A new method for electron momentum reconstruction in the experiment

2014 J. Phys.: Conf. Ser. 503 012008

(http://iopscience.iop.org/1742-6596/503/1/012008)

A new method for electron momentum reconstruction in the $\bar{\mathrm{P}}$ANDA experiment

Binsong MA on behalf of the PANDA Collaboration

Institut de Physique Nucléaire, CNRS-IN2P3 and Université PARIS-SUD, 91406 ORSAY FR

E-mail: binsong@ipno.in2p3.fr

Abstract. The Kalman Filter in existing PANDARoot framework of $\bar{\mathrm{P}}$ANDA experiment is not optimally suited for electrons, for which the highly non-Gaussian Bremsstrahlung process yields a tail in the momentum resolution distribution. A new method was therefore developed to improve the electron momentum reconstruction with an event by event procedure. The improvements of the electron momentum resolution will be shown. The interest of the method for the electromagnetic channels studies will also be presented.

1. Introduction

The antiproton beam of FAIR (Facility for Anti-proton and Ion Research), under construction at Darmstadt and the $\bar{\mathrm{P}}$ANDA (Anti-Proton ANnihilation at DArmstadt) detector [1] will offer an exciting opportunity for hadronic physics studies in $\bar{\mathrm{p}}\mathrm{p}$ annihilation reactions. In particular, the $\bar{\mathrm{P}}$ANDA experiment is well suited to investigate the electric and magnetic time-like proton form factors in the $\bar{p}p \to \mathrm{e}^+\mathrm{e}^-$ reaction at high q^2 , which currently lacks precise data [2].

Other electromagnetic channels of the $\bar{\mathrm{p}}\mathrm{p}$ reaction can be used to investigate the proton structure, for example the $\mathrm{e}^+\mathrm{e}^-\pi^0$ [3] or $\mathrm{J}/\Psi\pi^0$ [4] which give access to the proton-π^0 or antiproton-π^0 Transition Distribution Amplitudes (TDA).

Feasibility studies of measurements of both time-like electromagnetic form factors of the proton [5, 6, 7] and of TDA using the $\mathrm{e}^+\mathrm{e}^-\pi^0$ channel [8] have been performed. A major challenge of the measurements of these electromagnetic channels is the huge hadronic background, which requires excellent identification as well as an optimum angular and momentum resolutions for the reconstructed electrons.

2. $\bar{\mathrm{P}}$ANDA sub-detectors and the tracking system

$\bar{\mathrm{P}}$ANDA is a fixed target experiment, and its spectrometer can be divided into two parts: a forward spectrometer with covering angle lower than $10°(5°)$ in horizontal (vertical) direction and a target spectrometer at larger angles. Both parts consist of tracking detectors, detectors for charged particle identification, electromagnetic calorimeter (EMC) and muon detection systems. PANDARoot, a framework based on ROOT and Virtual Monte Carlo [9], is used for simulation and reconstruction.

The tracking system of $\bar{\mathrm{P}}$ANDA includes three types of detectors: Straw Tube Tracker (STT), Micro Vertex Detector (MVD) and Gas Electron Multiplier (GEM) [10].

In the following part, we will focus on the algorithm of track reconstruction in the central tracking system. First, the measured points which belong to the same track are selected (pattern recognition). Then, these points are fitted by a helix parametrization (prefit). Next, a Kalman Filter [11] is applied to refine the parameters provided by the prefit. The Kalman Filter is applied in three steps: first the track parameters and the associated errors at the next plane of detector are predicted, using the knowledge at the previous plane. Then a weighted mean between the predicted and the measured values is calculated taking into account the corresponding errors. Eventually, the final parameters of the track at the vertex are deduced from the backward propagation of the particle. For the propagation of the particle in the first and the third steps, the GEANE track follower [12, 13], which takes into account energy loss by ionization and the angular deviation due to multiple scattering between two measurement planes.

3. Electron reconstruction and the Bremsstrahlung correction method

Unlike other charged particles for which the dominant causes of worsening momentum and angular resolution when going through the material of the detectors are ionization and multiple-scattering. The electron tracking resolution is strongly affected by Bremsstrahlung photon emission in the material of the tracking system.

3.1. The electron tracking problem

Simulation and reconstruction of electrons and muons with a momentum equal to 1 GeV/c with PANDARoot show that the momentum resolution distribution of electrons has a large tail and the center of the peak is also shifted to positive value (0.4%) compared to the result for muons. The proportion of events inside two standard deviations of the Gaussian fit of the resolution spectra is only about 60% in the Barrel EMC detection region ($22° < \theta < 140°$) and 45% in the Forward Endcap EMC detection region ($5° < \theta < 22°$) where the material budget is larger (Figure 1).

