MONTE CARLO SIMULATIONS FOR ANKE EXPERIMENTS

Izabella Zychor for the ANKE Collaboration *
(COSY - Jülich)

The Andrzej Sołtan Institute for Nuclear Studies, PL-05400 Świerk, Poland

The Monte Carlo code ANKE-GEANT is used to simulate experiments with the ANKE spectrometer - an experimental facility for the spectroscopy of products from proton-induced reactions on internal targets, placed in the accelerator ring of the cooler synchrotron COSY of the Forschungszentrum Jülich, Germany. Monte Carlo simulations are needed to determine a detector acceptance, estimate background, understand measured particle spectra. Calculations are also necessary to identify particles and to obtain their energy losses. The Monte Carlo simulations are the *only* method to reconstruct, without free parameters, momenta of ejectiles using information from scintillation counters and hit wire numbers in multi-wire proportional chambers.

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1. ANKE Spectrometer

The **A**pparatus for studies of **N**ucleon and **K**aon **E**jectiles (ANKE) is a new experimental facility [1] for the spectroscopy of products from proton-induced reactions on internal targets, placed in the accelerator ring of the cooler synchrotron COSY of the Forschungszentrum Jülich, Germany. It is a magnetic spectrometer with a large acceptance $\sim$50 msr for ejectiles emitted under forward angles and COSY independent setting of the field strength in its dipole magnets and, thus, momentum range.

COSY provides both unpolarized and polarized proton beams with momenta varying from 0.294 GeV/c to 3.450 GeV/c.

ANKE enables various hadron-physics experiments like meson production in elementary proton-nucleon processes, studies of medium modifications of heavy meson production in proton-nucleus reactions [2, 3], investigation of nucleon-nucleon final state interaction.

* For a complete collaboration list see: http://www.fz-juelich.de/ikp/anke

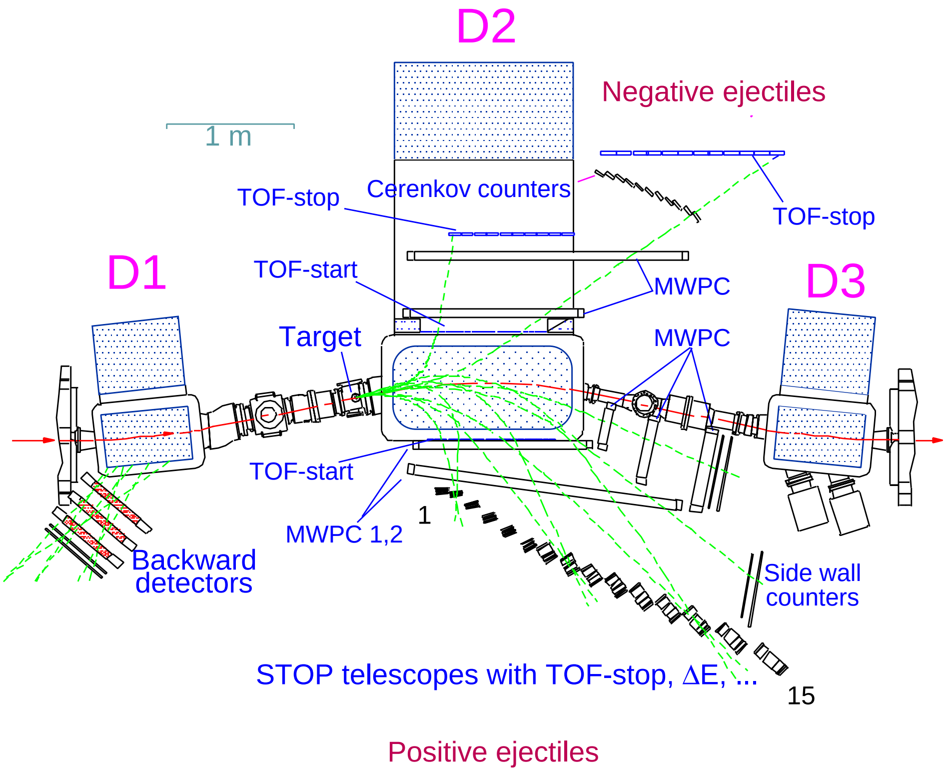

Fig. 1. ANKE spectrometer and detectors [1].

The device consists of three dipole magnets, various target installations and dedicated detection systems (see Fig. 1).

Three magnets (D1, D2 and D3) are used to deflect the circulating COSY beam off its straight path, to analyze momenta of reaction products and to deflect the beam back to the nominal orbit, respectively. The momentum range covered by the individual detection system depends on the field strength in the spectrometer dipole D2. For example, at the maximum field strength of 1.57 T kaons with momenta of 130 up to 635 MeV/c are detected.

