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Report on Harp Data Comparisons

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Introduction

The Harp Time Projection chamber (TPC) suffered from large track distortion due to a non-optimal operation of the TPC during the data taking period. The analysis of the tracks in the TPC is therefore particularly difficult and the collaboration has followed different track reconstruction strategies. This has developed in a serious scientific dispute inside the collaboration.

End of the year 2006 the Harp collaboration has published a description of the HARP detector and its performance in NIM. One of the analysis groups composed of physicists from CERN, Dubna and Protvino (called CDP in the following) has not signed this publication and have sent comments to the editor. They claimed a better understanding of the TPC effects and advocated that the analysis of the Harp collaboration (called official Harp or OH) suffers from serious mistakes. These comments together with a rebuttal from OH have been published in the same issue of NIM [1, 2, 3].

During the year 2007 on-going activities of the Harp collaboration have continously been monitored by the SPSC and reports have been given at every of its meetings.

Early 2007 a Review Board for the Harp experiment (RBH) was called in by the main HARP Funding Agencies (INFN and CERN). This board was chaired by L. Foa and the SPSC referees participated as members. The RBH looked in detail into the analyses of the Harp collaboration and produced a report[1].

The main conclusion was that a track momentum bias of the TPC reconstructed tracks was identified in the OH data analysis as presented in their publications. The bias was estimated in a qualitative way to be a systematic momentum shift to lower values (for positive tracks in positive magnetic field) of about 15 % for track momenta of 600 MeV.

It was suggested that this advocated bias is probably due to distortions in the TPC that have not been fully corrected for. The main evidence for the momentum bias was based on an observed shift in the relation between the energy loss and the track momentum for protons and also on a mismatch of the time measured by the Harp resistive plate chambers surrounding the TPC (RPC) and the time obtained from the TPC track momentum. The RBH also noted that track momentum distributions from CDP analysis group are different than the ones of OH.

On the 18th of April 2007, at the SPSC81 meeting the conclusions of the RBH report, that there is most likely a bias due to distortions in Harp TPC data in reconstructed momentum beyond the systematic uncertainties in one of the two independent analysis, were endorsed. The SPSC took also note that those members of the Harp collaboration, whose analysis was considered to suffer from the momentum bias find themselves in disagreement with the conclusion of the report.

After the report several meetings between the spokespersons of the Harp collaboration and the SPSC have been taken place, but the SPSC was not convinced by the arguments of OH against the conclusions of the RBH report. The arguments against the RBH report have first been formulated in an internal note that was made available to the SPSC [4] in June 2007, in September 2007 made publically available [5, 6] and submitted to journals [7].

The impact and relevance of such a possible bias in the final physics results (i.e. the measured cross-sections) and the difference between the two analyses were then considered

[1] See: Report of the Review Board for Harp (RBH), March 1st 2007.

as a crucial question to follow and to quantify as much as possible. This topic was proposed as an important subject to discuss during the annual review of the Harp experiment scheduled for October at the SPSC83 meeting.

On the 22nd June 2007, CERN and INFN representatives held a meeting together with the two Harp analysis groups. After this meeting the SPSC received, on 5th July 2007, a letter by the CERN research director, J. Engelen, stating that the funding agencies wish to see a comparison of the results of the two analyses on the same data set. The SPSC was invited to consider the outcome of such a comparison in the normal course of their reviewing procedure and the funding agencies asked for assistance of the SPSC to define the details of the comparisons.

In July 2007, the SPSC started discussing with both groups what kind of data comparisons would best be carried out to arrive to scientific conclusions on the differences between the two analyses. While there was agreement on the best data set, it was not possible to find a consensus of what should be compared. Both groups pointed out the difficulty to compare individual tracks. CDP was not willing to produce cross-sections as published by OH. OH stated that they were not able to work on anything beyond the cross-sections they had made public in scientific journals or preprints.

In view of this difficult situation, the SPSC was seeking a way forward to arrive at a data comparison in the widest possible kinematic range for pions as well as for protons. The aim was that this data comparison should cover not only the results already published by OH, but also as much as possible future results. Also, the SPSC aimed at initiating a comparison which would be a logical continuation of the first comparisons of track distributions already shown in the RBH report. To this end, the SPSC suggested on 23rd July 2007 to both groups to compare individual tracks of the proton Beryllium (pBe) and the hydrogen data sets and to compare single inclusive track cross-sections for pions and protons in the pBe data set as a function of the inverse track momentum. Finally, on 2nd August, both groups were asked to provide the SPSC with a specific set of information on the 24.9.2007 latest. The text of this request, which was also sent to the CERN Research Director, can be found in Appendix A.

