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# **An Experiment to Study Strong Electromagnetic Fields at RHIC.**

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## **ABSTRACT**

We present a description of an experiment which can be used to search for effects of strong electromagnetic fields on the production of  $e^+e^-$  pairs in the elastic scattering of two heavy ions at RHIC. A very brief discussion of other possible studies of electromagnetic phenomena at RHIC is also presented.

## 1. Introduction.

When two high energy heavy ions approach one another to a distance comparable to their nuclear radius, electromagnetic fields of high intensity will be created. The presence of these fields will result in a wide range of electromagnetic processes, involving both the production of particles and photoexcitations of nuclei. The significance of such phenomena for a physics program at RHIC is threefold: first, the production of particles by electromagnetic fields will naturally accompany all central or semi-central collisions. Electromagnetic processes must be carefully considered as a possible background in some investigations of central collisions. Second, two very abundant electromagnetic processes constitute the primary limitation to the lifetime of stored beams at RHIC. One of them is a nuclear decay following the electromagnetic excitation of the giant dipole resonance, and the second one is a creation of an  $e^+e^-$  pair accompanied by the capture of an electron in the atomic level of one of the ions. <sup>1</sup> Third, (last but not least) it is of significant interest to study the physics of particle production by strong electromagnetic fields. Even conventional QED calculations indicate that collisions of heavy ions at RHIC will produce unique electromagnetic phenomena which cannot be studied by any other means. Of particular interest seems to be the production of  $e^+e^-$  pairs by energetic heavy ions. This process can no longer be described by perturbative methods, since the S-matrix for single  $e^+e^-$  pair production violates unitarity bounds. <sup>2</sup> Non-perturbative approaches to QED can be studied in this system through measurements of the pair multiplicity (as well as other properties of pairs) in collisions with small impact parameters. Finally, one must not exclude the possibility that new, as yet unknown phenomena due to strong fields can be observed in collisions of heavy ions. In the remainder of this paper we will present an outline of some experimental concepts which can be used to study the physics of strong electromagnetic fields with relativistic heavy ions.

## 2. Experimental concepts.

### 2.1 Definitions.

Let us consider a symmetric collision of two ions with a charge  $Z$ , a mass number  $A$ , an energy per nucleon corresponding to the lorentz factor  $\gamma$ , and with an impact parameter  $b$ . Using the impact parameter  $b$ , we will divide all collisions into three categories:

if  $R$  is the nuclear radius of either ion,

$b < 2R$  is a hard hadronic collision in which at least one nucleon in each ion was shifted out of the beam rapidity range.

$b > 2R$  is a collision without a nuclear contact. Only electromagnetic phenomena can occur in such a collision.

$b = 2R$  is a nuclear grazing collision in which no nucleons are lost from the beam rapidity range, but both ions interacted strongly. This type of a collision can leave one or both ions in an excited state, and it can also lead to the production of particles through a two pomeron exchange.

### 2.2 Experimental studies of electromagnetic phenomena.

The primary difficulty in using heavy ions to study electromagnetic phenomena lies in a proper selection of collisions without a nuclear contact. A true electromagnetic event has quite low multiplicity and should not present one with any particular instrumental problems. One must expect however, that potentially serious problems may appear at the trigger level. A typical electromagnetic trigger carries a small amount of energy when compared to the total energy which is available in a collision. Hence, a trigger on the electromagnetic process must be restrictive (clever) enough not to be overwhelmed by a background due to hadronic interactions. A triggering scheme must be based on the primary trigger which selects the desired process and a set of veto detectors which reject spurious triggers due to hadronic events. More violent hadronic interactions can be easily detected with the use of a multiplicity detector of some sort. Events with a smaller multiplicity (close to the nuclear grazing collision) can perhaps be vetoed by forward calorimeters detecting beam rapidity nucleons emitted in a process of a particle decay of

excited ions. This type of veto must be applied judiciously, due to the high probability of exciting one or both ions electromagnetically. We will discuss these issues in more detail later in the paper.

### 2.3 Controlling the intensity of the field.

The intensity of electromagnetic fields which are created in a collision is controlled by three parameters: charges of ions ( $Z$ ), their lorentz  $\gamma$ , and impact parameter ( $b$ ). Two of these three parameters ( $Z, \gamma$ ) can be varied quite trivially (in principle at least), by varying the charge of a beam and/or its energy. The ability to study electromagnetic phenomena as a function of  $Z$  and  $\gamma$  with a single apparatus is one of the most attractive features of RHIC. Such a study will allow one to vary the average strength of the field in a controlled manner, thus observing the onset of phenomena which are associated with strong fields. As an example, let us consider the production of  $e^+e^-$  in a collision without a nuclear contact. In fig.1 we show a perturbative calculation of the probability of producing a pair in a collision with the impact parameter equal to the compton wavelength of the electron ( $b=385\text{fm}$ ).<sup>3</sup> A solid arrow points to the maximum energy at RHIC (this calculation assumes a fixed target reference frame). For the U+U collision the calculated probability exceeds unity, thus implying that the perturbative calculation can no longer describe this phenomenon correctly. At the same time the probability for producing a pair in Zr+Zr collision is well below unity, which implies that for beams with lower charges the perturbative approach is valid. By varying the charge of the beam one can study a transition from a perturbative to a non-perturbative regime in a production of  $e^+e^-$  pairs. A similar transition can be induced by lowering the energy of a heavy beam. The dotted arrow in fig.1 points to the value of  $\gamma$  which corresponds to 1/5 of the maximum energy at RHIC. At this energy even in U+U collision the perturbative estimate does not violate the unitarity bounds. Hence, one can study a similar transition between a perturbative and a non-perturbative regime using different means.

## 2.4 Controlling the impact parameter.

The dependence of electromagnetic cross sections on the charge and the energy of a beam is a powerful tool with which one can study some aspects of non-perturbative QED. This tool is likely to be insufficient however, if one wants to search for new phenomena induced by strong fields. Since the electromagnetic interaction is a long range interaction, processes like the production of particles or photonuclear excitations occur within a wide range of impact parameters. To be more quantitative, let us consider again an example of the  $e^+e^-$  pair production. In fig.2 we show the dependence of  $e^+e^-$  cross section on the impact parameter in U+U and p+p collisions. <sup>4</sup> The impact parameter scale is expressed in the units of the Compton wavelength of the electron (385fm). We observe that the calculated cross section in U+U collision is nearly flat (slightly decreasing) in the region 15fm-385fm, while the maximum field intensity must vary by nearly three orders of magnitude in the same interval of  $b$  (with weaker fields favored by the phase space). Hence, if one would like to look for effects of strong fields which go beyond the present QED predictions, some method of selecting collisions with a small impact parameter seems necessary.

