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HARP Analysis Note 07-003
13 November 2007
http://cern.ch/dydak/AN.protontimingstudy.pdf

Proton timing in the HARP RPCs

CERN-HARP-CDP-2007-005
13/11/2007

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Abstract

In this note, we study the effect of the use of the reconstructed p_{T} and polar angle θ of protons in the measurement of the time of flight from the RPCs minus the time of flight calculated from the proton momentum.

Contents

1 Introduction

The discovery of, and insistence on, the '500 ps effect' by 'Official' HARP (OH) [1, 2, 3, 4, 5] in the HARP RPCs has given the measurement of the time of flight (TOF) from the RPCs minus the TOF calculated from the proton momentum, Δt, more importance than had been foreseen. We use '500 ps effect' as a short-hand notation for the claimed 500 ps time advance in a multi-gap RPC of protons with respect to minimum-ionizing pions.

One way of studying the 500 ps effect is to compare the RPC TOF of recoil protons in the elastic scattering of pions and protons on protons at rest, with the TOF predicted from kinematics. The prediction of the proton momentum can either come from the measured forward-scattering angle of the beam particle or else from the measured scattering angle θ of the recoil proton in the TPC.

In the former case, the measurement of the forward-scattering angle of the beam particle is considered unbiased. No TPC measurement is employed. The latter case depends on the measurement of the polar angle θ in the TPC which is only little affected by track distortions and hence is also considered unbiased.

When calculating the recoil proton momentum from the forward scattering angle, the angular resolution (1.5 mrad to 2 mrad) propagates into a $\sigma(1/p_{\mathrm{T}})$ of about 0.03 $(\mathrm{GeV}/c)^{-1}$ [6]. When calculating the recoil proton momentum from the scattering angle measured in the TPC, the angular resolution (some 15 mrad) propagates into a $\sigma(1/p_{\mathrm{T}}) \sim 0.08$ $(\mathrm{GeV}/c)^{-1}$ [6]. Even when further taking into account the additional resolution from fluctuations of energy loss in materials before the proton enters the TPC, the precision of the proton momentum remains considerably better than the resolution $\sigma(1/p_{\mathrm{T}}) \sim 0.20$ $(\mathrm{GeV}/c)^{-1}$ of the measurement in the TPC [7].

What happens when the proton momentum is not derived from the kinematics of elastic scattering, but measured with considerably worse resolution in the TPC?

This note shows that there is a non-negligible fake effect, arising from the resolution of the p_{T} measurement in the TPC, on the difference Δt of TOF from the RPCs minus the TOF calculated from the proton momentum.

2 Recoil proton momentum from elastic scattering kinematics

In this Section, we discuss our measurement Δt of the difference of TOF from the RPCs minus the TOF calculated from the proton momentum derived from elastic scattering kinematics.

The recoil protons are divided into bins of polar angle θ as measured in the TPC (the forward-scattered beam particle is not used in any way). In every bin the protons are produced within a narrow range on momentum. Therefore, the TOF to the RPCs for such protons is also in a narrow bin. To predict this time for each θ bin is non-trivial because the TOF is affected by the energy loss in materials (Inner Trigger Counter, TPC inner and outer walls, RPCs). We use GEANT to calculate a correction to obtain for each θ bin the correct TOF of a proton to the RPCs.

This method has two possible systematic errors: wrong measurement of θ and wrong description of material in GEANT. For OH both biases are present: their drift velocity measurement is wrong by 1-2% and the detector material is not correctly described in their simulation program. However, the contribution of these effects is of the order of 1.5% of the proton TOF and are neglected here.

The time measured in the RPCs minus the time predicted from θ is in reasonable agreement between OH and our CDP group. We interpret this as confirmation that both analyses calibrated the $t0$'s of the RPCs with relativistic pions more or less in the same way.

Both results also agree with the predictions of our theoretical model of RPC pulse formation, see Ref. [8].

