tions and approximations still untested by experiment. It is also possible that the antenna is operating in a more sensitive mode than ordinarily assumed. Frozen-in metastable configurations within each detector might decay to equilibrium as a result of collective excitation by gravitational radiation, releasing far more energy than implied by the gravitational-radiation flux.

I am also studying the possibility that cosmological gravitational radiation is being observed, focused by the galactic center.

Conclusion.—The large (exceeding 6 standard deviations) sidereal anisotropy is evidence that the gravitational-radiation–detector coincidences are due to a source or sources outside the solar system. The location of the peaks suggests that the source is the 10^{10} solar masses at the galactic center.

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POSSIBLE EXOTIC EXCHANGE IN $pn \to \Delta^- \Delta^{++}$ at 6.98 GeV/c

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The reaction $pn \to \Delta^- \Delta^{++}$, where Δ^- is emitted in the forward direction in the c.m. system, is observed at 6.98 GeV/c with a cross section of 0.09 ± 0.03 mb. The ratio between this reaction and the reaction $pn \to \Delta^{++}\Delta^-$ with Δ^{++} in the forward direction in the c.m. system is found to be $\sigma(\Delta^{++}\Delta^-)/\sigma(\Delta^-\Delta^{++}) = 12.2 \pm 4.5$. The $\Delta^-\Delta^{++}$ production is discussed in terms of exotic meson exchange and double meson exchange.

In this Letter we report on the reaction

$$pn \to \Delta^-(1236)\,\Delta^{++}(1236) \qquad (1)$$

at 6.98 GeV/c, where the Δ^- is emitted in the forward direction in the c.m. system with respect to the incident proton. Reaction (1) cannot be described by the exchange of any known meson in the t channel. In this sense (1) is considered a forbidden reaction, and it is expected to have, at higher energy, much smaller cross section than the allowed reaction

$$pn \to \Delta^{++}\Delta^-, \qquad (2)$$

with the Δ^{++} emitted in the forward direction in the c.m. system.

The peripheral description of Reaction (1) requires either (a) the exchange of a doubly charged exotic meson in the t channel or (b) the successive exchange of two charged mesons (see Fig. 1). Both Reactions (1) and (2) were observed at 3.7 GeV/c by Cohn et al.[1]

The 94 000 pictures of the pd experiment at

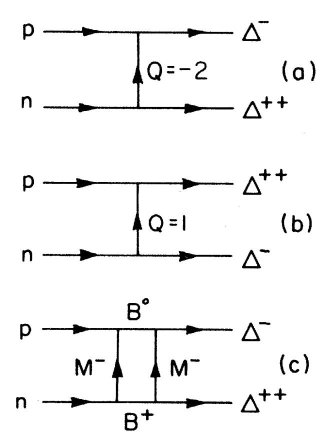

FIG. 1. Exchange diagrams for the reactions (a) $pn \to \Delta^-\Delta^{++}$ with a single $Q=-2$ exchange, (b) $pn \to \Delta^{++}\Delta^-$ with a single $Q=1$ exchange, and (c) $pn \to \Delta^-\Delta^{++}$ with the exchange of two negative mesons.

6.98 GeV/c, taken in the 80-in. Brookhaven National Laboratory bubble chamber, were used to study double $\Delta(1236)$ production in pn collisions.[2] A strong $\Delta\Delta$ production was found in the final state,

$$pd \to p_s pn\pi^+\pi^-, \tag{3}$$

where p_s is the spectator proton, defined as the nucleon with the least momentum in (3). With this choice and the restriction $p_s < 300$ MeV/c, we were able to select a sample of 4400 events of the type

