Searches for new physics with ultra-peripheral collisions at the LHC

Nazar Burmasov

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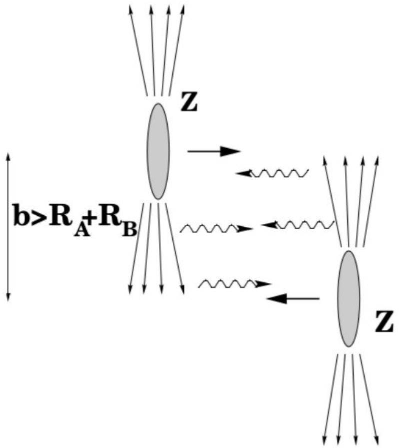
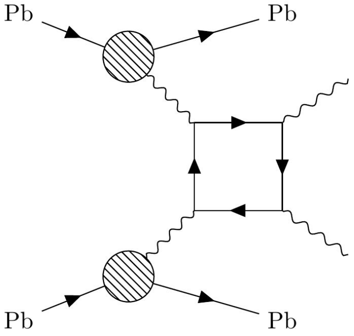
Ultra-peripheral collisions

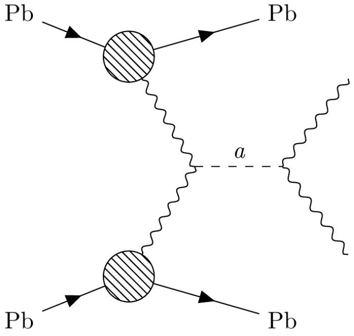
- $b > R_A + R_B$

  Hadronic interactions strongly suppressed
- Nuclei create strong electromagnetic fields
  - Can be described in terms of equivalent photon fluxes
  - Quasi-real photons with $q < \hbar c/R \sim 30$ MeV
  - Photon fluxes ∝ Z^2
  - Cross sections of $\gamma\gamma$ interactions ∝ Z^4

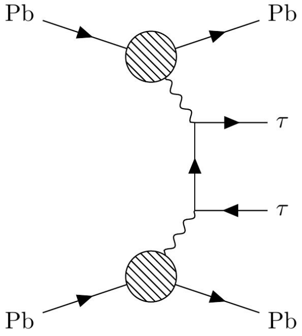




Light-by-light scattering

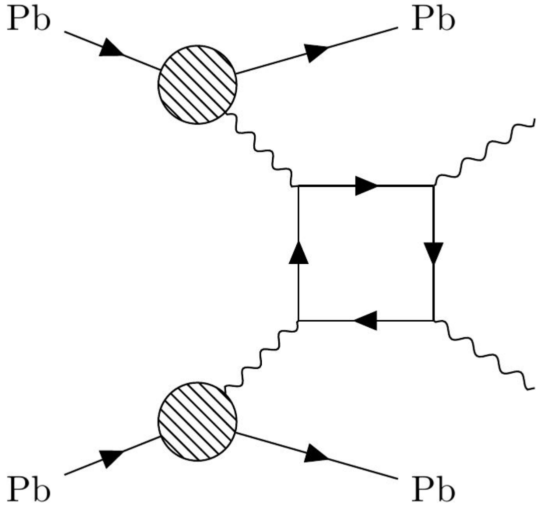


Axion-like particle searches



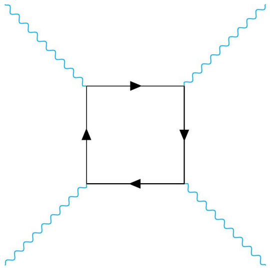
Tau pairs production

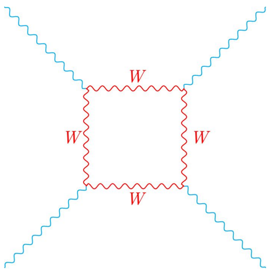
Light-by-light scattering and ALP searches