Conceptually, the most direct method of tagging a collision with its impact parameter would be to measure the transverse momentum transfer to both ions. Since relativistic heavy ions follow essentially classical Rutherford trajectories these two quantities can be related to each other. Unfortunately, a measurement of the transverse momentum transfer in an elastic collision of heavy ions appears to be extremely difficult (probably impossible). The maximum momentum transferred to each ion in gold on gold collisions is approximately 1.1GeV/c, while the incident momentum of each ion is nearly 20000 GeV/c (at relativistic energies the transverse momentum transfer is nearly independent of the incident energy). This means that the maximum deflection angle due to the Rutherford scattering is less than .06mrad, too small to be measured. Some other, more indirect method of tagging collisions with the impact parameter must be found.

In this paper we will discuss an indirect method of measuring an impact parameter which is based on the measurement of a cross section for a coincidence between two electromagnetic processes. Such measurements are not feasible at presently available energies due to prohibitively low coincidence rates. The situation will be far more favorable at RHIC

energies however, as probabilities for some electromagnetic processes approach unity. As a first example let us consider a measurement of the coincidence between  $\mu^+\mu^-$  pairs and  $e^+e^-$  pairs in a collision of two gold ions at  $\gamma = 100$  (a collision without a nuclear contact). Suppose, that we trigger the experiment on a single pair of muons and measure its invariant mass. Having established a trigger, we detect all electrons which were produced in the same event. We can now vary the invariant mass of a muon pair, observing that massive pairs can only be created in a collision with a small impact parameter. To illustrate this point quantitatively, let us assume that we detect a pair with mass  $M$  at the rapidity zero. Using the Weizsacker-Williams approximation one can estimate the range of impact parameters within which this pair could have been created. The upper limit of this range is given by:

$$b_{max} = \frac{2\gamma hc}{2\pi M} \quad (2.1)$$

If one sets a detection threshold for the minimum mass of

$$M_{min} = 4M_{0,\mu}$$

where  $M_{0,\mu}$  is a rest mass of a muon, the maximum impact parameter  $b_{max}$  is equal to 95fm. Hence, a trigger pair with the invariant mass equal to  $4M_{0,\mu}$  would span the 14fm-95fm range of impact parameters. The lower limit of this range is determined by the requirement of a collision without the nuclear contact. Through the same approximation one can estimate the maximum mass of a  $\mu^+\mu^-$  pair to be  $2.9\text{GeV}/c^2$ . A trigger on such massive pairs will therefore select collisions with the smallest impact parameter ( $b_{min} = 2R$ , where  $R$  is a radius of an ion). One should stress, that by requiring a trigger pair of a given mass one does not select a single value of the impact parameter, but a range of impact parameters from the minimum ( $b_{min} = 2R$ ) to the  $b_{max}$  which was defined in Eq. (2.1).

As a second example let us consider an experiment in which  $\mu^+\mu^-$  pairs are measured in coincidence with beam rapidity neutrons on either side of the interaction diamond. Beam rapidity neutrons can be emitted in a process of a decay of an excited beam ion. An excitation can be induced electromagnetically or through a nuclear grazing collision. For the purpose of this discussion we will assume that electromagnetic and nuclear components can be accurately separated. Implications of this assumption will be discussed later.

We present calculations concerning two types of events which include beam rapidity neutrons. First, an event in which only one neutron is detected on either side of the interaction region, with no neutron on the complementing side. This type of an event will be denoted as  $T(1n,0n)$ . Second, an event in which two neutrons are detected, one on each side of the interaction region. This type of an event will be denoted as  $T(1n,1n)$ . In fig 3 we show probabilities of the both types of events,  $P[T(1n,0n)]$  and  $P[T(1n,1n)]$ , plotted against the impact parameter. We observe two features of these distributions: (a) in collisions with a small impact parameter both  $P[T(1n,0n)]$  and  $P[T(1n,1n)]$  are large, 50% and 20% respectively. Consequently, these two channels are suitable as an element of a coincidence measurement. (b) Both probabilities depend very differently on the impact parameter.  $P[T(1n,0n)]$  changes *roughly* like  $\frac{1}{b^2}$ , while  $P[T(1n,1n)]$  changes like  $\frac{1}{b^4}$ . A measurement of  $\mu^+\mu^-T(1n,0n)$  and  $\mu^+\mu^-T(1n,1n)$  channels can be viewed as a first step in a separate study of a dependence of the  $\mu^+\mu^-$  pair production and electromagnetic excitation of nuclei on the impact parameter. Since both these processes should be calculable within a perturbative formalism, we do not select (or declare) any of them as a trigger process. It is a consistency check, which can nevertheless reveal new phenomena in case a discrepancy is observed. One can go further and study channels  $T(2n,0n), T(2n,1n), T(2n,2n)$ , etc..... . These channels will introduce even stronger bias towards collisions with a small impact parameter, albeit at the cost of introducing growing experimental problems. First, the absolute value of a probability of inducing a more complex decay will be decreasing, which will decrease the coincidence rate. Second, as the probability of an electromagnetic excitation decreases one must worry more about the background due to the same decay induced in a nuclear grazing collision. These problems should be addressed in future studies (calculations) in order to examine the feasibility of a more extensive program.

## 2.5 Quality of a trigger.

Several times in the preceding discussion we have referred to possible problems with the quality of a trigger. Before proceeding to describe an experimental apparatus, we will discuss the problem of a trigger quality in more general terms.

A trigger for an electromagnetic process must consist of two parts, the first one to select the desired process and the second one in the form of veto detectors which attempt to



discriminate against hadronic interactions. For example, in the case of  $\mu^+\mu^-e^+e^-$  measurement the primary trigger would be defined as two and only two penetrating tracks in the muon region. Veto detectors would probably consist of crude multiplicity detectors covering forward and central regions. The quality of this trigger rests on the identification of muon tracks and a completeness of veto detectors. Although various tests of the performance of such a trigger can be devised, the final test of its quality must be accomplished by measuring the dependence of a trigger rate on the charge of a beam and/or its energy. A precise calculation of the  $Z$  dependence of trigger rates should be possible, as long as the rate of a trigger process can be calculated with perturbative methods.

