THE JETSET EXPERIMENT AT LEAR

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ABSTRACT

The Jetset experiment (PS 202) at LEAR will search for gluonic hadrons and other exotics in the interaction of in-flight antiprotons with protons at rest. The mass range to be covered extends from 1.96 to 2.43 GeV. Our experiment uses a molecular hydrogen cluster jet target which is inserted in the LEAR ring and is surrounded by a general-purpose detector of advanced design. In "Phase I" the detector has been constructed to provide selection at the trigger level of four kaon events, allowing a search for resonances in the OZI-forbidden, gluon-rich reaction $\bar{p}p \rightarrow \phi \phi \rightarrow 4K$. The combination of LEAR with our detector is unique in that it allows scanning over a large momentum range with excellent momentum resolution, implying correspondingly excellent mass resolution. The physics interest in this process is outlined briefly, and the design of the detector elements is described in some detail. A brief discussion of possible upgrade paths ("Phase II") for the detector is given at the end.

INTRODUCTION

The last few years has seen a growing interest in the search for gluonic matter and exotic quark-gluon formations. The importance of these objects lies simply in the fact that, being allowed and expected states of matter in the standard model, evidence of their existence should be forthcoming. In fact, the lack of a clear signature of such states could be a genuine problem for QCD. Because of this, there has been recently a heightened interest in experimental searches for such exotica, and indeed some of the data point to the possible existence of interesting new physics at masses above 2 GeV. A number of recent review articles and conferences¹⁻⁶ have stressed the importance of these studies and the need to continue work in this area in both the experimental and theoretical domains.

We have begun a new experimental program (PS202) at CERN/LEAR that is intended to examine these questions in more detail. The general purpose is to study rare or "OZI-forbidden" formation reactions of the type $\bar{p}p \rightarrow M_1 M_2$, where the new forms

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4K production via rearrangement and subsequent ss production.

4K production via $\phi\phi$ intermediate state.

4K and Phi Phi Pseudodata

Resonance appearing on top of the 4K and $\phi\phi$ production cross sections. The relative sizes are exaggerated for the purpose of illustration.

FIGURE 1

HYDROGEN CLUSTER JET TARGET

Plan view of the hydrogen cluster jet target, now installed on the LEAR facility.

FIGURE 2

of matter are most likely to be visible. We have divided our study into two phases; the focus of "Phase I" is to study in detail the in-flight production of $K^+K^-K^+K^-$, including ϕKK and most importantly $\phi\phi$. In Fig. 1 we indicate two possible ways of reaching the 4K final state -- one process proceeding via an intermediate state that is "pure glue" to form the $\phi\phi$ state that subsequently decays to 4K with a 25% branch; the other possibility proceeds directly to 4K by a combination of rearrangement and subsequent $s\bar{s}$ pair creations. (Other paths to formation of $\phi\phi$ exist; these include the possibility of freeing strange sea quarks from the proton, connections to d or u quark admixtures in the ϕ , or ϕ - ω mixing.) The bottom part of the figure is a schematic drawing of what we hope to see: the onset of 4K production at its threshold of 646.8 MeV/c, followed by an increase in cross section at the $\phi\phi$ threshold (866.6 MeV/c), followed by the appearance of a resonance in $\phi\phi$ at some undetermined point. The drawing is intended to be illustrative only. In "Phase II" we intend to improve the detector in ways that will make possible the study of a much wider variety of related physics channels. Here we describe the design of "Phase I" and indicate the direction that we envision for "Phase II".

THE "PHASE I" JETSET EXPERIMENT

The central feature of the Jetset apparatus is the **molecular hydrogen cluster jet target** which is installed in the south straight section (SD2) of the LEAR ring. First tests show that the jet presently has a density of about 2×10^{13} atoms/cm²; we expect another factor two improvement. The jet provides a "massless" pure gaseous hydrogen cylindrical target of about 1 cm diameter (see Fig. 2).

