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OVER 30 YEARS OF SUCCESSFUL COLLABORATION BETWEEN **JINR** AND **INFN**

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1 Some history

1.1 Early contacts, the streamer chamber: a thin triggerable target

Two circumstances were instrumental in establishing the collaboration between the Torino INFN group of physicists led by Prof. G. Piragino and the group of the JINR Laboratory of Nuclear Problems (LNP) headed by Prof. Yu. A. Scherbakov: common interests of the two groups in studying pion-nucleus physics with diffusion cloud chambers, and the decision to apply the then recently invented streamer chamber both as a nuclear target and as the actual tracking device.

A discussion of common scientific interests between Prof. G. Piragino and Prof. Yu. A. Scherbakov at an international conference held in Dubna in 1967 resulted in an agreement to combine efforts in joint studies of pion-helium physics using a streamer chamber to be installed in the pion beam of the JINR Laboratory of Nuclear Problems (LNP). The research program was strongly supported both by the JINR Directorate and by the Accademia dei Lincei, that provided financial support at the first stage of collaboration, and, in particular, by G. V. Wataghin, who at the time was Director of the Institute of General Physics of the Turin University. V. P. Dzhelepov, who was LNP Director for many years, was always interested in the research carried out by the collaboration and rendered all possible material and physcological support, also.

The first experiments performed by the TOFRADUB (TOrino–FRAscati–DUBna) collaboration made use of the LNP self-shunted streamer chamber that could be filled with helium, for instance, at pressures up to 4 atm. The chamber served simultaneously as a target and a tracking device, and was actually a perfect vertex detector. The density of helium at atmospheric pressure is only 0.000178 g/cm^3, so even at 4 atm the streamer chamber represents a very thin target, in which slow secondary charged particles produced in pion-helium reactions have quite definite and measureable path ranges (see Table.1).

Table 1: Energies (MeV) of various particles corresponding to given track ranges in ^{4}He at NTP

R (cm)	Particle:	π	p	d	t	^{3}He	α
1.0		0.16	0.17	0.17	0.14	0.25	0.3
5.0		0.27	0.55	0.70	0.75	1.70	1.8
10.0	(He)	0.40	0.85	1.20	1.30	2.90	3.3
	(Ne)	1.40	3.40	4.20	5.50	11.10	12.9
20.0		0.57	1.30	1.70	1.90	4.50	5.0

Such low density, together with the streamer chamber being a triggerable particle track detector, actually make it a unique device for studying nuclear reactions involving the production of low-energy secondary charged particles.

1.2 The 1970-ies, $\pi^{\pm}$–helium interactions

In the seventies a wide range of elastic and inelastic pion-helium reactions was investigated using the LNP self-shunted streamer chamber filled with helium isotopes at pressures up to 5 atm.

The first reactions studied by the collaboration were elastic pion scattering on ^{3}He and ^{4}He [1] (Fig.1, Fig.2, Fig.3)

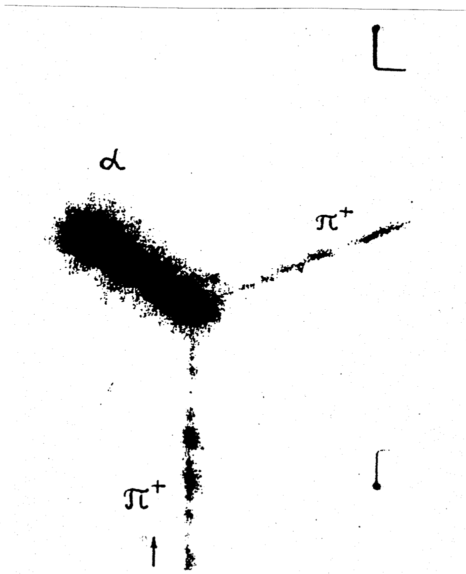

Fig. 1. Typical picture of π-He elastic scattering event.

and most of the existing data on ^{3}He and ^{4}He are still the data obtained in our previous experiments at the JINR phasotron using the high-pressure helium self-shunted streamer chamber.

Since the streamer chamber was operated without magnetic analysis, the information on the recoil helium nucleus (outgoing recoil angle, track range of stopping recoil nucleus) was decisive in identifying elastic scattering events. Although the statistics provided by the streamer chamber is lower, by an order of magnitude, than in the case of modern fast electronic detectors, the advantage presented by the possibility of measuring very low energies of secondary particles is quite evident. The curves in Figs. 2 and 3 were obtained with optical-model calculations using potentials of the Kisslinger and Laplacian forms modified by Mach [2] taking into account the Fermi motion of the nucleons in the nucleus. A rather good agreement can be seen between the experimental data and the theoretical previsions.

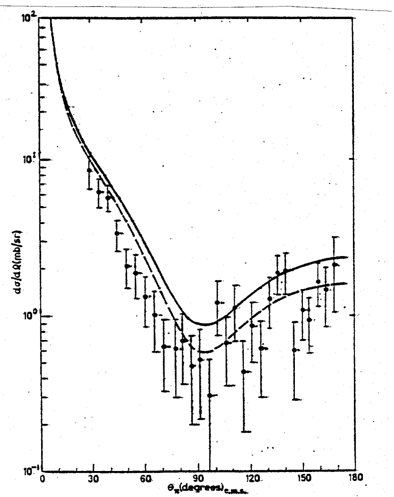

Fig. 2. (π^-,^{3}He) elastic scattering differential cross-section at 68 MeV. The full-line and the dashed-line curves show the optical-model previsions for Kisslinger and Laplacian modified potentials [2], respectively.

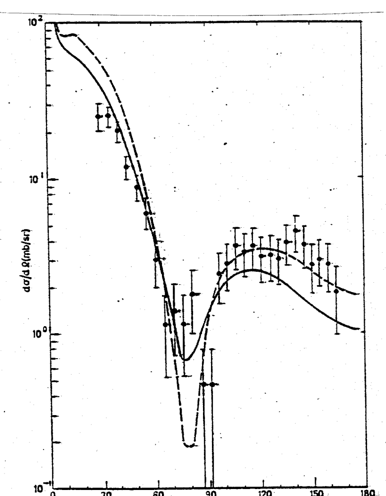

Fig. 3. (π^+,^{4}He) elastic scattering differential cross-section at 120 MeV. The full-line and the dashed-line curves show the optical-model previsions for Kisslinger and Laplacian modified potentials [2], respectively.

