SIMULATION OF THE $\eta\pi^-$ DIFFRACTIVE PRODUCTION AND DETECTION AT COMPASS

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Abstract
We present preliminary results of simulation of the $\eta\pi^-$ system production, detection and reconstruction at the COMPASS hadron set-up.

1. INTRODUCTION

At present several groups have evidence for $J^{PC} = 1^{-+}$ meson production (Tab. 1), which is forbidden for ordinary quarkonia and hence might be a good candidate for a hybrid [1,2]. Here J is the total angular momentum, P is the parity, C is the charge parity. The $\pi_1(1400)$ meson shows up in the $\eta\pi$ final state in two experiments [3–5]. The VES group found that the results of the $\eta'\pi^-$ and $b_1\pi$ system Partial-Wave Analysis (PWA) at 37 GeV/c agree with the production of the higher mass $\pi_1(1600)$ [6], evidence for which in the $\eta'\pi^-$ has been also confirmed by E852 at BNL [7, 8]. The latest analysis by VES of the 2.5 times larger data sample collected at 28 GeV/c [9] confirmed in general the results of the $\eta\pi^-$, $\eta'\pi^-$ and $b_1\pi$ system PWA of the 37 GeV beam data.

However, they pointed to the possible non-resonant nature of the 1^{-+} state in the $\eta\pi^-$ and $\eta'\pi^-$ systems.

A PWA of the diffractively produced $\eta\pi^-$ state shows that two partial waves are significant:

- the $J^P M^\eta = 2^+1^+$ with the intensively produced $a_2(1320)$ meson, denoted by D_+,
- the $J^P M^\eta = 1^-1^+$ with exotic quantum numbers, denoted by P_+,

where M is an absolute value of the total angular momentum z projection, η reflectivity [10]. The result of the $\eta\pi$ PWA is intensities and a relative phase of the P_+ and the D_+ partial waves. The issue is: Does the phase of the P_+ wave show a resonant behaviour?

Table 1: Evidence for $J^{PC} = 1^{-+}$ exotics.

Exp.	Mass (MeV)	Width (MeV)	Reaction
BNL	1359^{+16+10}_{-14-24}	314^{+31+9}_{-29-66}	$\pi^-p \to \eta\pi^-p$
CBar	$1400 \pm 20 \pm 20$	$310 \pm 50^{+50}_{-30}$	$\bar{p}n \to \pi^-\pi^0\eta$
CBar	1360 ± 25	220 ± 90	$\bar{p}p \to \pi^0\pi^0\eta$
VES	(1316 ± 12)?	(287 ± 25)?	$\pi^-Be \to \eta\pi^-Be$

2. EVENT PROCESSING SCHEMA

To get an answer to the question whether COMPASS can collect a much larger data sample, the following scheme of event processing has been carried out (see Fig. 1). An event was generated by a stand-alone program. Simulated momenta and a vertex were passed to the input of the COMGEANT program. COMGEANT is a standard COMPASS tool for simulation of the set-up response to a transversing particle. Then tracks were reconstructed by a standard COMPASS reconstruction program CORAL, slightly fitted to the hadron set-up. Physical quantities (energy and intercept with a calorimeter) of the detected gammas were smeared, according to the calorimeter resolution taken from the proposal [11]