A similar test can be applied to the emission of nucleons from excited ions. The calculation of the dependence of a cross section on the charge of a beam is not as straightforward as in the case of particle production. The main difficulty lies in the fact that the change in the charge of a beam implies simultaneous changes in the nuclear structure which must be taken into account in all calculations. These difficulties are less severe when cross sections are measured as a function of the beam energy, rather than the beam charge. Hence, the dependence of a cross section on the beam energy seems to be the most appropriate test of a trigger quality in this case.

In summary, the issue of a trigger quality definitely requires further study, mainly through Monte Carlo simulations. We note however, that direct experimental tests of this quality can (and should) be performed. Once again, it is apparent that the ability to study the same process with beams of different charge and energy is a very important feature of RHIC.

### 3. An outline of the apparatus.

The apparatus which will be *sketched* in this section is designed to perform three basic measurements which were discussed in previous sections: massive  $\mu^+\mu^-$  or  $e^+e^-$  trigger pairs, low energy  $e^+e^-$  pairs and beam rapidity nucleons. The actual design of an experiment requires far more work than has been done thus far. In most instances we will simply outline problems which must be studied further, rather than provide ready solutions.

### 3.1 Low energy electrons.

We begin with a discussion of what seems to be the most difficult task, namely detecting low energy electrons. The kinetic energy spectrum of electrons (positrons) which are produced in a heavy ion collision peaks at energies between 1 and 2 MeV. Hence, a complete measurement of non-perturbative QED phenomena in a heavy ion collision requires a serious effort to detect electrons and positrons down to very low energies. Two features of a collider make it a particularly complicated task at RHIC. First, the length of the interaction diamond (22cm RMS) complicates the geometry and the acceptance of a detector. This length combined with the absence of a target constraint makes tracking of low energy electrons very difficult. Second, due to the stringent vacuum requirements inside the beam pipe ( $10^{-10}Tr$ ) it is very difficult to put detectors directly into the beam vacuum. A silicon strip detector is perhaps the only presently available type of a detector which does not cause a conflict with vacuum requirements. As an alternative solution one can use a thin beam pipe made of a low  $Z$  material and position a detector immediately outside the beam pipe. Although the latter choice is probably more practical both solutions should be studied seriously. In fig.4 we show a schematic view of an electron detection region. It consists of an interaction diamond and two adjacent regions of a magnetic field in which more energetic electrons are bent away from the beam and analyzed. One may also consider applying a weak magnetic field to the region of the interaction diamond. The purpose of such a field would be to bend all electrons and positrons out of the beam. Since low energy electrons (positrons) have quite broad angular distributions, it is not clear whether this field is really needed. This question must be studied further. Angular distributions become more focused with respect to the beam axis as the energy of an electron (positron) increases. Hence, one needs two regions of the magnetic field (one on each side of the interaction diamond) to bend more energetic electrons (positrons) out of the beam. The magnetic field will also provide some opportunity for the momentum analysis, albeit an uncertainty due to the absence of a target constraint.

The primary objective of the low energy region should be to measure the multiplicity of  $e^+e^-$  pairs and energy distributions of electrons and positrons. It is obviously desirable to measure other kinematic variables like an invariant mass distribution of  $e^+e^-$  pairs

or transverse momenta of singles and pairs. The feasibility of measuring an invariant mass spectrum depends to a large degree on the actual multiplicity of pairs. If it is true that multiple pairs are created in a collision, any measurement of the invariant mass will be difficult due to a combinatorial background. It will also be very difficult to measure transverse momenta of electrons (positrons) due to problems which were described above. A detector which is chosen to meet these objectives should have a good granularity as well as a capability to measure the total energy of individual electrons. A simple range detector composed of layers of scintillator tiles (perhaps separated by thin absorber plates) would seem a good choice in the low energy region. Crystals of CsI can be used to detect energetic electrons above 100MeV or so (a trigger pair). The choice of a granularity depends on the expected multiplicity of pairs which is still an object of some controversy (and may remain so until the measurement is done). Consequently, it is difficult to say at this time what granularity is really needed. In fig.5 we show a schematic design of a simple range detector. The design of the low energy electron spectrometer requires much more work than has been done thus far. One of the issues which must be carefully looked at is the feasibility of tracking in the intermediate energy range (5-10MeV). Some less conventional designs of the spectrometer should also be considered.

### 3.2 A trigger pair.

A trigger pair can be a massive  $e^+e^-$  pair or a  $\mu^+\mu^-$  pair. There are some technical advantages to the use of an  $e^+e^-$  rather than a  $\mu^+\mu^-$  pair. These advantages are partially offset by a potential for a combinatorial background when multiple pairs of electrons are produced. This ambiguity can be reduced to an arbitrarily low level however, by imposing a lower limit on the invariant mass of a trigger pair. The probability of producing two massive pairs in a single event will then be very low. The technical advantage of an electron pair is in the fact that the total energy of an electron can be measured in a shower detector. The detector can be relatively small, since electromagnetic showers are both short and narrow. This facilitates both the total energy measurement and a particle identification. The electron can be tracked prior to entering the total absorption detector, giving one more complete and precise information about its kinematic variables than a muon would. It is obviously very interesting to have a capability to trigger both on electron and on muon

pairs and compare the two results in the limit of a high invariant mass of a trigger pair. In fig.6 we show a scheme for a combined measurement of a trigger pair and low energy electron-positron pairs. This design is based on the assumption that the transverse momentum of a high energy muon or electron is small when compared to its longitudinal momentum. A high momentum electron (muon) propagates nearly undisturbed through the first region of a weak magnetic field and is analyzed in the downstream region with a stronger field. The detection of an electron should involve tracking backed by a small electromagnetic calorimeter. Muons must be identified by a range detector, perhaps coupled with a detection of a muon decay. At the limit of the invariant mass range of a trigger pair one expects two back to back electrons (muons) with the momentum of the order of 1.4 GeV/c. The identification of an electron above a few hundred Mev poses no problems if one uses a suitable total energy detector (eg. CsI crystals) to identify its electromagnetic shower. A positive identification of muons in this energy range (and particularly their separation from pions) may be difficult. Even so, the suppression of a background due to hadronic interactions should be feasible by requiring two and only two penetrating tracks, one on each side of the beamline. According to our earlier discussion the quality of the trigger can be examined experimentally. One should also mention the fact, that the increase in the invariant mass of a trigger pair is coupled to some broadening of angular distributions of single electrons (muons). Consequently, one may be forced to modify the simple design which is shown in fig.6 to avoid losses of experimental acceptance for high mass pairs. As with most other experimental issues in this paper, the detection of a trigger pair requires further study.