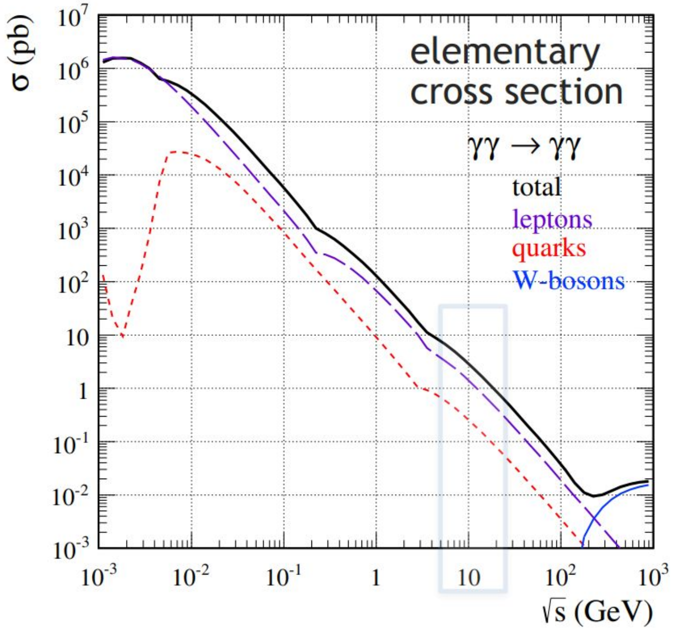


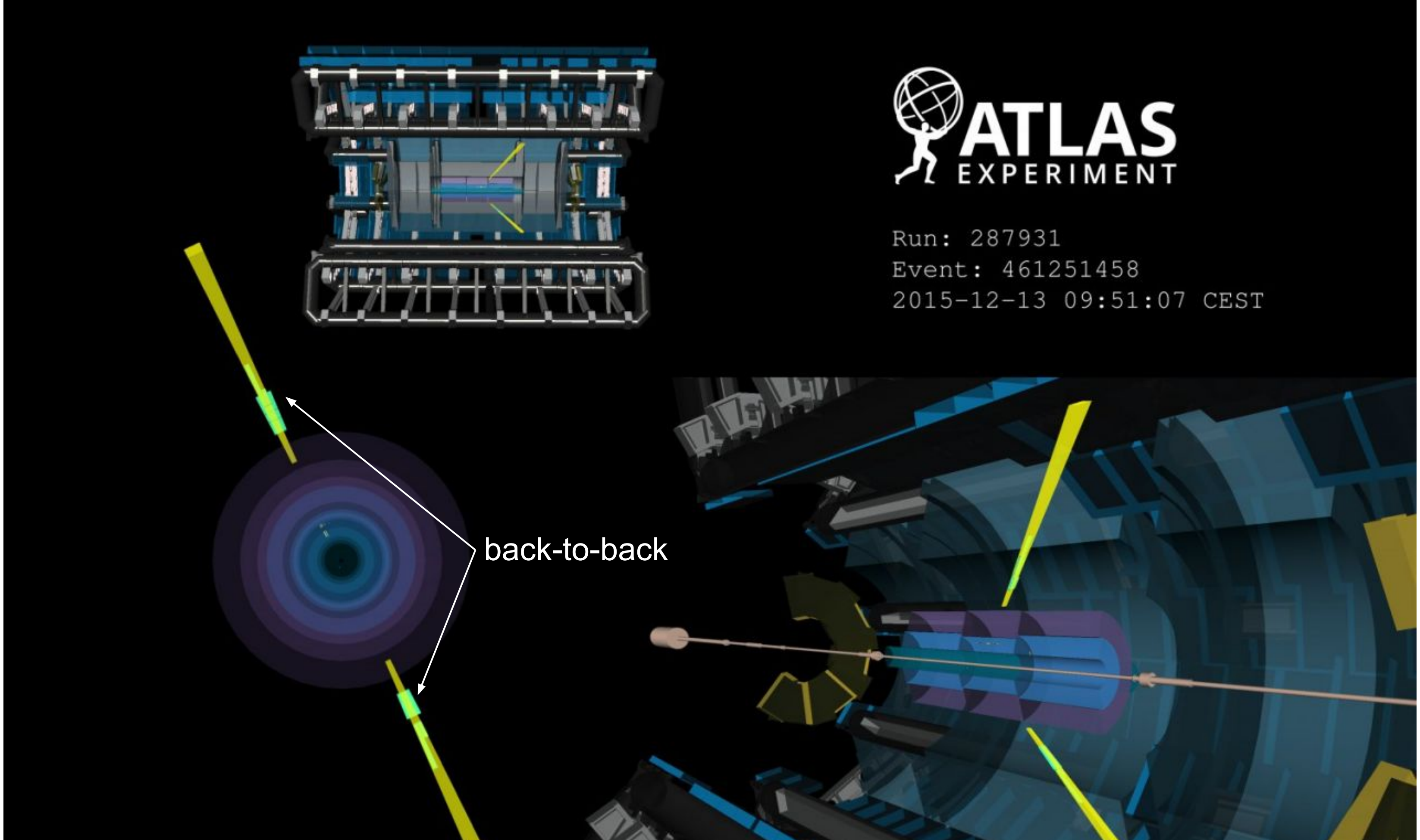
Light-by-light scattering

- In the Standard Model:
  - Leptons, quarks, W
- Sensitive to new physics, e.g.:
  - Born-Infeld theory
  - Supersymmetry
  - Searches for axion-like particles
- First evidence: ATLAS (*Nature Phys. 3, 852, 2017*) and CMS (*Phys.Lett.B, 797, 134826, 2019*) with Pb-Pb UPCs





