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PERFORMANCE OF A LARGE SCALE MULTILAYER IONIZATION DETECTOR
AND ITS USE FOR MEASUREMENTS OF THE RELATIVISTIC RISE
IN THE MOMENTUM RANGE OF 20-110 GeV/c

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ABSTRACT

The relativistic rise of ionization has been measured with $\pm 3\%$ FWHM resolution at 20, 30, 40, 50, 64, 70, 90 and 110 GeV/c. The measurements were performed during tests of a large 128 layer proportional detector system (EPI) designed for identification of fast secondary particles in connection with the big hydrogen bubble chamber BEBC. Results of linearity tests of the detector, using X-ray sources, are presented. Factors affecting the long term stability of the detector are analysed and the method used for the off-line data treatment is described.

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1. INTRODUCTION

The External Particle Identifier (EPI) is a multilayer gas proportional detector system consisting of 4096 vertical individual counters of $6 \times 6 \text{ cm}^2$ section and about 1 m height, arranged in a matrix 32 cells wide and 128 layers deep. It has been developed at CERN to work in connection with the 3.7 m Big European Bubble Chamber (BEBC). The device allows for identification of fast charged secondary particles emerging from interactions in the bubble chamber. The primary particles are provided by a radio frequency separated hadron beam (S3) designed for full separation of $\pi/K/p$ up to 70 GeV/c.

The ionization of a particle track is measured in the EPI detector by digitizing the pulse height of each hit proportional counter. Final resolution of $\pm 3\%$ FWHM in the ionization is achieved by off-line processing of the 128 independent measurements for each track. The relativistic rise of the ionization in the gas used for the detector (Ar + 5% CH_4 at NTP) enables an effective separation of pions, kaons and protons up to about 70 GeV/c and of pions from protons up to about 100 GeV/c.

The EPI hardware has been described in detail in [1]. Fig. 1 shows assembly of the detector from individual 32 cell double-layer modules. Two meter long printed circuit boards containing all electronic circuits for each detector layer, are connected on the top. Each cell has its amplifier, 8 bit ADC and buffer. The read-out of data towards the on-line computer is performed via a shift register chain and a 16 bit parallel data link, interfaced into a CAMAC DMA channel.

The premixed gas from a battery of bottles is fed first into a distribution manifold (cylinder seen on fig. 1) and then in parallel into 64 detector modules. The exhausts from the top corner of each module have U-shape tubes fitted, acting as syphons. From here the gas flows freely into the tight outer casing. The vessel is closed by a lid with rubber seal. A calibrated exhaust flap valve mounted on the top

maintains a constant overpressure of 2 g/cm^2 inside. The ends of the vessel are provided with double mylar windows for beam entry and exit. The gas flow used is typically about 5 l/min, the active volume of the detector being about 17 m^3 . The lid contains also a set of heat exchangers for water cooling of the electronics, which dissipates about 1.5 kW. The inner walls of the box and the lid are lined with a layer of expanded plastic thermal insulation.

The first and the last modules in the detector stack have an additional 25 μ thick aluminized Mylar foil stretched at a distance of 11 mm from the external H.T. planes. A negative potential of 100 - 200 V on these foils with respect to the overall H.T. value was sufficient to compensate for loss of gain in the first and last layer caused by the relative electrostatic transparency of the H.T. planes. The electrostatic shielding effect was improved by another set of grounded aluminized mylar foils stretched across the entry and exit windows. Free circulation of the gas is allowed around all foils to prevent any mechanical deformation by pressure gradients.

Fig. 2 shows the installation behind the bubble chamber. The beam axis is at 4 m above ground level. The EPI structure is mounted on a chariot allowing for 3 independent movements necessary for correct alignment at a particular primary beam momentum. There is a possibility to move the box up/down by $\pm 10 \text{ cm}$, to rotate it by ± 10 degrees and to move the assembly on rails by several metres perpendicular to the beam axis, at speeds of typically about 20 cm/min. All movements are done by compressed air motors under local control, because the area is subject to strict hydrogen safety regulations. For the same reason the detector box is pressurized as already mentioned above. The power supplies for the electronics, the local control circuits for the data acquisition and the data transmission circuits are mounted inside a separate smaller box pressurized by nitrogen to 10 g/cm^2 and fixed to the side of the structure which is not visible on fig. 2. Water cooling and forced ventilation are installed inside this box. The total weight of the assembly is about 52 tons, including 16 tons of detectors. The mechanical deformations and reproducibility of

the positions should be below the 1 mm level. A set of fiducial marks welded to the structure is used for exact determination of the actual detector position with respect to BEBC.