$$pn \to pn\pi^+\pi^-, \tag{4}$$

with a cross section $\sigma_4 = 3.72 \pm 0.22$ mb. The $\Delta^{++}\Delta^-$ events (2) are found in a subsample (4a) of events of Reaction (4) where, in the c.m. system, the protons are emitted in the forward hemisphere and the neutrons are emitted in the backward hemisphere. The amount of $\Delta^{++}\Delta^-$ in the subsample (4a) was found by a two-dimensional fit of the observed mass distribution in the $[M(p\pi^+), M(n\pi^-)]$ plane by a linear combination of the final states $\Delta^{++}\Delta^-$, $\Delta^0 n\pi^+$, $\Delta^{++}n\pi^-$, $\Delta^+ p\pi^-$, $\Delta^- p\pi^+$, and $pn\pi^+\pi^-$. The resonance was described by a modified Breit-Wigner function: $f_R(M) = MM_R\Gamma(q)\Gamma_R\{(M^2-M_R^2)^2+[\Gamma(q)M_R]^2\}^{-1}(q_R/q)$, where $M_R = 1236$ MeV, $\Gamma = 120$ MeV, q_R and q are the decay momenta for M_R and M, respectively, and $\Gamma(q) = \Gamma_R(m_\pi^2+q_R^2)(m_\pi^2+q^2)^{-1}(q/q_R)^3$. The two-dimensional fit gave $(45\pm5)\%$ $\Delta^{++}\Delta^-$ production and a cross section $\sigma_2 = 1.1 \pm 0.2$ mb. The percentage of $\Delta^{++}\Delta^-$ in (4) did not change by including in the fit more final states, like $N^{*+}(1688)n$.

A detailed study[2] of reaction (2) shows that in the forward direction it can be explained by the one-pion-exchange (OPE) mechanism. In order to study more closely Reaction (1), a subsample (4b) of 1300 events of Reaction (4) with a forward neutron and a backward proton emitted in the c.m. system of (4) was selected. The scatter diagram of $M(p\pi^+)$ against $M(n\pi^-)$ [see Fig. 2(a)] shows a concentration of $\Delta^-\Delta^{++}$ events.

The amount of $\Delta^-\Delta^{++}$ events in the subsample (4b) was estimated in two ways: (a) by a two-dimensional fit of the plot $M(n\pi^-)$ against $M(p\pi^+)$, similar to the one used to estimate the $\Delta^{++}\Delta^-$ percentage in the subsample (4a); and (b) by a combined fit of $M(p\pi^+)$ in the final state $\Delta^-p\pi^+$, and $M(n\pi^-)$ in the final state $n\pi^-\Delta^{++}$ [see Fig. 3(b)]. In this way an amount of $(8\pm3)\%$ of $\Delta^-\Delta^{++}$ events was found in the subsample (4b), which corresponds to a cross section of $\sigma_1 = 0.09 \pm 0.03$ mb for Reaction (1).

