Ultra-Peripheral Collisions in CMS

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Coherent peripheral collisions of atomic nuclei involve electromagnetic or long range hadronic interactions at impact parameters, where both nuclei survive intact. Recently such ultra-peripheral collisions were observed at RHIC. The effect of the electromagnetic field can be interpreted as a photon-photon collision with an effective center of mass energy up to a few GeV at RHIC. At the Large Hadron Collider the effective center of mass energy will be increased by more than an order of magnitude. This opens new opportunities, ranging from the study of non-perturbative QCD to the search for new physics.

1. Heavy Ions in LHC

The Large Hadron Collider (LHC) plans to operate as a heavy ion collider for one month each year starting in 2007. LHC will be capable of accelerating a variety of ions up to beam energies of 7 TeV/charge. The design, peak and three-hour-fill-averaged luminosities are presented in Table 1 along with the maximum center of mass energy[1].

Ion	L_{max} ($cm^{-2}s^{-1}$)	$\langle L \rangle$ ($cm^{-2}s^{-1}$)	$\sqrt{s_{NN}}$ (GeV)
$^{208}Pb^{82}$	$1.0 \cdot 10^{27}$	$4.2 \cdot 10^{26}$	5500
$^{120}Sn^{50}$	$1.7 \cdot 10^{28}$	$7.6 \cdot 10^{27}$	5800
$^{84}Kr^{36}$	$6.6 \cdot 10^{28}$	$3.2 \cdot 10^{28}$	6000
$^{40}Ar^{18}$	$1.0 \cdot 10^{30}$	$5.2 \cdot 10^{29}$	6300
$^{16}O^8$	$3.1 \cdot 10^{31}$	$1.4 \cdot 10^{31}$	7000

Table 1

LHC planned ion beams with design, maximum and fill-averaged luminosities along with maximum center of mass energies.

2. CMS

The Compact Muon Solenoid (CMS) [2] experiment is a general-purpose facility to study hadronic collisions at the LHC. The detector consists of a tracking system, electromagnetic and hadronic calorimeters, and muon detectors. A solenoidal magnet providing

a 4 Tesla magnetic field surrounds the tracking and calorimetric systems. The tracker, covering the rapidity region $|\eta| < 2.5$, is based on silicon technology. The electromagnetic calorimeter consists of about 83000 lead-tungstate crystals arranged in a central barrel covering $|\eta| < 1.48$ and the endcaps, which extend its range to rapidity $|\eta| < 3$. In the central barrel, the granularity is as high as $\eta \times \phi = 0.0175 \times 0.0175$. The hadronic calorimeter consists of barrel and endcap sections, each made of sandwiches of copper plates and plastic scintillator. In the central region ($|\eta| < 2$) the $\eta \times \phi$ segmentation is 0.087×0.087 . The combination of electromagnetic and hadronic calorimeters provides coverage of the central rapidity region with excellent energy resolution. In addition, coverage at large rapidity ($3 < |\eta| < 5$) is achieved by two very forward calorimeters. The large calorimetric coverage and good energy resolution makes CMS an optimal detector for jet studies. The muon system covers the $|\eta| < 2.5$ region. In the barrel ($|\eta| < 1.5$), muons must have a transverse momentum larger than $3.5 \text{ GeV}/c^2$ to be efficiently detected.

3. Ultra-Peripheral Collisions

Nuclear Interactions without direct hadronic collisions are referred to as Ultra-Peripheral Collisions. The impact parameter of the collision should be larger than the sum of the radii of the two interacting nuclei. Therefore the only possible interactions are due to the electromagnetic and/or diffractive processes (See Figure 1). For the former the field is very strong due to the coherent action of all the protons in the nucleus, and the resulting flux of equivalent photons is large, since it is proportional to Z^2 , where the Z is the nuclear charge. If the nuclei are required to interact coherently, the momentum transfer should be smaller than $\hbar/L$, where L is the dimension of the nuclei. In the longitudinal direction the nuclei are Lorentz contracted by a factor γ , and therefore the longitudinal momentum, p_L must be smaller than $\gamma \hbar/R$, where R is the nuclear radius. For Pb(Ar) at LHC energies $\gamma = 2950(3380)$, what translates into a maximum longitudinal momentum transfer of about $100(200) \text{ GeV}$. This scale determines the maximum mass of the objects produced in this type of collisions. In the transverse plane the nuclei are not contracted, and therefore $p_T < \hbar/R \approx 30(60) \text{ MeV}$ for Pb(Ar). This low value of the total transverse momentum is an important experimental feature for the separation of signal from background.

