Forward Time of Flight in GlueX

B. Zihlmann

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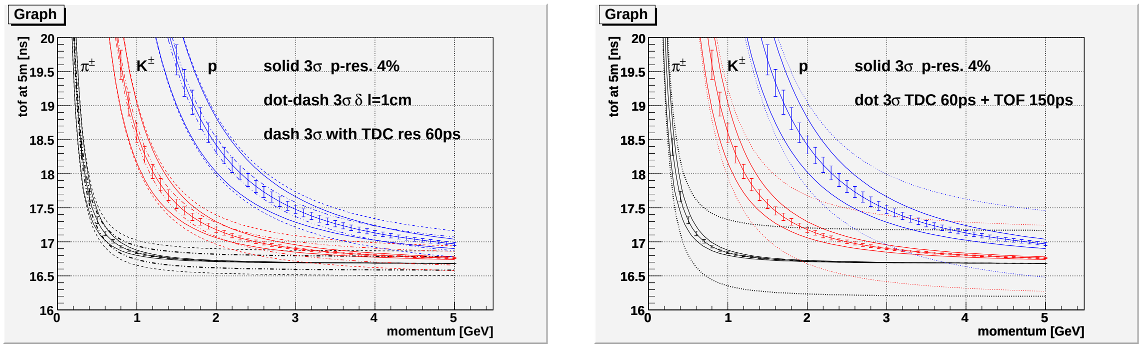
Abstract

This document looks at the requirements of a time of flight (TOF) detector in the GlueX experiment and the current technical hardware and knowledge we have in order to build such a device.

1 Requirements

The purpose of the TOF detector is to identify particle types on the basis of measuring their time of flight (TOF). In particular the separation between pions and kaons is of importance. As an example, fig. 1 shows the TOF for particles as a function of their momentum for a fixed path length of 500 cm. In fig. 1(a) the effect on the TOF from a fixed 4% momentum resolution is indicated by the error bars and the solid lines indicate the 3σ boundaries. The smearing of a fixed 4% momentum resolution (a rather conservative assumption) is negligible compared to all other effects that contribute to the TOF resolution. The dot-dash line indicates the 3σ level of an assumed 1 cm path length resolution in the tracking which is always smaller than the 60 ps timing resolution given by the TDC itself (dotted line 3σ). The 1 cm path length resolution is for educational purposes only. The effective path length resolution will depend strongly on the vertex position resolution in particular for forward going tracks with hits in the forward drift chambers (FDC) only. Any additional transverse track with hits in the central drift chambers (CDC) will improve the vertex resolution at the event level. From fig. 1(a) one can deduce a pion-kaon separation at the 3σ level up to a momentum of 2 GeV/c and a kaon-proton separation up to about 3.5 GeV/c.

In addition to this the TOF detector itself introduces smearing. This is demonstrated in fig.



(a) Momentum, path-length, TDC **(b)** TDC and TOF

Figure 1: *Fig. a) shows the TOF for pions, kaons and protons with a momentum resolution of 4%, a path length resolution of 1cm and a TDC resolution of 60 ps separately. The curves show the 3σ boundaries. Fig. b) shows the momentum resolution and the combined TDC+Detector resolution, where the detector resolution is assumed to be 150 ps.*

1(b) where in addition to the TDC resolution of 60 ps a TOF-detector resolution of 150 ps is assumed. To be more specific the resolution of each individual readout channel by photo multiplier tubes is currently assumed to be 200 ps. This is a conservative assumption and has potential for improvement [2],[3],[4],[5]. It results in a timing resolution per plane of about 150 ps. In this case a 3σ separation in TOF between pions and kaons is reached at 1.4 GeV/c and for kaons and protons this is reached at 2.2 GeV/c. To illustrate this the TOF of π^+ and K^+ with momenta of 2 GeV/c are plotted in fig. 1. The HallD monte carlo is used to generate 1000 π^+ and K^+ with a momentum of 2 GeV/c at a fixed polar angle of 5 degree. Note that in fig. 1 an equal number of particles for

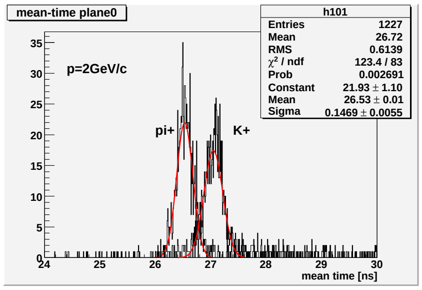


Figure 2: *Particle time of flight using the HallD MC. The polar angle is fixed at 5 degree with azimuthal angle zero after a flight path of 500cm.*

each species has been generated. In practice the multiplicity ratio between particle species will be generally different from 1 which requires a much larger separation than 3σ in TOF in order to keep misidentification at an acceptable level.

