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HIGH-ENERGY NUCLEUS-NUCLEUS INTERACTIONS**

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Recent results from experiments on high-energy nucleus-nucleus collisions in both nuclear emulsions and solid-state nuclear track detectors are reviewed. In particular, criteria for the efficient selection of central events and searches for signals of the possible formation of a quark-gluon plasma are discussed.

1. INTRODUCTION

The main motivation for producing heavier and heavier nucleus-nucleus interactions at increasing energies is to obtain, over a sufficiently large volume, an energy density of a magnitude such that a quark-gluon plasma (QGP) approaching thermal equilibrium can be formed.

It is hoped that direct or indirect signals of QGP formation can be obtained from the plasma itself (through γ -rays, pairs of leptons, etc.) as well as from hadronization (through fluctuations and correlations due to local instabilities, different pairing of quarks, etc.).

After the successful acceleration of oxygen ions to 60 and 200 GeV/N at CERN and 14.5 GeV/N at Brookhaven, beams of 200 GeV/N sulfur ions at CERN and of 14.5 GeV/N silicon ions at Brookhaven also became available during the last year, thus extending considerably the range of high-energy projectiles available for a fascinating series of experiments.

As the physics of high-energy ions interactions is, to a large extent, a totally new area of study, most experiments followed a twofold approach: one a systematic study and possibly understanding of what is a 'normal' interaction, the other an extensive search for 'unusual' signals in a sample of events selected to enhance the likelihood of observing the formation of a QGP. The first approach usually contained in addition a comparison of nucleon-nucleon and of proton-nucleus interactions at the same energy. Of course, one cannot forget that, even at ultrarelativistic energies, ion beams are both nuclear and electromagnetic probes, with implications involving different fields such as, for example, low-energy nuclear physics, when studying target or projectile electromagnetic dissociation in interactions with a large impact parameter.

In this scenario the role of nuclear emulsions is quite clear. In fact, as often happened in the past, owing to their continuous sensitivity, to their exceptional spatial resolution in three dimensions ($\approx 1 \mu\text{m}$) and to their 4π solid angle coverage, emulsions are perfectly suited for pioneering work that can then guide far more refined experiments. Illuminating is, for instance, the role played by cosmic ray events detected in nuclear emulsions in triggering new ideas and methods of analysis. Moreover, unexpected features, not specifically included as a trigger in another experiment (suppose, for example, the

occurrence of an event with many low-energy hyperfragments!), are recoded in emulsion anyway and can be studied at any time. It should be noted, in addition, that in the last 15 years new methods of exposure and of analysis of nuclear emulsions were developed, primarily with the aim of exploiting their characteristics in the search for short-lived particles carrying heavy flavours (charm, beauty, ...).

As a consequence, on the one hand the hybrid experiments linking emulsion with external electronic apparatus permitted the selection of rare or very rare events (rejection factors down to 10^{-4} – 10^{-5} were achieved) and added information otherwise not available (through spectrometers, calorimeters, etc.), while preserving the high spatial accuracy and the multitrack and multivertex discrimination; on the other hand, sophisticated semiautomatic or automatic scanning and measurement devices overcame one of the biggest drawbacks experienced in the past, namely the long analysis time, to such an extent that now high statistics experiments are quite common. Finally, the increasingly wide use of emulsion chambers, whilst limiting the accepted solid angle, permits a range of targets to be chosen, up to for example Au, Pb, W or U, and overcomes the fact that nuclear emulsion is an heterogeneous medium in which silver is the heaviest element.

The data presented here (often preliminary) were obtained by several collaborations and groups. Briefly:

- EMU01^{*}), a large collaboration, exposed emulsion stacks and chambers;
- Berkeley (EMU02 at CERN) and Siegen (WA87 at CERN) exposed chambers with solid state nuclear track detectors (SSNTD);
- KLM^{*}) (EMU07 at CERN), EMU03 (Cairo) and EMU08^{*}) (Buffalo) exposed emulsion stacks;
- EMU05^{*}) (Huntsville-Tokyo) exposed emulsion chambers in a magnetic field;
- EMULSION-HELIOS, again a large collaboration, exposed emulsion stacks and chambers coupled to the HELIOS (NA34) spectrometers and calorimeters.

