LBNL–41111
November, 1997

Two-Photon Physics at RHIC: Separating Signals from Backgrounds

Joakim Nystrand and Spencer Klein

Lawrence Berkeley National Laboratory
Berkeley, California 94720, U.S.A.

Abstract. This presentation will show the feasibility of studying two–photon interactions in the STAR experiment at RHIC. Signals, detection efficiencies, backgrounds, triggering and analysis techniques will be discussed.

Presented at Hadron '97, Brookhaven National Laboratory, August 25–30, 1997

In the Relativistic Heavy–Ion Collider [1] (RHIC), under construction at the Brookhaven National Laboratory and scheduled to begin operation in 1999, beams of heavy–ions as massive as gold (A=197) will collide at center–of–mass energies of 100+100 A GeV. The main purpose of RHIC is to study central nucleus–nucleus collisions in order to investigate the properties of nuclear matter under extreme conditions. Of particular interest will be to search for a possible transition from ordinary hadronic matter to a quark–gluon plasma. However, due to the strong electromagnetic and nuclear fields created when two ions sweep past each other, many interesting interactions occur when the nuclei miss each other. This includes two–photon interactions, γ–Pomeron and perhaps Pomeron–Pomeron interactions. Studying the production of hadrons in $\gamma\gamma$ interactions can probe the quark content of exotic hadronic states. Measurements of γ–Pomeron or Pomeron–Pomeron interactions will reveal how the Pomeron couples to the nucleus. The Peripheral Collisions Program within the STAR (Solenoidal Tracker At RHIC) collaboration [2] will study interactions of this type. This talk will discuss the feasibility of extracting a signal from two–photon interactions and separating it from background.

TWO–PHOTON INTERACTIONS

Two–photon interactions have been previously studied at e^+e^-–colliders. Heavy–ion colliders are particularly attractive for investigating these reactions because the electromagnetic fields of the protons add coherently.

In the Weizsäcker–Williams method the electromagnetic field of a relativistic, charged particle is treated as a pulse of photons. For a spherically symmetric charge distribution with radius R, the photon energy spectrum integrated over impact parameter from R to infinity is:

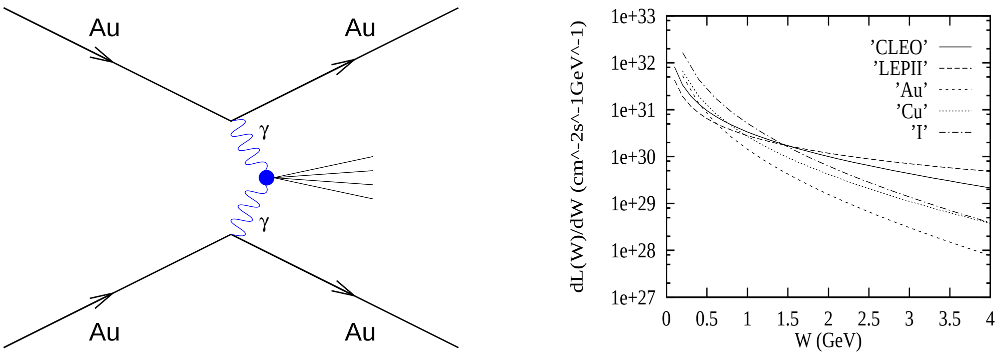

FIGURE 1. Left: A schematic illustration of a two–photon interaction $Au + Au \rightarrow Au + Au + X$. Right: The two–photon luminosity at RHIC compared with that at LEP and CLEO.

$$E_\gamma \frac{dN}{dE_\gamma} = \frac{2Z^2\alpha}{\pi} \left\{ x K_0(x) K_1(x) - \frac{1}{2} x^2 \left(K_1^2(x) - K_0^2(x) \right) \right\} \tag{1}$$

where $x = E_\gamma R/\gamma$ and E_γ is the photon energy [3].

When calculating the $\gamma\gamma$–luminosity in heavy–ion collisions, it is necessary to exclude the region of nuclear overlap ($b < R_1 + R_2$), as in this region hadronic interactions dominate. The equivalent two–photon luminosity is [4–6]:

$$\mathcal{L}_{\gamma\gamma}(E_\gamma^1, E_\gamma^2) \propto f(E_\gamma^1) f(E_\gamma^2) - \Delta F(E_\gamma^1, E_\gamma^2) \tag{2}$$

where $f(E_\gamma)$ is the single photon distribution (Eq. 1) and $\Delta F(E_\gamma^1, E_\gamma^2)$ is a function which takes into account the overlap effect:

$$\Delta F(E_\gamma^1, E_\gamma^2) = 4\pi \int_R^\infty b_1 db_1 \int_{b_{min}}^{b_1+2R} b_2 db_2 \frac{d^2 f}{db_1^2} \frac{d^2 f}{db_2^2} \arccos\left(\frac{b_1^2 + b_2^2 - 4R^2}{2b_1 b_2}\right) \tag{3}$$

The two–photon luminosity thus essentially scales as Z^4, and this is a major advantage of heavy–ion colliders. Figure 1 shows the luminosity for various nuclear systems at RHIC [7,8]. The two–photon luminosity will be competitive with that at e^+e^-–colliders, such as CLEO and LEPII, up to a center–of–mass energy of about 1.5 GeV.

