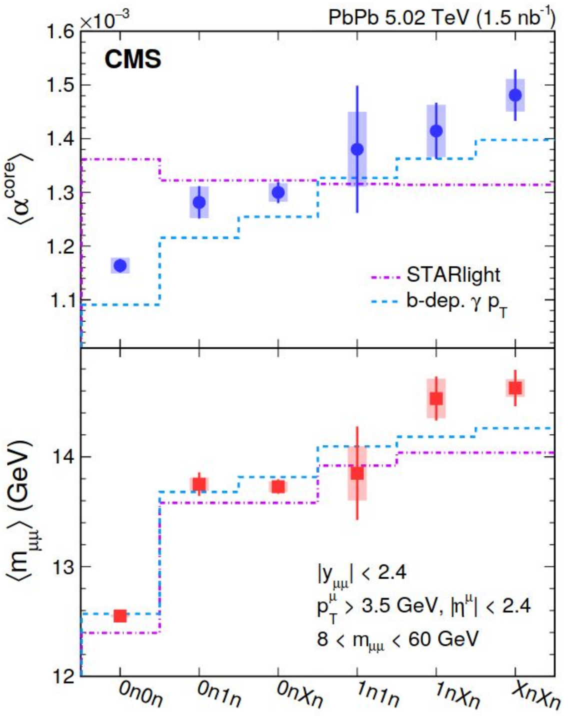
<cos(2φ)> well described up to QT < 15 GeV by **theory calculations (Hatta et al., *PRL* 126, 142001 (2021))** with out-of-cone soft gluon emissions (resummation of large logs of $\alpha_s^n \ln^n(P_T/Q_T)$) in the transverse momentum distribution (TMD) formalism.

Important to carefully treat these radiative contributions to extract the linearly polarized gluon distribution from the experimental data.

Summary

- Constraining photon-flux modeling with precision measurements at the LHC.
- ***New*** standard candle process ($\gamma\gamma \rightarrow \tau+\tau-$ scattering) available to test the SM and study UPCs.
- Elliptic gluon Wigner distributions can potentially be probed in exclusive dijet production. Soft-gluon emissions need to be treated carefully to understand possible gluon polarization effects.

arXiv:2011.05239,
Phys. Rev. Lett. 127, 122001 (2021)



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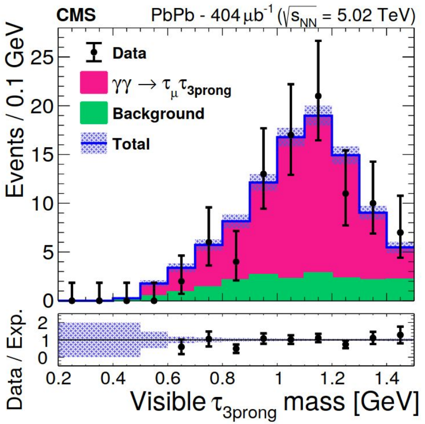