2. RAPIDITY DISTRIBUTIONS

In order to select nucleus-nucleus interactions with a sufficiently high energy density, several criteria can be used, but the impact parameter of the colliding nuclei must be small, much smaller than the sum of the radii ($b \ll R_P + R_T$). Obviously, in fixed target experiments, it is convenient that the target be as big as possible, certainly bigger than the projectile. When such conditions are fulfilled, one may assume that all the nucleons of the projectile interacted and therefore no 'spectator' nucleon or cluster of nucleons remained; otherwise each one would carry almost the same energy per nucleon as that of the beam and would be emitted at an angle to the beam determined by its initial Fermi momentum within the original nucleus ($\theta \ll 1$ mrad for nucleons, $\theta \ll 0.25$ mrad for α particles, etc.).

In terms of pseudorapidity [$\eta = -\ln \tan(\theta/2)$], although the concept loses its initial meaning in these extreme conditions, spectator nucleons or fragments are then expected to have $\eta \gtrsim 7$. Figure 1 shows rapidity distributions of $z = 1$ particles (dominantly protons) emitted at small angles in peripheral oxygen-emulsion and sulfur-emulsion interactions at 200 GeV/N. The contribution of spectator (S.F.) and of quasi-elastically scattered fragments (Q.E.) is clear, and tends to disappear in central events.

Therefore, it is seen that the requirement of no spectator fragments is equivalent to a trigger that vetoes on forward energy, as it is used in some experiments such as NA35 or

^{*}) All groups marked with an asterisk presented data at this conference.

Fig. 1 Rapidity density distributions of spectator (S.F.) and of quasi-elastically scattered fragments (Q.E.) with $z = 1$, obtained by EMULSION-HELIOS in peripheral ion-emulsion interactions at 200 GeV/N.

WA80. Of course, the very presence of a projectile fragment with $z \geq 2$ indicates a peripheral interaction. Moreover, other features of a central interaction with a heavy nucleus are usually observed, namely a high multiplicity of produced particles and a noticeable excitation, with consequent evaporation, of the residual target nucleus. Both these features are, in fact, related to the effective number of nucleon-nucleon collisions inside the nucleus. For the same reason, in turn, a high transverse energy E_T indicates a central collision (trigger used by many experiments), being on average proportional to the multiplicity.

The KLM group extended previously reported results with protons and light ions to Si- and S-emulsion interactions, showing that, indeed, the average charged multiplicity per interacting nucleon depends only on energy, and therefore on the average charged multiplicity in pp collisions at the same energy.

EMULSION-HELIOS¹⁾ and EMU01²⁾, on the other hand, measured a clear correlation between spectator fragments and average number of evaporation prongs, whereas the strong correlation between evaporation prongs and charged multiplicity was already present in proton-emulsion interactions.

EMULSION-HELIOS, a hybrid experiment, selected central events by triggering either on multiplicity or on E_T , both measured in the external apparatus. The linear relationship between these two quantities is shown in Fig. 2a [here the charged multiplicity (N) is as measured in emulsion], and it is quite sharp when both are measured in the same pseudorapidity interval; however it is still maintained, on average, also if multiplicity and E_T refer to different η intervals³⁾. The fact that data obtained with different projectiles lie on the same line suggests again a simple dependence on the number of nucleon-nucleon collisions.

In conclusion, either selection on a specific feature, or rather a combination of them, can easily provide an efficient trigger for central events, almost equivalent to those used in other experiments by requiring high E_T , high multiplicity or low forward energy. For instance EMU01⁴⁾, by requiring $N \geq 200$ in ^{16}O interactions at 200 GeV/N, selects the most central events in Ag/Br (1.5% of the sample; 6% with $150 \leq N \leq 200$); KLM⁵⁾, by requiring the

Fig. 2 a) Total charged multiplicity as a function of E_T ; b) cross-section as a function of E_T for different targets.

Fig. 3 Rapidity distributions obtained in central collisions of S ions with different targets by EMULSION-HELIOS (a) and EMU01 (b).

number of evaporation prongs $N_H > 15$ and no forward fragment with $z \geq 2$, selects 17% of the events in ^{16}O emulsion interactions at different energies. From the E_T distributions obtained in HELIOS with different targets⁶⁾, and schematically shown in Fig. 2b, it is seen that EMULSION-HELIOS, with a sufficiently high cut-off on E_T , efficiently selects not only central events but also the heaviest target: Ag or Br, in the emulsion, by requiring $E_T > 170$ GeV within $0 \leq \eta \leq 3$ with ^{32}S at 200 GeV/N; W, in the emulsion chambers, by requiring $E_T > 250$ GeV in the same conditions.

