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DIMUON PRODUCTION IN ULTRARELATIVISTIC LIGHT ION INTERACTIONS AT THE SPS

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1. INTRODUCTION

Ultrarelativistic nucleus-nucleus collisions, at 200 GeV per incident nucleon, may open up a new field of physics, one very desirable aspect of the future SPS program. Oxygen nuclei are expected to be extracted at relatively low energy in the West Area in 1986. The attractive opportunity of accelerating them in the SPS has been extensively discussed in the recent SPS workshop.

We propose to perform an exploratory experiment based on detection of muon pairs produced in nucleus nucleus interactions. We believe that our NA3 dimuon spectrometer, slightly modified for this new experiment, offers the simplest and most suitable device for this purpose. The dimuon signature is a powerful tool for investigating new fields of physics as it has been proven in the past. We stress that the dimuon detection part of the proposed experiment exists together with the necessary know-how in the group of proponents. This is a very important feature in view of the expected limited availability of running time with nuclear beams and the need to perform simple and efficient experiments with quick feedback from data analysis.

2. PHYSICS OBJECTIVES

We propose to use the NA3 dimuon spectrometer [1] with 200 GeV/c per nucleon beams of protons, alphas and oxygen ions on different targets. Among the several interesting aspects of nucleus-nucleus interaction physics, we would like to underline the following points:

2.1 High mass dimuon production

The Drell-Yan mechanism producing dimuons has been extensively studied in the range $M_{\mu\mu} > 4$ GeV/c² in hadron-nuclei interactions, essentially at $x_F > 0$. The cross-section is found to be a linear function of the atomic number A of the target nucleus: $\sigma \propto A^{\alpha}$ with $\alpha = 1.0 \pm 0.02$ [2]. This A-dependence is not yet explained by theory [3]; it is of great importance to study the dependence of the dimuon production cross-section on both the atomic number of the projectile and the target. Moreover, this dependence has to be correlated to the "centrality"(*) of the reaction.

2.2 Vector mesons and low-mass continuum

As in the initial NA3 set-up, the trigger accepts dimuons around the J/ψ mass with a good acceptance (around 25%) and dimuons can be studied down to masses around 1 GeV/c^2, with transverse momentum above 1.5 GeV/c.

2.3 Detection of the quark-gluon plasma [4]

Recent developments in the application of lattice techniques, and independently, of thermodynamics to QCD have made the strong prediction that, while colour confinement should prevail under normal circumstances, deconfinement should occur at sufficiently high temperatures (i.e. energy densities) and/or high quark densities.

Other than glueball states, deconfinement is THE crucial prediction of the non-perturbative domain of QCD.

Oxygen-platinum collisions at 200 GeV/nucleon will probably enable us to reach the necessary conditions for quark-gluon deconfinement. The resulting plasma will however have a very short lifetime. Due to the absence of final-state interactions, prompt lepton pairs radiated from the volume of the thermalized plasma should provide a relatively clean signal of the earliest (i.e. hottest) stage of the collision.

(*) A phenomenological definition of "centrality" for each event may be based on the total number of interacting nucleons belonging to each projectile nucleus. Nucleons are called "spectators" if, after the collision, they have a transverse momentum p_T < 300 MeV/c and a longitudinal momentum P_L > 90% of its initial value. All other nucleons are considered as "interacting". Geometrical considerations and results at 2 GeV/c per nucleon from BEVALAC show that a 15% of all $O^{16} + U^{238}$ collisions correspond to maximum centrality. This should also be valid at 200 GeV/c per nucleon.

3. THE EXPERIMENTAL SET-UP

3.1 Most important items

The main part of our apparatus will be the NA3 spectrometer in its "closed" configuration, as used from 1978 to 1980 for Drell-Yan, J/ψ and Υ physics. We recall some important properties of this spectrometer:

- It has been operated with hadron beams from 150 to 400 GeV/c, with intensities ranging from $2 \cdot 10^7$ to $2 \cdot 10^9$ particles per SPS burst, depending on the hadron filter length.