CDP provided in time before the Harp annual SPSC review meeting all necessary information. OH sent only a preliminary data set with tracks from the pBe data set. The details of the received information and data sets can be found in appendix B. Therefore by the time of the SPSC83 meeting a rather limited comparison of the reconstructed tracks was possible. The SPSC referees discussed in a meeting prior to the SPSC83 session these results with the relevant groups, OH and CDP. The results presented by the SPSC referees were accepted by all persons in this meeting and agreed to be shown as preliminary in the closed session of the SPSC83. Clear differences were observed for the momenta of the same identified track in the same event reconstruct with the two different approaches of the two analysis groups in the pBe (8.9 GeV) data set. In fact, these differences were larger than the systematic uncertainties claimed in any of the analyses. The SPSC noted at SPSC83 that the data comparisons should be concluded by the time of its next meeting.

In the present report the final results of the data comparison between the two Harp groups, OH and CDP, are presented.

Results of the Comparison

As stated in appendix A, the requested events for the comparison of individual tracks belonged to the pBe (8.9 GeV) and the hydrogen data sets.

In fact, from the data set of the hydrogen target events can be selected where the pion or proton scattered elastically on a proton in the target. The overconstrained kinematics of this process allows to predict the momentum of the proton measured in the TPC by the angle of the other proton measured in the forward detectors and either the angle in the TPC or the momentum in the forward detectors. Therefore, including these data appears to be of crucial importance for the data comparisons. This, however, has not yet been possible, since OH, for the time being, has not provided these data (see appendix B). It should be noticed that this process is the main calibration processes in the OH analysis.

Since OH did also not provide the track momentum including the energy loss between the vertex and the TPC, as explained in appendix B, tracks without this energy loss have been compared. Using the information provided by CDP it was found that the energy loss modifies the track momentum by $1-3\%$ between 0.2 and 0.5 GeV. The size of the effect depends on the transverse track momentum and affects tracks of either charge in the same way.

Comparison of Individual Tracks

In order to find the same tracks in the two data sets the following procedure is used: First the same run and event numbers for the two data sets are selected. Tracks that have similar azimuthal ϕ and polar θ angle are selected, by looking for the track pair with the minimal $dR = \sqrt{\Delta\phi^2 + \Delta\theta^2}$. Tracks are called matched, if $dR < 0.1$. Tis procedure is rather save, since the angular measurement of the TPC is not so much affected by the TPC distortions.

The circles in Fig. 1 shows the comparison of the difference of the same tracks divided by the mean transverse momenta (p_t) as a function of the mean transverse momenta of the two analyses. The histogram represents the two-dimensional distributions. The black circles indicate the mean of the normalised p_t difference.

At small mean p_t the mean differences are of the level of about 5 %. The mean differences become larger towards increasing p_t. At 0.4 GeV they are about 15%. The differences have opposite sign for negative and positive tracks. While for positive tracks the CDP transverse track momentum is larger than the one from OH, for negative tracks the CDP transverse track momentum is smaller.

The disagreement between the transverse momenta of the identified tracks is similar with the disagreement already found in the RBH report based on comparisons of distributions of inverse transverse track momenta.

The first physics publications of OH were based only on the first 100 events in the PS spill, since the TPC suffered from large distortions (called dynamic) that depend on the position of a given event in the spill. Probably theses distortions are due to a cloud of positive ions flowing back into the drift volume. As a result the trajectories of the drift electrons are systematically displaced laterally. At the time of the RBH report the CDP results where already based on the full spill. Meanwhile also OH has worked out corrections for the dynamic distortions.

In Fig. 2 the mean transverse track momentum for OH, for CDP, and the ratio of

OH over CDP, is shown for positively and negatively charged tracks as a function of the position in the PS spill. No dependence on the position in the spill is seen in neither of the two analyses nor in the ratio. The information on the position in the PS spill is taken from the CDP data set.

The large spread of the reconstructed transverse momentum of the two analyses is rather surprising. Since the same physical tracks are compared, the differences can only be due to differences in the track reconstruction of the two analyses.

We conclude that the differences between the two analyses are larger than the quoted systematic uncertainty on the track momentum scale. OH claims an understanding of the absolute momentum scale of $\pm 3\%$ for tracks up to momenta of $p < 0.8$ GeV and $p_t < 0.5$ GeV (in the first 100 events in a PS spill) [8], CDP claims an understanding of the absolute momentum scale of $\pm 2\%$ (for all events in the spill) [10].

The momentum scale uncertainties is mainly based on an analysis of elastic scattering data which allows to compare the measured momentum to the one predicted by the angles and exploiting the overconstrained kinematics. The prediction is valid for the momenta of the particles at the vertex. In [8] the analysis is done using the tracks for a fit without the beam point. This only allows to reconstruct the momentum in the TPC gas. A correction for the energy loss of the particle before entering the TPC is applied.