For a stored beam containing 4×10^{10} antiprotons moving with a circulation frequency of 3.2×10^6 Hz, the peak luminosity will be about 5×10^{30} /cm²/sec in an interaction volume of about 1 cm³ and will exceed the most optimistic external target experiment by about a factor of 20. It thus offers the possibility of searching efficiently for rare physics channels such as $\bar{p}p \rightarrow \phi\phi$. Such luminosities provide rates of about 5×10^5 events/ μ b/day, so that we will double the world's existing sample of $\phi\phi$ events in a very short running time.

Unfortunately, the desired signal is small compared to a number of other physics channels of much less interest to us. Fig. 3 shows some of the relevant total cross sections for these processes in the LEAR energy range. The high luminosity of the jet target apparatus also means that the detector must be equipped to allow extraction of good events from a background rate of about 1 MHz. To do this we use the characteristics of the events we wish to study: they have (only) 4 charged prongs; they are forward of 90° in the lab frame; they each have a moderate β value. At least 3 of the 4 particles are almost always forward of 45°. Thus we will apply cuts at the trigger level that focus on the multiplicity, the event geometry and the β values of the outgoing particles.

With a trigger based on the above ideas, the very large "purely pionic" background can be reduced to a small fraction of the good event rate. Other, more troublesome, reactions are $\pi^+\pi^-K^+K^-$ and $\bar{p}p\pi^+\pi^-$; these provide signatures looking much more like good events. However, the "Phase I" detector is designed to distinguish these in both the on-line and off-line analysis.

A plan view of the "Phase I" detector is given in Fig. 4. It is a compact (≈ 1 m³) device that surrounds the jet with 85% of 4π solid angle. Although the LEAR beam pipe (an oval shape with major and minor half-axes 6.8 and 3.0 cm resp.) limits the very forward acceptance below about $\theta = 8^\circ$, it will be possible to measure the $\phi\phi$ production cross section near threshold with reduced efficiency.

The detector includes a number of advanced features, as described in [7]. A major constraint in the design is the need to be able to dismount it rapidly in case of needed maintenance on either the detector itself or the LEAR facility.

FIGURE 3

EXPERIMENT PS202

- (1) SCINTILLATORS
- (2) STRAW TRACKER
- (3) SILICON dE/dx
- (4) THRESHOLD CHERENKOV
- (5) RICH
- (6) GAMMA VETO
- (7) E/M CALORIMETER
- (8) JET TARGET PRODUCTION
- (9) JET TARGET SINK

Plan view of Jetset.

FIGURE 4

The **pipe trigger scintillators**, which lie directly on the LEAR beam pipe, are arranged in two layers, each of which consists of scintillator strips 2 mm thick: the first set (40 scintillators, each 10 mm wide) covers the θ range from 15° to 45° . Because of the oval shape of the beam pipe the length of these strips varies in order to keep fixed the angular range covered by each strip. A second set of 20 scintillators (each 20 mm wide) covers the θ range from 45° to 65° .

The purpose of these scintillators is to provide a fast multiplicity and time-zero trigger, in conjunction with the "outer" trigger counters (discussed below). These have the advantage of being close to the interaction region so that they will be less affected by kaon decay, secondary interactions, or multiple scattering. At low momentum (near threshold), where these effects are large, they play a major role in keeping the acceptance at a reasonable level. This is done by exploiting the fact that at low momentum the four outgoing kaons are mostly forward of 45° , whereas the contaminant pion reactions are more uniformly spread out in θ .