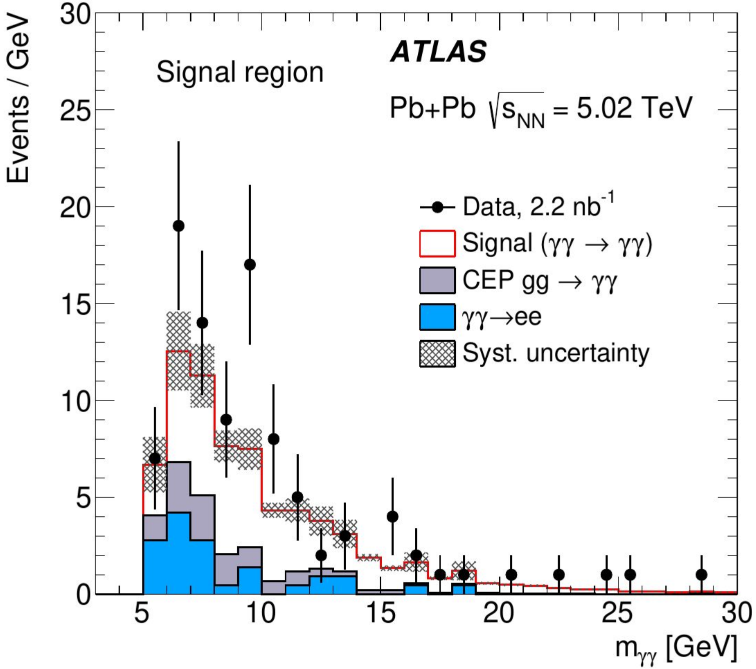




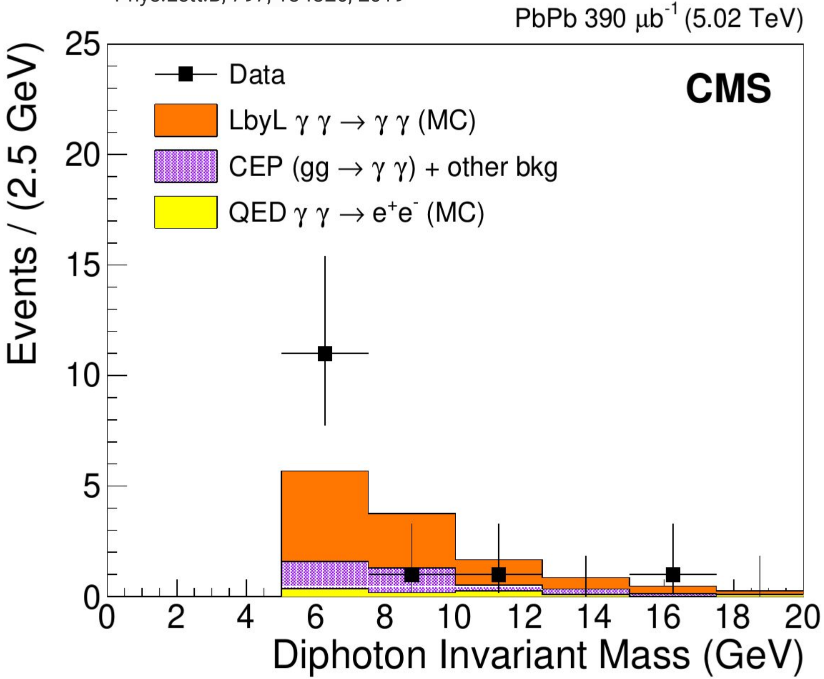
- ★ Two photons in calorimeters
- ★ No additional activity in other detector systems

Light-by-light scattering

JHEP, 03, 243, 2021



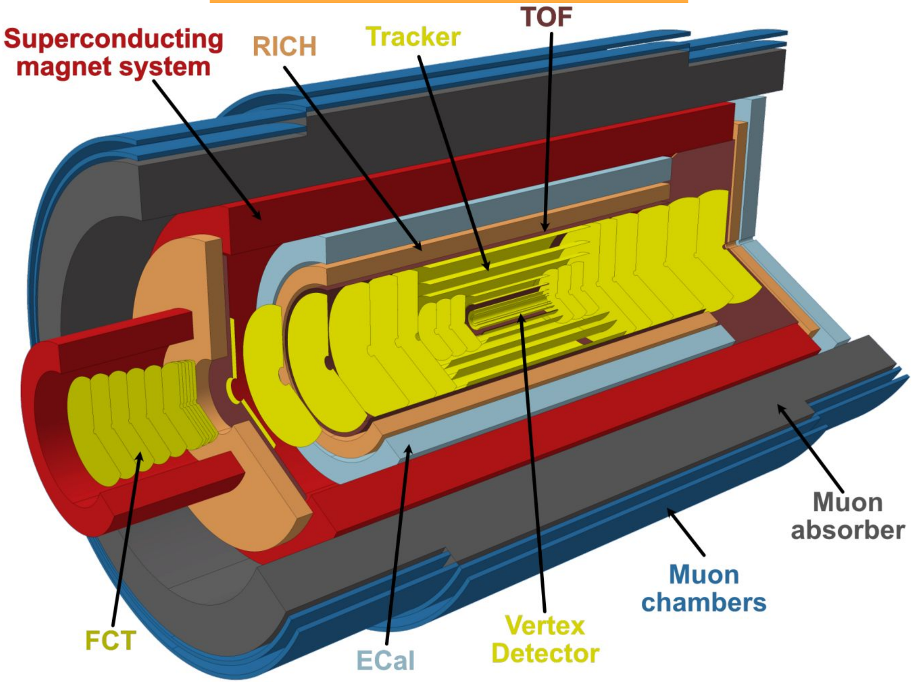
Phys.Lett.B, 797, 134826, 2019



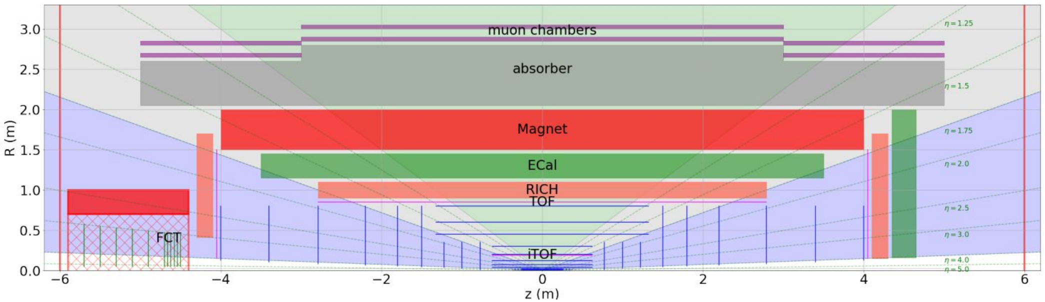
- The results are in good agreement with SM
- Measurement is limited by trigger: $m_{\gamma\gamma}$ > 5 GeV
- Precision is limited by statistics

