Simulated momentum and scattering angle reconstruction with BigBite

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Introduction

Scattering angle and Momentum reconstruction have been simulated using the existing Geant4 simulation of BigBite. The simulations were done using the existing detector package which include the Trigger and Auxilliary scintillator planes. All simulations were done assuming a point-like target. Different algorithms using both TOF and position information have been tested and compared.

Momentum reconstruction using TOF.

Determination of the particle Momentum by this method requires measuring the TOF for a known distance.

Two different paths where tested for the reconstruction -

a. Auxiliary plane to Trigger plane.

TDC signals:
Tl - Hit time (ns) on left PM of the E counter
Tr - Hit time (ns) on right PM of the E counter
Taux - Hit time (ns) on Auxiliary PM

n = E plane Bar Number + dE plane bar number. = (1-48)
na = Auxiliary Bar number = (1-56).

Xtc,Ytc,Ztc - Trigger planes center coordinates (mm) .

Xac,Yac,Zac - Auxiliary planes center coordinates (mm) .

V = C/1.58 - The speed of the light inside the scintillator media.[mm/ns]

Wt - Trigger plane bar half width 45[mm].
Wa - Auxiliary plane bar half width 12.5[mm].
The hit position calculation will be done as follow :

On the Trigger plane:

$$Zt = (n - 24) * Wt * cos(25^{\circ}) + Ztc \tag{1}$$

$$Xt = (24 - n) * Wt * sin(25^{\circ}) + Xtc \tag{2}$$

$$Yt = \frac{(Tl - Tr)L}{2} + Ytc \tag{3}$$

(4)

On the Auxiliary plane:

$$Za = (na - 28.5) * Wa * cos(25^\circ) + \mathrm{Zac} \tag{5}$$

$$Xa = (28.5 - na) * Wa * sin(25^\circ) + \mathrm{Xac} \tag{6}$$

$$Ya = Yt * \frac{\sqrt{(Xa - Xe)^2 + (Za - Ze)^2}}{\sqrt{(Zt - Ze)^2 + (Xt - Xe)^2}}$$

(7)

The total path length from the Auxiliary plane to the Trigger plane :

$$d = \sqrt{(Xa - Xt)^2 + (Ya - Yt)^2 + (Za - Zt)^2} (\approx 980[mm]) \tag{8}$$

The total TOF with time correction:

$$TOF = (Tl + Tr)/2 - Taux - (250 - 185. + abs(Ya))/V[ns] \tag{9}$$

The particle momentum is :

$$\mathrm{P} = \frac{d/tof}{\sqrt{1-(d/tof)^2 * 10^{-16}}} * \frac{1.6726*3}{1.6*10^{-6}} [MeV/c] (10)$$

(11)

The major cause of uncertainty in this method is the Auxiliary plane time resolution.(see figure 1)
Based on resolution test report, we assume that the time resolution of the Aux plane is 0.8 [ns], and that of the E Counters is 0.2 [ns].

b. Target to Trigger plane.

To obtain the time between the target and the trigger plane, we assumed an initial timing trigger is available from coincidence between the HRS's with a resolution of 1 ns, and calculated the particle TOF along the entire path.

The entire path of the particle was divided to 3 segments -

-From the target to entry face.

$d1 = \sqrt{Zi^2 + d^2}$[mm]

-Curved path through the magnetic field.

$d2 = R * abs(atan(\frac{Xe-Xo}{Zo-Ze}) + atan(\frac{Xi-Xo}{Zo-Zi}))[mm]$

-From the point on the exit face to the Trigger plane hit point.