The target can be a thin strip ($\leq$1.5 mg/cm^2) made of any solid material, a cluster jet, a frozen pellet or a polarized storage cell gas.

Luminosities up to $3 \times 10^{32}/(\mathrm{cm}^2\mathrm{s})$ are achieved with solid targets and up to a few $10^{30}/(\mathrm{cm}^2\mathrm{s})$ for cluster-jet.

The horizontal acceptance of ANKE is approximately $\pm(12°\text{-}15°)$ for positively charged particles which are emitted in the forward direction. The vertical acceptance depends on the exit position at D2 and typically ranges between $\pm 3^{\circ}$ and $\pm 5^{\circ}$.

Detection systems allow to identify different ejectiles, e.g. protons, deuterons, positive and negative pions and kaons. A large side detector, optimized for the detection of K^{+}-mesons, is built of START scintillators, two multi-wire proportional chambers MWPC and STOP telescopes.

2. ANKE-GEANT Package

One of the major parts of the ANKE-GEANT [4] program is the geometry package which has two main functions: (1) define, *during the initialization of the program*, the geometry in which the particles will be tracked, (2) communicate, *during the event processing phase*, to the tracking routines the information for the transport of the particles in the geometry which has been defined.

The ANKE-GEANT geometry package precisely describes the full spectrometer: magnets, vacuum chambers, target chambers, detector systems etc. The real setup is divided into parts easily converted into shapes supported by GEANT. Preparation of description of the ANKE geometry for the Monte Carlo code was a time consuming task which has started from measurements of dimensions and positions of all ANKE elements. Measured dimensions and positions of all elements of the ANKE setup are then used to calculate shape parameters and positions of volumes according to the GEANT convention.

For the description of the magnetic field in the space occupied by the ANKE facility, measured field maps are used in combination with three dimensional field calculations made with the MAFIA code. The MAFIA calculations were checked by comparison with floating wire measurements [5].

All physical phenomena (pair production, Compton scattering, photoelectric effect, Rayleigh scattering, bremsstrahlung, hadronic process, annihilation, δ-rays, muon nuclear interaction, photofission, decay in flight, energy loss, multiple scattering, Čerenkov photon generation, Čerenkov light absorption, synchrotron radiation generation, different energy fluctuation models) can be switched on or off by the user.

Full information about events is written to output files. One event consists of several tracks and more than one particle can appear in it. Typical parameters of the particle track, like time of flight, energy loss in various counters and path length from the target to each detector, are stored.

Fig. 2 shows a dependence of the average ejectile momentum on the START detector obtained in ANKE-GEANT simulations. The difference between the expected and simulated values is observed for all STOP detectors and is caused by placing them not in the focal plane of D2.

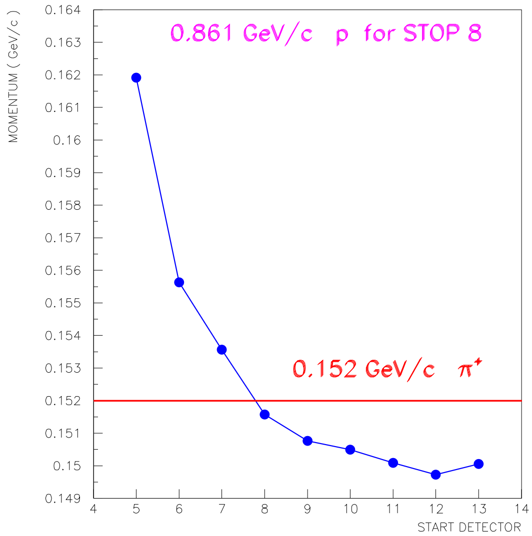

Fig. 2. Dependence of the average ejectile momentum on the number of the hit START detectors calculated for STOP #8. The momentum of 0.152 GeV/c corresponds to the π^+ momentum from the two-body reaction 0.861 GeV/c $\mathsf{pp} \to \mathsf{d}\pi^+$.

3. Reconstruction of ejectile momenta

Monte Carlo simulations are very useful to determine a detector acceptance, estimate background, understand measured particle spectra. These calculations are also necessary for identification of particles and calculations of their energy losses. The Monte Carlo simulations are the *only* method to reconstruct the momenta of ejectiles, without free parameters, from measured hits in MWPC's for the two body calibration reactions. Calculated and measured parameters are used to verify positions of setup elements, or even to find correct values (e.g. by comparing the simulated and experimental hit distributions in MWPC's).