3 Recoil proton momentum from measurement in the TPC

In this Section, we determine Δt as the time measured in the RPCs minus the time calculated from the proton momentum as measured in the TPC from the p_{T} and the scattering angle θ.

3.1 What mathematics say...

Even if the p_{T} scale of the TPC is unbiased, the momentum of each track is reconstructed with a certain resolution. The fluctuations of the momentum reconstruction give rise to a shift of Δt away from zero. This shift of Δt depends on the momentum resolution and on the shape of the momentum spectrum.

We first consider a simple case: protons with a true momentum of $p^{\mathrm{true}} = p_{\mathrm{T}}^{\mathrm{true}} = 0.75$ GeV/c. The momentum of the protons has no bias but is smeared with a resolution $\sigma(1/p) = 0.25$ (GeV/c)$^{-1}$. Figure 1 shows the difference between the Δt calculated with the true and with the smeared momentum, as a function of the smeared momentum.

This example underlines that *a priori* one cannot expect that the plot Δt versus momentum shows the correct Δt. Rather, a correction must be applied that will depend on the momentum spectrum and on the momentum resolution.

Our example represents the extreme case of a δ-function proton momentum 'spectrum'. For a realistic smooth spectrum the correction is much smaller but still significant.

3.2 ...what GEANT adds

We use GEANT to simulate the Δt of protons with a momentum spectrum similar to the experimentally observed proton momentum spectrum. The true proton momentum is smeared