Of the results obtained on elastic pion-nucleus scattering we would like to point out the revelation of clustering effects [3]; in this work, excitation functions of differential cross-sections in pion-nucleus scattering at intermediate energies were derived by fitting in the c.m.s with Legendre polynomials all the existing data on ^{1}H, ^{2}H, ^{3}He, ^{4}He, ^{12}C, and ^{16}O. The spectra were deduced by calculating the maximum-likelihood Lorentz lines applying the Monte Carlo method. Among the main features, a resonant behaviour was found of the excitation functions at energies much lower than the free Δ-resonance position (Fig. 4).

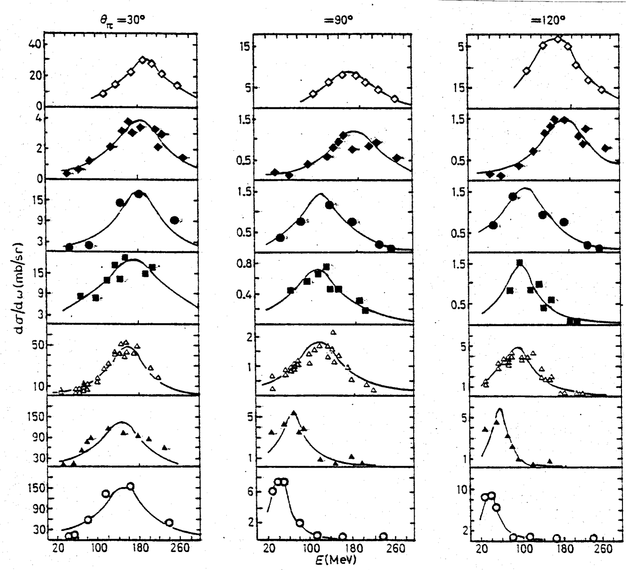

Fig. 4. Excitation functions of differential elastic cross-sections of $\pi^{\pm}$ on proton and light nuclei at 30°, 90°, and 120°. Symbols: ◇ (π^+,p), ◇ (π^-,p), • ($\pi^{\pm}$,^{2}H), ⊔ (π^-,^{3}He), △ ($\pi^{\pm}$,^{4}He), △ ($\pi^{\pm}$,^{12}C), ○ (π^+,^{16}O). They represent the best-fit values obtained at the energies where differential cross-section data are available. The solid curves are Lorentz lines.

The shift was seen to be angle dependent and A-dependent. The possible explanation of the downward energy shift was based on the collective isobaric resonance model [4]. Actually, the collective resonance model turns out to be strongly dependent on the model assumptions: for example, on the coupling constants, or on oscillator parameters, or on the size of the configuration space etc. So, obviously, more experimental data are required to clarify the physics underlying the behaviour of the excitation functions of differential cross-sections. Such data should, probably, include invariant mass distributions for various combinations of secondary particles produced in inelastic nuclear reactions and based on a complete analysis of the reaction kinematics.

A thorough investigation was also carried out by the INFN–JINR collaboration of various inelastic pion interactions with ^{3}He and ^{4}He, such as knock-out reactions, pion absorption etc., at different pion energies (between 68 MeV and 208 MeV) [5]. Thus, the $(\pi^\pm p^3H)$ proton knock-out reactions mechanism were shown to be predominantly quasi-free (πp) scattering with Δ-resonance excitation. The ratio between the $(\pi^+ p^3H)$ and $(\pi^- p^3H)$ cross-section values indicated the influence of nuclear field effects. The Δ-resonance was produced, also, in the $(\pi^\pm 2p2n)$ reactions. The (3pn) absorption cross-section was shown to confirm the hypothesis that the absorption of positivie pions on ^{4}He is predominantly due to a quasi-deuteron. But, for more accurate revelation of the physics of such reactions, it is obviously necessary to perform analysis based on a complete knowledge of the reaction kinematics. For this purpose, one, naturally, requires momentum analysis with a magnetic field.

Besides elastic scattering, one more $(\pi^{+4}He)$ reaction permits completely unambiguous identification: double charge exchange (DCX) in which a negative pion and four protons are produced. So, the measurements of the pion DCX cross-section in ^{4}He performed in 1974 [6] and 1976 [7] seem to have yielded the first indication of an enhancement of the cross-section of $\pi^+ + {}^4He \rightarrow \pi^- + 4p$ in the region of 100 MeV. In Fig. 5 a picture of a pion DCX event in the self-shunted streamer chamber is presented. The four protons and the two pions (incident and outgoing) clearly differ in ionization.

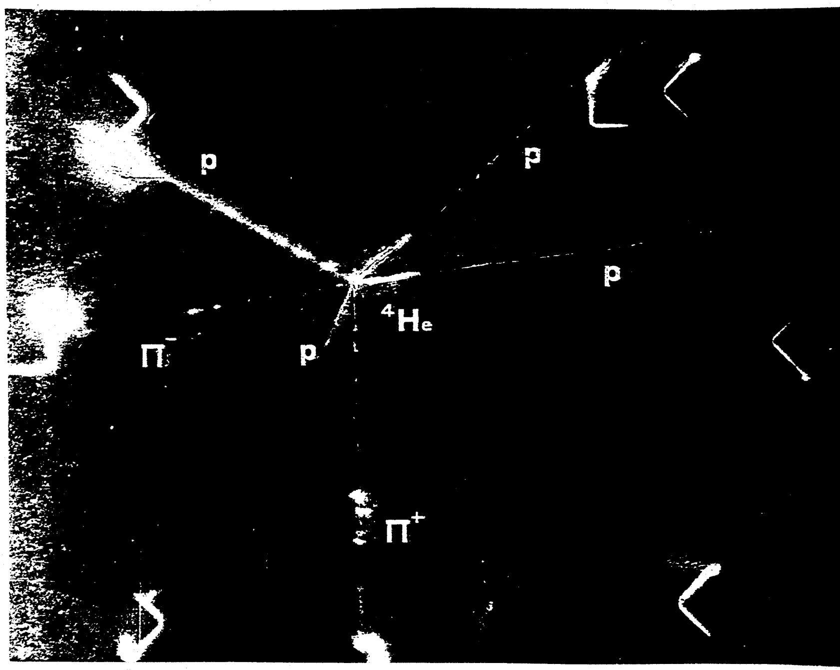

Fig. 5. $\pi^+ + {}^4\text{He} \rightarrow \pi^- + 4\text{p}$ DCX event in self-shunted streamer chamber

In Fig. 6 we present the ^{4}He(π^+, π^-) cross-sections measured at TRIUMF with the CHAOS spectrometer [8].