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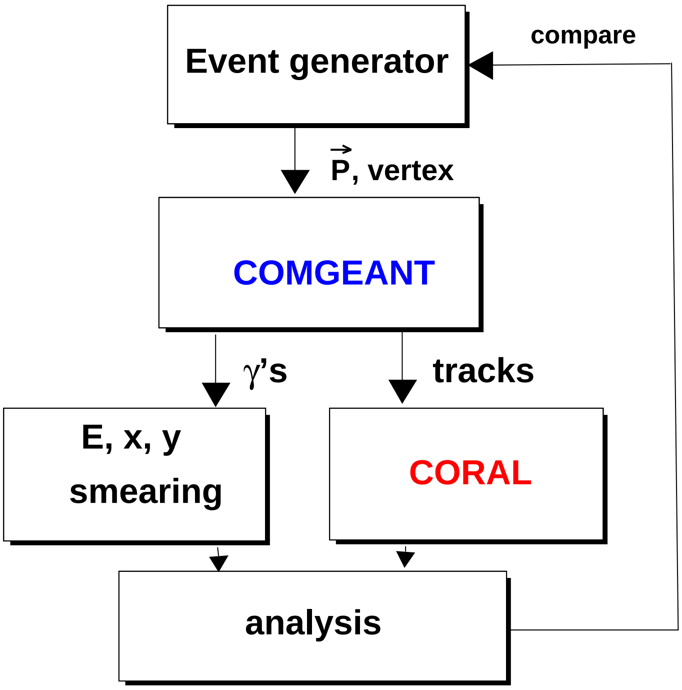

Fig. 1: An event processing scheme.

$\sigma_E/E = 1.5\% + 5.5\%/\sqrt(E)$, and $\sigma_{XY} = 6\ \mathrm{mm}/\sqrt(E)$, ($E$ in GeV). The $ECAL_2'$ option of the COMPASS hadron set-up was studied. Description of the $ECAL_2'$ option can be found in Ref. [12]. Trigger requirements have not been studied in this work. A procedure of a physical analysis was applied to the reconstructed event and the results were compared to Monte Carlo simulations.

3. SIMULATION OF THE PRODUCTION AND DECAY PROCESSES

An exclusive diffractive process $\pi^- p \to Xp$ was simulated as a first step. A monochromatic pin-like beam $P_x = P_y = 0$, and $P_z = 190$ GeV and a rotational symmetry about the beam were assumed. A vertex is always in the centre of the target. A momentum transfer squared distribution was taken in the form $\frac{d\sigma}{t'} \sim \exp(-bt')$, where $t' = t - t_{min}$ and $b = 8\ \mathrm{GeV}^{-2}$ is a typical slope value for diffractive production on the hydrogen target. It is essential for the PWA to measure not only a partial wave under study (P_+ wave in our case), but a relative D_+ wave too. Therefore two options of the X state have been studied:

- the $D_+(\eta\pi)$ with mass in the range $[0.92 \div 2.12\ \mathrm{GeV}]$ with $0.2\ \mathrm{GeV}$ step,
- the $P_+(\eta\pi)$ produced with intensity as was presented by VES at Hadron2001 [9].

The following X decay chain was selected: a decay $X \to \eta\pi^-$ in the P or D wave, is followed by the $\eta \to \pi^+\pi^-\pi^0$ and the $\pi^0 \to \gamma\gamma$. Therefore we finally have the reaction $\pi^- p \to \pi^+\pi^-\pi^-\gamma\gamma + p$ with three forward moving charged pions and two gammas and a recoil proton.

The $D_+(\eta\pi)$ state kinematics with $M_{\eta\pi} = 1.32$ GeV is shown as an example in Fig. 2 and Fig. 3. The recoil proton is soft, according to the diffractive nature of the production process. The $\cos\Theta_{GJ}$ distribution of the D wave decay has two peaks, corresponding to the mainly forward or backward production of the η meson, where Θ_{GJ} is a polar angle of the η meson in the Gottfried–Jackson reference frame. The Gottfried–Jackson reference frame is a rest frame of the $\eta\pi^-$ system with the z-axis in the

