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EVALUATION OF RICH-1 PERFORMANCES IN 2003

F. Sozzi, S. Dalla Torre and P. Schiavon

1 Introduction

We summarise in this note the work done up to now to estimate RICH-1 PID efficiency for particles from clean physical sources; the work is in progress. The method and part of the results (mainly those obtained analysing 2002 data) have been already presented to the COMPASS collaboration at two Analysis Meetings [1] and are described in details in a thesis [2]. Most of the results obtained using 2003 data are new.

We extract the RICH-1 efficiency for kaon identification in the phase space region relevant for D^0 and $\overline{D^0}$ reconstruction. For the same phase space, also an estimate of the purity of the kaon signal is given.

2 Particle samples

Clean pion samples are obtained from $\mathrm{K^0}_S$ decays in charged particles. The combinatorial background under the $\mathrm{K^0}_S$ peak, after applying the kinematical selection, is estimated to be 6%. The resulting peak is shown in Fig. 1; the details of the $\mathrm{K^0}_S$ selection can be found in [2].

A reasonably clean charged kaon peak is obtained from Φ decays in two charged particles. Φ exclusively produced are used to get a purer kaon source: this limits in polar angle the phase space of the resulting samples. The combinatorial background under the exclusively Φ peak, after applying the kinematical selection, is estimated to be 16%. The resulting peak is shown in Fig. 2; the details of the Φ selection can be found in [2].

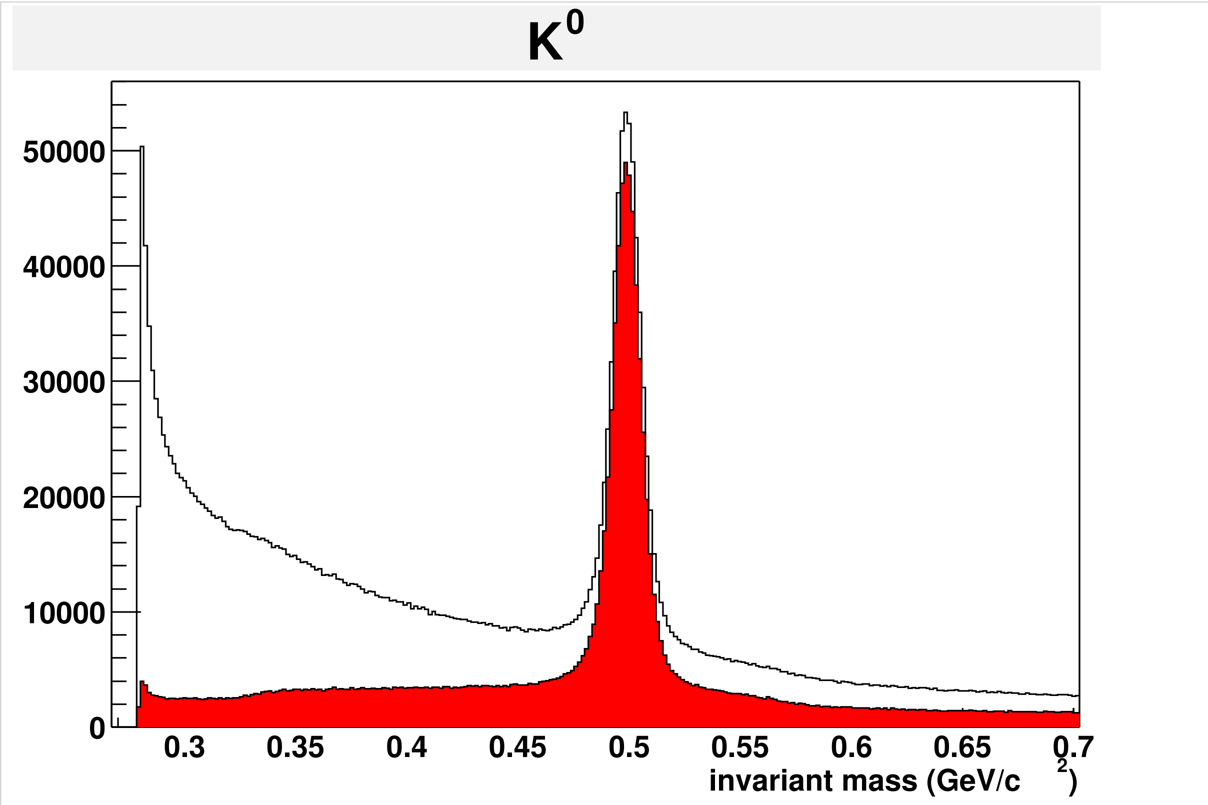

Figure 1: $K^0{}_S$ invariant mass spectrum without and with the rejection of the tracks belonging both to primary and secondary vertexes, as described in [2], 2002 data.

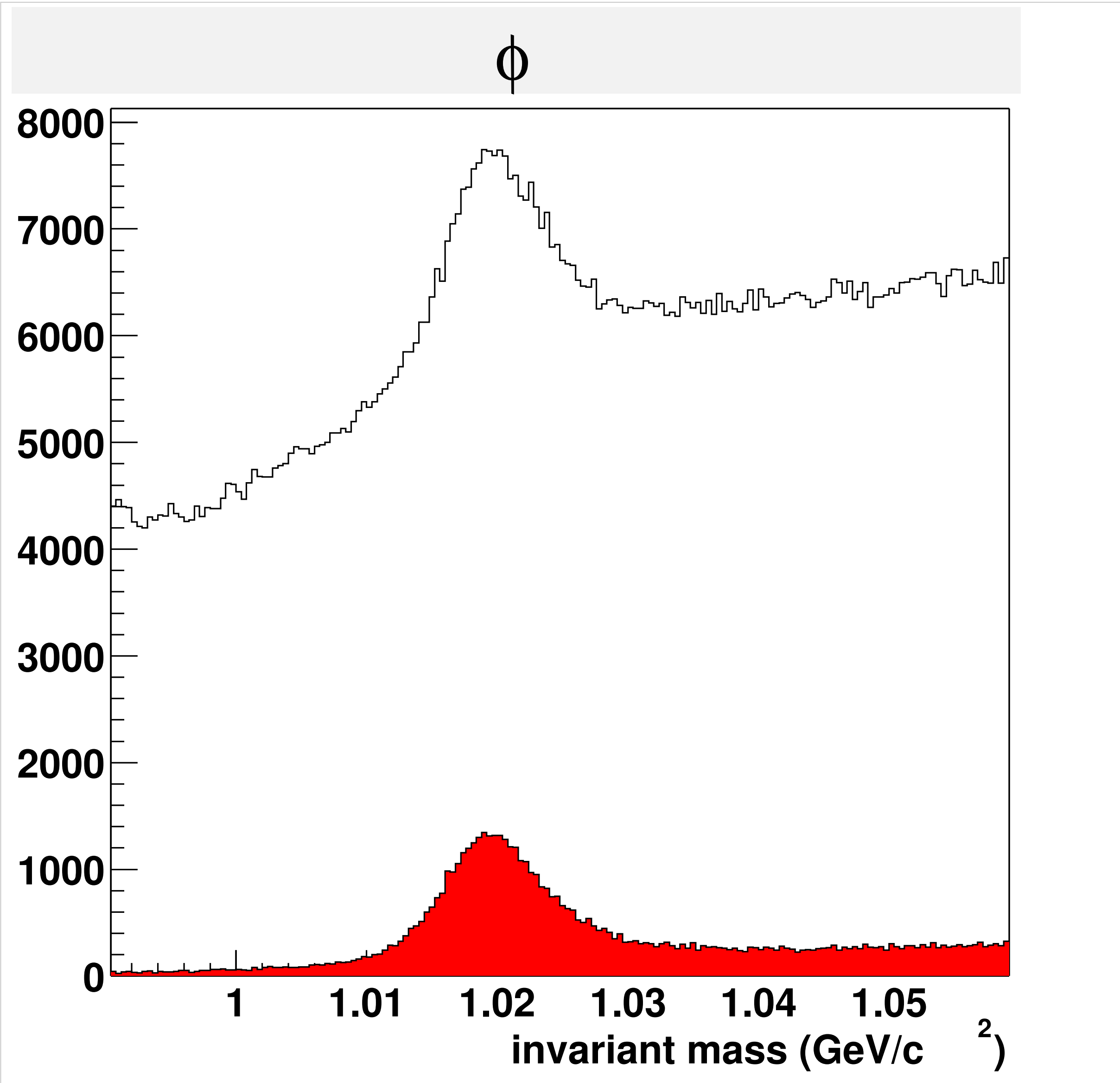

Figure 2: Φ invariant mass spectrum without and with the inelasticity cut described in [2], 2002 data.

