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Comments on TPC and RPC calibrations reported by the HARP collaboration

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ABSTRACT: The HARP Collaboration recently published calibrations of their TPC and RPC detectors, and differential cross-sections of large-angle pion production in proton-nucleus collisions. We argue that these calibrations are biased and cross-sections based on them should not be trusted.

KEYWORDS: Gaseous detectors; Time projection chambers; Timing detectors; Instrumentation and methods for time-of-flight (TOF) spectroscopy.

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Contents

1. Why these ‘comments’?

The larger part of the HARP Collaboration (hereafter referred to as ‘HARP’ or ‘authors’) recently published a paper entitled ‘Momentum scale in the HARP TPC’ [1]. Therein, they claim that they calibrated the momentum scale of the HARP TPC with a precision of 3.5%. They published a paper entitled ‘The time response of glass resistive plate chambers to heavily ionizing particles’ [2]. Therein, they claim a 500 ps time advance of protons with respect to minimum-ionizing pions in the HARP multi-gap timing RPCs [3]–[6]. Further, they published differential cross-sections of pion production on Ta [7], C, Cu and Sn [8], and Be, Al and Pb [9] targets.

We, also members of the HARP Collaboration and referred to as ‘HARP-CDP’,[1] have not signed the above-cited papers because we are unable to take responsibility for the reported calibrations and physics results.

We shall argue that there is no reason to invoke a new detector physics effect in multi-gap timing resistive plate chambers (RPCs), yet there are good reasons why HARP’s time projection chamber (TPC) and RPC calibrations should not be trusted, and also cross-sections of large-angle pion production on nuclear targets based on them.

[1] CDP stands for CERN-Dubna-Protvino

2. HARP's biased p_T scale and bad p_T resolution

The performance of the HARP TPC was affected by dynamic track distortions that were primarily caused by the build-up of an Ar^+ ion cloud during the 400 ms long spill of the CERN Proton Synchrotron. This ion cloud emanates from the TPC's sense wires and drifts across its active volume toward the high-voltage membrane.[2]

These dynamic track distortions increase approximately linearly with time in the spill. Their size in the $r{\cdot}\phi$ coordinate typically reaches 15 mm, at small radius, at the end of the spill. That exceeds the TPC's design $r{\cdot}\phi$ resolution of 500 μm by a factor of 30 and therefore requires very precise track distortion corrections.

The authors published two quite different analysis concepts to deal with dynamic track distortions.

The first concept is to use only the first 100 events out of typically 300 events in the whole accelerator spill. From the 'physics benchmark' of proton-proton elastic scattering they claim that dynamic distortions do not affect the quality of the first 100 events, and hence dynamic track distortions need not be corrected at all. The second concept is a correction of the distortions based on a specific radial dependence of the charge density of the Ar^+ ion cloud.

In the HARP TPC, with a positive magnetic field polarity, dynamic distortions shift cluster positions such that positive tracks are biased toward higher p_T (conversely, negative tracks are biased toward smaller p_T). The authors chose — in principle correctly — to fit TPC tracks with the constraint of the beam point because the increased lever arm permits an approximate doubling of the p_T precision. While the beam point remains unaffected, the cluster positions get shifted by dynamic distortions. Assigning a sufficiently small position error to the beam point renders its weight (the inverse error squared) in the track fit so large that positive tracks get biased toward lower p_T, i.e., the trend of the bias is even reversed with respect to the fit without beam point. This — artificially enforced — decrease of the p_T of positive tracks with the time in the spill is demonstrated in the right panel of figure 15 in ref. [7].

This makes clear that the weight assigned in the track fit to the beam point is of paramount importance. Despite this importance, the weight of the beam point has never been quantitatively stated by HARP.

Because the bias has different size and opposite sign depending on whether the beam point has been used in the fit or not, we recall that in the cross-section results reported by HARP the fit with the beam point has been used, but not in all their 'physics benchmarks'.

There is no claim that HARP's p_T scale is wrong *per se*. Rather, we claim that HARP's initially (more or less) correct p_T scale develops a bias that increases about linearly with the time in the spill. This bias is a direct consequence of the development of dynamic track distortions with time in the spill. This means that the percentage of the claimed bias is not constant but proportional to p_T. This means that the claimed bias is *a priori* different from data set to data set since dynamic distortions are different in different data sets. Therefore, conclusions on a bias in one data set (e.g., elastic scattering of 3 GeV/c protons on protons at rest) cannot be applied quantitatively to other data sets.

[2]The cause of this hardware problem, the physics of the track distortions, their quantitative assessment, and their corrections, are described in refs. [10]–[13].

In their first analysis concept (that underlies the cross-sections published in refs. [7]–[9]), the authors fit the distorted track together with the undistorted beam point. The beam point is assigned a weight *'similar to a TPC hit'* [7] which implies that the beam point's error is constant and not what it must be: the convolution of the errors of two extrapolations to the interaction vertex, of the beam particle's trajectory and of the secondary track's trajectory. Primarily because of the momentum-dependence of multiple scattering, the correct error of the beam point varies considerably for different beam momenta and from track to track. The authors fit a circle to distorted TPC cluster positions that deviate in a radius-dependent way by up to 5 mm from their nominal positions, and to the undistorted beam point that has a wrong weight in the fit. Under such circumstances, the fit of p_{T} cannot be unbiased.

How large is the bias in this concept? The authors give the answer themselves in the upper left panel of figure 17 in ref. [7] where they show the measurement of the specific ionization $\mathrm{d}E/\mathrm{d}x$ of protons as a function of momentum. One reads off that an 800 MeV/c proton is measured with a momentum of 650 MeV/c. From this $\sim$20% scale error for positive particles at $p = 800$ MeV/c, one infers a scale error of $\sim$20% in the opposite direction for negative particles. Expressed as a shift of q/p_{T} (where q denotes the particle's charge), the bias is of order $\Delta(q/p_{\mathrm{T}}) \sim +0.3\ (\mathrm{GeV}/c)^{-1}$ for positive magnet polarity.