The **precision barrel tracker** provides both azimuthal and z-direction position information for off-line analysis of the charged tracks in the barrel region ($\theta > 45^\circ$). It consists of about 1500 individual "straw" drift-tube counters running parallel to the beam direction and glued together into a self-supporting unit (see Fig. 5). The straws fill about 85% of the available volume. Such a construction reduces the amount of supporting material needed in the forward direction and thus minimizes multiple scattering. For this reason all of the electronics connections and gas handling fittings are mounted on the barrel upstream endplate. Each wire is equipped separately with drift-time readout in order to measure the radial distance of impact. In order to measure the longitudinal coordinate by means of charge division, two wires are connected to each other using resistors (in SMD technology) that are located at the forward end of the assembly. The combined information from TDC's (drift time) and ADC's (charge division) will provide unambiguous three-dimensional information for off-line track finding and fitting.

To allow for perpendicular entry of the jet, about 400 of the straws are split roughly at their midpoint. In order to disassemble the tracker easily the entire unit is split along its horizontal midplane into two halves.

Each "straw counter" consists of a tube that is 8 mm in diameter and 400 mm in length with a resistive anode wire (30 μ m diameter stainless steel, $R \approx 1\text{k}\Omega/\text{m}$) running down its center at a tension of about 100 g. The tubes are pure aluminum extruded tubing with a wall thickness of 60 μ m (about 0.001 radiation length).

Using a gas mixture of $\text{Ar}/\text{CO}_2 = 1/1$ at atmospheric pressure we have obtained drift time resolutions corresponding to about 160 μm . For this mixture a charge division resolution of σ/L of about 1% has also been obtained. These figures are easily maintained at the rates characteristic of this experiment and will provide excellent tracking.

A monolithic preamplifier (Fujitsu MB 43468) is used for each of the drift tubes. The preamplified signals are then fed into a receiver card which contains a differential amplifier ($\mu\text{A} 733$), analog drivers for the connection to the ADC's, and fast discriminators (LeCroy MVL 407) for the connection to the TDC's. This system comprises 2560 channels because it serves both the barrel and forward trackers.

The **precision forward tracker** provides tracking information for the forward-going ($\theta < 45^\circ$) charged particles. It is constructed from the same aluminum tubes and electronics as described above. These straws, numbering 1020, are mounted in 12 layers perpendicular to the beam axis, three each for the x-, y-, and u-, v- coordinates. We have achieved essentially the same resolution figures as mentioned above for the barrel. As is

(Top) Exploded view of the barrel "straw" tracker. Note the rear entry of the gas and electronics connections, and the side entry of the jet. (Bottom) End view of the tracker showing the cutout for the jet. This region will not be instrumented in Phase I.

FIGURE 5

the case with the barrel tracker, the independence of each straw insures that there will be no track ambiguities from this source in the off-line analysis.

The silicon dE/dx forward counters measure β of the charged tracks and thus greatly help to distinguish 4K events from the $\bar{p}p\pi^+\pi^-$ (and other) backgrounds off line. The silicon complements the threshold Cerenkov and RICH counters, as it measures β best at low energies. Cuts on dE/dx , used in conjunction with the trackers, will reduce backgrounds to a fraction of a percent without loss of the desired signal.

The forward silicon will be mounted in two modules, each of which yields an (x,y) measurement for a passing charged particle. Half of one module is displayed in Fig. 6. These will thus provide two energy loss measurements as well as geometric information about each particle track. The silicon planes consist of units 1.95×2.40 cm² in area, each made up of four pads of 280 μ m thickness. There are 924 such detectors in the forward counter covering an area of 0.43 m². The amount of material at normal incidence is estimated to be $\approx 3.5\%$ of a radiation length with the silicon itself representing about 0.6%. The silicon is supplied by SI/AME, Norway. The electronics are mounted on the same printed circuit board as the detector elements. The front-end VLSI electronics are based on the Amplex chip developed at CERN/EF Division for UA2. An elaborate multiplexing scheme will be used to read out the 3696 pads in the forward region.

Tests have been made at the CERN T₁₁ test beam which clearly show the ability to measure dE/dx adequately for our purposes.