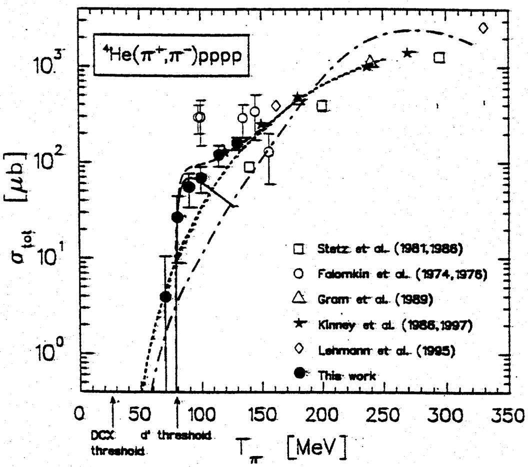

Fig. 6. ^{4}He(π^+, π^-) total cross sections. The dot-dashed curve shows results from the Gibbs-Rebka model, the dotted curve represents the MC model, the full curve the d' mechanism and the dashed curve the incoherent sum of the MC model and the d' mechanism.

The plot also shows cross-sections obtained by other groups, including the INFN–JINR collaboration. Could such behaviour of the DCX cross-section be somehow related to the behaviour of the excitation function of differential cross-sections in pion-nucleus scattering at intermediate energies revealed in ref. [3]? A complete analysis of the kinematics involving determination of the various possible invariant mass distributions might provide an answer. We shall raise this issue again, when dealing with future plans.

1.3 The 1980-ies, antiproton physics at CERN

The next decade saw the self-shunted streamer chamber technique applied in a study of antiproton annihilation in helium isotopes and neon carried out at the LEAR facility of CERN.

We shall not go into details of the extensive work performed by our collaboration at CERN, but only mention three results that underline the advantages presented by the self-shunted streamer chamber filled with helium or neon and used simultaneously as a target and a track detector.

One of the first works [9] carried out by the INFN–JINR collaboration at CERN fully exploited the unique features of the streamer chamber. Actually, we were able to impose a restriction on the amount of antimatter in the early Universe (at times $t \geq 10^3\ s$):

$$R \leq (1.03 \pm 0.70) \cdot 10^{-3}$$

(the error includes the uncertainties in the light-element abundances).

The point is the following. Today we can observe only the products of annihilation of the antimatter that could have existed in the Universe before $t \approx 10^3\ s$. So, to estimate the possible amount of antimatter that remained in the early Universe one must measure the cross-sections for the different reaction channels in the $\bar{p}^4$He interaction and compare such data with the present abundances of ^{2}H, ^{3}He, and ^{4}He. Reactions involving the production of ^{3}He were readily identified in the streamer chamber, since of all the possible annihilation reactions only these involve an even number of charged particles in the final state. Applying this very clear signature, we determined the ^{3}He production cross-section to be $\sigma_{^3He} = (35.7 \pm 2.7)$ mb. This value together with the observed mass abundances of ^{3}He and ^{4}He [10] ($X_{^3He} = (4.2 \pm 2.8) \cdot 10^{-5}$, $X_{^4He} = (0.23 \pm 0.02)$) yielded the above-quoted value of R.

Another result achieved with the streamer chamber was the measurement [11] of the $\bar{p}^4$He annihilation cross section averaged over the 40–50 MeV/c interval, which is the lowest momentum at which measurements of antiproton annihilation in flight have been performed. The beam momentum at the entrance of the chamber was adjusted so as to make the antiprotons stop in a central fiducial region of the sensitive volume (± 22.5 cm around the center of the chamber), where the detection efficiency was close to 100% (Fig. 7). Since the entire track of an interacting proton was seen, its change in curvature (i.e. in antiproton momentum) could be traced down to the interaction (or stopping) point, so the antiproton's energy was determined at the very interaction point.

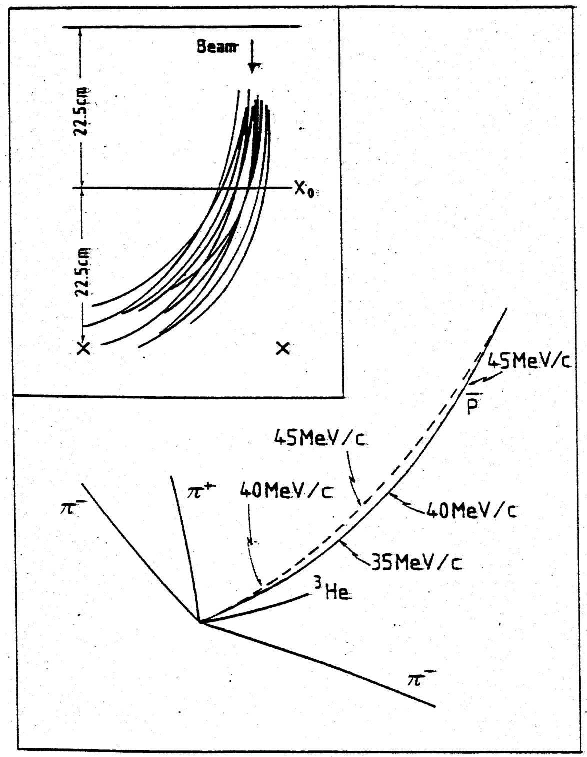

Fig. 7. The inset shows a sample of projected stopping tracks. The crosses are fiducial marks. The main figure shows a schematic drawing of the projection of a true annihilation event at rest (full lines). The curvature of the antiproton track is compared with that of a reference track which in its last point corresponds to a momentum of 35 MeV/c (dashed line). The arrows indicate the points around which the momentum on the tracks is 35, 40 and 45 MeV/c.

As usual for other nuclei, we parametrized our measured antiproton-helium annihilation cross-sections according to the equation $\sigma(p) = A + B/p$. We fit the above equation to ^{4}He our earlier data between 200 and 600 MeV/c [12] and found A=135.6±11.4 mb and B=49.3±4.3 mb GeV/c. The measured value of σ at 45 MeV/c was compatible with the best fit line of our data at higher momenta. So, within the errors, the cross section seems to behave as $1/p$ around 45 MeV/c, also (see Fig.8).