The effect of this bias is well visible in a comparison of HARP's q/p_{T} spectrum with the one from our group, see figure 10 in ref. [14].

In their second analysis concept, the authors apply a correction of dynamic track distortions and use data from the whole spill. The correction stems from the electric field of a charge density of Ar^{+} ions that falls with the radial distance R from the beam like $1/R^2$ [15].

Is a $1/R^2$ distribution realistic? The answer is no. The radial charge distribution depends on beam energy, beam polarity, beam intensity, beam scraping, target type, photon conversion in materials and spiralling low-momentum electrons. Therefore, the correction algorithm cannot be expected to work with adequate precision.

This expectation is confirmed by the difference between the data shown in figure 2 (right panel) in ref. [1] and the same data analysed by our group, see figure 1 that shows the q/p_{T} spectra of secondary particles from the interactions of $+8.9$ GeV/c protons in a 5% λ_{abs} Be target.

The difference of the spectra is again consistent with a HARP bias of $\Delta(q/p_{\mathrm{T}}) \sim +0.3\ (\mathrm{GeV}/c)^{-1}$ with respect to our results from the same data.

The authors claim [3, 5, 7] a resolution of

$$\sigma(p_{\mathrm{T}})/p_{\mathrm{T}} = (0.25 \pm 0.01)\, p_{\mathrm{T}} + (0.04 \pm 0.005)\ (\mathrm{GeV}/c)^{-1}$$

or, approximately, $\sigma(1/p_{\mathrm{T}}) \sim 0.30\ (\mathrm{GeV}/c)^{-1}$. This claimed resolution refers to fits with the beam point included (in fits without the beam point the resolution is around 0.60).

The information given by the authors on the experimental p_{T} resolution for fits with the beam point included (on which all reported cross-sections are based) is very scarce. It consists of a mere three points in figure 9 in ref. [7]. One reads off the resolution $\sigma(1/p_{\mathrm{T}}) \sim 0.5\ (\mathrm{GeV}/c)^{-1}$. Although this resolution represents a convolution with the $\mathrm{d}E/\mathrm{d}x$ resolution, it is hardly compatible with the claimed 0.30 $(\mathrm{GeV}/c)^{-1}$.

Confirmation that the p_{T} resolution is much worse than claimed is given in refs. [5] and [6]. Therein, the RPC time-of-flight resolution of $p \sim 200$ MeV/c pions that is equivalent to the p_{T}

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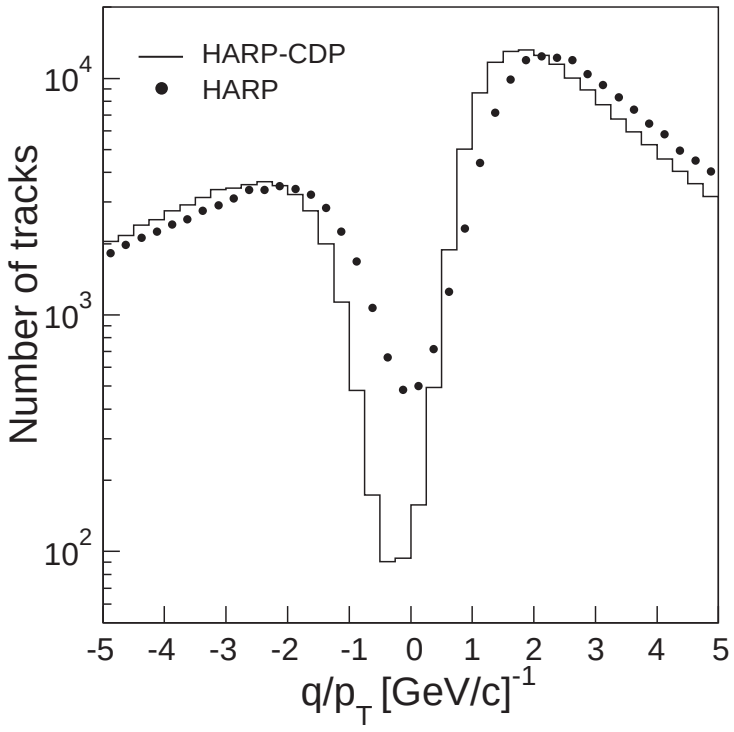

Figure 1. q/p_{T} spectra of secondary particles from the interactions of $+8.9\,\mathrm{GeV}/c$ protons in a 5% λ_{abs} Be target; the black points are taken from figure 2 in ref. [1], the histogram represents the HARP-CDP analysis of the same data.

resolution in the TPC is quoted as 260 ps. As succinctly proven in refs. [16] and [17], a time-of-flight resolution of 260 ps of pions with $p_{\mathrm{T}} = 200\,\mathrm{MeV}/c$ is equivalent to a resolution $\Delta p_{\mathrm{T}}/p_{\mathrm{T}}$ of 46%, which is worse by a stunning factor of 4.6 than the claimed resolution.[3]

Figure 1 also proves that HARP's p_{T} resolution is much worse than claimed. The depth of the dip at $q/p_{\mathrm{T}} = 0$ reflects directly the p_{T} resolution, and HARP's dip is considerably more shallow than ours.

The difference between HARP's and our q/p_{T} spectra is consistent with a HARP bias of $\Delta(q/p_{\mathrm{T}}) \sim +0.3\ (\mathrm{GeV}/c)^{-1}$, and a HARP resolution of $\Delta(q/p_{\mathrm{T}}) \sim 0.55\ (\mathrm{GeV}/c)^{-1}$.

The discrepancy between the q/p_{T} spectra means that cross-sections are different by factors of up to two.