### 3.3 Detecting beam rapidity nucleons.

Detecting beam rapidity nucleons at RHIC should not be particularly difficult. Neutrons can be detected at zero degrees behind the first bending magnet, while protons will emerge from the beam at twice the bending angle of the beam, also after the first bending magnet. If one assumes a maximum transverse momentum of a neutron to be 400 MeV/c (a conservative assumption), then at a distance of 20 meters from the interaction region all neutrons are still confined within a circle 16cm in diameter. Hence, beam rapidity neutrons remain well focused even at large distances from the interaction region. The most

appropriate technique for detecting a neutron with an energy of 100GeV is a hadronic calorimeter. The main purpose of this calorimeter should be to count the number of neutrons in an event. Even if an overall energy resolution of such a detector is about 20%, one can still count beam rapidity neutrons without much trouble. A two neutron peak would be separated from a one neutron peak by more than five standard deviations, quite enough for a reliable classification of the event. In reality, one should expect the energy resolution to be better than 20%. A good hadronic calorimeter (available today) can offer an energy resolution of 5% at an energy of 100GeV. The fermi momentum distribution will broaden the laboratory energy distribution of a neutron to about 12% of its average value. Hence, even if one assumes that the instrumental energy resolution is a factor of three worse than the 5% quoted above, one still arrives at the overall width of the energy spectrum equal to 19% of the average value. The separation can be further improved if one uses a segmented calorimeter, so that a simple pattern recognition can be used. A similar discussion applies to beam rapidity protons.

### 3.4 Event rates and multiple interactions per bunch crossing.

The cross section for producing a  $\mu^+\mu^-$  pair in an extremely peripheral collision of two gold ions at  $\gamma = 100$  is approximately 300 mb. At the design luminosity of  $2 * 10^{26} \text{ cm}^{-2} \text{ sec}^{-1}$  one expects 60  $\mu^+\mu^-$  pairs per second. Triggering on the invariant mass interval which corresponds to 1% of the total cross section one still expects .6 pairs per second, a respectable trigger rate.

Since the cross section for producing  $e^+e^-$  pairs is very large, one must worry about the possibility of multiple interactions per one bunch crossing. The geometric cross section for a passage of two ions within a distance smaller than 385fm is of the order of 5kb, which corresponds to .22 of an interaction per bunch crossing. Hence, the probability of two interactions of this kind in a single bunch is of the order of 5%. In this simple estimate we assume that coherent effects in a crossing of two beam bunches are not important (this assumption needs some further investigation). One should also say, that the 5% estimate is probably somewhat low, since  $e^+e^-$  pairs can be produced at impact parameters which are larger than 385fm. The probability to produce a pair drops quite rapidly with the

impact parameter however, making this region of impact parameters less significant. More theoretical work on the impact parameter dependence of the  $e^+e^-$  pair production may be needed to improve our estimates. In practice, it will be quite important to compare measurements taken with beams of varying luminosity, to make sure that no significant contamination due to multiple interactions is present.

#### 4. Summary.

##### 4.1 Summary of the experimental program.

In this section we will summarize the experimental program which was outlined thus far.

1. A measurement of the  $\mu^+\mu^-e^+e^-$  channel can provide an insight into non-perturbative aspects of  $e^+e^-$  pair production, as well as allow one to search for new phenomena in strong fields. All QED calculations predict that the multiplicity of  $e^+e^-$  pairs depends very weakly on the impact parameter in a collision, as long as the impact parameter is smaller than 385fm. This result can actually be tested by measuring the multiplicity of  $e^+e^-$  pairs as a function of the invariant mass of a  $\mu^+\mu^-$  pair. Any significant variation (particularly an increase) in the multiplicity of  $e^+e^-$  pairs when the mass of a  $\mu^+\mu^-$  pair increases would point to the possibility of new phenomena in  $e^+e^-$  pair production. We note, that massive  $e^+e^-$  pairs can also be used as a trigger. It would seem very worthwhile to repeat the same measurement with  $\mu^+\mu^-$  and  $e^+e^-$  pairs as a trigger. In the limit of a large invariant mass of a trigger pair both measurements should produce identical results. Any strong field phenomenon should depend very sensitively on the combined charges of beams. Hence, it is essential to repeat this measurement with a variety of beams and study its results as a function of the charge of a beam.

2. A measurement of the coincidence between  $\mu^+\mu^-$  or  $e^+e^-$  pairs and beam rapidity nucleons can be viewed as a trigger study for the previous experiment, or as an independent study of the dependence of dilepton production and electromagnetic excitation of nuclei on the impact parameter. A coincidence measurement provides a consistency test between the two processes. The failure of this test can be interpreted as a signature of new phenomena in either one of the two processes. Further measurements would be necessary to understand

such a failure. It is again essential to do the experiment with a variety of beams and at several beam energies.

A measurement of the coincidence between two electromagnetic processes provides one with the equivalent of a *minimum bias*, indirect trigger on collisions with small impact parameters. One can interpret a  $\mu^+\mu^-$  pair as a minimum bias trigger for the study of  $e^+e^-$  pairs. Using this trigger one can study properties of the *average*  $e^+e^-$  pair created in a collision with a small impact parameter. If one searches for rare events due to strong fields, this experimental method becomes insufficient. One must then construct a trigger which explicitly searches for such events. Events with an abnormally high multiplicity of  $e^+e^-$  pairs can be an example of a rare event.

#### 4.2 Other possibilities.

There are other experiments in the general area of extremely peripheral collisions of relativistic heavy ions which are of interest, but have not been discussed in this paper. It has been suggested by E.Teller<sup>5</sup> that strong magnetic fields which are created in heavy ion collisions without the nuclear contact can lead to the enhanced production of mesons. His suggestion was motivated by the earlier work of J.Schwinger,<sup>6</sup> who speculated that quarks can have a magnetic charge in addition to their known electric charge. Best candidates for such studies would probably be simple non-flavored mesons like  $\pi^0, \eta, \eta_c$ . An anomalous dependence of cross sections for producing these mesons on the charge of a beam could then indicate a new mechanism of meson production due to strong fields. The measurement of a coincidence between mesons and  $e^+e^-$  pairs (and/or electromagnetic decays of nuclei) can provide further insights into the impact parameter dependence of meson production.

