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EXPERIMENTAL INVESTIGATION OF THE PRODUCTION OF
GLUEBALLS AND MESON RESONANCE STATES

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Progress Report #9A

for period January 16, 1990 - January 15, 1991

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1.

Technical Progress Report for DOE Contract DE-AC02-83ER40107 (A)

We have made striking and considerable progress^{15-17,20,21} in our AGS program (E-810) which is searching for a Quark-Gluon Plasma or other new phenomena at the AGS. We are employing a TPC Tracking Magnetic Spectrometer that has handled up to ≈ 100 tracks, the maximum observed in $14.5 \text{ GeV/c} \times A$ Si ions incident on Au and Cu. In essence the TPC covers more than the forward half hemisphere in the nucleon-nucleon cms (i.e. $\geq 2\pi$) and thus allows tracking, momentum and angular analysis of the charged particles emitted in these heavy ion collisions. Particle identification for negative pions can be made approximately by assuming negative particles are pions. Then by subtraction of negatives from positives in a suitable manner the proton characteristics can be determined. Λ and K_S^0 V particles have been identified singly in events and ≈ 50 double Λ and 2 triple Λ events have been observed in the relatively small data sample ($\sim$ central like events) we have obtained and analyzed this year.

Anti-proton identification by Time-of-Flight is included in the apparatus and this data is under analysis.

The distribution of events involving multi lambdas (and K_S^0) is a sensitive test for the strangeness enhancement expected from a QGP. This is so since for practically any model one will likely use up all the adjustable parameters available to produce multi-lambda etc. events in fitting the one Λ and at most 2Λ events. If the observed 3Λ and 4Λ event

rates then rise faster than predicted we believe it will be very difficult to explain them within the context of QCD without invoking formation of a Quark-Gluon Plasma (QGP). Table I compares our present observations on the distribution of Λ multiplicity per event with cascade predictions. Although there is an excess of 2Λ events this is not statistically significant and it is clear we must obtain and analyze at least one and preferably two orders of magnitude more data to have a statistically significant result. We plan to do part of this during this year and especially in the renewal contract year.

With the time-of-flight we can add $\bar{p}$ production to these events and may detect the rate of $\bar{\Lambda}$ and multi $\bar{\Lambda}$ production if sufficient statistics are available.

Table II illustrates the power of correlations in drastically tilting the distribution of multi Λ events toward higher multiplicity. In almost any model if one then adjusts to the observed single (and even perhaps double if necessary) Λ rate the triple and quadruple etc. Λ rate from a plasma is expected to be hard to explain.

First let us address ourselves to the question of single Λ and K_S^0 production in Si-Au and Si-Cu collisions at $14.6 \times A$ GeV/c we have determined at AGS with our TPC Magnetic Spectrometer.¹⁷ We have obtained ~ 750 Λ events and ~ 300 K_S^0 events from the Au target and ~ 850 Λ events and ~ 400 K_S^0 events from the Cu target. The arrangement, triggering cuts, etc are described in Ref. 17. Figure 1 shows the experimental arrangement Figure 2 shows an isometric view of a typical Si-Au event with the automatic computer pattern recognition reconstruction of tracks. Figure 3 shows the Λ yield in the Lab rapidity range $1.2 < y < 3.0$ for Au and Cu targets as a function of negative track multiplicity (detected). The Λ

yield has been corrected for acceptance and the neutral decay made branching ratio. Negative particles that go through at least the first TPC module (there are three) with $y_{\text{Lab}} > 1.7$ have a good acceptance, and we chose those for this comparison. We have chosen the multiplicity of these negative particles which ranges up to ~ 20 for both Au and Cu as a measure of the energy deposited in the interaction. It should be noted that the forward half hemisphere in lab rapidity for the nucleon-nucleon system is 1.75 to 3.5. We have chosen rapidity intervals which have good acceptance for our analysis.