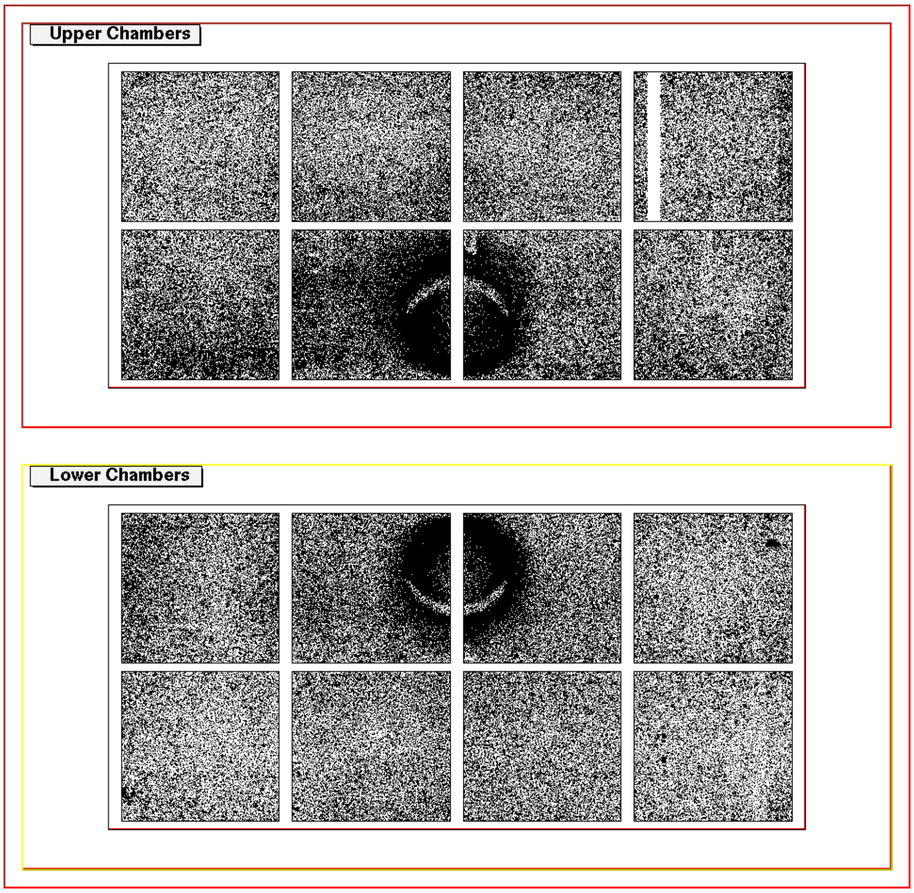

Figure 3: Overlap of event images on photon detector plane, for raw data without any selection, 2003 data.

3 Phase space regions

It has been put in evidence that the response of RICH-1 for particles at small polar angles is degraded by the contribution of the relevant physical background due to the Cherenkov photons produced by the muons of the beam far halo (see Fig. 3) and by the central dead zones, due to the He beam pipe, the hole in the mirror wall and the screens intercepting photons in front of the hottest photon detector regions (see Fig. 4 [3]).

RICH-1 performances are studied in different phase space regions to understand and put in evidence the behaviour near and far from the central region. For this purpose, 6 regions are defined on the base of the expected position of the centres

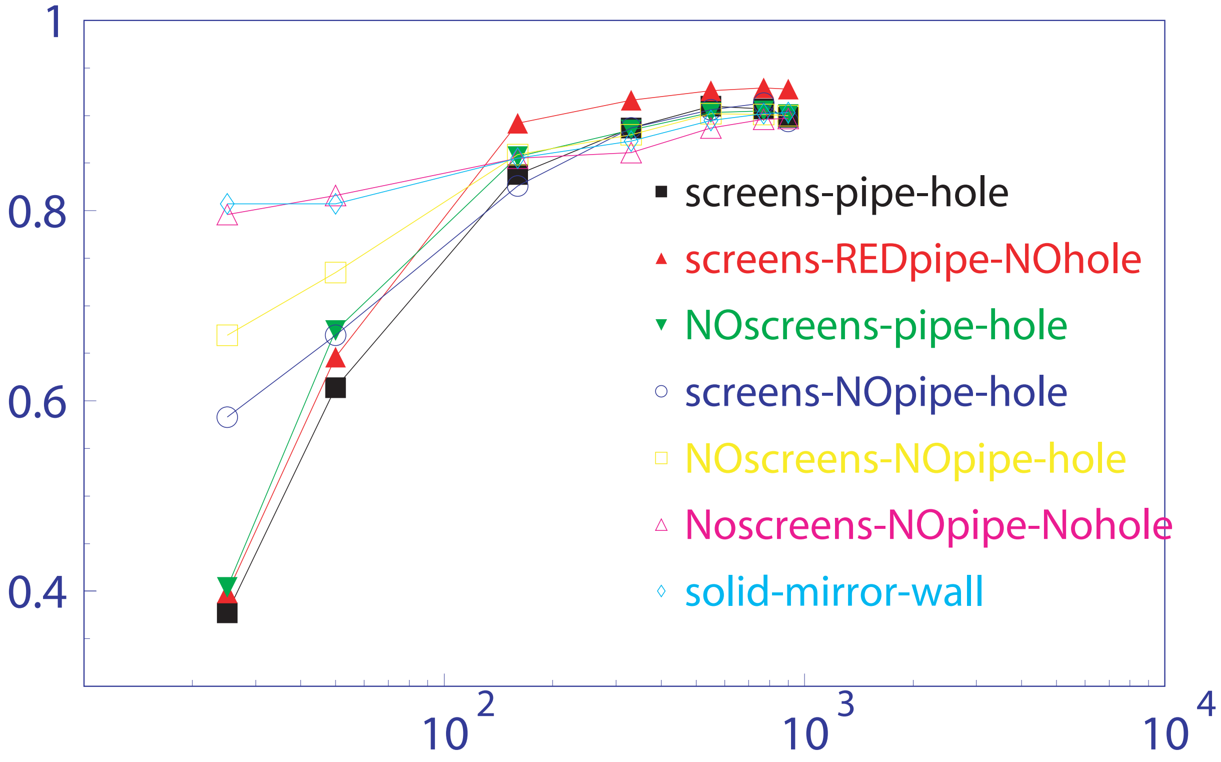

Figure 4: The effect of RICH-1 central dead zones, studied with Monte Carlo simulation taking into account only geometrical effects; beam halo and photon detector memory are not included in the simulation used.

of the ring image on the photon detector planes (the ring centre can be calculated knowing the track parameters). On each of the two planes (top and bottom ones), the distance R between the ring centre and the centre of a ring produced by particles parallel to the beam axis is calculated; the 6 regions are then defined as follows:
R < 10 cm
10 cm < R < 20 cm
20 cm < R < 30 cm
30 cm < R < 40 cm
40 cm < R < 50 cm
50 cm < R < 60 cm
and, as an example, the distributions of the ring centres, for a sample of pions from $K^0{}_S$ is given in figure 5. Please, note that, in the implemented algorithm, the geometrical variable used is the impact point of the "virtually reflected" trajectory: it corresponds with good accuracy to the ring centre. The phase space interpretation of the 6 regions defined above is straightforward, as it can be seen in Fig. 6: the correlation between R and the particle polar angle is almost complete. These regions have been introduced several months ago, to study the response of RICH-1 in the central region [4].