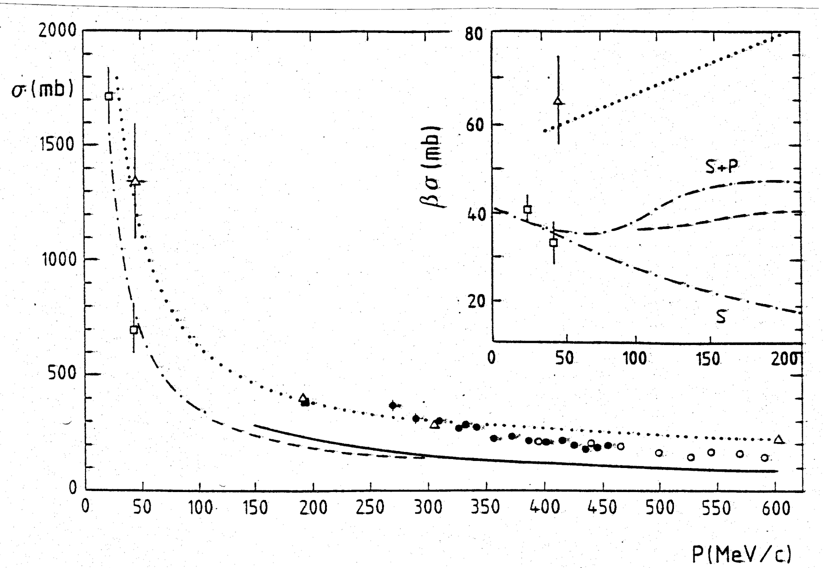

Fig. 8. This figure (ref. [11] and references therein) shows the annihilation cross section for different nuclei. $\bar{p}^4$He: (△) from refs. [12] and [11] (for 45 MeV/c). The dotted line comes from a best fit procedure on the data above 200 MeV/c.

Finally, a few words concerning low-energy antiproton-neon interaction. Fig. 9. shows the behaviour of the cross-section versus the multiplicity M measured for ($\bar{p}$Ne) inelastic events occurring in the streamer chamber volume at different momenta [13].

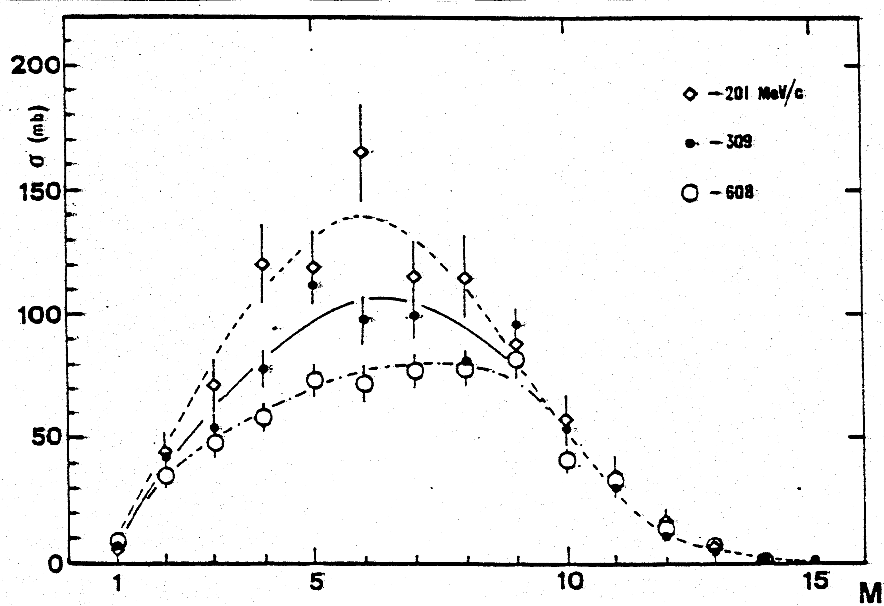

Fig. 9. Charged-prong multiplicity cross-sections for $\bar{p}$Ne inelastic events.

Two regions can be distinguished: the first one, where the cross-sections increase as the $\bar{p}$ momentum decreases, and the second (M $\geq$ 9), where the interaction probability is independent of the $\bar{p}$ kinetic energy. The total percentage of these high multiplicity events increases with the $\bar{p}$ momentum, suggesting that these events result from $\bar{p}$ annihilations inside the nucleus, where the nuclear density is approximately constant (at these momenta the kinetic energy is negligible as compared with the annihilation energy). The average multiplicity of these events is nearly constant. A similar behaviour (see Fig. 10) was found, also, for the multiplicity distributions of ($\bar{p}$,Ag/Br) interactions [14]. Like in the case of Ne, the high multiplicity tail increases with the $\bar{p}$ momentum, suggesting that these events with constant average multiplicity are produced by $\bar{p}$ annihilations deep inside the nuclei [14].

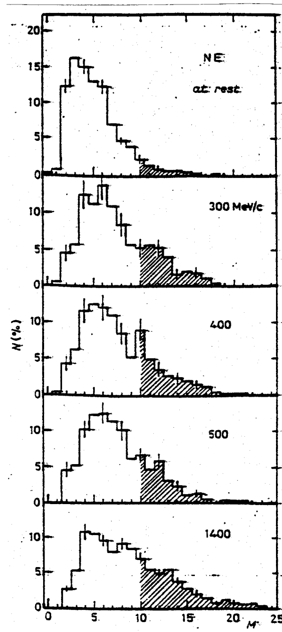

Fig. 10. Charged-prong multiplicity of $\bar{p}$ reaction events in nuclear emulsion. The high-multiplicity tail ($M10$, hatched area) increases with the $\bar{p}$ energy. The data at 1.4 GeV/c are from ref. [15].

To conclude, our experience of work with the self-shunted streamer chamber in pion and antiproton beams seems to indicate that nuclear matter behaves not only like a set of individual nucleons, but rather like spread-out nuclear matter, giving rise to collective resonance-like signatures or to interactions occurring deep inside the nucleus. In studying such behaviour we lacked the possibility of studying invariant mass distributions, since at the beginning of such research the chamber was operated without any magnetic analysis, and in the case of antiprotons a complete kinematical analysis was difficult, owing to the high multiplicities of secondaries, including neutrals, that had to be dealt with. A streamer chamber placed in a magnetic field and allowing measurement of secondary particle energies below 1 meV is a perfect device for studying nuclear reactions involving the production of a limited number of secondary particles, providing for a complete kinematical analysis.