The Λ yield shows a monotonic (approximately linear) increase with Λ multiplicity hence the largest yields correspond to the most central events. The highest multiplicity bin corresponds to 0.28 barns interactions cross section for Au. The estimated systematic uncertainty in the stated cross sections is $\sim 20\%$. The HIJET model was modified to include all the known meson-nucleon rescattering channels.²⁴

The formation time of the secondaries is the adjustable parameter in the model. We tried our best to achieve agreement with the data and this had the consequence that we set the formation time to zero (hardly a physically acceptable value) to maximize rescattering. This led to good agreement within our errors for the Λ data and model data but the slope of the increase is still flatter in the modified HIJET.

Figure 4 represents a comparison of K_s^0/event versus negative prongs also in the rapidity range where our acceptance is good, with the modified HIJET model. Here we find too many K_s^0 to be explainable by the modified HIJET model even when their production is maximized by setting the formation time equal to zero. However we are adding meson-meson scattering to the model and this may reduce or explain the discrepancy. However I

believe the critical test of this and other models will be, as I stated previously, the comparison with the distribution curves of Λ multiplicity (better yet augmented by $\bar{p}$, K_S^0 , and $\bar{\Lambda}$). This will require the higher statistics analysis we plan to be working on in the renewal contract period.

From the usual method of using inverse slopes of $\log(\frac{1}{N_{ev}} \frac{dN}{dp_T})$ plotted vs. $m_T = (m_0^2 + p_T^2)^{1/2}$ to determine effective temperatures of the fireball we find ~ 150 MeV for both Λ 's and K_S^0 's on both Au and Cu targets (see Fig. 5).^{16,17}

Now let us turn to discussion of global variables. Figure 6 shows a typical Si-Au event. The pattern recognition efficiency is high (approaching $\sim 90\%$ for long enough tracks) and the results are quite clear. Figure 7 shows the acceptance corrected pseudorapidity for all charged tracks for Cu and Au targets. The two curves cross at $\eta \sim 3$. The shape presumably reflects the lower stopping power of the Cu nucleus.

Figure 8 shows the acceptance corrected rapidity distribution for negative tracks from Au, assuming they are essentially all pions, compared to the results from E-802 which used small acceptance telescopes and identified particles.²⁵ The pion mass was used to calculate the rapidity for our data. The agreement is good considering the totally different techniques used and the small overlap in phase space coverage.

Figure 9 shows the negative particle rapidity for Cu and Au targets assuming negatives are pions. The points lie on top of each other. We have attempted to get information on the proton rapidity distributions by assuming that π^+ production is identical to π^- and neglecting the excess K^+ contamination. The results of subtracting negative from positive, and

calculating the rapidity on the basis of the proton mass in each case are shown in Fig. 10. The main features namely enhanced production from Au in the target region and larger production from Cu in the fragmentation region are believed to be too large to be accounted for by systematic uncertainties.

In Fig. 11 we show preliminary estimates for the temperature parameter (as previously defined) as a function of rapidity and note that there is a tendency for the temperature to be higher near the central (nucleon-nucleon) region but obviously this needs to be investigated more thoroughly.

Thus it is clear we have made considerable progress in AGS E-810 (search for a QGP) during this contract year and are planning on much more progress during the renewal period (next contract year).

Glueball Program

We have continued to show that the only viable explanation of our discovery of the $\phi\phi$ resonances $g_T(2010)$, $g_T(2300)$ and $g_{T^*}(2350)$ is that 1-3 primary $I^G_{J^{PC}} = 0^{+2^{++}}$ glueballs are produced in the OZI suppressed reaction $\pi^- p \rightarrow \phi\phi n$.^{1,2}

The many theoretical attempts to explain these states, and their striking complete breakdown of the OZI rule by alternate mechanisms other than glueball(s) have been shown to be theoretically incorrect, irrelevant, or do not fit our data or all three.³⁻⁷ The latest attempt has been made by J. Ellis, E. Gabathuler and M. Karliner.⁸ In a publication during this contract year we have shown this work to be irrelevant and not affect our glueball arguments and conclusions.⁷

We have continued to work on our analysis of the relevant world's data in the 0^{++} and 2^{++} channels and continue to demonstrate that the status of the other glueball candidates are unclear.