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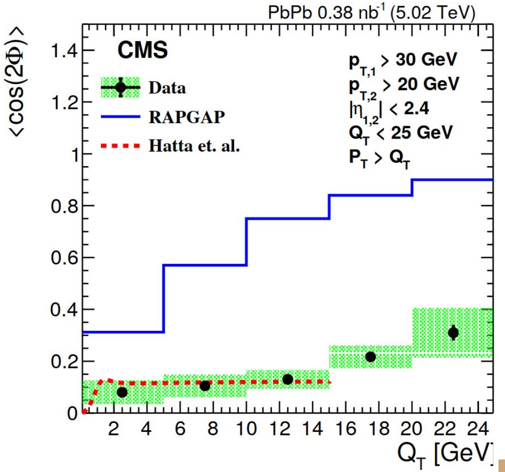
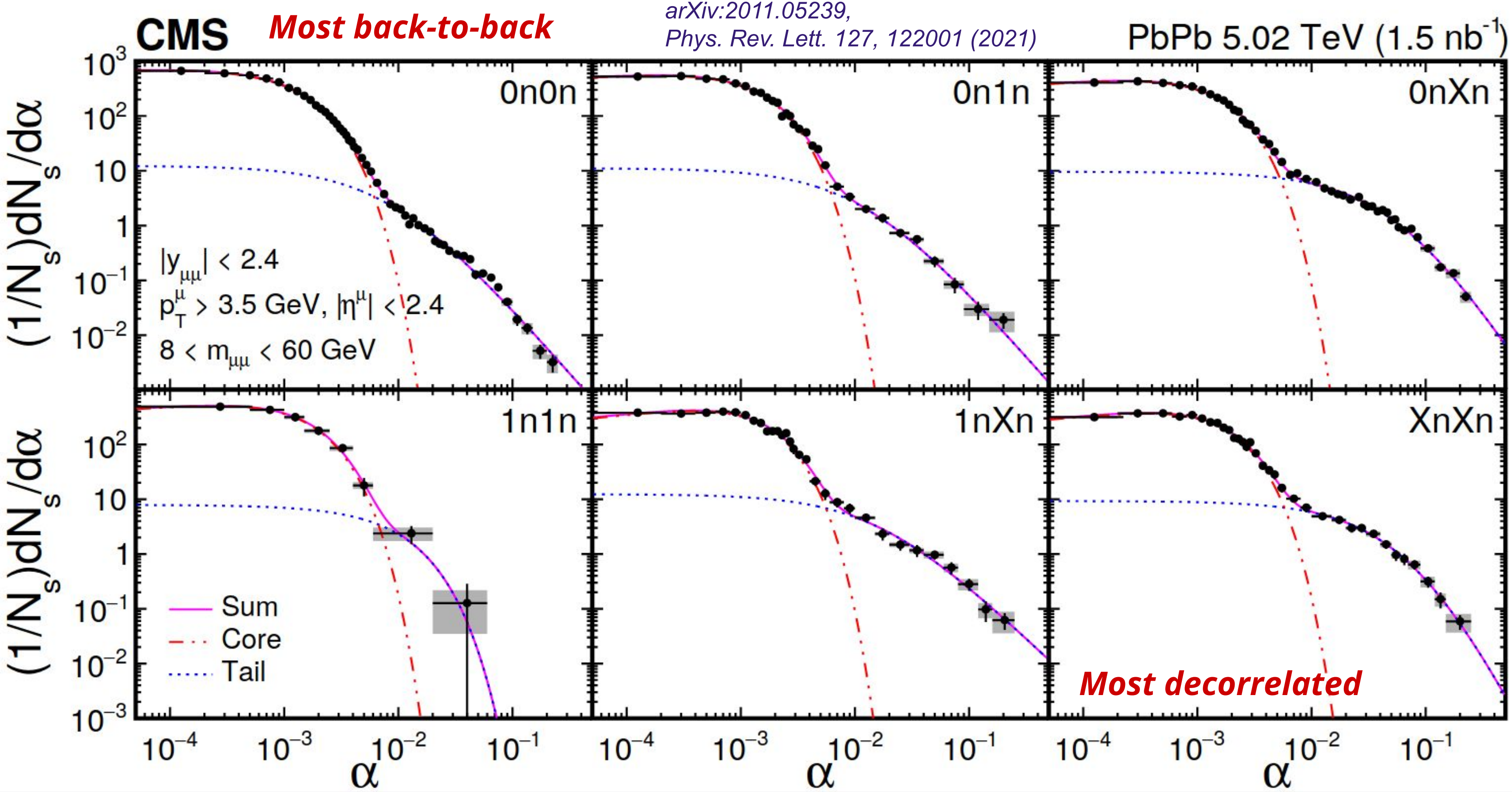


Back-up

Forward neutron multiplicities modulate azimuthal angular correlations between muon pairs

arXiv:2011.05239,
Phys. Rev. Lett. 127, 122001 (2021)



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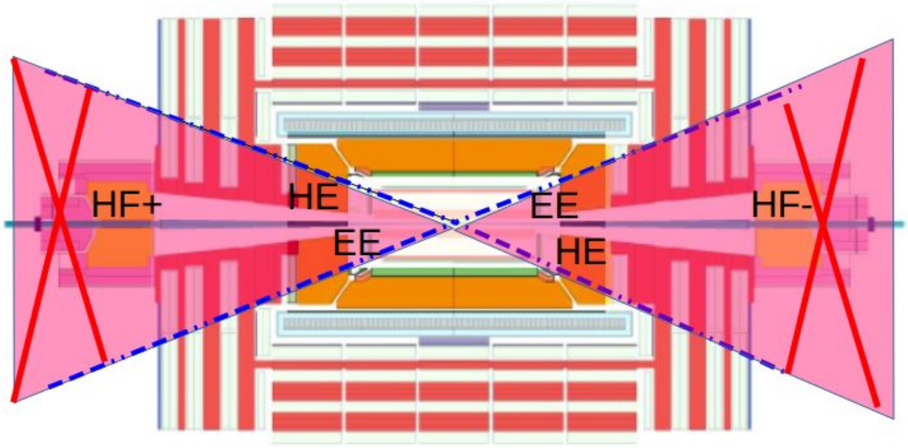

arXiv:2205.00045, submitted to PRL

Measurement compatible with existing analytical calculations

arXiv:2206.05192, submitted to PRL