The silicon dE/dx barrel counters provide two energy loss measurements in the barrel. We use the same silicon pads here as in the forward counter, in this case arranging them in a cylindrical geometry. The barrel Si counters extend to $\theta = 78^\circ$, which corresponds to the maximum value of θ for the process $\bar{p}p \rightarrow \phi \phi \rightarrow K^+ K^- K^+ K^-$. This counter will be installed in 1991.

The threshold Cerenkov counters are used to reject the fast charged pion background at the trigger level. The detectors consist of "liquid freon" (C₆F₁₄) filled plexiglass wedges (3 mm wall thickness) in the barrel and forward regions (see Fig. 7). The "liquid freon" material (3M Corporation FC-72) has an index of refraction $n = 1.26$, making the detector sensitive to particles of $\beta > 0.8$.

In the barrel counter the wedges run along the beam direction. They have a trapezoidal cross section of thickness 3.5 cm in the radial direction and a length of about 60 cm. The barrel counter (29 cm radius) is formed of 24 such wedges. Light is collected at the upstream end of each wedge due to lack of space downstream and our wish to avoid putting more material there.

The forward threshold Cerenkov counter is formed of 24 pie-shaped wedges of outer radius about 30 cm and thickness in the beam direction of 5 cm. The segmentation matches that of the trigger scintillator and the gamma calorimeter/veto.

The Ring-Imaging Cherenkov (RICH) counter will provide additional (off line) information about the momentum of the charged tracks. This device is in the R&D stage. It is presently conceived to have a 1 cm thick CaF₂ or quartz ($n = 1.56$, $\beta_{\text{threshold}} = 0.64$) radiator and a 6 cm empty "drift space" whose purpose is to allow the Cherenkov light cone to broaden as much as is practical before detection. We estimate that for particles of $\beta > 0.64$, measurement of the cone under these conditions will yield β with about 10% uncertainty. This device therefore complements very well the measurements we will obtain from the Si layers.

Plan view of mounting for one of the four silicon half-planes for the silicon dE/dx forward counter. The vertical strips are rows of silicon detectors and associated Amplex electronics. Two half-planes have this orientation; the other two have the silicon running perpendicular to what is shown here. This arrangement gives full coverage for the dE/dx counter.

FIGURE 6

FORWARD CHERENKOV SYSTEM

(not to scale)

total 24 elements

BARREL CHERENKOV SYSTEM

(not to scale)

total 24 elements

(Top) Schematic view of the forward Cherenkov system. (Bottom) Cross section of the Cherenkov counters for the barrel region. There are 24 counters in each.

FIGURE 7

Photons in the arc will be converted into photoelectrons by striking TMAE gas carried in He-ethane at room temperature. This mixture is contained in a two-dimensional "honeycomb" module consisting of 64 miniature wire chambers, each operating independently. The module is 64 mm on a side, and each wire chamber cell has dimensions of 8 mm by 8 mm. The pattern of struck cells provides the information necessary to determine the β value. The wires of the honeycomb are perpendicular to the radiator surface and are cloisonné. An assembly of such modules make up the RICH photosensitive detector.

The fast outer trigger counters in the barrel and forward regions (Fig. 8) perform several functions. In conjunction with the "pipe trigger scintillators", these counters define the time reference for the trackers and measure the event multiplicity. In addition, they will provide: a charged particle veto shield for the forward and barrel gamma detectors; crude first-level kinematic filters (e.g. rudimentary momentum balance); additional dE/dx information (especially for the non-annihilation background in the forward region); and fast θ - ϕ coordinates for possible use in the next level trigger, where additional constraints characteristic of true 4K events can be applied.

In both the barrel and the forward regions the fast charged trigger counters are constructed by overlapping 3 scintillator layers to form a high-granularity charged multiplicity detector. In the barrel region the counter is constructed of one straight (ie parallel to the beam axis) and two helical layers, the each of the latter being "wound" with opposite screw sense. This construction gives rise to 288 cells. In the forward detector the 3 layers are planar; one consists of 48 wedge-shaped segments, while the other two are each made from 24 curved segments, each layer again having opposite sense of rotation. Overlaying these segments provides 2304 sensitive regions. All scintillator layers are made of 5 mm NE-110 equivalent material. Tests of the trigger counter segments at the CERN T11 test beam, and with sources, have shown that light collection from these somewhat unorthodox counters is not a problem. Collection efficiencies remain high regardless of the source position along the counter. This enables measurement of the multiplicity with very high reliability (>99%).