4. Photon-Photon Interactions

In recent years, considerable progress has been made in understanding photon-photon collisions in heavy ion collisions. The basic process is two virtual (space-like) photons emitted by the nuclei colliding to form a final state f . In the equivalent photon approximation (EPA), it is assumed that the square of the 4-momenta of the virtual photons is small ($q_1^2 \approx q_2^2 \approx 0$), and therefore the photons can be treated as quasi-real. This is a good approximation except for the production of e^+e^- and $\mu^+\mu^-$. When EPA is utilized the cross section factorizes as the product of the $\gamma\gamma \rightarrow f$ cross section and the $\gamma\gamma$ effective luminosity.

Figure 4 depicts the effective $\gamma\gamma$ luminosities for Pb+Pb and Ca+Ca and LHC as a function of the effective $\gamma\gamma$ center of mass energy. In addition values for proton-proton collisions at LHC, LEP 200 (Large Electron Positron collider) and a proposed Next Linear Collider (NLC) are shown for comparison. As can be seen, LHC Ca+Ca has the larger

Figure 1. Two fast moving nuclei are an abundant source of quasi-real photons, which can collide with each other and with the other nucleus. For peripheral collisions with impact parameters $b > R_1 + R_2$, isolated photon-photon and photon-nucleus collisions can be studied.

effective luminosity for $M_{\gamma\gamma} < 50\text{GeV}$.

5. Photon-Photon Physics

Photon-photon interactions open a new window into non-perturbative QCD, since they provide an independent view of meson and baryon spectroscopy. They contribute powerful information on the flavor and spin/angular momentum internal structure of the meson. Using the real photon approximation, general symmetry principles restrict the possible final states, in particular spin 1 states are forbidden. In e^+e^- annihilation only states with $J^{PC} = 1^{--}$ can be produced directly. Two photon collisions give access to most of the $C=+1$ mesons, while $C=-1$ mesons can only be produced by the fusion of three or more photons. This allows for interesting studies of light quark spectroscopy in ultra-peripheral nuclear collisions, extending the results already obtained at e^+e^- colliders [3]. The measurement of meson production via $\gamma\gamma$ fusion is also of great interest for glueball searches. The two-photon width of a resonance is a probe of the charge of its constituents. Thus the magnitude of the two-photon coupling can serve to distinguish quark-dominated from gluon-dominated resonances. Low mass mesons ($m \lesssim 2\text{ GeV}$) are accessible at RHIC energies [5]. Detailed studies on the possibilities at LHC have been performed [6].

Figure 3 shows the production cross section, and rates per second and year, for different final states in Ca+Ca interactions at LHC. As can be seen, millions of C -even charmonium states will be produced in a one-month (10^6 s) run. Assuming a detector efficiency of 10%, the number of expected charmonium events in Ca+Ca(Pb+Pb) collisions is $\approx 10^6 (5 \cdot 10^3)$. This is three orders of magnitude larger than what was expected during five years of running at LEP2000.

There are various mechanisms to produce hadrons in photon-photon collisions. It is of great theoretical interest to understand the relative importance of those mechanisms and

Figure 2. Effective $\gamma\gamma$ luminosities for Pb+Pb and Ca+Ca at LHC. For comparison the same quantity is shown for LEP200 and a future Next Linear Collider (NLC), where photons are obtained by laser backscattering. The following parameters were used: LHC Pb+Pb ($E_{beam}=2250$ GeV, $L = 10^{26} cm^{-2} s^{-1}$); LHC Ca+Ca ($E_{beam}=3500$ GeV, $L = 4.10^{30} cm^{-2} s^{-1}$); LHC p+p ($E_{beam}=7000$ GeV, $L = 10^{30} cm^{-2} s^{-1}$); LEP 200 ($E_{beam}=100$ GeV, $L = 10^{32} cm^{-2} s^{-1}$); NLC ($E_{beam}=500$ GeV, $L = 2.10^{33} cm^{-2} s^{-1}$)