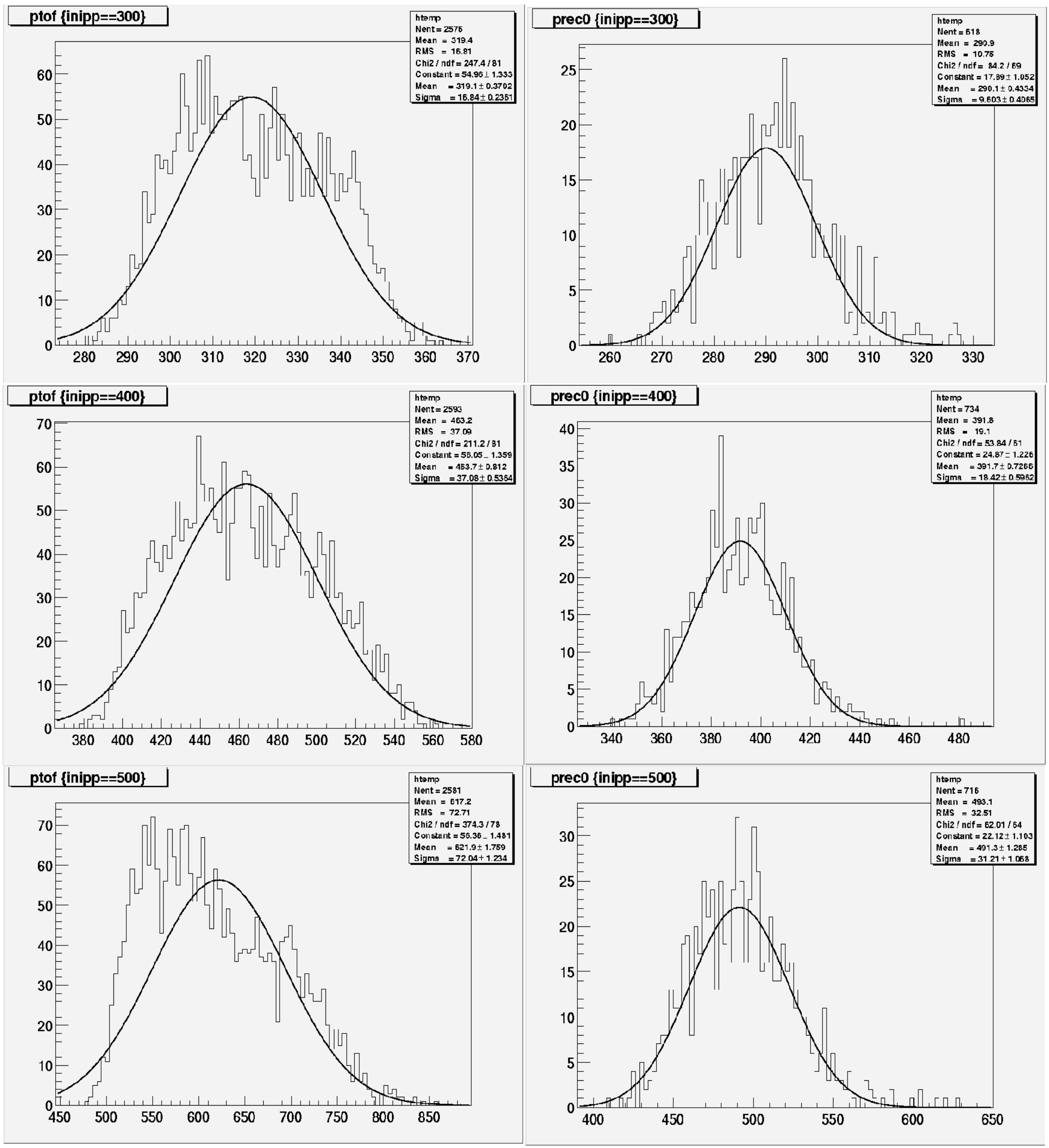
$d3 = \sqrt{(Xt - Xe)^2 + (Yt - Ye)^2 + (Zt - Ze)^2}[mm]$

The total path is then given by :

d = $\sum_{i=1}^{3}$di ($\approx$ 2700 [mm]) (12)
T(HRS) - the time from the HRS's coincidence (13)
TOF = (Tl+Tr)/2 - 250/V- T(HRS) [ns] (14)
$ParticleMomentum-$ (15)
P = $\frac{d/tof}{\sqrt{1-(d/tof)^2*10^{-16}}} * \frac{1.6726*3}{1.6*10^{-6}}[MeV/C]$ (16)

P [MeV]	ΔP/P % Aux-E	ΔP/P % Target-E
300	6	3
400	9	3.5
500	14	6

Table 1: Momentum reconstruction resolution.



(Fig 1) Reconstructed Momentum for initial momentum of 300 - 500 MeV/c
Left side - TOF Auxiliary to trigger plane.
Right side - TOF target to trigger plane.

Momentum and scattering angle reconstruction using Hit Position.