CDP has analysed the data of the hydrogen target only in the course of this data comparison. From the data sets made available to the SPSC, it was possible to produce figures similar to the one in [8]. Fig. 3a) shows the difference of predicted and measured mean inverse p_t as a function of the predicted p_t and Fig. 3b) the resolution for a Gaussian fit wihtin $\pm 1.5\sigma$ around the peak. The measured momentum agrees with the prediction momentum within $\pm 2\%$. The point at the lowest momentum is lower that for the other momenta. This is presumably due to the large energy loss of the scattered proton in the material before the TPC. The energy loss leads to an asymmetric depletion of the resolution function of large proton scattering angles and this causes an asymmetric depletion of tracks with small predicted transverse momentum.

The relative resolution of about 10 % is much better than the one shown in [8] (30%). A direct comparison is, however, not possible since the analysis in [8] is based on track fits without vertex constrained. A worse resolution is therefore expected and firm conclusions could only been drawn from a direct comparisons of the same tracks.

In conclusion, both groups claim an uncertainty of the absolute momentum scale of $2-3$ %. However, differences between $5-15$ % of the momenta of the same reconstructed tracks have been found. It was not possible to resolved this contradiction by comparing the tracks from the elastic scattering data, since the necessary information has not been provided by the OH group.

Comparison of Cross-Sections

Fig. 4 shows the cross-section provided by the CDP group as requested in the SPSC proposal. Shown is the pion and proton cross-section as a function of the inverse transverse momentum in bins of polar angle. The negatively charged tracks are shown in the negative transverse momentum range, the positive ones in the positive range.

Fig. 5 shows as closed circles the OH cross-sections as published in their recent analysis [9] as a function of the track momentum[2] . Since CDP provided the mean $sin\theta$ and $sin^2\theta$

[2]The numbers used here are a bit different than the ones in [9], since they have been obtained from

values for each θ and p_t bin, it was possible to calculate from the cross-section shown in Fig. 4 the cross-section corresponding to the OH analysis. The result is shown as open circles in Fig. 5. Large differences are seen between the two analyses.

To quantify these differences, we approximated the transformed CDP cross-sections using a spline and the integrated CDP cross-sections in the OH momentum bins, where possible. The ratio of the pion cross-sections of the two analyses is shown in Fig. 6. For all polar angles large differences between approximately 10 % to 50 % are observed. The largest differences of up to a factor of 2 are found in the forward region.

The cross-section of the CDP group only contains statistical uncertainties (as the requested in the SPSC proposal). In certain bins some uncertainty might be introduced by the procedure to transform the cross-section from transverse momentum to momentum.

OH claims a statistical uncertainty between $0.4 - 1.1$ % depending on the bin. The systematic error is dominant and ranges between $3.1 - 8.8$ %. The full uncertainty is shown in Fig. 5. In Fig. 6 no uncertainty is shown.

If one takes the systematic uncertainties as an indiction of the uncertainties CDP would obtain, the differences between the cross-section obtained by OH and CDP are larger than the systematic uncertainties.

In particular in the forward region, the difference between the cross-section seems larger than one would expect from the track-to-track comparison. The strong dependence on the polar angle is puzzling.

Conclusions

The data comparisons reveal clear differences at the level of the reconstructed track momenta. The cross-sections as published by OH and as inferred from the cross-sections requested for the data comparisons of CDP show discrepancies much larger than the quoted systematic uncertainties. These discrepancies can only be due to the different data correction procedures applied by the two groups, OH and CDP. The difference can not be accommodated by a simple normalisation and must be due to effects modifying the shape like track momentum reconstruction, efficiency, particle identification or acceptance corrections.

The disagreement between the transverse momenta of the identified tracks is similar with the disagreement already found in the RBH report based on comparisons of distributions of inverse transverse track momenta.

There is no dependence of the track differences as a function of the time when the event was collected in the PS spill. Comparison based on the hydrogen data comparison could not be included in the present report as the required information has not been provided by one of the groups. The hydrogen data provided by CDP are consistent with the uncertainty they quote on the momentum scale.

Under normal circumstances all the discussions which took place at the SPSC level should have happened within the Harp collaboration. The SPSC continues to encourage the Harp collaboration to investigate the source of the discrepancy within the collaboration.

all events in the spill. Therefore a larger data set has been used.

APPENDIX A: The Proposal for Data Comparisons

In the following the proposal made by the SPSC to the two analysis group of the Harp collaboration is reproduced (document 2nd of August):

In view of the forthcoming annual review of the HARP experiment at the next SPSC meeting and in view of the wish of the main funding agencies to compare results of the two Harp groups on a common data set, we would like ask you to provide us with the following information on the 24.9.2007 latest.