Figure 3. Cross sections and production rates, per second and per year (10^6 s), of various final states in Ca+Ca collisions at LHC [4].

their properties. LEP has measured the total $\gamma\gamma \rightarrow \text{hadrons}$ cross section to invariant masses up to 70 GeV. Figure 4 depicts cross sections for hadronic production along with di-lepton and $Q\bar{Q}$ production. As can be seen, the production rates per year are large, what will allow CMS to make important contributions in this field.

The high effective $\gamma\gamma$ luminosities at LHC also offers interesting possibilities for the search of new physics. It has been proposed to look for the Standard Model Higgs in these collisions. Unfortunately the rates are of only a few events a year, as can be seen on Figure 3. However alternative scenarios with light Higgs bosons with larger couplings to $\gamma\gamma$ are possible and have been proposed in the literature [7]. Any new particles with strong couplings to the $\gamma\gamma$ channel, will have large production cross sections [8,9]. Since the $\gamma\gamma$ width of a resonance is mainly proportional to the wave function at the origin, huge values can be obtained for very tightly bound systems, like composite scalar bosons. Therefore the search for this kind of resonances in the $\gamma\gamma$ channel will be possible at the LHC.

6. Photon-Nucleus

The ep collider HERA has studied γp interactions up to center of masses $W_{\gamma p}=200$ GeV in great detail. At LHC photon-nucleus interactions, with a center of mass energy up to $W_{\gamma p}=950$ GeV, will be produced with sizeable cross sections [10]. Moreover γA interaction rates are expected to be very large at LHC. As an example, Table 2 shows the

Figure 4. Cross sections and production rates, per second and per year (10^6 s), per GeV for different dileptons and $Q\bar{Q}$ pairs in Ca+Ca collisions at LHC. Also shown is the total hadronic cross section. [4].

rates for coherent $\gamma A \rightarrow f$, with $f = \rho^0, \omega, \phi$ and J/Ψ for AuAu collisions at RHIC, along with Pb+Pb and Ca+Ca at LHC [11]. These very large rates turn relativistic heavy ion colliders into vector meson factories, with rates that may be competitive with accelerators dedicated to this physics. Recently the STAR collaboration has reported the observation of the ρ meson in coherent γA collisions [5], showing that it is possible to separate those events from the background from peripheral hadronic events. A more comprehensive discussion on the γA physics at CMS can be found elsewhere [4].

Meson	RHIC-Au	LHC-Pb	LHC-Ca
ρ^0	120	520	230000
ω	12	49	23000
ϕ	7.9	46	15000
J/Ψ	0.058	3.2	780

Table 2

Meson production rates, in Hz, at design luminosity for various beams [11].

7. Conclusions

LHC plans to provide one month of heavy ion running every year. This opens unique opportunities for the study of photon-photon and photon-nucleus collisions. CMS with its large acceptance is well equipped to address many of the physics topics of this field.

REFERENCES

1. D. Brandt, 5th *CMS Heavy Ion Meeting*, St. Petersburg, June 11-14, 2000.
2. The Compact Muon Solenoid, Technical Proposal, CERN/LHCC 94-38, LHCC/P1, Dec 15, 1994.
3. Ch. Berger and W. Wagner, Phys. Rep. 146 (1987) 1.
4. G. Baur et al., *Heavy Ion Physics Programme in CMS*, CMS Note 2000/060, December 22, 2000.
5. S. Klein in these proceedings.
6. FELIX, Letter of Intent, CERN/LHCC 97-45.
7. D. Choudhury and M. Krawczyk, Phys. Rev. D55 (1977) 2774.
8. F.M. Renard, Phys. Lett. B126 (1983) 59.
9. U. Baur, H. Fritzsche and H. Faissner, Phys. Rev. B 135 (1984) 313.
10. G. Baur, K. Hencken and D. Trautmann, Topical Review, J.Phys. G24 (1998) 1657.
11. S. Klein and J. Nystrand, Phys. Rev. C60 (1999) 014903.