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The Gold Flashlight: Coherent Photons (and Pomerons) at RHIC

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The Relativistic Heavy Ion Collider (RHIC) will be the first heavy ion accelerator energetic enough to produce hadronic final states via coherent $\gamma\gamma$, γP, and PP interactions. Because the photon flux scales as Z^2, up to an energy of about $\gamma\hbar c/R \approx 3$ GeV/c, the $\gamma\gamma$ interaction rates are large. RHIC γP interactions test how Pomerons couple to nuclei and measure how different vector mesons, including the J/ψ, interact with nuclear matter. PP collisions can probe Pomeron couplings. Because these collisions can involve identical initial states, for identical final states, the $\gamma\gamma$, γP, and PP channels may interfere, producing new effects. We review the physics of these interactions and discuss how these signals can be detected experimentally, in the context of the STAR detector. Signals can be separated from backgrounds by using isolation cuts (rapidity gaps) and $p_\perp$. We present Monte Carlo studies of different backgrounds, showing that representative signals can be extracted with good rates and signal to noise ratios.

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1 Physics Processes

The Relativistic Heavy Ion Collider[1] (RHIC) will be energetic enough to produce massive final states via $\gamma\gamma$, γP, and PP interactions that coherently couple to the nuclei as a whole. As the number of virtual photons associated with each nuclei goes as Z^2 up to a photon energy of approximately $\gamma\hbar c/R \approx 3$ GeV/c, the $\gamma\gamma$ rate at intermediate energies will be comparable to those of the next generation e^+e^- colliders. RHIC will also produce a high number of coherent photon-Pomeron interactions (γP) and two-Pomeron interactions.

1.1 $\gamma\gamma$ Interactions

The luminosity of $\gamma\gamma$ collisions at heavy ion colliders has been discussed by several authors.[2 3 4] To avoid events where hadronic particle production overshadows the $\gamma\gamma$ interaction, events where the nuclei physically collide (with impact parameter $b < 2R_A$, R_A being the nuclear radius) are excluded from calculations of the usable luminosity. This reduces the luminosity by about 50%, depending on the energy.

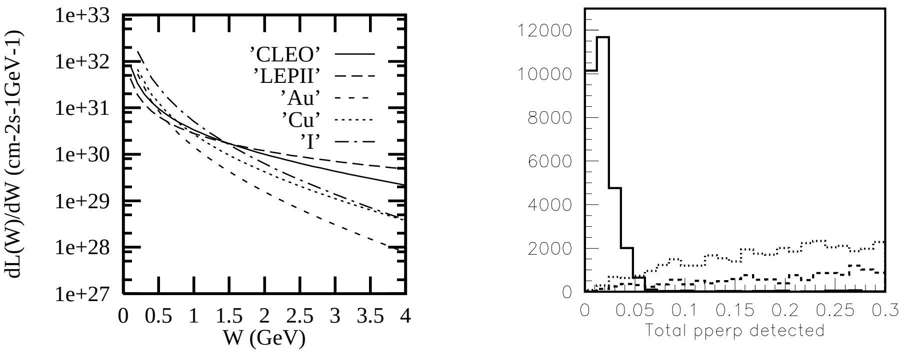

Figure 1: Left: Comparison of $\gamma\gamma$ luminosities at RHIC, for gold, iodine and copper beams, with those of CESR(CLEO) and LEP II. Right: Comparison of $p_\perp$ between $\gamma\gamma$ and background passing our cuts. The solid curve is for $\rho^0\rho^0$ production near threshold. The short dashes are beam-gas and the long dashes are peripheral nuclear backgrounds.

The usable $\gamma\gamma$ luminosity for gold, copper and iodine collisions at RHIC design luminosity is given in the left panel of Fig. 1. The lighter nuclei benefit from the higher AA luminosity, slightly higher beam energy, and smaller nuclear radius, which more than compensates for the reduced Z. Comparison curves for CLEO at CESR and LEP2 are also shown.

Due to the nuclear form factor, the photons are almost real, with a Q^2 cutoff given by the nuclear size, about (30 MeV/c)^2 for gold. Because of this cutoff, the perpendicular momentum of the photons is small, $p_\perp < \hbar c/R$; this is important for separating coherent from incoherent interactions. This is illustrated in the right panel of Fig 1.

1.2 γP Interactions

γP interactions on proton targets have been studied extensively at HERA. RHIC can study these interactions in a nuclear environment. For the reaction $\gamma P \rightarrow V$, where V is a vector meson, RHIC will reach higher center of mass energies and luminosities than the NMC[6] and E-665[7] studies, producing 100,000's of exclusive ρ and ϕ mesons per year, along with large numbers of excited states. RHIC will also produce significant numbers of J/ψ. In the Vector Dominance Model, these rates measure the interaction between the vector meson and the nucleus[5]. Measurements of how vector meson production scales with A can probe meson absorption by nuclear matter. Because meson scattering has a similar form factor to the photon coupling, this reaction has similar kinematics to $\gamma\gamma$ processes.

1.3 *PP Interactions and Interference Measurements*

Unobscured PP interactions can only occur in the impact parameter range $2R_A+2R_P > b > 2R_A$, where R_P is the range of the Pomeron. A measurement of the PP cross section can thus measure the range of the Pomeron. The difficulty in this measurement is separating $\gamma\gamma$ and PP interactions; the two reactions have very similar kinematics and a statistical separation is required. However the relative rates will change as A varies; for protons, PP interactions will dominate, while $\gamma\gamma$ should dominate for Au. The $\gamma\gamma$ luminosity can be measured from $\gamma\gamma \rightarrow e^+e^-$ and the PP luminosity found by subtraction. It may also be possible to use impact parameter dependent signals of nuclear breakup to better distinguish γ and P emission[4].