4 RICH-1 PID efficiency as a function of the particle momentum

Figure 7 presents the PID efficiency for charged pions from $K^0{}_S$ in the 6 regions defined in section 3. $K^0{}_S$ are from the sample described in section 2. The momentum spectra for the pions of the 6 different regions are given in Fig. 8. The updated version of package RICHONE is used for this exercises (see also section 5).

Different momentum cuts are applied:

1. momentum > momentum corresponding to the threshold of the Cherenkov effect for pions (2.6 GeV/c in 2003)

2. momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 0.5 GeV/c (corresponding to the momentum value at which the average number of detected photoelectrons per ring is 5 assuming, from data, that 15 photoelectrons are detected, on average, at saturation)

3. momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 1.2 GeV/c (corresponding to the momentum value at which the average number of detected photoelectrons per ring is 8 assuming, from data, that 15 photoelectrons are detected, on average, at saturation)

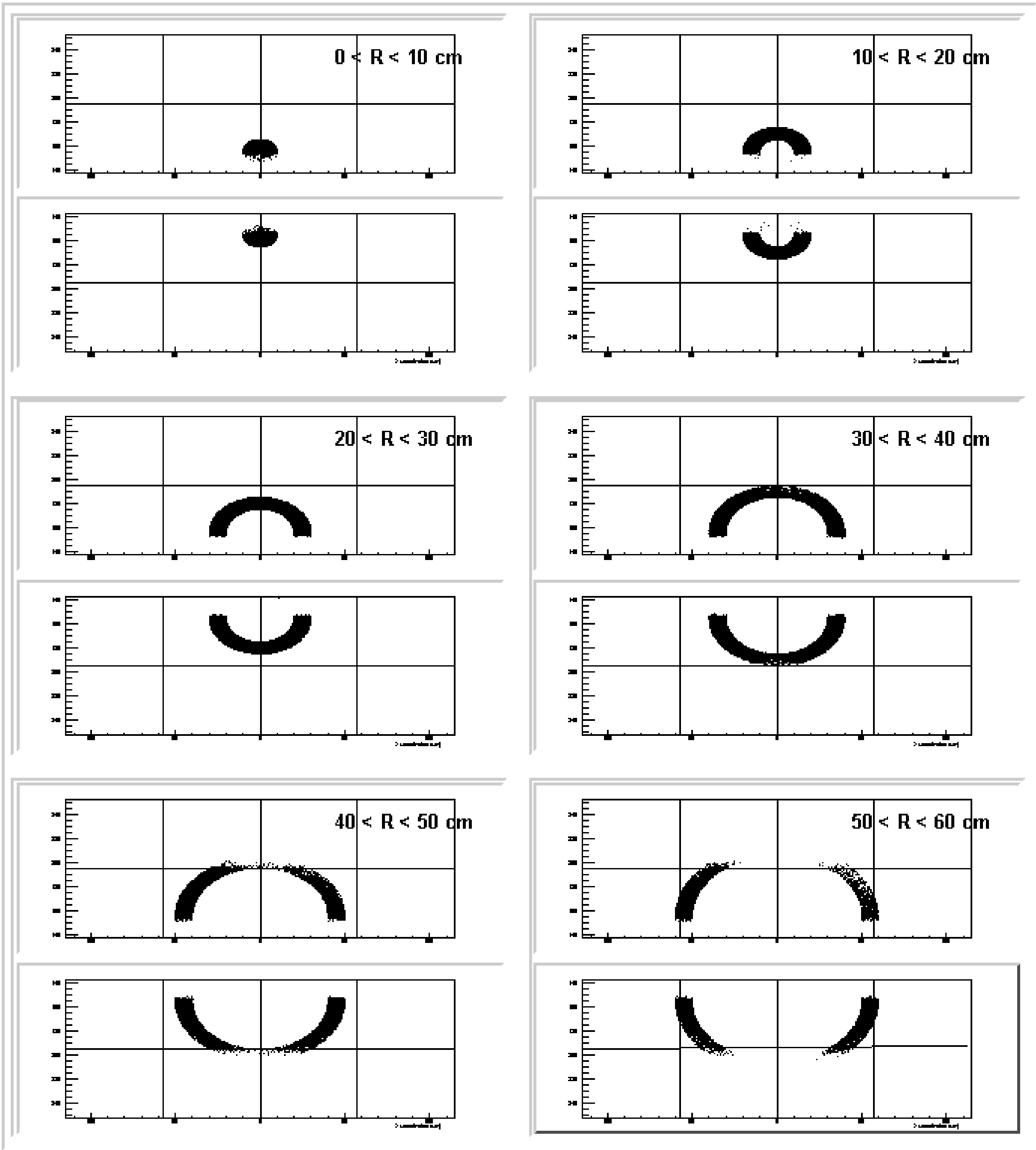

Figure 5: Impact point of the "virtually reflected" trajectories of pions from $K^0{}_S$ decays on the photon detector planes, divided in the 6 regions described in the text.

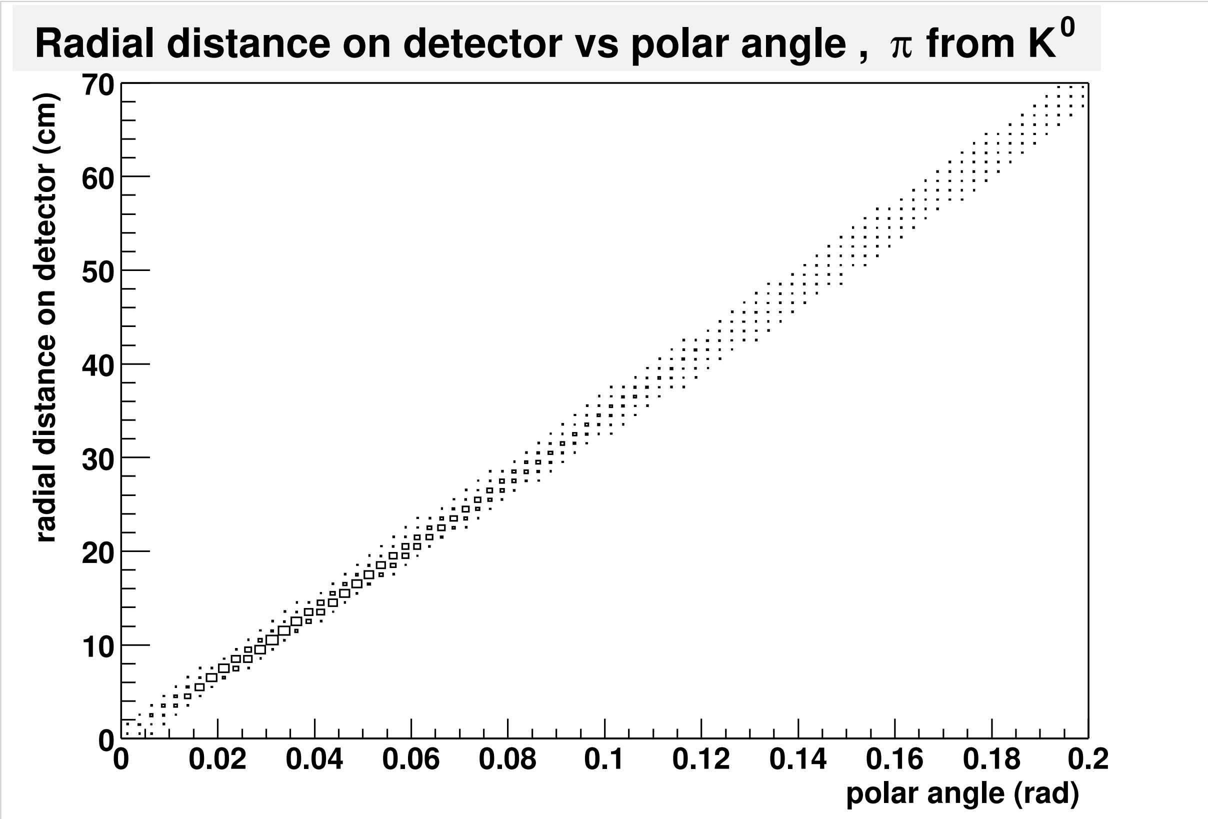

Figure 6: The ring parameter R (defined in the text) and the polar angle of the particle trajectory.