The authors claim that results from the second concept of correcting dynamic track distortions and using the data from the full spill, is in *'excellent agreement'* [1] with results from the first concept of not correcting for dynamic track distortions and using the first 30% of the spill only.

We agree that there is no difference in the results from these two concepts. Both are affected by a comparable p_{T} bias and a comparably bad p_{T} resolution. That the biases in HARP's two analysis concepts happen to have the same size and sign, is accidental.

[3]This result is obtained when taking literally two more claims by HARP: a beam-particle timing resolution of 70 ps and an RPC timing resolution of 141 ps; however, it is more likely that the overall discrepancy of 4.6 stems from all three sources and not only from the bad p_{T} resolution.

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3. HARP's '500 ps effect'

The authors reported in ref. [3] a 500 ps advance of the RPC timing signal of protons with respect to the one of pions. They confirmed their discovery in three subsequent publications [4]–[6], and most recently in ref. [2]. In the latter paper, the authors acknowledge that *'... it has been pointed out that a similar behaviour can be obtained when a systematic shift in the measurement of momentum is present'* but conclude that *'Momentum measurement biases in the TPC, if any, have been eliminated as possible cause of the effect.'*

In stark contrast, our group's interpretation of the authors' result is that their p_{T} scale is systematically biased by $\Delta(1/p_{\mathrm{T}}) \sim 0.3$ (GeV/c)$^{-1}$ which leads to the prediction of a longer time of flight for non-relativistic protons (whereas the time of flight of relativistic pions is unchanged). In turn, if the proton momentum is considered correct, the RPC timing of protons would appear to be advanced.

The relevant experimental variable is the proton time of flight as measured by the RPCs minus the time of flight calculated from the proton momentum.

Figure 2 shows HARP's respective data, taken from their most recent papers [1] (version 1 dated 17 Sep 2007) and [2] (dated 24 Sep 2007), data which are based on their p_{T} measurement in the TPC and hence affected by a bias in the TPC p_{T} scale.[4] Also shown are data from the calculated momentum of recoil protons in elastic proton-proton scattering, published by HARP in ref. [2], data that are not affected by a bias in the p_{T} measurement in the TPC.

All three data sets should show the same time advance but disagree seriously with each other. This hardly supports the notion of a novel detector physics effect.

Figure 3 shows the comparison of HARP and HARP-CDP data on the timing difference of recoil protons from elastic proton-proton scattering. There is good agreement between the data which confirms that both HARP and HARP-CDP correctly calibrated the RPCs with relativistic pions. The data from elastic proton-proton scattering are consistent with the theoretically expected time advance (for the calculation of the theoretically expected time advance, we refer to our pertinent discussion in ref. [18]).

Figure 4 shows the comparison of HARP and HARP-CDP data for the case that the p_{T} reconstruction in the TPC is used to determine the time of flight of the recoil proton. While the HARP-CDP data confirm the results from proton-proton elastic scattering, the HARP data are inconsistent with these results.

Figure 5 shows that HARP's time advance of protons (black points; data from ref. [2]) is satisfactorily explained by a simulation of the time advance that results from a bias $\Delta(1/p_{\mathrm{T}}) \sim 0.30$ (GeV/c)$^{-1}$.

There is no need and no room for a novel detector physics effect.

4. HARP's 'physics benchmark'

The authors make extensive use of elastic scattering of 3 and 5 GeV/c protons and pions on protons at rest to support the claim that their p_{T} scale is correct within 3.5%. In the following we show that their arguments are not conclusive.

[4] All data shown in this Section refer to the RPC padring 3, i.e., to tracks with polar angles $\Theta \sim 55$–80°.

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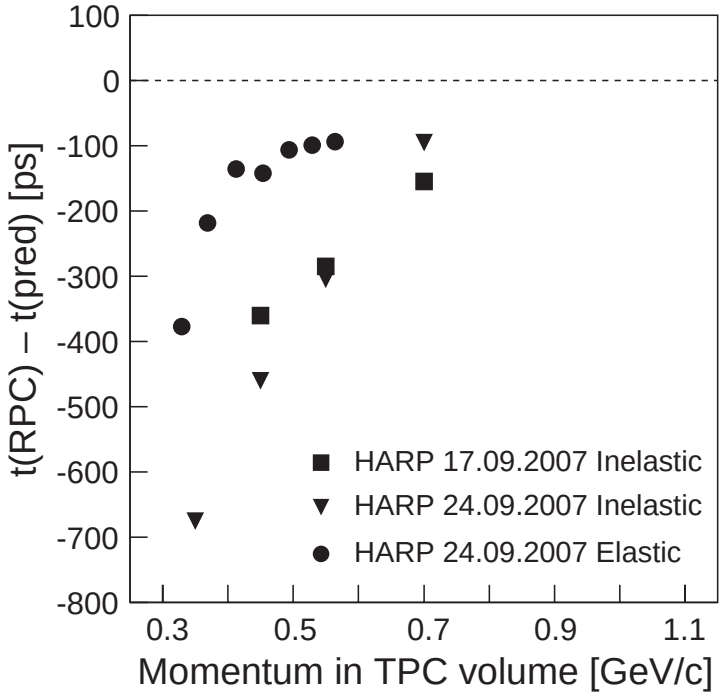

Figure 2. Time advance of protons (HARP data): time of flight measured by the RPCs minus the time of flight calculated from the momentum measured in the TPC ('Inelastic') and calculated from the kinematics of proton-proton elastic scattering ('Elastic'), respectively.

4.1 Fits of recoil protons with and without beam point

In stark contrast with our claim of a positive bias in q/p_{T} in fits with the beam point, and a negative bias in fits without the beam point, the authors write *'The ratio of the unconstrained and constrained fits was checked to be unity with a high precision'* and show figure 5 (right panel) in ref. [1] in support of this claim. For its importance, this figure is reproduced in the left panel of our figure 6.