The particle momentum P and the scattering angle θ can be calculated using only the hit position in the two planes.

We have tried three different approaches in order to solve this problem :
-Exact geometric solution for the path. (calculation)
-2 dimensional fit using minuit(CERN lib)
-2 dimensional fit using MLP (Multi-Layer-Perceptron).

Exact solution -
We defined the following quantities (see figure 2):
(X0,Z0) the center coordinates of the circular path.

axz = $\frac{Zt-Za}{Xt-Xa}$: incline of exit vertex.
$\alpha = arctan(-1/azx)$
$ai = Zi/d$: incline of entry vertex.
$t2 = tan(25deg)$: detector and exit face angle.
$bby = 817.4mm$: y length of BigBite.
$bbx = 752.9mm$: base x length of BigBite.
$bbx2 = bbx - bby * t2$: top x length of BigBite.
$xm = (bbx + bbx2)/4$: mid point x.
$xce = bbx - bby * t2/2$: x of exit point at z=0.
$xin = 0$: x of entry point in to BigBite.
(16)

we now find the intersection point of the exit vertex and the mid-field line.

$$xtemp = \frac{axz * Xt - Zt + 2 * xin/t2}{axz + 2/t2} \tag{17}$$
$$ztemp = xtemp * axz + Zt - axz * Xt$$

(18)

We now find the Coordinates of center of the "circle arc"

$$X0 = \frac{-axz*ze*ze+2*axz*ze*zi-axz*xi*xi+axz*xe*xe-axz*zi*zi-2*ze*xe+2*zi*xe}{2(-ze-xi*axz+axz*xe+zi)}$$

$$Z0 = \frac{xe*xe-ze*ze-2*xi*axz*ze+2*axz*ze*xe+xi*xi+zi*zi-2*xi*xe}{2(-ze+axz*xe-xi*axz+zi)}$$

$$R = \frac{\sqrt{1+axz*axz}*(ze*ze-2*ze*zi-2*xi*xe+xi*xi+xe*xe+zi*zi}{-ze-xi*axz+axz*xe+zi}$$

The solution for P and θ is then given by :

P = B*R*300

*where B is the Magnetic field in [Tesla] (= 0.92), R is in [cm] and P in [MeV/c].