The γ calorimeter in the forward region (see Fig. 9) will measure the energy of γ rays coming from the decay of neutral mesons. This detector is a part of the full-scale γ calorimeter which will be completed only for "Phase II"; at present it is used as a part of the overall γ veto scheme in the first-level trigger and to measure the charged particle multiplicity. The forward calorimeter is segmented in such a way as to match the segmentation of the forward threshold Cerenkov counter and the trigger scintillators. Hence it contains 300 individual "Pb-Sci/Fi" modules grouped in 8 theta rings with either 12, 24 or 48 modules per ring in the phi direction. The individual detectors are referred to as "towers" and are mounted in a geometry which "points" toward the interaction region but slightly upstream to preserve hermeticity. Each tower is machined from a basic "element" that consists of a block of Pb-scintillator fiber mixture. The block consists of scintillator fibers (1 mm diameter) embedded in a matrix of Pb made of sheets of corrugated Pb/Sb alloy laid on top of one another; overall the block is mixed in the volume ratio 50%/40%/10% : scintillator/Pb/glue. In this construction each scintillator fiber is completely surrounded by Pb. Because of this an excellent resolution has been achieved with a Pb/SciFi element of dimensions $(7.5 \text{ cm})^2 \times 22 \text{ cm}$ (14 radiation lengths). In tests with electrons ranging in energy from 88 to 5000 MeV, nearly constant energy resolutions ($\sigma(E)/E$) of about $6.3\%/\sqrt{E}$ (E in GeV) have been achieved.

The γ veto counter in the barrel region is intended to detect the γ rays from the decay of neutral mesons possibly produced in $\bar{p}p$ collisions, and then veto those events.

(Top) Schematic drawing of the fast scintillator outer counters in the barrel region. There are 24 straight sections and 12 (each) left and right going twists. (Bottom) End views of the front fast outer counters. There are 48 wedges and 24 (each) for the left and right going twists. The number of counters has been doubled to reduce possible ambiguities.

FIGURE 8

(Top) Front view of the 300-element electromagnetic SciFi calorimeter. (Bottom) Schematic view of an individual element showing the Pb-scintillator fiber matrix. The element contains 50% Pb, 40% fiber, and 10% glue by volume.

FIGURE 9

It is intended to "fill the gap" in the barrel region for the "Phase I" program while the full barrel calorimeter is under construction. The geometry of the barrel gamma veto will be similar to that of the barrel Cherenkov counter; there are 24 wedge-shaped elements in the azimuthal direction, each 1 m long in the beam direction and 9.5 cm (6 radiation lengths) thick. Each wedge is constructed using the same techniques described above, but in this case the fibers are arranged to lie along the beam direction.

The data acquisition computer array is based on the CERN Valet-Plus (VME-based) system with a fast Transputer interconnect. Seven Valets will be used to control the experiment: one for the dE/dx silicon counters; one for the barrel and forward straw trackers; one for the γ calorimeter and γ veto; one for the outer trigger scintillators; one for the pipe scintillators and threshold Cherenkovs; and one for the slow controls. The results from this first-level processing are assembled by the Transputer event builder in the last Valet into an "event" that can be further analyzed and written to tape. Analysis takes place in a system of μ VAX computers which monitor the experiment.

TRIGGERING AND EVENT RECOGNITION IN "PHASE I"

The triggering for Jetset must be capable of bringing a 1 MHz rate for all events (the vast majority of which are due to unwanted interactions) down to a rate of about 100 Hz that can be handled by the data acquisition system with tolerable deadtimes. In doing this, as few good events as possible should be sacrificed.