One would expect to see a Gaussian distribution in the authors' variable $(p1-p2)/p2$ ($p1$ is the momentum from a fit without the beam point, and $p2$ the momentum from a fit with the beam point). Since the claimed resolution with the beam point included is 0.30, and without the beam point about 0.60, the Gaussian should have a $\sigma \sim 0.50$. Their plot shows something very different, though: a narrow spike centred at zero, on top of a broad distribution. The authors interpret this as evidence that the two fits give the same result.

The spike at zero is an artefact which stems from the assignment of a wrong error in the $r{\cdot}\phi$ position of clusters: the authors multiply the $r{\cdot}\phi$ error of each TPC cluster with $\cos 2\phi$ (a conceptual mistake of their algorithm as discussed in ref. [19]) and hence produce nearly infinite weights of clusters close to the ϕ angles 45°, 135°, 225° and 315°. In comparison with these wrong large weights, the weight of the beam point becomes negligible, which explains that the fits of tracks close to the singular ϕ angles yield the same p_{T} with and without the beam point.

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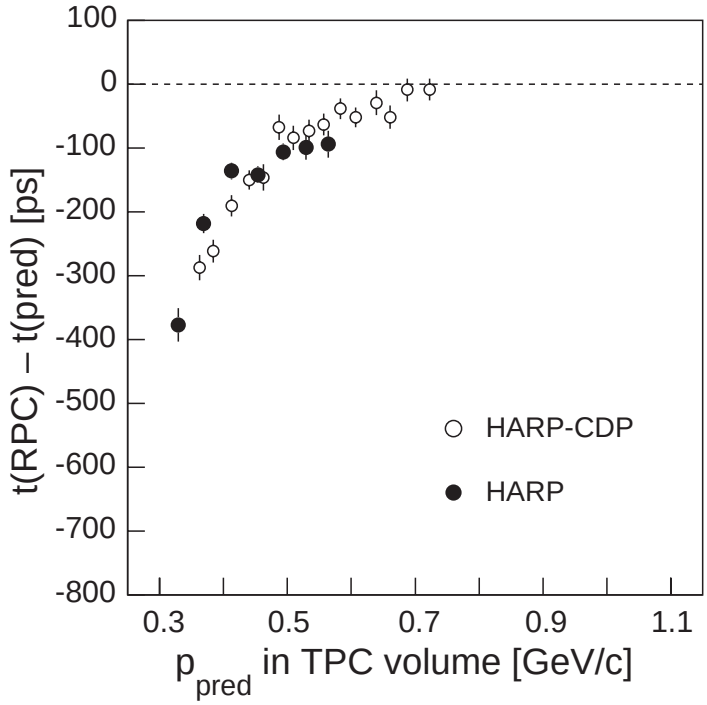

Figure 3. Time advance of protons (HARP data and HARP-CDP data): time of flight measured by the RPCs minus the time of flight calculated from the kinematics of proton-proton elastic scattering.

The expected Gaussian distribution with σ of about 0.50 is indeed visible in their plot: it is the broad distribution below the artifical spike. This is evident from the right panel in figure 6 which shows a simulation how the Gaussian becomes deformed by the $\cos 2\phi$ term.

We conclude that the authors did not prove that the fits with and without beam point give the same result. Rather, they proved that their track fit is seriously compromised.

4.2 Missing mass from elastic scattering

The authors write *'A fit to the distribution [of missing mass squared] provides* $M_x^2 = 0.8809 \pm 0.0025$ *(GeV/c^2)^2 in agreement with the PDG value of 0.88035 (GeV/c^2)^2 ... a momentum scale bias of 15% would produce a displacement of about 0.085 (GeV/c^2)^2 on* M_x^2*. As a result, we can conclude that the momentum scale bias (if any) is significantly less than 15%.'*

For its importance, their supporting figure 3 in ref. [1] is reproduced in our figure 7.

The authors state that the fit of the recoil protons included the beam point. But they do not give important information: which fraction of the spill was used,[5] and they do not state how the significant energy loss of protons in materials before the TPC volume was handled.[6]

Since the beam point was used, the bias in $1/p_T$ will be positive. For the typical p_T of the recoil proton of 0.45 GeV/c, we estimate from the strength of the dynamic distortions in the respective

[5] We assume that the first 100 events of the spill were used.

[6] We assume that the proton energy loss was corrected as a function of the proton momentum measured in the TPC.

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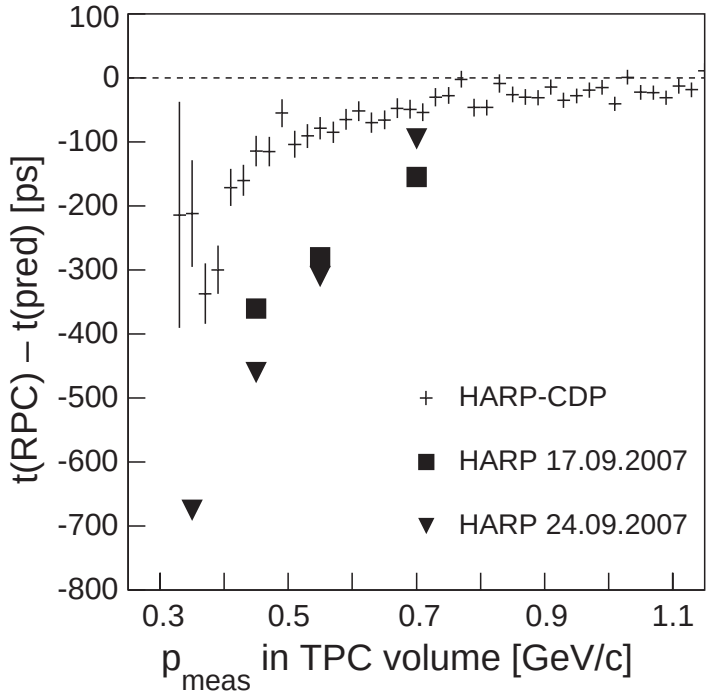

Figure 4. Time advance of protons (HARP data and HARP-CDP data): time of flight measured by the RPCs minus the time of flight calculated from the momentum measured in the TPC.

data taking a bias $\Delta(1/p_{\mathrm{T}}) \sim +0.20$ or, equivalently, $\Delta p_{\mathrm{T}}/p_{\mathrm{T}} \sim -10\%$. The difference to +15% in figure 7 is important since the missing mass squared is not Gaussian-distributed.

