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Workshop "Can RHIC be used to test QED?", BNL, 4/20-21/90, Upton, NY

CAN RHIC BE USED TO TEST QED

Workshop Summary

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The two day workshop entitled "Can RHIC be Used to Test QED" took place on April 20 - 21 at Brookhaven National Laboratory. It was attended hy approximately 50 physicists from both the U.S. and Europe. Although most of the attendees were theorists, a large portion of the second morning was devoted to pending experiments and the experimental difficulties associated with strong field electromagnetic phenomena. The workshop was remarkably multidisciplinary in nature, attracting elementary particle, nuclear and atomic theorists and experimentalists.

We note that at RHIC, fully stripped Au ions will be accelerated to beam energies of 100Gev/u in a collider mode. At these energies the S-matrix for single $e^+ + e^-$ pair production violates unitarity bounds, thus implying that multiple pair production will occur. The theoretical language for investigating this phenomena is contained within the so-called virtual two photon representation of the heavy ion electromagnetic fields.

Three general subjects were addressed during the workshop. These subjects were:

1. To understand the validity of the best available descriptions of $e^+ e^-$ pair production in peripheral heavy ion collisions, especially for the domain where this process is known to be non-perturbative.

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2. To understand the prospects for using relativistic heavy ions to produce Higgs Bosons or Weak Bosons (Z_0, W+, W-). This production mechanism proceeds through the virtual two photon representation of the heavy ions, and is considered a reason for accelerating heavy ions in both the LHC and the SSC.

3. To study the interference mechanisms between the two processes for hadron production in peripheral heavy ion collisions. These two processes are two photon exchange and two pomeron exchange.

$e^+ e^-$ Pair Production in Heavy Ion Collisions

In addition to the fundamental questions regarding $e^+ e^-$ pair creation and non-perturbative QED, it is important for both detector design and collider performance to understand the pair creation mechanism during the heavy ion beam crossing. The created pairs could be a source of background in the detectors at heavy ion colliders. Of equal importance to the detector background is the so-called capture problem, associated with a heavy ion capturing one of the produced electrons in an atomic orbital. Changing the charge state of the heavy ion by one unit will eventually cause the ion to be lost from the beam. This mechanism is a major component in determining the luminosity lifetime in a heavy ion collider.

As discussed by Brodsky and Strayer, the $e^+ e^-$ pair production cross sections in the lowest order perturbative limit was shown to be 33.7K barns for Au beams at top energy in RHIC. This number came from both exact Monte Carlo evaluation of the perturbative matrix element, and by applying the analytic formula due to Racah (Nuovo Cimento 14 (1937) p. 70). Since the workshop, it has been shown (C. Bottcher, private communication) that the Racah formula and Monte Carlo calculations for $e^+ e^-$ pair production agree extremely well for Lorentz gamma values spanning nearly 4-orders of magnitude (beginning at $\gamma=2$).

Strayer showed that with modern computers, the multidimensional integrals associated with pair creation can be efficiently evaluated using a million or so Monte Carlo points. Detailed Monte Carlo calculations with nuclear form factors showed that the form factors act to suppress the p_T momentum dependance of the differential cross sections $d\sigma/dp_T$. The total cross section for electron pair creation is not affected by the nuclear form factor. Calculations for the single e^+ or e^- distribution $d\sigma/dp_T$ showed that most of these particles are produced in the forward (or backward) direction along the beam axis, with the perpendicular component of the singles momentum falling several orders of magnitude as p_T grows from 0 to 100Mev. Thus, most of the singles or pairs may be considered soft in nature. Further calculations of the energy distributions and the angular distributions of the singles and pairs are expected to be performed at the forthcoming RHIC workshop (July 1990). Strayer also showed his calculations for mu-pair production, including the interesting result that for invariant mass values M<4Gev, the coherent differential cross section $d\sigma/dydM$ from beam crossing is larger than the Drell Yan background.

For a certain class of detectors at RHIC, the total integrated cross section may not be the most relevant quantity. If the detector gates on a limited range of impact parameters, the pair production probability for these impact parameters might be more relevant. Further studies are needed on this impact parameter question.

The fact that $e^+ e^-$ pair production at RHIC violates unitarity was clearly shown by Brodsky and Baur, the latter stating that the probability for producing a single pair at an impact parameter corresponding to the Compton wavelength is 2.5 for Au beams at top RHIC energies. This result clearly suggests that higher order QED effects, most notably multiple pair production, could be observed at RHIC. Estimates for the number of $e^+ e^-$ pairs per ion interaction varied greatly. Brodsky, using an argument based on counting the number of equivalent photon-photon interactions per unit of rapidity interval for each heavy ion, gave an upper limit of 2000 pairs per interaction at RHIC. Baur, using an analogy of exciting harmonic oscillators by a time dependent force, schematically sums multiple pair diagrams to arrive at a Poisson distribution for the probability of producing pairs of multiplicity N at a given impact parameter. This technique suggests only a few pairs are produced, but after intense discussion, it was suggested (Muller) that the accuracy of neglecting the time ordering in the perturbation series needs to be explored in more detail.

Two theories for understanding non-perturbative QED phenomena were presented. Bottcher described a promising technique for non-perturbative electron pair production, based on the light cone representation of the Dirac equation. This high energy representation takes advantage of the weak coupling between the longitudinal and transverse momenta of the produced pair. For Au beams at RHIC, calculations based on this method indicate a factor of two reduction in the total electron pair cross section from the perturbative result. In contrast, Schied described a coupled-channels calculation for non-perturbative $e^+ e^-$ pair creation. This calculational technique is difficult to implement at RHIC energies, but at lower energies ($\gamma=10$), two orders of magnitude enhancement over perturbative estimates were claimed for the pair production cross section. Enhancements of this order were also shown for the electron capture cross section.