THE STAR EXPERIMENT AT RHIC

The main detector of the STAR experiment at RHIC will be a large ($\sim$50 m^3), cylindrical Time Projection Chamber (TPC). The TPC will track and reconstruct momenta of charged particles in the pseudo–rapidity interval $-2 < \eta < 2$. Two smaller forward time projection chambers (FTPC) will cover the interval $2.5 <| \eta |< 3.75$.

One of the major challenges in studying two–photon interactions in a nuclear experiment will be to trigger on these interactions without collecting too many background events. The STAR trigger system is well suited for this purpose. The main TPC will be covered with an array of 240 plastic scintillators, which will measure the charged particle multiplicity in the interval $\mid \eta \mid < 1.0$ and which will serve as trigger detectors. The TPC anode wires will provide multiplicity information for $1.0 < \mid \eta \mid < 2.0$ for the trigger.

The raw data from the scintillator array and the wire chambers will be available in less than 1 μs. More accurate multiplicity information will be available after about 100 μs. In the highest trigger level, after 10 ms, some tracking and momentum information from the TPC will also be available. This will enable the primary vertex to be located and the $\sum p_T$ to be determined. The different trigger levels and their respective time–scales are summarized in Table 1.

Central Au+Au events will be recorded at a rate of about 1 Hz. The data acquisition system will, however, be flexible enough to allow the recording of smaller events, such as two–photon interactions, at a higher rate.

Trigger Level	Decision Time	Selection
0	~ 1 μs	$2 \leq n_{ch} \leq 5$, event topology
1	~ 100 μs	n_{ch} =2 or 4, event topology
3	~ 10 ms	$\sum p_T \leq 100$ MeV/c, vertex position

TABLE 1. A summary of the trigger levels in STAR and cuts applied in the peripheral collisions analysis. Level 2 is not used for peripheral collisions.

SIGNAL AND BACKGROUND RATES

The production and background rates of the following three systems have been studied: a lepton pair ($\mu^+\mu^-$), a single meson decaying into 2 charged particle ($f_2(1270) \rightarrow \pi^+\pi^-$) and a meson pair decaying into 4 charged particles ($\rho^0\rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$). These systems should thus be representative of a wide selection of two–photon final states. All three systems were simulated using STARLight, a two–photon Monte–Carlo generator [7,8]. In STARLight, photon transverse momenta are generated with a Gaussian form factor with width $\hbar c/R$.

Four sources of background have been considered: peripheral (hadronic) nucleus–nucleus collisions, beam–gas interactions, γ–nucleus interactions, and cosmic rays. Cosmic rays and beam–gas reactions are a problem mainly at the trigger stage. Off–line, it will be possible to accurately find the primary vertex and thence minimize the cosmic ray contribution and reduce the background beam–gas interactions.

Background interactions have been simulated with several different models. For hadronic nucleus–nucleus collisions and beam–gas interactions, two standard nucleus–nucleus Monte–Carlo models, FRITIOF 7.02 [9] and VENUS

Trigger Level	Hadronic A+A FRITIOF	Hadronic A+A VENUS	Beam–Gas FRITIOF	Beam–Gas VENUS	γ+A DTUNUC	Cosmic Rays HemiCosm
0	19	21	53	53	63	30
1	7	9	27	28	37	30
3	0.1	0.2	0.2	0.3	1.9	0.6

TABLE 2. Trigger Rates (in Hz) of the various background processes discussed in the text.

4.12 [10], have been used. Photonuclear interactions have been simulated with the model DTUNUC 2.0 [11]. For cosmic rays, the Monte–Carlo HemiCosm has been used [12].

The background trigger rates obtained using these models are shown in Table 2. The trigger selection used at each level is summarized in Table 1. At level 3, reactions are required to occur inside the interaction diamond, $\mid z \mid \leq 20$ cm, and have $\mid \sum \overline{p}_T \mid \leq 100$ MeV/c. The largest background component is photonuclear interactions. The trigger rates can be compared to the trigger rate from muon–pairs from $\gamma\gamma$ interactions, 4.7 Hz. The ratio of signal to background for μ–production will thus be roughly 2:1, already at the trigger level.