2 Experiment DUBTO

At present the INFN–JINR collaboration (now termed **DUBTO**) has completed construction of the experimental setup **STREAMER**: a spectrometer (a self–shunted streamer chamber in a magnetic field, equipped with two CCD videocameras) developed for studying pion interactions with light nuclei at the JINR phasotron. The **DUBTO** collaboration is, thus, reviving the streamer chamber technique and modernizing data acquisition.

2.1 State of affairs; experimental setup STREAMER

Although streamer chambers did contribute to studies in particle physics in the seventies and eighties, they seem to have lost their attractiveness in the times of very fast gas-discharge detectors, such as MWPCs, that are applied in most modern high-energy experiments and provide for very high measurement statistics. But we have seen that a streamer chamber can really play a significant role: when the filling gas (at 1 atm) serves as a low-density target, and the chamber is used simultaneously as a triggerable vertex detector and the tracking device. Its memory time of $\sim 1\,\mu$s permits dealing with charged particle beam intensities up to $10^6\,\mathrm{s}^{-1}$.

The development of particle detectors in high energy and nuclear physics has resulted in the creation of a broad spectrum of track detectors mainly based on discharge phenomena in gases. MultiWire Proportional Chambers have become the most widely used track detectors in particle physics. They combine excellent time and space resolution together with extremely high statistics.

However, it seems no device can be totally universal. The extraordinary parameters exhibited by MWPC (and other gas-discharge detectors, as well) can be achieved only if the gas discharge develops in a special gas mixture, meaning that the actual gas volume of a MWPC must be separated from the target volume, within which the nuclear reaction of interest takes place, since, usually, the target is either a solid, or a liquid, or a light gas (helium, for instance) allowing unambiguous interpretation of the measured nuclear events. Thus, the walls of the detector and of the target itself do not permit slow secondary particles or, as a matter of fact, slow incident beam particles to enter the detector volume. For this reason, no present-day particle detector, with the exception of the streamer chamber, can be used for measuring the kinematics of nuclear reactions in which several slow charged particles, say, protons with energies below ≈20 MeV, take part. Thus, an entire range of energies between ∼1 MeV and 20 MeV is totally lost from the point of view of complete kinematical analysis.

Actually, only the streamer chamber makes possible a complete kinematical analysis of nuclear reactions involving the production of low-energy secondaries, such as protons with energies down to 0.5 MeV.

To apprehend the expedience of reviving the streamer chamber technique, one can, once again, take a look at the range-energy Table 1 for various charged particles in helium, which, like other inert gases, is a typical filling gas for the self-shunted streamer chamber. From Table 1 one can see that the range of a 1 MeV proton coming to a stop in helium exceeds 10 cm and is quite measurable; an α-particle with an energy of about 3.5 MeV has the same range.

The self-shunted streamer chamber technique [21, 22, 23, 24, 25] developed at the end of the 60-s was applied by the JINR–INFN collaboration in studies of pion-helium [18, 31, 32] and antiproton-nucleus [13, 26, 27, 33, 34, 28, 29, 30] interactions. Particle tracks in a self-shunted streamer chamber are extremely luminous and make possible the utilization of conventional photography for obtaining pictures of nuclear reaction events (see Figs. 5: π^+ DCX in helium without magnetic field, 11: $\bar{p}$Ne annihilation in magnetic field).

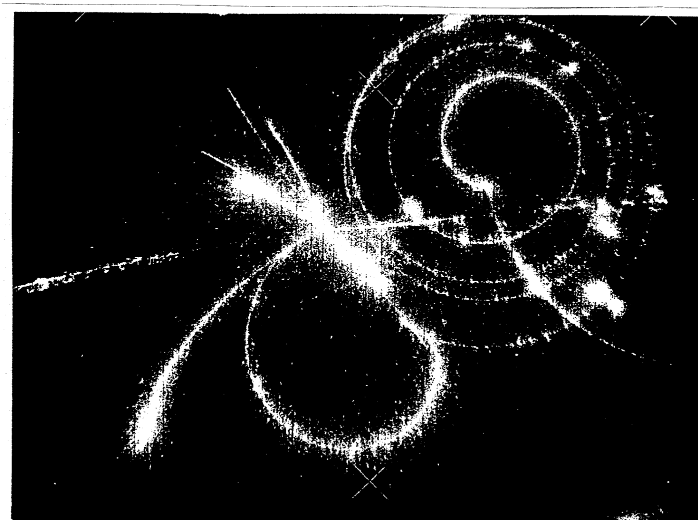

Fig. 11. ($\bar{p}^{20}$Ne) reaction in magnetic field: CERN experiment PS-179.

An outline of the experimental setup mounted in the experimental hall of the JINR Laboratory of Nuclear Problems is shown in Fig. 12.

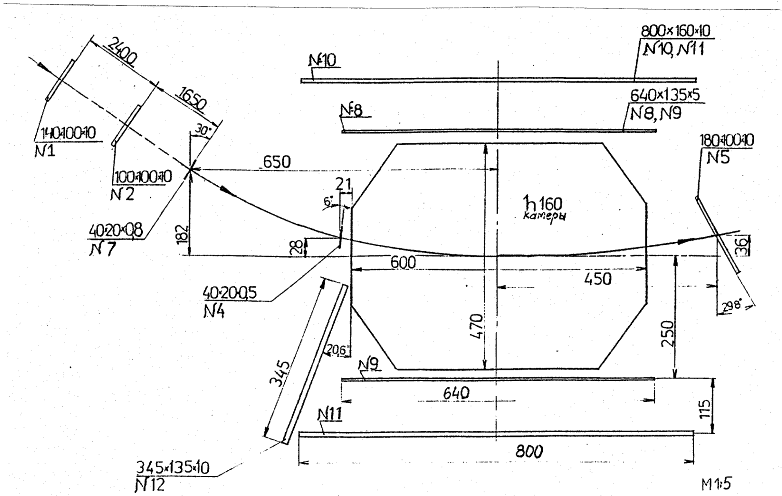

Fig. 12. Layout of experimental setup **STREAMER**:

STREAMER represents a magnetic spectrometer comprising a self–shunted streamer chamber (SSC) [21, 22, 23, 24, 25] that is filled with the working gas (inert gases and small admixtures for regulating the size of the luminous centers along tracks) at atmospheric pressure and is placed in an analysing electromagnet (MC-4A); two SenSys Photometrics CCD videocameras (VC) serve for recording two stereo-views of nuclear events occurring in the chamber volume. The self-shunted streamer chamber is exposed to the pion beam of the JINR phasotron, and a set of scintilation counters ($C_{1\div 7}$) provides the trigger for the high-voltage pulse generator (HVPG). The intensity of the pion beam passing through the chamber is $10^4 - 5 \times 10^4\, s^{-1}$ at 195 MeV/c, and is to be enhanced up to $10^6\, s^{-1}$.