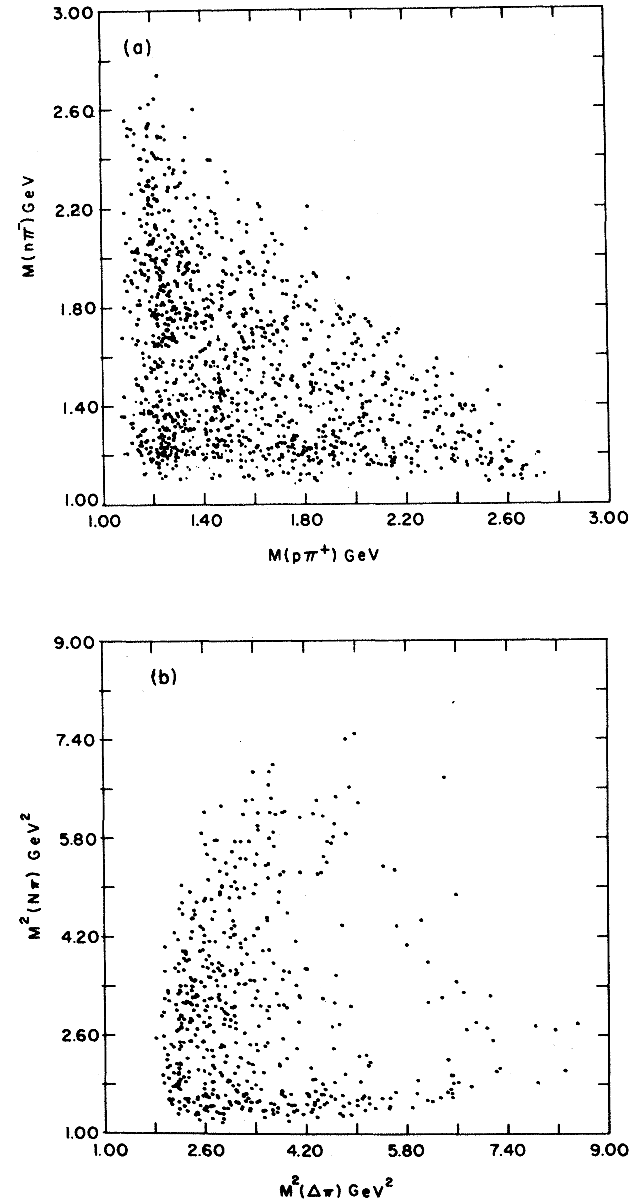

FIG. 2. (a) A scatter plot of $M(p\pi^+)$ against $M(n\pi^-)$ and (b) combined Dalitz plot of the final states $\Delta^-p\pi^+$ and $n\pi^-\Delta^{++}$. Both plots are for the subsample (4b). (See text).

The Dalitz plots of $\Delta^-p\pi^+$ and $n\pi^-\Delta^{++}$ are similar and they are combined together in Fig. 2(b). The combined Dalitz plot of $\Delta N\pi$ is dominated by (a) an $N\pi$ peak in the Δ region and (b) a low-mass enhancement of the $(\Delta\pi)$ combination. Most of the $\Delta\Delta$ points on the Dalitz plot are not correlated to the low-mass enhancement $(\Delta\pi)$. Therefore the observed $\Delta^-\Delta^{++}$ events are not due to a kinematic reflection of the reactions $pn \to (\Delta^-\pi^+)p$ and $pn \to n(\pi^-\Delta^{++})$ as suggested by Berger[3] for the forbidden forward peaks observed in reactions

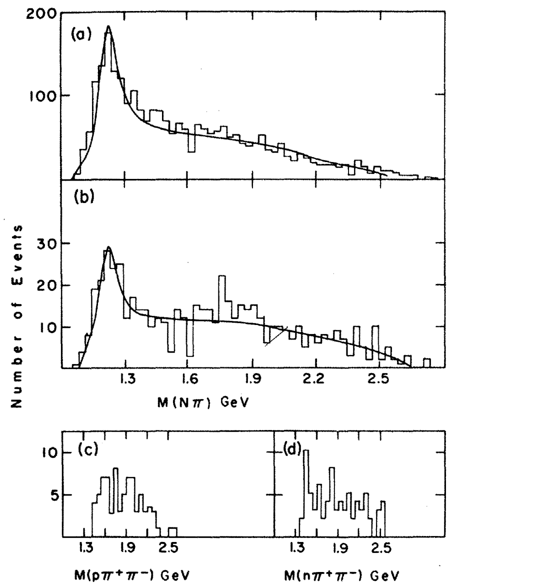

FIG. 3. Mass plots: (a) $M(p\pi^+)$ and $M(n\pi^-)$ combined for the subsample (4b); (b) $M(p\pi^+)$ and $M(n\pi^-)$ for the final states $\Delta^- p\pi^+$ with forward Δ^-, and $n\pi^-\Delta^{++}$ with backward Δ^{++}, respectively; (c) $M(p\pi^+\pi^-)$; and (d) $M(n\pi^+\pi^-)$, both for events of Reaction (1).