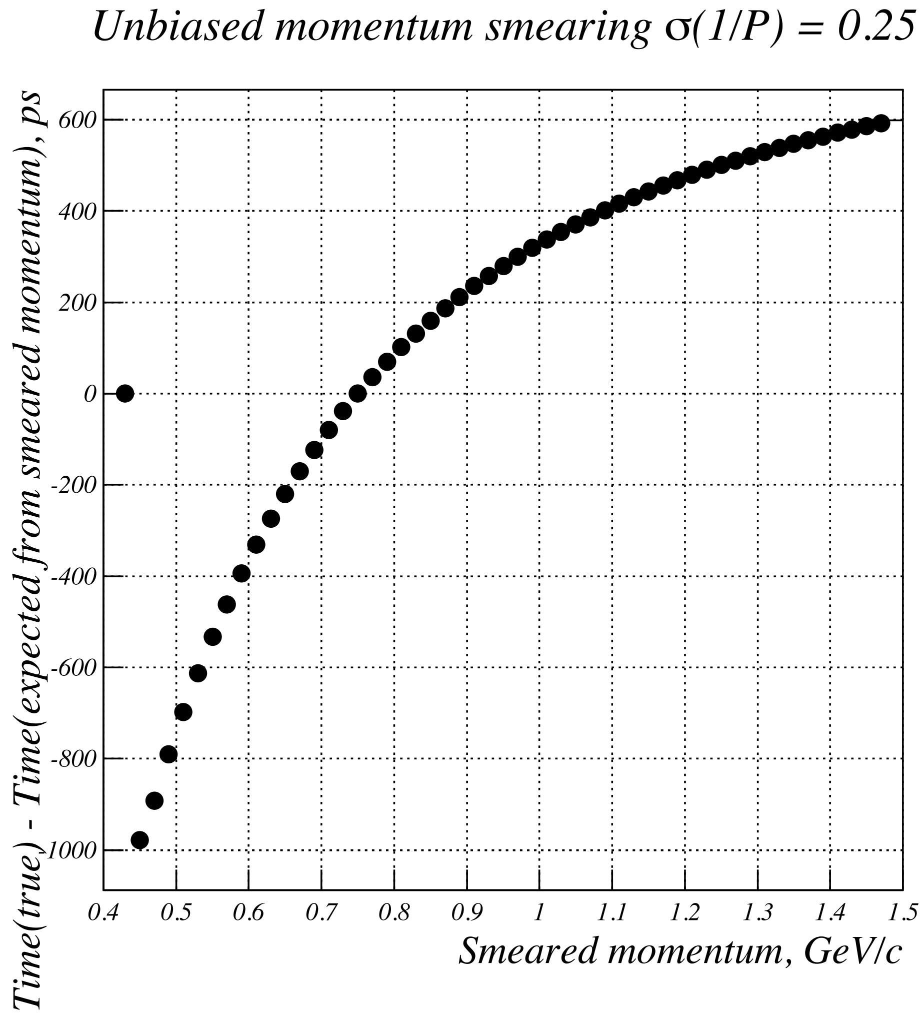

Figure 1: Demonstration of the difference between Δt calculated with the true and with the smeared momentum, for a fixed true momentum, as a function of the smeared momentum.

according to the experimental TPC resolution. The true TOF (calculated by GEANT) is used instead of the 'measured RPC time' (thereby any intrinsic time advance of protons in the RPCs is ignored). The crosses in Fig. 2 show how Δt calculated from the true proton momentum gets biased when calculated from the smeared proton momentum. Obviously, the shift of Δt away from zero cannot be neglected.

3.3 ...and what the data show

The black points in Fig. 2 show the results for Δt from secondary protons generated in the interactions of +8.9 GeV/c protons with a 5% $\lambda_{\rm abs}$ Be target. We conclude that a significant fraction of the observed non-zero Δt is caused by momentum resolution and is fake. However, it is also clear that the measured points differ from the points predicted by GEANT.

In Fig. 3 we show the measured points corrected for the GEANT predictions. The corrected points represent the intrinsic time advance of protons in the RPCs.