We would like to compare cross-section (1) and tracks (2) on the pBe +8.9 GeV proton sample. In addition, it would be interesting to compare the π^+ and the π^- Be sample at 8 GeV to compare effects due to the reversed magnetic field:

1) *We would like to compare double differential cross-sections in bins of the polar angle θ and the signed inverse transverse momentum Q/p_t. Signed inverse momentum distributions have already been compared on raw tracks in the "Report of the Harp review board" and a considerable disagreement has been found between the two groups. By pushing this comparison to cross-sections the impact on forthcoming cross-section measurements can be quantified.*

   We propose to compare:

   1. *raw number of tracks*
   2. *number of the sub-samples of pions and proton candidates*
   3. *final cross-sections for pions and protons*

   As bins in polar angle we propose the theta bins of the HARP paper on the proton Tantalum data set (hep-ex/0706.1600v1), i.e.

   $$0.35,\ 0.55,\ 0.75,\ 0.95,\ 1.15,\ 1.35,\ 1.55,\ 1.75,\ 1.95,\ 2.15$$

   and as inverse signed transverse momentum bins 100 bins from -10 to 10 GeV^{-1}. The cross-section should be inclusive, i.e. tracks in θ and Q/p_t bins are counted.

   To produce the cross-sections the two groups are free to choose their analysis strategy. This means that only cross-sections can be compared in the strict sense.

   Cross-sections should be given in the form of plots and numbers in tables (or something readable in root).

2) *We would like to compare individual tracks between the two groups in the Be +8.9 GeV proton sample and in the hydrogen data with positive and negative beam polarity for the 3 GeV beam over the full detector acceptance (full available θ and p_t range).*

   Both groups should provide Ascii-files (or something readable in root) with the following information:

   Event-nr, track-nr, p_t, θ, ϕ, particle-id hypothesis, number of hits, Cutflag, corr-factor, $\mathrm{mom}_{\mathrm{pred}}$,

   where:

   - *The signed p_t, θ, ϕ should correspond to the best estimate of the group for the momentum at the vertex.*

- *particle-id hypothesis says whether the track is considered an electron, pion or proton*
- *CutFlag is a flag that gives the information whether the track is accepted in the final analysis (i.e. satisfies all analysis cut). CutFlag=0 means track is accepted, positive number could be used to indicate why the track has not been accepted.*
- *corr-factor is the correction factor to go from the momentum in the gas to the momentum at the vertex*
- $\mathrm{mom}_{\mathrm{pred}}$ *is the predicted momentum from the polar angle measured in the TPC (as done in the Harp missing mass analysis)*

To prepare the track-to-track comparisons we would like to ask both groups to provide us with a first table by 31.8.2007. This data sample will remain absolutely confidential and will only be used to develop the code that does the comparisons and, if necessary, to add further refinements.

APPENDIX B: Received Data Sets

Received Data Sets from CDP

From the CDP analysis group all required information was received, i.e. the raw particle distributions as in Q/p_t bins and the cross-sections of pion and protons in the pBe-data set. Furthermore, we received spectra for the data set of positively charged pions and negatively charged pions on the Beryllium target. In these data sets the magnetic field of the TPC was reversed.

We also received data for all individual tracks passing the CDP analysis cuts for the pBe sample and for the data set of positively charged pions and negatively charged pions as well as of positively charged protons on the hydrogen target.

For each track the number of hits, the transverse momentum, polar and azimuth angle under the particle hypothesis that the track be a pion, a proton or a electron were given. These quantities were provided for the fit of the momentum in the gas and for the fit for the momentum at the vertex. The ratio of the transverse momenta for the fit of the gas and the one at the vertex corresponds to the energy loss of the particle in the material before the TPC. For the elastic scattering sample of the hydrogen data also the predicted momentum was given.

Only tracks within the OH fiducial reconstruction volume were provided, i.e. track with azimuthal angles within $2.7 < \phi < 3.7$ rad and $\phi > 5.7$ and $\phi < 0.55$ rad were excluded. These ranges corresponds to the horizontal ranges 2 and 5 of the TPC, for which CDP says that it is difficult to work out corrections. In addition, the regions in between TPC sectors are taken out. The polar angle range is limited to $0.35 < \theta < 2.15$ rad. Only tracks with a transverse momentum at the vertex with $p_t > 0.1$ GeV are considered in the analysis. CDP includes all events in the spill for the track reconstruction.

Received Data Sets from OH

On 26th Sep 2007 one preliminary data set based on the run 17891 of the pBe data set was received. One data set was provided where all tracks identified as pions and passing the OH analysis were provided and another file where only the events with one tracks were contained. The OH analysis cuts only accept events with $p < 0.8$ GeV and $p_t < 0.5$ GeV. This was the data set on which the first preliminary data comparisons shown in the SPSC83 meeting were based on.

On 4th Oct 2007 the numerical values of the published pBe cross-section, i.e. with momenta $p < 0.8$ GeV and $p_t < 0.5$ GeV and only for pions and as a function of momentum p were provided. These cross-sections are based on 231000 negatively charged pions and 294000 positively charged pions. In the cross-section analysis only the first 100 events in the spill have been considered.