MWPC planes will be fixed at the entry and exit windows of the EPI. Each chamber has 3 anode planes at 0° (vertical), $\pm 30^\circ$, and 4 mm wire spacing for the signal wire diameter of 20 μ . Shift register buffers provide for a capacity of $16 \times 0.25 \mu\text{s}$ time slots per wire for the total of 3000 active wires. The choice of the gas mixture is limited to Ar + 5% CH₄ or Ar + CO₂ because of the hydrogen safety restrictions. The MWPC planes are used for reconstruction of particle tracks inside the EPI detecting volume and for connection to the tracks measured on the BEBC pictures. In certain cases the MWPC data could be used to improve the precision of momentum measurements inside the bubble chamber.

2. TESTS OF DETECTOR LINEARITY

In applications of gas proportional counters for ionization measurements in the region of the relativistic rise it is extremely important to achieve the best linearity of the detector response. Any space charge saturation effect will considerably reduce the slope of the relativistic rise and consequently the upper limit in momentum at which particle separation is still possible will be reduced. The response of individual detector cells and the limits of the gas amplification factor were determined using radioactive X-ray sources. Table 1 shows a list of sources used for the energy loss calibration. Fig. 3 shows an example of a spectrum of Am²⁴¹ as measured in one of the 6 x 6 cm² cells. Starting from the right the detected peaks are 26.4 keV (γ), 20.8 keV (NpL _{γ}), 17.8 keV (NpL _{β}), 13.9 keV (NpL _{α}) and 11.9 keV (NpL _{ρ}) X-rays. The resolution is comparable with the results obtained using semiconductor detectors, as presented for example in ref. [2]. Superimposed is a β -spectrum of Sr⁹⁰ (0.546 MeV) measured by the same cell. Averaging between Sr⁹⁰ and

Cs¹³⁷ spectra gives an energy loss of about 9 keV in a 6 cm layer as the most probable value (peak) of the distribution. This corresponds to about 1.3 keV/cm of energy loss at the minimum of ionization.

Fig. 4 shows the linearity of the detector response up to 60 keV of the X-ray energy for H.T. values of 2.0, 2.1, 2.2 and 2.3 kV. The small differences of the experimental points from the ideal straight line are caused mainly by the pile-up problems and related difficulties in collimating various X-ray sources of different intensities. The integral non-linearity measured at 20 keV energy loss is undetectable (within $\pm 0.5\%$) up to about 2.15 kV on the detector. At 2.2 kV the non-linearity is $(1.8 \pm 0.5)\%$ and it is rising rapidly to 4.3% at 2.3 kV and to 9.7% at 2.5 kV. The detector response should be verified to at least twice the maximum working range in energy loss, because e.g. cosmic-ray muons traversing vertically the full cell length will deposit about 16 times more ionization than the particles traversing horizontally. Recovery of the electronics to such overload should be fast, without spurious after pulses.

The H.T. value of 2.15 kV was selected as an upper limit for linear response. This is shown on fig. 5 together with the behaviour of the detector resolution (shaded area) as a function of the X-ray energy. The required working range is indicated in terms of minimum ionization and the Fermi plateau level. The upper limit of the range is given by the saturation of the 8-bit ADC at 255, assuming that the most probable value of the distribution of the ionization losses is peaked at 100. This corresponds to a gas amplification factor of about 4×10^3 . The minimum ionizing particle is, therefore, producing on the average about 0.15 pC of charge at the amplifier input. The electron drift velocity in our mixture is, under those conditions, about 4 cm/ μ s according to ref. [3].

Fig. 6 shows the limits for selection of an optimum working point and best resolution as a function of the H.T. for 6 keV and 22 keV energy loss (upper limit imposed by the ADC saturation). At lower H.T. values and for low energy losses the resolution is rapidly reduced by increasing influence of the noise from the detector and electronics.