The fast trigger will be produced for each event within 200 ns by the pipe trigger scintillators (PS), the outer trigger scintillators (OS), the electromagnetic calorimeter (EC) and γ veto (GV), and the threshold Cherenkov counters (TC). Events with the wrong charged/neutral multiplicity are discarded, and some decisions based on β are made.

At this time the readout system ADC's are latched and TDC's stopped, beginning the various event digitizations. For the $\phi\phi$ (4K) events of Phase I, this involves the following rather stringent but simple conditions: (1) a multiplicity of 4 charged particles, not more than 1 backward of 45° ; (2) no gammas; (3) not more than 1 of these charged particles with $\beta > 0.8$ (the threshold of the fast Cherenkov counter). A crude test of momentum conservation ("balance") can be applied by simply checking that not all tracks emerge on one side of the detector. At this level the potentially troublesome $\bar{p}p\pi^+\pi^-$ reaction can be substantially reduced by its topology and possibly by the detection of the antiproton in the EC. The multiplicity is determined by the PS, the segmented OS systems, and the forward EC.

The pipe trigger scintillators can be used with the outer trigger scintillators and the calorimeter elements to establish hit correlations. Ideally, this will clean up the trigger sample significantly, leaving for further processing in a second level trigger four (θ, ϕ) prongs pointing to the vertex.

Neutrals are rejected by the EC and GV layers; this is important because these processes are quite prominent (eg, $\sigma(\bar{p}p \rightarrow 4\pi^\pm + n\pi^0) > 20\text{mb}$). The GV efficiency has been studied for the proposed detectors, including all known effects such as construction cracks, thresholds, and charged particle "blinding" (from true charged particles entering the same ϕ segment as a potential gamma). It is found to be essentially 95% effective for events where a single π^0 accompanies 4 charged particles.

Since the threshold Cherenkov counters give a reasonable signal for charged fast pions, we do not expect any problems in keeping the event sample which passes these first-level trigger quite pure. Thus the level-one trigger will be a series of "yes" signals from all of the detector subsystems and can be thought of as a number of loose cuts on the event sample.

We hope to reduce the initial 1 MHz rate to less than one kHz after the first level without allowing the deadtime to exceed 20%. During the commissioning of Jetset the luminosity will be lower than the design figure, and the trigger will at first be somewhat loose in order to be as bias-free as possible. Multiplicities will be "windowed" around the desired 4 charged particle value, and at least 1 gamma will be allowed in the event. We will run above and below the $\bar{p}p\pi^+\pi^-$ threshold to test the effects of that unwanted interaction on our event sample. As always, we must accumulate "luminosity" events in order to measure not only the total number of $\bar{p}p$ interactions (to normalize the data), but also to determine the performance of our detector and thus to develop more stringent on-line triggers based on hardware cuts.

THE "PHASE II" JETSET EXPERIMENT

"Phase II" in JETSET is intended to broaden our study considerably, searching for other interesting physics channels in which exotica may appear. An example in which one might expect to observe new phenomena is the channel $\bar{p}p \rightarrow \phi \omega$, which is also an OZI-forbidden decay from an ordinary $\bar{q}q$ state. To make such searches requires a more advanced detector than will exist in "Phase I". Thus, we plan to augment the "Phase I" detector by the addition of (1) a complete electromagnetic calorimeter in the barrel region; (2) Si dE/dx counters in the barrel; (3) the RICH counter; and (4) for the more distant future, a magnetic field. These devices will provide the necessary means to permit a complete identification of the momentum and sign of the outgoing charged particles, and will also allow the investigation of channels containing neutral particles. With such a detector, a broad attack on the important, basic questions involving gluonic and exotic quark matter can be undertaken with great confidence. Another promising approach is to build an atomic beam target capable of providing polarized protons. The ability to explore spin degrees of freedom will enhance our studies even further.

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