ALICE 3

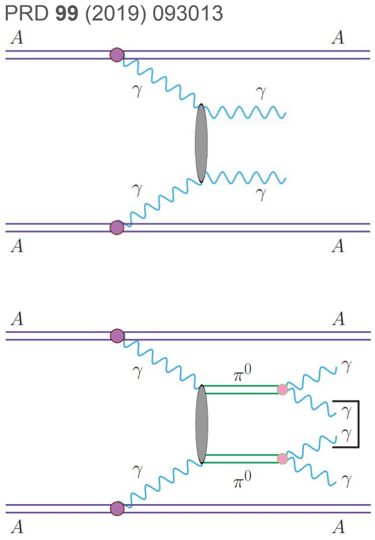
Run 5: 2032+
CERN CDS: LHCC-I-038

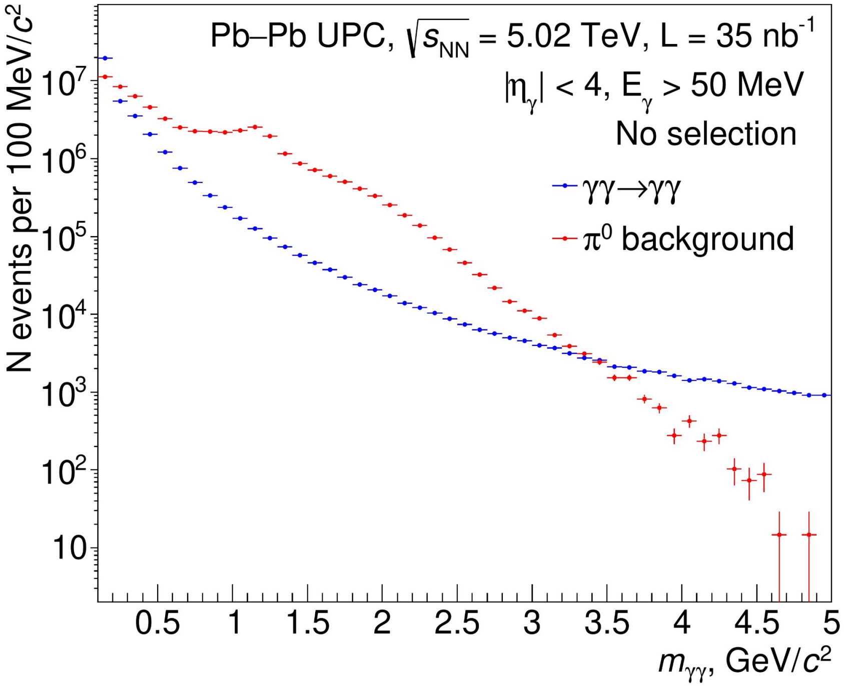


- Magnetic field up to ~2 T
- Large pseudorapidity range $|\eta| < 4$
- Charged particle tracking down to p_T ~ 10 MeV → soft photons measurements with photon conversion method



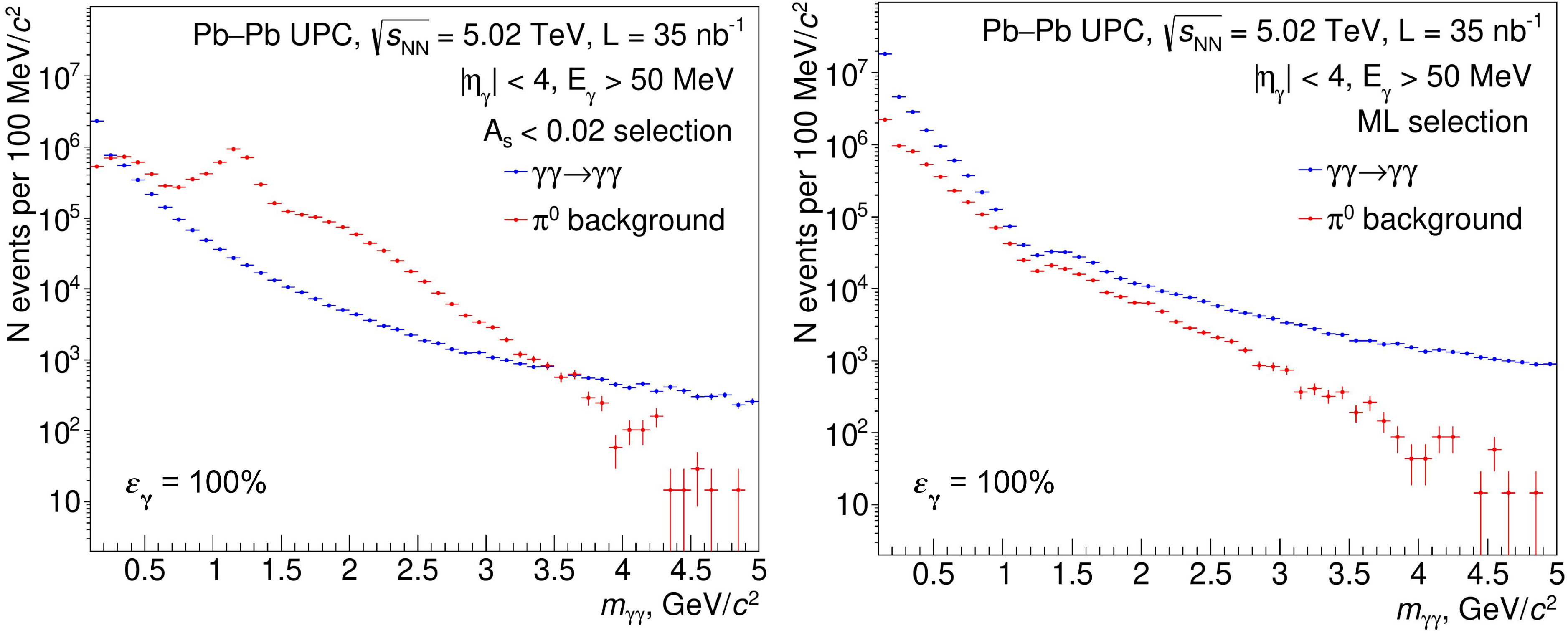
Difficulties at low invariant masses





- Simulations of signal and background with a dedicated event generator — Upcgen [CPC 277 (2022) 108388]
- Significant $\gamma\gamma$ background from $\pi^0\pi^0$ decays at $m_{\gamma\gamma}$ < 3 GeV

Event selection



- Asymmetry cut slightly improves the situation at low masses
- Selection with gradient boosted decision tree suppresses the background a wide mass interval

Axion-like particles

- Axions were introduced in the Peccei-Quinn theory to approach strong CP symmetry problem

$$\mathcal{L}_a = \frac{1}{2}(\partial a)^2 - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}\frac{a}{\Lambda}F\widetilde{F}$$

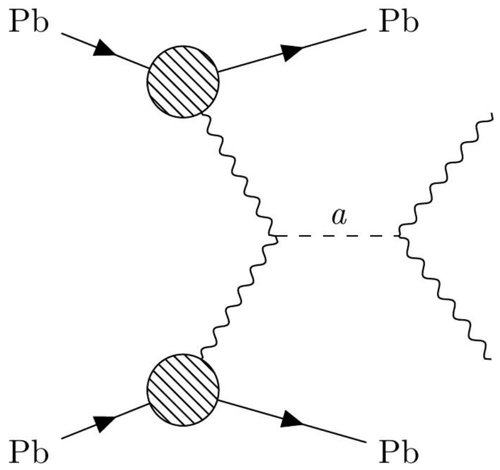
- Axion-like particles — a more general class of pseudoscalar particles