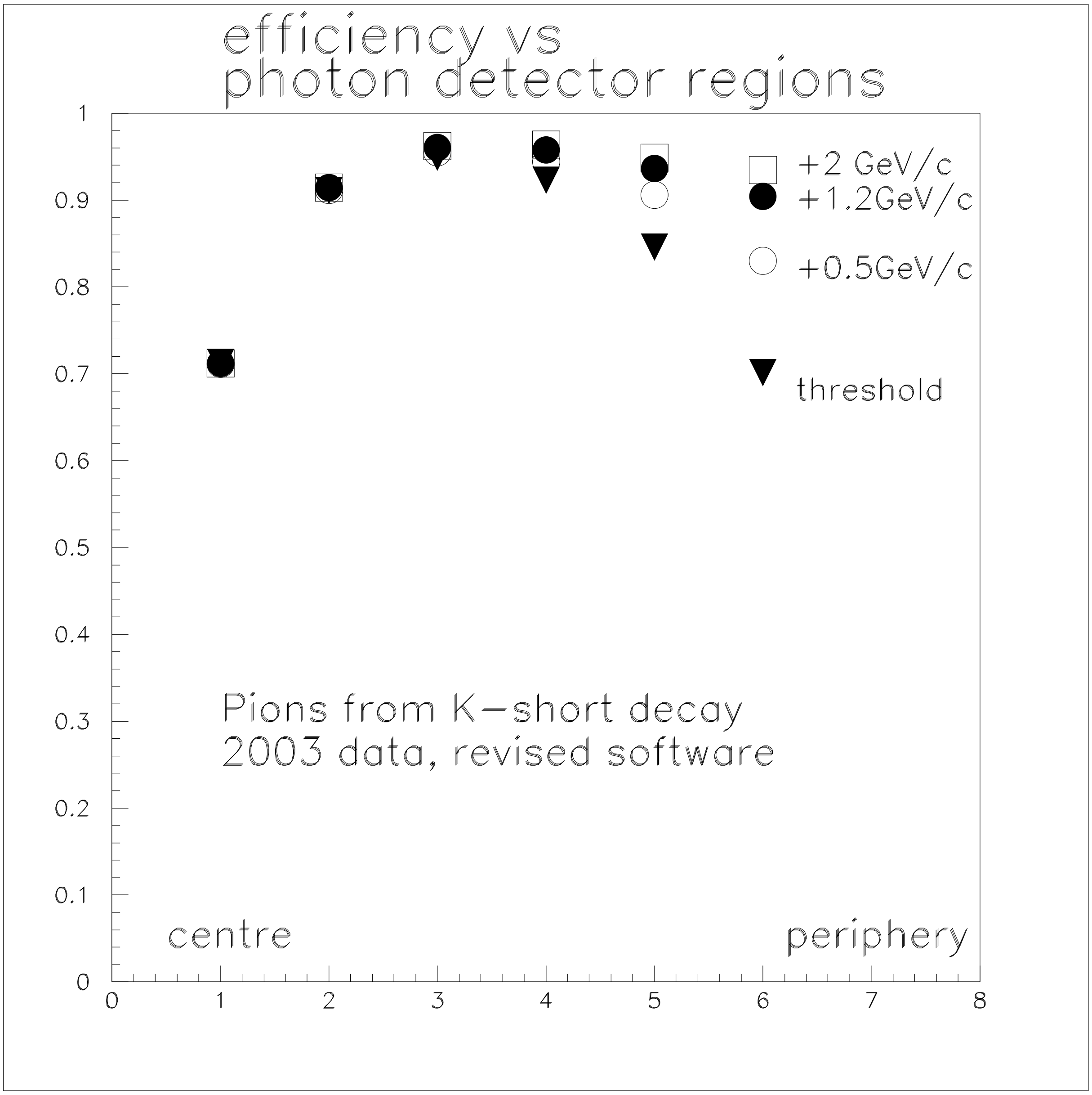

Figure 7: PID efficiency for charged pions from $K^0{}_S$ decay in the 6 phase space regions defined in the text; triangles: momentum > momentum corresponding to the threshold of the Cherenkov effect for pions; open circles: momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 0.5 GeV/c; dots: momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 1.2 GeV/c; open squares: momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 2 GeV/c.

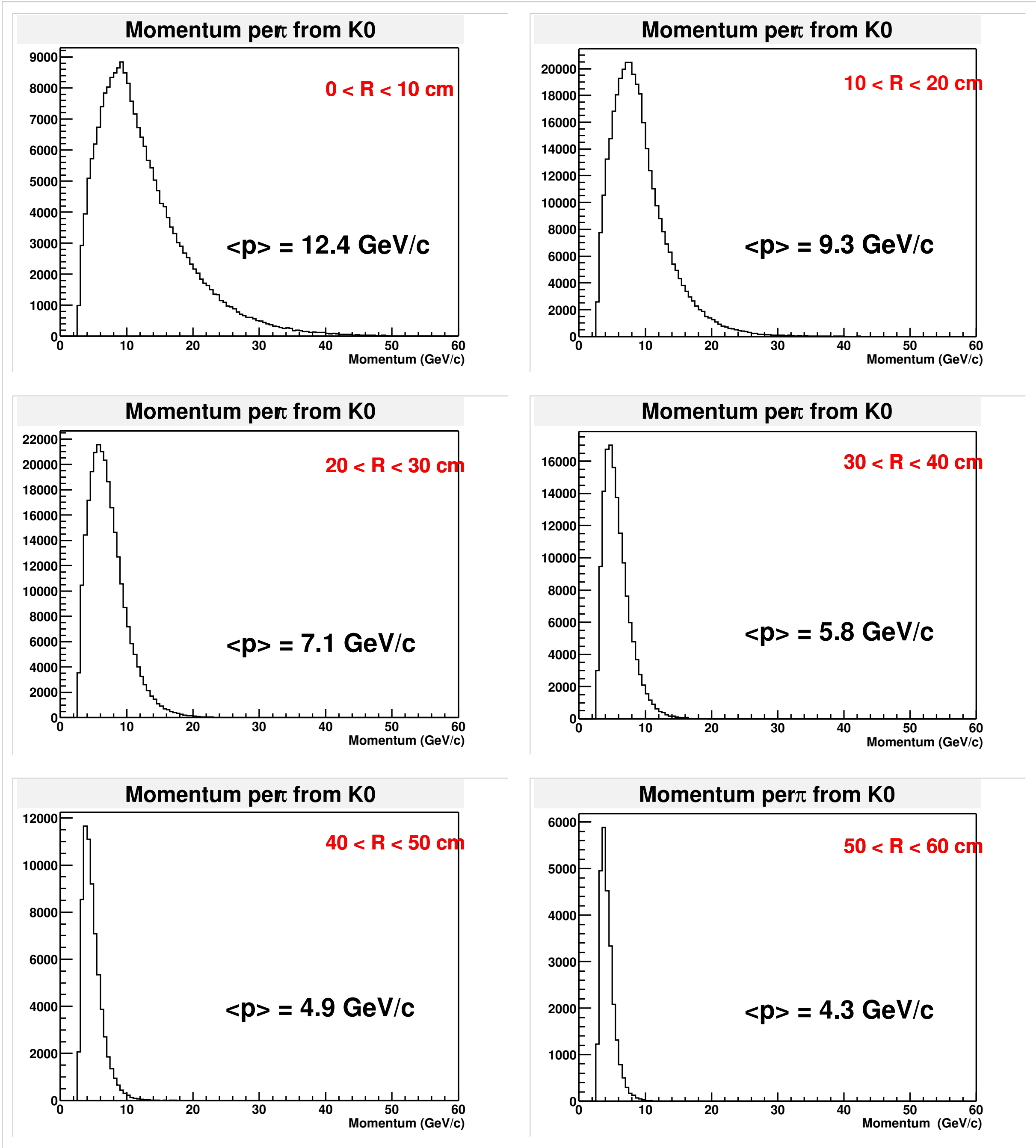

Figure 8: The momentum spectra for the charged pions from $K^0{}_S$ decay separated according to the 6 different phase space regions defined in the text, 2002 data.

4. momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 2 GeV/c (corresponding to the momentum value at which the average number of detected photoelectrons per ring is 10 assuming, from data, that 15 photoelectrons are detected, on average, at saturation)

The inspection of Fig. 7 puts in evidence the following aspects:

- increasing the momentum threshold there is no efficiency increase in the first and second regions and limited in the third one: the momentum spectra for these two regions are peaked at high values and the slight change in momentum spectrum does not reduce the samples substantially
- the PID efficiency increases remarkably raising the threshold in the three most external regions because the momentum spectra are limited to the small momentum range and the effect of the higher momentum threshold is to remove a substantial portion of the samples and the most critical one (less detected photoelectrons)
- the PID efficiency increases passing from the internal to the external regions, and reaches a plateau with values higher than 90% .

Summarising, the central phase space region exhibits a PID efficiency which is limited by the effects described in section 3, while out from the centre, the efficiency is good as soon as the particle momentum ensures a reasonable mean number of detected photoelectrons.

5 Evolution in time of RICH-1 PID performances

This study is performed using samples of charged pions obtained as above and applying the momentum cut number 2 described in the previous section. Figure 9 presents the 4 sets of efficiency values:

1. 2002 data, processed using the version of the RICHONE package used for the production of 2002 data
2. 2002 data, processed using the version of the RICHONE package used for the production of 2002 data, with a geometrical cut: the particle trajectories for which the expected ring loci are in the photon detector sector Jura-up are removed to understand the performances using only the properly working photon detectors: in 2002, PD6, the central photon detector in sector Jura, top was operated at too low high voltage, due to its electrical unstable behaviour

3. 2003 data, processed using the version of the RICHONE package used for the production of 2002 data
4. 2003 data, processed using the new version of the RICHONE package [5], since recently in use for the production of 2003 data; the effect of the revised code is also illustrated with Fig. 10.

It is evident that:

- the increase in PID efficiency is relevant with better hardware:
  - the increase between point sets 1 and 2 demonstrate the effect of better photon detectors
  - the increase between point sets 2 and 3 account for the contribution of the largely better radiator conditions, both in transparency and gas filling
- the better hardware performances affect mainly the external regions; this is again related to the momentum spectra for the samples of the different regions (Fig. 8): in the central region the the mean momentum is pretty far from the threshold for Cherenkov effect and thus the increase in the number of detected photoelectrons has very limited effect on the PID efficiency
- the efficiency increase between point sets 3 and 4 is remarkable in the central regions and limited elsewhere: as explained in [5], the new algorithm mainly correspond to a reduction of the noise level in the central regions, where a substantial fraction of rings is splitted between the two spherical mirror surfaces; this also proves that a reduction of background in the central region can really result in a gain in PID efficiency.

6 RICH-1 efficiency for kaons.

The PID efficiency for charged kaons from exclusively Φ decay (see section 2) in the regions defined in section 3 is presented in Fig. 11. Only the first 3 regions are populated due to the exclusively Φ space phase. The applied momentum cut is momentum > momentum corresponding to the threshold of the Cherenkov effect for kaons (approximately ~ 9.2 GeV/c for 2003 data) + 2 GeV/c (corresponding to the momentum value at which the average number of detected photoelectrons per ring is 5 assuming, from data, that 15 photoelectrons are detected, on average, at saturation).

The momentum spectra for the kaons of the 3 different regions are given in 12. The 3 data sets in Fig. 11 correspond to:

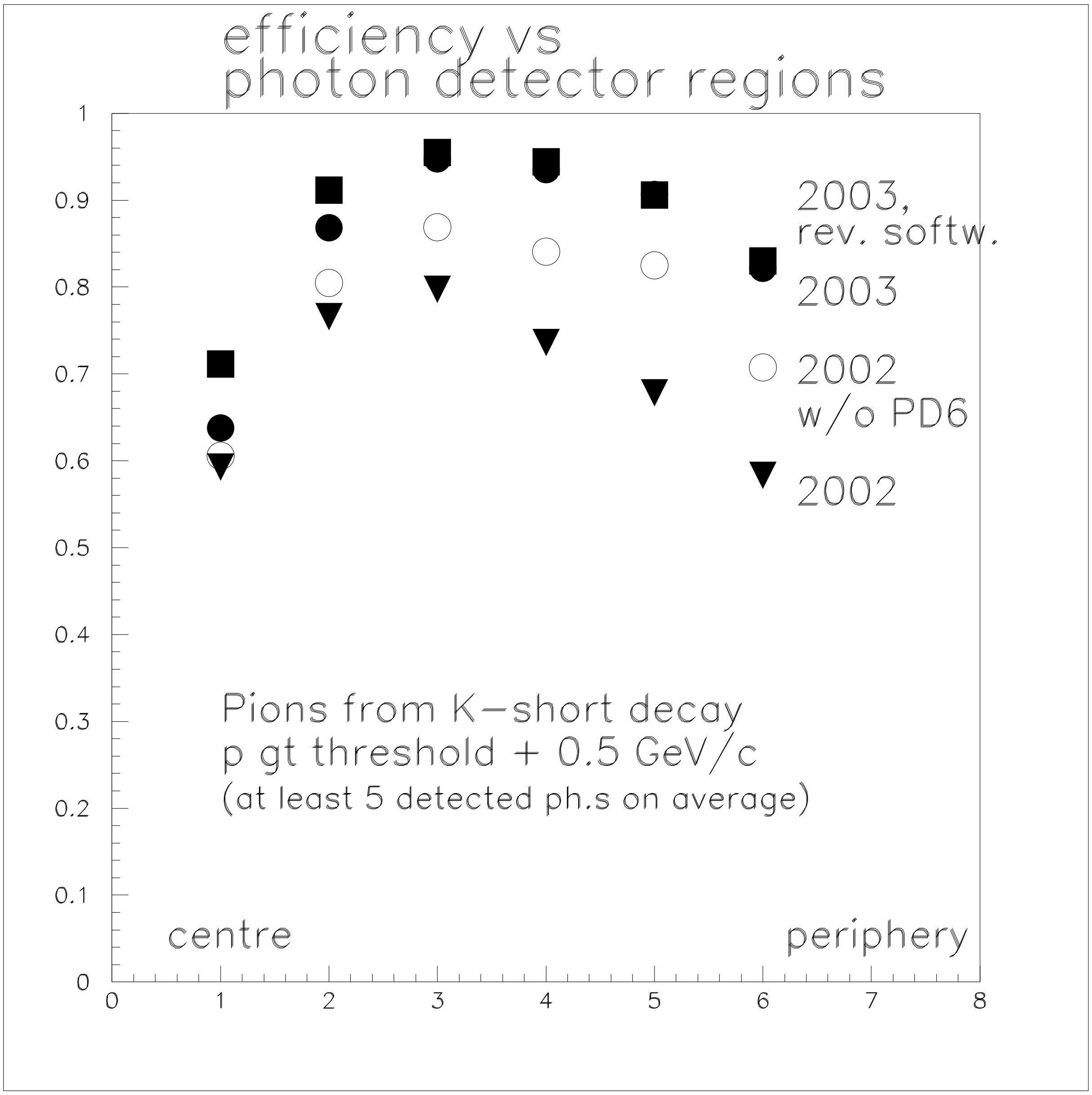

Figure 9: PID efficiency for charged pions from $K^0{}_S$ decay in the 6 phase space regions defined in the text for momentum > momentum corresponding to the threshold of the Cherenkov effect for pions + 0.5 GeV/c; triangles: 2002 data; open circles: 2202 data without Jura-up region; dots: 2003 data; squares: 2003 data using the revised version of RICHONE.