$\theta = \text{atan}\ \frac{ztemp}{xtemp+dist2target}$

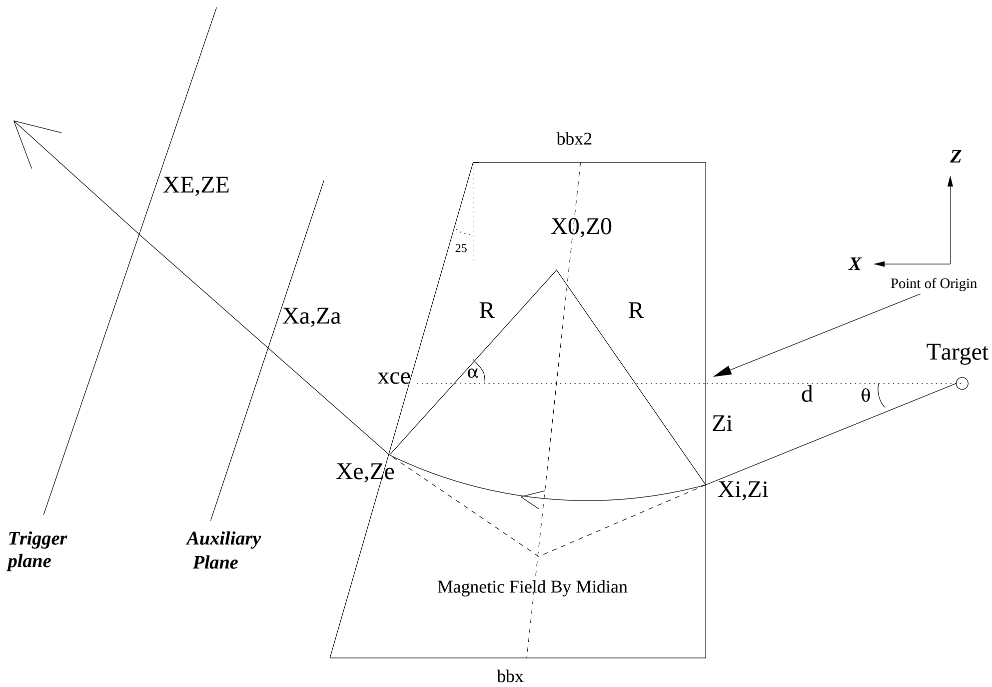


Figure 2 : A Trajectory of a proton detected in BigBite

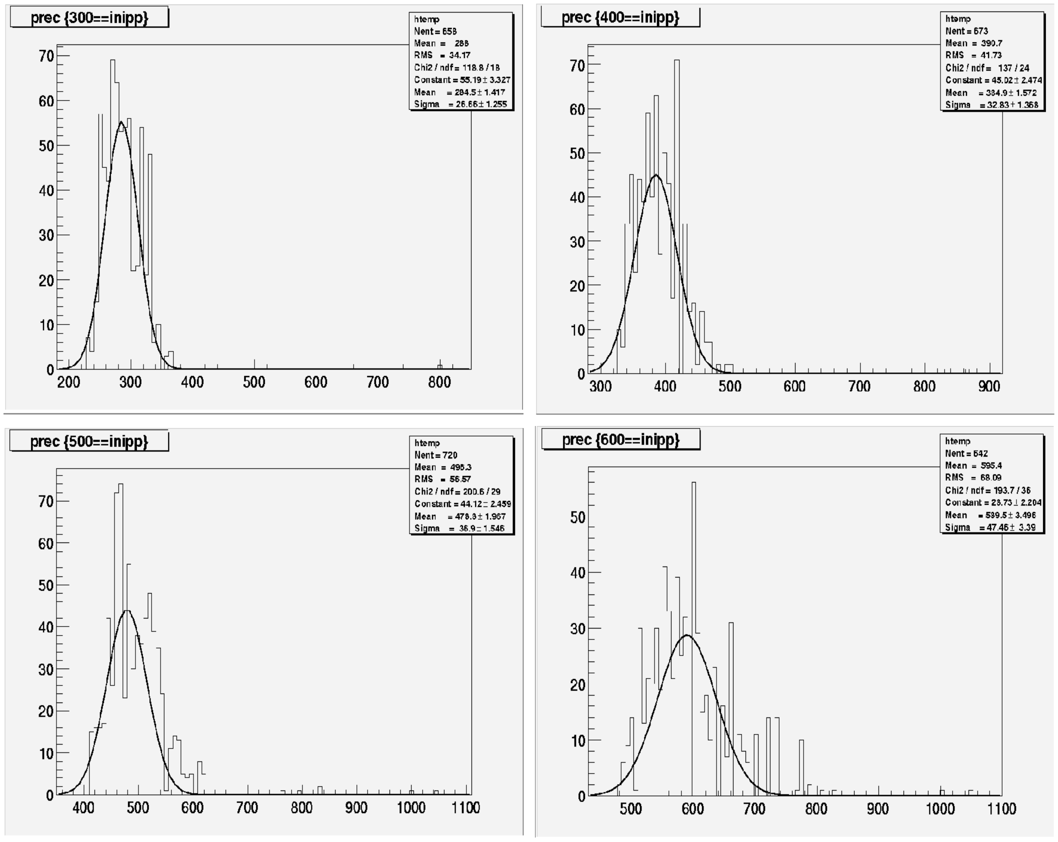


Figure 3 :Momentum reconstruction using the analytical formula, based on hit positions.
$\Delta P/P$ is ≈ 8 % for the Momentum range 300-600 MeV/c.