➢ Possible dark matter candidates

- Estimates for Λ limits:
  - Signal from Upcgen:

$$\sigma(\gamma\gamma \to a) = \frac{8\,\pi^2}{m_a}\,\Gamma_{a\to\gamma\gamma}\,\delta(m_a - s) \quad \Gamma_{a\to\gamma\gamma} = \frac{1}{64\,\pi}\frac{m_a^3}{\Lambda_a^2}$$

  - Background: light-by-light scattering, $\pi^0\pi^0$ decays

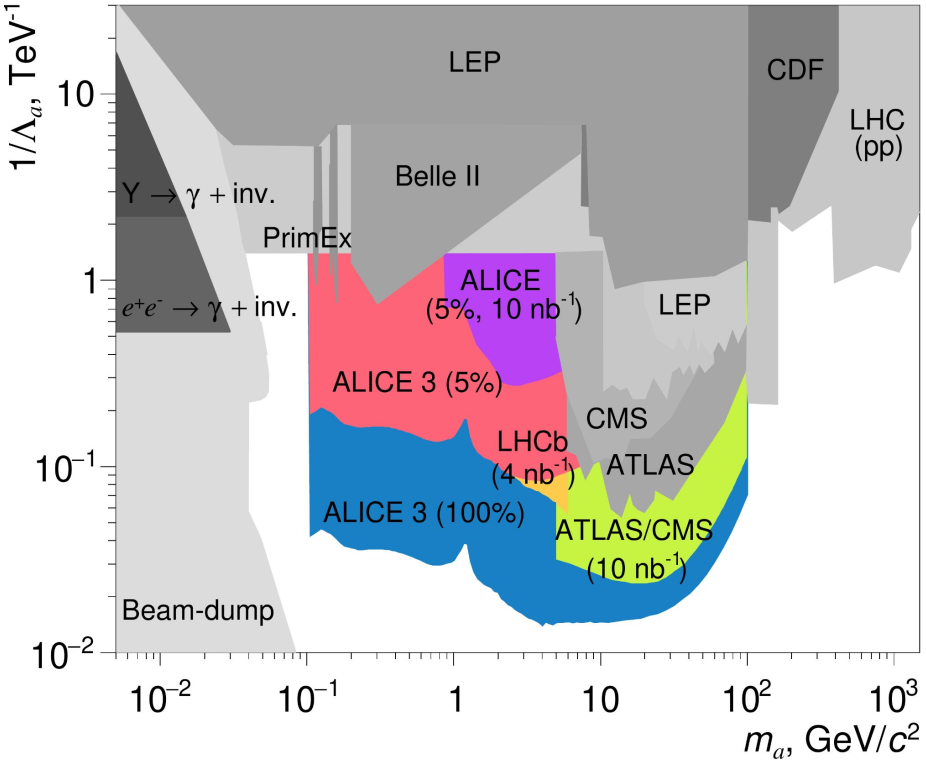


Limits on ALPs with ALICE 3

- Photon reconstruction efficiency:
  - 5% — photon conversions
  - 100% — ideal
- Searches are hardly possible near π^0, η, η', χ_c

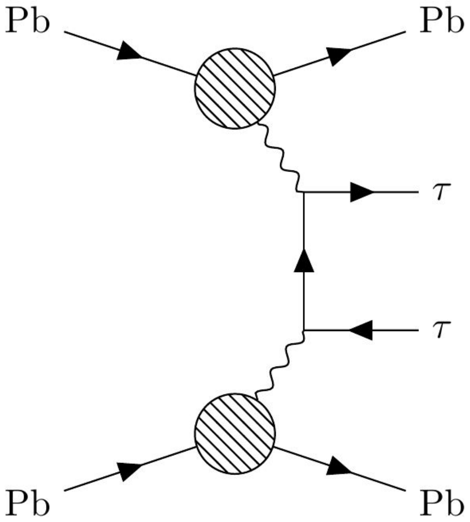
➢ Possibility to cover masses < 5 GeV

➢ Ideal case can be approached with calorimeters



Limits from ATLAS, JHEP 03, 243 (2021)
Projections for ATLAS/CMS from PRL 118 (2017), 171801
Projections for LHCb from Goncalves et al. EPJC 81 (2021), 522

Anomalous magnetic moment of τ lepton

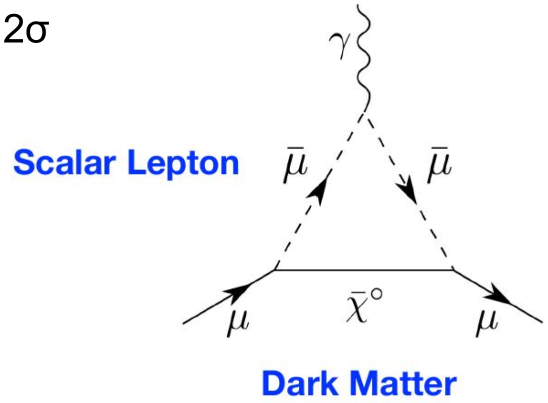


Anomalous magnetic moment of τ lepton

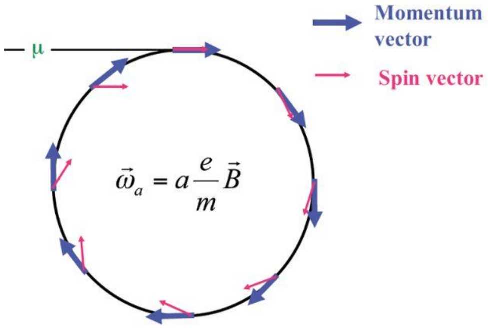
- Muon anomalous magnetic moment deviates from SM predictions by 4.2σ
- Sensitivity to supersymmetry effects depends on lepton mass