Figure 8 shows simulations of the missing mass squared in the elastic scattering of 3 GeV/c protons on protons at rest.

The left panel shows the difference, for a proton recoil angle of 69°, between a distribution with a resolution of $1/p_{\mathrm{T}}$ of 0.55 and no bias, and a distribution with the same resolution and a bias of +0.20. The missing mass squared distribution is less sensitive to a p_{T} bias than purported by the authors.

The right panel shows for a resolution of $1/p_{\mathrm{T}}$ of 0.55, and a bias of +0.20, the differences between the proton recoil angles of 65°, 69° and 73°, where the contributions from the three angles are weighted with their cross-sections. The sum of the three contribution may look 'Gaussian' but the central value of this 'Gaussian' cannot be taken as the physical missing mass squared.

The rather erratic nature of results from this analysis is corroborated by the fit results of the missing-mass-squared distribution published by the authors in figure 15 in ref. [3] and reported in ref. [20]. The result is 15.6σ away from the PDG value.

We conclude that the authors did not prove that their p_{T} from fits with the beam point included is unbiased, certainly not with the precision claimed by them. Rather, they proved that their analysis of missing-mass-squared distributions is too simplistic.

For comparison, we show in figure 9 our own results for the missing mass squared in the elastic scattering of 3 GeV/c protons on protons at rest, and compare them with a GEANT simulation. We

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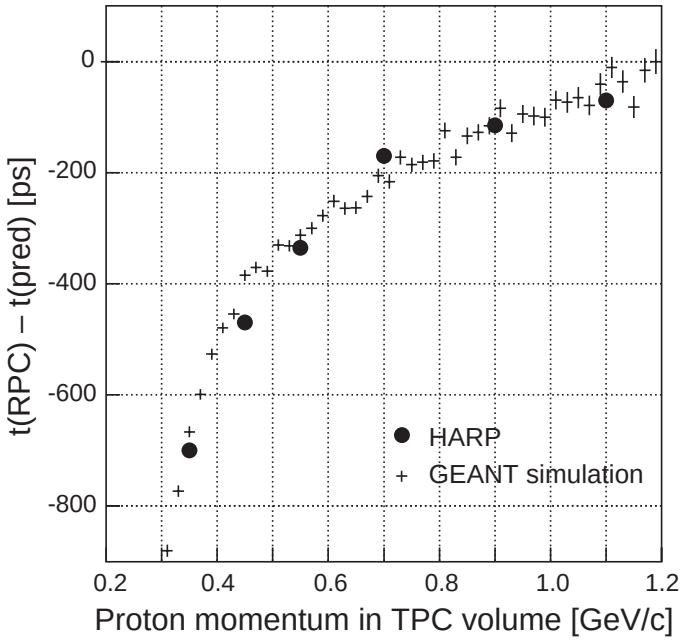

Figure 5. HARP's time advance of protons (black points; data from ref. [2]) compared with a simulation of the time advance that will result from a bias $\Delta(1/p_{\mathrm{T}}) \sim 0.30\ (\mathrm{GeV}/c)^{-1}$.

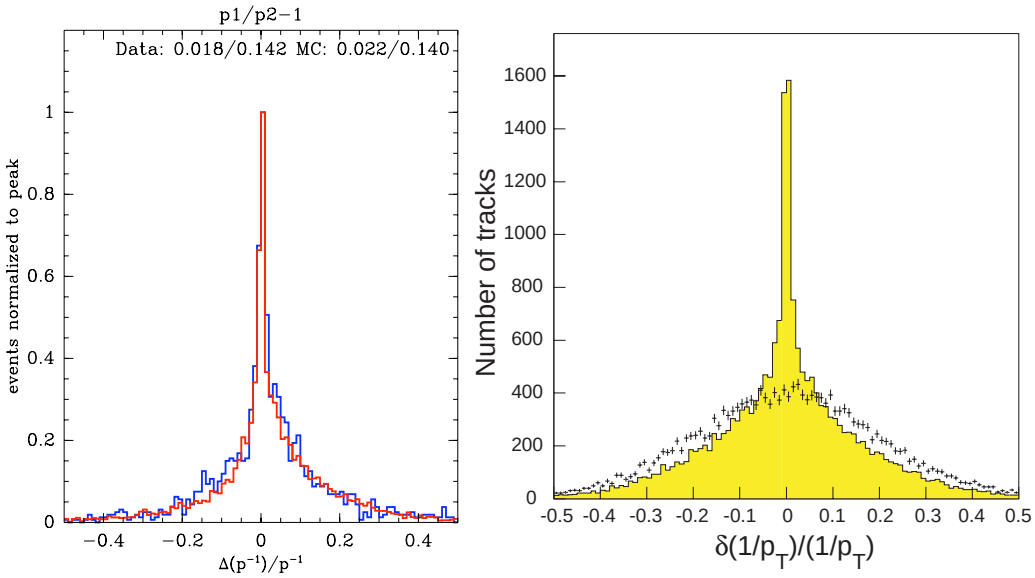

Figure 6. Left: HARP's comparison $(p1-p2)/p2$ of the fit without beam point ($p1$) and with the beam point ($p2$), for data and Monte Carlo; this figure is a copy from figure 5 (right panel) in ref. [1]; right: simulation of the expected Gaussian distribution of $(p1-p2)/p2$ (crosses) and of its deformation (shaded histogram) by HARP's $\cos 2\phi$ factor applied to the position error of TPC clusters.