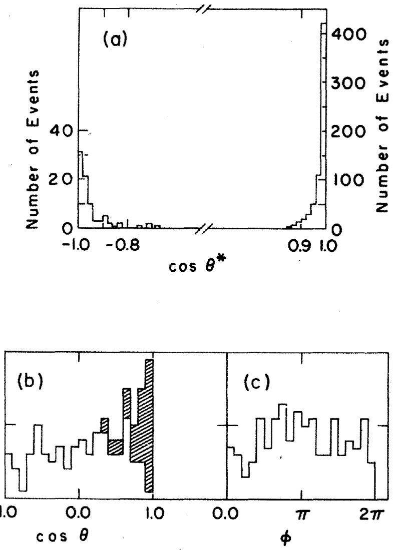

FIG. 4. Angular distributions for the following processes: (a) Δ^{++} production in $pn \to \Delta^{++}\Delta^-$ and $pn \to \Delta^-\Delta^{++}$, where θ^* is the c.m.-system angle between Δ^{++} and p; and (b) and (c) the decay of $\Delta^{++} \to p\pi^+$ and $\Delta^- \to n\pi^-$ (combined) in Reaction (1), where θ and φ are the polar and azimuthal decay angles, respectively, in the Jackson frame of reference. The shaded area in (b) is due to background events.

like $\pi^+ n \to \pi^-\Delta^{++}$.[4] The plots $M(\Delta^-\pi^+)$ and $M(\Delta^{++}\pi^-)$ of the $\Delta^-\Delta^{++}$ events [see Figs. 3(c) and 3(d)] do not show that the $\Delta\Delta$ effect is due to a kinematical reflection of some $N^{*0}p$ or nN^{*+} final states.

The following two-step process of $\Delta^-\Delta^{++}$ production in pd collisions was also considered: (a) charge exchange $p_i n \to np$ of the incident proton (p_i) on the target neutron and (b) $\Delta^-\Delta^{++}$ production by the energetic neutron emitted in (a) and the spectator proton p_s in the deuteron, i.e., $np_s \to \Delta^-\Delta^{++}$. However, because of the small cross section for pn charge exchange near 7 GeV/c,[5] this process will contribute a negligible part, less than 0.1 μb, to $\Delta^-\Delta^{++}$ production.

The production and decay of the Δ resonance in Reaction (1) were studied in an enriched sample of $(60 \pm 10)\%$ pure $\Delta^-\Delta^{++}$ events selected by the criterion $f_R(M(p\pi^+))f_R(M(n\pi^-)) > 0.2$. The production angular distributions of $\Delta^{++}\Delta^-$ (2) and $\Delta^-\Delta^{++}$ (1) are given in Fig. 4(a).

The differential cross section of (1) can be described by $d\sigma/dt' = (0.53 \pm 0.06)e^{(5.9\pm1.2)t'}$ mb $(\mathrm{GeV}/c)^{-2}$. The decay angular distributions $W_\Delta(\cos\theta)$ and $W_\Delta(\varphi)$ of both $\Delta^{++} \to p\pi^+$ and $\Delta^- \to n\pi^-$, where θ and φ are the polar and azimuthal angles, respectively, in the Jackson frame of reference, are shown in Figs. 4(b) and 4(c). The shaded area of Fig. 4(b) is the background contribution to $W_\Delta(\cos\theta)$, estimated from the angular distribution of non-$\Delta^-\Delta^{++}$ events. After background subtraction, $W_\Delta(\cos\theta)$ behaves more like $\sin^2\theta$ and has a density-matrix element of $\rho_{33} = 0.32 \pm 0.10$. This is in contrast to Reaction (2)[2] where the Δ-decay angular distribution is essentially like $\cos^2\theta$ with $\rho_{33} = 0.1 \pm 0.1$ in agreement with the OPE model.

Further information on Reaction (1) can be obtained by comparing its cross sections at 3.7 and 6.98 GeV/c. At 3.7 GeV/c[1] a ratio of $\sigma_2/\sigma_1 \simeq 2$ was found, while at 6.98 GeV/c the same ratio is $\sigma_2/\sigma_1 = 12.2 \pm 4.5$. Now if we assume[2] that $\sigma_2 \propto p_{1\mathrm{ab}}^{-2}$, as expected by the OPE model for Reaction (2), then $\sigma_1 \propto p_{1\mathrm{ab}}^{-5\pm1}$, where $P_{1\mathrm{ab}}$ is the incident momentum in the laboratory system.