In order to separate signals from background, cuts have been developed which utilize the characteristics of two–photon interactions. The most important of these cuts are: (a) Multiplicity: Many two–photon reactions lead to a final state with either 2 or 4 charged particles, and in the analysis it is required that no additional particles are present in the event. (b) Transverse momentum: The summed transverse momentum ($\mid \sum \overline{p}_T \mid$) of the final state will be small ($\sim \sqrt{2}\hbar c/R$). In the analysis presented here a cut of $\mid \sum \overline{p}_T \mid \leq 40$ MeV/c was used. (c) Center–of–mass rapidity: The rapidity distribution of the $\gamma\gamma$ system is centered around 0 with a fairly narrow width ($y_{cm} \lesssim 1-2$). In the analysis a cut of $y_{cm} \leq 1.0$ was applied. A cut on y_{cm} reduces the number of beam–gas and photonuclear interactions, since these are characterized by asymmetric particle emission relative to the Au+Au center–of–mass system.

The expected integrated rates for $f_2(1270)$ and $\rho^0\rho^0$ near threshold ($1.5 \leq m_{\rho\rho} \leq 1.6$ GeV/c^2) for one year of running is presented in Table 3. One year corresponds to 10^7 s of beam–time at the RHIC design luminosity for Au+Au ($\mathcal{L} = 2.0 \cdot 10^{26}$ cm^{-2}s^{-1}). For the rates in Table 3, a cut was also applied in invariant mass of the final state. For $f_2(1270)$, $m_{\pi\pi}$ was required to be within $\mid m_{\pi\pi} - m_{f_2} \mid \leq \Gamma$, where Γ is the natural width, and for $\rho^0\rho^0$ it was required that $1.5 \leq m_{inv} \leq 1.6$ GeV/c^2.

Both of these signals can be clearly separated from background. The backgrounds estimated by FRITIOF and VENUS differ considerably for hadronic A+A interactions. The reason for this is not entirely understood. The two models are in general agreement regarding multiplicity. The differences occur when cuts are applied in for instance $\mid \sum \overline{p}_T \mid$. Of course, neither of these

	System	
	$f_2(1270)$	$\rho^0\rho^0$
Produced at RHIC	1,900,000	42,000
Within STAR Acceptance	660,000	12,000
Peripheral AA (FRITIOF/VENUS)	1,000/5,000	200/800
Beamgas (FRITIOF/VENUS)	1,000/1,000	100/100
γ+A (DTUNUC)	24,000	1,200
Total Background	26,000/32,000	1,500/2,100

TABLE 3. Estimated signal and background rates (Events/year) for production of $f_2(1270)$ and $\rho^0\rho^0$.

models have been compared with data from heavy–ion reactions at RHIC energies. The difference between the models can be taken as a measure of the systematic error in the estimate. As at the trigger level, the largest source of background seems to be photonuclear interactions.

CONCLUSIONS

To summarize, we have shown that ultra–relativistic heavy–ion colliders provide high rates of $\gamma\gamma$ interactions, and that STAR is well suited to study this type of physics. Using appropriate cuts, signals can be separated from background both at the trigger and analysis level.

We thank S. Roesler for providing the DTUNUC Monte Carlo code and for valuable discussion. We also thank our colleagues in STAR for their support. This work was supported by the U.S. DOE under contract DE–AC–03–76SF00098.

REFERENCES

1. *Conceptual Design of the Relativistic Heavy Ion Collider*, BNL–52195, May 1989, Brookhaven National Laboratory.
2. STAR Collaboration, *STAR Conceptual Design Report*, LBL–PUB–5347, June 1992.
3. Jackson, J.D., *Classical Electrodynamics*, New York: John Wiley & Sons, 1975, ch. 15, pp. 719–724.
4. Baur, G. and Ferreira Filho, L.G., *Nucl. Phys.* **A518**, 786 (1990).
5. Cahn, R.N. and Jackson, J.D., *Phys. Rev.* **D42**, 3690 (1990).
6. Hencken, K., Trautmann, D., and Baur, G., *Z. Phys.* **C68**, 473 (1995).
7. Klein, S. and Scannapieco, E., LBNL–40457 to be published in Proc. Photon '97 Egmond aan Zee, The Netherlands, May 10–15, 1997.
8. Klein, S. and Scannapieco, E., STAR Note 243, Feb. 1995 (unpublished).
9. Pi, H., *Comp. Phys. Comm.* **71**, 173 (1992).
10. Werner, K., *Phys. Rep.* **232**, 87 (1993).
11. Engel, R., Ranft, J., and Roesler, S., *Phys. Rev.* **D55**, 6957 (1997).
12. Bringle, M.P., BaBar Note 163 (1994) (unpublished).