The striking mismatch between theories for the effects of higher order QED was not resolved at the workshop. The light cone approach is probably not applicable at lower energies (γ=10), and the coupled channels technique is technically difficult to implement at higher energies. However, it is important for both RHIC luminosity lifetime questions, and heavy ion collider detector design, to address the questions on "just how important are higher order QED effects?". As discussed by McLerran, this will require evaluation of higher order diagrams, including box diagrams, as well as detailed comparison with experimental data.

Datz and Belkacem described their experimental procedures for measuring pair production and electron capture at CERN (S beams) and Berkeley (U beams) respectively. Although these fixed target experiments are at energies considerably below what will be achieved at RHIC, they will be an essential component in helping to understand some of the above theoretical discrepancies. Within two years, Au beams will become available at the AGS (γ=10), and thus could provide another set of experimental data.

After the workshop, it was suggested (Fatyga) that the impact parameter dependence of the non-perturbative $e^+ e^-$ production could be studied through a coincidence experiment of $\mu^+ \mu^-$ pairs with $e^+ e^-$ pairs. It is expected that perturbation theory will be accurate for the production of the $\mu^+ \mu^-$ pairs. This concept will be further developed in the July 1990 RHIC workshop.

Producing Higgs Bosons and Weak Bosons in Heavy Ion Colliders

Mueller, Couture, Brodsky, Strayer and Smith discussed in detail the γ-γ physics that would be accessible at the proposed heavy ion colliders (RHIC, plus heavy ions in LHC and SSC). Of particular interest was the probability of producing a Higgs particle or W+ W- pairs via the virtual two photon spectrum of relativistic heavy ions. This mechanism is out of the question at RHIC, because the nuclear size imposes a cut off in the energy of the virtual photon spectra at 3Gev. At LHC or SSC this cutoff extends to 100Gev or 250Gev respectively.

Much of the focus of discussion at the workshop was the then recent preprint of Cahn and Jackson (LBL 28592, 1990). In contrast to the earlier work of Drees, et al (Phys. Lett B223 [1989] 454), Cahn and Jackson used a cutoff in impact parameter space to exclude the finite size of the nucleus. Drees, et al, included this effect through an elastic form factor. Cahn and Jackson showed that for Pb-Pb collisions, production of a Higgs Boson with an intermediate mass of 100Gev is reduced by a factor of 0.14 from Drees' estimate for SSC energies, and reduced a factor of 0.037 at LHC energies. These are discouraging rates, and the workshop left on a pessimistic note that the production rate for Higgs Bosons, using heavy ions, is too low to be experimentally useful.

Since the meeting, preliminary calculations on the Higgs, as shown by Strayer, have been completed. This preprint (Wu, et al, ORNL preprint ORNL/CCIP/90/02) suggests that the results of Cahn and Jackson based on the Weissacker-Williams method were too pessimistic. The Weissacker-Williams method assumes the transverse momentum of the produced pair is zero, an assumption that is not realistic in this case. Using a Monte Carlo evaluation of the impact parameter dependence of the Higgs production matrix elements, Wu, et al, show that the original calculations of Drees, et al, are reduced by only a factor of 1.9 at LHC energies and a factor of 1.4 at SSC energies, if the constraint that the heavy ions remain intact is imposed. At this time the prospects for producing intermediate mass Higgs Bosons from coherent two photon production appears more promising than at the time of the workshop. At the SSC, Wu, et al, now calculate up to 500 Higgs a year, if a luminosity of 10^{28} cm^{-2} sec^{-1} can be achieved. We note that this value of the luminosity is nearly two orders of magnitude beyond initial RHIC operation values.

Hadron Production from Peripheral Heavy Ion Collisions

Mueller and Brodsky discussed the hadron resonances available through so-called γ-γ physics. Of particular interest at RHIC energies are the η_0, f(1270) and η_c(2980) resonances. As indicated by Brodsky, heavy ion colliders make good γ-γ factories, particularly in the low mass region. It was also pointed out by Brodsky that a heavy ion collider can be very competitive with $e^+ e^-$ machines, if the luminosity can be increased to 10^{28}.

As part of this discussion, Mueller and Brodsky raised the question of a background to photon photon reactions from Double Pomeron Interactions. For intermediate nuclear A and Z values, the γ-γ and p p amplitudes are comparable, resulting in an interference that needs to be taken into account. For very heavy nuclei, the γ-γ interactions will dominate. Thus, an experiment designed to measure hadron resonance production as a function of the mass and charge of the colliding nuclei could, in principle, study this interference effect. This ability to conduct such a set of comprehensive measurements using the same apparatus and minimal change to the experimental acceptance is a unique capability of RHIC.

Conclusion

The Relativistic Heavy Ion Collider at Brookhaven will be a machine offering some special capabilities in the areas which were discussed during this workshop. One should be able to do comparison measurements of various electromagnetic phenomena with a variety of beams, thus varying the strength of electromagnetic fields in a well-controlled manner. These measurements can be done with a single apparatus and at a fixed value of the Lorentz γ, eliminating many systematic errors due to acceptance corrections or different beam energies. As an example, gold beams can be used to study non-perturbative phenomena in $e^+ e^-$ pair production, with lighter beams providing a reference measurement in which no strong non-perturbative corrections are expected. A search for possible anomalies in the production of hadrons ($q \bar{q}$ pairs) by strong electromagnetic fields can be conducted in a similar manner.

A study of electromagnetic phenomena in extremely peripheral collisions of relativistic heavy ions can become a rich and exciting field that will complement studies of central collisions.