As the momentum resolution is a crucial parameter for the signal selection in electromagnetic channels, it is important to investigate possible improvements. The existing software with the Kalman Filter as tracking tool uses the mean energy loss and the fluctuation calculated by the track follower GEANE [12, 13]. However, electron energy loss by Bremsstrahlung has a highly non Gaussian distribution, so that the process cannot be easily treated by the Kalman Filter. Alternative methods, like the Gaussian Sum Filter [14] or Dynamic Noise Adjustment (DNA) [15] are sometimes used. As explained further in more details, we follow a different procedure based on an event by event treatment.

The scheme presented in figure 2 shows an electron produced at the target emitting a Bremsstrahlung photon when it travels through the tracking system (the STT and the MVD). Due to the energy loss, the curvature of electron track increases after the γ emission.

Most of the Bremsstrahlung photons are emitted in the MVD which is close to the target. For an electron emitted at 90° the average thickness of MVD is about 0.07 radiation length, about a factor of 4 more than for the STT. So as result, there are four to five times more photons emitted in MVD than in STT. In addition, the MVD provides only four to six points to the track, depending on the θ and ϕ direction, which is much less than the twenty five points provided by the STT. The track is therefore mostly defined by the STT points which are mainly measured after the γ emission. Therefore, in most cases, the Kalman Filter will give a reconstructed electron momentum (P_{KF}) close to the momentum after the γ emission.

3.2. Bremsstrahlung correction method

A new attempt to handle the problem of Bremsstrahlung event by event using the energy of photons measured in the EMC is proposed. In this method, for each event, a photon will be searched for in an angular window around the electron track, then the reconstructed momentum (P_{rec}) will be corrected by adding the photon energy (E_γ).

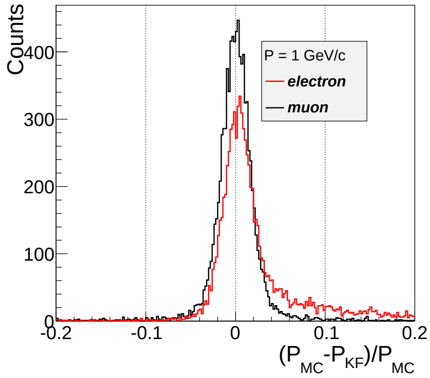

Figure 1. Comparison of electron (red) and muon (black) momentum resolution for P=1 GeV/c and θ=90° . P_{MC} is the Monte-Carlo momentum, P_{KF} is the reconstructed momentum.

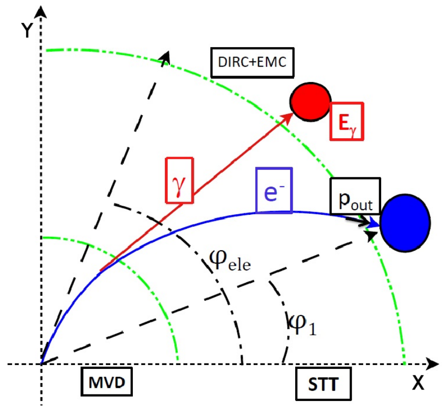

Figure 2. Scheme of an electron track with emission of photon in the $\bar{\text{P}}$ANDA central tracking system.

The existing algorithm identifies "bumps" in the distribution of energy deposits in the EMC crystals which correspond to a set of neighboring hit crystals. Photon signals are identified as those bumps which do not match with a track.

Two cases can be considered. The first one corresponds to low energy electrons (transverse momentum p_T below 1 GeV) with large curvature. If the photon is emitted at the beginning of the track, the "bumps" of electron and photon in EMC are separated. In the second case, the curvature of the electron track is not large enough, the photon bump is merged in the electron bump and the existing software can not distinguish between the two signals. For these two cases, different methods to pick up the photon energy are used.

The new algorithm first looks for photon bumps, in order to find possible Bremsstrahlung photons emitted in the tracking system. As the Bremsstrahlung photons are emitted close to the electron direction, angular information can be used. Since the magnetic field is parallel to the beam axis, only the azimuthal angle of the momentum vector of the electron is changing along the track. The photon bump has therefore to be found with a polar angle θ_γ close to the reconstructed electron one θ_{ele}. The azimuthal angle ϕ is expected to be between the reconstructed electron value ϕ_{ele} and the value at the exit of the tracking system ϕ_1 (see figure 2). The chosen limits for these angles are indicated as a rectangle in figure 3. The energy of the selected photons is then added to the reconstructed electron momentum.