All the emulsion experiments determined the energy density of charged particles [$\epsilon = 1/N_{ev} (dN/d\eta)$] for various incident nuclei and energies. As an example, Fig. 3 shows the distributions obtained by EMULSION-HELIOS with ^{32}S on emulsion nuclei at 200 GeV/N by requiring $E_T > 170$ GeV and by EMU01 with ^{32}S on Au by requiring $N > 300$ within 30° to the beam. In both cases, on average, $\epsilon_{max} \approx 120$. With ^{16}O at 200 GeV/N it has been previously found that $\epsilon_{max} \approx 70$. From these figures it is possible to estimate the energy density attained in the interactions. For instance, using the Bjorken formula

$$\epsilon = \frac{dE_T}{d\eta} \frac{1}{\pi\tau_0 R^2} \approx \frac{3}{2} \epsilon m_T \frac{1}{\pi\tau_0 R^2}, \quad (1)$$

$\epsilon = (1.2 \text{ to } 1.5) \text{ GeV/fm}^3$ is found for both central oxygen- and sulfur-emulsion interactions. In this calculation, the values $\tau_0 = 1 \text{ fm/c}$, $\langle p_T \rangle = 350 \text{ MeV/c}$ and $R =$ projectile radius have been used; the factor $3/2$ takes into account the unseen neutral

multiplicity. However, in the highest multiplicity events, much higher local rapidity densities have been observed, corresponding to energy densities as large as $(2.5-3) \text{ GeV/fm}^3$.

From the data presented above it can be concluded that nucleus-nucleus interactions studied with different beams, energies, targets, and selection criteria suggest that, on average, the main features of central events can be interpreted as a superposition of p-p interactions. On the other hand, 'measured' energy densities are in the range of a few GeV/fm^3 with no big increase from O to S apart, of course, from the larger volume involved.

These facts do not rule out the possible formation of QGP, at least in some of the interactions, but more specific signals must be searched for.

3. SEARCH FOR SPECIFIC SIGNALS

3.1 Fractional charges

According to theoretical arguments, in high-energy nucleus-nucleus interactions, a situation very different from p-p or e^+e^- collisions, no absolute quark confinement is required and there is the possibility that single quarks are trapped within a heavy fragment of either the projectile or the target. In the first case, since for high values of the Lorentz factor γ , the ionization of the fragment depends on z^2 and not on the momentum, the presence of fractional charges should be relatively easy to detect. In addition, abnormally dense droplets of nuclear matter with a charge larger than that of the projectile could be formed and emitted as projectile fragments. They could be easily detected if they are sufficiently long-lived.

A search for projectile fragments with fractional charges has been carried out by the Berkeley⁷⁾ and the Siegen⁸⁾ groups. They exposed stacks of CR39 plastic track detectors to a variety of beams up to the maximum available energy, and used a selection of different targets. After having treated the plastic sheets, exposed perpendicular to the beam, the area (or diameter) of the etched cones at the detector surface has been measured on several sheets. Whereas a single measurement provides an estimate of the charge with an uncertainty of the order of 0.2 charge units, a combination of measurements on several surfaces along the trajectory of the same fragment can reduce the uncertainty to as little as 0.03 such units. As shown in Fig. 4, but also based on other, similar results, at present not a single projectile fragment with fractional charge or with $z > z_P$ has been found.

Fig. 4 Distributions of charges of projectile fragments obtained by the Siegen (a) and Berkeley (b) groups. Not a single fractional charge was observed.

3.2 Charmed particles

A single collaboration, EMULSION-HELIOS, is performing a systematic search for charmed particles in central ion-emulsion interactions. Events with charged particle multiplicity $N > 190$ and no forward fragment with $z \geq 2$ have been selected from a sample of oxygen interactions at 200 GeV/N; a search for decays is being performed by a volume scan within a cylinder of 300 μm radius and 2.6 mm length along the beam, downstream of the primary interaction. In these conditions, it is estimated that in 42% of the cases both charmed particles of a pair decay within the scanning volume, and in 64% of the cases, at least one does. Preliminary results based on some 350 events are as follows: 5 events with two decay topologies and 25 events with a single decay topology were detected. The main source of background is that of interactions with no evaporation prong (white stars); they dominate single decay topologies and contribute to about 50% of the double topologies. By taking into account also the scanning efficiency ($\sim 50\%$), it is estimated that one pair of charmed particle is produced in about 40 central collisions.

It is planned in the future to carry out a similar search in sulfur-emulsion interactions, also at 200 GeV/N. At this stage, it seems premature to draw from this result any inference which could have bearing on other results, such as those on J/ψ suppression.