On 10th Oct 2007 a more extended pBe data set based on 10 runs (17887-17997) containing only events with one track has been provided. Finally, on 14th Nov 2007, events with one track in the full pBe data set of the was made available to the SPSC.

This (as the previous data sets) were done under the following conditions:

1. usual analysis OH cuts, i.e. tracks with ≥ 12 hits in the TPC, $p < 0.8$ GeV and $p_t < 0.5$ GeV for identified pions

2. only proton beam

3. momentum "refit" using vertex constraint

4. dynamic and static distortion corrections applied, i.e. all events in the spill are used

5. no energy loss information of the track before the TPC

We note that OH has provided only partially the required information. The cross-sections and the track data are given for pions only and in a restricted kinematic range. The hydrogen data are so far missing.

OH says that they cannot provide tracks reconstructed at the vertex because in the analysis they apply a momentum and polar angle dependent average correction and this information track by track is not available. The data set with the momentum as reconstructed in the TPC gas has been promised, but not received.

References

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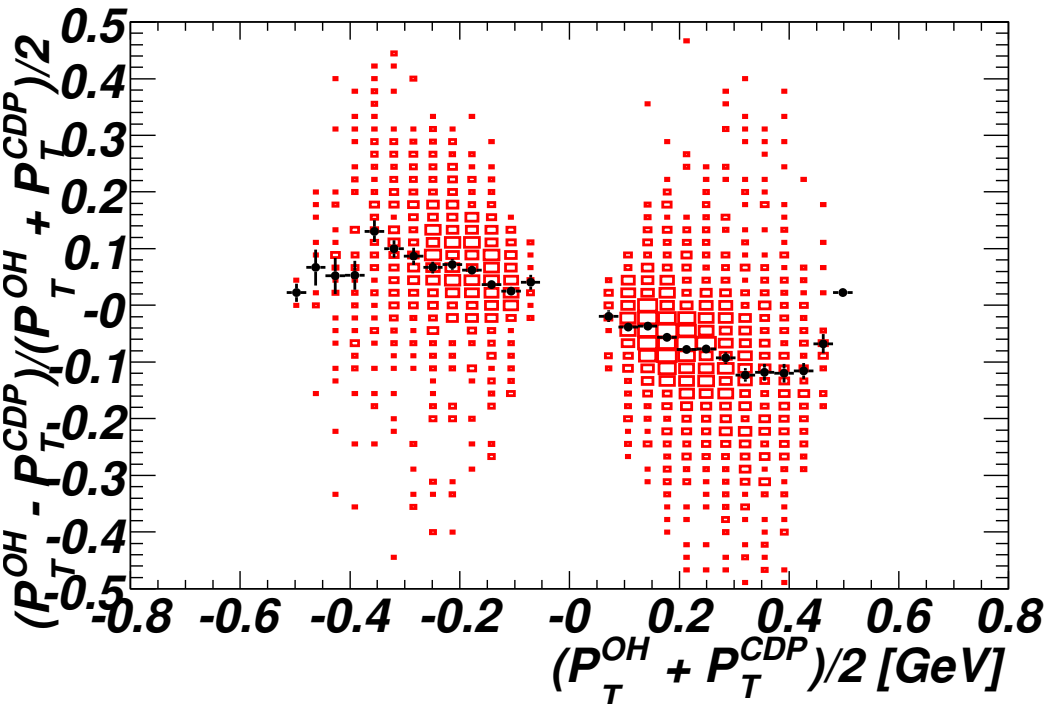


Figure 1: Normalized difference of the two momenta as reconstructed by the two different groups, Official Harp (OH) and CDP, as a function of mean of the two momenta values. The transverse momenta of the negatively (positively) charged tracks are shown in the negative (positive) transverse momentum range.