The peripheral Reaction (1), if described by an exchange diagram, requires either (a) the successive exchange of two known mesons with total charge $Q = 2$, or (b) the exchange of an exotic meson with $I = 2$ in the t channel. The exotic meson could be the $b\bar{b}$ meson of Rosner[6] required to build the non-Pomeranchuk exchanges in baryon-antibaryon scattering.

It is expected[7] that the contributions from double meson exchange (or its Regge cut) will have a different energy dependence from that resulting from exchange of an exotic meson (or its Regge trajectory). However in the case of Reaction (1), present knowledge is not sufficient to distinguish between these two exchange mechanisms.

"Single-exchange forbidden" reactions, like (1), were also observed in $\bar{p}p$ and meson-nucleon collisions. The reaction $\bar{p}p \to \bar{\Sigma}^+\Sigma^-$ was observed between 2 and 7 GeV/c.[8] However its cross section is smaller than (1) and it drops faster with energy, like $p_{1\mathrm{ab}}^{-6.5\pm2.0}$.[9] Substantial forward peaks were observed in the reactions $\pi^+n \to \pi^-\Delta^{++}$ and $\pi^-p \to K^+Y^*(1385)$ between 2 and 4 GeV/c.[4] However it is not clear that all these reactions can be explained in the same way as (1). For instance, the exotic $b\bar{b}$ meson of Rosner[6] is not coupled to mesons and cannot explain the meson-nucleon reactions.

More experiments on forbidden reactions above 4 GeV/c and direct search for exotic mesons are required in order to solve the basic questions of the existence of exotic states and their importance in high-energy reactions.

We would like to thank Brookhaven National Laboratory for enabling us to obtain the pd exposure at 6.98 GeV/c. We also acknowledge the contribution of Dr. O. Benary to the pd experiment.

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PROPERTIES OF THE $N^*(1730)$ †

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The $N^*(1730)$ with a mass of 1730 ± 15 MeV and a width of 130 ± 30 MeV is produced in the reaction $\pi^-p \to \pi^-N^*(1730)^+$ at 6 GeV/c. The principal decay mode of this N^* is $N\pi\pi$ and not $\Delta\pi$. The $N\pi$ decay rate is found to be much smaller, and the ΛK decay rate is found to be much larger than the accepted rates for the well-known $N_{1/2}^*(1680)$ states ($D_{5/2}$ and $F_{5/2}$), thus establishing that the object that we observe is not the $N_{1/2}^*(1680)$.

Recent production experiments have indicated that there may exist a nuclear isobar decaying into $N\pi\pi$ and ΛK with a mass of ~1710 MeV, somewhat above that of the well-known $N_{1/2}^*(1680)$.[1-3] Arguments that this object differs from the $N_{1/2}^*(1680)$ rest primarily on the small mass difference, since no single production experiment has observed all possible decay modes. Formation experiments indicate one or more possible resonances decaying into $N\pi$ and/or ΛK in the $N^*(1680)$ region with a branching ratio $N\pi/N\pi\pi$ of approximately 1.[4]

The data presented here come from an exposure of the Brookhaven National Laboratory (BNL) 80-in. hydrogen bubble chamber to a 6 GeV/c $\pi^\pm$ beam.

The reactions of interest are

$$\pi^-p \to \pi^-X^+$$
$$X^+ \to N\pi\pi,\quad \to N\pi,\quad \to N\eta,\quad \to \Lambda K,$$

$$\pi^+p \to \pi^+X^+$$
$$X^+ \to n\pi^+.$$

Our sample consists of ~70 000 two-prong, 30 000 four-prong, 4000 six-prong, 1000 eight-prong, and 20 000 strange particle events. These events were measured on the BNL flying-spot digitizer.