2.1.1 The self-shunted streamer chamber

The self-shunted streamer chamber technique has been described in detail elsewhere [21, 22, 23, 24, 25]. A detailed investigation [31, 32] of pion-nucleus interactions in helium at JINR (1965-1980), as well as studies [33, 34, 28, 29, 30] of antiproton-nucleus (helium, neon) interactions at the LEAR facility of CERN (experiment PS-179) have been carried out with the self-shunted streamer chamber technique during the period from 1981 to 1993. This technique permits obtaining well-localized ($\sim 2\,mm$ along the electric field) and highly luminous (by two orders of magnitude more than in conventional streamer chambers) charged particle tracks by addition to the filling gas of small amounts ($\sim 0.01\%$) of complex molecules (water vapour, hydrocarbons, etc.).

The streamer chamber, with a $470\times600\times160\,mm^3$ inner volume, is enclosed between lateral steel walls and the poles of the analyzing magnet (Fig.13). A 20 mm thick lower lucite glass plate separates the chamber volume from the high voltage electrode and is immersed, together with the electrode, in an insulating oil to avoid electric discharges to the surrounding steel walls and the metal parts of the magnet. The upper lucite glass of the chamber, through which events occurring in the fiducial volume of the chamber are photographed, is $15\,mm$ thick. The lateral walls of the chamber are made of 200 μm thick mylar (with a density of 0.94 g/cm^3). The two beam windows for the entrance (⌀ 50 mm) and exit (15×41 cm^2) of the beam pions are made of 50 μm thick mylar, so as to have as little matter as possible in the way of the incident pions.

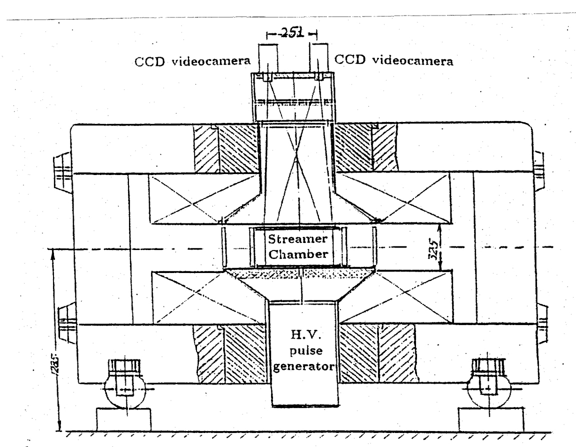

Fig. 13. Streamer chamber inside magnet MC–4A.

2.1.2 The electromagnet

We use the $MC-4A$ magnet designed at the JINR Laboratory of Nuclear Problems. The gap between the poles of the magnet is $330\,mm$, the diameter of the hole in the pole is $462\,mm$. the magnetic field at the centre of the gap amounts to $0.690 \pm 0.005\,T$, for a current of 800 A. The field drops with a rate that varies from $0.0001\,T/cm$ at the centre to $0.003\,T/cm$ at the edge of the coil. For a $470 \times 600 \times 160\,mm^3$ chamber fiducial volume the drop in the magnetic field at the edges of the chamber does not exceed 1.5%. The variation of the field within the chamber volume along the vertical direction amounts to approximately 1%.

2.1.3 The gas filling

The filling gas of the streamer chamber serves both as the target and as the detecting medium. The chamber is flushed with the chosen target gas mixture (typically: ^4He, CH_4 - 0.1%, H_2O vapour - 0.1%, air - 0.05%) yielding localized bright particle tracks. The gas pressure in the chamber exceeds atmospheric pressure by ~15 mm Hg.

2.1.4 The high-voltage pulse generator (HVPG)

For operation of the streamer chamber electric pulses are applied that are few hundreds of kV high; no special shaping of the high-voltage pulse applied to the electrodes of the chamber is required, and the shape of the pulse is determined by the electric discharge in the gas volume [21].

In our case, the negative pulse applied to the lower electrode of the chamber is ~200 kV high. We have constructed a 35-stage HVPG quite similar to the ones described in our previous publications [23, 25]. For charging the capacitor sections of the HVPG two standard $2.5\,KW$ industrial voltage supplies are used, which makes possible operation of the pulse generator with a repetition rate of $10\,Hz$. The delay of the output high-voltage pulse of the HVPG relative to the trigger pulse does not exceed $0.23\,\mu s$.

2.1.5 The trigger system

The trigger of the HVPG is also similar to the one described in our previous ref. [25]: it transforms the pulse from the electronic logic into the pulse required to start the generator.

The trigger system (see Fig. 12) involves a set of scintillation counters that provide pulses for the electronic logic.

Particles entering the chamber are detected by two thin entrance scintillation counters of which the first is $5\,mm$ thick and the second – $1\,mm$. The second counter has to be thin so as to reduce the background triggers due to interactions of the pions with the scintillator of the counter. The total thickness of the the gas (^4He) in the chamber amounts to $58\,mg/cm^2$, while the effective thickness of the thin counter is $106\,mg/cm^2$.

Upstream, immediately near the chamber, there is a counter of dimensions $100 \times 70 \times 5\,mm^3$. For monitoring the amount of pions passing through the chamber, this counter is operated in coincidence with the two counters situated in front of the chamber. When this counter is operated in anticoincidence with the two counters in front of the chamber, pions are detected that undergo interaction in the gas volume of the chamber.

The scintillation hodoscope also includes lateral counters for identifying secondary protons passing through the lateral walls of the chamber volume.

The lateral scintillation counters are located inside the shielding vessel in the immediate vicinity of the lateral walls of the streamer chamber itself. Since the walls of the chamber are made of mylar $0.2\,mm$ thick $6\,MeV$ pions and $18\,MeV$ protons will be capable of passing through the chamber walls.