3.3 Non-statistical fluctuations and correlations

The formation of a QGP in a nucleus-nucleus interaction would be followed by a phase transition during which the plasma hadronizes. This transition, which occurs quickly and with large energy release, is expected to generate local deflagrations and hence cause the formation of clusters of particles in restricted pseudorapidity intervals. The outgoing particles might therefore be expected to show correlations and fluctuations in rapidity density. Such effects, however, would be difficult to detect in single events with the projectiles and energies now available, as they would be masked by the statistical fluctuations of random emission. On the other hand, distributions obtained as the incoherent sum of a number of events are likely to 'wash out' the effect, even if present.

EMU01^{*)}, for instance, finds very good agreement between experimental data and the results of calculations based on random emission for central O-emulsion and S-Au interactions at 200 GeV/N, when the frequency of the charged particles emitted at mid-rapidity ($2 < \eta < 4$) is computed for smaller and smaller rapidity intervals.

For these reasons, more refined methods are needed to detect non-statistical fluctuations and correlations on selected samples of interactions.

Białas and Peschanski⁹⁾ recently proposed a method of analysis to determine whether the fluctuations observed in a rapidity density spectrum are statistically significant. This analysis involves computation of the scaled factorial moments of order i as a function of the rapidity resolution δy :

$$\langle F_i \rangle = M^{i-1} \left\langle \sum_{m=1}^M \frac{K_m (K_m - 1) \dots (K_m - i + 1)}{N(N - 1) \dots (N - i + 1)} \right\rangle \quad (2)$$

Here, given a rapidity window Δy containing N particles, K_m is the multiplicity within δy and $M = \Delta y / \delta y$. The authors show that $\langle F_i \rangle$ must saturate as δy decreases if the fluctuations are purely statistical, or when a correlation exists with a range larger than δy . Moreover, if 'intermittency' is present, i.e. rapidity correlations of many different sizes, the following power law is predicted

$$\langle F_i \rangle \propto (\Delta y / \delta y)^{\phi_i} \quad (3)$$

Fig. 5 Scaled factorial moments as a function of the pseudorapidity interval in central ion-emulsion collisions. The slope, increasing with the order i of the moments, suggests an 'intermittency' pattern.

and hence a straight line with slope ϕ_i in a plot of $\log \langle F_i \rangle$ against $\log \delta y$. Evidence of such behaviour has been found in a cosmic ray event from JACEE¹⁰⁾.

KLM^{*}) also finds evidence of intermittency both in O-emulsion central interactions at 60 and 200 GeV/N (Fig. 5a) and in proton-emulsion interactions at 200 and 800 GeV. Similar results were observed by EMULSION-HELIOS in ion-emulsion (Em) central interactions triggered by high E_T , namely O-Em ($E_T > 70$ GeV) and S-Em ($E_T > 140$ GeV) at 200 GeV/N (Fig. 5b).

EMU01^{*}) finds intermittency in S-Au but not in O-Em central interactions, both at 200 GeV/N.

All these results are preliminary; more clarification is expected soon and this should take into account both the different event selection criteria and the different rapidity intervals used in the above experiments.

A different analysis, proposed by Hwa¹¹⁾, consists of computing $C_2 = \langle n^2 \rangle / \langle n \rangle^2$ for increasing intervals of δy , all centred around the value corresponding to the maximum of the rapidity distribution. In this way

$$C_2 \langle n \rangle = 1 + S \langle n \rangle \quad (\langle n \rangle \propto \delta y) , \quad (4)$$

where $S (= \mu_2 + \nu_2)$ is the sum of two terms representing, respectively, geometrical and dynamical contributions to the fluctuations. For a sample of central interactions the condition $\mu_2 \rightarrow 1$ must hold and any contribution from dynamical fluctuation can thus be isolated. The experimental results of the Buffalo group¹²⁾ show values of C_2 in the range from 1.15 to 1.26, whereas EMULSION-HELIOS³⁾ finds $C_2 \approx 1$ in the sample of most central events (selected by E_T) and increasing values of C_2 for less stringent selection criteria (see Table 1).