#### 4.3 Conclusions.

We have discussed some possibilities of studying the physics of strong electromagnetic fields in extremely peripheral collisions of relativistic heavy ions. A physics motivation for these studies ranges from confirming already predicted non-perturbative phenomena in QED processes, to searches for new phenomena due to strong electromagnetic fields. Because of the long range nature of the electromagnetic interaction it seems necessary to

find a way in which an experiment can be triggered on collisions with a small impact parameter. One such method which is based on the coincidence between two electromagnetic processes has been presented in this paper.

It seems that the general area of the physics of extremely peripheral collisions of relativistic heavy ions has a potential to develop into an experimental program at RHIC. This program is quite distinct from the study of central collisions both in terms of its goals and instrumental requirements. Peripheral events have a relatively low multiplicity, with accurate triggering as the main experimental problem. In contrast, triggering is not a problem in studies of central collisions. Backgrounds due to high multiplicities of produced particles are the greatest obstacle in these experiments. Some of the measurements which relate to peripheral interactions can be done parasitically, using detectors which are designed with central collisions in mind. Given the differences in essential requirements however, it would seem most effective to construct modest, dedicated experiments for the study of peripheral interactions rather than attempt parasitic measurements with large detectors. For example, most detectors avoid particle tracking in the immediate vicinity of the interaction diamond due to the background of charged pions. This is a nonexistent problem in peripheral collisions, where some form of tracking close to the interaction region is actually very desirable. For the same reason of enormous charged particle multiplicity, most detectors tend to have high granularity and be located at large distance from the interaction diamond (to reduce the occupancy rate). Again, from the point of view of peripheral interactions such a design is needlessly complex and expensive. Last but not least, physics goals of both programs are quite different, and one probably should avoid mixing them in a single experiment.

We hope that the area of extremely peripheral collisions of relativistic heavy ions will become an integral part of the physics program at RHIC.



## References.

1. Conceptual Design of the Relativistic Heavy Ion Collider  
Brookhaven National Laboratory Internal Rep. 52195  
May 1989.
2. Can RHIC be used to test QED? - Workshop Proceedings  
ed. M.Fatyga, M.J.Rhoades-Brown, M.J.Tannenbaum  
Brookhaven National Laboratory Report 52247  
April 20-21, 1990.
3. C.A.Bertulani and G.Baur, Phys.Rep. 163(1988) 299.
4. C.Bottcher, M.R.Strayer, J.S.Wu, A.K.Kerman, M.J.Rhoades-Brown in:  
Can RHIC be used to test QED? - Workshop Proceedings  
ed. M.Fatyga, M.J.Rhoades-Brown, M.J.Tannenbaum  
Brookhaven National Laboratory Report 52247  
April 20-21, 1990.
5. E.Teller, Proc. of the 9th International Conference on the Application of Accelerators  
in Research and Industry, ed. J.L.Duggan North Holland Amst. 1986.
6. J.Schwinger, Science v165, N3895(1969)757.

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### Figure Captions.

- Fig.1 A perturbative calculation of the probability for  $e^+e^-$  pair production in a collision with the impact parameter 385fm (Ref. 3).
- Fig.2 The cross section for  $e^+e^-$  pair production as a function of the impact parameter in U+U and p+p collision at RHIC. Colliding beams at  $\gamma = 100$  (Ref. 4).
- Fig.3 Probabilities of removing a neutron from one ion only (  $P[T(1n,0n)]$  ) and removing one neutron from each ion (  $P[T(1n,1n)]$  ) in a collision of two Au nuclei with  $\gamma = 100$  (colliding beams). Both probabilities are plotted against the impact parameter.
- Fig.4 A schematic view of the low energy electron region.
- Fig.5 A schematic view of the low energy electron detector.
- Fig.6 A schematic view of the combined measurement of a trigger pair and low energy electrons.