The lateral scintillation counters of the triggering system are $5\,mm$ thick, the first counter is $650\,mm$ long and the second $890\,mm$. If only the first internal lateral counters are used for the trigger, then the lower threshold for detecting the pions is $10\,MeV$ and $23\,MeV$ for protons (taking into account the losses in the material covering the scintillators for shutting out light). If the second set of lateral counters participates in the trigger, the detection threshold for pions is $20\,MeV$, and $30\,MeV$ for protons.

2.1.6 Photoregistration: the CCD videocameras

All videoregistration of nuclear events by experimental devices, permitting literal visualization of such events, such as streamer chambers, was hitherto performed with the aid of photographic techniques. Such techniques involve mechanical apparatuses requiring maintenance, and time-consuming development and actual measurement of the photographs of nuclear events for further image processing.

At present, highly sensitive sensors based on charge-coupled devices (CCD) are available on the market, which, together with the rapid development of computer technology, make possible immediate filmless registration of digitized images of nuclear events and further rapid data handling. The following characteristics of such nuclear events occurring in the self-shunted streamer chamber have to be taken into account:

- their impulse nature requiring synchronization of the videosystem and the external pulse triggering the streamer system;
- the large dynamic luminosity range ($\leq 10^4$) of the tracks;
- the high and irregular nature of background luminosity.

The system realized by the DUBTO collaboration utilizes two high-resolution digital CCD videocameras SenSys–1400 of the Photometrics Ltd (3440 East Britannia Drive, Tucson, Arizona 85706, tel: 520/889–9933, fax: 520/295–0299).

The SenSys–1400 videocamera is based on a cooled CCD matrix with 1317×1035 photosensitive cells (pixels) of dimensions $6.8\times6.8\,\mu m^2$. The SenSys CCDs are scientific-grade, exhibit good resolution, low noise, and linearity over the dynamic range and are used in scientific applications. The camera precision electronics, that converts the analog videosignal produced by the CCD into a digital signal, permits obtaining a 12-bit dynamic range (up to 4096 gray levels) for a noise level of $\sim$17e rms and a quantum efficiency of the photosensor amounting to $\sim$40%.

The entire system of registration, accumulation, and processing of images comprises two digital SenSys videosensors connected to a Pentium II (266 MHz), the software for processing and analysing images (Image–Pro Plus software for Windows), and storage devices for temporary and long-term recording of images on a 4,5 Gb HD and on 1 Gb removable hard disks Jaz.

A user's interface "DUBTO Monitor" has been developed that makes possible totally automatic control of the operation of cameras in the mode of image accumulation and storage, and of creation of a database of recorded events.

Such an accumulation system permits the registration and storage on removable disks Jaz of up to 2 per second digitized images of pictures consisting of 650×440 pixels, which provides for the required resolution of 1 mm in the streamer chamber space.

Preliminary data processing is also performed on–line and includes scaling, storage, compression, and the creation ofa database of images.

2.2 Research to be performed

The physical motivation for using the streamer chamber technique and, subsequently, the future plans of the **DUBTO** collaboration are naturally based on its technical characteristics.

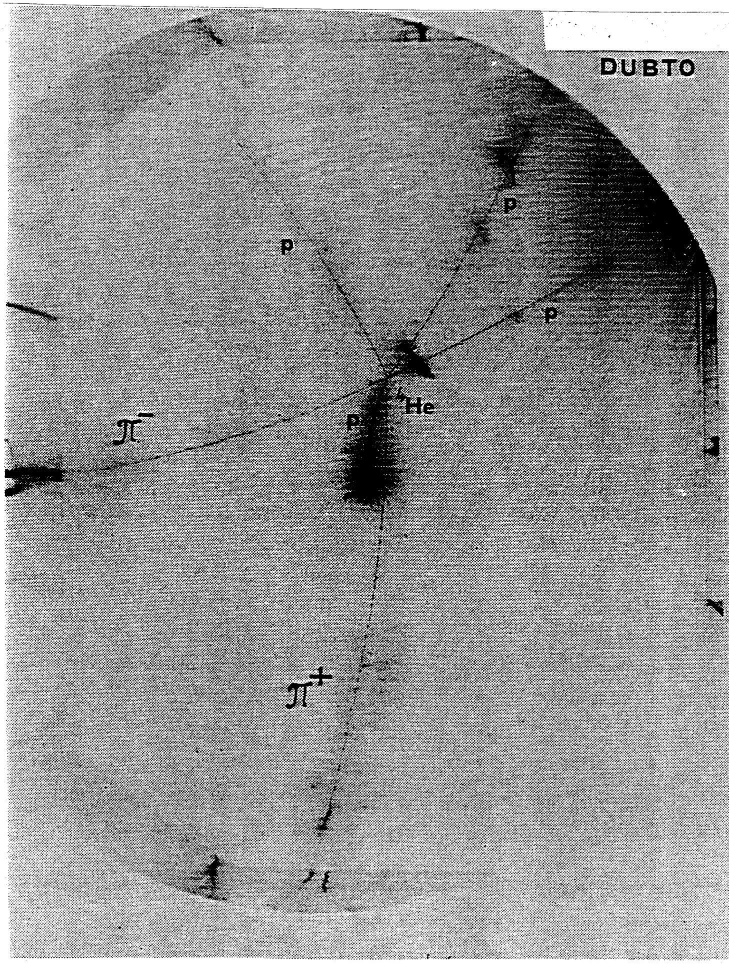

Fig. 14. DCX of positive pion on ^{4}He nucleus.

Indeed, there exist several problems (at least, in low-energy pion-nucleus physics) that can be resolved, only if the kinematics of slow charged particles is completely measurable. The following examples seem to illustrate this point quite clearly. Actually the **DUBTO** collaboration intends to perform such studies, which can be seen as milestones in the future research program with the **STREAMER** spectrometer:

- **Clarification of the collective resonance behaviour exhibited in pion-helium scattering. Search for exotic responses in inelastic pion-helium interactions and for the d' Dibaryon in Pionic Double Charge Exchange on Helium.** As pointed out above, the behaviour of pion elastic scattering cross-sections on different nuclei seem to point to the nuclear matter being uniform inside the nucleus. For understanding this phenomenon, it would be expedient to determine various invariant mass distributions for the secondary particles produced in pion-helium inelastic scattering. This can be done with our technique, since a complete kinematical analysis of the reaction products is possible, owing to the low target density and the presence of the magnetic field.