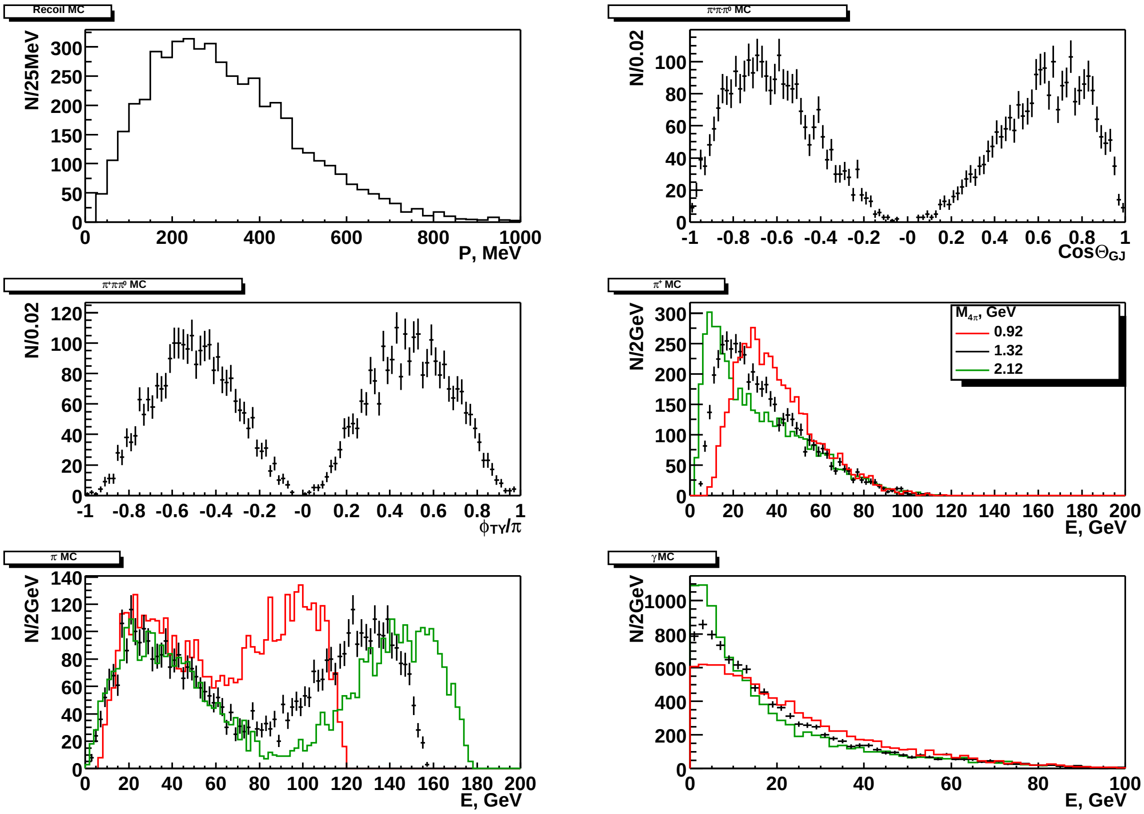

Fig. 2: Kinematical properties of the $D_+(\eta\pi)$ events.

direction of the beam and the y-axis perpendicular to the production plane. A superimposed plot shows a more spherical feature of the P_+ wave $\eta\pi^-$ system decay. An axial angle of the η in this frame the ϕ_{TY} is called a Treiman–Young angle and has a $\sin^2\phi_{TY}$ form, which stands for the $\eta\pi^-$ production with $M = 1$. Plots for three different $\eta\pi$ mass values show the mass dependence of the final state particles' momenta. The distribution shown in Fig. 3 reflects the spatial dispersion of tracks and gammas. A fact that only a small tail of the maximal laboratory γ polar angle distribution is greater than 30 mrad means, that nearly almost all γ's move through the hole in the $ECAL_1$ and strike the $ECAL_2'$. One might expect to have a large γ acceptance. An angular distance $\Delta = \sqrt{(\delta\frac{P_x}{P_z})^2 + (\delta\frac{P_y}{P_z})^2}$ is a distance between particles in a plane divided by a distance to the vertex. The distribution for tracks of it's minimal value peaks near 3 mrad. The angular distance between γ's is in general greater than the angle size of a $ECAL_2'$ cell and therefore means a rare π^0 meson loss caused by the unseparated γ's.