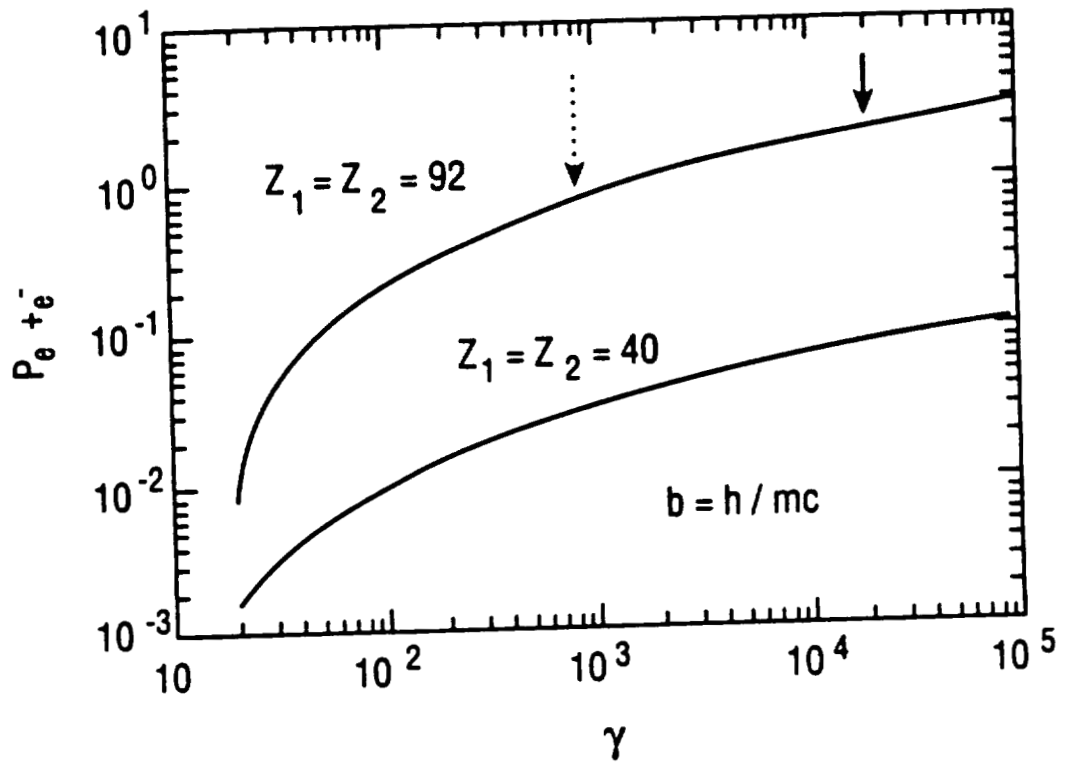


Fig. 1

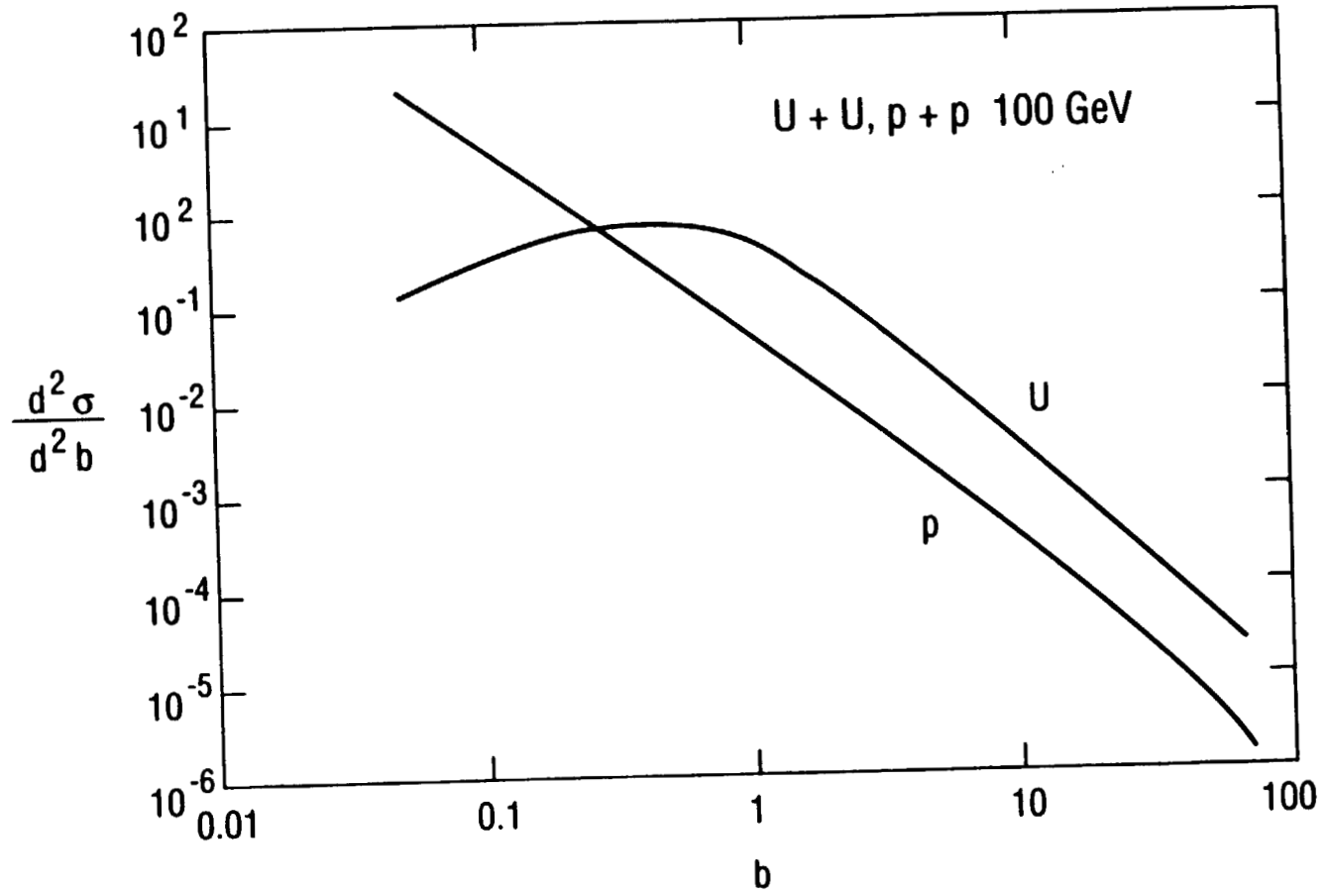
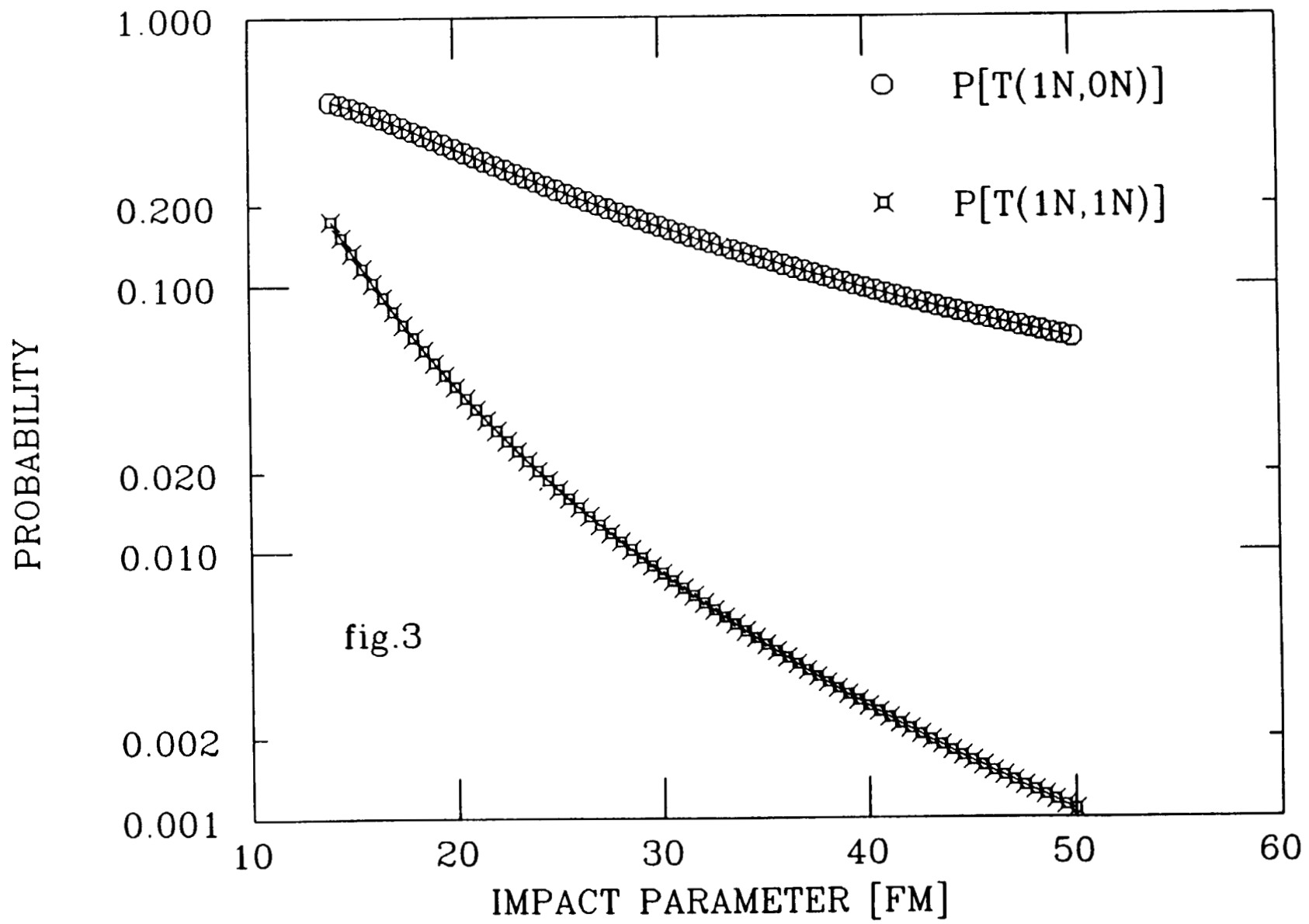