  An interesting example of such inelastic scattering, in which a resonance (the d') is produced is pion double charge exchange (DCX: see Fig. 14) on the ^{4}He nucleus. The most recent measurement [35] of the energy dependence of the $^4\mathbf{He}(\pi^+,\pi^-)$ total cross section at TRIUMF shows a steep rise occurring at the d' production threshold (see Fig. 6). However, a proof of the existence of the d' should involve measurement of the πNN invariant mass, for which a complete analysis of the reaction kinematics is necessary. Since any FSI between the two nucleons in the πNN system would imply the pion recoiling against both nucleons, the energy distribution of the nucleons produced in DCX on helium via a πNN coupling would be shifted toward low energies. Actually (in the πNN cms), most of the nucleons would have energies below $10\,MeV$. In the case of positive pions undergoing DCX on helium, the streamer chamber is an ideal device for implementing a comprehensive analysis of the DCX reaction kinematics.

- **Determination of the pion–nucleon sigma term $\Sigma_{\pi p}$.** Determination of the pion–nucleon sigma term $\Sigma_{\pi p}$ could provide information on chiral symmetry breaking in strong interactions and, also, on the possible strange quark content of a nucleon. Actually, the problem experimentally reduces to the measurement of the isoscalar scattering lengths in S– and P–waves low-energy $\pi\mathbf{p}$ scattering. The hydrogen self-shunted streamer chamber equipped with a CCD videocamera and developed at PINP (Gatchina, Russia) [16] is an ideal device for implementing such measurements, in which the kinematical parameters of both the incident pions and slow recoiling protons would be determined.

Moreover, the streamer chamber could also be applied in studies of low-energy kaon–nucleon and kaon–helium eleastic scattering.

- **Measurements of pion interaction sections on ^{4}He.** An unambiguous and illustrative justification for applying the streamer chamber technique is presented by comparison (Table 2) of the total pion absorption cross sections [19] and the total SCX cross sections [20] on ^{4}He measured at PSI using the LADS spectrometer [36] with those measured at the same incident pion energies using a diffusion cloud chamber [17] and a self-shunted streamer chamber [18].

Table 2: Cross sections (mb) of π^+-^{4}He reaction

E_π, MeV	SCX ($\pi^0 p\,^3$He)	$3pn$	$3pn$ + SCX	SCX/ (SCX+NCX),%	device	refs.
120±15	23±7	11±4	34	7.2	diff.ch.	[17]
120	-	≥3.0	-	-	str.ch.	[18]
118	18.0±2.2	52±4	70	18	LADS	[19, 20]
145±10	28±6	12±4	40	6	diff.ch.	[17]
165±10	47±10	11±4	58	5.4	diff.ch.	[17]
135	-	≥7.1	-	-	str.ch.	[18]
156	-	≥3.3	-	-	str.ch.	[18]
162	34.2±3.7	51±5	85.2	23	LADS	[19, 20]
239	33.1±2.9	27±2	60.1	26	LADS	[19, 20]

The absorption cross sections obtained with LADS [19] seem to be the sums of two processes: single charge exchange and actual absorption, since the two processes most likely could not always be distinguished in LADS, if the proton energy did not exceed 20 MeV and taking into account the simultaneous detection efficiency of two photons (0.3×0.3=0.09). The absorption cross sections based on the low statistics obtained using the diffusion cloud chamber could be determined, since the low-density target together with the magnetic field made possible an analysis of the kinematics and, thus, separation of the two channels. The values obtained with the streamer chamber are lower limits; they also seem to point to lower values, than those of LADS. From Table 2. one can see the significant discrepancy between the fractions of SCX in the pion inelastic total cross sections on ^{4}He determined by different techniques. Such discrepancy might be due to the absorption cross sections determined with LADS being overestimated. We believe it necessary, if possible, to perform a complete kinematical analysis of the reactions for reliable identification of the actual reaction channel.

With the complete kinematical analysis in mind, a self-shunted streamer chamber in a magnetic field seems quite an appropriate device for studying a wide range of pion interactions with light nuclei. The overall efficiency of data acquisition and analysis of results will be significantly enhanced by utilization of modern and sensitive photoregistration devices, such as CCD telecameras, thus eliminating the stage of actual measurement of photographs of nuclear events and further preparation of the images for calculations.

- **Measurement of pion-helium interaction cross-sections at very low pion energies** Such measurements are to be performed precisely like in the case of antiprotons (see above, ref. [11]).

- **Direct measurement of Fermi momentum distribution of spectator nucleons produced in pion-helium inelastic interactions** Such measurements are to be made, since measureable tracks are produced in the streamer chamber starting from proton energies below $\sim$30 MeV/c ($\sim$0.5 MeV), so the low-energy part of the Fermi distribution will be determined.

3 Conclusion: research milestones for the near future

In conclusion we would once more like to stress that the collaboration between JINR and INFN initiated in 1968 has been extremely successful in producing numerous and interesting scientific results in particle and nuclear physics. It has been successful in developing its own technique (the self-shunted streamer chamber) used in its studies and in essentially modernizing this technique.

We shall now also briefly outline the main issues ("milestones") to be affronted by **DUBTO** in the nearest future (up to the year 2002):

1. clarification of discrepancies in $\pi^{\pm}$-absorption;
2. collective resonance behaviour of nuclear matter:
   - determination of invariant mass distributions;
   - search for exotic response in pion-nucleus interactions;
   - search for d'-resonance;
3. direct measurement of low-energy part of Fermi distribution.
4. measurement of pion interaction cross-sections at very low energies;

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Пираджино Г., Понтекорво Д.Б. E15-2000-7
Свыше 30 лет успешного сотрудничества между ОИЯИ и НИЯФ Италии

Представлено краткое описание успешного 30-летнего сотрудничества туринской секции НИЯФ Италии и Лаборатории ядерных проблем ОИЯИ. Полученные результаты обсуждаются вместе с планами на будущее.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2000

Piragino G., Pontecorvo G.B. E15-2000-7
Over 30 Years of Successful Collaboration Between JINR and INFN

A short account of the successful 30-year long collaboration between the INFN section of Turin and the JINR Laboratory of Nuclear Problems is presented. Results obtained are discussed together with future plans.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2000

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