A search for correlations between both like- and opposite-sign particles has been carried out by EMU05^{*}), using emulsion chambers situated in a magnetic field of 1.8 T and irradiated by ^{16}O and ^{32}S beams of 200 GeV/N. As also observed by NA35^{13,*)}, Bose-Einstein interference (the Hanbury-Brown-Twiss effect) gives rise to correlations at small values of the momentum difference and this permits the size of the emission volume to be determined. Figure 6 shows a preliminary result from EMU05 in S-Pb central

Table 1
Experimental values of the slope S in Eq. (4)

Beam	Energy (GeV/N)	S	Selection	Experiment
^{16}O	60	1.196 ± 0.006	no forward fragment with $z \geq 2$	EMU08 ¹²⁾
^{16}O	200	1.260 ± 0.005		
^{32}S	200	1.157 ± 0.003		
^{16}O	200	1.13 ± 0.05	$E_T < 70 \text{ GeV}$	EMULSION- HELIOS ³⁾
^{16}O	200	1.06 ± 0.02	$E_T > 70 \text{ GeV}$	
^{32}S	200	1.12 ± 0.02	$E_T < 140 \text{ GeV}$	
^{32}S	200	1.02 ± 0.01	$E_T > 140 \text{ GeV}$

Fig. 6 Correlation between negative pairs of particles as a function of their momentum difference in central S-Pb interactions at 200 GeV/N.

interactions at 200 GeV/N. Correlations between opposite-sign particles, strongly influenced by resonances, could signal a phase transition into a regime where chiral symmetry is restored and hence the mass of the resonances is much reduced. No evidence of such a transition has been observed as yet.

EMULSION-HELIOS performed both rapidity correlations and azimuthal angle correlations between particles with a small pseudorapidity separation ($\Delta\eta < 0.1$). The rapidity correlations do not appear to differ appreciably from those found in proton-emulsion interactions, where a positive correlation is found in the target region. Azimuthal angle correlations, shown in Fig. 7, appear to be present in all the samples with a similar relative enhancement for small values of $\Delta\phi$.

Finally, EMU01⁹⁾ performed a study on the clustering of a fixed number of charged particles (from 2 to 36) and compared the results with those expected from random emission. This study, conducted on samples of O-Em and S-Au central interactions at 200 GeV/N, showed no obvious correlation pattern in the first sample, but possibly a small effect in the second.

Fig. 7 Number of pairs of particles with $\Delta\eta < 0.1$ as a function of their difference in azimuthal angle from interactions in emulsion with different beams and for different selection criteria.

4. OTHER SEARCHES

Among experiments not connected with the search for QGP, those searching for evidence of 'anomalons' were fewer during the last year than previously. Anomalons are defined as projectile fragments, from relativistic ion interactions, which are observed to have an anomalously small interaction length. The first evidence for their existence came from cosmic ray studies. Indeed, recently Pshenin and Voinov¹⁴⁾ made a comprehensive analysis of the results of the published data on this subject and showed that, although single results support the existence of anomalons, this evidence disappears, except in very few cases, when all the experimental results are compared. In other words, the hypothesis of statistical fluctuations cannot be ruled out. For these reasons, single experiments searching for evidence of anomalons should collect much higher statistics than in the past, in order to provide a decisive result.

On the contrary, a very active field of study in the last year was the analysis of electromagnetic dissociation (EMD) of ultrarelativistic projectiles in the Coulomb field of target nuclei. The phenomenon occurs because the electric field of the target is seen by the projectile as a flux of virtual quanta, one of which can excite the projectile, generally by absorption in the giant resonance region. The projectile will then dissociate into two or more fragments and, with generally small energy release in the c.m. system, it is seen to split into very closely spaced fragments in the laboratory system: typical separation angles are fractions of a mrad at 200 GeV/N.

The cross-section for projectile EMD (σ_{EMD}) is expected to increase with energy and charge of both projectile and target roughly as $\ln E$, z_P and z_T^2 , respectively; in some cases it can exceed the corresponding nuclear cross-section (σ_{nuc}) at the maximum available beam energy.

The Berkeley¹⁵⁾ and Siegen¹⁶⁾ groups, with the chambers used in the search for fractional charges, measured charge-changing cross-sections for different incoming beams, energies and targets. From these data σ_{EMD} was extracted. As an example, Fig. 8 shows the cross-sections and the ratio $\sigma_{\text{EMD}}/\sigma_{\text{nuc}}$ obtained by the Siegen Group as a function of z_T for S projectiles of 200 GeV/N.

EMULSION-HELIOS performed a study of projectile EMD on emulsions exposed with the surface parallel to 200 GeV/N O¹⁷⁾ and S beams. Here, the most effective targets are Ag

Fig. 8 Nuclear and total charge-changing cross-section (a) and ratio between EMD and nuclear cross-sections (b) as a function of target charge for interactions induced by 200 GeV/N S nuclei.