3. BEAM TESTS

The principal aim of the test runs was to check out the correct functioning of the device and to determine the relativistic rise of ionization for the gas filling used, over the full design momentum range. This is essential as a calibration reference curve for mass identification. The tests of the fully equipped detector were undertaken in the RF separated S3 beam in the West Area. This beam line is about 900 m long from target to BEBC and runs with a very short spill time of 2-4 μ s. Since the final position behind BEBC is not well suited for extended testing due to incompatibilities with the normal running of the chamber for neutrino physics and the hydrogen safety regulations in this area, it was decided to place the EPI in the beam about 100 m upstream of BEBC for all test runs. The beam intensity from the 1 x 2 x 50 mm Be target was reduced to less than one particle per SPS burst by closing down the acceptance collimators. This is necessary, since the time resolution of the detector is comparable to the beam spill time. The 800 m distance between the target and EPI location presented certain problems due to pion decays at lower momenta.

Tests at 50 and 70 GeV/c were performed during the April-May 1977 period. For the other momenta (several periods between June and September 1977) a tagging system consisting of a set of threshold Cerenkov counters and scintillation counter hodoscopes installed in front of BEBC (ref. [4]) was used to cross-check the separation of particles in the design momentum range of EPI and to help in separation at momenta above this range. The overall data taking efficiency was only about 50% caused mainly by the SPS and ejection troubles and power cuts during the Summer thunderstorm period. Typically, about 2-3 days of stable running conditions were required to accumulate a reasonable sample of events at a given momentum.

The EPI detector was aligned so that the beam, which is almost parallel at this point and has a spot size of a few square centimeters, traversed the full detector length of 128 layers through the second slice from the edge. A trigger telescope composed of two 4 x 5 cm² scintillators at the front and back windows provided a data acquisition trigger. In such an

arrangement all beam tracks are straight lines through the same string of 128 cells, so no tedious track reconstruction is necessary and background particles are easily separated. A temporary data link was established between the EPI and the S3 beam control room for data transmission to the on-line computer. This is a dedicated NORD-10 machine with 48 k words of 16-bit core memory, a 10 M byte cartridge disk and a heavy duty 1600 bpi magnetic tape running under the real-time operating system SINTRAN III. Error output and graphic display terminals allow to monitor data acquisition continuously and display events as they are processed. External data input/output is performed via a set of CAMAC modules. For beam tagging and EPI data direct memory access through CAMAC is used. In the latter case the full 4096 bytes of EPI information are read into the computer each SPS cycle.

Fig. 7 shows examples of events taken with increased flux to check the functioning of all cells in the detector volume. The top view of the EPI is presented in the on-line display. Each point represents a hit registered in one of the 4096 $6 \times 6 \text{ cm}^2$ proportional counters. The beam arrives from the right, aligned as mentioned on the second row of cells (slice 2) from the bottom. The final cleaning stage of the beam is unfortunately situated behind the only practical EPI test location, therefore, the background due to scattered slightly off-momentum particles was still rather high, especially when the RF separators were used to keep the π/p ratio within acceptable limits. Nevertheless, in normal running conditions of less than one particle per SPS pulse usually only slice 2 was traversed with very little background to right and left, which was later filtered out easily. Furthermore, the off-momentum particles registered in the EPI did not reach the Cerenkov counters in the tagging system situated behind the next bending magnets and were therefore discarded for analysis on the basis of missing tagging information.

Fig. 8 shows an on-line display of part of the data accumulated with a 20 GeV/c positive unseparated beam containing a mixture of protons and pions. The use of a "mixture" of particles to consecutively measure ionization is essential for calibration, tests and relativistic rise

measurements, since the long-term stability monitoring and corrections for drifts are much more difficult if the measurements are performed by alternatively using protons and then negative pions for fixed time intervals. The histograms on fig. 8 represent uncorrected raw data from the EPI alone. From a sample of 128 ionization values for each event (this is the maximum, in reality there could be 1 or 2 cells not working properly which are not taken into account) the 40% smallest values are taken and their mean plotted. The first peak contains protons, the second positive pions plus some muons and there is a small bump attributed to positrons. Even if using uncorrected data only, the resolution of the detector is such that the double particle peaks of two protons ("simultaneous" in terms of the time resolution comparable to the beam spill), proton + pion, and two pions can be distinguished. Note that the double peaks are at values slightly higher than twice the single peak values. This is explained by the well-known fact that the folding of two asymmetric probability distributions produces a narrower sum distribution, so that the mean of the lowest 40%, in contrast to the overall mean, shows the above effect. Obviously, this has no influence on linearity for single particles.