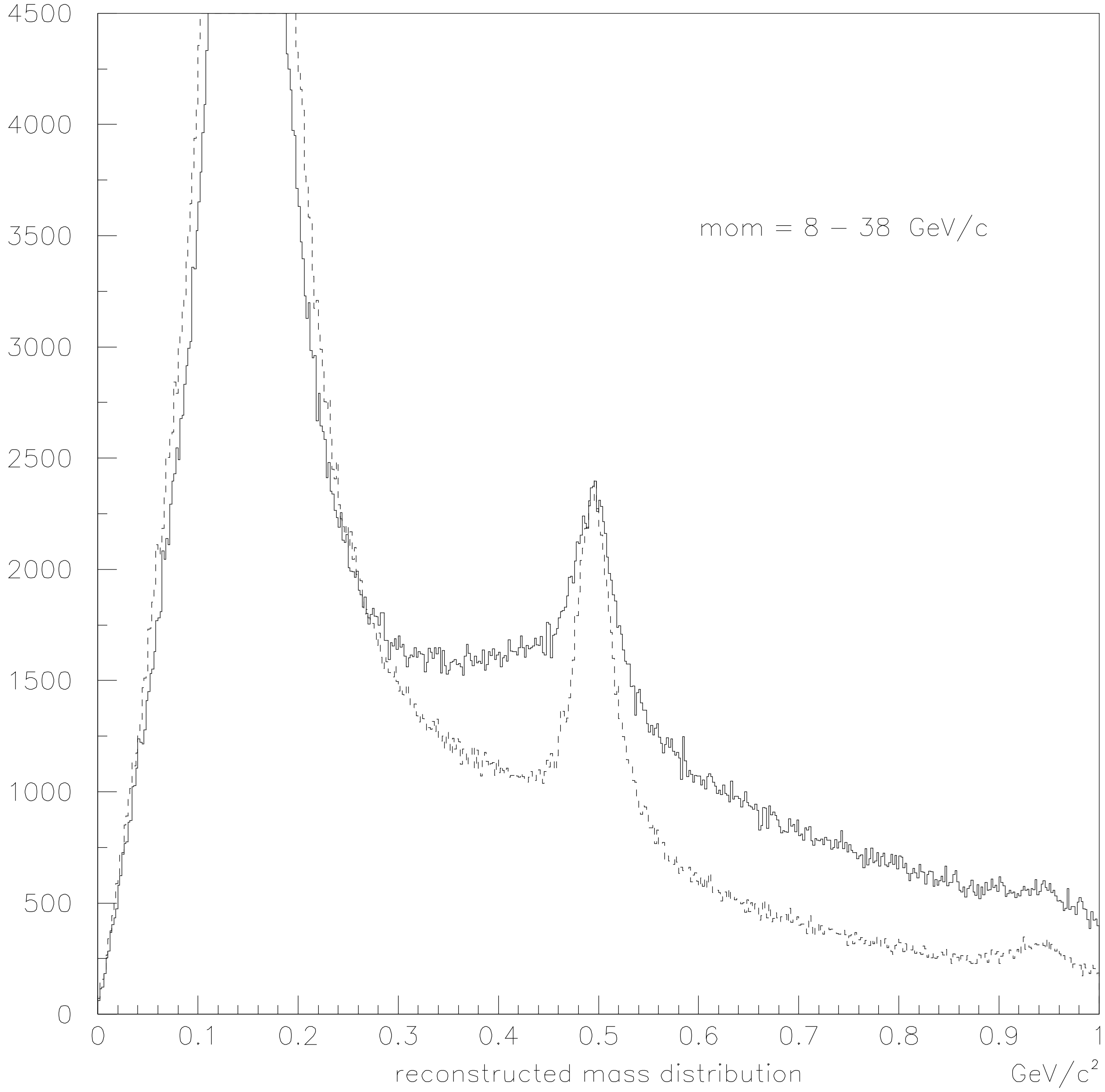

Figure 10: 2003 data, mass spectrum obtained with RICHONE version used for the 2002 data processing (solid line) and with the revised version (dashed line); the normalisation is done equalising the heights of the kaon mass peaks.

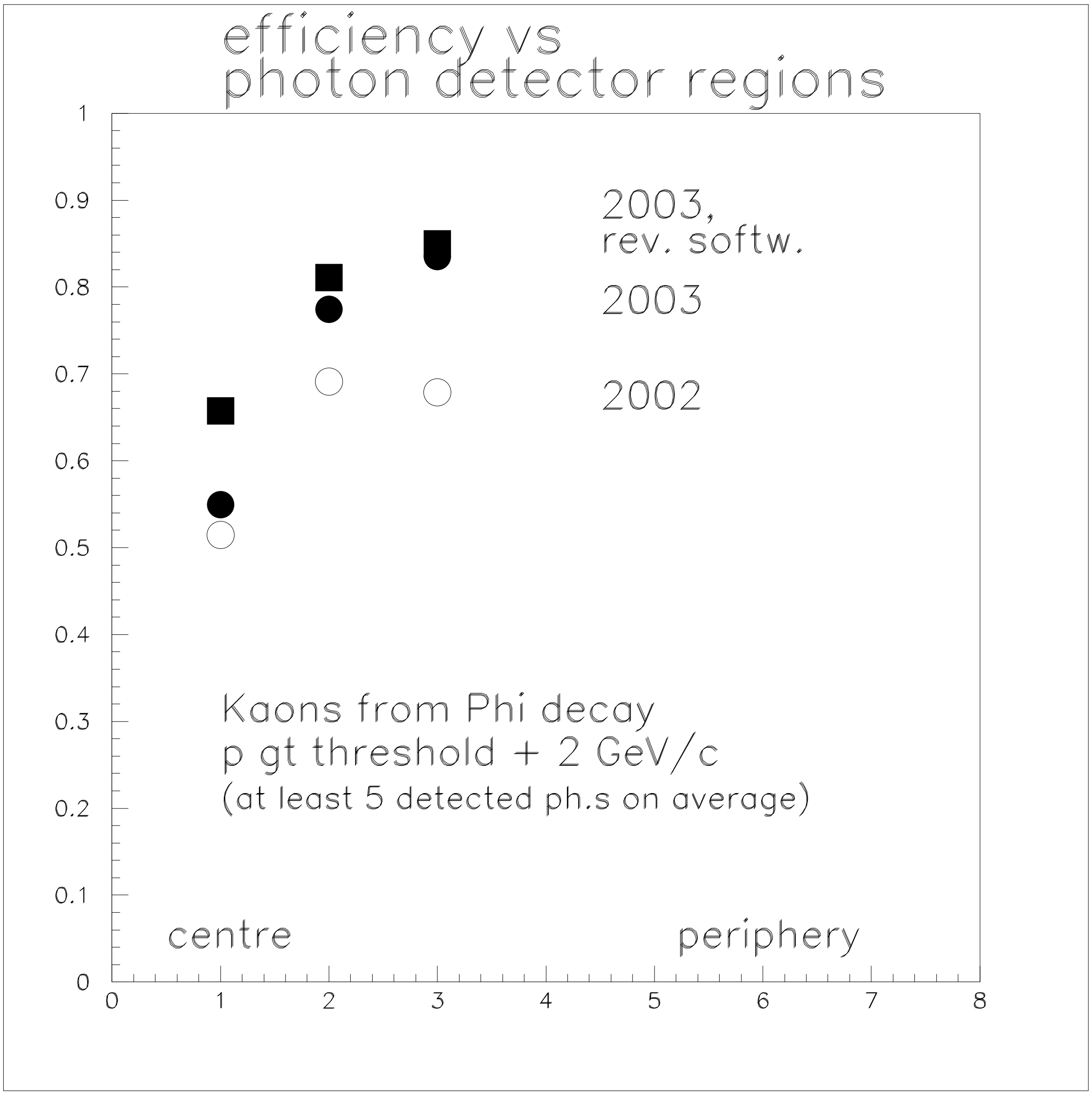

Figure 11: PID efficiency for charged kaons from exclusively Φ decay in the first 3 phase space regions defined in the text for momentum > momentum corresponding to the threshold of the Cherenkov effect for kaons + 2 GeV/c; open circles: 2002 data; dots: 2003 data; squares: 2003 data using the revised version of RICHONE.