4. EFFICIENCIES

A capability of the $\eta\pi^-$ system detection is expressed by an efficiency, which is a product of the track and the γ detection efficiency and the track reconstruction efficiency. The γ reconstruction efficiency was assumed to be equal to 1 in our work. The sources of inefficiency can be exemplified by Fig. 4, where the efficiencies of the $D_+(\eta\pi)$ events with the relatively high-mass $M_{\eta\pi} = 2.12$ GeV are shown. A low track reconstruction efficiency is due to the poor reconstruction procedure in the presence of a background, originating from the particle interaction with the material of the set-up. One observes a sharp decrease for soft tracks ($E_{track} < 10$ GeV). A fall is observed in the Δ_{min} dependence of the efficiency of events with narrow tracks and of very dispersed ones. These track inefficiencies cause the objectionable fall of the event efficiency for the backward moving η meson in the Gottfried–Jackson

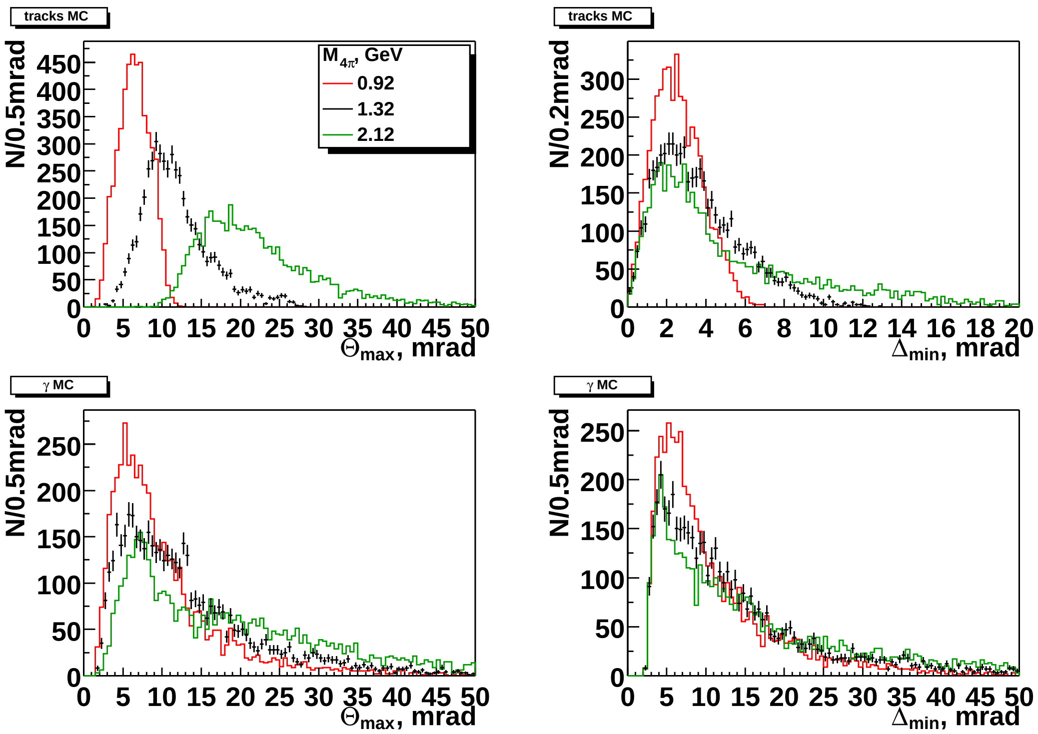

Fig. 3: Spatial dispersion of the $D_+(\eta\pi)$ events.