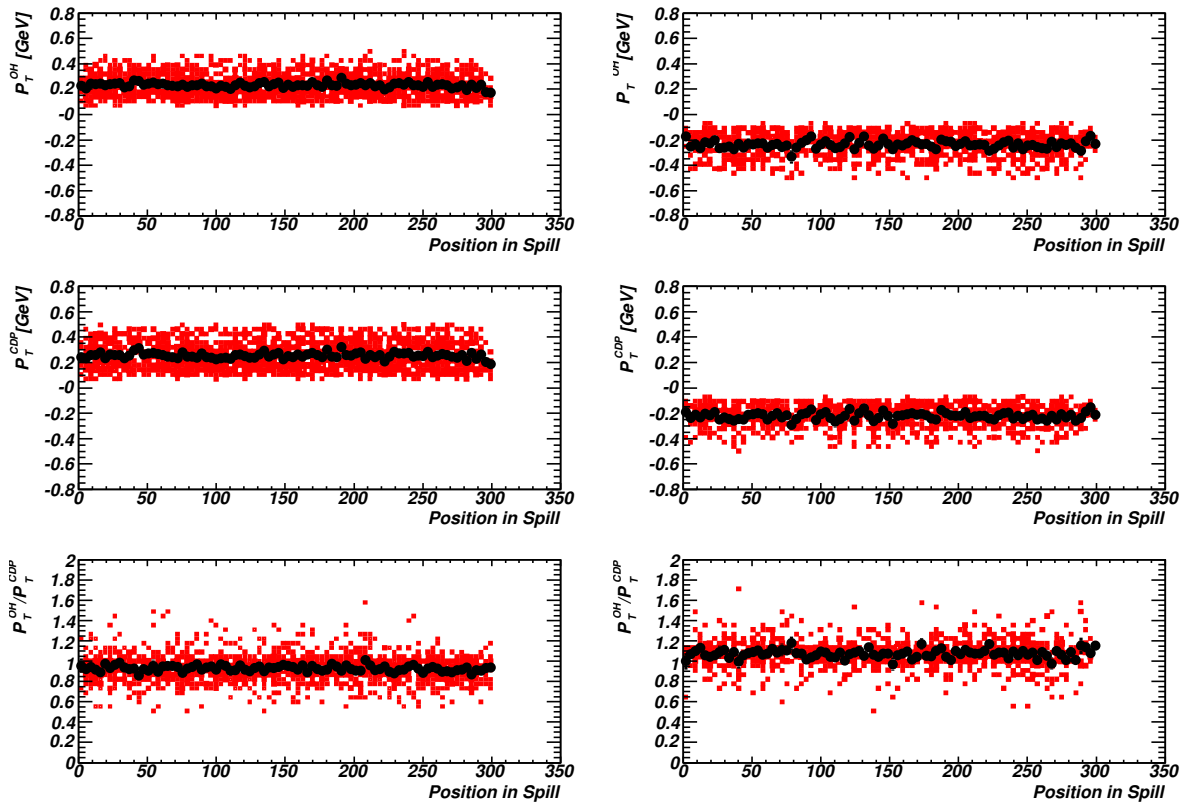
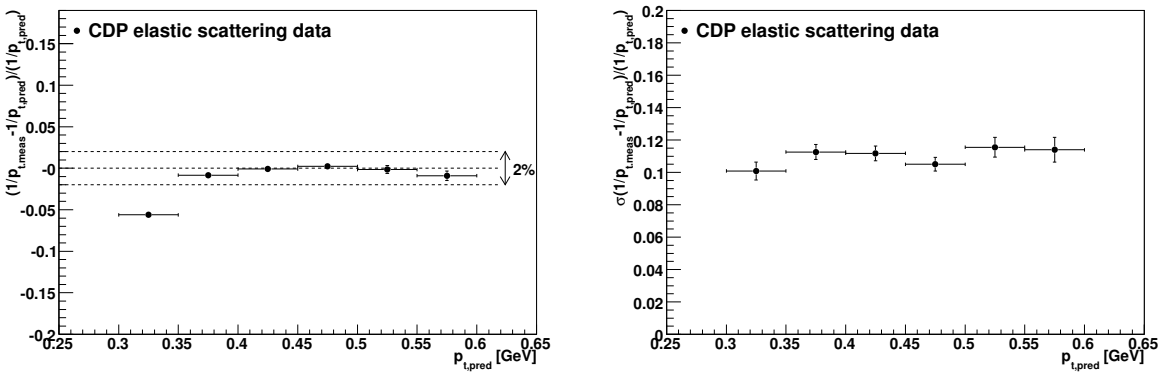


Figure 2: Transverse track momenta of the OH (top) and the CDP (middle) analysis as a function of the event position in the PS spill. In the bottom the ratio of the transverse momenta is shown. Positively charged tracks are shown on the left, negatively charged tracks are shown on the right.



a) b)

Figure 3: a) Mean measured minus predicted inverse transverse momentum divided by the predicted inverse transverse momentum as a function of the predicted transverse momentum for elastic scattering events in the proton hydrogen target. b) resolution of the quantity shown in a).