The similarity between $\gamma\gamma$, γP and PP events allows for the possibility of interference between the two channels. One example is dilepton production from $\gamma\gamma \rightarrow e^+e^-$ and $\gamma P \rightarrow V \rightarrow e^+e^-$; the two channels can interfere, and a measurement of the phase of the interference is sensitive to the real part of the Pomeron and the interaction of the vector meson with the nuclear potential[8].

2 Experimental Feasibility

For any of these measurements to be feasible, it must be possible to separate these coherent interactions from incoherent backgrounds at both the trigger and analysis levels[9]. The major backgrounds that we have identified are grazing nuclear collisions, photo-nuclear interactions, beam gas interactions, debris from upstream beam breakup, and cosmic ray muons; the latter two only affect triggering.

Two useful factors for separating these signals from backgrounds are rapidity gaps and perpendicular momentum. We have concentrated on final states that can be completely reconstructed. We then require that the detector contain nothing except the final state in question. For central events, this naturally reduces to requiring rapidity gaps. Because of the coherence, the $p_\perp$ scale is $\sqrt{2}\hbar c/R$, about 45 MeV/c for gold, much smaller than the typical hadronic momentum scale of 300 MeV/c.

2.1 *STAR*

The Solenoidal Tracker at RHIC (STAR) is a general purpose large acceptance detector[10]. A time projection chamber tracks charged particles with pseudorapidity $-2 < \eta < 2$. A silicon vertex tracker measures impact parameter over $-1 < \eta < 1$. A time of flight (TOF) system and dE/dx in the TPC help with particle identification. Two forward TPCs are sensitive to charged particles with $2.5 < |\eta| < 4$, and an electromagnetic calorimeter detects photons in the range $-1 < \eta < 2$.

STAR has a multi-level trigger which is well suited to studying peripheral collisions. Scintillators and wire chamber readouts surrounding the TPC measure the charged multiplicity for $-2 < \eta < 2$ on each beam crossing. Events are selected based on multiplicity and topology. At higher trigger levels, the calorimeter can contribute to the trigger and TPC tracking information can be used to select events based on the location of the event vertex and total $p_\perp$.

2.2 Signal and Background Simulation

We have performed Monte Carlo calculations of the $\gamma\gamma$ signals and backgrounds from grazing nuclear and beam gas interactions.[11] Other backgrounds have been estimated by scaling and other methods.

We calculated tables of $\gamma\gamma$ luminosity as a function of invariant mass and rapidity, and then generated simulated events based on these tables. Transverse momentum spectra were included using a Gaussian form factor with a characteristic width of $1/R$. Cuts were applied to simulate the detector acceptance and planned analysis procedure.

Grazing nuclear collisions and beam gas events were simulated using both the FRITIOF and Venus nuclear Monte Carlos. These events were subject to the same cuts. Photo-nuclear collision rates were estimated by scaling from the beam gas rates, making use of the similar kinematics; a more detailed estimate is in progress.

To determine the feasibility of studying $\gamma\gamma$ interactions with STAR, we have considered 3 sample analyses: $\gamma\gamma \rightarrow f_2(1270) \rightarrow \pi^+\pi^-$, $\gamma\gamma \rightarrow \rho^0\rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \rightarrow \eta_c \rightarrow K^{*0}K^-\pi^+$. These reactions were chosen to be representative of a wide range of reactions that produce two or four charged particles in the STAR TPC. To separate these events from backgrounds, we have applied cuts to the charged and neutral multiplicity visible in STAR, required that $p_\perp < 100$ MeV, and required an appropriate invariant mass cut. The predicted rates and backgrounds for these analyses are given in Table 1. Although the FRITIOF and Venus predictions are very different, this analysis shows that $f_2(1270) \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow \rho^0\rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ reactions should be clearly separable from backgrounds, while more challenging measurements such $\Gamma(\gamma\gamma)$ for the 2960 MeV $J^{PC} = 0^{-+}$ $c\overline{c}$ resonance $\eta_c \rightarrow K^{*0}K^-\pi^+$ may be possible with appropriate particle identification by TOF and dE/dx.

We have also considered the problem of triggering on these events. In addition to the grazing nuclear collisions, beam gas events and photonuclear interactions, at the trigger level there are backgrounds from beam nuclei inter-

Table 1: Rates and backgrounds for $\gamma\gamma$ events for gold on gold collisions at RHIC for 3 sample analyses. The $\rho^0\rho^0$ events were near threshold, with invariant masses between 1.5 and 1.6 GeV/c^2. The last line assumes particle identification by dE/dx and TOF.

Channel	Efficiency	Detected Events/Yr	FRITIOF Background	Venus Background
$f_2(1270) \rightarrow \pi^+\pi^-$	85%	9.2×10^5	53,000	100,000
$\rho^0\rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$	38%	1.6×10^4	3,500	1,400
$\eta_c \rightarrow K^{*0}K^-\pi^+$	57%	70	210	510
η_c (w/ PID)	57%	70	8	20

actions upstream of the detector and cosmic ray muons. Monte Carlo studies have shown that, using the multi-level trigger in STAR, it is possible to devise trigger algorithms with good acceptance for coherent interactions and good background rejection. The trigger algorithms are based on requiring two or four tracks in the central TPC, with nothing else visible in the detector.

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