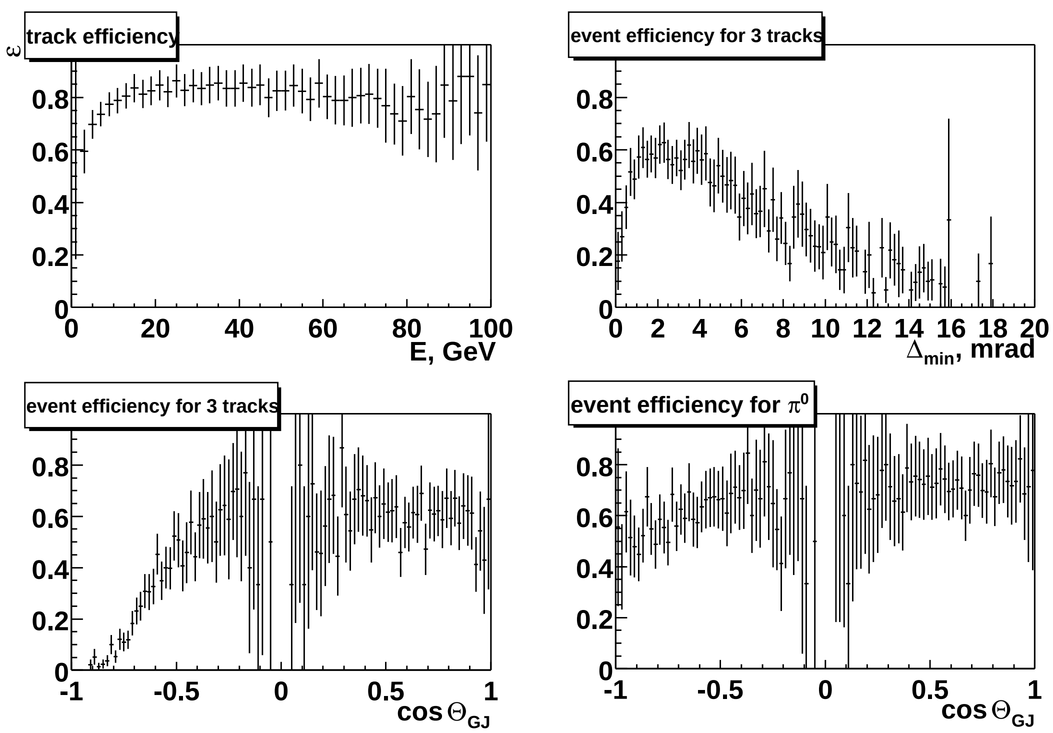

Fig. 4: Efficiency of the $D_+(\eta\pi)$ events with $M_{\eta\pi} = 2.12$ GeV.