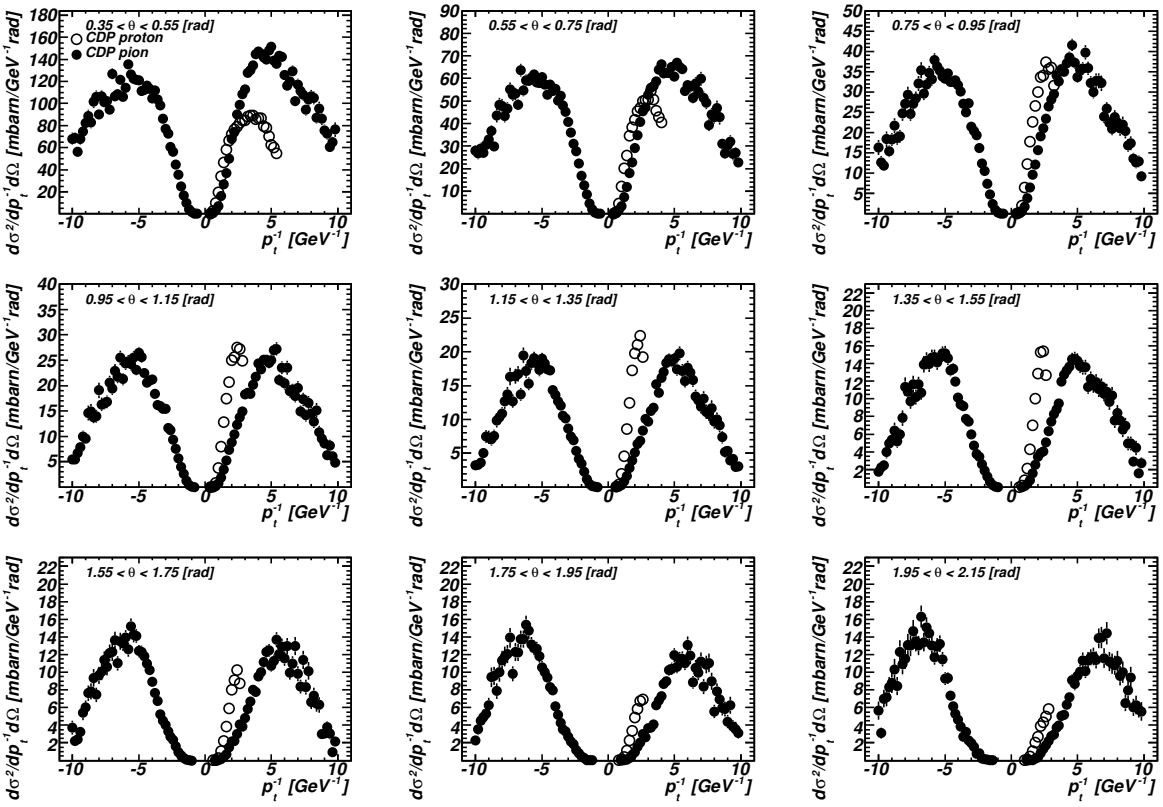


Figure 4: Measured cross-sections by the CDP group for pions and protons for the pBe 8.9 GeV data sets as a function of the inverse transverse momentum and in bins of polar angles. The transverse momenta of the negatively (positively) charged tracks are shown in the negative (positive) transverse momentum range.