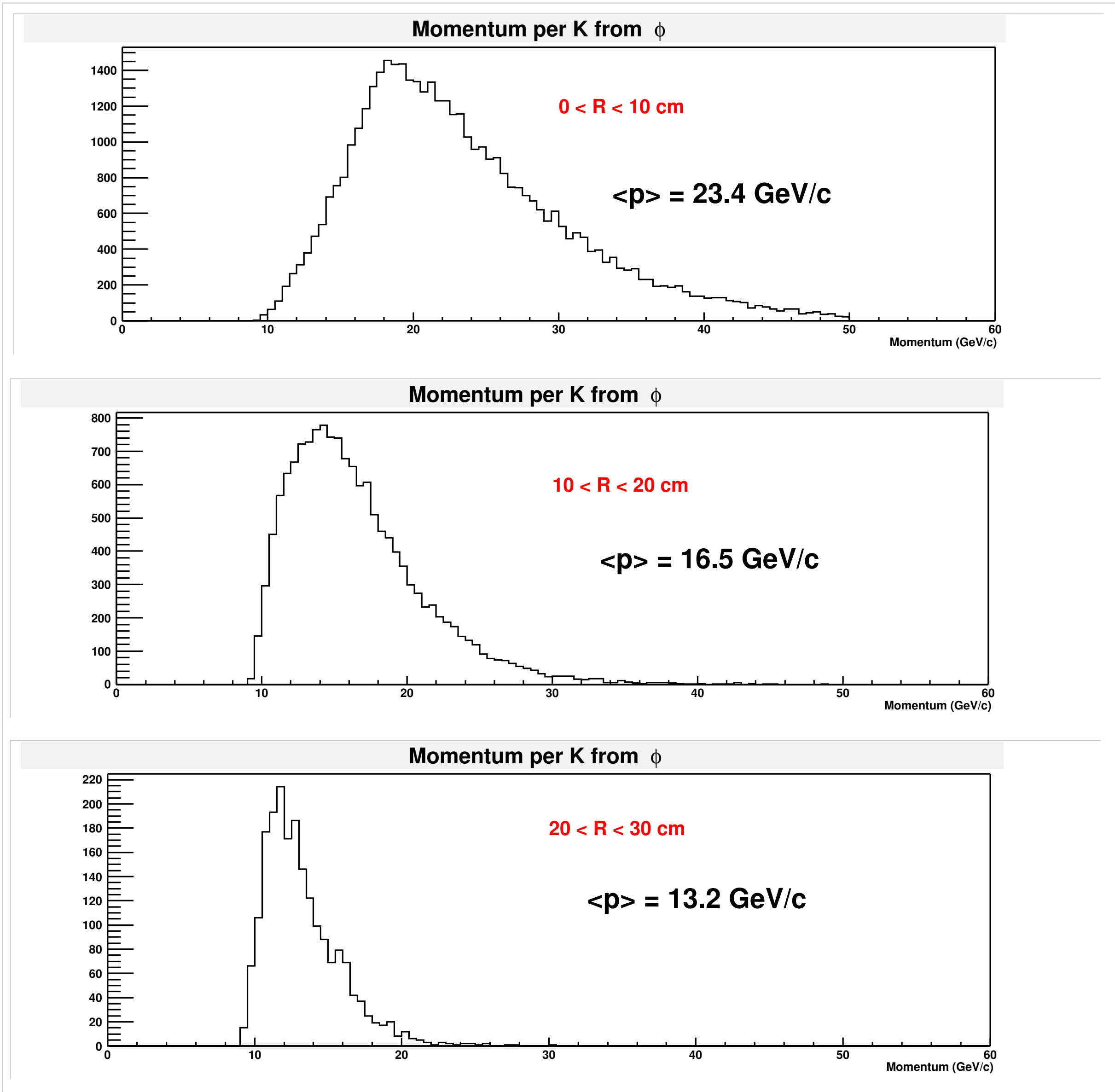

Figure 12: The momentum spectra for the charged kaons from exclusively Φ decay separated according to the first 3 different phase space regions defined in the text.

- 2002 data, processed using the version of the RICHONE package used for the production of 2002 data
- 2003 data, processed using the version of the RICHONE package used for the production of 2002 data
- 2003 data, processed using the new version of the RICHONE package [5].

The analysis of the figure indicates that:

- the increased PID efficiency already observed for pions and related to the better hardware performances and the upgraded algorithm are confirmed
- the efficiency plateau value seems lower than for pions; if the reduced purity of the exclusively Φ sample (see section 2) is taken into account together with the reasonable assumption that the combinatorial background below the exclusively Φ peak is largely contributed by pions, the efficiency is comparable with that obtained for the charged pions: a conservative value larger than 90% for regions 2 and 3 can be assumed.

7 RICH-1 performances in identifying kaons from D^0 and $\overline{D^0}$ decay.

The phase space of charged kaons from D^0 and $\overline{D^0}$ decay simulated using AROMA generator and applying the standard COMPASS cuts (spectrometer acceptance, $\cos(\theta)$ and z_D cuts) in the (polar angle, kaon momentum) plane is shown in figure 13 [6]. Applying the following extra cuts:
polar angle $>$ 25 mrad
particle momentum $>$ 11.2 GeV/c
25% of the sample is rejected [6]. For the remaining sample (75% of the original one), the momentum spectrum near the momentum threshold is similar to the one of the kaons in regions 2 and 3, shown in Fig. 12. The momentum spectrum of kaons from D^0 and $\overline{D^0}$ decay extends to somewhat higher momenta. The angular cut at 25 mrad corresponds to the rejection of region 1. Thus the PID efficiency obtained for kaons from exclusively Φ decay, regions 2 and 3 is a very good estimate of the PID efficiency for kaons from D^0 and $\overline{D^0}$ decay, applying the extra cuts indicated above.

To estimate the purity of the kaon peak in the same phase space region defined above, the mass spectrum for all reconstructed rings of a raw sample to which only the momentum and polar angle cuts mentioned in this section have been applied, has been produced, Fig. 14. The signal to noise ratio is $>$ 2.5 and the purity is $>$ 70%.