Table 2

Results from EMULSION-HELIOS on projectile EMD at 200 GeV/N

Process $\sigma_{\text{EMD}}/\sigma_{\text{NUCL}}$	$^{16}\text{O-Em} \rightarrow ^{16}\text{O-Ag}$ ($12.4 \pm 0.7\%$) $\rightarrow$ ($28 \pm 2\%$)	$^{32}\text{S-Em} \rightarrow ^{32}\text{S-Ag}$ ($22.5 \pm 1.4\%$) $\rightarrow$ ($55 \pm 4\%$)	
Channel ^{*)}	Frequency (%)	Channel ^{*)}	Frequency (%)
O $\rightarrow$ N H	56 $\pm$ 4	S $\rightarrow$ P H	54 $\pm$ 4
$\rightarrow$ C H H	14 $\pm$ 2	$\rightarrow$ Si H H	24 $\pm$ 3
$\rightarrow$ C H e	11 $\pm$ 2	$\rightarrow$ Si H e	4 $\pm$ 1
$\rightarrow$ B H H H	0.9 $\pm$ 0.5	$\rightarrow$ Al H H H	3 $\pm$ 1
$\rightarrow$ B H e H	4 $\pm$ 1	$\rightarrow$ Al H e H	5 $\pm$ 1

*) Neutral particles not detected; isotopes not separated.

(62%) and Br (34%), with a marginal contribution from lighter elements such as C, N, and O (4%). Since nuclear emulsions are sensitive to minimum ionizing particles with unit charge, this experiment determined relative rates of some exclusive channels and also energy spectra from angular distributions. Some of these results are summarized in Table 2.

5. CONCLUSIONS

The results from experiments using nuclear emulsions or solid state nuclear track detectors in high-energy nucleus-nucleus interactions have been reviewed. The main aims of these searches were a systematic study to understand the 'normal' features of the interactions, and more detailed work on samples of selected events to try to find evidence of QGP formation.

Different selection criteria to tag central events were discussed. Rapidity densities measured at the highest available energy, namely with 200 GeV/N ^{32}S ions, lead to an estimate of an energy density up to a few GeV/fm³ in the most central collisions.

On average, these interactions can be interpreted as a superposition of proton-proton collisions at the same energy and the search for direct signatures of QGP gives no evidence of fractional charges or of localized fluctuations in the rapidity density. However, more sophisticated methods of analysis did show, in some cases, the presence of correlations and of non-statistical fluctuations (intermittency).

Finally, among the searches not directly linked to QGP, the electromagnetic dissociation of projectile nuclei in the Coulomb field of heavy targets was shown to be an important process, whose cross-section was found to be, in some cases, larger than the corresponding nuclear cross-section.

REFERENCES

- 1) N. Ardito et al., *Europhys. Lett.* **6** (1988) 131.
- 2) M.I. Adamovich et al., Berkeley preprint, LBL-25464 (1988).
- 3) EMULSION-HELIOS Collab., *Proc. 34th Int. Conf. on High Energy Physics, Munich, 1988* (to be published).
- 4) M.I. Adamovich et al., *Phys. Lett.* **201B** (1988) 397.
- 5) L.M. Barbier et al., *Phys. Rev. Lett.* **60** (1988) 405.
- 6) T. Åkesson et al., *Phys. Lett.* **214B** (1988) 295.
- 7) G. Gerbier et al., *Phys. Rev. Lett.* **59** (1987) 2535.
- 8) A. Hoffmann et al., *Phys. Lett.* **200 B** (1988) 583.
- 9) A. Białas and R. Peschanski, *Nucl. Phys.* **B273** (1986) 703 and **B308** (1988) 857.
- 10) JACEE Collab., *Phys. Rev. Lett.* **50** (1983) 2062.
- 11) R.C. Hwa, *Phys. Lett.* **201B** (1988) 165; preprints OITS 385 (1988) and OITS 393 (1988).
- 12) K. Sengupta et al., *Phys. Lett.* **213B** (1988) 548.
- 13) A. Bamberger et al., *Phys. Lett.* **203B** (1988) 320.
- 14) E.S. Pshenin and V.G. Voinov, *Z. Phys.* **A328** (1987) 363.
- 15) P.B. Price et al., *Phys. Rev. Lett.* **61** (1988) 2193.
- 16) C. Brechtman and W. Heinrich, Siegen preprints SI-88-08 and SI-88-16 (1988).