- It has a powerful and flexible two-level trigger system, which selects muons according to their transverse momentum, giving a low triggering rate. 80% of the triggers were reconstructed as true high mass dimuons.

- It has a large acceptance and a reasonable dimuon mass resolution (5% f.w.h.m. at the J/ψ mass).

- A precise time information on the tracks (within $\pm$ 2 ns) allows clean multimuon physics.

The entire set-up behind the hadron filter should remain unchanged in the proposed experiment. Since it contains only the superconducting magnet, trigger hodoscopes and multiwire proportional chambers, it will not require an important maintenance. However, it will probably be necessary to replace a fraction of the chamber electronics, to restore the original efficiency.

3.2 Necessary modifications

The use of ion beams implies nuclear interactions characterised by very high nucleon, pion, kaon multiplicities (by about a factor of 16 for central collisions of incident O^{16} with respect to protons).

We think it is necessary to introduce modifications to the target region (target, beam dump, hadron filter) to reduce secondary interactions and decays in flight:

i) We propose to reduce the decay path of hadrons to 20 cm instead of 40 cm as in the old set-up, and to replace the first collision length of iron in the hadron filter by tungsten. This implies that a hole should be drilled around the beam in the beam dump, in order to give a good off-line vertex separation; for instance, a target-dump separation of 70 cm is necessary to assign a proper vertex to dimuons with $M_{\mu\mu} < 2$ GeV/c^2 and $P_T > 1.5$ GeV/c.

ii) The hadron filter length may be kept to its 1.5 m value: the neutral background behind the filter will be the same for 3 10^6 oxygen ions per pulse and for 5 10^7 protons per pulse, which was the intensity typically used in the previous experiment.

iii) With incoming oxygen beams, the target must be thin enough to avoid both the reinteraction of spectator nucleons and the electromagnetic shower development from π^0's. This implies the use of several thin targets and probably a small planar wire chamber detecting the large angle secondaries to identify the target segment related to a given dimuon pair.

3.3 Special items for tagging central collisions

Complementary ways of identifying central collisions may be of the utmost importance, especially for the detection of quark-gluon plasma formation. Several ideas are under study to measure the following quantities:

a) the sum of the spectator fragment square charges ΣZ_i^2;

b) the multiplicity of secondary charged hadrons;

c) the energy flux associated with the forward emitted spectator nucleons and fragments, i.e. the energy complementary to the one available in central collisions.

i) The first quantity can be simply measured in putting a small detector (4 x 4 mm^2) in the beam between the target and the front of the hadron filter. This detector is formed by 3 planes of silicon strips, with a 100 μm granularity, directly measuring $\Sigma_i Z_i^2$ [6].
Upstream from the target, a similar detector would tag the beam on an event by event basis. The correct performance of such a device, which is crossed by the beam and which should operate in the high radiation area near the beam dump, must be thoroughly tested.

ii) The multiplicity of charged secondaries should be measured in a given rapidity gap by a three-plane hodoscope of modest dimension (around 10x10 cm^2) dowstream from the target. If only relatisvistic particles are detected (by the use of a 2 cm thick lucite hodoscope [7]) a simple pulse-hight analysis would measure the number of relativistic secondaries for laboratory angles between 10 to 500 milliradians.

iii) An appealing possibility, the measure of the forward energy flux would be associated to a perforated hadron filter. Due to the very good optical properties of the ion beam, a small hole, covering a solid angle of a few mrad angular aperture, would let both the beam and the spectator fragments pass through the hadron filter. In this configuration the NA3 spectrometer and a small forward calorimeter would measure the charged and neutral forward energy flux on an event by event basis. The ΣZ_i^2 measurement would still be possible under much reduced background conditions (Cerenkov counters along and around the beam line after the spectrometer could be envisaged). The problem of the target-dump separation would be also eliminated, since all the beam which does not interact in the target, discharges its energy far from the spectrometer. A preliminary test should investigate background conditions and particle flux in chambers and counters after the hadron filter.