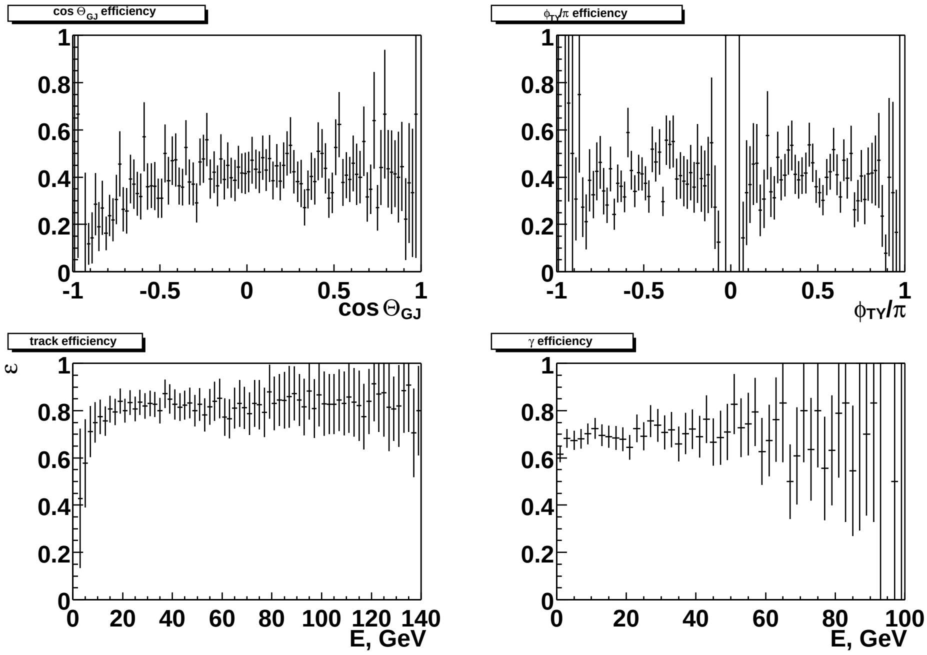

Fig. 5: The detection and reconstruction efficiency of the $P_+(\eta\pi)$ events.

reference frame and hence an asymmetry in the cosine of the Gottfried–Jackson angle distribution (see Fig. 4). There is also a weak dependence of the event efficiency upon the detection of the π^0. The γ acceptance is large enough thus making the γ absorption in the material of the set-up the dominant contribution to the event inefficiency. However, the absorption in the target, which is $\approx 5\%$ of the radiation length, is relatively small.

Integral efficiencies of the $P_+(\eta\pi)$ events over the whole range are shown in Fig. 5. There are no strong mass dependence of the event efficiency, which decreases by $\approx 25\%$ with the mass increasing for both states under study, as shown in Fig. 6 and Fig. 7. The individual contributions of the track and γ efficiencies to the total efficieny are nearly equal (see Fig. 6).

5. RESOLUTIONS

The $D_+(\eta\pi)$ mass resolution at $M_{\eta\pi} = 1.32$ GeV is shown in Fig. 8. The lower histogram and curve show the difference between generated and reconstructed Monte Carlo events for the 4π invariant mass for the case that the reconstructed momenta of the charged pions are coupled to the Monte Carlo momentum of the π^0 meson. The upper histogram and curve are for the case that the reconstructed momenta of the charged pions are coupled to the reconstructed momentum of the π^0 meson after a $1C$ fit to the π^0 mass has been applied to the γ energies. An approximate equality of the widths means that the dominant contribution to the 4π mass resolution is the charged track resolution. To which, in turn, a multiple scattering in the material of the set-up gives a major contribution.

The $\eta\pi$ mass dependence of the resolution is shown in Fig. 9. A σ_M/M ratio is $\approx 0.5\%$, which slightly increases when M becomes larger.

Resolutions of the $\pi^+\pi^-\pi^0$ mass, the cosine of the Gottfried–Jackson angle, the Treiman–Young angle, the axial angle and the transverse momentum of the recoil proton in the laboratory frame are presented in Table 2. It is worth pointing to a nice $\pi^+\pi^-\pi^0$ mass resolution, which is only 2.7 MeV.

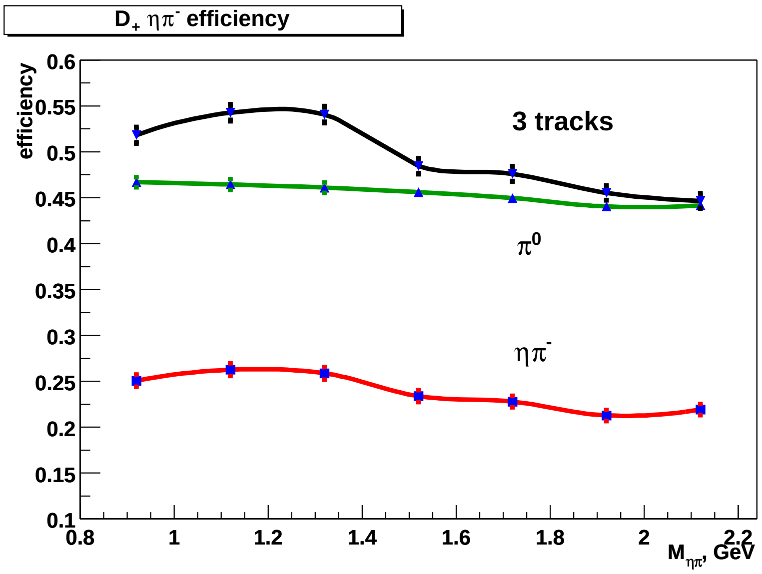

Fig. 6: Mass dependence of the $D_+(\eta\pi)$ events efficiencies.