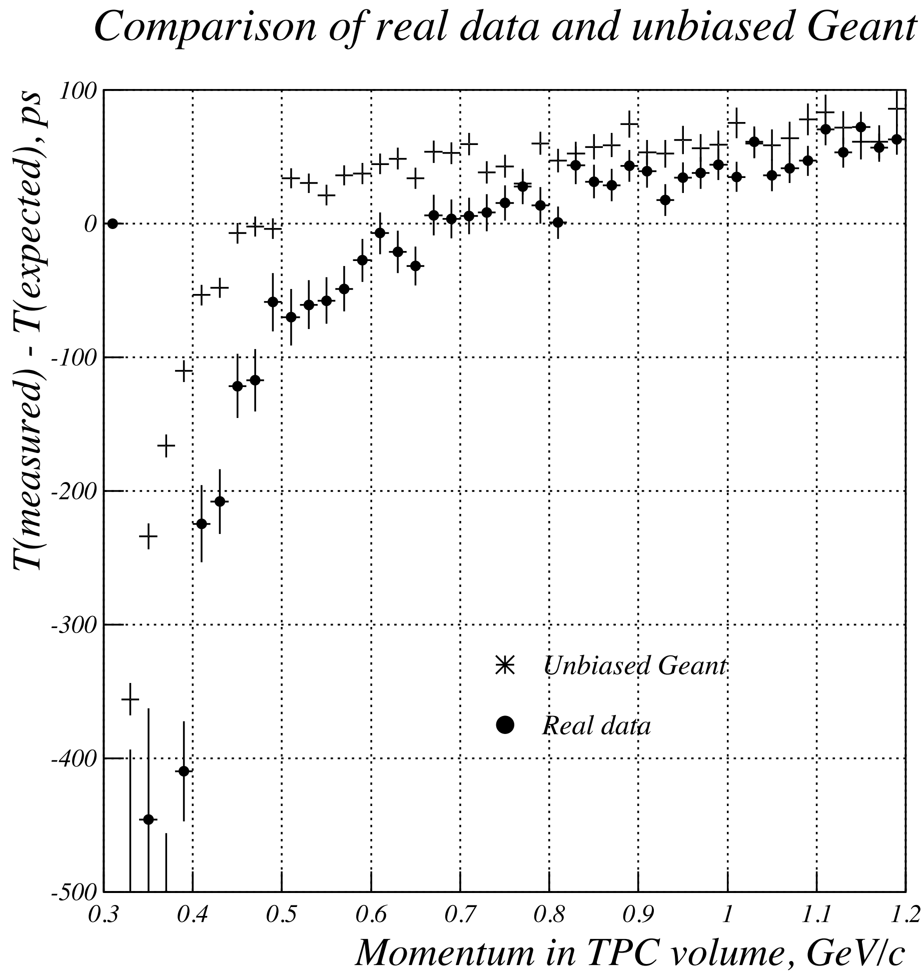

Figure 2: GEANT simulation of Δt with a realistic proton momentum spectrum (crosses); and Δt for protons from '+8.9 GeV/c 5% λ_{abs} Be' data (black points).

4 Comparison of all available data

In Fig. 4 we compare all available data: data with the proton momentum derived from the kinematics of elastic scattering (CDP and OH); and data with the proton momentum as measured in the TPC.

The CDP data have been corrected for the fake Δt caused by the momentum resolution.

While all data from elastic scattering and the CDP data with the proton momentum measured in the TPC agree reasonably well with each other, the OH data with the proton momentum measured in the TPC are markedly different. The OH data are not corrected for the fake Δt, however a comparison with Fig. 2 makes clear that the discrepancy with the other data sets cannot be explained by the fake Δt.

We conclude

1. that the RPC calibration is not much different between CDP and OH;