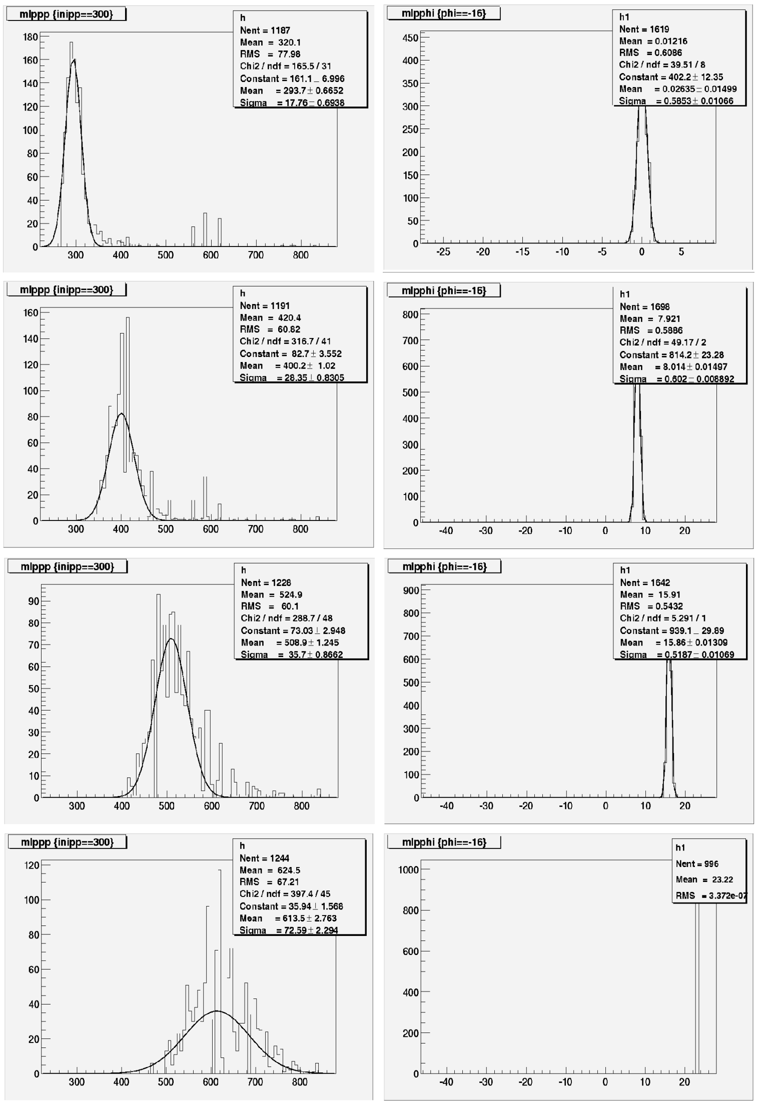


Figure 4 :Neural-Network reconstruction ,based on hit positions; Left -Momentum reconstruction for P = 300,400,500,600 MeV/c Right -Out-Of-plane angle reconstruction for $\phi = 0°$,$8°$,$16°$,24 °. ΔP/P is 7 % for the Momentum range 300-500 MeV/c. $\Delta\phi$ is .5 °

Position and TOF combined algorithm

In order to test ways to clean background signal, an additional algorithm was tested.

In this method, we used the consistency of the hit positions reconstructed momentum,and the TOF recostructed momentum (which has a smaller uncertainty but larger tails due to random hits), to clean background events.

We simulated 50 % random hits by generating random times, and applied a cut, by demanding that P(tof) minus P(position) would be less then a specific treshold, which was a fraction of Ptof.

i.e abs(P(tof) - P(position)) $\leq$ P(tof)*5%

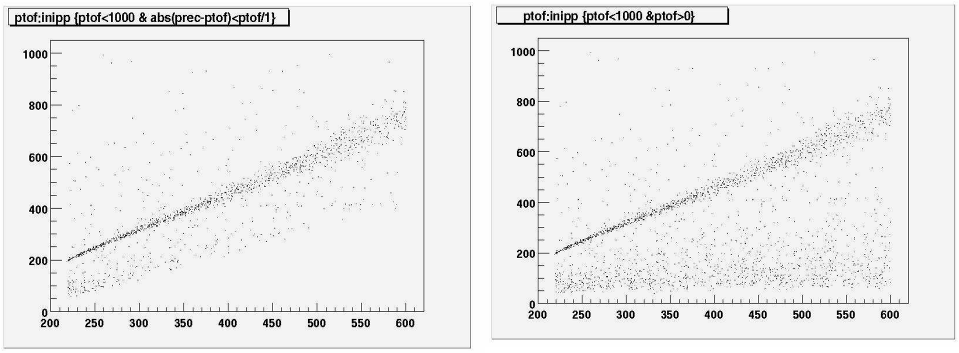


Figure 6 : TOF reconstructed momentum before and after Position cut. (50 % background random events).

Next step

We plane to expand the algorithm to be able to work in cases where in addition to the hits by the real particle, there are up to extra 2-3 random hits in the auxiliary and trigger planes.