To take into account the case of γ merged into the electron bumps, another algorithm based on the azimuthal distribution of the energy deposited in the EMC crystals in the electron bumps was developed. In the example of figure 4, two local maximums can be recognized in the energy distribution of a negative electron. As expected, the smaller one on the left part is due to a Bremsstrahlung photon and its energy can be extracted and added to the electron reconstructed momentum.

3.3. Improvement of the electron momentum resolution

As the geometry of EMC is not the same for the Barrel and the Forward Endcap, this method is tested separately for these two regions.

Figure 5 shows the new electron momentum resolution after correction for a transverse momentum p_T =1 GeV/c and 2 GeV/c. The result obtained when only the separated γ and electron bumps are used is also displayed as a blue line in figure 5. It can be noticed that

Journal of Physics: Conference Series **503** (2014) 012008 doi:10.1088/1742-6596/503/1/012008

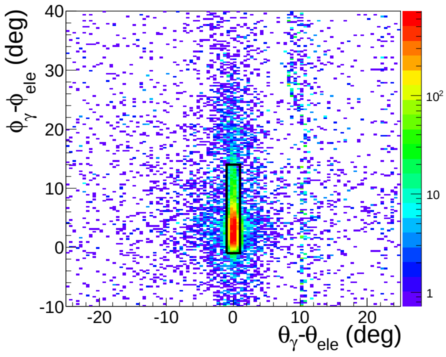

Figure 3. Correlation between the difference azimuthal and polar angles of the γ bumps and the electron track for an electron of $p_T = 1$ GeV/c. The rectangle shows the limits for the selection of Bremsstrahlung photon.

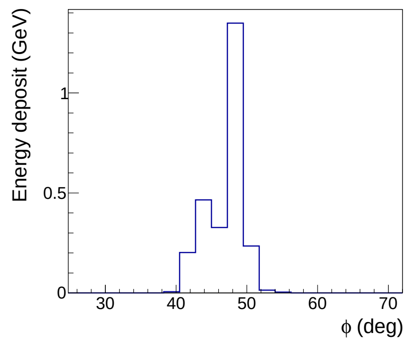

Figure 4. An example of the azimuthal distribution of electron energies deposited in the EMC crystals for an e^- bump with p_T=1 GeV/c.

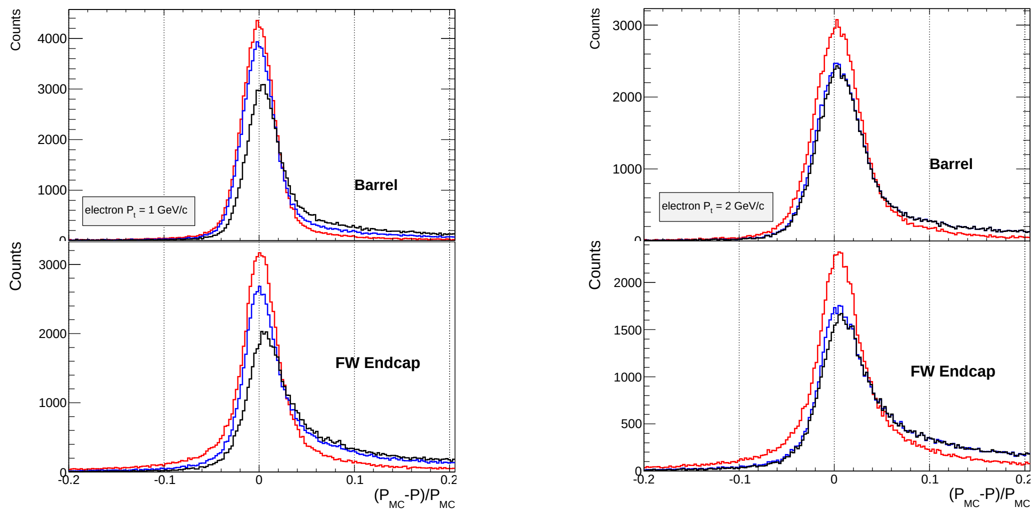

Figure 5. Comparison of the electron momentum resolution before (black) and after (red) using the Bremsstrahlung correction method. The blue line shows the result when only the separated γ bumps are used.

the analysis of the shapes is most important, especially for the large p_T. The method with combination of the two cases of photon detection (separated and merged photon and electron bumps) can strongly reduce the tail of the resolution peak, and the shift of the peak can also be fixed. After the correction, the proportion of events inside 2σ of the Gaussian fit is increased by a factor of 1.33 in the Barrel region and of 1.8 in the Forward Endcap region.