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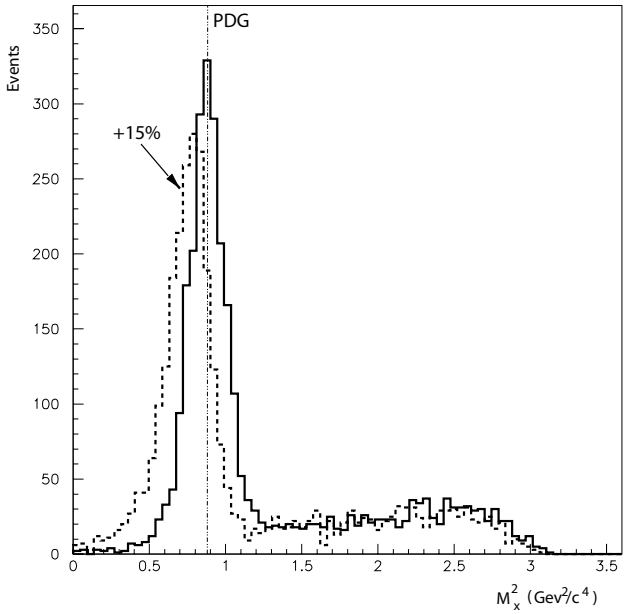

Figure 7. HARP's missing mass squared in the elastic scattering of 3 GeV/*c* protons on protons at rest; this figure is a copy of figure 3 in ref. [1].

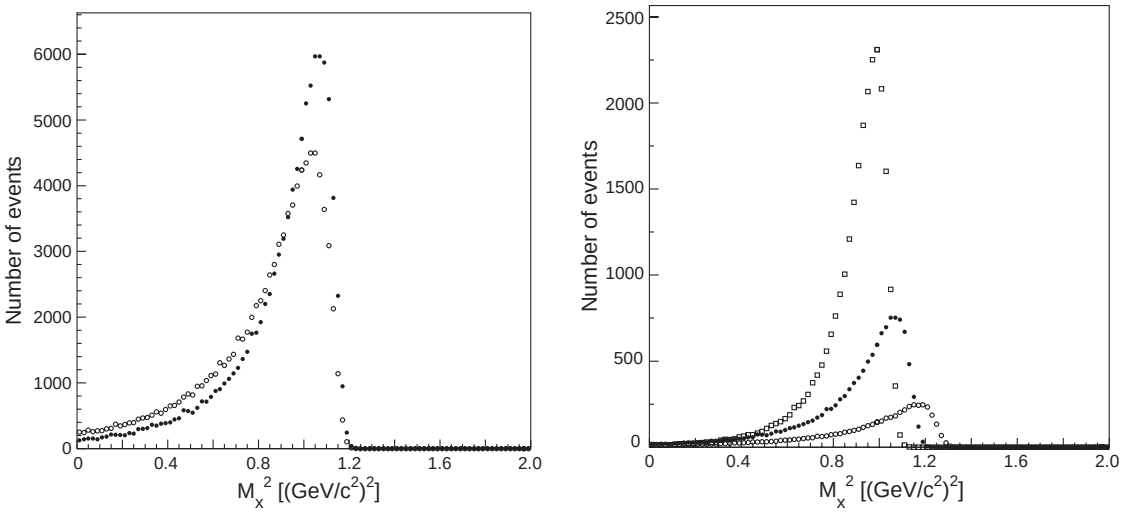

Figure 8. Simulation of the missing mass squared in the elastic scattering of 3 GeV/*c* protons on protons at rest. Left: Simulation for a recoil proton angle of 69° with a resolution of $1/p_T$ of 0.55 and no bias (open circles), with a resolution of 0.55 and a bias of +0.20 (black circles). Right: Simulation with a resolution of $1/p_T$ of 0.55 and a bias of +0.20 for proton recoil angle of 65° (open circles), 69° (full circles) and 73° (open squares).

show the data for two bins in the proton recoil angle, with a view to highlighting the differences both in shape and in rate.

