Ultraperipheral nuclear collisions: experiment and theory

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ULTRAPERIPHERAL $\equiv$ LARGE IMPACT PARAMETERS

b$> 2R_A$ - unmeasurable!

Measure fiducial cross section and compare with theory!

Interactions of ions colliding at large impact parameters proceed as the interaction of photons from the electromagnetic clouds surrounding both ions.

E. Fermi, Z.Physik 29, 315 (1924)

C.F.V. Weizsäcker, Z.Physik 88, 612 (1934)

L.D. Landau, E.M. Lifshitz, Phys.Zs.Sowjet 6, 244 (1934)

NOTE: 2019-1934=85 - the **IG**-birthday present!

E.J. Williams, Kgl. Danske Vidensk. Selskab. Mat.-Fiz. Medd. 13, 4 (1935)

LL (1934) $\gamma\gamma \to e^+e^-$

M. Vysotsky, E. Zhemchugov, arXiv:1806.07238 (ATLAS)

$\gamma\gamma \to \mu^+\mu^-$ - purely electromagnetic interactions!

D. d'Enterria, arXiv:1808.03524 (CMS)

$\gamma\gamma \to \gamma\gamma$ (e- and q-loops)

I.M. Dremin, arXiv:1903.12377

$\gamma\gamma \to$R (hadron resonance!), i.e. $\gamma\gamma \to q\bar{q}$

Asymptotics and preasymptotics.

LL $\sigma \propto \ln^3 \gamma \rightarrow$ asymptotics $(\gamma = E/m)$

D $\sigma \propto \ln^3 \frac{\gamma}{2R_A m_R} \rightarrow \gamma > 2R_A m_R$ - pre

VZh $\sigma \propto \ln^3 \frac{\tilde{q}\gamma}{\omega} \rightarrow \gamma > \omega/\tilde{q}$ - pre

($\tilde{q}$ defined by nuclear formfactors, i.e. by R_A)

The most fascinating common feature is the rather fast increase of the cross section with increasing energy as $\ln^3 s$. The growth of the photon flux density at low photon frequences is its main source. It overshoots the famous Froissart bound $\ln^2 s$ for increase of hadronic cross sections. The long-range electromagnetic forces admit such a possibility.

Preasymptotics (ignored by LL!) is determined by factors inside logarithms. It depends on the fiducial cuts!

Theory.

The photon flux dn/dx is dominated by photons carrying small fractions of the nucleon energy x:

$$\frac{dn}{dx} = \frac{2Z^2\alpha}{\pi x} \ln \frac{1}{4R_A x m},$$

where the ion radius is R_A (≈ 7 fm for Pb), Z is its charge and m is a nucleon mass. Large Z!

The exclusive cross section of production of a resonance R by the two-photon interactions $A + A = A + (\gamma\gamma \to R) + A$ may be written as

$$\sigma_{AA}(R) = \int dx_1 dx_2 \frac{dn}{dx_1}\frac{dn}{dx_2}\sigma_{\gamma\gamma}(R),$$

The cross section of $\gamma + \gamma \to R$:

$$\sigma_{\gamma\gamma}(R) = \frac{8\pi^2 \Gamma_{tot}(R)}{m_R} Br(R \to \gamma\gamma) Br_d(R) \delta(x_1 x_2 s_{nn} - m_R^2).$$

Here m_R is the mass of R, $\Gamma_{tot}(R)$ its total width and $Br_d(R)$ denotes the branching ratio to a considered channel of its decay. The δ-function approximation is used for resonances with small widths compared to their masses.
The integrals can be easily calculated so that one gets the analytical formula
$\sigma_{AA}(R) =$
$\frac{128}{3} Z^4 \alpha^2 Br(R \to \gamma\gamma) Br_d(R) \frac{\Gamma_{tot}(R)}{m_R^3} \ln^3 \frac{\sqrt{s_{nn}}}{4 R_A m m_R}$.

Experiment.

d'E Evidence for light-by-light (LbL) scattering, $\gamma\gamma \to \gamma\gamma$, in ultraperipheral PbPb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV is reported. LbL scattering processes are selected in events with just two photons produced, with transverse energy $E_T^{\gamma} > 2$ GeV, pseudorapidity $|\eta^{\gamma}| < 2.4$; and diphoton invariant mass $m^{\gamma\gamma} > 5$ GeV, transverse momentum $p_T^{\gamma\gamma} < 1$ GeV, and acoplanarity < 0.01. After all selection criteria, 14 events are observed, compared to 11.1 ± 1.1 (theo) and 3.8 ± 1.3 (stat) events expected for signal and background processes respectively. The significance of the signal excess over the background-only hypothesis is 4.1σ. The measured fiducial LbL scattering cross section, $122 \pm 469(stat) \pm 29(syst) \pm 4(theo)$ nb is consistent with the standard model prediction.

VZh Equivalent photon approximation is used to calculate fiducial cross sections for dimuon production in ultraperipheral proton-proton and lead-lead collisions. Analytical formulae taking into account experimental cuts are derived. The results are compared with the measurements reported by the ATLAS collaboration.
Predict σ=34.4 μb at 5.02 TeV with 3 fiducial cuts on invariant mass of $\mu^+\mu^-$ pair, the muon transverse momentum and muon pseudorapidity.
Agrees with ATLAS data (PbPb, 32.2$\pm$0.34$\pm$3.5 μb).
pp is OK also (with $\sigma \approx 3$ pb).
Parameter $\tilde{q} \propto 1/R_A$ (pp-200 MeV; PbPb-20 MeV at 0.8 fm$\rightarrow$7 fm); $\omega \propto m_R$

Estimates of the resonance cross sections

D PbPb($\gamma\gamma$) $\rightarrow$PbPbR
π^0: $\sigma_{AA} = 15.2$ mb at 2.76 TeV (22 mb at 5.02 TeV)
$\eta' \rightarrow \rho^0 + \gamma$: $\sigma_{AA} = 1.6$ mb at 2.76 TeV (2.8 mb at 5.02 TeV).
Strong condition - impact parameter $b > 19$ fm

Conclusions

- The cross sections of ultraperipheral processes increase as $\ln^3 s$ at asymptotically high energy s.

- Preasymptotics depends on fiducial cuts.
- Comparison with experimental data on LbL-scattering (CMS) and with ATLAS data on $\mu^+\mu^-$ production in pp and PbPb collisions shows good agreement.
- The estimated values of the cross sections for ultraperipheral production of resonances are quite optimistic for high energy experiments at RHIC and LHC.
- Fiducial cuts strongly diminish the measured values of the cross sections. Their impact on possible experimentation at NICA should be carefully studied.