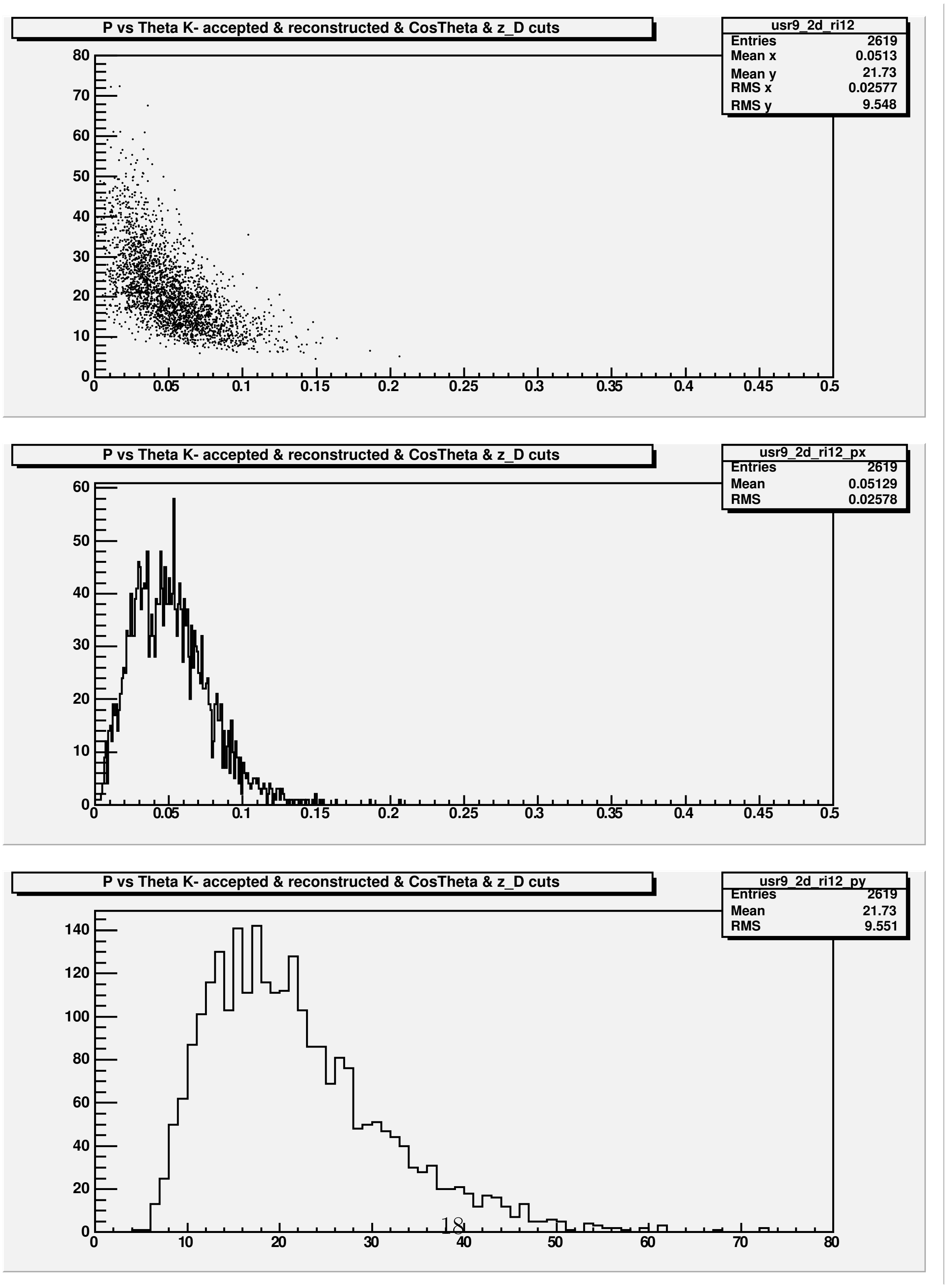

Figure 13: Distribution of the charged kaons from D^0 and $\overline{D^0}$ decay simulated using AROMA generator and applying the standard COMPASS cuts in the (polar angle, kaon momentum) plane, and projections onto polar angle axis and the kaon momentum axis.

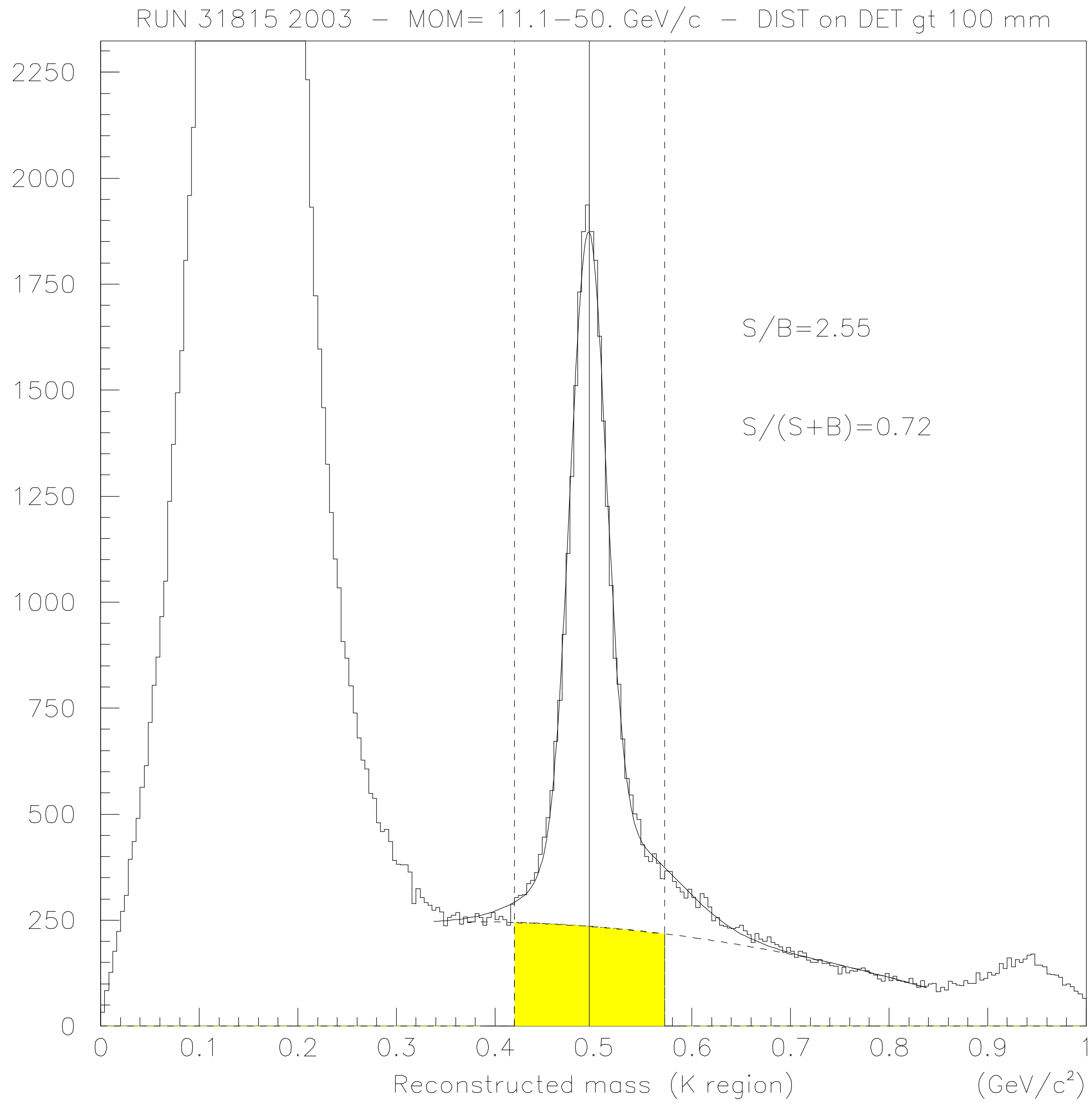

Figure 14: Mass spectrum for all reconstructed rings of a raw sample with momentum and polar angle cuts mentioned in the text, 2003 data.

8 Conclusions

It has been shown that

- RICH-1 performances in 2003 are largely better than in 2002 due to major hardware improvements (photon detectors electrically stable, remarkable gas quality, better than in original specifications)
- an up-grade of the RICHONE package has allowed for an extra increase in PID efficiency, in particular at small angles where the background effect is dominant
- the present best estimates of PID efficiency and purity for charged K's from D^0 and $\overline{D^0}$ decays for $\sim 75\%$ of the decays in the region of interest (COMPASS canonical cuts) are:
  efficiency $> 90\%$ purity $> 70\%$, in good agreement with the preliminary estimates presented at the end of last year [7]; these values must be used when evaluating the present RICH-1 FOM and the experiment potential.

The present (2003 data) RICH-1 performances outside the central region (above ~ 25 mrad) are already pretty good, even all possible improvements will be pursued by the RICH group. In parallel, the studies of RICH-1 PID and efficiency in different phase space regions will be continued for an even more detailed understanding of these crucial parameters.

References

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F.Sozzi, *RICH efficiencies versus position on Photon Detectors*, at COMPASS Analysing Meeting, 28-29 January, 2004.

[2] F.Sozzi, *Identificazione di particelle con il RICH dell' esperiemnto COMPASS al Superprotosincrotrone del CERN*, Trieste, 21 May, 2004.

[3] see, for example, A. Bressan, *RICH studies*, at COMPASS Analysing Meeting, 25-26 February, 2004.

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[5] P. Schiavon, *RICH mirror alignments*, at COMPASS Analysing Meeting, 25-26 March, 2004.

[6] A. Mielech, private communication, May 2004.

[7] F. Bradamante, *RICH performance*, at COMPASS Analysing Meeting, 30 October, 2003 and at Technical Board Meeting, 5 November, 2003.