4. Application of the method on electromagnetic channels

For the proton structure studies, an important issue is the rejection of the hadronic background. Both Particle Identification (PID) and kinematical cuts are used. A larger efficiency of the kinematical cuts can be achieved by using the Bremsstrahlung correction method.

Two examples are taken to show the advantage of the method.

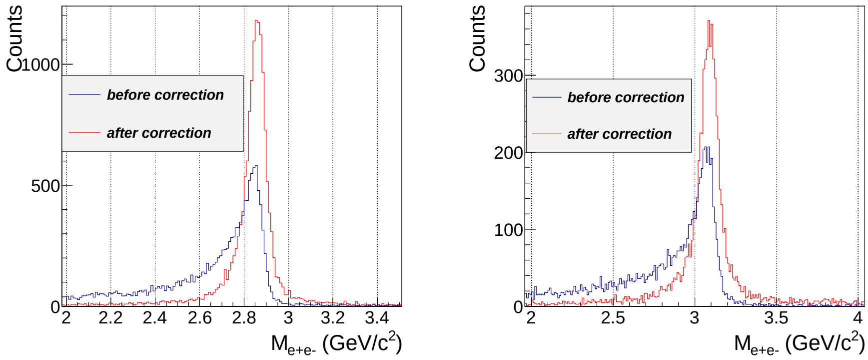

Figure 6. Distribution of the e^+e^- invariant mass before (blue) and after (red) using the method for $\bar{p}p \to e^+e^-$ (left) and $\bar{p}p \to J/\Psi\pi^0$ (right) reactions.

The first one is the proton time-like form factor measurement in the $\bar{p}p \to e^+e^-$ reaction with an antiproton beam momentum of 3.3 GeV/c. Another one is the Transition Distribution Amplitude measurement in the $\bar{p}p \to J/\Psi\pi^0$ reaction with an antiproton beam momentum of 5.51 GeV/c.

Figure 6 shows the distribution of e^+e^- invariant mass after simulation and reconstruction with PANDARoot. For the $\bar{p}p \to e^+e^-$ reaction, a selection of e^+e^- invariant mass larger than 2.72 GeV/c^2 (corresponding to $\sqrt{s} - m_{\pi_0}$) will be applied to suppress the background from the $\bar{p}p \to \pi^+\pi^-\pi^0$ reaction, in addition to PID cuts. The efficiency of this cut on the signal ($\bar{p}p \to e^+e^-$) selection is increased by a factor 1.7 when using the new method.

The second one is TDA measurement by using the $\bar{p}p \to J/\Psi\pi^0$ reaction, the e^+e^- invariant mass is used for the J/Ψ reconstruction. When using the new method, the signal yield within two standard deviations is also increased by a factor of 1.6.

5. Conclusion

The proton structure studies with $\bar{\text{P}}$ANDA need an optimized electron momentum resolution to limit the huge hadronic background. A new method to correct the Bremsstrahlung effect based on an event by event treatment and using the photon detection in the EMC is proposed. The test shown for the electromagnetic form factors and TDA measurements demonstrate that the method is well suited to handle the problem. This method will be very useful for the signal selection and background rejection in the electromagnetic channels.

[1] Physics Performance Report for PANDA, arXiv:0903.3905, hep-ex, (2009).
[2] J. Lees *et al.*, Phys.Rev. **D87**, 092005 (2013).
[3] J. Lansberg *et al.*, Phys.Rev. **D86**, 114033 (2012).
[4] B. Pire *et al.*, Phys.Lett. **B724**, 99 (2013).
[5] M. Sudol *et al.*, Eur.Phys.J. **A44**, 373 (2010).
[6] J. Boucher, Ph.D. thesis, University of Paris-Sud, France, (2011).
[7] A. Dbeyssi, Ph.D. thesis, University of Paris-Sud, France, (2013).
[8] M. Mora-Espi, Ph.D. thesis, Mainz university, Germany, (2012).
[9] I. Hřivnáčová *et al.*, Proc. of Computing in High Energy and Nuclear Physics, (2003).
[10] W. Erni *et al.*, Eur.Phys.J. **A49**, 25 (2013).
[11] R. E. Kalman, Journal of Basic Engineering 35 (1961).
[12] V. Innocente, M.Maire, and E.Nagy, GEANE, CERN Program Library, (1991).
[13] A. Fontana *et al.*, J.Phys.Conf.Ser. **119**, 032018 (2008).
[14] W. Adam *et al.*, J. Phys G: Nucl. Part. Phys. 31, 9 (2005).
[15] M. Elsing *et al.*, ATLAS Detector Paper Back-Up Note: Electrons and Photons, ATLAS NOTE, (2008).