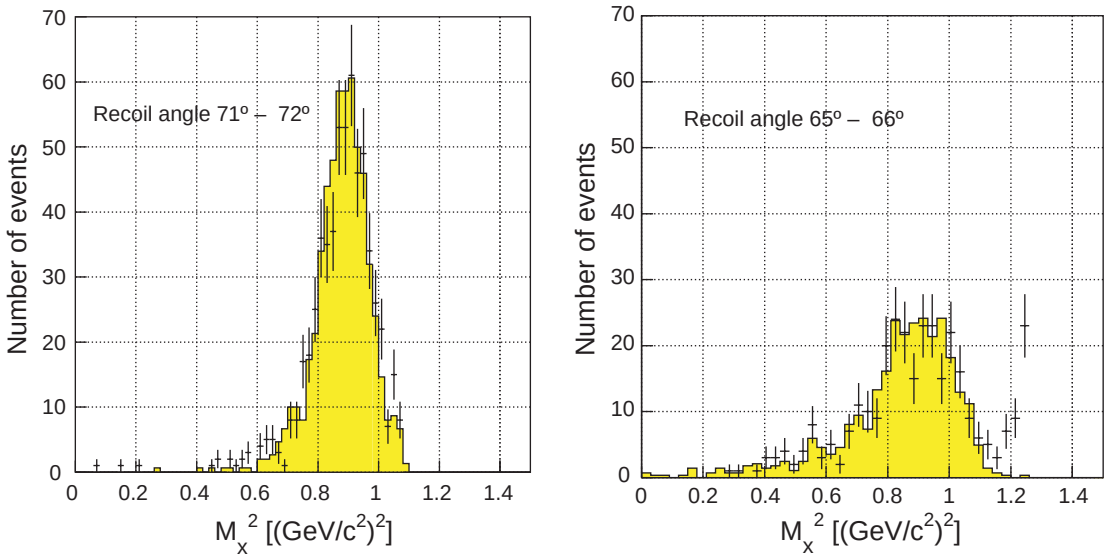

Figure 9. HARP-CDP data on, and GEANT simulation of, the missing mass squared in the elastic scattering of 3 GeV/c protons on protons at rest; data are shown as crosses, the GEANT simulation (elastic scattering events only) as shaded histograms; left: proton recoil angle between 71° and 72°; right: proton recoil angle between 65° and 66°.

4.3 p_T scale from elastic scattering

From the comparison of the momentum of recoil protons from the scattering of 3 and 5 GeV/c protons and pions on protons at rest as measured in the TPC, and as predicted from the measurement of the scattering angle of the forward-going beam particle in the forward spectrometer, the authors conclude that '*. . . a 10% bias [of the momentum scale] is excluded at 18 σ level (statistics only). . .* ' [1] (version 1 dated 17 Sep 2007).

In this comparison, a fit without the beam point was used. This is important: (i) the p_T resolution will be about twice worse than in fits with the beam point; and (ii) the expected bias from dynamic distortions will have different magnitude and opposite sign compared to the bias from fits with the beam point.

Since all data published by HARP are based on fits with the beam point, evidence on a bias from dynamic distortions from fits without beam point is irrelevant; furthermore, conclusions from the dynamic distortions in one data set cannot be applied to another data set.

We conclude that the authors have not proven that the p_T scale of fits with the beam point is unbiased, and we could stop our argumentation here.

Nevertheless, we follow the argumentation of the authors a bit further.

We note that the authors chose to use only the first 50 events in the spill which reduces the expected bias from dynamic distortions by a factor of about two compared to the use of the first 100 events in the spill.

We note that for reasons of acceptance, the use of the scattering angle of the forward-going beam particle restricts the recoil protons to the two horizontal sectors 2 and 5 of the TPC. These

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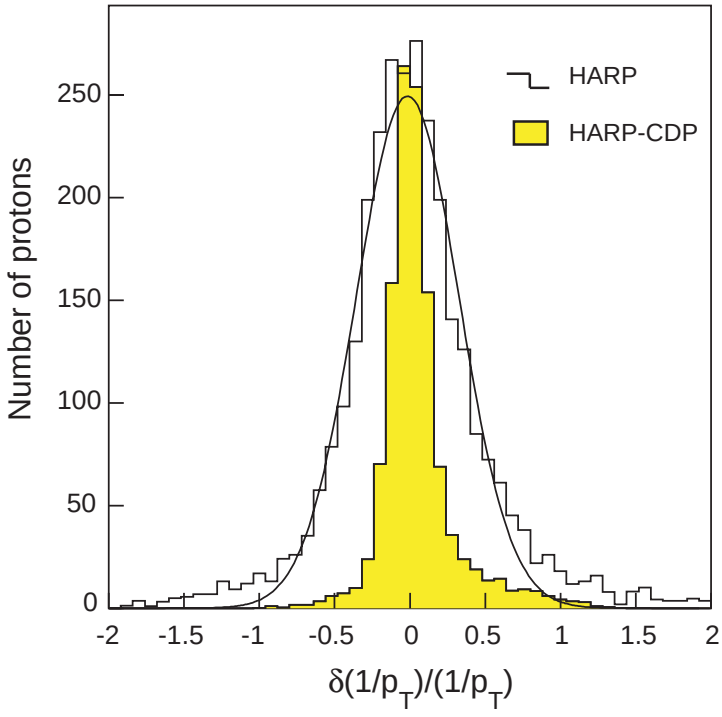

Figure 10. Resolutions $\delta(1/p_{\mathrm{T}})/(1/p_{\mathrm{T}})$ from HARP-CDP (shaded histogram) and from the HARP Collaboration (open histogram).

are the two sectors which our group decided not to use for data analysis, for the much stronger electronics cross-talk and the many more bad electronics channels in comparison with the four other TPC sectors, and for the absence of cross-calibration of performance with cosmic-muon tracks.

Still, one is puzzled why HARP find good agreement between the measured and the predicted momentum of the recoil proton.

We know from our own analysis of the same data that they are affected by fairly strong dynamic distortions, albeit smaller in amplitude than the $+8.9\,\mathrm{GeV}/c$ 5% λ_{abs} data shown in section 2, and with a steeper radial decrease of the Ar^{+} ion cloud in the TPC. We have shown in ref. [21] that at the start of the spill, the so-called 'margaritka' effect is dominant with a sign that is opposite to the sign of the so-called 'stalactite' effect that becomes by far dominant later in the spill. Near the start of the spill, there is a partial cancellation between the two effects (the cancellation is not complete since the radial distributions of these track distortions are different). It is this accidental cancellation that has been exploited by HARP to claim that their analysis is not affected by a bias in the p_{T} scale.