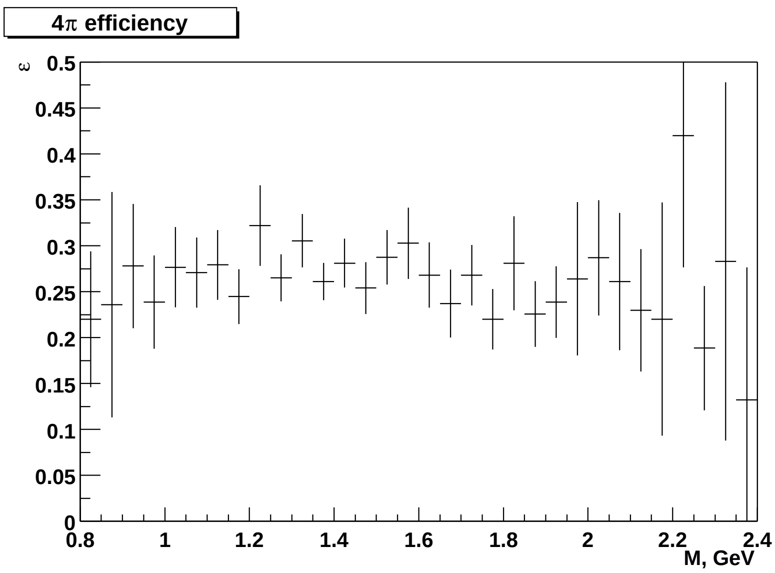

Fig. 7: Mass dependence of the $P_+(\eta\pi)$ events efficiency.

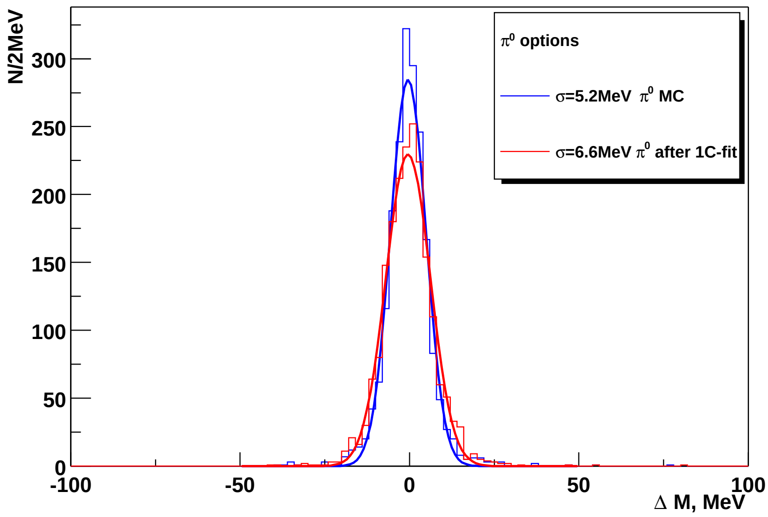

Fig. 8: The $D_+(\eta\pi)$ mass resolution at $M_{\eta\pi} = 1.32$ GeV.