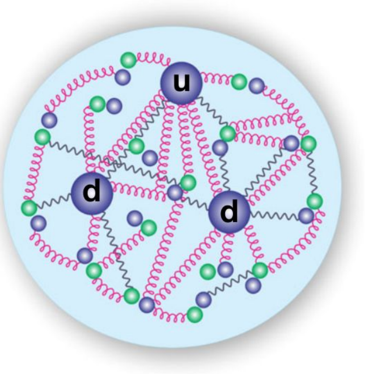
$$\delta a_\ell \sim m_\ell^2 / M_\mathrm{S}^2$$

  - ➢ τ is up to ~280 more sensitive to new physics than μ
- Possible deviations may indicate composite nature of leptons
  - ➢ Example — neutron and proton *g-2*
- Short lifetime (10^{-13} sec) makes direct measurements with spin precession methods very difficult



$$a = \frac{g-2}{2}$$





Anomalous magnetic moment of τ lepton

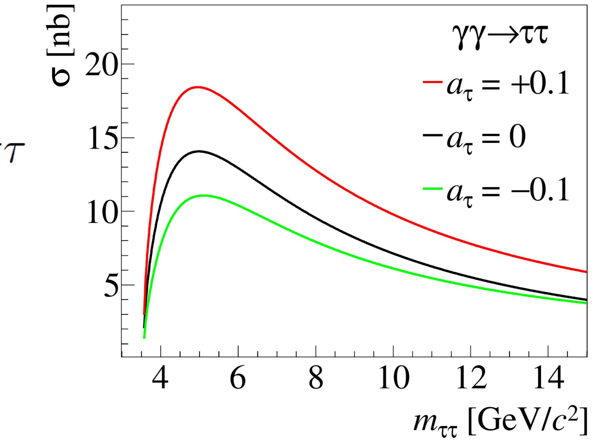
- Alternative: cross section of tau pairs production in two-photon interactions is sensitive to a_τ
- One of the most strong constraints by DELPHI with $e^+e^- \rightarrow e^+e^-\tau\tau$

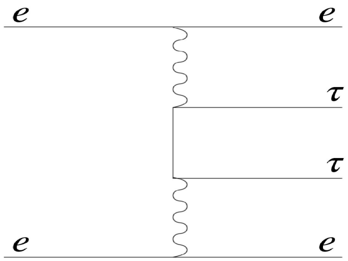
Theory: $a_\tau^{\mathrm{SM}} = 0.00117721(5)$

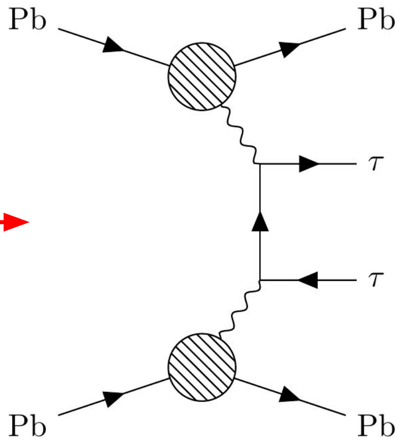
Experiment: **$-0.052 < a_\tau < 0.013$ (95% CL)**

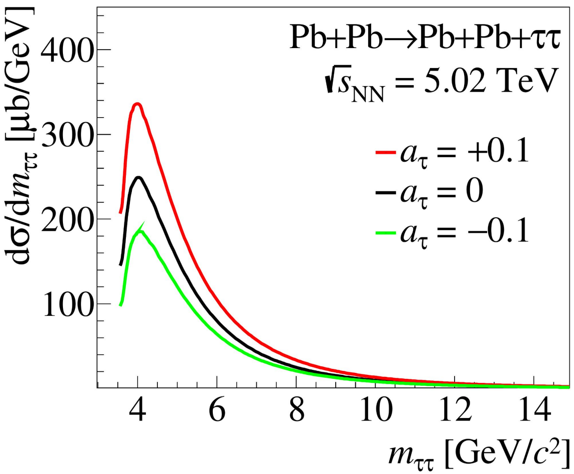
EPJC, 35, 159, 2004

- F.del Aguila et al., PLB, 271, 256-260, 1991:
  Pb-Pb UPCs can be used for the measurement