We show in figure 10 with the shaded histogram the absence of any momentum bias, and the momentum resolution, obtained by our group in the elastic scattering of $3\,\mathrm{GeV}/c$ pions and protons on protons at rest. Our resolution, from fits with the beam point included, is $\sigma(1/p_{\mathrm{T}}) \sim 0.20\ (\mathrm{GeV}/c)^{-1}$, well consistent with what is expected from our TPC calibration work [21]. It is

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unclear why the authors avoid proving their claim of a resolution of $\sigma(1/p_{\mathrm{T}} \sim 0.30$ (GeV/$c)^{-1}$ by showing their analogous distribution. Rather, they argue their case with the much worse resolution from fits without the beam point (although the authors' missing-mass analysis is based on fits with the beam point). For comparison, their data (copied from the middle panel of figure 7 in ref. [1]), are shown as open histogram in figure 10. Superimposed on their data is a Gaussian fit with $\sigma = 0.33$. With an approximate $p_{\mathrm{T}} = 0.45$ GeV/c the authors' resolution is $\sigma(1/p_{\mathrm{T}}) = 0.73$ (GeV/$c)^{-1}$, worse than the 0.60 (GeV/$c)^{-1}$ expected for fits without beam points. This is consistent with the evidence shown in section 2 that their resolution $\sigma(1/p_{\mathrm{T}})$ is much worse than 0.30 (GeV/$c)^{-1}$.

5. Concluding commentary

We presented evidence of serious defects in the large-angle data analysis of the HARP Collaboration: (i) the p_{T} scale is systematically biased by $\Delta(1/p_{\mathrm{T}}) \sim 0.3$ (GeV/$c)^{-1}$; (ii) the p_{T} resolution is by a factor of two worse than claimed; and (iii) the discovery of the '500 ps effect' in the HARP multi-gap RPCs is false.

In defiance of explicit and repeated criticism of their work at various levels, including published 'Comments' [22]–[23], HARP keep insisting on the validity of their work [4, 6].

Yet HARP have been unable to disprove any of the critical arguments against their results. Their arguments in their defence confirm, rather than disprove, our claims of serious defects in their large-angle data analysis.

In this unusual and regrettable situation, we warn the community that cross-sections that are based on the TPC and RPC calibrations reported by HARP, are wrong by factors of up to two.

References

[1] HARP collaboration, *Momentum scale in the HARP TPC*, arXiv:0709.2806.

[2] A. Artamonov et al., *The time response of glass resistive plate chambers to heavily ionizing particles*, 2007 *JINST* **2** P10004.

[3] M.G. Catanesi et al., *The HARP detector at the CERN PS*, *Nucl. Instrum. Meth.* **A 571** (2007) 527.

[4] HARP collaboration, *Rebuttal of "Comments to The HARP detector at the CERN PS" Nucl. Instrum. Meth.* **A 571** (2007) 564.

[5] M. Bogomilov et al., *Physics performance of the barrel RPC system of the HARP experiment*, *IEEE Trans. Nucl. Sci.* **54** (2007) 342.

[6] M. Bogomilov et al., *Rebuttal of comments on "Physics performance of the barrel RPC system of the HARP experiment", IEEE Trans. Nucl. Sci.* **54** (2007) 1455.

[7] M.G. Catanesi et al., *Measurement of the production of charged pions by protons on a tantalum target*, *Eur. Phys. J.* **C 51** (2007) 787.

[8] M.G. Catanesi et al., *Large-angle production of charged pions by 3 GeV/c–12 GeV/c protons on carbon, copper and tin targets*, arXiv:0709.3464.

[9] M.G. Catanesi et al., *Large-angle production of charged pions by 3 GeV/c–12.9 GeV/c protons on beryllium, aluminium and lead targets*, arXiv:0709.3458.

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[10] F. Dydak, *On distortions of TPC coordinates: inhomogeneities of electric and magnetic field*, HARP memo 03-001, http://cern.ch/dydak/TPCdistortions.ps.

[11] F. Dydak, A. Krasnoperov and Yu. Nefedov, *TPC track distortions: correction maps for magnetic and static electric inhomogeneities*, HARP Memo 03-002, http://cern.ch/dydak/TPCdistortions2.ps.

[12] I. Boyko et al., *TPC track distortions III: fiat lux*, HARP Memo 05-101, http://cern.ch/dydak/TPCdistortions3.pdf.

[13] V. Ammosov et al., *TPC track distortions IV: post tenebras lux*, HARP Memo 07-102, http://cern.ch/dydak/TPCdistortions4.pdf.

[14] http://evalu29.ific.uv.es/neutrino/IMG/pdf/rbh-report-final.pdf.

[15] http://evalu29.ific.uv.es/neutrino/IMG/pdf/harp_status_2007_04_16.pdf.

[16] F. Dydak et al., *Comments on "Physics performance of the barrel RPC system of the HARP experiment"*, *IEEE Trans. Nucl. Sci.* **54** (2007) 1454.

[17] V. Ammosov et al., *Second addendum to the HARP WhiteBook*, HARP Memo 07-101, http://cern.ch/dydak/WhiteBookAddendum2.pdf.

[18] V. Ammosov et al., *The HARP resistive plate chambers: Characteristics and physics performance*, *Nucl. Instrum. Meth.* **A 578** (2007) 119.

[19] V. Ammosov et al., *The HARP WhiteBook*, HARP Memo 06-101, http://cern.ch/dydak/WhiteBook.pdf.

[20] S. Borghi, *Hadron production cross section measurement with the HARP large angle detectors*, Ph.D. Thesis, University of Geneva, Switzerland (2006), http://cdsweb.cern.ch/collection/Theses.

[21] A. Bolshakova et al., *The HARP time projection chamber: characteristics and physics Performance*, CERN-PH-EP-2007-030 (10 August 2007), submitted to *Nucl. Instrum. Meth. A.*

[22] V. Ammosov et al., *Comments on: 'The HARP detector at the CERN PS'*, *Nucl. Instrum. Meth.* **A 571** (2007) 562.

[23] V. Ammosov et al., *Comments on 'Measurement of the production of charged pions by protons on a tantalum target'*, submitted to *Eur. Phys. J. C*, http://cern.ch/dydak/CommentsOnTaPaper.pdf.

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