For a more refined data analysis several corrections have to be taken into account. Systematic differences of response from individual cells are contained within about $\pm 10\%$. This spread could be reduced by adjustment of the individual amplifier gains to below $\pm 3\%$. As shown in ref.[5], this is sufficiently low to be covered by the predominant distribution of ionization losses. For our tests those corrections were applied during the off-line data processing.

Because of the rather impressive dimensions of the detector the long-term stability features must be known in detail. Additional heat exchangers were fitted inside the detector box at the bottom and at both sides. The temperature gradients could be compensated for and a uniform distribution of temperatures inside the detector volume could be established. At least two days of gas flushing at 10-20 l/min are required to achieve relatively stable conditions. This represents three to four times the full change of the detector volume. The parasitic volume inside the pressurized box is

roughly equal to the effective detecting volume. To stabilize the electrostatic field distribution after the first switching on of the H.T. or after a complete power break, several hours are needed. When the gas was stopped after a few weeks of running, the degradation of the resolution was rather slow so that one month later the device was usable almost immediately.

When the gas and the H.T. are stable, the variations of response caused by the atmospheric pressure changes become predominant. A set of Cd^{109} , Fe^{55} and Sr^{90} collimated radioactive sources was mounted inside the vessel near the corners of the detector matrix and these dedicated edge cells were used as monitors. The signals were amplified and connected to a set of 10-bit resolution ADC's and corresponding 1024 channel (16-bit capacity) multichannel analysers interfaced to the on-line computer. The source spectra were accumulated independently during, typically, about 15 minutes to 1 hour intervals. Muon background from slow ejection counter beams was gated out. Iterative smoothing procedures were applied after reading in of the data to determine the peak positions for the X-ray sources and the point half way up the left steep part of the spectrum in the case of Sr^{90} . The behaviour of the monitors was checked by comparison with the subsamples of the data. This is shown on fig. 9 for the 64 GeV/c run, together with the atmospheric pressure variations registered during the same period. The average of the monitors is in good agreement with the pion peak data in spite of different accumulation intervals and two complete power failures during the run.

The ratio between the amplitude of the measured variation in the ionization value and the corresponding atmospheric pressure change was $-(6.5 \pm 0.5)\%$ for + 1% increase in the pressure. Some hysteresis in the monitor's characteristics was detected during periods of rapid, large up/down pressure changes. It is not easy to monitor and conserve the absolute energy loss scale over extended periods without periodic checks using known-momentum particles. Clearly, very high precision and stability is required for the monitor's electronics. One big problem of reliable monitoring still remains to be solved: the possible systematic difference

between the data from the monitors reflecting the behaviour of a single individual cell in a given position mostly at the periphery of the detector and an "average" response of many cells traverses by the detected particles.

4. DATA ANALYSIS AND RESULTS

The accumulated data on the magnetic tapes were analysed off-line on the CERN central computer facility using the IBM 370/168. For the evaluation of the ionization data several methods of optimization were looked into in detail. Maximum likelihood fitting was studied using the experimental overall energy-loss distribution as a reference curve as well as a symmetrized subset of this distribution. It was found that advantages which might be gained in this method were offset by the effect of uncertainties in the tail of the distribution caused by the fixed upper-bound cut-off (8-bit ADC resolution). Because of this, it is more reliable to base the analysis on the lower portion of the energy-loss distribution. The mean of 40% smallest values of a sample was found to be an adequate estimator of the ionization of a traversing particles.

To clean the sample several cuts were applied. A background cut-off at values below 32 filtered out electronic noise. Events containing crossing of background tracks were excluded by allowing not more than 6 hits in the adjacent slices on both sides. In order to avoid contribution from double particles, limits in the number of overflows and the overall mean were used. The monitor and single channel corrections described earlier were applied before calculating the mean of 40% smallest values. As an example, fig. 10 shows the final distributions for protons and pions at 50 GeV/c as measured in a positive unseparated beam working without Cerenkov counter tagging. The resolution is $\pm 3\%$ FWHM which is in agreement with predictions from ref. [6]. The dotted curves represent a gaussian fit to the experimental data.