Fig. 2



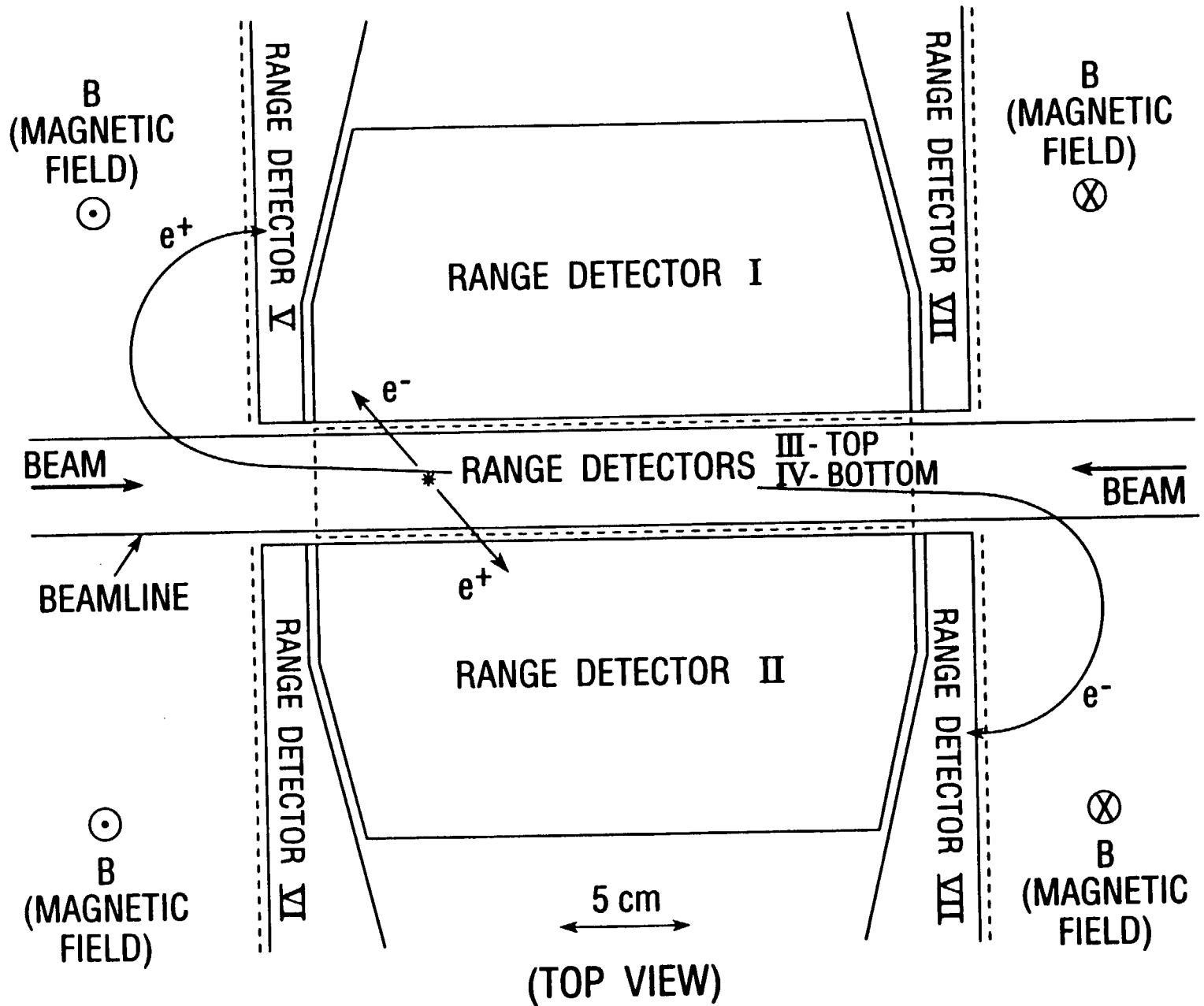


Fig. 4

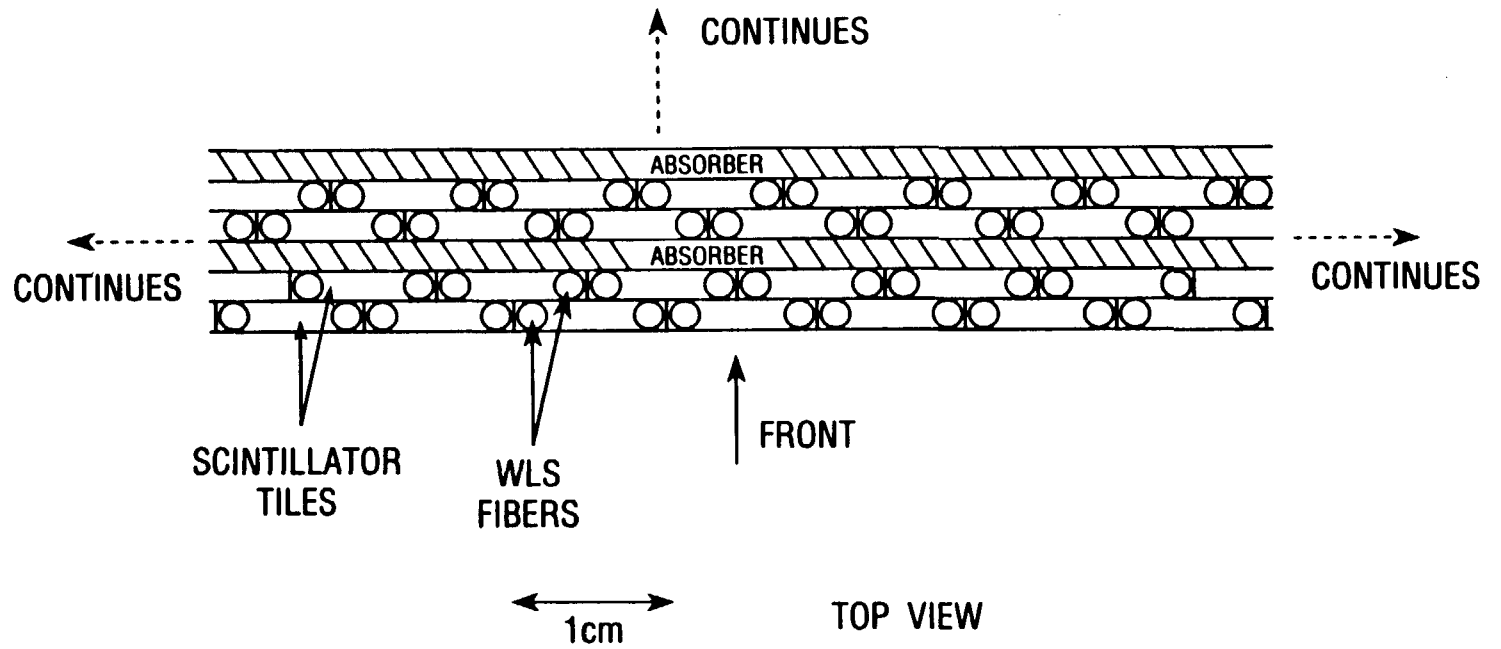