3.4 Data acquisition and off-line analysis

It must be pointed out that all the existing on-line and off-line facilities developed for the previous NA3 data taking could be used immediately for the proposed experiment. The data acquisition system remains unmodified, with a PDP 11/45 central computer and about a dozen various microprocessors. Concerning off-line analysis, a hardware processor specifically designed for the experiment performs since 1980 on-line pattern recognition of straight lines in the chambers behind the magnet. This allows powerful on-line checks on dimuons, and a very fast off-line processing of events (less than 20 milliseconds C.P. for one trigger on IBM 3081 or CDC 7600). Thus, as was the case in the previous NA3 beam dump experiment, the analysis may be expected to be very fast.

3.5 Cost estimates for the proposed modifications

Taking into account the following modifications:

- Silicon strip detectors and associated electronics.
- Multiplicity hodoscope.
- Wire chamber for the "vertex detector" near the targets.
- Replacement of amplifiers on the triggering chambers,

we estimate a total amount of 400 KSF for all these items.

To summarize, the modifications and upgrading of the NA3 spectrometer are rather modest. The existing equipment is used as much as possible, as well as the software environment already developed for previous experiments.

4. BEAMS AND SCHEDULE

4.1 Beams

High energy ion beams will produce a new environment to be understood: fragmentation, multiplicities, and characterization of central collisions. Therefore, we think that, in addition to protons and ^{16}O collisions, at comparable energies (i.e. 200 GeV/nucleon), an "intermediate" nucleus, the He nucleus (and/or eventually ^{2}D) would be useful in order to establish regularities, to test the scaling laws concerning the A dependence, and to explore the fragmentation phenomena.

4.2 Tests

Even if the experiment is among the easiest that can be performed to get a hint of new phenomena, there are a number of experimental and physical facts that deserve the most careful consideration. In our opinion it is crucial to show that experiments can cope with the high multiplicities associated with ultrarelativistic ion-nucleus collisions. The second crucial point is the ability to identify "central" collisions.

In order to better understand these points, we intend to perform an extended set of tests concerning:

- The exact design of the target, and the modifications of the dump and hadron filter.

- The use of silicon strip detector.

- The determination of the charged multiplicity flow.

A first set of tests could be performed at the CERN SPS, behind the NA3 set-up, in fall 1983, and would require 2 or 3 days of beam time. A second test concerning Si detectors can be performed at Berkeley or at Saclay with light ion beams.

4.3 Possible schedule

The schedule of the proposed experiment is given by reasonable guesses on oxygen beams, and by the number of events expected.

Concerning the latter point, 10 days of running with $2 \cdot 10^6$ oxygen ions per pulse on a 1 cm segmented P_t target will give, from central collisions: (including an overall inefficiency factor of 1/2):

$\sim$ 3000 J/ψ events.

$\sim$ 1000 Drell-Yan events below 2.5 GeV/c^2.

$\sim$ 30 Drell-Yan events above 4 GeV/c^2.

From these numbers we can envisage the following schedule:

1. Tests at CERN SPS in Fall 1983 for 2-3 days.

2. End of the 84 fixed target period: return to the muon set-up, with modifications.

3. Two 17-days periods with 200 GeV/c protons (5.10^7/pulse) in the summer of 1985 to test the new set up and to perform a semi-inclusive p+A program.

4. For the light ions (alphas) and oxygen ions, it is more difficult to propose a schedule. A reasonable guess is that for each year, 1986-1987, we could ask for a suitable tuning period (10 days) and a 17 day period for measurements.

5. CONCLUSIONS

We believe that a first look at the new field of ultrarelativistic nucleus nucleus collisions should be attempted by a simple and well tested experimental apparatus which demands only minor modifications (and consequently only small manpower and financial investment)to provide indications for new phenomena.

All this is particularly attractive and well suited to the present NA3 collaboration; it also offers to the collaborating institutions the opportunity to maintain a high level of research activity before LEP experiments.

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