The momentum calibration of ANKE is performed with pions emitted under forward angles from the two-body reaction $\mathsf{pp} \to \mathsf{d}\pi^+$ [6]. For emission angles $\leq 5^\circ$ these pions are almost monoenergetic compared to the momentum resolution of ANKE. Calibrations have been done for the STOP telescopes with numbers from 6 to 15 and for low D2 magnetic field values from 0.6493 to 0.8946 T. The COSY beam projectile momenta were in the range from 0.826 to 1.136 GeV/c. The corresponding π^+ momenta from the two-body reaction are then from 0.121 to 0.352 GeV/c, respectively. Information from START and STOP detectors and from hit wire numbers in two MWPC's is used in ANKE experiments for particle tracking to determine the ejectile momenta.

Typical distributions of hit wires from the 0.86 GeV/c p+p simulated reaction are shown in Fig. 3. Observed discrepancies in simulated and measured distributions are then used to find precise positions of the ANKE detectors.

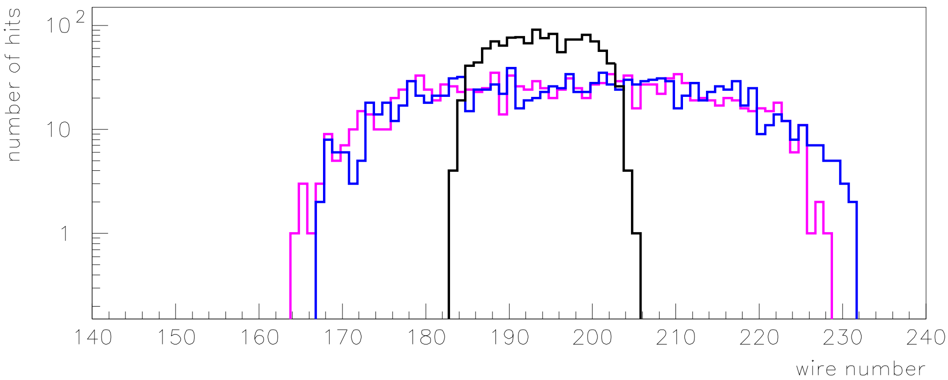

Fig. 3. Simulated distributions of hit wires in the 1^{st} MWPC for START #8 and STOP #8. The most narrow distributions correspond to vertical wires in chambers, the broader ones to inclined.

To obtain ejectile momenta measured in a certain STOP detector it is assumed that there exists a unique dependence between momentum and 6 wires hit in the MWPC's. A 2^{nd} order polynomial of 6 variables with 28 coefficients is fitted through a set of data points with the standard MINUIT program. Coefficients which are obtained from ANKE-GEANT simulations are then used to reconstruct momenta from measurements. The resolution of reconstructed momenta does not depend on the particle type.

Fig. 4 shows the reconstructed π^+ momenta, both for simulated and measured two-body events. It can be seen that the resolution for measured data is slightly worse than the value expected from the simulations. The difference is minimized by taking into account only events corresponding to a single START-STOP combination.

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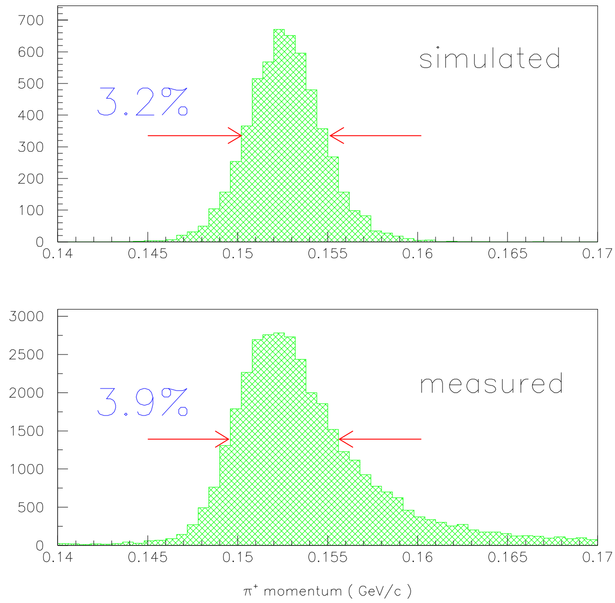

Fig. 4. Simulated and measured (reconstructed) momenta of π^+ from the 0.861 GeV/c $pp \to d\pi^+$ reaction. The coefficients were calculated for STOP #8 and START #7 and #8, then applied for all START's and STOP #8.

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