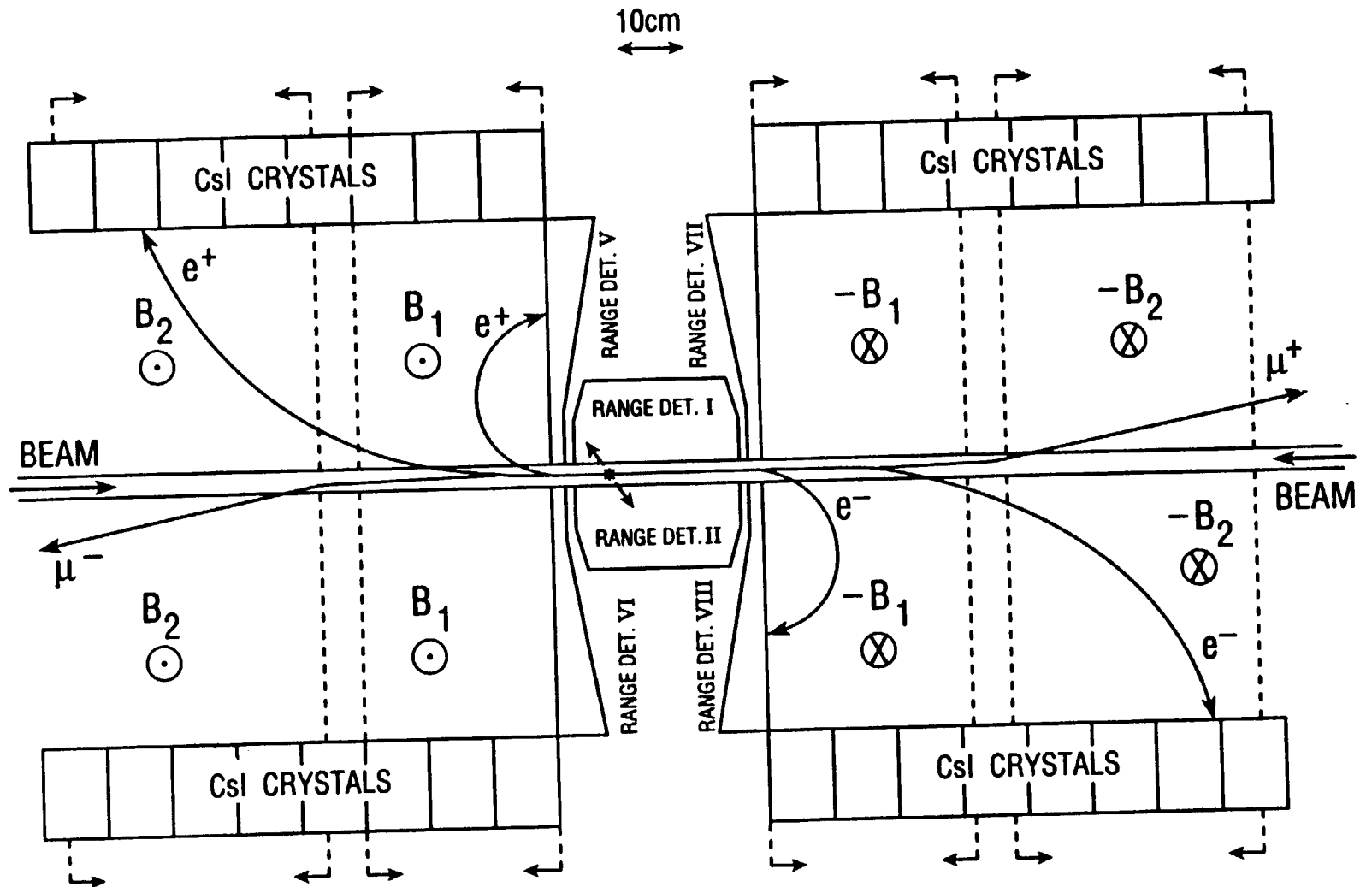


Fig. 5



$B_1 = 0.1 - 0.2 \text{ T}$

$B_2 = 1 - 2 \text{ T}$

TOP VIEW

Fig. 6