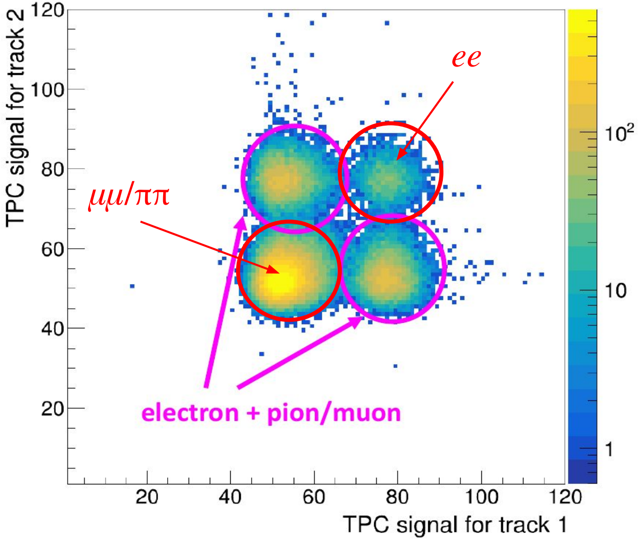


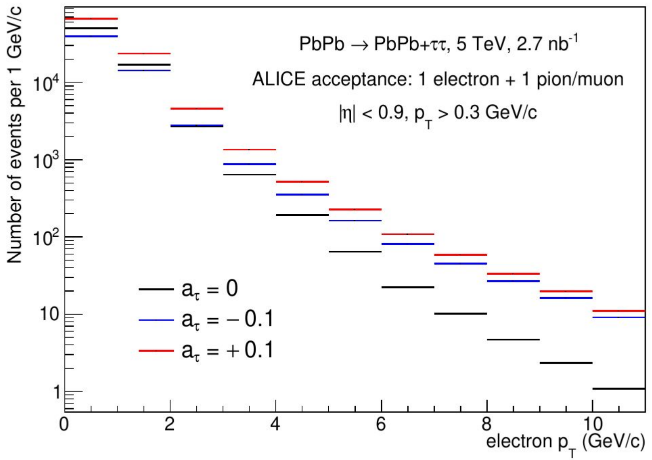




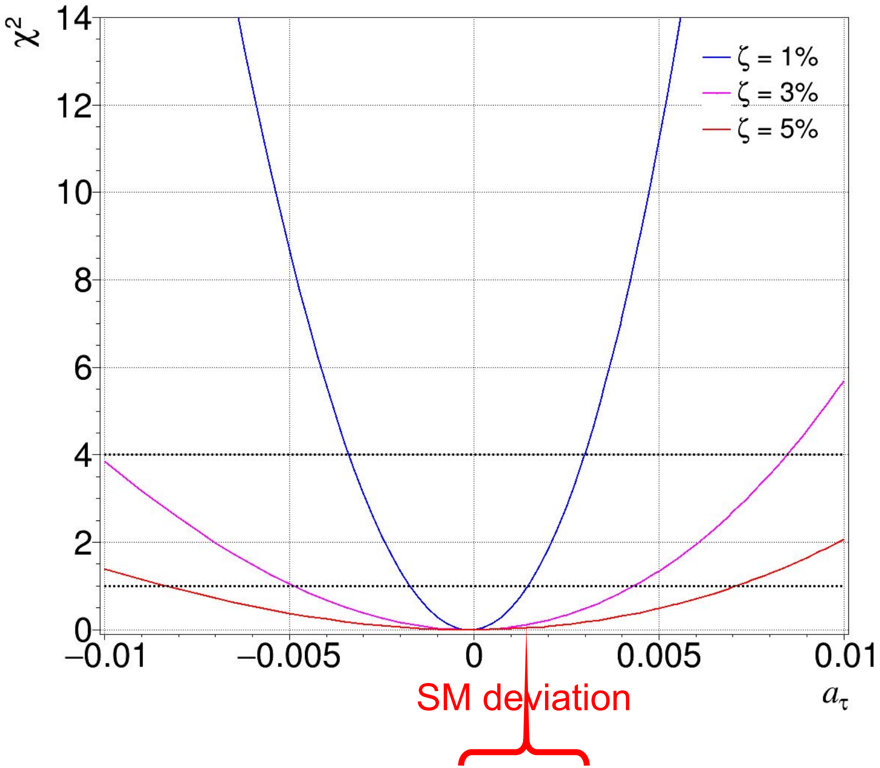
Transverse momentum spectra

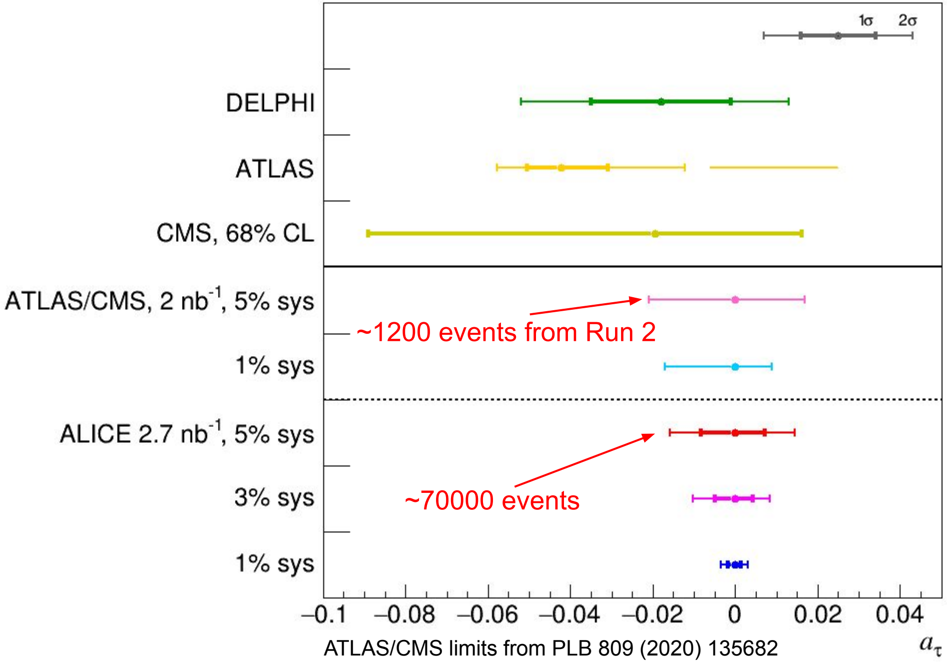
- ATLAS/CMS:
  - $p_T \gtrsim 4$ →precision is limited by statistics
  - ~1200 events from Run 2 (2 nb^{-1})
- ALICE:
  - Upcgen+Pythia 8 for tau production simulations
  - 1 electron + 1 π/μ
  - Central barrel: $|\eta| < 0.9$
  - $p_T^e > 300$ MeV→for good TOF matching
  - Approximately 70000 events are expected during the first year of Run 3 (~2.7 nb^{-1})





a_τ limits with LHC experiments



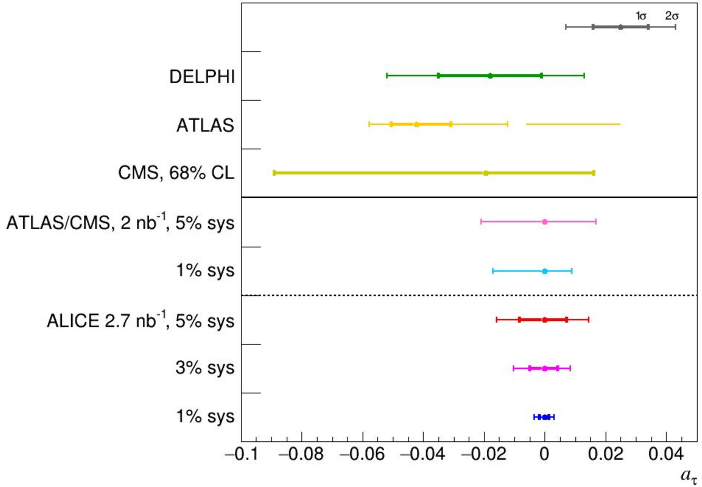


ATLAS/CMS limits from PLB 809 (2020) 135682
ATLAS results from arXiv:2204.13478
CMS results from DIS 2022