Research Program for the new Contract Period (January 16, 1991 - January 15, 1992)

We are requesting a one-year renewal of our present contract grant to continue our successful new search program for a Quark-Gluon Plasma¹²⁻¹⁸ at AGS and our investigation of the status of glueball and related meson spectroscopy.^{3-7,9,23} All of this work on all three fronts has one common theme - namely to critically confront non-perturbative QCD. This is of extreme importance since the weakest link in the standard model at present energies is the lack of a critical demonstration that non-perturbative QCD is correct.

Since the standard model is considered by many theorists to be the bedrock foundation of modern high energy theory, it is clearly of great importance to explore this weakest link to the extent feasible.

Thus our various programs have this one primary goal - to do critical investigations which either more or less establish non-perturbative QCD or find a contradiction to it. We have been making very good progress in this task and wish to continue to actively pursue this program in the renewal period.

Search for a Quark-Gluon Plasma

One of the most important predictions of QCD is confinement of particles with color. However it has been concluded that at high enough temperatures or pressures (i.e. nuclear densities) phase transition(s) will lead to deconfinement over $>$ several Fermi in energetic heavy ion collisions. The deconfinement region is expected to contain a so-called

TABLE I

We use 1 A detected central like events to adjust Monte Carlo to fit non-plasma events.
Then predict rate of 2A and 3A detected events.

14.5 GeV/c $\times$ A Si on Au

AGS - E810 Runs.

	<u>Predicted</u>	<u>Observed</u>
1A	≈ 765	767
2A	≈ 35	53
3A	≈ 1	2

There is an excess of 2A events which is not statistically significant.

It is obvious that 10-100 times more statistics will allow a statement to be made which is relatively model insensitive.

TABLE II

Illustration of the Power of Correlations
from AGS - E810

Monte Carlo Study

14.5 GeV/c $\times$ A Si on Au.

Assume plasma formed with 25% of the incident energy, 7.5% of the time.

Increase Relative to Cascade Model

1A rate increased by 18%

2A rate increased by 100%

3A rate increased by 500%

4A rate increased by 2,000%

Including $\bar{p}$'s in the correlations would increase sensitivity.

MPS E-810 Detectors

Plan view

Figure 1

Plan view of the apparatus

Figure 2

Reconstructed tracks in the TPC modules for a
typical Si-Au interaction

Λ Data ($1.2 < y < 3.0$)

Figure 3

Λ yield in the rapidity region $1.2 < y < 3.0$ as a function of negative track multiplicity. The errors shown are statistical only.

K_s^0 Data ($2.2 < y < 3.0$)

Figure 4

K_s^0 yield in the rapidity region $2.2 < y < 3.0$ as a function of negative track multiplicity. The errors shown are statistical only.

Si on Au & Cu - Λ & K_S^0 p_T Distributions

Figure 5

Transverse momentum distributions as a function of transverse mass m_T for Λ 's and K_S^0 's from both Au and Cu targets. The errors shown are statistical only.

Run 5
Tape 14631
Date 25 JUN 89
Time 05:12:26
Event 8

Figure 6

Three views of a Si Au event.

Charged Prongs 14.5xA GeV/c E-810

Figure 7

The pseudorapidity for all charged tracks.

Si-Au 14.5xA Gev/c

Figure 8

The rapidity distribution for negative tracks from

14.5xA GeV/c (π^-) E-810

Figure 9

The rapidity for negative tracks for Au and Cu.

(+)-(-) 14.5xA GeV/c E-810

Figure 10

The rapidity distribution for positive minus negative.

Si-Au 14.5x A GeV/c

Figure 11

Results of fits to the T parameter.

END

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