The relativistic rise measurements are summed up in table 2, including our earlier measurements (refs [5,6,7]) with smaller detectors. The first column indicates the effective number of layers in the detector and layer thickness. The number of events for different particles and momenta does not generally represent the "natural" $\pi/K/p$ ratios because in certain cases the RF separators were used to keep the mixture ratio close to 1:1. The experimental resolution expressed in percent FWHM still contains some uncorrected residual influence of beam background, electronics noise, slope differences in the individual monitors etc. The relative resolution remains constant over a wide range of momenta. This reflects the behaviour of the relative width of the single-layer energy-loss distribution, which is also constant for $10 \leq (p/mc) \leq 10^3$. The ratios of peak values of ionization distribution for pions, kaons (and electrons) with respect to proton peaks at a given momentum are given. The corresponding absolute values of ionization expressed in terms of I/I_0 (I_0 is the minimum ionization value) were rounded to 0.5% precision. In spite of difficulties with absolute calibration for very long running periods, interrupted brutally by frequent power failures, the results are consistent as could be seen from pairs of particles with almost identical (p/mc) values (e.g. π at 16 GeV/c and proton at 108 GeV/c, π at 19.6 GeV/c and K at 68.8 GeV/c etc.). These results are plotted on fig. 11, where the dotted curve shows the theoretical predictions of Sternheimer and Peierls, including the density effect. The beam momentum definition is in all cases $\Delta p/p = \pm 0.25\%$. The error in the ionization caused by this momentum spread is typically about seven times smaller and could be neglected. If the beam would have been seriously contaminated by muons, the peaks interpreted as pions would be shifted and consequently the relativistic rise slope would be changed. Fortunately in our experiment this contamination was small, due to the length and small acceptance of the beam which has three powerful bending stages. No broadening of the pion peaks was observed. This effect would have been evident because its contribution is in our case comparable to about 2/5 of the final resolution, assuming a contamination of 50% of muons. By comparison, the hysteresis in the exhaust valve maintaining the overpressure inside the detector box to $\pm 0.3 \text{ g/cm}^2$, is introducing a modulation of $\pm 0.2\%$ which cannot be corrected.

It is interesting to note that the distribution of means from values following the highly asymmetrical energy-loss distribution themselves have a symmetrical distribution, which can be fitted by a gaussian expression, as expected from the central limit theorem and shown in fig. 5. This leads to a simple probability prediction for different mass hypotheses, as required in bubble chamber data analysis. Given a sample n and its mean of 40% smallest values x then at momentum p the probabilities for a particle to have mass m (m being discretely the mass of π , K or p) are

$$P(m, p) = \frac{a}{\sqrt{2\pi} \sigma_n} e^{-\frac{[x - \bar{x}(m, p)]^2}{2\sigma_n^2}}$$

where $\bar{x}(m, p)$ is the mean of the distribution of the mean of 40% smallest values as derived from the calibration curve on fig. 11. σ_n is its variance corrected for the number of cells sampled; the probability normalization is given by a .

5. CONCLUSIONS

The tests of the EPI performance have shown the practical limits of resolution and stability of a large-scale multilayer proportional detector system. It seems that a resolution of $\pm 2.5\%$ FWHM in the ionization measurements could be achieved in practice in an argon-filled detector working at atmospheric pressure. Absolute calibration can probably not be maintained over long running periods to better than a 1% level and periodical checks using known particles of known momentum are necessary. This is relatively easy to realize continuously using the edge of the non-interacting beam emerging from the bubble chamber and letting it bypass the beam hole region of the EPI.

The reliability of the system is determined in our case by the fault incidence in the weakest link in the component chain, i.e. the C-MOS digital circuits. We hope to keep the number of faulty cells at a level of one percent. The stability requirements and the relative inaccessibility of the electronics in the hydrogen safety zone mean that necessary reparations will be executed during longer shut down periods between different runs. Periodical tests of the digital part of the electronics are easily performed under computer control. So far the influence of the bubble chamber stray magnetic field and vibrations caused by the BEBC expansions was not detectable.

Certain modifications could be envisaged in order to improve the EPI performance and to extend the working range to higher momenta. What could be realistically envisaged for the EPI improvement programme is the reduction of the gas pressure to about 0.5 atm. which is still tolerable for the rigidity of the mechanical structure, providing that the entry and exit windows could be reinforced. Argon should be replaced by to compensate for the loss in resolution. Closed loop circulation of gas will be obviously needed for economical reasons. The detector performance could then be extended to 100 GeV/c or higher momenta. A combined hardware/software servo-loop is already foreseen for the EPI to maintain automatically the gain of the system via the H.T. setting. The use of higher pressure of the gas in the detector with the aim of obtaining better resolution is, on the contrary, drastically limiting the momentum range by a considerable reduction of the Fermi plateau level as shown experimentally for 10 and 20 atmospheres in ref. [8]. Also, the existing mechanical structure of the detector box is not strong enough to withstand much higher pressures.