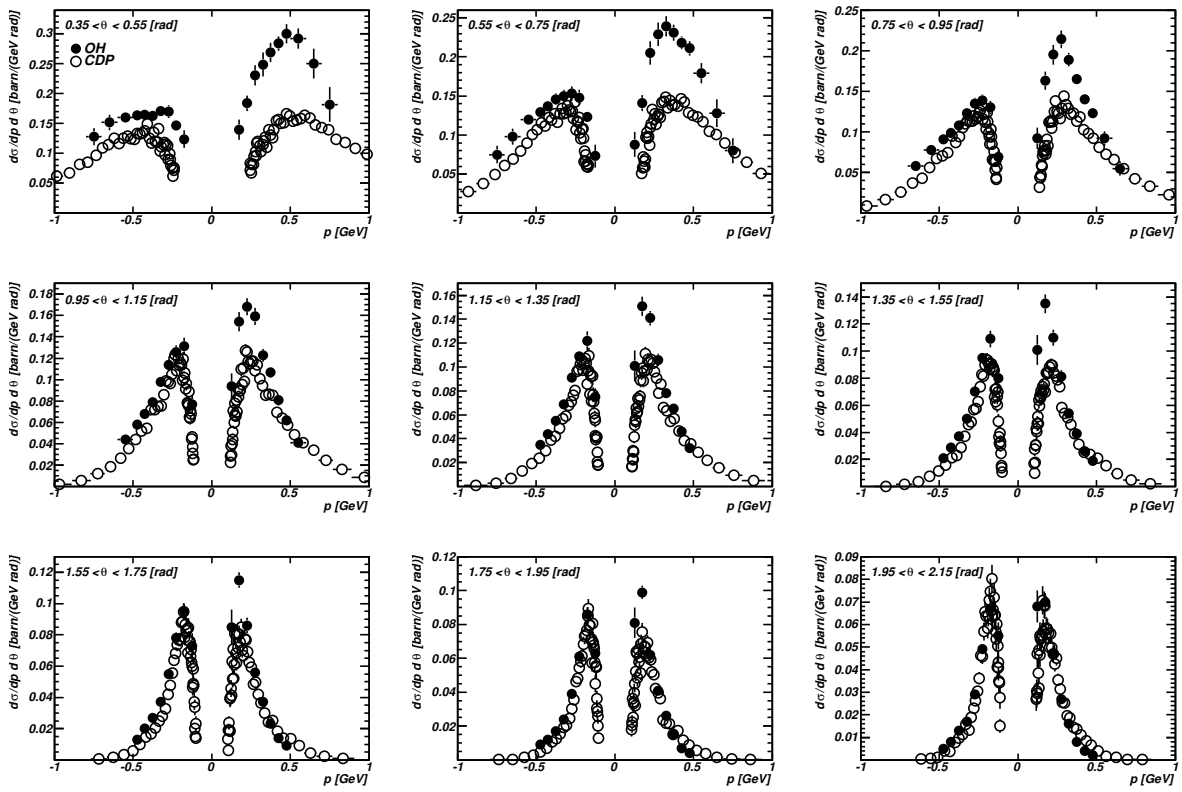


Figure 5: Pion cross-sections comparison for the pBe 8.9 GeV data set between the two groups for pions, OH and CDP, as a function of the track momentum and for different polar angle ranges. The OH cross-sections correspond to the published ones. The CDP cross-sections have been derived from the cross-sections provided for the data comparisons. The transverse momenta of the negatively (positively) charged tracks are shown in the negative (positive) transverse momentum range.

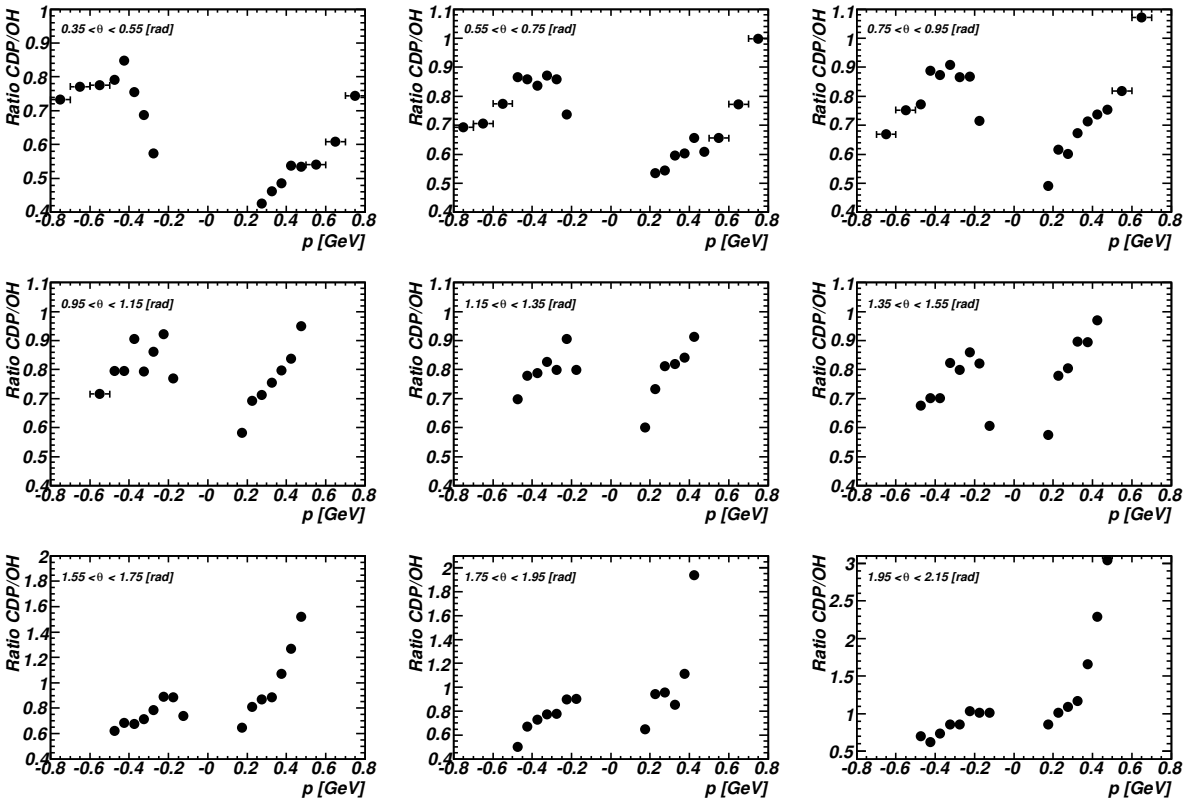


Figure 6: Ratio of the two pion cross sections for the pBe 8.9 GeV data set and for the two groups, Official HARP (OH) and CDP as a function of the momentum and for different polar angle ranges. No uncertainties are included in the figure. The transverse momenta of the negatively (positively) charged tracks are shown in the negative (positive) transverse momentum range.