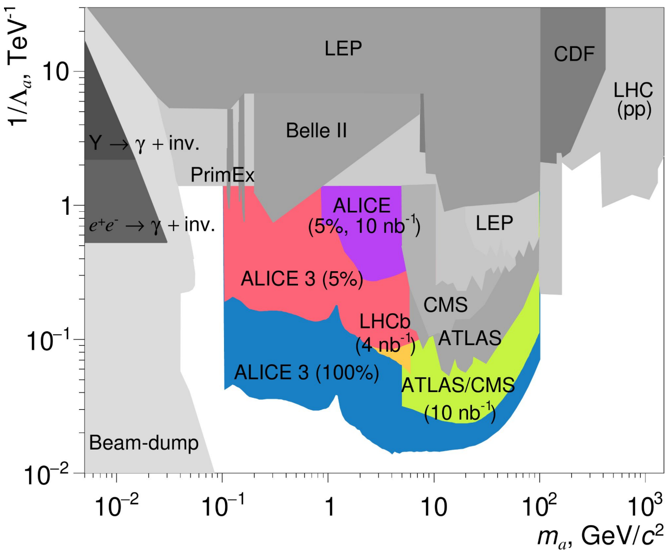
$$\chi^2 = \sum_{i=1}^{N_{\text{bins}}} \frac{[S_i(0) - S_i(a_\tau)]^2}{\sigma_{\text{stat}}^2 + (\sigma_{\text{syst}}^{\text{uncorr}})^2}$$

- Uncorrelated systematic uncertainties: ζ = 1%, 3%, 5%
- Precision is limited by systematics

Summary and outlook

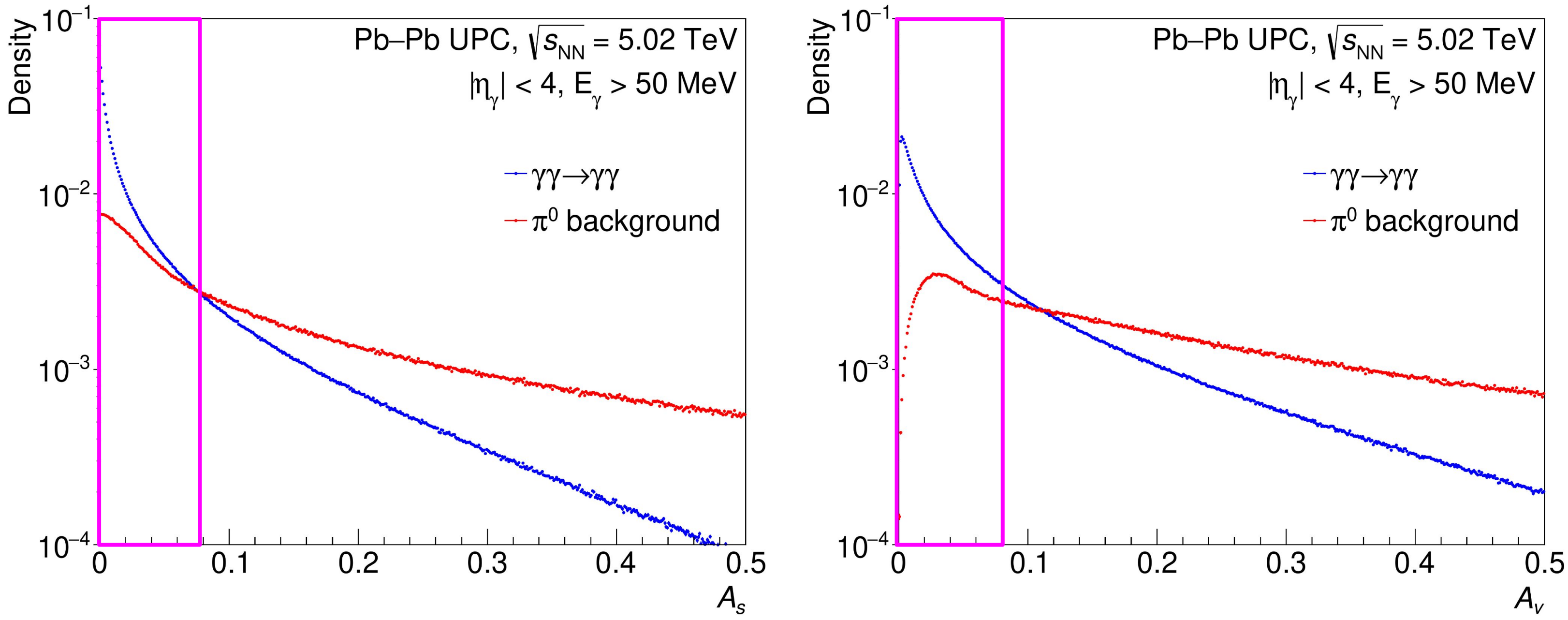


- LHC experiments can obtain competitive results
- In this work, a realistic simulation of ALICE/ALICE 3 is planned for event selection strategy developments



BACKUP

Asymmetry selection



- Combinatorial background can be suppressed with asymmetry cuts

$$A_s = \left| \frac{|p_T^1| - |p_T^2|}{|p_T^1| + |p_T^2|} \right| \qquad A_v = \frac{|p_T^1 - p_T^2|}{|p_T^1 + p_T^2|}$$