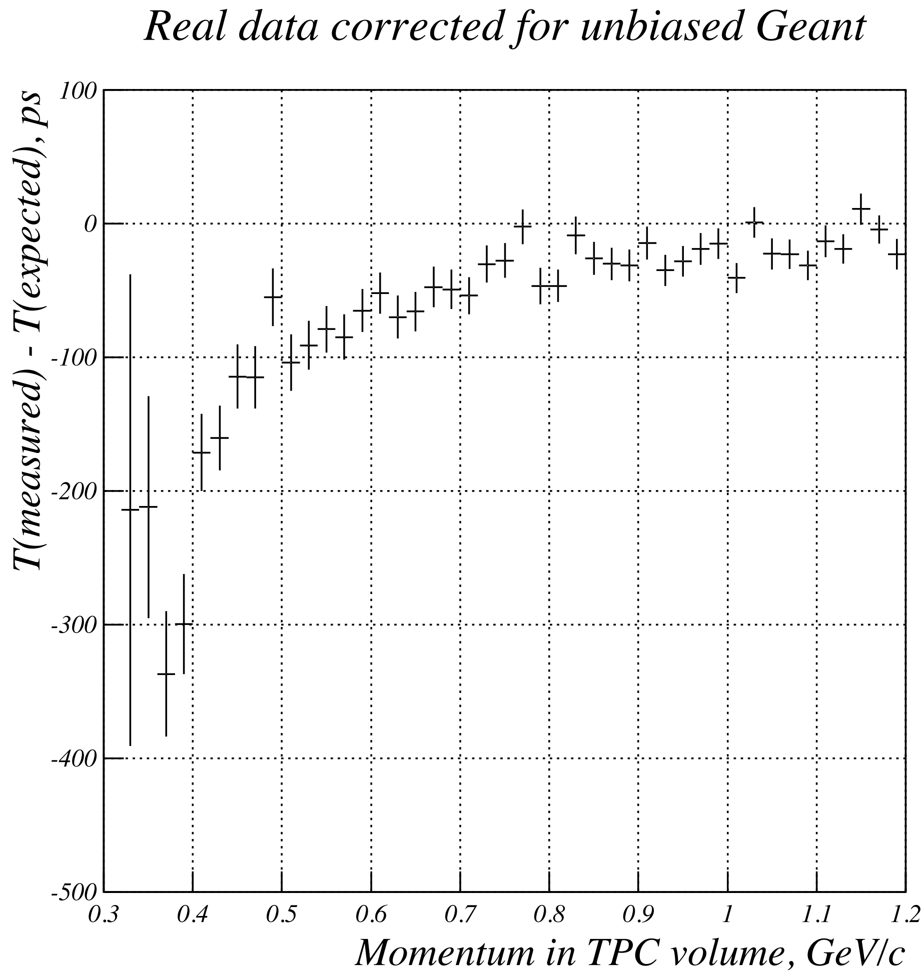

Figure 3: Intrinsic time advance of protons in the RPCs for protons with their momentum measured in the TPC.

2. that the momentum calibration of CDP is unbiased within the statistical error of this study;
3. that the momentum calibration of OH has a strong bias; and
4. that this momentum bias is the cause of OH's '500 ps effect'.

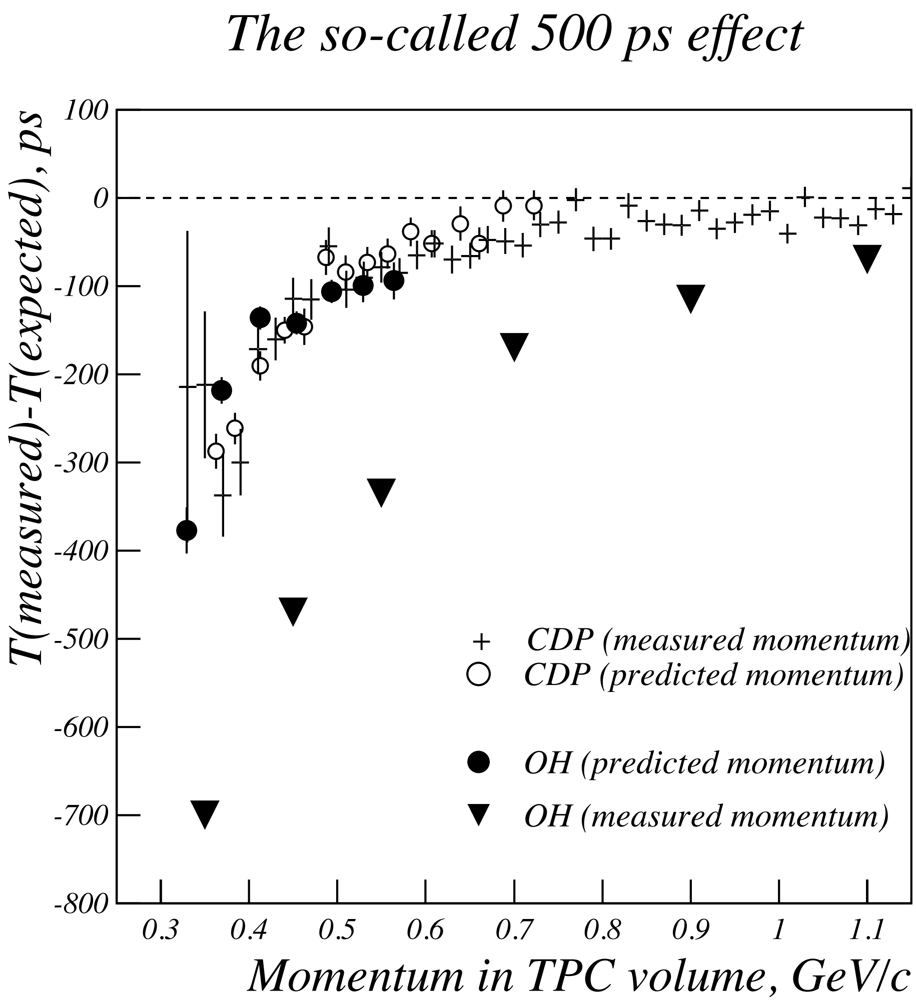

Figure 4: Time advance Δt of protons in the HARP RPCs for all available data sets.

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