2 TOF Detector

The TOF detector has to cover about 12 degree in polar angle which leads to an area of 252 cm × 252 cm to be covered. The current design of the detector envisions a plastic scintillation detector based on the material EJ-200 (BC-408, Pilot-F). This material has a fast rise time and decay time with a high photon yield and large attenuation length [1]. The photons will be detected by XP2020 photo multiplier tubes (PMTs) at both ends of the scintillator paddles. These PMTs provide a fast signal rise time and have a transit time spread of 250 ps.

2.1 Timing resolution

The timing resolution depends on many factors. The two most important are the geometry of the detector itself, as this determines the dispersion of the photon path length, and the performance of the PMT used.

The intrinsic rise-time and decay-time of EJ-200 are 0.9 ns and 2.1 ns respectively. The precision with which the timing of the these photons can be measured using a PMT depends in particular on the spread of the arrival time of these photons at the PMT photo cathode, the number of photons that convert to photo-electrons and the transit time spread of the secondary electrons in the PMT. In order to see this lets for simplicity assume that the photo-electrons are Gaussian distributed. The accuracy with which one can determine the peak position (equivalent to determine the arrival time) depends on the number of events building up this Gaussian distribution. In other words: the more scintillation photons the PMT sees, the better the achieved timing resolution. The geometry of the detector influences this in two ways. First, the longer the detector, the longer the path length to the PMT, the smaller is the number of photo-electrons. This can be somewhat compensated by making the detector thicker so that more scintillation photons are generated by the charged particle. However, as a second effect, the longer path-length and thicker detector also cause more dispersion in the arrival time of these photons. This causes a larger width of the Gaussian distribution. This means that the photo electrons are distributed over a larger area and hence the determination of the peak position becomes less accurate, or the smaller the width of a Gaussian distribution is the more the events are bunched in the horizontal scale and the better the peak position can be determined. The transit time spread (TTS) of the secondary electrons in the PMT due to the different paths of the electrons through the PMT add an additional source of smearing to this Gaussian distribution diminishing the accuracy of the determination of the peak position even more. This behavior is

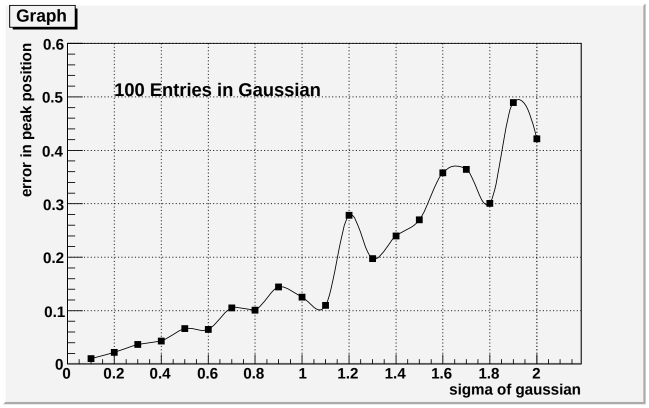


Figure 3: *Dependence of the uncertainty of the peak position as a function of the width of a Gaussian distribution*

illustrated in fig. 3. For a given statistics the uncertainty in determining the peak position of a Gaussian distribution is plotted as a function of the width with which this Gaussian has been generated. The number of entries in the distribution is fixed at 100. The following list emphasized the crucial points to be optimized in order to reach the best timing resolution

- detector thickness large to get lots of scintillation light
- detector cross section small to minimize dispersion
- PMT minimize transit time spread of secondary electrons.

while the following points may have degrading effects on the timing resolution

- large count rates
- large transverse detector size

In addition these points are not independent of each other. For example, the larger the paddle width, the higher the count rate, the fewer channels are needed hence resulting in lower costs for the full detector. But a larger width will also increase the dispersion in the TOF path.