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Table 1

X-ray source	energy keV
(Ar)	2.96 (esc.)
$^{49}_{23}\text{V}$	4.51
$^{51}_{24}\text{Cr}$	4.95
$^{54}_{25}\text{Mn}$	5.41
$^{55}_{26}\text{Fe}$	5.9
$^{65}_{30}\text{Zn}$	8.05
$^{75}_{34}\text{Se}$	10.54
$^{57}_{27}\text{Co}$	6.4 14.4
$^{88}_{39}\text{Y}$	14.16
$^{109}_{48}\text{Cd}$	22.16 24.9
$^{113}_{49}\text{Sn}$	24.21
$^{133}_{56}\text{Ba}$	30.9
$^{241}_{95}\text{Am}$	11.9 13.9 17.8 20.8 26.4 59.5

FIGURE CAPTIONS

- Fig. 1 Assembly of the detector from individual 32 cell double layer modules.
- Fig. 2 Complete detector installed behind BEBC.
- Fig. 3 Spectra of Am^{241} and Sr^{90} measured in a single $6 \times 6 \text{ cm}^2$ cell.
- Fig. 4 Linearity of a single cell response to X-ray energy deposit for several H.T. settings.
- Fig. 5 Single cell linearity (for an optimum H.T. value) and resolution as a function of X-ray source energy.
- Fig. 6 Single cell resolution for Fe^{55} and Cd^{109} X-rays as a function of the H.T.
- Fig. 7 Examples of events recorded in the EPI. Top view, beam coming from the right, aligned on the second slice from the bottom.
- Fig. 8 Part of on-line uncorrected data accumulated at 20 GeV/c in unseparated positive beam. Mean of 40% smallest values from slice 2 of the EPI.
- Fig. 9 Monitoring of the detector performance by radioactive sources.
- Fig. 10 Protons and pions at 50 GeV/c (corrected data) as measured in unseparated positive beam. Mean of 40% smallest values per event in the slice 2 of the EPI. The resolution is $\pm 3\%$ FWHM.
- Fig. 11 Relativistic rise of the ionization in $(\text{Ar} + 5\% \text{CH}_4)$ at NTP as a function of $\beta\gamma = p/mc$. Dotted curve shows the theoretical predictions of Sternheimer and Peierls.

Table 2

Layers	Momentum GeV/c	Particle	p/mc	Events	Resolution FWHM %	Peak ratio	I/I _o	Ref.
1 x 3 cm	1.45	π^- e^-	10.4 2837.6	different method		1.38 ± 0.04	1.090 1.505	[7]
62 x 4 cm	9.0	p_+ π_+	9.6 64.5	19700	± 4.9	1.21 ± 0.01	1.080 1.310	[6]
32 x 4 cm	16.0	p K^+ π^+	17.1 32.4 114.6	100 500 300	± 10	1.10 ± 0.03 1.235	1.140 1.255 1.410	[5]
126 x 6 cm	19.6 (*)	p_+ π_+ e^+	20.9 140.4 39139	1030 2490 100	± 3.3	1.202 ± 0.008 1.335 ± 0.03	1.180 1.420 1.575	This exp.
	29.5 (*)	p_+ π_+	31.4 211.3	380 1140	± 3.5	1.172 ± 0.008	1.250 1.465	
	39.3 (*)	p_+ π_+	41.9 281.5	330 860	± 3.4	1.157	1.275 1.475	
	49.1	p_+ π_+	52.3 351.7	890 1450	± 3.0	1.145	1.305 1.495	
	62.9 (*)	p_+ π_+	67.0 450.6	550 720	± 3.0	1.135	1.330 1.510	
	68.8	p_+ (*) K_+ π_+	73.3 139.3 492.8	540 550 1120	± 3.1	1.051 1.130	1.350 1.420 1.525	
	88.4 (*)	p_+ π_+	94.2 633.2	1040 1220	± 3.3	1.113	1.375 1.530	
	108.0 (*)	p_+ π_+	115.1 773.6	500 470	± 3.5	1.093	1.410 1.540	

(*) Tagged beam.

fig. 1

fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

EVENT - 973

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11