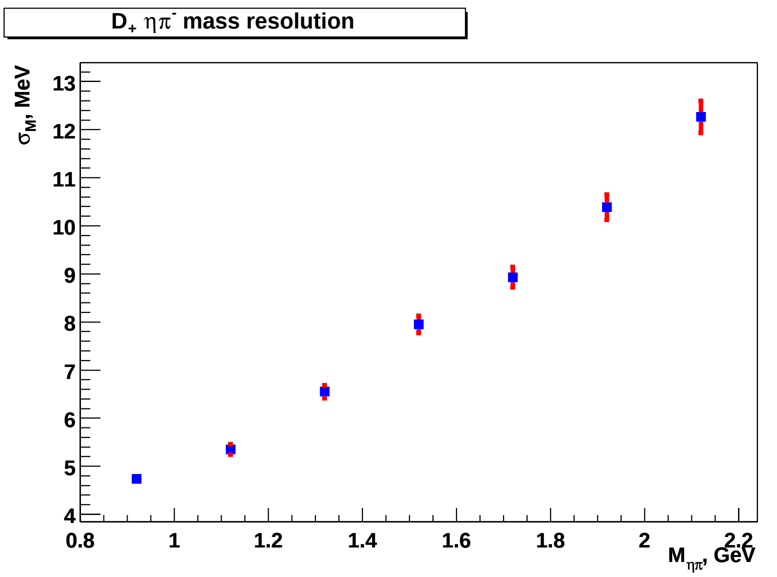

Fig. 9: The $\eta\pi$ mass dependence of resolution.

Table 2: Parameters of the $\pi^+\pi^-\pi^0$ process

Quantity	1σ resolution
$M(\pi^+\pi^-\pi^0)$	$\sim$ 2.7 MeV
$\cos(\Theta_{GJ})$	(9.5–5.5) 10^{-3}
ϕ_{TY}/π	(8.2–11.5) 10^{-3}
recoil ϕ/π	(1.2–1.5) 10^{-2}
recoil P_T	(6.8–8.2) MeV

6. ESTIMATION OF RATES

The obtained efficiency allowed us to estimate the $a_2(1320) \to \eta\pi^-$ event rate according to: $N_{\eta\pi} = N_0 \frac{N_A}{A} \rho l \sigma_{a_2} BR(a_2 \to \eta\pi) BR(\eta \to \pi^+\pi^-\pi^0)\epsilon$, where:

- N_0 is the beam flux;
- $N_A = 6 \times 10^{23}$ /mol the Avogadro number;
- $A = 1.01$ g/mol the atomic number of the target material [13];
- $\rho = 0.0708$ g/cm^3 the target density [13];
- $l = 40$ cm the target length;
- $\sigma_{a_2} = 25$ μb the $a_2(1320)$ production cross-section [14];
- $BR(a_2(1320) \to \eta\pi) = 0.145$ [13];
- $BR(\eta \to \pi^+\pi^-\pi^{0)} = 0.226$ [13];
- $\epsilon = 0.25$ the detection and reconstruction efficiency.

Substitution of these values results in the $a_2(1320) \to \eta\pi^-$ rate being $N_{\eta\pi} = N_0 \cdot 34 \times 10^{-8}$. If we assume a beam flux to be equal to $N_0 = 10^8/\text{min}$, then we will have $N_{a_2 \to \eta\pi} \approx 50\,000$/day. This value can be converted using the ratio from Ref. [3] into the P_+ state $\eta\pi^-$ system production rate, which then will be equal to $N_{P_+(\eta\pi)} \approx 2500/\text{day}$

7. CONCLUSION

The detection, track reconstruction procedure and a physical analysis of the $\eta\pi^-$ system were simulated. As a result the production rate of the $J^{PC} = 1^{-+}$ $\eta\pi^-$ events was found to be ≈ 2500/day. This allows one to conclude that:

- COMPASS can measure the shape of the exotic $J^{PC} = 1^{-+}$ $\eta\pi^-$ wave with the best precision.
- COMPASS can collect simultaneously the largest data samples to study the exotic wave production not only in the $\eta(\pi^+\pi^-\pi^0)\pi^-$, but also in the $\eta(2\gamma)\pi^-$, $\eta'\pi^-$, $\rho^0\pi^-$ and $b_1(1235)(\omega\pi)\pi$.

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