3 TOF simulation

The simulation of the TOF detector is part of the HallD monte carlo software package `HDGeant` up to the level where particle hits in the detector are recored with position, time and energy. The main file containing the code for the TOF detector handling is `programs/Simulation/HDGeant/hitFTOF.c` For each primary particle the hit position in the TOF detector as well as the time and energy loss are registered. A primary particle is a particle originating from the target as generated by the physics event generator. Any particle originating from a decay or interaction is referred to as a secondary particle. For each particle that hits a TOF paddle the arrival time is propagated towards each end of the scintillator to the location of the PMT using the signal speed in the plastic scintillator. Particles that are within a given time window hitting the same paddle are added together, summing the energy losses and averaging the time by energy weighing. The particle type and hit position for the particle with the largest momentum of such an averaged hit is also recored. For each event all these hits are written to a file. The data structure where the hits are stored for each PMT looks as:

```
 typedef struct {
   float              E;
   float              dE;
   int32_t            ptype;
   float              px;
   float              py;
   float              pz;
   float              t;
   float              x;
   float              y;
   float              z;
} s_FtofNorthHit_t;
```

and similar for `s_FtofSouthHit_t`. However, the only value different for the two PMT data structures is the time t.

From here on the JANA/DANA frame work is used to further evolve the data in the context of `Factories`. The `DHDDMTOFHit` factory provides each hit of an event as an object with the information from the geant simulation. These hit objects are then used by the `DTOFMCResponse` factory which does the actual digitization of the MC generated hits. The timing on each side of the paddles are smeared with the time resolution coming from test data and a TDC value is calculated. The energy deposition is transformed into N, the number of scintillation photons with an uncertainty given by $\sqrt(N)$. These photons are propagated from the hit location in the paddle to the PMTs on each side and photo electrons are generated thereof. These photo-electrons are amplified by a PMT gain factor and the total charge is transformed into an ADC value. The resulting object for each hit in a paddle has the following data structure:

```
int orientation;  // 0: vertical,  1: horizontal
int ptype;        // particle type
int bar;          // bar number
float y;          // x/y position of bar center
float t_north;          // time of light at end of bar  (smeared)
float E_north;          // attenuated energy deposition  (smeared)
float t_south;          // time of light at end of bar  (smeared)
float E_south;          // attenuated energy deposition  (smeared)
int ADC_north;
int ADC_south;
int TDC_north;
int TDC_south;
```

In a further step actual hit positions in the paddle and time of flight data are calculated from the ADC and TDC values of both sides of the paddle. This is implemented for the MC data by the factory `DTOFMCHit`. The TDC values are transformed into time in units of nano seconds and using the signal speed of the paddles the hit position along the paddle is determined in units of centimeters. The mean time of flight is calculated as well as the mean deposited energy at the hit location in terms of ADC values. A calibration constant is needed to transform this mean ADC value into an energy in units of GeV. The resulting output structure looks as follows:

```
int orientation;  // 0: vertical,  1: horizontal
float meantime;
float timediff;
float pos;       // hit position in paddle
float dpos;      // estimated uncertainty in hitposition
float dE;        // weighted energy deposition
```

The uncertainty in the hit position is currently just a fixed value of 3 cm while the energy deposition dE is not converted to energy yet. Note that the TDC information of both sides of a paddle are necessary to calculate the position and mean time of flight. Paddles which have only one PMT to begin with (close to the beam line) or only one side delivers a signal above threshold, will have their `DTOFMCHit` initialized to values like -999. These *single side hits* can be used when combining hit information from different TOF planes to form space points.

References

[1] Eljen Technology: http://www.eljentechnology.com/products.html#Plastic%20Scintillators

[2] E. Chen, et. al, hep-ex/9606007

[3] S. Denisov, et. al, NIM A 494 (2002)495

[4] S. Denisov, et. al, NIM A 478 (2002)440

[5] S. Denisov, et. al, NIM A 525 (2004)183